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Detectors for CBA

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I. INTRODUCTION

The physics potential of CBA was discussed in Newsletter No. 4. For purposes of estimating event rates, a nominal luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ was assumed. In fact, several different types of straight sections (insertions) have been designed, to meet various physics objectives. At start-up, three of the six intersection regions will have "Standard" insertions, designed for maximum free space between magnets (58 m) for experimental apparatus. These areas will offer luminosities of $2 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$. The other three will have "High Luminosity" ($2 \times 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$) insertions, with 18 m of free space. Other kinds of insertions may be added later. One interesting type is the "Small Diamond" with a 2 cm long beam overlap, allowing vertex detectors to move in close. Here the luminosity will be $1.3 \times 10^{32} \text{ cm}^{-2} \text{ sec}^{-1}$ and the free space will be only 6 m. Table 1 gives more details on various types of insertions. Still others may be designed, as experimental requirements dictate. For example, even higher luminosities may be desirable for certain experiments (one example is given below).

The question of whether most detectors could operate properly at luminosities in the 10^{33} range was addressed at the recent workshop at LBL, sponsored by the Division of Particles and Fields of the American Physical Society. The workshop was exciting and showed that there is strong and widespread interest in this question. The conclusion was that for essentially all components of a large solid angle general purpose detector, there is no known technological barrier to operation at $L = 10^{33}$. What is needed is a finer segmentation of the various components and a consequent increase in complexity--in particular, the number of electronic channels. Interestingly, however, it appeared that the same increase in segmentation is generally required on physics grounds. Independent of

Table 1
CEA Performance

	Standard		Low- β	High- β	Small Diamond	High Luminosity
Energy (GeV)	400.0	30	400	400	400	400
Current (A)	8	8	8	4	8	8
Luminosity ($\text{cm}^{-2}\text{sec}^{-1}$)	2.0×10^{32}	0.5×10^{32}	3.9×10^{32}	1.6×10^{31}	1.3×10^{32}	2.1×10^{33}
Tune Shift	1.5×10^{-3}	5.5×10^{-3}	8.0×10^{-4}	2.5×10^{-3}	2.5×10^{-4}	4.6×10^{-3}
Crossing Angle (mrad)	11.2	11.2	11.2	11.2	35	2.0
Free Space (m)	± 29	± 29	± 29	± 29	± 3	± 9
l_{int} (m)	± 0.13	± 0.47	± 0.13	± 0.22	± 0.02	± 0.73
β_v^* (m)	7.5	7.5	2.0	75	2.0	2.0
β_h^* (m)	42.8	42.8	42.8	75	10.0	42.8
β_{max} (m)	170	170	550	~ 170	~ 550	550
σ_v^* (mm, rms) ^a	0.21	0.77	0.11	0.66	0.11	0.11
σ_h^* (mm, rms) ^a	0.51	1.90	0.51	0.66	0.24	0.51
$\Delta p/p$ (total %) ^b	0.075	1.0	0.075	0.04	0.075	0.075

^aThe normalized emittances (enclosing 95% of the particles in phase space) are: $E_v = E_h = 15\pi \times 10^{-6}$ rad-mm.

^bTo obtain the value of $\Delta p/p$ at 400 GeV simple adiabatic damping was assumed. Some small dilution factor probably will have to be included to take into account rebunching, acceleration and debunching of the CEA beam.

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luminosity, there is a need to reduce electronic front end costs. In Section II of this issue, we discuss some current approaches to a large solid angle detector.

An alternative approach for utilizing the high rate of events at CBA is to design special purpose detectors for specific physics goals which can be pursued within a limited solid angle. In many cases this will be the only way to proceed, and then high luminosity has a different significance. The total rate in the restricted acceptance is less likely to be a problem, while the need for high luminosity to obtain sufficient data is obvious. Section III surveys 8 such experiments from studies carried out in the community. Such experiments could be run on their own or in combination with others at the same intersection, or even with a large solid angle detector, if a window can be provided in the larger facility. The small solid angle detector would provide the trigger and special information, while the facility would provide back-up information on the rest of the event.

In Section IV we consider some possibilities of refurbishing existing detectors for use at CBA. This discussion is motivated by the fact that there is a growing number of powerful detectors at colliding beam machines around the world. Their builders have invested considerable amounts of time, money and ingenuity in them, and may wish to extend the useful lives of their creations, as new opportunities arise. Obviously, the examples given here are purely illustrative; any actual use of existing detectors must compete for approval through the usual process of proposal and review, and the initiative clearly lies with their owners.

With regard to the experimental program, many questions need to be settled. A CBA Policy Committee, chaired by Val Fitch, is being set up to consider such matters as the timetable for proposals, policies and procedures for selection of experiments, possible modes of financing equipment and the

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relations between users and facilities. In the meantime, we hope that this Newsletter will be of interest and will perhaps stimulate the development of actual proposals.

II. DESIGNING A GENERAL PURPOSE DETECTOR FOR HIGH LUMINOSITY

Several examples of general purpose detectors have been given in the 1981 and previous summer studies. These detectors fall into two categories, "open" and "closed" geometry. "Closed" refers to the placement of absorbing material as close to the interaction point as possible. For these detectors, a luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ is not a problem and in fact such detectors could operate at $10^{34} \text{ cm}^{-2} \text{ sec}^{-1}$ and even higher.¹ The LBL Workshop concentrated on open geometry detectors. Some design considerations for these detectors will be reviewed. Then an example of a closed geometry detector will be given.

An open general purpose detector to study $W^\pm$ and Z^0 physics, W^+W^- pairs, massive lepton pairs, high P_T and other large energy scale processes at CBA will be comparable in scope to detectors at other high energy colliders. In order to fully exploit the high counting rates at a luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$, the detector must be designed with a high degree of segmentation. It was pointed out at the DPF-LBL workshop that such additional segmentation is also required to measure individual particles within jets and would be necessary in any case for second generation detectors, now that first generation large aperture detectors at hadron colliders have shown such dramatically clean signatures for jets^{2,3} and W bosons.^{4,5}

A typical general purpose detector might have a central region with a cylindrical geometry covering the full azimuth and ± 1.5 units in rapidity. A central tracking chamber in a magnetic field, with enough depth and wires, could measure the

momentum of a 100 GeV/c charged particle with a precision of 10 to 30 percent. This would be surrounded by an electron identifier followed by an electromagnetic and hadronic calorimeter. Segmentation of the calorimeter into $40 \times 40 = 1600$ towers, each covering $\Delta\phi = 0.16$ radians, $\Delta y = 0.10$, is probably adequate. Finally, there would be muon identification.

The region forward of 25° would have segmented calorimetry to fill out the solid angle for missing E_T studies. Precision tracking along with particle identification would also be desirable.

