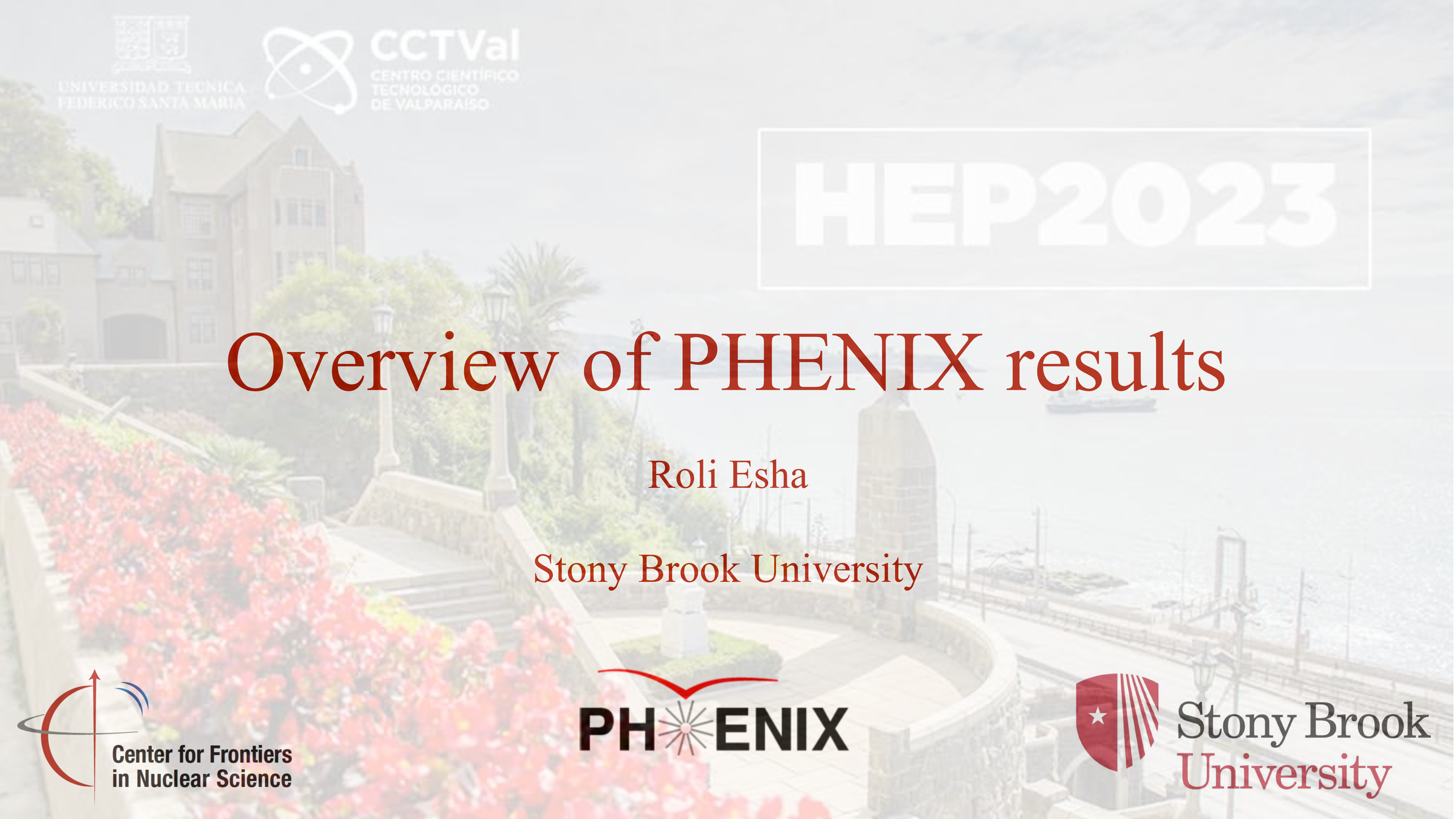

Overview of PHENIX results

Roli Esha

Stony Brook University

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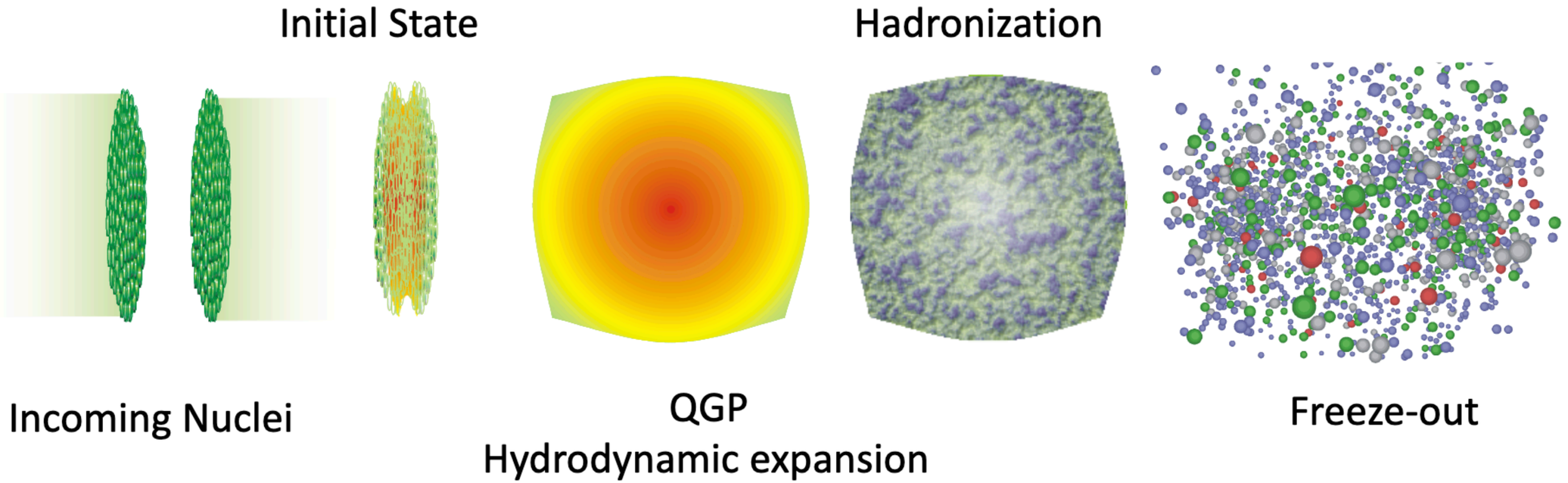
PHENIX

Stony Brook University

Organization

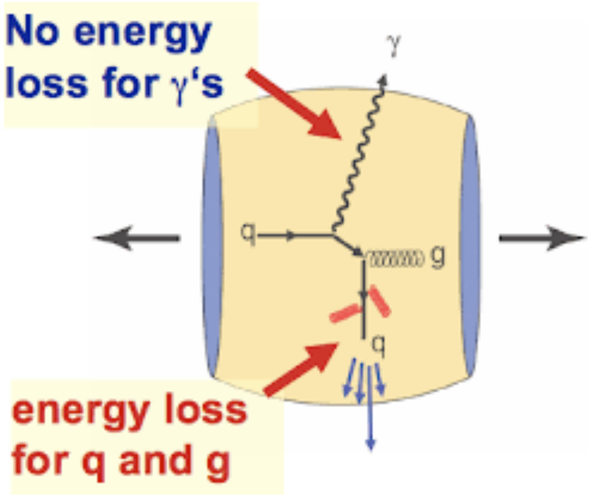
- Introduction
- Detailed study of QGP in large collision systems
- Study of final state effects in small collision systems
- Summary and outlook

Quark Gluon Plasma

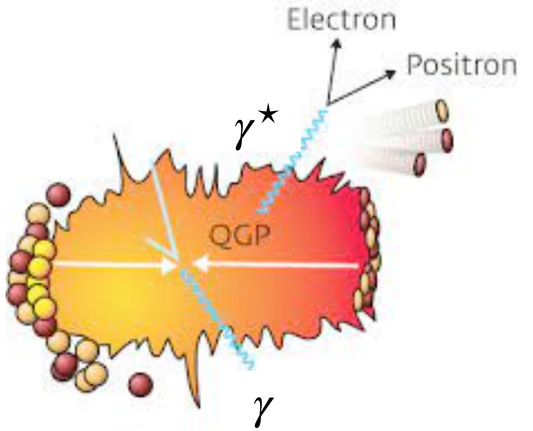


A comprehensive understanding from the initial hard scattering to final freeze-out is needed to understand the properties of strong interaction

