Jet measurements in proton-proton and PbPb collisions with the ALICE experiment at LHC

Rishat Sultanov

ITEP, Moscow

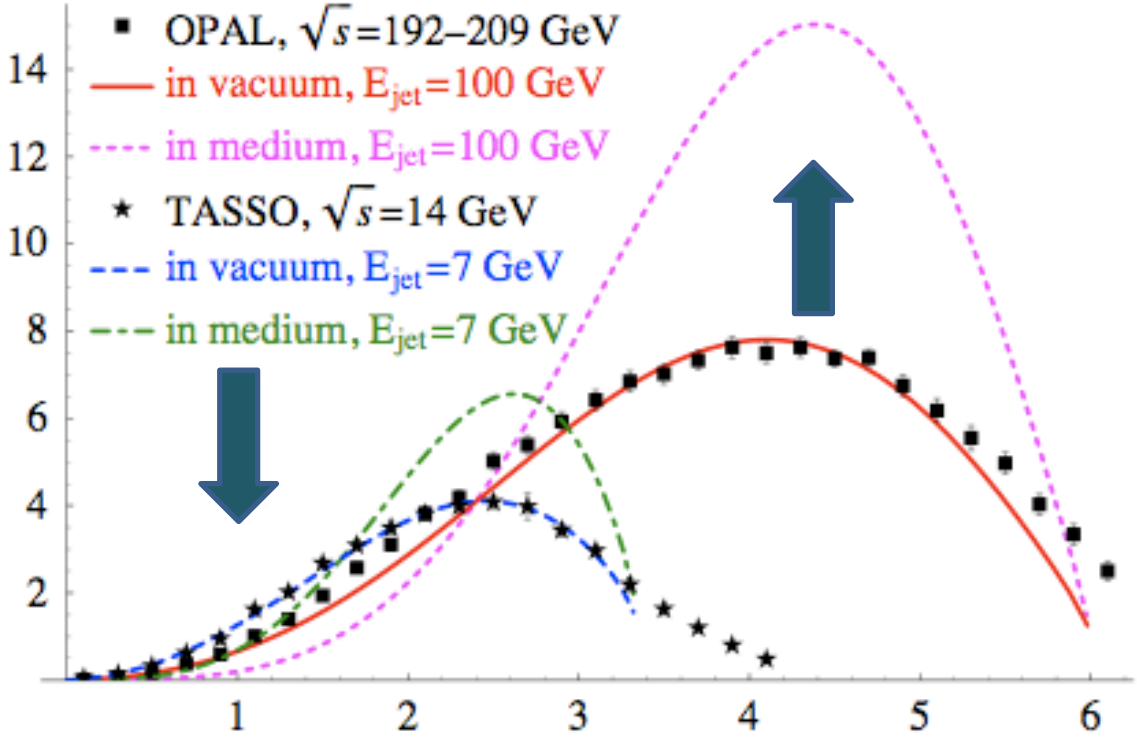
for the ALICE collaboration

Outline

- Jet reconstruction in ALICE
  - Input and algorithms
- pp jets
  - Cross-section, spectra
  - Comparison to other experiments
- PbPb jets
  - Background fluctuations
  - Spectra
  - R_{AA}
- Summary

Jets as a tool in testing QCD

- Probes to study properties of medium
- Due to interaction of the jet with the medium, the jet is modified: Jet Quenching
- The amount of medium induced gluon radiation depends on the medium density

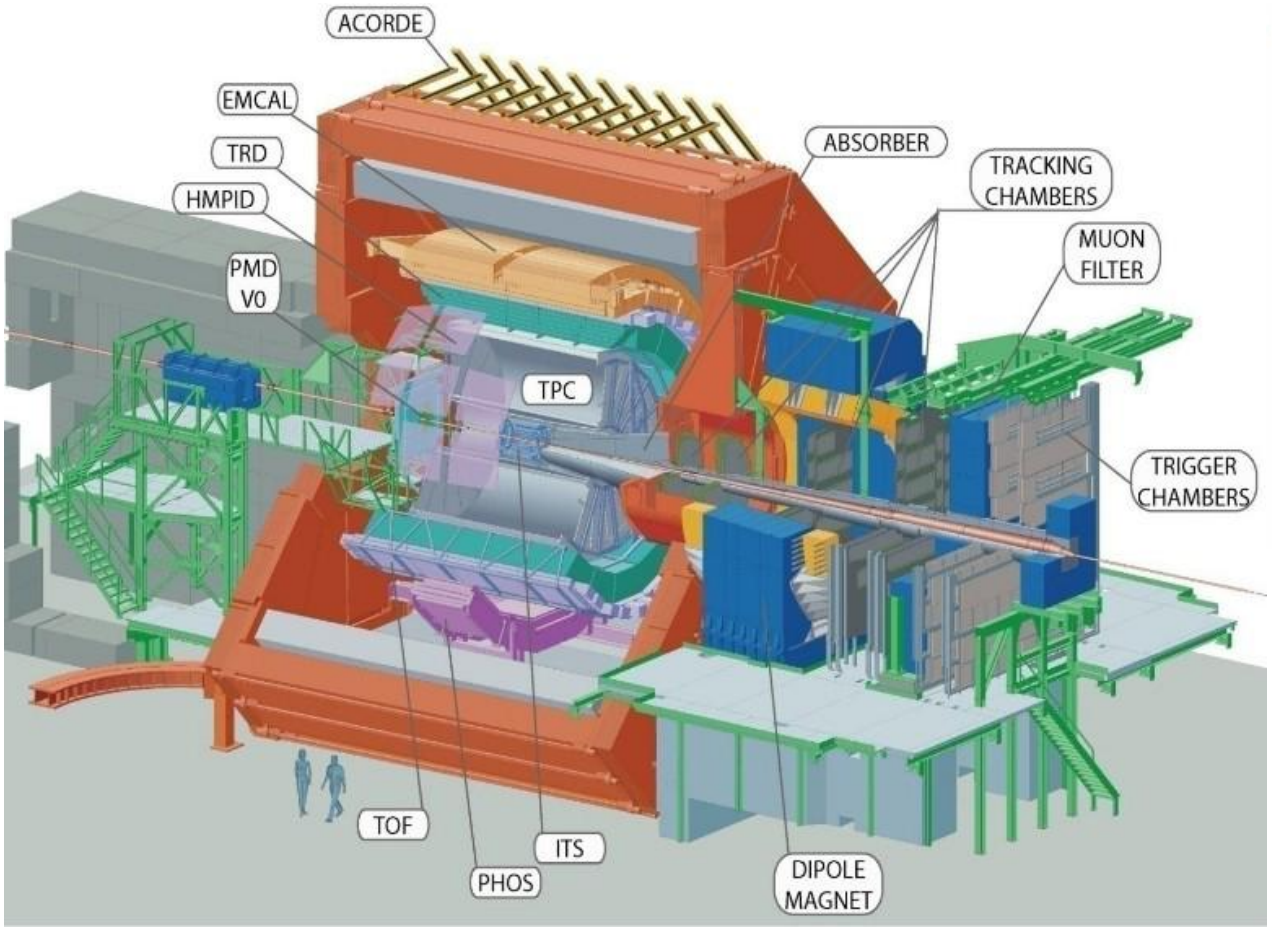


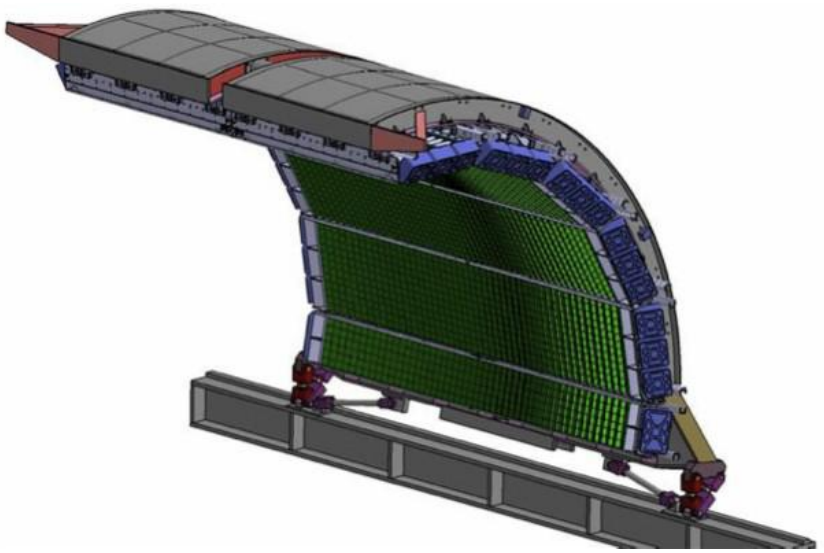
Borghini, Wiedemann, hep-ph/0506218

Experimental challenge in HI collisions:

Separate jet signal from large soft background originating from bulk

Jet Reconstruction in ALICE





Energy and direction of neutral particles

EMCal: Pb-scintillator sampling calorimeter which covers:

$|\eta| < 0.7, 80° < \varphi < 180°$

- 11520 towers with each covers

$\Delta\eta \times \Delta\varphi \sim 0.014 \times 0.014$

4-momenta of charged particles

Tracking: $|\eta| < 0.9, 0 < \varphi < 360°$

TPC: gas detector

ITS: silicon detector

Charged constituents

Neutral constituents

JET

Track selection for jet reconstruction

- Charged Jets
  - Input: tracks with $p_T > 150$ MeV/c

  Advantage: full azimuthal (φ) coverage
- Fully reconstructed jets
  - Tracks with $p_T > 150$ MeV/c
  - EMCal clusters $E_T^{clus} > 150$ MeV after correction for energy from charged particles
  - Jet required to be fully contained in EMCal acceptance

