High p_T direct photon analysis in d+Au system

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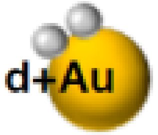
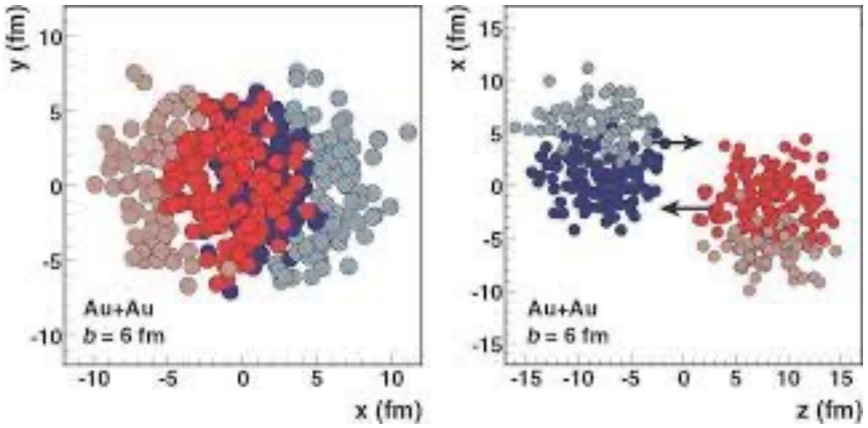
Definition
Nuclear Modification Factor

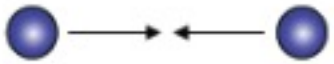
$$R_{AB}(p_T) = \frac{\left(\frac{d^2N}{dp_T d\eta}\right)_{AB}}{\langle N_{coll}\rangle_{AB} * \left(\frac{d^2N}{dp_T d\eta}\right)_{pp}} = \frac{Y(AB)}{\langle N_{coll}\rangle_{AB} * Y(pp)}$$



This ratio teaches us how different a heavy ion collision is from just considering it as a scaled p+p collision



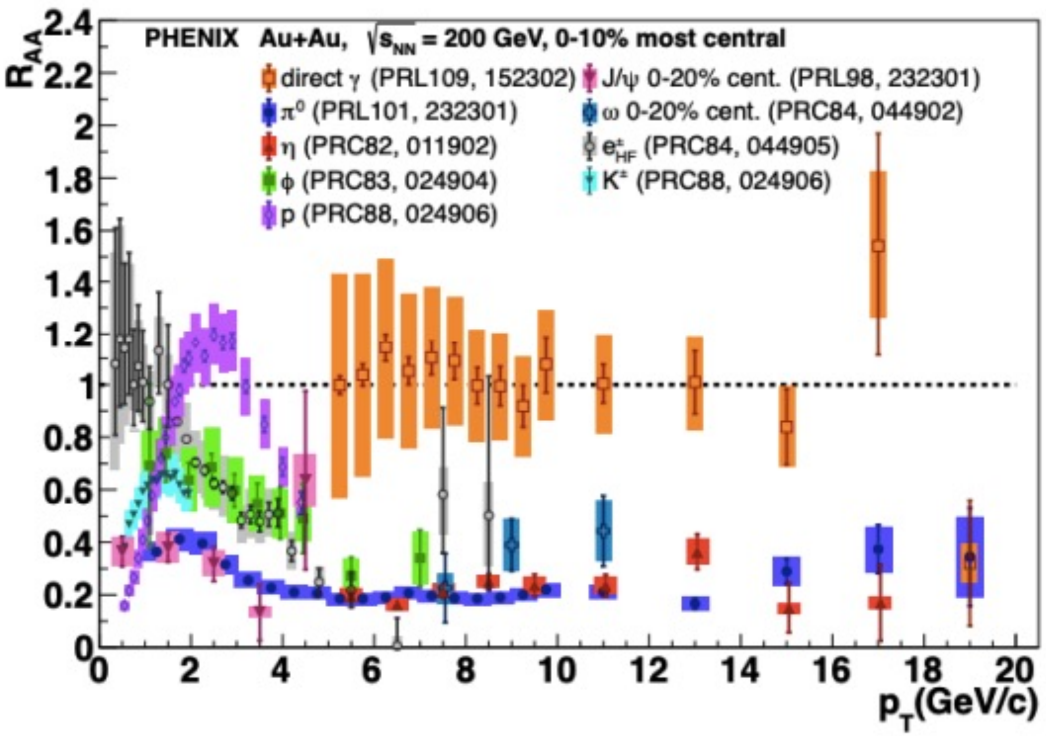
$\stackrel{?}{=}$ 60 *



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

1) $\pi^0, \eta, \phi, J/\psi, \omega$ all interact with the QGP and loses momentum in it and thus its $R_{AB}(p_T)$ is suppressed.

2) The direct photon does not interact via the strong nuclear force and its $R_{AB}(p_T)$ scales exactly with p+p collisions

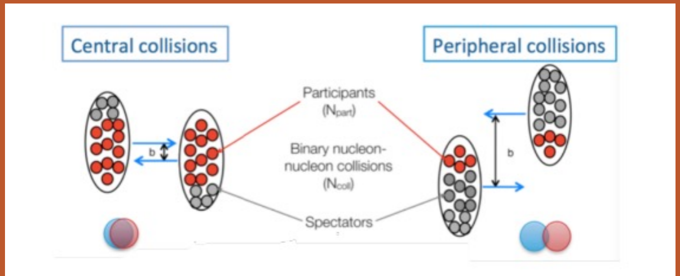


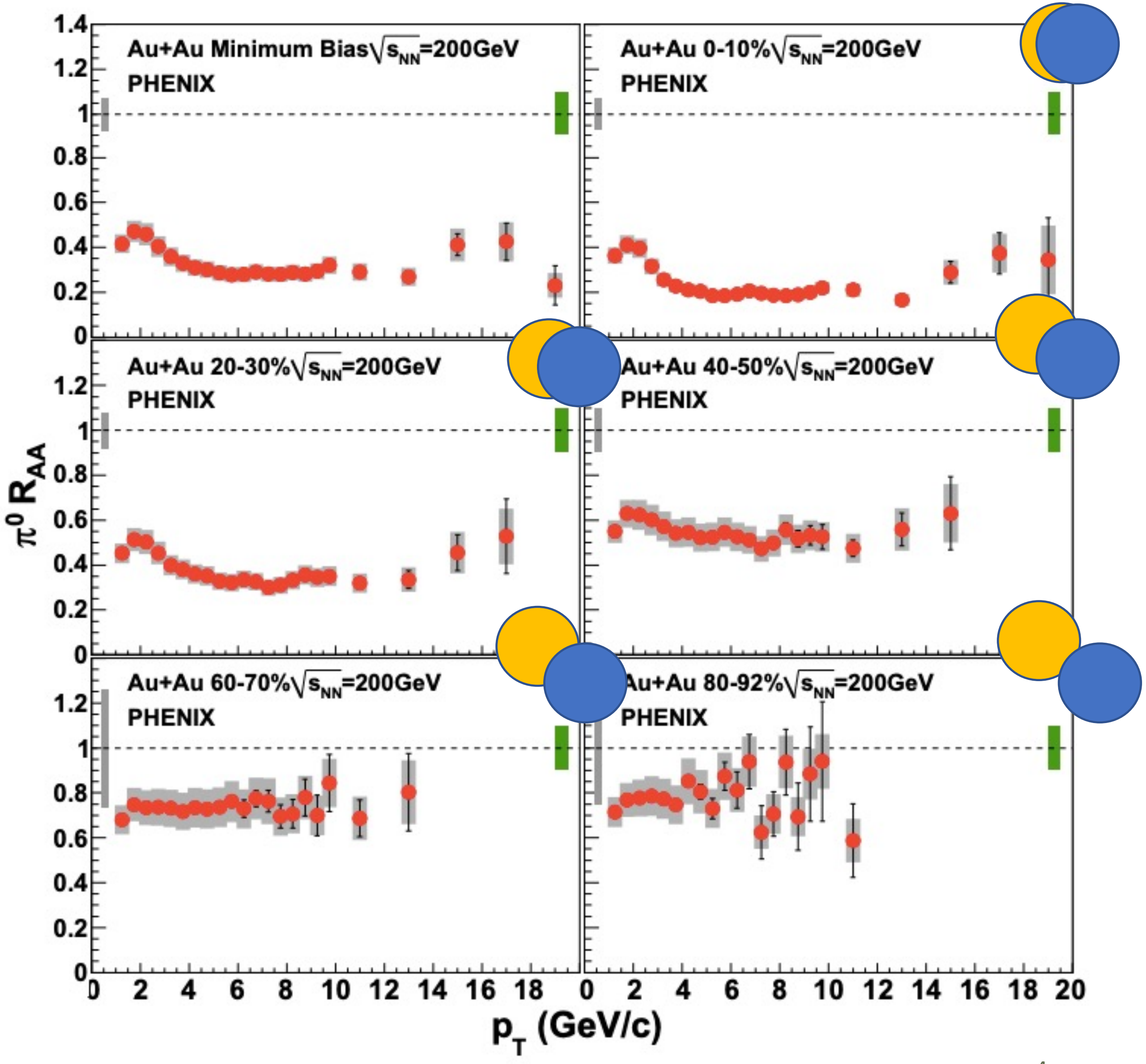
Centrality binned RAA of π^0 in Au+Au collisions

- Most Central collisions show the most suppression.

- The degree of suppression decreases as we move to more peripheral collisions and almost vanish at 80-92%

-The trend is intuitive to what we expect in a collisions in which QGP is formed.



