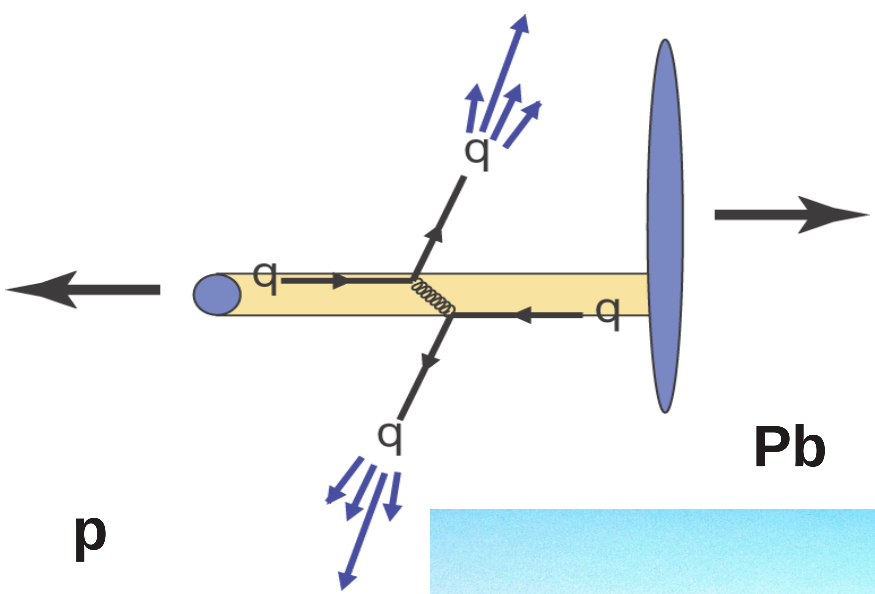
ALICE Measurements in **p-Pb** Collisions
Charged Particle **Multiplicity**
Centrality Determination
and implications for **Binary Scaling**

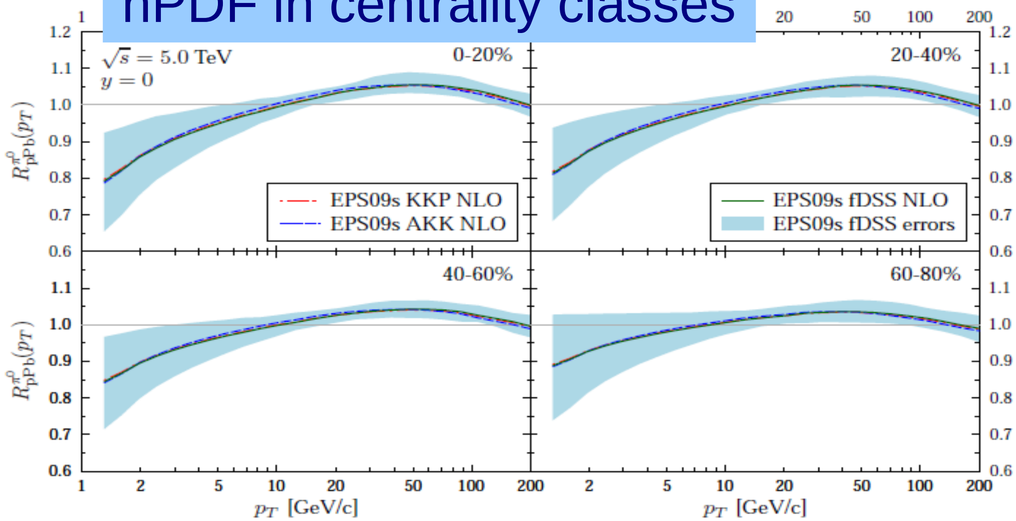
Alberica Toia (INFN Padova)
on behalf of the ALICE Collaboration



IS2013
Illa de A Toxa, Spain
8-14 September, 2013

Physics Motivations

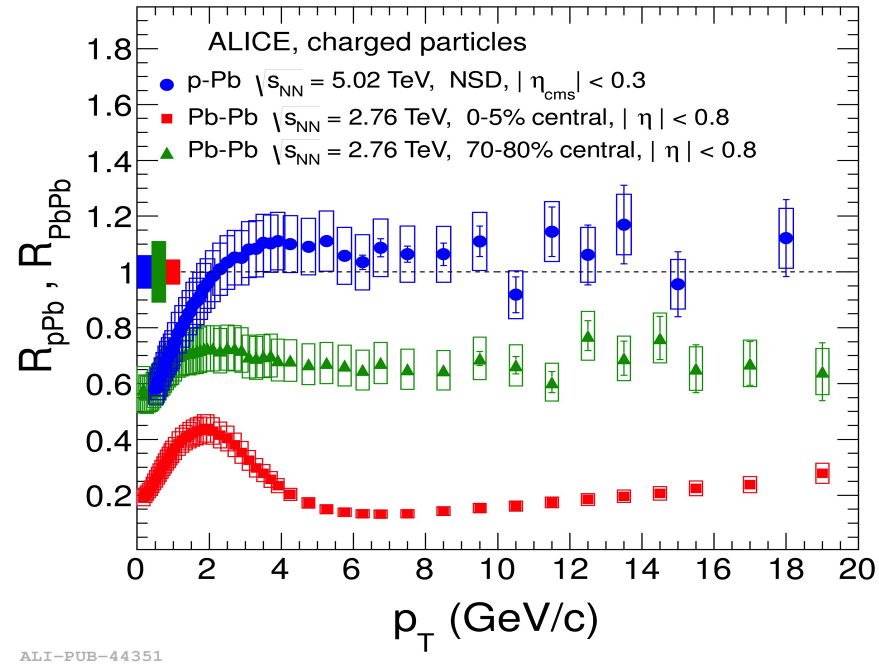
nPDF in centrality classes



I.Helenius, K.Eskola, H.Honkanen and C.Salgado, HP2012

Many initial state effects are expected to vary as a function of the impact parameter or the number of collisions.

ALICE, arXiv:1210.4520



ALICE has measured min bias R_{pA}

Average p-Pb overlap function $\langle T_{pA} \rangle$ determined by total (geometric) p-A cross-section:

$$\langle N_{coll} \rangle = 208 \sigma_{pN} / \sigma_{pA} = 6.9 \text{ with}$$

$$\sigma_{pN} = 70 \text{ mb}$$

$$\sigma_{pPb} = 2100 \text{ mb}$$

$$\langle T_{pPb} \rangle = \langle N_{coll} \rangle / \sigma_{pN} = 208/2100 \text{ mb}^{-1} = 0.098 \text{ mb}^{-1}$$

p-A nuclear modifications: incoherent superposition of p-N collisions?

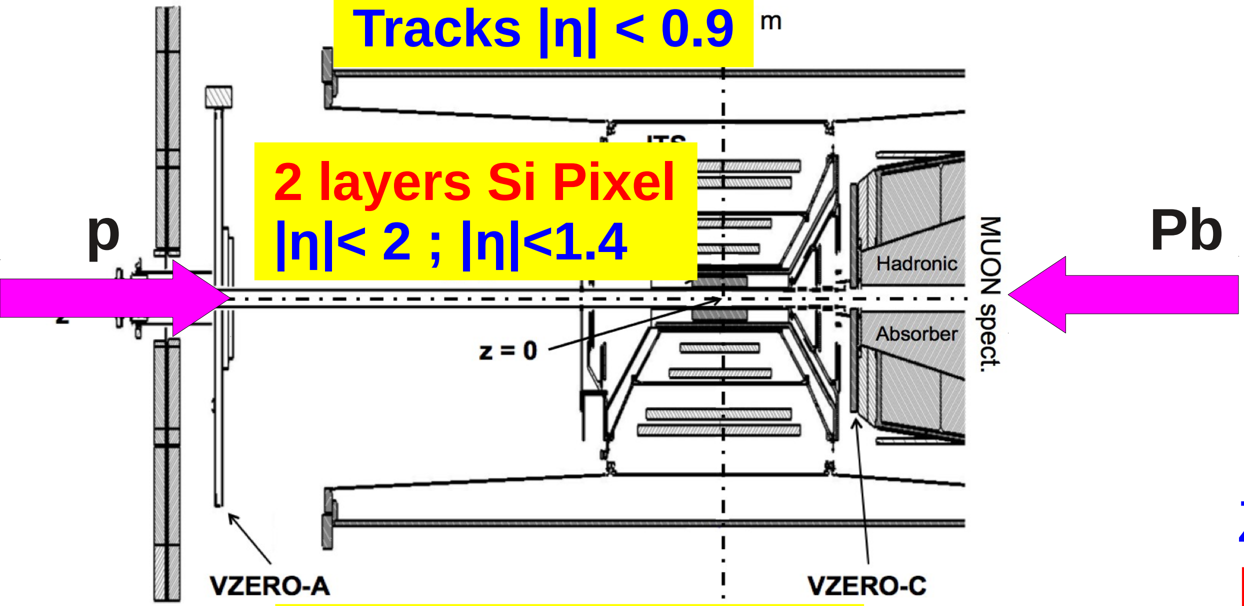
1) how many collisions (N_{coll})?

2) what is the bias?

Detectors used for Centrality

MID-RAPIDITY

TPC+ITS
Tracks |η| < 0.9



2 layers Si Pixel
|η|< 2 ; |η|<1.4

VZERO Scintillators

z = 340 cm
2.8 < η < 5.1

z = -90 cm
-3.7 < η < -1.7

Particle production modeled by
Negative Binomial Distribution
Pb-fragmentation more relevant
at forward rapidity

ZERO-DEGREE

Quartz-Fiber "Spaghetti"
Zero Degree Calorimeters

z = ± 112.5 m

ZDC sensitive to slow nucleons
Nucleus fragmentation model:
Black nucleons: evaporation
Grey nucleons: knock-out

Centrality Estimators:

CL1: Clusters in 2nd Pixel Layer
V0M: VZERO-A+C Multiplicity
V0A: VZERO-A Multiplicity
ZNA: ZDC-A Neutron Energy

1. Ncoll

1.a Glauber + NBD

1.b Glauber + SNM

1.a Glauber + NBD Fit

- Same procedure as for Pb-Pb (ALICE, arXiv:1301.4361)
- Centrality classes: Multiplicity distribution sliced into percentiles of cross-section
- Obtain P(N_{part}) from Glauber Monte Carlo
  - N_{part} is equal to number of ancestors

