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by

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Indications of $b\bar{b}$ Production and Decay at PETRA

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We present a jet analysis of the high energy e^+e^- data in the region 9.4 GeV $\leqslant E_{CM} \leqslant$ 17.0 GeV measured recently at DORIS and PETRA. The event topology is well explained if one includes $b\bar{b}$ pair production and decay at PETRA energies.

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Recent experiments have shown that the hadronic final states in e^+e^--annihilation consist predominantly of two back-to-back jets at centre of mass energies (E_{CM}) larger than 5 GeV [1]. These jets are characterized by a limited transverse momentum of the hadrons in the jet relative to the jet axis with a $\langle p_T \rangle \sim 0.3$ GeV. Since the multiplicity is rising logarithmically, one anticipates the jet angular width to decrease as $\frac{p_T}{p_{\parallel}} \sim \frac{\ln E_{CM}}{E_{CM}}$. The jet analysis at SPEAR [1] and DORIS [1,2] confirm this trend.

When a new quark threshold is crossed the topology of events is expected to change. This comes about since near the threshold the $Q\bar{Q}$ production is dominated by a heavy meson pair production ($H\bar{H}$, $H\bar{H}^*$ etc.). The lightest of these heavy hadrons is stable against strong interactions and decays weakly, through the mechanism ($H = Q\bar{q}$)

$$Q \longrightarrow \begin{matrix} q' \ell^{\pm} \nu_{\ell} \\ q' \bar{q} q \end{matrix}$$

Depending upon the form of the weak current, the quark q' may decay further, thus giving rise to an almost isotropic distribution near the $Q\bar{Q}$ threshold.

The quantitative studies of the event topology in e^+e^--experiments are done through the measurement of scalar jet measures which characterize the "jettiness" of a typical e^+e^--event. Among these are sphericity [3], thrust [4] and acoplanarity [5].

We present a jet analysis, using a quark pair production model, of the recent e^+e^- data in the energy range 9.4 GeV $\leq E_{CM} \leq$ 17.0 GeV, measured recently at DORIS [2] and PETRA [6,7]. The sphericity distribution measured by the PLUTO group at 9.4 GeV [2] is well described by our model for charm pair production and subsequent weak decays. We compare our model calculation with the experimental sphericity and thrust distributions measured at 13.0 and 17.0 GeV by the PLUTO [6] and TASSO [7] groups at PETRA. The data is well explained if one <u>includes</u> $b\bar{b}$ pair production and decay at 13.0 and 17.0 GeV, with the $b\bar{b}$ threshold lying in the energy range 9.4 GeV $< E_{CM} <$ 13.0 GeV.

Our basic framework for the weak decays of charm and bottom quarks is the current x current interaction with the charged current given by the six quark V-A model, first written down by Kobayashi and Maskawa (KM) [8]. For the charm quark we assume the dominant GIM coupling [9]:

$$c \rightarrow s + u + \bar{d}$$

and for the bottom the decay chain

$$b \rightarrow c + \bar{u} + d$$
$$\qquad \hookrightarrow s + u + \bar{d}$$

Thus we describe the $c\bar{c}$ production and decay by an effective six quark final state and the $b\bar{b}$ production and decay through a 10 quark state. To be definite we have assumed the following masses for the quarks.

m_b = 5.0 GeV

m_c = 1.8 GeV

m_s = 0.5 GeV

$m_u = m_d = 0$

The results presented in this paper however are not very sensitive to the precise value of these masses. The production process $e^+e^- \longrightarrow Q\bar{Q}$ is given by the lowest order one photon exchange diagram and is described by the Lorentz-invariant density matrix element:

$$|m|^2 = \frac{\alpha^2}{q^4}\left\{(\ell_+ p_1)(\ell_- p_2) + (\ell_+ p_2)(\ell_- p_1) + \frac{m_Q^2 q^2}{2}\right\} \qquad (1)$$

with the normalization:

$$\sigma = \frac{1}{(2\pi)^2}\int \frac{d^3p_1\, d^3p_2}{8E_1E_2 q^2}\, |m|^2\, \delta^4(\ell_+ + \ell_- - p_1 - p_2) \qquad (2)$$

Here $\ell_-(\ell_+)$ is the electron (positron) four-momentum and $p_1(p_2)$ is the four-momentum of the heavy quark $Q(\bar{Q})$ $q = (p_1 + p_2) = (\ell_+ + \ell_-)$ and m_Q is the heavy quark mass.

The dynamics of the 3-jet decay process

$$Q(p) \longrightarrow q_1(q_1) + \bar{q}_2\,(q_2) + q_3\,(q_3)$$

is computed from the following Lorentz-invariant density matrix element according to a (V-A) interaction [10]:

$$|m_{weak}|^2 = 64\, G_F^2\, (q_1 \cdot q_3)(p \cdot q_2) \qquad \text{(c quark decay)} \qquad (3)$$

and

$$|\mathcal{M}_{weak}|^2 = 64 G_F^2 (q_1 \cdot q_2)(p \cdot q_3) \qquad \text{(b quark decay)} \qquad (4)$$

with the normalization:

$$\Gamma = \frac{1}{(2\pi)^5} \int \frac{d^3q_1 \, d^3q_2 \, d^3q_3}{(16\, m_Q E_1 E_2 E_3)} \, \delta^4(p - q_1 - q_2 - q_3) \, |\mathcal{M}_{weak}|^2 \qquad (5)$$

