Overview of Jet Physics with ALICE at the LHC

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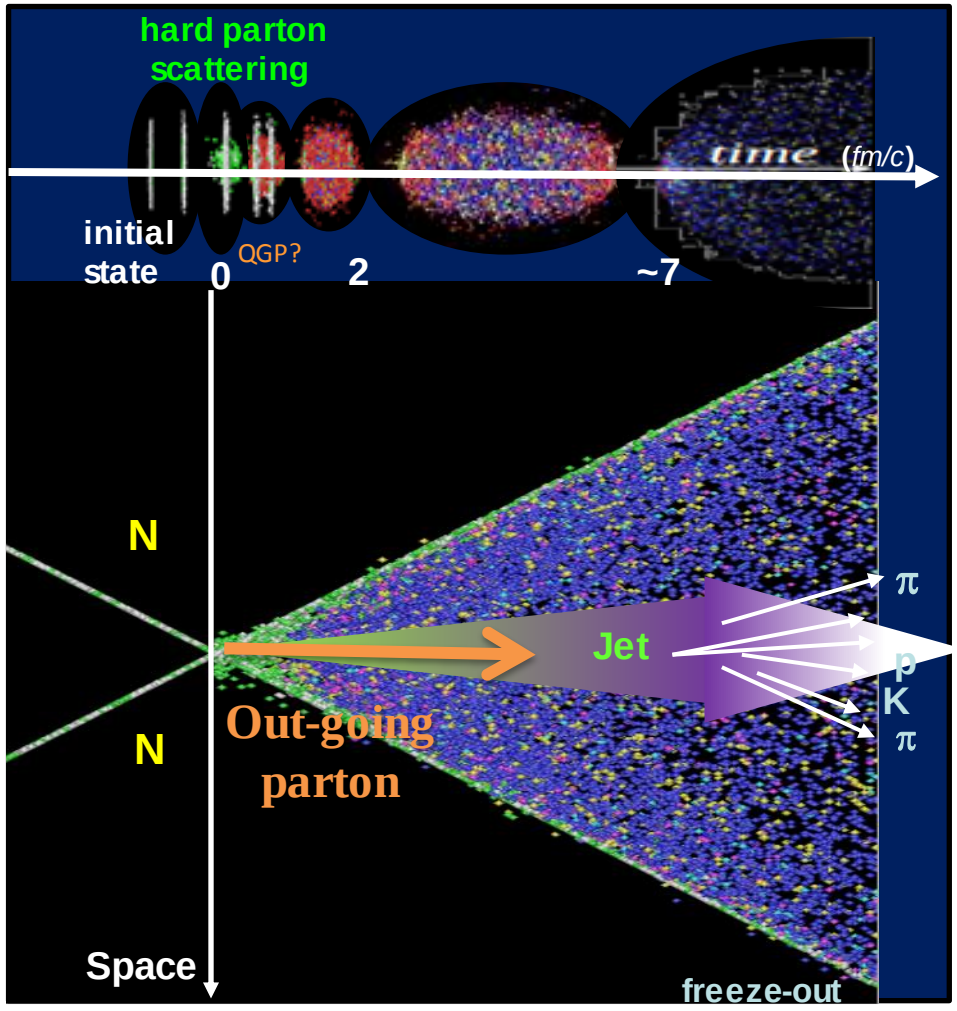
Mengliang WANG (for the ALICE Collaboration)
CCNU & SUBATECH

Outline

- Physics motivations
- How do we measure jets with the ALICE detector?
- A selection of jet results

  in pp, p-Pb and Pb-Pb collisions
- Summary & outlook

Physics motivations



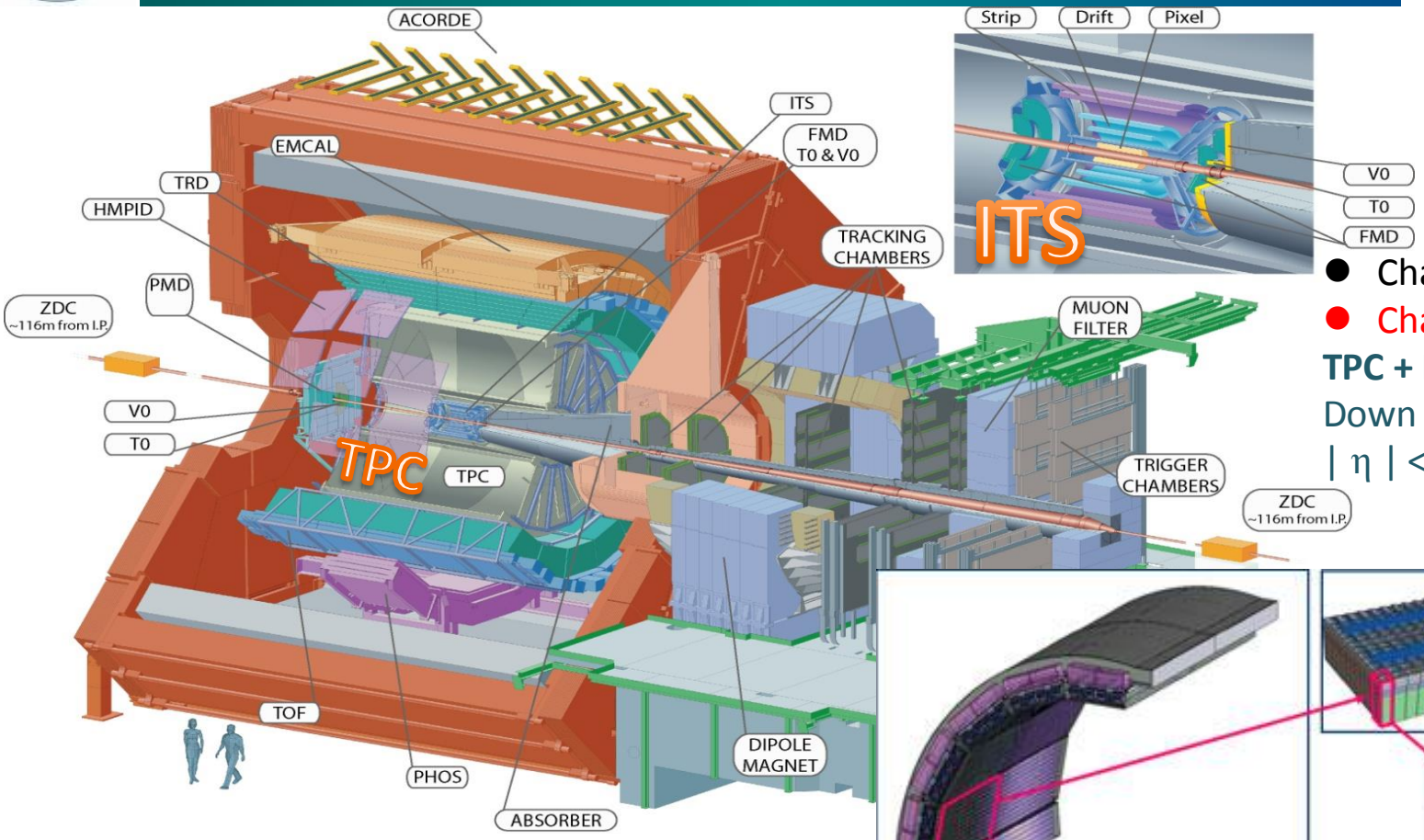
Hard probes, as jets, are created at early stages of heavy ion collisions. As a consequence, their properties may be modified by the medium. They can be used to probe the Quark Gluon Plasma (QGP):

