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PROPOSAL TO STUDY ψ PRODUCTION USING THE E-416 APPARATUS

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ABSTRACT

We propose to study Ψ production in the reaction π^- + Lucite ($C_5H_8O_2$) $\rightarrow$ $\mu^+\mu^-$ + anything at 225 GeV, using a streamer chamber to detect the hadrons produced in association with the di-muons.

I. INTRODUCTION

A number of experiments have been performed at FNAL to study hadronic production of ψ mesons by observing the $\mu+\mu-$ decay mode. These experiments have mainly concentrated on the production of the ψ. The momenta of the muons were determined, from which the Feynman x and P_T distributions of the ψ production are obtained. The hadrons which are produced in association with the ψ mesons have been either ignored or not very well studied.

We are proposing to study the reaction $\pi^- + \text{Lucite}\ (C_5H_8O_2) \rightarrow \psi +$ anything using the apparatus of E-416. (See Fig. 1) The target is placed at the upstream end of a streamer chamber which is in an approximately 8 kg magnetic field. Downstream of the streamer chamber magnet there is a muon spectrometer containing magnetized iron and eight muon telescopes which allows us to trigger on 1, 2 or more muons in the final state. The ψ mesons can be selected by reconstructing the mass of the $\mu+\mu-$ pairs from the bend information obtained in the SCD magnet. The apparatus is identical to that used in E-416. The only changes we propose to make to the apparatus of E-416 in this experiment is to: (i) improve the multitrack efficiency of the spark chambers at the downstream end of the muon telescope; (ii) include a small multiwire proportional chamber between the downstream end of the streamer chamber magnet and the upstream end of the muon filter - shown dotted in Figure 1; (iii) close the ± 9 mr gap in the muon telescopes.

II. E-416 Results

E-416 had a total of four calendar days of running. Preliminary results for the new particle search were presented at the Vanderbilt Conference. The Paper is attached as Appendix 1.

The salient results obtained from E-416 are: (i) we are triggering on prompt muons; (ii) half of our di-muon interactions occur in the lucite target, the other half in the absorber; (iii) the hadrons obtained with the muons do not look significantly different from hadrons obtained in an ordinary interaction not requiring a muon trigger; (iv) we observe a few ψ events.

The $\mu+\mu-$ mass spectrum for interactions in the target are given in Fig 2. These show a low mass continuum and a clustering of a few events at higher masses. This spectrum was obtained using $\int Bdl$ = 56 kg-m. We are now in the process of using beam muon data to obtain a better value for the field of the SOD magnet. Although we had a total of 837 2μ triggers, because of the multi-track inefficiencies and the solid angle covered by our wire spark chambers, only approximately 15% of these events gave information on both muons in the spark chamber.

Conservatively, we estimate that in the new apparatus we will increase the efficiency by at least a factor of 3. Also, in E-416 we left a ±9 mr radian gap in the horizontal plane (see inset figure 1) in order to avoid low mass di-muon pairs. In this experiment we plan to fill in that gap and leave only a 4-inch hole around the beam. If the rate from events in this region is too high we would only sample this trigger.

Additional preliminary results for the $m(\mu V^{O})$ spectrum is given in Fig 3.

III. Trigger Rates

In E-416 we had a 2μ trigger every 6 to 8 accelerator bursts with an 800 ms spill of 225 GeV $\pi-$ beam. The total data taking time during that experiment was 4 days. In this experiment we are requesting 4 weeks of beam time. Thus, from improvement of the wire spark chamber efficiency and the increased beam time we would expect to have roughly 15 times the number of ψ's obtained in the previous experiment. In addition, the ±9 milliradian gap gave us only a 10% efficiency for detecting a $\mu+\mu-$ pair from the ψ meson. By filling in this gap we expect to increase this efficiency. Because we are not sure about our low $m(\mu+\mu-)$ background it is difficult to estimate the gain. However, it seems not unlikely that we should have another factor of 2 from this source. Therefore, we estimate that there should be a factor of 30 increase in the number of Ψ's we can obtain in this run. From the seven events in the Ψ region obtained in E-416 (Fig. 2), we then estimate approximately 200 Ψ's in this experiment.