Here G_F is the Fermi coupling constant $G_F = 1.02 \times 10^{-5} m_p^{-2}$.
One should also take into account the fact that the heavy quark looses some of its longitudinal momentum prior to its weak decay by fragmenting off ordinary hadronic matter. We shall describe this by an effective quark fragmentation function $D_Q^H(z)$ of Q fragmenting into a heavy meson H, where

$$z = |p_H| / |p_Q| \qquad (6)$$

with the normalization (of 1 H per Q):

$$\int_0^1 D_Q^H(z)\, dz = 1 \qquad (7)$$

The hadronic fragmentation process also introduces transverse momentum components on the scale of the non-perturbative $\langle p_T \rangle \sim$ 0.3 GeV. Compared to the transverse momentum scales provided by the bottom weak decays, these non-perturbative transverse components can be neglected. However, for the $c\bar{c}$ production, the non-perturbative p_T cannot be neglected since $\langle p_T \rangle_{\text{non perturbative}} \simeq \langle p_T \rangle^{c\bar{c}}_{\text{weak decay}}$. We take this into account for $c\bar{c}$ by folding the weak distributions with a non-perturbative distribution given by

$$D(p_T) = b\, e^{-b p_T^2} \qquad (8)$$

with $b = 12\ \mathrm{GeV}^{-2}$

For the numerical calculations we used a Monte Carlo phase space program to generate the process $e^+e^- \longrightarrow Q\bar{Q}$ with the density matrix (1) at a given center of mass energy. Next, we implement the fragmentation procedure with a fragmentation function for each quark separately. Then events are generated for the decay process $H = Q\bar{q} \longrightarrow (q_1 + \bar{q}_2 + q_3)\bar{q}$ in the rest frame of the heavy hadron H described by (3) or (4). Finally, the events are Lorentz-boosted to the frame of their respective hadrons. For bottom quark the process of fragmentation and weak decay is repeated to implement the cascade decay

$$b \longrightarrow \underbrace{c}_{\longrightarrow\ s + u + \bar{d}} + \bar{u} + d$$

Having described our model for the description of the heavy quark production and their subsequent weak decays, all we need to make a comparison with the experimental data is the inclusion of the light (u,d,s) quark pair production in e^+e^- annihilation experiments. This is done by using the Feynman-Field Monte Carlo program, which describes the light quarks'(hadrons) phenomenology adequately [11]. The normalization of each $Q\bar{Q}$ pair without taking into account any acceptance cuts is fixed by the charge formula (σ_0 is the lowest order hadronic cross section).

$$\frac{\sigma_{Q_a \bar{Q}_a}}{\sigma_0} = \frac{Q_a^2}{\sum_{i=1}^{n} Q_i^2} \qquad (9)$$

where n is the number of flavours whose threshold have been crossed.

Before comparing our results with the data we would like to point out that the trigger and selection criteria of the PLUTO and TASSO groups are different. In particular, the acceptance has a non-trivial effect on both the distributions and average quantities like thrust and sphericity due to the (u,d,s) quark pair production. We have, therefore, used the acceptance corrected Feynman-Field distributions from PLUTO and TASSO for comparison with their respective data. We have, however, not corrected the distributions due to charm and bottom which, because of the large multiplicity from charm and bottom, are not expected to change very much.

In Fig. 1 we compare the sphericity distribution measured at E_{CM} = 9.4 GeV by the PLUTO group at DESY. Note that the contribution of the light (u,d,s) quarks calculated à la Feynman-Field falls off more steeply as compared to the data. For comparison we show the $c\bar{c}$ distribution (normalized to 4/10) using a charm quark fragmentation

$$D_c^D(z) = 2(1-z) \tag{10}$$

The data is well described by adding the two contributions. We would like to remark that a satisfactory fit is also obtained with the choice

$$D_c^D(z) = 1 \tag{11}$$

The choice (10) and (11) are favoured by the recent inclusive D-meson momentum measurement in e^+e^- experiments [12] and an analysis of the ν-induced dimuon events [13]. The p_T distribution measured at 7.4 GeV at SPEAR [1] and at 9.4 GeV at DORIS [2] are also well described by the $c\bar{c}$

component as calculated above. This comparison together with a more detailed account of the present work will be published elsewhere [14].

In Figs. 2 (a) and (b) we compare the distribution $\frac{1}{\sigma_0}\frac{d\sigma}{dS}$ measured at 13.0 GeV by the PLUTO and TASSO groups at PETRA. The light quark (u,d,s) and the charm quark distributions are calculated as stated above. The cuts due to acceptance and selection criteria have been taken into account. The cuts on the data reduce the (u,d,s) components by $\sim$ 20 % and increase the $\langle S \rangle$. We find the data is well described if we take into account $b\bar{b}$ pair production, which gives a very isotropic distribution at 13.0 GeV, resulting in flatter sphericity and thrust distributions. The same distributions at 17.0 GeV are compared in Figs. 3a and b. Since 17 GeV lies much above the $b\bar{b}$ threshold, we have taken into account the fragmentation of the b quark by assuming a fragmentation function

