EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/79-112
3 October 1979
(10 October 1979)

A MEASUREMENT OF THE PRODUCTION OF MASSIVE e^+e^- PAIRS IN PROTON-PROTON COLLISIONS AT $\sqrt{s}$ = 62.4 GeV

CERN-Columbia-Oxford-Rockefeller (CCOR) Collaboration

ERRATUM

Line 21 of page 3 should read:

... from the relation $B\sigma(\Upsilon)/B\sigma(J/\psi) = (m_{J/\psi}/m_{\Upsilon})^3 \times \Gamma(\Upsilon \to e^+e^-)/\Gamma(J/\psi \to e^+e^-)$ at fixed $m/\sqrt{s}$. The ...

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(To appear in Physics Letters)

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ABSTRACT

An apparatus consisting of a superconducting solenoid magnet, cylindrical drift-chambers, and two arrays of lead-glass Čerenkov counters has been used at the CERN ISR to study the production of e^+e^- pairs of invariant mass above 6.5 GeV/c^2. Cross-sections for the continuum and the Υ family of resonances are presented, as well as the mean transverse momentum $\langle p_T \rangle$ of the electron-positron pairs in the continuum and resonance region.

The production of massive electron-positron pairs in proton-proton collisions has been measured at a centre-of-mass energy ($\sqrt{s}$) of 62.4 GeV at the CERN ISR as part of a general study of high transverse momentum processes[1,2]. In this letter, after a description of the apparatus and event selection procedure, three topics are discussed: the e^+e^- continuum for $m_{e^+e^-} > 6.5$ GeV/c^2 [3], the cross-section for the Υ family of resonances[4], and the mean transverse momentum $\langle p_T \rangle$ of the lepton pair for both the continuum and the resonances. The data presented here come from an integrated luminosity of 8.5×10^{37} cm^{-2}.

The experimental apparatus (Fig. 1) can be considered in two parts. The inner detector, designed to track charged particles, consisted of a set of four double-gap cylindrical drift-chambers inside a thin-walled superconducting solenoid magnet[5,6] (B = 1.4 tesla). The outer detector, used to identify electrons and photons and measure their energies, consisted of two large arrays of lead-glass Čerenkov counters[1], one on either side of the intersection region. The pulse-heights recorded in the scintillation counters "B" on the outer face of the magnet were used to correct, event by event, for the apparent energy loss of electrons passing through the magnet coil and cryostat (1 radiation length of aluminium). This correction was typically 260 MeV *). The r.m.s. momentum resolution of the tracking system was $\Delta p/p = 6\%\ p$ (p in GeV/c). The mass of the electron pair was calculated using the energies as measured in the lead-glass counters, with an r.m.s. mass resolution of 4% at 10 GeV/c^2. The geometric acceptance covered the range $-0.5 < y < 0.5$ and was 9% for this interval assuming a cross-section flat in y, the rapidity of the lepton pair. The acceptance did not depend significantly on the decay angular distribution.

The trigger required that more than 2 GeV be deposited in a cluster of 3 × 3 counters in each lead-glass array, and was dominated by π^0 pairs. Off-line, tracks in the inner detector and the clusters in the lead-glass arrays were reconstructed independently, and only events with tracks pointing to clusters in both arrays were retained. The genuine electron pairs formed less than 6% of this sample, which

*) The relation between the apparent energy loss in the coil and cryostat and the B counter pulse-height was determined empirically in tests with an electron beam at the CERN Proton Synchrotron (PS).

consisted of backgrounds in roughly equal amounts from three sources: a) the spatial overlap of a charged hadron with a π^0; b) electrons and positrons from Dalitz decays of π^0's and external conversions in the beam pipe and the first layer of the innermost drift chamber; and c) charged hadrons which deposited most of their energy in the lead-glass arrays after interacting in the magnet coil or the lead glass itself. To reduce these backgrounds, some further cuts were made, of which the most important were as follows. The momentum of each track was required to match the energy of its corresponding cluster within the measurement uncertainties. This reduced the background from spatial overlaps and conversions, while leaving background (c) largely unaffected. To reduce this background, the energy within each cluster was required to be concentrated in a cone around the track direction*). In addition, particles whose trajectories crossed more than one lead-glass counter were required to have deposited more than 300 MeV in the first counter. The analysis and reconstruction efficiencies are given in Table 1.

Of the remaining 226 events, there were 174 where the two particles were of opposite charge, and 52 where they were of the same charge. It is assumed that the contribution of background processes to the opposite-charge class is given by the number of events in the same-charge class. This is clearly true for electromagnetic backgrounds (photon conversions) which are charge symmetric. For the hadronic backgrounds, which are not charge-symmetric, this assumption depends on the absence of opposite-side charge correlations and is shown to be valid by the data of Albrow et al.[7]. Since the apparatus acceptance for positive and negative particles was the same, a direct subtraction was performed to obtain the electron-positron signal (Fig. 2).