Alternately, if we take a typical $\sigma_{\Psi} B_{\mu\mu} = 5$ nb. and our observed 4% interaction rate in a 5 cm. lucite target. Assuming 5×10^5 π-/burst, an effective 5×10^3 bursts/day, a total cross section of 20 mb., and an overall acceptance plus efficiency of 20%, we obtain 5 Ψ/day. This implies on the order of 100 Ψ's in four weeks of running.

We will, of course, have the full information from the streamer chamber; that is, we will obtain the momentum spectrum of the V^o's observed in the chamber, the rapidity of all of the charged particles, and the multiplicity distribution of charged particles. We would expect to have on the order of 100-200 events from interactions in the target and an equal number in the Fe shield in this experiment. We stress the fact that it requires essentially no new equipment; it simply requires reinstalling equipment with which we have had considerable experience, namely the streamer chamber and the muon telescope.

The low mass (below the Ψ) muons are also of considerable interest. More experimental data is required to resolve the question of Drell-Yan verses other production mechanisms (e.g. Farrar-Frautschi). Having information about the hadrons which are produced in association with these low mass pairs may help in understanding the production mechanism. For a summary of the current status see the proceedings of the 1976 Vanderbilt Conference, expecially the review by J. D. Sullivan.[1]

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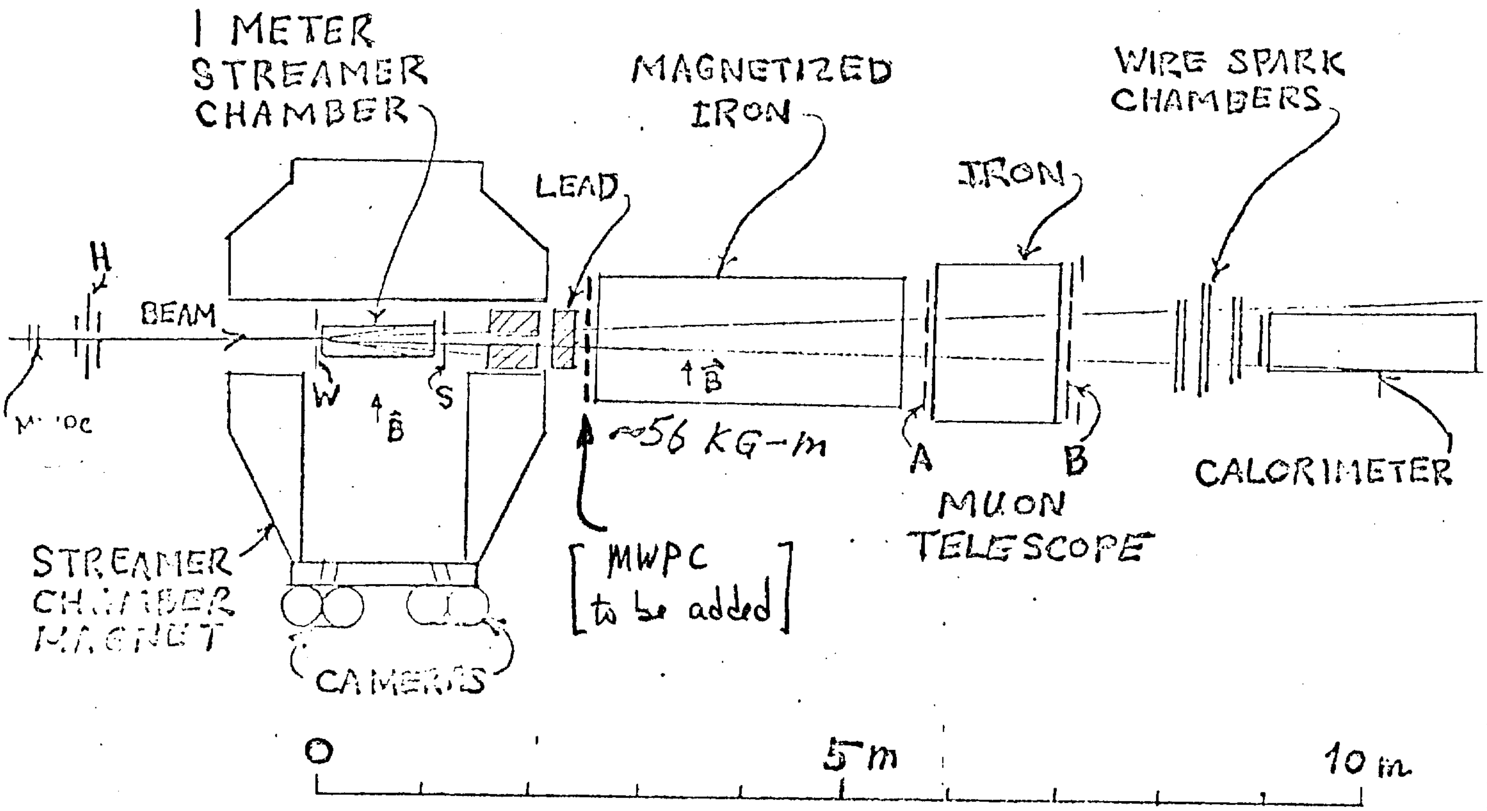
[1] J. D. Sullivan "Review of Theoretical Ideas on Prompt Lepton Production" University of Illinois Preprint Ill-(TH)-76-07, April, 1976.

