Overview of Recent Results from the PHENIX Experiment at RHIC

Rachid Nouicer
For the PHENIX Collaboration
Brookhaven National Laboratory

- PHENIX has several recent findings. Few (relevant) selected results:

  1. Results in Small Systems: Evidence of QGP Droplets
  2. Results in Large Systems
  3. Summary and Outlook

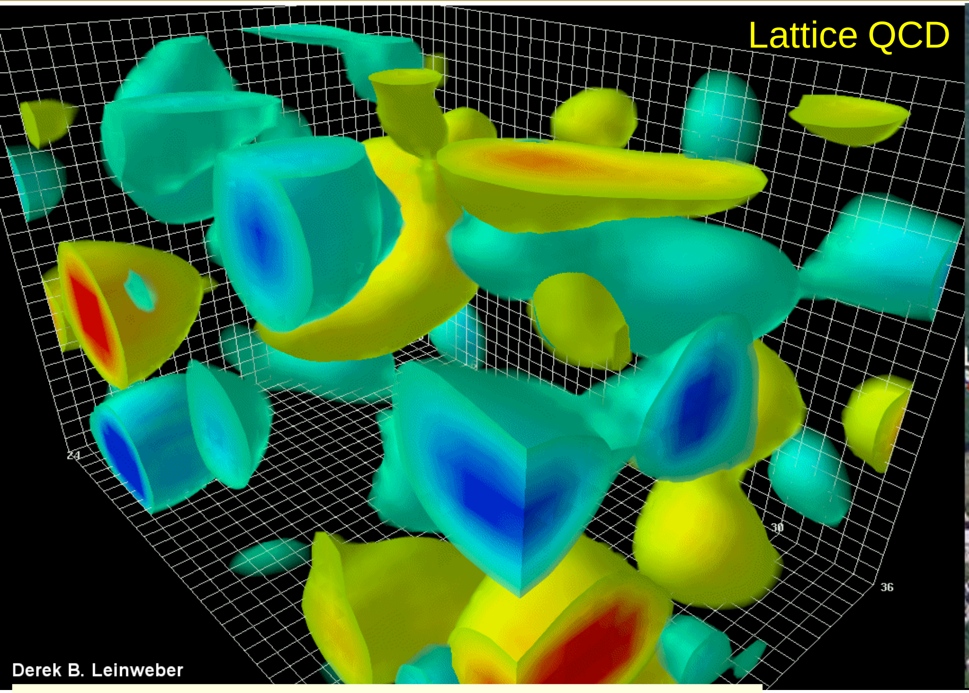
- Latest News of Electron-Ion Collider (EIC)

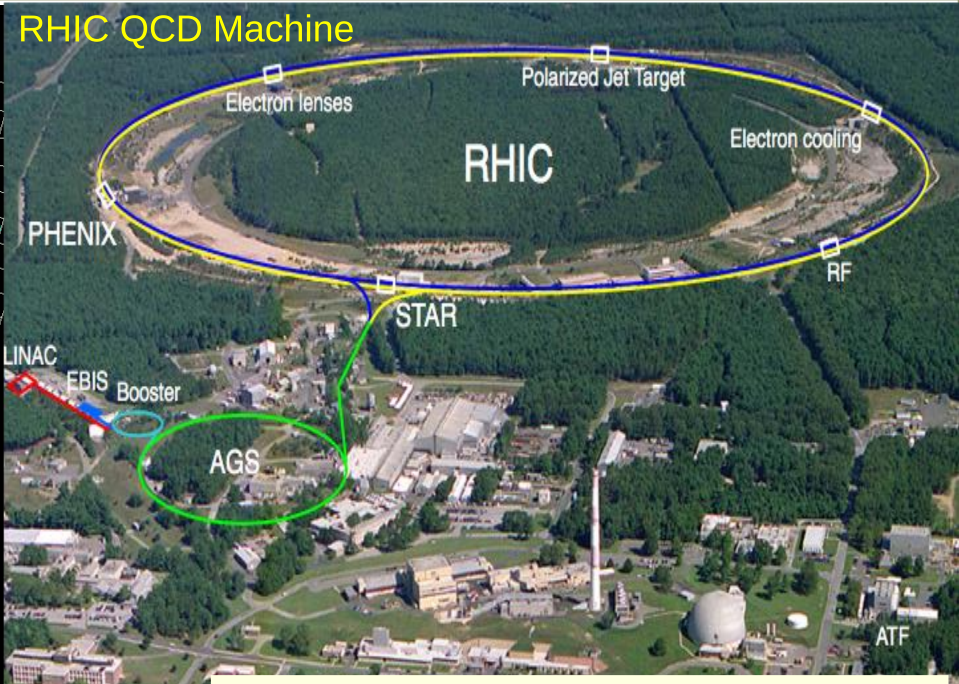
BROOKHAVEN NATIONAL LABORATORY
a passion for discovery

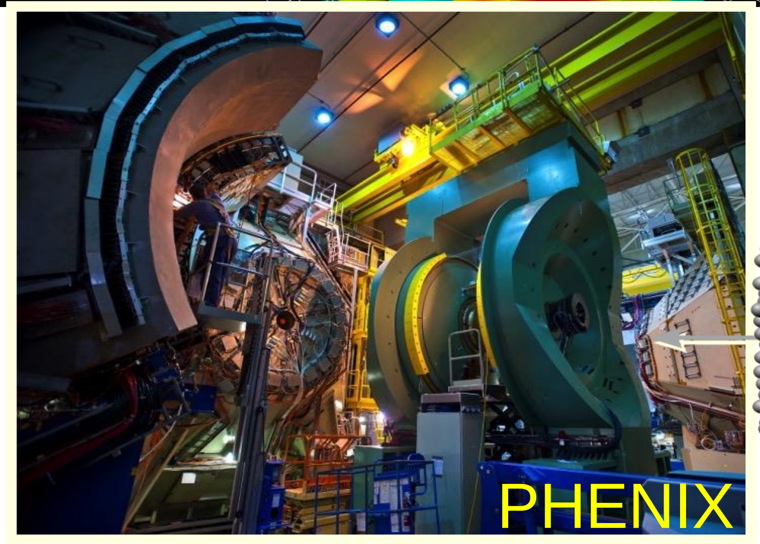
Office of Science
U.S. DEPARTMENT OF ENERGY

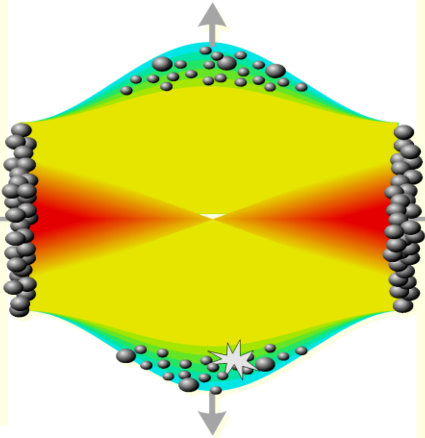
Excited QCD 2020 Workshop, 2-8 February 2020, Krynica Zdrój, Poland

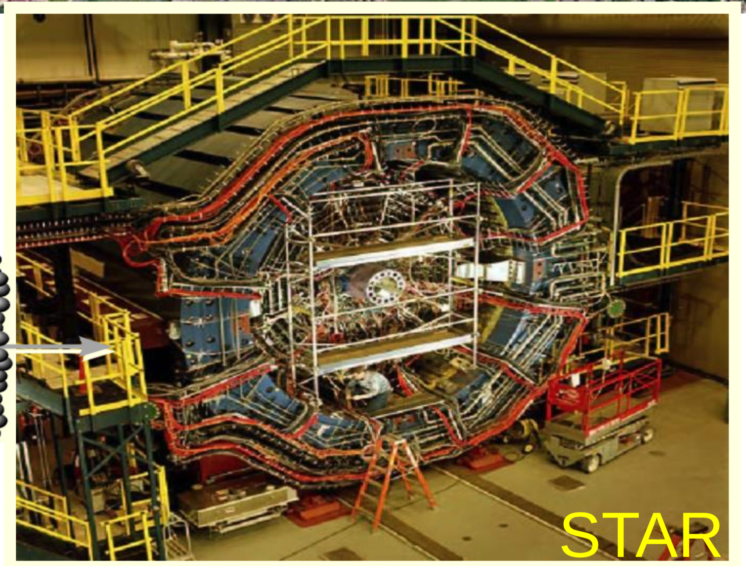
RHIC Amazing QCD Machine: Many Species and Many Energies











