Modification of hadron production in small and large systems observed by PHENIX

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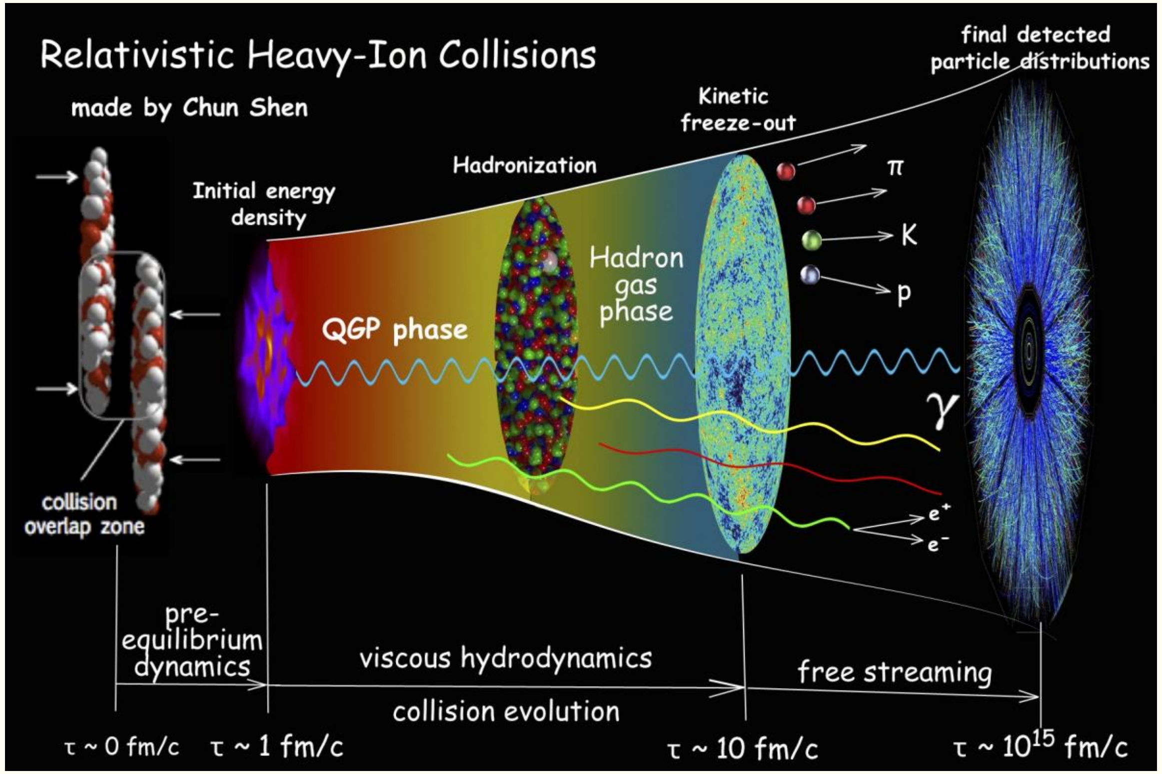
For PHENIX collaboration

Motivation

- Light flavor hadrons in A+A & p+A → properties of the produced medium & reaction dynamics



Motivation

- Light flavor hadrons in A+A & p+A → properties of the produced medium & reaction dynamics

- Different hadrons properties → observables in the soft sector & high p_T probes & signatures of the onset of collectivity in collisions of small systems (possible QGP formation)

	π^0	η	ω	K*	K_S	φ
Mass, MeV	135	548	782	892	498	1019
Quark content	$u\bar{u}\|\|d\bar{d}$	$\frac{1}{6}(u\bar{u}+d\bar{d}-2s\bar{s})$	$\frac{1}{\sqrt{2}}(u\bar{u}+d\bar{d})$	$d\bar{s}$	$\frac{1}{\sqrt{2}}(d\bar{s}+s\bar{d})$	$s\bar{s}$
Lifetime, fm/c	$2.5\cdot10^7$	$1.6\cdot10^5$	23	4.16	$2.7\cdot10^{13}$	46

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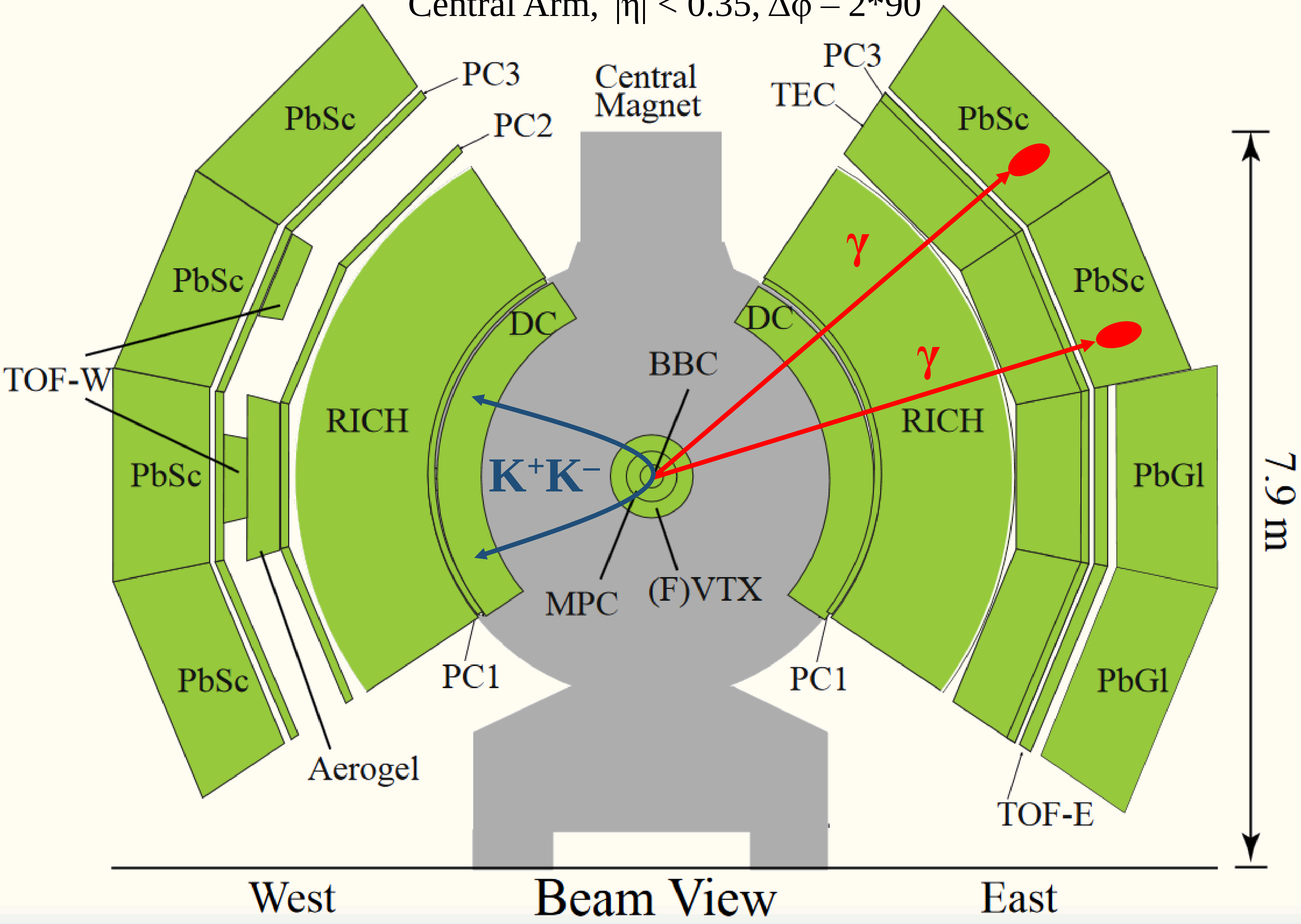
- Different hadrons properties → observables in the soft sector & high p_T probes & signatures of the onset of collectivity in collisions of small systems (possible QGP formation)

- PHENIX measured
    - $(p+\overline{p})/2$, π^0, η, K*, K_S, φ & ω
    - in **p+p, p+Al, p/d/^{3}He+Au, Cu+Cu, Cu+Au, Au+Au & U+U:**
        - Baseline measurements in p+p collisions
        - Study of the parton energy loss in heavy ion collisions
        - Cold nuclear matter effects

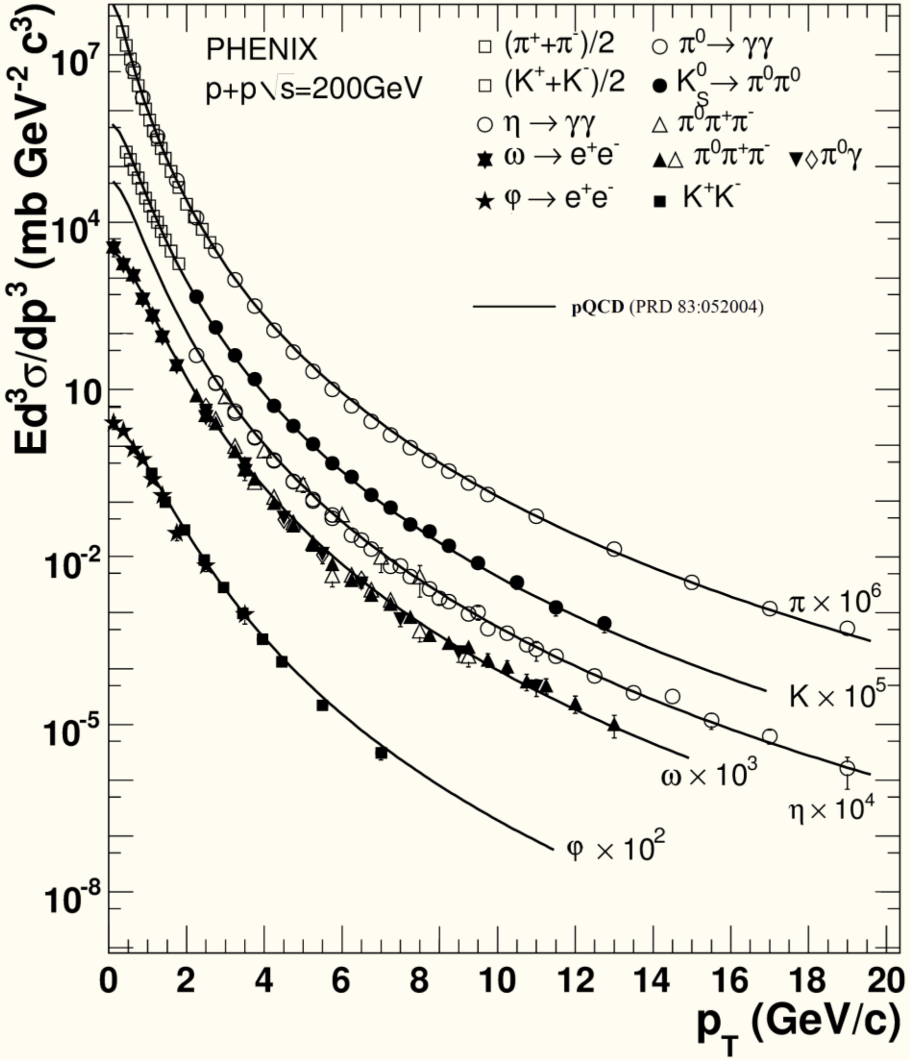
- Comparison to theoretical model predictions

