Hot and cold

Recent Quarkonia studies in PHENIX

Richard Hollis
University of California, Riverside

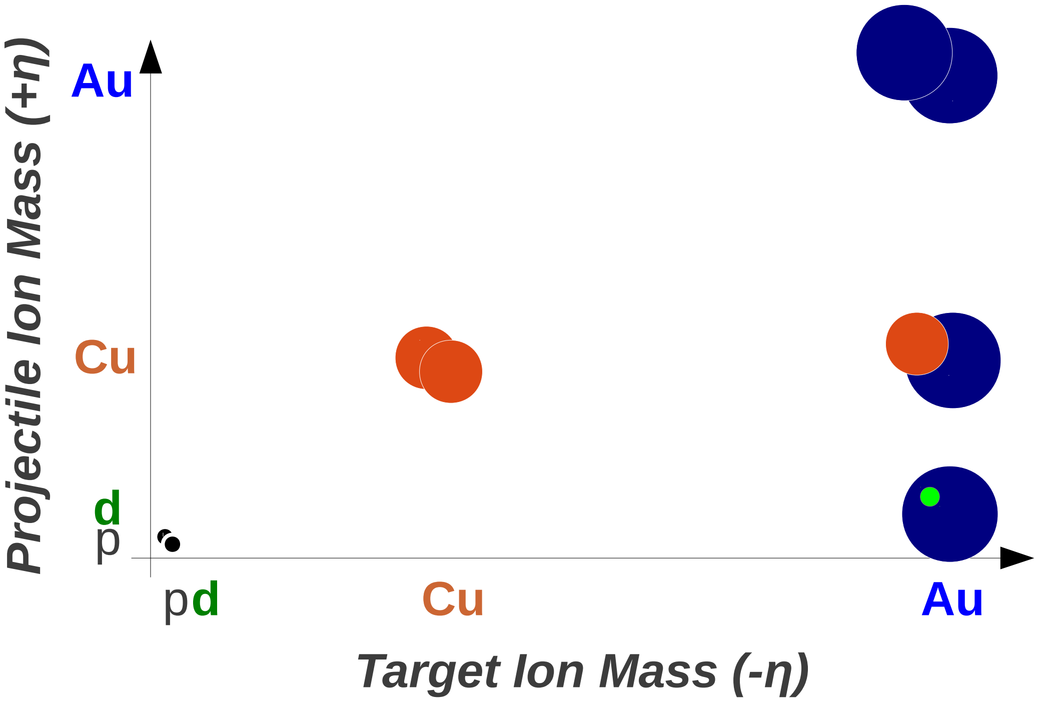
PHENIX Collaboration

Outline

- Landscape of PHENIX Results
- Studies of the initial state
- Systematic studies of AB collisions
- Summary

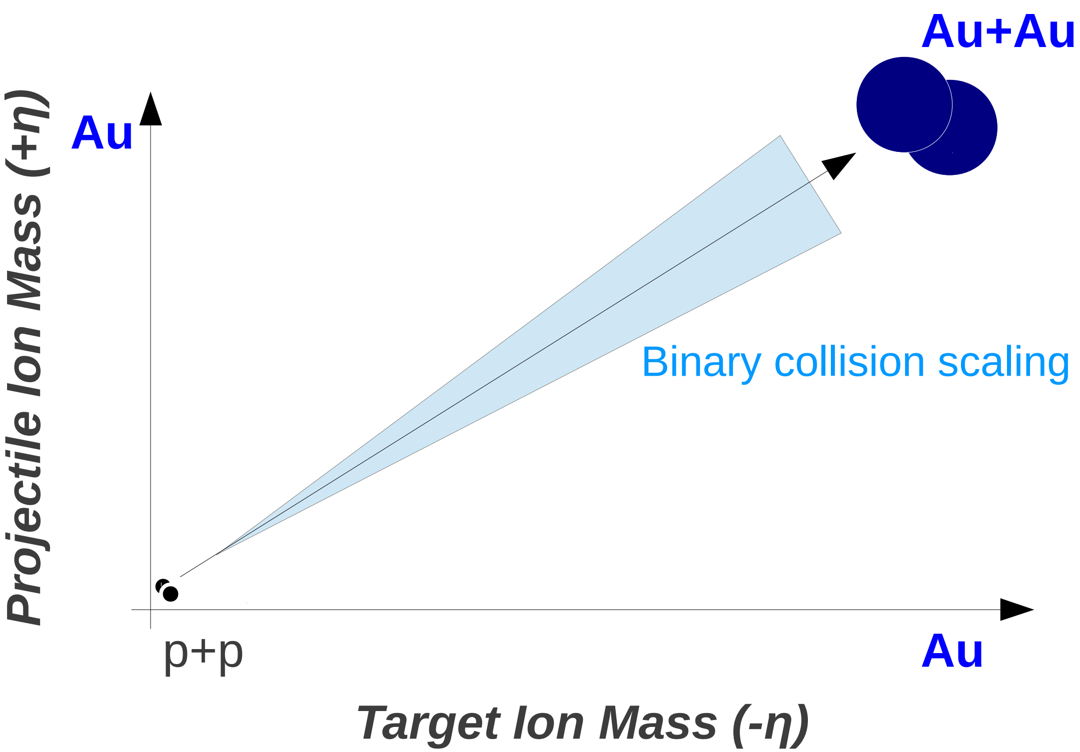
Landscape of PHENIX Measurements

- Aim:
  - Understand relative production of heavy-quarks in AA compared to pp collisions
    - How are heavy-quarks quenched in the QGP?
- Tools:
  - **p+p** collisions
  - **d+Au** collisions
  - **A+A** collisions
  - **A+B** collisions
  - Energy Scan (39-200 GeV)



Landscape of PHENIX Measurements

- Heavy-ion collisions are very complicated:
  - What we believe we start with: **p+p** collisions → binary (N_{coll}) scaled to **Au+Au**



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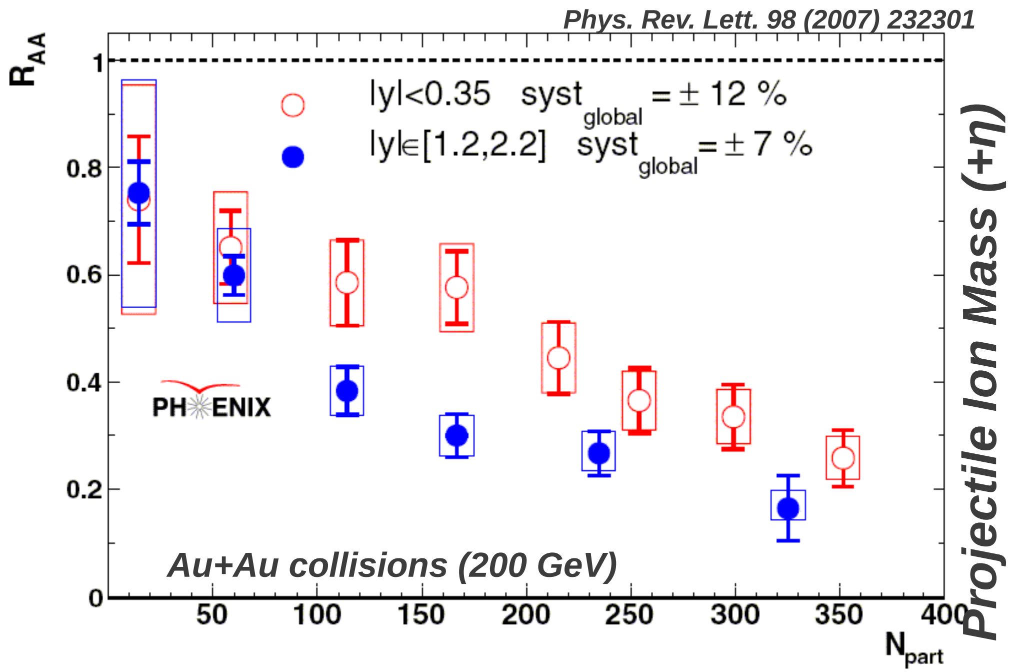
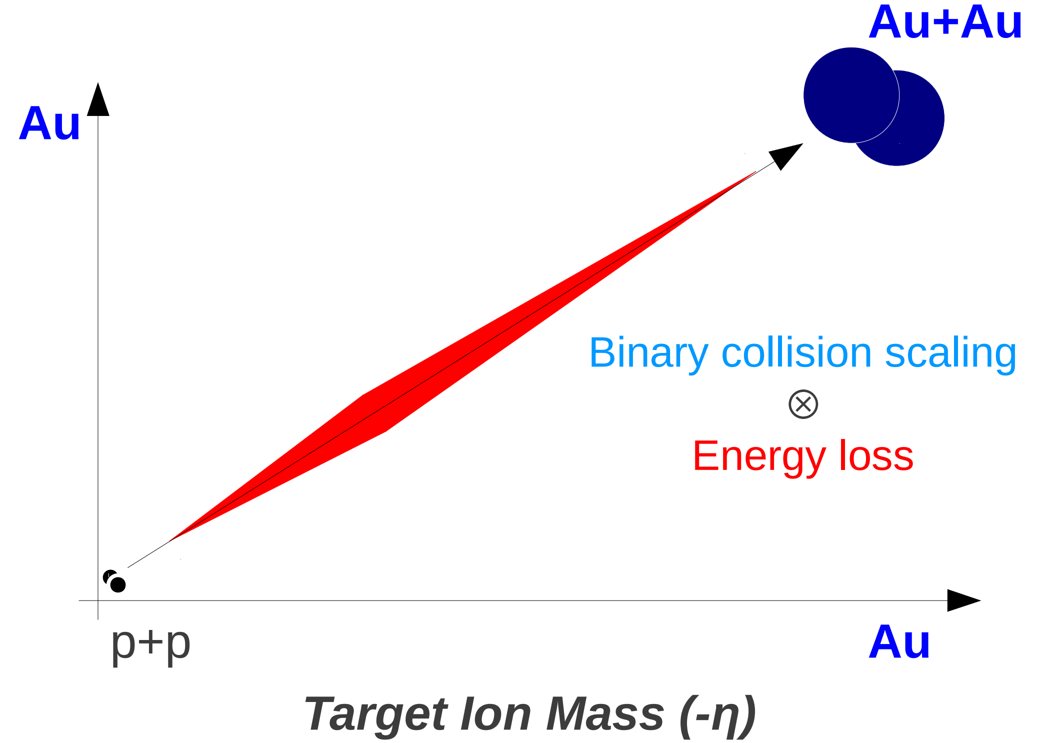


