STUDY OF HIGH-PT DIRECT PHOTONS IN SMALL SYSTEMS AT PHENIX

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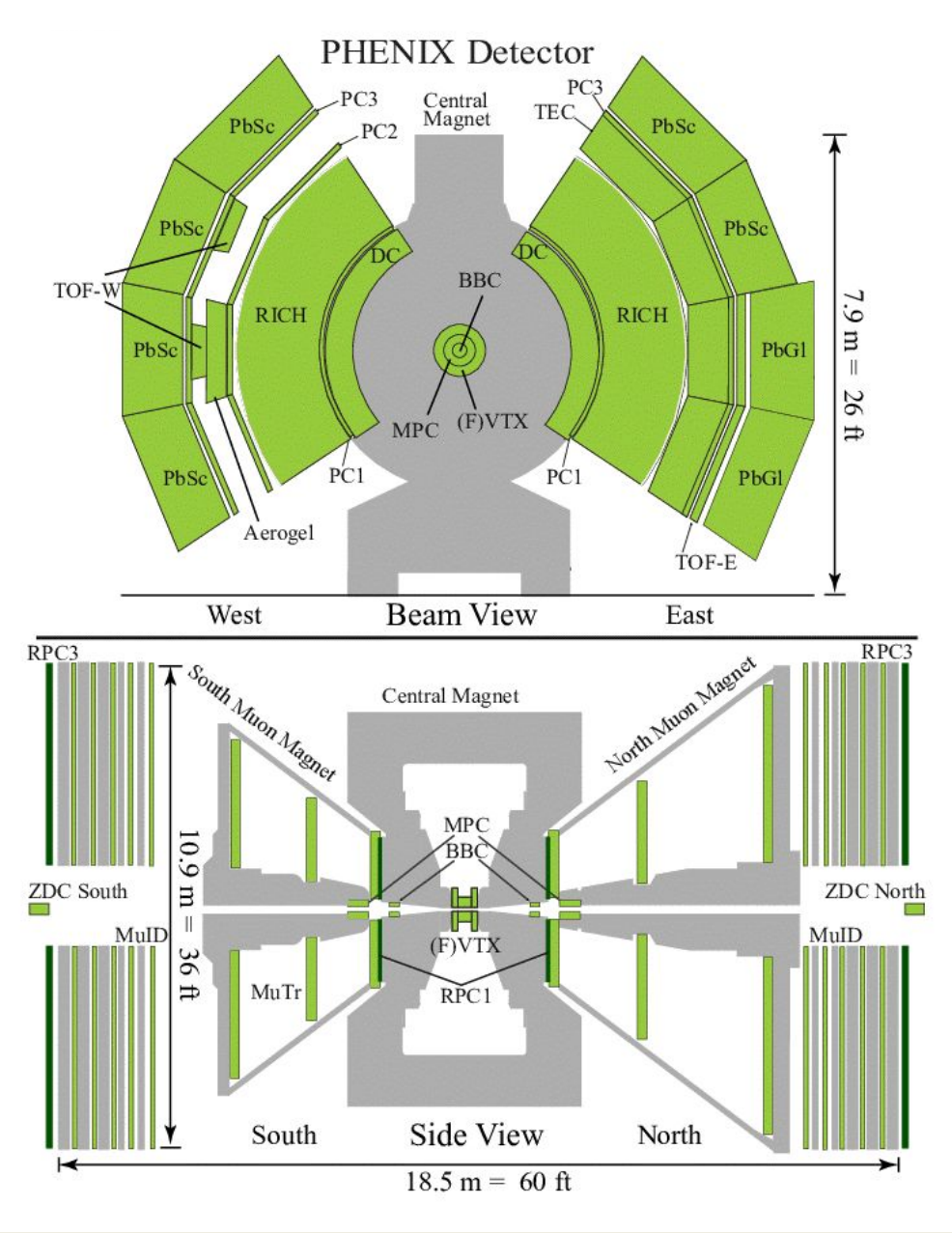
Mar. 4th, 2022



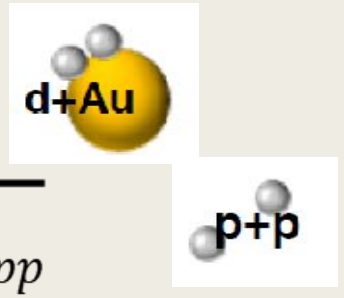
Outline

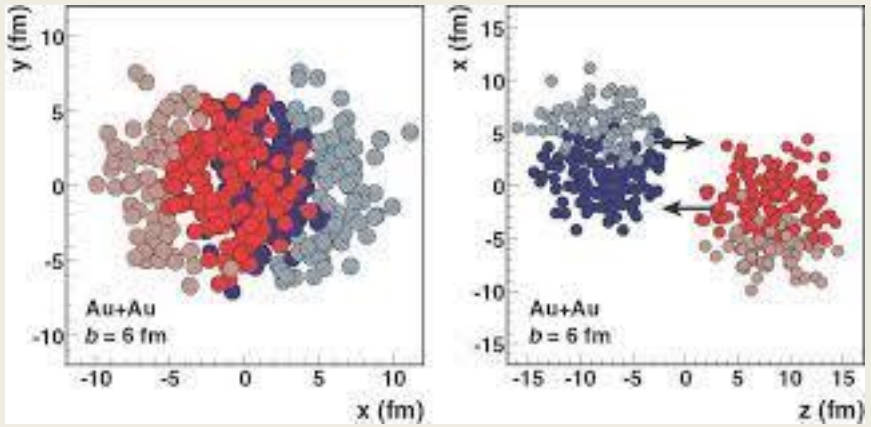
- Motivation
- Possible centrality bias in small systems
- 2D response matrix method
- Results and discussions
- Summary

Nuclear Modification Factor

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

$$R_{AB}(pt) = \frac{\frac{d^2N_{AB}}{dp_T d\eta}}{\langle N_{coll}\rangle * \frac{d^2N_{pp}}{dp_T d\eta}} = \frac{Y_{AB}}{\langle N_{coll}\rangle * Y_{pp}}$$





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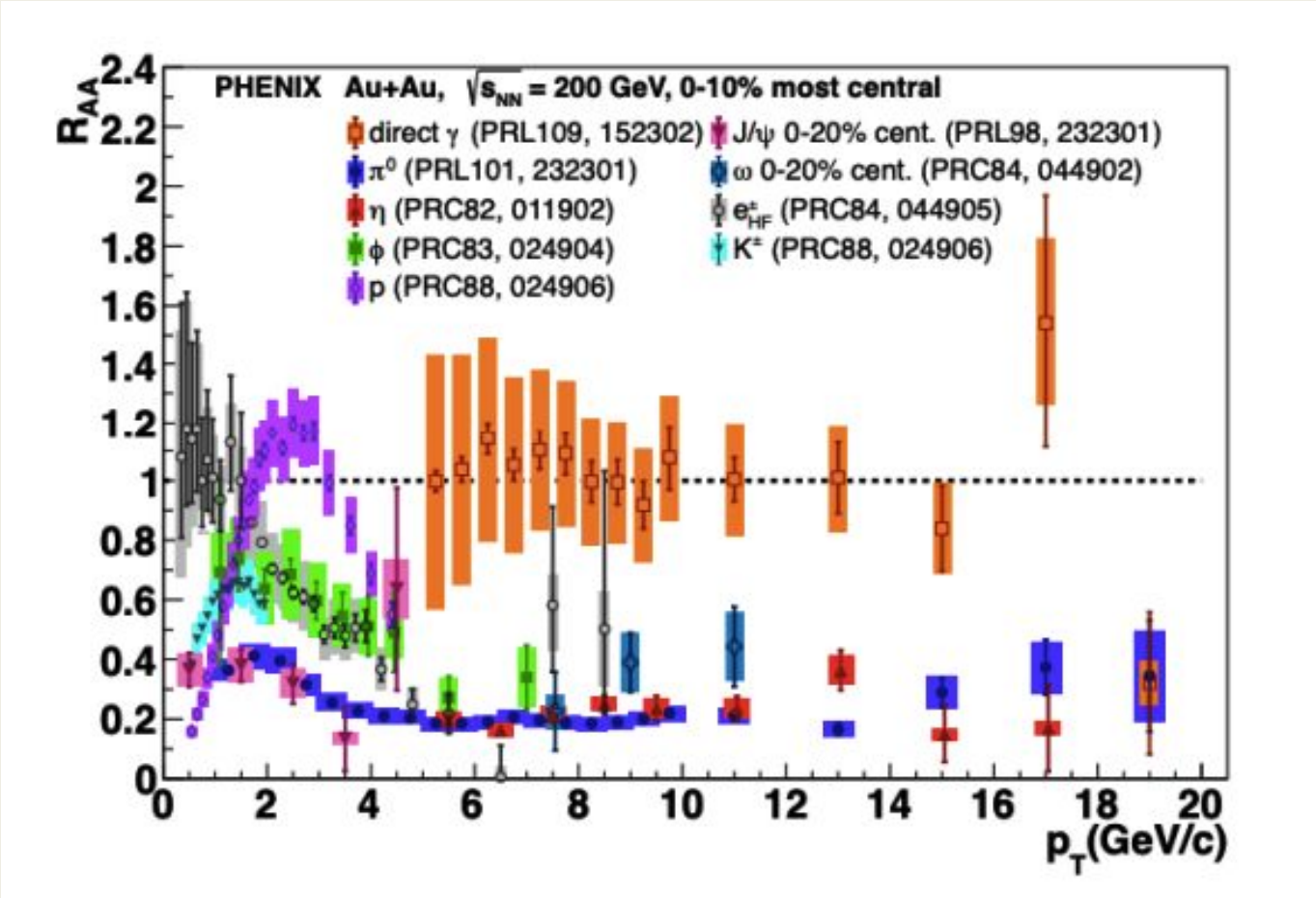
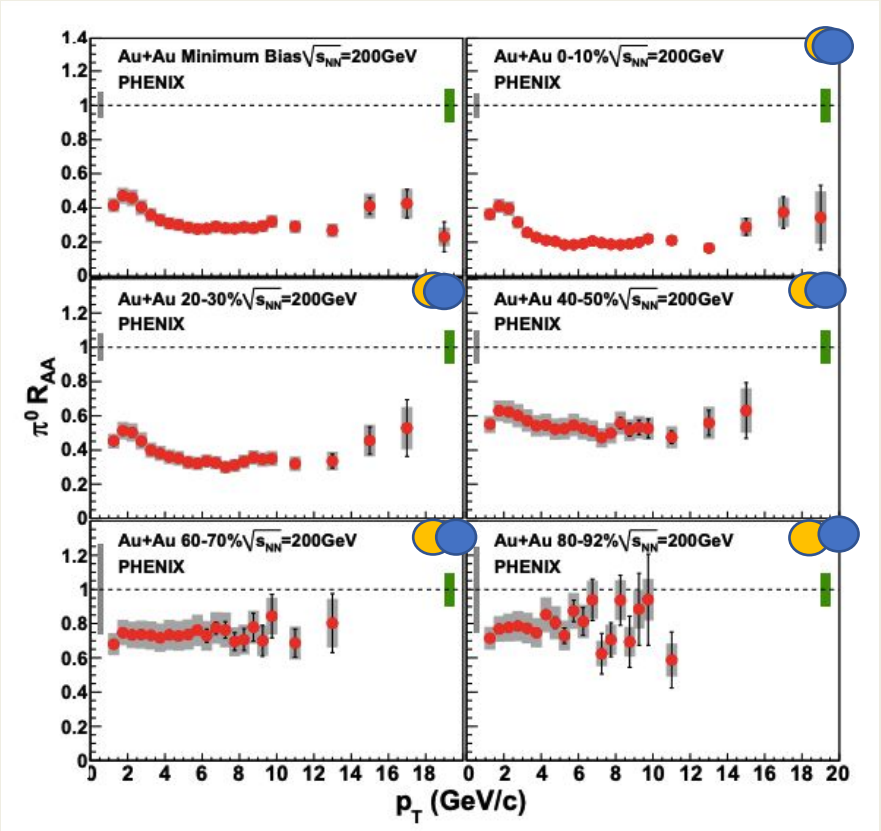
$R_{AB} < 1$ is a signature of QGP