The cross-section $d^2\sigma/dmdy)_{y=0}$ for $m > 6.5$ GeV/c^2 is given in Fig. 3. The peak in the mass region 8.5 – 11 GeV/c^2 corresponds to the Υ resonances[8,9], and there is a continuum region below 8.5 GeV/c^2 and above 11 GeV/c^2; the line is a

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*) This cut was developed in tests using electron and pion beams at the CERN PS and insisted that 98% of the total cluster energy be contained in the counters included in a truncated cone constructed around the track, with a radius of 3 cm where the track entered the lead-glass array and a radius of 10 cm at the back of the array.

fit excluding the Υ region. In addition to the statistical errors shown, uncertainties in the luminosity measurement, analysis efficiency, and acceptance give an over-all normalization uncertainty of ±12%, and there is an uncertainty of 5% in the mass scale. The scaling hypothesis[10] predicts that the quantity $m^3(d^2\sigma/dmdy)_{y=0}$ or equivalently $s^{3/2}(d^2\sigma/dmdy)_{y=0}$ should be a function of $(m/\sqrt{s})$ only. To test this we compare our data with results from Fermilab[8]. Figure 4 shows that the values for the scaled cross-sections from the two experiments are quite consistent with this prediction. Note that the fit given in Ref. 8 implies that the cross-section at $\sqrt{s}$ = 62.4 should exceed that at $\sqrt{s}$ = 27.4 by a factor of 4 at a mass of 7 GeV/c^2 and a factor of 200 at 14 GeV/c^2.

The excess of 40 events above the continuum fit in the mass range 8.5–11 GeV/c^2 is due to the Υ family of resonances and corresponds to a cross-section $B(d\sigma/dy)_{y=0}$ = $= 9 \pm 2\ (\pm 1) \times 10^{-36}$ cm^2 for the Υ, Υ′, and Υ″; the error includes the uncertainty from the continuum subtraction. This value is in good agreement with the values reported by two other ISR experiments[11]. Our cross-section for the Υ family is 25 times the cross-section at $\sqrt{s}$ = 27.4, and it is interesting to note that the behaviour of the cross-section for Υ production is similar to that of the J/ψ as a function of $(m/\sqrt{s})$ with a relative magnitude of 2.0×10^{-3} (Fig. 5). While the similarity in shape of the excitation curves for the Υ and J/ψ has been expected[12], the absolute value of the Υ cross-section is a factor of 5 lower than would be predicted from the relation $\sigma(\Upsilon)/\sigma(J/\psi) = (m_{J/\psi}/m_\Upsilon)^3 \times \Gamma(\Upsilon \to e^+e^-)/\Gamma(J/\psi \to e^+e^-)$. The ratio of the resonances cross-section $B(d\sigma/dy)_{y=0}$ to the continuum $(d^2\sigma/dmdy)_{y=0}$ at 9.5 GeV/c^2 is 3 ± 0.7 GeV/c^2 in the present experiment, compared to the value 1.66 ± 0.06 measured at $\sqrt{s}$ = 27.4 [9]. No event is observed in the present experiment with mass > 16 GeV/c^2, which implies a 95% confidence level upper limit on $B(d\sigma/dy)_{y=0}$ for any heavier resonances of 7.5×10^{-37} cm^2.

The mean transverse momentum of the lepton pair for the mass ranges 6.5–8.5 GeV/c^2, 8.5–11 GeV/c^2, and above 11 GeV/c^2 is shown in Fig. 6. Except for the first point, which is affected by the energy threshold in the trigger and where the error has been increased accordingly, the mean p_T is essentially independent of the form taken for the p_T distribution, and is also independent of the decay angular distribution of the leptons. (The effect of the background subtraction is included in the errors shown.) The trend for $\langle p_T \rangle$ to increase with $\sqrt{s}$ at a fixed mass, as observed at Fermilab[8], is clearly continued to the ISR energy range.

Acknowledgements

We are particularly grateful to our secretary and data aide Ms. M.A. Huber and our technician Mr. R. Gros. Dr. C. Onions provided invaluable programming assistance. We should like to acknowledge the remarkable performance of the ISR machine itself, the contributions of the ISR support staff, the support staffs at our respective institutes, and the PA group at the Rutherford Lab. We should like to put on record our appreciation for the excellent service provided by the CERN Computer Centre.

Table 1

Analysis and cut efficiencies

	Efficiency per event (%)
Track reconstruction	71 ± 5
Cluster reconstruction	98 ± 1
Momentum-energy matching	88 ± 2
Energy within cone	81 ± 5
Other cuts	96 ± 1
Over-all analysis efficiency	47.5 ± 5

REFERENCES

[1] A.L.S. Angelis et al., Phys. Letters 79B (1978) 505.

[2] A.L.S. Angelis et al., Physica Scripta 19 (1979) 116.