$$D_b^B(z) = 2z \qquad (12)$$

Again the excess of large sphericity events on top of the u,d,s quarks is noticeable (more so in the TASSO data) and a very satisfactory fit is obtained by including the $c\bar{c}$ and $b\bar{b}$ contributions. We remark that the choice (12) is not essential and a good fit is obtained also by assuming $D_b^B(z)$ = constant. In Figs. 4 and 5 we compare $\langle S \rangle$ and $\langle T \rangle$ respectively as a function of E_{CM} with the PLUTO and TASSO data. We remark that the measured $\langle S \rangle$ and $\langle T \rangle$ at 13.0 and 17.0 GeV lie much above the acceptance corrected Feynman-Field (u,d,s) contribution. The agreement improves if one adds the $c\bar{c}$ component but the best fit is obtained by adding the $b\bar{b}$ contribution as well [F1].

We would like to comment on the energy dependence of $\langle S \rangle$ and $\langle T \rangle$ in the interval 9.4 GeV $\lesssim E_{C.M.} \lesssim$ 17.0 GeV. The PLUTO group quotes 0.82 $\pm$ 0.01, 0.82 $\pm$ 0.01, 0.84 $\pm$ 0.01 for $\langle T \rangle$ and 0.27 $\pm$ 0.01, 0.26 $\pm$ 0.02, 0.22 $\pm$ 0.02 for $\langle S \rangle$ measured at 9.4, 13.0 and 17.0 GeV, respectively. Note that both $\langle S \rangle$ and $\langle T \rangle$ are almost identical at 9.4 GeV and 13.0 GeV whereas $\langle S \rangle$ decreases and $\langle T \rangle$ increases between 13.0 GeV and 17.0 GeV. On the other hand, one anticipates a monotonic decrease in $\langle S \rangle$ and increase in $\langle T \rangle$ with energy in a two jet process with fixed p_T and a logarithmically rising multiplicity [F2]

We would like to interpret the constancy of $\langle S \rangle$ and $\langle T \rangle$ as seen at 9.4 GeV and 13.0 GeV, as well as the flatter distributions in $\frac{1}{\sigma_0} \frac{d\sigma}{dS}$ and $\frac{1}{\sigma_0} \frac{d\sigma}{dT}$ in comparison with a 2 jet production as a very clear indication of the onset of a $b\bar{b}$ threshold in the energy region 9.4 GeV $< E_{C.M.} <$ 13.0 GeV.

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[F1] The PLUTO detector acceptance and the selection criterion modifies the Feynman-Field (u,d,s) sphericity distribution appreciably. For example $\langle S_{(u,d,s)} \rangle$ increases from 0.11 to 0.17 at 17.0 GeV. The corresponding acceptance effect for the TASSO detector is rather mild, with $\langle S_{(u,d,s)} \rangle$ increasing only to $\sim$ 0.12. Our theoretical distributions for the charm and bottom quarks can therefore be readily compared with the TASSO data. On the other hand, the charm distributions are expected to become somewhat broader due to the PLUTO acceptance cuts. This tends to increase $\langle S \rangle$ and $\langle 1-T \rangle$ slightly.

[F2] The numbers quoted by the PLUTO group are without taking into account QED radiative correction due to bremsstrahlung off the initial electron or positron. The radiative corrections should change the distribution in the small S or large T region. However, the excess of large S events is very unlikely from this effect.

References

1 G.G. Hanson et al., Phys. Rev. Lett. 35 (1975) 1609;
Ch. Berger et al., Phys. Lett. 78B (1978) 176;
G.G. Hanson, SLAC Reports SLAC-PUB 1814 (1976), SLAC-PUB-2118 (1978) and Proceedings of the 13th Recontre dé Moriond on High Energy Leptonic and Hadronic Interactions, Les Arcs, March 12-24, 1978.

2 Ch. Berger et al., PLUTO collaboration, DESY Report, DESY 78/71 and Phys. Lett. (to be published).

3 J.D. Bjorken and S.J. Brodsky, Phys. Rev. D1 (1970) 1416.

4 H. Georgi, M. Machacek, Phys. Rev. Lett. 39 (1977) 1237;
see also S. Brandt et al., Phys. Lett. 12 (1964) 57.

5 A. de Rujula, J. Ellis, E.G. Floratos and M.K. Gaillard, Nucl. Phys. B138 (1978) 387.

6 Ch. Berger et al., PLUTO collaboration, DESY Report 79/11 (1979)

7 R. Brandelik et al., TASSO collaboration; DESY Report 79/14 (1979)

8 M. Kobayashi and K. Maskawa, Prog. Theor. Phys. 49 (1973) 652.

9 S.L. Glashow, J. Iliopoulos and L. Maiani, Phys. Rev. D2 (1970) 1285.

10 A. Ali, J. Körner, G. Kramer, J. Willrodt, DESY Report 78/47 and to be published in Z.f. Physik C.

11 R.D. Field and R.P. Feynman, Nucl. Phys. B136 (1978) 1.

12 Lead Glass Wall Collaboration, Proceedings of the XIX International Conference on High Energy Physics, Tokyo, Japan (1978)

13 R. Odorico, Phys. Lett. 71B (1977) 121

14 A. Ali, J. Körner, G. Kramer, J. Willrodt, DESY Report (in preparation)

Figure Captions

Fig. 1: Comparison of PLUTO sphericity distributions [2] at E_{CM} = 9.4 GeV with model calculation.

