

ϕ Meson Production at Forward Rapidity with the PHENIX Detector at RHIC

Murad Sarsour
(for the PHENIX Collaboration)
Georgia State University

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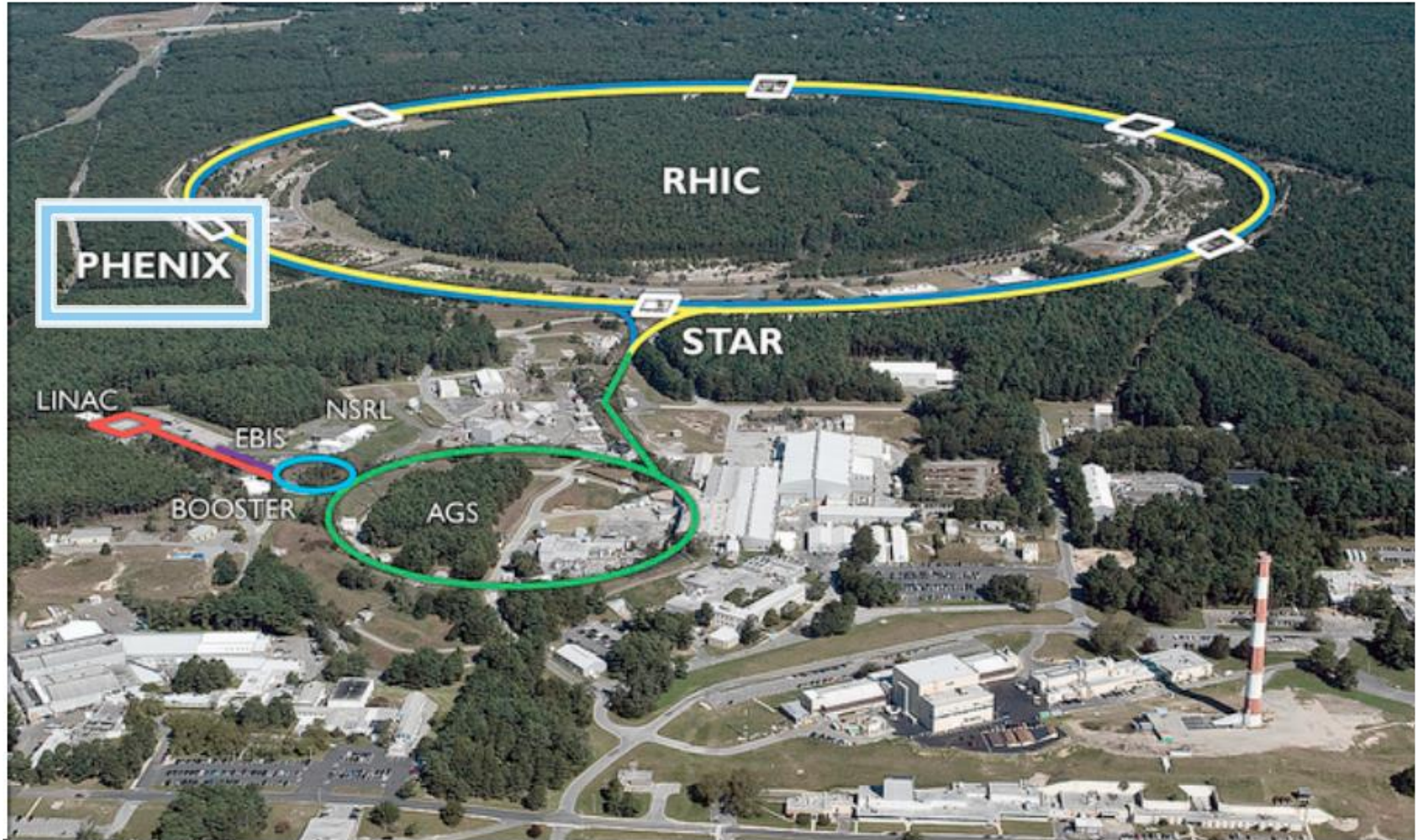
Motivation

- ❑ In Au+Au collisions: an excellent probe for studying the hot and dense state of strongly interacting matter formed (QGP) - sensitive to several aspects of the collision, including modifications of strangeness production in bulk matter.
- ❑ In $p+p$ collisions: provide baseline for heavy ion collisions.

Beyond that, ϕ meson is of general interest:

- Could have similar production mechanism as for J/ψ and Υ
- The heaviest easily accessible meson made of light quarks
 \Rightarrow it provides the largest lever arm accessible for anything that scales with mass (like collective effects).
- ❑ In $d+Au$ collisions: Understand cold nuclear matter effects in order to disentangle hot nuclear (QGP related) effects in A+B collisions.
 - Cold nuclear matter effects: Modification of the production cross section in a nuclear target. Generally depend on rapidity, p_T , and mass of the probe.
 - The absence of strong interactions between muons & the surrounding hot hadronic matter makes the $\phi \rightarrow \mu^+ \mu^-$ decay channel particularly useful
 - The rapidity dependence of ϕ production in asymmetric heavy-ion collisions (Cu+Au collisions) provides the means of accessing different mixtures of initial & final state effects

The Relativistic Heavy Ion Collider (RHIC)



- RHIC is an extremely versatile machine, located at Brookhaven National Lab (BNL), that has collided a variety of collision species at various energies
- Two operating experiments at RHIC are PHENIX and STAR