$$R_{AA}=\frac{1}{Ncoll}\frac{Yield(AA)}{Yield(pp)}$$



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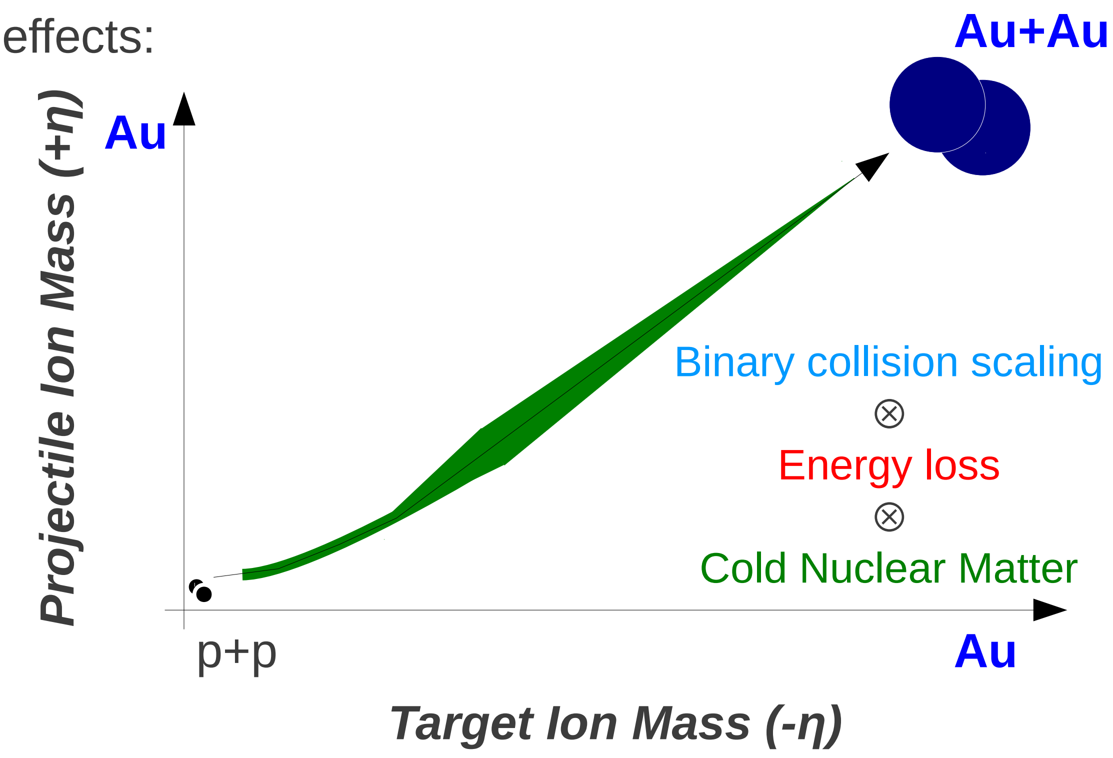
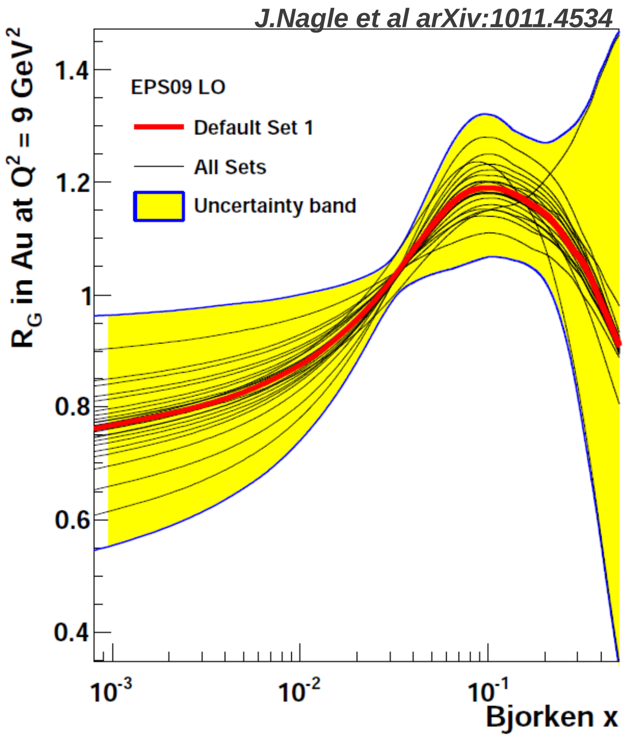
- Heavy-ion collisions are very complicated:
  - What we believe we start with: **p+p** collisions → binary (N_{coll}) scaled to **Au+Au**
  - Lower production rate measured: due to in-medium energy loss
  - Underlying cold-nuclear matter effects:
    - is p+p the correct starting point?



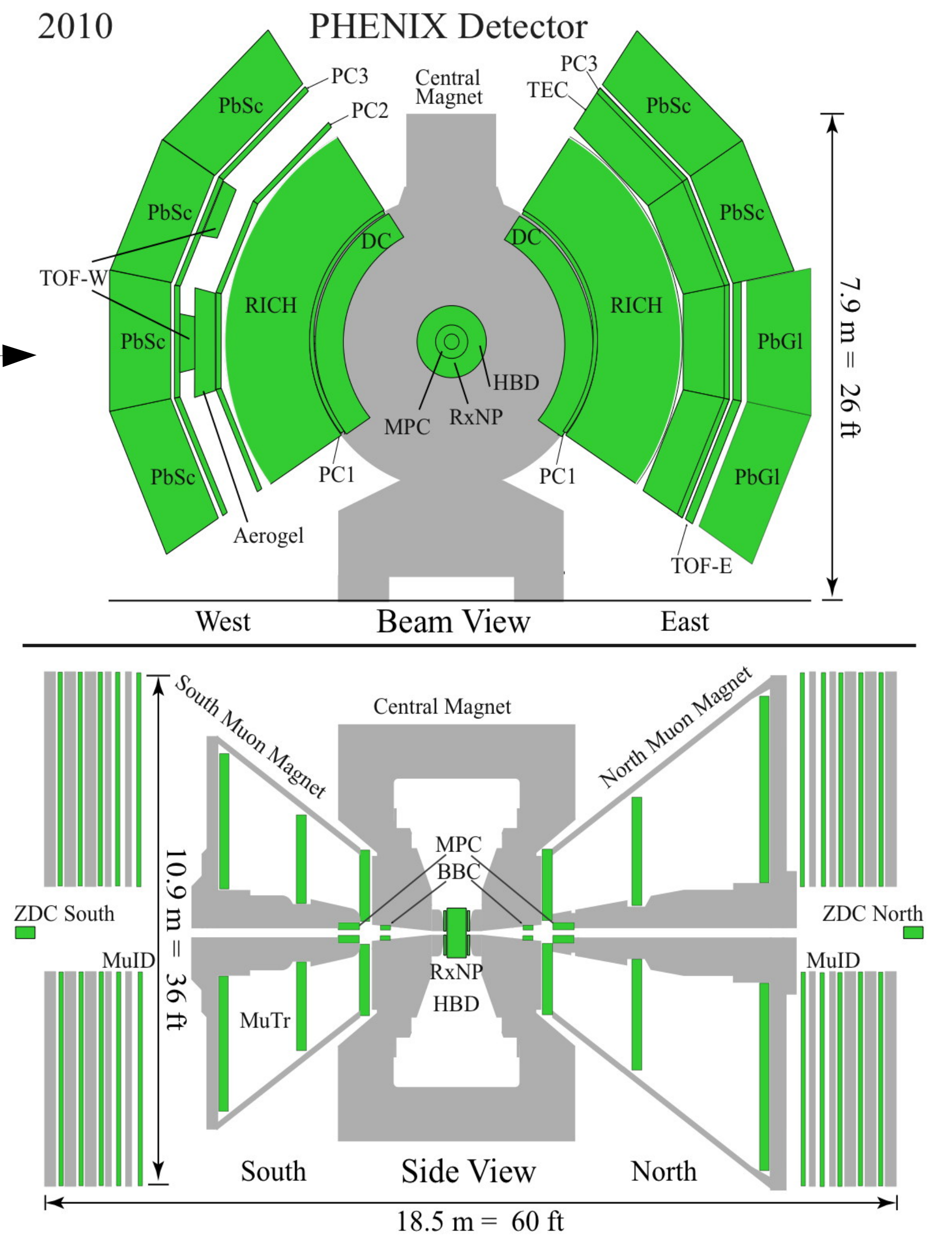
Cold Nuclear Matter

- Before one can understand A+A collisions, we must know what we start with: explore the realm of cold nuclear matter to understand the initial state
- Probe the state of the initial collision
  - Production dominated by gluon fusion
  - Modified by
    - (c-cbar) Break-up
    - Cronin
    - Shadowing
    - Anti-shadowing



PHENIX Detector

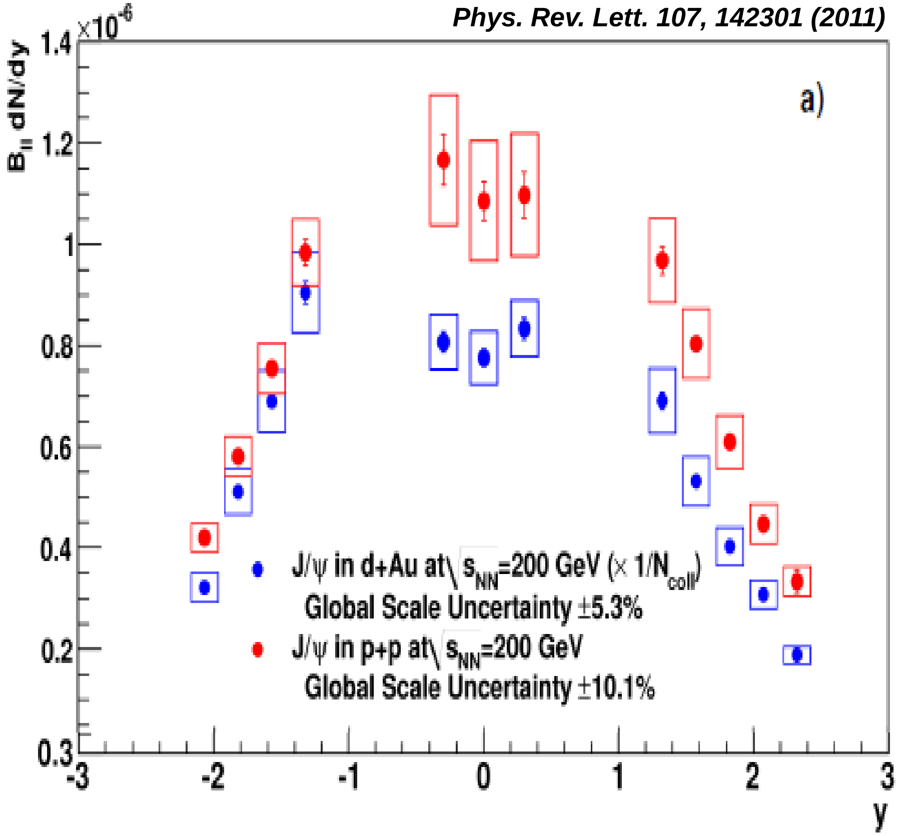
- Wide angular coverage for quarkonia
  - Central arms
    - Electron measurements
      - $|\eta|<0.35$
      - $\Delta\varphi \sim \pi$
  - Forward muon arms
    - Muon measurements
      - $1.2<|\eta|<2.2$
      - $\Delta\varphi \sim 2\pi$



d+Au – testing the initial state

- Hard collisions in the nucleus
  - J/ψ in pp collisions
  - J/ψ in dAu collisions
    - Binary scaled
- Forward/backward asymmetry
  - Larger “suppression” at forward rapidity

Phys. Rev. Lett. 107, 142301 (2011)



