

# Aspects of Centrality Determination in p(d)-A Collisions

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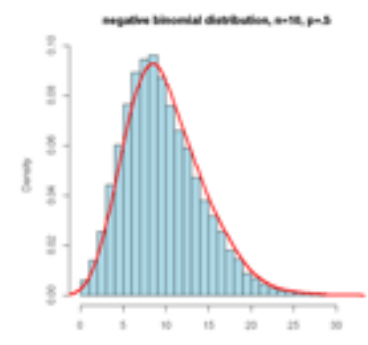
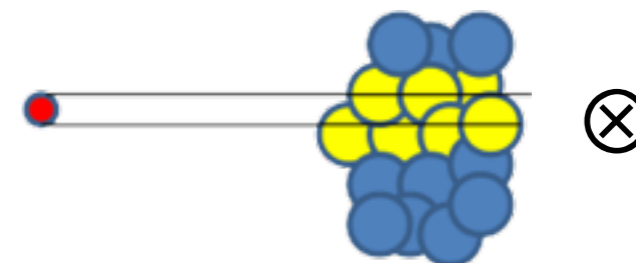
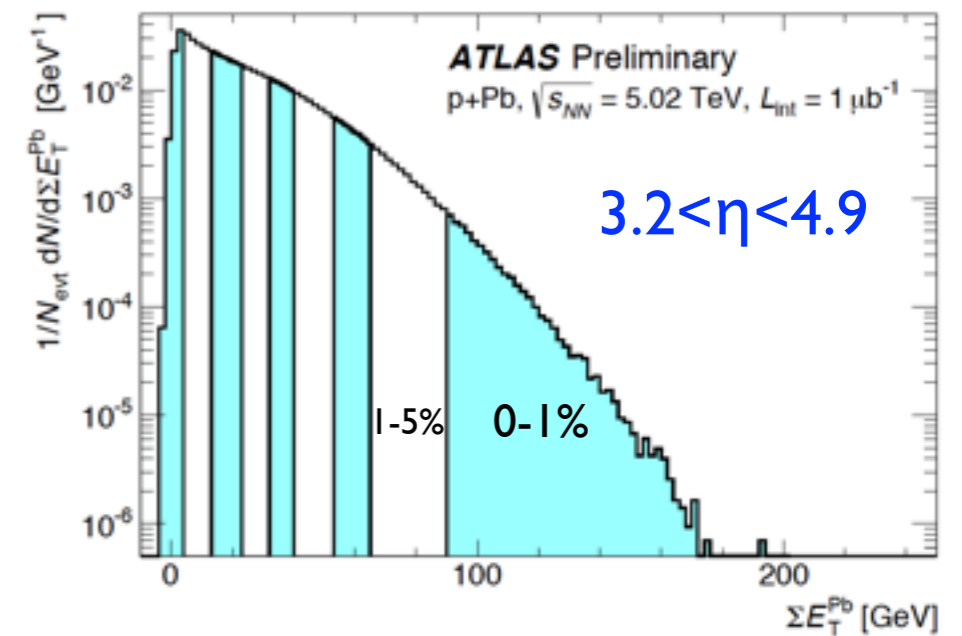
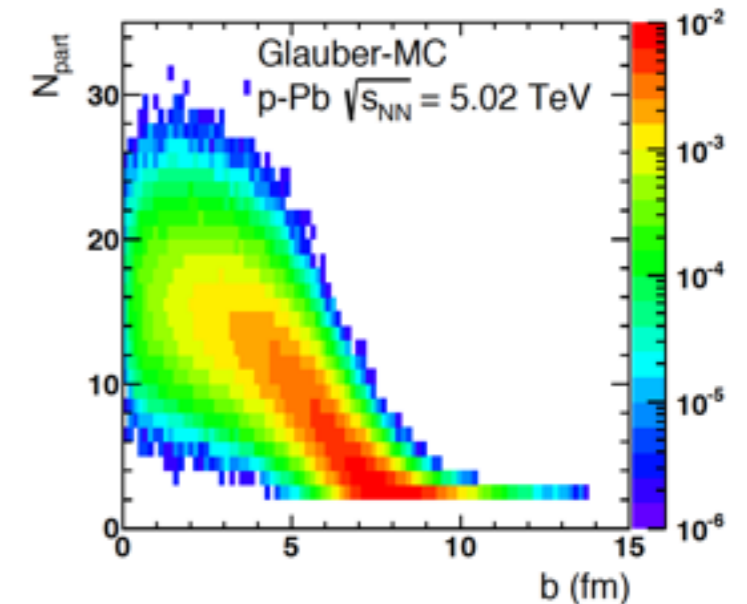
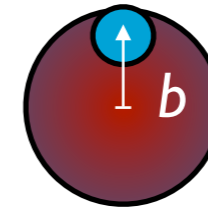
IS2014

# Overview

- Basic procedure for centrality determination
  - Specific aspects of  $p(d)$ -A
  - Example: RHIC d+Au centrality
- Glauber model extensions and possible selection biases
- Centrality determination combining slow-nucleon and yields at central rapidities (“hybrid approach”)
- Conclusions

# Basic Procedure

- **Impact parameter** not observable and for small systems weakly correlated to number of participants
- Classify events in terms of **event activity** (**centrality estimator,  $E$** )
  - estimator should vary monotonously with number of participants
  - multiplicity, summed energy, slow nucleon energy, ...
- Order as percentiles of cross-section
- Establish relation to **Glauber Model** parameters ( $N_{\text{part}}, N_{\text{coll}}$ ) via particle production model

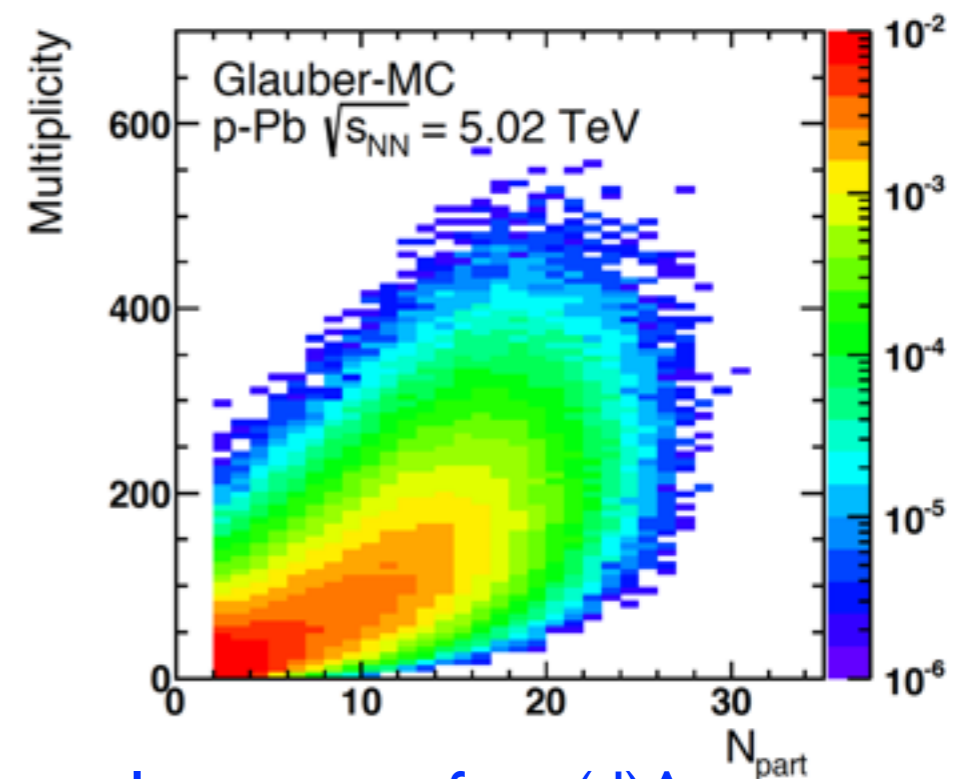
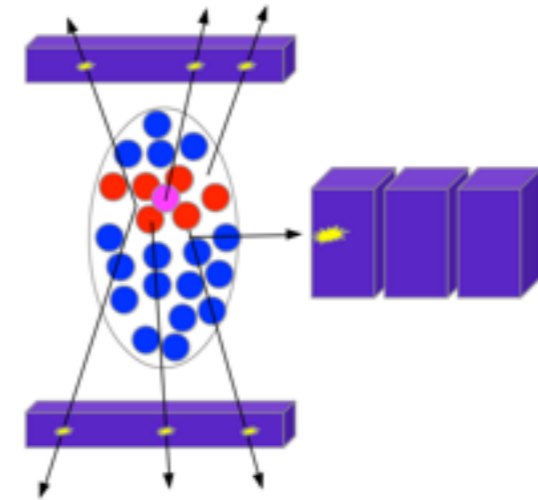


Glauber MC:  $\pi(N_{\text{coll}})$

Model:  $P(E | N_{\text{coll}})$

# Essential Two Additional Steps

- Demonstrate relation of measurement to collision geometry
  - via correlation of observables from region that are causally disconnected after collision
- Demonstrate completeness
  - Other relevant geometry parameters that are biased by the selection with respect to minimum bias ?
  - What are their possible influence on centrality dependent measurements ?



Importance for p(d)A:  
Small range large fluctuations !

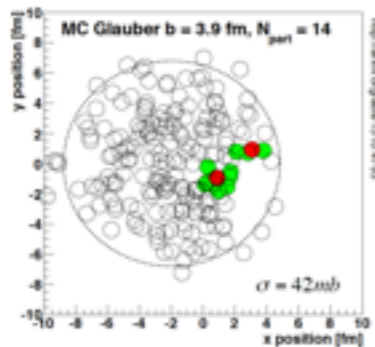
No physics results without addressing these issues !

# Example: PHENIX d+Au

arXiv:1310.4793 [nucl-ex]



From Glauber:



Probability to produce  $N_{\text{coll}}$  binary collisions:  $\pi(N_{\text{coll}})$

Charge distribution for one collision (Negative Binomial):

$$P_{\text{NBD}}(n; \mu, k) = \frac{\Gamma(n+k)}{\Gamma(n+1)\Gamma(k)} \frac{\left(\frac{\mu}{k}\right)^n}{\left(\frac{\mu}{k+1}\right)^{n+k}}$$

For  $N_{\text{coll}}$  collisions assume  $\langle \text{BBC} \rangle \propto \langle N_{\text{coll}} \rangle$

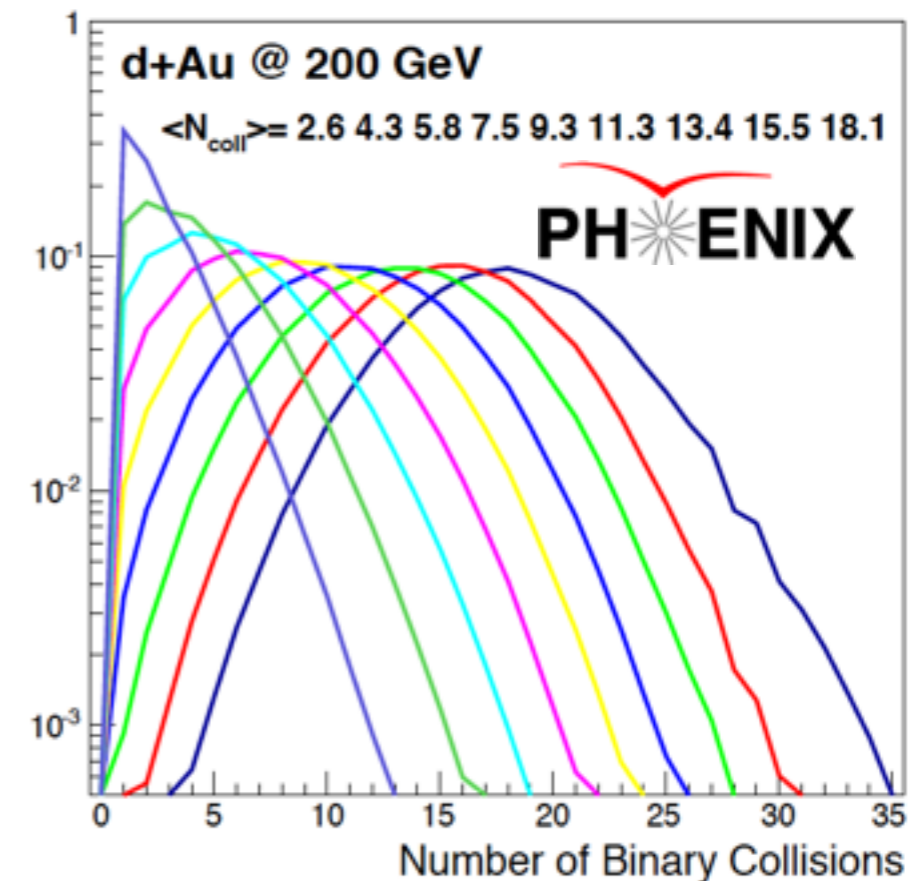
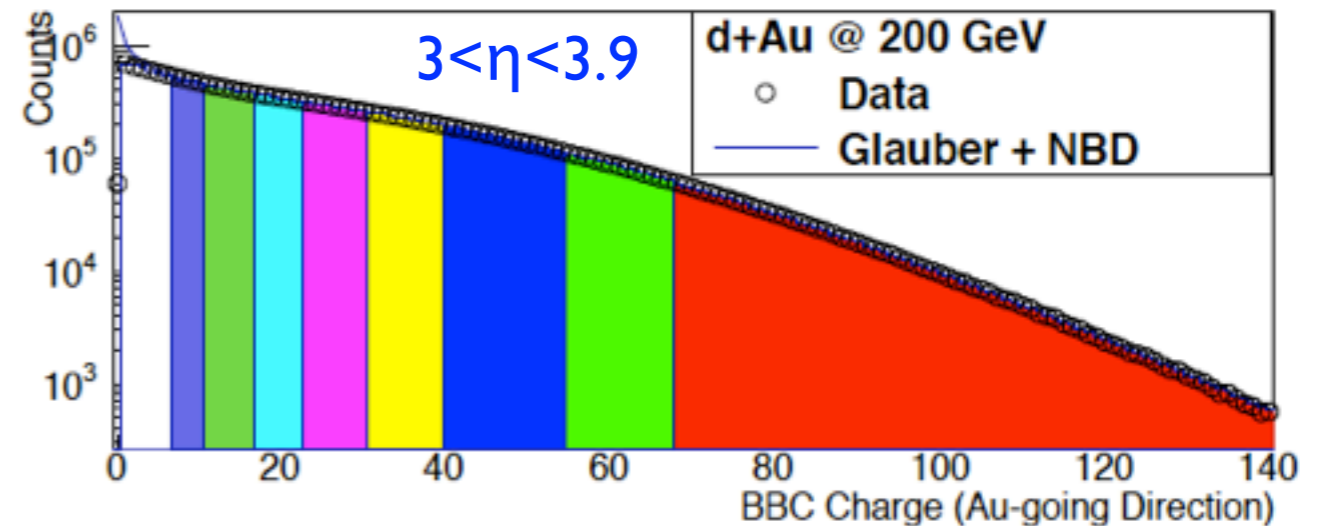
$$P(\text{BBC} | N_{\text{coll}}) = P_{\text{NBD}}(\text{BBC}; N_{\text{coll}} \cdot \mu, N_{\text{coll}} \cdot k)$$

Fit to measured distribution:

$$P_{\text{BBC}}(\text{BBC}) = \sum_1^{N_{\text{coll}}^{\text{max}}} \pi(N_{\text{coll}}) P_{\text{NBD}}(\text{BBC} | N_{\text{coll}})$$

with  $k, \mu$  fixed:

