Nuclear modification of hard scattering processes in small systems at PHENIX

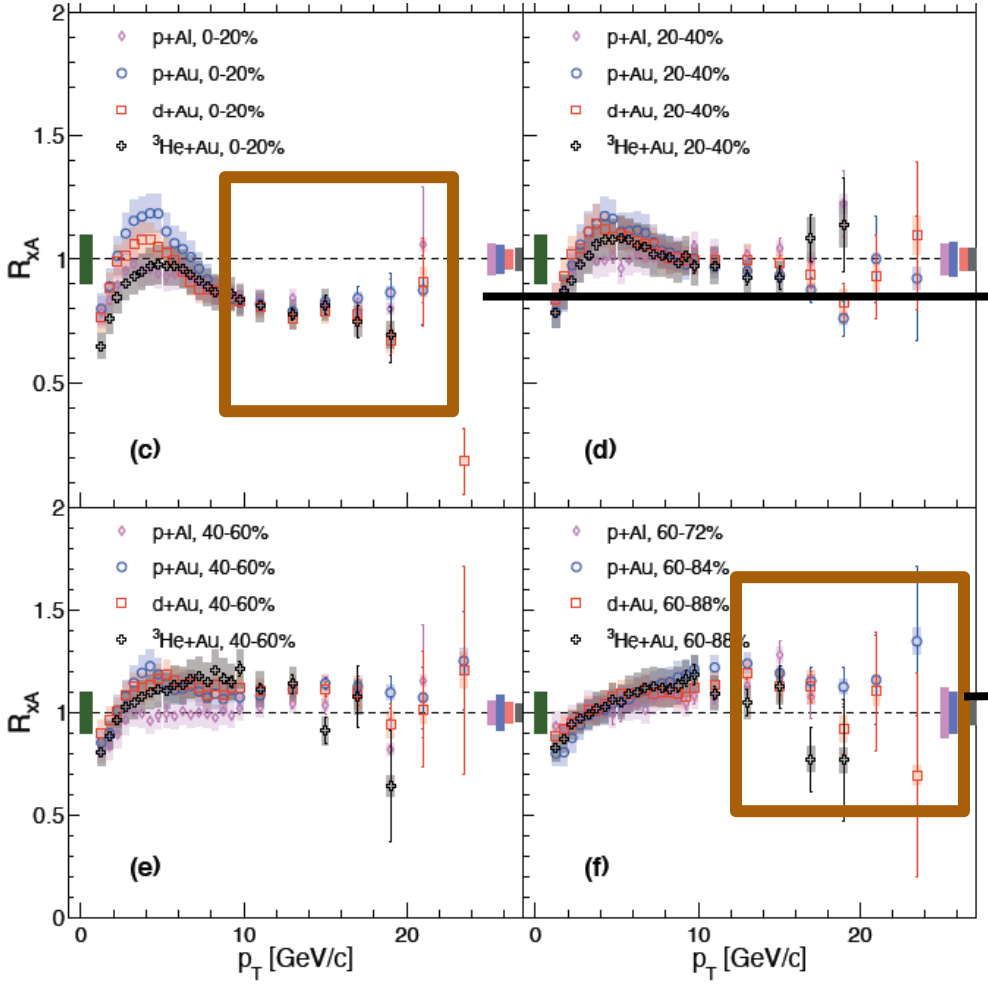
NIVEDITHA RAM

07/04/2022

QUARK MATTER 2022

What to expect in this talk

Using direct photons at high p_T to measure the number of binary collisions (N_{coll}) in a system



Observed supression in central collisions remains even after correcting for bias in N_{coll} determination

Observed enhancement in peripheral collisions is an artifact of bias in the N_{coll} determination using Glauber model for small systems

arXiv:2111.05756

Definition

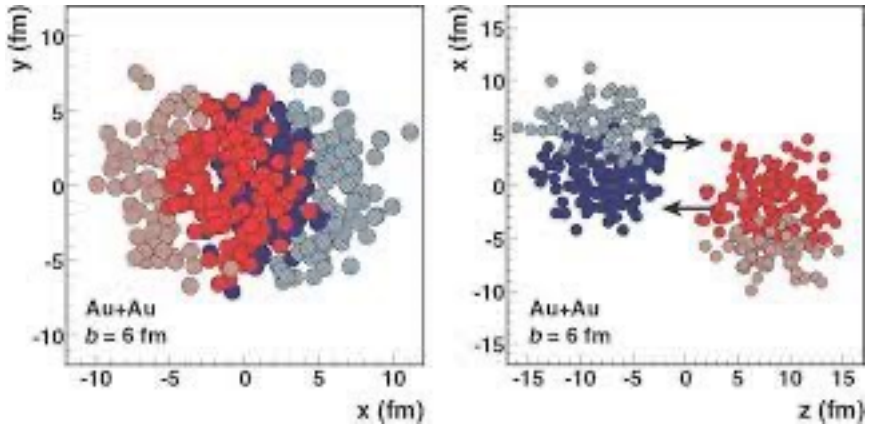
Nuclear Modification Factor

$$R_{AB}(p_T) = \frac{\left(\frac{d^2N}{dp_T d\eta}\right)_{AB}}{\langle N_{coll}\rangle_{AB} * \left(\frac{d^2N}{dp_T d\eta}\right)_{pp}} = \frac{Y(AB)}{\langle N_{coll}\rangle_{AB} * Y(pp)}$$

d+Au

p+p

How is heavy ion collision different from a scaled p+p collision



?

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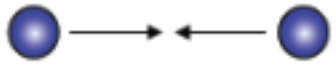
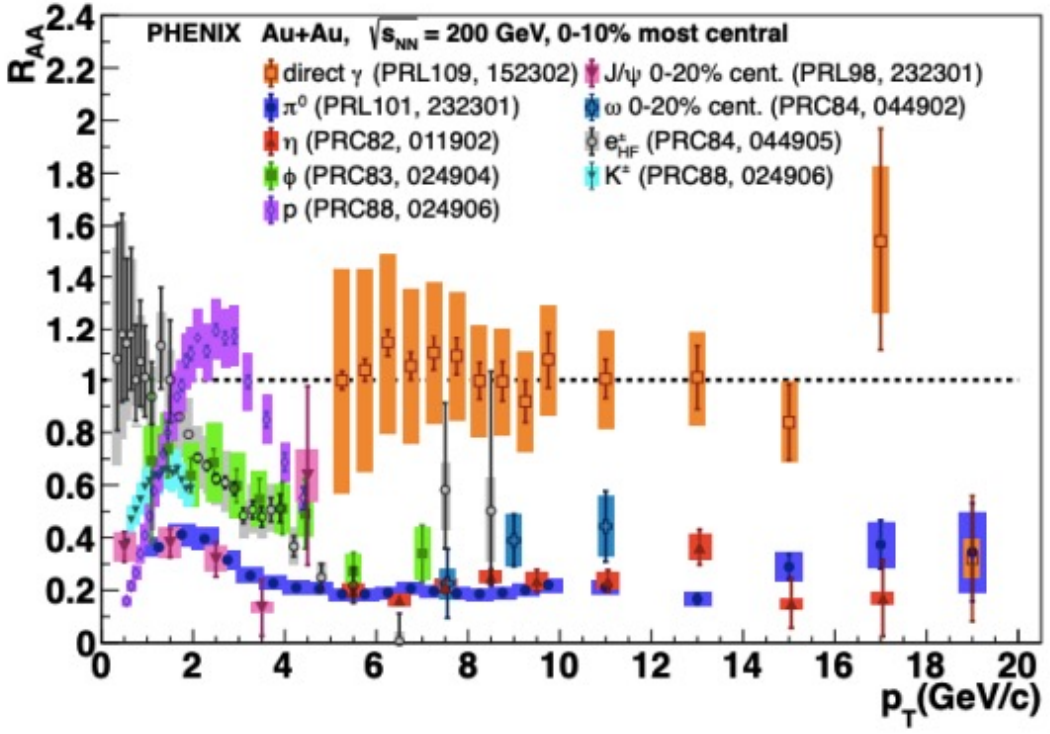


$R_{AB}(p_T) < 1$ is a signature of QGP

1) $\pi^0, \eta, \phi, J/\psi, \omega$ interact with the QGP ➔ $R_{AB}(p_T)$ is suppressed

2) Direct photon is transparent to the QGP ➔ $R_{AB}(p_T)$ is unity



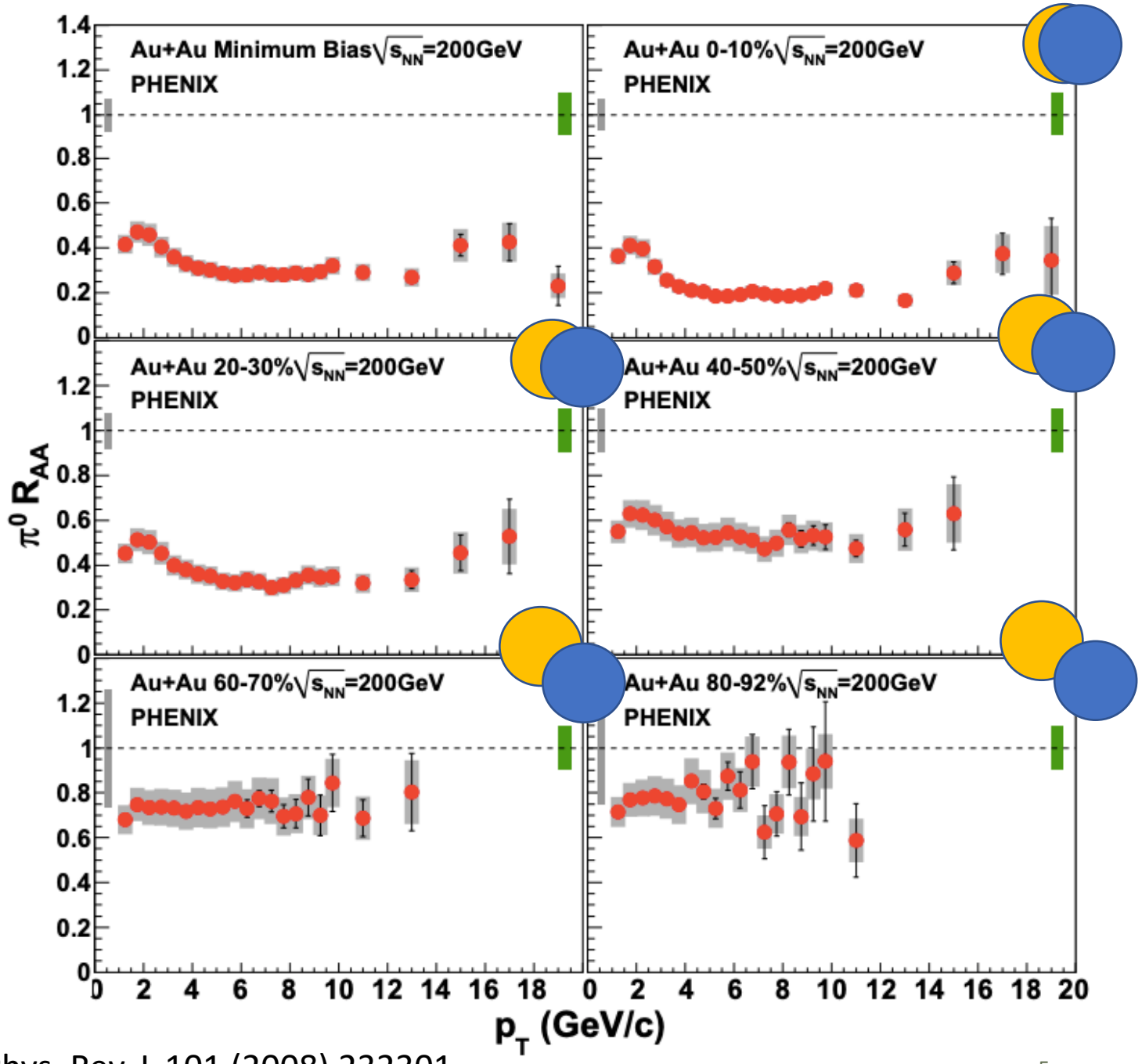
Centrality binned R_{AA} of π^0

in Au+Au collisions

- Most central collisions show the most suppression.

