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SEARCH FOR MASSIVE DILEPTONS

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ISR PROPOSAL

Search for Massive Dileptons

Addendum No. 1

(July 1970)

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1. Introduction

We submit here, several items which should be of interest to the ISRC. These involve some new theoretical ideas and some encouraging experimental tests of the planned detectors. No action of the ISRC is required at this time.

2. Neutral Currents

Our experiment proposes to study lepton pairs:

$$p + p \rightarrow e^{+} + e^{-} + \text{anything}$$

as a probe of hadronic electromagnetic structure, as a search for resonant structures produced either electromagnetically by virtual photons or by neutral weak currents such as would be generated by W^{o} particles. The pleasant dilemma may arise of how to distinguish among these as a source of an observed bump. One solution is that heavy ρ-type particles should have large branching ratios into hadrons. However, a recent suggestion by N. Christ (Columbia University) stimulates this addendum.

Christ points out that weak neutral currents can be distinguished by observing the term:

$$\vec{P}_{beam} \cdot \vec{P}_{e^+} \times \vec{P}_{e^-}$$

i.e., for parity violation in the decay of the dilepton. The identification of such an "up-down" asymmetry would be unambiguous proof of the existence of a neutral lepton current in spite of the ever-present electromagnetic competition.

In the ISR experiment there are two problems: the absence of a magnetic field and the ambiguity in the definition of $\vec{P}_{beam}$. However, both problems are handled by the modification:

$$\vec{P}_{beam} \cdot \left(\vec{P}_{>} \times \vec{P}_{<}\right) \left[\vec{P}_{beam} \cdot \vec{P}_{>}\right]$$

where $P_{>}$ signifies the momentum of the more energetic electron in the detected pair. (This term simply defines as $\vec{P}_{beam}$ that direction favored by the higher energy electron.) We note that there is today no evidence against neutral currents involving charged leptons for $\Delta S=0$ processes because of the masking by electromagnetic forces.

The implications for scheduling are not clear yet but could only be that greater care would have to be taken to verify the lack of systematic bias in the energy measuring (lead-glass) detectors.

3. Photon Pairs

The recent BNL study of massive lepton pairs and the ISR proposal have stimulated a theoretical note by E. Paschos (Rockefeller University) on the relationship between lepton pair emission in high energy pp-collisions and the emission of gamma pairs. In the Drell-Yan model, where lepton pairs are the result of parton-antiparton annihilation, two-quantum final states compete and Paschos predicts that the ratio is a measure of the charge of the protonic constituents (partons) and is of the order of unity. We wish to note that our arrangement can probably detect photon pairs of this kind over the background of π^0-γ's of the production of massive pion pairs is not overwhelming. We would record prompt coincidences of large pulses in the Pb-glass counters (unaccompanied by spatially correlated charged tracks). A study of double two-core showers would be required to study the double π^0 background. The difficulty of this must await Monte Carlo calculations.

4. Progress Report on BNL Studies for Electron Detectors and Background Suppression

a) Hadron veto. We are now studying the absorption of pions on lead at the AGS. This is because we plan to identify hadron-induced pulses in the lead glass counters via a lead-shielded veto counter placed after the Pb-glass blocks. The idea was that very few high energy pions would fail to project some ionization through ~25 radiation lengths of lead -- which is only 1.5 nucleon mean freepaths. The preliminary data is shown in Fig. 1 for 8, 12 and 14 GeV pions. The lead glass block is equivalent to about 10 cm of lead. We believe the absorption to be overestimated because of the geometry and the quality of the pion beam. Nevertheless it shows that of the order of ~99% of the hadrons will survive the Pb-glass plus additional Pb. A total hadron suppression of $\sim 10^{-4}$ is then obtained in the energy region where the gas Cerenkov counter is not useful. It remains to determine how many electrons will be lost by this process. Measurements of electron attenuation (at 8 GeV) show that ~50% of the showers generated in 30 r.l. of the Pb survive to give a count in a 1/4" plastic scintillator. These counts have been identified as conversion of soft (2-10 MeV) photons from the debris of the electromagnetic cascade. A two-fold coincidence requirement reduces the survival rate to $(.5)^2 = .25$. Thus a large pion-electron discrimination is certain to be achieved by this system.

b) Pb-glass tests. Figure 2 is an example of an ungated set of pulses in a large Pb-glass block (kindly lent by Dr. C. Rubbia) exposed to 6 GeV beam where the electron component is ~1%. It is clear that the Pb-glass is an additional strong suppressor of hadrons in that much higher energy pions are required to simulate a given electron pulse and further that these pions do so very inefficiently.

Tests of the resolution of various configurations of Pb-glass, of new types of shower counters and of phototubes will continue through the summer. As a "standard" we have the CERN (Rubbia) unit, a hexagonal, 30cm glass block coupled to a 5" EMI tube. Using this tube, the Rubbia group achieved, under ideal conditions, a resolution $\approx \frac{9\%}{E}$ at ≈ 1 GeV. We have observed resolution widths (FWHM) of ~5% at 8 GeV but must subtract an as yet unknown incident beam spread.

In summary, all tests are encouraging.

