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DIRECT PHOTON PRODUCTION FROM NEGATIVE AND POSITIVE PIONS AND PROTONS AT 200 GeV/c

NA3 COLLABORATION

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ABSTRACT

Direct photon production has been studied in the NA3 spectrometer at CERN, using incident negative and positive beams at 200 GeV/c interacting with an isoscalar Carbon target. Two different triggers have been used; one of them requires the photon conversion. The experiment is sensitive to photons with $2.5 < P_T < 6$ GeV/c and center-of-mass rapidity $-0.4 < y^* < 1.2$. Preliminary results from incident pions and protons are given and compared to previous data. Preliminary results on the γ/π^0 ratio and on the charge asymmetry between π^- and π^+ induced direct photons are presented and discussed in the framework of QCD predictions.

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1. INTRODUCTION

We report on a search for direct high transverse momentum photons produced in $\pi^{\pm}$-Carbon and p-Carbon interactions at 200 GeV/c [1]. This experiment was motivated by the discovery, at the CERN ISR, of single high P_T photons produced in proton-proton collisions [2]. These events were explained, in the framework of QCD, by the so-called QCD gluon Compton scattering, with a possible contribution of quark bremsstrahlung at very high P_T. In π-induced collisions, the annihilation ($q\bar{q} \rightarrow \gamma g$) is expected to contribute substantially, with a larger yield for incident π^- than for π^+. Thus, in principle, a simple way to isolate the annihilation graph is to measure direct photons from π^- and π^+ interactions on an isoscalar target.

2. THE EXPERIMENTAL SET-UP

We used a secondary beam with an intensity of 1.5 10^7 particles per SPS spill, the incoming particles being identified by 2 differential DISC Cerenkov counters (CEDARS), in conjunction with 2 threshold Cerenkov counters for the positive beam. A complete intensity monitoring system ensured the knowledge of the incoming flux within ±1%.

The experiment was performed with the CERN NA3 spectrometer. This spectrometer has been already described [3] in the beam dump configuration used for muon pair studies at high energy. With respect to this previously described set-up, major modifications have been made. We focus here only on the features concerning the data presented in this publication.

a) The targets were 3 graphite cylinders 2 cm thick (10.6 g/cm² total), spaced 15 cm apart. This separation avoids most of secondary interactions, and it is sufficient to ensure a very good determination of the event vertices.

b) The spectrometer was used in its complete configuration with 44 MWPC planes, giving a momentum resolution on charged tracks $\Delta p/p = 2\ 10^{-4} p$ (GeV/c).

c) The electromagnetic calorimeter is of the lead scintillator type; it is divided in 40 horizontal strips (9 x 500 cm) (20 strips in the upper part, 20 in the lower) and segmented longitudinally in 3 parts : $\gamma 1(5X_0)$, $\gamma 2(8X_0)$ and $\gamma 3(12X_0)$. The horizontal strips in $\gamma 2$ and $\gamma 3$ are divided into 2 parts with a mirror in the middle, while the strips in $\gamma 1$ are undivided. Each strip is viewed by photomultipliers at both ends. All output signals from the calorimeter are digitized. The calorimeter, whose linearity has been checked with electrons from 4 to 70 GeV has an energy resolution given by the relation :

$$\Delta E/E = 0.004 + 0.22/\sqrt{E} \qquad \text{(E in GeV)}$$

All strips were calibrated by an electron beam of known momentum, before each running period. During data taking, a relative calibration was obtained by 2 independent systems of light emitting diodes; the stability of the PM's gain was checked during the spill. A system of TDC's measured the timing of the γ_1 signals.

d) The calorimeter does not provide the spatial resolution needed to separate direct photons from energetic π^0's. A position measuring device was therefore added between $\gamma 1$ and $\gamma 2$. It consists of two 4 x 2 m^2 MWPC's, with analog read-out on the horizontal wires anode and on both cathodes. One cathode is segmented in vertical strips 12 mm large, the other is divided into independent square cells of various sizes (5 x 5, 10 x 10, 20 x 20 cm^2).

This chamber and the electronics corresponding to the 2240 analog channels have been described in ref. [4]. The gain of the analog channels is monitored and recorded during data taking; this verification and the survey of the gas composition inside the chambers allow a control of the whole detector's stability within ± 2%.

The spatial resolution of this chamber has been measured to be σ = 3 mm for the shower localization; the two showers separation is about 3 cm, which allows in the experiment to identify symmetric decays of π^0's with energies up to 120 GeV.

3. THE TRIGGERS

Two different triggers were used :

a) The "conversion trigger" : a lead converter (0.15 X_0 thick i.e. 10% of conversion probability) was put in front of the CH1 chamber. Whenever an energetic photon converted, the event was recorded on tape, if the following conditions were fulfilled :

- the hardware processor, associated to the triggering chambers M1 and M2, recognized a candidate for an e^+e^- topology with the vertical component of the transverse momentum $P_{Tv} > 1.85$ GeV/c
- the corresponding strips in the calorimeter registered electromagnetic energy corresponding to a $P_{Tv} > 2.5$ GeV/c.

b) The "calorimeter trigger" : in this trigger, the only requested condition was a high P_{Tv} measured by the electromagnetic calorimeter. A threshold corresponding to a $P_{Tv} > 3.5$ GeV/c was chosen to give an acceptable trigger rate. We were sensitive to showers with P_{Tv} up to 6 GeV/c.

4. MONTE-CARLO SIMULATION

We generate π^0 mesons according to the differential cross section $Ed^3\sigma/dp^3$ parametrized by Donaldson et al. [5]. One set of parameters is used to generate π^0's by incident pions and a different set is used for incident protons. We take into account the nuclear effects in the carbon target and in our P_T range, by using a nuclear dependence of the cross section of the type : $\sigma(\text{carbon}) = A^\alpha \sigma(\text{proton})$ where A = 12 and $\alpha = 1.12$ [6].

Direct photons are generated according to a parametrization of the Born terms of the QCD annihilation and Compton graphs.

These generated events are then processed through a Monte-Carlo program using the CERN GEANT package, simulating electromagnetic interactions of photons and electrons in the experimental set-up, the detector responses and the trigger conditions. Electromagnetic showers in the calorimeter and in the shower chamber were separately generated by EGS and the results were parametrized in order to best fit the data obtained by electron beam calibrations between 4 and 70 GeV.