-.-.- acceptance corrected Feynman-Field sphericity distribution for u,d,s quarks with the normalization 6/10

---- charm distribution with the fragmentation function $D_c^D(z) = 2(1-z)$ and normalization 4/10

—— sum of u,d,s and charm quark contributions

Fig. 2: Comparison of sphericity distributions at 13.0 GeV with a) PLUTO data [6], b) TASSO data [7]

- - - acceptance corrected Feynman Field distribution for u,d,s quarks plus charm, normalized to the data points

-.-.- bottom contribution normalized to 1/11

—— sum of u,d,s,charm and bottom quark contributions normalized to the data points

Fig. 3: Sphericity distributions at 17.0 GeV, with the same definitions as in Fig. 2.

Fig. 4: $\langle S \rangle$ as a function of E_{CM}.
a) PLUTO data [6], b) TASSO data [7]

- - - acceptance corrected Feynman Field $\langle S \rangle$ for (u,d,s) quarks

—— sum of u,d,s, charm and bottom quark contributions

Fig. 5: $\langle 1-T \rangle$ as a function of E_{CM}, with the same definitions as in Fig. 4, compared with the PLUTO data [6].

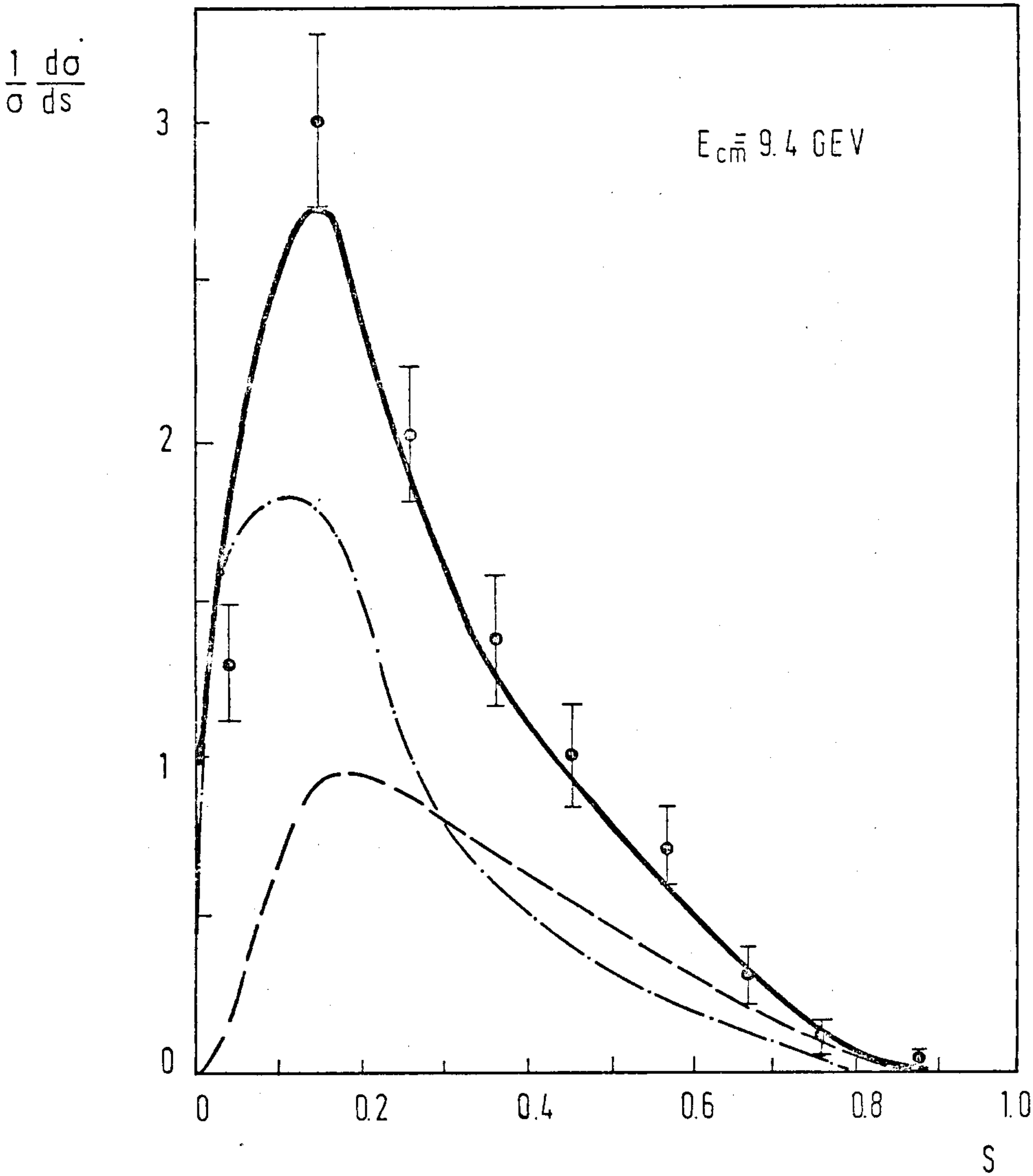
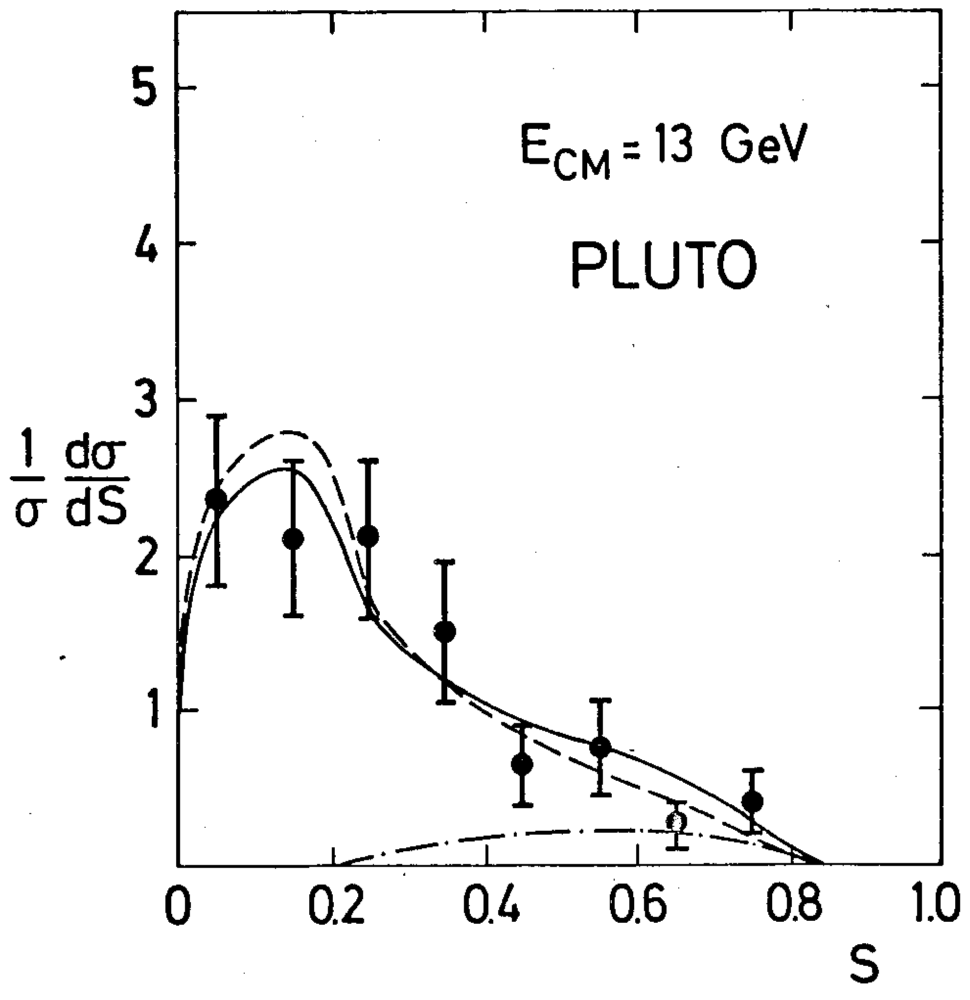
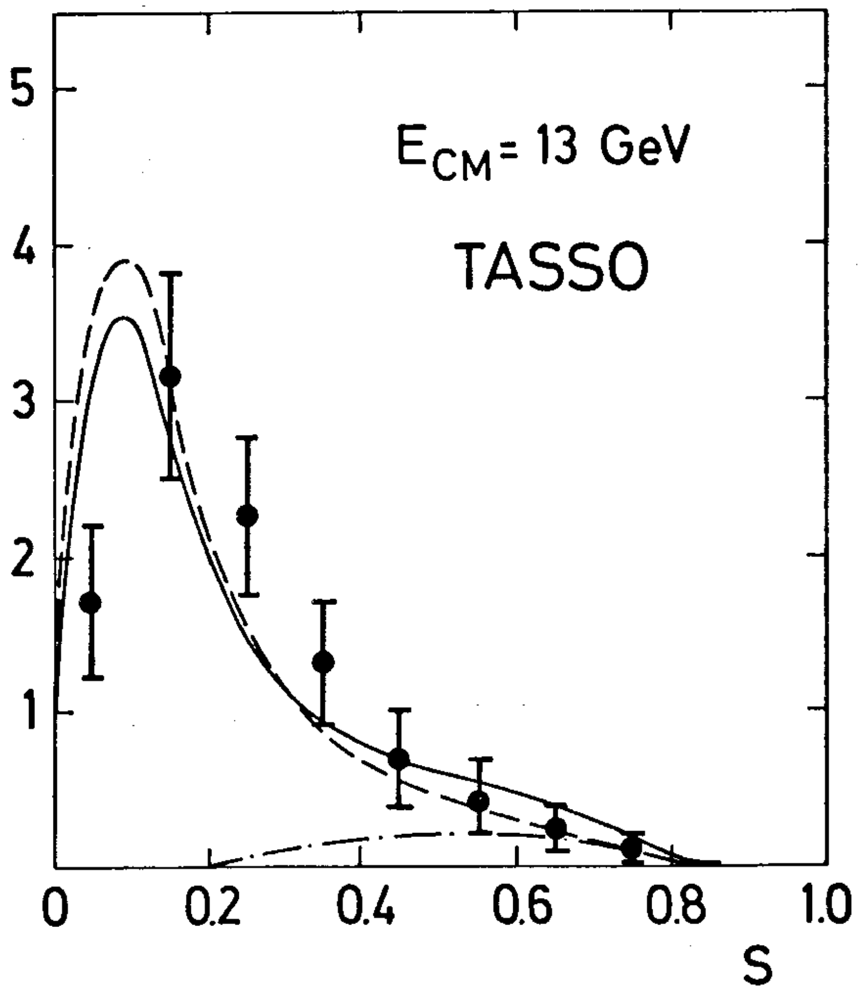


