# Final Technical Report
## High Energy Ion Collisions

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Principal Investigator: Barbara V. Jacak

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## Synopsis

This grant supported one year of work on Relativistic Heavy Ion Collisions at the University of New Mexico. The Principal Investigator, an Adjunct Associate Professor at UNM, recruited a student (Mikhail Kopytine), sent him to CERN for several months to participate in the final data taking period of the NA44 experiment at CERN, then initiated analysis of the data collected during the run. A Hewlett-Packard workstation was purchased and Mr. Kopytine performed calibration, software development, and data analysis using it.

A collaboration between Los Alamos National Laboratory and other faculty members at the University of New Mexico was begun, with the goal of working closely together on the PHENIX experiment for RHIC. At this time, a close collaboration continues, centered around the Muon tracking detectors for PHENIX. Station 1 of the tracking system is under construction at UNM, while stations 2 and 3 are the responsibility of LANL.

In January, 1997 Barbara Jacak moved to the State University of New York, to accept a position as Professor of Physics. Mikhail Kopytine decided to complete his graduate studies at Stony Brook and moved also. The work on experiment NA44 is being completed at Stony Brook, and Stony Brook is a collaborator on the PHENIX experiment.

## Accomplishments

1. Participated in final data taking period of NA44
2. Worked on commissioning of aerogel cerenkov trigger and performed offline analysis to demonstrate its performance.
3. Calibrated the Uranium Calorimeter in NA44 in preparation for Data Summary Tape production.
4. Performed an optimized DST production for tapes with single pion, kaon, and proton triggers for Pb+Pb collisions.
5. Began analysis of pion and kaon distributions and production cross sections from Pb+Pb collisions.
6. Participated in MVD development meetings and contributed to planning of the analysis software for MVD.

## Progress Report

NA44 studies single particle distributions and correlations among pairs of identified pions, kaons, and protons as a function of $p_t$ to determine the space-time extent of the central region. In 1996, the NA44 collaboration completed data taking on Pb + Pb collisions, with an emphasis on sufficient statistics for single particle distributions, rare particles such as deuterons and anti-deuterons, kaon pair correlations, and three pion correlations. The UNM group was present for-commissioning, calibration, data collection, and dismantling of the NA44 spectrometer. The collaboration agreed that UNM would focus on the analysis of single kaons and pions from Pb + Pb, with a goal of clarifying the role of associate production in the enhancement of position kaon production in heavy ion collisions.

Ever since the E802 experiment at the AGS found $K^+/\pi^+$ to be twice as large in heavy ion collisions at 14 GeV/nucleon as in nucleon-nucleon collisions[1], we have wondered whether the enhancement is completely due to associated production via the channel $\pi + N \to K + \Lambda$.[2] A similar enhancement was found in 200 GeV/nucleon S + W at CERN, in the target rapidity region by the HELIOS experiment[3]. At rapidity near 1, the baryon to meson ratio is approximately one to one, corresponding nearly exactly to that at midrapidity at the AGS. Clearly, an excellent way to investigate the extent of associated production would be to look in a region of different baryon density. This is best achieved at central rapidity at CERN, where there are many more pions than nucleons.