SEATTLE – ORSAY – DAVIS COLLABORATION
PLAN VIEW OF EXPERIMENTAL LAYOUT

225 GeV TAGGED π^- BEAM
5 cm LUCITE TARGET ($C_5H_8O_2$)

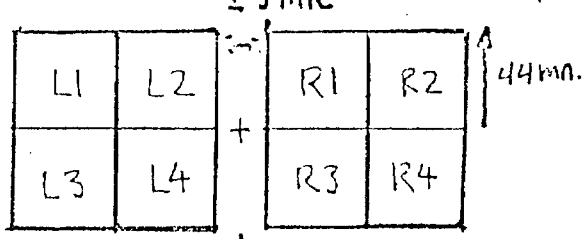


TRIGGER

$BEAM = B = T \cdot \bar{H} \cdot \bar{W}$

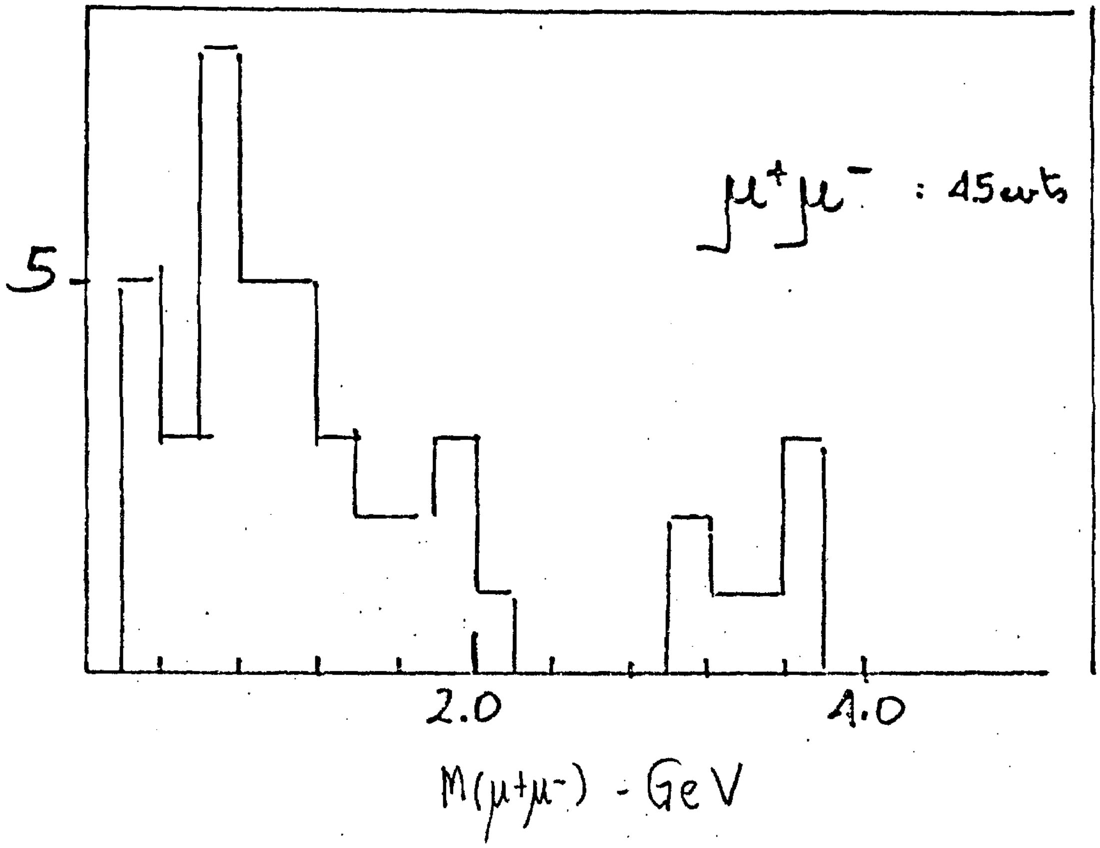
$EVENT = B \cdot S = E$

$2\mu\ Event = 2\mu \cdot E$



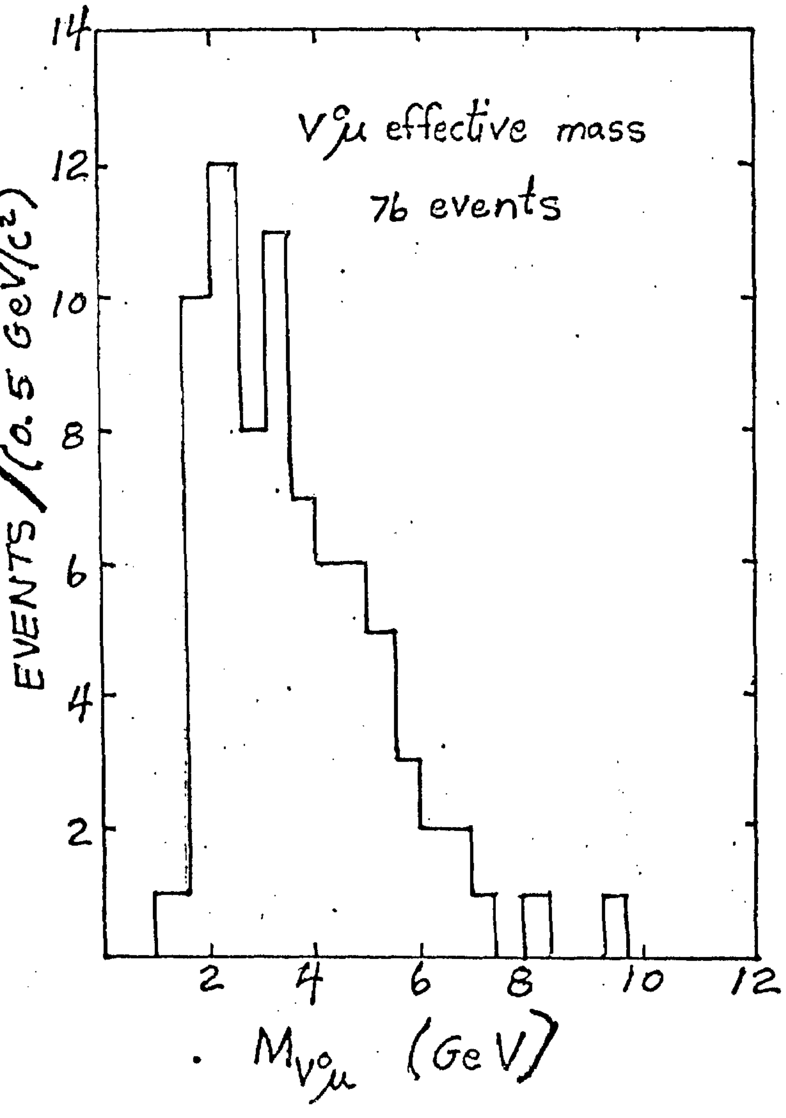
MUON TELESCOPE
COUNTER LAYOUT
(VIEWED FROM UPSTREAM)