- Vanishing suppression at peripheral collisions

- Intuitive trend in centrality for a system with QGP creation



Phys. Rev. L 101 (2008) 232301

Centrality binned R_{AA} of direct γ

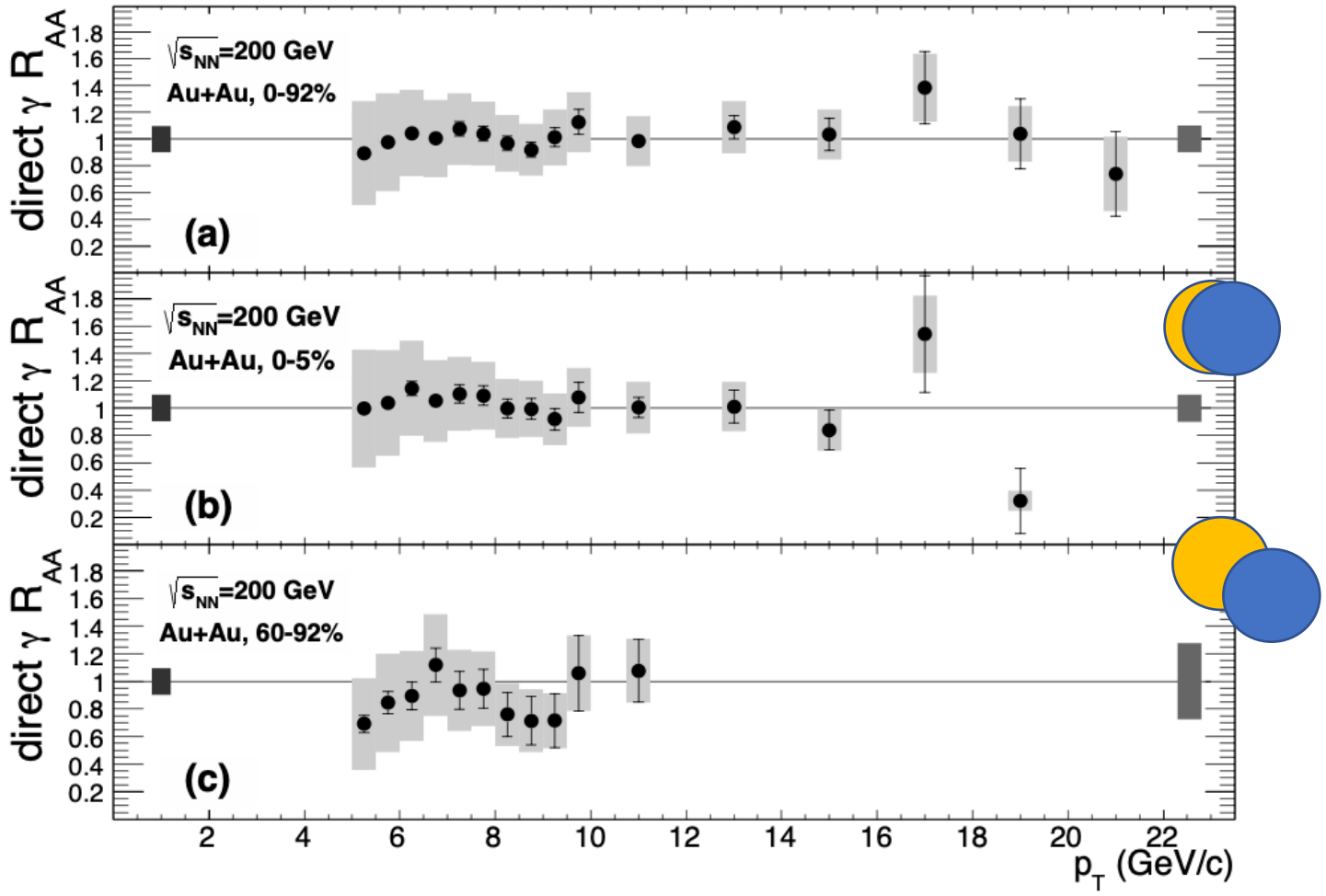
in Au+Au collisions

- Unity at all centralities.

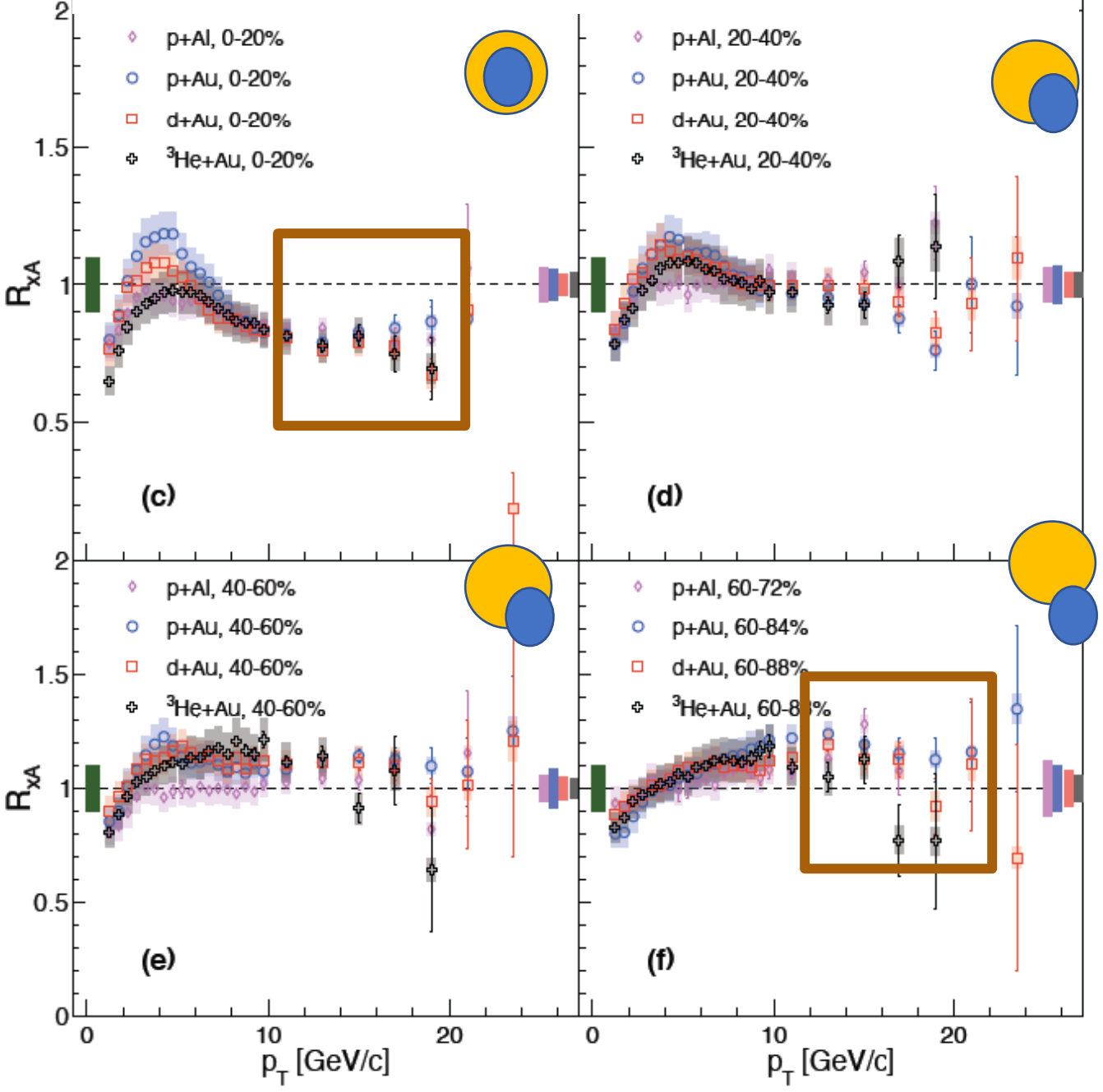
- Direct photons are transparent to QGP

- Using high p_T direct photons, we obtain :

$$N_{coll}^{exp} = \frac{Yield_{AA}^{\gamma}}{Yield_{pp}^{\gamma}}$$



Phys. Rev. L 109 (2012) 152302



Puzzling behavior of R_{AA} in small systems

- Supression in central collisions ➔ Formation of QGP droplets?
- Enhancement in peripheral collisions?

