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THE MEASUREMENT OF BETHE-HEITLER BREMSSTRAHLUNG IN MUON-HYDROGEN INTERACTIONS AT 200 GeV

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Abstract

Using a lead glass detector installed in the EMC forward spectrometer radiative photons have been measured in 200 GeV muon-hydrogen collisions. The results are compared with the standard QED one photon emission theory of Mo and Tsai and also with the more recent predictions of a multi-photon emission theory of Chahine. We conclude that there is no evidence for any deviation from the standard theory, when applied to the study of the yield and angular distribution of photons with fractional energy, $z > 0.7$.

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Introduction

In the analysis of deep inelastic charged lepton scattering it has become customary to apply radiative corrections based on single photon emission theory as formulated, for example, by Mo and Tsai [1]. Recent work by Chahine [2] however, has questioned these calculations and indicated that in some kinematic regions they lead to an under-estimate. Within the framework of this latter theory, which may be thought of as the radiative correction to wide angle bremsstrahlung, higher order processes lead to an enhancement of the number of hard photons. These are associated with events which, according to the kinematics of the incident and scattered lepton, have the appearance of a deep inelastic process but are, in fact, due to elastic scattering in which multiple photon emission has occurred. Here we limit ourselves to the discussion of an attempt to observe these photons experimentally.

Radiation of a photon from the lepton vertex in muon scattering is illustrated in fig. 1. We use the standard variables for the 4-momentum, Q, and energy, ν, of the apparent virtual photon calculated from the incident and scattered muon 4-vectors alone: $Q^2 = (\vec{p}_\mu - \vec{p}_\mu')^2 - (E_\mu - E_\mu')^2$, $\nu = E_\mu - E_\mu'$. The mass, W, of the hadronic system plus the radiated photon, the Bjorken variable, x, and the fractional energy y are given by

$$W^2 = 2M_p\nu + M_p^2 - Q^2$$
$$x = Q^2/2M_p\nu$$
$$y = \nu/E$$

Such radiated photons peak predominantly in the direction of the apparent virtual photon (the so-called t-peak) and, to a lesser extent in the directions of the incident muon (the s-peak) and the scattered muon (the p-peak) in our region of interest. These real photons are described by the energy fraction $z = E_\gamma/\nu$ and angle θ_γ (fig. 1) relative to the apparent virtual photon in the laboratory frame.

In an earlier study [3] of radiative photons with a coarse grained calorimeter we found that our results, while completely consistent with the calculations of Mo and Tsai [1], were insufficient to discriminate conclusively between them and the modification suggested by Chahine. The inclusion of a finer grained lead glass detector in the forward spectrometer combined with improved statistical and kinematical precision has enabled that discrimination to be made.

Experimental Method

The EMC forward spectrometer (FS) has been described in detail elsewhere [4] and is essentially an apparatus for measuring the momentum and direction of the scattered muon and secondary particles produced in high energy collisions between muons and nucleons over a wide range of Q^2 and ν. The inclusion of a hybrid lead glass/multi-wire proportional chamber system in the central region of this forward spectrometer has allowed the extension of the study of secondary particles to include π^o and single photons. Measurements of the distribution of the former are discussed elsewhere [5] together with the details of the photon detector. For this reason, we limit ourselves to a brief description of the main features of the lead glass system.

The detector, shown schematically in fig. 2, is situated downstream of the FS magnet 13.5 m from the end of the 6 m hydrogen target. It consists of a 'back array' matrix of 450 lead glass (F_2) blocks (8 x 8 x 40 cm^3) and a double preshowering system of transverse glass blocks (160 x 8 x 8 cm^3) and multi-wire proportional chambers (MWPC). These latter sample the shower in its early development and enable its lateral position to be determined within 7 mm. The photon energy is determined through a process of cluster analysis in the back array and addition of energy deposited in the adjacent transverse preshower blocks described in detail in ref. [5]. The energy calibration factors are determined: a) in the central region using μ-e scattering events where the electron energy is measured in the FS, and b) in the outer regions using relative calibrations based on the pulse heights due to halo muons which pass through the blocks. The observed energy resolution above 100 GeV, which is about 5% and independent of energy, arises mostly from systematic errors in the muon calibration and uncertainties in the preshower contribution. However, energy resolution of this order is not a limiting factor in the present work.

