

## Measurement of the Threshold Behaviour of

 $\tau^+ \tau^-$  Production in  $e^+ e^-$  Annihilation\*

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## ABSTRACT

We have observed 692 events of the type  $e^+ e^- \rightarrow e^\pm X^\mp$  ( $X \neq e$ ) in the center of mass energy range  $3.1 < E_{CM} < 7.4$  GeV. The observation of events below  $D^0 \bar{D}^0$  threshold clearly precludes their association with charm. The data are well fitted by a pointlike spin 1/2  $\tau$  lepton with mass  $(1782_{-7}^{+2})$  MeV, electronic branching ratio  $(0.160 \pm 0.013)$ , and branching ratio to  $\geq 3$  prongs  $(0.32 \pm 0.05)$ .

Submitted to Phys. Rev. Letters

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\* Work supported in part by the U.S. National Science Foundation and the Department of Energy.

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Since the original observation by Perl et al.,<sup>1)</sup> of anomalous  $e\mu$  events in  $e^+e^-$  annihilation, evidence<sup>2)</sup> has accumulated that they result from the production and decay of a pair of heavy leptons,  $\tau^+\tau^-$ . Since  $\tau$  decays yield mainly one charged particle,<sup>3)</sup> the primary evidence comes from the  $e\mu$  final state and the inclusive 'anomalous' two prong lepton events,  $e(\mu) X$ ,  $X \neq e(\mu)$ . The proximity of the thresholds for these events and for charmed particle production makes it imperative to exclude the charm interpretation of their origin. A keystone of the argument against charm has been the observation<sup>2),4)</sup> of a cross section consistent with point-like production. We present in this paper a detailed cross section measurement, emphasizing the threshold region, based on a large sample of  $eX$  events with low background and a broad electron momentum acceptance ( $P_e > 0.2$  GeV/c).

The data were obtained at SPEAR using the DELCO detector. The apparatus, described previously<sup>5)</sup>, consists of a set of cylindrical multi-wire proportional chambers (MWPC) and a threshold Cerenkov counter, sensitive only to electrons, followed by spark chambers and shower counters. The latter consist of 3 layers of Pb (6r1 total) and 3 layers of scintillator viewed by individual phototubes. These components subtend 60% of the full solid angle. Charged particles are tagged over 95% of the solid angle by means of the MWPC and pie-shaped (P) counters covering the region between  $15^\circ$  and  $35^\circ$  relative to the beam axis. A magnet provides 3.5 kG over the MWPC volume and allows a momentum measurement accuracy  $\Delta P/P = 8 P$  (GeV)%.

The accepted eX events were required to have two and only two tracks of opposite charge, both with an associated shower counter pulse exceeding 0.3 minimum ionizing particles (mips) and deviating from collinearity by at least  $20^\circ$  when viewed along the beam axis. In addition one particle had to be identified as an electron by an in-time Cerenkov pulse in the appropriate cell and the other as not an electron by the absence of such a pulse. The efficiency of the Cerenkov counter as a function of electron momentum reaches its asymptotic value of about 94% at 300 MeV/c and drops to zero at about 100 MeV/c. We therefore allowed a minimum momentum of 0.2 GeV/c for the electron and of 0.3 GeV/c for the X particle. Finally, events were rejected if they had an in-time P counter tag.

The presence of a photon was indicated by a pulse in a shower counter unassociated with any charged track, whose total pulse height exceeded 3 mips. We rejected events consistent with the process  $e^+e^- \rightarrow e^+e^-\gamma$  (presumably remaining in the sample due to a missed Cerenkov tag). The number of events satisfying these requirements is 840 of which 535 have no photons.

We will now consider the residual backgrounds, firstly due to particle misidentification. Since the tracks are identified solely by the Cerenkov counter, the observed shower counter pulse heights (Fig. 1) provide an independent determination of the particle nature. The electron pulse height distribution shows no evidence of any non-showering particles but the enhanced tail on the X distribution betrays a 10%

contribution from misidentified electrons. Accordingly a requirement of less than 3.3 mips is made on the X particle. This results in a loss of 12% of real events and a final data sample of 692 events of which 459 have no photons. From Fig. 1 we estimate the background from particle misidentification to be less than 28 events. This estimate has been confirmed by selecting either  $e^+e^-$  or  $X^+X^-$  events which satisfy all the other cuts except for the pulse height cut.

The feed down from the two photon interaction,  $e^+e^- \rightarrow e^+e^- \mu^+\mu^-$  has been measured as  $< 2 \pm 0.5\%$  by counting the events with same-sign tracks in agreement with an independent calculation.<sup>6)</sup> An upper limit both on this background and on that due to particle misidentification has been obtained from data at  $E_{CM} = 3.10(\psi)$ , 3.50 and 3.52 GeV.