Fig. 1



5
$\mu^+\mu^-$: 45 evts
2.0
4.0
M($\mu^+\mu^-$) - GeV

Fig 2.



14
12
10
8
6
4
2
EVENTS /(0.5 GeV/c²)
V°μ effective mass
76 events
2
4
6
8
10
12
$M_{V^0\mu}$ (GeV)

Fig 3

APPENDIX I

SEARCH FOR NEW STATES WHICH DECAY SEMI-LEPTONICALLY*

SOD COLLABORATION

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The results of a search for new particle production with decay modes which include neutral strange particles (V^o) and muons are reported.[1] The number of neutral strange particles produced by interactions of a pion beam on a nuclear target was measured when muons were and were not required in the final states. Excess production of V^o's associated with a muon could result from production of a pair of new states ($\bar{D}D$) which can decay:[2] (i) both semi-leptonically; (ii) one leptonically and the other semi-leptonically, (iii) both leptonically. Cases (i) and (ii) would give an increase in the V^o rate observed in the streamer chamber and the momentum distribution of these V^o's would reflect their origin. The cross section with which we would observe this phenomenon is given by

$$\Sigma \equiv \left[B_{SL}^2 \, g_1 + 2 \, B_{SL} B_L \, g_2 \right] \sigma_{+-} \qquad (1)$$

where B_{SL} and B_L are the branching ratios of the new state into leptonic and semi-leptonic modes, the g_i are the appropriate efficiencies for detecting 2 muons and at least one V^o, and σ_{+-} is the cross section for producing charged particle anti-particle pairs.

A beam of negative pions of 225 GeV was incident on a Lucite ($C_5H_8O_2$) target, 5 cm thick, at the entrance of the University of Washington streamer chamber[3] (see Fig. 1). The apparatus shown in Fig. 1 consists of a $1 \times .5 \times .3\ m^3$ streamer chamber placed in a large magnet whose field in the visible volume is approximately 8 kG. Immediately downstream of the streamer chamber is a muon filter which consists of lead and iron absorbers. A 3m magnetized iron absorber (SOD magnet) of cross section 0.56 m x 0.9 m transverse of the beam with $\int B d\ell \approx 56$ kG-m hardens the muon spectrum and determines the

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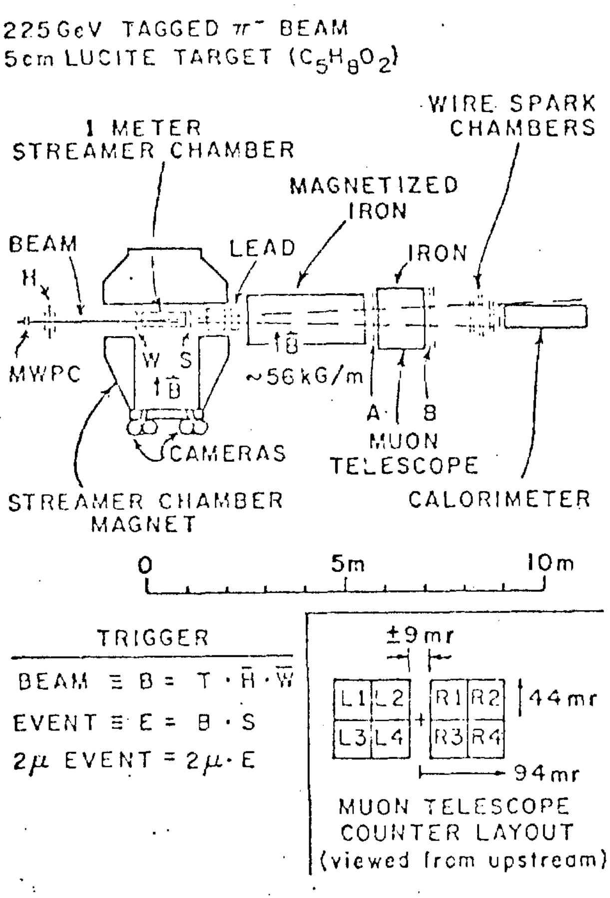

