ϕ Meson Measurement in Cu+Au Collisions at $\sqrt{s_{NN}}$ = 200 GeV with the PHENIX Muon Arms at RHIC

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Introduction

- A major objective in the field of nuclear physics is to characterize the quark-gluon plasma (QGP) formed in high-energy heavy-ion collisions
- The ϕ meson is a good probe for studying the QGP properties because it is sensitive to several aspects of the collision, including strangeness enhancement [1]
- Due to its small inelastic cross section for interaction with nonstrange hadrons [2, 3], the ϕ meson may reflect the initial evolution of the system
- Furthermore, the y dependence of ϕ production in asymmetric heavy-ion collisions provides the means of accessing different mixtures of initial & final state effects
- The absence of strong interactions between muons & the surrounding hot hadronic matter makes the $\phi \rightarrow \mu^+\mu^-$ decay channel particularly useful
- Presented is the measurement of ϕ meson production & nuclear modification in Cu+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV at both forward Cu-going direction ($1.2 < y < 2.2$) & backward Au-going direction ($-2.2 < y < -1.2$) rapidities over the dimuon p_T range 1-5 GeV/c

Muon Detection in PHENIX

- The PHENIX Detector at RHIC is optimized to measure hadrons, photons & electrons in the Central Arm ($|y| < 0.35$) & muons in the forward Muon Arms ($1.2 < |y| < 2.2$) [4]
- Here, the Muon Arms were used to study dimuons coming from ϕ mesons

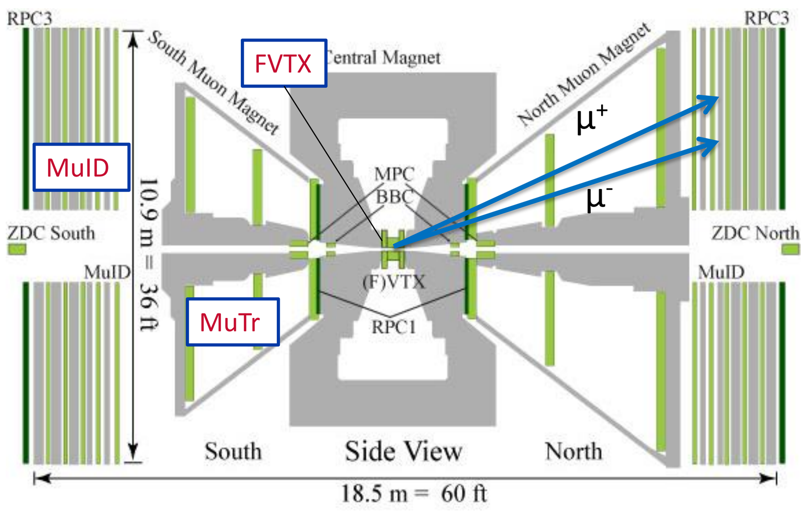

FIG 1. The PHENIX Muons Arms during the 2012 run.

- The Muon Arms consist of [4]:
  - Absorbers to enhance the muon-to-hadron acceptance
  - Muon Tracker (MuTr) to measure muon momenta
  - Muon Identifier (MuID)
  - Forward Silicon Vertex Detector (FVTX)

Data Analysis

- In this analysis, ϕ meson candidates are selected from two reconstructed muons in the RHIC Cu+Au dataset from 2012. 4.73 billion ($\mathcal{L} = 0.97\ \mathrm{nb}^{-1}$) sampled MB events are used within ± 10 cm z-vertex & $0\% - 93\%$ centrality.
- A set of quality assurance cuts is applied to select good muon candidates &improve signal extraction, as detailed in Ref. [5]
- To evaluate nuclear matter effects, the invariant yield is measured as described in Ref. [5] & compared to that measured at the same energy in the RHIC p+p dataset from 2009 ($\mathcal{L} = 14.1\ \mathrm{pb}^{-1}$) [6] via the nuclear modification factor R_{CuAu} as follows:
  - $$R_{\mathrm{CuAu}} = \frac{N_{\mathrm{CuAu}}}{N_{\mathrm{coll}} N_{pp}}, \qquad (1)$$

  where N_{CuAu} & N_{pp} are the yields in Cu+Au & p+p collisions, respectively, & N_{coll} is the number of nucleon-nucleon collisions as determined by a Glauber simulation
- Ref. [5] contains more details, such as the detector acceptance & efficiency & an estimation of systematic uncertainties