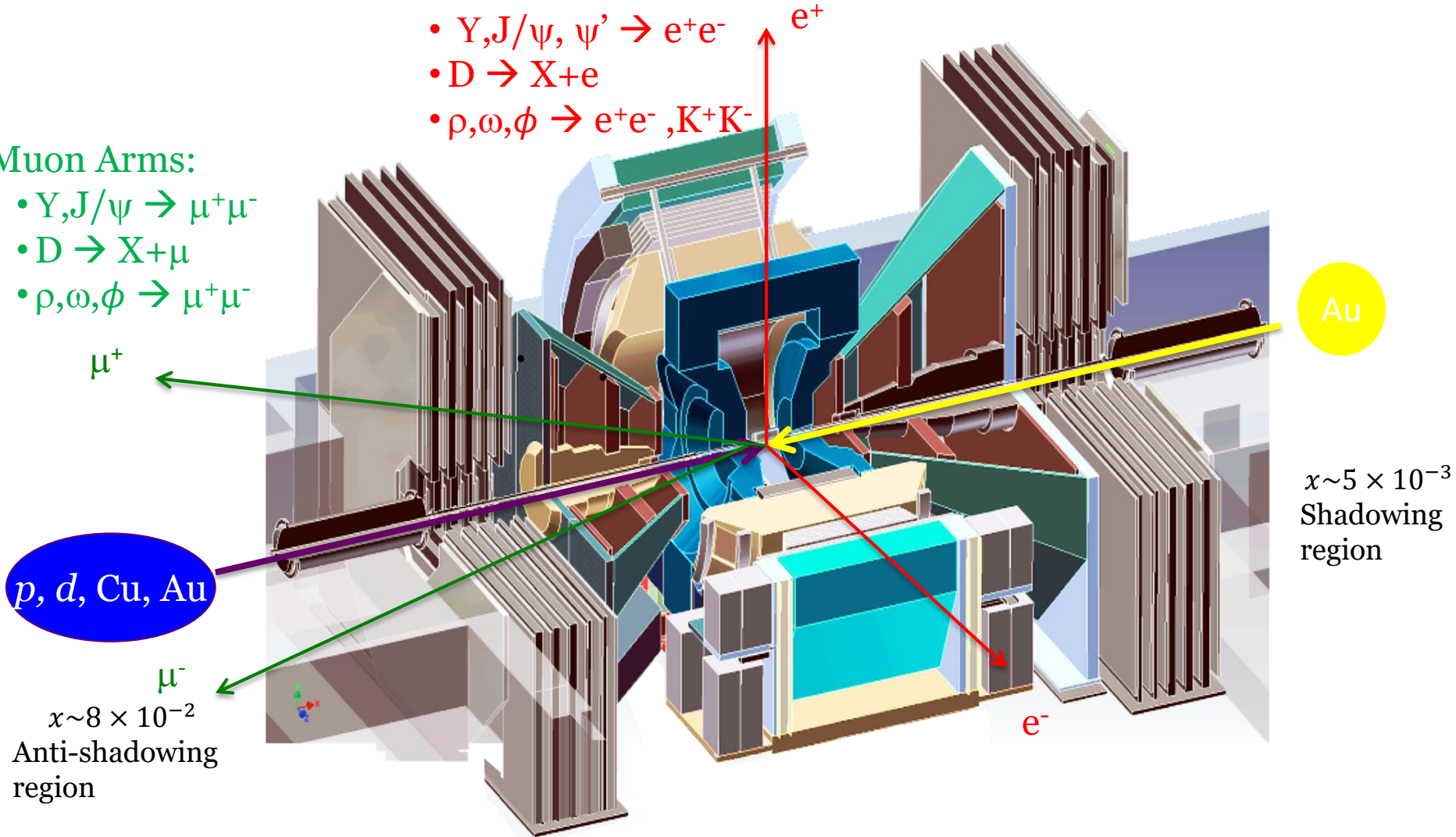
The PHENIX Detector

Central Arms:

- $\Upsilon, J/\psi, \psi' \rightarrow e^+e^-$
- $D \rightarrow X+e$
- $\rho, \omega, \phi \rightarrow e^+e^-, K^+K^-$

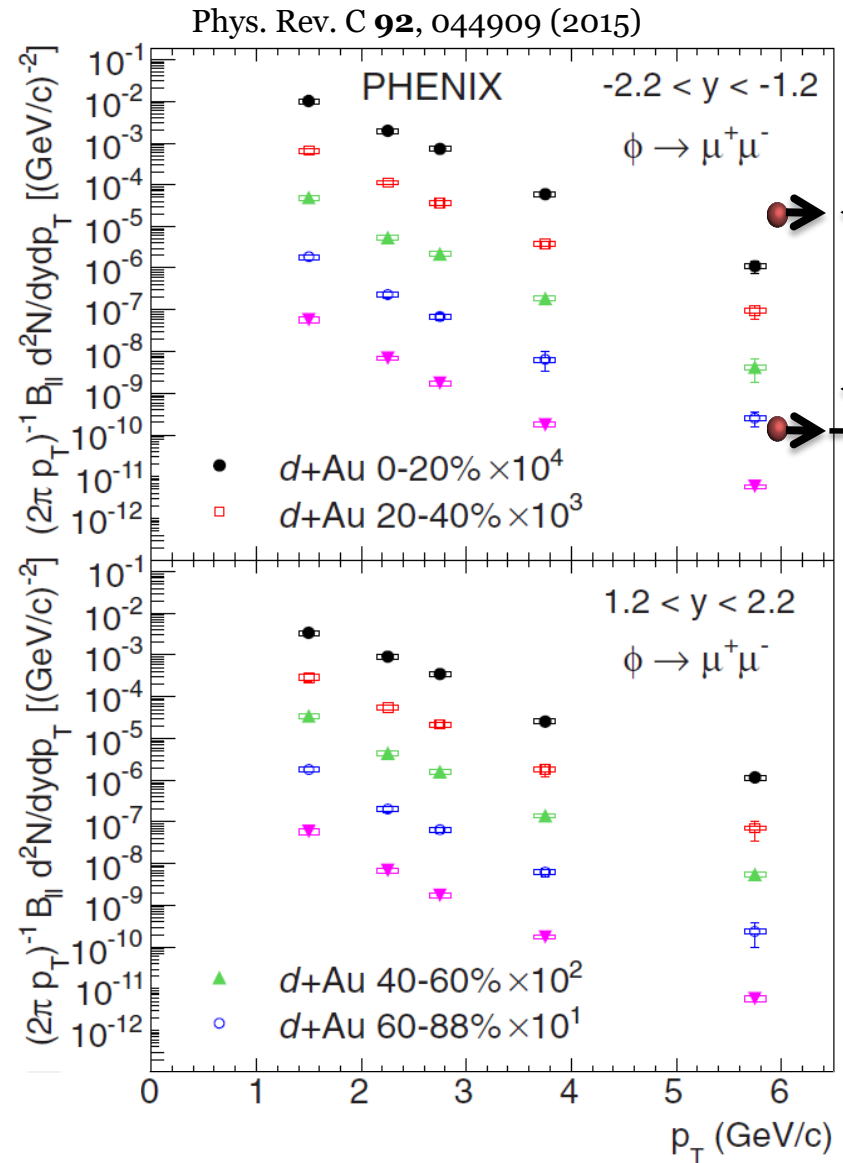
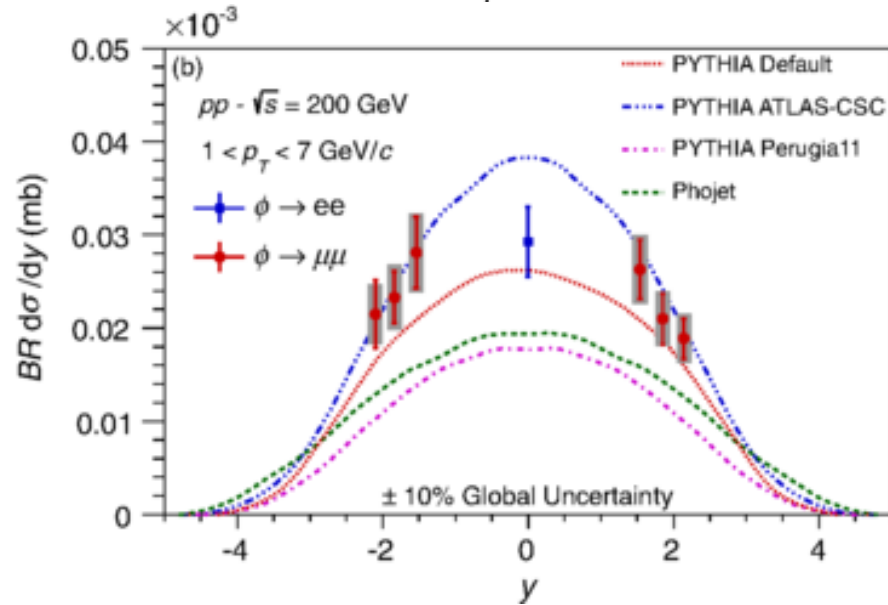
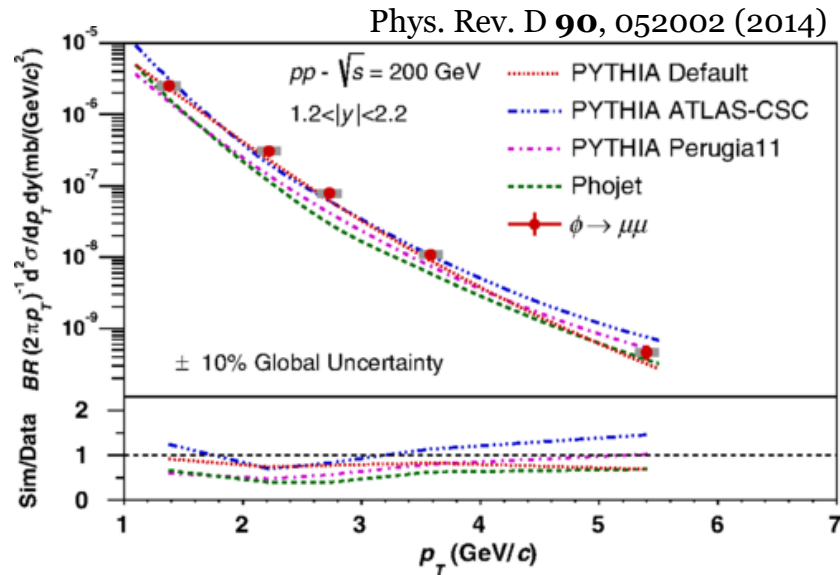
Muon Arms:

- $Y, J/\psi \rightarrow \mu^+\mu^-$
- $D \rightarrow X + \mu$
- $\rho, \omega, \phi \rightarrow \mu^+\mu^-$



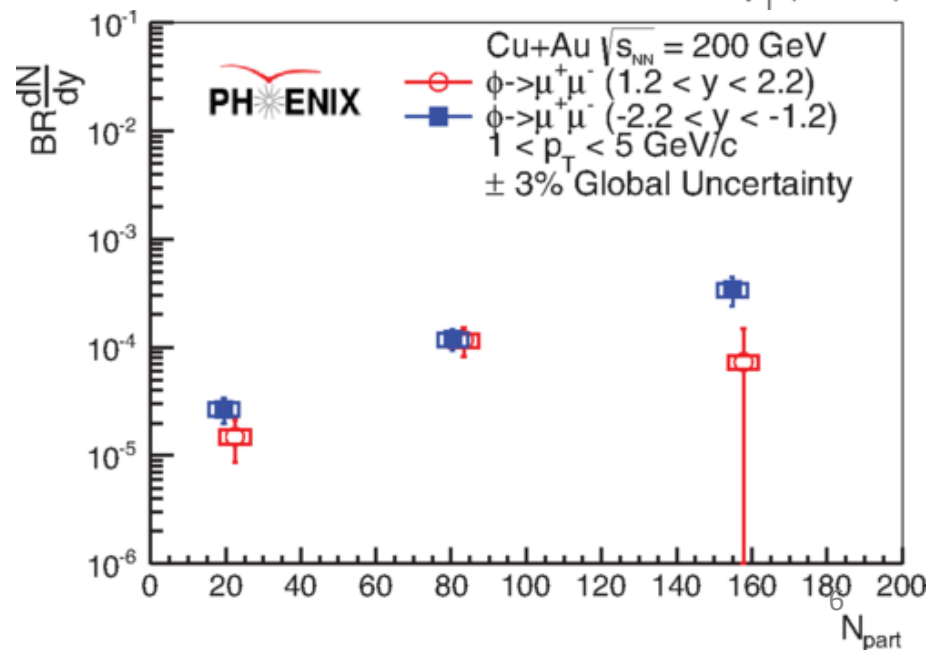
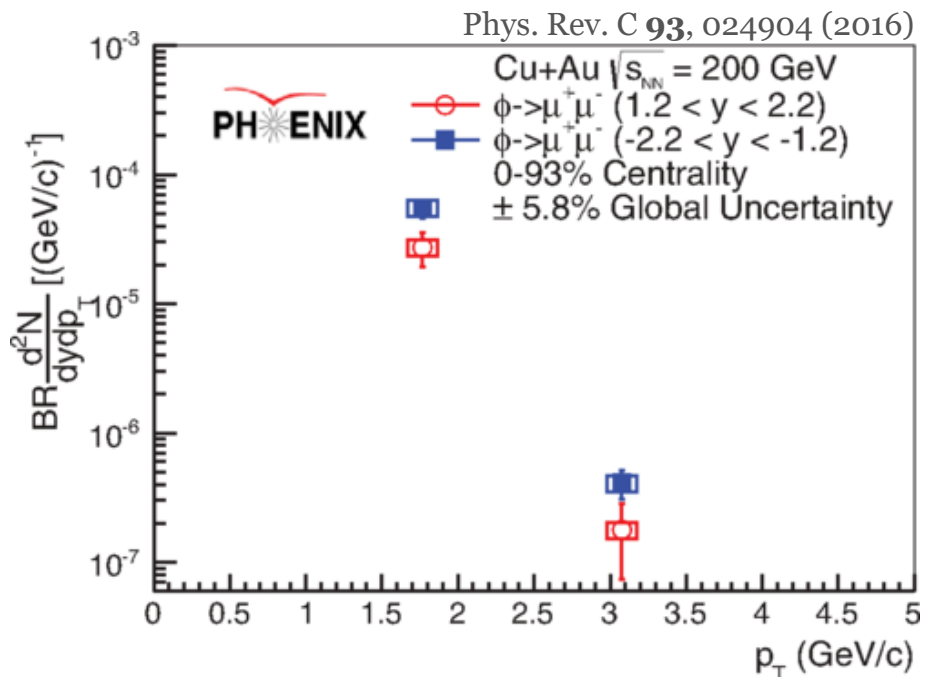
- Large rapidity coverage: $1.2 < |y| < 2.2$ and $|y| < 0.35$
- PHENIX recorded $p+p$, $p+Au$, $p+Al$, $d+Au$, $He+Au$, $Cu+Au$ and $Au+Au$ collisions @ $\sqrt{s_{NN}} = 200$ GeV and $p+p$ collisions @ $\sqrt{s_{NN}} = 510$ GeV.