  Advantages: trigger capability, higher $p_{T,Jet}$ reach, less biased fragmentation

Jet Finders

Jet reconstruction using FastJet* package

R = 0.2, 0.3, 0.4 (up to R=0.7 in pp)

Anti-k_T for signal jets

– Area cut A > 0.1-0.4 avoids extremes

– jets are clustered around a high p_T track with almost concentric area

– robust against the soft event

k_T for background estimate (Pb-Pb)

– recombination process starts with low p_T tracks

– cluster with highest p_T are excluded and the median over remaining clusters is taken

* M. Cacciari, G.P. Salam and G. Soyez, Eur.Phys.J. C72 (2012) 1896 [arXiv:1111.6097]

Distance Definition

$$D_{ij} = \min(p_T^{2p}{}_i, p_T^{2p}{}_j)\frac{\Delta Rij2}{R2}; D_i = p_T^{2p}$$

k_T (anti k_T): p=1(−1)

Compute all D_{ij}, D_i, d=min(D_{ij}, D_i)

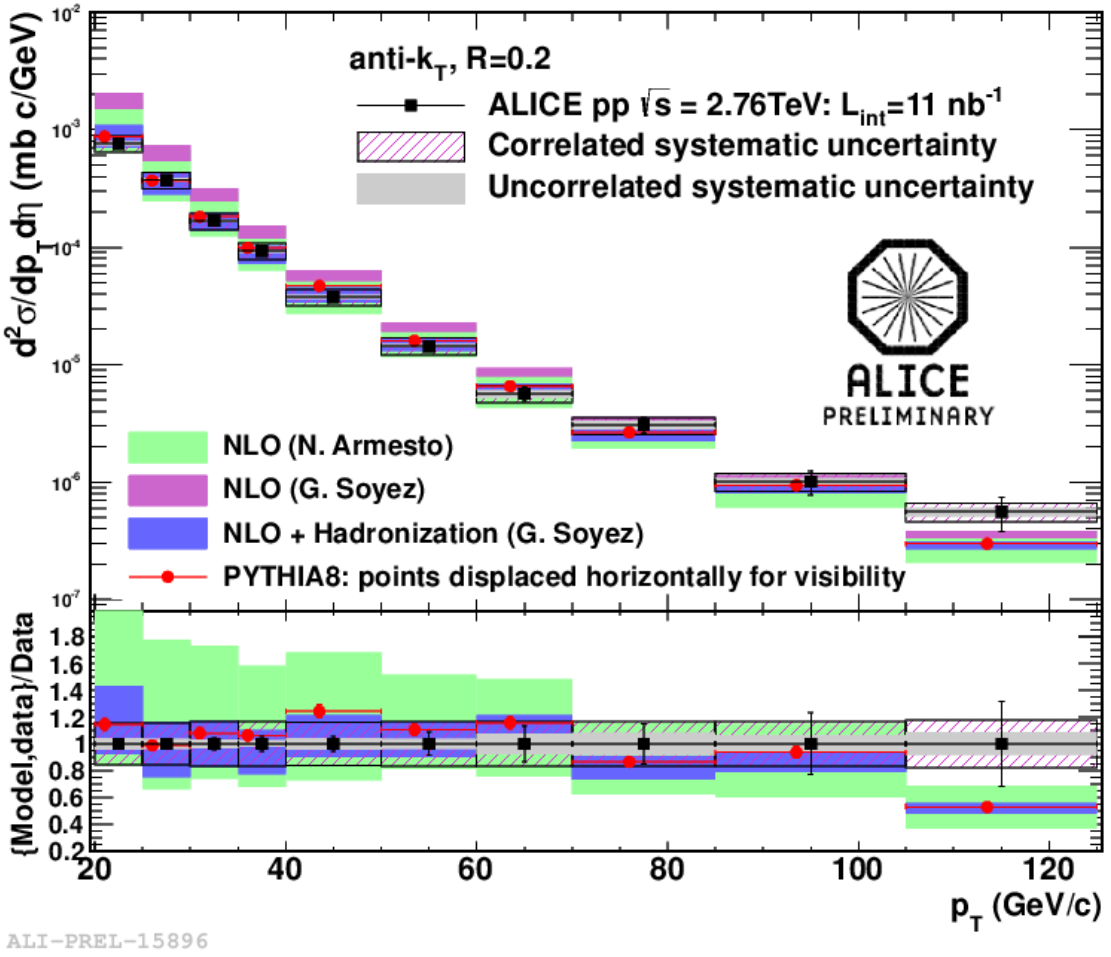
if d=D_{ij} : combine i with j

if d=D_i : i is final state jet

Full jets in pp at √s = 2.76 TeV

anti k_T : R = 0.2

- JES uncertainty: 4%
  - Missing neutral energy
  - Tracking efficiency
  - Energy double counting (charged particle correction)
- Jet p_T resolution 20%
  - Event-by-event fluctuations of JES
  - Track Δp_T / p_T= 40 GeV/c: 4%
  - EMCal resolution at E = 40 GeV: 3%
- Effects of efficiency and resolution on jet spectrum are corrected bin by bin.

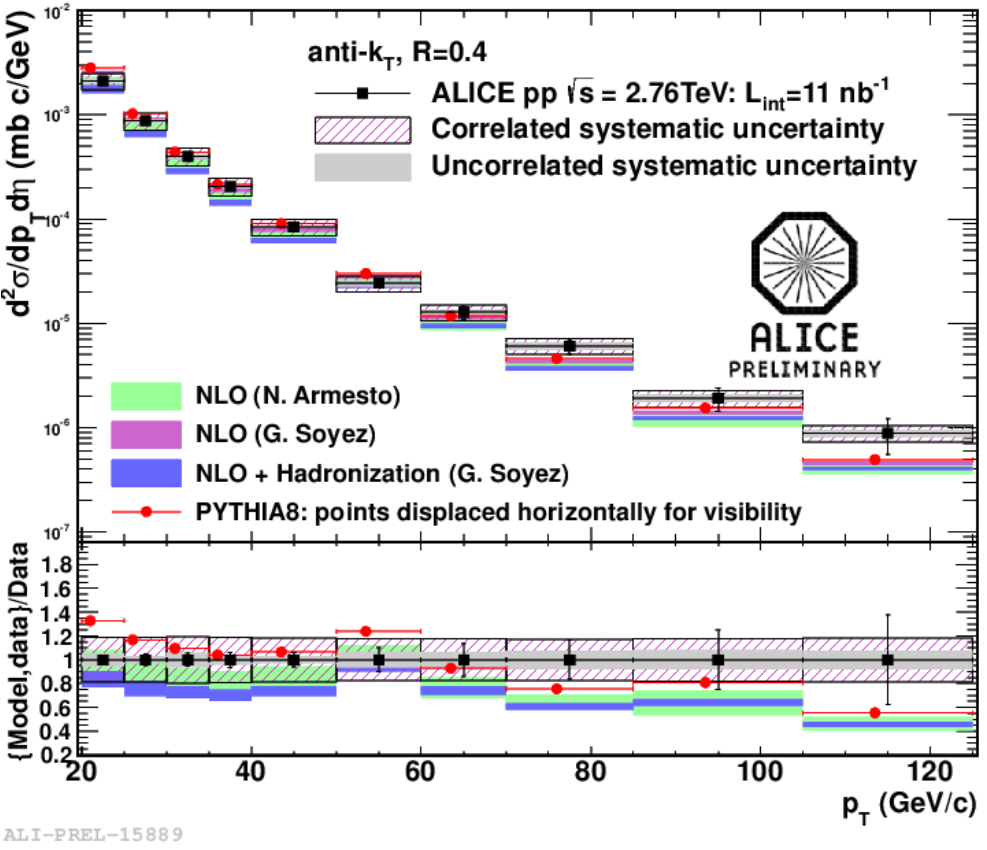


- Good agreement with NLO pQCD + hadronization and Pythia8
- Important reference for Pb-Pb analysis

