Analysis of the apparent nuclear modification in peripheral 5.02 TeV Pb-Pb collisions

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Introduction

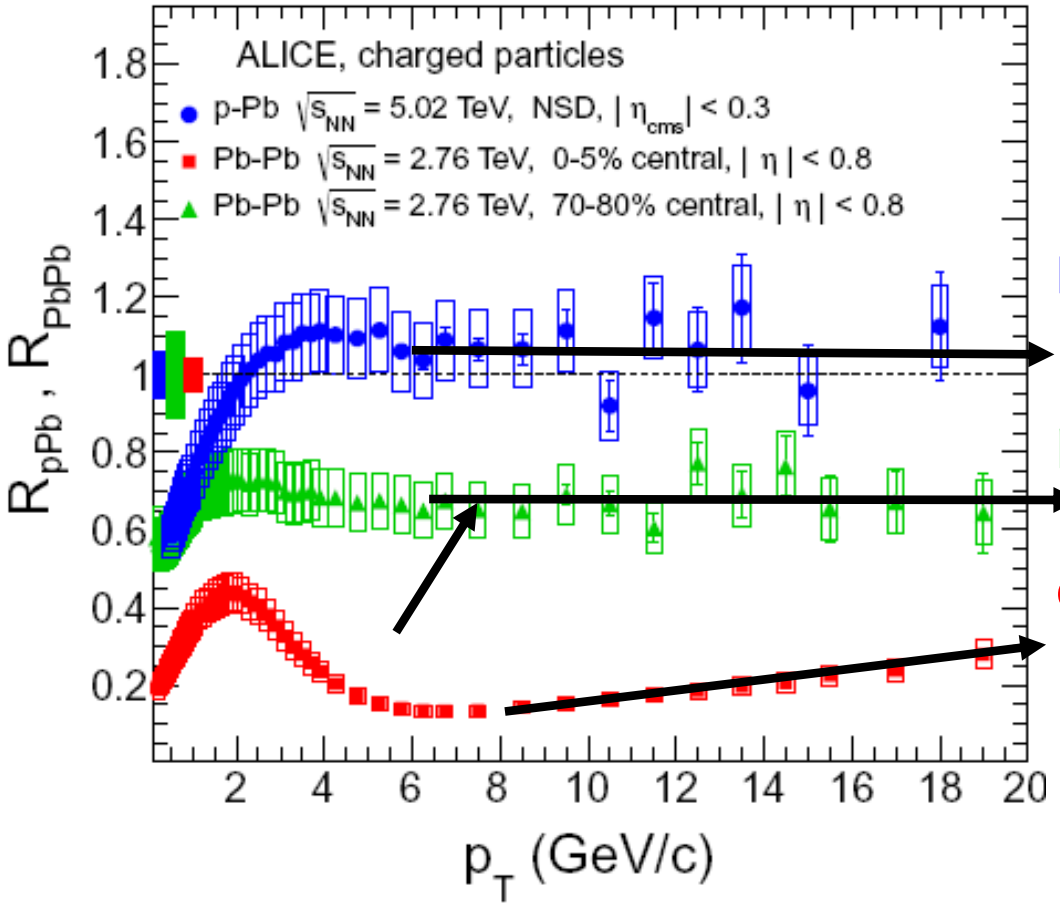
- «AA effects» normally associated with collectivity are also present in p-A (or even pp) collisions:
  - e.g. radial flow, anisotropic flow, correlations, ...
- several observables show a continuous trend as function of multiplicity, independent on the collision system:
  - e.g. identified particle spectra, particle ratios, ...
- it seems that (central) p-A and high multiplicity pp collisions are not so different from Pb-Pb collisions

- one distinct exception is the parton energy loss (jet quenching) which is not observed in p-Pb collisions
- quantified by the nuclear modification factor R_{AA}:

$$R_{\mathrm{AA}}\left(p_{\mathrm{T}}\right)=\frac{d^{2}N^{\mathrm{Pb-Pb}}/d\eta dp_{\mathrm{T}}}{\langle N_{\mathrm{coll}}\rangle\cdot d^{2}N^{\mathrm{pp}}/d\eta dp_{\mathrm{T}}}$$

p-Pb vs. Pb-Pb

ALICE Collaboration, Phys. Rev. Lett. 110 (2013) 082302



- **hard processes scale with N_{coll} => R_{AA} = 1 in absence of nuclear effects**

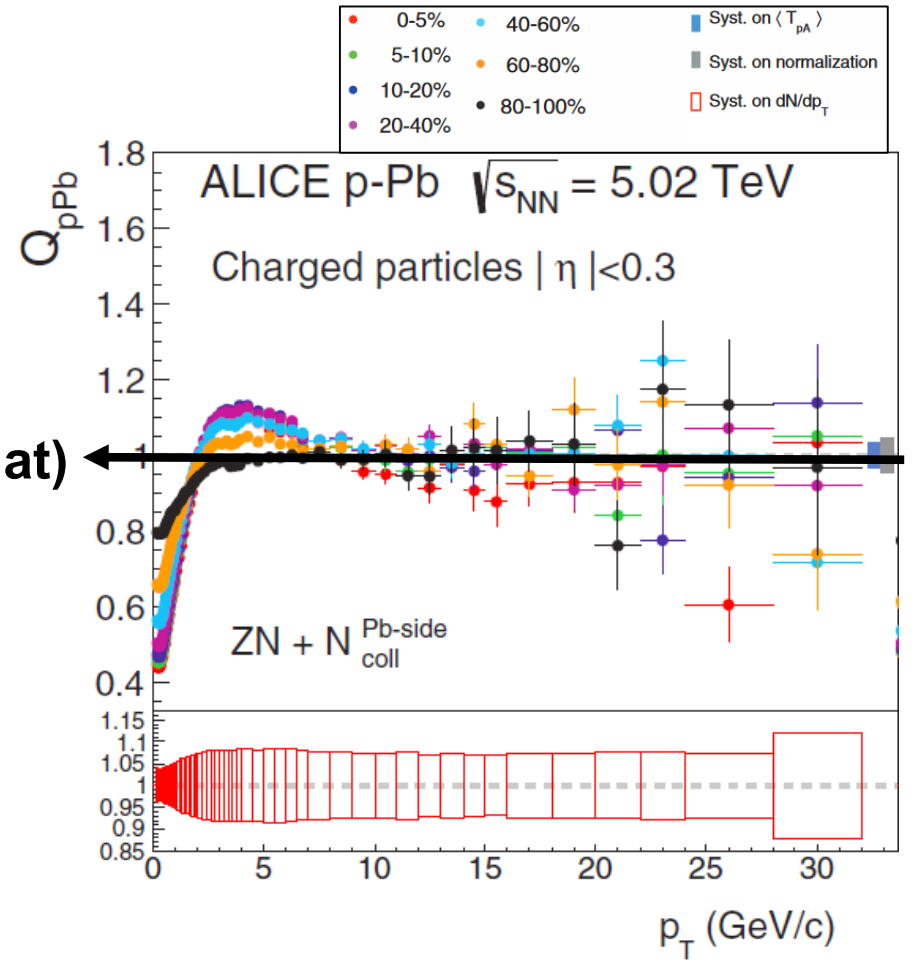
MinBias R_{pPb} ≈ 1 (~flat)

peripheral R_{PbPb} ≈ 0.7 (~flat)

central R_{PbPb} ≈ 0.2-04 (rising)

hybrid Q_{pPb} ≈ 1 (~flat)

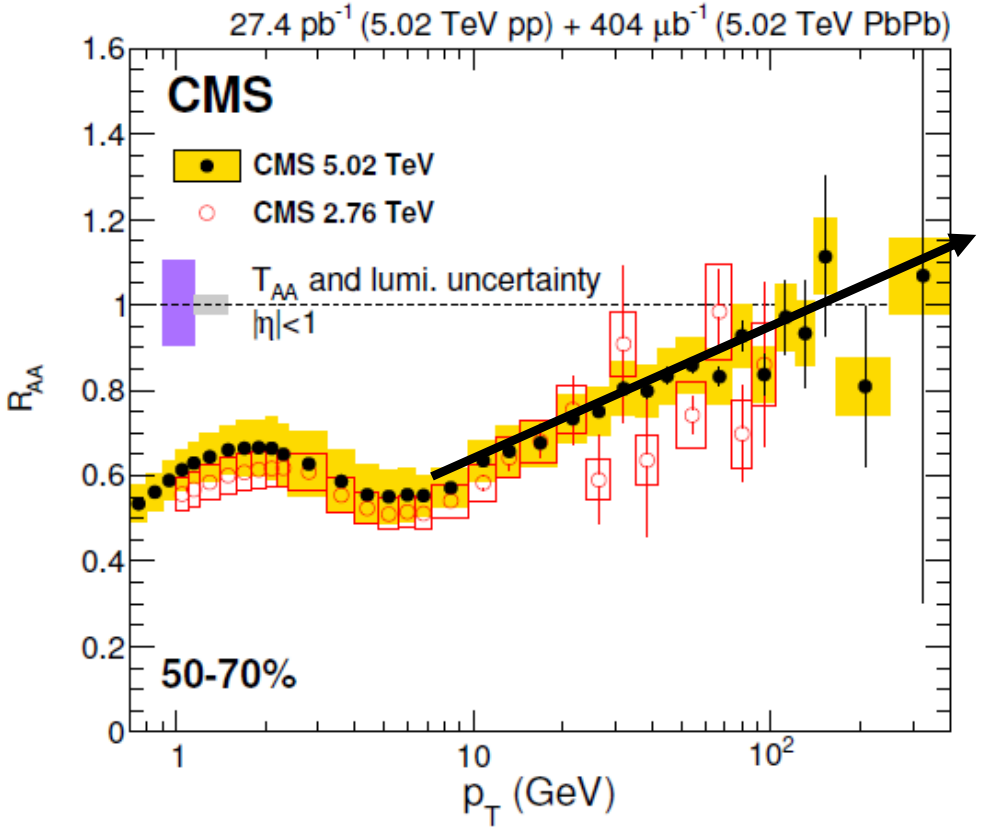
ALICE Collaboration, Phys. Rev. C 91 (2015) 064905

