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OBSERVATION OF DIRECT SOFT PHOTON PRODUCTION IN π^-p INTERACTIONS AT 280 GeV/c

SOPHIE/WA83 Collaboration

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Abstract

The OMEGA spectrometer, equipped with a hydrogen target and two electromagnetic calorimeters, was used to investigate the production of soft gammas in hadronic collisions. The E and P_T distributions of the measured γ's are compared with the corresponding distributions of γ's arising from hadronic decays and of γ's expected from QED inner bremsstrahlung. An excess of gammas by a factor 7.9 ± 1.4 over the QED prediction is measured in the low energy ($0.2 < E_\gamma^{lab} < 1.0$ GeV) and low P_T(< 10 MeV/c) kinematical region and confirms the original observation of a similar effect in a bubble chamber experiment.

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1) Dedicated to the memory of our friend and colleague Dr. Y. Goldschmidt-Clermont.

The SOPHIE/WA83 experiment [1] was designed to study soft photon production in π^-p collisions at 280 GeV/c. The experiment was motivated by the observation in a bubble chamber experiment [2] of an excess of soft photons, by a factor of 3, above that expected from QED inner bremsstrahlung. The signal appeared as a spike over a large background around $x_F = 0$ and as an enhancement in the low P_T spectrum. More recently the EMC [3] and NA22 [4] collaborations have found positive evidence for soft photon production in a similar kinematical region ($P_T < 20$ MeV/c) to the bubble chamber experiment, whereas the HELIOS [5] collaboration has found no evidence for such an effect in the region $-2 < y_{cms} < 0$. Several models have been proposed to explain the excess of photons annihilation of slow $q\bar{q}$ pairs, production of a transient quark-gluon plasma, radiative decay of a low-mass large-width hadronic state, multiple scattering of quarks in the colour field filling hadron bags and the Cold Quark Gluon Plasma mechanism [6]. See ref. [7] for a review of theoretical and experimental results.

The present experiment studies soft photon production in a region of phase space where the contribution of gammas from hadronic decays is relatively small.

The WA83 experiment was performed at the CERN SPS accelerator, using the OMEGA spectrometer. An interaction trigger was used to collect the analysed 1×10^6 events of π^-p interactions produced by a beam of momentum 280 GeV/c, with an intensity of 8×10^4 particles per pulse, incident on a 1 m long liquid hydrogen target. The layout of the OMEGA spectrometer is shown in fig. 1 and consisted of 13 MWPCs placed inside a magnetic field of 1.1 Tesla and of two lever arm drift chambers. In addition two electromagnetic calorimeters positioned at 11.5 m from the centre of the target were used to detect the electromagnetic showers. The outer calorimeter (Geneva Photon Detector, GPD) covered an area of 4 m × 4 m and consisted of successive layers of Pb sheets and teflon tubes filled with liquid scintillator. The central hole of the GPD corresponding to a cone of approximately 20 mrad half angle around the beam direction, contained the inner calorimeter (PLUG) of a type which has recently been named SPACAL. It had a surface area of 42 cm × 42 cm and consisted of scintillating fibres embedded in Pb blocks of 25 radiation lengths in depth. A 4 m × 4 m MWPC was placed 20 cm in front of these detectors in order to record the charged tracks incident on the calorimeters.

The PLUG electromagnetic calorimeter was used to observe the photons in the low x_F and low P_T region. The converter blocks of this calorimeter were constructed from thin grooved lead sheets which enclosed of 1 mm plastic scintillating fibres which undulated around the beam direction. The light was collected via a 13 × 13 array of light guides and photomultipliers. One block out of the 169 was removed to allow the passage of non-interacting beam tracks. Each photomultiplier was read by a 12-bit ADC set to saturate at an energy equivalent to 40 GeV. The detector was calibrated by applying an iterative method which used the mass of the reconstructed π^0 as a constraint. The calibration has been checked in a wide energy range. The invariant mass distributions of $\gamma\gamma$ pairs, when both γ's were measured in the inner calorimeter and when one was in the inner calorimeter and the other was in the outer or was an e^+e^- pair reconstructed inside the OMEGA spectrometer, show a π^0 peak well-centred around the nominal value mass having HWHM less than 20 MeV for a wide energy range of the showers. The energy distribution of the calorimeter's showers associated with charged tracks projected on to this detector, shows a clear peak around 315 MeV (with a HWHM of 30 MeV) which is the energy expected to be deposited by the non-interacting, minimum ionizing, charged tracks. A comparison of the lateral development of the showers in the PLUG detector with the shower simulation program EGS [8] gave good agreement between the data and the simulation.