- Jet studies in pp collisions:
  - **Reference for Pb-Pb**
- Jet studies in p-Pb collisions
  - **Cold Nuclear Matter effect (CNM)**
- Measure global observables (e.g. R_{AA}) in Pb-Pb to extract medium properties like:
  - **energy loss,**
  - **path length dependence,**
  - **medium density.**

A selection of jet results from ALICE (spectra, R_{AA}, R_{pA}, recoil jets, fragmentation) will be discussed

How do we measure jets with the ALICE detector?

Measuring jets with ALICE

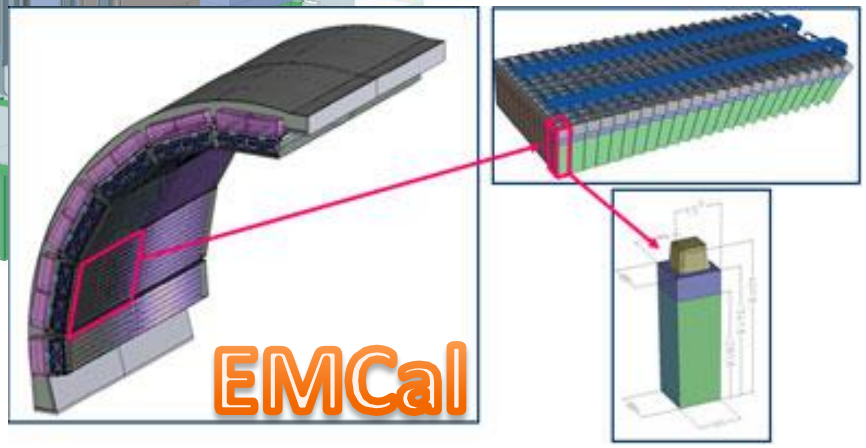


- Charged particles
- Charged jets

TPC + ITS:

Down to p_T = 150 MeV/c

$|\eta| < 0.9, 0 < \phi < 2\pi$



- + electromagnetic components
- Full jets

EMCal:

Sampling electromagnetic calorimeter (can be used as a Trigger)

Energy resolution: 11%/√E ⊕ 1.7%*.

Acceptance (**starting from 2011**): $|\eta| < 0.7$ and $\Delta\phi = 107^\circ$

* from beam test result of EMCal, NIM A615 (2010) 6-13

A selection of jet results

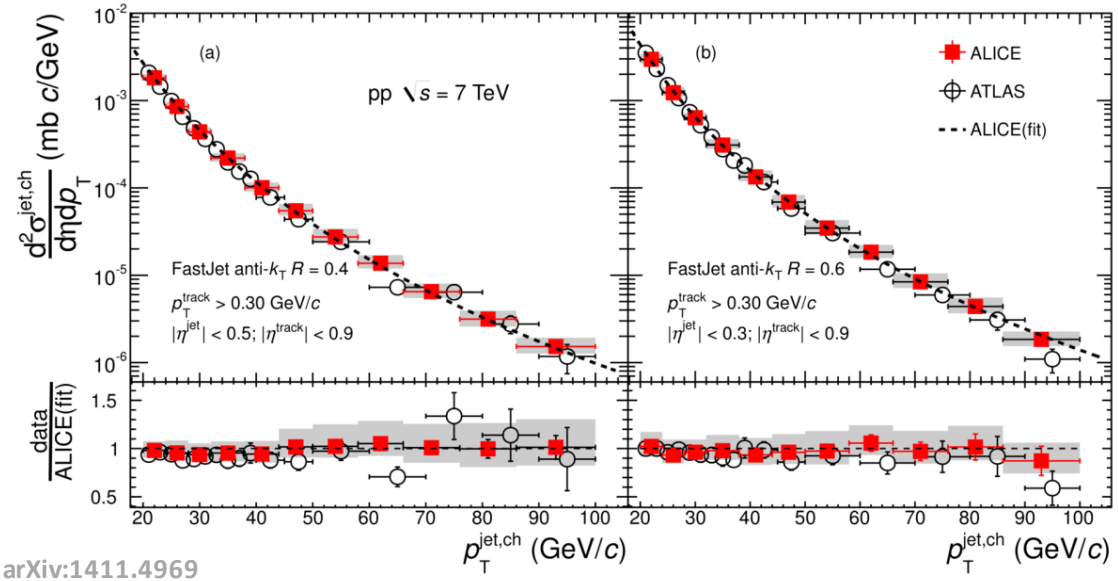
in pp, p-Pb and Pb-Pb collisions

Let's start with pp…

Jet cross-sections in pp collisions

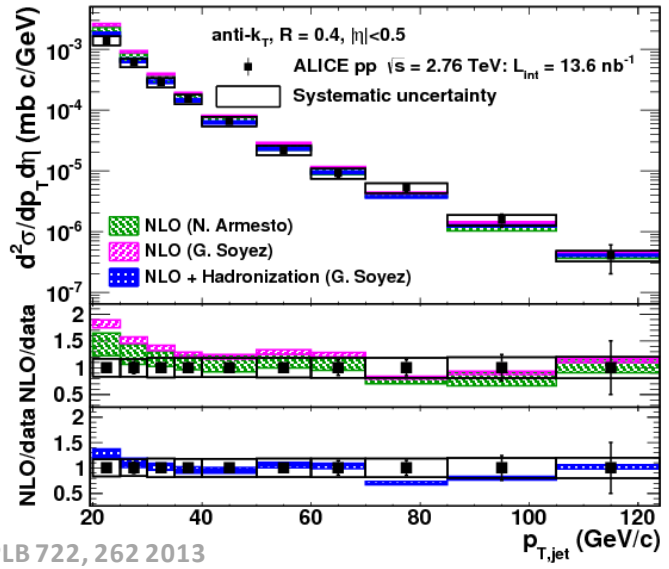
Jet is reconstructed with anti-k_T algorithm, where R is the resolution parameter