- **Partons** interact with the QGP and lose momentum in it and thus its $R_{AB}(p_T)$ is suppressed.
- The **direct photon** does not interact via the strong nuclear force and its $R_{AB}(p_T)$ scales exactly with p+p collisions



Au+Au
π^0 suppression as a function of centrality



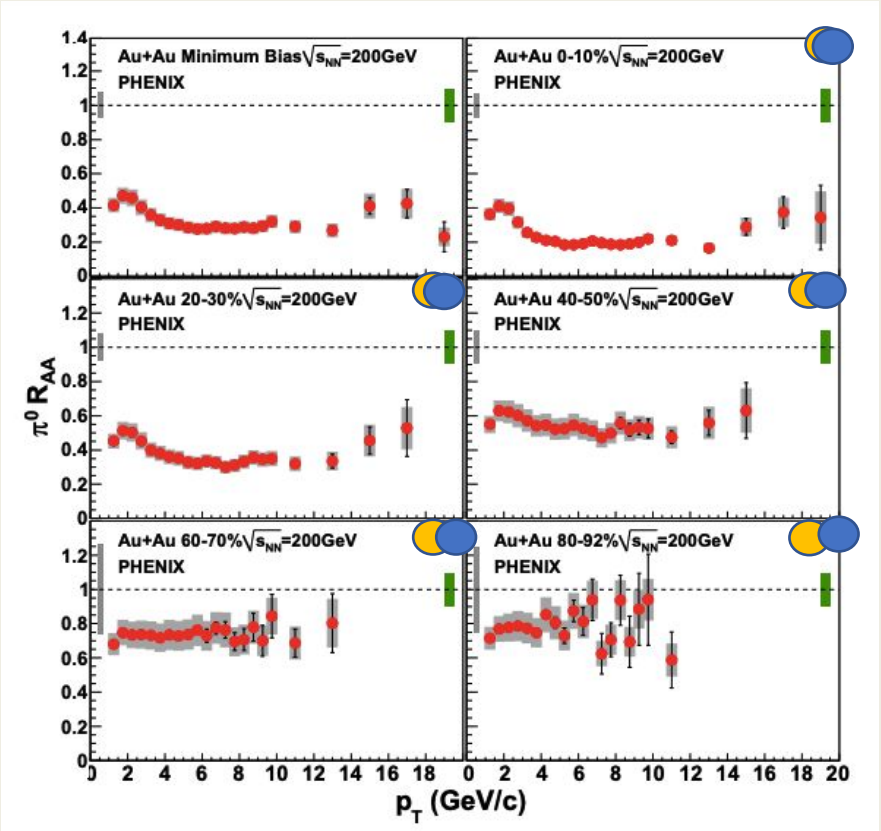
Phys. Rev. L 101 (2008) 232301

- 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 collisions in which QGP is formed.

Au+Au
Suppression of π^0 and non-suppression of direct γ



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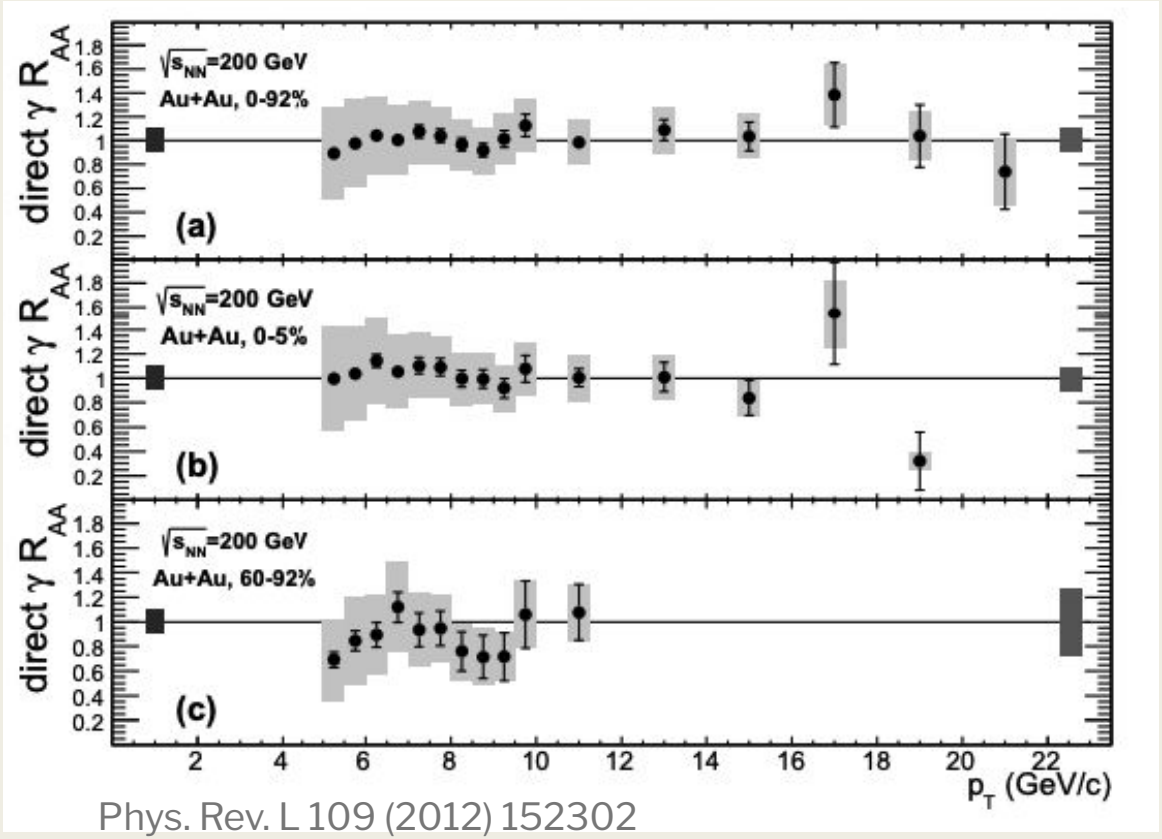
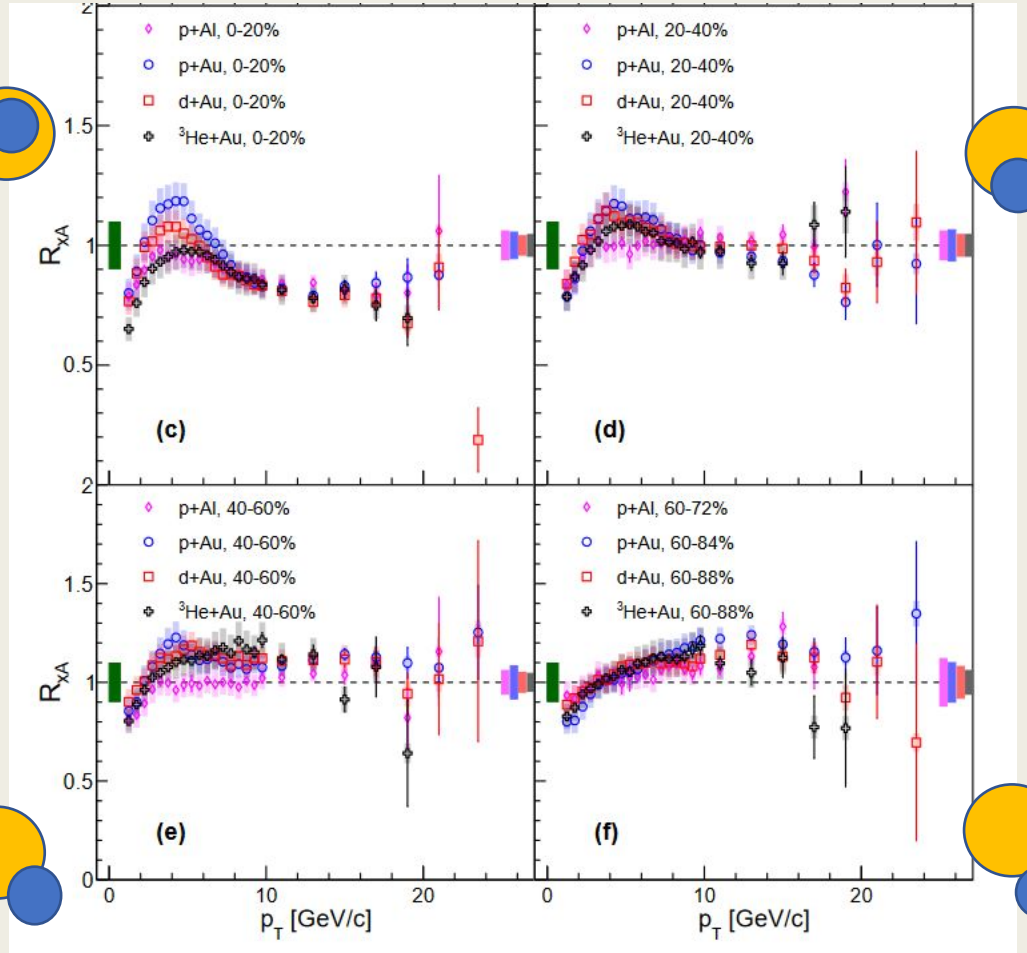


Phys. Rev. L 109 (2012) 152302

- It is unity at all centralities.

- As expected, the QGP is transparent to direct photons

Nuclear modification factor for π^0 in p/d+Au collisions



axiv: 2111.05756

Reading the plot…

$$R_{AA}(pt) = \frac{\frac{dN_{AA}}{dp_T}}{\langle N_{coll} \rangle \frac{dN_{pp}}{dp_T}}$$

- Both p+Au and d+Au show large centrality dependence.
- In high p_T we observe suppression in central events and enhancement in peripheral events.
- While formation of QGP could explain suppression in central, there's no obvious explanation for the enhancement in peripheral collisions

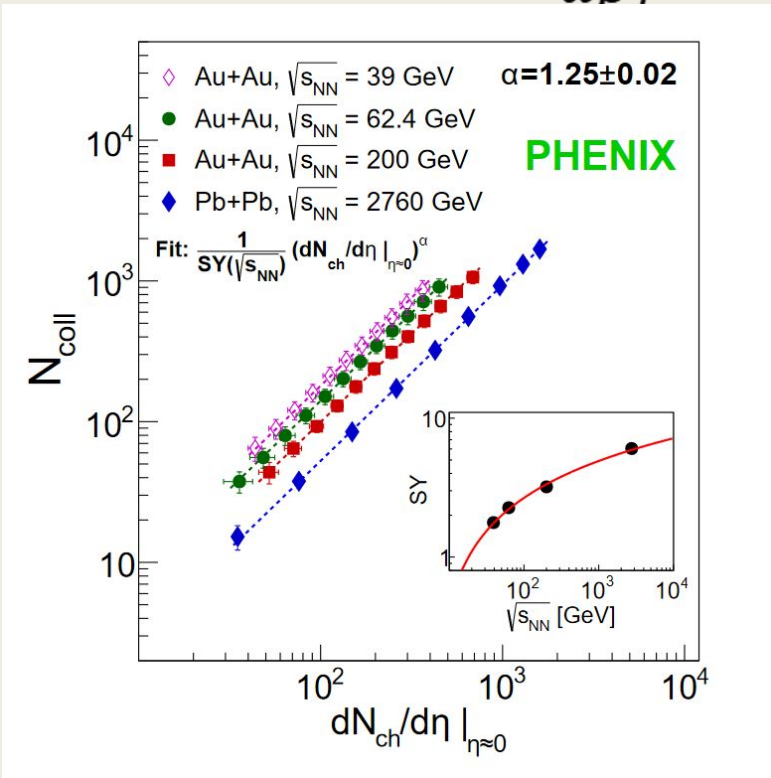
Is the centrality dependence a physics effect or an artifact of the way we bin centrality itself?
Are events mis-binned in centrality?