Glauber MC Parameters

$$\rho(r)=\rho_0 \frac{1}{1+\exp\left(\frac{r-R}{a}\right)}$$

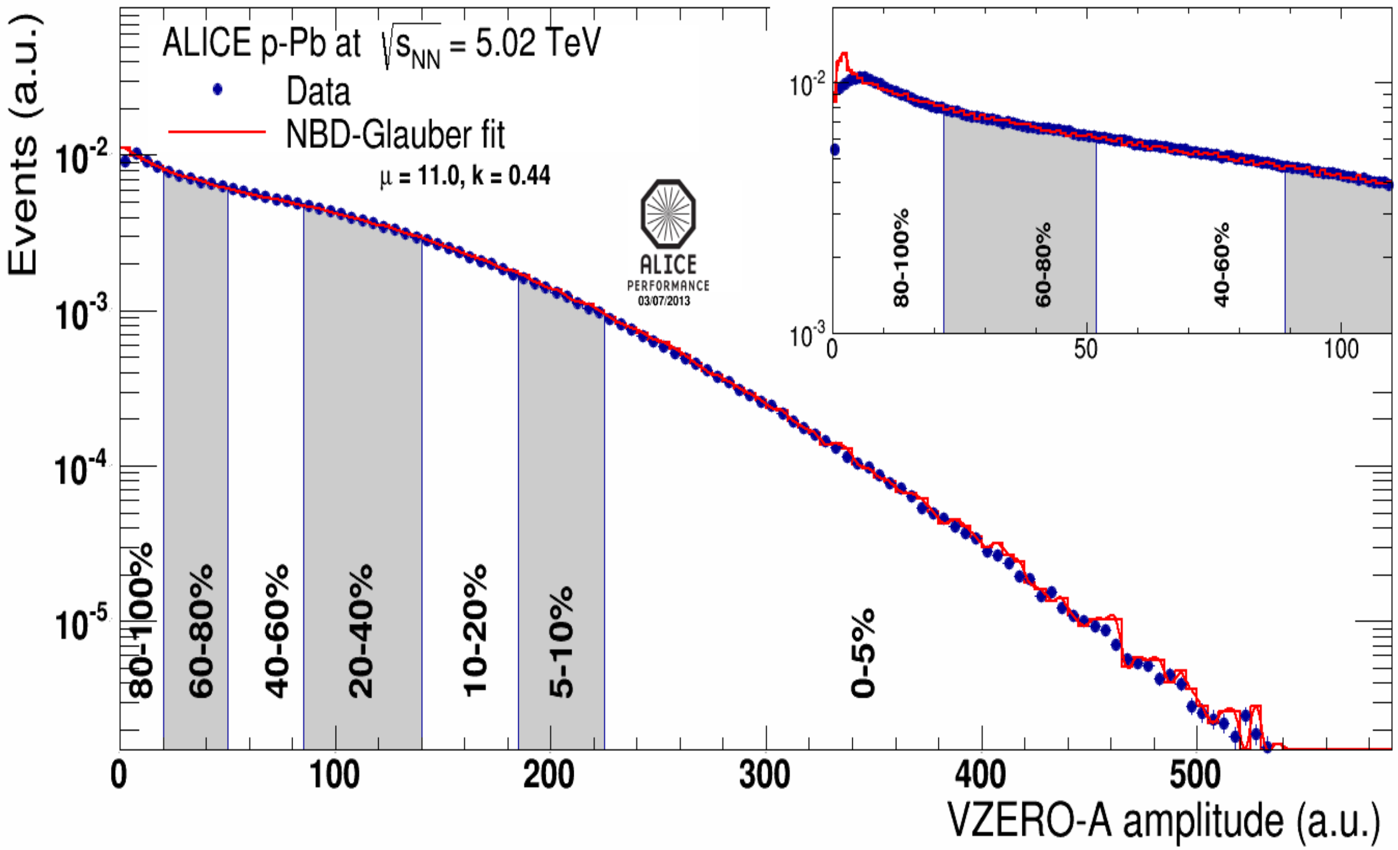
R = 6.62 ± 0.06 fm

a = 0.546 ± 0.01fm

Minimum NN distance: 0.4±0.4 fm

pN Cross-section: σ_{pN} = 70 ± 5 mb

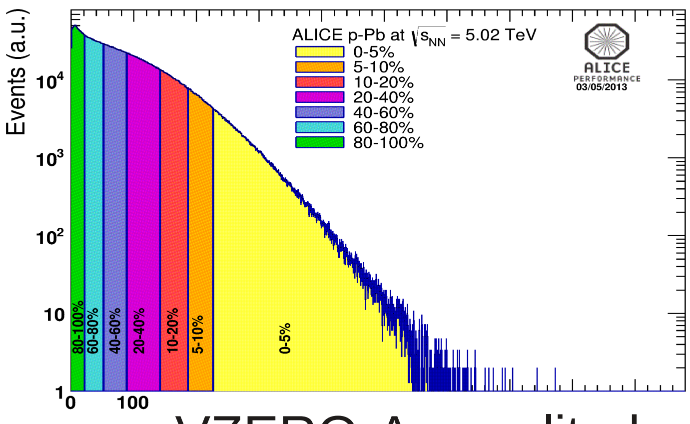
Proton radius: R_p = 0.6 ± 0.2 fm



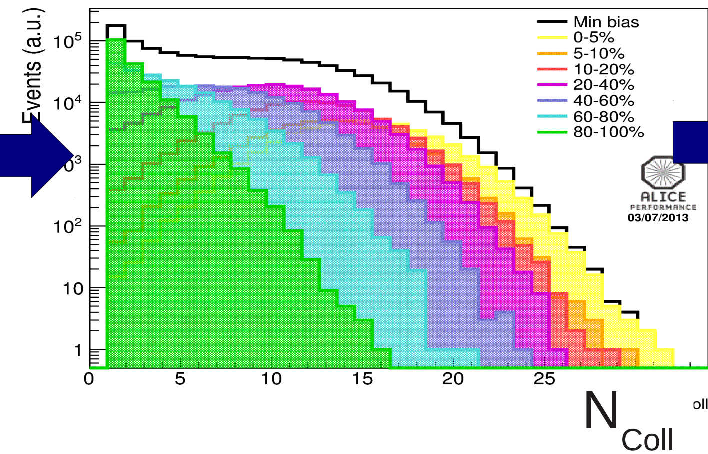
- For each ancestor obtain multiplicity from Negative Binomial Distribution (NBD) iterated to fit NBD parameters
- Obtain <N_{coll}> for each centrality class

1.a Results from Glauber+NBD

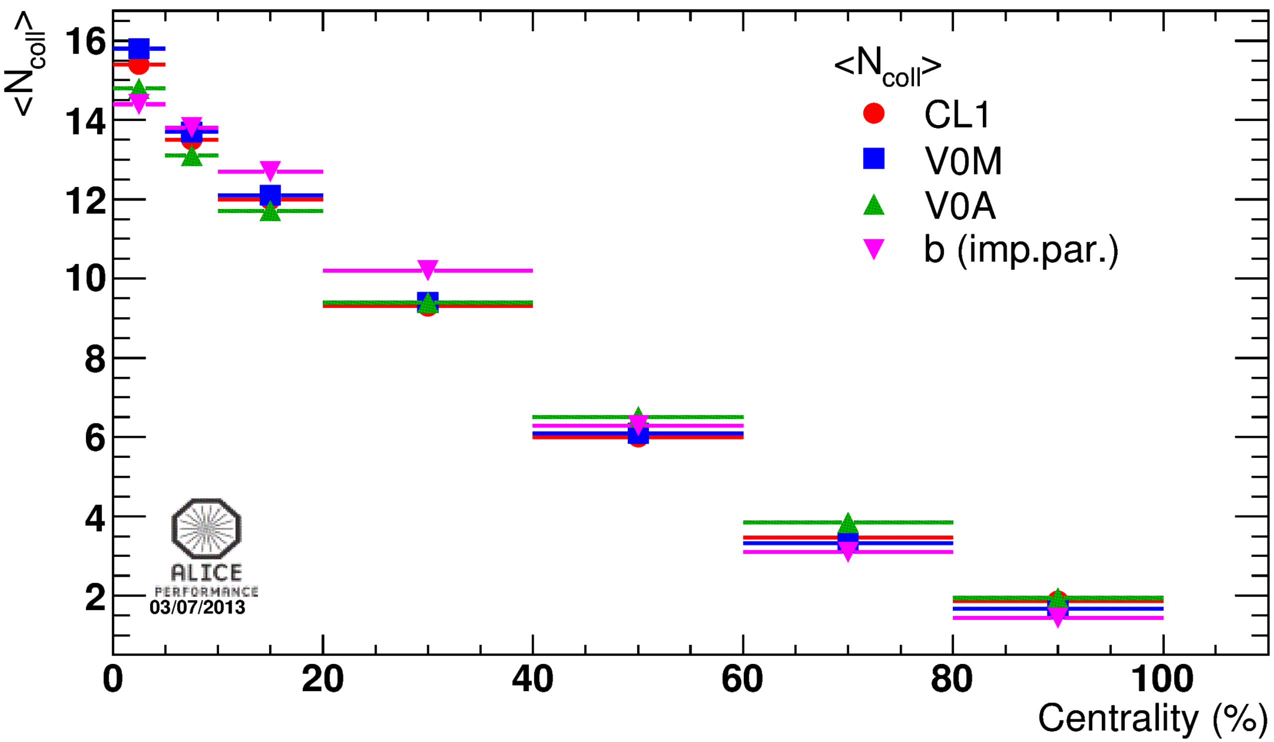
Slice in fitted MULT



Classes of N_{coll}

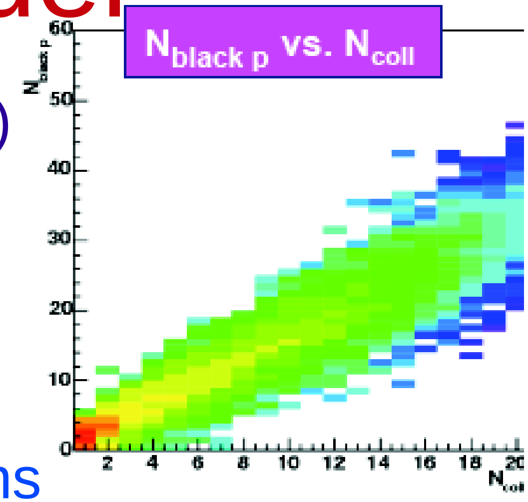


→ $\langle N_{coll} \rangle$



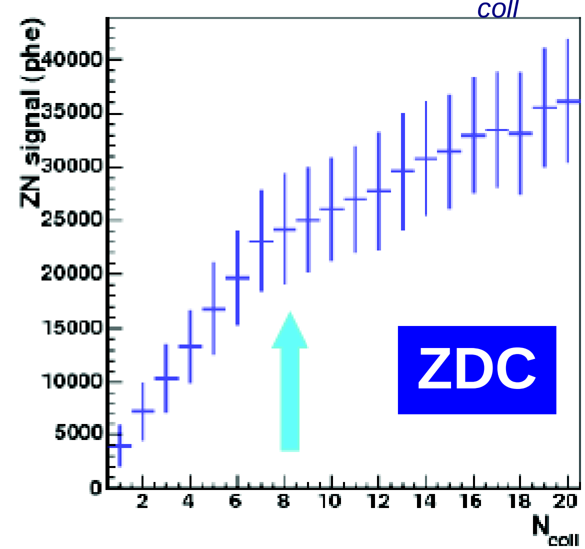
- $\langle N_{coll} \rangle$ similar for different estimators
- Systematic error estimated by varying Glauber MC parameters.
- MC closure test performed with HIJING

1.b Slow Nucleon Model



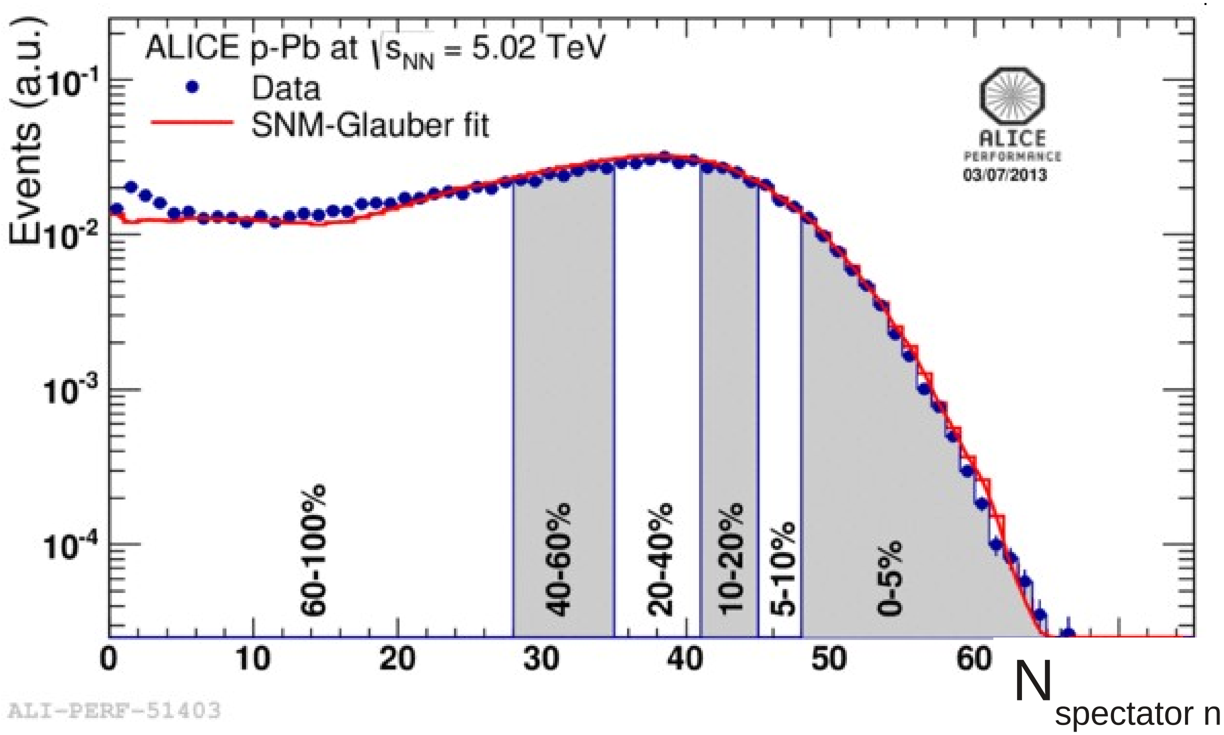
- Features of N_{ch} ~ independent of $E_{projectile}$ (1GeV → 1 TeV)
- **Slow nucleons** emission dictated by collision geometry → Maxwell-Boltzmann (independent statistical emission) classified from emulsion experiments
  - Gray: soft nucleons knocked out by wounded nucleons
  - Black: low energy target fragments from de-excitation, evaporation
- Glauber model → distribution of N_{coll}
- implemented model used a parameterization of results from low energy experiments
  C.Oppedisano https://edms.cern.ch/document/682801/1
  F. Sikler, hep-ph/0304065

saturation in N_{black} vs N_{gray}
→ also in ZDC vs N_{coll}

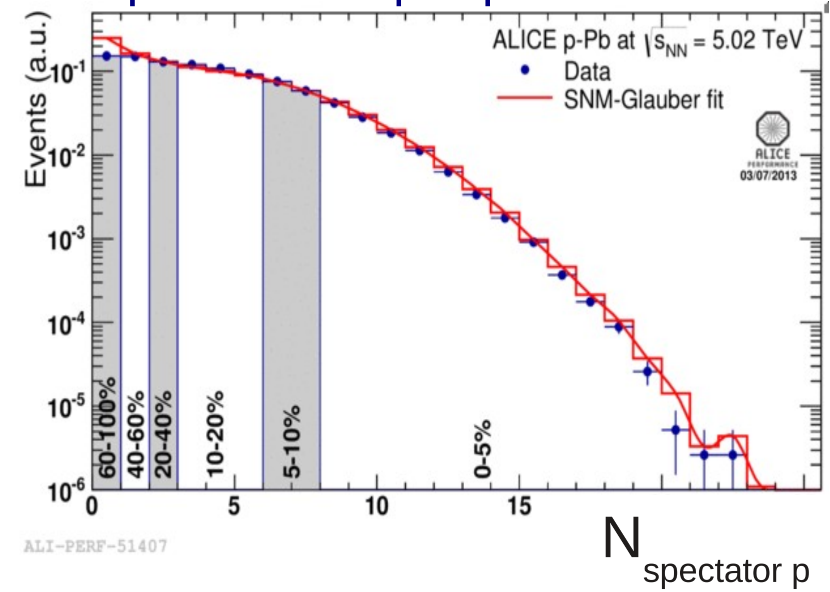


SLOW NUCLEONS	β [c units]	p [MeV/c]	E_{kin} [MeV]
Black	0 ÷ 0.25	0 ÷ 250	0 ÷ 30
Gray	0.25 ÷ 0.70	250 ÷ 1000	30 ÷ 400

