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EVIDENCE FOR ANOMALOUS PROMPT PHOTONS IN DEEP INELASTIC
MUON SCATTERING AT 200 GEV

The European Muon Collaboration

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ABSTRACT

The inclusive yield of photons has been measured from deep inelastic interactions of 200 GeV muons on hydrogen. After subtracting the contributions from hadron electromagnetic decays and Bethe-Heitler muon bremsstrahlung, residual photons are observed at low p_T and low z at a mean level of 0.13 ± 0.05 per interaction. The quark Compton scattering process is unable to explain the data, thus indicating an anomalous photon production.

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INTRODUCTION

We report a new measurement of the inclusive production of prompt photons in 200 GeV deep inelastic muon-proton interactions. Previously, using the same apparatus and beam [1], measurements were confined to high energy photon production as a test of the standard QED theory of muon bremsstrahlung [2]. In this paper, evidence is presented of a significant emission of lower energy photons in a kinematic domain which excludes muon radiation as being the only source.

The inclusive yield of these prompt photons is derived from the observed residue remaining in a combined sample of deep inelastic events after subtraction of indirect photons associated with hadron electromagnetic decays. Since complete event reconstruction is not normally possible owing to finite acceptance, the anticipated yield of the decay photons was determined by Monte Carlo simulation. The systematic errors in this procedure were carefully evaluated from the comparisons found between this simulation applied to π^0 inclusive production and their direct measurement in the same apparatus.

The resulting inclusive distributions of prompt photons are normalised to all deep inelastic events, and presented in transverse momentum p_T to the virtual photon current, azimuthal angle ϕ in both the current and muon beam directions and fractional energy z , defined as E_Y/ν where ν is the energy lost by the interacting muon.

The original aim of the experiment was to search for indirect evidence of quark bremsstrahlung by measuring the asymmetry in yield of photons expected from comparable experiments carried out with muons of each charge polarity. For high p_T photons, such an asymmetry arises from the interference between the Bethe-Heitler and Compton radiation amplitudes associated with the muon and struck quark respectively [3].

Previous measurements of this interference yield have given only a two standard deviation effect [4]. A similar phenomenon has been measured in e^+e^- annihilation [5] and the result implies that the radiating quarks have conventional fractional charges. However, no lepton scattering experiment in this energy range has observed a significant asymmetry. By contrast, high p_T photons have been observed in photoproduction [6] in this energy regime with a cross section given by deep-inelastic Compton scattering corrected for known QCD effects [7].

EXPERIMENTAL DETAILS

The experiment was performed in the M2 muon beam line at the CERN SPS using the European Muon Collaboration forward spectrometer [8] to detect the scattered muons, forward charged hadrons and photons produced from deep inelastic scattering events. Data were taken with approximately equal luminosities of 200 GeV μ^+ and μ^- beams incident on a 6 m liquid hydrogen target. Scattered muon events were restricted to the downstream 1 m portion of the target in order to limit the rate of photons arising from electromagnetic decay of hadrons produced from secondary interactions in the hydrogen. An electromagnetic calorimeter was located centrally in the forward direction downstream of the tracking detectors. It consisted of an array of 450 lead glass blocks, each 80 mm square, 400 mm long, with an active preshowering section built of a double layer of lead glass (2.7 radiation lengths per layer) and MWPCs with 4 mm pitch strip analogue readout [9]. After a cut imposed to define the minimum scattering angle of the interacting muon, the deep inelastic events retained extended over $3 < Q^2 < 100 \text{ GeV}^2$, $100 < W^2 < 300 \text{ GeV}^2$ and $x_{Bj} > 0.02$. The mean values within these bands were $\langle Q^2 \rangle = 19 \text{ GeV}^2$, $\langle W^2 \rangle = 195 \text{ GeV}^2$ and $\langle \nu \rangle = 113 \text{ GeV}$. The data presented here were obtained from an exposure of $\sim 1.2 \times 10^{12}$ incident muons. After target and muon kinematic cuts the sample retained comprised 18640 events.

