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THE ASSOCIATED CHARGED PARTICLE MULTIPLICITY OF HIGH-p_T π^0 AND SINGLE-PHOTON EVENTS

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ABSTRACT

The associated charged particle multiplicities of high-p_T π^0 and single-photon events were measured at the CERN Intersecting Storage Rings using lead/liquid-argon calorimeters and a scintillation counter array placed around the intersection region. The average multiplicity on the trigger side for the single-photon events was found to be significantly lower than that for the π^0 events. The away-side multiplicity for both π^0 and single-photon events increases with the trigger particle p_T, but, at a fixed p_T, the direct photon sample was found to have a slightly lower average multiplicity. The differences in the event structure can be explained if a large fraction of the single photons are produced via $qg \rightarrow \gamma q$ constituent scattering.

In this letter we report the first measurements of differences between the structure of events containing high transverse momentum (p_T > 3 GeV/c) π^0's and single photons. The production of single photons at large p_T has been extensively studied both experimentally [1-5] and theoretically [6-13]. The present theoretical view is that high-p_T π^0's are produced from the hard scattering of the proton constituents (quarks, gluons, and antiquarks) and their subsequent fragmentation. The high-p_T mesons are expected to be the leading fragments of the scattered constituents. The production of a single direct photon at large p_T in pp collisions is thought to proceed predominantly from the scattering of a quark and a gluon; the quark subsequently fragments into a hadronic jet. A smaller contribution is also expected from photons radiated in a bremsstrahlung process from a scattered quark [13]. For pp collisions the contribution of quark-antiquark annihilation into a high-p_T photon and a gluon should be very small in the region near $x = 0$ covered by this experiment. The difference in the production mechanisms of single-photon and π^0 events may be manifested in a different event structure.

The apparatus used in this experiment consisted of two identical lead/liquid-argon calorimeters and a scintillator counter array surrounding the intersection region. The calorimeters were located 2.15 m away from the intersection region; each had an acceptance of $\sim$ 0.14 sr covering 75°-105° in polar angle and 15° in azimuth. Each module was centred in azimuth at 156° away from the centre-of-mass motion of the colliding protons (see fig. 1). A detailed description of the calorimeter properties as well as the selection criteria used for obtaining π^0 and single-photon candidates are given in refs. 1 and 2. The counter array consisted of 44 scintillation counters surrounding the intersection region at a distance of 18 cm. Each counter was 1 m long and 2.5 cm wide and covered 8° in azimuth. The light from each end of the scintillation counter was collected by a photomultiplier. A scintillator was considered to be struck if signals from both ends were in time with the event. The apparatus did not allow us to discriminate between one or more particles traversing a single scintillation counter nor to determine the charge or momentum of the particles.

The selection criteria for photons and π^0 events detected in the calorimeters are described in detail in refs. 1 and 2. They include requirements on the longitudinal and radial development of the electromagnetic showers, and a cut on the invariant mass of the photon pair in the π^0 events. In addition, it was necessary to require that no additional electromagnetic showers or no unassigned energy were present in the calorimeter [1-2]. These requirements were imposed in order to remove background in the single-photon sample coming from electromagnetic decay of mesons, where only one shower is reconstructed in the calorimeter, but where the other photon leaves energy not assigned to a reconstructed shower. Most charged particles traversing the active volume of the calorimeter will deposit sufficient energy, due to their ionization loss, to exceed the level of our cut on unassigned energy. The effect of these cuts is thus to eliminate events with additional charged particles or electromagnetic showers traversing the active volume of the calorimeter. The cuts affect 25% of all π^0 events. This fraction is independent of p_T within the errors. These cuts affect the numerical results for the same-side multiplicity; however, each calorimeter covers only 0.14 sr, and only tracks with angles close to those of the trigger particle are affected. Finally, since the cuts were applied in the same way to both the single photon and π^0 events, they cannot by themselves produce a difference in the observed event structure where none in fact exists. They might, however, modify the magnitude of an existing difference.