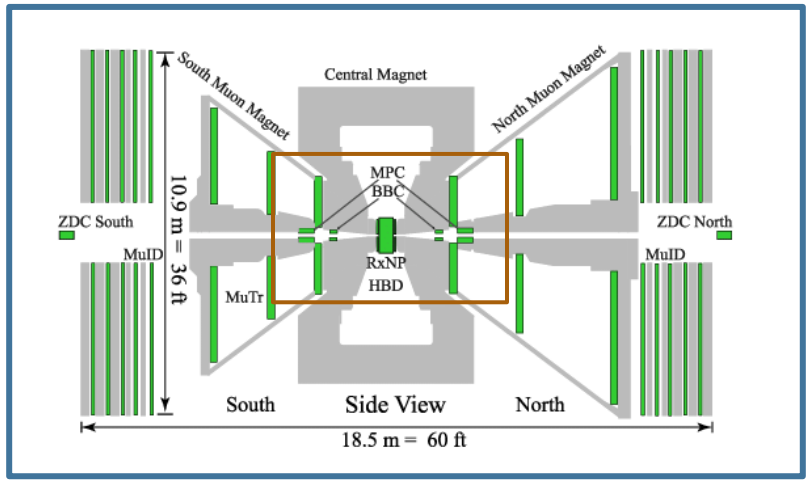
Is the determination of N_{coll} in different event classes biased

arXiv:2111.05756

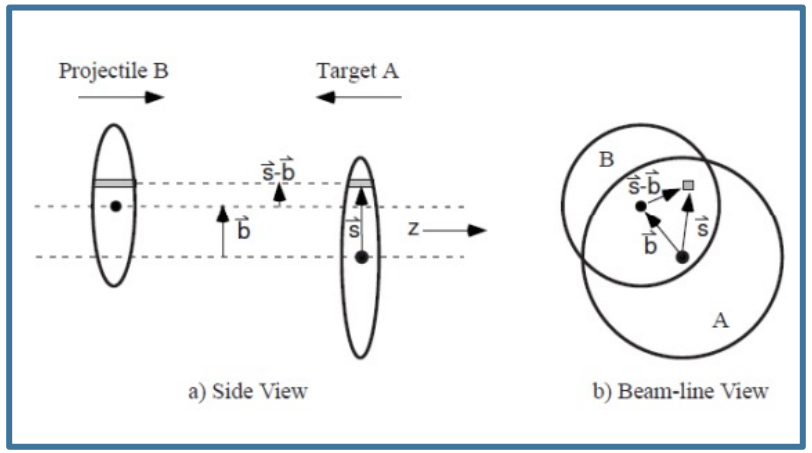
Measurement of average number of binary collisions from bulk observables

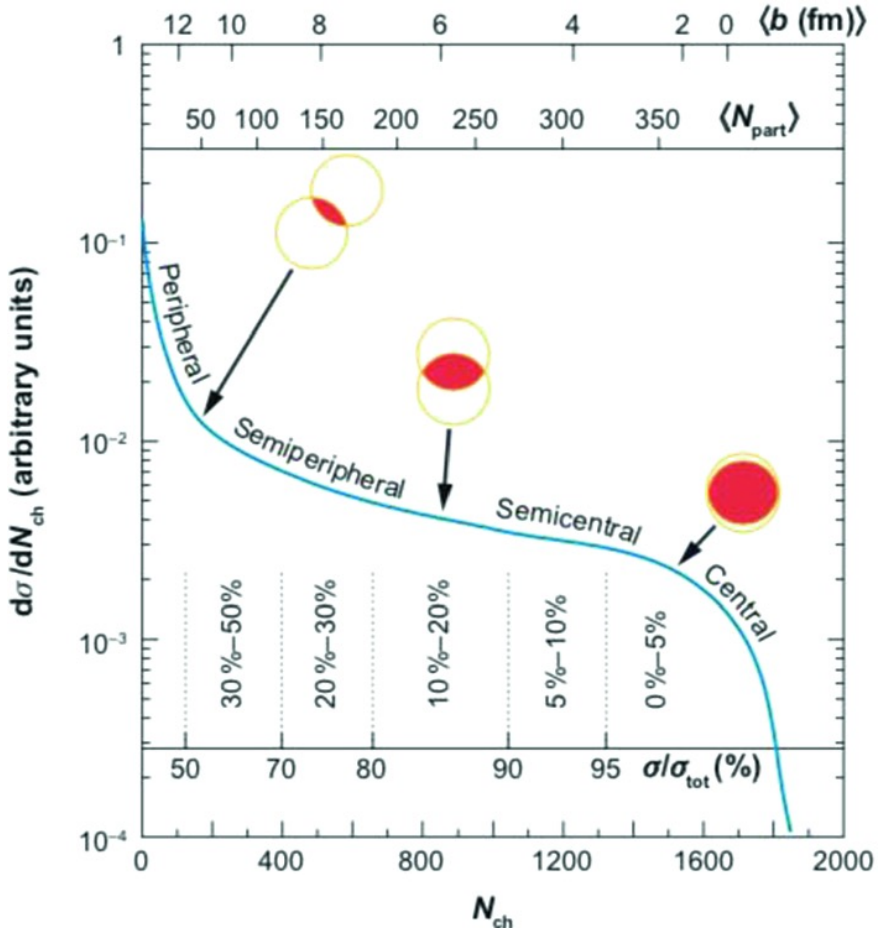
$$\frac{Y(AB)}{\langle N_{coll}\rangle_{AB} * Y(pp)}$$

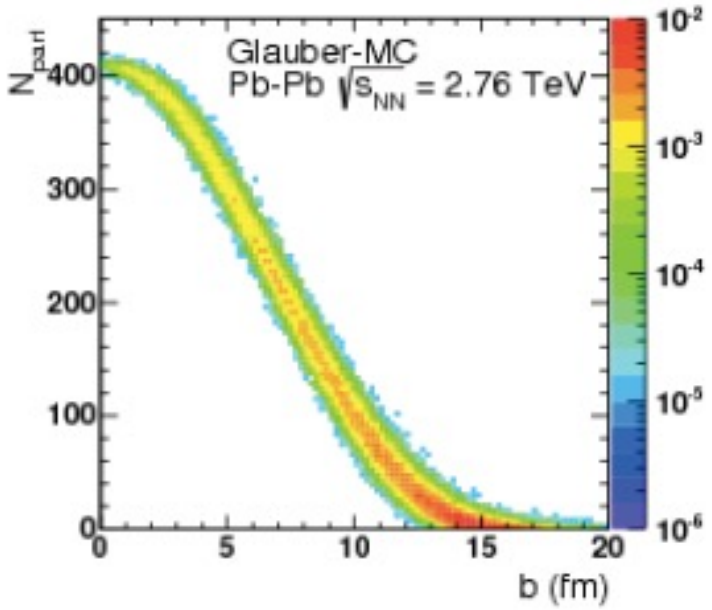
Number of charged particle from BBC $3.1<|\eta|<4$

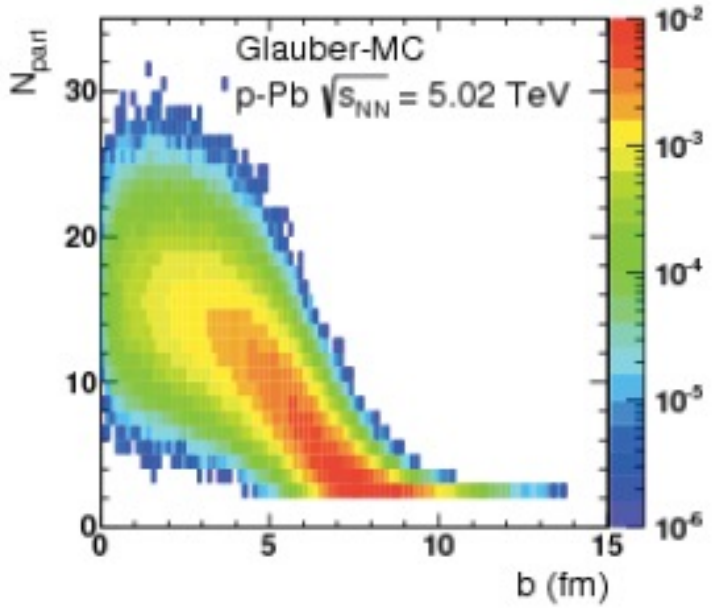


Standard Glauber model gives mapping of charged particle in forward region to number of binary collisions of the event.









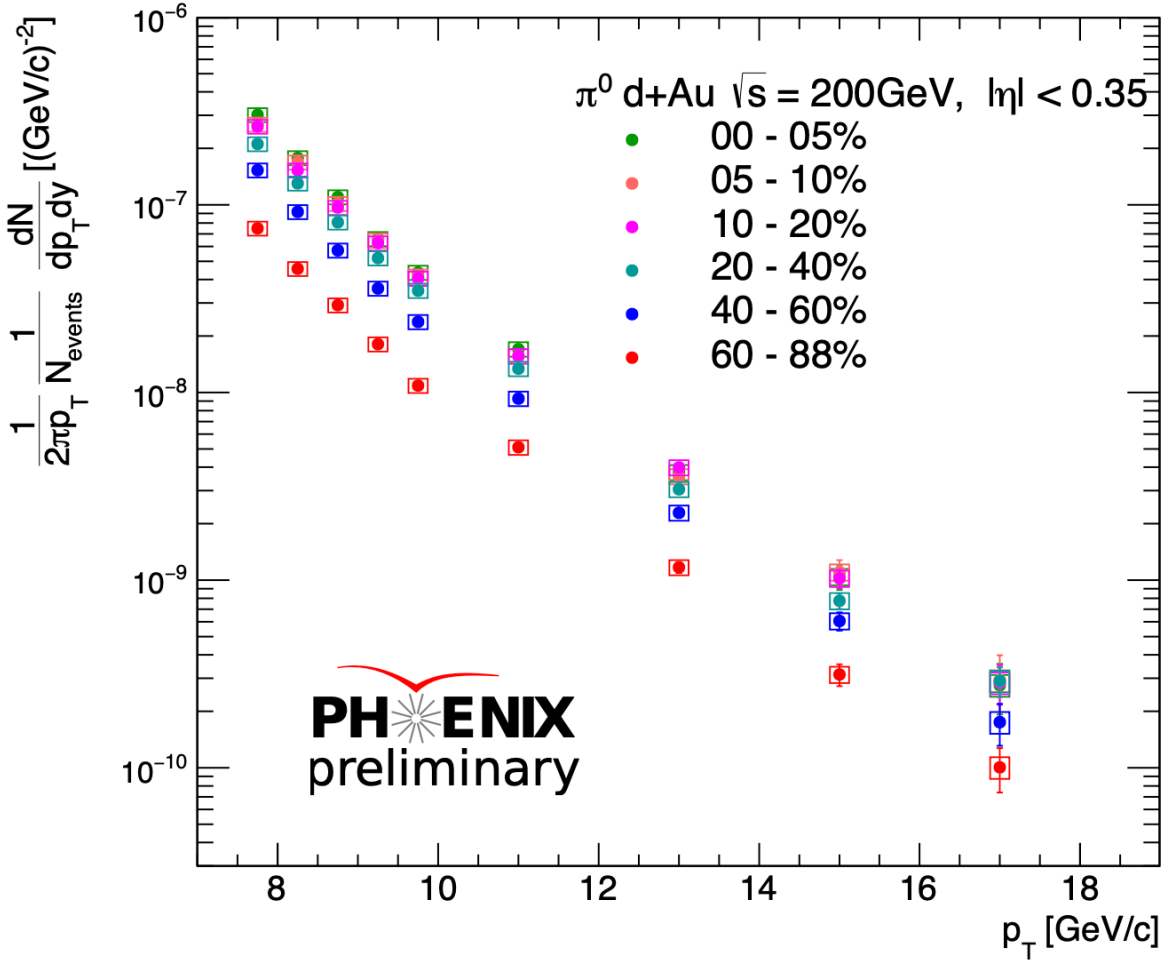
Is Glauber model valid for small systems?

