XI International Conference on New Frontiers in Physics

Comparison of centrality dependent high p_T direct photon and π^0 production in d+Au collisions

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for the PHENIX collaboration

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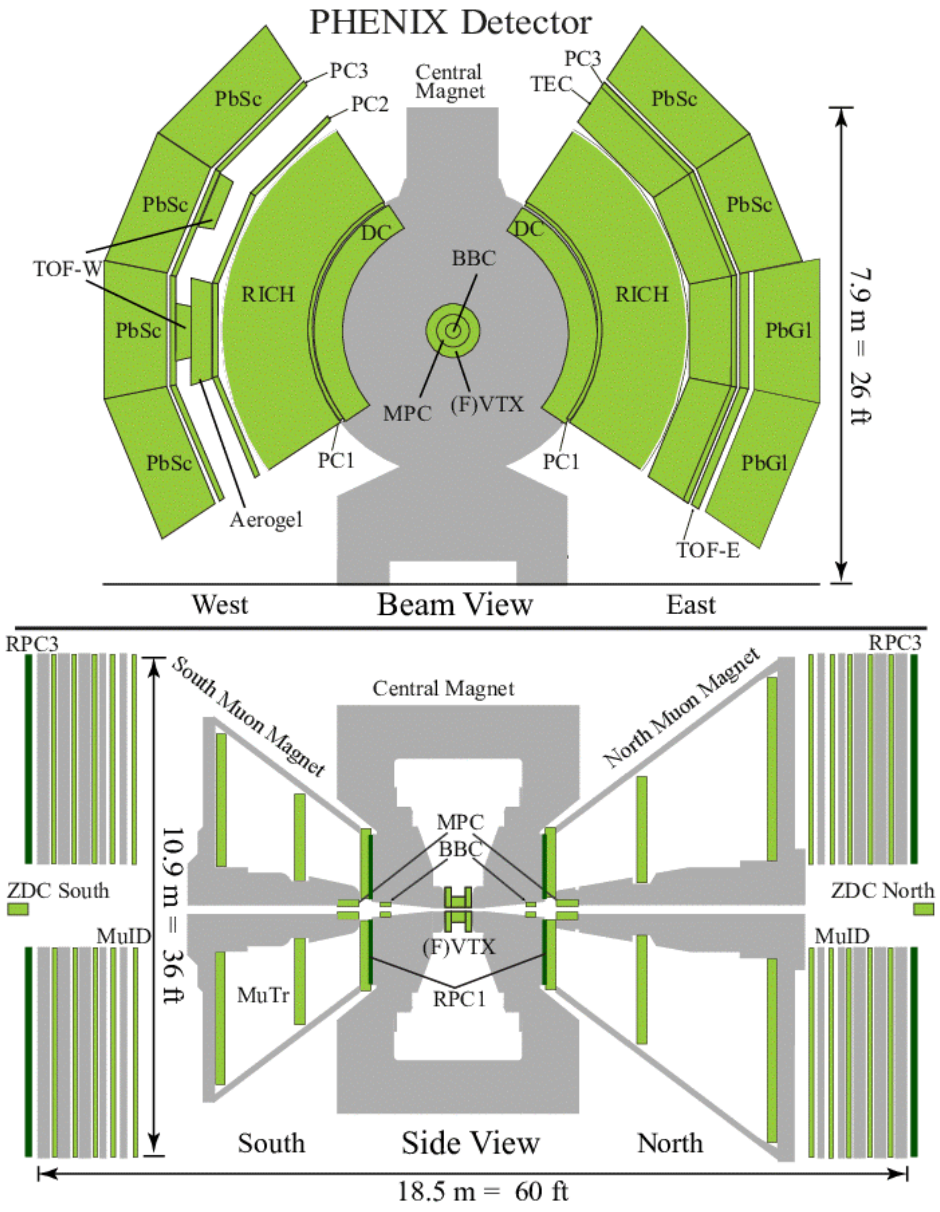
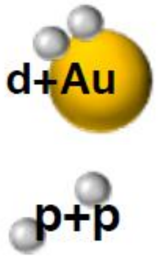


Outline

- Motivation
- Centrality determination in Glauber model
- Bias in Centrality determination
- Extraction of π^0 and photon
- γ/π^0 in AuAu and dAu
- Double ratios
- Summary

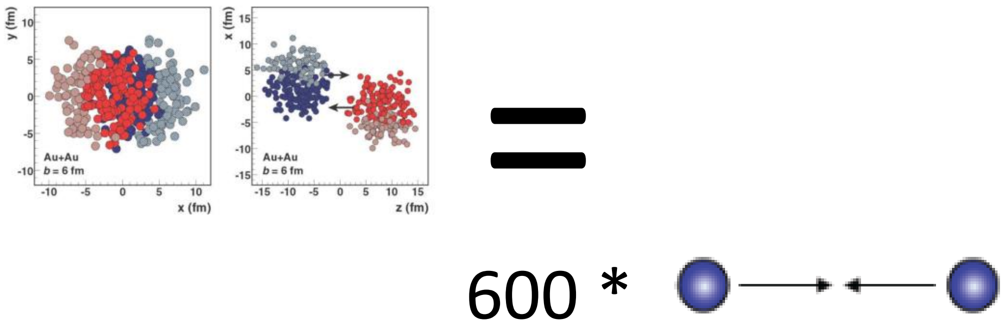
Nuclear Modification Factor

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



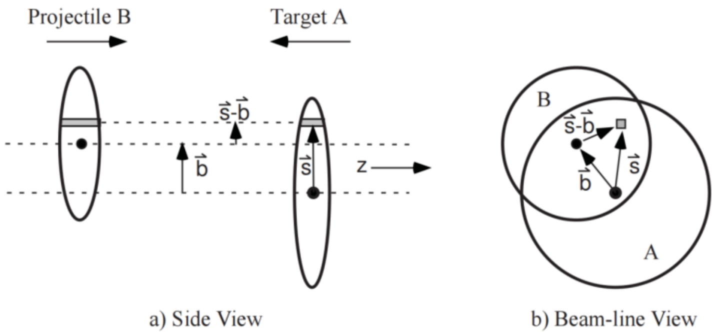
***N**$_{coll}$* : Average number of binary collisions in a type of event according to Glauber Model.

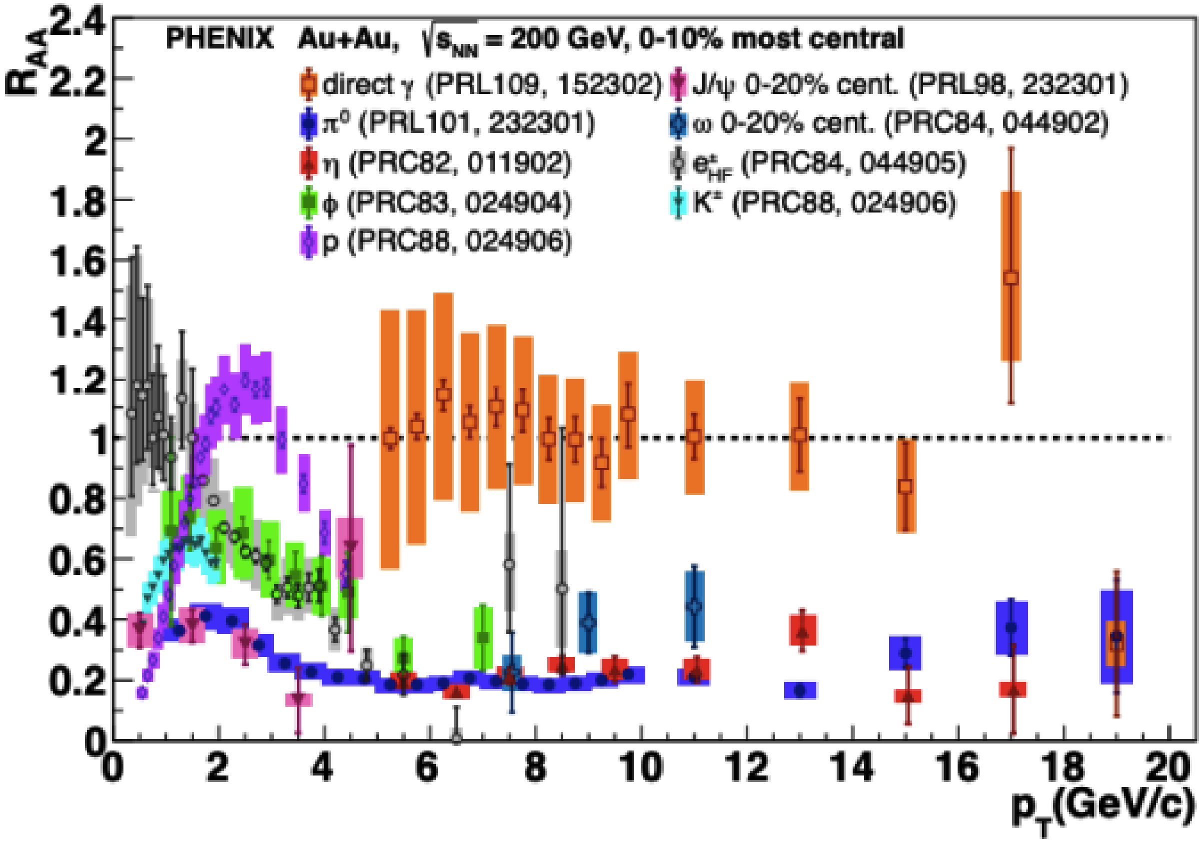
This ratio teaches us how different a heavy ion collision is from just considering it as a scaled p+p collision