The results presented here use the data at $\sqrt{s}$ = 63 and $\sqrt{s}$ = 45 GeV of the previous paper. In fig. 2a we show the observed γ/π^0 ratio together with the curve for the expected ratio from known sources of photons, such as electromagnetic decay of π^0 and η. The resulting fraction of directly produced single-photon events in the total single-photon sample is shown in fig. 2b. In the lower p_T bins the single-photon contribution is small [1-2] and the background from known sources is large. With increasing p_T the signal increases, the background is reduced, and the single-photon fraction increases to over 60% for a value of p_T greater than 6 GeV.

For the investigation of the structure of single-photon and π^0 events, the data were divided among the p_T bins of the triggering particle. The scintillation counters are numbered from 1 to 44, with counter 1 intersecting the line of flight of the triggering particle. The other counters are numbered in a counterclockwise (clockwise) direction for the upper (lower) calorimeter modules (fig. 1), to symmetrize the effects of the centre-of-mass motion.

In fig. 3a we show the distribution of the probability that a scintillator is struck for minimum bias events [14,15]. Since no triggering particles were involved in these events, the numbering of the scintillators was done as if a trigger particle were present at the centre of each calorimeter. The effect of the centre-of-mass motion is clearly visible as a broad enhancement in the direction of this motion. This distribution is essentially the same as that obtained by assuming that the particles have zero mass and a flat rapidity distribution in the centre of mass. The deviation from flatness is due to the azimuthal variation in pseudorapidity covered by the scintillators (from ±1.45 to ±2.20). In figs. 3b and 3c the probability distributions for the selected π^0 and γ events are shown for the p_T bins 3-4 and 6-7 GeV, respectively. The distributions are normalized to give the probability that a given scintillator will be struck for a given event type. Clearly the effect of the trigger is to enhance significantly the chance that a scintillator on the away side will be struck. The peak position on the away side for the triggered events is collinear with the trigger particle direction, and is slightly shifted from the peak position observed in minimum bias events. Inspection of the probability distribution plots on the trigger side reveals that for p_T in the 3-4 GeV/c region the π^0 and γ candidate samples give nearly identical distributions, while in the 6-7 GeV/c region the probability that a scintillator near the single-photon line of flight (0° or 360°) will be struck is lower than the probability for triggered π^0 events. A similar but less significant effect can be seen on the side away from the trigger particle.

In fig. 4a the total average multiplicity recorded in the array of the 44 scintillation counters is shown. At large trigger-p_T we observe a clear difference between the average multiplicities in the two samples of events. The events with a single-photon candidate have a lower multiplicity than that for the π^0 events. The true average multiplicities of the single photons can be obtained from the multiplicities of the π^0 and single-photon candidate samples, using the fraction of true single photons in the candidate sample as determined in the previous paper. The result is consistent with a nearly constant multiplicity for the direct single-photon events, which is lower than that in π^0 events. The observed p_T dependence in the candidate sample reflects primarily the increasing fraction of real single-photon events. Figures 4b and 4c show the average observed multiplicity on the away side and trigger side, in a region of ±3 counters from the counter intersecting the line of flight of the triggered particle, for both π^0 and single-photon events. The dotted line represents the same quantity obtained from minimum bias events. The difference between the trigger and the away side for the minimum bias events is due to the centre-of-mass motion only. The trigger-side multiplicity for the π^0 events is consistent with being constant for all p_T bins, while the single-photon sample shows a decrease with increasing p_T. If one corrects for the meson decay background in the single-photon sample, assuming it has a multiplicity structure similar to that of the events with identified π^0's, one obtains a value of the multiplicity for the real direct single-photon events which is consistent with being constant for all p_T bins, but which is lower than that of the π^0 events. On the away side, both reactions show an increasing multiplicity with increasing p_T. The π^0 multiplicity is consistently higher than for the single-photon average, but the difference is less marked than that for the same-side multiplicity.

