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SEARCH FOR SHORT-LIVED PARTICLES AND STUDY OF HADRONIC JETS USING A MULTIPARTICLE SPECTROMETER WITH A VISIBLE TARGET

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I. Introduction and Overview

There is extensive literature [1] on the experimental study of quark and gluon induced jets at current proton accelerator energies. In addition, there have been, and continue to be, searches for narrow resonances and short-lived particles [2] at these accelerators.

We propose to extend this work into the TEV region, taking advantage of the long flat top of the Fermilab doubler in combination with a multiple particle spectrometer utilizing a visible target. This combination will provide a unique opportunity to study these phenomena in a manner which is unavailable at lower energies.

A visible target as a component of a multiparticle spectrometer furnishes many advantages for our proposed study. One such advantage is the small reconstructed bubble diameter of 70 microns around the point of interaction. This bubble diameter results in a spatial resolution of 15 microns and allows for a search for particles with lifetimes as short as 10^{-14} seconds. By the use of special optics and monochromatic laser light, it may be possible to further reduce this resolution by a factor of 2. The excellent spatial resolution at the vertex of an interaction would allow the analysis of complicated events with high track multiplicities and is invaluable for isolating jets as well as for studying their structure.

The visible target would be designed to operate at 60 Hertz and will certainly perform at 30 Hertz. With a moderate run ($\sim$ 2,000 hours), this device can explore cross sections at the microbarn level and jets with $P_T \sim$ 5 GeV/c.

Current beam dump experiments [3] indicate that the cross section for charm production may be in the range of 10-500 microbarns. A 2,000 hour experiment with this equipment would yield 1000 events/microbarn. This assumes a 30 Hertz operating frequency, a 45cm fiducial volume, 10 incident particles/expansion, and a $33\frac{1}{3}\%$ DUTY cycle of the accelerator. Thus, a 100 microbarn cross section would result in 100,000 events, of which 2,500 would be detected and can be used to measure a lifetime (we assume a 10% branching ratio for the semi-leptonic branching ratio for charmed particles and a 25% efficient trigger). A simple muon identifier behind our present E570 downstream particle identifier would, on the basis of some models, offer acceptances of the order of 25%. This is a clear advantage of the higher energy since the muon acceptance for a given geometry is improved.

Careful design of the optics for the visible target would result in the desired 70 micron equivalent bubble size in space. This is based on a demagnification of seven (using 70 millimeter film) and an airy disc on film of 10 microns. The spatial resolution would be of the order of 15 microns which, along with 800 GeV/c incident particle momentum, allow lifetime measurements of the order of 10^{-14} seconds.

In the event the lifetime is established by an earlier experiment[(4)] prior to the running of this one, we would put emphasis on the study (depending of course on the actual cross section and lifetime) of production mechanisms and decay modes.

The study of jets would probably proceed along our current lines of investigation (E154-E299) which is to consider all events (nontriggered) with information within each event determining whether or not it contains a cluster of particles that fits our definition of a jet. As can be seen in Appendix 1, the P_T distribution of our jets join on in a smooth manner to that found in a counter experiment at Fermilab (E260). Our current work, based on an exposure of 10^5 expansion, extends to a P_T of about 3 GeV/c. A 2,000 hour run would result in 7.2×10^7 expansions which should yield sufficient data to allow a study out to P_T of 5 GeV/c. Of course an appropriate trigger, the details of which are discussed in Appendix 2, is required.

We request 2,000 hours of data running in a π beam of 800 GeV/c with a spill structure equivalent to an average of 30 pings/second (300-1,000μs ping width) with an average of 10 particles/ping within a beam profile of 1cm x 10cm.

The goals of this experiment are as follows:

1. Search for short-lived particles.
2. A detailed jet study out to P_T of 5 GeV/c.

The advantages of our proposal to carry out goal (1) are:

1. Production is on hydrogen.
2. Momentum analysis for all charged particles and for gamma rays with $x > .03$.
3. Particle identification for $P_{lab} < 50$ GeV/c.
4. 4π acceptance at the vertex which allows search for pair production of short-lived particles.
5. Possibility of measuring the mass of the short-lived particles.

