Event selection and centrality bias in pA collisions (*)

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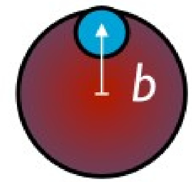
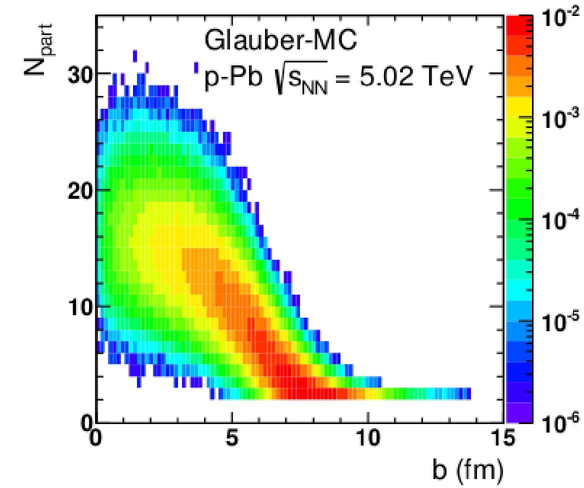
(*) based on talk by A.Morsch at IS2014
and ALICE paper arXiv:1412.6828
on pPb centrality

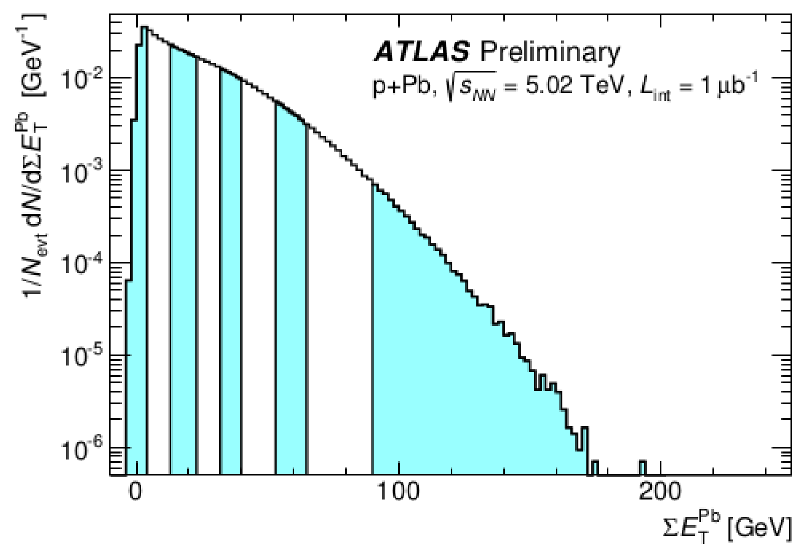
RBRC workshop on "Collectivity in small colliding systems"

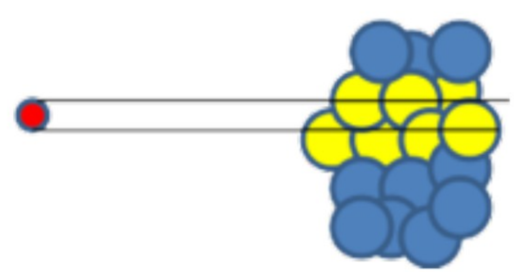
2 Basic procedure

- Impact parameter not observable
  - And for small systems only weakly correlated to number of participants (N_{part})
- Classify events in terms of event activity (or centrality estimator E)
  - E should vary monotonously with number of participants
  - Multiplicity, energy, slow neutron energy
  - Order as percentile of cross section
- Establish relation to Glauber model parameters (N_{part}, N_{coll}) via particle production model









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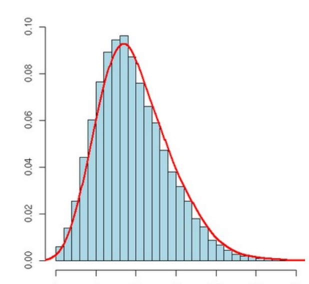
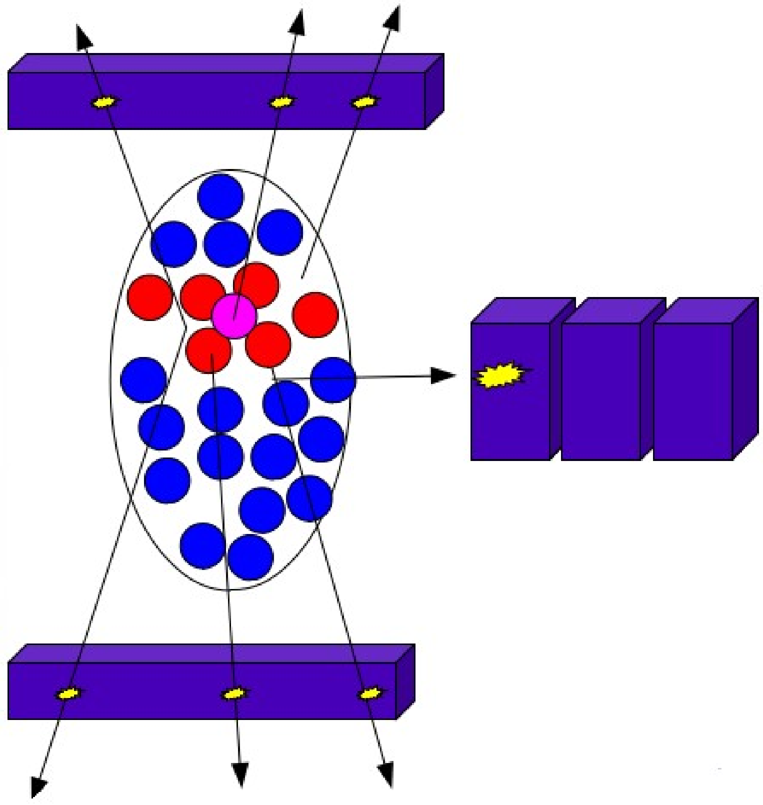
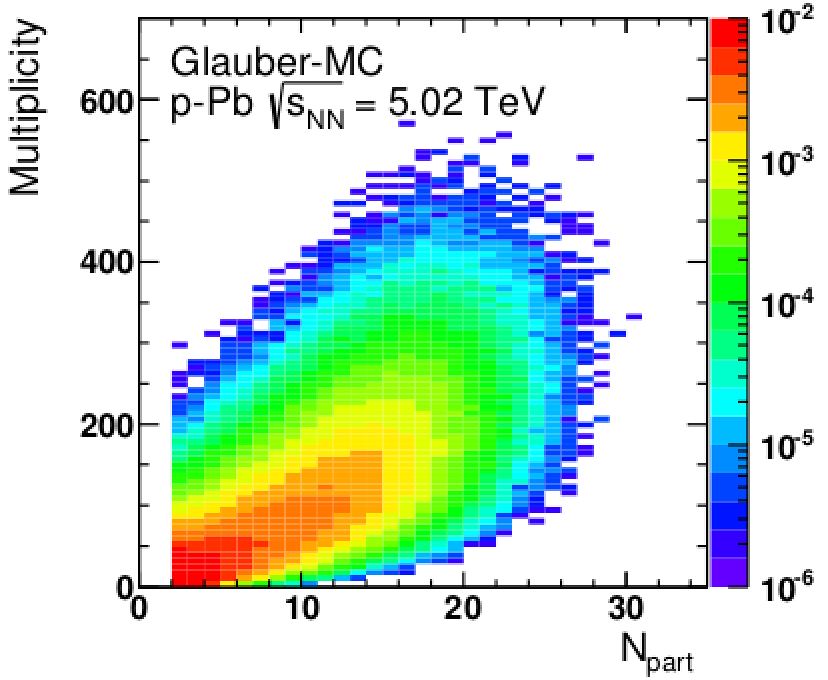


Glauber MC: $\pi(N_{col})$ Model: $P(E \mid N_{col})$

3 Essential requirements



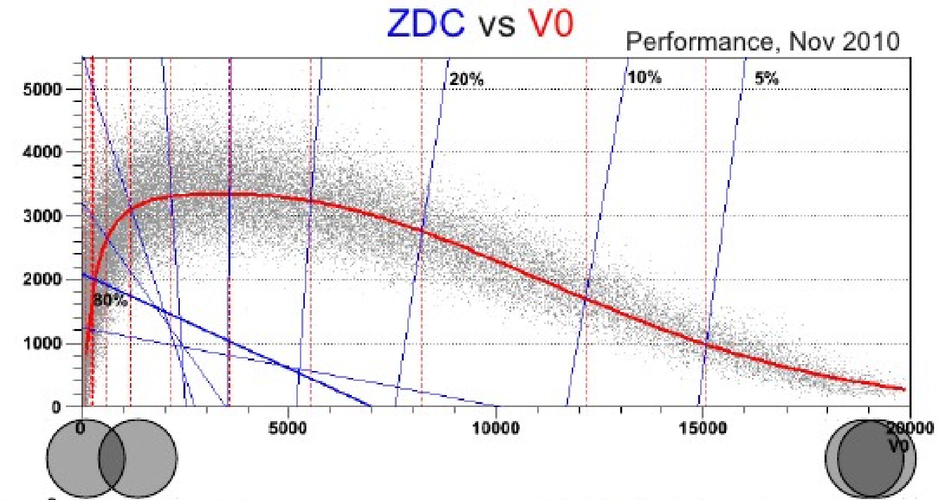
- Demonstrate correlation of measurement to collision geometry
  - Via correlation of observables that are causally disconnected after collision
- Demonstrate completeness
  - Are there other relevant geometry parameters that are biased by the selection wrt minimum bias?
  - What are their possible influence on centrality dependent measurements?
    - Importance for p(d)A: small dynamic range leads to large fluctuations

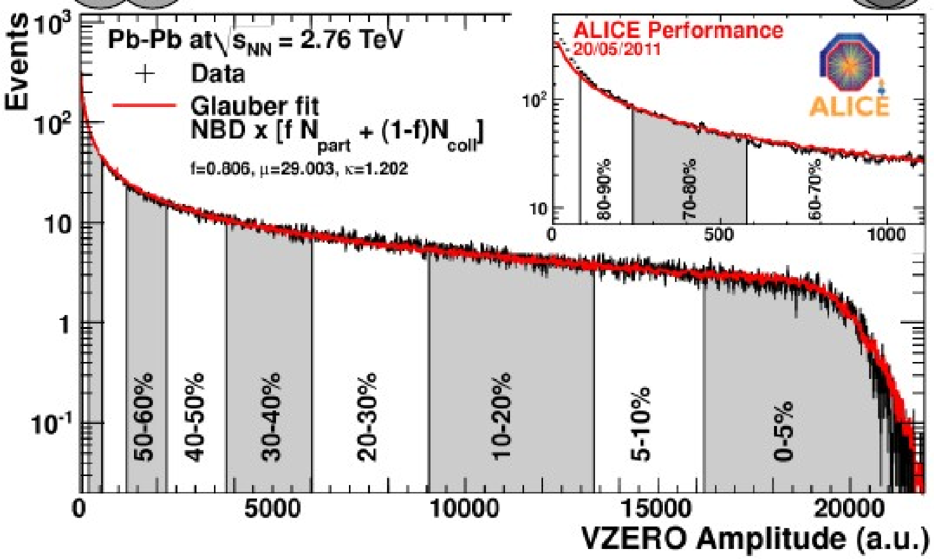


Example large system: ALICE Pb+Pb

Miller et al., Ann. Rev. Nucl. Part. Sci 57 (2007) 205
ALICE, Phys. Rev. C 88 (2013) 044909

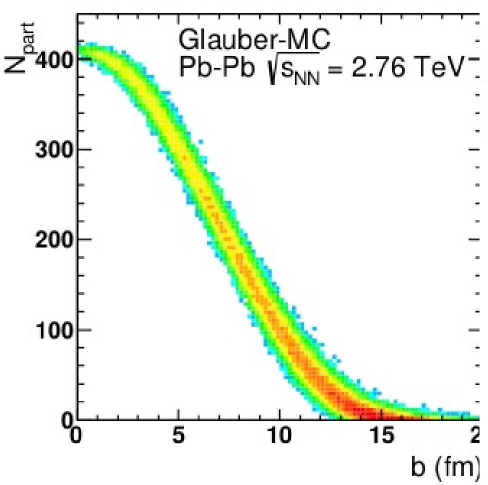
Forward neutrons

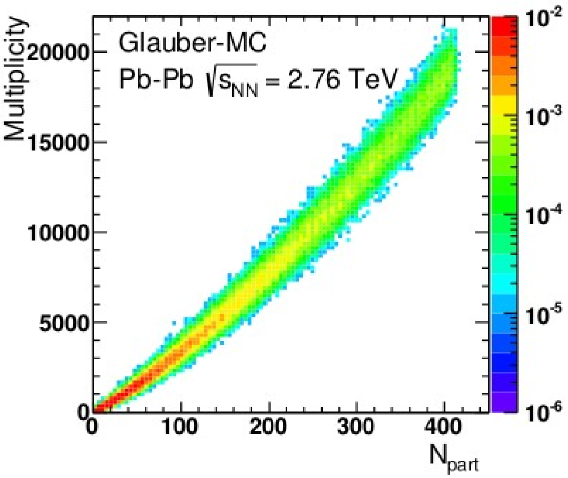




Charged hadrons η~3

- Correlate particle yields from disconnected parts of phase space
  - Correlation arises from common dependence on collision impact parameter

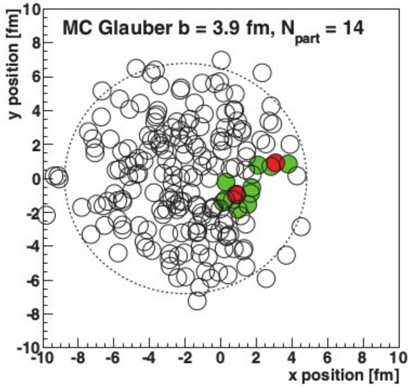


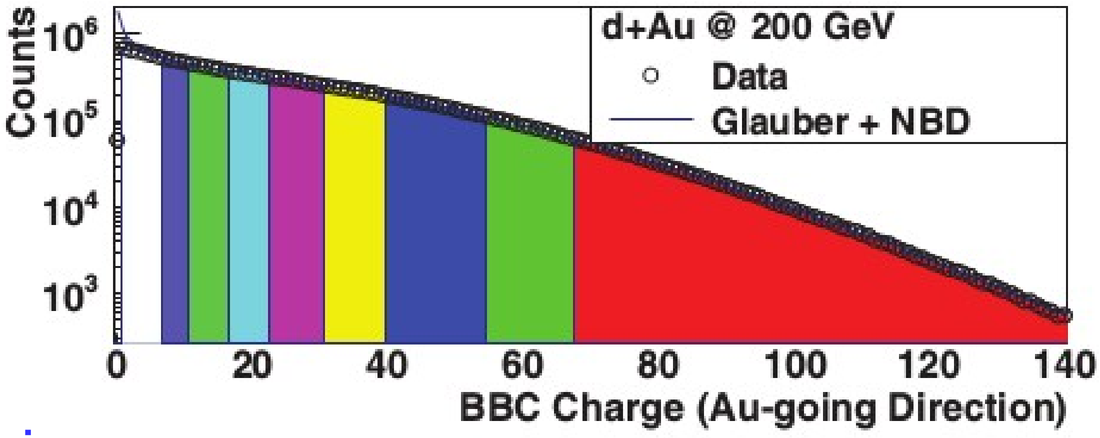


5 Example small system: PHENIX d+Au

PHENIX, PRC 90 (2014) 034902

- Probability for Ncoll binary collisions $\pi(N_{coll})$ from Glauber





- Charge distribution for one collision (Negative Binomial)

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

- For N_{coll} collisions, assume <BBC>~<Ncoll>

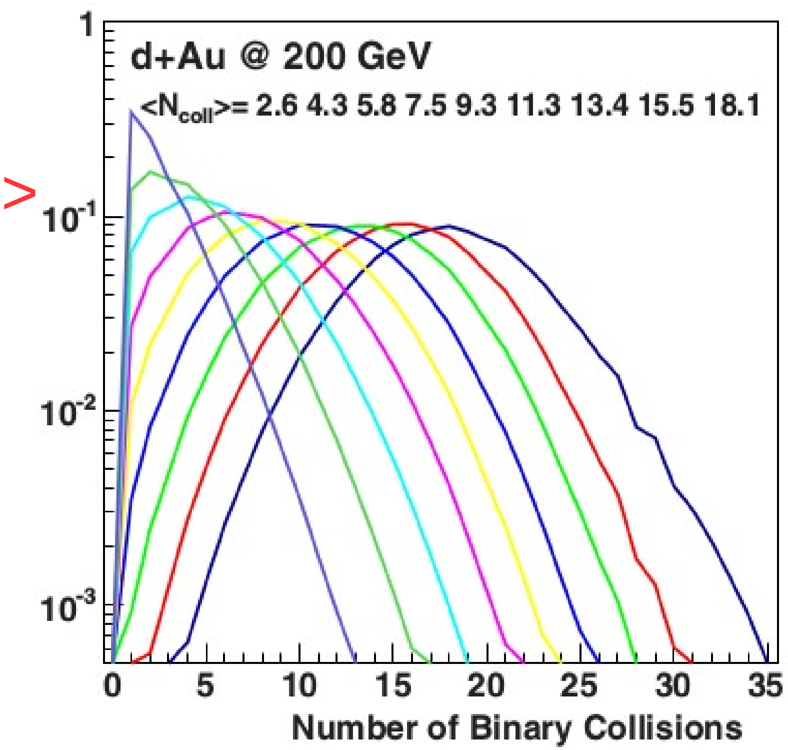
$$P(BBC|N_{\mathrm{coll}})=P_{\mathrm{NBD}}(BBC;N_{\mathrm{coll}}\times\mu,N_{\mathrm{coll}}\times k)$$

- Fit to measured distribution

$$P_{\mathrm{BBC}}(BBC)=\Sigma_1^{N_{\mathrm{coll}}^{\mathrm{max}}}\pi(N_{\mathrm{coll}})P(BBC|N_{\mathrm{coll}})$$

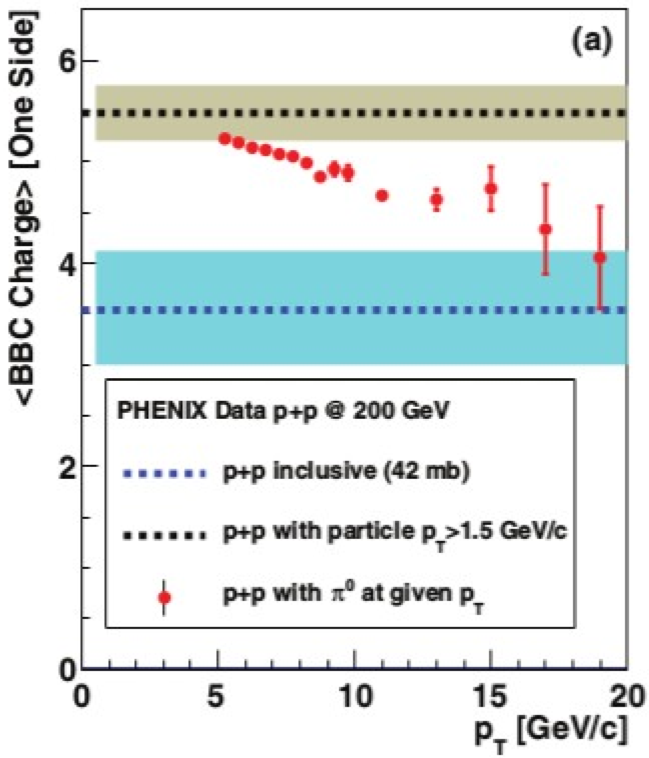
- For fixed k and μ

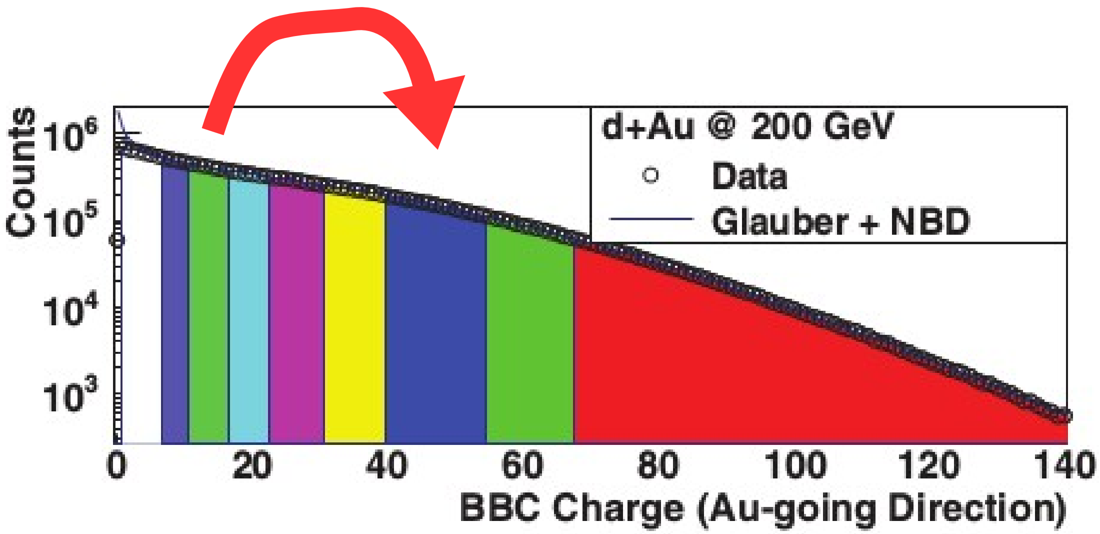
$$P(N_{\mathrm{coll}}|BBC)=P(BBC|N_{\mathrm{coll}})\pi(N_{\mathrm{coll}})/P(BBC)$$



