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Confirmation of an Enhancement in the $\mu^+\mu^-$ Mass Spectrum at 9.5 GeV

D. A. Garelick, P. S. Gauthier, M. J. Glaubman,(a) E. W. King,(b)
M. L. Mallary, J. Moromisato, E. Pothier, E. von Goeler
and
R. Weinstein
Northeastern University, Boston, Massachusetts 02115
G. S. Hicks,(c) P. M. Mockett, J. P. Rutherfoord, S. R. Smith
and
R. W. Williams
University of Washington, Seattle, Washington 98195
W. P. Oliver
Tufts University, Medford, Massachusetts 02115

(a) Visitor (1977-78), Max Planck Institute fur Physik und Astrophysik (Munich), CERN, CN-1211 Geneve 23.

(b) Now at Physics Department, University of Massachusetts, Amherst, Massachusetts 01002.

(c) Now at Bell Laboratories, Holmdel, New Jersey 07733.

ABSTRACT

The reaction $p+Fe \rightarrow \mu^{+}+\mu^{-}+$ anything has been measured at an incident momentum of 400 GeV. An enhancement of the order of 80 events is observed with $M_{\mu\mu} = 9.5$ GeV at approximately the 4 standard deviation level.

We report here results of an experiment carried out at the Fermi National Accelerator Laboratory which confirms the existence of an enhancement in the $\mu^+\mu^-$ mass spectrum at $M_{\mu\mu} = 9.5$ GeV first reported by S. Herb _et_ _al_.[1] and called the Υ. We have measured the reaction $p+Fe \rightarrow \mu^+ + \mu^- +$ anything at an incident proton momentum of 400 GeV. The results reported here are from data recorded in April, 1977 during an 80 hour run taken with an average beam intensity of 3×10^9 protons per one second accelerator pulse.

The apparatus is shown schematically in Figure 1. The μ's were created in the iron at the front of the first magnet as indicated. Muon momenta and angles were determined from measurements of the μ trajectories with proportional chambers (PC's) after the μ's traversed the 91 kG-m field of the gapless magnets which also acted as a 5.5 meter iron filter for hadrons. The magnetic field was horizontal causing the μ's to be bent in the vertical direction.

To obtain high mass events the trigger required one or more μ's on both the left and right side of the apparatus each having a transverse momentum $p_T \gtrsim 1.5$ GeV. Accidental triggers in which the left and right μ were out of time by 37.6 nsec (2 r.f. beam buckets) were also recorded.

Recorded events were reconstructed using an algorithm which constructed roads defined by the hodoscope counters registering hits. Proportional chamber hits aligned within these roads were used to fit tracks. A muon track required at least 5 out of 6 of the PC's to have hits along the muon direction. Events in which more than two μ tracks were found were rejected[2].

The dimuon invariant mass $M_{\mu\mu}$ was calculated from the tracks measured by the PC's under the assumption that the dimuon was created inside the iron target one absorption length (17.1 cm) from its front edge along the beam line. The muon momentum and angles were reconstructed by taking into account the bending and average energy loss of the muons in the magnetized iron spectrometer.

In the horizontal projection of the track, where there is no bending to first order, each muon track was extrapolated back to the region of the production point. In this region the tracks were required to deviate horizontally from the production point by no more than 3.2 times the expected standard deviation. The standard deviation was calculated from the position and angle resolution of the straight track in the PC's and the expected multiple scattering of the muon in the spectrometer. This cut provided a reliable rejection of μ's not produced in the target. Measurements of $\psi(3.1)\rightarrow\mu^+\mu^-$ using the same apparatus but without a p_T selection on the individual μ's were carried out to determine the mass scale and as a check of the mass resolution of the spectrometer.

Figure 2 shows the unlike sign mass spectrum ($\mu^+\mu^-$) for in-time dimuons, uncorrected for the acceptance of the apparatus. The acceptance of the detector is changing rapidly in the region of the ψ(3.1) resonance so that this peak appears to be slightly shifted up in mass. Measures of our $\mu^+\mu^-$ background are also shown in Figure 2. The like sign (sum of $\mu^+\mu^-$ and $\mu^-\mu^-$) in-time dimuons include time random coincidences as well as events having two prompt muons or muons from pion decay or any combination of the above. Comparison of the in-time and out-of-time like sign dimuon spectra suggests that most of the in-time background is due to accidentials. The difference between the out-of-time like sign and unlike sign spectra is due to differences in acceptance. In any case, the backgrounds are quite small at high mass, roughly two orders of magnitude below the unlike sign signal.