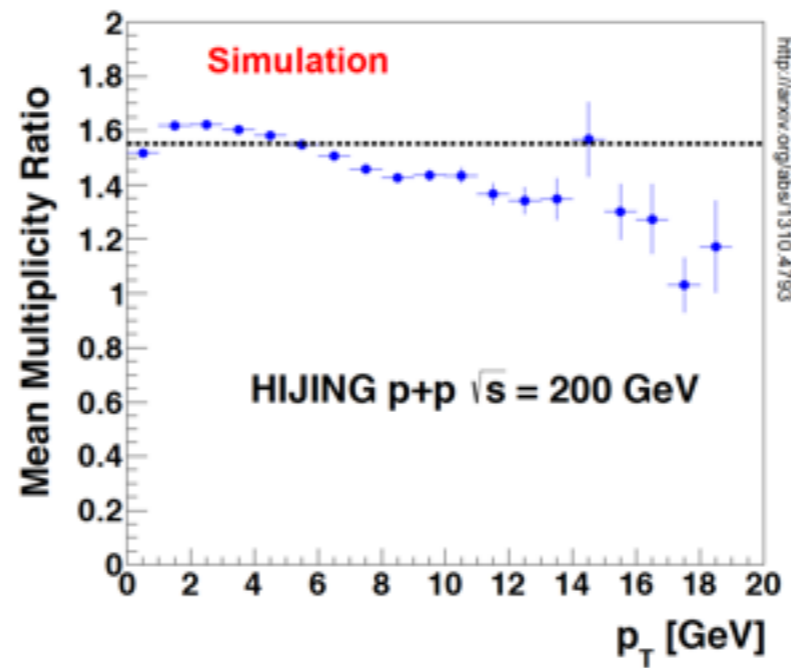
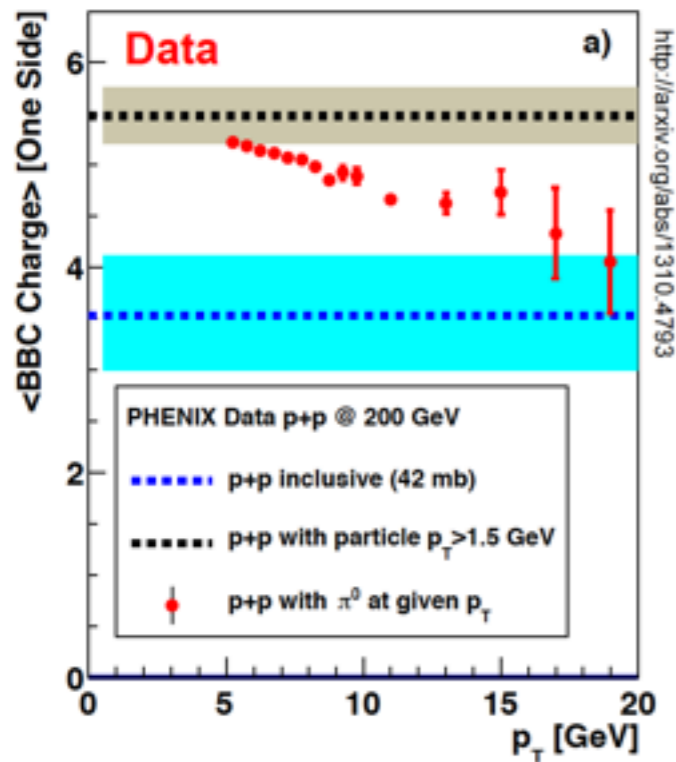
$$P(N_{\text{coll}} | \text{BBC}) = P(\text{BBC} | N_{\text{coll}}) \pi(N_{\text{coll}}) / P(\text{BBC})$$



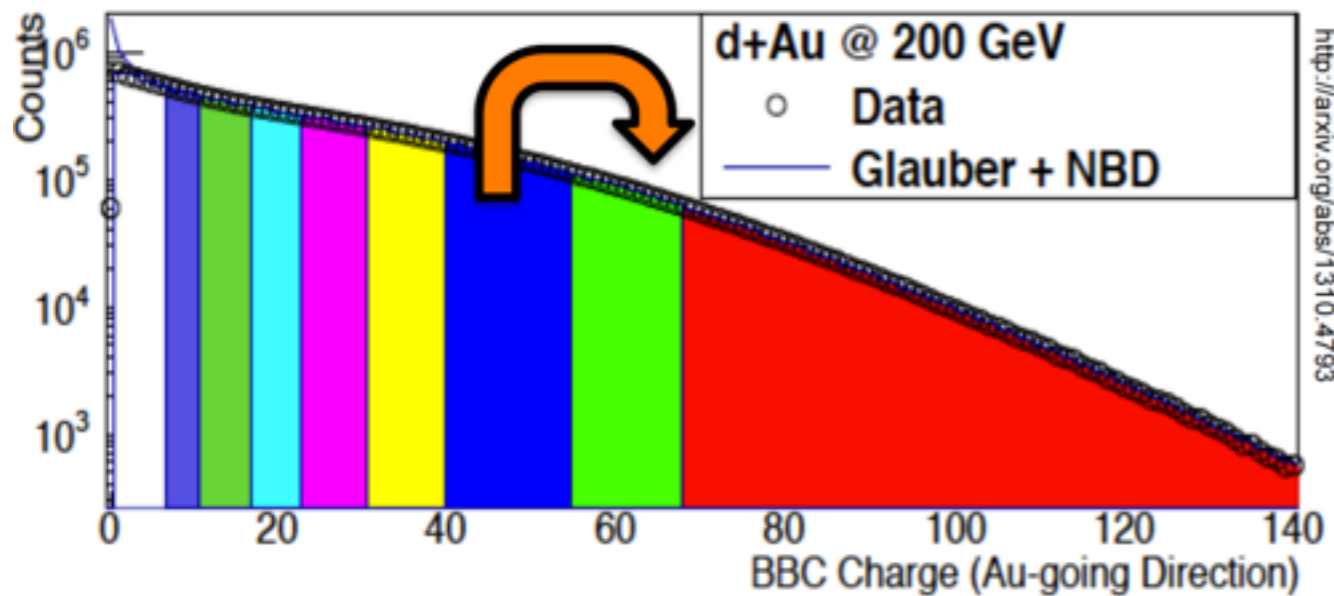
# Bias Factor Correction

arXiv:1310.4793 [nucl-ex]

Presence of high- $p_T$  particle at central rapidity increases BBC charge

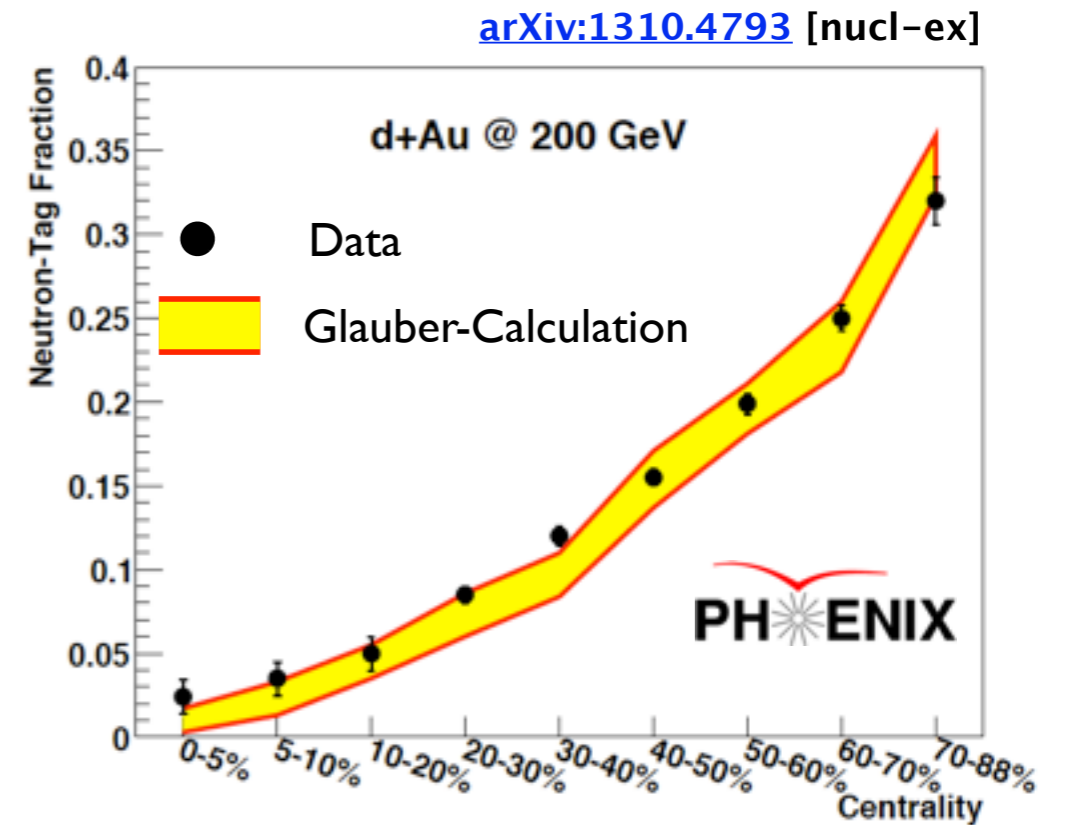
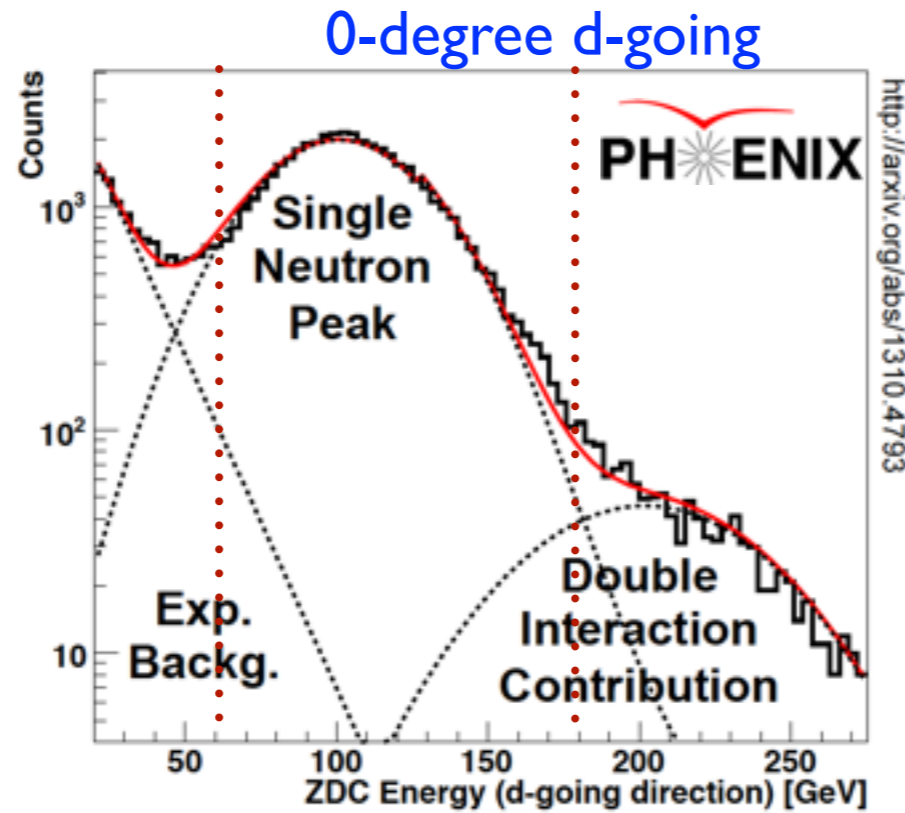
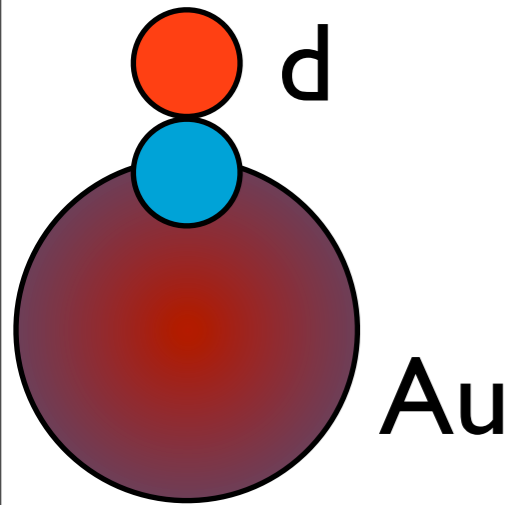


Quantify bias using Glauber Model and HIJING

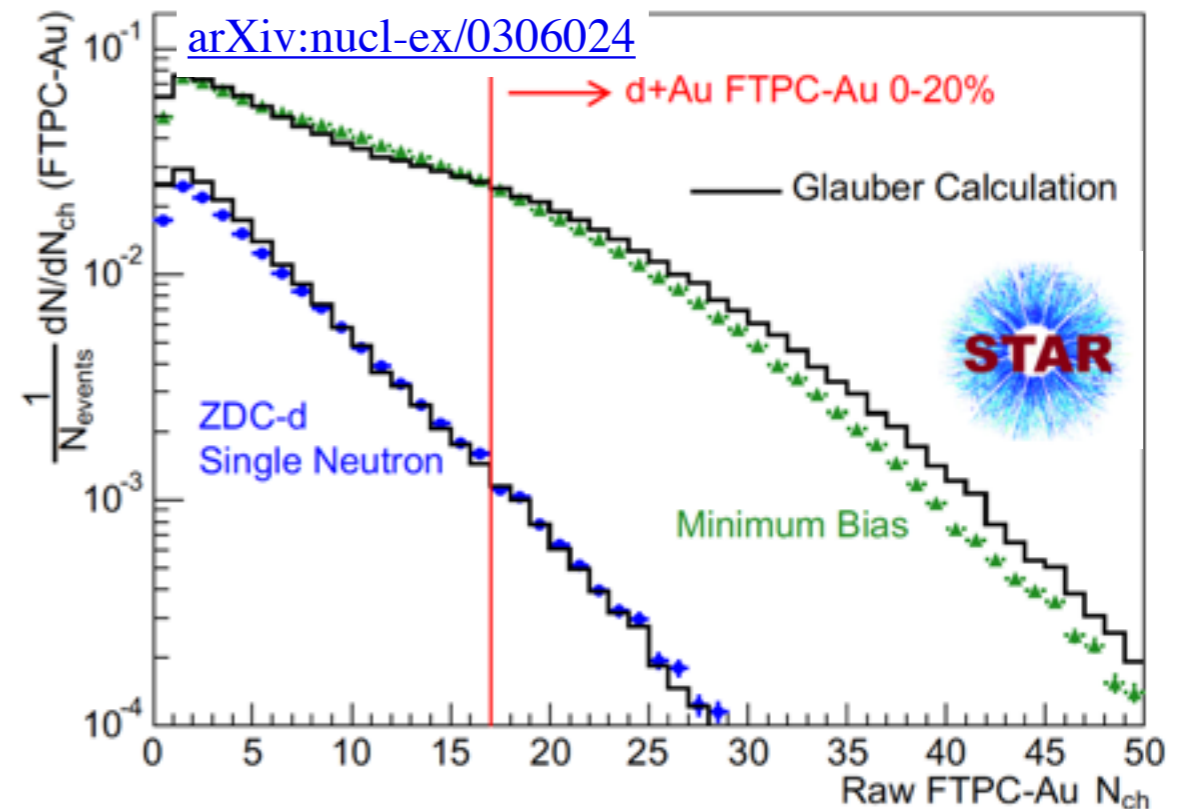


	Glauber Model	HIJING
<b>Centrality</b>	<b>Bias Correction Factor</b>	<b>Mean Bias Factor <math>1 &lt; p_T &lt; 5</math> GeV/c</b>
0-20%	$0.94 \pm 0.01$	$0.951 \pm 0.001$
20-40%	$1.00 \pm 0.01$	$0.996 \pm 0.001$
40-60%	$1.03 \pm 0.02$	$1.010 \pm 0.001$
60-88%	$1.03 \pm 0.06$	$1.030 \pm 0.001$

# Correlation with d-dissociation



- Essential cross-check
- Establishes unambiguously relation of centrality estimator to collision geometry
- Note: d-going ZDC energy not a centrality estimator



# Remarks

- Need of Glauber fit with specific particle production model  $P(M|N_{\text{coll}})$  consequence of defining centrality classes and determining  $N_{\text{coll}}$  with the same estimator.
- Biases can be consequence of
  - correlation with collision parameters other than  $N_{\text{part}}$
  - correlations induced after collision (eg jet fragmentation)
- Bias corrections are not necessarily corrections of  $N_{\text{coll}}$ 
  - The physics origin has to be understood

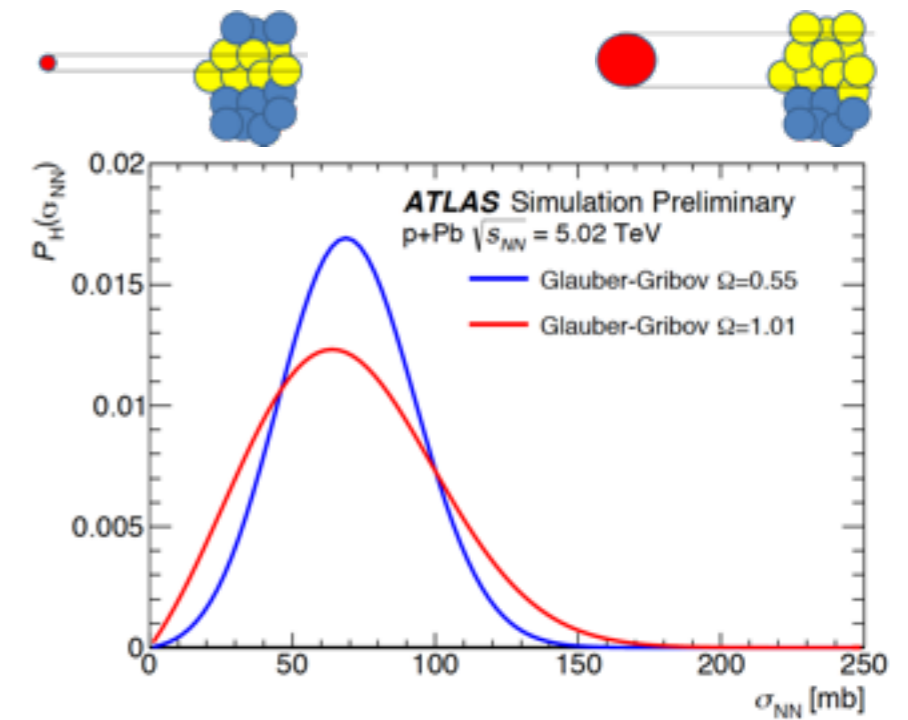
Look at non trivial extensions of the Glauber Model ...



