Differential Analysis of High p_T Direct Photon and π^0 Production in small system collisions at 200 GeV

ZIMÁNYI SCHOOL 2024

24th ZIMÁNYI SCHOOL
WINTER WORKSHOP
ON HEAVY ION PHYSICS
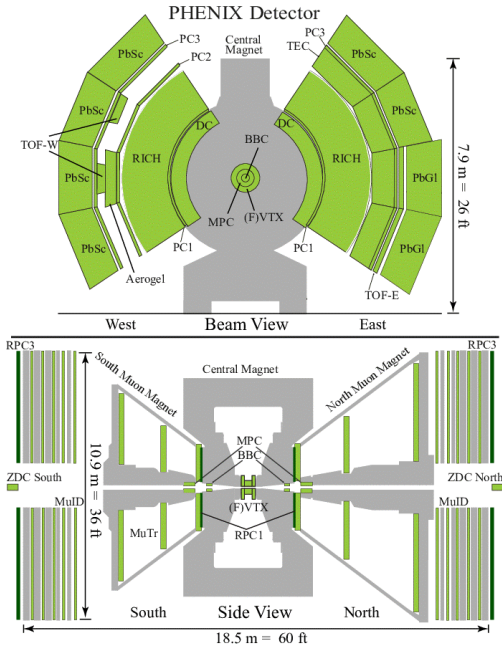
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Budapest, Hungary

L. Kassák: Image architecture

József Zimányi (1931 - 2006)

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Outline

- Motivation

- Bias in centrality determination in Glauber Model

- Yield of High p_T π^0 and γ

- Experimentally defined *N_{coll}*

- Summary

Nuclear Modification Factor

d+Au

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

p+p

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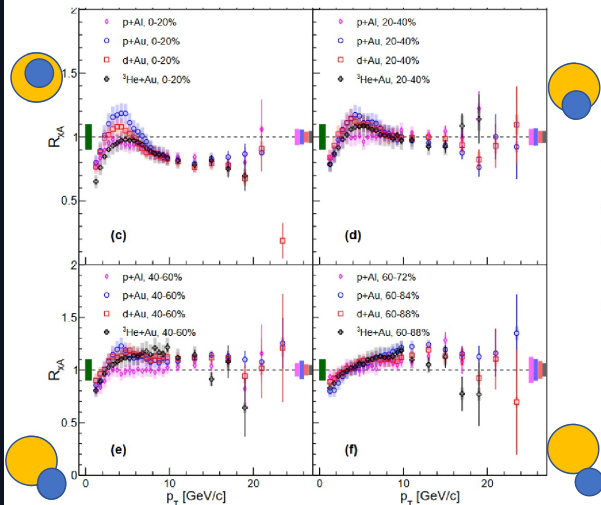

- *For photon, R_{AA} is consistant with 1*
- *For hadrons, R_{AA} shows supression at high pT*

This ratio teaches us how different a heavy ion collision is from just considering it as a scaled p+p collision
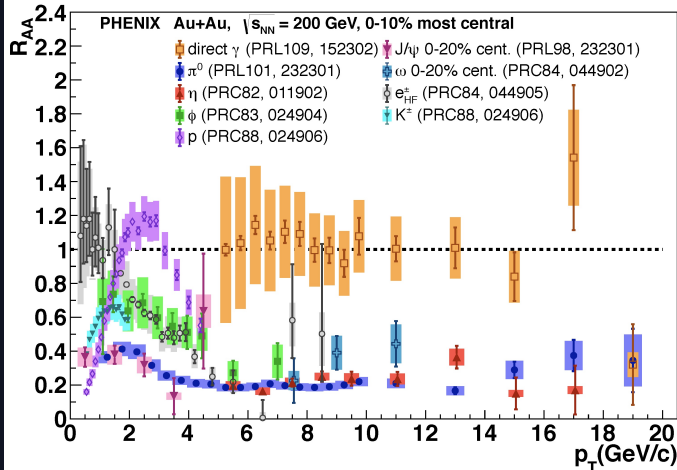
Nuclear modification factor for π⁰ in small systems

