PION AND KAON PRODUCTION OF CHARM AND CHARM-STRANGE STATES

A Proposal to Fermilab

November 12, 1985

By

J. C. C. Anjos, A. F. S. Santoro, M. H. G. Souza
Centro Brasileiro de Pesquisas Fisicas, 22290 Rio de Janeiro, BRAZIL

J. A. Appel*, R. Dixon, D. Green, P. M. Mantsch, T. Nash, K. Sliwa, W. J. Spalding
Fermilab, Batavia, IL 60510, USA

P. Karchin
University of California at Santa Barbara, Santa Barbara, CA 93106, USA

S. B. Bracker, B. R. Kumar, G. J. Luste,
University of Toronto, Toronto, Ontario, CANADA M5S 1A7

T. Kafka, R. Milburn, A. Napier, J. Schneps
Tufts University, Medford, MA 02155, USA

*Spokesperson

TABLE OF CONTENTS

I.	Proposal Summary	3
II.	Introduction	5
III.	Physics Objectives	6
IV.	Comparison with Other Related Efforts	12
V.	Beam Requirements & Target	18
VI.	Forward Spectrometer Apparatus	25
VII.	Data Acquisition System	31
VIII.	Rates and Triggers	37
IX.	Schedule and Cost	43
X.	Bibliography and References	45

I. PROPOSAL SUMMARY

We propose an experiment to measure the properties of hadronic charm production using the Tagged Photon Spectrometer facility. We shall measure the flavor, x and A dependence of this process at the same time and in a single apparatus. In addition to collecting several times more charm than any completed or proposed hadronic experiment, we expect to have a sample of F mesons as much as two orders of magnitude more than published efforts. High statistics lifetime measurements of several charm states are expected. The experiment is proposed for the next running period.

The experiment will record equal numbers of π and K induced events using a fast transverse energy trigger and a modified data acquisition system capable of recording more than 300 events per second. The transverse energy trigger used in E691, providing an enrichment of about 3 over a simple interaction trigger while keeping 80% of the charmed particles, will be used. It will provide at least 300 million events to be examined for possible writing to tape. A new data acquisition system includes "Level 3" filtering capability before writing events to tape.

The experiment requires a minimal hardware extension to an existing and proven facility and will take advantage of the significant software developments already focussed on the charm photoproduction experiment. The existing forward spectrometer and silicon microstrip detectors (SMDs) are augmented by a beam DISC Cerenkov counter, a new beam transition radiation detector (TRD) and 6 new planes of beam defining SMDs. The new equipment is associated with (1) defining and identifying the incident charged beam and (2) increasing the recordable event rate by a factor of at least 3 relative to E691.

The proponents of this new experiment consist of a subset of the E691 collaboration with new collaborators having multiparticle spectrometer experience. We anticipate additional collaborators joining us if approval is granted.

II. INTRODUCTION

This proposal is submitted following the successful completion of the running of E691 using an incident tagged photon beam. Nearly 90,000,000 events were written to tape using a transverse energy trigger. The analysis of this data has begun and quantitative indications of the amount and quality of data on tape are now available.

It is proposed to use the Tagged Photon Spectrometer (TPS) as used in E691 for this new experiment. It is a large acceptance, high resolution magnetic spectrometer. It is equipped with electromagnetic and hadronic calorimetry, Cerenkov particle identification and a silicon microstrip detector (SMD) for vertex reconstruction. The fast trigger of E691 (incident particle plus a greater than minimum calorimetric total transverse energy signal) is essentially the same for the new experiment.

From a preliminary analysis of less than about two percent of the E691 data, approximately 50 $D \rightarrow K\pi$ are seen after a vertex cut. The signal to background for this sample is about one-to-one.

Using such photon induced events, we can determine characteristic efficiencies for charm particle detection and measurement and, using actual data from a test run with an incident hadron beam, determine the rates for rejection of the uninteresting background. This current experience gives us confidence in the projections that we make for the results of the proposed experiment.

III. PHYSICS OBJECTIVES

Our physics objective is to make a decisive impact on the state of knowledge of charm hadroproduction. The present data on charm hadroproduction is fragmentary and its interpretation is replete with assumptions. Directly observed charm particles in hadroproduction experiments are very few in number. Multimuon experiments require assumptions about both x and A dependence to reach conclusions on cross-sections. There is, in fact, almost no coherent data on any of this nor on the flavor dependence of charm production. The situation cries out for rectification.

In spite of the poor record of hadroproduction experiments, our experience in E691 with the improved trigger, vertex definition, data recording rate, and off-line analysis capability gives us confidence in our projection of large numbers of clearly identified charm particles. Where rates exceed those in photoproduction in E691 (e.g., F 's produced by K 's), improved lifetime measurements should be obtained in this new experiment.

A. Cross Section

Much higher rates for heavy flavor production are predicted from QCD-based calculations as compared to pre-QCD models (e.g., statistical model). As we have mentioned, the existing measurements are mostly fragmentary and the total cross sections are obtained only after applying substantial acceptance corrections. Having in mind the very limited statistics on which the current measurements are made, there is need of a high statistics charm hadroproduction experiment performed in a large acceptance spectrometer like that in the Tagged Photon Laboratory.

B. Production Mechanisms (x dependence)

A priori, one expects two qualitatively different production mechanisms to be present - central and diffractive (or leading). There is some confusion in the literature about the meaning of these words. One way of classifying the production is to look at the large Feynman x behavior of charm particle cross sections and to invoke counting rules.¹ Protons produce Λ_c with $(1-x)^1$ and D^- 's with $(1-x)^3$. (Similarly, diffractively produced K 's are softer than lambdas. They contain one valence quark instead of two.) In π^- beam experiments one expects D^0 and D^- to be produced at equal rates with $(1-x)^1$ distribution. K^- beams should produce F^+ at similar rates to D^- , and similarly to D 's in a pion beam. In this picture, the Feynman x dependence of central production is $(1-x)^5$. The above dependences are valid ignoring mass effects. In reality, all distributions are expected to be softer due to QCD gluon effects.

