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WA93 collaboration

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Soft Photon Production in Central 200 GeV/Nucleon ^{32}S + Au Collisions

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Inclusive photons down to low transverse momenta have been measured in 200 GeV/nucleon ^{32}S+Au collisions at the CERN SPS. Data were taken in the WA93 experiment using a small acceptance BGO detector with longitudinal segmentation. The results are compared to WA80 measurements for the same system and results from hadron decay calculations.

I. INTRODUCTION

The production of photons in ultrarelativistic heavy ion collisions is of special interest because electromagnetic radiation from the hot system created in such reactions can leave the reaction volume undisturbed by hadronic interactions. Such *direct* photons may yield information from the early dense phase of the reaction. Direct photon measurements can provide constraints on the initial temperature and lifetime reached in these collisions. In order to disentangle a possible surplus of direct photons on top of the overwhelming photon background from hadronic decay photons, a careful study of the inclusive photon spectrum is mandatory. This analysis will provide insight into the various sources of hadronic decay background.

Limits on direct photons in 200 GeV/nucleon ^{32}S + Au collisions have recently been published by the WA80 collaboration [1]. In the WA80 experiment photons have been measured with a lead glass calorimeter, which has natural limitations for the measurement of low energy photons because the detection process relies on the Cherenkov effect.

Therefore a small detector using BGO scintillating crystals has been developed for the WA93 experiment. It consists of an 8×8 matrix of 64 crystals each with a cross section of $25 \times 25\,\mathrm{mm}^2$ (approx. 1 Molière radius) and a length of 250 mm (22 radiation lengths). Part of these crystals (35) are longitudinally segmented (70 mm + 180 mm), which yields additional information about the longitudinal shower development and thus improves the hadron rejection particularly at low incident energies. The light from the crystals is detected by two PIN-photodiodes (four in the case of segmented crystals), which are readout via custom designed preamplifiers, shaping amplifiers [2] and commercial

ADCs. The detector is embedded in a sophisticated temperature stabilization system, ensuring a stability of better than 0.1 K. A Xenon flasher and an electronic pulser are used to monitor the signal of each readout channel. Details about the detector can be found in [3].

This detector was constructed to explore the use of a scintillation detector to improve the photon detection performance in heavy ion reactions. It was used successfully in the WA93 experiment to measure inclusive photon spectra. In this paper we present the results obtained for the most central 800 mb ($\approx$ 22 %) of the 200 AGeV ^{32}S + Au cross section. The centrality selection was performed via the transverse energy measured with the Mid-Rapidity Calorimeter [4].

II. ANALYSIS

The WA93 experiment is a successor of the WA80 experiment and is described in detail in [5]. The setup has been enlarged by adding the Photon Multiplicity Detector [6] and a magnetic spectrometer for negative particles which consists of the magnet GOLIATH and 4 multi-step avalanche chambers [7]. Furthermore the BGO detector has been added. It covers the pseudorapidity range between 2.35 and 2.45 and a range of approx. 7° in azimuth, and is positioned at a distance of 10 m from the target.

The energy signals from the detector are processed by a clustering algorithm, which identifies hits and calculates their characteristics. It also allows to separate overlapping hits, when they are not closer then 1.8 module units [3].

The depth of the detector corresponds to little more than 1 hadronic interaction length. Therefore charged hadrons are effectively suppressed in this detector, since they have low probability of producing a shower. However, at low energy depositions the separation of photons and charged hadrons is problematic, because minimum ionizing charged particles may be misidentified as low energy photons. In this study the identification of photons was performed with two different techniques:

1. the analysis of the lateral dispersion, which is significantly smaller for electromagnetic as compared to hadronic showers (*dispersion method*) [8] and
2. the analysis of the longitudinal depth of the energy distribution, which differs considerably for minimum ionizing particles and hadron showers on one hand and electromagnetic showers with equivalent energy deposit on the other hand (*forward/total method*) [3].