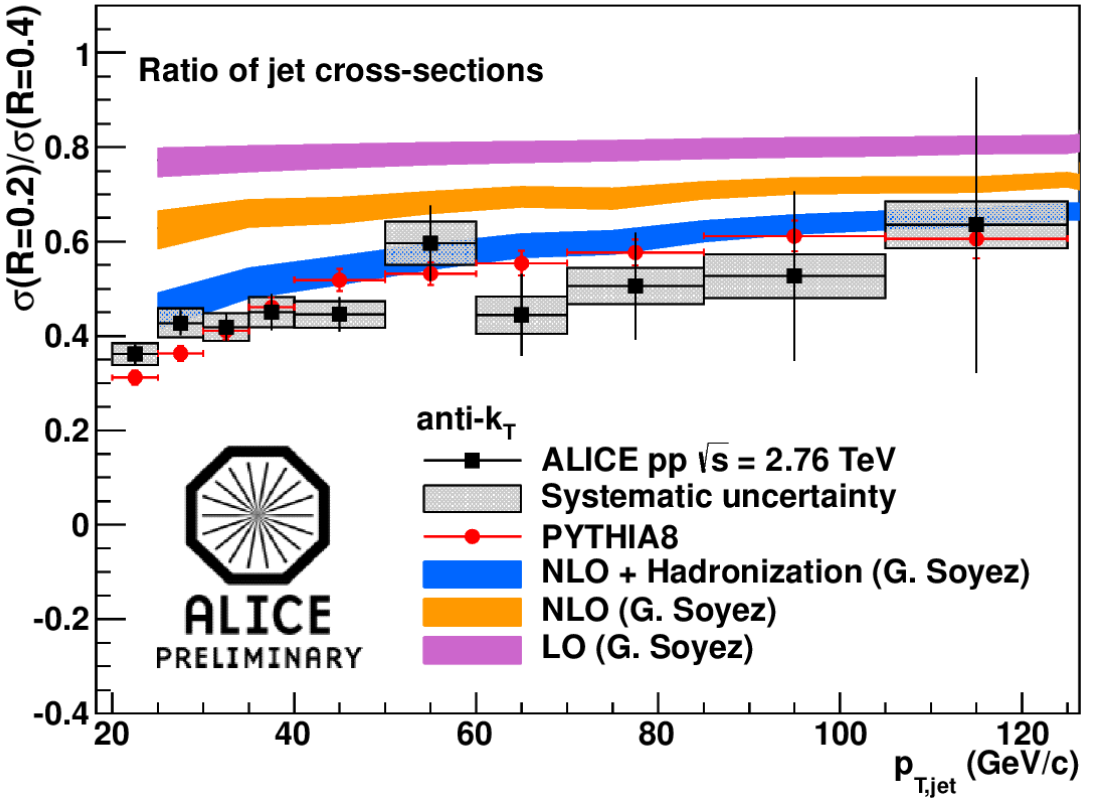
Jets in pp at √s = 2.76 TeV

anti k_T : R = 0.4

$d^2\sigma/dp_T d\eta$(mb c/GeV)



