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MEASUREMENTS OF $\sigma(e^+e^- \to \mu^\pm\mu^\mp)$ IN THE ENERGY RANGE 1.2-3.0 GeV

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ABSTRACT

The analysis of 1,466 events of the type $e^+e^- \to \mu^\pm\mu^\mp$, in the time-like range from 1.44 to 9.00 GeV^2, shows that the absolute value of the cross-section and its energy dependence follow QED expectations within (±3.2%) and (±1.2%), respectively.

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Using the Frascati (e^+e^-) storage ring, we have measured the cross-section of the reaction

$$e^+e^- \rightarrow \mu^\pm\mu^\mp \tag{1}$$

at 14 values of the total centre-of-mass energy, from 1.2 to 3.0 GeV, as reported in Table 1.

In the one-photon approximation, reaction (1) is described by the diagram of Fig. 1, where the wavy line represents a time-like photon. Omitting accidental cancellations, the study of reaction (1) allows us to check at once if the photon propagator, the ($e\gamma$) vertex and the ($\mu\gamma$) vertex follow the standard QED prescriptions in the time-like range ($1.44 \leq s \leq 9.00$) GeV^2, which corresponds to the energy limits specified above. [$s = (2\ E)^2$; E is the colliding beam energy.]

The experimental apparatus was the Bologna-CERN-Frascati set-up, which has already been described[1]. It consisted of: i) thin-foil optical spark chambers for precise geometrical reconstruction; ii) heavy-plate spark chambers for particle identification; iii) plastic scintillator counters for precise time-of-flight (TOF) measurements[2]. This TOF technique was specially developed to a ($\pm$ 0.3) nsec level, in order to allow an efficient rejection of cosmic-ray muons[2], which are the most serious source of background for reaction (1).

The basic data of the present investigation are reported in Table 1, where, for each of the 14 values of the (e^+e^-) colliding beam energy, are quoted:

i) the corresponding number of (e^+e^-) electrons detected under the same experimental conditions as the ($\mu^+\mu^-$) pairs and with the same acollinearity angle $|R| \leq 10°$ [notice that R is the angle in space between the two final-state leptons and that R = 0 corresponds to a collinear pair (see later for the choice $|R| \leq 10°$)];

ii) the corresponding number of ($\mu^+\mu^-$) pairs with $|R| \leq 10°$;

iii) the corresponding number of ($\mu^+\mu^-$) events simulated by cosmic-ray background;

iv) and finally the values of the cross-section for process (1) integrated over the experimental apparatus.

The monitor for comparing reaction (1) with QED predictions was the process

$$e^+e^- \rightarrow e^\pm e^\mp , \tag{2}$$

detected in the same angular region as process (1), and the analysis was done using the same acollinearity, R, cuts for both electrons and muons. These cuts were chosen to be $|R| \leq 10°$ in order to minimize the background from multibody pion events[3] whilst restricting the loss of true events to a few per cent.

The data were corrected for first-order radiative effects using the peaking approximation[4].

Figures 2a and 2b show an example of acollinearity distribution at 1050 MeV colliding beam energy. The dotted line shows the theoretical expectations based on first-order radiative effects with peaking approximation and with the experimental resolution folded in. This check has been repeated at all energies, where a similar good agreement has been found between experimental data and theoretical expectations.

Having checked that at all 14 energies the experimental data follow the expected $|R|$-distribution, we have applied the first-order radiative corrections to all data for acollinearity ($|R| \leq 10°$) cuts at each energy. The values of the cross-section integrated over our solid angle, versus the time-like four-momenta transfer s, are shown in Fig. 3.

If the cross-section for process (1) is parametrized in the form

$$\sigma(e^+e^- \to \mu^+\mu^-) = A \cdot s^{-n} ,$$

the best fit to the data gives

$$A_{exp} = 15.87 \pm 0.48$$
$$n_{exp} = 1.000 \pm 0.012 ,$$

the theoretical predictions being

$$A^{QED}_{theor.} = 15.70$$

$$n = 1.000$$

We notice that the χ^2 of the fit, $\chi^2 = 10.75$, with $P(\chi^2) = 55\%$, is very satisfactory.

