Jet Results in pp and Pb-Pb Collisions at ALICE

Oliver Busch for the ALICE Collaboration

- Motivation
- Jet reconstruction in ALICE
- Jets in pp
- Jets in Pb-Pb
- Hadron triggered recoil jets

Motivation

- Jets originate from hard parton scattering (large Q^2)

- Fragmentation = parton shower + hadronization
  → collimated spray of hadrons

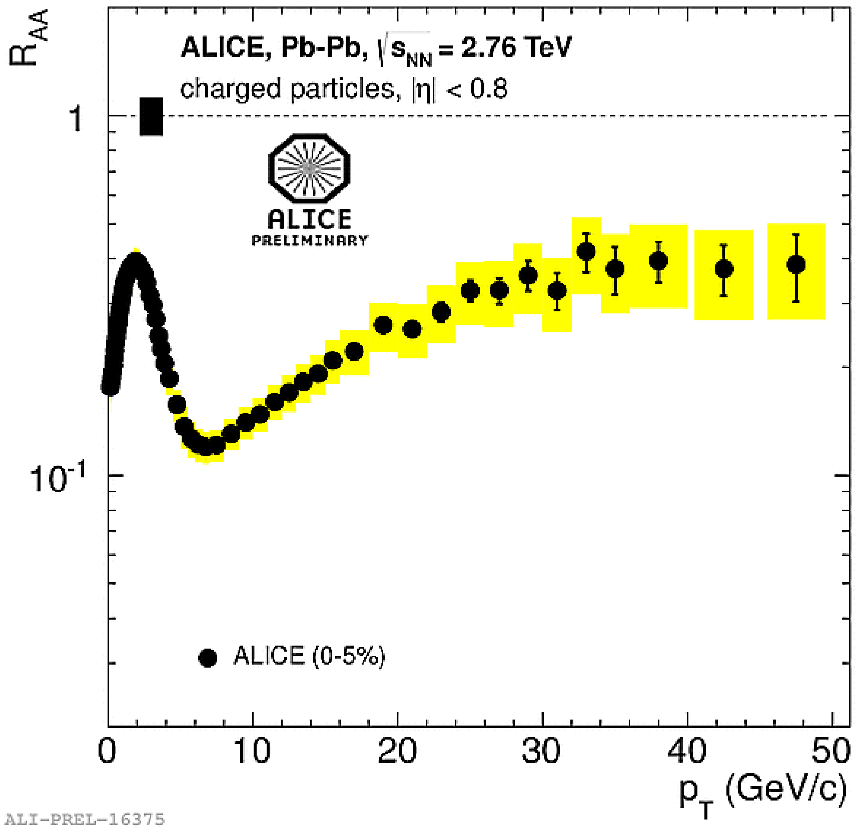
- In pp: jet cross section + jet structure provides test of
  perturbative and non-perturbative aspects of QCD

- In nuclear collisions:
  - hard partons produced early
  - traverse the hot and dense QCD matter

  → **calibrated probes for medium effects**

- compare heavy-ion results to expectations from superposition of independent pp collisions:

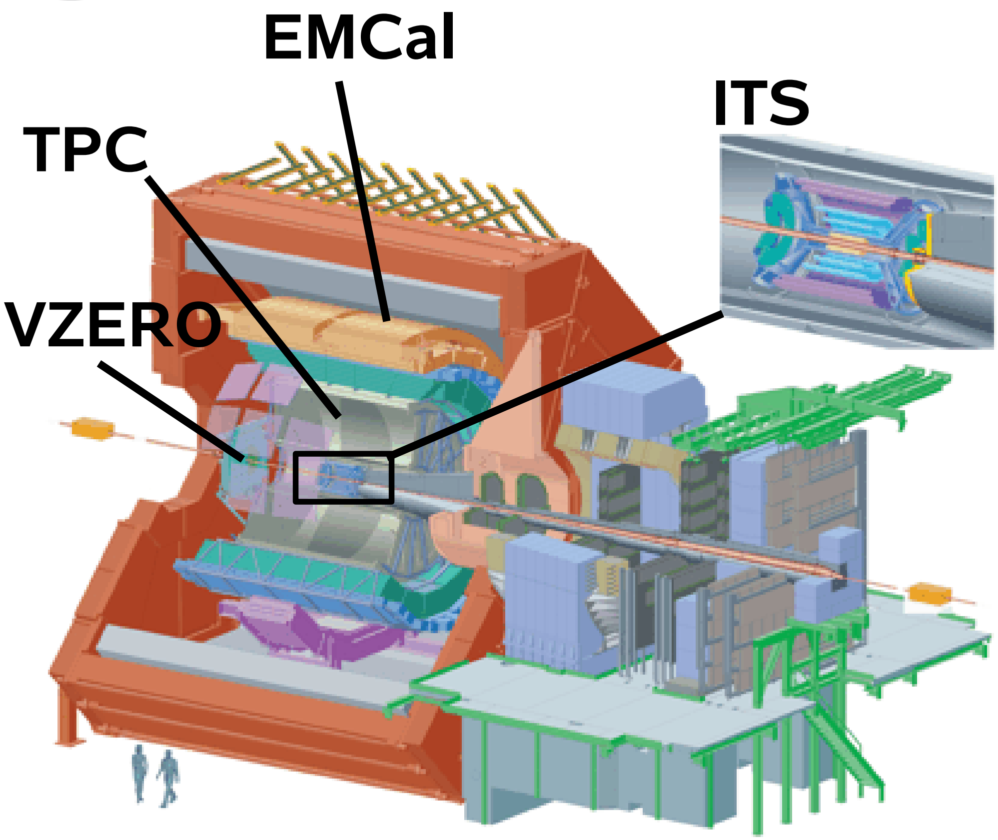
$$R_{AA}(p_{\rm T}) = \frac{1}{\langle T_{AA} \rangle} \frac{{\rm d}^2 N_{\rm ch}/{\rm d}\eta\,{\rm d}p_{\rm T}}{{\rm d}^2\sigma_{\rm ch}^{\rm pp}/{\rm d}\eta\,{\rm d}p_{\rm T}}$$



PLB 720 (2013) 52.

- High $p_{\rm T}$ single particle suppression ('jet quenching'): parton energy loss by enhanced gluon radiation in the medium?
- Sensitive to leading fragment
- Where does the energy go? → move from single particles (R=0) to jets (R>0)

Jets at ALICE



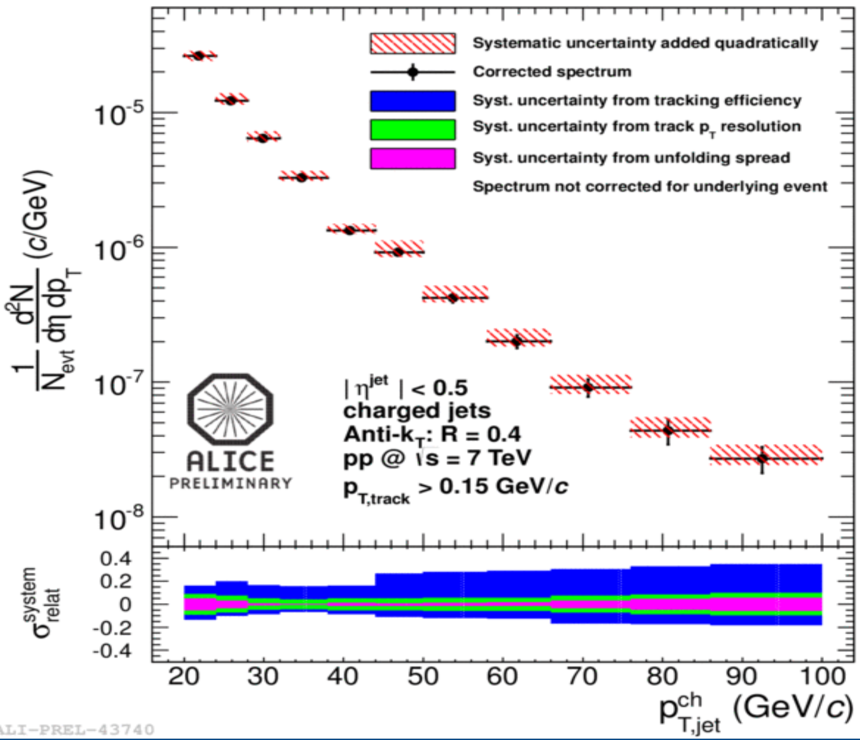
- VZERO
  - MB trigger and centrality
- Charged particle tracking:
  - Inner Tracking System
  - Time Projection Chamber
  - $|\eta| < 0.9$, $p_T > 150$ MeV/c
- EMCal: neutral particles
  - $|\eta| < 0.7$, $1.4 < \varphi < \pi$
  - cluster $E_T > 300$ MeV
  - jet trigger

