EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/86-84
4 July 1986

INCLUSIVE η PRODUCTION AT LOW TRANSVERSE MOMENTUM IN 63 GeV pp COLLISIONS AT THE CERN INTERSECTING STORAGE RINGS

The Axial Field Spectrometer Collaboration

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ABSTRACT

The inclusive production of η-mesons in pp collisions at $\sqrt{s} = 63$ GeV and $\theta_{cm} = 90°$ has been measured for $p_T < 1.5$ GeV/c. The η/π ratio decreases from its previously measured asymptotic value of $\eta/\pi \sim 0.5$ at high transverse momentum, to $\eta/\pi \approx 0.3$ at $p_T = 750$ MeV/c and $\eta/\pi \approx 0.01$ at $p_T = 300$ MeV/c, in a way that is consistent with phase-space considerations, e.g. m_T scaling. The η/π ratio, integrated from 0.2–1.5 GeV/c, is found to be $\eta/\pi = 0.07 \pm 0.055$.

(Submitted to Physics Letters B)

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1. INTRODUCTION

Despite the fact that η mesons are copiously produced in various high-energy reactions and that their decay parameters are well studied, experimental data on cross-sections are scarce and are only available over a restricted kinematical range. The production of η's is not merely of interest in itself because of speculations about the η-flavour content; it is also relevant for measurements of prompt γ or electron production at low p_T, where various η decay modes contribute a significant fraction to the background. Owing to the large combinatorial background inherent in the detection of η particles in high-multiplicity hadronic final states, differential cross-sections in hadronic interactions are known only at high x_F (Regge regime), in the central region ($x_F \simeq 0$) at high p_T [1], or in semi-inclusive channels [2]. In the central region, all data at high centre-of-mass (c.m.) energies ($\sqrt{s} \approx$ 10–540 GeV) are consistent with an η/π ratio close to 0.5 in the transverse momentum range covered ($p_T \geq 1$ GeV/c). Topological cross-sections, however, measured in various bubble chamber experiments [3], yield a much lower ratio of η/π = 0.1–0.2. These are dominated by low-p_T production and therefore indicate a decrease of η/π at lower p_T. Such a p_T dependence, expected from phase-space considerations and the sequential production of low-p_T pions from resonance decays, can be described by parametrizing the inclusive production in terms of the transverse mass, $m_T = \sqrt{m^2 + p_T^2}$, rather than the transverse momentum. This concept, called m_T scaling, which is also inherent in more sophisticated models such as the Lund string fragmentation, describes rather successfully the p_T variations of various meson-to-pion ratios [4], when the absolute scale is adjusted to experimental results in the region $p_T >> m$. However, the need to use phenomenological models rather than experimental data on η production would have been a major source of systematic uncertainty in a measurement of prompt electron production [5] which was carried out by our group. We therefore reanalysed the data sample used for this e/π measurement to determine directly the η/π ratio in pp interactions at $\sqrt{s}$ = 63 GeV/c. The η was detected by identifying the converted photons of the decay $\eta \rightarrow \gamma\gamma$. The resulting η cross-section, measured in the p_T range below 1.5 GeV/c, was indeed found to decrease in a way that is consistent with m_T scaling.

2. EXPERIMENTAL SET-UP

The experiment was performed at the Axial Field Spectrometer (AFS) [6] at the CERN Intersecting Storage Rings (ISR). For this measurement, the spectrometer was reconfigured as shown in fig. 1. To obtain efficient electron identification at the trigger level, two gas Cherenkov counters, filled with CO_2 at atmospheric pressure, were added at $\theta_{cm} = 90°$ in front of one of the NaI crystal walls. The NaI counters, segmented into 600 crystals of 5.3 radiation lengths each, covered an area of $60 \times 80\ cm^2$ on either side of the intersection. To allow for time-of-flight identification, one wall of the box-shaped uranium/scintillator calorimeter was moved back to a distance of 5 m from the intersection. Two scintillator counters placed behind the Cherenkovs were used to define the π trigger together with a minimum-bias interaction trigger, provided by the beam–beam counters positioned around the beam pipes downstream of the spectrometer, or by the inner hodoscope counters which surround the interaction region. For the e trigger, an additional signal was required from the corresponding Cherenkov and, for about half of the data, a minimum energy deposit of 250 MeV in the NaI wall.