The advantages of our proposal to carry out goals (2) are:

1. Good momentum resolution on all charged particles and for gamma rays with $x > .03$. Hence, the momentum structure of the jet can be studied in detail.
2. The complete event containing the trigger jet can be studied.
3. Particle identification with $P_{lab} \leq 50$ GeV/c will allow a limited study of the quantum states associated with the jet.

This experiment is being proposed under the joint U. S. -Japan Cooperative Science Program and it is expected that funding for this work will come under its auspices. The costs, funding, and construction are discussed in Section III.

II. Apparatus and Experimental Method

Figure 1 shows our proposed experimental configuration. Particles with $P_{lab} < 100$ GeV/c are momentum analyzed with the fringe field of the visible target and PWC_1, PWC_2, DC_1, DC_2, and DC_3. Particles with $P_{lab} > 100$ GeV/c are analyzed with PWC_1, PWC_2, DC_1, DC_2, DC_3, the bending magnet BM, DC_4, DC_5, and DC_6. $\frac{\Delta p}{p}$ will be less than 10% for all momenta. All charged particles with $P_{lab} < 50$ GeV/c will be identified by CRISIS and the FGD will detect and measure all gamma rays with $x > .03$. It should be noted that PWC_1, PWC_2, DC_1, DC_2, DC_3, CRISIS, and the FGD presently exist (E570). New equipment consists of the visible target (but not the magnet which presently exists), the bending magnet BM, DC_4, DC_5, DC_6, and the muon detector MD.

The most complex component among the new equipment will be the visible target. The bending magnet will be of modest aperture, 30cm width by 50cm height by 300cm length, with a field of 40 kilogauss. The PWC-DC array will yield angular resolutions of $\frac{.2}{6000} = .03$ milliradians and the combination of this array with the analyzing magnet will yield $\frac{\Delta p}{p} \cong .004p\%$ (p in GeV/c). The other components of this spectrometer are well known and their performance capabilities can be found in Appendix 3.

The triggering technique and event rates are discussed in Appendix 2.

Finally, it should be noted that the visible target along with the rest of the equipment will be operated by the users.

III. Funding, Costs, and Construction

As mentioned earlier, this experiment is being presented as a candidate for the joint U. S.-Japan Cooperative Science Program. We expect the funds for the construction of the required equipment to come from this program. A possible allocation of joint funds would be for the visible target, superconducting bending magnet, the drift chamber system, and the muon detector. The components to be furnished by the Japanese sector and those to be furnished by the American sector of the collaboration would be decided later.

We estimate the costs for the visible target to be $\$1.6 \times 10^6$, that for the superconducting bending magnet to be $\$0.5 \times 10^6$; and $\$0.1 \times 10^6$ for the DC system (all 1978 dollars). The cost of the muon detector (except for the absorber material) would be of the order of $\$0.5 \times 10^6$.

The visible target would be designed by SLAC. The magnet could be designed by Fermilab and the DC's and muon detector could be designed at any of the American universities. We estimate that design, construction, and installation would require two to three years after approval by the U. S. -Japan Cooperative Science Program. This time scale would dovetail nicely into the Tevatron program.

IV. Conclusions and Summary

We propose to search for the direct evidence of charmed particle production with sensitivity in the lifetime range $\sim 10^{-14}$ to 10^{-11} seconds. We request a 2,000 hour run in a 800 GeV/c π^- beam.

The aims of this segment of the experiment are:

a. to establish the existence of particles with short lifetimes and determine their production cross section.

b. measure the lifetime of these short-lived particles if they are detected.

c. check for associated charm (pair)production.

d. study decay branching ratios.