PHENIX Collected and Enjoying Every Bit of RHIC Data

Run	Species	Total particle energy [GeV/nucleon]	total delivered Luminosity [μb^{-1}]
I (2000)	Au+Au Au+Au	56 130	< 0.001 20
II (2001/2002)	Au+Au Au+Au p+p	200 19.6 200	25.8 0.4 1.4x10^{-6}
III (2003)	d+Au p+p	200 200	73x10^{-3} 5.5x10^{-6}
IV(2004)	Au+Au Au+Au p+p	200 62.4 200	3.53x10^{-3} 67 7.1x10^{-6}
V (2005)	Cu+Cu Cu+Cu Cu+Cu p+p p+p	200 62.4 22.4 200 410	42.1x10^{-3} 1.5x10^{-3} 0.02x10^{-3} 29.5x10^{-6} 0.1x10^{-6}
VI (2006)	p+p p+p	200 62.4	88.6x10^{-6} 1.05x10^{-6}
VII (2007)	Au+Au Au+Au	200 9.2	7.25x10^{-3} Small
VIII (2008)	d+Au p+p Au+Au	200 200 9.6	437x10^{-3} 38.4x10^{-6} Small

Run	Species	Total particle energy [GeV/nucleon]	Total delivered luminosity [μb^{-1}]
IX (2009)	p+p +p	500 200	110x10^{-6} 114x10^{-6}
X (2010)	Au+Au Au+Au Au+Au Au+Au Au+Au	200 62.4 39 7.7 11.5	10.3x10^{-3} 544 206 4.23 7.8
XI (2011)	p+p Au+Au Au+Au Au+Au	500 19.6 200 27	166x10^{-6} 33.2 9.79x10^{-3} 63.1
XII (2012)	p+p p+p U+U Cu+Au	200 510 193 200	74x10^{-6} 283x10^{-6} 736 27x10^{-3}
XIII (2013)	p+p	510	1.04x10^{-9}
XIV (2014)	Au+Au Au+Au ^{3}He+Au	14.6 200 200	44.2 43.9x10^{-3} 134x10^{-3}
XV (2015)	p+p p+Au p+Al	200 200 200	282x10^{-6} 1.27x10^{-6} 3.97x10^{-6}
XVI (2016)	Au+Au d+Au d+Au d+Au d+Au	200 200 62.4 19.6 39	52.2x10^{-3} 46.1x10^{-3} 44.0x10^{-3} 7.2x10^{-3} 19.5x10^{-3}

Selected Results

- **Small System and Evidence of QGP Droplets**
  - **Flow**
  - **Jet modification**
  - **Quarkonia**
  - **Thermal photons**

- **Large Systems**
  - **Hadron production**
  - **Jet modification**
  - **Heavy flavor probes**

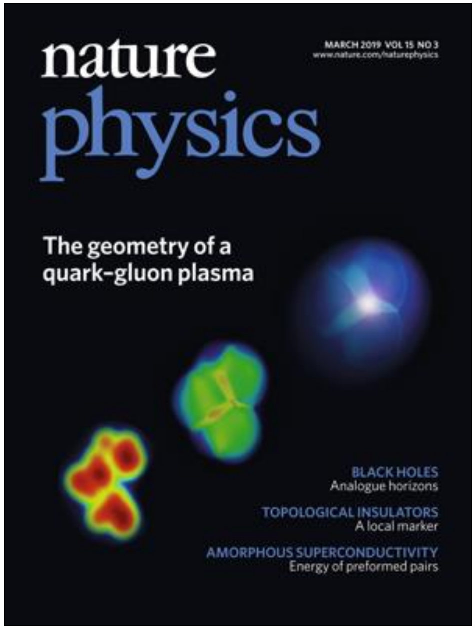
New Results

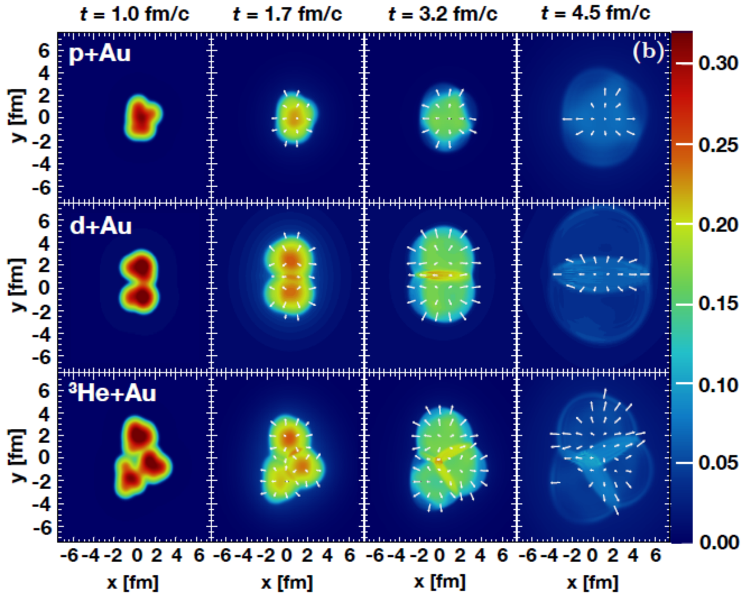
√s [GeV]	p+p	p+Al	p+Au	d+Au	^{3}He+Au	Cu+Cu	Cu+Au	Au+Au	U+U
510	✓								
200	New	New	New	New	New	✓	New	New	New
130								✓	
62.4	✓			✓		✓		✓	
39				✓				✓	
27								✓	
20				✓		✓		✓	
14.5								✓	
7.7								✓	

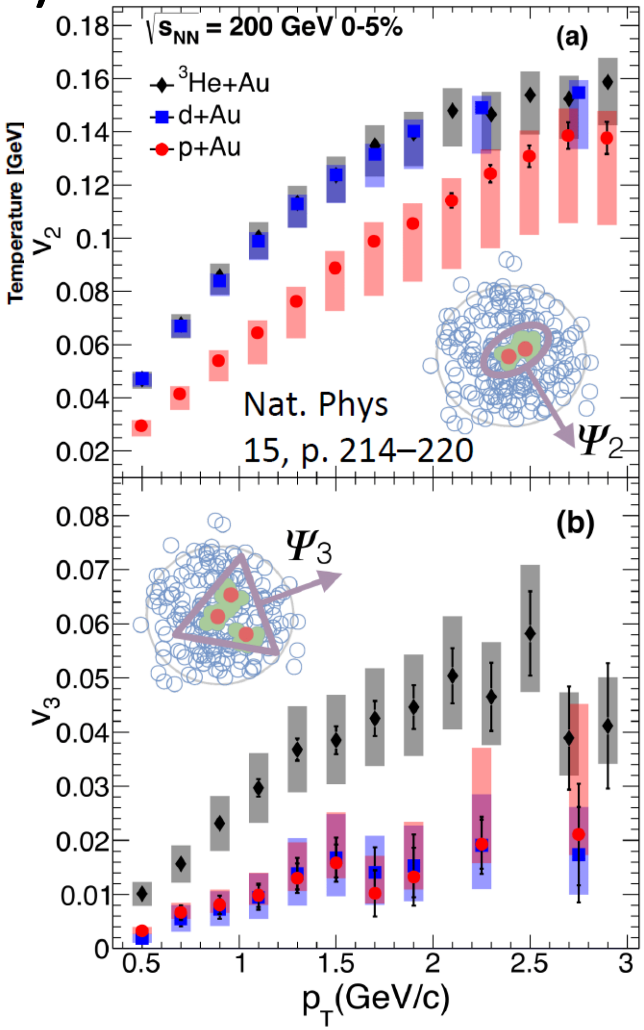
- **Thermal Photon Scaling: Large to Small Systems**