How is centrality determined in A-A (large-on-large) collisions?

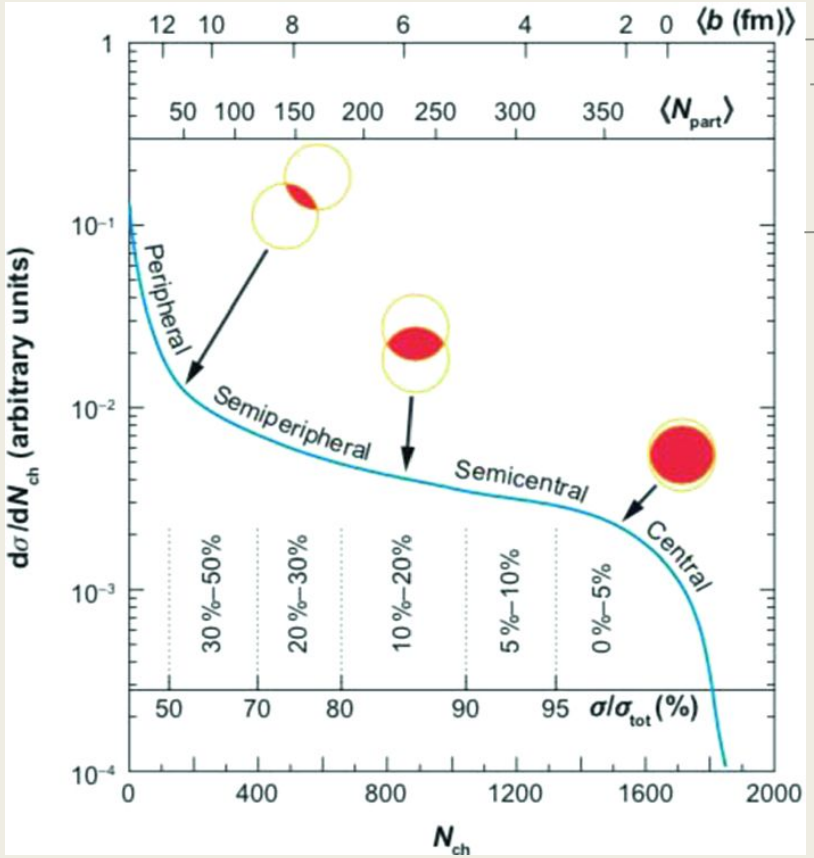
$$R_{AA}(pt) = \frac{\frac{dN_{AA}}{dp_T}(N_{ch})}{\langle N_{coll}\rangle \frac{dN_{pp}}{dp_T}}$$

N_{coll} : Average number of binary collisions in a type of event according to Glauber Model.

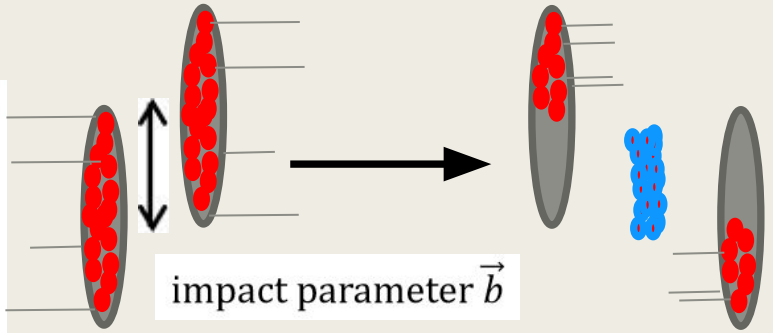
N_{part} : number of participating nucleon



Phys. Rev. Lett. 123.022301



Annu. Rev. Nucl. Part. Phys. Vol. 57:205-243



In heavy ion collisions, we manipulate the fact that the majority of the initial-state nucleon-nucleon collisions will be analogous to MB p+p collisions, with a small perturbation from much rarer hard interactions.

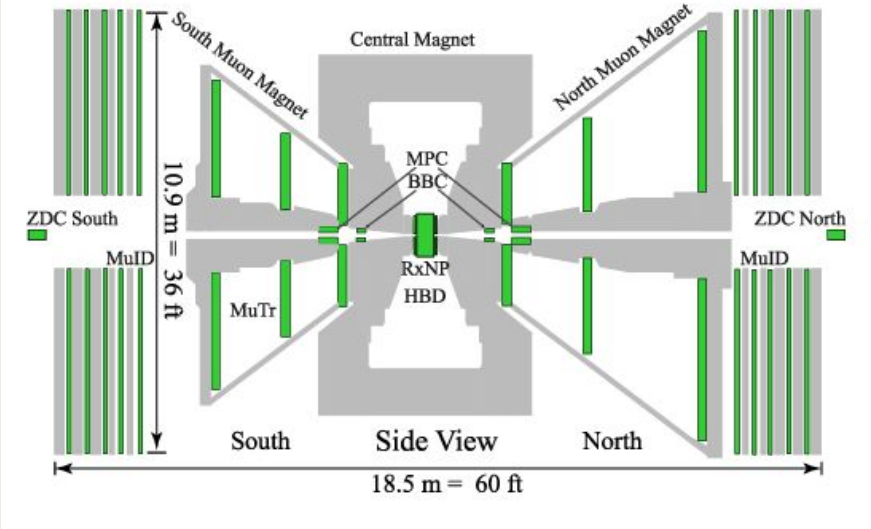
Annu Rev Nucl Part Sci 2007.57:205

- $N_{charge} \leftrightarrow N_{coll}$

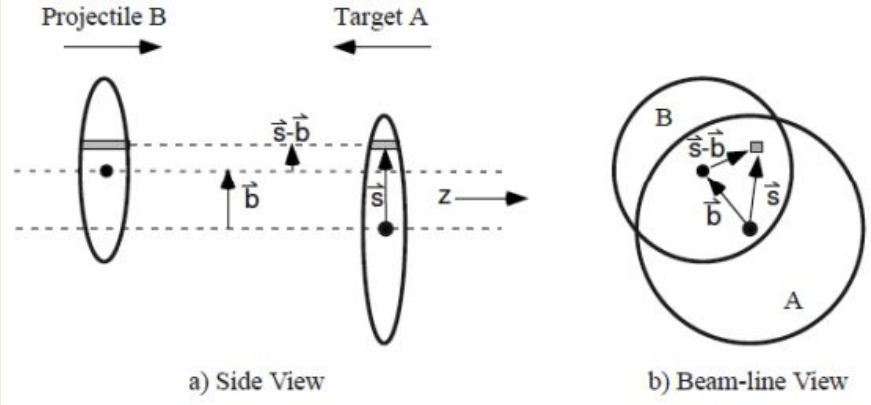
Measurement of number of binary collisions

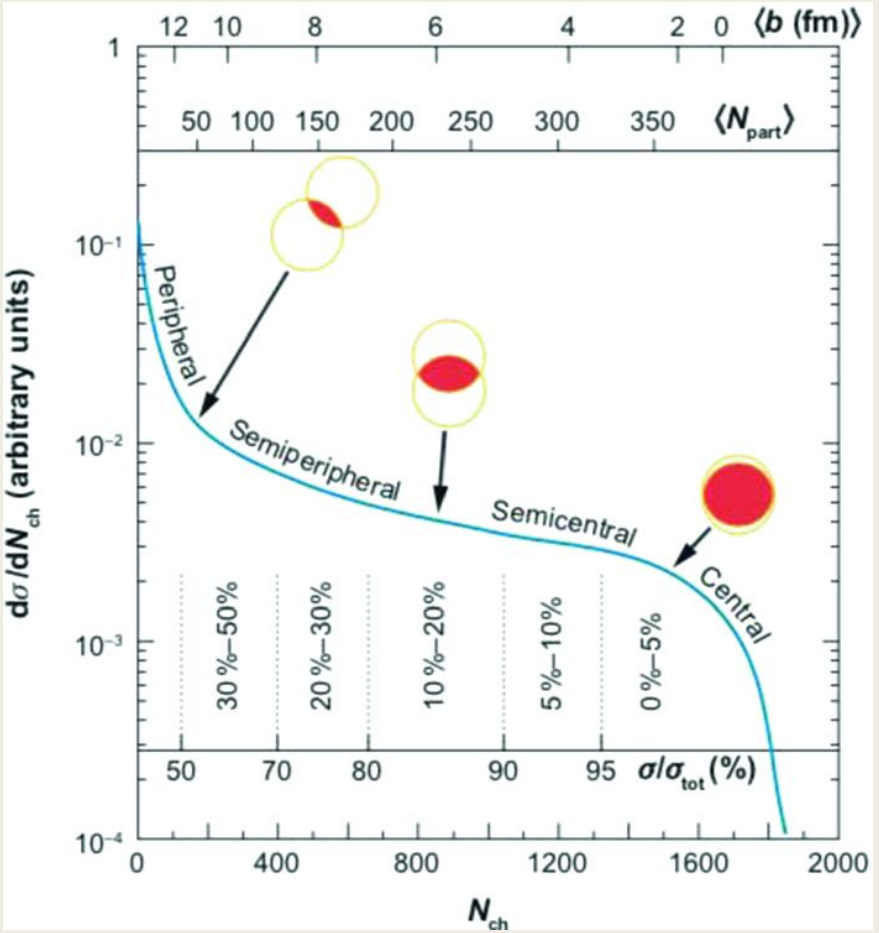
$$R_{AA}(pt) = \frac{\frac{dN_{AA}}{dp_T}}{\langle N_{coll} \rangle \frac{dN_{pp}}{dp_T}}$$

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 this to your specific detector.





