

## Measurement of Dimuon Production at $s^{1/2} = 62$ GeV

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Prompt dimuon production has been measured. Events with mass up to  $25 \text{ GeV}/c^2$  are observed, as well as the  $J$  and  $\Upsilon$  resonances. Cross sections are given for  $J$  and  $\Upsilon$  production. For the continuum, the scaling function  $F(\tau)$  is measured at very small values of  $\sqrt{\tau} = m/\sqrt{s}$  covering the range  $0.05 < \sqrt{\tau} < 0.20$ .

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We present data from an experiment measuring

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

which was carried out at the CERN intersecting storage rings at a center-of-mass energy of  $\sqrt{s} = 62$  GeV and an integrated luminosity of  $1.11 \times 10^{38} \text{ cm}^{-2}$ . This experiment has obtained 12 300 muon pairs with an invariant mass above  $2.8 \text{ GeV}/c^2$ . The high cross section of muon pair production, the small scaling variable values  $\tau = m^2/s$ , and the absence of nuclear shadowing corrections from pure  $pp$  collisions provide a sensitive search for new particles<sup>1</sup> and a test of scaling models.<sup>2</sup>

The detector is shown in Fig. 1. It is a large-acceptance spectrometer composed of seven magnetized iron toroids, excited to 18 kG and totaling 450 tons, which provide both the hadron absorber and the magnetic field for the momentum analysis of muons. This method minimized 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  $\sim 40$  cm from the interaction point. Muons are identified by penetration, requiring a minimum of  $1.8 \text{ GeV}/c$  momentum to traverse the absorber.

Large-size drift chambers serve to determine the muon momenta. These chambers<sup>3</sup> of sizes up

to  $6.0 \times 2.7 \text{ m}^2$ , measure both coordinates twice with a resolution of  $\sigma = 430 \text{ } \mu\text{m}$ . There are 4800 wires with 10 cm spacing covering  $800 \text{ m}^2$  of sensitive area.

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

Coincidences of the scintillation hodoscopes  $A$ ,  $B$ ,  $C$ ,  $D$ ,  $E$  (Fig. 1) are used to define muon tracks.

The magnetic spectrometer has a large acceptance of  $15^\circ < \theta < 120^\circ$  and  $P_\mu > 1.8 \text{ GeV}/c$ . The large  $\theta$  range implies a wide acceptance in  $x \approx 2p_L/\sqrt{s}$ . Having little  $\varphi$  restriction the acceptance in  $p_T$ , the transverse momentum of the muon pair, is rather uniform for  $m \geq 8 \text{ GeV}/c^2$ .

We have observed events with masses up to  $25 \text{ GeV}/c^2$ . The computer reconstructed top view of one event with  $m = 24.5 \text{ GeV}/c^2$  has been imposed onto the cut view of the detector in Fig. 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 open-