- Charged jet spectrum with different R @ 7 TeV



arXiv:1411.4969
ATLAS results: Phys. Rev. D84 (2011) 054001

- Full jet spectrum @2.76 TeV



PLB 722, 262 2013
G. Soyez, Phys. Lett. B 698 (2011) 59

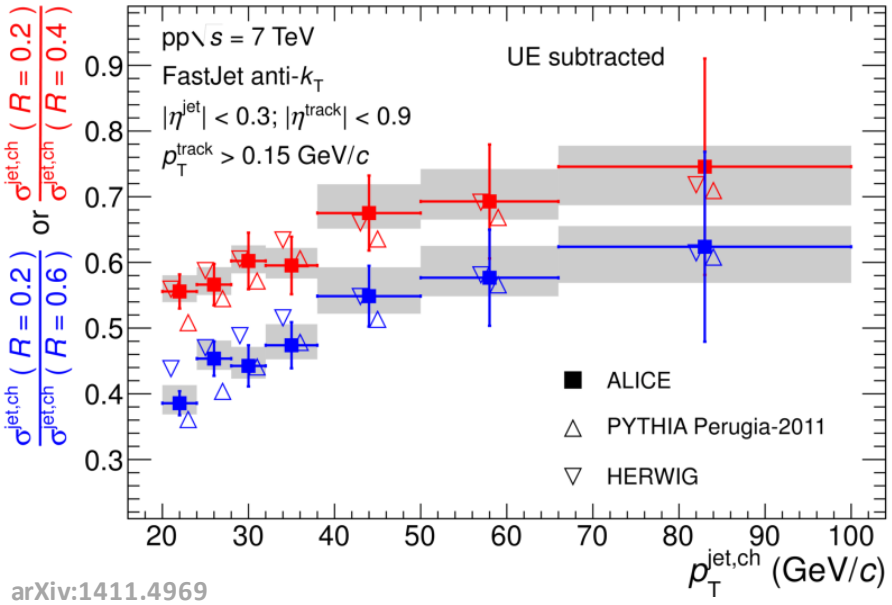
Good agreement with ATLAS

Good agreement with NLO pQCD (+ hadronization)

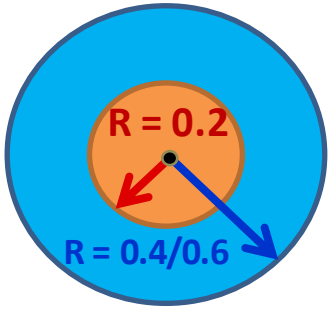
Important reference for p-Pb & Pb-Pb analyses

Ratio of jet cross-sections in pp collisions

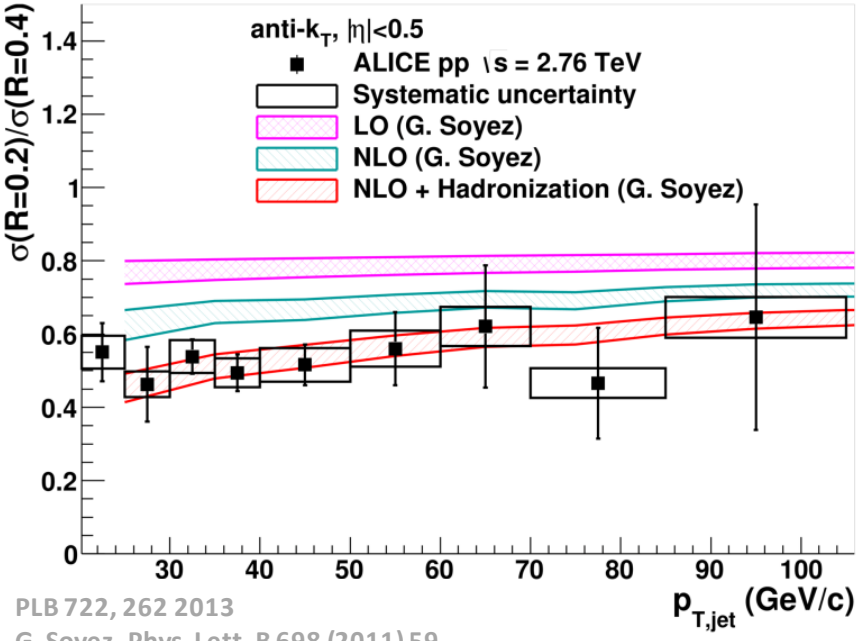
- Charged jets (R=0.2/R=0.4 or R=0.2/R=0.6)



arXiv:1411.4969



- Full jets (R=0.2/R=0.4)