5. Theoretical Interest

We append here, for the information of ISRC, a report to the Kiev Conference of the BNL dimuon experiment. We call attention especially to the flood of theoretical interest (reference 1) and to the predictions for ISR and NAL of one of these theories both for electromagnetic pairs and for charged intermediate bosons with which this research is intimately related.

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1. Berman, Levy and Neff, Phys. Rev. Letters 23, 1363 (1969).
2. Kogerler and Muradyan, JINR, E2-4791 (1969).
3. Matveev, Muradyan and Taukhelidze, JINR, E2-4968 (1970).
4. S. Drell and T-M. Yan, SLAC preprint (1970).
5. Altarelli, Brandt and Preparata, Rockefeller Univ. preprint (1970).
6. John Harte, SLAC - Pub. 641 (1969).
7. J.J. Sakurai, Phys. Rev. Letters 24, 968 (1970).
8. T.D. Lee, G.C. Wick, Columbia Univ. preprint (1970).
9. O. Nachtman, (CERN) private communication (1970).
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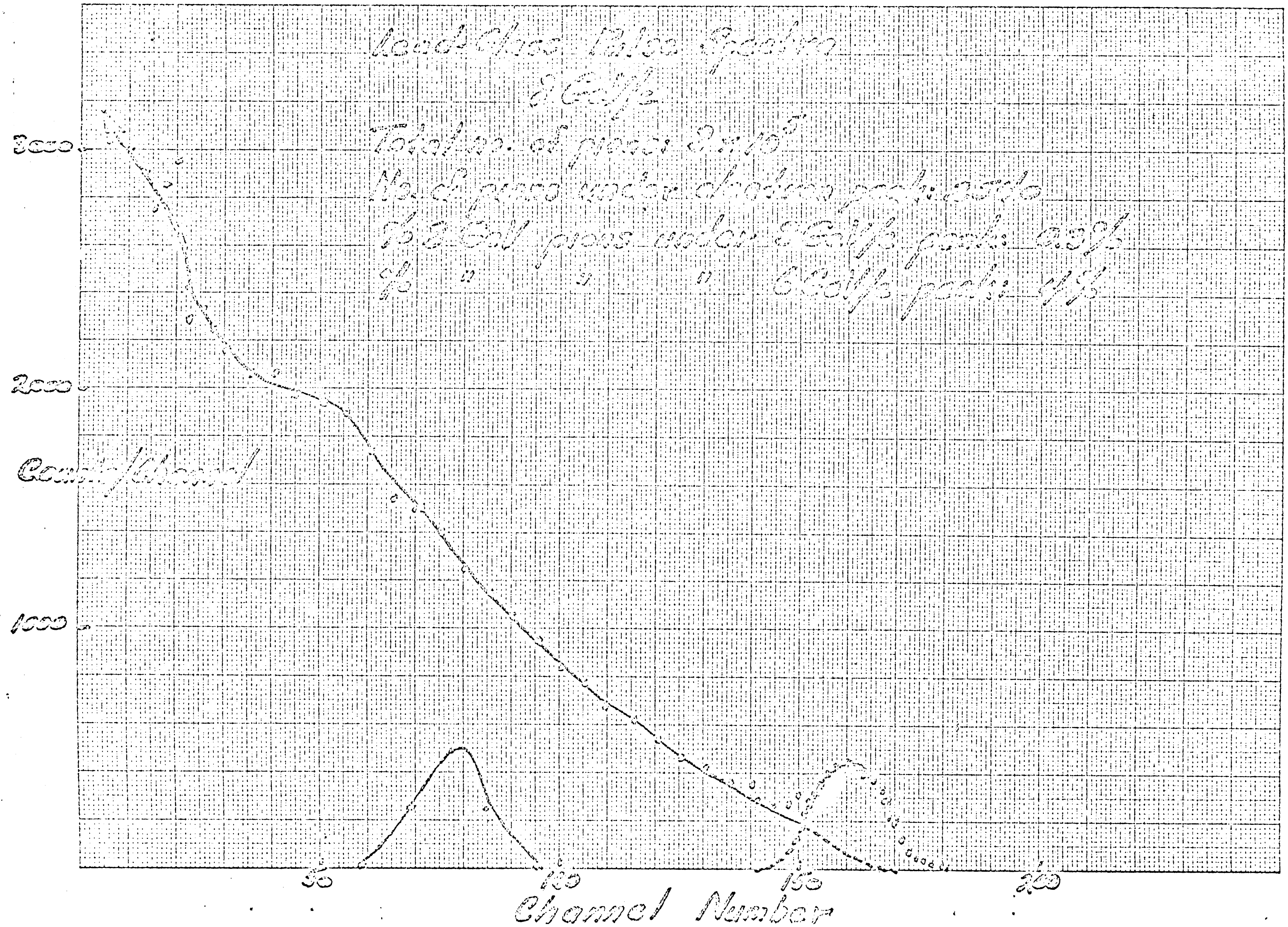
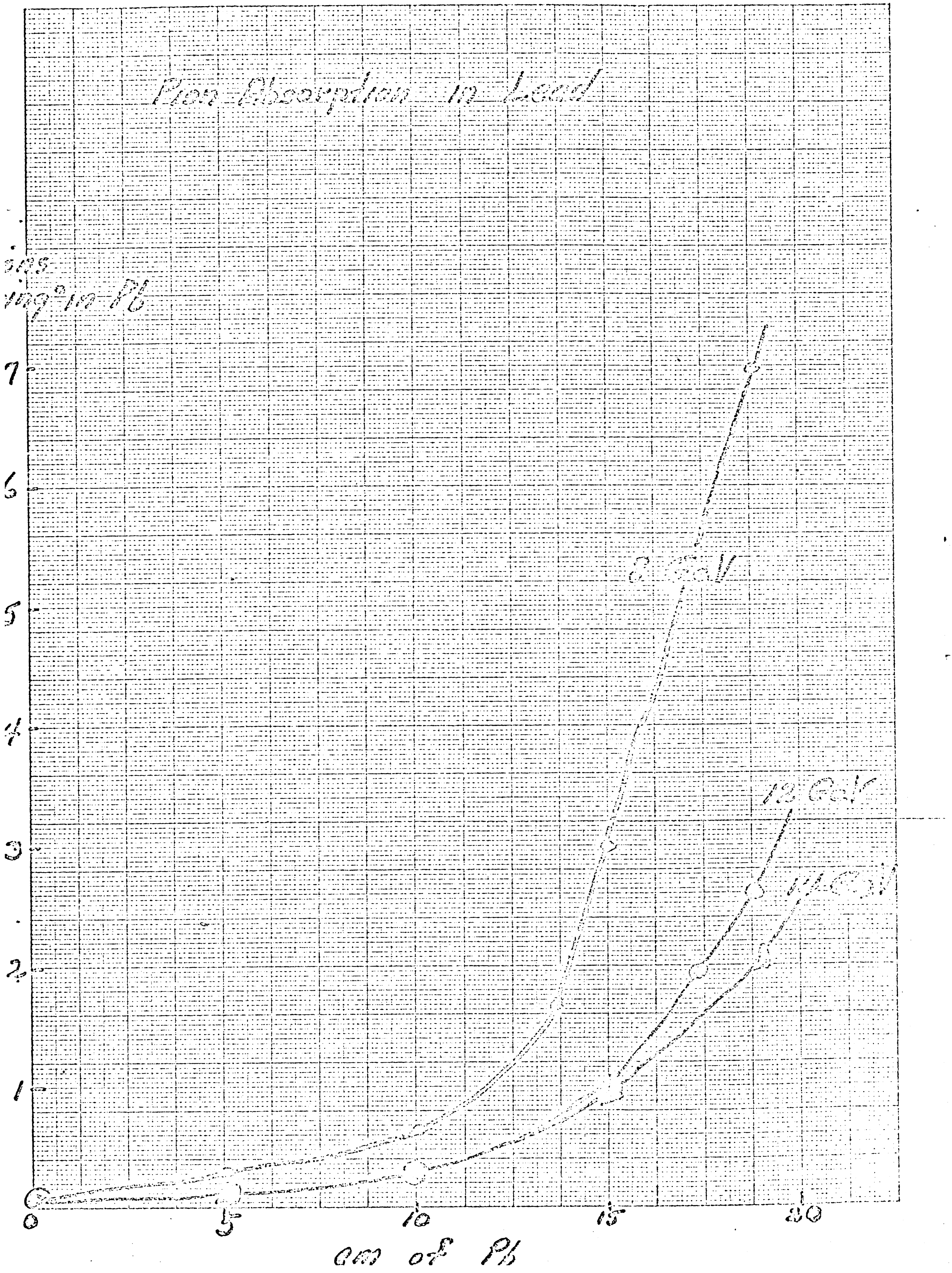