The results given in this report are based on the total statistics of 310 390 events with a total energy deposited in the calorimeter less than 50 GeV. This condition was applied in order to select events with better reconstruction efficiency of the soft photon showers and it was the main reason for the data reduction. The events were required to have a well-measured vertex and well-reconstructed charged tracks. Only the electromagnetic showers recorded by the inner calorimeter were used in the present analysis. They were required to be a cluster of at least two elements, to be fiducially contained within the calorimeter and to have a lateral energy distribution consistent with an electromagnetic shower. Those showers which could be associated with charged tracks were removed.

The efficiency of the PLUG calorimeter in detecting photons was studied by implanting well measured showers randomly into different events and the resulting events were processed with the same chain of production programs used on the real data. The implanted photon was considered to have been found if its energy and position agreed with the original values to within 2.5 standard deviations. Figures 2(a) and 2(b) show the P_T and the x_F distributions, before and after correcting for the γ detection efficiency for showers with energies lying between $0.2 - 20$ GeV and having $y_{cms} > 0.004$.

Figures 3(a) and 3(b) compare the observed efficiency corrected P_T and E distribution with the γ's coming from known hadronic sources (i.e. $\pi^0, \omega, \eta, \Sigma^0$, etc.) as a result of a simulation of the experiment using the FRITIOF Monte Carlo program [9], which also took into account the showers caused by the K^0_L and neutrons. The effect of the total energy cut of 50 GeV in the PLUG was simulated in the Monte-Carlo stream. The normal bremsstrahlung originating from the e^+ or the e^- of a photon having materialised inside the OMEGA spectrometer was calculated to be 0.9% and was subtracted from the data distributions. The Monte Carlo distributions agree well with these data in the region expected to be dominated by hadronic decays. Therefore the Monte Carlo results were normalised to the experimental data points for $E > 5$ GeV.

Figures 4(a) and 4(b) show the γ spectra after having subtracted the hadronic γ's, using the above normalisation procedure. In these figures the expected distribution of γ's arising from QED inner bremsstrahlung under the WA83 experimental conditions are shown. For calculating the QED inner bremsstrahlung the Low formula [10] was used which implies an integration over the momentum distribution of the charged particles participating in the interaction. The integration was performed using the charged particle momenta in each event from the FRITIOF Monte Carlo. A similar value was obtained using the charged tracks of the real data.

An excess of photons above that expected from QED inner bremsstrahlung predictions is present in both P_T and E distributions [figs. 4a and 4b]. This excess can be given quantitavely in the kinematical region $0.2 < E_\gamma < 1$ GeV and $P_T < 10$ Mev/c, where the photons from hadronic decays make an insignificant contribution, as an excess factor of $7.9 \pm 0.8 \pm 1.1$. The two errors are systematic, the statistical errors being negligible. The first error is dominated by the uncertainty in the detection efficiency for the low energy photons and the second error comes from the uncertainty in the energy scale at 0.2 GeV. The above ratio corresponds to the observation of 1 low energy photon per 6 inelastic interactions, whereas the calculated inner bremsstrahlung is 2.1%.

Comparing the measured P_T distribution of the soft photons to the corresponding bremsstrahlung distribution [see fig 4a] a striking similarity in shape is observed. At low energies, where bremsstrahlung dominates over hadronic decays, the similarity is also present in the energy (fig. 4b) distribution.

The peaks in P_T and E_{lab} are found to be strongly correlated, much in the way expected for QED inner bremsstrahlung [10]. Indeed, the lab angle ($\approx P_T/E_{lab}$) distribution of photons of non-hadronic origin has a strongly peaked shape, which depends little on energy. This is also further evidence for the purity of our sample, since none of the conceivable background sources such as neutrons, K_L^0's, charged particles or even satellites (isolated low energy photons produced by a nearby high energy shower) would produce such apeak.

