SEARCH FOR MASSIVE MUON PAIRS

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ABSTRACT

We propose a proton beam dump experiment to scan the mass spectrum of muon pairs in the mass range $5 < m_{2\mu} < 20$ GeV/c^2. Both muons are momentum-analyzed in a solid-iron magnet spectrometer. The mass resolution varies from 14% at 5 GeV/c^2 to 8% at 20 GeV/c^2, being largely determined by multiple scattering in the hadron shield.

In a few hundred hours, one should be able to measure cross sections as small as 10^{-41} cm^2.

We propose a proton beam dump experiment to search for massive muon pairs in the range $5 < m_{2\mu} < 20$ GeV/c^2. This work would be an extension of an experiment recently completed at the AGS[1] and considered briefly in the 1968 Summer Study by Lederman.[2]

The AGS experiment yielded a dimuon signal that varies as $\sim 1/m^6$ and has a cross section of $\sim 10^{-33}$ cm^2/GeV/c^2 at a mass of 1 GeV/c^2. This result extrapolates to $\sim 10^{-38}$ cm^2/GeV/c^2 at 5 GeV/c^2 and to $\sim 10^{-41}$ cm^2/GeV/c^2 at 20 GeV/c^2, ignoring any dependence on the incident proton energy. An experiment at NAL, sensitive to cross sections like 10^{-41} cm^2, would provide a considerably elevated and expanded mass range to permit discrimination between the various mechanisms proposed to explain this phenomenon. Further, this technique is a sensitive probe for any new vector particles of large mass. Also, any observed muon pair signal may be related to the W production cross section[3] and thereby establish the sensitivity needed in any meaningful W search.

In the AGS experiment, the invariant mass of the dimuon was determined by momentum-analyzing each muon by range. This technique does not extrapolate to

NAL energies--the iron required would far exceed that needed for the bubble-chamber neutrino shield. The muons must instead be analyzed magnetically, but by a system with a very large aperture in order to maintain high cross-section sensitivity. A large iron toroid seems to satisfy all requirements.[4]

APPARATUS

The apparatus is shown schematically in Fig. 1. All protons interact in a uranium target, subsequent strongly interactive particles being removed by the target itself and the iron hadron shield. Those pions that decay to muons before interacting provide a background muon flux and potentially limit the sensitivity of the experiment. By varying the target density, one may eliminate muons from long-lived sources such as π's and K's. Unlike muons from the decay of massive states, those muons from pion decay tend to have small momenta and low transverse momentum and are preferentially removed by the momentum threshold of the tapered steel and uranium absorber. This absorber is thick enough to reduce the $\pi \rightarrow \mu$ rate to a tolerable level but thin enough to allow the detector to be placed close to the target.

The detector accepts muons in an angular range from 30 to 100 mrad. The first plane P1 (wire chambers, perhaps) serves to define the muon angle, assuming the particle originated in the uranium target. Because of multiple scattering, this angle is most precisely determined by measuring the displacement from the beam axis and not the emergent angle.

A typical muon of interest has a momentum of ~ 70 GeV/c, but loses ~ 30 GeV/c in the wall and thus emerges with ~ 40 GeV/c. The momentum is measured by means of a 5-meter thick iron magnet, straddled by two pairs of wire-chamber planes. To afford large azimuthal coverage with a minimum of iron, an octagonal magnet is considered (see Fig. 2). The central, field-free hole may be filled with uranium to better remove the large flux of muons present at small angles. The field falls linearly with radius in this magnet; if undesirable, the fall off could be eliminated by providing a very small tapered air gap between iron sectors.

The experimental mass resolution is dominated by multiple scattering in the 17-meter absorber and varies from ± 12% at a mass of 5 GeV/c^2 to ± 4% at 20 GeV/c^2. The magnet adds (in quadrature) 7% to this resolution, so that the overall mass resolution of the magnet is limited by multiple scattering and varies as (magnet length)$^{-1/2}$, independent of momentum. At 15 kilogauss, 5 meters of iron is adequate. An inter-plane spacing of 2 meters affords an angular resolution considerably smaller than the multiple scattering contributions from the magnet iron and thus makes no contribution to the resultant momentum resolution.

The detection efficiency as a function of mass is shown in Fig. 3. The calculation was based on the assumption that the process is

$$p + p \rightarrow N + N + V^{o}$$
$$\hookrightarrow \mu^+\mu^- ,$$

with the V^{o} uniformly filling the available three-body phase space. The V^{o} is assumed to decay isotropically in its center-of-mass. Figure 4 illustrates the sensitivity to the V^{o} production angle for various masses.

