Study of
Heavy-flavored Particles

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1 Progress Report

1.1 Introduction

The Albany High Energy Physics Group has made significant contributions to the CLEO collaboration in terms of physics analysis and hardware development.

First of all, W.C. Li has completed the partial requirement for Ph.D. by successfully carrying out the Measurement of $\overline{B}^0 \rightarrow D^{*+} \pi^-$ Branching Ratio using partial reconstruction techniques and is now employed by SSC.

Currently we have two papers being reviewed for publication. The first is the continuum production of the charmed baryon Λ_c^+ in six different decay modes which has finally reached the editor's desk of Physical Review. We expect it will be published after some minor revisions. The second is a paper on the B meson decay into baryons and has been reviewed by the CLEO collaboration and is now near its final form for publication.

Our work on the search for new Charmed baryon states vigorously continues. We have now found signals in two decay modes of the Ω_c^0 charmed baryon:

$$\begin{aligned}\Omega_c^0 &\rightarrow \Xi^- K^- \pi^+ \pi^+ \\ \Omega_c^0 &\rightarrow \Omega^- \pi^+\end{aligned}$$

The weighted average mass of Ω_c^0 is found to be $2752.8 \pm 2.1 \text{ Mev}/c^2$. The Albany group has circulated the preliminary results as a CBX note to the CLEO collaboration and other members are trying to verify our results. In the mean time, we are also reanalyzing our data with more stringent cuts to assure our

claim.

A year ago we reported and published our observations of Ξ_c^0 and Ξ_c^+ in the following decay modes:

$$\Xi_c^0 \rightarrow \Xi^- \pi^+$$

$$\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+.$$

During the past year we have successfully observed another decay channel, the $\Xi_c^0 \rightarrow \Xi^- \pi^+ \pi^- \pi^+$, with a mass agreeing with the published mass of $\Xi_c^0 \rightarrow \Xi^- \pi^+$. With limited statistics, we have also seen evidence of $\Xi_c^0 \rightarrow \Omega^- K^+$.

The above discussed physics analysis are all based on the data obtained with CLEO 1.5 detector. Now with the completion of the new CLEO II detector, the collaboration has been accumulating data during the past year, and we at Albany are also getting ready for the CLEO II physics analysis.

At Wilson Lab, we have been tuning the endcap time-of-flight counters which had been designed, constructed and installed in the CLEO II detector by the Albany Group. The counters worked well and the photomultipliers performed excellently in the 1.5 T magnetic field. Our new research associate Dr. Bijan Nemati arrived at Wilson Lab in August. He immediately took charge of the entire time-of-flight system including the endcap counters built by Albany and the barrel counters built by Harvard. This responsibility fell upon him because of the departure of the Harvard post doctor Mike Procario. In a period of 3 to 4 months Nemati has reported very significant progress at the last CLEO collaboration meeting. We feel confident that he will succeed in optimizing the system and fulfilling this important assignment which has been delegated to Albany by the CLEO collaboration.

At Albany, we have built and tested a full-size next generation prototype TOF counter which has achieved a timing resolution of 65 picoseconds. We are now trying to build a prototype that should have a timing resolution of less than 50 picoseconds.

At Fermilab, we have completed the run of E761 this summer. For the Σ^+ magnetic moment measurement using crystal channeling technique, we have successfully collected 280 thousand triggered Σ^+ events of which we expect some 3,000 to 5,000 channeled Σ^+ candidates which we believed to be adequate for our final analysis.

In summary, this past year has been a very fruitful one for us. We will discuss the details of our progress and outline of our plans for the future in the following sections

1.2 CLEO-II Time-of-Flight System Status Report

The CLEO-II Time-of-Flight (TOF) system is comprised of a barrel system consisting of 64 scintillators and two endcap groups with 28 scintillators each. These are designed to provide particle identification in the momentum range 0 to about 1.1 GeV/c. In order to provide pion-kaon separation by more than 2σ , the TOF system must attain a resolution of better than 170 picoseconds on the average. Bench tests of the barrel system indicate that the two-inch-thick scintillators used can deliver resolutions of about 120 picoseconds. Thus the relatively modest requirement of 150 picoseconds should be attainable and exceeded.

In the case of the endcap counters, which use only one photomultiplier tube per scintillator, the best resolution attainable will be considerably large than in the barrel. In order to offset this disadvantage and to improve the endcap performance, the Albany group has made use of the new Hamamatsu R2490 photomultiplier tubes mounted directly on the endcap scintillators in the 1.5 Tesla magnetic field. Extensive studies of the endcap timing resolution indicate that the system will achieve a timing resolution of better than 200 picoseconds, as compared with the 450-picosecond resolution expected from the conventional design with long light guides.

Having completed the construction of the CLEO-II endcap TOF system, the Albany High Energy Physics Group has directed attention to the development of the software for both the barrel and endcap TOF systems. The main components of the TOF software are the online and offline calibration programs and the offline reconstruction program.

The online calibration program makes pedestal and slope corrections to the raw output of the timing ADC's and converts the readout to standard time units (i.e., nanoseconds). In the course of performing the online calibration, a problem has been discovered with the CLEO-II's computer-controlled pulser, which is used

for the calibration of many of the other detector components. It was found that the pulser did not meet the advertised specifications in delay setting accuracy. In order to eliminate any future problems due to pulser delay inaccuracy, a separate controllable delay unit using relays and fixed-length cables is being built.

In the offline calibration program corrections are made for light-travel-time in the scintillators, constant timing offsets due to cable lengths, etc., and the time-to-threshold effect which depends on the size of the pulse from the photomultiplier tube. The barrel TOF system has undergone the first pass of offline calibration using a preliminary calibration algorithm. The timing resolution currently achieved is about 243 picoseconds per tube, and 191 picoseconds per counter in the barrel. Figures 1 and 2 show the distribution of measured time with respect to expected time for each tube and each counter, respectively, averaged over a large sample of Bhabha tracks. Figure 3 shows a scatter plot of track beta determined using the TOF system versus track momentum obtained by using the drift chamber. Bands can be seen for pions, kaons and protons. Shown in Figure 4 is the dE/dx distribution for hadrons from the data as a function of momentum. Even at this early time, one can see that the barrel TOF system extends the $\pi - K$ and $K - p$ range of momentum for 2σ separation considerably over that achieved by the dE/dx alone. As discussed in the next section, one of the goals of the Albany group is to improve the performance of the TOF system by using a more sophisticated offline calibration program. The endcap offline calibration software is also being developed and is expected to be finished at the same time as the final barrel offline calibration.

In Figure 5, we show the distribution of measured time with respect to expected time from a typical endcap counter for a large sample of Bhabha tracks. A timing resolution of $\sigma = 258$ picoseconds is achieved. In Figure 6, we show the scatter plot of $1/\beta^2$ plotted against the momentum for a small sample of charged hadrons. Already, the pion, kaon and proton bands can be discerned. We expect to achieve better than 200 picosecond resolution for the endcap counters.

The reconstruction of the time of flight comprises the final stage of the data preparation for physics analysis. This phase involves the sorting out of event characteristics and providing relevant information. These include track topologies, multiple hits per counter, cases where only one of the two photomultiplier

tubes on a counter fired, as well as the estimation of the errors and correlations in each measurement. The development of this program is still in progress.

1.3 Physics Analysis – CLEO (1.5)Data

The Albany High Energy Physics Group has pursued an active program of physics analysis as part of the CLEO collaboration at the Cornell Electron Storage Ring (CESR). We have been playing a major role in carrying out the study of charmed baryon production at CESR. Here we will describe the physics analysis program which has been pursued very actively by the Albany group:

- i) Continuum production of the charmed baryon Λ_c^+ .
- ii) Search for new decay modes and new charmed strange baryons.
- iii) Charmed and charmless baryons from B meson decays.
- iv) Measurement of $\overline{B}^0 \rightarrow D^{*+} \pi^-$ Branching ratio.
- v) Determination of α_s .

The physics analysis have all been carried out with the latest block of data recorded by the improved CLEO detector operating at CESR during 1986-87. The data sample consists of 101 pb^{-1} at centre-of-mass energies below the $\Upsilon(4S)$ ($\sqrt{s} = 10.2 - 10.5 \text{ GeV}$), 213 pb^{-1} at the $\Upsilon(4S)$ ($\sqrt{s} = 10.58 \text{ GeV}$) and 117 pb^{-1} at the $\Upsilon(5S)$ ($\sqrt{s} = 10.87 \text{ GeV}$). The hadronic event selection criteria and the CLEO detector are described in detail elsewhere¹ and will thus be described only briefly here.

We accept hadronic events if they satisfy the following criteria: The primary vertex must lie within 5 cm of the center of the interaction region along the beam line and within 2 cm transverse to the beam line. There should be three or more charged tracks reconstructed in the drift chamber. The total visible energy should be at least 30 % of the center-of- mass energy.

The improved CLEO detector consists of a 3-layer drift tube and a 10-layer precision drift chamber vertex reconstruction system followed by a 51-layer, 1-meter radius drift chamber tracking system operating inside a superconducting solenoidal coil producing a 1.0 Tesla magnetic field. The momentum resolution of charged tracks as measured jointly by the two devices is given as

$$(\sigma_p/p)^2 = [0.23\%(GeV/c)^{-1}p]^2 + [0.7\%]^2$$

Furthermore, another major improvement is the instrumenting of the drift chamber wires for the recording of ionization loss of charged tracks (dE/dx), thus providing 51 dE/dx measurements for each charged track. This provides particle identification over 90 % of 4π solid angle based on dE/dx measurements with a resolution of about 7 %. Thus at the 2σ level, pions and kaons can be separated up to 1 GeV/c and pions and protons up to 1.5 GeV/c.

We now present a summary of the completed physics results and status report on the analysis in progress.

1.3.1 Continuum Production and Decay of Λ_c^+ Charmed Baryon

The success of the qualitative quark model encourages detailed dynamic calculations of quark binding, using different models of confinement. Charmed baryons provide a means of comparison of light-light and light-heavy type of interquark forces.² The hadronization process, by which charm quarks fragment into charmed mesons and baryons, is important information for the QCD process. We need to know the relative importance of various decay mechanisms.

Both theoretical calculations and experimental measurements for charmed baryons have been scarce compared to that for charmed mesons. As a continuing effort to study charm baryons, Albany has recently reported the first observation³ of Ξ_c^0 and the measurement of isospin mass splitting between Ξ_c^0 and Ξ_c^+ .⁴ These results have been compared to and confirmed by other experiments. The theoretical predictions are widely varied. We have completed the analysis of the continuum production of the Λ_c^+ . The result has been submitted to Physical Review D for publication by CLEO collaboration. We will briefly summarize these results.

Here we present our measurements of Λ_c^+ fragmentation distribution, inclusive cross-section and decay branching fractions into decay modes of $pK^-\pi^+$, $p\bar{K}^0$, $p\bar{K}^0\pi^+\pi^-$, $\Lambda\pi^+\pi^-\pi^+$ and $\Xi^-K^+\pi^+$. Our results are compared to model predictions and other experiments.

Our data have been collected with the CLEO detector at CESR during 1987. The sample consists of 212 pb^{-1} at the $\Upsilon(4S)$ resonance (10.58 GeV), 101 pb^{-1} at energies just below the $\Upsilon(4S)$ (10.52 GeV) and 117 pb^{-1} at $\Upsilon(5S)$ (10.87 GeV).

We consider only Λ_c^+ events produced from e^+e^- annihilations to $c\bar{c}$ quark pairs on the continuum. Thus the confusing Λ_c^+ events from B meson decays are excluded by requiring $x_p > 0.5$. Here $x_p = p/p_{max}$ where p and p_{max} are the momentum of the Λ_c^+ and its maximum kinematically allowed value respectively.

Based on the 1987 430 pb^{-1} data, we have obtained the invariant mass distributions for the Λ_c^+ decay into the above modes with $x_p > 0.5$. To reduce the combinatorial background, criteria based on the ionization of charged particles are used to identify the secondary particles such as the protons and kaons. Λ 's are identified through their decay to $p\pi^-$ and $\bar{K}^0$'s are detected as $K_s^0 \rightarrow \pi^+\pi^-$. We require both the secondary vertices be separated from the primary vertices by at least 1 mm in the radial direction. The mass of the Λ and K_s^0 candidates are restricted to within 6 and 12 MeV/ c^2 of Λ and K_s^0 mass respectively. The Ξ^- candidates are identified through their decay to $\Lambda\pi^-$. The mass of Ξ^- candidates are restricted to within 5 MeV/ c^2 of Ξ^- mass and is required to be at least 4 mm away from the primary vertex. In the $\Lambda\pi^+$ mode we require that the cosine of the angle between the pion and Λ_c^+ direction in the Λ_c^+ rest frame be greater than -0.7. In the $\Lambda\pi^+\pi^-\pi^+$ mode, the mass distribution for the wrong strangeness and charge combinations, e.g., $\Lambda\pi^+\pi^-\pi^+$, shows no enhancement in the region of Λ_c^+ mass. The invariant mass distributions for six decay modes of Λ_c^+ are shown in Fig. 7. The weighted average of the fitted masses determined from the six decay modes is $2285.0 \pm 0.6 \pm 0.7 \text{ MeV}/c^2$, in good agreement with the Particle Data Group⁵ value of $2285.2 \pm 1.5 \text{ MeV}/c^2$.

In order to study the fragmentation of the charm quark into the charm baryon Λ_c^+ we present in Fig. 8, the distribution of $B \cdot \frac{d\sigma}{dx_p}$ versus x_p and $B \cdot \frac{d\sigma}{dx^+}$ versus x^+ , for the three statistically significant decay modes, i.e. $pK^-\pi^+$, $p\bar{K}^0$ and $\Lambda\pi^+\pi^-\pi^+$, where $x^+ = (E + p)/(E_{max} + p_{max})$ and E and p are the energy and momentum of Λ_c^+ .

We tested three theoretical models proposed by Peterson *et al.*⁶, Collins and Spiller⁷ and Bowler,⁸ respectively by fitting each of the proposed fragmentation function to the above distributions of all 3 modes simultaneously.

The fits are shown in the figures and results are presented in Table 1.

Table 1. Values of Fitted Parameters for Fragmentation Functions

Parameter	ϵ_Q (Peterson)	ϵ'_Q (Collins)	β (Bowler)	B(Bowler)
Fitted Value	0.29 ± 0.05	1.19 ± 0.44	2.86 ± 0.52	1.06 ± 0.23
χ^2/DOF	23/23	54/23	12/16	

We find Collins function fails to describe our data, whereas the Peterson and Bowler functions do. It is cautioned, however, that the comparison have been made without QCD and QED radiative corrections.

We obtained the total inclusive cross-sections $B \cdot \sigma$ by integrating the measured $B \cdot \frac{d\sigma}{dx_p}$ for all x_p in the case of $pK^- \pi^+$ mode. For other modes we used the measured inclusive cross-sections with $x_p > 0.5$ and extrapolated the $B \cdot \sigma$ for $0 < x_p < 0.5$ with the help of Peterson and Bowler functions fitted to $pK^- \pi^+$ data for $x_p > 0.5$. The resulting $B \cdot \sigma$ for the six modes are presented in Table 2. Here we also present the branching fractions of each decay mode relative to that of the $pK^- \pi^+$ mode calculated from $B \cdot \sigma$ for $x_p > 0.5$. Our results are an improvement from Mark II⁹ and agree with those from ARGUS¹⁰ and E691¹¹. We obtained a set of weighted averages from these 3 sets of data. From these averages we evaluated the average absolute branching fractions, as shown in Table 2, for each decay mode, by assigning the absolute branching fraction of the $pK^- \pi^+$ mode to be $4.3 \pm 1.4\%$. The latter is obtained by combining $B(B \rightarrow \Lambda_c^+ x)$ and $B(\Lambda_c^+ \rightarrow pK^- \pi^+)$ as measured by CLEO and ARGUS. Corresponding values from Particle Data Book are shown in the last column in Table 2. for comparison.

Table 2. Λ_c^+ Inclusive $B \cdot \sigma$ and Branching Fractions

Decay	$B \cdot \sigma$ (pb)	$B \cdot \sigma$ (pb)	Relative	Absolute Bran.Frac. (%)	
Mode	$x_p > 0.5$	$x_p > 0.0$	Bran.Frac.	New Ave.	P.D. Book
$pK^- \pi^+$	$7.2 \pm 0.7 \pm 1.1$	$10.0 \pm 1.5 \pm 1.5$	1	4.3 ± 1.4	2.8 ± 0.8
$p\bar{K}^0$	$3.2 \pm 0.4 \pm 0.3$	$4.6 \pm 0.6 \pm 0.8$	$0.44 \pm 0.07 \pm 0.05$	2.1 ± 0.7	1.6 ± 0.6
$p\bar{K}^0 \pi^- \pi^+$	$3.1 \pm 0.9 \pm 0.6$	$4.5 \pm 1.3 \pm 1.1$	$0.43 \pm 0.12 \pm 0.04$	1.8 ± 0.8	8.1 ± 3.5
$\Lambda \pi^+$	$1.3 \pm 0.2 \pm 0.1$	$1.9 \pm 0.3 \pm 0.3$	$0.18 \pm 0.03 \pm 0.03$	0.7 ± 0.3	seen
$\Lambda \pi^+ \pi^- \pi^+$	$4.7 \pm 0.7 \pm 0.5$	$6.8 \pm 1.0 \pm 1.3$	$0.65 \pm 0.11 \pm 0.12$	2.8 ± 1.0	1.9 ± 0.7
$\Xi^- K^+ \pi^+$	$1.1 \pm 0.3 \pm 0.2$	$1.6 \pm 0.4 \pm 0.3$	$0.15 \pm 0.04 \pm 0.03$	0.6 ± 0.3	

To further compare with theoretical models, we evaluated the partial decay widths to the $\Lambda\pi^+$ and $p\bar{K}^0$ modes from the absolute branching fractions and the known Λ_c^+ lifetime of $(1.7^{+0.23}_{-0.17}) \times 10^{-13}$ seconds. We obtain $\Gamma(\Lambda\pi^+) / \Gamma(p\bar{K}^0)$, however, from the measured $B \cdot \sigma$ for $x_p > 0.5$ as listed in Table 2. This is to reduce systematic errors. We compared our results on the partial widths Γ , in Table 3, with values calculated by Korner, Kramer and Willrodt (KKW)¹², Husain and Scadron (HS)¹³, Pakvasa, Rosen and Tuan (PRT)¹⁴ and Ebert and Kallies (EK)¹⁵.

Table 3. Comparison of Γ between theory and experiment (Γ in units of 10^{11}sec^{-1})

Γ	Model				Experiment
	KKW	HS	PRT	EK	
$\Lambda\pi^+$	0.8	0.77	1.0	0.32	0.39 ± 0.17
$p\bar{K}^0$	8.9	1.64	2.78	0.17	1.17 ± 0.42
$\Gamma(\Lambda\pi^+) / \Gamma(p\bar{K}^0)$	0.09	0.47	0.36	1.88	0.41 ± 0.09

The results show that naively expected color suppression of $p\bar{K}^0$ relative to the $\Lambda\pi^+$ mode is not present.

We observe that the measured widths for the decay into two body final states disagree with two of the models.

1.3.2 Search for New Decay Modes and New Charmed Baryons

One of the most important contributions we have made in the search for the charmed baryons this year is on the evidence for the production of Ω_c^0 at CESR. However, these results are preliminary and are in the process of being verified by other members of the CLEO group. In an experiment with Σ^- beam at CERN, WA62 has reported a cluster of three events in the invariant mass distribution of $E^- K^- \pi^+ \pi^+$ combinations at a mass of $2740 \pm 20 \text{ MeV}/c^2$ and identified it as Ω_c^0 (css).¹⁶ We have searched for the Ω_c^0 production in e^+e^- annihilations at CESR through the following decay modes:

$$\begin{aligned}
\Omega_c^0 &\rightarrow \Omega^- \pi^+ \\
&\rightarrow \Omega^- \pi^+ \pi^- \pi^+ \\
&\rightarrow \Xi^- K^- \pi^+ \pi^+ \\
&\rightarrow \Xi^- \bar{K}^0 \pi^+ \\
&\rightarrow \Lambda \bar{K}^0 K^- \pi^+ \\
&\rightarrow \Lambda K^- K^- \pi^+ \pi^+
\end{aligned}$$

The data sample used in this analysis are the same 430 pb^{-1} used in the Λ_c^+ analysis. Among the six decay modes studied, we have found evidence for the production of the Ω_c^0 in two decay modes.

1.3.2.1 The Study of the $\Omega_c^0 \rightarrow \Xi^- \pi^+ \pi^- \pi^+$ Decay Mode

For the study of $\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$ decay mode, we have reconstructed Ξ^- candidates by pairing each Λ candidate with each of the negatively charged tracks which are assumed to be a π^- . We have obtained $1250 \pm 44 \Xi^-$'s at a mass of $1321.4 \pm 0.1 \text{ MeV}/c^2$. We then further make combinations of Ξ^- candidates with pairs of positively charged tracks in the event assuming them to be π^+ 's and the remaining negatively charged tracks assuming them to be K^- 's. For the K^- tracks, the measured ionization losses are required to be consistent with the K^- assumption. Figure 9 shows the invariant mass distribution of all $\Xi^- K^- \pi^+ \pi^+$ combinations with $x_p > 0.3$, where $x_p = p/p_{max}$. Here p is the momentum of Ω_c^0 and $p_{max} = \sqrt{E_{beam}^2 - m_{\Omega_c^0}^2}$, where E_{beam} is the beam energy and $m_{\Omega_c^0}$ is the mass of Ω_c^0 . If a Ω_c^0 is produced from a B meson decay, it will be accompanied by a $\bar{\Xi}$ and a π . Because of the heavy mass of the combined Ω_c^0 , $\bar{\Xi}$ and π , little energy is left for the kinetic energy of these decay products. Actually, the Ω_c^0 produced from the B meson decay is kinematically limited to $x_p < 0.3$ region. By requiring x_p of the Ω_c^0 be greater than 0.3, we exclude any Ω_c^0 's produced from B meson decay. Only Ω_c^0 's produced from the continuum events are included in Figure 9.

A fit to this mass distribution with a width fixed at the Monte Carlo predicted value of $22 \text{ MeV}/c^2$ yields a signal of 27.8 ± 7.3 events at a mass of 2751.5 ± 3.0

MeV/c^2 . We identify this as the $\Omega_c^0(\text{css})$ baryon. Several theoretical models predicted the mass of Ω_c^0 to be in this region.¹⁷ After correcting for the efficiencies of observing the decay mode using a Monte Carlo simulation, the production cross section times branching fraction is measured to be $1.30 \pm 0.34 \text{ pb}$ for $x_p > 0.3$. The error is statistical only. The results are presented in Table 4.

