

# $\phi$ Meson Production at Forward Rapidity with the PHENIX Detector at RHIC

Murad Sarsour  
(for the PHENIX Collaboration)  
Georgia State University

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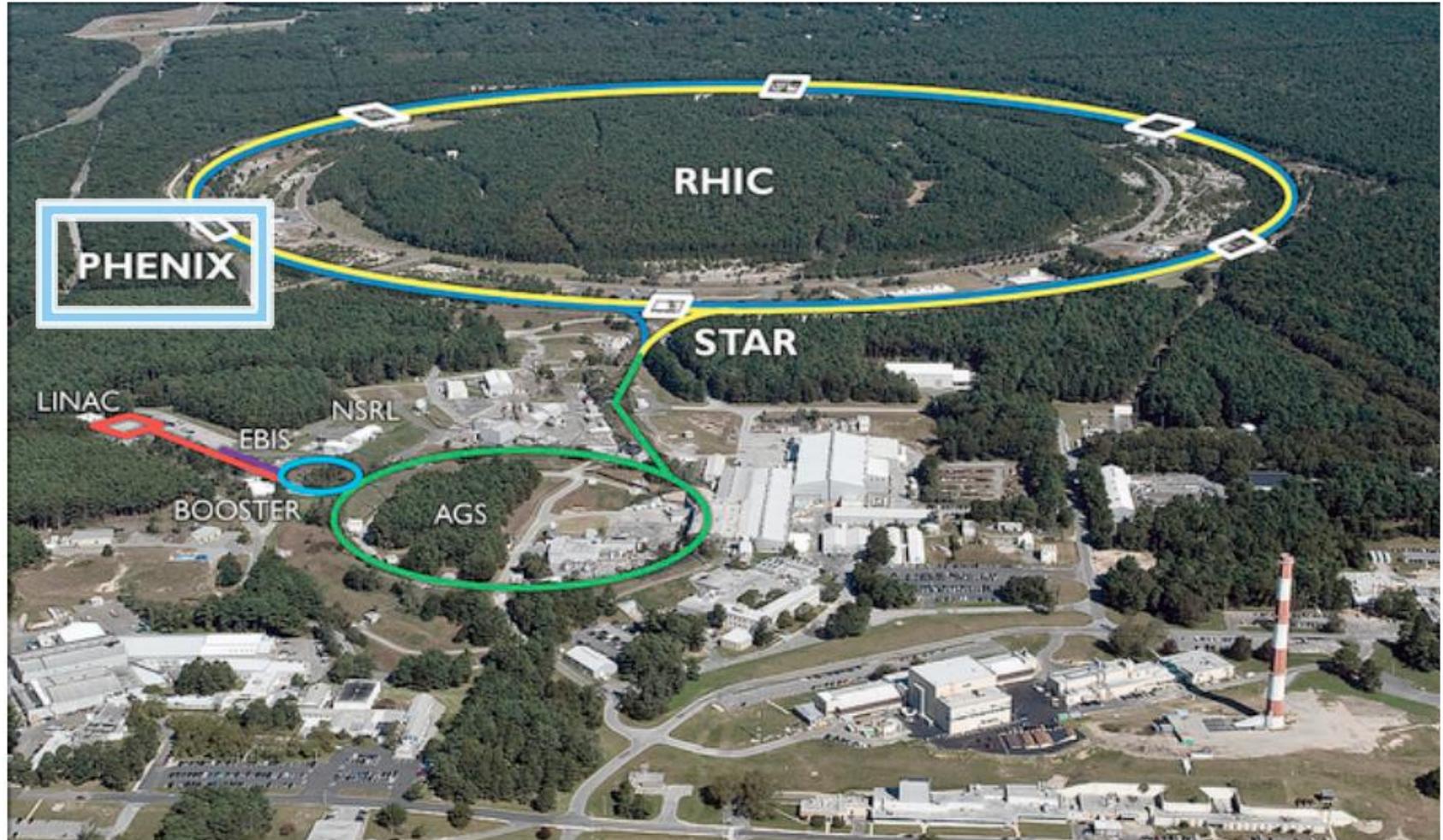
# Motivation

- ❑ 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,  $\phi$  meson is of general interest:

- Could have similar production mechanism as for  $J/\psi$  and  $\Upsilon$
- 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  $\phi$  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