ϕ Meson Production in $p+p$ & $d+Au$ Collisions



ϕ Meson Production in Cu+Au Collisions

- The first measurement of ϕ meson production and its nuclear modification in a heavy ion system at forward/backward rapidity at RHIC
- Extends measurements of ϕ from smaller systems, $p+p$ and $d+Au$
- Suppression at forward rapidity relative to backward rapidity. Most apparent at most central events.



Nuclear Modification Factor, R_{AB}

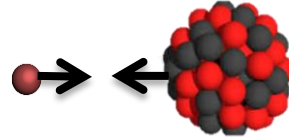
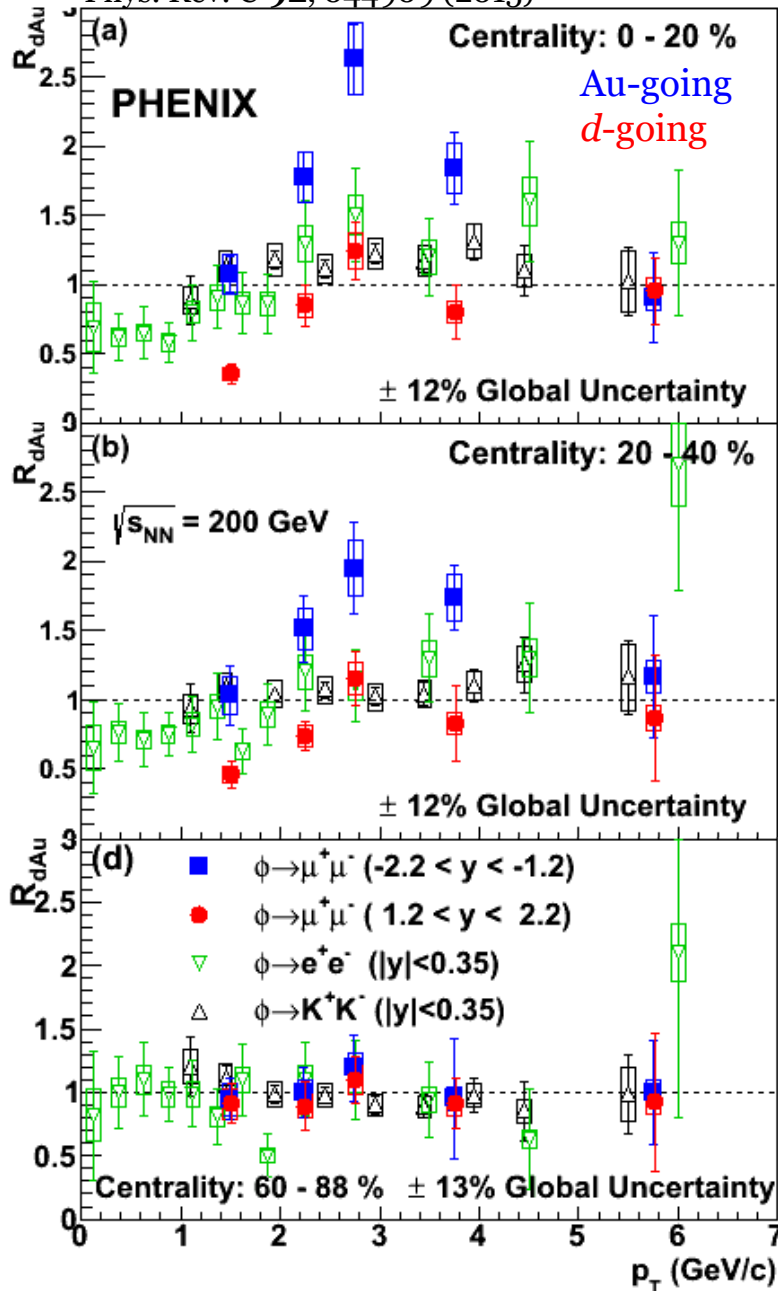
Modification of the production cross section in a nuclear target (cold) and QGP related (hot). Generally, depend on rapidity, p_T , and mass of the probe.

$$R_{AB} = \frac{d^2 N_{AB}/dydp_T}{N_{coll} \times d^2 N_{pp}/dydp_T}$$

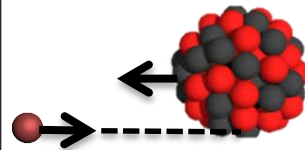
where $d^2 N_{AB}/dydp_T$ is the per-event yield of particle production in $A+B$ collisions and $d^2 N_{pp}/dydp_T$ is the per event yield of the same process in $p+p$ collisions. Scaled by the number of nucleon-nucleon collisions in the $A+B$ system, N_{coll} .

CNM for ϕ Meson / d +Au Collision

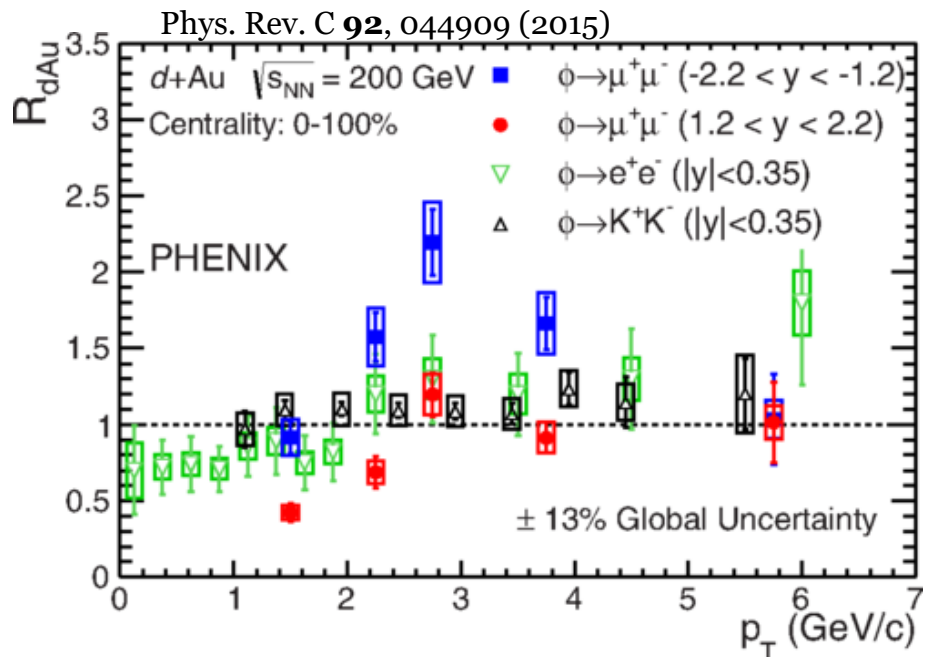
Phys. Rev. C **92**, 044909 (2015)