The charged tracks were recorded by the central vertex detector, a cylindrical drift chamber 1.40 m long and extending in radius from 20 to 80 cm. The AFS magnetic field was reduced to 0.1 T in order to optimize the detection of low-momentum tracks.

About 2 million events (sample A) were recorded in two ISR runs dedicated to the measurement of the e/π ratio mentioned before. However, most of them were triggered by Dalitz decays and photons, which converted somewhere in the apparatus or in the material between the vertex and the drift chamber (4.9% of a radiation length). This large data sample of low-mass pairs could then be used in this study to detect the 2γ decays of π^0 and η mesons, in which both γ's converted before entering the drift chamber.

In addition, we analysed a smaller number (sample B) of $\approx$ 60,000 minimum-bias events, recorded with the standard AFS set-up, i.e. no Cherenkov counters and all walls in their nominal position. In this sample, the $\eta \to \gamma\gamma$ decay could be detected directly in the two opposite NaI walls for η's of low transverse momentum, where the photons were in a back-to-back configuration.

3. ANALYSIS OF THE DATA

The events were processed through the AFS track-finding and track-and-vertex fitting programs. For sample A, the reconstructed tracks were extrapolated through the magnetic field to the trigger detectors in front of the uranium calorimeter wall. As even high-energy e^+e^- pairs opened up sufficiently in the magnetic field, events with exactly one track extrapolating to the scintillators were selected for further analysis. This requirement removed the large fraction of events triggered by the soft-electron background not originating from the intersection region. The triggering track was then identified as an electron by means of time of flight, Cherenkov pulse height, and dE/dx measured in the drift chamber, thus achieving a pion rejection factor of more than 1000 [5].

To recognize γ conversions, the reconstructed tracks of other particles inside the drift chamber were used. Combining all other tracks of opposite charge with the trigger track, the pair was accepted as a converted photon if

i) a secondary vertex (= conversion point) could be reconstructed close to the beam pipe, inner hodoscope, or inner drift chamber wall;
ii) the opening angle between the particles was small ($< 18°$) and the invariant mass less than 25 MeV/c^2 (fig. 2);
iii) the reconstructed γ pointed back to the primary vertex;
iv) the dE/dx information of the second track was consistent with electron identification.

In about 10% of the events, more than one conversion could be found by using the same criteria as listed above for combinations between the remaining tracks. Owing to the lack of good electron identification for non-triggering tracks, the background contamination, estimated by the number of like-sign pairs satisfying the selection cuts, was $<$ 10% for the second γ, compared to $<$ 1% for the triggering conversion (fig. 2).

At this stage of the analysis, approximately 20,000 events were left with at least two γ candidates. Figure 3a shows the two-photon invariant mass distribution for the NaI-triggered part of data sample A, using only the two γ's with the highest transverse momentum in each event, and restricting the 2γ system to $|y| < 0.6$ and $p_T = 0.2$–1.5 GeV/c. A clear peak at the π^0 mass can be seen, with a resolution of $\sigma = 15$ MeV/c^2, which is dominated by the momentum resolution of the drift chamber, $\Delta p/p = 8\%$ at the low field used. The shape of the combinatorial background, drawn as a full line in fig. 3a, was determined from the data by mixing reconstructed γ's from the electron-triggered events with the uncorrelated γ's from π-triggered events. Two Gaussian distributions were then fitted to the data simultaneously (shown separately in fig. 3b). Figure 3b shows the mass spectrum after background subtraction. In the mass region, where the η meson is expected, a small enhancement of data over background is found at the 3σ level, corresponding to 96 ± 35 events, which can be fitted by a Gaussian with $m = 570 \pm 20$ MeV/c^2, $\sigma = 37 \pm 20$ MeV/c^2, the width being consistent with the expected detector resolution.

