CERN/EP 84-50

13 April 1984

OBSERVATION OF DIRECT SOFT PHOTON PRODUCTION IN K^+p INTERACTIONS

AT 70 GeV/c

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ABSTRACT

The inclusive γ cross section in K^+p interactions at 70 GeV/c shows an excess of $(4.5 \pm 0.9)\text{mb}$ over the contributions arising from hadron decays. The excess consists of soft γ 's with $-0.001 < x < 0.008$ and $p_T < 0.06 \text{ GeV/c}$. The shape of this soft γ spectrum is consistent with that expected from QED inner bremsstrahlung, but the measured total cross section exceeds the QED expectation, indicating the presence of other source(s) of soft photons.

Submitted to Physics Letters B

(*) Participating under the terms of the 1967 agreement between CERN and the USSR State Committee for the Utilization of Atomic Energy.

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A study of the production of γ 's in K^+p interactions at 70 GeV/c [1], indicated the presence of an excess γ cross section over the contributions expected from π^0 production and decay, which could not be completely accounted for by γ 's emitted in the electromagnetic decays of known hadrons. Here, we present a detailed experimental study of this excess, and attempt to relate it to the QED process of inner bremsstrahlung.

The data arise from an experiment using the BEBC bubble chamber and an incident RF separated beam. The identification of γ 's observed by their materialization in e^+e^- pairs is described in detail in a previous study of γ and π^0 production [1], based on a sample of 82,000 measured events corresponding to a sensitivity of 4.5 events/ μ barn. Kinematic fitting yielded a total of 33,766 γ 's associated with 24,804 primary interactions. To account for scanning and processing losses, Compton scattering, conversions outside the fiducial volume or too close to the production vertex, and for loss of γ 's with soft e^+ or e^- [$p(e^{+-})_{lab} < 30$ MeV/c], a weighting factor was assigned to each event. The measured photon inclusive cross section was (91.4 ± 2.3) mb. To minimize the systematic errors arising from scanning losses at low γ momenta, we applied in the present paper an additional cut

$$p_\gamma > \frac{m_{\pi^0}}{2} \quad (1)$$

where p_γ is the photon laboratory momentum and m_{π^0} the π^0 mass. This cut reduces the inclusive cross section to $\sigma_\gamma = (86.0 \pm 2.2)$ mb. Additional checks showed that a possible contamination of the sample due to interactions occurring in the entrance window of the bubble chamber is negligibly small.

In order to isolate the γ 's arising from other sources than hadron decay, the following procedure was followed. As a first step, we subtracted from the experimental sample the contribution arising from γ 's emitted in the decay of known hadrons other than π^0 's. In a second step, we fitted the remaining spectrum over almost the whole kinematic region of observed γ 's using a parametrization of π^0 production and decay, which we subjected to two independent cross-checks. Finally, we subtracted the γ 's arising from π^0 decays. The remaining γ signal is the subject of our study.

The contribution to the γ cross section arising from non- π^0 decays of η , η' , ω , ϕ and $\Sigma^0/\bar{\Sigma}^0$ amounted to $(4.7 \pm 1.5)\text{mb}$ above the cut (1). It was estimated as previously [1], on the basis of the measured cross sections for production of ρ^0 [2], ϕ [3], and $\Sigma/\bar{\Sigma}^0$ [4], and of an upper limit for the production cross section of η [1]. Simulations based on the Lund model^(*) [5] were used to obtain the ratios $\sigma(\eta')/\sigma(\eta) = 0.54$ and $\sigma(\omega)/\sigma(\rho^0) = 0.88$. The semi-experimental value of $(4.7 \pm 1.5)\text{mb}$ is in reasonable agreement with the corresponding estimate using the Lund model only, of 5.2 mb.

The Lund model^(*) was further used to compute the differential cross sections $d\sigma/dx$ and $d\sigma/dp_T$ for these decays, shown by curves in figs 1(a) and 1(b). The sum of these spectra, also drawn on the figures, was subtracted from the experimental data. The resulting difference is represented by the data points on the same figures.

