ϕ Meson Measurements at RHIC with the PHENIX Detector

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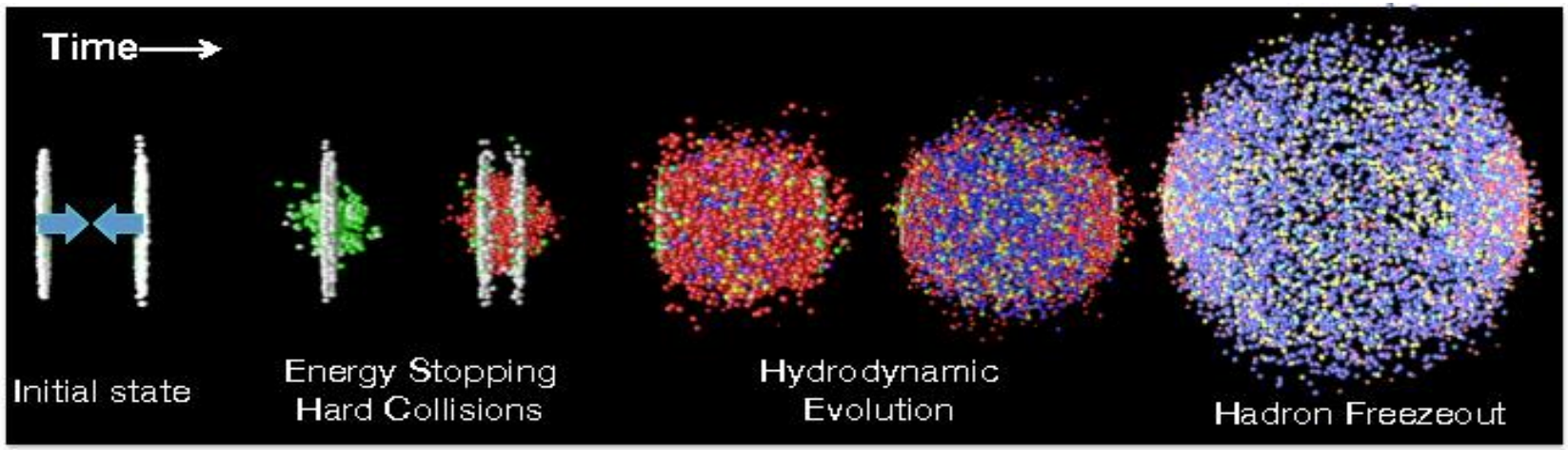
PHENIX

Why Is This Work Interesting?

❖ Characterize the properties of the QGP



- Great successes using heavy quarks (charm and beauty) and jets, together with theoretical studies based on perturbative quantum chromodynamics (QCD)

- However, huge uncertainties still remain in understanding the soft particle production given the limited theoretical guidance (i.e. non-perturbative QCD regime). **More data is needed in order to constrain phenomenological models.**

- **Strange hadrons as a probe! (Proposed decades ago, PRL 48, 1066 (1982))**

Focusing on the ϕ Meson

- In Au+Au collisions: an excellent probe for studying QGP - sensitive to several aspects of the collision, including modifications of strangeness production in bulk matter.

- In small systems (e.g. p+Al, p+Au, d+Au, ^{3}He+Au): Understand cold nuclear matter effects in order to disentangle hot nuclear (QGP related) and cold nuclear matter (Modification of the production cross section in a nuclear target) effects exiting in A+B collisions.

  - The lepton decay channel is of particular interest because of the absence of strong interactions between muons and the surrounding hot hadronic matter.
  - 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

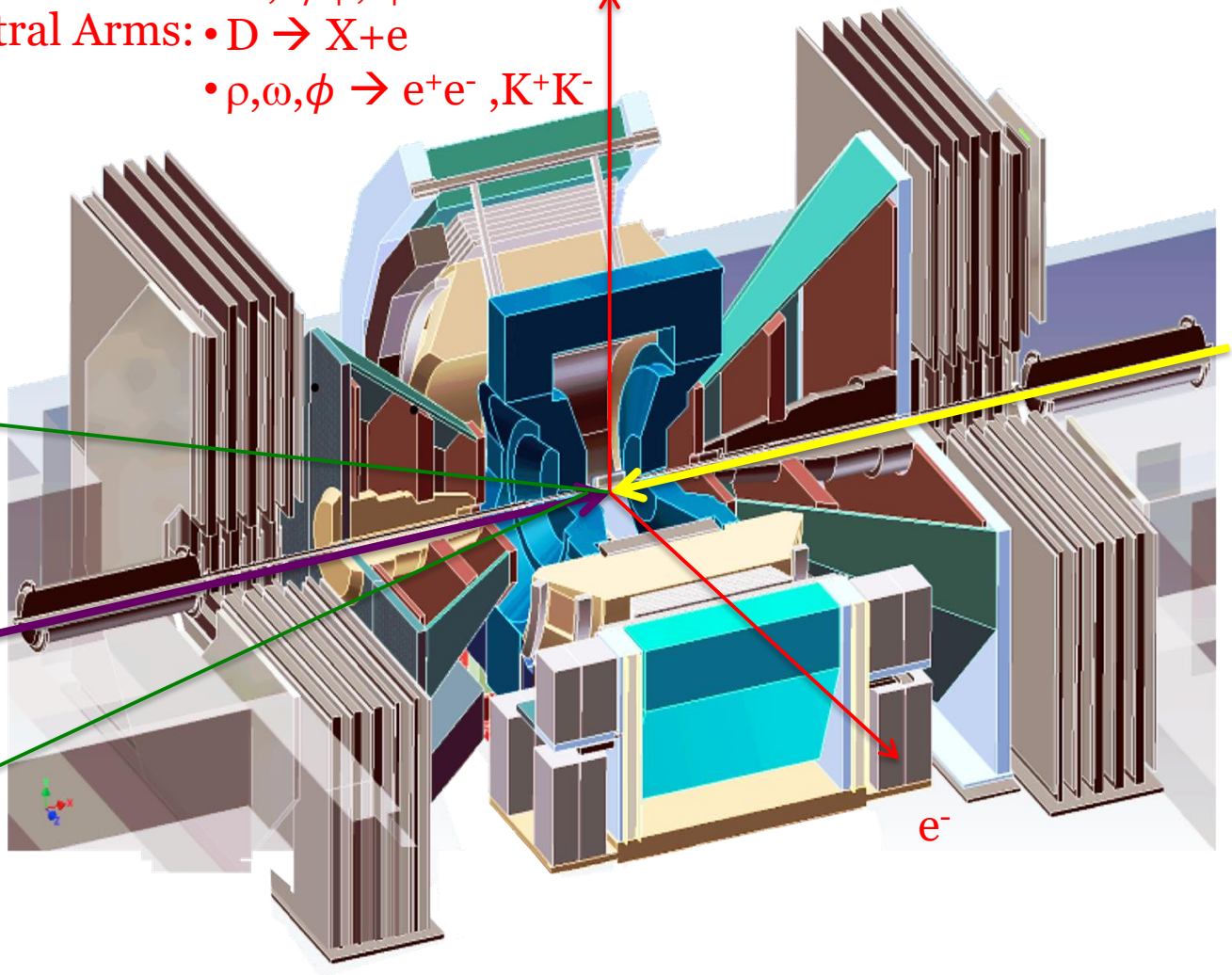
The PHENIX Detector

PHENIX: optimized to measure leptons: rapidity coverage: 1.2<|y|<2.2 & |y|<0.35

- high rate capability with emphasis on mass resolution & particle ID
- first level e&μ triggers

