EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN-EP/80-02
15 January 1980

A MEASUREMENT OF DIRECT PHOTON PRODUCTION AT LARGE p_T AT THE CERN ISR

M. Diakonou, C. Kourkoumelis and L.K. Resvanis
Athens University, Athens, Greece

T.A. Filippas, E. Fokitis and C. Trakkas
National Technical University, Athens, Greece

A.M. Cnops, E.C. Fowler[1], D.M. Hood[2]
R.B. Palmer, D.C. Rahm, P. Rehak and I. Stumer
Brookhaven National Laboratory, Upton, NY, USA[3]

C.W. Fabjan, T. Fields[4], D. Lissauer[5], I. Mannelli[6]
W. Molzon, P. Mouzourakis and W.J. Willis
CERN, Geneva, Switzerland

ABSTRACT

We have measured direct photon production in pp collisions at the CERN Intersecting Storage Rings for c.m. energies $31 < \sqrt{s} < 63$ GeV and transverse momenta up to 9 GeV/c, using segmented lead/liquid-argon calorimeters. The ratio of direct photon to π^0 production is significantly larger than zero, starting at $p_T \approx 4$ GeV/c and increasing to values of about 0.4 at 9 GeV/c. No significant $\sqrt{s}$ dependence is seen.

(Submitted to Physics Letters)

---

1) Permanent address: Purdue University, W. Lafayette, Ind., USA.
2) Now at David Lipcomb College, Nashville, Tenn., USA.
3) Research supported under auspices of the US Department of Energy.
4) Permanent address: Argonne National Laboratory, Argonne, Ill., USA.
5) Permanent address: Tel-Aviv University, Ramat Aviv, Israel.
6) On leave of absence from the University of Pisa, and INFN, Sezione di Pisa, Italy.

There has recently been increasing interest in the hadronic production of large p_T prompt photons. This interest stems from the possibility of using this process to probe the constituent structure of hadrons, as recognized by many authors [1-7]. The photon can couple to quarks in a point-like manner via their electric charge; it can thus be emitted in the hard scattering of constituents which is known to produce high p_T phenomena. Unlike quarks and gluons, the photon does not have to fragment into hadrons and can be directly observed as a final-state particle. Because of this unique feature, direct photon production can provide an insight into the dynamics of hadronic constituents which is not obscured by their fragmentation.

In the present experiment we have measured the direct photon yield at the CERN Intersecting Storage Rings (ISR) for c.m. energies between $\sqrt{s}$ = 31 GeV and $\sqrt{s}$ = 63 GeV and transverse momenta between 3.5 and 9 GeV/c, thus extending our previous results [8] to higher p_T values. The direct photon yield has been normalized to that of π^0's, detected in the same apparatus and under the same conditions [9]. It should be noted that over the full p_T range the two photons from π^0 decay are individually resolved in almost every case in our detector, providing a very clear π^0 signature.

The apparatus used for the direct photon measurement consisted of two lead/liquid-argon calorimeters, which are described in more detail elsewhere [10-11]. These were subdivided both longitudinally (in the direction of shower development) for effective hadron-photon discrimination, and laterally. A position resolution of $\sigma_x \sim 5$ mm and the ability to resolve two showers reliably down to a transverse separation of 50 mm resulted from the high degree of lateral segmentation.

We have deliberately changed a number of features of the set-up used for our previous experiment, so that these results may be considered a largely independent confirmation of those obtained earlier. The two calorimeters were placed at a distance of 2.15 m from the centre of the ISR interaction diamond, rather than at 1.6 m, and at an inclination of ±24° to the horizontal plane. In this position, the angular coverage of each module was 69° to 111° in polar angle and about 17°

in azimuth. The modules were also positioned away from the ISR c.m. motion rather than towards it. Their effective acceptance in the c.m. frame ($\sim$ 0.14 sr) was somewhat smaller than in the laboratory. These changes gave increased π^0 resolution at high p_T and minimized the beam-gas background. In addition, the trigger was modified to equalize the trigger efficiencies for π^0's and single photons.

An event triggered the detector whenever the following requirements were met:

i) A coincidence between the hodoscopes on the two arms was detected, indicating a beam-beam interaction, or a signal was present in a set of barrel scintillation counters surrounding the bicone. This pre-trigger was more than 98% efficient, thus presumably creating no significant bias.

ii) The energy deposited in localized regions of the second longitudinal section of the calorimeter, as determined by two independent and interleaved views, exceeded a suitable threshold. This section extended from 3 to 5.5 radiation lengths after the front calorimeter face and thus provided a good hadron-photon discrimination at the trigger level.

iii) The total energy deposited in the calorimeter, i.e. the sum over all calorimeter sections, exceeded about 2 GeV.

