First Results of the CERES Electron Pair Spectrometer from p+Be, p+Au and S+Au Collisions

The CERES/NA45 collaboration, presented by A. Drees

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Abstract

The CERES experiment (CErenkov Ring Electron Spectrometer) studies the production of low mass e^+e^- pairs in proton-proton, proton-nucleus and nucleus-nucleus interactions at the CERN SPS. The CERES spectrometer, has a novel design based on two Ring Imaging Cherenkov (RICH) counters, and it operates close to its design specifications. Data were recorded with 200 GeV/u sulfur beam and 450 GeV proton beam. The analysis is in progress. We have extracted first e^+e^- -pairs samples for p+Be, p+Au and S+Au collisions. In addition other physics topics were addressed. Inclusive photon spectra were measured in S+Au interactions. No excess over known hadronic sources was found within our present systematic error of 11%. Results on high p_t charged pion spectra are presented up to 4 GeV/c. We also studied the production of e^+e^- -pairs in the strong electromagnetic fields of very peripheral S+Pt collisions. The data are well described by a first-order perturbative QED-calculation.

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1. Introduction

The CERES experiment [1] belongs to the second-generation of heavy-ion experiments at the CERN SPS. The main goal is to systematically study the production of e^+e^- -pairs in the mass range $100 < m_{e^+e^-} < 3000 \text{ MeV}/c^2$ in proton-proton, proton-nucleus and nucleus-nucleus interactions at CERN SPS energies. In addition the experiment is able to measure real photons by the e^+e^- -pair of the photons converting in the target. The acceptance covers the central rapidity region $2 < \eta < 2.6$ with 2π azimuthal symmetry.

According to the common expectation, in ultrarelativistic nuclear collisions a state of free quarks and gluons, the quark gluon plasma (QGP), should be formed. One of the most promising signatures proposed is the thermal emission of lepton pairs and photons. Electromagnetic probes are ideal since they carry information of the hot and early state of the collision without being obscured by hadronic final state interactions. However, their measurement is also very difficult. The main problem detecting e^+e^- -pairs is the need to extract a weak source of $\sim 10^{-5} e^+e^-/\pi^0$ from a huge combinatorial background arising from photon conversions and π^0 Dalitz decays, in particular in the high multiplicity environment of nuclear collisions. The CERES experiment uses a non-conventional, highly specialized spectrometer. The essential properties of the setup that allow to cope with the difficulty of the measurement are described in section 2 of this paper. Section 3 gives a short account of the data taken so far and the analysis procedure. The preliminary invariant mass distribution from p+Be is presented in section 4. Limits on direct photon production in S+Au collisions are quoted in section 5. Results on high p_t pion production in S+Au and e^+e^- -pairs produced in the strong electromagnetic fields of S+Pt collisions are reported in the last two sections.

2. Experimental Setup

The layout of the the CERES spectrometer is shown in figure 1. Particle identification and directional tracking are based on two azimuthally symmetric Ring Image Cherenkov (RICH) counters, one (RICH-1) situated before, the other (RICH-2) after a superconducting solenoid ('main coils' in fig.1). The RICH detectors are virtually "hadron-blind", i.e. most of the charged hadrons do not produce photons, while essentially all electrons create Cherenkov rings of asymptotic radius. This is achieved by using CH_4 at atmospheric pressure as the radiator gas, which results in a Cherenkov threshold of $\gamma \simeq 32$.

The double solenoid provides a localized azimuthal momentum kick for the momentum measurement and charge analysis while leaving the scattering angle unchanged. The field in the region of RICH-1 is compensated to nearly zero using currents of different magnitude and polarity in the two superconducting coils. Therefore the original direction of the particles is preserved and trivial pairs can be rejected by applying cuts on the opening angle or the number of hits per ring in RICH-1. A set of coils ('correction coils') shape the field in RICH-2 such that it points back to the target as indicated by the field lines in the lower part of figure 1. The particle trajectories are thus parallel to the field lines and undeflected within RICH-2, an essential requirement for sharp ring images.