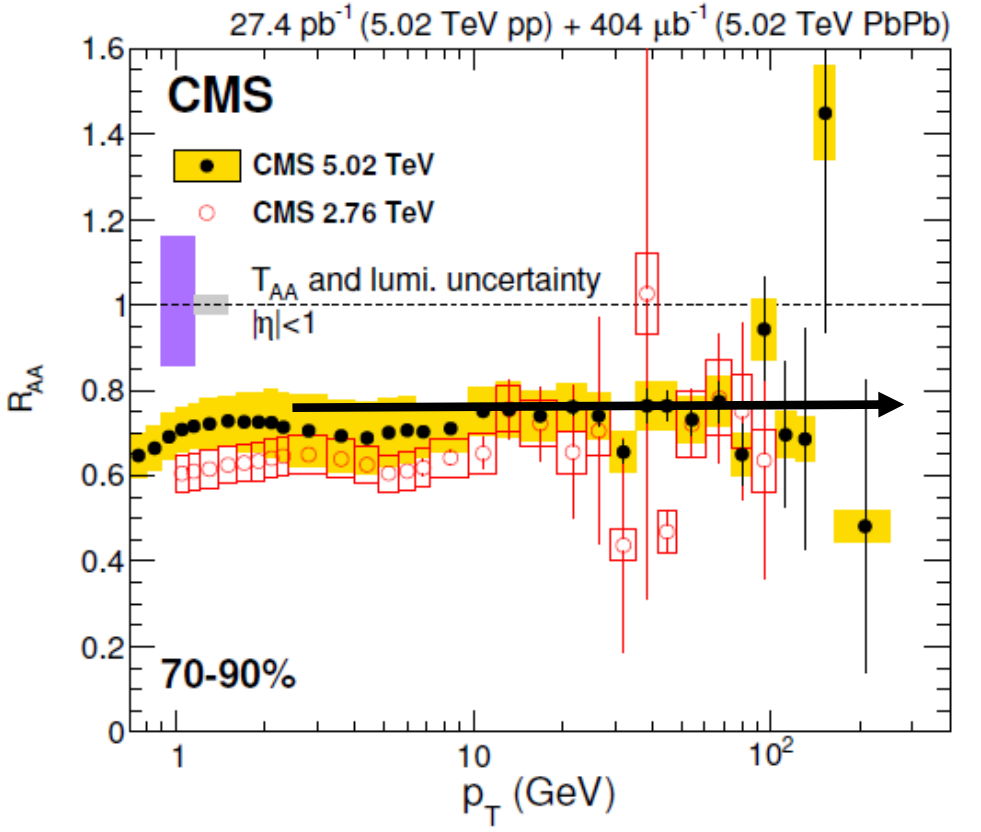


from N_{coll}, N_{part}, dN_{ch}/dη:

- **0-5% p-Pb ~ 70-80% Pb-Pb**
- **0-100% p-Pb ~ 80-90% Pb-Pb**

Central vs. peripheral Pb-Pb





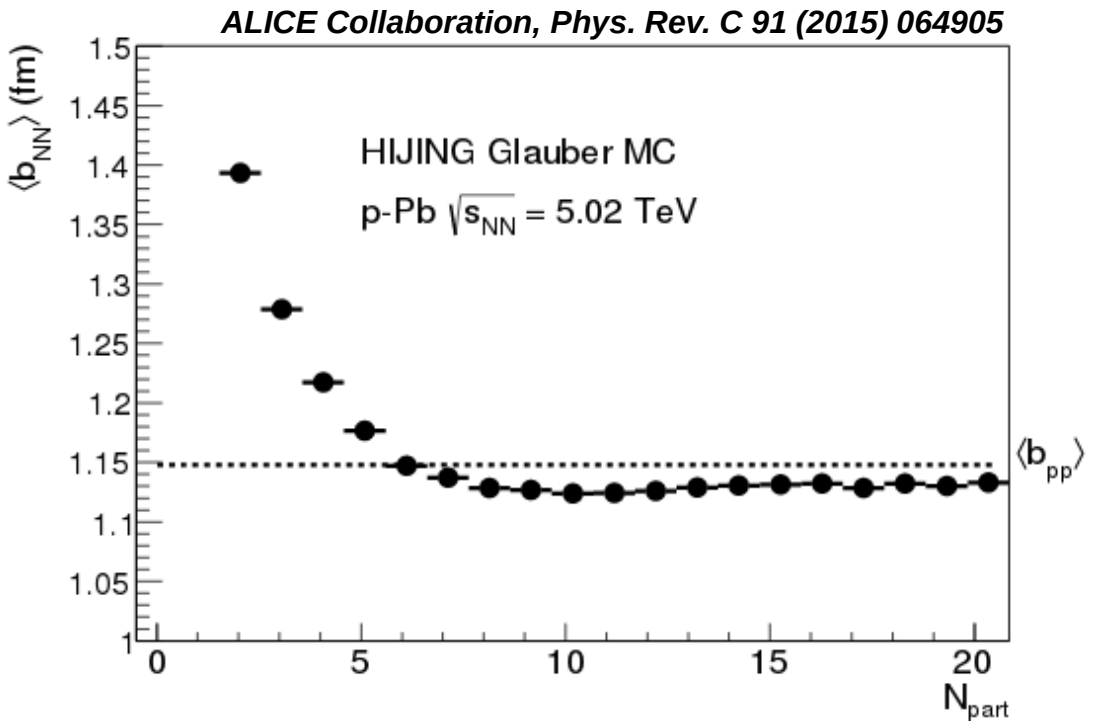
CMS Collaboration, JHEP 04 (2017) 039

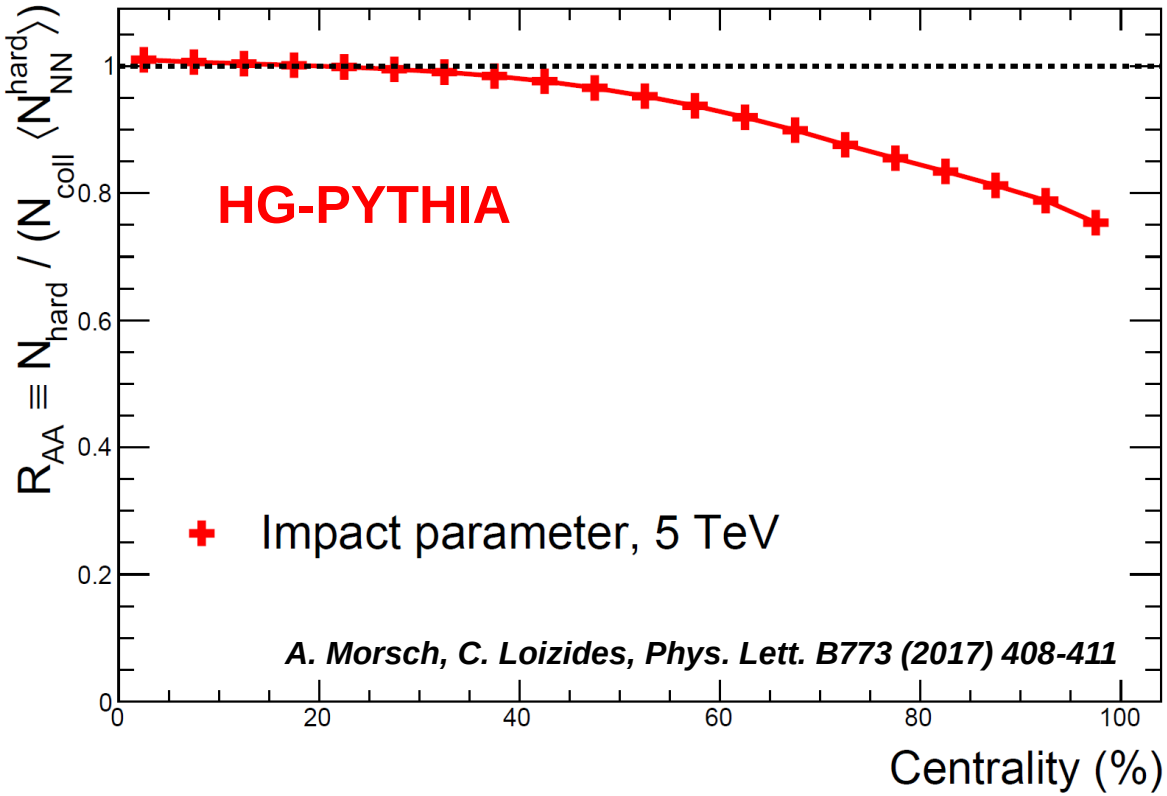
- change in R_{AA} behavior vs. p_T : rising (central) -> flat (peripheral)
- apparent suppression in peripheral caused by biases in measurement?

