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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 1x.5 x .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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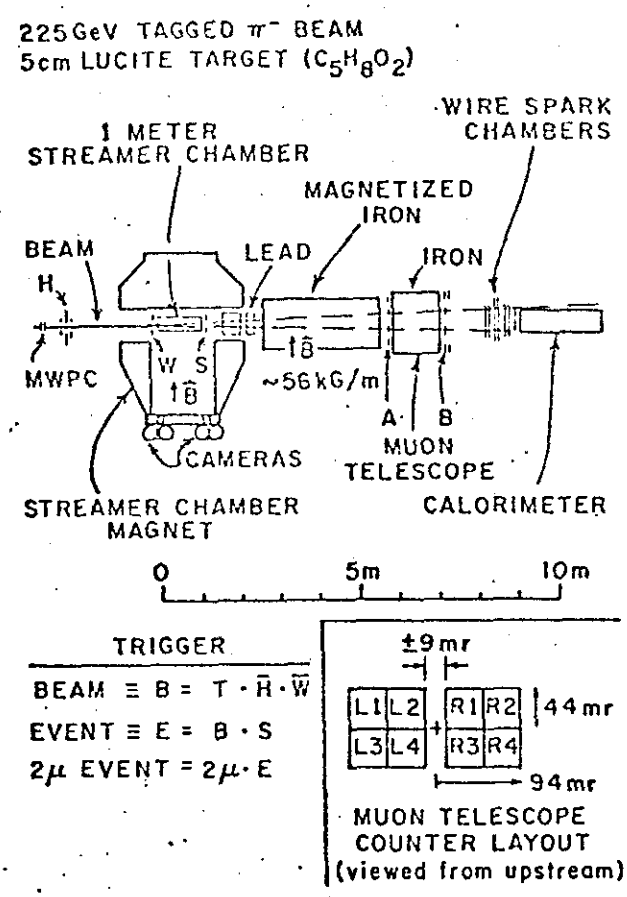

Fig. 1. Experimental Layout

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 $B \equiv T \cdot \bar{H} \cdot \bar{W}$. 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 $E \equiv B \cdot S$. 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 $2\text{-}7 \times 10^5$ 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

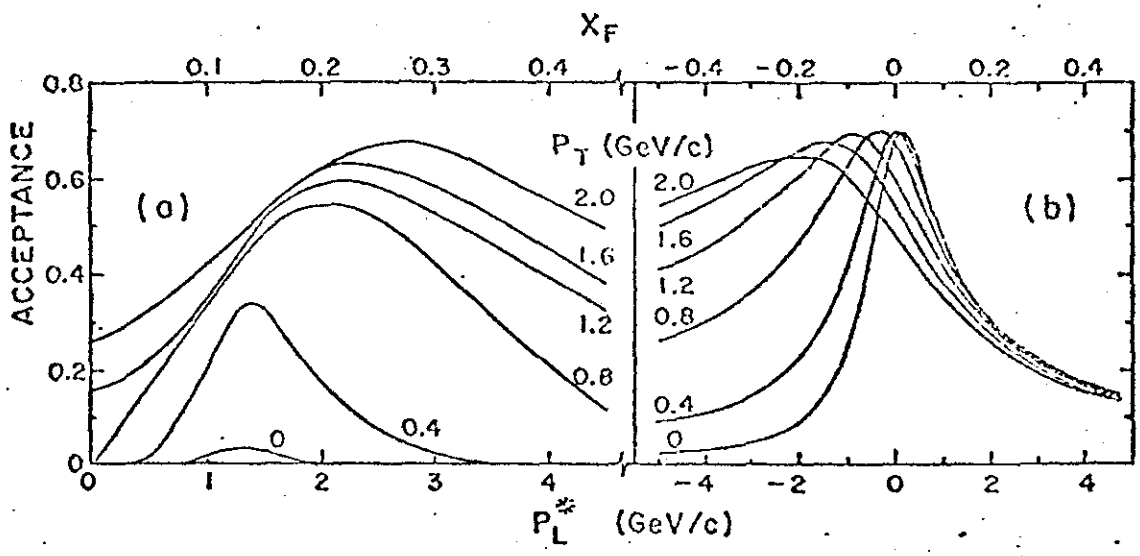

Fig. 2. Detection efficiency a) single muon b) k_s^o

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	$1\mu \cdot E/E = 0.8 \times 10^{-3}$	15.7 μb	–
2μ·E	$2\mu \cdot E/E = 4.3 \times 10^{-6}$	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 2μ·E triggers are prompt muons from interactions in the 5 cm target in the streamer chamber.

A detailed scan of the 2μ·E and E triggers was made and all V^o's were recorded and measured. Since the streamer chamber contains Ne gas, there is a very low probability that an observed V^o 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^o sample, we have removed those V^o'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^o's denoted by α is the same for the 2μ·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 2μ·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^o'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 2μ·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

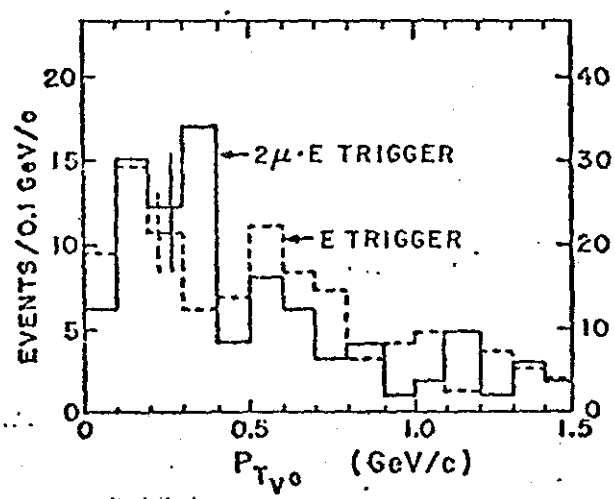

Fig. 3a. Transverse momentum distributions of V^o's. Left and right vertical scales apply respectively to the 2μ·E and E triggers.

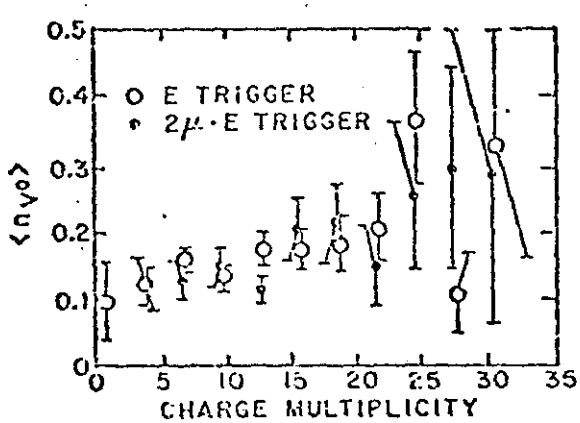

Fig. 3b. Average number of V^o's $\langle n_{V^o} \rangle$ vrs. charged multiplicity.

Table II Average Charged Multiplicity and Dispersion of the 2μ·E and E Triggers

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

than 1 nb in our 2μ·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).

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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 2μ·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 $\langle n \rangle$.
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