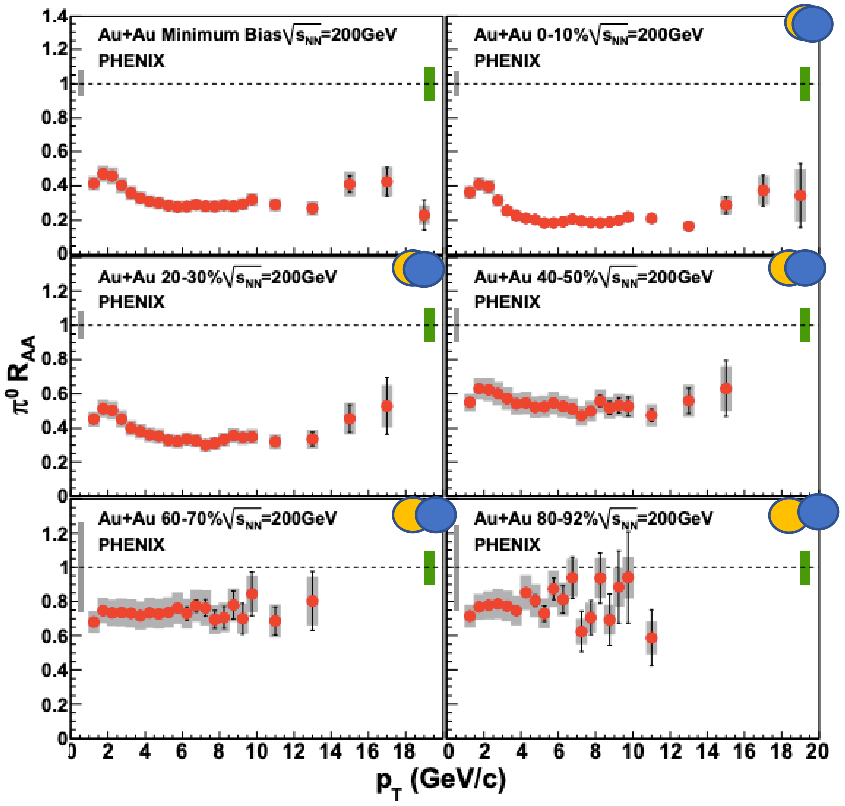
b = 6fm corresponds to ***N**$_{coll}$* = ~600

Impact parameter *b*





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



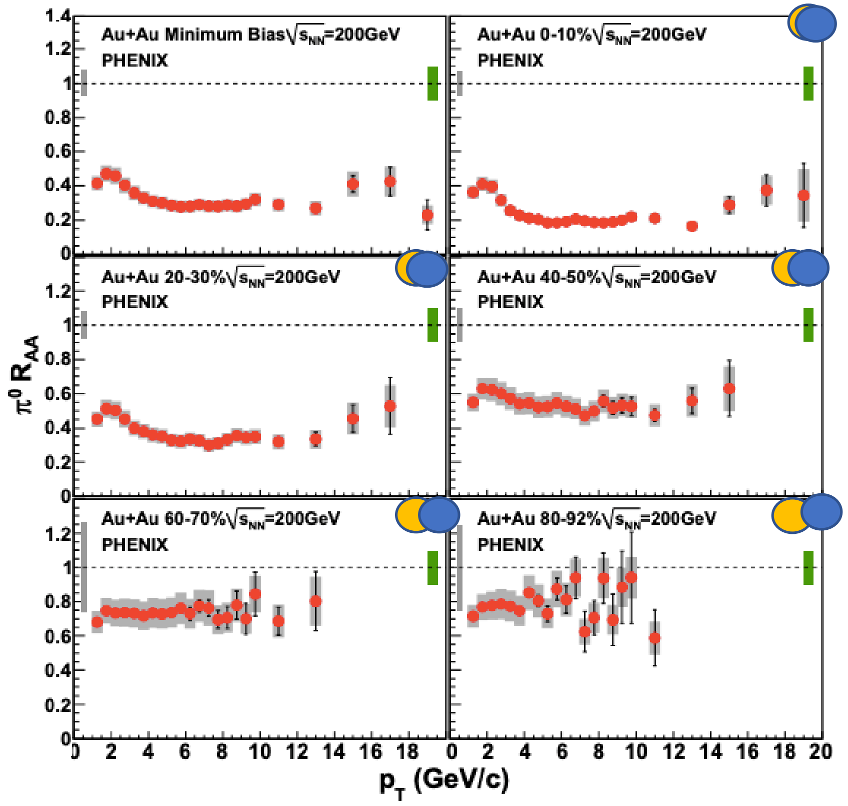
Phys. Rev. L 101 (2008) 232301

- 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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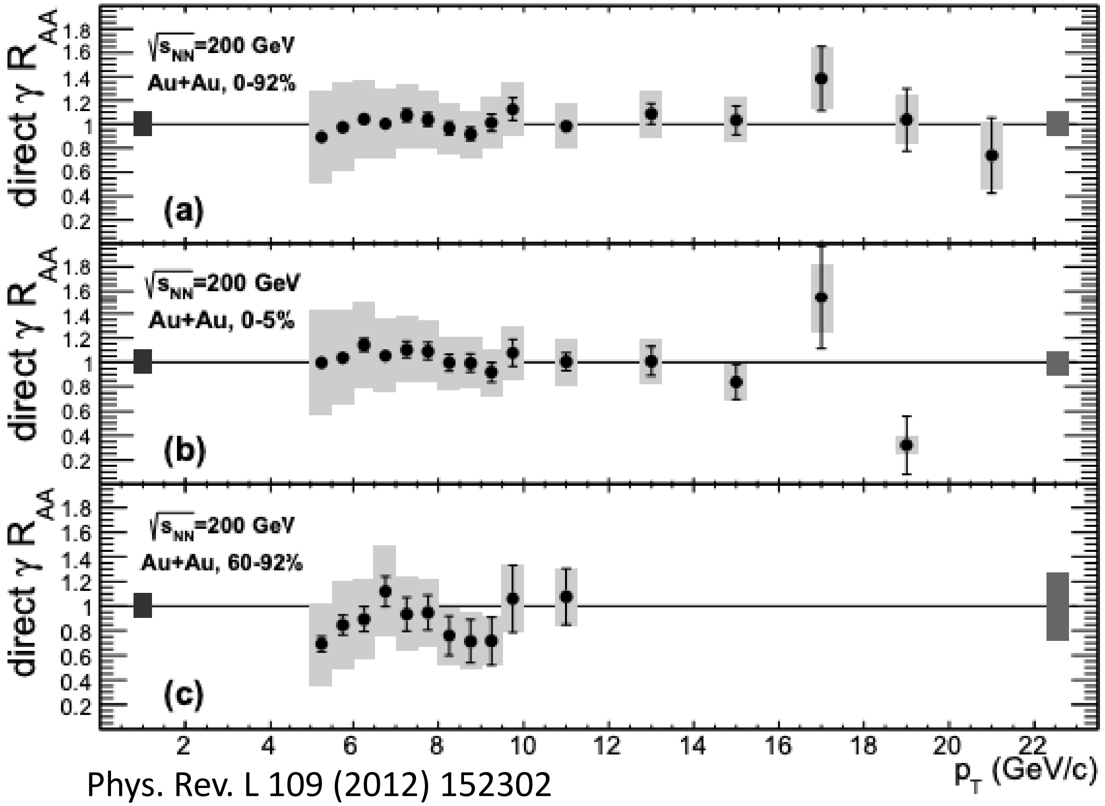

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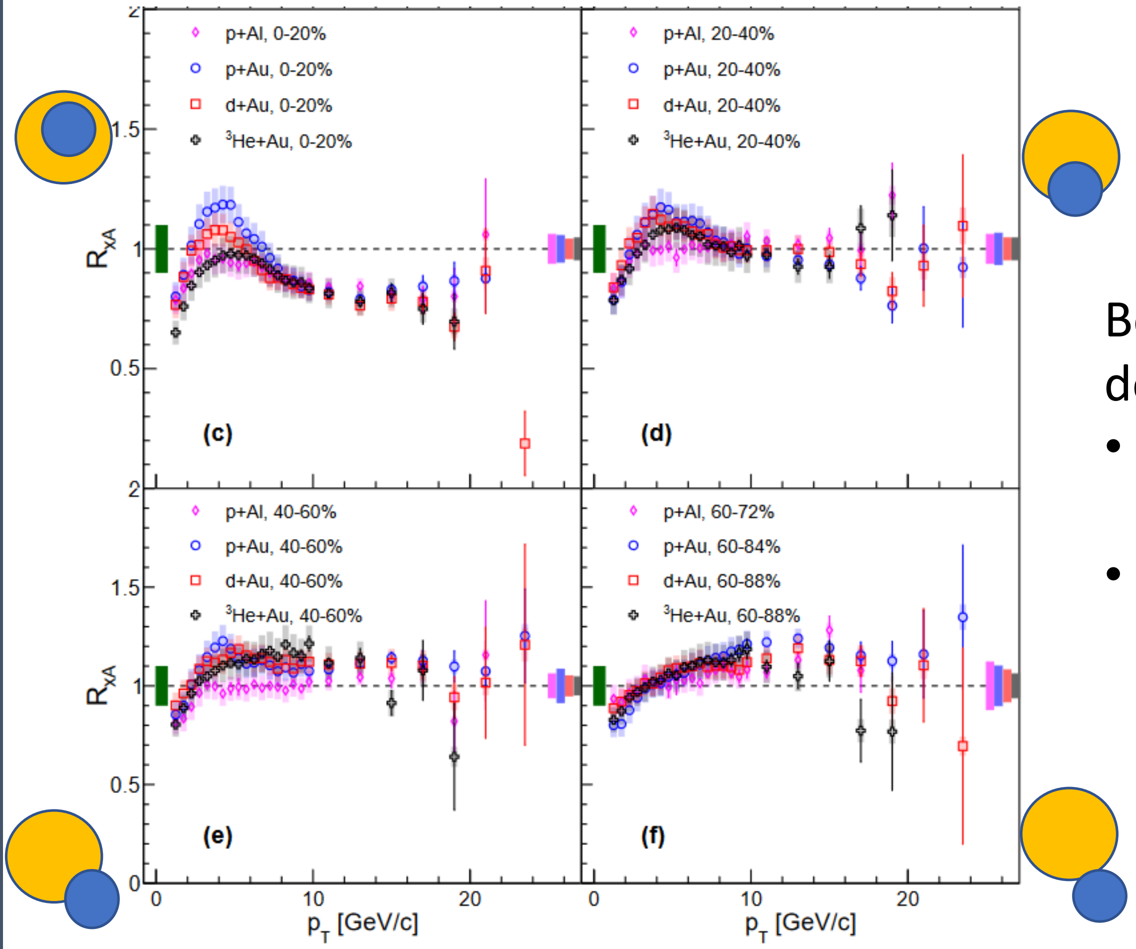
- It is unity at all centralities.

- As expected, the QGP is transparent to direct photons

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



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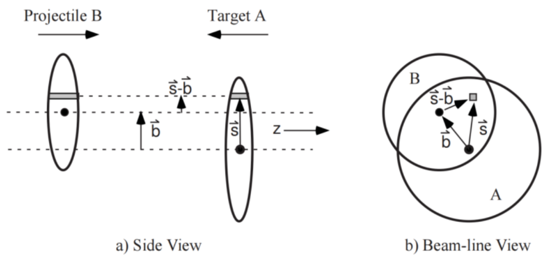
$$R_{AA}(pt) = \frac{\frac{dN_{AA}}{dp_T}}{\langle N_{coll}\rangle \frac{dN_{pp}}{dp_T}}$$

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?



- The basic assumption underlying centrality classes is that the impact parameter ***b*** is monotonically related to particle multiplicity.

