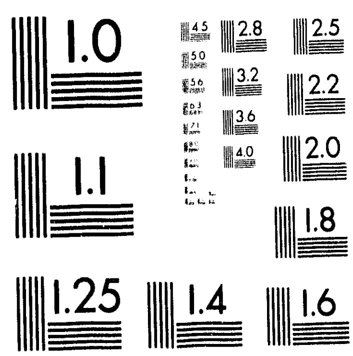
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BNL-49453

submitted to the Proceedings of Quark Matter '93
Borlange, Sweden, June 20-24, 1993

Low p_T Photon Production in Proton-Nucleus Collisions at 18 GeV/c.

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Abstract

The inclusive single photon spectrum has been measured in the p_T range from a few MeV/c up to approximately 1 GeV/c at several rapidities in the interval from $-2.1 < y_{cm} < +0.5$ in 18 GeV/c proton-beryllium and proton-tungsten collisions at the Brookhaven AGS. The measured photon distributions are compared with the expected distribution of photons from π^0 decays and hadronic bremsstrahlung in a search for new sources of "soft" photons at low transverse momentum.

1. Introduction

Photon production at very low p_T ($\sim$ few MeV/c) has been a subject of considerable interest in recent years. Several experiments have observed the level of photon production at low p_T to exceed that expected from hadron decays and hadronic bremsstrahlung [1, 2, 3], while others have reported no significant signal other than from conventional sources [4, 5, 6]. The results reported on here were obtained from AGS Experiment E855 carried out at Brookhaven National Laboratory during the spring of 1990. The experiment was designed to measure photon production in the p_T range from a few MeV/c up to several GeV/c in proton-nucleus collisions at 18 GeV/c, and was the first dedicated experiment to study this phenomenon at lower beam energies. Some of the detectors and analysis techniques employed were similar to those used in ref. [4], which measured low p_T photon production in pBe collisions at 450 GeV/c.

*Research supported by the U.S. Department of Energy.

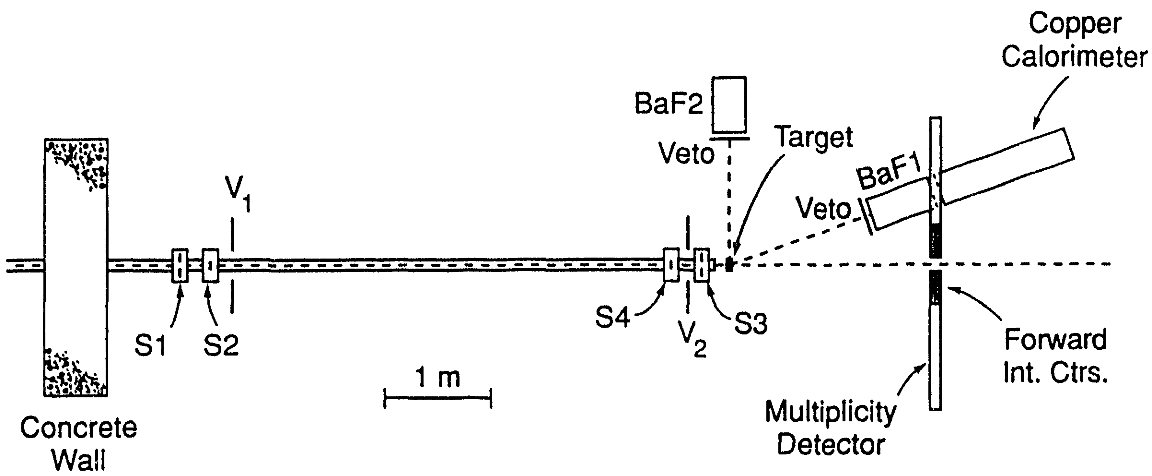

Figure 1: E855 Experimental layout.

2. Experimental method

Figure 1 shows the layout of detectors deployed within the E814 heavy ion spectrometer. Two barium fluoride arrays, BAF1 and BAF2, measured photons over a large rapidity and p_T range. The detectors were arranged in an open geometry around the target in order to minimize production of low energy photons from secondary interactions in surrounding material. The detectors were located approximately 1.4 meters from the target and were moved to various angular positions to cover a large range of pseudorapidities. Detector BAF1 covered the rapidity range from y_{cm} = +0.5 to -1.0, and detector BAF2 covered the rapidity range from -1.3 to -2.1. Thin plastic scintillation counters were placed in front of both BAF detectors, and were used in the offline analysis to veto against charged particles. Each detector consisted of 19 BaF_2 crystals that were read out with fast, quartz window photomultiplier tubes to provide good time-of-flight resolution ($\sigma_{TOF} \leq 400$ ps). The TOF measurement was used to reject photons not originating from the target and low energy neutrons hitting the detectors. A four interaction-length deep hadron calorimeter located behind BAF1 at $y_{cm} = 0$ measured energy leaking out of the back of the barium fluoride array and was used to discriminate against high energy neutrons.