RATES

The angular dependence of the single rates at P1 and P3 is shown in Fig. 5. The total rate at P1 is $\sim 10^5$/pulse over a large area and is easily handled by the wire chambers. The rate at the trigger plane P4 is down by three orders of magnitude and the accidental left-right coincidence rate is entirely negligible. A feeling for the cross-section sensitivity may be gained by asking for ~ 100 events at a mass of 15 GeV/c^2 in 100 hours of running, say

$$N_V = 100 = N_p \times (N_0 P \Lambda_{int})(\sigma_V \beta_{2\mu}) \times (\text{efficiency})$$

$$= (10^5 \times 10^{13}) \times (6 \times 10^{23} \times 18 \times 10)(\sigma_V \beta_{2\mu})(0.03)$$

$\sigma_V \beta_{2\mu} \simeq 3 \times 10^{41}\,\text{cm}^2$, where $\beta_{2\mu}$ is the branching ratio.

CONCLUSION

An experiment to search for muon pairs in the range $5 < m_{2\mu} < 20$ GeV/c^2 appears feasible, permitting cross sections as small as 10^{-41} cm^2 to be measured. The experiment is not complex and argues for early running at NAL. It might be constructed as the first portion of a neutrino shield, where the proton beam is brought down the neutrino beam decay channel for this experiment. In fact, it is conceivable that this apparatus be used to measure the neutrino flux in a long spill neutrino beam. The magnet is massive but may also prove useful for sweeping muons from a neutrino shield.

REFERENCES

[1] J. H. Christenson, G. Hicks, L. M. Lederman, P. Limon, B. Pope, and E. Zavattini, (to be published).

[2] L. M. Lederman, Beam Dump Experiment: Dimuons and Neutrinos, National Accelerator Laboratory 1968 Summer Study Report B.2-68-85, Vol. III, p. 45.

[3]Y. Yamaguchi, Nuovo Cimento 43, 193 (1966).

[4]A magnet of this type was considered by D. Frisch for use as a muon sweeper in a neutrino beam.

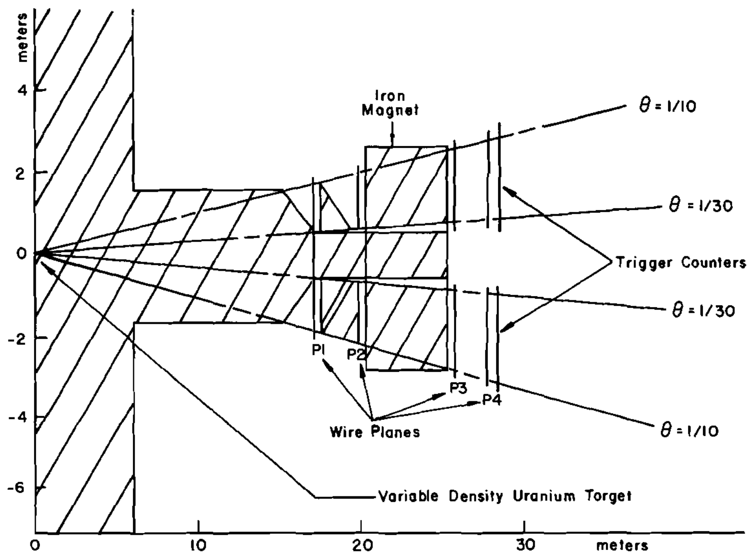

Fig. 1. Experimental layout--plan view.

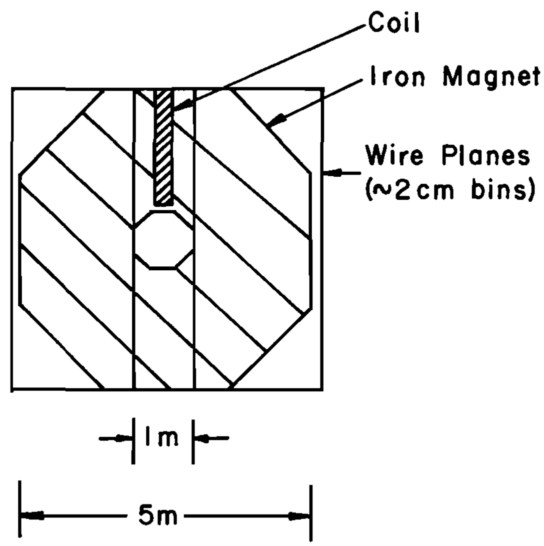

Fig. 2. Spectrometer magnet cross section.

