Direct photon search in pA collisions at 160 GeV/c

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ABSTRACT: Photon data collected by the WA98 collaboration in ^{208}Pb + ^{208}Pb collisions at 158A GeV show evidence for a direct photon excess which can be interpreted as the thermal radiation from a quark-gluon plasma. To set a reference for the production expected in the absence of the a quark-gluon plasma we have studied the production of π^0 and photon with transverse momenta in the range $0.5 < p_T < 3.5$ GeV/c and measured in $p/\pi^{+}+^{208}$Pb collisions at a similar energy, 160 GeV/c, and with the same experimental setup. The existence of a possible thermal photon radiation is discussed by comparing the direct photon yield measured in AA collisions with the scaled yield measured in pA collisions.

1. Introduction

One of the major objectives pursued in Nuclear Physics for the last twenty years is the formation and observation of a nuclear matter phase transition from normal confined nuclear matter to hot deconfined partonic matter, the Quark-Gluon Plasma. Lattice calculations of the Quantum Chromodynamics theory predict such a transition to occur when nuclear matter reaches energy densities of about 700 MeV/fm^3 and $T_c = 175$MeV [1]. Such values are within the reach of Pb-Pb collisions at SPS energies. The various experiments performed at SPS have shown the existence of several critical behaviour, like an enhancement of strangeness production[2], an anomaluous suppression of the J/ψ charmonium bound state[3], or an excess of direct photon [4]. Although all of the observations can be interpreted by the formation of a quark-gluon plasma such an interpretation is not unique.

From the beginning photons have been put forward as the most favourable probe that could evidence the formation of a QGP. Indeed photons have the unique advantage among all other probes to interact in the final state only weakly through the electromagnetic force, so that they carry intact information on the condition of matter from which they were produced. Direct photons, in opposition to decay photons, are produced in hot partonic medium for these energies through Compton ($q(\bar{q})g \to q(\bar{q})\gamma$) and annihilation ($q\bar{q} \to g\gamma$)

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processes. Such processes also occur during the initial stage, where partons undergo hard interactions producing photons. In addition the interaction among hadrons in hot hadronic matter are also a source of direct photons. Finally the most abundant source of photons is provided by the electromagnetic decay of hadrons during the freeze-out phase.

The WA98 collaboration has measured the photon spectrum and has shown in the most central Pb-Pb collisions the existence of a direct-photon excess with respect to the decay photon contribution[4]. To provide an experimental measurement of the contribution from the initial parton interactions and hence to extract the thermal contribution, we have studied within the same experimental conditions the production of direct photons in proton induced collisions on lead nuclei, a system in which thermal equilibrium is unlikely to be attained. We will present first the setup of the WA98 experiment, then we will discuss the method used to extract direct photons, and finally we will present still preliminary results.

2. WA98 experimental setup

The WA98 experiment (figure 1) (see ie. [5]) that was setup at CERN was a general purpose experiment for the measurement of charged hadrons and photons. It consists of two large acceptance spectrometers, one to detect the electromagnetic signal and the other for the hadronic signal. The information collected by the spectrometers is correlated to the information from additional detectors which characterize the beam profile and the centrality of the collision on an event-by-event basis. The electromagnetic spectrometer was composed on a lead glass calorimeter, LEDA, located at mid-rapidity, and a charge-particle veto detector CPV, a streamer tube array, placed in front of the calorimeter. Data were collected for proton and pion secondary beam at 160 GeV/c impinching on Pb target. The minimum bias cross section for p/π^{+}+Pb collisions was measured equal to 1390 mb.

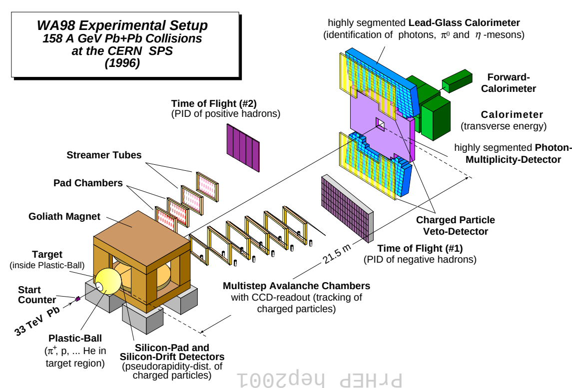

Figure 1: *WA98 experimental setup.*

Several plastic scintillators and Čerenkov detectors placed upstream are devoted to the beam study: two plastic scintillators count the beam particles and validate the interaction, another set of three scintillators are used to reject the beam halo and two Čerenkov detectors are used for the identification of the beam particle, proton or pion.

The MIRAC calorimeter, placed 24 m downstream, covers the pseudorapidity interval $3.5 < \eta < 5.5$, and measures the total transverse energy, E_T. MIRAC plays a central role to define the minimum bias trigger by selecting events with E_T above a given threshold.

