Centrality dependence of charged jets in p–Pb collisions measured with the ALICE detector

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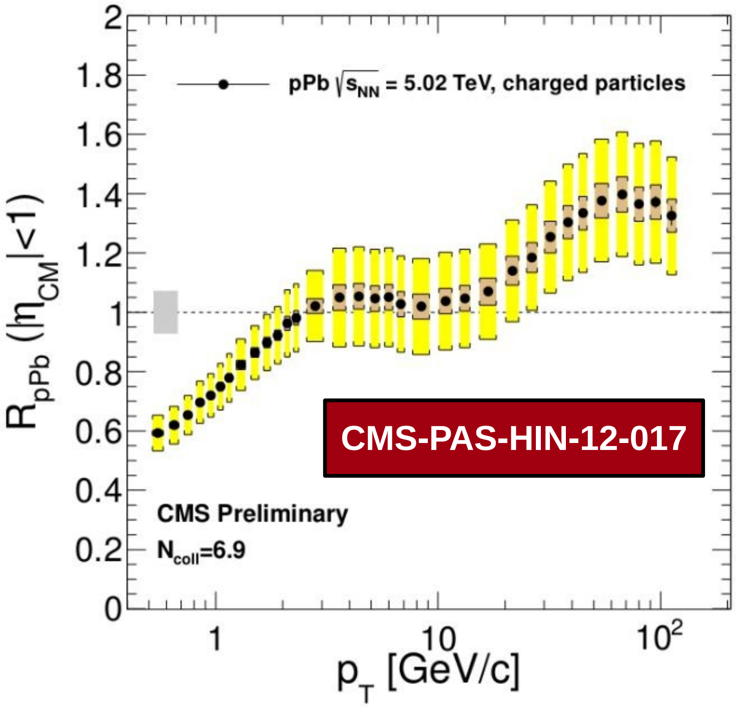
ALICE
A JOURNEY OF DISCOVERY

Motivation for p–Pb

- Study of cold nuclear matter effects
  - Initial state effects (Nuclear PDFs, ...)
  - Final state effects (Nuclear absorption, ...)
- Necessary for interpretation of heavy-ion collisions (cold nuclear matter effects vs. hot nuclear matter effects, QGP formation not expected)

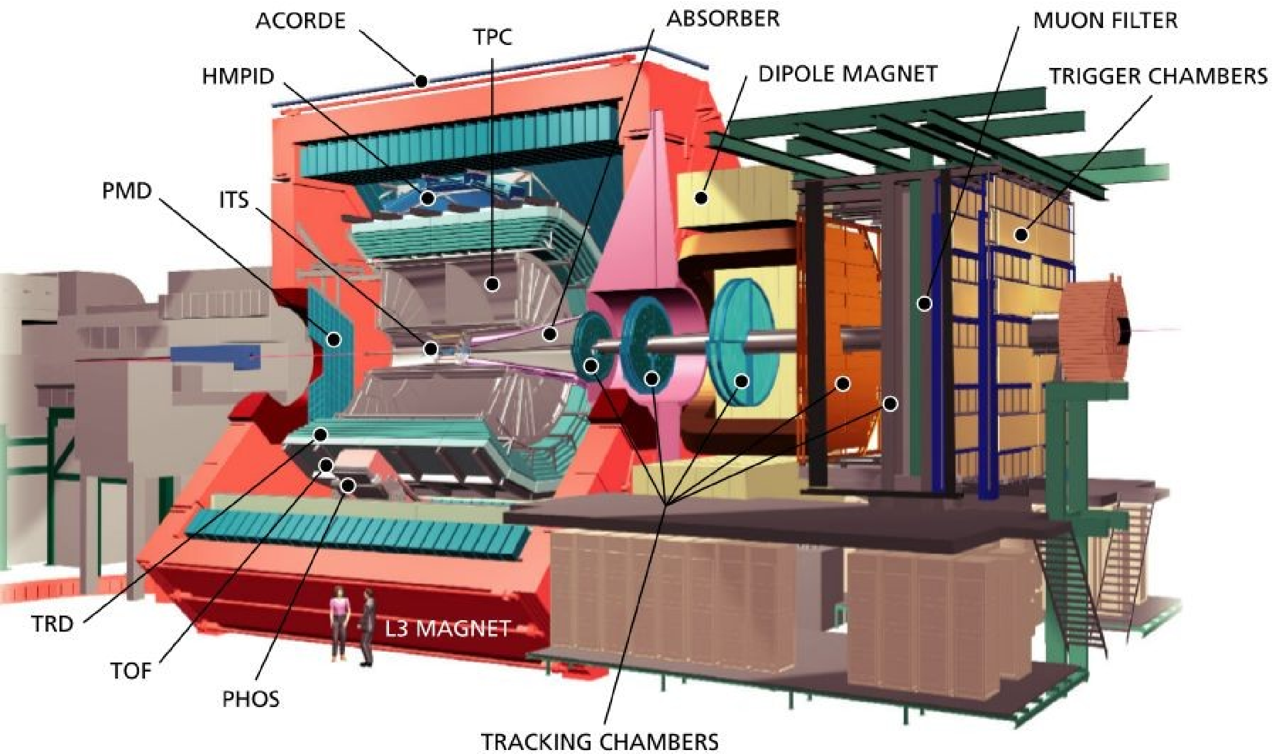


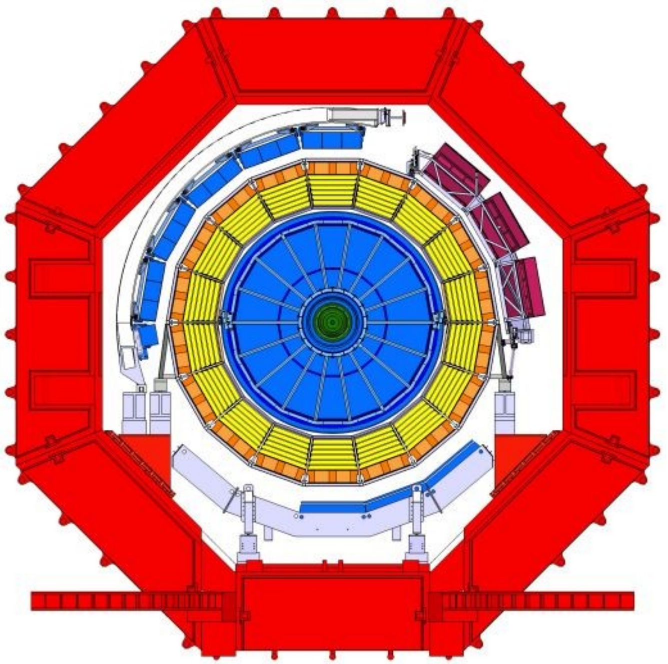
- Track centrality evolution of nuclear matter effects allows more differential analysis
- Final state effects expected to be strongest in central collisions

Outline

- Experimental setup and charged jet reconstruction with the ALICE detector
- Centrality determination in p–Pb collisions
- Correction techniques
- Results

Experimental setup and charged jet reconstruction with the ALICE detector





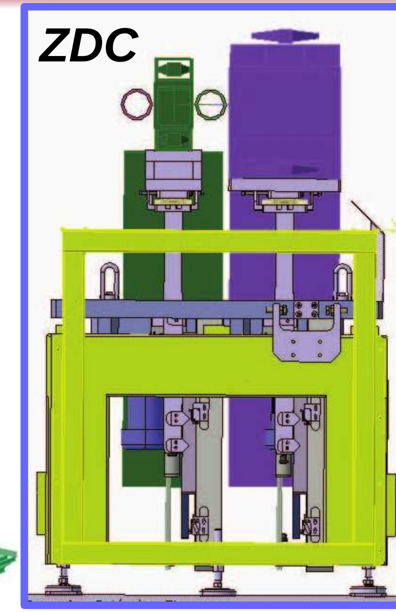
The ALICE detector

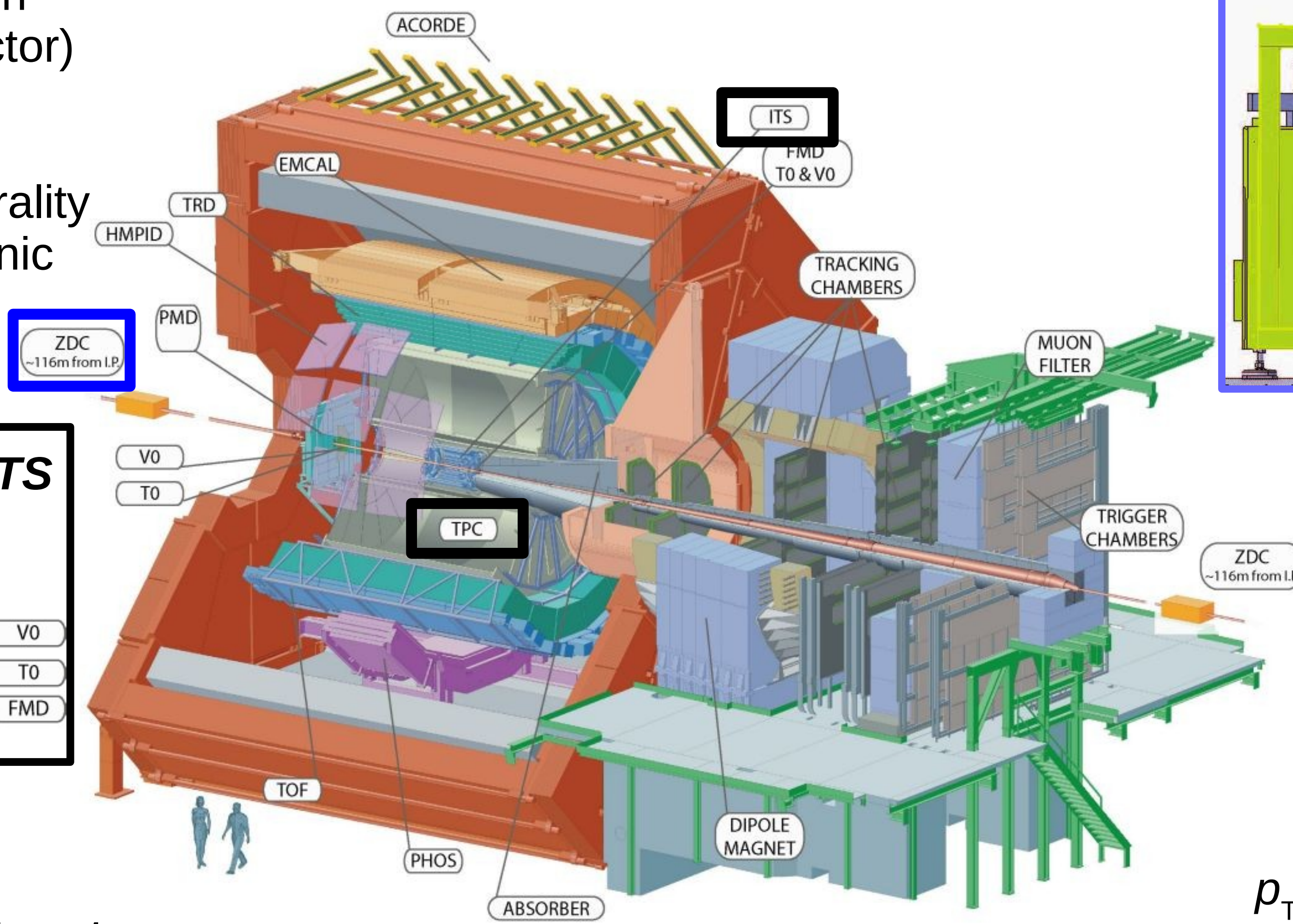
ITS: Inner Tracking System (silicon detectors)