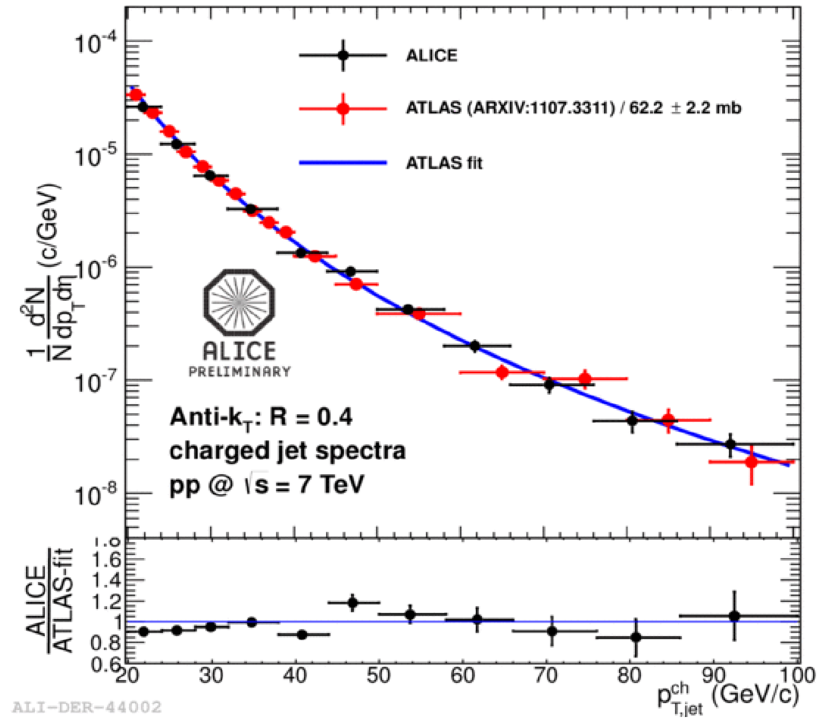
- Jets from charged tracks in central barrel and EMCal: complementary to traditional approach based on EM + hadronic calorimetry
- FastJet anti-k_T R=0.4, $|\eta^{jet}| < 0.5$

pseudo-rapidity
$\eta = -ln\,(tan(\theta/2))$

pp charged jet cross sections

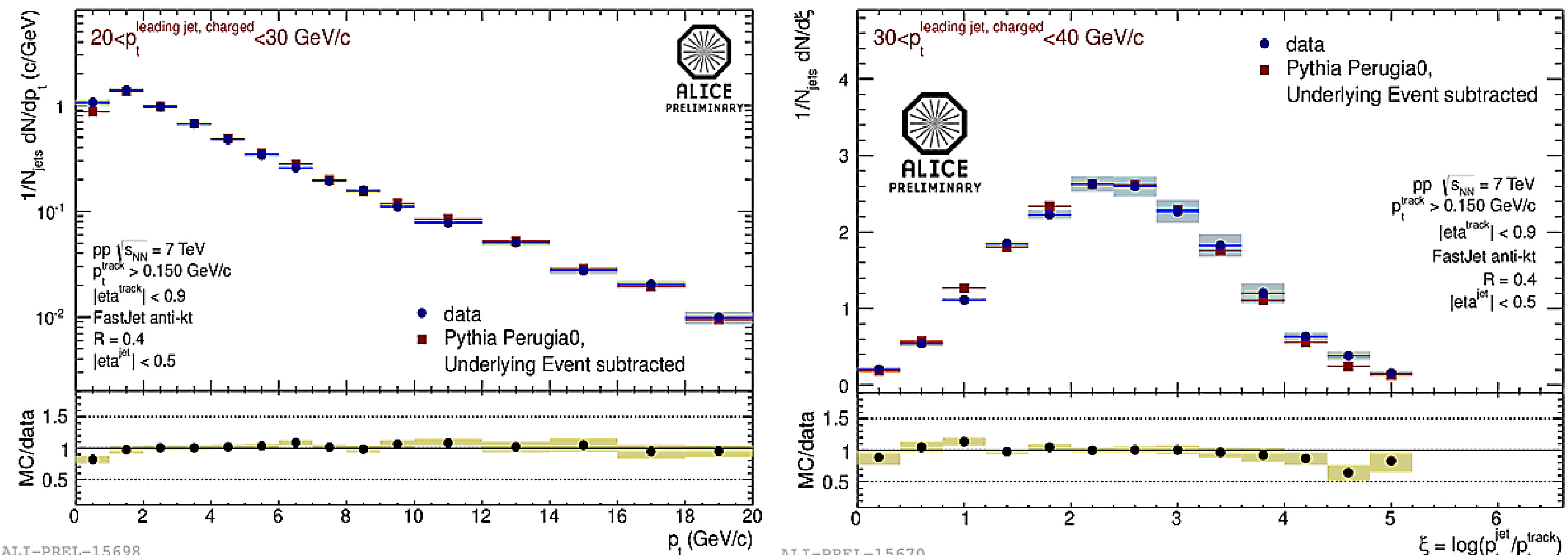
- Measured in minimum bias collisions at $\sqrt{s}$ = 7 TeV
- Good agreement with ATLAS charged jet measurements (despite slightly different acceptance and track p_T range)





pp charged jet fragmentation at $\sqrt{s}$ = 7 TeV

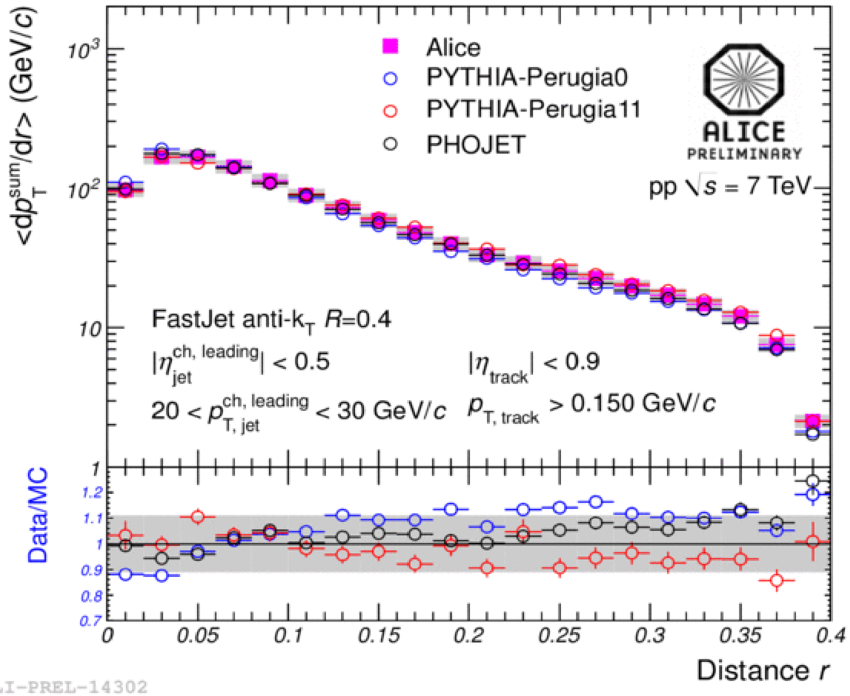
- p_{T} distribution of particles in jet
- Scaled momentum $\xi = ln\,(p_{\mathrm{T}}^{\mathrm{jet,ch}}/p_{\mathrm{T}}^{\mathrm{particle}}) \longrightarrow$ hump-backed plateau
- Underlying event subtracted from data + and PYTHIA MC



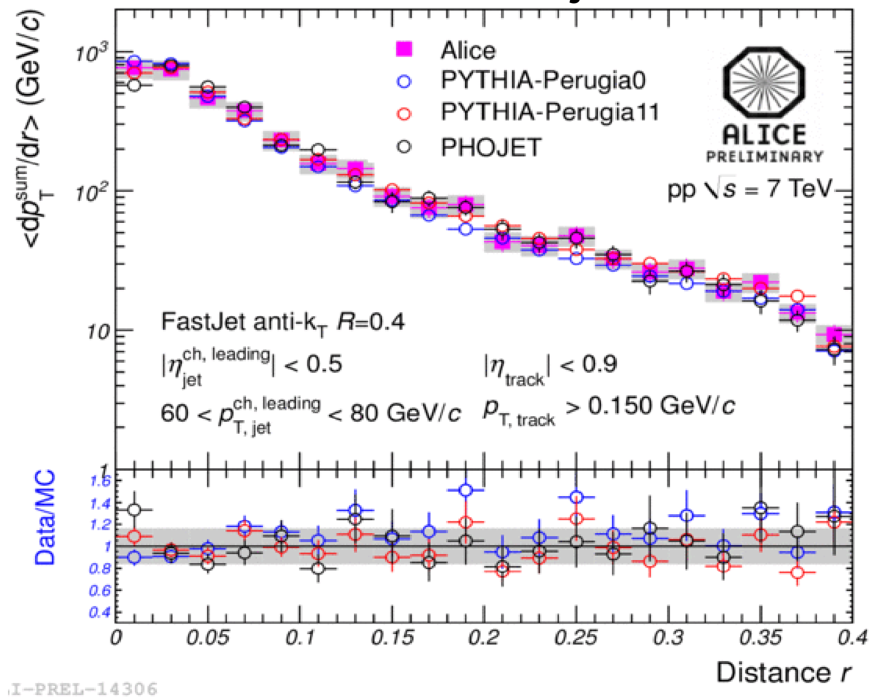
pp charged jet shapes at 7 TeV

- Transverse structure: p_T sum in radial slices
- Increasing collimation for higher p_T jets