A hole (16 x 16 cm^2), corresponding to 4 back array blocks, allows unimpeded passage of the incident muon beam through the centre of the detector. Corresponding regions of the proportional chambers were also made inactive.

Since most of the radiative photons are clustered around the centre of the detector this hole is a major limitation on the photon acceptance which varies from 20-60% over the kinematic range used.

The present data arise from an exposure of 6.5×10^{11} incident muons of 200 GeV energy. After muon track reconstruction there remained about 300 K events with a scattered muon and a good vertex. The requirement that at least one photon was observed reduced the sample to about 20K events. To eliminate μ-e events a Q^2 of larger than 1 GeV^2 was required and the contamination by meson decays was reduced by placing a lower limit of 20 GeV/c on the scattered muon momentum. This latter restricted y to be less than 0.9. Due to drift chamber inefficiency in the central region we rejected all events in which the muon passed within a radius of 35 cm around the beam axis immediately in front of the lead glass. Photons which hit the detector within 2 cm of the edge of the central hole were eliminated to ensure good energy measurement and to avoid the insensitive regions of the MWPC. In order that this selection could be reliably applied only events with a measurement of both chamber projections for the photon were considered.

The sample was further restricted to include only those events where no charged particle other than the scattered muon was observed. As described in ref. [3], this procedure substantially reduces the background from neutral hadron decays at lower z.

The data were divided up into bins according to the muon kinematic variables x and y and the contents of each bin normalized to the total number of scattered muons observed in that interval independent of the detection of photons and charged hadrons. The observed z distribution for low x and high y of all neutral energy clusters which survived the above selection procedures is shown in fig. 3. A clear peak is observed at $z \sim 1$ which is attributed to radiative photons. On the basis of this distribution we have chosen a cut of $z > 0.7$. Simple fits to the z distributions in individual x and y bins indicate that above this cut, the contamination from neutral mesons is always less than 5%. No attempt is made to remove this residual contamination.

Comparison with Theoretical Predictions

To compare the data with the theoretical predictions we have used a full Monte Carlo simulation based on the Mo and Tsai radiative photon calculation [1]. The simulation incorporated the observed beam phase space and the same geometrical and kinematical cuts on the scattered muon and real photon as were made in the data selection. The loss due to photon conversion in the target and subsequent material was also included together with the energy and spatial resolution of the photon detector.

The requirement of no charged hadrons in the selected events led to a small loss of radiative photons from genuine deep inelastic events. This was corrected for in the Monte Carlo simulation.

We have made two measurements: 1) the absolute number of radiative photons with $z > 0.7$ and 2) the angular distribution of these photons relative to the apparent virtual photon direction. The latter was possible owing to the excellent spatial resolution of the photon detector. Corrected for apparatus acceptance, the absolute number of photons per scattered muon event, $(N_\gamma/N_{\mu'})$ are plotted in fig. 4 as a function of y for four regions in x. The quoted errors are statistical only. An overall systematic error of 10% is not shown. The predictions of the Mo and Tsai calculation are shown as full curves in this figure. In the Chahine model, we have calculated the total production yield of photons with $z > 0.7$ at the mean value of each of these four x regions. These predictions are shown as dashed curves in fig. 4. It is clear that the curves of the standard model are in good agreement with the data whereas those of Chahine are comparable only at low y. The angular distributions in four x, y bins are shown in fig. 5 plotted as a ratio of data to Monte Carlo prediction from the standard theory. Again, there is no evidence for any deviation from this standard theory for photons with $z > 0.7$.