Fig. 1. Experimental Layout

muon momentum. Both the streamer chamber and SOD magnets bend in the vertical plane. The muon telescope consists of two planes of 8 scintillation counters each separated by 48 inches of iron. The acceptance is ± 94 mr in the horizontal plane and ± 44 mr in the vertical plane. A gap of ± 9 milliradians is left in the central plane (see inset Fig. 1). A small acceptance calorimeter, 12" x 12", was used during part of the run in order to determine the hadronic punch through. This was found to be negligible.

The beam is defined by a beam telescope (T) and hole veto counters (H,W) to be B ≡ T·$\bar{H}$·$\bar{W}$. A 5 cm lucite target $C_5H_8O_2$ is placed at the upstream end of the streamer chamber. A scintillator (S) which has a 4.5 cm diameter hole for beam exit defines the interaction. Thus, an event trigger is E ≡ B·S. A muon is defined to be a coincidence between two corresponding scintillators in the A and B planes (eg, $LA_i \cdot LB_i$). During the experiment, the beam intensity was in the range 2-7 x 10^5 π^-/pulse with an 800 ms spill.

Downstream of the muon telescope, three planes of wire spark chambers provide muon bend angle information; by swimming the tracks backward to intersect in the target at the upstream end of the streamer chamber, the charge and momentum of the muon is obtained.

The 1μ acceptance as a function of Feynman x and P_T is given in Fig. 2a. We note that for P_T < 600 MeV/c, the acceptance falls rapidly.[4] The k^o detection efficiency in the streamer chamber is given in Fig. 2b.

Trigger rates for the E, 1μ·E and 2μ·E triggers are given in Table I along with the corresponding cross sections. In order to avoid scanning biases, these triggers were mixed. From the 1μ rate, we find $(1/2)(1\mu\cdot E/E)^2 \sim 0.3 \times 10^{-6}$, which is an upper limit on the 2μ rate we expect from pion or kaon decay. The factor of 1/2 compensates for double counting. Thus, we would expect the 2μ rate from π