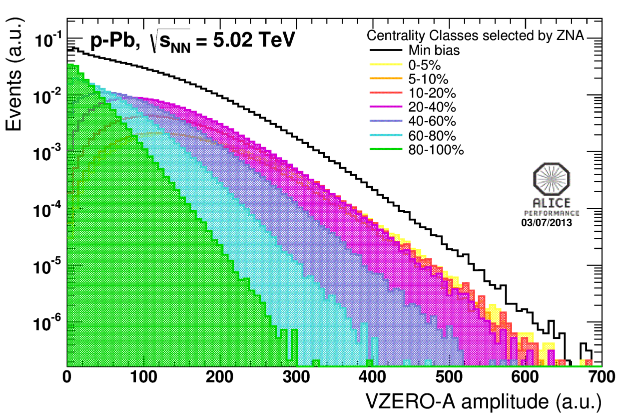
1.b Results from Glauber+SNM

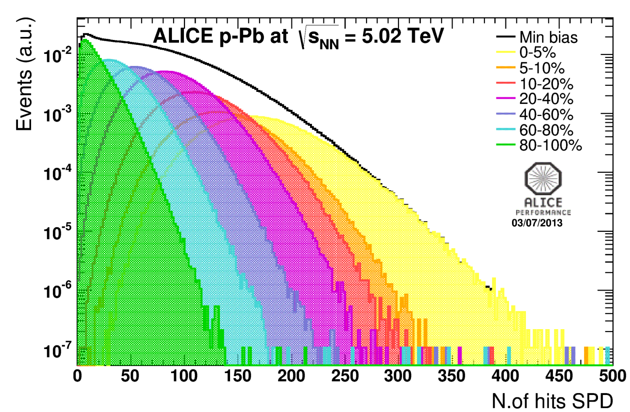


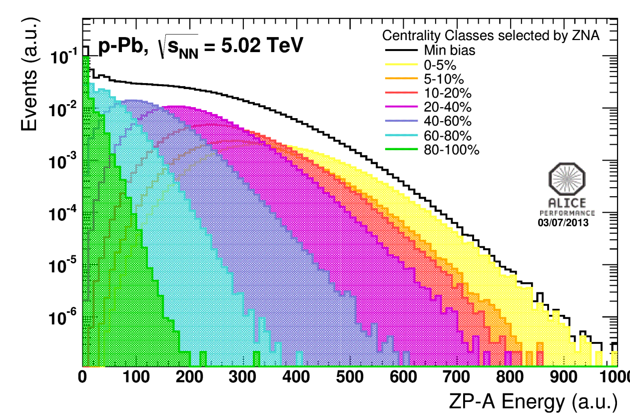
Reasonable description of spectra except for most peripheral



- N_{coll} from Glauber+SNM and Glauber+NBD similar except for most peripheral
- Despite of saturation, ZNA still able to select for centrality







2. Bias

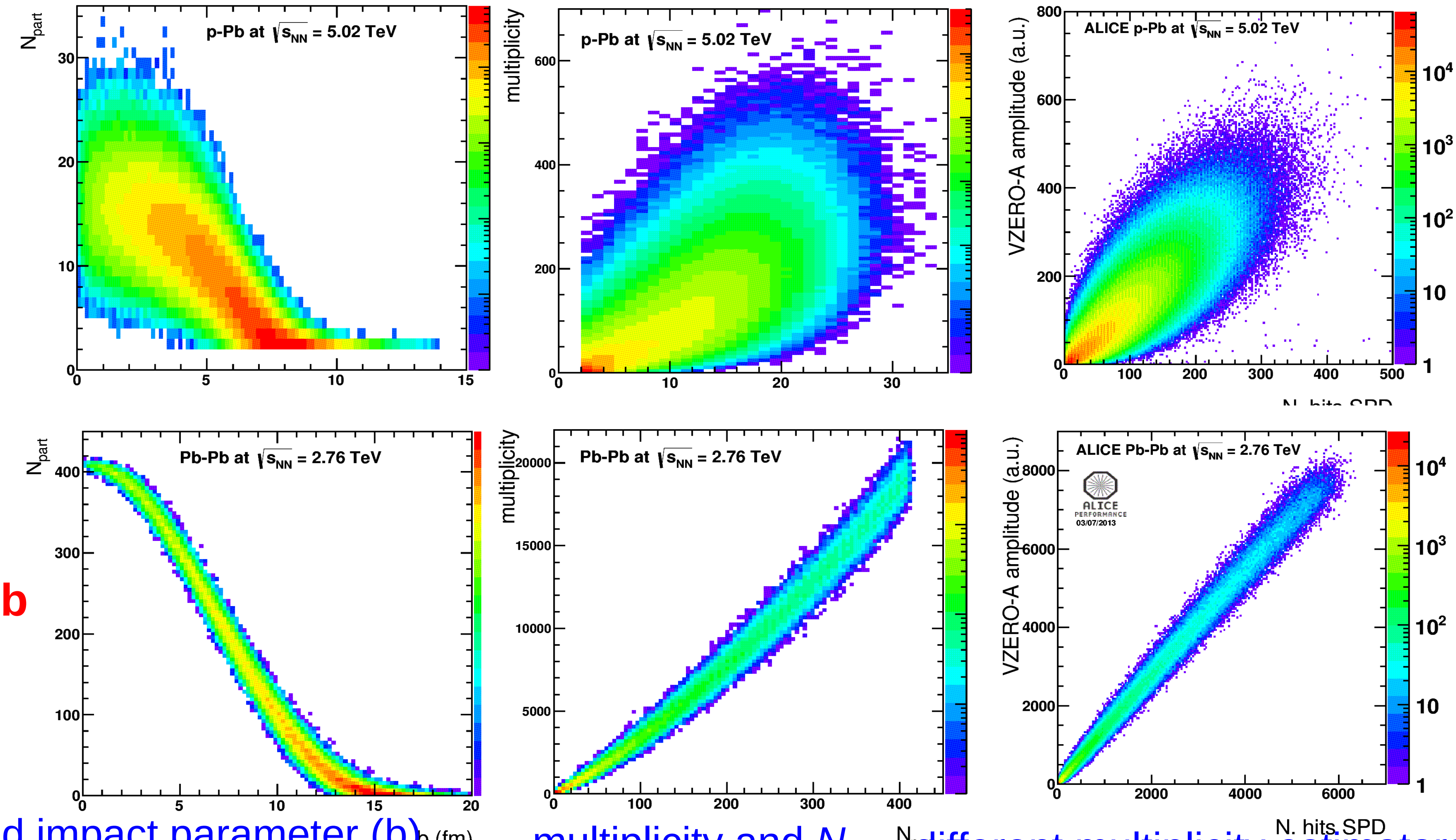
2.a multiplicity fluctuations
2.b impact parameter
2.c jet-veto

Origin of the Bias in pA

Looser correlation between

p-Pb

Pb-Pb



N_{part} and impact parameter (b)   multiplicity and N_{part} different multiplicity estimators

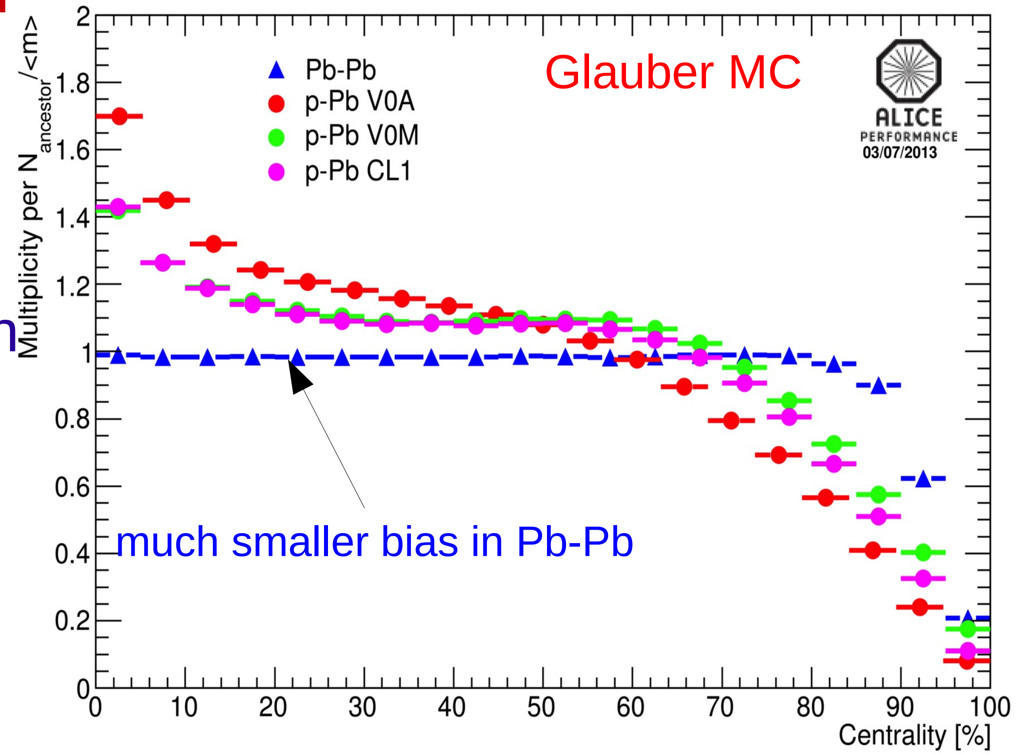
Fluctuations at the origin of physical bias

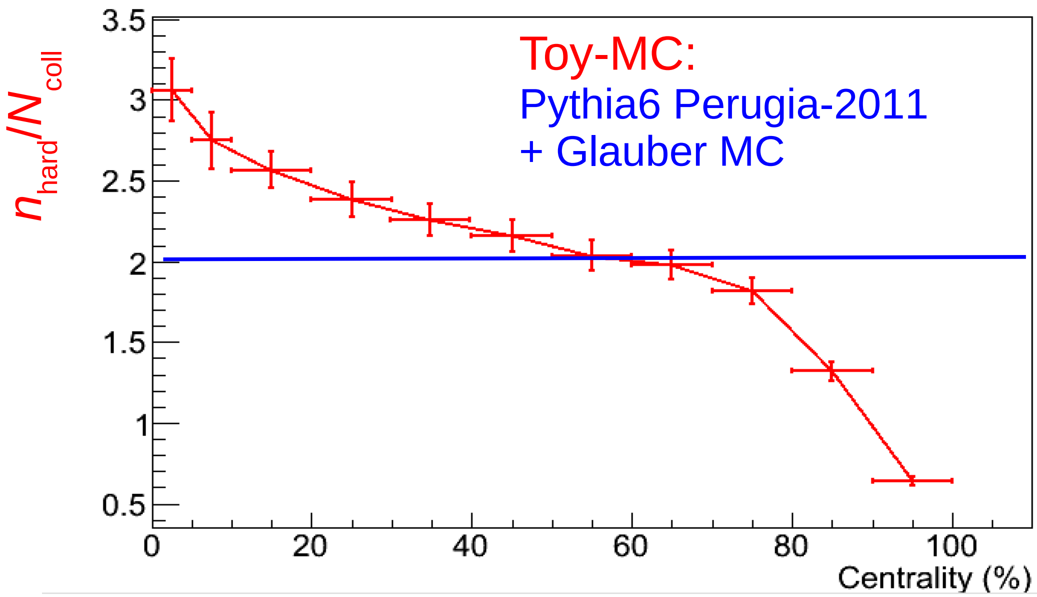
2.a Bias in pA

- **2.a** Multiplicity fluctuations sizable
  → Bias on Mult/N_{part} at central and peripheral collisions

- MC models with multi-parton interaction (MPI) include fluctuations of particle sources (hard scatterings)
  HIJING (X.N. Wang, M. Gyulassy, nucl-th/9502021)

  → bias in mult ~ bias in hard scattering





Toy-MC (Glauber+Pythia)