As both mesons were measured in the same decay mode, efficiencies and systematic uncertainties largely cancel in the η/π ratio; the remaining correction caused by the p_T dependence of the reconstruction efficiency and the different decay Q-values of π^0's and η's was calculated by means of a detector Monte Carlo. This program simulated the geometrical acceptance, detection efficiency, and trigger efficiency of the NaI detector. In order to test the Monte Carlo, the p_T spectrum of π^0's was compared with published π^+ and π^- distributions [7]. Assuming $\pi^0 = 1/2(\pi^+ + \pi^-)$, the data agree within statistical errors in the p_T range studied, i.e. 0.2 GeV/c $< p_T <$ 1.5 GeV/c. The remaining systematic uncertainties for the relative ratio η/π were estimated both in the data and the Monte Carlo, and found to be negligible compared with the statistical errors.

In the minimum-bias triggered data (sample B), the energy of the two γ's, measured in the NaI, was required to be above 120 MeV and, for at least one of the γ's, to be above 250 MeV in order to reduce the combinatorial background. The sensitivity for η's was restricted by the geometrical acceptance to $p_T <$ 500 MeV/c, whereas π^0's could be reconstructed only with a p_T above 500 MeV/c, where both γ's were detected in the same NaI wall. The integrated π^0 cross-section, needed for normalization, was extracted below 500 MeV/c from the charged-track spectrum measured in the drift chamber, and below 200 MeV/c from published results [7]. No η signal was found in this data sample.

4. RESULTS

The efficiency-corrected ratios of η to π^0 production are given for different p_T intervals in table 1, where the error includes the statistical errors in the number of events in the π^0 and η mass intervals as well as the scale error of the background normalization as given by the least squares fit. The data are split into two samples corresponding to the different trigger conditions. In data sample B, where the photons were measured in the NaI detector, no η signal is found, and therefore upper limits (2σ) are given. The p_T dependence of η/π is also shown in fig. 4, together with the results from other experiments which have measured η/π at high c.m. energies.

For comparison, a particular parametrization of m_T scaling, normalized to $\eta/\pi = 0.55$ at $p_T = 5$ GeV/c, is shown as a dashed line in fig. 4 (Bourquin et al., [4]).

Whereas at high p_T the η/π was found to be constant at a level of ≈ 0.5, the ratio is now seen to drop considerably below $p_T \approx$ 1–2 GeV in a way that is consistent with m_T scaling. Integrated over the p_T range 0.2–1.5 GeV/c, we find $\eta/\pi = 0.07 \pm 0.055$, compatible with the published topological cross-section ratios of $\eta/\pi \simeq 0.1$ [3]. The m_T scaling prediction, in itself uncertain by 10%-30% depending on the parametrization used [4], is $\eta/\pi \approx 0.18$.

In summary, we measured the inclusive η cross-section in pp interactions at central rapidities in the p_T range 0.2–1.5 GeV/c to be $\eta/\pi = 0.07 \pm 0.055$. This ratio increases from $\eta/\pi = 0.01 \pm 0.06$ at $p_T = 0.3$ GeV/c to its asymptotic value $\eta/\pi \approx 0.5$ found at high transverse momenta. Within the limited accuracy of this experiment, the p_T dependence is consistent with phase-space estimates, e.g. m_T scaling, and is therefore similar to the behaviour observed in the production of various other mesons.