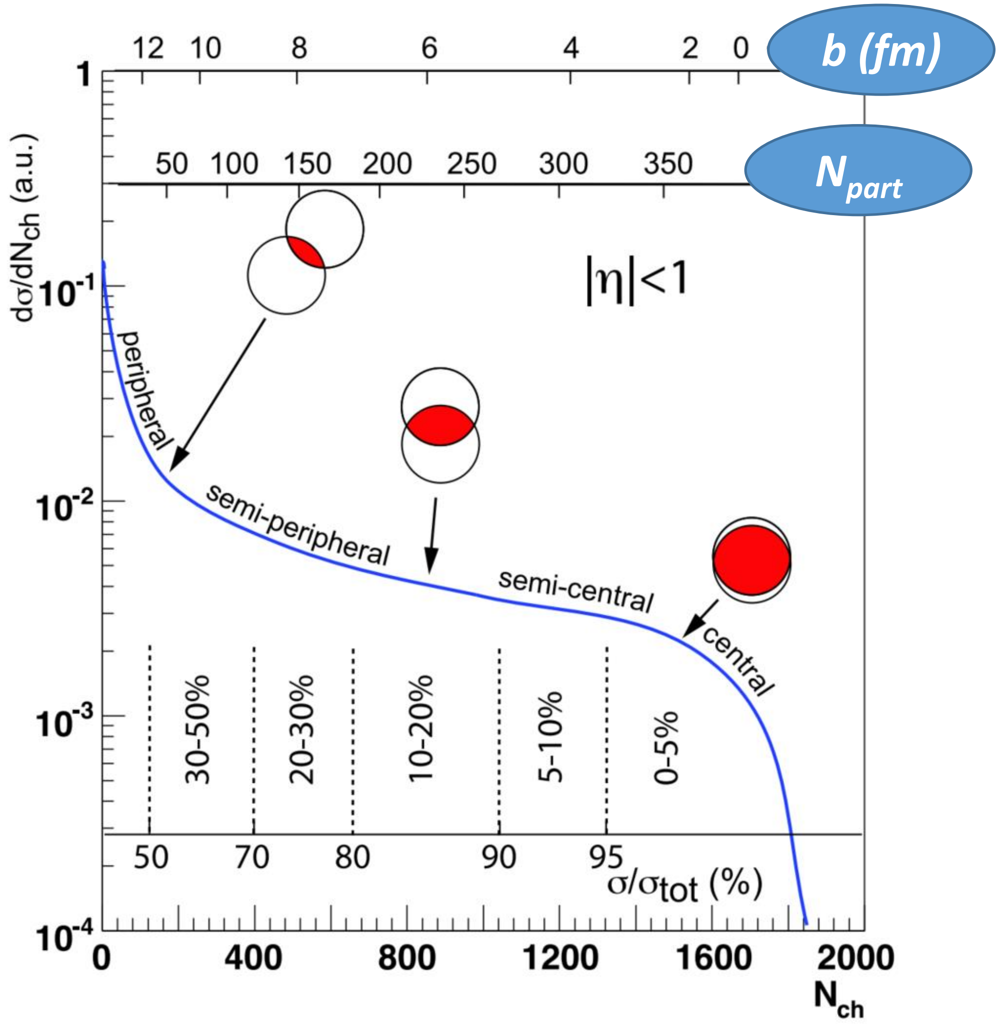
- For large ***b*** events("peripheral"), we expect low multiplicity, where as for small ***b*** events("central") we expect large multiplicity.

Impact parameter b (Theoretical)

N_{part} (Theoretical)

N_{ch} (Observable)

N_{part} - number of participating nucleon



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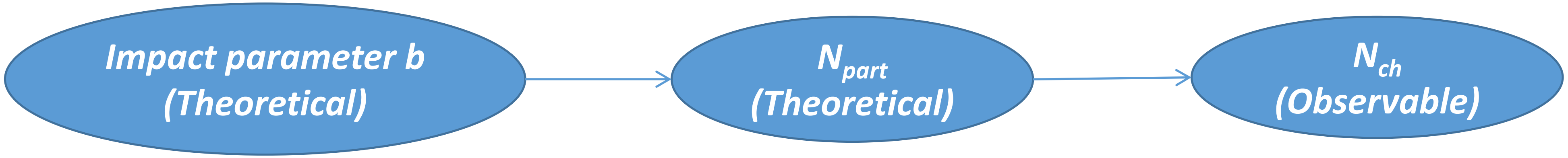
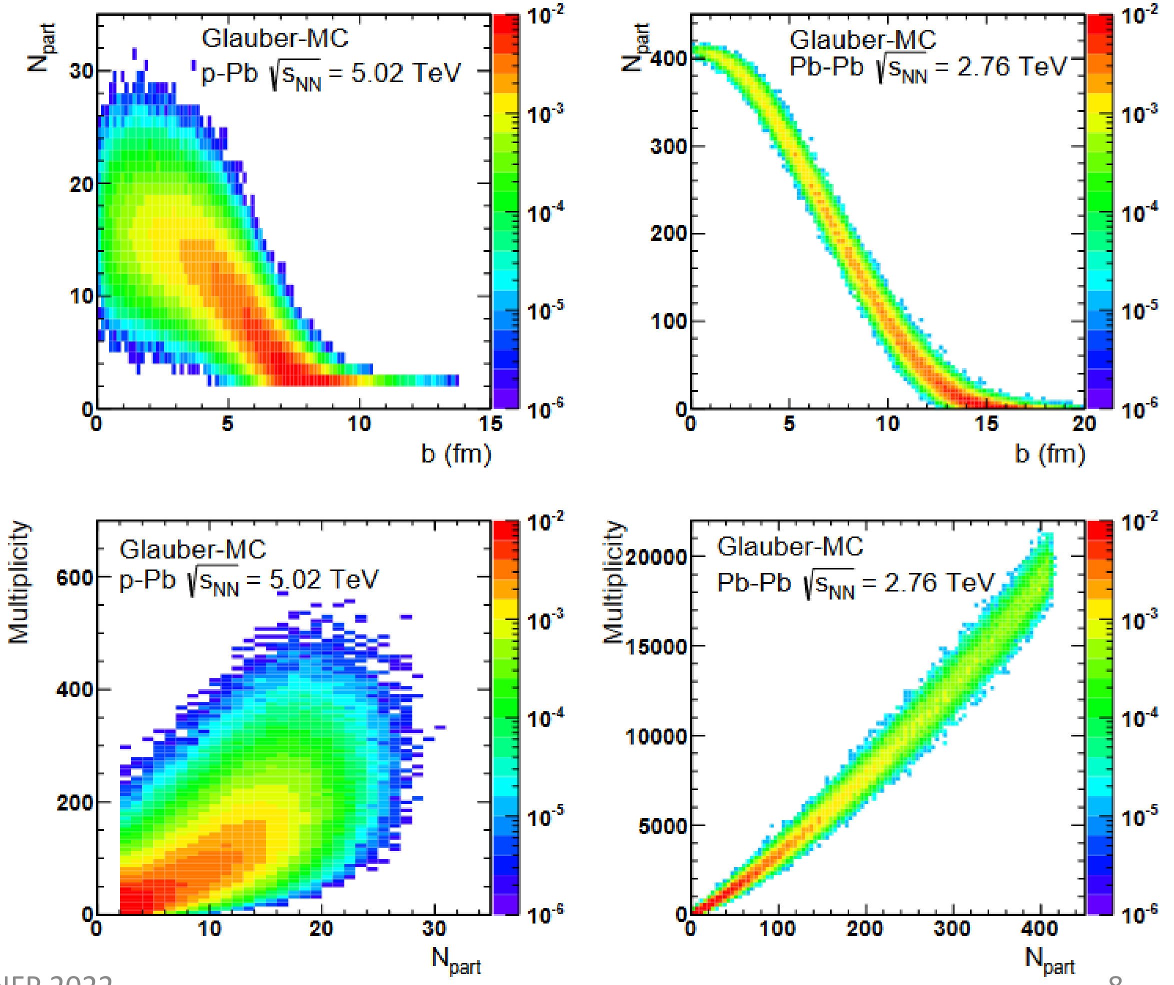
Is Glauber model valid for small systems?

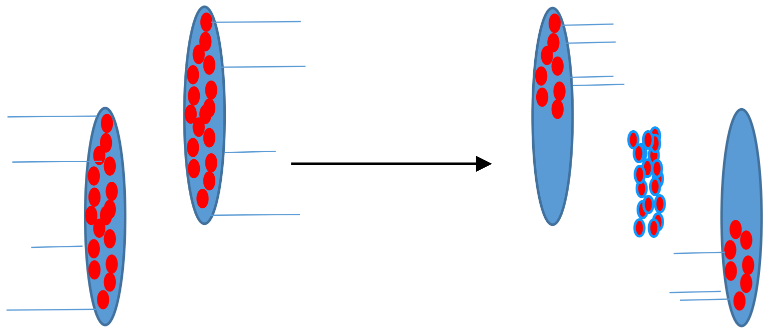


- Analyzing the 0-20% centrality bin in Pb+Pb is equivalent to studying the class of events with average impact parameter of 3fm with a very small variance.
- Analyzing the 0-20% centrality bin in p+Pb is also equivalent to studying the class of events with average impact parameter of 3fm but with a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

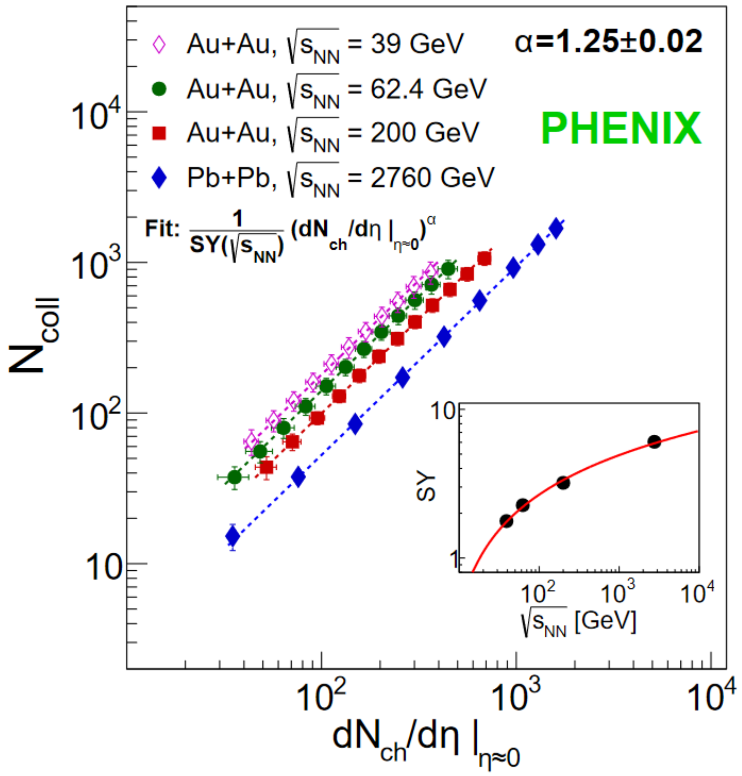


PR C 91, 064905 (2015)

