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MEASUREMENT OF DIMUON PRODUCTION AT THE ISR

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ABSTRACT

Prompt dimuon production has been measured from $p + p \to \mu^+\mu^- + X$ at the CERN Intersecting Storage Rings with the highest center of mass energy, $\sqrt{s}$ = 62 GeV, and a large statistical sample of about 12,300 events. Events with mass up to 25 GeV are observed, as well as the J and T resonances. Cross sections are given for J and T production. For the continuum, the scaling function $F(\tau) = m^3\, d\sigma/dm$ is measured at very small values of $\sqrt{\tau} = m/\sqrt{s}$ covering the range $0.05 < \sqrt{\tau} < 0.20$.

1. INTRODUCTION

We present data from an experiment measuring

$$pp \rightarrow \mu^+\mu^- X \qquad (1)$$

which was carried out at the CERN Intersecting Storage Rings (ISR) at a center of mass energy of $\sqrt{s}$ = 62 GeV and an integrated luminosity of 1.11 x $10^{38}cm^{-2}$. This experiment has obtained 12,300 muon pairs with an invariant mass above 2.8 GeV.

High mass dimuon production is a clean process in providing a variety of information on the nature of the basic constituents of hadrons and their interactions:

i. The observation of vector mesons[1] by detecting their leptonic decays can demonstrate the existence of new quark flavors since these mesons are now understood to be quark-antiquark bound states.

ii. The study of the $\mu^+\mu^-$ continuum in the framework of the Drell-Yan model [2] determines the parton momentum distributions inside the nucleon.

iii. The muon pair cross section, and the dependence of the muon pair transverse momentum distribution on $\sqrt{s}$ can be used to examine QCD corrections to the simple Drell-Yan picture. Therefore the role of gluons as constituents of the proton can be probed.

The ISR provides the highest possible collision energy at present, with the following consequences:

i. cross sections are larger for the production of high mass particles;

ii. most of the region covered in the scaling variable $\tau = m^2/s$ is inaccessible at other accelerators.

Furthermore, colliding protons on protons yields results which are free of corrections for the motion of nucleons and for shadowing of one nucleon by another inside a heavy nucleus.

2. EXPERIMENTAL SET UP

The detector is shown in Figure 1. It is a large-acceptance spectrometer composed of seven magnetized iron toroids, excited to 18 KGauss and totalling 450 tons, which provide both the hadron absorber and the magnetic field for the momentum analysis of muons. This method minimizes background from hadron punch-through, because there is more than 1.3 m of magnetized iron in the path of a penetrating track. To reduce background from hadron decays, the absorber starts about ~ 40 cm from the interaction point. Muons are identified by penetration, requiring a minimum of 1.8 GeV/c momentum to traverse the absorber.

Large size drift chambers between the magnets and around the detector serve to determine the muon momenta. These chambers [3)] of sizes up to 6.0 x 2.7 m^2 measure both coordinates twice with a resolution of $\sigma = 430\ \mu m$. There are 4800 wires with 10 cm spacing covering 800 m^2 of sensitive area.

Immediately around the interaction region an array of 136 drift chambers [4)] determines 3-5 points for each charged track emitted within $9^o < \theta < 171^o$ and $0 < \phi < 360^o$ with a precision of 0.3 mm along the beam and 2.6 mm transverse to it. Chambers [5)] mounted further downstream extend the range to $\theta = 1^o$. The observed muon tracks together with the hadron tracks determine the vertex.

Coincidences of the scintillation hodoscopes A, B, C, D, E (Figure 1) are used to define a coarse muon track. The counter combinations form 24 azimuthal ϕ sectors in the non-bending plane. To reduce beam-gas background the second track is required to be in $130^{\circ} < \phi < 230^{\circ}$ from the first. Counters D (0.83×4.00 m^2) have fast 5" photomultipliers on each end. The time difference between the two photomultipliers enables us to locate the muon track position to σ = 25 cm. The time sum yields a position independent signal (2ns) enabling the rejection of cosmic rays, which are 15ns out of time. In summary the magnetic spectrometer has a large acceptance

$$15^{\circ} < \theta < 120^{\circ} \qquad P_{\mu} > 1.8 \text{ GeV}$$

and all ϕ with the above trigger constraint. The large θ range implies a wide acceptance in $x_F = 2p_L/\sqrt{s}$. Having little ϕ restriction the acceptance in p_T, the transverse momentum of the muon pair, is rather uniform for $m \geq 8$ GeV.