[3] J.H. Christenson et al., Phys. Rev. D 8 (1973) 2016.
D.C. Hom et al., Phys. Rev. Lett. 36 (1976) 1236.
D.C. Hom et al., Phys. Rev. Lett. 37 (1976) 1374.

[4] S.W. Herb et al., Phys. Rev. Lett. 39 (1977) 252.

[5] L. Camilleri et al., Nucl. Instrum. and Methods 156 (1978) 275.

[6] M. Morpurgo, Cryogenics 17 (1977) 89.

[7] M. Albrow et al., Nucl. Phys. B145 (1978) 305.

[8] J.K. Yoh et al., Phys. Rev. Lett. 41 (1978) 684.
See also:
L. Kluberg et al., Phys. Rev. Lett. 37 (1976) 1451.
D. Antreasyan et al., Phys. Rev. Lett. 39 (1977) 906.

[9] K. Ueno et al., Phys. Rev. Lett. 42 (1979) 486.

[10] S. Drell & T.M. Yan, Phys. Rev. Lett. 25 (1970) 316.

[11] D. Antreasyan et al., CERN-Harvard-Frascati-MIT-Naples-Pisa Collaboration, Dimuon spectra from 62 GeV proton collisions, Paper submitted to the EPS Int. Conf. on High-Energy Physics, Geneva, 1979.
C. Kourkoumelis et al., Athens-BNL-CERN-Syracuse-Yale Collaboration, Electron pairs at the ISR, Paper submitted to the 19th Internat. Conf. on high-Energy Physics, Tokyo, 1979.
See also, J. Cobb et al., Phys. Letters 72B (1977) 273.

[12] For the values of $\Gamma_{e^+e^-}$ see:
A.M. Boyarski et al., Phys. Rev. Lett. 34 (1975) 1357.
J.K. Bienlein et al., Phys. Lett. 78B (1978) 360.
Ch. Berger et al., Z. Phys. C1 (1979) 343.

For predictions of σB for the resonances,

T.K. Gaisser et al., Phys. Rev. D 15 (1977) 2572.

J. Ellis et al., Nucl. Phys. B131 (1977) 285, and references therein.

Figure captions

Fig. 1 : A view of the apparatus normal to the beams.

Fig. 2 : Raw mass-spectra: i) Same-sign events; ii) opposite-sign events; iii) net signal.

The dashed line is the apparatus acceptance in %.

Fig. 3 : Cross-section $d^2\sigma/dmdy$ for $6.5 < m < 15$ GeV/c^2. The solid line is an exponential fit to the continuum.

Fig. 4 : Scaling comparison.

Fig. 5 : $B(d\sigma/dy)_{y=0}$ for the J/ψ and Υ versus $m/\sqrt{s}$. The J/ψ cross-section has been multiplied by 10^{-3}.

References for Fig. 5:

A) This experiment.

B) See ref. 9.

C) See ref. 8.

a) A.G. Clark et al., Nucl. Phys. B142 (1978) 29.

b) F.W. Büsser et al., Nucl. Phys. B113 (1976) 189.

c) H.D. Snyder et al., Phys. Rev. Lett. 36 (1976) 1415.

d) K.J. Anderson et al., Phys. Rev. Lett. 36 (1976) 237.

J.G. Branson et al., Phys. Rev. Lett. 38 (1977) 1331.

e) Yu.M. Antipov et al., Phys. Lett. 60B (1976) 309.