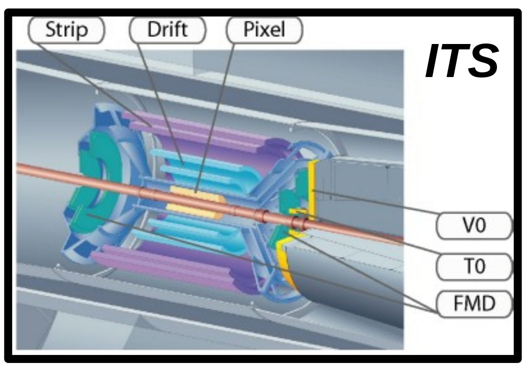
TPC: Time Projection Chamber (gas detector)

ZDC: Zero-Degree Calorimeter for centrality classification (hadronic calorimeters)

ZDC: 116 m distance to interaction point





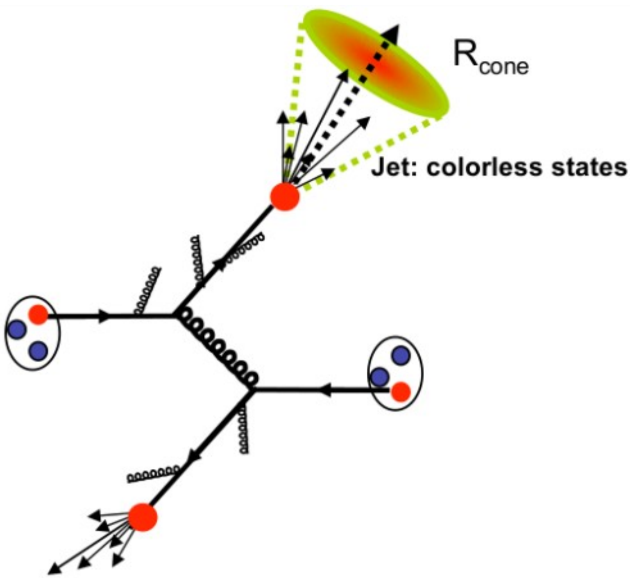


ITS+TPC coverage:
$|\eta| < 0.9$
full azimuth
$p_T > 150$ MeV/c

Charged jet constituents:
Tracks mainly reconstructed with ITS+TPC

Jet physics

- Conceptually, a jet is the final state of collimated hadrons that fragmented from a hard scattered parton



- Jets can be used to shed light on the very early stage of a hadron collision

- There is no unambiguous jet definition

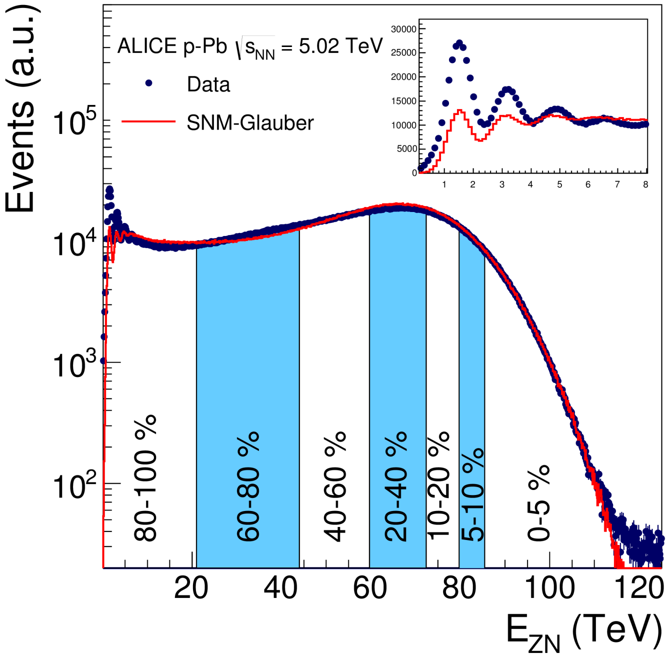
- The reconstructed *jet observable* is defined by the jet finding algorithm used to clusterize tracks and calorimeter clusters into jets

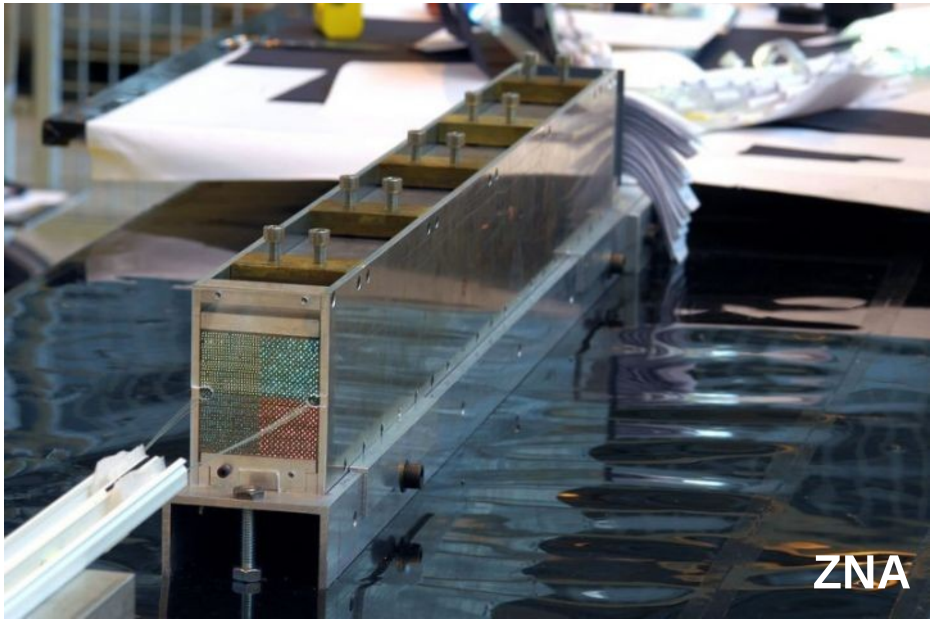
Jet reconstruction

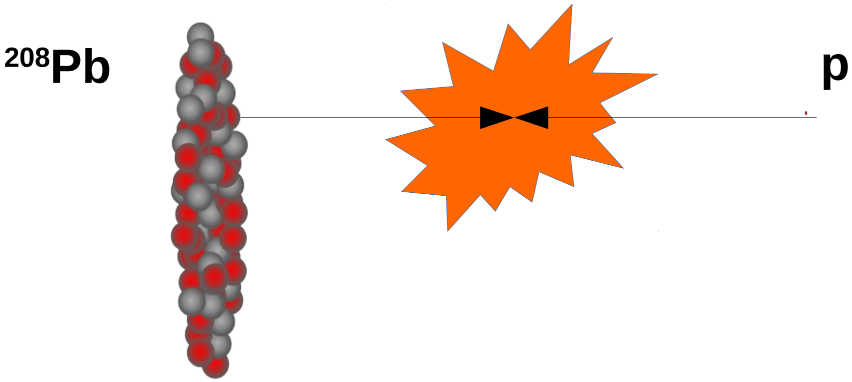
- FastJet[1] is used for jet finding
  - anti-k_T algorithm for signal jets
  - k_T algorithm for background correction
  - Resolution parameters $R = 0.2$ & $R = 0.4$
  - Transverse momentum calculated by using p_T particle recombination scheme
- Analyzed only jets fully contained in detector
- Background density and fluctuation correction applied
- Jet spectra corrected for detector effects

[1] Cacciari, Salam. Phys. Lett. B641(2006), `arXiv:0512210` [hep-ph]

Centrality determination in p–Pb collision with ALICE



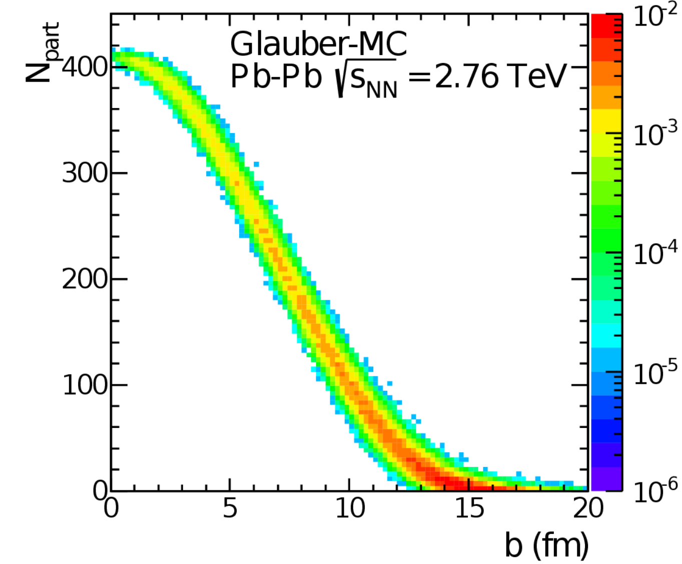


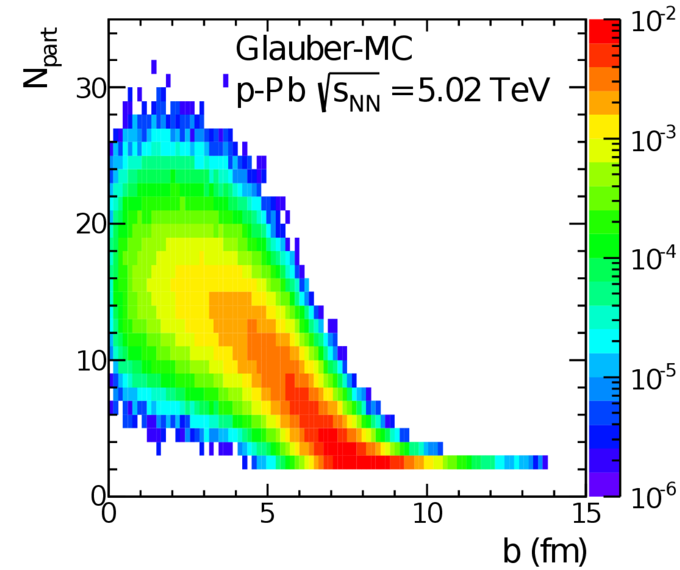


Centrality determination in p–Pb

- Centrality = measure for collision geometry
- Centrality determination approach in Pb–Pb
  - Glauber MC + NBD fit of multiplicity distribution
  - Strong correlation of multiplicity and N_{part} / impact parameter
- Same approach not applicable in p–Pb
  - Correlation much worse
  - Relatively high probability to measure high-multiplicity upward fluctuations of low-centrality events
- Additional bias: Jet-veto bias (veto on high-multiplicity events in peripheral collisions)