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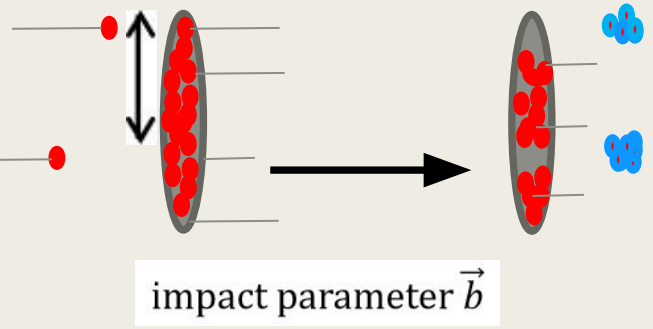
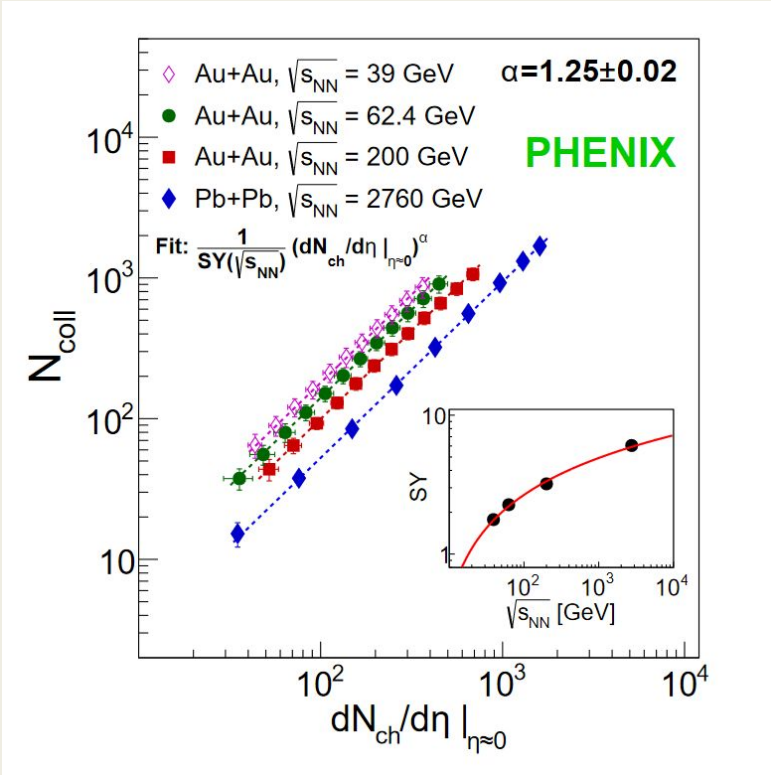
What's happening in p/d+Au collisions?

$$R_{AA}(pt) = \frac{\frac{dN_{AA}}{dp_T}(N_{ch})}{\langle N_{coll}\rangle \frac{dN_{pp}}{dp_T}}$$

N_{coll} : Average number of binary collisions in a type of event according to Glauber Model.

N_{part} : number of participating nucleon





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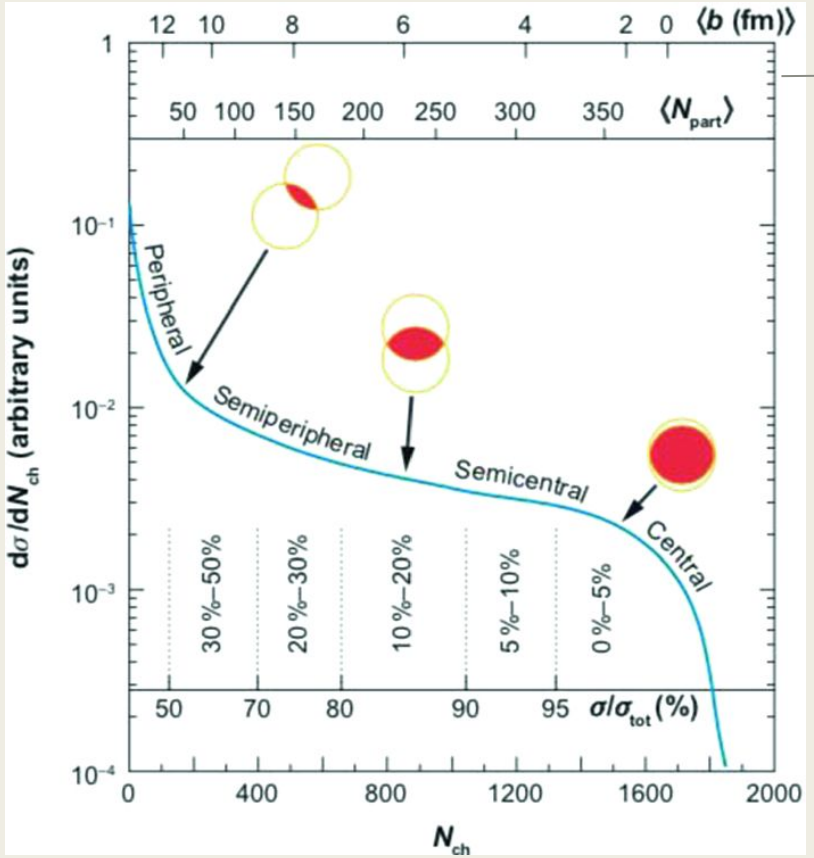

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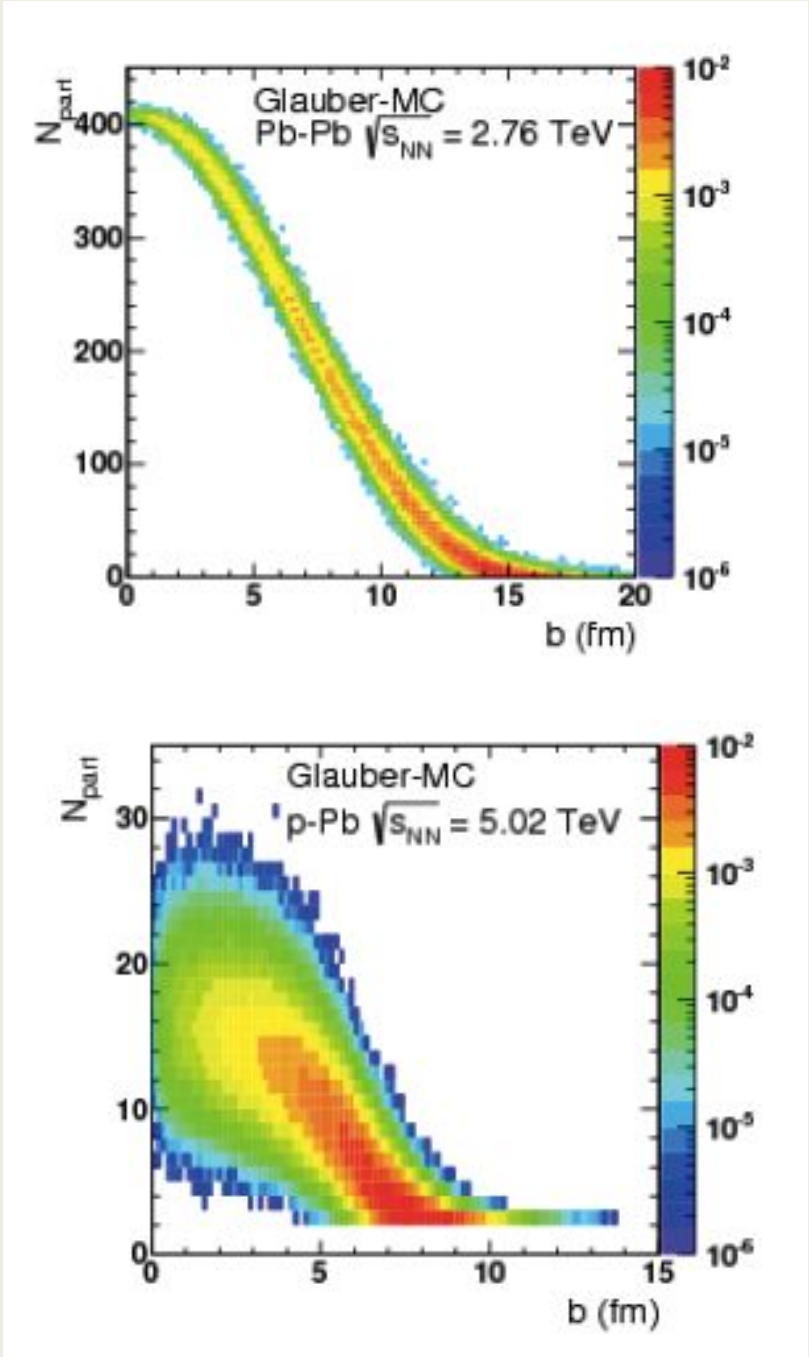
However, is it still true that in small systems…

- $N_{charge} \leftrightarrow N_{coll}$

Direct photons

Is Glauber model valid for small systems?

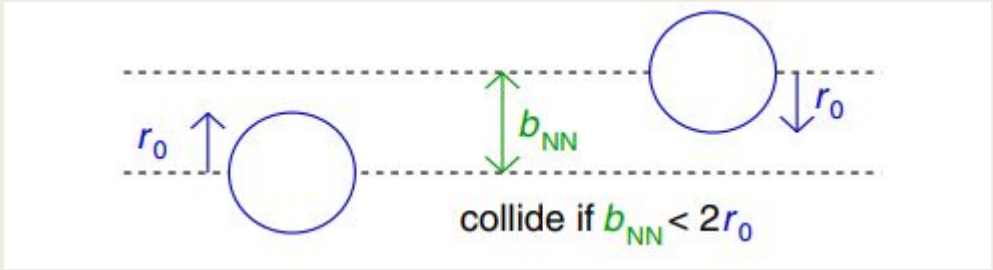
- Analyzing the 0-20% centrality bin in Pb+Pb is equivalent to studying the class of events with average impact parameter of 3fm with a very **small** variance.
- Analyzing the 0-20% centrality bin in p+Pb is also equivalent to studying the class of events with average impact parameter of 3fm but with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



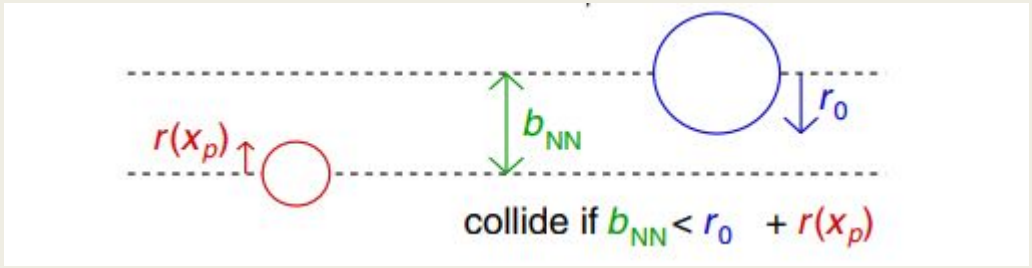
PR C 91, 064905 (2015)