3. MASS SPECTRUM

We have observed events with masses up to 25 GeV. The computer reconstructed top view of one event with m = 24.5 GeV has been imposed onto the cut view of the detector in Figure 1. The two muons emerge from a vertex well within the interaction diamond accompanied by 16 charged hadrons. All trigger counters are in time within 1.6 ns. This fact, in addition to the dimuon opening angle $\theta_{\mu\mu} \neq 180^{\circ}$ clearly excludes a cosmic ray. The event is clean, as it does not contain any spurious chamber coordinates. This feature is quite common to all events, demonstrating the effectiveness of the iron shielding.

Figure 2a shows the observed mass spectrum of dimuon events and background with m < 5 GeV. The background from decay and punch through of hadrons is determined from the amount of like sign muon pairs. It is negligible for m > 8 GeV.

The mass resolution is limited by multiple scattering in the iron. We expect $\Delta m/m = 11\%$ almost independent of mass. This is in good agreement with the direct measurement of J in Figure 2a, yielding 10.8%. There are 2580 events with $m > 5$ GeV, 1150 events with $m > 8$ GeV and 3 events with $m > 20$ Gev. All events with $m > 8$ GeV have been visually scanned.

Two independent detection systems of small angle hodoscopes have recorded the luminosity. Over a period of .. months they agreed to better than 6%. In view of the importance of the normalization of the cross section, many checks on the data sample have been performed. The event sample has been obtained independently by two different selection and fitting programs.

The mass acceptance for $m > 5$ GeV was calculated by Monte Carlo using a production mechanism[6] of $d\sigma / dx_F \, dp_T \, d\cos\theta \sim (1 - | x_F |)^{3.0} \exp(-1.1 p_T) \cdot (1 + \cos^2 \theta_{cs})$ consistent with our continuum data[11]. Multiple scattering, energy loss, trigger and fiducial constraints are taken into account. The resulting mass acceptance rises from 5% at $m = 5$ GeV to a plateau of 16% for $m \geq 8$ GeV. It is insensitive[7] to x_F and p_T distributions, but increases ~20% for isotropic emission in θ_{cs}, the Collins Soper [8] angle.

4. J AND Υ RESONANCES

For $m > 5$ GeV the resulting cross section after background subtraction is shown in Figure 2b. A clear enhancement from the Υ family is apparent at 9-10 GeV.

An ansatz of a continuum [9] and the Υ resonances was fitted to our cross section. The observed resonance shape is dominated by the resolution of the apparatus. In the following formula we used a mass resolution $\frac{\Delta m}{m}$ of 11.5% at ~10 GeV.

$$\frac{d\sigma}{dm} = A\left[\exp -\left(\frac{m - 9.46}{\sqrt{2}\cdot \Delta m}\right)^2 + 0.30 \quad \exp -\left(\frac{m - 10.05}{\sqrt{2}\cdot \Delta m}\right)^2 + 0.15 \quad \exp -\left(\frac{m - 10.4}{\sqrt{2}\cdot \Delta m}\right)^2\right] + B\left[\frac{(1 - m/\sqrt{s})^a}{m^4\sqrt{s}}\right]. \qquad (2)$$

We take $a = 10$ from Kinoshita et al.[9] and the relative Υ branching ratios from Ueno et al.[10]. We obtain a good fit, with $\chi^2/DF = 27.4/26$ shown as the solid line in Figure 2b.

The fitted A value from equation (2) measures directly the integrated cross section for the Υ family. We obtain $\sigma\,(\Upsilon + \Upsilon' + \Upsilon'' \to \mu^+\mu^-) = (18.0 \pm 4.4)$ pb. Our measured angular distribution in this mass region is consistent to be isotropic[11]. This implies a 20% reduction in the Υ cross section. Thus we obtain

$$\sigma\,(\Upsilon + \Upsilon' + \Upsilon'' \to \mu^+\mu^-) = (14.5 \pm 3.5)\ \text{pb}.$$

