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AN INVESTIGATION OF HIGH-MULTIPLICITY GAMMA EVENTS IN pp COLLISIONS WITH c.m. ENERGIES BETWEEN 22 AND 62 GeV

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ABSTRACT

In an exploratory experiment at the CERN ISR to investigate high-multiplicity gamma events at 90° to the colliding beam directions within an angular region of 18% of 4π solid angle, it was found that the gamma-ray multiplicity is considerably greater than that computed from the independent emission model which has been used as a basis for comparison. This result indicates a multiparticle correlation.

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Results of an exploratory experiment, on the investigation of high-multiplicity gamma-ray events, which was carried out using the colliding proton beams of the CERN Intersecting Storage Rings, are described. This work was carried out by sharing the detector and recording systems of the CERN-Columbia-Rockefeller Group[1]) and by using a separate logic system to provide a trigger on high-multiplicity gamma-ray events (multigamma events).

The main objective of the investigation was to look for multigamma events which could reveal interesting features of π^0 multiple production as well as other possible mechanisms of γ-ray production[2]).

The detector system consisted of two identical units placed at 90° to the beams on the inside and outside of the interaction region. Each unit consisted of ten planes of spark chambers, three scintillation counter hodoscopes, and two arrays of lead-glass Čerenkov counters. In the first array, there were 16 lead glass counters (called HV) 35 × 14.8 cm and 3.1 radiation lengths thick. The second array, placed at the back of the unit, contained 60 counters 14.8 × 14.8 cm and 14.8 radiation lengths thick. The total solid angle covered by the entire detector system amounted to 18% of 4π around the 90° region. Thus, the results presented below apply only to a narrow interval of c.m. rapidities (0.8 to +0.8) in the pionization region.

The event trigger was obtained from the 32 HV counters. The trigger can be described symbolically as

$$M_t \cdot \Sigma\Sigma \cdot \bar{V} \quad \text{or} \quad M_t \cdot BB \cdot \bar{V} \ ,$$

where $\bar{V}$ is a veto against spark chamber and other types of pickup, $\Sigma\Sigma$ or BB is a coincidence between two scintillation counters [BB is (40 cm)^2, $\Sigma\Sigma$ is (100 cm)^2] placed around the beam pipe about 5.5 m from the interaction region to require a pp interaction. The $\Sigma\Sigma$ counters were designed for detecting a large fraction of the interaction (72%), while the counting rate of BB counters was 5 times lower. M_t means that at least t of the 32 HV counters were fired in coincidence, each with an energy above the trigger threshold E_{th}. To ensure that a triggered event was due mostly to gamma-rays, the trigger threshold E_{th} was set originally to about 160 MeV (more than twice the equivalent energy produced by a fast charged particle in an HV counter). The value of E_{th}, however, changed during the experiment, mainly because of the radiation damage undergone by the lead glass[1]). We have corrected our data by applying the same procedure followed by the CCR group. After making these corrections, we consider $E_{th} \approx 250$ MeV as a better estimate of the actual average threshold involved in our measurement. However this effect should not, in any case, affect appreciably our results on the photon multiplicity.

Once an event was triggered, the energies in all the Čerenkov counters, as well as the information on all the charged particles given by the scintillation counters and spark chambers, were recorded on magnetic tape. Runs were made at various values of the momentum p_0 of the proton beams and with different trigger modes, t = 1, 2, 3, and 4. The runs with t = 1 were essential for converting our counting rates into cross-sections for production of gamma-rays that could be compared with the results of other workers.

The one-photon inclusive cross-section, in principle, should differ from our cross-section based on data obtained by requiring that the observed photons are in coincidence with at least one charged particle in each of the downstream counters. However, one can prove rigorously that the ratio of the cross-section which was obtained under these conditions to the one-photon inclusive cross-section is equal to a factor F, the value of which is at most 1.3 [3]. We actually found that within these limits our absolute cross-section agrees with that deduced by other authors. The same argument also explains why the slope of our single-photon energy spectrum agrees, within the experimental error (±6%), with the slope obtained by other authors.

Furthermore, the background in our detection system was quite small, i.e. $\sim$ 1% when using the BB coincidence and at most $\sim$ 10% when using ΣΣ coincidence with full beam intensity in the ISR.