A large array of plastic scintillation counters, covering the rapidity range $-0.5 < y_{cm} < +0.5$ and an azimuthal range of approximately 300 degrees, was used to trigger on central collisions and to provide a measure of the overall charged particle multiplicity. A valid photon trigger required the energy deposited in either BAF1 or BAF2 to be greater than a certain threshold, which was typically ≤ 10 MeV ($p_T \sim 3$ MeV/c at $y_{cm} = 0$). In the offline analysis, the maximum energy was required to be within one of the seven central crystals in order to minimize the effects of side leakage and interactions in the material surrounding the crystals. The data were corrected for geometrical acceptance, trigger efficiency, empty target subtraction, and the probability of accidental charged particle overlap. The effects of energy and position resolution, energy leakage and photostatistics were studied and determined to be negligible.

3. Determination of hadron decay photons

In order to estimate the contribution of hadron decays to the measured photon spectra, it was assumed that all photons in the p_T range 50-400 MeV/c are due to π^o decays. It was determined from the LUND Monte Carlo [7] that other sources of photons (η, η', ω and Σ^o) make a negligible contribution in this p_T region. A fitting procedure was then used to determine the π^o rapidity and p_T distributions from the inclusive photon spectra measured at different rapidities. The π^o distribution was parameterized in terms of lab rapidity and p_T in the following form:

$$f_{\pi^o}(y,p_T) = a_1 \cdot p_T \cdot exp[-(a_2 + a_4|y-y_o|^3) \cdot m_T] \cdot exp[-(y-y_o)^2/(2 \cdot {a_3}^2)].$$

The fit used the measured and fully corrected inclusive photon dN_γ/dp_T and dN_γ/dy distributions as input, and took into account the kinematics of the $\pi^o \rightarrow \gamma\gamma$ decay. The parameter y_o, which was held fixed, corresponded to the laboratory rapidity value of the measured peak of the dN_γ/dy distribution (note $y_{NN}^{lab} = 1.83$). Table 1 gives preliminary values of the fitted parameters, along with y_o, of f_{π^o} for the pBe and pW data. The results of the fit were then used to extrapolate the inclusive photon spectra from π^o decays to low p_T, and the extrapolation was compared with the data at various rapidities. Although this method is not a true deconvolution procedure, it does allow a determination of the global π^o distributions, and the number of photons from π^o decays at low p_T, from the *measured* photon data at higher p_T.

Parameter	pBe	pW
a_1	arbitrary	arbitrary
a_2	8.22	8.84
a_3	0.99	1.03
a_4	0.31	0.40
y_o	1.35	1.19

Table 1: Preliminary values for the parameters of the π^o distribution function f_{π^o}.

The results of the fit for the π^o rapidity and p_T distributions and the resulting photon distributions were checked against various Monte Carlos, as well as against other data. It was found that the rapidity distribution for the decay photons was nearly the same as for the parent π^o's, and is well described by a gaussian with a $\sigma \approx 1$. Figure 2 shows our measured photon dN_γ/dy distribution and the fitted gaussian π^o distribution, compared with the rapidity distributions for π^+ and π^- measured in pBe collisions by the E802 collaboration [8]. Our measured photon p_T distributions also agree well with the predictions of LUND and ARC [9].