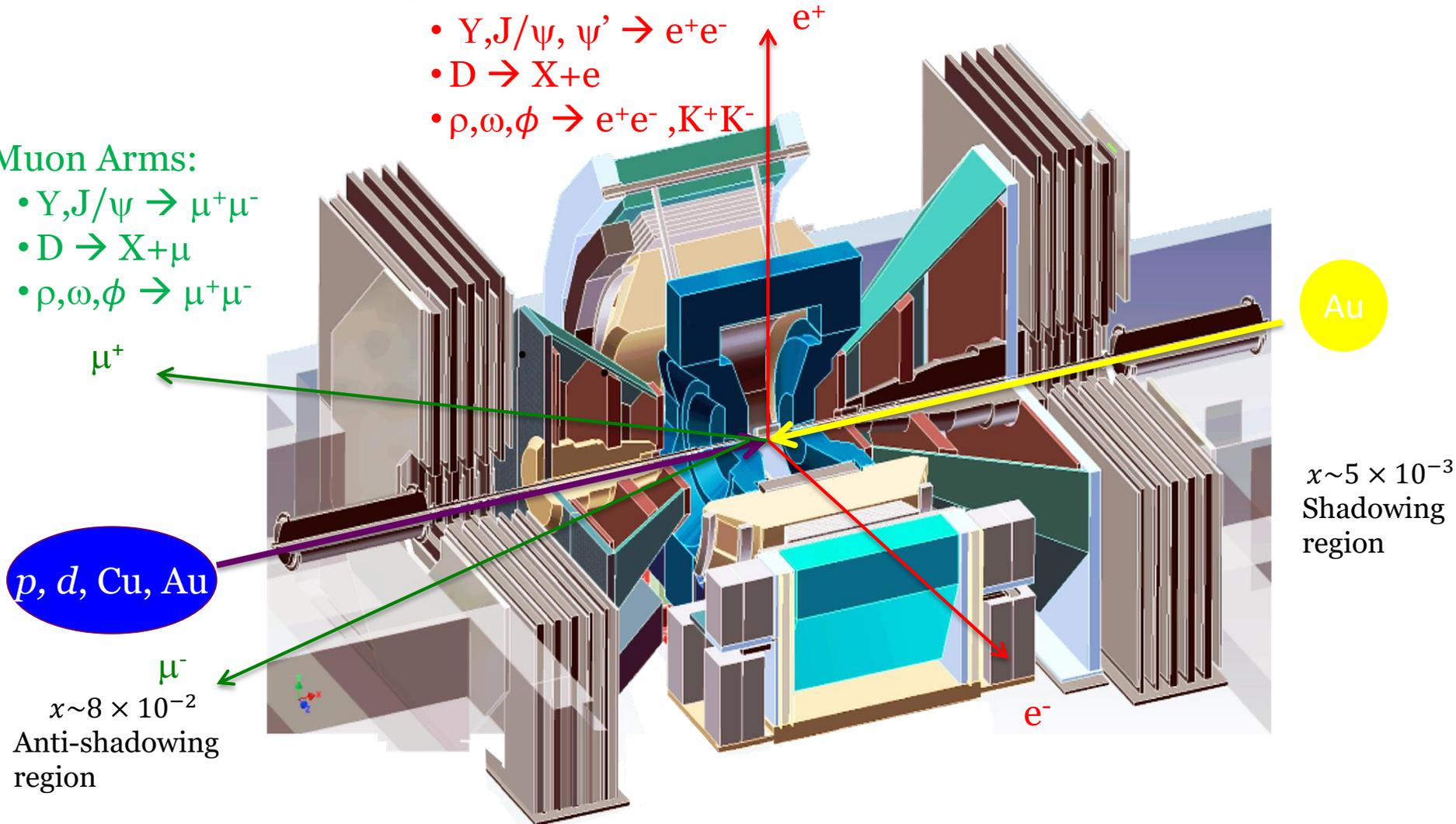
# The PHENIX Detector

## Central Arms:

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

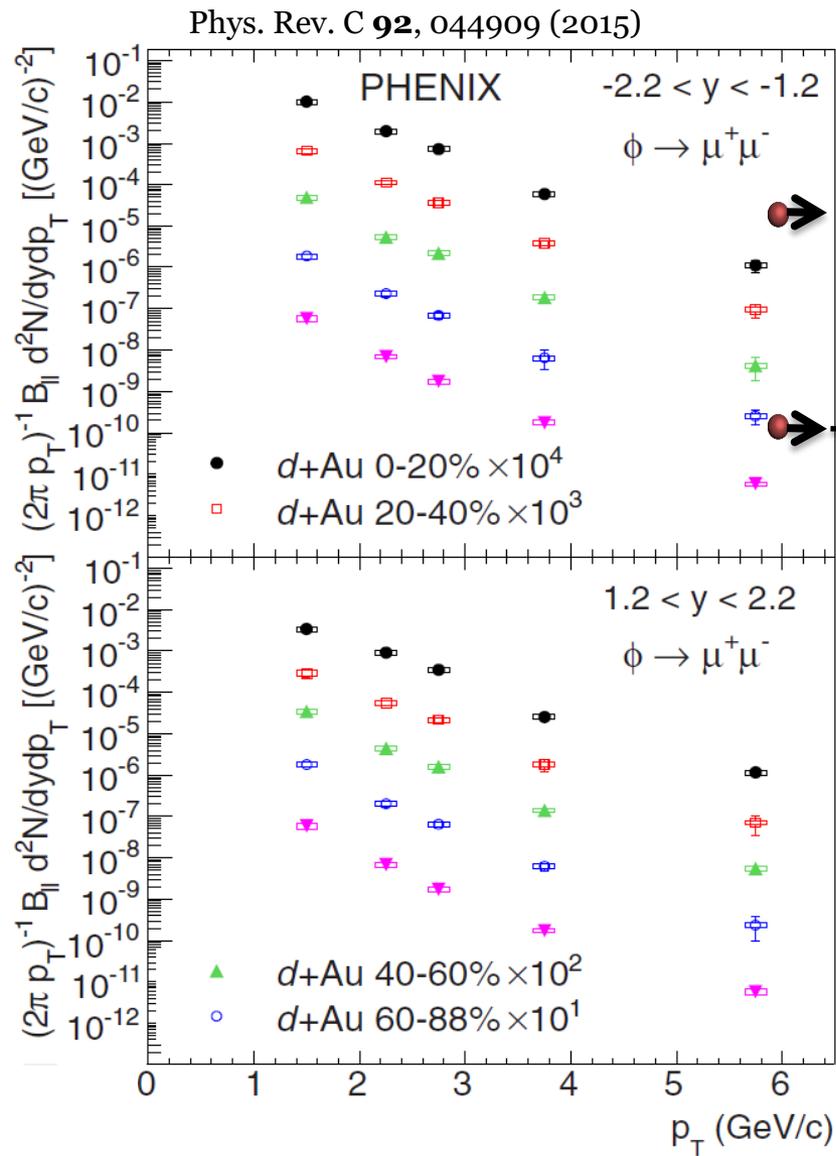
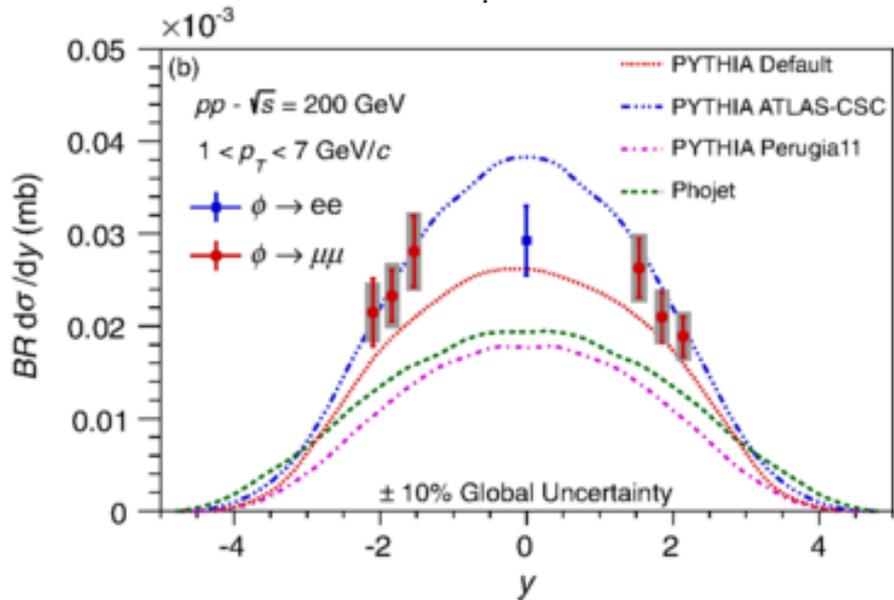
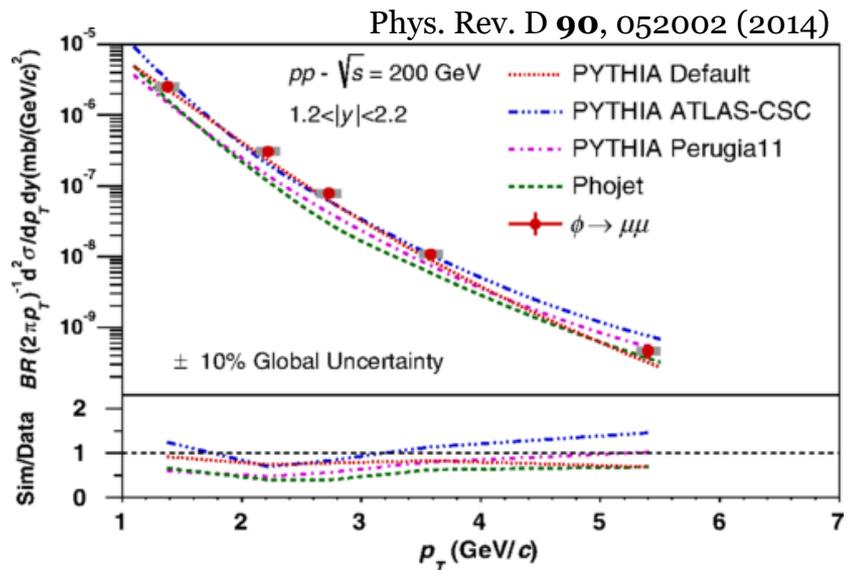
## Muon Arms:

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



