ϕ Meson Production in Au - Au Collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract

ϕ mesons were reconstructed in the K^+K^- channel in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV by the PHENIX experiment. ϕ invariant masses were reconstructed using a high resolution Time of Flight detector and Electromagnetic Calorimeters for particle identification, in conjunction with the excellent momentum resolution of the PHENIX tracking detectors. A description is given of the techniques for signal extraction and the corrections applied to obtain yields.

1 Introduction

The production of ϕ mesons in relativistic heavy ion collisions is of considerable interest for a variety of reasons. An enhanced ϕ meson yield has been suggested as a signature for the formation of a deconfined phase. Medium modifications of ϕ meson properties may be related to the expected chiral phase transition [1]. Finally, the strangeness content of ϕ mesons makes them a sensitive probe for strangeness production [2]. The measurement of ϕ mesons via the K^+K^- channel in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the PHENIX experiment at RHIC is presented in this paper. Momenta of charged particles are obtained from the PHENIX central arm tracking detectors. The additional velocity measurements from the Time-of-Flight Detector and the Electromagnetic Calorimeter give PHENIX excellent capabilities to identify charged kaons.

2 Data Selection

2.1 Run Selection

This analysis is based on the 200 GeV Au-Au data collected by the PHENIX experiment in 2001. The integrated luminosity delivered by RHIC within the PHENIX fiducial region of $z = \pm 45$ cm was 42 μb^{-1}, corresponding to about 92 million minimum bias events.

The results presented here are obtained using the east arm of the PHENIX central detector[3] that covers a pseudorapidity range $|\eta| < 0.35$. The analysis uses the drift chamber (DC), two sets of pixel-pad detectors (PC1 and PC3), the Time of Flight detector (TOF), and the lead-scintillator Electromagnetic Calorimeter (EMC). Events in which the detector was working optimally were selected based on a variety of conditions such as the average number and momenta of reconstructed tracks and projection matching requirements between sub-detectors. The sample was further reduced after applying a z-vertex cut of ± 30 cm, leaving about 20 million events.

2.2 Single Track Selection

Tracks are reconstructed using the collision vertex provided by the Beam Beam counters, the Drift Chamber, and hit positions on PC1, which is physically located just behind the Drift Chambers. Tracks are assigned a "quality" depending on the reconstruction. Only the best quality tracks are considered for this analysis. These tracks are then matched to PC3 and either the TOF or the EMC depending on the track location. A 3σ track projection matching cut is applied at the TOF. For tracks identified in the EMC we impose track projection matching cuts both at PC3 and the EMC.

2.3 Particle Identification

PHENIX has an excellent particle identification capability. Particle identification of hadrons is achieved using the high resolution TOF detector that is located in two sectors of the east arm. Additional time of flight information is obtained from the Electromagnetic Calorimeters. There are two types of Electromagnetic Calorimeters in the east arm covering all four sectors: the lead-scintillator sampling calorimeter (EMC) and lead-glass Cerenkov Calorimeter (PbGl). The PbGl is located behind the TOF and is not used for particle identification. The TOF has a timing resolution of about 120 ps whereas the EMC has a timing resolution of about 480 ps. For this analysis the momentum range for the selected kaons in the TOF is 0.3 GeV/c $< p <$ 2.0 GeV/c. In the EMC the momentum range for the selected kaons is 0.3 GeV/c $< p <$ 1.0 GeV/c. In both cases we choose a 2σ band of kaons from the calibrated kaon mass squared.

3 Analysis Procedure

3.1 Single Kaon Analysis

Before presenting the results of the $\phi \rightarrow K^+K^-$ analysis, we show first the results of an inclusive kaon analysis. The inclusive kaon analysis is based on exactly the same single track and pair track cuts described previously. The $\frac{1}{2\pi\, m_T}\frac{d^2N}{dm_T\, dy}$ for this inclusive kaon yield will be compared with that obtained independently by a separate PHENIX analysis which used much tighter cuts with about a factor of about 2 less acceptance than we can afford for the ϕ analysis. When these two sets of acceptance factors are used in the extractions of the yields for the inclusive kaons, one obtains the results shown in Fig. 1 and 2. It is evident that they are in good agreement. The agreement of the two independent analysis on the kaon spectra gives us confidence in the cuts and corrections used for single tracks in the ϕ analysis including particle identification requirements, tracking efficiencies, single track embedding corrections and run-by-run kaon efficiency corrections.