Evidence of QGP Droplets in Small Systems

Nature Physics **15, pages 214–220 (2019)**







Lower v_2 in p+Au

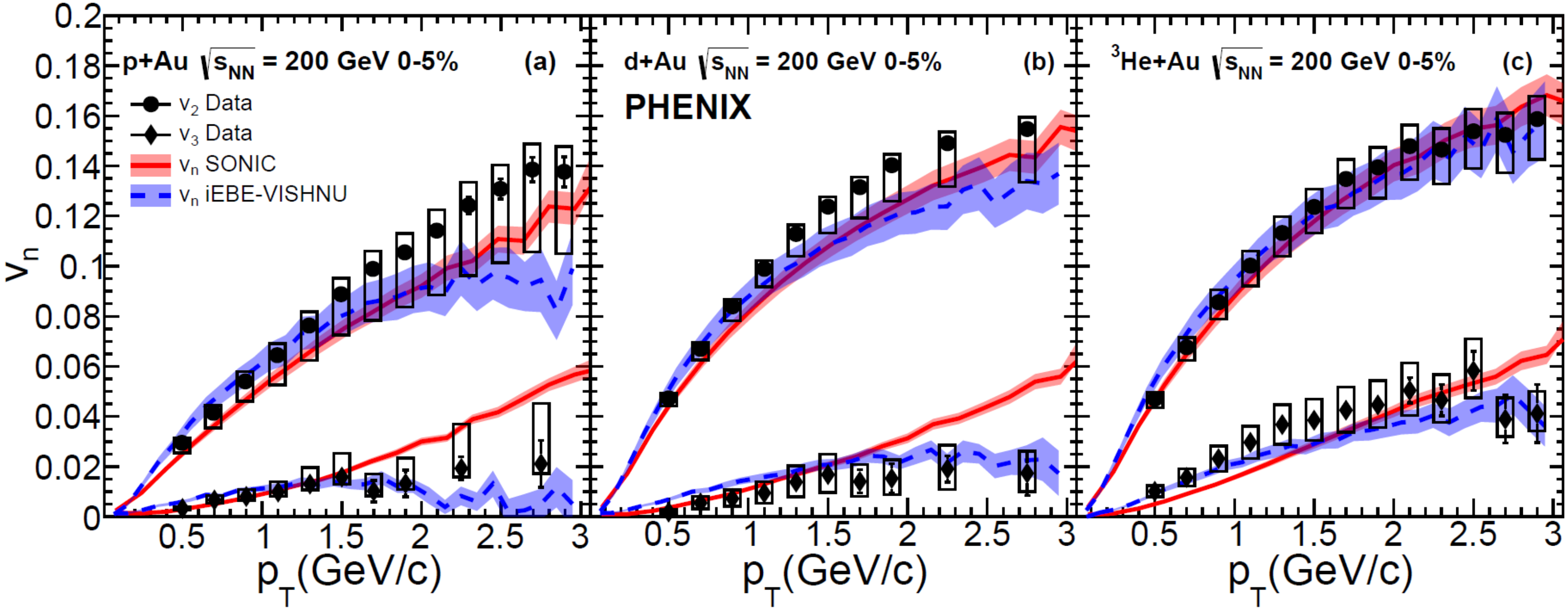
Higher v_3 in ^{3}He+Au

Importance of initial state geometry

Evidence of QGP Droplets in Small Systems

Nature Physics **15, pages214–220 (2019)**

Central Collisions: 0-5%

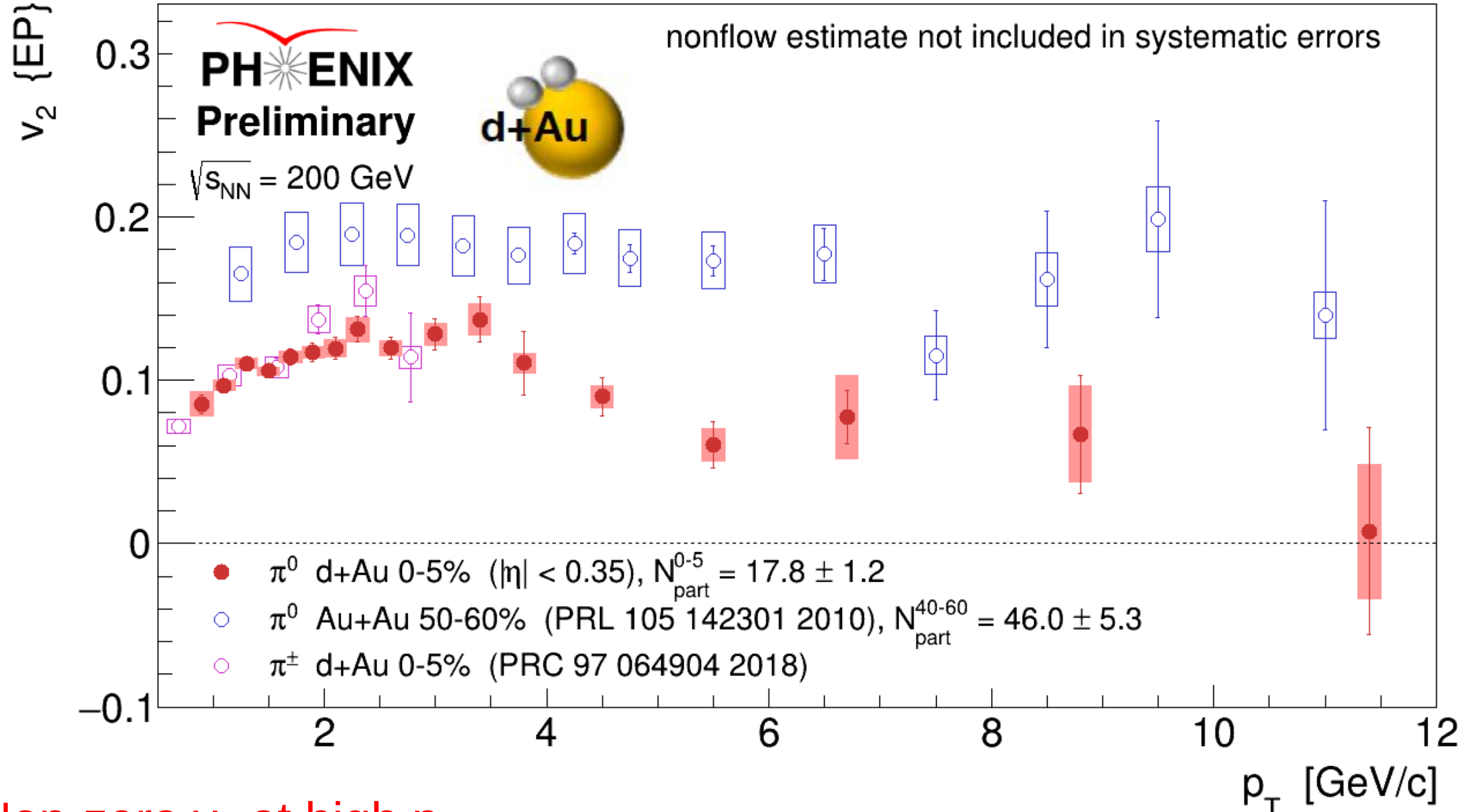


Excellent agreement between data and hydrodynamic predictions

Only hydrodynamic models reproduce the data

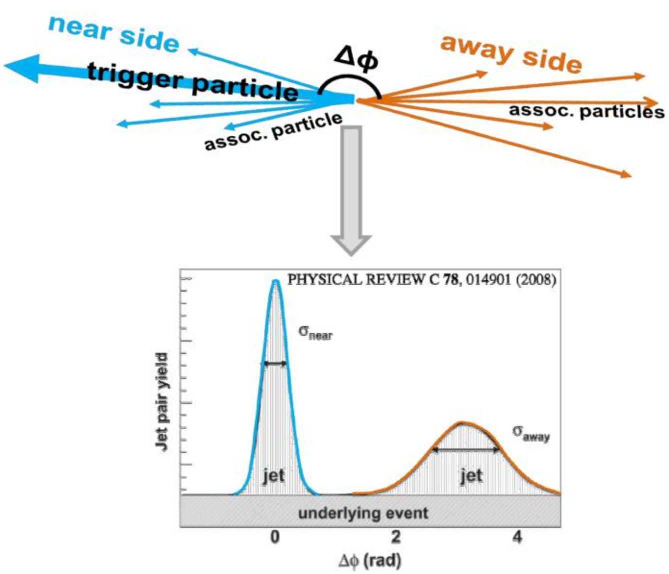
Models indicate the temperatures achieved in small systems sufficient for QGP formation: **QGP Droplets!**