Table 4. Results of Fits to the Ω_c^0 Mass Distributions in Figures 9 and 10

Decay Mode	Fitted Mass	Fitted Width	MC Width	Signal Area	$B \cdot \sigma(x_p > 0.3)$
	MeV/c^2	MeV/c^2	MeV/c^2	candidates	pb
$\Xi^- K^- \pi^+ \pi^+$	2751.5 ± 3.0	24.0 ± 7.6	22.3 ± 0.5	27.8 ± 7.3	1.31 ± 0.35
$\Omega^- \pi^+$	2754.1 ± 3.0	24.6 ± 6.9	22.3 ± 0.6	16.2 ± 4.5	0.87 ± 0.25
Weighted Average Mass = $2752.8 \pm 2.1 MeV/c^2$					
Simultaneous Fitted Mass = $2752.7 \pm 2.1 MeV/c^2$					

1.3.2.2 The Study of the $\Omega_c^0 \rightarrow \Omega^- \pi^+$ Decay Mode

For the decay mode of $\Omega_c^0 \rightarrow \Omega^- \pi^+$, we have reconstructed Ω^- candidates by pairing each Λ candidate with each of the remaining negatively charged tracks which are assumed to be K^- . By requiring the measured ionization losses of K^- candidates to be consistent with the K^- assumption, we eliminate the reflection of Ξ^- 's to Ω^- 's due to π^- 's faking K^- 's. We have obtained $57 \pm 12 \text{ } MeV/c^2$ Ω^- 's at a mass of $1671.7 \pm 0.5 \text{ } MeV/c^2$. We then make combinations of Ω^- candidates with other positively charged tracks remaining in the event assuming them to be π^+ 's. Figure 10 shows the invariant mass distribution of $\Omega^- \pi^+$ combinations with $x_p > 0.3$. A fit to this mass distribution with a width fixed at the Monte Carlo predicted value of $22 \text{ } MeV/c^2$ yields a signal of 16.2 ± 4.5 events at a mass of $2754.1 \pm 3.0 \text{ } MeV/c^2$. After correcting for the efficiencies of observing this decay mode by Monte Carlo simulation, the production cross section times branching fraction is measured to be $0.87 \pm 0.25 \text{ pb}$. The results are presented in Table 4.

1.3.2.3 The Summary of the Ω_c^0 Study

We have seen the evidence for the production of the Ω_c^0 by reconstructing it through two different decay modes, $\Omega_c^0 \rightarrow \Omega^- \pi^+$ and $\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$. A simultaneous fit to the two mass distributions with Gaussian functions constrained to have a common mean mass but with width fixed at the Monte Carlo predicted values for each mode, results in a mass at $2752.7 \pm 2.1 \text{ MeV}/c^2$ and a combined signal area of 43.9 ± 8.6 . The weighted average mass of the two fitted masses is $2752.8 \pm 2.1 \text{ MeV}/c^2$, which agrees well with the value obtained by the simultaneous fit. These values are presented in Table 4.

1.3.2.4 New decay modes of Ξ_c^0 production

Our observations of Ξ_c^0 and Ξ_c^+ , combined with independent observation of them by J. Yelton from Florida, have been published by CLEO in two papers.^{18,19} We have further investigated $\Xi_c^0 \rightarrow \Xi^- \pi^+ \pi^- \pi^+$ mode and the Figure 11 shows the invariant mass distribution of the combinations of $\Xi^- \pi^+ \pi^- \pi^+$ in the region of $x_p > 0.4$. The threshold x_p for the Ξ_c^0 decayed from B meson is $x_p < 0.4$. A fit to this mass distribution with a width fixed at the Monte Carlo predicted value of $20 \text{ MeV}/c^2$ yields a signal of 35.8 ± 12.0 events at a mass of $2472.5 \pm 3.6 \text{ MeV}/c^2$, which agrees with the mass measurement $2472 \pm 3 \text{ MeV}/c^2$ obtained from the decay mode $\Xi_c^0 \rightarrow \Xi^- \pi^+$.¹⁹

We have investigated the decay mode of $\Xi_c^0 \rightarrow \Omega^- K^+$. This decay mode is possible only through W exchange between the c quark and d quark in the Ξ_c^0 and the measurement of the branching ratio of this mode will give us more information on the c quark decay mechanism. Figure 12 shows the invariant mass distribution of the combinations of $\Omega^- K^+$. A fit to this mass distribution with a width fixed at the Monte Carlo predicted value of $20 \text{ MeV}/c^2$ yields a signal of 9.8 ± 3.5 events at a mass of $2474.1 \pm 3.4 \text{ MeV}/c^2$, which agrees with the previous measurement by CLEO.¹⁹ The statistics for this mode is not enough to draw any firm conclusion with the present data. We have investigated the decay mode of $\Xi_c^+ \rightarrow \Omega^- K^+ \pi^+$ and found no evidence of any signal.

1.3.2.5 Search for $B \rightarrow \Xi_c X$

All the Ξ_c^0 produced from B meson decay are kinematically limited in the $x_p < 0.4$ region. We have searched for $B \rightarrow \Xi_c$ by investigation of the Ξ_c production in the $x_p < 0.4$ region through its decay mode of $\Xi_c^0 \rightarrow \Xi^- \pi^+$. Figure 13 shows the invariant mass distribution of the combinations of $\Xi^- \pi^+$ from the data on the $\Upsilon(4S)$ and the data just below the $\Upsilon(4S)$ energy (continuum) in the region of $x_p < 0.4$. There is an excess of 23.5 ± 8.3 events from the data on the $\Upsilon(4S)$ after subtracting the properly scaled contribution from the continuum data, though the data is statistically limited to derive any firm conclusion.

1.3.2.6 Search for Ξ_c^{*0} and Ξ_c^{*+}

There are several spin-excited states of charmed strange baryons which are expected to decay to $\Xi_c^0(c[sd])$ and $\Xi_c^+(c[su])$ by emitting either π or γ , namely $\Xi_c^{0'}(c\{sd\})$, $\Xi_c^{+'}(c\{su\})$, $\Xi_c^{*0}(\{csd\})$ and $\Xi_c^{*+}(\{csu\})$.¹⁷ The mass splittings between these excited states and Ξ_c show very strong model dependency. But the mass splitting $\Xi_c' - \Xi_c$ is always found to be less than $140 \text{ MeV}/c^2$,^{17,20} so that Ξ_c' should decay into Ξ_c through γ emission. Since CLEO 1.5 cannot measure γ momentum, we cannot see Ξ_c' from our data, if the theoretical prediction is correct. However, the transition $\Xi_c^* \rightarrow \Xi_c \pi$ is allowed for some models.^{21,22} The mass measurements of these states are very crucial to test many different theoretical models.

We have searched Ξ_c^* through the following decay modes:

$$\begin{aligned}\Xi_c^{*0} &\rightarrow \Xi_c^+ \pi^- \\ \Xi_c^{*+} &\rightarrow \Xi_c^0 \pi^+\end{aligned}$$

and have not found any statistically significant evidence for these states.

1.3.3 Baryons from B Meson Decay

Since B mesons can decay into charmed or non-charmed baryons, they offer a unique laboratory for the study of baryon production in weak decays. The non-

charmed baryons such as protons, Λ 's and Ξ^- 's may be produced either from the secondary decays of charmed baryons or directly from hadronization processes via virtual W^- or spectator quark fragmentation. Inclusive decays of B mesons into non-charmed baryons have already been reported by CLEO^{23,24} and ARGUS,²⁵ who have also presented the first direct evidence²⁶ for B decays to the charmed baryon Λ_c^+ . Here, we report on improved measurements of these processes.

In this analysis, we define a track to be *consistent* with a pion, kaon or proton hypothesis if its measured dE/dx is within 2σ of the expected value, with σ being the rms experimental dE/dx resolution. A charged track is loosely (positively) *identified* as a kaon or proton if, in addition to being consistent with the specific mass hypothesis, the measured dE/dx is at least $1\sigma(2\sigma)$ away from that expected for the pion hypothesis. Similar definitions are introduced for the *TOF* measurements on protons, for which σ is then the timing resolution.

1.3.3.1 Inclusive Baryon Production in B Decays

To measure the inclusive branching fraction $B(B \rightarrow pX)$,²⁷ we use only antiprotons because interactions of particles in the beam pipe produce a large background in the proton sample. Further, a stronger definition of identification is used to select the $\bar{p}$ candidates; the specific ionization (dE/dx) or time-of-flight (*TOF*) measurement for the track must be within 2σ of the expected value for antiproton and at least 2σ away from that expected for *both* pion and kaon.

Even for this *strong* identification defined above, pions and kaons are occasionally misidentified as antiprotons. To subtract this background, we also measure the number of *positively* identified π^- 's and K^- 's in each momentum interval. Knowing the detection efficiencies for these particles and the rates at which π^- 's and K^- 's are misidentified as $\bar{p}$'s (and vice versa), which are calculated using clean samples of identified π^- 's, K^- 's and $\bar{p}$'s from the data, we can then derive the number of π^- 's and K^- 's faking protons and subtract this contribution.

Since hadrons produced in B decay at CLEO are kinematically limited to momenta below $2.5 \text{ GeV}/c$ and furthermore, antiprotons below $0.3 \text{ GeV}/c$ suffer large energy losses in the beam pipe, we restrict our analysis to the momentum range $0.3\text{--}2.5 \text{ GeV}/c$. This momentum range is then divided into bins of $0.2 \text{ GeV}/c$, and the number of $\bar{p}$ candidates for the $\Upsilon(4S)$ and continuum data is

found for each bin independently.

Contamination from muons is negligible over the whole momentum range of interest; electrons, however, may be confused with $\bar{p}$ in the momentum interval $0.9 - 1.1 \text{ GeV}/c$. In this momentum range, the *TOF* (but not the dE/dx) rejection of electrons is still useful. It is for this reason, combined with the pure dE/dx detection efficiency for $\bar{p}$'s above $1 \text{ GeV}/c$ (but excellent efficiency in the region $0.4 - 1 \text{ GeV}/c$), that we chose to use only dE/dx measurements at low momenta (0.3 to $0.7 \text{ GeV}/c$) and only *TOF* measurements at higher momenta (0.9 to $1.7 \text{ GeV}/c$). In the momentum range common to both devices (0.7 to $0.9 \text{ GeV}/c$), we use the weighted average of the measurements from the two devices.

To find the raw $\bar{p}$ yield from B decay, the continuum yield in each momentum bin is scaled by a factor $f = 2.08 \pm 0.01$ and then subtracted from the $\Upsilon(4S)$ yield. This scale factor accounts for the differing integrated luminosities and continuum cross sections at the two energies in the data sample. The corrected yield in each momentum interval is then calculated by dividing this raw yield by the momentum dependent efficiency, which is obtained from Monte Carlo simulation; This simulation includes particle identification efficiencies, geometrical acceptances of the different devices, and track reconstruction efficiencies. The corrected $\bar{p}$ yields are then multiplied by 2 to take into account the assumed equal contribution from protons. Finally, we also calculate the corrected hadron yields per B decay:

$$\frac{1}{N_B} \cdot \frac{dY_c}{dp} = \frac{1}{2 \cdot N_{B\bar{B}}} \cdot \frac{\Delta Y_c(p)}{\Delta p},$$

where ΔY_c denotes the corrected yield in the momentum interval Δp , $N_{B\bar{B}}$ is the total number of $B\bar{B}$ events and $N_B = 2 \cdot N_{B\bar{B}}$.

Since there is no observed $\bar{p}$ signal from B decays beyond $1.7 \text{ GeV}/c$, we sum the contributions from 0.3 to $1.7 \text{ GeV}/c$ and arrive at 35218 ± 2511 p and $\bar{p}$ candidates from B decays. Based on fits using simple functions and our Monte Carlo model (see below), $(90 \pm 5)\%$ of the events lie in this momentum range, with the stated uncertainty representing the range of values found. Correcting for this unseen portion of the spectrum, we obtain $39131 \pm 2790 \pm 2247$ p 's and $\bar{p}$'s actually produced. From this, we calculate the inclusive branching ratio $B(B \rightarrow pX) = (8.2 \pm 0.6 \pm 0.5)\%$, with the first error being statistical and the second error being systematic.

Using the $p\pi^-$ decay mode of the Λ , we have measured $B(B \rightarrow \Lambda X)$.²⁷ Λ candidates are formed from pairs of oppositely charged tracks which intersect at a radial distance of more than 1 mm from the primary vertex. The dE/dx measurements of the positive tracks had to be consistent with those expected for protons. The Λ reconstruction efficiency, which includes the branching fraction $B(\Lambda \rightarrow p\pi^-)$,²⁸ varies from 5% at 0.3 GeV/c to 30% above 1.2 GeV/c. We therefore consider only $p\pi^-$ combinations with momentum from 0.3 to 2.5 GeV/c. The total number of Λ 's from B decays is found according to the momentum-dependent analysis procedure described above for protons. The corrected yield of Λ from B decays in the momentum region 0.3 to 2.5 GeV/c is 15949 ± 1830 , with the error being statistical only. Correcting for the momentum acceptance, which is estimated to be $(85 \pm 10)\%$, we find $18764 \pm 2153 \pm 2735$ Λ 's produced, for an inclusive branching fraction $B(B \rightarrow \Lambda X) = (3.9 \pm 0.4 \pm 0.6)\%$.

The inclusive branching fraction $B(B \rightarrow \Xi^- X)$ is measured through the decay chain $\Xi^- \rightarrow \Lambda\pi^-$ and $\Lambda \rightarrow p\pi^-$. Λ candidates are selected as before. We then consider combinations of Λ with additional negatively charged tracks in the event such that vertex of the Ξ^- candidate be at least 4 mm away from the primary vertex and closer to it than the Λ vertex. Further, since the contribution of Ξ^- 's produced from continuum e^+e^- annihilations is large, we require that the Fox-Wolfram shape parameter²⁹ R_2 be less than 0.5, the upper limit for $B\bar{B}$ events in this decay channel. The Ξ^- reconstruction efficiency, which includes the branching fractions into the observed final state, varies from 8% at 0.25 GeV/c to 13% above 1.5 GeV/c. The raw and corrected yields are determined as described previously. Integrating the contributions from momenta below 2.5 GeV/c, we find 1365 ± 235 Ξ^- 's from B decays, from which we calculate $B(B \rightarrow \Xi^- X) = (0.28 \pm 0.05 \pm 0.04)\%$.

We have used the $pK^-\pi^+$ decay mode of the Λ_c^+ to search for the decay $\bar{B} \rightarrow \Lambda_c^+ X$. All $pK^-\pi^+$ combinations are formed using loosely identified kaon and positively identified proton candidates, with the remaining charged tracks in the event interpreted as pion candidates. The pion candidates are required to have momenta greater than 0.3 GeV/c, reducing the combinatorial background significantly with only a small loss in Λ_c^+ reconstruction efficiency. Only $pK^-\pi^+$ combinations with momentum less than the kinematic limit of 2.5 GeV/c are con-

sidered. Figure 14 shows the resulting invariant $pK^-\pi^+$ mass distributions for the $\Upsilon(4S)$ and the scaled continuum data, clearly demonstrating an excess at the resonance. We fit this distribution with a Gaussian signal of width $FWHM = 16 \text{ MeV}/c^2$, as predicted by Monte Carlo simulation. The mean from this Gaussian fit is $2284.9 \pm 1.5 \text{ MeV}/c^2$, consistent with the Λ_c^+ mass of $2285.0 \pm 0.6 \pm 1.5$ obtained from Λ_c^+ continuum production at CLEO³⁰ and with the current world average of $2285.2 \pm 1.2 \text{ MeV}/c^2$.²⁸ We have studied the possibility that the observed Λ_c^+ signal is artificially produced from the decays $D^+ \rightarrow K^-\pi^+\pi^+$ and $D_s^+ \rightarrow K^-K^+\pi^+$, with either a pion or a kaon misidentified as a proton. Recalculating the invariant masses of $pK^-\pi^+$ candidates within 2σ of the Λ_c^+ mass with the proton candidate interpreted as a pion or a kaon, we see no evidence for an enhancement in the region of the D^+ or D_s^+ mass.

Since the branching ratio $B(\Lambda_c^+ \rightarrow pK^-\pi^+)$ is not known, the measured Λ_c^+ momentum spectrum, which is displayed in Figure 15, is necessarily multiplied by this unknown factor. We calculate $1291 \pm 312 \Lambda_c^+$ baryons produced in B decays and detected in the $pK^-\pi^+$ decay mode, from which we extract the product branching fraction $B(B \rightarrow \Lambda_c^+ X) \cdot B(\Lambda_c^+ \rightarrow pK^-\pi^+) = (0.269 \pm 0.065 \pm 0.039)\%$.

Using above results together with reasonable assumptions, it is possible to estimate from our data the value of the relative ratio $R_{\Xi_c} = B(\bar{B} \rightarrow \Xi_c X) / B(\bar{B} \rightarrow \Lambda_c^+ X)$. We expect the decay $\bar{B} \rightarrow \Xi_c X$ ³¹ to be suppressed relative to $\bar{B} \rightarrow \Lambda_c^+ X$, since the former can only proceed through $s\bar{s}$ creation from the vacuum sea. Here, we assume that all Ξ^- and Ξ^0 have Ξ_c parentage and that all Λ 's are produced either from Λ_c^+ or from Ξ_c via an intermediate Ξ^- or Ξ^0 . If we further assume $B(\Xi_c \rightarrow \Xi^- X) = B(\Xi_c \rightarrow \Xi^0 X)$, we find that the ratio of interest can be expressed as:

$$R_{\Xi_c} = \frac{\alpha \cdot N_{\Xi^-}}{N_{\Lambda} - 2 \cdot N_{\Xi^-}},$$

where $\alpha = B(\Lambda_c^+ \rightarrow \Lambda X) / B(\Xi_c \rightarrow \Xi^- X)$ is assumed to be of the order of 2. Substituting the fully corrected yields of $N_{\Lambda} = 18764 \pm 2153 \pm 2735$ and $N_{\Xi^-} = 1365 \pm 235 \pm 193$ presented earlier, we obtain

$$R_{\Xi_c} = \alpha \cdot (8.5 \pm 2.9)\% = \alpha \cdot 12.2\% \text{ (90\% C.L.)}$$

Of course, this estimate depends on our choice of a value for α . Further, since we have already observed the decay $\Lambda_c^+ \rightarrow \Xi^- K^+ \pi^+$ the assumption that all Ξ^- 's

are from the secondary decays of Ξ_c 's is an overestimate. The choice of $\alpha = 2$ gives the more conservative upper limit of $R_{\Xi_c} < 24\%$ at the 90% C.L..

1.3.3.2 Determination of Baryon Production Mechanisms

There are many different mechanisms for baryon production in B meson decay; they depend on the b quark coupling ($b \rightarrow cW^-$, $b \rightarrow uW^-$ or $b \rightarrow sg$) and the type of diagram (spectator, exchange, annihilation or penguin). To conserve baryon number, the final state must always contain a baryon/antibaryon pair, limiting the number of forms.

After considering all possible mechanisms which require popping of less than two $s\bar{s}$ pairs from the vacuum sea (those would be doubly suppressed), we conclude that final states of the forms $\Theta_c \bar{N} X$ ($\Xi_c \bar{Y} X$) and $DN \bar{N} X$ ($DY \bar{Y} X$) should be dominating in B decays to baryons. The forms given in parentheses would be suppressed since they require the creation of one $s\bar{s}$ pair. Here, N stands for charmless non-strange baryons (such as p , n , Δ , N^*), Y for charmless strange baryons (Λ , Σ^0 , Σ^+ , Σ^-), Θ_c denotes charmed non-strange baryons (Λ_c^+ , Σ_c^0 , Σ_c^+ , Σ_c^{++}), Ξ_c represents charmed strange baryons (Ξ_c^0 , Ξ_c^+), and D symbolizes a charmed non-strange meson (D^0 and D^+). X is any combination of charmless mesons, with or without leptons.

We now present the results of our correlation studies (Λ - $\bar{\Lambda}$, Λ -lepton, Λ - $\bar{p}$, p - $\bar{p}$) which were undertaken in order to discriminate among the above two forms of final states.

If decays of the form $\Lambda^0 \bar{\Lambda}^0 X$ were the source of all Λ 's in B decay, the ratio $f_{\Lambda \bar{\Lambda}} = B(B \rightarrow \Lambda^0 \bar{\Lambda}^0 X) / B(B \rightarrow \Lambda^0 X)$ would be 0.5. Since only the forms $\Xi_c \bar{Y} X$ and $DY \bar{Y} X$ can result in a final state of $\Lambda^0 \bar{\Lambda}^0 X$, a value of $f_{\Lambda \bar{\Lambda}}$ near 0.5 would indicate that these forms are dominant; a small value of $f_{\Lambda \bar{\Lambda}}$, on the contrary, would mean the forms $\Theta_c \bar{N} X$ and $DN \bar{N} X$ dominate in B decays to baryons.

In order to form $\Lambda \bar{\Lambda}$ candidates, we select events containing both a Λ and $\bar{\Lambda}$, each satisfying the same criteria as in our inclusive Λ analysis, except for the Λ mass cut. We then require the $\Lambda(\bar{\Lambda})$ momenta to be within 0.4 and 2.3 GeV/c , and the masses of the Λ and $\bar{\Lambda}$ candidates to satisfy the relation:

$$\sqrt{\Delta M_{\Lambda}^2 + \Delta M_{\bar{\Lambda}}^2} \leq 6 \text{ MeV}/c^2,$$

where $6 \text{ MeV}/c^2$ is the width of the Λ signal in the $p\pi^-$ mass distribution. After subtracting backgrounds, which are estimated by applying similar mass cuts on the sidebands of the $\Lambda\bar{\Lambda}$ signal, and after taking into account the continuum contribution, we find $57 \pm 35 \Lambda\bar{\Lambda}$ events from direct $\Upsilon(4S)$ decays. From this number, we still have to subtract the contribution for the case where Λ and $\bar{\Lambda}$ candidates originate from different B 's. Utilizing the measured branching fraction $B(\bar{B} \rightarrow \Lambda^0 X)$ and the Λ reconstruction efficiency found from Monte Carlo studies, we calculate this contribution to be 6.5 ± 3.5 events.

To arrive at the actual number of $\Lambda\bar{\Lambda}$ events produced in $B\bar{B}$ decays, we divide the adjusted number of $\Lambda\bar{\Lambda}$ candidates by the $\Lambda\bar{\Lambda}$ reconstruction efficiency, which is derived from Monte Carlo studies to be $(4.0 \pm 0.4)\%$. We obtain 1263 ± 891 as the contribution from $B \rightarrow \Lambda^0 \bar{\Lambda}^0 X$, which corresponds to an inclusive branching fraction $B(B \rightarrow \Lambda^0 \bar{\Lambda}^0 X) < 0.50\%$ and ratio $f_{\Lambda\bar{\Lambda}} < 13\%$, both at the 90% C.L. This result suggests that it is unlikely that the forms $\Xi_c \bar{Y} X$ and $DY\bar{Y} X$ are dominant in B decay.

Measuring Λ -lepton correlations in B decays can help determining whether final states of the form $\Theta_c \bar{N} X$ or $DY\bar{Y} X$ are dominant in Λ formation. Studying these correlations therefore complements our study of $\Lambda\bar{\Lambda}$ correlations. The two decay processes of interest here, resulting in a high momentum lepton with which to tag the B flavor, are:

1. $\bar{B} \rightarrow \Theta_c \bar{N} X_h, \Theta_c \rightarrow \Lambda X_h; B \rightarrow X_h l^+ \nu;$
2. $\bar{B} \rightarrow \Lambda^0 \bar{\Lambda}^0 X_h; B \rightarrow X_h l^+ \nu,$

where X_h denotes one or more hadrons. All other processes, which produce leptons of lower momentum, are considered backgrounds in this study. These processes include decay mechanisms incorporating secondary leptons, Λ -lepton correlations due to $\psi(\psi)$ production and those due to misidentification of hadrons as leptons.

