EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/88-26
February 29th, 1988

A Study of π and K Production in 200 GeV/A Proton-Uranium and Oxygen-Uranium Interactions Using Decay Muons.

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Abstract

The like-sign dimuons copiously recorded in the NA38 experiment both in $p-U$ and $O-U$ reactions at 200 GeV/nucleon are interpreted as resulting from decays of π and K mesons in comparable proportions. The $++/--$ ratio is large ($\simeq 1.7$) and ascribed to the K^+ being more copiously produced than the K^-. Both the average transverse momentum and the $++/--$ ratio are comparable for $p-U$ and $O-U$ reactions, and both increase only slightly with the transverse energy E_T.

Presented at Quark Matter 87
by
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π and K Decay Muons.

1. INTRODUCTION.

We present a preliminary analysis of like-sign dimuons ($\mu^+\mu^+$ and $\mu^-\mu^-$) detected in the NA38 experiment in proton-uranium and oxygen-uranium interactions at 200 GeV/nucleon.

A dimuon experiment aims mainly at a study of virtual photons (e.g. Drell-Yan pairs) and/or of vector mesons (ρ, ω, J/Ψ, Ψ' etc.) which couple to a muon pair. But decays of π's and K's cannot be completely suppressed and lead to a background, which can however be subtracted since this mechanism produces like-sign pairs with comparable probability. The signal is given to a good approximation, and in straightforward notation, as

$$N_{\mathrm{Signal}} = N_{+-} - 2 * \sqrt{N_{++} * N_{--}} \qquad (1)$$

N_{Signal} stands for the number of "signal" dimuons which consist of virtual photons, vector mesons, and also higher flavour meson pairs which yield mostly opposite-sign muon pairs.

For ion beams, the number of pions and kaons produced is roughly proportional to the projectile mass number A_{proj}; the same is true for the Drell-Yan dimuons. The background increases therefore, at a given energy per nucleon, roughly as A^2_{proj}, i.e. A_{proj} times faster than the signal, and becomes a cumbersome problem for dimuon masses from threshold up to somewhat above 2 GeV/c^2. The only practical way to limit the background level is to absorb the produced mesons right after the target. For this reason, the NA38 experiment has a very compact layout, with 85 % of a proton interaction length within the first 44 cm after the target center (i.e. the electromagnetic calorimeter preceded by low Z absorbers). Subsequently, 11 interaction lengths of carbon (5 metres) stop the remaining hadrons. For a description of the apparatus, see ref.[1] and its Figs. 1 and 2.

Still, the vast majority of the dimuons recorded in $^{16}O - ^{238}U$ collisions are due to pion and kaon decays, with the like-sign pairs being unambiguously recognized as such. We show in Section 2 how these can be used to extract physics information on the parent meson p_T distributions and on the strangeness content. The most directly interpretable and useful aspect of this information is the E_T dependence both of the strangeness content (Section 3) and of the average transverse momentum (Section 4). (E_T is the sum of the neutral and a small part of the hadronic transverse energy measured in the range $1.9 < \eta_{\mathrm{lab}} < 4.1$, as in ref. [1]). We address here questions such as the few JACEE events of exceptionally high $\langle p_T \rangle$ found at their highest energy densities [2], and speculations about a rapid rise of strange particle production when quark-gluon plasma formation sets in [3]. Experimentally, these results are in first order independent of acceptance corrections, which we do not apply here, and of muons from hadronic reinteractions in target and absorbers, which are not negligible (we estimate them at 20 %), but which are roughly proportional to primary hadron decay muons.

A bonus is the excellent statistics achieved, with some 200 decay muons (from like-sign pairs) recorded per burst, yielding a total of 437'150 decay muons from oxygen-uranium reactions and 4786 muons from $p-U$ reactions which we analyze in the following. Also, the dimuon trigger strongly emphasizes reactions with high transverse energy (low impact parameter). The like-sign dimuon cross section should be proportional to the hadronic cross section times the meson multiplicity squared, which in turn should be proportional to the transverse energy squared:

$$d\sigma(LS)/dE_T \propto (n_{\pi,K})^2 * d\sigma_{\mathrm{had}}/dE_T \propto E^2_T * d\sigma_{\mathrm{had}}/dE_T \qquad (2)$$

Fig. 1 shows that this relationship is quite well satisfied in $O-U$ reactions; the highest transverse energies reached are slightly smaller for the dimuon trigger than those obtained with the minimum bias trigger, which can be at least qualitatively understood since in the first case two mesons decay to muons and leave almost no energy in the calorimeter.

The data are basically those shown at the Nordkirchen Conference ("Quark Matter 1987"). The $p-U$ data have been reanalyzed, the p_T fits have been improved, and an estimate of the (almost negligible) contribution of D and higher flavour decays has been added.

2. UNDERSTANDING THE LIKE-SIGN PAIRS IN TERMS OF π AND K DECAYS.

The NA38 trigger accepts muons in a lab pseudorapidity range $2.8 < \eta_{lab} < 4$, and of $p_L > 4$. GeV/c The trigger rejects muons with $p_T < 0.4$ GeV/c. Furthermore, events with both muons in the range $0.4 < p_T < 0.6$ GeV/c are rejected on-line. Fig. 2 shows the strongly biased p_T distribution of the observed muons. In the present analysis, events with three or more muons (few %) are disregarded.