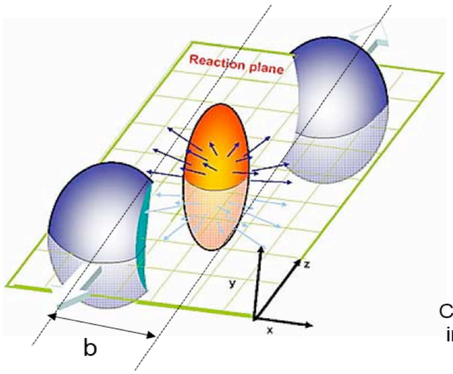
Key observables

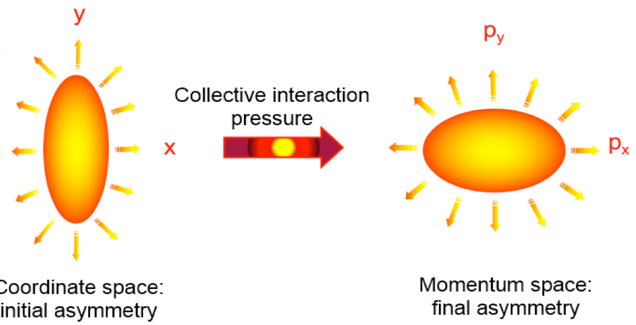


Energy loss

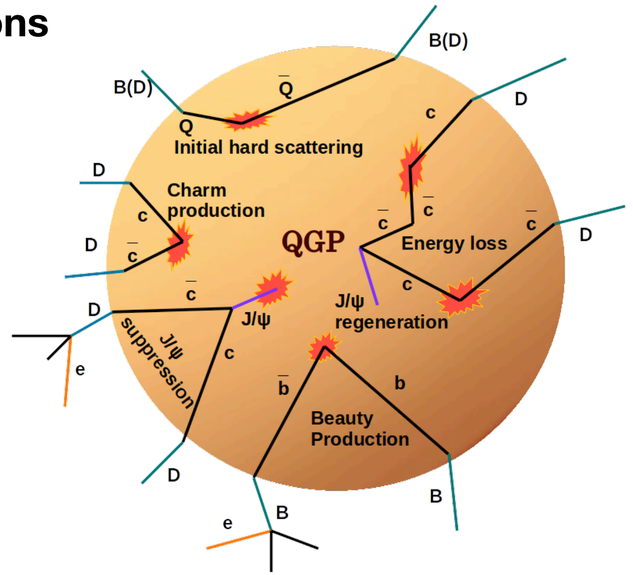


Thermal radiations





Collective motion

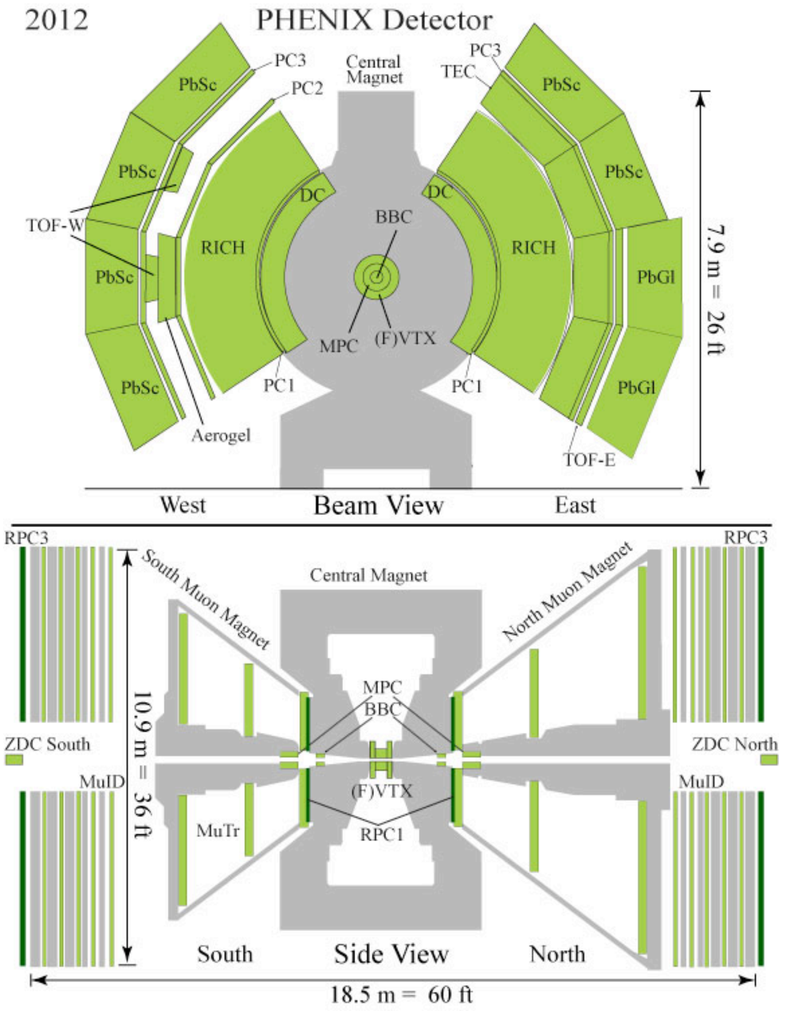


Heavy flavor

PHENIX experiment

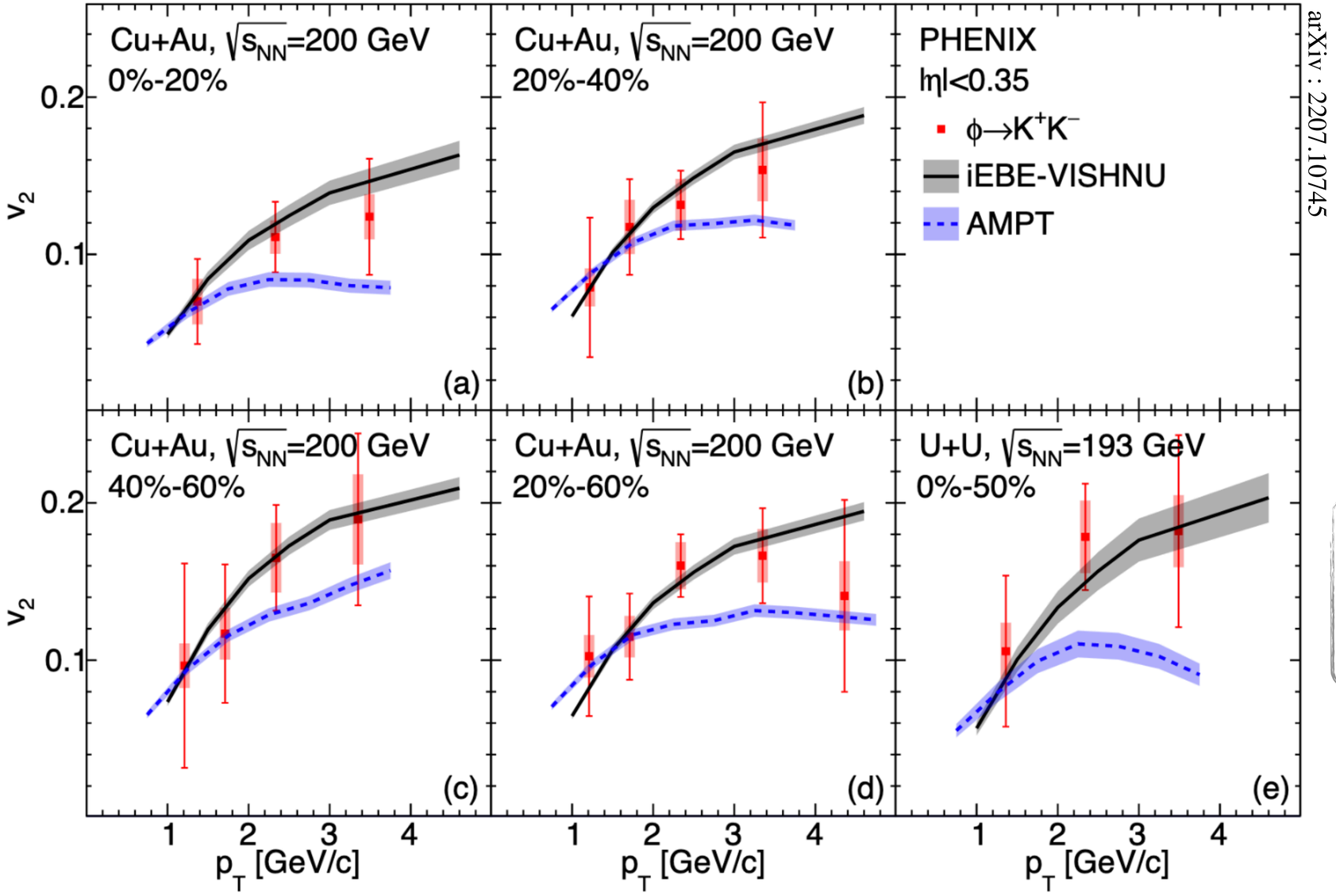
√s [GeV]	p+p	p+Al	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓								
200	✓	✓	✓	✓	✓	✓	✓	✓	✓
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	

9 collision species
9 collision energies



- Stopped taking data in 2016
- Ongoing analysis of large datasets taken in 2014, 2015 and 2016

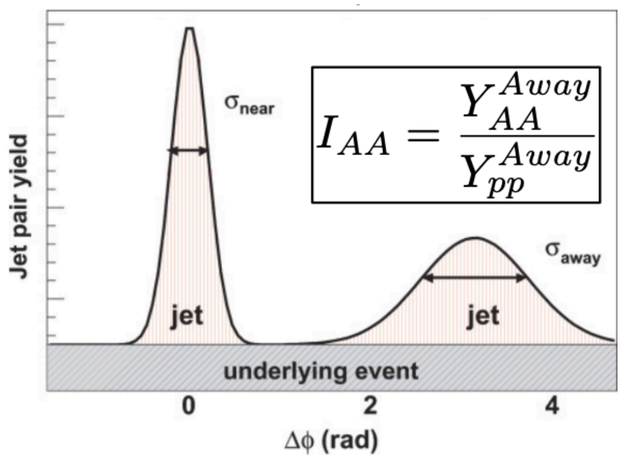
Elliptic flow



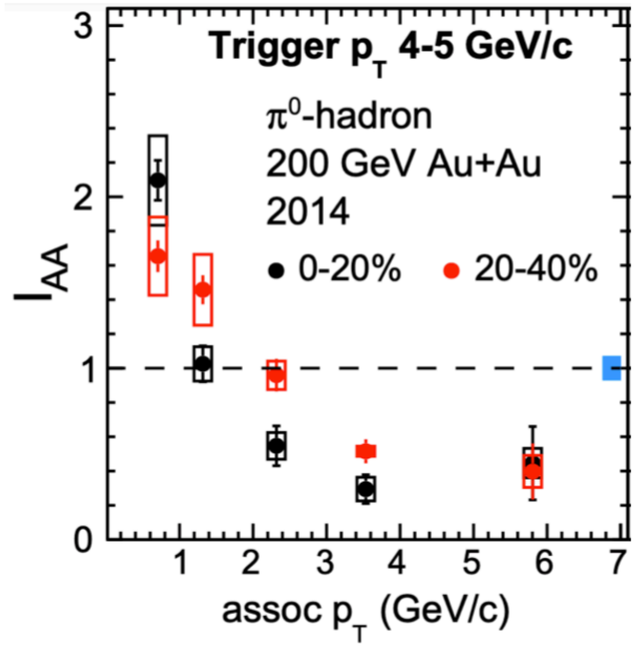
arXiv : 2207.10745

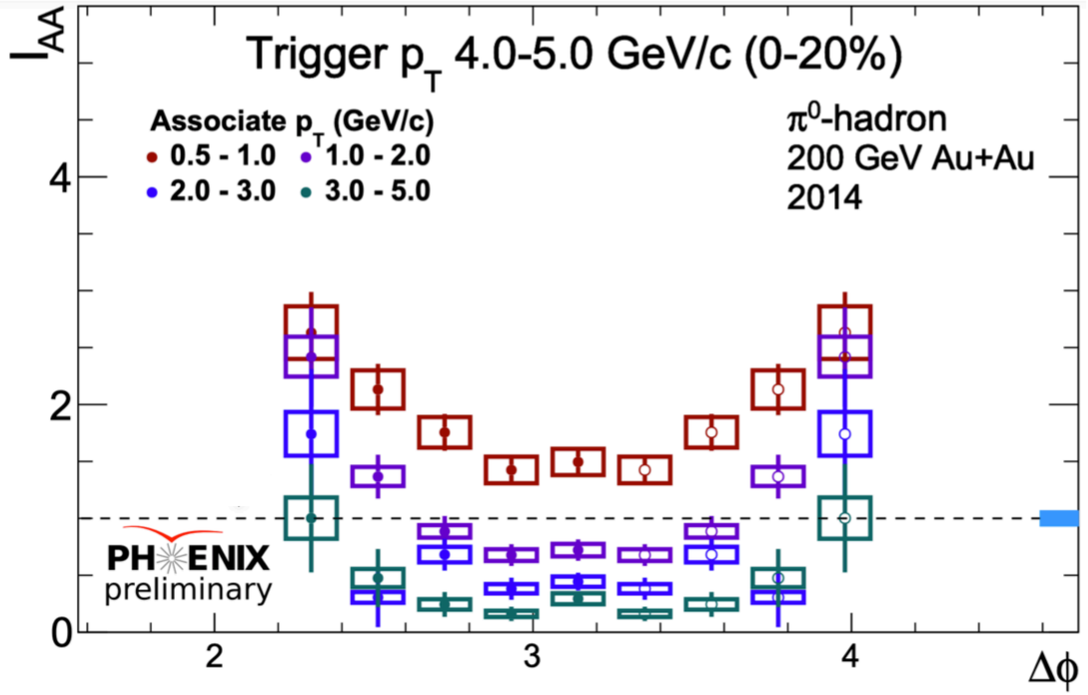
Agrees with predictions from hydrodynamical models

Jet modification



$$I_{AA} = \frac{Y_{AA}^{Away}}{Y_{pp}^{Away}}$$



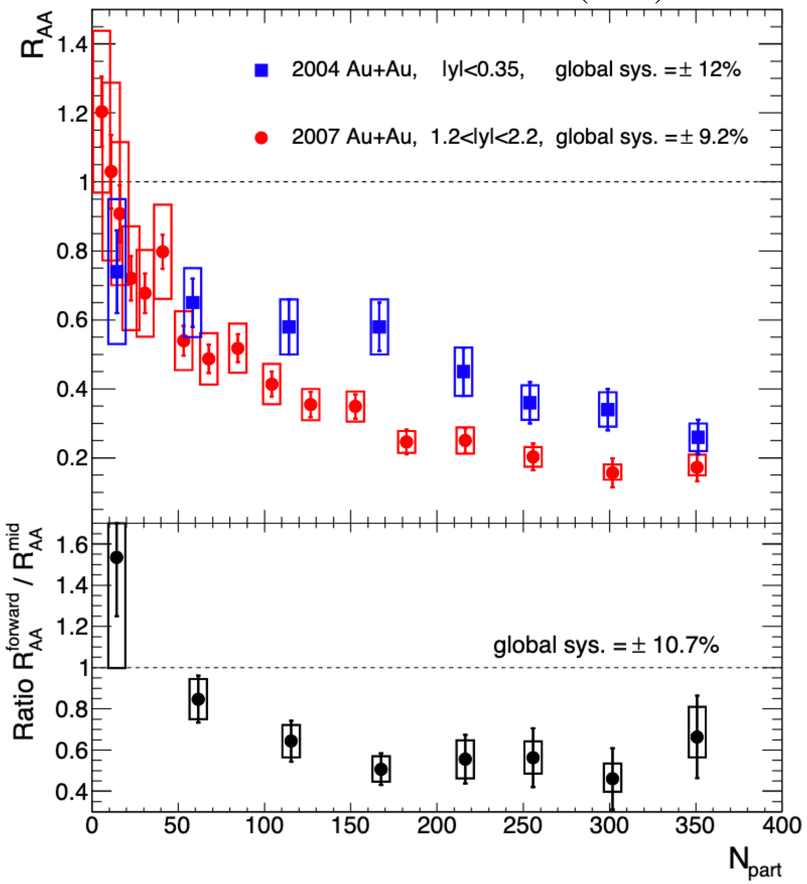


Modification of particles associated with away-side jets relative to $p + p$

Evidence for broadening of jet and momentum transfer from core to low momentum particles over large $\Delta\phi$