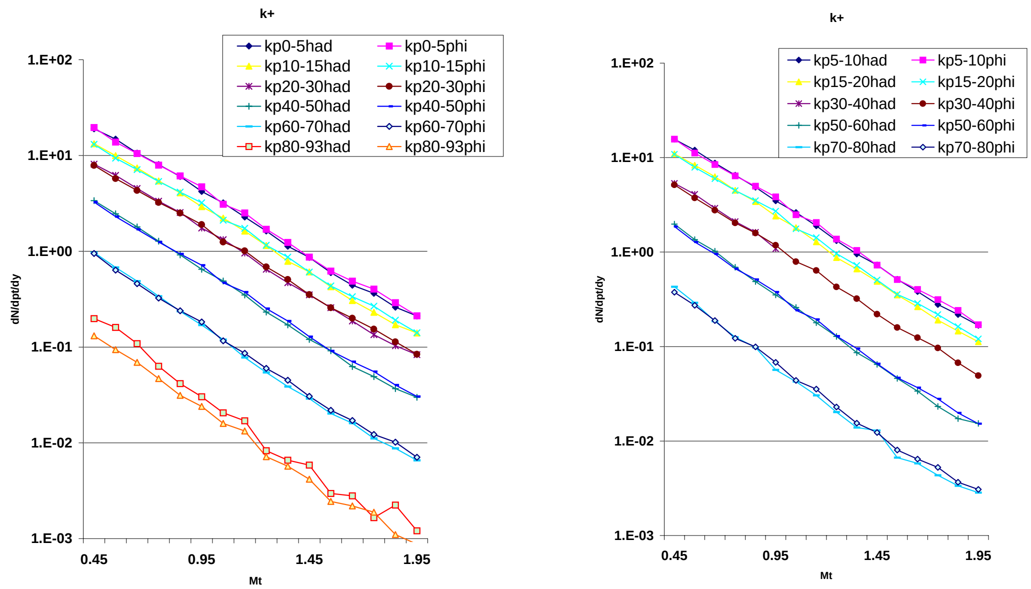

Figure 1: Comparison of the yields for K^+ as a function of centrality and transverse momentum, as determined by this analysis and the PHENIX Hadron Physics Working Group analysis. Points labeled as "had" come from the Hadron Physics Working Group. Points labeled "phi" are from this analysis. The left plot is for K^+ for odd bins in centrality, the right one is for even bins in centrality.

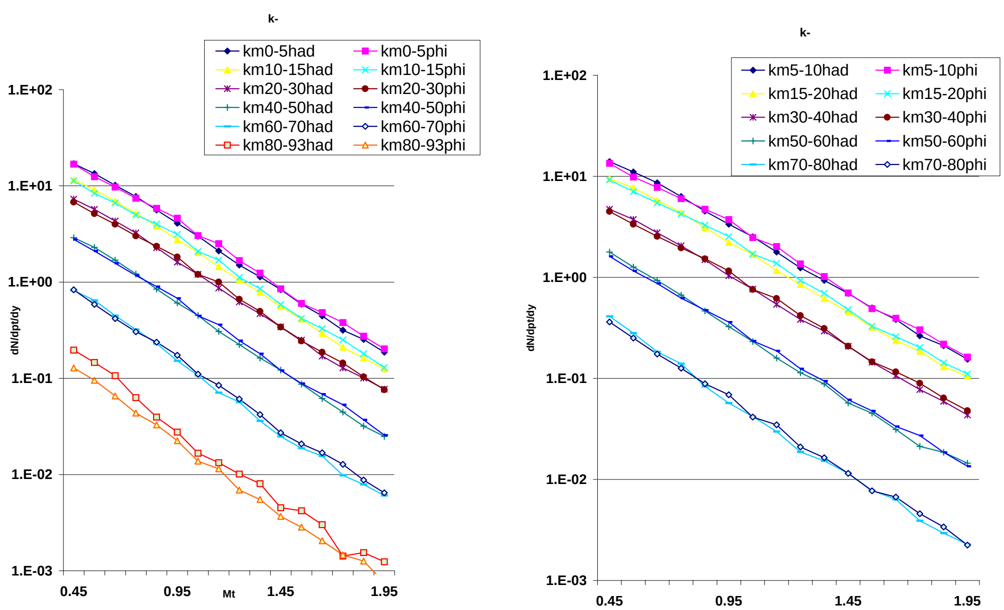

Figure 2: Same as Figure 1 for K^-.