Whereas the first method has been successfully used with the lead glass detectors in WA80, the second one can only be applied for a detector which is longitudinally segmented. Especially for lower energies this method drastically improves the photon identification. The lateral segmentation into small modules results in a good separation of neighboring hits and a good position resolution. Moreover, the excellent energy resolution, one of the major advantages of the BGO detector compared to e.g. a lead glass detector, combined with the longitudinal segmentation leads to superior identification capabilities.

While the two-particle separation power of the detector is good owing to its high granularity, there still is a finite probability of an overlap of particles due to the high particle densities in our experiment. This can result in the loss or misidentification of particles. So special care has to be taken to investigate the detection efficiency as a function of the particle density.

To study the detection efficiency, the GEANT [9] simulation package has been used to create artificial signals for the BGO modules corresponding to different particles hitting the detector. In total, ca. 30000 charged pions and ca. 40000 photons have been simulated with a uniform transverse momentum distribution. The momentum distributions have then been weighted according to the corresponding particle distributions obtained from VENUS 3.11 [10]. This event generator is known to reproduce fairly well the spectral shape of the produced particle spectra.

The signals can then be analyzed with the same analysis programs as the real data. These simulated particles have to be studied in a realistic particle density environment, which has been done by a superposition onto real measured events. In this way also effects of the detector noise are treated correctly.

However, adding a single simulated shower in a small acceptance detector already causes a significant change of the effective local particle multiplicity. To study particle density effects the signals have been superimposed onto measured central ^{32}S + Au reactions and onto empty events, which only contain the detector noise. From an extrapolation of the detector acceptance to 2π in azimuth one can see, that these two cases effectively correspond to average hit multiplicities of $\approx$ 150 and $\approx$ 50 respectively, while the real central events show a multiplicity of $\approx$ 100. A good estimate of the detection efficiency can therefore be obtained from an interpolation between the two cases studied using the simulated data. The difference in the number of detected photons for these two cases is below 20 % for most of the momentum range and reaches 30 % only for $p_T \leq 100\,\mathrm{MeV}/c$.

From the simulation we have in this way obtained the probabilities that

1. a photon is correctly identified and

2. a hadron is erroneously identified as a photon.

These probabilities are used to correct the measured distributions. The photon efficiency is above 80 % for most of the p_T range. The hadron contamination is on the level of a few % at medium and high p_T and reaches values of 50-70 % in the lowest p_T bin.

To estimate the systematic errors in the particle identification and efficiency correction, this study has been performed for different identification criteria, namely by applying

1. only the dispersion method and

2. a combination of the dispersion method and the forward/total method.

Figure 1 shows the photon transverse momentum distribution for the two methods after correction. The ratio of the two distributions is displayed in the inset. The corrected spectra show a reasonable agreement with deviations of < 10 % for most of the transverse momentum range, although the two uncorrected spectra are significantly different. Only for very low p_T the deviation is of the order of 20 %. While the cross sections will be taken as the weighted mean of these two results, the deviations yield a good estimate of the systematic error of the photon reconstruction efficiency.

III. RESULTS AND DISCUSSION

Figure 2 shows the cross section of inclusive photons for central reactions of 200 AGeV S + Au as a function of the transverse momentum. The data show the expected fall-off, which is only approximately exponential in this representation. Data from WA80 are included for comparison [1]. In the region of overlap both data sets are in good agreement. However, this measurement enlarges the p_T-range of the photon measurement down to very low values with a high accuracy.

One can compare the low p_T cross section of inclusive photons with the expectation from hadron decays. For this purpose we have taken π^0 spectra measured by WA80 [11] for ^{32}S + Au and calculated the decay photons from π^0, η, η' and ω, where m_T-scaling following the method used in [1] was applied for the heavier mesons. Below $p_T = 0.4$ GeV/c the π^0 spectrum has been extrapolated with an exponential in m_T of inverse slope parameter $T = 210$ MeV. The decay photon spectrum has been normalized to the measured distribution for $p_T = 0.5$ GeV/c. The result is included in figure 2 as a solid histogram (simulation 1). While the shape of the inclusive photon spectrum is well described by the decay photons for $p_T > 0.5$ GeV/c, the measured photon yield deviates from this prediction for lower transverse momenta - the measured yield is significantly larger.