20-30 GeV/c jets



60-80 GeV/c jets

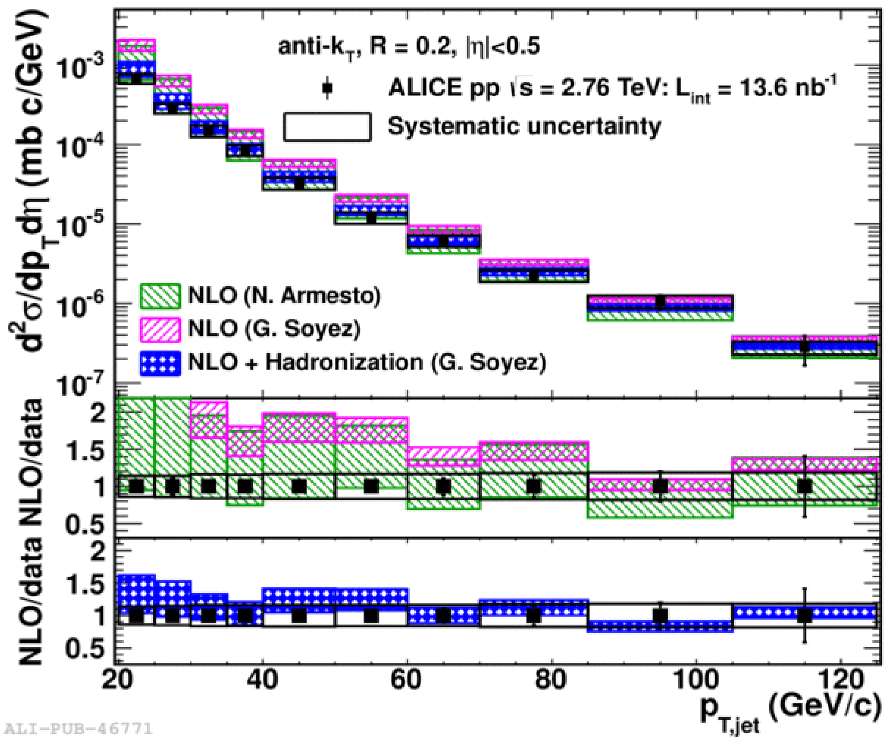


- Fragmentation and jet structure reasonably described by event generators

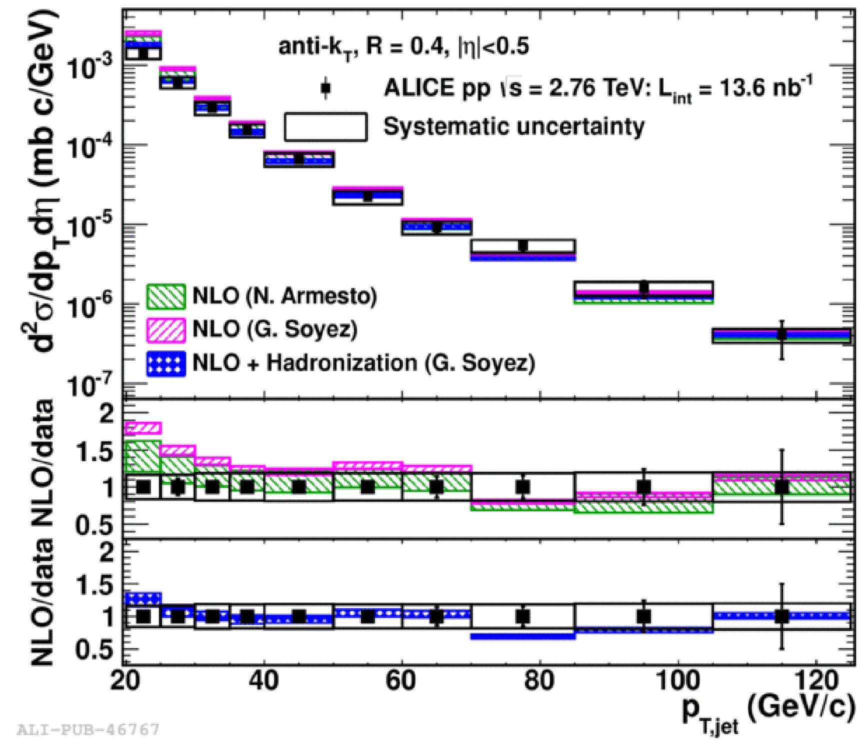
Full jets in pp at $\sqrt{s}$ = 2.76 TeV

- Good agreement to NLO calculations for R = 0.2 and R = 0.4
- Reference for Pb-Pb at same energy

R = 0.2



R = 0.4



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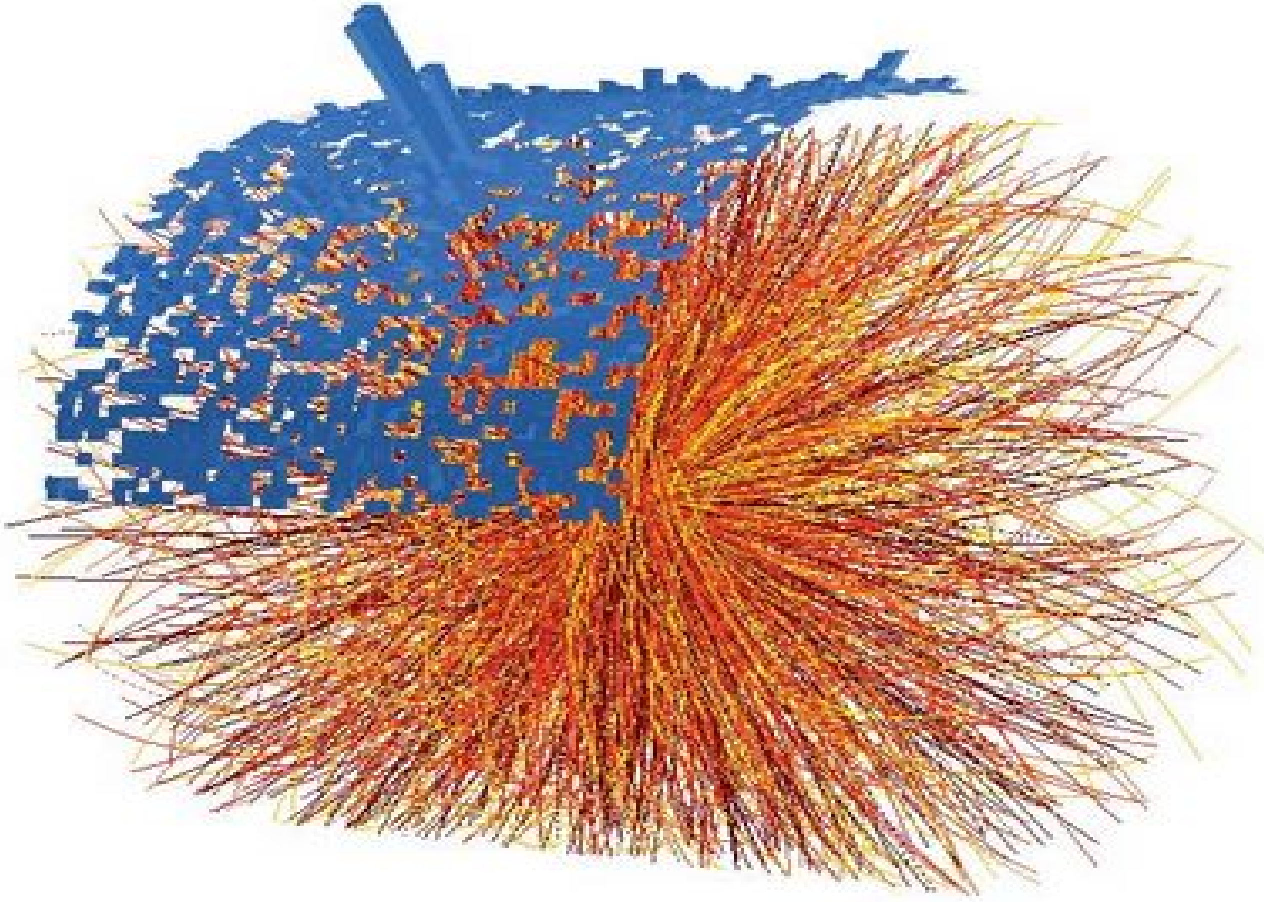
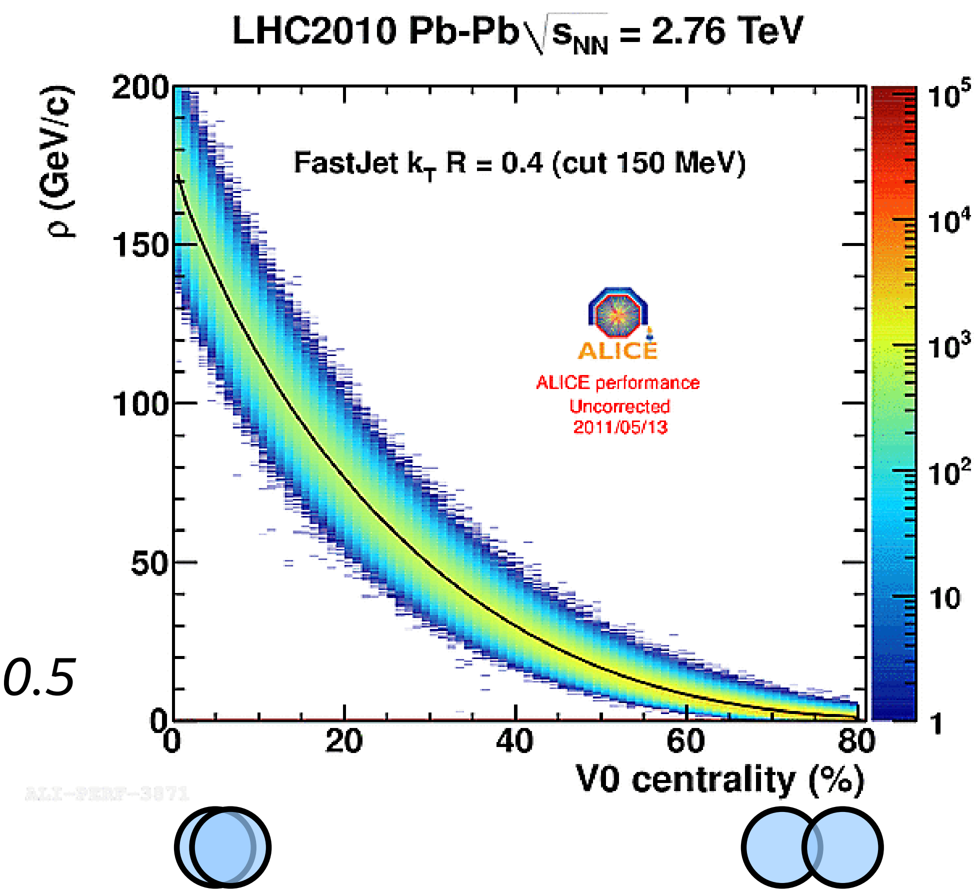
Jets in heavy-ion collisions



