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ABSTRACT

We report preliminary results on the production of electron-positron pairs in the mass range 2.5 to 20 GeV in 400 GeV p-Be interactions.

Twenty-seven high mass events are observed in the mass range 5.5-10.0 GeV corresponding to $\sigma = (1.2 \pm .5) \times 10^{-35}$ cm^2 per nucleon. Clustering of 11 of these events between 5.8 and 6.1 GeV suggests that the data contains at least one new resonance at 5.97 GeV.

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This is a first report of a double arm spectrometer study of electron-positron pairs produced in the reaction

$$p + Be \rightarrow e^+e^- + \text{anything} \quad (1)$$

using 400 GeV protons at Fermilab. The experiment is designed to observe e^+e^- pairs at high effective mass as a probe of continuum and resonant structures in the mass range of 2.5 to 20 GeV. Earlier observations of lepton pairs[1,2] at the Brookhaven AGS in the mass interval 1.5-5 GeV demonstrated the existence of a continuum and of one narrow resonance. This experiment is sensitive to masses which approach the kinematic limit at Fermilab. A strong J/ψ(3100) peak and a higher mass signal between ~4.0 and 10.0 GeV is observed. In particular we observe a new narrow ($\leq$ 100 MeV) resonance at 5.97 GeV.**

Measurements of electron-positron pairs with high effective mass are made with the apparatus shown schematically in Fig. 1. The 400 GeV extracted beam of the Fermilab accelerator strikes a 224-micron wide and 10-cm long Be target in the Proton Center Laboratory. Two symmetric spectrometer arms viewing the target at about 90° in the cm system detect electrons by essentially the same techniques used by this group[3] in the observation of direct electron production at high transverse momentum (p_t). One spectrometer arm bends charged particles up (labeled by the letter U) and the other (label D) down. The magnetic spectrometer is composed of scintillation trigger counters, proportional wire chambers and vertical scintillation counter hodoscopes. The angular acceptance of each spectrometer arm is ±3.5 mrad. vertically and extends from 50 to 95 mrad. horizontally. Detection is done downstream of the magnet only and results in a typical momentum resolution of $\Delta p/p = 1.5\%$ (rms).

Electrons deposit virtually all of their energy in the 27 radiation-length deep lead and lead-glass calorimeter while muons and hadrons typically deposit less of their energy in the corresponding 1.5 absorption lengths. After calibration and corrections for particle entry position, the energy resolution of the lead-glass is represented approximately by $\Delta E/E$ (rms) = $(0.6 + 4/\sqrt{E})\%$ for energy E (GeV).[3] Equality of the energy deposited in the lead-glass and the measured particle momentum ($E/P = 1$) indicates the probable passage of an electron through the spectrometer. The additional requirement of a characteristic energy distribution of the electromagnetic shower in the four layers of glass leads to a hadron rejection of better than 4×10^{-4} in each arm independently. The efficiency for electrons remains .80 ± .08 with these electron cuts.

The observed mass spectrum $d\sigma/dm$ for electron-positron pairs is presented in Fig. 2. To obtain cross sections we assumed that the production at all masses is similar to that which we observe for the $\psi(3100)$[4] and specify below in Eq. (2). Cross sections reported here have been corrected for trigger and reconstruction efficiencies which lead to a combined efficiency before electron cuts of .8 ± .1 for electron pair events. Corrections have also been made for target absorption of the proton beam and for events lost due to bremsstrahlung of the electrons (estimated to be 10 ± 5% of the events at 6 GeV) although approximately half of these will appear in the mass spectrum at lower masses.

The $\psi(3100)$ resonance is observed with a width of 40 MeV (rms) which is in good agreement with the calculated resolution of the apparatus. We measure a mass value of 3.096 ± .015 GeV. Further details on the ψ physics will be published separately.[4] We use, however, an inclusive yield:

$$E\frac{d^3\sigma}{dp^3} \propto (1 - |x|)^{4.3} \cdot e^{-1.6p_t} \quad -1 \leq x \leq 1 \tag{2}$$

which characterizes data from this and other experiments on ψ production.[5] This form is used in all subsequent calculations of acceptance although measurements are made only for $|x| \lesssim .1$.