There are two competing experiments [5] at lower energies. One involves a streamer chamber at Fermilab and the other a small rapid cycling bubble chamber at CERN. Regardless of the results from the streamer chamber experiment, this experiment is of critical importance since production is on hydrogen, the invariant mass of the short-lived particles can be measured, and the new regime of 800 GeV is studied. While the CERN experiment is also on hydrogen, it will be performed at a lower energy, and, therefore, even if it is successful, the study of production mechanisms at this higher energy would yield valuable new information.

We also propose to search for jet configurations at 800 GeV/c. The aims here are:

a. to study jets with an acceptance of 4π solid angle for charged particles and a total acceptance for gamma rays in the forward hemisphere.

b. to study in detail the internal structure of jets by utilizing particle identification of jet fragments with $5 \leq P_{lab} \leq 50$.

c. to look for two, three, and four-jet structures.

d. to study jet dynamics as a function of P_T out to a P_T of 5 GeV/c.

There are many experiments in progress and in planning for the study of jets. However, this experiment could furnish a more complete picture on an event by-event basis than any other experiment we know of.

It is probably obvious, but worth noting, that this powerful multiparticle spectrometer can also be used for other studies at Tevatron energies. It is certainly our intention to propose such studies, based on the physics knowledge at the time and using this spectrometer (possibly modified). As an explicit example of this possibility, we are considering an experiment with a high energy photon beam. While many exposures of the type possible with this equipment have been made at lower momenta (120 GeV/c), there is none in the 100-600 GeV/c region. The rapid cycling aspect of our proposed multiparticle spectrometer plus a suitable (and quite simple) hadron trigger would permit the exploration of a totally new area of physics.

Indeed, if our spectrometer were approved and constructed in a timely manner, a photon experiment might be the first round experiment utilizing the current 400 GeV/c machine. However, this consideration obviously is dependent on the actual Tevatron schedule.

References

(1) J. W. Cronin et al., Phys. Rev. D11, 3105 (1975); D. Antreasyan et al., PRL 38, 112 (1977); P. Darriulat et al., NPB107, 429 (1976); C. Bromberg et al., CALT-68-590 March 1977; M. Jacob, CERN/TH Report, No. 21, March 1977.