A high statistics experiment with wide acceptance in Feynman x is very much needed. Figure III.1 shows a typical x acceptance for the TPS with the magnet settings as run for E691 and proposed for this experiment. Given the wide x acceptance, we can separately measure central and diffractive production at the same time. Furthermore, taking data with π^- and K^- makes it possible to study the flavor dependence of each.

While the acceptances of Figure III.1 are from photoproduction, where the projectile quarks tend to be at large x , we note that the same is true for the diffractive part of hadroproduction. In any event, the acceptance is not very sensitive to the production dynamics, but rather to such things as apertures and magnet settings. This can be seen from the lower beam energy acceptance shown for comparison.

Fig.III.1. Total reconstruction efficiency for the $D^* \rightarrow D^0 \pi$, $D^0 \rightarrow K \pi$ mode. Calculated events coming from γp interactions for two energies of the parent e^- beam.

C. A Dependence

As a summary of the A dependence situation, we quote A. Gurtu from a recent review¹⁷.

"To convert the cross section to $\mu\text{b}/\text{nucleon}$, one has generally tended to take an A^α dependence with $\alpha = 1$. The motivation for this is that J/ψ production exhibits this A dependence. Strange particle production indicates a different and complicated dependence of α on x and P_T , with $\alpha \sim 0.45$ at high x , low P_T (central production). Diffractive production models would naively indicate an $\alpha \sim 2/3$. The only charm experiment to measure the A dependence is the μ beam dump experiment which used Be and W targets and obtained a value of $\alpha = 0.74 \pm 0.07$ from the measured ratio of the rates of prompt ν production in W and Be. Supporting evidence, with large errors, comes from the BIS-2 experiment that $\alpha_{\text{charm}} \sim \alpha_{\text{inel}} = 0.7 - 0.72$."

We would only add to this summary that our experiment combines a series of targets of varied A with a large x acceptance. This combination, coupled with the quality of the spectrometer, is unique.

D. K^+K^- and ϕ Triggers to Study F and D Production from π^-

The production characteristics of both $F^\pm$ and $D^\pm$ mesons can be studied with K^+K^- and ϕ triggers. Although the decay $D^+ \rightarrow \phi \pi^+$ is Cabibbo-suppressed, it is well established. $D^\pm \rightarrow \phi \pi^\pm$ decays have been reported by ACCMOR², Fermilab E623³, and Mark III⁴. The branching fraction has been measured by Mark III⁴ to be: $BR(D^\pm \rightarrow \phi \pi^\pm) = (0.084 \pm 0.021 \pm 0.011) \times BR(D^\pm \rightarrow K^- \pi^+ \pi^+)$ or about 0.4%. E623 observed 234 ± 43 events (5.4 σ) from 3×10^6 $\phi\phi$ triggers from 400 GeV/c pN interactions.³ On the other hand, most of the reported $F^\pm$ production data have been in the $\phi \pi^\pm$ decay modes,⁵ with $BR(F^\pm \rightarrow \phi \pi^\pm) \sim 3-4\%$ (except for TASSO $\sim 13\%$). ACCMOR has reported a few events in the final state $K^+K^- \pi^\pm$ where K^+K^- do not have a mass near the ϕ , and a few $F^\pm \rightarrow \phi \pi^\pm$.^{2,6} However, E623 observed no signal at the F mass (~ 1.975 GeV) and e^+e^- data⁵ indicate no signal at the D mass. This is puzzling, given the e^+e^- $BR(F^+ \rightarrow \phi \pi^+) \sim 3-4\%$ and expected F/D production suppression ~ 0.15 , which result in comparable numbers of $F^\pm \rightarrow \phi \pi^\pm$ and $D^\pm \rightarrow \phi \pi^\pm$. Clearly, this is interesting to pursue with higher statistics.

One can search for $D^0 \rightarrow \phi \pi^+ \pi^-$ which is not reported, but is expected at rates comparable to $D^+ \rightarrow \phi \pi^+$. The decay $F^+ \rightarrow \phi \pi^- \pi^+$ was reported by ARGUS⁵ with a cross section larger than that for $F^+ \rightarrow \phi \pi^+$. In addition to our ignorance of other F decay modes, we do not understand the F production mechanism. One could, for example, conserve charm and strangeness by 3-body production⁷ (e.g. $D^- F^+ K^0$) as well as by the expected 2-body process $F^+ F^-$. In principle, DFK modes might be easier to detect than $F^+ F^-$ due to longer $D^\pm$ lifetime.

D. Lifetimes

While the measurement of charm particle lifetimes is not the primary focus of this experiment, we expect to be able to contribute here too. One element in this is the fact that we are not triggering on the charm particle decay as do experiments looking for changes in ionization in active targets, etc. Secondly, knowledge of the incident particle trajectory and z location of the primary interaction reduces the potential bias inherent from uncertainties in the event vertex present in some other lifetime experiments. Finally, on the basis of statistical sample alone, we would hope to make a significant contribution. Although E691 should have more signal and less background in the D channels, the final count on F's and Λ_C 's is not truly predictable in advance.

IV. COMPARISON WITH OTHER EXPERIMENTS

We have compared our proposed experiment with other existing and proposed experiments, concentrating on fixed target experiments with vertex detection capabilities. Table IV.1 gives a list of these experiments together with their status as far as could be determined. Also given are the numbers of charm events found or anticipated.

The following emerged from this comparison.