# Non Trivial Glauber Extensions

- **Glauber-Gribov Color Fluctuations**

- Size of proton changes event-by-event due to color fluctuations
- Configuration frozen for a single p-A collision
- Parameter  $\Omega$  = width of Gaussian fluctuations



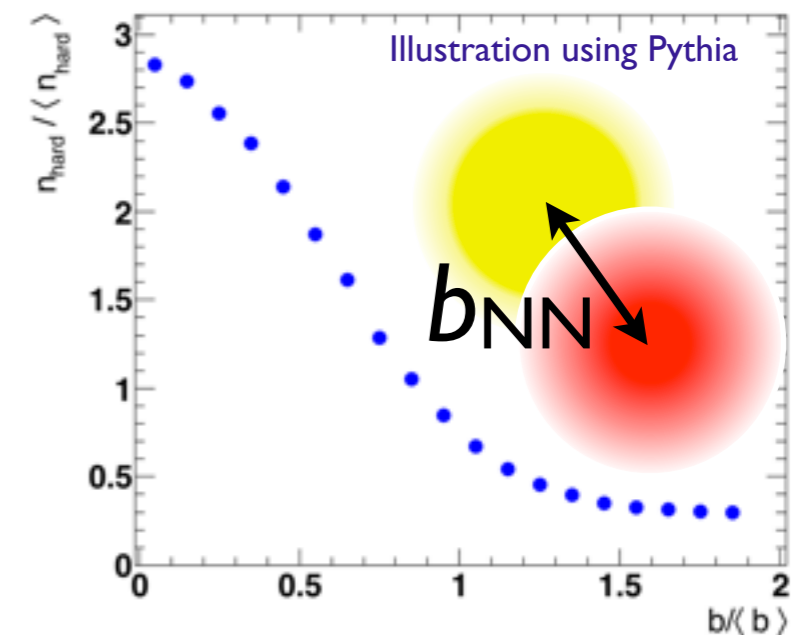
- **HIJING-Glauber**

- Mean number of pQCD  $2 \rightarrow 2$  scattering (MPI:  $n_{\text{hard}}$ ) depends on nucleon-nucleon overlap  $T_N(b_{NN})$
- No fluctuations of spatial distribution
  - Only Poissonian fluctuations of  $n_{\text{hard}}$

- **Flickering of the Interaction strength**

- Generalized gluon distribution and fluctuations

Alvioli, Frankfurt, Strikman  
arXiv:1402.2868v3 [hep-ph]



# Non Trivial Glauber Extensions

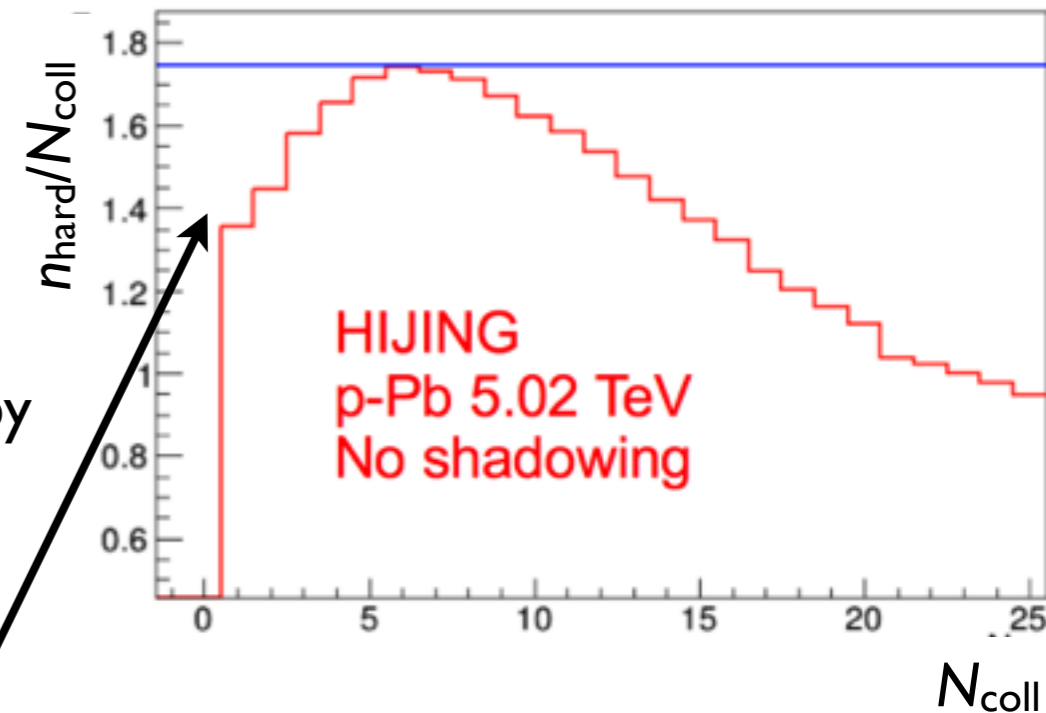
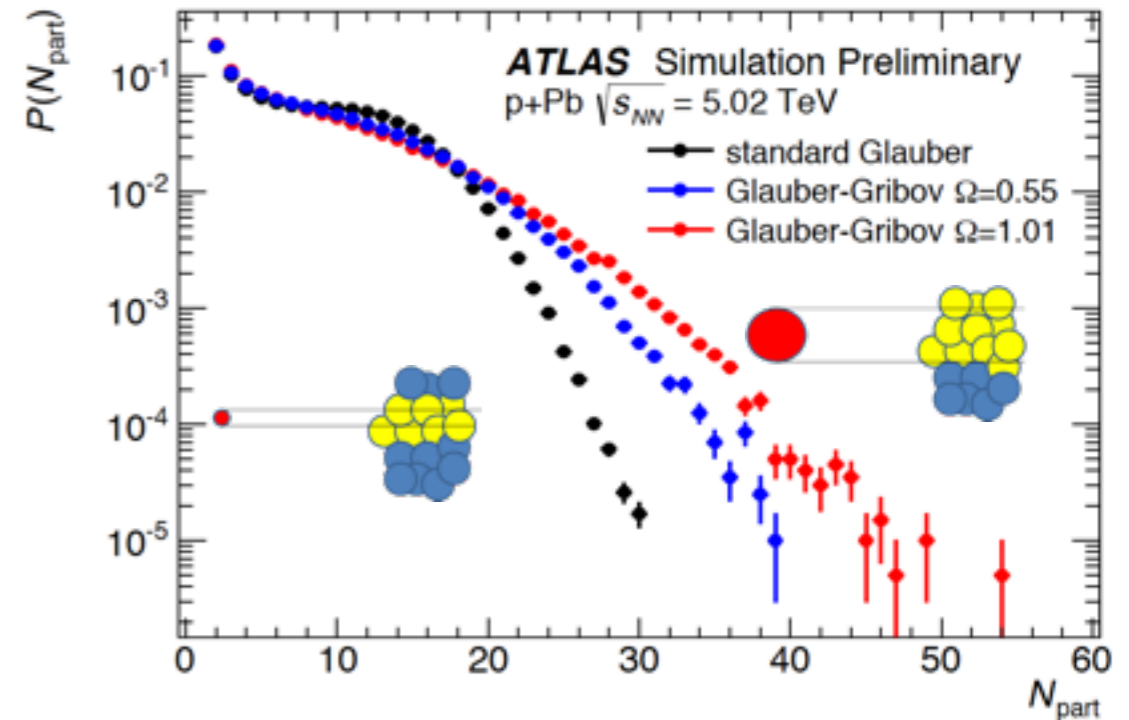
- Glauber-Gribov Color Fluctuations

- Changes  $\pi(N_{\text{coll}})$

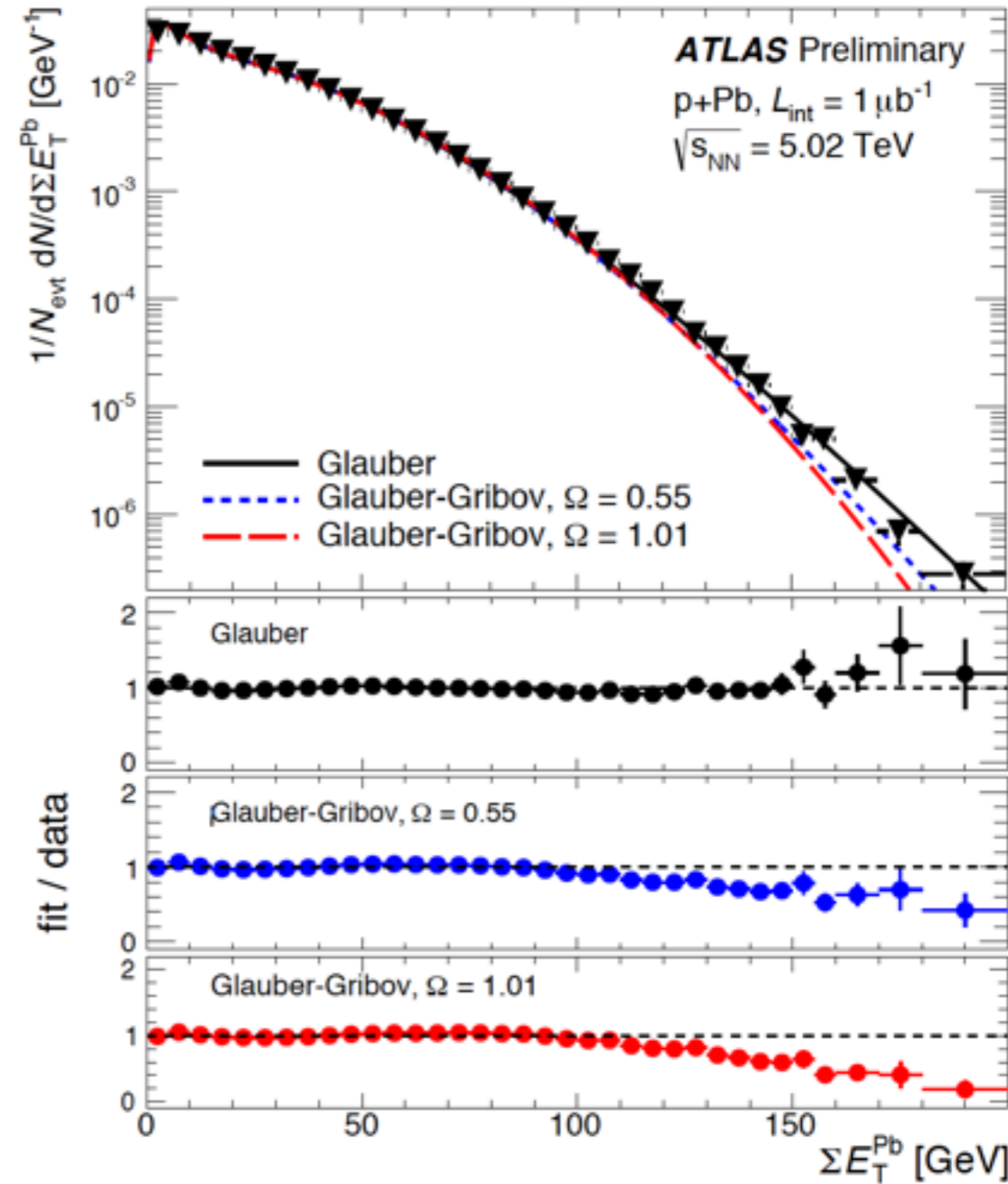
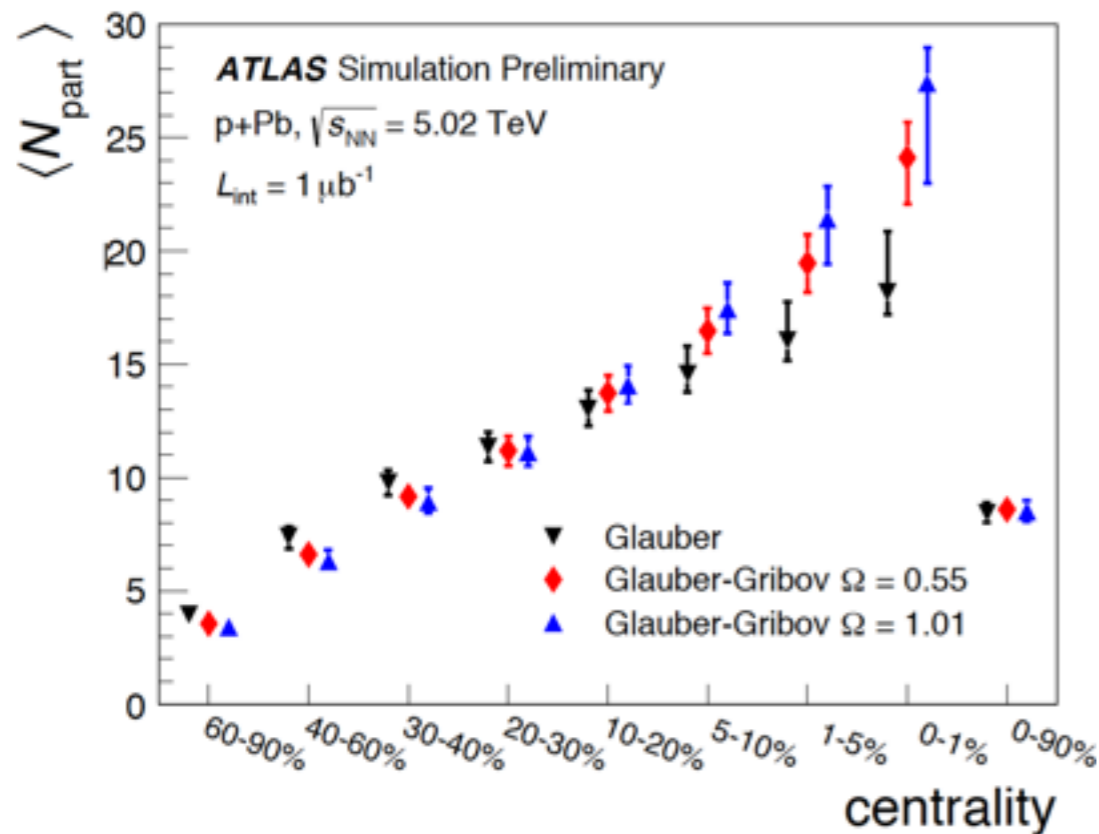
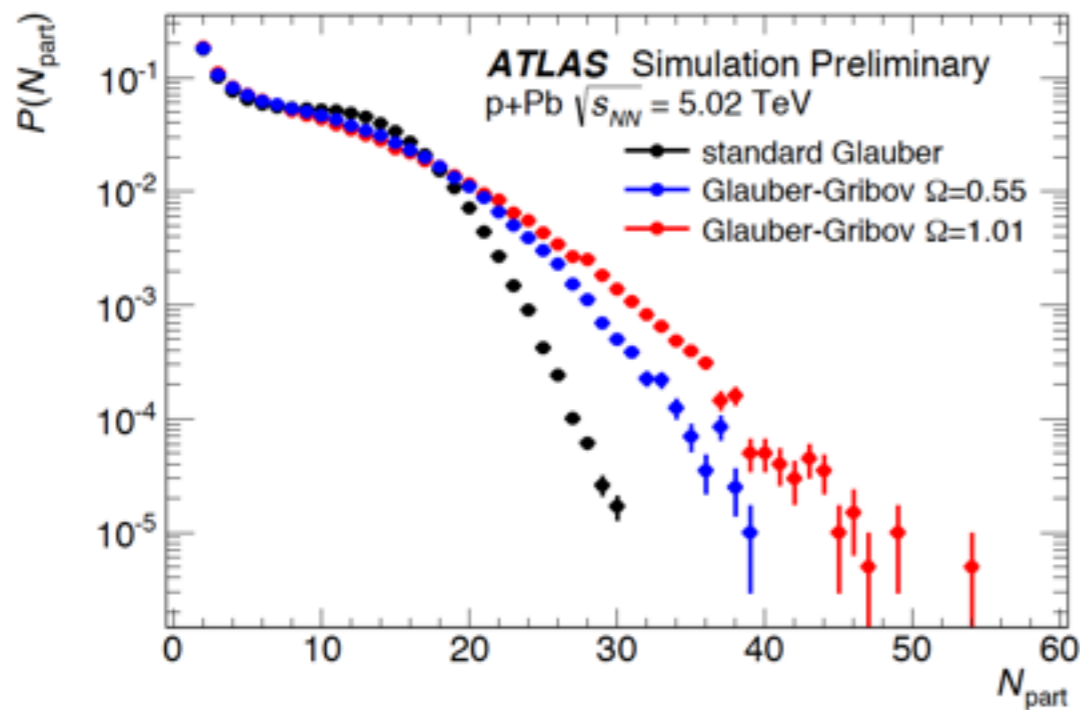
- HIJING-Glauber

- Does not change  $\pi(N_{\text{coll}})$
- Provides correlation between hard and soft particle production
- Long range correlation via  $b_{\text{NN}}$
- **Caveat:** in HIJING high values if  $n_{\text{hard}}$  are suppressed by energy conservation

Geometry bias  
see also Jiangyong Jia, arXiv:0907.4175 [nucl-th].