Jets in heavy-ion collisions

- Underlying event: large abundance of low momentum particles
  - uncorrelated background to ‘true’ hard scattering
  - purely combinatorial 'low'-momentum jets
- Background density ρ:
  - median p_T density / area from k_T clusters

jet area: ~ 0.5

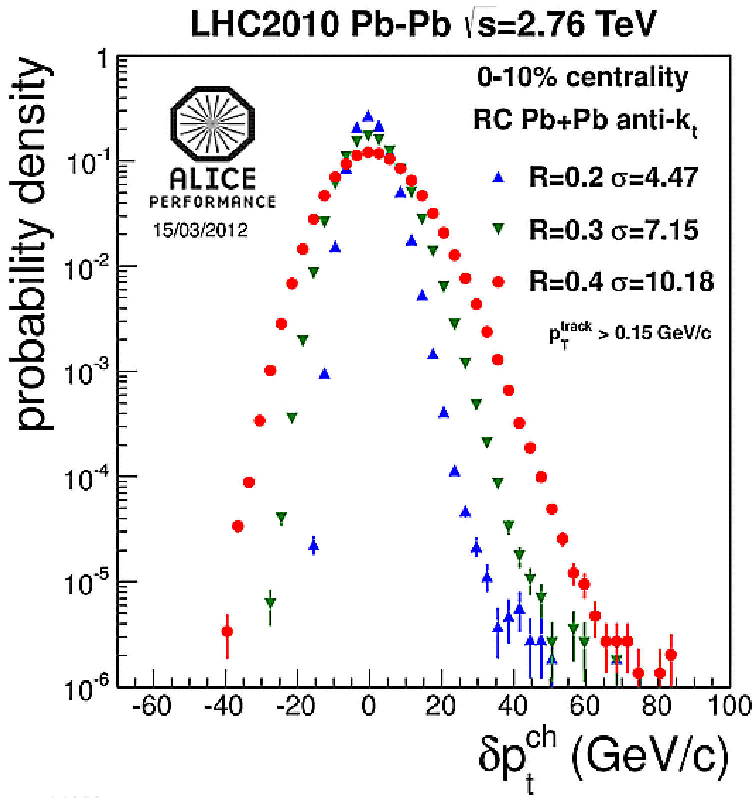


Background fluctuations

- Subtraction of event average background: $p_{\mathrm{T}} = p_T^{\mathrm{raw}} - \rho \times A$

- Region-to-region fluctuations measured via random cones embedded into data events

$$\delta p_{\mathrm{T}} = p_T^{\mathrm{cone}} - \rho \times \pi R^2$$



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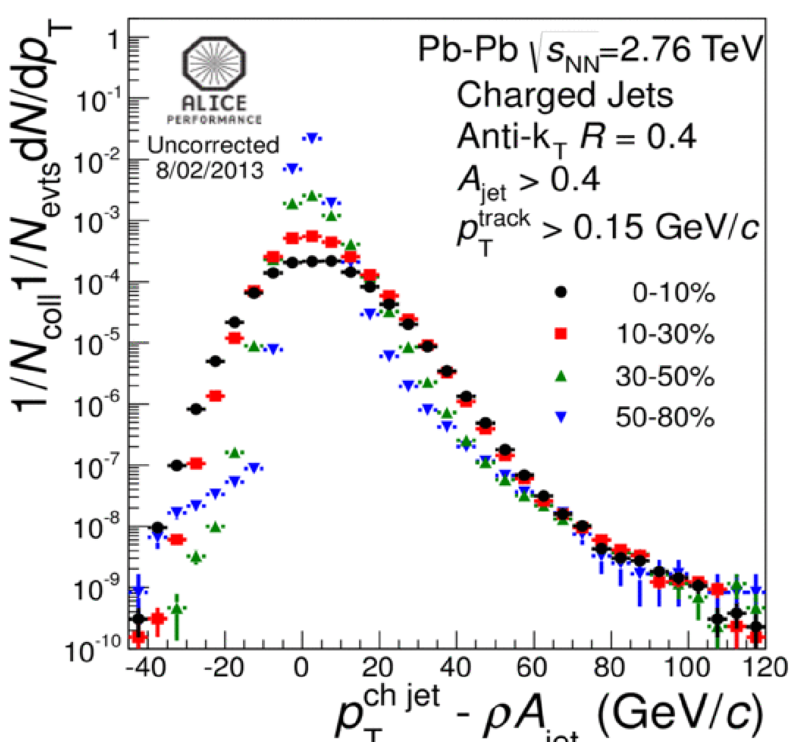
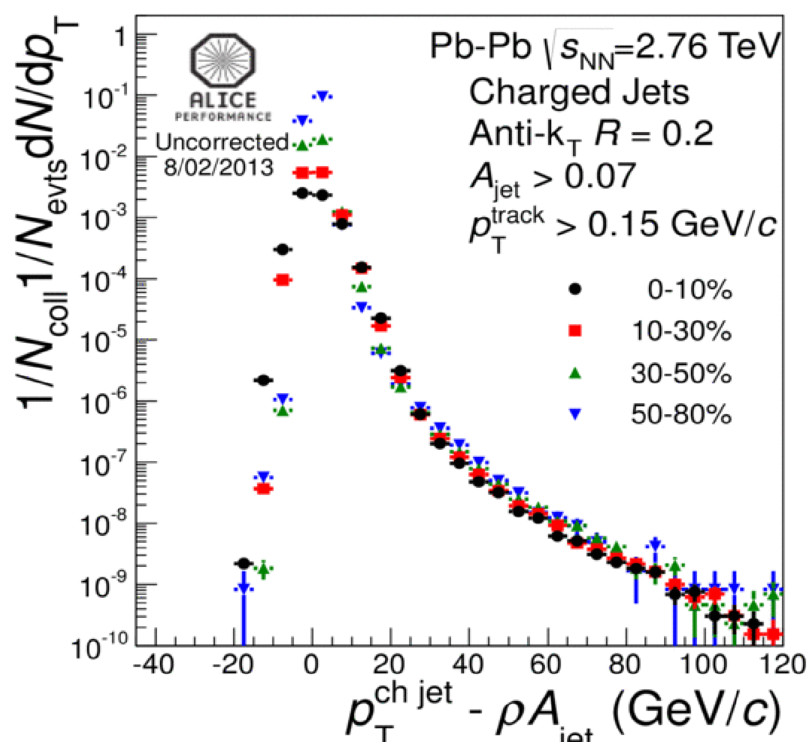
Raw charged jet spectra

- Less background by smaller R
- Caveat: may also reduce sensitivity to jet quenching

R = 0.4



R = 0.2



Unfolding

- Fluctuations smear the reconstructed jet energy
  $\rightarrow$ correction analog to 'standard' detector introduced resolution

- Unfolding to correct for fluctuations and detector effects using response matrix RM:

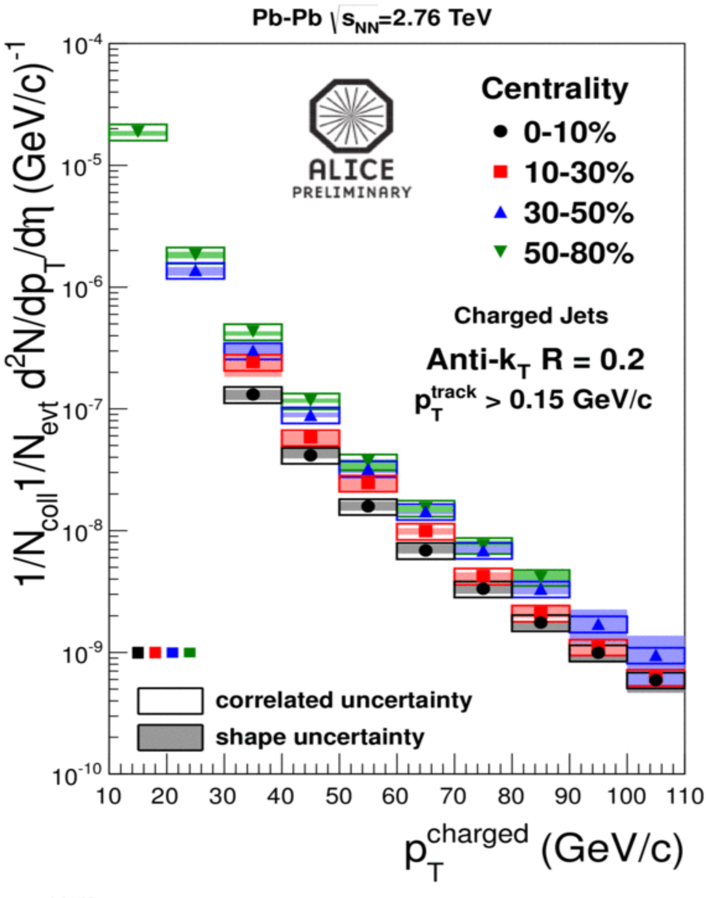
$$f^{\text{measured}} = RM_{\text{bkg}} \times RM_{\text{det}} \times f^{\text{true}}$$