1. No other existing experiment has done or will do the physics which is one of the principal aims of this experiment, namely a high statistics comparative study of charm production by π^- and K beams. The only measurement so far comes from NA32 which in 1984 took 22 million π^- , 11 million p and 5.5 million K $^-$ interaction trigger events at 200 GeV/c with a Si active target and Si microstrip detector (SMD) configuration. They reported¹¹, from an analysis of 60% of their K $^-$ data where only those events with a K K π mass in the 1.8-2.1 GeV range were fully analyzed, that 14 events had a distinct K K π vertex. The K K π mass plot shows a clear F signal of 7 events and 2 Cabibbo-suppressed D decays. Three of the seven F candidates have KK mass within 10 MeV of the ϕ mass, and 3 out of the 7 have $x_F > 0.5$ indicating a diffractive type of production in K $^- \rightarrow F$. No results have yet been reported from the π^- beam sample. In the 1985 run, NA32 obtained 15 million triggers with a π^- beam and a 2-kaon trigger from a 2mm Cu target followed by a charge-coupled detector (CCD)

and SMD planes; they have yet to decide whether their next running period in summer 1986 should be devoted to pi or K beam running.

Some results comparing charm production by pions and protons have been published by NA27^{13,14} and more results should be obtained from NA32's proton beam data and from E653 if their next run is with a pion beam.

The only other potential experiment which could study this physics is that of a CERN-Geneva-Milano-Mons-Santander group¹⁵ who have just submitted a proposal to use the CERN Omega Spectrometer to carry out an experiment with pi and K beams at 250 or 350 GeV/c with an impact parameter trigger; their aim is to obtain 1000 events in decay channels such as $D \rightarrow K \pi$ and $F \rightarrow K K \pi$. The authors propose to carry out a feasibility test during the 1986 CERN fixed target running period and, if this is successful, take data in 1987.

2. All but the latest experiments have obtained fairly low numbers of charmed events. The pioneering experiments NA11 (ACCMOR) and NA27 (LEBC + EHS) showed that charm hadroproduction experiments were feasible, and despite observing only a few tens of events per channel, were able to obtain results on charm production mechanisms, decays and lifetimes. NA11 showed that the introduction of a vertex detector can improve the signal to background in a charm channel from about 1:4⁸ to better than 6:1⁹. However, the subsequent experiments NA32 (ACCMOR), with one run

yet to come, and E743 (LEBC + MPS), with data taking complete, will still only number their total charm yield in hundreds of events. The present data obtained by the CERN photoproduction experiment NA14 should yield about 250 $D \rightarrow K \pi$, with next year's running expected to quadruple this. The CERN emulsion experiment WA71 experienced technical difficulties in their run, exposing much less emulsion than expected, and will only get about 50 charm events; they will probably not have another run. The data obtained by E653 this year apparently contains several thousand charm events in the emulsion, with future running expected to do better. The data currently being analyzed by E400 should contain up to 2000 D^* . In photoproduction at Fermilab, the tagged photon experiment E691 has completed data-taking and anticipates several thousand reconstructed $D \rightarrow K \pi$, while the wideband photon experiment E687 is still to run and should do better.

3. The early hopes of developing triggers to substantially increase the fraction of charm events in the data sample have largely faded, at least for the current experiments, and have been replaced by quasi-interaction triggers or triggers aimed at specific final states. Thus, in the ACCMOR experiment, for example, the Si active target proved to be unsuitable for triggering on a rise in multiplicity and even of limited value in identifying primary and secondary vertices. Both this and the

prompt electron trigger have been replaced by an interaction trigger, and a 2-kaon trigger designed for F and Cabbibo-suppressed D decays. The recoil proton trigger of E516 gave way to E691's transverse energy E_T trigger, while NA14 gave up WA4's kaon trigger in favor of a trigger requiring 2 stiff tracks through the spectrometer. However, E400 used a kaon trigger whose charm enhancement factor was ~ 5 for low multiplicities and ~ 2.5 for high multiplicities.

Thus, the E_T , KK and phi triggers proposed for this experiment (Section VIII) have proved successful for other experiments.

4. The relatively low numbers of charm events obtained hitherto is, of course, principally due to the low fractional charm cross section. However, another limiting factor is clearly the absolute numbers of events which the previous experiments have been able to record and analyze. The NA14 photoproduction experiment has so far taken only 6 million events and expects to take another 15 million next year to complete the experiment. Since their trigger is essentially an interaction trigger, this may fairly be compared with about 2-3 (the enrichment of the E_T trigger) times the 90 million events recorded by E691 in 5 months of data-taking this year. The ACCMOR experiment, in four runs in as many years, accumulated only 75 million events, the NA32 part of this comprising 55 million events. E400 obtained about 80 million triggers.

In this experiment, we will enhance our data-acquisition rate to allow the collection of a significantly larger data-sample than any other charm hadroproduction experiment.

5. With the exception of ACCMOR and E400, the main contenders in the charm hadroproduction endeavor are emulsion or bubble chamber experiments. Analysis procedures which require scanning, however automated, are necessarily lengthy.

It seems reasonable to expect that, given adequate computing power and the E691 reconstruction programs and analysis experience, the proposed experiment could be analyzed on a competitive timescale.