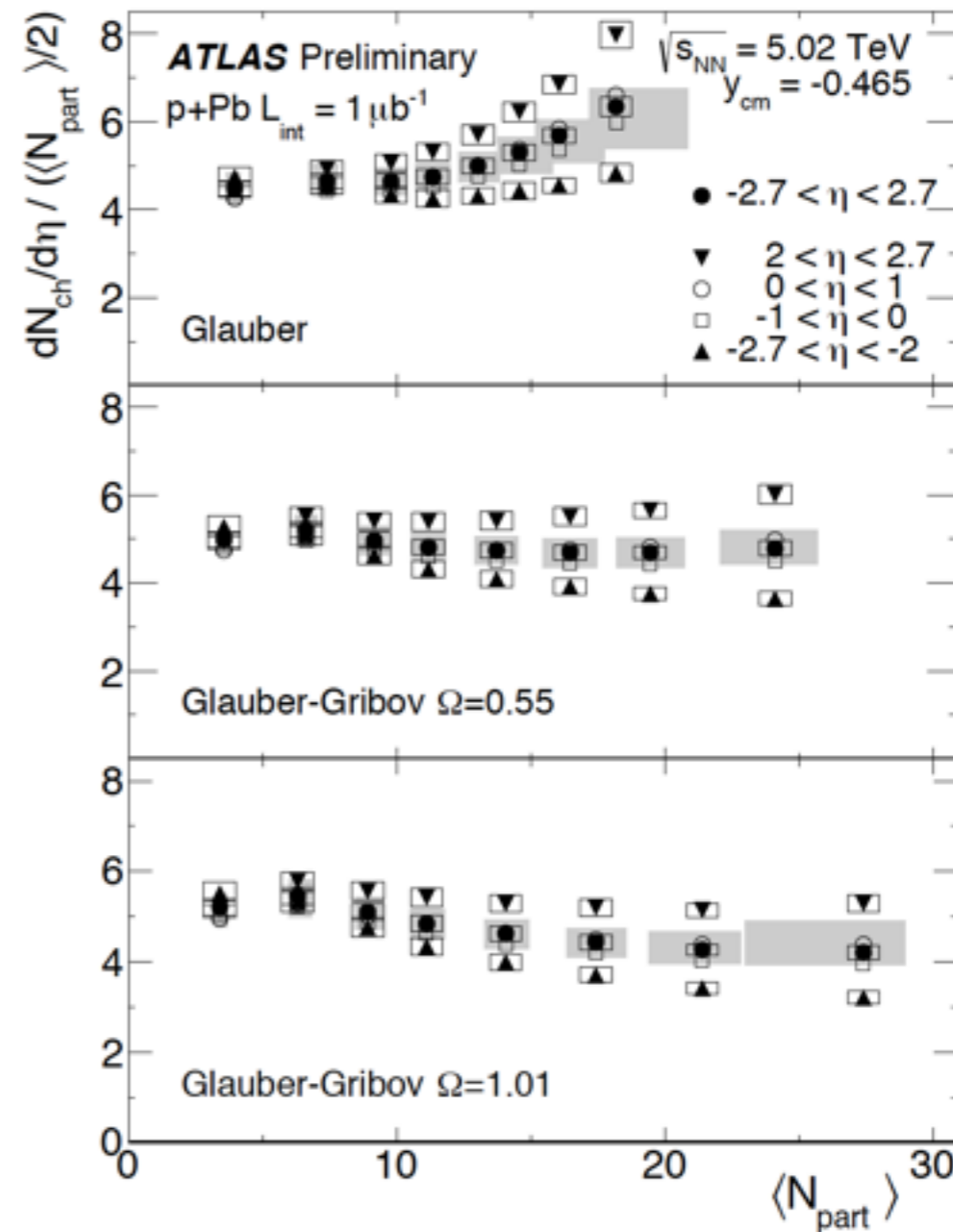
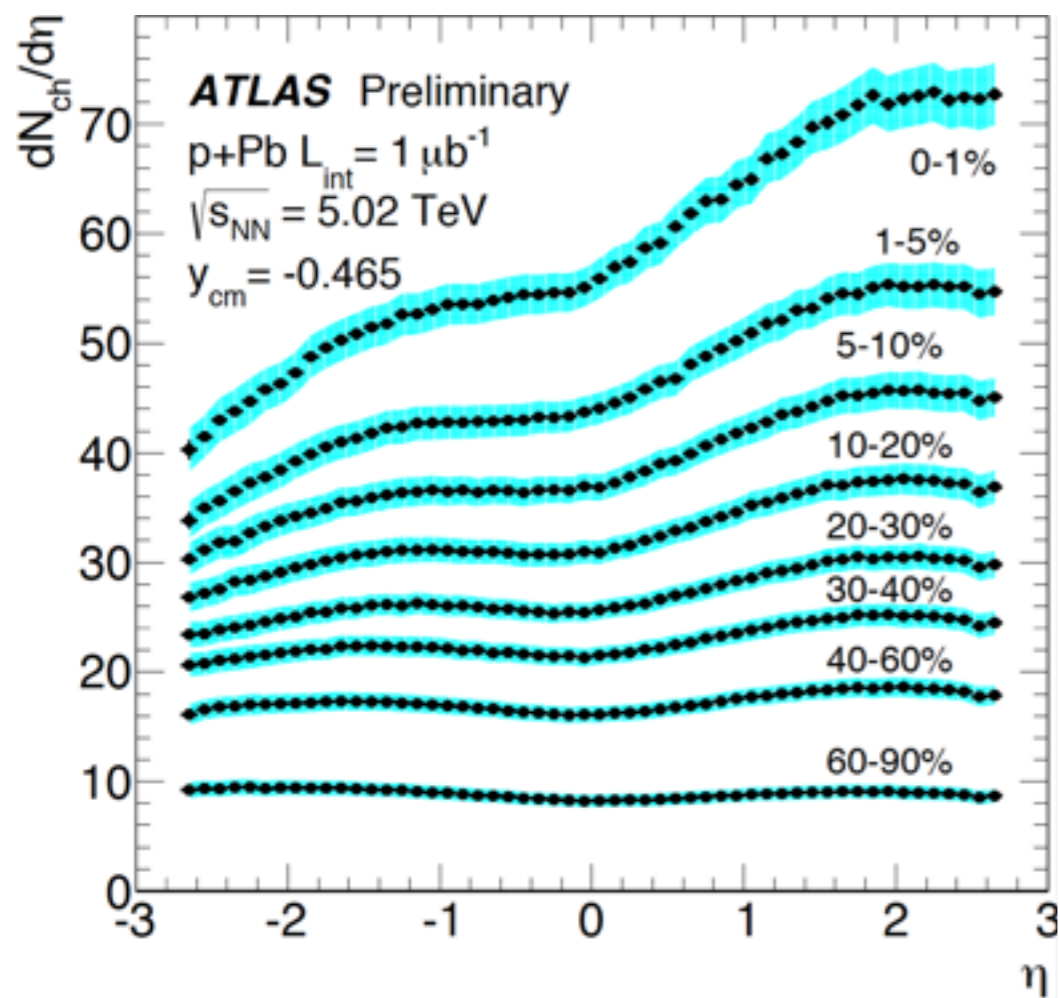


# Glauber-Gribov



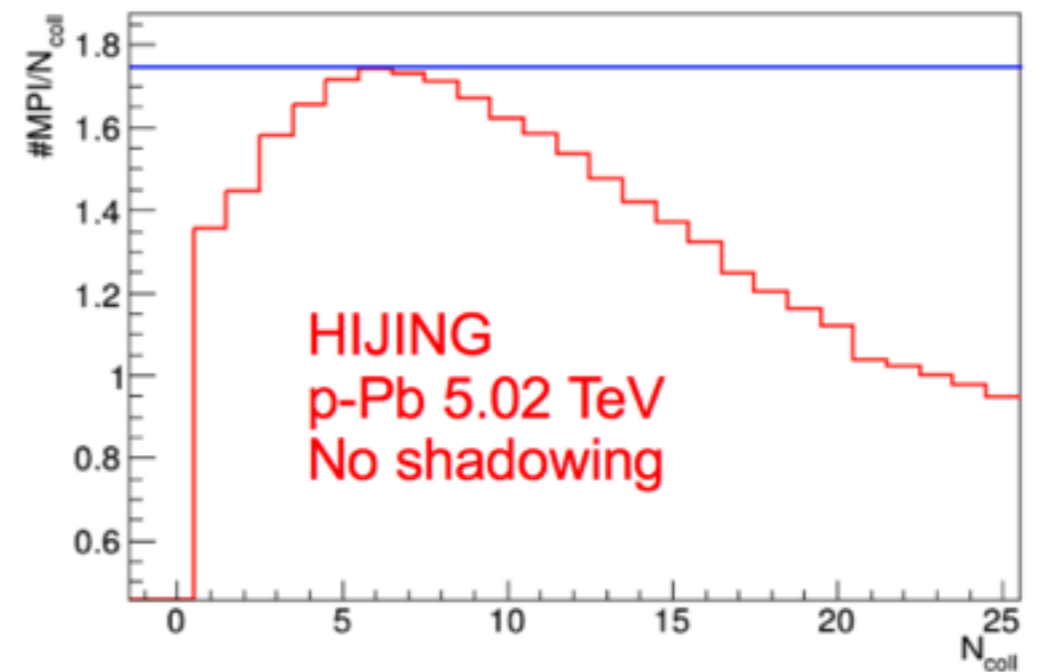
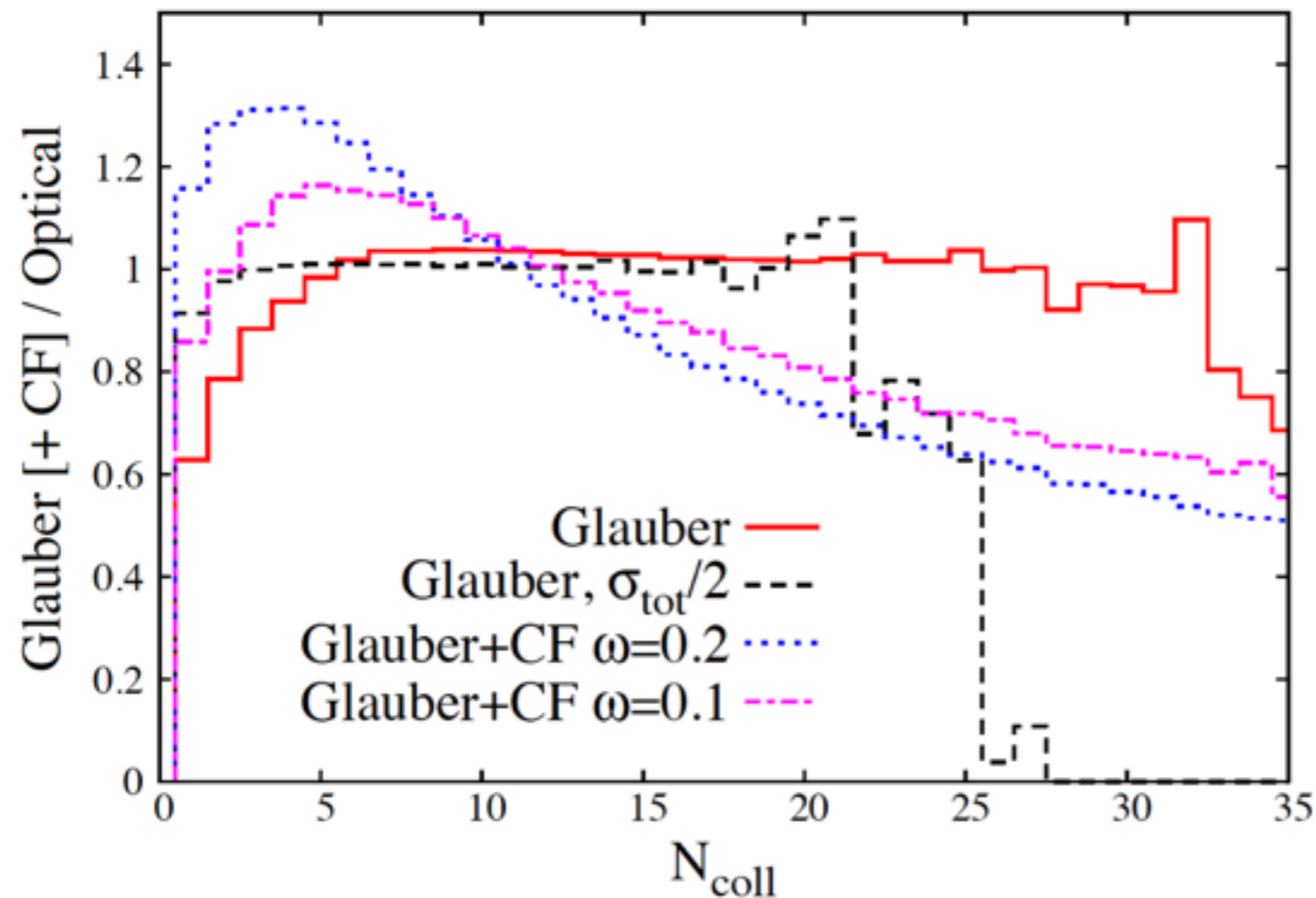
- Glauber fit slightly worse
- However particle production parameters closer to wounded nucleon expectation

# Centrality dependent $dN/d\eta$



- $N_{part}$  Scaling depends on  $\Omega$
- Presence of bias open question

# Centrality Dependent Measurements



M. Alvioli, L. Frankfurt, V. Guzey, M. Strikman  
Revealing flickering of the interaction strength in pA collisions at the LHC

- Rich phenomenology if one can take measurement of  $N_{\text{coll}}$  as granted
- However, systematics of centrality determination itself has to be discussed **first** in the context of particle production models

# Multiple Parton Interactions (MPI)

- Naive factorization

$$\langle n_{2 \rightarrow 2} \rangle = \frac{\sigma_{2 \rightarrow 2}}{\sigma_{\text{tot}}}$$

> 1 at perturbative scale!

$$P_n = \frac{\langle n_{2 \rightarrow 2} \rangle^n}{n!} \exp(-\langle n_{2 \rightarrow 2} \rangle)$$