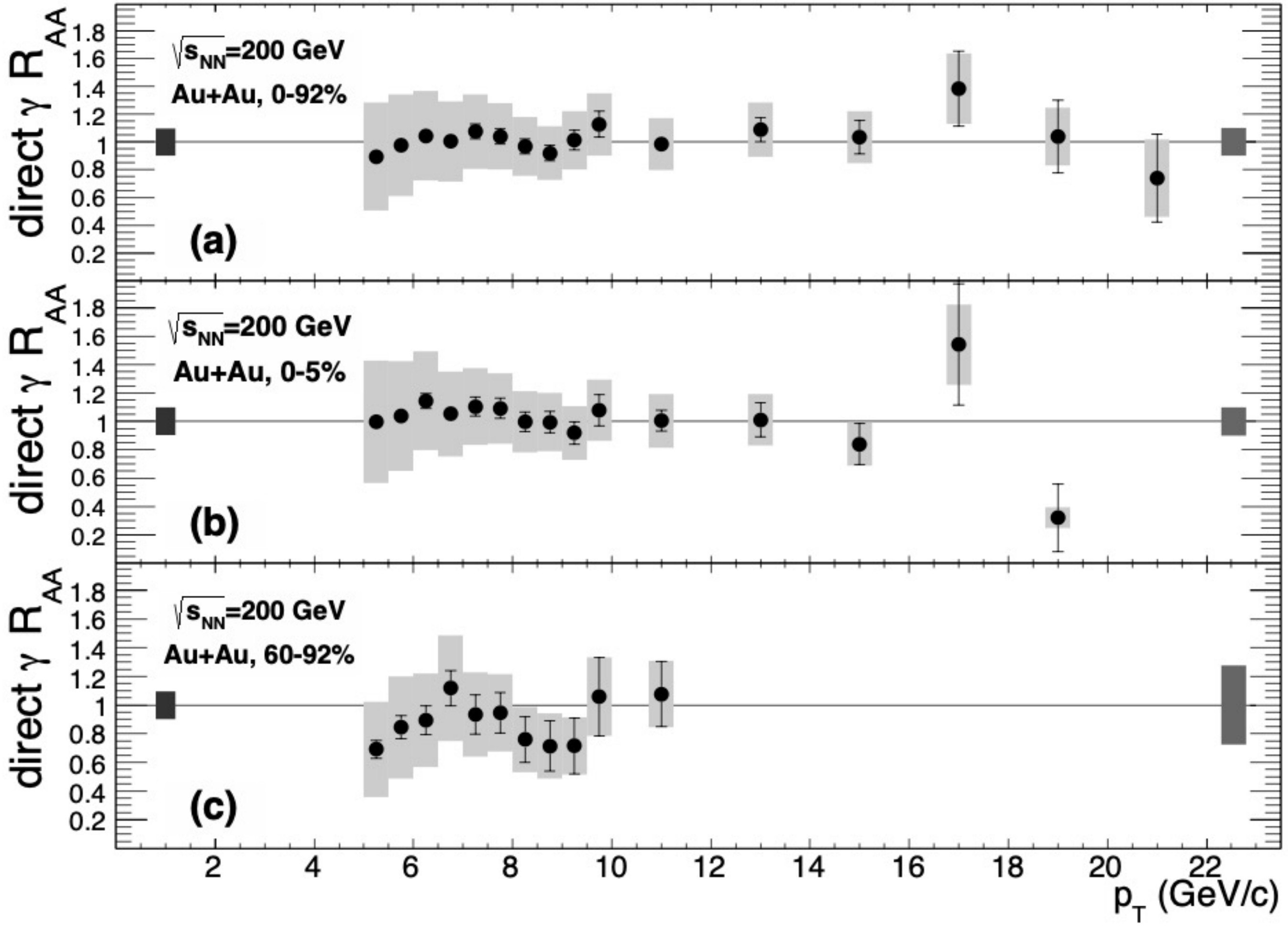


Phys. Rev. L 101 (2008) 232301

Centrality binned R_{AA} of π^0 in Au+Au collisions

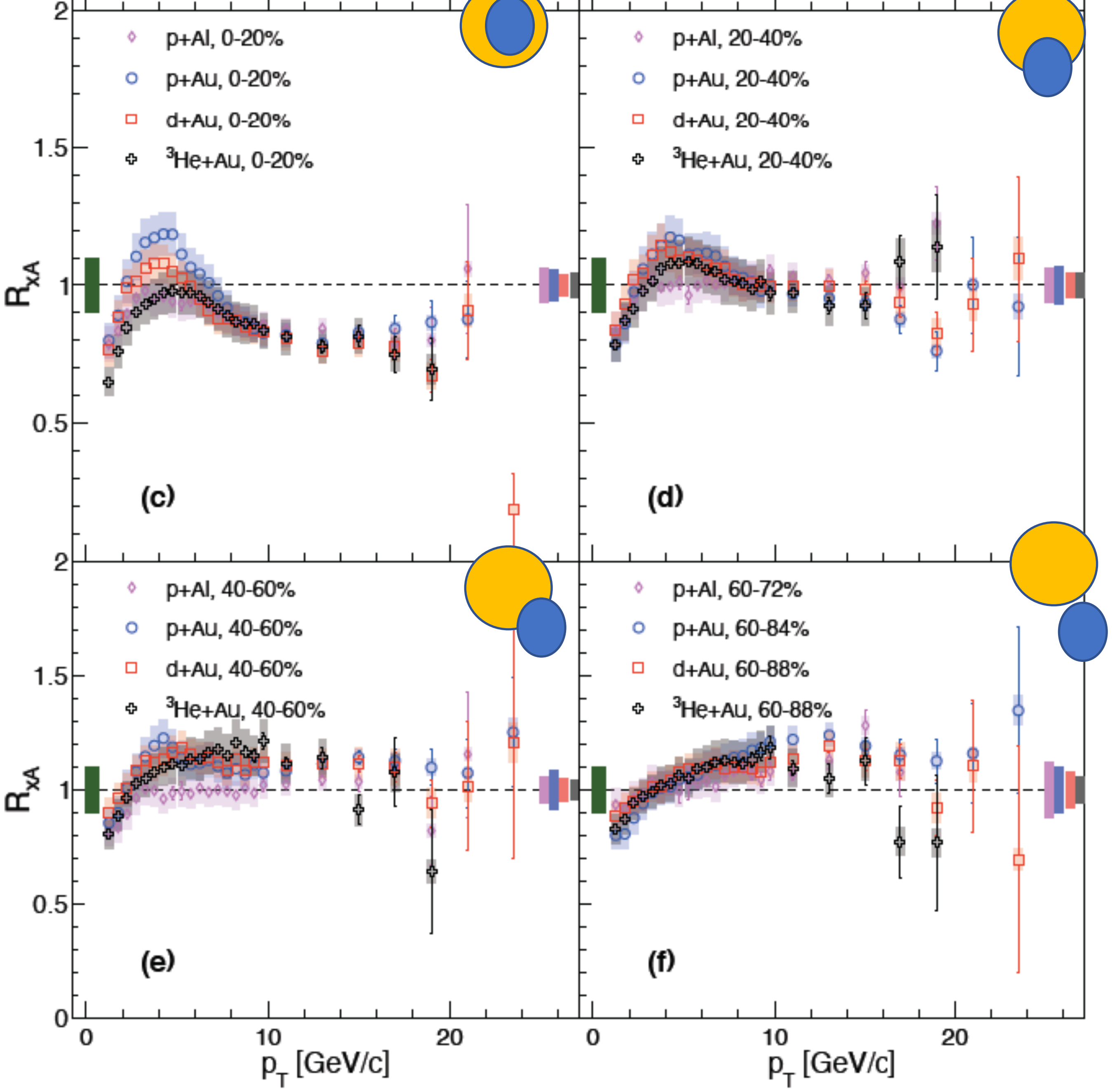
- It is unity at all centralities.

- As expected, the direct photons are transparent to QGP



Phys. Rev. L 109 (2012) 152302

What about small system collisions?



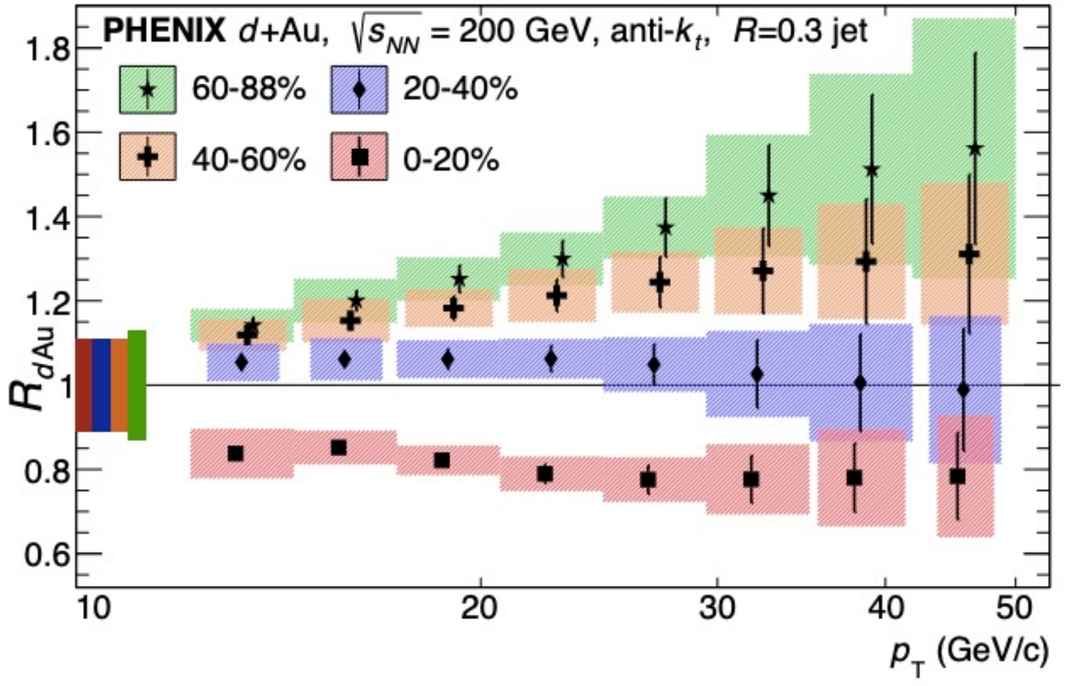
Centrality binned d+Au collisions

- p+Au shows large centrality dependence.
- In high p_T we observe suppression for central events and enhancement in peripheral events.

