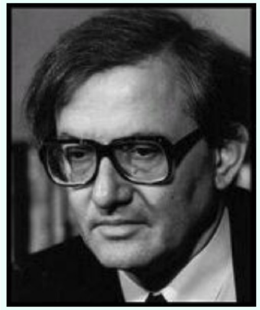
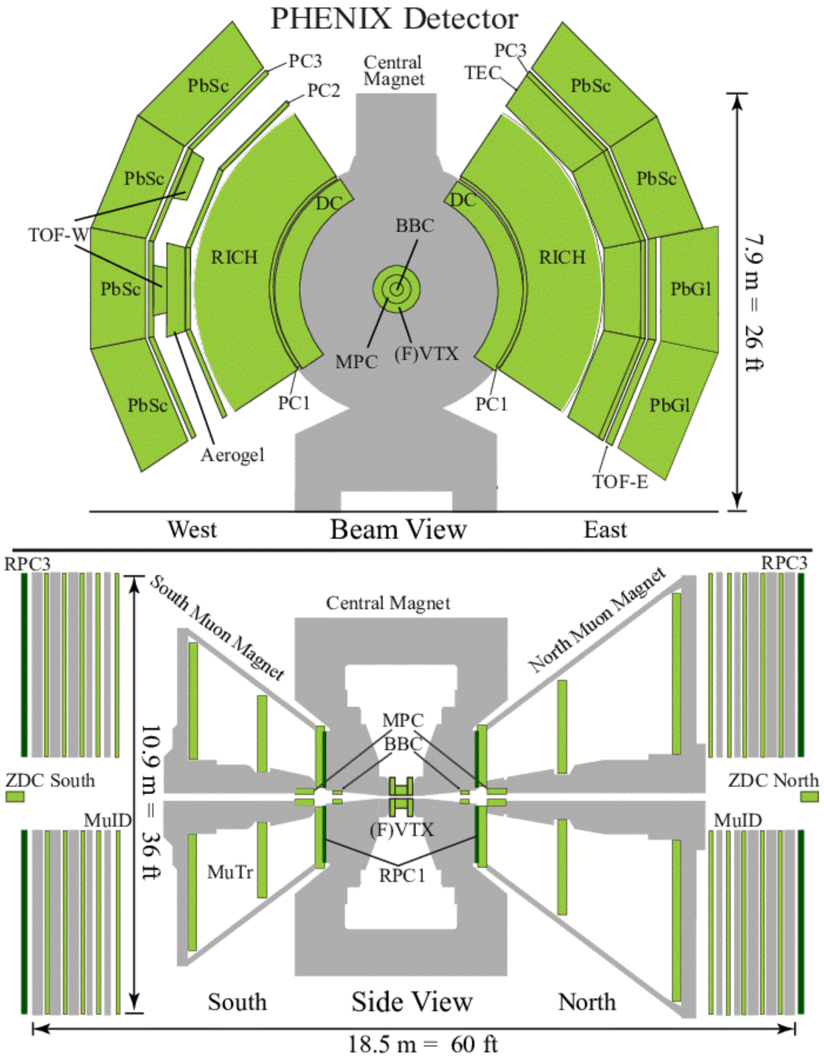
23rd ZIMÁNYI SCHOOL WINTER WORKSHOP ON HEAVY ION PHYSICS



József Zimányi (1931 - 2006)

Study of high pT π^0 and direct photon in small system collisions at 200 GeV

Zhandong Sun
for the PHENIX collaboration

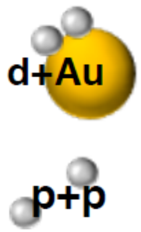


Outline

- Background and Motivation
- Centrality determination in Glauber Model
- Bias in centrality determination
- Yield of High p_T $\boldsymbol{\pi^0}$ and γ
- Determination of $\boldsymbol{N_{coll}}$ experimentally
- Summary

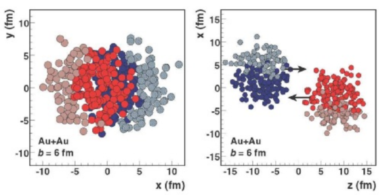
Nuclear Modification Factor

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



***N**$_{coll}$* : Average number of binary collisions in a type of event according to Glauber Model.

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



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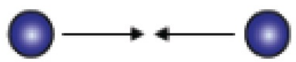
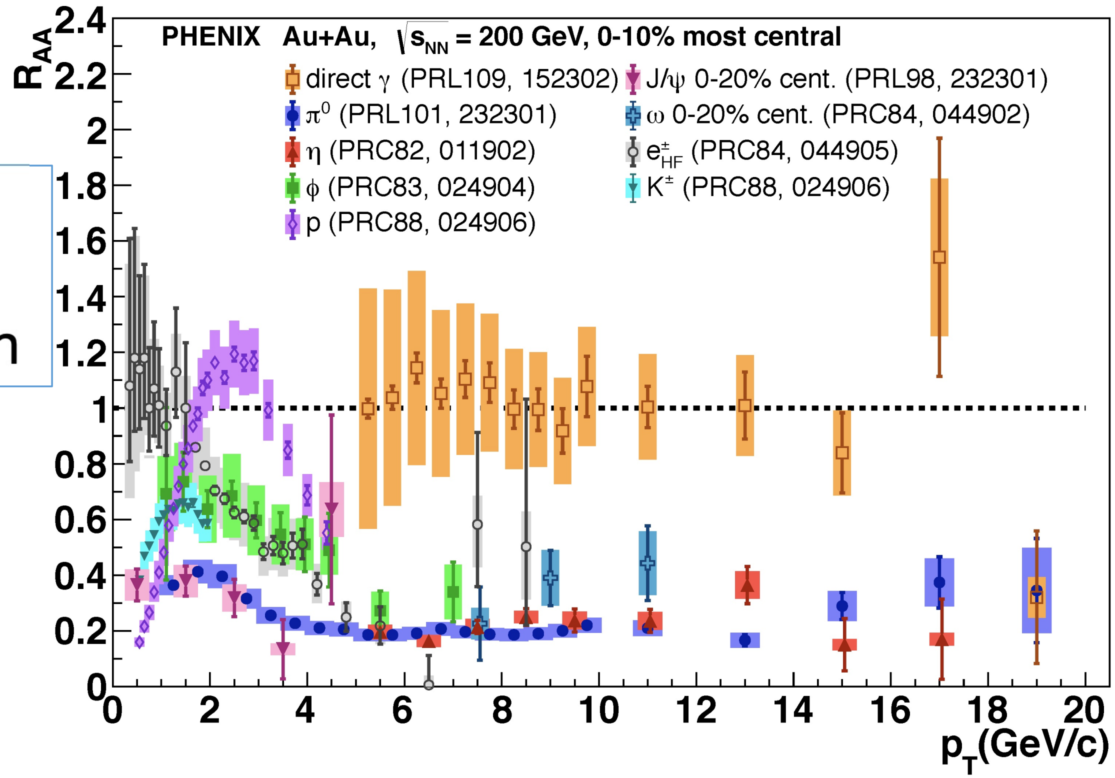
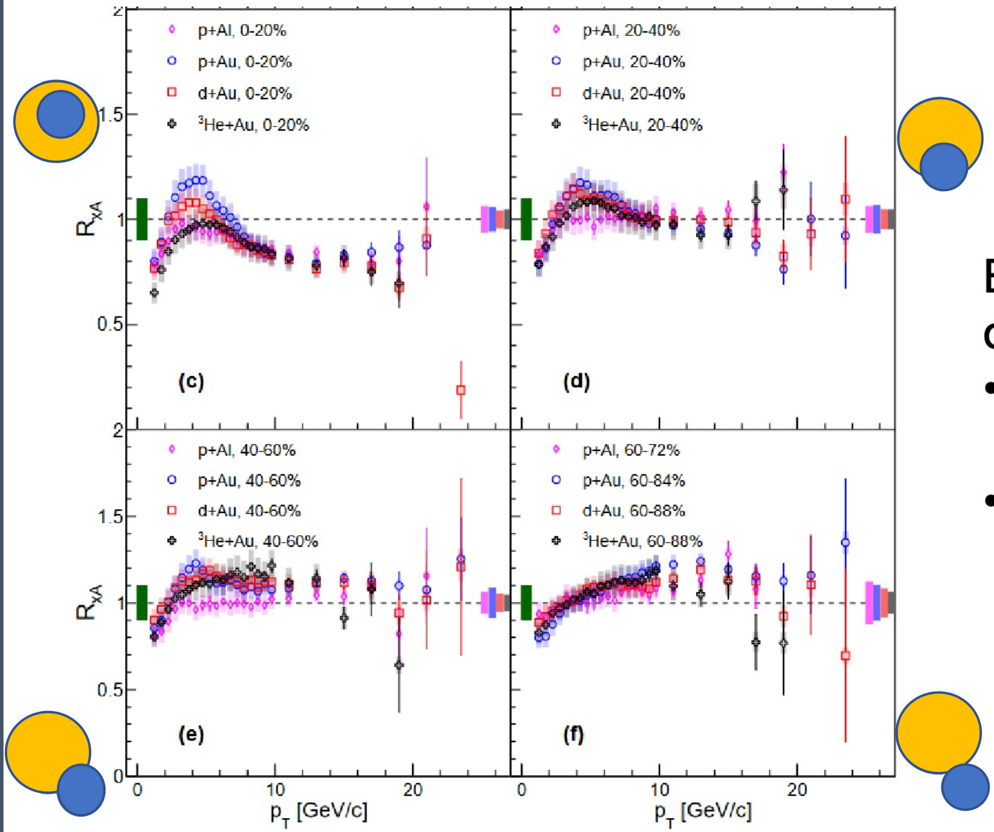




