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EVENT SHAPE IN MOMENTUM SPACE OF PROTON-PROTON INTERACTIONS AT 360 GeV/c AND COMPARISON TO e^+e^- DATA

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ABSTRACT

An analysis of event shape structure in momentum space is presented in non diffractive proton-proton interactions at $\sqrt{s}$ = 26 GeV. The data have been compared with those obtained in other low-p_T hadronic collisions and also with those from e^+e^- annihilations. The jet-like behaviour becomes more pronounced at higher cm energies in the low-p_T hadron data. There is, however, no evidence of 3-jet like events in the present data as observed in e^+e^- annihilations.

Striking similarities have been observed on the event shape (in momentum space) of particle collisions of different origin: e^+e^- annihilations, lepton-hadron collisions and low-p_T hadron interactions [1,2]. Whereas the jet behaviour which is observed in e^+e^- annihilations and deep inelastic lepton-hadron collisions is reasonably well understood in terms of a simple quark parton picture, the low-p_T hadron interactions present, a priori, a more complex situation. The similarities and differences which are observed between these two classes of interactions can therefore shed some light on the production mechanism at work in the latter one.

We present in this letter the results of an analysis made on proton-proton interactions at $\sqrt{s}$ = 26 GeV and compare them to e^+e^- annihilations at $\sqrt{s}$ = 29 GeV [3]. The proton data were obtained from the experiment NA23 performed at CERN using the Rapid Cycling Bubble Chamber (RCBC) coupled to the European Hybrid Spectrometer (EHS). RCBC, filled with liquid hydrogen, was exposed to a 360 GeV/c proton beam. A detailed description of the experimental set-up has been given elsewhere [4,5].

In this analysis, it is essential to deal with fully reconstructed events (i.e. the 3-momenta of all charged particles observed in the final state are accurately measured). To this aim, a sample of 24 000 events has been measured, reconstructed and properly weighted to compensate for the losses due to various cuts applied on the data in order to obtain a clean sample of fully reconstructed events. In order to present a meaningful comparison of our results with e^+e^- data, we have removed diffractive events (by introducing a cut on positive tracks: $|x_F| > 0.85$ and a cut on the rapidity gap between the fastest positive track and its neighbour: $\Delta y > 2.5$). Events with charged multiplicity $n_{ch} = 2$ are also removed.

To determine the 3-momenta of each secondary charged particle in the total cm system, the mass of these particles must be known. RCBC-EHS provides charged particle identification and this information is used here as described in details in [6]. When particle identification is missing, the pion mass is assumed. This assumption has no significant effect on the conclusions of the present analysis.

To study the shape of the events in the 3-momentum space, we follow the classical procedure [7] by defining for each event a 3 x 3 real symmetric matrix Q with

$$Q^{\alpha\beta} = \sum_{i=1}^{n} p_i^\alpha p_i^\beta \qquad (\alpha,\ \beta = 1,\ 2,\ 3),$$

n being the number of secondary charged particles in the event and $p_i = (p_i^1, p_i^2, p_i^3)$ the 3-momentum of particle i in the cm system. Diagonalizing Q one gets the eigenvectors $\hat{z}_k$ with the associated normalized eigenvalues Q_k ordered in such a way that

$$Q_1 > Q_2 > Q_3.$$

Q1 measures the "length" along $\hat{z}_1$, the principal axis of the event. Q_2 corresponds to its "width" and Q_3 to its "flatness". The "sphericity" is then given by

$$S = \frac{3}{2}(1 - Q_1) = \frac{3}{2}(Q_2 + Q_3).$$

A jet-like event is expected to have $S \to 0$.

Fig. 1 shows the sphericity distribution obtained for the non-diffractive proton-proton interactions. It is compared to 29 GeV e^+e^- data [3]. This comparison underlines the global similarity observed between the two classes of interactions. The small difference at low sphericity can be attributed to the 3-jet events present in the e^+e^- data (see later in text).