An attempt was made to correct the probability distributions and the average multiplicities for the effect of more than one hit in a given scintillation counter, assuming Poisson probability distribution for the hit number. The effect on the frequency distribution is to sharpen the away-side peak and enhance the difference in the p_T dependence of the away-side frequency distribution. The total average multiplicity of π^0 events increases to a value of ∿ 16, only weakly dependent on p_T. The same-side multiplicity does not change significantly in magnitude or shape, because the probability of a counter being hit is relatively small. The effect on the average away-side multiplicity (fig. 4d) is large, and increases the magnitude of the p_T dependence of both the observed average multiplicity and the difference between single-photon and π^0 events.

The observation of significant differences in the associated charged particle multiplicity between π^0 and single-photon events is new supporting evidence for single-photon production.

The difference in the multiplicity structure observed between π^0 and single-photon events may be explained by a dominant contribution of $qg \rightarrow \gamma q$ scattering to the single-photon production. A photon produced via this process replaces the normal trigger-side scattered constituent and has no additional multiplicity associated with it. A high-p_T π^0 is a part of the jet produced by the fragmentation of the scattered constituent. It is expected to carry most of the constituent energy because of the "trigger bias" [16] effect, but will on the average be accompanied by a small number of associated particles from the fragmentation of the scattered constituent. The observed difference in the trigger-side multiplicity supports the hypothesis that a single photon has no additional particles associated with it on the trigger side.

On the away side there is a strong p_T dependence of the average multiplicity observed for the π^0 events. If all single-photon candidates came from asymmetric decays of π^0's and η's, one would then expect the away-side multiplicity to be somewhat larger than for π^0 events. If the undetected photon had been measured, the reconstructed π^0 would have been assigned a higher p_T, corresponding to a higher away-side multiplicity. The fact that this is not so is further supporting evidence for the single-photon production. The lower average away-side multiplicity of the single-photon event is thus consistent with the statement that the photon represents the total scattered constituent momentum while the π^0

represents only a fraction of it, with the result that the away-side multiplicity will be larger for a π^0 at the same given trigger p_T. On the other hand, if quark and gluon "jets" have different average multiplicities, and if they are present in different proportions opposite single-photon and π^0 triggers, a more complicated interplay of effects may be present.

In conclusion, a different charged multiplicity structure in the central region has been observed for π^0 and single-photon events. Differences were observed in both the same-side and the away-side multiplicity. In particular, the data are consistent with the hypothesis that single high-p_T photons are not accompanied by other charged particles additional to the normal soft pionization, in contrast to high-p_T π^0's.

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Figure captions

Fig. 1 : The experimental set-up of the liquid-argon calorimeters and barrel scintillator counter array in the ISR.

Fig. 2 : a) The observed γ/π^0 ratio: the smooth line indicates the Monte Carlo prediction for the ratio assuming no direct photon production ($\sqrt{s}$ = 63 GeV);

b) The fraction of direct photons in the total sample of photon events ($\sqrt{s}$ = 63 GeV).

Fig. 3 : The percentage probability that a scintillation counter will be struck for

a) minimum bias events.

For π^0 (dots) and γ candidates (crosses) in the p_T range of

b) 3-4 GeV/c.

c) 6-7 GeV/c.

Fig. 4 : The average multiplicity of scintillator counters struck for π^0 (dots) and single-photon candidates (crosses) for:

a) all 44 scintillation counters;

b) the away side (±3 scintillators);

c) the trigger side (±3 scintillators);

d) the away side corrected for multiple hits in a scintillator.