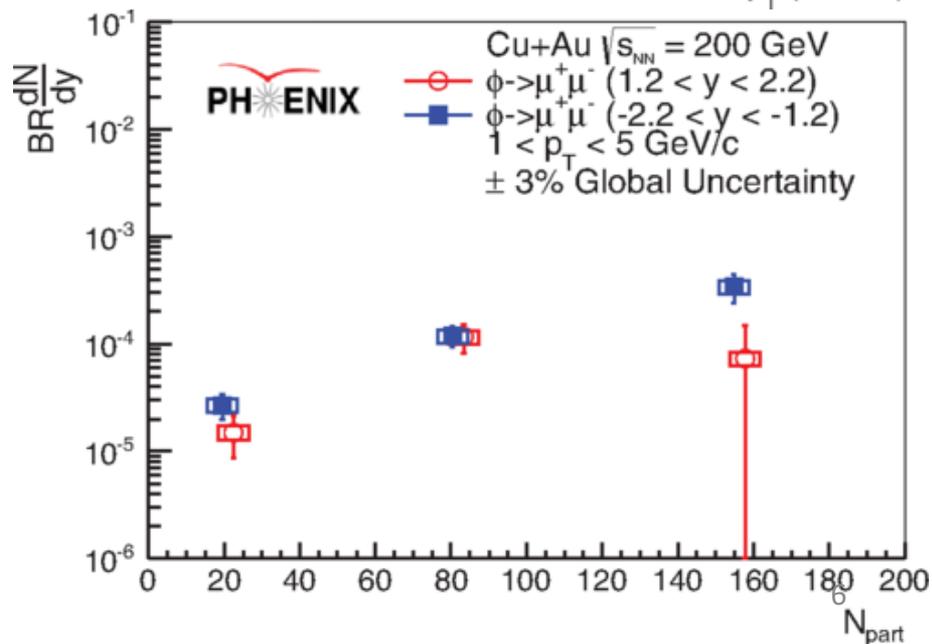
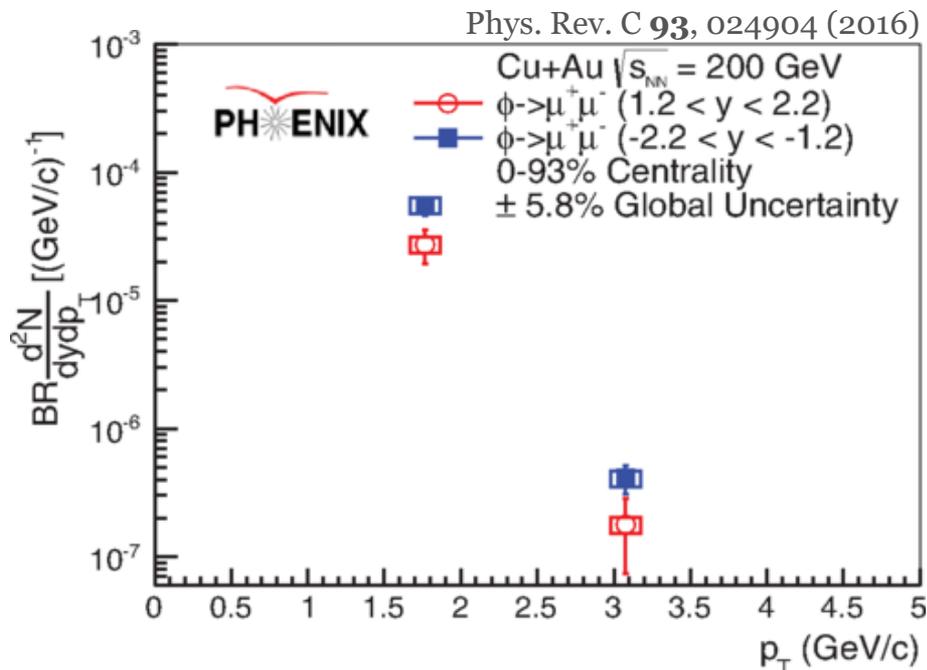
- Large rapidity coverage:  $1.2 < |y| < 2.2$  and  $|y| < 0.35$
- PHENIX recorded  $p+p$ ,  $p+Au$ ,  $p+Al$ ,  $d+Au$ ,  $He+Au$ ,  $Cu+Au$  and  $Au+Au$  collisions @  $\sqrt{s_{NN}} = 200$  GeV and  $p+p$  collisions @  $\sqrt{s_{NN}} = 510$  GeV.