TABLE IV.1

Fixed Target Charm Experiments

<u>Expt.</u>	<u>Beam</u>	<u>Target and Vtx.</u>		<u>Trigger</u>	<u>No. of charm events</u>	<u>Reference, Status</u>
NA11	120, 175 pi	Be	None	Single e ⁻	115±34 D0 → K pi	8
	200 pi±	Be	SMD	Single e ⁻	35 D → K npi	9
	100, 120 p ⁻			Phi	17 D → K K pi	10
					12 F → K K pi	11
NA32	200 pi ⁻ , p, K ⁻	Active Si SMD		Interaction	14 D/F → K K pi 60% of kaon data	11
	200 p ⁻ (200 pi ⁻ or K ⁻)	Cu	CCD+SMD	2 kaon		1985 (1986)
NA25	200 p/pi 360 p	HOBC		Muon	48 charm decays in 60% of 360 GeV data	12
NA27	360 pi 360 p	LEBC+EHS		Interaction	21 charm decays 29 D, 3 F	13 14
E743	800 p	LEBC+MPS		Interaction	Expect 500 charm events	1985
E653	800 p (800 pi)	Emulsion SMD		Single mu	Expect several 1000 charm	1985 (1986)
WA71	350 p ⁻	Emulsion SMD			Expect 50 charm	1985
E691	<250 gamma	Be	SMD	E _T	50 D → K pi in 2% of data	1985
NA14	<150 gamma (<150 gamma)	Active Si SMD		2 tracks	Expect 250 D→K pi	1985 (1986)
E687	(<600 gamma)					(1987)
E400	<400> n	Active Si	PWC	Kaon	Expect 2000 D*	1984
Proposed Experiment	(250 pi, K)	A's	SMD	E _T , KK, φ	Several Thousand	(1987)

V. BEAM REQUIREMENTS AND TARGET

The beam and target are chosen so that we receive 300 fast triggers per second, half of them kaon induced and half of them pion induced. The incident pion flux (essentially the incident charged particle flux) is prescaled at the trigger level to achieve this. The target is made up of very thin foils in order to facilitate the reconstruction and separation of primary and secondary vertices in the Level 3 processors (discussed later). Since some of the target foils are high Z materials, the total target thickness is kept small (approximately 2% of an interaction length total) in order to keep the multiple scattering in the target at manageable levels. As detailed below, all of this can be achieved with a total beam on target of approximately 3×10^{12} primary protons per 20 second spill.

A. The Beam Itself

We propose to use a negative hadron beam of 250 GeV. A scheme for producing such a beam at 2 mrad production angle is already incorporated in the present P-East beam layout. The 250 GeV negative charged particle yield of this beam is estimated to be 2.2×10^{-4} per incident 1000 GeV proton, with K^- and $\bar{p}$ components of ~6% and ~3%. (If a zero degree production angle can be achieved, the total yield would increase by a factor ~3, with the K^- component increasing by a factor ~2.3.)

We will use both the Fermilab DISC Cerenkov counter and a transition radiation detector (TRD) to tag the beam. Use of the DISC counter requires that the beam be nearly parallel. The beam can be tuned to give an rms dispersion of ~50 μ rad, but this then requires collimation to reduce the spot size at the

experiment target to an RMS of ~ 0.3 inches, reducing the yield by a factor 4. Thus, we expect $\sim 7.5 \times 10^6 \pi^-$, $\sim 4.5 \times 10^5 K^-$ on target, and $\sim 2.3 \times 10^5 \bar{p}$ on target, per 1.5×10^{11} 1000 GeV incident primary protons (i.e., per second).

B. Beam Particle ID

To accomplish the physics goals of this experiment, we propose to implement a tagging system to identify pions and kaons without forcing an unreasonable reduction in beam flux. We propose to install two devices to achieve this; one to tag K's, the other to tag π 's.

1. DISC Counter

Fermilab owns an imaging Cerenkov counter, called a DISC counter, whose performance characteristics are known. It is the device used extensively in the M6 beam line over many years. As a figure of merit, the device can separate two particle species provided their velocity difference, $\Delta\beta$ is at least 4×10^{-7} . We note that, at 250 GeV/c, $\Delta\beta$ for pions and kaons is about 1.8×10^{-6} and for kaons and protons is about 5×10^{-6} , affording a fairly comfortable factor before the resolution limit is reached. Furthermore, the DISC counter provides a positive signal for the minority kaons, an important advantage. It is available for this experiment.

As stated above, use of the DISC does impose some severe conditions on the beam optics, however. In particular, it is necessary that the beam be parallel over the 5.5 meter length of the counter to within ± 20 microradians. Studies of this beam, performed so far with the present apertures, have shown that 50 microradians rms divergence can be achieved by simple retuning of the beam. This is larger than we want but, fortunately, does not lead to misidentification

of pions as kaons, but rather to the reverse which is equivalent to inefficient tagging. More specifically, for a roughly gaussian distribution of divergence angles with $\sigma = 50$ microradians, 8% of the distribution lies with ± 20 microradians. If we say that the tagging efficiency goes to zero beyond that, we then conclude that the DISC is 8% efficient for tagging kaons. Alternatively and preferably, collimation can be added to the beam to achieve the same result in terms of useful K^- per incident proton.

Given the above $5 \times 10^5 K^-$ per second on target, we will have 4×10^4 tagged K^- per second on target. These tagged K 's with a 2% interaction length target (see below) and a factor 3 trigger rejection rate (again, see below) provide the desired 150 kaon induced triggers per second.

2. Transition Radiation Detector

A second beam tag comes from a transition radiation detector (TRD). The discussion of the DISC counter above was predicated on the choice of 250 GeV/c as the nominal beam momentum. This choice follows mostly from the limitations imposed by the DISC. Should we decide to run at a higher beam momentum, the DISC is no longer useful. We note that, at 250 GeV/c, pions and kaons have γ of 1800 and 500 respectively. At 450 GeV/c, these values become 3200 and 900 respectively and clearly suggest the use of a TRD. Unlike the DISC, a TRD enjoys improved performance with increasing beam momentum (see Table V.1) and, in general, does not impose severe conditions on the beam line optics. It is difficult to be very specific at this point since, unlike the DISC, there is no existing beam line TRD available. Consequently, one would have to be designed and constructed. What does exist is a certain amount of experience with TRD's since they have been used in at least two experiments at Fermilab (E715 and

E743). In both of these experiments, the detectors were used downstream of the target where things are more complex and difficult. Nevertheless, at least in the case of E715, the device appears to have been a resounding success. The predicted performance of Table V.1 is derived from the E715 experience.⁹ We propose to copy this device; i.e., 12 cells, but of a size appropriate for beam use.