6 High-p_T bias factor correction

PHENIX, PRC 90 (2014) 034902

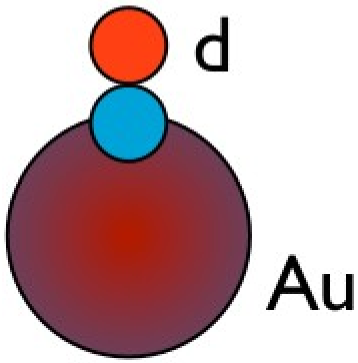


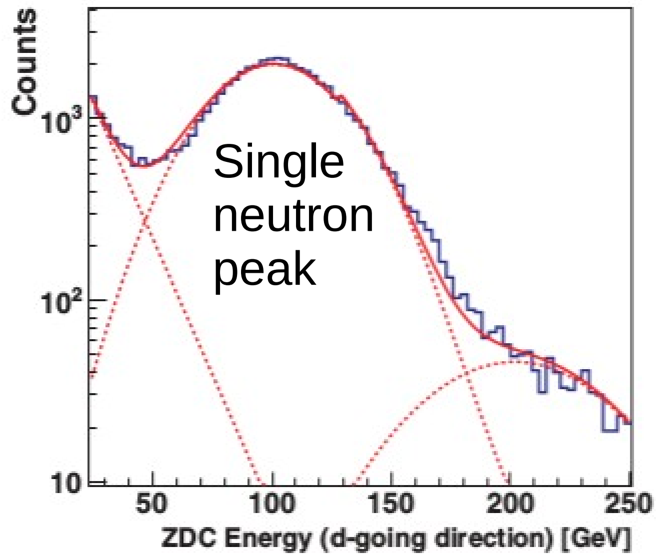


- Presence of high p_T particle at central rapidity increases BBC charge
- Quantify bias using pp data coupled with the Glauber model
  - And check with HIJING

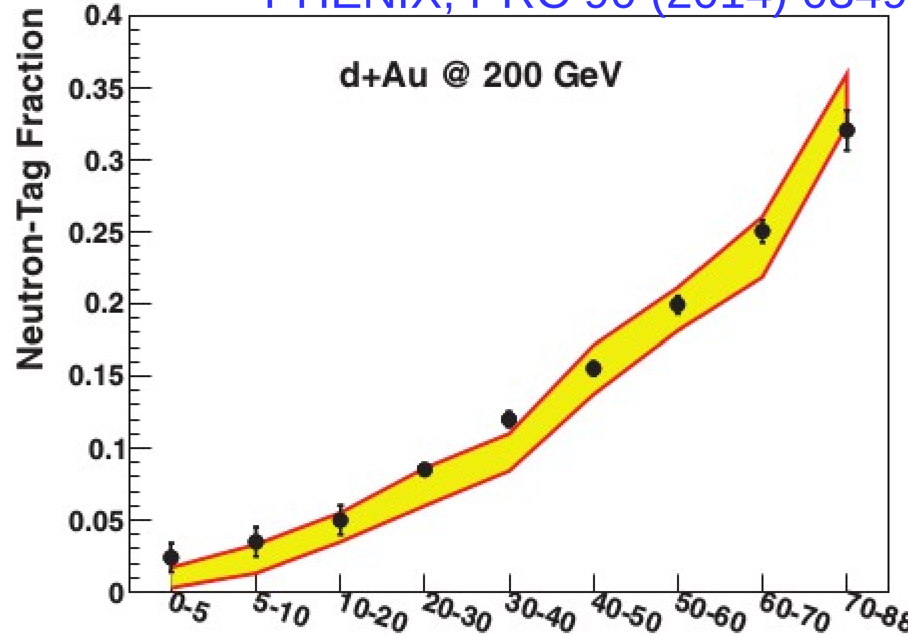
Centrality (%)	Glauber + NBD	HIJING $1 \leqslant p_T < 5$
0–20	0.94 ± 0.01	0.951 ± 0.001
20–40	1.00 ± 0.01	0.996 ± 0.001
40–60	1.03 ± 0.02	1.010 ± 0.001
60–88	1.03 ± 0.06	1.030 ± 0.001

7 Correlation with d-dissociation



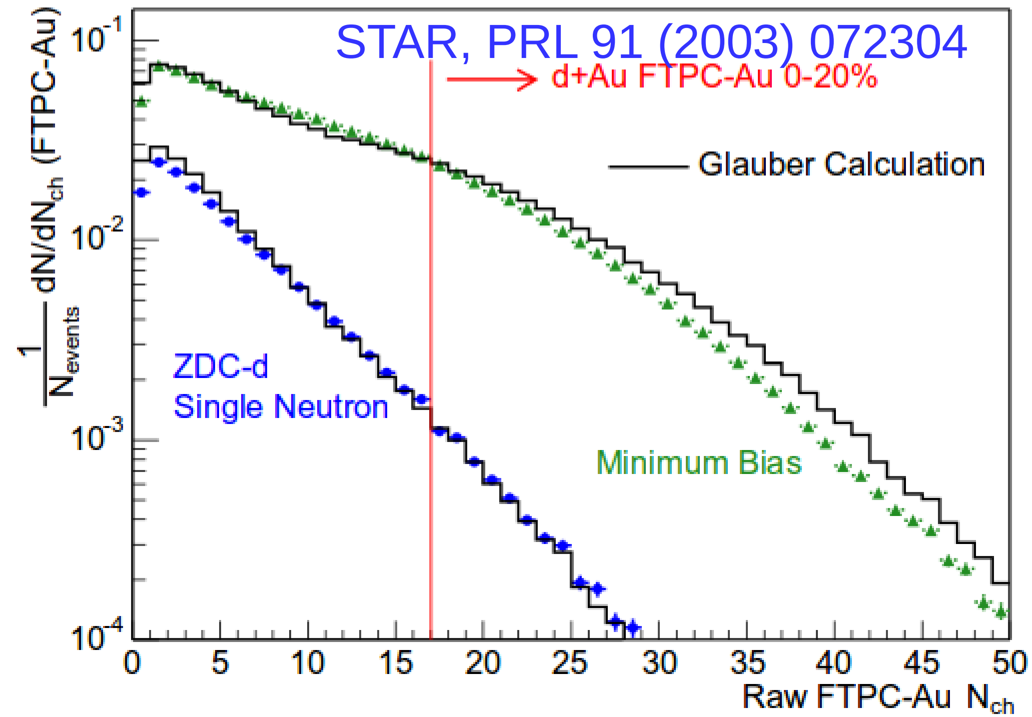


PHENIX, PRC 90 (2014) 034902



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

STAR, PRL 91 (2003) 072304



8 Remarks

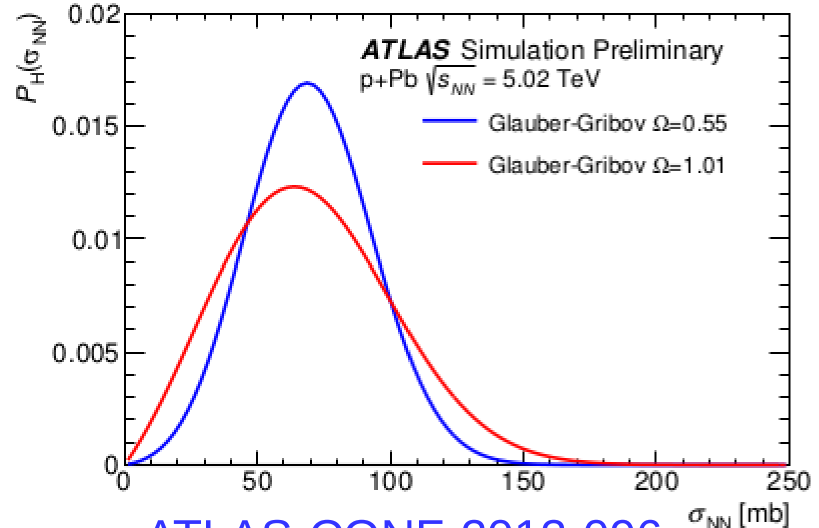
- Need Glauber fit with specific particle production model because of defining centrality and determining N_{coll} from the same estimator
- Biases can be consequence of
  - Correlations of collision parameters other than N_{part}
  - Correlations induced after collision (eg. jet fragmentation in the example of PHENIX)
- Bias corrections are not necessarily corrections of N_{coll}
  - Physics origin has to be understood

Look at non-trival extensions of the Glauber model

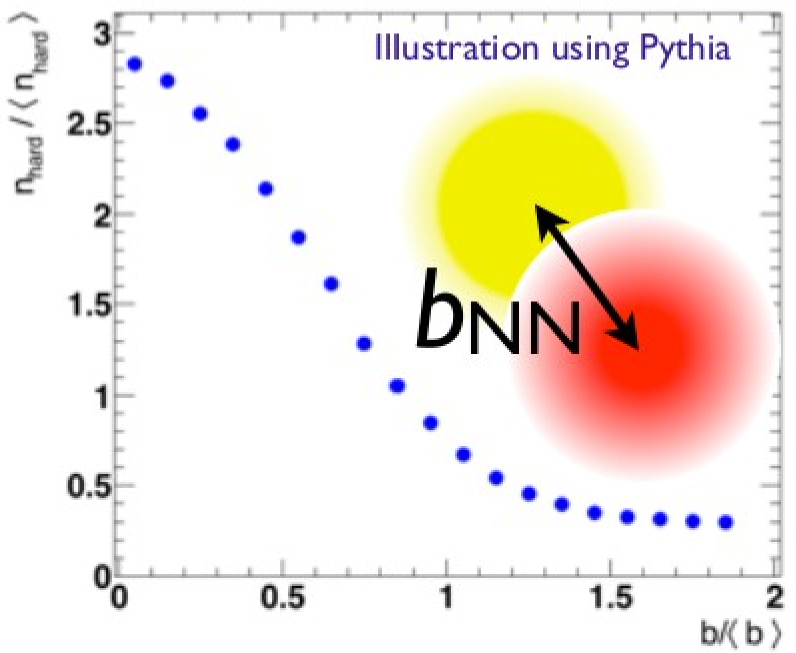
9 Glauber extensions

- Glauber-Gribov color fluctuations
  - Size of proton varies e-by-e
  - Configuration frozen for a single p-A collision
  - Parameter Ω equals width of Gaussian fluctuations
- HIJING Glauber
  - Mean number of hard scatterings (n_{hard}) depends on NN overlap
  - No fluctuations of spatial distribution
    - Only Poisson fluctuations of n_{hard}
- Flickering of the interaction strength
  - Generalized gluon distribution and fluctuations

Alvioli et al., PRC 90 (2014) 034914



ATLAS-CONF-2013-096



10 Glauber extensions

- Glauber-Gribov color fluctuations
  - Changes $\pi(N_{coll})$

- HIJING Glauber
  - Does not change $\pi(N_{coll})$
  - Provides a correlation between hard and soft particle production
  - Long range correlation via b_{NN}
  - Note: Large n_{hard} values suppressed by energy conservation

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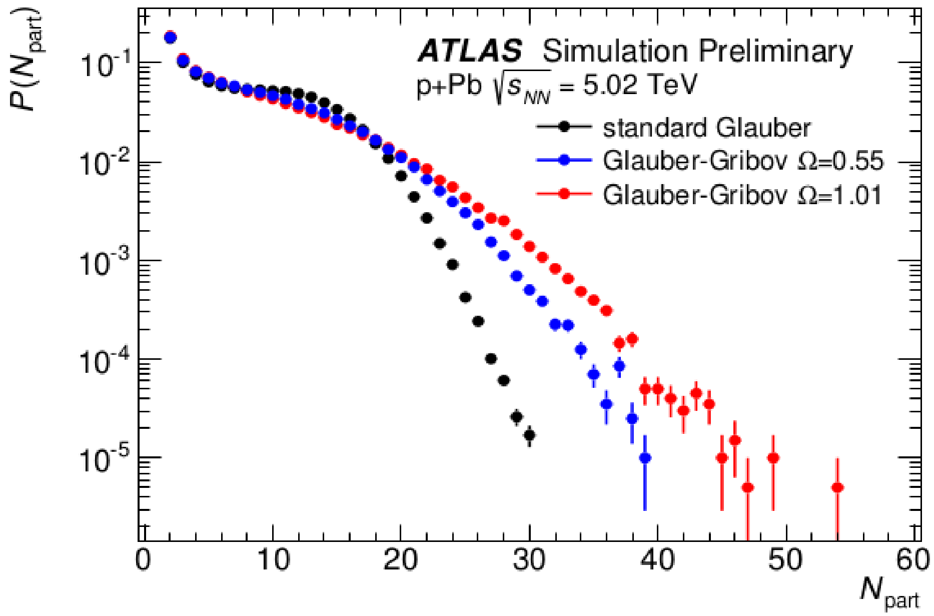
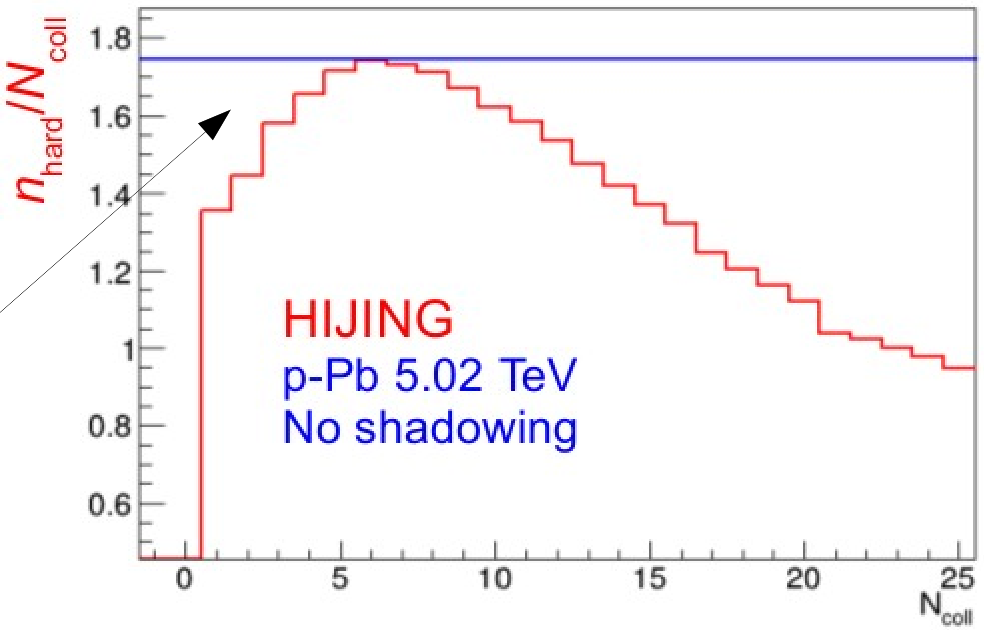
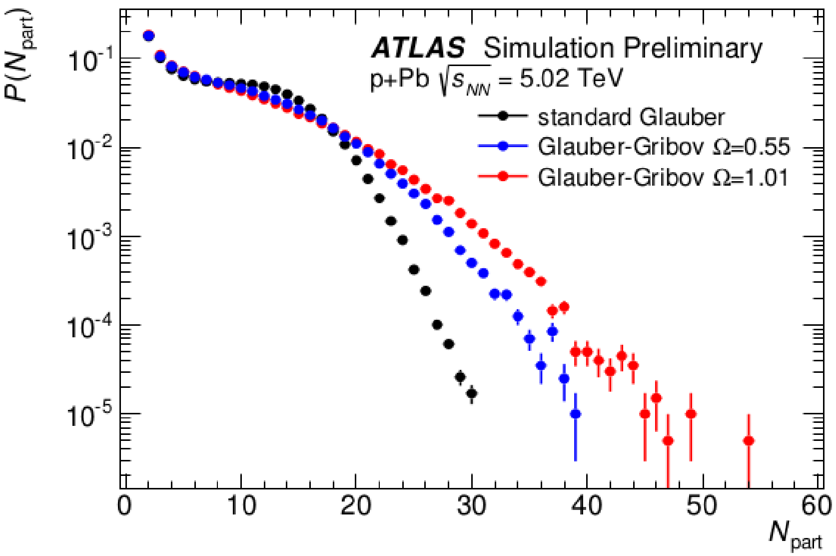