In order to estimate the dominant contribution of $\pi^0 \rightarrow \gamma\gamma$ decay to the remaining spectra, we used a procedure proposed by Elliot et al. [6]. The differential cross section $d\sigma/dx$ was fitted to the following parametrization:

$$\frac{d\sigma(\gamma)}{dx} = \frac{1}{2} \int_{x - \frac{m^2}{4v^2}}^1 (m^2 + v^2)^{-1/2} dv \frac{d\sigma(\pi^0)}{dv} \quad \text{for } x > 0 \quad (2a)$$

$$= \frac{1}{2} \int_{-1}^{x - \frac{m^2}{4v^2}} (m^2 + v^2)^{-1/2} dv \frac{d\sigma(\pi^0)}{dv} \quad \text{for } x < 0 \quad (2b)$$

where v is the c.m. longitudinal momentum of the π^0 , $v = xp_{\text{max}}$ with

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(*) We used the standard version of the Lund Monte-Carlo [5(b)], but with a strange sea suppression factor $\lambda = 0.27$ and with a width of the gaussian transverse momentum distribution of the sea quarks $\sigma = 0.62 \text{ GeV/c}$.

$$\frac{d\sigma(\pi^0)}{dx} = [A + B(x-x_0) + C(x-x_0)^2] \exp[-D(x-x_0) - E(x-x_0)^2] \quad x \geq x_0 \quad (3a)$$

$$= [A + F(x-x_0) + G(x-x_0)^2] \exp[-H(x-x_0) - I(x-x_0)^2] \quad x < x_0 \quad (3b)$$

where A, B...I are free parameters adjusted by the fit.

The fit was performed in the intervals defined by $-0.4 < x_Y < -0.02$ and $0.02 < x_Y < 0.9$, i.e. excluding the very central region. The result of the fit describes the data very well ($\chi^2/ND = 45/52$) in the fitted interval (dashed line on fig. 1(a)). Extrapolating the fitted curve into the region $-0.02 < x_Y < 0.02$, and comparing to the expected $\pi^0 \rightarrow \gamma\gamma$ contribution we note a significant excess of the data, compared to the expected $\pi^0 \rightarrow \gamma\gamma$ contribution.

The difference is shown in more detail by the data points in fig. 2, as a function of x_Y . The excess γ production is seen to occur in a very narrow region, $-0.001 < x_Y < 0.008$, and shows a distinct forward-backward asymmetry.

In this region, the experimental γ cross section above the cut (1) amounts to $(17.7 \pm 0.7)\text{mb}$, the estimated contribution to this cross section from the decays of known hadrons, other than π^0 , is $(0.4 \pm 0.2)\text{mb}$ (the Lund estimate is 0.5 mb) and the cross section arising from π^0 decay equals $(12.9 \pm 0.5)\text{mb}$. Thus the excess γ production in the region $-0.001 < x_Y < 0.008$ is found to be

$$\sigma(\gamma) = (4.5 \pm 0.9)\text{mb}$$

where all errors include a generous allowance for the contribution of systematic errors. Inspection of the curves of fig. 1(a) shows that the observed excess has a narrower x_Y spectrum than those arising from hadron decay, indicating that it is unlikely to be due to unknown hadron decays.

As a first cross-check on the γ -spectrum from π^0 decays, we compare on fig. 3 the experimental π^0 spectrum [1] obtained from $\gamma\gamma$ pairs (open dots) with the fitted π^0 spectrum (full dots) given by (3a) and (3b). The agreement is very satisfactory, as is further evidenced by the values of the π^0 inclusive cross sections, in the region above the cut (1), $\sigma_{\text{tot}}^{\text{exp}}(\pi^0) = 37.2 \pm 1.9 \text{ mb}$ and $\sigma_{\text{tot}}^{\text{fit}}(\pi^0) = 38.7 \pm 0.3 \text{ mb}$.

A second cross check was performed as follows. The experimental π^- -spectrum [7] was weighted by a smooth, adjustable empirical function of x and used instead of (3) in the parametrization (2). The resulting $d\sigma(\pi^0)/dx$ distribution agreed very well with that resulting from the previous fit, yielding a total cross section above the cut (1) of $\sigma_{\text{tot}}(\pi^0) = 37.7 \pm 2.0$ mb.

The latter method was also used to predict the inclusive $d\sigma(\gamma)/dp_T$ spectrum by a simulated $\pi^- \rightarrow \gamma\gamma$ "decay". The result is shown in fig. 1(b) (dashed curve normalized to $\sigma_{\text{tot}}^{\text{fit}}(\pi^0) = 38.7$ mb). The excess of observed γ 's above the predicted curve is concentrated at very small values of p_T ($p_T < 0.06$ GeV/c). To summarize, our results clearly provide evidence for a mechanism of "soft" - low energy - photon emission, not related to electro-magnetic decays of known hadrons.