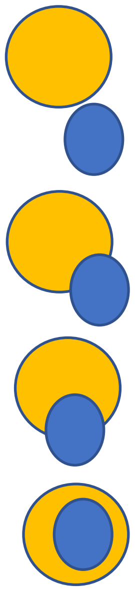
- d+Au also shows centrality dependence, but smaller than p+Au.
- d+Au agrees with p+Au in high p_T region. Especially for most central collisions.

arXiv:2111.05756

Centrality binned d+Au collisions



arXiv:1509.04657



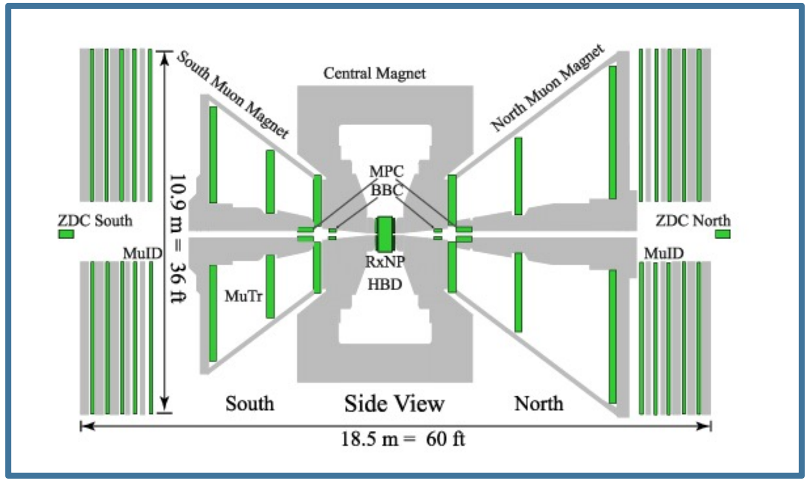
- Jets have higher reach in momentum as compared to pions
- In high p_T we observe suppression for central events and enhancement in peripheral events.

Is the centrality dependence a physics effect or an artifact of the way we bin centrality itself?
Are events mis-binned in centrality?

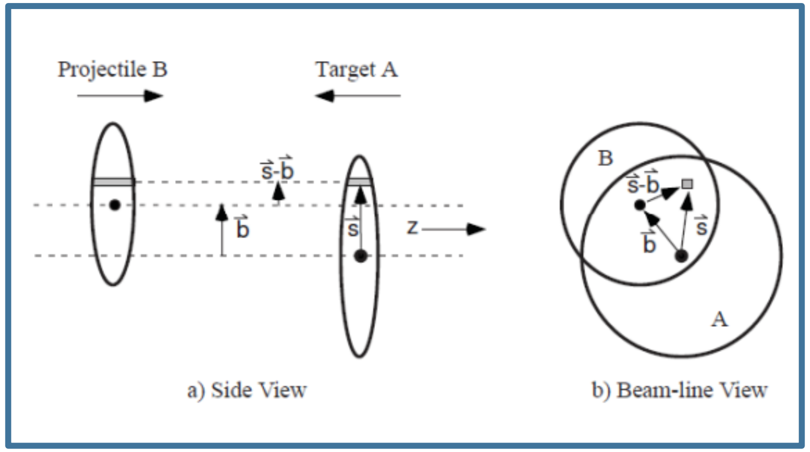
Experimental Measurement of average number of binary collisions

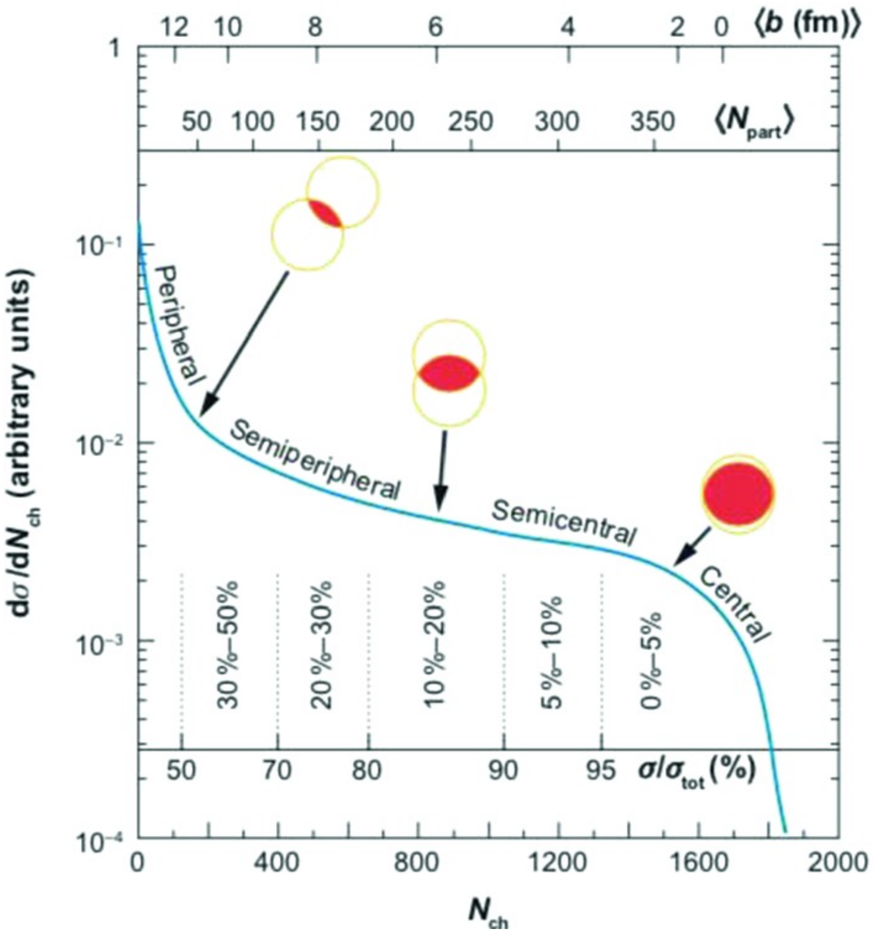
$$\frac{Y(AB)}{\boxed{\langle N_{coll}\rangle_{AB}} * Y(pp)}$$

Number of charged particle from experiment



Glauber model gives mapping of charged particle in forward region to number of binary collisions of the event. Tune to this to your specific detector.





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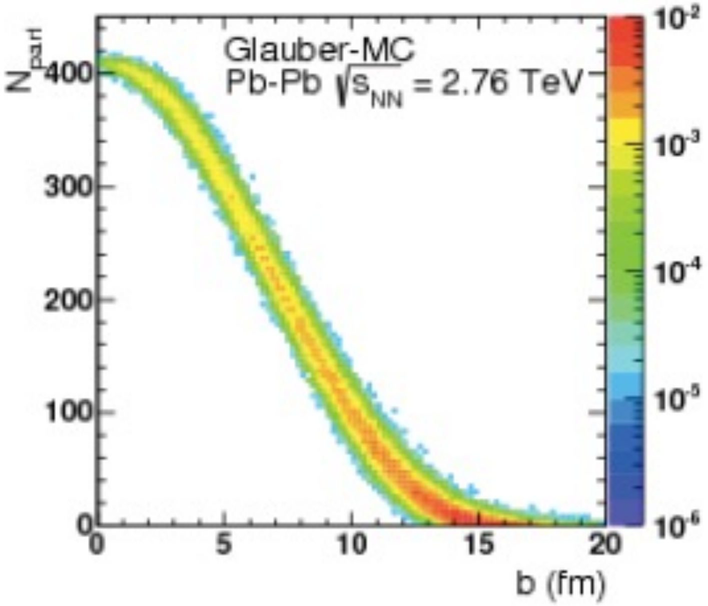
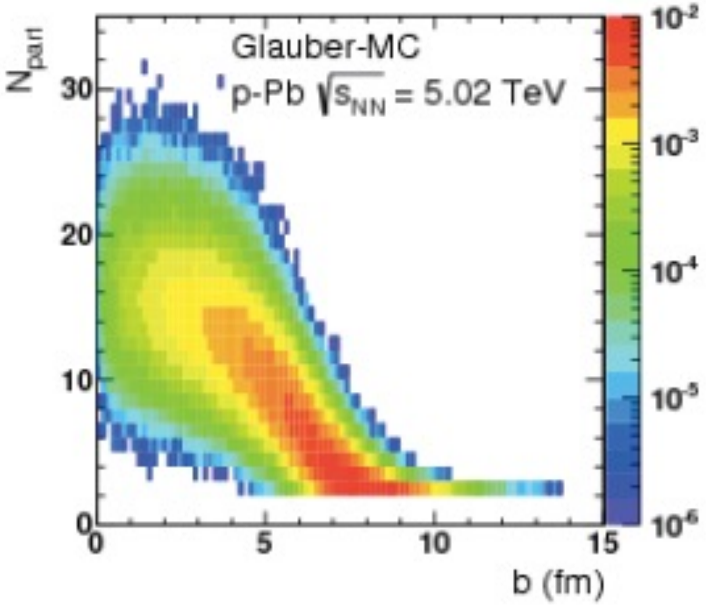