The PHENIX Detector

Central Arm, |η| < 0.35, Δφ – 2*90



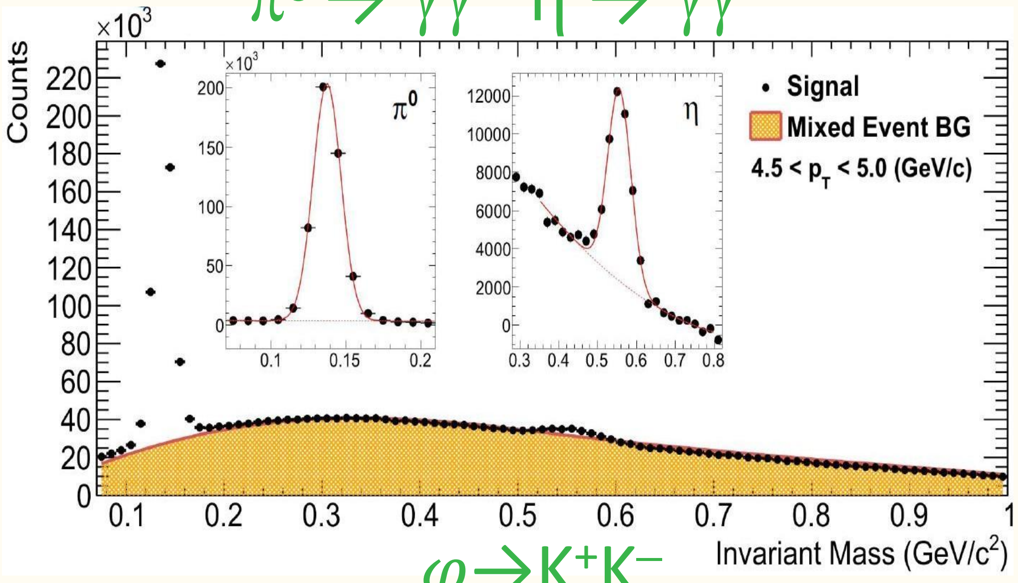
Mesons spectra in p+p @ 200 GeV



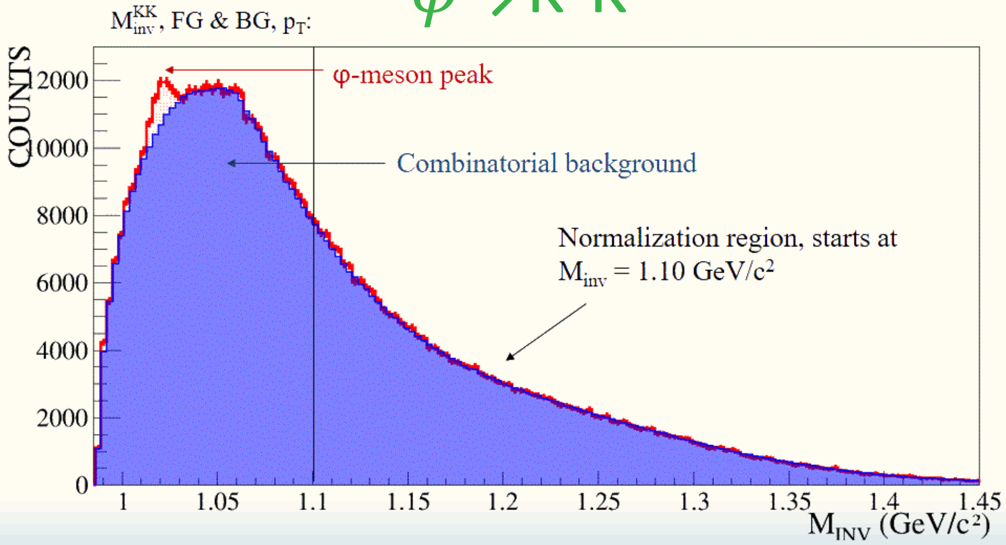
- All measured results were found to be consistent between the different decay modes
- Well described by the Tsallis distribution functional form with only two parameters:
  - $T = 112.6 \pm 3.8 + (11.8 \pm 7.0)m_0[GeV/c^2]$ MeV
  - $n = 9.48 \pm 0.14 + (0.66 \pm 0.39)m_0[GeV/c^2]$ (Phys.Rev.D83:052004)
- These spectra are used as a baseline to compare with more complex and heavy colliding systems such as p+A and A+A
- These spectra are also needed for tuning event generators and parameters of fragmentation functions

π^0, η, K_s, K*, φ & ω Reconstruction in p+A & A+A

$\pi^0 \rightarrow \gamma\gamma$ $\eta \rightarrow \gamma\gamma$



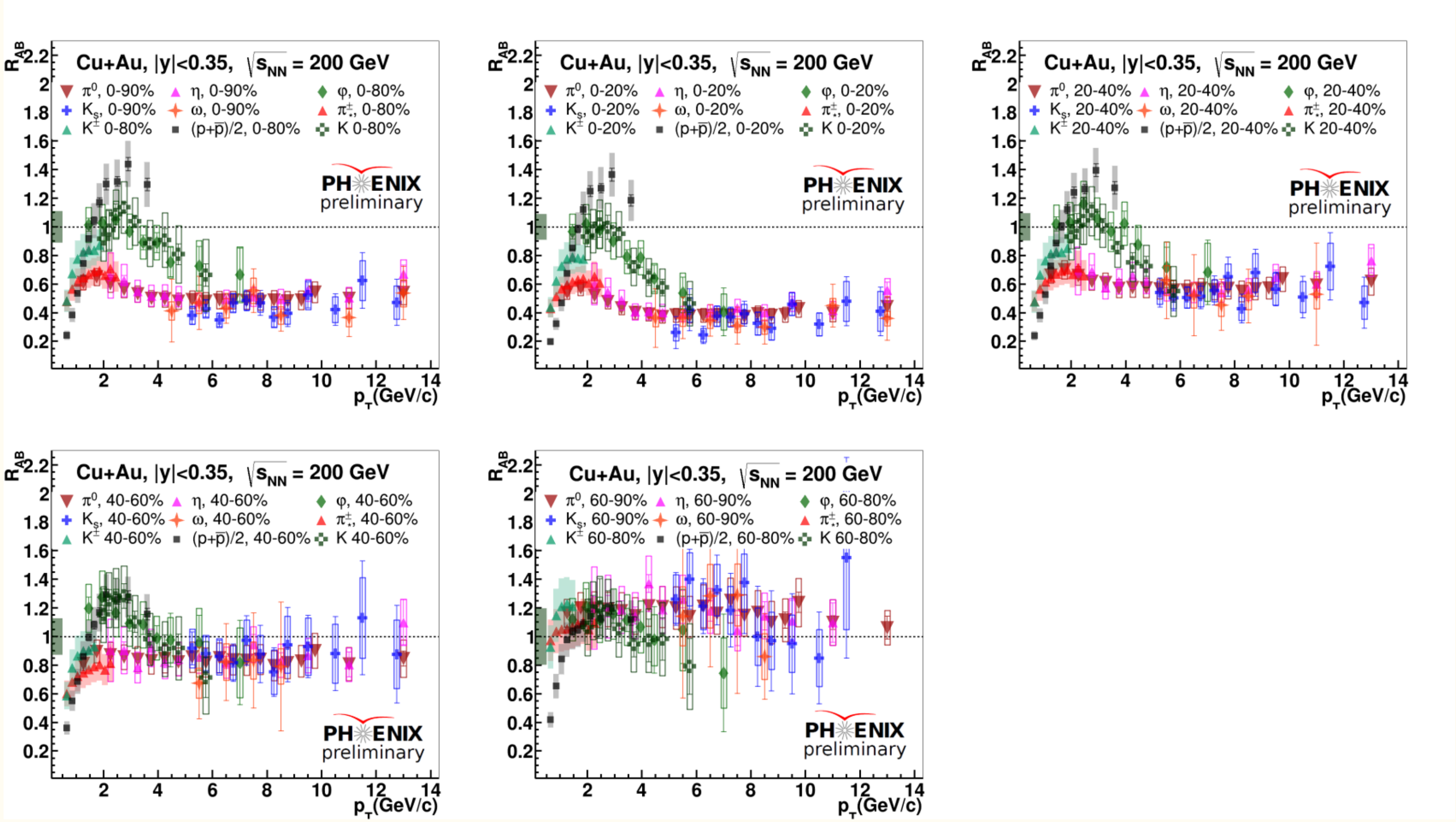
$\varphi \rightarrow K^+K^-$



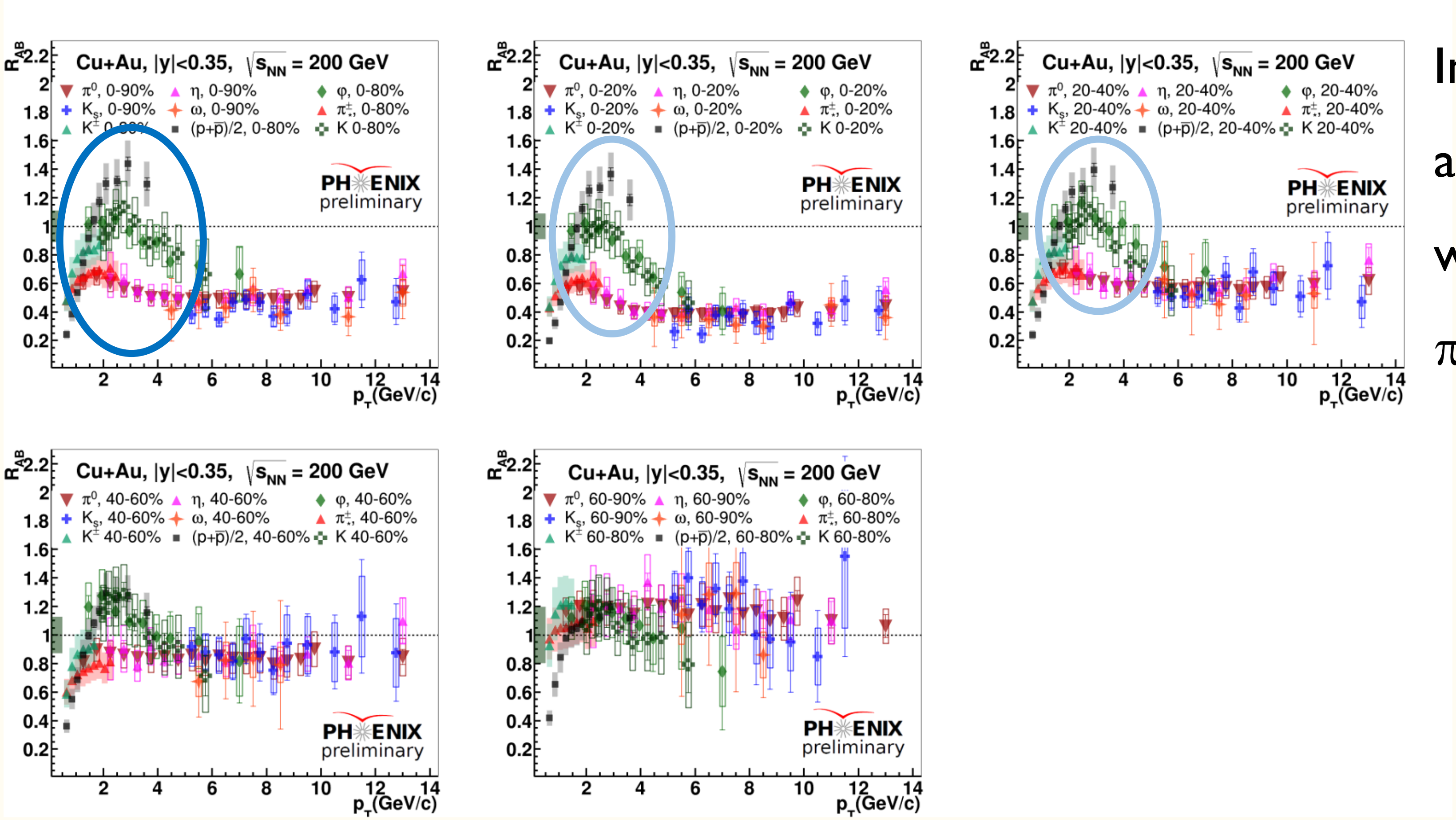
	System	Decay modes	BR,%	Detector
π^0	p+p, d+Au, Cu+Cu, Au+Au, Cu+Au, U+U, p/³He+Au	$\gamma\gamma$	~99	EMCal
η	p+p, d+Au, Cu+Cu, Au+Au, Cu+Au, U+U	$\gamma\gamma$	~39	EMCal
ω	p+p, d+Au, Cu+Cu, Au+Au, Cu+Au, U+U	$\pi^0\gamma$	~8.4	EMCal
K*	p+p, d+Au, Cu+Cu, Cu+Au, U+U, ³He+Au	$K^\pm\pi^\pm$	~67	DC+ToF
K_S	p+p, d+Au, Cu+Cu, Cu+Au	$\pi^0\pi^0$	~30	EMCal
ϕ	p+p, d+Au, Cu+Cu, Au+Au, Cu+Au, U+U, p/³He+Au	K^+K^-	~49	DC+ToF