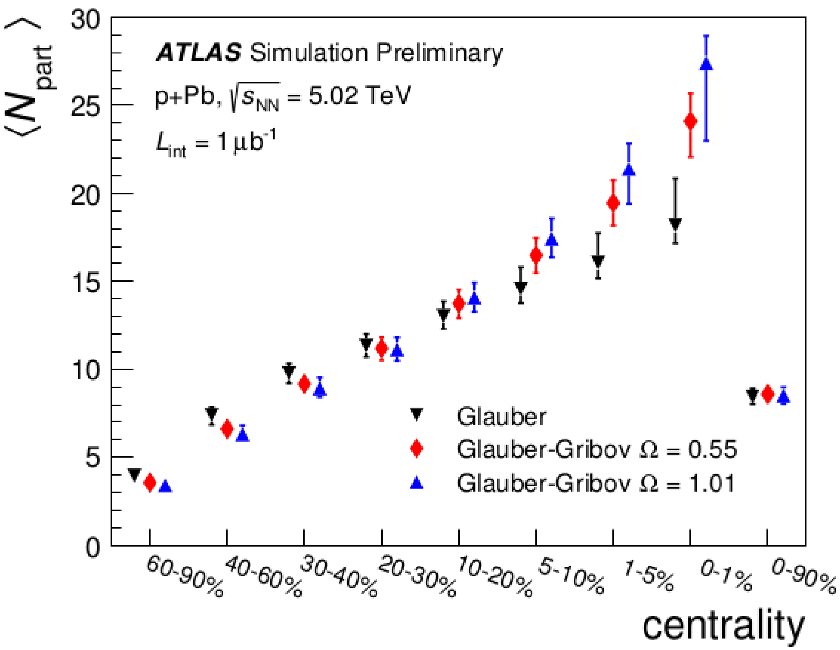


Geometric bias

Jia, PLB 681 (2009) 320

11 Glauber-Gribov





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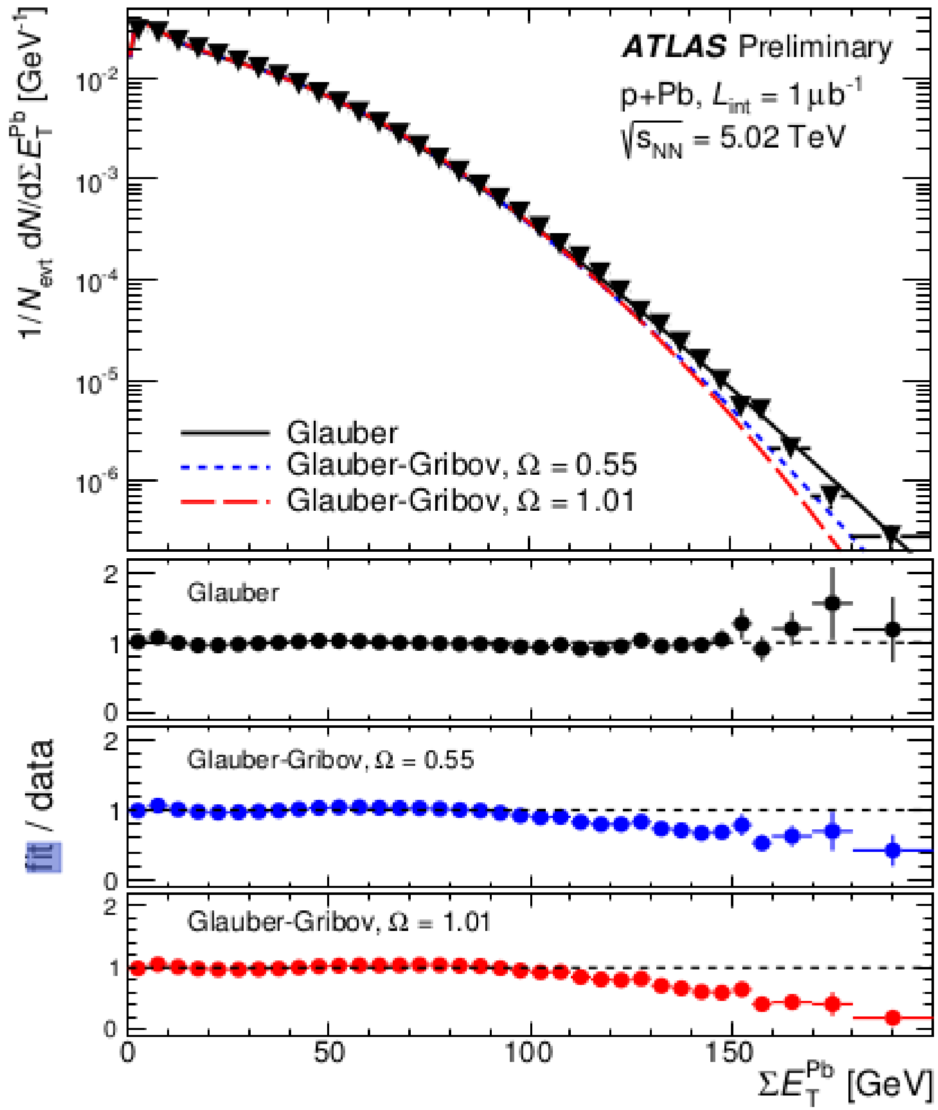
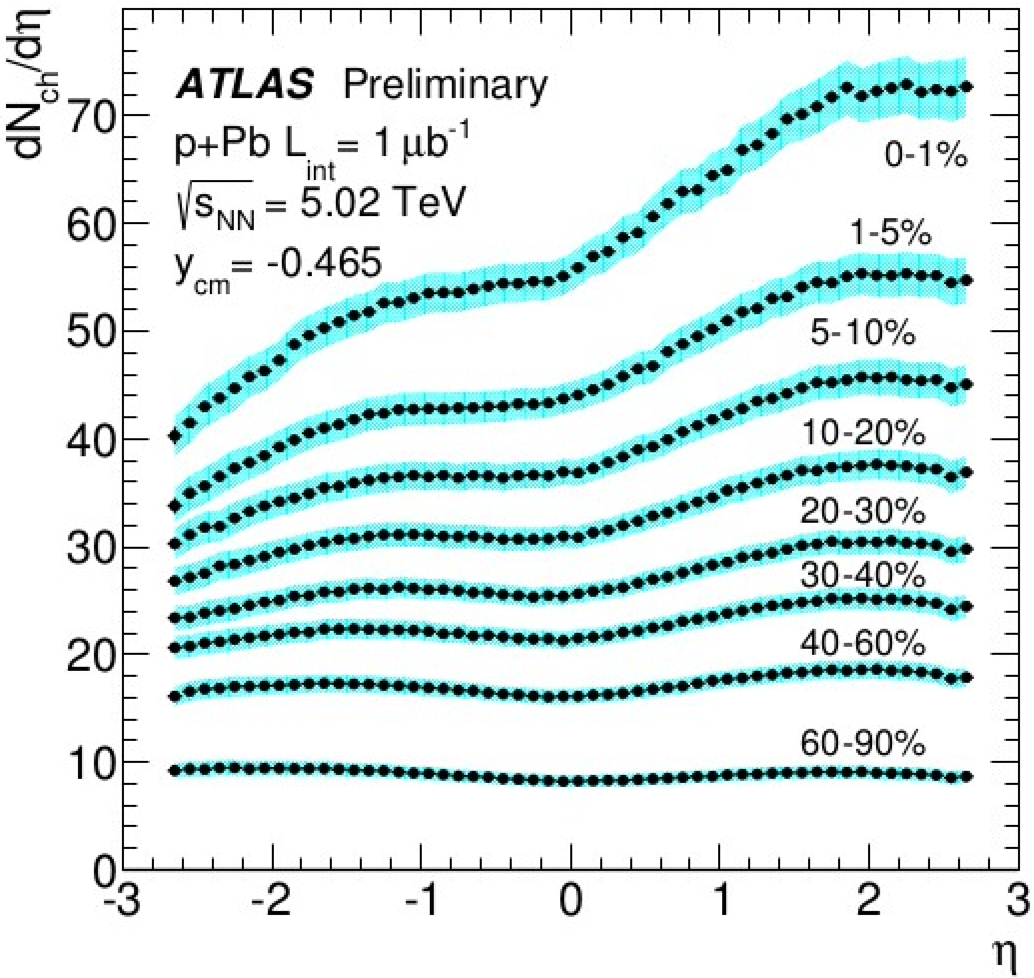


- Glauber-Gribov fits slightly worse
- However, extracted parameters closer to WN expectation

12 Centrality dependent dN/dη



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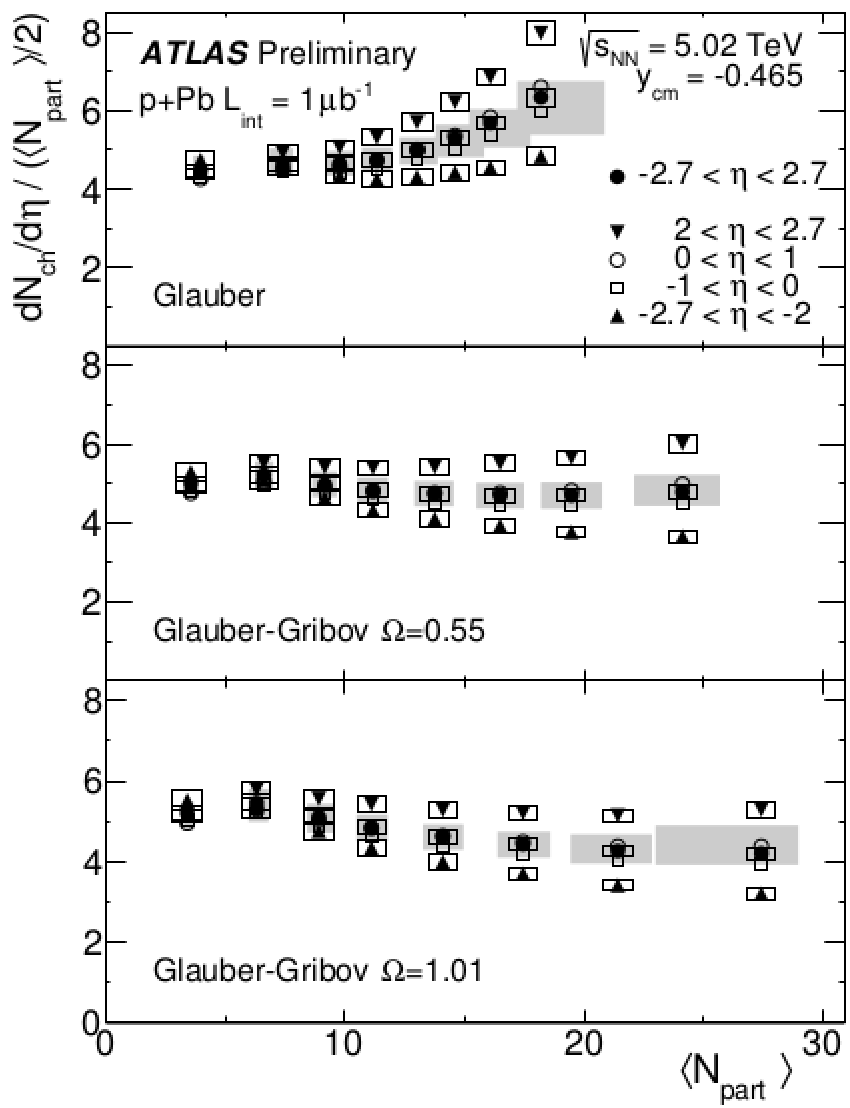
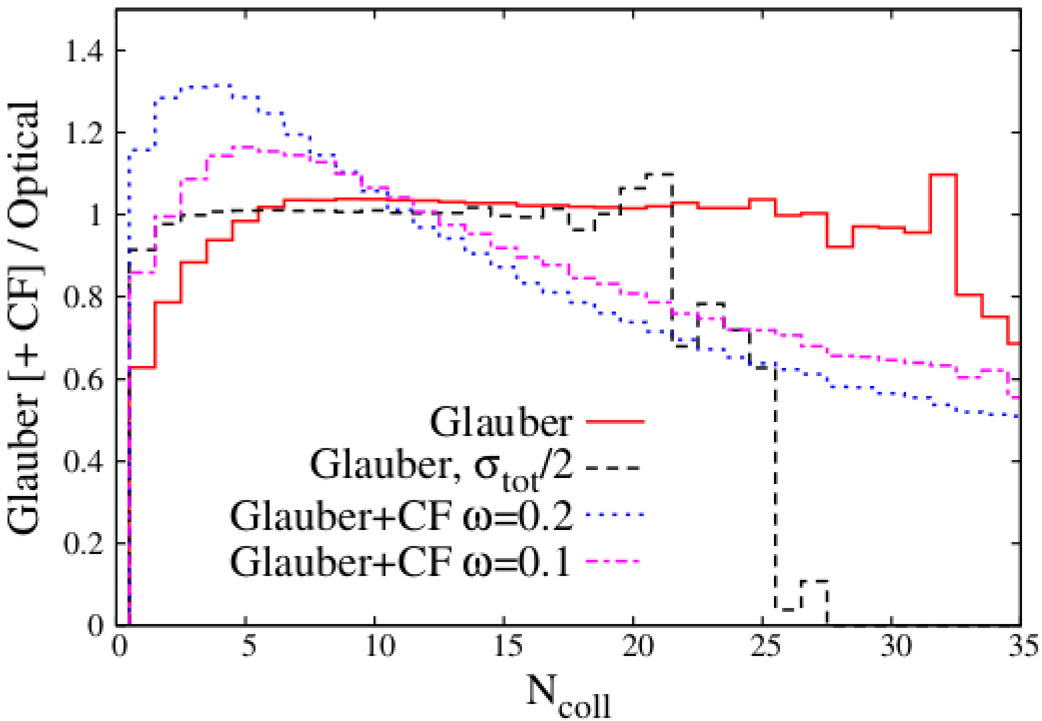
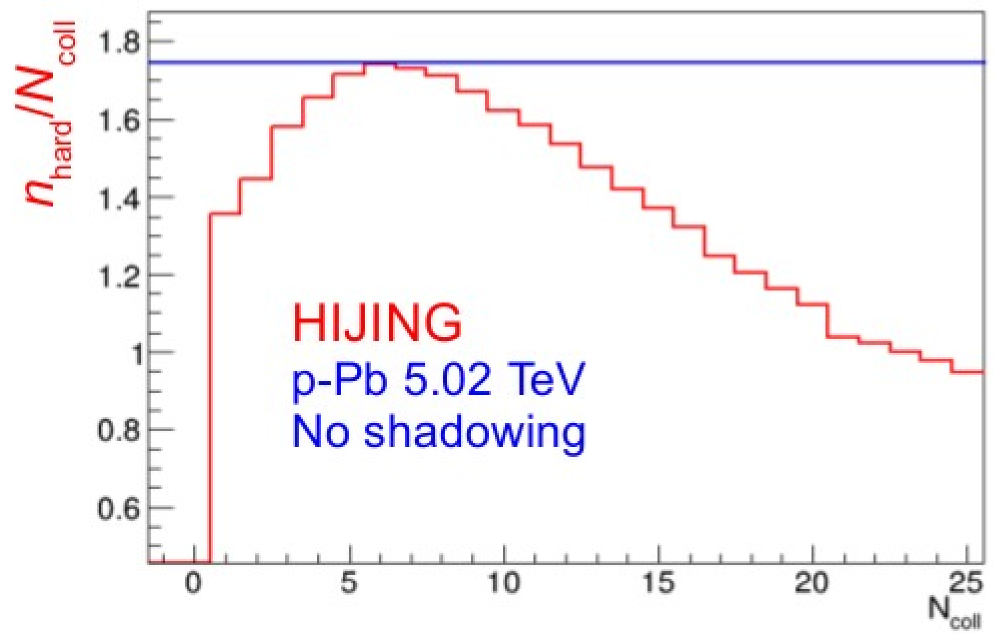


- N_{part} scaling depends on Ω
- Presence of bias open question

13 Centrality dependent measurements



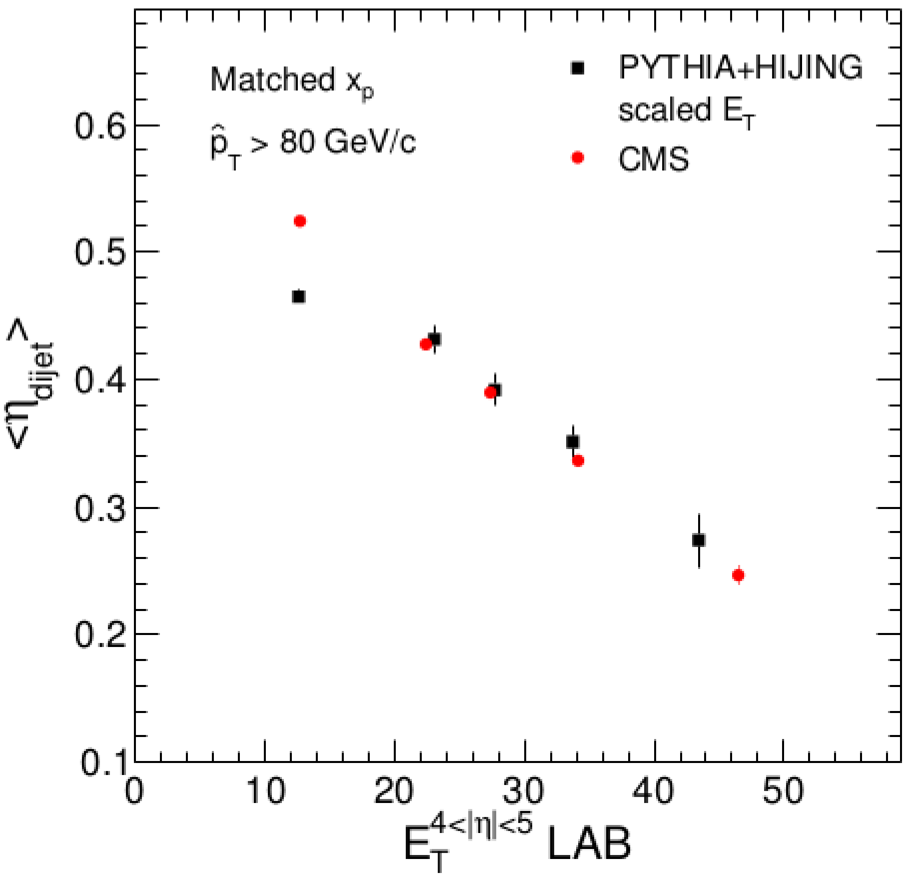
Alvioli et al., PRC 90 (2014) 034914

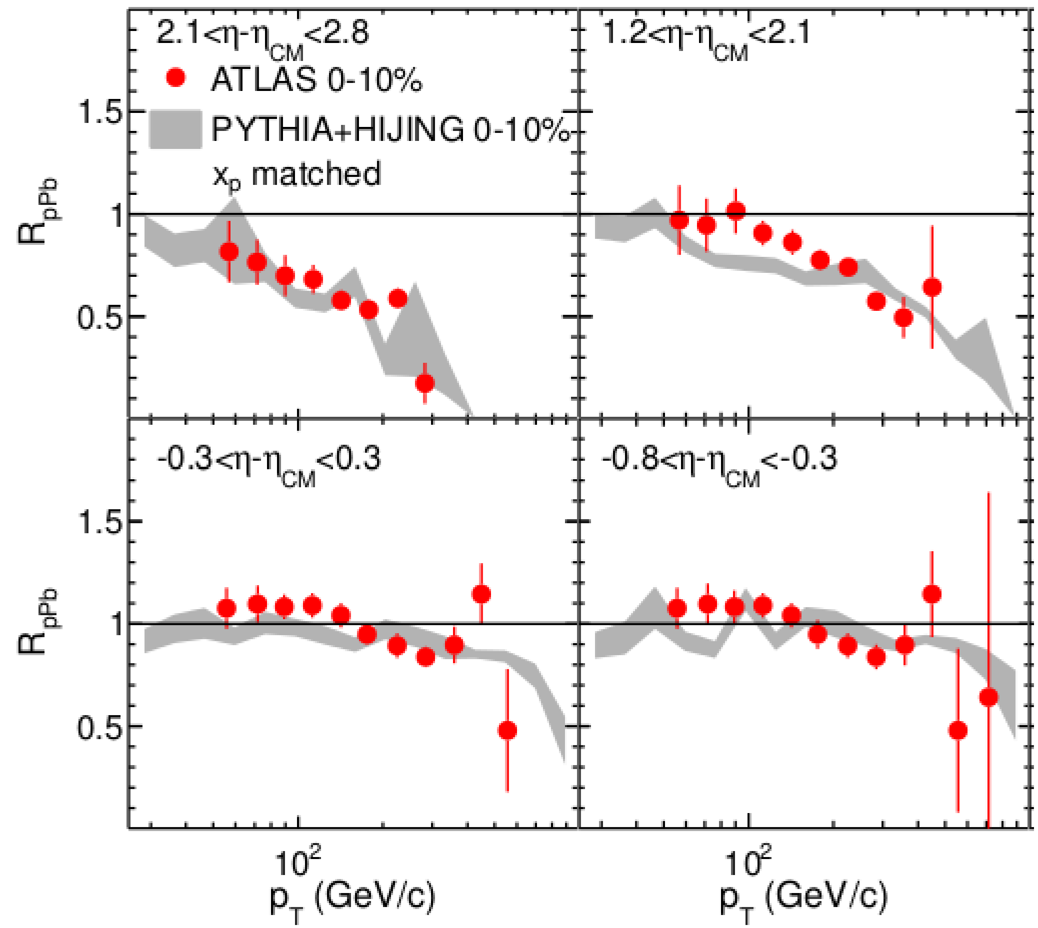


- Rich phenomenology if one trusts the measurement of N_{coll}
- However, systematics of centrality determination itself has to be discussed first in the context of particle production models

14 Kinematic bias on centrality from jets

Armesto et al., arXiv:1502.02986





Taking into account energy-momentum conservation in the proton in a toy simulation of pp (hard) PYTHIA plus pPb (UE) HIJING events describes main features of data

15 Multiple parton interactions (MPI)

- Naive factorization

$$\langle n_{2\to2}\rangle = \frac{\sigma_{2\to2}}{\sigma_{\rm tot}}$$

>1 at pert. scale

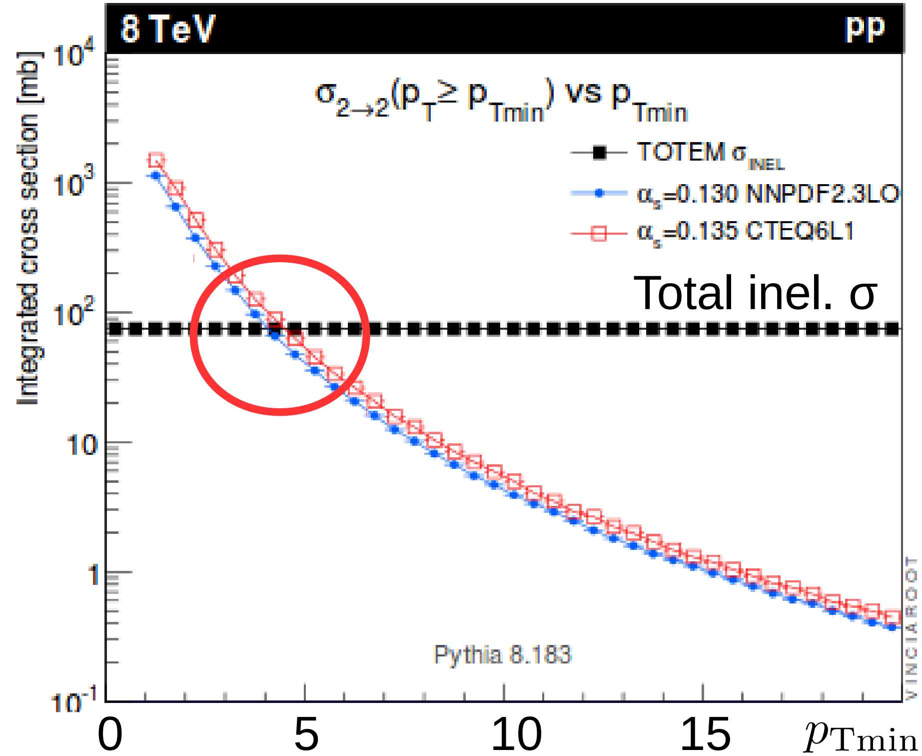
$$P_n = \frac{\langle n_{2\to2}\rangle^n}{n!}\, exp\left(-\langle n_{2\to2}\rangle\right)$$