PLB 722, 262 2013
G. Soyez, Phys. Lett. B 698 (2011) 59

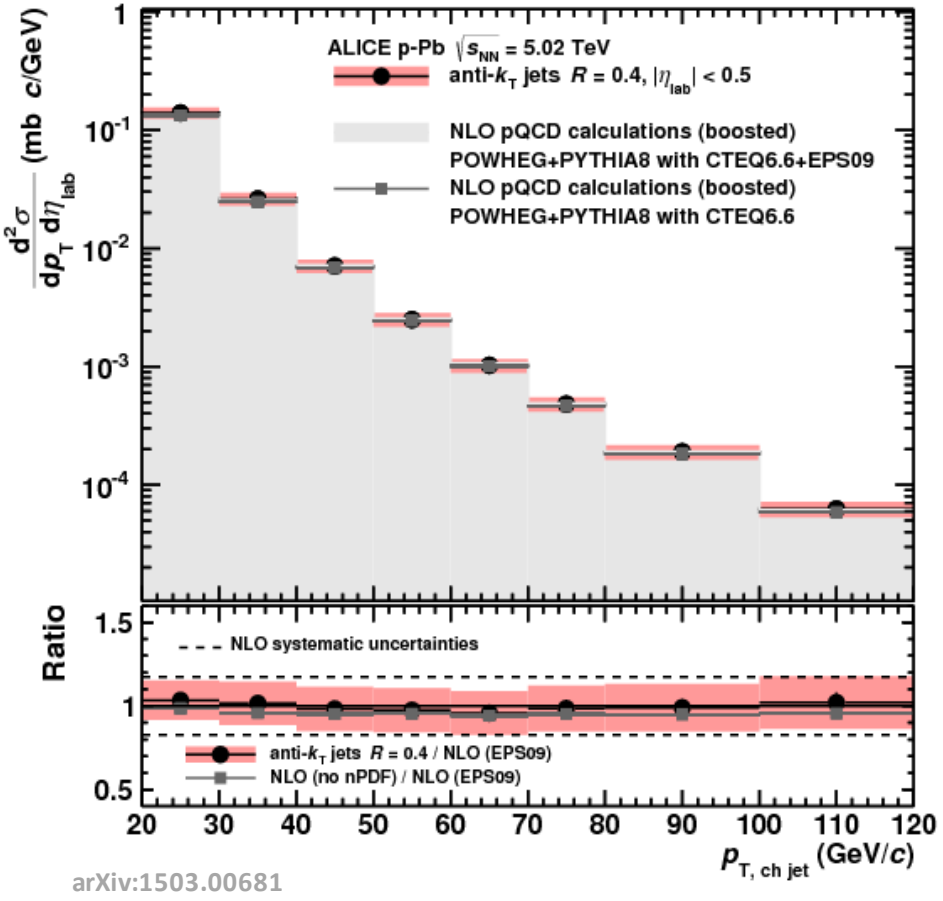
Good agreement with PYTHIA and HERWIG
Jet collimation increases with jet p_T

Good agreement with NLO pQCD (+ hadronization)

Results from p-Pb collisions @ 5.02 TeV

Jet cross-section in p-Pb collisions

- Charged jets



arXiv:1503.00681

$$p_{T,jet} = p_{\mathrm{T,rec}} - \rho A$$

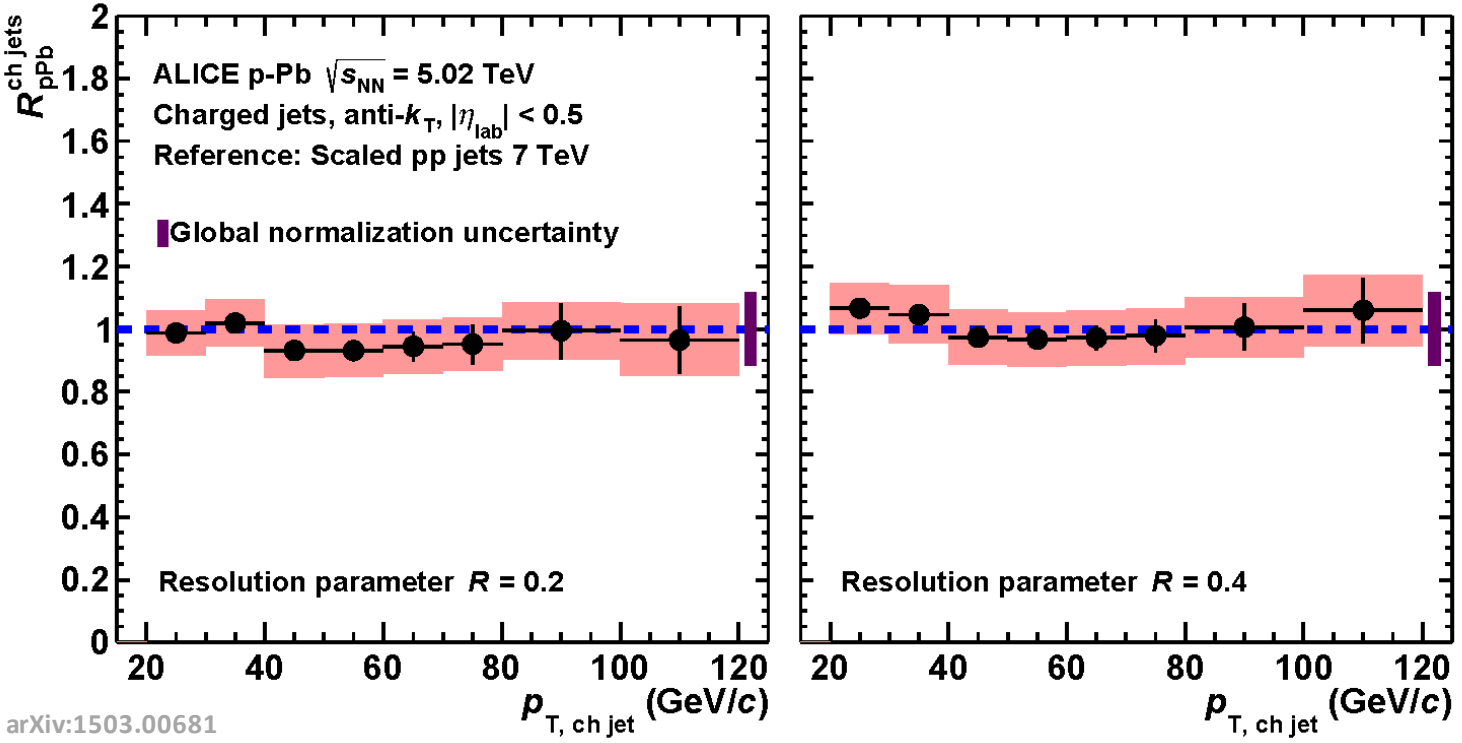
$$\rho = C \times median\left(\frac{p_{\mathrm{T}}^{\mathrm{jet},i}}{A_i^{\mathrm{jet}}}\right), \quad where\ C = \frac{\sum_j A_{j,kT}}{A_{acc}}$$

Good agreement with scaled NLO pQCD (POWHEG+PYTHIA8)
Within error bars, nuclear PDF effect negligible