The combined efficiency of the last two requirements above 3 GeV/c of transverse momentum was greater than 97% for γ's and for π^0's.

The recorded events were then processed by a version of the reconstruction program with improved shower-finding capabilities, and subjected to a set of selection criteria:

i) All showers were required to lie within a fiducial region of 56 × 140 cm compared with a total active area of 67 × 164 cm. The remainder of the calorimeter was used as a veto region in which no additional showers were allowed.

ii) The fractions of the total shower energy deposited in the first and second calorimeter sections were required to be consistent with the expected electromagnetic shower development, within certain limits. This cut was found to be more than 95% efficient for electromagnetic showers while rejecting most of the background events due to beam-gas collisions.

iii) The "unassigned energy" in the calorimeter was required to be less than 35 MeV. This quantity corresponds to the total of the energy deposits in the first two sections of the calorimeter which are not combined by the program into reconstructed showers. This cut very effectively eliminates events with additional showers which failed to be reconstructed and also events with one or more charged particles going through the calorimeter. Events with larger unassigned energy will be discussed in the last part of the paper.

iv) Single-photon candidates were also required to be unaccompanied by other showers in the calorimeter and to have a radius of less than 13.5 mm. This requirement is found to be 90% efficient for single-photon candidates satisfying all other requirements, while it rejects the majority of merged π^0's that would otherwise fake single showers.

v) Shower pairs with an invariant mass $90 < M_{\gamma\gamma} < 180$ MeV and no additional shower in the calorimeter were taken to be π^0's for the purpose of this analysis. A typical invariant mass spectrum is shown in fig. 1.

The ratio of these two samples is the raw or apparent γ/π^0 ratio, shown in fig. 2 as a function of p_T for $\sqrt{s} = 63$ GeV.

The apparent γ/π^0 ratio contains the contribution of meson decays ($\pi^0 \to \gamma\gamma$; $\eta \to \gamma\gamma$; $\omega \to \pi^0\gamma$; $\eta' \to \gamma\gamma$), which have to be subtracted in order to obtain the direct photon signal. These background contributions are computed for the actual geometry of the set-up using the π^0 and η spectra [12], and also the ω/π^0 and η'/π^0 production ratios [13], all measured in this experiment. The contributions of the ω and η' to the raw γ/π^0 ratio are quite small; those from other meson decays are believed to be negligible. The bulk of the background is due to π^0 and η decays where one of the decay photons misses the calorimeter. An important background component arises, however, from very asymmetric decays, where the soft photon is not reconstructed but the resulting unassigned energy is less than 35 MeV. There is also a small number of apparent single γ's due to merged π^0's. These contributions are calculated on the basis of a detailed simulation of shower development in the liquid-argon calorimeters, carried out using the EGS shower Monte Carlo [14].

Besides known meson decays, there are a number of effects that could, in principle, contribute to the apparent γ/π^0 ratio. In particular we have considered the following:

i) *Cosmic rays and beam-gas interactions:* These sources produce showers that will not in general point back to the interaction diamond; these showers also tend to have a greater lateral extent than true photon showers, thus being rejected by the selection cuts. The background from beam-gas events is estimated to be less than 2% of the observed γ/π^0 ratio. The cosmic-ray background has been measured in special runs with the ISR off; it was found to be negligible except at the highest values of p_T, where a small correction has been applied to the data.

ii) *Hadrons interacting in the calorimeter and simulating single showers:* The contribution of hadrons to the γ/π^0 ratio can be estimated from the analysis of an exposure of a calorimeter module to a π^- beam at the CERN Proton Synchrotron (PS). The rejection power of the calorimeter, together with the steepness of the p_T spectra of particles produced at the ISR, result in a total contamination of less than 2%.

iii) *A non-linear energy response of the calorimeters:* This could artificially create an excess of single photons, or change the ratio significantly. The limits obtained experimentally on the liquid-argon calorimeter non-linearity [8] are such that the resulting contribution to the γ/π^0 ratio would be less than 9%. This contribution has been included in the total systematic error.