- In reality

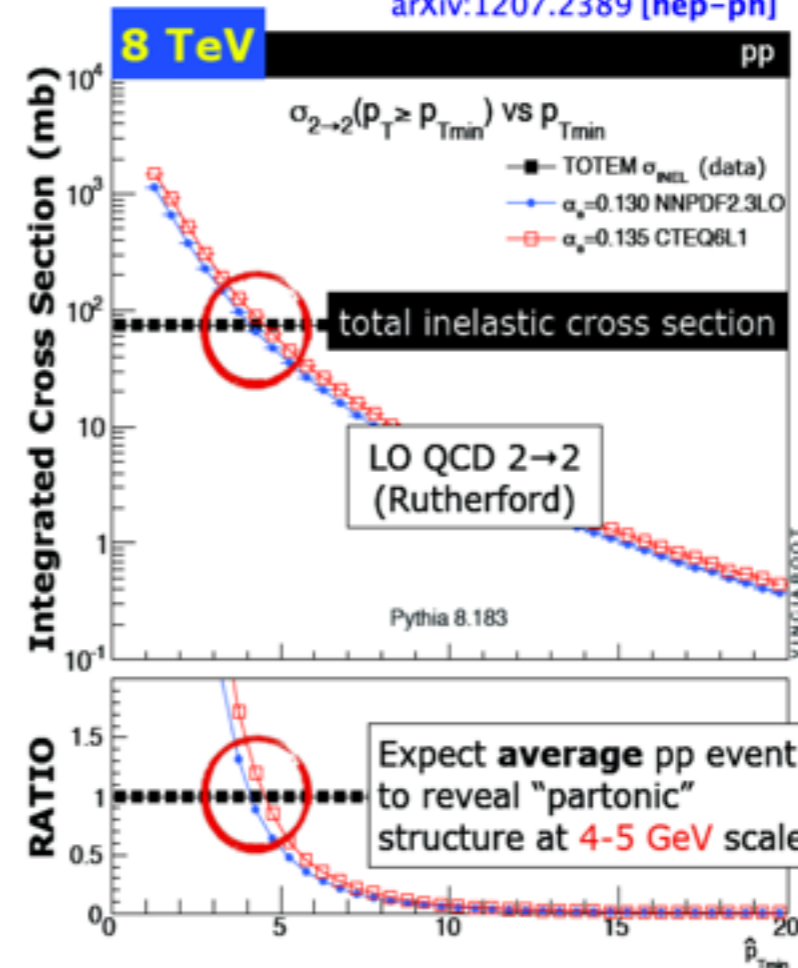
- Impact parameter dependence

$$n_{\text{hard}} = \sigma_{\text{hard}} T_p(b)$$

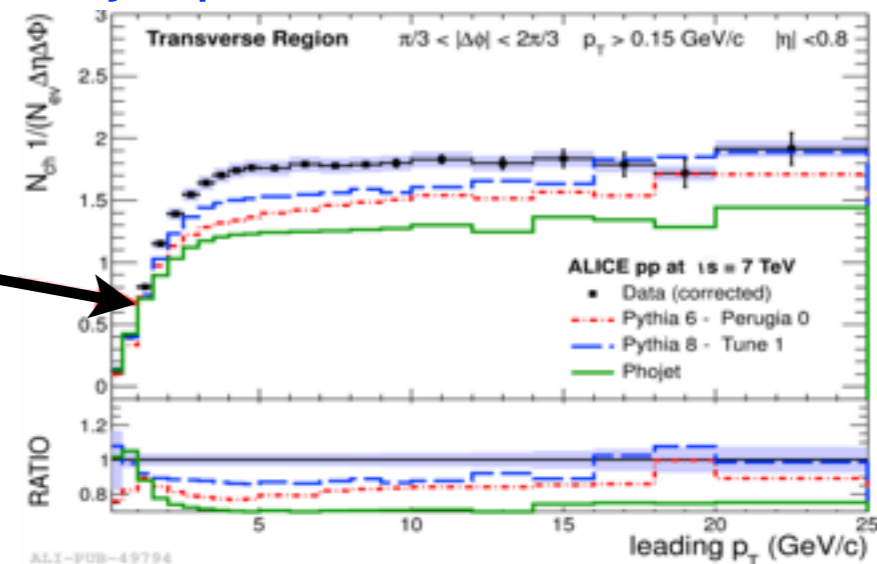
- Leads to correlation between hard and soft as in A-A

- Color screening regularizes rise of hard cross-section at low- $p_T$
- Cut-off at high  $n$  because of energy conservation
- Coherence between scatterings

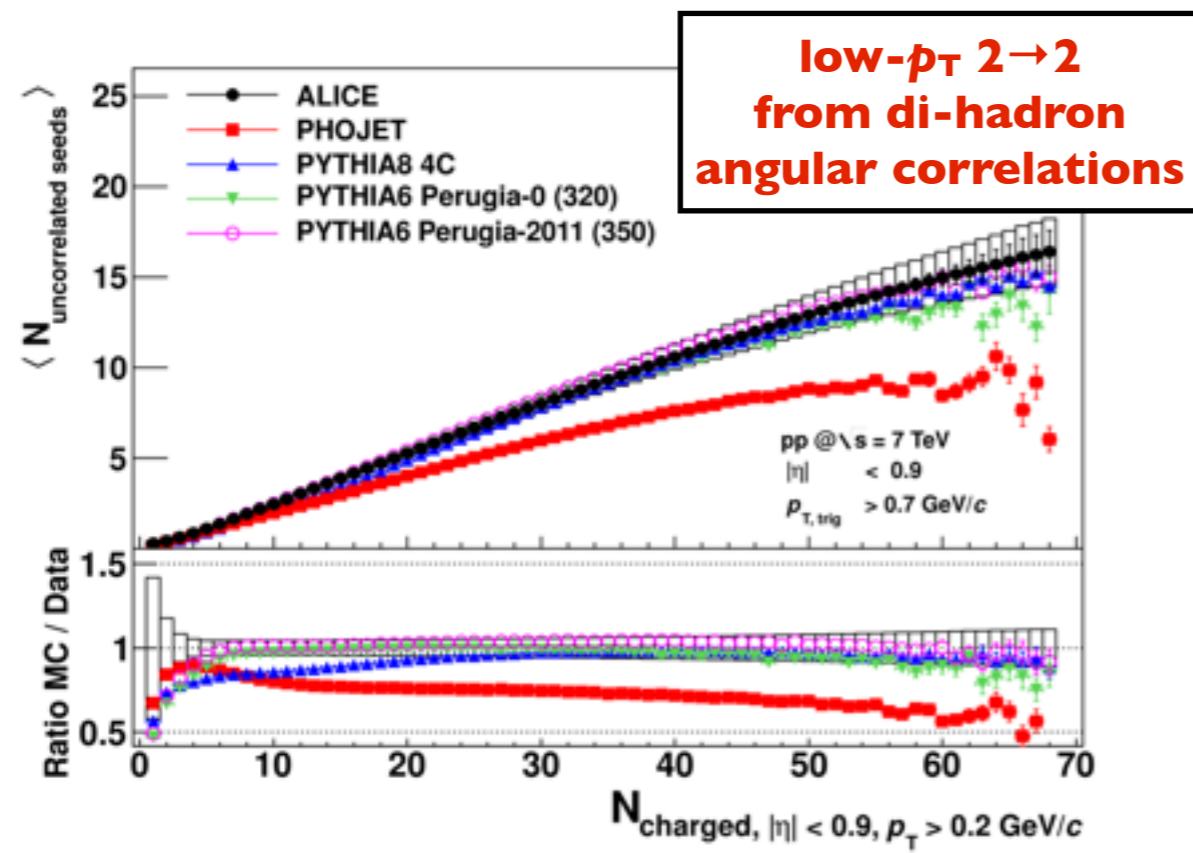
Peter Skands  
arXiv:1207.2389 [hep-ph]



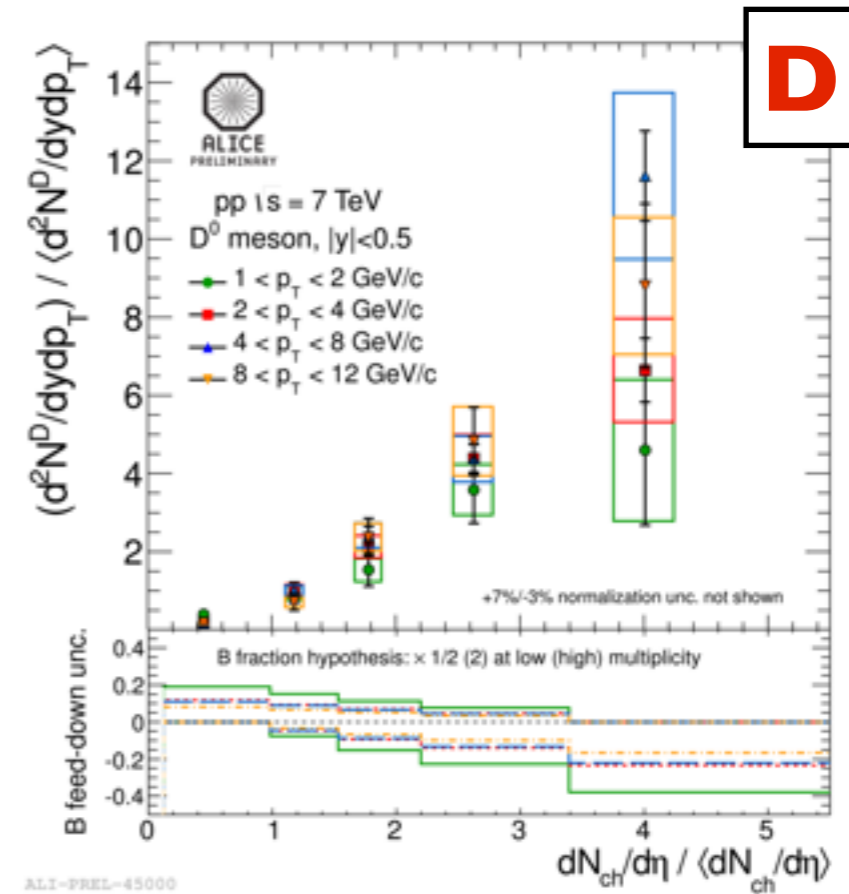
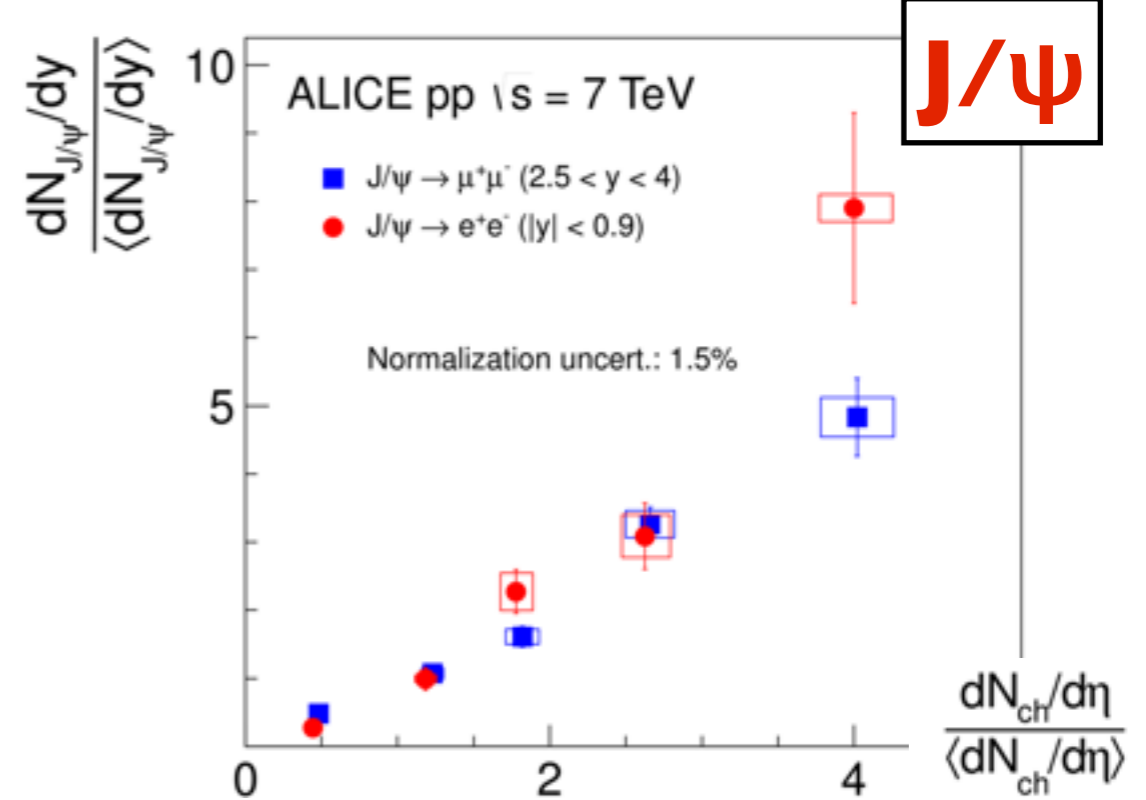
## Jet pedestal effect



# Scaling of Hard Probes with Multiplicity



ALI-PUB-62528

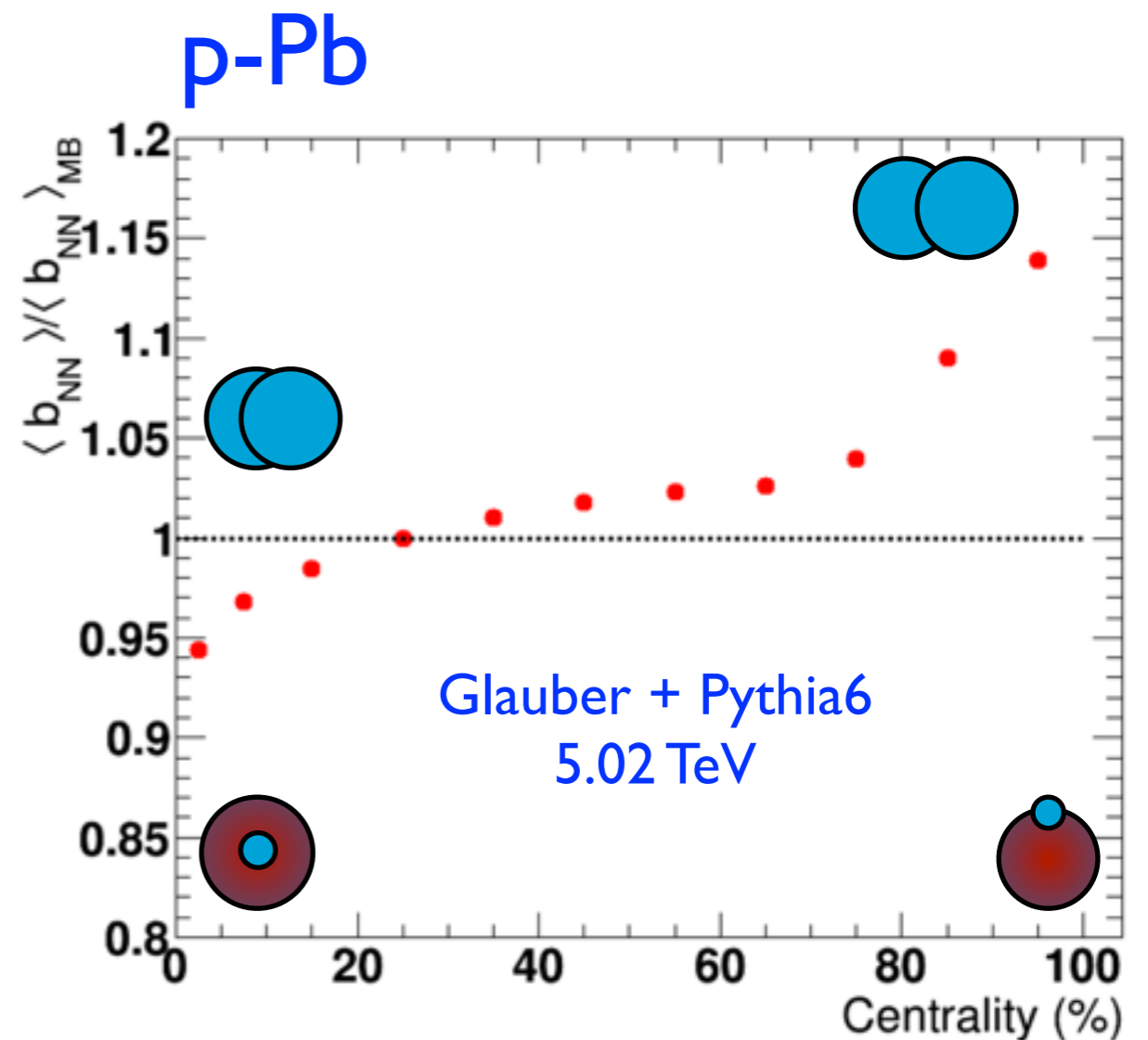
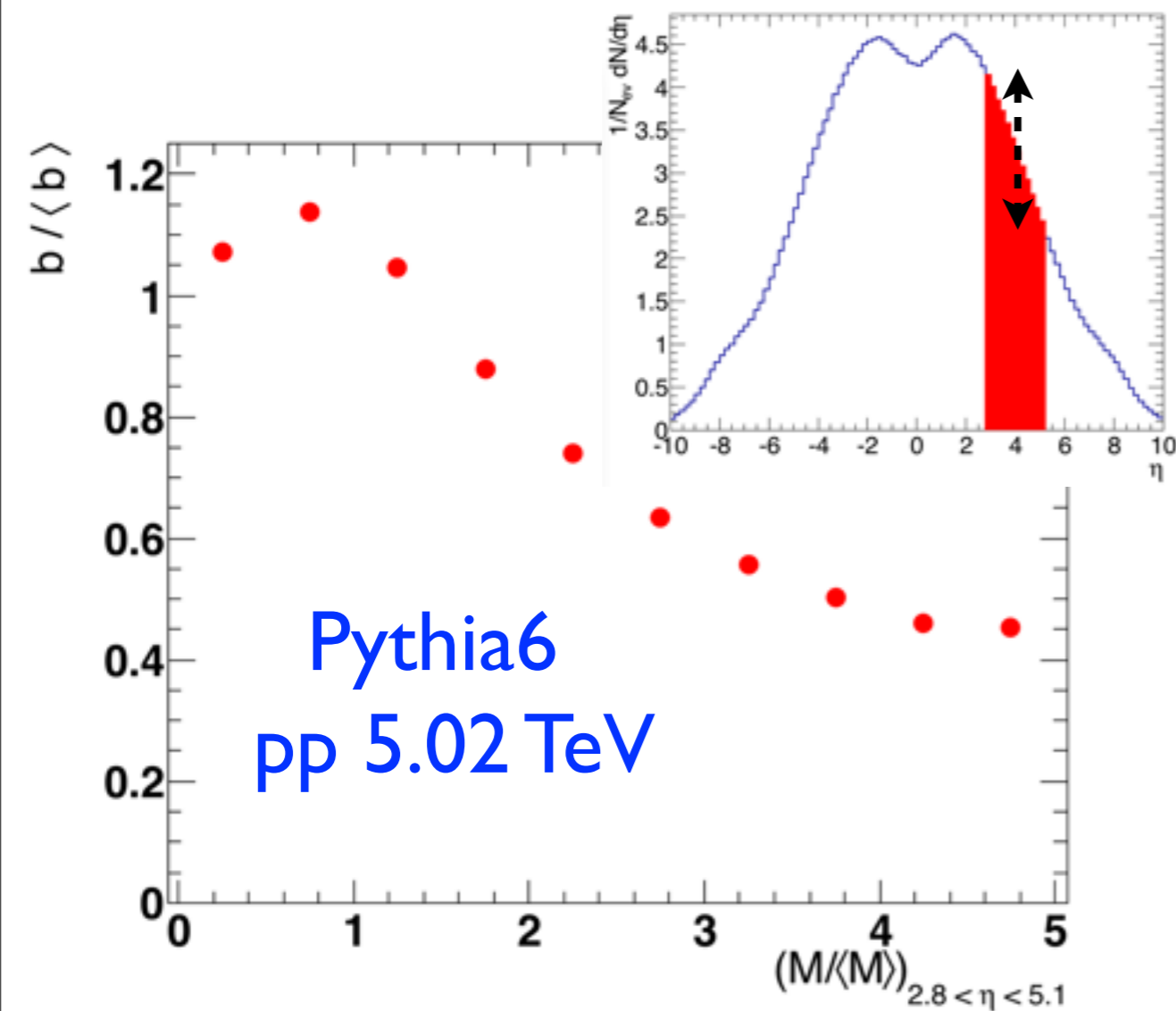