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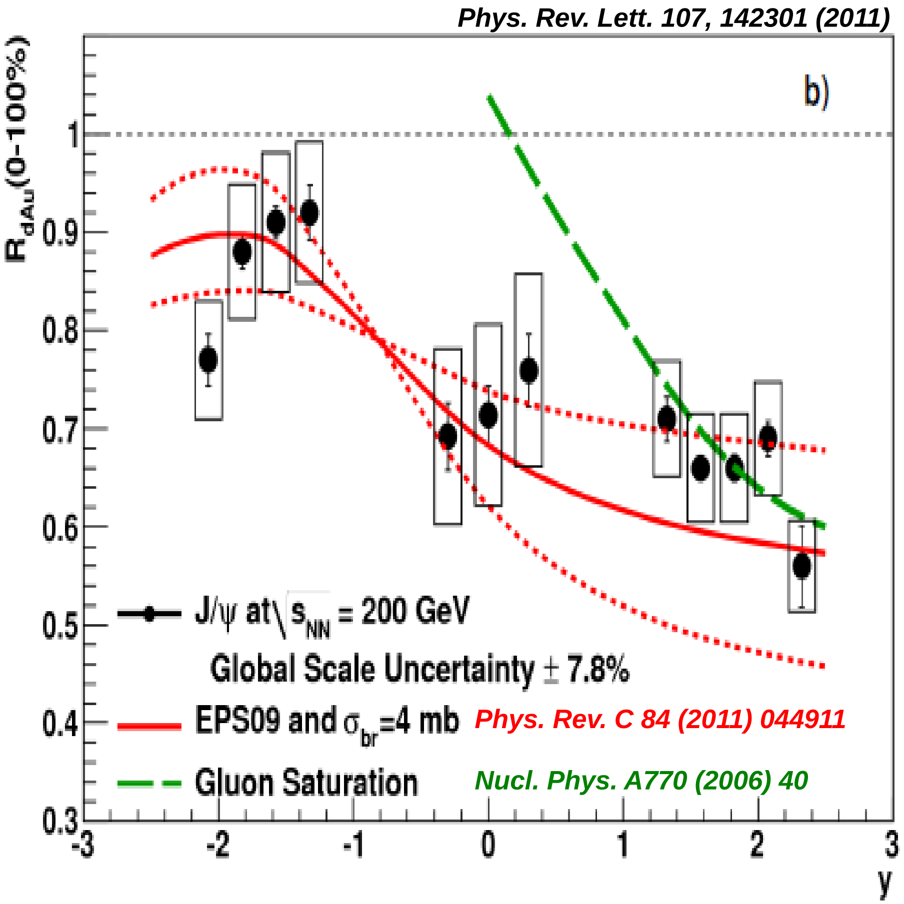
- Hard collisions in the nucleus
  - $R_{dAu}(J/\psi)$
- Forward/backward asymmetry
  - Larger "suppression" at forward rapidity
- Model:
  - EPS09 with break-up cross-section
  - Linear thickness dependence on shadowing
  - Provides a good description of the ***minimum bias*** data



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- Model:
  - EPS09 with break-up cross-section
  - Linear thickness dependence on shadowing
  - Provides a good description of the ***backward/midrapidity centrality dependence***
  - Over-predicts forward suppression in peripheral collisions

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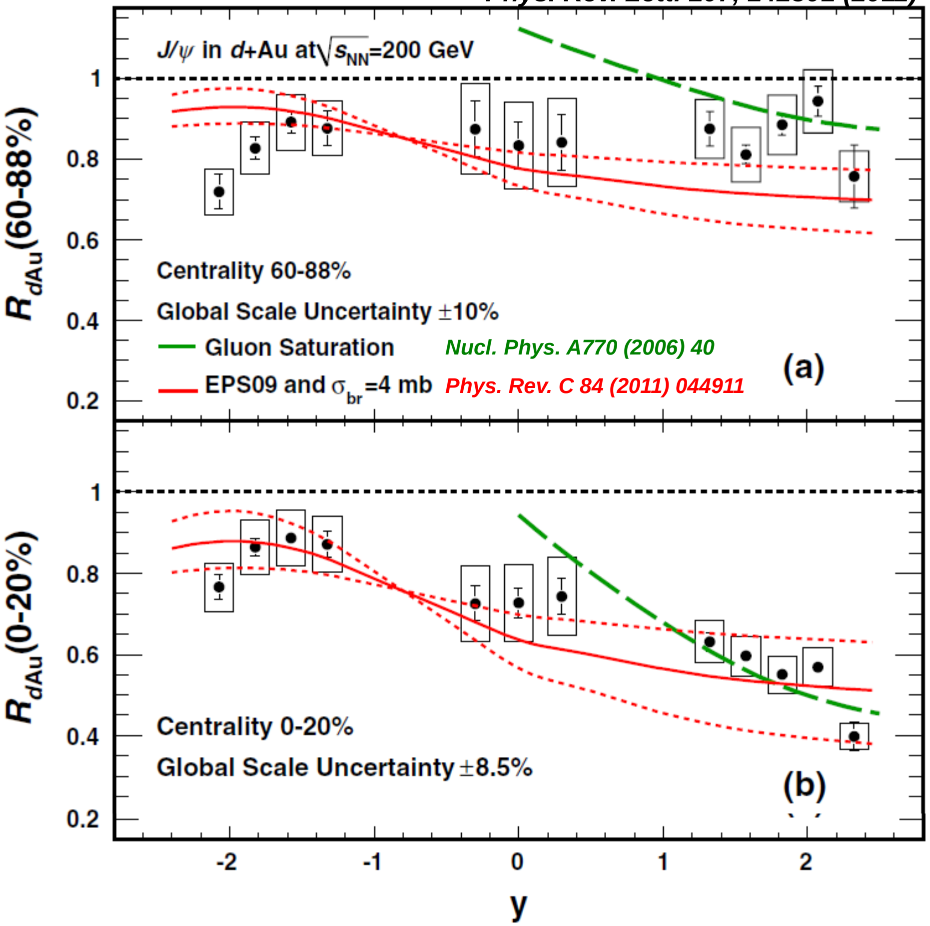
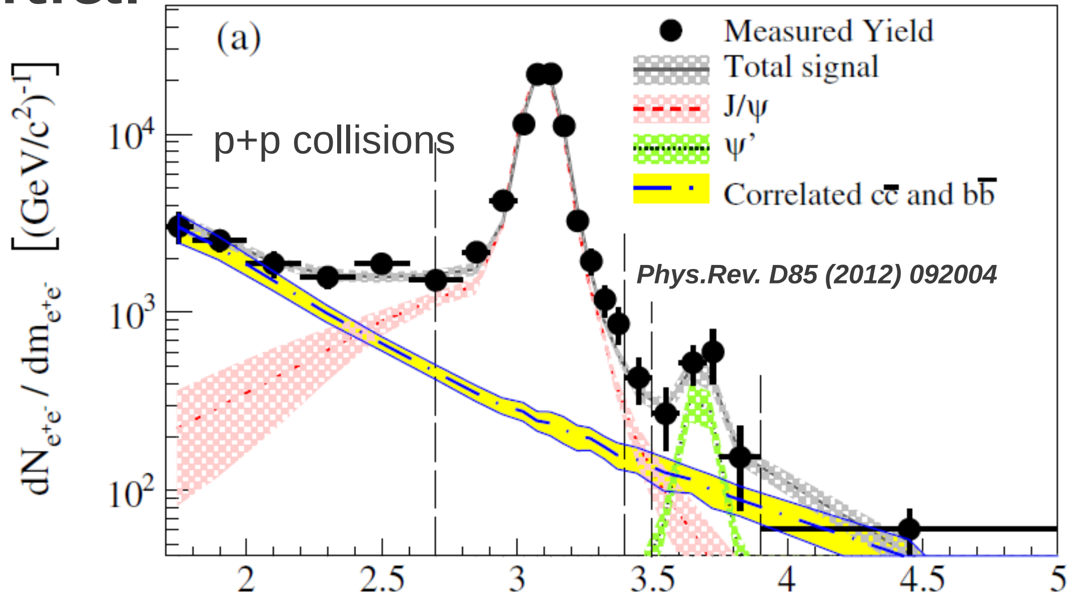
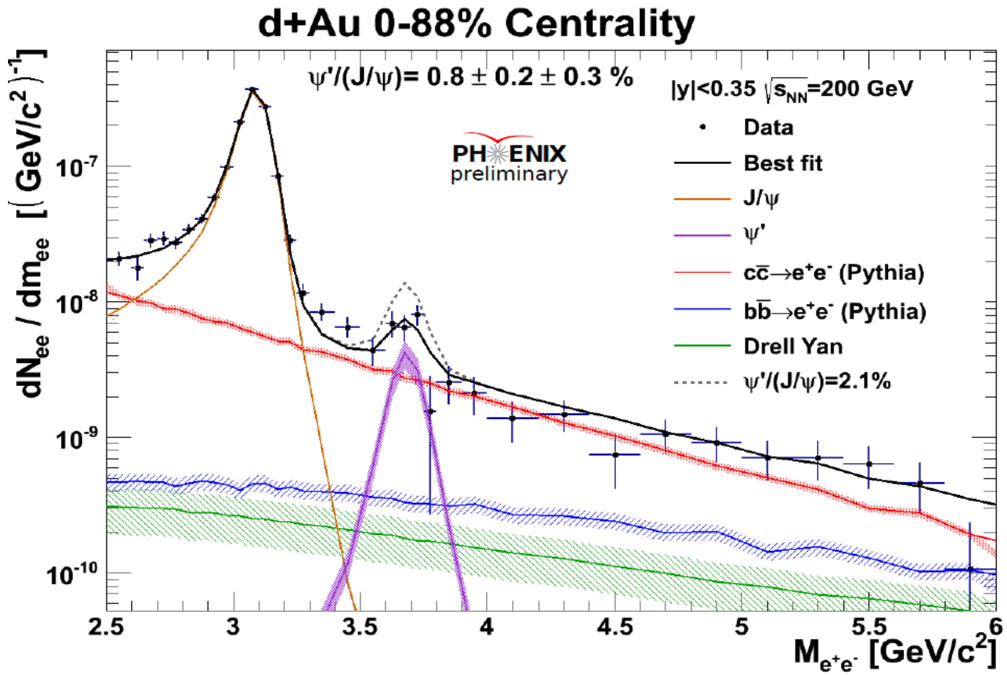


d+Au – testing the initial state

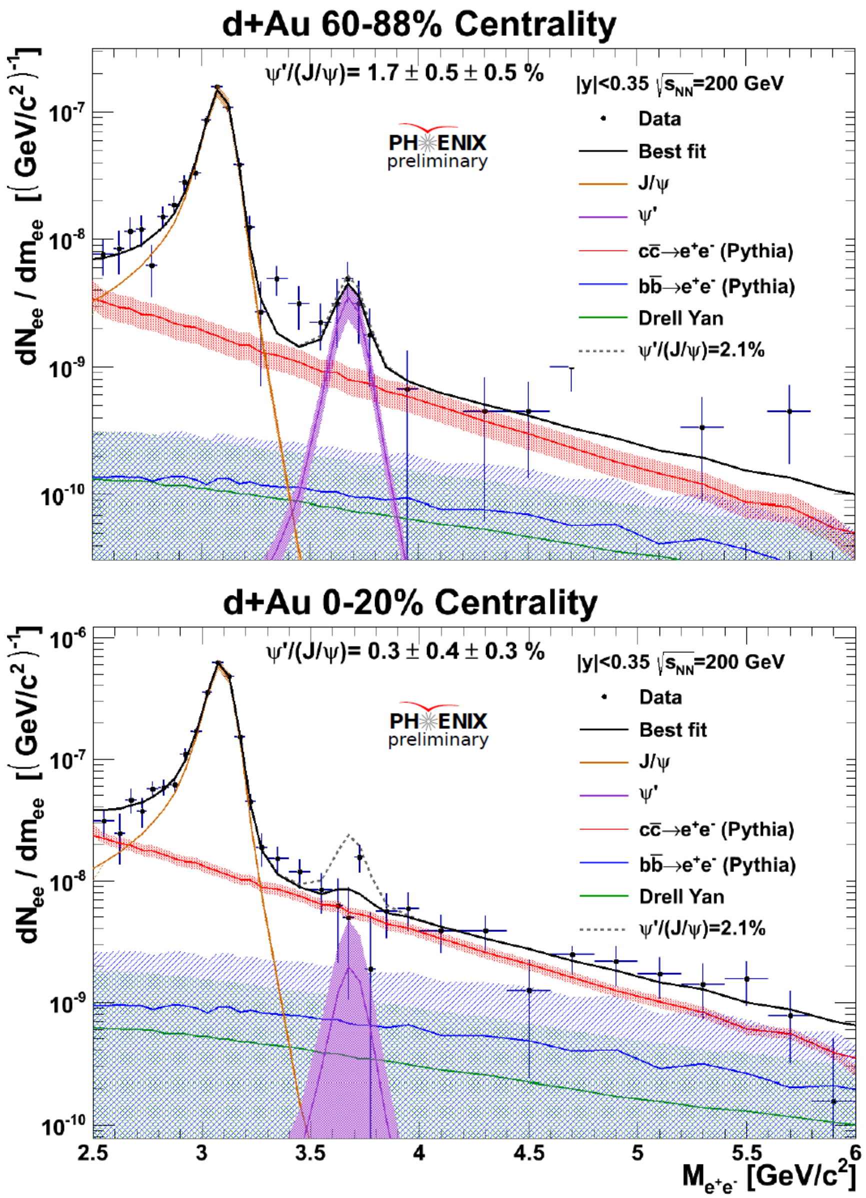
- Relative production of mid-rapidity J/ψ and ψ' in p+p, and d+Au collisions
  - ***Relative suppression*** of loosely bound ψ'





d+Au – testing the initial state

- Relative production of mid-rapidity J/ψ and ψ' in p+p, and d+Au collisions
  - ***Relative suppression*** of loosely bound ψ'
- Strong centrality dependence
  - Unmodified production ratio ψ'/(J/ψ) in peripheral collisions
  - Strong suppression of ψ' in most central collisions