5. DATA ANALYSIS

Conversion Trigger

Let E_1 be the energy of the converted photon as measured by the spectrometer. For a π^0, the angle (α) between the two photons is related to their energies (E_1 and E_2) by $\alpha^2 = m^2_{\pi^0}/E_1E_2$. We define a search region around the converted photon direction ($\alpha < \alpha_{max} = m_\pi/\sqrt{E_1}$) corresponding to $E_2 > 1$ GeV for the second photon of the π^0. This cut eliminates most of the background in the shower chamber. An angular cut $\alpha < 1.6$ mrad eliminates Bremsstrahlung photons from the the converted γ electrons.

We classified the event as "π^0 candidate" when the converted photon, combined with any other γ in the search region, yielded a mass $60 < M_{\gamma\gamma} < 210$ MeV , as "η^0 candidate" when $480 < M_{\gamma\gamma} < 620$ MeV (without α_{max} cut) and as "γ candidate" when no π^0, nor η^0 was reconstructed.

Calorimeter trigger

A similar analysis has been performed for this trigger. E_1 corresponds to the highest P_T photon. For π^0 and η^0 candidates we require an asymmetry $A < 0.9$ where $A = |E_1 - E_2|/(E_1 + E_2)$.

The results presented in the following correspond to the analysis of 80% and 50% of all data collected with the conversion trigger and with the calorimeter trigger respectively.

π^0 Production

The two photon mass spectrum for the calorimeter trigger, is displayed in Fig. 2a) and shows a clear signal at the π^0 and η^0 masses. The normalized event distribution as a function of P_T (Fig. 2b) is in good agreement with the Monte Carlo simulation.

Fig. 3a shows the ratio of the event distributions

$\frac{dN}{dP_T}(pC \to \pi^0X) \Big/ \frac{dN}{dP_T}(\pi^+C \to \pi^0X)$ for the conversion trigger, and Fig. 3b the ratio $\frac{d\sigma}{dP_T}(\pi^- C \to \pi^0 X) \, / \, \frac{d\sigma}{dP_T}(\pi^+ C \to \pi^0 X)$ for both triggers.

γ/π^0 Ratio

For the analysis that follows we use only data corresponding to the conversion trigger. The ratio of the single photon yield to the inclusive reconstructed π^0 yield is shown for π^-, π^+ and protons in Fig. 4. Also shown is the expected γ/π^0 ratio, calculated by Monte Carlo method in the hypothesis of contributions coming from π^0 and η^0 identified or unidentified decays. The folded trigger and detection efficiency to $\pi^0(\epsilon_\pi)$ and to $\gamma(\epsilon_\gamma)$ is displayed in Fig. 5 as a function of P_T.

After subtraction of Monte Carlo calculated contribution and efficiency corrections we obtain the corrected γ/π^0 ratio shown in Fig. 6a for π^-, π^+ and protons. In Fig. 6b the corrected γ/π^0 ratio obtained by incident protons is compared with the same quantity measured by experiments E629 at FNAL ($pC \to \gamma X$ at $\sqrt{s} = 20$ GeV) and by R806 at ISR ($pp \to \gamma X$ at $\sqrt{s} = 63$ GeV).

Charge Asymmetry

In QCD the cross section difference $[\sigma(\pi^- C \to \gamma + X) - \sigma(\pi^+ C \to \gamma + X)]$ is determined by the contribution of the annihilation graph ($q\bar{q} \to$ single γ) only. Note that any background from π^0, η^0,...., is also cancelled in the $(\pi^- - \pi^+)C$ difference, because Carbon is isoscalar.

Fig. 7 shows this charge asymmetry $(\gamma/\pi^0)_{\pi^- C} - (\gamma/\pi^0)_{\pi^+ C}$ as a function of P_T.

Comparison to QCD

The data were compared to next-to-leading log QCD calculations, which were carried out as follows. We used a computer program developed by P. Aurenche et al. [7], in which QCD graphs are explicitely calculated up to α_s^2 terms, taking into account the interferences between α_s and α_s^3 terms. We used the following inputs :

- Nucleon and pion structure functions as given in the most recent compilation [8].
- $\alpha_s(Q^2) = 12\pi/25 \text{ Log } (Q^2/\Lambda^2)$ with $\Lambda = 0.2$ GeV. All graphs are calculated with the scale $Q^2 = P_T^2$.

- No intrinsic P_T distribution of the partons is assumed.
- The π^0 cross section needed to compute the γ/π ratio is the one parametrized [5] and used for the π^0 event generation.
  For center-of-mass energies above $\sqrt{s}$ = 30 GeV, in order to compare the predictions to the ISR data [9], we have scaled this parametrization of π^0's by en empirical factor $F = \sqrt{s}/10 - 2$, which is independent of y and P_T.

With respect to the Born terms, these next-to-leading log calculations introduce corrections - or "K-factor" - which are nearly P_T - independent for the Compton graph ($K_C \sim 2.3$) and rapidly decreasing for the annihilation graph (K_A = 2.5 at 2 GeV/c, K_A = 1.5 at 6 GeV/c).

To reproduce our experimental γ/π^0 ratio, all theoretical predictions have to be scaled up by another factor $K' = 1.7 \pm 0.1 \pm 0.2$ (Fig. 6); this gives also a good agreement with ISR data. The additional K' factor could be due to one or more effects, such as :

- the sum of all higher order QCD contributions not yet calculated
- the parton intrinsic P_T distributions (in this case K' would be P_T dependent)
- the parametrization of the π^0 cross section used as input for the comparison of data to QCD.

CONCLUSIONS

We measured the prompt photon production in $\pi^{\pm}$C and pC collisions at 200 GeV/c; we found, in the transverse momentum region $2.5 < P_T <$ 6 GeV/c, a γ/π^0 ratio compatible with previous experimental results either with incoming protons [2,10] or π^+ mesons [10].

The measured γ/π^0 ratio cannot be explained using only next-to-leading log QCD calculations : in the absence of large intrinsic transverse momentum of partons, these calculations have to be scaled by a factor $K' \sim 1.7$ to account for the data.

Subtracting the π^+ from the π^- yields, we find a very small asymmetry for prompt photon production, compatible with present QCD calculations.

ACKNOWLEDGEMENTS

We are indebted to the authors of ref. [7] for allowing us to use their computer program on next-to-leading log QCD calculations of the annihilation, Compton and Bremsstrahlung graphs.

