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INVESTIGATION OF DIRECT PHOTON PRODUCTION IN 200 A GEV S + AU REACTIONS

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ABSTRACT

Direct thermal photons in the p_T range of 0 – 5 GeV/c are expected to provide a sensitive probe of the early conditions of the Quark Gluon Plasma which may be formed in relativistic heavy ion collisions. The production of single photons in 200 A GeV S+Au reactions has been investigated using the 3800 element Pb-glass calorimeter of CERN experiment WA80. Neutral π^0 and η cross sections have been measured via their two-photon decay branch yields. The measured π^0 and η cross sections have been used to calculate the expected inclusive yield of decay photons. Excess photon yield, beyond that attributed to radiative decays and background sources, may be associated with thermal photon emission. Excess, "direct" photon yields have been extracted from high-statistics S+Au photon data for different event centrality classes. A slight excess photon yield above that which may be accounted for by hadronic decays was observed for central events.

1. Introduction

Directly radiated thermal photons have long been considered an interesting penetrating probe with which to study the early phase of the hot and dense matter produced in relativistic nucleus-nucleus collisions.¹⁾ It is hoped that thermal photon emission should provide information about the initial conditions of the system and thereby provide evidence for the possible formation of a Quark Gluon Plasma (QGP).

A major emphasis of the WA80 experiment has been to search for direct thermal photon production in nucleus-nucleus collisions. First results from WA80 found a slight photon excess in central collisions of $^{16}\text{O} + \text{Au}$ at 200 A GeV which, however, was within rather large experimental errors, and hence not significant.²⁾ For the case of $^{32}\text{S} + \text{Au}$ reactions the direct

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photon sensitivity of WA80 has been improved by many factors³⁾ including an increased data sample, an increased detector coverage, a coverage closer to mid-rapidity, and improved analysis techniques, as well as the improvement expected due to the increased projectile mass. For the S run period of WA80, photons have been measured in a 3800 element Pb-glass array which covers 60% of the azimuth in the rapidity range from 2.1 to 2.9. The total data sample of $8 \cdot 10^6$ S+Au events has been analyzed for the results presented here.⁴⁾ The WA80 S+Au minimum bias cross section is 3600 mb. All results presented here have been corrected for geometrical acceptance and reconstruction efficiencies but should be considered preliminary as possible sources of systematic error, primarily efficiencies, are still under study.

2. Production of Neutral Mesons

In order to search for single direct photon radiation, it is first necessary to accurately determine the much more abundant photon production from radiative decays, predominantly those of the π^0 and η mesons. For this reason, it is necessary to measure the π^0 and η cross sections in the same p_T and rapidity region over which one wishes to search for direct photons. This is done by extracting the π^0 and η yield as reconstructed from their two-photon decay branch from their mass peaks in the two-photon invariant mass distributions. In the search for thermal photon radiation in relativistic heavy-ion collisions, it is the p_T region below 5 GeV/c which is of primary interest. Unfortunately, due to the large photon multiplicity in high-energy heavy-ion reactions (up to 30 photons in the WA80 Pb-glass detector in central S+Au interactions), a large number of false combinatorial pairs will be taken in the two-photon invariant mass distribution, with the result of very low peak-to-background ratios in the π^0 and η mass regions. However, through the application of an event-mixing technique⁵⁾, similar to that used in Hanbury-Brown-Twiss type analyses, it is possible to reconstruct the combinatorial background and accurately extract the π^0 and η yield, even with peak-to-background ratios as low as 0.002. The results are mainly limited by the statistical significance of the peak above the combinatorial background.

The π^0 cross sections as a function of transverse momentum are shown in Fig. 1 for central and peripheral events from S+Au reactions at 200 GeV/nucleon. Note that the measured results extend over seven orders of magnitude. The transverse momentum spectra are best described by a power-law dependence on p_T , but may be well described over a limited p_T region by an exponential form. Such limited exponential fits are indicated in Fig. 1, together with the corresponding slope parameters, to provide a comparison between the central and peripheral π^0 p_T slopes. It is observed that the π^0 p_T slope increases by about 10% between the peripheral and central event classes.