Conclusions

This experiment has been performed with a finer grained electromagnetic calorimeter than our previous work [3] enabling us to measure the angular distribution of the radiative photons; and to extend to higher values of y where better discrimination between the models can be made.

Our measurements of both the absolute number and angular distribution of radiative photons produced in 200 GeV muon hydrogen interactions are in agreement with calculations based on the work of Mo and Tsai [1]. We have found no evidence to support the modifications to this theory suggested by Chahine [2].

We would like to thank Dr. Chahine for providing us with a version of his computer program, used in the estimation of the production yield.

References

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Figure Captions

Fig. 1 - Kinematic variables of the lepton bremsstrahlung process.

Fig. 2 - Plan view of the lead glass wall showing the arrangement of the preshower elements.

Fig. 3 - The z distribution of all neutral energy clusters for low x and high y. The cut imposed to separate radiated photons from those which originate from hadronic decays is shown at $z = 0.7$.

Fig. 4 - Experimental results for the absolute number of photons per scattered muon as a function of y in the four x regions indicated. The full lines are obtained using the standard procedure [1], while the broken line shows the modification expected on the basis of the work of Chahine [2].

Fig. 5 - Angular distributions of the observed photons with respect to the apparent virtual photon direction plotted as a ratio with Monte Carlo predictions based on the standard radiative theory [1] for four different regions of x and y.