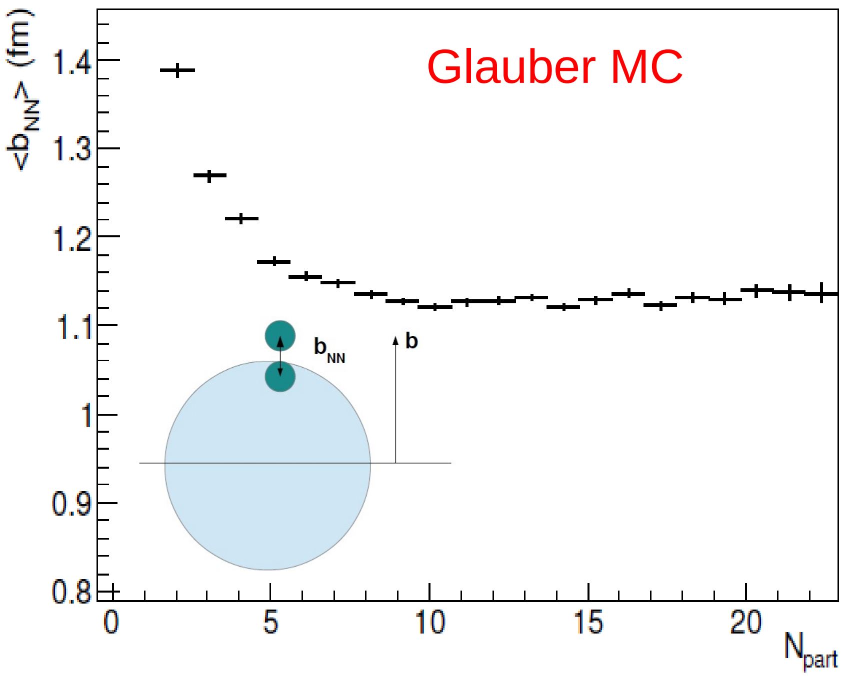
- build a Toy-MC by adding a Pythia (pp) event N_{coll} (from Glauber pPb calculation) times
- slice it in multiplicity as the real data
→ centrality classes

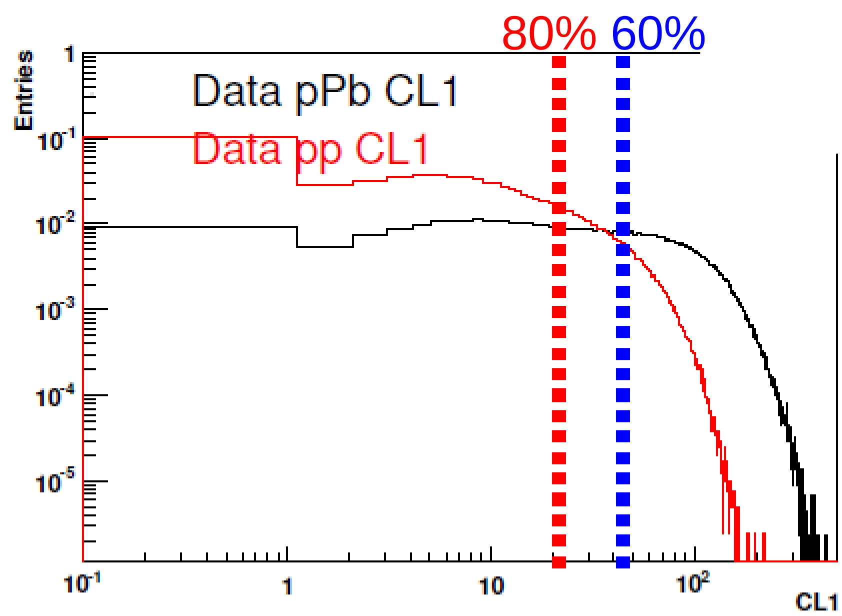
2.b,c Bias in pA --peripheral

- **2.b** Mean nucleon-nucleon impact parameter (b_{NN}) increases in peripheral collisions
- Due to MPI mult. fluctuations depend on fluctuations in particle sources (hard scatterings)
  - Mean number of scatterings per event obtained from impact parameter (b_{NN})-dependent proton-nucleon overlap function $T_N(b_{NN})$

→ bias in mult ~ bias in hard scattering emphasized at peripheral

- **2.c** Jet-veto: multiplicity range in peripheral events represent an effective veto on hard processes





Bias from different estimators

Centrality Estimators:
CL1: Clusters in 2nd Pixel Layer
V0M: VZERO-A+C Multiplicity
V0A: VZERO-A Multiplicity
ZNA: ZDC-A Neutron Energy

- Different centrality estimators expected to show different deviations from Ncoll scaling
  - **CL1 (Clusters Pixel Layer 2)**: strong bias due to full overlap with tracking region.
    - Additional bias in peripheral event from "Jet veto effect"
    - Jets contribute to the multiplicity and shift events to higher centralities (p_T - dependent)
  - **V0M (V0A+V0C Multiplicity)**: reduced bias since outside tracking region
  - **V0A Multiplicity**: reduced bias because of important contribution from Pb fragmentation region.
  - **ZNA**: small bias slow nucleon production independent of hard processes

At high p_T

$$Q_{\mathrm{pA}}(p_{\mathrm{T}};cent)=\frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{N_{\mathrm{coll}}^{\mathrm{Glauber}}\,\mathrm{d}N^{\mathrm{pp}}/\mathrm{d}p_{T}}=\frac{\mathrm{d}N^{\mathrm{pA}}/\mathrm{d}p_{\mathrm{T}}}{T_{\mathrm{pA}}^{\mathrm{Glauber}}\,\mathrm{d}\sigma^{\mathrm{pp}}/\mathrm{d}p_{T}}\neq 1$$

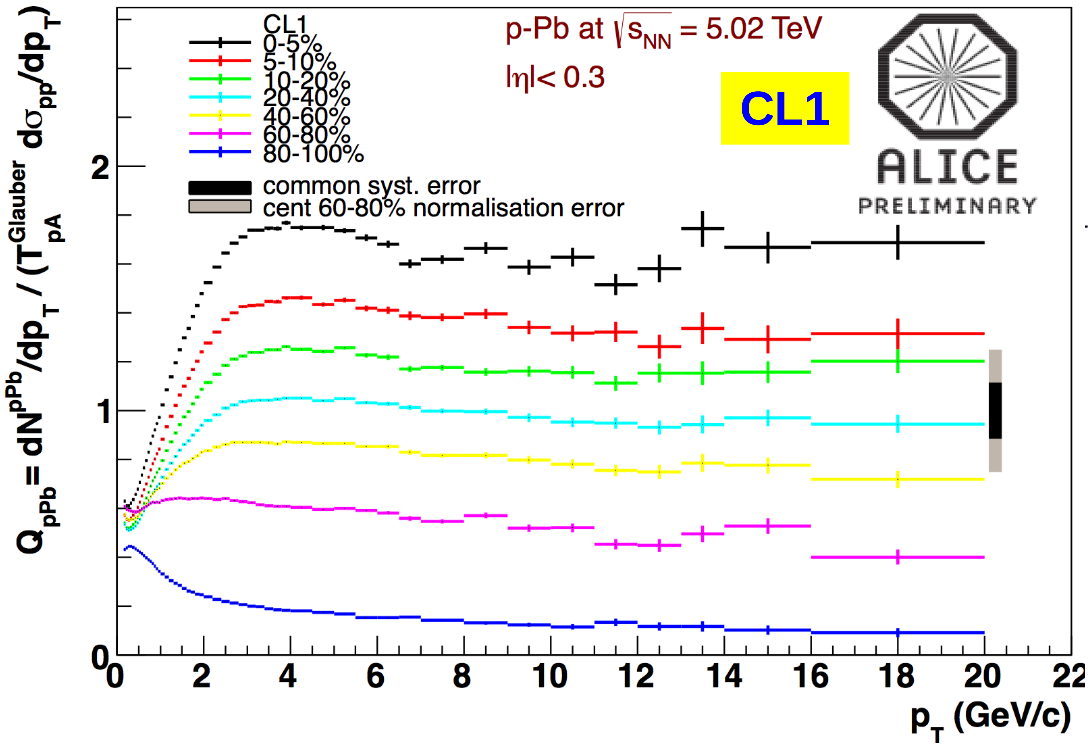
In general N_{coll} for a given centrality class can not be used to scale the pp cross-section !

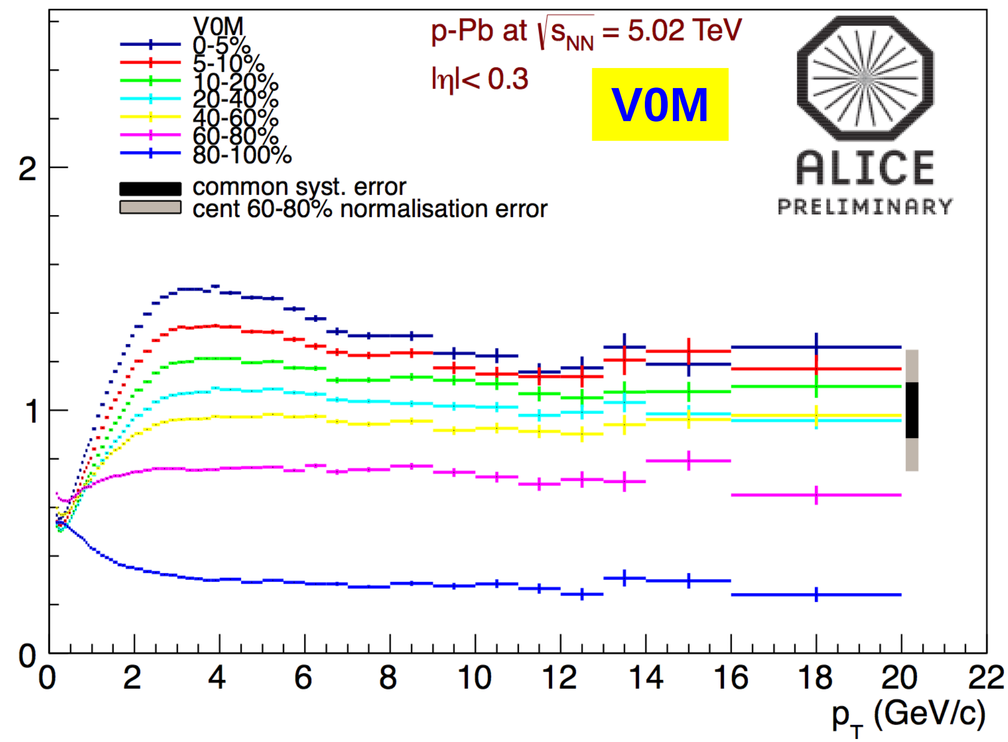
3. Implications for binary scaling

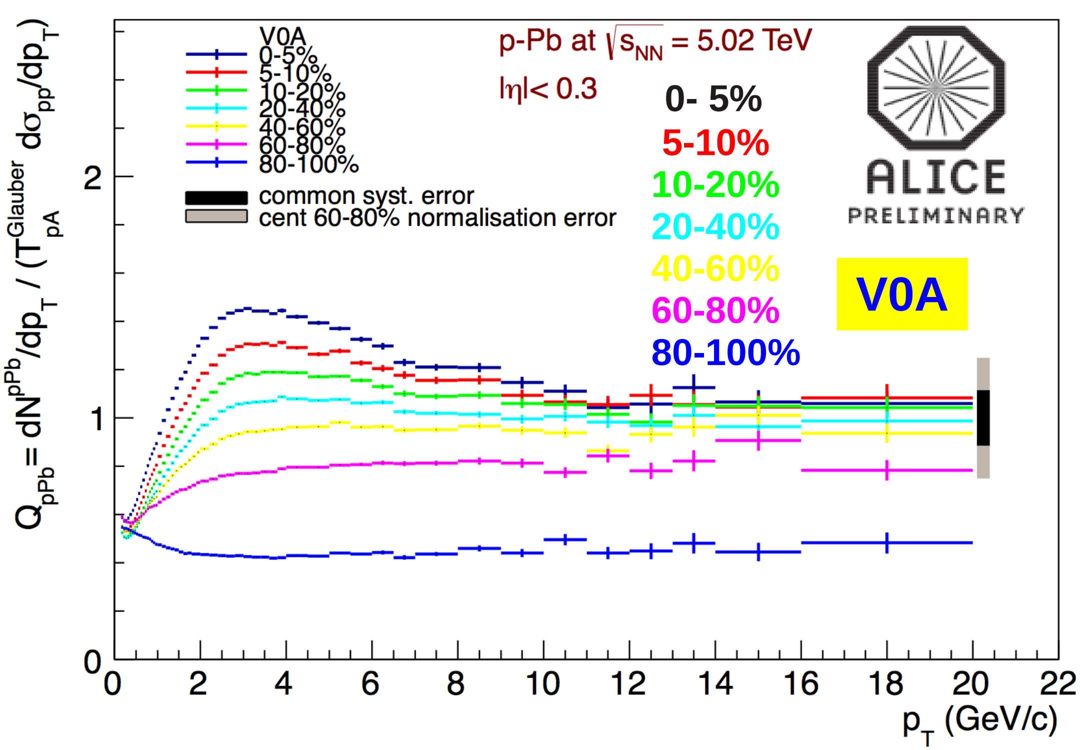
3.a Q_{pA} as biased R_{pA}

3.b incoherent superposition of pN

3.c un-biased selection?





