Centrality Categorization and its Application to Physics Effects in High-Energy d+A Collisions

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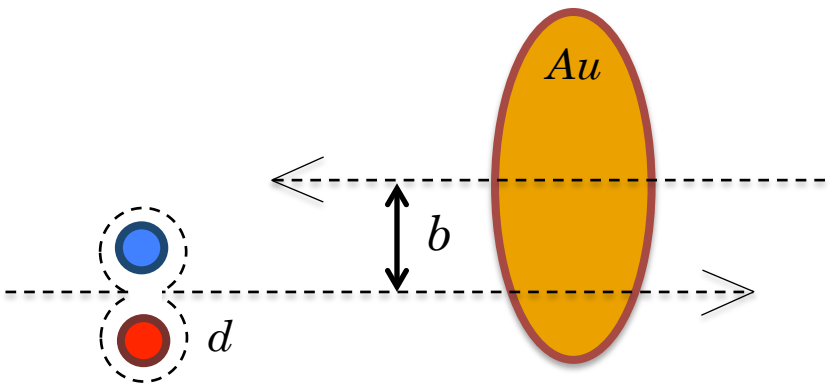
Motivation

Numerous physics effects can be studied in **d+Au** collisions.

- Modifications of parton distribution functions in nuclei
- Gluon saturation
- Color neutralization
- **Collective flow in small systems (!)**

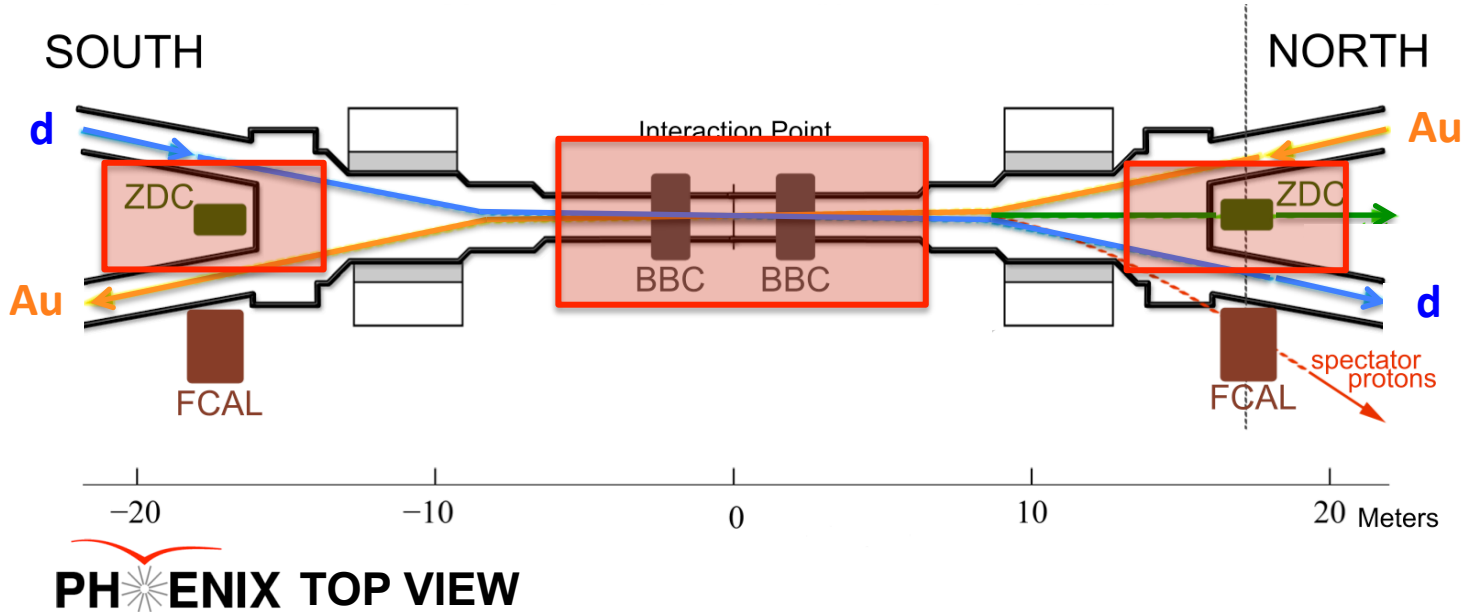
We need to characterize the event geometry!



- How to select centrality classes?
- How to validate the selection?
- Are there any **bias effects**?
- How do they affect 'the physics' at the **GeV** and **TeV** scales?

Experiment

PHENIX determines centrality by cutting on backward (Au-going) rapidity multiplicity.



BBCs

- Vertex pos.
- Centrality
- Event timing

BBC Range: $3.0 < |\eta| < 3.9$

ZDC

- Spectator neutrons

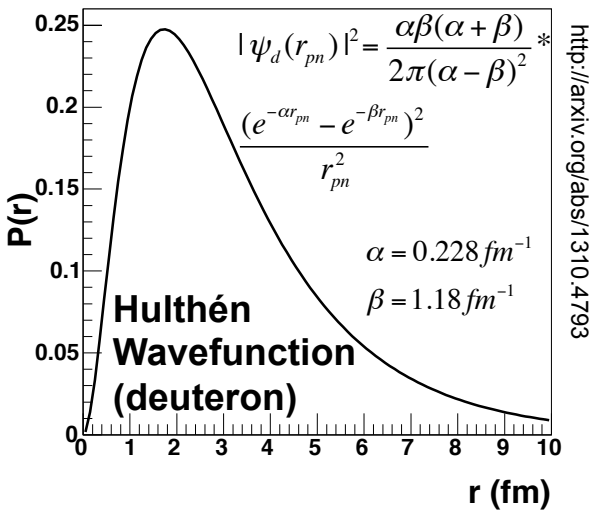
ZDC Range: $|\eta| > 6$

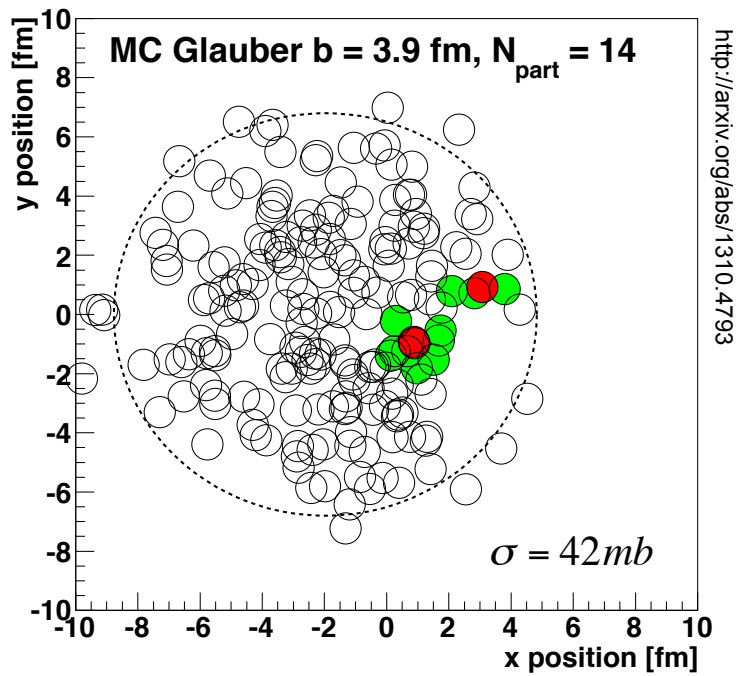
Centrality Categorization

Physical Observable
Charge in BBC (Au-going)