FIG.1



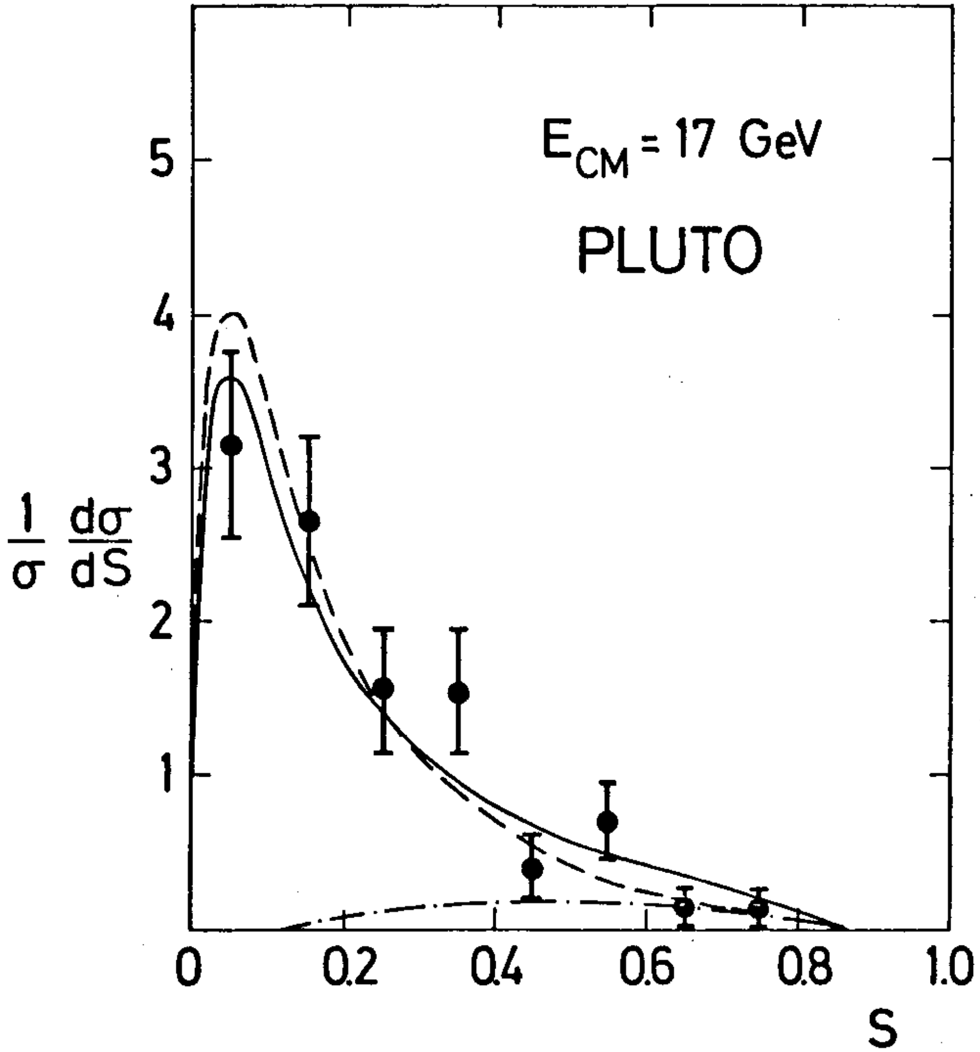
$\frac{1}{\sigma}\frac{d\sigma}{dS}$
E_{CM} = 13 GeV
PLUTO
S