b = 6fm corresponds to ***N**$_{coll}$* = ~600 in Au+Au

MOTIVATION

Nuclear modification factor for π^0 in small systems



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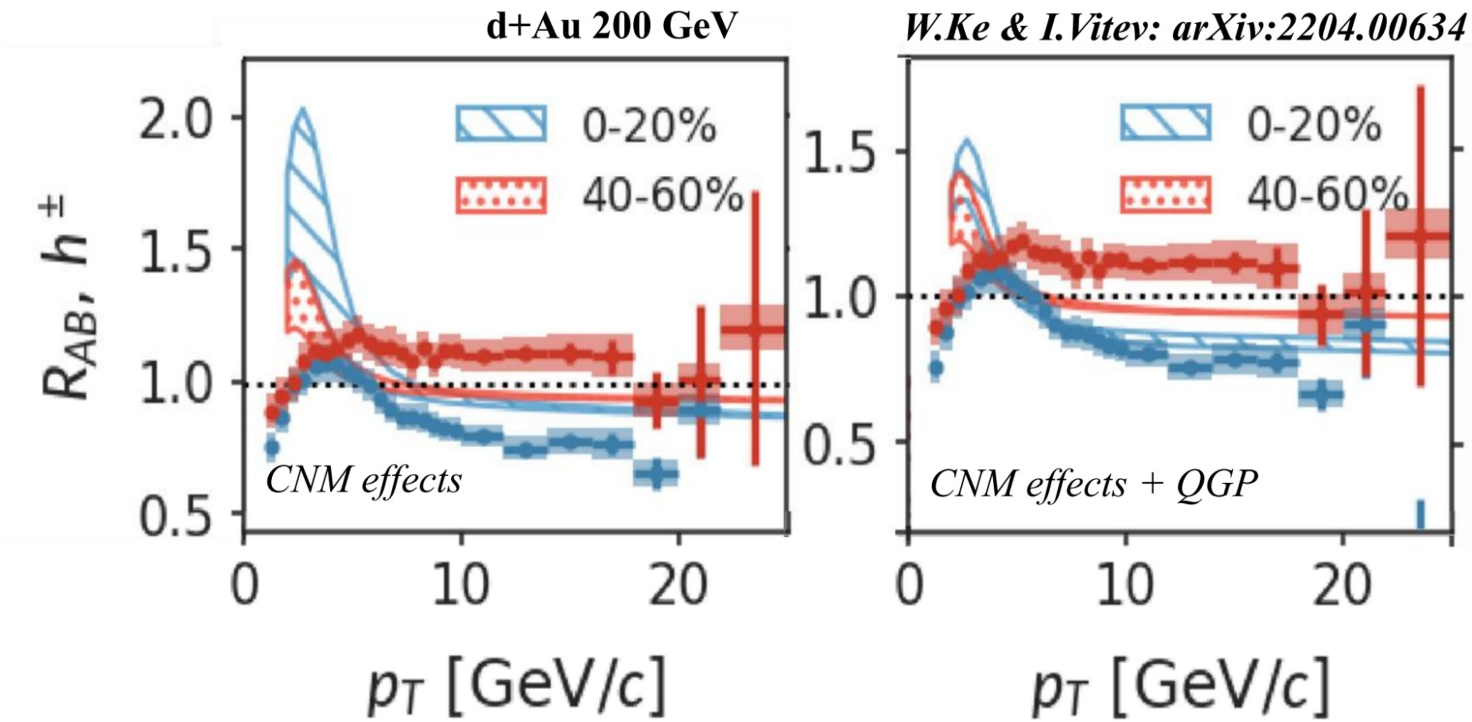
$$R_{AB}(p_T) = \frac{\frac{dN_{AB}}{dp_T}}{\langle N_{coll}\rangle \frac{dN_{pp}}{dp_T}}$$

Both d+Au and p+Au show large centrality dependence.

- At 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 determine centrality itself?
Are events mis-binned in centrality?

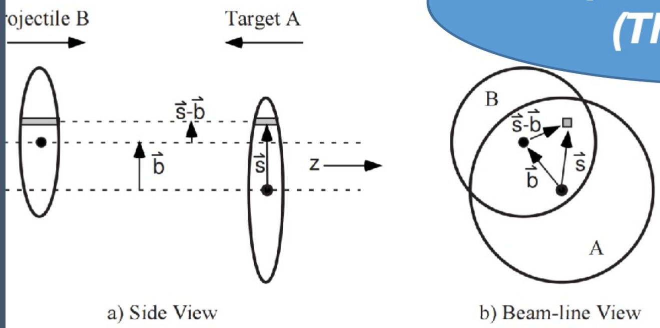
Theoretical prediction of two extreme limits of small colliding systems