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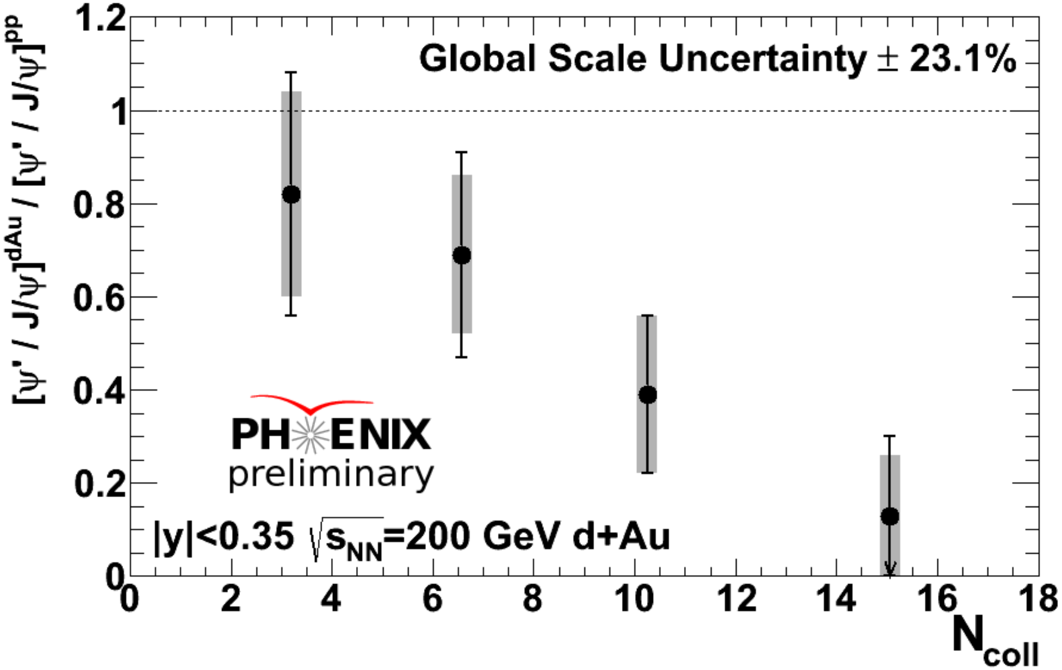
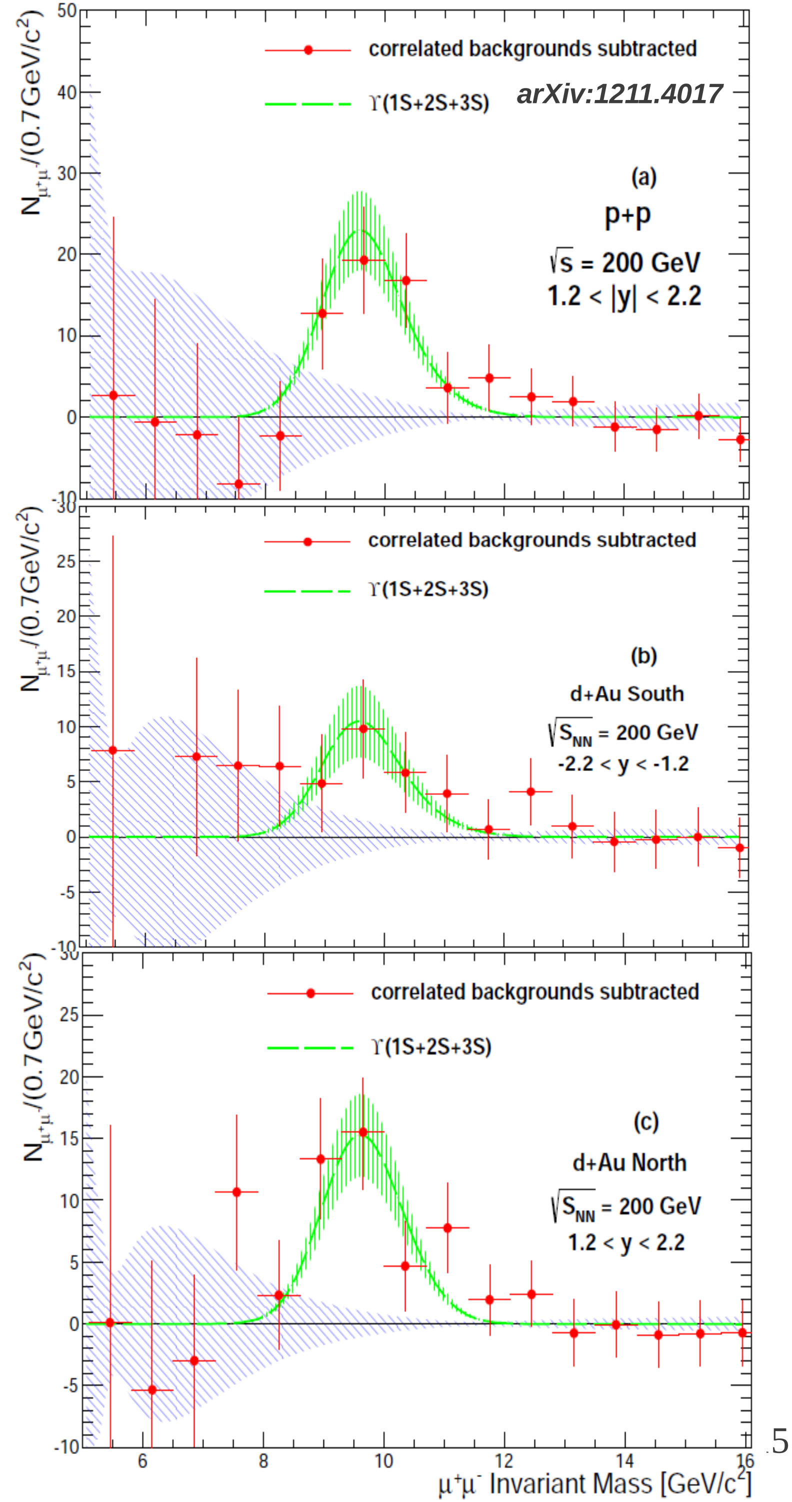


Upsilon

- Measurement of $\Upsilon(1S+2S+3S) \rightarrow \mu\mu$
  - pp
  - Minimum bias d+Au

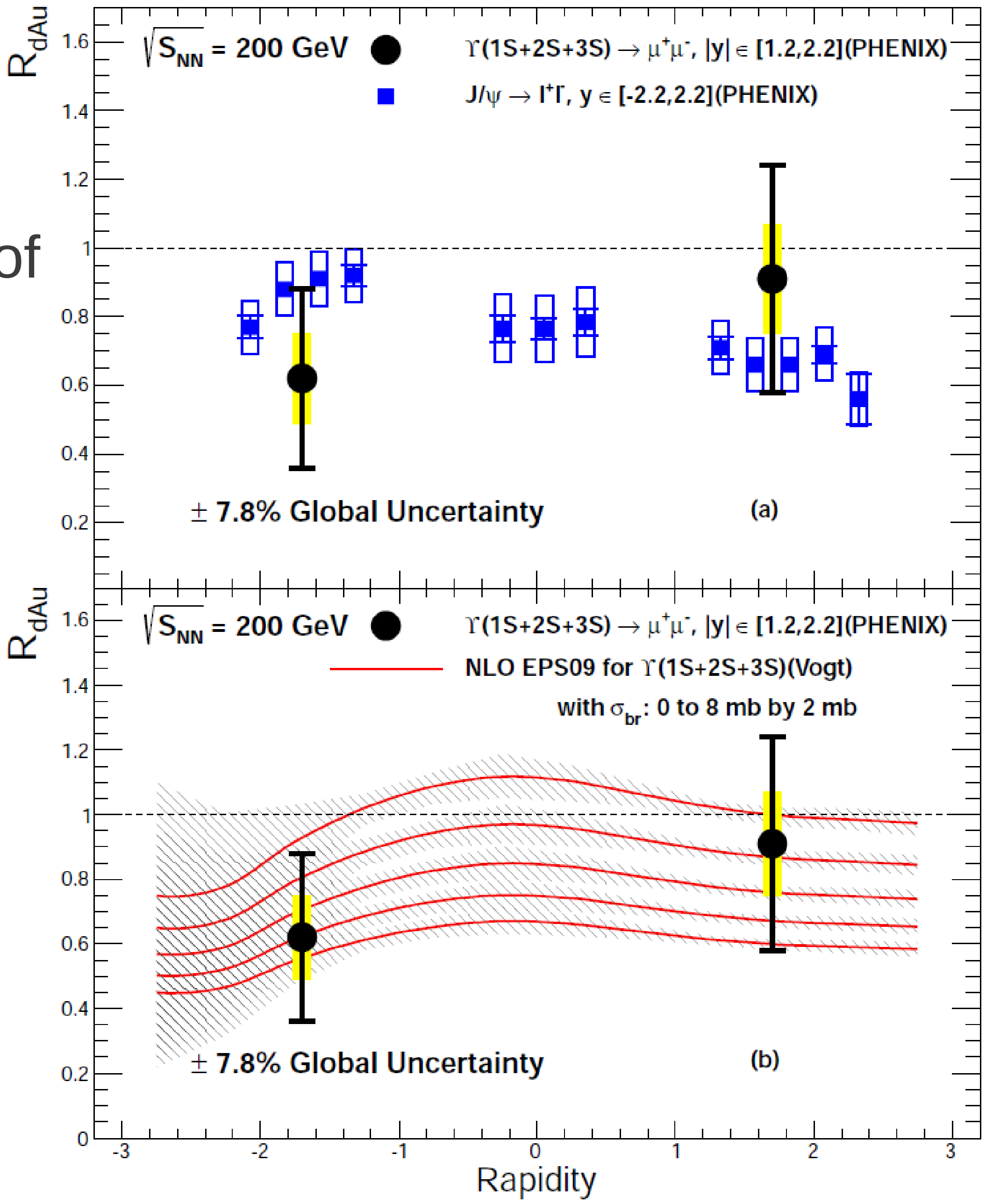
- Higher mass: higher average x (in Au nucleus) compared to J/ψ.