We simulated pion and kaon production, decay, and detection of the decay muons in the NA38 apparatus, using as input the most relevant measurements, mainly those of Cronin and coworkers [4] for 200 GeV/c p−W reactions at 77 mrad and $p_T = 0.77$ and 1.54 GeV/c.

We also used a specially adapted HIJET simulation to estimate the effect due to reinteractions of secondaries in the target or the various absorbers, and found that these contribute some 20 % of the detected muons.

As shown in Fig. 3, there is good correlation between the p_T's of the decay muon and of the parent meson; we find, for $p_T > 0.7$ GeV/c, and for $\pi \to \mu\nu$ and $K \to \mu\nu$ decays respectively,

$$p_{T,\mu} \text{ from } \pi = (0.85 \pm 0.10)\, p_{T,\pi} \qquad (3a)$$

$$p_{T,\mu} \text{ from K} = (0.87 \pm 0.17)\, p_{T,K} \qquad (3b)$$

The probability for a K to decay to a μ detected in the NA38 layout is found to be ≃ 4 times larger than for π's. Both the K/π^- and the K^+/K^- ratios are rather large in the relevant kinematical region. Ref. [4] gives a K^+/π^+ ratio of 0.23 ± 0.02 (0.39 ± 0.02) at $p_T = 0.77$ (1.54 GeV/c), well above the K^-/π^- ratio of 0.15 ± 0.015 (0.20 ± 0.01). (The considerable excess of K^+ over K^- is due to the associated K-hyperon production reactions which give K^+ but not K^-.) The π^+/π^- ratio is ≃ 1 at $p_T = 0.77$, and ≃ 1.19 at $p_T = 1.54$ GeV/c for p−W reactions [4]. For the isospin symmetric oxygen beam, we use nevertheless $\pi^+/\pi^- = 1.0$ throughout. Oxygen-uranium reactions might even produce more π^- than π^+ in the backward region, but some of the other results of ref. [4] (comparison of p−p, p−d, p−Be, p−W data) indicate that the target nature has little influence on the π^+/π^- ratio in the NA38 acceptance region.

We then find that roughly 40 % of the decay muons come from K decay. D meson decays are found to contribute negligibly, and only through mixed $\mu_K\, \mu_D$ or $\mu_\pi\, \mu_D$ pairs (4 % in the most extreme hypothesis of a $D\bar{D}$ production cross section of 15 μbarn (for p−p) times target times projectile mass numbers). We also estimate the ratio $N_{++}\, /\, N_{--}$ of positive to negative like-sign pairs using the formulae:

$$N_{++}\, /\, N_{--} = \left(\frac{\pi^+/\pi^- * (1 + 4 * K^+/\pi^+)}{1 + 4 * K^-/\pi^-}\right)^2 \qquad (4a)$$

$$N_{++}\, /\, N_{--} = \left(\frac{1 + 4 * K^+/\pi^+ * \sqrt{\pi^+/\pi^-}}{1 + 4 * K^-/\pi^- * \sqrt{\pi^-/\pi^+}}\right)^2 \qquad (4b)$$

for p−U (4a), and O−U (4b), using the p−W particle ratios of ref. [4], at the two indicated p_T values. These correspond, on average and according to our simulation, to dimuon transverse masses M_T around 1.3 and 2.7 GeV/c². ($M_T = \sqrt{(M^2_{\mu\mu} + p^2_{T,\mu\mu})}$ is used here as a convenient variable since it is roughly equal to the sum of the p_T's of the two muons which in turn are related to the parent mesons' p_T). We obtain $N_{++}\, /\, N_{--} = 1.4 \pm 0.2$ and 2.4 ± 0.25 for O−U, and 1.4 ± 0.2 and 2.9 ± 0.4 for p−U. Fig. 4 shows the experimental $N_{++}\, /\, N_{--}$ ratios whose average is 1.7, and which are well encompassed by these estimates. We conclude that for O−U interactions, the $N_{++}\, /\, N_{--}$ data reflect essentially the K content, according to formula (4b).

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3. RESULTS ON STRANGENESS CONTENT.

A first physics result, demonstrated in Fig. 4, is the basic similarity of the strangeness content in $p-U$ and $O-U$ collisions. In fact, the excess of $++$ over $--$ pairs is somewhat weaker, at high M_T, in $O-U$ than in $p-U$ collisions. The difference has been ascribed in the preceding section to the slight excess of π^+ over π^- production in $p-U$, while both are assumed to be equal in $O-U$ collisions.

We ask now whether the strangeness content, or rather its experimental signature which is the $++/--$ ratio, changes with neutral transverse energy E_T. Fig. 5 shows a distinct increase of this ratio of (5.5 ± 1.5) % over a practical E_T range from 0 to 60 GeV. (Only 0.7 % of all hadronic events (minimum bias trigger) have $E_T > 60$ GeV).

Obviously we cannot deduce K/π ratios from a single measured parameter; we interpret it by using charge symmetry for the pions plus one additional assumption which may be one of the following:

If the entire effect were ascribed to an increase in K content, with a constant K^+/K^- ratio, then it would correspond, according to formula (4b), to an increase of about 25 % in the K/π ratios.