Charged jet R_{pA}

- Nuclear modification factor (R_{pA}) definition:

$$R_{pA}^{jet} = \frac{dN_{pA}^{jet}/dp_T^{jet}}{N_{coll}\, dN_{pp}^{jet}/dp_T^{jet}} \cdot \frac{N_{pp}^{event}}{N_{pA}^{event}}$$



arXiv:1503.00681

Consistent with no CNM effect
(expecting 5 TeV pp data in Run2)

Dependence on jet resolution parameter

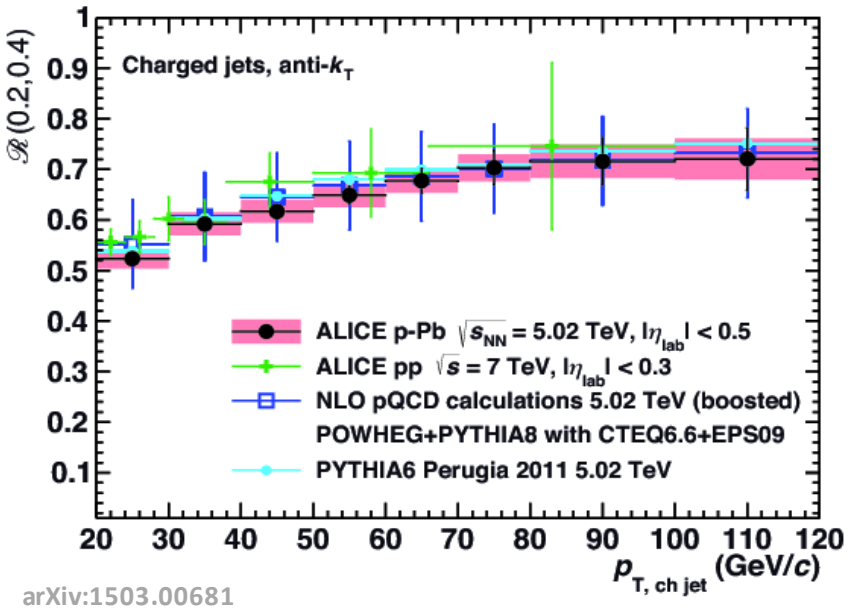
- Jet structure study in p-Pb collisions

$$\mathscr{R}(0.2, 0.4) = \frac{d\sigma^{jet,ch}(R=0.2)/dpT}{d\sigma^{jet,ch}(R=0.4)/dpT}$$

Comparing to pp simulations, no differences observed within error bars Collimation increases with jet p_T as in pp.

No significant energy dependence or change with collision species is observed.

Almost no centrality dependence



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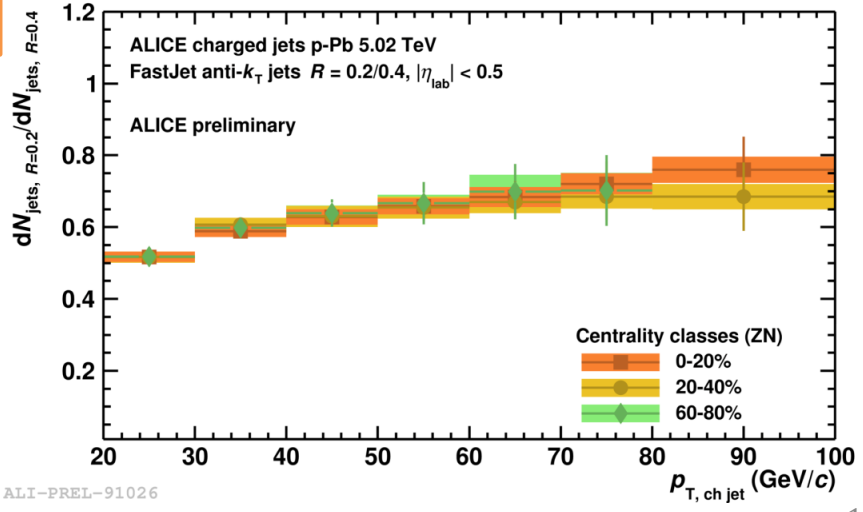
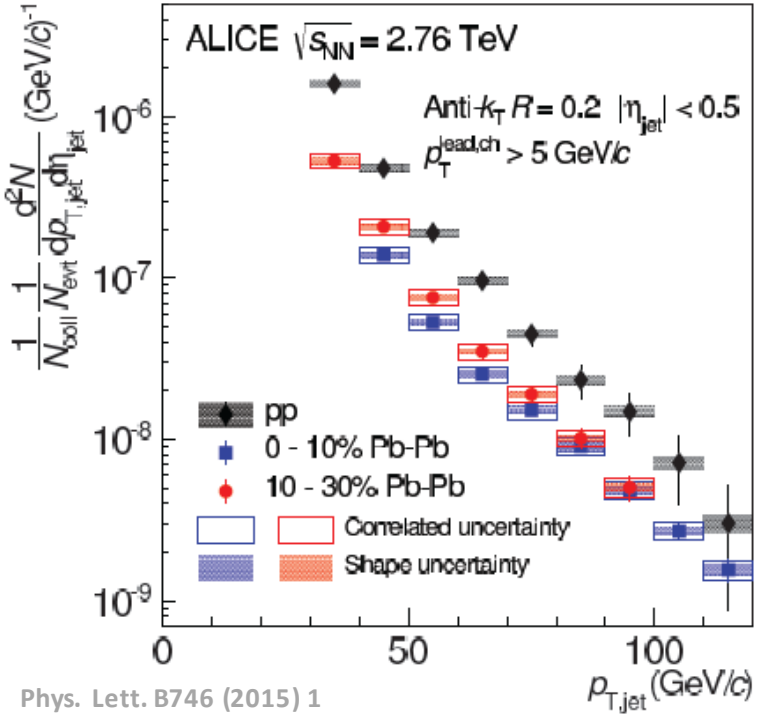