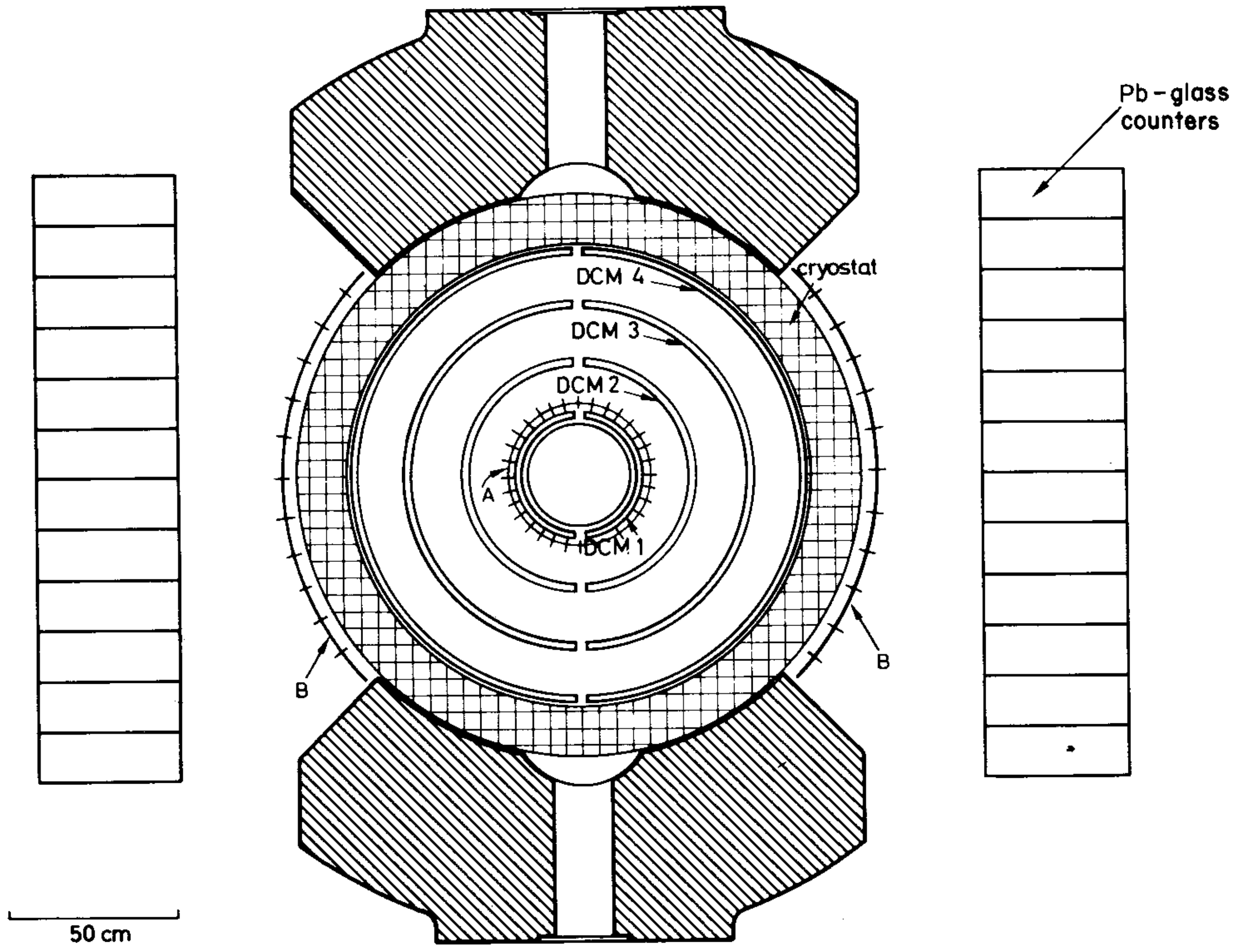
f) M.J. Corden et al., Phys. Lett. 68B (1977) 96.

g) U. Becker, private communication to K.J. Anderson et al.

h) A. Bamberger et al., Nucl. Phys. B134 (1978) 1.

Only experiments with acceptance at $y = 0$ have been included, and where the quoted papers do not give $d\sigma/dy$ or $(d\sigma/dx)_{x=0}$ explicitly, the x distributions given in (e) have been used to obtain $(d\sigma/dy)_{y=0}$. Where a choice has been given, the cross-section for the J/ψ corresponding to an isotropic decay angular distribution and a $\langle p_T \rangle$ of 1.1 GeV/c have been taken.

Fig. 6 : $\langle p_T \rangle$ versus mass for different values of $\sqrt{s}$.