If the K^-/π^- ratio stayed constant (which does not seem a likely scenario), then the measured increase of the ratio would indicate a more modest increase of 5 % in the K^+/π^+ ratio.

Conversely, we may invoke the experimental fact that the ratios π^+/π^-, K^-/π^+, and K^+/K^- all increase slightly in $p-A$ collisions with increasing target mass number A [4,5].The E_T range under consideration does correspond to a range of interaction volumes. A not unreasonable increase of 3, 2 and 2 % in the mentioned ratios reproduces the observed result, which would then indicate a trivial reason for the observed increase of strange relative to non-strange particle production.

4. RESULTS ON AVERAGE TRANSVERSE MOMENTUM.

We recall that the like-sign muons originate almost exclusively from π ($\simeq$ 60%) and K ($\simeq$ 40%) decay, and that the low p_T muons are strongly suppressed at the trigger level. We disregard therefore the low p_T region and fit a Boltzmann distribution

$$dN/dp_T = p_T * \exp(-\,p_T / p_{To}) \qquad (5)$$

to the measured muons in an intermediate transverse momentum range $0.7 < p_T < 2.8$ Gev/c, where the acceptance is roughly constant (see Fig. 6). Above the chosen upper limit, the measured distribution exceeds the Boltzmann fit somewhat. For the $p-U$ data, the fitted interval ends at $p_T = 2.1$ GeV/c, since there are only few events beyond that value.

Results are again similar for $p-U$ and $O-U$ interactions, with an inverse exponential slope parameter $p_{To} = 0.206 \pm 0.004$ GeV/c for $p-U$ and $p_{To} = 0.199 \pm 0.0004$ GeV/c for $O-U$ collisions.

We then fit the $O-U$ data for different E_T bins. and obtain an inverse slope p_{To} which again increases with E_T, by 11 % from 0.180 GeV/c at $E_T = 0$, to 0.200 GeV/c at and above $E_T = 40$ GeV (Fig. 7).

Whether part or all of this increase is due a trivial reasons, such as rescattering in an interaction volume which is larger at higher E_T, or to acceptance effects (the average p_L is found to slightly decrease with increasing E_T), remains to be investigated.

5. CONCLUSIONS.

Results on π and K production have been obtained through a study of decay muons. These were recorded with a trigger biased against low p_T in a pseudorapidity range $2.8 < \eta_{lab} < 4.0$. A comparison of p − U and O − U data and a study of O − U data as a function of the transverse energy E_T have been made, without need to correct for acceptance and for reinteractions (since these do not depend, to first order, on E_T nor on the projectile mass). Results show

i) similar patterns in p − U and O − U collisions regarding both K/π ratios and slope the inverse exponential p_{To}

ii) a slight increase of p_{To} and of K/π ratios with E_T.

These results have good statistics, and offer a useful testing ground for models. No spectacular effects are seen, neither in the strangeness sector nor in the behaviour of p_{To}.

Useful discussions with D. Treille, R. Wigmans and Y. Zolnierowski are gratefully acknowledged.

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FIGURE CAPTIONS.

Fig. 1.
The E_T dependence of the cross section for like-sign pairs divided by E^2_T closely resembles the hadronic cross section, as expected if E_T is proportional to the pion and kaon multiplicity in the spectrometer acceptance region. Data were obtained in successive dimuon and minimum bias trigger runs at 60 GeV/nucleon. The maximal transverse energies E_T reached are slightly smaller for the muon pair events since two hadrons decay instead of depositing their energy in the calorimeter.

Fig. 2.
The p_T distribution of the like-sign muons from O – U interactions. The strong bias against low p_T is due to the magnet configuration and the trigger.

Fig. 3.
The p_T of the decay muon is closely correlated to the p_T of the parent pion (a) and, to a lesser extent, of the parent kaon (b), for the muons accepted by the spectrometer (dashed line), and especially for those with $p_T > 0.7$ GeV/c (solid line).

Fig. 4.
The ratio of positive to negative like-sign pairs vs. dimuon transverse mass, for p – U (open circles) and O – U (black circles) interactions. A model based on formualae (4a, b) (see text) and using the large measured K/π and K^+/K^- ratios of ref. [4] reproduces qualitatively the rather large ratios (open and black squares with dashed error bars).

Fig. 5.
The ratio of positive to negative like-sign pairs averaged over all masses vs. the transverse energy E_T, for O – U interactions. The linear fit yields $N_{++} / N_{--} = 1.62 * (1 + (0.0015 \pm 0.0004)*E_T)$.

Fig. 6.
The p_T distribution for muons from O – U (crosses) and the exponential fit (see formula (5) and text) for $p_T > 0.7$ GeV/c, where the acceptance is roughly constant.

Fig. 7. The inverse slope p_{T0} (see text and formula (5)) vs. E_T, for O – U collisions.