Central Arms:
- Υ,J/ψ, ψ' → e^+e^-
- D → X+e
- ρ,ω,ϕ → e^+e^- ,K^+K^-

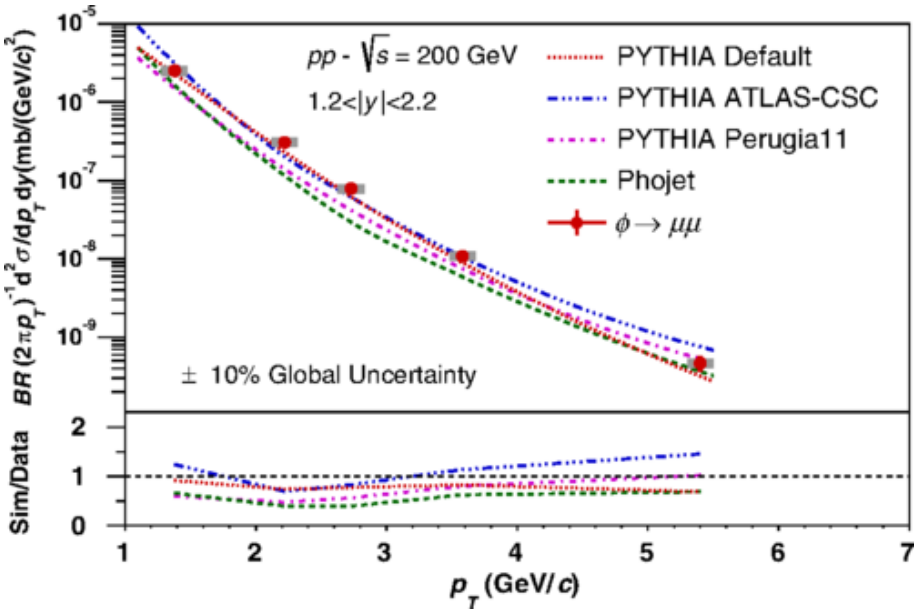
Muon Arms:
- Υ,J/ψ → $\mu^+\mu^-$
- D → X+μ
- ρ,ω,ϕ → $\mu^+\mu^-$

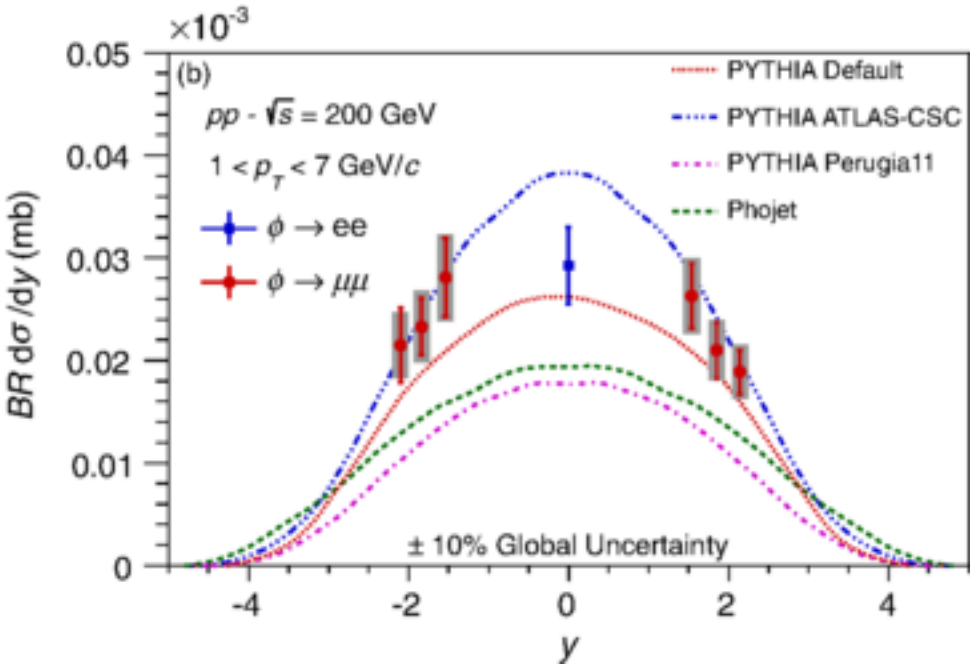


$x \sim 5 \times 10^{-3}$ Shadowing region

$x \sim 8 \times 10^{-2}$ Anti-shadowing region

ϕ Meson Production in p+p Collisions





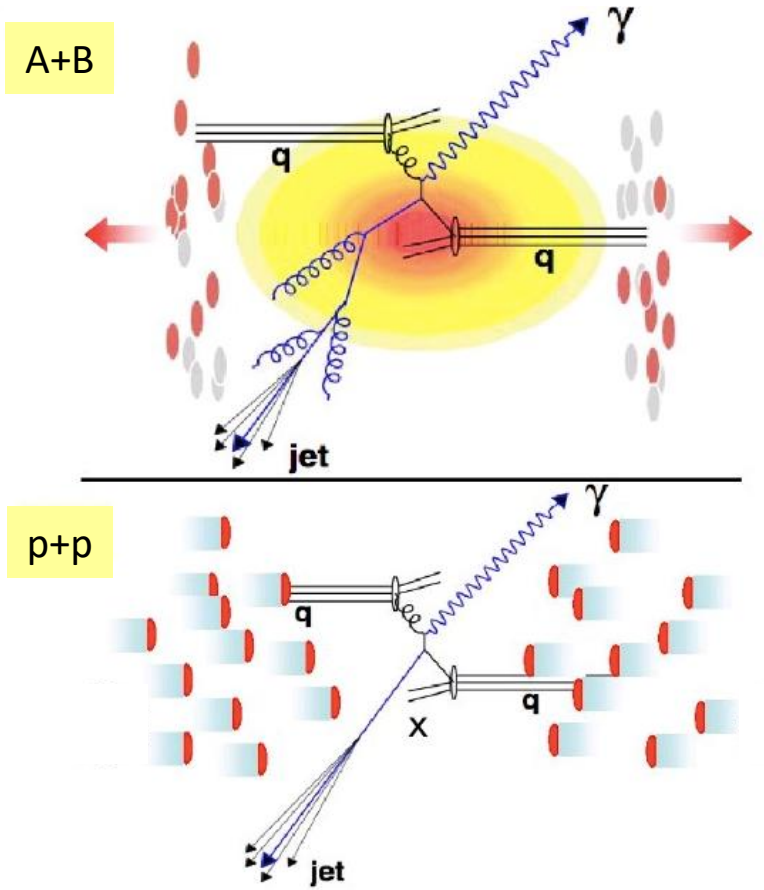
- Very important for validating the phenomenological models of strangeness production.
- Provide baseline measurement for studying nuclear modification of ϕ production in p+Al, p+Au, d+Au, Cu+Cu, Cu+Au and Au+Au collisions at RHIC.