ALI-PREL-91026

Results from Pb-Pb collisions @ 2.76 TeV

Full jet spectrum & R_{AA} in PbPb collisions

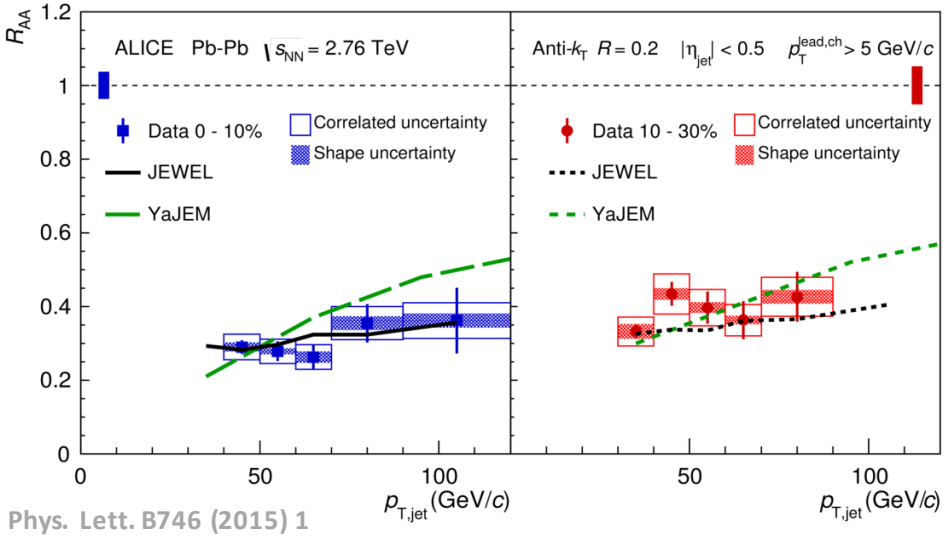
- Full jet spectrum in Pb-Pb: large and fluctuating background
  (JHEP03 (2012) 053)



Phys. Lett. B746 (2015) 1

- Full jet R_{AA}:

$$R_{AA}^{jet} = \frac{dN_{AA}^{jet}/dp_T^{jet}}{N_{coll}\, dN_{pp}^{jet}/dp_T^{jet}} \cdot \frac{N_{pp}^{event}}{N_{AA}^{event}}$$



Phys. Lett. B746 (2015) 1

- **Suppression quantified by R_{AA} for different centralities: 0-10% $R_{AA} \approx 0.28 \pm 0.04$**
  10-30% $R_{AA} \approx 0.35 \pm 0.04$
- **Both models use a fit to hadron R_{AA} to adjust their parameters.**

Strong suppression observed in spectra and R_{AA}

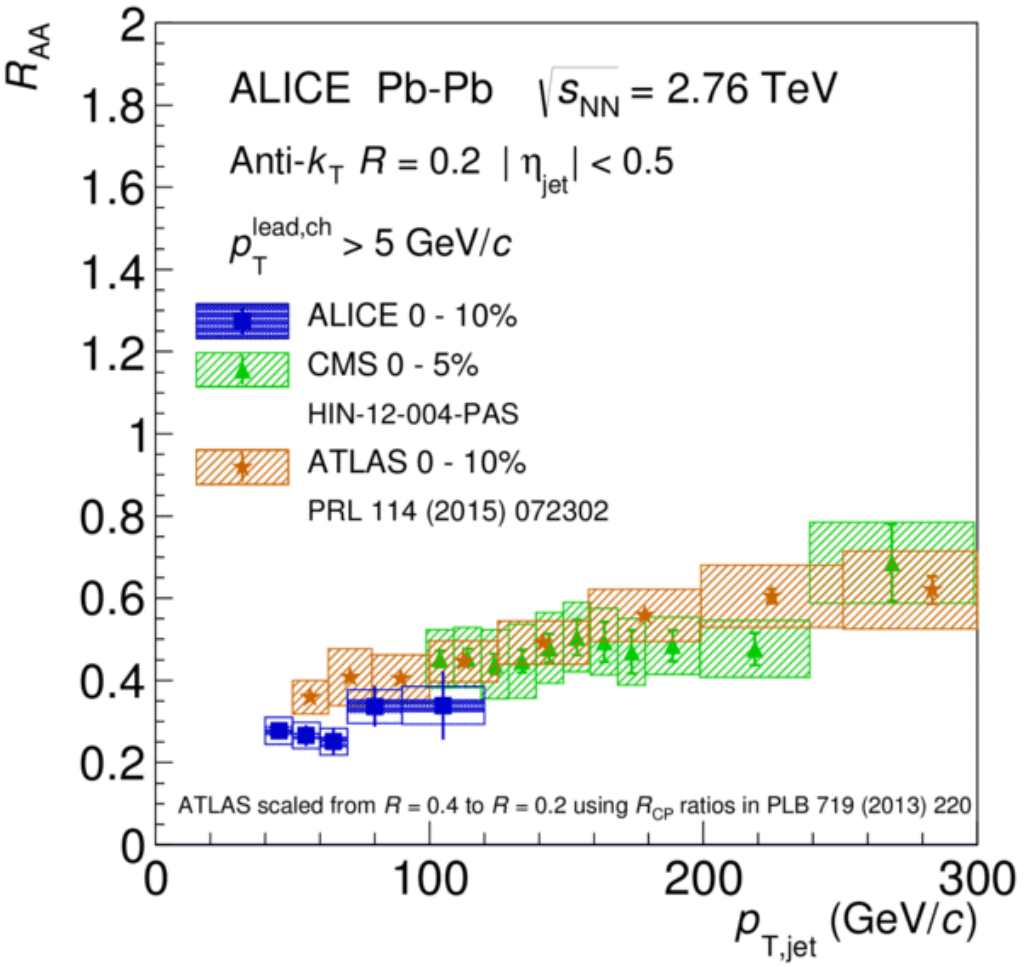
Both models are in agreement with data

Full jet R_{AA}: at LHC

- Full jet R_{AA} in central Pb-Pb collisions,
- Different jet reconstruction techniques (ATLAS: Calo Jets, CMS: Particle-Flow Jets, ALICE: Ch+En Jets) used by the different experiments
- R=0.2