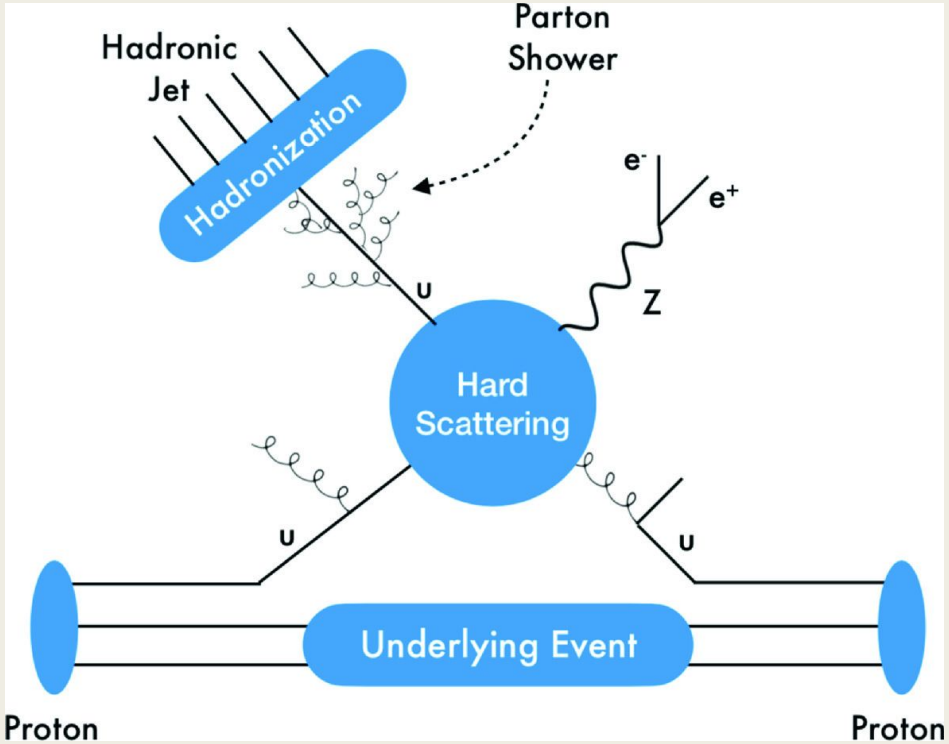
high-x (effective) size fluctuations

Typical N+N collisions



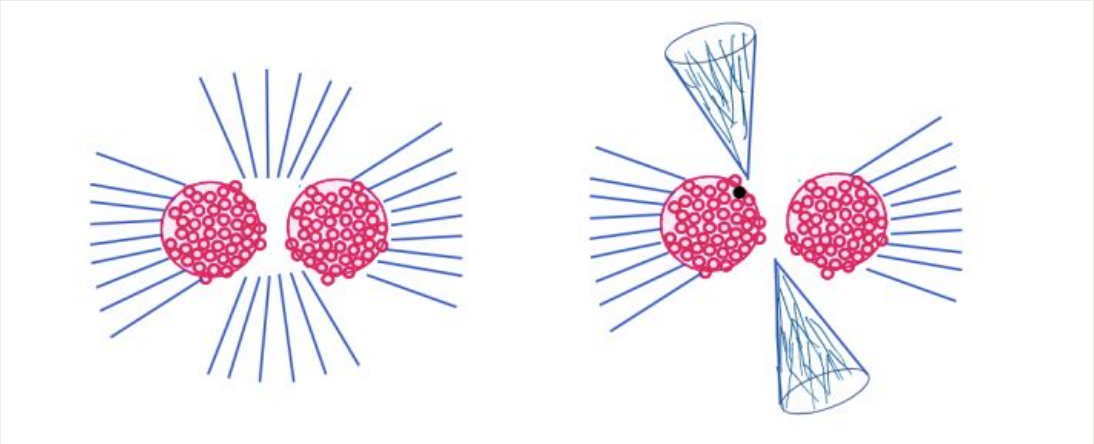
N+N collisions with large-x_p projectile nucleon





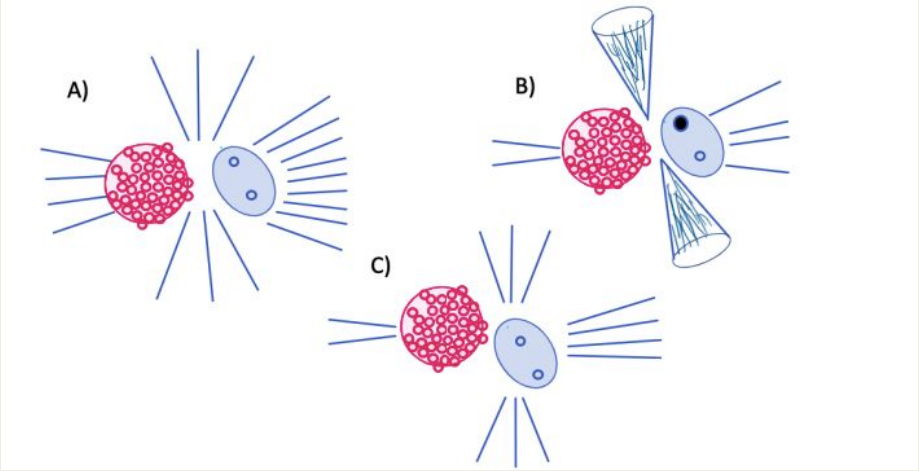
The high-X parton creates the hard scattering event. But the underlying event is severely depleted.

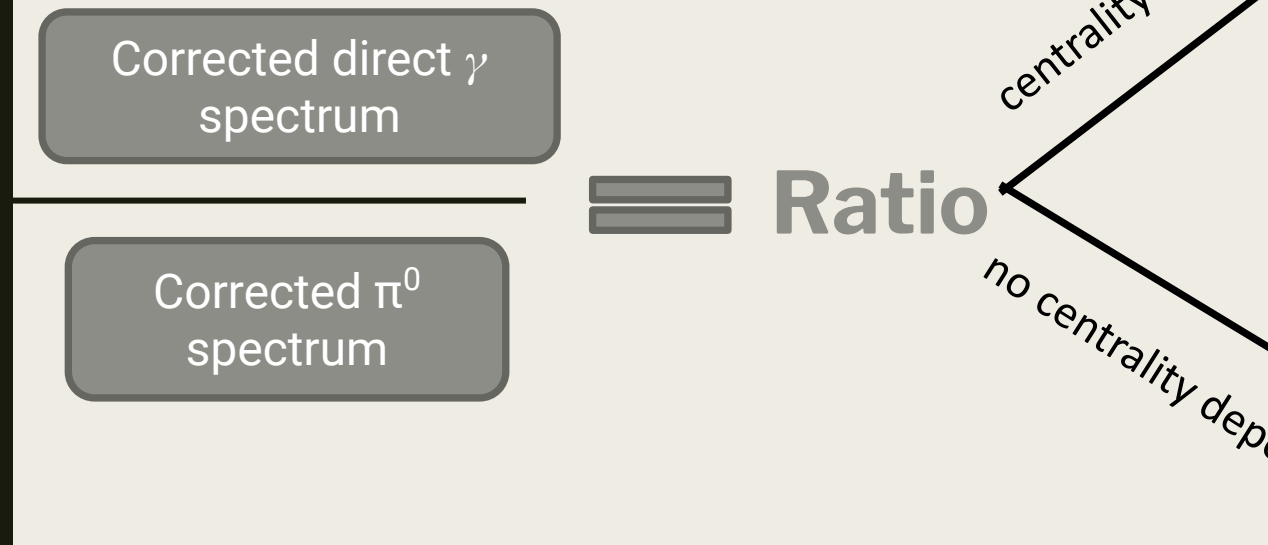
This can be thought of as
a) energy conservation or Phys. Rev C 97, 054904 (2018)
b) change in the cross-section of the nucleons due to the presence of high-X parton. Phys. Rev. C 94 (2016), 024915



In a heavy-ion collision, the presence of one high-X parton nucleon, 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 often look more like a peripheral d+Au event.
This is a p_T (or x) dependent change. The bin-shift is larger at higher momentum.

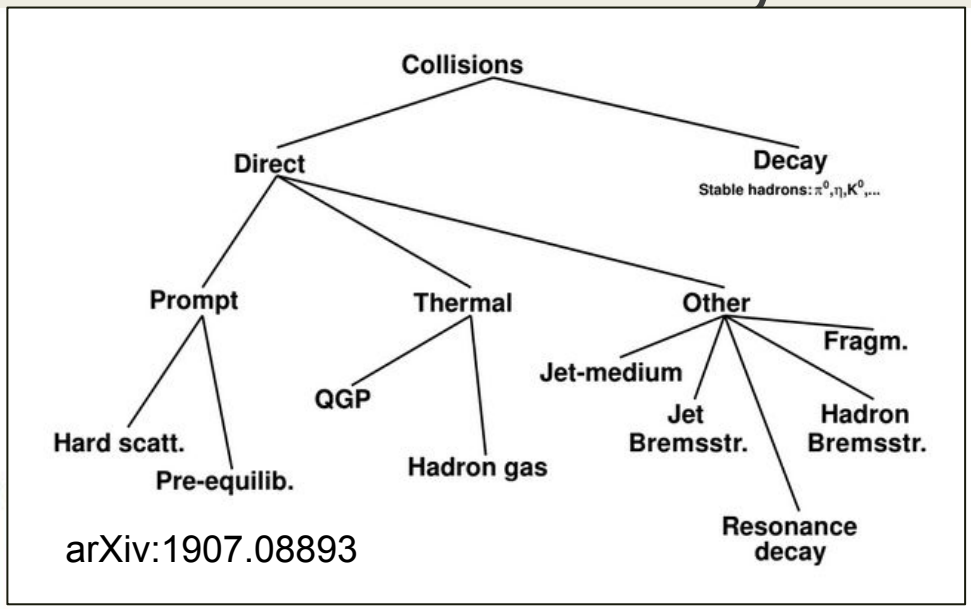




The centrality dependence that we see in π^0 spectrum is because of true physics effects, which do not affect direct photons.

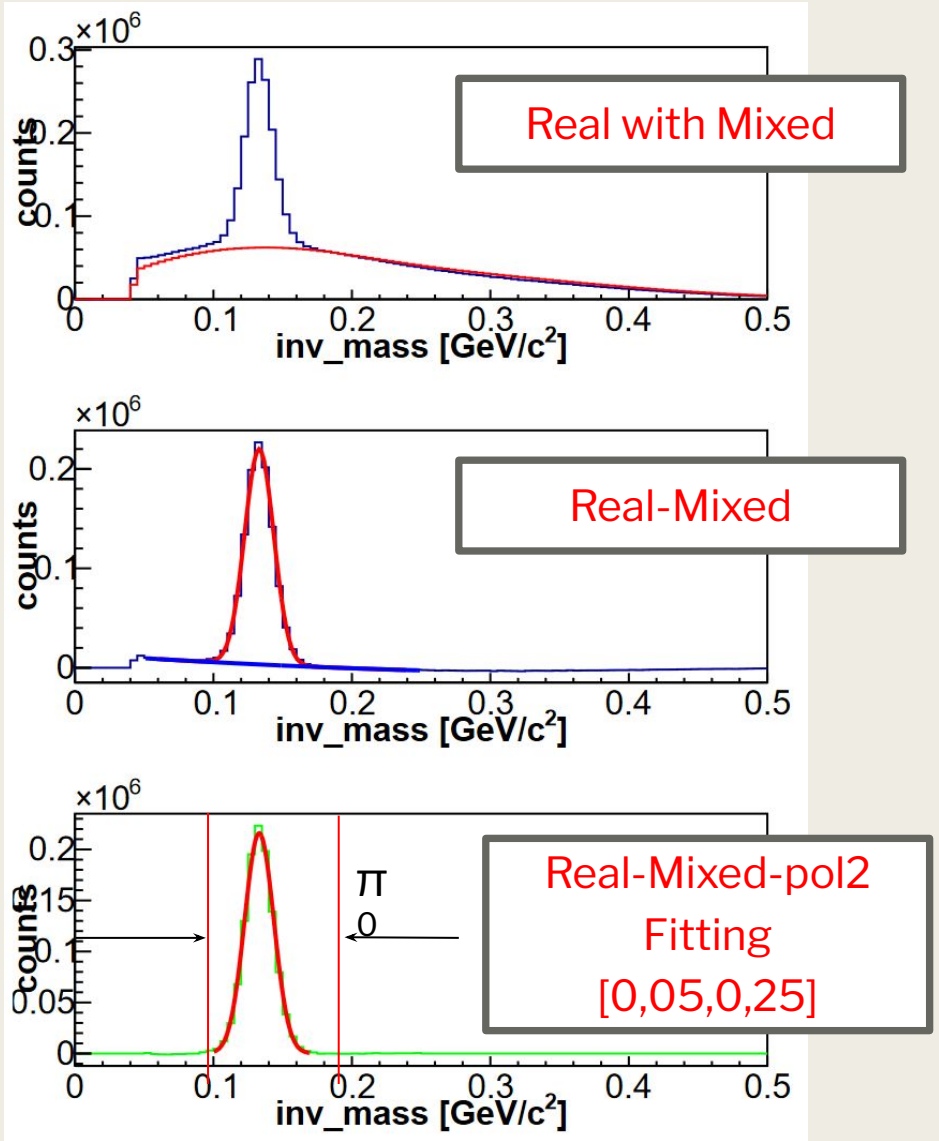
The centrality dependence that we see in π^0 spectrum is because of mis-binning of centrality. This affects direct photons equally.