arXiv:1412.6828



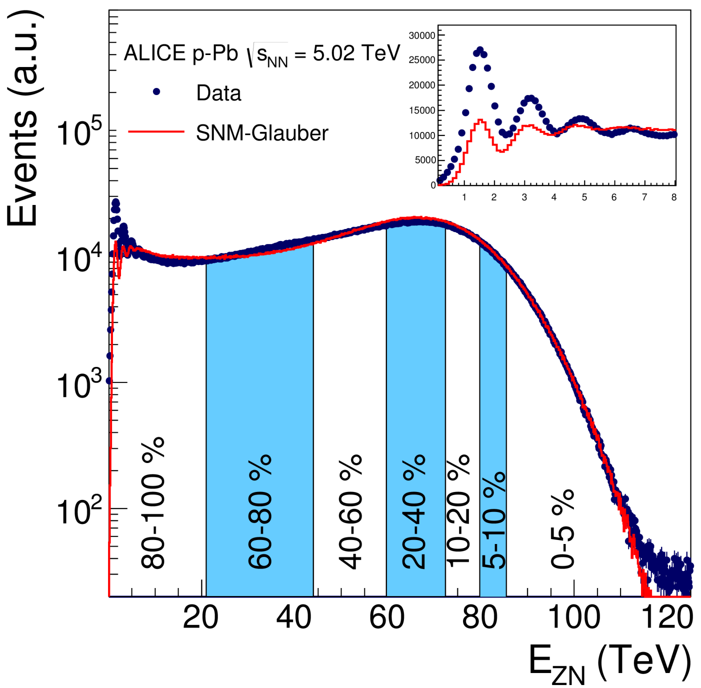


Centrality determination in p–Pb

- Much work done by ALICE on *hybrid approach* using ZDC (details see arXiv:1412.6828)
- Procedure:

1. Event classification

Use deposited energy in ZDC neutron calorimeter (ZN) (monotonically connected to N_{part}) for “slicing” of the data sample
Divide data sample into centrality classes
Here: 0-20%, 20-40%, 40-60%, 60-80%



Centrality determination in p–Pb

- Much work done by ALICE on *hybrid approach* using ZDC (details see arXiv:1412.6828)
- Procedure:

1. Event classification
2. Estimate number of binary collisions in one event

Two different assumptions utilized to calculate N_{coll}:

- $N_{coll,\,mult}$: charged particle multiplicity at midrapidity is proportional to N_{part}

$$N_{\mathrm{coll}}^{\mathrm{mult}}(c) = N_{\mathrm{part}}(\mathrm{MB}) \cdot \left(\frac{\langle \mathrm{d}N/\mathrm{d}\eta \rangle (c)}{\langle \mathrm{d}N/\mathrm{d}\eta \rangle (\mathrm{MB})} \right)_{-1<\eta<0} - 1$$

- $N_{coll,\,Pb\text{-}side}$: charged particle multiplicity on the Pb-going side is proportional to N_{coll}

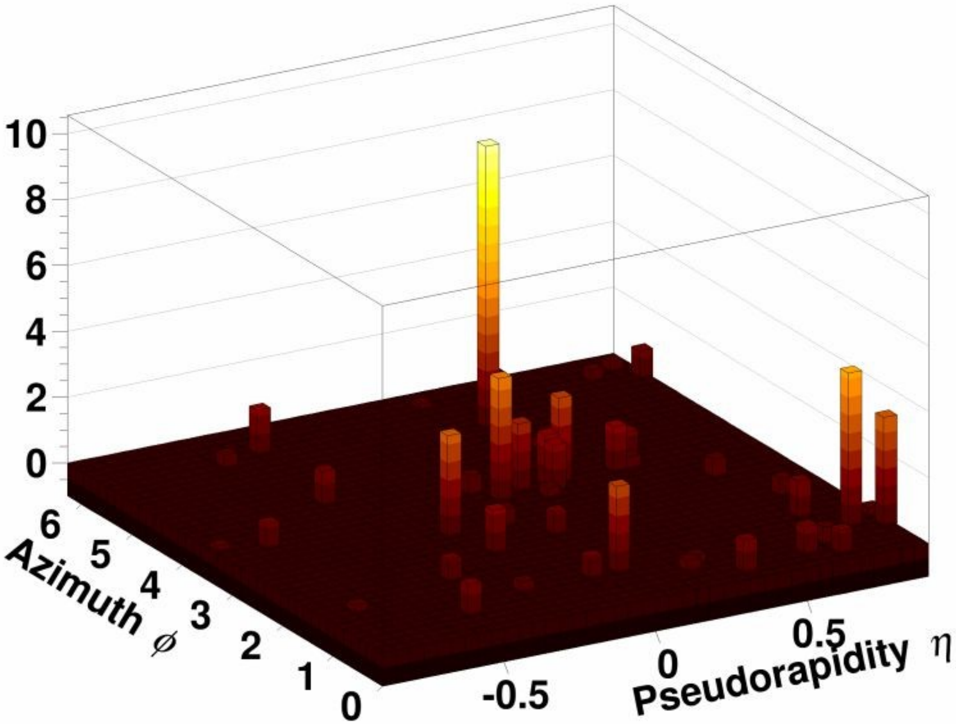
$$N_{\mathrm{coll}}^{\mathrm{Pb-side}}(c) = N_{\mathrm{coll}}(\mathrm{MB}) \cdot \frac{\langle S \rangle (c)}{\langle S \rangle (\mathrm{MB})}$$

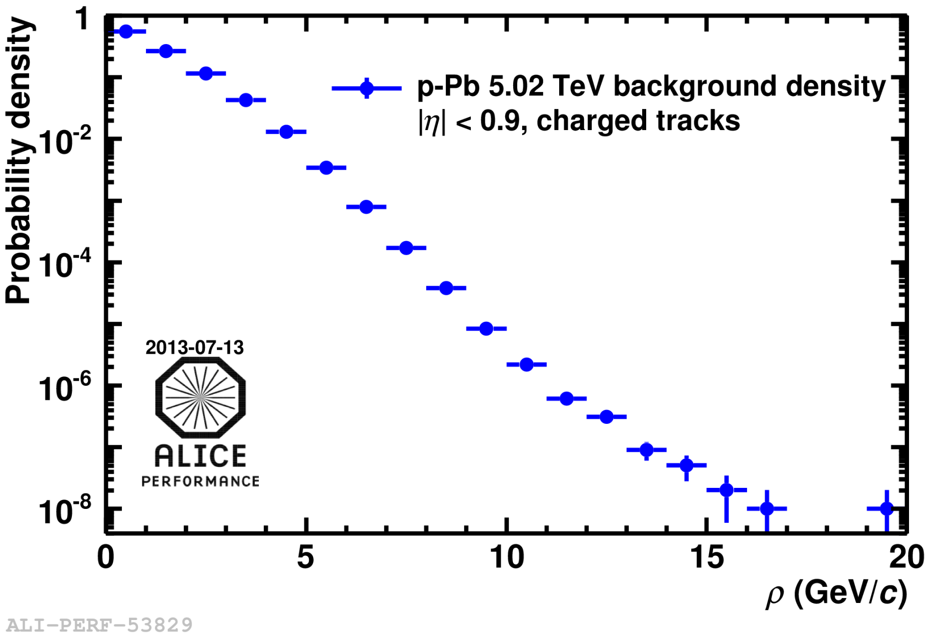
$\langle S \rangle$: mean multiplicity signal

Both estimates are applicable for jet measurements and will be tested

Note: Glauber fit principally possible for ZDC distribution but this relies on slow nucleon emission models

Correction techniques





Default background approach[1]

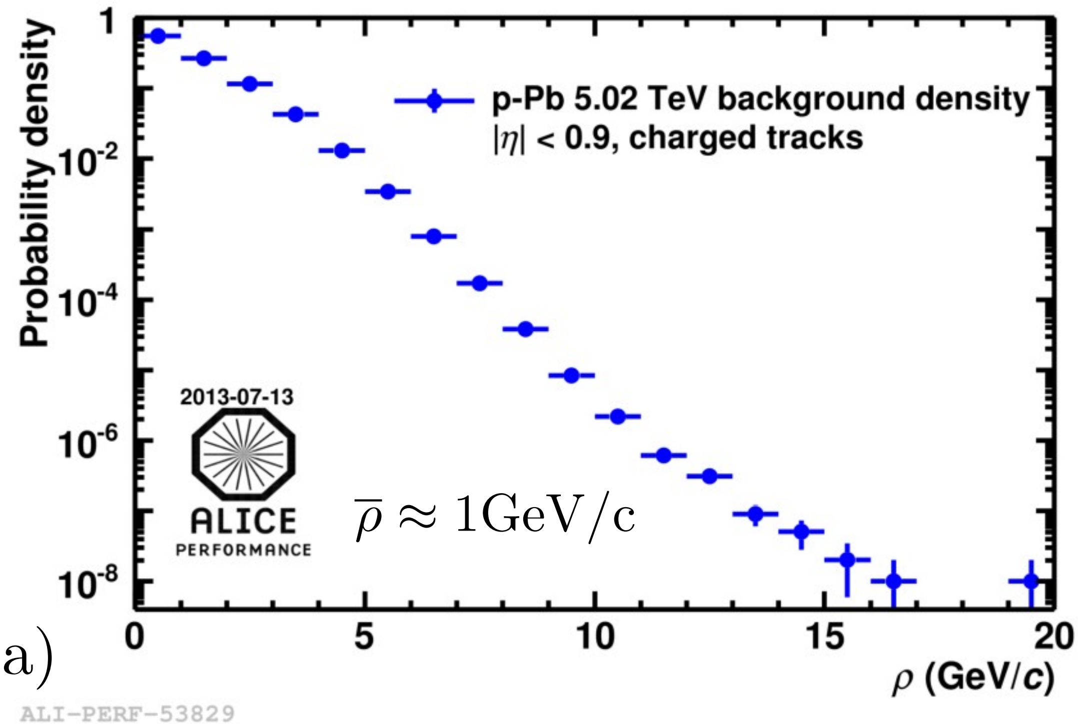
Corrected jet-by-jet

- clusterize k_T jets (susceptible to background)
- take median of the p_T densities

$$\rho = \text{median}\left\{\frac{p_{T,i}}{A_i}\right\}_i \cdot C$$

$(A_i : \text{jet area})$

neglect those k_T jets overlapping with signal jets



- correct for event occupancy (how dense or sparse the event is)