=> measure R_{AA} in finer centrality bins (5%) and for all (0-100%) centralities

Geometric bias

- standard Glauber model: all individual nucleon-nucleon (NN) collisions are the same
- but they differ in NN impact parameter b_{NN}
- peripheral collisions are biased towards larger b_{NN}
- larger b_{NN} => lower number of hard scatterings (MPIs)
- bias independent of centrality estimator (even for impact parameter slicing)



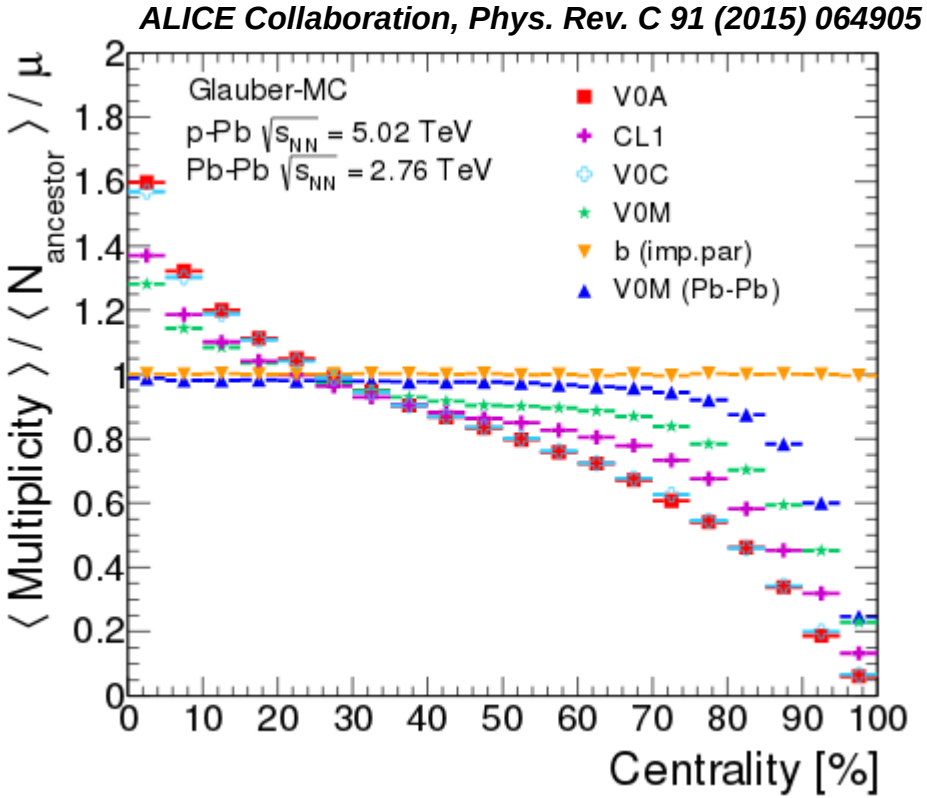


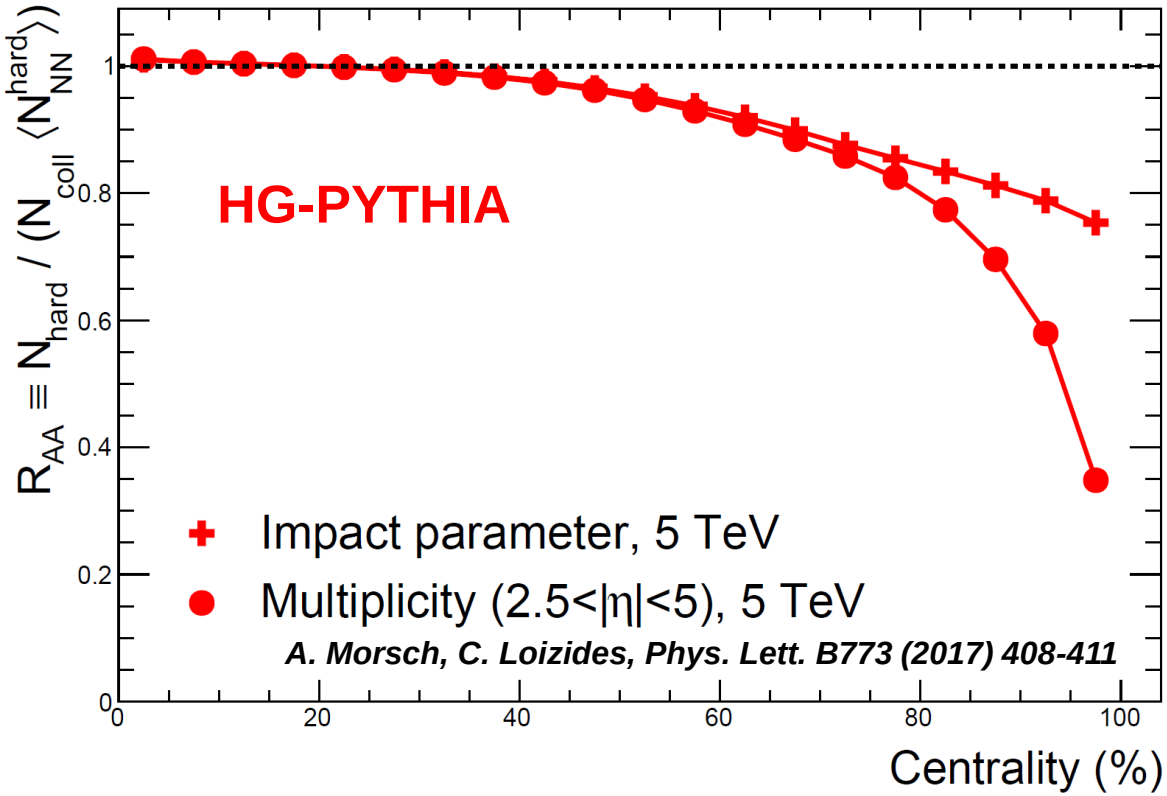
- Effect estimated in absence of nuclear effects with HIJING-Glauber-PYTHIA (HG-PYTHIA):
  - incoherent superposition of PYTHIA pp collisions with each #MPI from HIJING-Glauber
  - Glauber model with HIJING b_{NN} dependence yields #MPI for each NN collision

(A. Morsch, C. Loizides, Phs. Lett. B773 (2017) 408-411)

Multiplicity selection bias

- **experimentally, we select centrality not by collision geometry, but by slicing in multiplicity in some detector (VZERO)**
- **this way when selecting peripheral collisions => selecting events with lower multiplicity per N_{part}**
- **bias on the number of hard scatterings (MPIs)**