Large Systems

Light hadrons R_{CuAu} at $\sqrt{s_{NN}}$=200 GeV



Light hadrons R_{CuAu} at $\sqrt{s_{NN}}$=200 GeV



In most central collisions $(p+\bar{p})/2$ are less suppressed than φ & K*, which are less suppressed than π^0, and η in the intermediate p_T range

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St.Petersburg Polytechnic
University

Light hadrons R_{CuAu} at $\sqrt{s_{NN}}$=200 GeV

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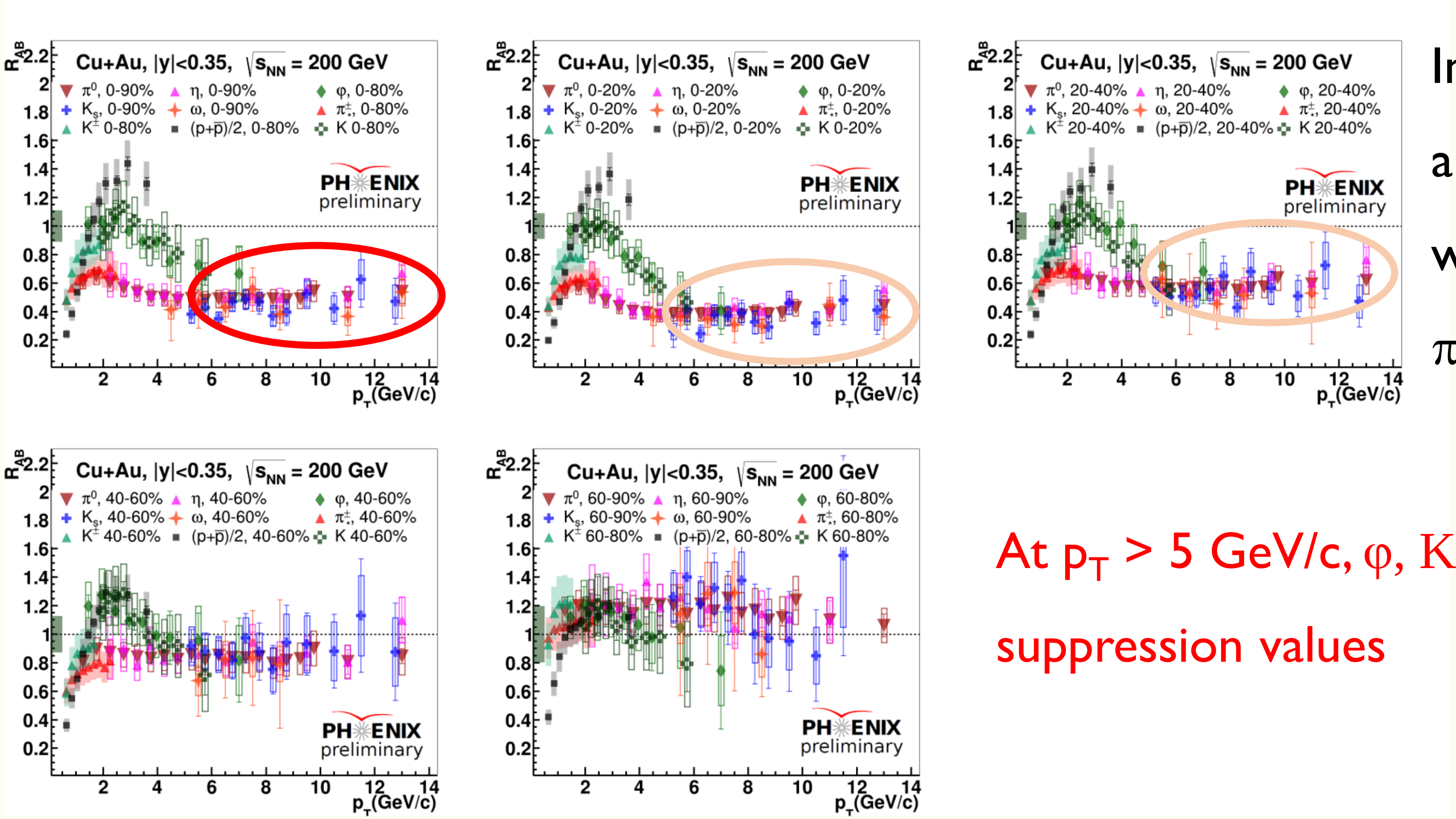
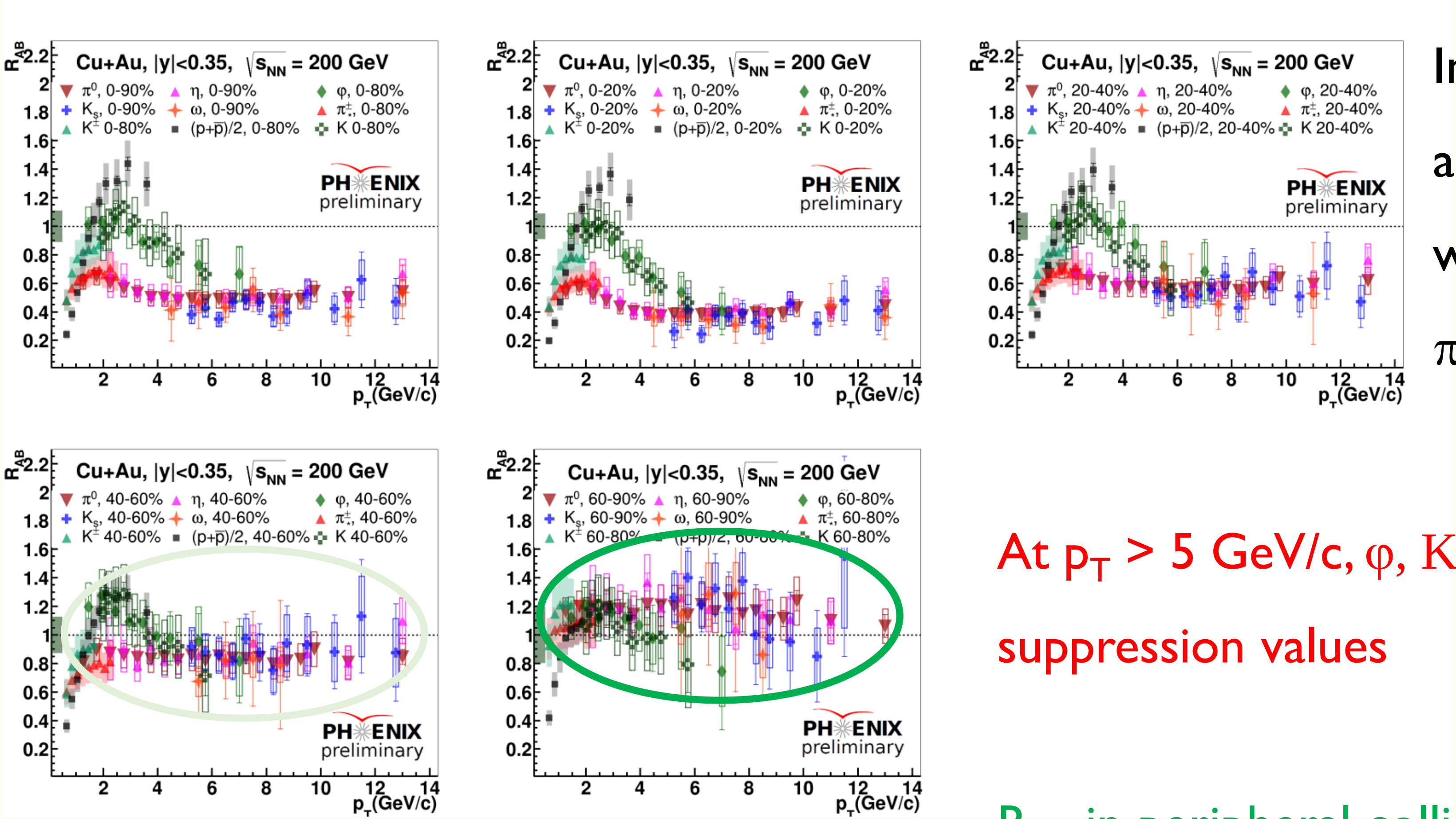


In most central collisions $(p+\bar{p})/2$ are less suppressed than φ & K*, which are less suppressed than π^0, and η in the intermediate p_T range

At p_T > 5 GeV/c, φ, K*, π^0, η, K_S, ω show similar suppression values

Light hadrons R_{CuAu} at $\sqrt{s_{NN}}$=200 GeV



In most central collisions $(p+\bar{p})/2$ are less suppressed than φ & K*, which are less suppressed than π^0, and η in the intermediate p_T range

At p_T > 5 GeV/c, φ, K*, π^0, η, K_S, ω show similar suppression values

R_{AB} in peripheral collisions consistent with each other within uncertainties.

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Light hadrons integrated R_{AB}