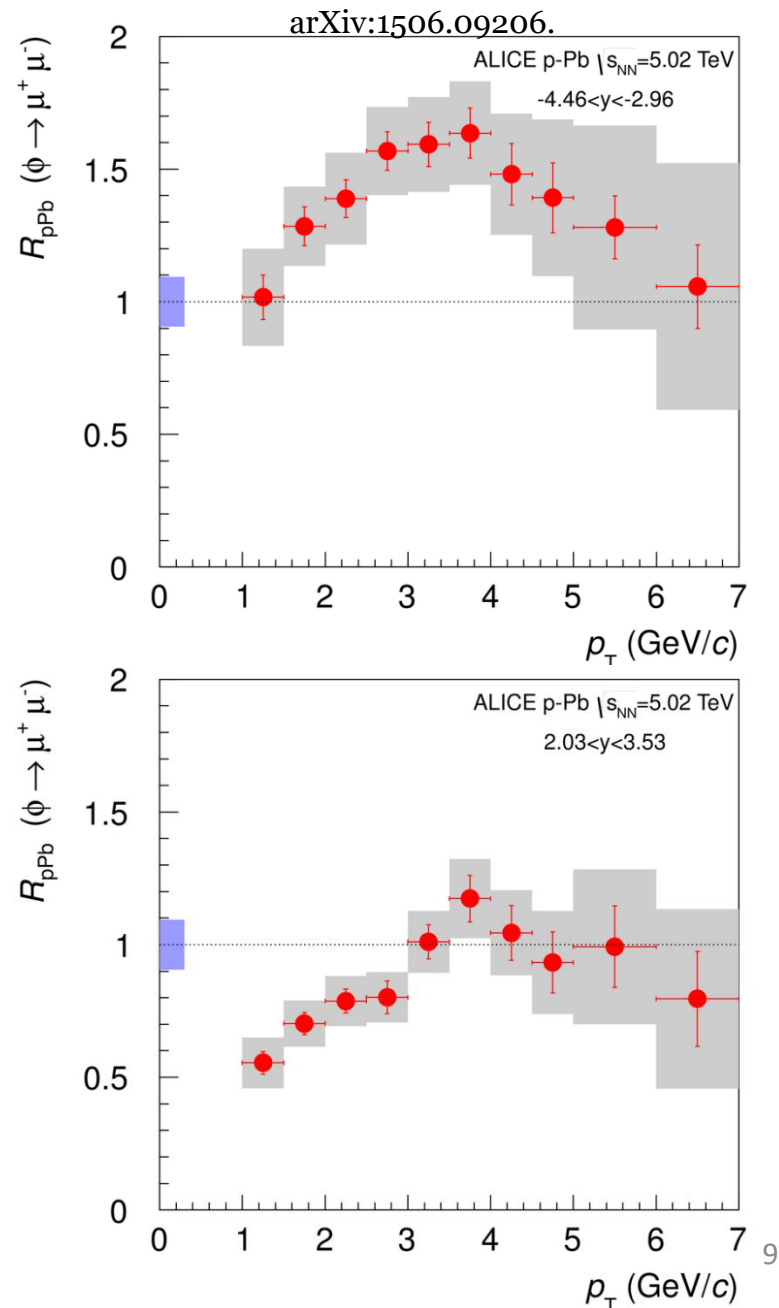
- An **enhancement** (**suppression**) has been observed at **backward** (**forward**) rapidity region in most central d +Au collision.
- ❖ The observed **enhancement** at **backward** rapidity is a typical behavior of a Cronin effect.



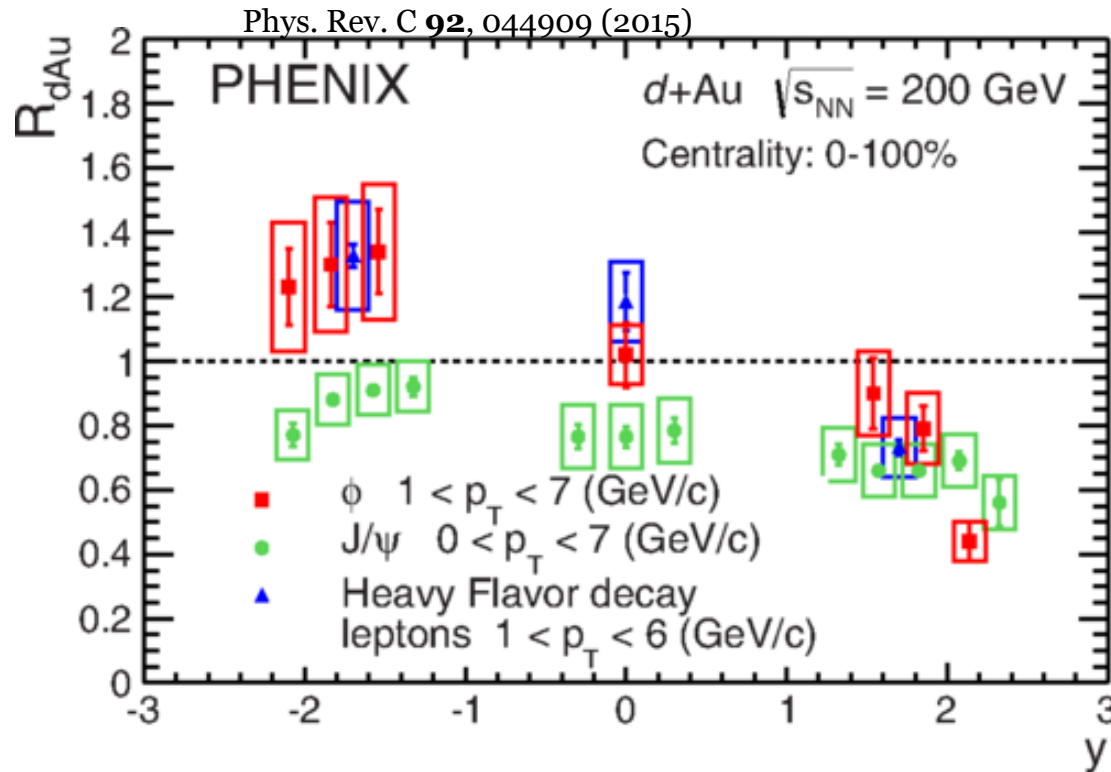
Other ϕ Measurements



- ❖ The R_{dAu} enhancement (suppression) in the Au-going (d -going) direction is consistent with what is observed by the **ALICE** collaboration at $\sqrt{s_{NN}} = 5.02$ TeV in $p+Pb$ collisions