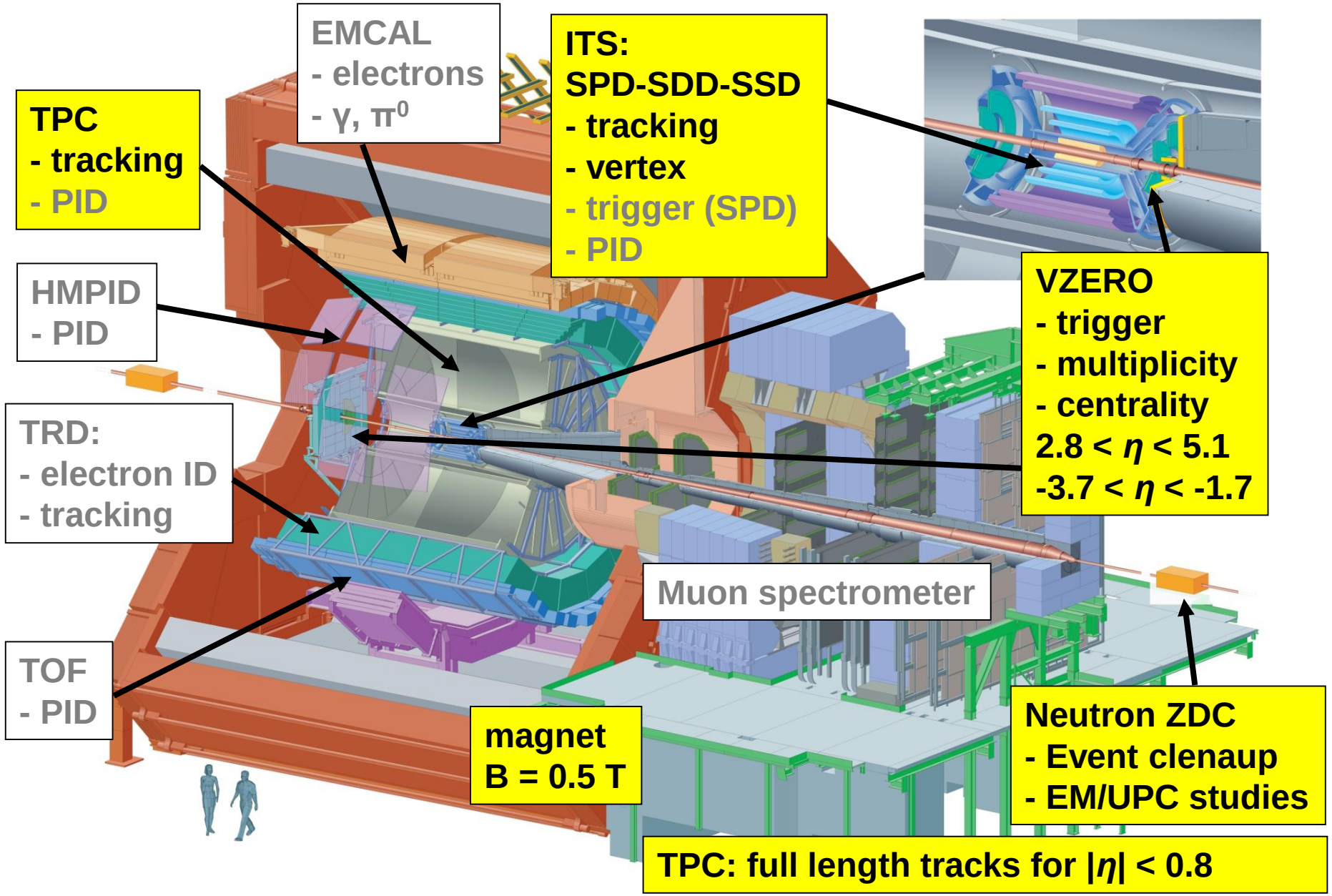




- **can not be separated experimentally from geometry bias**
- **estimate in HG-PYTHIA (in addition to the geometry bias):**
- **becomes relevant already for mid-central collisions**
- **huge effect in the most peripheral bins**

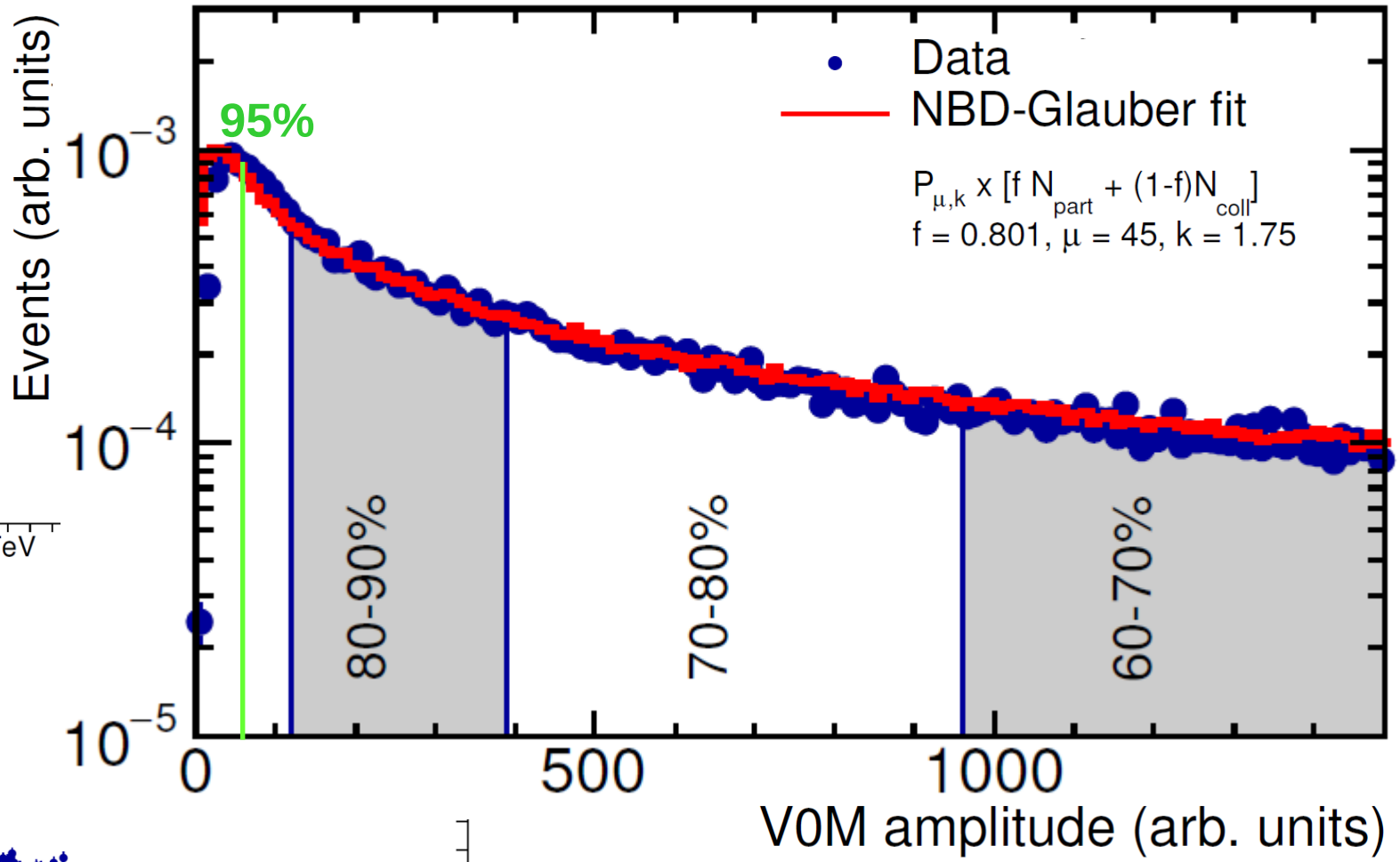
=> look in data for the effect in peripheral collisions

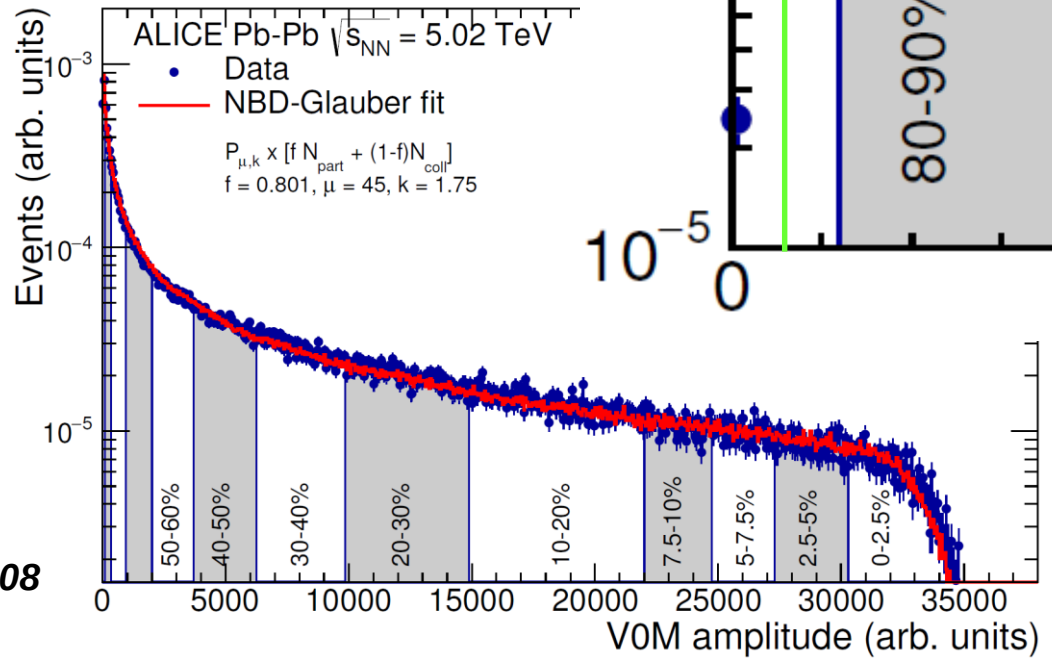
The ALICE detector



Selecting „peripheral“ Pb-Pb collisions

- **Centrality: experimentally multiplicity in VZERO scintillators**
- **trigger: VZERO-AND**
- **background rejection with neutron ZDCs**
- **reconstructed event vertex required**