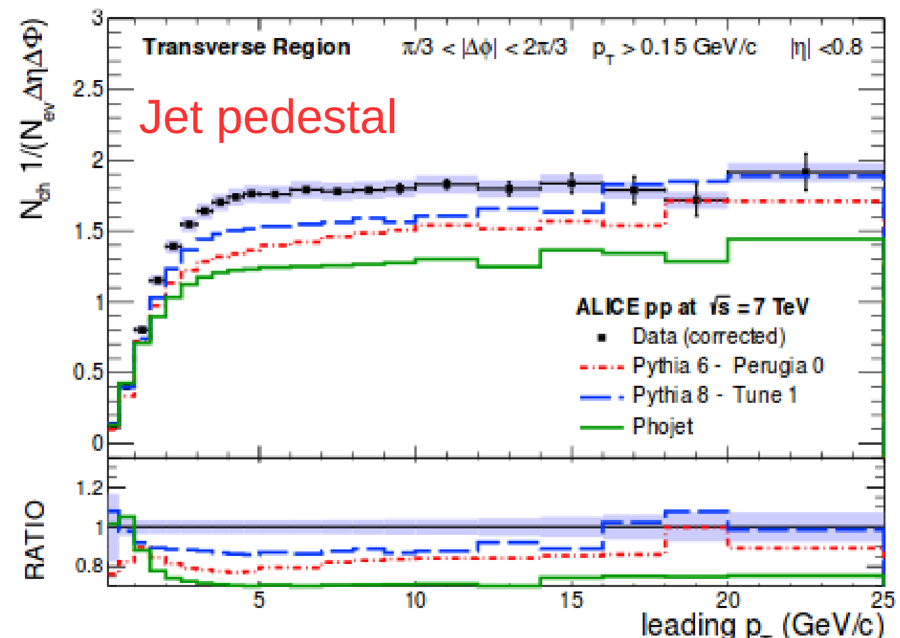
- In reality
  - Color screening to regularize hard cross section at low p_T
  - Cut-off at high n because of energy conservation
  - Coherence between scatters
  - Impact parameter dependence

$$n_{\rm hard}(b) = \sigma_{\rm hard} T_{\rm p}(b)$$

    - Leads to a correlation between hard and soft as in AA

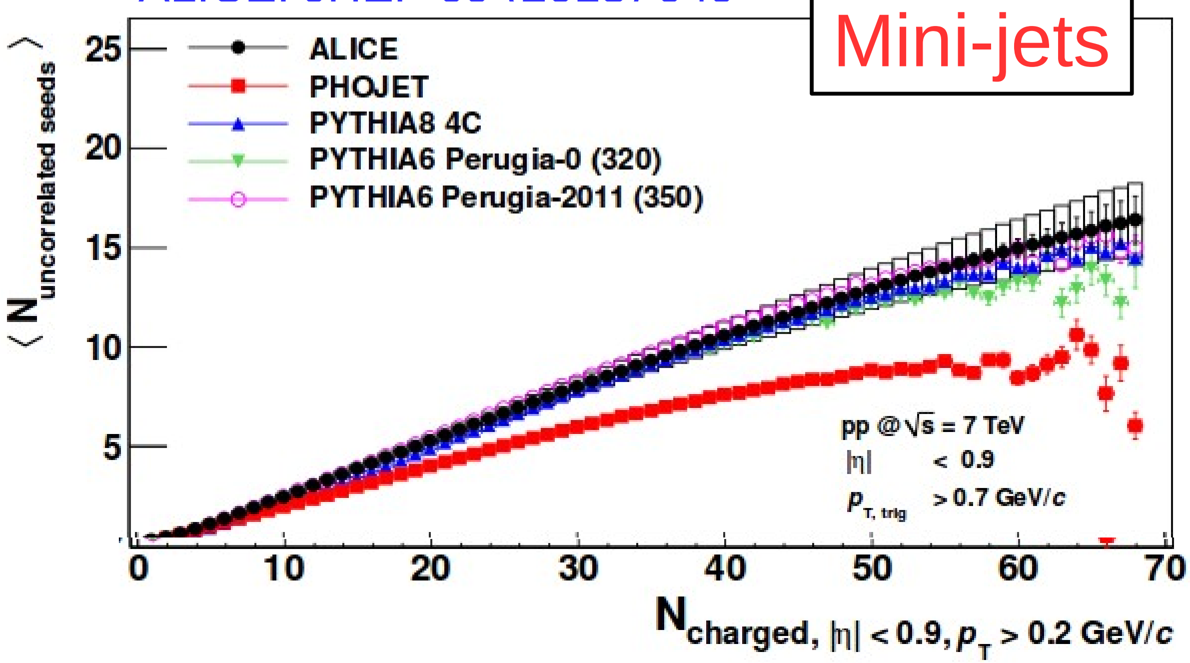
Skands, arXiv:1207.2389



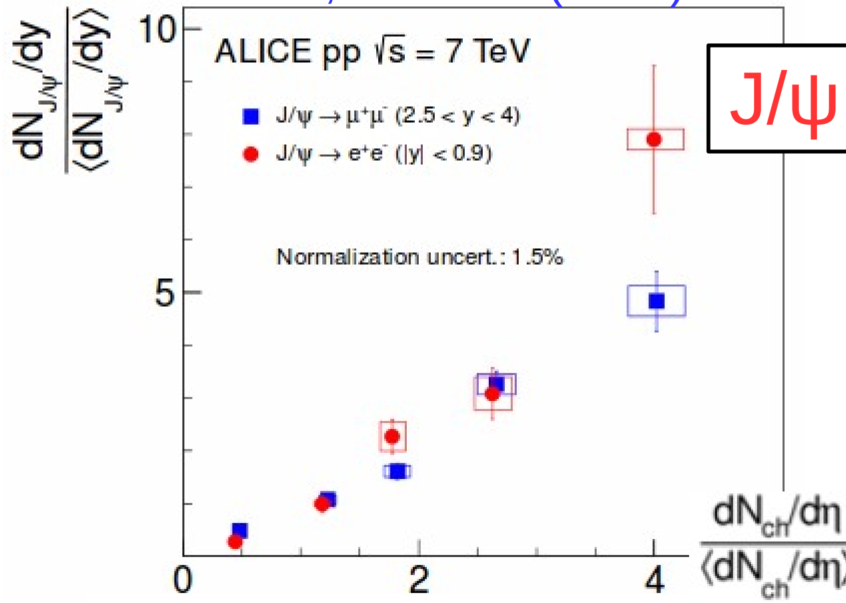


16 Scaling of hard probes with multiplicity

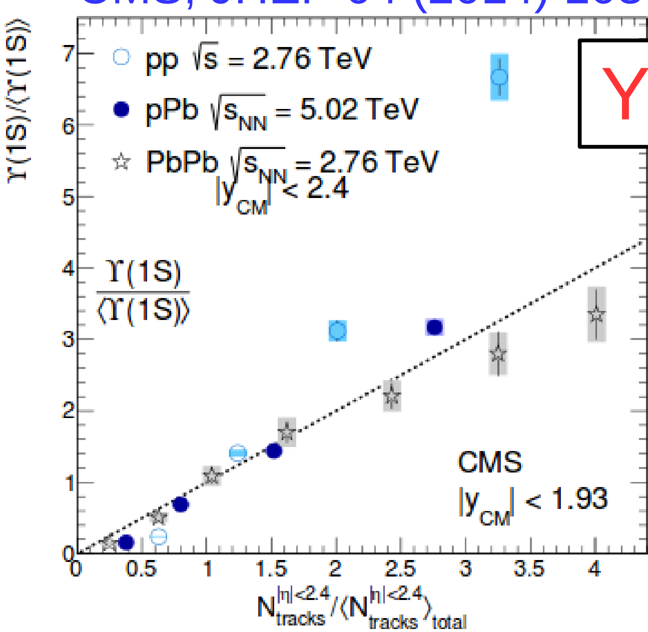
ALICE. JHEP 09 (2013) 049

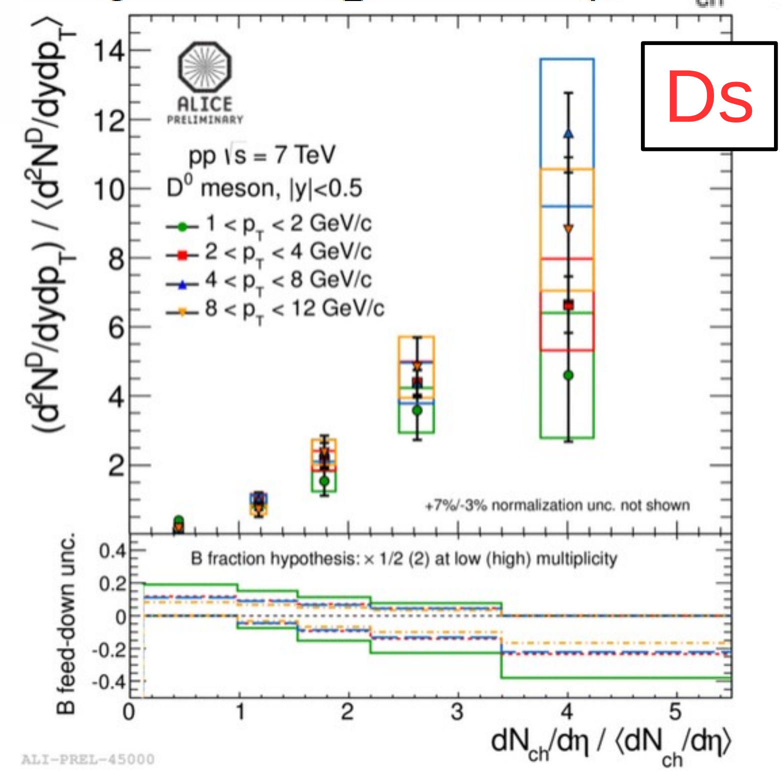


ALICE, PLB 712 (2012) 165



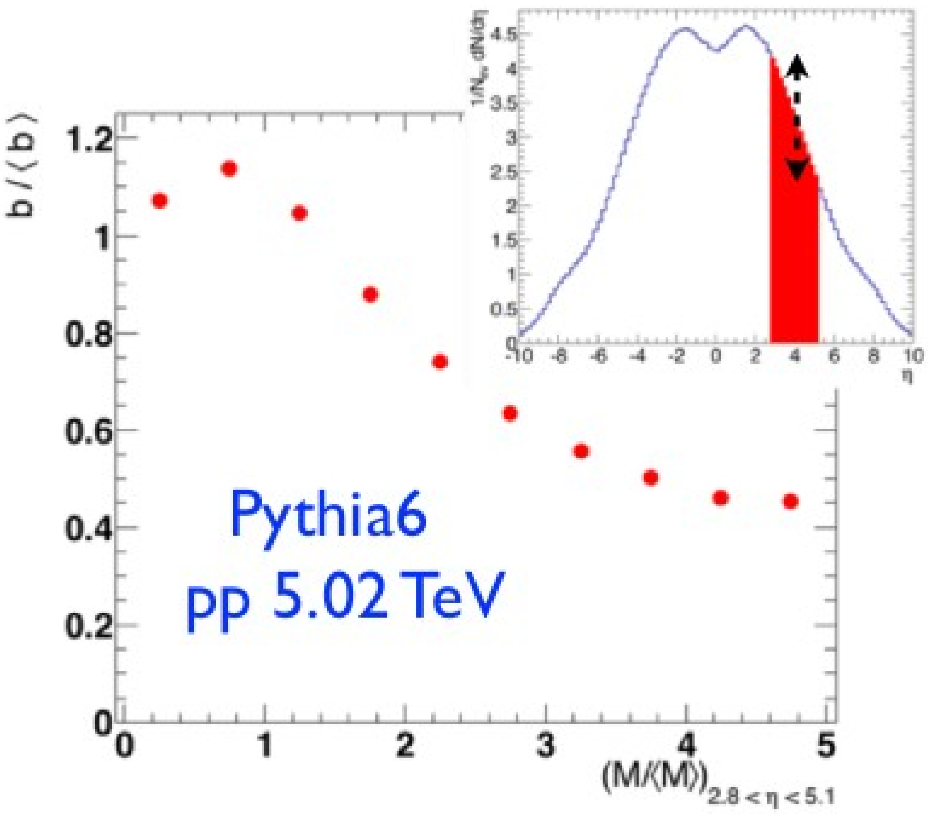
CMS, JHEP 04 (2014) 103

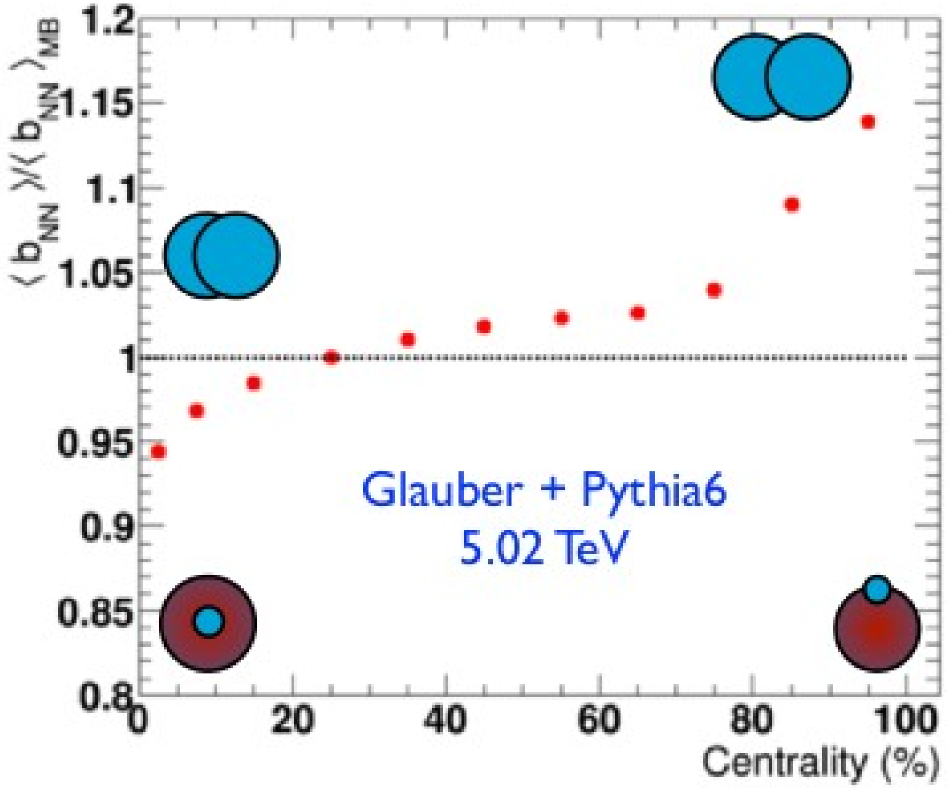




17 Nucleon-nucleon impact parameter studies

Morsch, IS2014



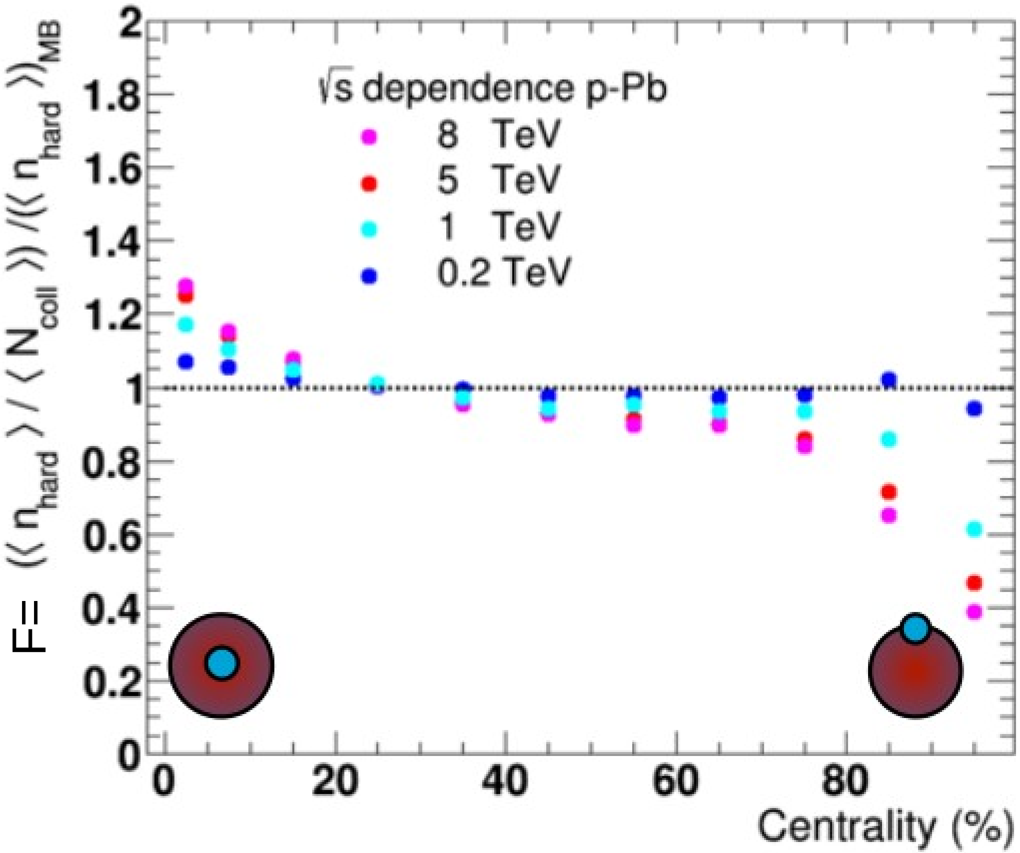


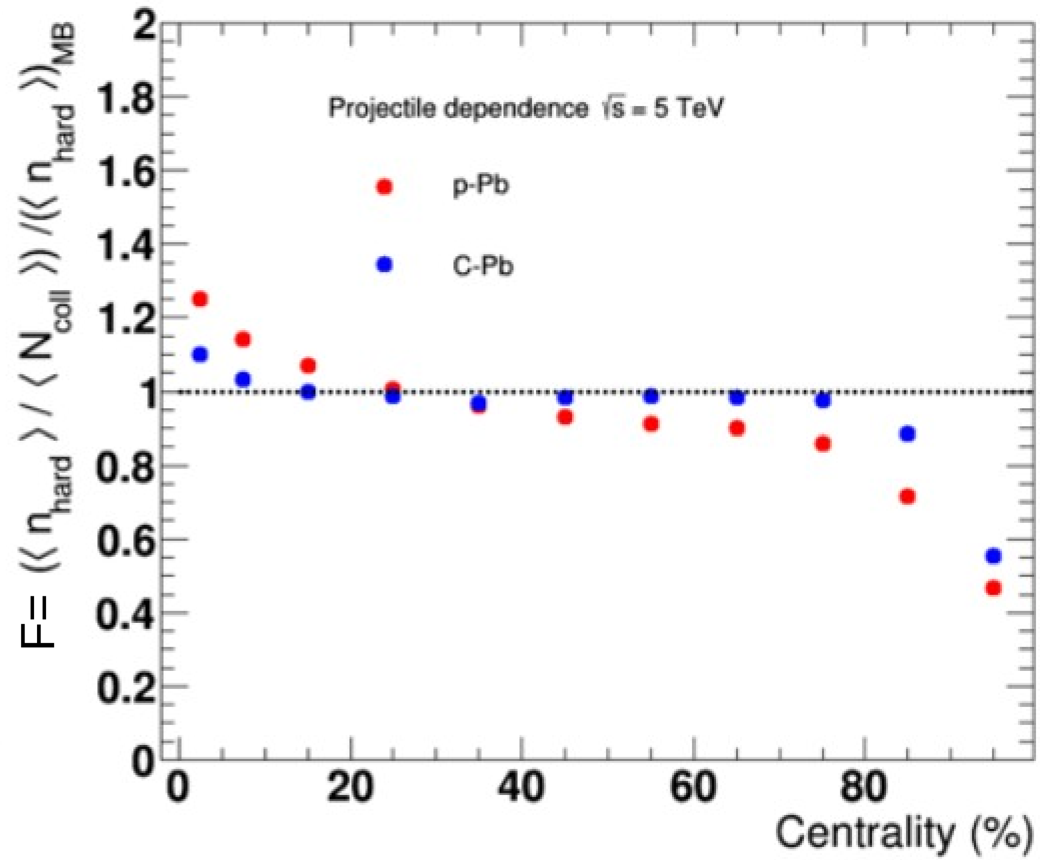
(obtained from slicing superposition of N_{coll} pp collisions in 2.8<η<5.1)

Leads to long range (η) correlations.
How much of this effect survives in pPb?