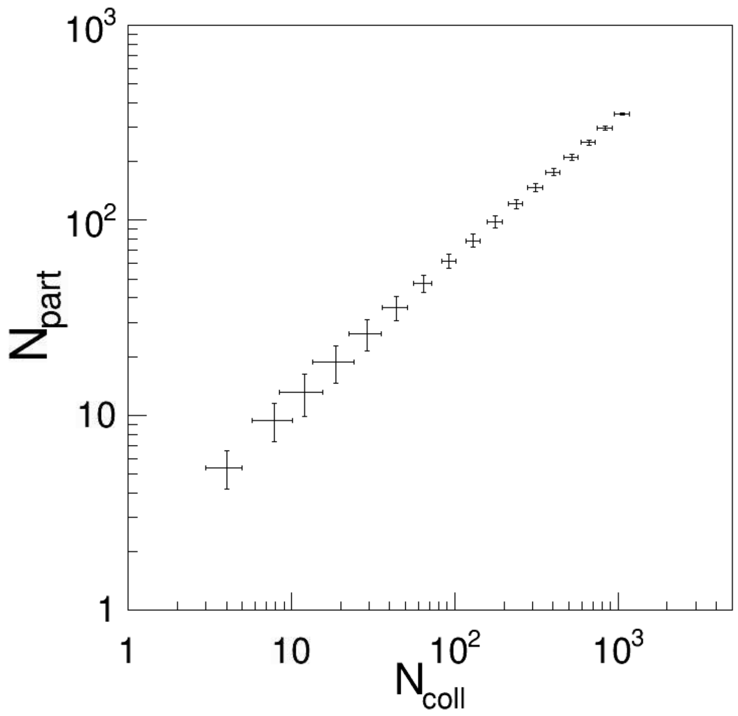
How is centrality determined in A-A (large-on-large) collisions?



In heavy ion cllisions, 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.

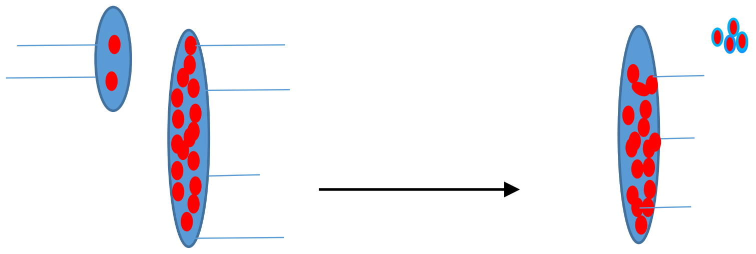


Phys. Rev. Lett. 123.022301



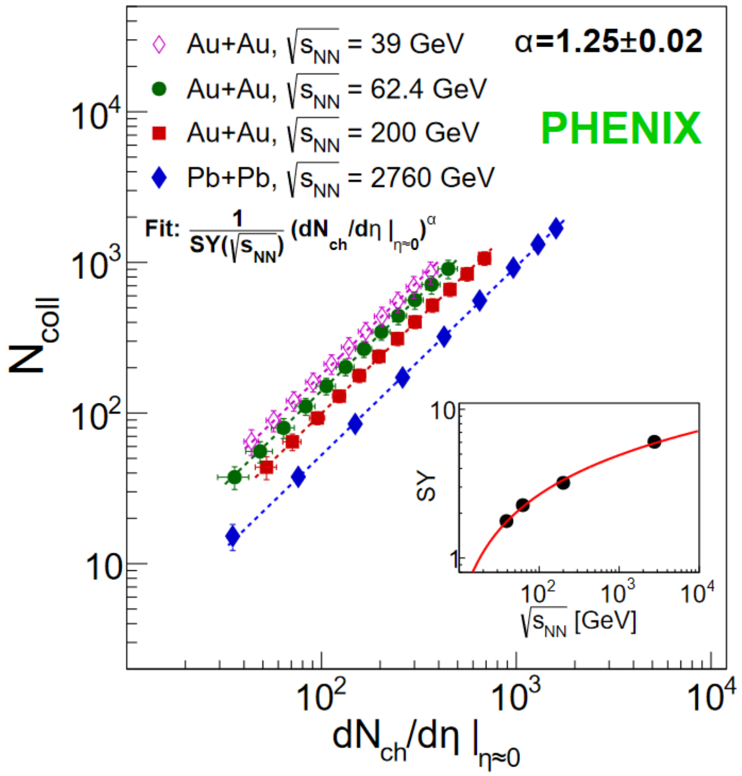
Data table from
Phys. Rev. C 89, 044905

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



However, is it still true that in small systems…

Direct photons



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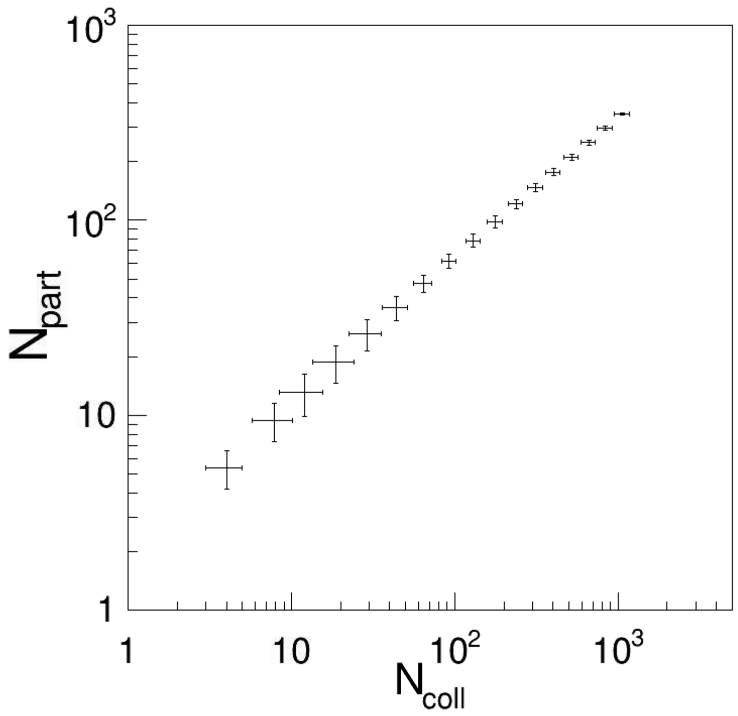
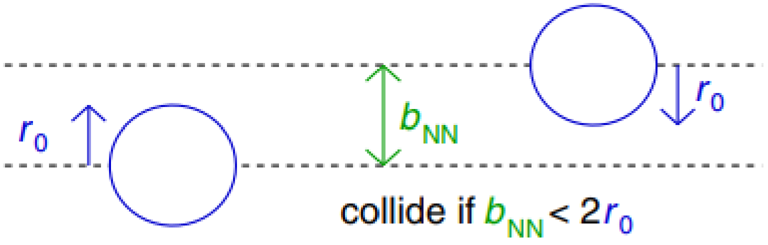


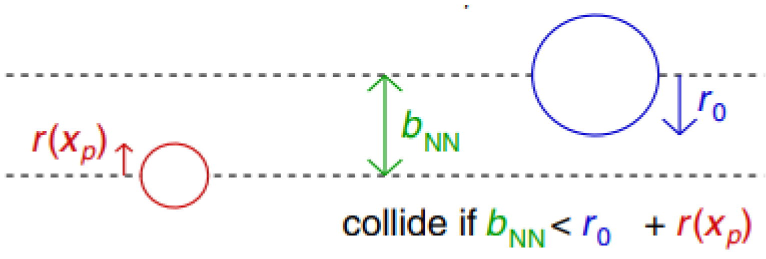
Data table from
Phys. Rev. C 89, 044905

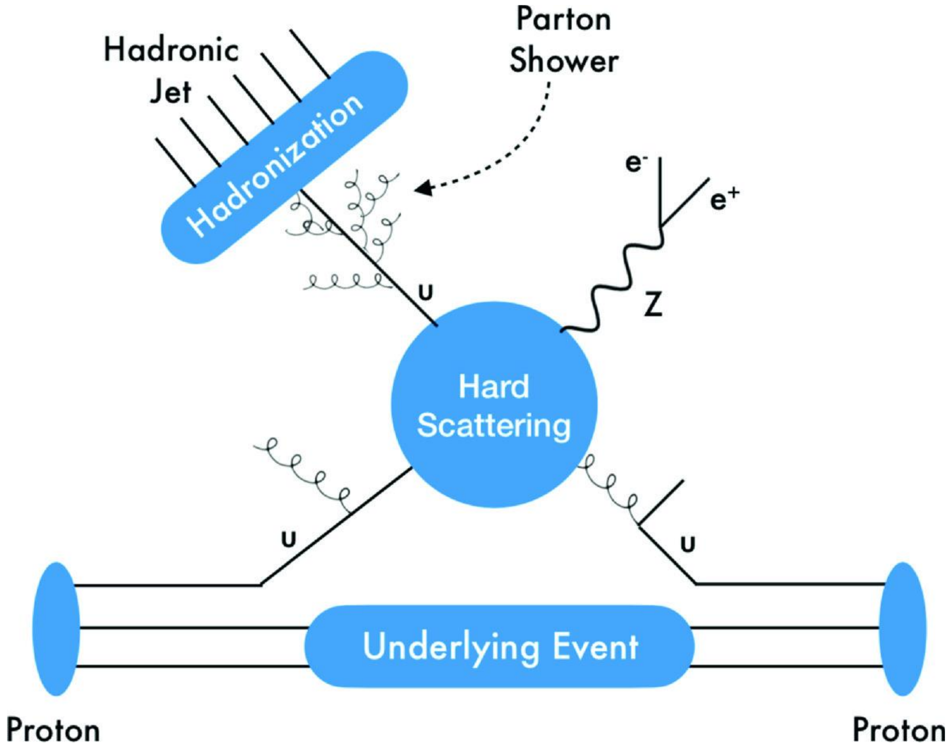
high-x (effective) size fluctuations

Typical N+N collisions



N+N collisions with large-x_p projectile nucleon

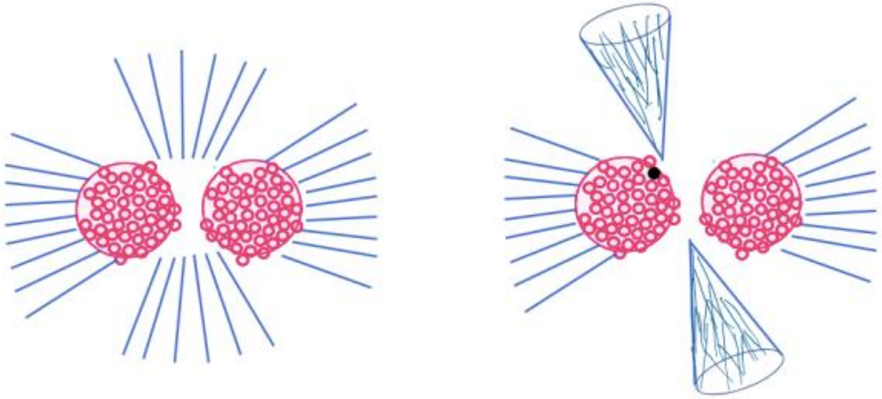




The high-X parton creates the hard scattering event. But the underlying event is severely depleted. This can be thought of as