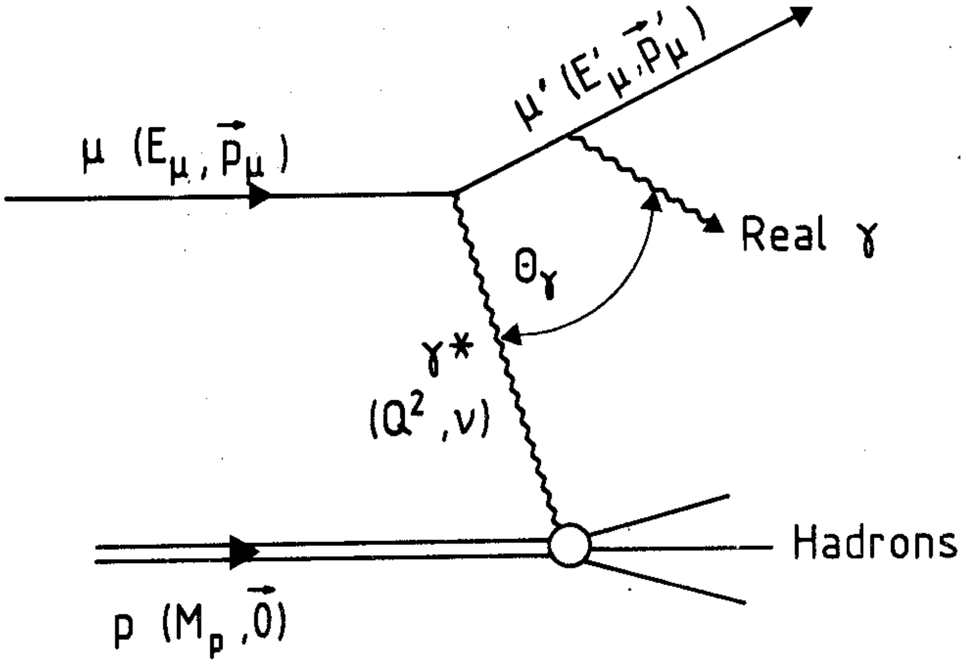


FIG. 1

PLAN VIEW