The yield for $M_{\mu\mu} > 5$ GeV corrected for acceptance, is shown in Figure 3. The acceptance and resolution were calculated by detailed Monte Carlo calculation. The assumptions included a uniform decay angle distribution, a p_T distribution with an average value of 1.2 GeV, and a Feynman x distribution suggested by Drell-Yan models. These distributions are consistent with our data[3]. The calculated resolution of the apparatus is $\Delta M_{\mu\mu}/M_{\mu\mu} = 8\%$ r.m.s. We have fitted the mass distribution above $M_{\mu\mu} = 5.0$ GeV with a smooth continuum plus a Gaussian centered at

$M_{\mu\mu}$ = 9.5 GeV and with a fixed width of σ = 760 MeV, our mass resolution at 9.5 GeV. For a continuum of the form $d\sigma/dM_{\mu\mu} = \alpha M_{\mu\mu}{}^{n}(1-M_{\mu\mu}/\sqrt{s})^{m}$ where s = 751 GeV^2 we find in the Gaussian 78 ± 21 events above the continuum, i.e., the excess at 9.5 GeV is a 3.8 standard deviation effect. This implies $B(T \to \mu^+\mu^-)\ \sigma\ (pN \to TX) = (0.50 \pm 0.13) \times 10^{-36}\ cm^2$/nucleon assuming an $A^{1.0}$ dependence. The quoted error is statistical only and comes out of the fitting routine. The χ^2 is 20.6 for 26 degrees of freedom and the result of this fit is shown in Figure 3. The resonance to continuum ratio is $B(T \to \mu^+\mu^-)\ \sigma\ (pN \to TX)/(d\sigma/dM_{\mu\mu}(M_{\mu\mu} = 9.5\ GeV)) = 1.2 \pm 0.5$ GeV where the error includes an estimate of the uncertainty in the continuum. We have also attempted to fit the continuum with an exponential above $M_{\mu\mu}$ = 6.0 GeV. This fit gives $B(T \to \mu^+\mu^-)\ \sigma\ (pN \to TX) = (0.70 \pm 0.14) \times 10^{-36} cm^2$, i.e., a 5.0 standard deviation effect with a χ^2 of 26.3 for 22 degrees of freedom. This parameterization underestimates our yield above $M_{\mu\mu}$ = 11 GeV and so is not preferred by us. The continuum region in the data of S. Herb *et al*.[1] appears to be exponential but this is not necessarily a contradiction to our observations since they measured $d^2\sigma/dM_{\mu\mu}dy$ at y = 0 whereas we measured $d\sigma/dM_{\mu\mu}$ averaged over the region $y \geq 0$. The statistical errors in the cross section should be combined with a ±40% uncertainty in the absolute normalization and acceptance.