However, also in the WA80 pion spectra there is an indication of an excess over the fitted function for the lowest p_T bin. We have therefore tried a modified function which includes a second exponential in m_T. This function fits the experimental π^0 spectra very well with an additional slope of $T_2 = 100\,\text{MeV}$[1] [11]. The additional component represents almost 50 % of the total integrated yield in the spectrum. The result of the simulation using this function is displayed as a dashed histogram (simulation 2) in figure 2. This simulation describes the data much better, but still the measured photons for $p_T \leq 68\,\text{MeV/c}$ exceed the simulation by almost a factor of three. While there is some uncertainty related to the determination of the low p_T shape of the pion spectrum, which is very much influenced by resonance production, it is unlikely that the large excess can be fully explained by a change in the pion spectrum. Additional mechanisms which may contribute at low p_T, e.g. the γ-decay modes of resonances (Δ, Σ) or contributions from Bremsstrahlung, have to be investigated. One should also note that an uncertainty in the charged hadron/neutral pion ratio in the simulations would translate to an uncertainty in the low p_T region of the photon spectrum, because there the hadron contamination is largest. To fully explain the photon excess observed here, one would however need to assume an increase of the charged hadron yield relative to the neutral pion yield by about a factor of 4-5.

One can extract the average transverse momentum of the photons from the distribution of dN/dp_T (see figure 3), where a value of $\langle p_T \rangle = 149 \pm 12\,\text{MeV/c}$ is obtained[2]. Figure 3 exhibits a more exponential behavior than the previous figures, which allows to fit the photon spectrum with an exponential leading to an inverse slope parameter of

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[1] This fit parameter is almost entirely determined by the π^0 yield in the lowest p_T bin.

[2] The error is dominated by the systematic errors from the efficiency and from binning effects.

$T = 172 \pm 10$ MeV. The difference between the slope and the average p_T is mainly due to the deviation of the lowest data point from the exponential shape.

To summarize, inclusive photon spectra have been measured for $p_T < 1$ GeV/c in central ^{32}S + Au reactions with a small acceptance BGO detector. The complementary photon identification possibilities from both the dispersion method and the forward/total method allow to study the photon production down to very low transverse momentum. The assumption of an exponential shape of meson spectra at low m_T with an inverse slope of $T = 210$ MeV fails to reproduce the spectral shape of the photons. A second component of $T = 100$ MeV improves the description but fails for the lowest p_T.

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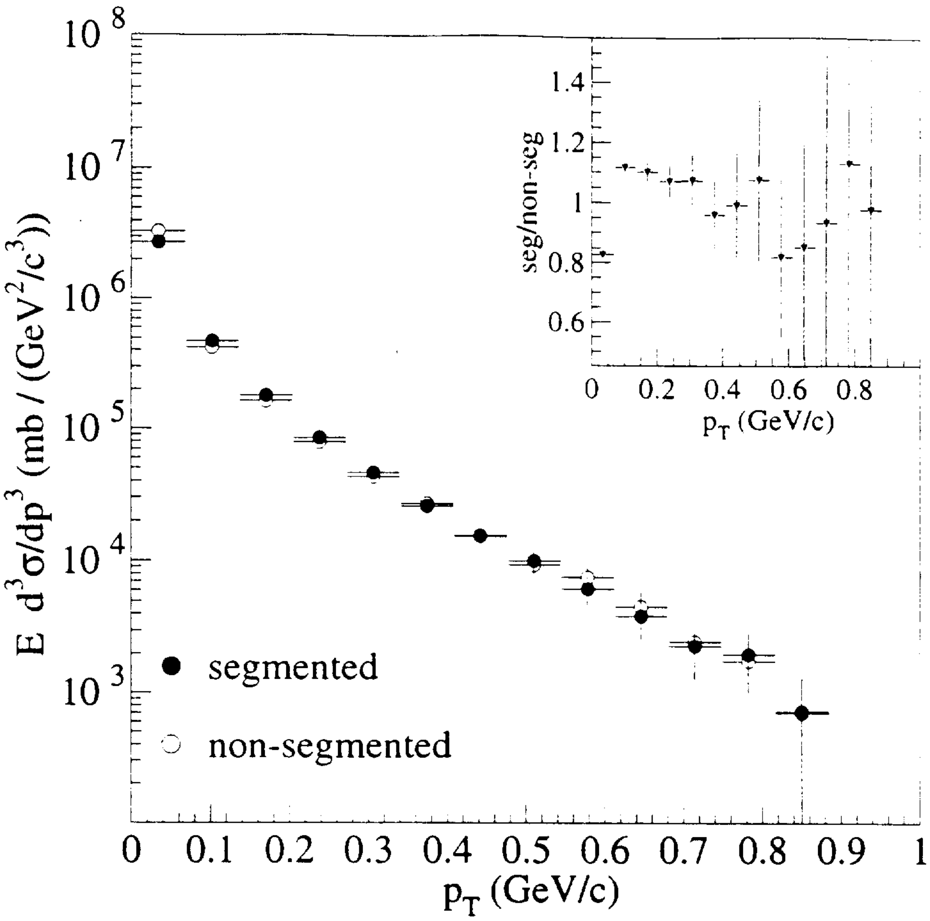