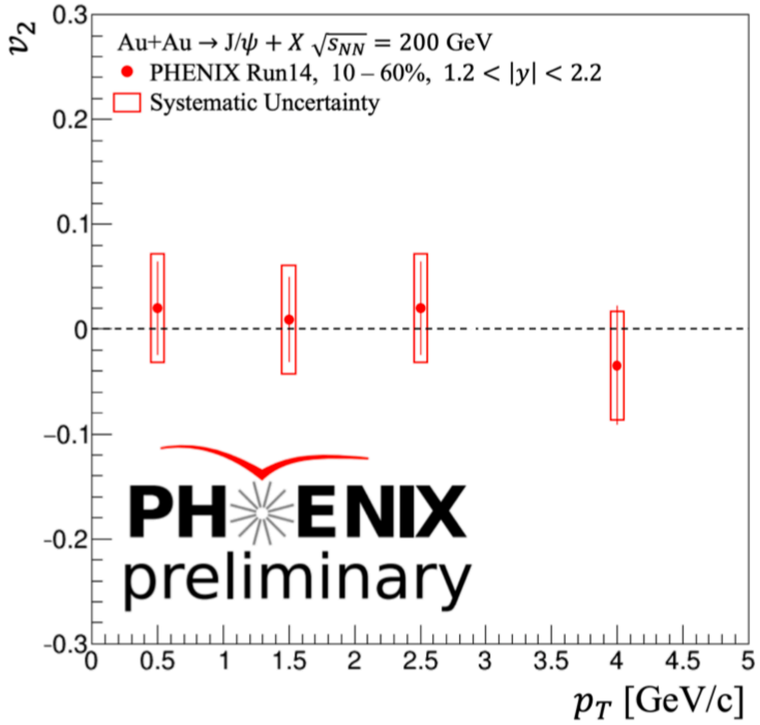
Heavy flavor — elliptic flow

PRC 84 (2011) 054912



At RHIC energies, J/ψ suppression larger at forward rapidity

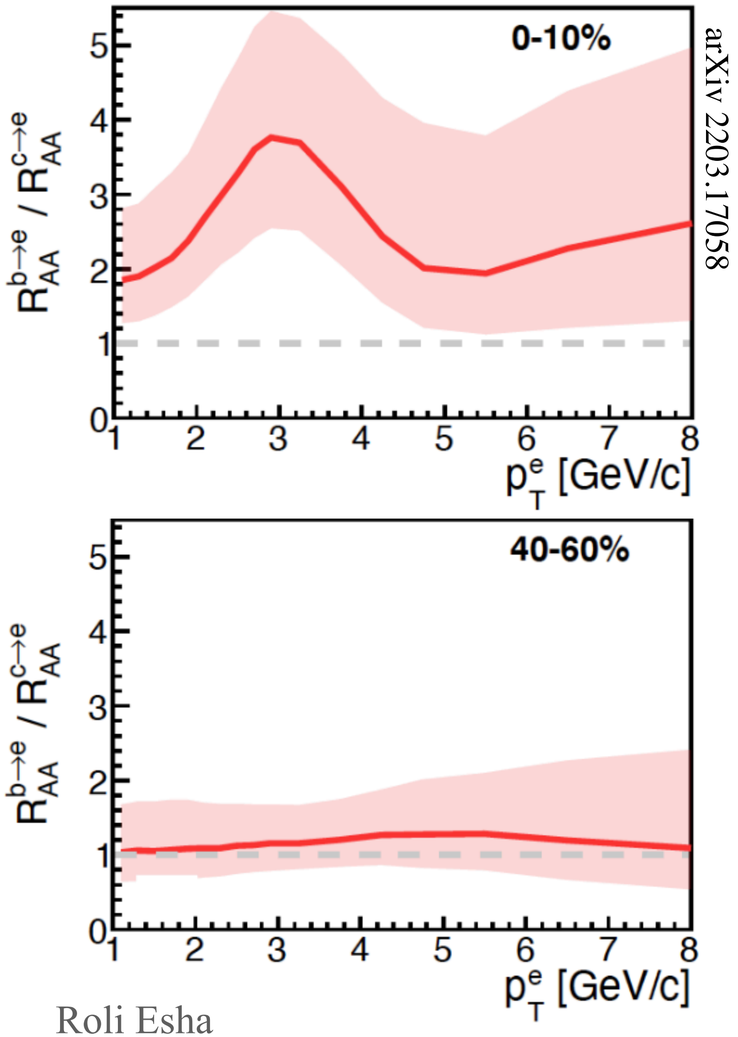
Expectation for recombination: Flow at mid rapidity, but no flow in forward direction

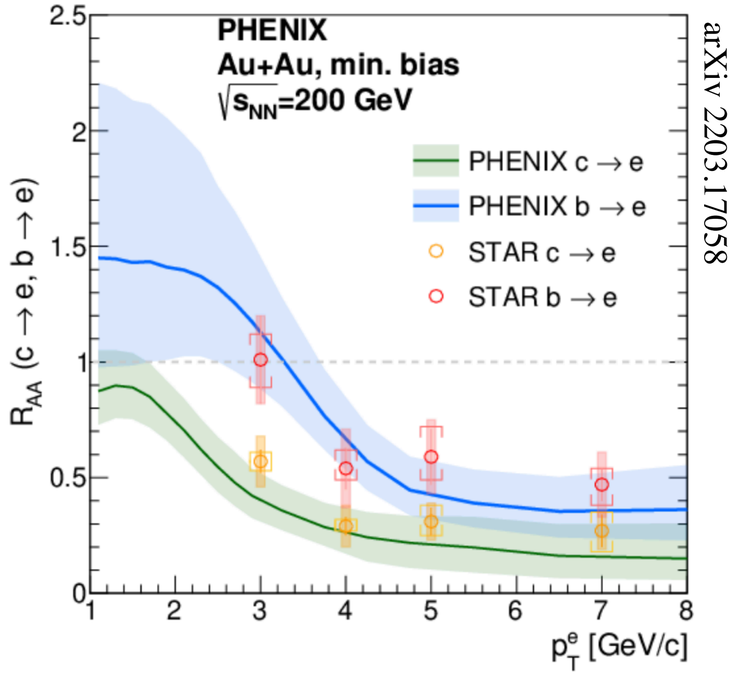


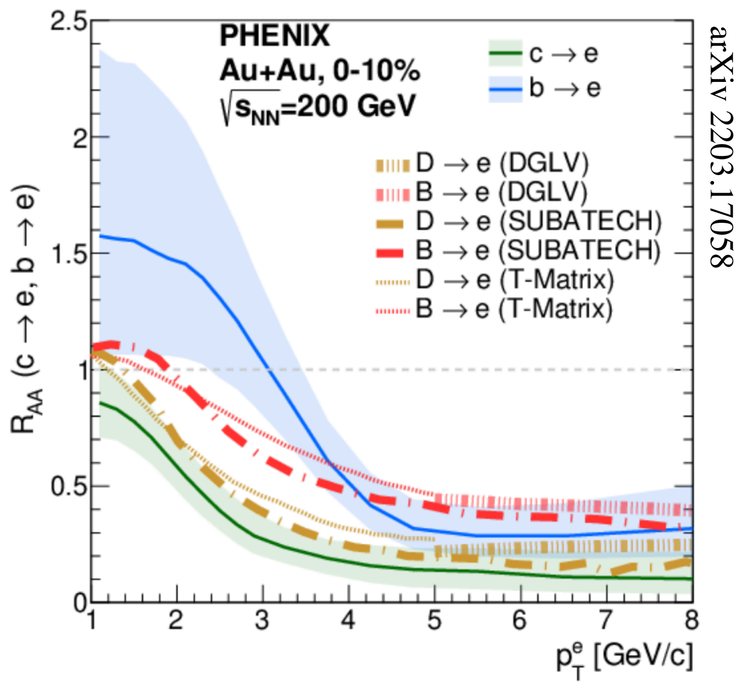
J/ψ flow at forward rapidity is consistent with zero

Heavy flavor — energy loss

$$R_{AA} = \frac{\text{Yield (AuAu)}}{< N_{coll} > \text{ Yield (pp)}}$$





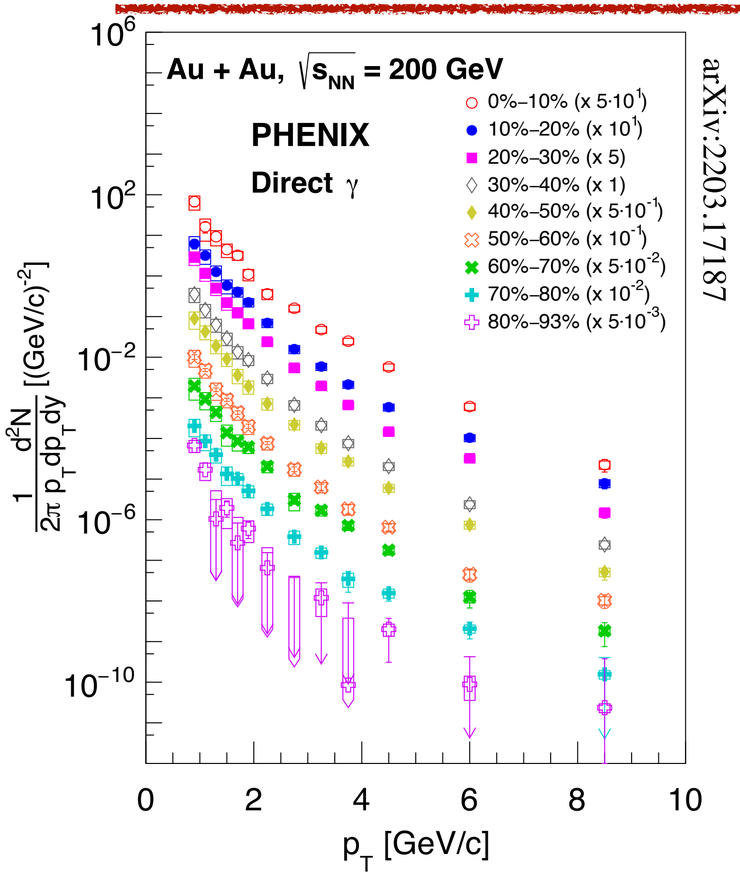


Unfolding technique to separate electrons from semi-leptonic heavy flavor bottom and charm decays

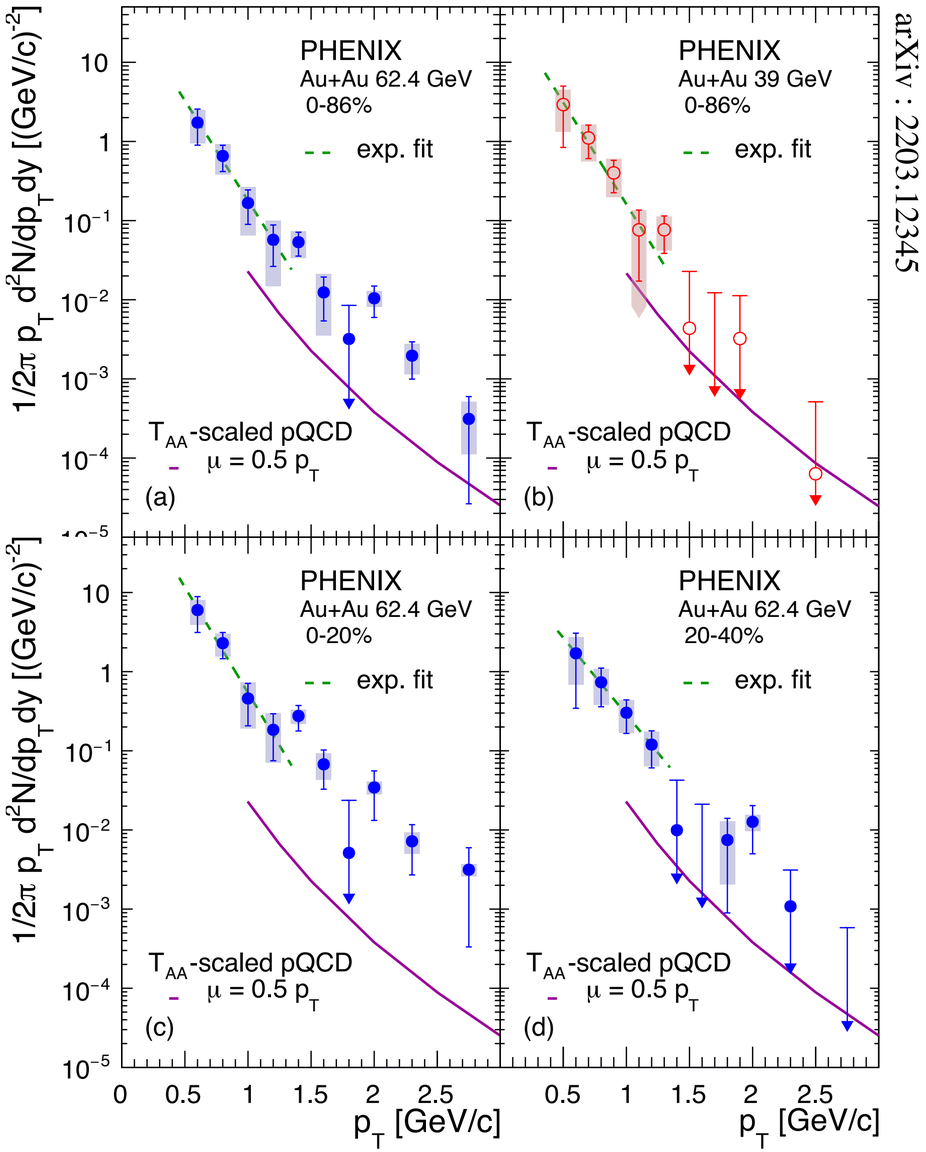
Centrality dependent suppression of charm and bottom in Au+Au collision