REFERENCES

[1] F.W. Busser et al., Nucl. Phys. **B106** (1976) 1.
G.J. Donaldson et al., Phys. Rev. Lett. **40** (1978) 684.
R.M. Baltrusaitis et al., Phys. Lett. **88B** (1979) 372.
E. Amaldi et al., Nucl. Phys. **B158** (1979) 1.
C. Kourkoumelis et al., Phys. Lett. **84B** (1979) 277.
J. Kanzaki et al., J. Phys. Soc. J p n, **50** (1981) 3849.
T. Åkesson et al., Z. Phys. **C18** (1983) 5.
T. Åkesson et al., Phys. Lett. **158B** (1985) 282.
M. Banner et al., Z. Phys. **C27** (1985) 329.

[2] J. Bartke et al., Nucl. Phys. **B118** (1977) 360.

[3] K. Jaeger et al., Phys. Rev. **D11** (1975) 1756.
A.C. Borg et al., Nucl. Phys. **B106** (1976) 430.
R.D. Kass et al., Phys. Rev. **D20** (1979) 605.
R. Barloutaud et al., Nucl. Phys. **B176** (1980) 285.
G. Levman et al., Phys. Rev. **D21** (1980) 1.
C. Poiret et al., Z. Phys. **C7** (1981) 283.
M. Barth et al., Z. Phys. **C22** (1984) 23.
L. Bailly et al., Z. Phys. **C22** (1984) 119.
S. Chakrabarti et al., Z. Phys. **C27** (1985) 1.

[4] M. Bourquin and J.M. Gaillard, Phys. Lett. **59B** (1975) 191.
M. Bourquin and J.M. Gaillard, Nucl. Phys. **B114** (1976) 334.
J. Bartke et al., Nucl. Phys. **B120** (1977) 14.

[5] T. Åkesson et al., Phys. Lett. **152B** (1985) 411.

[6] T. Åkesson et al., Nucl. Instrum. Methods **196** (1982) 303 and 315.
T. Åkesson et al., Phys. Scri. **23** (1981) 649.
R. Batley et al., Nucl. Instrum. Methods **A242** (1985) 75.

[7] B. Alper et al., Nucl. Phys. **B100** (1975) 237.
K. Guettler et al., Phys. Lett. **64B** (1976) 111.

Table 1

η/π versus p_T

Sample	p_T (MeV/c)	η/π
A	200–500 500–1500	0.01 ± 0.06 0.30 ± 0.15
B	0–500	< 0.22 (2σ)

Figure captions

Fig. 1: The arrangement of the AFS spectrometer used for the measurement of converted photons.

Fig. 2: Invariant mass distribution of electron pairs accepted as converted γ's for a) the triggering conversion and b) the non-triggering conversion.

Fig. 3: Invariant mass distribution of converted photon pairs a) before and b) after subtracting random combinatorial background. The shape of the background [full line in (a)] was generated by mixing events, and fitted to the data together with two Gaussian distributions [full line in (b)] of unconstrained width and position.

Fig. 4: The η/π ratio versus the transverse momentum, together with results from other experiments [1]. The dashed line represents the $m_T$scaling parametrization of Bourquin et al. [4], normalized to $\eta/\pi = 0.55$ at $p_T = 5$ GeV/c.