FIG. 1. Photon transverse momentum distributions after correction for efficiency. The filled circles shows the distribution obtained with the dispersion method and the forward/total method combined, the open circles show the results obtained by using only the dispersion method. In the inset the ratio of the two distributions is displayed

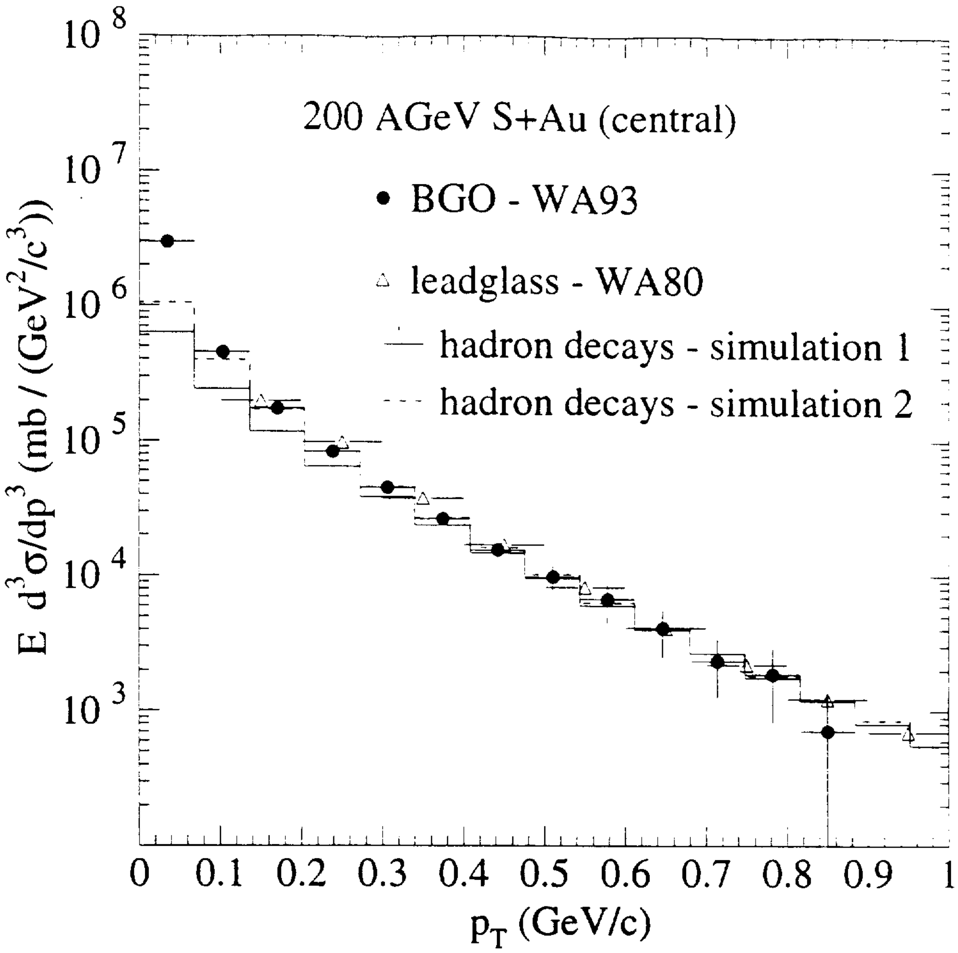

FIG. 2. Invariant cross section of inclusive photons for central reactions of 200 AGeV S + Au as measured with the WA93 