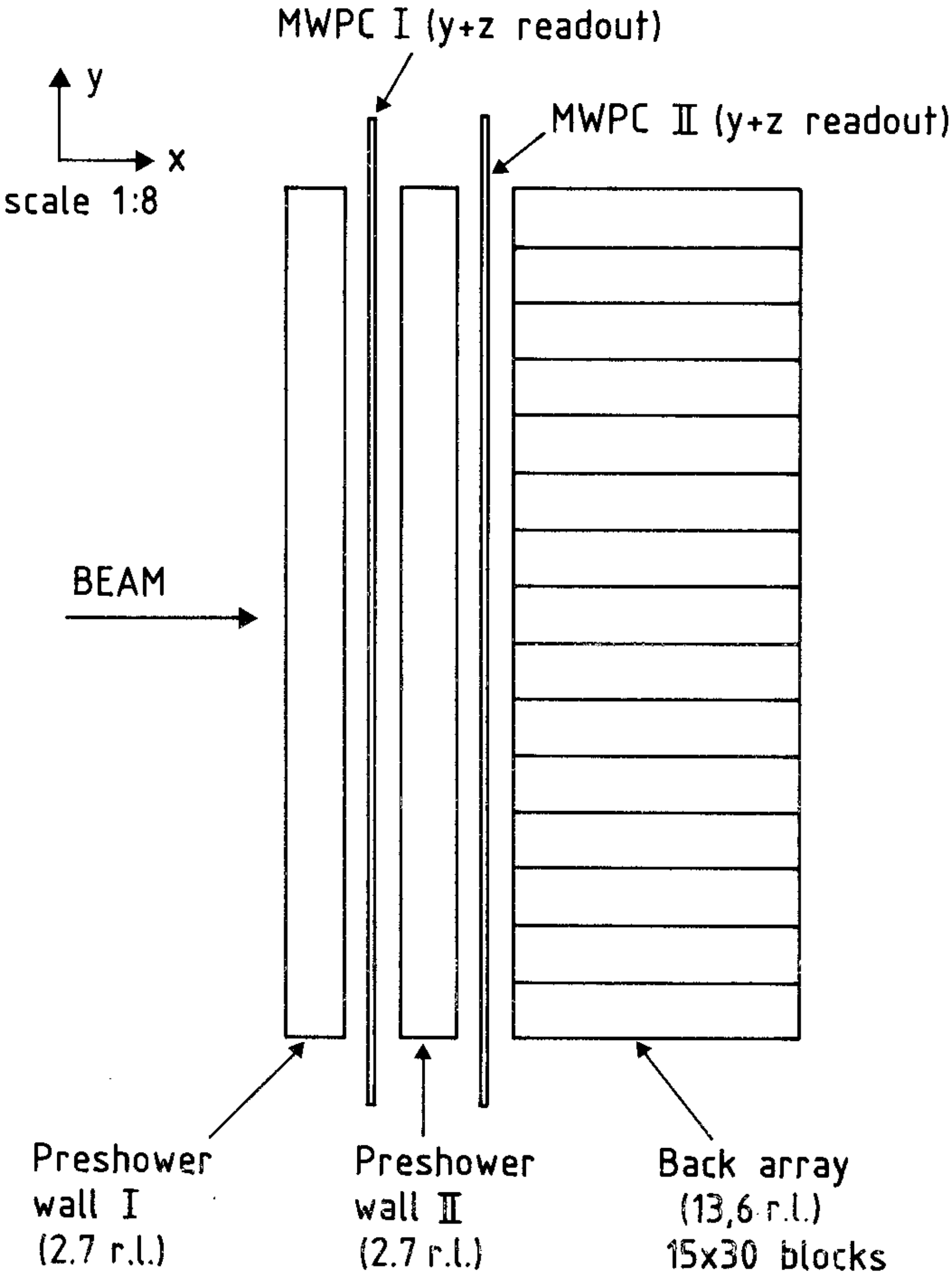


FIG. 2