Nuclear Modification Factor, R_{AB}

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

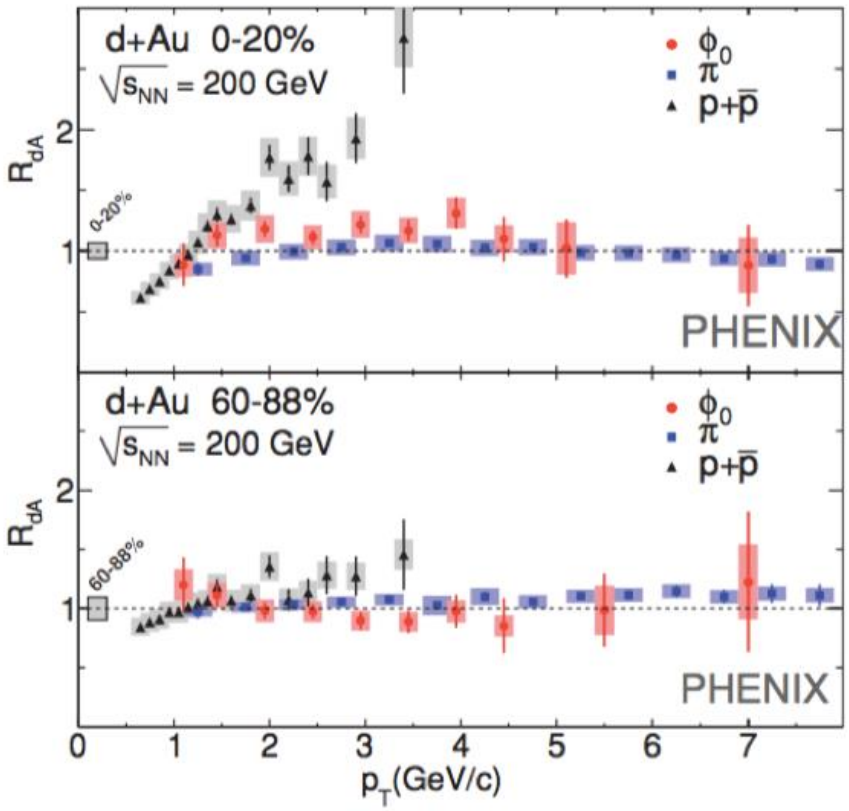
$$R_{AB} = \frac{d^2N_{AB}/dydp_T}{\langle N_{coll}\rangle \times d^2N_{pp}/dydp_T}$$

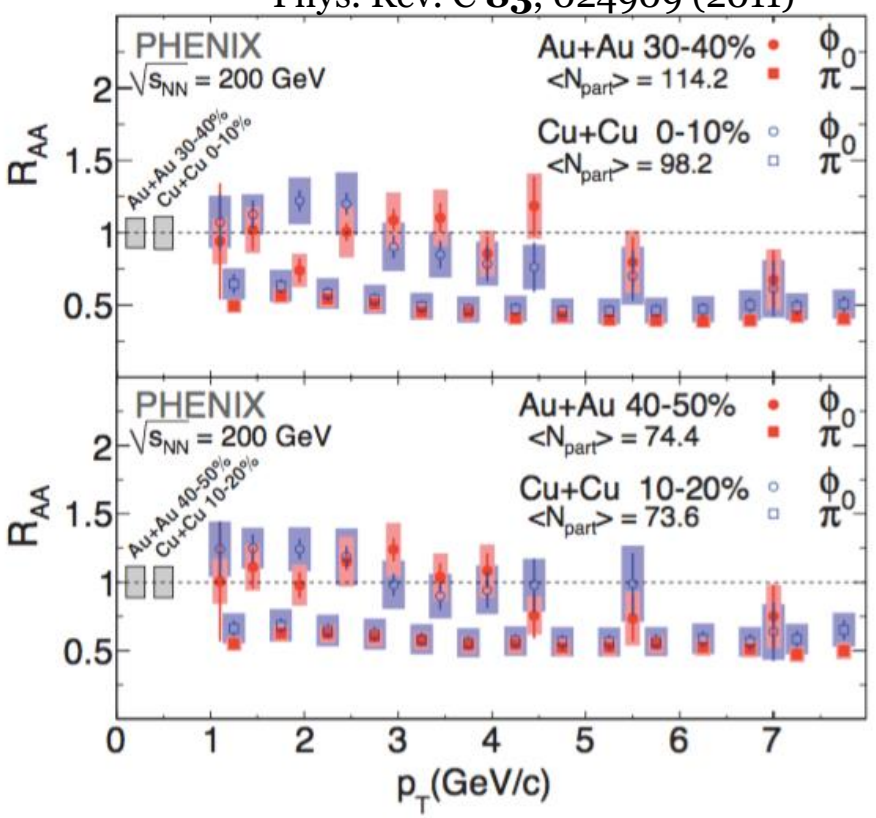
where $d^2N_{AB}/dydp_T$ is the per-event yield of particle production in A+B collisions and $d^2N_{pp}/dydp_T$ is the per event yield of the same process in p+p collisions. Scaled by the number of nucleon-nucleon collisions in the A+B system, N_{coll}.