$\sigma(R=0.2)/\ \sigma(R=0.4)$

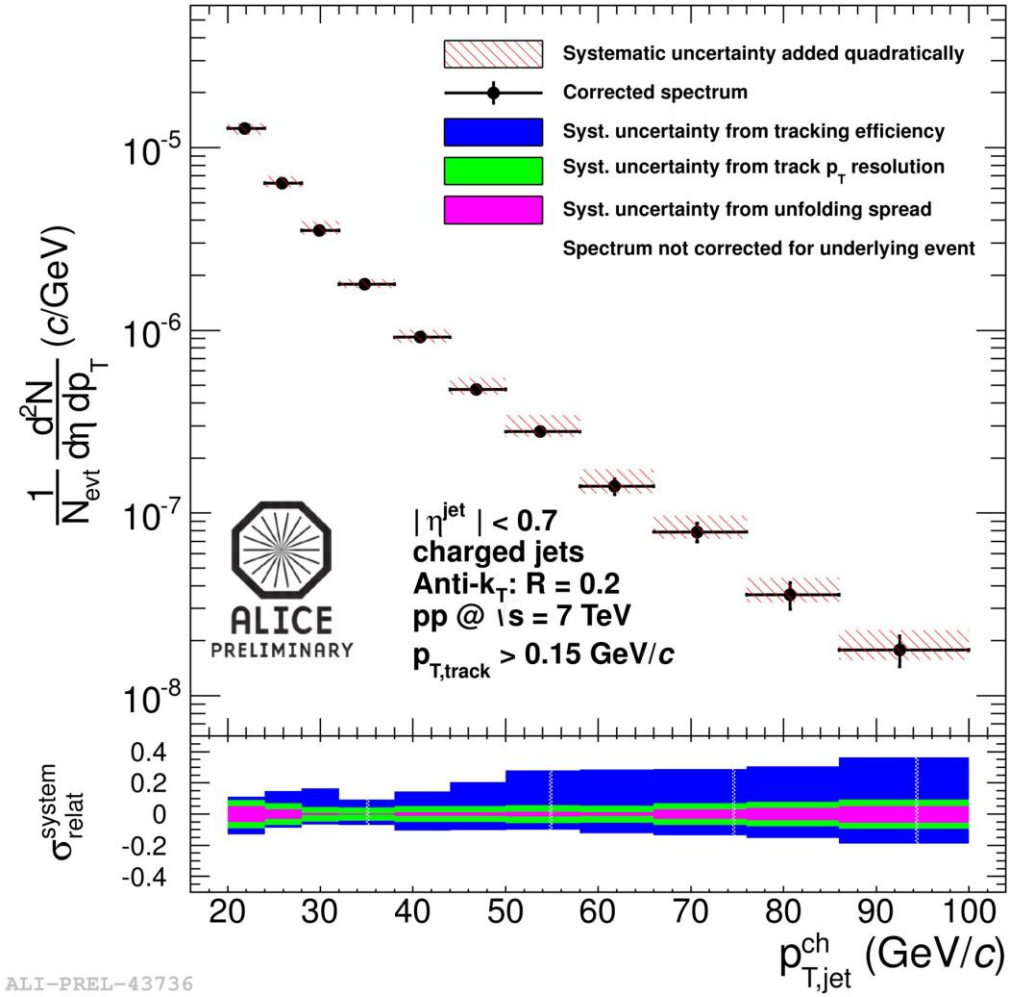


Good agreement with NLO pQCD and Pythia8

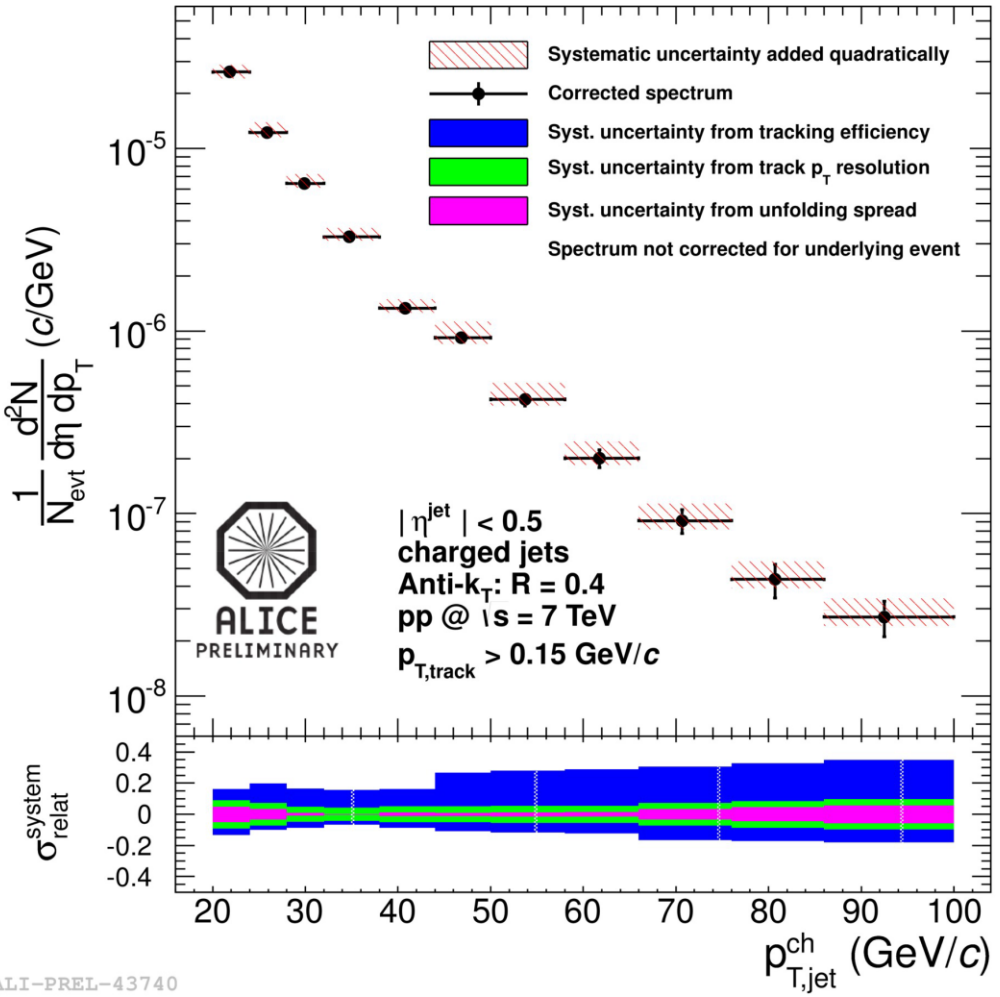
Corrected Jet Spectra

Charged jets at √s = 7 TeV

Anti-k_T: R = 0.2



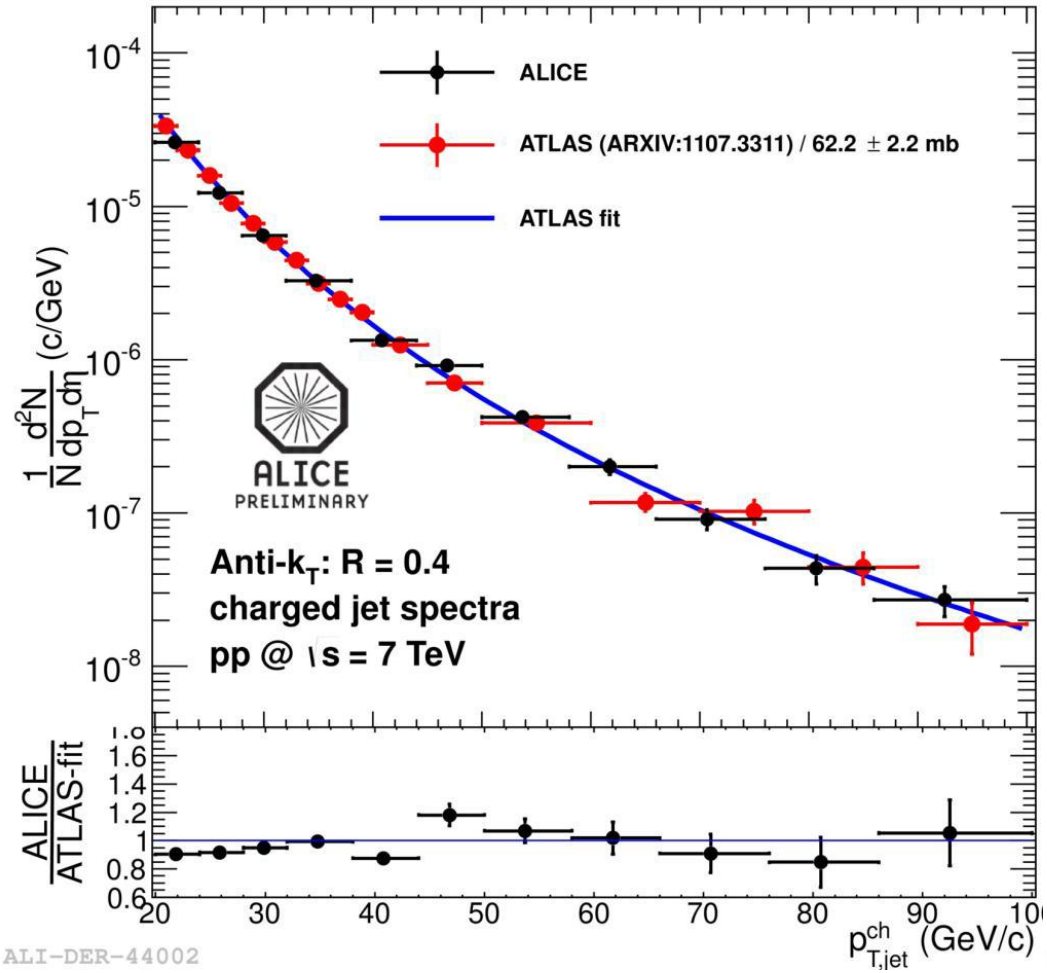
Anti-k_T: R = 0.4



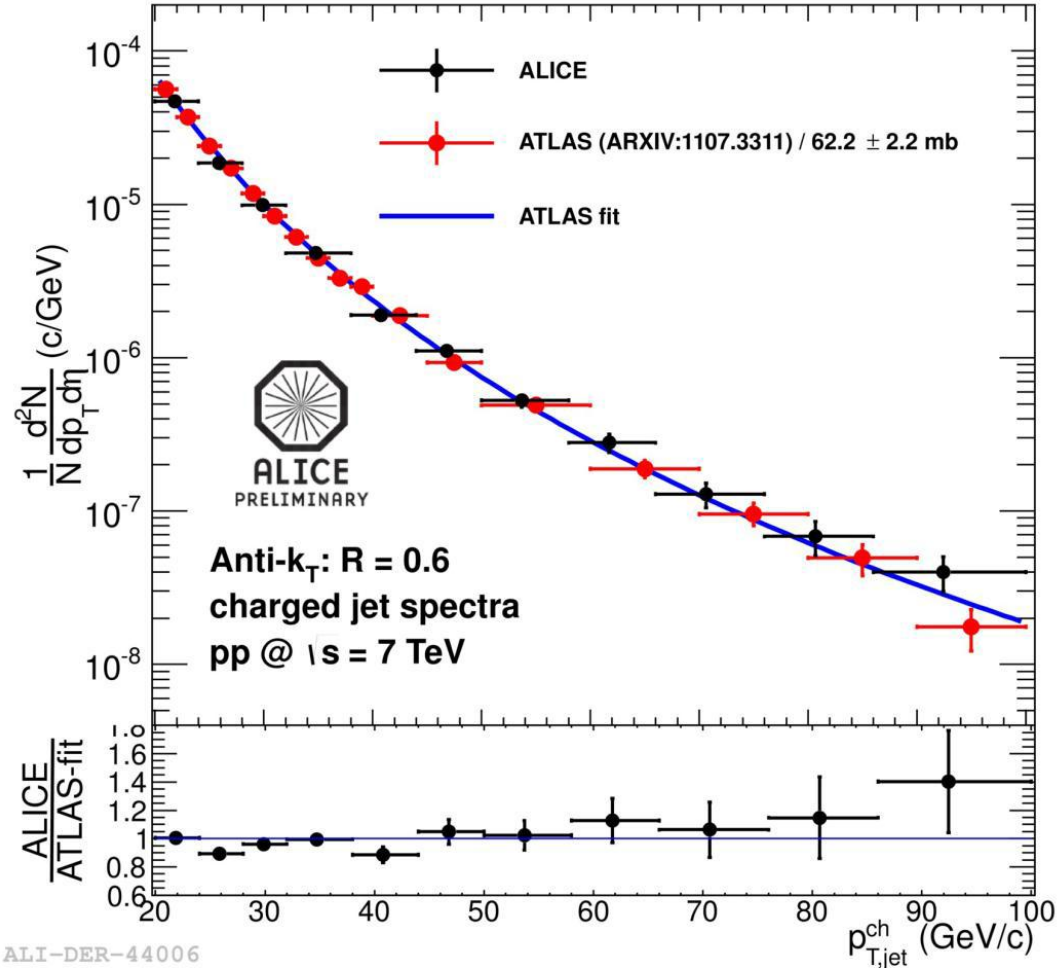
Comparison to ATLAS

Charged jets at √s = 7 TeV

Anti-k_T: R = 0.4



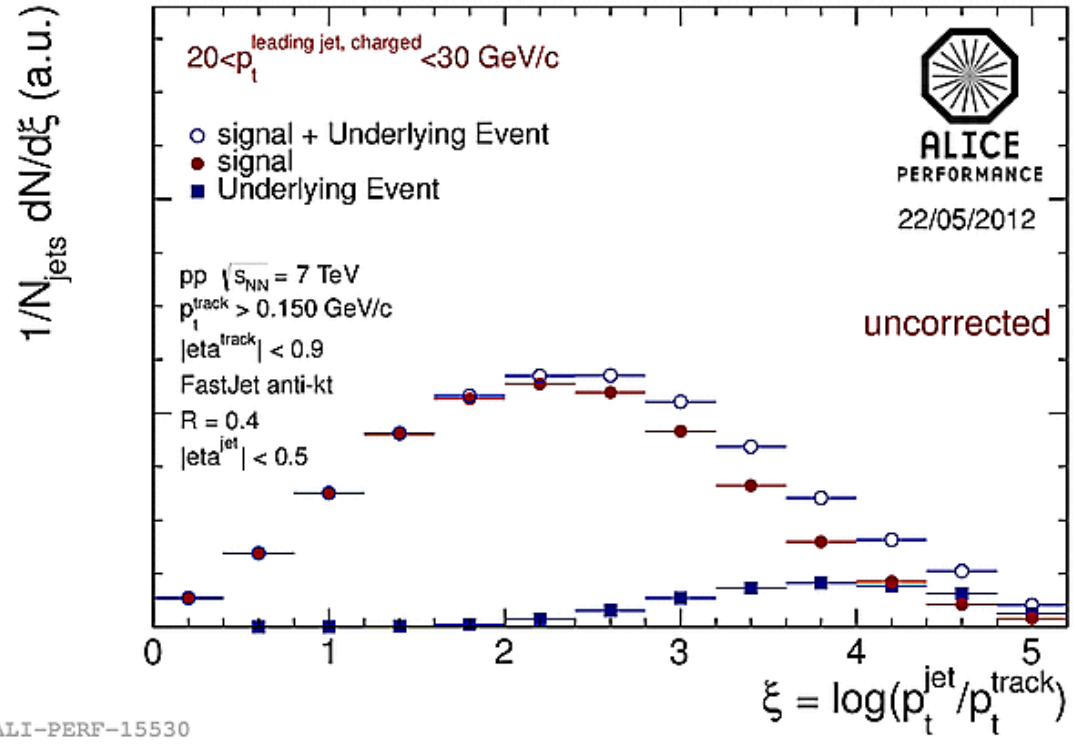
Anti-k_T: R = 0.6

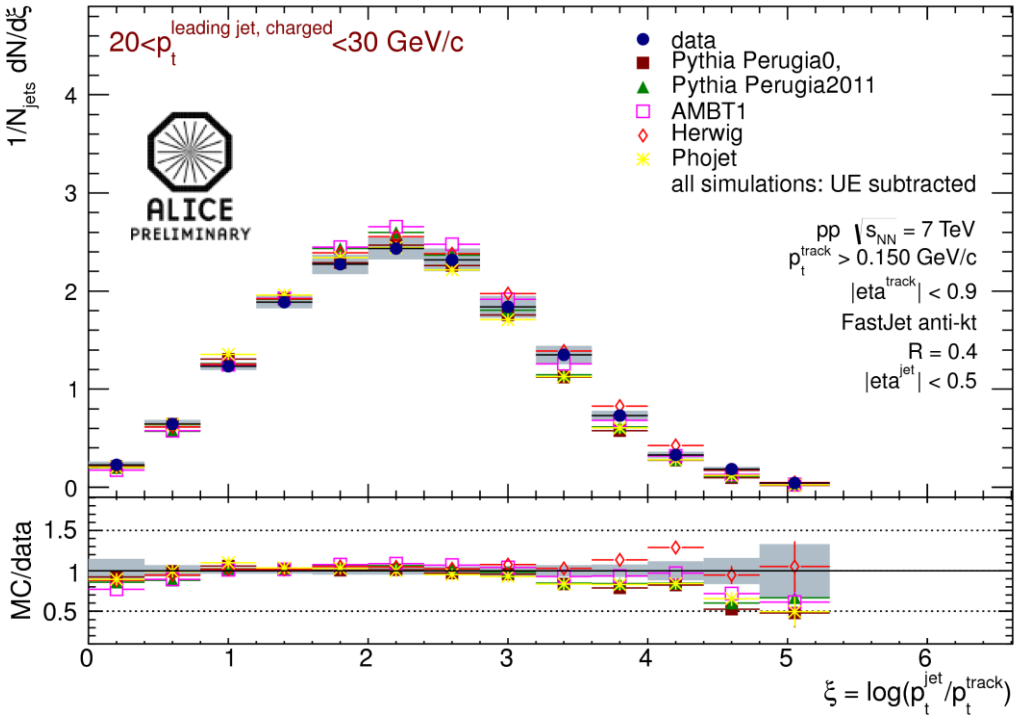


- ATLAS results from *PRD84 (2011) 054001*
- Good agreement of ALICE and ATLAS results