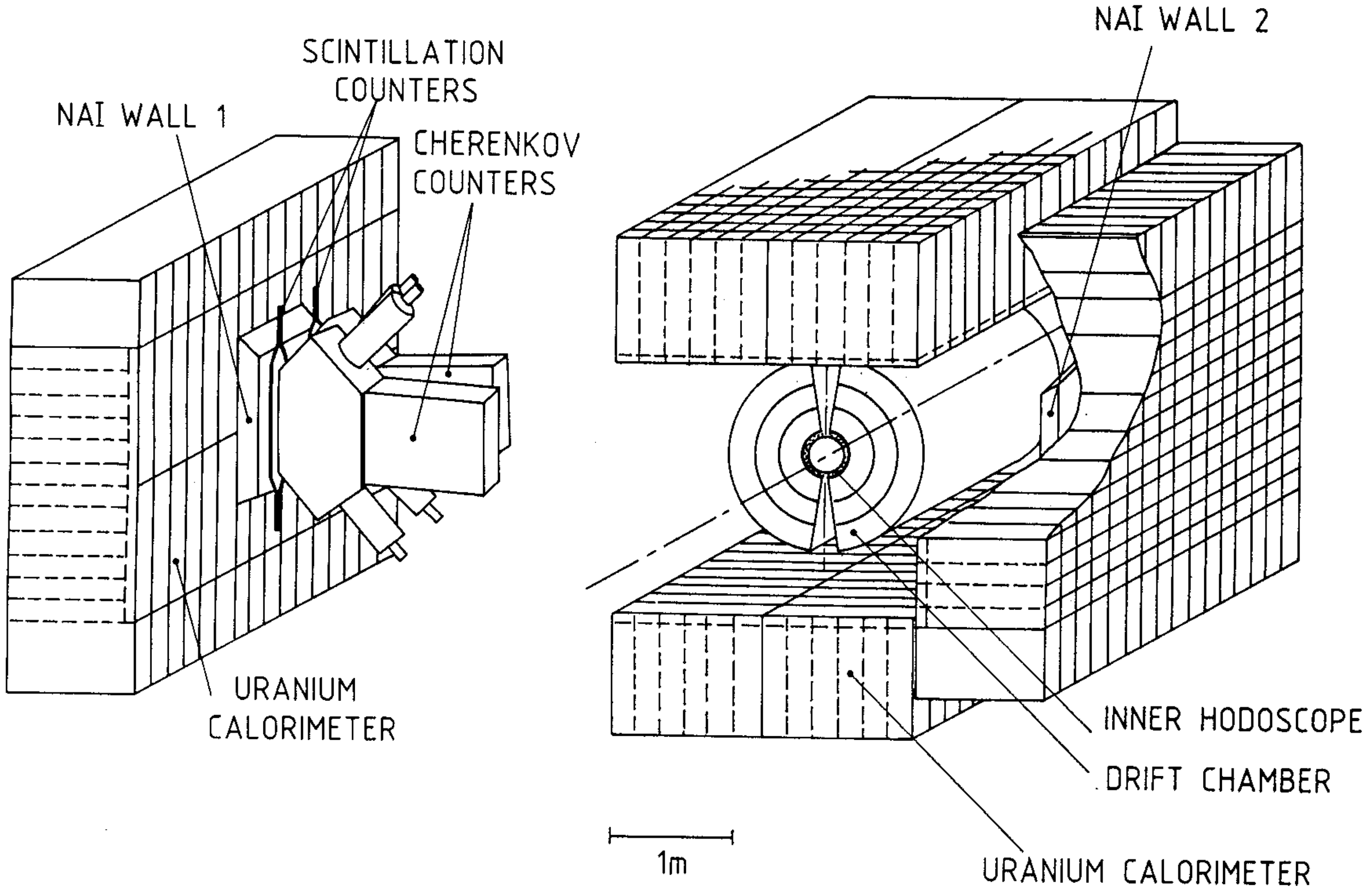
SCINTILLATION COUNTERS
NAI WALL 1
CHERENKOV COUNTERS
URANIUM CALORIMETER
NAI WALL 2
INNER HODOSCOPE
DRIFT CHAMBER
1m
URANIUM CALORIMETER