PR C 91, 064905 (2015)

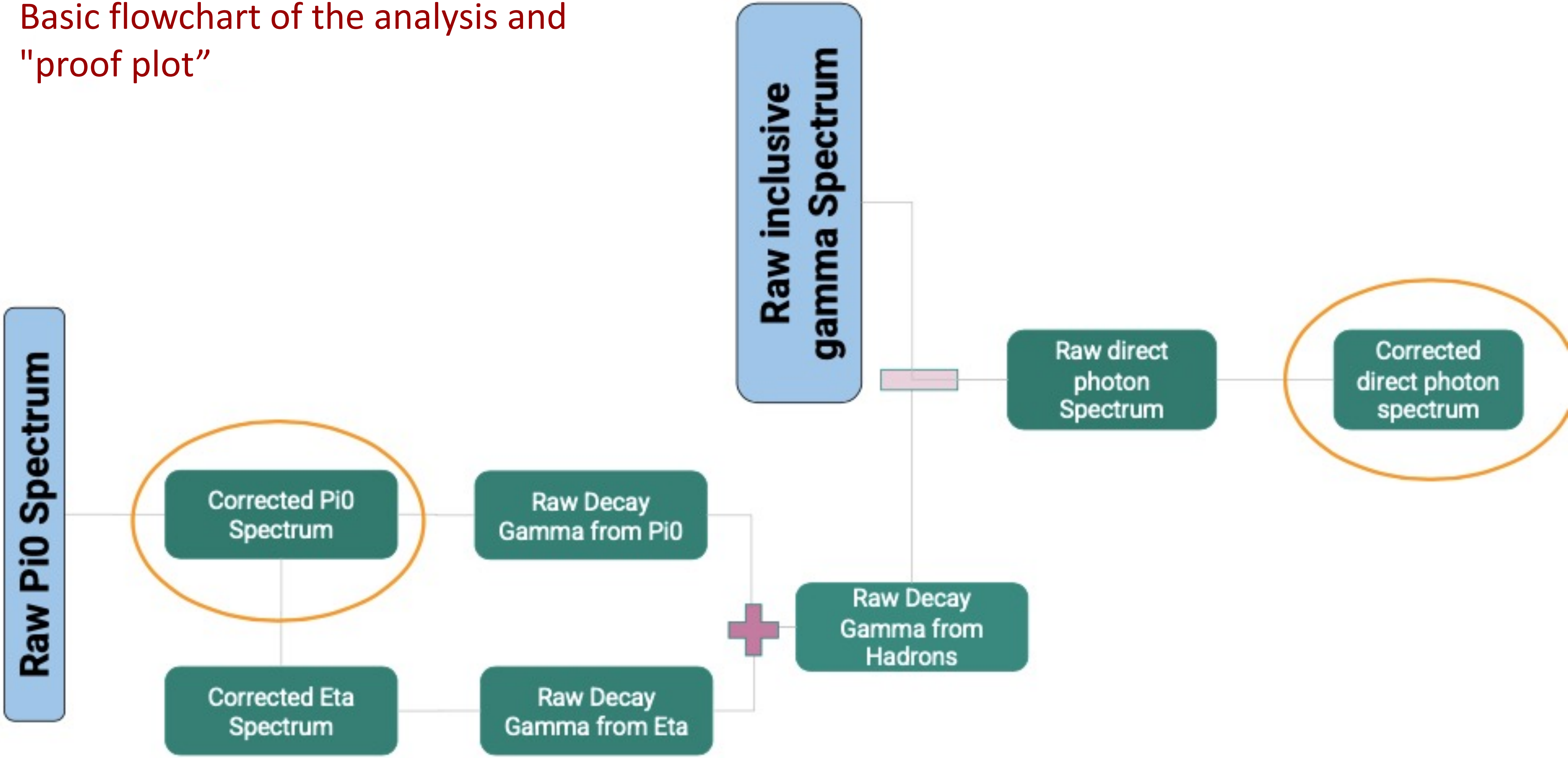
Is Glauber model valid for small systems?

- Analyzing the 0-20% centrality bin in Pb+Pb is equivalent to studying the class of events with average impact parameter of 3fm with a very small variance.
- Analyzing the 0-20% centrality bin in p+Pb is also equivalent to studying the class of events with average impact parameter of 3fm but with a large variance.
- This difference implies that we cannot draw equivalent physics conclusions about central p+Pb and Pb+Pb events.

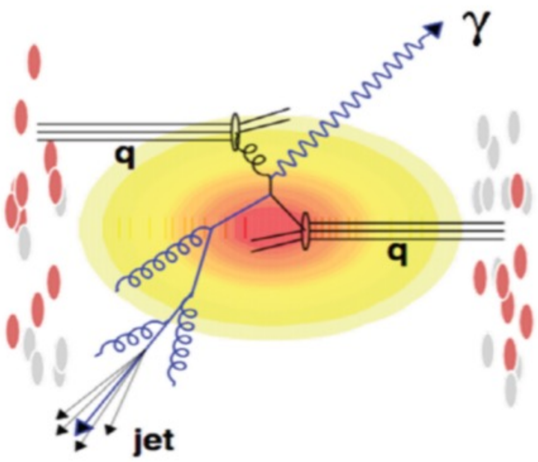
In addition to this, there are additional biases and difference which will be discussed next.

How do we use these spectra to study possible centrality bias?

Basic flowchart of the analysis and "proof plot”



$$\frac{\text{Corrected direct photon spectrum}}{\text{Corrected Pi0 Spectrum}}$$



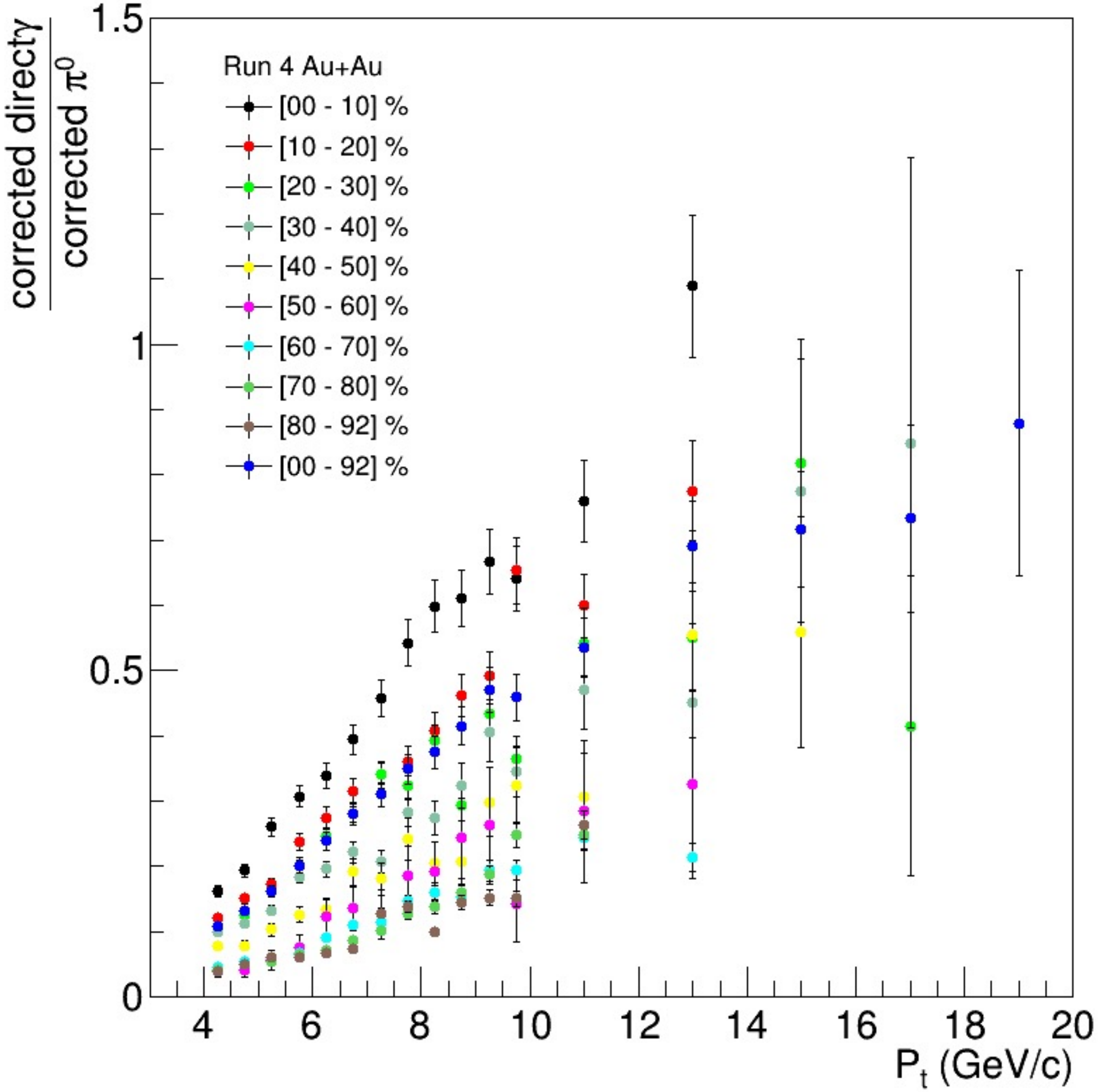
Option 1:
The centrality dependence that we see in Pi0 spectrum is because of true physics effects, if so, then this **shouldn't** affect direct photon. So the ratio will HAVE centrality dependence.