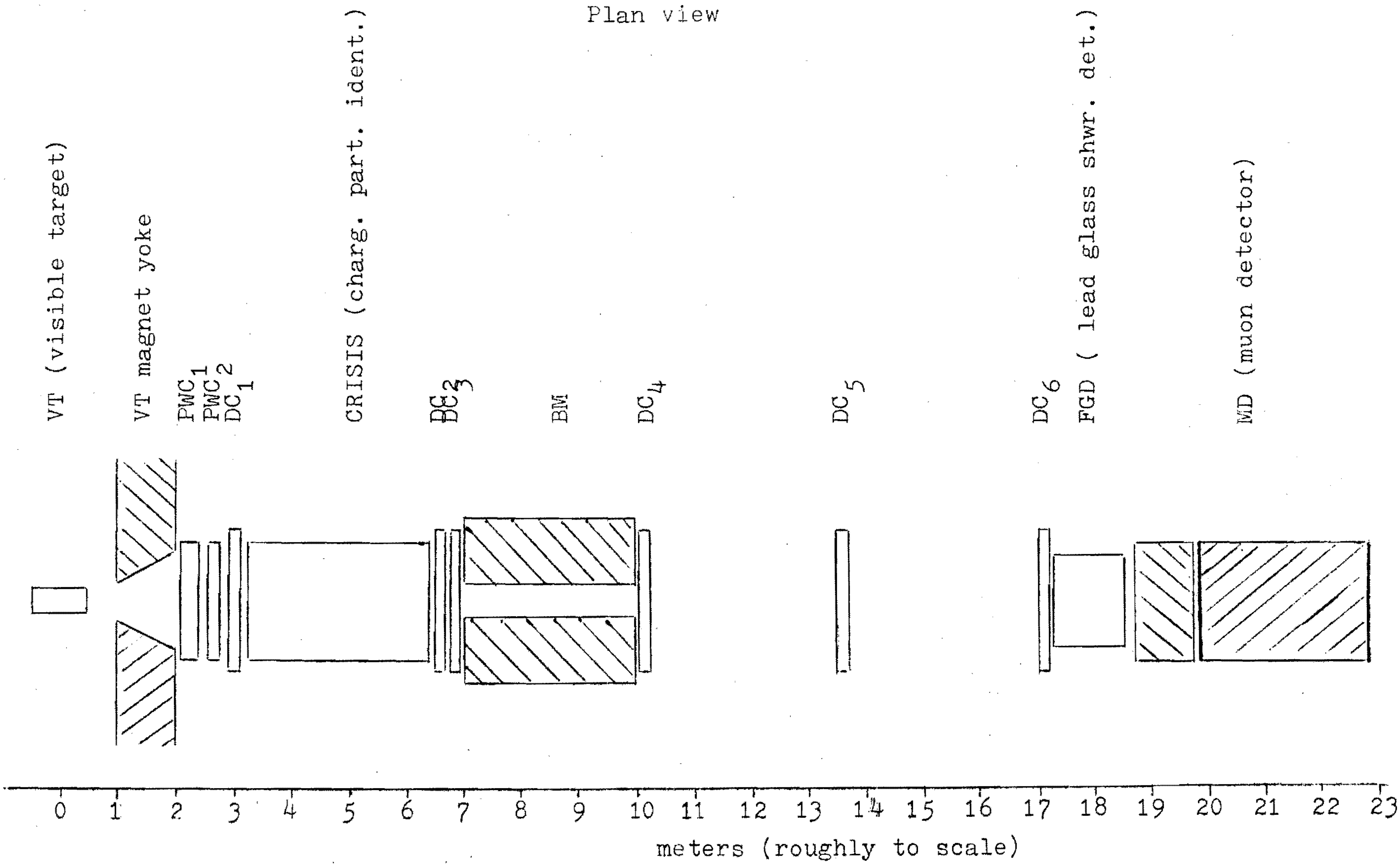
(2) G.Coremans-Bertrand et al., PL65B, 480 (1976); W. Bozzoli et al., Lett al Nuovo Cim. 19, 32 (1977); P. Alibran et al., PL74B, 134 (1978); T. Hansl et al., PL74B, 139 (1978); P. Bosetti et al., PL74B, 143 (1978); D. J. Crennell et al., R. L. -78-051.

(3) Fermilab Beam Dump Experiment, reported Oxford ν- conference 1978. CERN Beam Dump Experiments, see reference (2).

(4) Fermilab experiment E-490.