Phys.Rev.C 105 (2022) 064902

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

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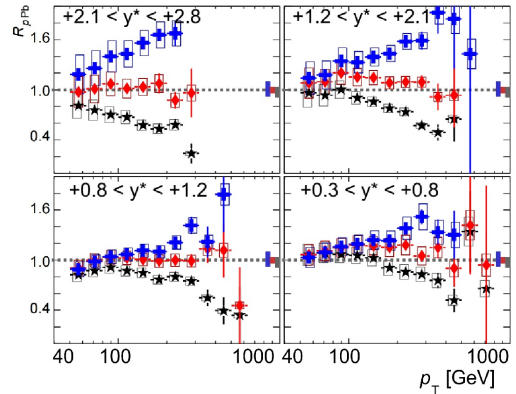
Is the centrality dependence a physics effect or an artifact of the way we determine centrality itself?
Are events mis-binned in centrality?

Jet results from ATLAS
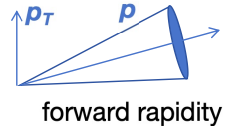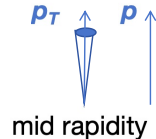
p going direction
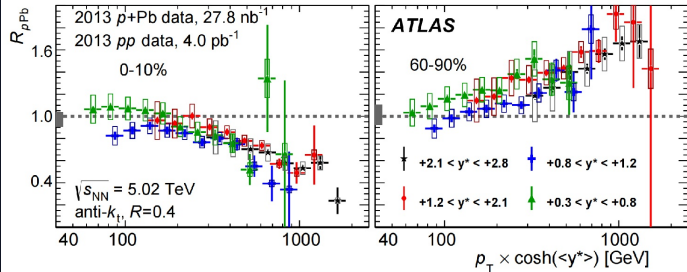
Phys. Lett. B 748, 392 (2015)

$$p_T \times \cosh\left(\langle y^* \rangle\right) \approx E$$

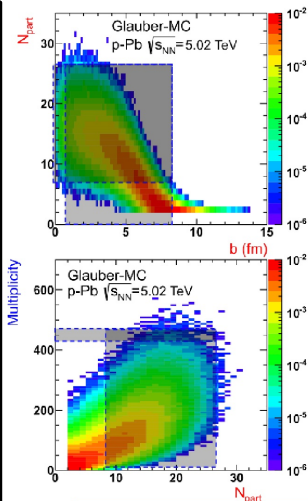$\langle y^* \rangle$ is the centre of the rapidity bin
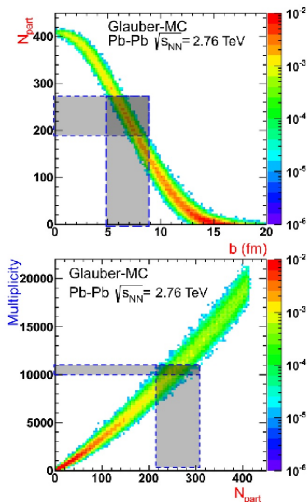E is the total energy of the jet.

Nuclear modification in the p-going direction
as a function of energy (not p_T)

mid rapidity   forward rapidity

Is Glauber model valid for small systems?

$$\frac{dN_{ch}}{d\eta} \Rightarrow N_{coll} \underbrace{=====\Rightarrow}_{Model/Theory} N_{par} \underbrace{====\Rightarrow}_{Theory} b$$