Fragmentation Function

Charged jets at √s = 7 TeV

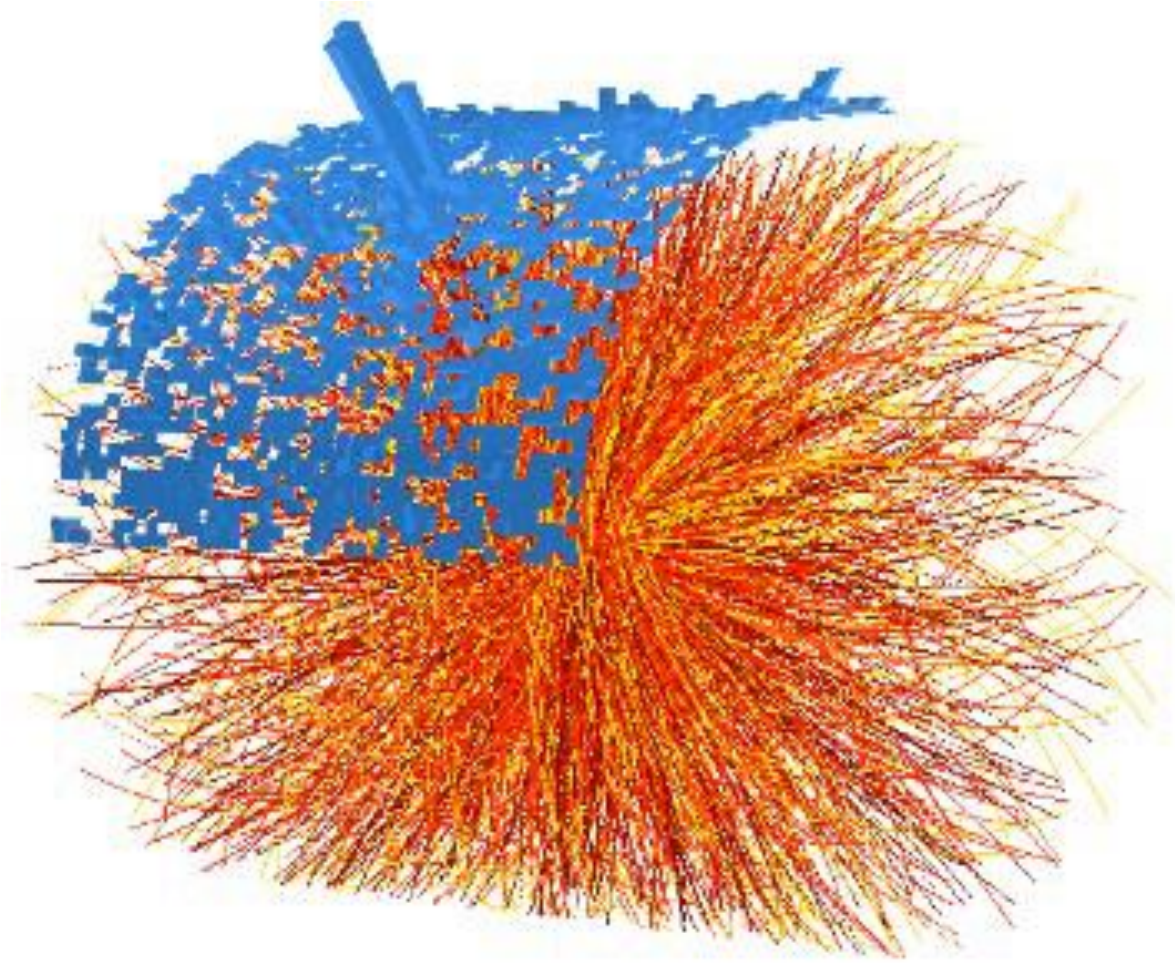




Effect of the underlying event subtraction for leading jets with $20 < p_T < 30$ GeV/c

Comparison data to different simulations
All with underlying event subtracted
Good agreement with simulations

Jet reconstruction in Pb-Pb



Challenge: Underlying event (UE)

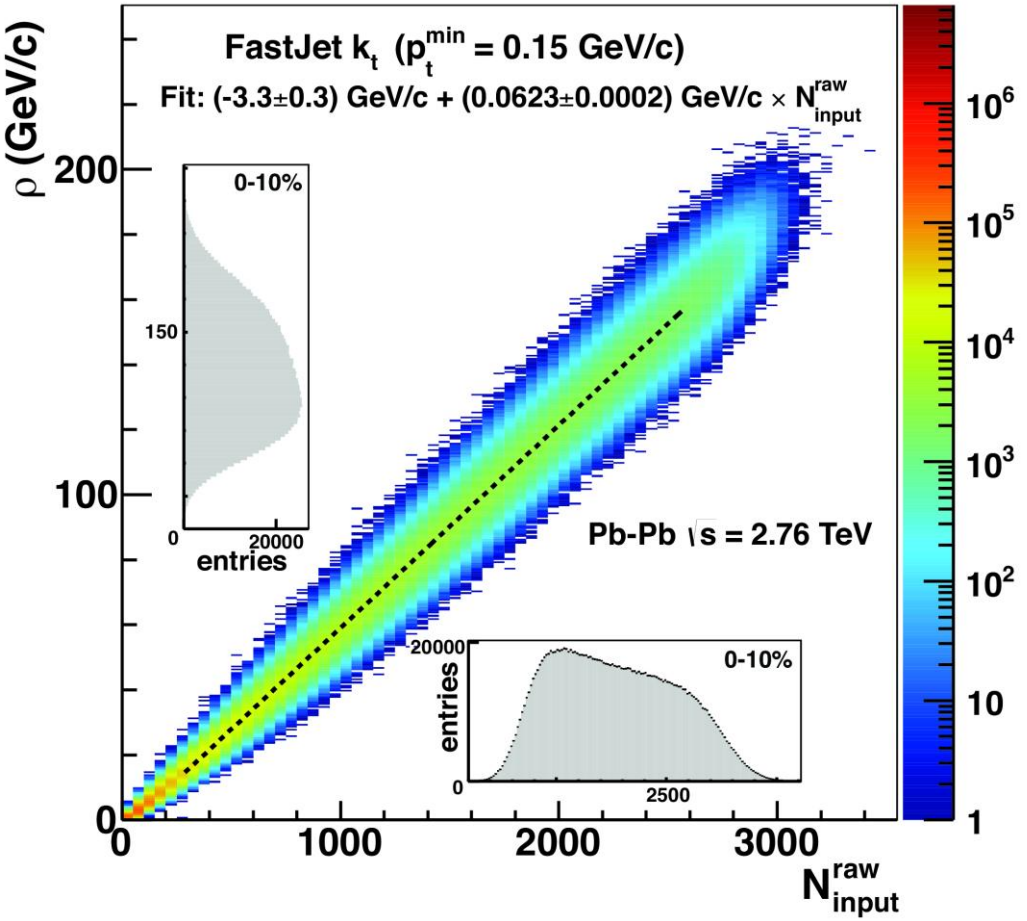
- Average background
- Background fluctuations
- Combinatorial (fake) jets

Event Background

- ρ: background density p_T/A
- estimation of ρ:
  - event-by-event
  - k_T clusterizer, $|\eta|<0.5$
  - $\rho = \mathrm{median}[p_{T,\mathrm{jet}}{}^{i}/A_{jet}{}^{i}]$

  exclude two hardest jets
- Background density scales with event multiplicity: $\rho \approx N\langle p_T \rangle$
- 0-10% centrality: $\langle\rho\rangle$ ~ 140 GeV/unit area

  →70 GeV/c for R=0.4 cone
- Event-by-event fluctuations of ρ for fixed multiplicity.