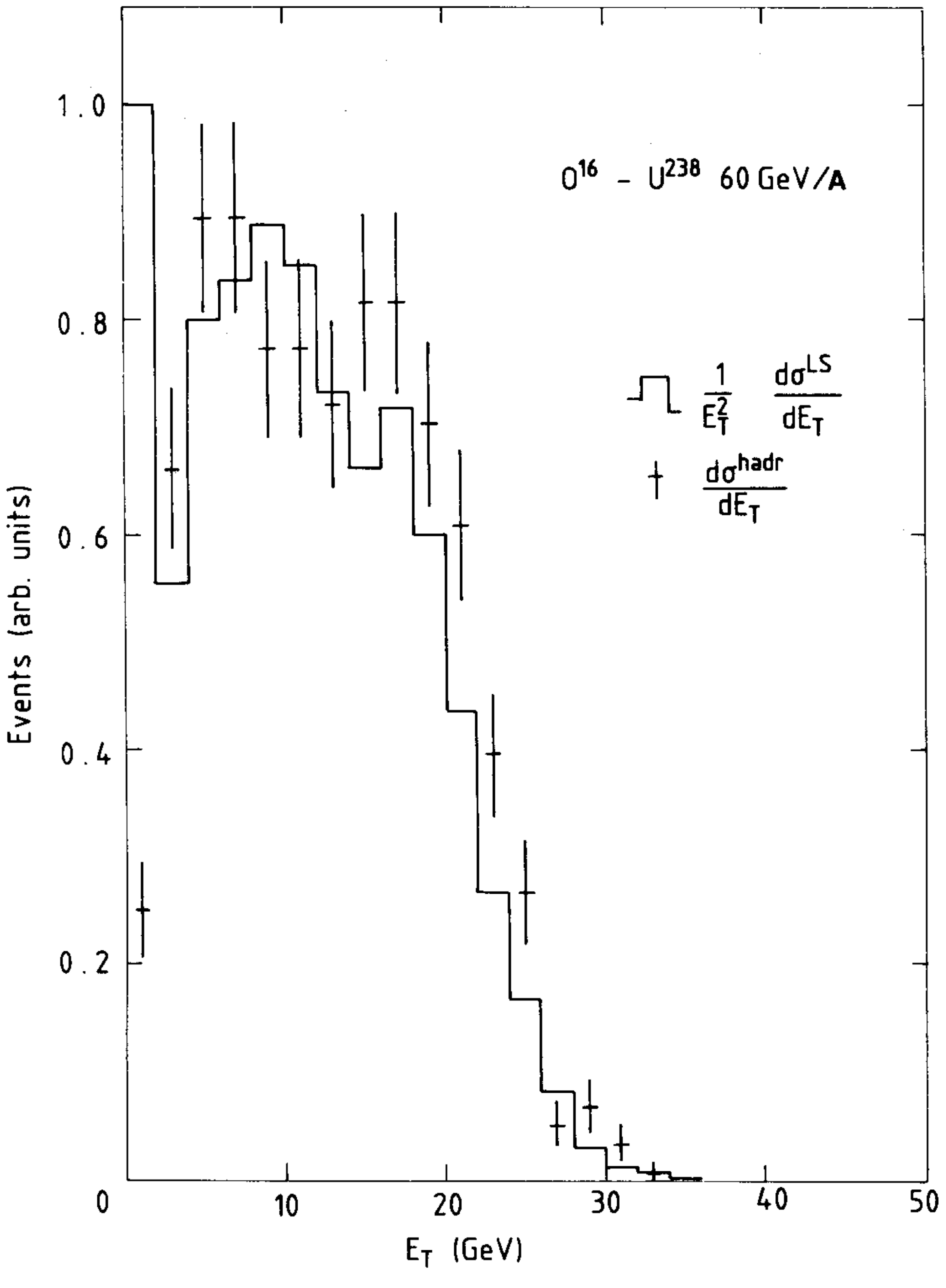
O^{16} - U^{238} 60 GeV/A
$\frac{1}{E_T^2} \frac{d\sigma^{LS}}{dE_T}$
$\frac{d\sigma^{hadr}}{dE_T}$
Events (arb. units)
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
E_T (GeV)