The dashed curve shown in the mass spectrum of Fig. 2 represents our determination of all sources of background. Observed single-arm electron candidates come from three sources: 1) direct electrons 2) misidentified charged hadrons and 3) conversion electrons from π^o or η^o. The background for pair events then arises from accidental coincidences between single arm electron candidates of these three types coming from different interactions or from correlated events giving electron candidates coming from the same interaction.

The accidental background is studied by taking single arm triggers at the same time as the pair data. Off-line pairing of the single arm electron candidates, reconstructed in exactly the same way as pair triggers, determines the <u>shape</u> of the mass distribution for the accidental background. Careful monitoring of the duty cycle using hadron single and uncorrelated, but in-time, pair rates then gives the normalization for these accidental mass distributions. Although during the course of the experiment the average run intensity varied by a factor of 3, investigation finds no sinister correlation between high intensity pulses and the accumulation of high mass events.

The correlated backgrounds are studied by several methods. Backgrounds with a misidentified charged hadron as the electron candidate are studied by looking at the effective mass distribution of events which fail the E/p electron criteria and thus are known to be charged hadrons. Backgrounds with a conversion electron as the electron candidate are studied by inserting thin converters in the secondary beams 6 meters downstream of the target. This results in a four-fold increase in the conversion electron rates in each arm.

The background curve of Fig. 2 is dominated for masses less than 4.0 GeV by accidental coincidences and except for the $\psi(3100)$ accounts for a major fraction of the observed events. However, at masses greater than 4.5 GeV, correlated hadron pairs begin to dominate the background curve. Finally, above 5.5 GeV all sources of background are negligible compared to the observed electron-positron signal consisting of 27 events. Details of these high mass events are given in Table I. It is interesting that twelve of the 27 events cluster at 6 GeV, falling within a mass range roughly consistent with the mass resolution of the apparatus ($\sigma \approx 70$ MeV).[6] Upper limits on $d\sigma/dm$ for masses above 10.0 GeV are indicated in Fig. 2.

The events near 6 GeV (5.97 ± .05 GeV) correspond to a total cross section of $\sigma \cdot B = (5.2 \pm 2.0) \times 10^{-36}$ cm^2 per nucleon under the assumptions of Eq. (2) and of a linear A-dependence.[7] The residual data are consistent with either a continuum, a series of broad resonances,[8] or additional narrow resonances, especially at ~7 and ~10 GeV. The background subtracted data including all events between 5 and 10 GeV, when binned in coarse intervals, (0.5 GeV) can be described by a distribution:

$$\frac{d\sigma}{dm} \approx \frac{4 \times 10^{-32}}{m^5} \text{ cm}^2/\text{GeV/nucleon} \qquad (3)$$

This mass dependence is not very well determined. The total cross section above 5.5 GeV is $(1.20 \pm .40) \times 10^{-35}$ cm^2 per nucleon. This cross section is approximately a factor of 5 lower than the predictions of recent versions of parton annihilation models[9] (without color) but tends toward the model at higher mass.

Throwing events according to smooth distributions like that in Eq. (3) leads to an estimate of the purely statistical probability of clustering such as is observed here of less than 2%. We note that the acceptance is smooth over the relevant mass range and that the data are free of background. The 6 GeV data are observed in three different current settings of the spectrometer. These factors strengthen the case for the existence of a narrow resonance at 5.97 GeV. There is weaker evidence of clustering near 7 GeV (5 events). Two isolated events at 10 GeV are also noted. The data, at a level of 5×10^{-4} of $\psi(3100)$ comes in at a long term average rate of .5 events per "ideal" day with 5×10^{9} interactions per pulse.