18 Energy and species dependence

Morsch, IS2014

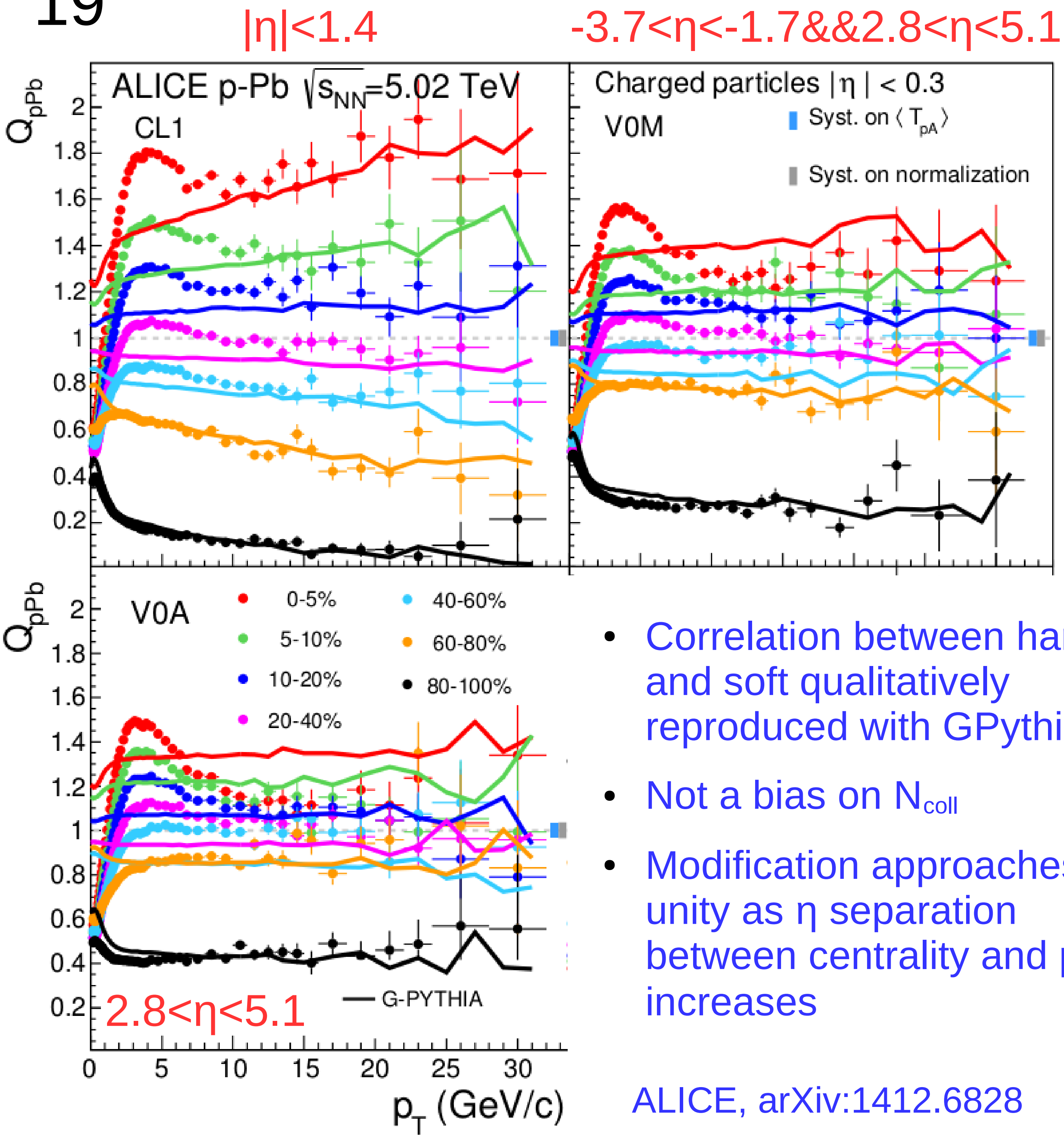




Bias on n_{hard} O(30%) at the LHC, and only O(5%) at RHIC

And decreases with projectile size

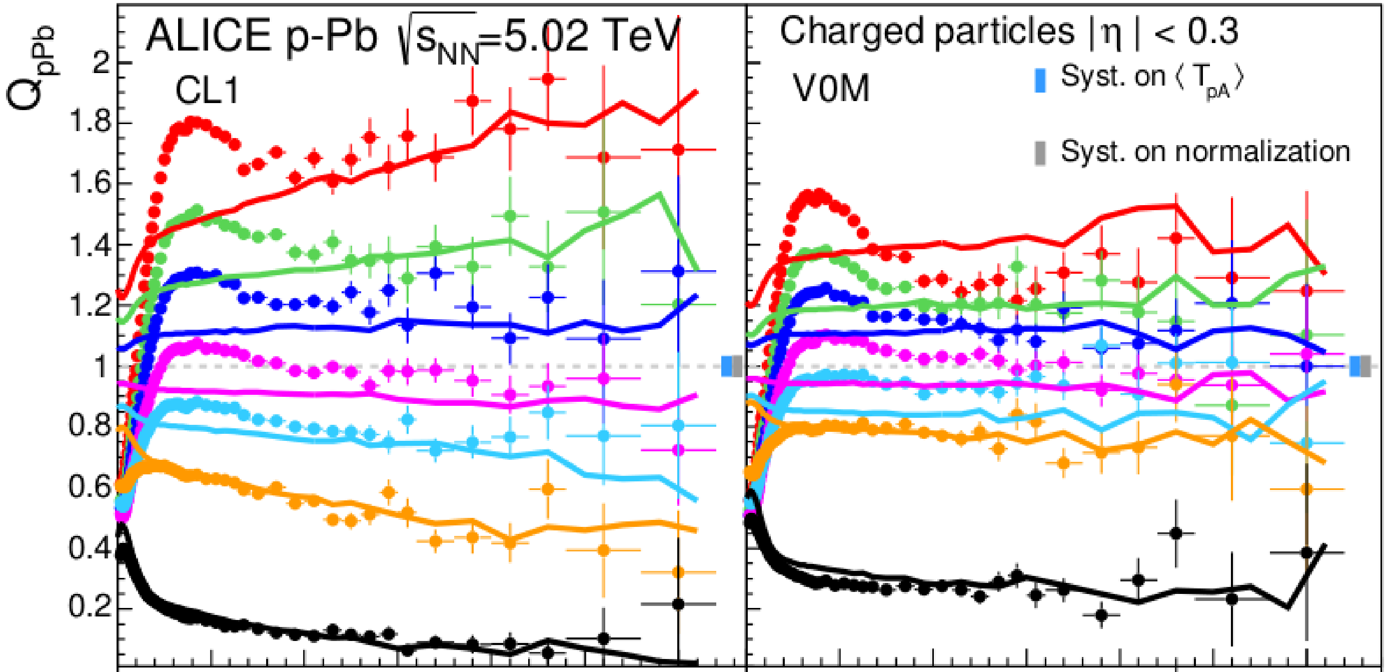
Deviation from binary scaling: $$\left.\frac{dN}{p_T}\right|_{pA} = N_{coll}\, F \left.\frac{dN}{p_T}\right|_{pp}$$

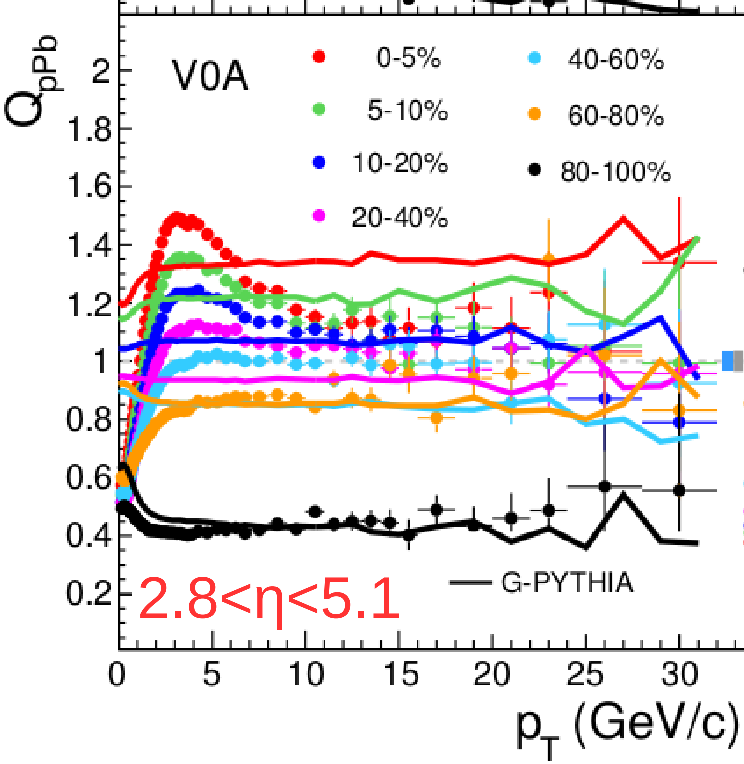


- Correlation between hard and soft qualitatively reproduced with GPythia
- Not a bias on N_{coll}
- Modification approaches unity as η separation between centrality and p_T increases

ALICE, arXiv:1412.6828

|η|<1.4 -3.7<η<-1.7&&2.8<η<5.1





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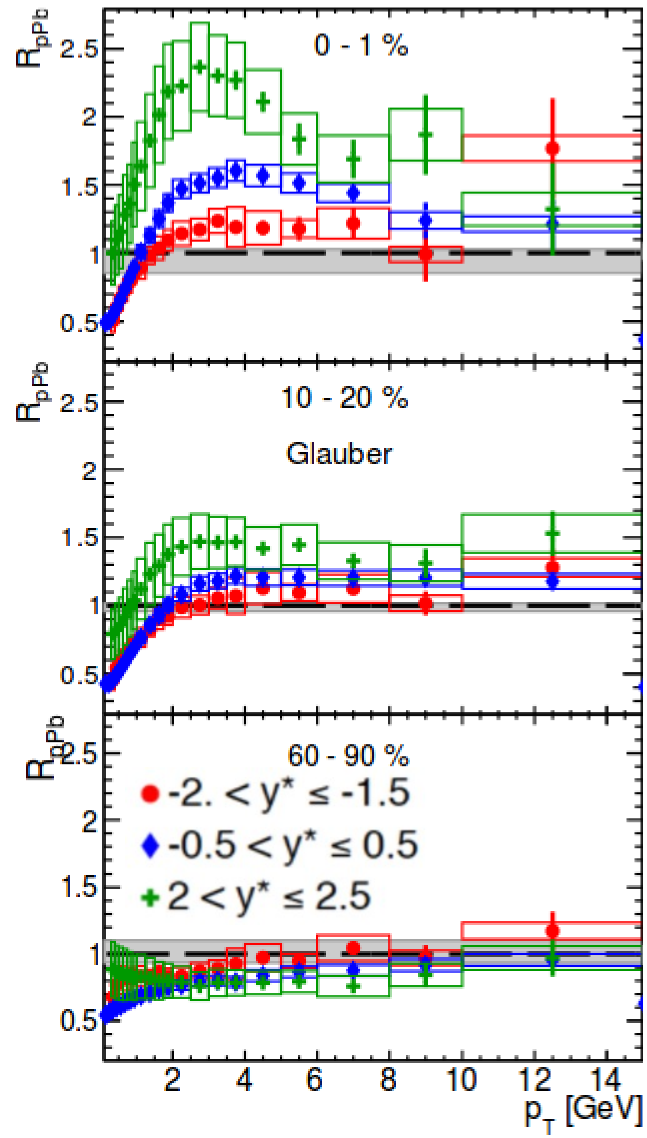
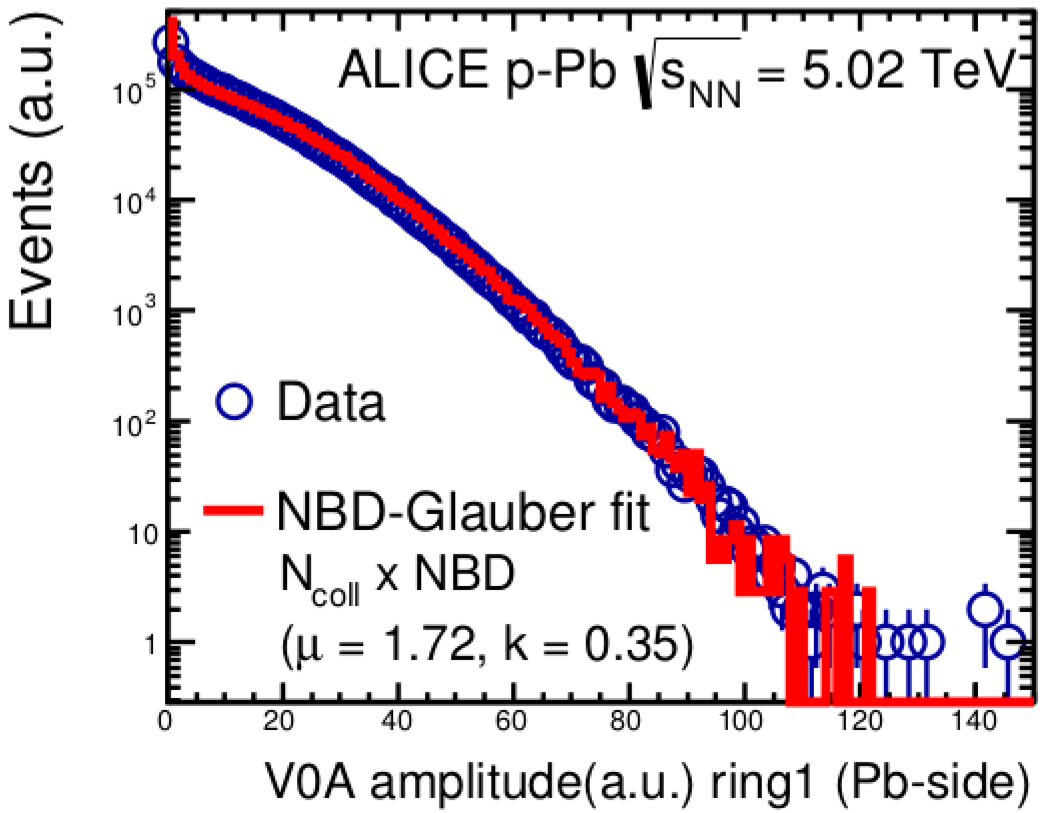


- Correlation between harc and soft qualitatively reproduced with GPythia
- Not a bias on N_{coll}
- Modification approaches unity as η separation between centrality and p- increases

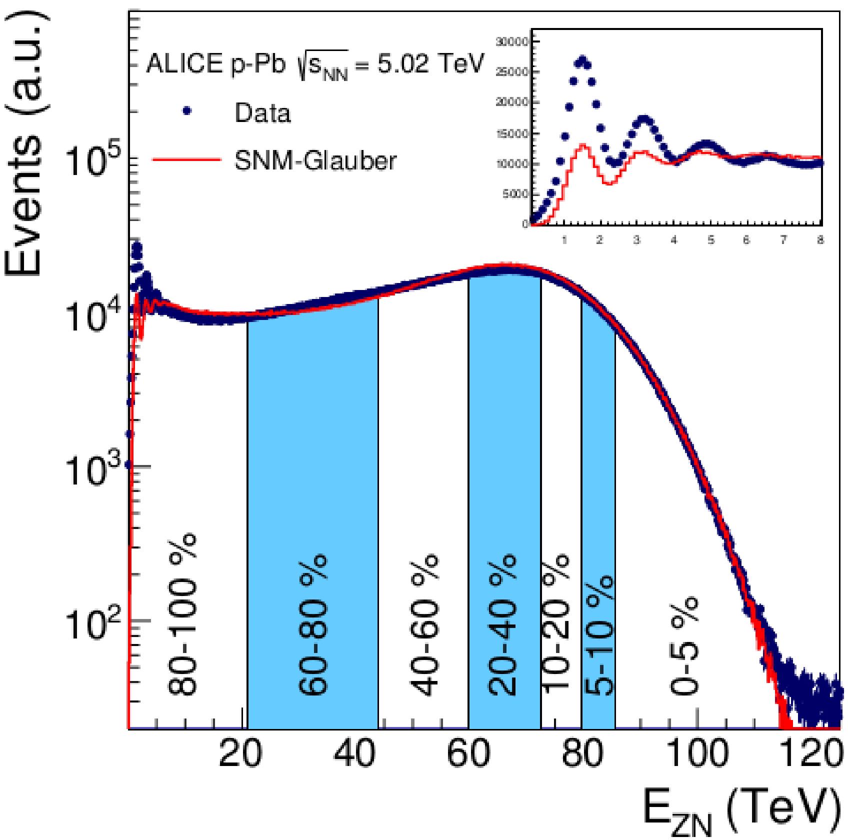
ALICE, arXiv:1412.6828

21 Forward neutron energy vs multiplicity

NBD method

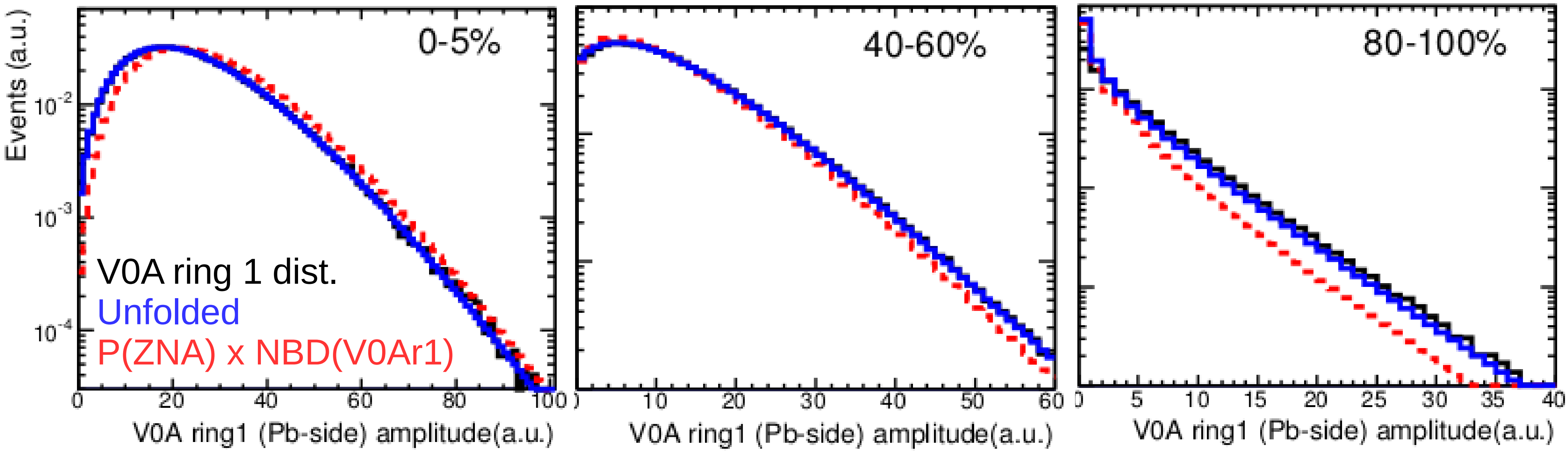


SNM method

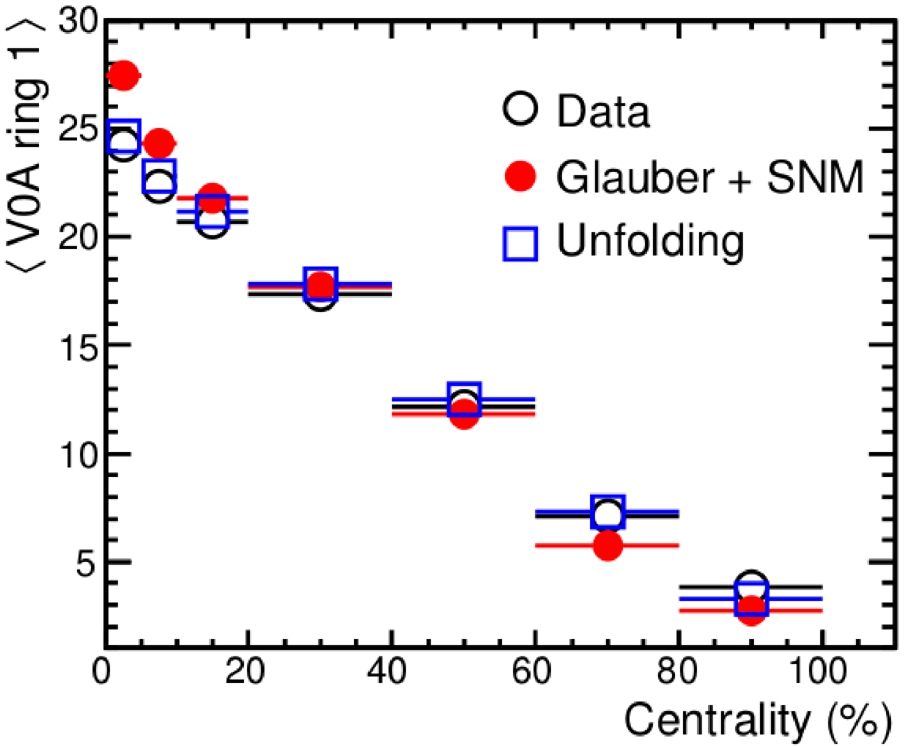


Correlation between forward neutron energy and multiplicity?