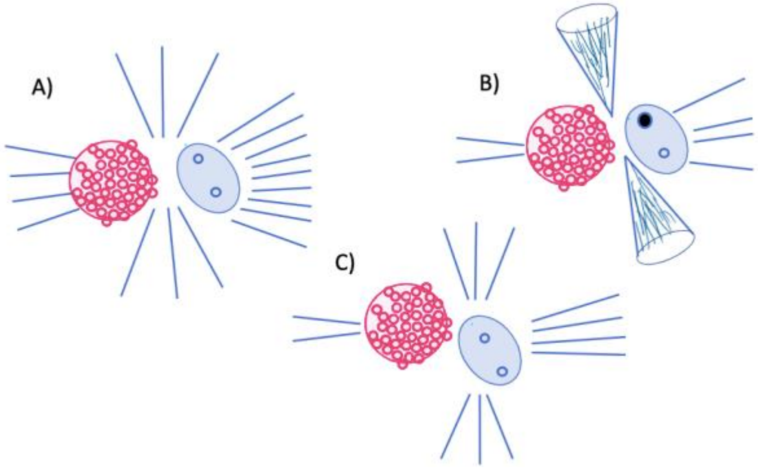
a) energy conservation or
b) change in the cross-section of the nucleons due to the presence of high-X parton.

What can bias the centrality Detemination ?



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.



Two possible scenarios

Corrected direct γ spectrum

Corrected π^0 spectrum

= **Ratio**

centrality dependence

The centrality dependence that we see in π^0 spectrum is because of true physics effects. And it should not affect direct photon.

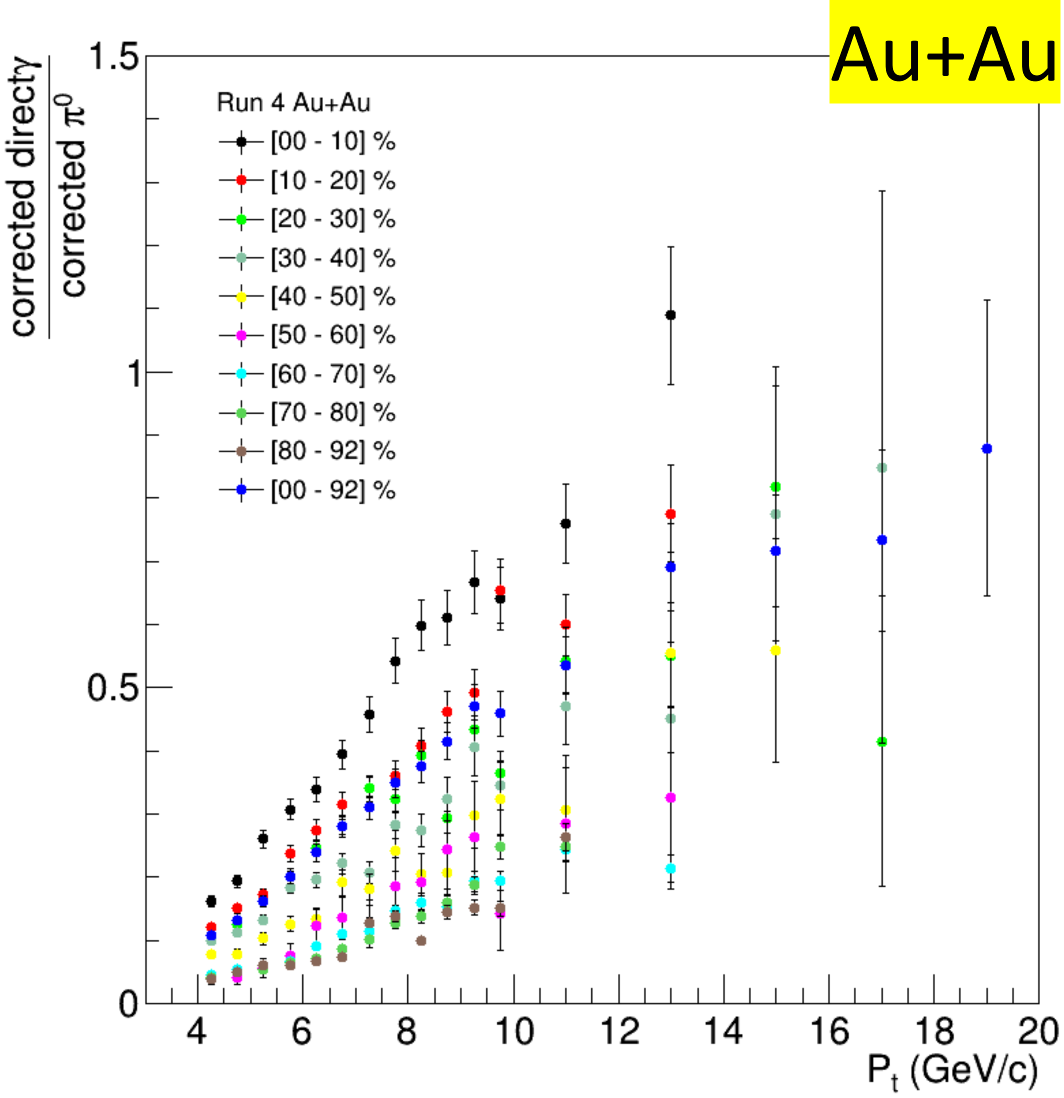
no centrality dependence

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

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 $\pi^{0'}$s but leaves the direct photons unaffected.

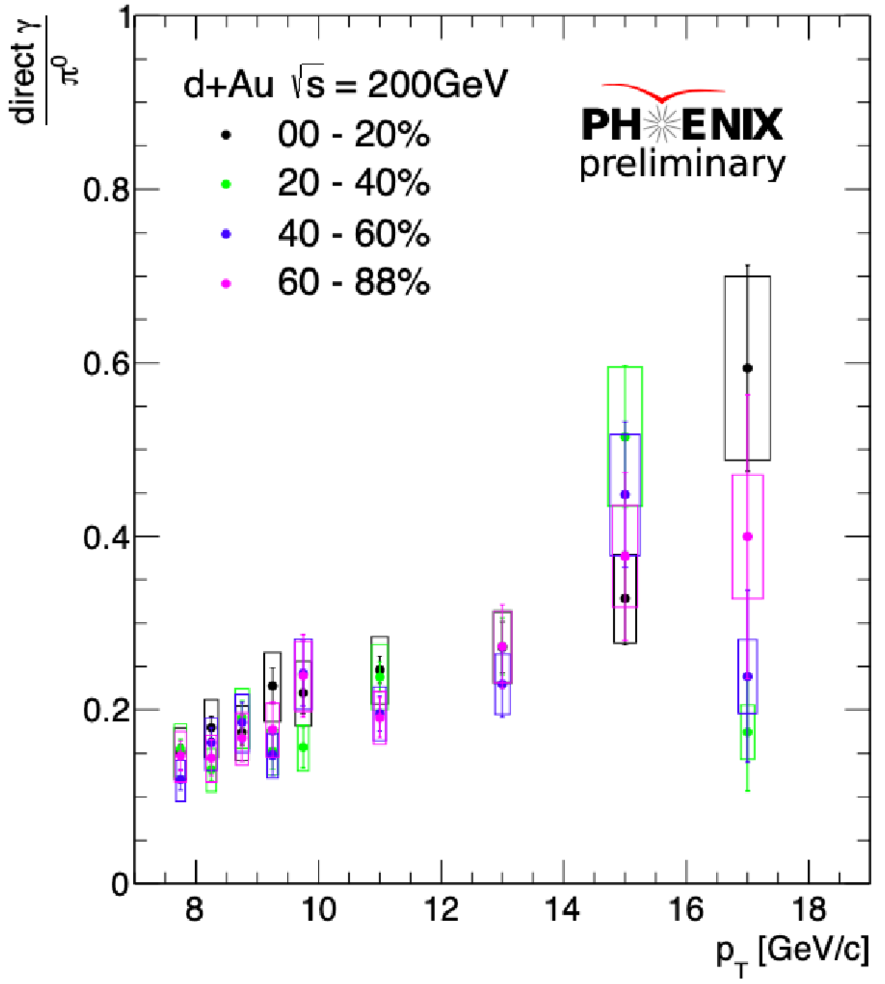
Neutral $\pi^{0'}$s : arXiv:0801.4020
direct γ : arXiv:1205.5759