Fig. 2a



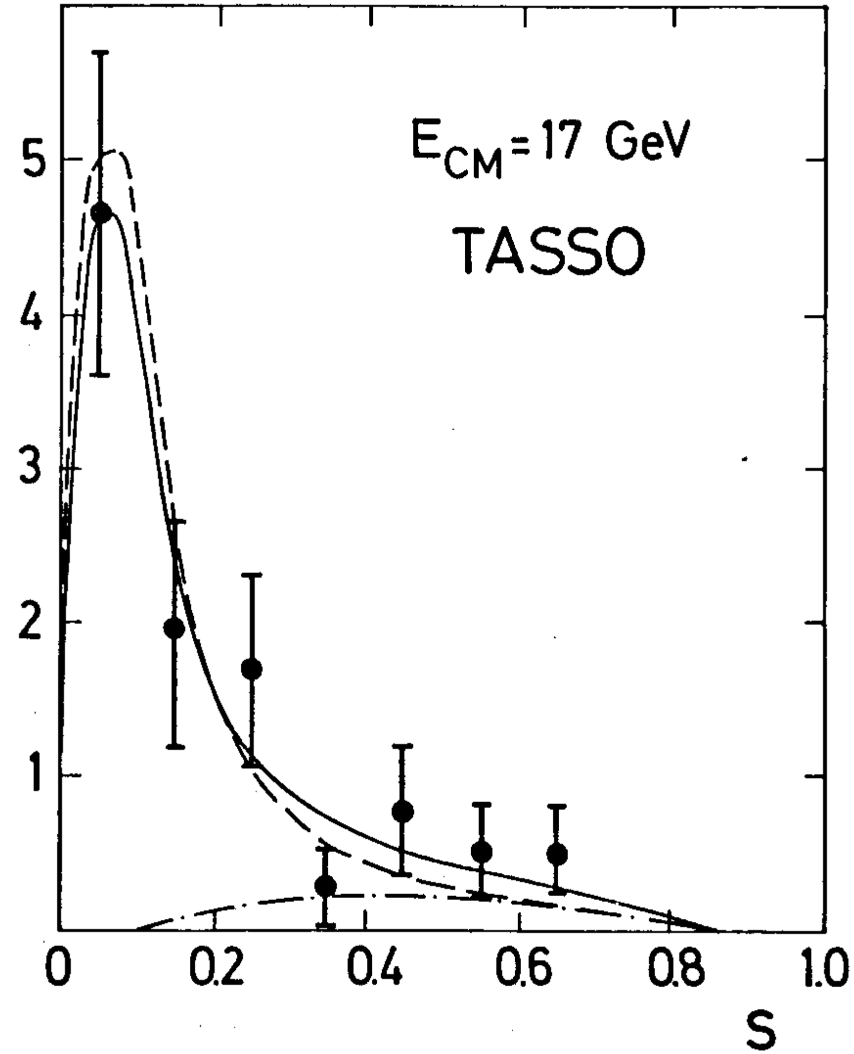
E_{CM} = 13 GeV
TASSO
S

Fig. 2b



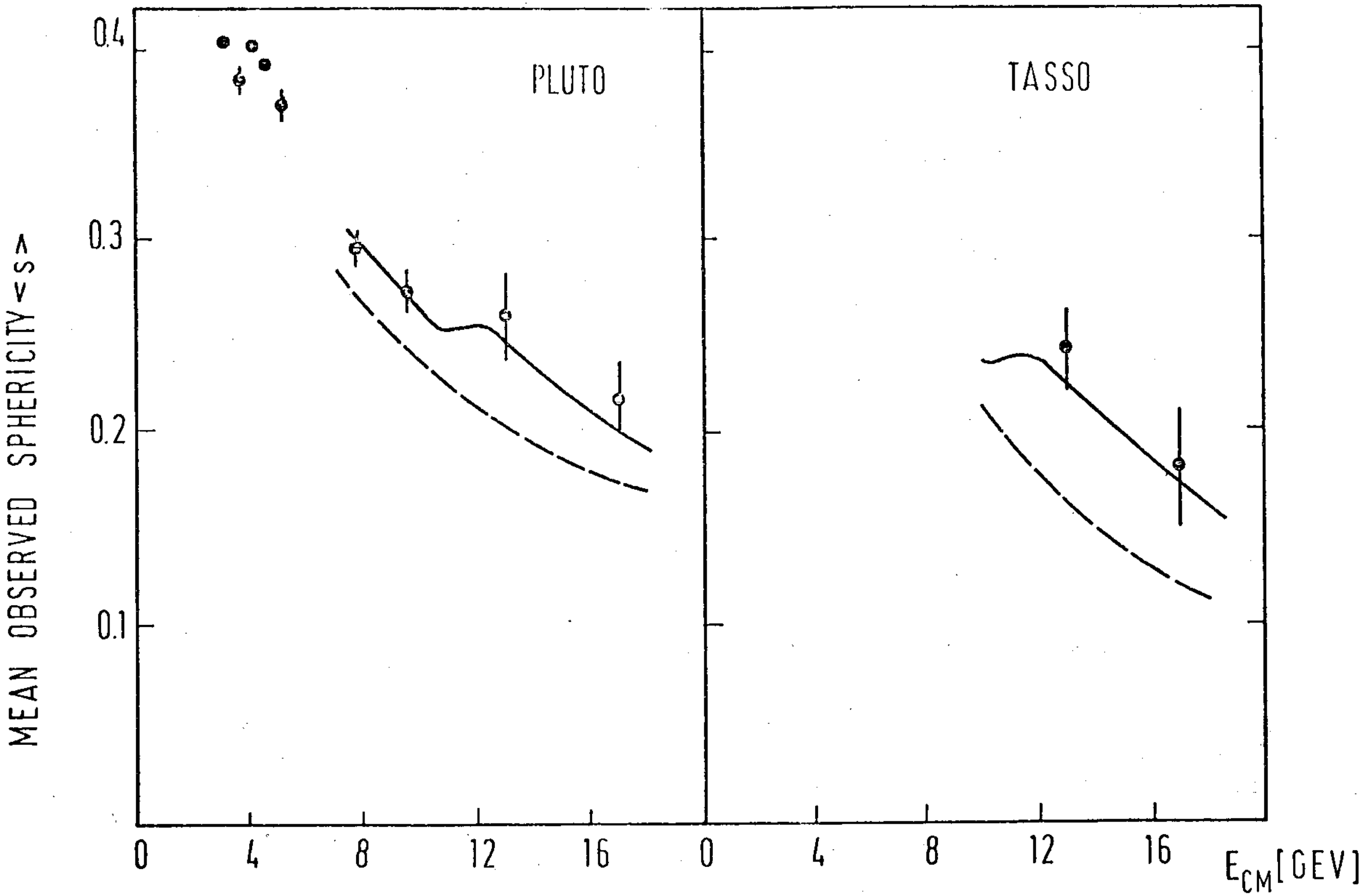
1/σ dσ/dS
E_CM = 17 GeV
PLUTO
0
0.2
0.4
0.6
0.8
1.0
S
1
2
3
4
5