Since the time-like region has been opened to direct investigation, the use of cut-off parameters Λ's, has lost its reason for being. The use of Λ's, started when high precision[5] but low momentum transfer experiments [such as the muon (g-2) *)] were used in order to investigate a possible deviation of QED at much higher momen-momentum transfers. This comparison has always involved the use of models of QED breaking which are full of trouble.

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*) Using cut-off-like models[6] our results would correspond to an upper limit for the deviation of the muon magnetic moment of $\delta\mu/\mu \lesssim 3 \times 10^{-8}$.

We do think that a direct experiment on the time-like region has a unique meaning in terms of its straightforward comparison with QED predictions. To translate these results in terms of cut-off parameters of odd theoretical models of QED-breaking introduces only confusion. This is why we continue to quote our results without any reference to cut-off parameters.

Conclusions: In the time-like range ($1.44 \leq s \leq 9.00$) GeV^2 the energy dependence and the absolute value of the cross-section for the purely leptonic process (1) follow QED, with first-order radiative corrections included, to within ±1.2% and ±3.2%, respectively. Once again the muon is seen to be just a heavy electron coupled in the standard QED way to the electromagnetic field. In the specified energy range these are the best available data for the knowledge of process (1).

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5) See, for example, A. Zichichi et al., Proc. Internat. Conf. on High-Energy Physics, CERN, 1962 (CERN, Geneva, 1962), p. 476.

6) A. Peterman, private communication.

Table 1

Colliding beam energy E (MeV)	e^+e^- $R \leq 10°$	$\mu^\pm\mu^\mp$ $R \leq 10°$	Cosmic-ray background	$\mu^\pm\mu^\mp$ (background subtracted) $R \leq 10°$	$\sigma(e^+e^- \to \mu^\pm\mu^\mp)$ integrated over the apparatus (nb)
600	691	54	10	44	10.8 ± 1.7
700	843	60	12	48	7.2 ± 1.1
750	2,080	174	20	154	8.2 ± 0.8
800	1,470	132	36	96	5.6 ± 0.6
850	1,754	153	24	129	5.5 ± 0.6
925	1,178	95	11	84	4.4 ± 0.5
950	2,118	163	24	139	4.9 ± 0.5
970	668	46	3	43	3.8 ± 0.6
990	747	68	15	53	4.1 ± 0.6
1,050	4,650	398	86	312	3.6 ± 0.3
1,200	741	70	10	60	3.3 ± 0.5
1,300	1,680	135	26	109	2.4 ± 0.3
1,400	1,296	97	14	83	2.4 ± 0.3
1,500	1,797	147	35	112	1.5 ± 0.2
	21,713	1,792	326	1,466	

Figure captions

Fig. 1 : Feynman diagram of the process $e^+e^- \to \mu^\pm\mu^\mp$, in the one-photon approximation.

Fig. 2a : Acollinearity distribution for events of the type $e^+e^- \to \mu^\pm\mu^\mp$ at 1050 MeV colliding beam energy. The heavy histogram represents the experimental data, the dotted histogram the theoretical expectations based on first-order radiative corrections, as mentioned in the text.

Fig. 2b : An expanded scale of Fig. 2a, in order to show the tail of the $|R|$-distribution.

Fig. 3 : The values of $\sigma(e^+e^- \to \mu^\pm\mu^\mp)$ integrated over the experimental apparatus at the 14 values of the time-like four-momentum transfer s. First-order radiative corrections, using the peaking approximation, have been applied to the data, after a detailed check at each energy of the acollinearity distributions, as mentioned in the text. The solid line is the QED prediction.