ϕ Meson Signal Extraction

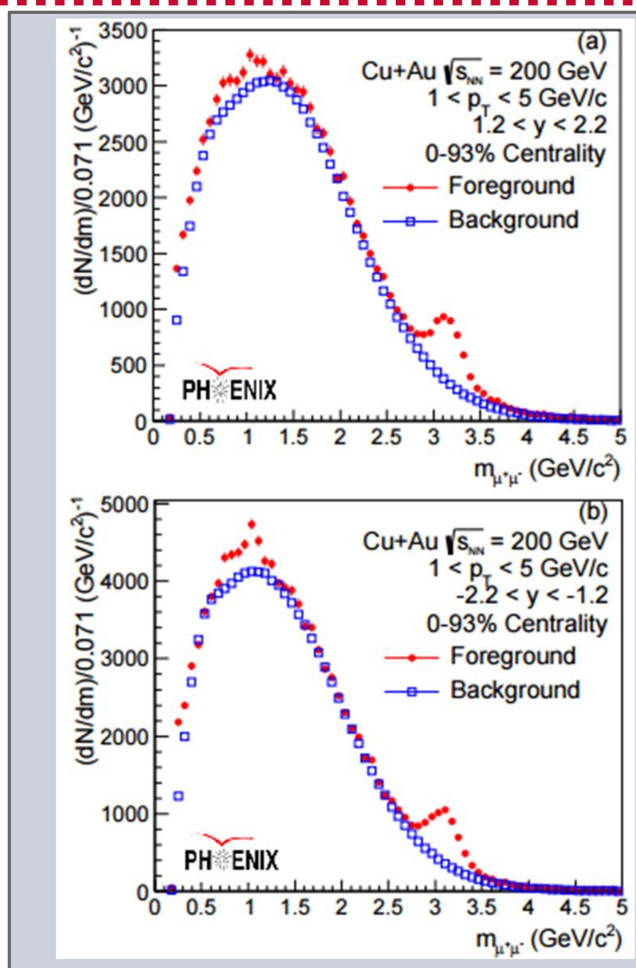

FIG 2. The unlike-sign mass spectra (red) & mixed-event background (blue) at forward (a) & backward rapidities

- In Fig. 2, the invariant mass distribution, which consists of unlike-sign dimuons, is shown in red
- The uncorrelated background, which comes from random associations, is described with a mass-dependent event mixing method as detailed in Ref. [5]. It shown in blue in Fig. 2.
- After background subtraction, the correlated background is fit with an exponential plus a linear, the ϕ & ω signals are each described by a Gaussian, & the ρ signal is fit with a Breit-Wigner distribution as seen in Fig. 3 to the right