In order to minimize the number of e^+e^- -pairs from conversions and to reduce the loss of momentum resolution due to multiple scattering, the amount of material within the acceptance is minimized. For this reason the mirror of RICH-1 is made of a carbon fiber

Figure 1. The CERES spectrometer; shown is a cross section of the azimuthally symmetric experimental setup. In the lower half the magnetic field lines are overlaid

laminar shell of only 1 mm thickness. The total radiation length was kept at about 0.7% and 1.6% of X_0 up to the first and second mirror, respectively, excluding the target. The target is segmented into many beam-size discs which keeps most of the target material out of the acceptance of the spectrometer.

The Cherenkov photons from the RICH radiators are registered in two UV-detectors which are placed upstream of the target, therefore they are not traversed by the intense flux of forward going particles. The UV-detectors are built as multi-step gas counters operated with TMAE as the photo-sensitive agent. The information of the UV-detectors is read out via a two-dimensional array of pads allowing the unambiguous reconstruction of single-photon hits. A subset of the information of RICH-1 is used in the trigger.

A silicon drift chamber [2] located close to the target, serves as a high-resolution vertex detector. Its prime role is to supply additional rejection of conversions necessary for nucleus-nucleus collisions. Another silicon detector, segmented in 64 pads, provides a fast multiplicity information used in the trigger [3]. A detailed description of the CERES spectrometer is in preparation, a shorter account can be found in [4].

3. Data collection and analysis procedure

The experiment was set up and first tested in 1990. The spectrometer was completed in 1991 and both RICH detectors operate close to their design specification with 10 to 11 detected Cherenkov photons per ring and a single-photon resolution of $\sigma \sim 1$ mrad, dominated by chromatic aberrations in the radiator gas. First data samples were collected in 1992 with 450 GeV proton and 200 GeV/u sulfur beams. We have recently completed a combined run of CERES with the BaF_2 calorimeter of the TAPS-collaboration [5] on p+Be and p+Au collisions. The main goal was to measure precisely the $\eta \rightarrow e^+e^-\gamma$, $\eta' \rightarrow$

Figure 2. Shown is a p+Be event (left) and a typical S+Au collision (right) both observed in RICH-1. The p+Be event contains the rings of an electron pair from a π^0 Dalitz decay. In the sulfur event in addition to Cherenkov rings one sees also a single-hit background which is found to be proportional to the event multiplicity.

$e^+e^-\gamma$ and $\omega \rightarrow e^+e^-\pi^0$ contributions to the low mass e^+e^- -pair continuum.

As an example, figure 2 (left side) shows a p+Be event as seen by RICH-1. The cleanliness of the detector and the quality of the ring images, here a e^+e^- -pair originating from a π^0 Dalitz decay, are striking. In addition to hits on the Cherenkov rings there is a very low background of scattered single hits. The source of these hits are pions slightly exceeding the Cherenkov threshold or low momentum electrons like δ -rays undergoing large multiple scattering. For central S+Au collisions the situation is different as shown on the right half of figure 2. The amount of background hits is more severe. Still the pad occupancy is rather low and rings can be recognized.

It is evident that the requirements of the data analysis differ depending on the charged multiplicity of the events to be analysed. Still most features of the analysis are similar. A pattern recognition algorithm is needed to reconstruct ring images without the prior knowledge of the ring centers. In the first step electronic noise and large hits from highly ionizing charged particles are removed. Ring candidates are then identified in the remaining picture. For these candidates, single-photon hits are reconstructed and used to determine the position of the ring by a fitting procedure. Several quality criteria, like the number of hits per ring, the distribution of hits along the circumference etc. are used to distinguish Cherenkov rings from random combinations of hits. The accepted rings in RICH-1 and RICH-2 are then matched to tracks by their common scattering angle. Most of the tracks originate from $\gamma \rightarrow e^+e^-$ and $\pi^0 \rightarrow e^+e^-\gamma$ decays. In order to filter the signal from the combinatorial background these tracks need to be rejected at a level $\gtrsim 90\%$. Since the original direction of the particles is preserved, conversions have a clear signature of an unresolved double ring in RICH-1 and can be rejected by a cut