arXiv:1201.2423

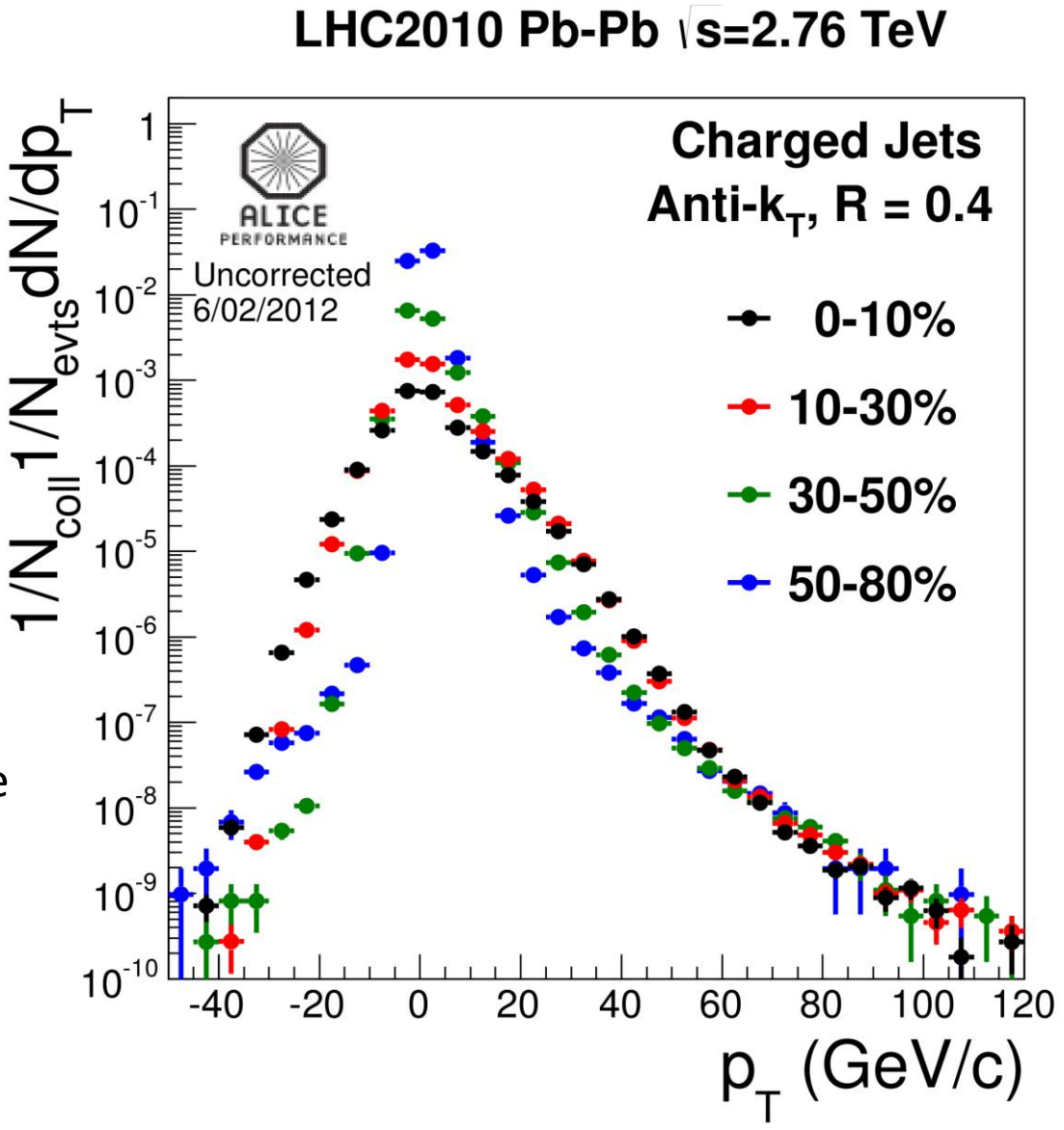
$$p_{T,jet} = p_{T,jet}{}^{rec} - \rho \times A_{jet} \pm \delta p_{T,bckg}$$

A_{jet} : jet area

$\delta p_{T,bckg}$: background fluctuations

Uncorrected Jet Spectrum

- Average background subtraction: event-by-event
- Some low p_T jets collect a lot of background energy and appear at very high p_T after clustering
- Fluctuations (region-to-region and event-by-event) of the background: low-p_T jet can migrate to high p_T



Background Fluctations

embed well defined probes into real Pb-Pb events

Different kind of probes:

– random cones
- fixed cone size
- randomly placed in full jet acceptance

– single tracks
- high-p_T seed
- delta probe for jet finder

– pp jet events
- real or PYTHIA+GEANT

Aim:
- study the influence of the background on the reconstruction observables of the jet
- verify the performance of the background subtraction methods ($\rho \times A_{jet}$)

background fluctuations measured as residuals:

$$\delta p_T = p_{T,jet}^{rec} - \rho \times A_{jet} - p_{T,(jet)}^{probe}$$

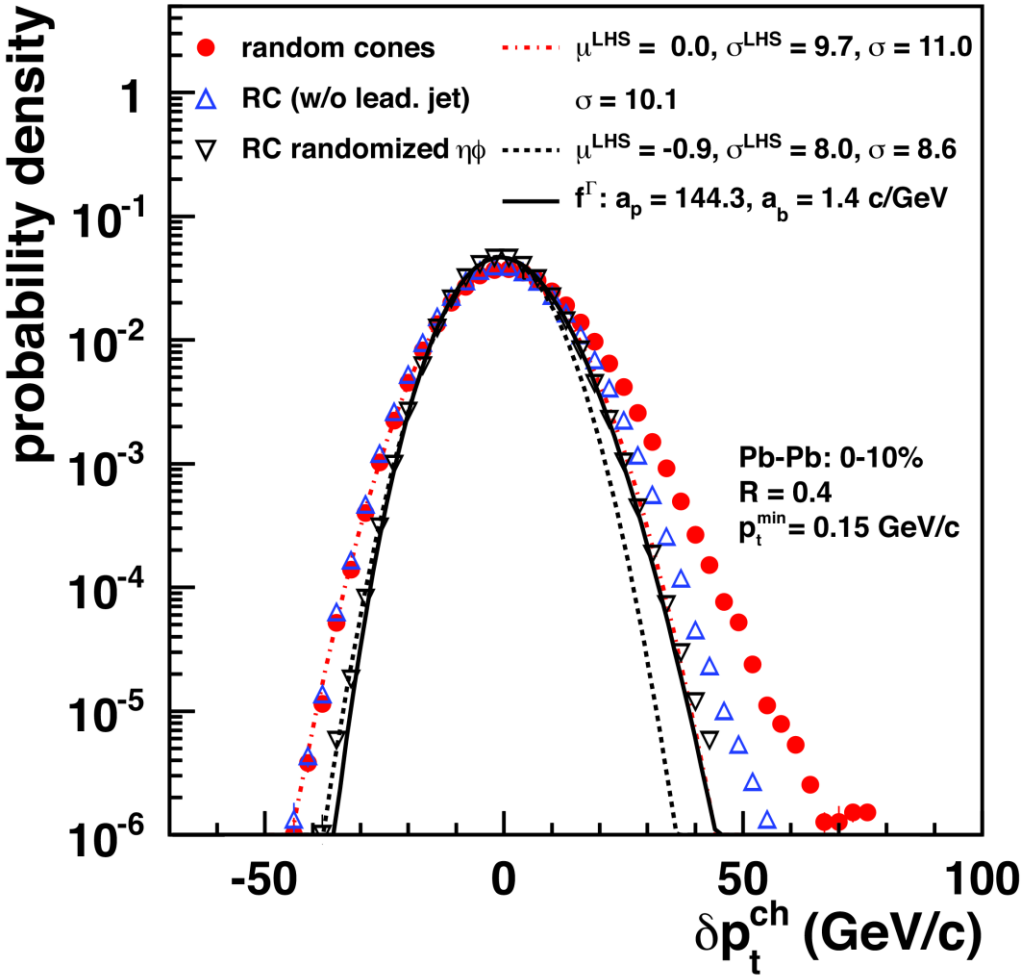
Random Cones (RC)

Non-overlapping cones of fixed area placed randomly within HI event.

arXiv:1201.2423

- 3 types of events:
  - Measured event
  - Measured event without 2 leading jets
  - Randomized event in η-φ
- Fluctuations centered around 0

  → quality check for background subtraction.
- RC with and w/o leading jets similar for $\delta p_T < 0$
- RC w/o 2 leading jets and RC randomized event similar for $\delta p_T > 0$
- Correlations removed by randomizing event