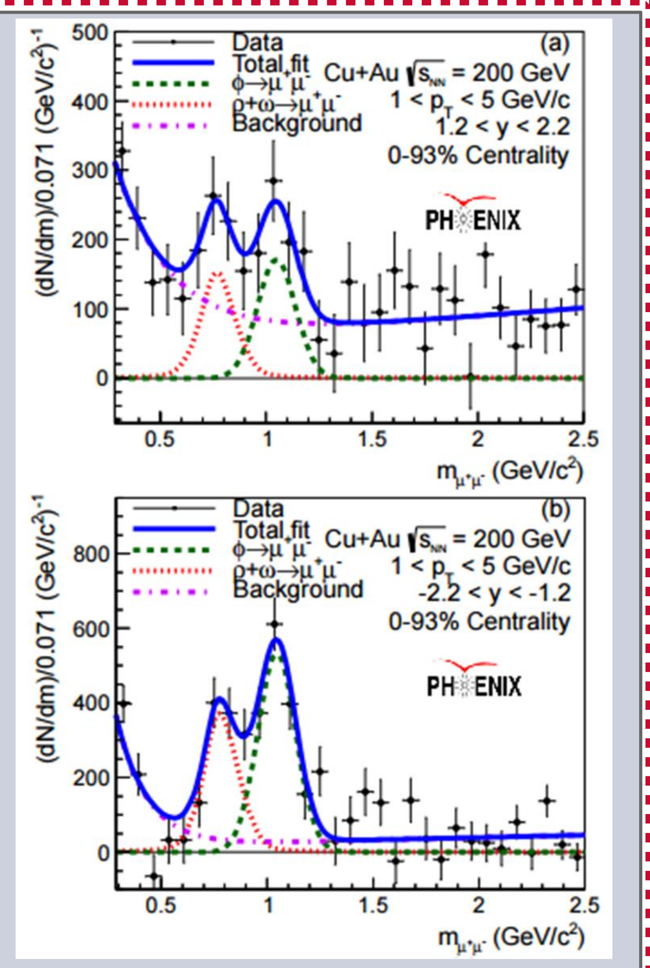

FIG 3. The background-subtracted mass spectra after fitting at forward (a) & backward (b) rapidities

Results & Discussion

Nuclear Modification Factor

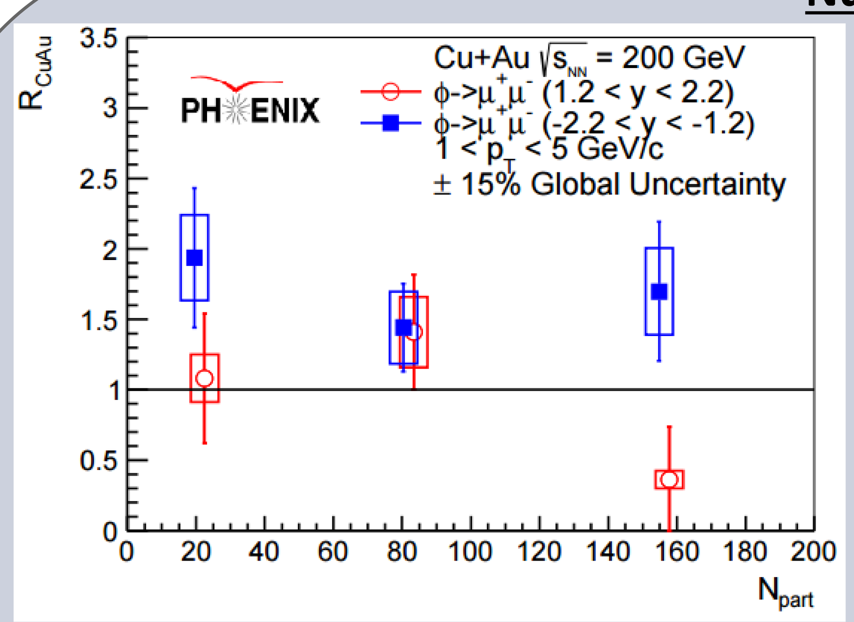

FIG 4. The ϕ meson nuclear modification factor as a function of N_{part} is measured over a range $1 < p_T < 5$ GeV/c & $1.2 < |y| < 2.2$. The Cu-going direction is shown in red & the Au-going direction is in blue. The centrality bins are 0%-20%, 20%-40%, & 40%-93%. The Cu-going points are shifted along the y-axis for visibility.