Monte Carlo Glauber

Event Geometry
N_{coll}, N_{part}, etc.





$$\rho(r) = \frac{\rho_0}{1 + e^{\frac{r-R}{a}}}$$

$R = 6.38\, fm$

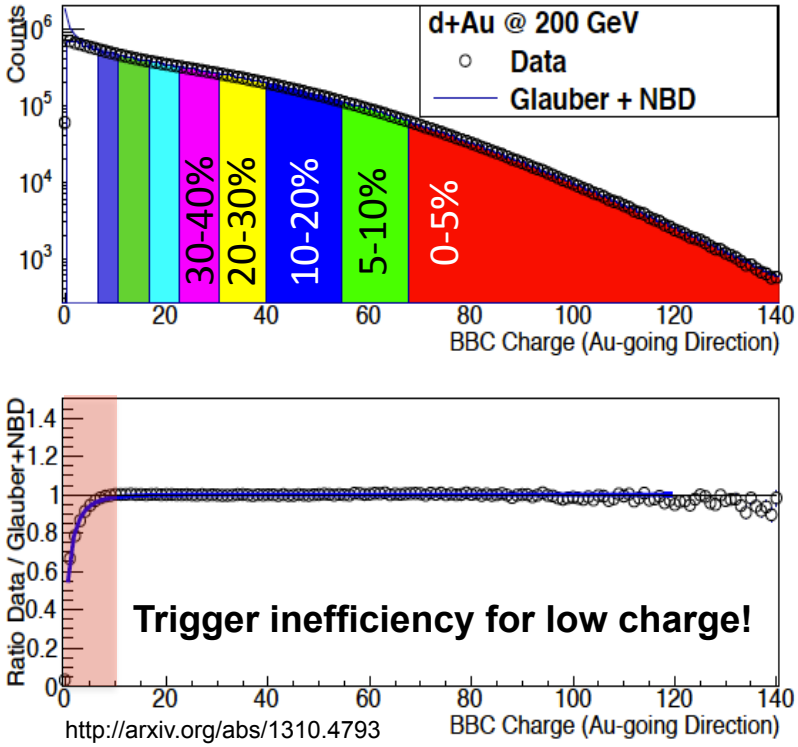
$a = 0.54\, fm$

Woods-Saxon Distribution (Au)

We use Monte Carlo methods to simulate d+Au collisions by sampling the position of nucleons from a Hulthén wavefunction (d) and a Woods-Saxon distribution (Au).

Centrality Categorization

Ok, so we know N_{coll} and N_{part} . How to map them to experimental observables?



http://arxiv.org/abs/1310.4793

MinBias trigger requirement:
At least one hit in both (Au-going and d-going) BBCs.

BBC Charge (Au-going) $\propto$ N_{coll}

Fluctuations from Negative Binomial Distribution

$$NBD(x;\mu,\kappa) = \left(1+\frac{\mu}{\kappa}\right)\frac{(\kappa+x-1)!}{x!(\kappa-1)!}\left(\frac{\mu}{\mu+\kappa}\right)^{x}$$

μ,κ **determined from fitting experimental data.**

Fold in the Glauber N_{coll} distribution *Gl(n)*

$$P(x) = \sum_{n=1}^{N_{binary}(max)} Gl(n) \times NBD(x;n\mu,n\kappa)$$

Centrality Categorization

Using Monte Carlo Glauber to map BBC multiplicity to geometry, we get numbers like…

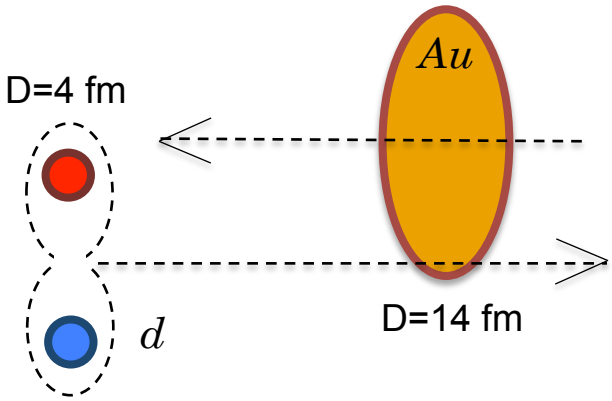
Centrality	0-20%	20-40%	40-60%	60%-88%
$\langle N_{coll} \rangle$	15.1 ± 1.0	10.2 ± 0.7	6.6 ± 0.4	3.2 ± 0.2
$\langle N_{part} \rangle$	15.2 ± 0.6	11.1 ± 0.6	7.8 ± 0.4	4.3 ± 0.2
$\langle N_{part}$ [Au]$\rangle$	13.3 ± 0.8	9.3 ± 0.6	6.2 ± 0.4	3.0 ± 0.2
$\langle N_{part}$ [d]$\rangle$	1.95 ± 0.01	1.84 ± 0.01	1.65 ± 0.02	1.36 ± 0.02

http://arxiv.org/abs/1310.4793

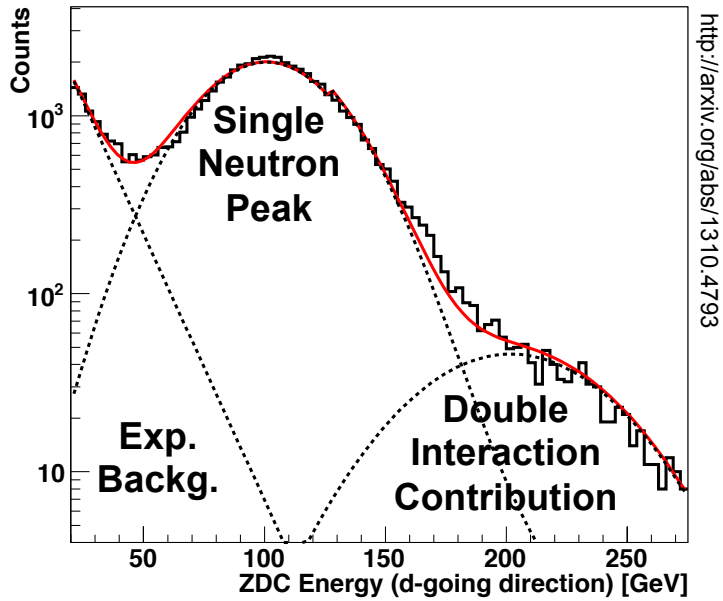
What about the ZDCs?
What information can they provide?