In summary we have established a signal of massive dileptons above 5 GeV. There is less than one chance in fifty that a continuum, smooth in mass, can give rise to the observed cluster. Subject to this caveat, there is a resonance at 5.97 GeV which uses up half the observed cross section. The remaining data contains some suggestive clusterings.

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REFERENCES

**We suggest that a provisional designation of this object be Υ (UPSILON): Υ(6.0) from Ὕψηλόν, "the lofty one".

[1]J. H. Christenson, et al., Phys. Rev. D8, 2016 (1973).

[2]J. J. Aubert, et al., Phys. Rev. Lett. 33, 1404 (1974).

[3]J. A. Appel, et al., Phys. Rev. Lett. 33, 722 (1974).
J. A. Appel, et al., Nucl. Instr. and Meth. 127, 495 (1975).

[4]Snyder et al., to be published.

[5]B. Knapp, et al., Phys. Rev. Lett. 34, 1044 (1975).
Y. M. Antipov, et al., IHEP 75-125, Serpukhov (1975).
F. W. Büsser, et al., Physics Letters 56B, 482 (1975).
K. J. Anderson, et al., submitted to Phys. Rev. Lett. (1975).

[6]The observed width becomes very comparable with our understanding of the apparatus if we attribute the event at 6.197 GeV to "continuum" and define Υ(6.0) as 11 events in 3 bins.

[7]We are aware of one previous indication of a structure at 6 GeV in a dimuon survey: D. Eartly, G. Giacomelli, and K. Pretzl, Fermilab Reports FN-275 (May 1975).

[8]A two-parent origin, such as $p + Be \to X^+X^- +$ anything; $X^\pm \to e^\pm \nu(\bar{\nu})$ might also give rise to such a slowly varying continuum of high mass events with $m_X \approx 6$. If so, the actual cross section $d\sigma/dm$ for these events would be approximately an order of magnitude larger than reported here because of the reduced correlation between the e^+ and e^- in a model of this type.

[9]S. D. Drell, T. M. Yan, Phys. Rev. Lett. 25, 316 (1970),
S. Pakvasa, D. Parashar and S. F. Tuan, Phys. Rev. Lett. 33, 112 (1974).

Table 1. Details of the High Mass Events ($m \geq 5.5$ GeV).

M GeV	ΔM(RMS) GeV	P_t GeV/c	x
5.59	±0.09	1.51	-0.008
5.64	0.09	0.40	0.097
5.81	0.07	0.31	0.012
5.84	0.09	0.08	0.059
5.89	0.09	0.01	0.081
5.94	0.07	2.15	-0.026
5.94	0.08	0.89	-0.020
5.97	0.07	1.86	0.036
5.99	0.15	2.15	-0.064
6.04	0.07	0.19	-0.082
6.04	0.07	2.85	-0.055
6.06	0.06	0.51	-0.060
6.09	0.08	1.05	0.056
6.20	0.07	0.70	0.006
6.33	0.08	1.06	0.087
6.72	0.16	0.25	-0.088
6.85	0.14	0.24	0.110
7.17	0.10	0.44	0.065
7.17	0.09	0.60	-0.010
7.19	0.10	0.32	0.050
7.20	0.11	1.71	0.060
7.32	0.10	0.18	-0.033
7.56	0.10	1.60	-0.085
8.07	0.12	1.83	-0.095
8.21	0.12	0.29	-0.001
9.62	0.35	0.39	0.068
9.99	0.19	0.66	0.078