v_2 for Hard Probes

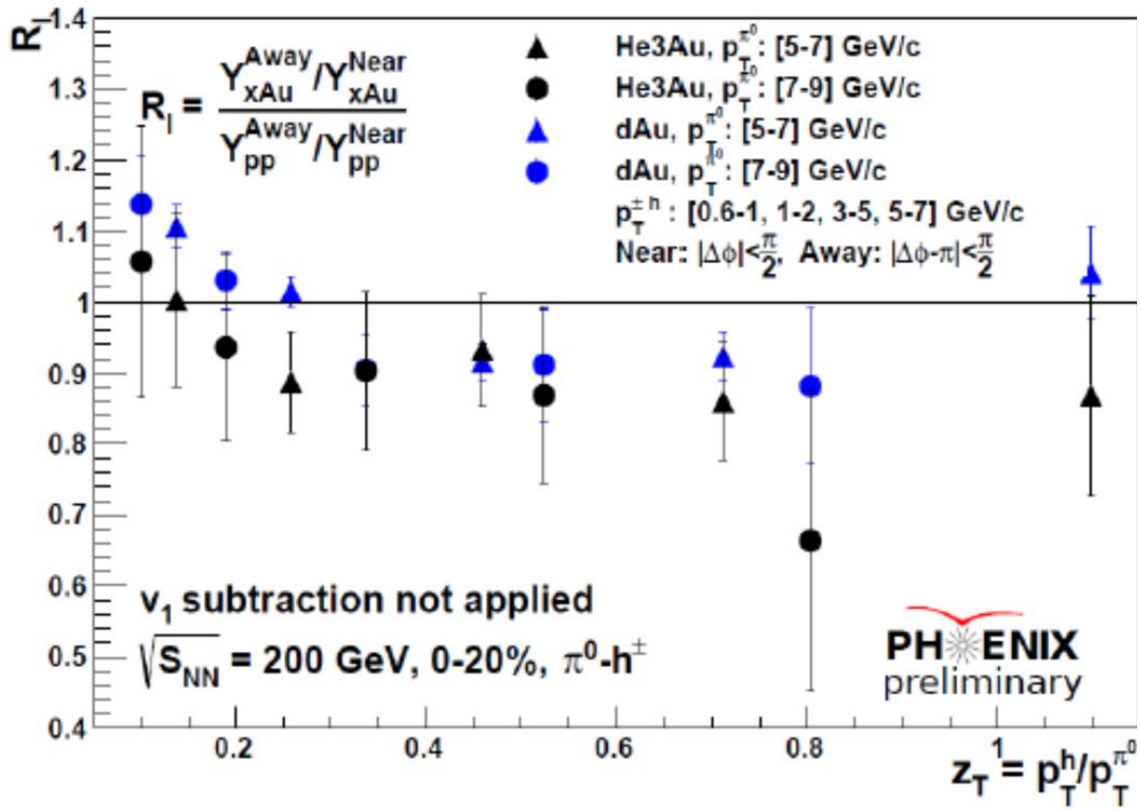


- Non-zero v_2 at high p_T
- In Au+Au this is attributed to pathlength dependent energy loss

Jet Modification in Small Systems

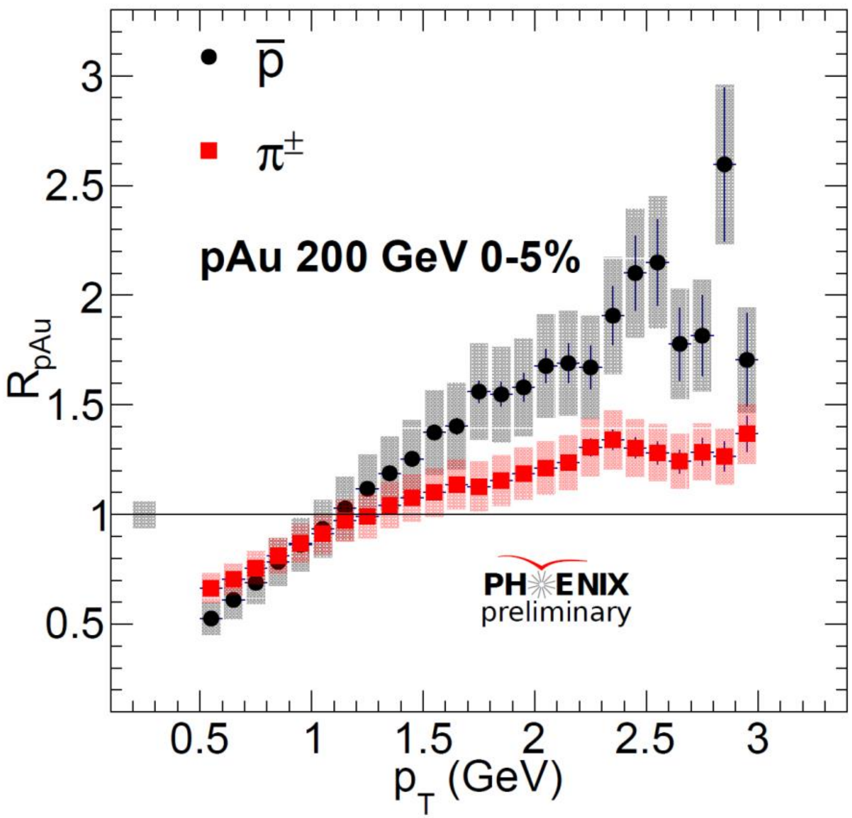


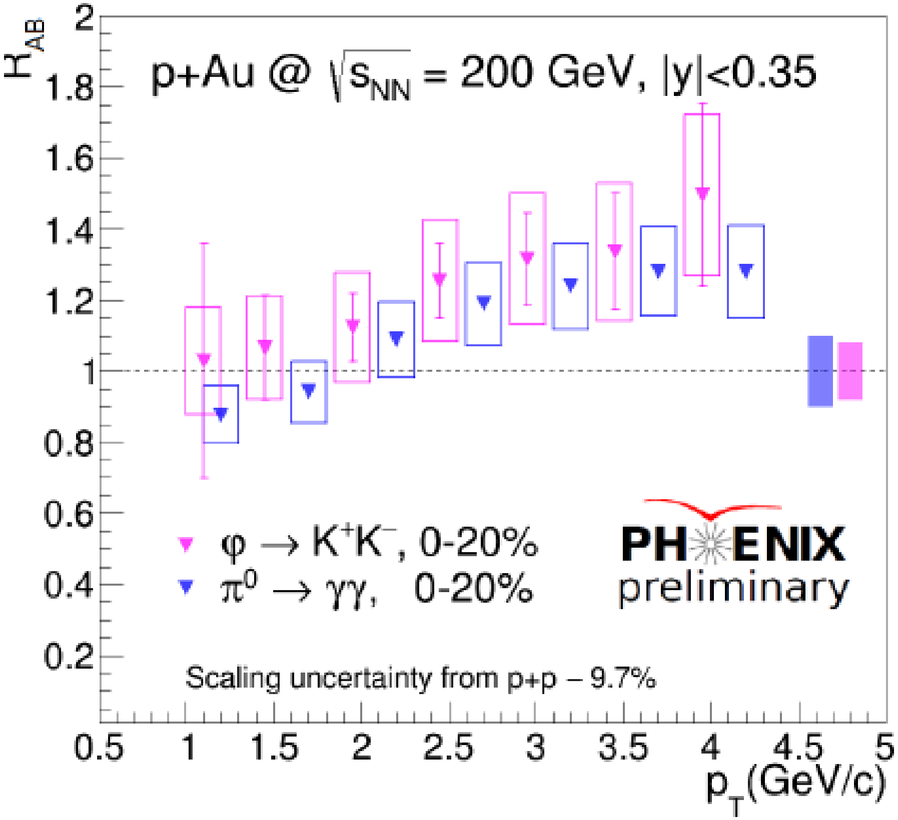
Double Ratio: $R_I = \frac{Y^{AA}_{away}/Y^{AA}_{near}}{Y^{pp}_{away}/Y^{pp}_{near}}$



- Hints of suppression in small systems at high z_T and enhancement at low z_T
- Similar to energy loss effect observed for jets in A+A