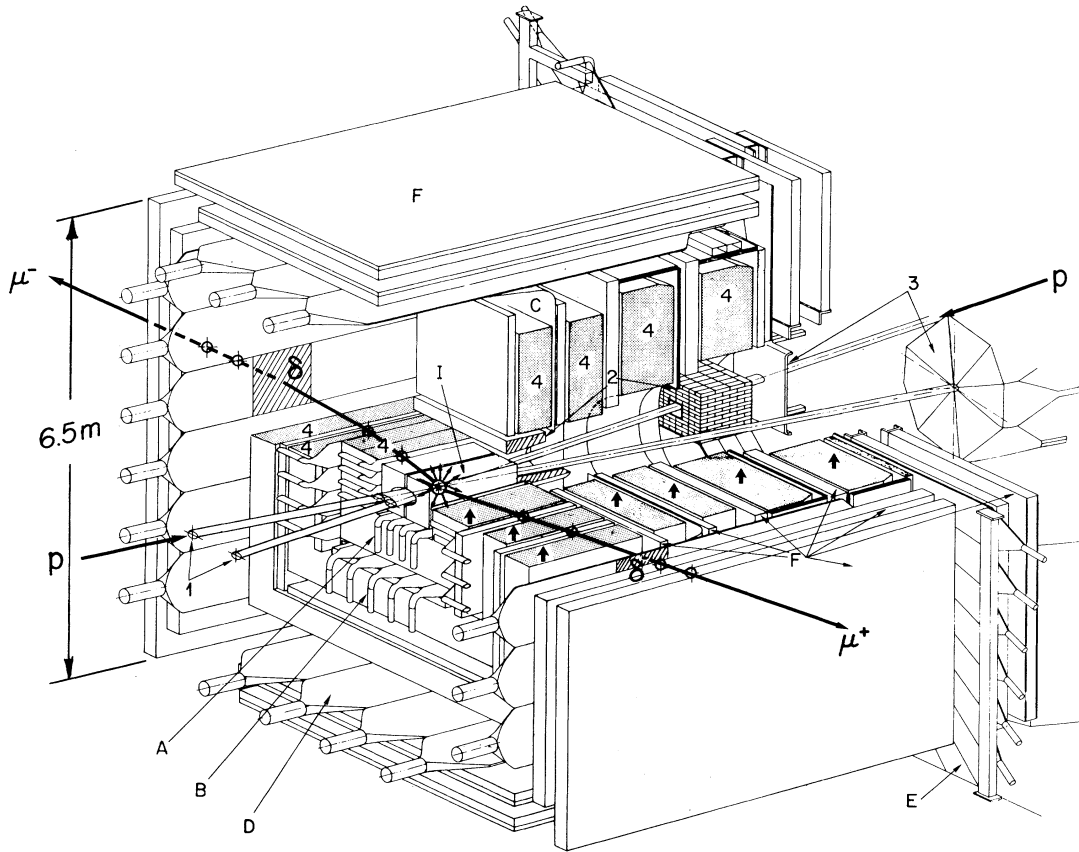


FIG. 1. Cut-away view of the detector at the CERN intersecting storage rings. Shown are beam pipes (1), interaction region and inner detector (I), lead absorbers (2), trigger counter hodoscopes (A), (B), (C), (D), (E), magnetized iron toroids (4), muon drift chambers (F), and luminosity monitors (3). Superimposed is the computer reconstruction showing a dimuon event of  $24.5 \text{ GeV}/c^2$  mass and  $p_T=1.2 \text{ GeV}/c$ .

ing 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 2(a) shows the observed mass spectrum of dimuon events and background with  $m < 5 \text{ GeV}/c^2$ . The background from decay and punch through of hadrons is determined from the amount of like sign muon pairs. It is negligible for  $m > 8 \text{ GeV}/c^2$ .

The mass resolution is limited by multiple scattering in the iron. We expect  $\Delta m/m = 11\%$  almost independent of mass. The direct measurement of  $J$  in Fig. 2(a) yields a mass resolution of 10.8%. There are 2580 events with  $m > 5 \text{ GeV}/c^2$ , 1150 events with  $m > 8 \text{ GeV}/c^2$ , and 3 events

with  $m > 20 \text{ GeV}/c^2$ . All events with  $m > 8 \text{ GeV}/c^2$  have been visually scanned.

The mass acceptance for  $m > 5 \text{ GeV}/c^2$  was calculated by Monte Carlo using the production mechanism<sup>6</sup>  $d\sigma/dx dp_T d\cos\theta \propto (1 - |x|)^{3.0} \times \exp(-1.1p_T)(1 + \cos^2\theta_{CS})$  consistent<sup>7</sup> with our continuum data.<sup>8</sup> It rises from 5% at  $m=5 \text{ GeV}/c^2$  to a plateau of 16% for  $m > 8 \text{ GeV}/c^2$ . Isotropic emission in  $\theta_{CS}$ , the Collins-Soper<sup>9</sup> angle, increases the acceptance by 20%.

For  $m > 5 \text{ GeV}/c^2$  the resulting cross section after background subtraction is shown in Fig. 2(b). A clear enhancement from the  $\Upsilon$  family is apparent at 9–10  $\text{GeV}/c^2$ .