From the results of the DPF-LBL workshop, it is clear that there is at least one approach using present technology for all the elements in a general purpose detector at a luminosity of $10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$. We anticipate that during the actual development of detectors for CBA, additional approaches will also emerge, leading to better, simpler and more economical techniques.

TRACK CHAMBERS

The requirements for wire chambers as large solid angle tracking devices in CBA at $L = 10^{33} \text{ cm}^{-2} \text{ sec}^{-1}$ were examined at the workshop.⁶ This luminosity corresponds to an event rate of 50 MHz. An average charged particle density $dn/dy = 3.6$ is assumed. Using the known performance of the CERN AFS⁷ and the Brookhaven MPS II drift chamber system,⁸ two criteria evolve for the safe extrapolation of these systems to the CBA:

- 1) The rate per wire should not exceed 2 MHz.
- 2) The sensitive time of the chambers (i.e., the maximum drift time) should be short enough to limit the average number of pile-up events to no more than 1 or 2.

These requirements lead to a high degree of segmentation -- the central and forward tracking systems each require $\sim 10^5$ channels. This fine granularity of detection elements is also

necessary if the tracking system is to have good efficiency for resolving individual tracks in jets. A jet consists of a high density cluster of tracks which occupies a small fraction of the detector area. Thus, for a given number of detection elements, it is best to have them as fine grained as possible in one coordinate, accepting coarser granularity in the other coordinate. Figure 1 shows how the efficiency for finding tracks varies with jet momentum and number of wires per layer for a solenoidal field of 15 kilogauss.

Fig. 1 Track efficiency vs. number of wires per layer for jets of various p_T . This is for a cylindrical geometry for $|y| < 1.5$.

One example of a central detector for CBA, meeting the above criteria, has been developed.⁶ Drift chamber wires in the bicycle-wheel configuration are arranged in 4 radial groups with 15 layers of sense wires per ring. Each wire has charge division readout. Although the charge division is rather coarse, it is also highly redundant so that the space points obtained lead to an extremely robust pattern recognition.⁷ For precise measurement of the Z coordinate, each ring has one special layer in which the position along the wire direction is

determined from the induced charge distribution on cathode pads.⁹ These "pad layers" are subdivided into many sections. Each section consists of a row of pads which are resistively coupled so that the position along the pad row is found by charge division (see Fig. 2). The accuracy of the measurement is $\sim 2\%$ of the length of the pad row, provided the section is not occupied with multiple tracks.

Fig. 2. Method of determining the precise Z coordinate by measuring the induced charge on resistively coupled pads.

The 25° half angle cones around the beams not covered by the central tracking chambers are most simply filled with

high-rate chambers such as those in MPS II which use simple planar frame construction. Here again the constraint is imposed that no anode shall have more than a 2 MHz event rate. Modules would be constructed having pairs of X, Y, U and V chambers, where each pair is staggered by a drift space. Since they are in a field free region, 4 sets of such modules will cleanly generate point slopes and eliminate left-right ambiguities. In order to cover the full 4π , including the central detector, one needs a grand total of 240 K channels. The electronics requires only the TDC function, so inexpensive MPS II-type electronics is applicable.

ELECTRONICS DEVELOPMENT

Time and amplitude electronics should be dead-timeless and pipeline delayed by at least 1 μ s in order to facilitate trigger decisions. Because of the desire to reconstruct jets as well as to provide high rate capability with good efficiency, fine granularity is necessary for both tracking chambers and calorimetry.

The total number of channels for amplifier/discriminators, TDC's and ADC's are all over 100 K. This number of components allows custom IC development and industrial levels of production which brings significant cost savings compared to conventional HEP methods. For example MPS II had a TDC system based on 3 custom IC's which had a development cost of $\approx$ \$0.5 M.

The detector system described here may also require a pipelined ADC system, probably with sampling rates of 200 MHz. The charge division ADC should have 8 bit resolution with 9 or 10 bit dynamic range. The current state-of-the-art device is a 6 bit, 100 MHz flash ADC costing \$50-100, available from 3 or 4 sources. There is also an 8 bit, 30 MHz ADC with 9 bit dynamic range currently available for $\approx$ \$8. These are examples of

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commercial products. With a reasonable engineering budget, i.e., \$1-2M, flash ADC's satisfying these more demanding requirements at the same cost can probably be produced in a time frame of 3 to 4 years.

The ADC requirements imposed by high speed calorimeters are similar to those of the tracking charge division channels except that the dynamic range is much greater. Here one requires a dynamic range of .1 GeV to 400 GeV with 2 bit resolution at .1 GeV improving to 8 bit accuracy and resolution at 400 GeV. Two of the above 9 bit ADC's can be used to cover this dynamic range while contributing negligible error to the measurements in a hadron calorimeter.

CALORIMETRY

Many studies have been done in the past year which show that with adequate segmentation^{10,11} existing technologies can operate effectively in the CBA environment¹². This can be understood since the concentration of large p_T in a limited solid angle seldom occurs from the pileup of multiple events. For example, Fig. 3 shows the small effect of the pileup of 10 additional events on triggering on jets above 100 GeV/c. This would correspond to a situation where the ADC gate would need to be 200 ns and so 10 additional events would be collected in addition to the trigger.

Another study¹³ considered the effects of pileup on the signal for $W \rightarrow e\nu$ detected in a calorimeter segmented into θ and ϕ cells each covering 5° excluding a cone of 5° around the beam pipe. Events with $W \rightarrow e\nu$ superimposed with minimum bias events were computer generated with ISAJET¹⁴ and propagated through the simulated detector. A series of cuts not unlike those used by UA1 at the SPS collider⁴ were applied to the data. For example, Fig. 4 shows the Σp_T in the ring of cells surrounding the

Fig. 3. Cross section for triggering on jets versus p_T . Curve is for finding the region of a calorimeter covering $|y| < 2$ which had the largest p_T . The region was defined as $\Delta y = 1$ and $\Delta\phi = 90^\circ$. Solid circles are for $\langle n \rangle = 10$ events in addition to the high p_T jet. Open circles are for $\langle n \rangle = 10$ events in addition to the high p_T jet, with $p_T > 1 \text{ GeV/c}$ required in each $\Delta y = 0.1$, $\Delta\phi = 9^\circ$ cell that contributes to the trigger.

electron with and without the pileup of additional events. If $\Sigma p_T < 1 \text{ GeV/c}$ is required, only 20% of the events would be lost. Figure 5 displays the effect of pileup on the measurement of the electron p_T from the calorimeter. The p_T spectrum is broadened slightly; however, an excellent determination of the Jacobian peak is still possible.

A similar study was done for the case of the search for supersymmetric particles such as the gluino.¹⁵ Figure 6 shows the signal for a 100 GeV gluino and the background with and without pileup. Beyond $p_{out} = 25 \text{ GeV/c}$ there are less than 500 background events as compared with 9000 signal for an integrated luminosity of 10^{40} cm^{-2} .