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FIGURE CAPTIONS

Fig. 1 Layout of the NA3 spectrometer (prompt photon configuration).

Fig. 2 a) Two-photon mass spectrum (calorimeter trigger).

b) P_T distribution of π^0 in $\pi^- C \rightarrow \pi^0 X$ at 200 GeV for the calorimeter trigger. The solid curve is the prediction of the Monte Carlo simulation using the parametrization of Donaldson et al. and an A-dependence $A^{1.12}$.

Fig. 3 Ratios of π^0 production at 200 GeV integrated over the center of mass rapidity interval ($-0.4 < y < 1.2$)

a) $dN/dP_T(pC \rightarrow \pi^0 X)/dN/dP_T(\pi^+ C \rightarrow \pi^0 X)$ (conversion trigger)

b) $d\sigma/dP_T(\pi^- C \rightarrow \pi^0 X)/d\sigma/dP_T(\pi^+ C \rightarrow \pi^0 X)$ (conversion and calorimeter trigger).

Fig. 4 γ/π^0 detected ratio for π^-, π^+ and protons. The curves represent the background contributions to the ratio, expected from Monte-Carlo calculation.

Fig. 5 Folded trigger and detection efficiency for $\pi^0(\varepsilon_\pi)$ and direct photons (ε_γ) from Monte Carlo calculation.

Fig. 6a γ/π^0 corrected ratio for π^-(a), π^+(b) and protons (c). Inner error bars are statistical errors. The outer error bars include systematic errors. The curves are the result of QCD calculations (see text) scaled up by a factor K' = 1.7.

6b Comparison of the corrected γ/π^0 (proton) NA3 data with the same quantity measured by E629 (FNAL) [10] and by R806 (ISR) [9].

Fig. 7 Charge asymmetry $(\gamma/\pi^0)_{\pi^- C} - (\gamma/\pi^0)_{\pi^+ C}$ as a function of P_T. The curve is a QCD prediction scaled up by a factor K' = 1.7.

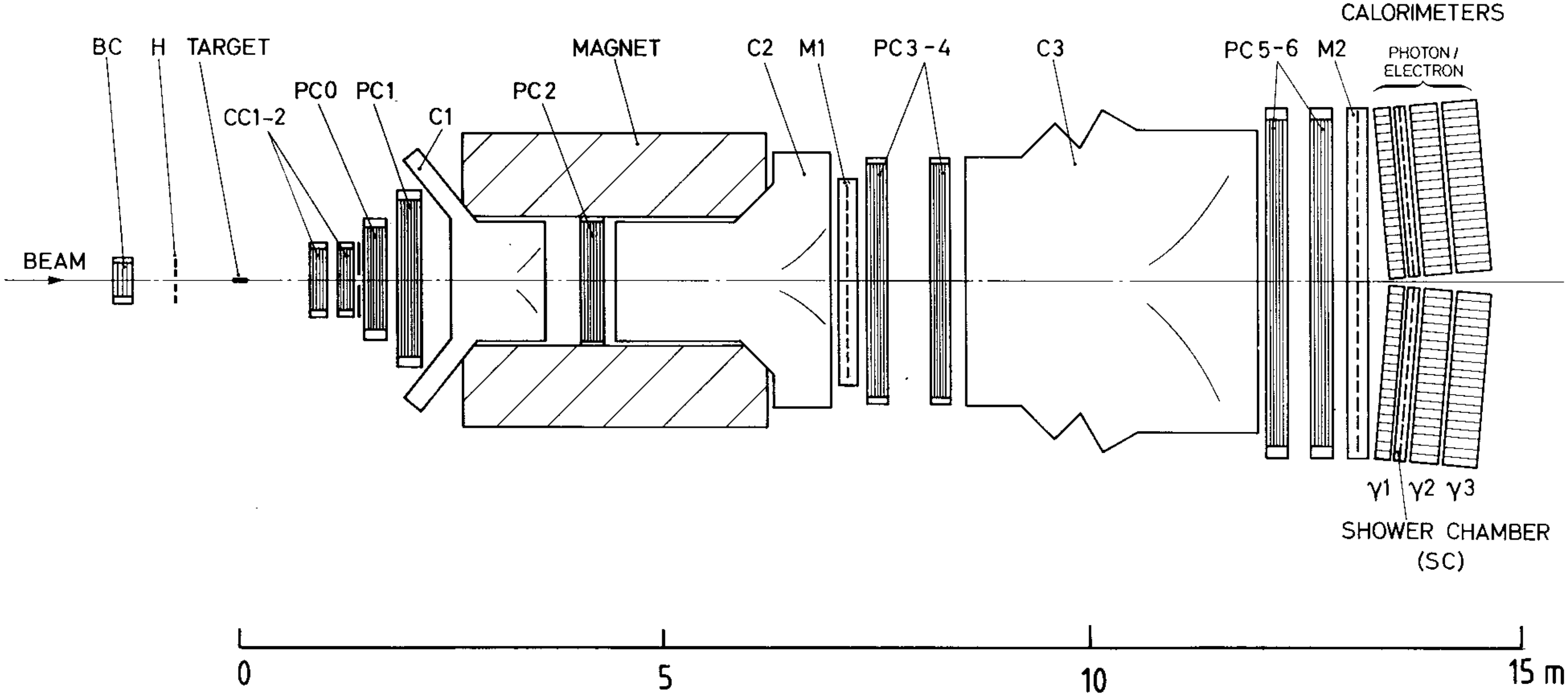
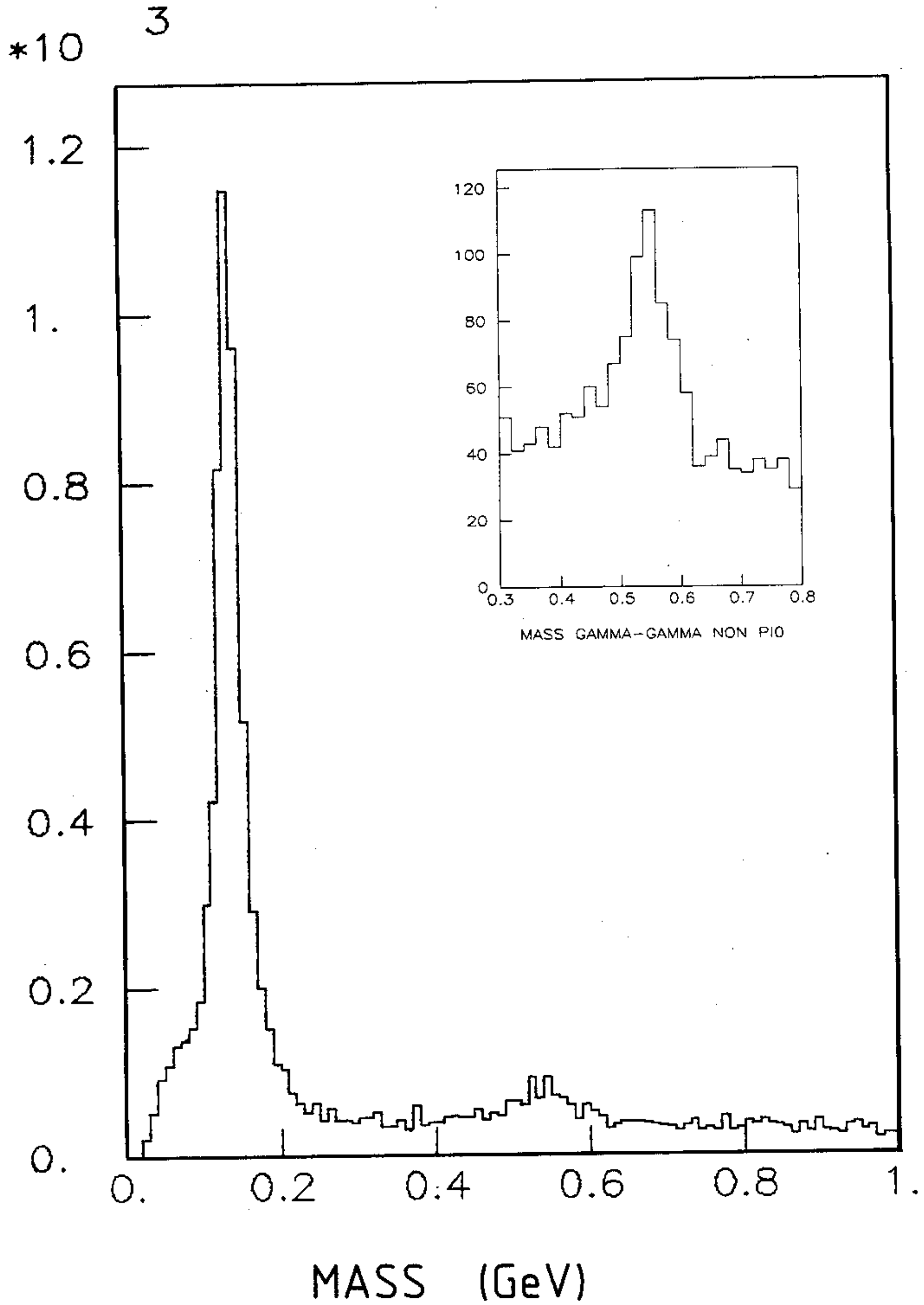