# $\phi$ Meson Production in $p+p$ & $d+Au$ Collisions



# $\phi$ Meson Production in Cu+Au Collisions

- The first measurement of  $\phi$  meson production and its nuclear modification in a heavy ion system at forward/backward rapidity at RHIC
- Extends measurements of  $\phi$  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, $R_{AB}$

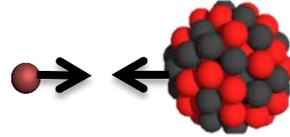
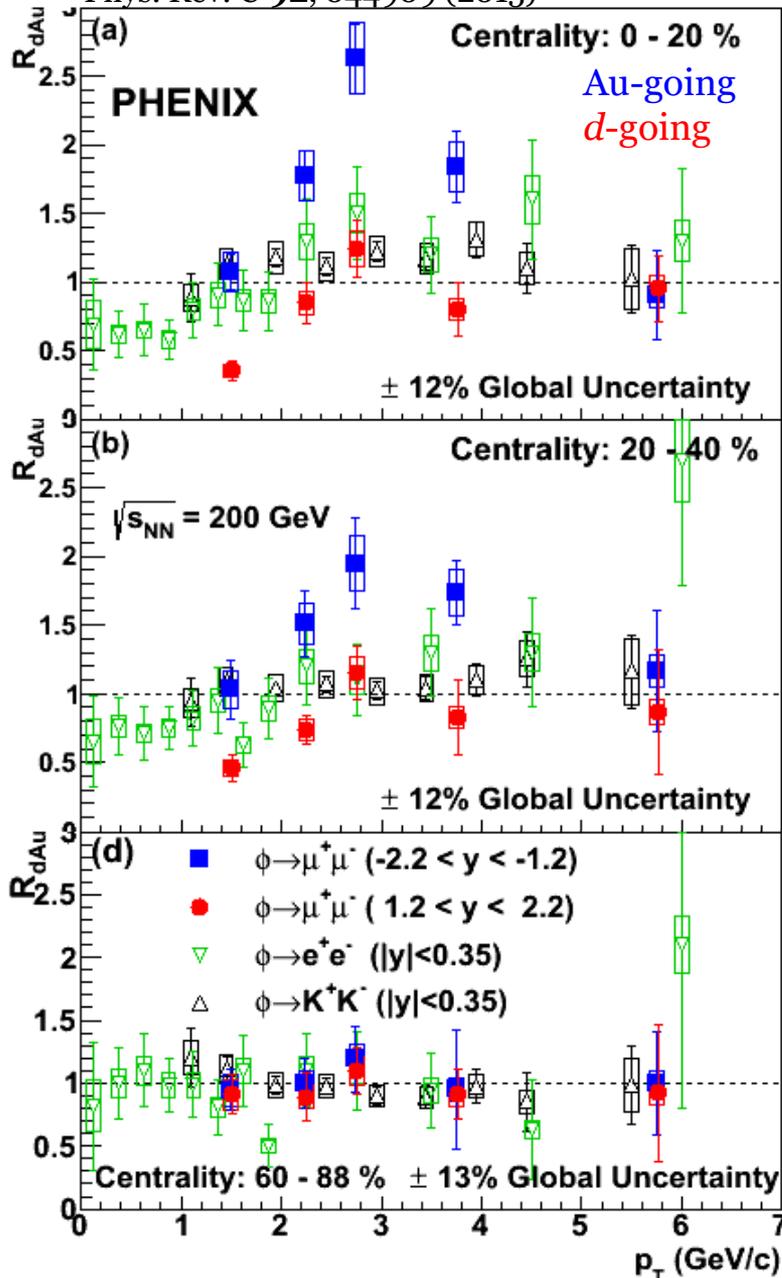
Modification of the production cross section in a nuclear target (cold) and QGP related (hot). Generally, depend on rapidity,  $p_T$ , and mass of the probe.