(5) Fermilab experiment E-490 and CERN Proposal, CERN/SPSC 78-103 SPSC/P 113

Plan view



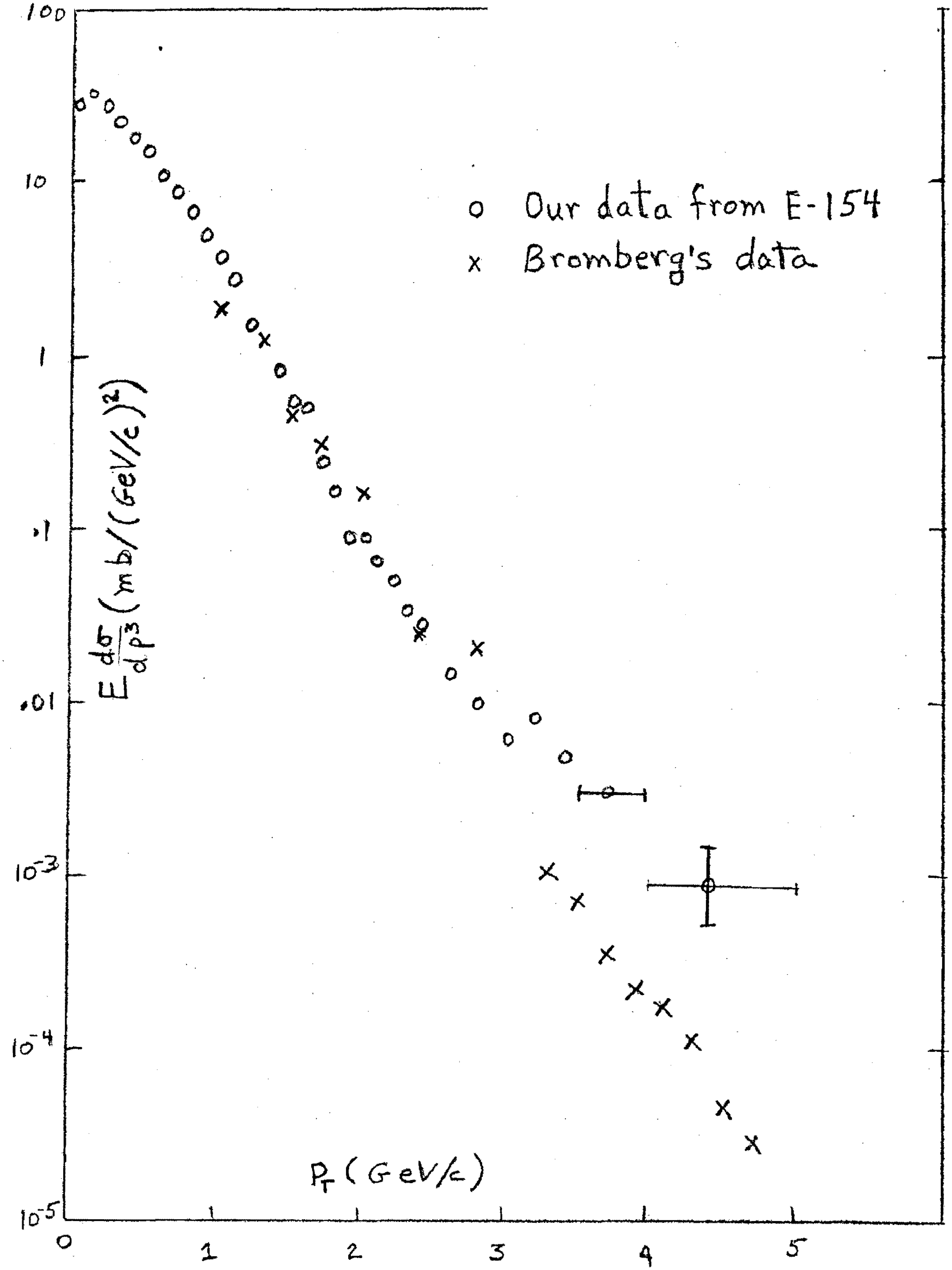
DETECTOR	TYPE	ACCEPTANCE
VT	rapid cycling BC	
PWC_1, PWC_2	multiwire prop. chamb.	1m x 1m
DC_1—DC_6	drift chamber	1.2m x 1.2m
CRISIS	drift chamber	1m x 1m
BM	superconducting bend mag	30cm x 50cm
FGD	lead glass/scint	75cm x 75cm
MD	Fe/concrete/scint/dc	1m x 10m

$$\frac{\text{transverse scale}}{\text{longitudinal scale}} = 2/1$$

Figure 1

Appendix 1

Figure A1-1 displays the measurements of Bromberg et al. (E260) (x) and our data (E154) (o). The observed phenomenon in both experiments is seemingly the same but the accuracy of measurement on individual particles is greater in the E154 data.



100
10
1
.1
.01
10^{-3}
10^{-4}
10^{-5}
0
1
2
3
4
5
$E\frac{d\sigma}{dp^3}$ (mb/(GeV/c)^2)
P_T (GeV/c)
o Our data from E-154
x Bromberg's data

Fig. A1-1

Appendix 2

Triggering Technique and Event Rate

For that part of the experiment concerned with a search for charmed particles, we will take advantage of the semi-leptonic decay of the D-meson and trigger on identified decay muons. At 800 GeV/c incident pion momentum, we expect about half of the decay muons to have momenta greater than 10 GeV/c. The majority of these muons will traverse the spectrometer and enter the muon detector. The muon detector, as shown in Fig. A2-1, is meant to be as simple as practical and as inexpensive as possible. However, due to its size, it is still an expensive item. It will consist of one meter of iron followed by three meters of iron-loaded concrete blocks with scintillator hodoscopes and two layers of drift chambers. The cross sectional area is 1 meter x 10 meters.