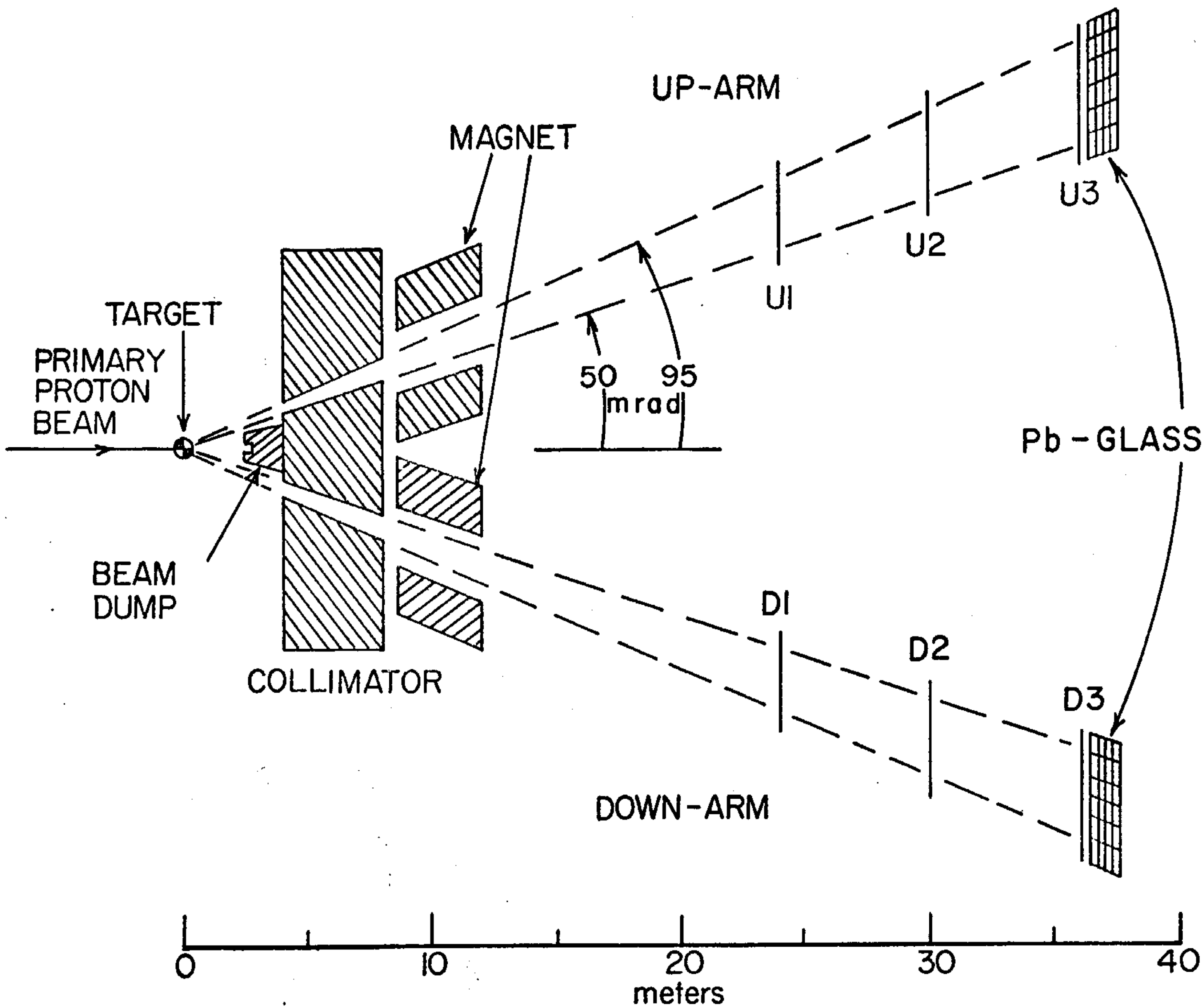

Fig. 1: Schematic Diagram of the Apparatus: U1 -3 and D1 -3 are sets of scintillation