Fig. 1

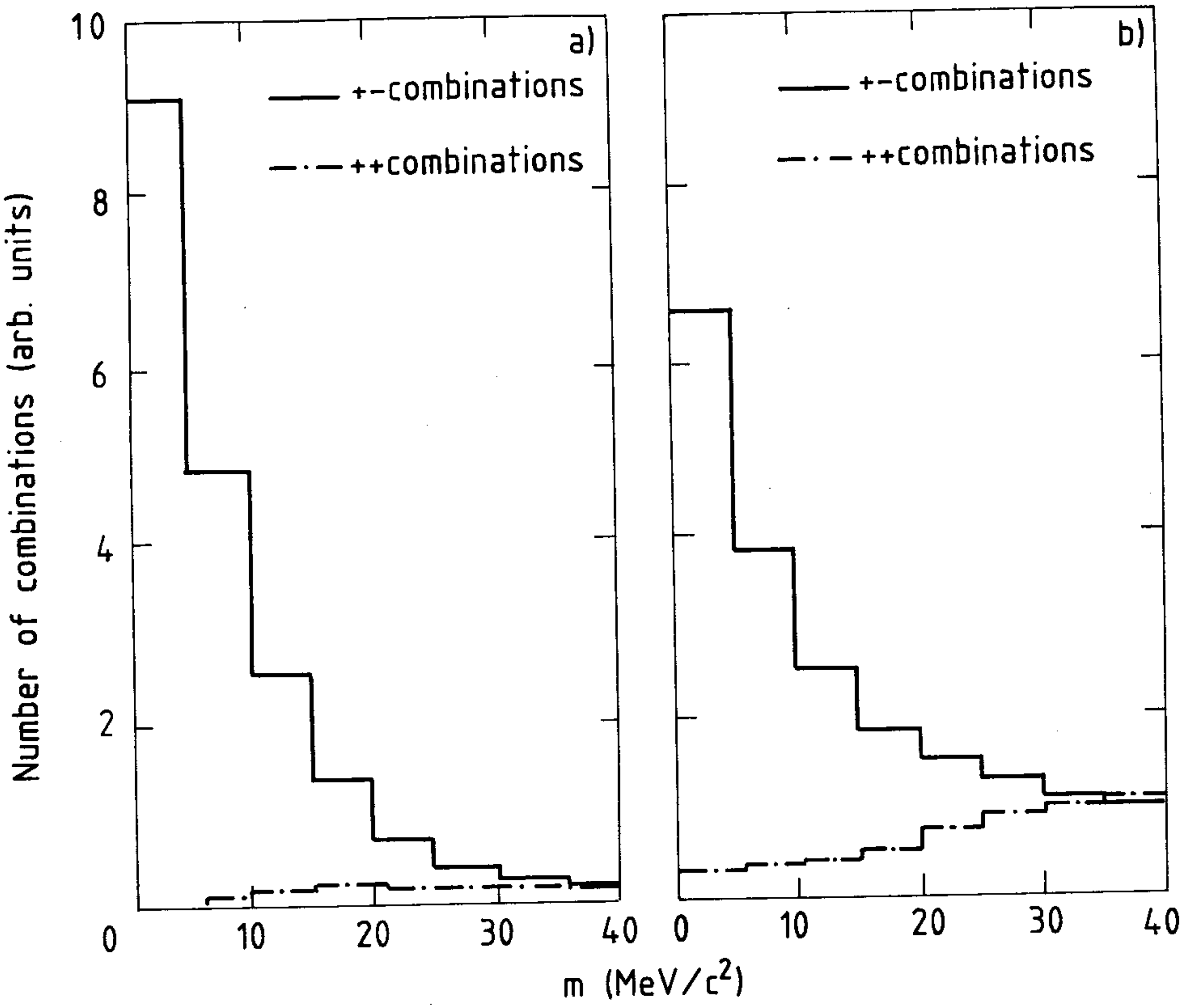
a)
b)
+-combinations
++combinations
+-combinations
++combinations
Number of combinations (arb. units)
0
2
4
6
8
10
0
10
20
30
40
0
10
20
30
40
m (MeV/c^2)