Option 2:
The centrality dependence that we see in Pi0 spectrum is because of X (some non-physics reason), if so, then this **should** affect direct photon **equally**. So the ratio will NOT HAVE centrality dependence.

Ratio of direct photon over π^0

This plot is obtained from making ratio of available published data for Au+Au system

There is a clear centrality dependent ordering suggesting that in Au+Au collisions, the observed suppression in central collision and not in peripheral collision is an effect of strong nuclear force (QGP), which affects the π^0 s but leaves the direct photons unaffected.

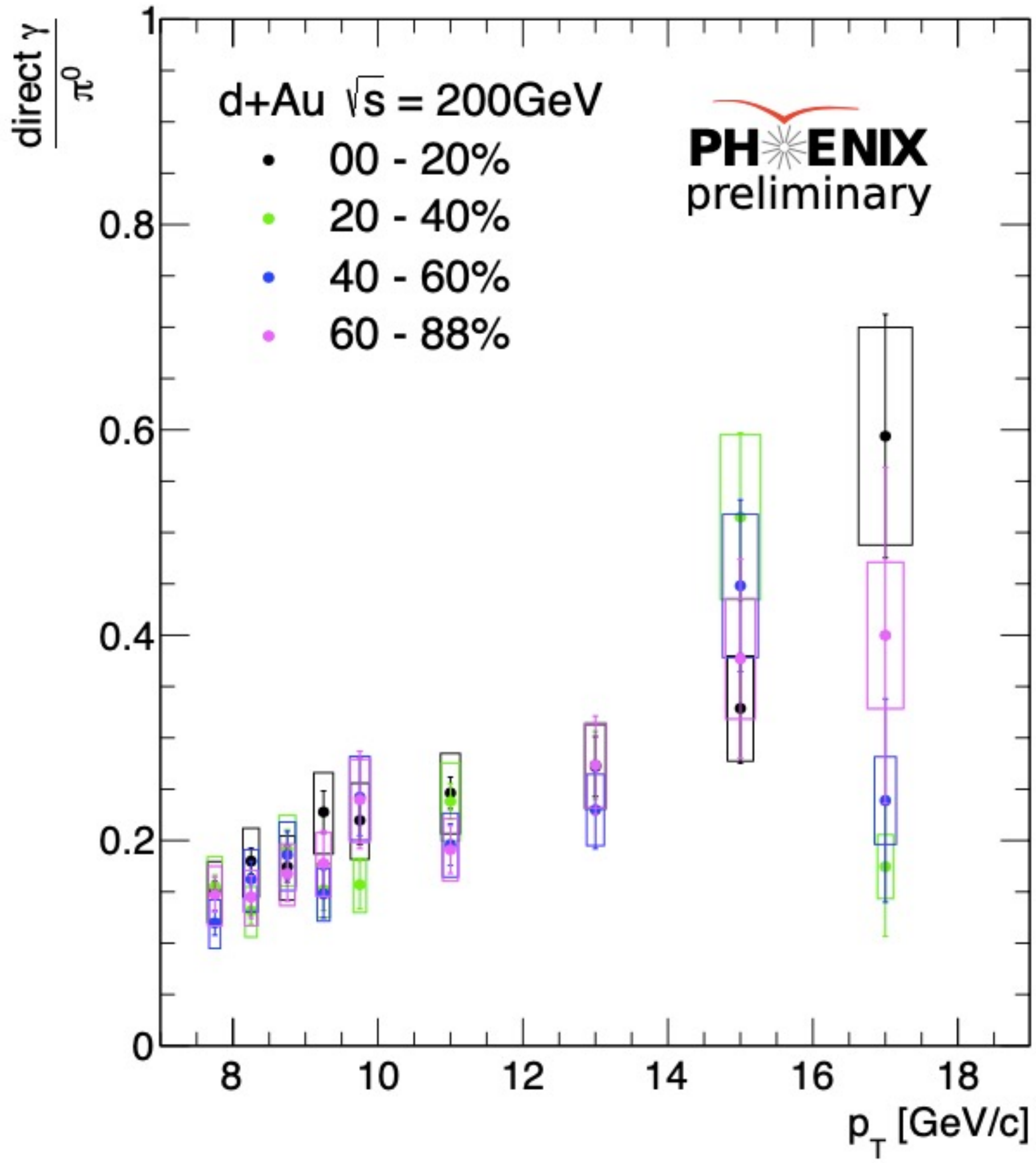


Neutral Pi0s : arXiv:0801.4020
direct Photon : arXiv:1205.5759

d+Au

Ratio of direct photon over π^0

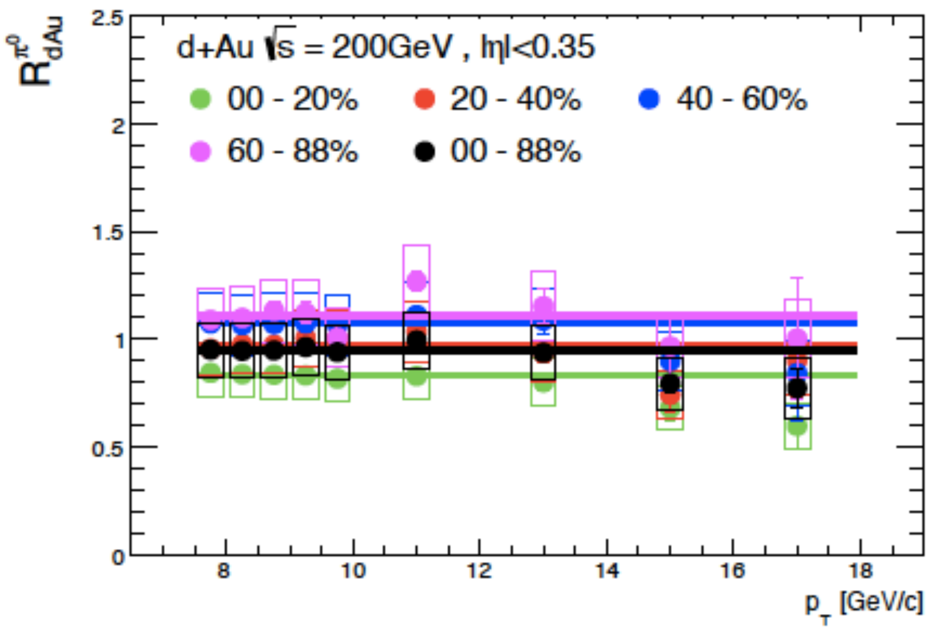
There is a clear LACK OF centrality dependent ordering suggesting that in d+Au collisions there is a Pt dependent bias in centrality determination which affects BOTH Pi0s and direct photons.

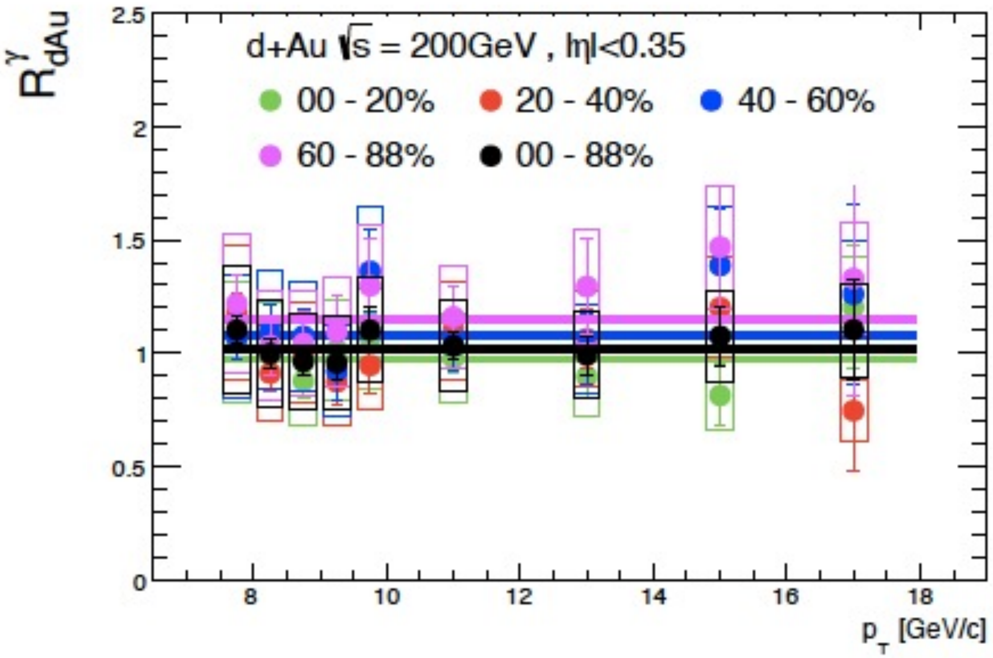


$$R_{AB}(p_T) = \frac{(\frac{d^2N}{dp_T d\eta})_{AB}}{\langle N_{coll}\rangle_{AB} * (\frac{d^2N}{dp_T d\eta})_{pp}}$$