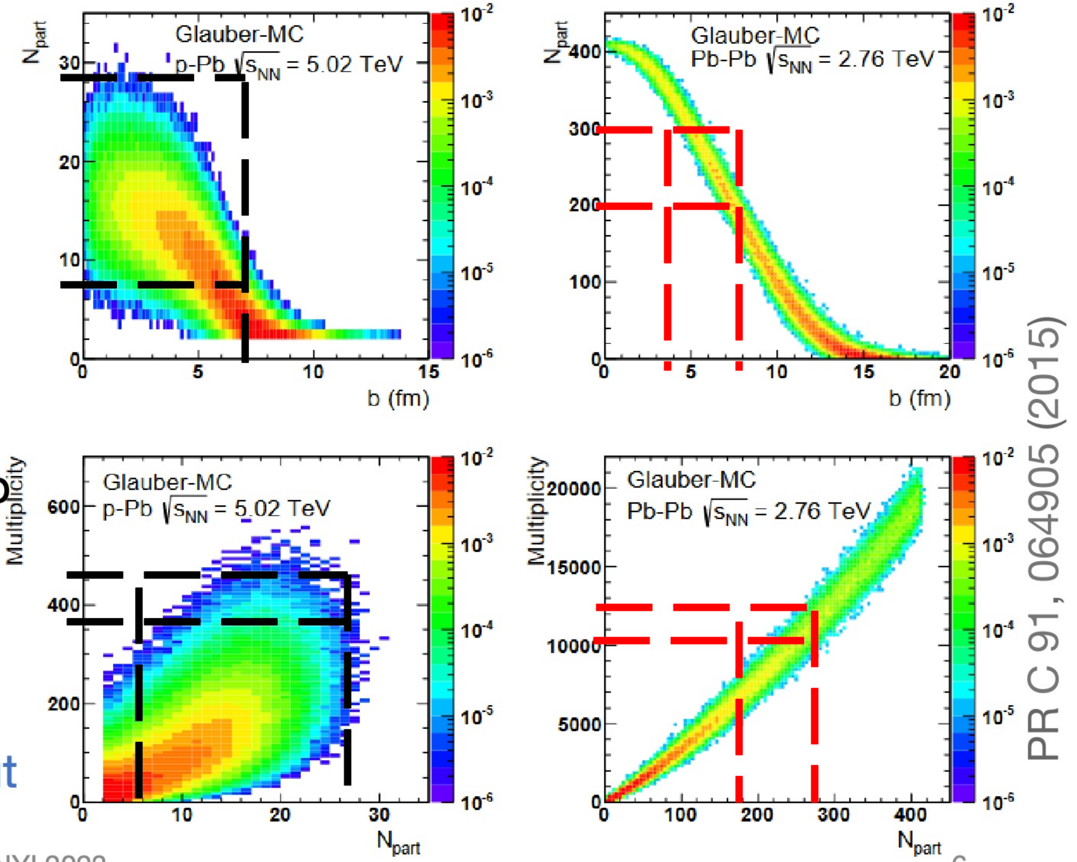


- Calculations with cold nuclear matter effect only.
- Calculations with cold and hot medium effects that assume the QGP is described by the hydrodynamic-based model.

Is Glauber model valid for small systems?

Impact parameter b (Theoretical) → ***N_{part} (Theoretical)*** → ***N_{ch} (Observable)***



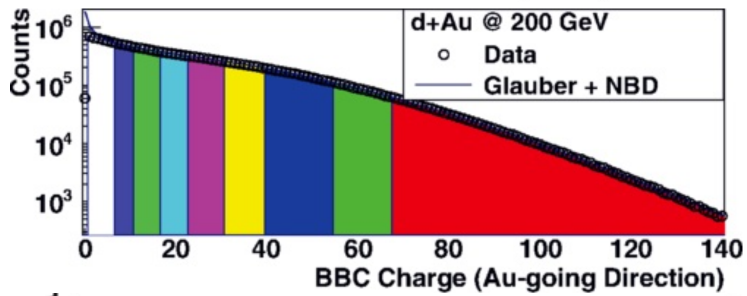


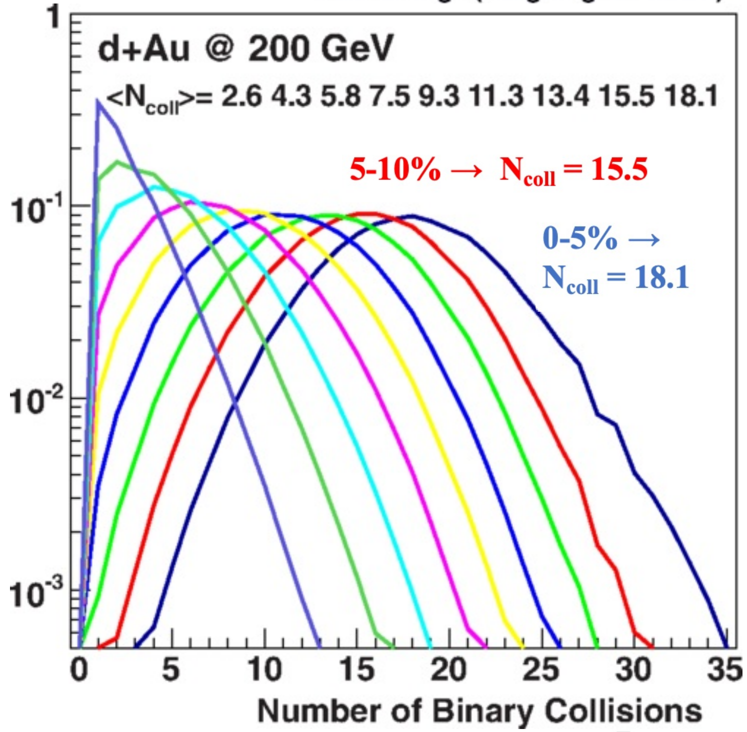
- Analyzing the 0-20% centrality bin in Pb+Pb is equivalent to studying the class of events with average impact parameter of 3fm with a very small variance.
- Analyzing the 0-20% centrality bin in p+Pb is also equivalent to studying the class of events with average impact parameter of 3fm but with a 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)

BBC N_{ch} mapped to N_{coll} with Glauber Model

PHENIX: PRC90(2014) 034902



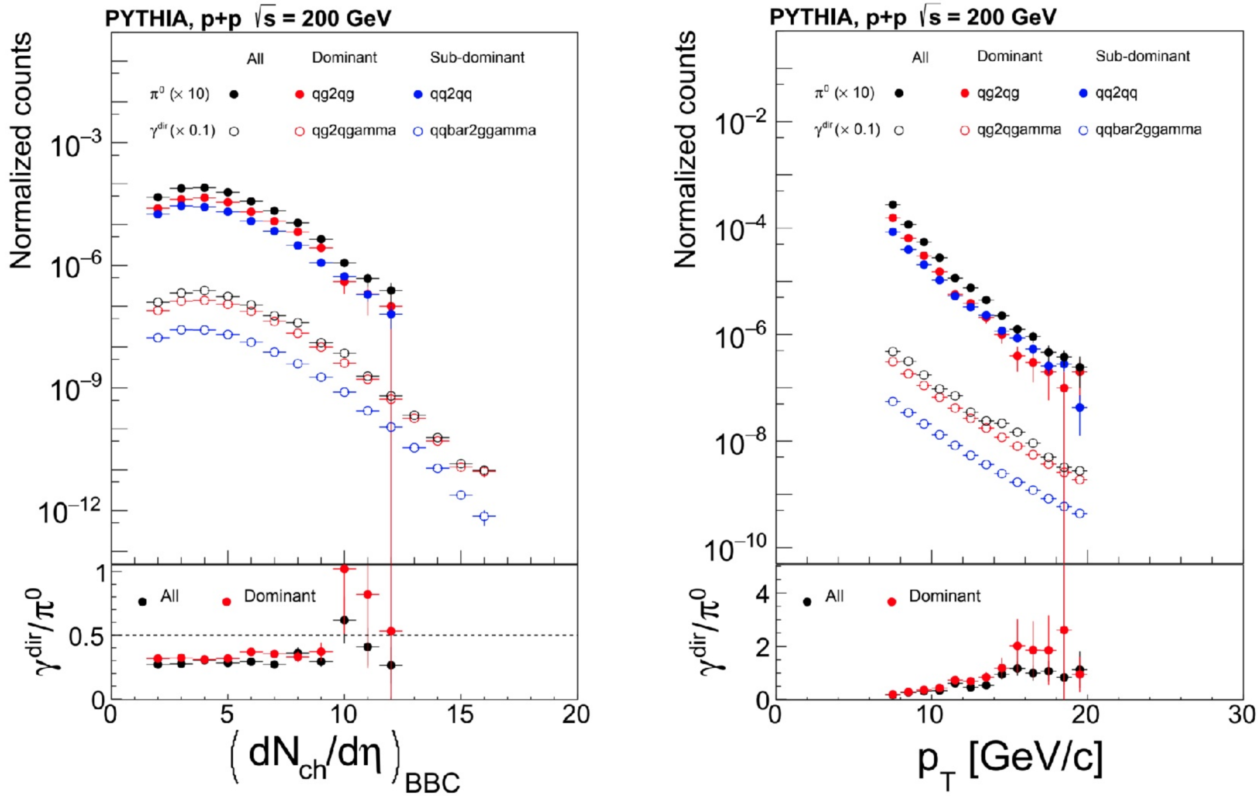


- Measure event activity (N_{ch}) in BBC on Au going side
- Fit event activity to superposition of negative binomial distributions for each nucleon-nucleon collision
- Select events in percentiles of event activity (0-5%, 5-10%, etc.) for data & model
- Assign N_{coll} from model to data

Using direct photons to minimize event selection bias

PYTHIA8 simulation using the Detroit tune

- For both γ^{dir} and π^0, the dominant source is quark-gluon scattering
- The fraction of the dominant source to all is about the same for γ^{dir} and π^0, independent of p_T and $dN_{ch}/d\eta$ by BBC



Direct photon production is proportional to the production of high p_T π^0 and is independent of the underlying event multiplicity.