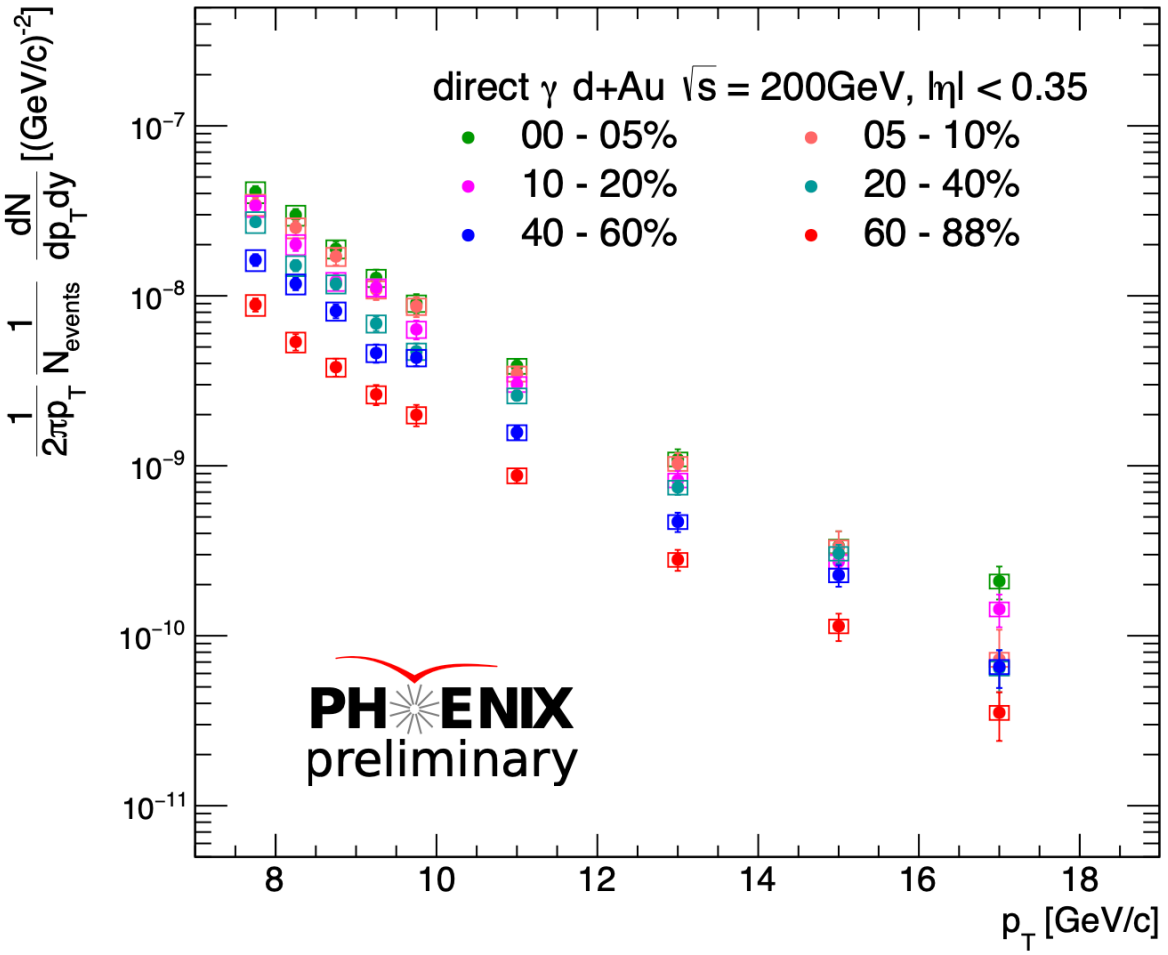
- 0-20% in Pb+Pb : average impact parameter of 3 fm with a very small variance.
- 0-20% in p+Pb : average impact parameter of 3 fm but with a large variance.
- **Cannot draw equivalent physics conclusions about central p+Pb and Pb+Pb events**.

In addition to this, there are additional biases and differences which will be discussed next.

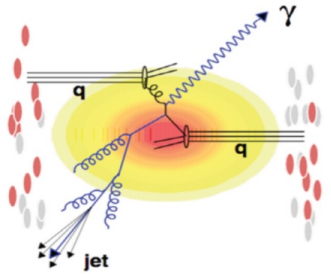
PR C 91, 064905 (2015)

How do we study the centrality bias in experiments?





Invariant yield of π^0 and direct γ



No dependence on centrality

Dependence on centrality

Invariant yield of direct **γ**

Dependence on centrality

NO dependence on centrality

Dependence on centrality

Dependence on centrality

Invariant yield of π^0

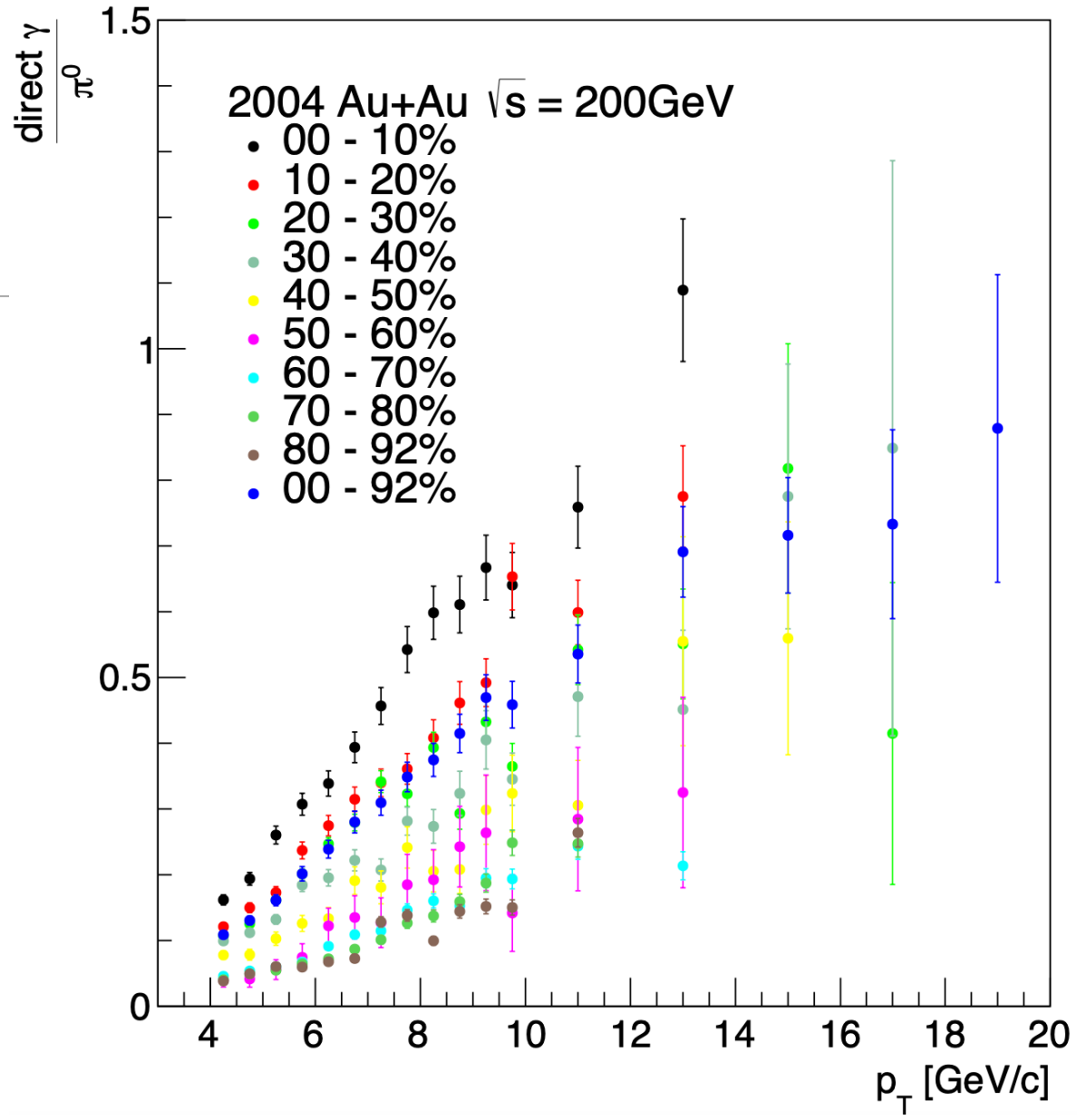
Hypothesis #1 : The centrality dependence of π^0 is from final state effect

Hypothesis #2 : The centrality dependence of π^0 is from bias in determination of N_{coll} in different centralities

Au+Au

Ratio of direct $\boldsymbol{\gamma}$ over π^0

Clear centrality dependence



✔ Hypothesis #1 :

The centrality dependence of π^0 is from final state effect

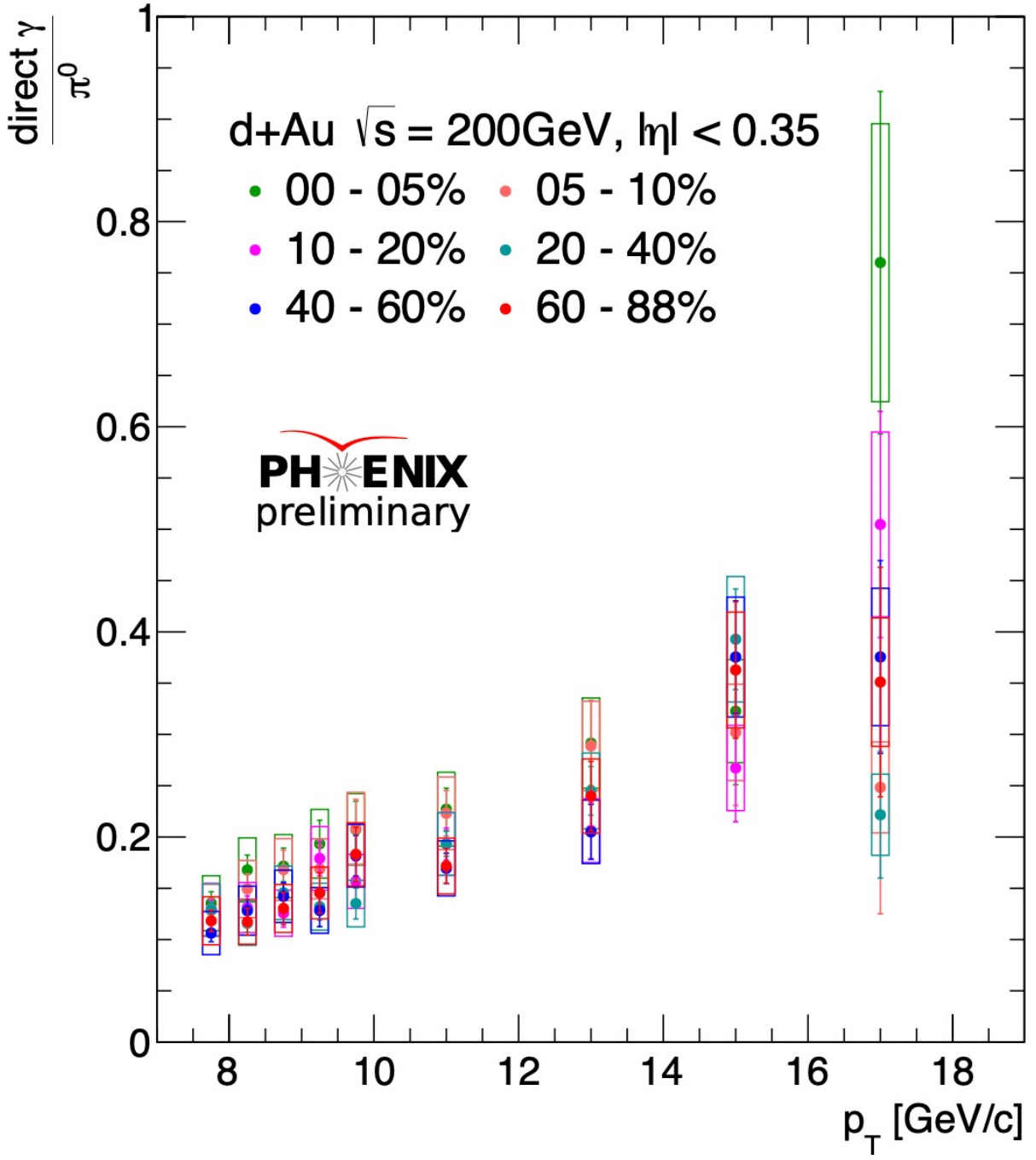
d+Au

Ratio of direct γ over π^0

to first order, NO clear centrality dependence

Hypothesis #2 :