In order to establish the relationship between the number of gamma-rays per event and the number of HV counters triggered by a neutral secondary, we have made a Monte Carlo computation in which, besides the geometry of the counters, various instrumental factors, such as the efficiency of the individual lead-glass counters (HV), the transparency of the lead glass to light, the lateral spread and the fluctuations of the showers, were all taken into account. For the energy spectrum and the angular distribution of the neutral pions, we used the experimental results obtained at the ISR for the energy $s^{\frac{1}{2}}$ = 53 GeV. The main results of this computation are: a) the probability for both decay photons of a π^0 to cross the detector is 24% of the number of π^0 with at least a single photon crossing the detector; b) with the trigger mode M_1, the ratio of the mean value of the number of HV triggered by photons to the average number of pions giving a detected gamma-ray is 0.99 ± 0.01. Therefore, we have adopted a practical rule of treating the number of HV counters which are fired by neutral secondaries as being equal to the number of π^0 that give a detected gamma-ray.

Figure 1 shows the results obtained for the distribution of the number of gamma-rays for various trigger modes t = 1, 2, 3, and 4 at a centre-of-mass energy of 53.2 GeV. The distributions shown in Fig. 1 are expressed in cross-section per steradian assuming σ_{inel} = 35.6 mb. The tail of these distributions seems to show about the same slope irrespective of the trigger mode. This is the behaviour one would expect for multiplicities m appreciably greater than the trigger multiplicity t.

Figure 2 shows the mean values of the average multiplicity of gammas and that of charged particles plotted as a function of the centre-of-mass energy $s^{\frac{1}{2}}$ for the trigger modes $M_4 \cdot \Sigma\Sigma \cdot \bar{V}$ and $M_4 \cdot BB \cdot \bar{V}$. As in all our analysed data, the results obtained with the BB trigger agree always within the statistical error with the results obtained with the ΣΣ trigger.

The question of possible influence on our results by background such as beam-gas or beam-wall interactions, the effect of neighbouring lead-glass counters due to shower production, the possible inefficiencies of track reconstruction, and other accidentals of various types have been extensively examined[3)] and were found to be small enough that they would not alter our results.

In order to understand the significance of these results, we have calculated the π^0 production by means of two different computations based on the same underlying assumptions, for the trigger mode t = 1 and $s^{\frac{1}{2}}$ = 53.2 GeV³: the π^0 production is completely uncorrelated and their angular and momentum distributions are those observed at the ISR in inclusive single-photon experiments. The first computation is an analytical treatment of the independent emission model (IEM). The second one is the Monte Carlo calculation (MC) mentioned above. From the MC, we obtain for t = 1, $\langle m \rangle_1 = 1.61 \pm 0.01$, which is appreciably lower than the observed value $\langle m \rangle_{1\,exp} = 2.78 \pm 0.17$. Figure 3 shows the corresponding integral distributions normalized to 1. We see that the experimental values are several orders of magnitude higher than the computed values at high multiplicities. This result is consistent with those obtained for the average multiplicities.

The comparison with the IEM is not made, of course, for ruling out this model, since the existence of correlations is by now well established. However, the difference between $\langle m \rangle_{exp}$ and $\langle m \rangle_{MC}$ provides a measure of the correlations in multiplicity, which embodies the global effect of correlations between any number of π^0's. An even more elementary way of showing this type of correlation is provided by the behaviour of the difference $\langle m \rangle_t - t$ as a function of t (Table 1). The systematic increase of $\langle m \rangle_t - t$ provides further evidence of the existence of multiparticle correlations already suggested by $\langle m \rangle_{exp} - \langle m \rangle_{MC}$, as well as by the distributions of Figs. 1 and 3. A further experiment with a specially designed detector system which covers ∿ 65% of the intersection region is in progress at the ISR.

We wish to express our deep appreciation and thanks to the CERN-Columbia-Rockefeller Group for the generous sharing of their detector equipment and the data-recording system, to the CERN NP Division for their generous help with electronic equipment and the construction of multiwire proportional chambers, and to the ISR staff.