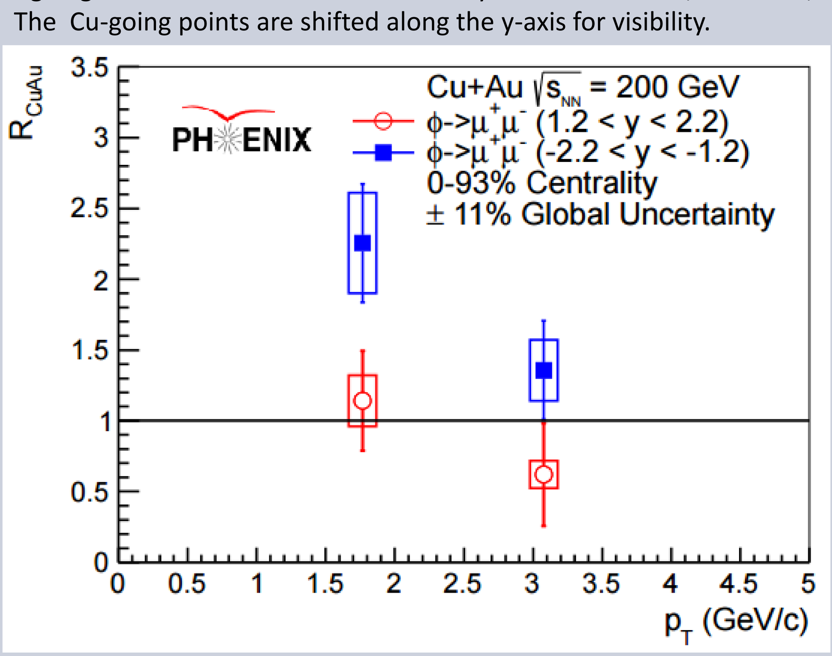

FIG 5. The ϕ meson nuclear modification factor as a function of p_T is measured for 0%-93% centrality & $1.2 < |y| < 2.2$. The Cu-going direction is shown in red & the Au-going direction is in blue. The p_T bins are 1-2.5 & 2.5-5 GeV/c.

- R_{CuAu} from Eqn. 1 was evaluated as a function of N_{part}, p_T, & y in Fig. 4-6, respectively
- Fig. 4 shows that ϕ meson production is enhanced over all centralities in the Au-going direction, while a suppression is observed for the most central collisions in the Cu-going direction
- Fig. 5 shows an enhancement at low p_T in the Au-going direction, while in the Cu-going direction R_{CuAu} is consistent with 1

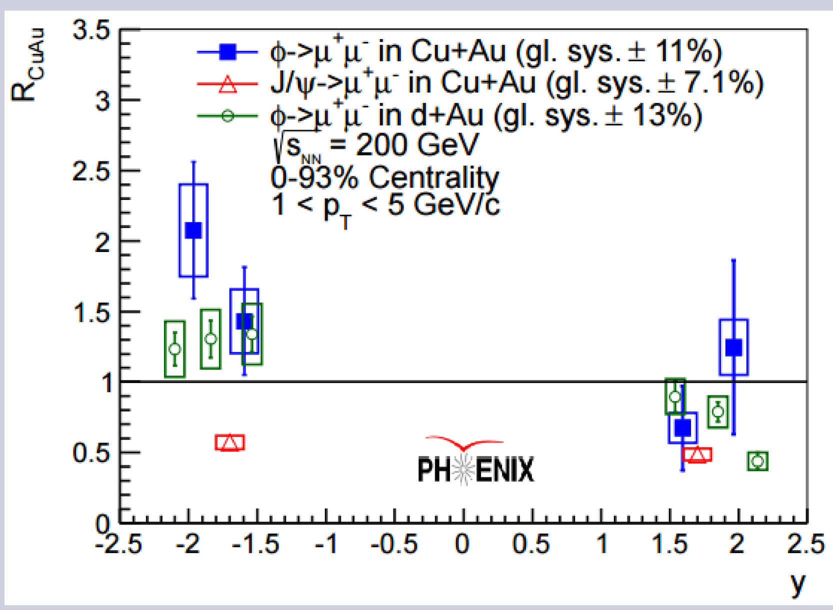

FIG 6. The ϕ meson nuclear modification factor as a function of y is measured over a range $1 < p_T < 5$ GeV/c & 0%-93% centrality & shown in blue. The bins are $1.2 < |y| < 1.8$ & $1.8 < |y| < 2.2$. Results for ϕ in d+Au (green) [7] & J/ψ in Cu+Au (red) [8] are shown.