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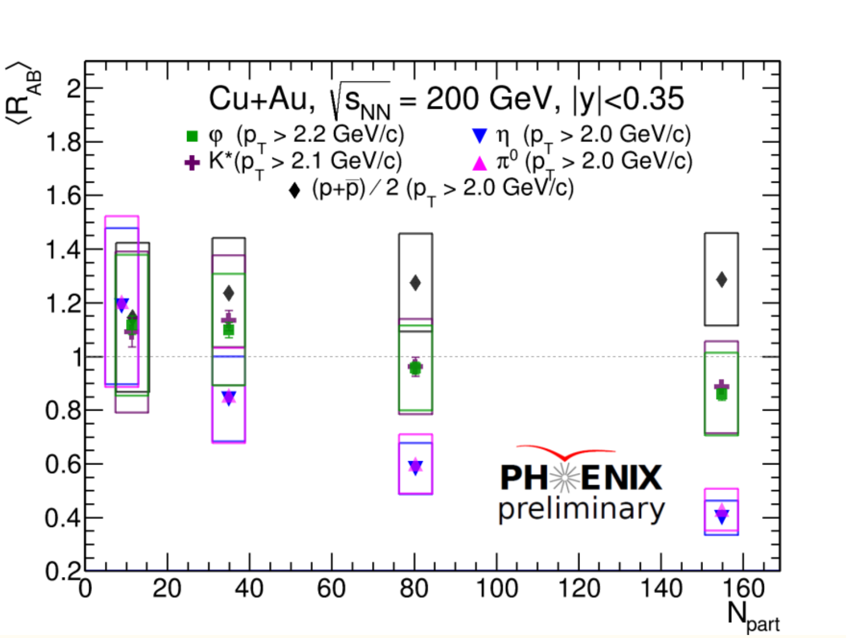
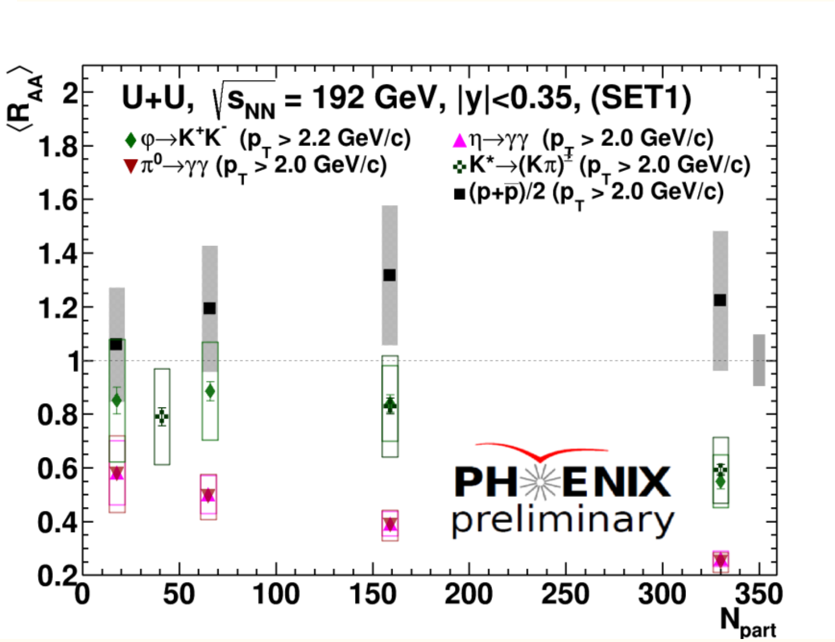
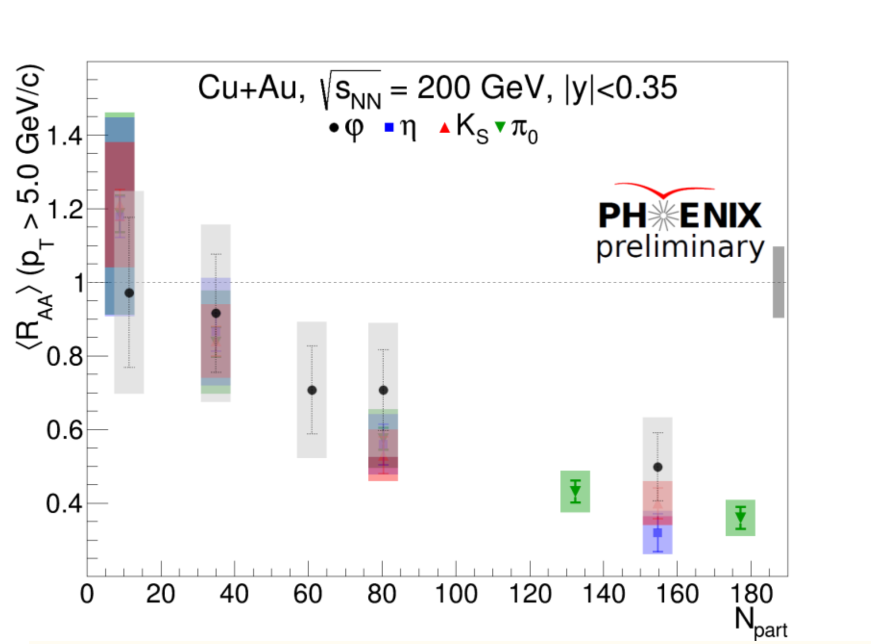
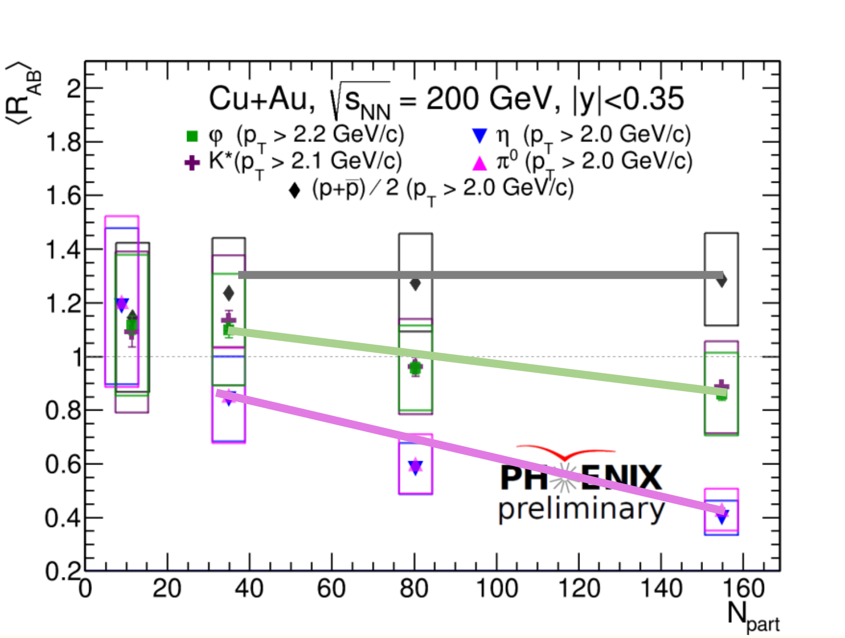
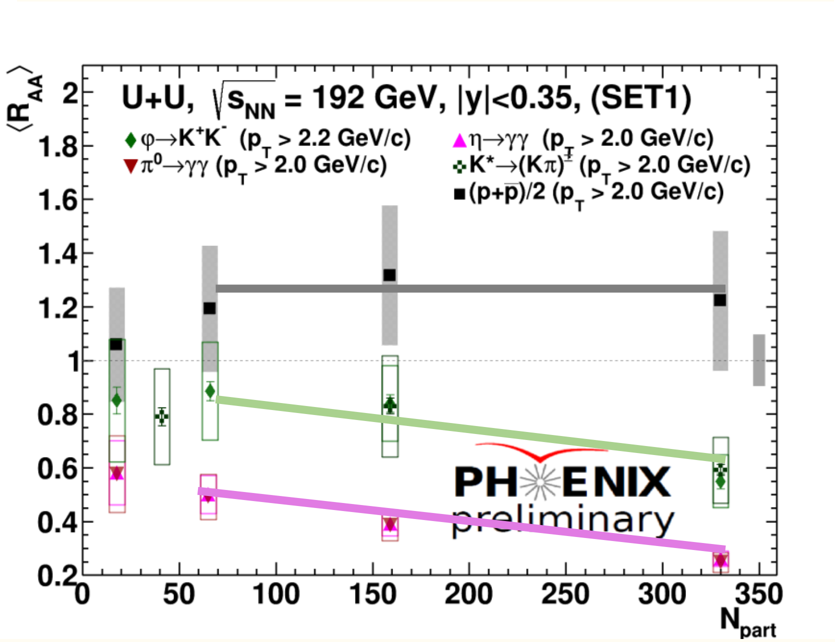


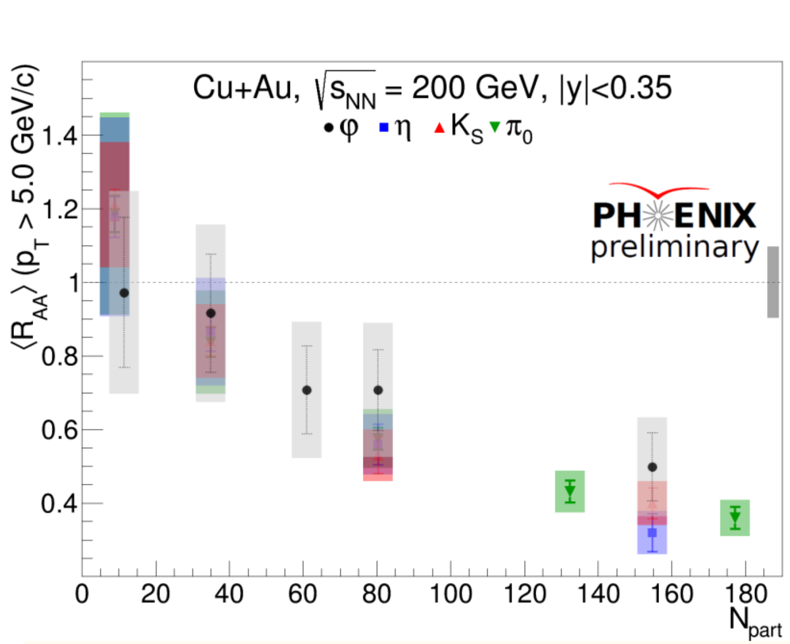




Light hadrons integrated R_{AB}



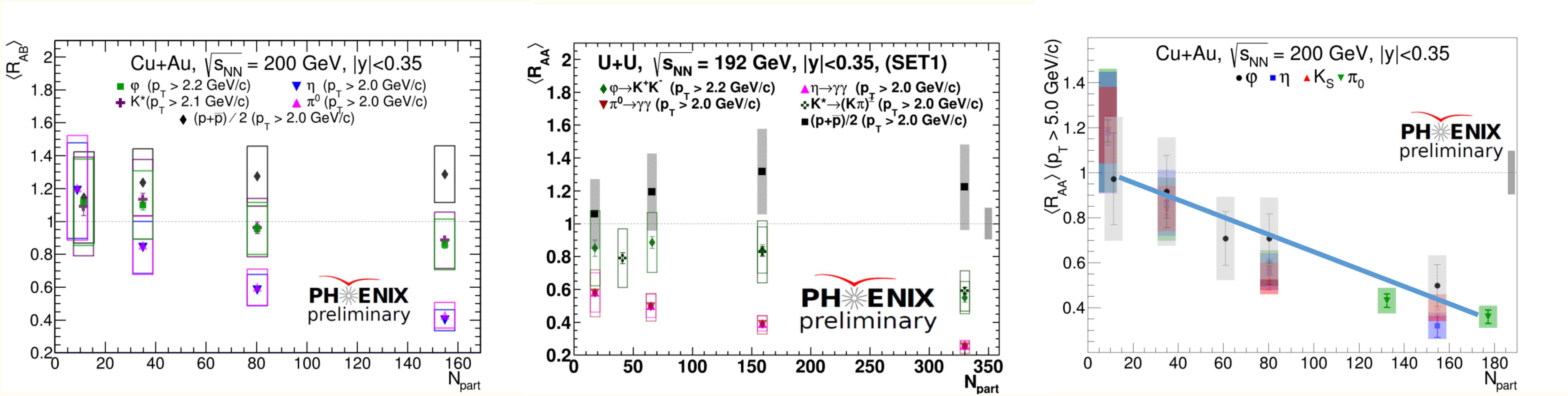




- The ordering is seen at $p_T \gtrsim 2$ GeV/c:

$$\pi^0 \,\&\, \eta \langle R_{AB} \rangle < \varphi \,\&\, K^* \langle R_{AB} \rangle < (p+\bar{p})/2 \, \langle R_{AB} \rangle$$

Light hadrons integrated R_{AB}

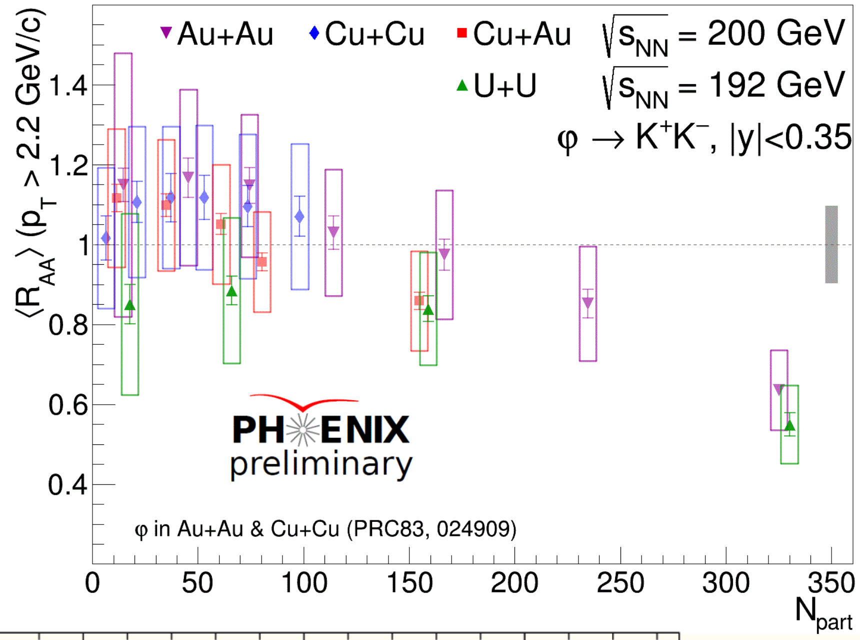


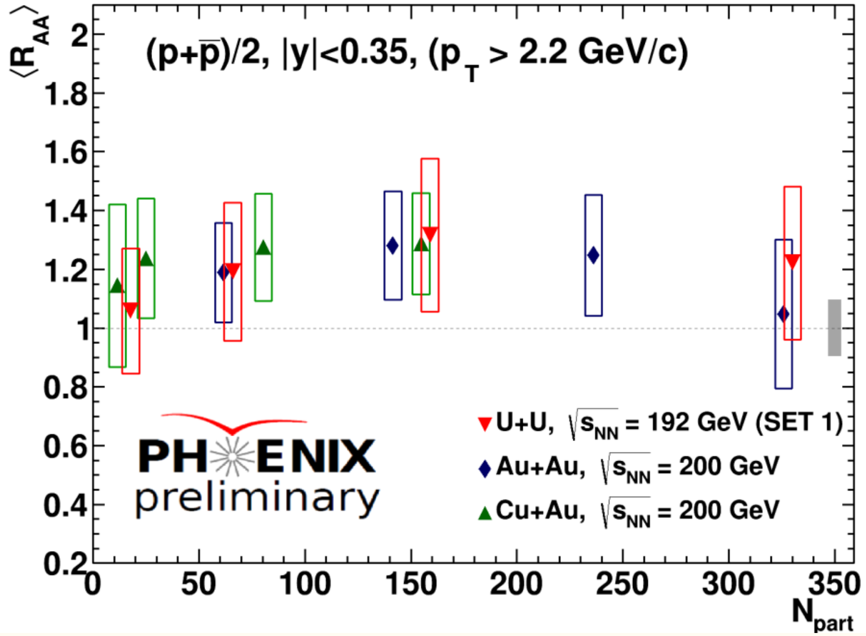
- The ordering is seen at $p_T \gtrsim 2$ GeV/c:

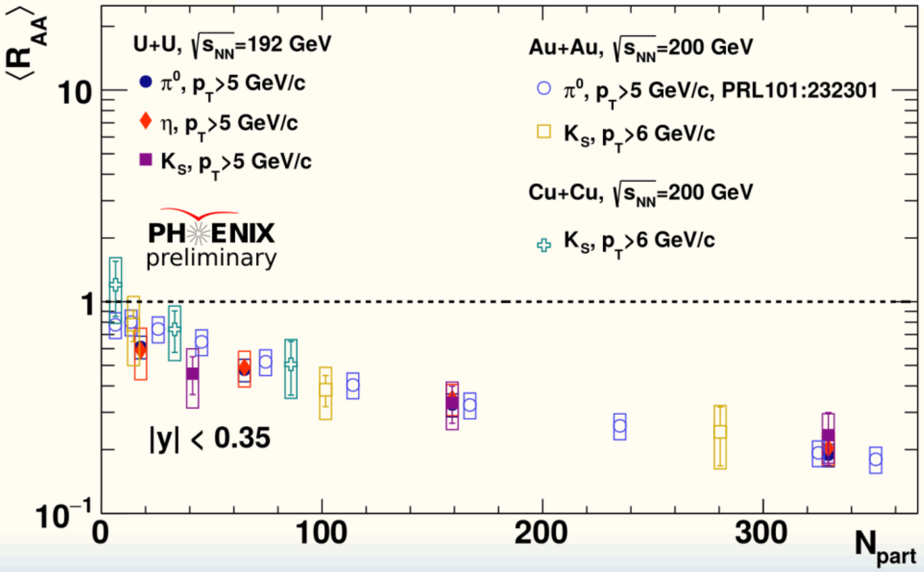
$$\pi^0 \,\&\, \eta \langle R_{AB} \rangle < \varphi \,\&\, K^* \langle R_{AB} \rangle < (p + \bar{p})/2 \, \langle R_{AB} \rangle$$

- The φ, π^0, η & K_S integrated R_{AB} at p_T>5 GeV/c show same suppression level

Light hadrons integrated R_{AA}

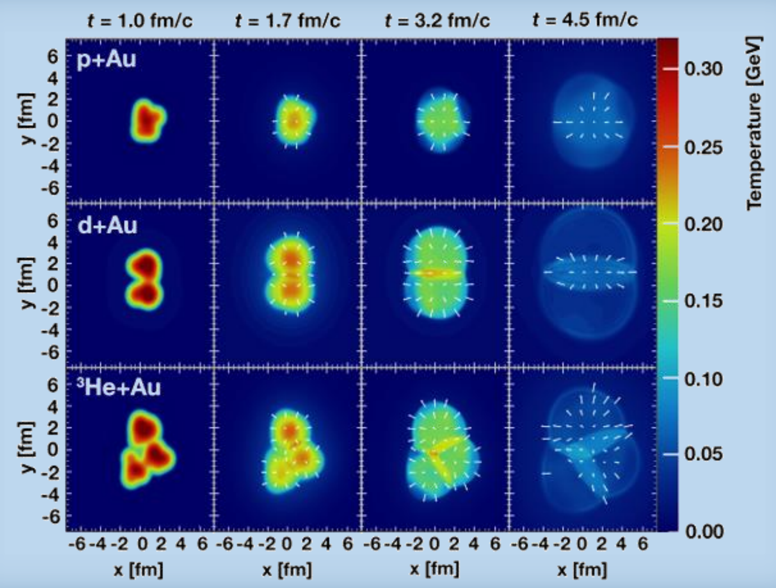




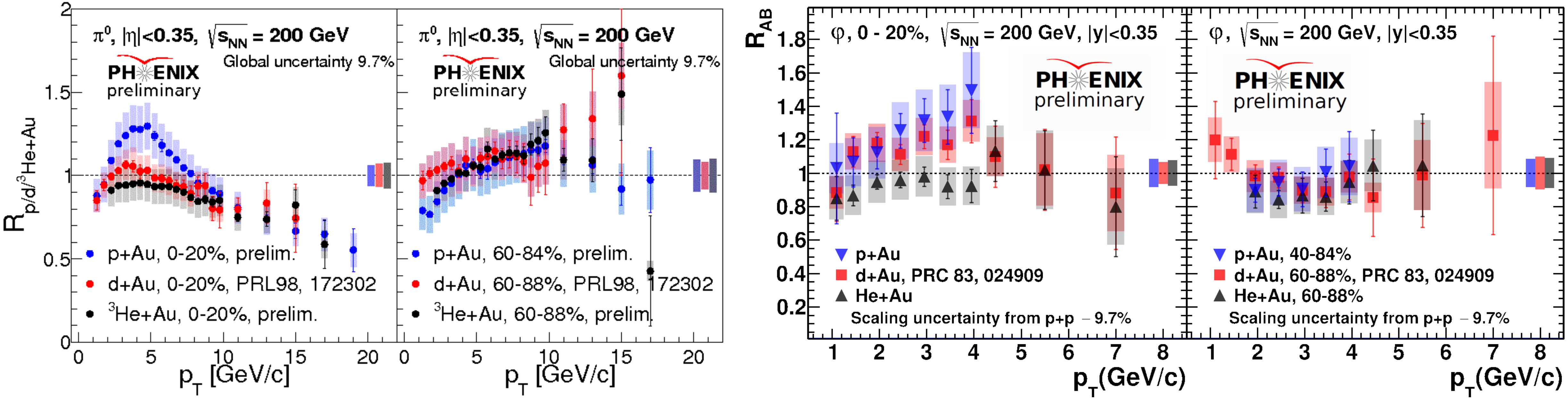


- Light hadrons integrated R_{AA} show approximately same suppression level
  - Production and suppression of the light mesons seem to depend on nuclear overlap size, but not on its geometry

Small systems: p+Al, p+Au, d+Au, ^{3}He+Au



π^0 & φ R_{AB} in p+Au, d+Au, ^{3}He+Au



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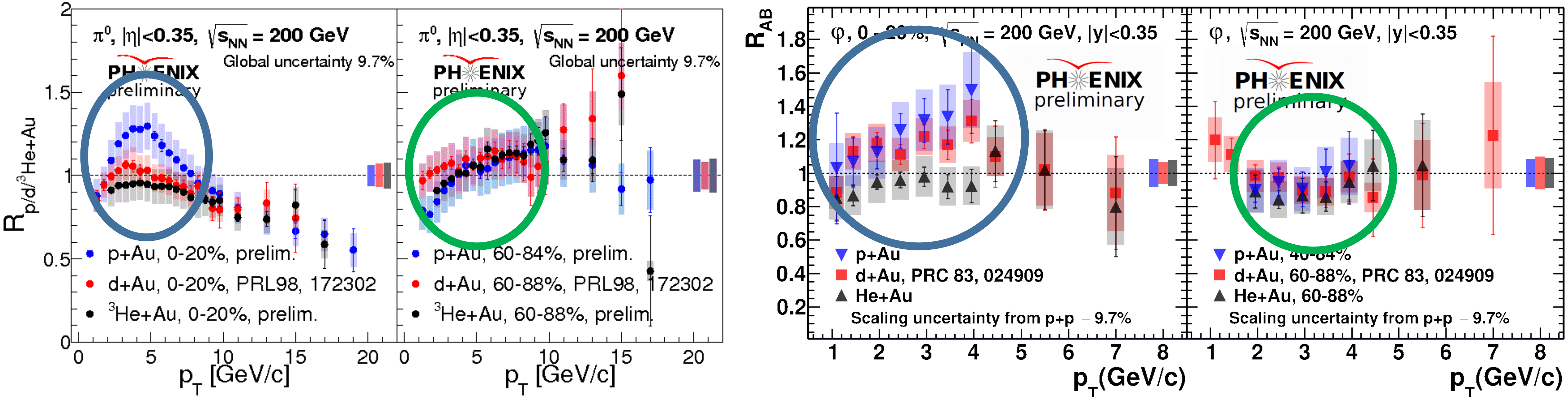
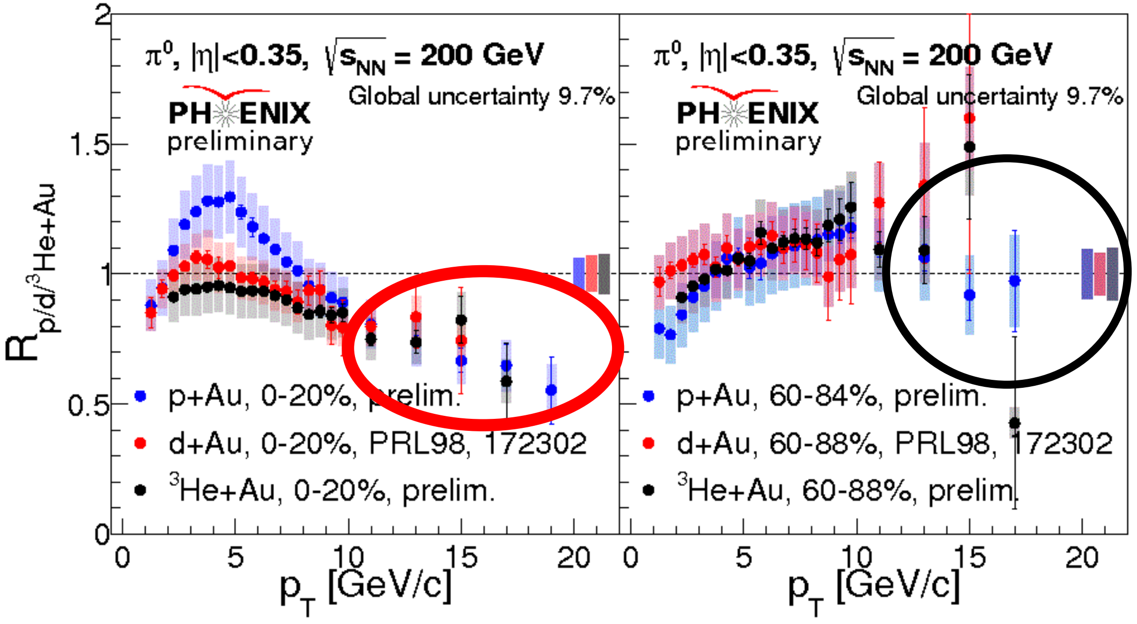


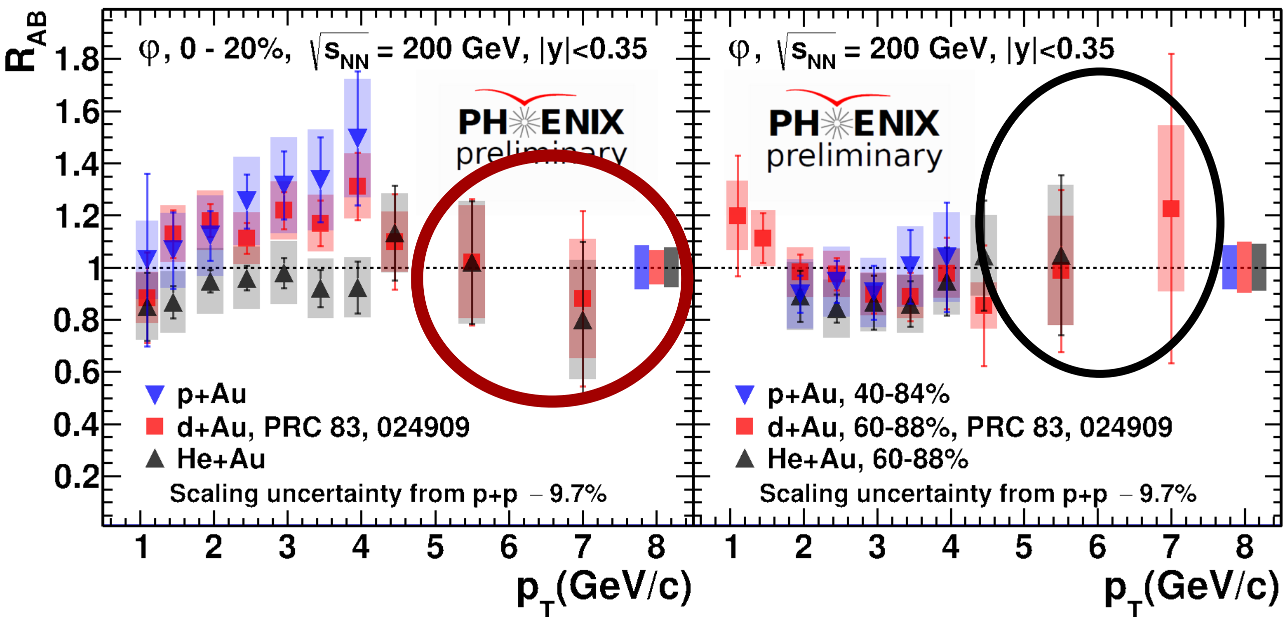
At intermediate p_T range:

Ordering $R_{pAu} > R_{dAu} > R_{HeAu}$ in 0-20%

π^0 and φ $R_{pAu} \approx R_{dAu} \approx R_{HeAu}$ in peripheral collisions

π^0 & φ R_{AB} in p+Au, d+Au, ^{3}He+Au





At intermediate p_T range:

Ordering $R_{pAu} > R_{dAu} > R_{HeAu}$ in 0-20%

π^0 and φ $R_{pAu} \approx R_{dAu} \approx R_{HeAu}$ in peripheral collisions

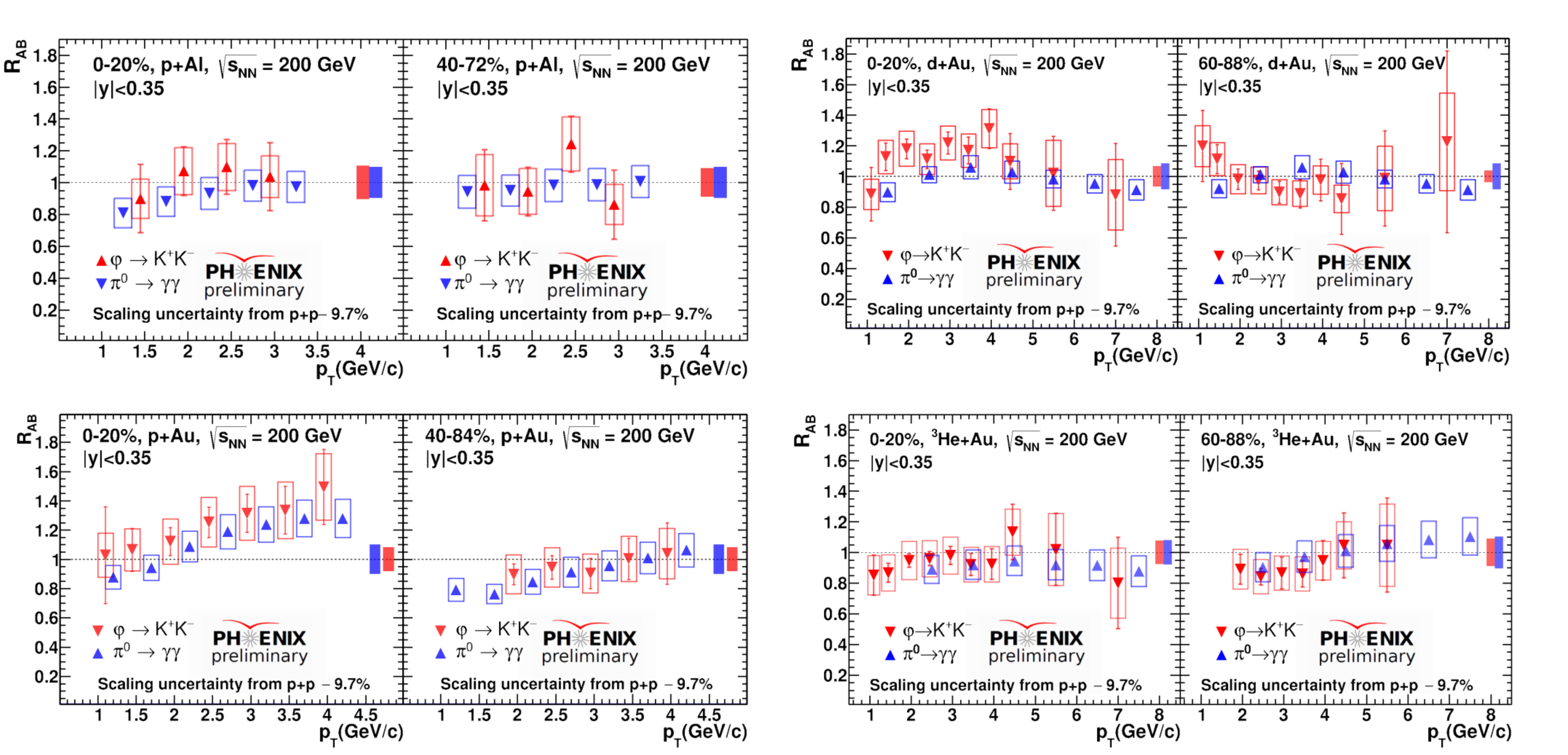
At high-p_T range:

π^0 R_{AB}'s consistent with each other at high-p_T

Hint of suppression in central collisions for π^0

Hint of enhancement in peripheral collisions

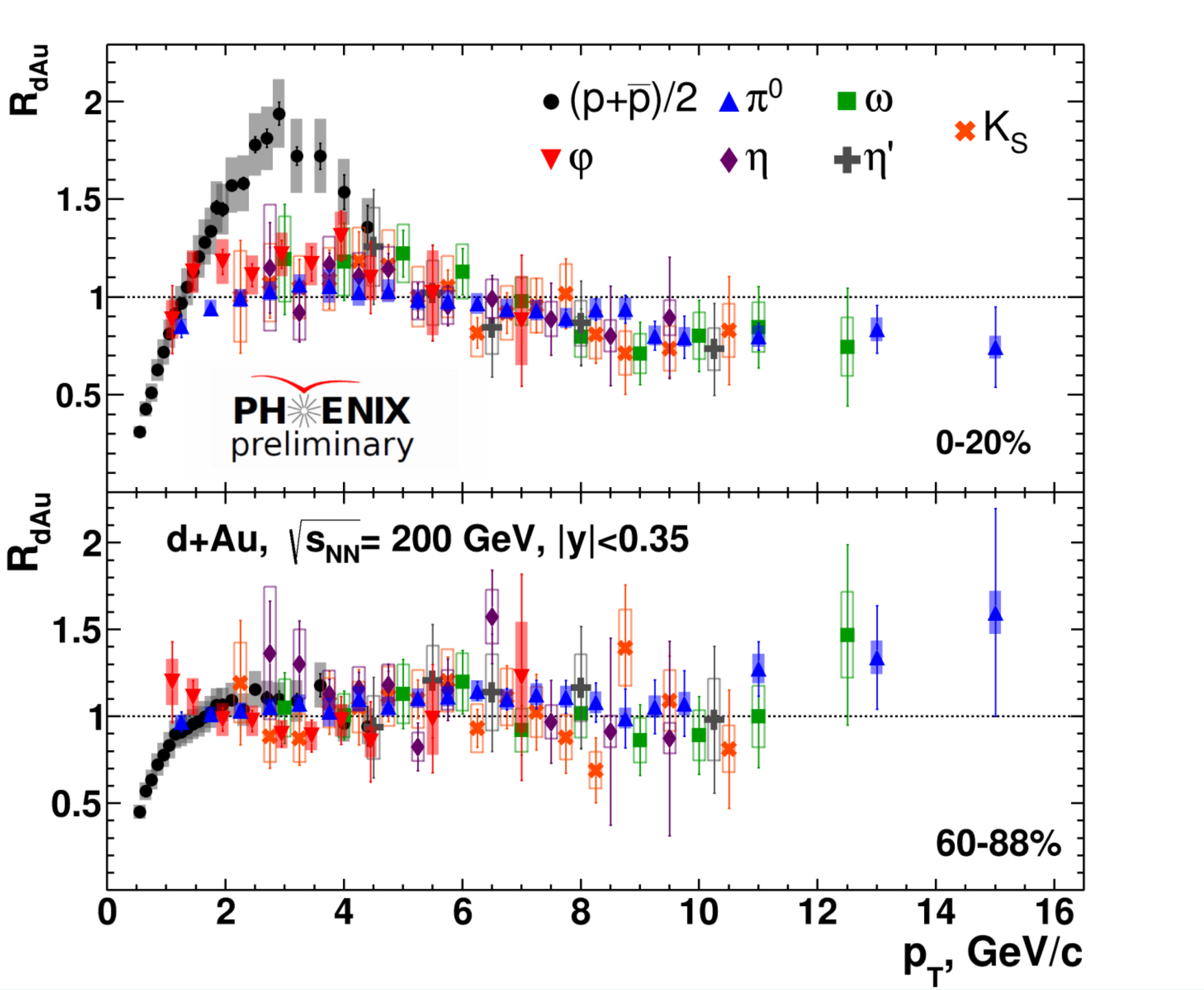
π^0 & φ R_{AB} in p+Al, p+Au, d+Au, ^{3}He+Au



In whole φ p_T range π^0 and φ mesons R_{AB}'s are similar in small systems

Might indicate that CNM effects are not responsible for the differences between φ and π^0 seen in A+A