$$\delta p_T = p_{T,jet}^{rec} - \rho \times A_{jet} - p_{T,(jet)}^{probe}$$

Comparison of probes

Random Cones ●

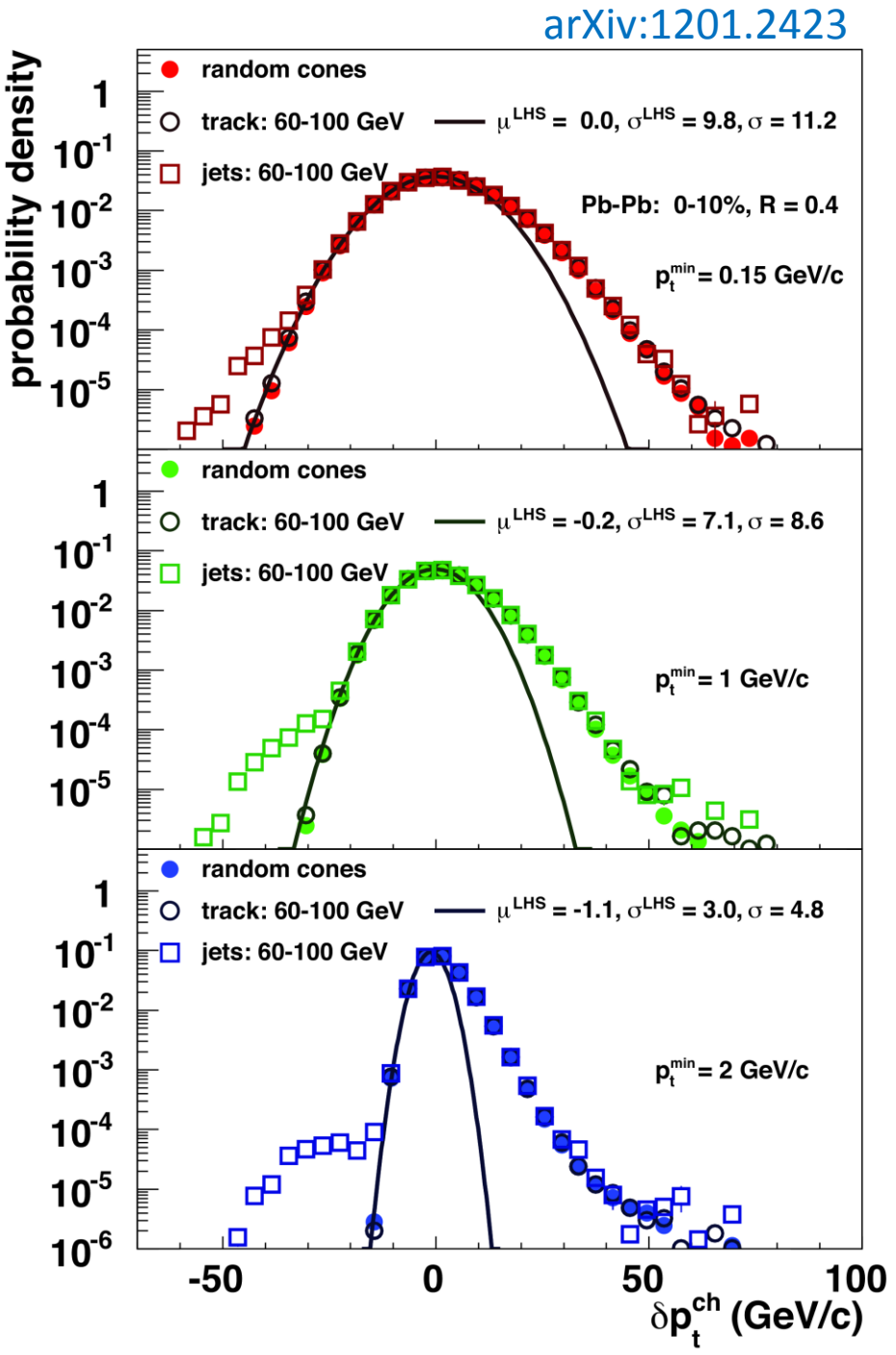
Single Tracks ○

PYTHIA jets □

- Fluctuations independent of type of probe
- No dependence on fragmentation pattern observed

  -Small back-reaction effect
- Fluctuations reduced by increasing minimum particle p_T
- High p_T tail looks similar to jet spectrum and goes far

  - Challenging for unfolding



Response Matrix and Unfolding

- Jet Response described by matrix

$$p_{T,rec} = R_{rec,gen} \cdot p_{T,gen}$$

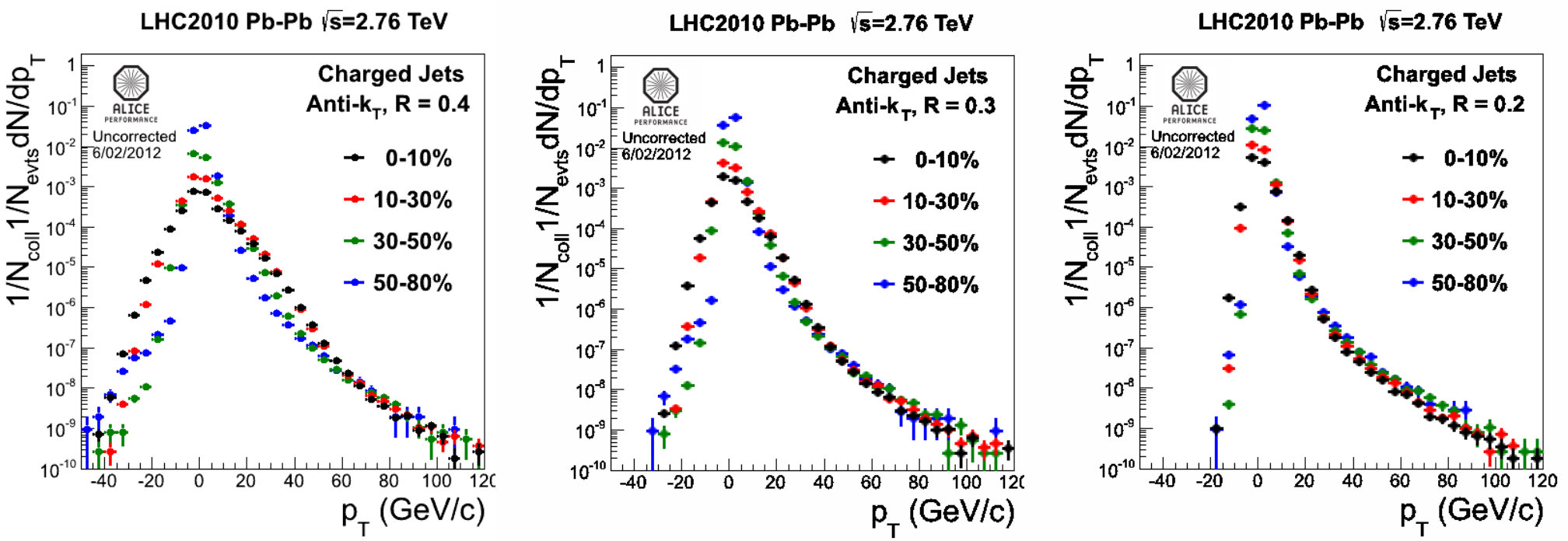
- Response $R_{rec,gen}$ matrix encodes:

  - Track reconstruction
    - Momentum resolution, efficiency and acceptance
    - Track cuts
  - Jet reconstruction
    - Shift and smear of jet momentum scale
  - Fragmentation
    - Via composition and cone size
    - Mixture of flavors
  - Underlying event