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FIGURE CAPTIONS

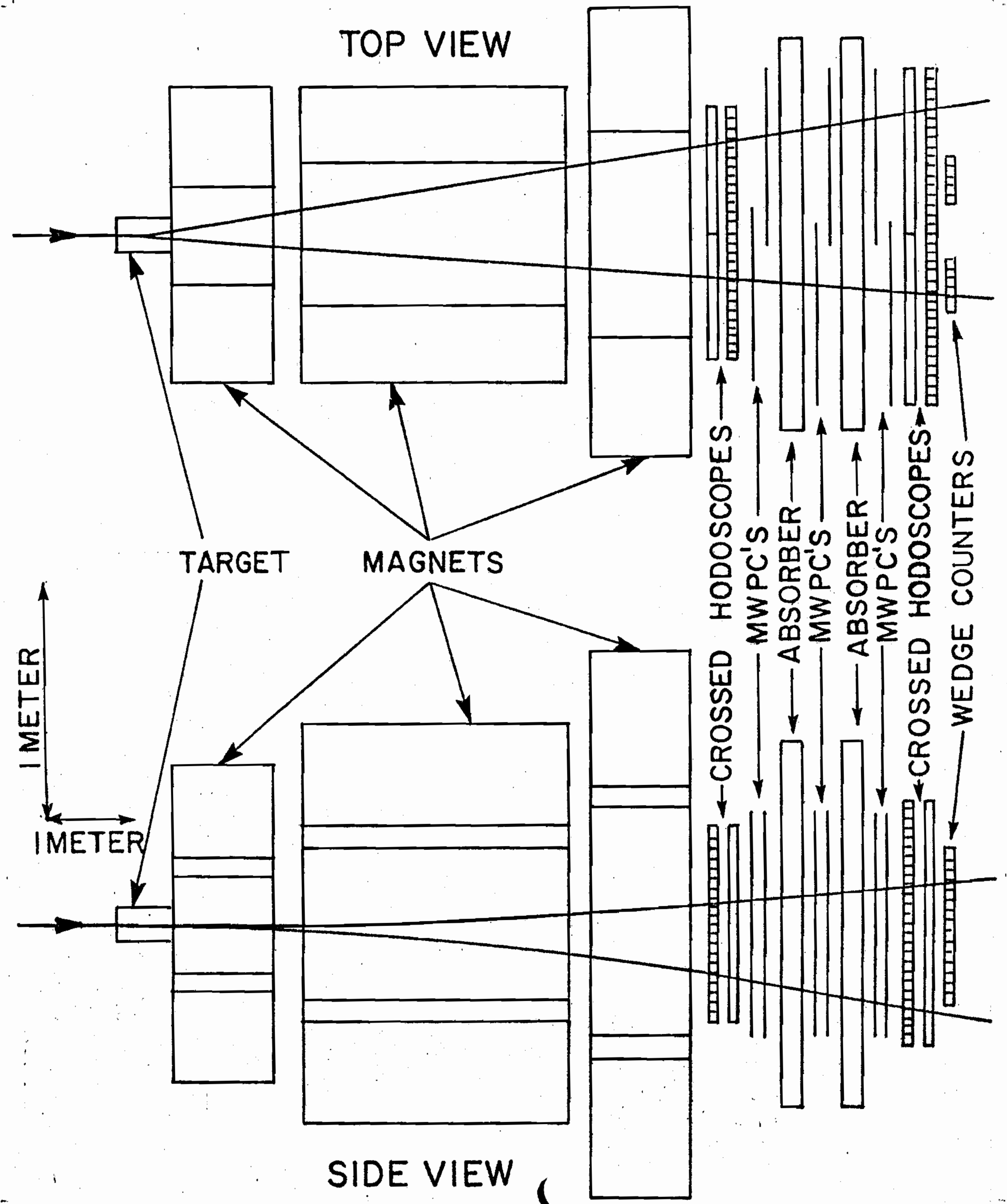
1. Schematic layout of the muon spectrometer. Separate hodoscope counters (172 total) and proportional chambers MWPC (12 total) cover the left and right sides of the rectangular detector aperture.
2. Yield of dimuons as a function of $M_{\mu\mu}$.
3. Acceptance corrected yield of the unlike sign, in-time dimuons as a function of $M_{\mu\mu}$. The curves are discussed in the text.