Nuclear Modification Factor

For pions and direct photons





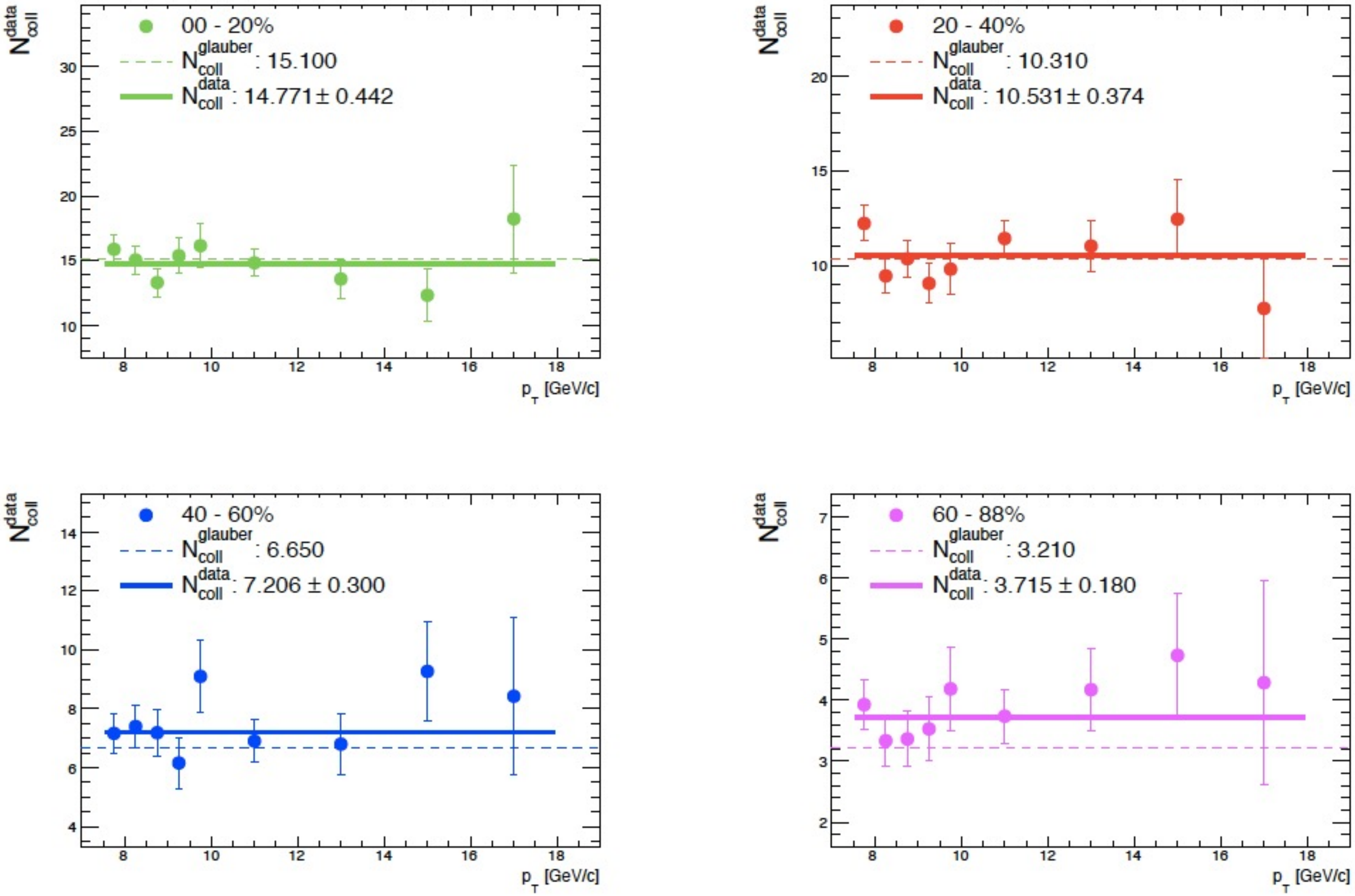
Looking at these plots, here are the following things we can learn

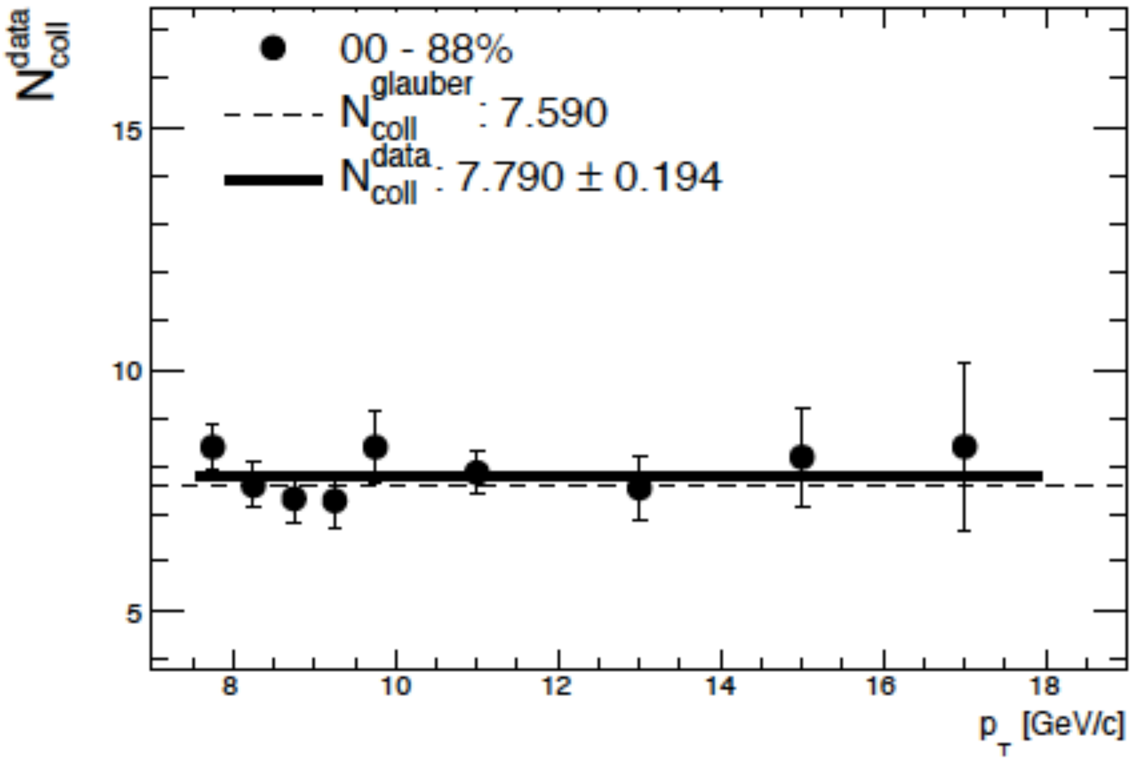
- There is a centrality dependence in both π^0 and direct ϒ.
- The most central events are suppressed (<1) and peripheral events are enhanced (>1)
- In central events the suppression of π^0 seem to be higher than those of direct ϒ.
- In most peripheral events, the degree of enhancement of π^0 matches that of direct ϒ.
- In the given p_T range, to first order R_{dAu} appears to be flat.

Deriving N_{coll} from data

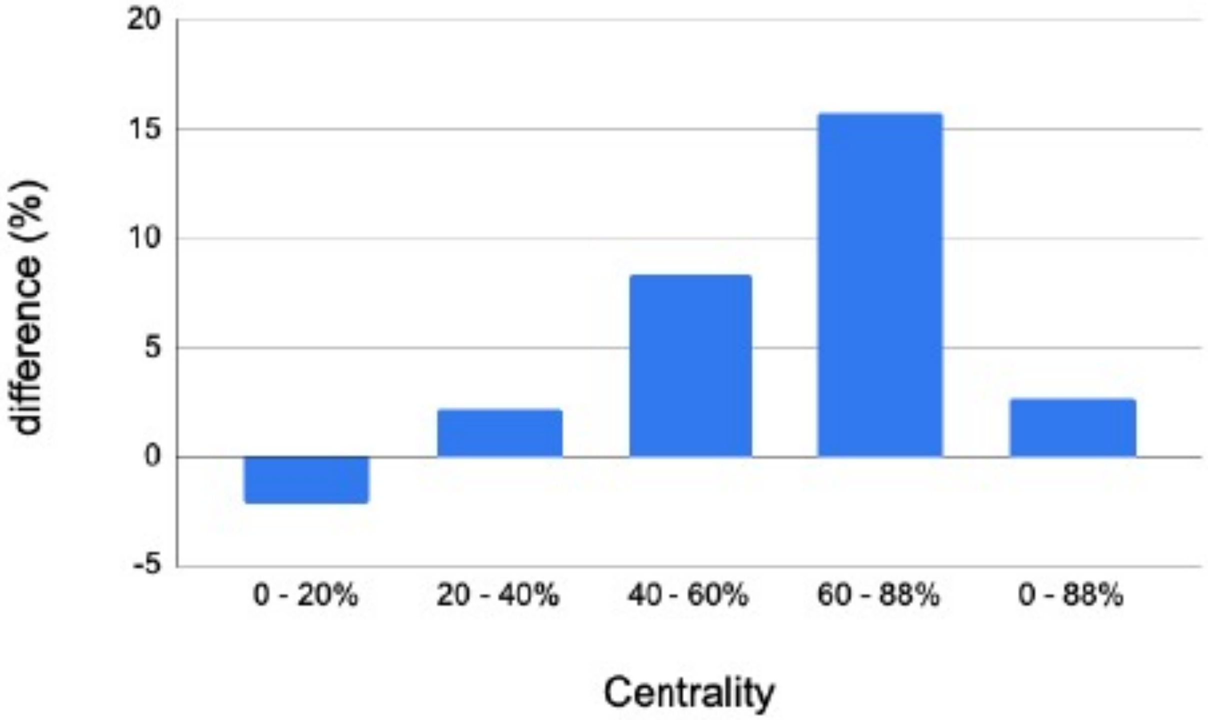
Given the above observation, it is clear that the N_{coll} derived for Glauber model has some intrinsic bias that is affecting both R_{dAu}. We know that the high p_T direct photon is unaffected by final state effect like QGP formation and thus should scale exactly with N_{coll}. Using this knowledge we can now derive N_{coll} from direct photons by dividing the invariant yield obtained in d+Au collisions with the invariant yield obtained in p+p collisions.