When all the above backgrounds are subtracted, an excess of single photons is found for all three values of the c.m. energy used in data taking. This excess rises significantly with p_T. After correcting for the relative geometrical acceptance and reconstruction efficiency of π^0's and single γ's, one obtains the ratio of direct photon to π^0 production, γ/π^0, shown in fig. 3. This ratio rises from values of about 5% at 3.5 GeV/c to about 35% at 9 GeV/c of p_T. No significant $\sqrt{s}$ dependence is seen. The data shown correspond to integrated luminosities of 1.4×10^{36} for $\sqrt{s}$ = 31 GeV, 1.2×10^{37} for $\sqrt{s}$ = 45 GeV, and 0.9×10^{37} for $\sqrt{s}$ = = 63 GeV.

It should be noted that, owing to the unassigned energy cut and to the demand that no additional reconstructed shower be present in the calorimeter, the direct photon to π^0 production ratios given in fig. 3 do not correspond to fully inclusive conditions. The bias thus introduced has been estimated by measuring, for direct photon candidates and for π^0's (without imposing for this analysis any condition on unassigned energy), the relative probability $P^{\gamma}(0)/P^{\pi}(0)$ that none of the barrel counters within a given azimuthal angular region centred around the direction of the γ or π^0 are hit by a charged particle. This probability increases linearly as a function of the angular coverage, and the observed slope can be interpreted in the sense that it is more likely for a π^0 than a direct photon to be accompanied by an extra charged particle within the calorimeter solid angle. Allowing for neutral particles as well, in order to obtain the fully inclusive γ/π^0 ratio, the values given in fig. 3 should be multiplied by a common factor of 0.85 ± 0.15. This bias was larger in our previous experiment [9] because of the larger solid angle covered. When a similar correction is applied to earlier data, the results are consistent with the present data. We have checked that the exclusion of events with additional reconstructed showers does not appreciably alter the γ/π^0 ratio.

Finally, we point out that a detailed study of the experimental distributions of unassigned energy, carried out using the EGS simulation of photon-induced shower development in the calorimeters, provides additional evidence that indeed a large fraction of high p_T single-photon candidates cannot be explained simply by assuming that the amount of background from known meson decays is somehow underestimated. As an example, we show in fig. 4 the unassigned energy distribution, above 50 MeV, for single-photon candidates with $4.5 \leq p_T \leq 5.5$ GeV/c. A Monte Carlo calculation of this unassigned energy distribution using known sources explains the experimental data well; 95% of the contribution comes from asymmetric π^0's, the rest from single photons with additional charged particles in the calorimeter. This result is shown by the solid line. The distribution, assuming no single photons, is obtained by normalizing the unassigned energy distribution to the total below 50 MeV (5791 events). This is represented by the dashed curve in fig. 4. It fails to fit the experimental data.

REFERENCES

[1] G.R. Farrar and S.C. Frautschi, Phys. Rev. Lett. 36 (1976) 1017.

[2] C.O. Escobar, Nucl. Phys. B98 (1975) 173.

[3] E.L. Feinberg, Nuovo Cimento 34A (1976) 391.

[4] H. Fritzsch and P. Minkowski, Phys. Lett. 69B (1977) 316.

[5] R. Rückl, S.J. Brodsky and J.F. Gunion, Phys. Rev. D 18 (1979) 2469.

[6] R.D. Field,Proc. 19th Int. Conf. on High-Energy Physics, Tokyo (Phys. Soc. Japan, Tokyo, 1979), p. 743.

[7] A.P. Contogouris, S. Papadopoulos and M. Hongoh, Phys. Rev. D 19 (1979) 2607.

[8] M. Diakonou et al., Phys. Lett. 87B (1979) 292.

[9] M. Diakonou et al., A measurement of the high p_T neutral pion production at the CERN ISR, in preparation.

[10] C. Kourkoumelis, CERN 77-06 (1977).
A.J. Lankford, CERN EP Internal Report 78-03 (1978).

[11] J.H. Cobb et al., Nucl. Instr. and Methods 158 (1979) 93.

[12] C. Kourkoumelis et al., Phys. Lett. 84B (1979) 271; Phys. Lett. 84B (1979) 277.

[13] M. Diakonou et al., Inclusive production of η' and ω mesons at the CERN ISR (to be published in Phys. Lett.).

[14] R.L. Ford and W.R. Nelson, SLAC Report 210 (1978).