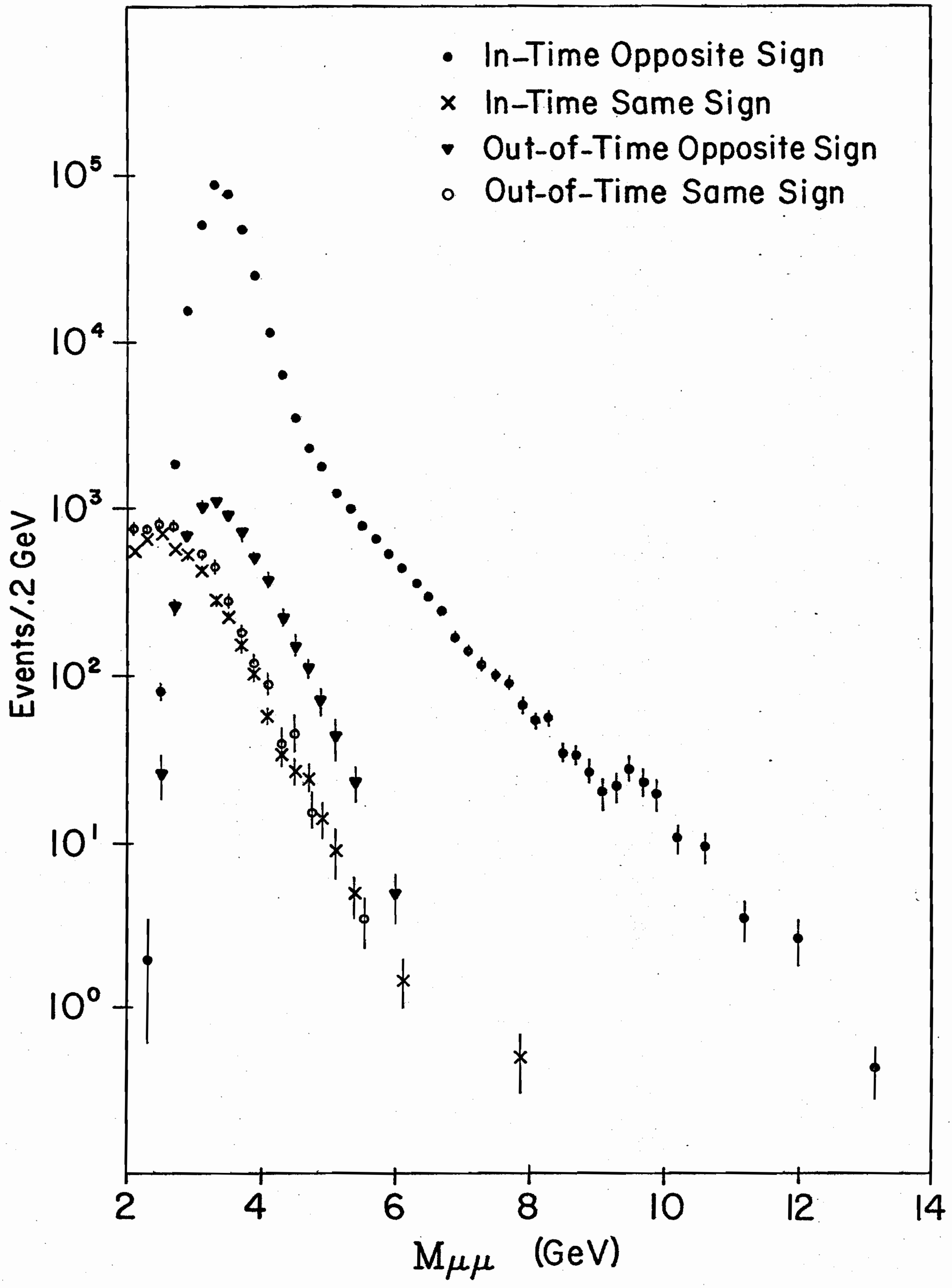
REFERENCES

[1] S. Herb _et_ _al_., Phys. Rev. Letters _39_, 252 (1977).