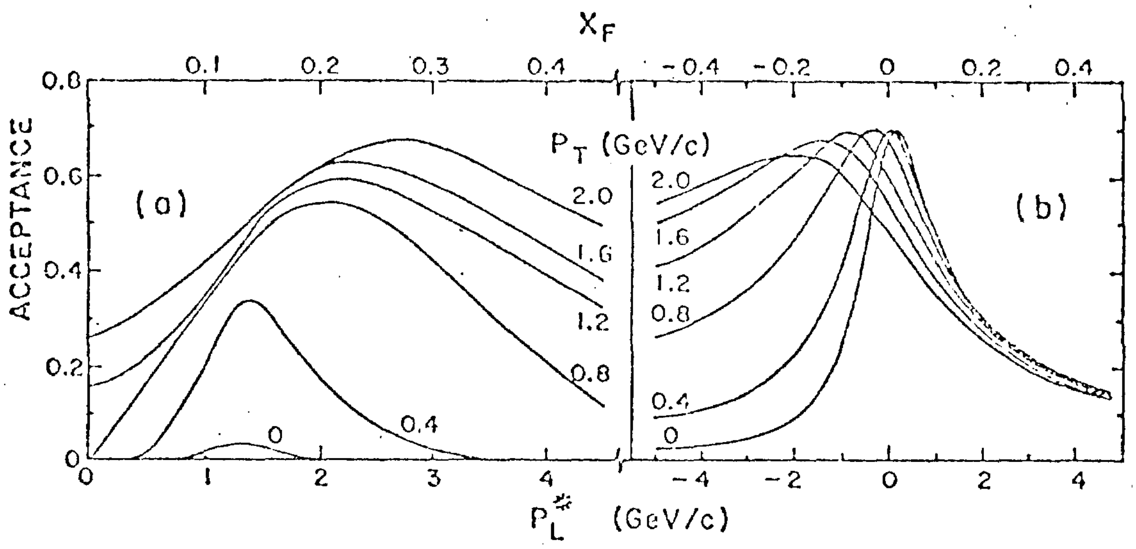

Fig. 2. Detection efficiency a) single muon b) k_s^o

Table I Trigger Rates and Cross Sections

Trigger	Rates	σ(A 2/3)	Scanned Events
E	E/B = 0.036	19.6 mb	1910
1μ·E	1μ·E/E = 0.8×10^{-3}	15.7 μb	-
2μ·E	2μ·E/E = 4.3×10^{-6}	84.3 nb	837

and k decay to be at least an order of magnitude less than the 2μ rate that is actually observed.

An independent check of the contamination has been made by taking $\pi^- p$ interactions at 200 GeV in the 30" FNAL bubble chamber from the Berkeley-FERMILAB collaboration.[5] We have calculated for each event and each charged prong, the probability of a π or K decay resulting in a trigger and find a rate which is 0.02 of our observed 2μ rate. Furthermore, we find that the like-charged dimuons are ∿ 5% of the oppositely-charged muons. Thus, we conclude that we are triggering on prompt muons.

A more complicated issue is whether the muons are, in fact, being produced in the target or in the absorber. We have checked this in two ways:[6] i) by taking those events in which two tracks can be reconstructed in the wire spark chambers, projecting them back through the absorber, and determining their intersection point in the horizontal (non-bend) plane; ii) by comparing χ^2 for fits to the wire chamber data which require that the track originate in the target and one interaction length into the absorber.[7] The two methods give results in good agreement, and we conclude that 50 ± 5% of our $2\mu\cdot E$ triggers are prompt muons from interactions in the 5 cm target in the streamer chamber.

A detailed scan of the $2\mu\cdot E$ and E triggers was made and all V^0's were recorded and measured. Since the streamer chamber contains Ne gas, there is a very low probability that an observed V^0 is a conversion electron-positron pair. However, γ's can convert in the central wire plane. In order to insure the purity of the V^0 sample, we have removed those V^0's whose vertex occurs within ± 1.5 cm of the central plane. (This removes approximately 25% of the sample.)

We find that the fraction of events which contains V^0's denoted by α is the same for the $2\mu\cdot E$ and the E triggers: $\alpha_E = 0.102 \pm 0.006$ and $\alpha_{2\mu\cdot E} = 0.097 \pm 0.010$. Thus, we obtain an upper limit with 90% confidence for expression (1) of $\Sigma < 1$ nb. In calculating this upper limit, we assume that the two samples of data are identical and that the contamination of $2\mu\cdot E$ triggers by muons produced in the absorber gives events in the streamer chamber which are identical to the events in the E trigger.

From Fig. 3, we observe that the transverse momentum distribution of the neutral strange particles and the average number of V^0's produced as a function of charged multiplicity is within statistics identical for the two triggers. The multiplicity distributions of the charged particles produced are also the same for the two triggers (c.f. < n > and D in Table II).[8] There are no significant differences between events obtained with the $2\mu\cdot E$ trigger and the E trigger. Our conclusion is that we do not produce neutral strange particles which are correlated with muons at an observable cross section greater