A narrow range of multiplicity (centrality class) in A+A maps to a narrow range of impact parameters
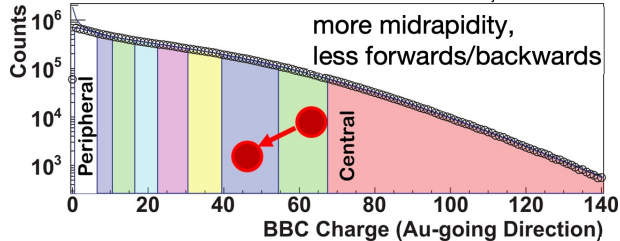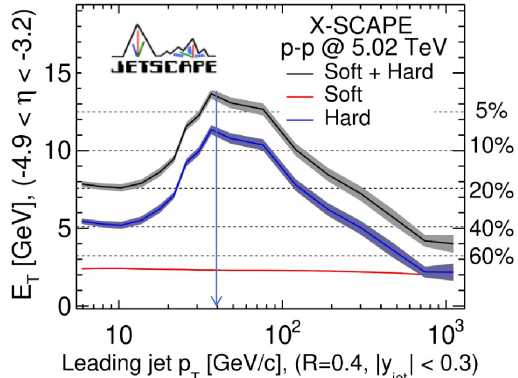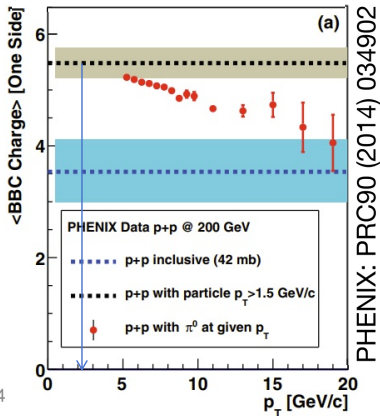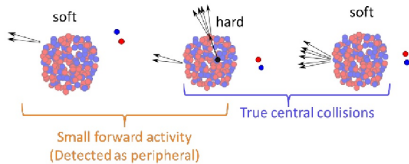
A narrow range of multiplicity (centrality class) in d+A maps to a wide range of impact parameters

Glauber model fails to describe small systems!

PRC 91, 064905 (2015)

Centrality Determination

Centrality is determined by event activity in the BBC, on the Au going direction (PHENIX)

soft   hard   soft

True central collisions

Small forward activity
(Detected as peripheral)

PHENIX: PRC90 (2014) 034902

⟨BBC Charge⟩ [One Side]

(a)

PHENIX Data p+p @ 200 GeV

p+p inclusive (42 mb)

p+p with particle p_T >1.5 GeV/c

p+p with π^0 at given p_T

p_T [GeV/c]

X-SCAPE
p-p @ 5.02 TeV
JETSCAPE
Soft + Hard
Soft
Hard

arXiv:2407.17443

5%
10%
20%
40%
60%

E_T [GeV], (-4.9 < η < -3.2)

Leading jet p_T [GeV/c], (R=0.4, $|y_{jet}|$ < 0.3)

more midrapidity,
less forwards/backwards

Counts

Peripheral

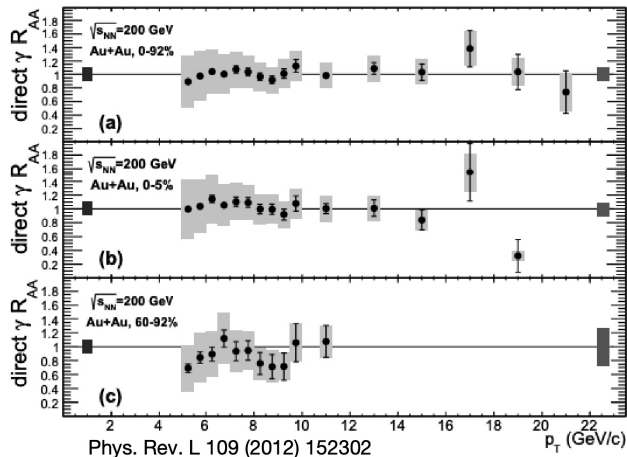Central

BBC Charge (Au-going Direction)