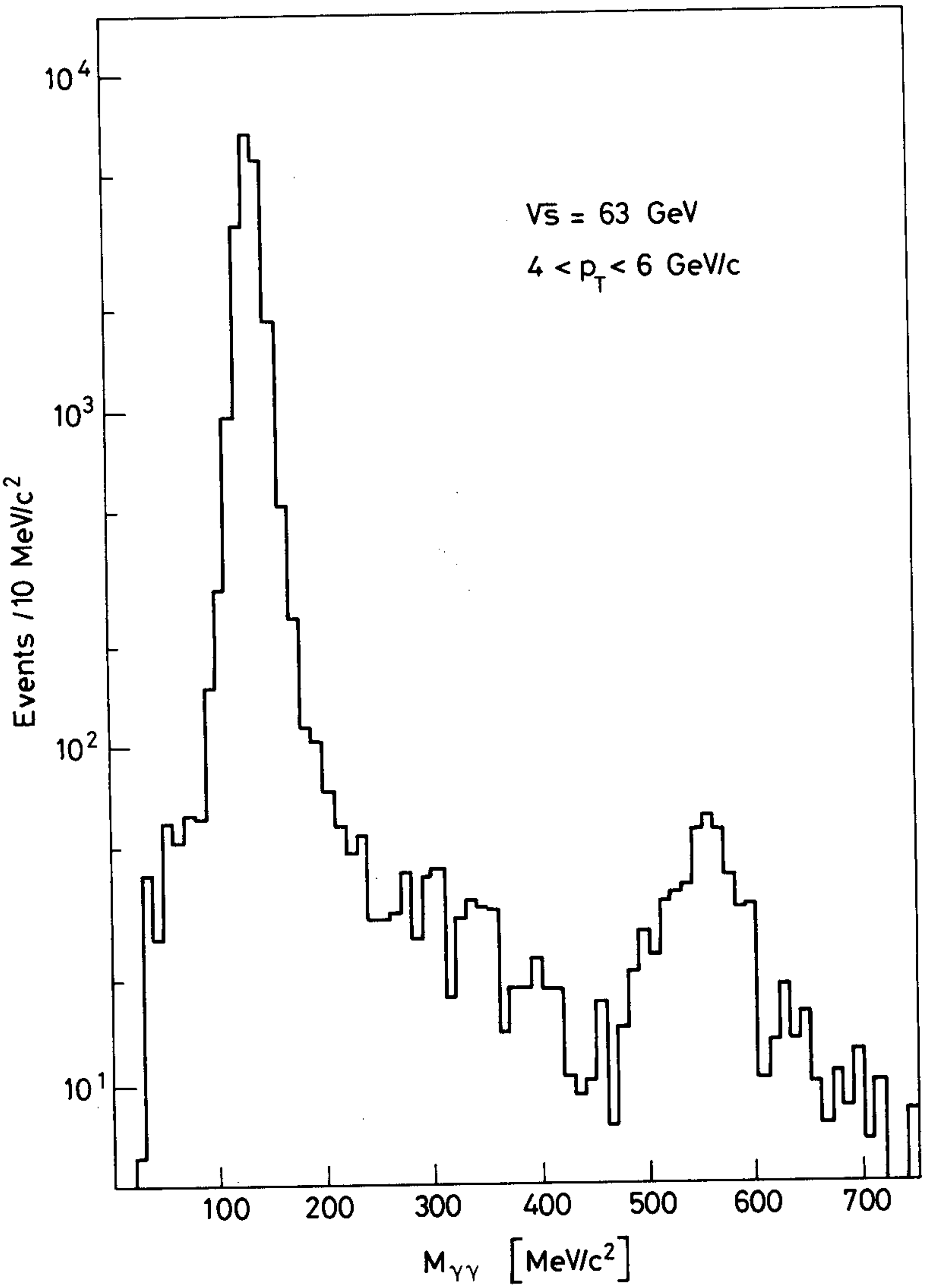
Figure captions

Fig. 1 : Mass spectrum for γ pairs.

Fig. 2 : Observed ratio of γ/π^0 at $\sqrt{s}$ = 63 GeV. Inner error bars are statistical errors. The outer error bars include possible systematic effects due to calorimeter non-linearity. The solid curve shows the Monte Carlo calculation for the ratio assuming no direct γ production. The shaded area indicates the one standard deviation systematic errors on the Monte Carlo simulation.

Fig. 3 : Final results for the γ/π^0 ratio after background subtraction and correction for relative efficiency a) at $\sqrt{s}$ = 31 GeV; b) at $\sqrt{s}$ = = 45 GeV; c) at $\sqrt{s}$ = 63 GeV.