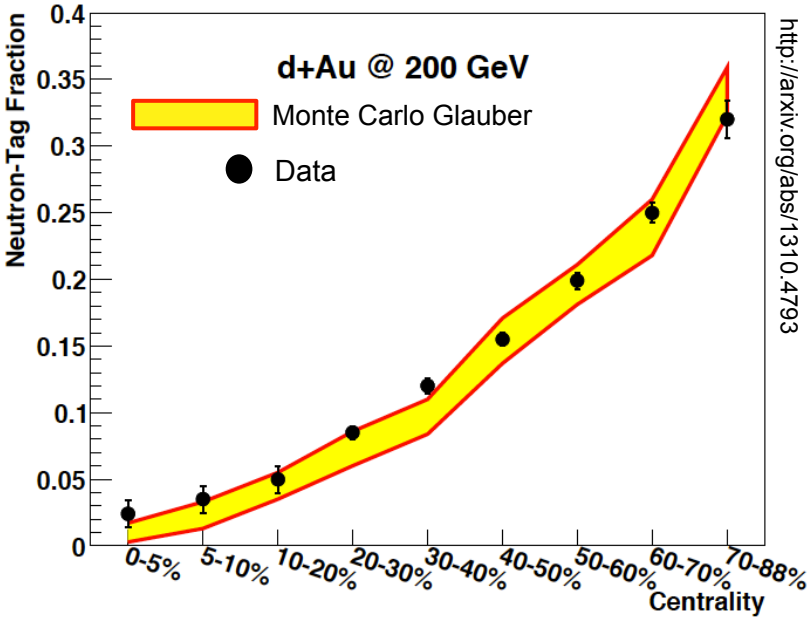
Checking Centrality Selection

What if only one nucleon in the deuteron collides with the Au?



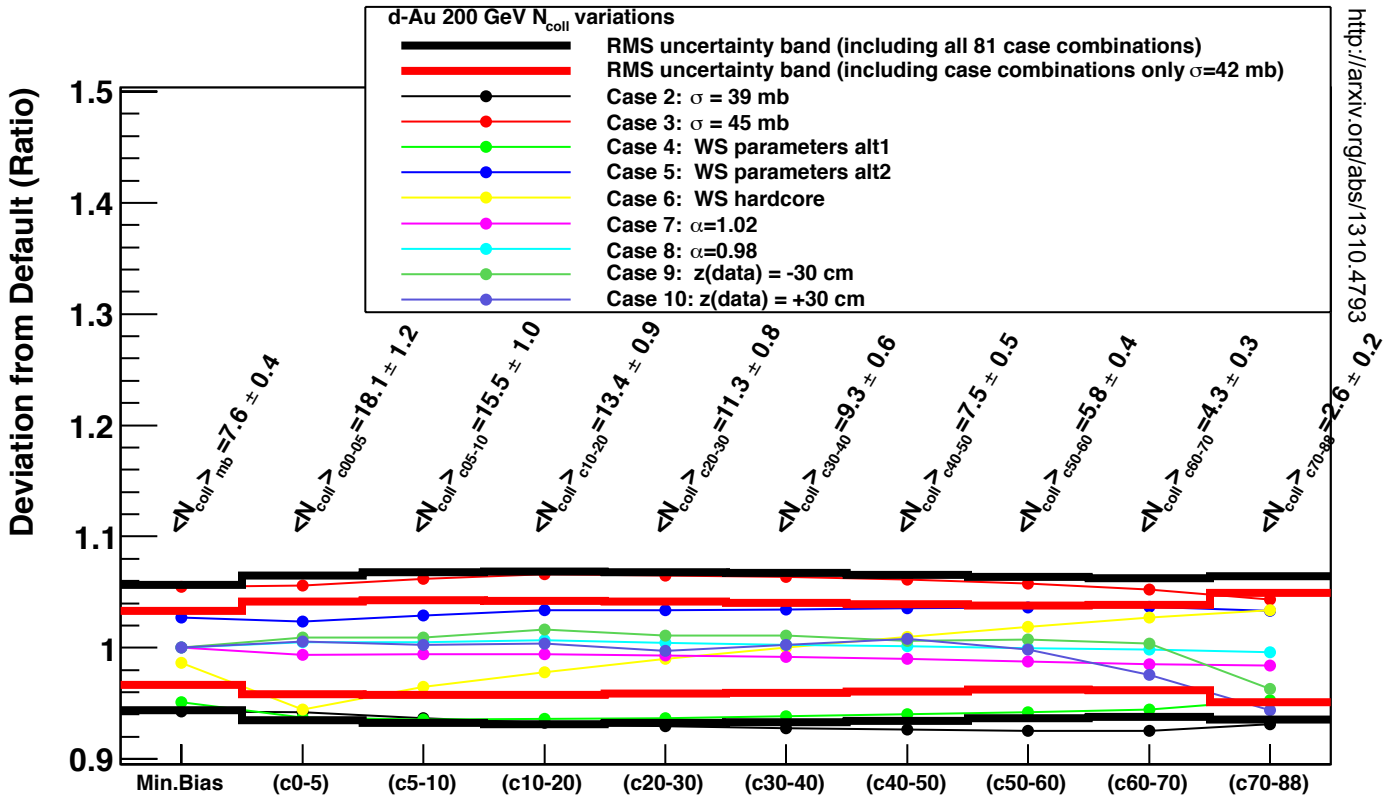
Measure spectator neutron energy with d-going ZDC.





Good agreement between data and Monte Carlo Glauber values!

Systematic Uncertainties



- Nucleon-nucleon inelastic cross section
- Woods-Saxon Au nucleus parameters
- Include hard-core repulsive potential
- Change z-vertex range
- BBC charge proportional to N_{part} (*not shown in plot*)

Bias Factor Corrections

BBC Multiplicity → **Event Geometry** → **Invariant Yields**

How is this mapping affected for events with charged particles at midrapidity?

Consider p+p @ 200 GeV

BBC MB trigger fires 52% of the time

BBC MB trigger fires 75% of the time for events with charged particle at midrapidity

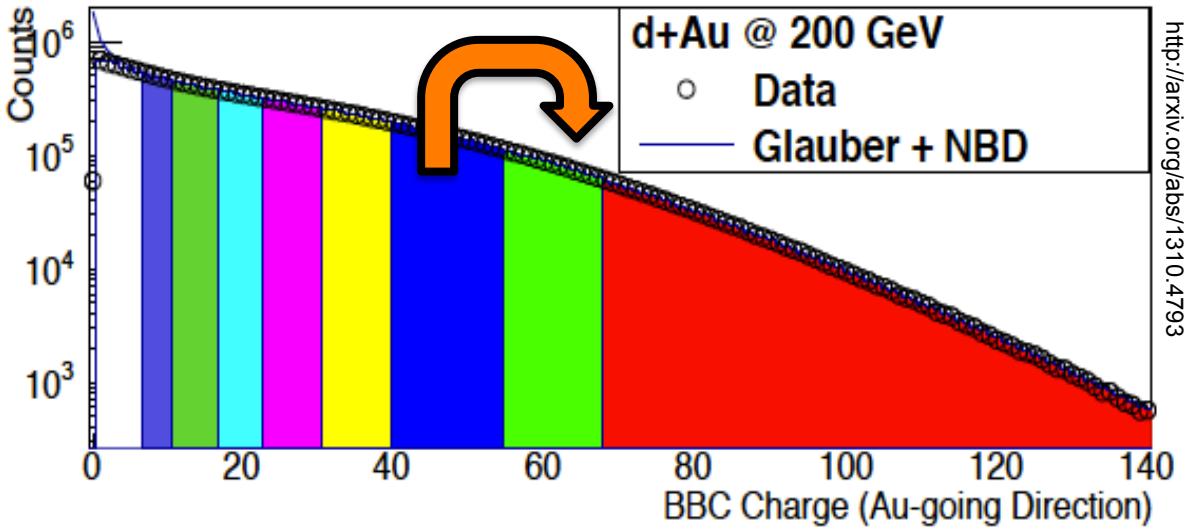
$$\sigma_{inel} = \sigma_{non-diff} + \sigma_{s-diff} + \sigma_{d-diff}$$

Small chance of particle production at midrapidity

MB Trigger biased towards non-diffractive events with greater particle production at midrapidity!