R_{AB} of ϕ Meson in d+A, Cu+Cu and Au+Au Collisions in Central Rapidity

Phys. Rev. C **83**, 024909 (2011)

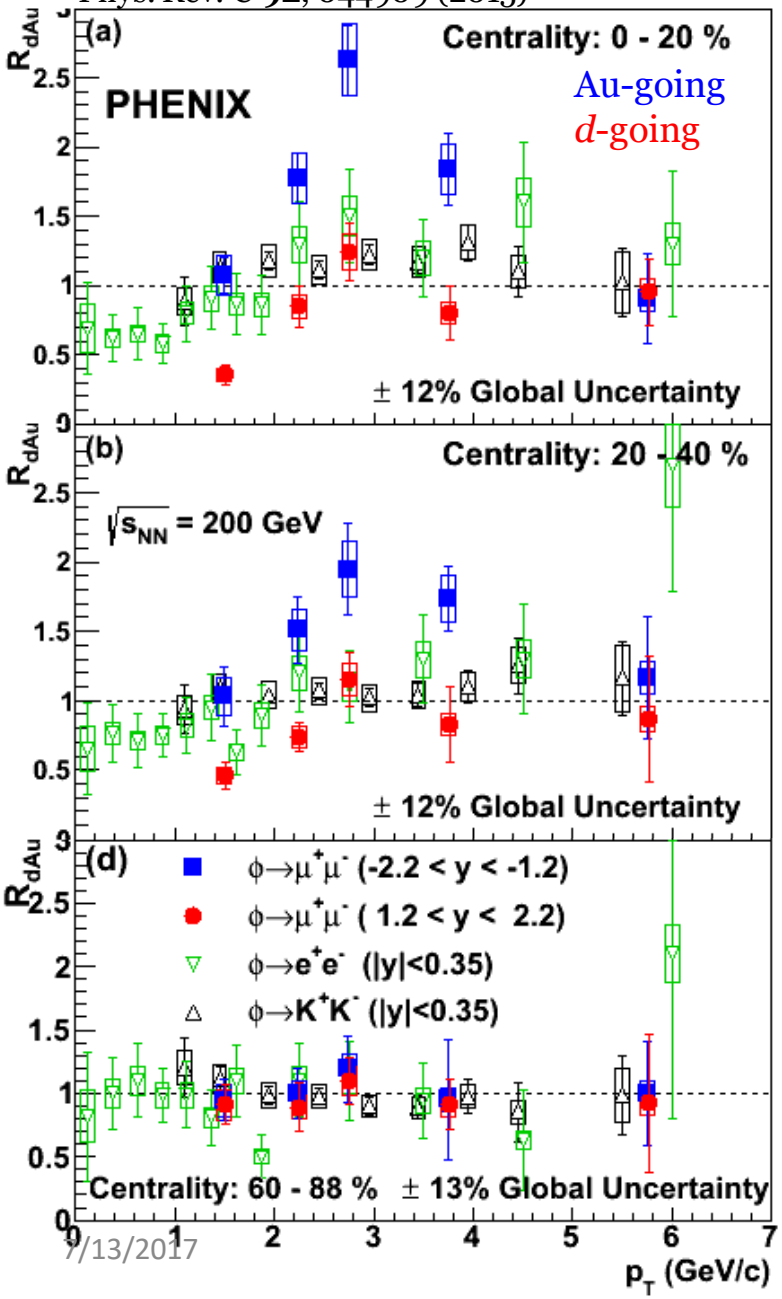


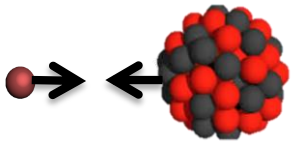


The ϕ meson exhibits a different suppression pattern compared to lighter mesons (π^0 and η) and baryons (protons and antiprotons) in heavy ion collisions. For all centralities, the ϕ meson is less suppressed than π^0 and η in the intermediate p_T range (2–5 GeV/c), whereas, at higher p_T , ϕ, π^0, and η show similar suppression values.