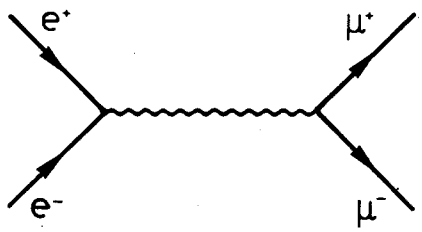

Fig. 1

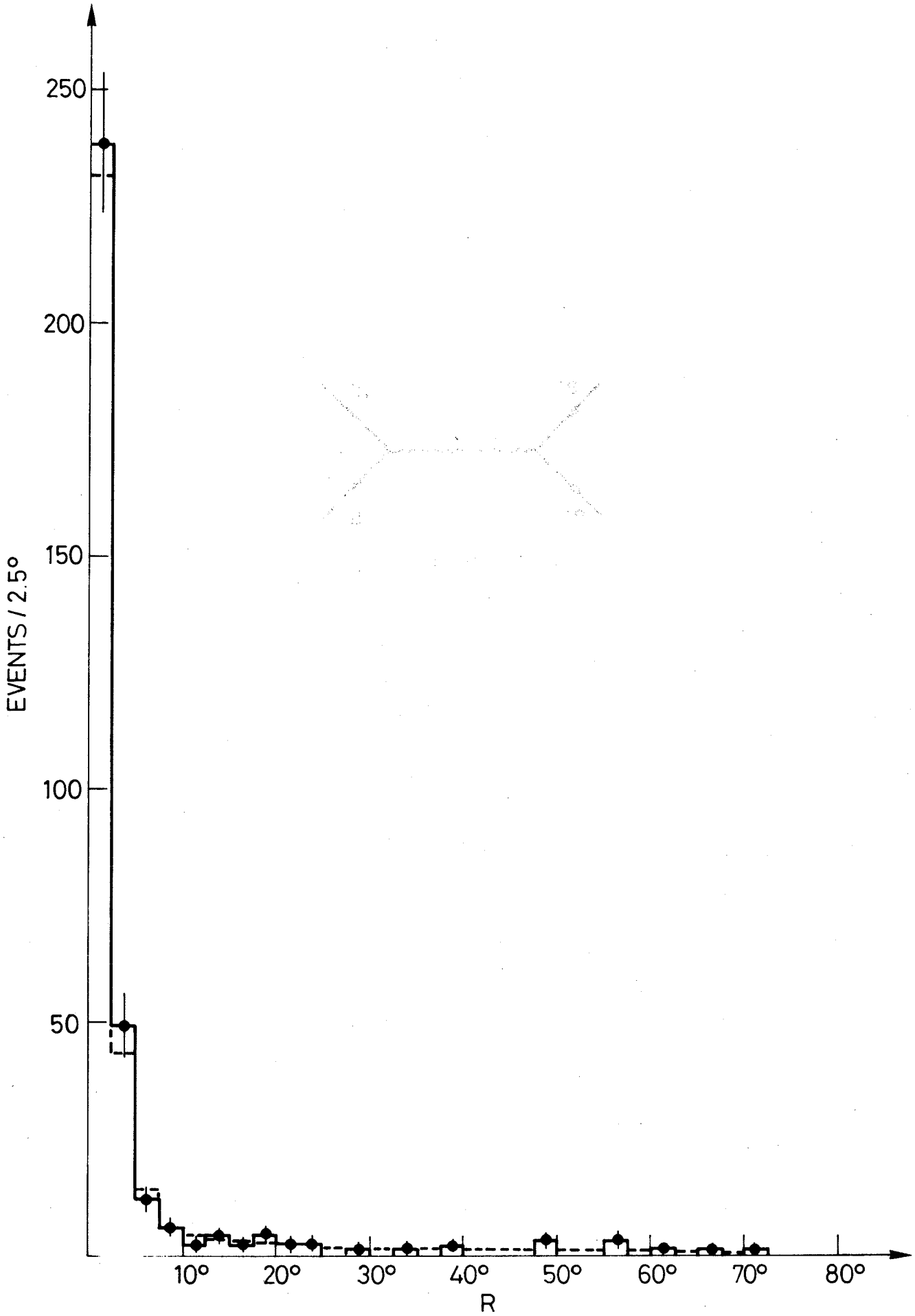

Fig. 2a

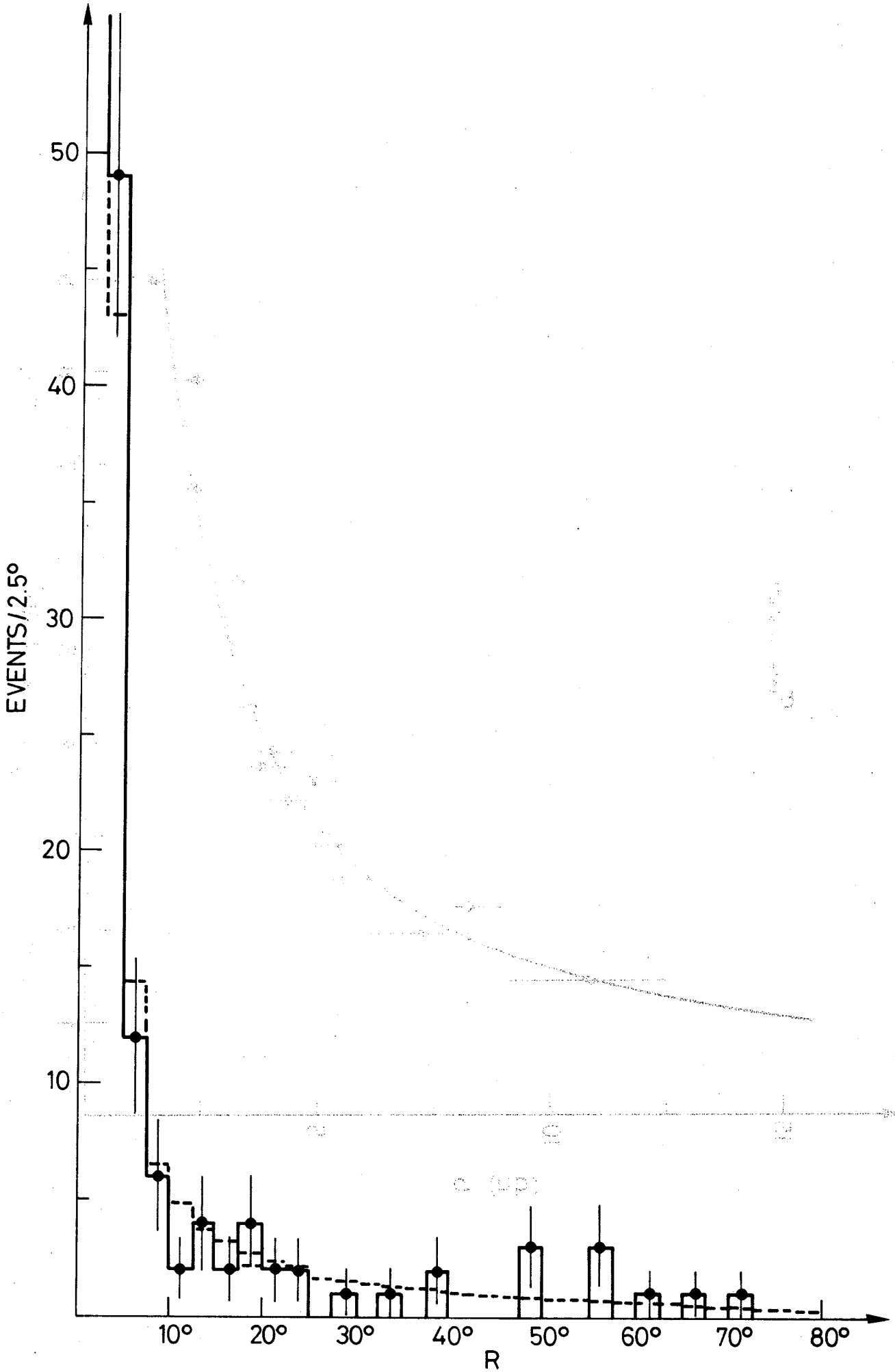