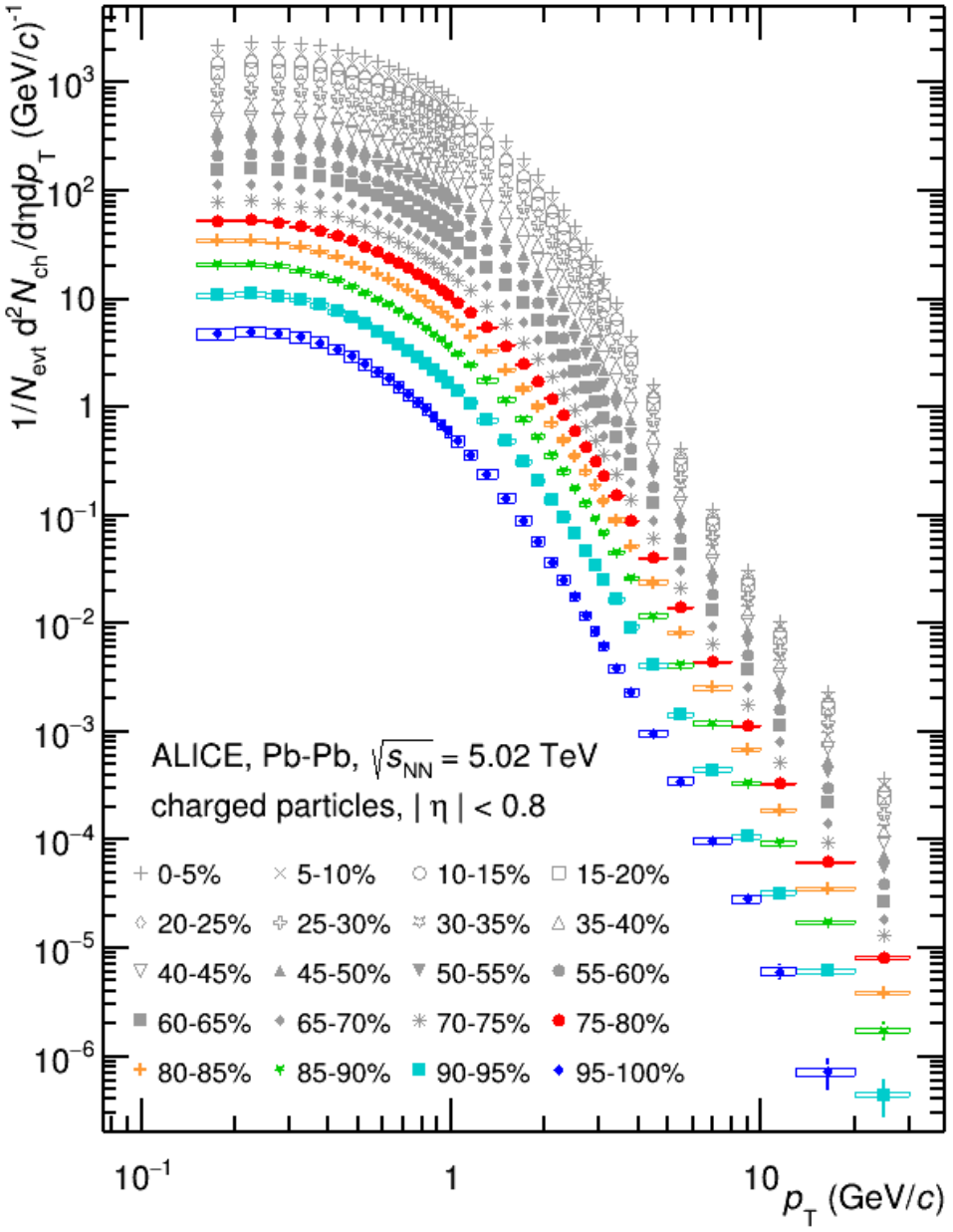




ALICE Collaboration, ALICE-PUBLIC-2015-008

90-95% and 95-100% classes based on Glauber-NBD fit (changed for syst. uncertainty)

Tranverse momentum spectra



- **Primary charged particles**
- **5% wide centrality bins**
- **covers 0-100%**
- **$0.15 < p_T < 30$ GeV/c**
- **most peripheral bin: $p_T < 20$ GeV/c**

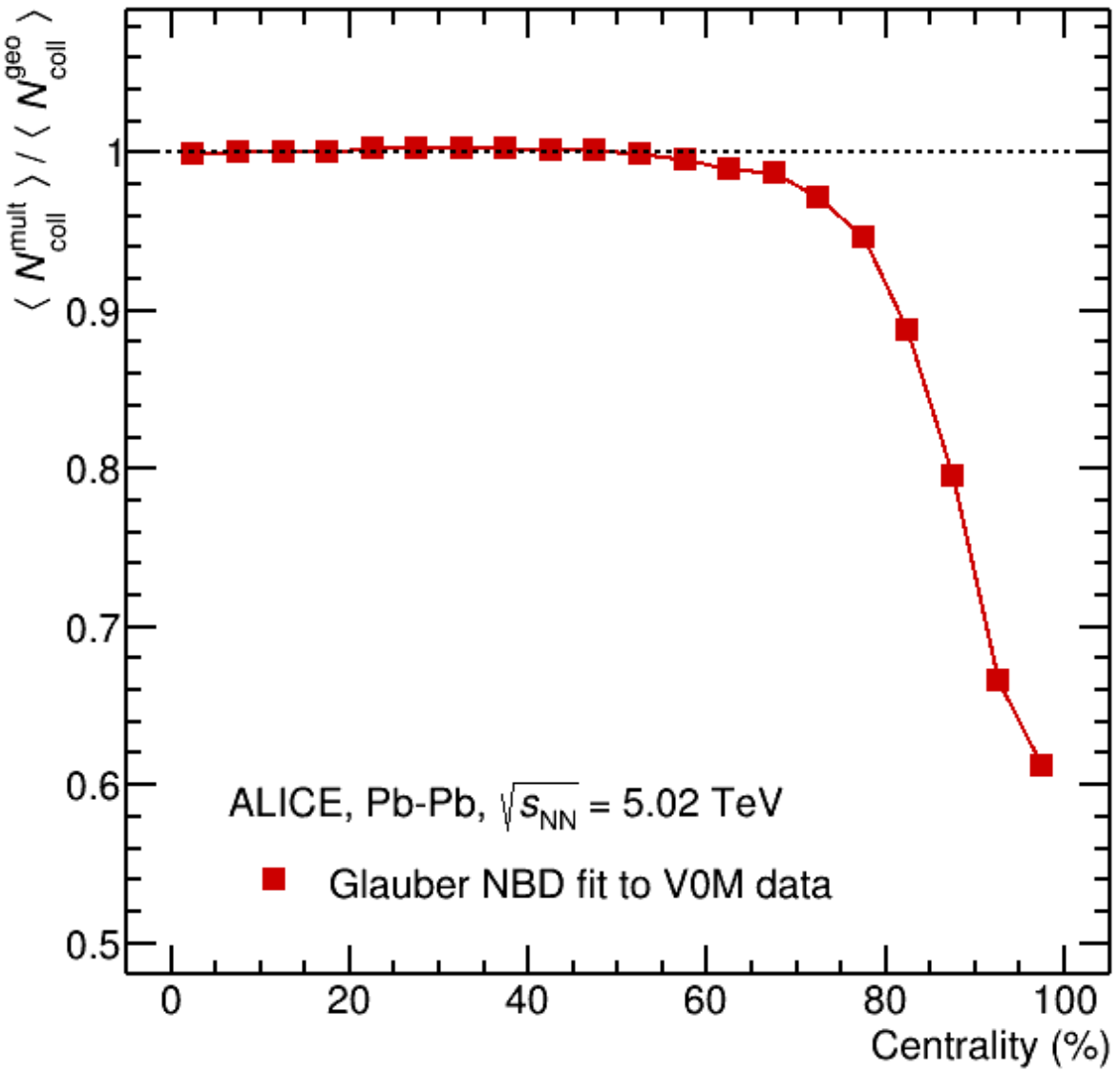
***ALICE Collaboration,* arXiv:1805.05212**

N_{coll} determination

- Normalization of R_{AA} based on N_{coll}
- N_{coll} values can be determined from impact parameter slicing (N_{coll}^{geo}) or from slicing in the Glauber-NBD fit (N_{coll}^{mult})
- Slicing in impact parameter leads to an overestimate of N_{coll} => bias on R_{AA}