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


00 - 20%
$N_{coll}^{glauber}$: 15.100
N_{coll}^{data} : 14.771 ± 0.442
N_{coll}^{data}
p_T [GeV/c]
20 - 40%
$N_{coll}^{glauber}$: 10.310
N_{coll}^{data} : 10.531 ± 0.374
N_{coll}^{data}
p_T [GeV/c]
40 - 60%
$N_{coll}^{glauber}$: 6.650
N_{coll}^{data} : 7.206 ± 0.300
N_{coll}^{data}
p_T [GeV/c]
60 - 88%
$N_{coll}^{glauber}$: 3.210
N_{coll}^{data} : 3.715 ± 0.180
N_{coll}^{data}
p_T [GeV/c]



N_{coll}^{data}
00 - 88%
$N_{coll}^{glauber}$: 7.590
N_{coll}^{data} : 7.790 ± 0.194
15
10
5
8
10
12
14
16
18
p_T [GeV/c]

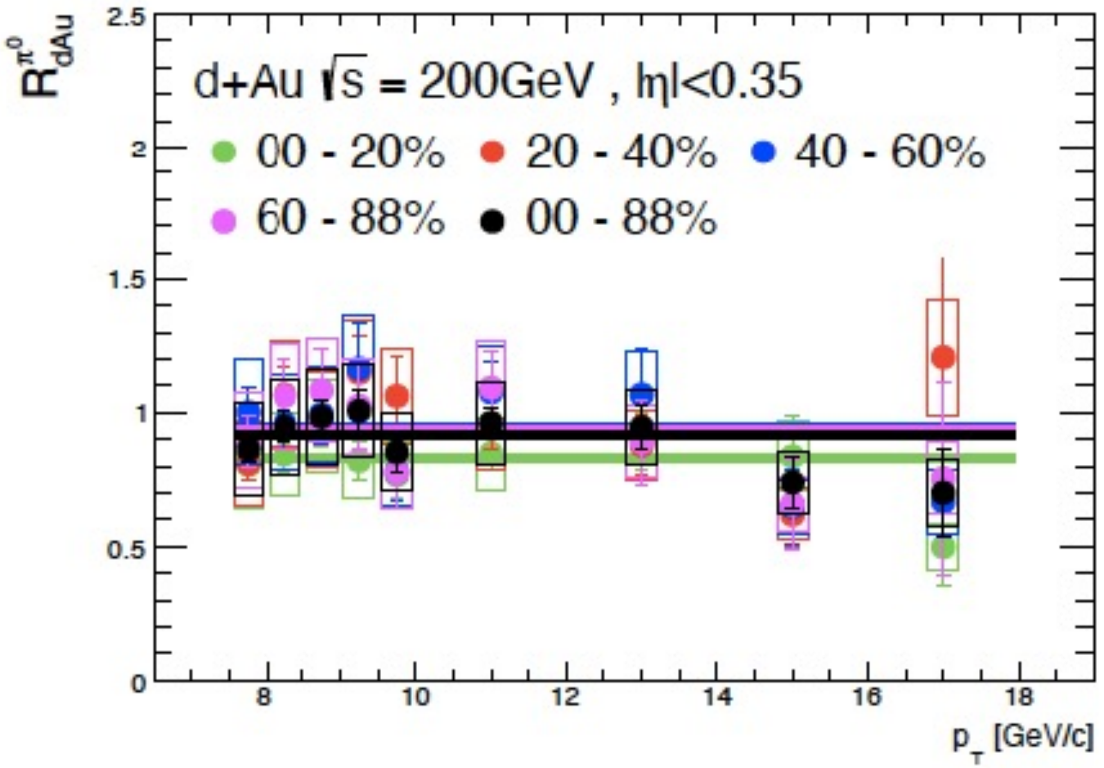


20
15
10
5
0
-5
difference (%)
0 - 20%
20 - 40%
40 - 60%
60 - 88%
0 - 88%
Centrality

Renormalising $R_{dAu}^{\pi^0}$ using R_{dAu}^{γ}

Given that we now have derived N_{coll} in a data driven fashion, we can now use this to re-obtain $R_{dAu}^{\pi^0}$. This can be done by simply using N_{coll}^{data} and considering the appropriate systematic error from the fitting procedure or we can use the R_{dAu}^{γ} directly. In this analysis, we chose the later option.

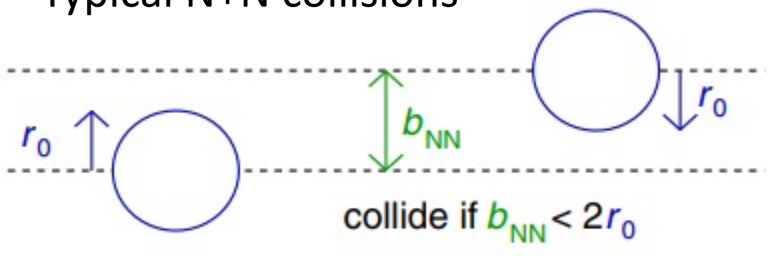
$$\frac{R_{dAu}^{\pi^0}}{R_{dAu}^{\gamma}} = \frac{(Y_{dAu}^{\pi^0}/Y_{pp}^{\pi^0})}{(Y_{dAu}^{\gamma}/Y_{pp}^{\gamma})} = \frac{(Y_{dAu}^{\pi^0}/Y_{dAu}^{\gamma})}{(Y_{pp}^{\pi^0}/Y_{pp}^{\gamma})} \tag{5.5}$$



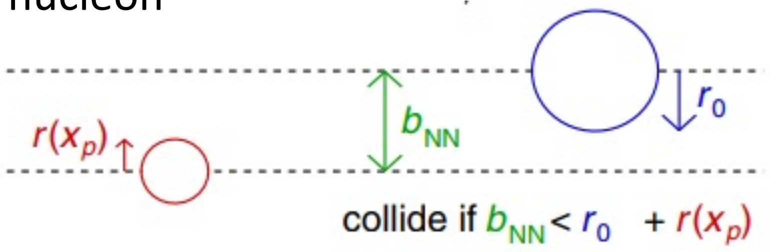
In this plot, there is no strange enhancement in peripheral bins. In fact all values in minimum bias, 20-40%, 40-60% and 60-88% are comparable. The average value in 0-20% for >7.5GeV appears to have residual suppression. Is this coming from energy loss in QGP? It is hard to say with this statistical error. More information can be gained by analysing the 0-20% centrality event class in finer bins of centrality. But that is outside the scope of this thesis.