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

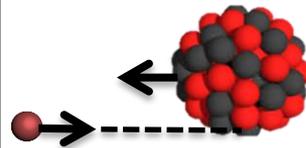
where  $d^2 N_{AB}/dydp_T$  is the per-event yield of particle production in  $A+B$  collisions and  $d^2 N_{pp}/dydp_T$  is the per event yield of the same process in  $p+p$  collisions. Scaled by the number of nucleon-nucleon collisions in the  $A+B$  system,  $N_{coll}$ .

# CNM for $\phi$ Meson / $d+Au$ Collision

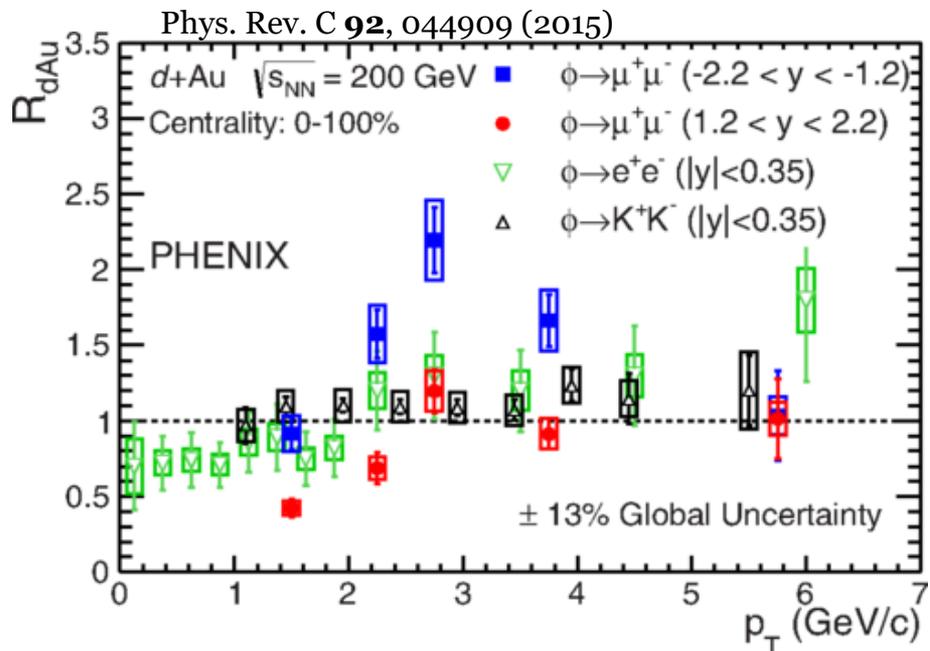
Phys. Rev. C **92**, 044909 (2015)



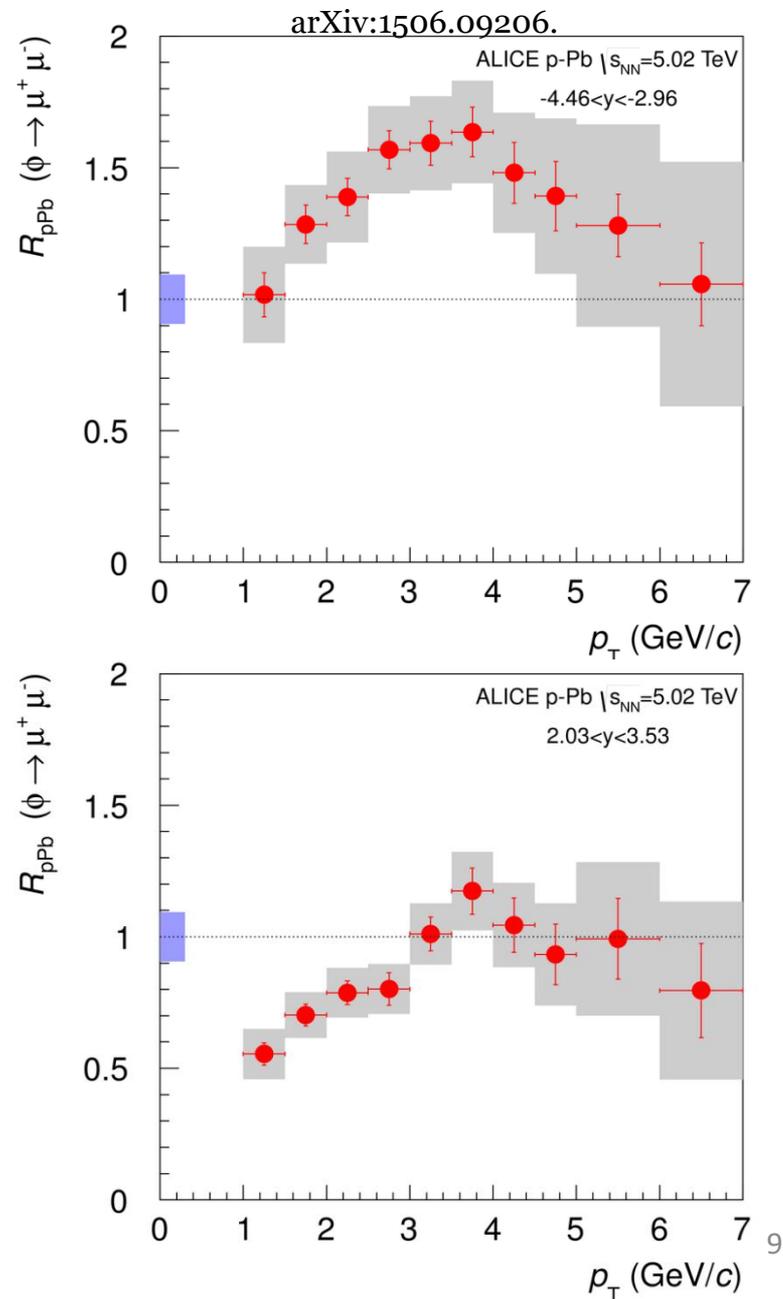
- An **enhancement** (**suppression**) has been observed at **backward** (**forward**) rapidity region in most central  $d+Au$  collision.
- ❖ The observed **enhancement** at **backward** rapidity is a typical behavior of a Cronin effect.