Fig. 4. a) Transverse energy in the vicinity of electrons from $W^\pm \rightarrow e^\pm \nu$. b) Same as a) but with $\langle n \rangle = 7.5$ events in addition to the W.

While the above studies have shown that a number of the most exciting experiments at CBA could be done using established techniques, it will certainly be important to optimize detectors at CBA for high rates and thus obtain sensitivity to processes which have less spectacular signatures. Toward this end an R&D project has been undertaken to optimize a sampling calorimeter for high rate.¹⁶ Figure 7 shows the timing characteristics of the AFS calorimeter which uses acrylic scintillator with 10% naphthalene and a BbQ wavelength shifter, compared to the

Fig. 5. P_T distribution for electrons from W decay with and without pileup.

Fig. 6. p_{out} distribution for gluino events for $\int L dt = 10^{40} \text{ cm}^{-2}$ compared to backgrounds with and without pileup.

Fig. 7. a) Typical pulse shape observed in the AFS calorimeter for a 4 GeV electron. b) Average pulse shape from test calorimeter with 23% 4 ns clip.

results obtained using a fast PVT based scintillator, Pilot U, coupled with a very fast wavelength shifter, BBOT. Preliminary tests show that it would be possible to use a 20 ns gate on the ADC. Similar timing characteristics can be obtained using vacuum photodiodes and fast scintillator.¹⁷

PARTICLE IDENTIFICATION

It is not expected that a general purpose CBA detector will initially require the identification of different hadrons. However, there has been a recent review of transition radiation,¹⁸ synchrotron radiation¹⁹ and ring imaging Cherenkovs²⁰ for use at high rates; again, adequate segmentation is critical. All these techniques could have application at CBA, and are discussed below in the sections on special purpose and refurbished detectors.

TRIGGERING

The problem of triggering has been studied intensively at BNL and at the recent Berkeley workshop.^{12,13,15,21} The general conclusions are that, for most interesting event topologies, an efficient trigger scheme can be found. For example, calorimetric triggers can include, in addition to weighted analog energy sums, information from hardware cluster finders. Then events can be read into the on-line computer to be further selected before being written on tape.

Specific details for an electron trigger, for example, demonstrate that with a hard wired asynchronous pretrigger the level structure of the CDF trigger scheme may be used.²² Figure 8 shows the various contributions to the trigger rate. Using fast trigger information such as transition radiation in coincidence with the calorimetric pretrigger, the rate is low enough to allow the time for additional computational power to

process events in real time, as in CDF, for electrons with $p_T > 4$ GeV/c. Clearly triggers for objects like W and Z^0 with $p_T > 15$ GeV/c electrons pose no problem.

Fig. 8. Trigger rates for low p_T electron triggers. Solid curve from π^0 's; dashed line from $\pi^\pm$ which deposit most of their energy in the calorimeter; long-short dashed line from the overlap of charged particles and π^0 's in the same jet; dotted line from real electrons due to internal and external conversions.

CLOSED DETECTOR

An example of a closed detector which optimizes muon identification is shown in Fig. 9.¹ In contrast to the open geometry, the calorimeter immediately surrounds the intersection region and serves as a hadron absorber. The calorimeter measures both electromagnetic and hadronic energy flow and is cylindrically symmetric around the beams.

A central drift chamber follows and both calorimeter and drift chamber are contained in a 15 kG solenoid. The drift chamber samples the muon tracks over 2 m in order to maximize the resolution which is proportional to BL^2 . The chamber has 5 m long signal wires parallel to the beam and to the magnetic field. They are supported in the middle so that the paths of muons emitted in either hemisphere are unobstructed. The chamber design has 96 elements of 160 wires each, 15,360 wires in total. Muons will penetrate the calorimeter, be momentum analyzed in the chamber and be identified by penetration into the outer chamber through the iron yoke. The muons are measured with high precision over the range $53^\circ < \phi < 143^\circ$ covering 60% of the solid angle. In the forward direction and down to 20° from the beam axis the muons are measured by three clusters of toroidal chambers with wires orthogonal to the beam. The design aims for muon pair mass resolution $\Delta m/m = 1\%$ at 100 GeV.

III. SPECIAL PURPOSE EXPERIMENTS AND DETECTORS

The trend, noticeable in recent years, toward large 4π detectors at colliding beam machines has been motivated by many considerations. Some experiments require hermetic 4π coverage for detection of missing E_T from neutrinos. Also, in an environment in which events are scarce, there is the desire to detect and measure as many events as possible. At CBA, there is no scarcity. The luminosity will be three orders of magnitude

Fig. 9. Side view of closed geometry high resolution muon detector: A, vacuum chamber; B, electron calorimeter; C, hadron calorimeter; D, precision drift chamber; E, superconducting coil; F, iron return yoke; G, muon trigger counters; H, muon drift chamber; I, interaction diamond; J, luminosity monitor; K, end cap drift chamber; L, end muon drift chamber.

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greater than that at other currently anticipated colliders. A detector viewing 9% of the solid angle at a CBA interaction region will still see 100 times the rate seen by a 90% solid angle detector at other colliders. This will make it practical for some of the interaction regions to be shared by several special purpose experiments. Some examples of such experiments and detectors are given below. It is hoped that these will serve as a stimulus for additional or improved ideas.

LARGE ANGLE ELASTIC SCATTERING²³

Elastic proton-proton scattering at the CBA should be a rich source of fundamental information about the proton. At this new energy range, $d\sigma/dt$ is expected to be similar to the lower energy data, shown in Figure 10, that was obtained at the ISR.²⁴ The interesting structure at $-t < 5 \text{ (GeV)}^2$, which can be described in terms of "geometrical models", has been discussed in previous workshops.²⁵ In addition, apparatus designed to measure these features has been suggested.²⁶ In this report the focus is on the region $-t > 5 \text{ (GeV)}^2$, where the data can be described by a power law as predicted by perturbative QCD.

The prospect that QCD can be used to calculate hadron scattering, even if only over a restricted kinematical range, is quite exciting. Wide angle elastic scattering is a promising reaction for interpreting in terms of QCD because the dominant mechanism may be perturbative due to the large momentum transfers involved. This is an important example of a class of phenomena described by "constituent counting rules".²⁷ Other examples include hadron form factors and structure functions. It is believed that realistic calculations of these processes in QCD will soon be practical.²⁸

Experimental data, which has revealed numerous regularities, has played an important role in developing the counting

Fig. 10. Elastic scattering cross section data obtained at the ISR. (from Ref. 24).

rules. Although p-p scattering is one of the more difficult processes to calculate, it has been measured extensively over a large kinematical range, and the quality of the data available makes it one of the most important testing grounds. The CBA with its unique combination of high energy and high luminosity, should produce data at 100 times greater values of s than previously available and provide a major extension to this data base. This will provide an important test for applied QCD.