Fig. 2

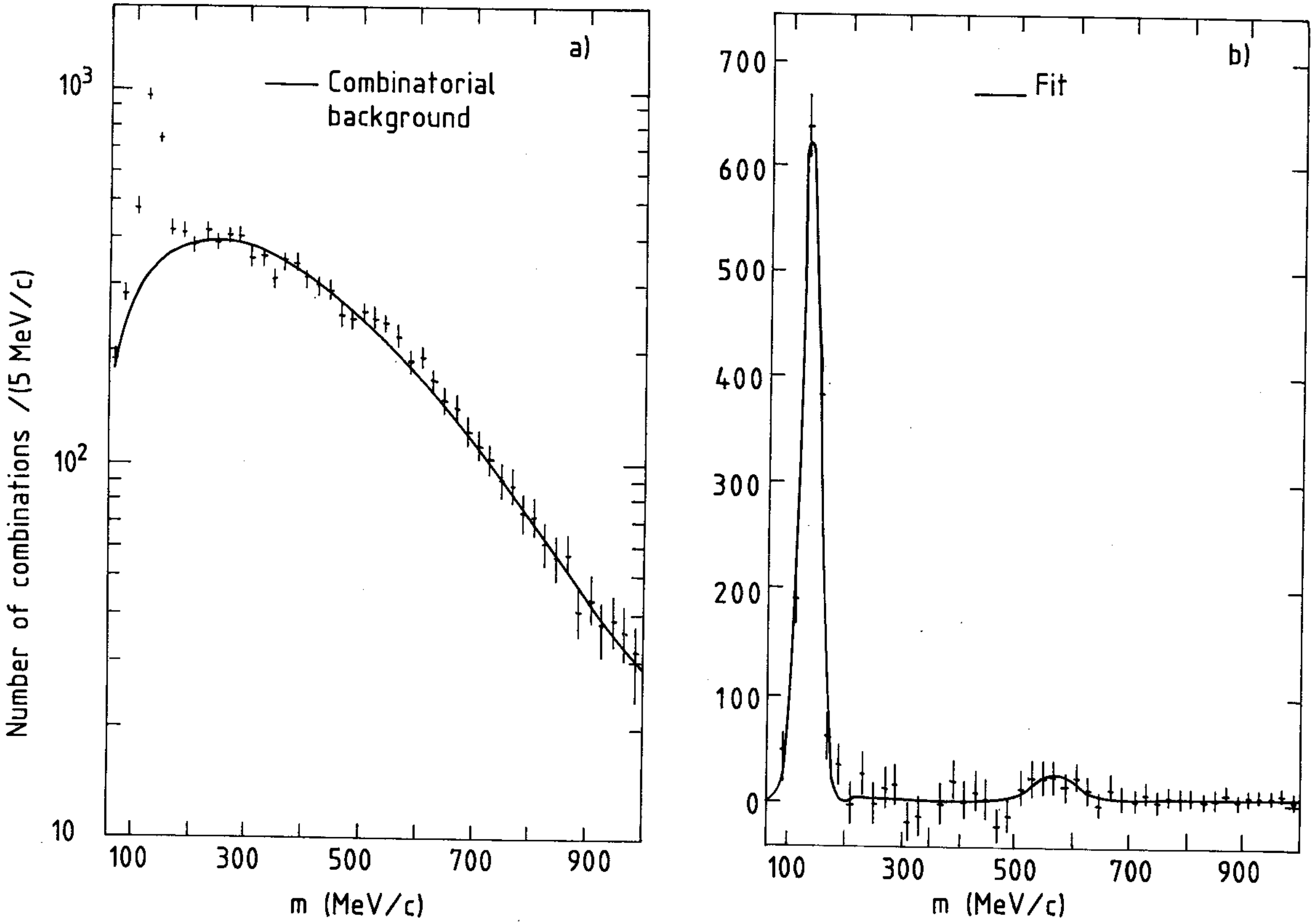
a)
Combinatorial background
Number of combinations /(5 MeV/c)
10^3
10^2
10
100
300
500
700
900
m (MeV/c)
b)
Fit
700
600
500
400
300
200
100
0
100
300
500
700
900
m (MeV/c)