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Table 1

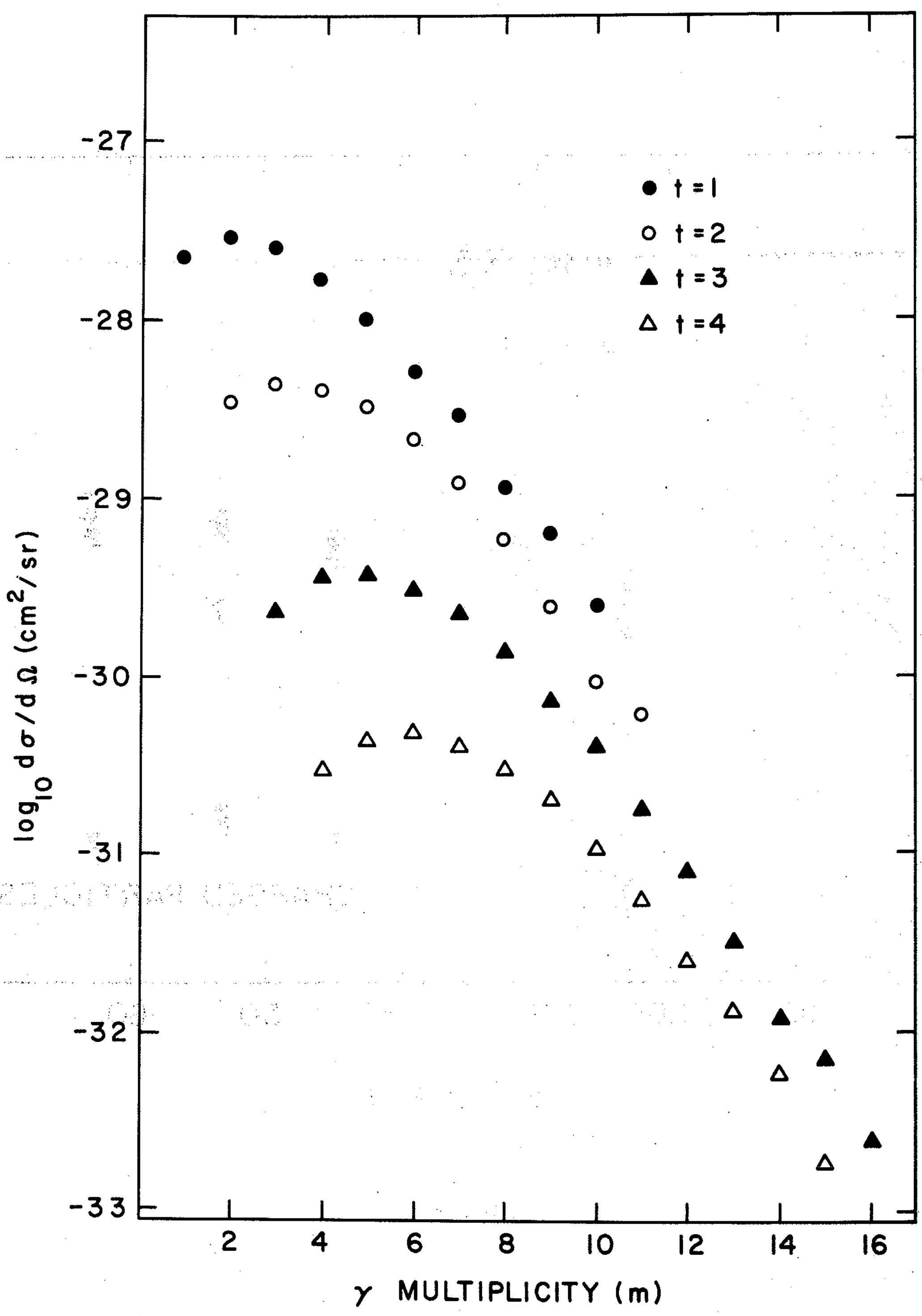
	t = 1	t = 2	t = 4
$\langle m \rangle_t - t$	1.78 ± 0.02	2.27 ± 0.04	3.35 ± 0.05

Figure captions

Fig. 1 : Distribution of the multiplicity of gammas for various trigger modes at a c.m. energy $s^{\frac{1}{2}} = 53.2$ GeV.

Fig. 2 : Average multiplicity of gammas and charged particles plotted as a function of c.m. energy.