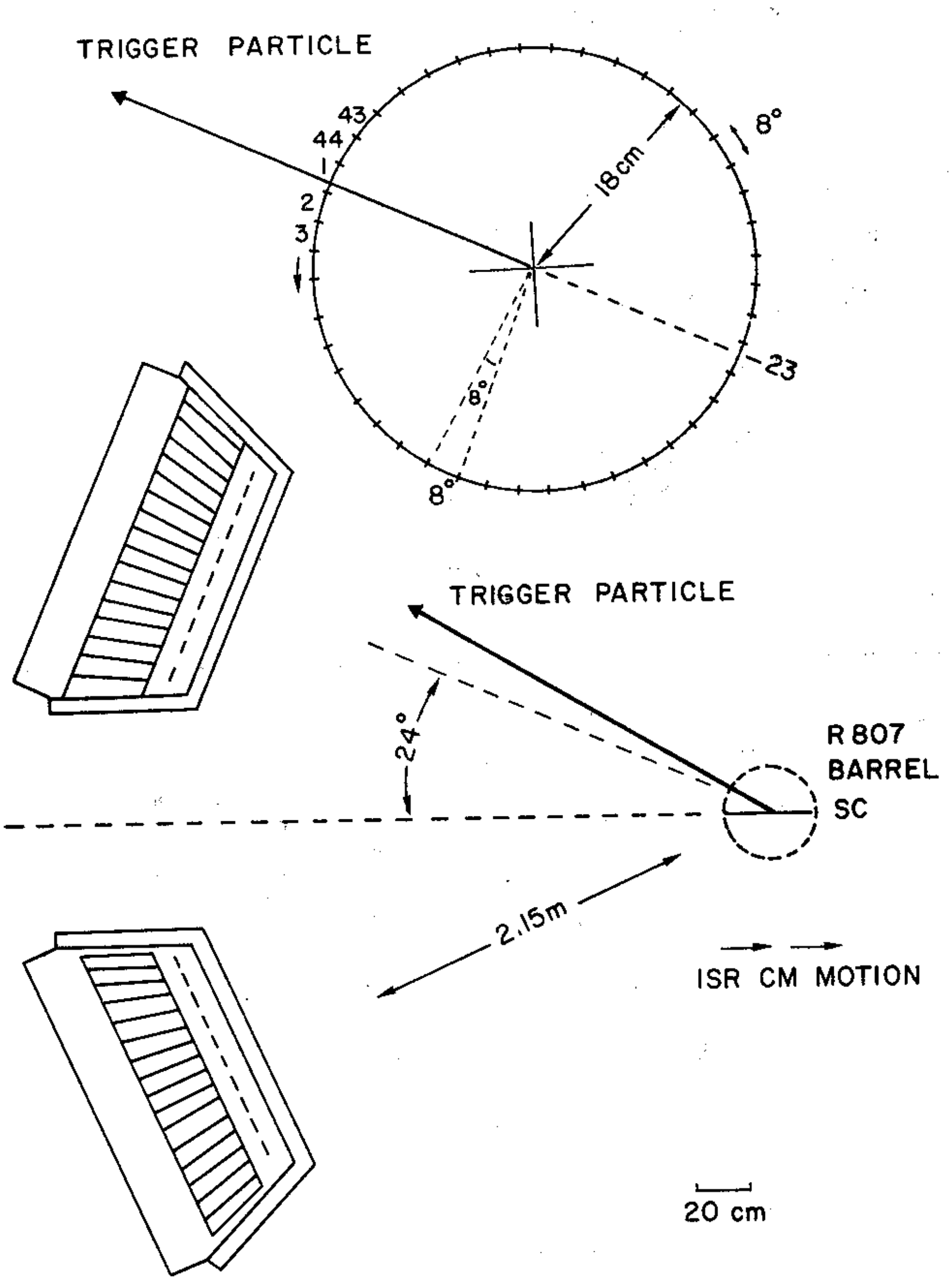
TRIGGER PARTICLE
43
44
1
2
3
18cm
8°
23
8°
8°
TRIGGER PARTICLE
24°
R 807
BARREL
SC
2.15m
ISR CM MOTION
20 cm