Upsilon

- No significant suppression of forward ϒ
  - larger backward suppression
- In reasonable agreement with NLO model expectations
- No significant constraint on the break-up cross-section
  - owing to statistical uncertainty

arXiv:1211.4017



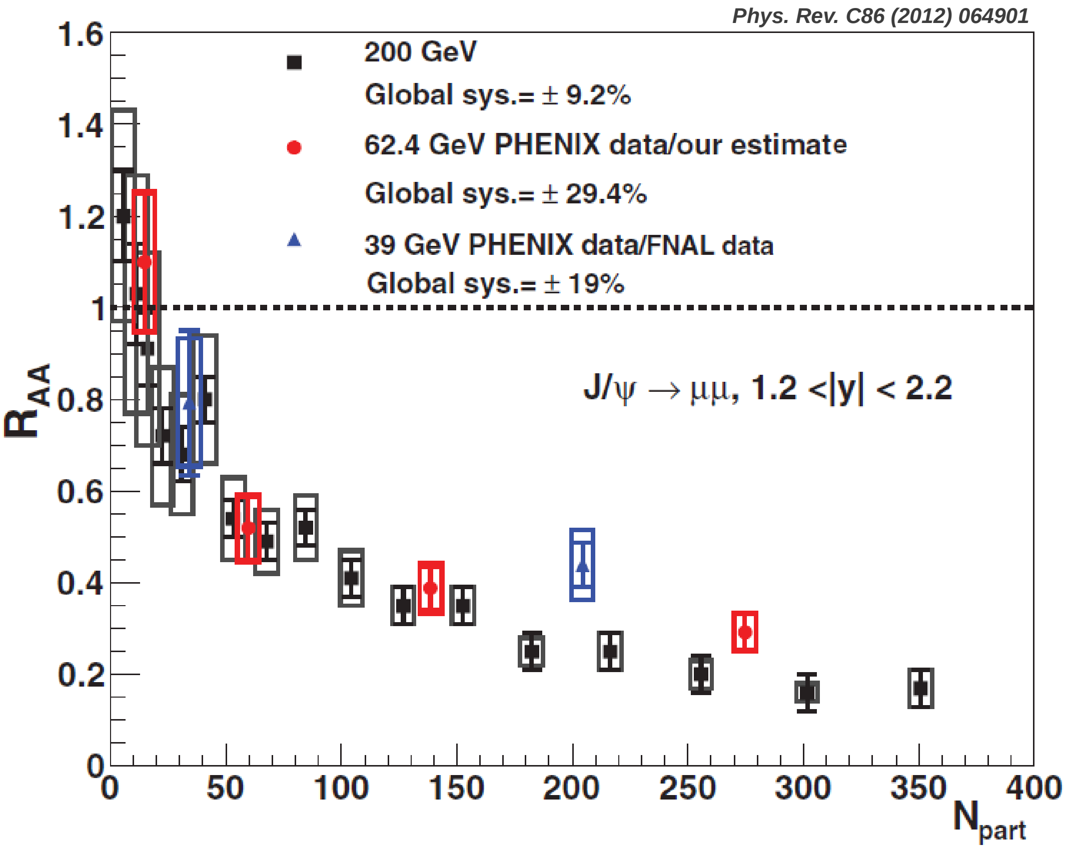
Initial state summary

- d+Au collisions impose significant modification of J/ψ and ψ'
  - Compared to p+p collisions
- Baseline for A+A collisions already modified before the creation of the hot-dense QGP matter

- Fresh look at A+A collisions
  - Energy Scan
  - Species Scan

Studies: Energy Scan

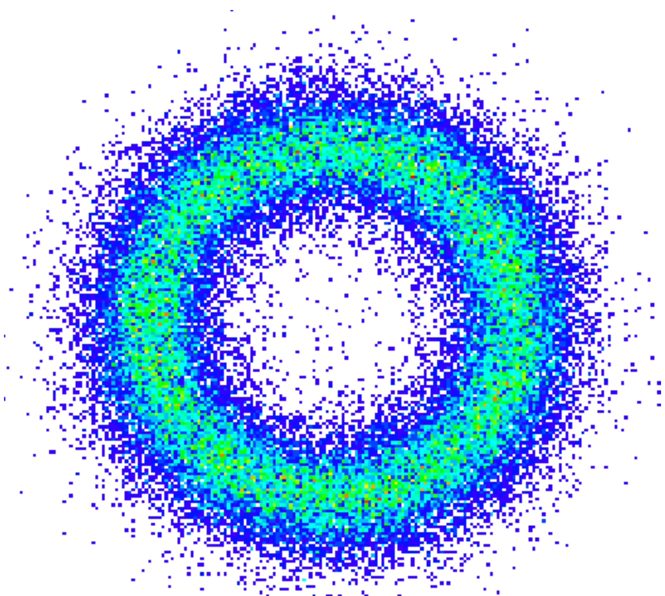
- Similar energy dependence
  - Energy-dependent role of CNM in AA collisions needs further investigation
- Cold nuclear matter effects at lower collision energies
  - Larger break-up cross-section
  - Sample higher x
- QGP effects
  - Energy loss
  - Regeneration



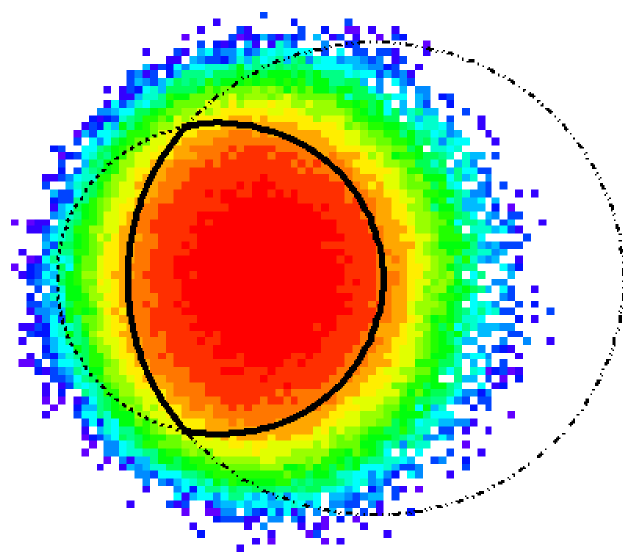
CuAu Collisions –
Exploiting the flexibility of RHIC

- Completely swallowed Cu-nucleus in central collisions
  - Cu-going corona vanishes
- Naturally odd harmonics
  - Possibility to investigate a “true v3”
- Large “corona” on Au-side
  - Investigation of it's size
  - “v_1-like” azimuthal dependence