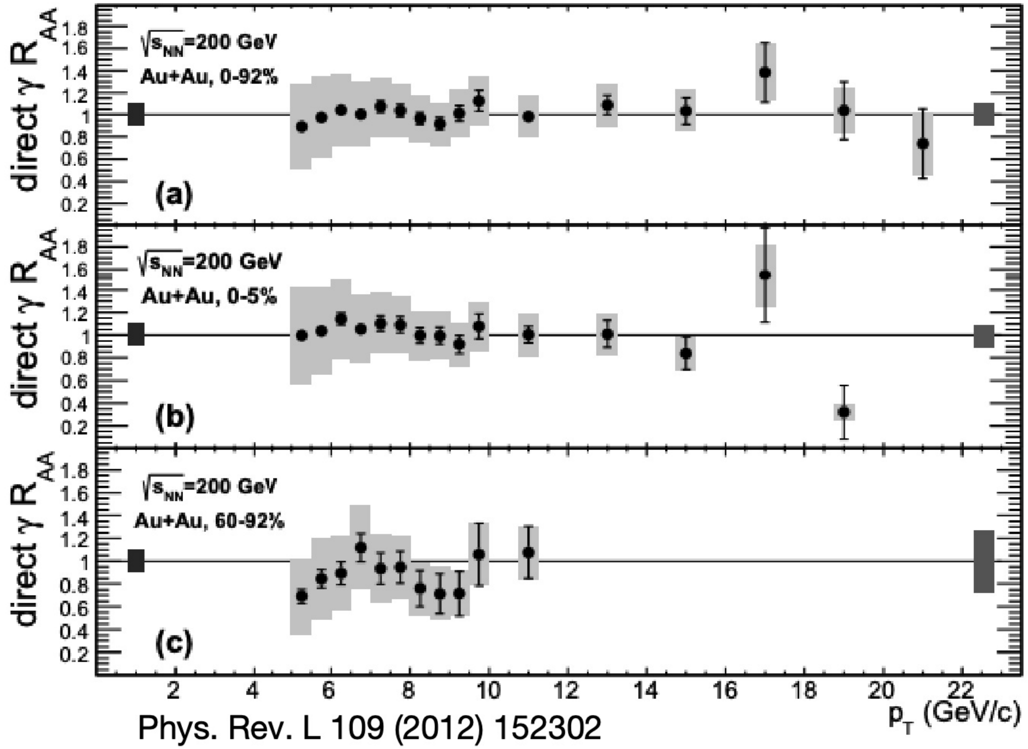
Using direct photons to minimize event selection bias

- Because of the color-neutral property, ***N*** $_{coll}$ redefined by ***γ*** ^{dir} yield experimentally

$$N_{\rm coll}^{\rm EXP}(p_T) = \frac{Y_{d\rm Au}^{\gamma^{dir}}(p_T)}{Y_{pp}^{\gamma^{\rm dir}}(p_T)}$$

- Using the new ***N*** $_{coll}$, R_{dAu} for π^0 is written as following

$$R_{d\rm Au,EXP}^{\pi^0} = \frac{R_{d\rm Au,GL}^{\pi^0}}{R_{d\rm Au,GL}^{\gamma^{dir}}} = \frac{Y_{d\rm Au}^{\pi^0}/Y_{pp}^{\pi^0}}{Y_{d\rm Au}^{\gamma^{dir}}/Y_{pp}^{\gamma^{\rm dir}}} = \frac{Y_{d\rm Au}^{\pi^0}}{N_{\rm coll}^{\rm EXP}\ Y_{pp}^{\pi^0}}$$



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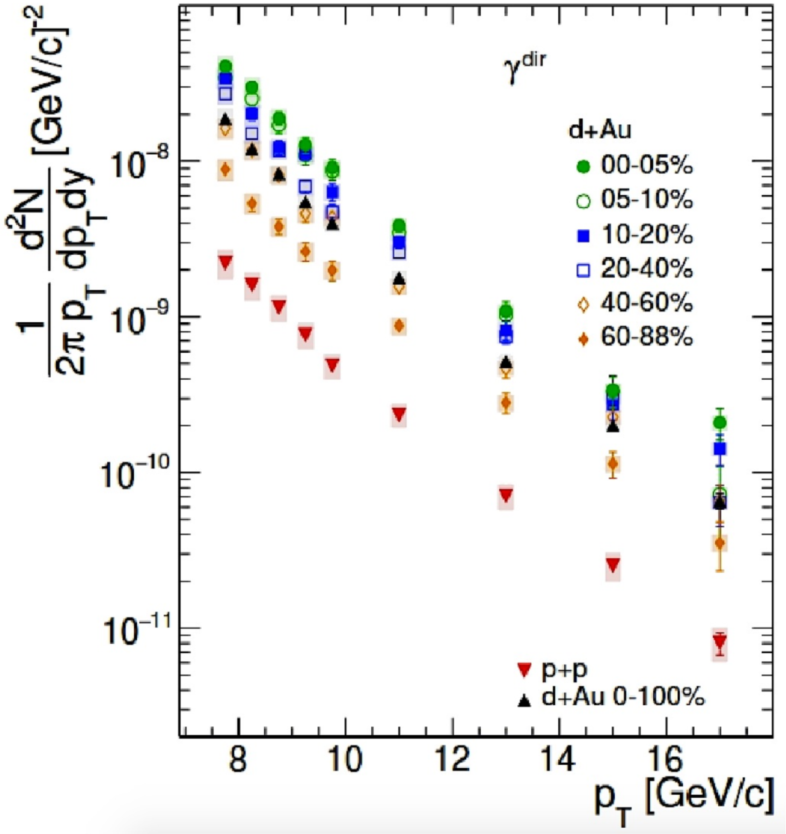
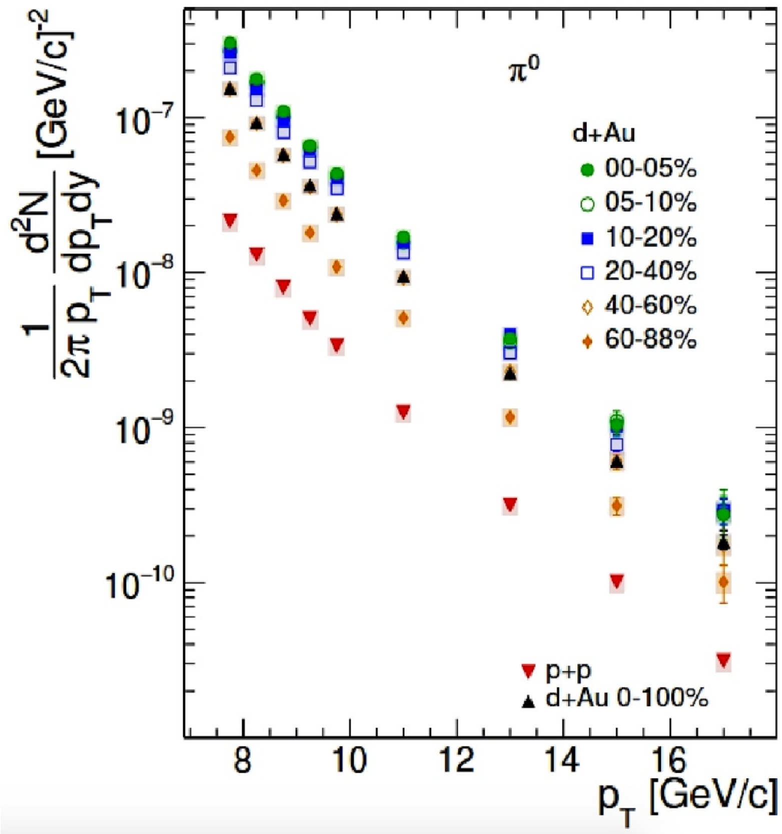
γ^{dir} and π^0 yields from d+Au and p+p at 200 GeV