Raw data from the calorimeter were analysed following earlier procedures [10] in particular with respect to the identification of single and overlapping electromagnetic shower depositions, the latter usually associated with π^0 's. These could be recognised up to 80 GeV at which the minimum 2γ separation is 40 mm. The measured relative longitudinal energy depositions in the preshower sections and back array were calibrated absolutely after comparison with detailed predictions from an EGS shower programme [11]. These predictions were fed into the full simulation of the apparatus. Such refinements were needed so that cuts could be applied to minimise the contamination from charged hadrons not detected due to inefficiencies in the tracking chambers upstream of the calorimeter. The relative energy calibration of each calorimeter element was carried out using the muon beam halo. The absolute calibration was fixed by the π^0 mass reconstructed from pairs of single photon shower depositions each up to 15 GeV. At higher energies, up to 170 GeV, the calibration was checked using the spectrum of Bethe-Heitler photons observed at high z [1]. The systematic uncertainty in these calibration procedures was $\leq 3\%$ up to 30 GeV increasing to 5% at the highest energies. The measured π^0 Gaussian width was reproduced in a Monte Carlo simulation where the photon energy resolution was parameterised by $\sigma/E = 0.05 + 0.25/\sqrt{E(\text{GeV})}$. A photon spatial resolution of ± 7 mm was obtained using the shower profiles in the MWPC's, from which the photon angles at the interaction vertex were measured to ± 0.5 mrad. This is comparable with the accuracy achieved in the determination of the virtual photon axis. Throughout this analysis only photons with laboratory energy $E_\gamma > 5$ GeV and $z > 0.05$ were kept. It was not possible to calibrate the calorimeter below 5 GeV with sufficient precision.

Direct Photon Signal

Photon candidates in the calorimeter arose from:-

- (i) Genuine direct photons from the interaction vertex which include Bethe-Heitler photons from the interacting muons.
- (ii) Indirect photons from hadron decay (e.g. π^0 , η^0 , ω^0 , Λ^0 , $D^*(2010)$), both separated and overlapping energy depositions.
- (iii) Charged particles, hadrons and electrons not reconstructed in the forward spectrometer due to tracking inefficiencies but satisfying the cuts imposed on the preshower and total energy depositions.
- (iv) Neutral hadrons (e.g. K_L^0 , neutrons) giving photon-like shower topologies in the lead glass.
- (v) Halo muon bremsstrahlung in the lead glass in random coincidence with the primary interaction and which fail to reconstruct tracks in the spectrometer chambers.
- (vi) External bremsstrahlung from interacting muons in the hydrogen target.
- (vii) Bremsstrahlung from atomic electrons scattered by the interacting muons in the hydrogen target.

Sources (i) to (iii) dominate and are considered in detail. The inclusive photon spectrum expected from hadron decays and QED radiative processes in the raw data was determined using a three stage Monte Carlo procedure described elsewhere [10]. The first stage describing the hadronisation process employed the Lund string model [12] with parameters chosen to match the measured π^0 and ρ^0 inclusive yields in the same experiment. Bethe-Heitler radiation [2] from the muon was

incorporated at this stage modifying the 4-momentum of the exchanged current and producing photons in the apparatus. The second stage generated showers in the calorimeter down to the level of digitisation in the readout electronics including the effects of ADC processor cuts, conversion losses in the hydrogen target, walls and other intervening materials before the dipole magnet. The final stage reconstructed photons in the calorimeter in the same way as the data analysis programme.

To establish the accuracy of simulation of the hadronic background, the Monte Carlo was used to predict the observed inclusive mass spectra of reconstructed photon pairs in the detector binned in 5 regions of p_T^2 and z . The dominant π^0 production was well reproduced by this simulation but the combinatorial background was a factor of 2 too small in the region $p_{T\gamma\gamma}^2 < 0.5 \text{ GeV}^2$, $z_{\gamma\gamma} < 0.4$ when compared with the data. In this kinematic domain the agreement between data and Monte Carlo for the extracted π^0 yields was found to be within 7% after fitting the mass spectra obtained. The resulting normalised π^0 inclusive cross sections in z and p_T^2 are shown in figs. 1a, b together with those from earlier analyses [10], [13] of π^0 and $\pi^\pm$ production in the same experiment, and with the corresponding Lund model predictions for comparison. There is reasonable agreement between the model predictions and the data.

The contamination in the photon yields from charged particles which simulate photons in the calorimeter and are not detected by the spectrometer was determined as a function of p_T^2 and z directly from the data. Charged particles with energy depositions in the preshower detectors characteristic of photons and correlated spatially with charged tracks in the forward spectrometer ($\sim 8\%$ of all hadrons impinging on the calorimeter) were weighted according to their individually determined tracking efficiency and then histogrammed in p_T^2 and z . The overall multiplicity of this charged particle background was 0.013 per deep inelastic event. This was subtracted

from all electromagnetic showers with $z > 0.05$ seen in the calorimeter to give a photon multiplicity of 0.59 ± 0.01 (stat.) per event. The predicted background from hadron electromagnetic decays was 0.489 ± 0.005 (stat.) ± 0.03 (syst.) per event, thus giving a residual photon multiplicity uncorrected for acceptance and conversion losses of 0.10 ± 0.03 (syst.). This includes Bethe-Heitler muon bremsstrahlung at a level of approximately 0.02 photons per event.