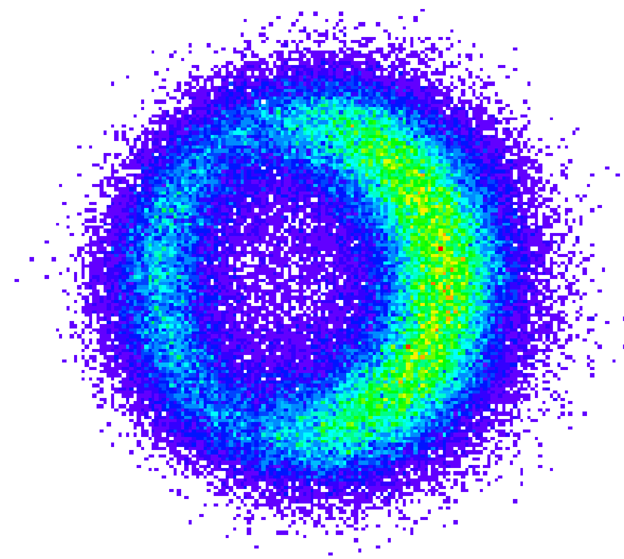
Glauber model CuAu



Spectators



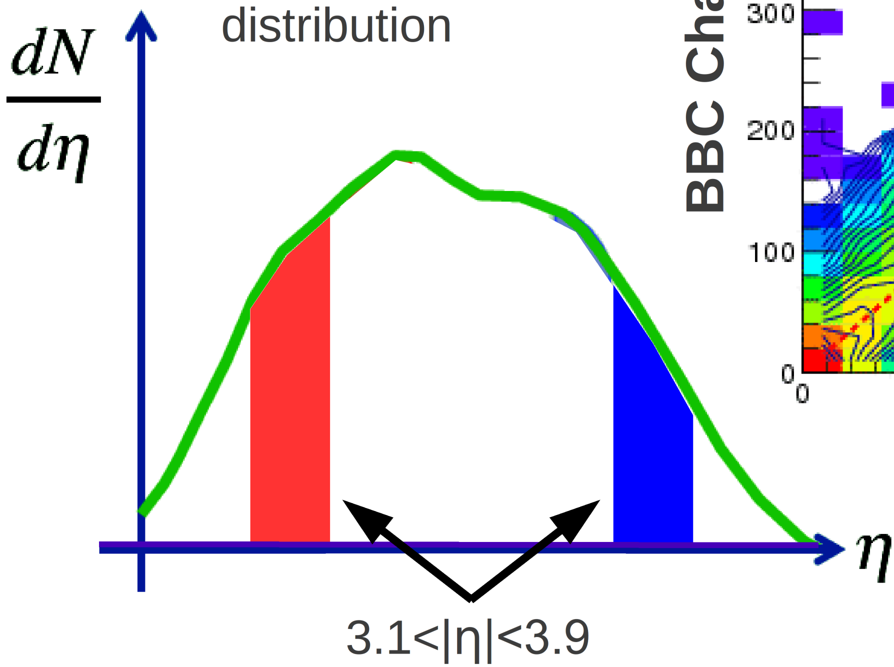
Participants

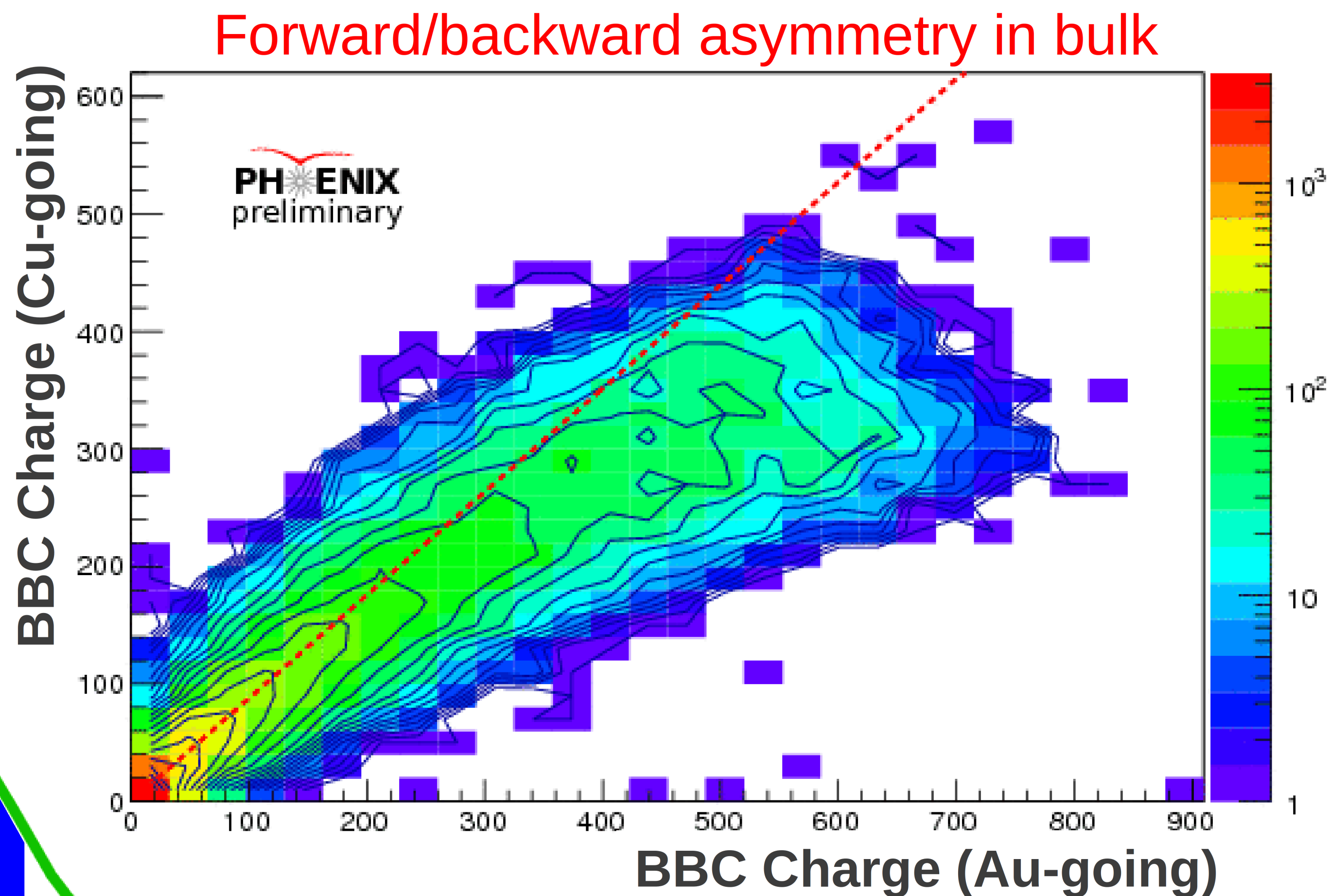


Corona

Energy density asymmetry

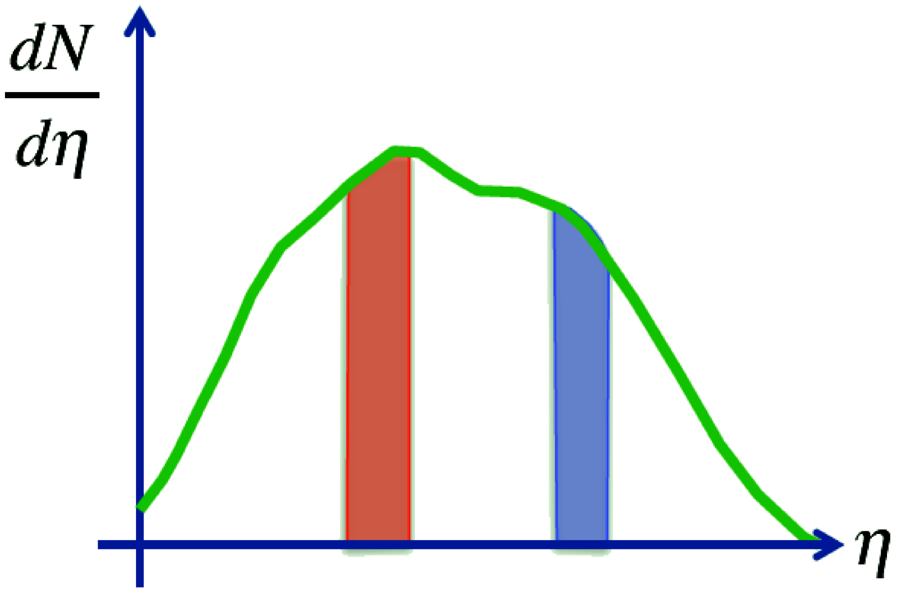
- Expect an asymmetric dN/dη
  - Measured in the Beam-Beam Counters (BBC) charge distribution

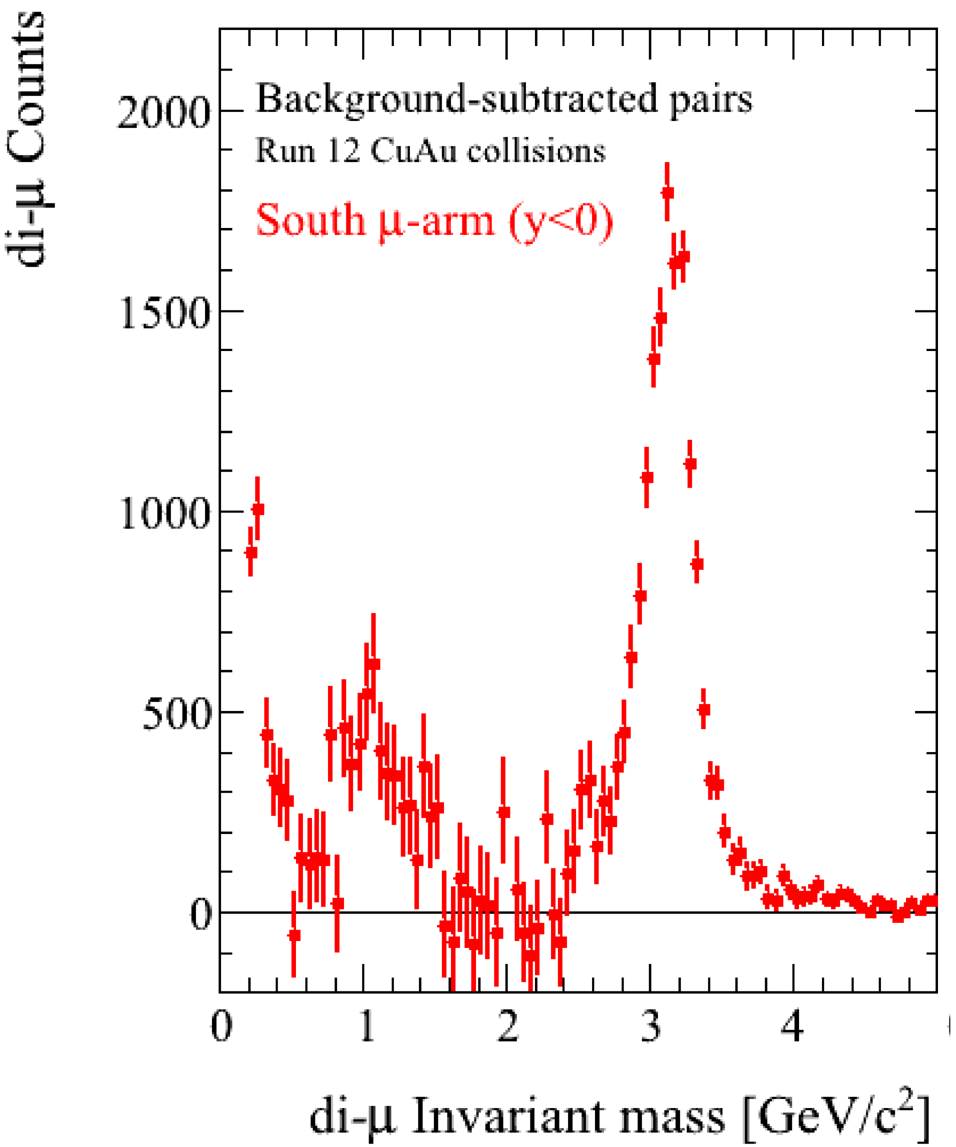




J/ψ measurement: forward rapidity

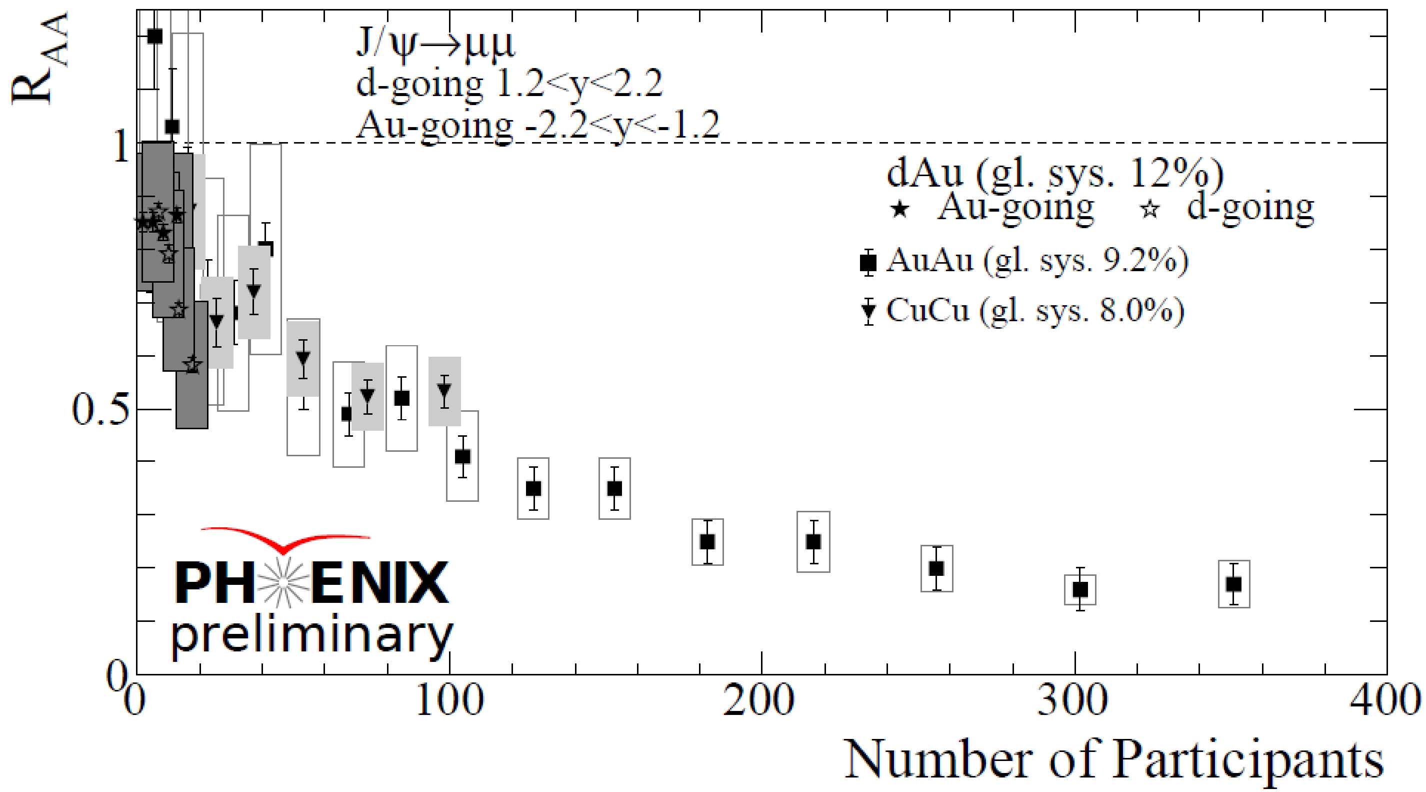
- Measure J/ψ
  - Forward, $y>0$, (Cu(d)-going)
    - Low-x parton in Au-nucleus
  - Backward, $y<0$, (Au-going)
    - Low-x parton in Cu-nucleus





Nuclear Modification Factor

- Comparison between particle yields in AA to pp (scaled by the expected number of collisions)
- CuCu and AuAu
  - CNM and final-state effects
  - Suppression observed
  - Independent of collision system