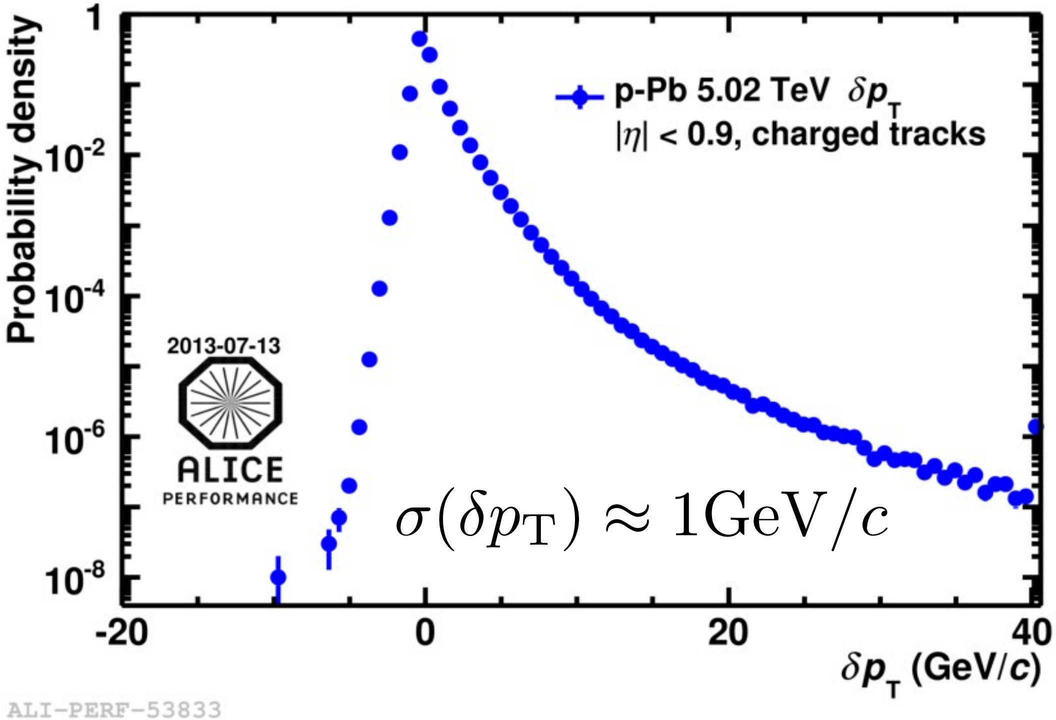
$$C = \frac{\text{Area of } k_T \text{ jets containing tracks}}{\text{Acceptance}}$$

[1] As in arXiv:1207.2392 [hep-ex]

Background fluctuations

- Background fluctuates within one event
- Estimated by
  - Randomly placing cone with radius *R* into acceptance
  - summing up p_T in cone and subtracting background

Corrected via unfolding



R: Radius of the jet finder

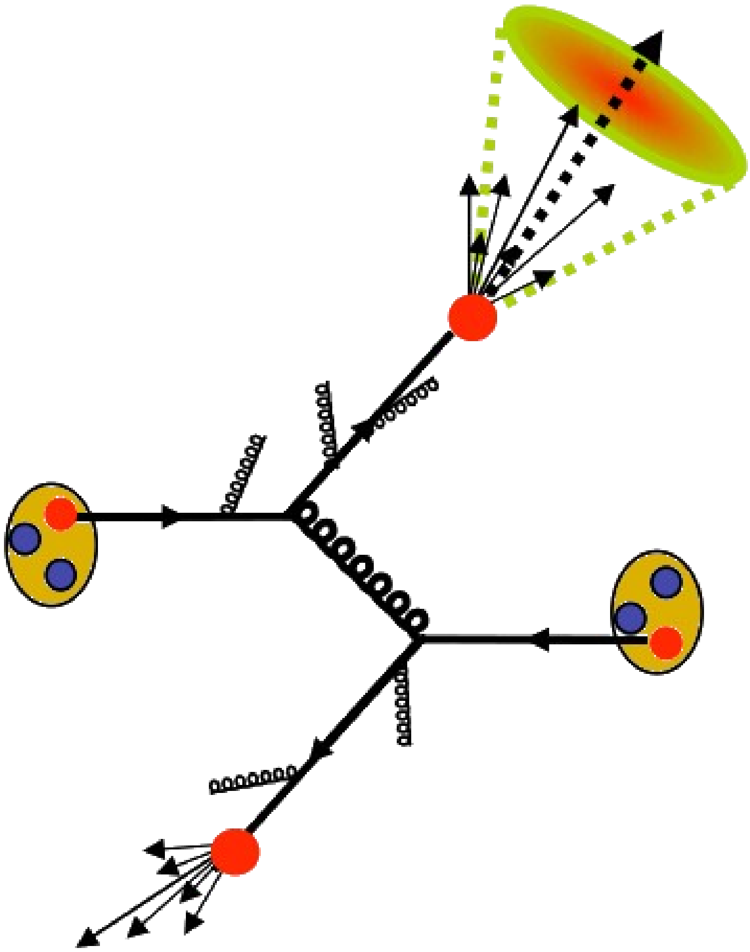
$$\delta p_{\mathrm{T}} = \sum_{\mathrm{RC}} p_{\mathrm{T}} - \rho A, \quad \text{with } A = \pi R^2$$

Detector effects

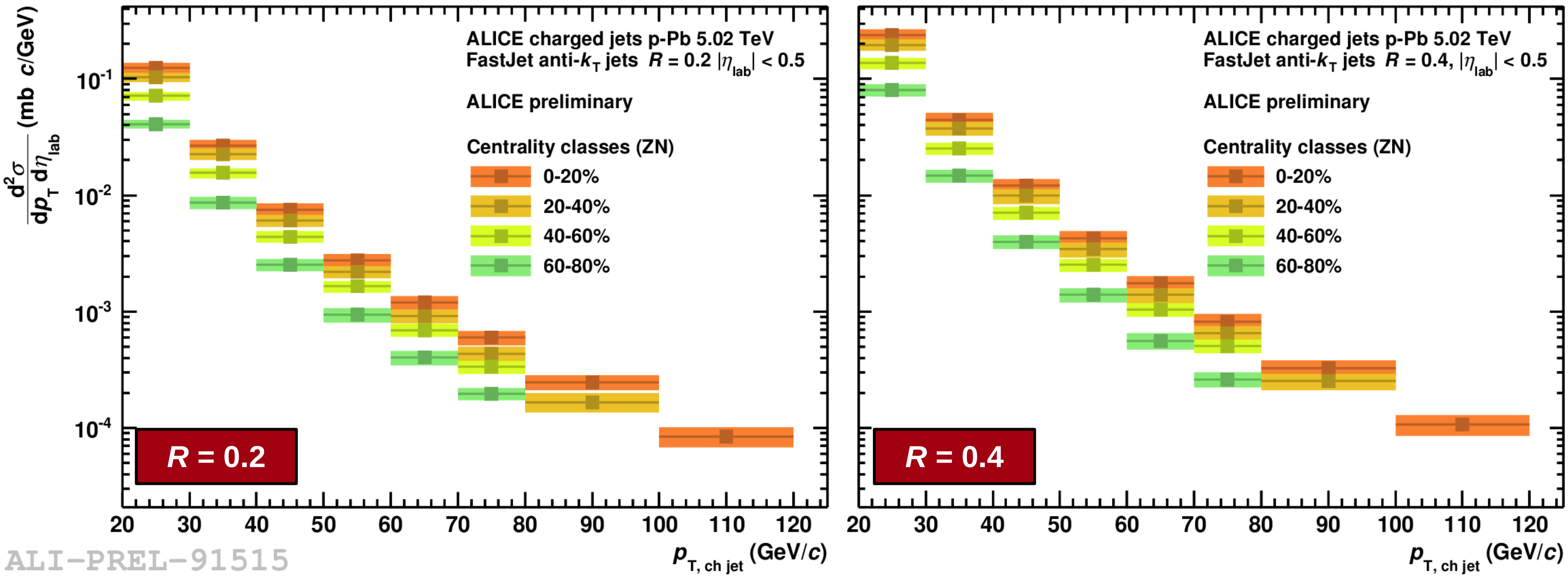
Corrected via unfolding

- Finite detector resolution (p_T resolution, tracking efficiency...)
- Detector effects estimated by calculating response matrix
  - Create full detector simulation (PYTHIA jets + Geant3 transport)
  - Run jet finder on particle level (output from PYTHIA) and on detector level (simulated output from detector)
  - Match particle-level and detector-level jets by geometrical criterion

Results



Centrality-dependent charged jet cross sections



Centrality-dependent charged jet production cross sections measured up to 120 GeV/c

Introducing the observables

Nuclear modification factor Q_{pPb}

- The nuclear modification factor Q_{pPb} is a measure for the influence of the nuclear environment in the collision (Q_{pPb} is centrality-biased R_{pPb})
- Definition:

$$Q_{\mathrm{pPb}} = \frac{\text{p-Pb yield}}{\text{pp x-section}} \cdot \frac{1}{T_{\mathrm{pPb}}}$$

T_{pPb}: Nuclear overlap function obtained from Glauber MC calculation

- Direct measure for suppression/enhancement of jets

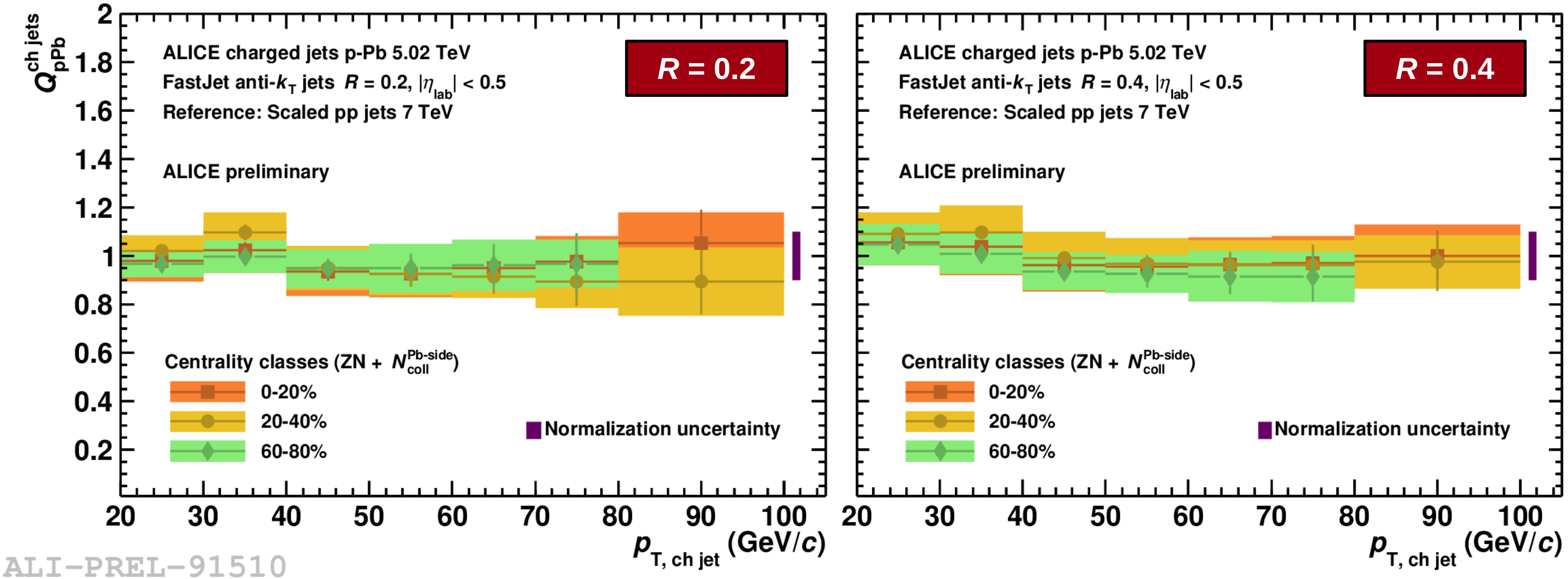
Jet cross section ratio

- Simplest measure for changes in radial jet structure, i.e. jet narrowing/ broadening (note: only indirectly sensitive to large changes)
- Definition:

$$\text{Ratio} = \frac{\text{Jets with } R_1}{\text{Jets with } R_2}, R_1 < R_2$$