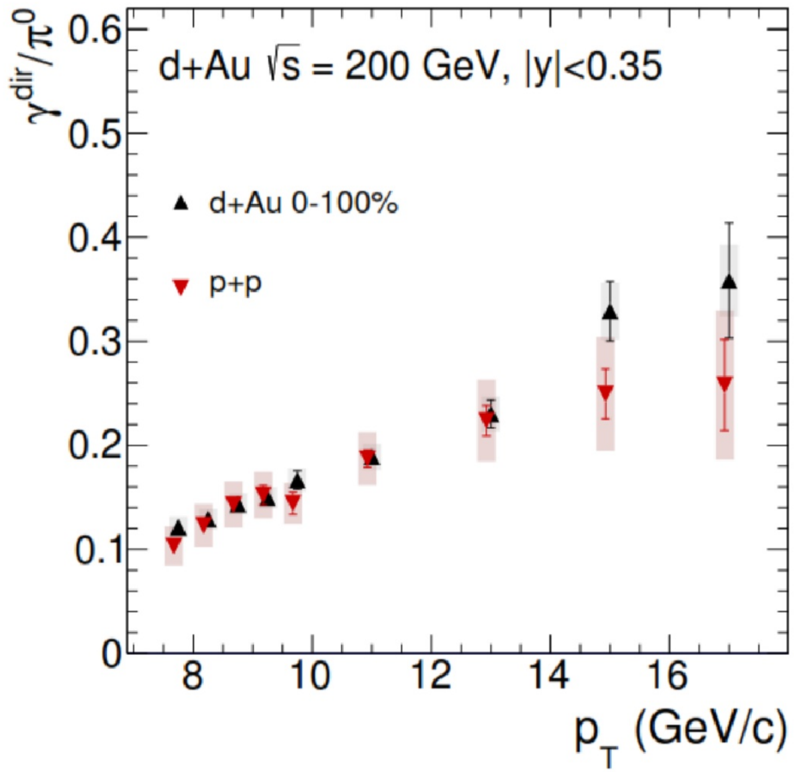


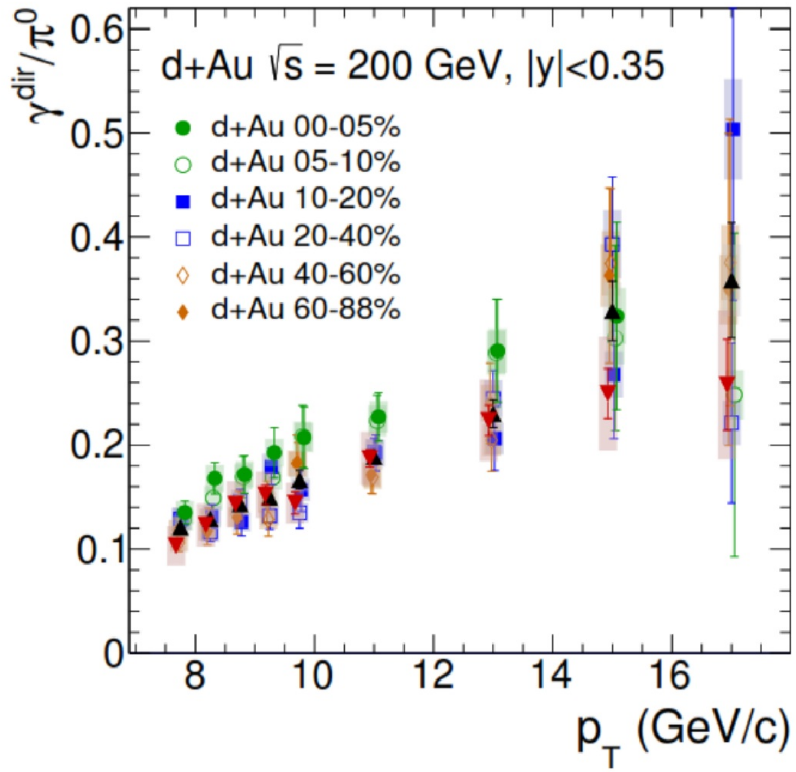


- γ^{dir} from d+Au in different centralities
- d+Au min. bias data 2003: ***PHENIX:PRC87(2013)54907***
- p+p data: ***PHENIX:PRD86(2012)72008***

- π^0 from d+Au in different centralities
- Consistent with 2008 d+Au data
- d+Au min. bias data: ***PHENIX:PRC(2022)64902***
- p+p data: ***PHENIX:PRC(2022)64902***

Ratio of γ^{dir}/π^0

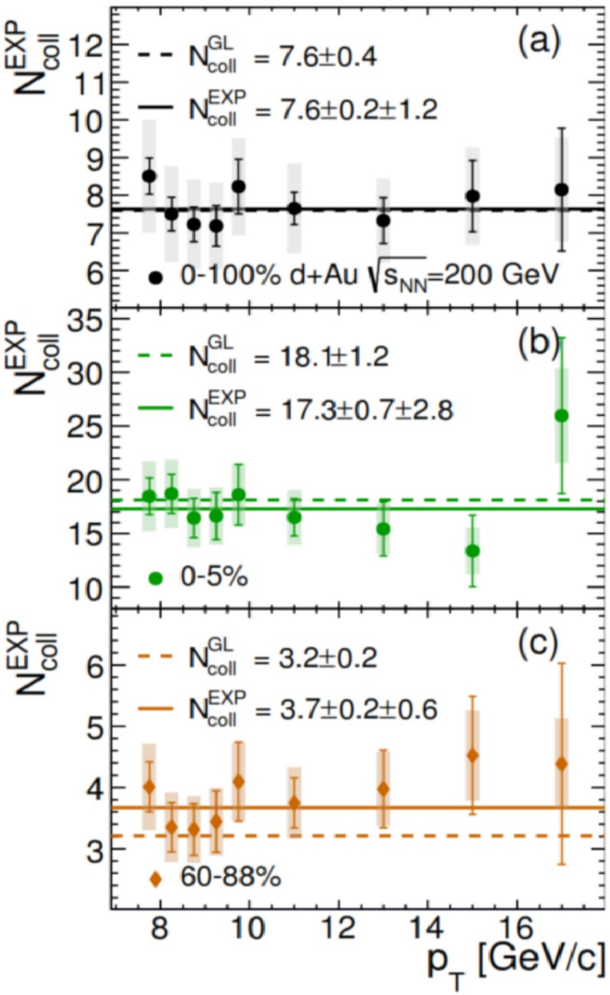




- p+p and d+Au are on top of each other

- Peripheral events consistent with min. bias
- Most central stands out

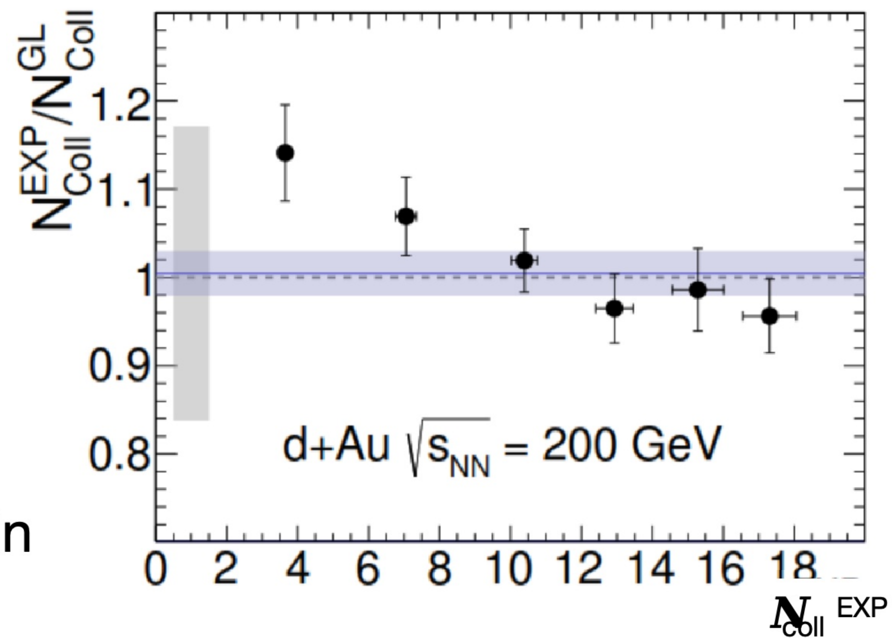
Evaluating bias in N_{coll} from Glauber Model



$$N_{\rm coll}^{\rm EXP}(p_T) = \frac{Y_{d\rm Au}^{\gamma^{dir}}(p_T)}{Y_{pp}^{\gamma^{\rm dir}}(p_T)}$$