Bias Factor Corrections

What are the implications for d+Au?



N collisions

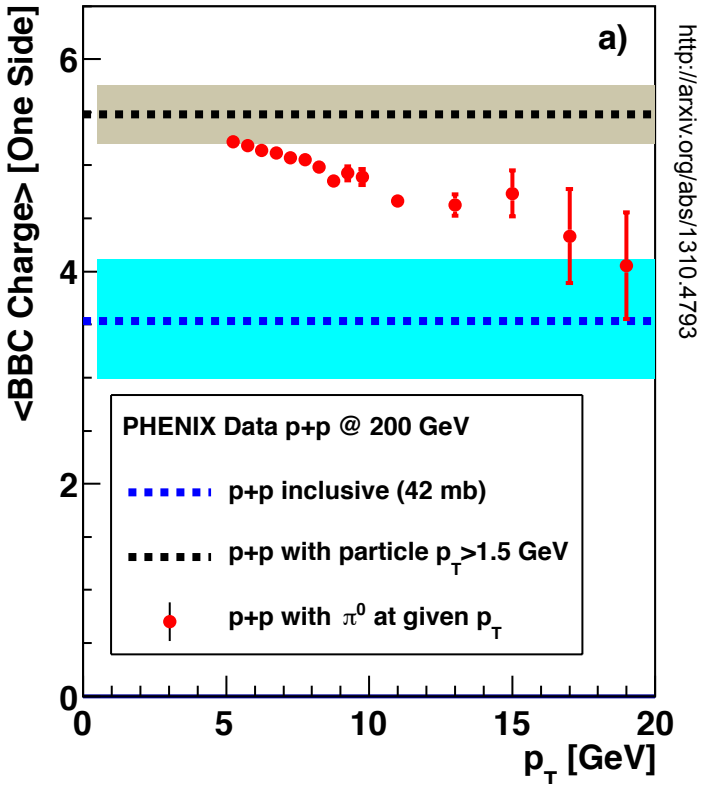
1 Biased

***N-1* Unbiased**

BBC charge deposition is scaled up!

	0%-20%	20-40%	40-60%	60%-88%
Bias Factor Correction	0.94 ± 0.01	1.00 ± 0.01	1.03 ± 0.02	1.03 ± 0.006

Bias Factor Corrections



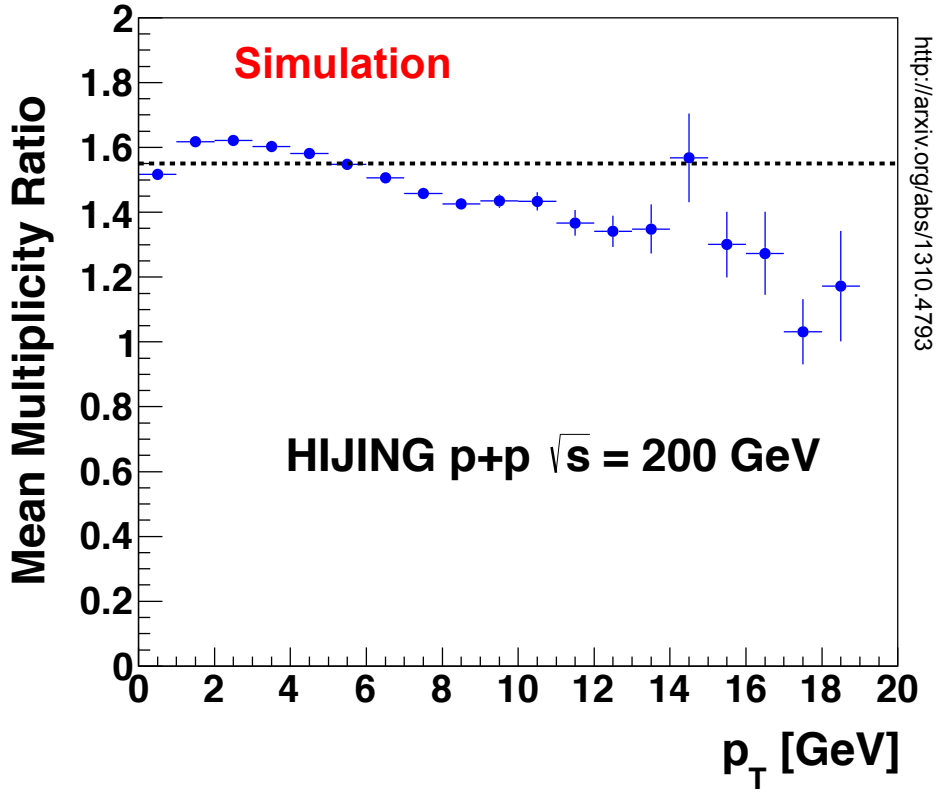
The bias effect seems to be p_T dependent.

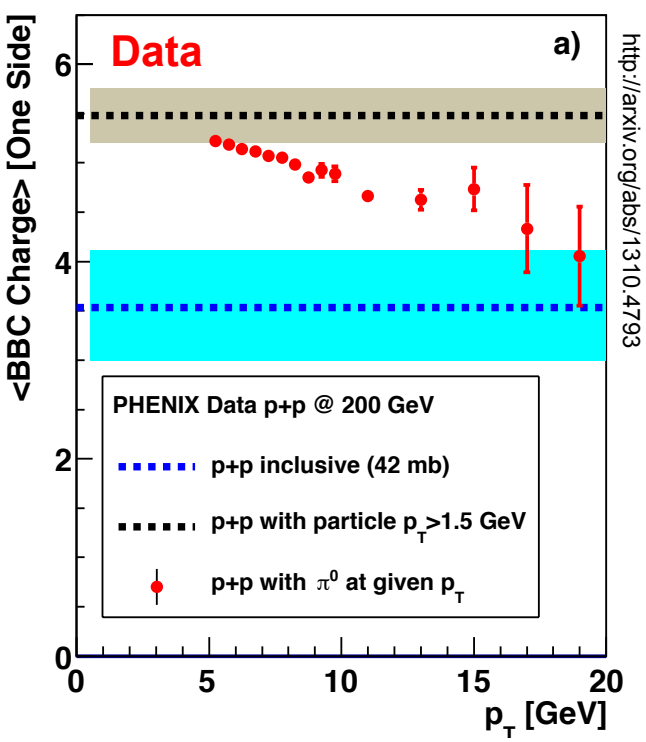
Conservation of energy?
Change in the rapidity distribution?