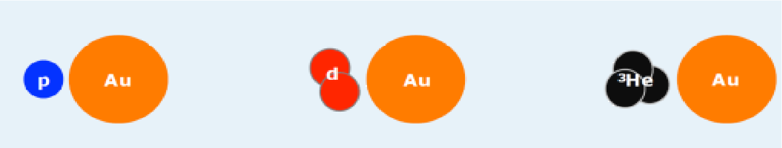
R_{pAu} for Different Particle Species

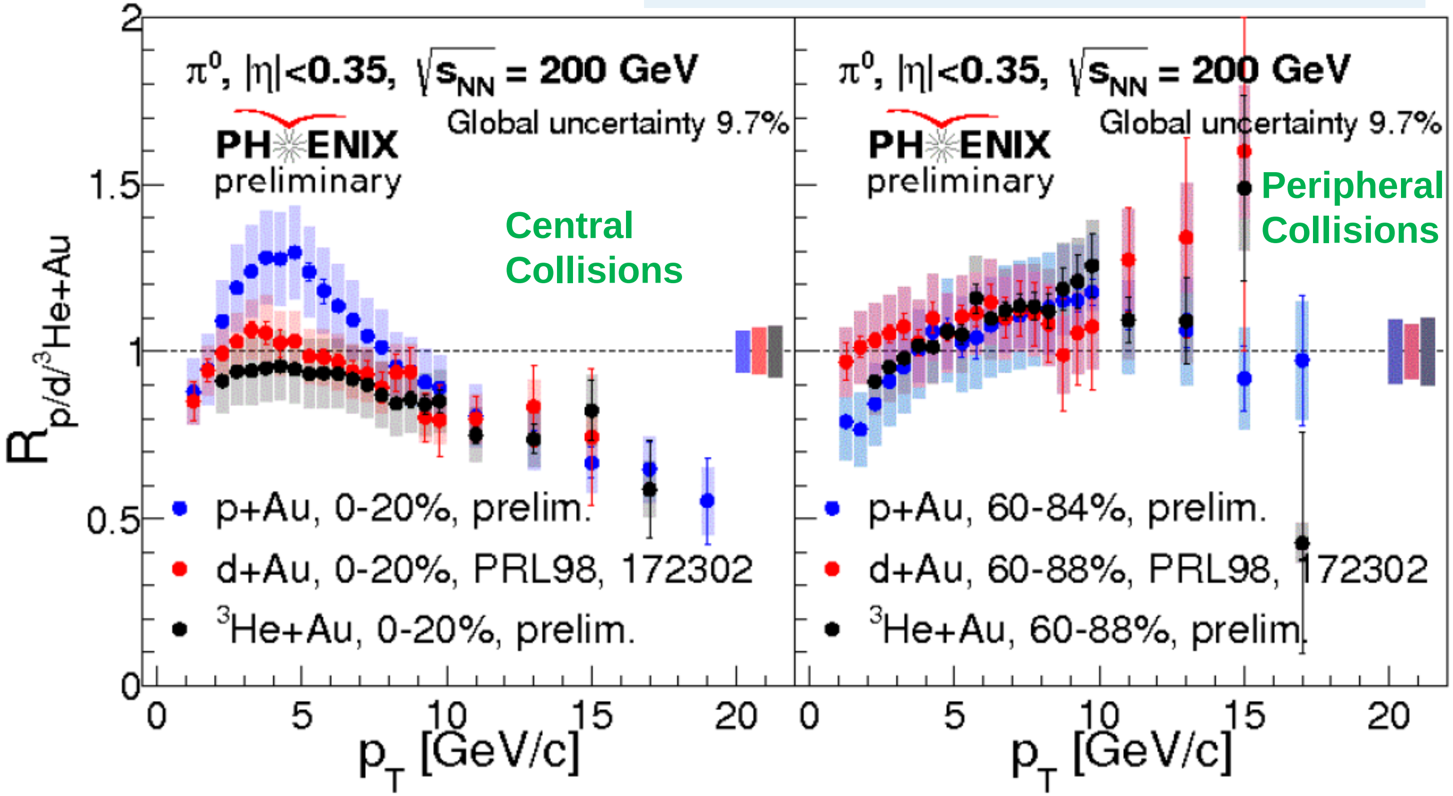




- Baryon enhancement observed in p+Au
- φ and π^0 show similar R_{pAu}
- Consistent with radial flow depending on number of quarks

R_{AB} Collision Dependences

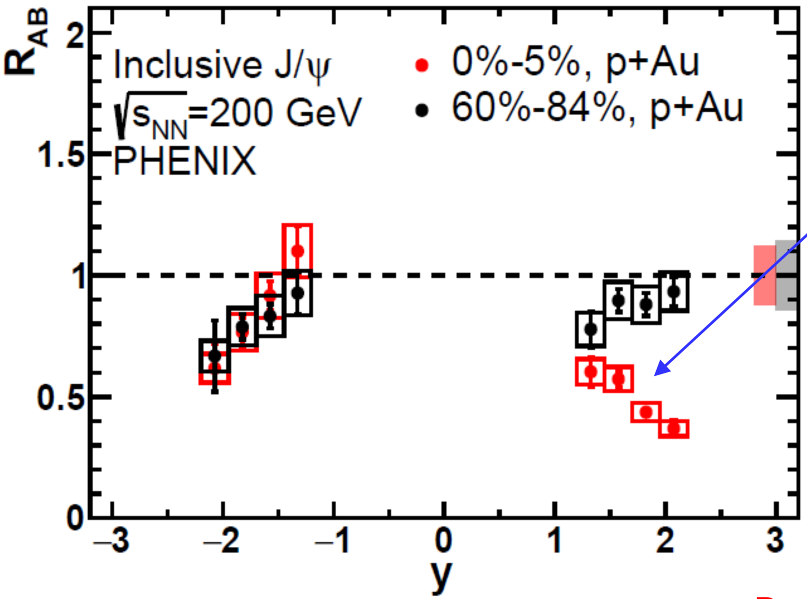




- Cronin enhancement at low p_T indication of projectile dependence
- Suppression seen at high p_T and it is same for all collision systems
- Peripheral consistent with 1 but also consistent with >1