Fig. 4 : Unassigned energy distribution, above 50 MeV, for apparent single-photon events with $4.5 \leq p_T \leq 5.5$ GeV/c at $\sqrt{s}$ = 63 GeV. The full-line smooth curve represents our calculated distribution and the solid histogram our measurement. Of the 5791 events with unassigned energy less than 50 MeV, 3671 are accounted for by meson decays. The 2120 events in excess are attributed to prompt single photons. The expected distribution, assuming no prompt single photons, is given by the dashed line.



$\sqrt{s}$ = 63 GeV
4 < p_T < 6 GeV/c
Events /10 MeV/c^2
10^4
10^3
10^2
10^1
100
200
300
400
500
600
700
$M_{\gamma\gamma}$ [MeV/c^2]

Fig. 1

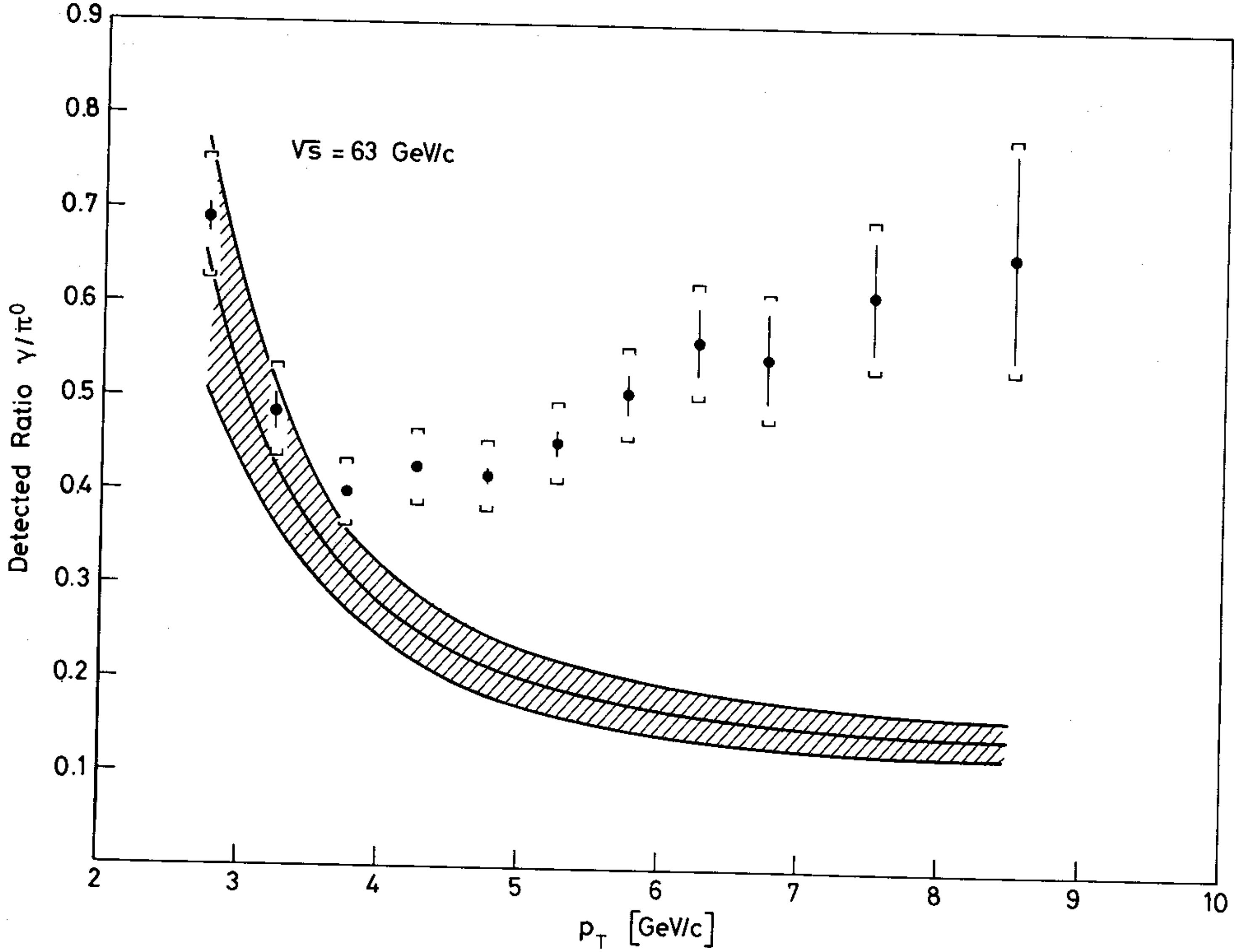
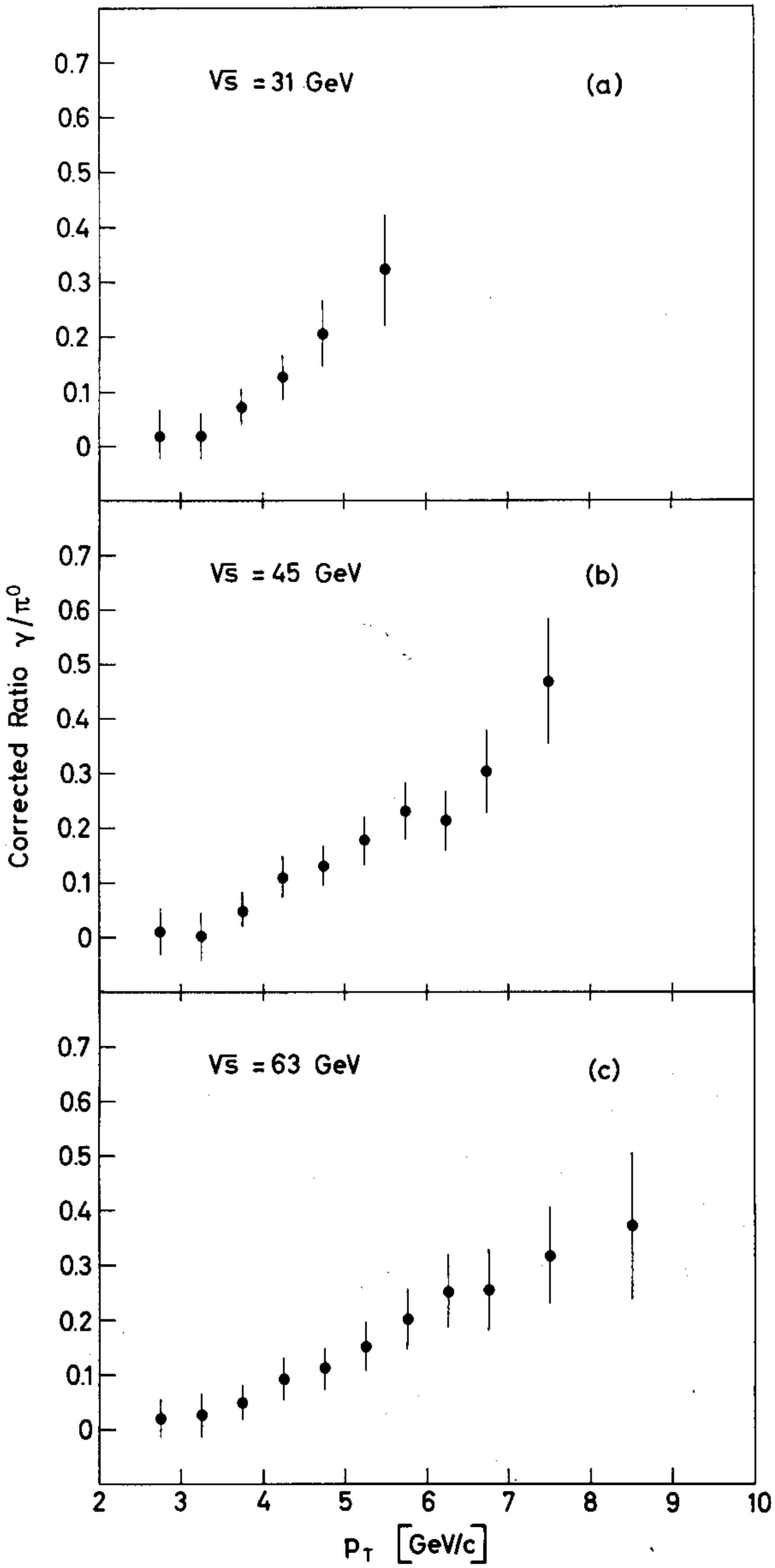

√s = 63 GeV/c
Detected Ratio γ/π0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2
3
4
5
6
7
8
9
10
pT [GeV/c]