Fig. 2b

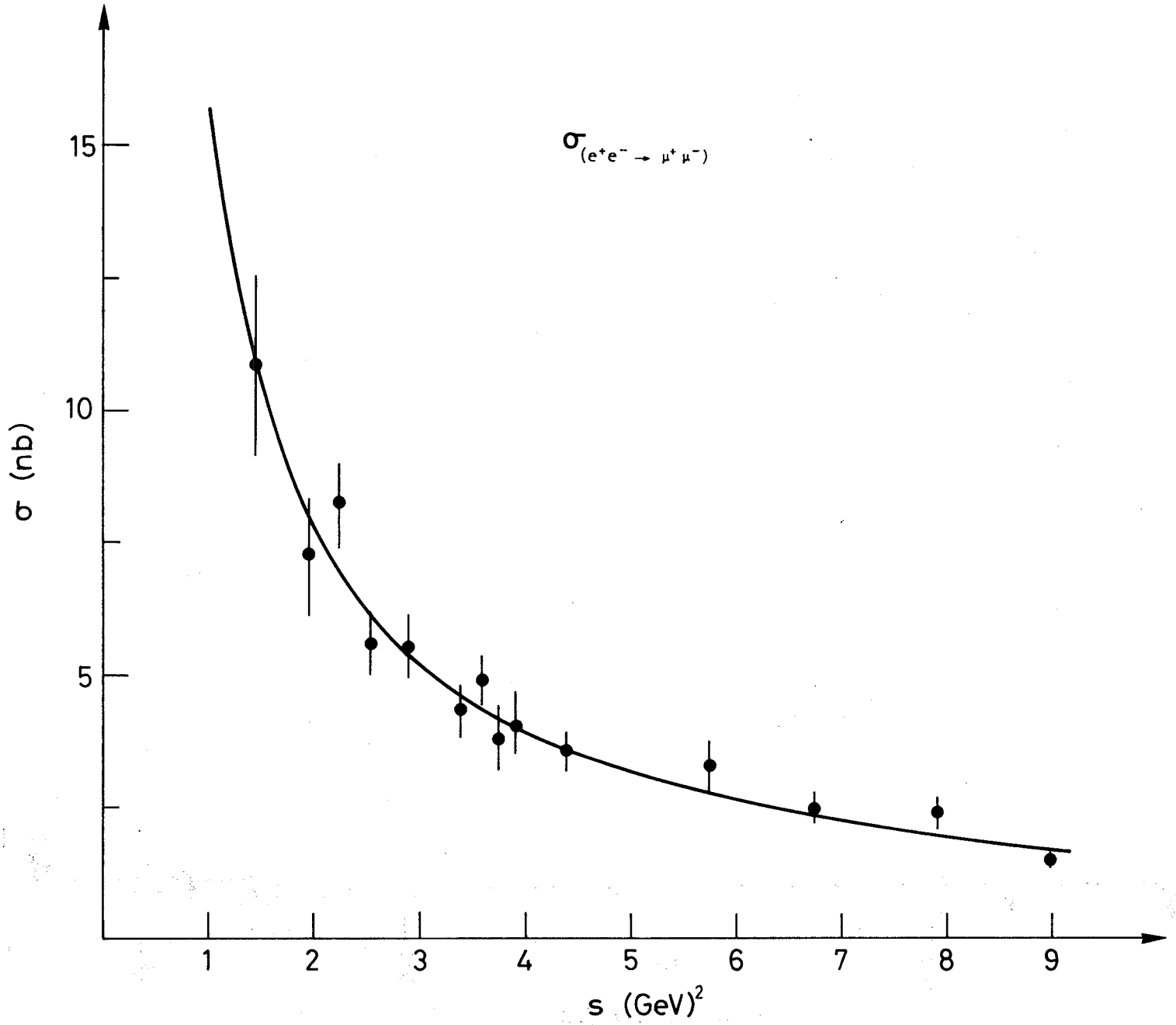

Fig. 3