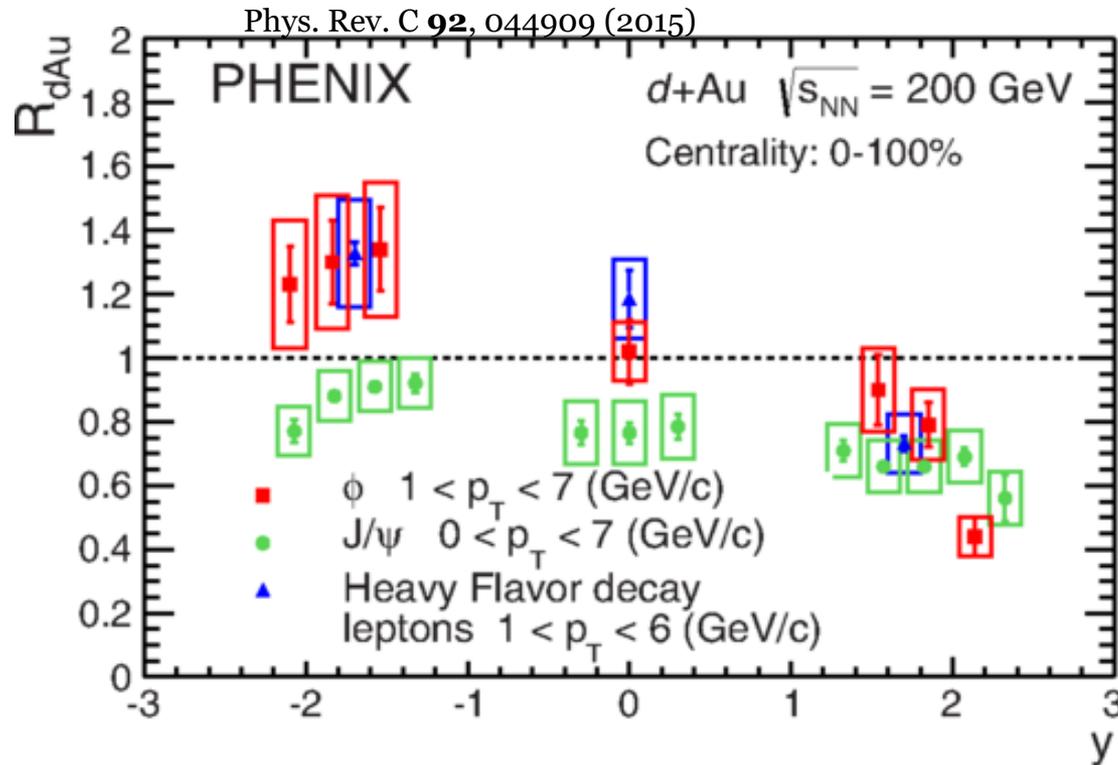
# Other $\phi$ Measurements



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



# $\phi$ Meson vs Open & Closed Heavy Flavor



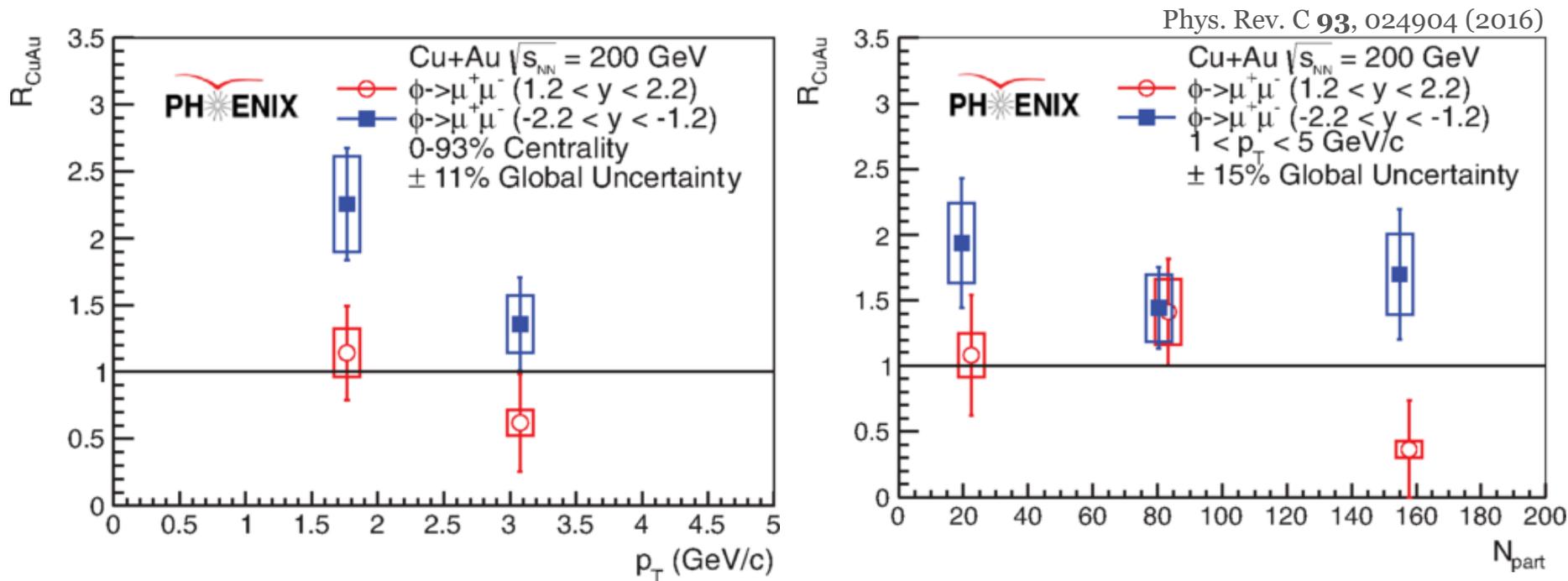
- ❖ Similar nuclear modifications to those in  $\phi$  production as a function of rapidity is observed in heavy flavor decay leptons and inclusive charged hadrons production  $\Rightarrow$