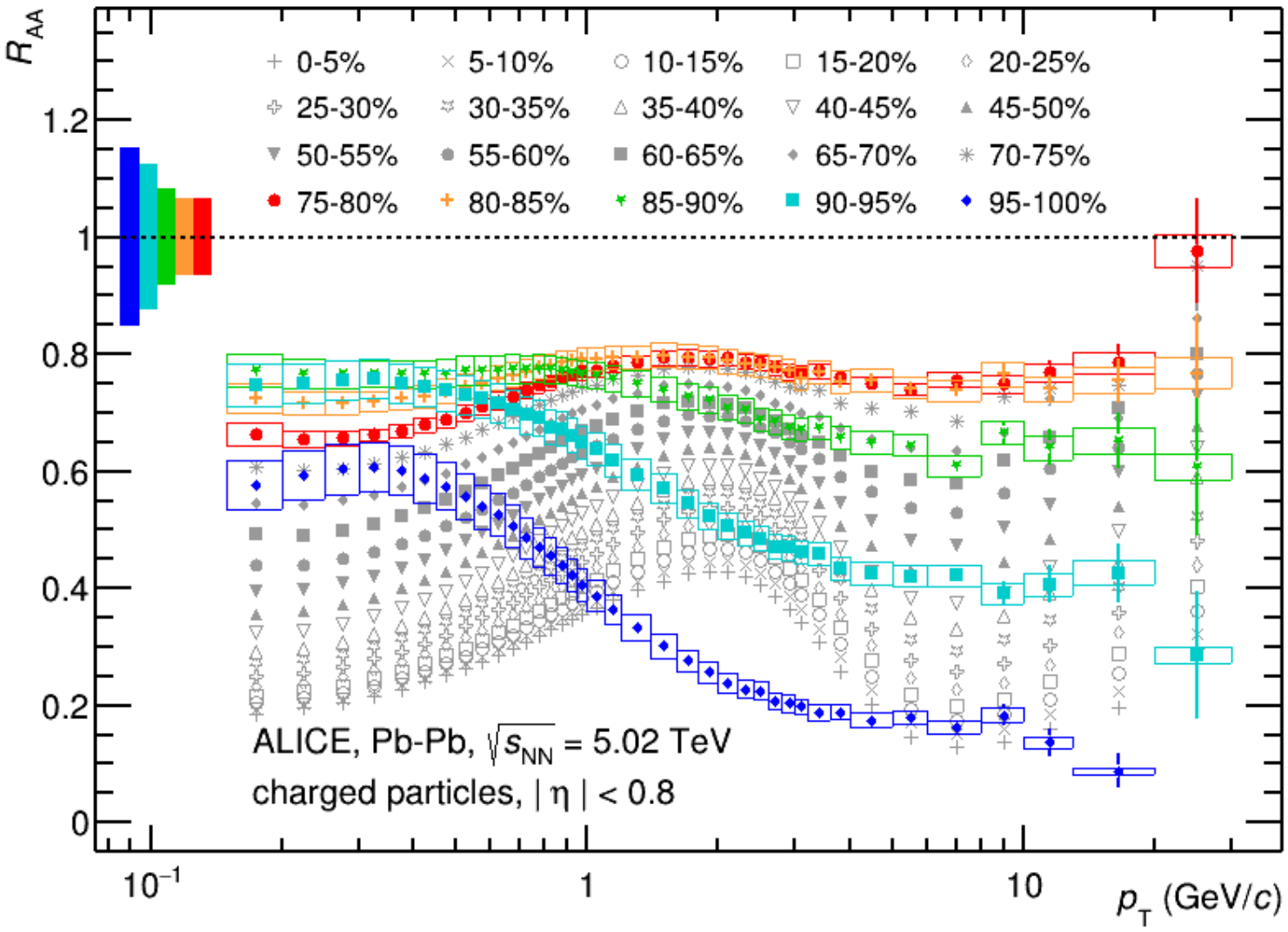
- We used average N_{coll}^{mult} extracted from NBD-Glauber fit sliced in multiplicity to avoid the bias from N_{coll}^{geo}

ALICE Collaboration, arXiv:1805.05212



Nuclear modification factor

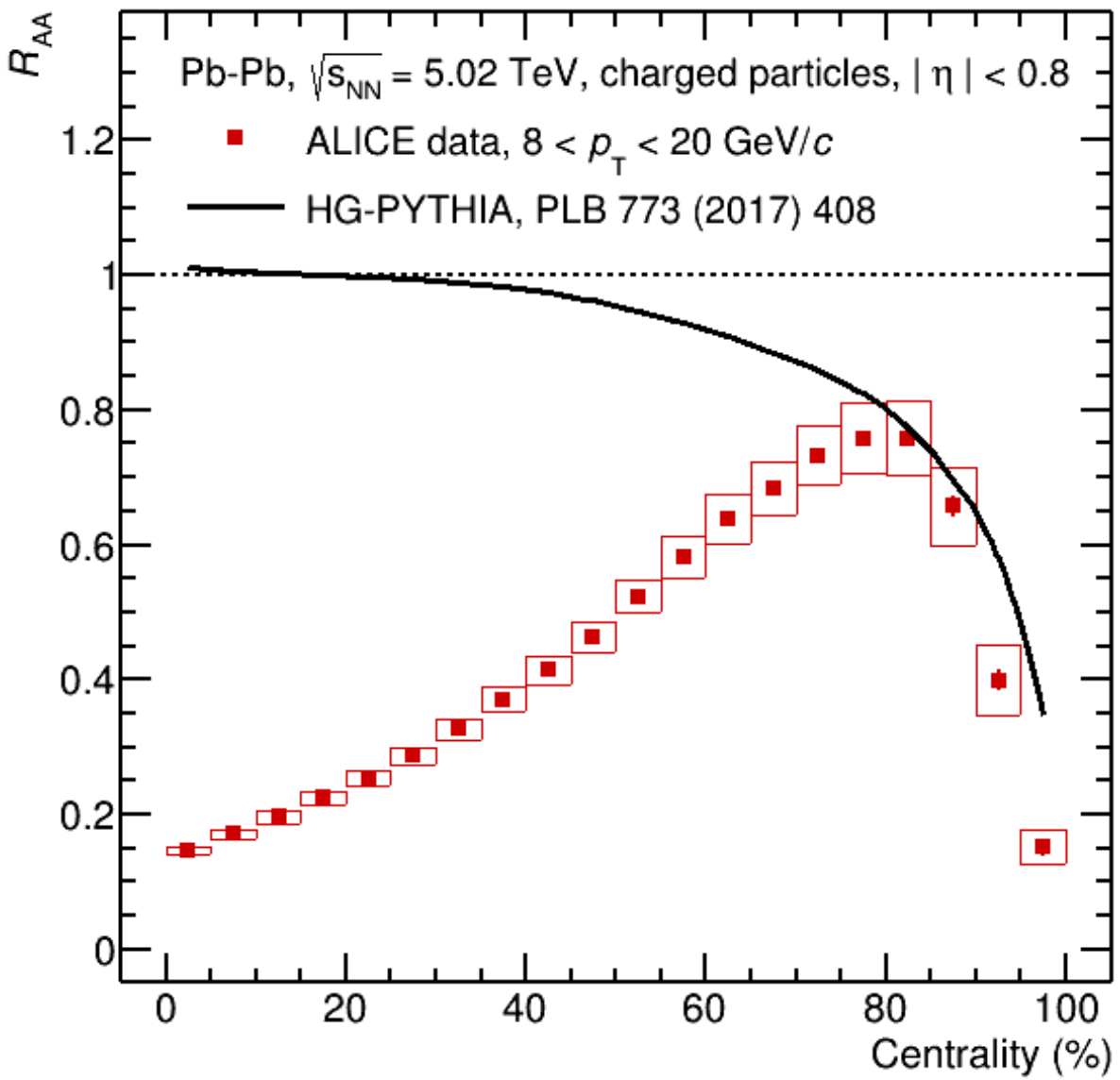
ALICE Collaboration, arXiv:1805.05212



- From central to ~80% peripheral collisions:
  - R_{AA} increases at large p_T => reduced parton energy loss
  - decreased radial flow
- shows dramatic change for centralities > 80%
- decrease of R_{AA}, sign change of slope at high and low p_T

R_{AA} at large p_T

ALICE Collaboration, arXiv:1805.05212



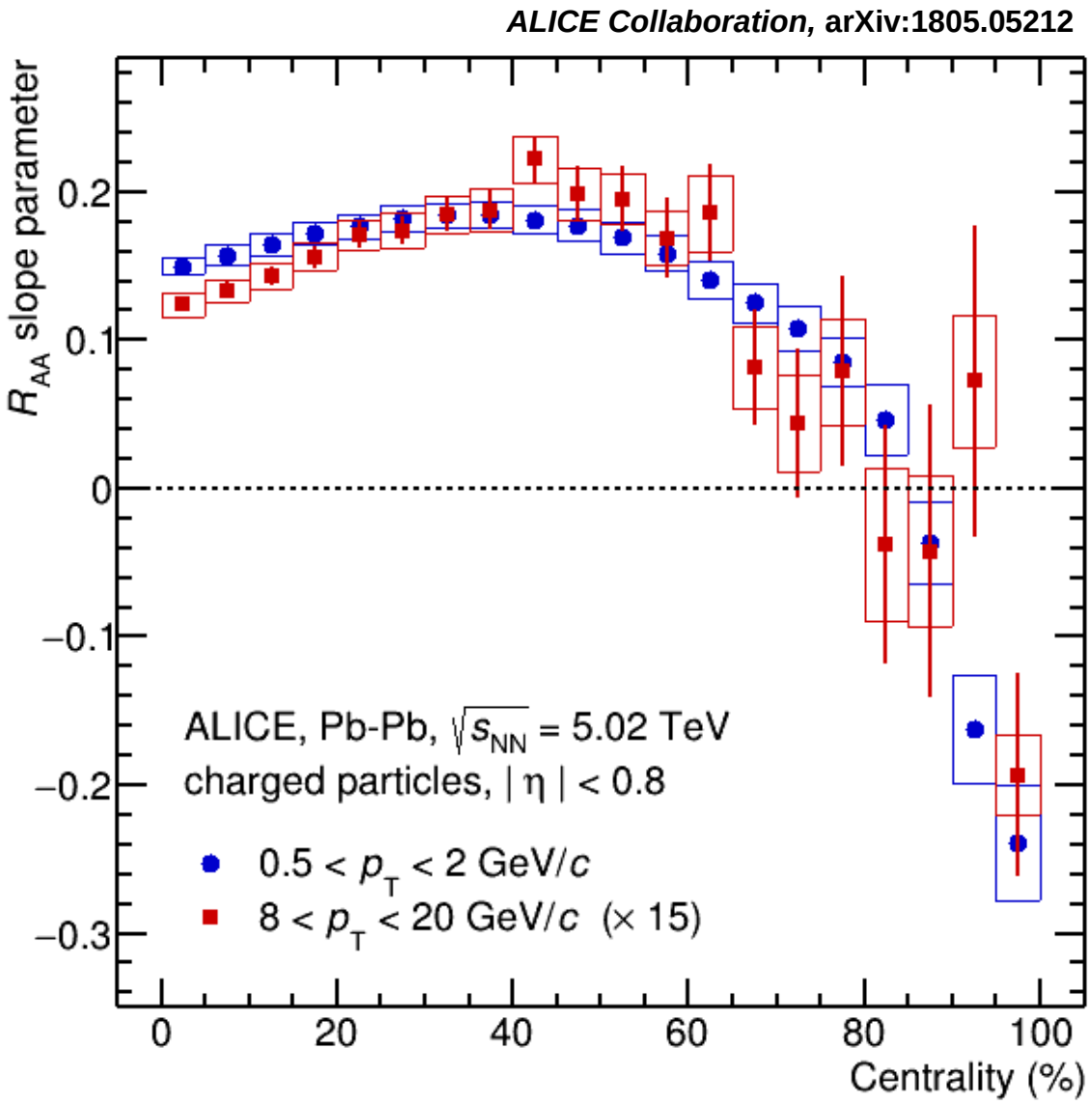
- **R_{AA} averaged over 8 < p_T < 20 GeV/c as function of centrality**
- **central collisions: strong quenching, reduced towards peripheral collisions**
- **minimal suppression (maximal R_{AA}) around 80%**
- **beyond 80% centrality: increased suppression because of selection bias**