VIEW PERPENDICULAR TO THE BEAMS

Fig. 1

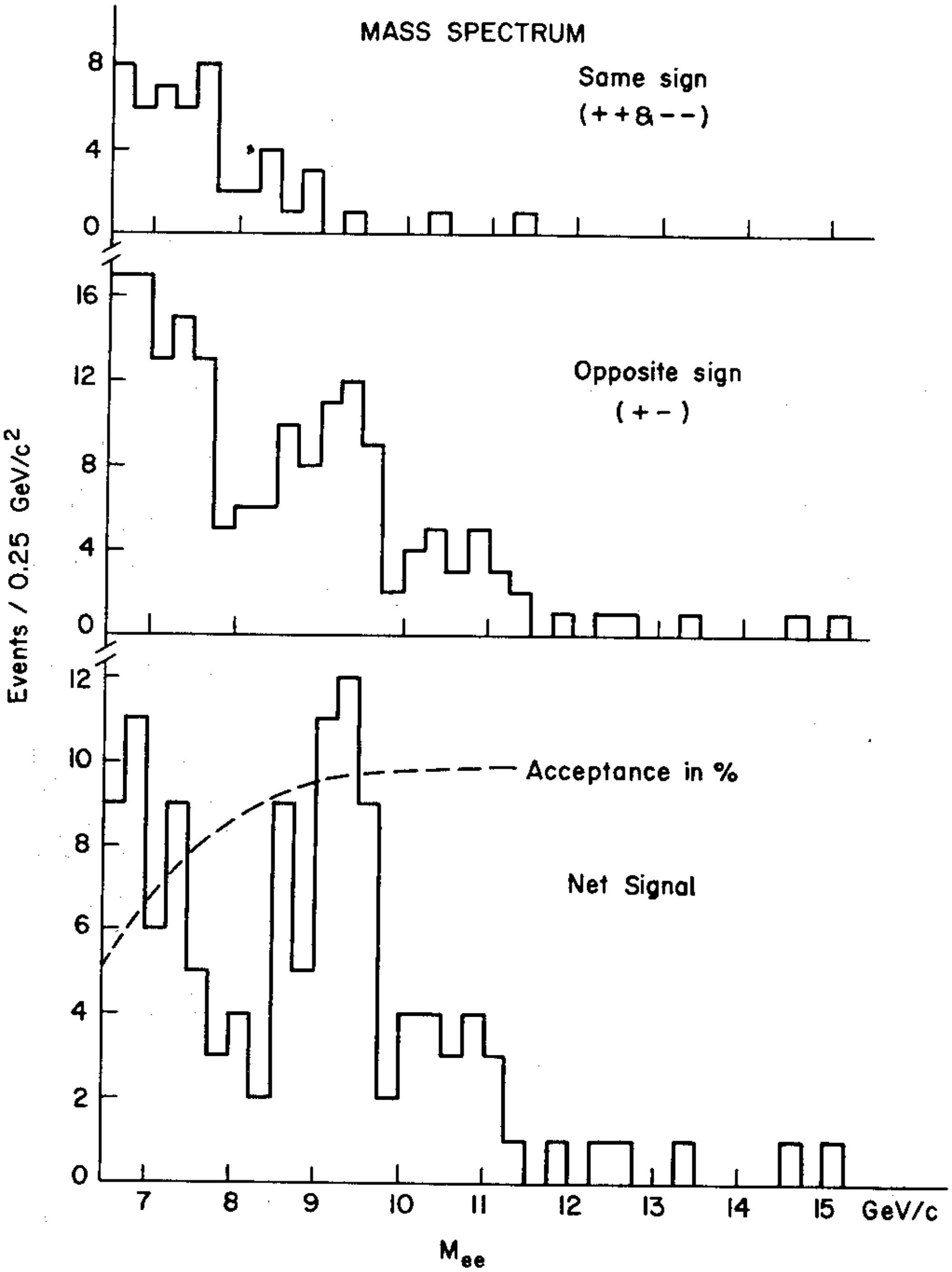
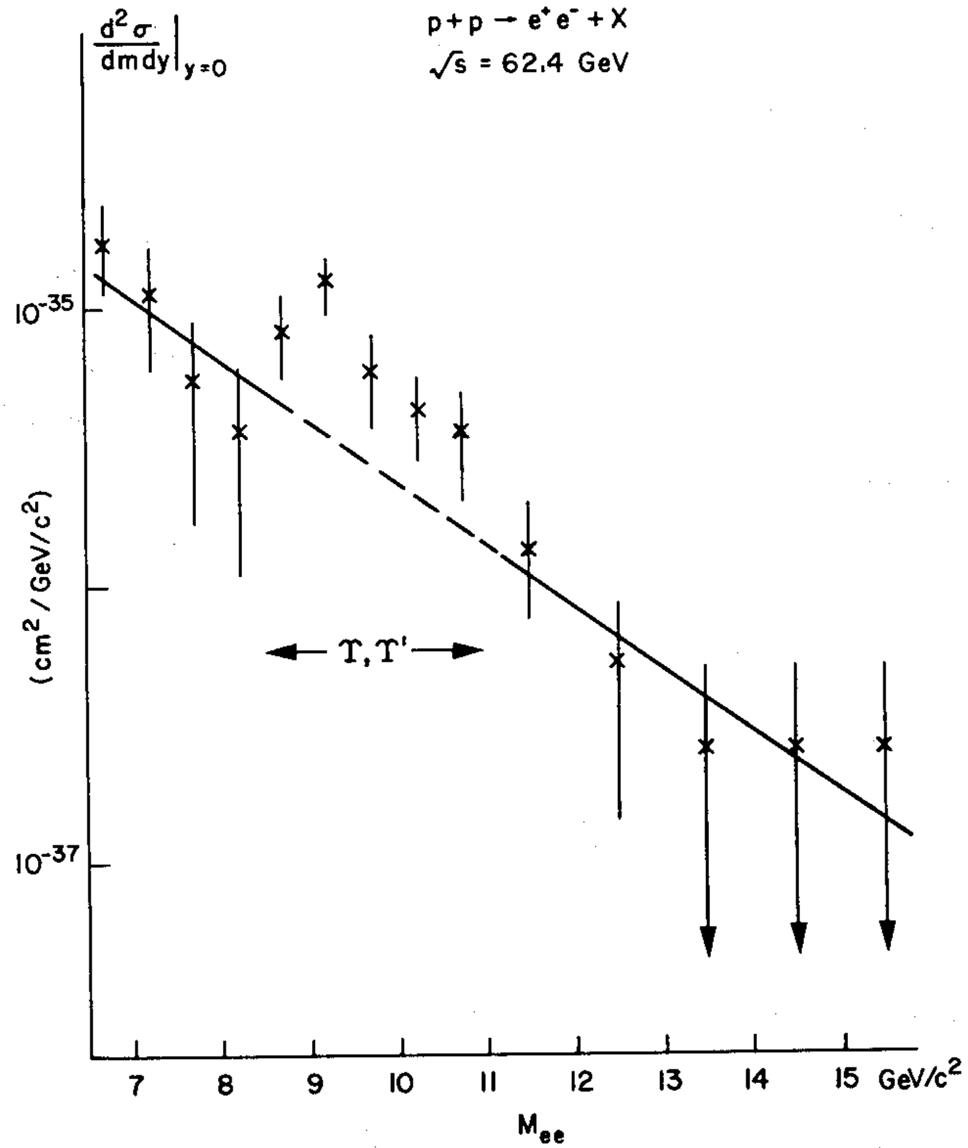