Ratio ≪ 1 = little collimation
Ratio ~ 1 = strong collimation

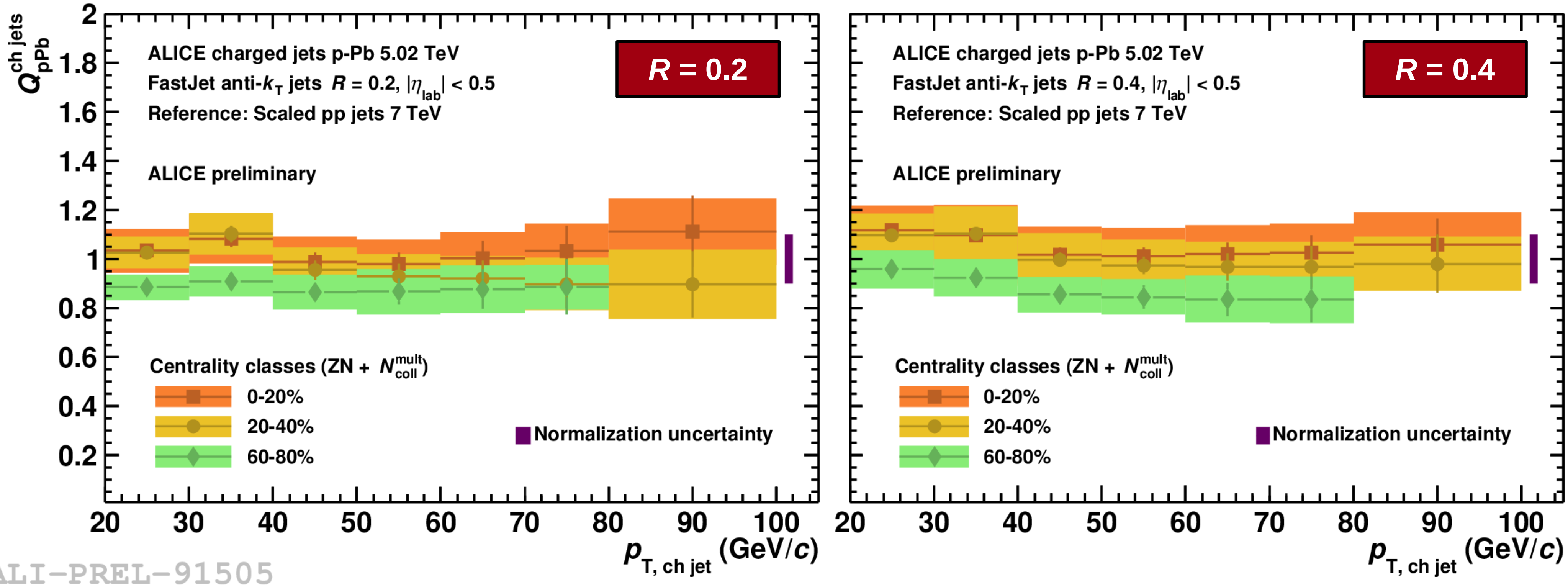
Nuclear modification factor Q_{pPb}



N_{coll} from Pb-side

- Centrality-dependent charged jet nuclear modification factor measured up to 100 GeV/c. Scaled with N_{coll} from Pb-side estimator

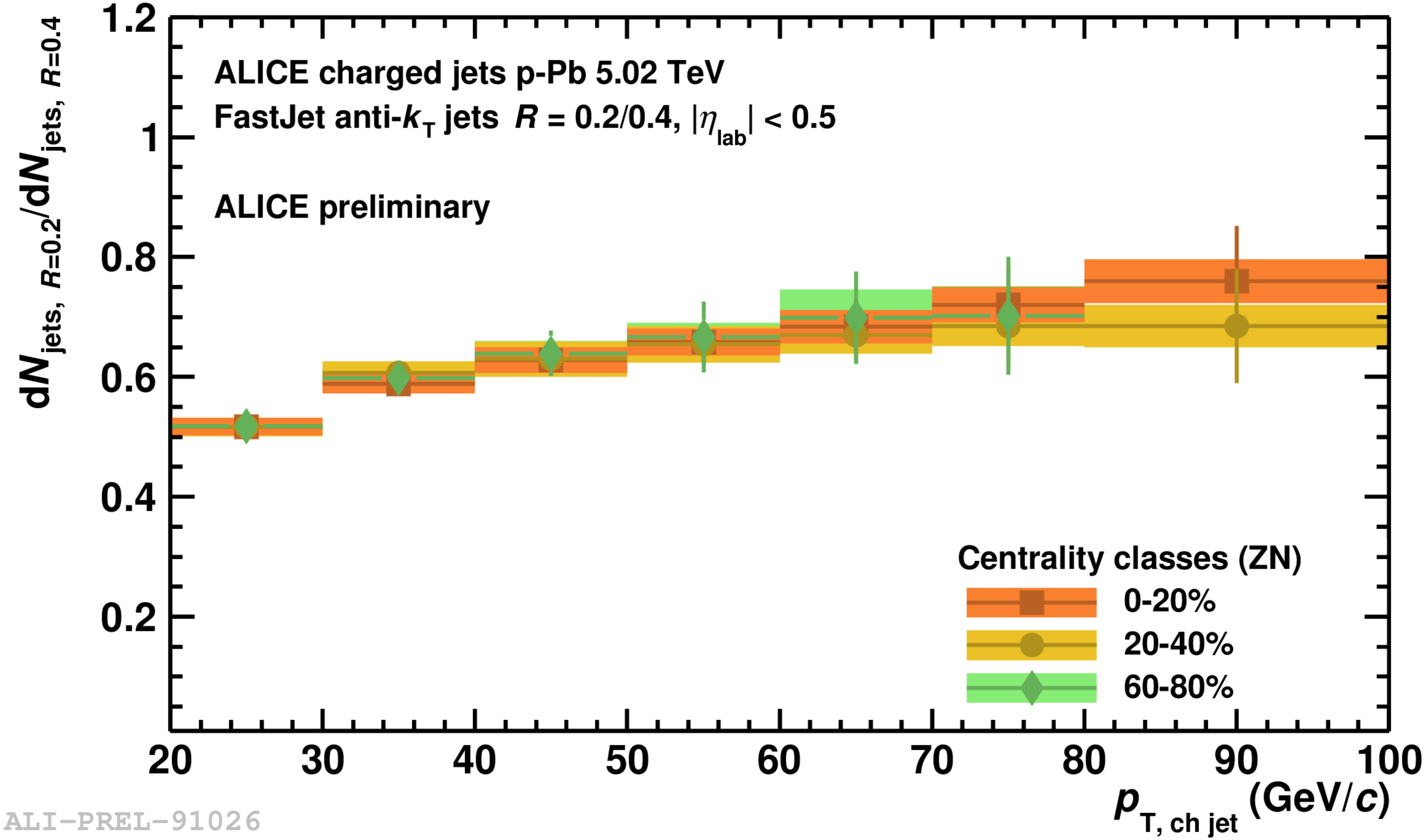
- Within the uncertainties, neither significant centrality dependence nor nuclear modification is observed



N_{coll} from multiplicity

- Centrality-dependent charged jet nuclear modification factor measured up to 100 GeV/*c*. Scaled with N_{coll} from multiplicity estimator
- Within the uncertainties, neither significant centrality dependence nor nuclear modification is observed

Centrality-dependent jet cross section ratio



No significant centrality dependence of the jet cross section ratio

→ no strong changes in the radial jet structure (as already expected from Pb–Pb)

Summary

- Centrality-dependent study of charged jet production performed
- Centrality approach based on arXiv:1412.6828
- Nuclear modification factors Q_{pPb} show no significant effect for both applied N_{coll} estimators

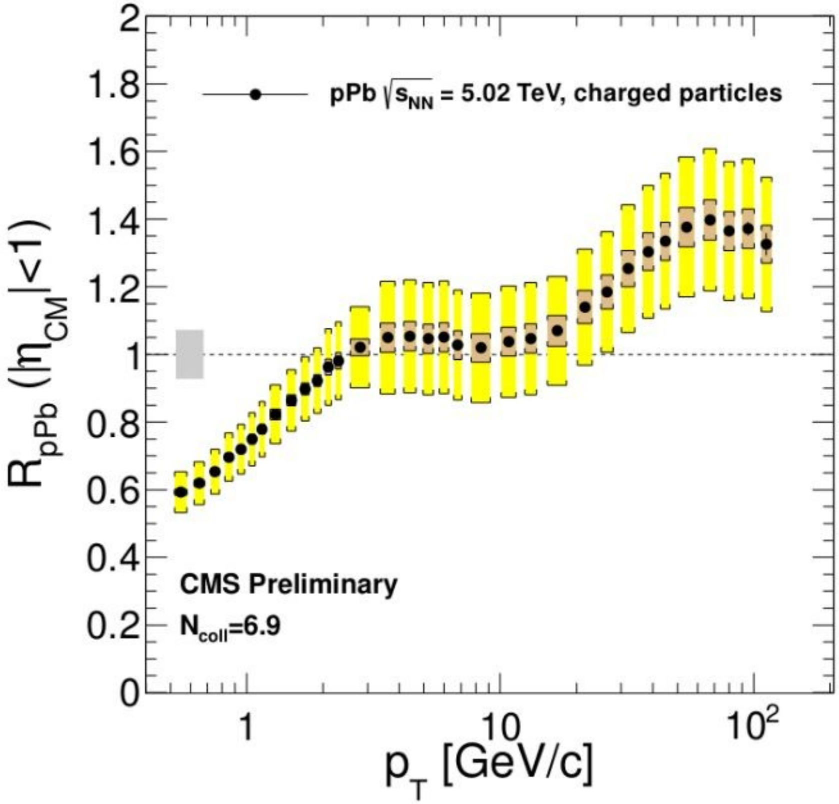
  → no strong centrality dependence
- Jet cross section ratios agree within uncertainties for the considered centrality bins