The production cross-section ratios,  $R_{eX}^{2P} \left[ \frac{\sigma(e^+e^- \rightarrow eX)}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)} \right]$ , for eX events with no detected photons are shown in Fig. 2a) and for all eX events in Fig. 2b). The normalization is made to wide-angle Bhabha pairs ( $e^+e^-$ ) except at the  $\psi$  and  $\psi'$  where we use  $\mu^+\mu^-$  pairs (in order to account for the vacuum polarization enhancement of the single photon propagator). The data were corrected for the detection efficiency which varies by less than 2% up to  $E_{CM} = 4.5$  GeV.

We now discuss a third potential background, charmed particle decays. We first demonstrate that the eX events are indeed observed below charm threshold ( $3726. \pm 1.8$  MeV). A comparison of the 70 events observed in the range  $3.57 \leq E_{CM} \leq 3.72$  GeV<sup>7)</sup> with those at higher energies in terms of rate, angular and momentum distributions and associated photons shows both sets of data to be consistent with the hypothesis of a common origin. For example the fraction of low energy events

containing photons is  $(34 \pm 7)\%$  as compared with  $(34 \pm 2)\%$  for all eX events (and  $(90 \pm 1)\%$  for XX events at the  $\psi'$ ). From the pulse height information (shown by the dashed lines in Fig. 1), we determine that the final sample of 70 events contains less than 5 misidentified events. We conclude that the anomalous two-prong electron events occur below charm threshold.

In addition, above charm threshold, we have observed multiprong electron events ( $e^\pm + \geq 2$  charged particles, denoted  $MP_e$ ) which are dominated by charmed particle decays.<sup>5)</sup> If eX events also come from decays of charmed particles then the  $MP_e$  and eX cross-section should have the same energy dependence. However, we find<sup>5)8)</sup> sharp dips in the  $MP_e$  cross sections at  $E_{CM} = 3.85$  and  $4.25$  GeV in clear disagreement with the eX data. Finally we expect the largest charmed contribution at the  $\psi''(3770)$  and the data (Figs 2 and 3) show this to be small.

The data of Fig. 2 are well fitted by the theoretical cross section for pair production of a spin 1/2  $\tau$  lepton and give a value for the  $\tau$  mass of  $(1782_{-7}^{+2})$  MeV. The abrupt threshold observed between  $E_{CM} = 3.52$  and  $3.57$  GeV (Fig. 3) argues against the assignment of integer spin for the  $\tau$  which would result in a much more gradual threshold dependence.<sup>9)</sup>

The decay branching ratios are determined as follows. The fit in Fig. 2b) determines  $2 b_e (1 - b_e - b_{MP}) = 0.168 \pm 0.008$ , where  $b_e$  is the branching ratio for  $\tau \rightarrow \nu_\tau e \nu_e$  and  $b_{MP}$  is the branching ratio for  $\tau \rightarrow \nu_\tau + \geq 3$  charged particles. The fit in Fig. 2a) yields  $2 b_e b_{X,0\gamma} = 0.105 \pm 0.007$ , where  $b_{X,0\gamma}$  is the branching ratio for  $\tau \rightarrow \nu_\tau + 1$  charged particle ( $\neq e$ ) + no detected photons. Theoretically, the value of  $b_{X,0\gamma}$  is expected to be dominated by three decay modes ( $\mu^- \nu \nu$ ,  $\pi^- \nu$  and  $\pi^- \pi^0 \nu$ ) and

have the approximate value  $(0.98 + 0.54 + 0.36 \times 1.09) b_e = 1.9 b_e$ .<sup>3)</sup>  
 The factor 0.36 indicates the probability that both photons in the  $\pi^0$   
 decay escape detection. A detailed determination of the ratio  $b_{X,0\gamma}/b_e$ , based  
 on the relative  $\tau$  decay rates of Ref.3, combined with the data of Fig.2a yields  
 $b_e = 0.160 \pm 0.013$ .<sup>10)</sup> Applying this value to the result of the fit to  
 Fig. 2b) gives  $b_{MP} = 0.32 \pm 0.05$ . The values for  $b_e$  and  $b_{MP}$  are in agree-  
 ment with earlier measurements.<sup>2)4)</sup>

In conclusion, we have observed a distinct threshold at  $E_{CM} =$   
 $3564_{-14}^{+4}$  MeV for production of events containing one electron and one  
 oppositely charged particle of a different type. The events are unam-  
 biguously dissociated from charmed hadrons since they are observed below  
 charm threshold and show different cross sectional behaviour above charm  
 threshold. The energy dependence near threshold and the absolute magni-  
 tude of the cross section for these events are consistent with a spin 1/2  
 heavy lepton. These data, combined with previous measurements in  $e^+e^-$   
 annihilation, provide overwhelming positive evidence for the existence  
 of the third charged lepton,  $\tau$ .