Results in Small Systems: Nuclear Modification Factor

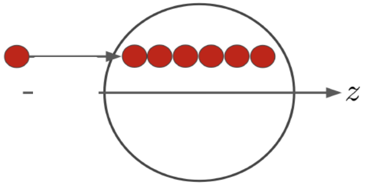
arXiv:1910.14487

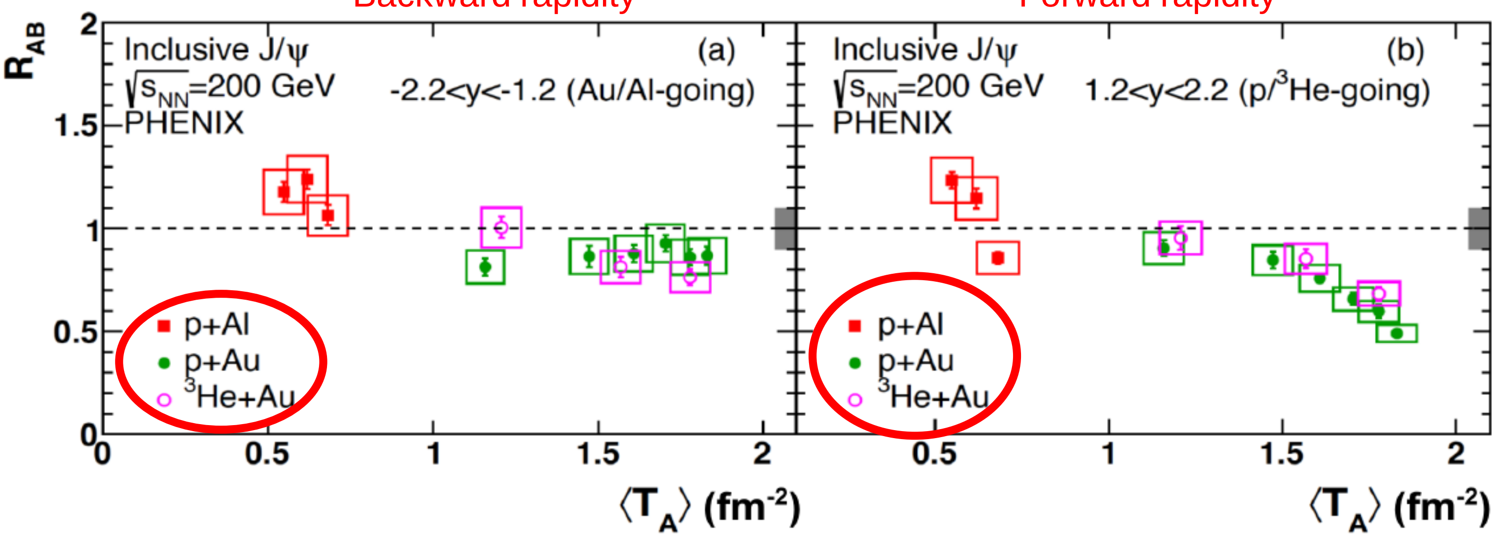


Quarkonia: J/ψ in Small Systems

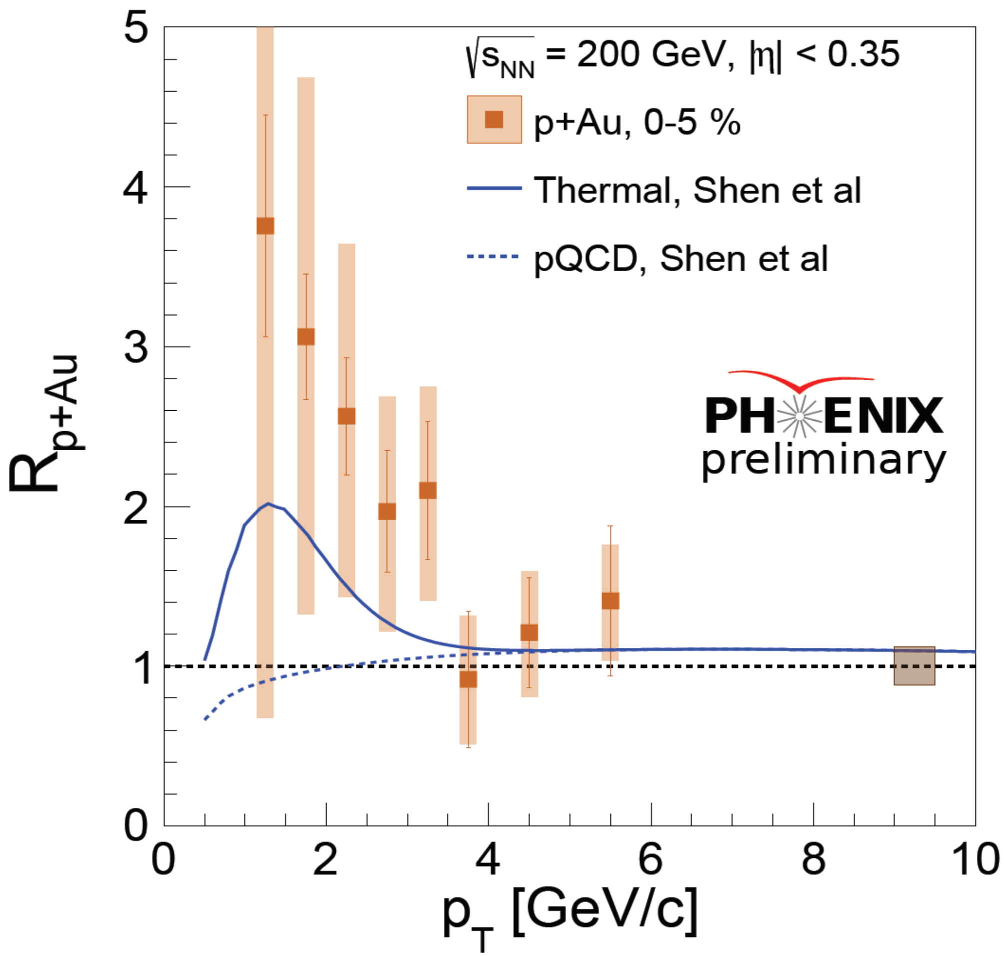
- p+Au: Very strong suppression at forward rapidity in 0-5% central bin
- Nuclear absorption effects at backward rapidity

- No projectile dependence at forward rapidity





Thermal Photons in Small Systems

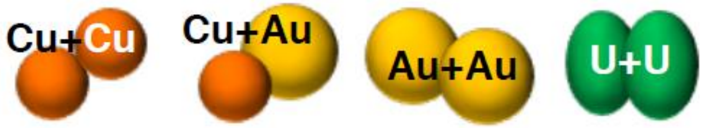


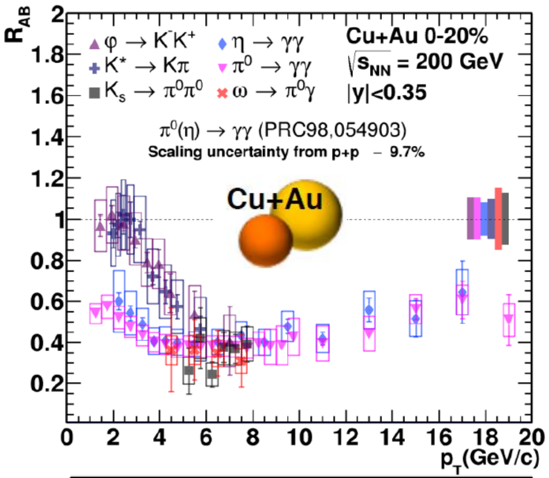
- Enhancement of low p_T photons in central p+Au
- Consistent with expected thermal photon production (PRC 95 014906 (2017))

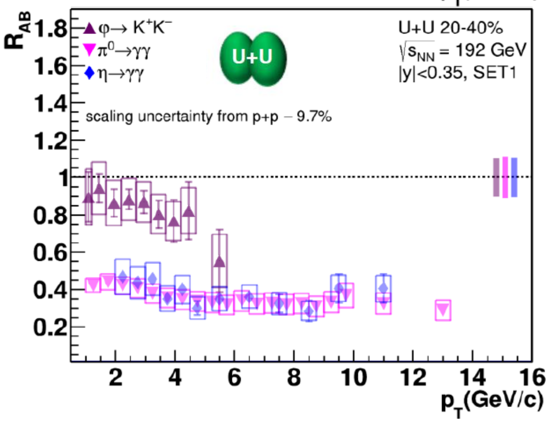
Small System Summary

- Clear evidence for QGP formation in small systems
  - Measured flow described only by hydrodynamics
  - Thermal photons
- Consistent with QGP formation
  - Intriguing jet measurements
  - Strong J/ψ suppression at forward rapidity
  - Baryon R_{pAu} > meson R_{pAu}

R_{AA} in Large Collision Systems

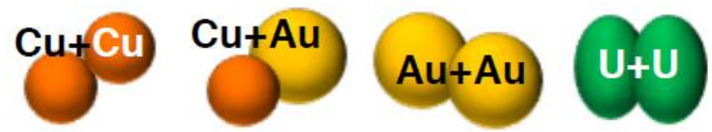




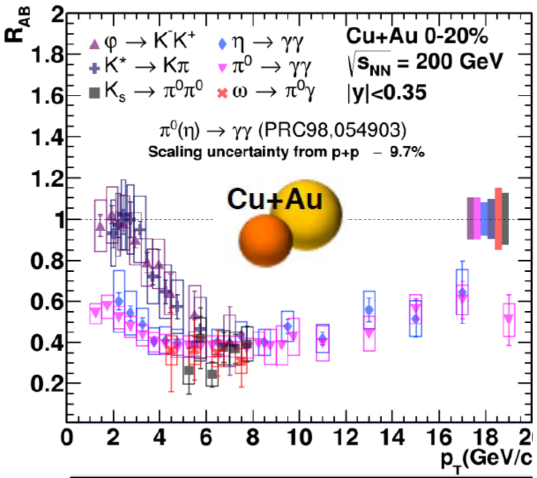


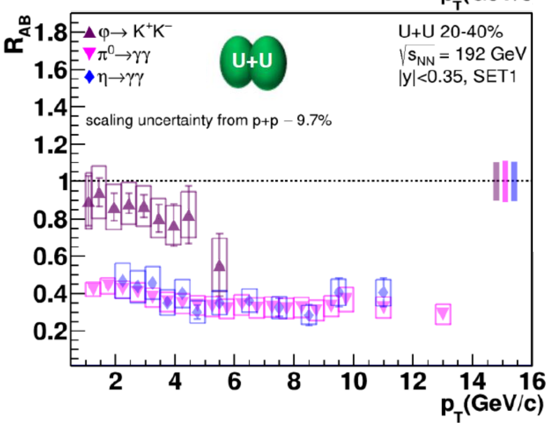
- At low p_T
  - φ is less suppressed then lighter mesons in Cu+Au and U+U
  - K* is also less suppressed in Cu+Au

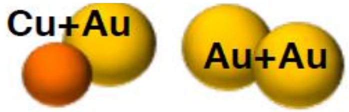
R_{AA} in Large collision systems

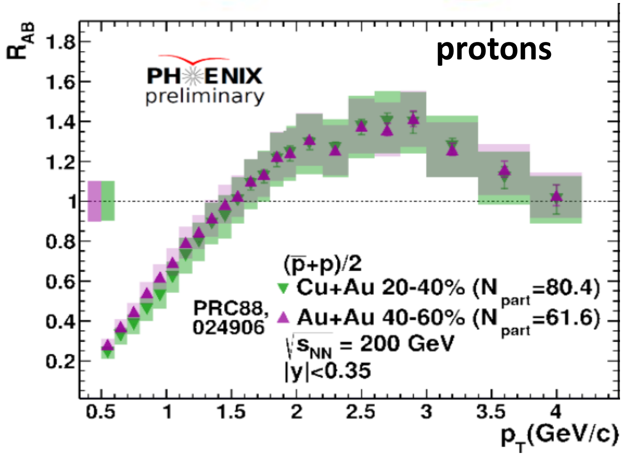


- At low p_T
  - φ is less suppressed then lighter mesons in Cu+Au and U+U
  - K* is also less suppressed in Cu+Au