Lead Glass Pulse Spectra
8 GeV/c
Total no. of pions: 3×10^5
No. of pions under electron peak: 2500
% of all pions under 8 GeV/c peak: 0.8%
% " " " " 6 GeV/c peak: 1.1%
Counts/Channel
3000
2000
1000
50
100
150
200
Channel Number



Pion Absorption in Lead
8 BeV
12 BeV
7
6
5
4
3
2
1
0
5
10
15
20
cm of Pb

Submitted to the XVth International Conference on High Energy Physics, Kiev (1970).

Observation of Muon Pairs in High Energy Proton Nuclear Collisions *

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I. INTRODUCTION

We have observed and measured muon pairs emerging from collisions of high energy protons from uranium:

$$p + \text{"P,n"} \rightarrow \mu^{+} + \mu^{-} + \text{anything} \quad .$$

The motivation was to use the easily observable dileptons as a sensitive probe of hadronic electromagnetism and weak (neutral) currents. The virtues of an unrestricted final state ("anything") was a unique feature when this research was proposed to the AGS in 1967. In particular, the many anticipated 1^{-} particles (either strongly produced, as the ρ' or weakly produced as a W^{o}) would manifest themselves as bumps on a continuous distribution in dimuon masses. The high energy and flux of primary protons assures a sensitivity down to typical weak cross sections. At the full energy of the AGS, the kinematic cutoff in dimuon mass is $\sim$ 6 GeV.

II. EXPERIMENTAL METHOD

A slow extracted proton beam is incident on a target consisting of 20 1-in. thick uranium plates. This is followed by a wall composed of 3.0 m of steel and 0.6 m of concrete to absorb strongly interacting particles. A tapered steel absorber follows, designed to maximize the signal of wide angle muon pairs over the background of single muons from pion and kaon decay. Muons are detected in scintillation counter hodoscopes which determine the angle of each muon and the momentum via range. See Fig.1.