The cross section for large $-t$ scattering is extremely small, so the highest possible luminosities are required. The ISR measurements, which extended to $|t| \approx 8 \text{ (GeV)}^2$, had an integrated luminosity of $\approx 10^{36} \text{ cm}^2$. At CBA a factor of 1000 in integrated luminosity might be gained, allowing data perhaps up to $|t| \approx 16 \text{ (GeV)}^2$, assuming negligible dependence of $d\sigma/dt$

on s. The large range would provide an excellent test of power laws. For elastic scattering, increasing the energy does not compensate for luminosity, and this experiment would probably prove impractical at the Tevatron or CERN collider.

The apparatus to detect the rare, large -t events will need to measure the angle and momentum of both scattered protons to eliminate backgrounds. Resolutions of 0.5 mr in angles and 5% for $\Delta p/p$ should be adequate if simple scaling from the ISR experiment is appropriate. A fairly sophisticated pair of magnetic spectrometers that can operate at full luminosity will be required. The spectrometers would also be appropriate for studying rare heavy states produced diffractively.

PARITY VIOLATION IN THE TOTAL CROSS SECTION²³

Another possible experiment, which is of a more speculative nature, is the measurement of the parity-violating helicity asymmetry in the total cross section. If one of the CBA beams is polarized, the asymmetry is defined as

$$A_L = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$

where $\sigma_+(\sigma_-)$ is the total cross section for the scattering of right (left) helicity proton from an unpolarized beam. A non-zero value for A_L would imply a parity-violating interaction and presumably provide interesting information about the weak interactions.

One important issue for this experiment is how large the asymmetry might be. Naive theory might predict values as small as $(M_p/M_W)^4$ or 10^{-8} , which would be too small to measure. However, asymmetries measured at low energies, have proved to be larger than this. At 50 MeV, $A_L = (-3.2 \pm 1.1) \times 10^{-7}$ (Ref. 29), and at 6 GeV, $A_L = (2.6 \pm 0.6) \times 10^{-6}$ (Ref. 30). The

latter number is approaching the size that could be measured at the CBA. Thus we must seek guidance from theory. Below 100 MeV, ρ exchange and similar effects are expected to dominate, and the data^{29,31} are in agreement with theoretical predictions.³² However, asymmetries due to this mechanism will not increase with energy.³³ Hence the asymmetry of $(2.6 \pm 0.6) \times 10^{-6}$ observed at 6 GeV has been viewed as somewhat surprising.

Motivated by this large asymmetry, several authors have predicted large asymmetries at high energies.^{34,35} The mechanism invoked is a parity-odd admixture in the proton wave function induced by a parity-violating quark-quark interaction. One paper³⁵ uses the ideas of QCD to predict that A_L will continue to rise with energy. This would greatly facilitate a measurement at the CBA. It is concluded that large, measurable parity violation effects are possible, and that observing them will provide important information about the weak quark-quark interaction and its influence on the proton wave function.

Measuring asymmetries on the order of $10^{-4} - 10^{-6}$ will require some novel approaches. The event rate of the CBA will be large enough so that very good statistics can be obtained, even if the luminosity suffers a bit when polarized beams are introduced. The major concern will be controlling systematic errors. Rapid reversal of the helicity will be one important technique. Studying the asymmetry as a function of beam position (akin to the Van der Meer method for measuring luminosity) will be another important test.

The apparatus for a high precision total cross section asymmetry measurement must detect a significant fraction of the events to achieve good statistics. However, good efficiency is probably not essential, at least for a first round effort, to establish the size of any effect, so long as the holes in the apparatus are not unusually sensitive to systematic errors. Most experiments studying small parity-violating asymmetries

integrate the signals from the detectors, eliminating problems with dead time. The trick here is that the analog signals from individual events must have approximately the same size. A crude total energy calorimeter might be a suitable detector for this approach. The problems of handling analog signals can be avoided by counting. However, then one must worry about subtle dead time or pileup effects. The 100% duty factor of the CBA helps minimize these problems, and rates on the order of $10^6/\text{sec}$ could be handled in this way. A highly segmented detector with special fast electronics might successfully handle even higher rates.

DIFFRACTION AND HEAVY QUARK PRODUCTION³⁶

Two different but related experiments that would benefit from special purpose detectors are measurements of diffraction dissociation and search for heavy quark production in the forward direction. The production of massive states in the reactions

$$p + p \rightarrow X + p$$

$$p + p \rightarrow X_1 + X_2$$

can proceed coherently via single and double diffraction and therefore with relatively large cross section, for masses given by:

$$M_X^2/s = 1 - x = 1 - 2p/\sqrt{s} < 0.1$$

$$M_X \approx 0.3 \sqrt{s} \approx 240 \text{ GeV},$$

or

$$p > 0.9 \sqrt{s}/2 = 360 \text{ GeV}/c.$$

The mass and momentum transfer distributions are of considerable interest. At Fermilab and the ISR, the differential cross section³⁷

$$\frac{d^2\sigma}{dt dM_X^2} = f_h(s, t, M_X^2)$$

has displayed a simple and universal behavior characterized by

- (1) Exponential t dependence: e^{bt}
- (2) Mass spectra varying as $1/M_X^2$
- (3) Weak energy dependence
- (4) Factorization of the vertices

In addition, diffractive multiplicities have an average value that depends only on the available mass.³⁸

Many of these facts can be explained by the dominance of the triple-Pomeron amplitude in diffraction and can be connected to models such as the Critical Pomeron Regge Field Theory.³⁹ Alternatively, QCD inspired ideas⁴⁰ such as quark and di-quark cascades can describe at least pieces of this physics.

One way to measure single diffraction dissociation is to measure the momentum distribution of the proton for $x > 0.9$. To obtain a mass resolution of $\Delta M_X/M_X = 10\%$ at, say, $x = 0.95$ requires a 1% measurement of the momentum, since

$$\frac{\Delta p}{p} = 2(1 - x) \frac{\Delta M_X}{M_X}.$$

This is not a difficult task for a modest spectrometer that includes a magnet and drift chambers.

A more difficult problem is how to get at the diffractive protons. Since the average transverse momentum of the recoiling protons is about 300 MeV/c, the protons have an average angle of only about 1 mrad at $\sqrt{s} = 800$ GeV. They will stay in the beam pipe unless coaxed out. Several schemes have been proposed.^{41,42} One of these⁴² would have the spectrometer surround the main beam, in which case something like a defocussing coaxial horn would be needed to exploit the cylindrical symmetry.