BEAM
BC
H
TARGET
CC1-2
PC0
PC1
C1
PC2
MAGNET
C2
M1
PC3-4
C3
PC5-6
M2
CALORIMETERS
PHOTON / ELECTRON
γ1
γ2
γ3
SHOWER CHAMBER (SC)
0
5
10
15 m

FIG. 1



*10 3
1.2
1.
0.8
0.6
0.4
0.2
0.
120
100
80
60
40
20
0
0.3
0.4
0.5
0.6
0.7
0.8
MASS GAMMA-GAMMA NON PI0
0.
0.2
0:4
0.6
0.8
1.
MASS (GeV)

FIG. 2a

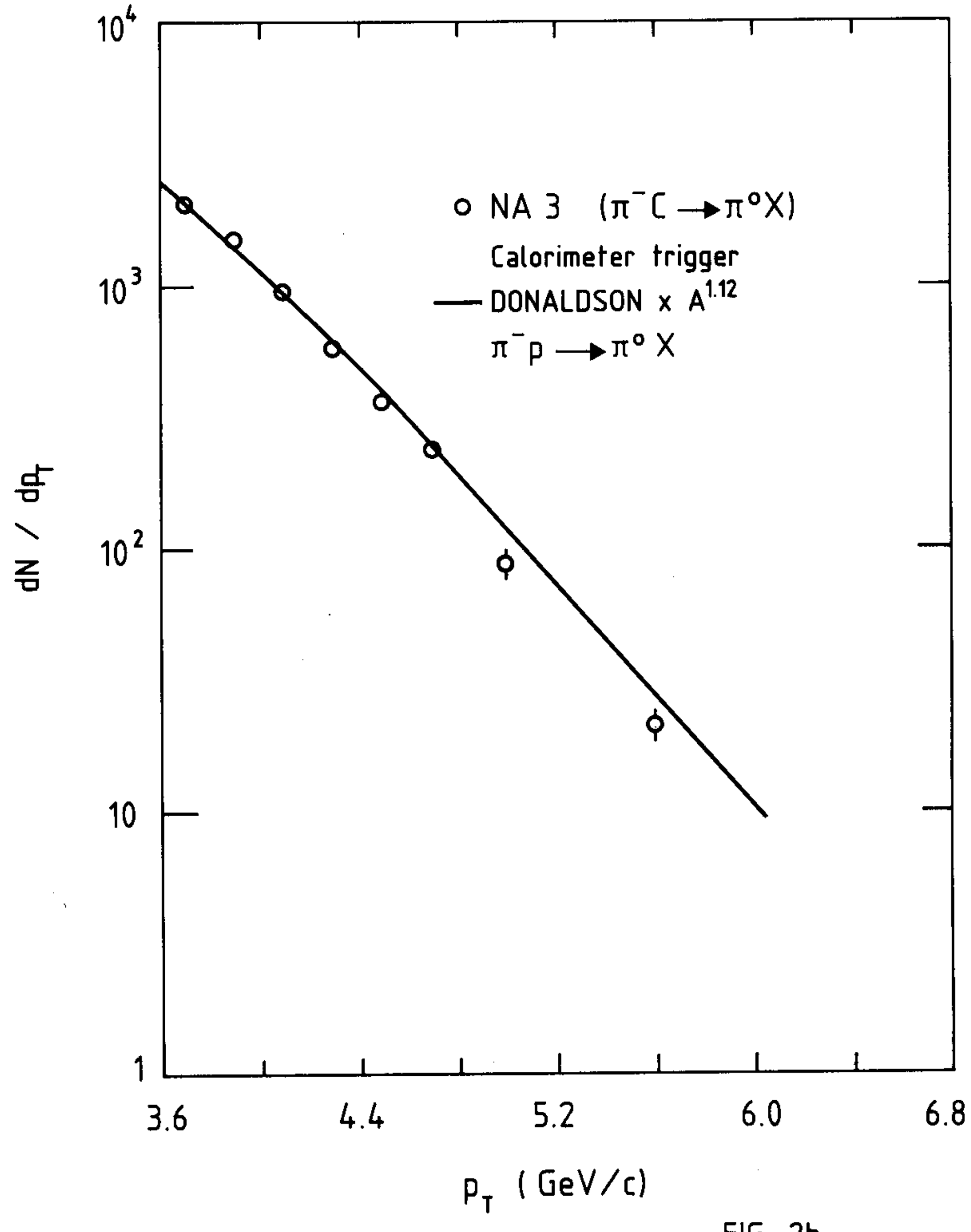
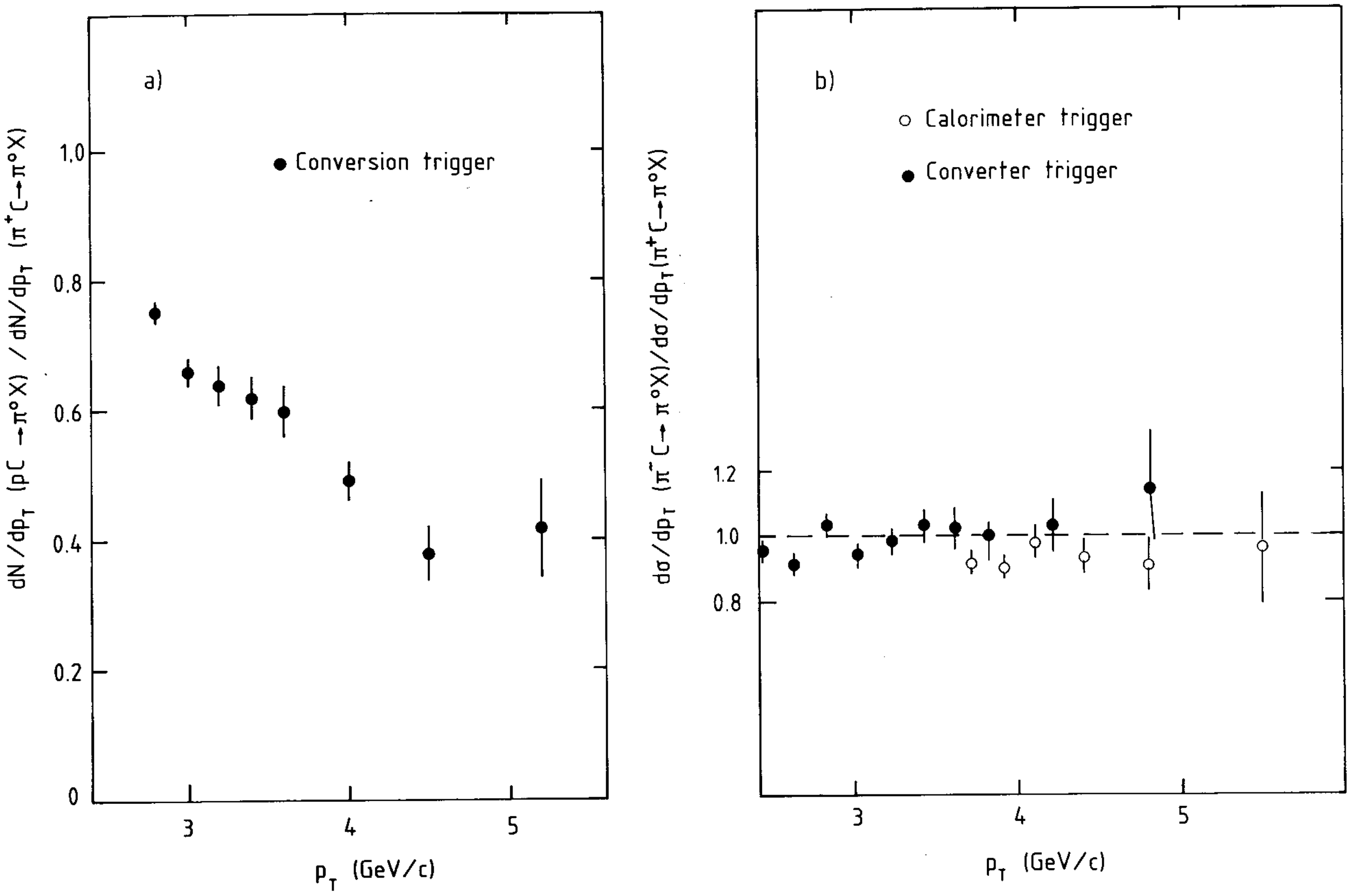

NA 3 (π⁻C → π°X)
Calorimeter trigger
DONALDSON x A^1.12
π⁻p → π° X
dN / dp_T
p_T (GeV/c)
10^4
10^3
10^2
10
1
3.6
4.4
5.2
6.0
6.8

FIG. 2b



a)
Conversion trigger
dN / dp_T (pC → π°X) / dN/dp_T (π⁺C → π°X)
1.0
0.8
0.6
0.4
0.2
0
3
4
5
p_T (GeV/c)
b)
Calorimeter trigger
Converter trigger
dσ/dp_T (π⁻C → π°X)/dσ/dp_T(π⁺C → π°X)
1.2
1.0
0.8
3
4
5
p_T (GeV/c)