The TRD can be used effectively to tag pions at 250 GeV (removing the K^- and $\bar{p}$ contamination). Alternately, if the requested primary beam intensity is not available, the TRD can be used at higher energy to veto pions, leaving a $K^-/\bar{p}$ sample, but without the DISC inefficiency due to beam divergence requirements. Even more appealing in the event that primary beam intensity is limiting, we can turn to a positive 250 GeV beam using a DISC K^+ tag and a TRD π^+ tag - ignoring the protons.

C. Target

In addition to providing materials of various atomic weight, the target configuration is optimized for simplification of on-line and later off-line reconstruction and filtering. We propose to use thin foils, each separated by eight resolution lengths (i.e., $8 * 150\text{--}250 \mu\text{m}$ in the beam direction, z). The foils are thin enough so that, having identified the foil in which the interaction occurred, the z position is known to better than the track reconstruction resolution.

A typical target configuration is sketched in Figure V.1. It shows foils of W^{184} , Cu^{63} , Al^{27} , and Be^9 . The $A^{2/3}$ values are 32, 16, 9 and 4.3 for these materials. A clear separation between A^1 and $A^{2/3}$ can be made since, for example, the ratio A_W/A_{Be} is 20 while $A_W^{2/3}/A_{Be}^{2/3}$ is only 7.5. In fact, with

TABLE V.1

TRD Performance Projections

Clusters Demanded (of 12)	250 GeV			450 GeV		
	π Effic.	K, p Effic.	S/B*	π Effic.	K, p Effic.	S/B*
>3	.97	.49	1.5	.9995	.49	100
>4	.96	.27	1.8	.998	.27	35
>5	.90	.12	0.9	.992	.12	11
>6	.83	.05	0.6	.98	.05	5

*S/B = Desired Beam Particles/Falsely Identified Pions

$$= (1.0 - K, p \text{ Efficiency}) * (K, p \text{ fraction}) / (1.0 - \pi \text{ Efficiency})$$

The K plus p fraction is assumed to total 10% for purposes of this table.

Note, the K and p "efficiency" is energy independent and is due to misidentifying normal ionization loss as transition radiation induced clusters.

the anticipated event sample, separate determinations should be possible at large and small x values.

Since multiple scattering in the high Z materials is significant, they are placed upstream of the others and the total amount of material is kept to less than 20% of a radiation length. The incident beam is only negligibly scattered by the heavy upstream material since its momentum is relatively high and the lever arm to the interaction point is small. This scheme limits the total nuclear interaction length to 2% (actually $2/3$ of this for π 's and K 's), even after putting in some extra Be foils and slightly de-emphasizing the tungsten target. The tungsten is split more than required by the above criteria so that the most upstream half can be deleted for any of the physics analyses for which the multiple scattering proves a problem.

Because the total target is thin, a scintillator will be used just downstream to indicate that an interaction has occurred in the target. In conjunction with this scintillator, another will be used upstream to guarantee a single incident particle. This upstream scintillator will also serve to guarantee that the incident particle did not interact in the TRD, that it is in the acceptable spot size region, and will provide the primary timing signal for the experiment.

Figure V.1. Proposed Target Configuration

Material	A	$A^{2/3}$	# Foils	Total Thickness		
				mm	$\% \lambda_I$	$\% X_0$
Be	9	4.3	10	3.5	.86	1.0
Al	27	9.0	5	1.8	.46	2.0
Cu	63	15.8	3	0.7	.47	5.0
W	184	32.4	2	0.35	<u>.36</u>	<u>10.0</u>
					2.15%	18.0%

VI. FORWARD SPECTROMETER APPARATUS

The forward spectrometer to be used in this experiment is identical to that used in E691. It is an improved version of the basic spectrometer of E516. The improvements included the silicon microstrip detectors just downstream of a solid target, higher magnetic fields in the two magnets of the spectrometer, six additional drift chamber planes (making a total of 35 planes) and improved optics and mirrors in the Cerenkov counters.

The configuration of the spectrometer is shown in Figure VI.1. The figure is actually taken from E516, but may be used to understand E691 and the proposed new configuration. All elements remain in place for the new experiment except the recoil detector and outriggers which were removed for E691.

Rather than discuss the spectrometer in detail, we show some preliminary mass spectra (Figure VI.2) obtained in E691. The data are taken from about 2% of the recorded events, but already indicate the quality of the spectrometer. We propose to use the spectrometer in exactly the same configuration such that the performance will be unchanged and all the forward spectrometer analysis software will be operational and debugged before the start of the run. In fact, this software will have been in use for more than a year before our run.

The K_S^0 , Λ and ϕ shown in Figure VII.2 indicate the apparatus resolution for the current version of the reconstruction programs. These spectra use tracks which passed through both of the magnets and have been reconstructed using the drift chamber and microstrip detector information. The

Figure VI.1 Tagged Photon Spectrometer

Figure VI. 2 K_s^0 , Λ and Φ Mass Spectra

first two spectra require that the two tracks come from a vertex at least 5 cm downstream of the primary vertex in the events. Charged kaons and protons are identified in the Cerenkov counters.

Somewhat more directly relevant to this proposal are the very preliminary spectra shown in Figures VI.3 and VI.4. The events in Figures VI.3 a and b are taken from a selection made with early versions of the reconstruction program. The two sets of spectra, however, show the significant improvements being made to the reconstruction programs. The spectra of VI.3a are obtained ignoring the microstrip information. Figure VI.3b is particularly interesting because it shows not only the improved resolution associated with using the microstrips in the charged particle reconstruction, but the reduction in background caused by the excellent resolution near the target which eliminates pion combinations which result in false K_S^0 . No new events are brought in to the spectra of VI.3b in these figures since the events were preselected. We now know that a renewed selection of events would increase the signal by about 50%.