22 Correlation between ZNA and V0A



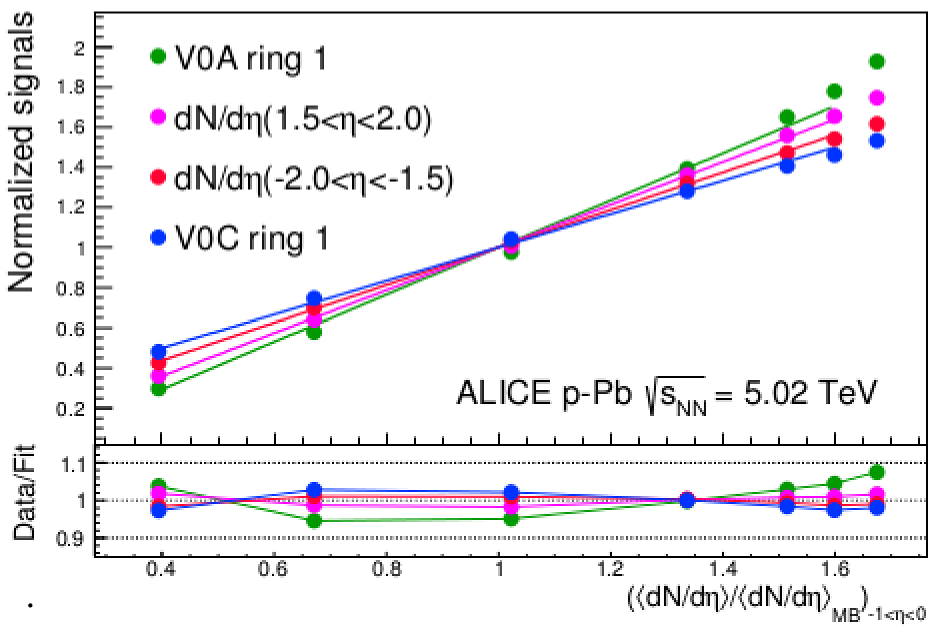
- For each ZNA centrality class
  - Plot the V0A ring1 distribution
  - Find input $\pi(N_{coll})$ distribution via Unfolding
    - Does not work for a biased estimator
  - Convolute the distribution of the SNM model with the NBD from the V0A glauber fit



ALICE, arXiv:1412.6828

23 Scaling of particle production

- $\langle S\rangle_i / \langle S\rangle_{MB}$ vs $\langle dN/d\eta\rangle_i/\langle dN/d\eta\rangle_{MB}(-1<\eta<0)$ sliced in ZN activity

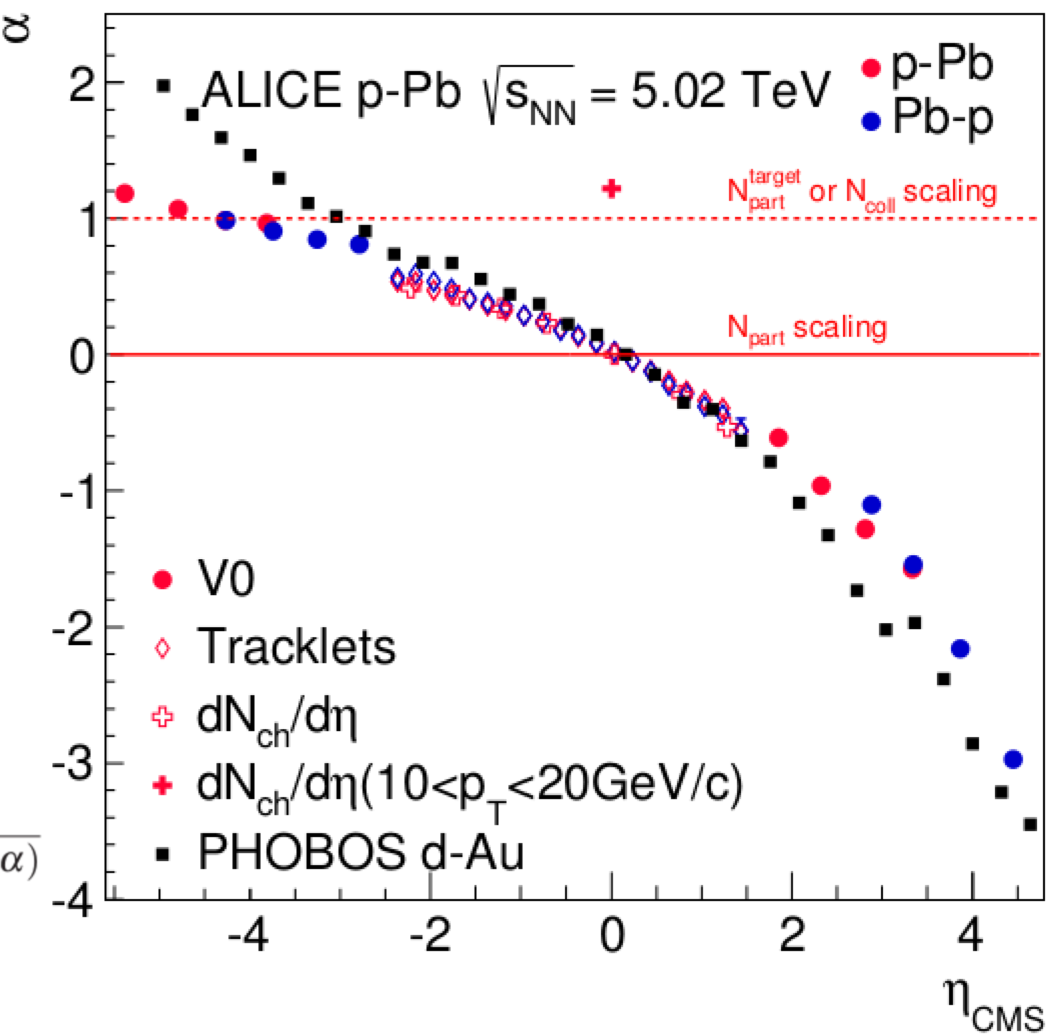


- Assume dN/dη scales with N_{part}

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

α = 0 – perfect N_{part} scaling

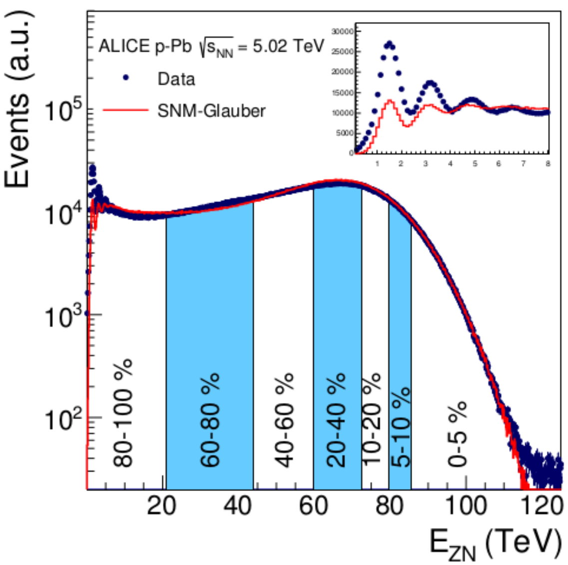
α = 1 – perfect N_{coll} (or N_{part}^{target}) scaling



Correlation between causally disconnected observables (slow neutrons vs multiplicity)
→ **connection to geometry**

ALICE, arXiv:1412.6828

24 Centrality from Hybrid method



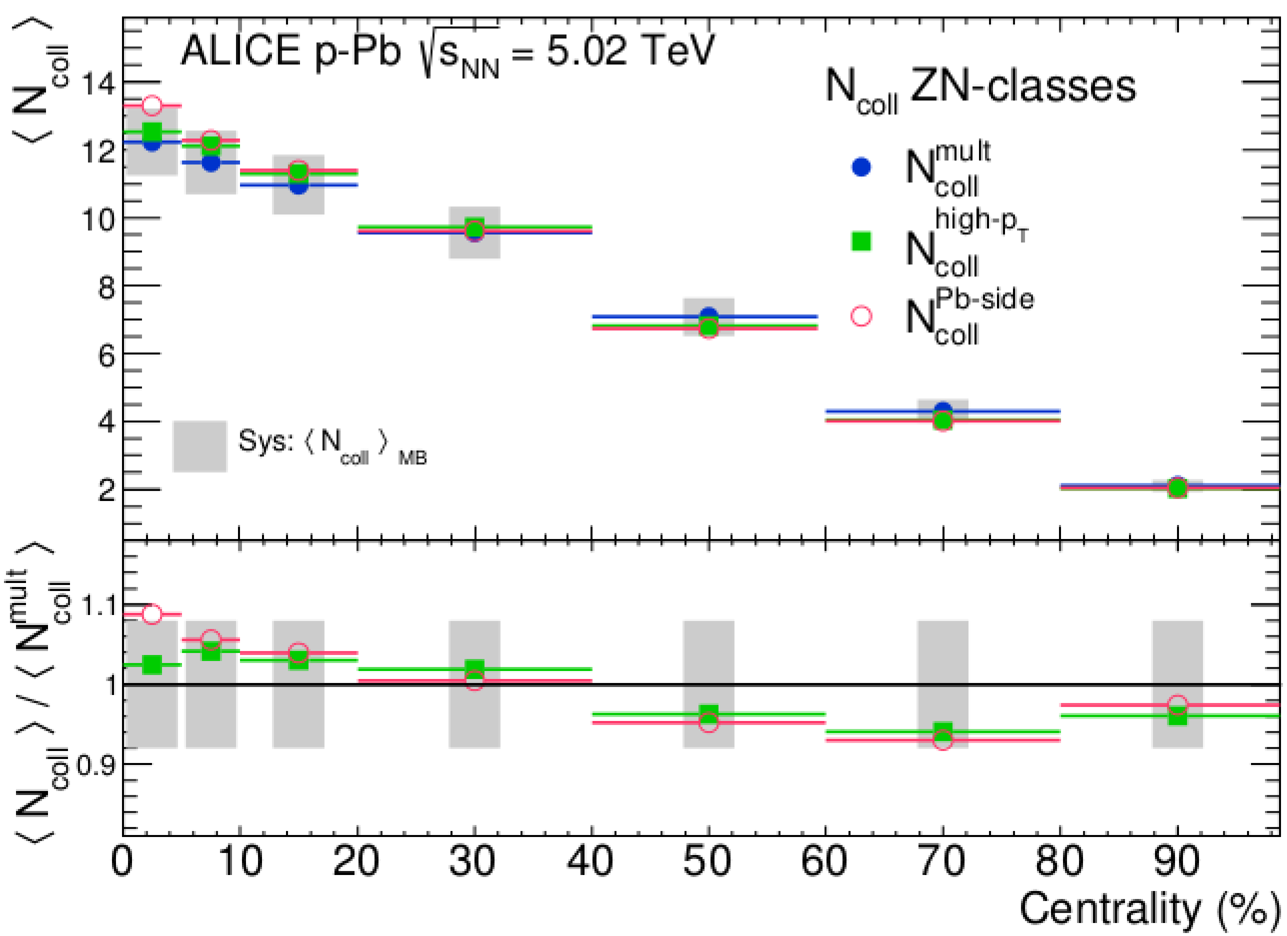
$$\langle N_{\mathrm{coll}}\rangle_i^{\mathrm{mult}} = \langle N_{\mathrm{part}}\rangle_{\mathrm{MB}} \left.\frac{\langle dN/d\eta\rangle_i}{\langle dN/d\eta\rangle_{\mathrm{MB}}}\right|_{-1<\eta<0} - 1$$

$$\langle N_{\mathrm{coll}}\rangle_i^{\mathrm{high}\,p_{\mathrm{T}}} = \langle N_{\mathrm{coll}}\rangle_{\mathrm{MB}} \frac{\langle Y_{10<p_{\mathrm{T}}<20}\rangle_i}{\langle Y_{10<p_{\mathrm{T}}<20}\rangle_{\mathrm{MB}}}$$

$$\langle N_{\mathrm{coll}}\rangle_i^{\mathrm{Pb\,side}} = \langle N_{\mathrm{coll}}\rangle_{\mathrm{MB}} \frac{\langle S_{\mathrm{V0Ar1}}\rangle_i}{\langle S_{\mathrm{V0Ar1}}\rangle_{\mathrm{MB}}}$$

1) Assume ZN is bias free + define centrality classes
2) Construct similar model as for the Glauber fits

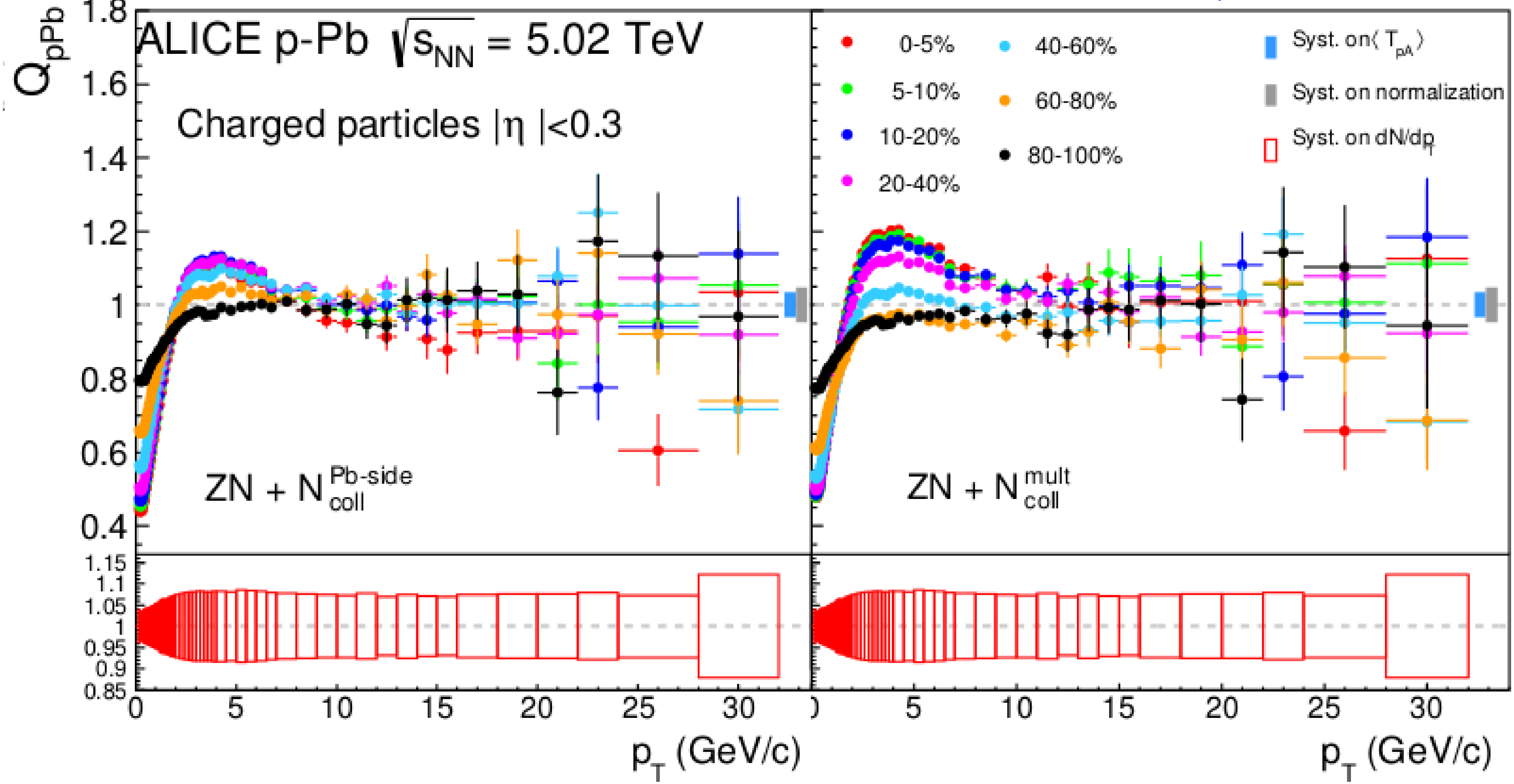
Resulting values within at most 10%



ALICE, arXiv:1412.6828

25 QpPb factors with hybrid method

ALICE, arXiv:1412.6828

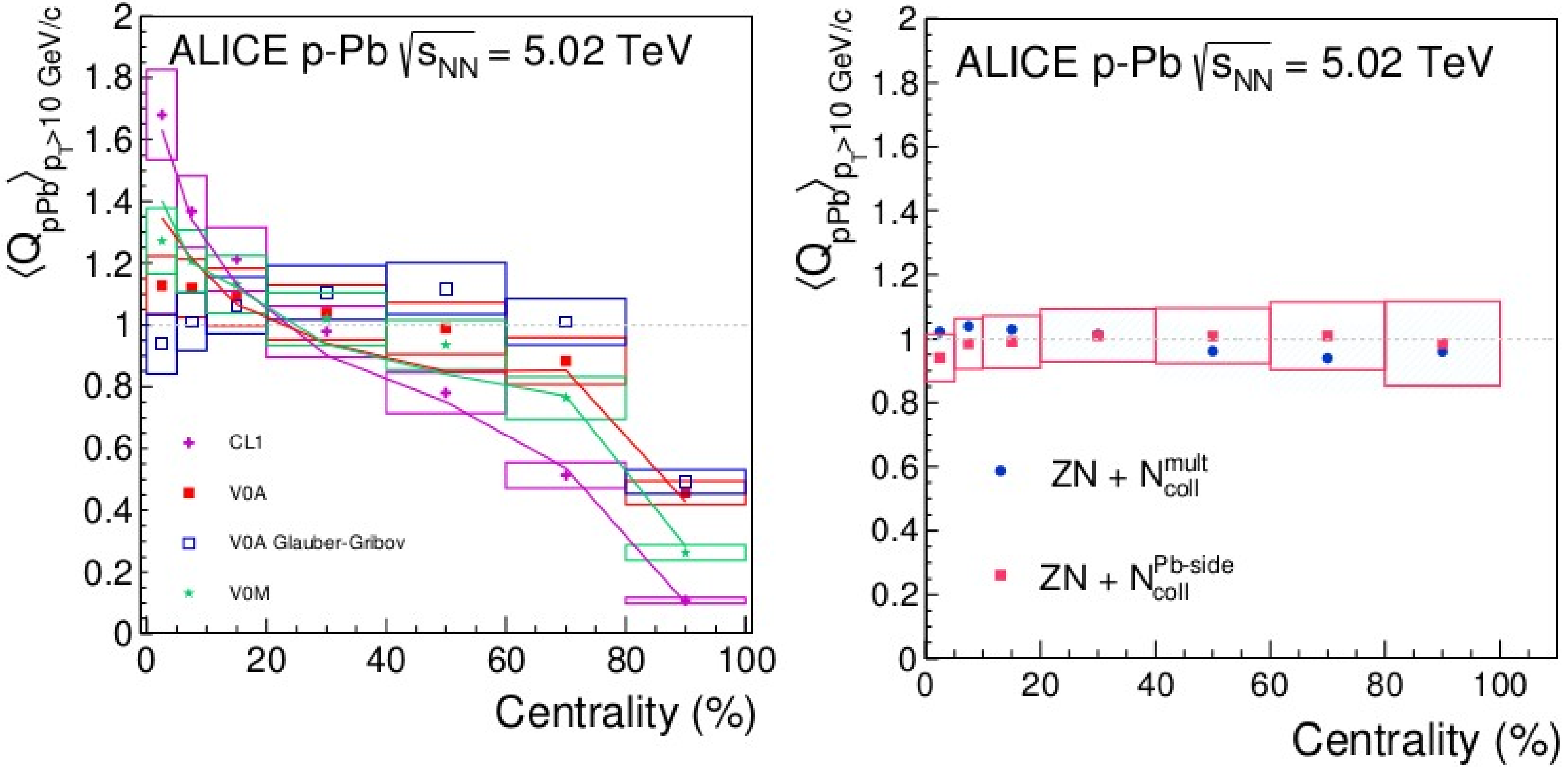


Hybrid method

- Charged particle Q_{pPb} consistent with unity at high p_T
- Cronin peak develops with multiplicity