Fig.1

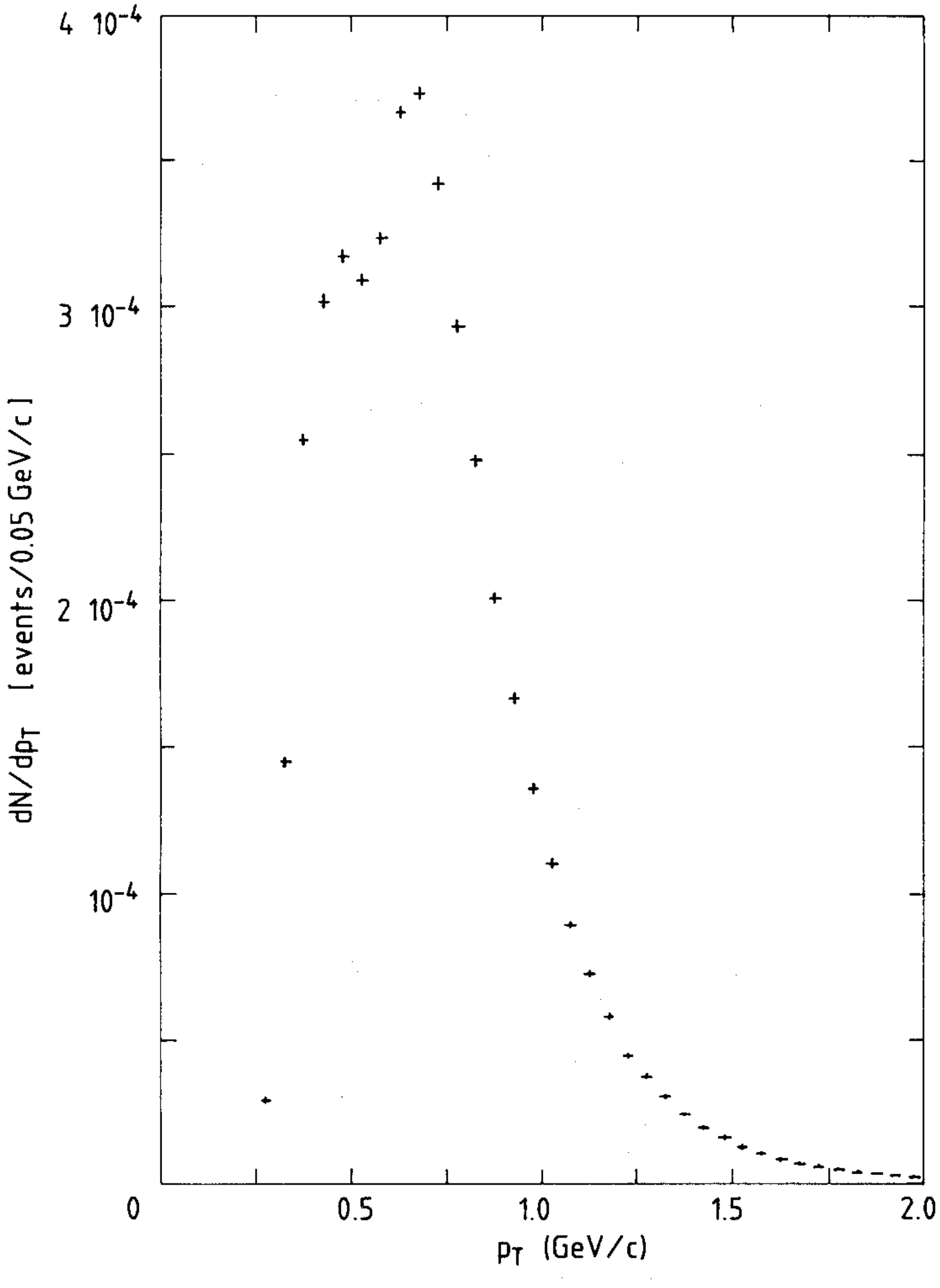

Fig.2

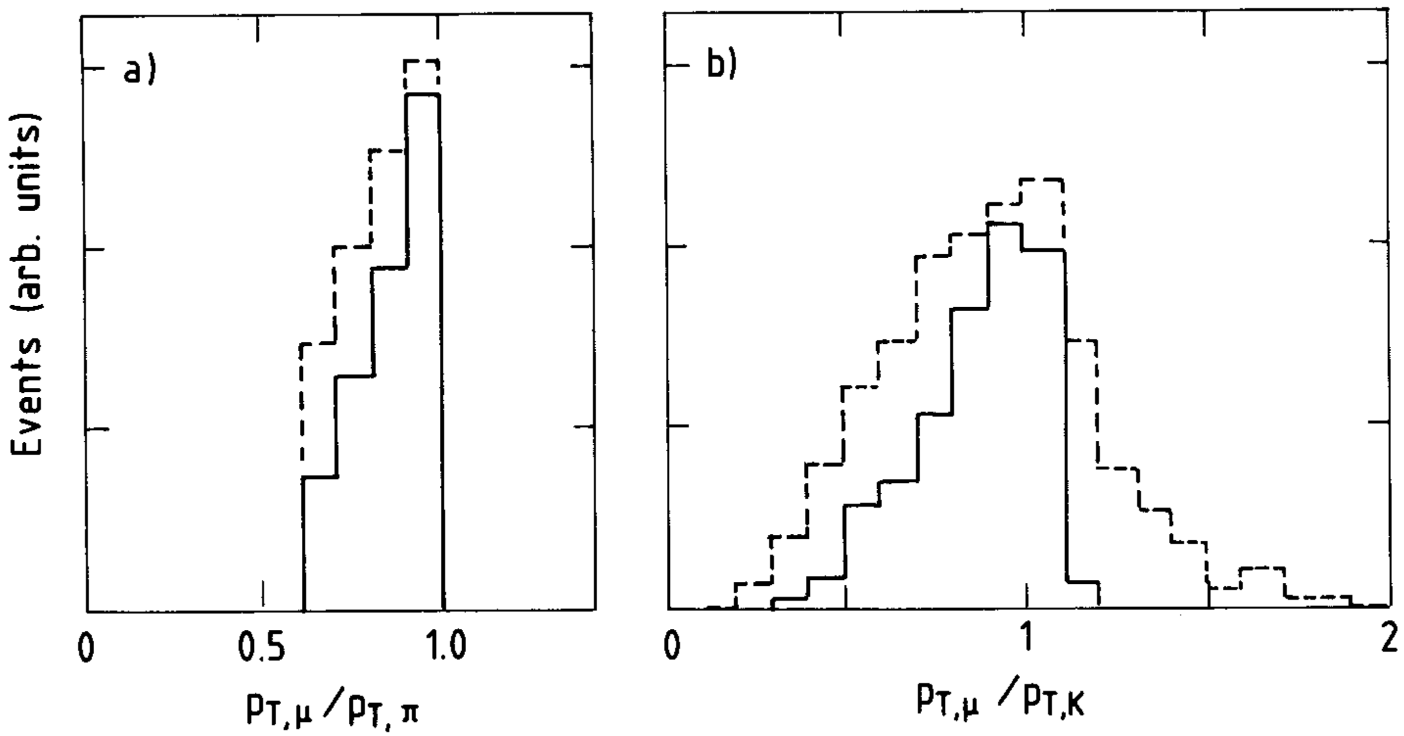