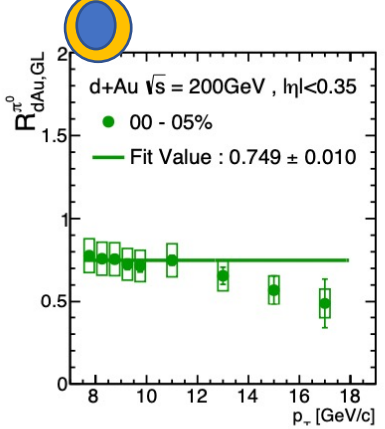
The centrality dependence of π^0 is from bias in determination of N_{coll} in different centralities

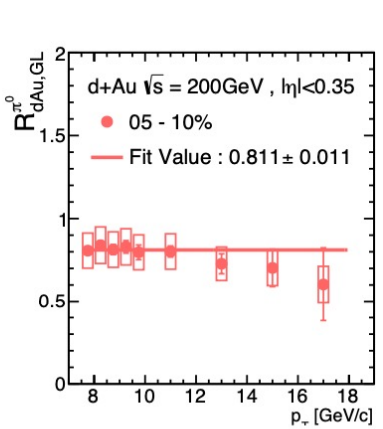


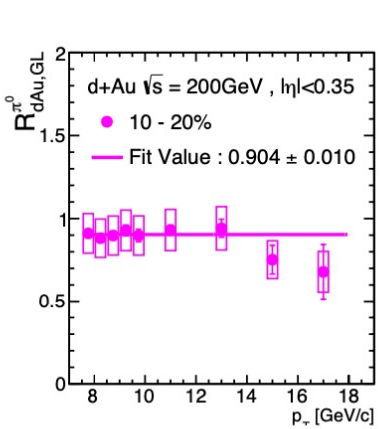
Nuclear Modification Factor of π^0 s

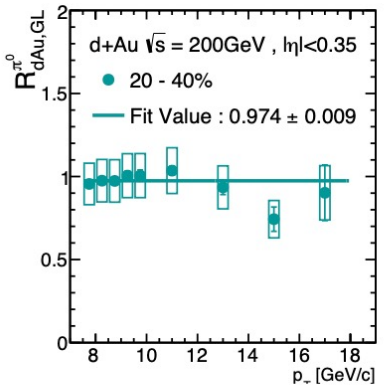
$$R_{AB,GL}(p_T) = \frac{(\frac{d^2N}{dp_T d\eta})_{AB}}{\langle N_{coll}^{GL}\rangle_{AB} * (\frac{d^2N}{dp_T d\eta})_{pp}} = \frac{Y(AB)}{\langle N_{coll}^{GL}\rangle_{AB} * Y(pp)}$$

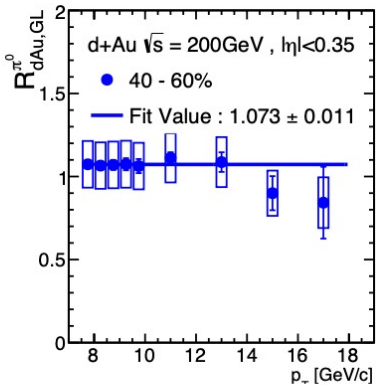
- There is a centrality dependence of π^0
- The most central events are suppressed (<1) and peripheral events are enhanced (>1)
- In the given p_T range, to first order R_{dAu} appears to be flat.