Flowchart of the analysis

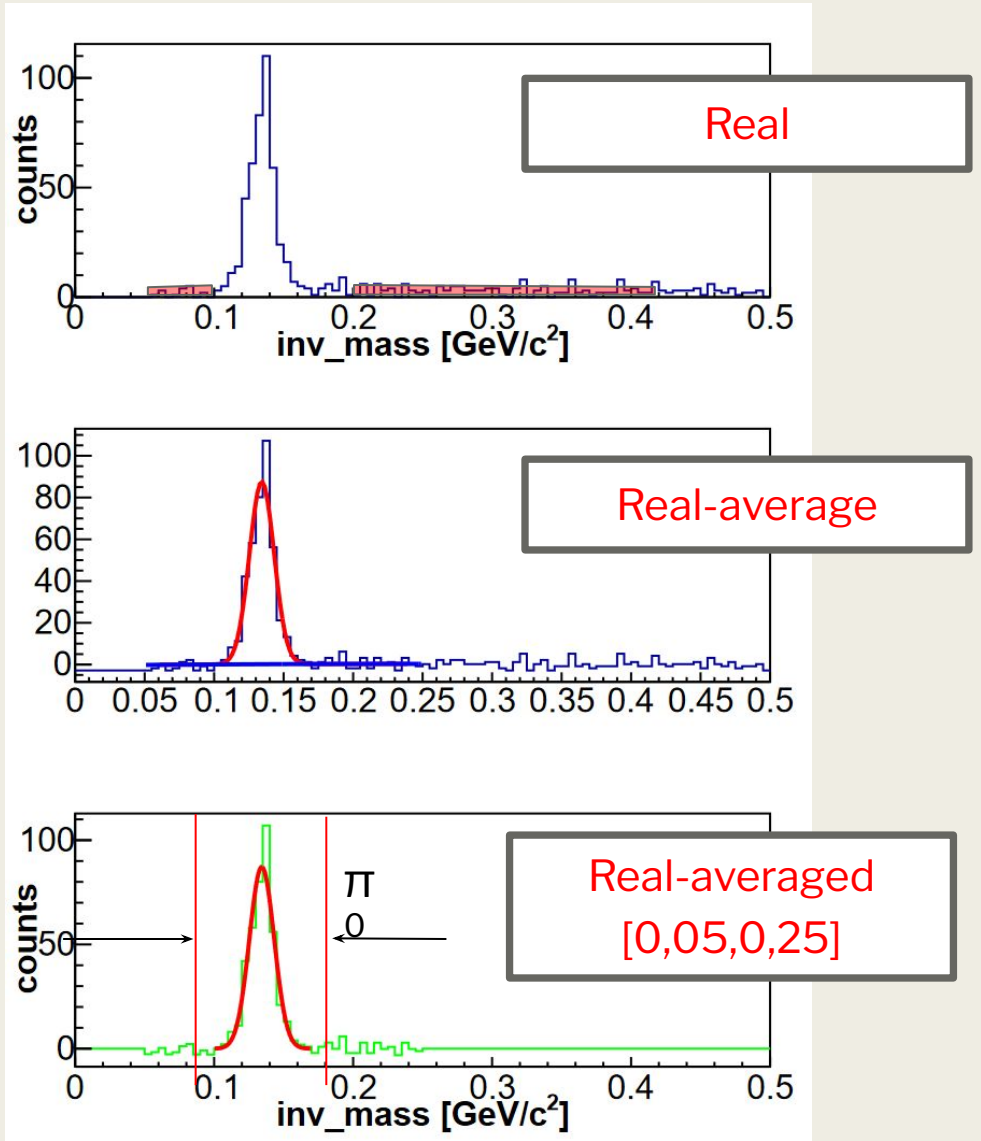


$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\emptyset)}$$

Mixed event method at low-p_T



Average bkg. subtraction method at high-p_T



What should be corrected ?

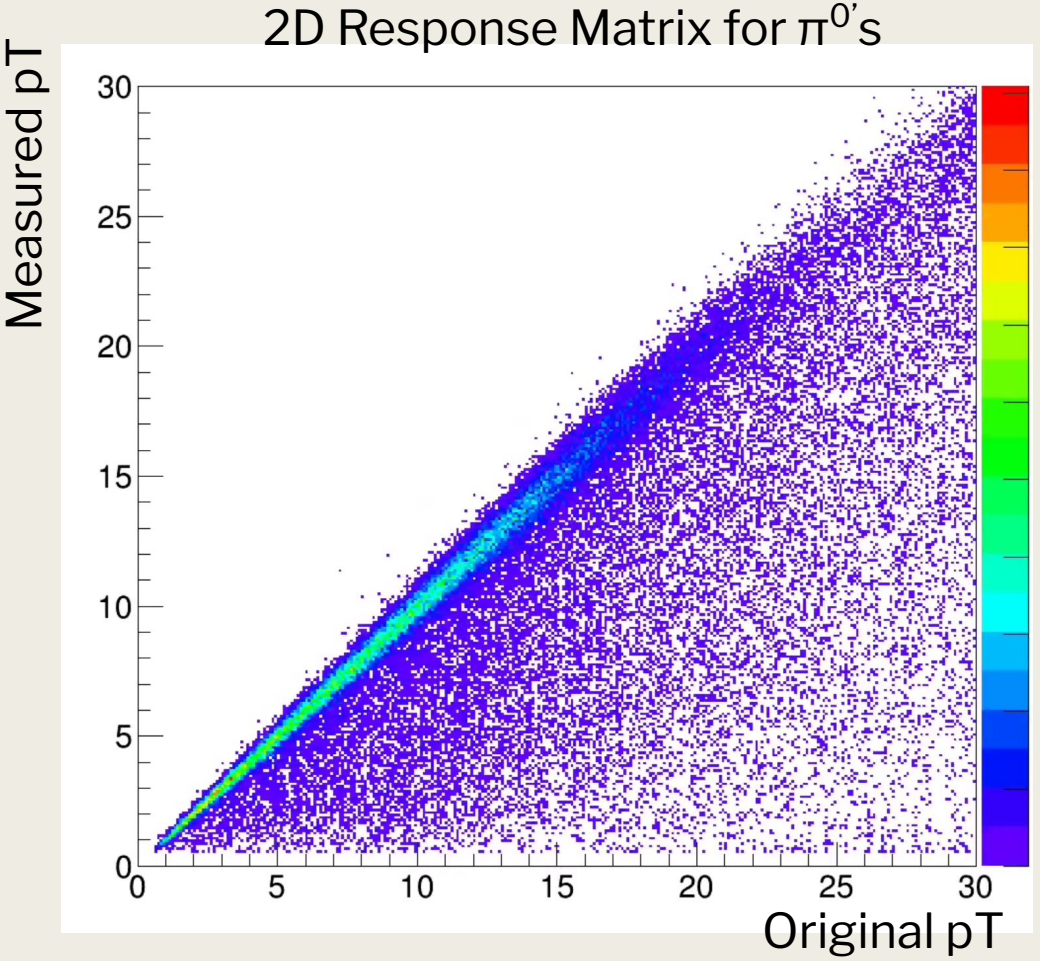
Acceptance:
- Coverage of rapidity $|\eta|<0.35$
- Dead/hot towers (3*3 exclusion) in EMCal
- Cluster selection geometrically for analysis

Efficiency:
- PID efficiency
- Merging effect at high p_T
- Cluster break-up at high p_T

Smearing:
- The p_T of the reconstructed π^0 might be different from the true p_T

Migration takes place between p_T bins.
True p_T is steep , so migration is mostly to lower p_T.

Inverting this response matrix is problematic due to the small, fluctuating off-diagonal elements.



Simulated response matrix -- true -> measured

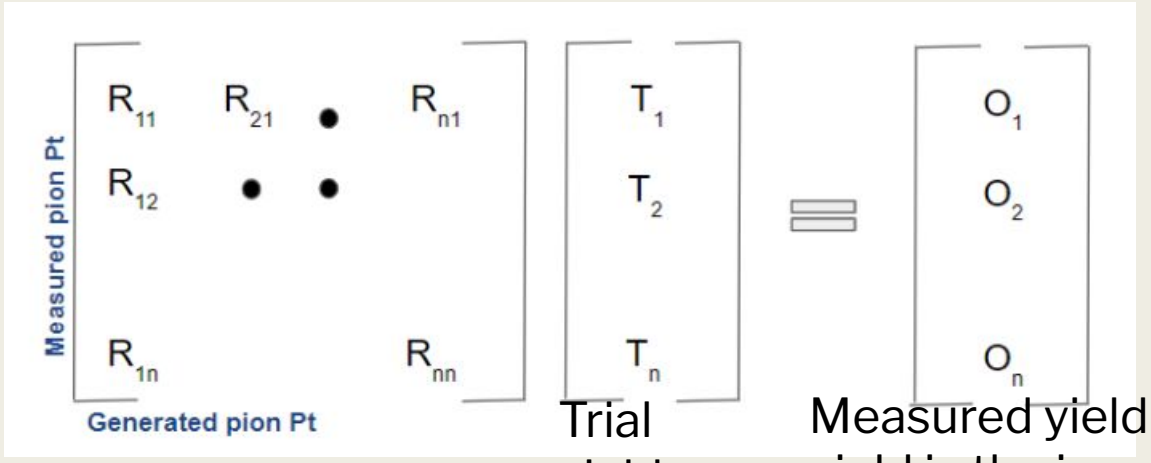
$$\begin{bmatrix} x_{11} & x_{12} & \dots & x_{1n} \\ x_{21} & x_{22} & \dots & x_{2n} \\ . & . & \dots & . \\ . & . & \dots & . \\ x_{m1} & x_{m2} & \dots & x_{mn} \end{bmatrix} \; elements\ divided\ with \begin{bmatrix} n_1 & n_2 & . & . & n_n \end{bmatrix}$$

n_n is the number of π^0 generated at p_T n

x_{mn} is the number of π^0 generated at p_T *n* but reconstructed as p_T *m*

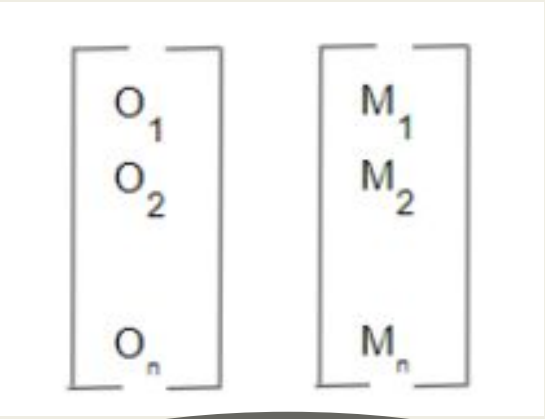
$$\longrightarrow \begin{bmatrix} \frac{x_{11}}{n_1} & \frac{x_{12}}{n_2} & \dots & \frac{x_{1n}}{n_n} \\ \frac{x_{21}}{n_1} & \frac{x_{22}}{n_2} & \dots & \frac{x_{2n}}{n_n} \\ . & . & \dots & . \\ . & . & \dots & . \\ \frac{x_{m1}}{n_1} & \frac{x_{m2}}{n_2} & \dots & \frac{x_{mn}}{n_n} \end{bmatrix}$$