Finally, Figure VI.4 shows the possibilities which come from a more complete use of the SMD when one demands that D^0 's appear to have decayed downstream of the primary vertex.

This E691 experience encourages us to maintain the Tagged Photon Spectrometer in its current configuration and gives us confidence in its ability to perform in this proposed hadroproduction experiment. We use this experience explicitly in making the estimates shown in the section on triggers and rates.

a) WITHOUT SMD INFORMATION

b) WITH SMD INFORMATION

Figure VI.3 Typical Mass Difference Plots

$$\Delta M = M(K_s^0 \pi^+ \pi^- \pi^+) - M(K_s^0 \pi^+ \pi^-)$$

with $|M(K_s^0 \pi^+ \pi^-) - M(D^0)| < 20 \text{ MeV}$

Figure VI.4 Histograms showing the effect of silicon microstrip detector cuts on D^0 events.

VII. DATA ACQUISITION SYSTEM

A. Existing System and New Goals

The existing data acquisition system, used in E691, is capable of writing 100 events per spill-second to tape with about 30% deadtime. The cap on the data taking rate is imposed because the system has no significant event buffering, and tape writing must be done as data is collected. However, providing a more capable tape logging facility would soon bring us up against another limit, imposed by the slow readout of CAMAC hardware through conventional branch highways. If both data readout and data logging were speeded up dramatically, we would then be faced with another problem -- the need for the experimenters to change tapes every few minutes.

We propose to upgrade the data acquisition system to achieve the following goals:

1. To reduce the deadtime imposed by CAMAC readout of each event from its present 2.5-3.0 milliseconds to 1.0 millisecond or less. This would permit us to collect 300 events per spill-second at 30% deadtime.
 2. To provide enough memory in the system to hold up to 2/3 of each spill's events, so that they can be examined and output to tape during the following interspill.
 3. To provide enough processing power in the data acquisition system that
-

we can partially reconstruct each event and discard those events which appear too hard to reconstruct or of too little scientific interest.

B. Description and Implementation of the New System

The proposed data acquisition system is shown in Figure VII.1. The CAMAC digitizing modules remain almost as they are now. The A-1 crate controllers are replaced with Smart Crate Controllers (SCCs) of the kind designed and used in E705. The branch drivers and branch highways are eliminated and replaced with E705 Readout FIFO (RFIFO) memories, which live in a VME crate.

Each SCC holds the event readout protocol for its crate. As soon as they see a digitizing trigger, the SCCs read out all the modules in their crates, with all SCCs operating in parallel. The SCCs dump their data directly into the RFIFOs. As soon as this is done, the experiment can be turned back on.

Next, a single-board computer in the VME crate assembles complete events from the event fragments contained in the RFIFOs, decides whether or not the events are interesting, discards those deemed uninteresting, and stores the interesting events in block buffers ready for output to tape. Now that ACP processor nodes are available, with their powerful CPUs, large memories, and low cost, it is natural to use the ACP node as the single board computer. In order to provide more memory for buffering events during the spill, and more processing time to decide the fate of each event, many ACP processors are used, each unit handling its share of the incoming events.

One boss ACP processor distributes the workload among the remaining processors and writes the assembled block buffers to tape, using a mag tape controller now in design at AVIV Corp. (If this controller is not ready in time, a standard Fermilab data logging computer can easily be substituted.)

Figure VII.1 -- The Proposed New Data Acquisition System

Data from the experiment is digitized in CAMAC, read out by Smart Crate Controllers (SCCs), and placed into Readout Fifo memories (RFIFOs). ACP processors take events from the RFIFOs, determine whether each event is interesting, discard the uninteresting events, and store the interesting events in internal buffers. The Boss ACP processor distributes the workload among the other ACP processors and writes filled block buffers to tape. The Vax monitors the experiment; it takes events from the memory buffers through a DR11-W / BBC / BVI link. The SCCs are controlled by software in the Vax; control is imposed through serial links between the Vax and the SCCs (dashed lines).

As in E691, monitoring of the experiment is performed on the VAX, using the standard E691 monitoring shell. The VAX is connected to the VME environment using standard ACP interface modules, which also support the software development facilities.

The ACP processors are programmed in FORTRAN, using the standard ACP software development tools. Components of the ACP operating software are also used for downloading of ACP nodes, passing data between the VAX and the ACP processors, etc. S. Conetti (E705) has offered to make available his software for initializing and operating the Smart Crate Controllers. The application-specific code in the ACP processors can be completed and tested well ahead of time.

Although we believe that bringing this system to timely completion is feasible if work begins January 1, we note that the present system is capable of doing a significant, if reduced, experiment. With the new system, we can examine around 300 million events, while writing a selected sample of around 100 million events to tape. Should we fail to gain enough confidence in our event selection algorithms to justify discarding data online, the new system is capable of writing all 300 million events to tape.

Table VII.1

Background information for the Data Acquisition and High Level Trigger (DAHLT) proposed for the Tagged Photon Lab for the hadronic charm experiment.

Number of CAMAC crates (excl. TDC crates)	6
Readout time, E691 (2 branch drivers)	2.5 - 3.0 ms
Maximum digitizing delay	< 0.5 ms
16-bit words per event (avg.)	1600 (3200 bytes)
Data collection rate within spill	100 events/sec.
Deadtime due to readout	250 - 300 ms/sec.
Percent deadtime	25% - 30%
Spill Structure	20 sec. of beam/minute (33% D.F.)