ALI-PREL-45000

# Nucleon-Nucleon Impact Parameter Systematics

Interesting since it leads to long range ( $\eta$ ) correlations  
 Additional geometry parameter in p-Pb ?

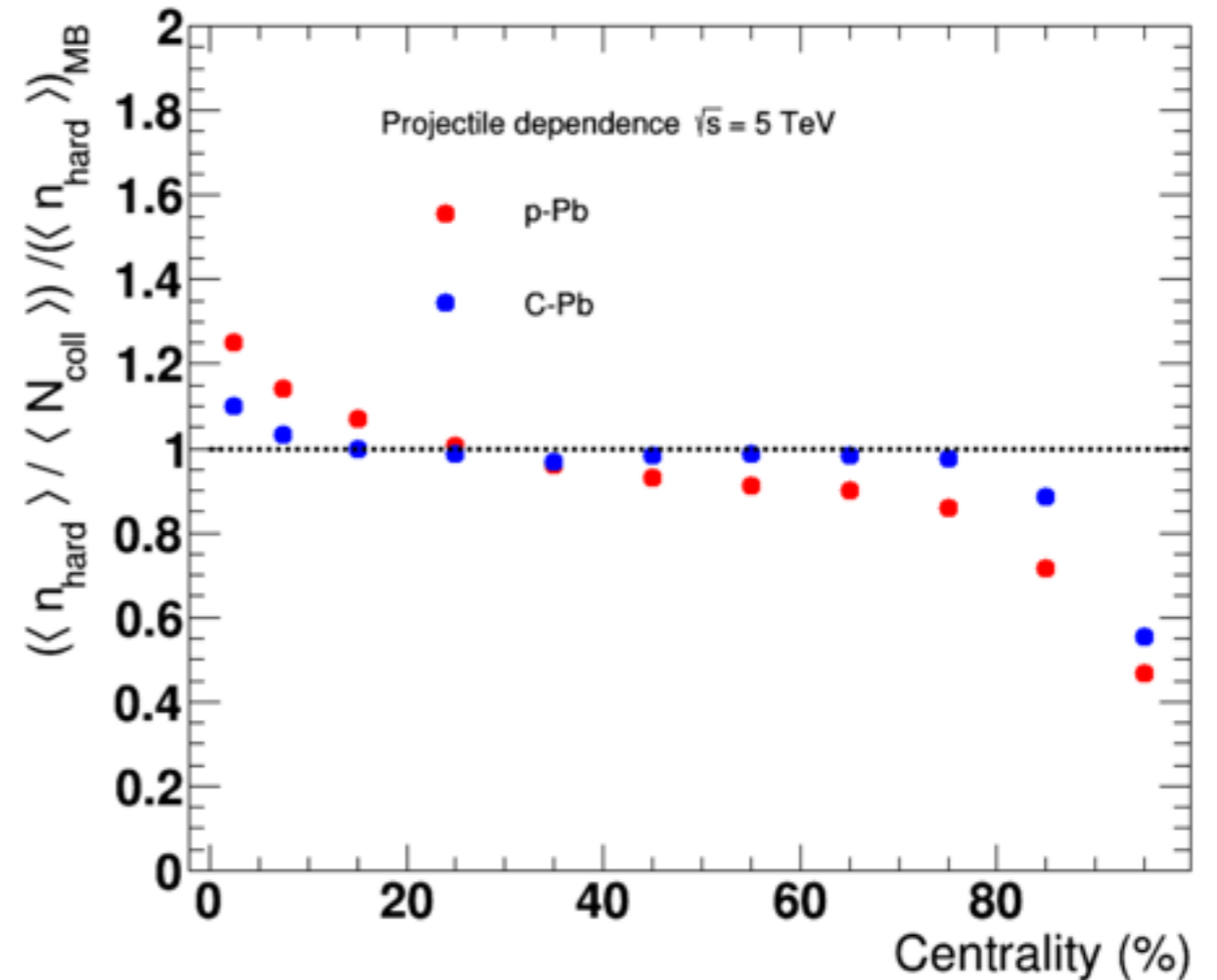
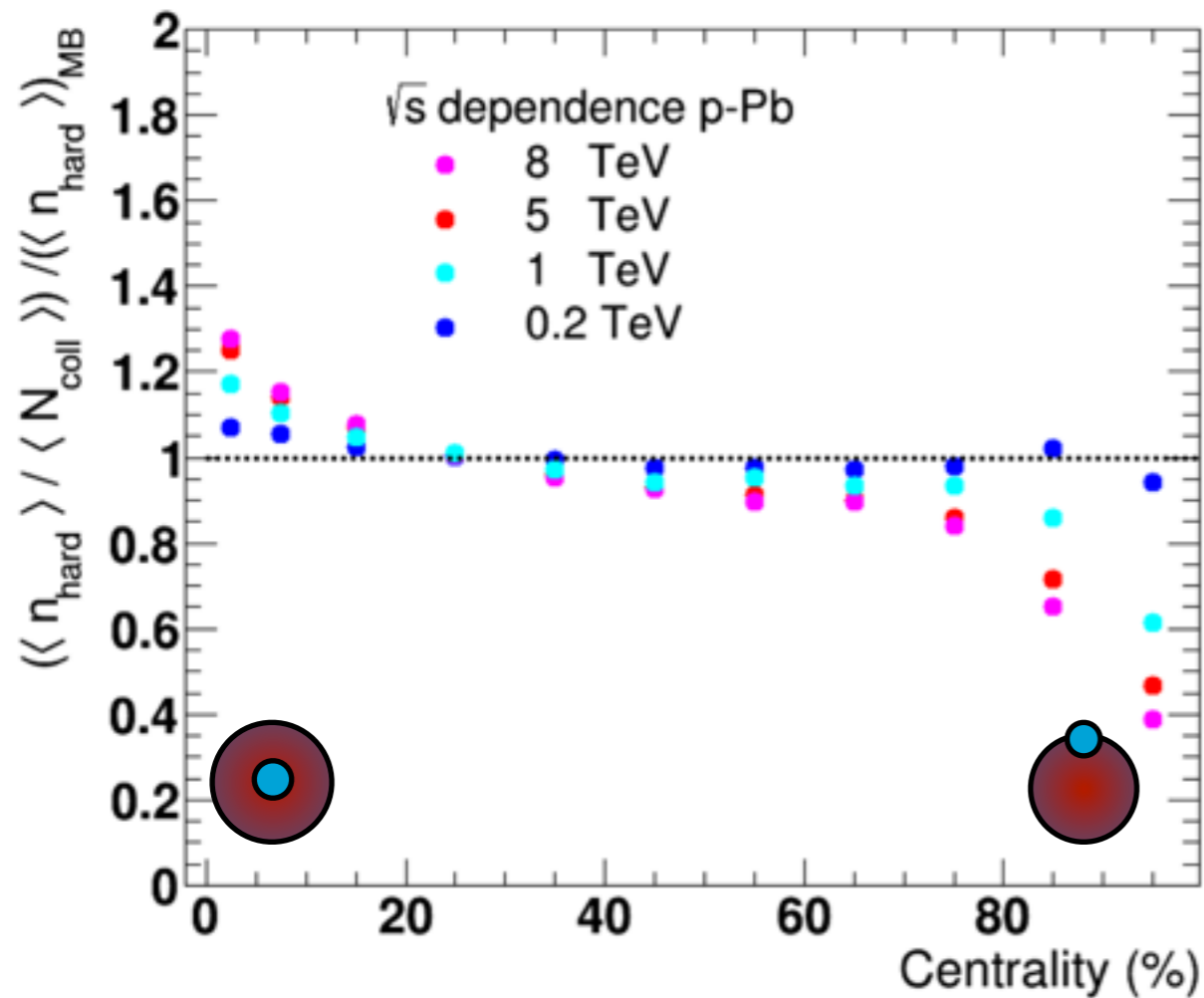
How much of this effect survives in p-Pb ?



← From slicing superposition  $M_{2.8 < \eta < 5.1}$  of  $N_{\text{coll}}$  pp collisions



# $\sqrt{s}$ and System Dependence



Bias on  $n_{\text{hard}}$  strong at LHC  $\mathcal{O}(30\%)$   
but small at RHIC  $\mathcal{O}(5\%)$ .

Bias decreases with projectile size

Deviation from binary scaling:

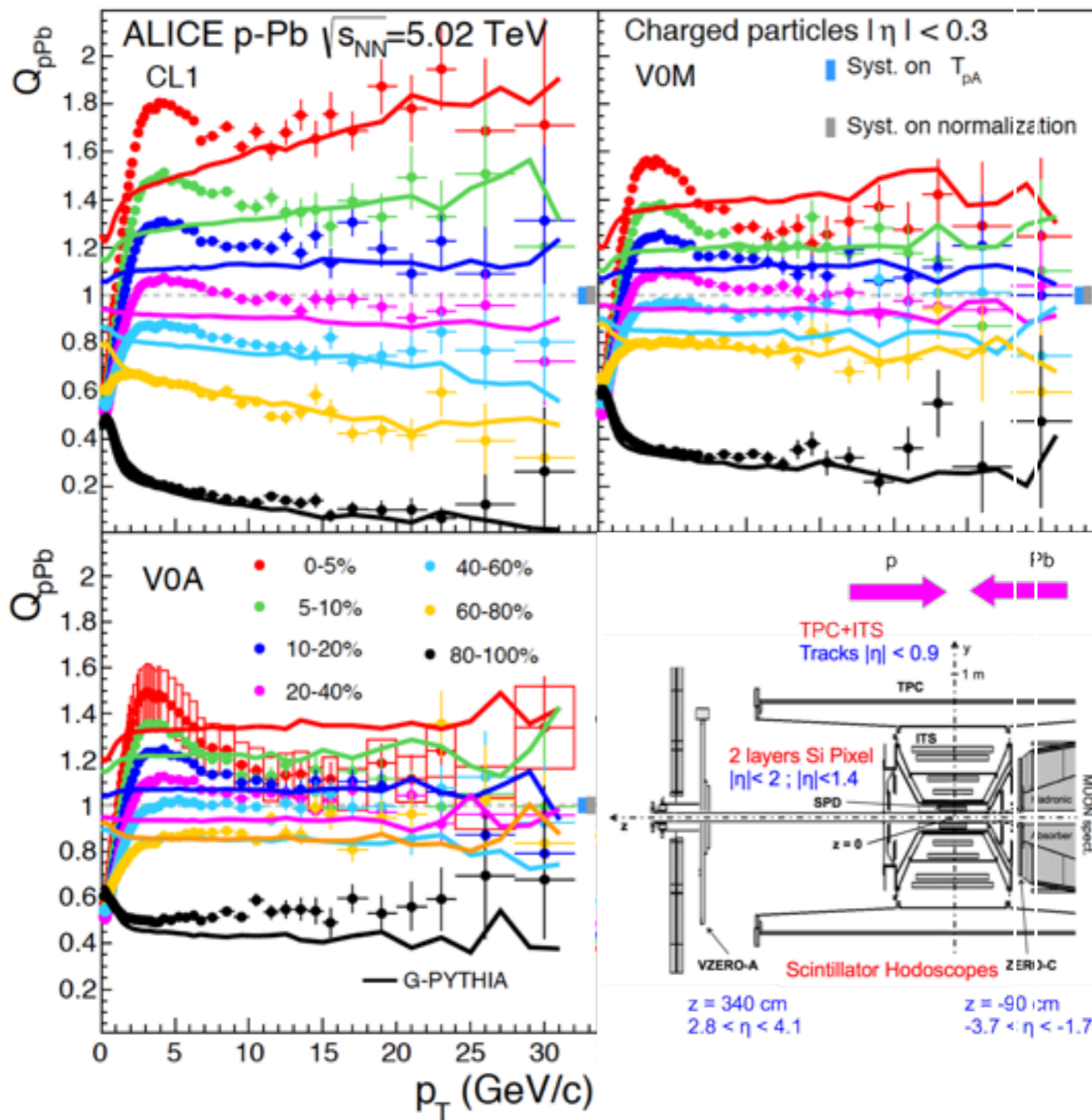
$$\left. \frac{dN}{dp_T} \right|_{\text{pA}} = N_{\text{coll}} F(\langle\langle b_{\text{NN}} \rangle\rangle) = N_{\text{coll}} \frac{\langle n_{\text{hard}} \rangle_{\text{cent}}}{\langle n_{\text{hard}} \rangle_{\text{MB}}} \left. \frac{dN}{dp_T} \right|_{\text{pp}}$$

see also PHENIX, [arXiv:1310.4793](https://arxiv.org/abs/1310.4793) [nucl-ex], AM [arXiv:1309.5525](https://arxiv.org/abs/1309.5525) [nucl-ex]