Fig. 11. A possible detector for diffraction dissociation. (Ref. 42). Particle identification is an option.

This spectrometer (Figure 11) consists of drift chamber modules with resolution of $150 \mu\text{m}$ sandwiching a magnet with maximum bending power of 20 Tesla-m. This provides more than adequate momentum resolution. After the drift chambers is a plane of scintillation counters for triggering, located so as to minimize multiple scattering. Minidrft chambers can be put close to the interaction region to extrapolate the position of the track with minimum error. An important part of the trigger is a set of scintillation counters or proportional chambers on the opposite side of the interaction region, located in "pots" inside the beam pipe and around the beam pipe. Hits in these counters in coincidence with a single track on the spectrometer side signals a single diffraction event.

This spectrometer would not need particle identification to measure inclusive diffraction. Measurements at Fermilab and the ISR show that pion background for $x > 0.9$ is small and falls

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rapidly with x . Nevertheless, particle identification would greatly enhance the utility of the detector: It becomes capable of measuring inclusive production of pions and kaons at high x and of reconstructing heavy quark states if a large enough solid angle spectrometer is used. This greater complexity allows the detector to study the many exclusive channels in diffraction dissociation and to map out the high mass spectroscopy of light quarks as well as that of the heavy quarks.

All evidence to date shows that a great deal of heavy quark production occurs at high longitudinal momenta in the center of mass. The evidence includes the stiff x distribution of Λ^0 , Σ (s quark) and Λ_c (c quark).⁴³ Whether this production can be considered strictly diffractive is controversial, but it effectively behaves so, suggesting that an apparatus oriented along the beam line to exploit this property is a good choice. Typical of the reactions the detector might measure are^{44,45}

The momenta of the final products in these decays will generally be in the range $30 < p < 200$ GeV/c with typical angles of a few mr. The multiplicities of these events are small compared with many of the other events expected to flow into the detector.

A VERTEX DETECTOR FOR STUDY OF HEAVY QUARK JETS⁴⁶

Heavy quark jets produced centrally can be identified by using a high resolution vertex detector to tag events with charm decays. In Figure 12, a "modest" size heavy quark detector

(HQD) is sketched. It covers $\phi = \pm 45^\circ$, $y = \pm 1$, and uses transition radiation detectors and calorimeters. This detector would use the CBA small diamond configuration (± 2 cm), with a luminosity of $10^{32} \text{ cm}^{-2} \text{ s}^{-1}$.

The inner vertex detector consists of four planes of high resolution position sensing elements. To be effective, it must be extremely close to the beams: the first plane is 1 cm from the beam axis. This does not seem to be a fundamental problem provided the chamber is placed either above or below the beams (i.e., not in the horizontal plane). The chamber would be in a rough vacuum separated from the beam by a thin wall ($< 250 \text{ } \mu\text{m}$) of titanium. It would have to be retracted during stacking and acceleration of the beams.

The detector sketched in Figure 12 will have excellent tracking capability -- the vertex detector alone measures track

Fig. 12. Single arm heavy quark detector at $\theta = 90^\circ$ featuring vertex detector.

angles to an accuracy < 1 mr. It is designed to handle high densities of low momentum tracks. Thus a very modest magnetic field will suffice for adequate momentum measurements.

The use of semiconductor detectors as very high resolution tracking devices in high energy physics experiments has been a subject of intense development over the past few years.⁴⁷ A number of such detectors are being constructed (one is operational⁴⁸) which give ≈ 10 μm space-point resolution in the high track density environment of heavy quark searches at fixed target machines. These "microstrip" detectors consist of silicon wafers whose surface area is finely subdivided into strips; each strip may be read out as a separate detection element. The strip-to-strip spacing is typically 20-50 μm . Charge division is used to interpolate among several strips as a way to reduce the number of external connections.⁴⁹ The size of a typical detector element is 2×6 cm^2 which is well matched to the small diamond.

The detector measures one coordinate only. We take this to be the azimuthal coordinate. To obtain space points in 2 dimensions (using strip detectors) would require at least 3 times as many detector planes. However, the cost in multiple scattering errors would outweigh the usefulness of such a scheme. Thus the proposed detector really provides a tag for charmed particles and not a fully reconstructed vertex. The error (σ_v) in the extrapolation of a track to the vertex position is $\sigma_v = 10$ μm .

The trigger would be implemented as a front-end processor of data from the silicon strip detector array. The proposed architecture makes use of data-flow hardware processor techniques.^{50, 51} The algorithm exploits the fact that the beam is all contained within ± 200 μm and looks for decay vertices originating nearest to five trial planes outside this region. A pretrigger using either the calorimeter or a lepton

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is required to reduce the vertex processor input rate to a few hundred hertz.

High-speed, high-multiplicity track-finding in a segmented multi-plane detector system has been studied extensively,⁵² and a system is currently under construction for experiment 766 at the AGS. It could be implemented here using essentially the same techniques, although perhaps at lower speed and cost. Processing time is dominated by production and testing of all pairwise combinations of hits on two planes. Assuming the maximum multiplicity $N = 30$, there are $N^2 = 1000$ combinations, so that even at TTL cycle times, only about 200 μ sec are required for track finding.

The second part of the algorithm, finding a vertex, is better implemented using an array of microcomputers, each executing the same algorithm on one trial plane. The output of each microcomputer will consist of two pieces of information: chi-square for the plane; and the result of the vertex test: yes or no. The microcomputer outputs would be made available via a bus structure to a hardware trigger logic box and/or a host minicomputer.

Each microcomputer would have 2 ms to perform approximately 10 N arithmetic operations per event; or about 300 maximum. Assuming 1.5 ms for this task, a high-performance device, such as a Motorola 68000, would be required. The cost would be roughly \$5K per micro, or about \$25K for 5 projection planes in the decay region.

FREE QUARK SEARCH⁵³

If the quark containment mechanism admits of small leaks, free quarks might be observed under certain conditions. Moreover, it is plausible that any such leakage will be very strongly energy dependent. In particular it might be observed

in measurements of quark-antiquark pairs produced with very large invariant masses. Of course, in conventional views of containment, these quark pairs are manifest as hadron jets with no production of free quarks.

A detector to search for free quarks might cover about 2π sr, from $\cos\theta = 0.5$ to $\cos\theta = -0.5$. Less than four charged particles per interaction¹⁰ will pass through the counters, giving a total rate of about 10^8 particles per second.

To survive the high flux rates, the detector is to be made up of 24 essentially independent elements where the rate in each will be only about 4×10^6 per second. In 1000 hours, a total of about 3.5×10^{14} particles will pass through the whole detector -- or about 1.5×10^{13} particles through each segment. Hence, if one quark is to be detected, the background rejection must be of the order of 10^{14} . In previous experiments⁵⁴ a rejection of 10^{11} has been demonstrated -- without reaching a rejection limit. Since the background pulses in each counter which simulate the small energy loss of a quark are not correlated in energy and largely uncorrelated in time, the rejection is a nearly exponential function of the number and energy resolution of detector units and the design presented here, an extrapolation of previous designs, is meant to achieve a discrimination of 10^{14} .