Fig. 2



√s = 31 GeV
(a)
√s = 45 GeV
(b)
√s = 63 GeV
(c)
Corrected Ratio γ/π⁰
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
2
3
4
5
6
7
8
9
10
p_T [GeV/c]

Fig. 3

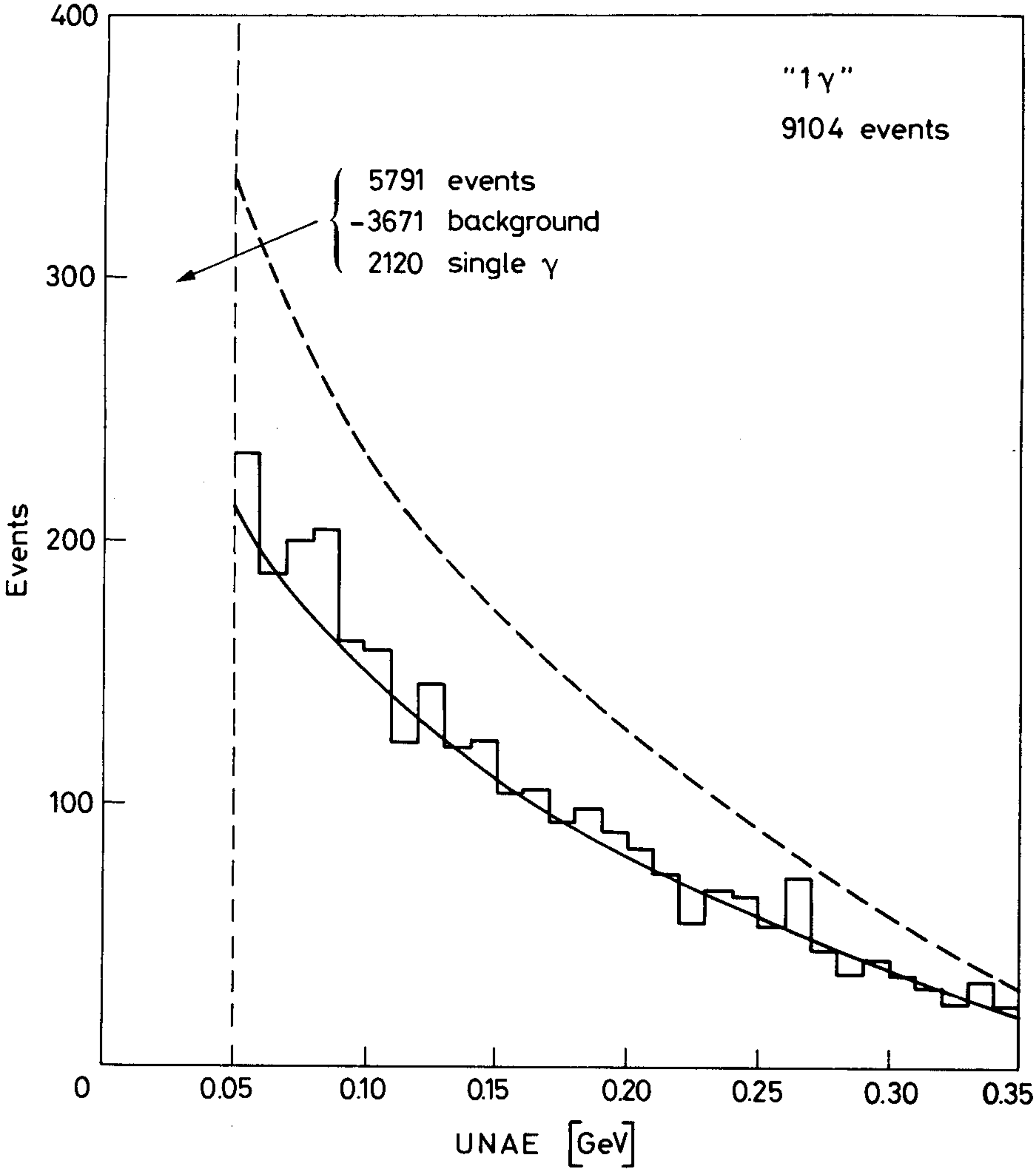

"1γ"
9104 events
5791 events
-3671 background
2120 single γ
400
300
200
100
Events
0
0.05
0.10
0.15
0.20
0.25
0.30
0.35
UNAE [GeV]

Fig. 4