Prior to the data taking period, we commissioned an aerogel cerenkov counter as a trigger to enrich kaon pairs in the NA44 data sample. Because there are only about 10% as many positive kaons as pions, the probabilty of a pair of particles both being kaons is only 1%. Early running showed that the contamination by pions of kaon pair triggered events was substantial. Consequently, the collaboration decided to develop the aerogel cerenkov to provide a positive trigger on the presence of kaons. The LANL group designed a novel Čerenkov counter to separate kaons from accompanying pions.[4] While ring-imaging Čerenkov counters exploit the fact that Čerenkov photons form a ring in the focal plane of the counter, it is possible to extract more information by placing the photon detector not in the focal plane, but in the image plane of the imaging mirror or lens. In the NA44 spectrometer, the particles follow nearly parallel paths, creating an environment well suited to a spot-imaging Čerenkov counter. Kaons and pions within a narrow momentum range impinge normally on the Čerenkov radiator. The particles produce photons in a cone according to the Čerenkov angle. At the exit face of the radiator, these form circular spots of photons, with one spot per incident particle. With a lens or mirror, we produce a real image of these spots on the detector, which, with suitable granularity, determines the position of the particle in the spectrometer. Pions and kaons were separated by taking advantage of the fact that all particles create rings of photons in the focal plane. Particles of a given type put photons into the same location on the focal plane, but the rings of pions and kaons have different radii. We masked off the pion photons and collected only the photons from kaons in the kaon image plane, using a single large photomultiplier tube. UNM personnel worked closely with VanHecke and Xu from LANL to analyze the detector's performance and demonstrate the enrichment of kaon pairs by including it in the trigger. The enrichment was substantial, though lower than we expected from prototype tests. After extensive analysis, and tests with aerogel from different manufacturers, we concluded that the problem was with our light collection system, primarily the acrylic Fresnel lens.

The first Pb + Pb single particle analysis was on proton and anti-proton production, by Dr. Nu Xu of Los Alamos, and Mikhail Kopytine of UNM. Use of information from the Uranium Calorimeter was important to provide a clean identification of antiprotons. The calorimeter registers the total electromagnetic and hadronic energy impinging on its towers. Generally, the kinetic energy of hadrons is measured, but the annihilation of antiprotons provides an additional energy equivalent to two nucleon masses (as the annihilation converts the antiproton and the proton it annhiliates on to energy). Using this energy in the calorimeter along with the time of flight, allows a very clean separation of antiprotons from negative kaons and from backgrounds. In order to perform this analysis, Mikhail Kopytine took responsibility for calibration of the UCAL detector.

In order to analyze the antiproton, kaon, and pion transverse mass distributions and dN/dy, Kopytine developed techniques to address the following:

1) correction for kaons and protons lost by the trigger-level pion rejection
2) separation of kaons and protons by a combination of time-of-flight data from the NA44 scintillator hodoscopes and information from the gas cerenkov counters
3) correction for data acquisition dead time, and other event counting losses in the scalers
4) determination of the trigger centrality selection
5) antiproton identification using the Uranium Calorimeter
6) absolute normalization to reconstruct the rapidity densities of pions, kaons, and antiprotons

Figure 1 shows the transverse momentum ($p_t$) and transverse mass ($m_t$, where $m_t^2 = m_0^2 + p_t^2$) distributions of positive kaons from Pb + Pb collisions, measured by NA44 using the 4 and 8 GeV spectrometer settings. These plots are from a presentation made by Koptine to the NA44 collaboration at a meeting several months after the completion of this grant. Work on the absolute normalizations continued at Stony Brook, in order to complete analysis of these results for publication. Figures 2 and 3 show the measured rapidity densities of positive and negative particles, respectively. The closed points are measured in different spectrometer settings, while the open points are reflected about the rapidity of the center of mass (this can only be done for collisions of symmetric systems, like Pb + Pb). The histograms show the predictions of the RQMD [5] event generator. It appears that RQMD slightly overpredicts the number of kaons, while reproducing the number of pions reasonably well. The ratio $K^+/\pi^+$ is observed to be approximately 14%, which is somewhat higher than in nucleon-nucleon collisions at 158 GeV, but lower than was observed at the AGS.

The PHENIX work supported by this grant consisted primarily of contributions to the software conceptual design by Kopytine and Jacak. We participated in discussions at Los Alamos about how this should look and contributed ideas and suggestions. Implementation was beginning in late 1996, but the bulk of the coding took place later. We also began development of application to data from silicon pad detectors of a novel method of multiparticle correlation analysis. This will lead to an eventual analysis of PHENIX MVD data, should the method prove useful when applied to simulated events. Kopytine and Jacak moved to Stony Brook before the actual production of MVD elements commenced, so were unable to work in the factory.

During the term of this grant, three NA44 papers were accepted for publication. UNM personnel contributed substantially to data collection, analysis and writing of these papers.