on the number of Cherenkov photons. Single tracks are rejected as π^0 Dalitz decays if a second ring is found in the vicinity of the track in RICH-1. The remaining tracks are combined to pairs. The vertex of each pair is now reconstructed by matching the tracks to hits in the silicon drift detector. Hence combinatorial background due to unrecognized conversions occurring downstream of the silicon drift detector is eliminated. Pairs are also discarded if the energy loss of one track in the silicon is twice the signal of a minimum ionizing particle. The combinatorial background left in the e^+e^- -pair sample is estimated by the number of like-sign pairs (e^+e^+ or e^-e^-). The e^+e^- -pair signal is then extracted by subtracting the like-sign contribution from the e^+e^- -pair sample.

4. Results for electron pair production

The total number of e^+e^- -pairs accumulated can be estimated from the known production rates of the hadronic sources and the number of triggers recorded, taking into account the enrichment factor of the electron pair trigger. The resulting sample sizes are 34000, 11000 and 3000 e^+e^- -pairs with an invariant mass $m_{e^+e^-} > 200$ MeV/ c^2 for p+Be, p+Au and S+Au, respectively. These figures include a single-track p_t -cut of 50 MeV/ c for proton and 200 MeV/ c for sulfur beam; they do not contain any reconstruction efficiency.

Figure 3. Invariant mass spectrum of e^+e^- -pairs in p+Be collisions. A p_t -cut of 50 MeV/ c is applied to each track. The combinatorial background, measured by like-sign pairs, is subtracted, but no correction for the reconstruction efficiency is applied.

At present we have analysed 20% of the p+Be and 10% of the p+Au data. The preliminary mass distribution of p+Be is shown in figure 3. The peak below 150 MeV/ c^2 is the π^0 Dalitz decay. The other immediately noticeable feature is the peak in the ρ/ω region. The mass resolution is about 10% (rms) in the range of the ρ/ω . At present the

pair reconstruction efficiency is approximately 15%. Similar results are obtained for the small fraction of reconstructed p+Au collisions.

It is evident that the higher charged multiplicity in S+Au events (a factor of ~ 40 higher compared to p+Be) complicates the pattern recognition, while at the same time it increases the combinatorial background. Although the analysis of S+Au events is much more difficult, even at the preliminary stage of the data analysis, a clear signal of 250 ± 64 electron pairs with $m_{e^+e^-} > 200 \text{ MeV}/c^2$ above the combinatorial background is visible. Recent developments applying artificial neural networks in the pattern recognition indicate that a significant increase both, in electron pair reconstruction efficiency and background rejection can be achieved.

5. Search for direct photons

We have measured inclusive photon spectra in S+Au collisions using the conversion method with the target as converter [7]. The shape of the inclusive photon p_t -distribution is well described by known hadronic sources. In the region $0.4 \leq p_t \leq 2.4 \text{ GeV}/c$ and $2 < y < 2.6$ we find a non-significant excess of $7.5 \pm 11\%$ of the data over hadronic sources; where the error is dominated by systematical uncertainties. The multiplicity dependence is of particular interest since the production of direct photons is expected to increase quadratically with n_{ch} and since the uncertainties of the absolute normalization are avoided. Our data show no rise above a linear dependence within the present systematical errors. We hope to reduce these systematic errors in future to the level of a few percent. A more detailed discussion can be found in a separate contribution to this conference [6].