The false trigger rate will be completely dominated by the 20 meter decay path from the vertex to the muon detector. For a 10 GeV/c pion, the decay length $\gamma c \tau = 546$ meters. Hence, 3.6% of 10 GeV/c pions decay within the 20 meter flight path. However, at 800 GeV/c incident pion momentum one can expect a large fraction of pions incident on the muon detector to have greater than 10 GeV/c momentum resulting in decay probabilities of the order of 1%. Our studies at 150 GeV/c indicate that the likelihood for two particles with momenta $\geq$ 10 GeV/c to be simultaneously incident on the muon detector is small. Hence, we will have one false trigger for every $\sim$ 100 interactions in the target. Assuming a total hadronic cross section of 25mb, a cross section of 100 microbarns for D production, a branching ratio for D decay to muons of 10%, and an overall muon detection efficiency of 25%, we expect to observe in our film one charmed event for every 100 triggers. Thus, in 500K pictures we would expect a sample of 5000 D events.

The trigger necessary for the jet study is somewhat more complicated. It is desirable to trigger not only on high P_T single particles but also on high P_T jets since the cross section for high P_T jets is an order of magnitude larger. Therefore, our trigger algorithm would also involve the correlations of momenta between two or more particles. From a careful study of trigger techniques with our 147 GeV/c data, we find the following simple scheme to be most appropriate for triggering on jets with $P_T > 1.5$ GeV/c:

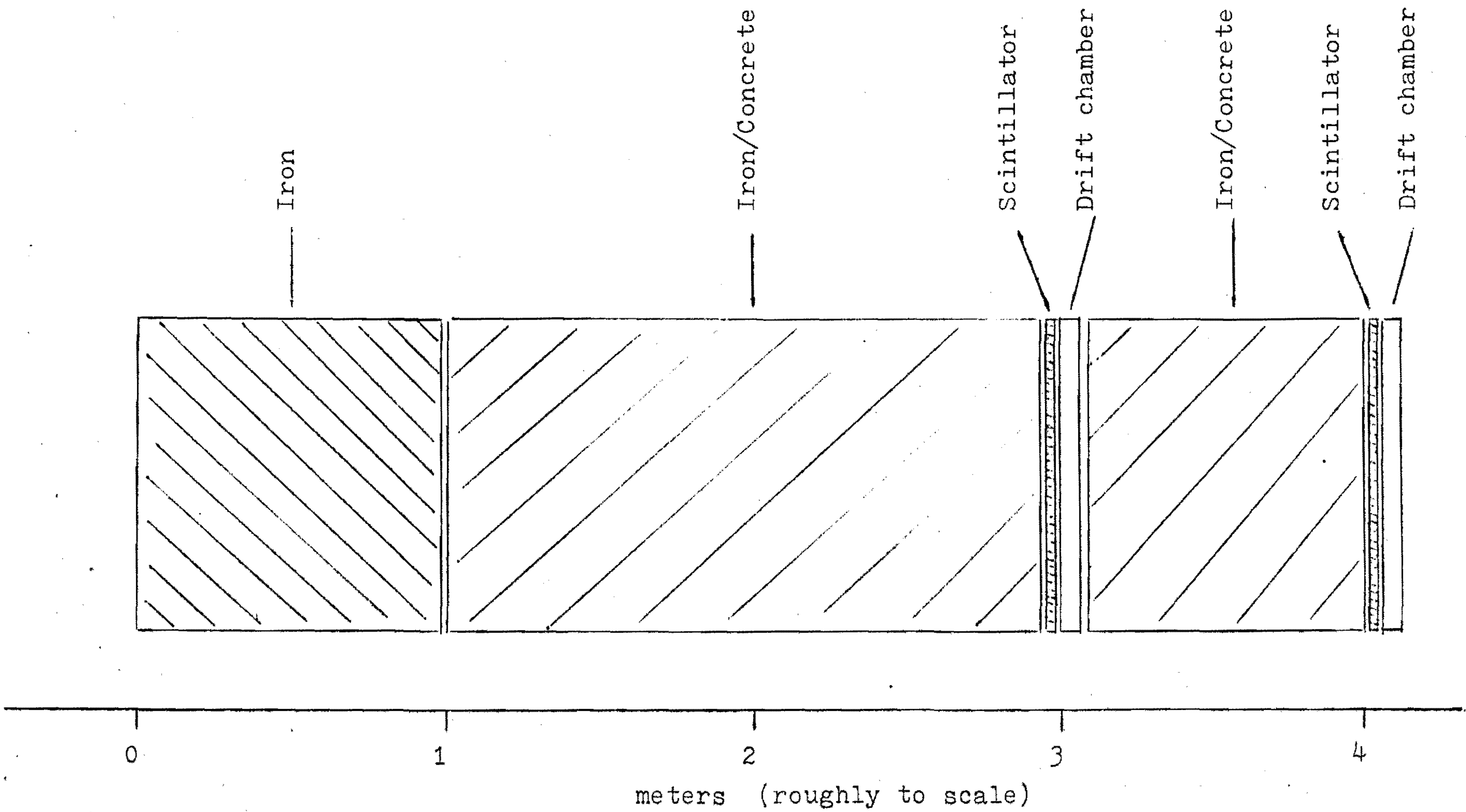
a. Trigger on any single particle in PWC_1, PWC_2, and DC_1 having a $P_T > 1$ GeV/c.