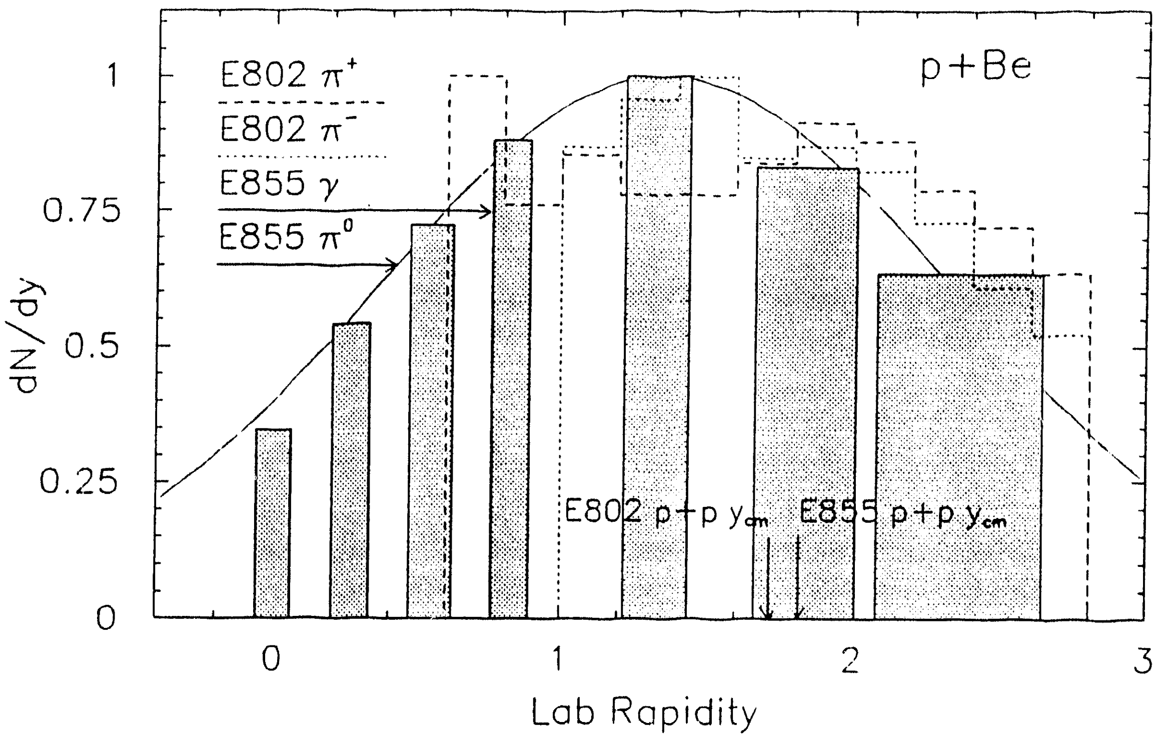

Figure 2: Measured photon and π^o rapidity distributions for pBe data compared with distributions for π^+ and π^- measured by ref. [8].

4. Bremsstrahlung

In the low energy limit, photon production due to the initial hard scattering of the projectile in the target is dominated by the external radiation of photons from the produced charged particles. This result is given by the Low Theorem [10], which states that any contributions due to internal scattering and radiation vanish in the soft photon limit, and implies that the production of photons with $\lambda \gg c\tau$ is highly suppressed. The bremsstrahlung spectrum resulting from the produced charged particles can be computed using classical formulas *if* the distribution of these particles is completely known. However, this is *not* the case in our experiment, so we must rely on a Monte Carlo calculation to give us the charged particle spectrum.

The LUND Monte Carlo program was used to generate the distribution of charged particles, which was then used to compute the bremsstrahlung photon spectrum. The bremsstrahlung cross section is given by:

$$\frac{d^3\sigma_\gamma}{dy\,dp_T\,d\phi} = \frac{\alpha}{4\pi^2}\frac{1}{p_T} < -J_{EM}(k) \times J_{EM}(k) >$$

where $J_{EM}(k)$ is the four-vector charged current propagator, summed *coherently* over all incident and outgoing charged particles, for an emitted photon of momentum k, in the limit as the photon energy goes to zero. This quantity was used to compute the ratio of bremsstrahlung photons to π^o decay photons as a function of rapidity and p_T for LUND events satisfying the same trigger conditions as the actual data. This ratio was then taken to be the ratio of bremsstrahlung photons to π^o decay photons in the data. The