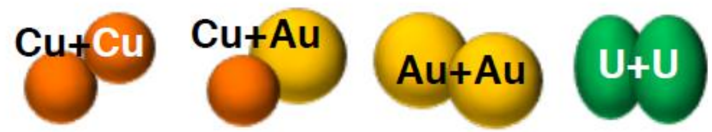


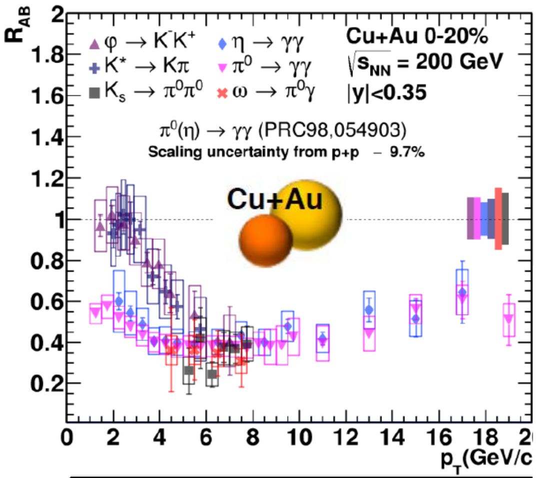


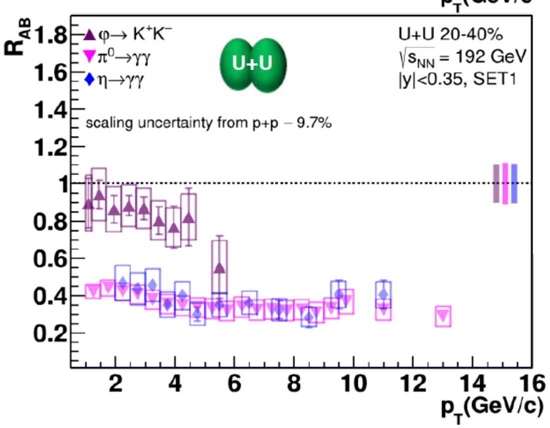




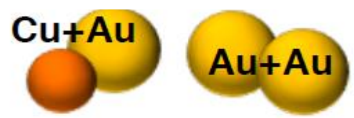
R_{AA} in Large collision systems

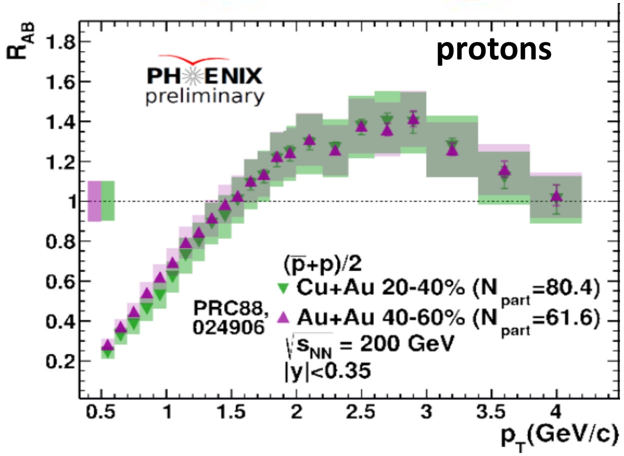


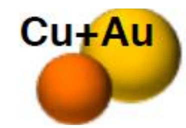


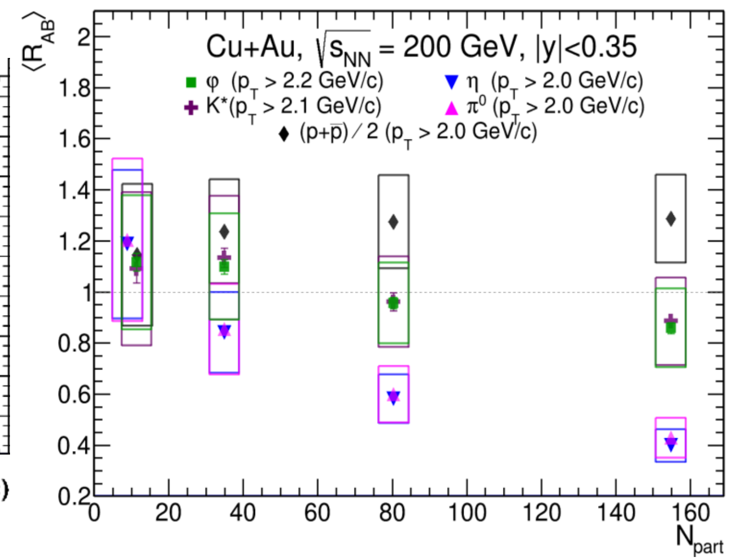


- At low p_T
  - φ is less suppressed then lighter mesons in Cu+Au and U+U
  - K* is also less suppressed in Cu+Au







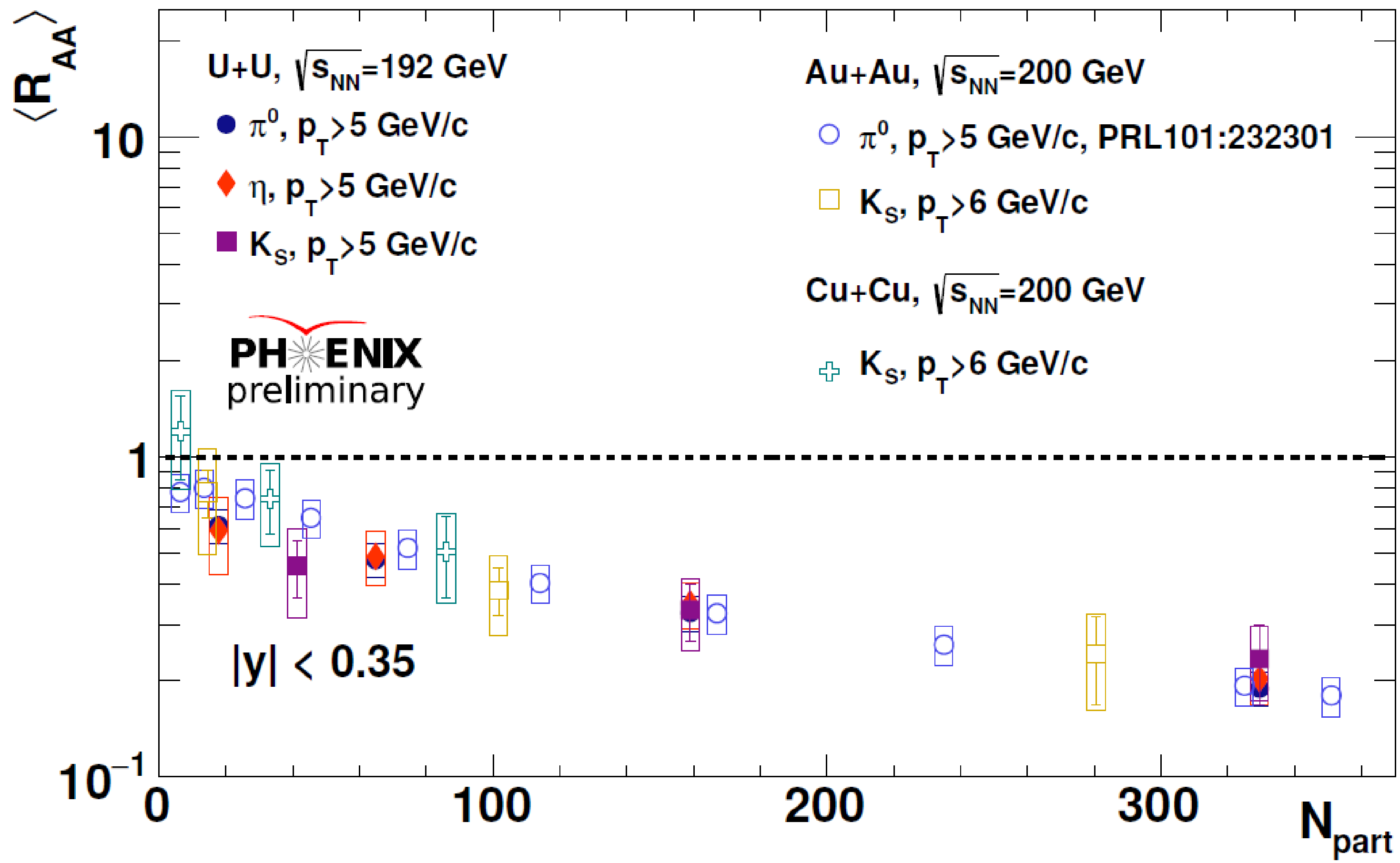


➢ Interplay of radial flow, strangeness + recombination and it is different from small systems