Similar mass ordering as expected from models with energy loss in QGP

Thermal radiations



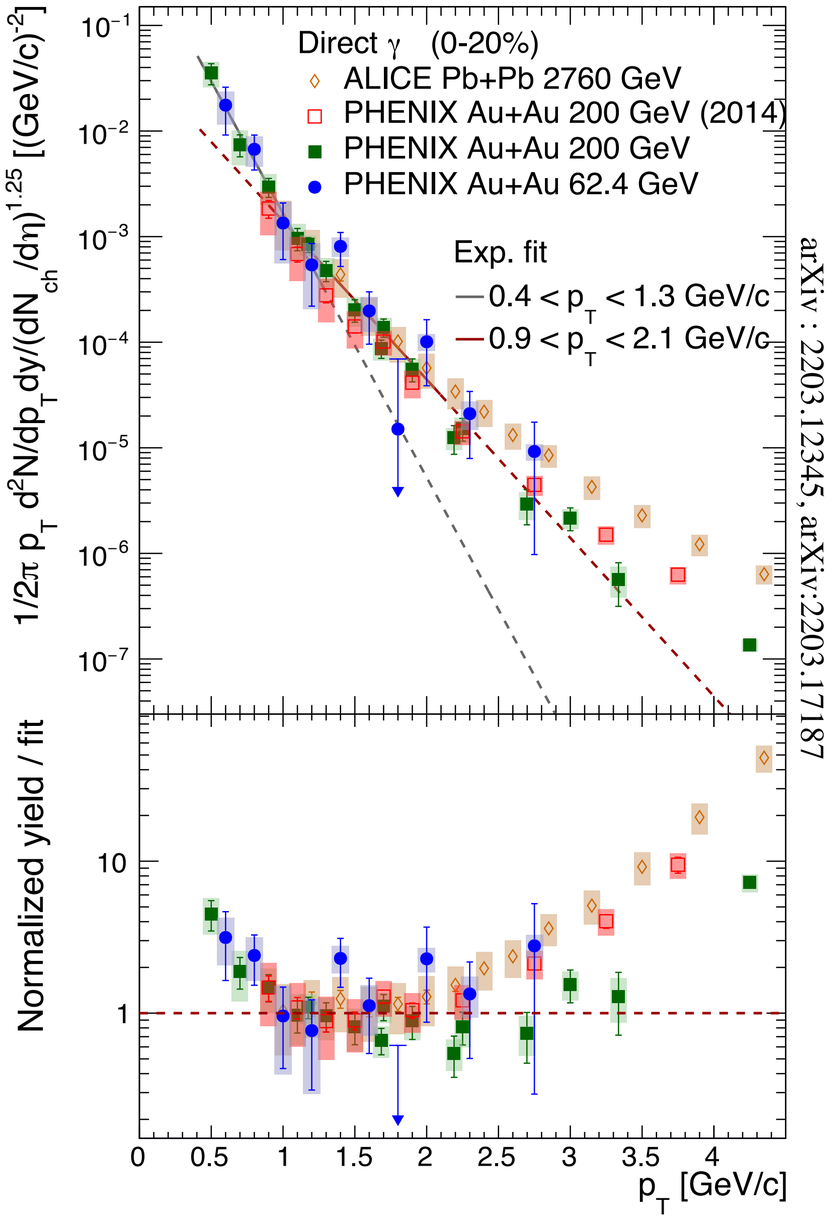
arXiv:2203.17187

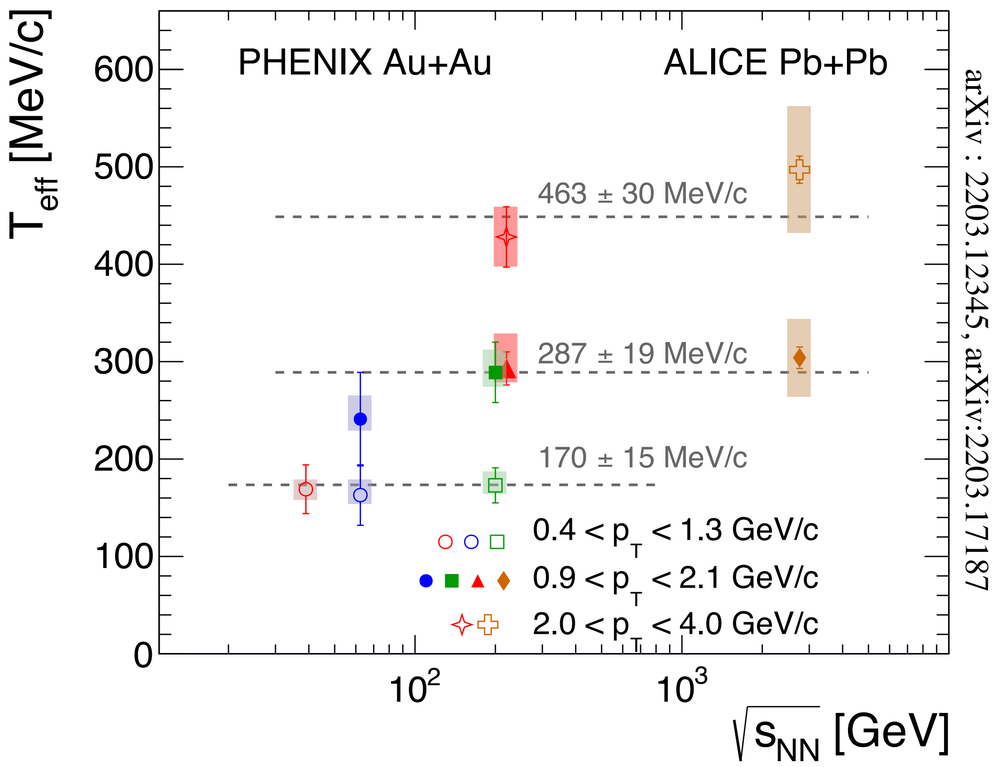


arXiv : 2203.12345

High statistics data allows for consistency check with previous measurements and more detailed investigations

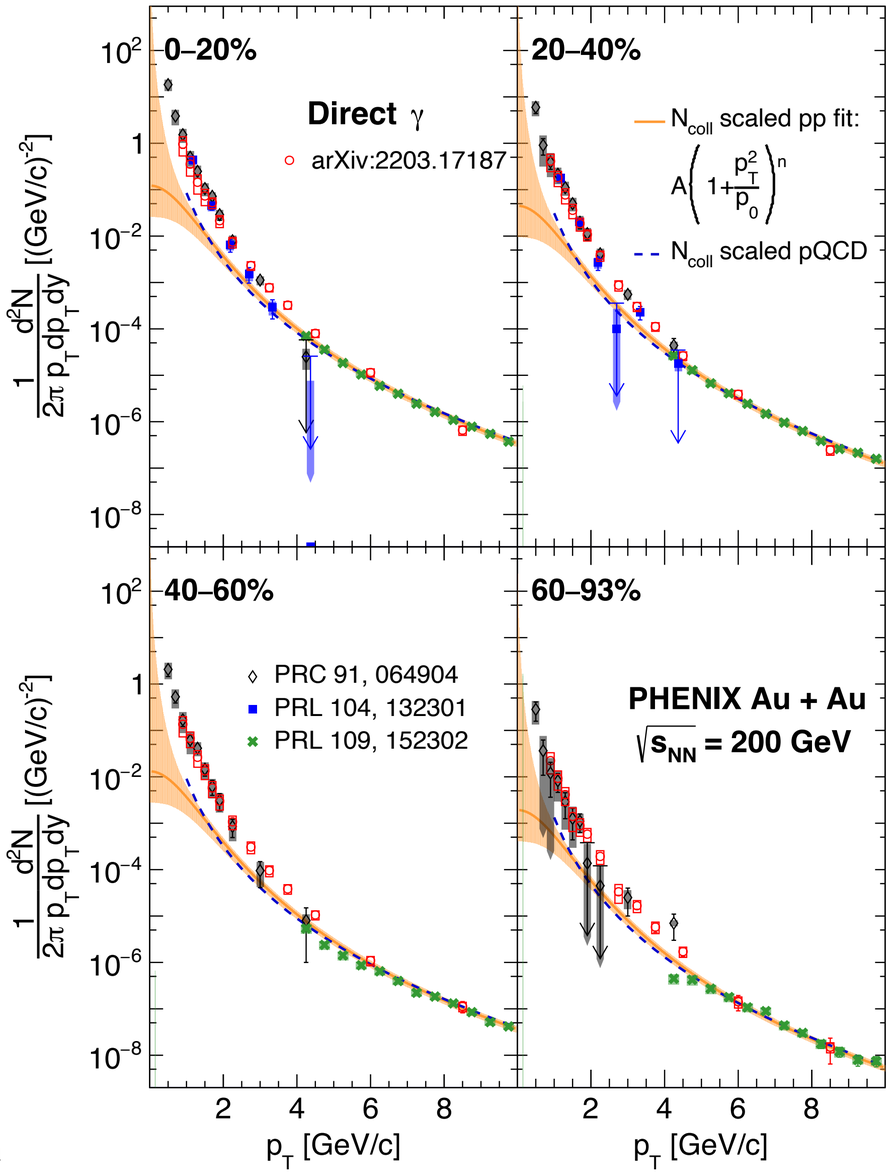
Effective temperature



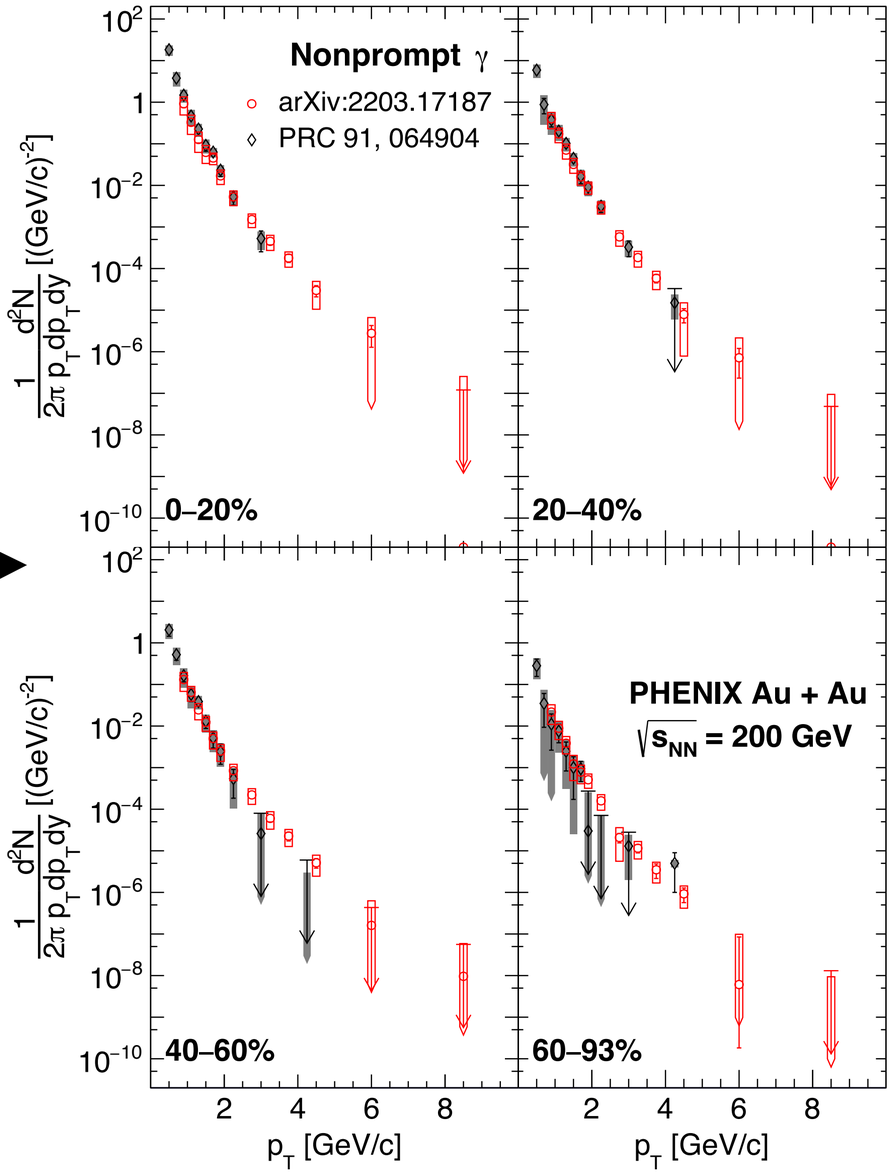


Similar spectra around 2 GeV/c — common source of photon production independent of $\sqrt{s_{NN}}$