We note that process (a) contributes only to Λl^+ correlations, whereas process (b) contributes to both Λl^+ and Λl^- correlations. After accounting for the contributions from all the background processes, the observation of Λl^+ and absence of Λl^- correlations would point towards the importance of $\Theta_c \bar{N} X$ as the dominant mechanism for B decay to Λ . Equal rates for the two correlations would support $DY\bar{Y} X$ as the dominant mechanism.

To search for Λ -lepton candidate events, we consider electrons and muons with momenta between 1.4 and 2.4 GeV/c and Λ candidates with momenta between 0.4 and 2.0 GeV/c . The lower lepton momentum cut suppresses leptons from the secondary decays of charmed particles. The upper Λ and lepton momenta cuts correspond to the upper limit of the corresponding observed momentum spectra in B decays. Another effective way of suppressing background is to require $-0.8 < \cos\theta_{\Lambda l} < 0.9$, where $\theta_{\Lambda l}$ is defined as the angle between the Λ and the lepton in the laboratory rest frame.³²

When fitting the data with the mass and width found from the inclusive Λ sample, we obtain $112 \pm 12 \Lambda l^+$ and $41 \pm 8 \Lambda l^-$ candidates. After subtracting all known backgrounds and taking into account the contribution from $B^0 - \bar{B}^0$ mixing^{33,34} (an expected Λl^+ correlation transforms to a Λl^- or $\bar{\Lambda} l^+$ correlation), we arrive at a final correlation signal of 110 ± 12 for Λl^+ as compared to -2 ± 9 for Λl^- , the latter one being consistent with zero. The absence of Λl^- and the observation of Λl^+ correlations strongly suggests that charmed baryons are the dominant source of all Λ 's observed in B meson decays.

So far, we have shown that B decays to baryons dominantly proceed via final states $\Theta_c \bar{N} X$ or $D N \bar{N} X$ and that all Λ in B decay have Θ_c parentage. If we now assume that Λ_c^+ saturates Θ_c then B decays resulting in Λ proceed via the form $\Lambda_c^+ \bar{N} X$. The study of $\Lambda \bar{p}$ correlations makes it possible to estimate the fraction of the time the $\bar{N}$ is a $\bar{p}$. Under the above assumption, all correlations between Λ and $\bar{p}$ observed in B decay are produced from decays of the form $\Lambda_c^+ \bar{p} X$, and we can express the relative fraction of $\bar{p}$ production in association with Λ_c^+ as:

$$f_p = \frac{B(B \rightarrow \Lambda_c^+ \bar{p} X)}{B(B \rightarrow \Lambda_c^+ X)} = \frac{B(B \rightarrow \Lambda \bar{p} X)}{B(B \rightarrow \Lambda X)} = \frac{N_{\Lambda \bar{p}}}{N_{\Lambda}},$$

where $N_{\Lambda \bar{p}}$ and N_{Λ} denote the total numbers of $\Lambda \bar{p}$ and Λ candidates produced in B decays. We note that if we define f_n as the according relative fraction of neutron production, then $f_p + f_n = 1$.

In our search for $\Lambda \bar{p}$ candidates, we use Λ 's with momenta between 0.4 and 2.0 GeV/c and strongly identified antiprotons with momenta from 0.3 to 1.1 GeV/c , where the upper momentum cut on the $\bar{p}$ sample reduces contributions from π^- being misidentified as $\bar{p}$'s. After continuum subtraction, we observe $1526 \pm 121 \Lambda \bar{p}$ and $190 \pm 68 \Lambda p$ candidates. Backgrounds to the $\Lambda \bar{p}$ sample arise from π^- 's

faking $\bar{p}$'s or from Λ and $\bar{p}$ produced from opposite B and $\bar{B}$. Since both of these sources are equally likely to contribute to $\Lambda\bar{p}$ and Λp candidates, we use the observed Λp signal as an estimate of the background for the $\Lambda\bar{p}$ signal. Subtracting this contribution, we observe 1336 ± 139 $\bar{B} \rightarrow \Lambda\bar{p}X$ correlations corresponding to 2825 ± 304 $B \rightarrow \Lambda X$ candidates with the Λ 's in the selected momentum range. Correcting for the antiproton identification efficiency, drift chamber track reconstruction efficiency and solid angle acceptance, and a momentum acceptance correction obtained from our Monte Carlo model for B decays to baryons, we arrive at $2136 \pm 222 \pm 217$ produced $\Lambda\bar{p}$ correlations. From this, we calculate $f_p = (76 \pm 11 \pm 8)\%$, and further $B(B \rightarrow \Lambda\bar{p}X) = (3.0 \pm 0.5 \pm 0.6)\%$, making use of the result on $B(B \rightarrow \Lambda X)$ derived earlier.

The forth correlation study carried out in this analysis is the one of $p\bar{p}$. These correlations arise from protons produced from secondary decays of Λ_c^+ and antiprotons produced in association with them, or from direct decays into $p\bar{p}X$ and $\Lambda\bar{\Lambda}X$. To measure the inclusive branching fraction $B(B \rightarrow p\bar{p}X)$, we use positively identified p 's and $\bar{p}$'s in the momentum range 0.3 to 0.9 GeV/c. This tight momentum cut is necessary to suppress the large background from pions and kaons faking protons. These processes, as well as contributions from random pairings of p and $\bar{p}$ from different B and $\bar{B}$, are expected to contribute equally to $p\bar{p}$ and pp or $\bar{p}\bar{p}$ correlations. We therefore use the observed pp and $\bar{p}\bar{p}$ signal as an estimate of the remaining backgrounds. After continuum and background subtraction, we obtain 3900 ± 140 $p\bar{p}$ candidates from B decay. This corresponds to $13015 \pm 467 \pm 170$ $p\bar{p}$ correlations actually produced, from which we derive $B_{p\bar{p}} = B(B \rightarrow p\bar{p}X) = (2.7 \pm 0.1 \pm 0.4)\%$. We also calculate $f_{p\bar{p}} = B(B \rightarrow p\bar{p}X)/B(B \rightarrow pX) = (33 \pm 3 \pm 5)\%$, where we made use of the measured inclusive branching fraction $B(B \rightarrow pX)$ reported on earlier.

1.3.3.3 Estimation of Absolute Branching Fractions

Building on our measured branching fractions and our observed correlations we can, using reasonable assumptions, estimate many absolute branching fractions. The study of $\Lambda\bar{\Lambda}$ correlations showed that the forms $\Theta_c\bar{N}X$ and $DN\bar{N}X$ are the main contributors to B decays to baryons, with $\Xi_c\bar{Y}X$ and $DY\bar{Y}X$ being

unlikely sources. The results on Ξ^- production also indicate that B decay to Ξ_c is small compared to that of Λ_c^+ . Our Λ -lepton correlation study indicates that in B decay all Λ , a natural source of p and n , come from Θ_c parentage. We now assume that *all* baryons in B decay originate from $\Theta_c \bar{N}X$ and that Λ_c^+ saturates Θ_c . These assumptions are supported by our Monte Carlo model, which assumes $\Lambda_c^+ \bar{N}X$ as the only source of baryons.

We define the following simplifying notations for B decays:

$$B_b = B(B \rightarrow bX), \quad b = p, n, \Lambda;$$

$$B_{\Lambda_c^+} = B(\bar{B} \rightarrow \Lambda_c^+ X).$$

These final state baryons include contributions from secondary decays of higher mass baryons. With the above notation, the fraction f_p used earlier is defined by

$$B_{\Lambda_c^+} \cdot f_p = B(\bar{B} \rightarrow \Lambda_c^+ \bar{p}X).$$

Following the decay model assumptions, $\bar{p}$ are produced in association with Λ_c^+ 's from decays of the form $\bar{B} \rightarrow \Lambda_c^+ \bar{p}X$; protons are produced from secondary decays of the Λ_c^+ 's. This can be expressed as

$$B_p = B_{\Lambda_c^+} \cdot f_p + B_{\Lambda_c^+} \cdot B(\Lambda_c^+ \rightarrow pX).$$

Proton-antiproton correlations arise when $\bar{B} \rightarrow \Lambda_c^+ \bar{p}X$ and $\Lambda_c^+ \rightarrow pX$ so that

$$B_{p\bar{p}} = B_{\Lambda_c^+} \cdot f_p \cdot B(\Lambda_c^+ \rightarrow pX).$$

In these last two equations we have already determined B_p , f_p and $B_{p\bar{p}}$, leaving two unknowns. Eliminating $B(\Lambda_c^+ \rightarrow pX)$ gives

$$B_{\Lambda_c^+} = (B_p \cdot f_p - B_{p\bar{p}}) / f_p^2 = (6.1 \pm 0.8 \pm 1.0)\%.$$

This result is consistent with the theoretical estimate $B(B \rightarrow \Lambda_c^+ \bar{N}X) \approx (2 \sim 13)\%$ calculated by I. Bigi³⁵ in the context of a simple-minded spectator model for B decays.

If instead we eliminate $B_{\Lambda_c^+}$ in these two equations, we obtain an expression for the inclusive branching fraction of Λ_c^+ to protons as

$$B(\Lambda_c^+ \rightarrow pX) = \frac{B_{p\bar{p}} \cdot f_p}{B_p \cdot f_p - B_{p\bar{p}}} = (58 \pm 11 \pm 17)\%.$$

Under our assumptions, all Λ_c^+ must eventually decay to either p or n , so that $B(\Lambda_c^+ \rightarrow nX) = (42 \pm 11 \pm 17)\%$. Using these same decay assumptions, the only source for Λ 's in B decay is given by the process $\Lambda_c^+ \rightarrow \Lambda X$; therefore, $B_\Lambda = B_{\Lambda_c^+} \cdot B(\Lambda_c^+ \rightarrow \Lambda X)$. With the value of $B_{\Lambda_c^+}$ we have just derived and our measured value of B_Λ , we obtain $B(\Lambda_c^+ \rightarrow \Lambda X) = (64 \pm 11 \pm 14)\%$. Applying our assumptions to inclusive B decays to neutrons results in an expression for B_n similar to that of B_p given earlier. Since all necessary branching fractions have been estimated, we can calculate $B_n = (4.0 \pm 1.1 \pm 1.3)\%$.

Finally, we can estimate the *exclusive* branching fraction $B(\Lambda_c^+ \rightarrow pK^-\pi^+)$, using the value of $B_{\Lambda_c^+} \cdot B(\Lambda_c^+ \rightarrow pK^-\pi^+) = (0.269 \pm 0.065 \pm 0.039)\%$ reported earlier and $B_{\Lambda_c^+}$ estimated above:

$$B(\Lambda_c^+ \rightarrow pK^-\pi^+) = (4.4 \pm 1.2 \pm 1.0)\%.$$

This measurement is consistent with the value $(4.1 \pm 2.4)\%$ reported by the ARGUS collaboration,³⁶ using the same procedure as ours. Both results are also consistent with the lower limit of 4.4% (90% C.L.) reported by the LEBC-EHS collaboration.³⁷ The new result is higher than the value of $(2.2 \pm 1.0)\%$ reported by the MARK II collaboration,³⁸ which was also a model dependent estimate of the branching fraction. However, it is consistent with the world value²⁸ of $(2.8 \pm 0.8)\%$.

1.3.3.4 A Monte Carlo Model of B Meson Decays to Baryons

We now describe a model of B decays to baryons, which simultaneously predicts the shape of the $\bar{p}$, Λ and Λ_c^+ spectra within the limits of the experimental errors. The success of this model further supports the results of our studies on $\Lambda\bar{\Lambda}$, Λ -lepton, and $p\bar{p}$ correlations in B decays. The salient features of this model are:

1. All decays of $\bar{B}$ mesons to baryons proceed through final states of the form $\Lambda_c^+\bar{N}X$. These states are generated using a Monte Carlo model in which $\bar{B} \rightarrow \Pi W^-$, where Π is an intermediate particle with mass M_Π , decaying into $\Lambda_c^+\bar{N}$. The W^- couples into $l\bar{\nu}$ and $\bar{u}d$ in ratios chosen to be consistent with the measured B semileptonic branching fractions. The mass of the intermediate Π is chosen according to a Breit-Wigner distribution,

whose peak, width, and minimum and maximum mass cutoff values are free parameters of the model.

2. All the Λ and p observed in B decays are from the secondary decays of the Λ_c^+ while the $\bar{p}$ are produced in association with it. Only a small fraction of the Λ_c^+ decay has been measured, so we chose a model which reproduces the observed branching fractions into Λ , p , and n and also agrees with the measured semileptonic branching fraction.
3. All ' $q\bar{q} \rightarrow \text{hadrons}$ ' processes are allowed to proceed according to the Lund prescription.³⁹

The Λ_c^+ , Λ and $\bar{p}$ momentum spectra were fit simultaneously by varying the parameters of the Π mass distribution. The best overall fit with a confidence level of about 23% was obtained for a distribution with peak at $3.35 \text{ GeV}/c^2$, width (FWHM) of $0.50 \text{ GeV}/c^2$, and an allowed mass range from 3.23 to $4.50 \text{ GeV}/c^2$; the minimum mass cutoff is dictated by the rest mass of the $\Lambda_c^+ \bar{N}$ combination. In Figure 15, we show the Monte Carlo prediction from this model for the case of the Λ_c^+ as a thick smooth curve over the measured momentum spectrum. In the same figure we also show Monte Carlo predictions for two, three and four body contributions of the form $\Lambda_c^+ \bar{p} m \pi$ ($m = 0, 1$ and 2). From the displayed curves it is clear that the decay is dominated by many-body exclusive channels.

We consider the Monte Carlo model for B decays to baryons outlined above as an algorithm for reproducing the inclusive momentum spectra. The $\bar{p}$, Λ and Λ_c^+ momentum spectra are reproduced fairly by our model. The assumption that all baryons are produced from final states of the form $\Lambda_c^+ \bar{N} X$ is further supported by our Λ -lepton and $\Lambda \bar{\Lambda}$ correlation studies, lending dynamical support for the model. The Ξ^- spectrum is not reproduced so well when fitted to our model predictions using $\Lambda_c^+ \rightarrow \Xi^- K^+ \pi^+$. This may be due to lack of information on all Λ_c^+ decay modes involving Ξ^- . But we found that we can reproduce the Ξ^- spectrum by introducing final states of the form $\Xi_c^0 \bar{\Sigma} X$ in analogy to $\Lambda_c^+ \bar{N} X$.

1.3.3.5 Conclusions

In conclusion, we have made improved measurements of the inclusive yields and momentum spectra of p , Λ , and Ξ^- in B decay. We have also presented convinc-

ing, direct evidence for B decay to Λ_c^+ . The lack of observation of the $\Lambda\bar{\Lambda}$ and observation of $\Lambda\bar{p}$ correlation suggest that B decays to baryons are dominated by decays of the form $\bar{B} \rightarrow \Lambda_c^+ \bar{p} X$ and $\bar{B} \rightarrow \Lambda_c^+ \bar{n} X$. The observation of strong Λl^+ and absence of Λl^- correlations in B meson decay is further evidence that all Λ 's produced in B meson decay arise from the secondary decay of charmed baryons. The relative suppression of $\bar{B} \rightarrow \Xi^- X$ with respect to $\bar{B} \rightarrow \Lambda X$ may be interpreted as evidence that B decays to the charmed baryons Ξ_c^+ and Ξ_c^0 must be small. Assuming that the B decay to charmed baryons is dominated by Λ_c^+ and that all light baryons are produced from or in association with Λ_c^+ , we have estimated the inclusive branching fractions of B mesons to Λ_c^+ , n , and the inclusive branching fractions of Λ_c^+ to Λ , p and n . In addition we estimated the absolute branching fraction $B(\Lambda_c^+ \rightarrow p K^- \pi^+)$. A numerical summary of our results is presented in Table 5.

Table 5. Summary of Quantitative Results

Measured Branching Fractions and Ratios (%)			
Result	CLEO'87	ARGUS'88	CLEO'89
$B(B \rightarrow pX)$	$8.8 \pm 0.7 \pm 1.0$	$8.2 \pm 0.5 \pm 1.3$ -1.0	$8.2 \pm 0.6 \pm 0.5$
$B(B \rightarrow \Lambda X)$	$4.2 \pm 0.6 \pm 0.4$	$4.2 \pm 0.5 \pm 0.6$	$3.9 \pm 0.4 \pm 0.6$
$B(B \rightarrow \Xi^- X)$		0.28 ± 0.14	$0.28 \pm 0.05 \pm 0.04$
$B(\bar{B} \rightarrow \Lambda_c^+ X)$			
$B(\Lambda_c^+ \rightarrow pK^- \pi^+)$	$0.31 \pm 0.05 \pm 0.06$	$0.30 \pm 0.12 \pm 0.06$	$0.27 \pm 0.07 \pm 0.04$
$B(B \rightarrow \Lambda \bar{\Lambda} X)$			$< 0.5(90\% C.L.)$
$f_{\Lambda \bar{\Lambda}} = \frac{B(B \rightarrow \Lambda \bar{\Lambda} X)}{B(B \rightarrow \Lambda X)}$		$< 42(90\% C.L.)$	$< 13(90\% C.L.)$
$R_{\Xi_c} = \frac{B(B \rightarrow \Xi_c^- X)}{B(B \rightarrow \Lambda_c^+ X)}$			$< 24(90\% C.L.)$
Results Assuming Λ_c^+ Saturates Θ_c			
$B(B \rightarrow \Lambda \bar{p} X)$			$3.0 \pm 0.5 \pm 0.6$
$f_{\Lambda \bar{p}} = \frac{B(B \rightarrow \Lambda \bar{p} X)}{B(B \rightarrow \Lambda X)}$		54 ± 15	$76 \pm 11 \pm 8$
$B(B \rightarrow p \bar{p} X)$			$2.7 \pm 0.1 \pm 0.4$
$f_{p \bar{p}} = \frac{B(B \rightarrow p \bar{p} X)}{B(B \rightarrow p X)}$		30 ± 5	$33 \pm 3 \pm 5$
Results Assuming $\Lambda_c^+ \bar{p} X$ Provides All Baryons			
$B(\bar{B} \rightarrow \Lambda_c^+ X)$	7.40 ± 2.40		$6.1 \pm 0.8 \pm 1.0$
$B(B \rightarrow n X)$			$4.0 \pm 1.1 \pm 1.3$
$B(\Lambda_c^+ \rightarrow p X)$			$58 \pm 12 \pm 13$
$B(\Lambda_c^+ \rightarrow n X)$			$42 \pm 12 \pm 13$
$B(\Lambda_c^+ \rightarrow \Lambda X)$			$64 \pm 11 \pm 14$
$B(\Lambda_c^+ \rightarrow pK^- \pi^+)$		4.1 ± 2.4	$4.4 \pm 1.2 \pm 1.0$

1.3.4 Measurement of $\bar{B}^0 \rightarrow D^{*+} \pi^-$ Branching Ratio

CLEO⁴⁰ and ARGUS⁴¹ have both observed the exclusive $\bar{B}^0$ decay to $D^{*+} \pi^-$; they report $\text{Br}(\bar{B} \rightarrow D^{*+} \pi^-) = (0.28 \pm 0.17)\%$ and $(0.35 \pm 0.22)\%$, respectively. A new measurement, based on 212 pb^{-1} of data on the $\Upsilon(4S)$ and 101 pb^{-1} in the continuum, has been recently reported.⁴² From a total of 240,000 $B\bar{B}$ pairs, they have observed $6.5^{+3.0}_{-2.3}$ events corresponding to $\bar{B}^0 \rightarrow D^{*+} \pi^-$ with $D^{*+} \rightarrow D^0 \pi^+$ and $D^0 \rightarrow K^- \pi^+$ and $8.5^{+3.3}_{-2.7}$ events corresponding to $\bar{B}^0 \rightarrow D^{*+} \pi^-$ with $D^{*+} \rightarrow D^0 \pi^+$ and $D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$. The branching ratio used^{43,44}

$$Br(D^{*+} \rightarrow \pi^+ D^0) = (57 \pm 4 \pm 4)\%, \quad (1.1)$$

$$Br(D^0 \rightarrow K^- \pi^+) = (4.2 \pm 0.4 \pm 0.4)\%, \quad (1.2)$$

and

$$Br(D^0 \rightarrow K^- \pi^+ \pi^- \pi^+) = (9.1 \pm 0.8 \pm 0.8)\% \quad (1.3)$$

Further, since the B^0 and B^- masses are consistent with being equal, they assumed $Br(\Upsilon(4S) \rightarrow B^0 \bar{B}^0) = Br(\Upsilon(4S) \rightarrow B^+ B^-)$. Thus we see that from 240,000 $B^0/\bar{B}^0$ mesons produced, they reconstructed $15^{+4.5}_{-3.8}$ events in the decay mode $D^{*+} \pi^-$. They report the $Br(\bar{B}^0 \rightarrow D^{*+} \pi^-) = (0.28 \pm 0.10)\%$, where the statistical and systematic errors have been added in quadrature. Thus about (672 ± 246) $\bar{B}^0 \rightarrow D^{*+} \pi^-$ were produced; giving our overall reconstruction efficiency to be about 2.3%. There are two reasons why our reconstruction efficiency is small. We use only $D^{*+} \rightarrow D^0 \pi^+$ and ignore $D^{*+} \rightarrow D^+ \pi^0$, $D^+ \gamma$ since the π^0 reconstruction efficiency and the low energy photon detection efficiency are low for the data sample used. We lose approximately 50% of our events due to this problem. But the real loss comes from the fact that we can use only a couple of decay modes to detect D^0 's. We use only about 13% of the D^0 decay branching fraction.

One way to overcome the poor D^0 detection efficiency is to not detect them at all. We describe in this chapter a partial reconstruction technique by which large samples of $(\bar{B}^0 \rightarrow D^{*+} \pi^-)$ events can be reconstructed. Of course, the mass resolution of the reconstructed B^0 's is somewhat poorer and the background under the signal is higher. None the less, the technique allows us to measure the branching fraction with greater accuracy. Further, the large sample of tagged B^0 's can be used to measure properties of B^0 mesons. we will show later that this technique can also be used for B^- reconstruction.

The partial reconstruction technique was first applied to the study of $\bar{B}^0 \rightarrow D^{*+} \pi^-$ by Kay Kinoshita and Martin Hemstead⁴⁶ in 1985 using a much smaller sample of data and the older drift chamber with poorer resolution. Our analysis is based on a much bigger sample of data using the updated drift chamber with improved resolution. We have also studied different ways of estimating the background under the signal.