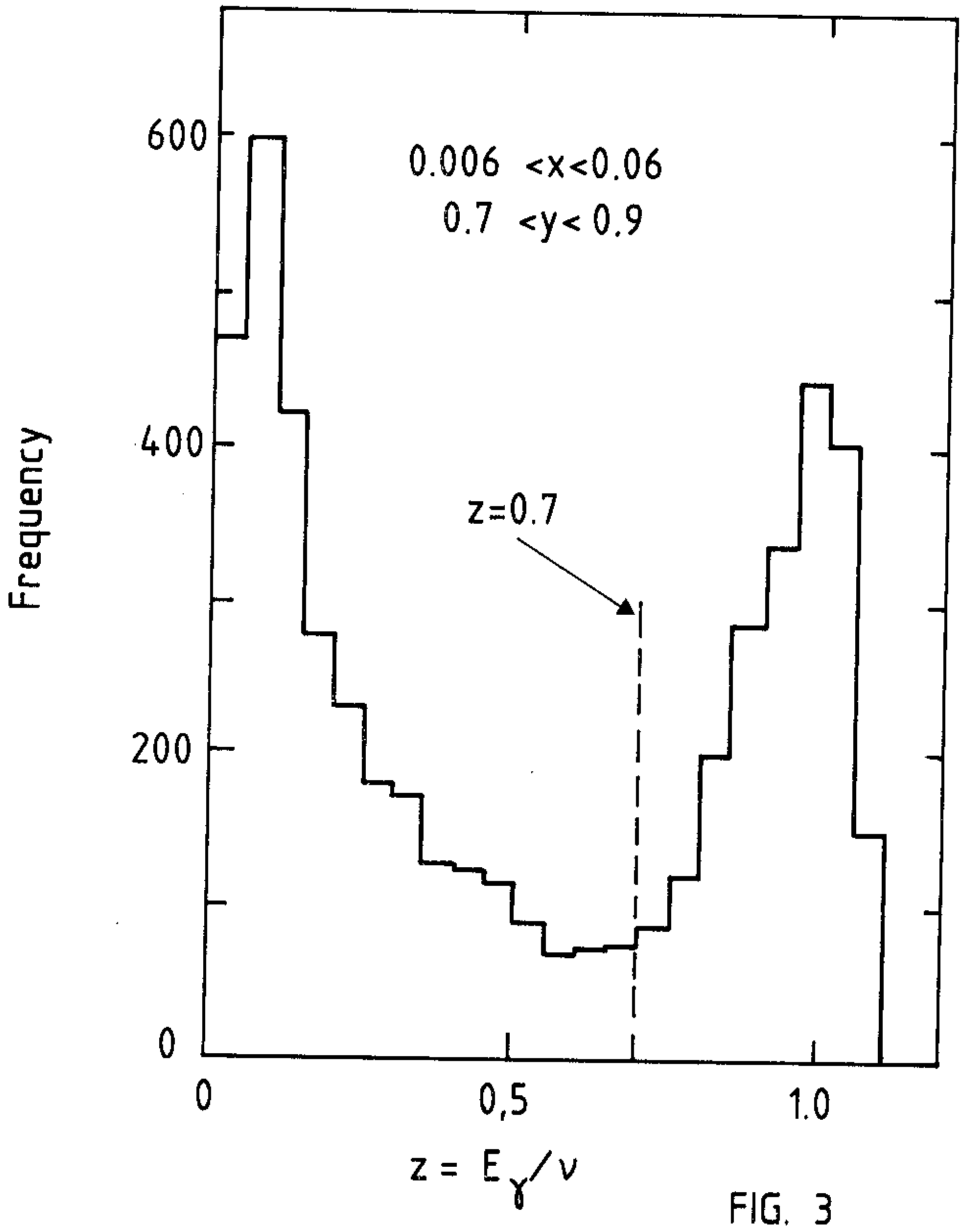
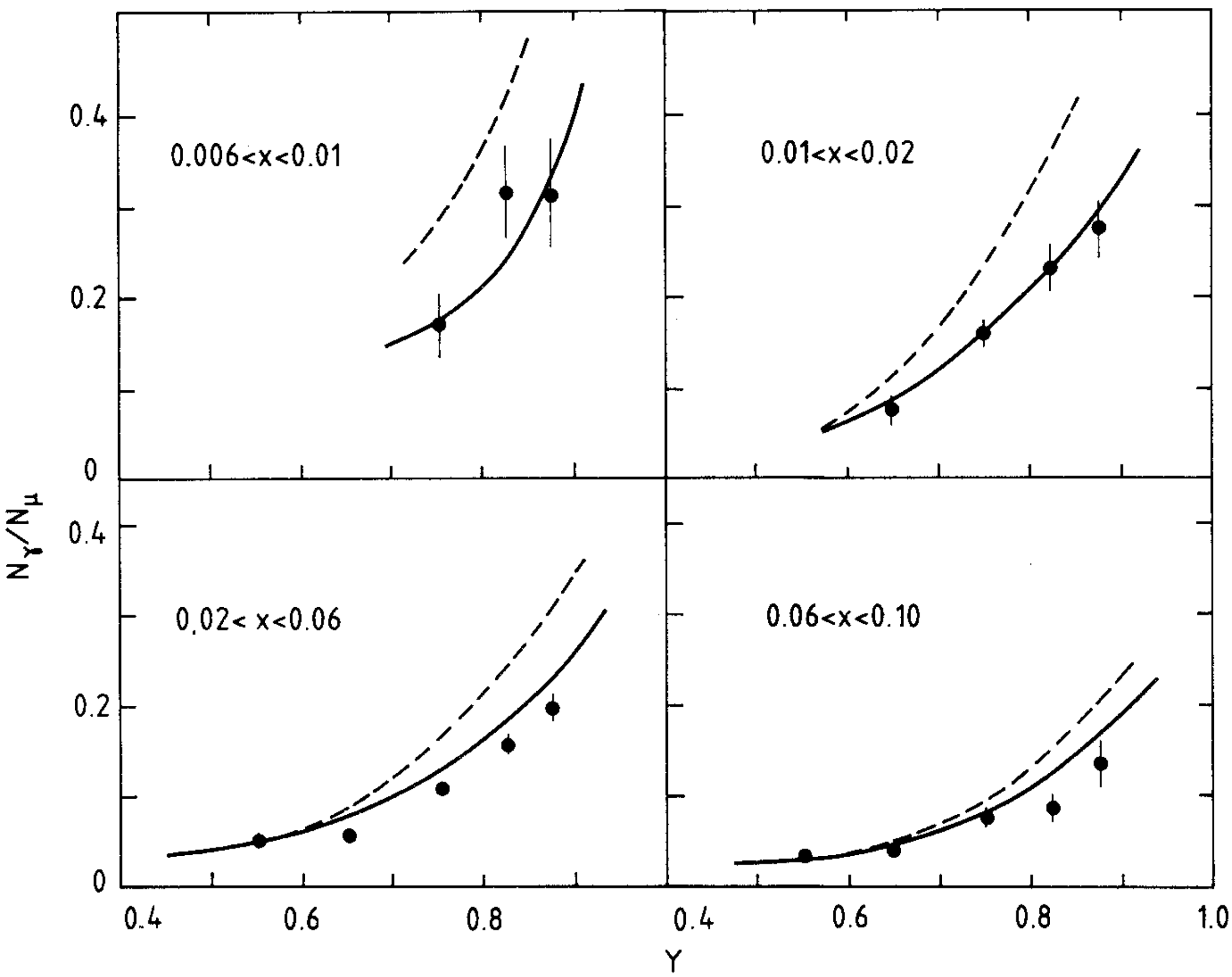