Similar cold nuclear matter effects

OR

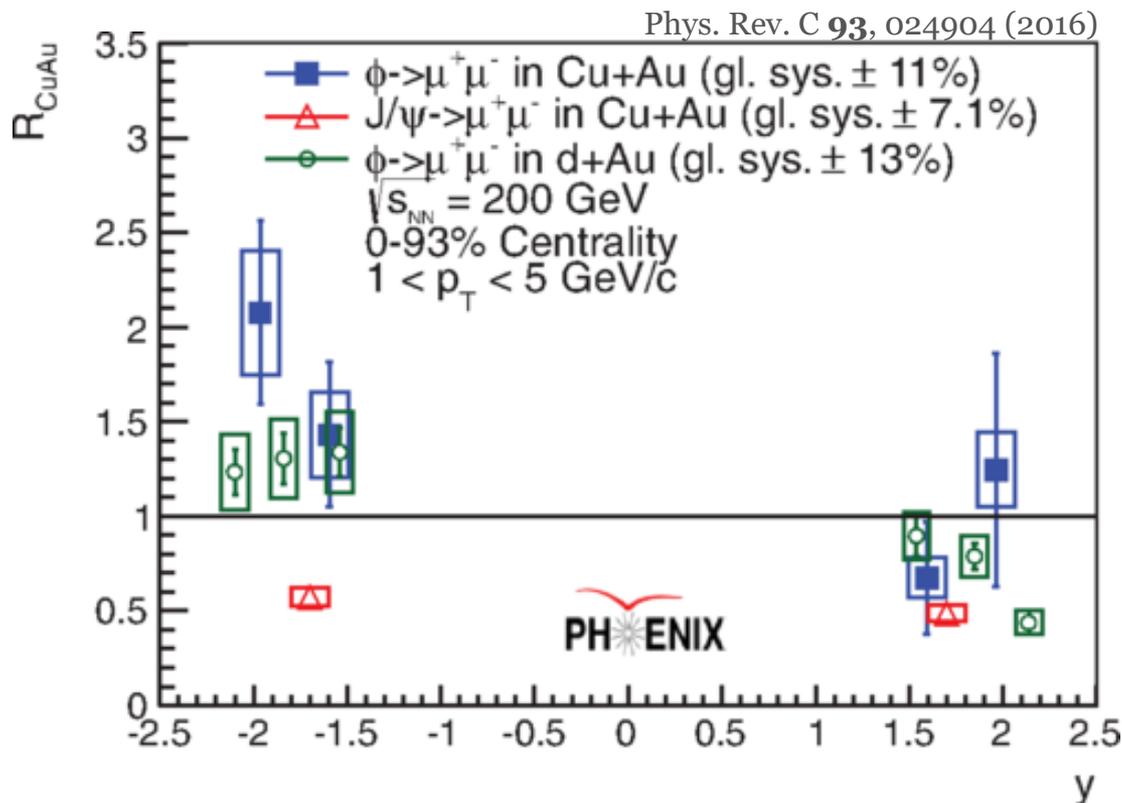
Different processes act on open HF and  $\phi$ . The match May be a coincidence