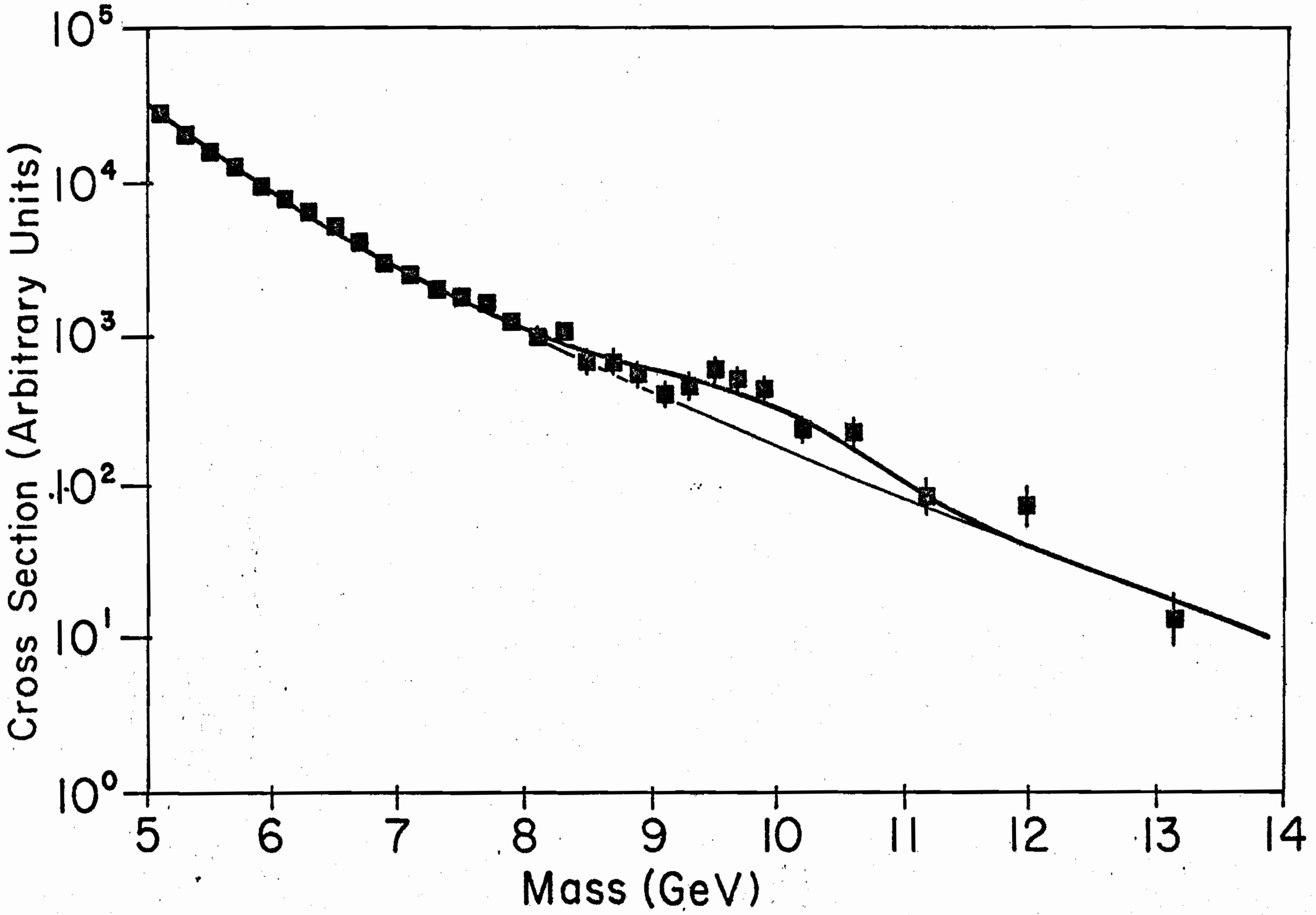
[2] Studies of these events indicate that this selection does not affect the shape of the $\mu^+\mu^-$ mass spectrum. We are investigating the physics of such events.

[3] Fits to the Feynman x and p_T dependences versus $M_{\mu\mu}$ will be reported elsewhere.


TOP VIEW
TARGET
MAGNETS
I METER
I METER
CROSSED HODOSCOPES
MWPC'S
ABSORBER
MWPC'S
ABSORBER
MWPC'S
CROSSED HODOSCOPES
WEDGE COUNTERS
SIDE VIEW



● In–Time Opposite Sign
× In–Time Same Sign
▼ Out-of-Time Opposite Sign
○ Out-of-Time Same Sign
Events/.2 GeV
10^5
10^4
10^3
10^2
10^1
10^0
2
4
6
8
10
12
14
$M_{\mu\mu}$ (GeV)



10^5
10^4
10^3
10^2
10^1
10^0
Cross Section (Arbitrary Units)
5
6
7
8
9
10
11
12
13
14
Mass (GeV)