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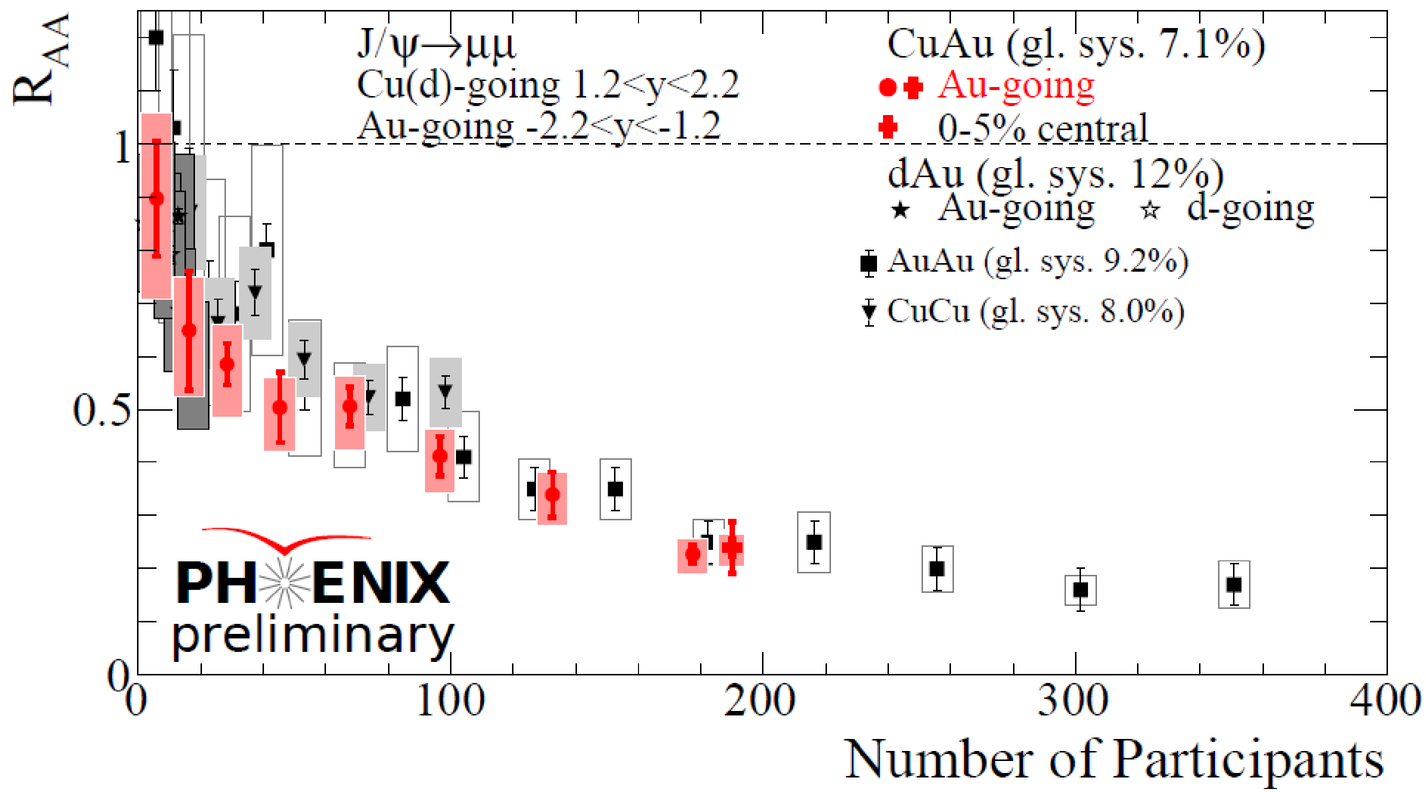

- CuAu collisions
  - Same suppression as AuAu/CuCu measured in the Au-going direction

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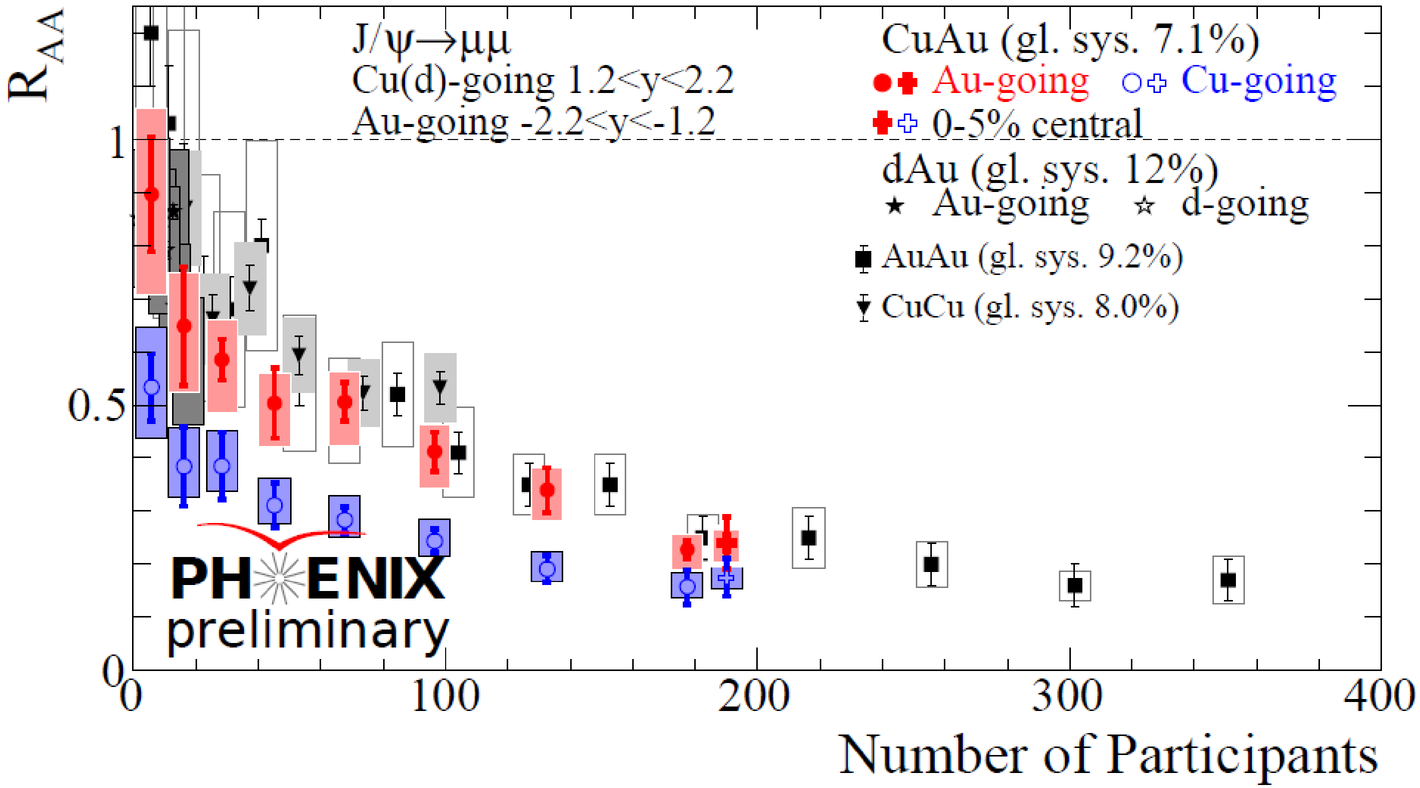
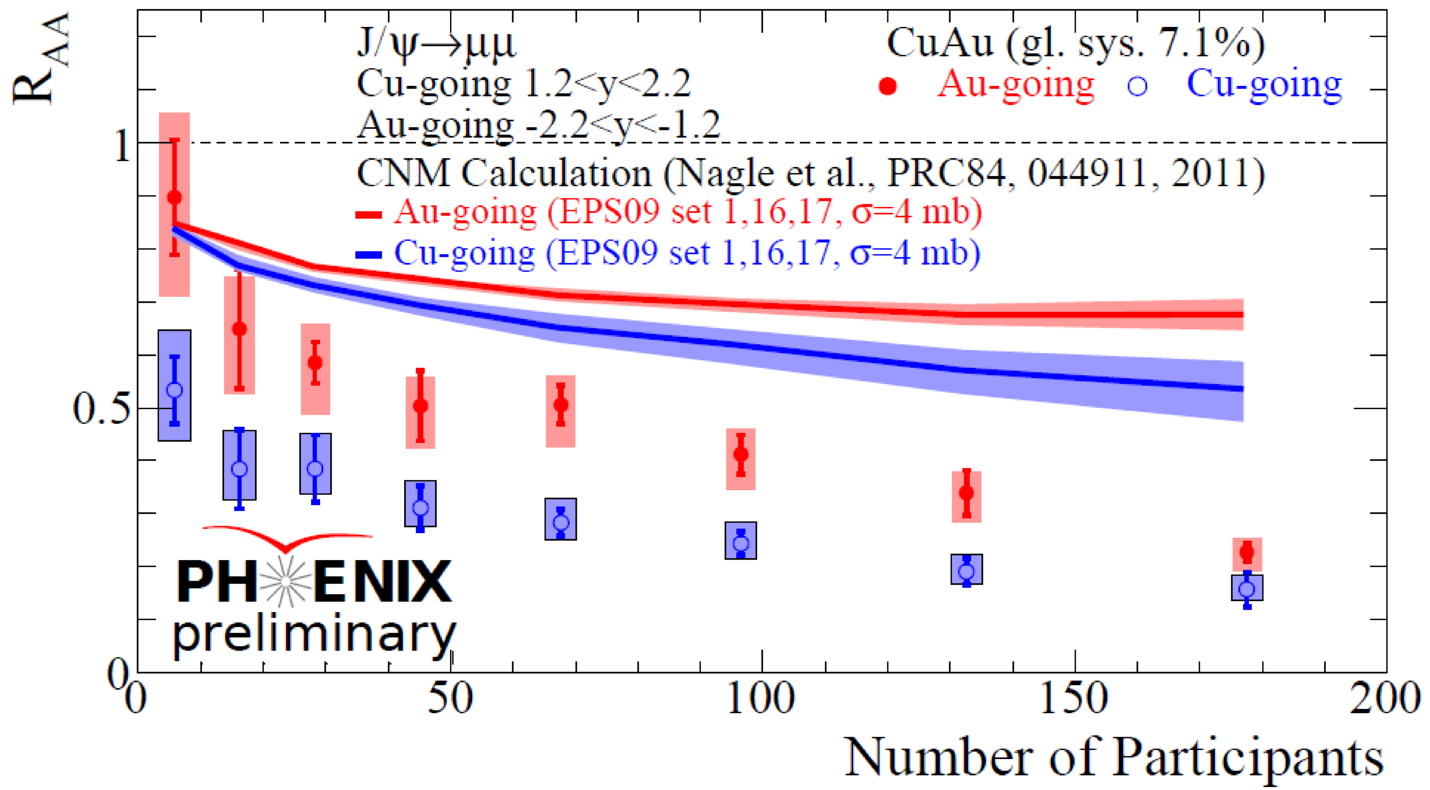


- CuAu collisions
  - Same suppression as AuAu/CuCu measured in the Au-going direction
  - More suppressed in the Cu-going direction
  - J/ψ not significantly more suppressed in completely swallowed-Cu (top 5%) events

Nuclear Modification Factor

- CNM effects (estimated from same model as earlier)
  - Can partially explain forward / backward difference
  - Final state effects must account for additional suppression

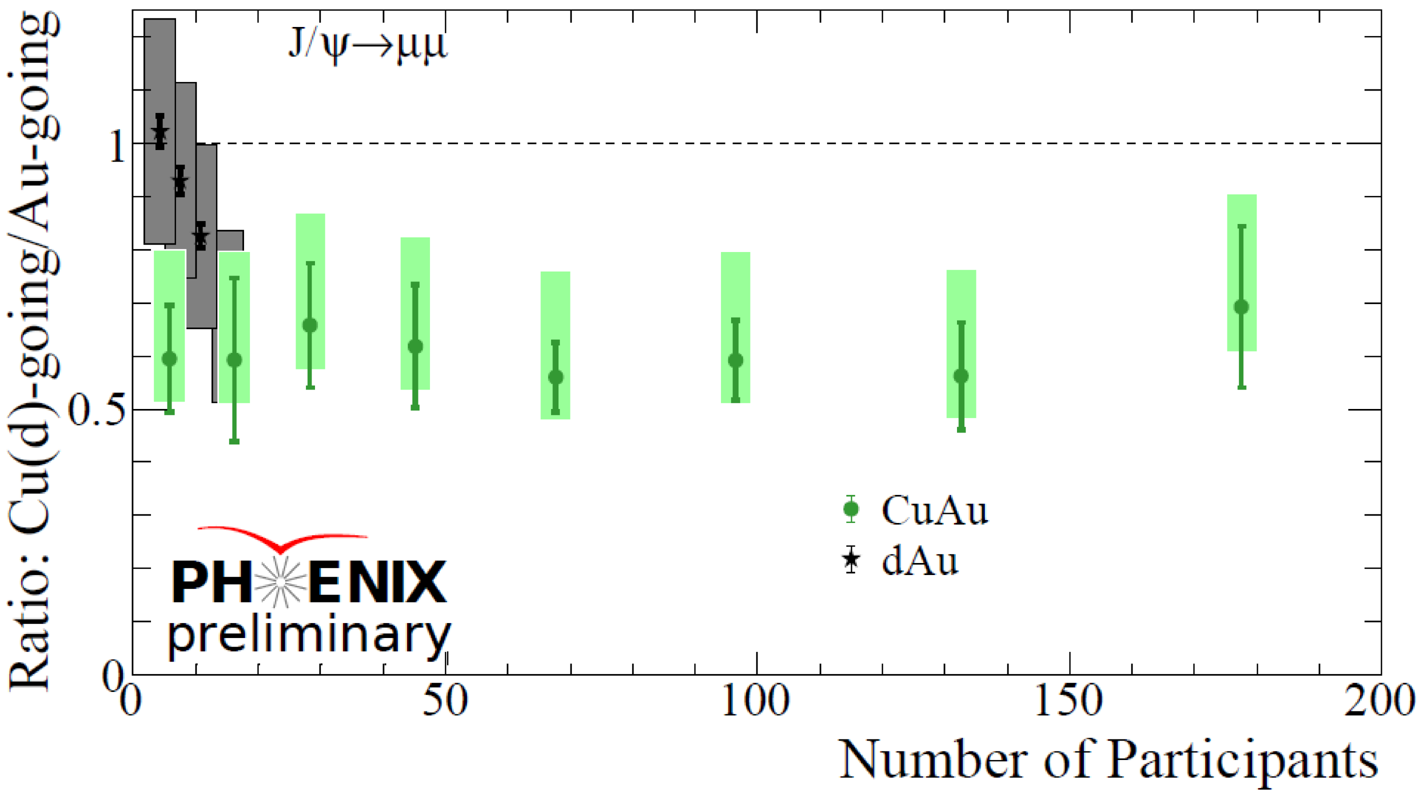
- Similar CNM observations in AuAu collisions