Using direct photons to minimize event selection bias

- Because of the color-neutral property, N_{coll} redefined by γ^{dir} yield experimentally
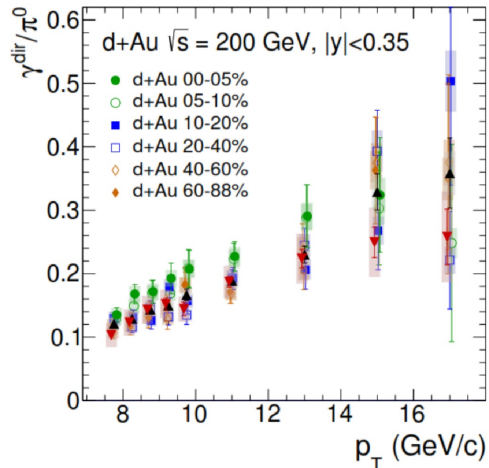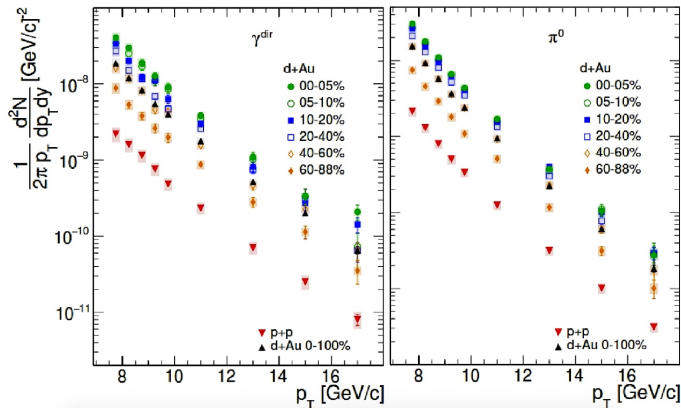
$$N_{coll}^{\mathrm{EXP}}(p_T) = \frac{Y_{dAu}^{\gamma^{dir}}(p_T)}{Y_{pp}^{\gamma^{dir}}(p_T)}$$

- Using the new N_{coll} , R_{dAu} for π^0 is written as following

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


Phys. Rev. L 109 (2012) 152302

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
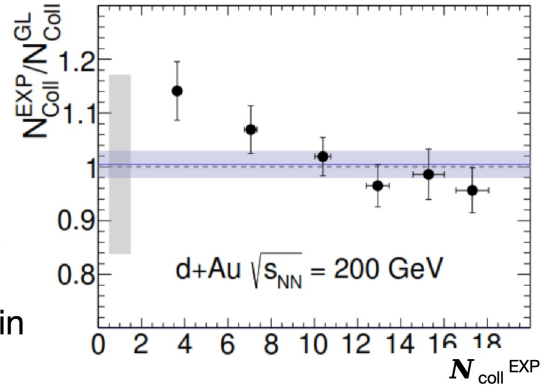- d+Au min. bias data: *PHENIX:PRC(2022)64902*
- p+p data: *PHENIX:PRC(2022)64902*

Evaluating bias in N_{coll} from Glauber Model
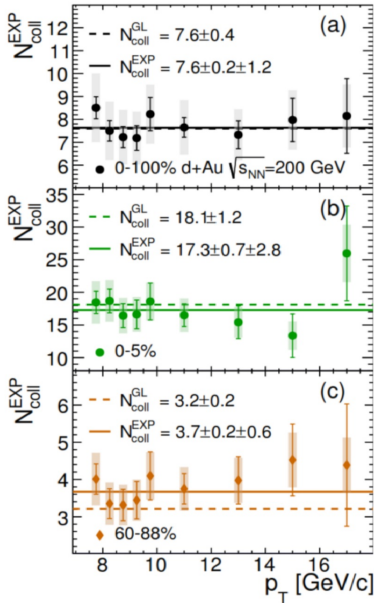
$$N_{\text{coll}}^{\text{EXP}}(p_T) = \frac{Y_{dAu}^{\gamma^{dir}}(p_T)}{Y_{pp}^{\gamma^{dir}}(p_T)}$$