How to use the response matrix without inverting it



Trial yield

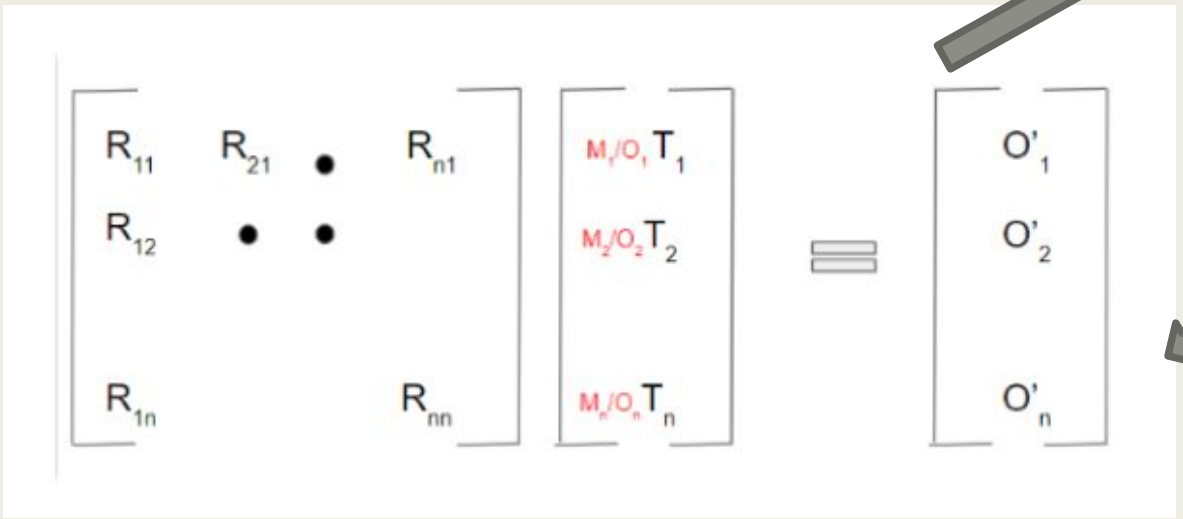
Measured yield if trial yield is the input



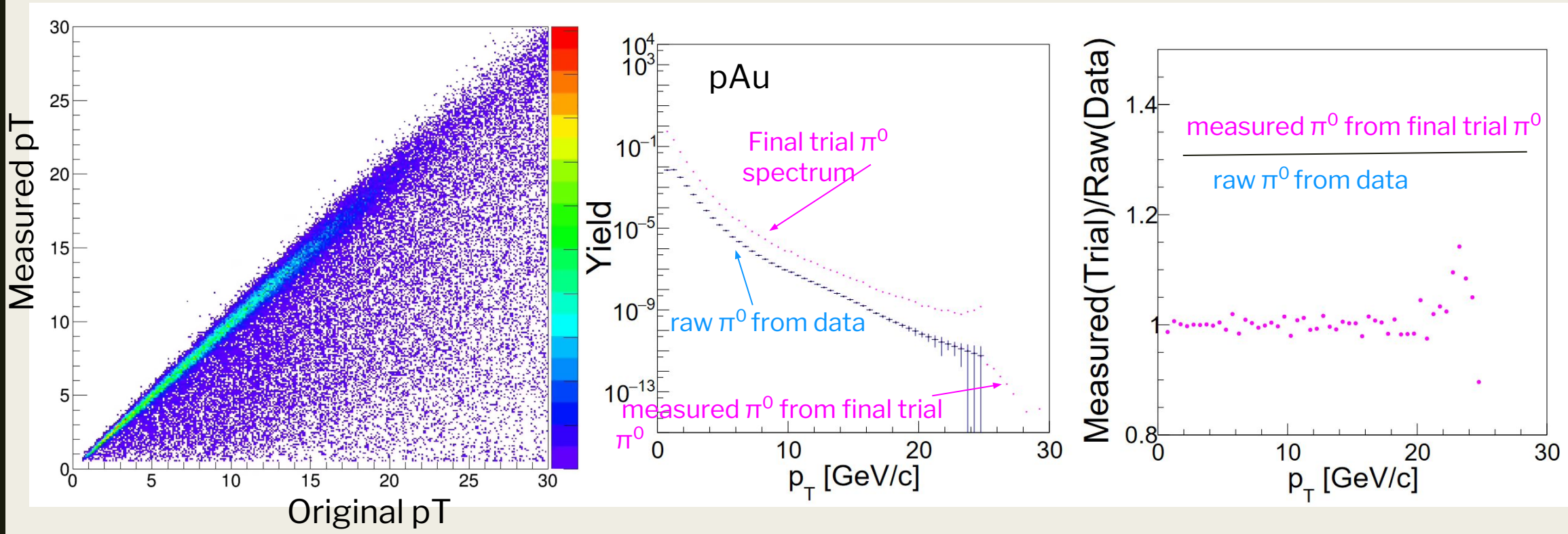
Compare to raw yield from data

Disagree

Agree



Final trial function is the corrected yield



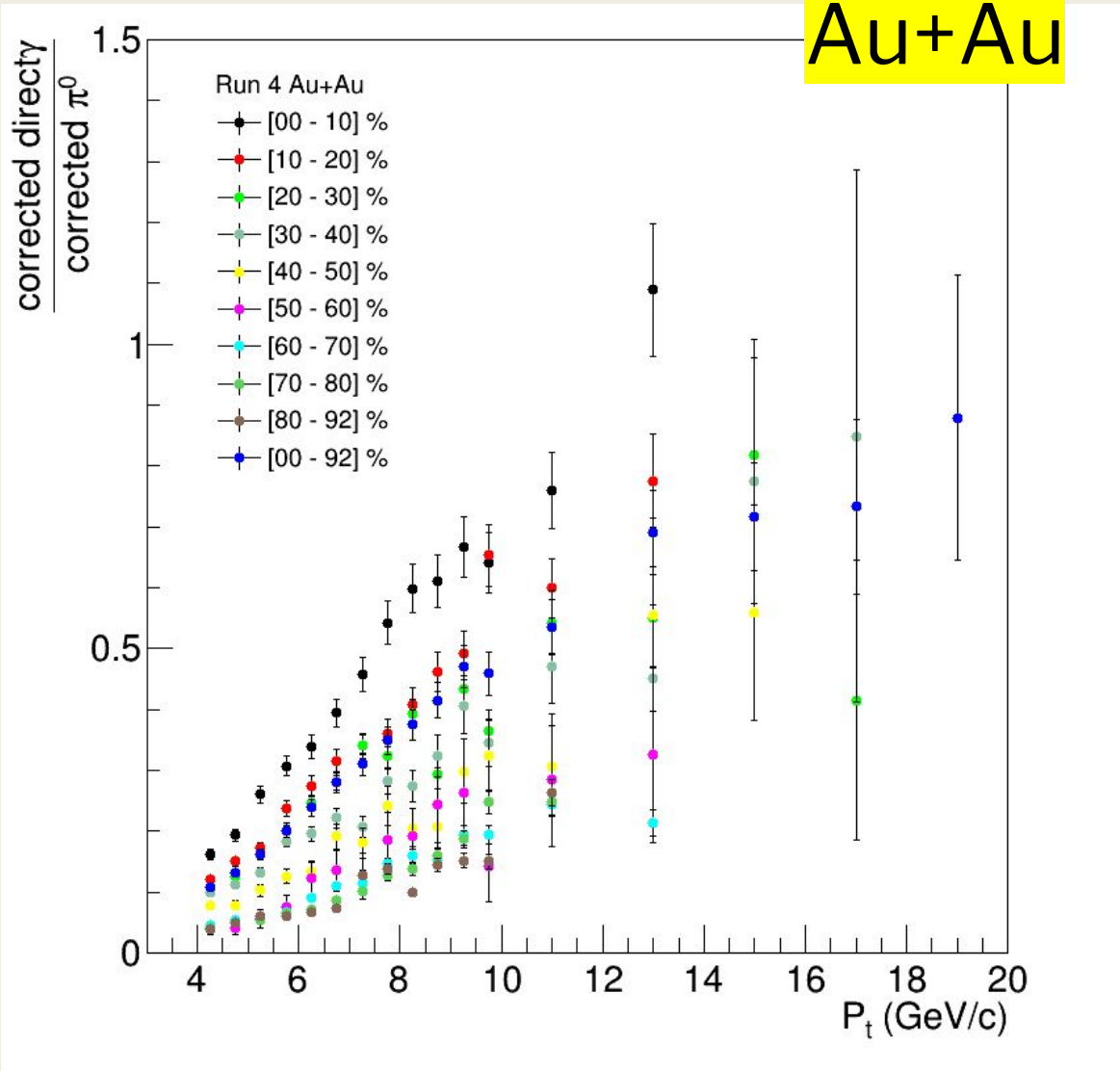
The blue curve is the raw spectrum extracted from data.
The magenta is the trial spectrum after 4 iterations.

Same procedures are done with π^0 decay and single γ correction.

Ratio of direct photon over π^0

Neutral π0's : arXiv:0801.4020
direct γ : arXiv:1205.5759

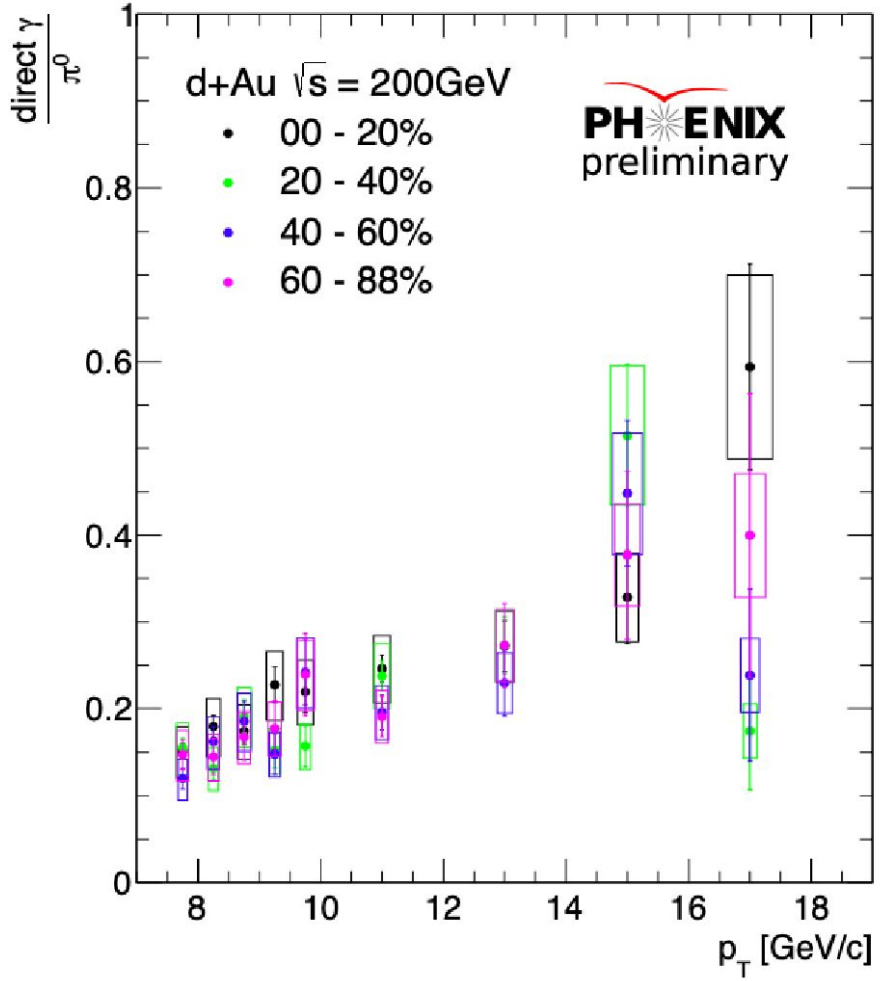
- This plot is obtained from making ratio of available published data for Au+Au system
- There is a clear centrality dependent ordering suggesting that in Au+Au collisions, the observed suppression in central collision and not in peripheral collision is an effect of strong nuclear force (QGP), which affects the π^0's but leaves the direct photons unaffected.