HIJING Study

We use the HIJING MC Generator to simulate p+p and d+Au events @ 200 GeV

HIJING results are model-dependent, but they capture the desired bias!





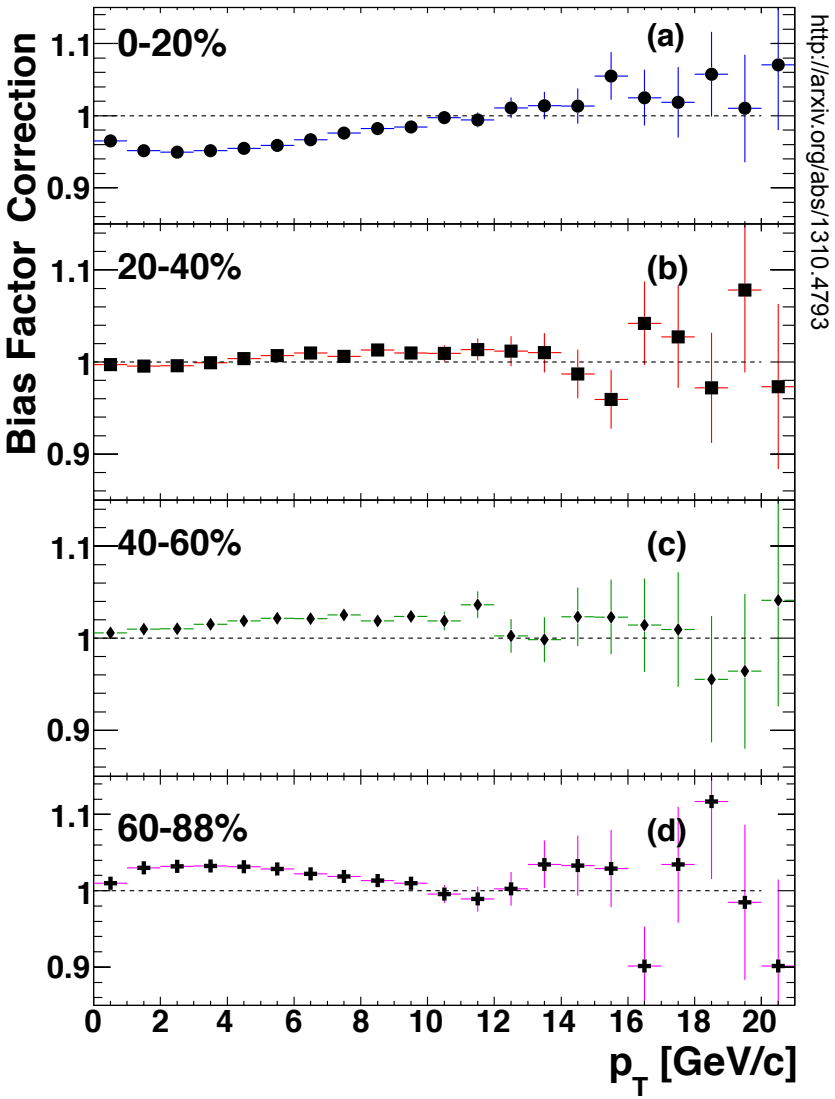
HIJING Study at RHIC Energy

d+Au @ 200 GeV

	Glauber Model	HIJING
Centrality	**Bias Correction Factor**	**Mean Bias Factor 1< p_T <5 GeV/c**
0-20%	0.94 ± 0.01	0.951 ± 0.001
20-40%	1.00 ± 0.01	0.996 ± 0.001
40-60%	1.03 ± 0.02	1.010 ± 0.001
60-88%	1.03 ± 0.06	1.030 ± 0.001

We observe a slight p_T dependence of the bias factors. Less than 5% variation.

Good agreement with Glauber calculation!