Acknowledgements. We thank F. Gilman and Y. Tsai for helpful discussions  
 and M. Schwartz for his stimulating support. In addition we acknowledge  
 the invaluable services of the Experimental Facilities Division, SPEAR  
 Operation Group and SLAC Computing Center.

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- 10) If the  $\pi\nu$  decay mode of the  $\tau$  is absent then we measure  
 $b_e = 0.187 \pm 0.015$ .

Figure Captions

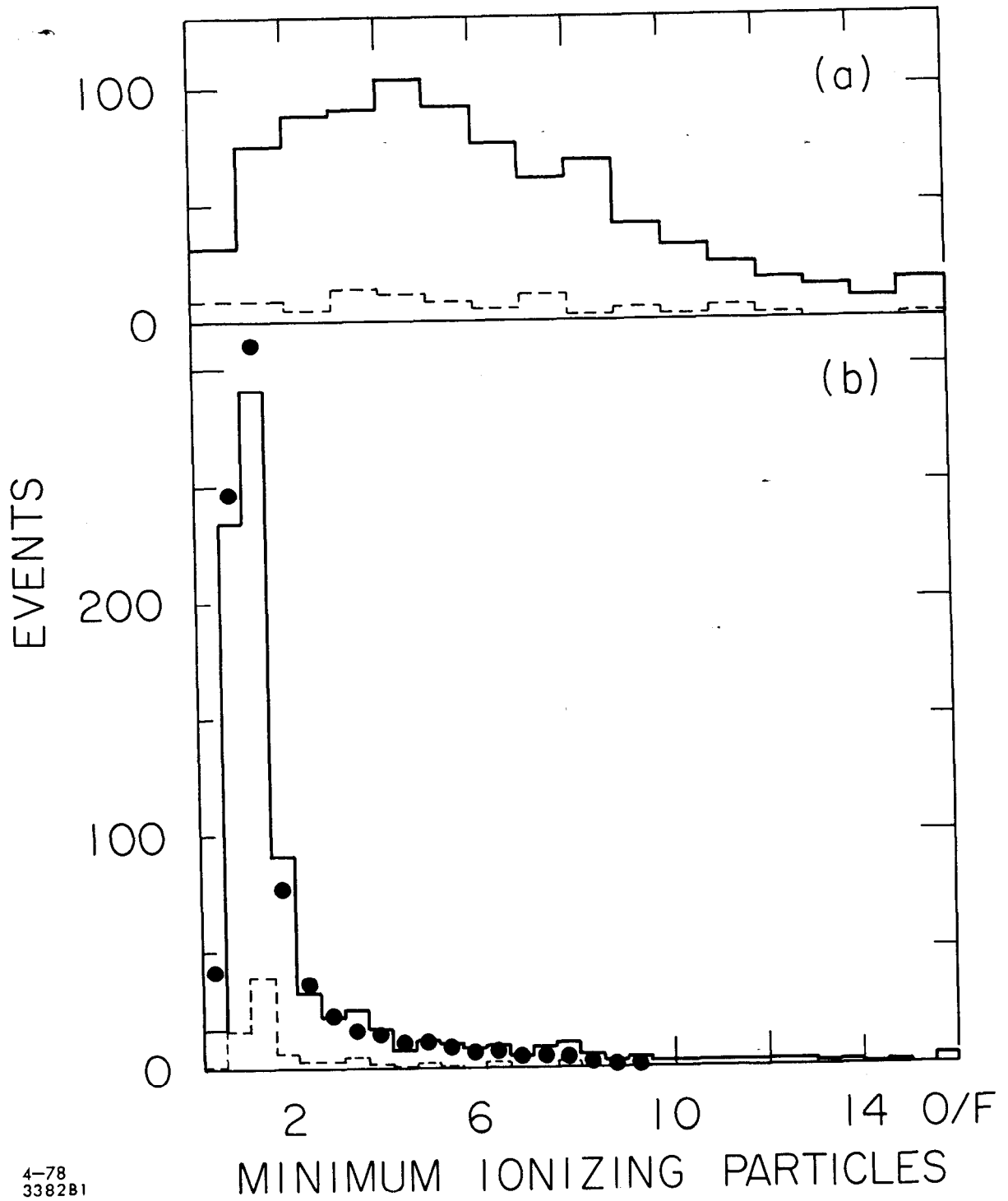
- Fig. 1 a) Shower counter pulse height distribution for electrons in the eX events.
- b) Pulse height distribution for the X particle. The dots indicate the pulse heights expected from a sample of 33%  $\mu$ 's and 66%  $\pi$ 's.