1.3.4.1 Description of the Partial Reconstruction Technique

We describe here the partial reconstruction technique as applied to the reconstruction of $\overline{B}^0 B^0$ mesons in the exclusive final state $D^{*+} \pi^- D^{*-} \pi^+$. By convention, $\overline{B}^0$ is the $b\bar{d}$ and B^0 is the $\bar{b}d$ meson. The complete process analysis is presented below:

$$e^+ e^- \rightarrow \Upsilon(4S) \rightarrow B^0 \overline{B}^0 \quad (1.4)$$

$$\overline{B}^0 \rightarrow D^{*+} \pi^- \quad (1.5)$$

$$D^{*+} \rightarrow D^0 \pi^+ \quad (1.6)$$

$$D^0 \rightarrow K^- \pi^+, K^- \pi^+ \pi^- \pi^+, \text{etc.} \quad (1.7)$$

Throughout the rest of this discussion the charge conjugate mode will always be implied. Further, when we refer to reconstruction of $\overline{B}^0$'s, we really imply both $\overline{B}^0 \rightarrow D^{*+} \pi^-$ and $B^0 \rightarrow D^{*-} \pi^+$ reconstruction.

In the partial reconstruction technique, we do not make an attempt to reconstruct the D^0 and therefore, we cannot calculate the invariant mass of $D^{*+} \pi^-$ combination as is done in the case of the full reconstruction. Instead, we calculate a pseudo invariant mass, for which the mass resolution is somewhat worse and the signal to combinatorial background ratio is of the order of 1.

We now present a discussion based on a Monte Carlo generation of the above process where the geometrical acceptance, reconstruction efficiency and the spatial resolution of the drift chamber is properly simulated. All Monte Carlo generated plots include the simulated momentum errors, geometrical acceptance and reconstruction efficiencies of the charged tracks used.

We show a typical picture (Figure 16) of the process equations 1.4 to 1.7. The π^- from equation 1.5 is called π_h as it will be shown in the next section to have a large momentum. The π^+ from equation 1.6 is called π_s as this will be shown to be quite soft. α is defined as the angle between the π_h and π_s . θ is the angle between the soft pion π_s and the missing D^0 . Both α and θ are defined in the $e^+ e^-$ center-of-mass frame.

We discuss now the production kinematics of $B^0 \overline{B}^0$ production in equation 1.4. Since the $\Upsilon(4S)$ rest frame is the lab frame, the B^0 and $\overline{B}^0$ are produced in

opposite directions to conserve momentum. Thus

$$m_{\Upsilon(4S)} = E_{B^0} + E_{\overline{B^0}} \quad (1.8)$$

$$\vec{P}_{B^0} + \vec{P}_{\overline{B^0}} = 0 \quad (1.9)$$

and since $2E_{beam} = m_{\Upsilon(4S)}$, we get

$$E_{B^0} = E_{\overline{B^0}} = E_{beam}, \quad (1.10)$$

where E_{beam} is the electron or positron beam energy which is measured very accurately. The mass of the $\Upsilon(4S)$ is $(10,580 \pm 3.5) \text{ MeV}/c^2$ while that of the B^0 is $(5279.1 \pm 3) \text{ MeV}/c^2$ as measured using full reconstruction technique.⁴⁷ Since the mass difference $m(\Upsilon(4S)) - 2m_{B^0} = 21.8 \text{ MeV}/c^2$, the B^0 's are produced nearly at rest in the lab. Figure 17(a) shows the reconstructed B^0 momentum from Monte Carlo generation. We can see the B^0 momentum is small around 350 MeV/c. Since the B^0 is heavy and nearly at rest, when it decays, the daughters D^{*+} and π^- are produced nearly back-to-back in the lab. The D^{*+} and π^- momentum in equation 1.5 are nearly monochromatic and hard as shown in Figure 18 (a)(b); the observed Doppler broadening is due to the B^0 momentum distribution. The π^- or π_h momentum is greater than 2.0 GeV/c and less than 2.5 GeV/c, which is the kinematic limit for this decay.

1.3.4.2 Description of the Mathematics and Derivation of Partial Reconstruction.

The mass difference between D^{*+} and D is only $5.9 \text{ MeV}/c^2$ in excess of the pion mass, so the π_s carries less than 250 MeV/c momentum in lab frame. The low Q value available in D^{*+} decay forces the direction of π_s to be almost collinear with that of D^{*+} . In Figure 17(b), we show the $\cos\alpha$ angular distribution from Monte Carlo study. We see that $\cos\alpha < -0.8$. The momentum distribution for the soft pion π_s is shown in Figure 19(a). In the D^{*+} rest frame, the π_s direction may be either in the same direction or opposite to the D^{*+} direction resulting in the double peak momentum distribution.

If the $\Upsilon(4S)$ decayed to $B^0\overline{B^0}$ with B's at rest ($Q = 0$), there would be 5 constraints to use in calculating the missing D^0 momentum vector, the D^{*+} mass

and 4-momentum conservation. Two of these 5 constraints are valid even if $Q \neq 0$. Conservation of energy allows us to calculate E_D , the energy of the missing D^0 from

$$E_D = E_{beam} - E_h - E_s, \quad (1.11)$$

where E_{beam} is the energy of the beam. Since the D^0 mass is known, the momentum of D^0 can be obtained from

$$P_D^2 = E_D^2 - M_D^2. \quad (1.12)$$

where E_{beam} is the energy of the beam. Track combination with negative E_D are rejected. Another constraint is the well-known D^{*+} mass

$$M_{D^{*+}}^2 = E_{D^{*+}}^2 - P_{D^{*+}}^2 = (E_D + E_s)^2 - (\vec{P}_D + \vec{P}_s)^2. \quad (1.13)$$

With these constraints, the momentum vector of D^0 is confined in a cone around π_s with a small opening angle $\theta < 16^\circ$. The Figure 19(b) shows the Monte Carlo generated $\cos\theta$ distribution. The cosine of the angle between the D^0 and the π_s , $\cos(\theta)$, is then calculated by requiring that the D^0 and π^+ form the D^{*+} mass:

$$\cos(\theta) = [(E_s + E_D)^2 - P_s^2 - P_D^2 - M_{D^{*+}}^2] / [2P_s P_D]. \quad (1.14)$$

On the right side of this equation, the P_D and E_D are substituted using 1.11 and 1.12. The one remaining unknown variable is the azimuthal angle of the D^0 about π_s . We force D^0 direction to be in the same plane as the hard and soft pions. The direction of D^0 still can have two choices. The first case, which has the smaller opening angle between D^0 and π_h , yields the maximum net momentum of B, or minimum mass of B. The other one with the bigger opening angle minimizes the net momentum of B, and maximizes the measured B mass. It is the latter that gives a narrow signal due to the fact the B mass is so close to the beam energy and can not exceed it. This is equivalent to force the B^0 momentum vector to lie in the same plane as the hard and soft pions in such a way as to minimize the net reconstructed momentum. Then the momentum of B^0 can be calculated using local coordinates, X-axis parallel to $\vec{P}_s$, and Y-axis perpendicular to $\vec{P}_s$. This approximation changes the measured mass by only a small amount. The pseudo mass is calculated as:

$$M^2 = E_{beam}^2 - P_B^2 = E_{beam}^2 - [P_s + P_D \cos(\theta) + P_h \cos(\alpha)]^2 - [P_D \sin(\theta) - P_h \sin(\alpha)]^2, \quad (1.15)$$

where $\cos(\alpha)$ is the cosine of the measured angle between the hard π_h and soft π_s , and is measured from the data according to equation below:

$$\cos\alpha = \frac{\vec{P}_s \cdot \vec{P}_h}{|\vec{P}_s||\vec{P}_h|}. \quad (1.16)$$

To obtain the best mass resolution, we actually plot the following pseudo mass,

$$M_r = 5.290 - (E_{beam} - M), \quad (1.17)$$

since in the term $E_{beam} - M$, the uncertainty due to the beam energy spread is partially canceled out. The 5.290 GeV is the upper limit of the beam energy run on $\Upsilon(4S)$ region. The calculated mass M is always less than E_{beam} , so the M_r is always less than 5.290. The Monte Carlo study later on will show that this M_r distribution from the real decay $\overline{B}^0 \rightarrow D^{*+} \pi^-$ is a half-Gaussian distribution. Another advantage of using this normalized mass M_r is that it makes the comparison with the continuum study very easy. In the rest of the discussion, unless otherwise specified all the pseudo mass plots refer to M_r .

The mass of $\overline{B}^0$ determined in this way lies between the true mass and the beam energy, which is only 11 MeV higher than the B^0 mass. Figure 20 shows the mass distribution from $\overline{B}^0 \rightarrow D^{*+} \pi^-$ Monte Carlo events, with the other B^0 decaying to all possible final states. The solid curve is a fit to the Monte Carlo data using a half Gaussian centered at 5.290 GeV/ c^2 with $\sigma = 7.9$ MeV/ c^2 . The reconstruction efficiency for $\overline{B}^0 \rightarrow D^{*+} \pi^-$ with $D^{*+} \rightarrow D^0 \pi^+$ is 63% and does not include the branching fraction $\text{Br}(D^{*+} \rightarrow D^0 \pi^+)$.

The dashed curve is the mass distribution that would be obtained if D^0 were detected and used in reconstructing the mass. Note that if we do not require the back-to-back angle cut on π_h and π_s , partial reconstruction does not rely at all on the low ΔQ value of the D^{*+} decay.

1.3.4.3 Search for $D^{*+} \pi^-$ in data

The search for $D^{*+} \pi^-$ is based on 212 pb^{-1} of data on the $\Upsilon(4S)$ and 101 pb^{-1} . The sample corresponds to approximate 240,000 $B\overline{B}$ pairs. Since the mass of B^0 and B^- are nearly equal to each other, we assume a 50:50 mix of $B^0 \overline{B}^0$ and

B^+B^- . Thus we assume there are 120,000 $B^0\bar{B}^0$ pairs or 240,000 $B^0\bar{B}^0$ mesons in the data sample.

To suppress continuum events under $\Upsilon(4S)$ resonance we also require the Fox Wolfram parameter R_2 to be less than 0.5, and the momentum of all tracks be less than half of the beam energy. Figure 21 shows the R_2 distribution from a $B\bar{B}$ Monte Carlo and the continuum data. Monte Carlo simulation indicates that 90% of the B events containing $D^{*+}\pi^-$ pass this cut while 50% of continuum events are rejected.

We search for oppositely charged pairs of tracks in the data which satisfy the following criteria.

- (1) The pion tracks are required to have $|DBDR| < 5 \text{ mm}$ so as to be consistent with the tracks coming from primary vertex.
- (2) We require that the dE/dx of the positive charged track or π , in the drift chamber be within three standard deviation of the expected value for a pion. Tracks with momentum less than 50 MeV/c are rejected since they are poorly measured in the drift chamber.
- (3) Since the negative charged track or π_h are hard, we do not expect any particle identification using dE/dx and hence use all negative charged tracks as π_h candidates.

The resulting pseudo mass distribution for all π, π_h combination from $\Upsilon(4S)$ data is shown in Figure 22. The smooth curve is the superposition of a second order polynomial background and a half-Gaussian with $\sigma(\frac{FWHM}{2.35})$ fixed at 7.9 MeV/ c^2 , the predicated Monte Carlo resolution. A very significant enhancement above the mass of 5275 MeV/ c^2 is quite evident. The size of the signal from the area of the half Gaussian is $370 \pm 40 \pm 35$. The first error is statistical, and the second is systematic which is estimated by changing the range of the fit and the order of the background function. Before interpreting this enhancement as evidence for $\bar{B}^0 \rightarrow D^{*+}\pi^-$, we must first convince ourselves that we understand all sources of background under the signal. We have used the continuum data and extensive Monte Carlo studies to understand all source of background under signal.

1.3.4.4 Estimation of the Background

There are several sources of background in the observed signal region. They are listed below:

- (i) Contribution from random combinations produced by the continuum under the $\Upsilon(4S)$.
 - (ii) Contribution from semileptonic decays of B meson, such as $\overline{B}^0 \rightarrow D^{*+} l^+ \nu_l$, where the l^- is misidentified as a π^- and the ν_l is missing.
 - (iii) Contribution from charged B meson decays, such as $B^- \rightarrow D^{*+} \pi^- \pi^-$, where one of π^- 's are not seen.
 - (iv) Contribution from random combinations produced by the B mesons.
- We now discuss how we estimate these contribution.

1.3.4.5 Continuum Background

The continuum background is easy to estimate since we have 101 pb^{-1} of data in the energy region below the $\Upsilon(4S)$ and above the $\Upsilon(3S)$. The dominant source of background events in Figure 22 arises from continuum events under the $\Upsilon(4S)$ resonance. This is evidenced by the pseudo invariant mass distribution shown in Figure 23(a) from the continuum data. To calculate the B mass, we renormalized the beam energy to $\Upsilon(4S)$ energy scale, i.e. the quantity M_r is actually plotted in Figure 23(a), where

$$M_r = 5.290 - (E_{beam} - M) \quad (1.18)$$

where M is calculated from 1.13. The number of events has been normalized by the ratio of $\Upsilon(4S)$ to continuum luminosities. The continuum subtracted distribution is shown in Figure 23(b). Any remaining background is from $B\overline{B}$ events. We estimate that 80% of the background in Figure 22 comes from continuum and only 20% from $B\overline{B}$ events. Actually the successful measurement of B^0 semileptonic branching ratio is based on the above fact because not many leptons can come from continuum.

1.3.4.6 Background from $\overline{B}^0 \rightarrow X l^- \nu_l$

It was once thought that the $\overline{B}^0 \rightarrow X l^- \nu_l$ decay channel could severely contaminate $\overline{B}^0 \rightarrow D^{*+} \pi^-$ signal. Mass distribution of 3000 $\overline{B}^0 \rightarrow X l^- \nu_l$ Monte Carlo events with ISGW model assumption in Figure 24 yields -6 ± 10 events. The background from this channel is negligible.

1.3.4.7 Background from Charged B meson

Since we are interested in tagging neutral B meson events, our analysis would be misled if we have charged B meson background under the $\overline{B}^0$ signal. Therefore, we concentrate in estimating the number of $B^\pm$ mesons which may contribute to the signal in Figure 22. We performed a Monte Carlo study of many charged B decay modes in order to determine the maximum charged B background possible in the mass peak. We used a Monte Carlo sample of 132,000 generic $B^\pm$ decays to investigate the contamination from B^+/B^- . Figure 25(a) shows the pseudo invariant mass of $\pi_s^+ \pi_h^-$ combinations obtained from these events satisfying the same criteria as those used for the data. There is no evidence for a peak near the B mass. To obtain a conservative estimation we fit the distribution in Figure 25(a) with a second order polynomial plus a half-Gaussian, the same way as we did to Figure 22. On the basis of this study we limit the contamination from B^+/B^- events to be less than 18 events at 90% confidence level.

The results of Figure 25(a) include known low multiplicity $B^\pm$ decays, for example $B^- \rightarrow D^{*+} \pi^- \pi^-$. However, other possible but yet unobserved modes such as $B^- \rightarrow D^{*0}(2420) \pi^-$, $D^{*0}(2420) \rightarrow D^{*+} \pi^-$, are not included. The product of branching ratio of this mode has been constrained by recent measurements⁴⁸ to lie below 0.4% at 90% confidence level. We focus on this decay because it has a topology very similar to $\overline{B}^0 \rightarrow D^{*+} \pi^-$. Figure 25(b) shows the pseudo invariant mass distribution of $\pi_s^+ \pi_h^-$ contamination from 3000 $B^- \rightarrow D^{*0}(2420) \pi^-$ Monte Carlo events, which is expected from data for $\text{Br}(B^- \rightarrow D^{*0}(2420) \pi^-) = 0.4\%$. The distribution does have a broad peak at high mass, but the shape is different from the peak in Figure 22. Fitting this peak with a Gaussian distribution, we obtain a fixed shape. Then we use this shape plus a smooth background to fit

Figure 22. An upper limit of 25 events in the last three bins is extracted from the Figure 26. This is the most conservative way to estimate the background from $B^- \rightarrow D^{*0}(2420) \pi^-$. Adding this 90% limit to the 18 events limit from Figure 26, we obtain a conservative upper limit on the $B^+ B^-$ contamination to the peak of less than 43 events. This will cause only a small systematic uncertainty on the measurement of $\overline{B}^0 \rightarrow X l^- \overline{\nu}_l$.

1.3.4.8 Generic $B\overline{B}$ Monte Carlo Study

In this section, we show that we can detect and measure the branching fraction $\text{Br}(\overline{B}^0 \rightarrow D^{*+} \pi^-)$ correctly by using a Monte Carlo simulation. Now we have used 212 pb^{-1} of data on the $\Upsilon(4S)$ which correspond to about 240,000 $B\overline{B}$ events. So we use a Monte Carlo generated sample of 254,000 $B\overline{B}$ for this study. The B mesons were decayed using best estimate of the branching ratios for all possible decay modes, with quark and gluon jets fragmented using the LUND Monte Carlo.^{49,50} This procedure reproduces most of the general features of B meson decays. The branching ratio of $\overline{B}^0 \rightarrow D^{*+} \pi^-$ was set as 0.34%. In Figure 27(a), we plot the pseudo invariant mass distribution of all $\pi_s^+ \pi_h^-$ combination from this sample, analyzed exactly the same way as we did to the data. We see a data peak corresponding to $\overline{B}^0 \rightarrow D^{*+} \pi^-$. However, if we remove at the Monte Carlo generation level all combinations that arise from real $\overline{B}^0 \rightarrow D^{*+} \pi^-$ decay, the corresponding pseudo invariant mass distribution does not have a peak (Figure 27(b)), showing that there are no processes in the B decay modes that tend to produce a peak in the signal region.

The Monte Carlo results for all charged and neutral B background in Figure 27(b) give an upper limit of 64 events at 90% confidence level contributing to the peak in Figure 22. It is easy to see from the above study that most B decays have little chance of faking the observed $\overline{B}^0$ signal. This is due to the fact that B's decay to final states with many soft particles.

Fitting Figure 27(a) with a half Gaussian plus a polynomial background in the same way as before, we get 303 ± 28 events from a sample of 127,000 $B^0 \overline{B}^0$ Monte Carlo pairs. The branching ratio can be calculated in the following formula,

$$MC : \quad \text{Br}(\overline{B}^0 \rightarrow D^{*+} \pi^-) = \frac{N_{tag}}{N_{B\overline{B}} \times 2 \times \epsilon_d \times f_{D\pi}} = (0.35 \pm 0.3)\%, \quad (1.19)$$

where $N_{tag} = 303 \pm 28$ is the number of $\overline{B}^0 \rightarrow D^{*+} \pi^-$ events found, $N_{B\overline{B}} = 127,000$ is the number of $B^0 \overline{B}^0$ Monte Carlo pairs, $\epsilon_d = 63\%$ is the detection efficiency and $f_{D\pi} = 57\%$ is the branching ratio of $D^{*+} \rightarrow D^0 \pi^+$. This measured branching ratio is very consistent with Monte Carlo input branching ratio 0.34%. Here we see that the partial reconstruction technique is quite successful in measuring the branching ratio accurately by this method.

1.3.4.9 The Branching Ratio of $\overline{B}^0 \rightarrow D^{*+} \pi^-$ From Data

For 212 pb^{-1} data we assume that $\text{Br}(\Upsilon(4S) \rightarrow B^0 \overline{B}^0) = 50\%$, which yields a total sample of 240,000 B^0 's, produced in our detector. The efficiency for partial reconstruction is 63%. We take $\text{Br}(D^{*+} \rightarrow D^0 \pi^+) = (57 \pm 4 \pm 4)\%^{45}$ and calculate

$$\text{Br}(\overline{B}^0 \rightarrow D^{*+} \pi^-) = \frac{370 \pm 40_{-72}^{+35}}{240000 \times 63\% \times 57\%} = (0.42 \pm 0.05_{-0.08}^{+0.04})\%. \quad (1.20)$$

The first error is statistical, and the second is systematic. This branching ratio can be compared to the branching ratio of $(0.28_{-0.07}^{+0.08} \pm 0.05)\%$ using full reconstruction method. The two measurements are consistent with each other within the statistical and systematic errors. But one can not rule out that our measurement using the partial reconstruction technique is not higher because of some systematic underestimation in our background subtraction.

1.3.4.10 Other Methods to Estimate the Random Background

We have calculated the pseudo invariant mass of $\pi_s^+ \pi_h^-$ combinations to detect $\overline{B}^0 \rightarrow D^{*+} \pi^-$. Another way to estimate the background is to calculate the pseudo invariant mass of the wrong charge combinations $\pi_s^- \pi_h^-$, satisfying the same selection criteria as before.

Figure 28(a) shows the pseudo mass distribution which passes the same cuts as Figure 22, but we further require the momentum of the hard pion to be greater than $2.0 \text{ GeV}/c$. This cut on the momentum does not affect the background under the signal. It only changes the shape of the background on the low mass side. Also shown in the Figure is the corresponding pseudo mass distribution of the

wrong charge $\pi_s^- \pi_h^+$ combination with the same set of cuts. After normalizing the two distribution in the mass region 5.10-5.20 GeV/c^2 , we find the shape of the wrong sign distribution to be similar to the right sign distribution in the low mass region. Clearly, we see a peaking effect in the background under the signal region, but there is a definite excess associated with B meson decay. In fact, the contribution from B meson decay is shown in Figure 28(b) after subtracting the wrong sign background. After fitting the signal in Figure 28(b) in the same way as earlier, we obtain 396 ± 43 events. The detection efficiency is the same as before. We therefore get the $\text{Br}(\overline{B}^0 \rightarrow D^{*+} \pi^-) = (0.46 \pm 0.05)\%$, which is nearly identical to the value obtained using the direct fitting method.

We perform the same analysis with the continuum data. In Figure 29(a), we show the pseudo mass for the right sign $\pi_s^+ \pi_h^-$ and wrong sign $\pi_s^- \pi_h^-$ combination from the continuum data. After subtracting the wrong sign from the right sign contribution, we show the cancellation is very good for the continuum data, giving no peak in the high mass region.

From the above study, we conclude that the wrong sign contribution is a reliable estimation of the background.

1.3.5 Determination of α_s

The basic assumption in Quantum Chromodynamics (QCD) is that the strong force is generated by the exchange of colored gluons between colored quarks, with hadrons being colorless combinations of either quark-antiquark pairs or three quarks. QCD is described by non-Abelian SU(3) group theory which predicts that α_s , the strength of the strong interaction, will depend on Q^2 , the square of the four momentum transfer of the gluon. α_s is expected to vanish for large Q^2 , leading to asymptotic freedom, and to approach infinity for small Q^2 , leading to the confinement of both quarks and gluons. SU(3) group theory perturbation calculations predict

$$\alpha_s(Q^2) = \frac{1}{(B \ln(Q^2/\Lambda^2))}$$

with $B = (33-2f)/12$, f = the number of quarks and Λ = the QCD scale parameter.

Λ may be intuitively described as the energy below which perturbation calculations for QCD are no longer reliable. Figure 30 shows α_s as a function of various values of Λ . The curves tend to converge for high Q^2 so that measurements of α_s at lower Q^2 provide a more sensitive determination of Λ . The effort described here will determine α_s at 10GeV and will incorporate this result with other measurements made over a wide range of Q^2 to demonstrate the SU(3) group prediction of the Q^2 dependence of α_s and thereby determine an accurate value for the QCD scale parameter Λ .