Fig.3

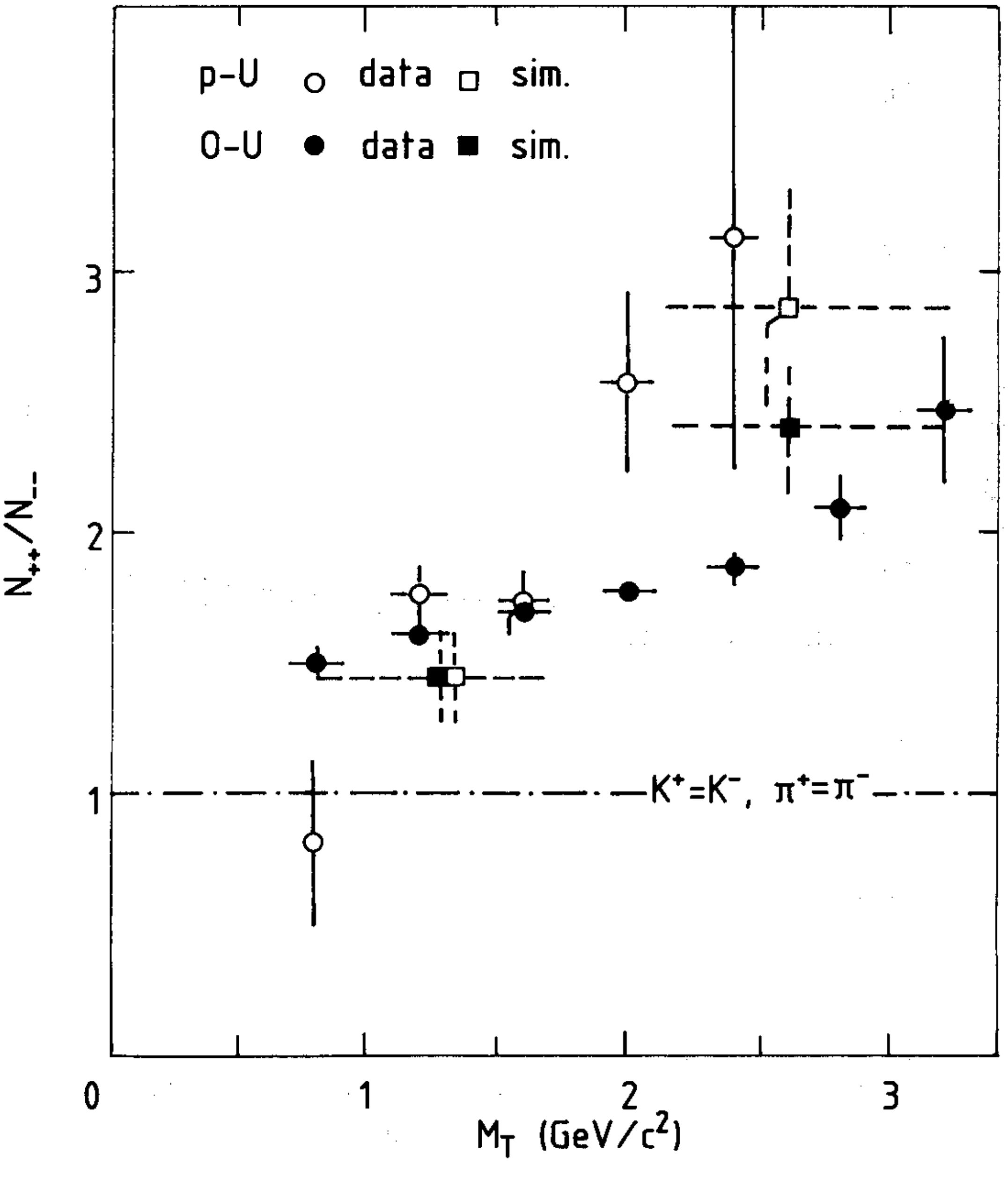

Fig.4

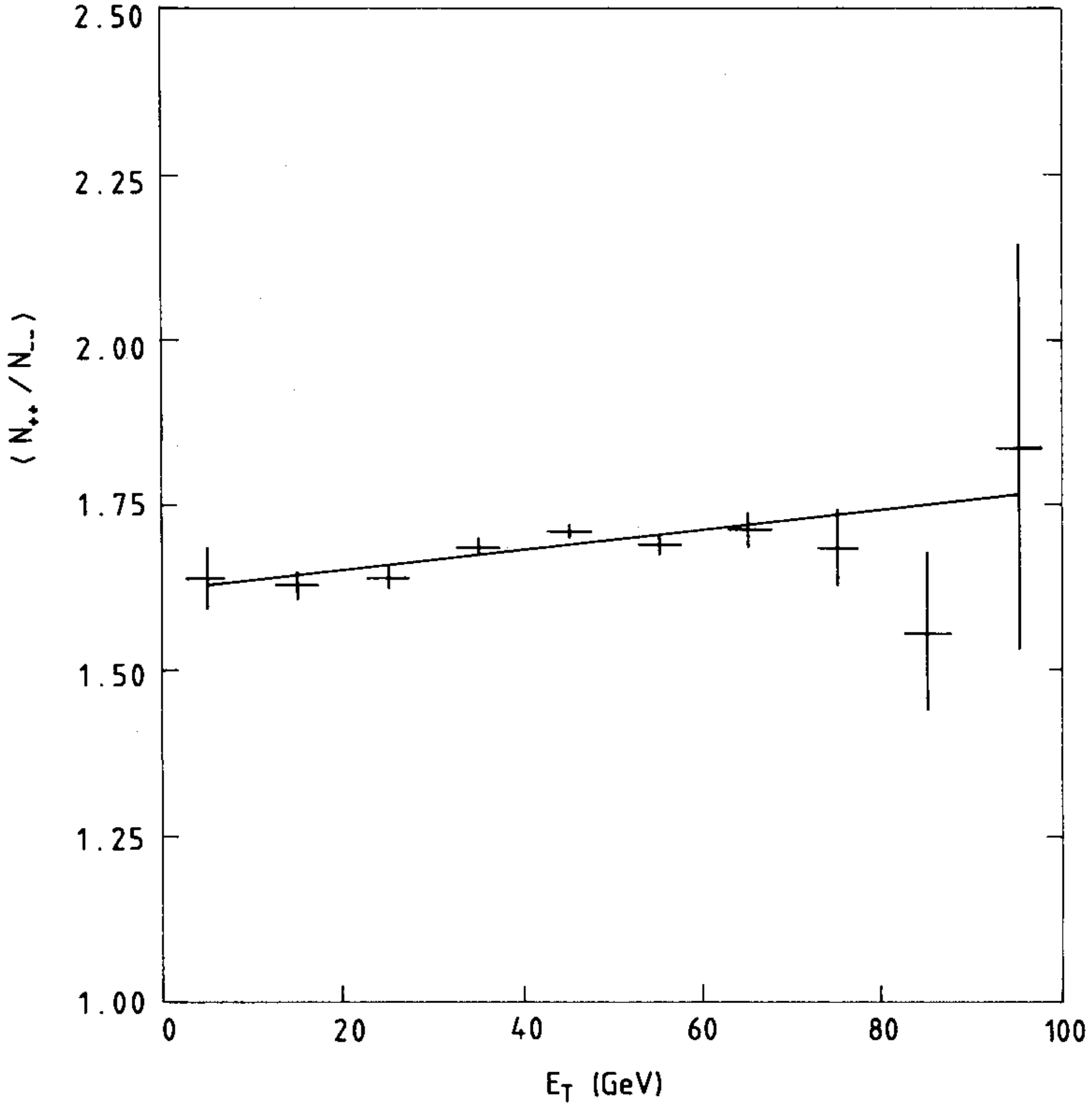
2.50
2.25
2.00
1.75
1.50
1.25
1.00
$\langle N_{++}/N_{--} \rangle$
0
20
40
60
80
100
E_T (GeV)