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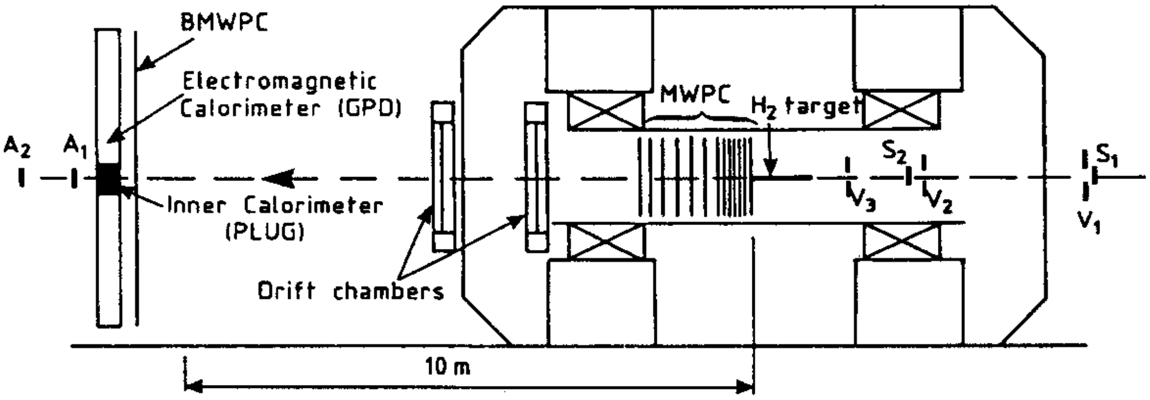


Fig. 1: Layout of the OMEGA spectrometer used in the present experiment.