Sterman and Weinberg⁵¹ showed that the observation of hadronic jets in e^+e^- annihilation is direct evidence for the validity of perturbation expansions in QCD. It was suggested that suitably chosen features of e^+e^- annihilations into hadrons may be directly calculated by the perturbation theory for the production of quarks and gluons, using a running coupling constant i.e. α_s . However, the experimentally observed final states contain hadrons and not free quarks and gluons. The process of fragmentation of the primary quarks and gluons into hadrons is a non-perturbative process, the details of which are not well understood.

The original promise of discovering experimental observables, which are well behaved in the perturbation expansion sense and have negligible non-perturbative contributions, has turned out to be less than straight forward. One such observable that has been calculated to second order in perturbation theory and is well behaved is the e^+e^- annihilation cross-section into hadrons. However, the measurements of the hadronic cross-section are plagued by systematic errors of the order of 5 to 10% arising out of the uncertainties in the luminosity measurement, triggering efficiencies, detector acceptances and radiative corrections. Three other experimental observables which have been used extensively for α_s measurements at different center of mass energies in e^+e^- annihilations are the jet thrust and jet mass distributions along with energy-energy correlations (EEC). The thrust is a measure of the jet three momentum obtained by dividing the final state particles into clusters or jets whose axis is chosen in the way that maximizes this three momentum. The jet masses are obtained by dividing each event into two jets in a way that minimizes the sum of two squared jet invariant masses. The energy-energy correlations measure the correlations between hadronic energy flow into two different directions in the same event.

Perturbation theory calculations to second order in α_s exist for the above experimental observables. Such calculations for the thrust distribution show they are not well behaved in the perturbation expansion sense; the second term can be as large as or larger than the first order term in the tails of the distribution. Measurements of α_s based on the thrust distribution are further flawed in the sense that they depend on the exact algorithm for defining the jet axis. In the case of jet mass analysis, the jets are defined in a self contained, combinatoric way that does not require the definition of a jet axis. Jet mass distributions are also better behaved in the perturbation sense. But, both jet mass and thrust distributions have been shown to require large non-perturbative contributions in attempts to fit the data with different Monte Carlo models. The energy-energy correlation is well behaved in the perturbation sense but measurements of α_s obtained by Monte Carlo models to fit the observed energy-energy correlations data show large corrections which depend on the specific details of the hadronization procedure used in the model.

The energy-energy correlations and jet distribution lack the proper perturbative and non-perturbative behavior to lead to reliable measurements of α_s . However, angular asymmetry in the energy-energy correlation (AEEC) has the desired behavior. Basham, Brown, Ellis and Love^{52,53} were the first to suggest the study of energy-energy correlations and the angular asymmetry as observed in e^+e^- annihilations into hadrons as useful tests of perturbative QCD. The energy-energy correlation cross-section is defined as the correlation between energy flows dE and dE' into two independent hadronic calorimeters subtending solid angles $d\Omega$ and $d\Omega'$. The AEEC measures the difference between the energy-energy correlation at $\cos(x)$ and $\cos(-x)$. The dominant fragmentation effects coming from the parton level cancel in the difference, since the quark and antiquark hadronize into opposite jets in a symmetrical manner. Further, the perturbation theory calculation shows that higher order perturbative contributions have a tendency to cancel out so that we expect this variable to be better behaved in the perturbative sense.

An analysis of 140,000 hadronic events from the CLEO detector to determine the AEEC has been completed. These results were fit to a second order perturbation expansion of the AEEC. The fit, shown in Figure 31, yields a value of

$\alpha_s = .119 \pm .002$ at 10 GeV. From the 140,000 events there was approximately 100,000 contributions to each angular bin in the EEC analysis. With this amount of data, the statistical uncertainty in each bin was extremely small. In order to account for systematic errors, the data was analyzed in groups of approximately 10,000 events, and the standard deviation in each angular bin was computed. This variation should account for changes in the detector system over the course of time, and showed that on the average there was about a 5% variation in each angular bin.

This analysis benefits from the fact that the effect of the detector efficiency is small due to the difference being taken in the energy-energy correlation to form the AEEC. However, any angular dependence in the detector must be accounted for. The angle here is taken with respect to the jet axis and should not be confused with the angle relative to the beam axis. The angular dependence was studied using the detector Monte Carlo at the EEC level of the analysis. Since the Monte Carlo analysis is computationally expensive, it was unreasonable to generate an amount of Monte Carlo data comparable to the raw data sample, which is needed to compute the difference in the EEC to a sound statistical level. Instead, enough Monte Carlo data ($\approx 10,000$ events) is generated to produce a statistically sound fit to a quadratic polynomial in the angular domain. The Monte Carlo analysis was done in two steps. First, the full Monte Carlo is run with different values of α_s in order to "tune" the Monte Carlo results to the raw data. This is done in the Monte Carlo by varying two input parameters f = the number of flavors and Λ = the QCD scale parameter. Thus far $\alpha_s = .19$ ($f = 6$, $\Lambda = .150$ GeV) has produce an adequate representation of the actual data. Second, only the event generator in the Monte Carlo was run with the "tuned" input parameters. The fitted equation at the particle generator level was compared to the fitted equation at the track (detector) level. This results in an efficiency of about 97% with a variation of about 2% in the angular region between 90 and 0 degrees. This study is still in progress in order to fine "tune" the Monte Carlo before applying the efficiency correction.

1.3.6 Software Implementation For CLEO II Physics

As it is said, "CLEO II software is not an upgrade, it is completely new". First, the software standards have been set up to adopt ANSI standards; secondly, CLEO II software is largely based on the packages developed in the last 20 years at CERN; thirdly, the data acquisition and event processing architecture are redesigned.

The Albany group should have the same computing facility for doing physics with the CLEO II data as that at Wilson laboratory. Starting early this year, we began to implement CLEO II software programs on our computer system.

CLEO decided to have two raw data formats for physics analysis, i.e. ZEBRA and ROAR. The first offline data skim (PASS 1) produces ZEBRA format raw data, while PASS 1.5 and PASS 2 produce ROAR format. Because the current detector simulation package for CLEO II can only produce ZEBRA format data, there is a need to implement both formats. The following is the list of CLEO II offline physics analysis packages already running at the Albany group computing facility:

CLEVER

This is the main event processing routine designed with new data analysis concepts such as *STREAM* and *PROCESSOR*. With this routine, the general user will be able to do event processing in a very organized and convenient way. We are going to use this package to study detection efficiencies of the CLEO II detector and analyze Time of Flight raw data.

CLEOG

This is the detector simulation routine based on CERN GEANT package.

MN_FIT

This fitting program is based on CERN MINUIT package. It can be used both for CLEO II data analysis and CLEO I data analysis. It is more flexible than the previous fitting program MULFIT.

PAW

This program is implemented from CERN. As its name says, PAW stands for Physics Analysis Workstation. It is a very powerful tool to do various kinds of high energy physics analysis with the help of sophisticated graphics utility and laser printer.

ROAR2

This is a set of libraries with which the user can link their own analysis programs to do ROAR data analysis. We are using it now to test our event reconstruction programs running on CLEO II $\Upsilon(3S)$ raw data.

CMZ

This is a code management system to support coding. We have used it to write all the Time of Flight Monte Carlo program CRTNY. We find it is very efficient when coding big routines.

KUIPC

This is a compiler for CERN KUIP package which is very helpful for developing user-friendly programs. It has been used for developing our Time of Flight Monte Carlo program CRTNY.

T_EXnew version

We have installed a new version of document preparation system, T_EX. With the ability of previewing on DEC windows and the GKS graphics output, the new version of T_EX will play an important role in our physics productivity.

1.4 Fermilab

1.4.1 The Measurement of the Magnetic Moments of Baryons at the Tevatron

1.4.1.1 The new Technique and the Goal

The observation of channeling of high energy (up to 800 GeV) positively-charged particles through bent crystals^{54,55,56,57,58} can be applied to the measurement of

the magnetic moments of short-lived ($\tau = 10^{-13}$ seconds) particles. The conventional technique for the measurement of magnetic moments involves the observation of the precession of the spin vector of a polarized beam of particles traversing a region of high magnetic field. For short-lived particles which may travel only a few centimeters even at Tevatron energies, the precession angle of the polarization vector in magnetic field achievable with conventional or even superconducting magnets is still too small to be practically measurable. However, the electric field between crystal planes which is seen as a magnetic field in the rest-frame of the moving charged particle is equivalent to $(10^7 - 10^8)$ gauss which is high enough to produce appreciable precession of the polarization of short-lived particles traversing a bent crystal of length equal to a few centimeters. The possibility of using bent crystals to measure magnetic moments of charmed particles was first suggested by L. Pondrom.^{59,60} A comprehensive study of the feasibility of this experiment has been carried out by I.J.Kim^{61,62}, a member of our group.

The study shows that the channeling technique can be applied to measure the magnetic moment of any positively charged particle whose lifetime is of the order of 10^{-13} seconds if it is produced in a polarized state with Lorentz γ -factor of the order of 100. If Λ_c^+ 's ($\tau = 2.3_{0.8}^{+1.0} 10^{-13}$ seconds, mass = $2.285 \text{ GeV}/c^2$) are produced in hadronic collisions at the Tevatron, in a polarized state and channeled through a 1 centimeter long, bent tungsten crystal, the polarization vector would be precessed by an angle $\Delta\phi \approx 0.76$ radian assuming $\mu_{\Lambda_c^+} = 0.34\mu_N$. On the other hand if we assume $\mu_{\Lambda_c^+} = 0.53\mu_N$, then $\Delta\phi \approx -0.98$ radian. Although the exact magnitude of $\Delta\phi$ will depend on the value of $\mu_{\Lambda_c^+}$, the above values are in the range where $\mu_{\Lambda_c^+}$ can be measured by observing the distribution of the final decay protons as done in the case of the measurements of the magnetic moments of the strange baryon^{63,64}.

Before we can carry out a program of measurement of magnetic moments of short-lived heavy-flavored particles, we decided to test our technique on a well established particle whose magnetic moment has been measured in a conventional method.

1.4.1.2 The measurement of the magnetic moment of Σ^+ using bent crystals and E 761 apparatus.

To test the ideas described in the previous section, we chose to measure the magnetic moment of Σ^+ . We have established a collaboration with V.M. Samsonov of the Leningrad group, Richard Carrigan, P.C. Cooper and J. Lach and A. Morales of Fermilab. We used the existing hyperon beam and the apparatus of the approved experiment E 761 which also involves the collaboration of groups from the Institute of High Energy Physics, Beijing, PRC, University of Iowa and Yale University.

It is expected that the hyperon beam are polarized to 20 %. We have inserted bent silicon single crystals ($1.4 \text{ cm} \times 0.045 \text{ cm} \times 4.5 \text{ cm}$) in the Σ^+ beam. The silicon crystals are housed in a goniometer and are aligned with its (111) plane horizontally. The 4.5 cm side of the crystal is in the beam direction while the 1.4 cm side is horizontal and the 0.045 cm side is vertical. With this thickness, bending the Σ^- beam up or down can be readily accomplished. The Σ^+ particle that is channeled through the crystal will be bent by an angle $\Delta\theta$ which is the crystal bending angle. The polarization vector $\vec{P}$ of the Σ^+ will precess around the induced magnetic field B which is horizontal through an angle $\Delta\phi$ which is related to $\Delta\theta$

$$\begin{aligned}\Delta\phi &= (2 - g - \frac{g}{\gamma^2}) \frac{\gamma}{2} \Delta\theta \\ &\approx (2 - g) \frac{\gamma}{2} \Delta\theta\end{aligned}$$

The hyperon beam is produced by 800 GeV/c protons. We have selected 350 GeV/c Σ^+ particle.

For Σ^+ :

$$\begin{aligned}\mu &= 2.379 \pm 0.20 \mu_n \quad (\mu_n = e\hbar/2m_p) \\ m &= 1189.35 \pm 0.06 \text{ MeV}/c^2 \\ g &= 4.1 \\ p &= 350 \text{ GeV}/c \\ \gamma &= 300\end{aligned}$$

Thus

$$\Delta\phi = 300\Delta\theta$$

Assuming $\Delta\theta = 1.5$ mR, being limited by the angle of acceptance of the spectrometer not the channeling capability, we find

$$\Delta\phi \approx 0.45 \text{ Radian}$$

This is a rather large effect and should be readily measured.

The decay mode we used is $\Sigma^+ \rightarrow p \pi^0$, where $B(\Sigma^+ \rightarrow p \pi^0) = 52\%$. The incident Σ^+ beam direction is measured by silicon microstrip detectors. The momentum vector of the decay proton can be determined by the PWC's and the magnets in the spectrometer downstream of the crystal. We have measured the directions of γ ray from the $\pi^0 \rightarrow \gamma\gamma$ decay by means of transition radiation detector. The energy of these γ 's is determined by lead glass detectors.

To tag channeled particles we attached multiple pairs of electrodes on the silicon crystal. These serve as semiconductor detector each of which record the ionization energy loss of particles going through the silicon crystal and between a pair of such electrodes. Since channeled particles lose less energy of ionization than non-channeled particles, the pulse height information can be used to tag the channeled Σ^+ 's. Furthermore channeled particle follows the curved trajectory of the bent crystal and must be detected by all the detectors along the crystal while non channeled or dechanneled particles will not be.

The E761 ran this year from Feb. to Aug. in the Fermilab Proton Center. Fig. 32 shows the E761 set-up. The hyperon targeting magnet (M1) with a curved channel would allow beams of 350 GeV/c to pass. Downstream of the magnet M1 is the silicon strip detector station SD1 (X,Y,U coordinate planes) which records input coordinates in the second hyperon magnet (M2). Two strip stations SD2 and SD3 (X,Y, U planes in each station) measure the hyperon direction after M2. The spectrometers (SD1, M2, SD2, SD3) give a good measurement of Σ^+ momentum. Following SD3 there is a goniometer holding the five channeling Si crystals. After the goniometer there is the Σ^+ decay region. At the end of the decay region, a proportional wire chamber(PWC1) determines the X and Y coordinations of the decay proton trajectory. Downstream of the PWC1 is the PWC2. The PWC1 and PWC2 give an angle of the decay proton before the magnet (M3). Another two chambers PWC3 and PWC4 measure the proton angle after M3. Therefore, with PWC1-4 and magnet M3 the momentum of the decay proton is obtained. About 20 m downstream of PWC1, a detector is

placed to intercept the γ from the π^0 decay. The detector consists of two parts. The energy and coordinate (approximately) are measured by a granulated lead glass calorimeter (LG1). LG1 has a hole ($7.5 \times 7.5 \text{ cm}^2$) in the center. The γ 's which pass through the hole are registered by another lead glass detector (LG2). For the precise measurement of the γ coordinate, a transition radiation detector (TRD) with 1 radiative length are used.

The crystals and the bending device are housed in a goniometer. This device can hold and bend up to seven crystals. We use only five of them due to the limitation of the Σ^+ beam phase space. The center crystal is not bent. Two groups of crystals (two crystals in each group) are bent in a symmetric way relative to the center crystal and have opposite sign of curvature. The upper two crystals are bent down 1.5 mrad and the lower two crystals are bent up 1.5 mrad. There are eight sensitive strips (p-n junction) on one surface of every crystal as shown in Fig.33. The crystal with the sensitive zones allows us to "mark" with 100 % efficiency all particles passed through the crystal and to measure their ionization losses. A particle which passes a crystal in channeling regime has small value of the ionization losses (about 50 % from "normal" losses in a silicon). The typical spectrum of ionization losses for 12 Gev particles passing through the crystal is shown in Fig.34.

Before the run Si detectors were checked using α - particle source attached the surface. It was found that almost half of the detectors were dead probably due to shipping. Only two crystals showed promise.

The experiment successfully matched the multi-crystal array to the sigma beam phase space and also succeeded in remotely adjusting the bends in the crystals in a precise fashion. Two problems that rose in the experiment were successfully overcome. One was an apparent dead layer of 100 - 150 microns in the crystals. It is not yet clear what caused this dead layer. It was also found that it was necessary to control the orientation of the goniometer and the bends very carefully to minimize distortion of the crystal. The dead layer problem has to be solved by offline analysis.

The crystals have been cut so that the atomic planes are parallel to the surface of the crystal within 300 micro radians. The crystal surface was first aligned in the beam and the crystals were rotated in steps of 50 microradians covering a

range of -600 milliradians and +600 milliradians. At each step data were recorded on tape. By offline analysis we found goniometer positions for best channeling for each crystal. We adjusted the front bending of each crystals and found a goniometer position best for channeling through two crystals whose downstream end was bent 1.6 milliradians in two different directions. With this we were ready to take data. Fig. 35 shows the beam deflection in the vertical direction at PW chamber C, the center peaks are the undeflected beam leaked through.

We tried another trigger configuration which add a photon trigger to detect photons from π^0 's resulting from the Σ^+ decay. This trigger however reduced the rate of data collection severely and we abandoned it.

We took a total of 90 tapes of data amounting to approximately 14 million triggered events.

We also searched for evidence of planar channeling of negatively charged particle and found no significant signal. This rules out the possibility of measuring the magnetic moment of negative particles.

We also took some data on lower momentum channeled particle in order to measure the critical channeling angles at these momenta. More over this may shed light on the transmission (surface acceptance) of channeling microchannel. We took a series runs at exponentially descending values of full momentum ($p=350$ Gev/c). This transmission information might be useful for the on - going discussion of crystal extraction at future accelerators such as UNK, LHC and SSC.

According to the information from the previous experiment , the Σ^+ particles are expected to amount to 2 % of the hyperon beam. This means we have collected 280,000 Σ^+ 's on tapes of which 25 % decay in the fiducial region amounting to 70,000. Reducing by the channeling efficiency of about 10%, our signal goes to 7,000. Taking into account of reconstruction efficiency, we expect to have 3000 to 5000 channeled Σ^+ .

From preliminary off line analysis, we have already found very clear Σ^+ signal as shown in Fig.36.

2 Future Plans

2.1 CESR

The Albany high energy physics group has assumed the responsibility for the offline calibration of the CLEO-II TOF system. This includes the endcap TOF counters built by the Albany group as well as the barrel system built by Harvard.

The first pass of offline calibration for the barrel has allowed a first look at the calibrated times and involves a simple sequence of corrections.

The first correction is the timing offset due to cable lengths, etc.; the second is the light travel time in the scintillator, and the third is the time-to-threshold correction known as "timewalk." Using this scheme an average timing resolution of about 290 picoseconds per photomultiplier tube (PMT) is achieved. Figure 37 shows the residual (measured - expected) time of flight distribution for bhabhas using this calibration program. This falls short of the design optimal resolution of approximately 180 picoseconds per PMT.

The production calibration program being written by the Albany group aims at approaching the design resolution by two principal means. The first is to determine the optimal form for the corrections due to the scintillator light travel time and the timewalk effect. Since both of these processes are in fact complicated, the simple functional forms used in the existing calibration program will have to be augmented. The second feature of the new calibration will be to introduce an iterative technique which minimizes the correlations among the final set of constants. This is particularly important in the case of the light-travel-time and the timewalk corrections, since the former depends on the track crossing point

along the scintillator and the latter depends on pulse from the PMT. Because the light produced by the passage of a charged particle through a scintillator is attenuated as it reaches the PMT, the final pulse from the PMT is strongly correlated with the track crossing position. Without iteration, the light-travel-time correction constant also partially corrects for the timewalk effect and vice versa for the timewalk constant. As a result, neither effect is optimally calibrated in the existing calibration. With these improvements it should be possible to approach the optimal resolution of about 180 picoseconds per tube, which will allow pion-kaon and kaon-proton separation by more than 3σ for up to 1.1 GeV/c of momentum.

2.1.1 Research and Development Towards a 50 Picosecond TOF System

Particle Identification is a very important issue for detectors being presently designed for the detailed study of B meson decays at both e^+e^- and $p\bar{p}$ colliders^{65,66}. In both cases, $\pi - K$ and $\pi - p$ separation is important for momentum ranges up to around 3 GeV/c. The momentum region between 0.8 and 1.6 GeV/c is a region of confusion for hadron identification using specific ionization or dE/dx measurements. For a 1 meter radius time-of-flight, a scintillation counter system with 50 picosecond timing resolution would achieve 2σ $\pi - K$ separation at 2.0 GeV/c and 3σ $\pi - p$ separation at 3.0 GeV/c. Thus a combination of dE/dx and TOF could provide hadron identification over the desired momentum range.

The CLEO II barrel time-of-flight counter⁶⁷ is made from a slab of BICRON BC408 scintillator $2.8m \times 10cm \times 5cm$. Light incident on each edge is piped out by 1.2 m long adiabatic light guides to magnetic field free region outside the detector where it is detected by Amperex XP2020 photomultipliers. The timing resolution from each counter as measured in the lab at Harvard University varied between 110 to 120 picoseconds. In our design, we decided to glue two Hamamatsu R2490 photomultipliers directly on both edges of the scintillator. These photomultipliers have been used on the CLEO II endcap counters⁶⁸ and have been found to operate inside the 1.5 Tesla magnetic field with gain degradation factors of 100 to 200. The gain degradation can be restored by using fast preamplifiers with high gain

and wide bandwidths without loss of timing resolution. In this paper, we present results from tests in zero magnetic field. Since we are doubling the number of time measurements, we expect the resolution to improve by a factor of $1/\sqrt{2}$. Another factor of 2 in light may be gained if particles go through the 10 cm thickness side.

Here we describe the test setup and the first set of results. Based on these results, we also describe future improved designs.

2.1.1.1 The TOF Setup

The test setup is shown in Figure 38. A cosmic ray trigger is formed using a start counter (START) at the top, two reference counters (REF1 and REF2) and two small counters B9 and B10 placed at equal distances above and below the test counter. The hit position along the length of the test counter is limited to a band of 5 cm or 50 cm around its center depending on whether the small counters are or are not part of the trigger, respectively. The TDC is started by an input from the start counter, while its stop inputs are triggered by signals from the reference and test counter PMT's. The total charge or pulse areas are recorded by an ADC. Thus for each PMT, a time and charge pair (t_i, Q_i) is recorded, where $i = 1$ to 8 as shown in Figure 38.

2.1.1.2 Data Analysis

The time measured at the TDC stop input for any of the PMT's consists of contributions from the start counter, from variations in time of emission of the triggering photon and its distance of travel to the photocathode, from the transit time jitter in the PMT and finally from the time walk correction due to varying PMT output pulse area. For a thick counter, there are contributions from the variations in the angle of incidence and the travel time of the particle in the scintillator. The time walk correction is taken out by fitting to the equation shown below:

$$t'_i = t_i - k/\sqrt{Q_i}$$

where t_i and t'_i are the measured and corrected times, Q_i is the pulse area and k is a calibration constant. It can be shown that the contribution from the start counter and that from different hit positions along the test counter length are cancelled out by using the proper choice of time differences such as $(t'_6 - t'_7)/2$ and $(t'_6 - t'_8)/2$ or $\{(t'_6 + t'_6)/4 - (t'_7 + t'_8)/4\}$. Let σ_{57} , σ_{78} and σ_{5678} denote the rms widths of the above distributions, respectively. Then it can be shown that these are the same as the rms widths for the mean times $(t''_6 + t''_7)/2$, $(t''_6 + t''_8)/2$ and $(t''_6 + t''_6 + t''_7 + t''_8)/4$ for tracks passing through the center of the test counter. The rms widths of the first two distributions are a measure of the timing resolution for a counter with two photomultipliers, while that of the third distribution corresponds to a counter with four photomultipliers. Further, one would expect $\sigma_{57} = \sigma_{68} = \sqrt{2} \sigma_{5678}$, since we have increased the number of measurements by a factor of 2.