- **R_{AA} never reaches unity**
- **HG-PYTHIA contains no nuclear effects**

⇒ no need for jet quenching above 75% centrality

⇒ 5-10% effect for 50-60% central

Slope of R_{AA} at low and high pT



fit a linear function to R_{AA} at low p_T (0.5-2 GeV/c) and high p_T (8-20 GeV/c)

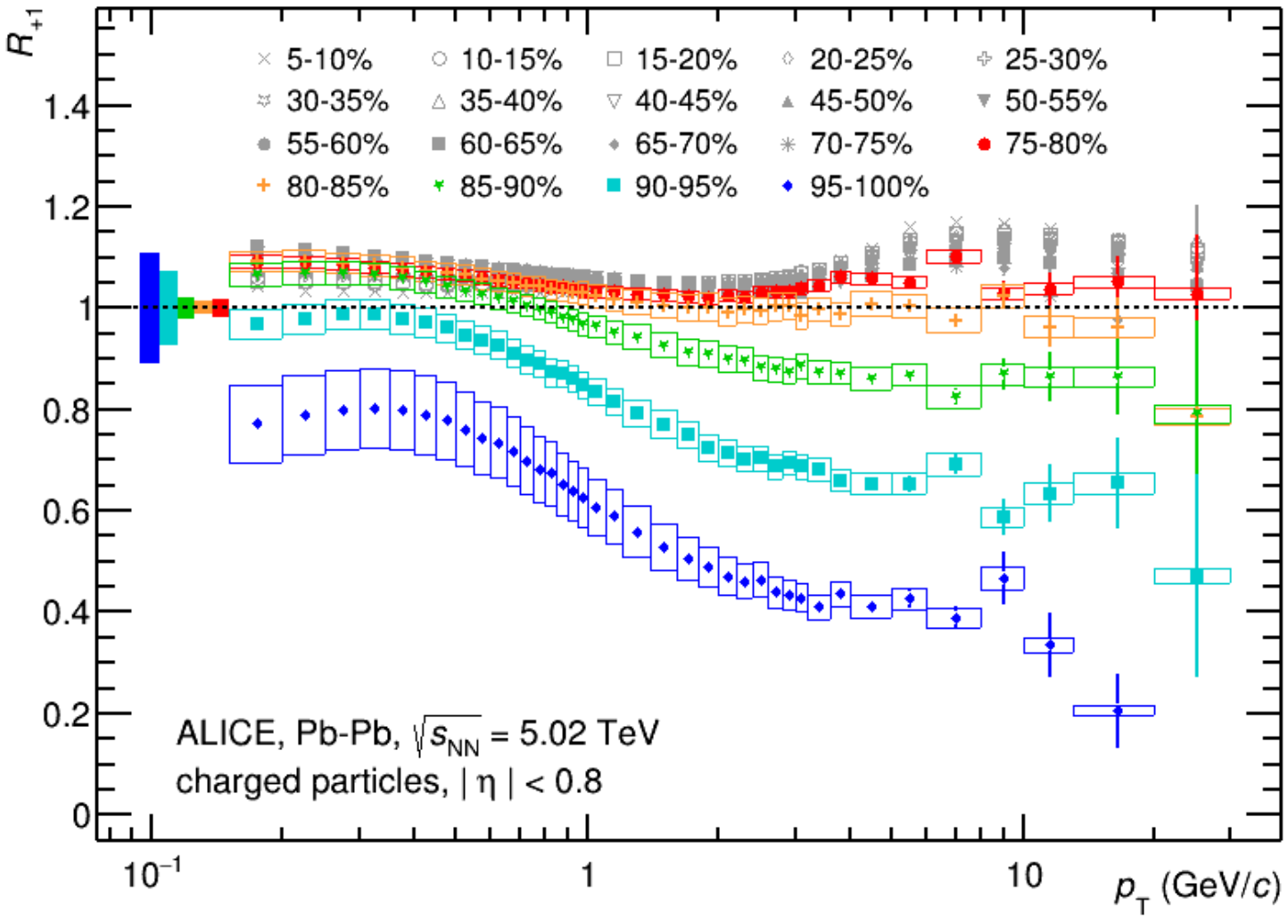
- **slope not affected by any normalization uncertainty**
- **the rise of R_{AA} gets stronger up to 40%**
- **slope at high p_T is consistent with zero for >80% central**

- **the slope at low and high p_T is different by a factor ~15**
- **origin of the rise is very different at low and high p_T**
- **but the centrality dependence is strikingly similar**

=> correlation between radial flow (low p_T) and energy loss (high p_T)?

R_{+1}

ALICE Collaboration, arXiv:1805.05212



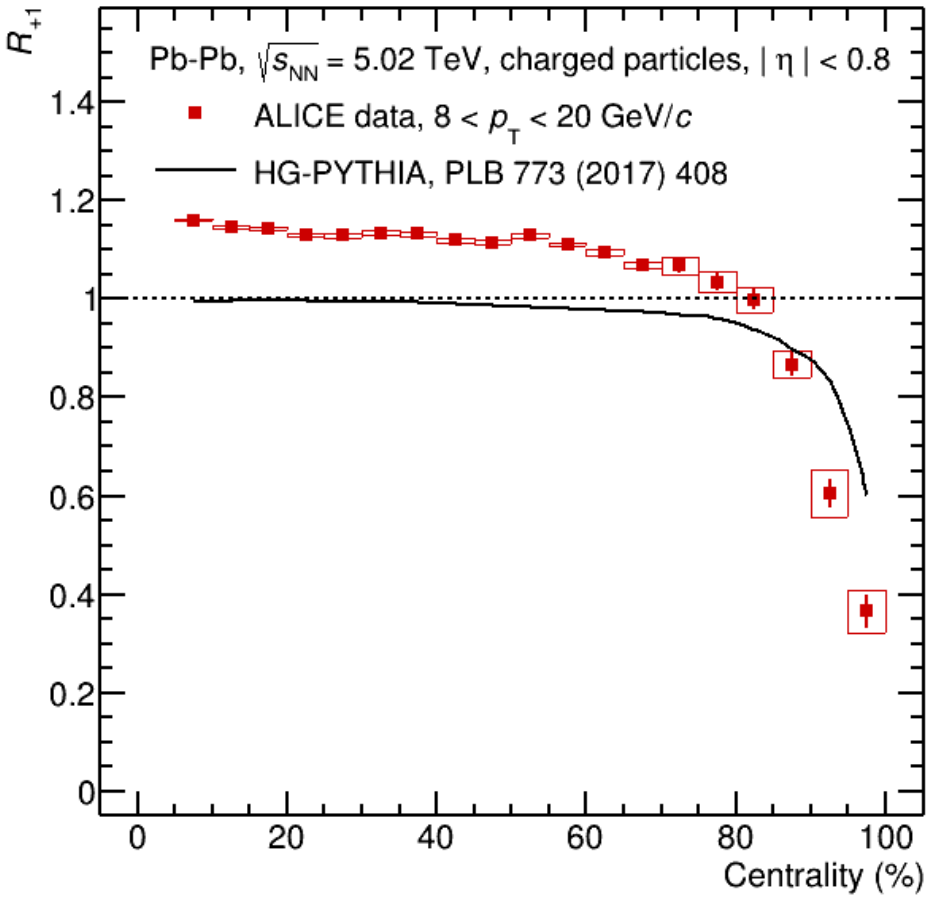
- R_{AA} suffers from large systematic uncertainties on normalization
- => ratios of adjacent centrality bins to cancel part of systematic uncertainties
- R_{+1} expected to be >1