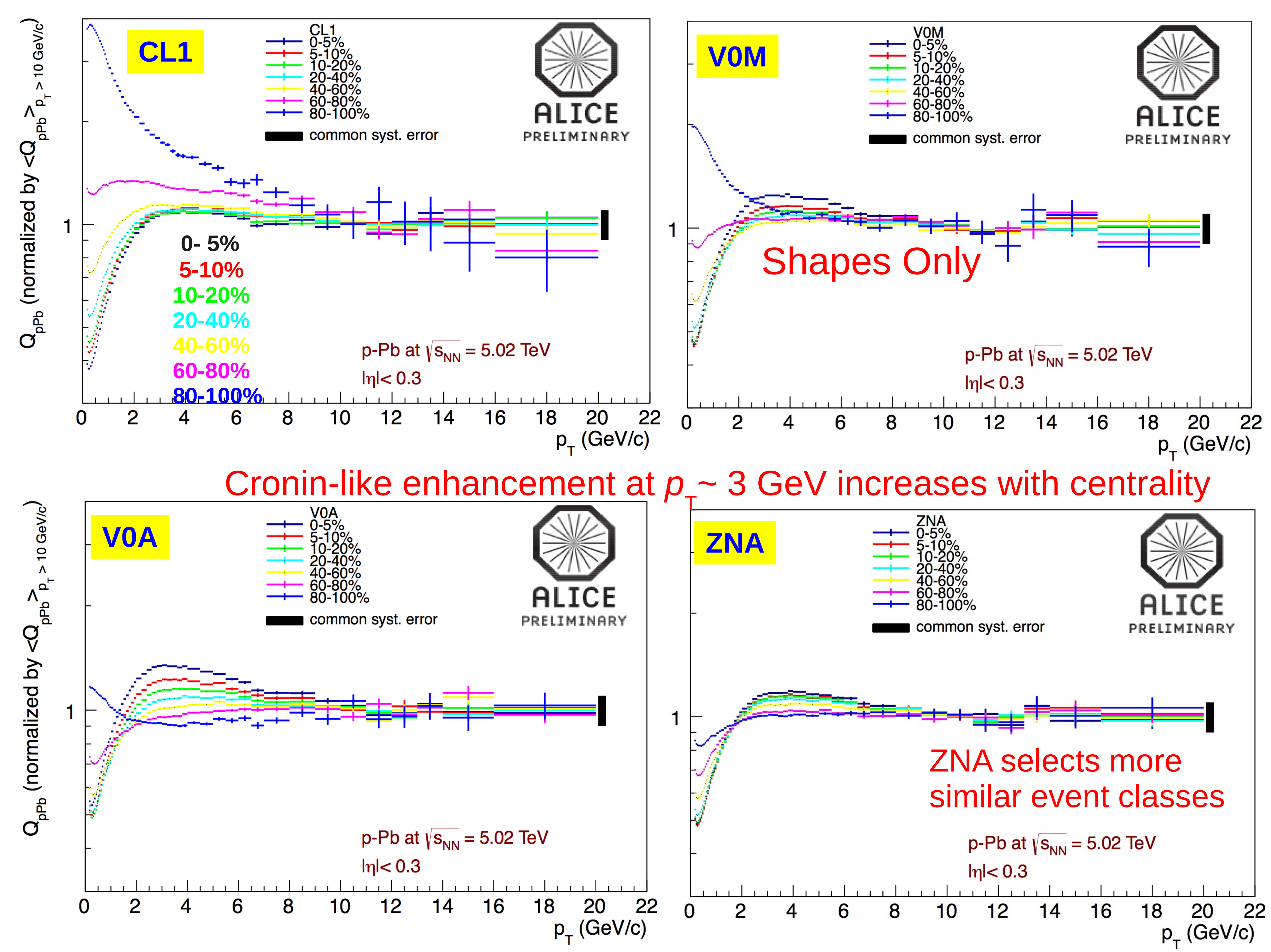


Not an R_{pPb} Measurement !

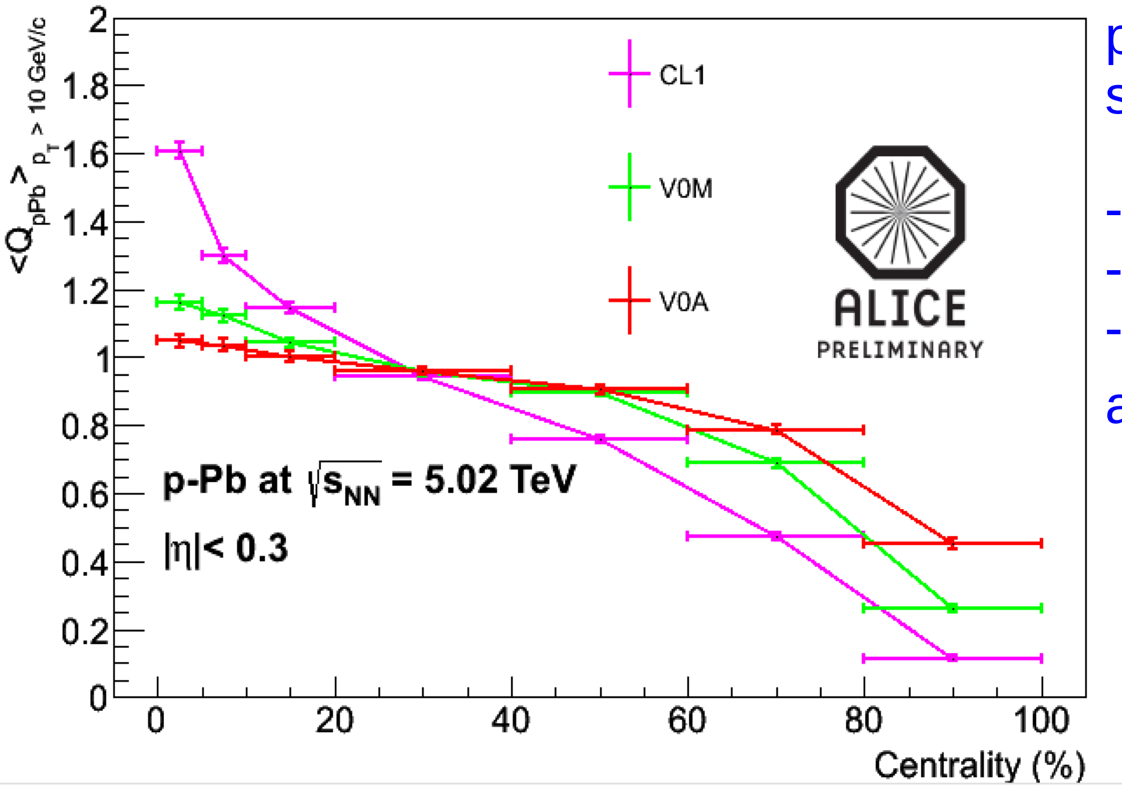
- Q_{pPb} spread between centrality classes reduces with increasing rapidity gap: CL1→V0M→V0A

- Clear “jet veto bias” in CL1 80-100%

- No (or little?) “jet veto” bias in V0A 80-100% but $Q_{pPb} < 1$

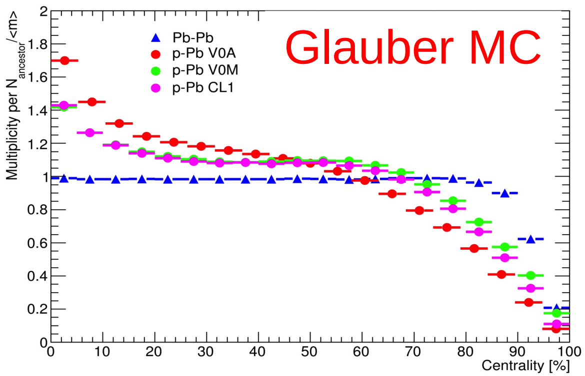

CL1
CL1
0-5%
5-10%
10-20%
20-40%
40-60%
60-80%
80-100%
common syst. error
ALICE
PRELIMINARY
0- 5%
5-10%
10-20%
20-40%
40-60%
60-80%
80-100%
p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
|η|< 0.3
Q_{pPb} (normalized by $<Q_{pPb}>_{p_T > 10\ GeV/c}$)
p_T (GeV/c)
V0M
V0M
0-5%
5-10%
10-20%
20-40%
40-60%
60-80%
80-100%
common syst. error
ALICE
PRELIMINARY
Shapes Only
p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
|η|< 0.3
p_T (GeV/c)
Cronin-like enhancement at p_T ~ 3 GeV increases with centrality
V0A
V0A
0-5%
5-10%
10-20%
20-40%
40-60%
60-80%
80-100%
common syst. error
ALICE
PRELIMINARY
p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
|η|< 0.3
Q_{pPb} (normalized by $<Q_{pPb}>_{p_T > 10\ GeV/c}$)
p_T (GeV/c)
ZNA
ZNA
0-5%
5-10%
10-20%
20-40%
40-60%
60-80%
80-100%
common syst. error
ALICE
PRELIMINARY
ZNA selects more
similar event classes
p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV
|η|< 0.3
p_T (GeV/c)

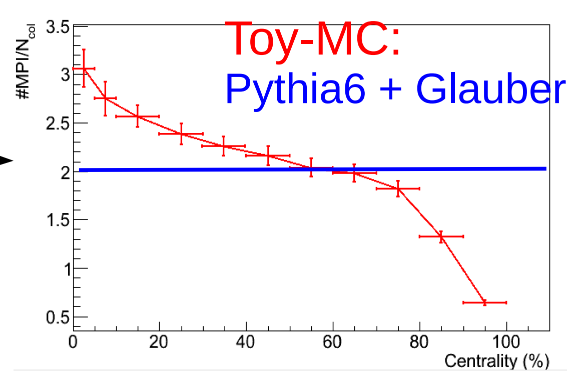
Mean Q_{pPb} at $p_T > 10$ GeV



p-Pb collisions described as incoherent superposition of nucleon-nucleon

- vs centrality from multiplicity $|\eta| < 1.4$
- only multiplicity bias
- strong deviation from N_{coll} -scaling at low and high centralities.

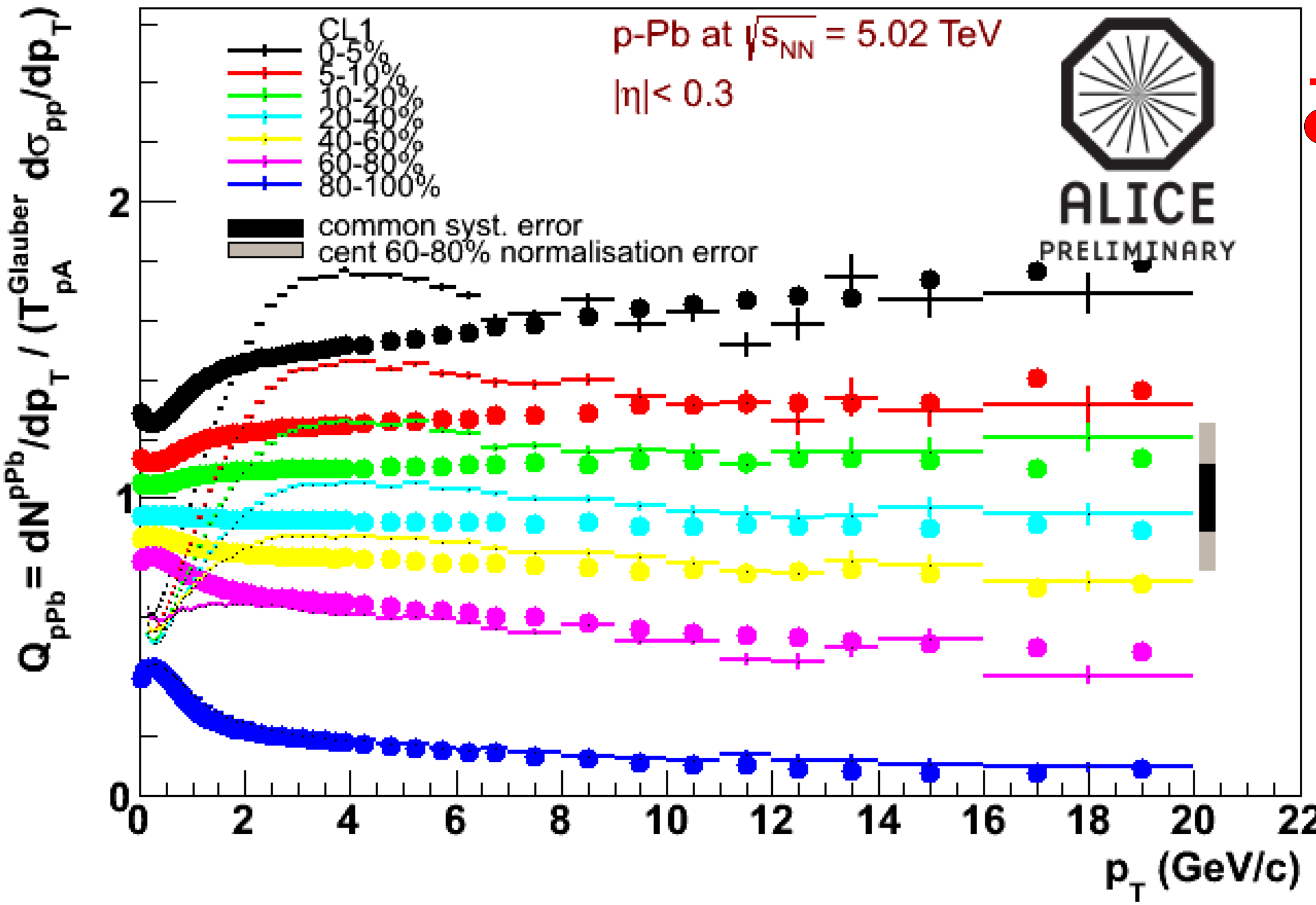




Same “S-shape” dependence as seen
- from multiplicity bias (Glauber + NBD fit)
- from Toy-MC (Glauber + Pythia)

Shape flattens with increasing rapidity gap:
CL1→V0M→V0A

Comparison with Glauber+Pythia



Centrality Estimator: CL1
+ data
● MC (Glauber + Pythia)

Toy-MC (Glauber+Pythia)
- build a Toy-MC by adding a Pythia (pp) event N_{coll} (from Glauber pPb calculation) times
- slice it in multiplicity as the real data

- Bias at high p_T described by incoherent superposition of pp collisions.
- For most peripheral, good agreement also in low- and intermediate p_T region.
- Strong deviations for all other centrality bins !