The counting rates are completely dominated by muons from pion and kaon decay in the uranium target. The experiment was designed to detect a real dimuon signal in a background of $\sim 10^{+4}$ accidental coincidences between "left" and "right" muon hodoscopes.

Actually, the signal of real muon pairs varied over the observed dimuon mass range from ~ 3% at 1.5 GeV to 40% at 5.5 GeV. The absence of contributions from long-lived sources (pions, kaons) was verified by varying the density of the absorber so as to enhance their contribution (by a factor of 10). An upper limit of ~ 100 μb for massive dipion production is set by the failure to observe any increase in the real signal.

Many other experimental checks of the reality of the dimuon signal were made and will be given in detail in a forthcoming publication. Corrections to the data (many 10 to 20% terms) were also carried out. A typical plot of raw data with accidentals subtracted is given in Fig. 2. Typical mass resolution is ± 10%.

III. ANALYSIS

To convert to absolute cross sections, differential in dimuon mass, the efficiency of the apparatus must be known. This in turn is not independent of the dynamics of dimuon production which can depend on the dimuon momentum and production angle, as well as on the decay angular distribution in the virtual photon rest system. All of these variables are in principle observed in our experiment. The procedure followed was to devise simple models for the dependence of the dilepton production process on these variables and adjust parameters until good fits were obtained with our observed histograms. These adjusted models were then used in a Monte Carlo program to compute the mass dependent apparatus efficiency. The efficiency so obtained was used to correct the observed data. Finally, the parameters were varied over unreasonably wide excursions and the sensitivity of the efficiency (and hence of the corrected data) studied. These are given as "roads" in the final data graphs e.g., Figs. 3,4. The roads are an envelope of maximum plausible deviations of the corrected data and illustrate the model dependence of the final results. The most serious cutoff in aperture is in the dimuon momentum which is set at 12 GeV.

A. Interpretation of Results

1. There is a continuum of dimuon masses extending to 6.7 GeV. From ~ 1.5 to 5 GeV, this is most simply given qualitatively by a distribution $d\sigma/dm \sim m^{-5}$ modified by 3 body phase space. The kinematic limit for 29.5 GeV incident is 5.7 GeV and Fermi motion is required to produce masses beyond this. The absolute cross sections have an overall scale error of about ± 50% and Monte Carlo statistics also contribute to individual error bars.

2. There are no clearly discernable bumps and the following limits can be placed on the existence of possible resonant structures:

Mass	$\sigma_V B_{\mu\mu}$ cm^2
1.5	$< 2 \times 10^{-33}$
2.5	$< 2.4 \times 10^{-34}$
3.5	$< 7 \times 10^{-35}$
4.5	$< 1 \times 10^{-34}$.

It should be noted that if one assumes a vector meson type decay branching ratio $B_{\mu\mu} \sim 10^{-4}$, we obtain cross sections for the strong production of vector mesons $\leqslant$ a few microbarns.

3. By comparing the data at incident proton energies of 22, 25, 28.5 and 29.5 GeV, one can obtain an estimate of the S-dependence of the cross section. Since all spectra behave as $1/m^5$, fixed q^2 and an integral over the aperture give identical results: Over our limited range, the cross section increases by about a factor of four.

4. There are now a large number of theoretical models[1] which predict mass distributions, s-dependence and the vector momentum distribution of the dimuon. At the time of this writing, definitive comparisons have not yet been made but should be available before the conference.

5. These data lead to estimates for the production cross section of intermediate bosons via the CVC arguments of Yamaguchi and Chilton.[2] For example, for $s = 60$ GeV^2 (BNL) and $M_W = 4$ GeV, the production cross section is estimated to be:

$$\sigma_W \cong d\sigma/dm_{\mu\mu} = 2 \times 10^{-35} \text{ cm}^2 \quad .$$

Some of the theoretical models mentioned above may also be used to extrapolate the BNL data to the s-values typical of the CERN ISR and the NAL Accelerator in order to predict the rates of production of pairs and of intermediate bosons. A graph giving the results of the parton model of Drell-Yan is given in Fig. 5.

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1i O. Nachtman, (CERN) private communication (1970).

See also pre-experiment papers:

1j F. Hadjouianou, CERN preprint (1962).

1k R.J. Oakes, Nuovo Cimento 44, 440 (1966).

1l E. Paschkos, Rockefeller Univ. Preprint (1970).

2a Y. Yamaguchi, Nuovo Cimento 43, 193 (1966).

2b Chilton, Sajarstein and Shrauner, Phys. Rev. 148, 1380 (1966).