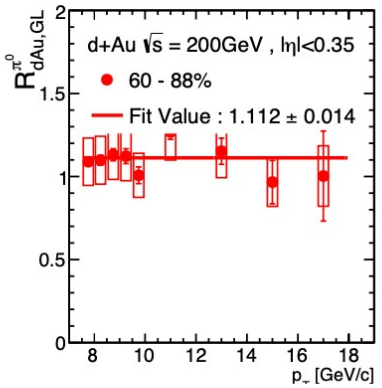


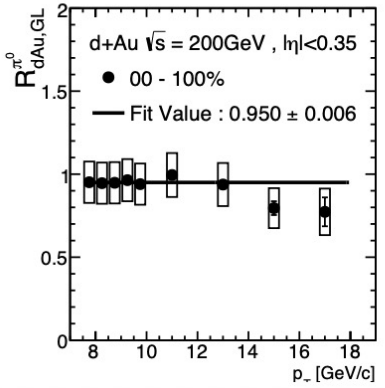










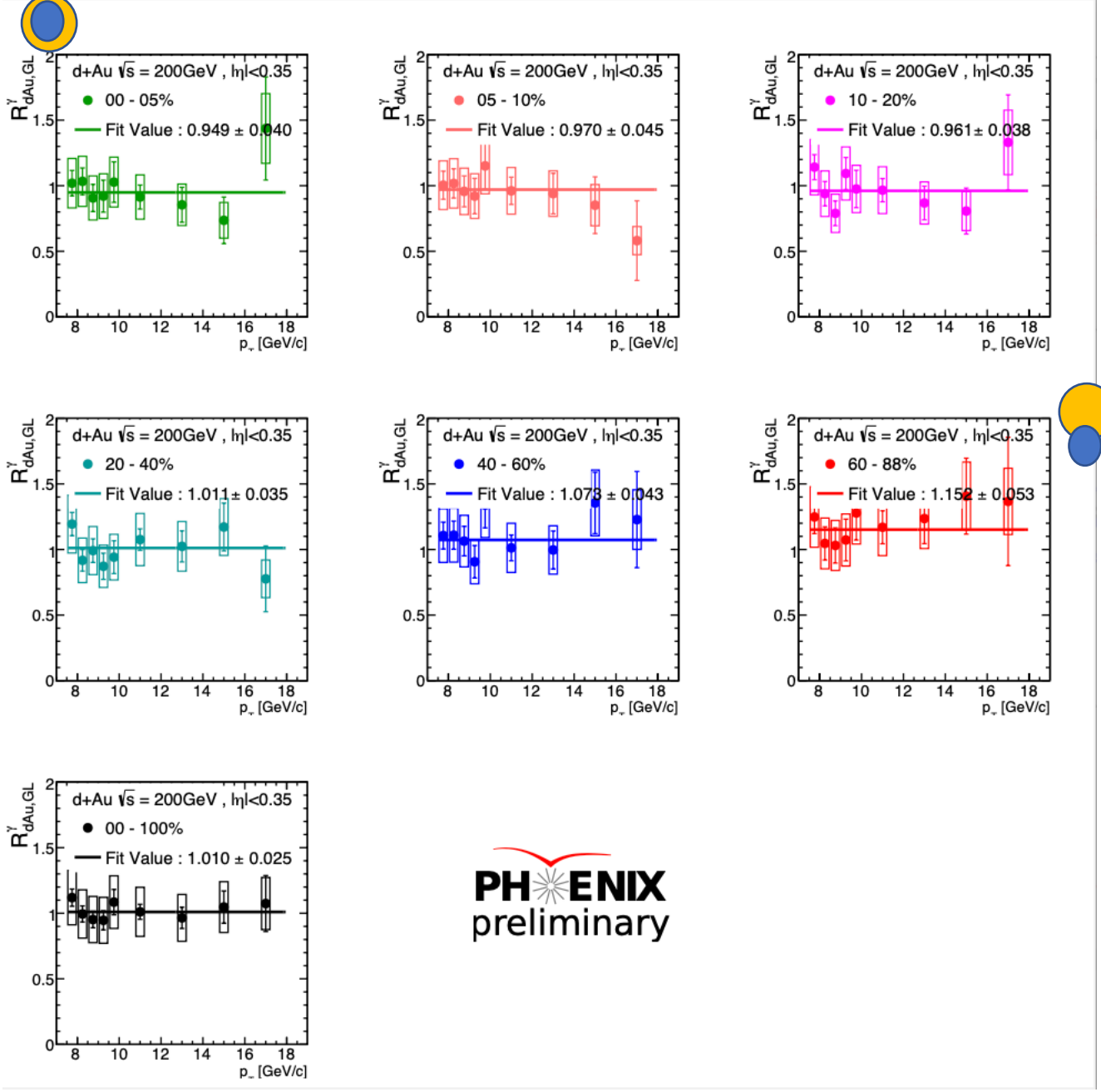


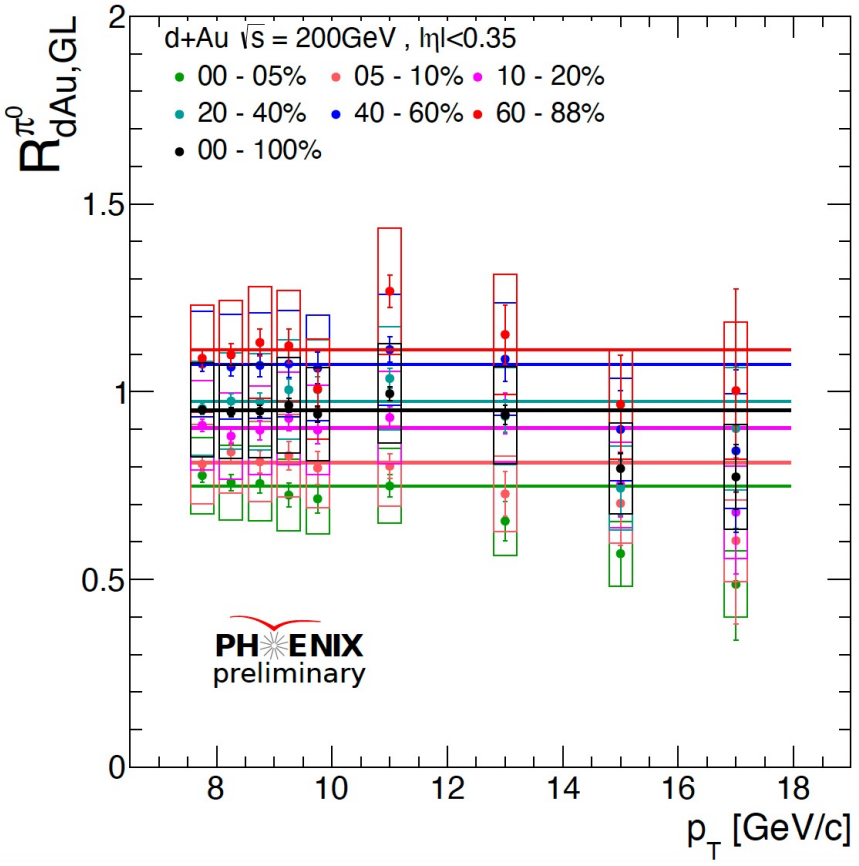
PHENIX
preliminary

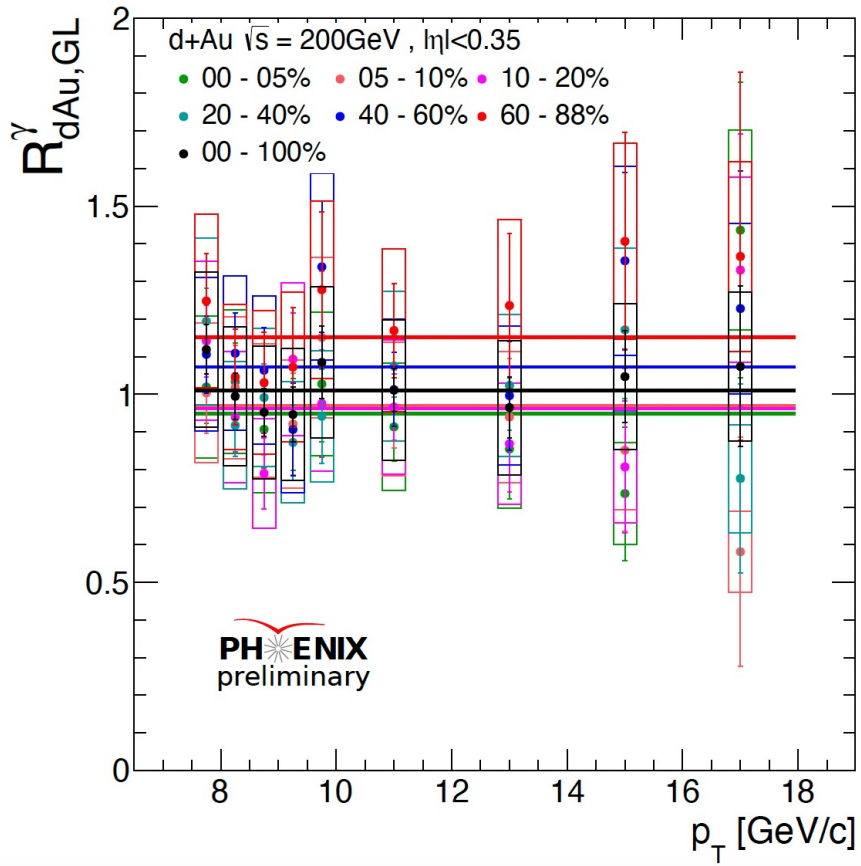
Nuclear Modification Factor of direct $\boldsymbol{\gamma}$s

$$R_{AB,GL}(p_T) = \frac{(\frac{d^2N}{dp_T d\eta})_{AB}}{\langle N_{coll}^{GL}\rangle_{AB} * (\frac{d^2N}{dp_T d\eta})_{pp}} = \frac{Y(AB)}{\langle N_{coll}^{GL}\rangle_{AB} * Y(pp)}$$

- There is a centrality dependence of direct γs
- The ~~most central events are suppressed (<1) and~~ peripheral events are enhanced (>1)
- In the given p_T range, to first order R_{dAu} appears to be flat.







The straight lines are fit to the datapoints at different centralities

- In central events the π^0s are suppressed and no suppression observed in direct γ.
- In most peripheral events, the degree of enhancement of π^0 matches that of direct γ.

Nuclear Modification Factor of π^0 s and direct γs

Experimentally determined N_{coll}

$$\langle N_{coll}^{exp} \rangle = \frac{\left(\frac{d^2N^\gamma}{dp_T d\eta}\right)_{dAu}}{\left(\frac{d^2N^\gamma}{dp_T d\eta}\right)_{pp}}$$

High p_T direct $\boldsymbol{\gamma}$s are transparent to QGP and scales exactly with the number of binary collisions in an event sample.

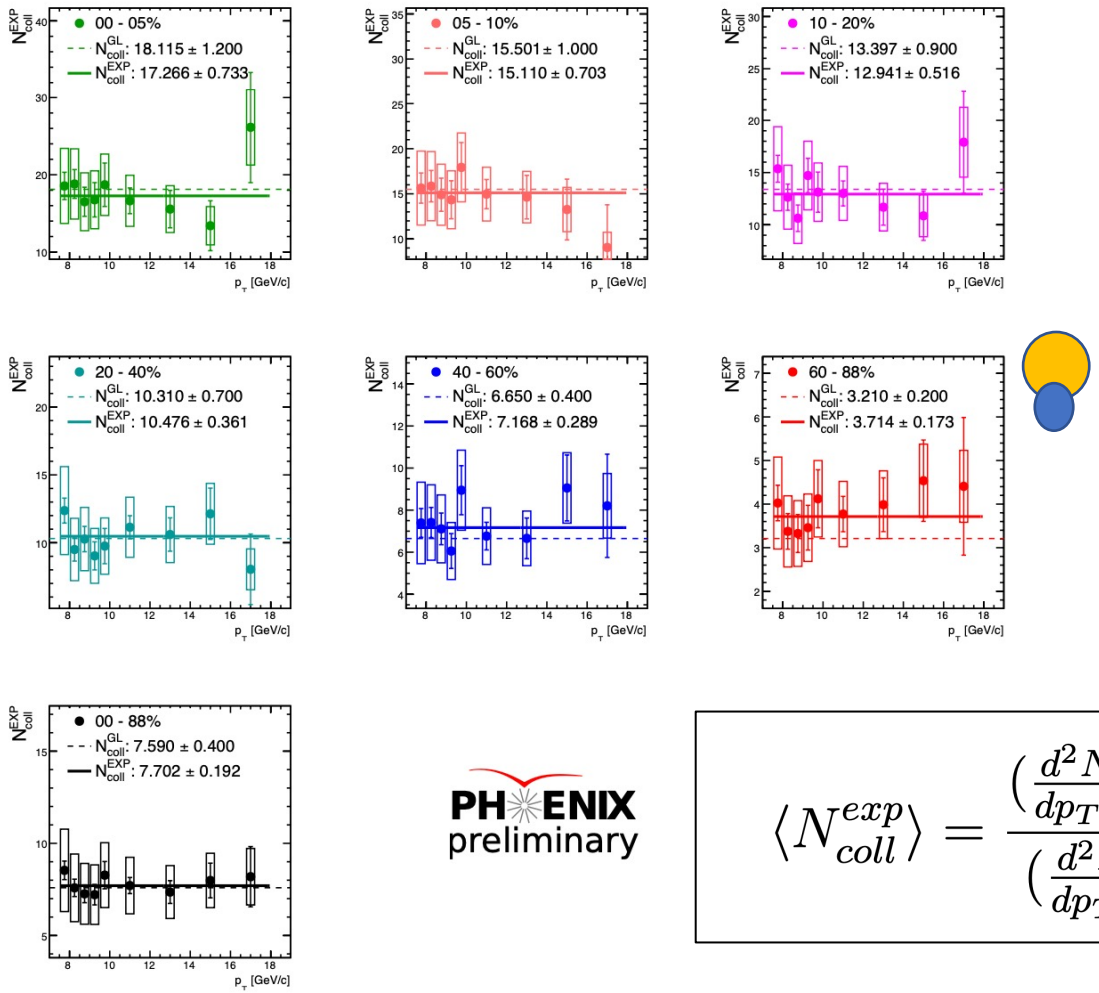
Better way to measure N_{coll} than standard Glauber model.

Can also be used to test the validity of any other modified Glauber models.

Note : on the right hand side, the numerator and the denominator are p_T dependent. The value on the left is obtained by dividing each p_T point and then doing a linear fit to get an average value.

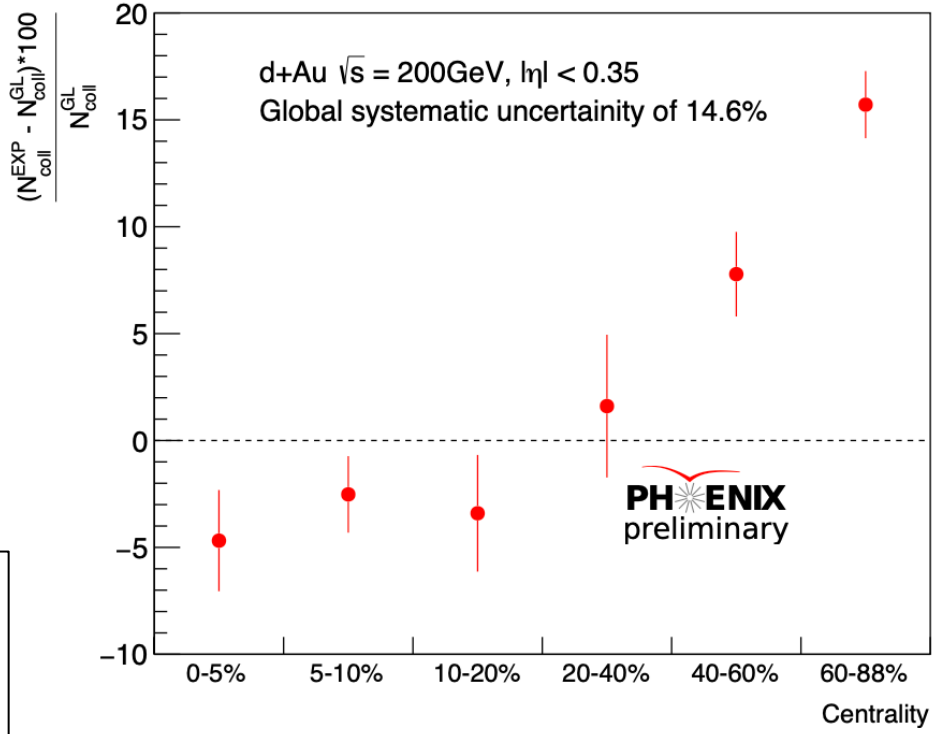
Deriving N_{coll} from direct $\boldsymbol{\gamma}$s

Bias in N_{coll} is observed in peripheral d+Au collisions



PHENIX preliminary

$$\langle N_{coll}^{exp} \rangle = \frac{\left(\frac{d^2N^\gamma}{dp_T d\eta}\right)_{dAu}}{\left(\frac{d^2N^\gamma}{dp_T d\eta}\right)_{pp}}$$