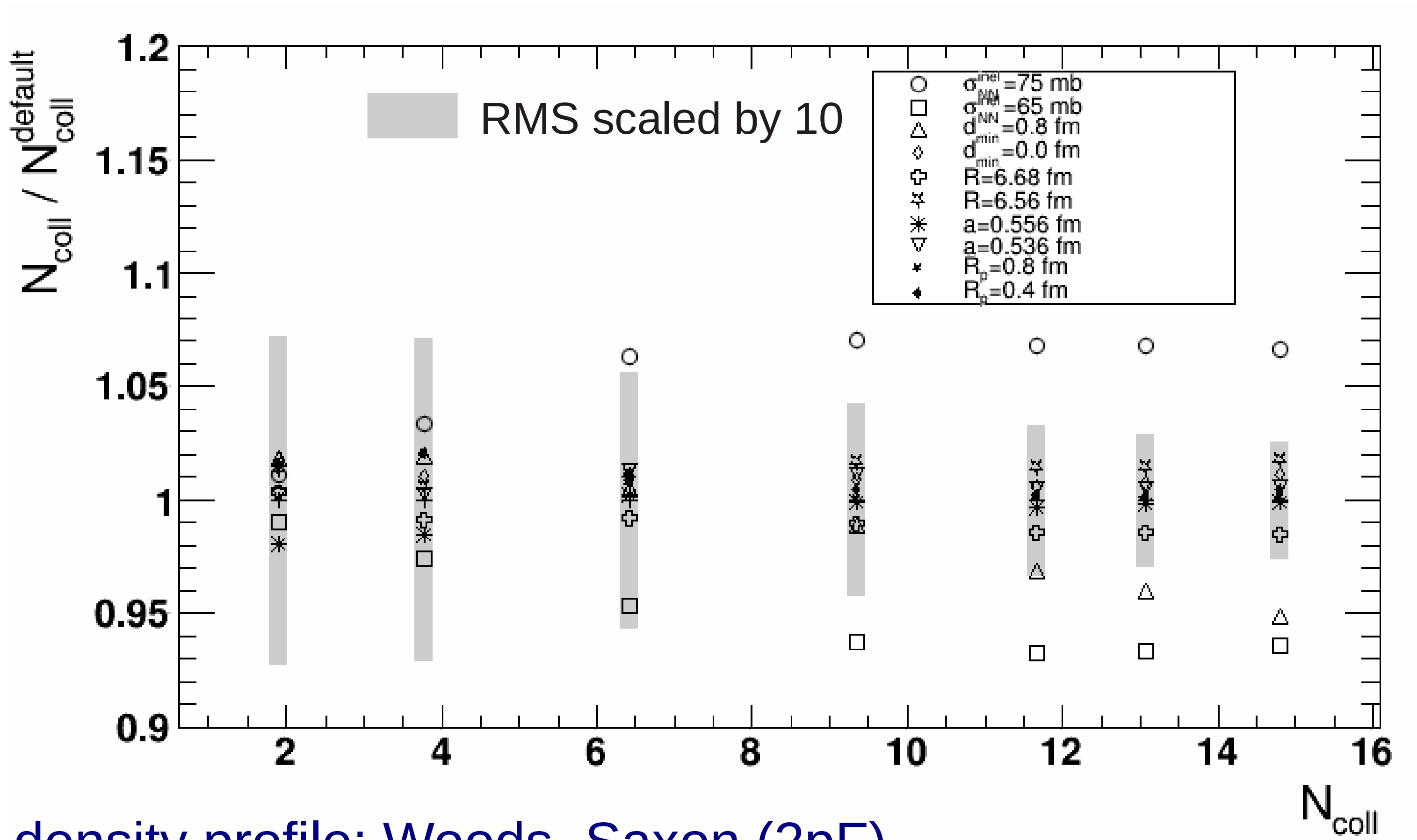
ALICE

Summary

- pA Centrality estimators based on multiplicity measurements in $|\eta| < 5$ induce a bias on the hardness of the pN collisions that can be quantified by the number of hard scatterings per pN collision.
  - Low (high) multiplicity p-Pb → lower (higher) than average number of hard scatterings.
- For "centrality" selected data, for which $\langle N_{coll} \rangle$ is not uniquely defined, we introduced Q_{pPb}, each biased by the use of the particular estimator for the event ordering
- To measure nuclear effects in pA: N_{coll} x pp is not the proper reference
  - Include full dynamical bias (incoherent superposition of pN collisions) → Glauber + pp
  - **ZDC** provides a measurement with minimal (absent?) bias, from which it should be possible to calculate R_{pPb}
    - On-going efforts to understand N_{coll} from Slow Nucleon Model

Extra

Systematic from Glauber



- Nuclear density profile: Woods−Saxon (2pF)
  - Radius = 6.62 ± 0.06 fm
  - skin depth = 0.546 ± 0.01 fm
  - Intra-nucleon distance = 0.4 ± 0.4 fm
- Cross-section σ_{NN} = 70 ± 5 mb
- Proton radius R_p = 0.6 ± 0.2 fm

Slow Nucleon Model

PROTONS

- E910 (p-Au @ 18 GeV/c) fit to N_{gray} vs. N_{coll} to determine the average number of gray protons [I. Chemakin *et al.*, Phys. Rev. C **60** 024902 (1999)]

  $<N_{gray\ p}> = (c_0 + c_1\ N_{coll} + c_2\ N_{coll})\ (A_{Pb}/A_{Au})^{2/3}$

- COSY (p-Au @ 2.5 GeV) measured the fraction of black over gray protons for the average number of black protons [A. Letourneau, Nucl. Phys. A 712 (2002) 133]

  $<N_{black\ p}> = f_{blackovergray} * <Ngray\ p>$ ➡ $f_{blackovergray} = 0.65$

- $N_{gray\ p}$, $N_{black\ p}$ extracted from binomial distributions

NEUTRONS

- from COSY: Light Charged Particle (Z<=7)

  $LCP = (<N_{gray\ p}> + <N_{black\ p}>)/\alpha$ ➡ $\alpha = 0.585$ (COSY) is left free

  $<N_{slow\ n}> = <N_{black\ n}> + <N_{gray\ n}> = a + b/(c\text{-}LCP)$ ➡ a (b, c) can be finely tuned

- results from p induced spallation reactions (0.1-10 GeV) for the fraction of black/gray neutrons

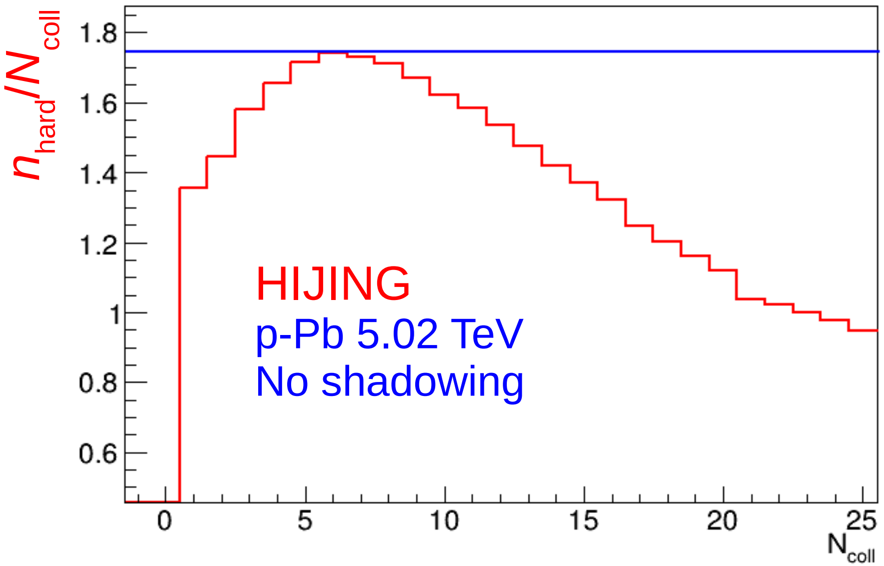
  $<N_{black\ n}> = 0.9 * (<N_{slow\ n}>)$

- $N_{gray\ n}$, $N_{black\ n}$ extracted from binomial distributions

15

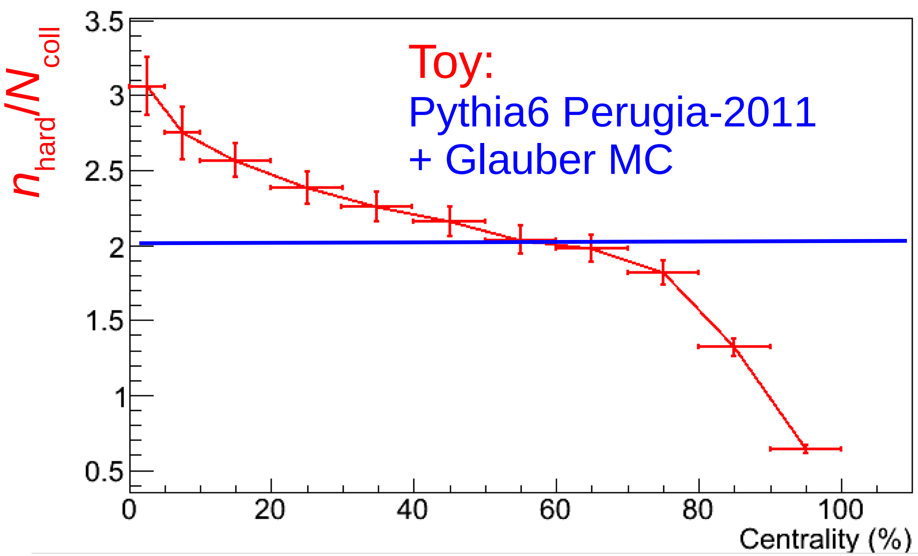
Insigths from Monte Carlo

N_{coll} scaling: n_{hard}/N_{coll} = const.



Number of hard scatterings per p-N collision

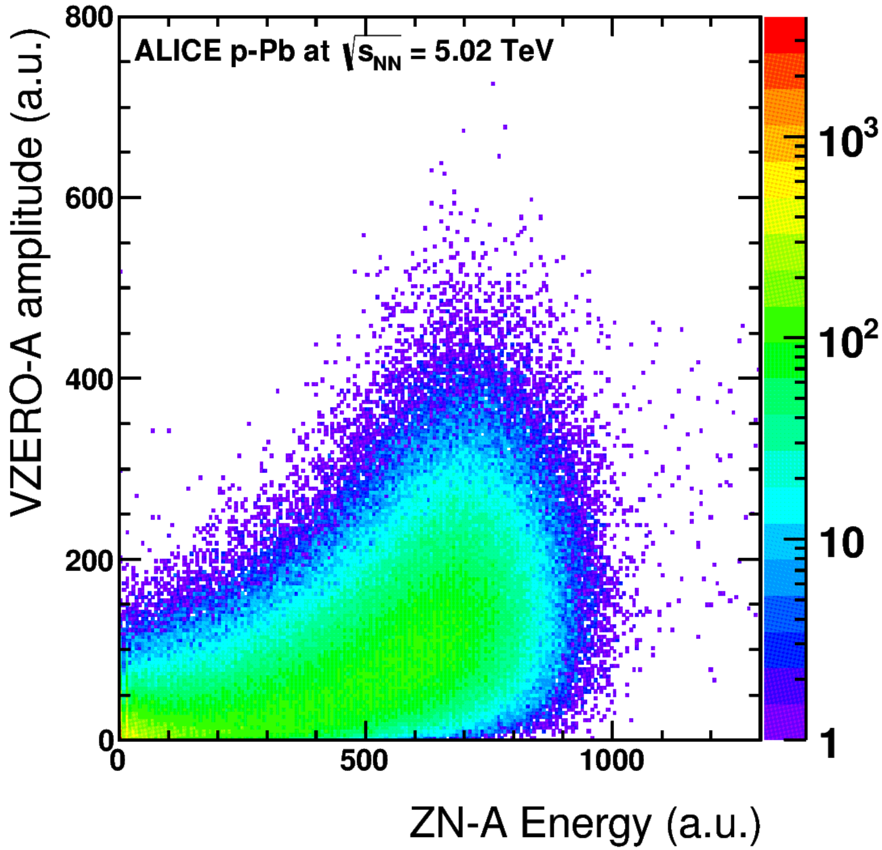
- vs N_{coll} (no multiplicity bias here !)
- Deviation from N_{coll} scaling
  - at low N_{coll} : geometry b_{NN}
  - at high N_{coll} : energy conservation (break down of factorization)