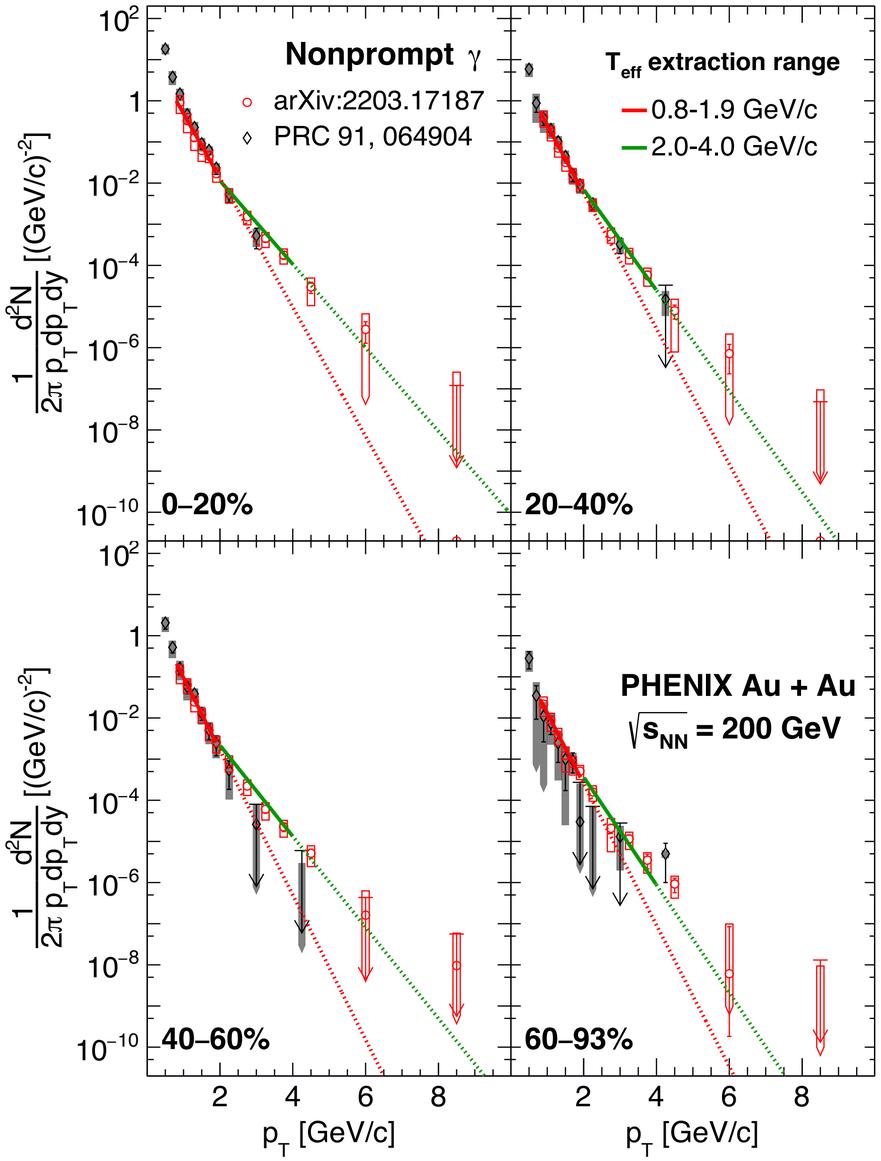
Non-prompt direct photons

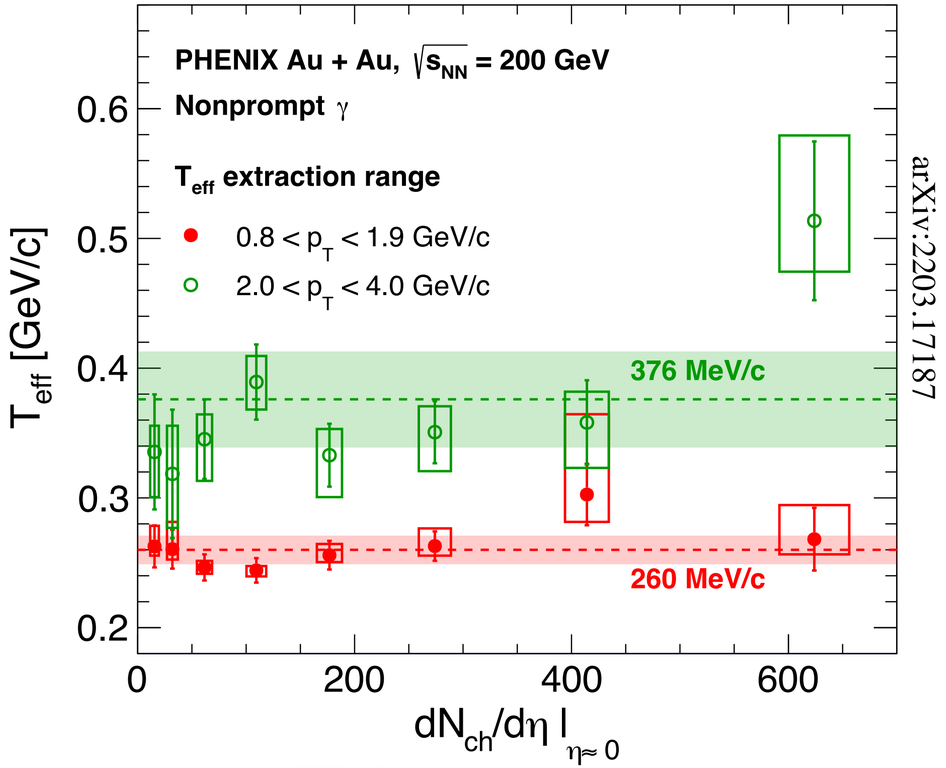


— N_{coll} **scaled p+p fit**



Effective temperature



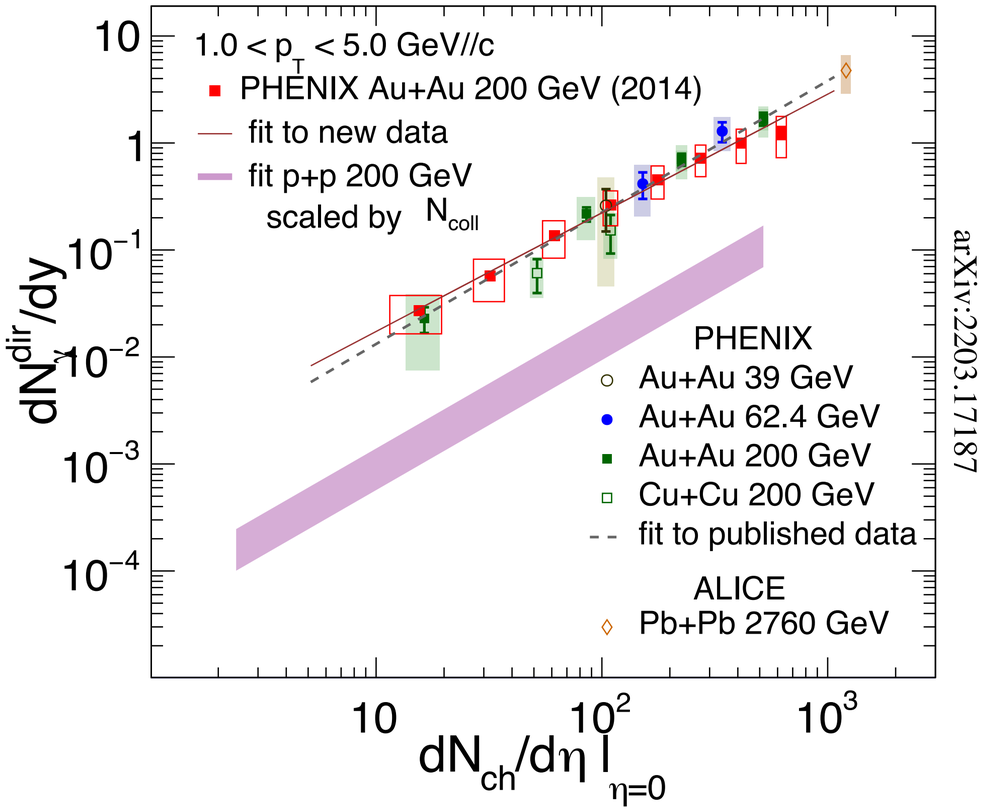


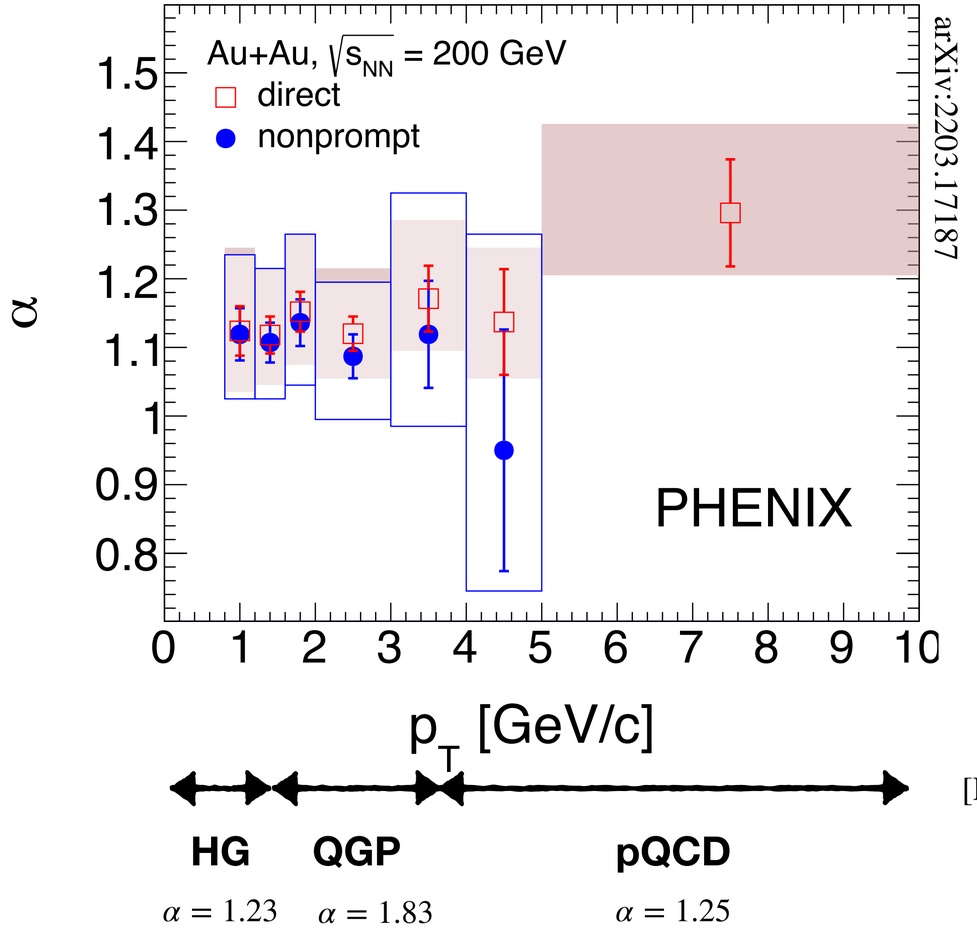
Increasing inverse slope with p_T to above 350 MeV/c suggests contributions from sources beyond those from Hadron Gas

Universal scaling

$$dN_\gamma/dy = A \times (dN_{ch}/d\eta)^\alpha$$

Universal scaling behavior in all A+A systems

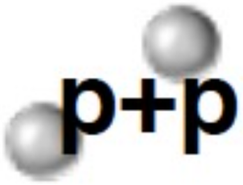


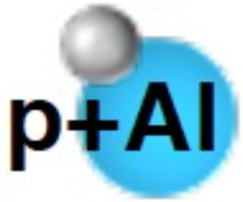


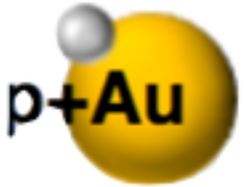
[PRC 89 (2014) 044910]

$\alpha > 1$ and independent of p_T

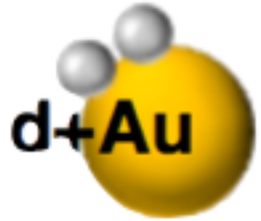
SMALL SYSTEM COLLISIONS



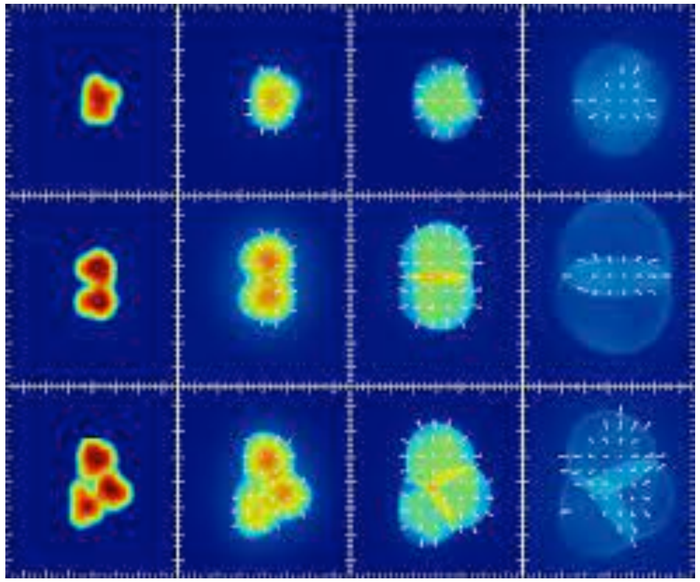




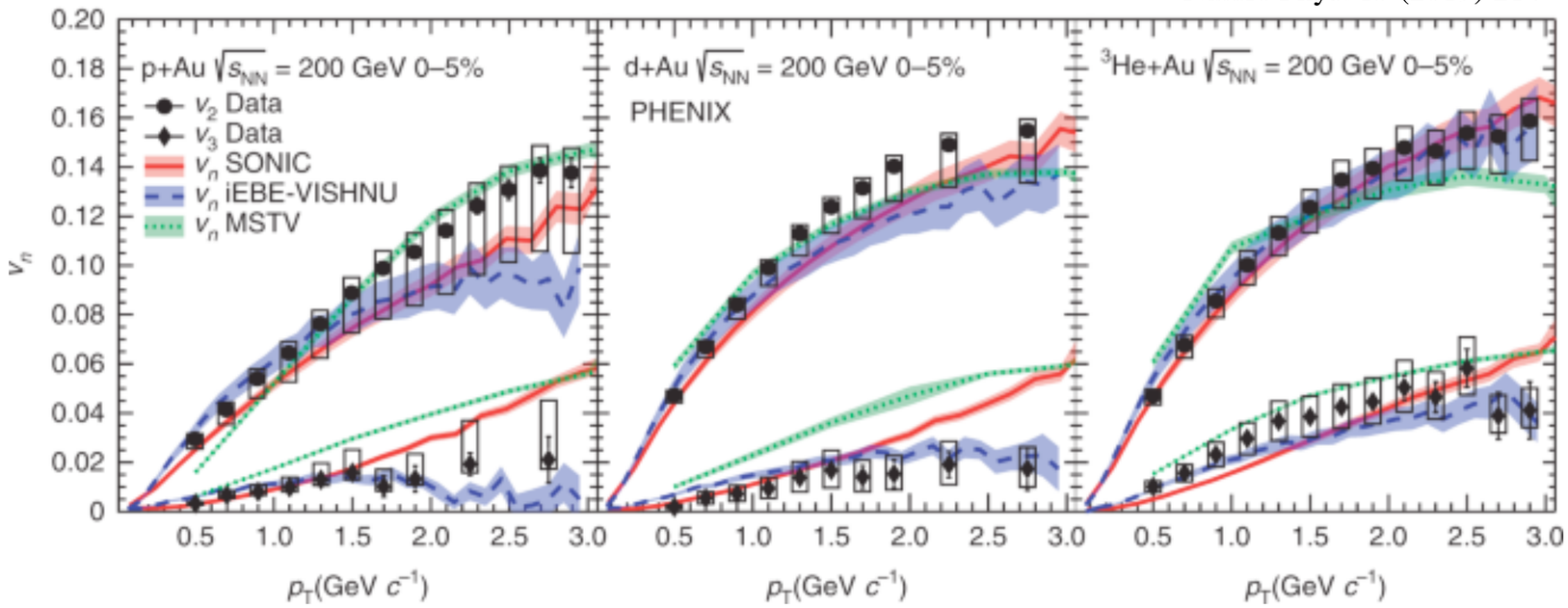
- $p + p$: Baseline for heavy-ion measurements — no QGP
- $p + A$: What happens when we bring in a nucleus
- What is the smallest droplet of QGP ?



