FERMILAB-PUB-74-149-E #100
EFI-74-29 PRL

Search for Massive Penetrating Particles Produced by 300-GeV Protons*

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ABSTRACT

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 x $10^9 \pi^-$. The 90%-confidence-level upper limit for the invariant production cross section per nucleon is $E d\sigma/d^3p = 5.4 \times 10^{-39}$ cm^2 GeV^{-2}.

In the course of an experiment on hadron[1] and direct muon[2] production at the 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 which, while searching for muons with large transverse momenta produced at the CERN 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 2.38 GeV/c $p_\perp$. 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]. It consisted of a single-arm magnetic spectrometer of 110 m length located at 77 mrad relative to the incident proton beam. In addition, the spectrometer was equipped with 2 Cerenkov counters of 2 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 gives 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 <u>each</u> outer channel of the 2 Cerenkov 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 Cerenkov 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 4 Cerenkov 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 2.38 GeV/c $p_\perp$ 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 $\lambda >> 110$ m; it should be multiplied by $\exp[1.22 \times 10^{-8}\ M/\tau]$ for a particle of mass M(GeV/c^2) and lifetime τ(sec). The Cerenkov 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., $N + N \rightarrow N + N + M^+ + M^-$, where N denotes a nucleon.

We thank the staff of the National Accelerator Laboratory, and especially of the Proton section, for their help and support. One of us (R.M.) wishes to thank NAL for its hospitality and support.

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*Work supported by the U. S. Atomic Energy Commission and the National Science Foundation.

†On leave at NAL from the University of Geneva.

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5. A detailed description can be found in Ref. 1.
6. See Ref. 2 for more details.

TABLE CAPTION

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

Footnote to Table I:

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

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 absorp.[a] factor	1.72
F.	Equivalent pion yield	1.28×10^9

TABLE I