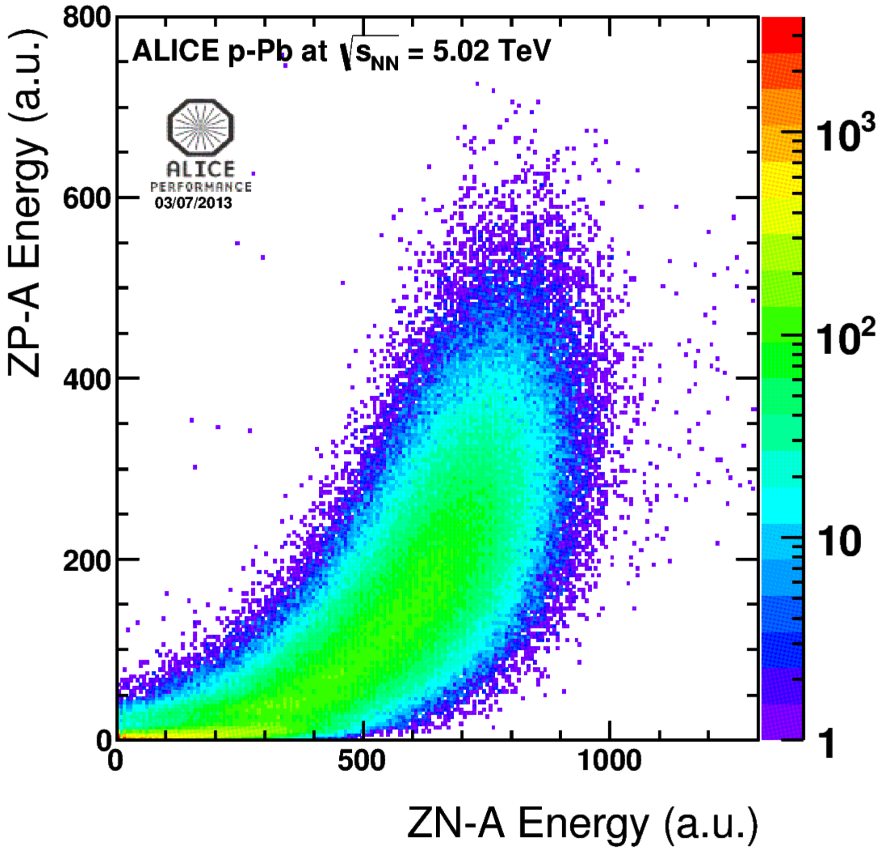


p-Pb collisions described as incoherent superposition of nucleon-nucleon

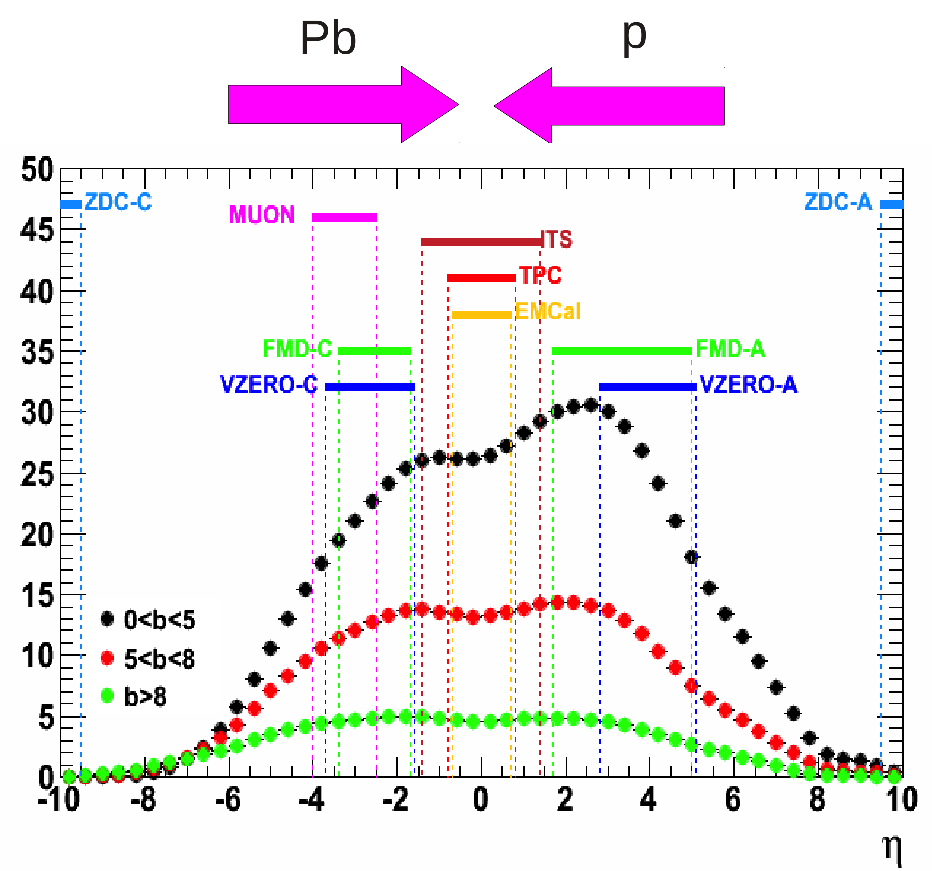
- vs centrality from multiplicity $|\eta| < 1.4$
- only multiplicity bias
- strong deviation from N_{coll} -scaling at low and high centralities.

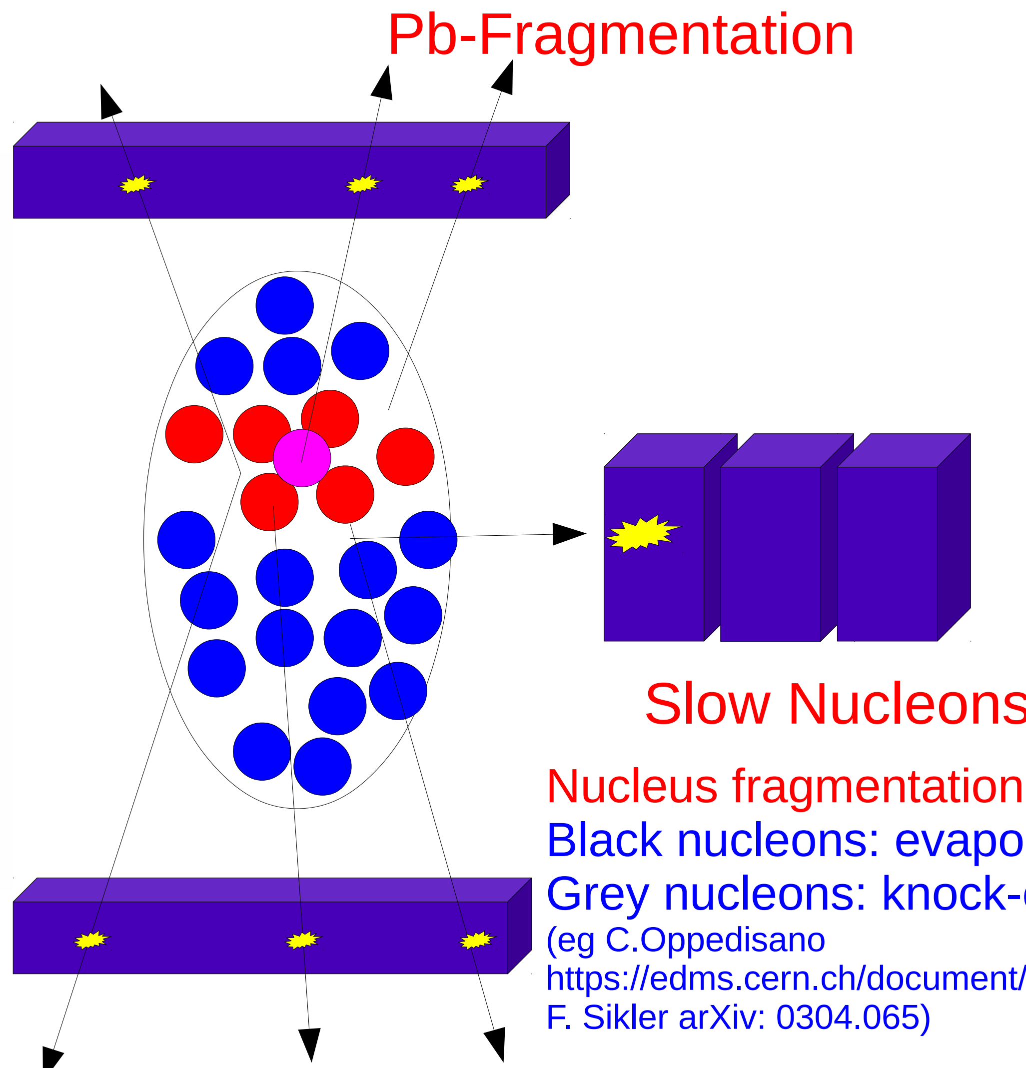
ZNA correlations





Detectors used for Centrality





Nucleus fragmentation model:
Black nucleons: evaporation
Grey nucleons: knock-out
(eg C.Oppedisano
https://edms.cern.ch/document/682801/1
F. Sikler arXiv: 0304.065)

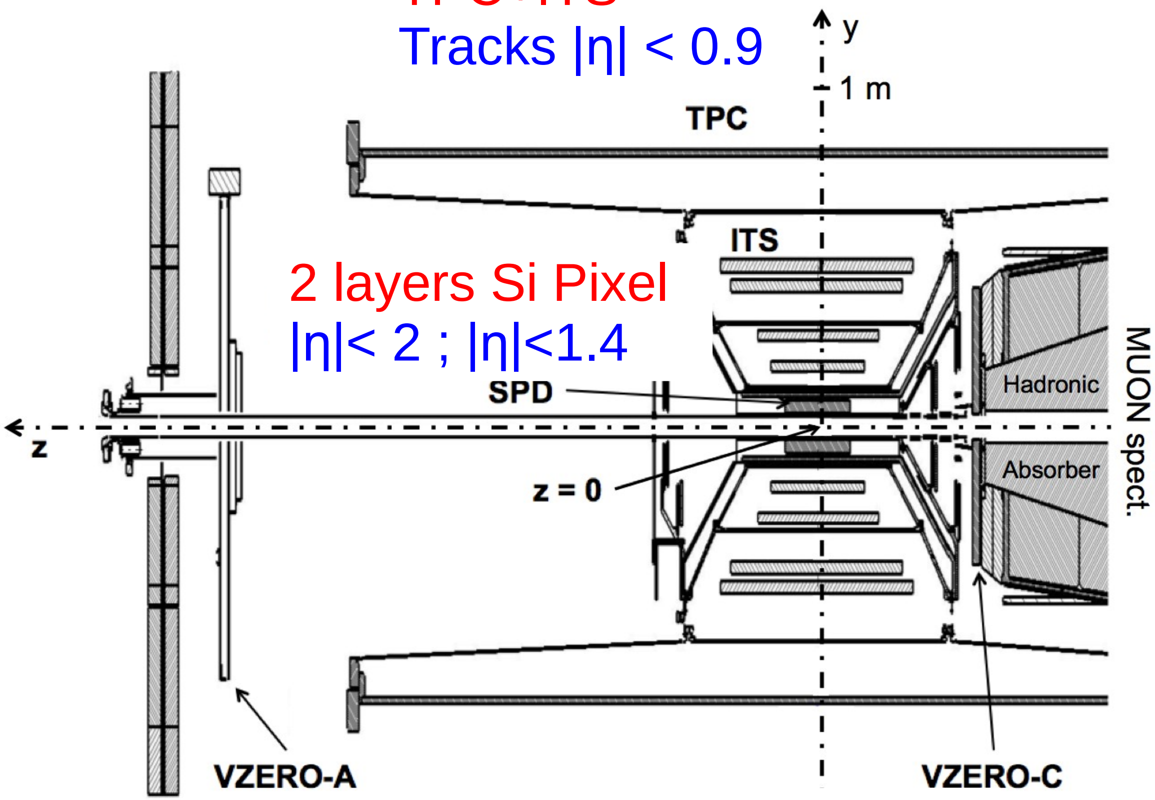
Particle production modeled by Negative Binomial Distribution (NBD)

Detectors used for Centrality

p → ← Pb

TPC+ITS
Tracks |η| < 0.9

2 layers Si Pixel
|η|< 2 ; |η|<1.4

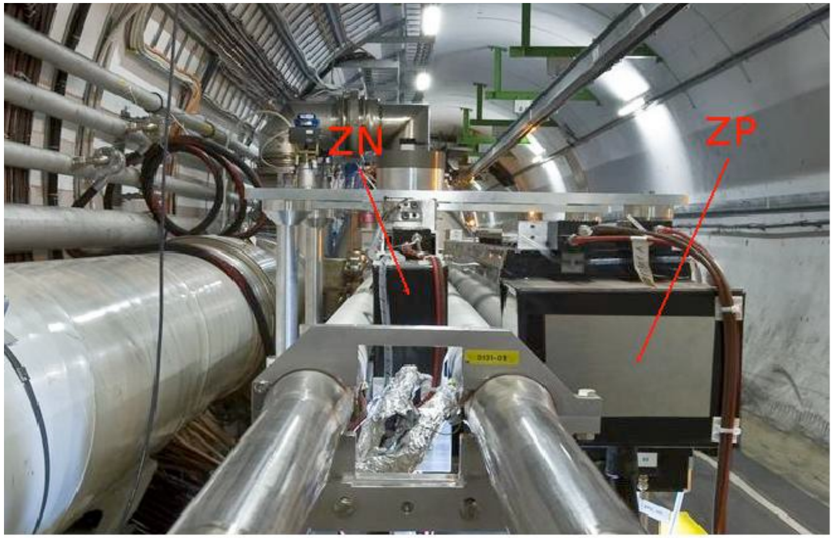


Scintillator Hodoscopes

z = 340 cm
2.8 < η < 5.1

z = -90 cm
-3.7 < η < -1.7

Quartz-Fiber "Spaghetti"
Zero Degree Calorimeters



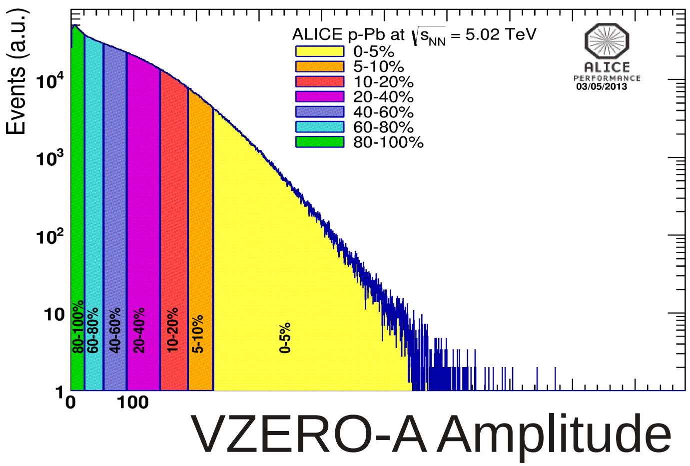
z = ·± 112.5 m

Centrality Estimators:

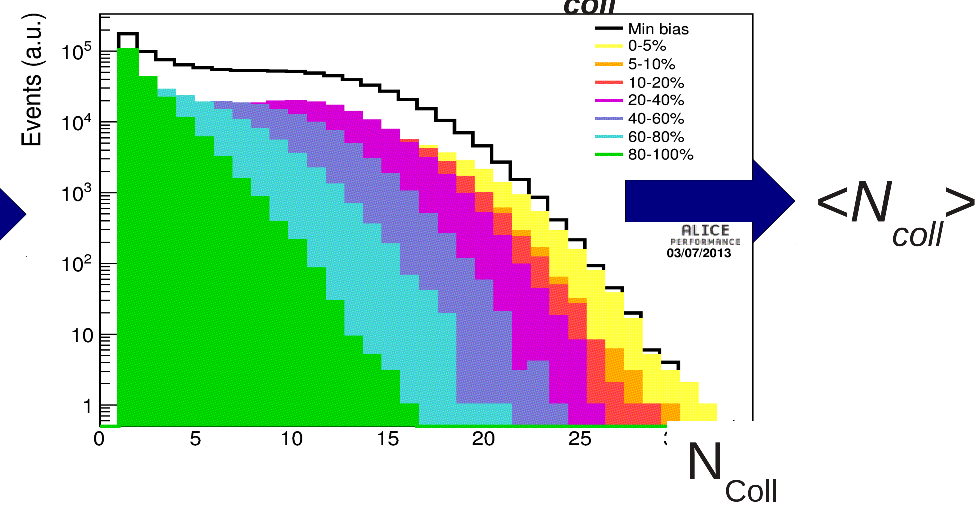
- CL1: Clusters in 2^{nd} Pixel Layer
- V0A: VZERO-A Multiplicity
- V0M: VZERO-A+C Multiplicity
- ZNA: ZN-A Energy

Results from Glauber+NBD

Slice in fitted MULT



Classes of N_{coll}



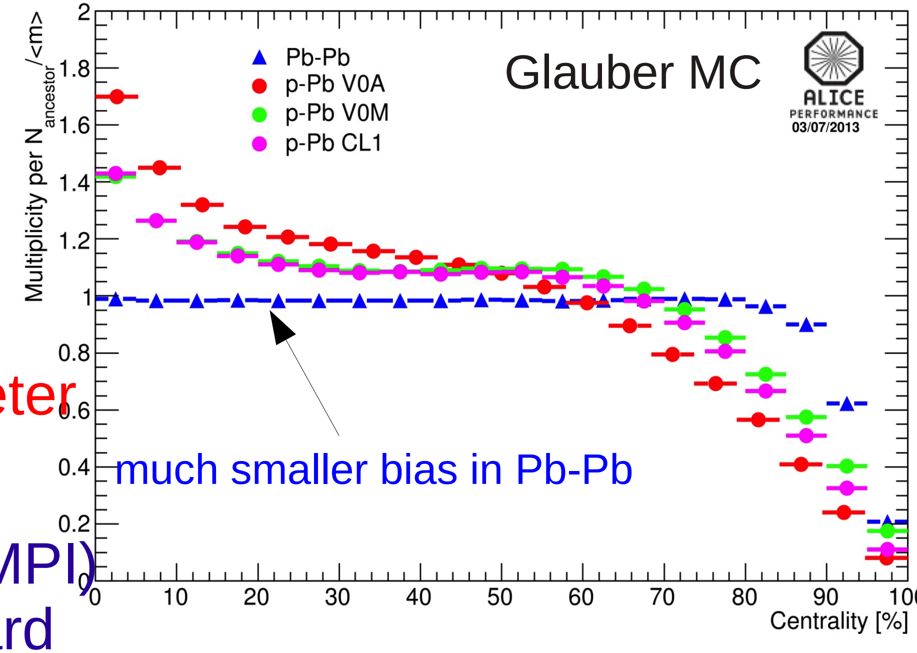
Centrality	$\langle N_{coll}\rangle$ CL1	$\langle N_{coll}\rangle$ V0M	$\langle N_{coll}\rangle$ V0A	Max Diff.	*Impact Parameter* Slicing
0 - 5%	15.4	15.8	14.8	6.8%	14.4
5 - 10%	13.5	13.7	13.1	4.5%	13.8
10 - 20%	12.0	12.1	11.7	3.4%	12.7
20 - 40%	9.3	9.4	9.4	1.1%	10.2
40 - 60%	6.0	6.1	6.5	6.6%	6.3
60 - 80%	3.46	3.33	3.85	16%	3.1
80 -100%	1.86	1.67	1.94	16%	1.44

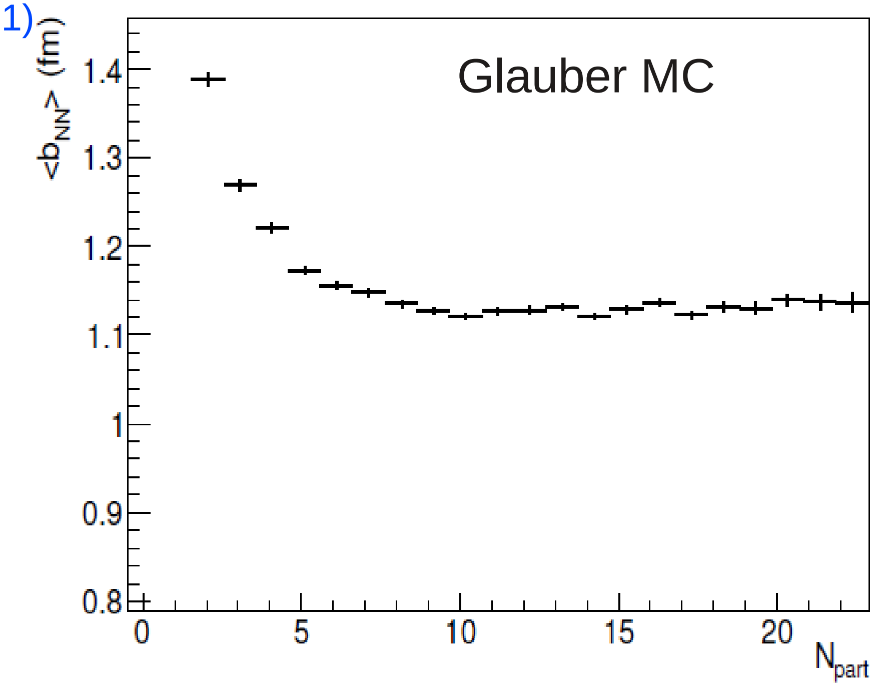
- N_{coll} similar for different estimators
- Systematic error estimated by varying Glauber MC parameters.
- MC closure test performed with HIJING

Bias in pA

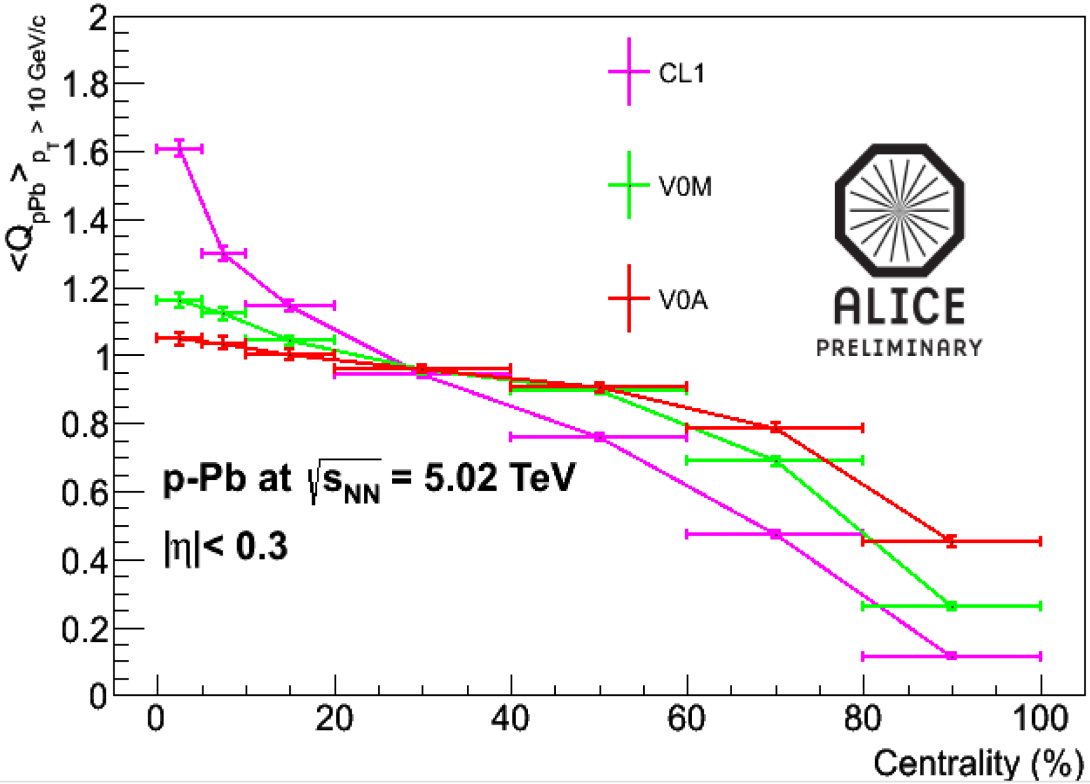
- **2.a** Multiplicity fluctuations sizable
  → Bias on Mult/N_{part} at central and peripheral collisions
- **2.b** Mean nucleon-nucleon impact parameter increases in peripheral collisions
- MC models with multi-parton interaction (MPI) include fluctuations of particle sources (hard scatterings) HIJING (X.N. Wang, M. Gyulassy, nucl-th/9502021)
  - Mean number of scatterings per event obtained from impact parameter (b_{NN})-dependent proton-nucleon overlap function $T_N(b_{NN})$

  → bias in mult ~ bias in hard scattering
- **2.c** Jet-veto: multiplicity range in peripheral events represent an effective veto on hard processes



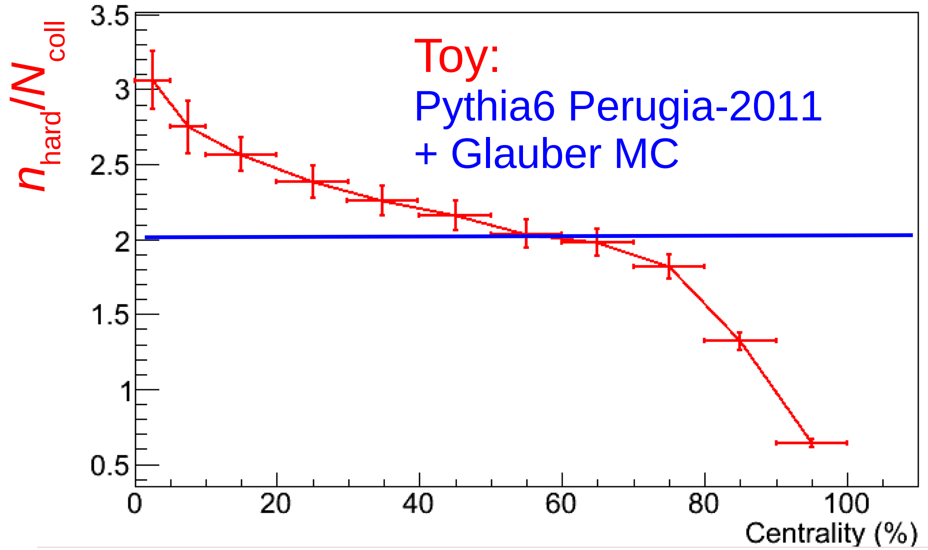


Mean Q_{pPb} at $p_T > 10$ GeV



p-Pb collisions described as incoherent superposition of nucleon-nucleon

- vs centrality from multiplicity $|\eta| < 1.4$
- only multiplicity bias
- strong deviation from N_{coll} -scaling at low and high centralities.



Same “S-shape” dependence as seen
- from multiplicity bias (Glauber + NBD fit)
- from Toy-MC (Glauber+Pythia)

Shape flattens with increasing rapidity gap:
CL1→V0M→V0A

Toy-MC (Glauber+Pythia)
- build a Toy-MC by adding a Pythia (pp) event N_{coll} (from Glauber pPb calculation) times
- slice it in multiplicity as the real data