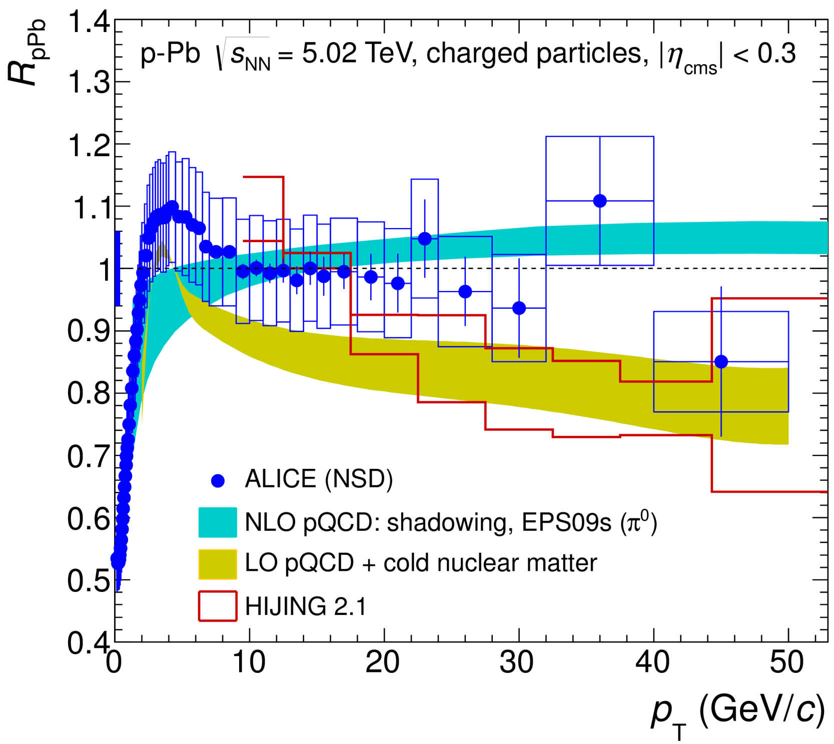
  → no change of jet collimation observed