MASS SPECTRUM
Same sign
(++&--)
Opposite sign
(+-)
Acceptance in %
Net Signal
Events / 0.25 GeV/c²
7
8
9
10
11
12
13
14
15
GeV/c
M_ee

Fig. 2



$\frac{d^2\sigma}{dm\,dy}\Big|_{y=0}$
$p+p \rightarrow e^+e^- + X$
$\sqrt{s}$ = 62.4 GeV
10^{-35}
10^{-37}
$(cm^2 / GeV/c^2)$
Υ, Υ'
7
8
9
10
11
12
13
14
15
GeV/c^2
M_{ee}

Fig. 3

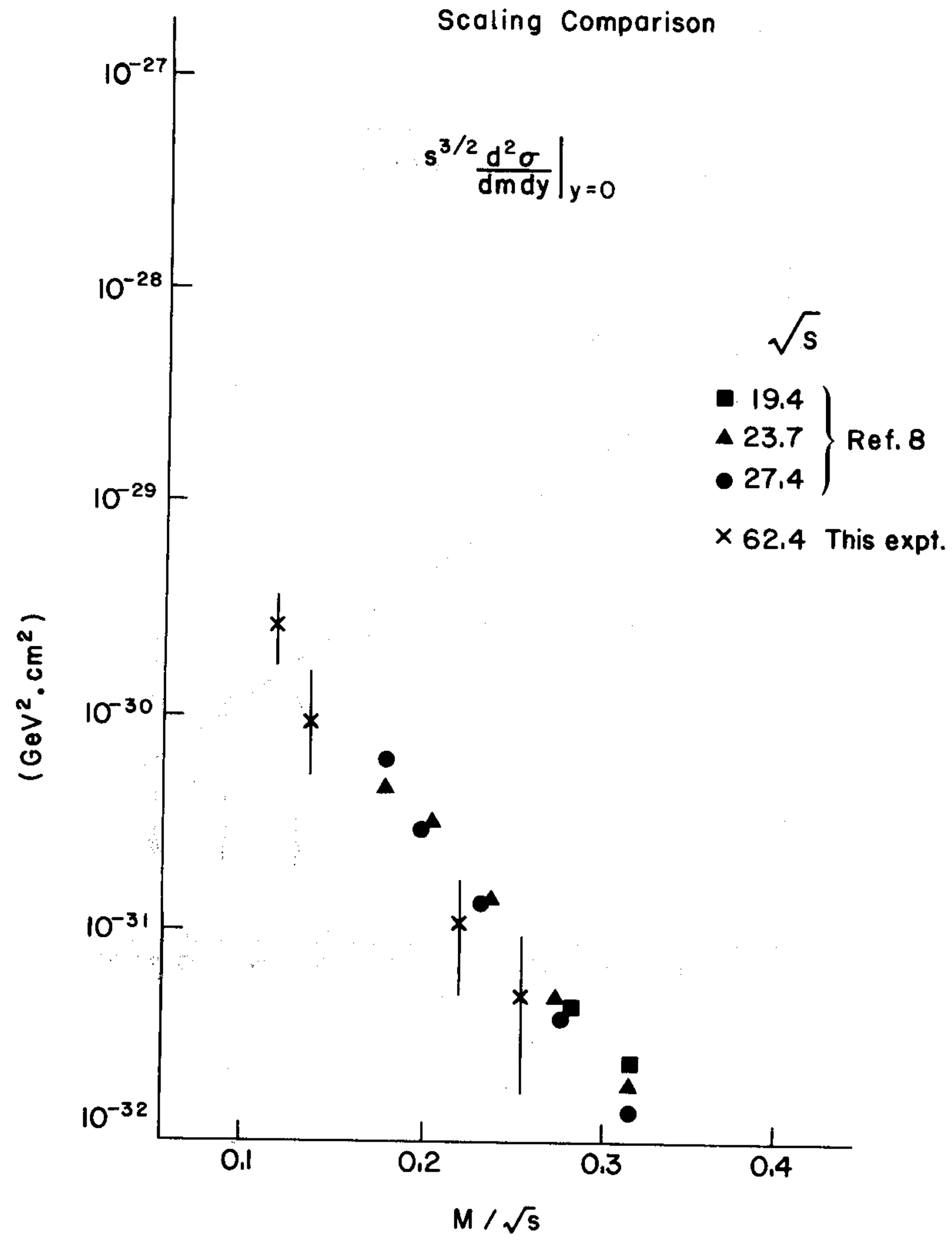

Scaling Comparison