Ratio of direct photon over π^0

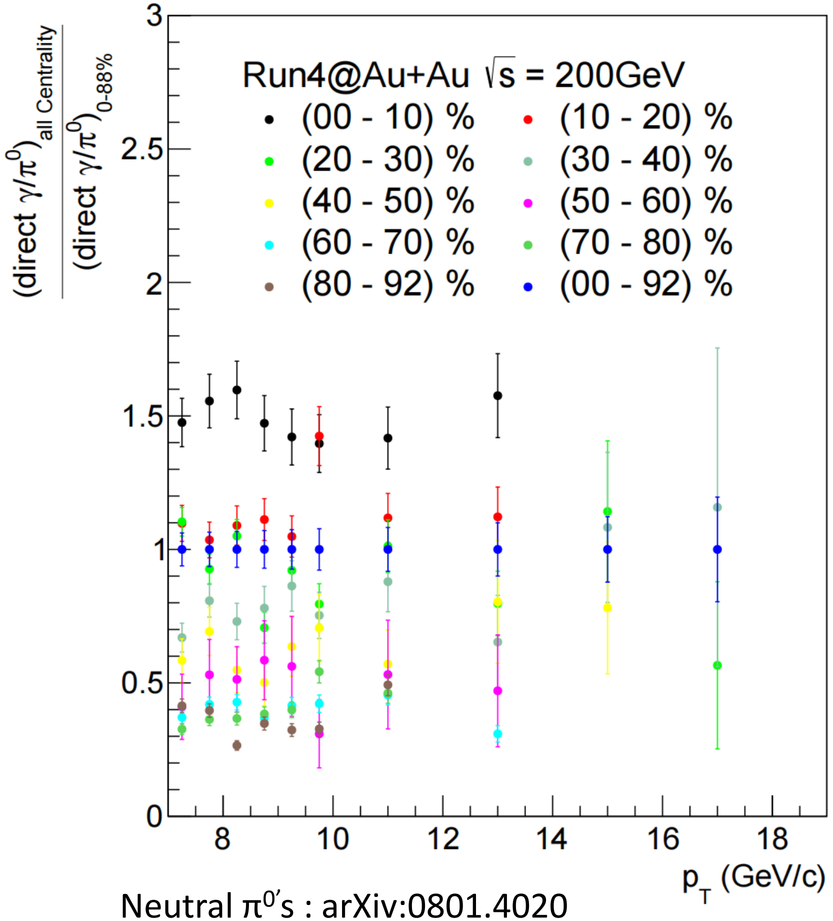
- There is a clear LACK OF centrality dependent ordering suggesting that in d+Au collisions there is a p_T dependent bias in centrality determination which affects BOTH π^0's and direct photons.

d+Au

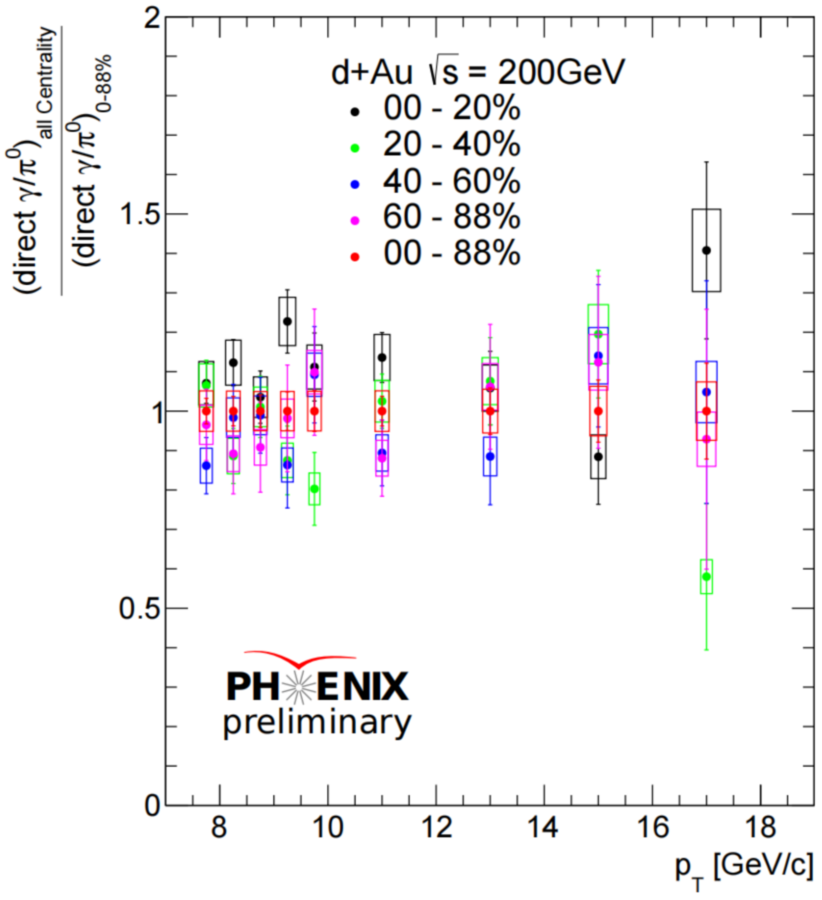


Comparison to MB in AuAu and dAu collisions

Centrality dependence can be found in the comparison to MB in AuAu, while in dAu, there is not likely a difference between centralities.



Neutral π^0's : arXiv:0801.4020
direct γ : arXiv:1205.5759

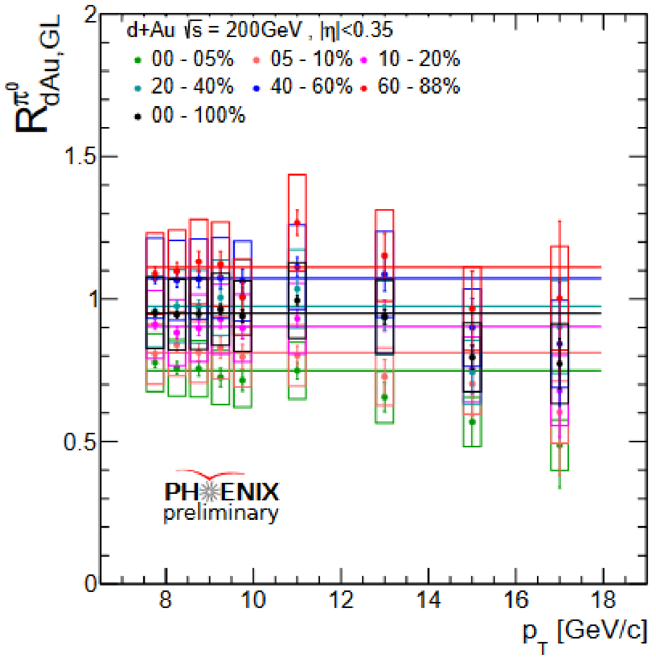


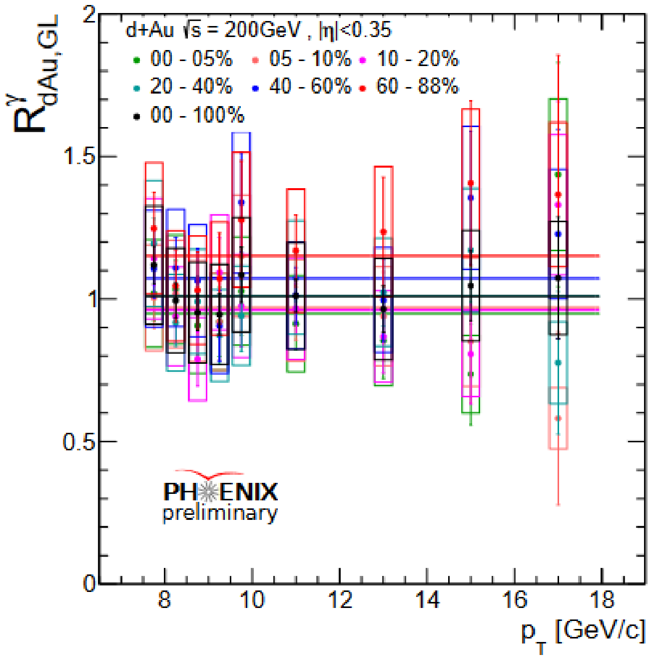
Double ratios in AuAu and dAu collisions

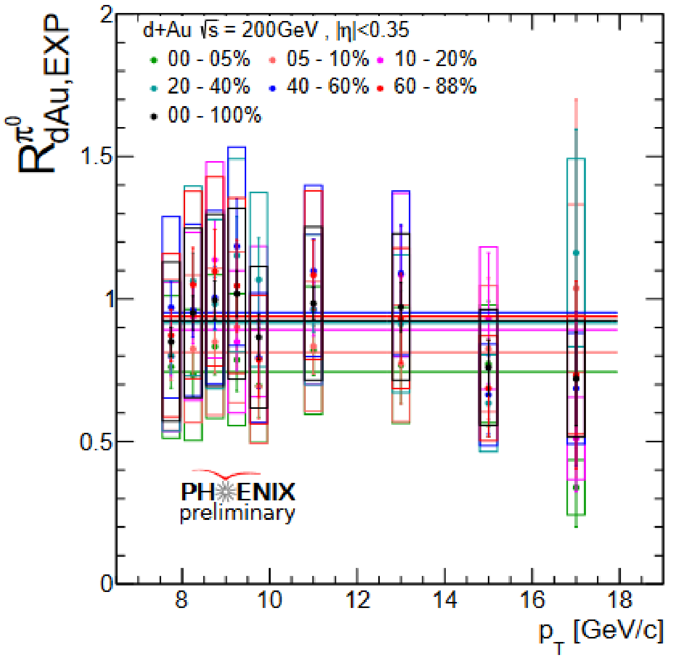
N_{coll} is redefined using the measurement of direct γ in experiment.

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

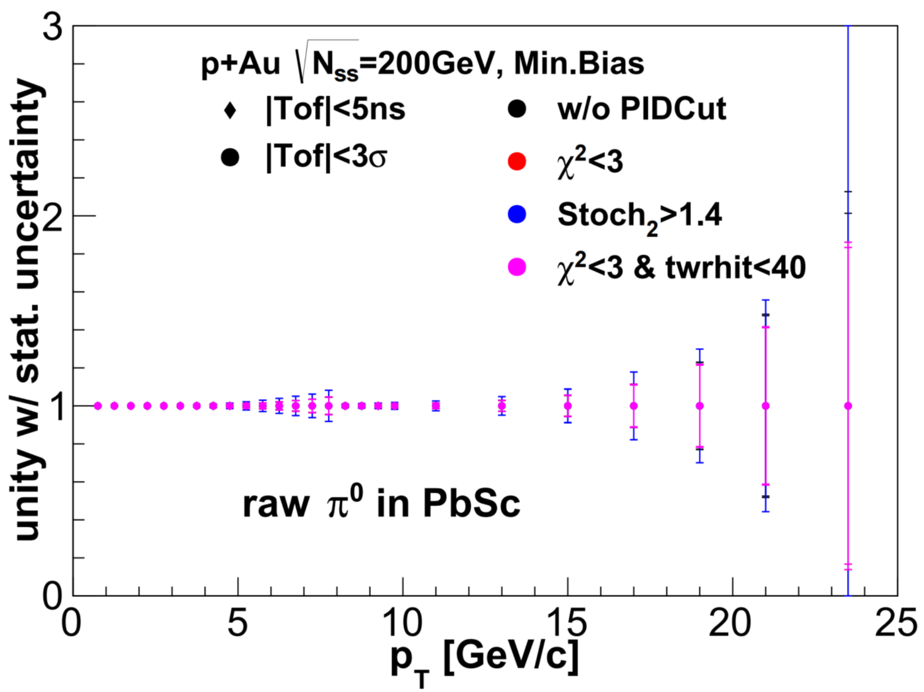
$$R_{\rm dAu,EXP}^{\pi^0} = \frac{R_{\rm dAu,GL}^{\pi^0}}{R_{\rm dAu,GL}^{\gamma^{dir}}} = \frac{Y_{\rm dAu}^{\pi^0}/Y_{pp}^{\pi^0}}{Y_{\rm dAu}^{\gamma^{dir}}/Y_{pp}^{\gamma^{\rm dir}}} = \frac{Y_{\rm dAu}^{\pi^0}}{N_{\rm coll}^{\rm EXP}\; Y_{pp}^{\pi^0}}$$