b. Trigger on any pair of particles in PWC_1, PWC_2, and DC_1 having a $P_T > 1$ GeV/c .

Assuming the interaction to take place in the center of our fiducial volume, P_T of the exit particle can be calculated since the incident beam and exit particle positions and directions are known. Due to the fact that an interaction can occur anywhere throughout the fiducial volume, the fractional error associated with P_T is at most $\sim$ 16%. The trigger computation can be carried out on-line with a fast microcomputer.

The efficiency of the trigger algorithm has been estimated from our 147 GeV/c data. The algorithm generated triggers on only 10% of the events. Thirty-seven percent of these triggers involved a "jet" and 25% of all jets with $P_T >$ 1.5 GeV/c was contained in these triggers. This study at 147 GeV/c indicates that more than one-half of the jets fail in having any of its associated particles to enter the spectrometer. Hence, the trigger is 50% efficient for those jets that enter the downstream spectrometer.

Monte Carlo studies corresponding to 800 GeV/c are presently being conducted and we expect the situation to be better at this higher energy since the increased Lorentz boost would enable more of the jet components to clear the magnet aperture and enter the spectrometer arm.



Plan View

Figure A2-1

Appendix 3

This appendix will include the following references:

1. NIM 152 (1978) 379-387.

2. IEEE Transactions of Nuclear Science 26, No. 1 (1979).

Search for Short-Lived Particles and Study of Hadronic Jets using a Multiparticle Spectrometer with a Visible Target

Summary

We propose to search for and, if found, measure the characteristics of short-lived particles. We also intend to study the properties of high P_T jets out to a P_T of about 5 GeV/c. The instrument for these studies will be a fully instrumental multiparticle spectrometer with a visible target. The complete device, including the visible target, will be user operated.

The device will detect photons with $x > .03$ and identify charged particles in the momentum range from 5 - 50 GeV/c. The momentum resolution on charged particles will be better than 10% out to a momentum of 800 GeV/c. A muon detector will detect all muons with momentum greater than 10 GeV/c.

We request a 2,000 hour run with 800 GeV/c incident π^-. We expect to detect short-lived particles with lifetimes $\sim 10^{-14}$ sec. We will study, in detail, jets out to a P_T of 5 GeV/c.