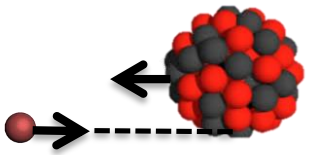
CNM for ϕ Meson / d+Au Collision

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





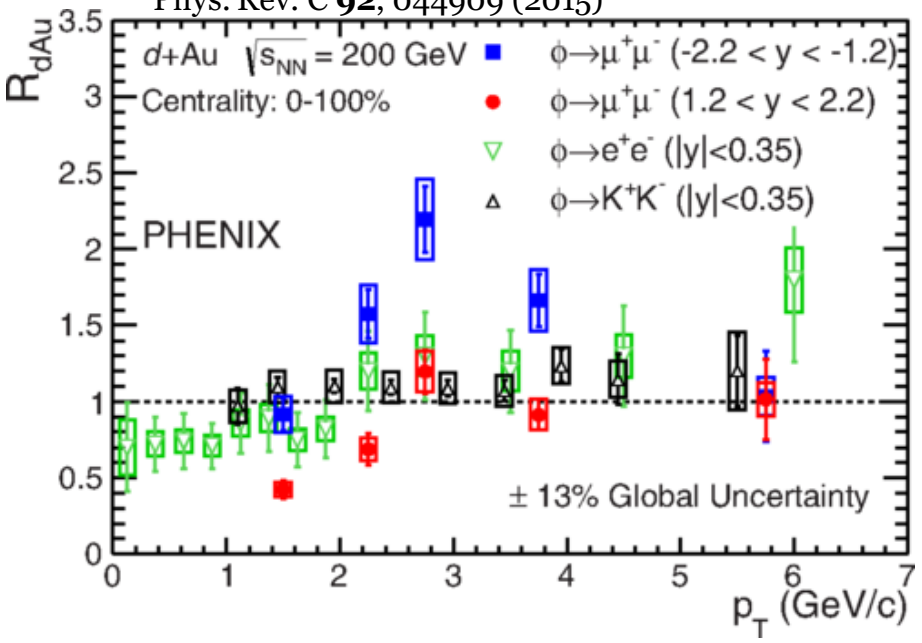
In Forward & Backward Rapidities



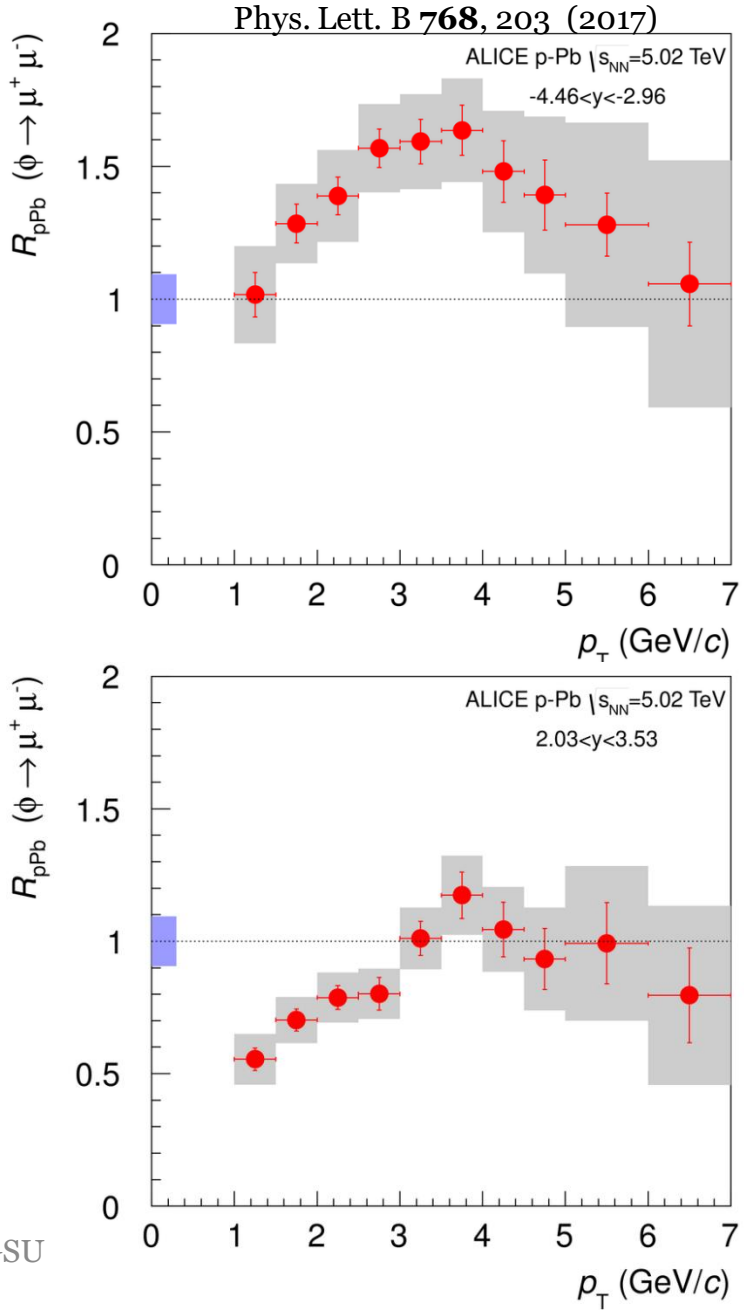
- An **enhancement** (**suppression**) has been observed at **backward** (**forward**) rapidity region in most central d+Au collision.
- The observed **enhancement** at **backward** rapidity is a typical behavior of a Cronin effect.

Other ϕ Measurements

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



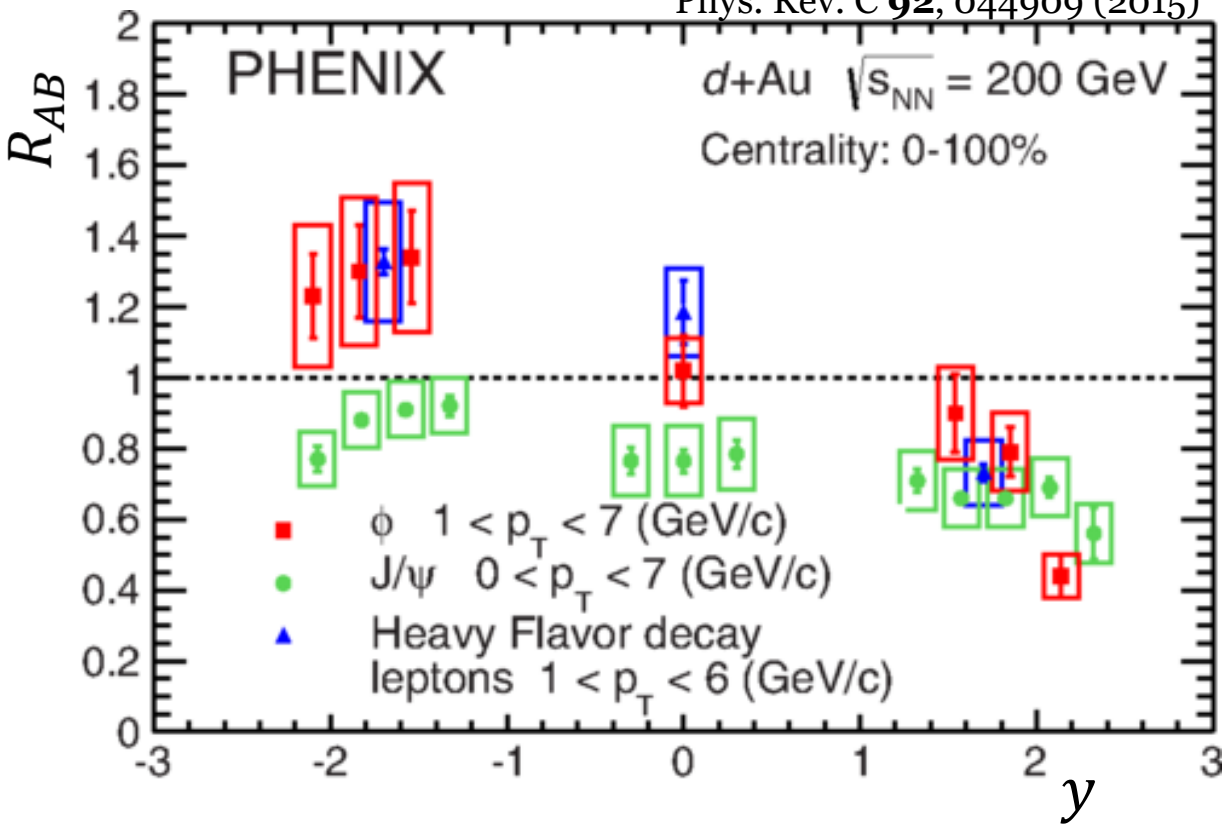
Phys. Lett. B **768**, 203 (2017)