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KOPYTINE
meeting, May 97
Stony Brook

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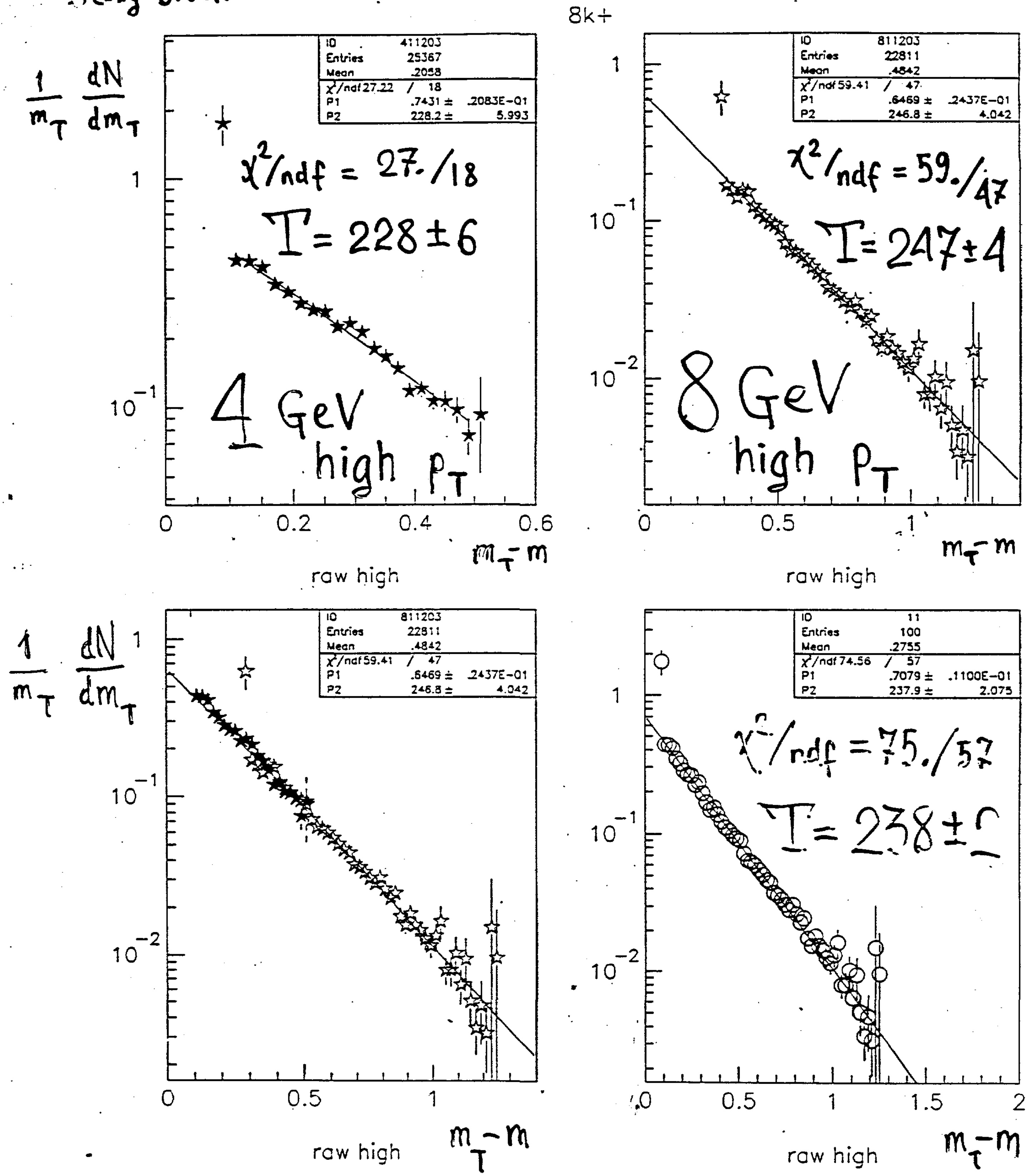
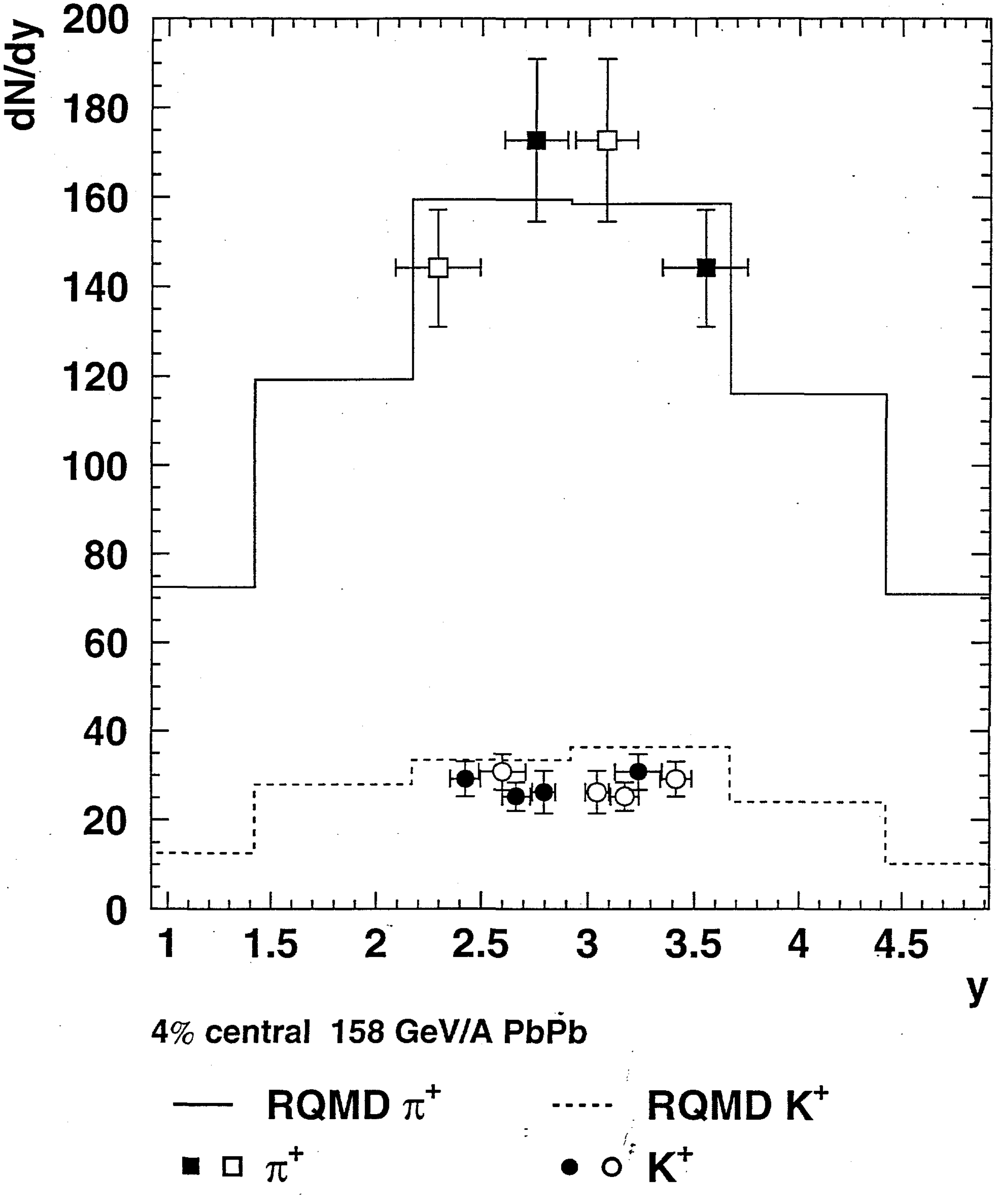