$s^{3/2} \frac{d^2\sigma}{dm\,dy}\Big|_{y=0}$
$\sqrt{s}$
19.4
23.7
27.4
Ref. 8
62.4 This expt.
10^{-27}
10^{-28}
10^{-29}
10^{-30}
10^{-31}
10^{-32}
$(GeV^2 . cm^2)$
0.1
0.2
0.3
0.4
$M / \sqrt{s}$

Fig. 4

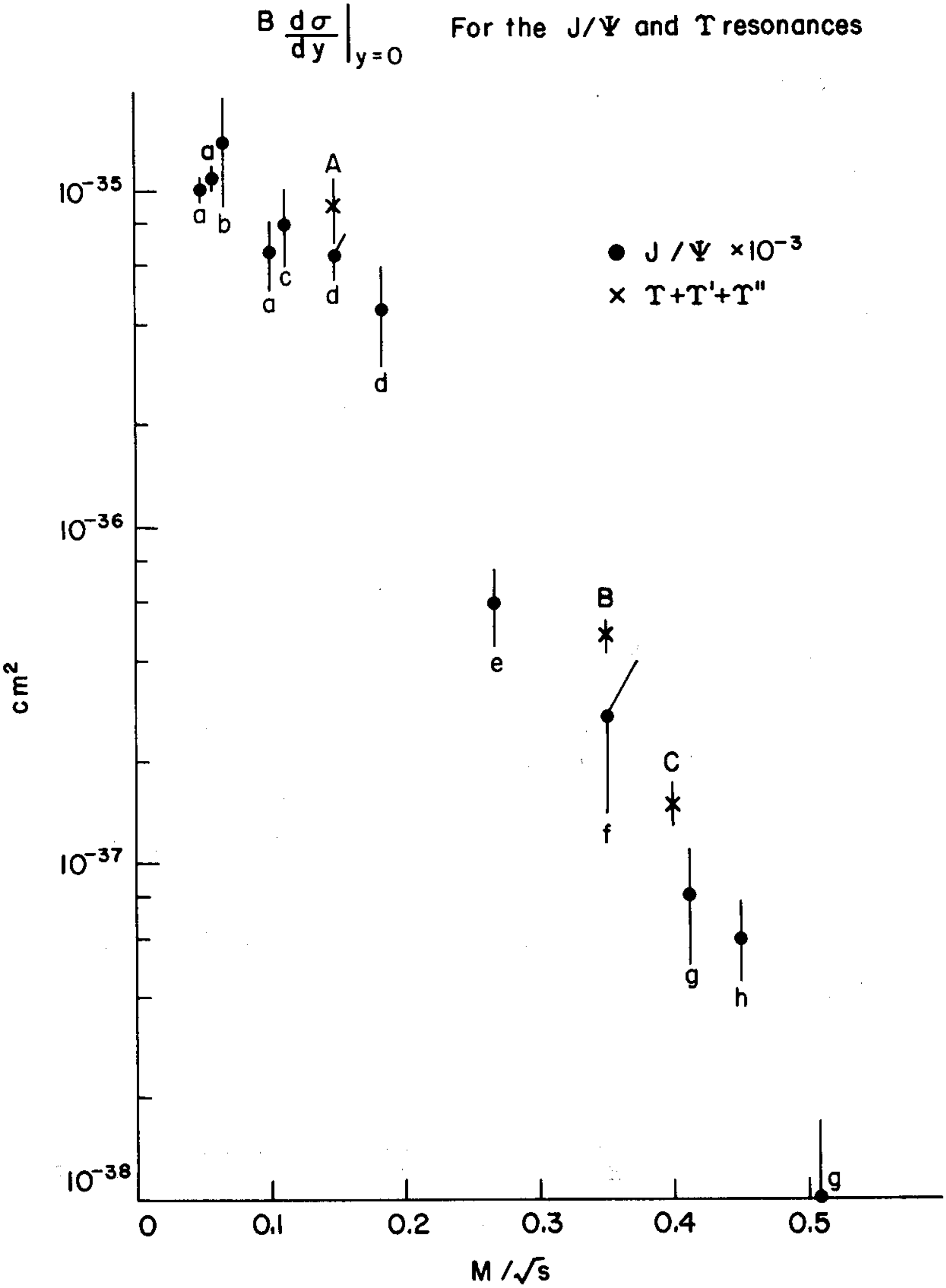

B dσ/dy |y=0 For the J/Ψ and ϒ resonances
cm²
10⁻³⁵
10⁻³⁶
10⁻³⁷
10⁻³⁸
J/Ψ ×10⁻³
ϒ+ϒ'+ϒ''
a
b
c
d
e
f
g
h
A
B
C
0
0.1
0.2
0.3
0.4
0.5
M/√s