FIGURE CAPTIONS

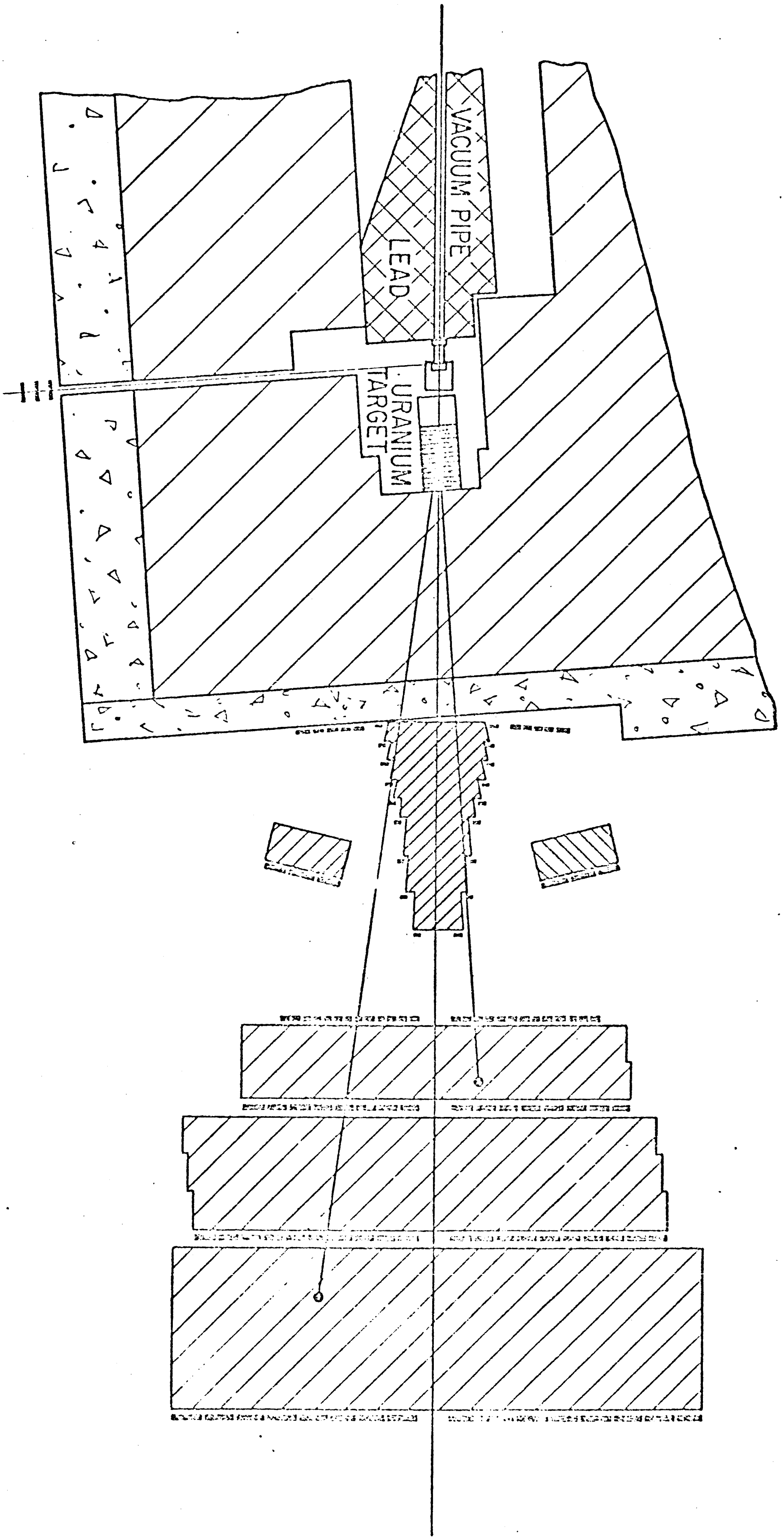
Fig. 1 Experimental Arrangement - BNL Dimuon Experiment

Fig. 2 Subtracted Raw Data

Fig. 3 Differential Mass Spectrum. The dashed lines are model dependence "limits".

Fig. 4 Spectrum at 29.5 GeV. The open circles are under angle muon pair data obtained from separate centers installed to extend the mass range.

Fig. 5 Drell-Yan estimates of dilepton pairs to be expected at ISR and at NAL operated at 500 GeV. The single Drell-Yan parameter λ^2 is taken to be unity. Comparison with BNL data suggests $\lambda^2 < 10$. The σ_W comes from simple Yamaguchi application of CVC with no contribution from axial vector currents.