- 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

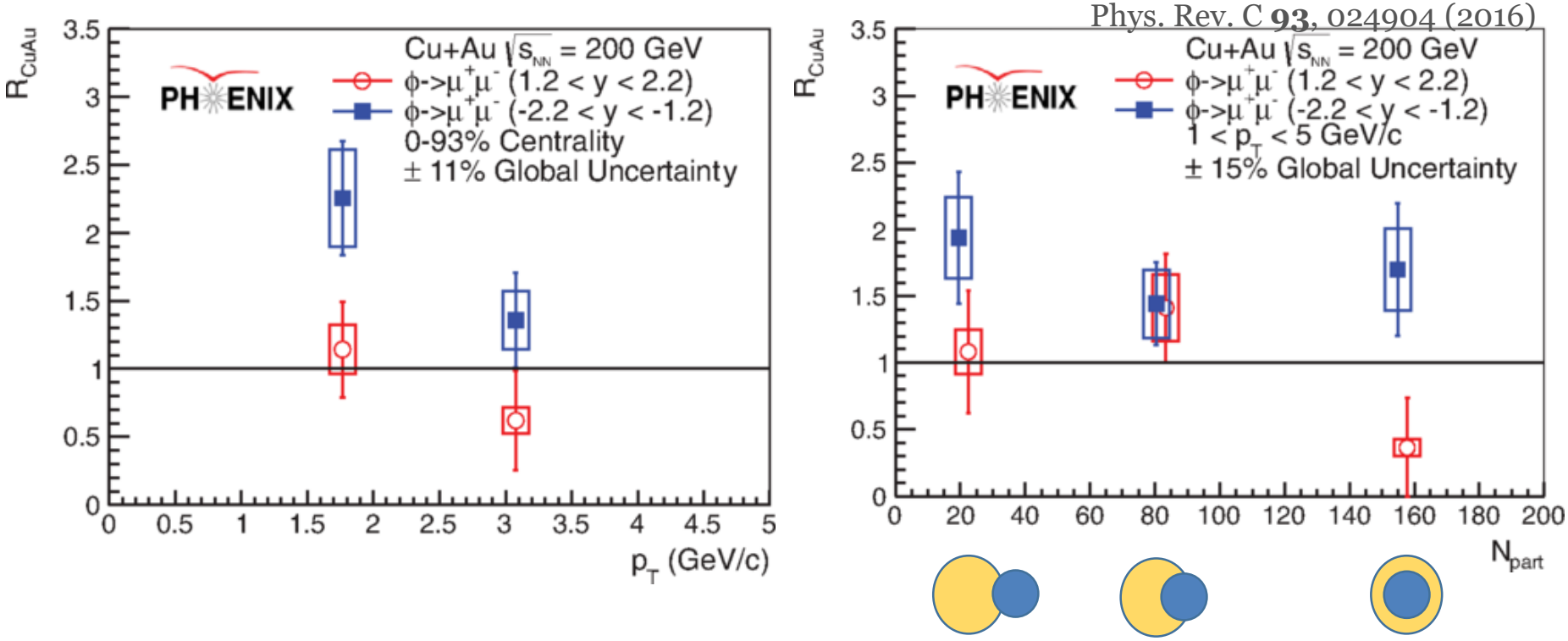
Phys. Rev. C **92**, 044909 (2015)



- 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

- Similar cold nuclear matter effects
- Different processes act on open HF and ϕ. The match May be a coincidence!

ϕ Meson R_{CuAu}

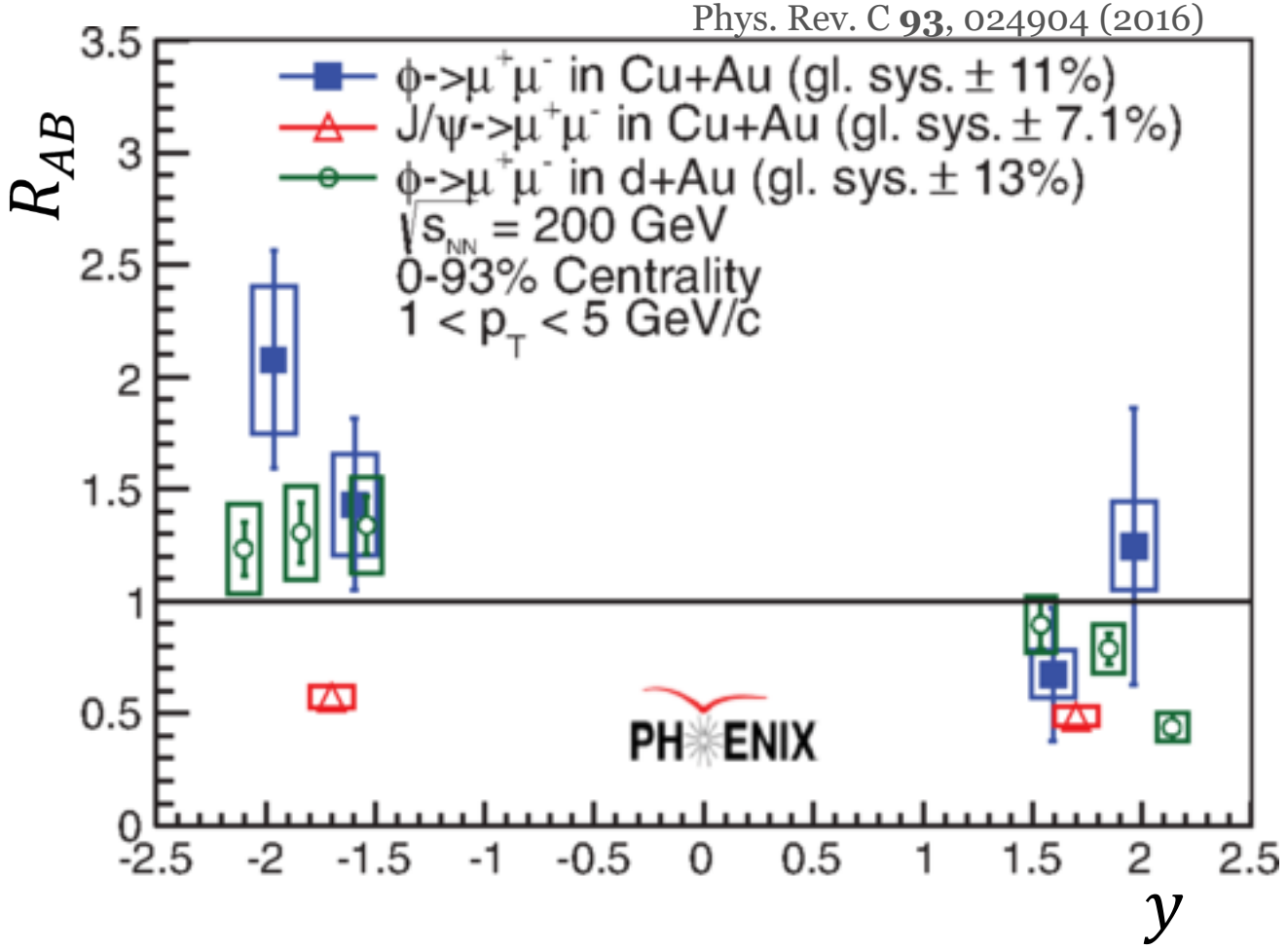


Phys. Rev. C **93**, 024904 (2016)