6. High p_t pion production

The p_t -spectra of hadrons from nucleus-nucleus collisions may indicate the degree of thermalization reached, and provide evidence for collective expansion of the highly excited central region. Nevertheless, any thermodynamic or hydrodynamic interpretation of p_t -distributions has to take into account other important effects like hard parton-scattering and rescattering of partons in the target or projectile nucleus. To clarify these issues it is useful to know the distributions at high p_t . In the CERES experiment pions above the Cherenkov threshold can be identified in the RICH detectors by their rings of non-asymptotic radius [8].

The pion momentum is determined by the ring radius, with a resolution of $\delta p/p \sim 0.06\% \cdot p^2$, much more accurate than $\delta p/p \sim 3.2\% \cdot p$ determined from the deflection in the magnetic field. Figure 4 shows the invariant transverse momentum distribution (p_t^2) for charged pions in the rapidity range $2 < \eta < 2.6$ for central S+Au collisions. In the same figure our data are compared with a π^0 p_t -spectrum measured by WA80 [9] in a similar rapidity interval ($2.1 < \eta < 2.9$) for the same collision system. Both data sets are in very good agreement. We have also investigated the dependence of the slope of the p_t -spectrum as a function of multiplicity. We observe no variation in the multiplicity range $50 \leq dn/dy|_{\Delta y=1} \leq 160$, similar to previous findings [10] at lower p_t . At present the p_t range accessible is limited by the electron-pion separation; an improved analysis and a comparison of p+Be and p+Au with S+Au data are in progress.

Figure 4. $d\sigma/dp_t^2$ of charged pions shown for central S+Au collisions. The data are compared to a π^0 p_t -spectrum measured by WA80 also for central S+Au collisions. The data sets are normalized to each other.

7. Electron-positron pairs from QED-production in nuclear collisions

Nucleus-nucleus collisions produce large and rapidly varying electromagnetic fields. Since the coupling constant is proportional to $(Z\alpha)^2$ the cross section for electron pair production is much higher in nuclear collisions than in those of singly charged particles. As a consequence, at very low invariant masses a high rate of e^+e^- -pairs is produced overwhelming those from hadronic interactions. However, it is negligible in the mass range relevant for our experiment. For future nuclear colliders this process needs to be considered as an important background. Only one measurement of inclusive e^+ production has been reported for nuclear collisions so far [11]. We have measured e^+e^- -pairs from QED-production in non-disruptive S+Pt collisions with slightly modified setup and trigger conditions [12].

As trigger we required 2 or 3 particles detected in the silicon pad counter within the RICH acceptance and the sulfur projectile identified downstream of the spectrometer. The magnetic field was lowered to 25% of its nominal value. To minimize the background from δ -rays, a platinum target of only 50 μm thickness was used and all material not needed for this measurement was removed from the target area. Under these running conditions electrons could be recognized even below 25 MeV/c momentum although the 'ring images' are very much distorted by multiple scattering. Our measurement is restricted to the mass range $10 < m_{e^+e^-} < 100 \text{ MeV}/c^2$ and the angular acceptance of 8° to 16° . We have checked the absolute normalization of the data by reconstructing events with two δ -electrons and found agreement with the δ -electron production cross section within 10%.

Figure 5 shows the measured invariant mass spectrum (a) of the e^+e^- -pairs and their opening angle distribution (b). The opening angle is peaked at 180° as expected from the production mechanism. In the kinematical region accessible we measure a total cross

Figure 5. Invariant mass distribution (a) of e^+e^- -pair produced in non-disruptive S+Pt collisions and the corresponding opening angle distribution (b). Both figures are compared with a first-order perturbative QED-calculation.

section of $\sigma_{tot} = 13.9 \pm 3.1$ (stat.) $^{+1.9}_{-3.1}$ (syst.) mb. The data are compared with a first-order perturbative QED-calculation for which the phase space integration is done with a Monte-Carlo method using the VEGAS code [13]; the result is $\sigma_{tot} = 14.0 \pm 0.4 - 1.4$ mb. The theoretical prediction not only agrees with the measured total cross section but also describes the slope of the mass distribution over two orders of magnitude.

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