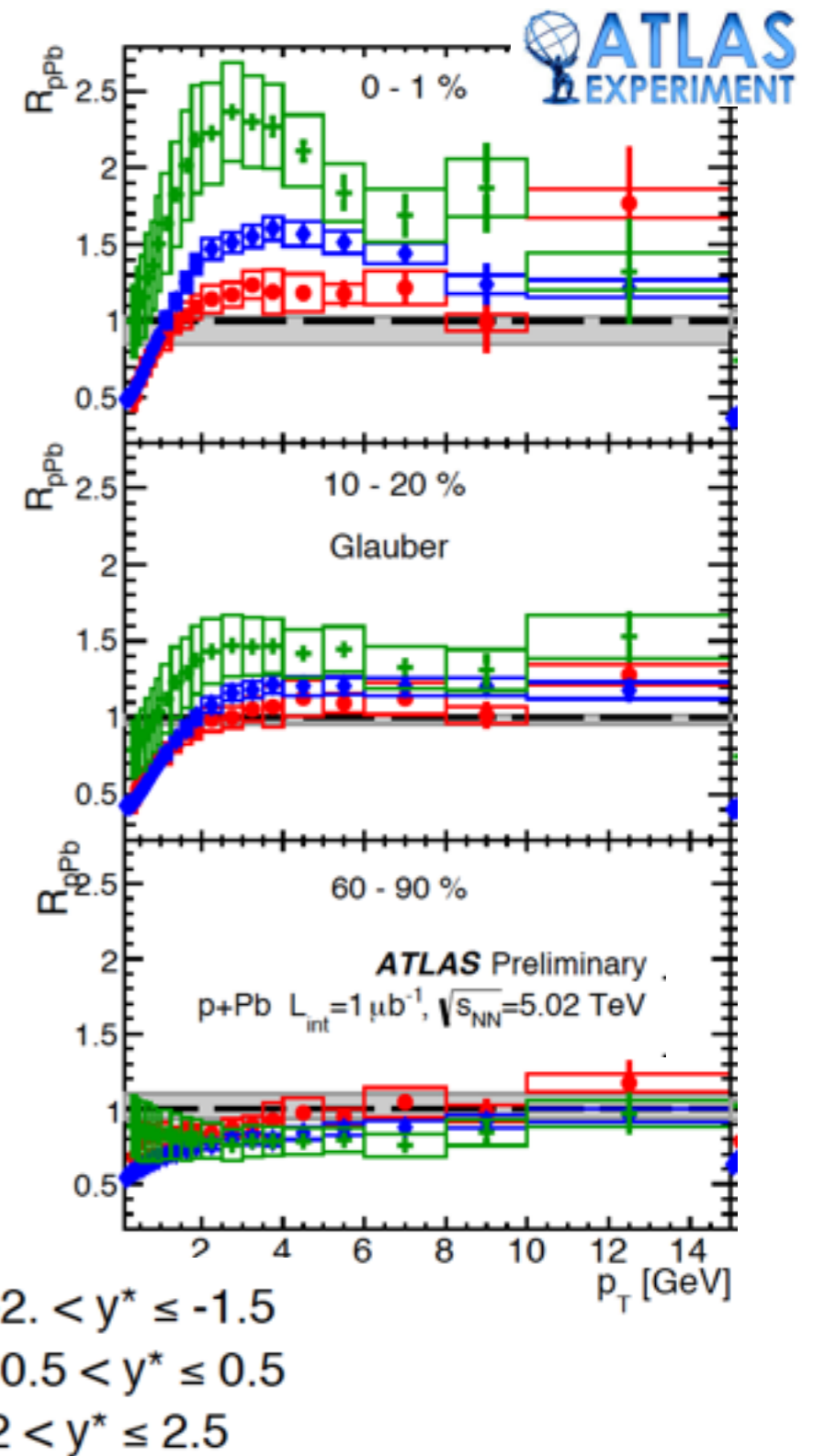
Model: Glauber+Pythia



Preliminary

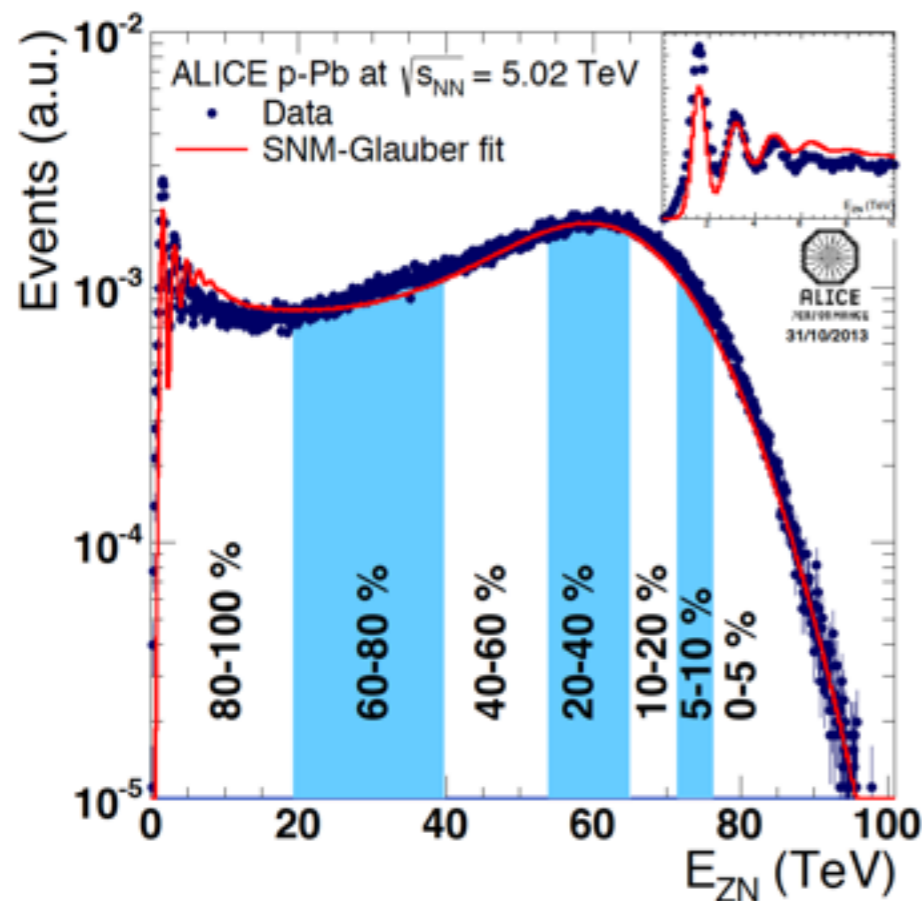


Centrality



- Correlation between hard and soft qualitatively reproduced by model (first shown SQM'13)
- Not a bias on Glauber  $N_{coll}$
- Modification approaches unity as  $\eta$  separation between centrality and  $p_T$  measurement increases

# Centrality from Hybrid Method



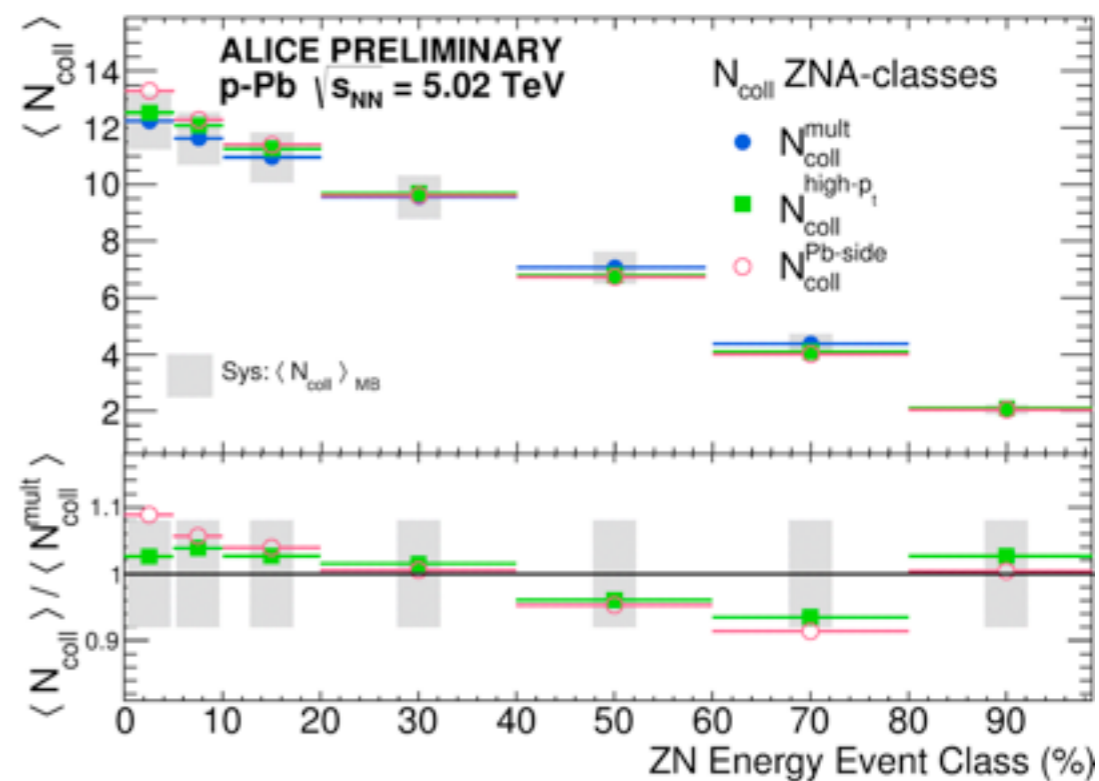
Define centrality classes  
with 0-deg n-energy (Pb-side)

With same assumptions as  
for standard Glauber fits:

$$\langle N_{\text{coll}} \rangle_i^{\text{mult}} = \langle N_{\text{part}} \rangle_{\text{MB}} \left( \frac{\langle dN/d\eta \rangle_i}{\langle dN/d\eta \rangle_{\text{MB}}} \right)_{-1 < \eta < 0}^{-1}$$

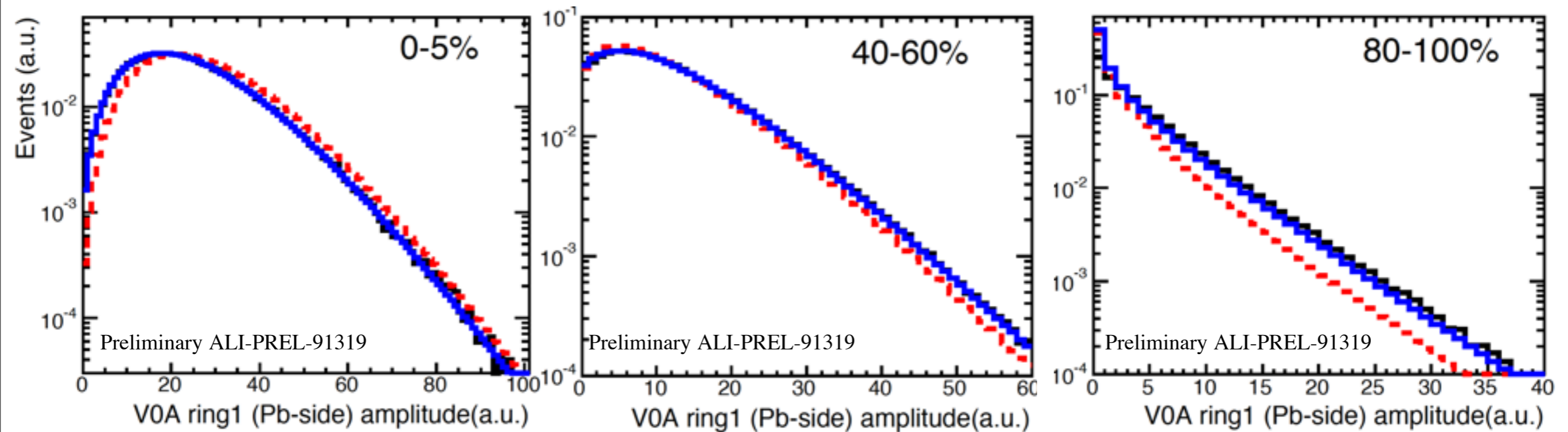
$$\langle N_{\text{coll}} \rangle_i^{\text{Pb-side}} = \langle N_{\text{coll}} \rangle_{\text{MB}} \left( \frac{\langle \text{VOA}_{\text{ring1}} \rangle_i}{\langle \text{VOA}_{\text{ring1}} \rangle_{\text{MB}}} \right)$$

$$\langle N_{\text{coll}} \rangle_i^{\text{high-}p_T} = \langle N_{\text{coll}} \rangle_{\text{MB}} \left( \frac{\langle Y \rangle_i}{\langle Y \rangle_{\text{MB}}} \right)_{10 < p_T < 20 \text{ GeV}}$$