NB: ATLAS scaled from R=0.4 to R=0.2

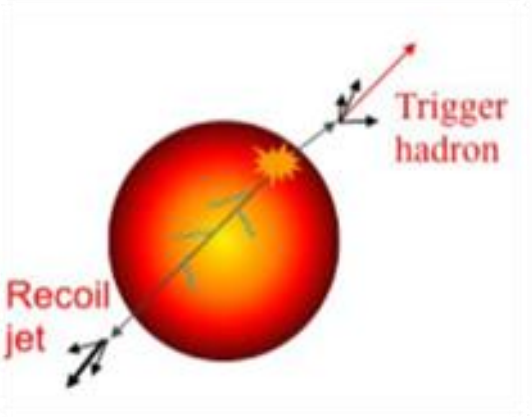
Results at LHC are in fair agreement



ALI-DER-92552

ALICE recoil jet measurement

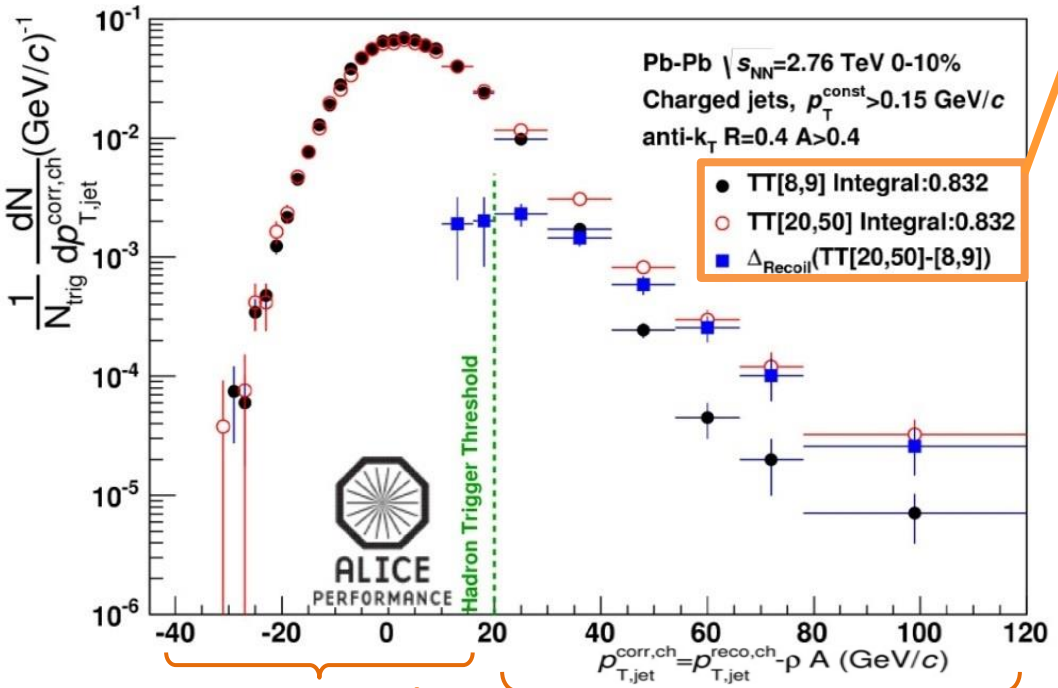
- h-jet correlation study



➢ **Surface bias effect:**
trigger hadron close to the surface, so the recoil jet biased towards higher in-medium path lengths

Low $p_{T,trig}$ (TT*[8, 9]) trigger recoil jet spectrum as a reference (dominated by combinatorial jet).
High $p_{T,trig}$ (TT[20, 50]) trigger recoil jet spectrum mainly from hard (high Q^2) process (signal).
Δ_{Recoil} is defined as the difference of these two spectra to remove bkg and uncorrelated component.

*** TT for triggered track**



$p_{T,jet}$ < 20 GeV/c:
Shape does not change with $p_{T,trig}$
➔ Combinatorial background

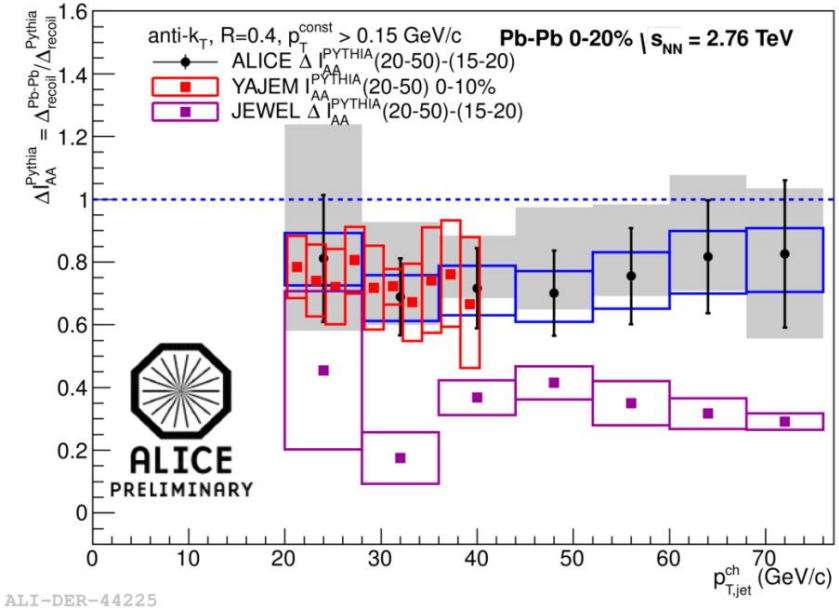
$p_{T,jet}$ > 20 GeV/c:
Recoil jet spectrum evolves with $p_{T,trig}$

ALI-PERF-64036

Semi-inclusive recoil jets in Pb-Pb

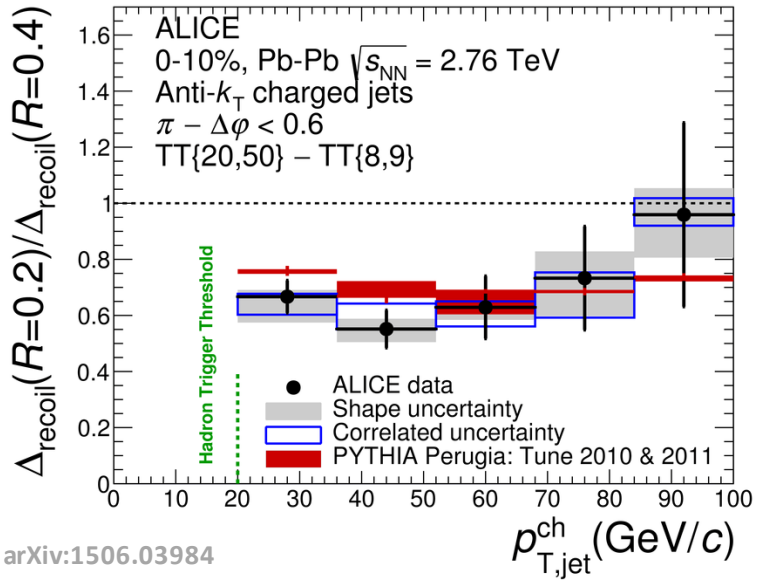
- Recoil jet measurement provides us with a good handle on the combinatorial background and allows measurement using larger R (0.5 not shown here)

$$\Delta I_{AA}^{jet} = \frac{\Delta_{recoil}^{AA}/dp_T^{jet}}{\Delta_{recoil}^{pp}/dp_T^{jet}}$$