The mass region $2.8 < m < 5$ GeV is dominated by $J \to \mu^+\mu^-$ decay (see Figure 2a). The continuum contribution was calculated from equation (2) and subtracted. An acceptance at $m = 3.1$ GeV is calculated weighted with $(1 - |x_F|)^{3.0} \exp(-1.5\, p_T)$ and isotropic decay[6]. The corresponding cross section is added to the continuum and is shown in Figure 2b. The muons from J's produced at rest have 1.55 GeV momentum each and cannot penetrate the iron. Instead we measure forward-moving J's produced with $0.1 < x_F < 0.35$. Averaged over the x_F range we obtain

$$B_{\mu\mu} \left.\frac{d\sigma}{dx}\right|_{\langle x\rangle = .2} (J) = (3.6 \pm 1.1) \times 10^{-32}\,\text{cm}^2$$

We observed 3 events at masses larger than 20 GeV. We expect one event from a smooth extrapolation of the continuum near 20 GeV. This allows us to set an upper limit on production of new resonances X with mass m > 20 GeV of

$$\sigma (X \rightarrow \mu^+\mu^-) \leq 40 \cdot 10^{-38} \ \mathrm{cm}^2.$$

5. SCALING

The fitted value B from equation (2) is a measure of the continuum size. We obtain:

$$B = (5.2 \pm 0.2) \cdot 10^{-33} \mathrm{cm}^2 \ \mathrm{GeV}^2.$$

In addition to the fit error, the overall normalization has a total uncertainty of ± 15% due to event selection and the luminosity measurement.

If the exponent (a) in equation (2) is treated as a free parameter we find $a = 8 \pm 1$ with $\chi^2/DF = 22.1/25$.

There have been many excellent[6, 10] experiments on hadron-nucleus production of $\mu^+\mu^-$ pairs at Fermilab, where the measured cross section in the mass region m > 5 GeV is a factor of 10-100 lower than our cross section.[12] Some of these experiments overlap with ours in τ and thus provide a unique opportunity to check the scaling phenomena of the time-like photon region.

In the scaling model, $F(\tau) = m^3 \ d^2\sigma/dmdx\big|_{x=0}$ depends only on the dimensionless variable τ. We have converted our data in the mass range not affected by resonances (4.5-8 and 12.5-17 GeV). The result is shown in Figure 3 and the solid line represents our continuum fit recast into the scaling form:

$$F(\tau) = m^3 \left.\frac{d^2\sigma}{dm dx}\right|_{x=0} = (1.04 \pm 0.16)^* \, 10^{-32} \, (1-\sqrt{\tau})^{10}/\sqrt{\tau} \, \mathrm{GeV}^2 \mathrm{cm}^2.$$

Our experiment overlaps with the high-statistics Fermilab experiment [10] at $\sqrt{\tau} \simeq 0.2$. The comparison is limited by the systematic uncertainty involved in an experiment using nuclear targets and by our statistical accuracy at masses above the T. Within these limitations, scaling holds despite the fact the cross sections in the same mass region differ by orders of magnitude. However, as can be seen in Figure 3, the phenomenological ansatz used to describe the high statistics, low energy Fermilab data[10] is not valid in the very small τ region measured in this experiment.

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7) The model dependence of the acceptance calculation is small due to the fact that most of the x and p_T range is covered. We find $\leq$ 5% variation in acceptance for $c = 3.0 \pm 0.5$ from the $(1 - |x|)^c$ dependence and $\leq$ 9% variation in acceptance for $b = 1.1 \pm 0.2$ from $\exp(-bp_T)$.

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FIGURE CAPTIONS

Figure 1 — Cut-away view of the detector at the ISR. Shown are: beam pipes (1), interaction region and inner detector (I), lead absorbers (2), trigger counter hodoscopes (A), (B), (C), (D), (E), magnetized iron toroids (4), muon drift chambers (F) and luminosity monitors (3). Superimposed is the computer reconstruction showing a dimuon event of 24.5 GeV mass and P_T = 1.2 GeV. For clarity only the lower half of the central yokes is shown and the event has been rotated 30^o into this cut plane. The tracks have an opening angle of $\theta_{\mu\mu} = 155^o$ and intersect the position range, δ as given by the D counters.

Figure 2

a) The events of the mass region 2-5 GeV display the J. Crosses denote the background estimated from combinations of measured $\mu^+\mu^+$ and $\mu^-\mu^-$ pairs. Open circles show the sum of background from $\Psi' \to \mu^+\mu^-$ and Drell-Yan contributions.

b) Measured cross section as a function of the dimuon mass. The solid line is the fit to the continuum and the Υ resonances, see text. The dotted lines are continuum extrapolations in the resonance regions.