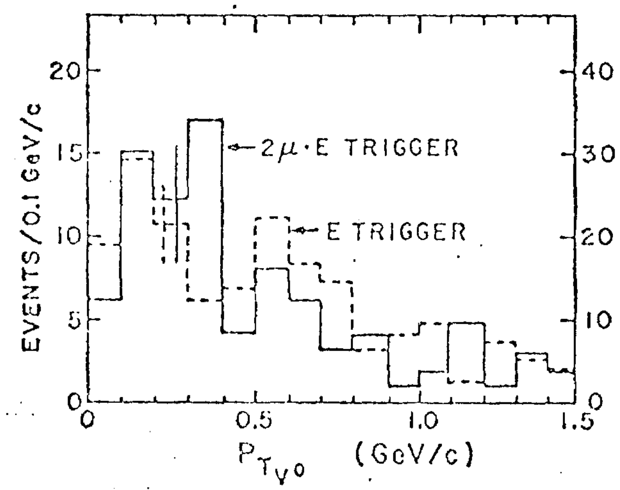

Fig. 3a. Transverse momentum distributions of V^0's. Left and right vertical scales apply respectively to the $2\mu\cdot E$ and E triggers.

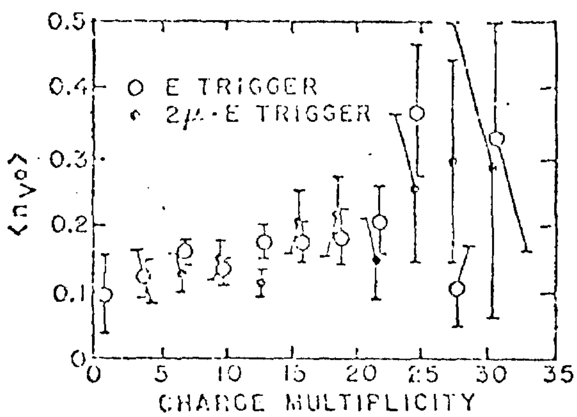

Fig. 3b. Average number of V^0's $\langle n_{V^0} \rangle$ vrs. charged multiplicity.

Table II Average Charged Multiplicity and Dispersion of the $2\mu\cdot E$ and E Triggers

Trigger	n_{ch}	$D = [\langle n_{ch}^2\rangle \; \langle n_{ch}\rangle^2]^{1/2}$
All E	12.5 ± 0.3	6.2 ± 0.3
All $2\mu\cdot E$	12.3 ± 0.5	6.5 ± 0.3
V^o(E)	13.3 ± 0.9	6.6 ± 0.7
$V^o(2\mu\cdot E)$	13.5 ± 1.4	6.7 ± 1.1

than 1 nb in our $2\mu\cdot E$ trigger.

This result can be used to place limits on charmed particle production. For instance, GIM[2] D mesons of mass 3 GeV (5 GeV) each with exp $(-P_T^2)$ and flat x_F distributions observed in ψ production, yields an upper limit of $\sigma_{+-}B^2 < 35$ (25) nb, assuming $B_{SL} = B_L \equiv B$ in relation (1).

We wish to thank R. R. Wilson for making the SOD magnet possible, P. Koehler and the staff of the Meson Laboratory at FNAL for assistance and encouragement, and the scanning staffs of our respective collaborators for their careful work. We are indebted to R. Kenyon, D. Forbush, P. Rancon, and G. Wurden for technical assistance and C. Jones for preparing the manuscript.

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3. V. Cook, et al. Proceedings of the International Conference on Instrumentation for High Energy Physics, Frascati, 171 (1973).
4. Due to the ± 9 mr gap in the muon telescope (see Fig. 1).
5. D. Bogert, et al., Phys. Rev. Lett. 31, 1271 (1973).
6. Spark chamber data was taken with a $2\mu\cdot E$ trigger which allows us to study muons from interactions in the absorber.
7. The χ^2 takes into account the measurement error and multiple scattering in the absorber.
8. $\langle n_{ch}\rangle$ is larger than observed in $\pi^- p$ interactions because many of the 2 and 3 prong events go through the hole in the s counter and do not trigger. Also, secondary interactions in the nucleus and the 5 cm target increase $\langle n \rangle$.
9. K. J. Anderson, et al., Phys. Rev. Lett. 36, 237 (1976).