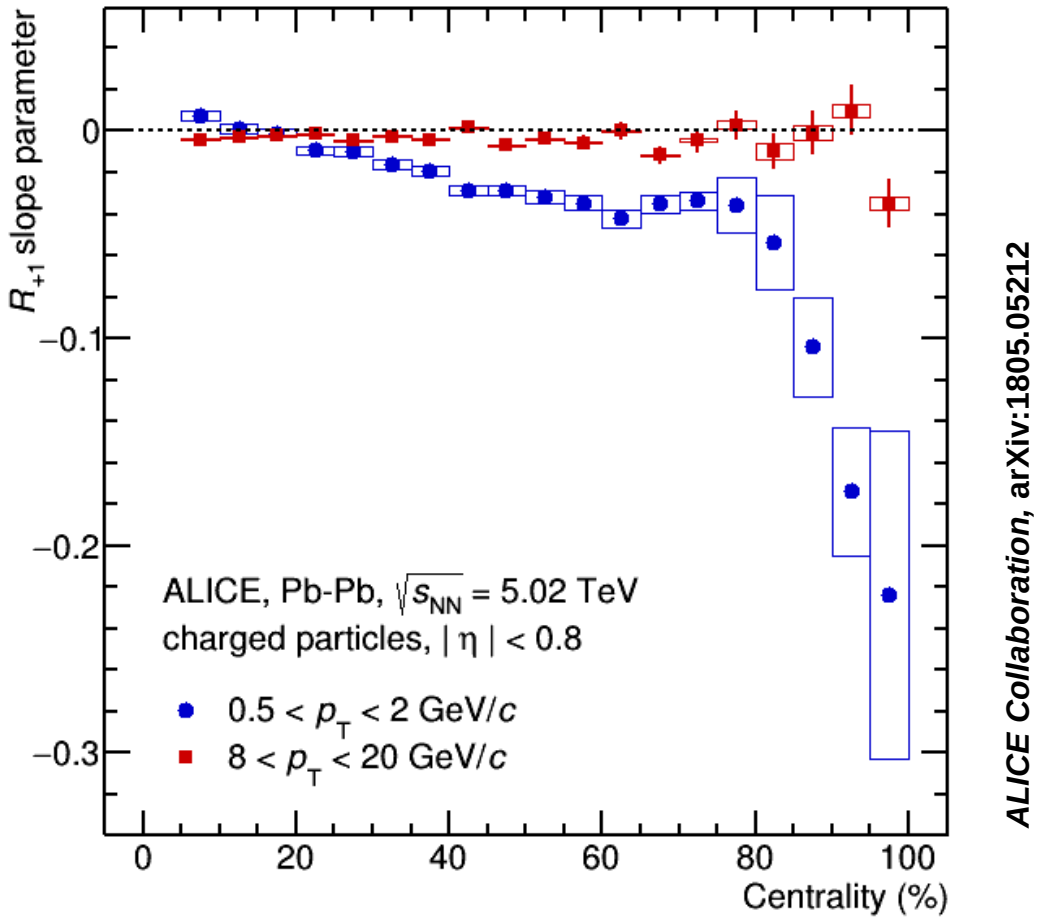
Example: $R_{+1}(75\text{-}80\%) = \frac{R_{AA}(75\text{-}80\%)}{R_{AA}(70\text{-}75\%)}$

- only mildly p_T dependent
- R_{+1} very similar over a wide centrality range (0-75%)
- significant change for peripheral beyond 75% centrality

Centrality evolution of R_{+1}

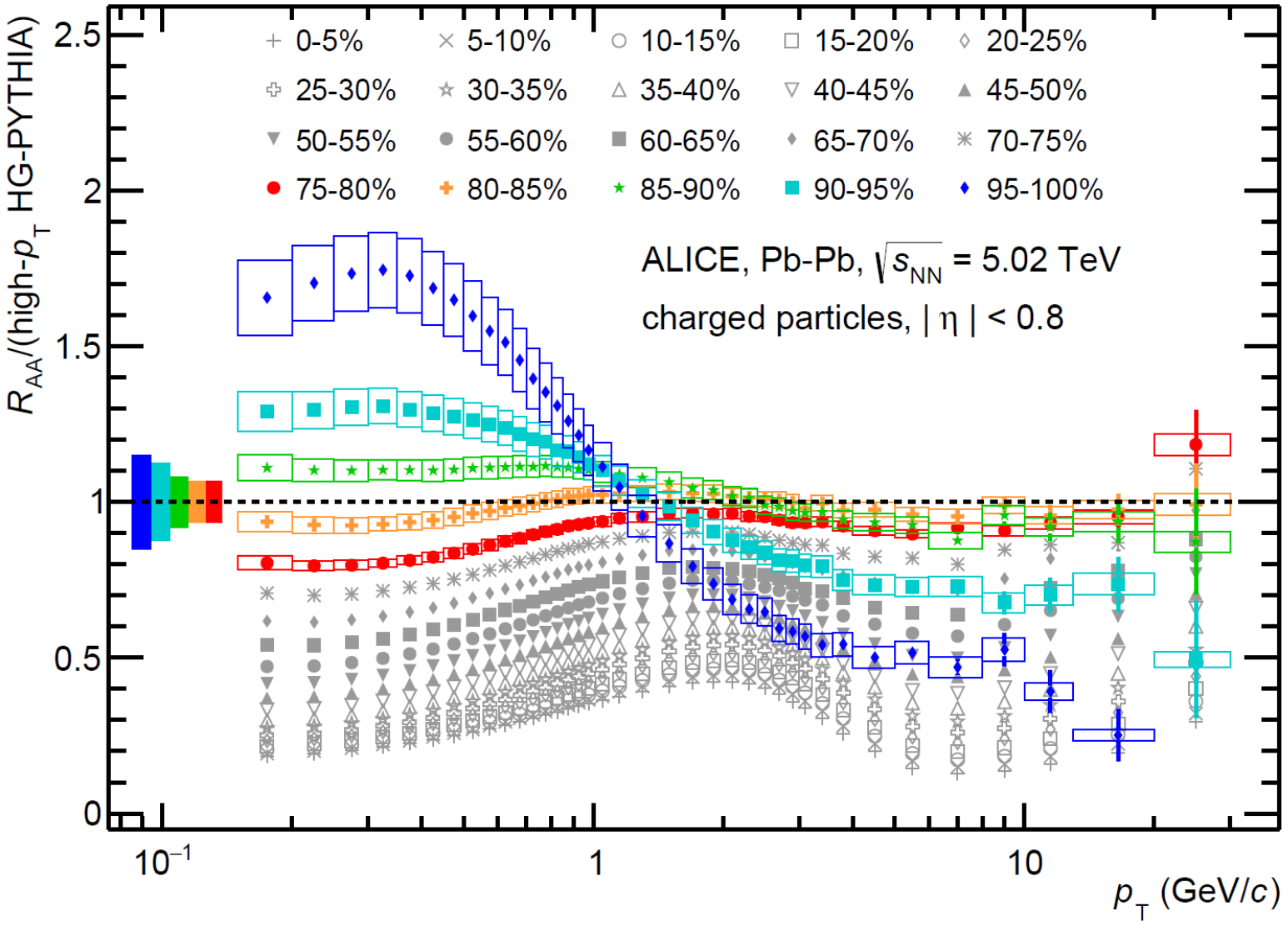
- R_{+1} averaged over $8 < p_T < 20$ GeV/c as function of centrality
- flat up to 60%, increasingly steep decline thereafter
- slope of linear fit to R_{+1} at low p_T (mild centrality depence with strong drop above 80%) and high p_T (no significant centrality dependence)





Scaled R_{AA}

ALICE Collaboration, arXiv:1805.05212



- R_{AA} scaled by the high p_T bias from HG-PYTHIA
- strong suppression (jet quenching) visible up to 75% centrality
- scaled R_{AA} ~ 1 for 75-90%
- drop below unity for even more peripheral
- could be caused by diffraction which is included in the data but not in HG-PYTHIA

Summary

- measurement of charged particle spectra and R_{AA} in fine centrality bins extending to most peripheral (0-100%)
- N_{coll} from a multiplicity selected Glauber-NBD fit
- slope of R_{AA} at low and high p_T remarkably similar
- R_{AA} and R_{+1} at large p_T drop strongly in peripheral collisions (>80%)
- trend consistent with a simple PYTHIA-based model with no nuclear modification and no soft component in particle production

$\Rightarrow$ apparent suppression of particle production in peripheral collisions can be caused by biases

$\Rightarrow$ peripheral collisions as baseline (R_{CP}) also affected

$\Rightarrow$ explains why R_{AA} is below 1 in peripheral Pb-Pb collisions, but equal to 1 in p-Pb collision at the same charged particle multiplicity

$\Rightarrow$ there is no need for jet quenching in peripheral heavy ion collisions