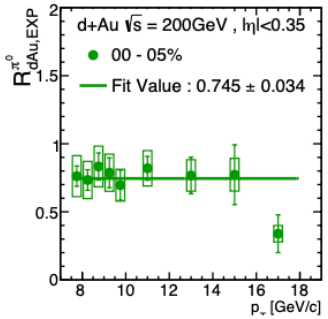
Deriving unbiased $R^{\pi^0}_{dAu}$

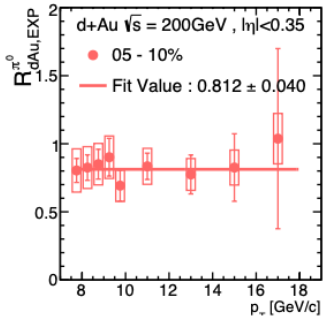
$$R^{\pi^0}_{dAu,EXP} = \frac{R^{\pi^0}_{dAu,GL}}{R^{\gamma}_{dAu,GL}} = \frac{(Y^{\pi^0}_{dAu}/Y^{\pi^0}_{pp})}{(Y^{\gamma}_{dAu}/Y^{\gamma}_{pp})} = \frac{(Y^{\pi^0}_{dAu}/Y^{\gamma}_{dAu})}{(Y^{\pi^0}_{pp}/Y^{\gamma}_{pp})}$$

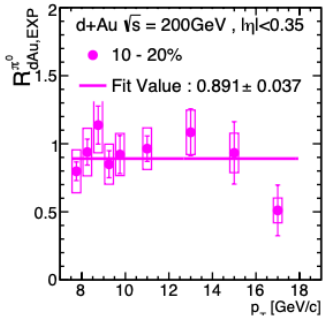
Using experimentally derived Ncoll = Renormalising $R^{\pi^0}_{dAu,GL}$ with $R^{\gamma}_{dAu,GL}$

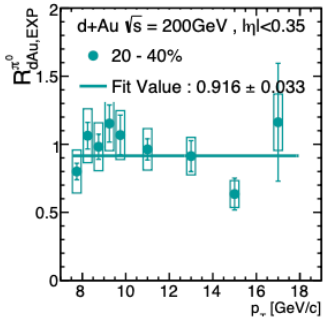
Unbiased $R^{\pi^0}_{dAu}$

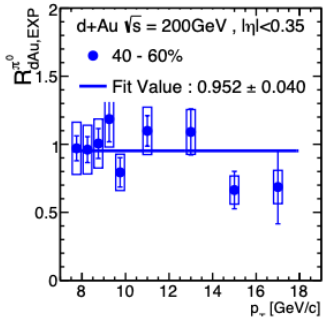
$$R^{\pi^0}_{dAu,EXP} = \frac{R^{\pi^0}_{dAu,GL}}{R^{\gamma}_{dAu,GL}} = \frac{(Y^{\pi^0}_{dAu}/Y^{\pi^0}_{pp})}{(Y^{\gamma}_{dAu}/Y^{\gamma}_{pp})} = \frac{(Y^{\pi^0}_{dAu}/Y^{\gamma}_{dAu})}{(Y^{\pi^0}_{pp}/Y^{\gamma}_{pp})}$$

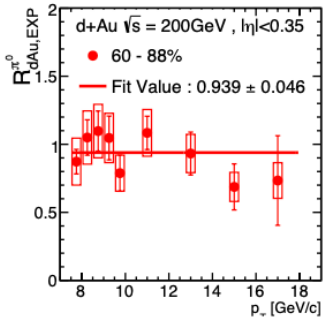


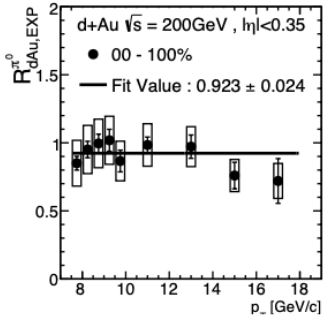




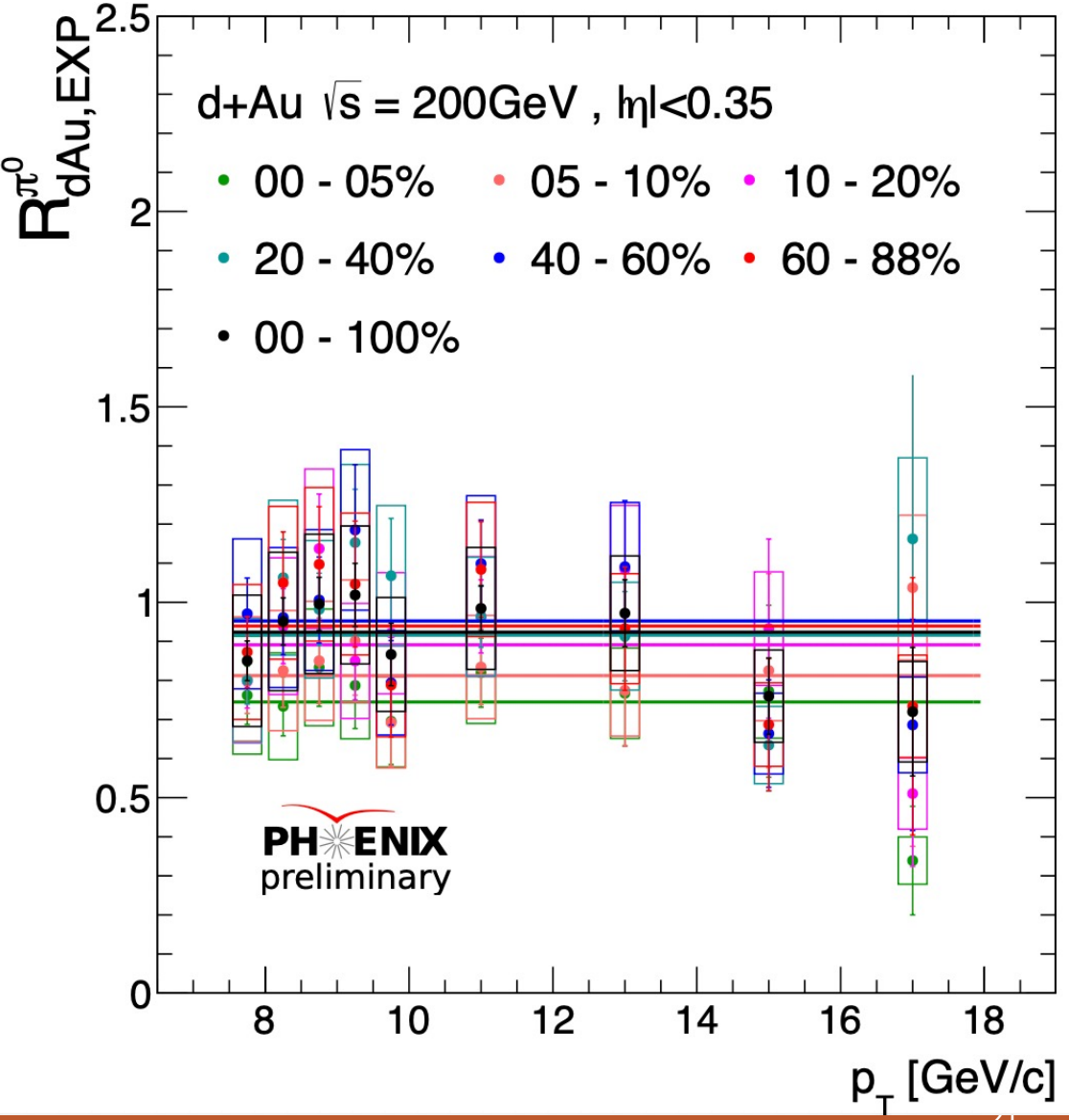






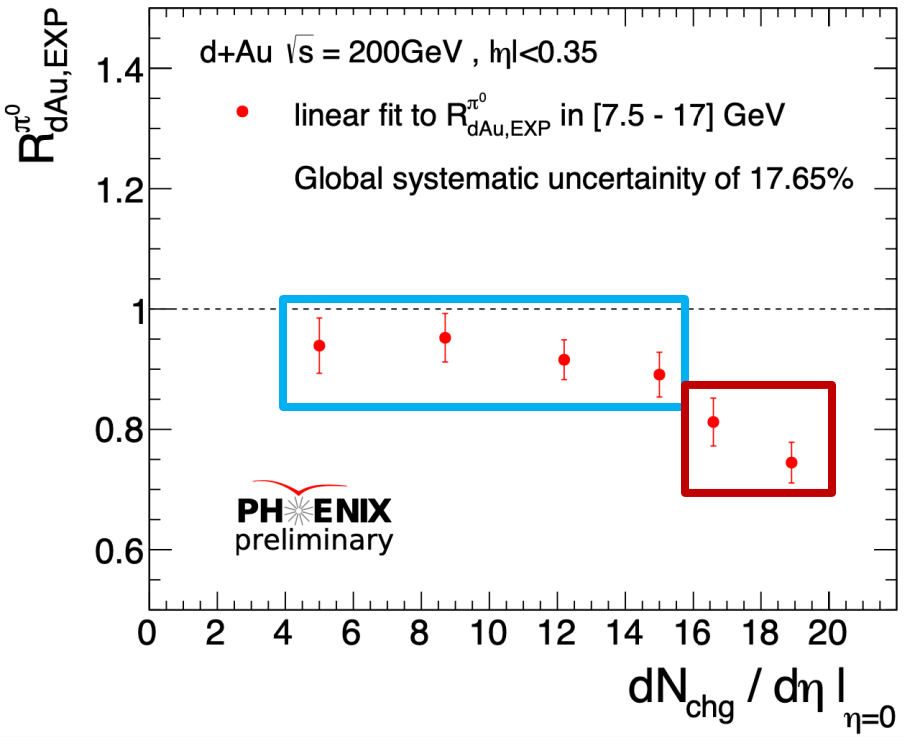


PHENIX preliminary



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

First evidence of suppression in $R^{\pi^0}_{dAu,EXP}$



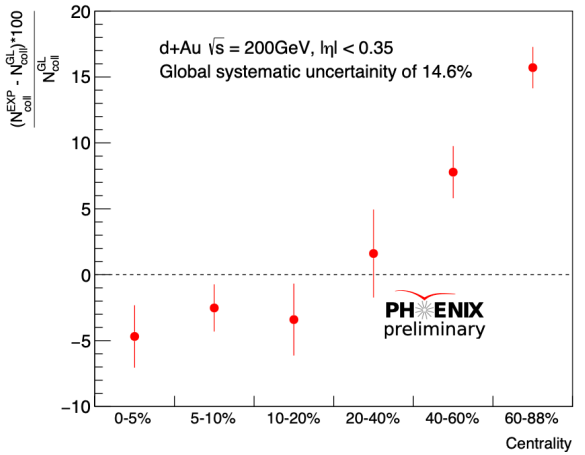
- After correcting for the bias, the $R^{\pi^0}_{dAu,EXP}$
  - Does not show any enhancement in peripheral collisions
  - Does show suppression in central collisions
- There is no identified source of systematic error which has centrality dependence.
- Detailed study including,
  - ongoing analysis of p+Au ,^{3}He+Au
  - initial state effects on the production mechanism of π^0s and direct γs

is necessary to understand whether this observed suppression is an initial or final state effect.