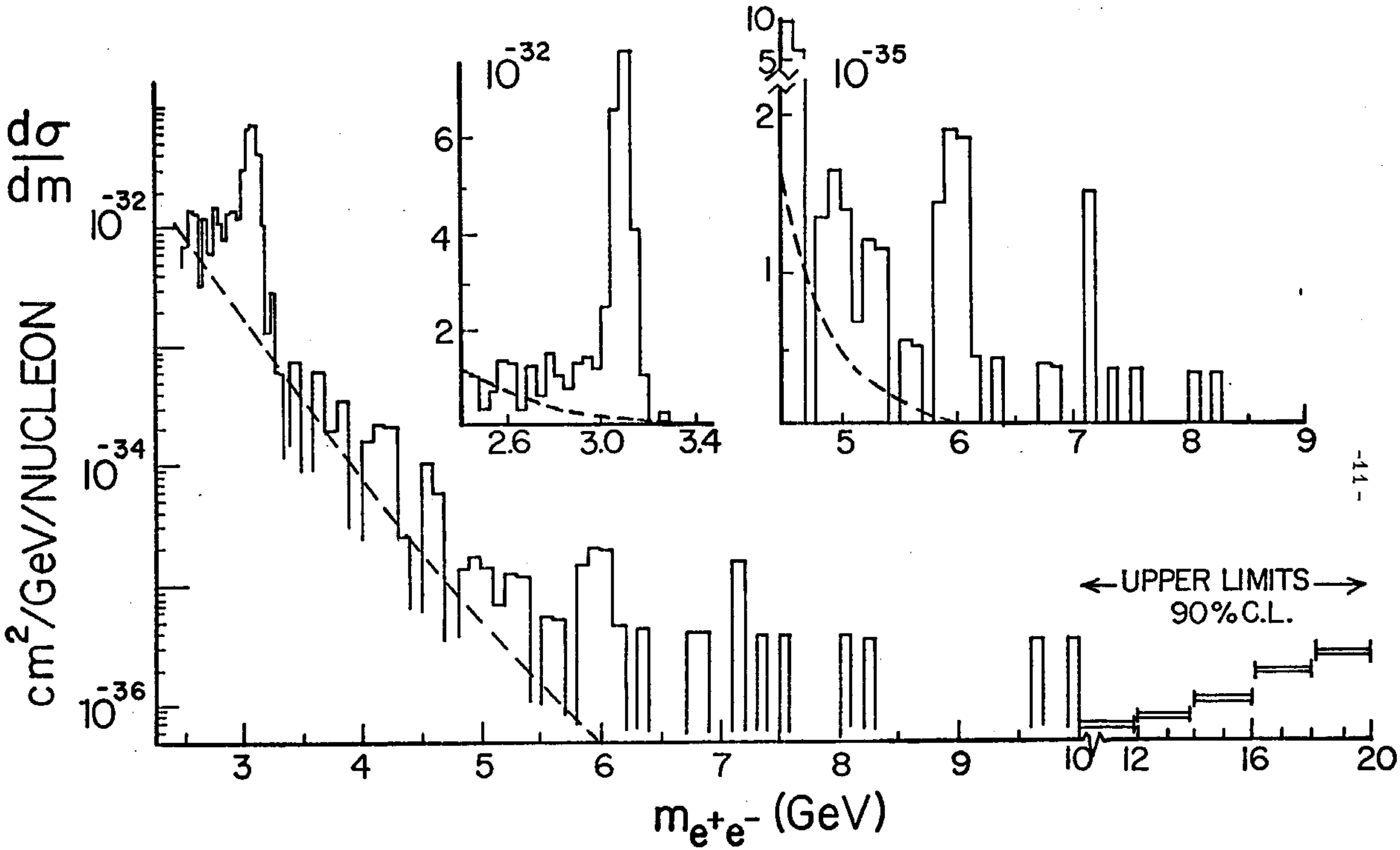

Fig. 2: Electron-Positron Mass Spectrum: dσ/dm per nucleon versus the effective mass. A linear A-dependence is assumed. Note bin width changes.