Total number of bytes per tape (no gaps)	180 million
Nominal inches per second (STC 1921)	75 ips
Nominal bytes per inch (STC 1921)	6250 bpi
Nominal data writing rate (STC 1921)	468 Kbytes/sec.
Time to write tape, highest speed	6.4 min.

Tape space efficiency, 16 Kword records	0.93
Tape time efficiency, 16 Kword records	0.86
Bytes per tape, 16 Kword records	167 million
Inches per second, 16 Kword records	67 ips
Data writing rate, 16 Kword records	403 Kbytes/sec.
Time to write tape, 16 Kword records	7.4 min.

The two scenarios for the hadron experiments, one with filtering (scenario 1) and one with no filtering (scenario 2):

6 CAMAC crates, 6 SCCs, 6 RFIFOs

1 20-slot VME crate

6 RFIFO's

1 QVI or Tape Controller

1 BVI

1 VME service module

1 VME display

10 ACP processors

from 6 CAMAC crates

to data logging computer or directly to tape drive

to data monitoring computer

clock, arbitration...

Digitizing time	0.5 ms max.
Readout time	0.5 ms max.
Deadtime per event	1.0 ms/event
Events per spill second from CAMAC	300 events/sec.
Deadtime per spill second	300 ms/sec. (30%)

Events per spill	6000
Events per second (avg. over spill cycle)	100 (10 ms per event)
ACP processor time per event	100 ms
Bytes per event	3200
Bytes stored at end of spill	12.8 Mbytes (4000 ev.)
Total memory, 10 ACP processors	20.0 Mbytes

Scenario 1

Filter in ACP processors	accept 1/3, reject 2/3
Accepted events per spill	2000
Bytes to tape per second (avg. over spill cycle)	107 Kb/sec. (27% of max.)
Time per tape	27.4 min.

Scenario 2

No filter in ACP processors	all events accepted
Accepted events per spill	6000
Bytes to tape per second (avg. over spill cycle)	320 Kb/sec. (80% of max.)
Time per tape	9.1 min.

VIII. RATES AND TRIGGERS

The basic trigger for the experiment, the E_T trigger, is the scalar sum of transverse energies of all the particles detected in the downstream electromagnetic and hadronic calorimeters. The trigger will be used in the same way as it was in E691 and in the incident hadron beam test done last year. This reduces the trigger total to 1/3 the sum of the inelastic total interaction trigger rate. Thus, we will be recording data at 1/3 the π and K cross section rates, about 8 mbarns. For a subset of the events, we will add the E623 trigger as discussed below.

A. E_T Trigger

The efficiency of the E_T trigger depends somewhat on production mechanisms and decay modes. Nevertheless, for totally hadronic decay modes, it is expected to be at least 80% efficient. Thus, for total charm, it is at least 65% efficient. Figure VIII.1 shows the E_T trigger efficiency as a function of the fully off-line reconstructed event E_T .

As an indication of the kind of data we expect to obtain, we show in Table VIII.1 the numbers of events expected in the signal and in the background for E691 and for the proposed hadron experiment. We point out that the estimates for the F meson are conservative in that no increment in the production by kaons is included. The 120 reconstructed F mesons in the table can be viewed as a lower limit or, alternately, the amount of background may be viewed as an upper limit. Cuts on the downstream nature of the F decay can be made tighter, decreasing the signal, but improving the signal to background rate.

TABLE VIII.1

Estimate of the Signal and Background for Various Charm Channels

<u>Channel</u>	<u>Signal/Background</u>	
	scaled from D^0 signals seen in E691	hadron expt. with VME upgrade
$D^0 \rightarrow K\pi^+ (+c.c.)$	3000/1500	1620/4500
all $D \rightarrow$ all 2, 3 and 4 body cabbibo allowed decays	12000/6000	6480/18000
$F^+ \rightarrow K\pi^+\pi^+ (+c.c.)$	220/110	120/330
$D^{*+} \rightarrow \pi^+ D^0$ $D^0 \rightarrow K\pi^+ (+c.c.)$	750/0	400/0

Assumptions

- 1) Hadroproduced charm signals are obtained by multiplying the anticipated E691 signals by 1.0/5.5 times the anticipated event sample ratio.
- 2) The spectrometer is assumed to have equal acceptance times efficiency for hadro- and photo-production of the same channel.
- 3) 300 million hadron events on tape taken with trigger $E_T > 2.25$ GeV, no ACP processor filtering.
- 4) The preliminary E691 signals (for the D^0) are multiplied by 1.5 to account for expected improvements in the production version of the E691 track reconstruction and fitting programs.
- 5) The estimate for the F signal in the hadron experiment does not include the production enhancement expected with a K beam.
- 6) All signal/background estimates include the effect of the microvertex cuts.

Figure VIII.1 Trigger Efficiency And D^* Distribution Vs. E_T

B. KK and ϕ Trigger

The trigger processor¹⁸ from E623 can be adapted to the TPS. One can estimate the rates from E623 by scaling the total cross section:

<u>Rate</u>	<u>Trigger</u>
18 mb	Interacting Beam
230 μ b	K^+K^-
73 μ b	ϕ
56 μ b	$K^+K^-K^+K^-$
31 μ b	ϕK^+K^-
7 μ b	$\phi\phi$

A sample of ~1100 ϕ events was obtained during the 1985 running period in the TPS with 250 GeV π^- incident on beryllium. This test data is being used to examine trigger algorithms for the processor. It is also interesting to compare $K^\pm$ and ϕ production in the test run with E623 final results.