VACUUM PIPE
LEAD
URANIUM
TARGET

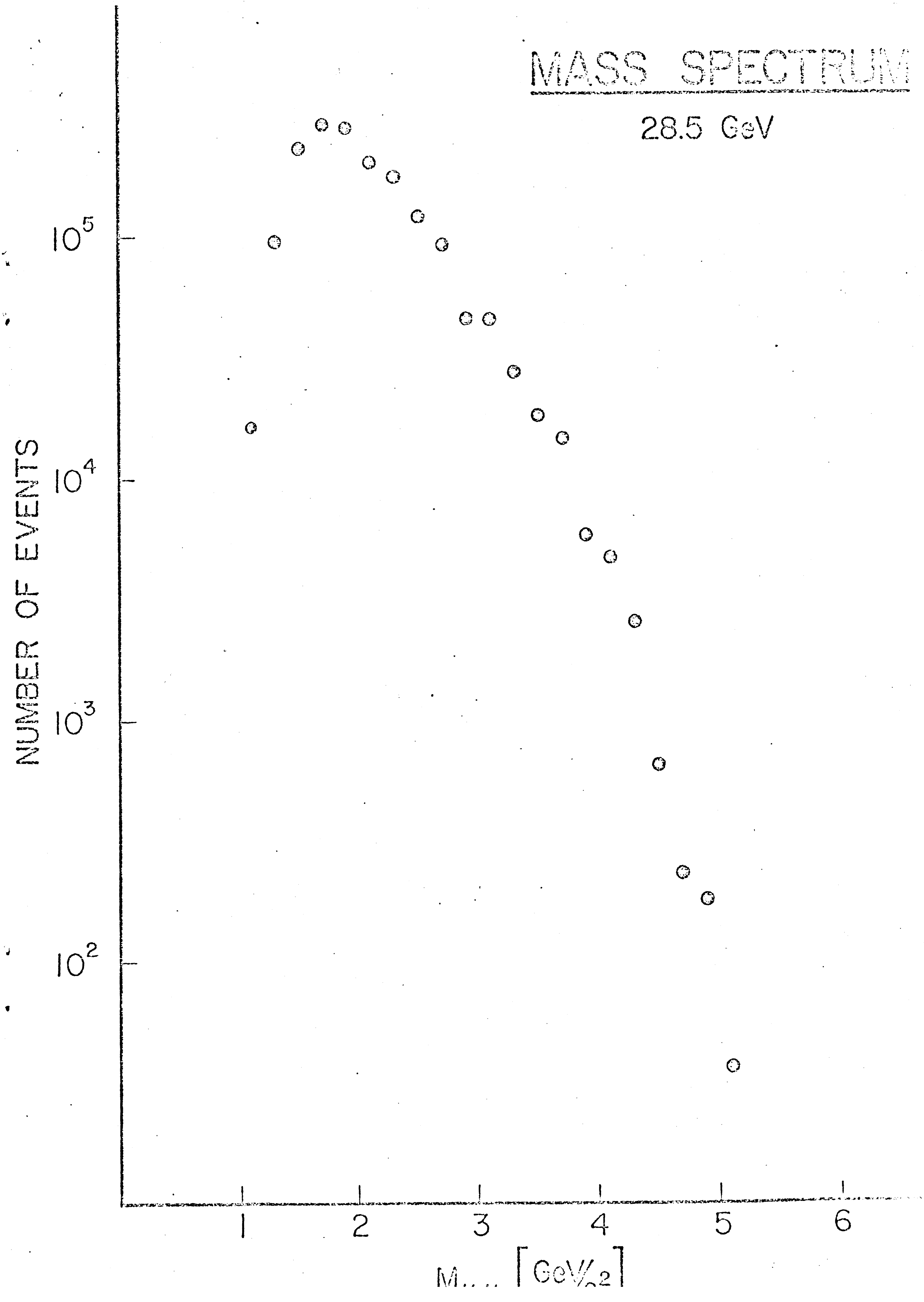
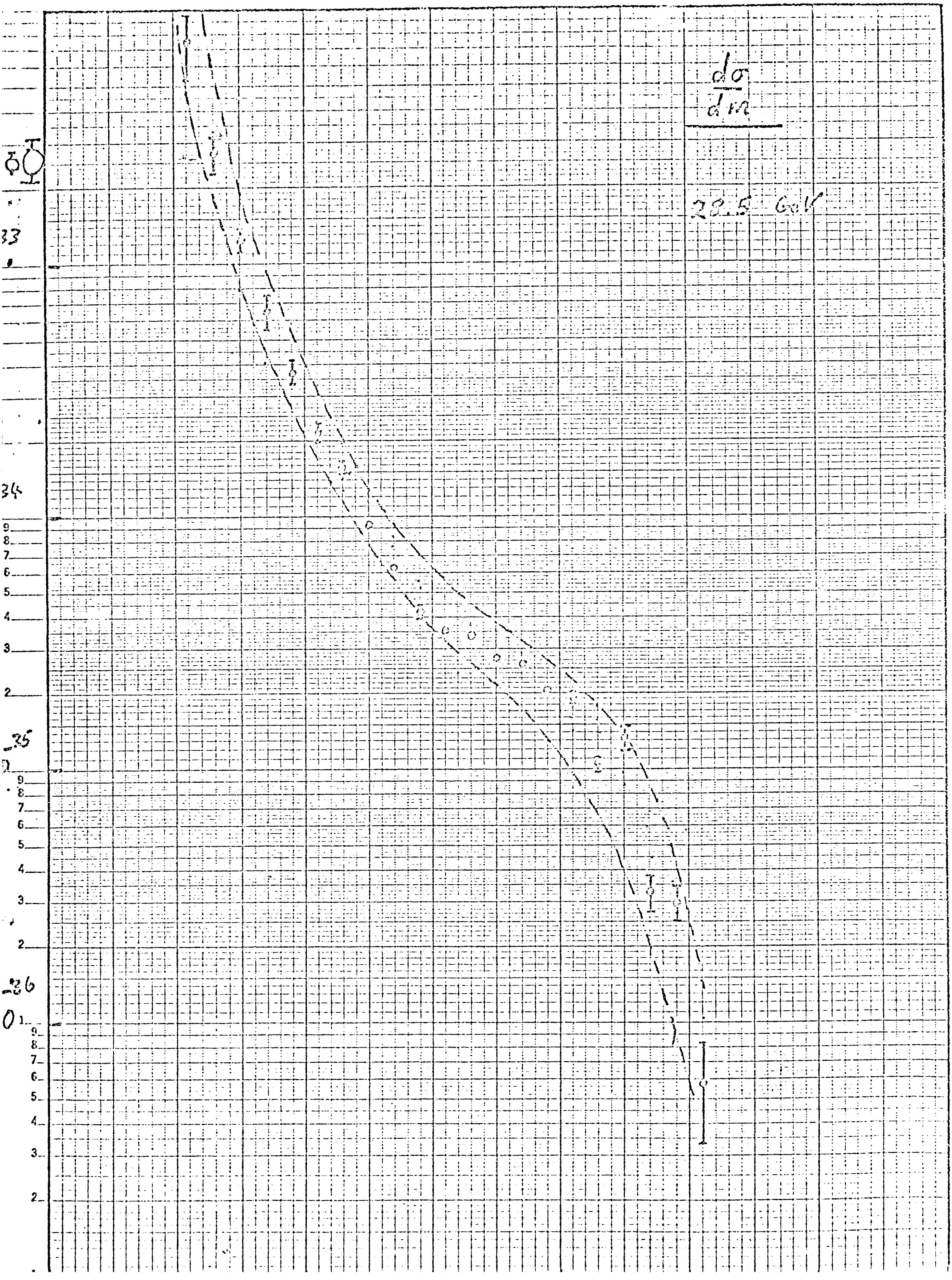
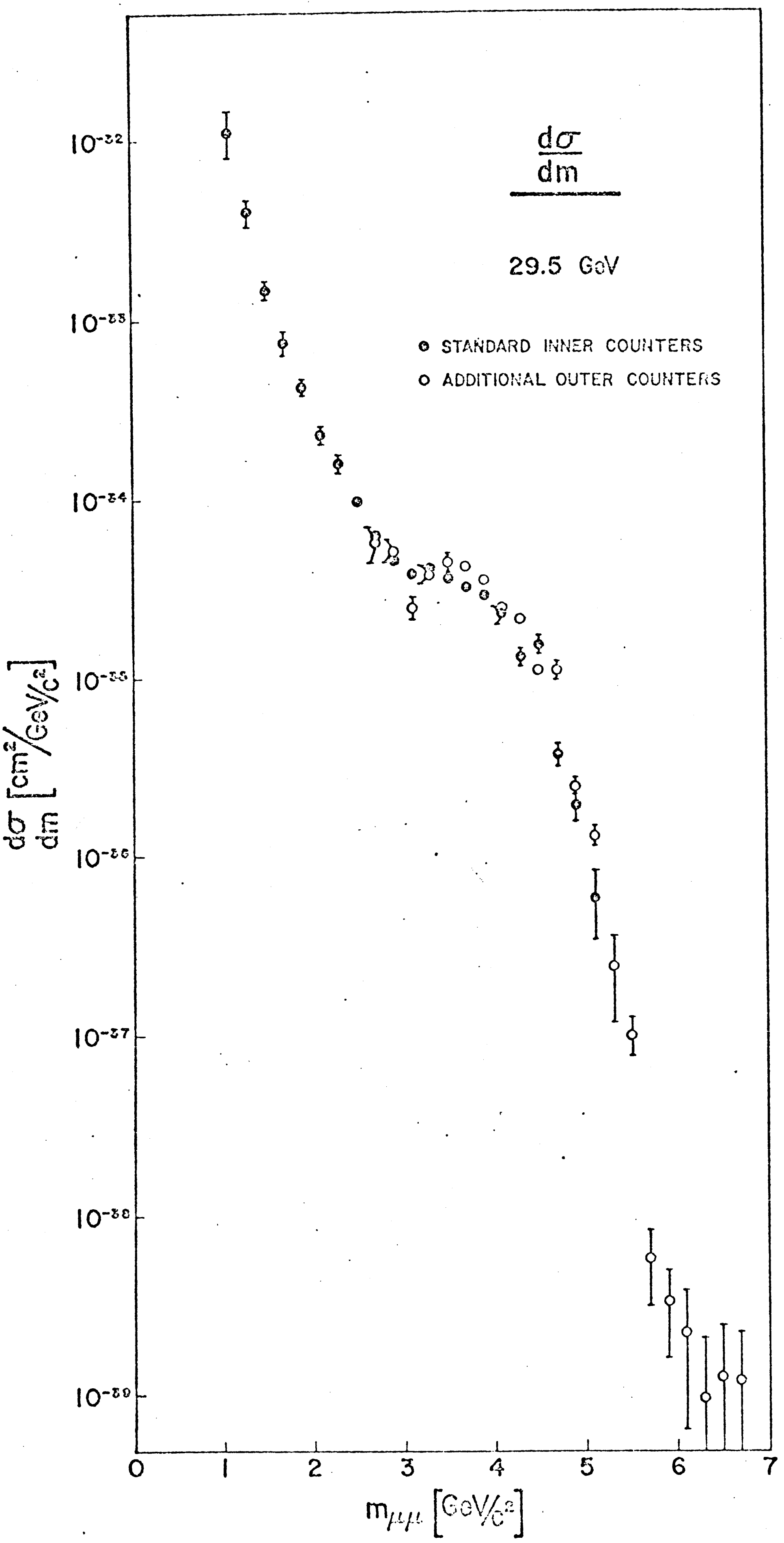
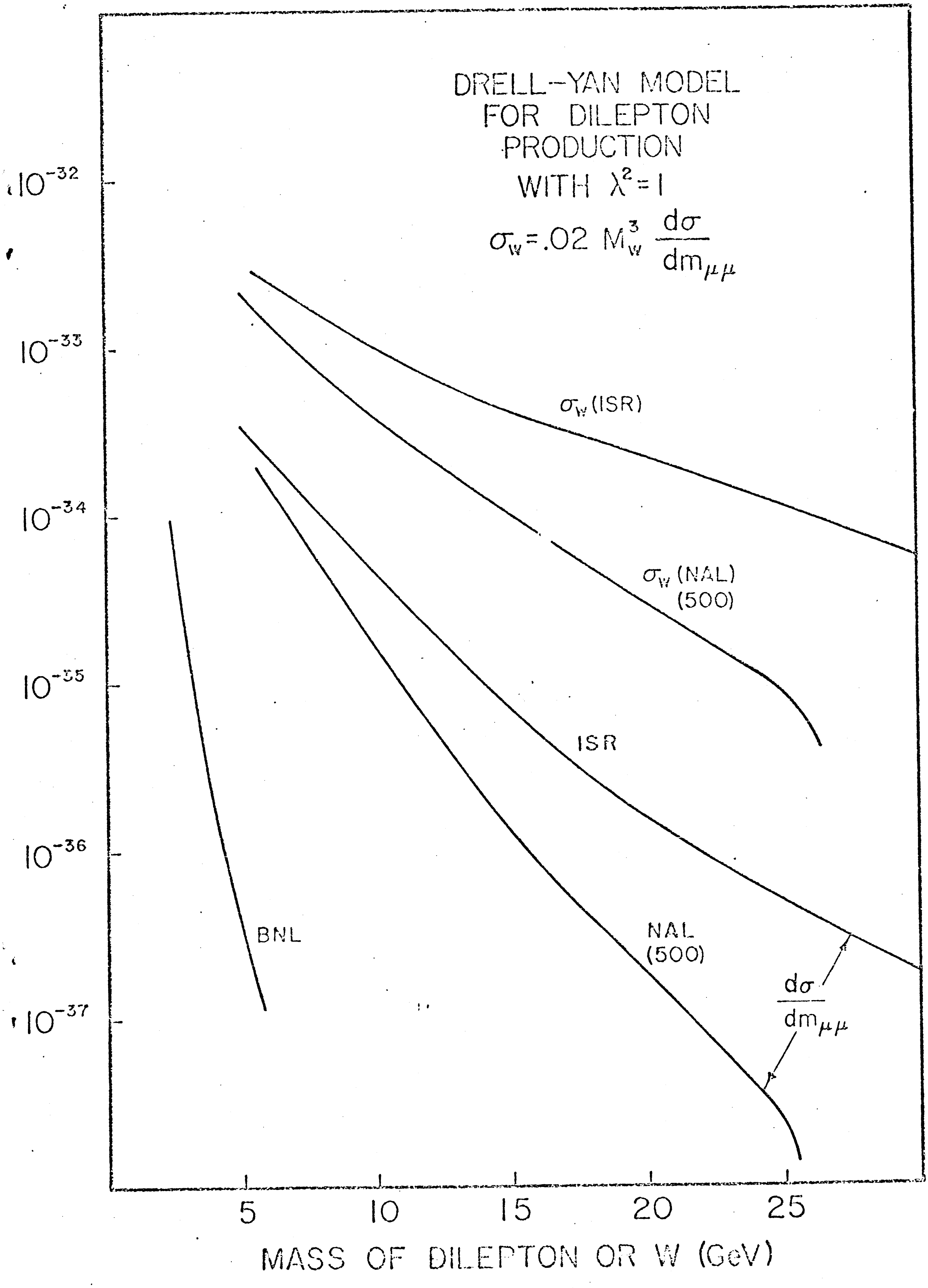

MASS SPECTRUM
28.5 GeV
NUMBER OF EVENTS
10^5
10^4
10^3
10^2
1
2
3
4
5
6

fig.3





dσ/dm
29.5 GeV
STANDARD INNER COUNTERS
ADDITIONAL OUTER COUNTERS
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
10^{-38}
10^{-39}
$\frac{d\sigma}{dm}\left[\mathrm{cm^2/GeV/c^2}\right]$
0 1 2 3 4 5 6 7
$m_{\mu\mu}\left[\mathrm{GeV/c^2}\right]$



DRELL–YAN MODEL
FOR DILEPTON
PRODUCTION
WITH $\lambda^2 = 1$
$\sigma_W = .02\, M_W^3 \frac{d\sigma}{dm_{\mu\mu}}$
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
σ_W (ISR)
σ_W (NAL) (500)
ISR
BNL
NAL (500)
$\frac{d\sigma}{dm_{\mu\mu}}$
5
10
15
20
25
MASS OF DILEPTON OR W (GeV)