3.2 Pair Signal Generation

After applying all relevant cuts on the data, we are left with a sample of kaons identified in either the TOF or the EMC. These kaons can now be combined to extract the ϕ invariant mass. Since the sample contains kaons from both the TOF and EMC with different momentum ranges, the combinatoric background will have different shapes depending on the p_T distribution of the single kaons. Therefore kaon pairs are combined in the following way. (1) TOF-TOF pairs: Both members of the K^+K^- pairs are identified in the TOF. (2) EMC-EMC pairs: Both members of the K^+K^- pairs are identified in the EMC. (3) TOF-EMC pairs: One of the members of the K^+K^- pairs are identified in the Time-of-Flight Detector and the other in the EMC.

Unlike sign kaons from the same event are paired together giving us the actual pair distribution with a signal riding over a large combinatoric background which must be subtracted. The combinatoric background is obtained by using kaons from different events. Kaon momenta are stored in a set of 15 z-vertex bins between -30 cm and +30 cm, and 18 centrality bins from 0% in increments of 5%, with the last bin between 85% and 92%. An invariant mass distribution is formed from a K^+ from one event and a K^- from a different event, but within the same centrality and vertex bin. The mixed pair invariant mass distribution is normalized to the number of same-event, like-sign pairs (N_{++}, N_{--}) as $2\sqrt{N_{++} \, . \, N_{--}}$. The validity of the normalization was tested by looking at the ratio between same-event, like-sign pairs and the predicted mixed-event, like-sign pairs. The subtraction of the properly normalized background from the same-event invariant mass distribution gives the ϕ signal.

3.3 Corrections

One of the two very important studies we aim to perform is the ϕ transverse mass distribution and extraction of ϕ yield and inverse slope parameters. (The other being the mass centroid and width of ϕ). Determination of the yield, dN/dy, requires correcting the raw ϕ yield for the detector and reconstruction acceptance. The PHENIX east arm has azimuthal acceptance of about 90^o. We generate single ϕ events in 2π azimuth with an exponential transverse mass distribution assuming an inverse slope of 320 MeV. The generated ϕ's were passed through the PHENIX detector simulation and reconstruction chain. From the number $N^{\phi}_{generated}$ of the generated ϕ's and $N^{\phi}_{accepted}$ of the accepted ϕ's in a given momentum range we find the detector acceptance correction for that momentum range

$$\epsilon_{acceptance} = \frac{N^{\phi}_{generated}}{N^{\phi}_{accepted}} \quad (1)$$

The second correction is for the efficiency loss due to high occupancy. Centrality (occupancy) dependence of $\phi \to K^+K^-$ pair reconstruction was found by embedding single pairs into the real data. The single particle embedding efficiency has two parts, the efficiency of track reconstruction and the particle identification efficiency. The embedding efficiency was estimated for centrality bins 0 - 92% in steps of 10% such that the effective yield from the raw data is $N^{eff}_{\phi} = \Sigma N^{raw}_{\phi} / \epsilon_{K^+K^-}$.

Another important correction is the raw kaon yield correction due to the run by run efficiency of the detector. The analysis is done for DC + PC1 + TOF/EMC. The run-by-run dead area variations of these subsystems influences the ϕ yields. The dead areas in the subsystems have different effects on the positive and negative kaons with different momenta.