- Model:
  - 4mb break-up cross-section
    - Best describes dAu data
  - Center line → best EPS09 fit
    - Band limits → outer limit of EPS09 nPDFs
  - Linear thickness dependence on shadowing
    - No centrality dependence

Relative suppression

- Ratios of yields at fixed centrality
- Relative suppression observed forward/backward
- Centrality-independent



Presents a challenge to theories trying to describe the data

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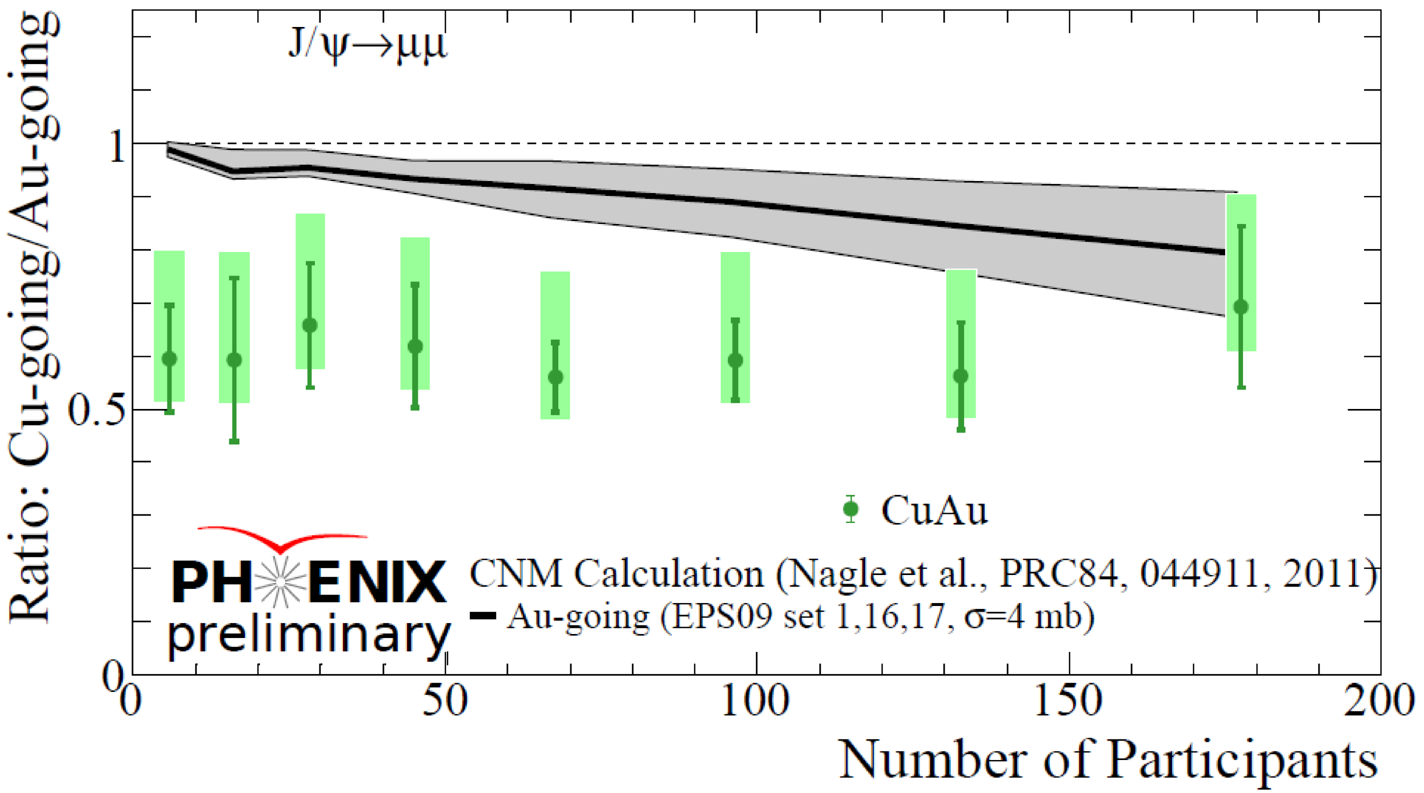
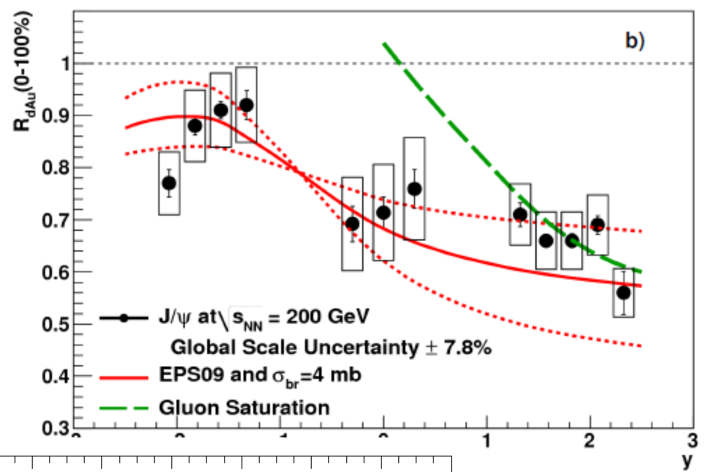
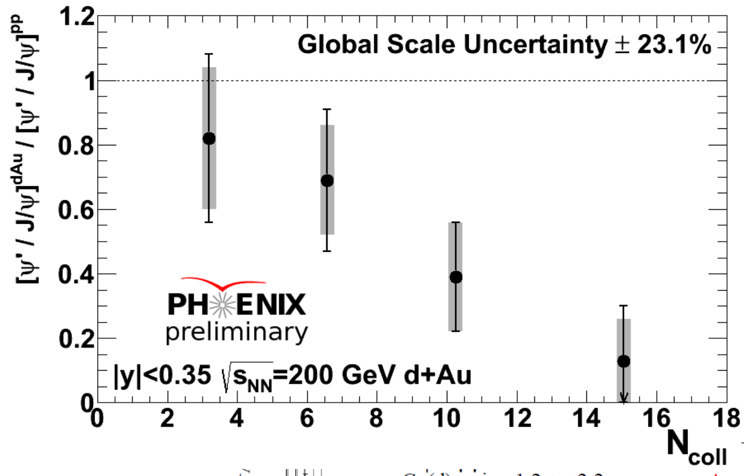


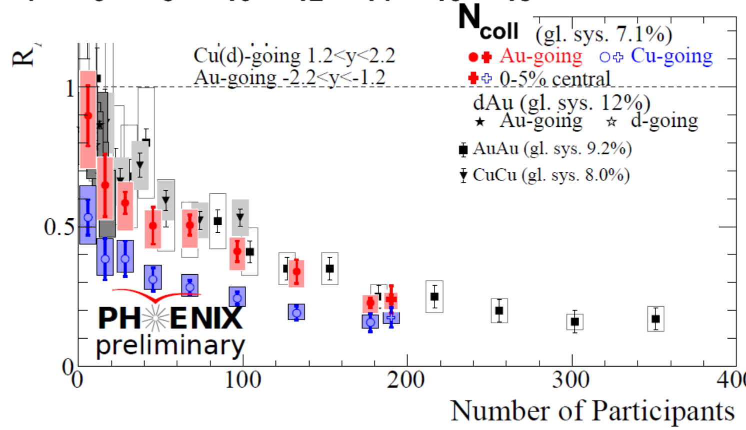
Presents a challenge to theories trying to describe the data

Summary

- AA collisions are a complex admixture of cold nuclear matter and hot nuclear matter effects
  - Understanding CNM effects are crucial
- Studied the effect of cold nuclear matter in d+Au collisions
  - Rapidity and centrality dependent production
  - Particle species dependence
- Cu+Au collisions yield new insights into J/ψ production
  - Stronger suppression at forward rapidities







CuAu Collisions –
Exploiting the flexibility of RHIC

- Why interesting?
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    - Possibility to investigate a “true v3”
  - Large “corona” on Au-side
    - Giving rise to more detailed investigation of it's size
    - “v_1-like” azimuthal dependence
  - Completely swallowed Cu-nucleus in central collisions
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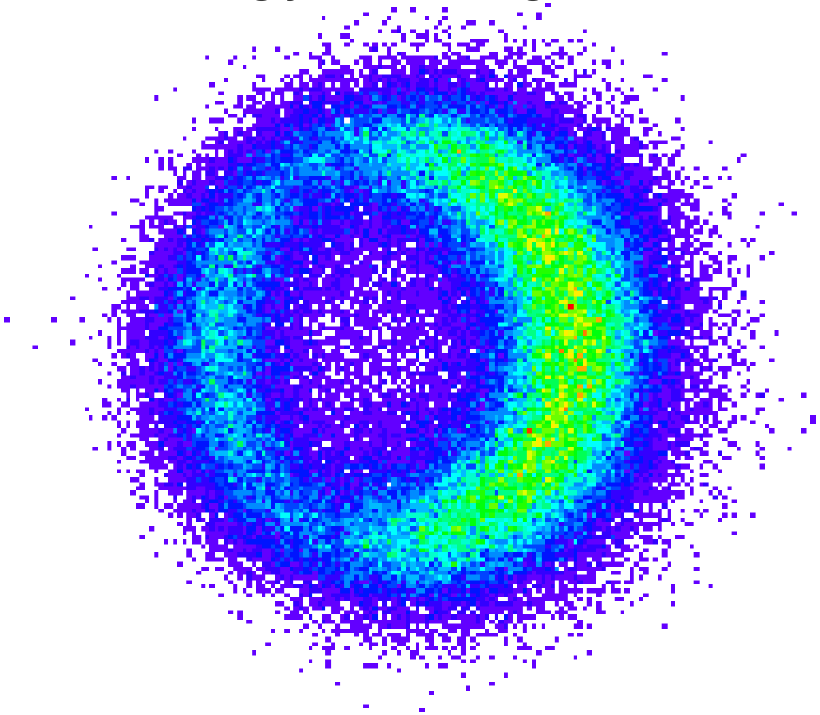
Singly-interacting nucleons



Glauber model CuAu, b=4fm

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Spectator nucleons

Glauber model CuAu, b=0fm

V_n

- Measure particle production relative to ***Au-spectator*** plane
  - Representative of the true reaction-plane

- In data → use the shower-max in the ZDCs (neutron reaction-plane)
  - Hadrons at mid-rapidity exhibit large v_2 ***and*** v_1 (not observed in AuAu)
  - Not consistent with a large v_3.