Results in Large Systems: Nuclear Modification Factor

R_{AA} at High-p_T

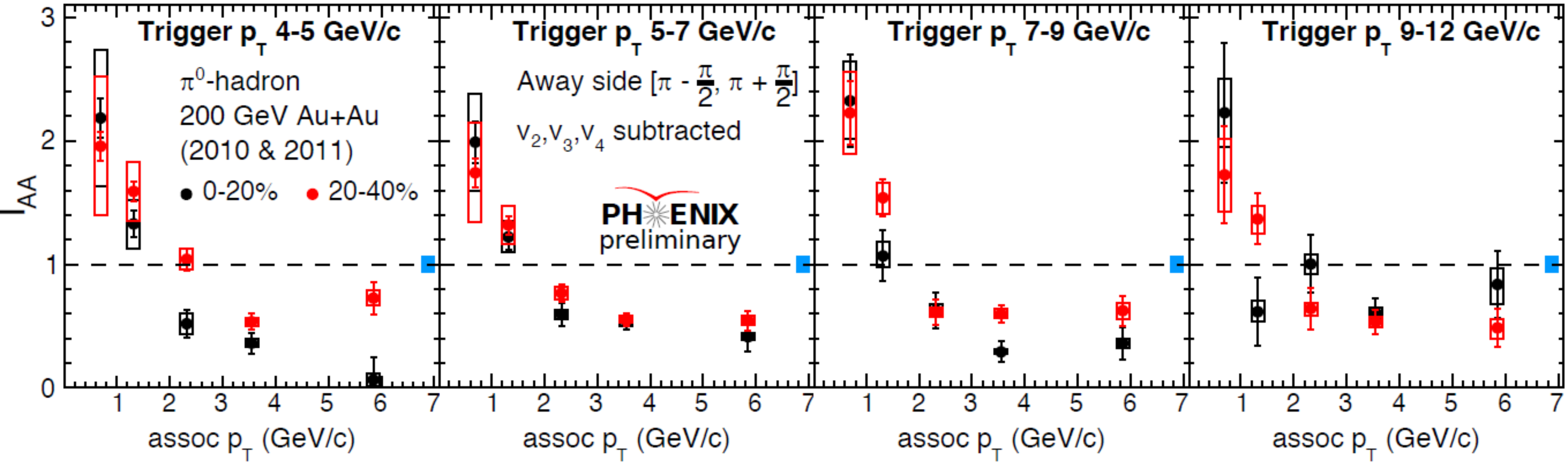
U+U vs Au+Au vs Cu+Cu Collisions



- For p_T> 6 GeV/c same trend for all systems and particles as a function of N_{part}

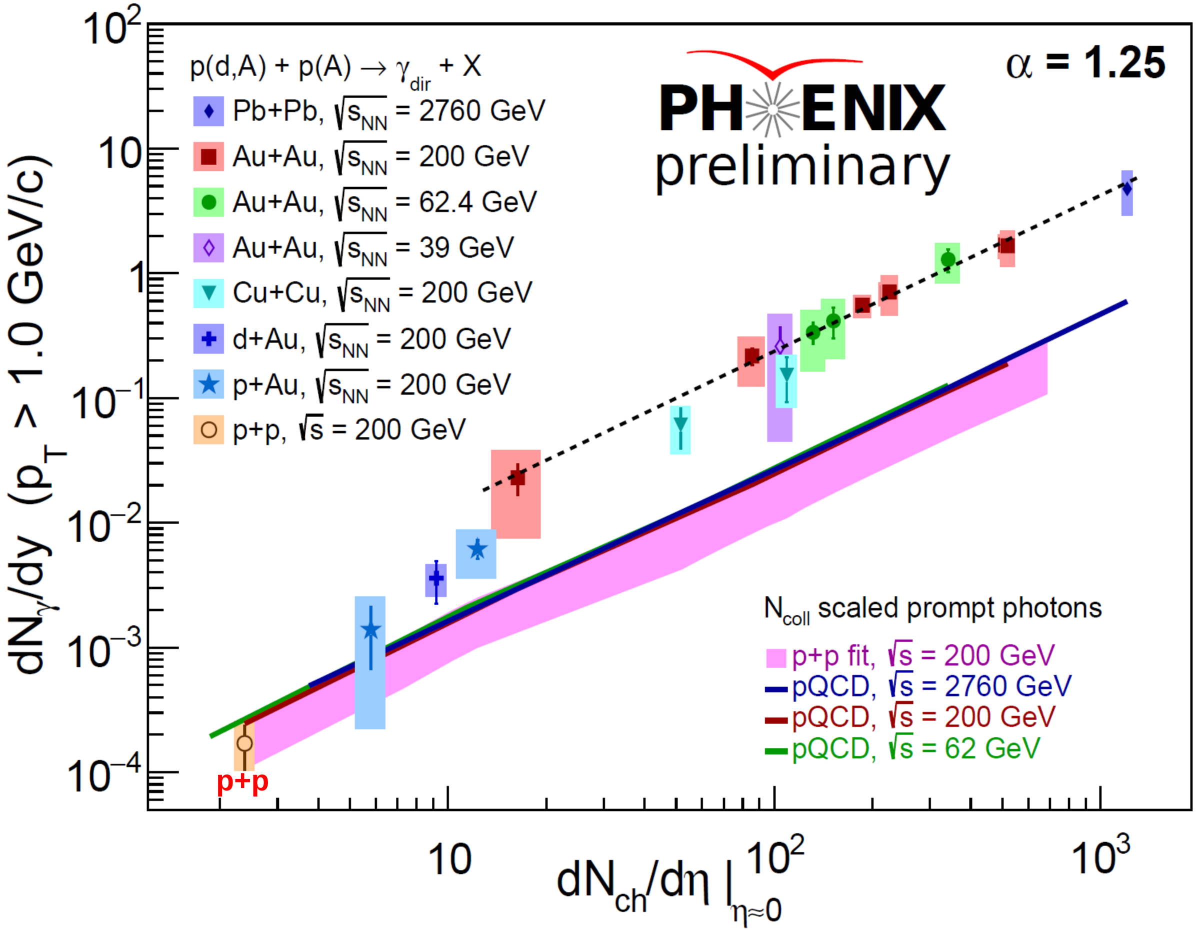
Jet Modification in A+A

$$I_{AA} = \frac{Y^{AA}_{Away}}{Y^{pp}_{Away}}$$



- Suppression at high-p_T
- Enhancement at low-p_T
- Transition at similar p_{Th} for all trigger p_T bins

Thermal Photons in Small Systems



- Similar scaling for heavy ion collision systems measured by PHENIX and ALICE

- Smooth trend between small and large systems

Summary and Outlook

- Summary of Large Systems

- Hadron spectra measured for different particles and in various collision systems
  - Different production mechanisms at different p_T
- Two particle correlations used to explore jet substructure
  - Enhanced low p_T particles at wide angles
- Thermal photon scaling indicates smooth trend from small to large systems

- Outlook

- ψ(2S) modification in p+Au and ^{3}He+Au at forward/backward rapidities
- Reconstructed jet R_{pAu}
- High p_T direct photons R_{pAu}
- Charm and bottom R_{AA} and v_2
- Direct photon-hadron measurements in Run 14+16 Au+Au

40B Au+Au events in 2014+16 data

- Without Doubt RHIC Collider is Amazing QCD Machine

- Many Species, Many Energies, and High Luminosity and Stability

RHIC collider at BNL has a bright future→ Electron-Ion Collider (EIC)

ENERGY.GOV | SCIENCE & INNOVATION | ENERGY ECONOMY | SECURITY & SAFETY | SAVE ENERGY, SAVE MONEY

Department of Energy

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

Home » U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

WASHINGTON, D.C. – Today, the **U.S. Department of Energy (DOE)** announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

The Electron Ion Collider (EIC), to be designed and constructed over ten years at an estimated cost between $1.6 and $2.6 billion, will smash electrons into protons and heavier atomic nuclei in an effort to penetrate the mysteries of the "strong force" that binds the atomic nucleus together.