Choice of reference spectrum PYTHIA (describes well pp data at 7 TeV)

- Δ_{Recoil} dependence with R



arXiv:1506.03984

Δ_{Recoil} for R=0.2/R=0.4 similar in pp and central Pb-Pb collisions

Recoil jet yields are suppressed
JEWEL overestimates the suppression

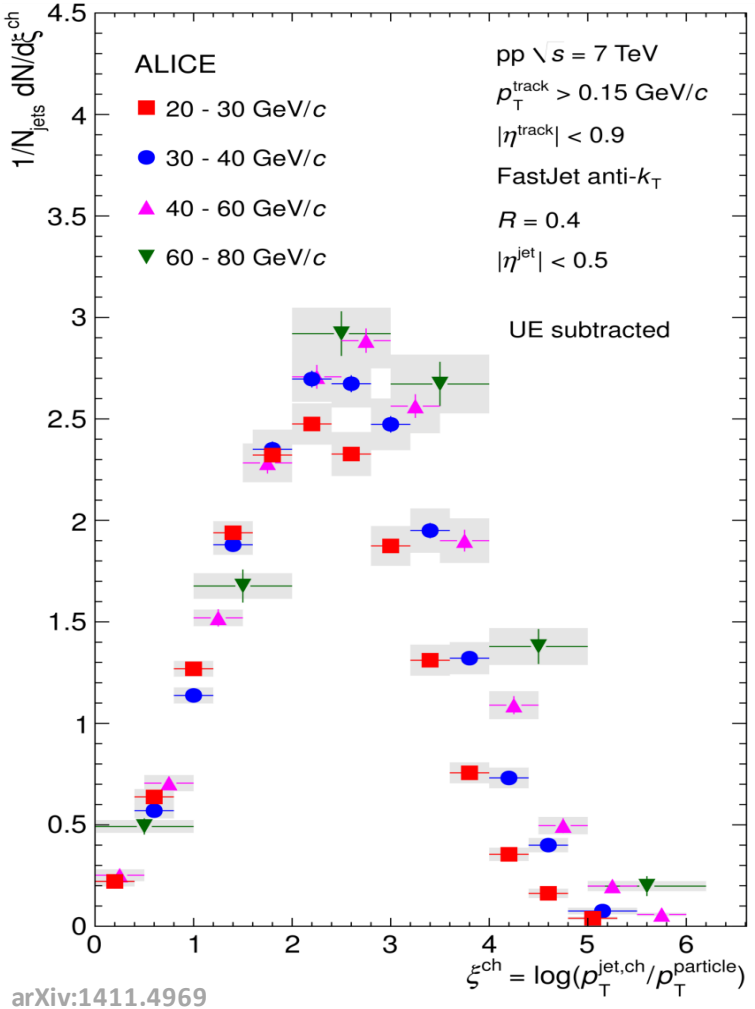
No evidence of intra-jet broadening

Jet fragmentation

Towards more differential measurements: study the momentum distribution of tracks in jets

- Charged jets in pp collisions @ 7 TeV: Expected evolution with jet p_T (angular ordering)

Measurement challenging in Pb-Pb collisions (large heavy ion background and fluctuations). New observables are under study.



arXiv:1411.4969

Summary

- Jets are measured in ALICE using **the TPC (+ ITS)** (charged jets) **and with EMCal** (full jets).
- In pp collisions:
  - jet spectra are in agreement with NLO pQCD + hadronization
  - the jet fragmentation have been measured (charged jet)
- In p-Pb collisions:
  - The jet cross-section is in **agreement** with NLO pQCD
  - The corresponding R_{pA} is consistent with no CNM effect (within the experimental uncertainties)
  - R=0.2/R=0.4 shows no significant energy dependence or change with collision species. The collimation increases with jet p_T (as in pp).
- In Pb-Pb collisions
  - the background contribution and **its fluctuations** are playing an important role
  - A strong jet **suppression** is observed in Pb-Pb collisions ($\mathbf{R_{AA}}$ ~ 0.3). This result is both **compatible** with results from the other LHC experiments and with models.
  - Recoil jet measurement provides us with a good handle on **the combinatorial background** and allows measurement using **larger R**

ALICE

Outlook

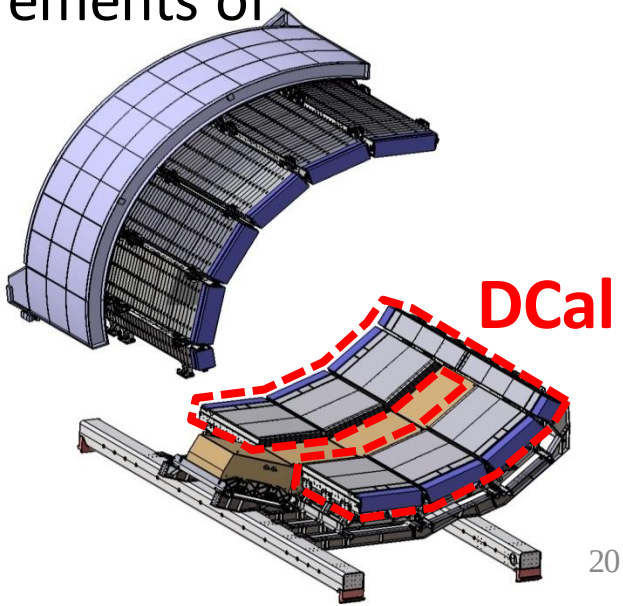
Some more results could not be covered in the talk (e.g. PID in jets)

- More differential studies of jet in Pb-Pb (Fragmentation functions, …) are hard to achieve due to the large heavy ion background and to its fluctuations

  New observables are under study

The LHC run 2 is just starting…

- The ALICE calorimeter system has been extended (**DCal added**) and will allow back to back measurements of jets and correlations studies (as well as improved triggering capabilities).
- many new exiting results are expected



Thank you