Fig. 3 : Comparison of the integral multiplicity distribution observed at $s^{\frac{1}{2}} = 53.2$ GeV with the trigger mode $[M_1 BB]$ with the results of the Monte Carlo computation and the independent emission model calculation.



-27
-28
-29
-30
-31
-32
-33
t = 1
t = 2
t = 3
t = 4
$\log_{10} d\sigma/d\Omega$ (cm^2/sr)
2
4
6
8
10
12
14
16
γ MULTIPLICITY (m)

Fig. 1

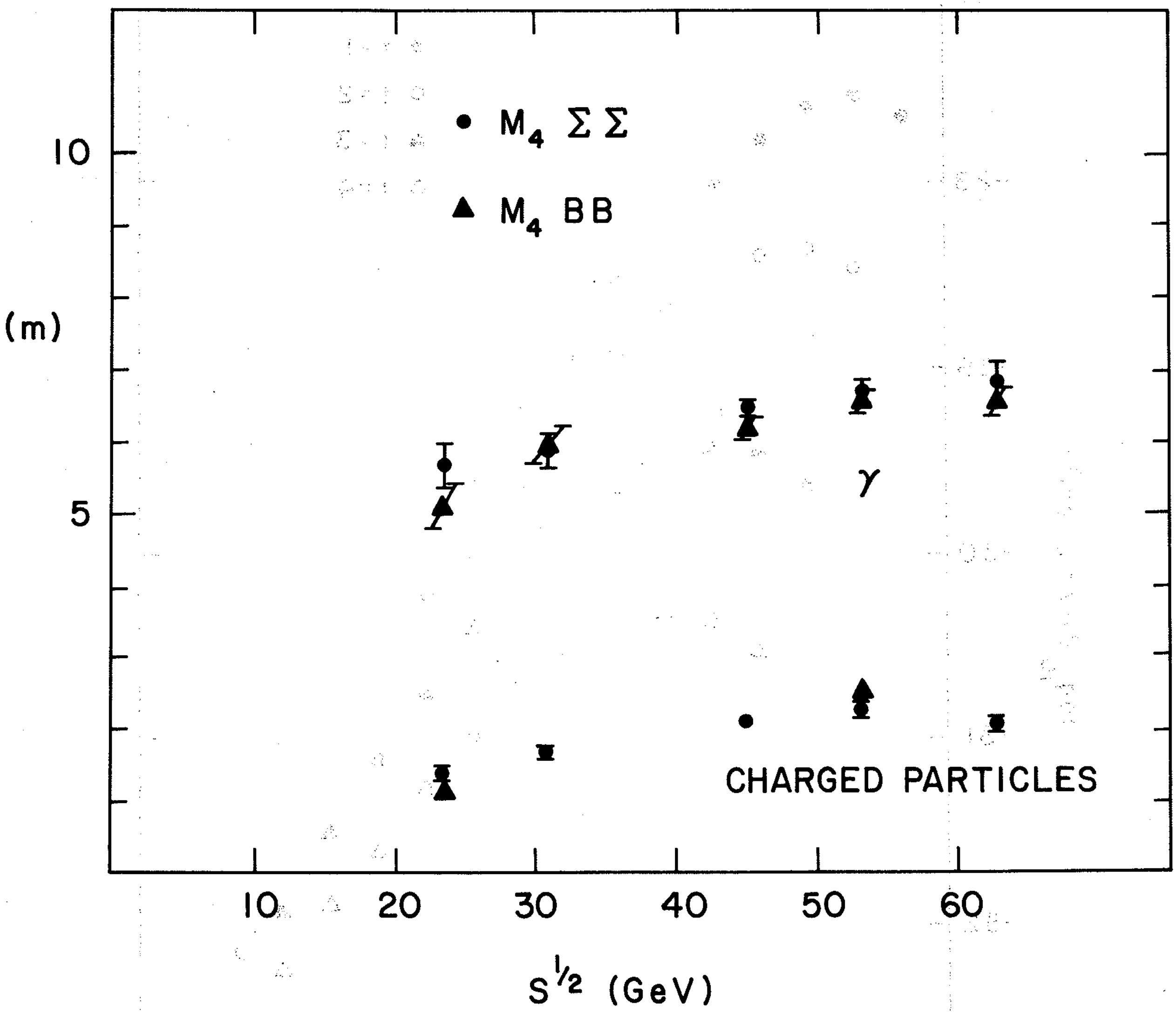


Fig. 2

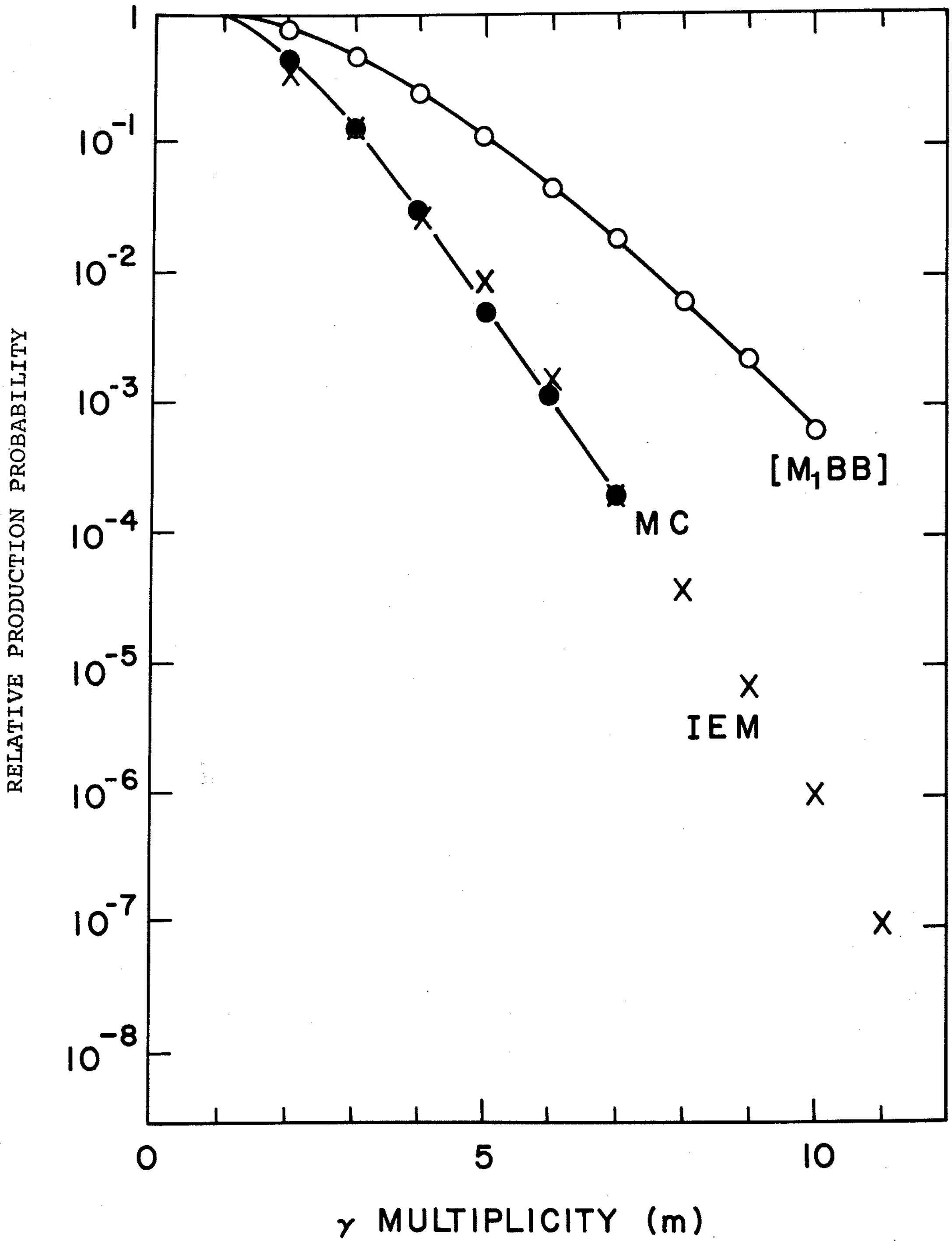

RELATIVE PRODUCTION PROBABILITY
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
0
5
10
γ MULTIPLICITY (m)
[M1BB]
MC
IEM

Fig. 3