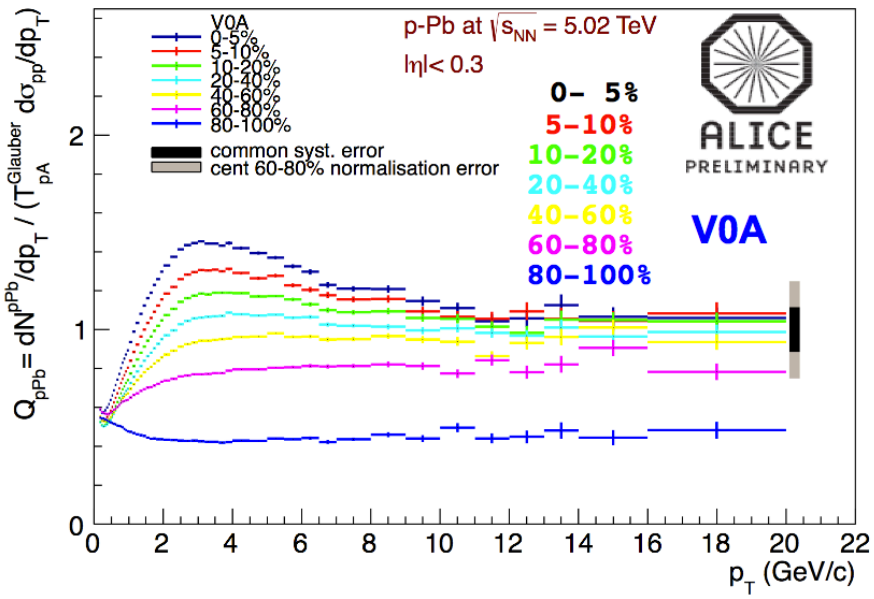


HIJING Study at LHC Energy

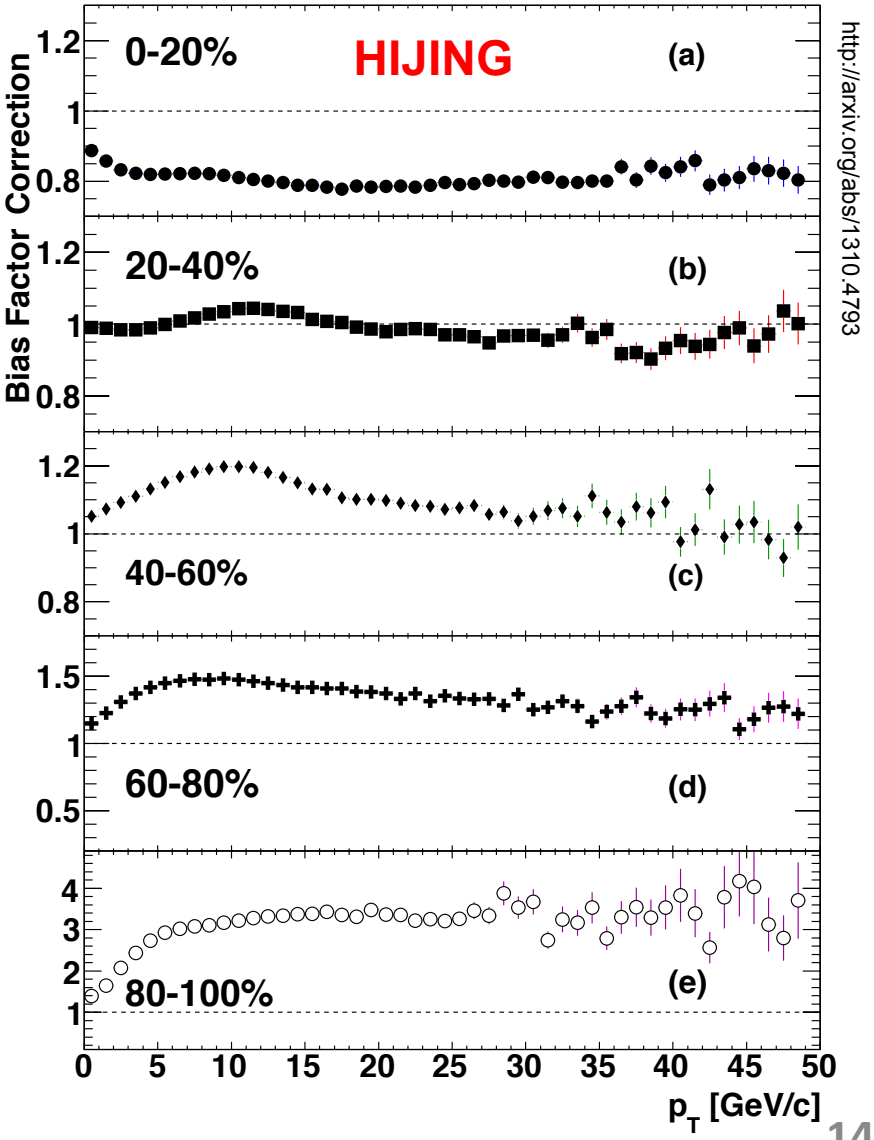
p+Pb @ 5.02 TeV

Large auto-correlation in p+p.

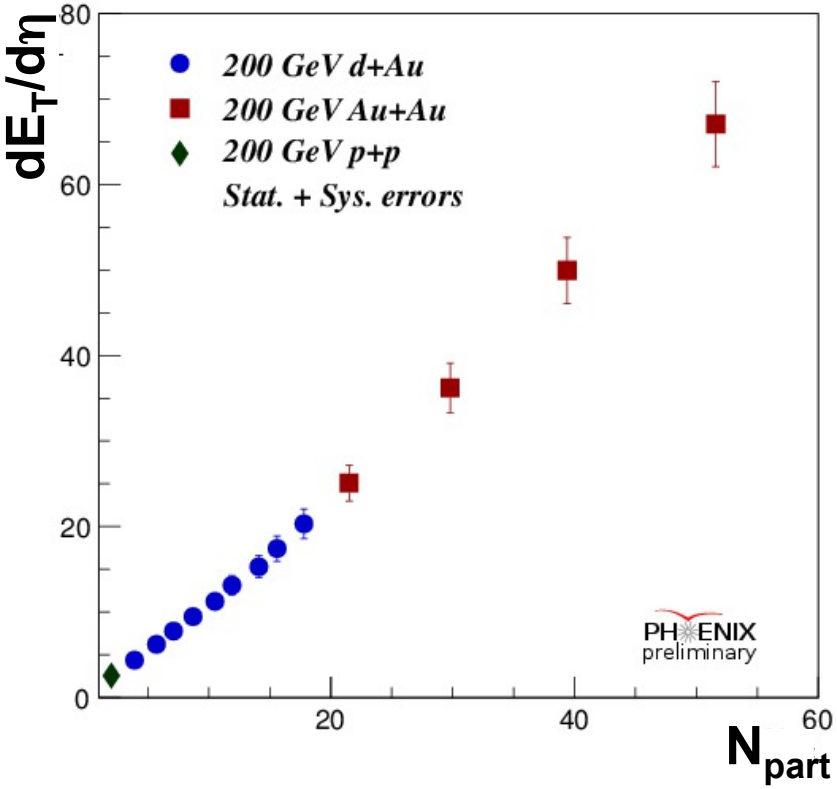
Large and strongly p_T-dependent bias correction factors.