Figure 3 — The scaling function $F(\tau) = m^3 d^2\sigma/dmdx\big|_{x=0}$ plotted as a function of $\sqrt{\tau}$. The dashed line represents the phenomenological fit to data of Reference 10. The solid line represents our fit given in the text.

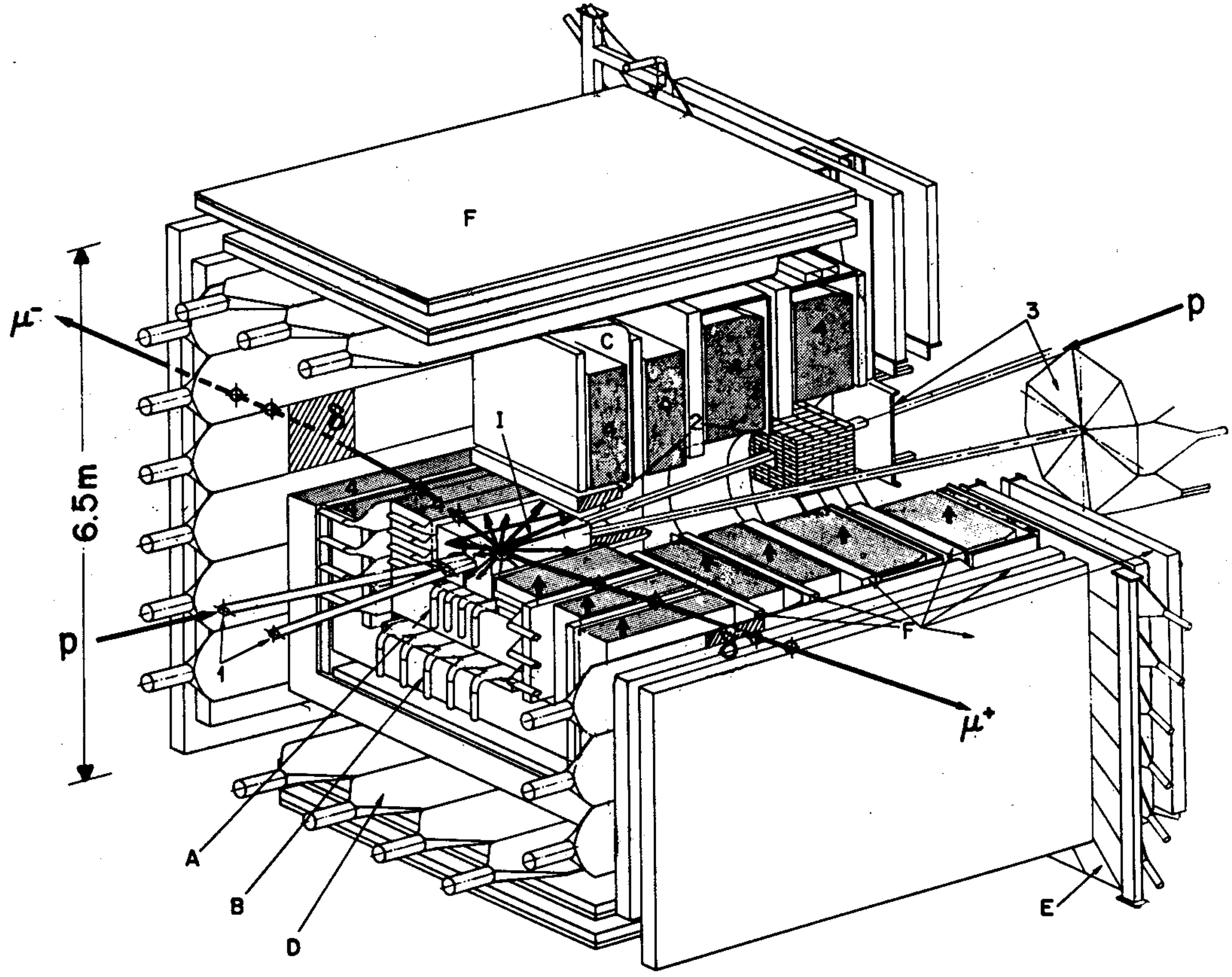
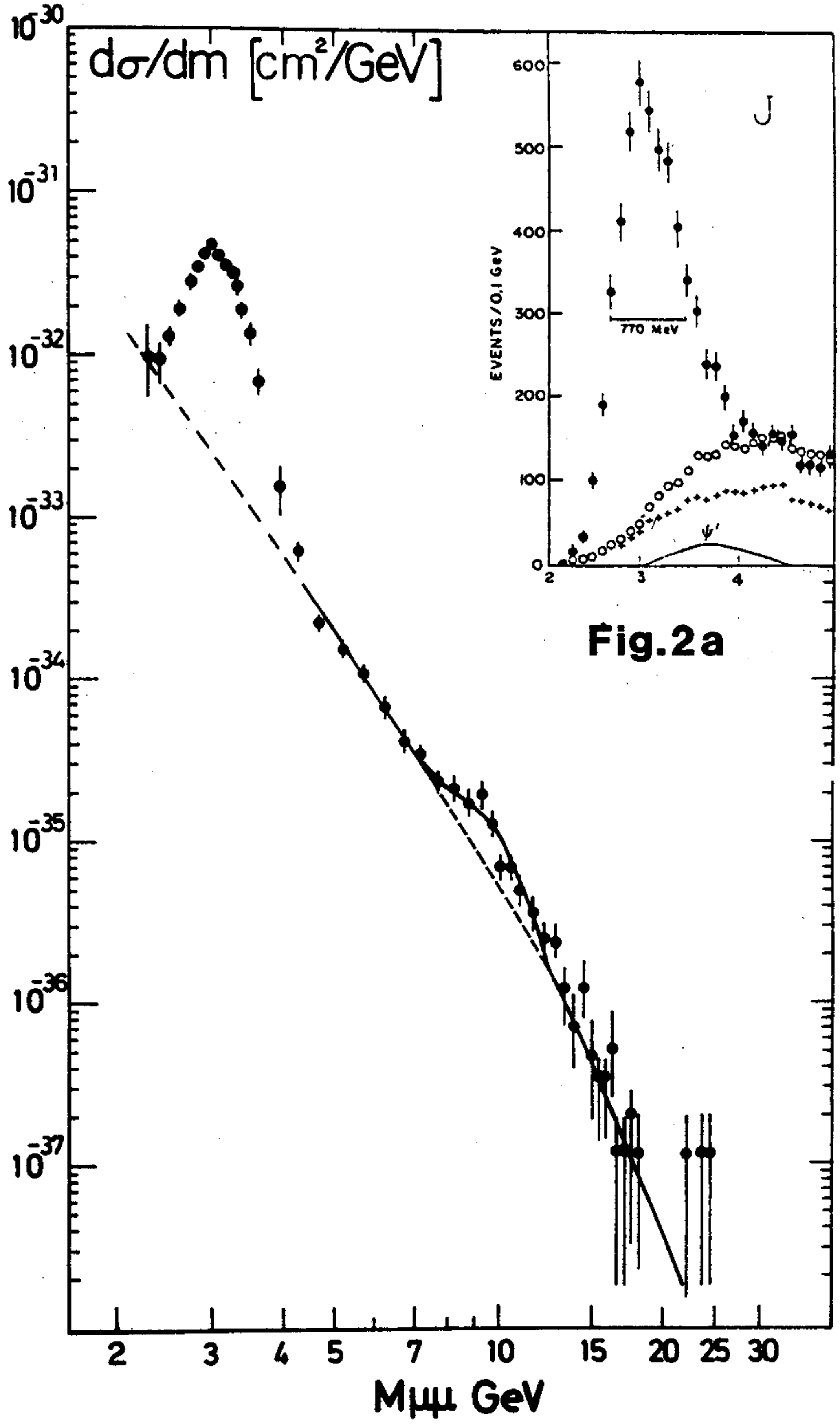