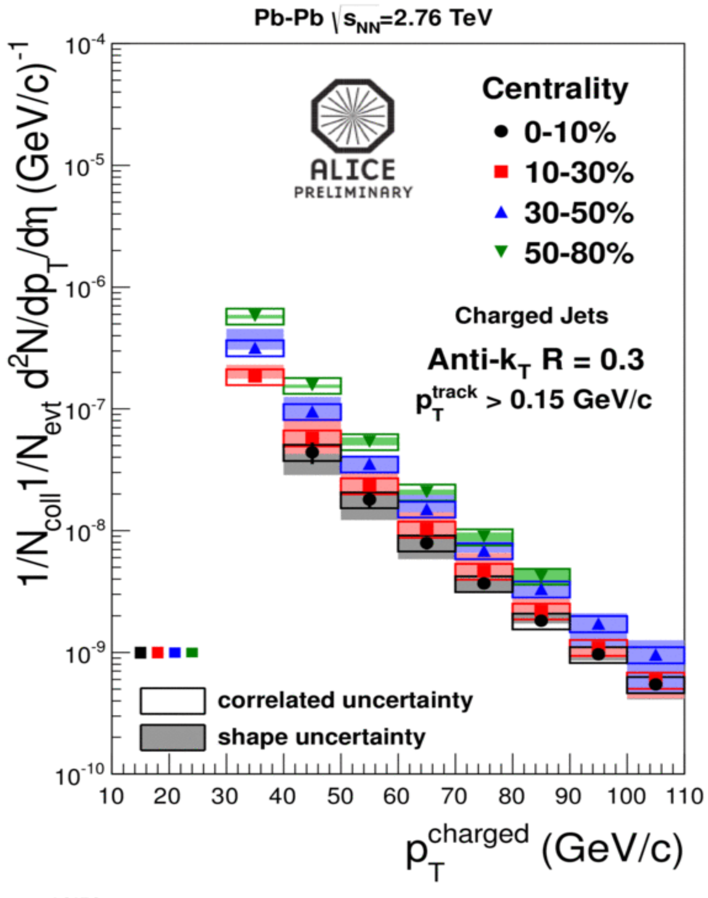
  - RM_{bkg} from δp_{T} distributions
  - RM_{det} from detector simulations
  - different methods: χ^2, Bayesian, Singular Value Decomposition

- Not possible down to 0 p_{T} !

Charged jet spectra

- $\sqrt{s_{NN}}$ = 2.76 TeV, R = 0.2, 0.3
- Strongly centrality dependent suppression





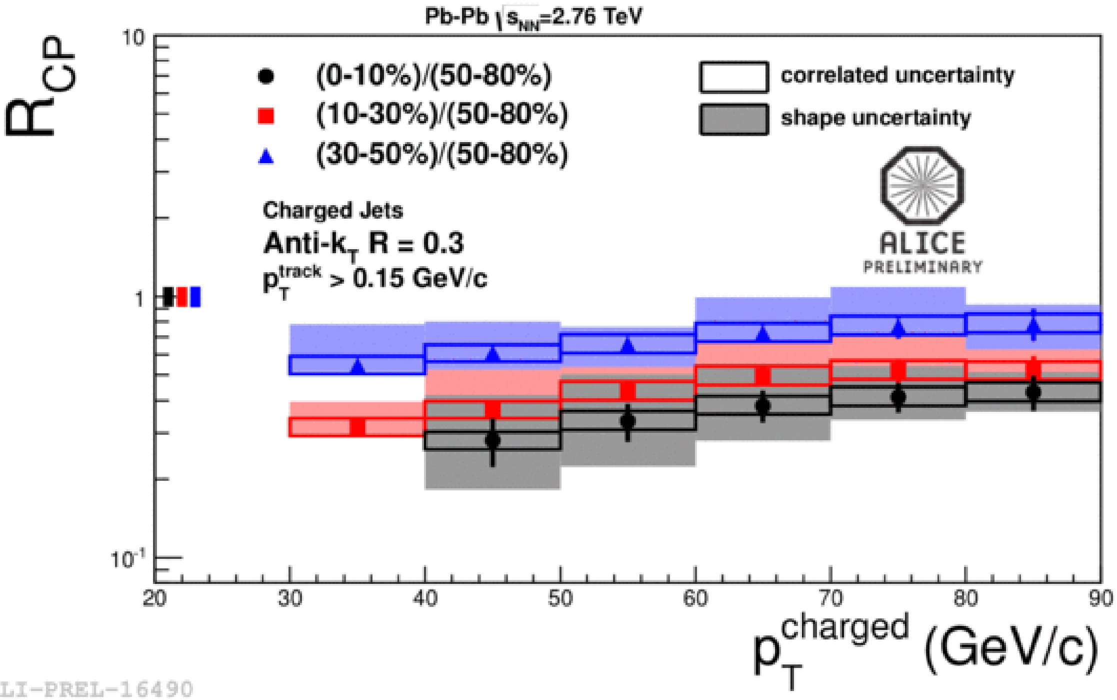
Charged jet R_{CP}

- R_{CP} : reference from peripheral Pb-Pb events

$$R_{CP}(p_{\mathrm{T}}) = \frac{\langle N^{p}_{coll} \rangle}{\langle N^{c}_{coll} \rangle} \frac{\mathrm{d}^2 N^{\mathrm{c}}_{\mathrm{ch}}/\mathrm{d}\eta\,\mathrm{d}p_{\mathrm{T}}}{d^2 N^{\mathrm{p}}_{\mathrm{ch}}/\mathrm{d}\eta\,\mathrm{d}p_{\mathrm{T}}}$$

- ~ similar to charged hadrons
- Momentum dependent suppression

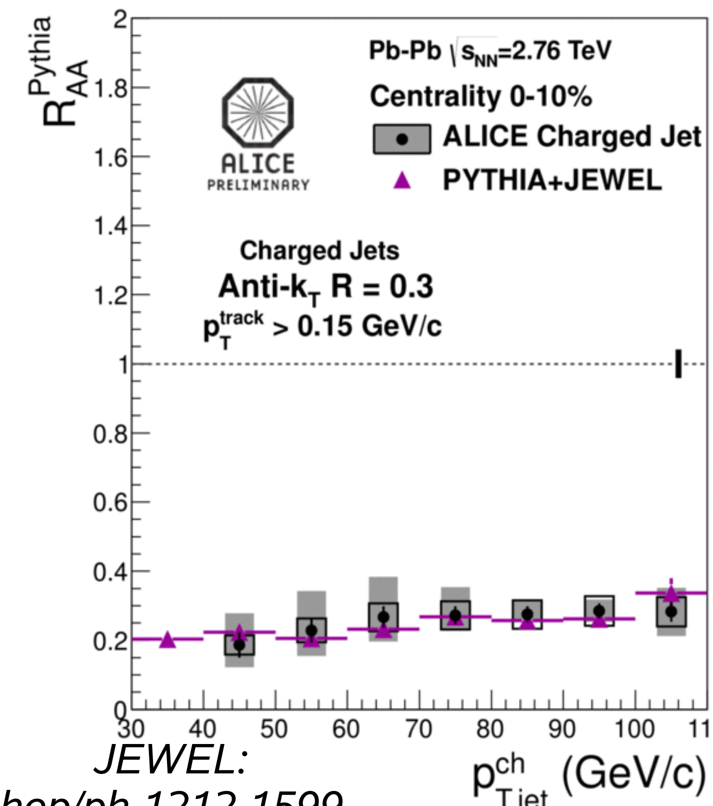
R = 0.3



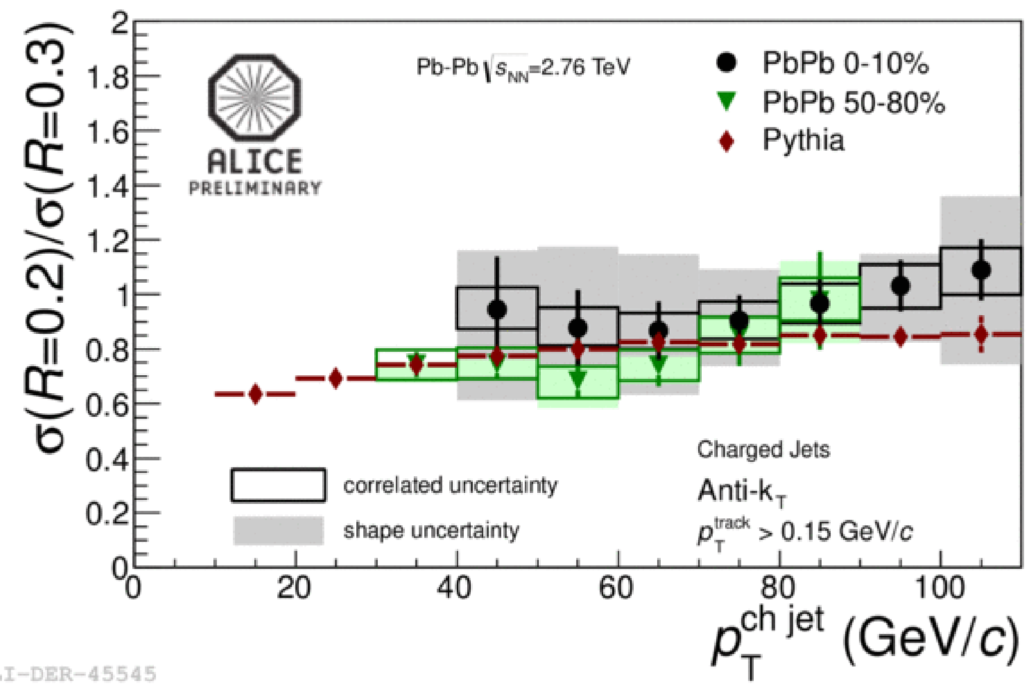
Comparison to models

- Charged jet R_{AA} with PYTHIA pp MC reference
- Well described by JEWEL energy loss MC
- ‘Jet structure’ via ratio R=0.2 / 0.3: consistent with PYTHIA

  → 'vacuum fragmentation' in small cones?