C. Comparison of E623 and TPS Hadron Test Results

	<u>E623 (4K Trig.)</u>	<u>TPS Test(E_T Trig.)</u>
Number of Triggers	3.0×10^6	1.0×10^6
Events with $1K^+K^-$	1.6×10^6	4.0×10^4
Events with ϕ	19,400	1100
Events with $2K^+2K^-$	1.2×10^5	603
$\phi\phi$ Candidates	1476	24
$\phi\phi$ (Background Removed)	177	0

The numbers in the TPS column (below the first line) are extrapolated from half of the test data which has been processed through the drift chamber reconstruction and Cerenkov analysis programs. Kaons are defined to be tracks which have kaon probability of at least 20% based on the Cerenkov analysis. It is clear that the E623 trigger provides a much greater sample of multiple kaon events. This is due, in part, to the requirement of 4 K's in the E623 trigger. The number of reconstructed ϕ 's per trigger differs by a factor of about 6, however, and the number of $\phi\phi$ events is at least 20 times greater in E623 than in the test. We conclude that it is easy to select events with at least $1K^+$ and $1K^-$ with high efficiency. The ϕ trigger

can be made more effective in the TPS since downstream tracks intersect two Cerenkov counters with the same straight line trajectory. A factor of at least 10 enhancement in the number of ϕ 's per event over the E_T trigger should be easily attainable. For incident tagged pions, a factor of 40 is expected in the number of events with at least two kaons.

Generalizing the ϕ trigger to K^+K^- may increase the trigger rate by a factor of 3, but would have the advantage of including $F^+ \rightarrow K^+K^-\pi^+$. This is certainly desirable if improvements can be made in secondary vertex measurements.

We propose to take 10% of the data with a combination of KK and ϕ triggers. These will require the E_T and beam pion (less prescaled than with E_T alone) signals as well.

IX. SCHEDULE AND COST

A. Schedule

We request that the run of this proposed experiment be scheduled for the upcoming fixed target running period. All components can be ready and the physics interest and potential upgrades of other experiments require early approval and execution of this effort. It is also anticipated that experience from this hadron experiment may be an important factor in allowing a future beauty search at Fermilab by this group or by other new efforts.

The experiment requires 10^6 beam seconds for data taking plus approximately 1 month for set up and for testing of the few new beam defining elements. Assuming 70 hours of delivered beam per week and a $1/3$ spill duty factor, we require 4 months of data-taking.

B. New Costs

The new costs for this experiment are quite modest for the scale of experiment being proposed. The total is approximately \$240K, consisting of the items listed below:

1. DISC Counter (move and mount) \$ 10K
2. TRD (build and operate) \$ 20K
3. BEAM SMD's
 - a. One dimension triplet \$ 15K

(using some existing spares)	
b. Second triplet	\$ 40K
4. Cerenkov counter phototubes	\$ 35K
5. Data acquisition system	\$ 80K
6. KK, ϕ Trigger Interface	\$ 40K

TOTAL	\$240K
-------	--------

The item listed for Cerenkov counter phototubes is a potential expense. In any event, 16 high quality phototubes were borrowed for the running of E691 and have been returned. The phototubes must be replaced either with tubes freed up from the MPS system or with new purchases. The renewed availability of the phototubes has been confirmed with RCA.

In addition to the above new costs there are, of course, the normal operational expenses of the experiment, mostly the large number of magnetic tapes required and gases for the chambers and Cerenkov detectors. Finally, computing time for data analysis is significant here. Production running will be on the ACP or other increased capacity at the Central Computing Facility at Fermilab. Physics analysis of the data summary tapes will be done at Fermilab and university facilities.

X. BIBLIOGRAPHY AND REFERENCES

1. J. Gunion, Phys. Lett. 88B (1979)150.
2. ACCMOR Collab., R. Bailey et al., Phys. Lett. 129B (1984)220.
3. E623 Collab., C. H. Georgiopoulos et al., Phys. Lett. 152B (1985)428.
4. Mark III, R. M. Baltrusaitis et al., Phys. Rev. Lett. 55 (1985)150.
5. CLEO Collab., A. Chen et al., Phys. Rev. Lett. 51 (1983)634.
TASSO Collab., M. Althoff et al., Phys. Lett. 136B (1984)130.
ARGUS Collab., H. Albrecht et al., Phys. Lett. 153B (1985)343.
HRS Collab., M. Derrick et al., Phys. Lett. 54 (1985) 2568.
6. C. Damerell, private communication.
7. Suggested by Dan Green in E623 proposal (1980).
8. R. Bailey et al., Phys. Lett. 132B (1983)230 and 132B (1983)237.
9. R. Bailey et al., Zeit. Phys. C28 (1985)357.
10. R. Bailey et al., Phys. Lett. 139B (1984)320.
11. E. Belau et al., "Observation of Hadronically Produced Charmed F Mesons",
International Conf. on Hadron Spectroscopy, College Park, Maryland, April
1985. NIKHEF-H/85-5. H. Dijkstra, "Measurement of Mass and Lifetime of
Hadronically Produced Charmed F Mesons", Moriond 1984, p259.
12. O. Erriquez et al., "A Measurement of the Total Charm Cross Section in 200
and 300 GeV/c pn Interactions Using a Holographic Bubble Chamber".
CERN/EP-85-165, October 1985.
13. M. Aguilar-Benitez et al., Phys. Lett. 132B (1983)98. M. E. Michalon,
"Production and Decay of Charm Particles in 360 GeV/c pi-p Interactions",
Moriond 1984, p267. P. Pelette, "Properties of the Neutral D Mesons
Produced in a 360 GeV/c pi-p experiment", Moriond 1984, p277.
14. M. Aguilar-Benitez et al., Phys. Lett. 123B (1983)103.

15. L. Rossi, Private communication.
16. A. Denisov, et. al., "Performance of the E715 Transition Radiation Detector", Fermilab-CONF-84/134-E.
17. A. Gurtu, CERN-EP/84-172 and XVth Multiparticle Dynamics Conf., Lund.
18. H. C. Fenker, et. al., "The E623 $\phi\phi$ Trigger Processor",
FERMILAB-PUB-82/62-EXP.