The diagram of Fig. 13 presents a schematic view of the basic assembly of the detector. The fundamental concept is similar to one used previously.⁵⁵ The quarks are to be identified by their characteristically small energy loss in passing through the 8 scintillation counters which make up each of the 24 scintillation counter sections; a charge $e/3$ quark ($p/mc > 1.5$) will lose $1/9$ as much energy as a minimum singly charged particle and a charge $2e/3$ particle will lose $4/9$ as much energy. The cross sectional dimensions of the scintillator will be 6" by $1/2$ ", yielding 15 photoelectrons initiated by the passage of an $e/3$ quark -- and 60 for a $2e/3$ quark.

Fig. 13. Schematic view of free quark detector.

Since real quarks are to be differentiated from backgrounds by the equality of the normalized pulses in each counter, it is important to establish the criteria for equality in a satisfactory manner. If too loose, they will admit excessive backgrounds; if too selective, they may throw out real events. The criteria are set by generating "fake" quark events regularly by measuring artificially produced "quarks" generated by particles with charge e passing through the scintillators where masks in front of the phototubes pass $1/9$ or $4/9$ of the scintillator light. Such a simulation is nearly exact, fitting the Landau dispersion as well as the mean pulse height. The masks are to be put in at intervals throughout the experiment and the relevant parameters adjusted so as to accept the (pseudo) quarks with high efficiency and discrimination against backgrounds.

The experiment will select events of interest through a hierarchy of acceptance criteria. Initially, events will be

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selected such that each of the eight elements of any one sector generates a pulse greater than 0.03 times minimum and less than 0.7 times minimum. This selection will be made through standard discriminator logic in no more than 10 nsec. Each such trigger will initiate 6 bit flash A to D converters acting on each element of that sector (and, perhaps, other sectors) to record the pulse heights with a resolution of about 0.015 times minimum. Such circuits act in about 25 nanoseconds. This information (i.e., 8 six-bit numbers) could be transferred directly to an on-line computer for final processing or further preprocessed in hard-wired logic within the framework of a FASTBUS data handling system.

SEARCH FOR HEAVY STABLE PENETRATING PARTICLES⁵⁶

Searching for heavy stable particle production in a new energy region of pp collisions is of fundamental theoretical interest. During the 1975 Summer Workshop, there were discussions of the feasibility of looking for long-lived penetrating particles in the fragmentation region of pp collisions. It was argued that the observation of such particles would indicate the existence of a stable heavy lepton or another massive system carrying new quantum numbers.⁵⁷ Experimentally, evidence of such particles has not been found for pp collisions either at FNAL^{58, 59} or at the CERN-ISR⁶⁰ for $\sqrt{s} = 23$ and 62 GeV respectively. However, many theories beyond the standard model do predict its existence on a mass scale ranging from 50 to a few hundred GeV.⁶¹ The high luminosity CBA is an ideal hunting ground for such an object.

A pair of spectrometers at large angles, with good time of flight measurement, would be well suited to look for the production of charged stable heavy particles. The $\beta = 1$ muons will be used as a reference for the time of flight (TOF) measurement. Figure 14a shows the TOF for heavy slow particles

in comparison with that of $\beta = 1$ reference particles. At CBA, events will be separated by 20 ns on the average. To distinguish the TOF of a heavy particle from that of the $\beta = 1$ background arising from different collisions, a set of TOF measurements for the particles should be sampled at different stages of the spectrometer. Figure 14b shows the time separations for one heavy particle with respect to the reference $\beta = 1$ muons at various distances. It is clear that the TOF of the heavy particle is highly constrained.

An optimum angle for the spectrometer with respect to the beam axis of CBA is about 40° .⁶² This avoids more forward angles where longer flight paths are required and the 90° region where many slow particles may prove confusing at high rates.

Fig. 14. a) TOF for a $100 \text{ GeV}/c^2$ massive stable particle with momenta 20 and 50 GeV/c in comparison with that of a $\beta = 1$ bunch of particles. b) Time separations observed from a heavy particle and the $\beta = 1$ background arising from different events. One can sample the $\Delta(\text{TOF})$ measurements at various locations along the spectrometer.

DIRECT SINGLE PHOTONS⁶³

The primary interest in direct single photon production is as a probe of quark and gluon interactions that may be particu-

larly clean. The dominant subprocess expected for the production of prompt photons in pp collisions is $gq \rightarrow \gamma q$.

Compared to jet experiments one has the advantage here of direct and unbiased access to one of the interacting constituents, the photon; hence there are no fragmentation effects and QCD tests are cleaner. The main experimental problem is a large background from $\pi^0 \rightarrow \gamma + \gamma$. Expected counting rates for π^0 and direct γ at CBA have been given elsewhere.⁶⁴

A special purpose detector is required for direct photons because the structure of the detector must be finely segmented to recognize coalescing pairs of photons from π^0 decays, the primary anticipated source of background. This recognition could be achieved by a matrix of electromagnetic calorimeter towers or PWC's interlaced with lead-scintillator layers. The latter configuration is probably less costly.

The minimum opening angle for $\pi^0 \rightarrow 2\gamma$ near 90° is

$$\theta_{\text{Min}}^{2\gamma} \approx 2m_{\pi}/p_T = \begin{array}{l} 27 \text{ mr at } p_T = 10 \text{ GeV/c,} \\ 2.7 \text{ mr at } p_T = 100 \text{ GeV/c.} \end{array}$$

Thus, to eliminate the coalescing background for any π^0 with p_T up to the design value, we assume a detector with $\sigma = 1$ cm resolution for separating a pair of γ rays and require a minimum separation of 5 cm for the two γ rays from a π^0 at the design p_T .

The other major source of background comes from asymmetric π^0 decays where one decay photon misses the detector. For a π^0 of a given energy, the opening angle containing 99% of the decay photon pairs is about 7 times the minimum opening angle. Thus, the fiducial area of a single photon detector must be surrounded by a fully sensitive 35 cm wide border, at the design p_T , in order to catch the asymmetric decays at the 99% level.

A 5 m $\times$ 5 m detector with 1 cm² elements can be considered as a prototypical detector. This would imply 250,000 individual tower elements, or a square matrix with 500 elements on a side.