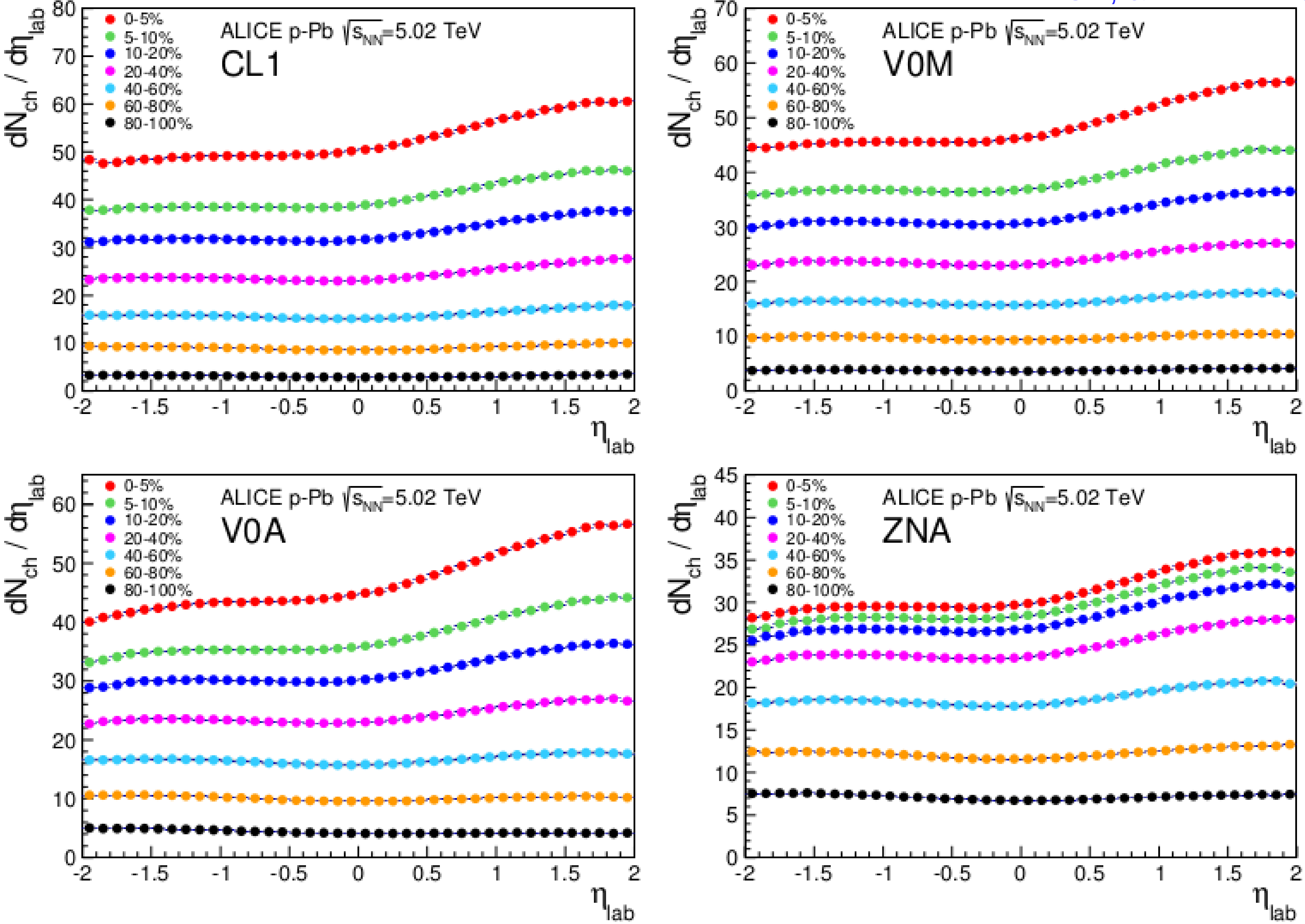
26 Average QpPb

ALICE, arXiv:1412.6828

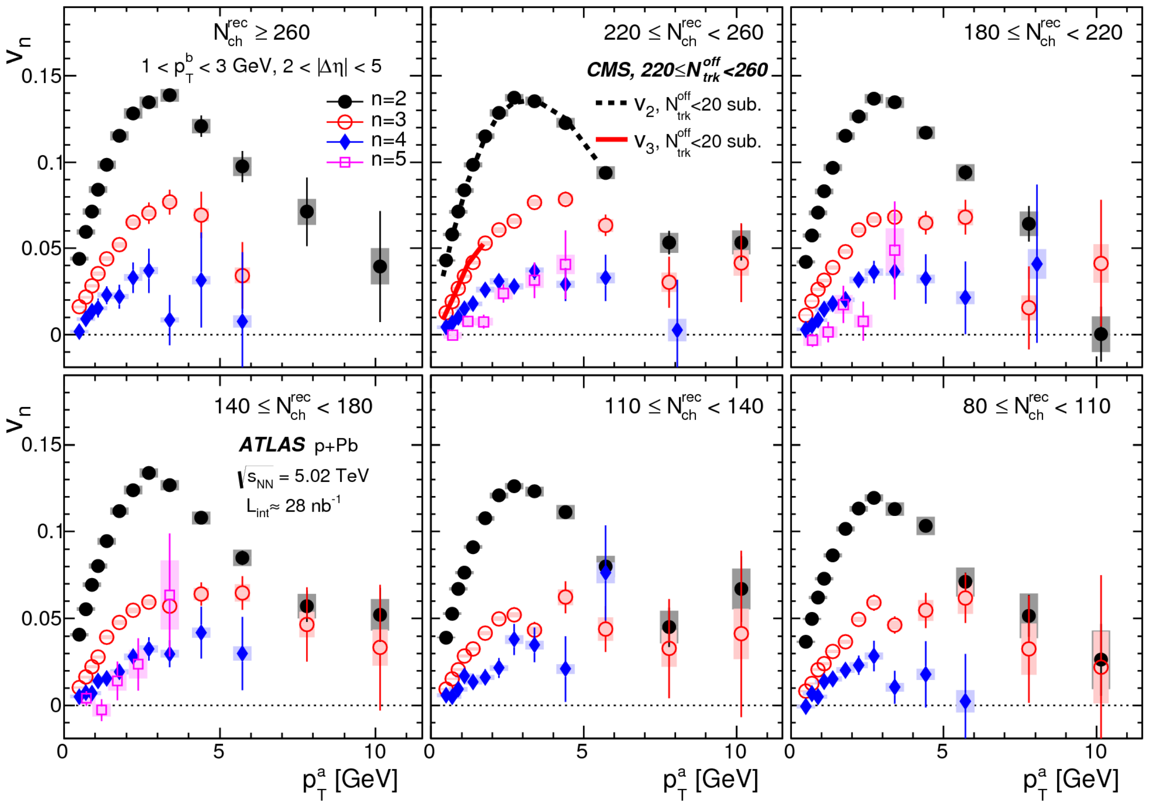


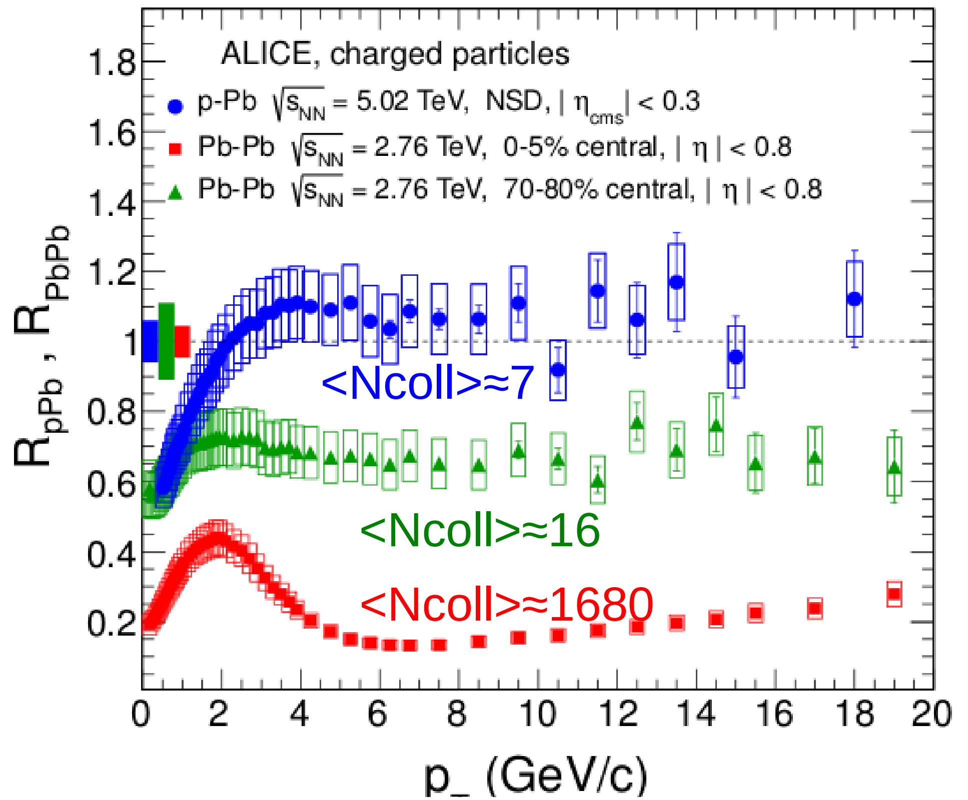
27 dN/dη measurements

ALICE, arXiv:1412.6828

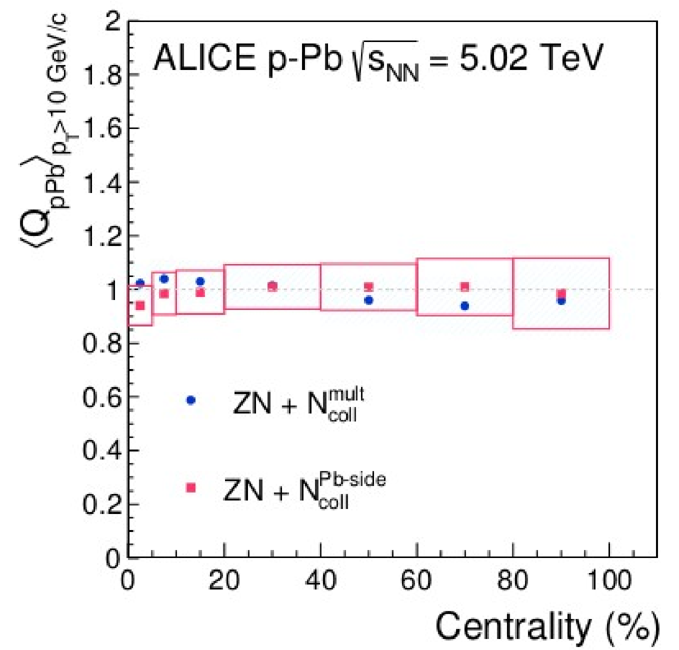


Wrt discussion of this morning





0-5% ZNA selection corresponds to roughly 2xminbias multiplicity, say roughly 100 tracks for ATLAS or CMS
QpPb close to 1 (but of course with uncertainty), but v2 non-zero!
Result in PbPb at Ncoll~16?



29 Conclusions

- Question of “bias vs no-bias” in general has no definite answer
- Systematics of centrality measurement and interpretation of data must be done in the same framework
- Using the hybrid approach avoids the bias (but at expense of limited dynamical range)

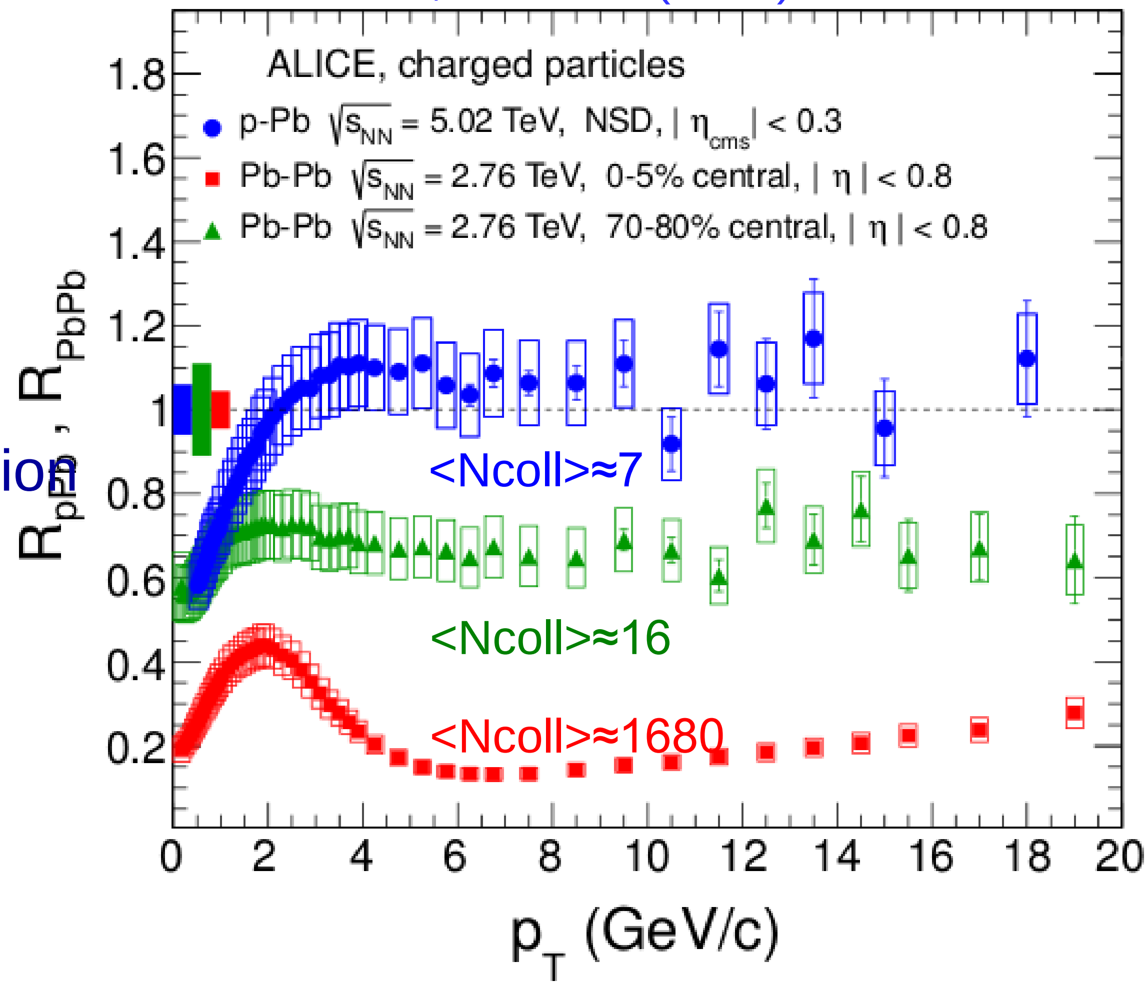
30 Extra

31 Centrality dependent nuclear modification

$$R_{AB} = \frac{\mathrm{d}N_{AB}/\mathrm{d}p_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle \mathrm{d}N_{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

- $\langle N_{coll} \rangle = A\, \sigma_{pp}/\sigma_{pA} \approx 7$ with
  - σ_{pp} = 70 mb from interpolation of existing data
  - σ_{pA} = 2090 ± 120 mb from LHCb-CONF-2012-034 (or use Glauber)
- Note: $\langle N_{coll} \rangle \approx 15$ is reached in "0-5% central" pPb collisions

ALICE, PRL 110 (2013) 082302

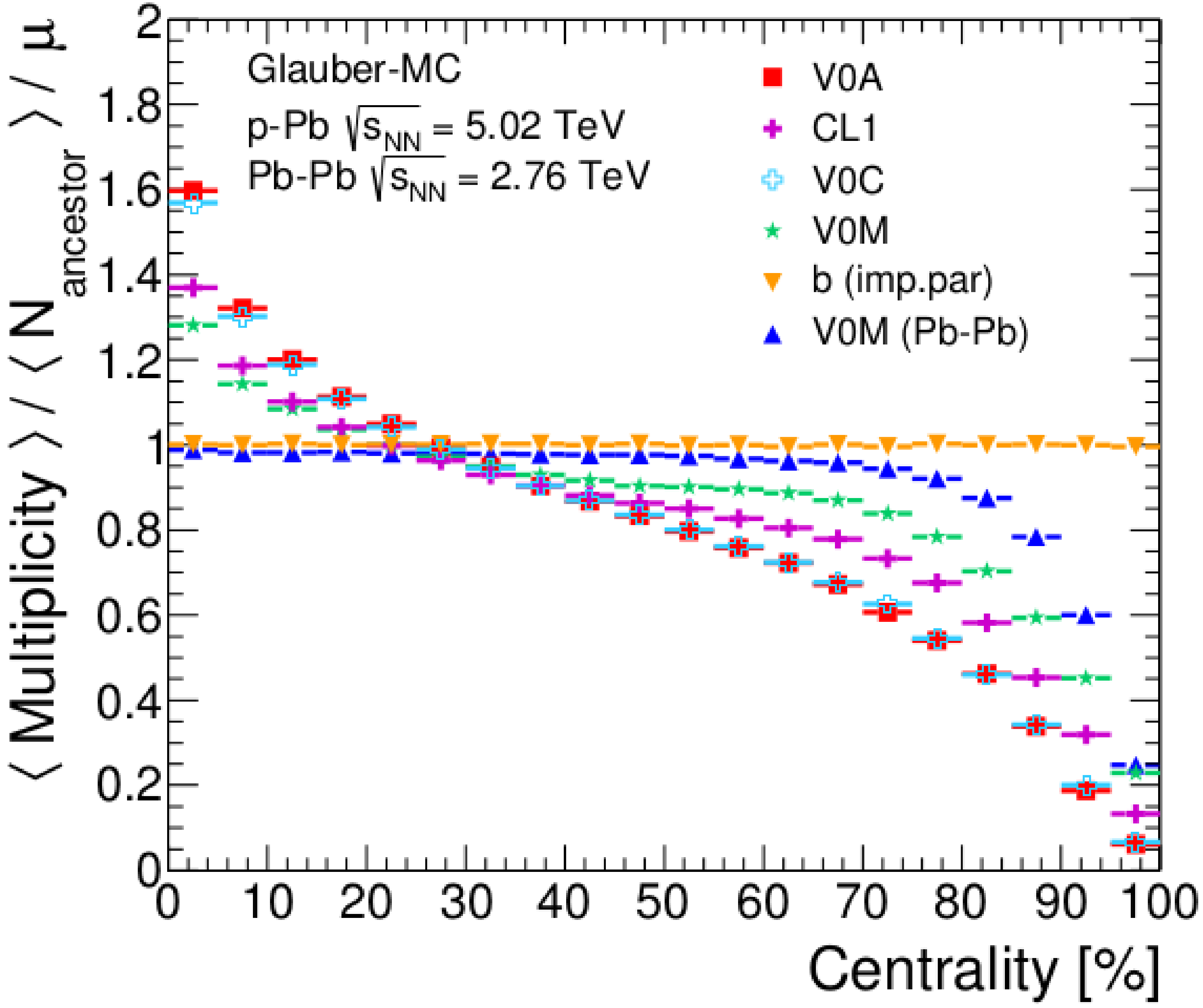


How to perform a centrality dependent measurement?

$$R_{\mathrm{pA}}^{\mathrm{cent}}(p_{\mathrm{T}}) = \frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{\langle T_{\mathrm{pA}}^{\mathrm{cent}}\rangle \mathrm{d}\sigma^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}} = \frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{\langle N_{\mathrm{coll}}^{\mathrm{cent}}\rangle \mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{\mathrm{T}}}$$