FIGURE1


dN/dy
200
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140
120
100
80
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20
0
1
1.5
2
2.5
3
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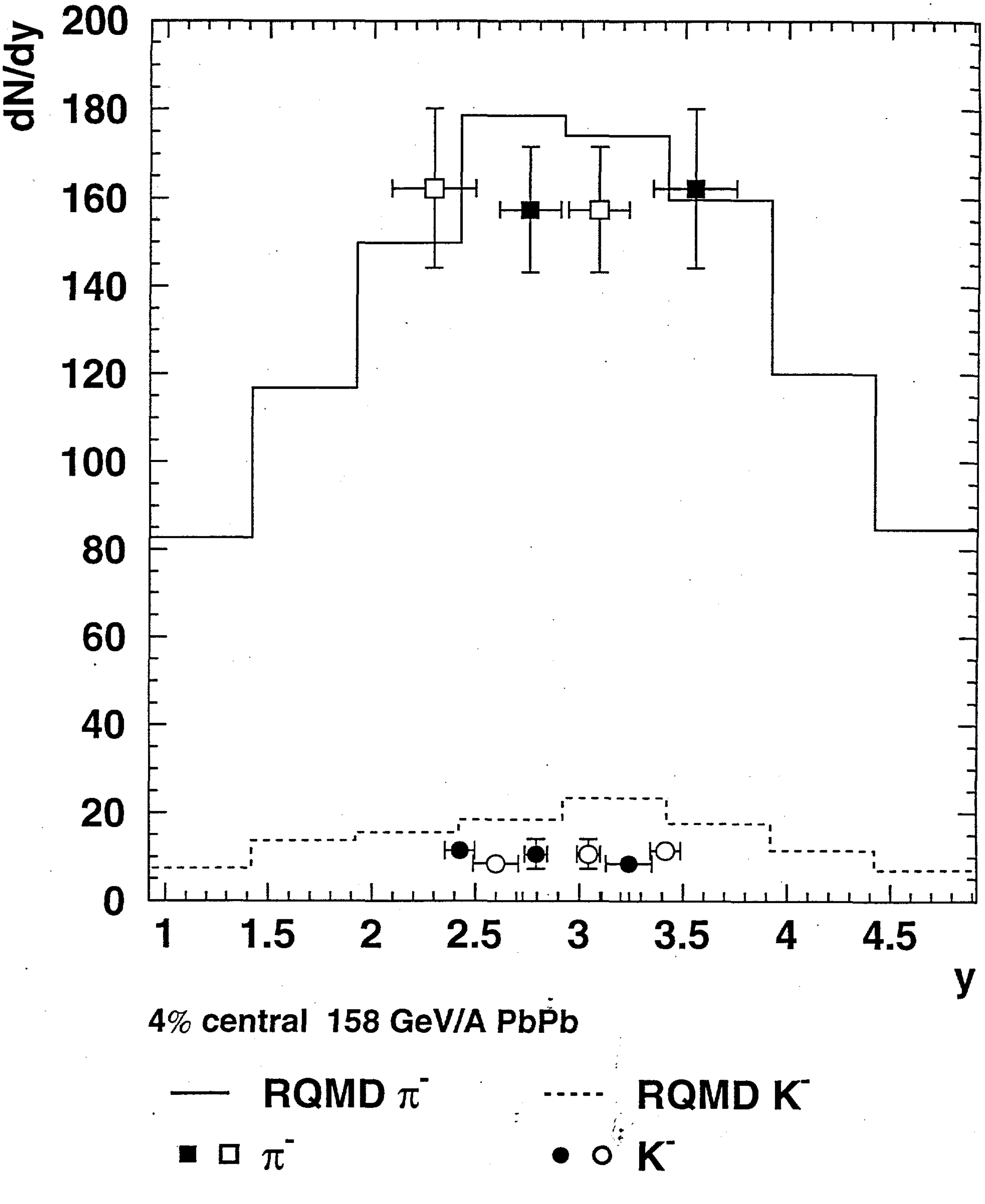
4
4.5
y
4% central 158 GeV/A PbPb
RQMD π+
RQMD K+
π+
K+

Figure 2


dN/dy
200
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y
4% central 158 GeV/A PbPb
RQMD π-
RQMD K-
π-
K-

FIGURE 3