Each of the remaining backgrounds (iv) to (vii) was calculated to be small, contributing overall $\lesssim 0.015$ photons per scattered muon event. It was assumed that neutron (antineutron) yields are the same as those measured for forward protons (antiprotons) [14]. Halo muons were $\sim 5\%$ of the reconstructed muon beam intensity. However, the probability of a muon depositing more than 5 GeV in the lead glass is $\sim 1.7 \times 10^{-3}$ which, when combined with the probability of observing this deposition randomly in the electronic gate time of 150 nsec, leads to an insignificant contribution.

Figures 2a, b show the z and p_T^2 distributions of observed photons in the calorimeter normalised to the number of scattered muon events. The extracted residue identified as prompt photons is plotted after bin-by-bin subtraction of the predicted hadronic electromagnetic decays. It can be seen that there is a large excess which cannot be explained by Bethe-Heitler muon radiation in the regions $z < 0.3$ and $p_T^2 < 0.5 \text{ GeV}/c^2$.

After subtraction of the muon radiation predicted by the simulation above, the extracted residue was corrected for calorimeter acceptance and target conversion losses. The correction factors per bin in each of the variables z , p_T^2 and ϕ were determined by the complete simulation procedure above replacing the Lund hadronisation by the QED Compton model of photon production described below. This model adequately reproduced the shape of the residual distributions and showed that the corrections were smoothly varying and averaged about 1.7 per bin. The final distributions thus obtained describe the anomalous production of prompt photons which follows.

For those photons with $p_T^2 > 0.05 \text{ (GeV/c)}^2$, the azimuthal angular dependence $1/N_\mu dN/d\phi$ is plotted as a function of ϕ around the virtual photon direction in (fig. 3a); and alternatively around the incident muon direction (fig. 3b). The latter distribution is peaked in the lepton plane along the direction of the virtual photon whereas the distribution around the current direction is flat. In addition, the mean p_T^2 relative to the muon direction is 0.12 (GeV/c)^2 compared with 0.06 (GeV/c)^2 measured relative to the virtual photon direction. These data show that the prompt photons are emitted preferentially along the struck quark direction and hence originate from the hadron vertex and not from QED processes at the muon vertex. Any form of beam related background would not produce such an effect.

Figures 4a,b show respectively the acceptance corrected differential multiplicity $1/N_\mu dN/dz$ and the inclusive distribution $1/N_\mu dN/dp_T^2$. Again the Bethe-Heitler muon radiation contribution has been removed. The corresponding differential multiplicities for all hadronic decay photons are plotted for comparison with the same cuts applied. Their form is different from the prompt photon distributions which are characterised by steeper slopes at low z and p_T^2 , suggesting that they radiate from a different source albeit at the hadron vertex. The bin-by-bin statistical and systematic errors are also given in figs. 4a,b. The systematic errors dominate everywhere arising principally from uncertainties in the Monte Carlo subtraction, although smaller contributions from the calorimeter energy calibration are also included. These errors in the Monte Carlo subtraction arise mainly from uncertainties in the Lund model description of hadronic resonance production. It is recognised that the model parameters chosen to describe the measured π^0 , ρ^0 and strange particle production in this experiment are not unique. Alternative solutions may predict significantly larger yields of hadronic decay photons. As an example, parameters in the Lund version

above were modified to those determined in a multiparameter fit to data from a specific e^+e^- experiment [15]. In particular, they were the vector-to-pseudoscalar ratio, the fragmentation function and the s/u quark ratio. These modifications substantially enhance $\eta(\eta')$ production whilst maintaining π^0 's unchanged within measurement errors. Unfortunately, $\eta(\eta')$ production is not measured in high energy μp scattering but measurements in e^+e^- annihilation [16] tend to favour the standard parameter values. However, this example shows that even though the additional predicted $\eta(\eta')$ decay photons would account overall for $\sim 60\%$ of the 'direct' signal observed, their p_T^2 distribution is not as steep as that observed and therefore does not provide an adequate explanation of the effect. It is concluded by this study that the model parameters used have been constrained well enough such that contamination of the prompt signal must be less than 30% for $p_T^2 \leq 0.1 \text{ GeV}^2$. Similarly, the influence of charmed particle decays was found to be negligible with the cuts applied.