The higher-statistics data and improved combinatorial background evaluation make it possible for the first time to extract η -meson p_T distributions in nucleus-nucleus collisions.⁵⁾ In Fig. 2 the measured η cross section is compared to the π^0 cross section, plotted as a function of the transverse mass, $m_T = \sqrt{m^2 + p_T^2}$, for minimum bias reactions of S+Au and of S+S. The solid lines are the results of power-law fits to the π^0 m_T -distributions with the form $A \cdot [\beta/(\beta + m_T)]^\alpha$. The dotted curves show the same power-law form renormalized to fit the η m_T -distributions. The present results are consistent with the conclusion that the η production cross section has the same functional form as the π^0 cross section when plotted as a function of m_T . The ratio of the normalizations of the m_T -distribution fits shown in Fig. 2 are $\eta/\pi^0 = 0.61$ and 0.51 for S interactions on Au and S, respectively. We conclude that m_T -scaling of η production in nucleus-nucleus collisions is consistent with the phenomenological m_T -scaling previously established in hadron-hadron and hadron-nucleus reactions.⁶⁾ In order

to estimate the photon decay background we will make use of this conclusion to extrapolate the η p_T distribution into unmeasured regions and also to estimate the distributions for other unmeasured hadrons which give small additional photon decay contributions.

Fig. 1: Neutral π^0 transverse momentum distributions for 200 A GeV $^{32}\text{S}+\text{Au}$ reactions for the most central 25% of the minimum bias cross section and for the most peripheral 30% of the minimum bias cross section. The curves indicate exponential fits over the p_T range 0.4 – 2.0 GeV/c with fitted slope parameters indicated.

Fig. 2: Neutral π^0 and η transverse mass distributions for minimum bias reactions. The solid curves represent fits to the π^0 m_T -distributions (see text) with $\beta = 6.85(7.65)$ and $\alpha = 37.3(41.7)$ for interactions on Au (S). The fitted results for the η , shown by the dotted curves, are assumed to scale with the same β and α parameters. The ratio of the η/π^0 normalization factors are 0.61 and 0.51 for interactions on Au and S, respectively.

3. Yields of Single Photons

The determination of the yield of single photons in nucleus-nucleus collisions is the primary goal of the WA80 experiment, since this yield may be related to the possible production of the QGP. Single “direct” photons are expected at high p_T from well-known had and QCD processes, but also possibly from thermal radiation from the QGP and/or from a hadron gas in the p_T region below several GeV/c.¹⁾ The dominant elementary production processes are quark-gluon Compton scattering and to a lesser extent quark-antiquark annihilation. In the low-temperature hadron phase, the photon production is dominantly via the $\pi^+ + \pi^- \rightarrow \gamma + \rho^0$ and $\pi^\pm + \rho \rightarrow \gamma + \pi^\pm$ processes.

In the WA80 experiment, the direct photon excess is determined on a statistical basis. The inclusive photon yield for a particular event class is extracted, and the inclusive photon yield expected from radiative decays of long-lived resonances for the same event class is calculated via simulation. The direct photon excess is then determined from the difference of

the measured and simulated distributions. The input to the simulation calculation is based on the measured WA80 cross sections for the π^0 and η mesons, and estimates (based on production rates taken from the literature and m_T -scaling) of the contributions from the decay of nonreconstructed mesons, such as ω , η' , and K_0 (the total contribution from the decay of nonreconstructed mesons is estimated to be less than 2% of that of the π^0 and η contributions). It is instructive to first study the γ/π^0 ratio since the dominant source of photons are those arising from π^0 decay and therefore the π^0 yield sets the scale for the sensitivity of the direct photon search.

Fig. 3: The inclusive γ/π^0 ratio for central and peripheral interactions of 200 A GeV S+Au. The open points indicate the experimental results while the histograms indicate the ratio expected from long-lived radiative decays. The errors on the experimental and simulation results include separate statistical and estimated systematic errors.