To exploit the other dimensions we present in fig. 2 the scatter plot of the two independent variables

$$x = \frac{3}{2}(Q_2 + Q_3), \qquad y = \frac{\sqrt{3}}{2}(Q_2 - Q_3).$$

In this plot, the "spherical" events ($Q_1 \simeq Q_2 \simeq Q_3$) accumulate near S, the "cigar" shaped events ($Q_1 \simeq 1$, $Q_2 \simeq Q_3 \simeq 0$) near C and the "disc" shaped ones near D. Coplanar events lie along CD ($Q_3 \simeq 0$). The region with $x \equiv S > 0.25$ and $Q_3 \leq 0.10$ is usually taken as the 3-jet enriched part of the plot. In e^+e^- annihilation at 29 GeV, a secondary density maximum is observed in this region. This is not the case of proton-proton interactions which exhibit only one clear density maximum near C.

One finds for the average values of Q_1, Q_2, Q_3 the values

$$\langle Q_1\rangle(26\ \mathrm{GeV}) = (0.920 \pm 0.003)$$

$$\langle Q_2\rangle(26\ \mathrm{GeV}) = (0.058 \pm 0.002)$$

$$\langle Q_3\rangle(26\ \mathrm{GeV}) = (0.025 \pm 0.001)$$

to be compared, respectively, to

$$\langle Q_1\rangle(11.5\ \mathrm{GeV}) = (0.853 \pm 0.001)$$

$$\langle Q_2\rangle(11.5\ \mathrm{GeV}) = (0.112 \pm 0.001)$$

$$\langle Q_3\rangle(11.5\ \mathrm{GeV}) = (0.035 \pm 0.001)$$

obtained for 70 GeV/c K^+p interactions ($\sqrt{s}$ = 11.5 GeV) [8]. One notes an increase of the length of the events with increasing energy, with a simultaneous decrease of their width and flatness.

To investigate more closely the transversal properties of the events, we show in fig. 3 the distributions of the two variables

$$\langle p_T^2\rangle_{out} = \frac{1}{n} \sum_{i=1}^{n} (\vec{p}_i \cdot \hat{z}_3)^2 .$$

and

$$\langle p_T^2\rangle_{in} = \frac{1}{n} \sum_{i=1}^{n} (\vec{p}_i \cdot \hat{z}_2)^2$$

$\langle p_T^2\rangle_{out}$ is not sensitive to the presence of 3-jet events and reflects mainly the intrinsic p_T properties of the partons, whereas $\langle p_T^2\rangle_{in}$ is expected to develop a tail at large values of $\langle p_T^2\rangle_{in}$ if 3-jet like events are present. The comparison with e^+e^- data [3] shows again similarities between the two classes of interactions (fig. 3(a)) for $\langle p_T^2\rangle_{out}$ but, in contrast, exhibits a clear difference for $\langle p_T^2\rangle_{in}$ (fig. 3(b)). It is natural to attribute this difference to the appearance of 3-jet events in e^+e^- data at this energy. This evolution of e^+e^- data as $\sqrt{s}$ increases is not observed for hadron interactions in the same range of energy: no significant difference is observed for the $\langle p_T^2\rangle_{in}$ distributions between K^+p data at $\sqrt{s}$ = 11.5 GeV and our pp data at $\sqrt{s}$ = 26 GeV.

The analysis of the shape in momentum space of the proton-proton interactions at $\sqrt{s}$ = 26 GeV and the comparison of the results of those obtained on hadron interactions at $\sqrt{s}$ = 11.5 GeV lead to the conclusion that the jet-like characteristics of the events become more pronounced as the energy increases. However, the comparison to e^+e^- data shows that the occurence of 3-jet events is specific of e^+e^- data and not of hadronic interactions at these energies. This confirms the $Sp\bar{p}S$ collider finding [9] that in hadronic interactions up to $\sqrt{s} \simeq 25$ GeV very little room is left for configurations other than those predicted by a p_T - limited phase space. A more complete comparison will be published elsewhere [10].

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FIGURE CAPTIONS

Fig. 1 Sphericity distribution for non diffractive proton-proton interactions at $\sqrt{s}$ = 26 GeV (black dots) and for e^+e^- interactions at $\sqrt{s}$ = 29 GeV (crosses) [3].

Fig. 2 Scatter plot of $\sqrt{3}/2\ (Q_2 - Q_3)$ versus $3/2\ (Q_2 + Q_3)$ for non diffractive proton-proton interactions at $\sqrt{s}$ = 26 GeV (Q_2 gives a measure of the "width" of the event, Q_3 a measure of its "flatness").