The dashed histograms were obtained at center of mass energies below charm threshold.

- Fig. 2 a) The production cross section ratio,  $R_{eX}^{2P}$ , for eX events with no detected photons. The fit ( $\chi^2/\text{dof} = 17.3/15$ ) indicates the cross section expected from a spin 1/2  $\tau$  lepton.
- b)  $R_{eX}^{2P}$  for all eX events ( $\chi^2/\text{dof} = 17.1/15$ ). Both fits have excluded the  $\psi''$  point ( $3.75 < E_{\text{CM}} < 3.80$  GeV) because of possible charm contamination.

- Fig. 3  $R_{eX}^{2P}$  for all eX events with  $3.50 \leq E_{\text{CM}} \leq 4.40$ . The three fitted curves indicate the threshold behaviour for different  $\tau$  spins.





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Fig. 1

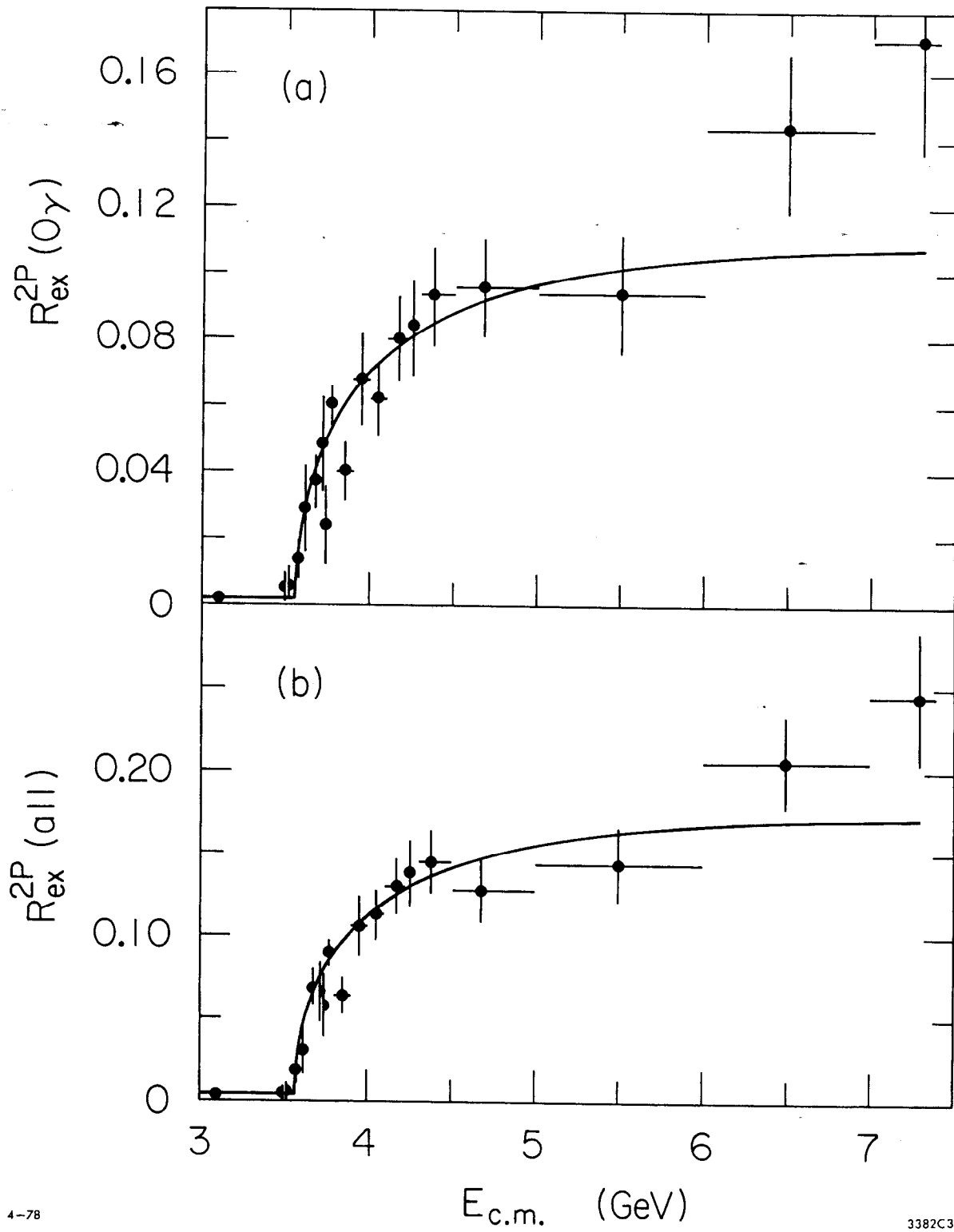


Fig. 2

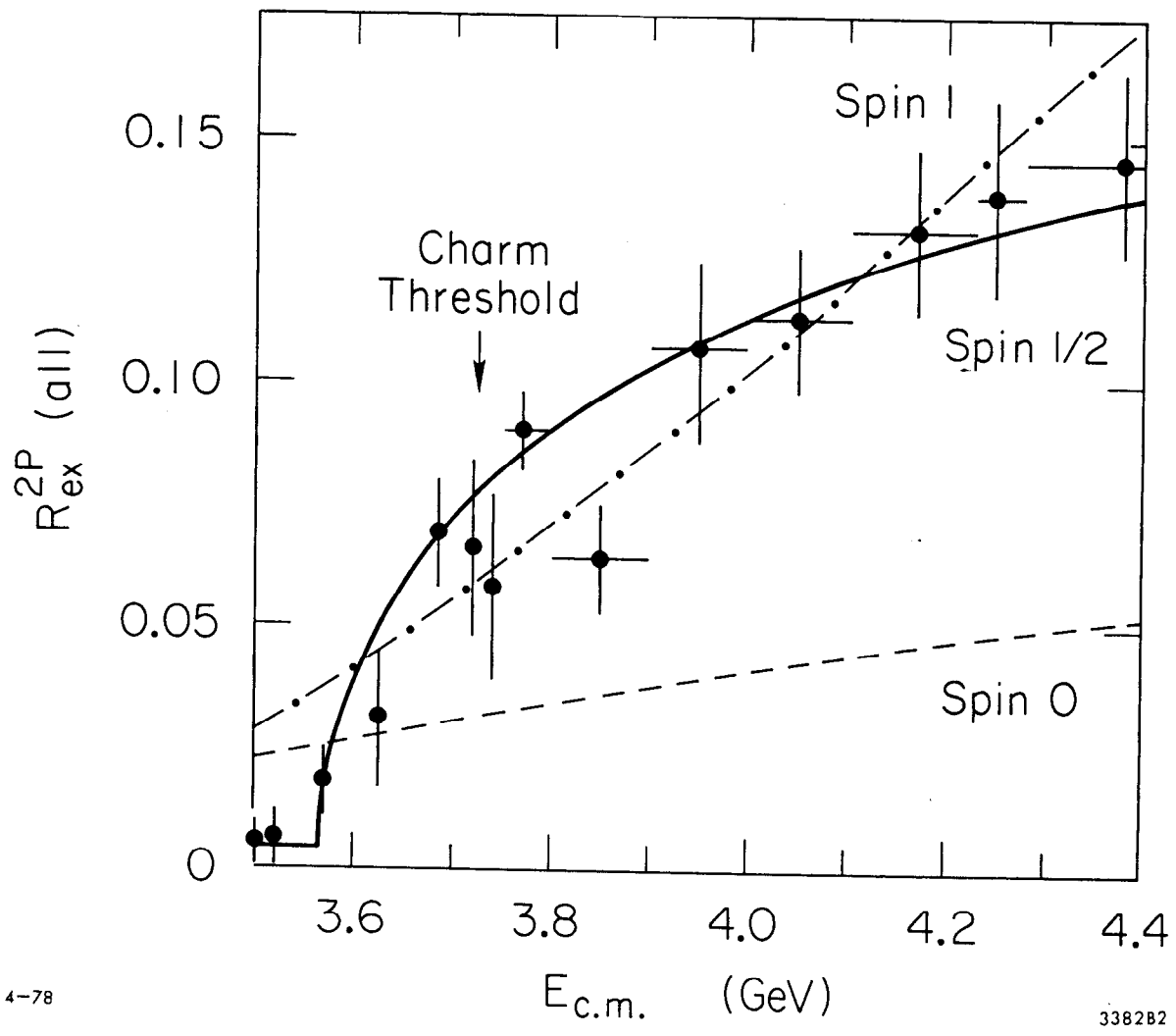


Fig. 3