An Ansatz of a continuum<sup>10</sup> and the  $\Upsilon$  resonances was fitted to our cross section:

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

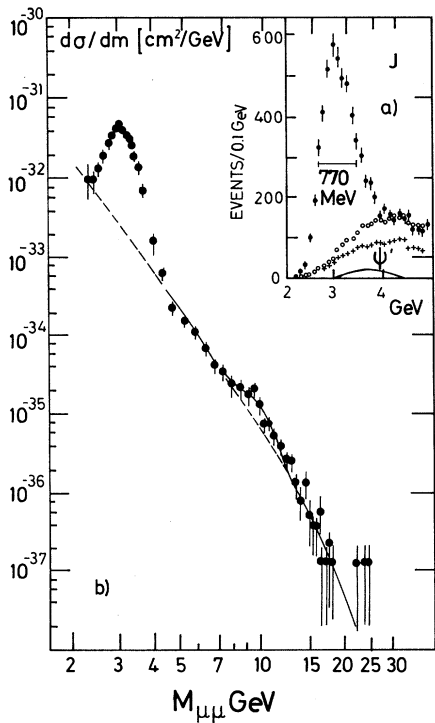


FIG. 2. (a) The events of the mass region 2–5 GeV/c<sup>2</sup> display the *J*. Crosses denote the background estimated from combinations of measured  $\mu^+\mu^+$  and  $\mu^-\mu^-$  pairs. Open circles include Drell-Yan, background, and  $\psi' \rightarrow \mu^+\mu^-$  (solid line) contributions. (b) Measured cross section as a function of the dimuon mass. The solid line is the fit to the continuum and the  $\Upsilon$  resonances, see text. The dotted lines are continuum extrapolations in the resonance regions.

We take  $\Delta m/m=11\%$ ,  $a=10$  from Kinoshita *et al.*,<sup>10</sup> and the relative  $\Upsilon$  branching ratios from Ueno *et al.*<sup>11</sup> We obtain a good fit, with  $\chi^2=27.4$  for 26 degrees of freedom shown as the solid line in Fig. 2(b).

From the fitted value of *A* in Eq. (2) corrected by a factor 0.8 for an isotropic angular distribution,<sup>8</sup> we obtain

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

The mass region  $2.8 < m < 5 \text{ GeV}/c^2$  is dominated by  $J \rightarrow \mu^+\mu^-$  decay. The muons from *J*'s produced at rest cannot penetrate the iron. Instead we measure forward-moving *J*'s produced with  $0.1 < x < 0.35$ . Averaging over the *x* range,<sup>6</sup> we obtain

$$d\sigma(J \rightarrow \mu^+\mu^-; \langle x \rangle = 0.2)/dx = (3.6 \pm 1.1) \times 10^{-32} \text{ cm}^2.$$

We observed 3 events at masses larger than 20 GeV/c<sup>2</sup> and expect one from the extrapolation of

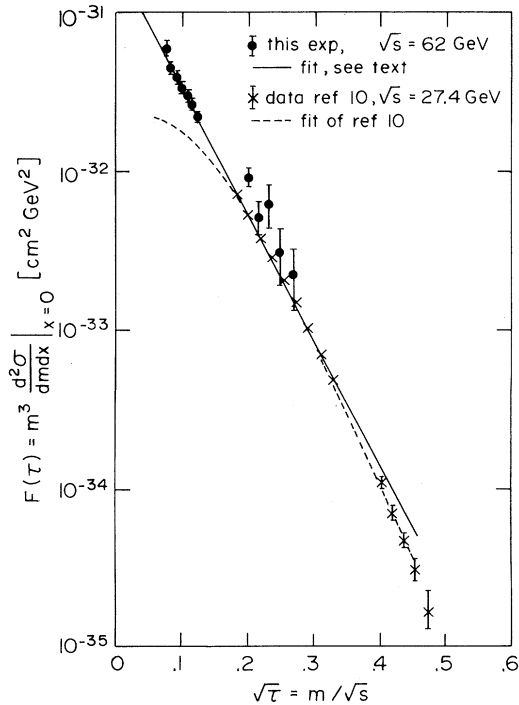


FIG. 3. The scaling function  $F(\tau)$  plotted as a function of  $\sqrt{\tau}$ .

the continuum fit. This allows us to set an upper limit on production of new resonances *X* with mass  $m > 20 \text{ GeV}/c^2$  of

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

The fitted value  $B = (5.2 \pm 0.2) \times 10^{-33} \text{ cm}^2 \cdot \text{GeV}^2/c^4$  from Eq. (2) is a measure of the continuum size. In addition to the fit error, the overall normalization has a total uncertainty of  $\pm 15\%$  due to event selection and the luminosity measurement.