2.1.1.3 Preliminary Results

We show the different configurations considered in Figure 39, referred to as Configurations A, B, C and D. Only the first two have been measured, the last two are projected designs to be measured later. Each of the first two configurations have been measured with and without the small counters. The results for these configurations are presented in Table 6. The rms widths of the time difference distributions are quoted. The statistical errors are negligible. The errors quoted are only the systematic one. In configurations A and B, particles traverse a 5 cm and 10 cm thickness respectively.

Table 6. Measurements of Timing Resolution

Configuration	σ_{57}	σ_{68}	σ_{5678}
	ps	ps	ps
Config. A1	120	112	83
Config. A2	122	117	86
Tim. Resol.	$\sigma_{2PMT} = 118 \pm 6$		$\sigma_{4PMT} = 85 \pm 2$
Config. B1	92	88	64
Config. B2	95	92	67
Tim. Resol.	$\sigma_{2PMT} = 92 \pm 4$		$\sigma_{4PMT} = 66 \pm 2$

2.1.1.4 Summary and Conclusions

The timing resolutions for the broader beam are only slightly worse than the narrow beam case. Further, σ_{2PMT} , the timing resolution using only two PMT's is about a factor $\sqrt{2}$ larger than σ_{4PMT} , the timing resolution using four PMT's.

In conclusion, we have built and tested a large scintillation counter suitable for hadron identification in the next generation of particle detectors being designed for B meson factories at e^+e^- and $p\bar{p}$ colliders. Timing resolutions of 85 ± 2 and 66 ± 2 picoseconds have already been achieved using two PMT's and four PMT's, respectively. In Figure 39, we show two designs (Configurations C and D) where we increase the number of measurements by a factor of 2 over the prototypes tested and hope to achieve an improvement of $1/\sqrt{2}$ in the timing resolutions. Timing resolutions of 46 to 60 picoseconds are expected for these configurations.

2.1.2 Time-of-Flight Device Monte Carlo

The goal of this project is to develop a Monte Carlo simulation of a time-of-flight (TOF) scintillation counter and associated electronics so that we can study the limitations to timing resolution for different counter designs and electronic triggering schemes. A scintillation counter consists of the plastic scintillator slab, followed by a lucite light guide for piping the light and adapting the varying shapes of the scintillator edge to the generally circular face of the photomultiplier device (PMT). The output pulse from the photomultiplier is then split into two using a 50:50 splitter. One half of the signal is then fed into an analog-to-digital converter (ADC) which measures the total charge Q of the pulse. The other half is fed either directly or after an amplifier stage to the input of an electronic discriminator circuit which puts out a marking square output pulse when the input PMT pulse crosses some voltage threshold. The output pulse from the discriminator is then used to stop a time-to-digital converter (TDC), which was started by a machine pulse marking beam-beam crossing in an electron-positron collider, thus providing the time-of-flight (TOF) of a charged particle from the interaction point to the scintillation counter. We list below the different physical processes to be simulated:

a) Production of Charged Hadrons in e^+e^- Annihilations.

- b) The Time-of-Flight From Interaction Point to Scintillation Counter.
- c) The Transfer of Energy or Energy Loss by Ionization to the Scintillator.
- d) Decay of Excited States and Consequent Emission of Light.
- e) Transmission of Light in the Scintillator.
- f) Transmission of Light in the Light Guide.
- g) Conversion of the Photon Pulse to an Electronic Pulse by the PMT.
- h) The Stop Time Trigger from the Discriminator.
- i) The Start Time Trigger from the Machine.

2.2 Physics Analysis

By the summer of 1991, approximately 500 pb^{-1} of CLEO II data will be available for the physics analysis. The CLEO II data will have two major improvements over CLEO 1.5 data. First, the particle identification of the tracks will be significantly improved by the information from TOF system. Secondly, the ability of detecting γ will enrich the physics we can study with the data.

2.2.1 Continuum Production Of Λ_c^+ , Σ_c^+ , New And Old Decay Modes

The fact that less than 20% of the branching fractions of the Λ_c^+ decay modes are known tells us that there are lots of decay modes to be found. For example, while the branching fraction of the decay mode $\Lambda_c^+ \rightarrow \Lambda X$ is expected to be approximately 30%, less than 5% of them are accounted for. With the ability of detecting γ and π^0 in CLEO II, we hope many of the unaccounted decay modes can be observed, namely;

$$\begin{aligned}
 \Lambda_c^+ &\rightarrow pK^+\pi^-\pi^0 \\
 &\rightarrow \Lambda\pi^+\pi^0 \\
 &\rightarrow \Lambda\rho\pi \\
 &\rightarrow \Lambda(n\pi)^+\pi^0 \\
 &\rightarrow p\overline{K}^0\pi^0
 \end{aligned}$$

$$\begin{aligned}
&\rightarrow p\bar{K}^0\pi^0\pi^0 \\
&\rightarrow \Lambda\pi^+\pi^0\pi^0 \\
&\rightarrow \Sigma^+\pi^+\pi^- \\
&\rightarrow \Sigma^0\pi^+
\end{aligned}$$

Also for the first time, we will be able to observe the third isospin state of the Σ_c baryon, Σ_c^+ , through its decay mode

$$\Sigma_c^+ \rightarrow \Lambda_c^+\pi^0$$

To achieve our goal, we will:

- 1) Tag Λ_c^+ using both its new and old decay modes.
- 2) Study π^0 characteristics in detail.
- 3) Understand detection efficiency using Monte Carlo simulation program.
- 4) Constantly compare the results with our previous analysis on charmed baryons.
- 5) Remove possible reflections from charmed meson and other charmed baryon (eg. Ξ_c , Ω_c) decays.

The search for $\Lambda_c^+ \rightarrow pK^+\pi^-$ has already been carried out using 150 pb^{-1} of new $\Upsilon(3S)$ data. We are trying to get good sample of skimmed data which we can work with. This has turned out to be a very time consuming process since there are 10 4mm tapes of data now and it takes approximately 8 hours to process 1 tape. Unless we get another hard disk soon, (Or a 20 MIP Unix station?), the physics analysis procedure would be slowed down significantly.

Since the $\Upsilon(3S)$ region is different from continuum region, we will also study how well we can get rid of $\Upsilon(3S)$ cascade decay events of the type

$$\begin{aligned}
\Upsilon(3S) &\rightarrow \Upsilon(2S)X, \\
\Upsilon(2S) &\rightarrow \Upsilon(1S)\pi^+\pi^+ \\
&\rightarrow \Upsilon(1S)\pi^0\pi^0, \\
\Upsilon(1S) &\rightarrow \text{lepton pairs}
\end{aligned}$$

to reduce our background level. We should have our analysis program ready by early next year so that when CLEO has full 500 pb^{-1} continuum and $\Upsilon(4S)$ data sample available by next summer, we can analyze them efficiently.

We are going to constantly run CLEOG Monte Carlo to simulate the physics processes which we are interested in. We can also debug our analysis program using Monte Carlo generated data. Although some parts of the Monte Carlo program are not as sophisticated as the previous one, we believe it is already very useful for our analysis.

We have converted the Λ_c^+ reconstruction routines from the AVEHST histogram version to the CERN HBOOK version. We are going to use this new version of programs to run on CLEO II data sample to tag as clean as possible the Λ_c^+ events and study excited medium states of Λ_c^+ decay such as $\Lambda_c^+ \rightarrow p K^{*0}$ and $\Lambda_c^+ \rightarrow \Delta^{++} K^-$.

Possible reflection sources for Λ_c^+ signal will come mainly from :

- a) $D^+ \rightarrow K^- \pi^+ \pi^+$, while a π^+ being misidentified as a proton.
- b) $D_s^+ \rightarrow K^- K^+ \pi^+$, where K^+ being misidentified as a proton.
- c) $D^+ \rightarrow \bar{K}^0 \pi^+$, π^+ being misidentified as a proton.
- d) $D^+ \rightarrow K^+ K^- \pi^+$, K^+ being misidentified as a proton.
- e) $\Xi_c^+ \rightarrow \Lambda K^- \pi^+ \pi^+$, K^- being misidentified as a π^- .

Possible reflection sources for Σ_c^+ signal will be:

- a) $D^+ \rightarrow K^- \pi^+ \pi^+ \pi^0$, a π^+ being misidentified as a proton.
- b) $D^+ \rightarrow \bar{K}^0 \pi^+ \pi^0$, the π^+ being misidentified as a proton.
- c) $D^+ \rightarrow \bar{K}^0 \pi^+ \pi^- \pi^+ \pi^0$, a π^+ being misidentified as a proton.

2.2.2 Ξ_c^0 and Ξ_c^+ Production

Significant amount of CLEO II data will be available by early next year. By combining these data with the data taken during 1987-88 runs, we will improve statistics significantly in the Ξ_c^0 and Ξ_c^+ analysis. We have already published the result of the investigation in the decay modes of $\Xi_c^0 \rightarrow \Xi^- \pi^+$ and $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ and shown the evidence for the signal in the decay modes of $\Xi_c^0 \rightarrow \Xi^- \pi^+ \pi^- \pi^+$

and $\Xi_c^0 \rightarrow \Omega^- K^+$ with 87-88 data. By including CLEO II data, we will be able to obtain statistically significant signals in both decay modes and the other decay modes we have searched for, namely:

$$\begin{aligned}\Xi_c^0 &\rightarrow \Lambda K^- \pi^+ \\ \Xi_c^+ &\rightarrow \Lambda K^- \pi^+ \pi^+ \\ \Xi_c^+ &\rightarrow \Omega^- K^+ \pi^+\end{aligned}$$

Especially, we should be able to make a definite statement about the strength of the W exchange model through the study of the decay mode of $\Xi_c^0 \rightarrow \Omega^- K^+$.

Since Cleo II detector can detect γ and therefore π^0 , we will be able to study any decay modes involving them, namely:

$$\begin{aligned}\Xi_c^0 &\rightarrow \Xi^- \pi^+ \pi^0 \\ \Xi_c^+ &\rightarrow \Xi^- \pi^+ \pi^+ \pi^0\end{aligned}$$

Moreover, we can reconstruct Ξ^0 through its decay mode of $\Xi^0 \rightarrow \Lambda \pi^0$, we can study the modes involving Ξ^0 namely:

$$\begin{aligned}\Xi_c^0 &\rightarrow \Xi^0 \pi^+ \pi^- \\ \Xi_c^+ &\rightarrow \Xi^0 \pi^+ \\ &\rightarrow \Xi^0 \pi^+ \pi^0\end{aligned}$$

Combining these measurements of the Ξ_c production cross sections with those of Λ_c^+ production cross section, we will be able to make a better estimate of the total charmed baryon cross section in e^+e^- interactions.

2.2.3 Search for $B \rightarrow \Xi_c X$

We have already seen the evidence for the Ξ_c^0 produced from the B meson decay in Figure 13. With additional data from CLEO II, we will be able to measure the branching ratio of the B decaying into Ξ_c^0 . We also hope to be able to measure the branching ratio of $B \rightarrow \Xi_c^+$ through the decay mode of $\Xi_c^+ \rightarrow \Xi^0 \pi^+$, where $\Xi^0 \rightarrow \Lambda \pi^0$.

2.2.4 Search for Excited States Ξ_c^{*0} , Ξ_c^{*+} , $\Xi_c^{0'}$ and $\Xi_c^{+'}$

As has been discussed before, there are several spin-excited states of charmed strange baryons which we are interested in investigating, namely, $\Xi_c^{0'}(c\{sd\})$, $\Xi_c^{+'}(c\{su\})$, $\Xi_c^{*0}(\{csd\})$ and $\Xi_c^{*+}(\{csu\})$.

All the theoretical models predict the mass splitting $\Xi_c' - \Xi_c$ to be less than $140 \text{ MeV}/c^2$,^{17,20} so that Ξ_c' should decay into Ξ_c through γ emission. Since CLEO II detector can detect the γ 's, we can search for the Ξ_c' state through following decay modes.

$$\begin{aligned}\Xi_c^{0'} &\rightarrow \Xi_c^0 \gamma \\ \Xi_c^{+'} &\rightarrow \Xi_c^+ \gamma\end{aligned}$$

For the excited states Ξ_c^{*0} and Ξ_c^{*+} the transition $\Xi_c^* \rightarrow \Xi_c \pi$ is allowed for some models.^{21,22} We will search Ξ_c^* through the following decay modes:

$$\begin{aligned}\Xi_c^{*0} &\rightarrow \Xi_c^+ \pi^- \\ &\rightarrow \Xi_c^0 \pi^0 \\ &\rightarrow \Xi_c^0 \gamma \\ \Xi_c^{*+} &\rightarrow \Xi_c^+ \pi^0 \\ &\rightarrow \Xi_c^0 \pi^+ \\ &\rightarrow \Xi_c^+ \gamma\end{aligned}$$

The measurements of these mass splittings are very important to distinguish many theoretical models.

2.2.5 Search for Ω_c^0

By including CLEO II data, we will improve the statistics for the decay modes of $\Omega_c^0 \rightarrow \Omega^- \pi^+$ and $\Omega_c^0 \rightarrow \Xi^- K^- \pi^+ \pi^+$, using Ω^- reconstructed through both decay modes of $\Omega^- \rightarrow \Lambda K^-$ and $\Omega^- \rightarrow \Xi^0 \pi^-$.

We will further search for the Ω_c^0 production in e^+e^- annihilations at CESR through following decay modes:

$$\begin{aligned}\Omega_c^0 &\rightarrow \Omega^- \pi^+ \pi^0 \\ &\rightarrow \Omega^- \pi^+ \pi^- \pi^+ \\ &\rightarrow \Xi^- \overline{K^0} \pi^+ \\ &\rightarrow \Lambda \overline{K^0} K^- \pi^+ \\ &\rightarrow \Lambda K^- K^- \pi^+ \pi^+ \\ &\rightarrow \Xi^0 K^- \pi^+\end{aligned}$$

With large statistics, we will be able to observe the Ω_c^0 produced from B decay.

Comparing the production of Ω_c^0 from B decay with the production of Ξ_c^0 from B decay, we may be able to understand more about the relative probability of producing s quark pairs from vacuum to those of light quark pairs.

2.2.6 B Decays to Baryons X

Michael Zoeller has taken over this analysis from X.C. Lou. By next summer, we will have 500 pb^{-1} of data from the CLEO II detector. We will repeat the analysis we have carried out earlier with this data. We should have much better proton identification besides improved Λ and Ξ reconstruction. We should be able to look for the Λ_c^+ 's in decay modes with π^0 's. With a large sample of reconstructed Λ_c^+ 's, we will be able to study $\Lambda_c^+ - lepton$, $\Lambda_c^+ - proton$, $\Lambda_c^+ - \Lambda$ and $\Lambda_c^+ - D$ correlations. The model dependent assumptions used in calculating the absolute branching fractions like $Br(B \rightarrow \Lambda_c^+ X, \Xi_c^+ X, etc)$ may be eliminated with better quality and higher statistics data.

2.2.7 Exclusive $B \rightarrow \Lambda_c^+ \bar{p} (n\pi)$ States

Lou and Alam have pursued this study during the past years without seeing any convincing evidence for a signal in any of the following decay channels studied.

- i) $\Lambda_c^+ \bar{p}$
- ii) $\Lambda_c^+ \bar{p} \pi^+$
- iii) $\Lambda_c^+ \bar{p} \pi^+ \pi^+$
- iv) $\Lambda_c^+ \bar{p} \pi^- \pi^+ \pi^+$
- v) $\Lambda_c^+ \bar{p} \pi^- \pi^+ \pi^- \pi^+$

There is some indication of a signal in the combined mass plot, but the background plots also seem to show similar signals. More work needs to be done before we can draw any conclusion. Of course, all the four decay channels of the Λ_c^+ should be exploited. Up till now, in the exclusive studies only the $pK^- \pi^+$ decay mode of the Λ_c^+ has been studied. We should be able to include other decay modes of the Λ_c^+ and with new CLEO II data have a good chance of seeing fully reconstructed B mesons in the above decay modes.

2.2.8 B Reconstruction and Studies with Tagged Sample

B reconstruction has always been the major thrust of physics at CLEO. In preparation for CLEO II, when we should be focussing on B physics, we have decided to explore partial reconstruction techniques for exclusive B states. The approach promises to provide us with a large sample of tagged B mesons for crucial studies besides high statistics measurements of some selected branching ratios. Clearly, if we have a tagged sample of B mesons in which $B^0, \bar{B}^0, B^+$ and B^- are further identifiable, we can measure $B^0 - \bar{B}^0$ mixing and semileptonic branching ratios of charged and neutral B mesons besides measuring differences in the inclusive properties of charged and neutral B mesons. We will name the different decay modes to which partial reconstruction technique may be applied. The different partial reconstruction techniques will not be discussed here, since they are still evolving. The only one we will mention here is the one in which the D_s^+ is represented by the slow π^+ from its $D^0 \pi^+$ decay mode. Here are the channels we wish to study:

$$D_s^+ \pi^- \pi^0 \text{ equivalent } \pi_s^+ \pi^- \pi^0$$

$$\begin{array}{ll}
D_s^+ \pi^- \pi^- & \pi_s^+ \pi^- \pi^- \\
D_s^+ \pi^- \pi^+ \pi^- & \pi_s^+ \pi^- \pi^+ \pi^+ \\
D^{*0} \pi^- &
\end{array}$$

2.2.9 Determination of α_s Future Work

Thus far all of the AEEC analysis has been conducted through the analysis of charged tracks. The perturbation expansion however, does not distinguish between charged and neutral particles. The next step in this analysis is to determine the effect of neutrally charged particles on the angular energy flow. Since the Monte Carlo program has been "tuned" to match the raw data to determine the detector effect in the angular distribution of the energy flow it will now be used to evaluate the effect of the neutrally charged particles. It is expected that the neutral particles follow the same "flow" patterns as do the charged particles, making the analysis of the CLEO data valid for all particles. After this is completed the value of α_s at 10 GeV will be combined with other values of α_s at different energies to determine the energy dependence of α_s on Q. This collection of data will then be used to determine the QCD scale parameter Λ .

2.2.10 Software Implementation For CLEO II Data Analysis

As mentioned before, we are being able to do CLEO II data analysis using Albany computing facility. In the coming year, more data will be collected on CLEO. The software implementation efforts in Albany will be put more on upgrading new common blocks where detector information being stored, constant files where run information being stored, libraries and other utilities for doing data analysis.

Some new utilities which might be helpful are listed below:

ZCOPY

This is a utility to backup ZEBRA format files.

DISPLAY

The utility will help user to show the real event structure on graphics window.

YPATCH

This is a code management system to help user generate compact and machine independent code.

LIBLIST

To search CLEO libraries quickly. Although we have a version working in Albany now, it does not include many routines developed in last several months.

Right now all the new libraries and include files are stored in user disk. This not only reduces efficiency of the user disk, but also make their upgrading difficult. As soon as we have a new hard disk, all the CLEO II software shall be isolated from general user disk. The final minimum installation of CLEO II data analysis including files, libraries, utility routines, constant files requires 140,000 blocks disk space.

In order to create a more convenient environment for doing data analysis, we shall implement more routines depending on the feasibility of our computing facility.

2.3 Fermilab

As soon as we reconstruct the channeled Σ^+ 's satisfactorily, we will go ahead using these channeled Σ^+ 's to study the polarization and precession angle of the polarization of the Σ^+ inside the crystal and then calculate the magnetic moment of Σ^+ .

There are a lot of offline procedures before we can reconstruct the Σ^+ 's correctly. First of all, we have to run the raw data through (PASS1) to check the data quality such as alignment constants, magnetic field constants, track finding with one hyperon track and one baryon track, acceptable momentum fitting etc. After studying the results from the PASS1, on the second pass (PASS2), we need to finalize the constants of alignment and magnetic field, using good physics data with correct track finding and momentum fitting.

After that, we need to understand the mechanics of the crystal. So far, we know that the out-going particle angle of channeled particle is wider than we expected. We also observed that there are some correlations between the x

position of crystal and the bending angle. One of the explanations is that the crystal is twisted and tilted in the x direction. We need to look into this more carefully and try to make corrections in order to reconstruct the channeled Σ^+ . The same is needed to study the polarization.

Futhermore, the Monte Carlo program is essential for us to understand the effects of the apparatus to the physics results. The study using Monte Carlo will lead us to understand the behaviour of the apparatus, to predict the physics result and to estimate the errors.

We expect to get some results on the magnetic moment of Σ^+ by the channeling method in about a year.

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$$B(B \rightarrow hX) \frac{(N_h + N_{\bar{h}})}{2 \cdot N_{B\bar{B}}}$$

where $\bar{h}$ is the antiparticle of the hadron, N_h and $N_{\bar{h}}$ are the measured numbers of hadrons and antihadrons after correcting for such factors as hadron detection efficiencies, detector geometrical acceptance and momentum acceptance. $N_{B\bar{B}}$ is the total number of $B\bar{B}$ meson pairs in the data sample, where both neutral and charged pairs are included. Thus, for example, $B(B \rightarrow pX)$ stands for $B(B \rightarrow pX) + B(B \rightarrow \bar{p}X)$ as averaged over charged and neutral B mesons and over B and $\bar{B}$ mesons. Consistent with this, unless specified in the text, any reference to a particle or to its decay mode implicitly applies to the complex conjugate states as well.
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4 Figure Captions

Figure 1. The distribution of measured time with respect to expected time for all tubes.

Figure 2. The distribution of measured time with respect to expected time for all counters.

Figure 3. A scatter plot of track beta determined using the TOF systems versus track momentum using the drift chamber.

Figure 4. The dE/dx distribution for hadrons from the data as a function of momentum.

Figure 5. The distribution of measured time with respect to expected time from a typical endcap counter for a large sample of Bhabha tracks.

Figure 6. The scatter plot of $1/\beta^2$ plotted against the momentum for a small sample of charged hadrons.

Figure 7. The invariant mass distributions of six decay modes of Λ_c^+ for $x_p > 0.5$.

Figure 8. Λ_c^+ fragmentation distributions. The smooth and dashed curves are the model predictions each fitted simultaneously to the data from three decay modes.

Figure 9. The invariant mass distribution of all $\Xi^- K^- \pi^+ \pi^+$ combinations with $x_p > 0.3$.

Figure 10. The invariant mass distribution of all $\Omega^- \pi^+$ combinations with $x_p > 0.3$.

Figure 11. The invariant mass distribution of all the combinations of $\Xi^- \pi^+ \pi^- \pi^+$ with $x_p > 0.4$

Figure 12. The invariant mass distribution of all the combinations of $\Omega^- K^+$ with $x_p > 0.4$

Figure 13. The invariant mass distribution of all the combinations of $\Xi^- \pi^+$ from the data on the $\Upsilon(4S)$ and the scaled continuum data.