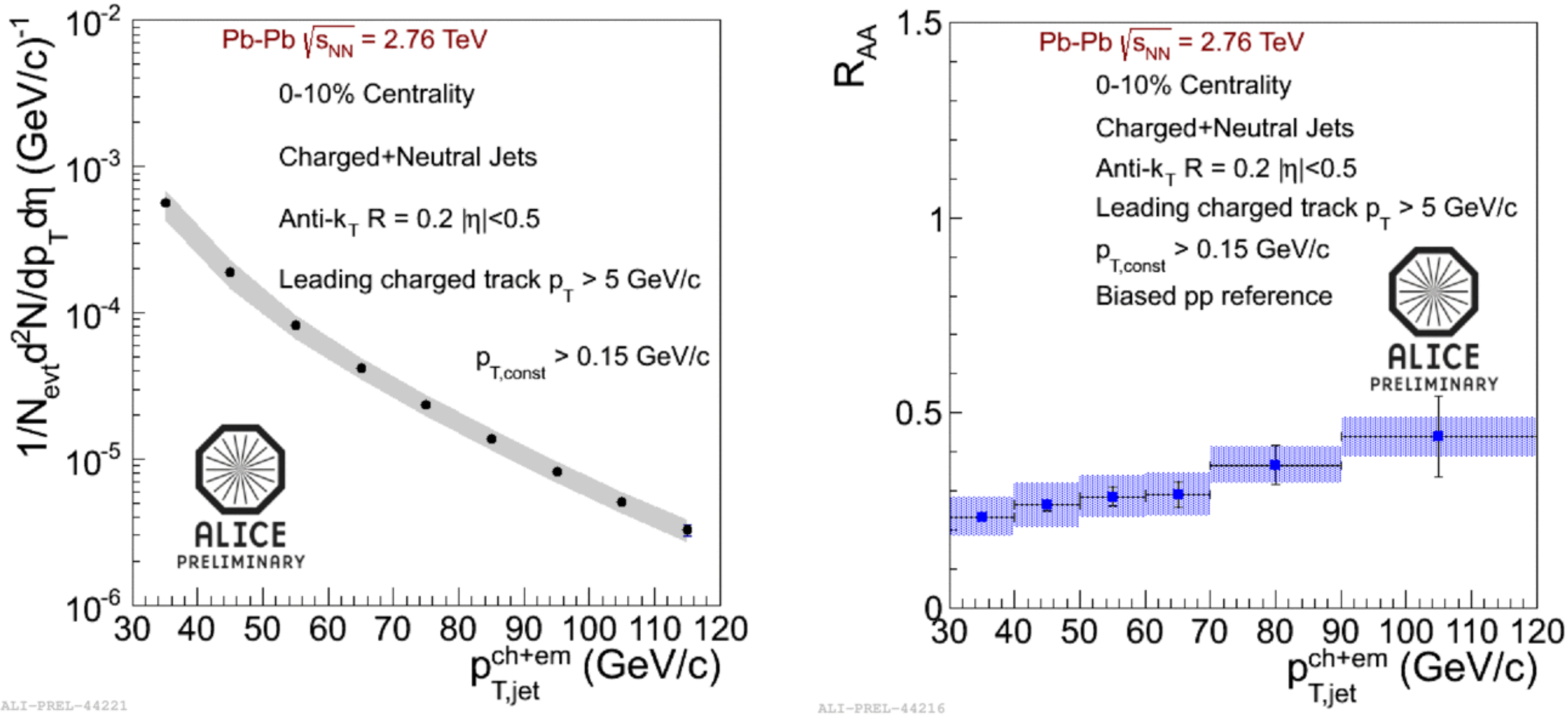


JEWEL:
hep/ph 1212.1599



Full jet R_{AA}

- Complete jet reconstruction from charged particles + EMCal
- R=0.2, 5 GeV/c fragmentation bias to reduce combinatorial jets
- Strong jet suppression: $R_{AA} \leq 0.5$

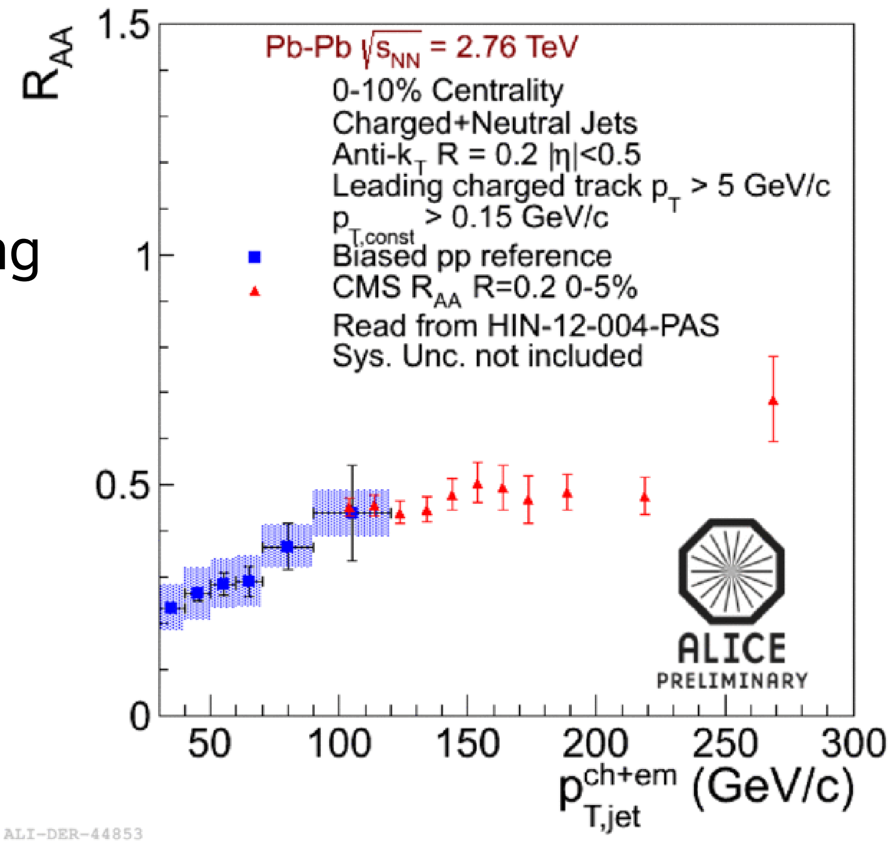


ALICE and CMS

- Complementary jet p_T coverage
- Good agreement in overlap region
  - despite larger constituent p_T threshold for CMS
- Rise + flattening similar to inclusive single particle R_{AA}

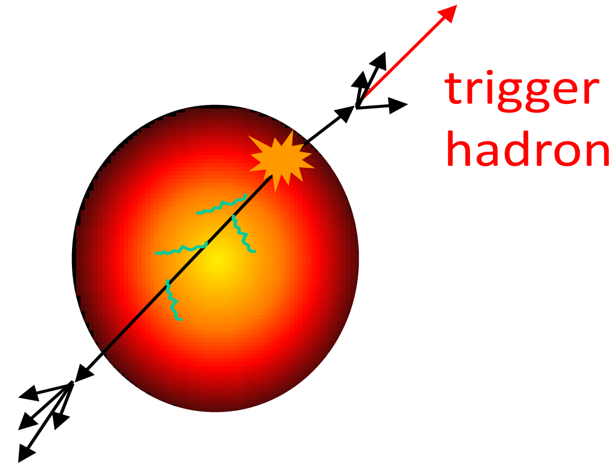
  → vacuum fragmentation for leading fragments?

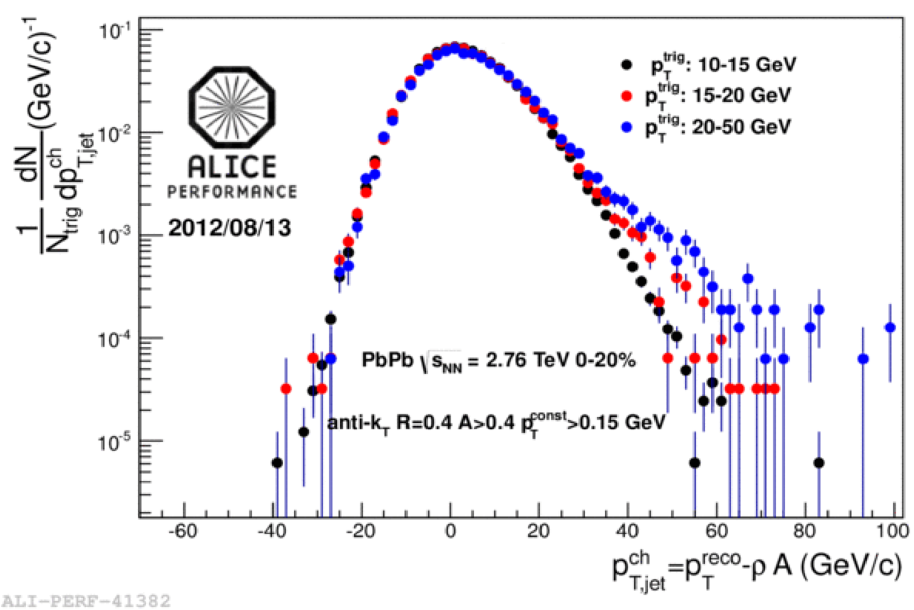
- Where does the energy go?
  - larger angles?
  - p_T < 150 MeV/c particles?
  - subtle effect on jet structure beyond present experimental sensitivity?