# $\phi$ Meson $R_{CuAu}$



- ❖  $\phi$  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

# $\phi$ Meson Production in Cu+Au Collisions

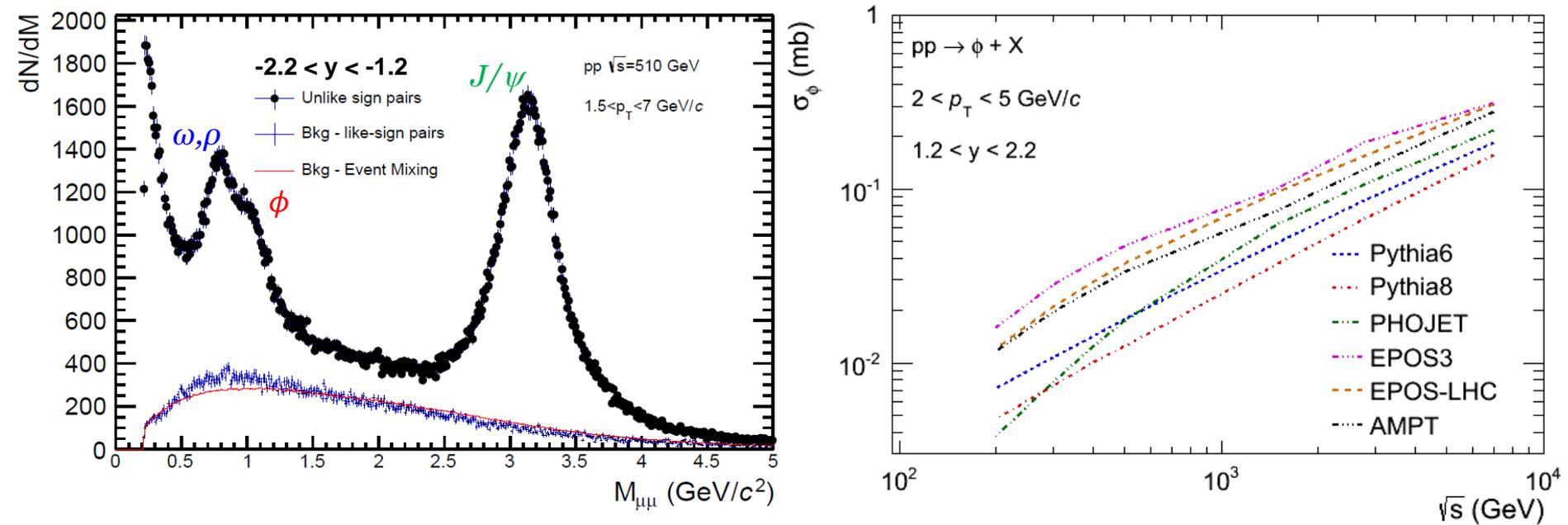


- Integrated over all centralities,  $\phi$  in Cu+Au is consistent with  $\phi$  in d+Au not with  $J/\psi$  in Cu+Au
  - In the most central collisions, the forward/backward ratio for  $\phi$  ( $\sim 0.2$ ) is smaller than for  $J/\psi$  ( $\sim 0.8$ ) (PRC **90**, 064908 (2014))
- May suggest that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

# Outlook!

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

❖ PHENIX collected  $135.87 \text{ pb}^{-1}$  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

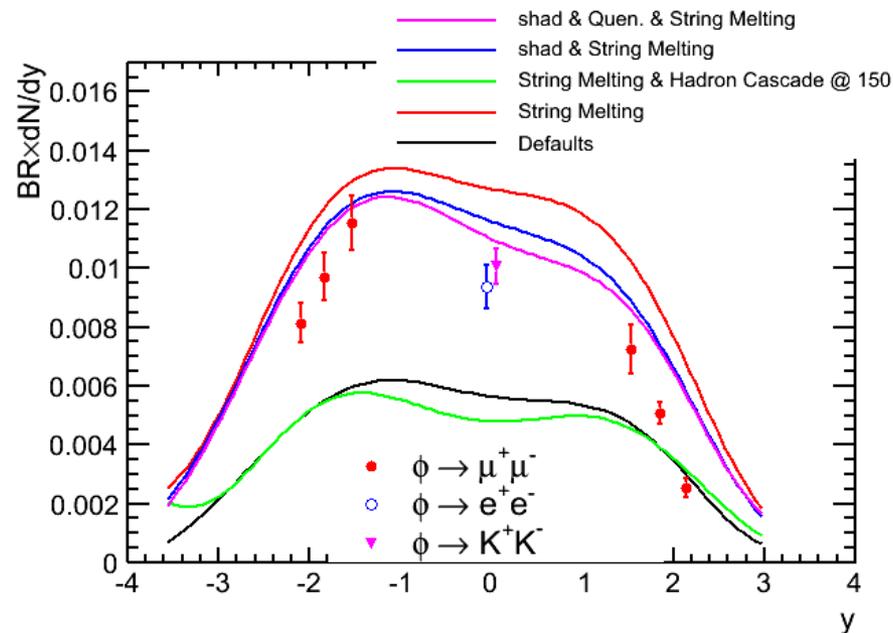
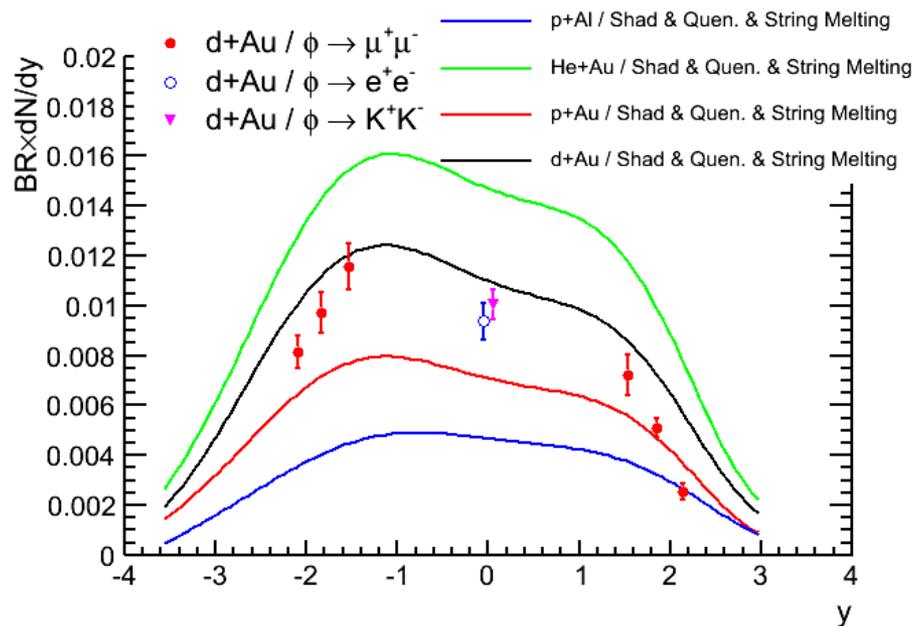
❖ In final review stage and to be released soon!

# $\phi$ 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  $\phi$  production at forward/backward rapidities and over a wide  $p_T$  range to study CNM & HNM effects.
- An **enhancement** (**suppression**) of  $\phi$  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?
- $\phi$  meson production in Cu+Au measurement suggested  $J/\psi$  &  $\phi$  mesons follow different production mechanisms.
- New data sets ( $p$ +Au &  $p$ +Al) collected in 2015 will allow  $\phi$  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