high-x (effective) size fluctuations

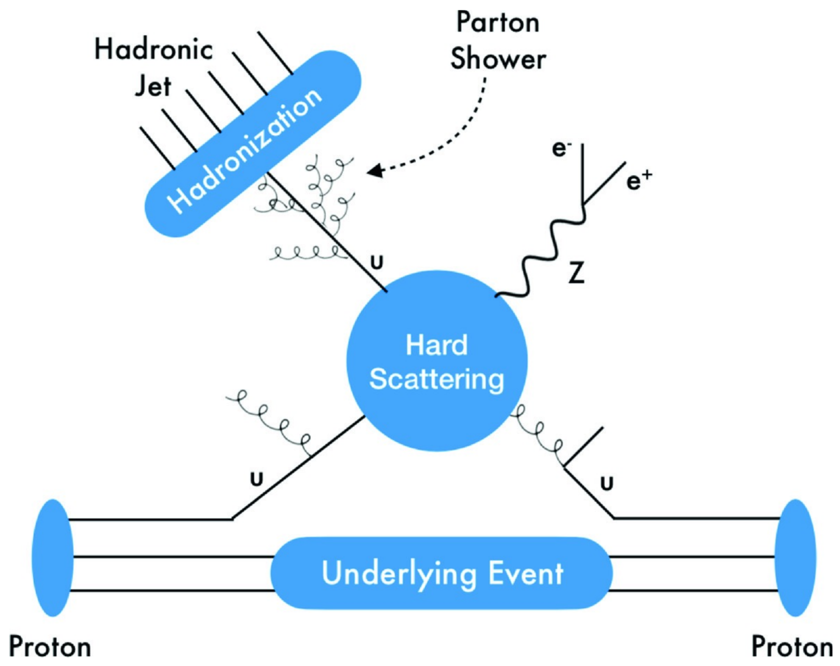
Typical N+N collisions



N+N collisions with large-x_p projectile nucleon

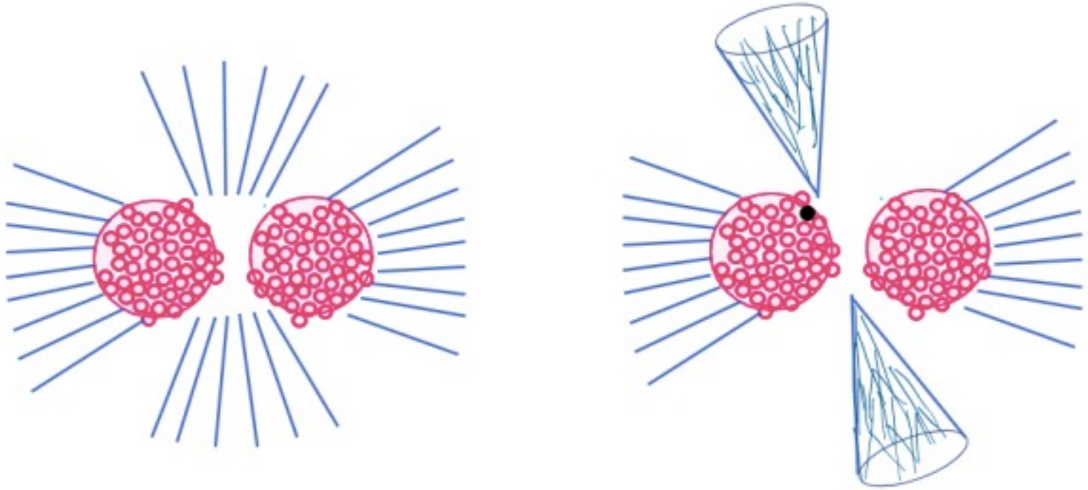


Phys. Rev. C 94 (2016), 024915



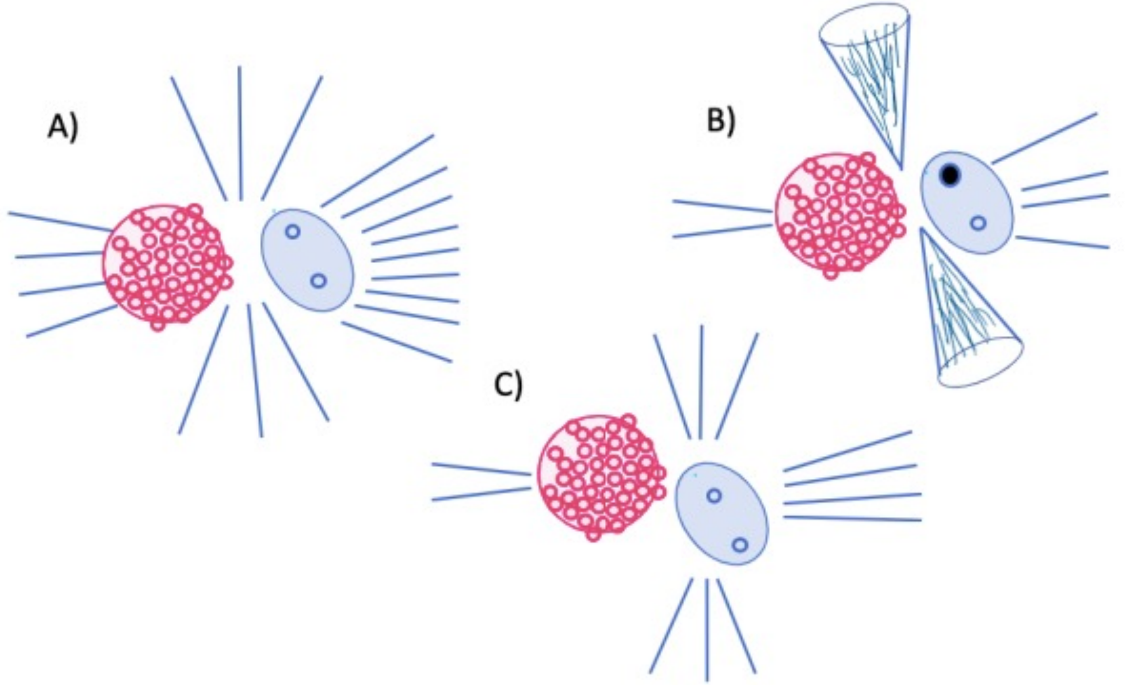
The high-X parton creates the hard scattering event. But the underlying event is severely depleted.

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.



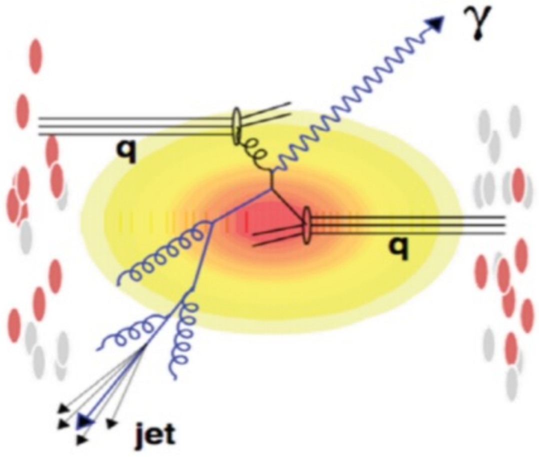
In a heavy-ion collision, the presence of one high-X parton nuclei, creates the jets, but the average underlying event isn't affected as there are several other partons for interactions.

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 pT (or x) dependent change. The bin-shift is larger at higher momentum.



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

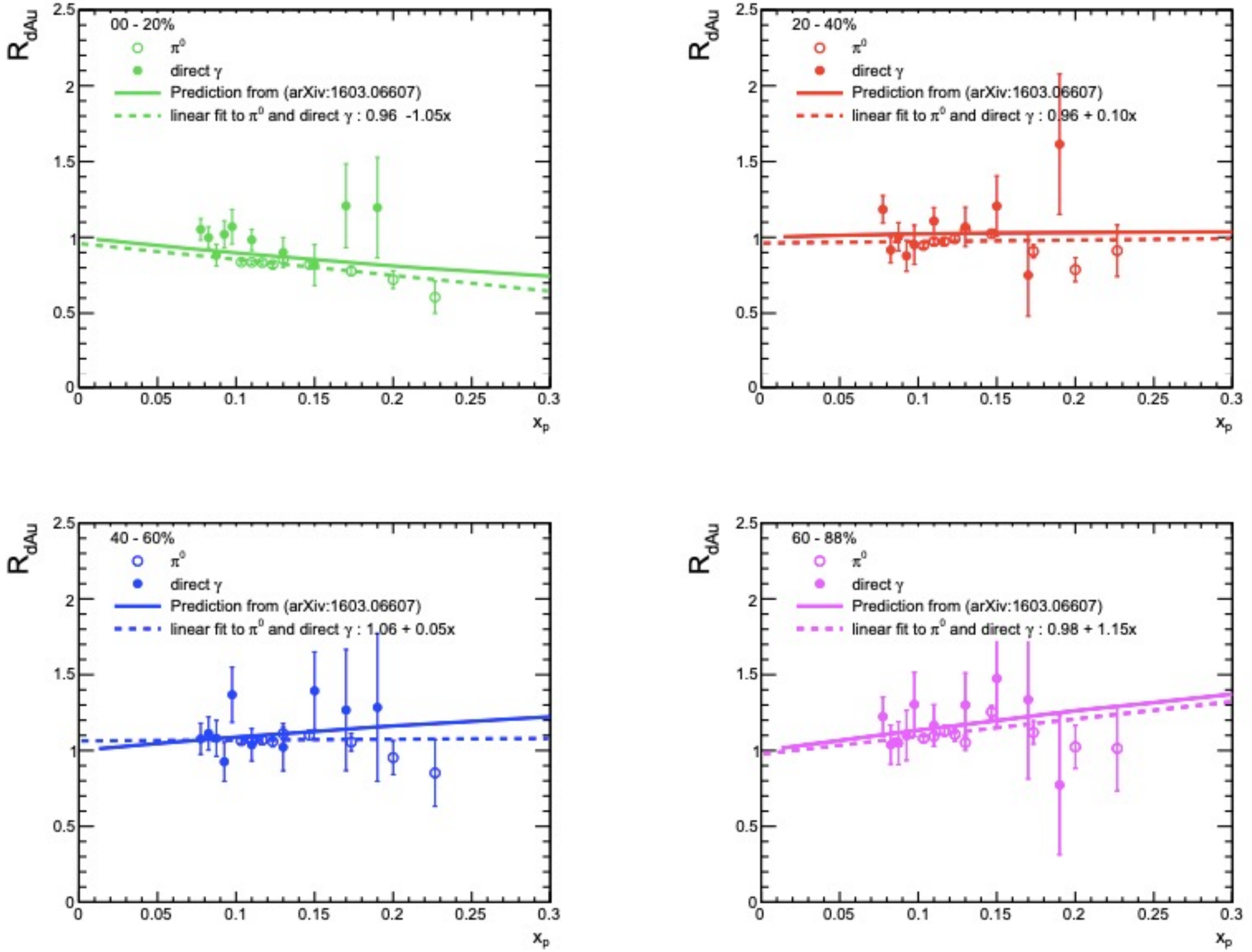
$R_{dAu}^{\pi^0}$ and R_{dAu}^{γ} as a function of parton momentum x



$$x_p = 2p_T^{jet}/\sqrt{s_{NN}} \approx 2p_T^{\pi^0}/(0.75 * \sqrt{s_{NN}})$$

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

Does our data fit the expectation from the "shrinking nucleon" picture?



SUMMARY

Analysis Motivation

- R_{dAu} (jets and Pi0) central events are suppressed and peripheral events are enhanced
- How is Ncoll obtained in experiments
  - Intrinsic bias in Glauber Model

Analysis Plots

- Ratio of gamma/Pi0 to prove that there is a bias.
- Nuclear Modification Factor of π^0 and direct ϒ.
- Modified $R_{dAU}(p_T)$ using direct ϒ.
- Raa(x) compared to “shrinking nucleon” model

Analysis Conclusion

- Determination of N_{coll} from Glauber Model is biased in small system collisions.
- New tool to bypass the requirement of using Ncoll using direct photons
- Future analysis in p+Au and He+Au system will provide more clarification.