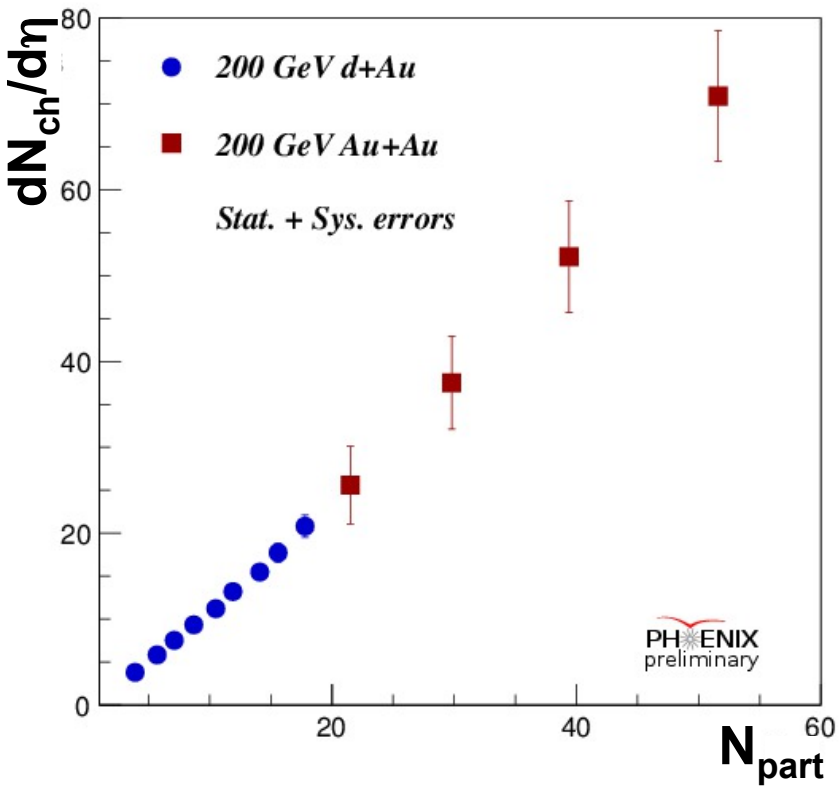


Recall Q_{pPb} ~ 1/Bias Factor



Charged Particle and E_T Production

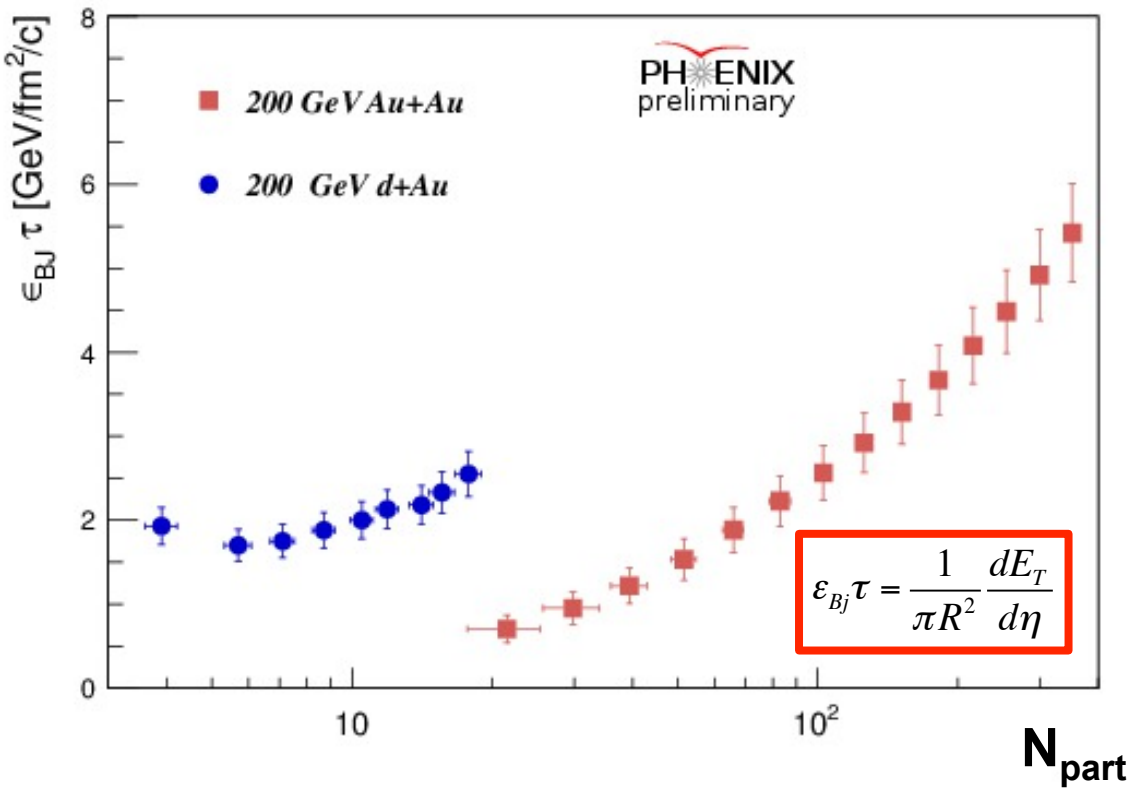




Linear scaling with N_{part}.

Central d+Au matches peripheral Au+Au.

Bjorken Energy Density



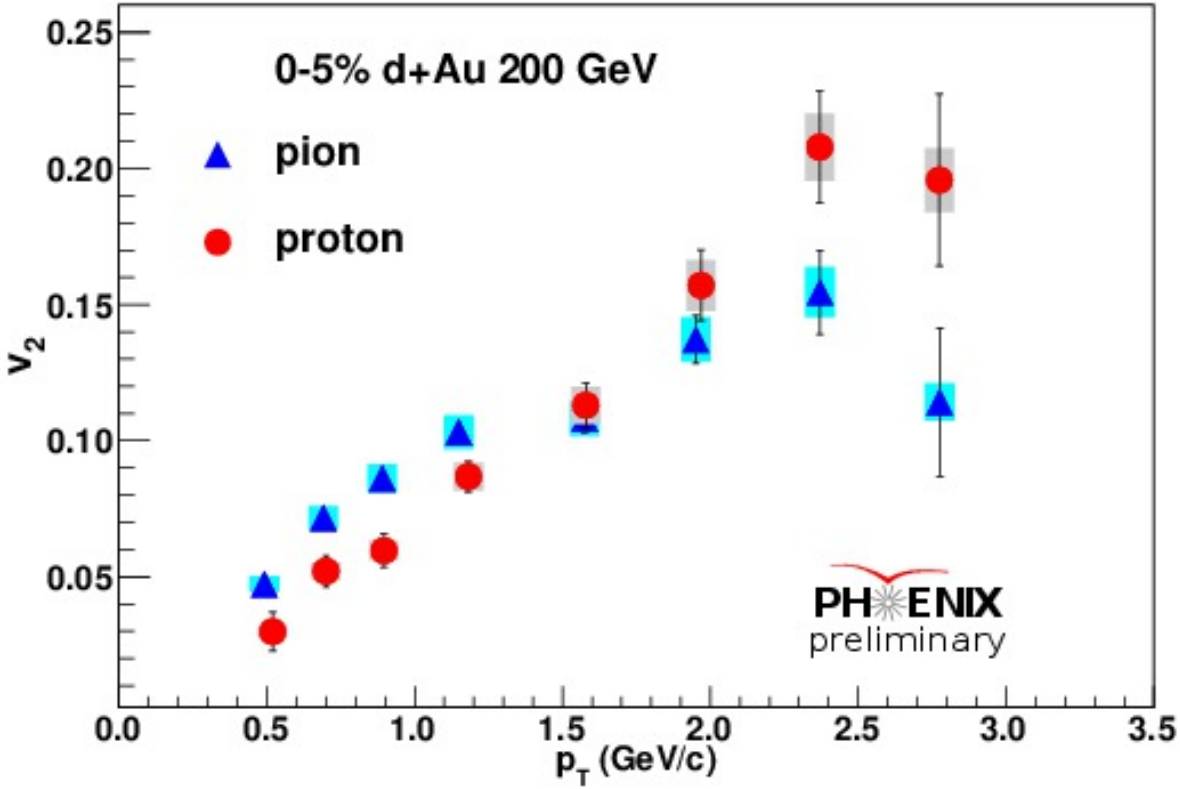
	0-100%	0-5%	20-30%	40-50%	70-88%
$\langle S_{pt\text{-}like} \rangle$	4.36 ± 0.24	8.0 ± 0.8	6.8 ± 0.4	4.8 ± 0.4	1.64 ± 0.02
$\langle S_{disk\text{-}nbd} \rangle$	6.96 ± 0.20	10.8 ± 0.8	9.2 ± 0.4	7.2 ± 0.4	4.28 ± 0.24