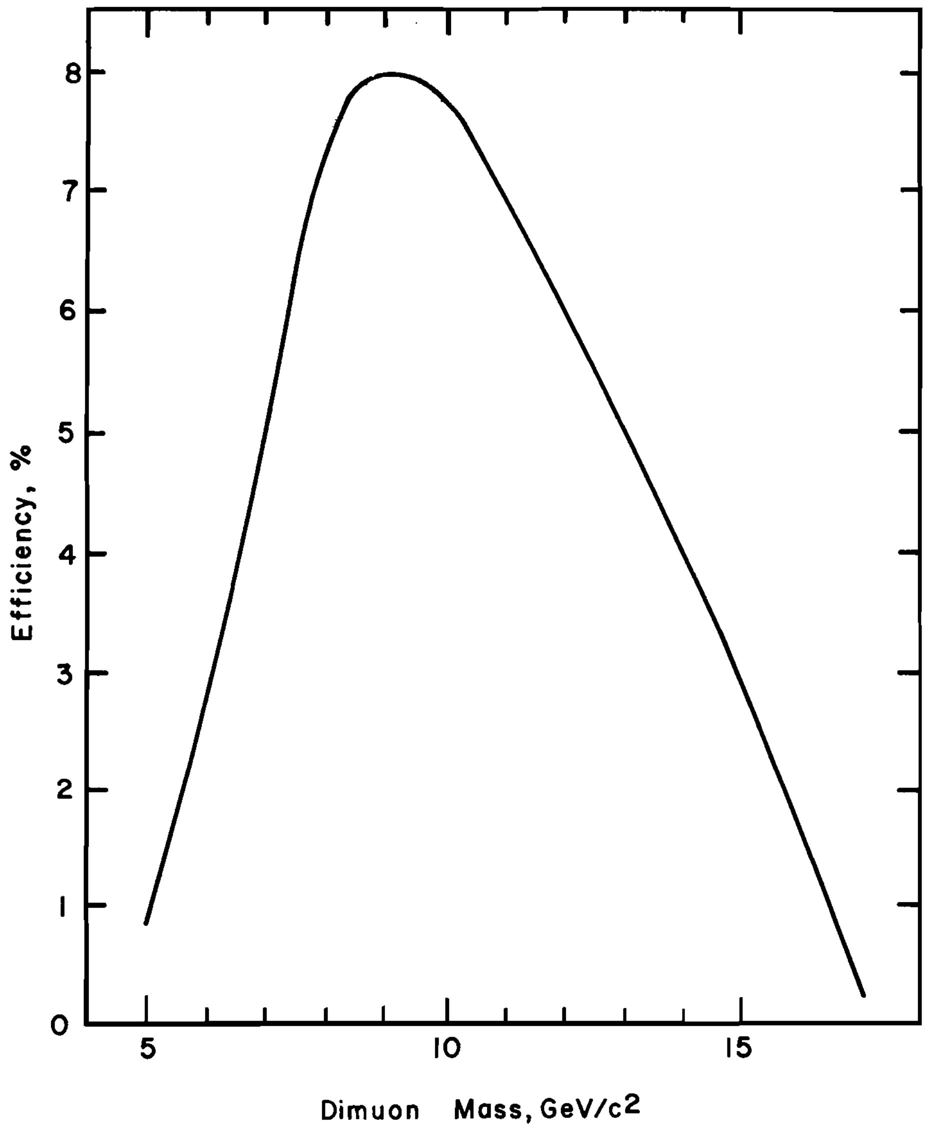

Fig. 3. Detection efficiency vs mass of dimuon.