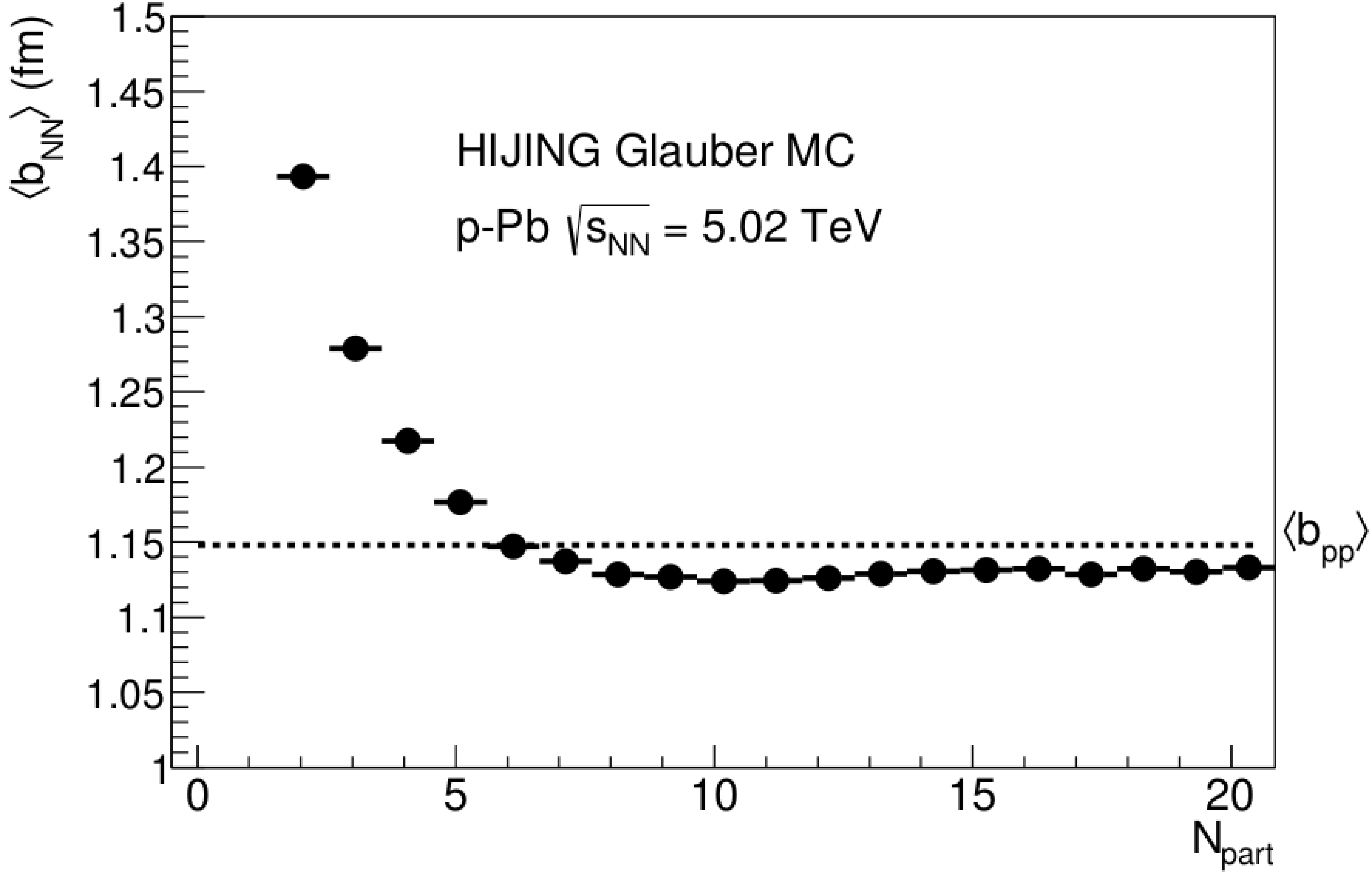
32 Multiplicity bias

ALICE, arXiv:1412.6828



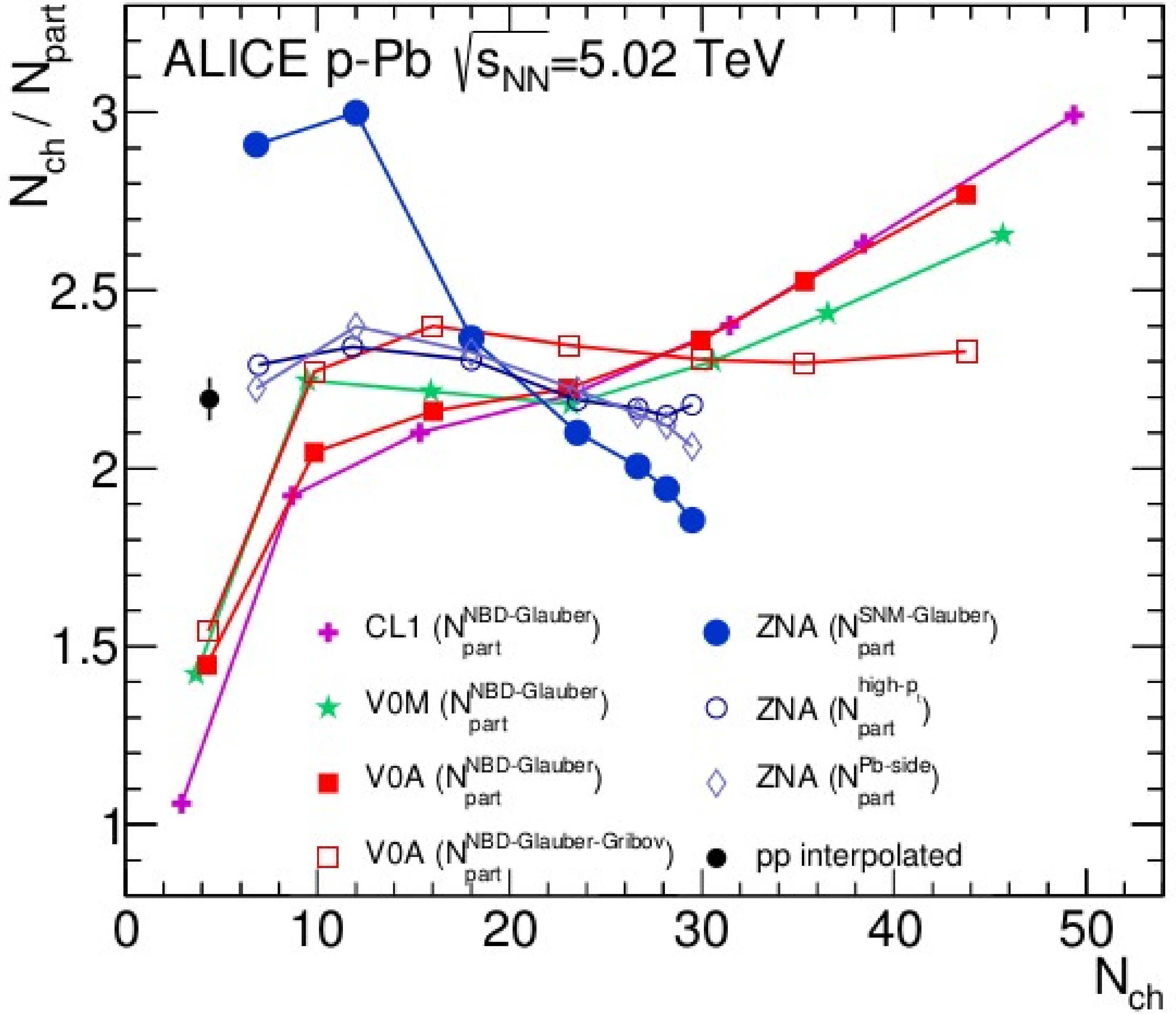
33 Geometry bias

ALICE, arXiv:1412.6828



34 Multiplicity scaled by different Npart

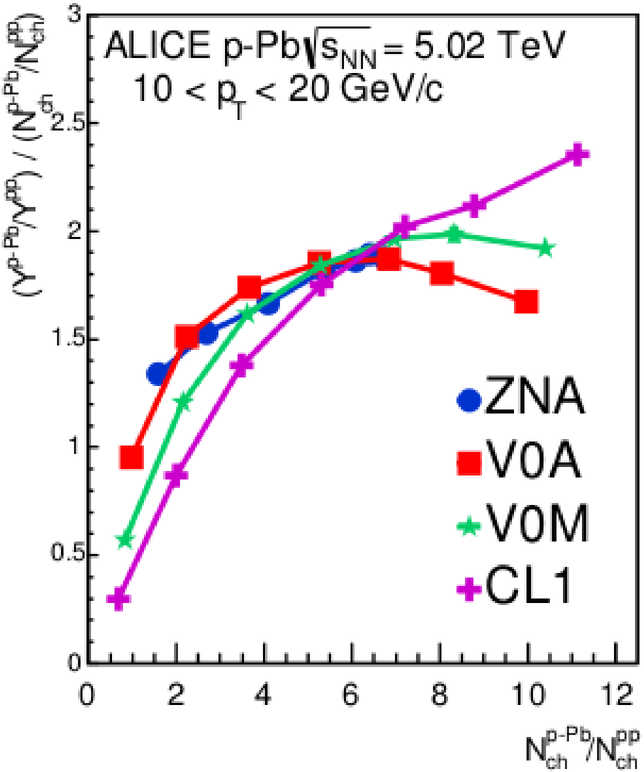
ALICE, arXiv:1412.6828



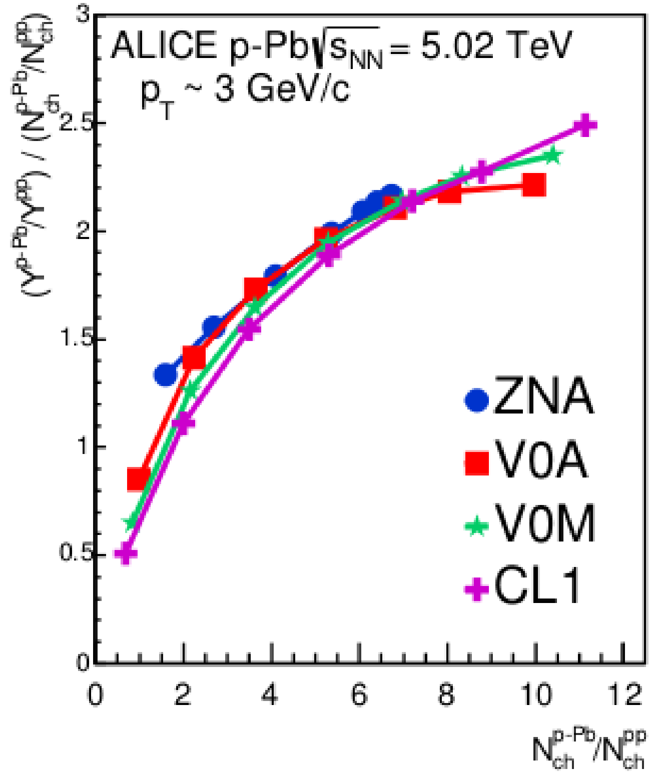
35 Cronin and high-p_T region vs Nch

ALICE, arXiv:1412.6828

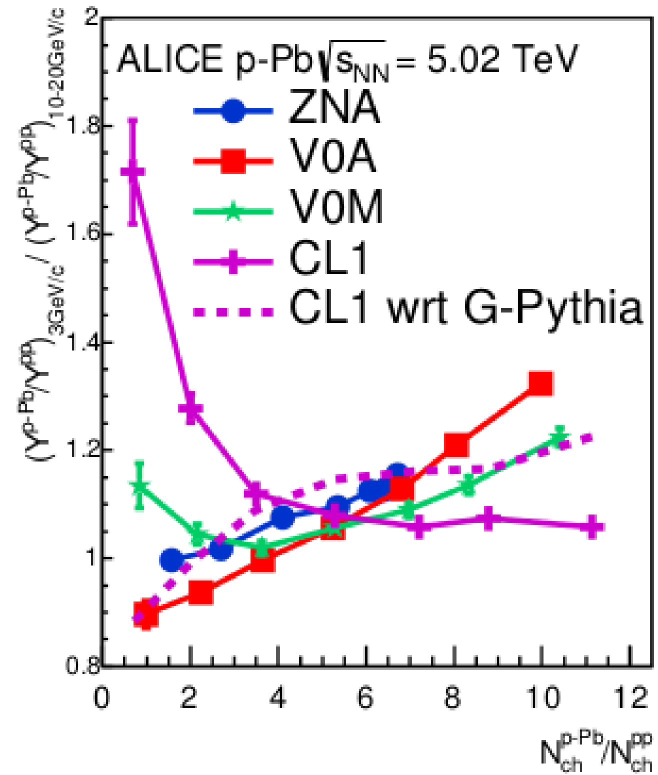
High p_T region



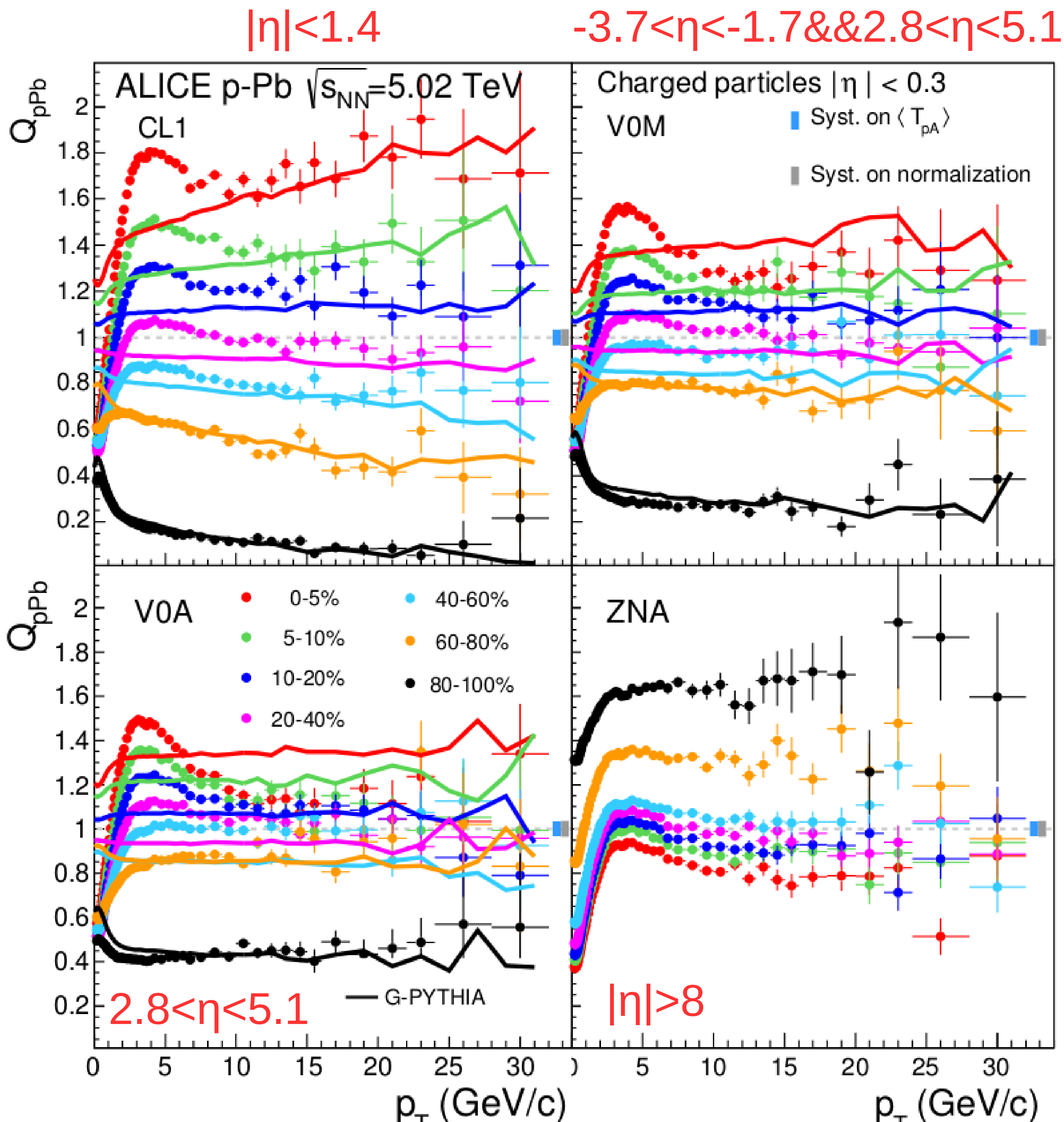
Peak region



Ratio peak / high p_T

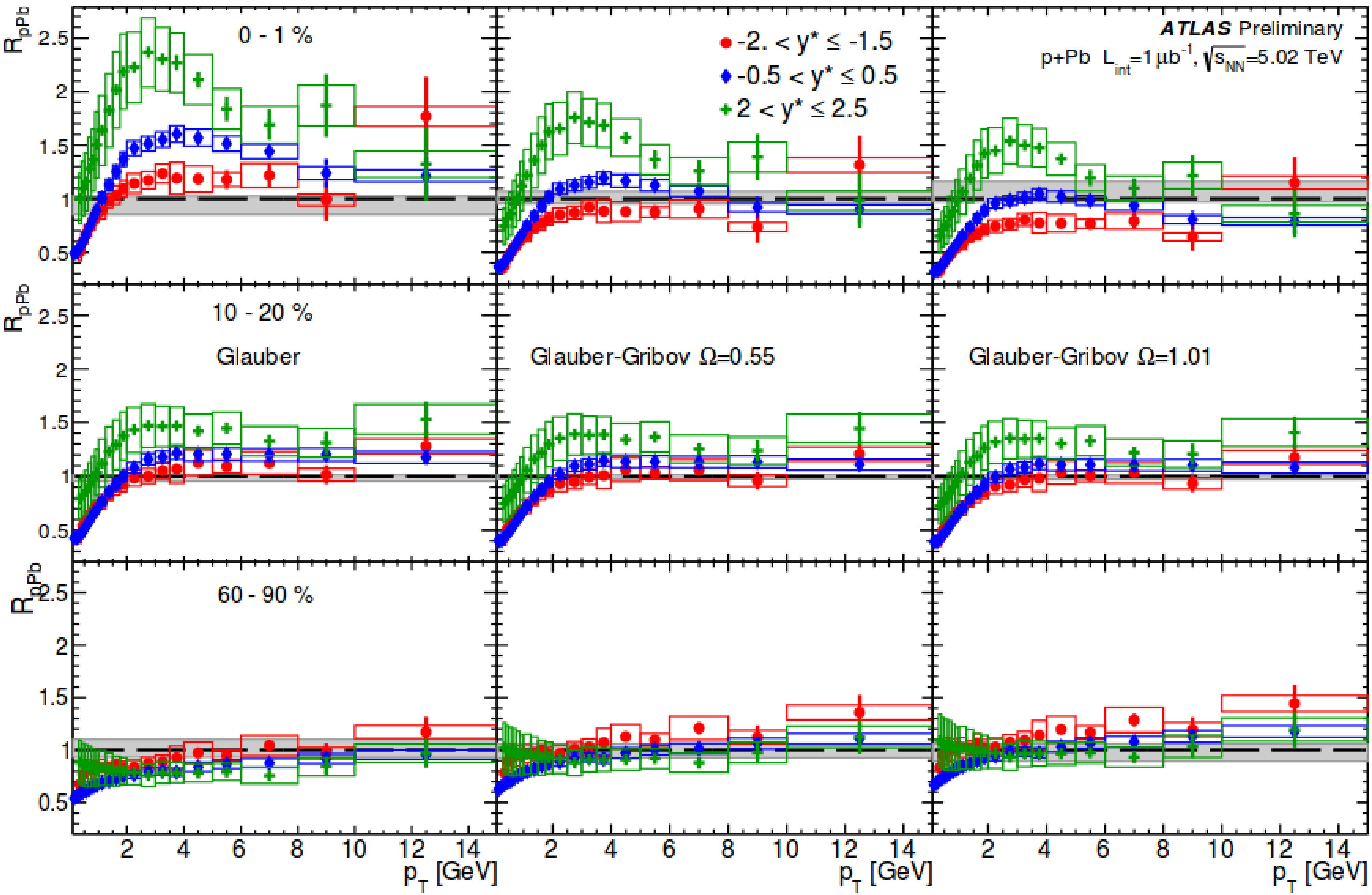


ALICE, arXiv:1412.6828



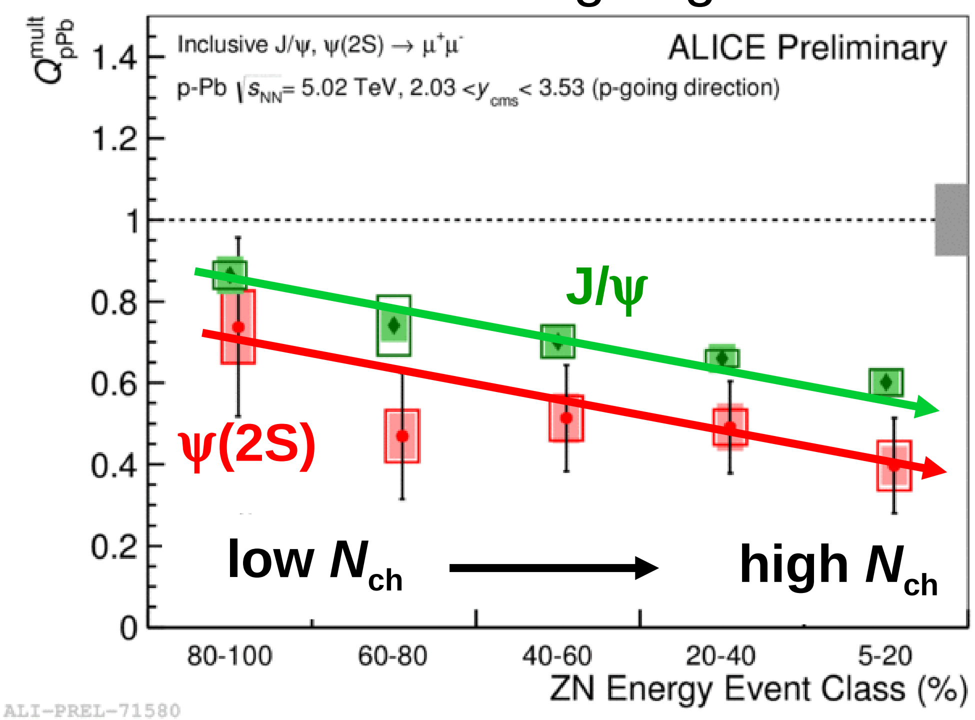
37 RpPb measurement

ATLAS-CONF-2013-107

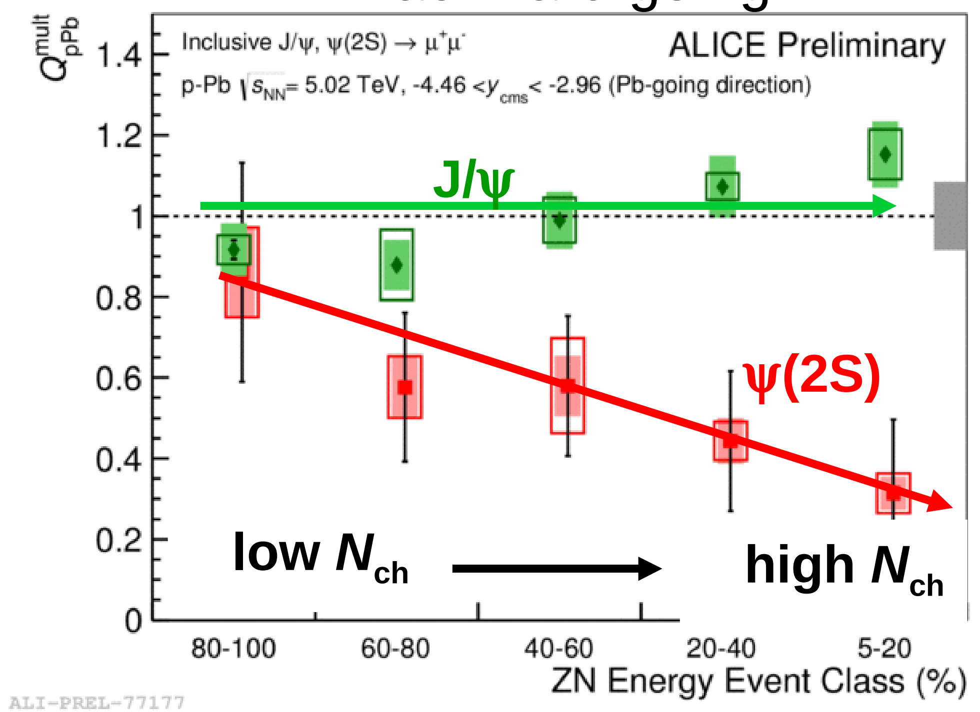


38 J/Ψ and Ψ(2S) suppression

Forward going



Backward going



- J/ψ → μμ: Multiplicity dependent suppression in p-going direction, and no suppression in Pb-going direction
  - Consistent with shadowing
- ψ(2S) → μμ: Multiplicity dependent suppression in both directions
  - Needs additional effect (Final state?)