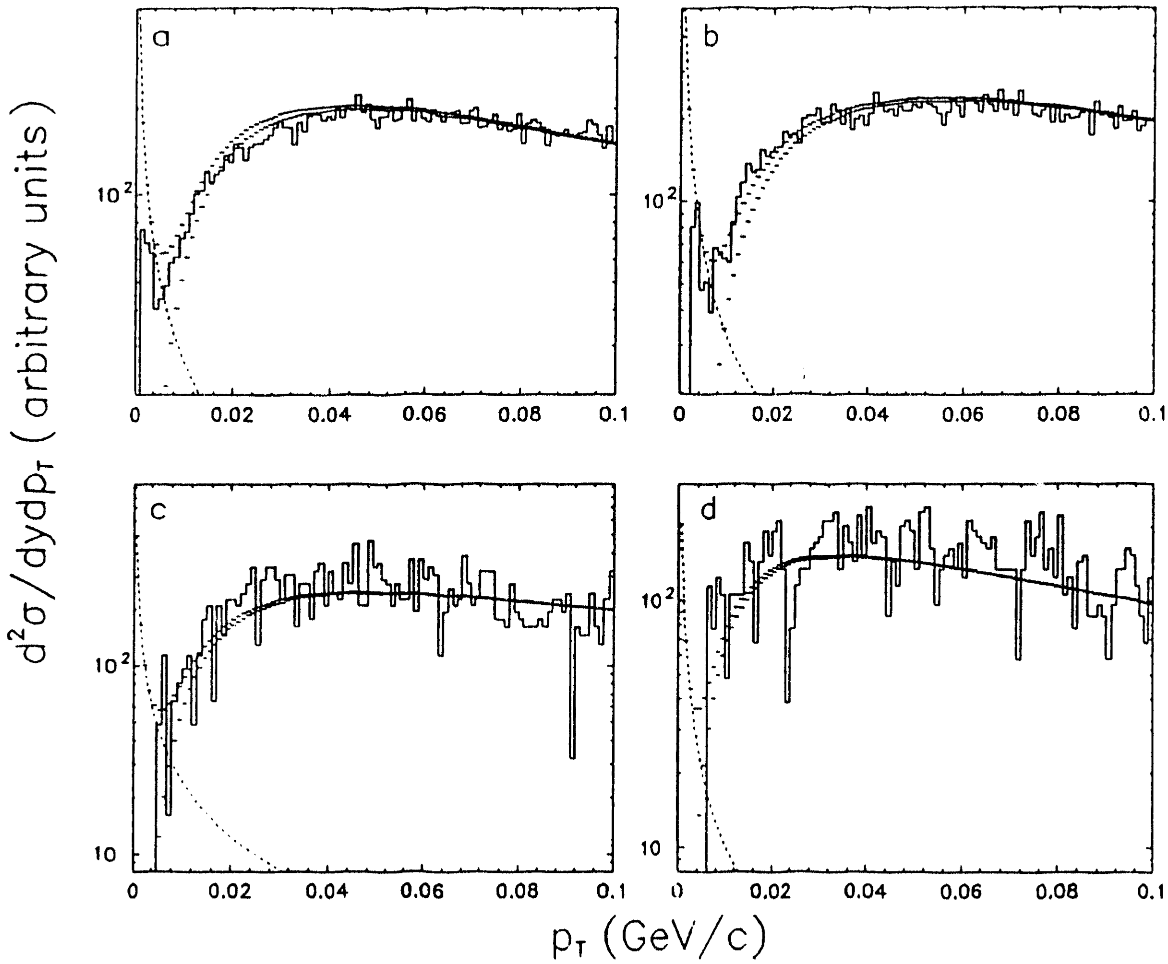

Figure 3: Photon p_T distributions for pBe data (solid curve) compared with π^o decay contribution derived from fit (lower dashed curve), estimated bremsstrahlung yield (dotted curve), and sum of both contributions (upper dashed curve). a: $y_{cm} = +0.5$, b: $y_{cm} = 0$, c: $y_{cm} = -1.28$, d: $y_{cm} = -1.83$.

bremsstrahlung yield was also computed assuming a spontaneous creation of charge at $t = 0$ (*e.g.*, like β-decay), and using an average value approximation method [11], which is valid for $y_{cm} \approx 0$. All three methods were found to agree within approximately 45%.

5. Comparison of data with known sources of photons

Figure 3 shows the measured photon p_T distributions for the pBe data at several rapidities, compared with the π^o decay contribution derived from the fit at high p_T, and the estimated bremsstrahlung yield computed using the method described above. The data are described well by the contribution from π^o decays and hadronic bremsstrahlung in the low p_T region. The data at the other rapidities show essentially the same result. Therefore, we conclude there is no significant excess in the photon yield at low p_T above the contribution from known sources in the pBe data. This result is also consistent with the recent results from the HELIOS collaboration for pBe interactions at 450 GeV/c [4].

It should be noted that photons resulting from hadronic bremsstrahlung from particles produced in the primary interaction are not the only source of low p_T photons that can be observed experimentally. Other processes can produce photons at low energies, such as secondary interactions in the target and surrounding material, as well as nuclear gamma rays resulting from the decay of excited nuclear target fragments. These effects are significant for the tungsten data, but they have not yet been thoroughly studied in our present analysis. Therefore, it is not possible to give a detailed comparison of the pW data with the expected contributions of photons from these various sources in the low p_T region of the photon spectrum at the present time.

6. Conclusions

The inclusive photon spectra have been measured as a function of p_T at several rapidities in pBe and pW collisions at 18 GeV/c. Photon production for $p_T \geq 50$ MeV/c is dominated by photons from π^o decay, and the shape of the measured p_T spectrum agrees well with that expected from π^o production. Photon production at very low p_T ($\leq$ 10 MeV/c) has a significant contribution due to bremsstrahlung generated by secondary charged particles produced in the collision. The measured photon spectrum in the region from a few MeV/c up to $\sim$ 50 MeV/c in pBe collisions agrees with what is expected from π^o decays and hadronic bremsstrahlung, and there is no significant evidence for anomalous photons from unknown sources in the pBe data at 18 GeV/c. This result is consistent with the results of ref. [4] for pBe interactions at 450 GeV/c. Since a number of secondary processes that could affect the results for the pW data have not yet been fully understood, no conclusion can be made about an excess of soft photons in the pW data at this time. However, the analysis of these data is continuing and the results will be forthcoming.

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