FIG. 3

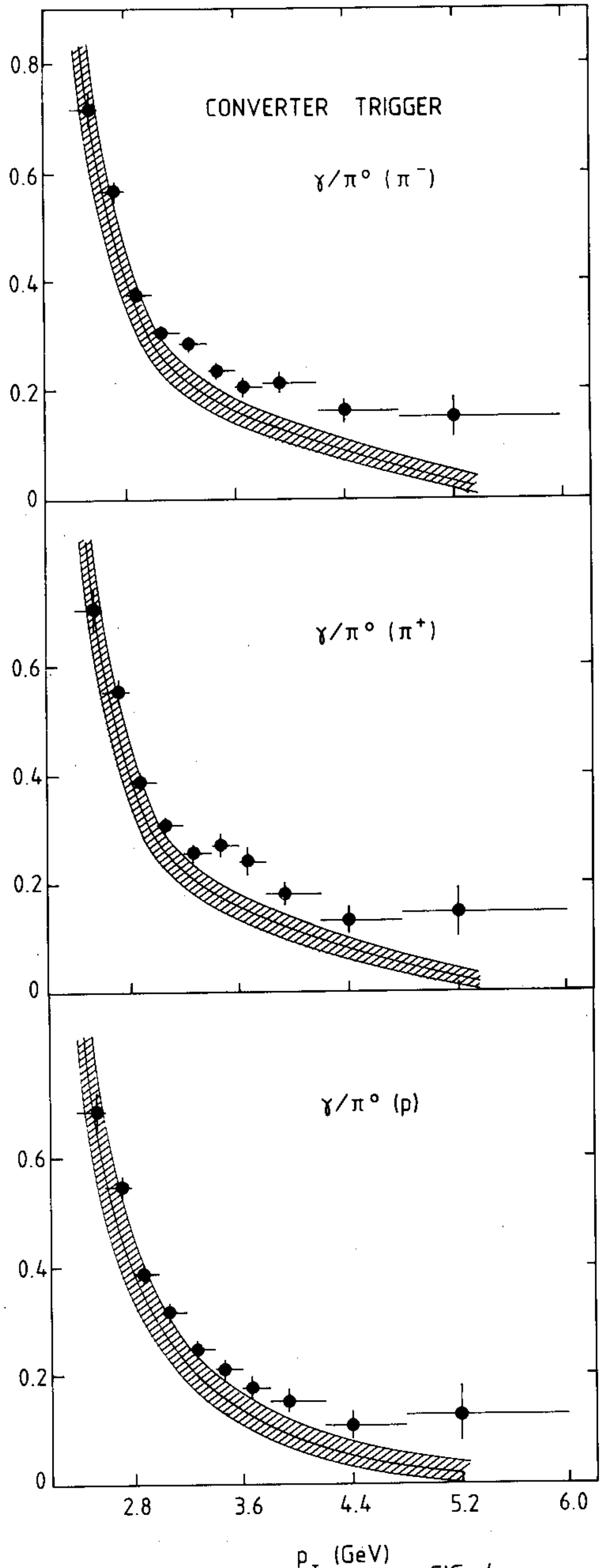
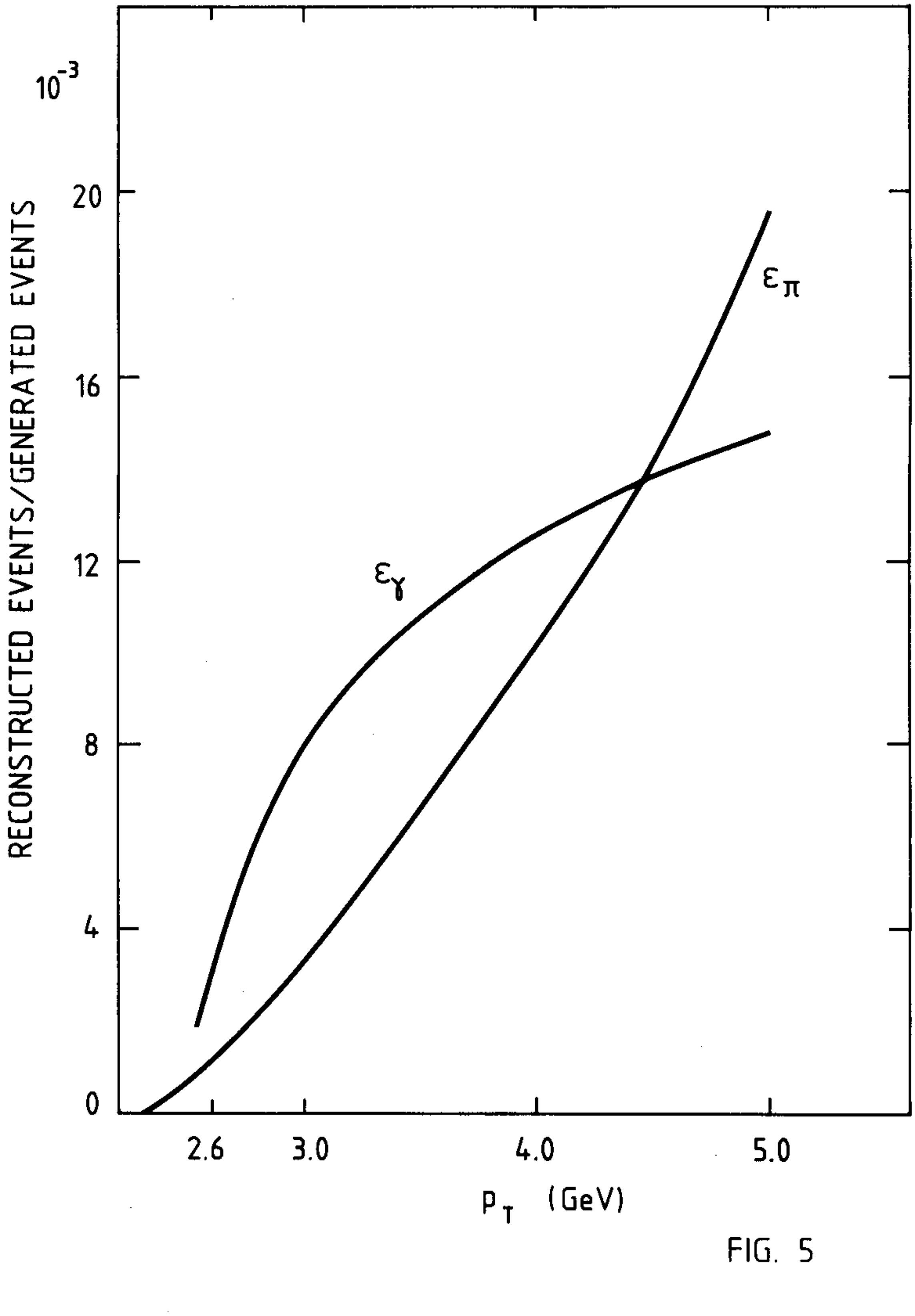