Using the criteria given above, the detector is set at a distance R from the interaction vertex, where

$$\frac{5 \text{ cm}}{R} = \frac{2m_{\pi}}{p_T}.$$

The fiducial solid angle at the design p_T is

$$\Delta\Omega = \left[\frac{(500-70)}{R(\text{cm})} \right]^2 = \frac{540 (\text{GeV}/c)^2}{p_T^2}.$$

A reasonable design value is $p_T = 70 \text{ GeV}/c$, with the resulting values $R = 13 \text{ meters}$ and $\Delta\Omega = 0.11 \text{ steradians}$. This would give over 100 single γ events in a 10% wide bin at the design value of $p_T = 70 \text{ GeV}/c$ in a canonical one year's run (integrated luminosity 10^{40} cm^{-2}). It is hard to imagine how such a detector could cover a much larger solid angle, hence high luminosity is essential in reaching the largest p_T .

Single photon and resolved π^0 cross sections can be measured from the design p_T down to about 1/5 of the design value. The fiducial solid angle decreases with decreasing p_T at fixed R because the asymmetric π^0 border must be made wider. Nevertheless, considerably more events will be observed at lower p_T values because of the predicted steep p_T dependence of the cross section. For p_T greater than the design value, resolved $\pi^0 \rightarrow \gamma\gamma$ can be measured as well as a combination of unresolved π^0 and direct γ .

A HIGH p_T SPECTROMETER ARM WITH PARTICLE IDENTIFICATION⁶⁵

In the Proceedings of the 1978 Summer Study⁶⁶ a high- p_T spectrometer pair was presented as a prototype high-luminosity experiment. An updated version of this apparatus is considered here. A single arm of the apparatus is discussed; physics considerations will dictate the most efficient use of the rest

of the solid angle. Some choices are: an identical arm in the opposite direction (as in Ref. 66), a larger acceptance arm with more modest particle ID and tracking, or an "energy-flow" device (i.e., mainly segmented calorimetry) covering as much of the remaining solid angle as possible.

Figure 15 shows the spectrometer arm. The acceptance, as defined by the magnet aperture, is as follows:

$$\Delta\Omega = 0.9 \text{ steradians}$$

$$\Delta y = \pm 0.5$$

$$\Delta\phi/2\pi = 0.15.$$

Fig. 15. Schematic representation of the high- P_T spectrometer. The components discussed in the text are labelled as follows: E = electron identifier; T_i = tracking chambers; C_i = ring imaging Cherenkov counters; em = electromagnetic calorimeters; h = hadronic calorimeters; P_i = proportional drift tube arrays; μ = iron muon filter.

With a 30 kG-m field integral all charged particles with $p_T < 0.45$ GeV/c are swept out of the aperture. The expected counting rates reaching the spectrometer are

$$R_{ch} \approx 5 \times 10^6/\text{sec}; R_\gamma \approx 30 \times 10^6/\text{sec}.$$

For present purposes, it is assumed that the spectrometer performs tracking, momentum analysis, calorimetry and particle identification of all particles in the aperture.⁶⁷ Interspersed in the detector are MWPC or drift planes. These are relatively sparse, as only straight-line tracking is involved. Sufficient information to resolve left-right and x-y ambiguities is available at each wire chamber location. Momentum analysis is derived from the apparent miss distance in the bend plane of the track and the interaction point.⁶⁶

Electromagnetic (> 20 radiation lengths) and hadronic (> 6 interaction lengths) calorimetry is provided over the whole aperture, plus wide angle coverage for charged particles with p_T down to 2 GeV/c which are bent away from the spectrometer axis.

The electromagnetic calorimetry is assumed to be finely enough segmented in depth to reject hadrons relative to electrons at the 10^{-3} level. Independent electron identification is provided by either transition radiation¹⁸ or synchrotron radiation.¹⁹ For this purpose the first tracking chamber following the magnet is assumed to be filled with Xe for good X-ray detection efficiency. In the transition radiation case, this would be a stack of several fiber or foil layers interleaved with Xe-filled MWPC's.

The hadronic calorimeter is followed by 6 more interaction lengths of steel with interleaved proportional drift tube arrays for muon identification.

A system of 3 ring-imaging Cherenkov counters²⁰ provides $\pi/K/p$ separation from about 1 GeV/c to over 50 GeV/c.

The charged particle flux given above is not large by accepted standards for fixed-target spectrometers of comparable area. There are $1-2 \times 10^4$ elements in the detector, with rates of 1-50 kHz/element. These numbers are not daunting; in fact the detector is not different in scope from many existing fixed target experiments.

The technologies employed in the particle identification components of this detector are either available or very close at hand. In particular, rate and particle density are not issues of fundamental importance in a limited solid angle apparatus such as this. The price paid for this rather intensive particle identification and analysis over ≈ 1 steradian is in numbers of detector elements (i.e. complexity). However detector systems with thousands of calorimeter cells and tens of thousands of wires are already in routine use.

IV. POSSIBILITIES OF REFURBISHED DETECTORS

In this section we have looked only at physics aspects of recycling and have entirely neglected the important practical questions of the interests and plans for present and future uses of the detectors by their builders and present users. Therefore this exercise should be taken in the spirit of a "Beispiel", i.e., demonstration examples, rather than proposals to move detectors.

LARGE-VOLUME MAGNETS USED AS MUON SPECTROMETERS

There are several very large magnets, most of them superconducting, now in use at various accelerators. In the next 5 years it is quite possible that one or more of these magnets could become available to form the basis of a CBA detector. Prominent examples are the Argonne 12' bubble chamber

magnet, the FNAL 15' bubble chamber magnet and the BEBC magnet at CERN. On a smaller scale, the BNL 7' bubble chamber magnet is already available. Exploiting an existing magnet, even if none of the detector elements of its present configuration could be used, would result in significant savings of time and money. We have chosen to consider in detail the Argonne 12' magnet, because it has already been converted successfully and, hence, is much better documented.⁶⁸ Conversion of the BEBC or FNAL 15' magnets would lead to detectors very similar in scale. The 7' magnet would be less desirable, but a study⁶⁹ has already indicated that it would also be of use.

The original Argonne 12-foot Bubble Chamber Magnet is now leading its second life at PEP as the high resolution spectrometer (HRS). It is a big superconducting solenoid with a 4 m long by 4.5 m diameter active volume and a 16 kG field. The thick coil is closely surrounded by the magnet yoke, about 1 m of iron covering the entire magnet.

The HRS magnet lends itself very naturally to a dedicated "poor man's" muon detector in the spirit of the large MIT muon detector design.⁷⁰ The large reduction in investment, compared to a major brand new detector, does of course have its own price; the detector envisaged here could not match the momentum resolution of the MIT design, which we will use as a benchmark for comparison.