Visible trend can be seen

- Good agreement in central collisions
- 15% deviation in periheral collisions

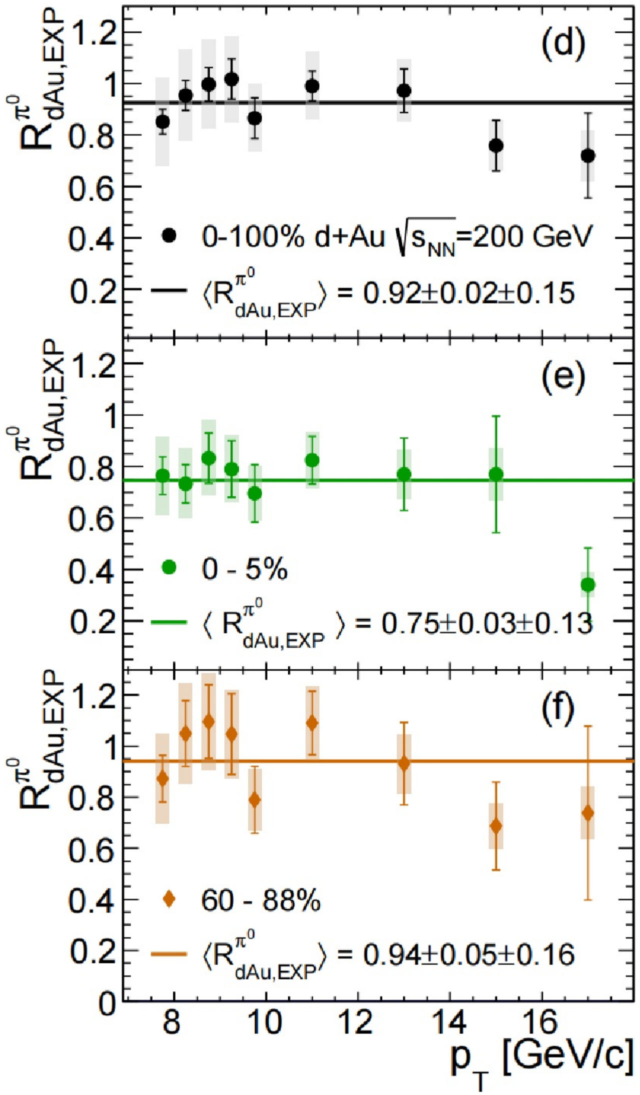


Bias in event selections based on event activity measured at forward rapidity!

Redefine R_{dAu} for π^0

$$R^{\pi^0}_{d\mathrm{Au,EXP}} = \frac{Y^{\pi^0}_{d\mathrm{Au}}}{N^{\mathrm{EXP}}_{\mathrm{coll}}\ Y^{\pi^0}_{pp}} = \frac{Y^{\pi^0}_{d\mathrm{Au}}/Y^{\pi^0}_{pp}}{Y^{\gamma^{\mathrm{dir}}}_{d\mathrm{Au}}/Y^{\gamma^{\mathrm{dir}}}_{pp}}$$

- In central collisions (0-5%), about 20% suppression of the π^0 yield
- In peripheral collisions, consistent with d+Au min. bias



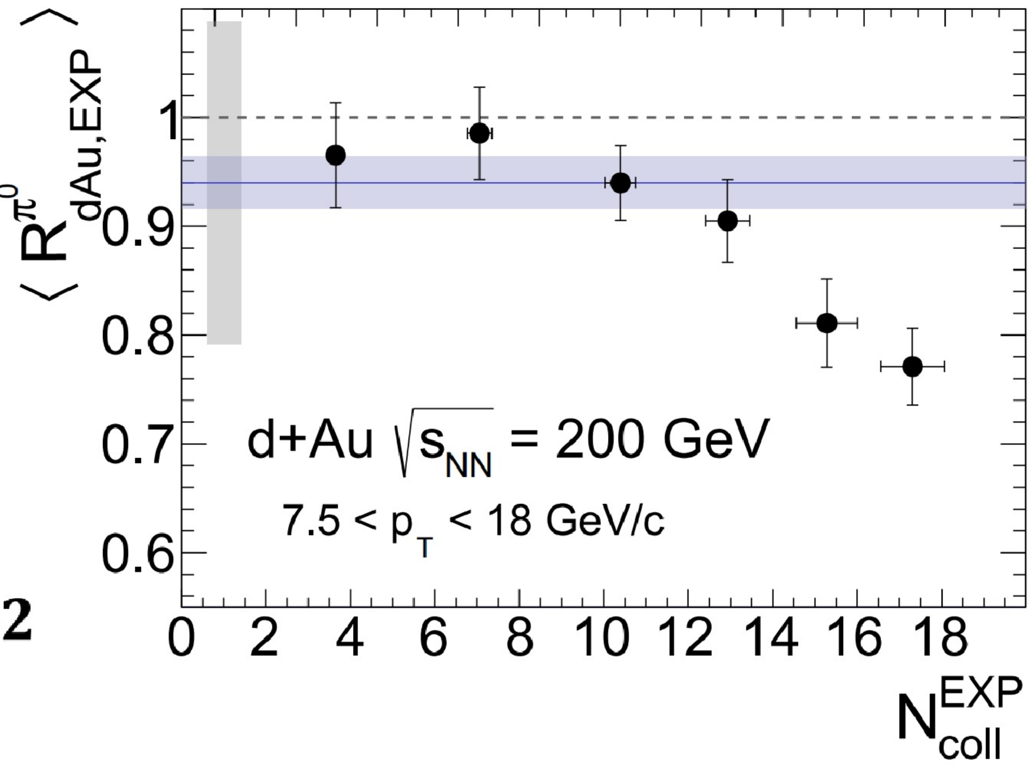
Redefined R_{dAu} for π^0 vs. N_{coll}^{EXP}

- N_{coll}^{EXP} <4 (60%-88% centrality)

$$\frac{R^{\pi^0}_{dAu,EXP}(60-88\%)}{R^{\pi^0}_{dAu,EXP}(0-100\%)} = 1.017 \pm 0.056$$

- N_{coll}^{EXP} >14 (top 10% centrality)

$$\frac{R^{\pi^0}_{dAu,EXP}(0-5\%)}{R^{\pi^0}_{dAu,EXP}(0-100\%)} = 0.806 \pm 0.042$$



SUMMARY

- First evidence for significant up to 20% final state suppression of high pT **π^0**(7.5 to 18 GeV/c) in central 0-5% d+Au collisions
- Previously observed enhancement of **π^0**in peripheral events due to an event selection bias
- Using N_{coll}^{EXP} to resolve ambiguity between final state and ***CNM*** effects – event selection bias inherent to ***Glauber model*** approach