Fig. 3

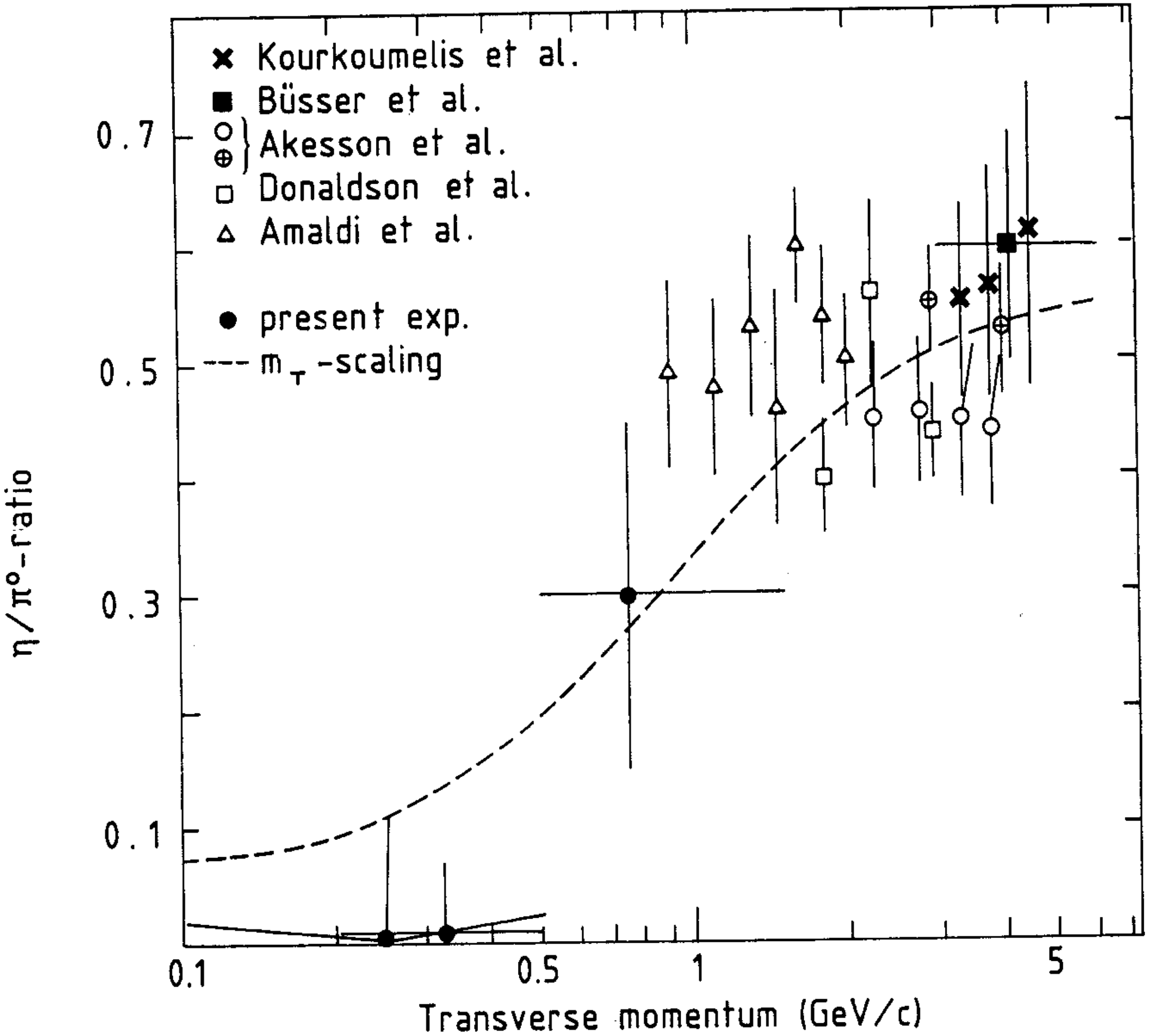
Kourkoumelis et al.
Büsser et al.
Akesson et al.
Donaldson et al.
Amaldi et al.
present exp.
m_T-scaling
0.7
0.5
0.3
0.1
η/π^o-ratio
0.1
0.5
1
5
Transverse momentum (GeV/c)

Fig. 4