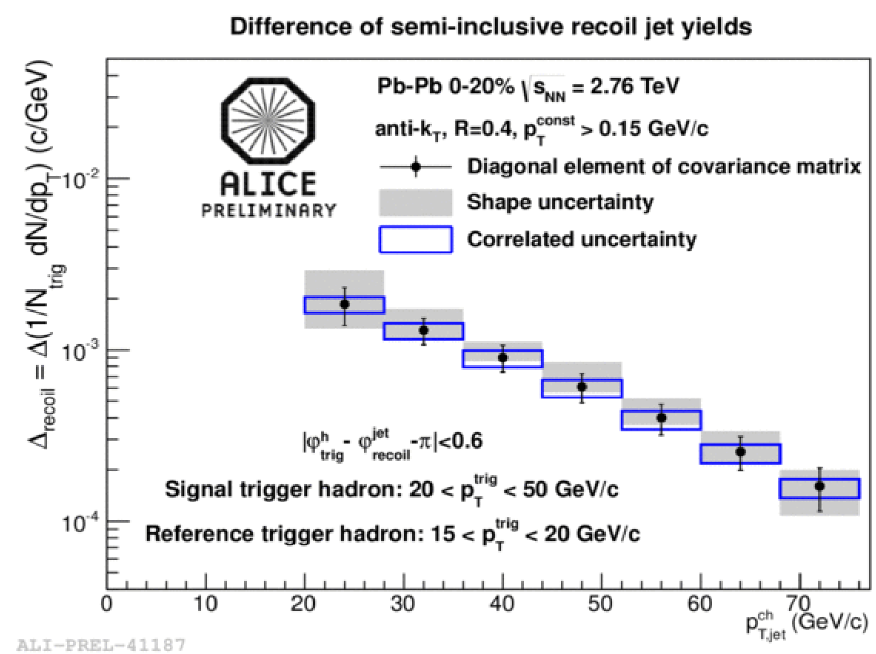


Hadron triggered recoil jets

- Jets recoiling from charged hadron
- Δ_{recoil}: remove residual combinatorial jets
  → extended low p_T reach and higher R
  (arXiv: 1208.1518)
- Sensitive to:
  - Q^2 dependence of jet quenching
  - path length dependence of energy loss



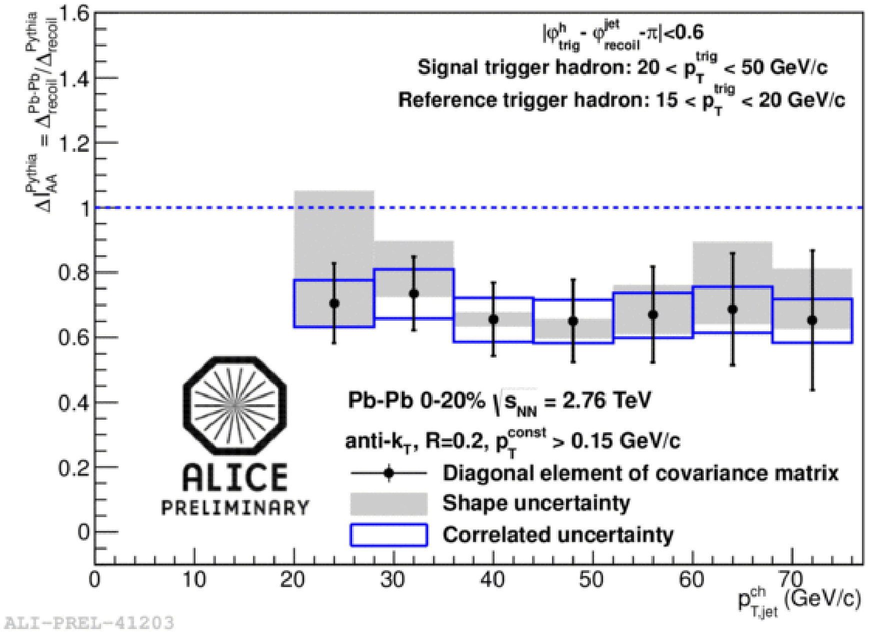




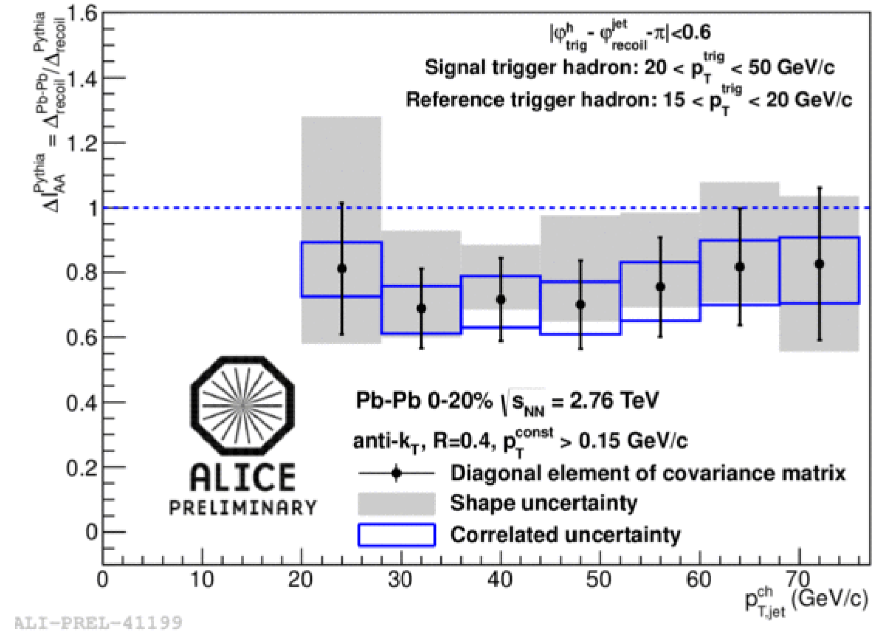
ΔI_{AA}

- $\Delta I_{\rm AA}$: $\Delta_{\rm recoil}$ divided by PYTHIA reference
- $\Delta I_{\rm AA} > R_{AA}$:
  - tangential emission? Medium kicked into cone?
  - flatter parton spectrum?
- Similar for both R

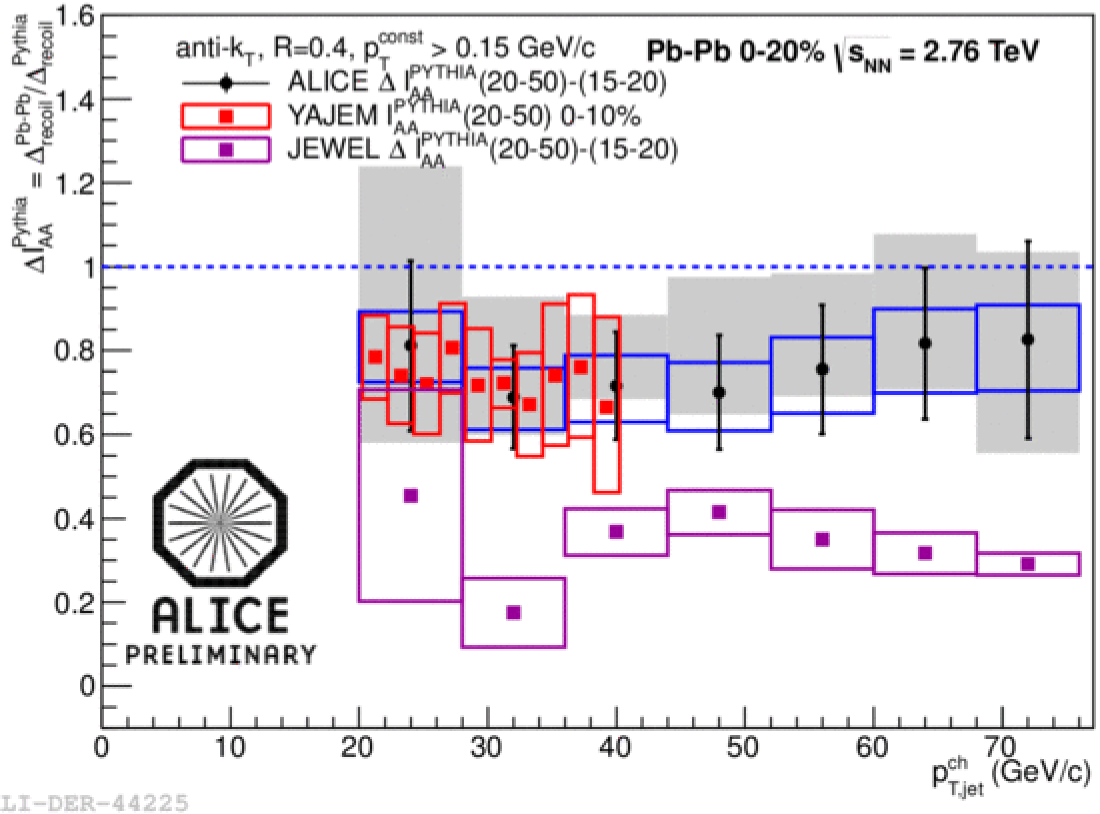
R = 0.2



R = 0.4



- Well reproduced by YAJEM
- Strong discrepancy to JEWEL+PYTHIA (preliminary)



YAJEM: Phys. Rev. C 83 (2011) 02490867

Conclusions & outlook

- Spectra, jet fragmentation & structure in pp
- Charged jet spectra and first investigations of jet structure in Pb-Pb
- Full jet R_{AA} for R=0.2, higher R to come
- Strong, energy dependent suppression of jet yield, jet structure consistent with pp
- Hadron triggered recoil jets allow to go to higher R with minimal fragmentation bias
- Prospects:
  - jet fragmentation & jet structure in Pb-Pb
  - identified particles in jets
  - charged jet trigger with TRD