Figure 14. The invariant mass distribution of $pK^- \pi^+$ combinations for the $\Upsilon(4S)$ and the scaled continuum data.

Figure 15. The measured Λ_c^+ momentum distribution in comparison with different Monte Carlo model predictions.

Figure 16. Diagram of $\overline{B}^0 \rightarrow D^{*+} \pi^-$ Decay Kinematics.

Figure 17. a) Momentum spectrum of $\overline{B}^0$ in Monte Carlo. b) Monte Carlo generated $\cos\theta$ distribution

Figure 18. a) Momentum spectrum of Monte Carlo generated D^{*+} 's. b) Momentum spectrum of Monte Carlo generated π_h^- .

Figure 19. a) Momentum spectrum of Monte Carlo generated π_s^+ . b) Monte Carlo generated $\cos\theta$ distribution.

Figure 20. Monte Carlo Simulated $\overline{B}^0 \rightarrow D^{*+} \pi^-$ decays, Dotted curve is the resolution expected using full reconstruction; Solid curve is the result of partial reconstruction technique.

Figure 21. Solid curve is R_2 distribution from $B\overline{B}$ Monte Carlo; dash curve is R_2 distribution from continuum data.

Figure 22. Pseudo mass of $\overline{B}^0$ from 212 pb^{-1} of $\Upsilon(4S)$ data

Figure 23. (a) Pseudo mass of $\overline{B}^0$ from 101 pb^{-1} scaled continuum data below $B\overline{B}$ threshold. found from continuum events from data.(b) Continuum subtracted mass distribution

Figure 24. Pseudo mass distribution from 3000 Monte Carlo simulated $\overline{B}^0 \rightarrow X l^- \overline{\nu}_l$.

Figure 25. (a) Mass from 132,000 Monte Carlo simulated $\Upsilon(4S) \rightarrow B^+ B^-$. (b) Mass from 3000 Monte Carlo $D^{*0}(2420)\pi^-$.

Figure 26. $D^{*0}(2420)\pi^-$ reflects to D^{*+} .

Figure 27. 254,000 generic BB Monte Carlo events. a) Mass of $\overline{B}^0$ in which D^{*+} decays have been eliminated. b) Mass of $\overline{B}^0$.

Figure 28. Mass distribution from 3000 Monte Carlo simulated $\overline{B}^0 \rightarrow X l^- \overline{\nu}_l$ decay.

Figure 29. (a) Solid square is the right sign combinations and histogram is the wrong sign combinations. (b) Scaled wrong sign combinations are subtracted from right sign combinations.

Figure 30. α_s as a function of various values of Λ .

Figure 31. Fit of 140,000 hadronic events from the CLEO detector to a second order perturbation expansion of the AEEC.

Figure 32. The E761 set-up at Proton Center of Fermilab.

Figure 33. Channeling silicone crystal with p-n junction strips as detector.

Figure 34. A typical spectrum of ionization losses for 12 GeV particles passing through the crystal.

Figure 35. The beam deflection in the vertical direction at PW chamber C. The center peaks are the undeflected beam leaked through.

Figure 36. Σ^+ signal from a preliminary result.

Figure 37. The residual (measured - expected) time of flight distribution for Bhabhas

Figure 38. TOF Test Setup for measuring timing resolutions

Figure 39. Different Experimental Configurations. a) Configuration 1a) Cosmic ray traverses 5 cm thickness of scintillator. b) Configuration 1b) Cosmic ray traverses 10 cm thickness of scintillator. c) Configuration 1c) Cosmic rays traverses 10 cm thickness of 10 cm x 10 cm cross-section and are viewed by four PMT's at each end.

MINUIT Likelihood Fit to Plot 2000&0

DELTA T for all tubes

File: ITEM.TOF.TOTBT0_3S03_12_REBIN.HBZ;1

15-NOV-90 23:59:43

Plot Area Total/Fit 5.32194E+05 / 4.91496E+05

Func Area Total/Fit 5.12238E+05 / 4.91911E+05

Likelihood = 385.2

$\chi^2 = 392.9$ for 25 - 3 d.o.f.,

C.L.=0.000E+00%

Errors

Parabolic

Minos

Function 1: Gaussian Distribution (sigma)

AREA 5.12238E+05 ± 710.2 - 0.0000E+00 + 0.0000E+00

MEAN 4.94315E-03 $\pm 3.8664E-04$ - 0.0000E+00 + 0.0000E+00

SIGMA 0.24306 $\pm 2.7851E-04$ - 0.0000E+00 + 0.0000E+00

Figure 1. The distribution of measured time with respect to expected time for all tubes.

MINUIT Likelihood Fit to Plots

tbar1

File: ITOF.IDAJALL.HIST;2

15-NOV-90 15:06:57

Plot Area Total/Fit 63217. / 59694.

Func Area Total/Fit 61878. / 59662.

Likelihood = 19.3

$\chi^2 = 19.4$ for 16 - 3 d.o.f.,

C.L. = 11.1%

Errors

Parabolic

Minos

Function 1: Gaussian Distribution (sigma)

AREA	61878.	± 125.3	- 257.9	+ 248.2
MEAN	3.20236E-03	$\pm 8.6661E-04$	- 8.6717E-04	+ 8.6726E-04
SIGMA	0.19055	$\pm 2.9612E-04$	- 8.0752E-04	+ 8.1473E-04

Figure 2. The distribution of measured time with respect to expected time for all counters.

Figure 3. A scatter plot of track beta determined using the TOF systems versus track momentum using the drift chamber.

File: :STM_:IDNBTEST.HST:9

ID	IDB	Symb	Date/Time	Area	Mean	R.M.S.
14	10	1	901109/0821	1.2278E+05	-5.3436E-02	33.37
					2.738	2.925

PQDR, DE50, NHIT, SINT, BHAB Proj. onto PQDR and DE50 axes

Figure 4. The dE/dx distribution for hadrons from the data as a function of momentum.

MINUIT χ^2 Fit to Plot 1&0

DELTA T (NS)

File: [PLS.MZ]HSTOUT_3S.DAT;1

9-JUL-90 17:37:27

Plot Area Total/Fit 798.00 / 798.00

Func Area Total/Fit 745.72 / 745.72

$\chi^2 = 54.4$ for 100 - 3 d.o.f.,

C.L.=100.0%

Errors

Parabolic

Minos

Function 1: Gaussian Distribution (sigma)

AREA	745.72	± 27.35	- 0.0000E+00	+ 0.0000E+00
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MEAN	4.64208E-03	$\pm 8.9757E-03$	- 0.0000E+00	+ 0.0000E+00
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SIGMA	0.25827	$\pm 6.2234E-03$	- 0.0000E+00	+ 0.0000E+00
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Figure 5. The distribution of measured time with respect to expected time from a typical endcap counter for a large sample of Bhabha tracks.

(35) hadrons

all counters

Figure 6. The scatter plot of $1/\beta^2$ plotted against the momentum for a small sample of charged hadrons.

Figure 7. The invariant mass distributions of six decay modes of Λ_b^+ .

Figure 8. Λ_c^+ fragmentation distributions. The smooth and dashed curves are the model predictions each fitted simultaneously to the data from three decay modes.

Figure 9. The invariant mass distribution of all $\Xi^- K^- \pi^+ \pi^+$ combinations with $x_p > 0.3$.

Figure 10. The invariant mass distribution of all $\Omega^- \pi^+$ combinations with $x_p > 0.3$.

Figure 11. The invariant mass distribution of all the combinations of $\Xi^- \pi^+ \pi^- \pi^+$ with $x_p > 0.4$

Figure 12. The invariant mass distribution of all the combinations of $\Omega^- K^+$ with $x_p > 0.4$

Figure 13. The invariant mass distribution of all the combinations of $\Xi^-\pi^+$ from the data on the $\Upsilon(4S)$ and the scaled continuum data.

Figure 14. The invariant mass distribution of $pK^-\pi^+$ combinations for the $\Upsilon(4S)$ and the scaled continuum data.

Figure 15. The measured Λ_c^+ momentum distribution in comparison with different Monte Carlo model predictions.

$$\theta < 16^\circ$$

$$\cos \alpha < -0.8$$

Figure 16. Diagram of $\overline{B}^0 \rightarrow D^{*+} \pi^-$ Decay Kinematics.

Figure 17. (a) Momentum spectrum of $\overline{B}^0$ in Monte Carlo. b) Monte Carlo generated $\cos \alpha$ distribution.

Figure 18. a) Momentum spectrum of Monte Carlo generated D^{*+} . b) Momentum spectrum of Monte Carlo generated π_h^- .

Figure 19. a) Momentum spectrum of Monte Carlo generated π_i^+ . b) Monte Carlo generated $\cos\theta$ distribution.

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Figure 25. (a) Pseudo mass from 132,000 Monte Carlo simulated $\Upsilon(4S) \rightarrow B^+ B^-$ events. (b) Pseudo mass from 3000 Monte Carlo $D^{*+}(2420)\pi^-$ events.

Figure 26. Estimate of $D^{*0}(2420)\pi^-$ background.

Figure 27. 254,000 generic $B\bar{B}$ Monte Carlo events. a) Pseudo mass of $\bar{B}^0$ in which $D^{*+}\pi^-$ decays have been included. b) Pseudo mass of $\bar{B}^0$ in which $D^{*+}\pi^-$ decays have been excluded.

Figure 28. (a) Solid square is the right charge combinations and histogram is the scaled wrong charge combinations. (b) Scaled wrong charge combinations are subtracted from right charge combinations.

Figure 29. Continuum data: a) Solid square is the right charge combinations and histogram is the wrong charge combinations. b) Scaled wrong charge combinations are subtracted from right charge combinations.

Figure 30. α_s as a function of various values of Λ .

Figure 31. Fit of 140,000 hadronic events from the CLEO detector to a second order perturbation expansion of the AEEC.

Figure 32. The E761 set-up at Proton Center of Fermilab.

top view of crystal
2.5cm*4.5cm , with eight
silicon detectors

Figure 33. Channeling silicon crystal with p-n junction strips as detector.

06/11/90 18:21

TMP761zSTR4260.DCPAW

Figure 34. A typical spectrum of ionization losses for 12 GeV particles passing through

Figure 36. Σ^+ signal from a preliminary result.

Figure 37. The residual (measured - expected) time of flight distribution for Bhabhas

Figure 39. Different Experimental Configurations

Figure 38. TOF Test Setup for measuring timing resolutions

5 Personnel

The Albany High Energy Group consists of the following members: C.R.Sun, Professor, Co-principal Investigator and Director of the Project. M.S.Alam, Associate Professor and Co-principal Investigator; I.J.Kim, Research Associate Professor, B. Nemati Research Associate, F. Sun, Research Assistant; D.Chen, J. O'liver, H. Severini, V. Romero, P.N. Wang and Mike Zoeller, Graduate students in the Ph.D. program.

Dr. B. Nemati and M. Zoeller are now in residence at Cornell University. Dr. Nemati served as a liason between CLEO and Albany. In addition to doing Physics analysis, he is now in charge of the entire CLEO II time-of-flight system which includes the endcap counter built by Albany and the barrel counter built by Harvard. This responsibility fell upon him because of the departure of Harvard post doctor Mike Procario. He arrived just on time for this important assigment.

M. Zoeller, in addition to his thesis studies, is also assisting Nemati on the time-of-flight soft-ware.

W.Li completed his Ph.D. degree and is now employed by SSC.

We have three other Graduate students, who are interested in and associate with our lab but not yet committed to the Ph.D. porgram: F. Assalliami, Z. Lin and J.Su

7. Vita

Curriculum Vita '90

Name: Chih Ree Sun
Address: Physics Department
State University of New York at Albany
Albany, NY 12222

Citizenship: United States

Education:

1947 B.S., University of Calcutta
1951 M.S., University of California at Los Angeles
1956 Ph.D., University of California at Los Angeles

Academic Experience:

1956-1962 Research Staff Member, Princeton University
1962-1965 Assistant Professor, Northwestern University
1965-1968 Associate Professor, Queens College, New York City
1968-1969 Consultant, Princeton University
1968-1978 Associate Professor, SUNY at Albany
1978- Professor, SUNY at Albany

Awards, Memberships:

American Physical Society

American Association of University Professors

Sigma Xi

Sigma Pi Sigma

Frank Hsu Fellowship - 1954-1956

Excellence in Research, Award by the President, SUNY/Albany, 1986

Patent

Minimum Ionization Particle Detector Produced by Gamma Ray Irradiation. Patented on Feb. 25, 1969 by U.S. Atomic Energy Commission work done under contract at Princeton University with H.A. Blumenfeld and F. P. Pandolfi. Token Cash Award by Princeton University.

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177. " Σ_c^{++} and Σ_c^0 production from e^+e^- annihilation in the Υ energy region", T. Bowcock et al.(CLEO), Phys. Rev. Lett. **62**, 1240 (1989)
178. "Study of the decay $\bar{B}^0 \rightarrow D^{*+}\ell^\pm\bar{\nu}$ ", D. Bortoletto et al.(CLEO), Phys. Rev. Lett. **63**, 1667 (1989)
179. "Search For Neutrinoless decays for the τ lepton", T. Bowcock et al.(CLEO collaboration), Phys. Rev. **D41**, 805 (1990)
180. "Observation of B-Meson Semileptonic Decays to Noncharmed Final States" R. Fulton et al.(CLEO collaboration), Phys. Rev. Lett. **64**, 16 (1990)
181. "Radiative $\Upsilon(1S)$ decays", R. Fulton et al.(CLEO collaboration), Phys. Rev **D41**, 1401 (1990)
182. "Observation of $\Upsilon(4S)$ decays into non- $B\bar{B}$ final states containing ψ mesons"
J. Alexander et al.(CLEO), Phys. Rev. Lett. **64**, 2226 (1990)
183. "P-wave charmed mesons in e^+e^- annihilation", P. Avery et al.(CLEO), Phys. Rev. **D41**, 774 (1990)
184. "Exclusive and inclusive decays of B mesons into D_s mesons", D. Bortoletto et al.(CLEO), Phys. Rev. Lett. **64**, 2117 (1990)
185. "Inclusive Production of the Charmed Baryon Λ_c^+ from e^+e^- Annihilations at $\sqrt{s} = 10.5\text{ GeV}$ ", P. Avery et al.(CLEO Collaboration), CLNS-90-992 (Jun 1990), submitted for publication to Phys. Rev. D
186. "Study of the Decays $D^0 \rightarrow K\bar{K}, \pi\pi$ ", J. Alexander et al.(CLEO), submitted for publication

187. "Study of K^+ production in tau-decay", M. Goldberg et al.(CLEO) , submitted for publication
188. "Measurement of the Λ_c^+ decay asymmetry parameter.", P.Avery et al., Phys. Rev. Lett. **65**, 2842 (1990)
189. "Determination of $B(D^{*+} \rightarrow \phi \pi^+)$ via observations of $D^{*+} \rightarrow \phi \ell \nu$." J.Alexander, et al.Phys. Rev. Lett. **65**, 1531 (1990)
190. " Measurement of $\gamma\gamma$ Widths of Charmonium States." W.Y.Chen, et al., Phys. Lett. **B243**, 169 (1990)

Curriculum Vita '90

Name: **Mohammad Sajjad Alam**

Department: **Physics Department**

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1. Employment

Institution	Title	Dates of Service
1. SUNYA Albany New York	Associate Professor	Sep.'88 - present
2. SUNYA Albany New York	Assistant Professor	Sep.'84 - Sep.88
3. Vanderbilt Univ. Nashville, Tennessee	Assistant Professor Research Assistant Professor	Sep.'81 - Aug.'84 Sep.'79 - Aug.'81
4. Dhaka Univ. Dhaka, Bangladesh	Junior Lecturer	Sep.'69 - Aug.'70
5. Stanford Linear Accelerator Centre, Stanford University, California	Research Physicist	Aug.'75 - July'79
6. Vanderbilt University	Research Associate	Aug.'74 - July'75
7. Indiana University Bloomington, Indiana	Research Assistant	Aug.'71 - Jun.'74

2. Earned Degrees

Institution	Specialization	Degree	Date Received
1. Indiana Univ. Bloomington, Indiana	Experimental Particle Physics	Ph.D.	1975
2. Dhaka Univ. Dhaka, Bangladesh	Theoretical Nuclear Physics	M.Sc	1970
3. Dhaka Univ. Dhaka, Bangladesh	Physics with Mathematics and Chemistry	B.Sc. (Honours)	1968

3. Scholarly Activities

(a) Invited and Contributed Talks

- (i)
- (ii) "Study of Inclusive Kaon Production on $\Upsilon(1S)$, $\Upsilon(2S)$ and Continuum", APS Meeting, New York, January 1981.
- (iii) "Search for Fractionally Charged Particles at C.E.S.R. Energies", APS Meeting, Baltimore, April 1981.
- (iv) "Review of Results from C.E.S.R.", Review Talk International Symposium on Multiparticle Physics, Notre Dame, Indiana, June 1981.
- (v) "Observation of B Mesons at CESR", High Energy Physics Seminar, April 14, 1983 Indiana Univ., Bloomington, Indiana.
- (vi) "The Quest for Quarks - the Ultimate Structure of Matter", Undergraduate Seminar, October 12, 1983, Physics Department, The University of the South, Sewanee, Tennessee.
- (vii) "New Results on $b\bar{b}$ Spectroscopy and the Decay of the b-Quark", Review Talk, Spring Meeting of the American Physical Society Washington, D.C., 23-26 April, 1984.
- (viii) "Preliminary Results on a Search for Exotic Mesons", APS Meeting, Chicago, February, 1984
- (ix) "Revelations of Strangeness, Charm, Beauty and Truth in Electron Positron Collisions", Departmental Colloquium, Mar. 10, 1985, Physics Department, SUNY Binghamton.
- (x) "New Results on the Decays of $B(b\bar{d}/b\bar{u})$ Mesons", Review Talk, Lake Louise Winter Institute '86 on New Frontiers in Particle Physics, Lake Louise, Alberta, Canada, February 16-22, 1986.

- (xi) "Quarks and Leptons, the Ultimate Stuff of Matter", New England Teachers Conference, Sturbridge, Massachusetts, April 23-24, 1987.
- (xii) "Production of Charmed Baryons at C.E.S.R. Energies", Friday Colloquium, Fermi National Accelerator Lab., June 12, 1987.
- (xiii) "CLEO Results on Charm Production from B Mesons and the Continuum", Review Talk, Eleventh International Workshop on Weak Interactions, St. John's College, Santa Fe, New Mexico, June 14 - 19, 1987.
- (xiv) "CLEO II Time-of-Flight Counters," Conference on Particle ID for High Energy Hadron Colliders, Fermi National Accelerator Lab., March 5 - 9, 1989.
- (xv) "Charmed Hadron Spectroscopy and Decays," , International Conference on Heavy Flavor Physics, Cornell University, June 13 - 18, 1989 "Rare B Decays and the Importance of Particle ID," Contributed talk at B Factory Workshop, Cornell University, October, 1989.
- (xvi) "Status of Charm Spectroscopy and Charm Decay at B Factories," , Contributed talk at the B Factory Workshop, Cornell University, October, 1989.
- (xvii) "Lectures on Particle Physics", World Laboratory School on Particle Physics and Cosmology, Islamabad, Pakistan, March 10 - 18, 1990.
- (xviii) "Review of B Meson Decays", World Laboratory School on Particle Physics and Cosmology, Islamabad, Pakistan, March 10 - 18, 1990.
- (xix) "Charmed Baryons at CESR", Friday Colloquium, September 18, 1990, Physics Department, S.U.N.Y.A., Albany, NY. "Research and Development Towards a 50 Picosecond TOF System," Sym-

posium on Detectors for Collider Physics at the SSC, October 18 - 21, Fort Worth, Texas.

(b) Articles Published in Conference Proceedings

- (i) "Review of Results from C.E.S.R.", Proceedings of the International Symposium on Multiparticle Physics, Notre Dame, Indiana, June, 1981
- (ii) "New Results on the Decays of $B(b\bar{d}/b\bar{u})$ Mesons", Proceedings of the Lake Louise Winter Institute'86 on New Frontiers in Particle Physics, Lake Louise, Alberta, Canada, February 16-22, 1986.
- (iii) "Report of the B-Factory Group: I. Physics and Techniques," G.J. Feldman, D.G. Cassel, R.H. Siemann, M.S. Alam et al., Proceedings of the High Energy Physics in the 1990's Conference, Snowmass, Colorado, 1988.
- (iv) "Report of the B Factories: II. Accelerator Technology," R.H. Siemann, D. Cassel, G.J. Feldman, M.S. Alam et al., Proceedings of the High Energy Physics in the 1990's Conference, Snowmass, Colorado, 1988.
- (v) "Research and Development Towards a 50 Picosecond TOF System," Proceedings of the Symposium on Detectors for Collider Physics at the SSC, October 18 - 21, 1990, Fort Worth, Texas.

(c) Editorial Contributions

- (i) "Novel Results in Particle Physics", Co-editor with R. S. Panvini and S. Csorna, AIP Conference Proceedings No. 93, Particles and Fields Subseries No. 27 (Vanderbilt University, 1982), 388 pages.

4. Unpublished Recent Internal Reports

1. "Direct Electron Production in $\Upsilon(4S)$ Region", M. S. Alam et al., Wilson Laboratory (Cornell University), Internal Report CBX 80-45 (1980).
2. "Inclusive $\Lambda^0(1115)$ Production at C.E.S.R.", with J. Kandaswamy et al., Wilson Lab. (Cornell Univ.), Internal Report CBX 81-10 (1981).
3. "Study of Inclusive $K^0 - \bar{K}^0$ Production at the $\Upsilon(1S)$, $\Upsilon(2S)$ and Continuum Near $\Upsilon(4S)$ ", M. S. Alam et al., Wilson Lab. Cornell Univ.), Internal Report CBX 81-15 (1981).
4. "Particle Spectra from the $\Upsilon(3S)$ ", M. S. Alam et al., Wilson Lab. (Cornell Univ.), Internal Report CBX 81-34 (1981).
5. "Learning to Use the dE/dX System", M. S. Alam et al., Wilson Lab. (Cornell Univ.), Internal Report CBX 81-35 (1981).
6. "A Weak $D^+ \rightarrow K^0 \pi^\pm$ signal on the $\Upsilon(4S)$ ", M. Alam, Wilson Lab. (Cornell Univ.), Internal Report CBX 82-44 (1982).
7. "Inclusive Production of $K^{*+} \rightarrow K^0 \pi^\pm$ at C.E.S.R.", M. S. Alam, Wilson Lab. (Cornell Univ.), Internal Report CBX 82-45 (1982).
8. "Observation of $B \rightarrow D^0 \pi^- / \bar{D}^0 \pi^+$ ", M. S. Alam, Wilson Lab. (Cornell Univ.), Internal Report CBX 83-36 (1983).
9. "Observation of $F^+ \rightarrow \bar{K}^{*0} K^+$ ", V. Tanikella, M. S. Alam and C.R. Sun, Wilson Lab. (Cornell Univ.), Internal Report CBX 85-12 (1985).
10. "Prototype design of the CLEO II Endcap T.O.F. System", V. Tanikella, V. Romero, M. Alam and C.R. Sun, Wilson Lab. (Cornell Univ.), Internal Report CBX 85-07 (1985).
11. "Evidence for the Decay $B \rightarrow FX$ ", P. Lubrano, V. Tanikella, S. Alam and A. Jawahery, Wilson Lab. (Cornell Univ.), Internal Report CBX 86-10 (1986).