- 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

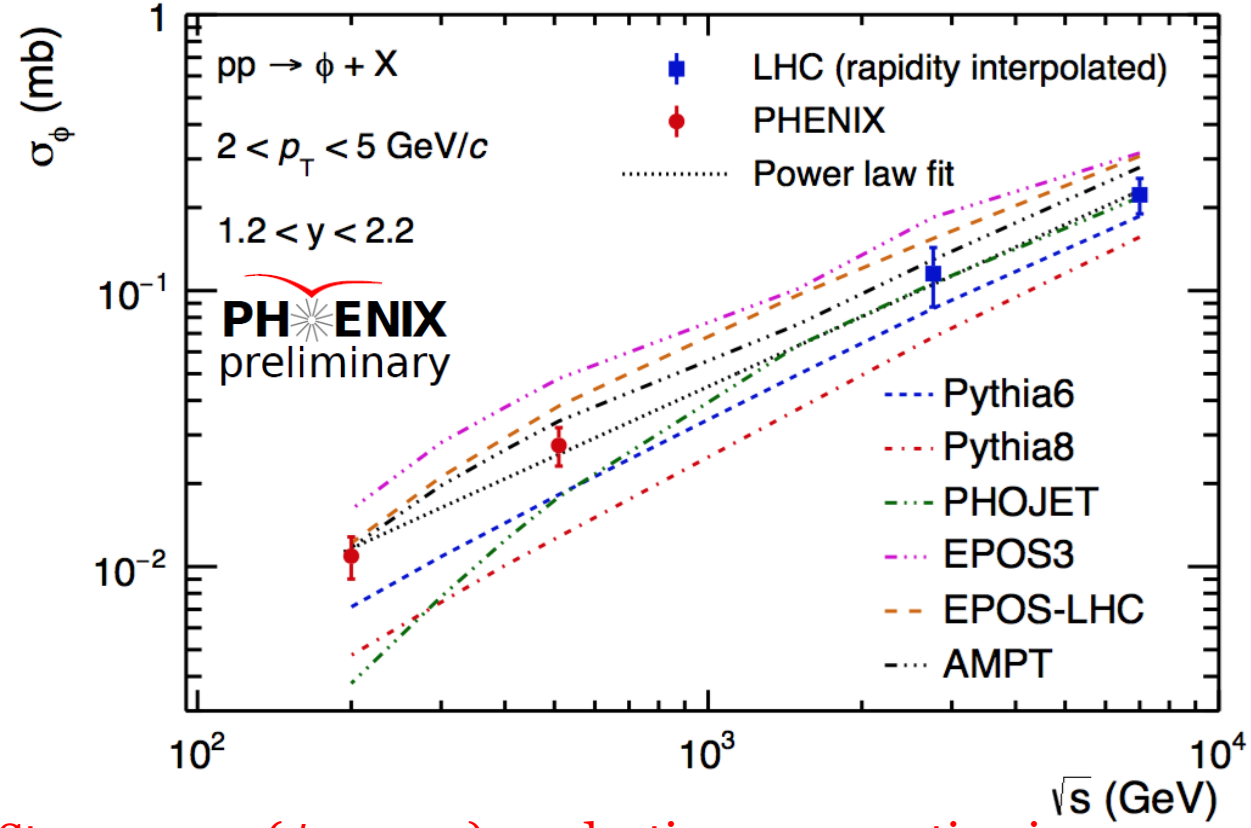
ϕ Meson Production in Cu+Au Collisions

Phys. Rev. C **93**, 024904 (2016)



- Integrated over all centralities, ϕ in Cu+Au is consistent with ϕ in d+Au not with J/ψ in Cu+Au
- May suggest that J/ψ & ϕ mesons follow different production mechanisms

Energy Dependent ϕ Production in p+p Collisions



RHIC/PHENIX:
- PRD**90**, 052002 (2014)

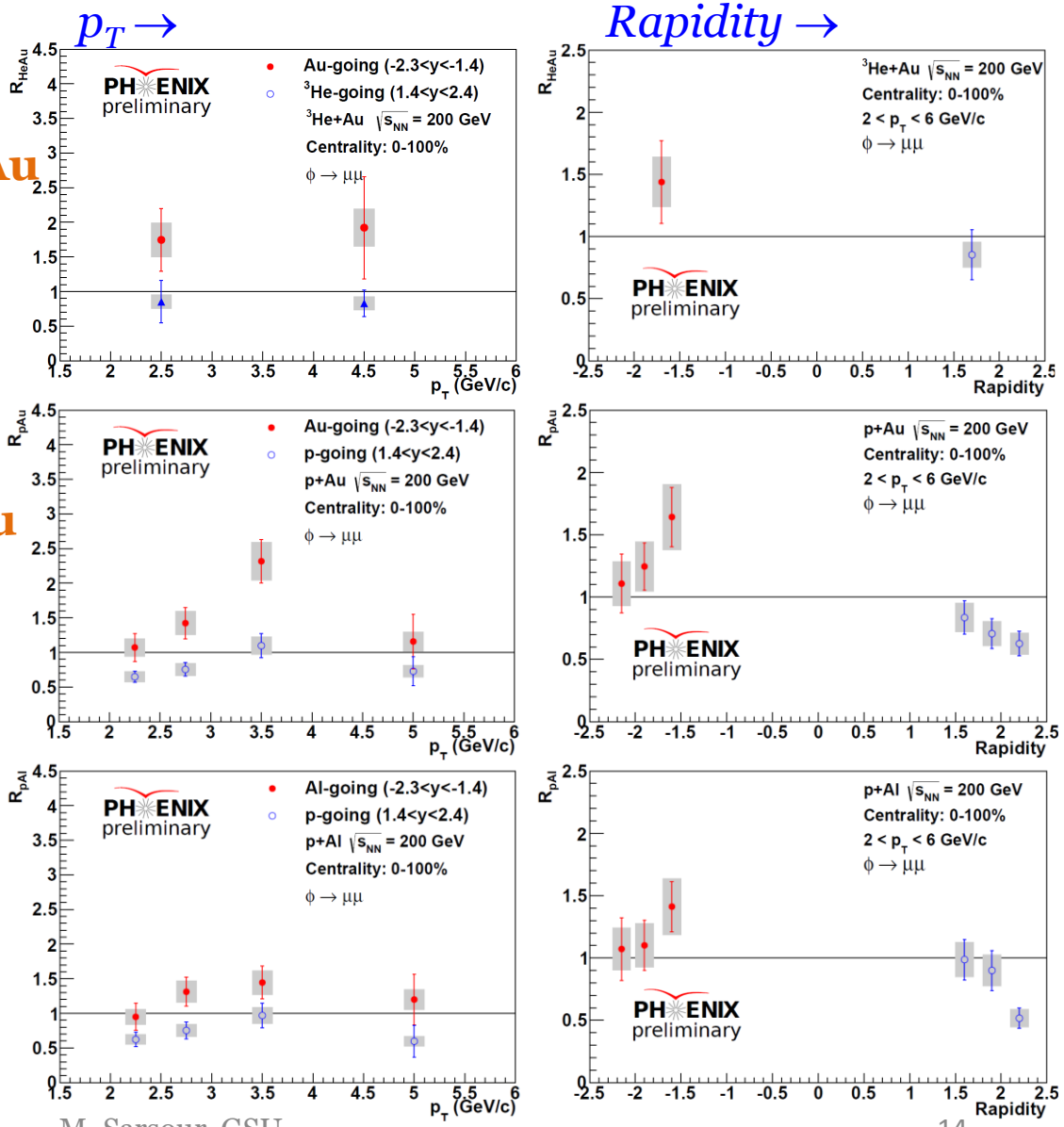
LHC:
- PLB**703**, 267 (2011)
- PLB**710**, 557 (2012)
- Eur. Phys. J. C **72**, 2183 (2012)
- PLB **768**, 203 (2017)

❖ Strangeness (ϕ meson) production cross section increases as a function of energy: from RHIC (PHENIX) to LHC (ALICE & LHCb).