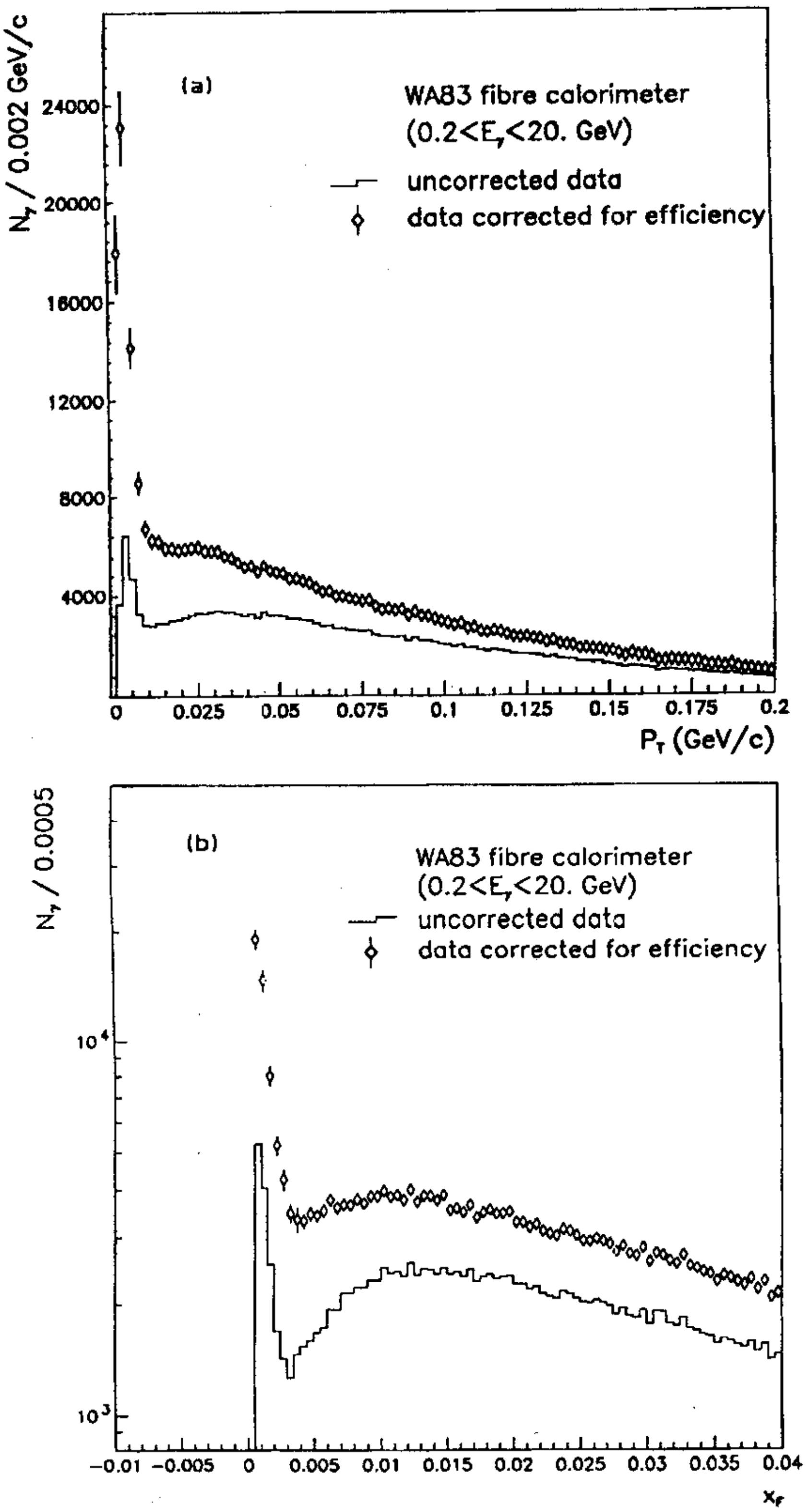
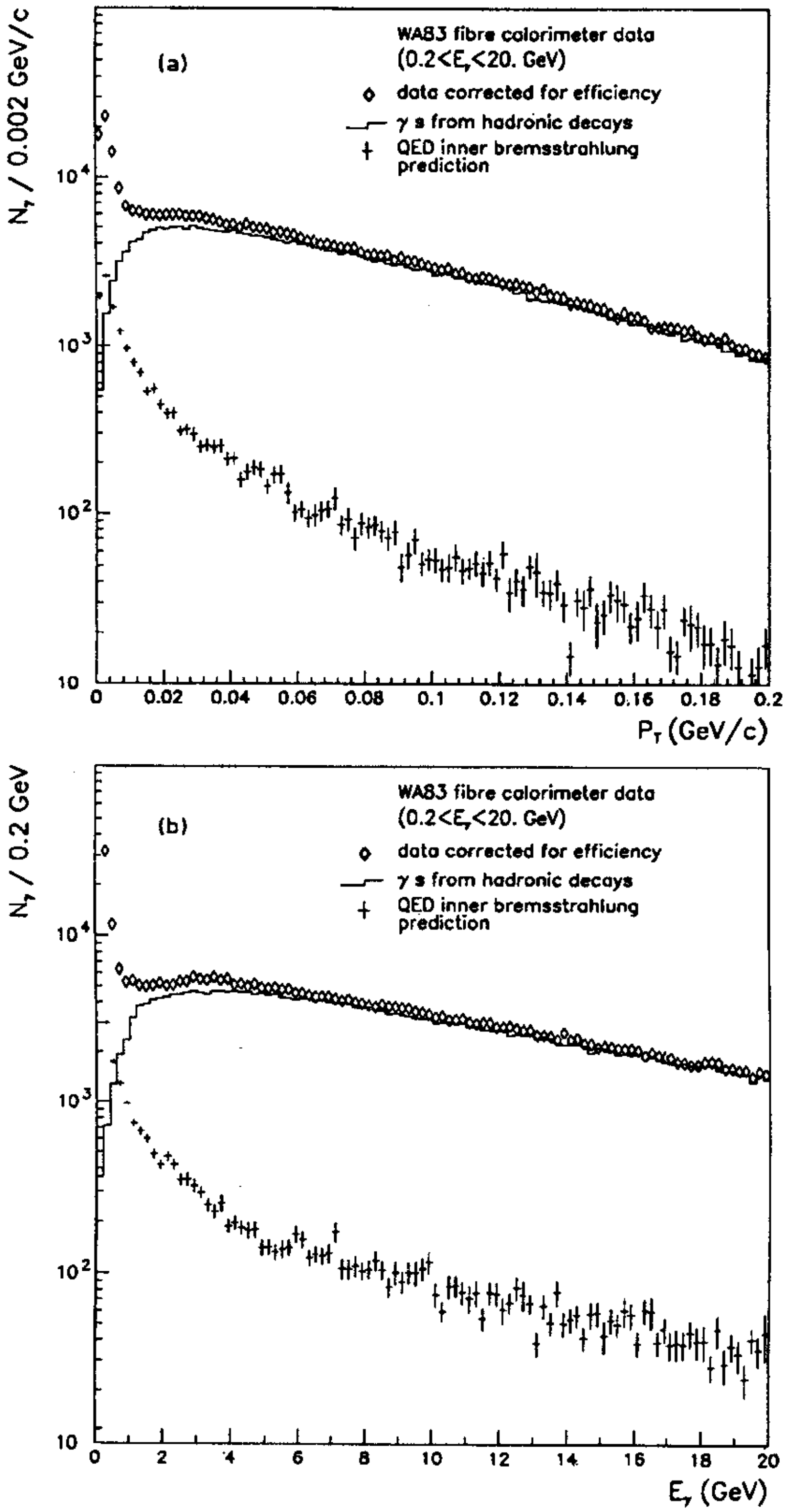
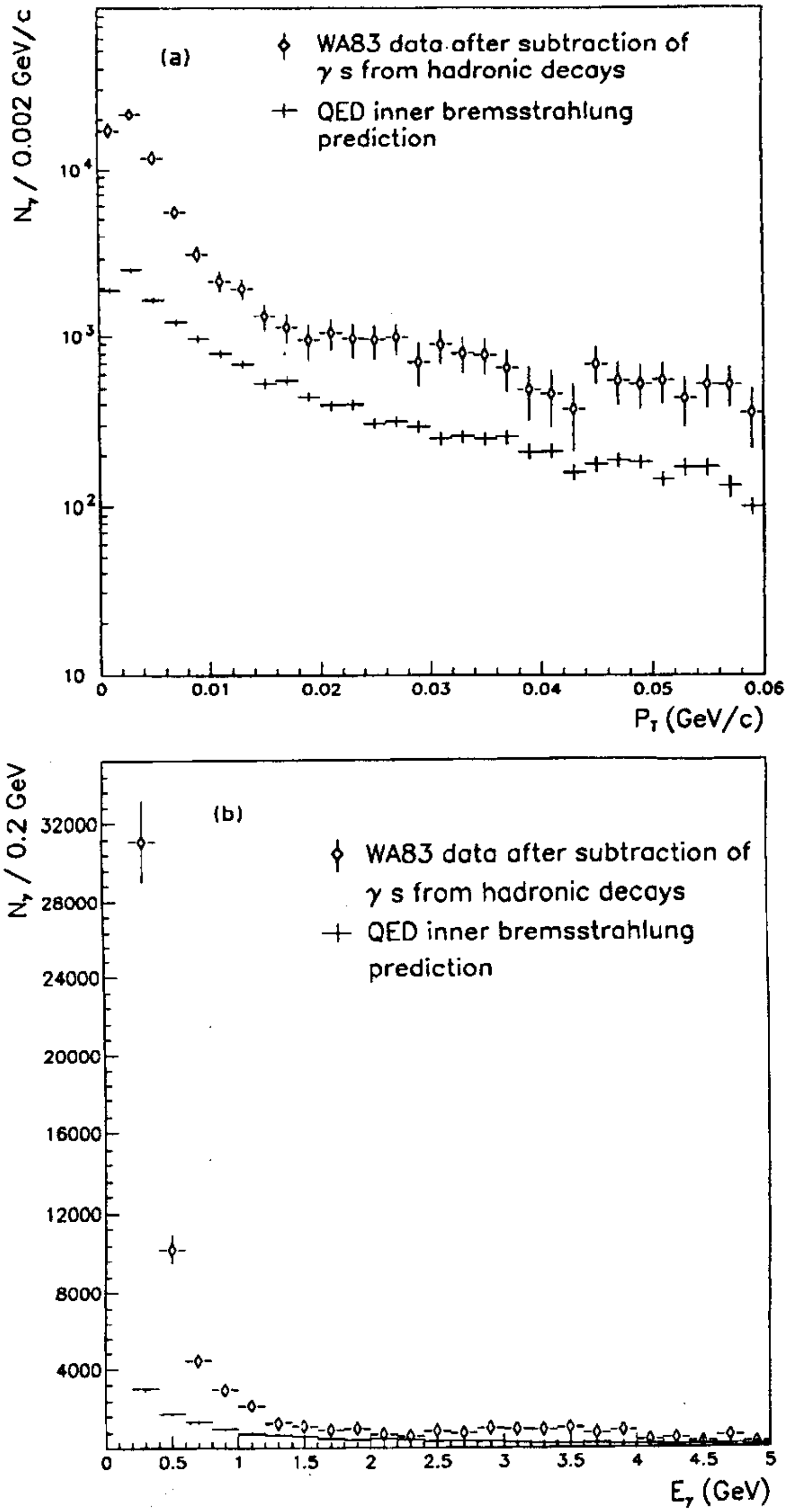


Fig. 2: (a) P_T distribution of the PLUG electromagnetic showers in the energy range 0.2–20 GeV corrected with the efficiency (open diamonds) together with the uncorrected data (full line).
(b) Feynmann x_F distribution of the electromagnetic showers of fig. 2 (a)



Figs. 3: (a) and (b) Respectively log P_T and log E distributions (open diamonds) compared with QED inner bremsstrahlung prediction (crosses). The full line histogram is the Monte Carlo prediction for γ's from hadronic decays.



Figs. 4: (a) and (b) Respectively log P_T and E distributions of γ's remaining after subtraction of hadronic γ's (open diamonds) compared with QED inner bremsstrahlung (crosses). The distributions of the hadronic γ's have been normalised to the data points for $E_\gamma > 5$ GeV.