- Fig. 6 shows $R_{\mathrm{CuAu}} > 1$ in the Au-going direction & ≤ 1 in the Cu-going direction, which is similar to the trend for ϕ in d+Au [7] as well as measurements made by ALICE at large rapidity in p+Pb [9]
- In Fig. 6, J/ψ in Cu+Au collisions [8] is more strongly suppressed than ϕ at backward rapidity, similar to what was seen in d+Au [7]

Forward/Backward Ratio

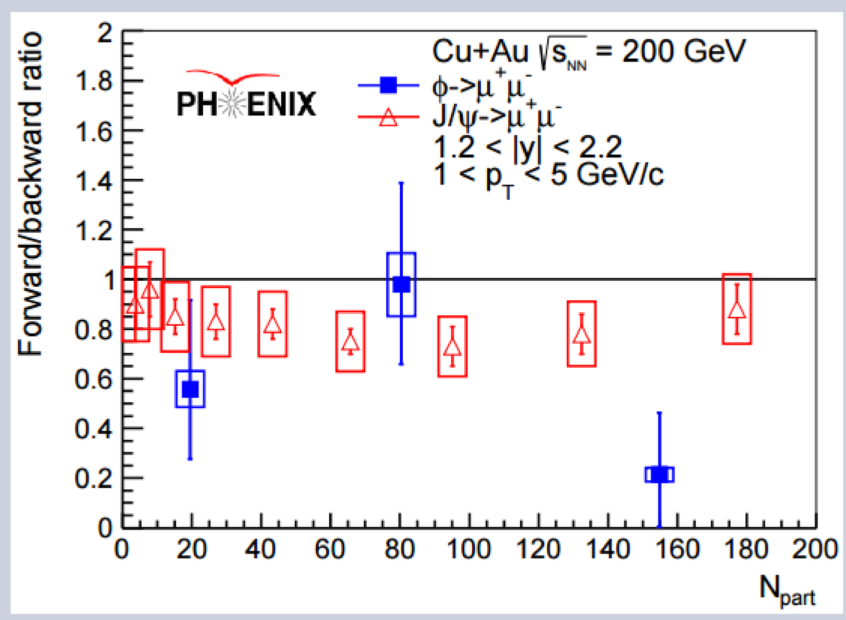

FIG 7. The ϕ meson forward/backward ratio (blue) as a function of N_{part} is measured over a range $1 < p_T < 5$ GeV/c & $1.2 < |y| < 2.2$. The centrality bins are 0%-20%, 20%-40%, & 40%-93%. The J/ψ results from Ref. [8] are plotted in red for comparison.

- The forward & backward differences can be quantified by taking the ratio of the yields as seen in Fig. 7
- In the most central collisions, the forward/backward ratio for ϕ (~0.2) is smaller than for J/ψ (~0.8) [8]
- This may suggest different effects on closed charm & closed strangeness production in Cu+Au collisions
- Or it may suggest that J/ψ & ϕ mesons follow different production mechanisms

- Additional results & discussion, including tables & more plots, can be found in Ref. [5]

Summary & Outlook

- Presented here was a first measurement of ϕ production in heavy-ion collisions in the forward & backward regions at RHIC
- This study was statistically limited & thus a precise measurement with high statistics, & theory calculations, are needed to make conclusions about the effects of hot & cold nuclear matter as well as other various physics processes

Acknowledgements

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