Fig. 4: The ratio of the excess photon yield, which cannot be attributed to long-lived radiative decays, to the inclusive π^0 yield for central and peripheral interactions of 200 A GeV S+Au. The errors shown include all statistical and estimated systematic errors of the experimental and simulation results.

Preliminary γ/π^0 ratios are shown in Fig. 3 as a function of p_T for central and peripheral events from S+Au reactions at 200 GeV/nucleon. The circles indicate the inclusive photon yield, and the histograms show the yield which can be accounted for by hadronic decays based on simulation. The errors shown on the experimental points and simulation results are the quadratic sum of the statistical errors and all estimated sources of systematic errors. The systematic errors on the data include those for γ and π^0 reconstruction efficiencies (including estimated uncertainties of the combinatorial background subtraction), geometrical acceptance, and detector non-linearities. The systematic errors on the simulation results include the estimated uncertainties on the η/π^0 ratio and the form of the m_T -scaling distribution, on the production rates of the unmeasured hadrons which contribute additional radiative decay photons, and extrapolation of the hadron distributions to phase-space regions outside of the region of measurement.

. The results of Fig. 3 are presented again in Fig. 4 but with the simulation results subtracted from the measured γ/π^0 ratio. The errors shown are the quadratic sum of all sources of error in the experimental and simulation results. Note that the errors are in the range of 6–8% in the p_T range of 0.3–2. GeV/c, which corresponds to nearly a factor of 2 improvement over the published WA80 O+Au results.²⁾ A small excess of photons (over those which can be attributed to hadronic decays) is observed in central collisions with a significance at about the 2σ level. However, within errors, no excess is observed in peripheral collisions. The fact that the central and peripheral data have been measured and analyzed under identical circumstances and that no excess is observed in peripheral collisions, for which photon emission is not expected to be important, suggests that the sources of systematic error are basically under control. However, it is important to note that other centrality-dependent effects might yet be responsible for the observed excess in central events. In particular, due to the large particle multiplicities in central collisions, the photon and π^0 reconstruction efficiencies are dependent on the event centrality, and therefore centrality-dependent efficiencies have been determined and used in the analysis presented here. Work is in progress to further study these and similar sources of possible systematic errors.

Fig. 5: The excess photon transverse momentum distribution for the 25% $\sigma_{min.bias}$ (900 mb) most central interactions of 200 A GeV S+Au. The errors shown include all statistical and estimated systematic errors of the experimental and background simulation results.

With those words of caution, the preliminary excess photon transverse momentum distribution corresponding to the results shown in Figs. 3 and 4 is shown in Fig. 5. The results are for the 25% most central events of the WA80 minimum bias cross section. The average direct photon multiplicity for this event class may be obtained by dividing by the corresponding integrated central cross section of 900 mb. It is observed that the excess photon p_T distribution is well described by an exponential with a slope parameter of 180 MeV. It is interesting that this preliminary result is in good agreement with the calculated photon production for central S+Au collisions in which a QGP is formed with a critical temperature of $T_c = 160$ MeV.⁷⁾ In fact, in this calculation the dominant source of photons is from the hadron gas phase with relatively little sensitivity to the initial temperature. However, should the QGP not be formed, an even greater photon excess would be expected as a result of emission from the hot hadron gas!

4. Conclusion

Preliminary results from the WA80 experiment of π^0 , η , and inclusive photon distributions in S+Au interactions have been presented. As a result of an increased detector coverage and improvements in data reduction techniques, errors associated with the search for excess direct photons in relativistic heavy-ion collisions have been reduced by about a factor of two. For the first time, the η meson p_T distributions have been obtained in nucleus-nucleus collisions, and are shown to be consistent with m_T -scaling. Also for the first time, a small excess of photons over those which can be accounted for by the radiative decay of long-lived mesons has been observed in central collisions of S+Au at 200 A GeV. These preliminary results appear to be consistent with the formation of a Quark Gluon Plasma.

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