Thank you for your attention

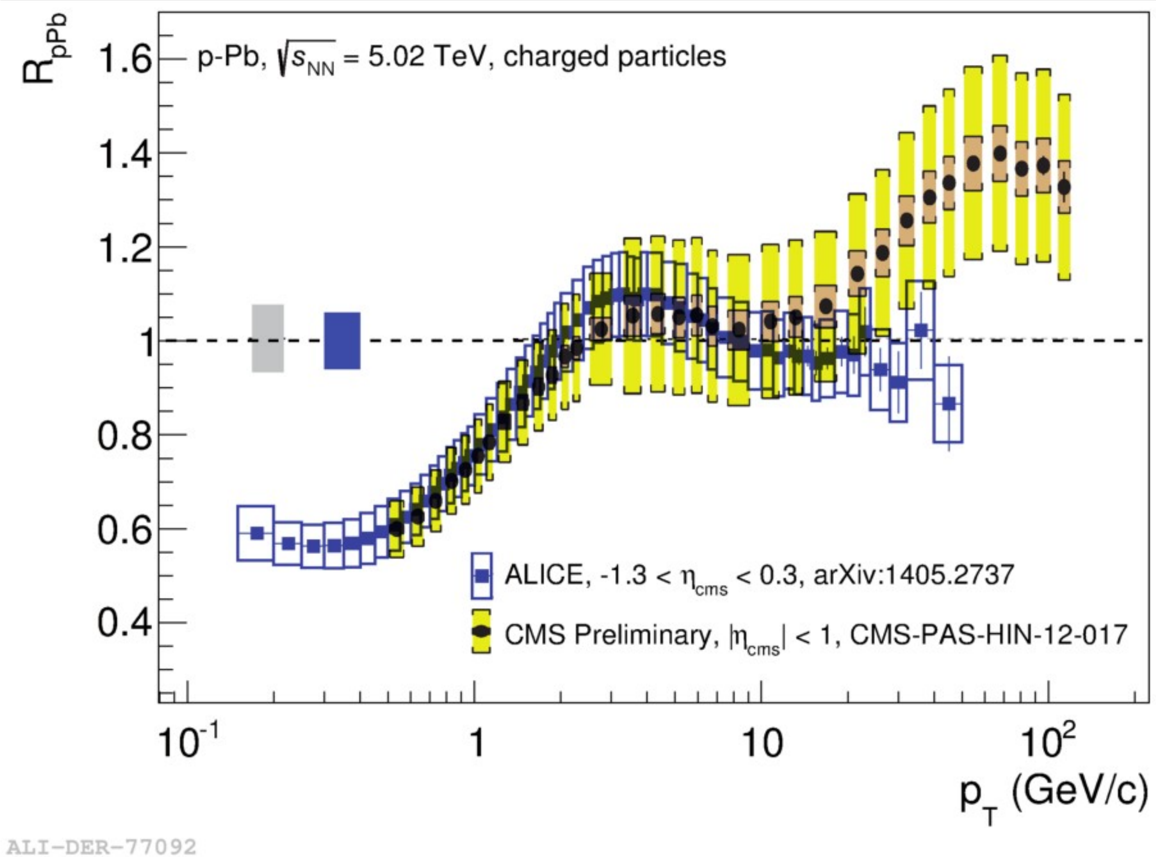
Backup

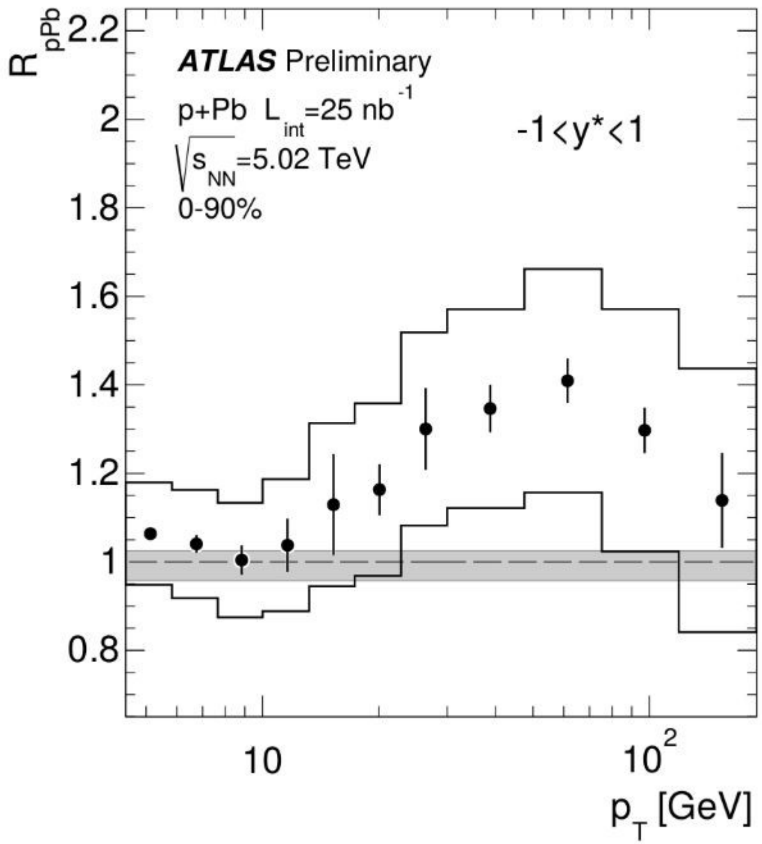
Charged particle R_{pPb} puzzle





Comparison of jet and charged hadron spectra at the LHC

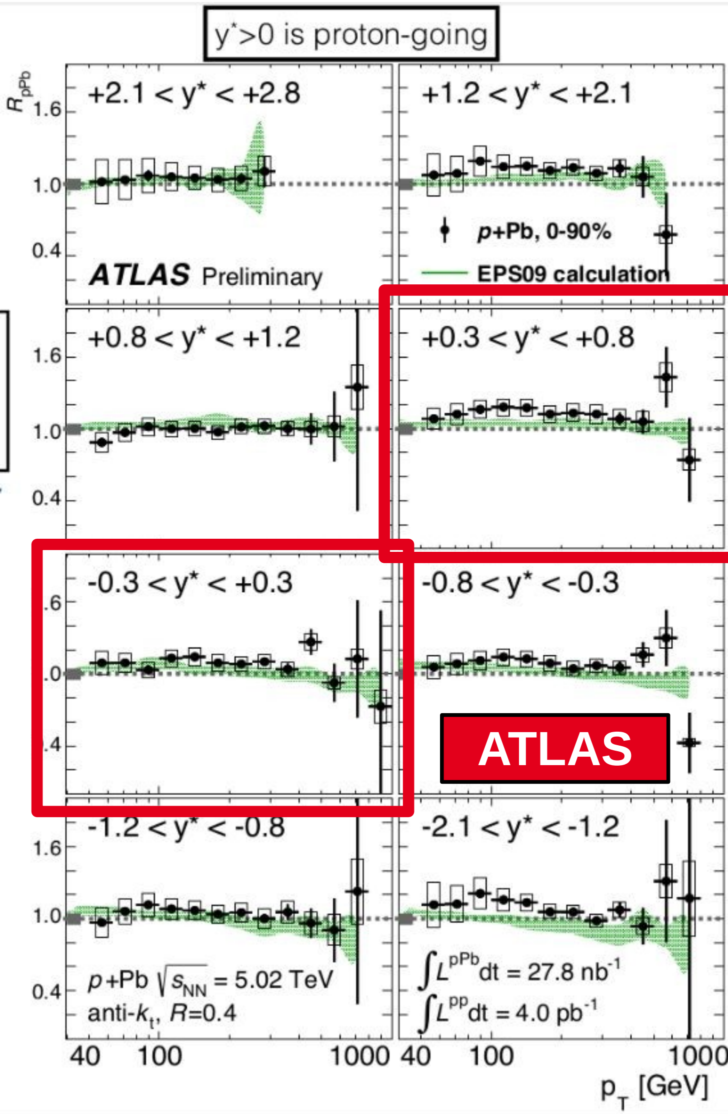


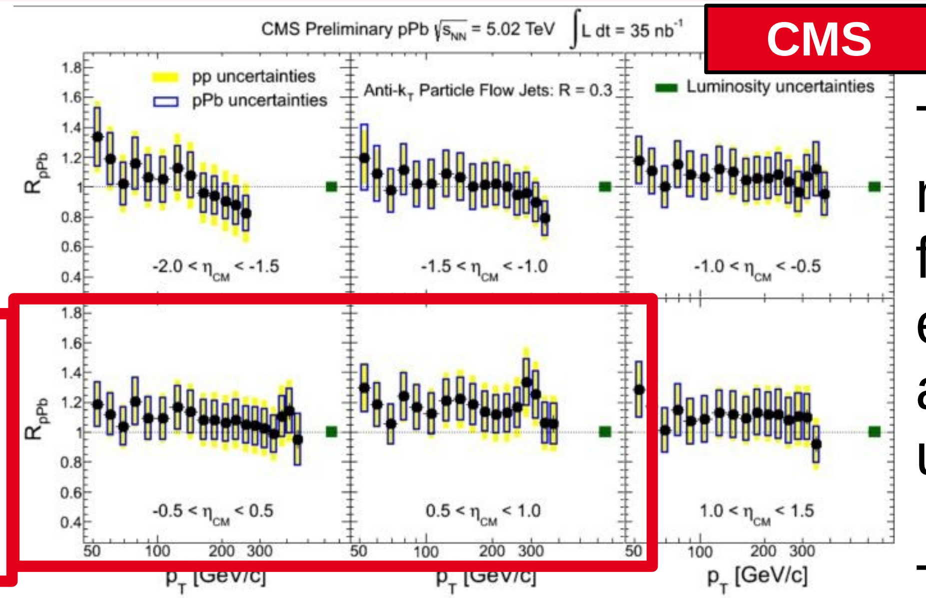


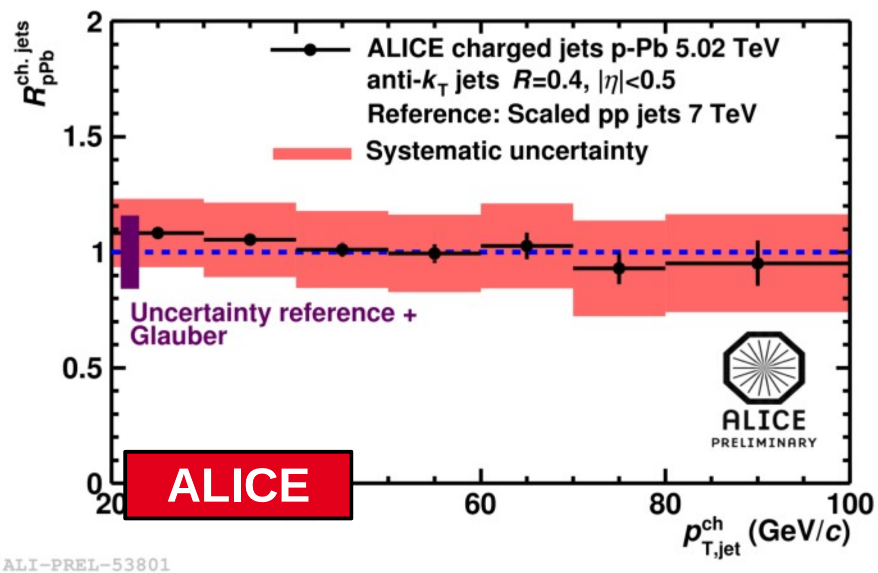
- CMS and later ATLAS observed interesting results for charged particle R_{pPb} → Enhancement at high p_T
- Unfortunately, the rise starts at the end of ALICE p_T coverage. Eventually, the ALICE result agrees within uncertainties

What about the jets?

Jet R_{pPb}



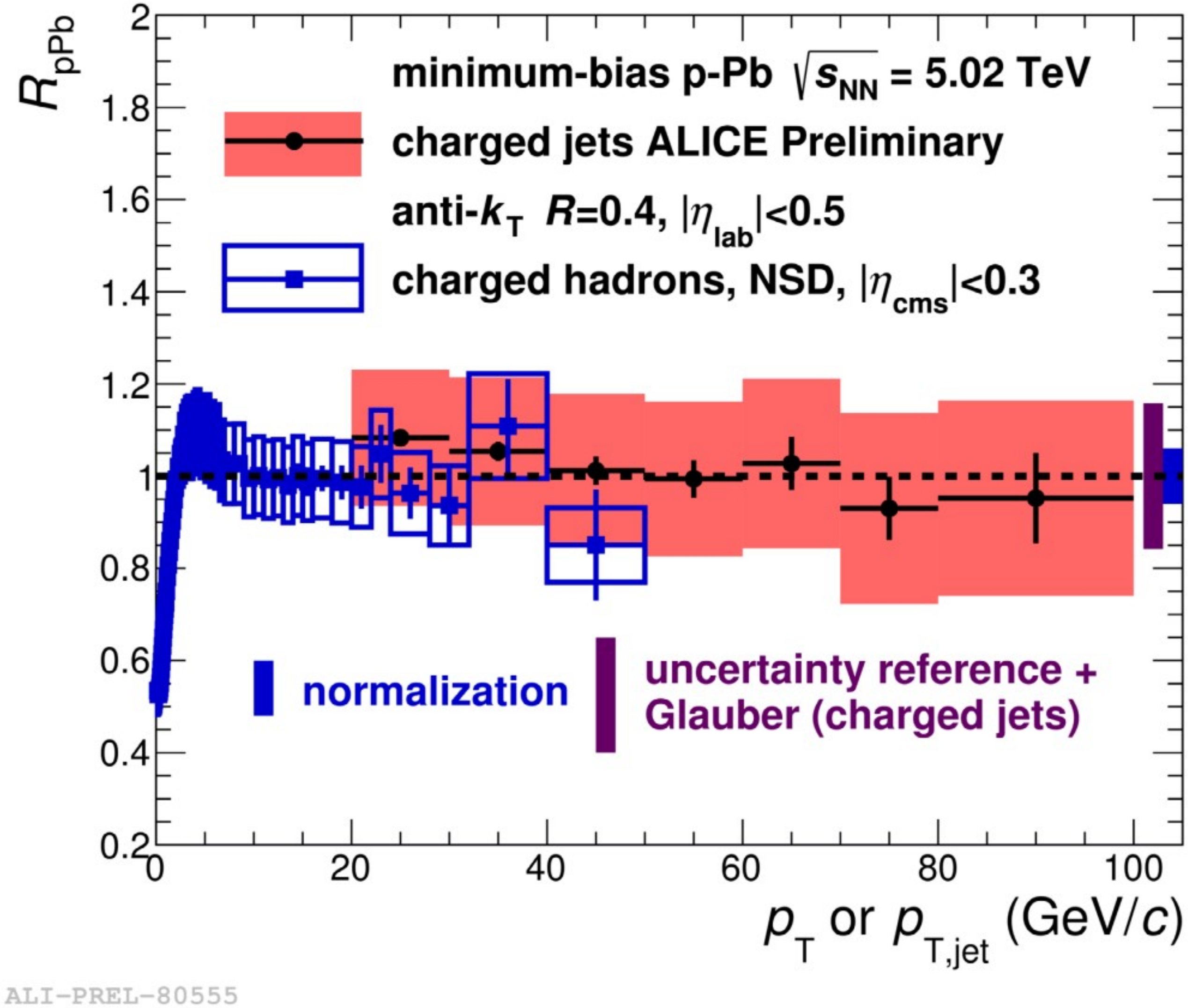




The jet nuclear modification factors of all LHC experiments agree within uncertainties

There is no high-p_T enhancement

Jet R_{pPb} compatible with small or no cold nuclear matter effects



Observation:

Nuclear modification factors for ALICE charged particles and jets agree within uncertainties

Relationship jets–particles

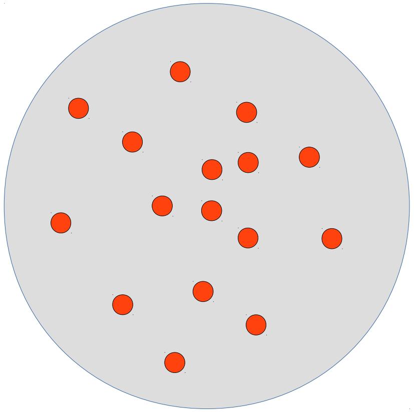
How do the different jet and particle R_{pPb} from ATLAS and CMS fit together?

- One should keep in mind: Jets are not “higher p_T particles”
- Although the spectra are often interpreted as extension of particle spectra to high p_T, they are more susceptible to differences in the hadronization like jet broadening etc.

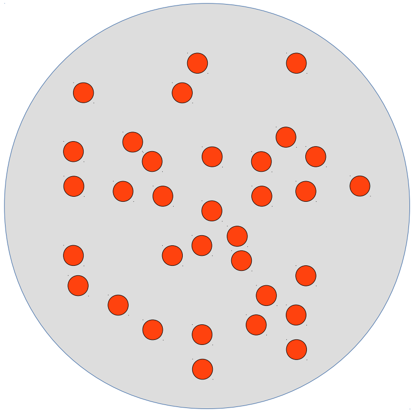
Relationship jets–particles

Example: quark/gluon jets

- A gluon jet fragments softer than a quark jet
- The transverse momentum of the initially scattered parton is distributed into more particles for those jets
- For the jet finder, those jets are very similar to quark jets but the particle spectrum is softer



50 GeV/*c* quark jet



50 GeV/*c* gluon jet

Relationship jets–particles

→ The jet fragmentation can introduce a difference between jet spectra and particle spectra
→ If there were more quark jets in p–Pb collisions, the particle R_{pPb} could show an enhancement at higher p_T which would not exist in the jet R_{pPb}

Note: This is just to show that it is *possible* to explain different R_{pPb}'s for jets and particles