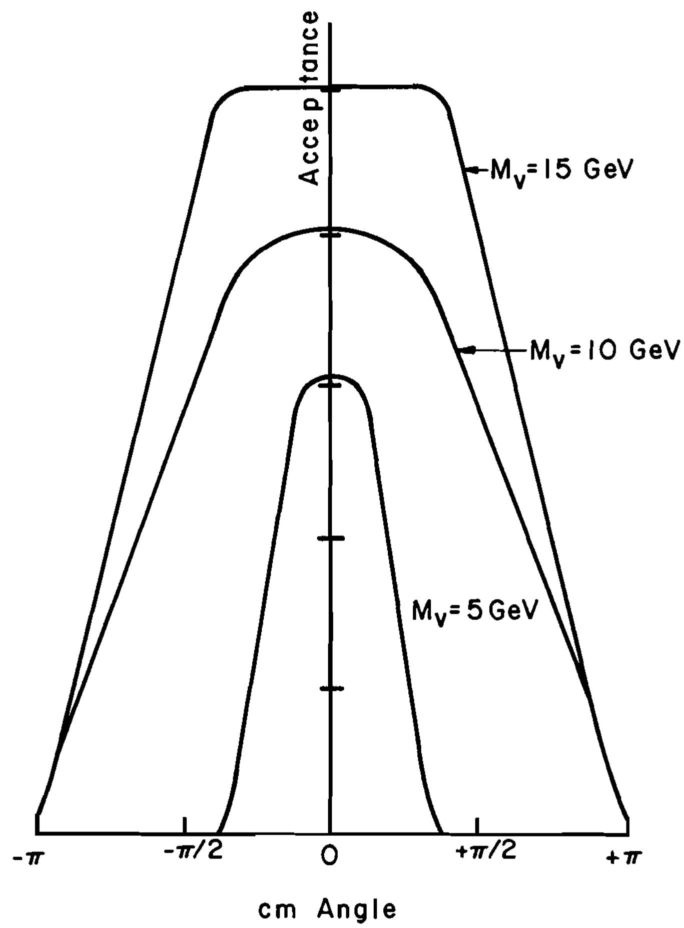

Fig. 4. Detection efficiency vs V^0 production angle for several mass values.

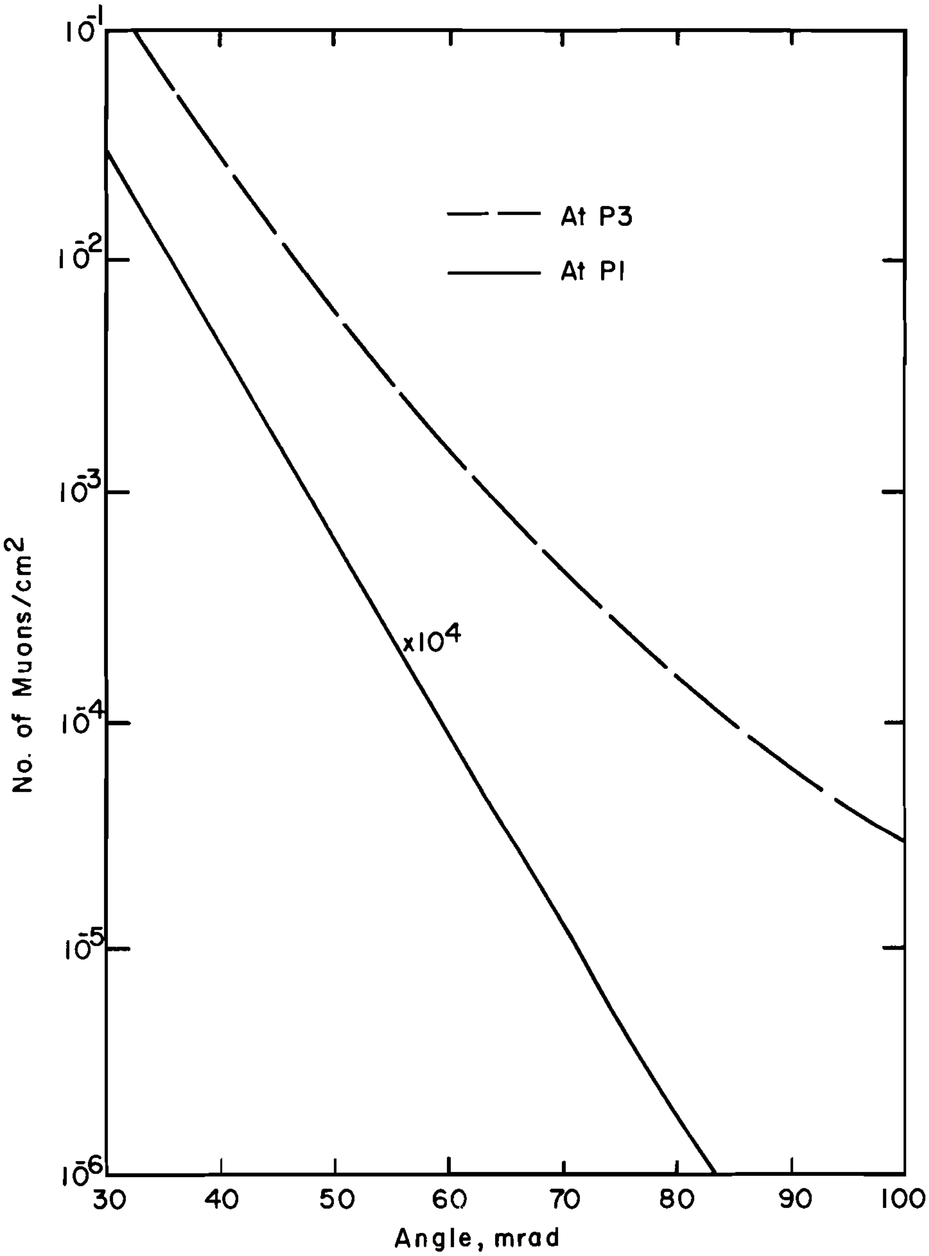

Fig. 5. Background muon rates vs production angle.