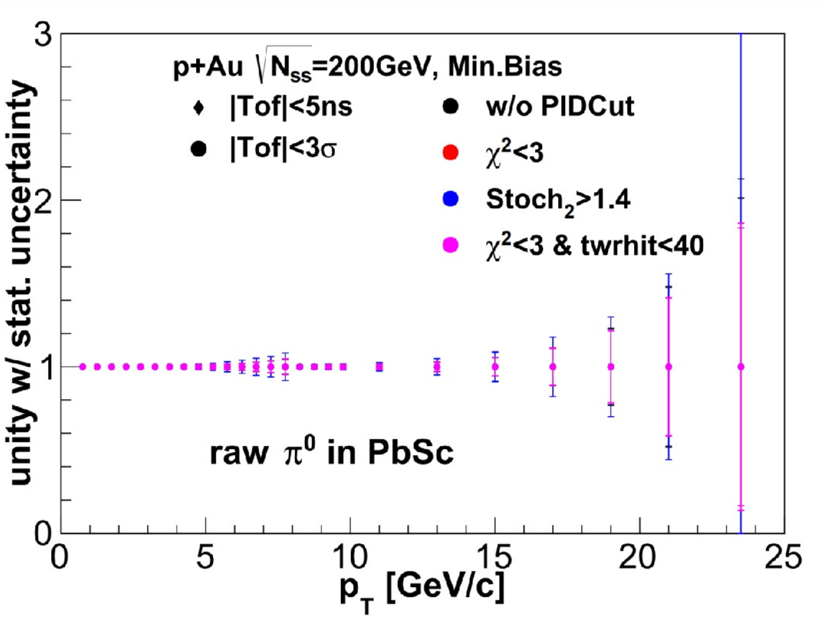
- Future analysis in p+Au and He+Au system will provide more clarification. Comparing the three systems, with gradually increasing the size, should differentiate between additional bias in centrality determination (predicting decreasing suppression for larger systems) and some unexpected medium effect (causing increasing suppression for larger systems)

THANK YOU FOR YOUR ATTENTION !

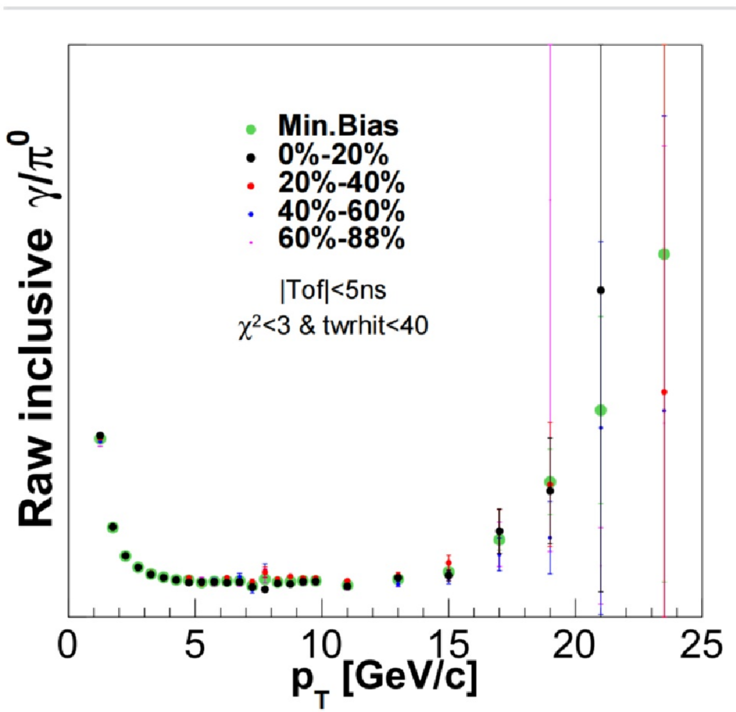
This work is supported
by OTKA 131991 and Atomki

BACKUP

- 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.

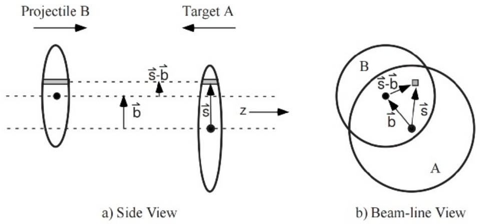


- The ratio of the raw inclusive photon and raw π^0 spectra is shown for p+Au collisions. NO corrections are applied yet.
- The fact that the raw γ/π^0 ratios for various centralities are similar is also a hint of the centrality bias in p+Au collisions.

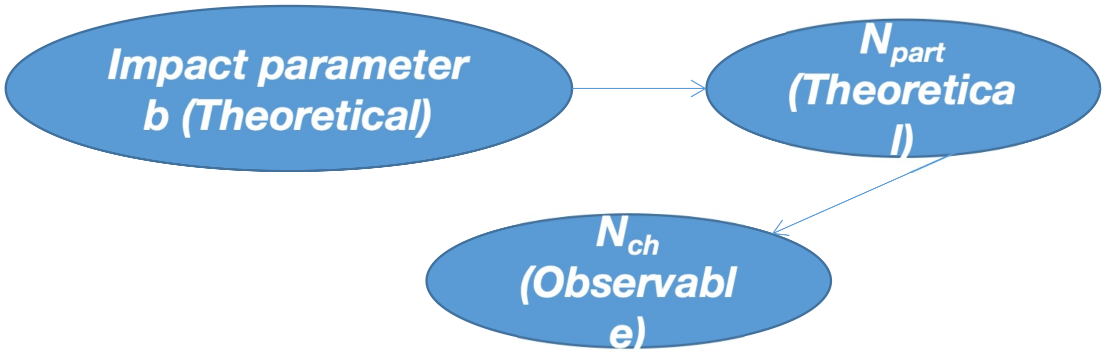


MOTIVATION

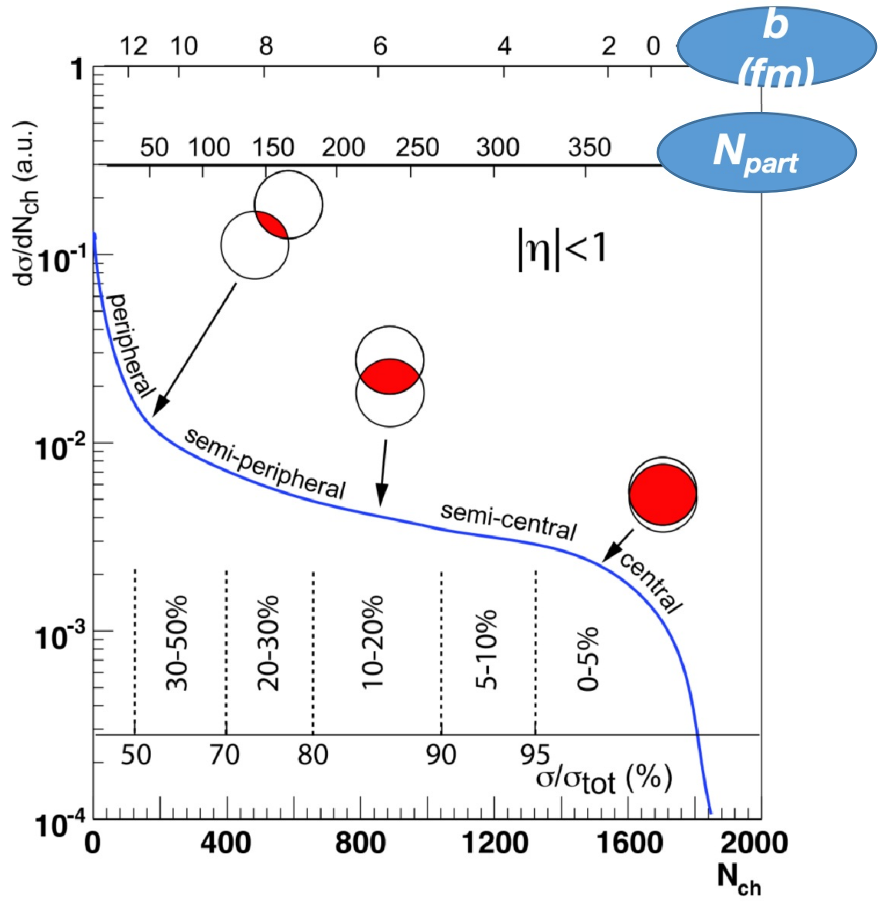
How is centrality determined in A-A (large-on-large) collisio



- The basic assumption underlying centrality classes is that the impact parameter ***b*** is monotonically related to particle multiplicity.
- For large ***b*** events(“peripheral”), we expect low multiplicity, where as for small ***b*** events(“central”) we expect large multiplicity.