Fig. 3 Distribution of $\langle p_T^2 \rangle_{out}$ [(a)] and $\langle p_T^2 \rangle_{in}$ [(b)] for non diffractive proton-proton interactions at $\sqrt{s}$ = 26 GeV (black dots) compared to e^+e^- data (crosses) [3].

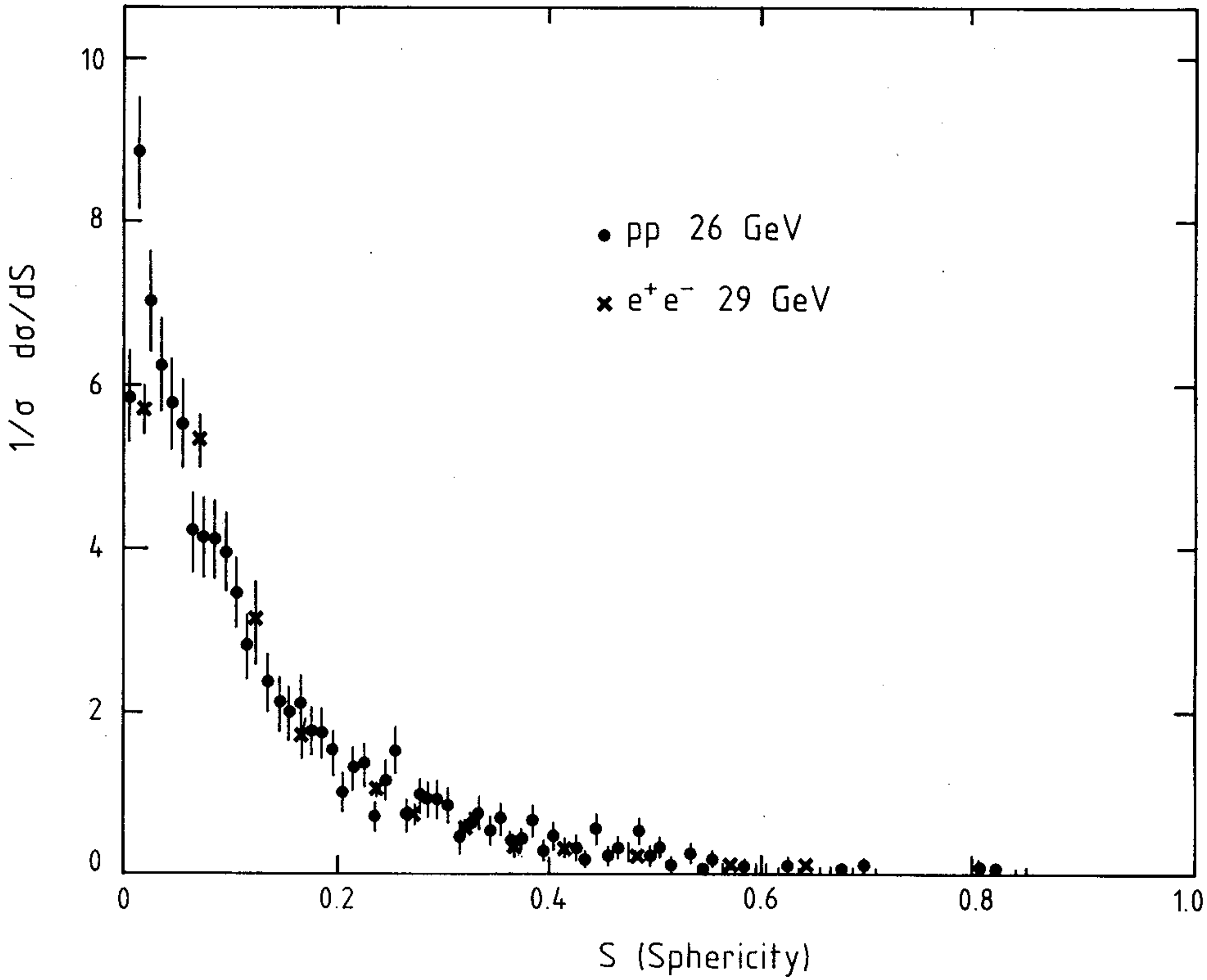


FIG. 1

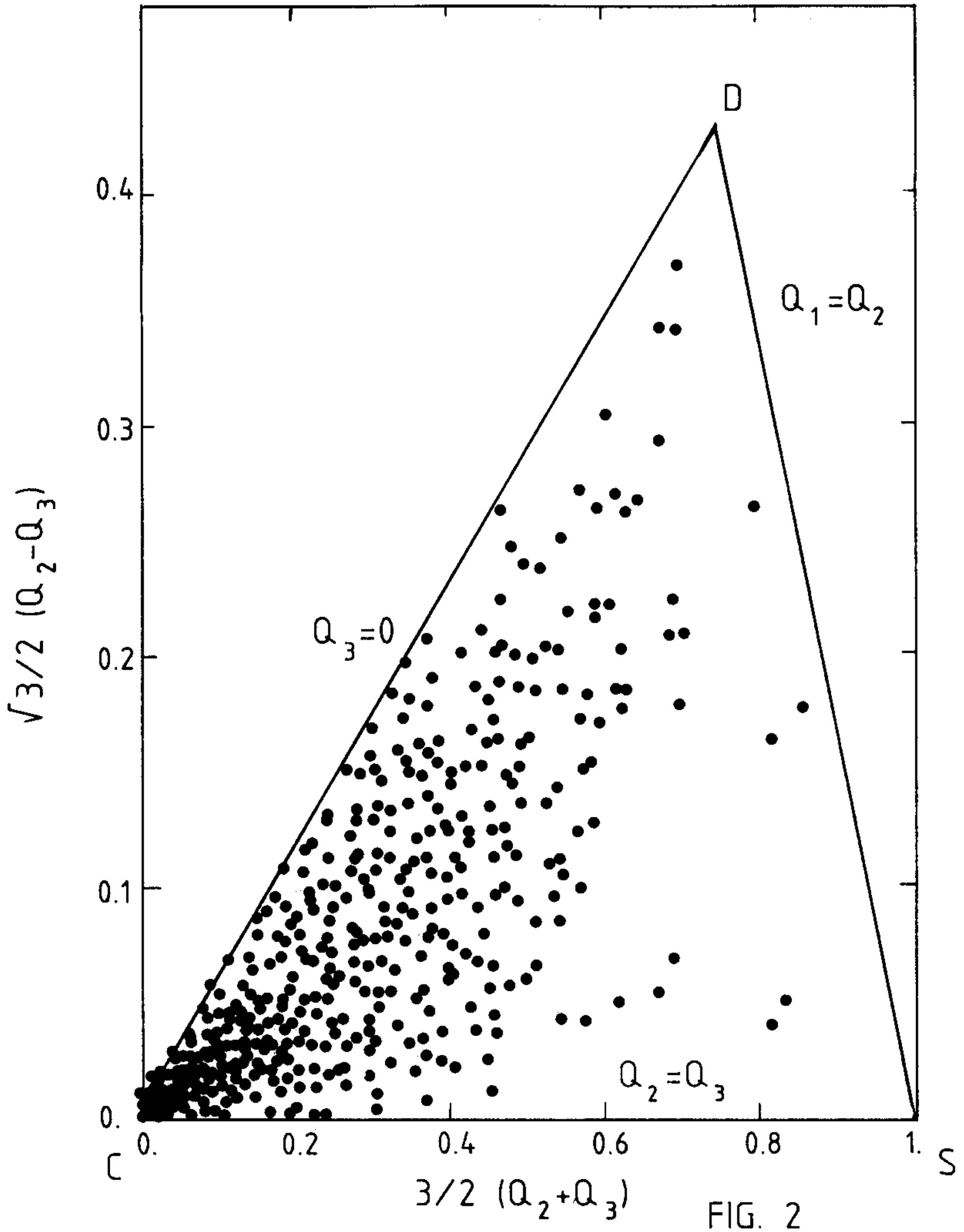
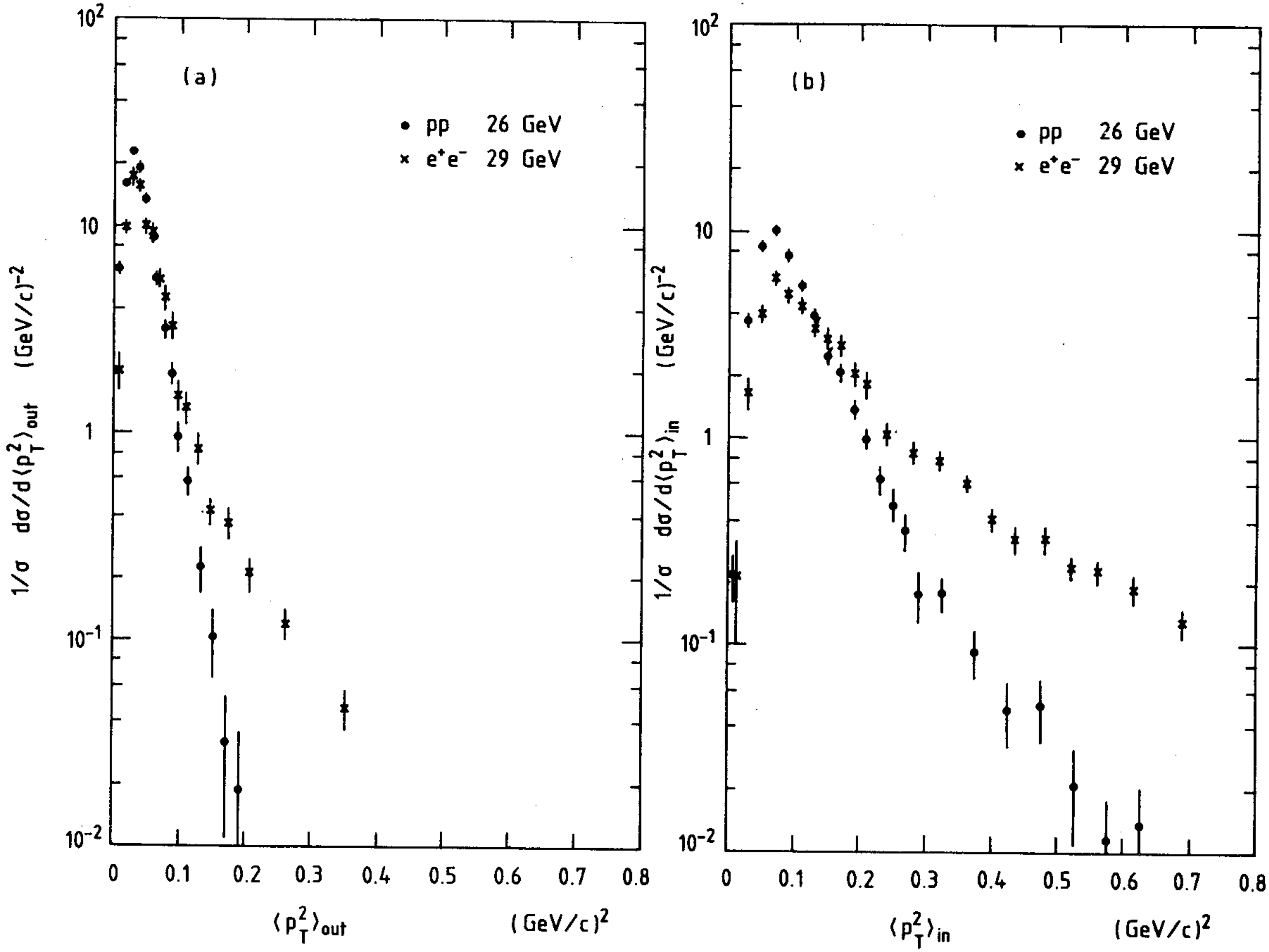


FIG. 2



(a)
• pp 26 GeV
× e⁺e⁻ 29 GeV
1/σ dσ/d⟨p_T^2⟩_out (GeV/c)^-2
⟨p_T^2⟩_out (GeV/c)^2
(b)
• pp 26 GeV
× e⁺e⁻ 29 GeV
1/σ dσ/d⟨p_T^2⟩_in (GeV/c)^-2
⟨p_T^2⟩_in (GeV/c)^2

Fig. 3