Uncorrected Jet Spectra

Charged jets in PbPb at √s=2.76 TeV

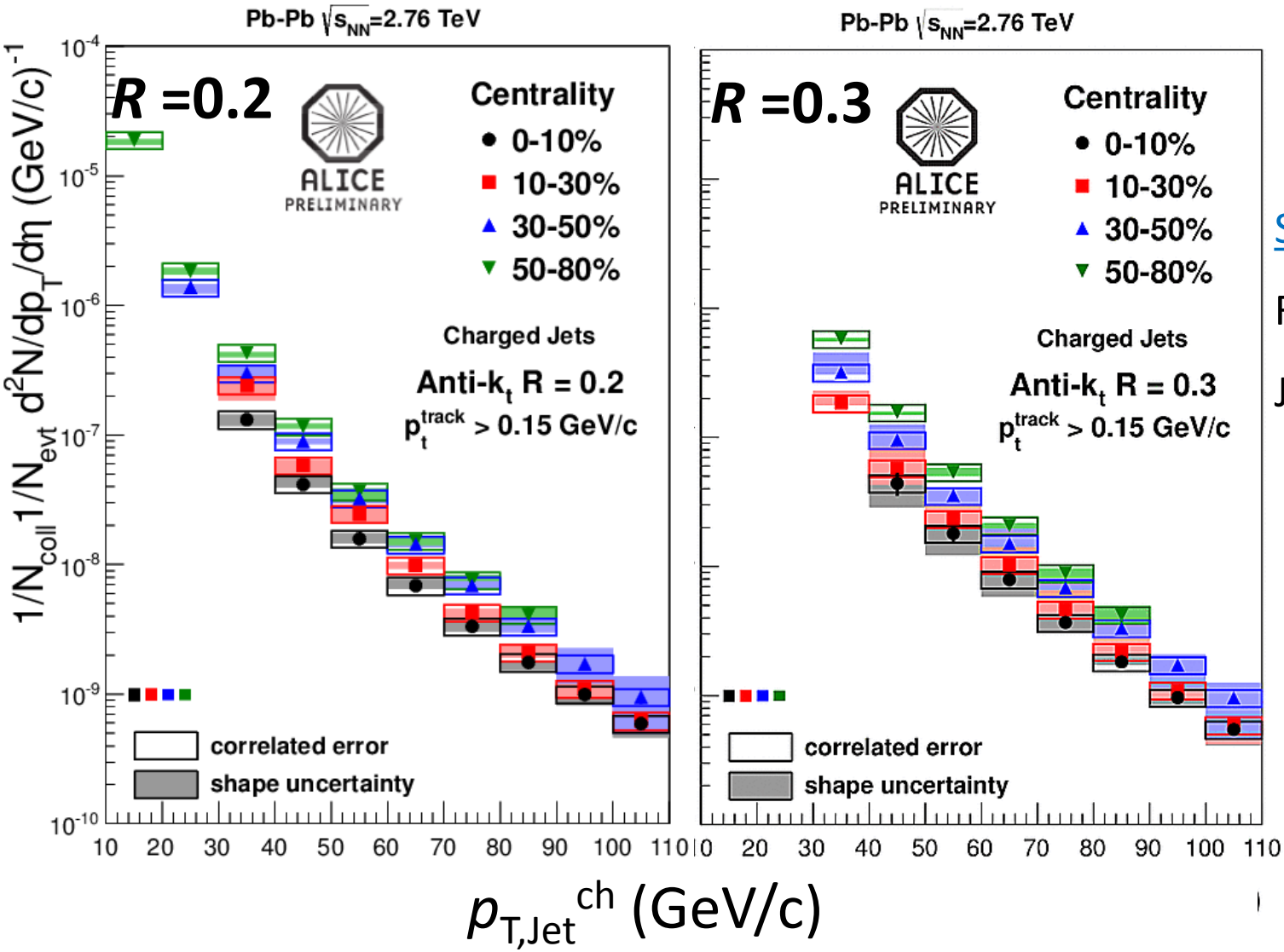
***R*=0.4** **R=0.3** **R=0.2**



Smaller Jets → Less Background Fluctuations

$p_{T,track}$ > 0.15 GeV/c

Charged Jet Spectra in Pb-Pb



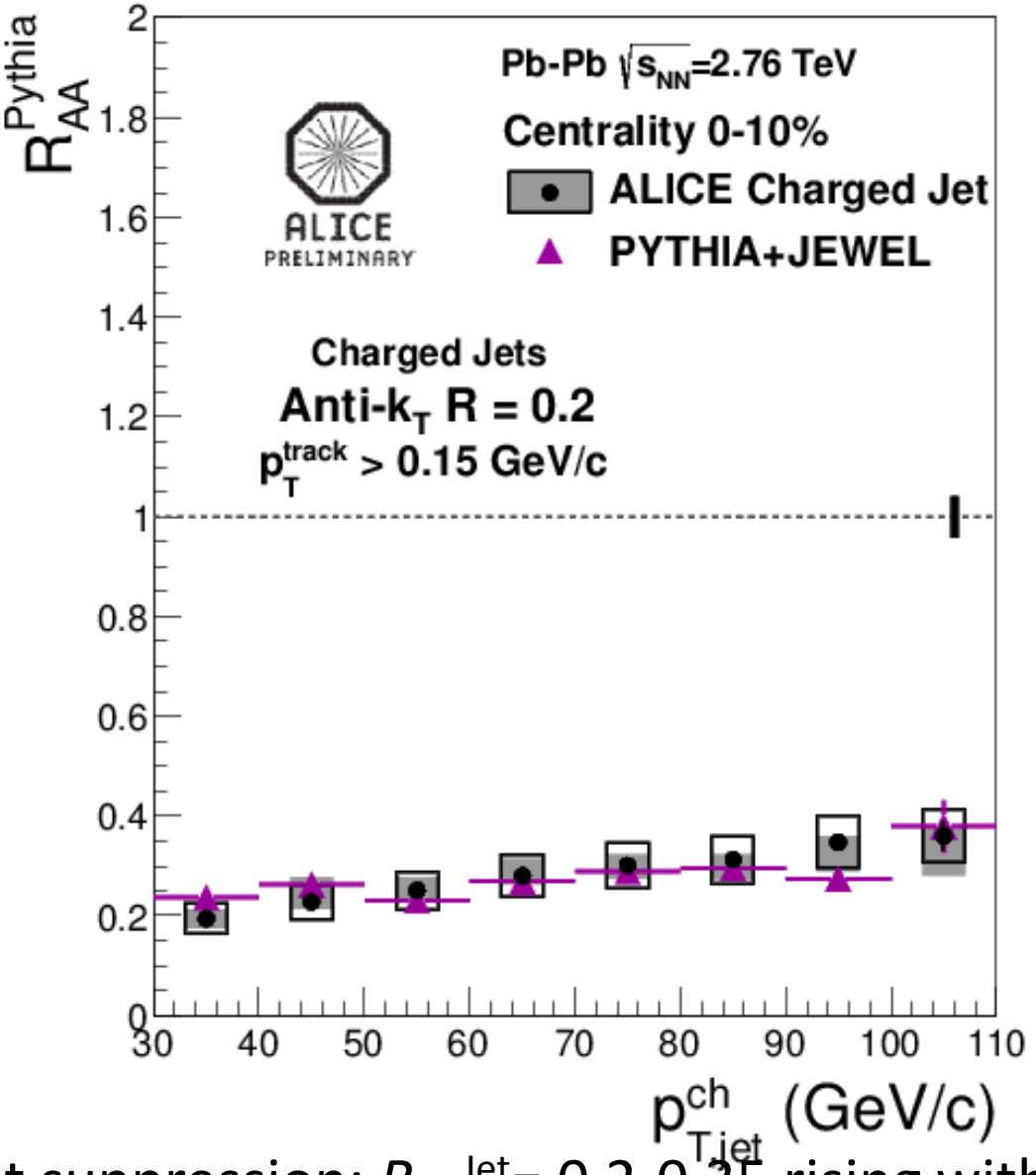
Systematic uncertainties:

Regularization scale: 4%

JES correction: 4-10%

Normalized yield shows suppression increasing with centrality.

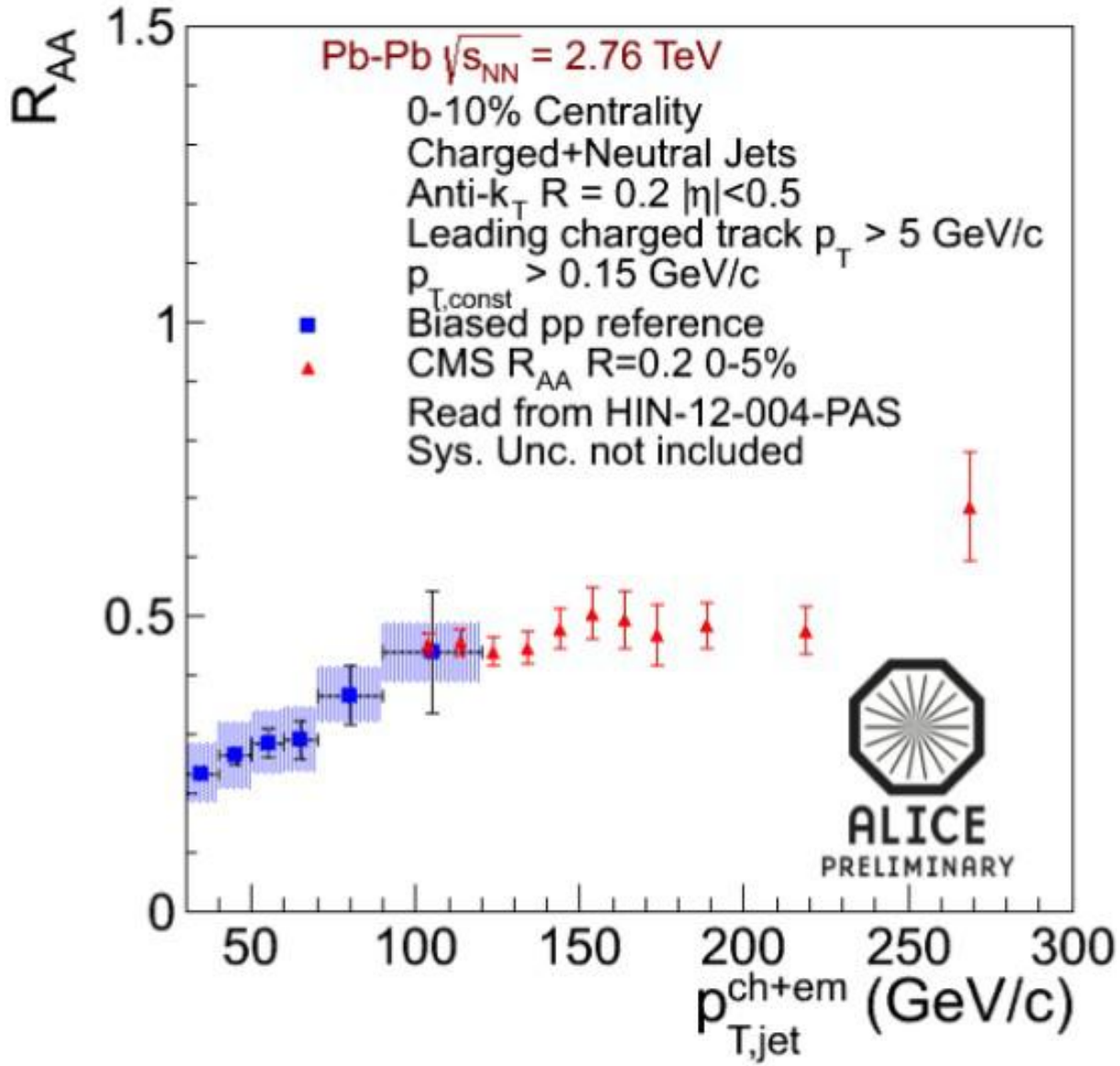
Charged Jet R_{AA}



wrt PYTHIA reference
For most central events:
Centrality 0-10%

- Strong jet suppression: R_{AA}^{Jet}= 0.2-0.35 rising with p_T^{Jet}
- Low R_{AA}^{Jet} reproduced by JEWEL MC
- R_{AA} increases as a function of p_T

Full jet R_{AA}



- R_{AA} is increasing with jets p_T
- Consistent with CMS prel. results in overlap region

Summary

Jet reconstruction

Background fluctuations are significant up to 80 GeV for charged jets (R = 0.4, 0-10% centrality)

Results on jet measurements in pp at 2.76 TeV and 7 TeV are presented

- No indication of energy redistribution observed from ratios of jet
- yields σ(R=0.3)/σ(R=0.4) within exp. uncertainties.

Results in Pb-Pb (R=0.2)

We observe a strong suppression of the inclusive charged jet yield in central Pb-Pb collisions at $\sqrt{s_{NN}}$= 2.76 TeV

– $R_{AA}^{\text{charged Jet}}$ = 0.2-0.35 in the 30 < $p_{T,\text{Jet}}^{\text{ch}}$ < 100 GeV/c

– We observe an increase in R_{AA} with jet p_T

– At ~100 GeV/c suppression consistent with CMS result