N_{part} - number of participating nucleon



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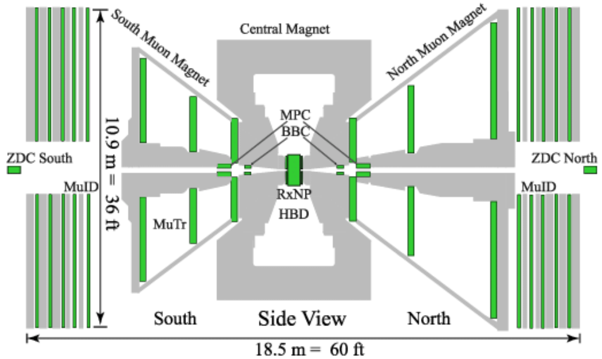
MOTIVATION

Measurement of number of binary collisions

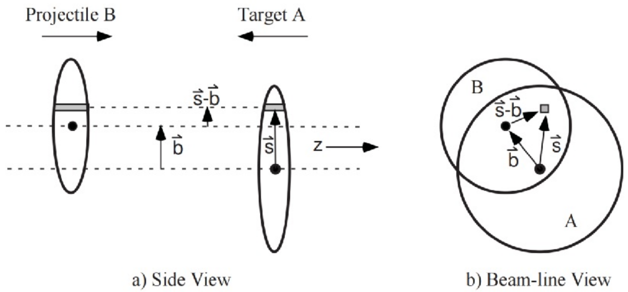
$$R_{AA}(pt) = \frac{\frac{dN_{AA}}{dp_T}}{\langle N_{coll} \rangle \frac{dN_{pp}}{dp_T}}$$

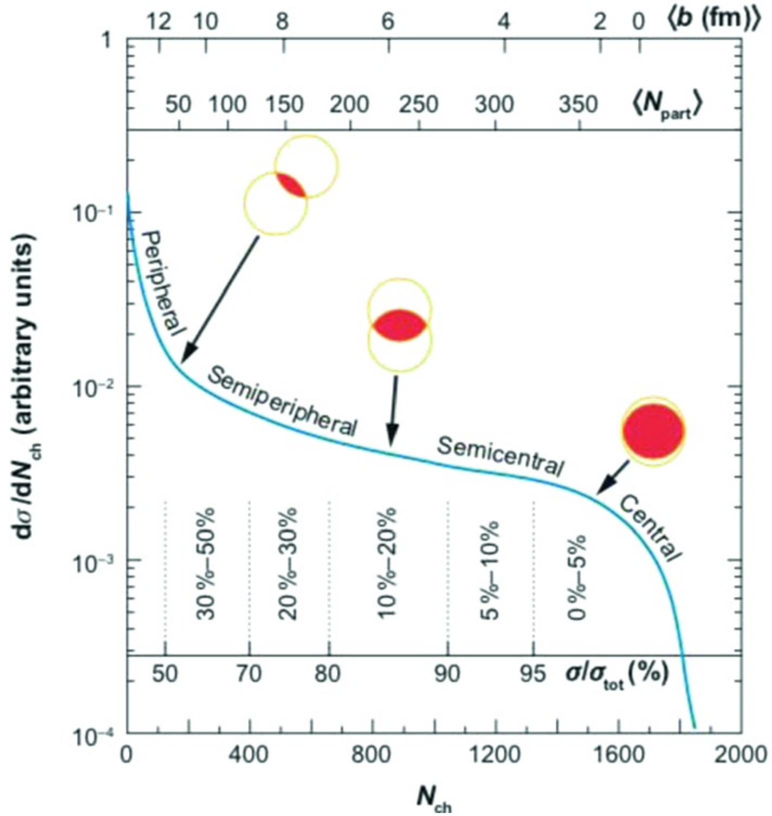
N_{part} - number of participating nucleon

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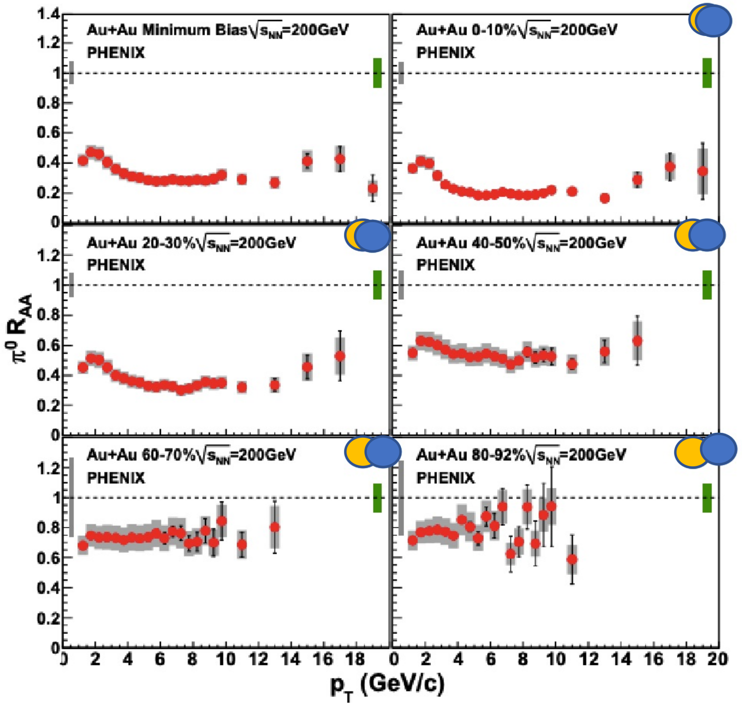
Au+Au
Suppression of π^0 and non-suppression of direct γ



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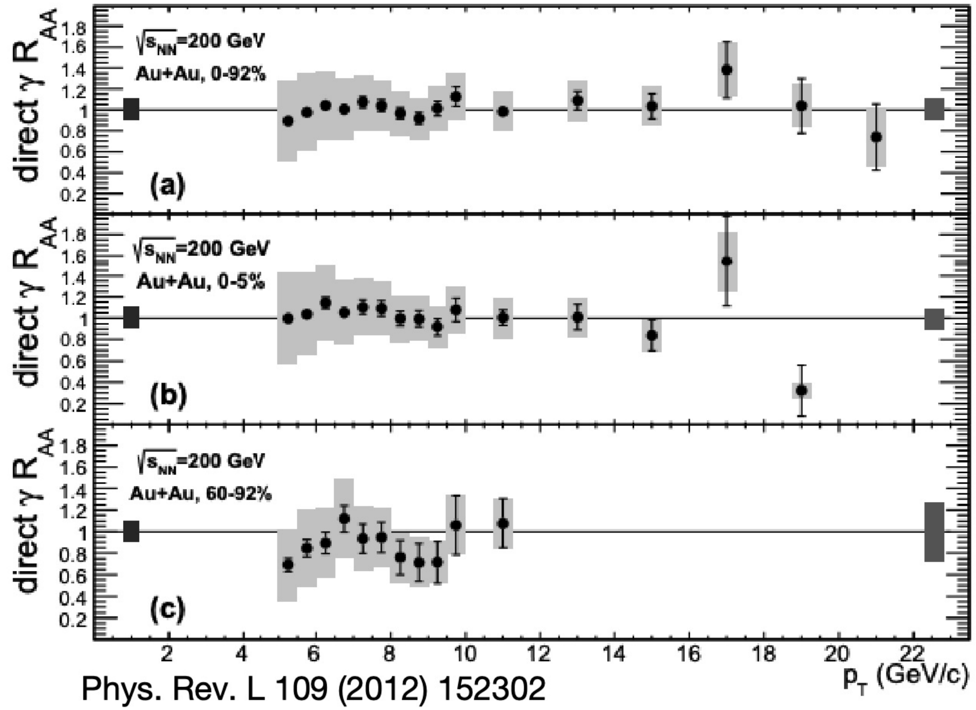

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- It is unity at all centralities.

- As expected, the QGP is transparent to direct photons