Following a previous investigation of Goshaw et al. [8] we show on fig 2 the x -spectrum expected from the QED process of inner bremsstrahlung, given by [9]:

$$\frac{d^3\sigma(\gamma)}{d\vec{p}_\gamma} = \frac{\alpha}{(2\pi)^2\omega} \int d\vec{p}_1 \dots d\vec{p}_n \sum_{ij} \frac{-Q_i Q_j (\vec{P}_i \cdot \vec{P}_j)}{(\vec{P}_i \cdot \vec{p}_\gamma)(\vec{P}_j \cdot \vec{p}_\gamma)} \frac{d^{3n} \sigma^h}{d\vec{p}_1 \dots d\vec{p}_n} \quad (4)$$

where $d^{3n} \sigma^h / d\vec{p}_1 \dots d\vec{p}_n$ is the n -charged particle hadronic cross section, Q_i , $\vec{P}_i$ and P_i are respectively the charge, the 3-momenta and the 4-momenta of the particles taking part in the interaction, and ω , $\vec{p}_\gamma$, p_γ the energy, the 3-momentum and the 4-momentum of the emitted γ . The sum in (4) extends over all charged particles (incoming and outgoing). The differential cross section (4) was computed by two methods, using either a grid spanning the photon phase space, or a Monte-Carlo sampling over this space. A truncation was made for the cut (1), thus excluding the very soft γ 's which escape detection. The value of the total γ cross section from (4) is very sensitive to this cut. In the calculation, the integration over the hadronic cross section is replaced by a sum over all the measured events. In practice, the calculated cross section and spectra turn out to be very insensitive to the structure of the hadronic cross section: since the bremsstrahlung γ 's are soft and of long wavelength as compared to the size of the interaction region, their production properties are insensitive

to details of the hadronic process^(*). The total cross section for inner bremsstrahlung in the $-0.02 < x < 0.02$ and $-0.001 < x < 0.008$ regions is found to be 1.85 and 1.1 mb respectively, using cut (1). These values are confirmed by an analytic integration of (4) as shown in [10].

The shapes of the predicted x (fig. 2) and p_T spectra (not shown) are in good agreement with the data. However, the experimental value of the total cross section is hardly compatible with the predicted one. The experimental points systematically lie above the predicted values, thus not excluding the possibility that other, unknown processes also contribute to the production of soft photons. No evidence for an excess of soft photons above the QED prediction was found in π^+p interactions at 10.5 GeV/c [8], but excesses of virtual photons, observed as e^+e^- and $\mu^+\mu^-$ pairs, were detected in several experiments, with values of invariant masses exceeding those expected from QED processes [11].

We are grateful to the operating crews of the SPS accelerator, RF separated beam and BEBC for their diligent efforts during this experiment. It is a pleasure to acknowledge the work of our scanning and measuring staff at our respective laboratories. Part of the data were collected and processed by our collaborators at Genova and Nijmegen. We thank them also for valuable discussions. We further wish to thank D. Lissauer and W. Willis for indicating to us the experiments published as refs [8] and [11]. We acknowledge valuable discussions with S.S. Gerstein and G. Ingelman, and the assistance of the latter for computations using the Lund model.

(*) Almost identical soft photon spectra were obtained in a calculation replacing the measured events by events generated according to the Lund model [5]. The spectra obtained with a constant value for the last two factors in (4) (mere photon phase space) are qualitatively similar.

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FIGURE CAPTIONS

- Fig. 1 Lower curves: (a) $d\sigma/dx_\gamma$ and (b) $d\sigma/dp_T$ for inclusive γ production predicted by the Lund model for the non- π^0 decays of known hadrons and normalized to the measured semi-experimental cross sections (see text). Points (with error bars): experimental spectrum, after subtraction of the above contribution. Dashed upper curves: fits for π^0 decay described in the text.
- Fig. 2 The $d\sigma(\gamma)/dx$ spectrum remaining after subtraction of all known hadron decays (dots). The curve is the predicted spectrum of inner bremsstrahlung.
- Fig. 3 The $d\sigma(\pi^0)/dx$ spectrum obtained from: $\gamma\gamma$ pairs (open dots); fit to the single γ spectrum described in the text (full dots).

Fig. 1a

Fig. 1b

Fig.2

Fig. 3