ϕ Meson vs Open & Closed Heavy Flavor



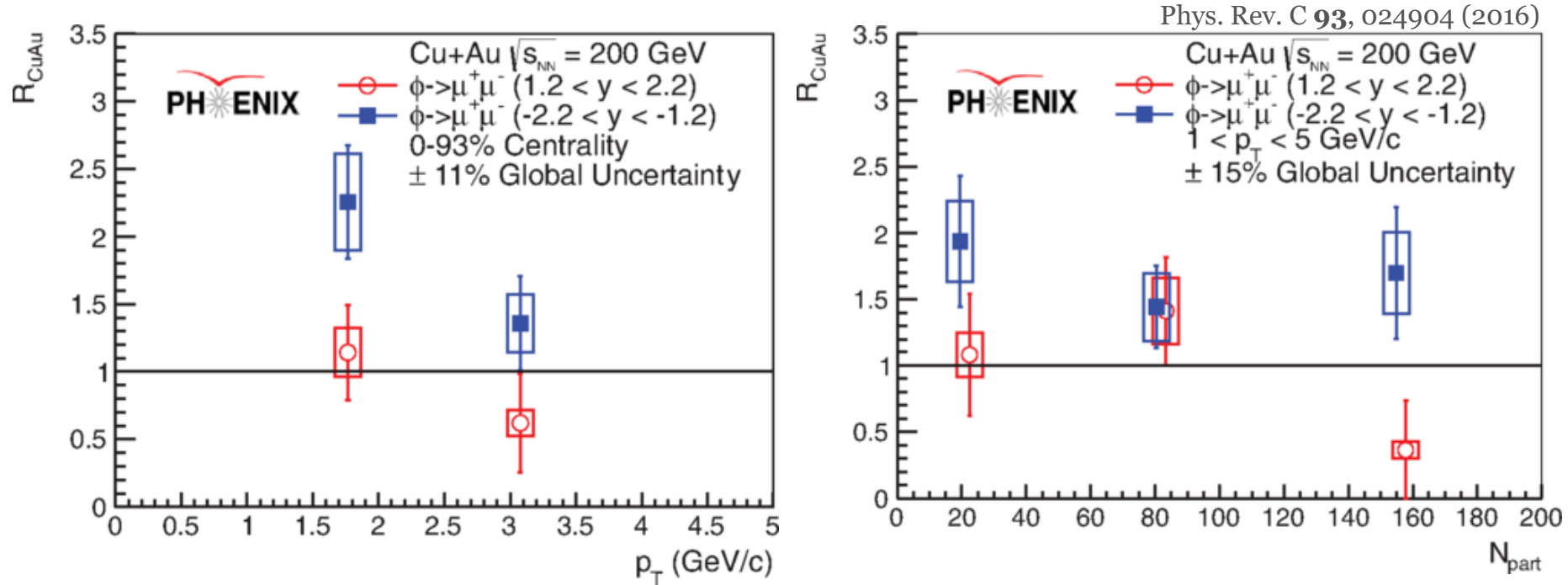
- ❖ Similar nuclear modifications to those in ϕ production as a function of rapidity is observed in heavy flavor decay leptons and inclusive charged hadrons production \Rightarrow

Similar cold nuclear matter effects

OR

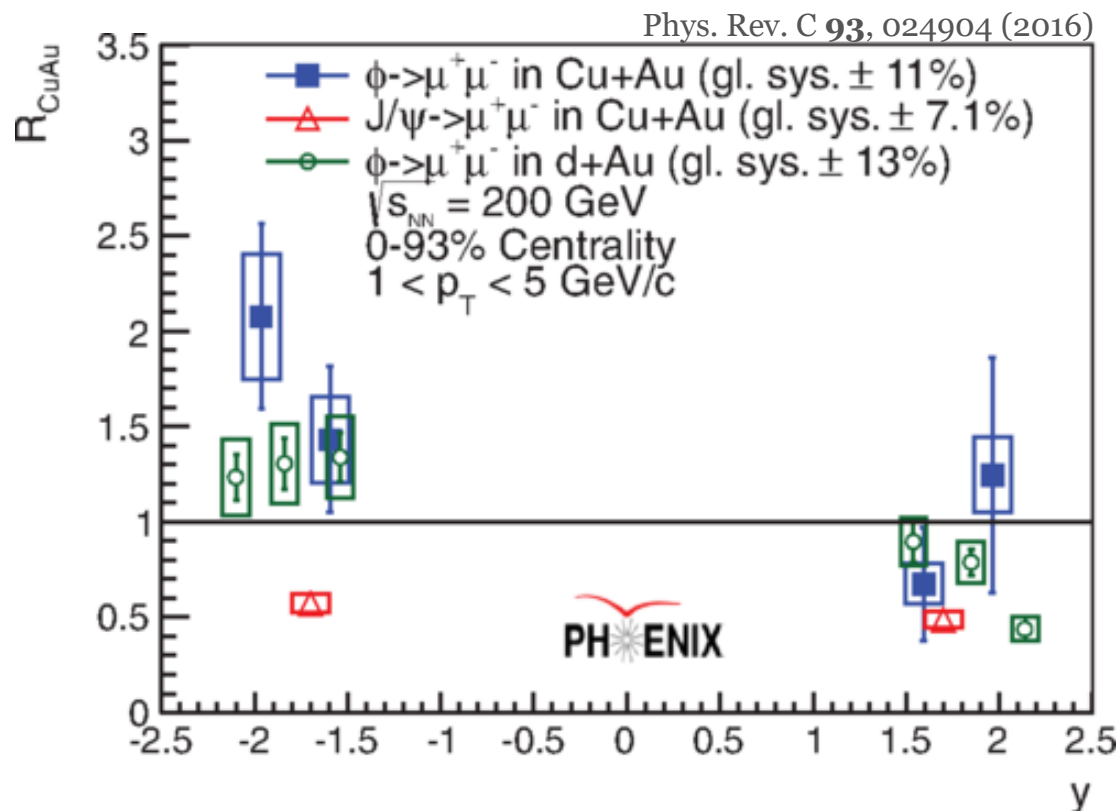
Different processes act on open HF and ϕ . The match May be a coincidence