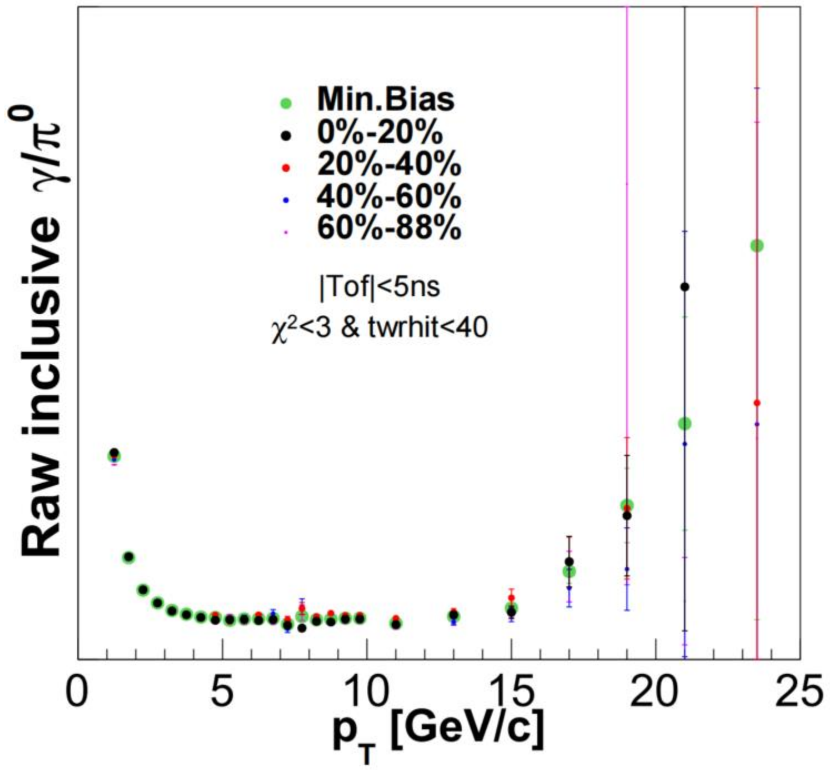




- The data of minimum bias (BBC) and triggered (ERT) p+Au collisions in PHENIX from the 2015 data taking period (Run 15) are used in the parallel study. The expected significance of the measurement based solely on statistical uncertainties is shown below.



- 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 are suppressed and peripheral events are enhanced
- Centrality determination
- Ratio of γ/π^0 and the double ratio to prove that there is a bias
- Determination of Ncoll from Glauber Model is biased in small system collisions
- New tool to bypass the requirement of using $\boldsymbol{N_{coll}}$ using direct photons
- Future analysis in p+Au and He+Au system will provide more clarification. Comparing the three systems, gradually increasing the size, should differentiate between the shrinking proton model (predicting decreasing suppression for larger systems) and some unexpected medium effect(causing increasing suprression for larger systems)

THANK YOU FOR YOUR ATTENTION !

BACKUP

TABLE IX: Test of whether the ansatz, $[(1-x)\langle N_{\mathrm{part}}\rangle/2 + x\langle N_{\mathrm{coll}}\rangle]$, from Eq. 6, with $x = 0.08$, is a proxy for N_{qp}. The errors quoted on $\langle N_{\mathrm{part}}\rangle$, $\langle N_{qp}\rangle$, $\langle N_{\mathrm{coll}}\rangle$ are correlated Type C and largely cancel in the $\langle N_{qp}\rangle$/ansatz ratio.

Centrality	$\langle N_{\mathrm{part}}\rangle$	$\langle N_{qp}\rangle$	$\langle N_{\mathrm{coll}}\rangle$	ansatz	$\langle N_{qp}\rangle$/ansatz
0%–5%	350.9 ± 4.7	956.6 ± 16.2	1064.1 ± 110.0	246.5	3.88
5%–10%	297.0 ± 6.6	789.8 ± 15.3	838.0 ± 87.2	203.7	3.88
10%–15%	251.0 ± 7.3	654.2 ± 14.5	661.1 ± 68.5	168.3	3.89
15%–20%	211.0 ± 7.3	540.2 ± 12.3	519.1 ± 53.7	138.6	3.90
20%–25%	176.3 ± 7.0	443.3 ± 10.4	402.6 ± 39.5	113.3	3.91
25%–30%	146.8 ± 7.1	362.8 ± 12.2	311.9 ± 31.8	92.5	3.92
30%–35%	120.9 ± 7.0	293.3 ± 11.0	237.8 ± 24.2	74.6	3.93
35%–40%	98.3 ± 6.8	233.5 ± 9.2	177.3 ± 18.3	59.4	3.93
40%–45%	78.7 ± 6.1	182.7 ± 6.8	129.6 ± 12.6	46.6	3.92
45%–50%	61.9 ± 5.2	140.5 ± 5.3	92.7 ± 9.0	35.9	3.91
50%–55%	47.6 ± 4.9	105.7 ± 5.5	64.4 ± 8.1	27.0	3.91
55%–60%	35.6 ± 5.1	77.3 ± 6.8	43.7 ± 7.6	19.9	3.89
60%–65%	26.1 ± 4.7	55.5 ± 7.1	29.0 ± 6.5	14.3	3.87
65%–70%	18.7 ± 4.0	39.0 ± 6.7	18.8 ± 5.3	10.1	3.86
70%–75%	13.1 ± 3.2	27.0 ± 4.9	12.0 ± 3.6	7.0	3.86
75%–80%	9.4 ± 2.1	19.0 ± 3.2	7.9 ± 2.2	5.0	3.83
80%–92%	5.4 ± 1.2	10.3 ± 1.5	4.0 ± 1.0	2.8	3.67
p+p	2	2.99 ± 0.05	1	1	2.99

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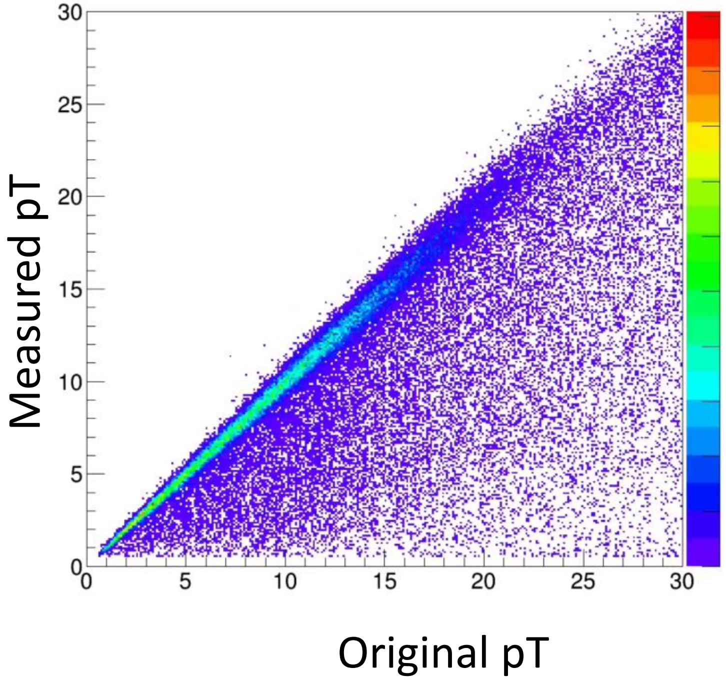
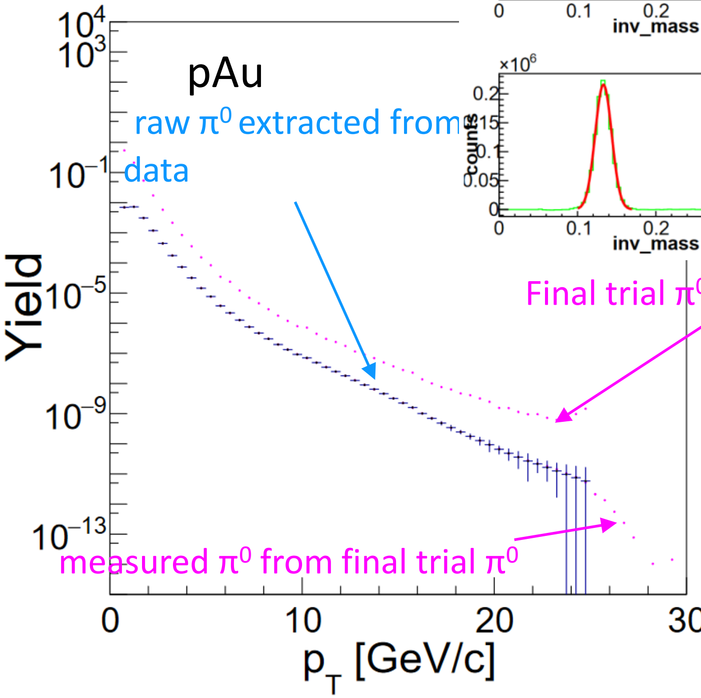
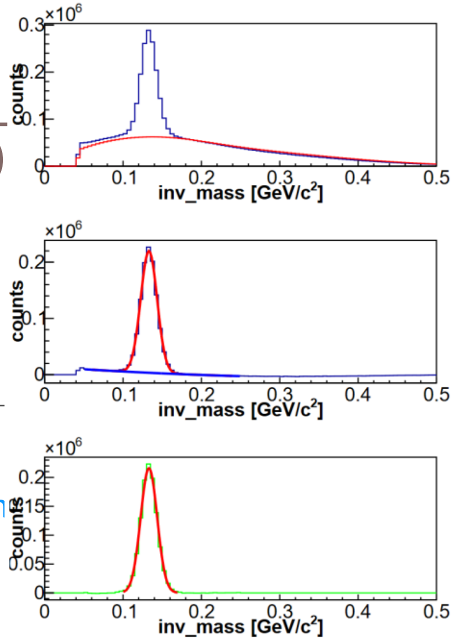
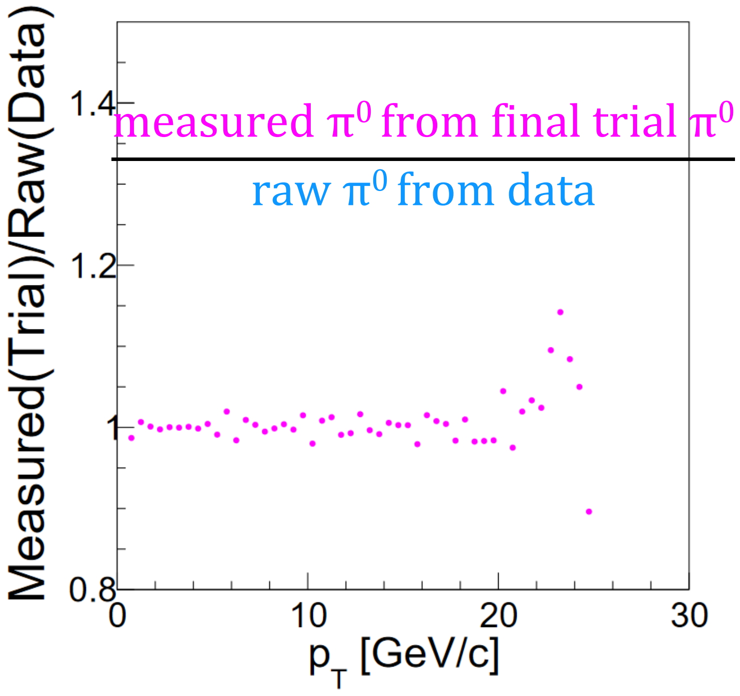
$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\emptyset)}$$