Fig. 5

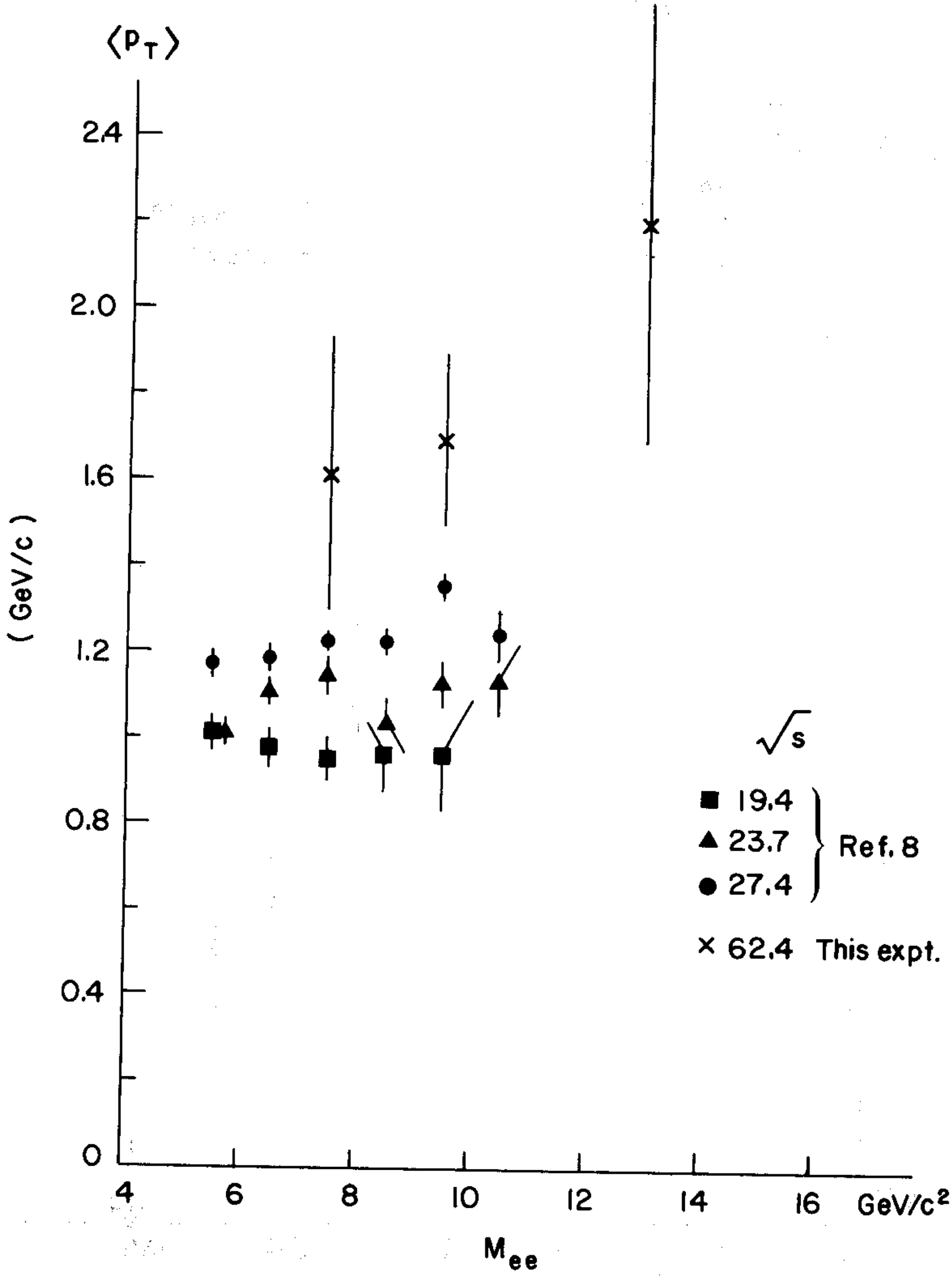

⟨pT⟩
(GeV/c)
2.4
2.0
1.6
1.2
0.8
0.4
0
4
6
8
10
12
14
16
GeV/c²
Mee
√s
19.4
23.7
27.4
Ref. 8
62.4 This expt.

Fig. 6