SUMMARY

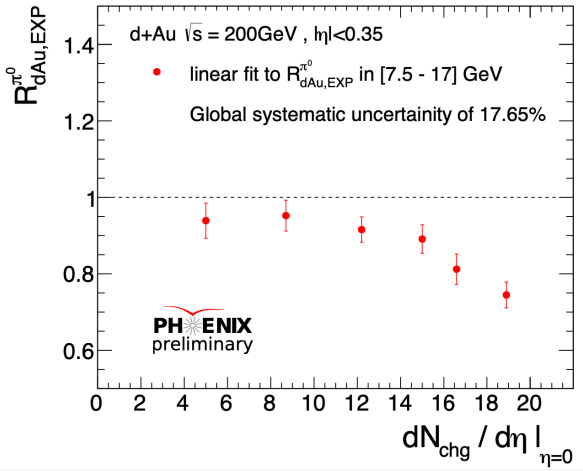
Bias in centrality determination in small system collisions

- Determination of N_{coll} by using Glauber Model is biased. Specifically for peripheral events
- Experimentally derived N_{coll} using high p_T direct γs
- Future analysis in p+Au and ^{3}He+Au system will provide more clarification on the origin of centrality bias



Evidence of $R_{dAu}^{\pi^0}$ supression in most central

- Normalized nuclear modification factor of π^0 s using direct γs
- Most central events show supression of ~15%
- Models studying the intial state effect in the production of π^0 s and direct γs will shed light on the origin of the observed suppression



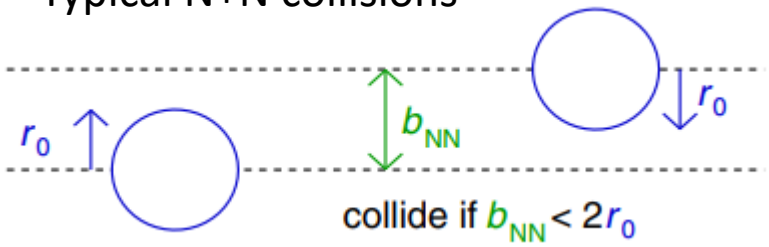
THANK YOU FOR YOUR ATTENTION

Backup

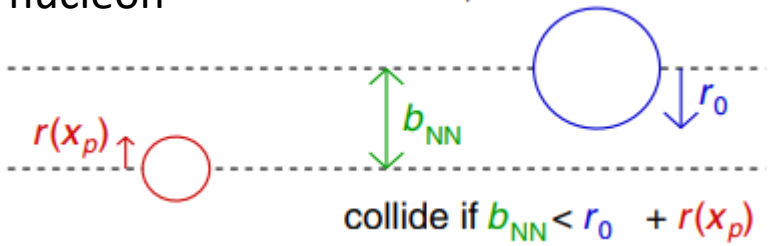
Origin of the bias…?

high-x (effective) size fluctuations

Typical N+N collisions



N+N collisions with large-x_p projectile nucleon



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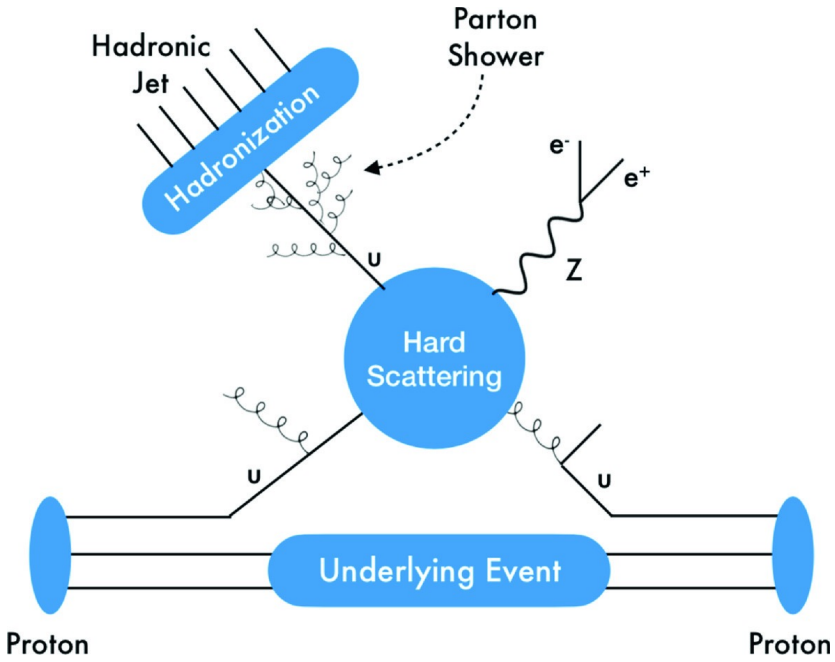
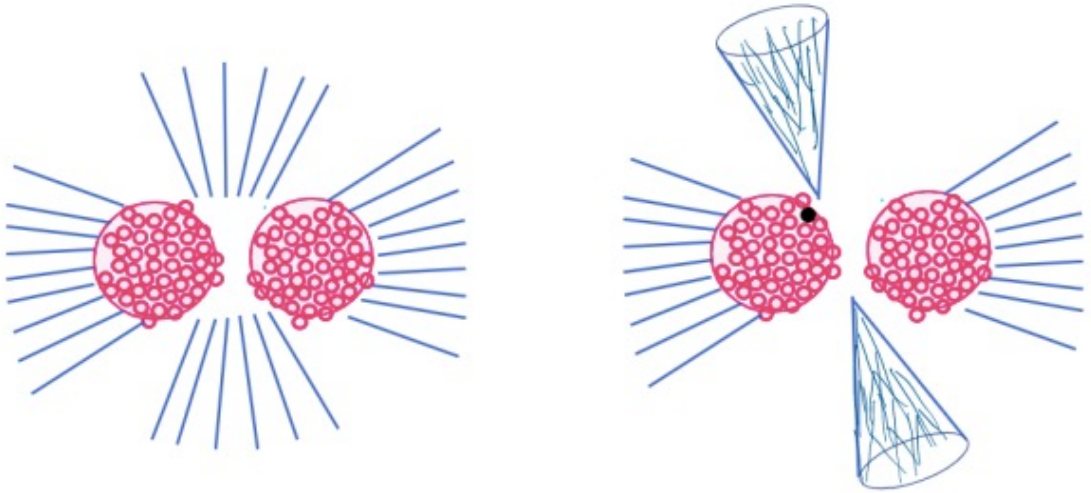


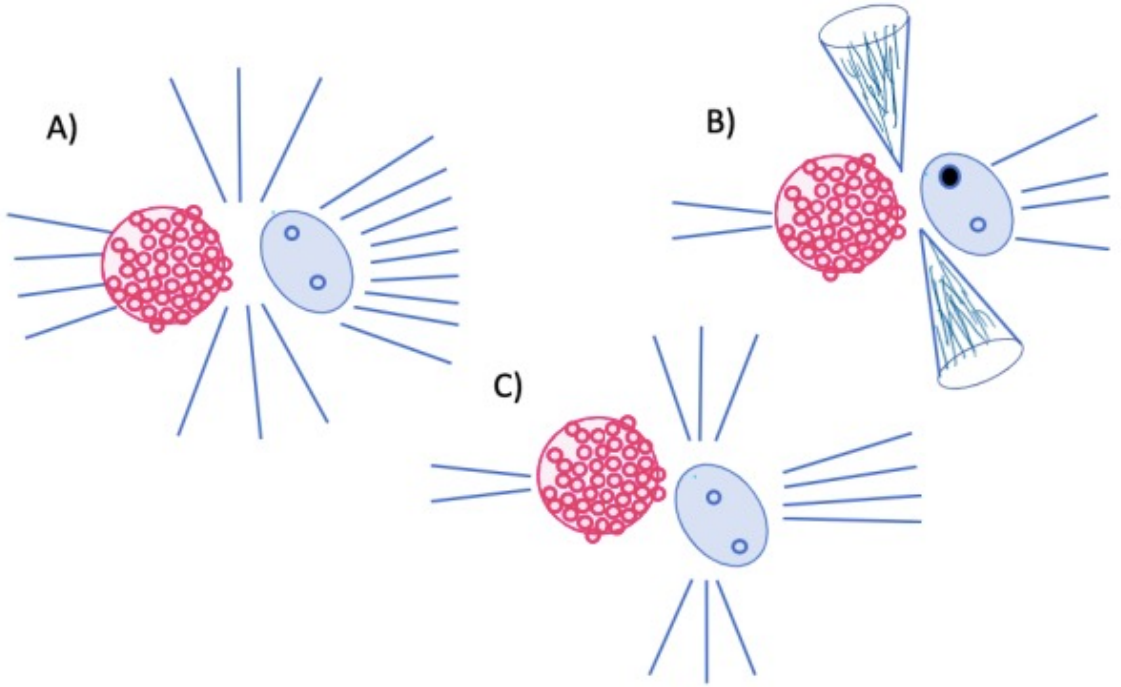
The high-X parton creates the hard scattering event. But the underlying event is severely depleted.

This can be thought of as
a) energy conservation or
b) change in the cross-section of the nuclei due to the presence of high-X parton.



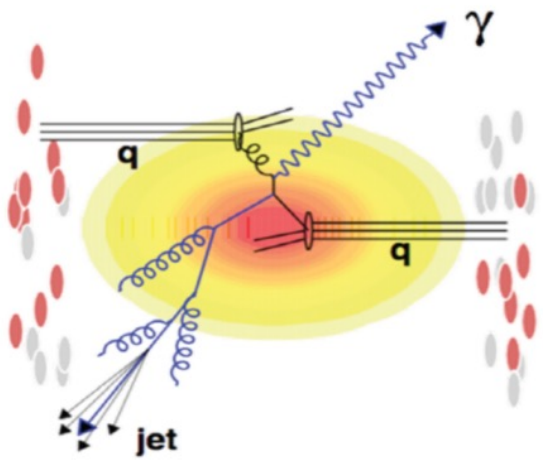
In a heavy-ion collision, the presence of one high-X parton nuclei, creates the jets, but the average underlying event isn't affected as there are several other partons for interactions.

In a d+Au collision, the presence of one high-X parton depletes the underlying event and there are not enough other interactions to compensate for this.
Thus a central d+Au event will look like a peripheral d+Au event.
This is a p_T (or x) dependent change. The bin-shift is larger at higher momentum.



This shrinking nucleon model has a prediction for R_{dAu} (x) and thus we can compare it to our data.

$R_{dAu}^{\pi^0}$ and R_{dAu}^{γ} as a function of parton momentum x



$$x_p = 2p_{T'}^{jet} / \sqrt{s_{NN}} \approx 2p_T^{\pi^0} / (0.75 * \sqrt{s_{NN}})$$

$$x_p = 2p_T^{direct\gamma} / \sqrt{s_{NN}}$$

Does our data fit the expectation from the “shrinking nucleon” picture?