TBD



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

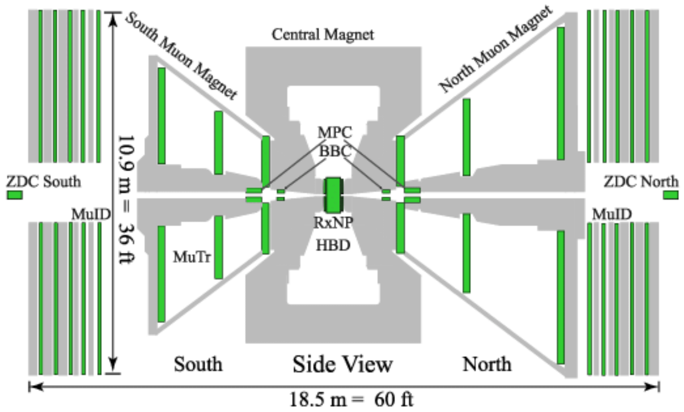
Same procedures are done with π^0 decay and single γ correction.

Measurement of number of binary collisions

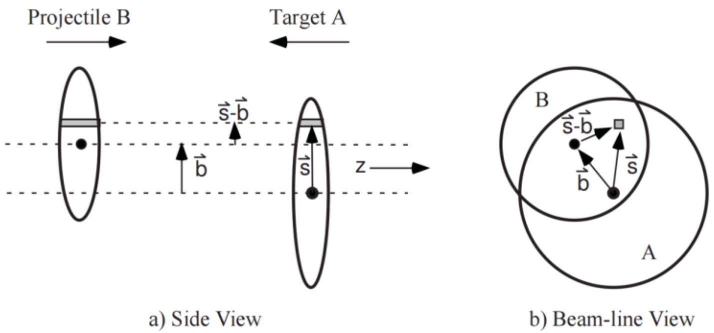
$$R_{AA}(pt) = \frac{\frac{dN_{AA}}{dp_T}}{\langle N_{coll} \rangle \frac{dN_{pp}}{dp_T}}$$

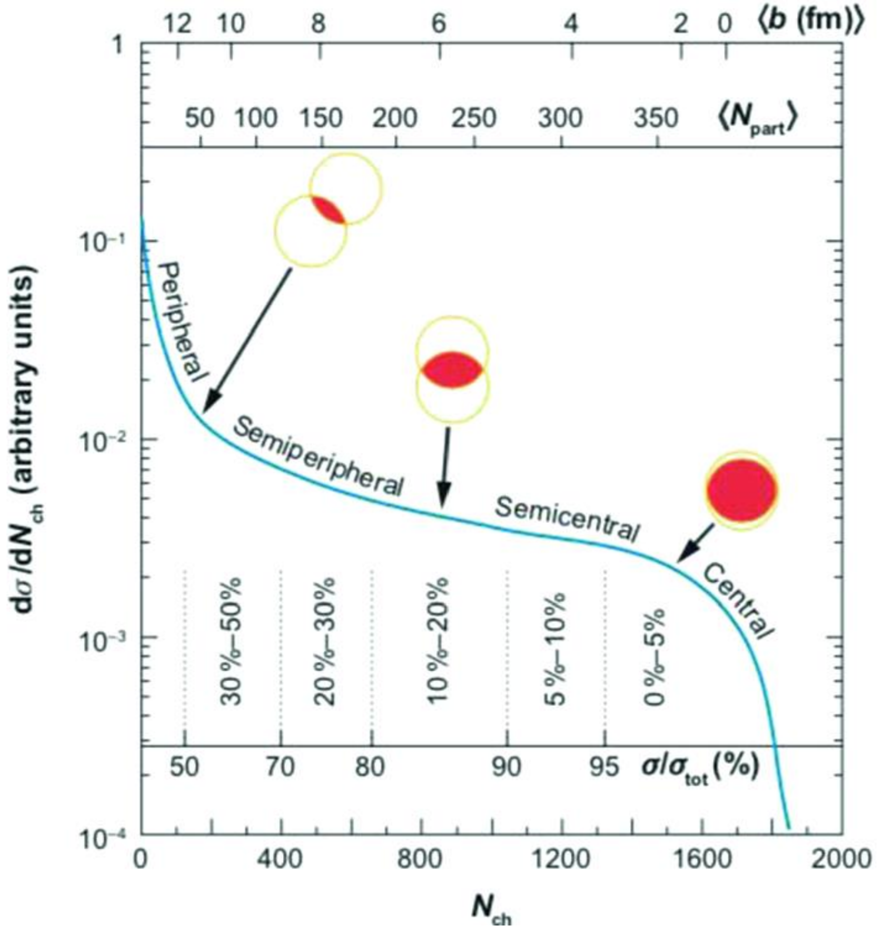
N_{part} - number of participating nucleon

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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D.2 Glauber Table

The results of the Glauber calculations are listed below. The centrality classes in the simulation were selected with the simulated BBC and ZDC signal for $\sqrt{s_{NN}} = 200$ GeV calculation [196].

Centrality	$\langle N_{part}\rangle$	sys. error	$\langle N_{coll}\rangle$	sys. error	T_{AA} (mb^{-1})	sys. error	$\langle b\rangle$(fm)	sys. error
0-10 %	325.2	3.3	955.4	93.6	22.75	1.56	3.2	0.2
10-20 %	234.6	4.7	602.6	59.3	14.35	1.00	5.7	0.3
20-30 %	166.6	5.4	373.8	39.6	8.90	0.72	7.4	0.3
30-40 %	114.2	4.4	219.8	22.6	5.23	0.44	8.7	0.4
40-50 %	74.4	3.8	120.3	13.7	2.86	0.28	9.9	0.4
50-60 %	45.5	3.3	61.0	9.9	1.45	0.23	11.0	0.4
60-70 %	25.7	3.8	28.5	7.6	0.68	0.18	11.9	0.5
70-80 %	13.4	3.0	12.4	4.2	0.30	0.10	12.8	0.5
80-92.3 %	6.3	1.2	4.9	1.2	0.12	0.03	14.1	0.6
min. bias	109.1	4.1	257.8	25.4	6.14	0.45	9.5	0.4

Table D.2: Results of $\sqrt{s_{NN}} = 200$ GeV Au+Au Glauber Calculations.

https://phenix-intra.sdcc.bnl.gov/phenix/WWW/publish/isobe/DoctorThesis/dthesis_isobe.pdf

TABLE IX: Test of whether the ansatz, $[(1-x)\langle N_{\rm part}\rangle/2 + x\langle N_{\rm coll}\rangle]$, from Eq. 6, with $x = 0.08$, is a proxy for N_{qp}. The errors quoted on $\langle N_{\rm part}\rangle$, $\langle N_{qp}\rangle$, $\langle N_{\rm coll}\rangle$ are correlated Type C and largely cancel in the $\langle N_{qp}\rangle$/ansatz ratio.

Centrality	$\langle N_{\rm part}\rangle$	$\langle N_{qp}\rangle$	$\langle N_{\rm coll}\rangle$	ansatz	$\langle N_{qp}\rangle$/ansatz
0%–5%	350.9 ± 4.7	956.6 ± 16.2	1064.1 ± 110.0	246.5	3.88
5%–10%	297.0 ± 6.6	789.8 ± 15.3	838.0 ± 87.2	203.7	3.88
10%–15%	251.0 ± 7.3	654.2 ± 14.5	661.1 ± 68.5	168.3	3.89
15%–20%	211.0 ± 7.3	540.2 ± 12.3	519.1 ± 53.7	138.6	3.90
20%–25%	176.3 ± 7.0	443.3 ± 10.4	402.6 ± 39.5	113.3	3.91
25%–30%	146.8 ± 7.1	362.8 ± 12.2	311.9 ± 31.8	92.5	3.92
30%–35%	120.9 ± 7.0	293.3 ± 11.0	237.8 ± 24.2	74.6	3.93
35%–40%	98.3 ± 6.8	233.5 ± 9.2	177.3 ± 18.3	59.4	3.93
40%–45%	78.7 ± 6.1	182.7 ± 6.8	129.6 ± 12.6	46.6	3.92
45%–50%	61.9 ± 5.2	140.5 ± 5.3	92.7 ± 9.0	35.9	3.91
50%–55%	47.6 ± 4.9	105.7 ± 5.5	64.4 ± 8.1	27.0	3.91
55%–60%	35.6 ± 5.1	77.3 ± 6.8	43.7 ± 7.6	19.9	3.89
60%–65%	26.1 ± 4.7	55.5 ± 7.1	29.0 ± 6.5	14.3	3.87
65%–70%	18.7 ± 4.0	39.0 ± 6.7	18.8 ± 5.3	10.1	3.86
70%–75%	13.1 ± 3.2	27.0 ± 4.9	12.0 ± 3.6	7.0	3.86
75%–80%	9.4 ± 2.1	19.0 ± 3.2	7.9 ± 2.2	5.0	3.83
80%–92%	5.4 ± 1.2	10.3 ± 1.5	4.0 ± 1.0	2.8	3.67
p+p	2	2.99 ± 0.05	1	1	2.99