➢ Extensive comparisons with Model calculations of strangeness (ϕ meson) production available in the market have been done! These models exhibit the same trends as data from RHIC to LHC energies.

ϕ Meson Production in Small Systems

- PHENIX collected the following data sets: ^{3}He+Au (2014) & p+Al and p+Au (2015) in addition to published d+Au (2008) results [PRC **92**, 044909 (2015)]
- At forward (observe suppression) / backward rapidity (enhancemnet)
- Wide range in p_T

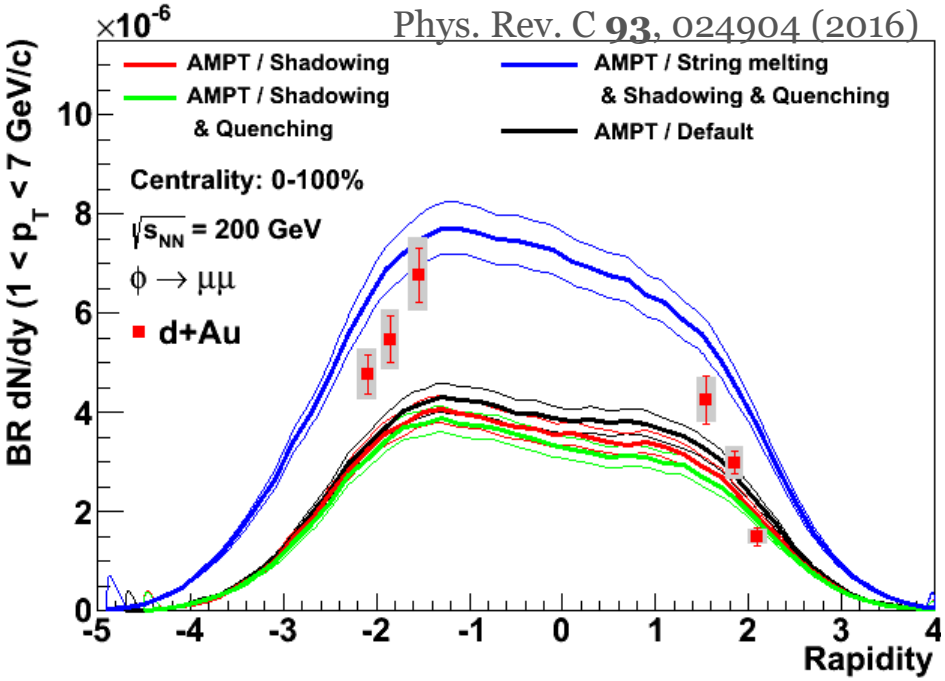


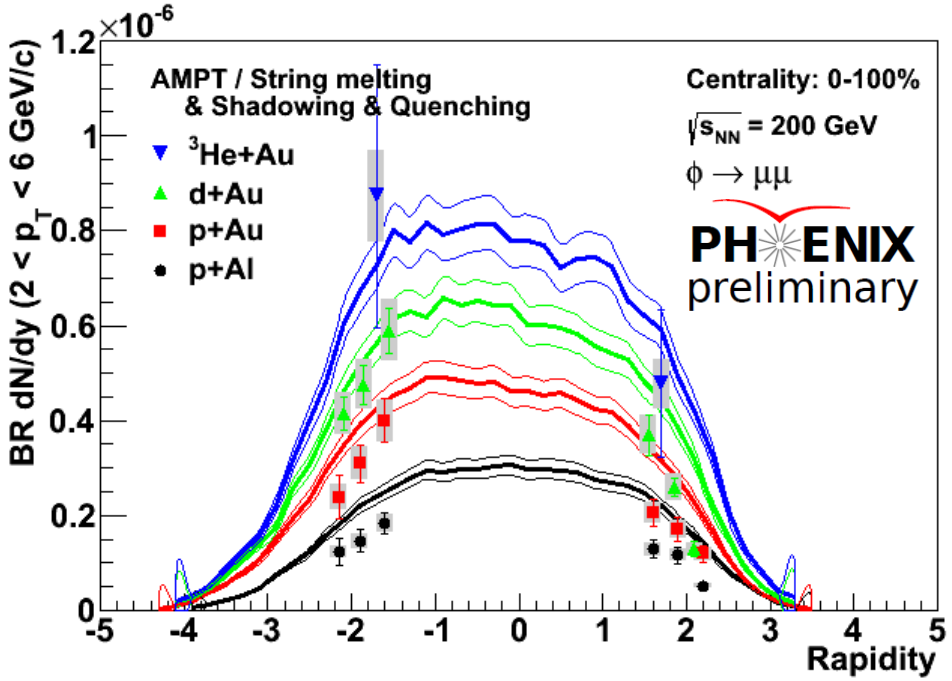
Using Small Systems to Study CNM

- dN/dy in *d*+Au collision.

- Variety of small systems: *p*+Al, *p*+Au, *d*+Au and ^{3}He+Au.

Phys. Rev. C **93**, 024904 (2016)





❖ Using these data sets allow to discriminate the various cold nuclear matter effects included in models like AMPT and EPOS.

Summary

- The PHENIX collaboration measured ϕ production in p+p, p+Al, p+Au, d+Au, Cu+Cu, Cu+Au and Au+Au collisions with a wide rapidity coverage to study CNM & HNM effects.

- The particle-dependent nuclear modifications in all colliding systems will provide stringent tests of theoretical model predictions.

- The ϕ meson cross section exhibits increase from RHIC to LHC energies.

- The data sets (^{3}He+Au, p+Au and p+Al) collected in 2014 & 2015 allowed ϕ measurements at backward and forward rapidities along with other probes in less complicated p+Au & p+Al collisions $\Rightarrow$ allow studying the different CNM effects on ϕ production using models like AMPT and EPOS.

Thank You