Fig. 1

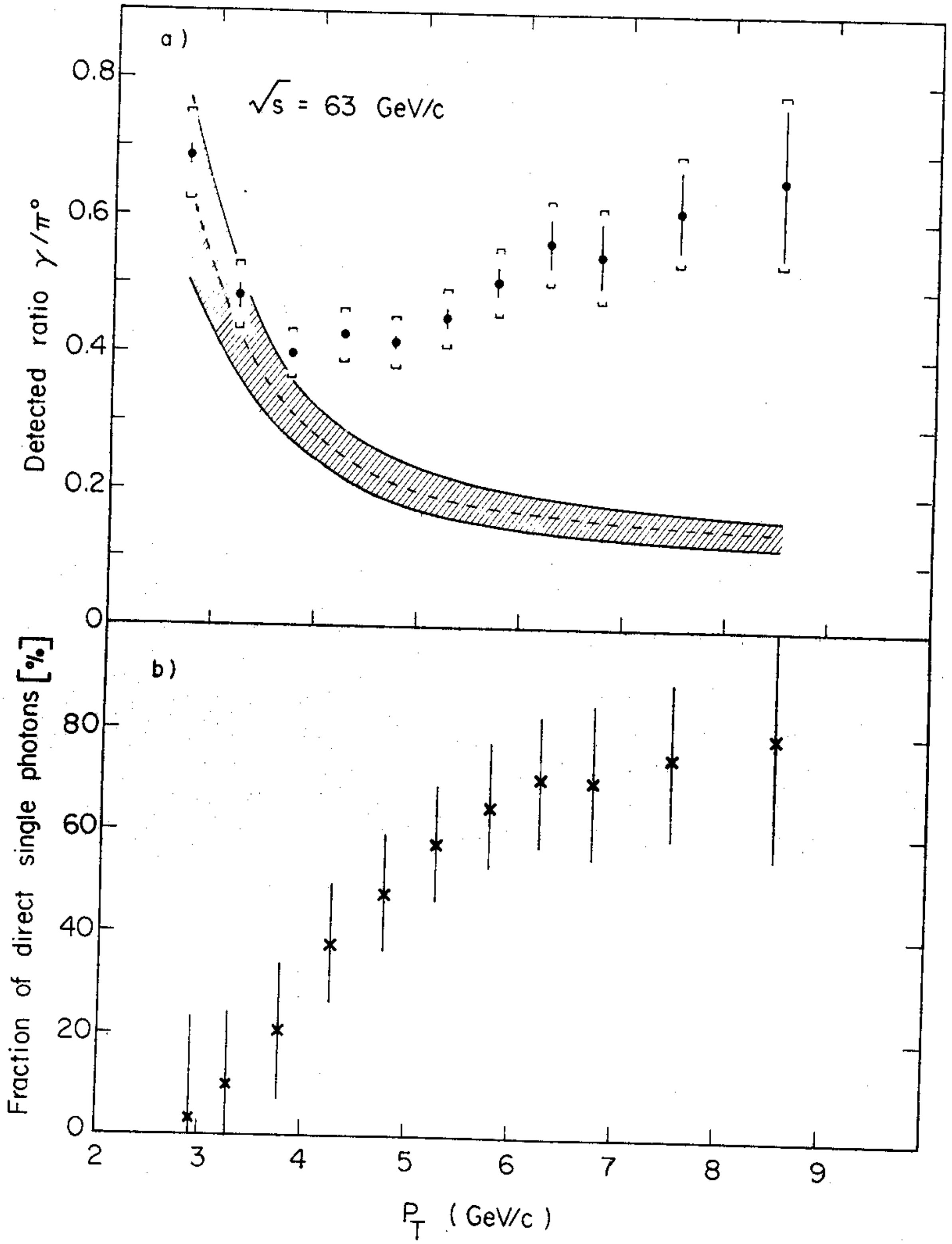
a)
√s = 63 GeV/c
Detected ratio γ/π°
0.8
0.6
0.4
0.2
0
b)
Fraction of direct single photons [%]
80
60
40
20
0
2
3
4
5
6
7
8
9
P_T (GeV/c)