At PEP the HRS has tracking down to the beam pipe with $L = 1.85$ m and an impressive $BL^2 = 55 \text{ kG m}^2$. At CBA one would use up some of the track length for the hadron absorbing central plug. As one extreme an uninstrumented 50 cm thick tungsten plug (5 nucl. absorption lengths or 9 nucl. collision lengths) can be used together with a 5 cm radius beam pipe and 5 cm of buffer space. This leaves a track length $L = 1.65$ m and BL^2 of 44 kG m^2 . Much better is a plug instrumented as a coarse calorimeter to allow the separation of jet-associated and single

muons. Diluting the plug density by 40% for detectors inside the tungsten leaves a track length of 1.45 m with a BL^2 of 34 kg m^2 .

There is no serious degradation in BL^2 relative to the MIT design: 60 kg m^2 for the full 2 m region between calorimeter and coil, and 39 kg m^2 for the 1.6 m drift chamber. The momentum resolution for the lumped 20 layer (200 μ) HRS drift is $^{71} dp/p^2 \approx 1.1 \text{ to } 1.3 \times 10^{-3} \text{ GeV}^{-1}$ which is about 3 to 4 times worse than for the 160 layer (140 μ) MIT design.

The central plug will not reduce hadron punch-throughs sufficiently to provide a muon trigger. However, the magnet yoke (typically 1 m of iron) is thick enough (total of 11 nucl. absorption lengths from interaction point) to provide muon identification with detectors outside it. The 600 m^2 surface could be comfortably instrumented with 4m $\times$ 4m modules from the BNL neutrino detector, with further iron walls, if needed, for a higher momentum trigger.

The conclusion is that the HRS, with its present instrumentation, could become a 2-muon detector with a mass resolution of 4% for a 100 GeV object (compare 1% in the MIT design). This would certainly be a respectable resolution for resonance hunting, if not for width measurement. By investing in a new, more elaborate, drift chamber system, the mass resolution could eventually be improved to 2% at 100 GeV.

THE ISR SPLIT FIELD MAGNET (SFM) AS A DOUBLE ARM SPECTROMETER⁷²

The Split Field Magnet is a pair of very long (conventional coil) dipoles of opposite polarity, set up at the ISR with the length of the magnets along the beam direction. It contains an extensive MWPC system for particle track measurement. (Figure 16).

By turning the magnet pair 90° relative to the beam direction, one could obtain a double arm 180° spectrometer (for

large p_T) of finite aperture and excellent momentum resolution. One could probably rotate the magnet by $\pm 30^\circ$ to look at tracks away from 90° . The open geometry in the mid-plane (no return yoke) would allow other detectors outside the magnet solid angle.

Fig. 16. Split field magnet at the CERN ISR.

The magnetic field of the SFM is 11.3 kG in a vertical aperture of 1 m. The effective length of each magnet is 4.5 m with a width of 3.5 m at the entrance and 2.0 m at the exit of the magnet. This yields very large BL^2 of 230 kG m² with a small solid angle of 0.15 sr when the full length of each magnet is used as a spectrometer. Alternatively, only half the length of each arm need be used, with a respectable BL^2 of 57 kG m² and solid angle of 0.7 sr.

The SFM is now instrumented with a 73,000 wire MWPC system, most of it with 2 mm wire spacing. This close spacing is an excellent match for the high rates of CBA. The resolution (in the MWPC mode) is $\sigma = 2 \text{ mm}/\sqrt{12} = 580 \text{ } \mu\text{m}$, giving $dp/p^2 = 0.7 \times 10^{-3} \text{ GeV}^{-1}$. For improved resolution one should consider upgrading the electronics to a mini-drift mode. In any case restringing of the MWPC's would be necessary to eliminate the large beam holes in the present chambers. Some additional chambers external to the magnet could also improve the momentum resolution considerably. The costs and difficulties of transportation from CERN to BNL also need to be investigated.

EVOLUTION OF THE AXIAL FIELD SPECTROMETER TO A CBA DETECTOR

The AFS⁷ employs a central drift chamber with bicycle-wheel geometry surrounded by 4 walls of uranium-copper-scintillator calorimeters. These elements cover approximately $|y| < 1$ at the CERN ISR. Two opposing calorimeter walls each have 600 sodium iodide crystals in a rectangular array, read out by vacuum photodiodes, to aid in electron and photon measurements. There is now a letter of intent⁷³ to take many components from the AFS and add some detectors which represent a distinct advance in the state of the art to achieve magnetic spectroscopy and calorimetry over the full solid angle for a fixed target experiment at the SPS. For example, a liquid argon detector is being developed with 1 mm gaps, where it is hoped to achieve a 25 ns ADC gate. A transition radiation detector utilizing polyethylene fibers is being pursued which would identify electrons at 0° in the laboratory where the track density is high.

If this spectrometer comes into operation at the SPS within the next few years, one can imagine making a mirror image of the experiment about the target as shown in Fig. 17. This would

Fig. 17. Conception of AFS-SFS evolution into CBA detector.

then be a candidate detector for CBA. A new drift chamber would need to be assembled but very likely the electronics for the SPS version could be reused. This conception features a hermetic calorimeter for measuring energy flow as well as good lepton identification. Many additional calorimeter modules would have to be built, but the majority would be from the SPS version.

ISR EXPERIMENT R-608 AS A LARGE ANGLE SPECTROMETER

This experiment utilizes a 16,448 wire mini-drift MWPC system in a forward multi-particle spectrometer at the CERN ISR⁷⁴ (Figure 18). Particle identification is provided by two 16 cell gas Cherenkov counters and an electromagnetic shower counter. The system performs well even at the highest ISR luminosities, with good multi-track efficiency and momentum resolution. The global spatial resolution, measured to be $\sigma = 180 \mu$, results in momentum resolution of $\sigma_p/p = 5.8\%$ at 26.7 GeV/c.

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With minor refurbishing, the detector currently in operation at the ISR could be used as a large angle multi-particle spectrometer with acceptance of $\pm 15^\circ$ centered at 90° at the CBA. (It could be mounted on a movable arm to explore angles away from 90°). The spectrometer could be used to measure particle production spectra and also to study flavor and other correlations in jets.

Fig. 18. R-608 Detector at the CERN ISR.

V. CONCLUSION

It is clear that the CBA is not designed as a single experiment. Its high luminosity, six areas, possibilities of special intersections, and special beams (polarized, deuterium, heavy ions, etc.) should allow a program of physics that will continue for many years. It would be inappropriate, therefore, to even discuss "the" full complement of detectors that will be built for the CBA. Hopefully the experiments and their detectors will be as varied as those that have operated at fixed target machines. Hopefully too, we are unable now to conceive

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of some of those detectors; physics will dictate them. It is even less appropriate to discuss such a complement of detectors before the first experiment has been proposed, let alone considered or accepted. What has been done in this report is a purely intellectual exercise; a discussion of the possible without trying to influence the outcome. Our conclusion is clear: there are many and varied possible detectors and detector techniques that can be used at CBA and at high luminosity.

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