The photon spectrum was measured with the LEDA spectrometer. It is located 21.5 m from the target and covers the rapidity region $2.3 < \eta < 3.0$. LEDA is divided into two almost symmetric arms and consists of 10080 lead glass modules each read out by a

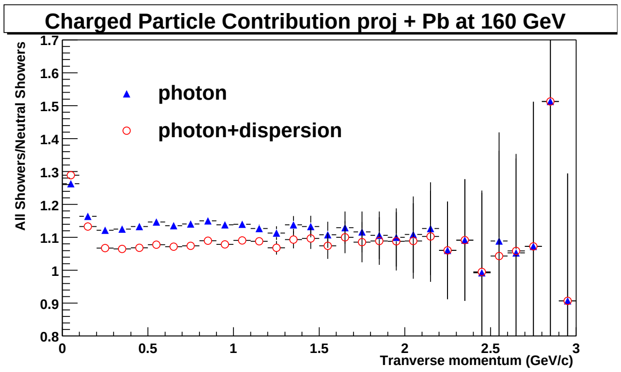

Figure 2: *Charged particle contamination of the photon spectra obtained with the CPV detector.*

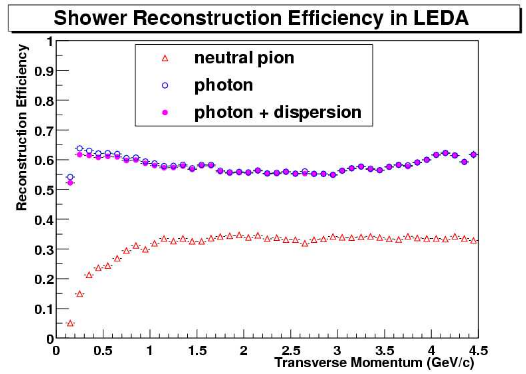

Figure 3: *LEDA γ and π^o reconstruction efficiency.*

photomultiplier. Particles incident on the calorimeter develop an electromagnetic shower and the Čerenkov light generated by the electrons of the shower is transported to the photomultiplier. The energy and impact of the incident particles is reconstructed from the energy deposited in the individual modules by a clustering algorithm. The geometrical acceptance of LEDA for photon emitted isotropically in the rapidity range between $2.0 < y < 3.2$ and in azimuth was found equal to 24.4%.

3. Direct photon excess analysis

We define the *direct photon excess* as the amount of photons that exceed the the contribution of decay photons from light neutral mesons. Since the π^0 mesons provide the largest source of photons the first step in our analysis is the construction of both the inclusive photon and π^0 meson spectrum.

The photon spectrum is obtained after clusterization of the LEDA modules to reconstruct the shower information. Then, we correct for the reconstruction efficiency which takes into account the correctness in the clusterization process, the defective modules, the shower overlapping effects and border effects. This efficiency is calculated by including test particles into each real event and by redoing the clusterization (see figure 3). The target-out contribution was corrected using data taken with an empty target and amounts to no more than 4.8%. The main source of particle contamination is the charged particles, which deposit a signal in the CPV detector. Two different procedures are used to reject this contamination. The first one implies a threshold in the photon energy > 0.750 GeV to reject the Minimal Ionizing Particles, MIP, and the second one is by combining the LEDA and the CPV information. To associate hits in CPV to hits in LEDA, we project the position of the CPV hits onto the LEDA surface, and consider a minimum distance between hits (see figure 2). With the charged particle correction, the photon conversion probability must be taken into account as well. This probability is calculated by measuring the lack of π^0 while studing the neutral showers with the CPV, the value is 10.2%. The neutron and antineutron contamination cannot be measured experimentally and it is necessary to rely

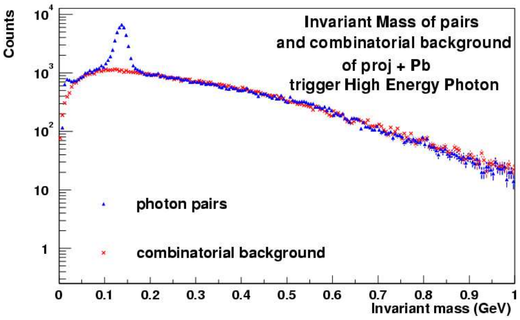

Figure 4: *Invariant mass distribution of the photons pairs for the π^0 rest mass region.*

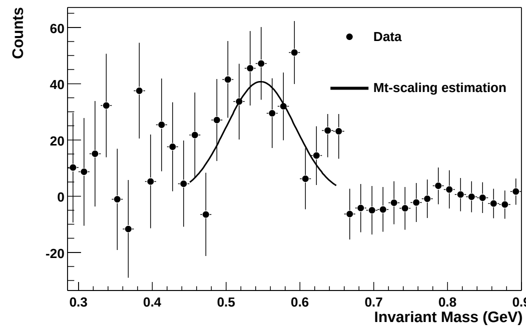

Figure 5: *Invariant mass distribution of the photons pairs for the η rest mass region.*

entirely on results from simulations. The incident n and $\bar{n}$ flux into the LEDA acceptance has been estimated by using predictions from the NeXus event generator. The LEDA response to this flux was simulated with GEANT, first with full tracking of the produced Čerenkov photons, and afterwards with a parametrization of this response. Three different hadronic packages were used to perform this calculation and all of them agree to predict an $n + \bar{n}$ contamination smaller than 2%.