Consistency of assumptions within 10%

# Consistency Checks

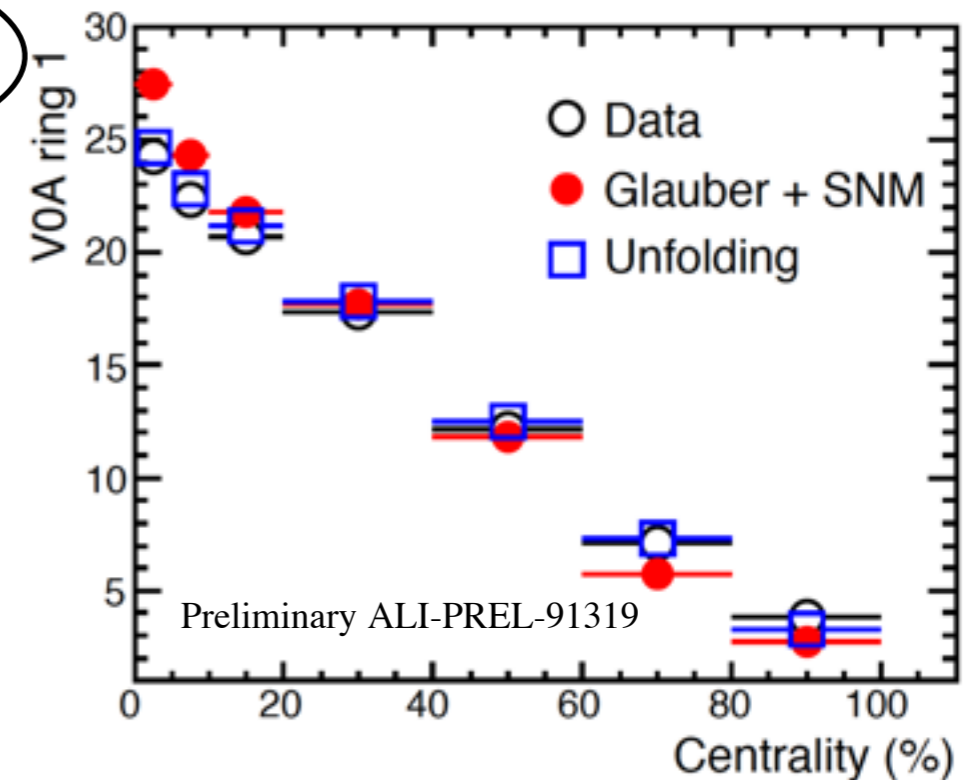


**For each centrality class:**

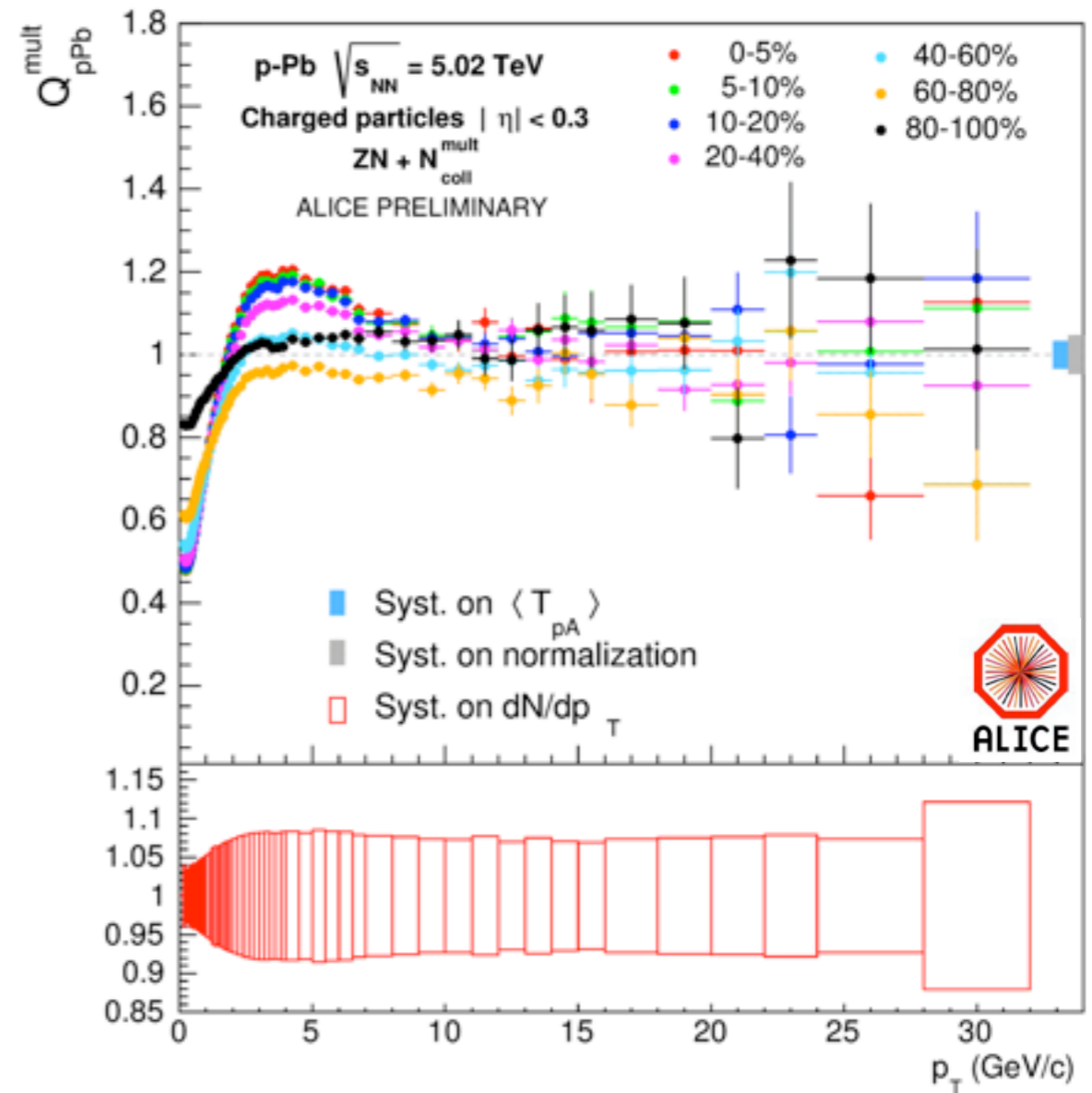
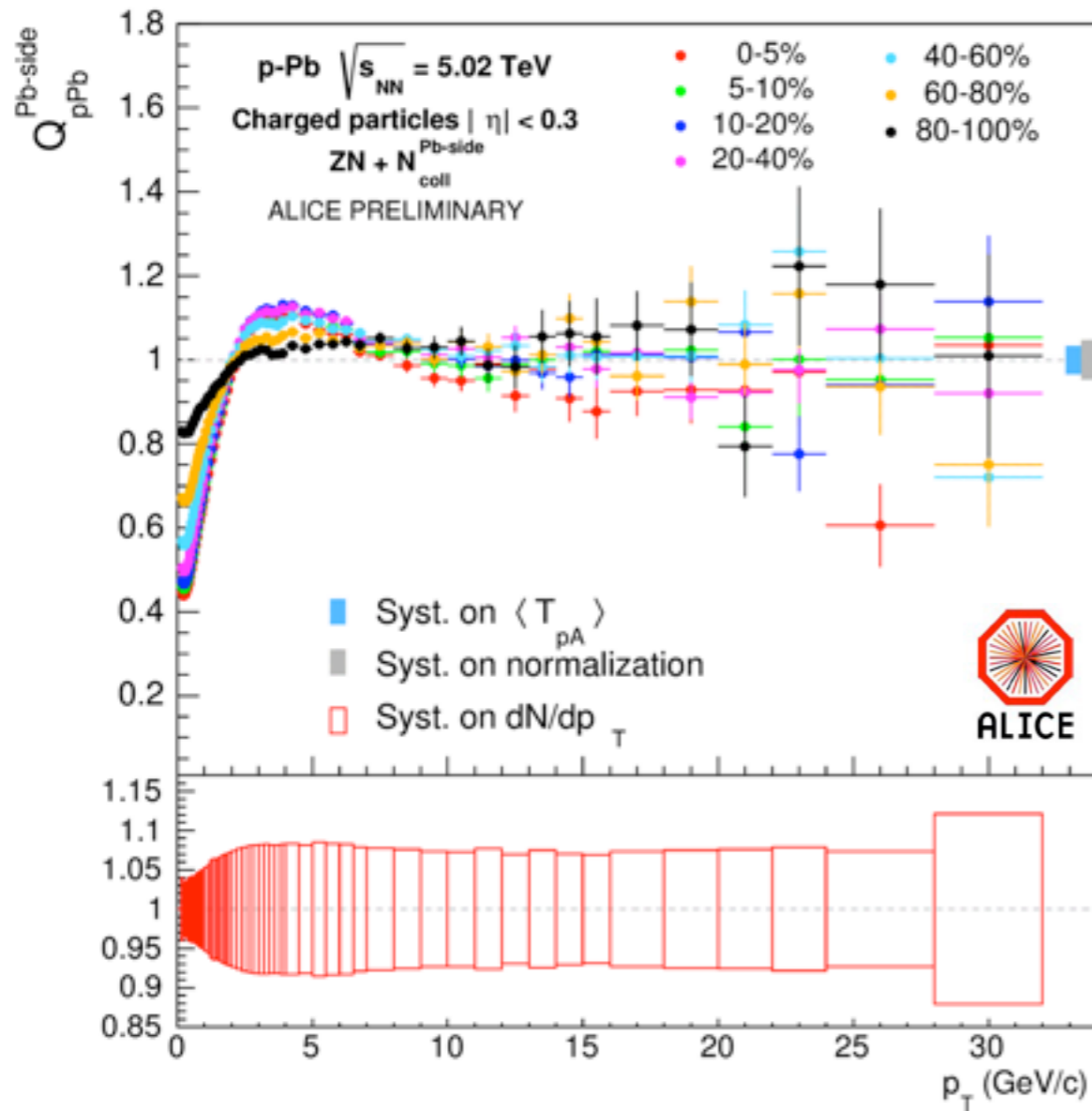
**Unfolding:** find input  $\pi_i(N_{\text{coll}})$  from fit

Does not work for biased centrality selection

**Glauber+Slow Nucleon Model (SNM):** find  $\pi_i(N_{\text{coll}})$  from Glauber fit to ZN energy distribution



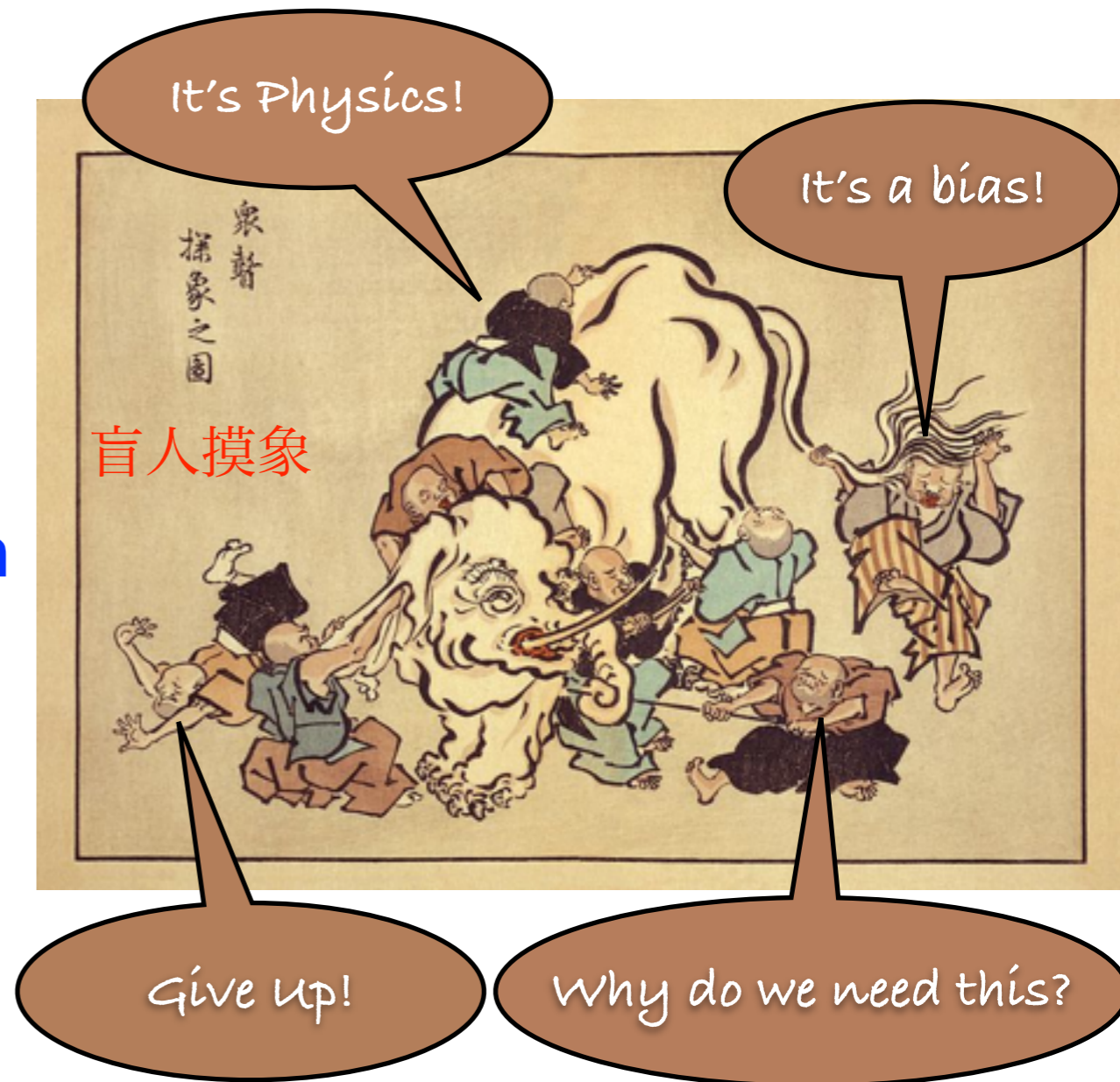
# Modification Factors



At high  $p_T$ , consistent with unity

# Conclusions

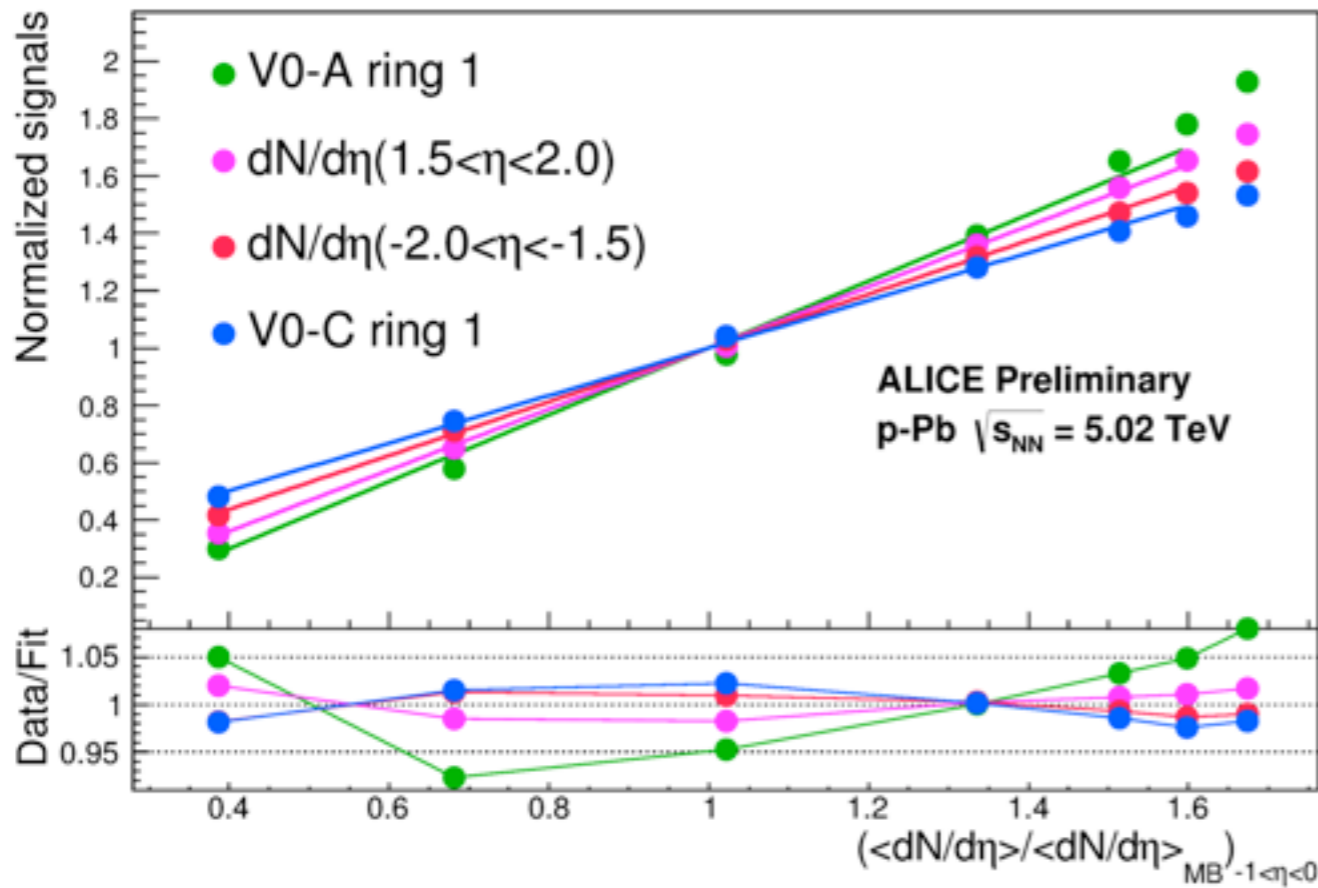
- For  $p(d)$ -A, question of “bias or physics” has in general no definite answer
- Systematics of centrality measurement and interpretation of data on particle production have to be performed (re-iterated) in the same framework.
- OR



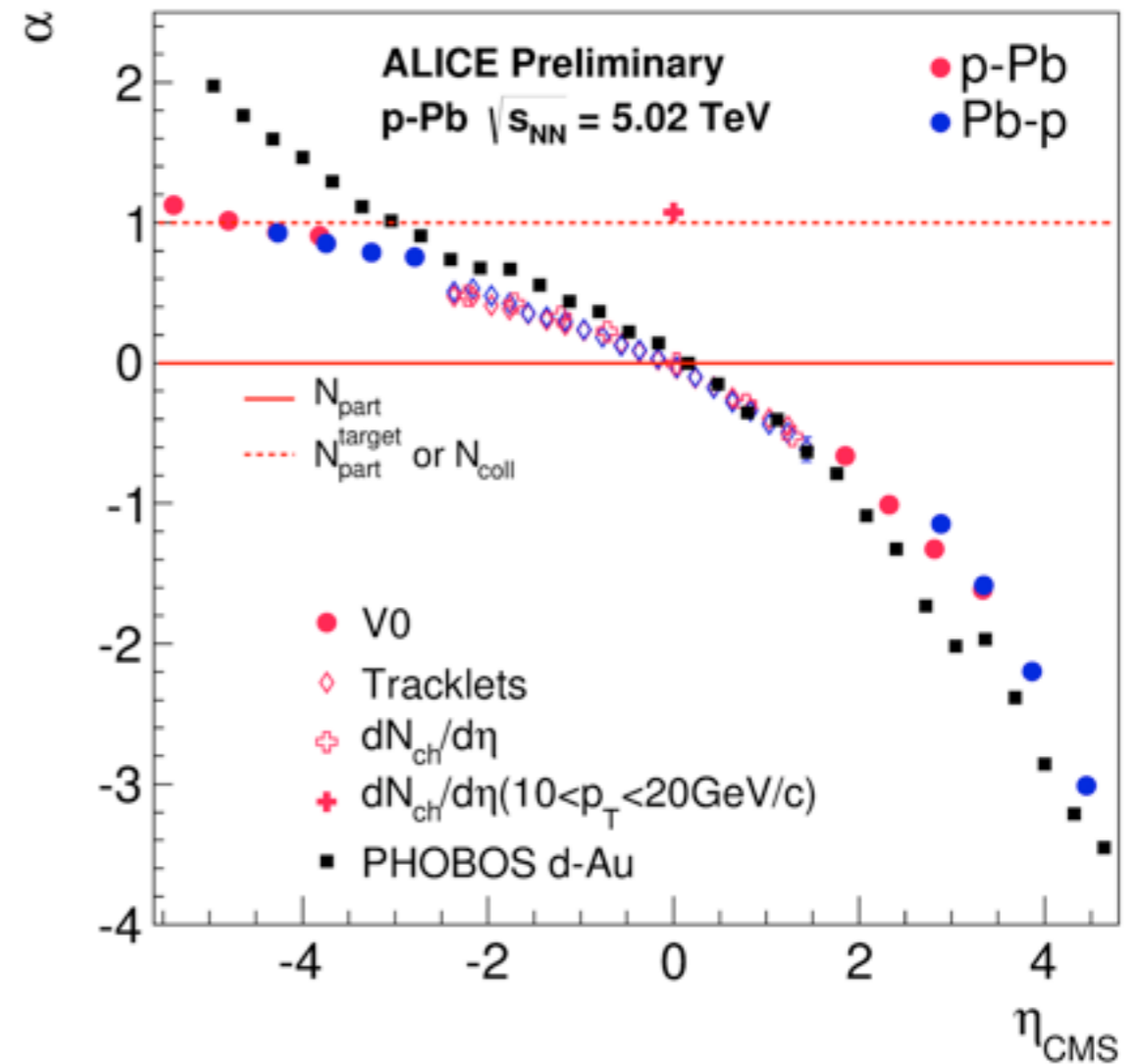
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# Scaling

## Self normalized signals vs central multiplicity



## Slope varies with $\eta$



## Fit assuming Linear Scaling

$$\frac{\langle S \rangle_i}{\langle S \rangle_{MB}} = \frac{\langle N_{part} \rangle_{MB}}{(\langle N_{part} \rangle_{MB} - \alpha)} \cdot \left( \frac{\langle dN/d\eta \rangle_i}{\langle dN/d\eta \rangle_{MB}} \right)_{-1 < \eta < 0} - \frac{\alpha}{(\langle N_{part} \rangle_{MB} - \alpha)}$$