4 Invariant Mass Distribution

The ϕ invariant mass spectra are extracted after subtracting the normalized mixed-event unlike-sign pairs from the same-event unlike-sign pairs. The spectra need to be fitted with a function that describes the width and the mass centroid of the reconstructed ϕ. The appropriate function for fitting the ϕ spectra is a relativistic Breit-Wigner function. However, since the invariant mass distribution incorporates the detector mass resolution, the detector mass resolution needs to be taken out from the relativistic Breit-Wigner function in order to obtain the actual mass and width of ϕ. Thus we use a relativistic Breit-Wigner function convoluted with a Gaussian where the width of the Gaussian is the detector mass resolution. PHENIX has excellent momentum resolution, which translates into an equally excellent mass resolution of about 1.2 MeV. We use 1-MeV bins for the invariant mass distributions and subtract the normalized background from the real pair distribution bin by bin to extract the ϕ spectra.

The minimum bias K^+K^- invariant mass spectra are shown in Fig 3 for the TOF-TOF, TOF-EMC and EMC-EMC combinations.The spectra are fitted with Breit-Wigner function convoluted with a Gaussian. More than half of the raw ϕ pairs come from the TOF-EMC combination. For the TOF-TOF combination the range of the transverse mass is 1.2 GeV/c^2 to 4.0 GeV/c^2. For TOF-EMC combination 1.2 GeV/c^2 $< m_T <$ 2.8 GeV/c^2 and for EMC-EMC combination it is 1.2 GeV/c^2 $< m_T <$ 2.2 GeV/c^2.

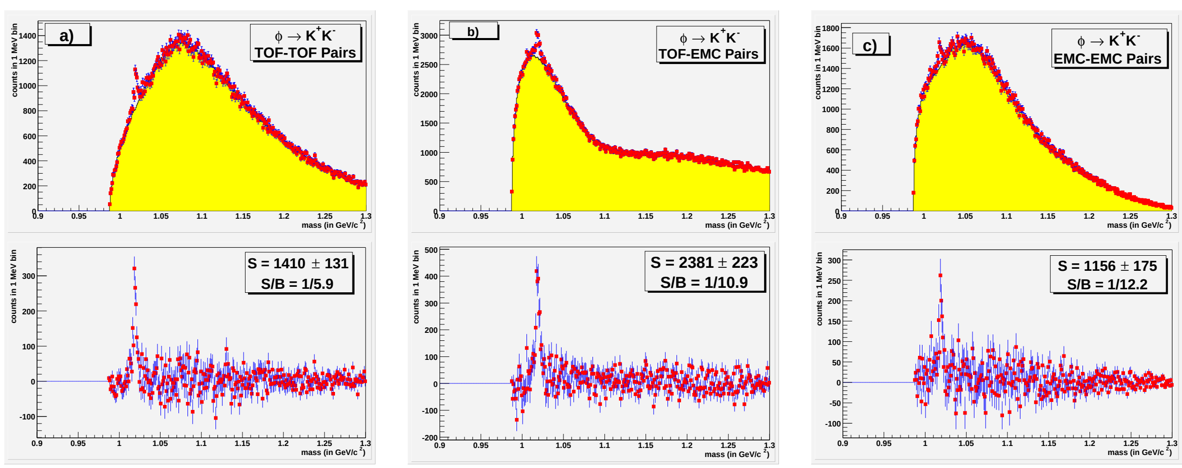

Figure 3: Invariant mass distributions of ϕ reconstructed in the K^+K^- channel for minimum bias events for (a-left) TOF-TOF Pairs, (b-middle) TOF-EMC pairs and (c-right) EMC-EMC Pairs. In the top row, raw invariant mass distributions are shown with the normalized mixed-event pairs superposed. The bottom row shows the subtracted spectra.

5 Summary and Outlook

ϕ mesons are reconstructed via the K^+K^- channel by the PHENIX experiment. The PHENIX preliminary dN/dy for $\phi \rightarrow K^+K^-$ was 2.01 $\pm$ 0.22$(stat)$ $^{+1.01}_{-0.52}(syst)$ [4] which used only the TOF for particle identification. We have included the EMC since then yielding about 3.5 times more statistics as compared to the TOF-TOF pairs. The higher statistics will enable us to measure the yield dN/dy with better precision. Also the excellent detector mass resolution combined with the higher statistics enables us to measure the ϕ width and mass with good precision and study the ϕ lineshape as a function of the centrality.

References

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