Measurements of charged hadron multiplicities and $\pi^\pm$ correlations show good agreement with the Lund model implying that the excess photon signal is not due to incorrect simulation of either multiple π^0 emission or spatial correlations between π^0 pairs in the same final state [17].

Taking into account all these systematic uncertainties and with the acceptance corrections described, the integrated multiplicity for $z > 0.05$ of the anomalous prompt photons was found to be 0.13 ± 0.05 per event. In the range $0 < p_T^2 < 0.25 \text{ GeV}^2$, this signal can be parameterised by the exponential form $1/N_\mu \frac{dN}{dp_T^2} = (2.2 \pm 0.2) \exp(-16 \pm 2) p_T^2$.

Table 1 summarises the integrated multiplicities and compares them with the yields of inclusive π^0 's and Bethe-Heitler bremsstrahlung in the same kinematic domain.

DISCUSSION

The inclusive yields of prompt photons including muon bremsstrahlung were found to be equal within statistical errors for positive and negative muon beams [18]. However, the data do show evidence of an excess of photons at low z and p_T^2 which was unexpected, and appears to be correlated with the current direction of the struck quark.

A first theoretical estimate of photon radiation from the struck quark can be given as an effective quark-to-photon fragmentation function [19] derived from the Compton scattering matrix element

$$D_q^Y(z) = \frac{\alpha}{2\pi} e_q^2 \frac{1 + (1-z)^2}{z} \ln \frac{Q^2}{m_q^2}$$

where e_q is the quark charge. The cut-off, m_q is in principle the quark mass but Λ_{QCD} is used to take QCD corrections into account. The resulting differential multiplicity $1/N_\mu dN/dz$ is then obtained by folding D_q^Y with the parton level cross section and the quark structure functions of the proton [20]. This gives a photon multiplicity of ~ 0.01 per event at $Q^2 \sim 10 \text{ GeV}^2$ which is strongly collimated in the struck quark direction, but is an order of magnitude smaller than the data. However, for the dashed curves in fig. 4 a Monte Carlo implementation [21] of the exact QED matrix element for deep inelastic Compton scattering is used folded with the proton structure functions [20] for fractionally charged quarks. The intrinsic transverse momentum of the quark was also included. The divergences for collinear and soft photon emission were avoided by taking explicit account of the quark mass in the matrix element and requiring a minimum photon energy of 5 GeV as in the experiment. The results using an effective (transverse) quark mass of 300 MeV are given in figs. 4a, b and correspond to an average multiplicity of 0.007

photons per event, a factor 18 smaller than observed! This multiplicity can be increased by a factor 3 using a 'bare' quark mass of 3 MeV, but as shown in fig. 4b this is concentrated at very low p_T^2 and does not follow the shape of the data.

Soft low p_T photons have been observed [22] in hadron-hadron interactions. Their dependence on $z(x_F)$ appears to be consistent with that calculated from the QED process of hadron final state inner bremsstrahlung [23], although at higher energies the measured yield is considerably in excess of expectation. A similar QED calculation has been performed here generating charged hadrons in the Lund model from deep inelastic interactions over our kinematic domain. The photon energy spectrum was found to be almost entirely below 5 GeV and as such cannot account for the signal observed. The mean laboratory energy of the prompt photons observed in this experiment above the 5 GeV threshold is 12.5 GeV.

This result shows for the first time in deep inelastic lepton scattering evidence for the production of low energy prompt photons which do not appear to be correlated with radiation from the interacting lepton. Their collimation in transverse momentum to the current axis suggests that their origin is at the quark level even though the multiplicity is an order of magnitude larger than expected from a radiating fractionally charged struck quark of conventional mass.