Collective flow



Nature Phys. 15 (2019) 214



Geometrical ordering as expected from hydrodynamical models

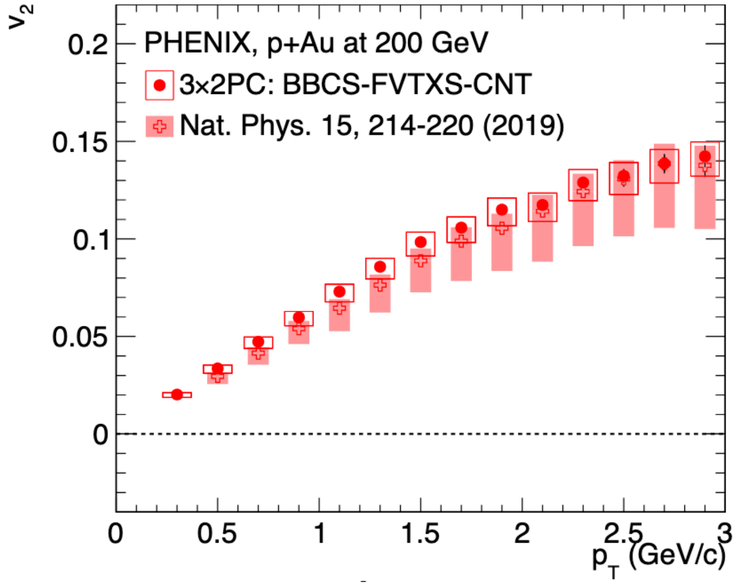
$$v_2 \;:\; p+Au \;<\; d+Au \;\sim\; {}^3He+Au$$

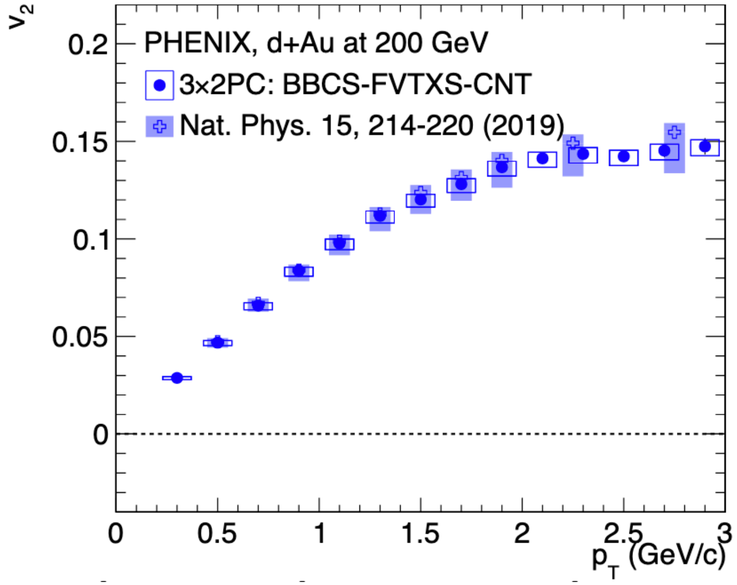
$$v_3 \;:\; p+Au \;\sim\; d+Au \;<\; {}^3He+Au$$

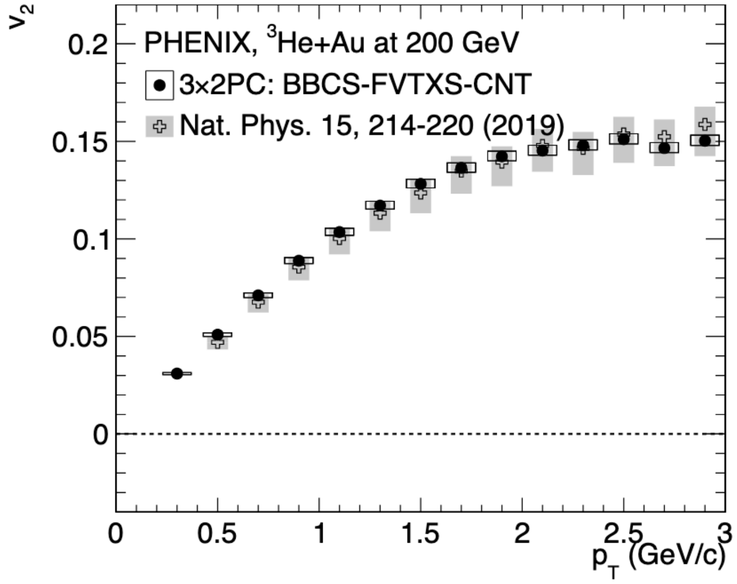
Anisotropy of charged particle production consistent with hydrodynamic expansion

Collective flow - revisited

PRC 105 (2022) 024901







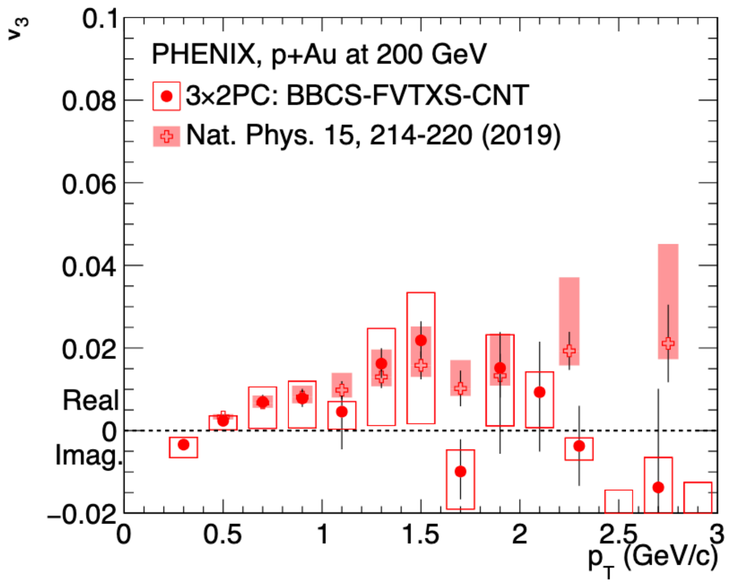
- Using two-particle correlations over large rapidity ranges

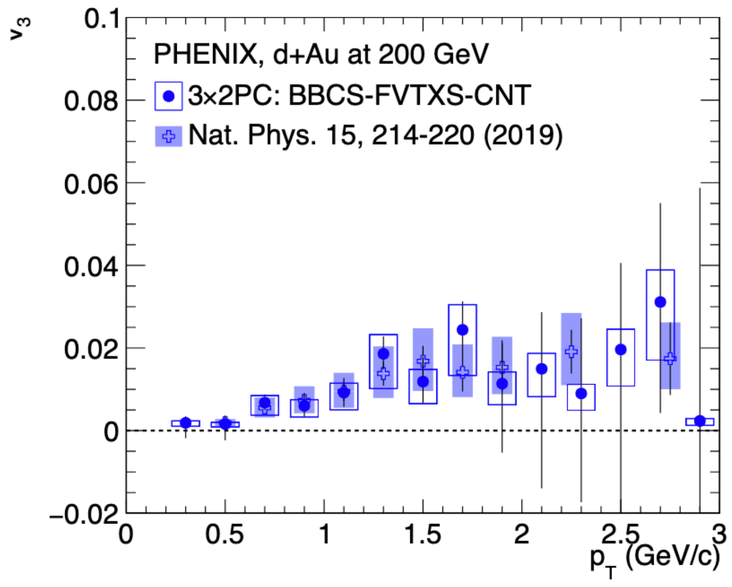
- Same detector combinations, but very different sensitivity to key experimental effects — beam position, detector alignment, other non-flow effects

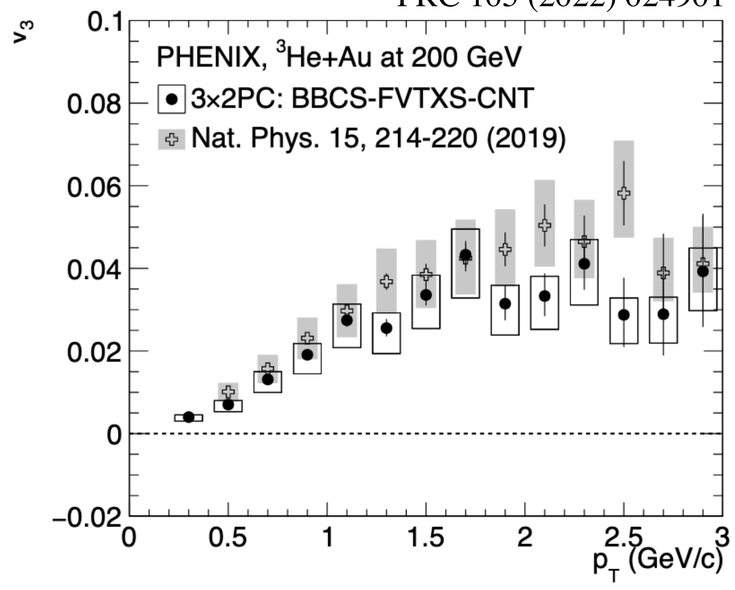
Consistent v_2

Collective flow - revisited

PRC 105 (2022) 024901





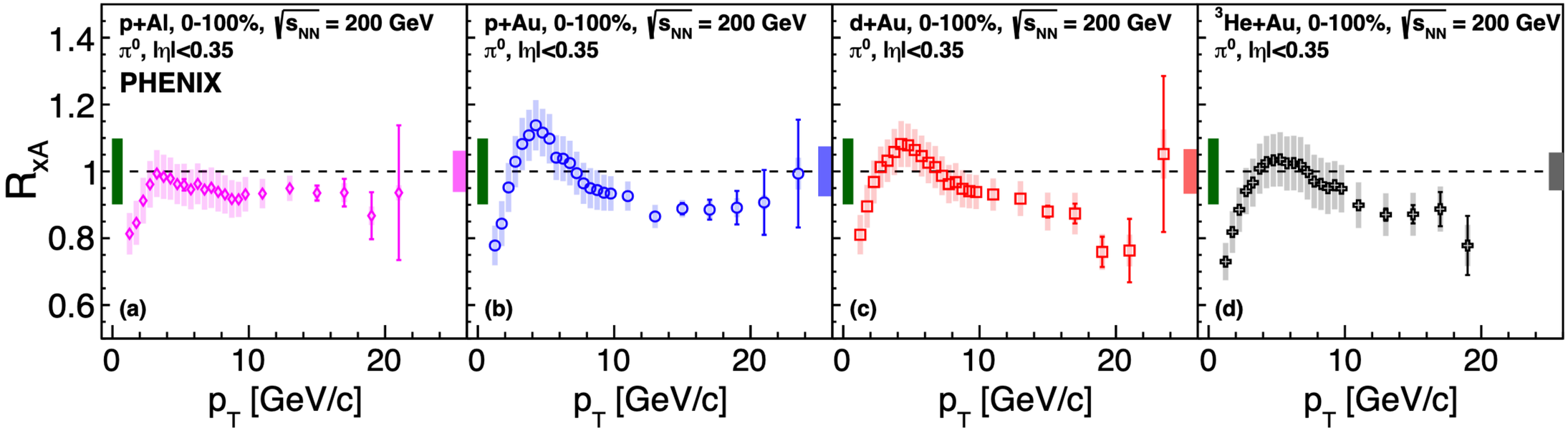


- Using two-particle correlations over large rapidity ranges
- Same detector combinations, but very different sensitivity to key experimental effects — beam position, detector alignment, other non-flow effects