Visible trend can be seen

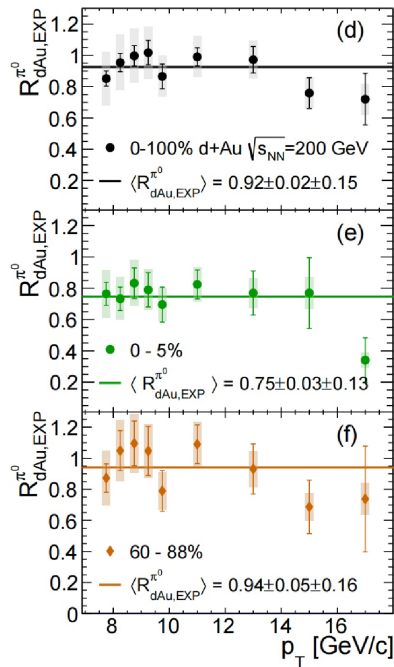- Good agreement in central collisions
- 15% deviation in periheral collisions

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

Redefine R_{dAu} for π^0

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

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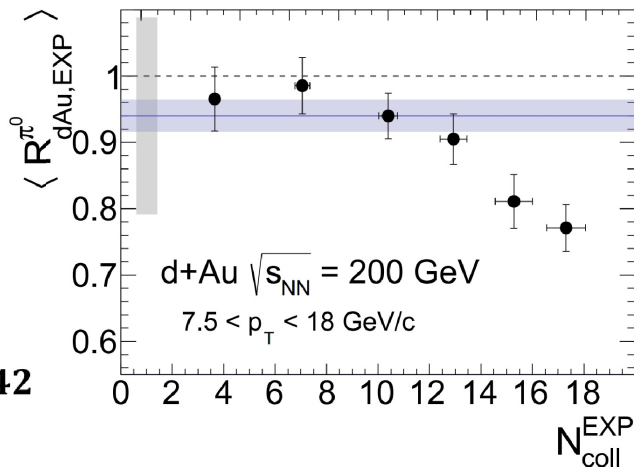
- In peripheral collisions, consistent with d+Au min. bias

Redefined R_{dAu} for π^0 vs. N_{coll}^{EXP}
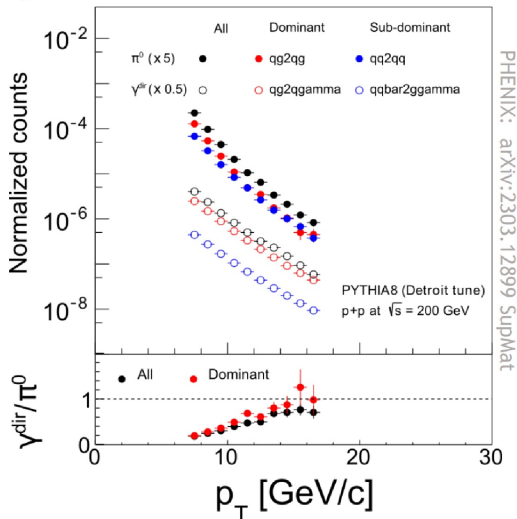
- N_{coll}^{EXP} <4 (60%-88% centrality)

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

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

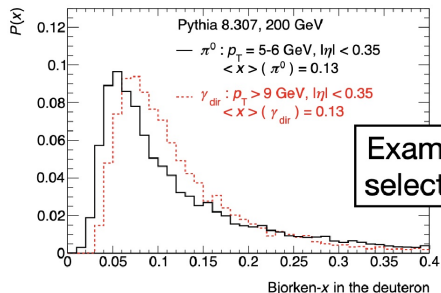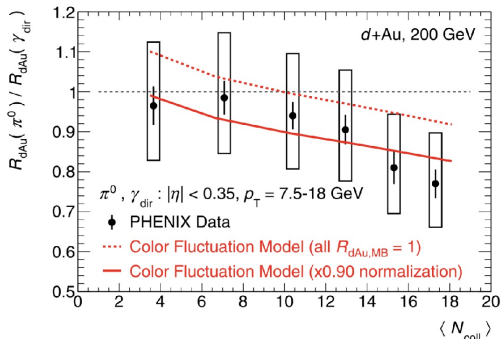$$\frac{R_{dAu,EXP}^{\pi^0}(0-5\%)}{R_{dAu,EXP}^{\pi^0}(0-100\%)} = 0.806 \pm 0.042$$

d+Au $\sqrt{s_{NN}}$ = 200 GeV

7.5 < p_T < 18 GeV/c

Bjorken-x

PRC 110, L011901 (2024)

