Comments and Addenda

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Search for massive penetrating particles produced by 300-GeV protons*

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We have searched for negative long-lived penetrating particles of mass between 1.0 and 6.8 GeV/c^2 produced by 300-GeV protons incident on Cu. At 2.38-GeV/c transverse momentum no event was found as compared to a yield of 1.28×10^9 π^-. The 90%-confidence-level upper limit for the invariant production cross section per nucleon is $Ed\sigma/d^3p = 5.4 \times 10^{-39}$ cm^2 GeV^{-2}.

In the course of an experiment on hadron[1] and direct muon[2] production at the Fermi National Accelerator Laboratory, we have searched for negative long-lived penetrating (i.e., not strongly interacting) particles of mass between 1.0 and 6.8 GeV/c^2 produced in a Cu target struck by 300-GeV protons. The initial motivation for such a search had come from a CERN-Rutherford group[3] which, while searching for muons with large transverse momenta produced at the CERN Intersecting Storage Rings (ISR), reported the observation of high-momentum "stopping" tracks. One of many possible explanations offered (instrumental as well as physical) was the existence of long-lived penetrating particles of several GeV/c^2 mass. Although the evidence presented was, as acknowledged by the authors themselves, very preliminary, we thought it might be of some interest to investigate because we had at our disposal an apparatus especially well suited for such a search.

On the presumption that the production of massive particles might be enhanced at relatively high transverse momenta ($p_\perp$), where substantial yields of heavy particles (e.g., $\bar{p}$, $\bar{d}$) have been observed,[1,4] we have made our measurements at $p_\perp = 2.38$ GeV/c. The production angle in the c.m. system of the incident proton and a single nucleon at rest depends on the particle mass: 94° for 1.0 GeV/c^2 and 166° for 6.8 GeV/c^2.

The apparatus[5] was identical to the one used in a search for direct muon production.[2] (See Fig. 1.) It consisted of a single-arm magnetic spectrometer

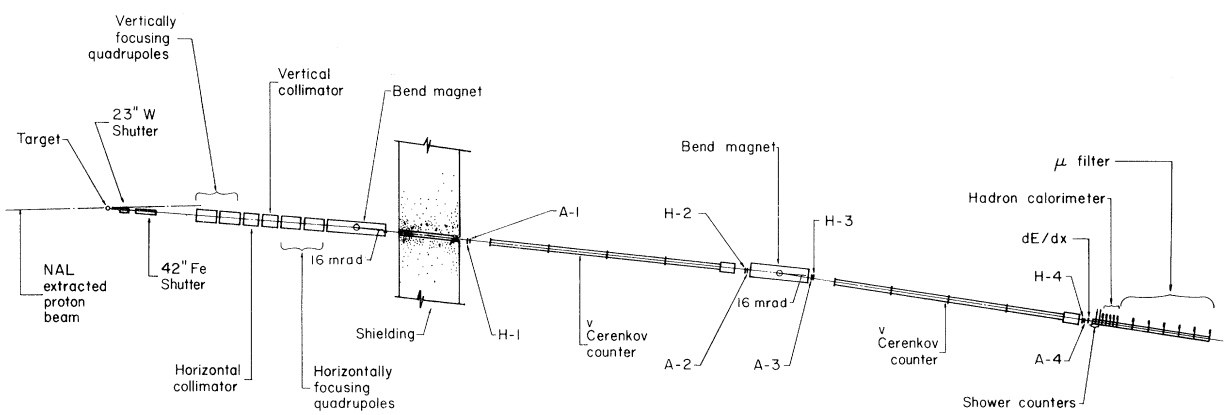

FIG. 1. The single-arm magnetic spectrometer used in this search. The 23-in. W absorber (shutter) and the 42-in. Fe absorber (shutter) were remotely movable in and out of the beam—during the experiment reported here, the 42-in. Fe absorber was removed from the beam.

of 110-m length located at 77 mrad relative to the incident proton beam. In addition, the spectrometer was equipped with two Čerenkov counters of two channels each, a hadron calorimeter, and a 15-ft-long steel filter to identify penetrating particles. (Each 2.5 ft of the filter had a dE/dx counter.) Before entering the spectrometer particles had to traverse a 23-in.-long W absorber whose upstream face was at 9.5 in. from the center of the 3-in.-long Cu target. Hadrons were measured to be attenuated by a factor of 334. A Monte Carlo calculation gave an attenuation factor of 1.8 for non-strongly-interacting particles, due mainly to multiple Coulomb scattering.[6] The remaining muons, pions, and kaons, as well as muons originating from π and K decays along the spectrometer, were identified in *each* outer channel of the two Čerenkov counters. The remaining antiprotons triggered each inner channel. Thus any charged particle of mass less than 1.0 GeV/c^2, penetrating or not, was independently tagged twice in the Čerenkov counters. With the added requirement that a particle be minimum-ionizing through the whole calorimeter and the muon filter, a very high rejection of muon-producing hadrons was achieved. For the muon itself the rejection ratio was $>10^5$.

The data, examined for the presence of single tracks through the calorimeter and muon filter, reconstructing satisfactorily back to the target, and with no light output in any of the four Čerenkov channels, revealed no acceptable candidate as compared to an equivalent yield of 1.28×10^9 negative pions at the same $p_\perp$ (2.38 GeV/c). The details of the π^- yield calculations are shown in Table I. The invariant cross section per nucleon, $Ed\sigma/d^3p$, for the production of negative pions of $p_\perp = 2.38$ GeV/c in p-Cu collisions at 300 GeV was measured to be 3.0×10^{-30} cm^2 GeV^{-2}. Hence, at the 90% confidence level, the corresponding production cross section for penetrating particles of mass between 1.0 and 6.8 GeV/c^2 is less than 5.4×10^{-39} cm^2 GeV^{-2}. This limit assumes a mean decay length $\lambda \gg 110$ m; it should be multiplied by $\exp(1.22\times10^{-8}M/\tau)$ for a particle of mass M (GeV/c^2) and lifetime τ (sec). The Čerenkov counters set the lower mass limit whereas the upper limit was obtained by assuming the penetrating particles (M) to be made in pairs, i.e., $N+N \to N+N+M^+ +M^-$, where N denotes a nucleon.

TABLE I. Calculation of the equivalent π^- yield.

A.	Observed hadrons	4 995 476
B.	Attenuation factors in W	
	hadrons	334
	muons	1.8
	hadron/muon	186
C.	Pion fraction at 2.38 GeV/c	0.77
D.	Pion decay factor	1.04
E.	Pion nuclear absorption[a] factor	1.72
F.	Equivalent pion yield	1.28×10^9

[a] Includes target (25%) and Čerenkov counters.

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[1] J. W. Cronin *et al.*, Phys. Rev. Lett. 31, 1426 (1973).

[2] J. P. Boymond *et al.*, Phys. Rev. Lett. 33, 112 (1974).

[3] R. Birge *et al.*, in *Proceedings of the XVI International Conference on High Energy Physics, Chicago-Batavia, Ill., 1972,* edited by J. D. Jackson and A. Roberts (NAL, Batavia, Ill., 1973), Vol. 2, p. 358.

[4] J. P. Boymond *et al.*, unpublished.

[5] A detailed description can be found in Ref. 1.

[6] See Ref. 2 for more details.