ϕ Meson R_{CuAu}



- ❖ 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

ϕ Meson Production in Cu+Au Collisions

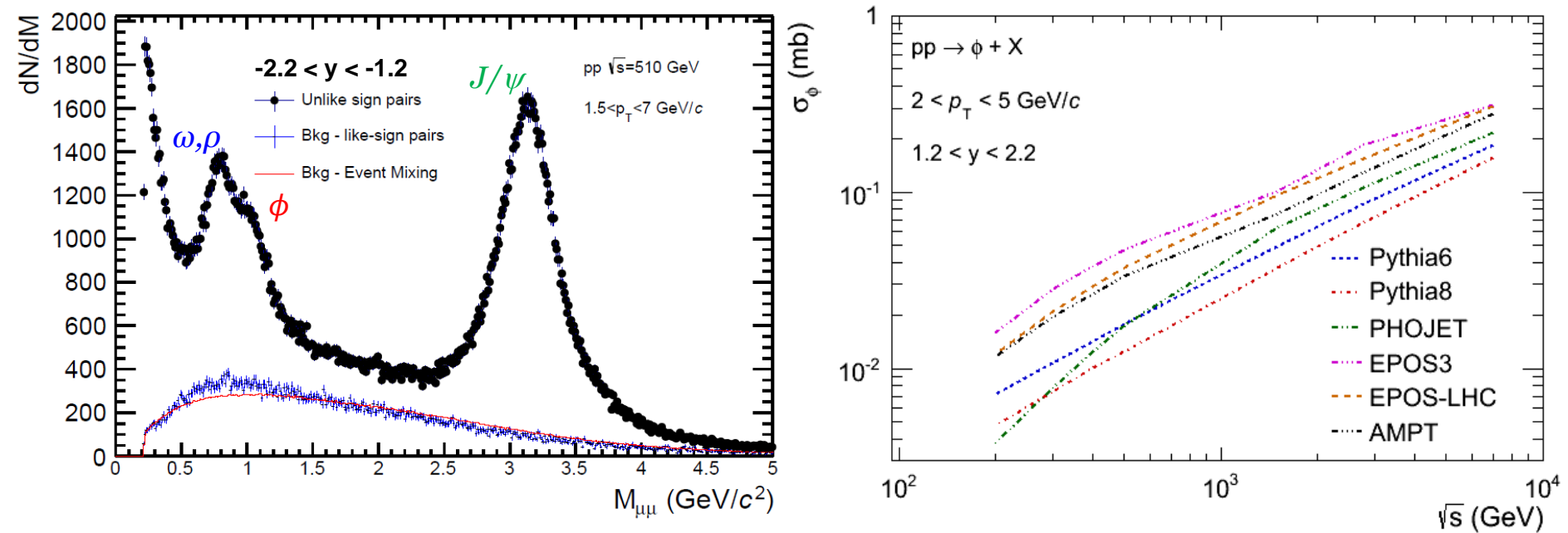


- Integrated over all centralities, ϕ in Cu+Au is consistent with ϕ in d+Au not with J/ψ in Cu+Au
 - In the most central collisions, the forward/backward ratio for ϕ (~ 0.2) is smaller than for J/ψ (~ 0.8) (PRC **90**, 064908 (2014))
- May suggest that J/ψ & ϕ mesons follow different production mechanisms

Outlook!

ϕ Meson Production in $p+p$ Collision at $\sqrt{s} = 510$ GeV

❖ PHENIX collected 135.87 pb^{-1} of $p+p$ collisions in 2013 @ $\sqrt{s} = 510$ GeV



- When added to 200 GeV, 2.76 TeV and 7.0 TeV data sets can be used to test various models take on the energy evolution

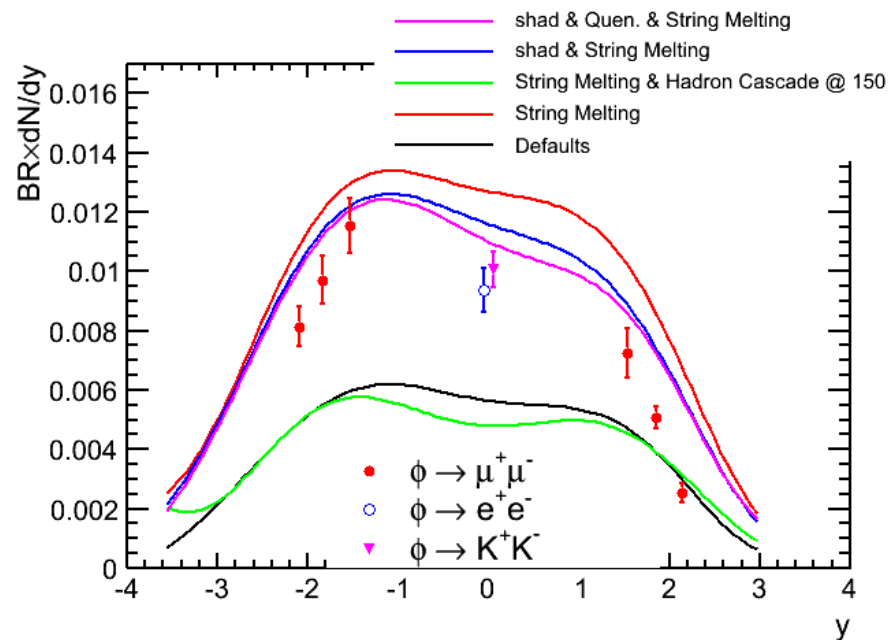
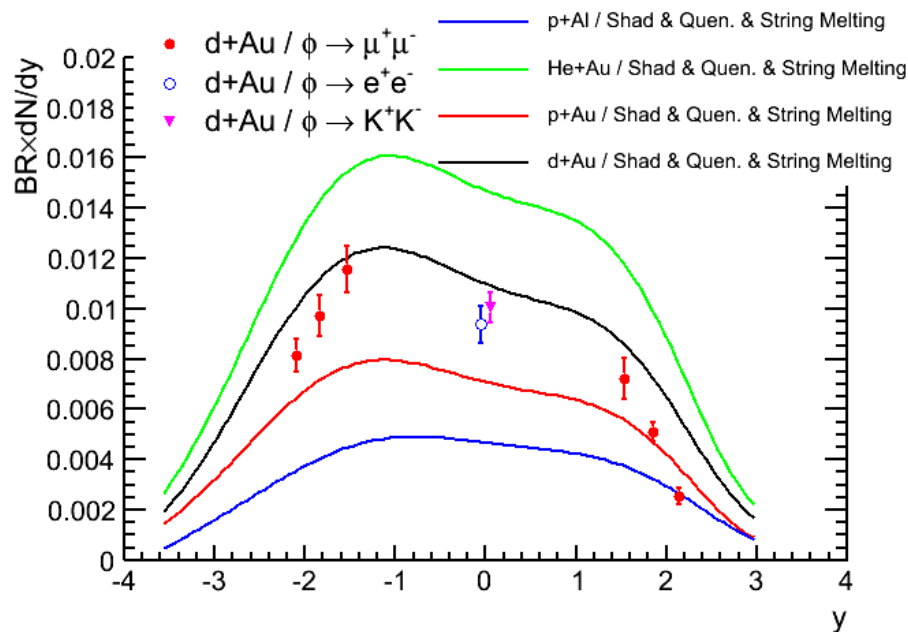
❖ In final review stage and to be released soon!

ϕ Meson Production in Small Systems

☐ PHENIX collected the following data sets: He+Au (2014) & p+Al and p+Au (2015)

– Can use these systems to disentangle the different cold nuclear effects- using the AMPT model for example!