The method to extract the π^0 transverse momentum distribution exploits the fact that 98.8% of pions decay into two photons. The invariant mass analysis of all possible photon pairs leads to a spectrum that exhibits a sharp peak at the π^0 rest mass on top of a combinatorial background. The amplitude and shape of this background have been evaluated by using mixed event technics (figure 4). The final π^0 spectra is obtained after corrections similar to the ones applied for the construction of inclusive photon spectrum: geometrical acceptance, target-out contamination and reconstruction efficiency. Although the π^0s are the most important photon source, we need to take into account other mesons with photons in their decay (η, ω, η, $K_{\rm short}$, etc). All these mesons cannot be measured by LEDA, because of their small production rate, and it is necessary to trust the m_T-scaling hypothesis to generate all the meson distributions from the measured π^0 one. This m_T-scaling hypothesis has been checked with the η meson distribution. The η has a two-γ decay: $\eta \rightarrow \gamma\gamma$, hence an analysis in invariant mass, as for π^0s, may extract its distribution. In the figure 5 the invariant mass distribution in the η region is shown . It is apparent that the measured distribution is compatible with the calculated one by using m_T-scaling, and this fact validates the m_T-scaling hypothesis which we will apply for all the mesons.

4. Results and discussion

To calculate the possible photon excess we compare two different photon multiplicities: the measured inclusive photon multiplicity and the calculated decay-photon multiplicity, based on the measurement of the π^0 production and the m_T-scaling hypothesis for η, ω, η' and $K_{\rm short}$.The latter is calculated by simulating the decay of measured pions and the other scaled mesons by using the PYTHIA event generator. The photon excess $d\sigma_{directs}/dp_T$ is defined as the difference between the experimental inclusive photons spectrum $d\sigma_\gamma/dp_T$

and the simulated decay-photon spectrum, $d\sigma_{decay}/dp_T$:

$$\frac{d\sigma_{directs}}{dp_T} = \frac{d\sigma_\gamma}{dp_T} - \frac{d\sigma_{decay}}{dp_T} = \left(1 - \frac{d\sigma_{decay}/dp_T}{d\sigma_\gamma/dp_T}\right) \cdot \frac{d\sigma_\gamma}{dp_T}. \tag{4.1}$$

To reduce systematic error it is preferrable to use the measured ratio γ/π to calculate the photon excess, because sources of error cancel. The following expression can be inserted in the excess calculation,

$$\frac{d\sigma_{decay}/dp_T}{d\sigma_\gamma/dp_T} = \frac{(\gamma/\pi^0)_{\text{Meas}}}{(\gamma/\pi^0)_{\text{Bkgd}}}, \tag{4.2}$$

since, by construction, both pion spectra are identical. The expression 4.2 give us the excess of photons for which we find a positive value of 20–25% an for $p_T > 0.7$ GeV

We can now compare this preliminary photon excess distribution obtained in pPb collisions with the distribution found for PbPb collisions at almost the same energy, with the same experimental setup and the same analysis method. To scale the hard photon spectrum measured in pA with the one measured in AA collisions, the mean number of binary collisions $< N_{bin} >$ is used. From calculations with a Glauber model [6] we obtain: $< N_{bin} >^{pPb}=$ 3.7 and $< N_{bin} >^{PbPb}=$ 635. The published PbPb direct photon distribution is presented with the pPb scaled one in the figure 6. This preliminary result indicates that there is still some excess that could account for the thermal radiation in PbPb collision, although with the complete error calculation, including the sytematic error, being still under study, we cannot conclude definitely on the existence of this radiation.

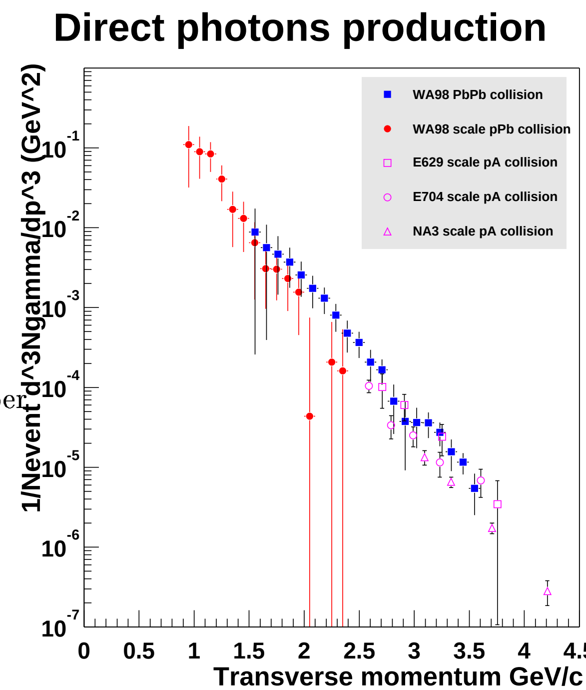

Figure 6: *Scaled pPb WA98 direct photons.*

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