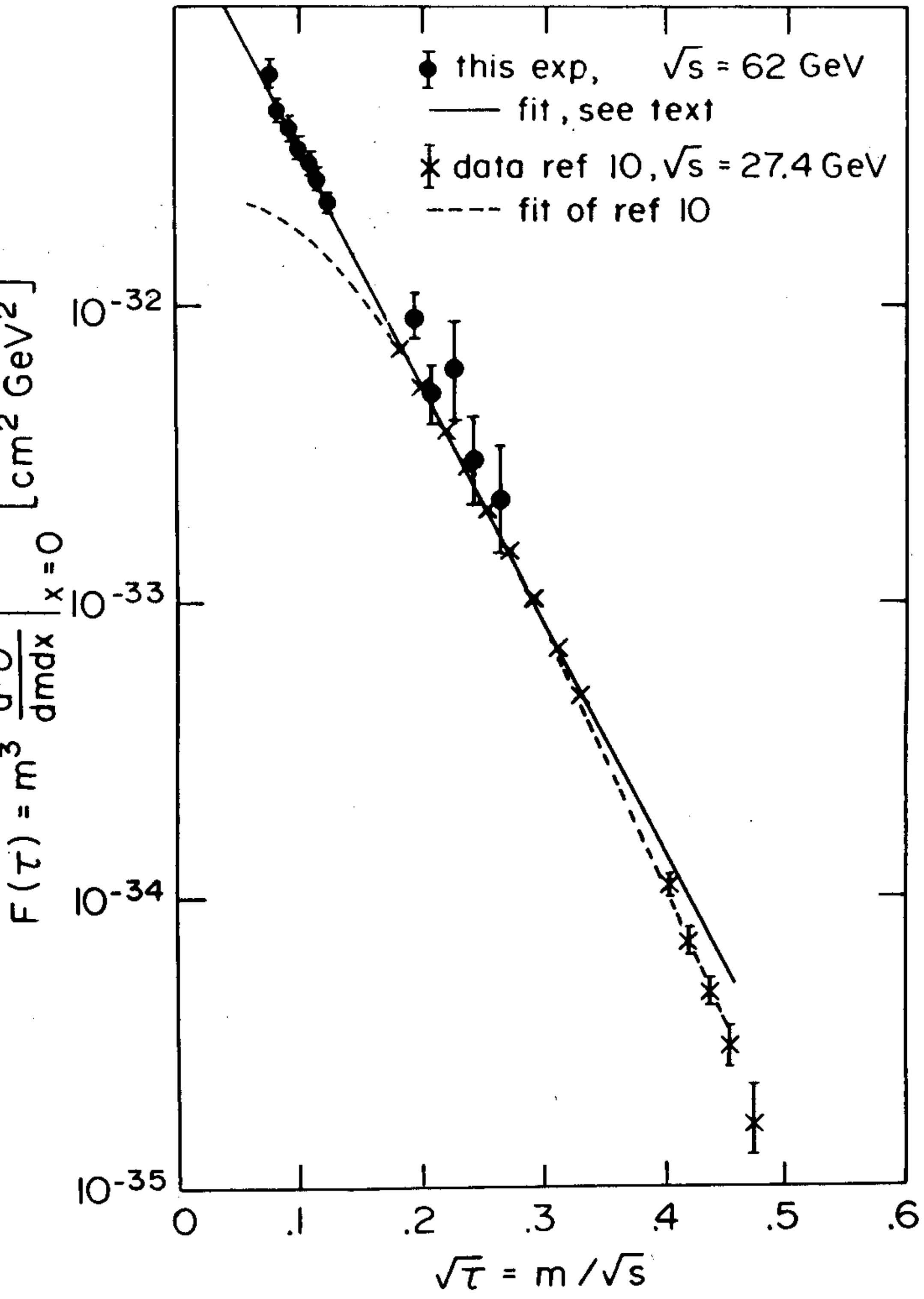
Figure 1



dσ/dm [cm²/GeV]
10^{-30}
10^{-31}
10^{-32}
10^{-33}
10^{-34}
10^{-35}
10^{-36}
10^{-37}
2
3
4
5
7
10
15
20
25
30
Mμμ GeV
EVENTS / 0.1 GeV
600
500
400
300
200
100
0
770 MeV
J
ψ'
2
3
4

Fig.2a

Fig.2b



this exp, $\sqrt{s}$ = 62 GeV
fit, see text
data ref 10, $\sqrt{s}$ = 27.4 GeV
fit of ref 10
$F(\tau) = m^3 \left.\frac{d^2\sigma}{dm dx}\right|_{x=0}$ [cm^2 GeV^2]
10^{-32}
10^{-33}
10^{-34}
10^{-35}
0
.1
.2
.3
.4
.5
.6
$\sqrt{\tau} = m/\sqrt{s}$

Figure 3