☐ PHENIX collected large Au+Au (2014) data set with the FVTX

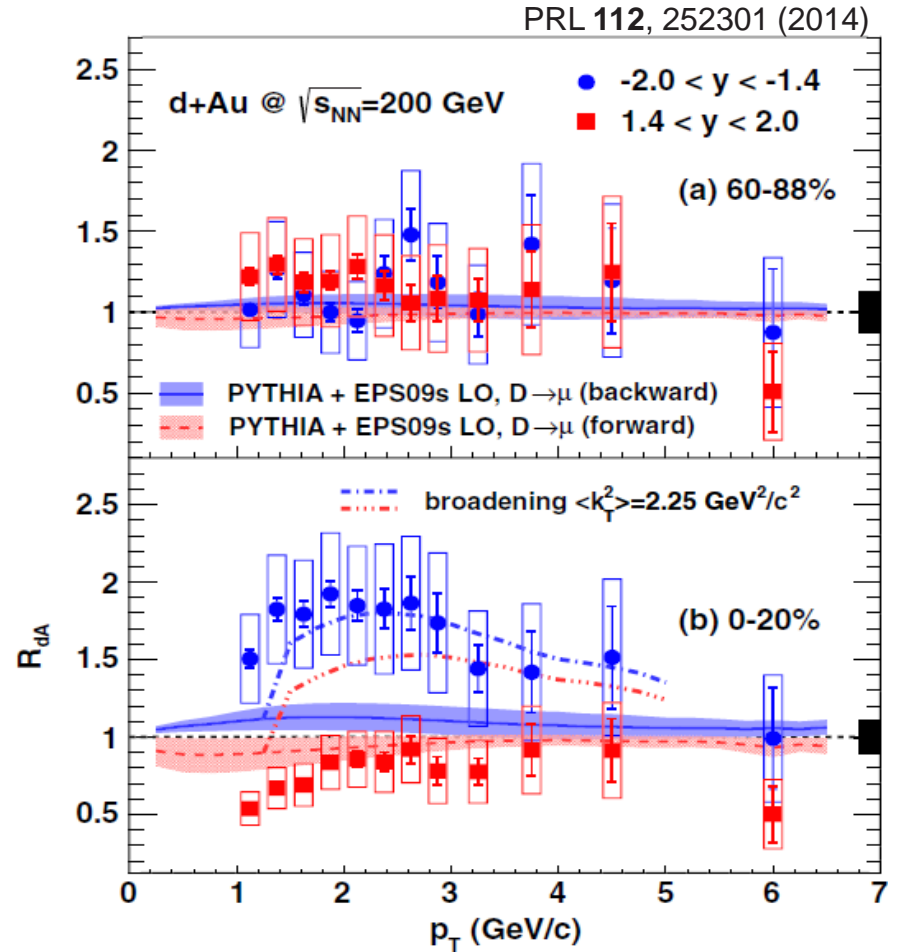
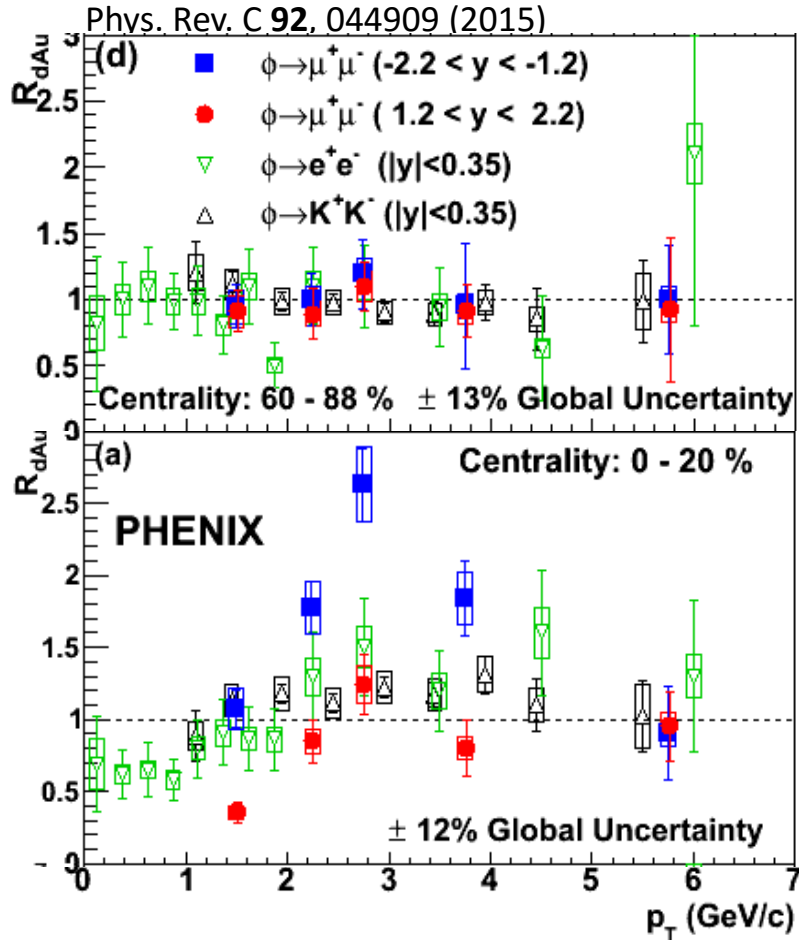


Summary

- The PHENIX collaboration measured ϕ production at forward/backward rapidities and over a wide p_T range to study CNM & HNM effects.
- An **enhancement** (**suppression**) of ϕ has been observed at **backward** (**forward**) rapidity region in most central d +Au collisions
- Similar behavior was previously observed for inclusive charged hadrons and open heavy flavor \Rightarrow similar cold nuclear matter effects?
- ϕ meson production in Cu+Au measurement suggested J/ψ & ϕ mesons follow different production mechanisms.
- New data sets (p +Au & p +Al) collected in 2015 will allow ϕ measurement at backward and forward rapidities along with other probes in less complicated p +Au & p +Al collisions \Rightarrow allow studying the different CNM effects using models like AMPT and EPOS.

Backup

ϕ Meson vs Open Heavy Flavor



- No modification in most peripheral
- Similar enhancement in most central

What can be done at PHENIX?

- PHENIX recorded $p+p$, $p+\text{Au}$, $p+\text{Al}$, $d+\text{Au}$, $\text{He}+\text{Au}$, $\text{Cu}+\text{Au}$ and $\text{Au}+\text{Au}$ collisions @ $\sqrt{s_{\text{NN}}} = 200 \text{ GeV}$ and $p+p$ collisions @ $\sqrt{s_{\text{NN}}} = 510 \text{ GeV}$.
- Large rapidity coverage: $1.2 < |y| < 2.2$ and $|y| < 0.35$