PHENIX: arXiv:2303.12899 SupMat

Example selection

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

SUMMARY

- Using a redefined number N_{coll}^{EXP} to bypass event selection bias inherent to **Glauber model** approach
- Evidence for up to 20% suppression of high pT π^0 (7.5 to 18 GeV/c) in central 0-5% d+Au collisions

- Future analysis in p+Au and He+Au system will provide more clarification. System size scan will help to prove origin of the suppression
  - System Size : p+Au < d+Au < ³He+Au
 - Suppression : p+Au ? d+Au ? ³He+Au

THANK YOU FOR YOUR ATTENTION !

Theoretical prediction of two extreme limits of small colliding systems

d+Au 200 GeV

W.Ke & I.Vitev: arXiv:2204.00634

CNM effects

CNM effects + QGP
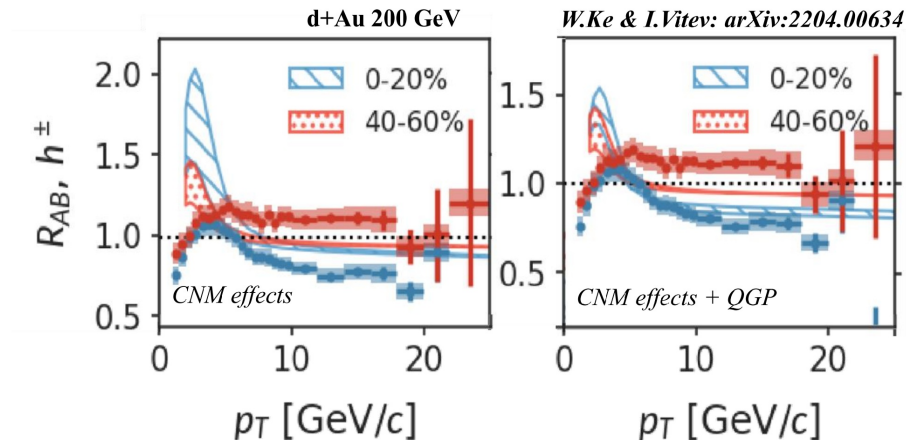
- Calculations with cold nuclear matter effect only.

- Calculations with cold and hot medium effects that assume the QGP is described by the hydrodynamic-based model.
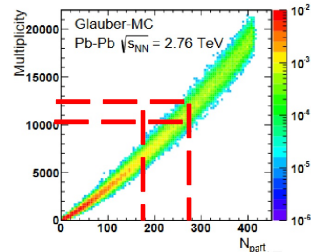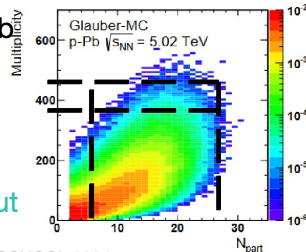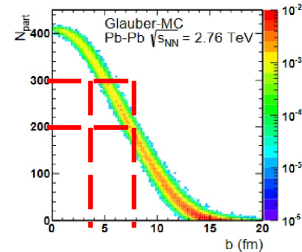
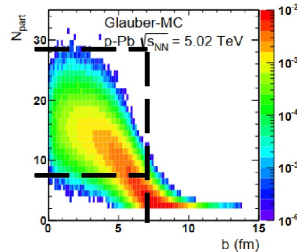# Is Glauber model valid for small systems?
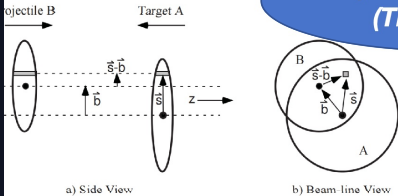
- Analyzing the 0-20% centrality bin in Pb+Pb is equivalent to studying the class of events with average impact parameter of 3fm with a very small variance.

- 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)

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.

Dijet