Comparisons to other light hadron's R_{AB} in d+Au collisions

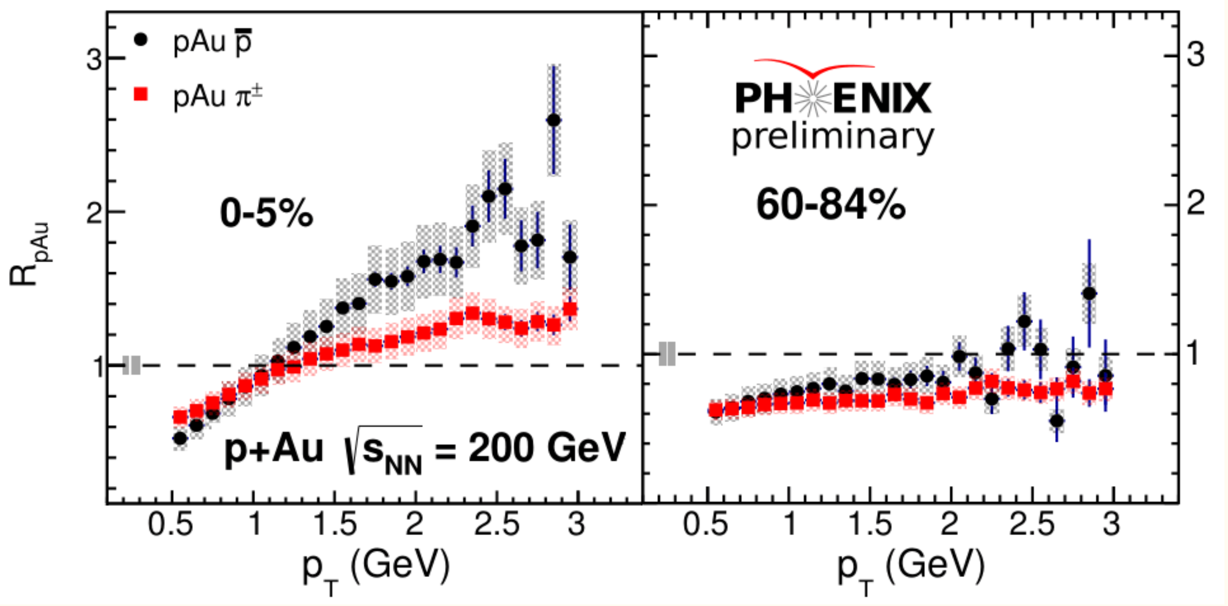


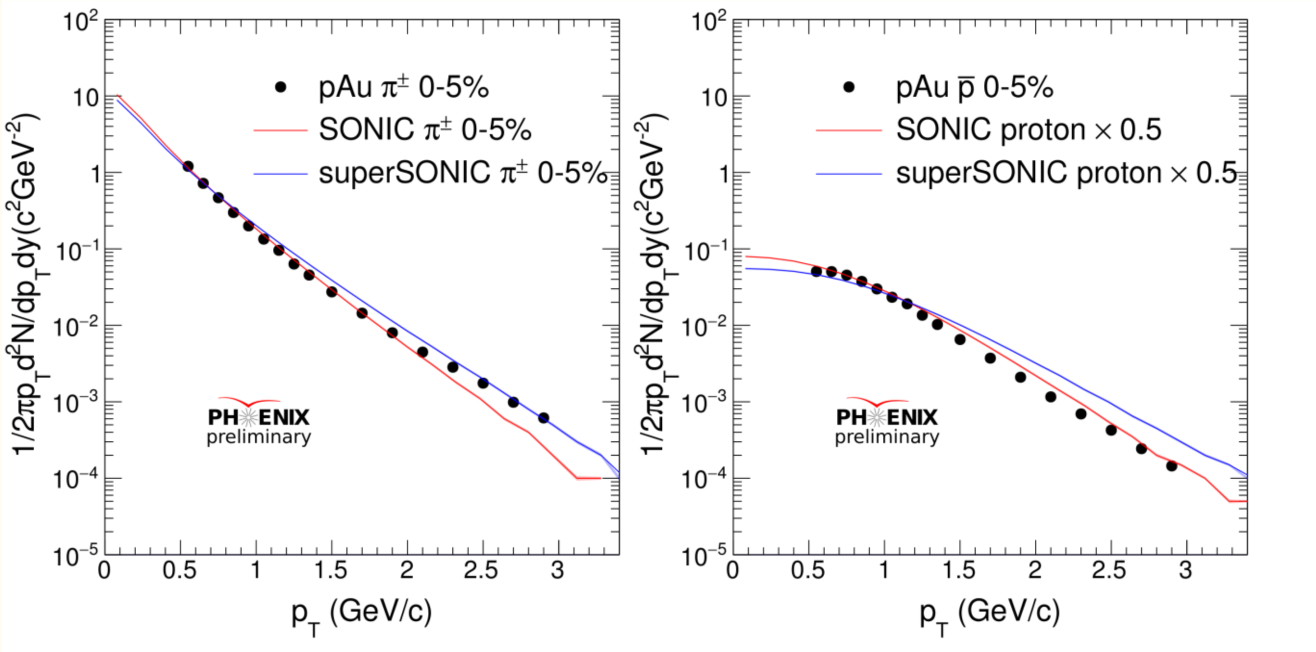
In contrast to heavy-ion, φ, π^0, η, η', ω & K_S exhibit similar shape

Protons R_{AB} show enhancement at moderate p_T as in the most central heavy-ion collisions

R_{AB} in peripheral collisions consistent with each other within uncertainties.

Comparisons to other light hadron's R_{AB} in p+Au collisions

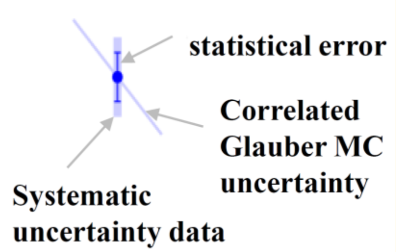


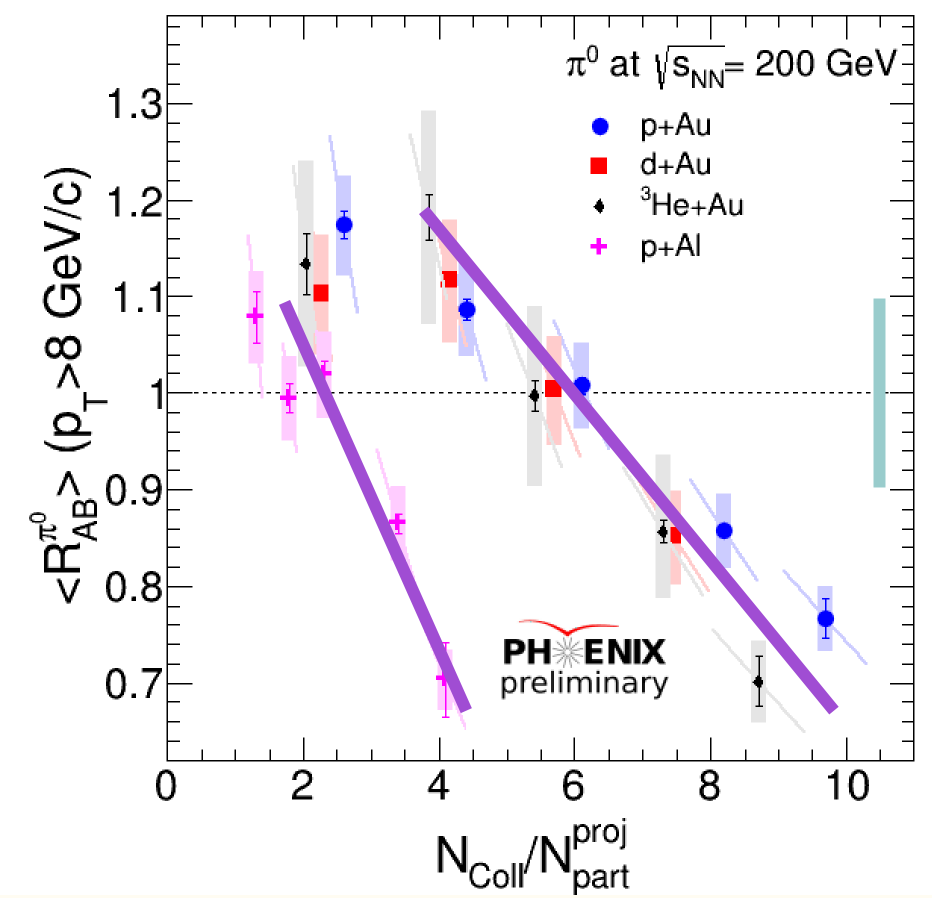


$\pi^{\pm}$& $\bar{p}$ invariant yield in 0-5% are well described by SONIC and superSONIC

FLOW might be responsible for proton enhancement

π^0 integrated yields & R_{AB} in p+Al, p+Au, d+Au, ^{3}He+Au

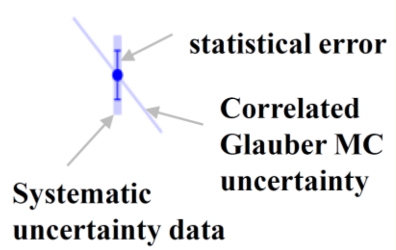


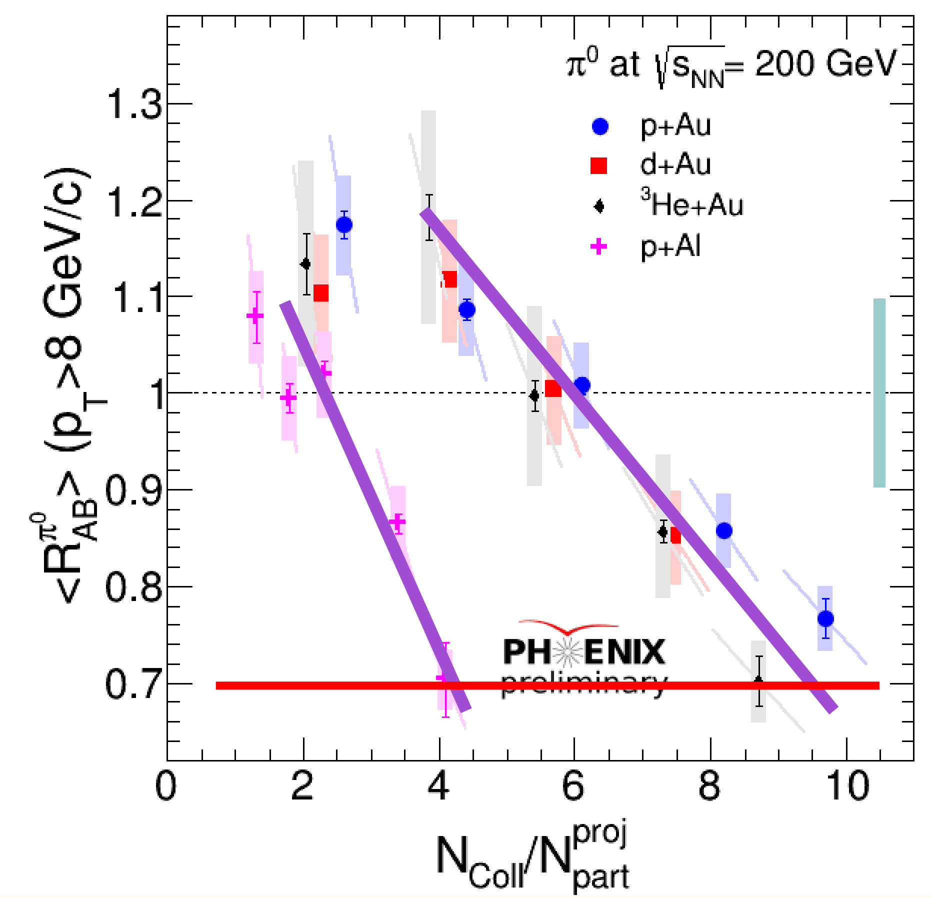


Model independent conclusions for the mechanism for high pT nuclear modification in small systems:

- mostly independent interaction of each projectile

π^0 integrated yields & R_{AB} in p+Al, p+Au, d+Au, ^{3}He+Au

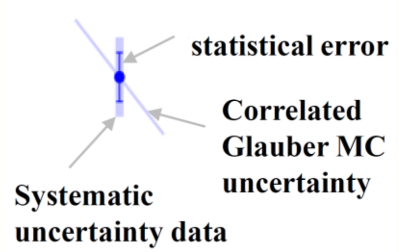


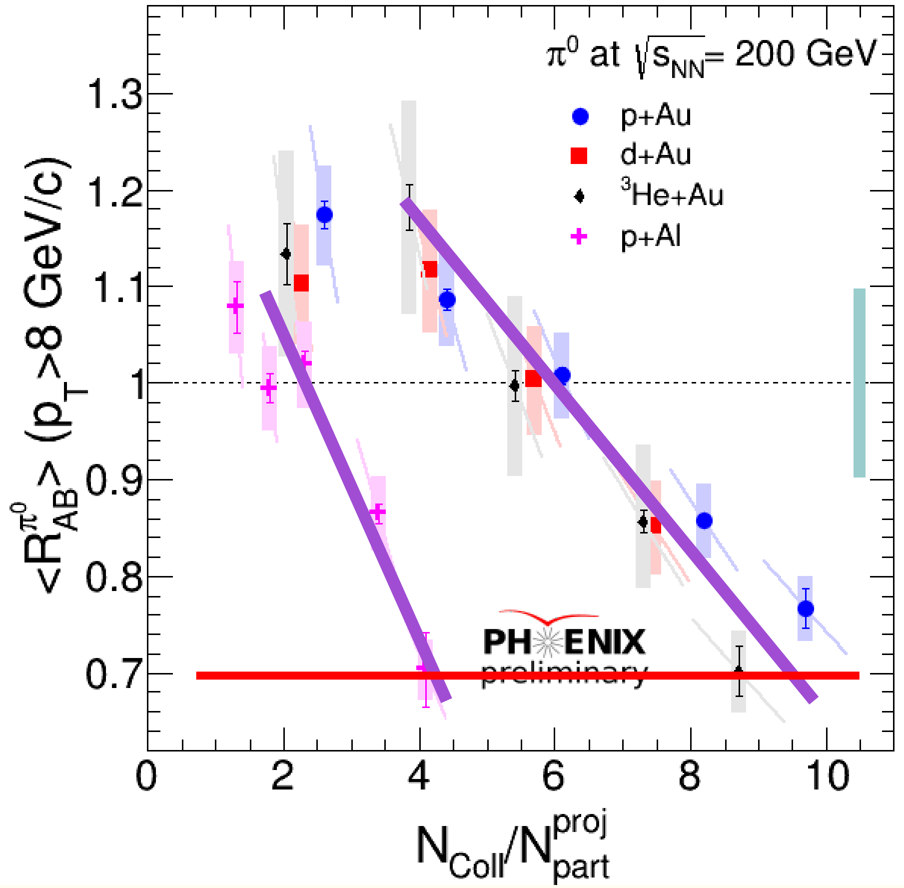


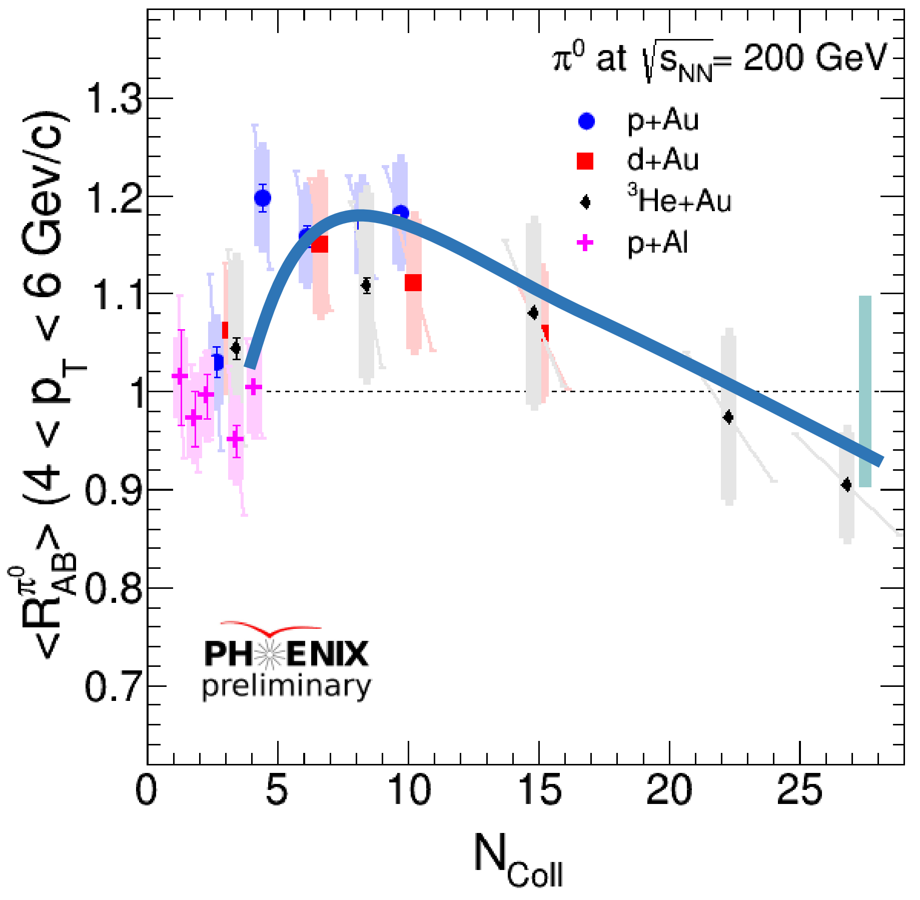
Model independent conclusions for the mechanism for high pT nuclear modification in small systems:

- mostly independent interaction of each projectile
- not driven thickness of matter traversed by projectile

π^0 integrated yields & R_{AB} in p+Al, p+Au, d+Au, ^{3}He+Au







Model independent conclusions for the mechanism for high pT nuclear modification in small systems:

- mostly independent interaction of each projectile
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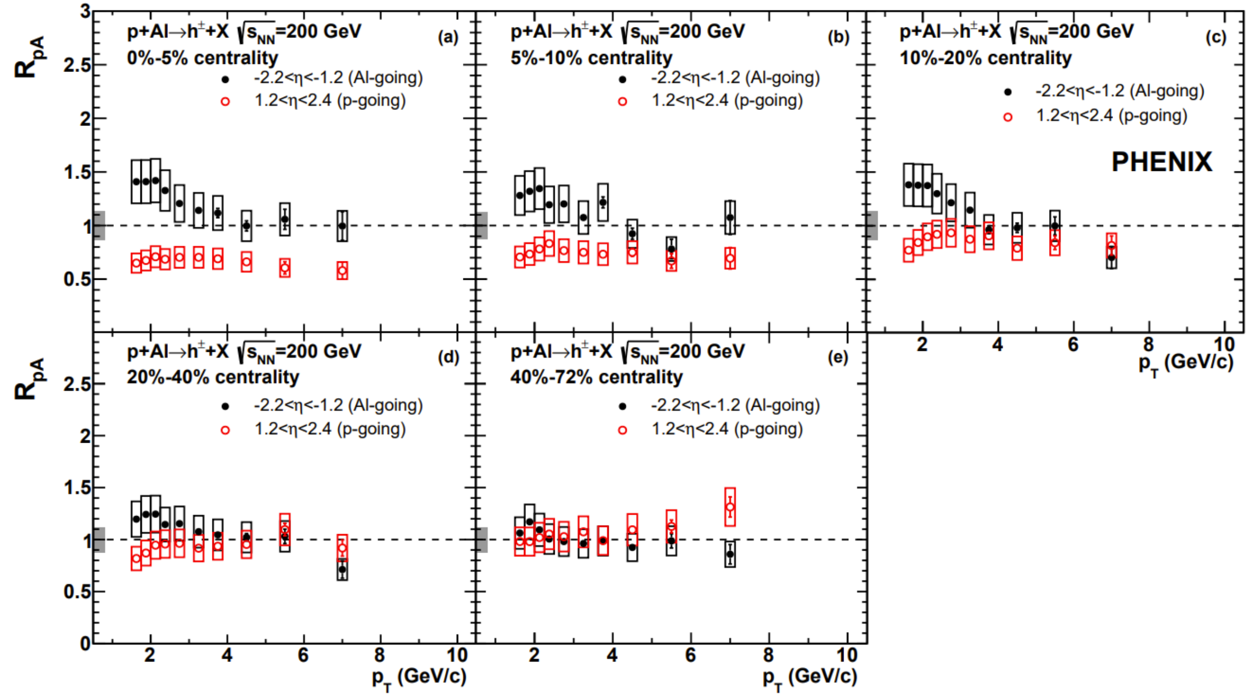
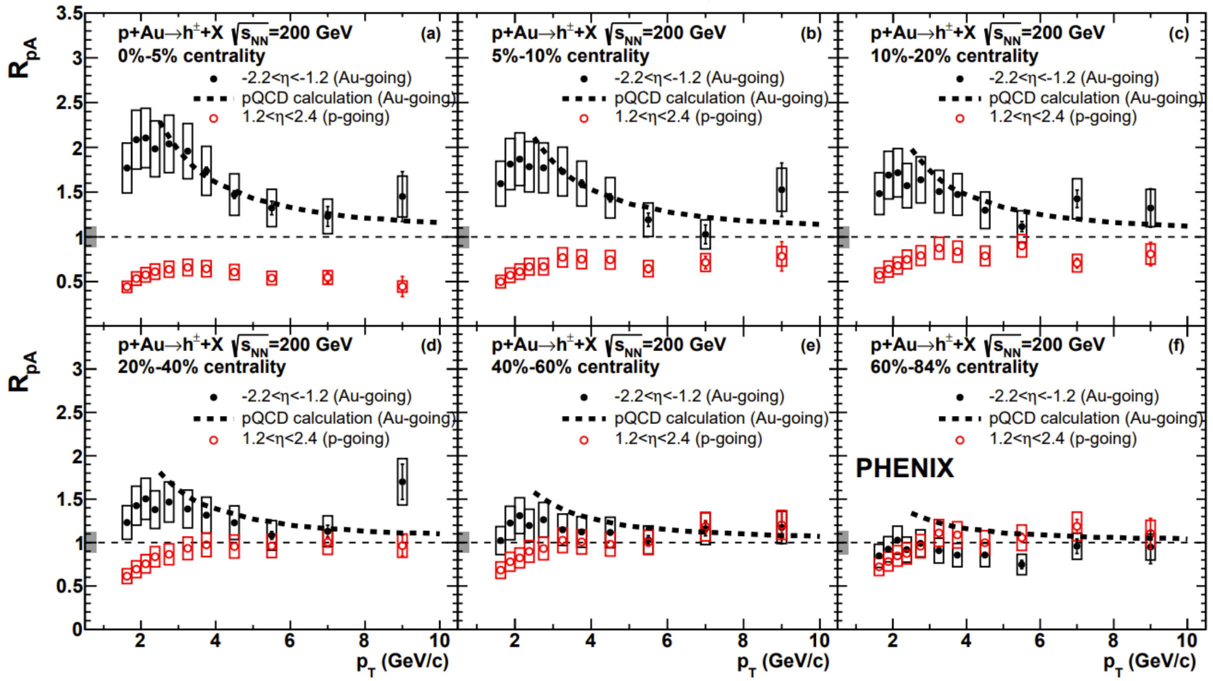
$h^{\pm}$ ⟨R_{AB}⟩ in p+Al and p+Au

arXiv:1906.09928v1

Phys. Rev. C 101, 034910 (2020)





In central collisions

Backward rapidity shows large enhancement

Forward rapidity shows suppression

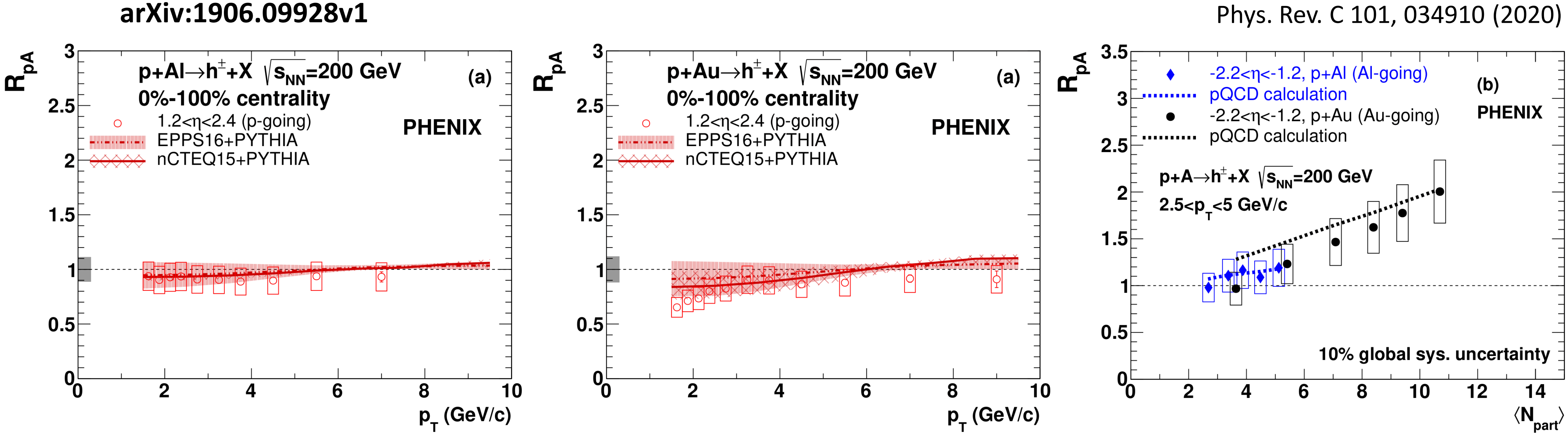
Au-going direction consistent with pQCD multiscattering calculation

Strong centrality dependence

$h^{\pm}$ in p+Al and p+Au

arXiv:1906.09928v1

Phys. Rev. C 101, 034910 (2020)



$h^{\pm}$ R_{AB} in p-going direction is described by EPPS16+PYTHIA and nCTEQ15+PYTHIA

$\langle R_{AB} \rangle$ vs. N_{part} in A-going direction is described by pQCD multiscattering calculations

Summary

Large Systems:

Light mesons R_{AB} in large systems for similar N_{part} values exhibit similar shape

- Production and suppression of the light meson seems to depend on nuclear overlap size, but not on its geometry and not on its density

Hadron's R_{AB} exhibit a three different suppression patterns: π^0 & $\eta\langle R_{AB}\rangle < \varphi$ & $K^*\langle R_{AB}\rangle < (p+\bar{p})/2\ \langle R_{AB}\rangle$

- The observation of these patterns in many collision systems can provide a contribution to the understanding of the strangeness enhancement competing with energy loss

Small systems:

The φ & π^0 mesons R_{AB}'s are consistent in p/d/^{3}He+Au collisions in all centralities

- That might indicate that cold nuclear effects are not responsible for the differences between φ & π^0 seen in Au+Au, Cu+Cu, Cu+Au and U+U collisions

In most central collisions in the intermediate p_T range there's an ordering of $R_{pAu}>R_{dAu}>R_{HeAu}$ for both φ & π^0 mesons:

- The ordering might indicate a system size dependence

These results can provide additional constraints for the models that try to explain CNM effects (like AMPT, EPOS)