Fig. 2

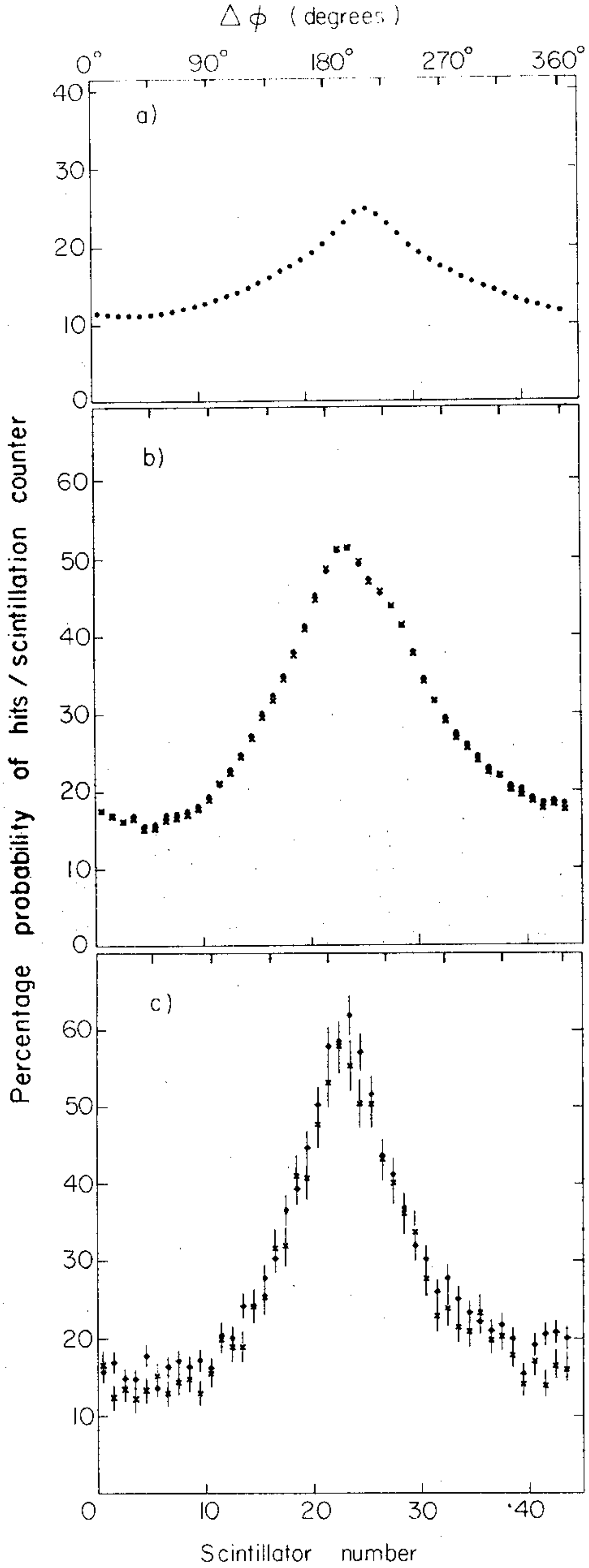
Δφ (degrees)
0°
90°
180°
270°
360°
a)
b)
c)
Percentage probability of hits / scintillation counter
0
10
20
30
40
50
60
Scintillator number
0
10
20
30
40