Ratio of direct photon over π^0

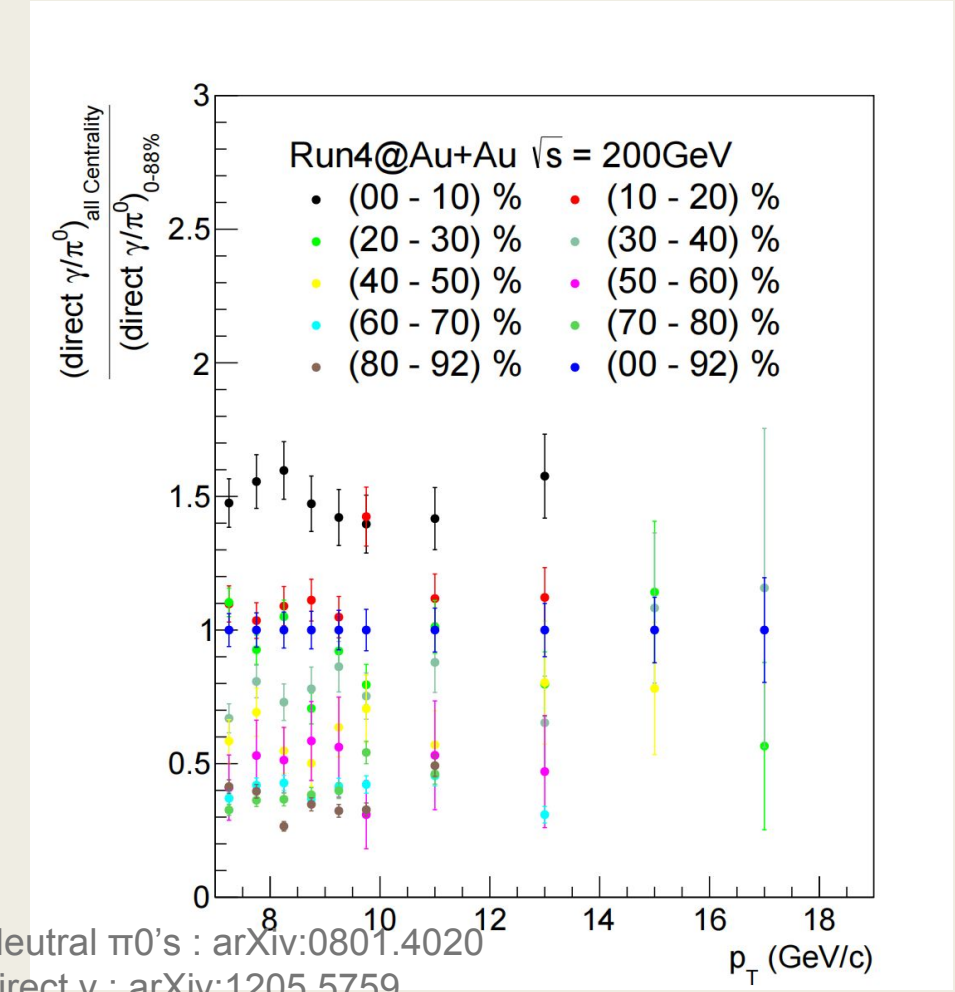
- There is a clear LACK OF centrality dependent ordering suggesting that in d+Au collisions there is a p_T dependent bias in centrality determination which affects BOTH π^0's and direct photons.

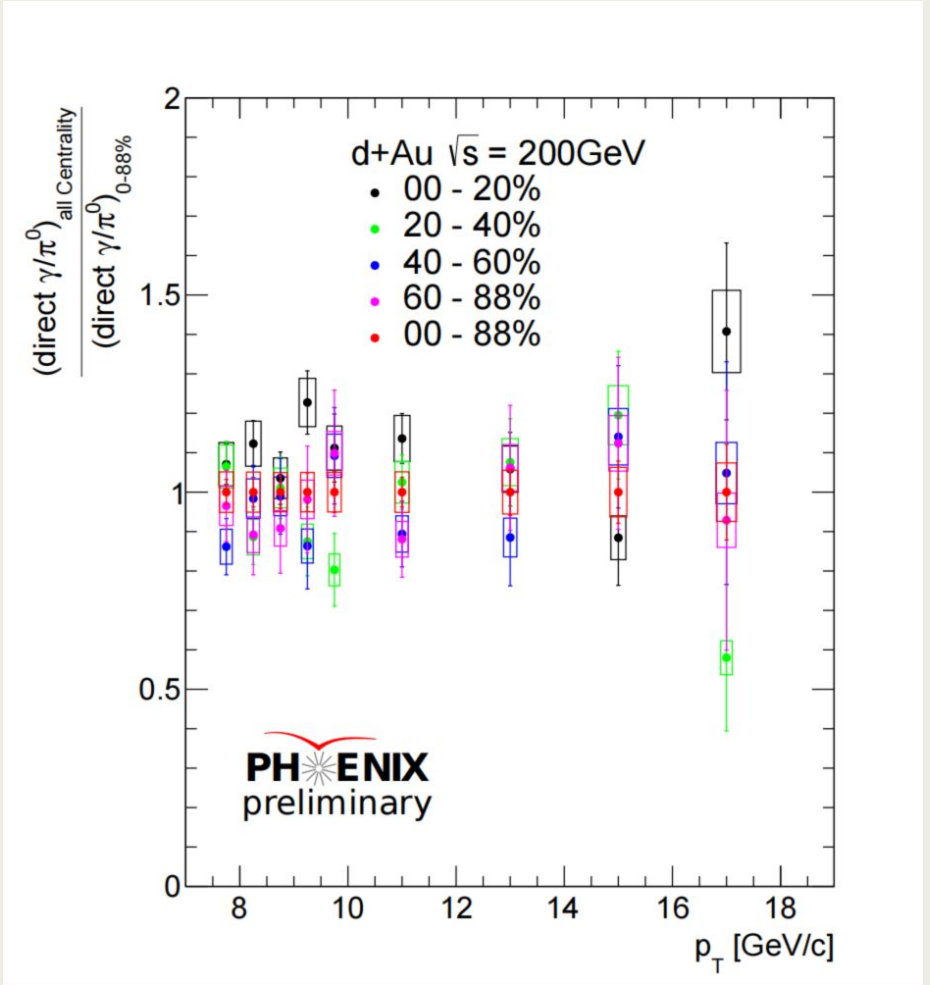
d+Au



Double ratios in AuAu and dAu collisions

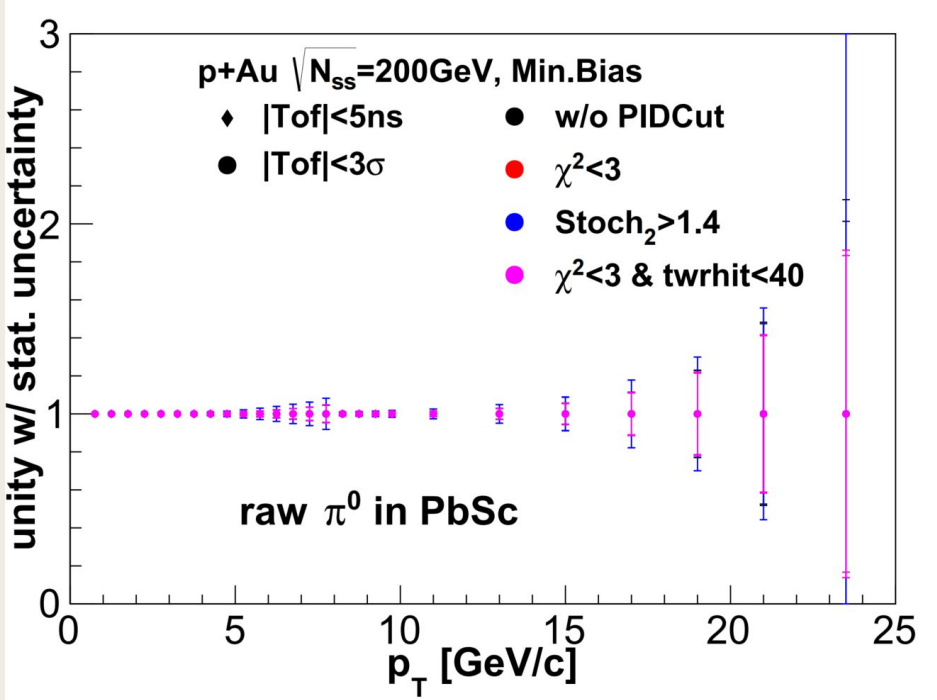
Centrality dependence can be found in the double ratio of AuAu, while in dAu, there is not likely a difference between centralities.



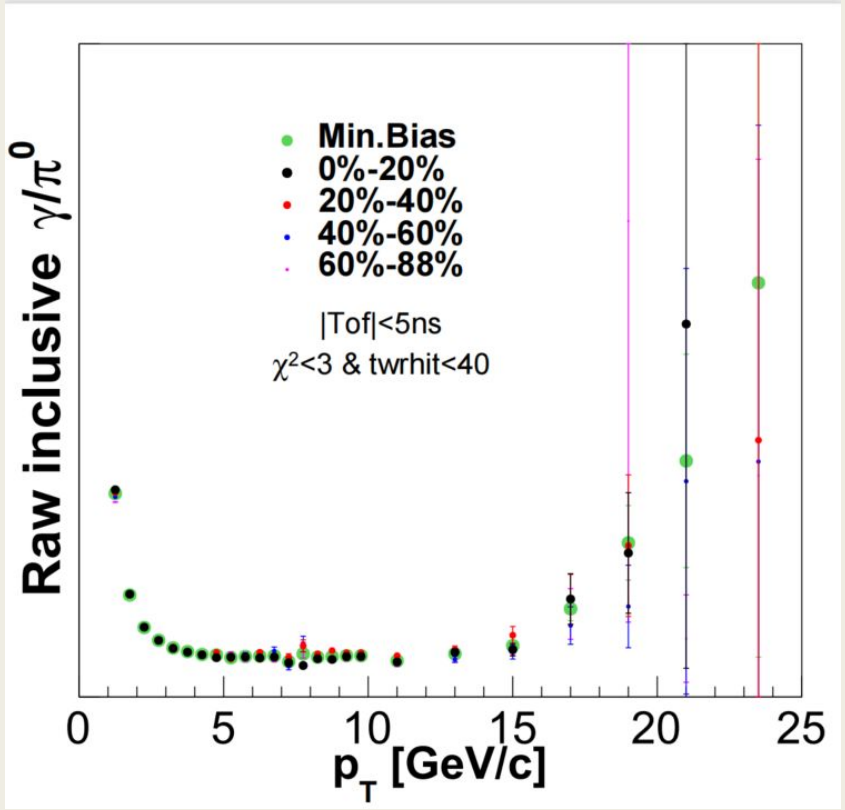


Neutral π0's : arXiv:0801.4020
direct γ : arXiv:1205.5759

- The data of minimum bias (BBC) and triggered (ERT) p+Au collisions in PHENIX from the 2015 data taking period (Run 15) are used in the parallel study. The expected significance of the measurement based solely on statistical uncertainties is shown below.



- The ratio of the raw inclusive photon and raw π^0 spectra is shown for p+Au collisions. NO corrections are applied yet.
- The fact that the raw γ/π^0 ratios for various centralities are similar is also a hint of the centrality bias in p+Au collisions.



SUMMARY

- R_{dAu} (π^0) central events appear to be suppressed and peripheral events appear to be enhanced
- Centrality determination in Glauber model and experiment
- 2-D response matrix in analysis
- Ratio of gamma/Pi0 and the double ratio to prove that there is a bias.
- Future analysis in p+Au and 3He+Au system will provide more clarification.

THANK YOU FOR YOUR ATTENTION !