Consistent v_2 and v_3

Hadron production — π^o

PRC 105 (2022) 064902

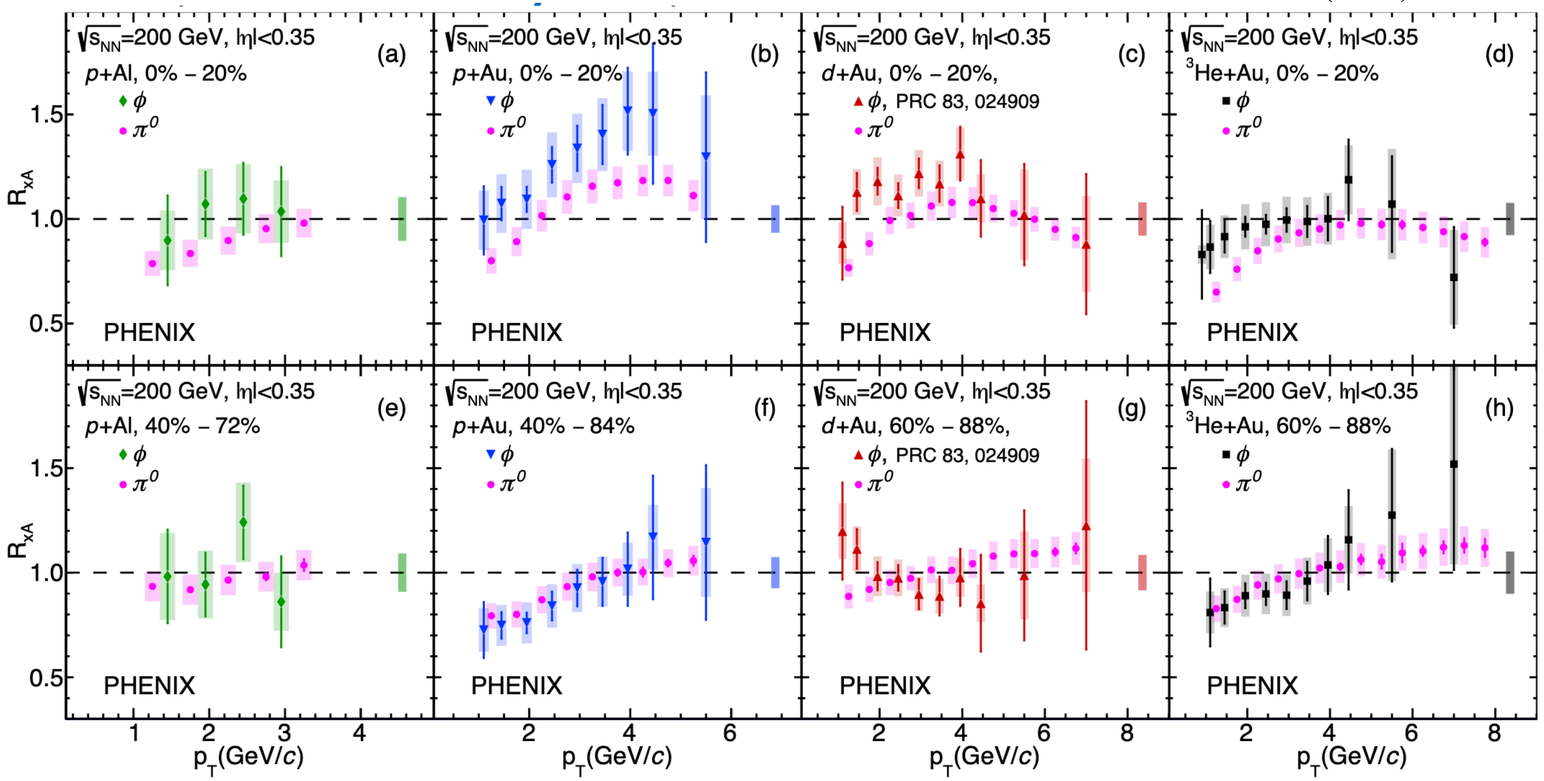


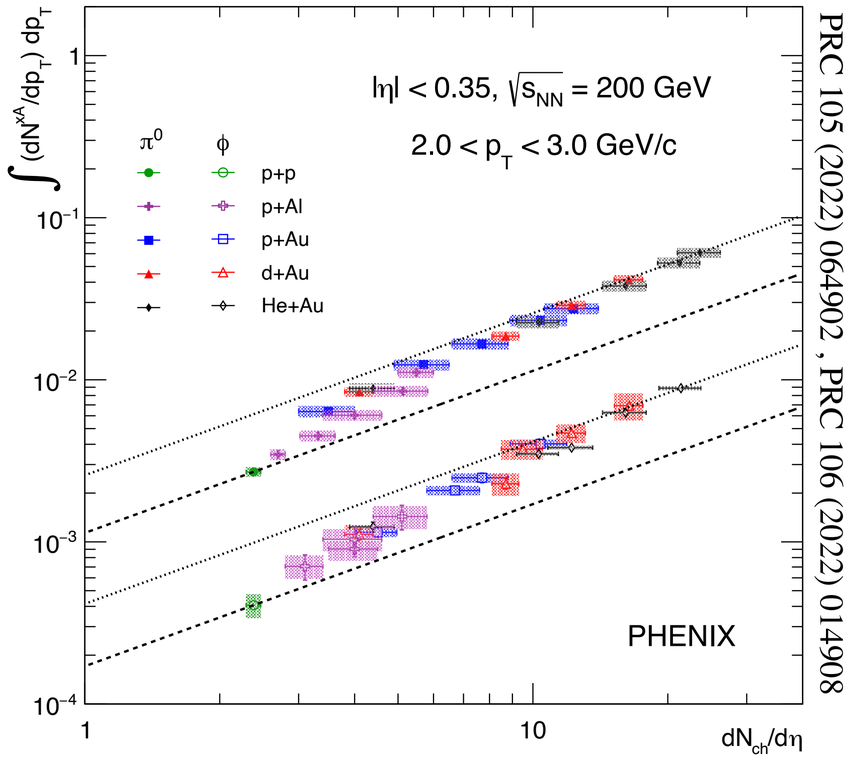
- Cronin enhancement at intermediate p_T
  - Lighter target shows smaller enhancement :
    $$p + Al \;<\; p + Au$$
  - Heavier projectile shows smaller enhancement :
    $$^3He + Au \;<\; d + Au \;<\; p + Au$$

Broadening consistent with expectations from radial flow

Hadron production — ϕ

PRC 106 (2022) 014908

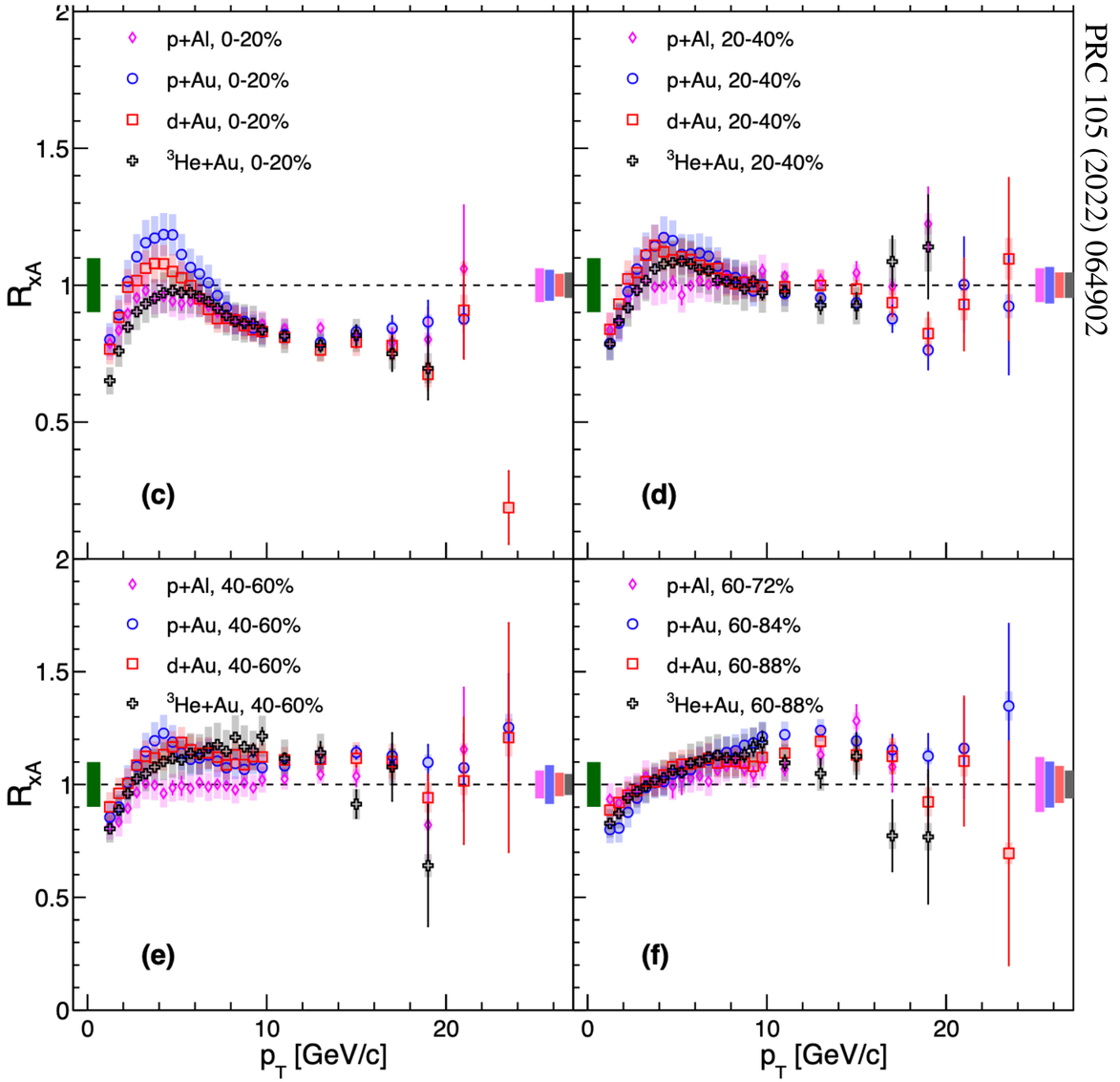




- R_{xA} of ϕ has a trend similar to π^o for peripheral collisions with hints of slight enhancement in central collisions

- Shift of yield from scaled $p+p$ to ^3He+Au starting around $\frac{dN_{ch}}{d\eta} > 4$ to 5

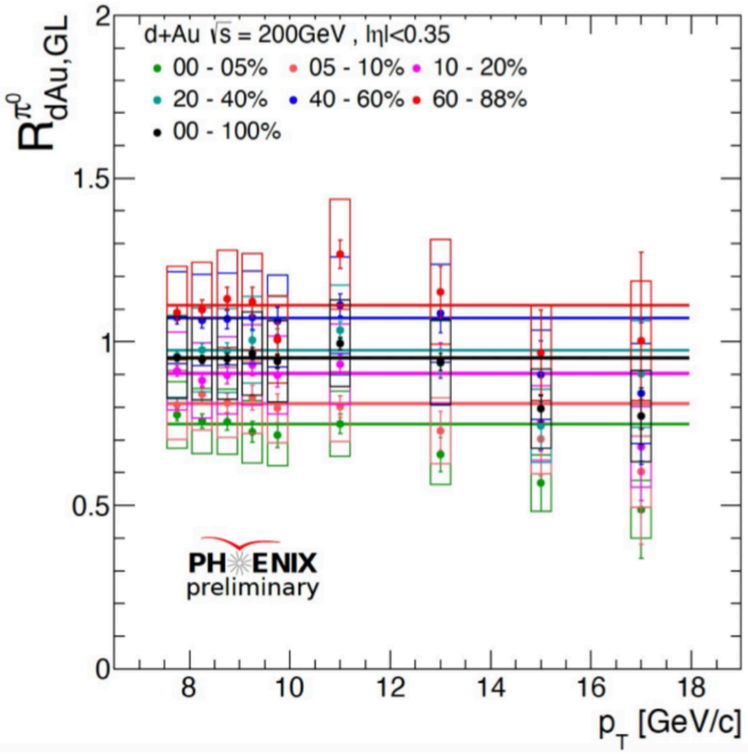
High p_T π^0

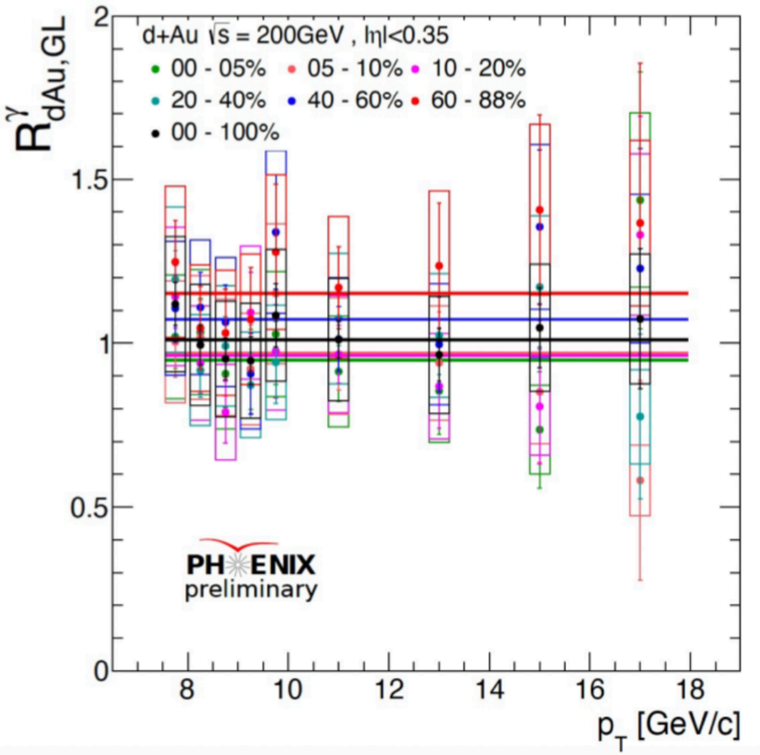


- Counter intuitive behavior of R_{xA} at high p_T
  - ~ 20% suppression in central collisions
  - ~ 15% enhancement in peripheral collisions

Bias of centrality determination or final state effects ?