12. "Measurement of $BR(F^+ \rightarrow K^+ K^- \pi^+)_{nr} / BR(F^+ \rightarrow \phi^0 \pi^+)$ and the Product $Br(B \rightarrow F^+ X) * BR(D^+ \rightarrow K^+ K^- \pi^+)_{nr}$," V. Tanikella, M. S. Alam and C.R. Sun, Wilson Lab. (Cornell Univ.), Internal Report CBX 86-47 (1986).
13. "Branching Ratio for the Decay $\bar{B}^0 \rightarrow D^{*+} \pi^-$," W. C. Li, M. S. Alam and C.R. Sun, Wilson Lab. (Cornell Univ.), Internal Report CBX 87-32 (1987).
14. "Direct Observation For the Decay $B \rightarrow \Lambda_c X$," X. C. Lou, M. S. Alam, I. J. Kim and C. R. Sun, Wilson Lab. (Cornell University), Internal Report CBX 88-25 (1988)
15. "Final Design of the CLEO II Endcap System", M.S. Alam, C.R. Sun C. Dong, W.C. Li, P.N. Wang and M. Zoeller, Wilson Lab. (Cornell University), Internal Report CBX 88-XX (1988).
16. "Inclusive Production of the Charmed Baryon Λ_c^+ from e^+e^- Annihilations at $\sqrt{s} = 10.55$ GeV," M.S. Alam, I.J. Kim, X.C. Lou, P.N. Wang and M. Zoeller, Wilson Lab. (Cornell University), Internal Report CBX 89-61 (1989).
17. "Measurement of Inclusive B Meson Decays into Baryons," M.S. Alam, X.C. Lou, X.C. Lou, P.N. Wang and M. Zoeller, Wilson Lab. (Cornell University), Internal Report CBX 90-XX (1990). In preparation.
18. "Inclusive Production of the Charmed Double Strange Baryon Ω_{cc} from e^+e^- Annihilations at $\sqrt{s} = 10.55$ GeV," I.J. Kim, M.S. Alam, C.R. Sun and P.N. Wang, Internal Report CBX 90-49, 1990.

5. Publications

1. "Search for Backwards-produced Exotic Meson Resonances in 8.4 GeV/c π^+p Interactions", M. S. Alam, et al., Physics Letters 53B, 207, 1974
2. "A study of Particle Spectra and Correlations in the Reaction $\pi^+ + p \rightarrow n(\text{forward}) + (2\pi, 4\pi, 6\pi)$ at 8.4 GeV/c", M. S. Alam, et al., Nuclear Physics, B90, 374 (1975).
3. "Observation in e^+e^- Annihilations of a Narrow State at 1865 MeV/c² Decaying to $K\pi$ and $K\pi\pi$ ", with G. Goldhaber et al., Phys. Rev. Lett. 37, 255 (1976).
4. "Observation of a Narrow Charged State at 1876 MeV/c² Decaying into an Exotic Combination of $K\pi\pi$ ", with I Peruzzi et al., Phys. Rev. Lett. 37, 569 (1976).
5. "Radiative Decays of $\psi(3095)$ and $\psi(3684)$ ", with J. S. Whitaker et al., Phys. Rev. Lett. 37, 1596 (1976).
6. "Evidence of Parity Nonconservation in the Decays of the Narrow States near 1.87 GeV/c²", with J. E. Wiss et al., Phys. Rev. Lett. 37, 1531 (1976).
7. "Properties of Anomalous $e\mu$ events Produced in e^+e^- Annihilations", with M. L. Perl et al., Phys. Lett. 63B, 466 (1976).
8. "Inclusive Anomalous Muon Production in e^+e^- Annihilations", with G. J. Feldman et al., Phys. Rev. Lett. 38, 117 (1977).
9. "Mesonic Decays of the $\psi(3095)$ ", with F. Vannucci et al., Phys. Rev. D15, 7 (1977).
10. "Observation of $D^{*+} \rightarrow D^0\pi^+$ ", with G. J. Feldman et al., Phys. Rev. Lett. 38, 1313 (1977).
11. " K^0 Production in e^+e^- Annihilations", with V. Luth et al., Phys. Lett. 70B, 120 (1977).

12. "Spin Analysis of Charmed Mesons Produced in e^+e^- Annihilations", with H. K. Nguyen et al., Phys. Rev. Lett. 39, 262 (1977).
13. "D and D^* Meson Production near 4 Gev in e^+e^- Annihilation", with G. Goldhaber et al., Phys. Lett. 69B, 503 (1977).
14. "D Meson Production and Decay in e^+e^- Annihilation at 4.03 and 4.41 Gev c.m. Energy", with M. Piccolo et al., Phys. Lett. 70B, 260(1977).
15. "Radiative Decays of the $\psi(3684)$ into High Mass States", with W. Tanenbaum et al., Phys. Rev. D17, 1731 (1978).
16. "A Search for Neutral Heavy Leptons", with D.I. Meyer et al., Phys. Lett. 70B, 469 (1977).
17. "Properties of the Proposed τ Charged Lepton", with M.L. Perl et al., Phys. Lett. 70B, 487 (197).
18. "Inclusive Baryon Production in e^+e^- Annihilation", with M. piccolo et al., Phys. Lett. 39, 1503 (1977).
19. "Anomalous e^+e^- and $\mu^+\mu^-$ Events Produced in e^+e^- Annihilation", with F. B. Heile et al., Nucl. Phys. B138, 189 (1978).
20. "Baryonic Decays of the $\psi(3095)$," with I. Peruzzi et al., Phys. Rev. D17, 2901 (1978).
21. "Observation of $\mu 3\pi$ Events in e^+e^- Annihilation", with J. Jaros et al., Phys. Rev. Lett. 40, 1120 (1978).
22. "Search for Charge-2 Mesons in the Reaction $\pi^- d \rightarrow (p-3) X^{--} p_{(forward)}$ at 13.2 -Gev/c", M.S. Alam et al., Phys. Rev. Lett. 40, 1685 (1978).
23. "Limits on Strength of Neutral Currents from $e^+e^- \rightarrow \mu^+\mu^-$ ", with T. Himel et al., Phys. Rev. Lett. 41, 449 (1978).
24. "Inclusive Production of D Mesons in e^+e^- Annihilation at 7 Gev," with P.A. Rapidis et al., Phys. Lett. 84B, 507 (1979).

25. "Observation of Cabibbo Suppressed Decays $D^0 \rightarrow \pi^+ \pi^-$ and $D^0 \rightarrow K^- K^+$ ", with G.S. Abrams et al., Phys. Rev. Lett. 43, 481 (1979).
26. "Measurement of the Radiative Width of the η in 2 Photon Interactions at SPEAR", with G.S. Abrams et al., Phys. Rev. Lett. 43, 477 (1979).
27. "Measurement of the Branching Fraction for $\tau \rightarrow \rho \nu$ ", with G.S. Abrams et al., Phys. Rev. Lett. 43, 1555 (1979).
28. "Observation of Charmed Baryon Production in $e^+ e^-$ Annihilation", with G.S. Abrams et al., Phys. Lett. 44, 10 (1980).
29. "Measurement of the Parameters of the $\psi(3770)$ Resonance", with G.S. Abrams et al., Phys. Rev. D12, 2716 (1980).
30. "Measurement of High-Energy Direct Photons in ψ Decays", with G.S. Abrams et al., Phys. Rev. Lett. 44, 114 (1980).
31. "Forward Low Mass Enhancement in $p\bar{p}$ Seen in the Reaction $\pi^- d \rightarrow n, p\bar{p}n$ and $\pi^- d \rightarrow p, \bar{p}n \pi^-$ ", with A.E. Kreymer et al., Phys. Rev.
32. "Measurement of $\gamma\gamma\psi$ Final States in ψ' Decay", with T. Himmel et al., Phys. Rev. Lett. 44, 920 (1980).
33. "Observation of Three Upsilon States", with D. Andrews et al., Phys. Rev. Lett. 44, 1108 (1980).
34. "Observation of a Fourth Upsilon State in $e^+ e^-$ Annihilations, " with D. Andrews et al., Phys. Lett. 45, 219 (1980).
35. "Observation of the Radiative Transition $\psi \rightarrow \gamma E(1420)$ ", with D.L. Scharre et al., Phys. Lett. 97B, 329 (1980).
36. "Measurements of the Properties of D Meson Decays", with R.H. Schindler et al., Phys. Rev. D24, 78 (1981).
37. "Direct Photon Production at the ψ ", with D.L. Scharre et al., Phys. Rev. D23, 43 (1981).

38. "Observation of the η -Charm (2980) Produced in the Radiative Decay of the $\psi'(3684)$ ", with T. Himel et al., Phys. Rev. Lett. 45, 1146 (1980).
39. "Measurement of the Branching Fraction for the Cabibbo Suppressed Decay $\tau \rightarrow K^{*-}(892) \tau^{-} \nu_{\tau}$ ", with J. Dorfan et al., Phys. Rev. Lett. 46, 215 (1981).
40. "Evidence for New Flavor Production at the $\Upsilon(4S)$ ", with C. Bebek et al., Phys. Rev. Lett. 46, 84 (1981).
41. "A Search for Stable Particles Heavier than the Proton and for $Q = -2/3$ Quarks Produced in $e^{+}e^{-}$ Annihilation", with J. Weiss et al., Phys. Lett. 101B, 439 (1981).
42. "A Measurement of the Cross Section for Four Pion Production in $\gamma \gamma$ Collisions at SPEAR", with D. L. Burke et al., Phys. Lett. 103B, 153 (1981).
43. "A Measurement of the Branching Ratio of $\Upsilon(2S) \rightarrow \pi^{+}\pi^{-}\Upsilon(1S)$ ", with J.J. Mueller et al., Phys. Rev. Lett. 46, 1181 (1981).
44. "Pion Pair Production in Photon-Photon Collisions at SPEAR", with A. Roussarie et al., Phys. Lett. 105B, 304 (1981).
45. "Observation of $S^{*} \rightarrow \pi^{+}\pi^{-}$ in ψ Decay", with G. Gidal et al., Phys. Lett. 107B, 153 (1981).
46. "A Study of the Decay $\tau^{-} \rightarrow \pi^{-} \nu_{\tau}$ ", with C.A. Blocker et al., Phys. Lett. B, submitted to.
47. "Decay of b-Flavored Hadrons into Single Muon and Dimuon States", with K. Chadwick et al., Phys. Rev. Lett. 46, 88 (1981).
48. "Hadron Production by $e^{+}e^{-}$ Annihilation at Center-of-Mass Energies Between 2.6 and 7.8 GeV. Part I: Total Cross Section, Multiplicities and Inclusive Momentum Distributions", with J.L. Siegrist et al., Phys. Rev. D26, 969 (1982).
49. "Hadron production by $e^{+}e^{-}$ Annihilation at Center-of-Mass Energies Between 2.6 and 7.8 GeV. Part II: Jet Structure and Related Inclusive Distri-

- butions", with G. Hanson et al., Phys. Rev. D
50. "D Meson Production in e^+e^- Annihilation at ECM Between 3.8 and 6.7 GeV", with M.W. Coles, et al., Phys. Rev. D
 51. "Experimental Upper Limits on Branching Fraction for Unexpected Decay Modes of the Tau Lepton", with K.G. Hayes et al., Phys. Rev. D
 52. "Particle Identification by Ionization Measurements: Description of the CLEO dE/dX System", with R. Ehrlich et al., Nucl. Inst. and Methods 211, 17-45 (1983).
 53. "Decay of B Mesons into Charged and Neutral Kaons", with A. Brody et al., Phys. Rev. Lett. 48, 1070 (1982).
 54. "Observation of Semileptonic Decays of Charmed Baryons", with E. Vella et al., Phys. Rev. Lett. 48, 1515 (1982).
 55. "Charged-Particle Multiplicities in B-Meson Decay", M.S. Alam et al., Phys. Rev. Lett. 49, 357 (1982).
 56. "Measurement of the Branching Ratio of $\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$, with J. Green et al., Phys. Rev. Lett. 49, 617 (1982).
 57. "Inclusive Charged D^* Production in e^+e^- Annihilations at $W = 10.4\text{GeV}$ ", with C. Bebek et al., Phys. Rev. Lett. 49, 610 (1982).
 58. "Measurement of the Branching Fraction for the Cabibbo Suppressed Decay $\tau \rightarrow K\nu_\tau$ ", with C.A. Blocker, et al., Phys. Rev. Lett. 48, 1586 (1982).
 59. "Measurement of $s d\sigma/dx$ for Hadron Production by e^+e^- Annihilation at $\sqrt{s}=5.2\text{-GeV}$, 6.5-GeV and 19.0-GeV ", with J.F. Patrick et al., to be published.
 60. "Observation of the Decay $\psi \rightarrow \gamma\rho^0\rho^0$ ", with D.L. Burke, et al., Phys. Rev. Lett. 49, 632 (1982).
 61. "Measurement of the Branching Ratio $\Upsilon(3S) \rightarrow \pi^+\pi^-\Upsilon(1S)$ ", with J. Green et al., Phys. Rev. Lett. 49, 617-620 (1982).

62. "Measurements of the Leptonic Branching Ratios of the $\Upsilon(1S)$, $\Upsilon(2S)$ and $\Upsilon(3S)$ ", with D. Andrews et al., Phys. Rev. Lett. 50, 807-811 (1983).
63. "Measurement of the Branching Fraction of the Decay $\Upsilon(1S) \rightarrow \tau^+ \tau^-$ ", with R. Giles et al., Phys. Rev. Lett 50, 877-881 (1983).
64. "Observation of Exclusive Decay modes of b-Flavored Mesons", with S. Behrends et al., Phys. Rev. Lett. 50, 881-884 (1983).
65. "Search for Axion Production in $\Upsilon(1S)$ Decay", M.S. Alam et al., Phys. Rev. D27 1665-1667 (1983).
66. "Ruling Out Exotic Models of b Quark Decay", with A. Chen et al., Phys. Lett. 122B, 317-321 (1983).
67. " D^0 Spectrum from B-Meson Decay", with J. Green et al., Phys. Rev. Lett. 51, 347-351 (1983).
68. "Evidence for the F Meson at 1970 MeV", with A. Chen et al., Phys. Rev. Lett. 51, 634-638 (1983).
69. "Production of Charmed Mesons in e^+e^- Annihilations at 10.5 GeV", with Paul Avery et al., Phys. Rev. Lett. 51, 1135-1139 (1983).
70. "Observation of Baryons in B Meson Decay", M.S. Alam et al., Phys. Rev. Lett. 51, 1139-1143 (1983).
71. "The CLEO Detector", Nucl. Instr. and Methods 211, 47 (1983).
72. "Decays of the $\psi(3097)$ to Baryon-Antibaryon Final States", with M.W. Eaton et al., Phys. Rev. D29, 804 (1984)
73. "A Search for the $\xi(2.2)$ in the Υ Region", with S. Behrends, et al., Phys. Lett. 137b, 277 (1984)
74. "Observation of Radiative Decays of the $\Upsilon(2S)$ ", with P. Haas et al., Phys. Rev. Lett. 52, 799 (1984).
75. "High-Statistics Study of $\Upsilon(2S) \rightarrow \pi^+ \pi^- \Upsilon(1S)$ ", with D. Besson et al., Phys. Rev. D. 30, 1433 (1984).

76. "Two-body Decay of B Mesons," R. Giles et al., Phys. Rev. 30D, 2279 (1984).
77. "Hyperon Production in e^+e^- Interaction in the Upsilon Region", M. S. Alam et al., P.R.L. 53, 24 (1984). "The Total Cross-Section for Electron-Positron Annihilation into Hadron Final States in the Upsilon Energy Region", with R. Giles, et al., Phys. Rev. D29, 1285 (1985)
78. "Observation of the Decay $B^0 \rightarrow D^{*+} \rho^-$ ", with A. Chen et al., Phys. Rev. D, Rapid Communications 31, 2386 (1985).
79. "Inclusive Hadron Production in Upsilon Decays and in Non-Resonant Electron- Positron Annihilation at 10.49 GeV", Phys. Rev. D 31, 2161 (1985).
80. "Observation of New Structure in the e^+e^- Cross Section above the (4s)", with D. Besson et al., P.R.L. 54, 381 (1985).
81. "Leptonic Branching Ratio of the $\Upsilon(2S)$ ", with P. Haas et al., Phy. Rev. D. Rap. Comm. 30, 1996(1984).
82. "Limit on the $b \rightarrow u$ Coupling from Semileptonic B Decay", with A. Chen, et al., Phy. Rev. Lett. 52, 1084 (1985).
83. "Inclusive Decay of B Mesons into Charged D^* ", with S.E. Csorna et al., Phy. Rev. Lett. 54, 1984 (1985).
84. " Λ_c Production from e^+e^- Annihilation in the Υ Energy Region", with T. Bowcock et al., Phys. Rev. Lett. 55, 923 (1985).
85. "Decay $B \rightarrow \psi X$ ", with P. Haas et al., Phys. Rev. Lett. 55, 1248 (1985).
86. "Bose-Einstein Correlation in e^+e^- Annihilations in the Υ Region", with P. Avery et al., Phys. Rev. D 32, 2294 (1985).
87. "New Determination of the Michel Parameter in Tau Decay", with S. Behr-ends et al., Phy. Rev. D Rap. Comm. 32, 2468 (1985).

88. "Inclusive ϕ Production in B-Meson Decay", with D. Bortoletto et al.,
Phy. Rev. Lett. 56, 800 (1986).
89. "Search for Monoenergetic Photons from $\Upsilon(1S) \rightarrow \gamma X$ ", with D. Besson et
al., Phy. Rev. D Rap. Comm. 33, 300 (1986).
90. "Observation of $B \rightarrow FX$," P. Haas et al., Phys. Rev. B 34, 905 (1986).
91. "Exclusive Radiative $\Upsilon(1S)$ Decays", A. Bean et al., Phys. Rev. Lett. 56,
2781 (1986).
92. "The Decay $D^0 \rightarrow \phi K^0$ ", C. Bebek et al., Phys. Rev. Lett. 56, 1893 (1986).
93. "Upper Limits for the Production of Light Short-Lived Neutral Particles in
Radiative Upsilon Decay", T. Bowcock et al., Phys. Rev. Lett. 56, 2676
(1986).
94. "Measurement of the Direct Photon Spectrum from the $\Upsilon(1S)$ ", with S.E.
Csorna et al., Phys. Rev. Lett. 56, 1222 (1986).
95. "Observation of the Decay $B \rightarrow FX$ ", with P. Haas, et al., Phys. Rev.
Lett. 56, 2781 (1986).
96. "Inclusive B Meson Decays into Charm", with D. Bortoletto, et al., Phys.
Rev. D35, 19 (1987).
97. "A Study of the Decay $B \rightarrow \psi X$ ", M.S. Alam et al., Phys. Rev. D34,
3279 (1986).
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 - (b) "Determining $|V_{bu}/V_{bc}|$ from the Semileptonic B Decay", with T. Bowcock et al..
 - (c) "The Decay $B \rightarrow \psi X$ ", with A. Bean et al..
 - (d) "A Measurement of the τ Lepton Lifetime", with P. Haas et al..
 - (e) "A Measurement of the D^0 Meson Lifetime", with S. Behrends, et al..
2. XXIII International Conference on High Energy Physics, Berkeley, CA July 16-23, 1986.

- (a) "Search for Magnetically Charged Particles Produced in e^+e^- Annihilations at $\sqrt{s}=10$ GeV", T. Gentile et al., (CLEO Collaboration).
 - (b) "Limits on Rare Exclusive Decays of B. Mesons", P. Avery et al., (CLEO Collaboration).
 - (c) "Study of $\pi^+\pi^-$ Transitions from $\Upsilon(3S)$ ", T. Bowcock et al., (CLEO Collaboration).
 - (d) "Limits on $B^0\bar{B}^0$ Mixing and τ_{B^0}/τ_{B^+} ", A. Bean et al., (CLEO Collaboration).
 - (e) "Exclusive Decays of B Mesons", C. Bebek et al., (CLEO Collaboration).
 - (f) "Measurement of Charm Production at $\sqrt{s}=10.55$ GeV", D. Bortoletto et al., (CLEO Collaboration).
 - (g) "Measurement of Heavy Quark and Lepton Lifetime at CLEO", S.E. Csorna et al., (CLEO Collaboration).
 - (h) "Limits on $\text{Br}(b \rightarrow u\ell\nu)/\text{Br}(b \rightarrow c\ell\nu)$ from Semileptonic Decay of B Mesons", S. Behrends et al..
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 - (j) "Branching Ratios of B Mesons to $K^+, K^-,$ and $K^0/\bar{K}^0$ ", M.S. Alam et al.,
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 - (l) "A Study of the Decay $B \rightarrow \psi X$ ", M. S. Alam et al..(CLEO Collaboration).
3. The 1987 International Symposium on Photon-Lepton Interactions, Hamburg, Germany, July 20-27, 1987.
- (a) "Search for Neutral Higgs in B-Meson Decay", with P. Avery, et al..

- (b) "Upper Limits on Charm-Changing Neutral-Current Interactions", with P. Haas, et al..
 - (c) " D^{*+0} Production in Continuum e^+e^- Annihilations at $\sqrt{s}=10.5$ GeV", with C. Bebek, et al..
 - (d) "Inclusive Production of the Charmed Baryon Λ_c^+ from e^+e^- Annihilations at $\sqrt{s} = 10.5$ GeV", M.S. Alam, et al..
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- (h) "Search for the Charmless Decays $B \rightarrow p\bar{p}\pi^+$ and $p\bar{p}\pi^+\pi^-$," C. Bebek et al. (CLEO Collaboration).
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Phys. Lett. **B243**, 169 (1990)

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Master of Science, Physics, University of Washington, Seattle, 1985

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EXPERIENCE

Predoctoral Research Assistant and System Expert

University of Washington, Seattle

At Stanford Linear Accelerator Center (1984-1990)

Participated in acquisition and analysis of data obtained with the Mark III detector at the SLAC storage ring SPEAR.

As the collaboration expert on the Mark III's Time-of-Flight system, held primary responsibility for the performance of the system, including calibrations, diagnosis and repair of hardware problems, and software upgrades.

Achievements included writing and implementation of an offline calibration program, as well as a sophisticated Time-of-Flight reconstruction program.

Determined inclusive decay properties of D mesons produced at the $\psi(3770)$ resonance. With data collected at 4.14 GeV, observed previously undetected decay of the charmed meson D_s^+ into the final state $\bar{K}^0 K^+$.

Undergraduate Research Assistant

University of Colorado, Boulder. (1981-1983)

With the high energy physics group, carried out detector efficiency studies related to the Fermilab tagged photon experiment.

In collaboration with the condensed matter physics group, performed theoretical calculations and carried out laser diffraction experiments with 2-dimensional crystals on thin membranes.

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