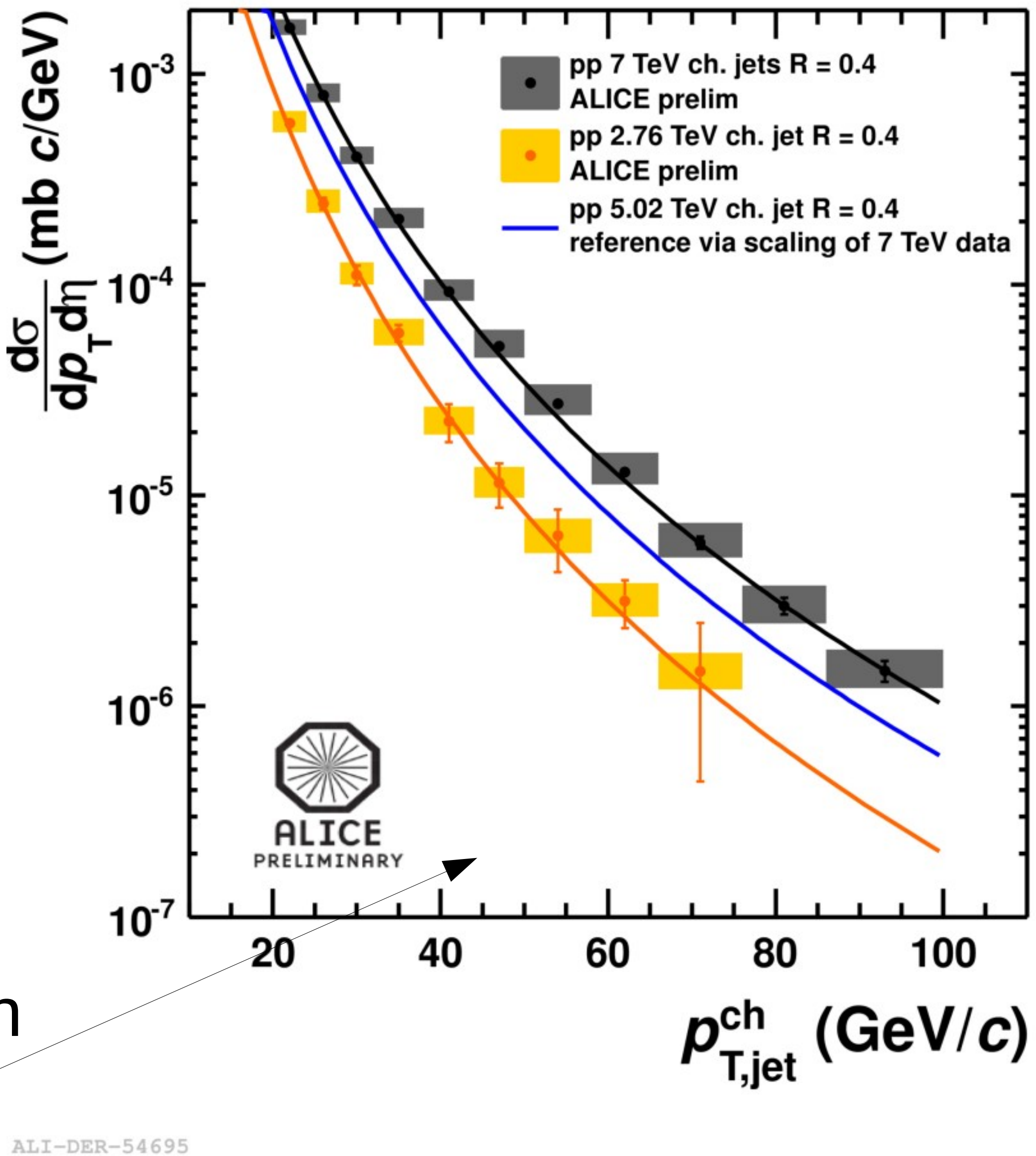
General approach:

- 5 TeV pp measurements not available
- Measured 7 TeV pp jets are scaled down to 5.02 TeV
- Scaling done bin-by-bin with:

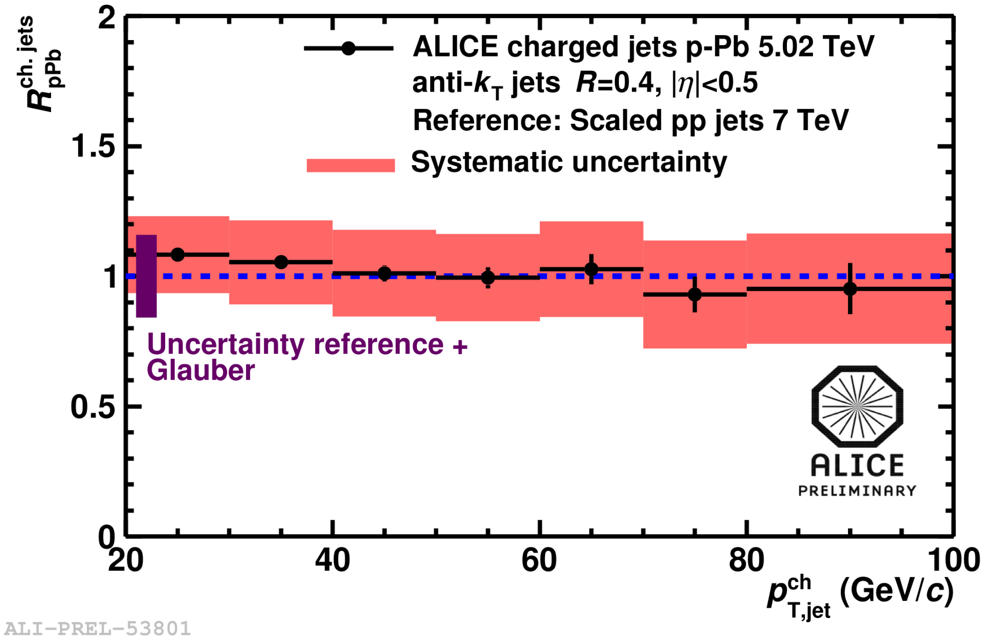
$$p = \frac{\text{yield}(5.023\ \text{TeV})}{\text{yield}(7\ \text{TeV})}$$

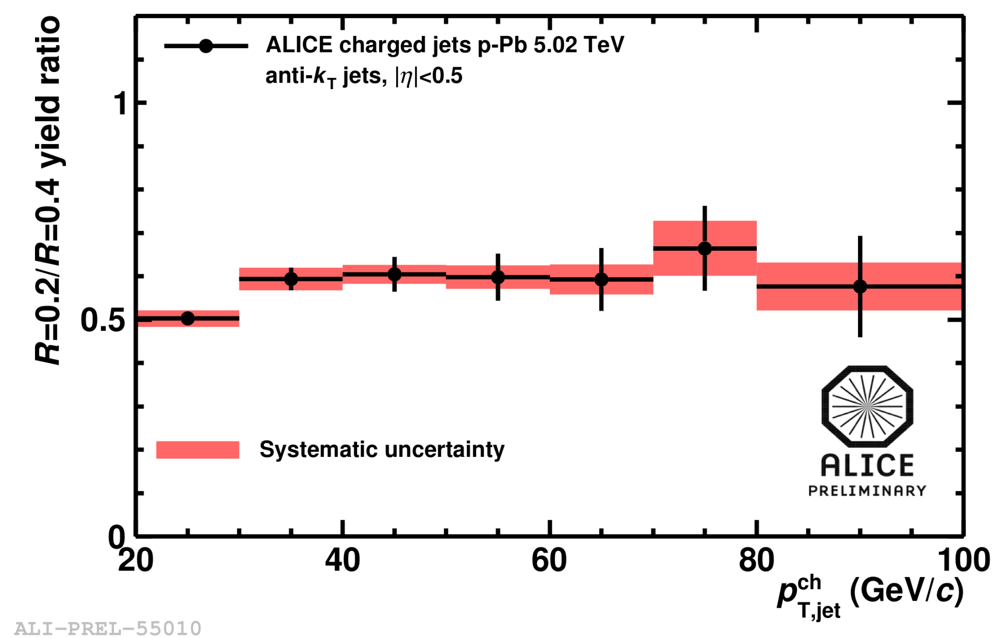
Yields taken from NLO pQCD calculations, including pPb boost

- Additionally tested: Bin-by-bin power-law extrapolations using 2.76 and 7 TeV jets



Preliminary minimum bias results

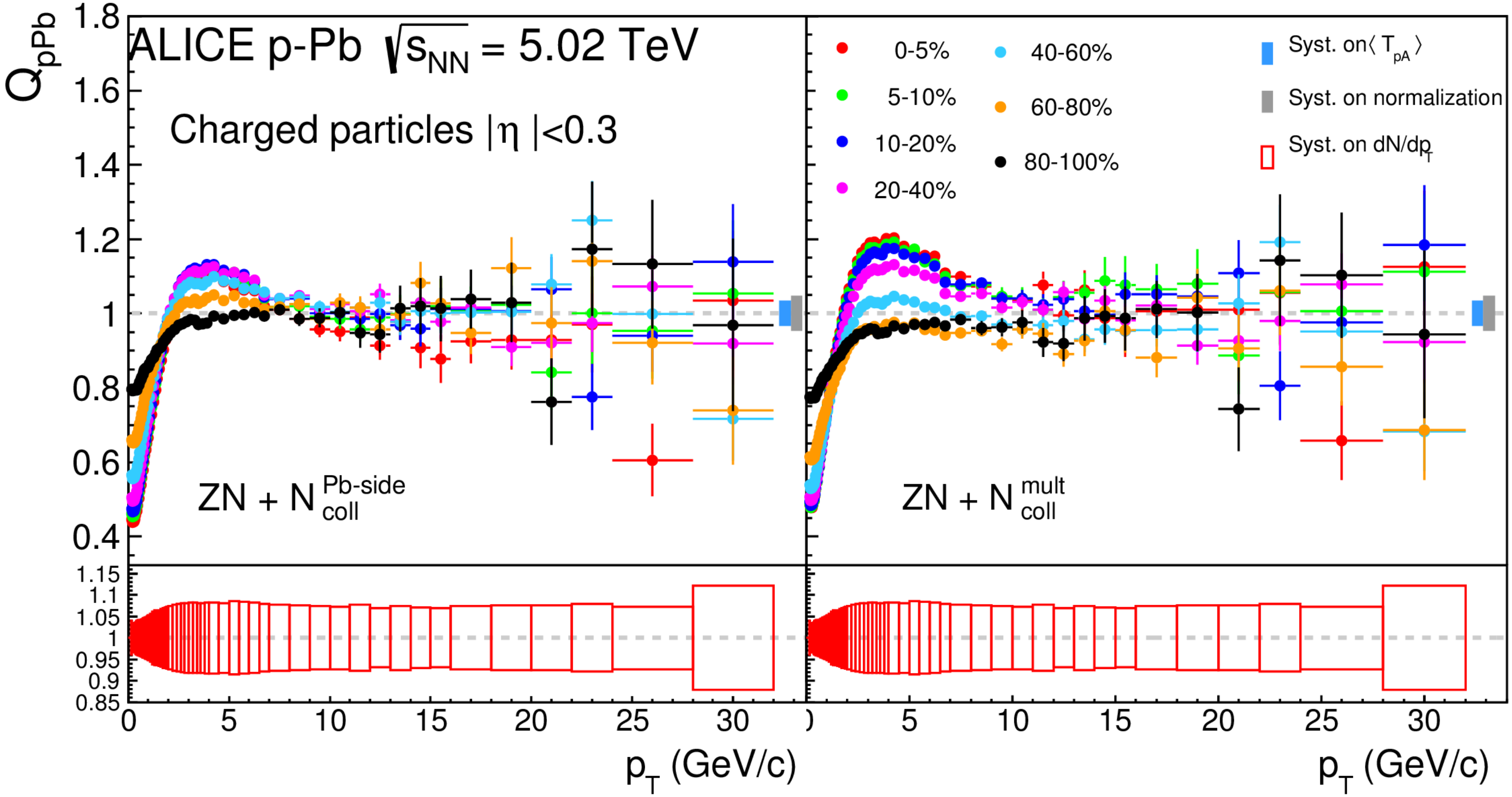




These are the first preliminary results on charged jets in pPb from July 2013

- Note that several fine details changed in the final results though the physics message stays the same
- Especially the preliminary jet yield ratio suffers from low statistics since the preliminary used only ½ of the data
- Final results publication is in collaboration review and will be published very soon

Compatibility with charged particle spectra



arXiv:1412.6828

Charged particle Q_{pPb} shows qualitatively the same behavior