Direct photons — standard candle





$$R_{dAu,GL} = \frac{\text{Yield (dAu)}}{< N_{coll} > \text{ Yield (pp)}}$$

High p_T direct photons

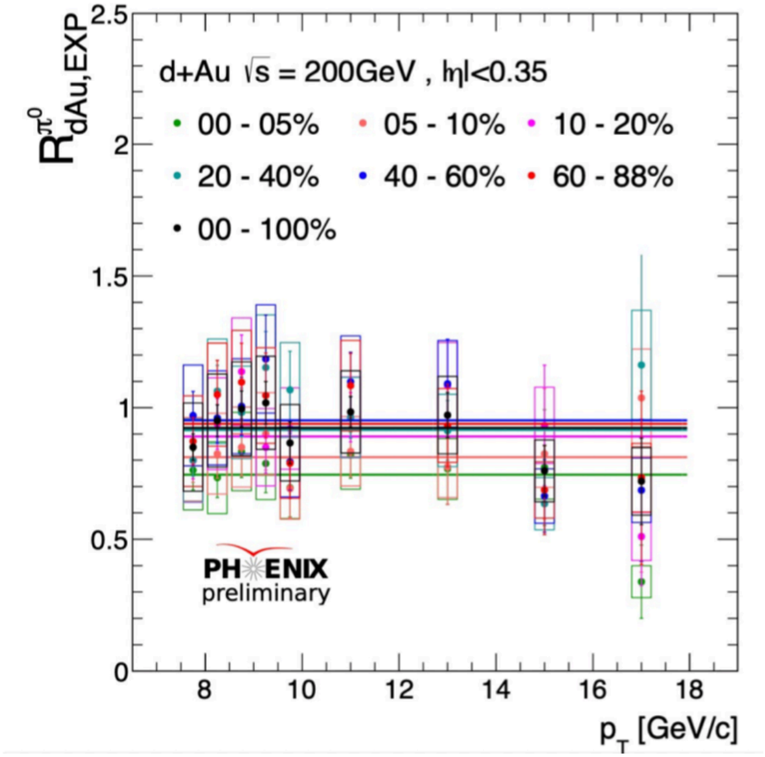
- produced in hard scattering
- have no final state effects
- yield proportional to N_{coll}

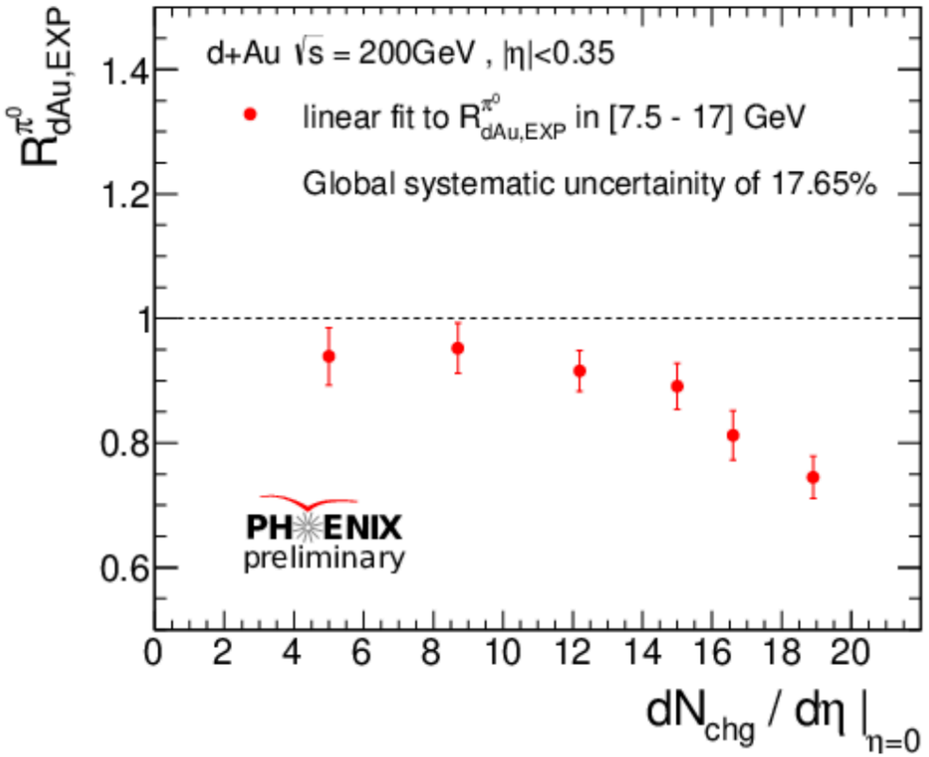
Direct photons shows similar centrality dependence, but should be unity — mean free path ~50 times larger than nuclear size

Use non-modification of photons to correct for bias in N_{coll} determination

R_{xA} revisited

$$R^{\pi^0}_{dAu,EXP} = \frac{R^{\pi^0}_{dAu,GL}}{R^{\gamma}_{dAu,GL}} = \frac{(Y^{\pi^0}_{dAu}/Y^{\pi^0}_{pp})}{(Y^{\gamma}_{dAu}/Y^{\gamma}_{pp})} = \frac{(Y^{\pi^0}_{dAu}/Y^{\gamma}_{dAu})}{(Y^{\pi^0}_{pp}/Y^{\gamma}_{pp})}$$

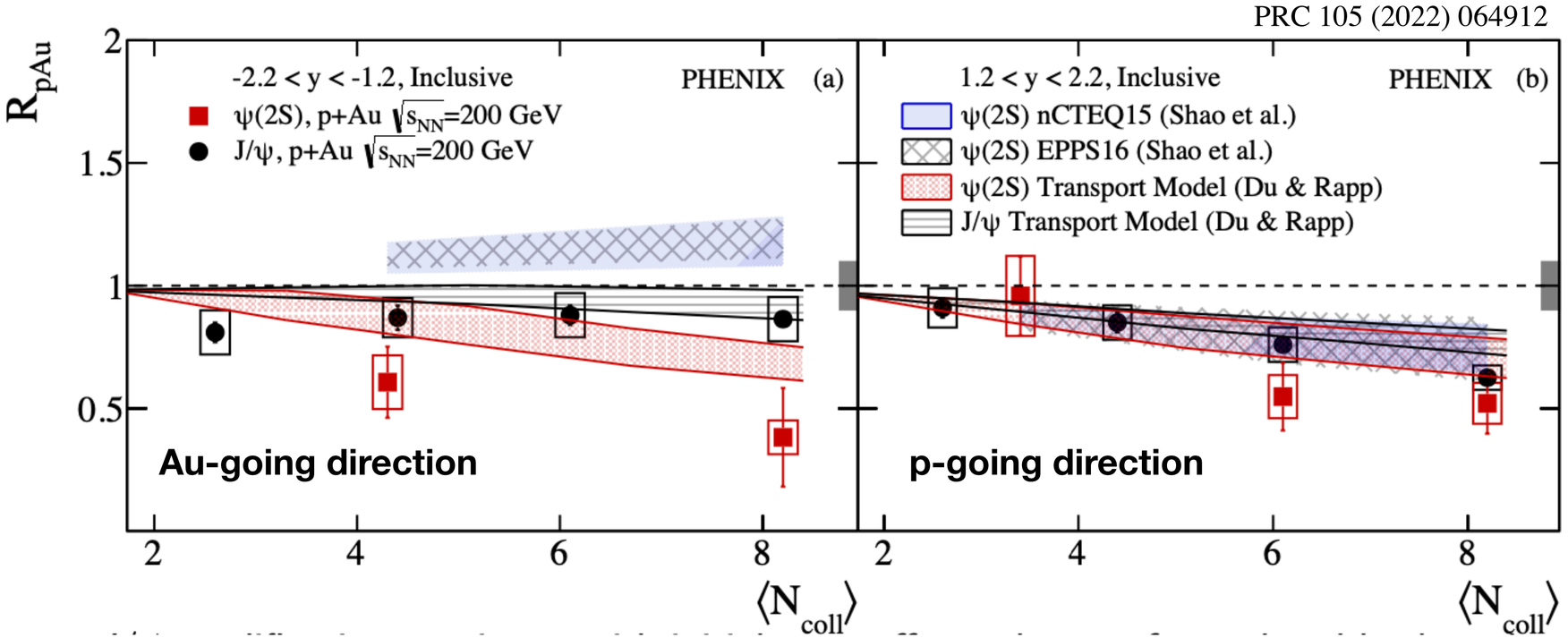




- Resolves a decade-long mystery of apparent enhancement in peripheral collisions
- Evidence for final state suppression of π^o suppression at high p_T in d+Au events with high event activity

Charmonia — J/ψ and $\psi(2S)$

PRC 105 (2022) 064912



Similar modification of J/ψ and $\psi(2S)$ in p-going direction

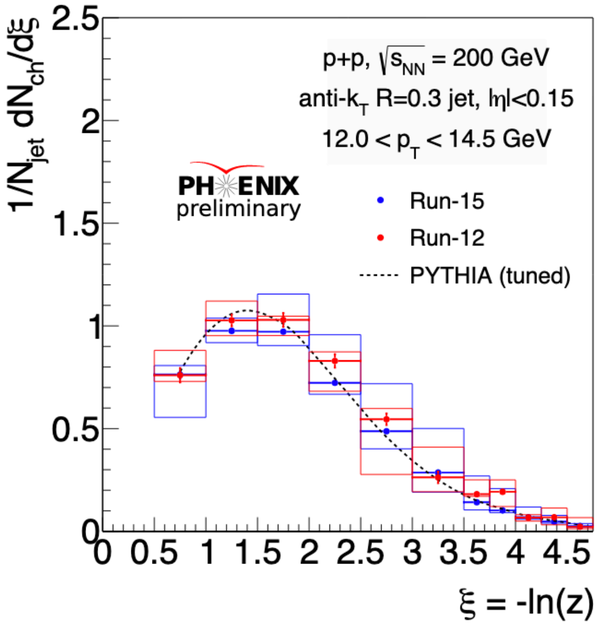
Stronger suppression of $\psi(2S)$ in Au-going direction

- nPDF only can not describe the data
- Qualitatively agree with the transport model with final-state effects

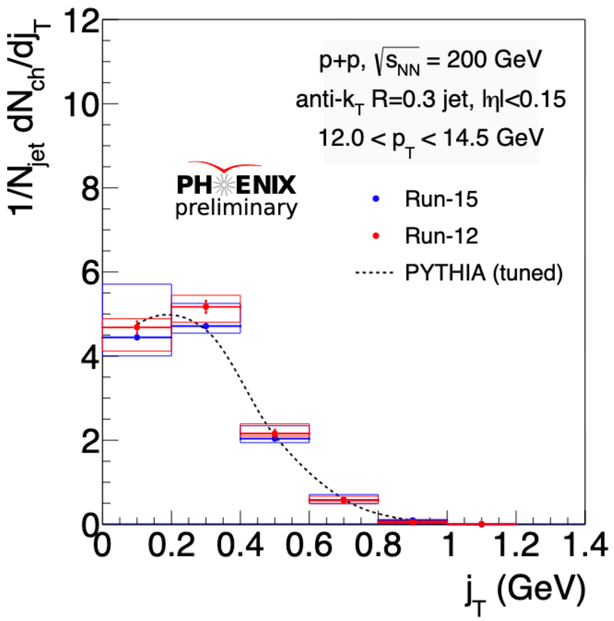
Qualitatively consistent with QGP formation

Jet substructure

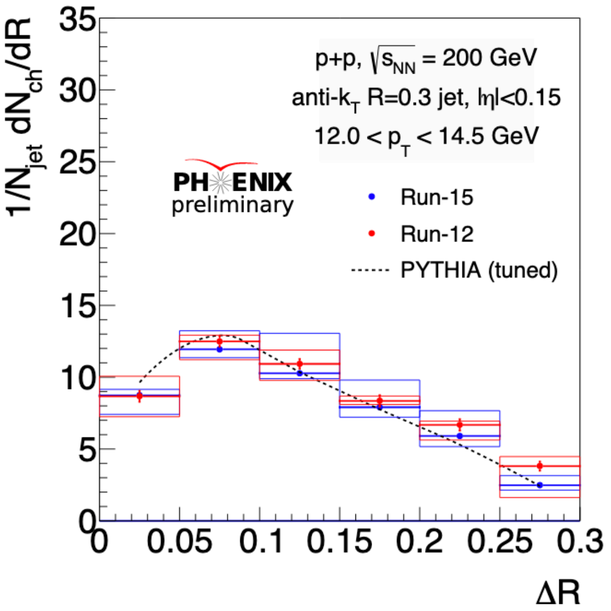
Fragmentation Function



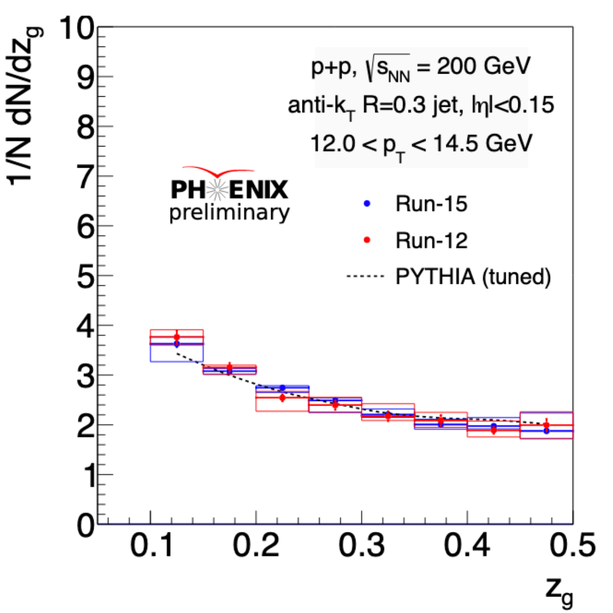
Transverse fragmentation



Radial profile



Jet splitting function



- PHENIX measured jet substructure with reconstructed jets in $p + p$
- Baseline for ongoing analysis with $p + Au$ — results coming soon

Summary and outlook

Large system

- Direct "thermal" radiations
  Integrated yield scales as $(dN_{ch}/d\eta)^{\alpha}$ with α independent of p_T
  Temperature and time evolution similar with centrality and $\sqrt{s_{NN}}$
- Jet broadening & redistribution of energy from jet core
- Hints of different energy loss for charm and bottom quarks
- J/ψ shows no flow at forward rapidity

Small system

- Geometrical ordering of v_2 and v_3 as expected from hydro calculations
- Possible effect of radial flow seen in hadron spectra
- Suppression of π^o yield at high p_T after correction for centrality selection bias using direct γ
- $\psi(2S)$ suppressed as expected from final state effects

Many more interesting and important measurements from PHENIX coming soon!

Thank you for your attention!