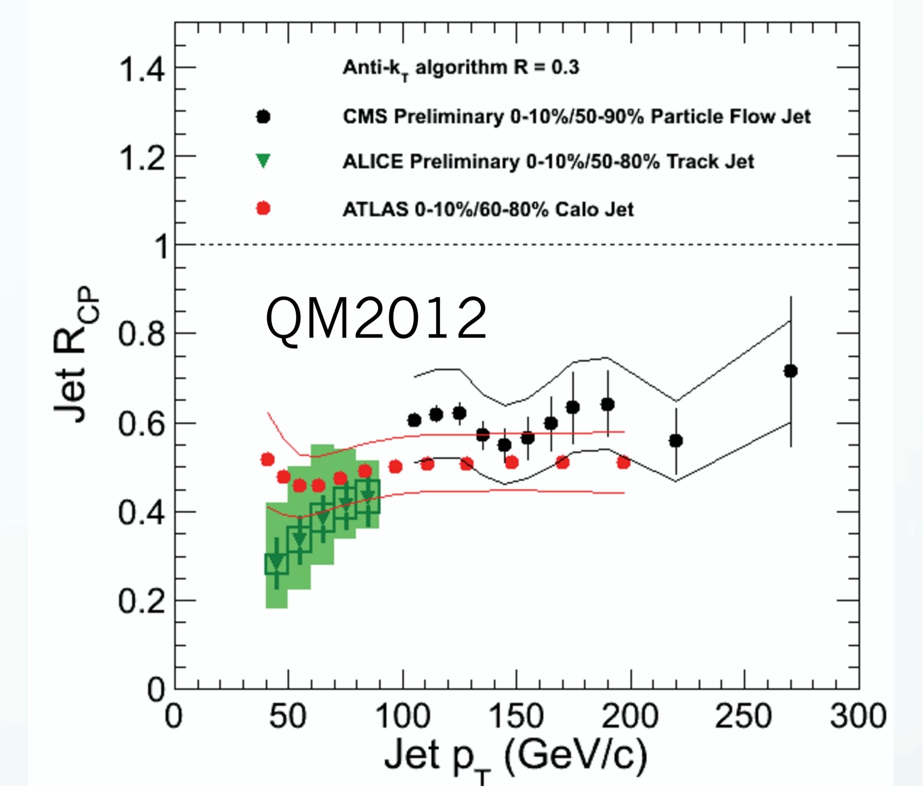
- backup -

Jet reconstruction algorithm

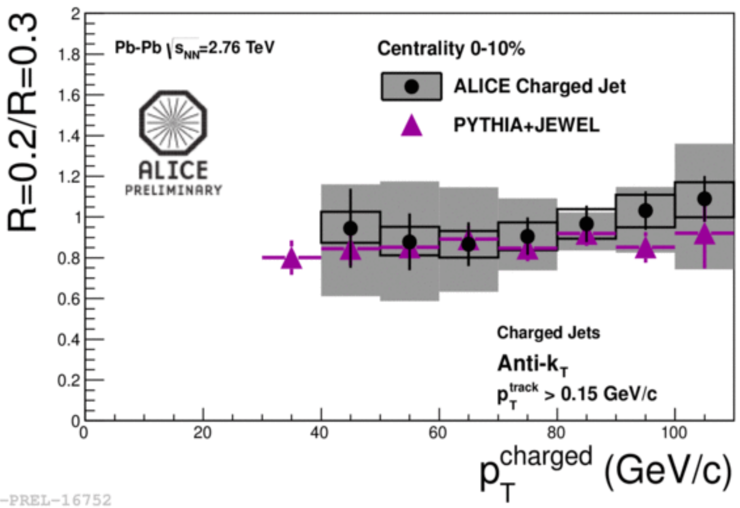
- FastJet anti-k_T jet reconstruction algorithm:
  iteratively combine pairs of particles to clusters,
  pairs of clusters to clusters ...
- Distance measure $\sim \sqrt{d\eta^2 + d\varphi^2}$, resolution parameter R
- Clusters high momentum particles first,
  mostly circular cones with area $A \approx \pi R^2$
- Boost invariant recombination scheme:
  sum up track p_T to jet p_T

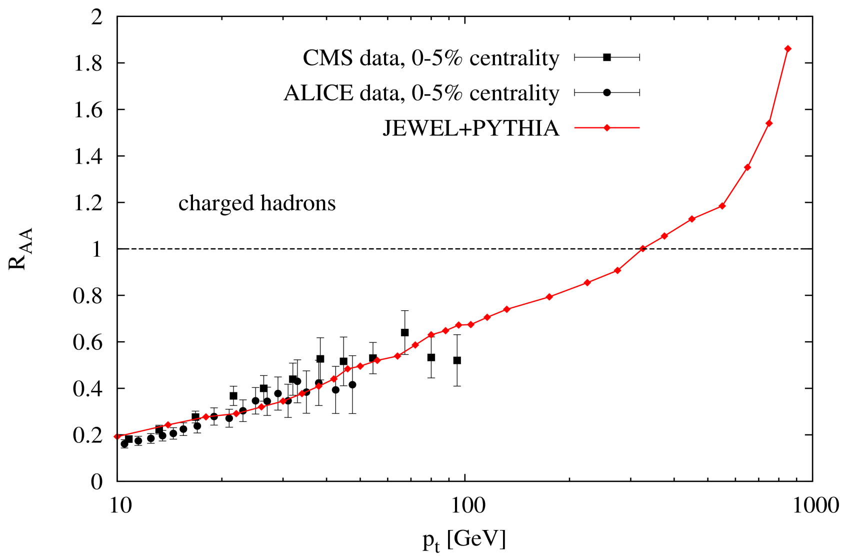
FastJet:
PLB 641 (2006) 57.

ATLAS / CMS / ALICE



JEWEL comparison



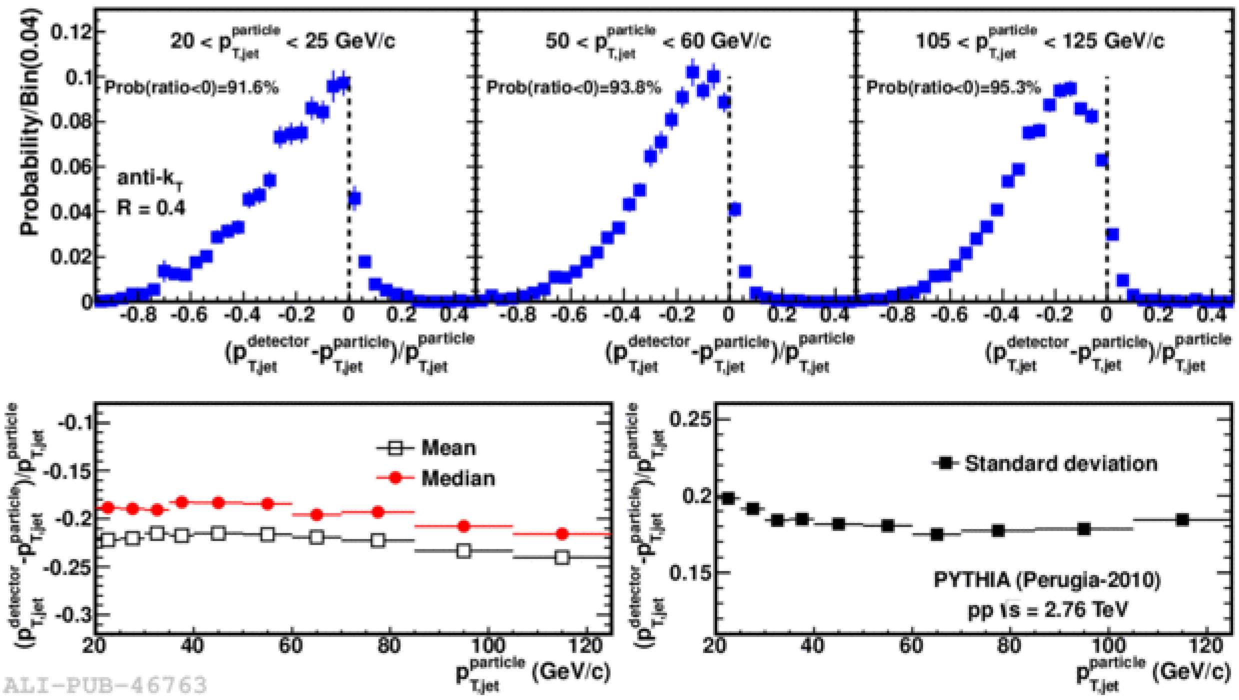


hep-ph/1212.1599

ALICE jet response

- Full jets: JE correction ~20%, 'resolution' ~18%,

  JES uncertainty ~3.6 %



- Tracking jets:
  - $|\eta|^{track} < 0.9$
  - R = 0.4, $|\eta|^{jet} < 0.5$
  - $p_T^{track} > 0.150$ GeV/c
  - hybrid approach for uniform tracking efficiency: combine tracks with / without full ITS
  - momentum resolution: $\delta dp_T/p_T$ = 4% (7%) at 40 GeV/c
- Full jets including EMCAL:
  - $|\eta| < 0.7$, $1.4 < \Phi < \pi$
  - cluster E_T > 300 MeV
  - hadronic correction for charged particles

Biased jet spectra

- Leading track bias:
  - reject combinatorial jets: test of unfolding stability
  - test for very soft fragmentation

- No significant change of R_{CP}
  -> no strong modification of leading hadron fragmentation