Fig. 3a



E_CM = 17 GeV
TASSO
0
0.2
0.4
0.6
0.8
1.0
S
1
2
3
4
5

Fig. 3b



MEAN OBSERVED SPHERICITY <s>
0.4
0.3
0.2
0.1
PLUTO
TASSO
0
4
8
12
16
0
4
8
12
16
E_{CM}[GEV]

FIG. 4a

FIG. 4b

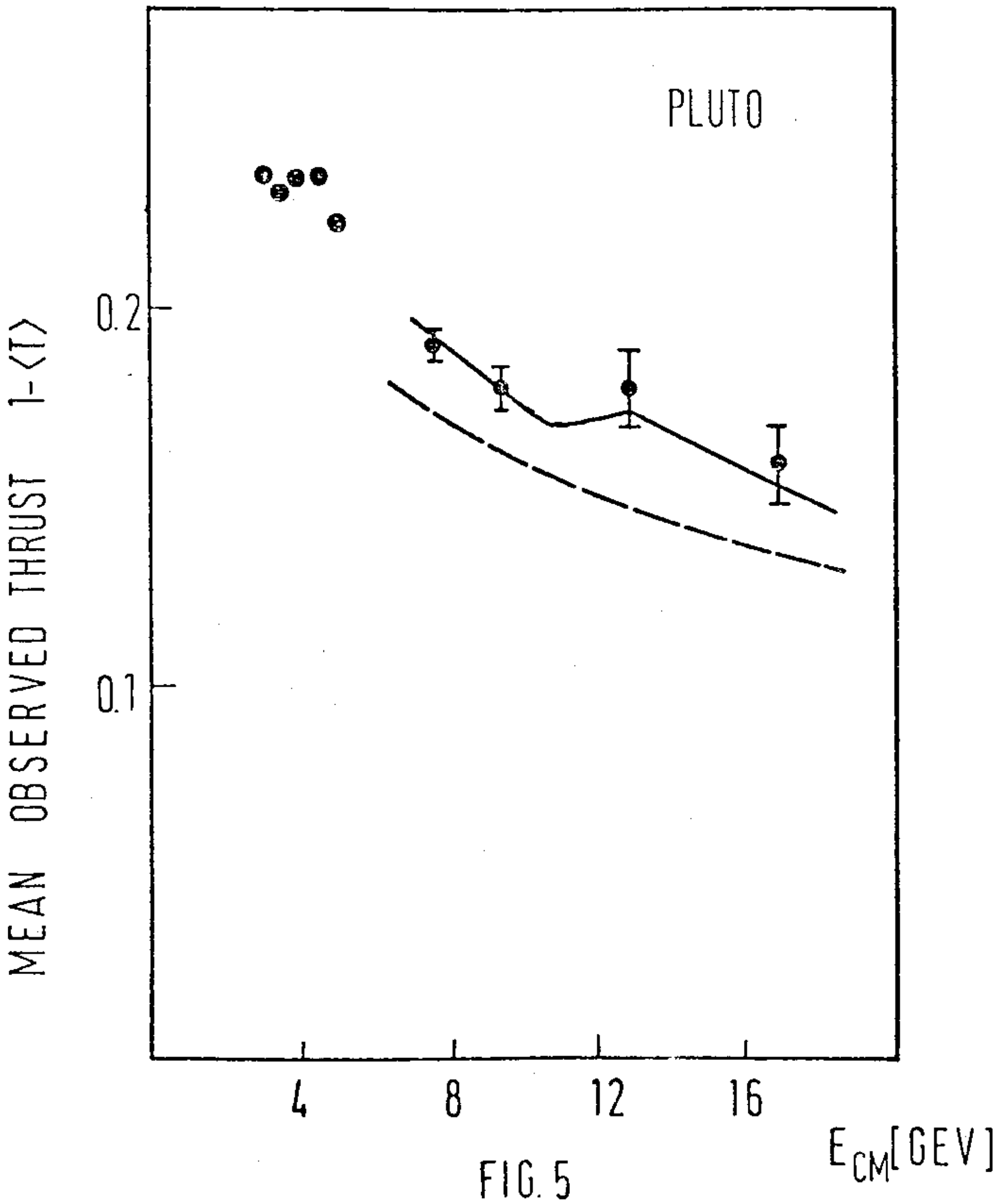


FIG. 5