FIG. 3



0.006<x<0.01
0.01<x<0.02
0.02< x<0.06
0.06<x<0.10
N_γ/N_μ
0.4
0.2
0
0.4
0.6
0.8
1.0
Y

FIG. 4

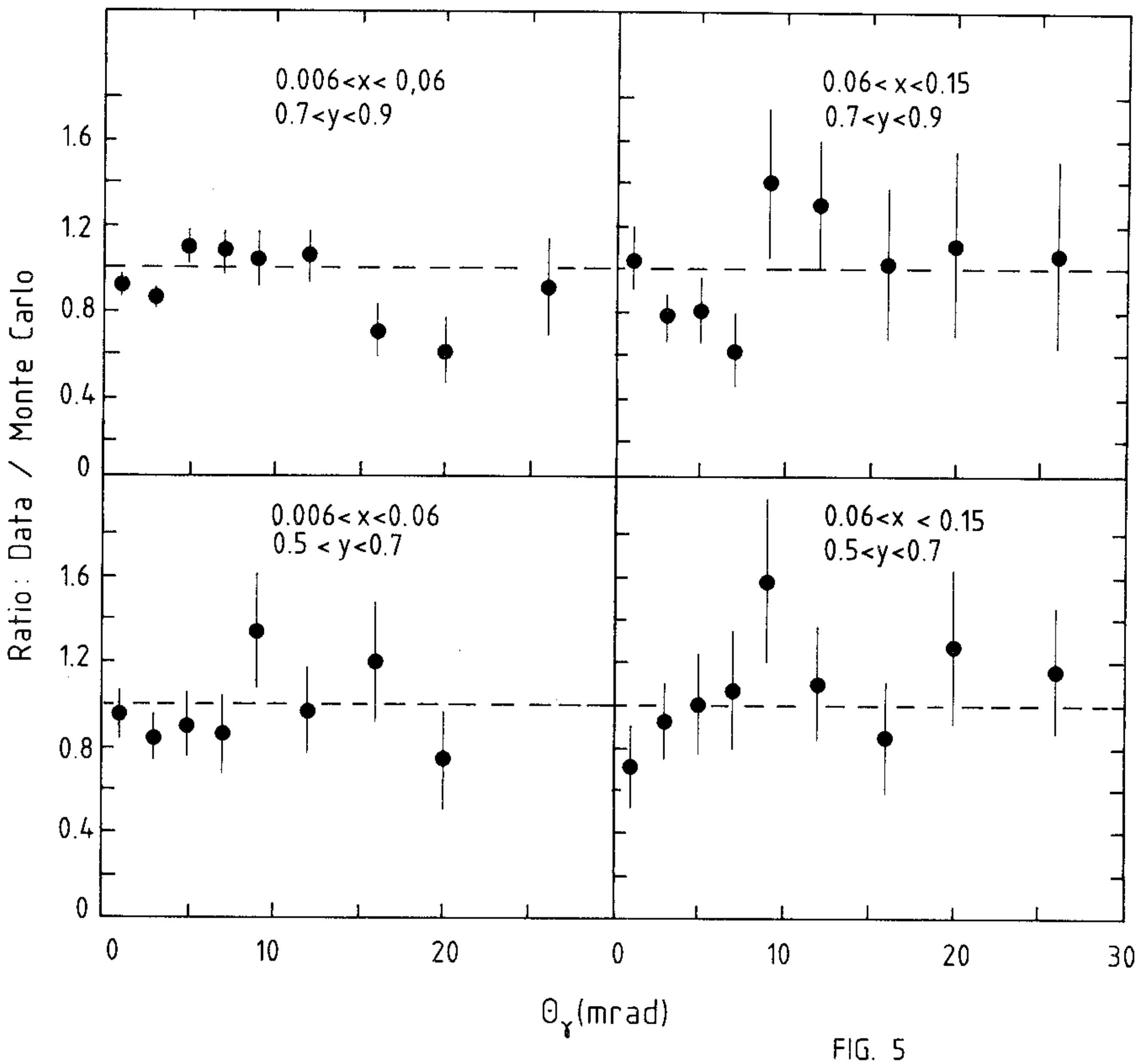

0.006<x< 0,06
0.7<y<0.9
0.06< x<0.15
0.7<y<0.9
0.006< x<0.06
0.5 < y<0.7
0.06<x < 0.15
0.5<y<0.7
Ratio : Data / Monte Carlo
1.6
1.2
0.8
0.4
0
10
20
30
Θγ(mrad)

FIG. 5