If the exponent (*a*) in Eq. (2) is treated as a free parameter, we find  $a = 8 \pm 1$  with  $\chi^2 = 22.1$  for 25 degrees of freedom.

In the scaling model,  $F(\tau) = m^3 [d^2\sigma/dm dx]_{x=0}$  depends only on the dimensionless variable  $\tau$ . We have converted our data in the mass range not affected by resonances (4.5–8 and 12.5–17 GeV/c<sup>2</sup>). The result is shown in Fig. 3 and the solid line represents our continuum fit recast into the scaling form:

$$F(\tau) = m^3 \left[ \frac{d^2\sigma}{dm dx} \right]_{x=0} = (1.04 \pm 0.16) \times 10^{-32} \times (1 - \sqrt{\tau})^{10} \sqrt{\tau} \text{ cm}^2 \cdot \text{GeV}^2/c^4.$$

Our experiment overlaps with the Fermilab experiment<sup>11</sup> at  $\sqrt{\tau} \approx 0.2$ . Within the knowledge from use of nuclear targets and our statistical accuracy at masses above the  $T$ , scaling holds despite the fact that the cross sections differ by two orders of magnitude. However, as can be seen in Fig. 3, the phenomenological *Ansatz* used to describe the high-statistics, low-energy ( $\tau > 0.2$ ) Fermilab data<sup>11</sup> cannot be extended into the very small- $\tau$  region measured in this experiment. Finally it should be pointed out that the CERN intersecting-storage-rings electron pair data<sup>12</sup> are in good agreement with our measured  $F(\tau)$ .

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<sup>1</sup>J. J. Aubert *et al.*, Phys. Rev. Lett. **33**, 1404 (1974); S. W. Herb *et al.*, Phys. Rev. Lett. **39**, 252 (1977).

<sup>2</sup>S. D. Drell and T.-M. Yan, Phys. Rev. Lett. **25**, 316, 920(E) (1970).

<sup>3</sup>U. Becker *et al.*, Nucl. Instrum. Methods **128**, 593 (1975).

<sup>4</sup>A. Bechini *et al.*, Nucl. Instrum. Methods **156**, 181 (1978).

<sup>5</sup>See F. Carbonara *et al.*, CERN Report No. EP-79/121 (to be published).

<sup>6</sup>D. Antreasyan *et al.*, Phys. Rev. Lett. **37**, 1451 (1976); J. Branson *et al.*, Phys. Lett. **38**, 1334 (1977); K. J. Anderson *et al.*, Phys. Rev. Lett. **42**, 944 (1979); G. E. Hogan *et al.*, Phys. Rev. Lett. **42**, 948 (1979); C. B. Newman *et al.*, Phys. Rev. Lett. **42**, 951 (1979); J. J. Badier *et al.*, Phys. Lett. **89B**, 145 (1979).

<sup>7</sup>The model dependence of the acceptance calculation is small because most of the  $x$  and  $p_T$  range is covered.

<sup>8</sup>D. Antreasyan *et al.*, "Dynamics of High Mass Muon Pairs Produced at the ISR" (to be published).

<sup>9</sup>J. C. Collins and D. E. Soper, Phys. Rev. D **16**, 2219 (1977).  $\theta_{CS}$  is the angle between  $\mu^+$  and the average direction of the incident protons in the dimuon rest frame.

<sup>10</sup>K. Kinoshita *et al.*, Phys. Rev. D **17**, 1834 (1977).

<sup>11</sup>K. Ueno *et al.*, Phys. Rev. Lett. **42**, 486 (1979); J. K. Yoh *et al.*, Phys. Rev. Lett. **41**, 684 (1978).

<sup>12</sup>For excellent electron pair experiments at the CERN intersecting storage rings, see A. L. S. Angelis *et al.*, Phys. Lett. **87B**, 398 (1979); C. Kourkoumelis *et al.*, Phys. Lett. **91B**, 475, 481 (1980).