FIG. 4



10^-3
RECONSTRUCTED EVENTS/GENERATED EVENTS
20
16
12
8
4
0
2.6
3.0
4.0
5.0
p_T (GeV)
ε_π
ε_γ

FIG. 5

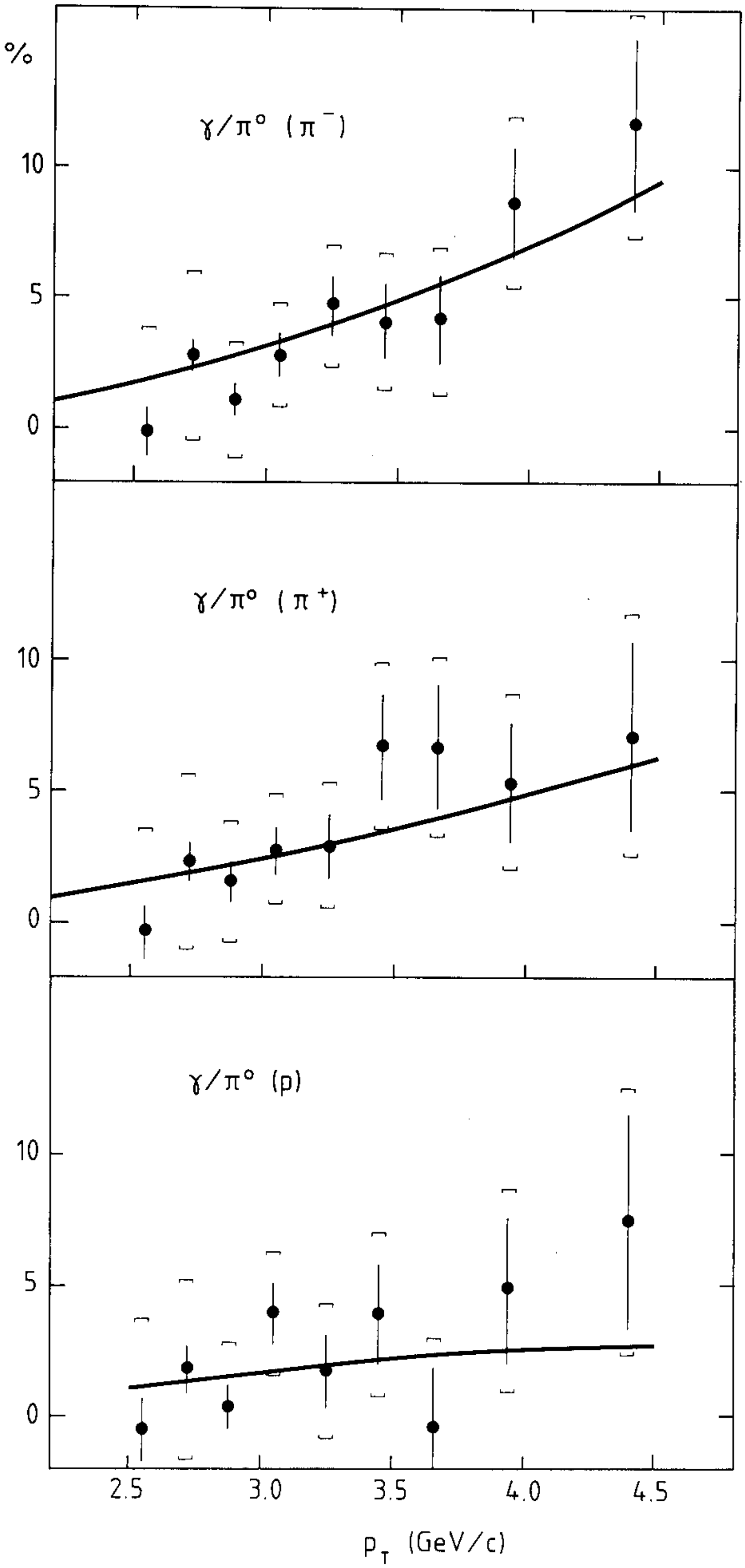
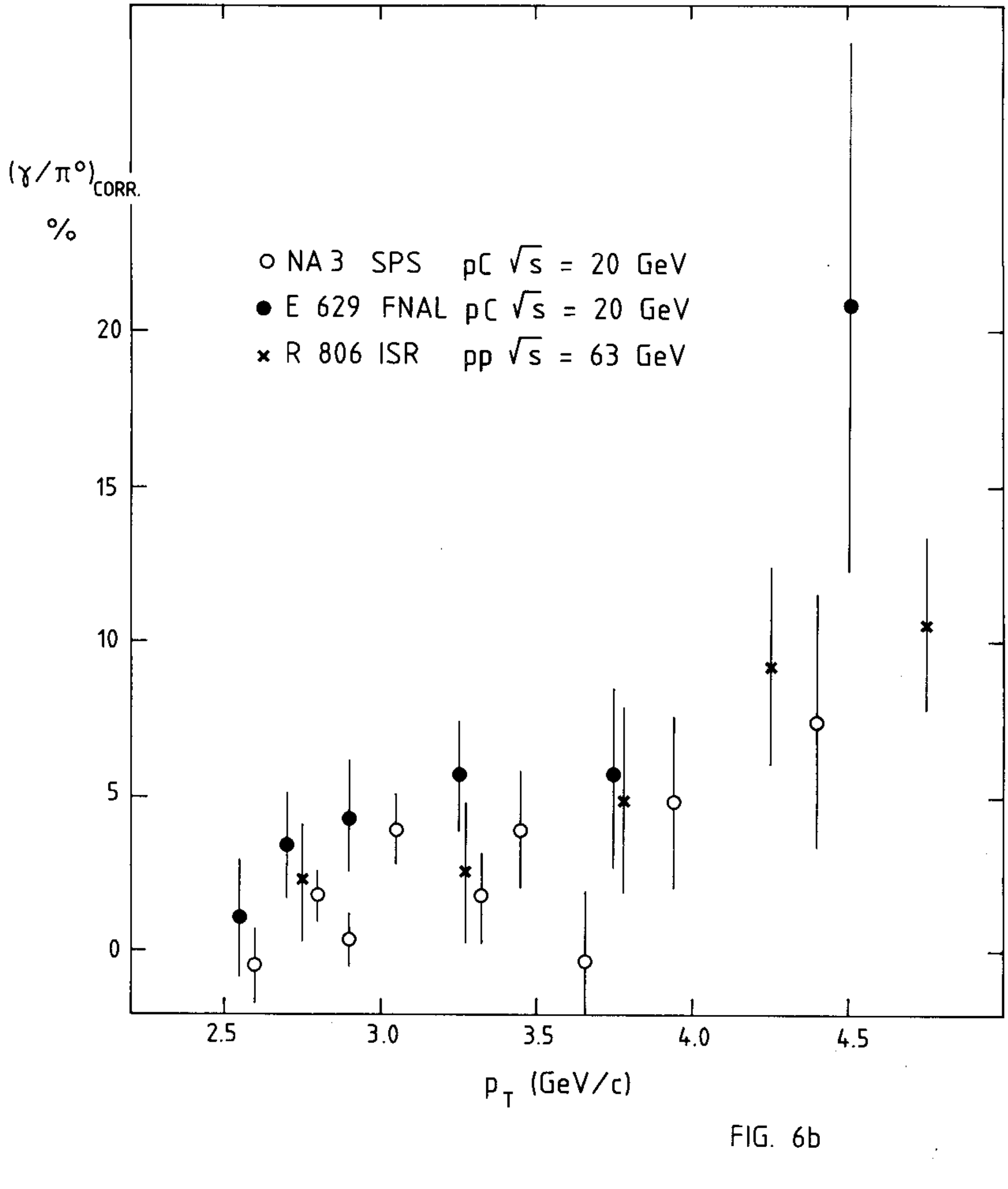
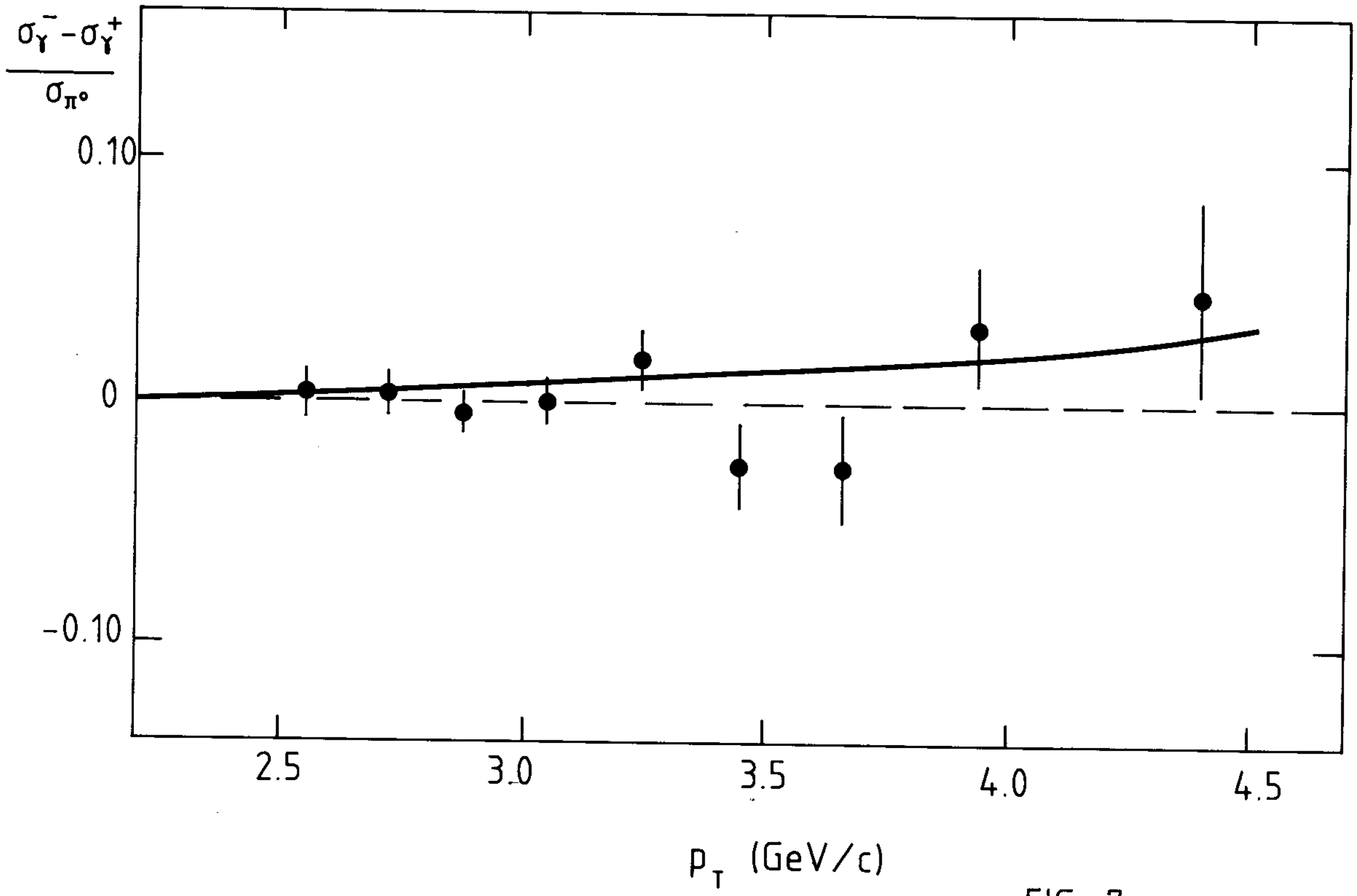


FIG. 6a



$(\gamma/\pi^0)_{CORR.}$
%
○ NA 3 SPS pC $\sqrt{s}$ = 20 GeV
● E 629 FNAL pC $\sqrt{s}$ = 20 GeV
× R 806 ISR pp $\sqrt{s}$ = 63 GeV
20
15
10
5
0
2.5
3.0
3.5
4.0
4.5
p_T (GeV/c)

FIG. 6b



$\frac{\sigma_\gamma^- - \sigma_\gamma^+}{\sigma_{\pi^0}}$
0.10
0
-0.10
2.5
3.0
3.5
4.0
4.5
p_T (GeV/c)

FIG. 7