BGO detector (filled circles). Also shown are data from the WA80 lead glass detector for a similar centrality selection (open triangles). In addition, the histograms show results from a simulation of hadron decays normalized to the data for $p_T = 0.5$ MeV/c (see text).

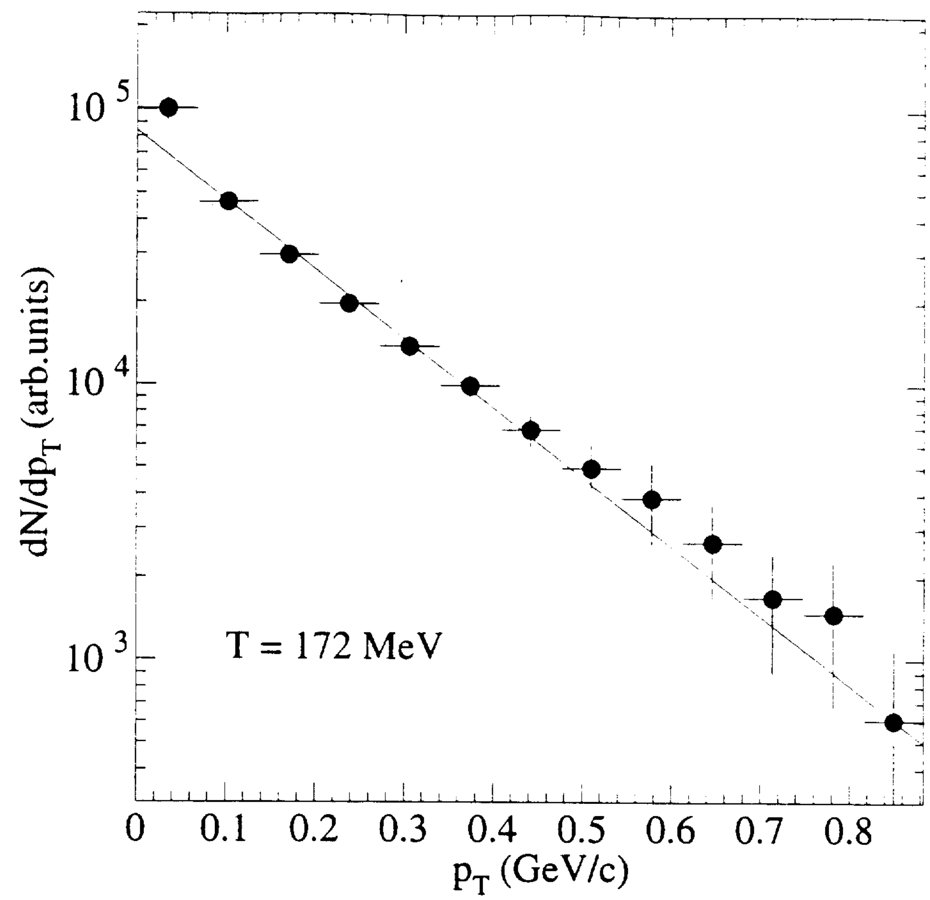

FIG. 3. Transverse momentum spectrum of inclusive photons for central reactions of 200 AGeV S + Au as measured with the WA93 BGO detector. The data are fitted with an exponential (solid line).