The overlap area is centrality-dependent

Collective Flow in d+Au

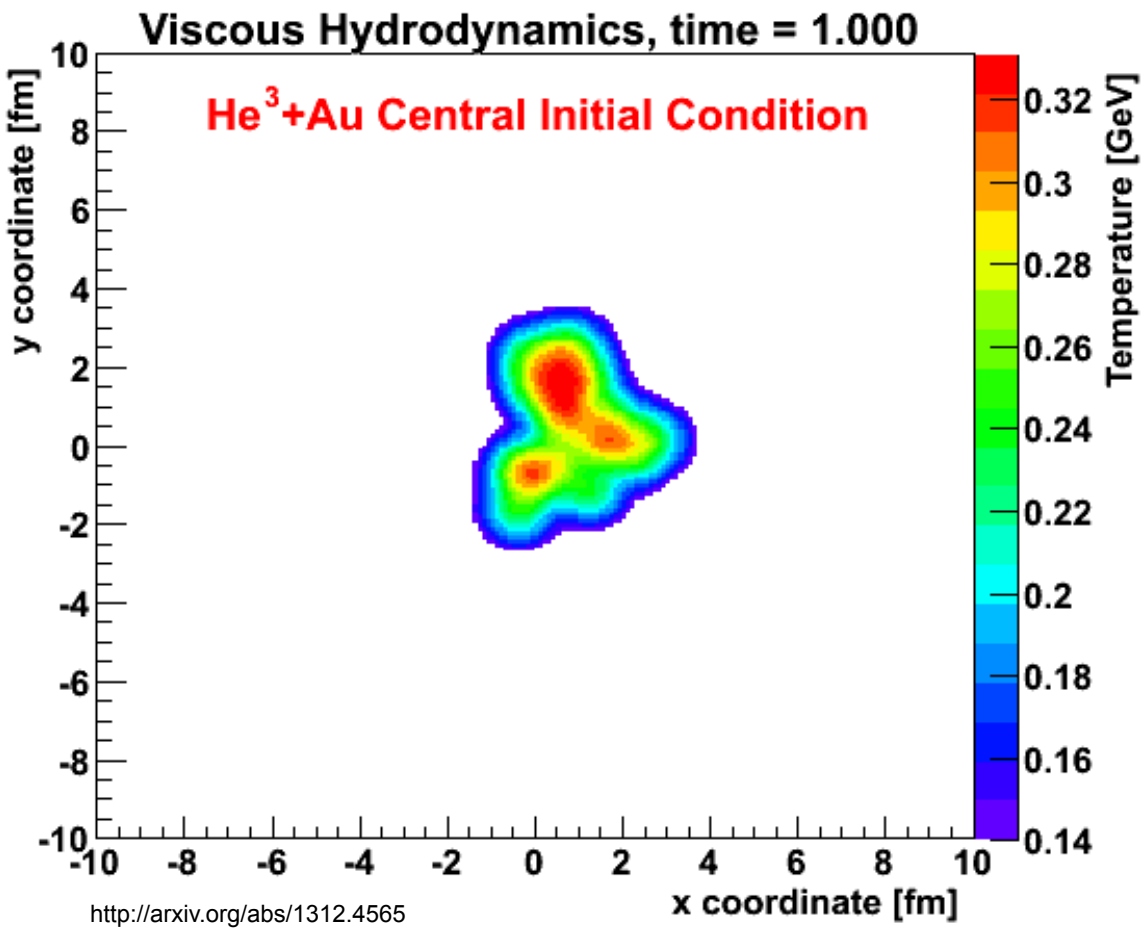
There is recent compelling evidence for collective flow in p+Pb and d+Au.

This is an example of a physics observable where comparison with theory requires an understanding of the geometry.



Collective Flow in ^{3}He+Au

^{3}He+Au collisions have been proposed as a test system whose intrinsic triangularity can be used to discriminate initial state effects and those from viscous damping.



http://arxiv.org/abs/1312.4565

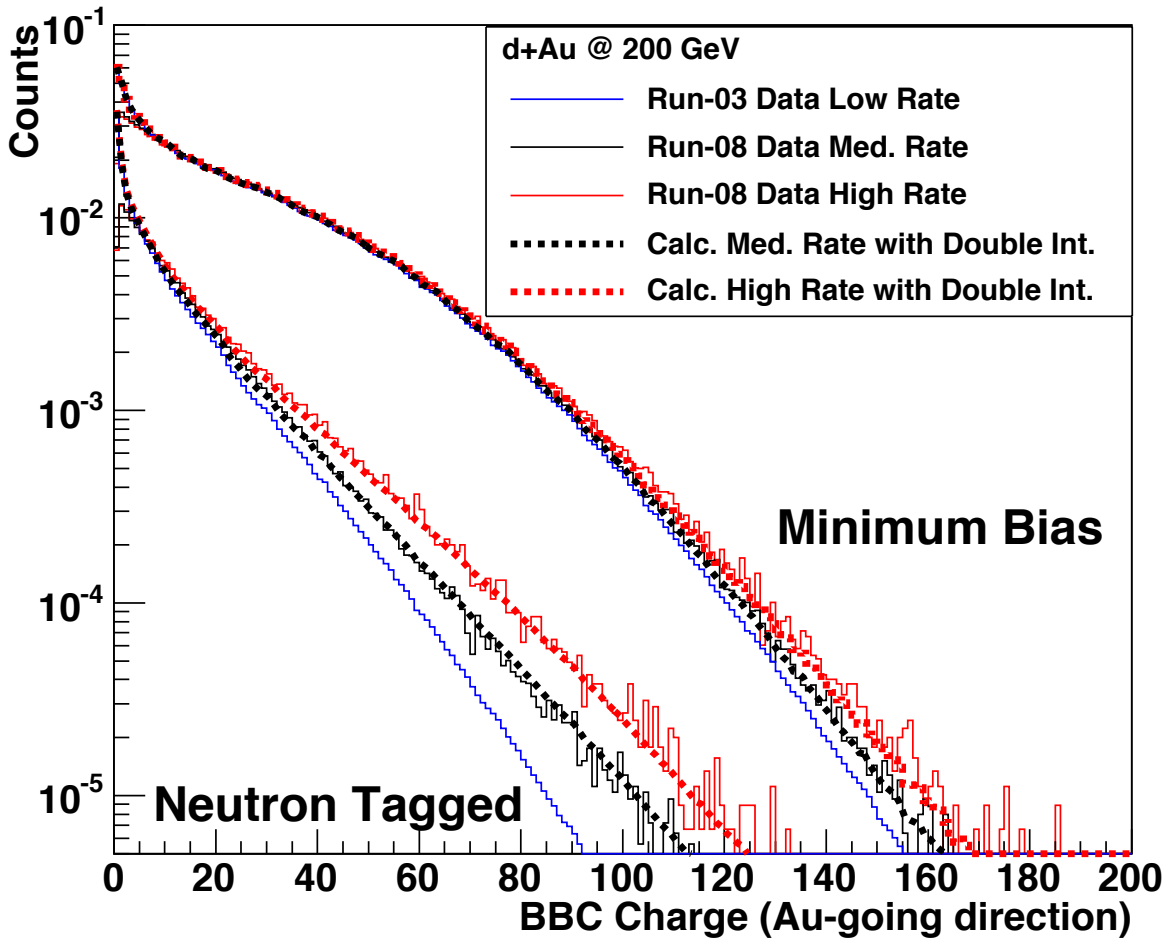
Summary

- We described the PHENIX methodology for selecting centrality classes.
- The centrality determination method is subject to inherent bias effects that can be accounted for.
- Bias correction factors are small for d+Au @ 200 GeV, but large and pT-dependent for p+Pb @ 5.02 TeV.
- There is evidence for collective flow in small systems.
- This is one of many physics analyses that depend on a careful characterization of the event geometry.

Thank you!

Backup Slides

Double-Interaction Study



Double inelastic interactions result in greater BBC charge deposition.
We need to account for this extra charge when categorizing centrality.