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REFERENCES

- [1] EMC, J.J. Aubert et al., Z. Phys. C22 (1984) 341.
- [2] L.W. Mo, Y. Tsai, Rev. Mod. Phys. 41 (1969) 205.
- [3] S.J. Brodsky, J.F. Gunion and R.L. Jaffe, Phys. Rev. D6 (1972) 2487.
- [4] D.L. Fancher et al., Phys. Rev. Lett. 38 (1977) 800.
- [5] MAC, E. Fernandez et al., Phys. Rev. Lett. 54 (1985) 95.
- [6] P. Astbury et al., Phys. Lett. 152B (1985) 419.
- [7] D.W. Duke and J.F. Owens, Phys. Rev. D26 (1982) 1600.
P. Aurenche et al., Z. Phys. C24 (1984) 309.
- [8] EMC, O.C. Alkofer et al., Nucl. Inst. and Meth. 179 (1981) 445.
- [9] E. Gabathuler et al., Nucl. Inst. and Meth. 157 (1978) 47.
- [10] EMC, J.J. Aubert et al., Z. Phys. C18 (1983) 189.
- [11] R.L. Ford, W.R. Nelson: The EGS Code System SLAC 210 (1978).
- [12] B. Anderson et al., Z. Phys. C9(1981) 233; *ibid* Phys. Rep. 97 (1983) 31.
G. Ingelman et al., Nucl. Phys. B206 (1982) 239.
- [13] EMC, J. Gayler, DESY (1981) 81-063.
- [14] EMC, J.J. Aubert et al., Phys. Lett. 103B (1981) 388.
- [15] TPC Collaboration, UCLA-85-015.
- [16] JADE, W. Bartel et al., Z. Phys. C28 (1985) 343;
A. Drescher, Thesis Inst. für Physik der Universität,
Dortmund, Jan. 1987;
EMC, M. Arneodo et al., Nucl. Phys. B258 (1985) 249;
J. Krüger, Thesis Univ. of Wuppertal WU-B-DI-85-4.
- [17] EMC, M. Arneodo et al., Z. Phys. C31 (1986) 333.
- [18] J. Williamson, Ph.D. thesis (Sheffield University, UK) 1986.
- [19] R. Rückl, S.J. Brodsky, J.F. Gunion, Phys. Rev. D18 (1978) 2469;
K. Koller, T.F. Walsh, P.M. Zerwas, Z. Phys. C2 (1979) 197;
P. Aurenche, J. Lindfors, Nucl. Phys. B168 (1980) 296.
- [20] M. Glück, E. Hoffmann, E. Reya, Z. Phys. C13 (1982) 119.
- [21] G. Ingelman, unpublished.
- [22] A.T. Goshaw et al., Phys. Rev. Lett. 43 (1979) 1065;
P.V. Chliapnikov et al., Phys. Lett. 141B (1984) 276.
- [23] L. Landau, E. Lifshitz, "Relativistic Quantum Mechanics"
Vol. 1 (Ed. Mir, Moscow, 1982) p475.

Table 1

$$100 < W^2 < 300 \text{ GeV}^2$$

$$x_{Bj} > 0.02$$

$$E_Y > 5 \text{ GeV}$$

Integrated Multiplicity	
Prompt: $\frac{1}{N_\mu} \int_{0.05}^1 \frac{dN_Y}{dz} dz (=n_Y)$	$0.13 \pm 0.01 \pm 0.05$ (stat.)(Syst.)
$\frac{1}{N_\mu} \int_{0.05}^1 z \frac{dN_Y}{dz} dz (= \text{fract. energy/event})$	0.014 ± 0.005
$\langle z \rangle (z > 0.05)$	0.11 ± 0.02
$\pi^0 : \frac{1}{N_\mu} \int_{0.05}^1 \frac{dN_{\pi^0}}{dz} dz (=n_{\pi^0}) \text{ (EMC Ref. 10)}$	1.5
B-H : $\frac{1}{N_\mu} \int_{0.05}^1 \frac{dN_Y}{dz} dz$	0.068

FIGURE CAPTIONS

Fig. 1 Inclusive distributions of π^0 in (a) z and (b) p_T^2 measured using photons with energies greater than 5 GeV in the region $100 < W^2 < 300 \text{ GeV}^2$, $Q^2 > 3 \text{ GeV}^2$ and $x_{Bj} > 0.02$. Earlier data of π^0 's [10] and charged hadrons [13] using similar cuts are shown as well as the Lund model predictions for π^0 's in the the same domain (continuous curves).

Fig. 2 Normalised inclusive distributions in (a) z and (b) p_T^2 of all photons observed in the calorimeter. The continuous and dashed curves show the predicted contributions from hadron electromagnetic decays and muon bremsstrahlung respectively calculated in a complete simulation of the apparatus. The residual photons shown are determined from subtraction of the hadronic background only.

Fig. 3 Normalised inclusive distributions in azimuthal angle for the anomalous prompt photons with respect to (a) the virtual photon direction and (b) the incident muon direction where $\phi = 0$ corresponds to the scattered muon. Only photons with $p_T^2 > 0.05 \text{ GeV}^2$ are included.

Fig. 4 Normalised inclusive distributions in (a) z and (b) p_T^2 of the anomalous prompt photons. The continuous curves show the predicted spectra from hadron decays in the Lund model, whilst the dashed curves illustrate the quark Compton scattering predictions for quark masses of 300 and 3 MeV respectively.

FIG. 1a

FIG. 1b

FIG. 2a

FIG. 2b

FIG 3

FIG. 4a

FIG. 4b