Fig. 3

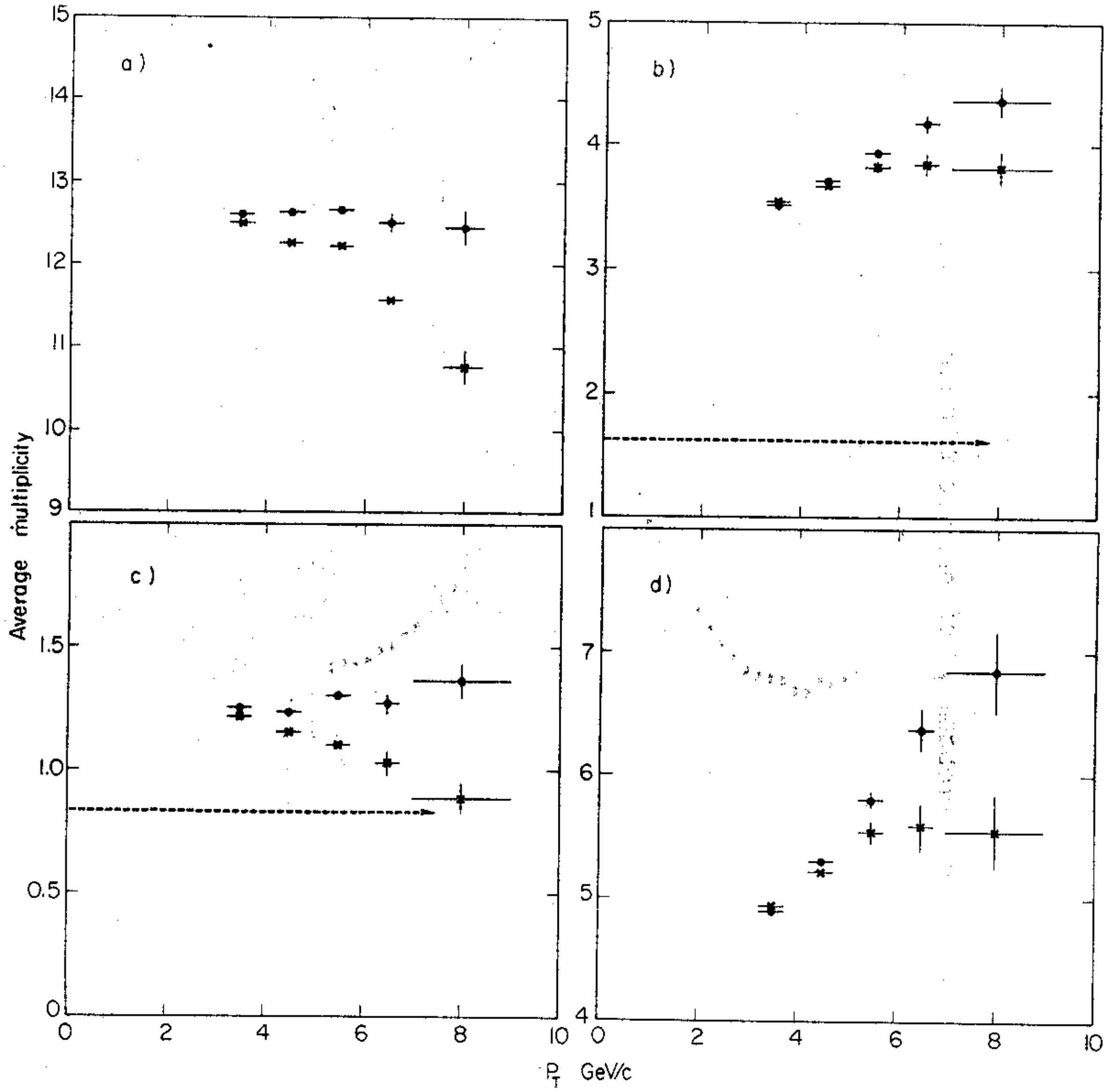
a)
b)
c)
d)
15
14
13
12
11
10
9
5
4
3
2
1
1.5
1.0
0.5
0
7
6
5
4
0
2
4
6
8
10
0
2
4
6
8
10
Average multiplicity
P_T GeV/c

Fig. 4