Fig.5

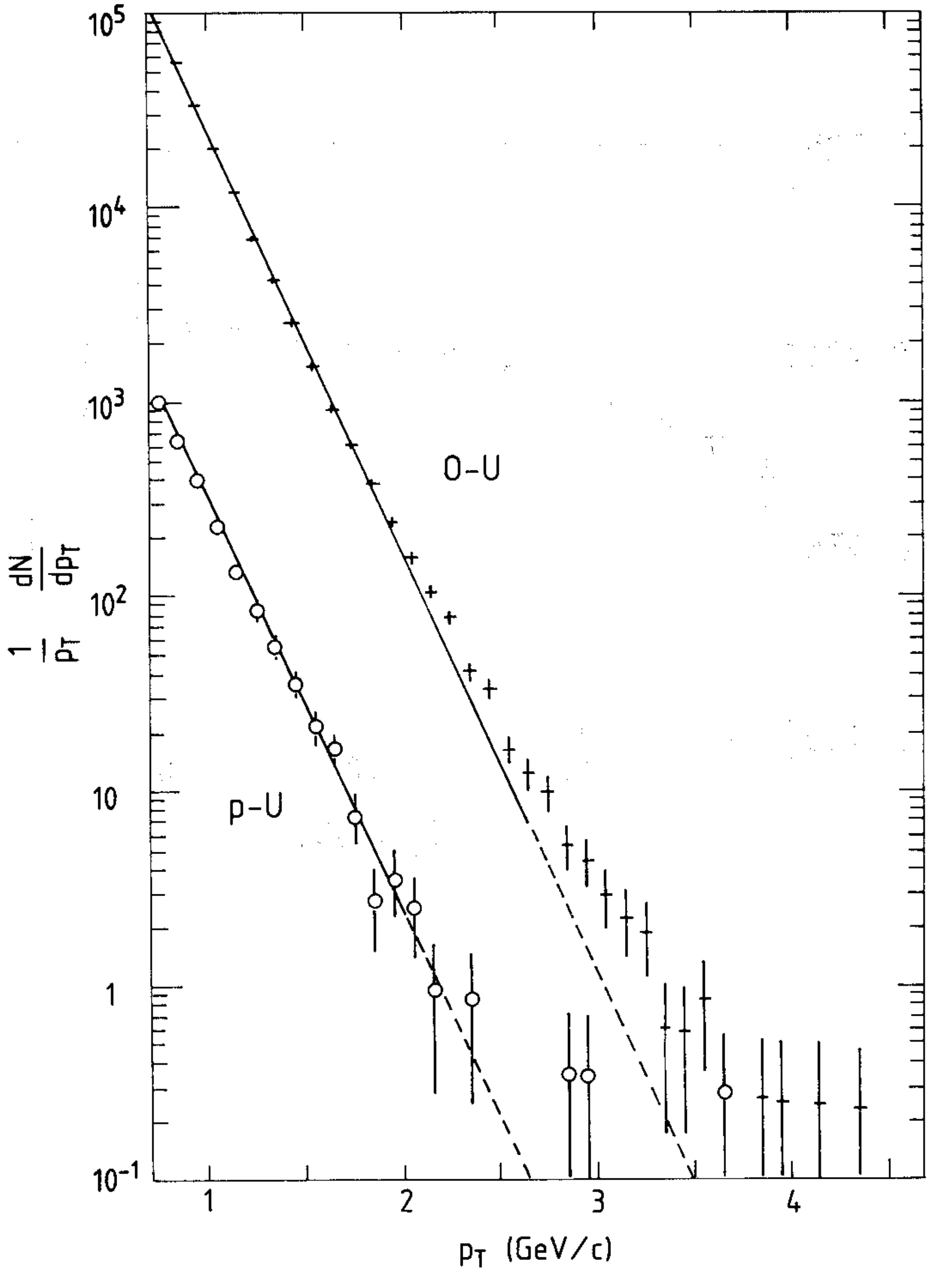

Fig.6

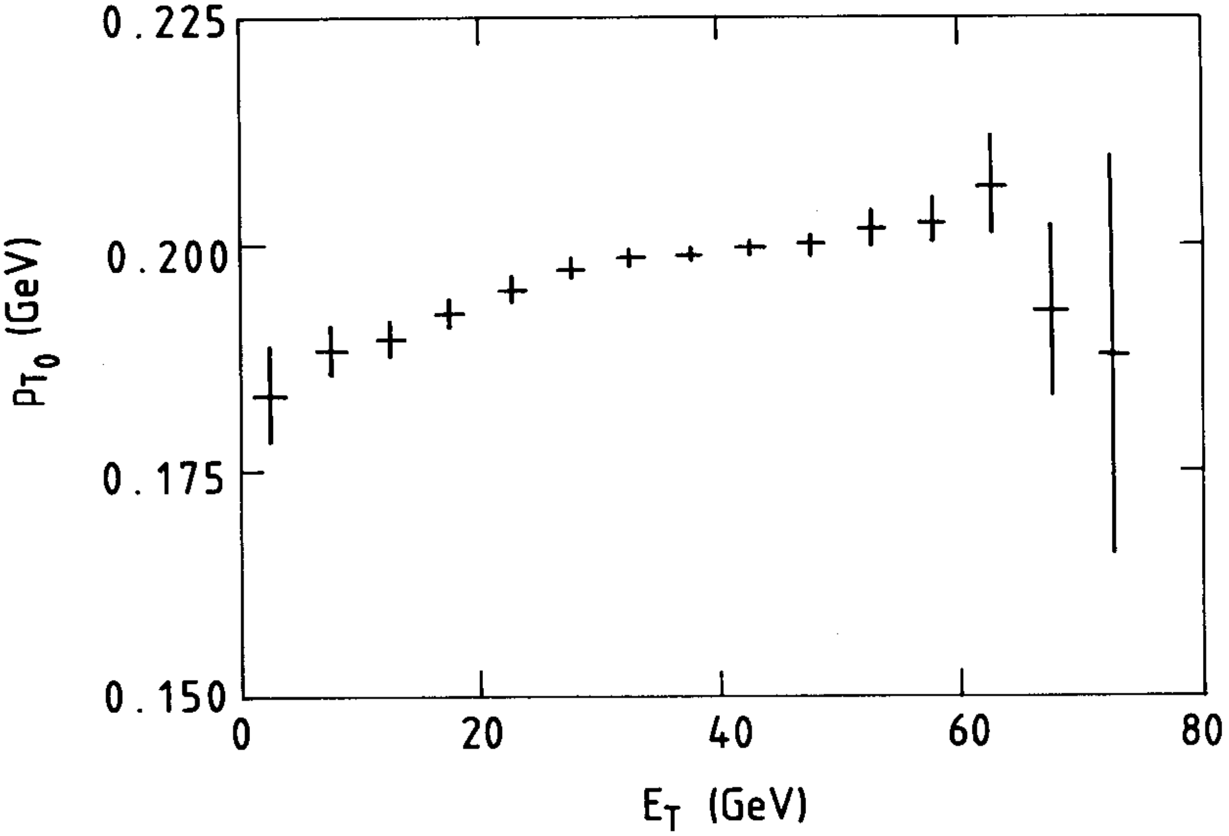

Fig.7