Jet Production and Structure in pp, p-Pb and Pb-Pb Collisions Measured by the ALICE Experiment

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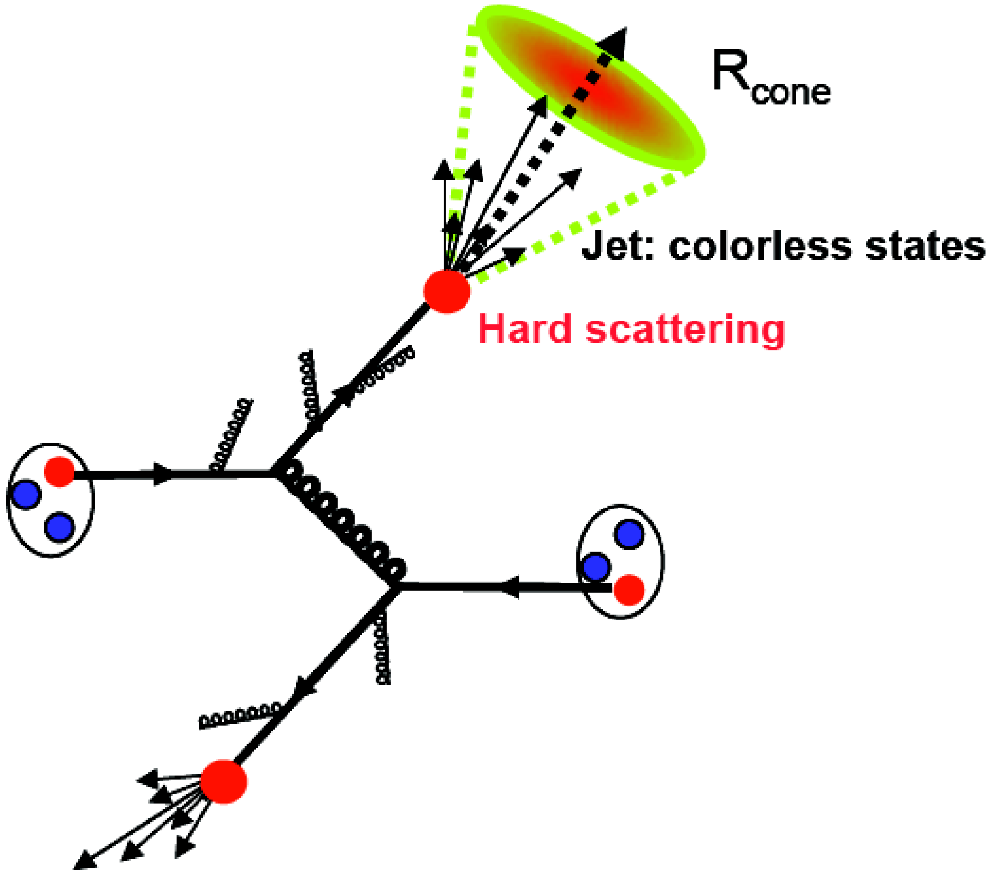
IS2013

Outline

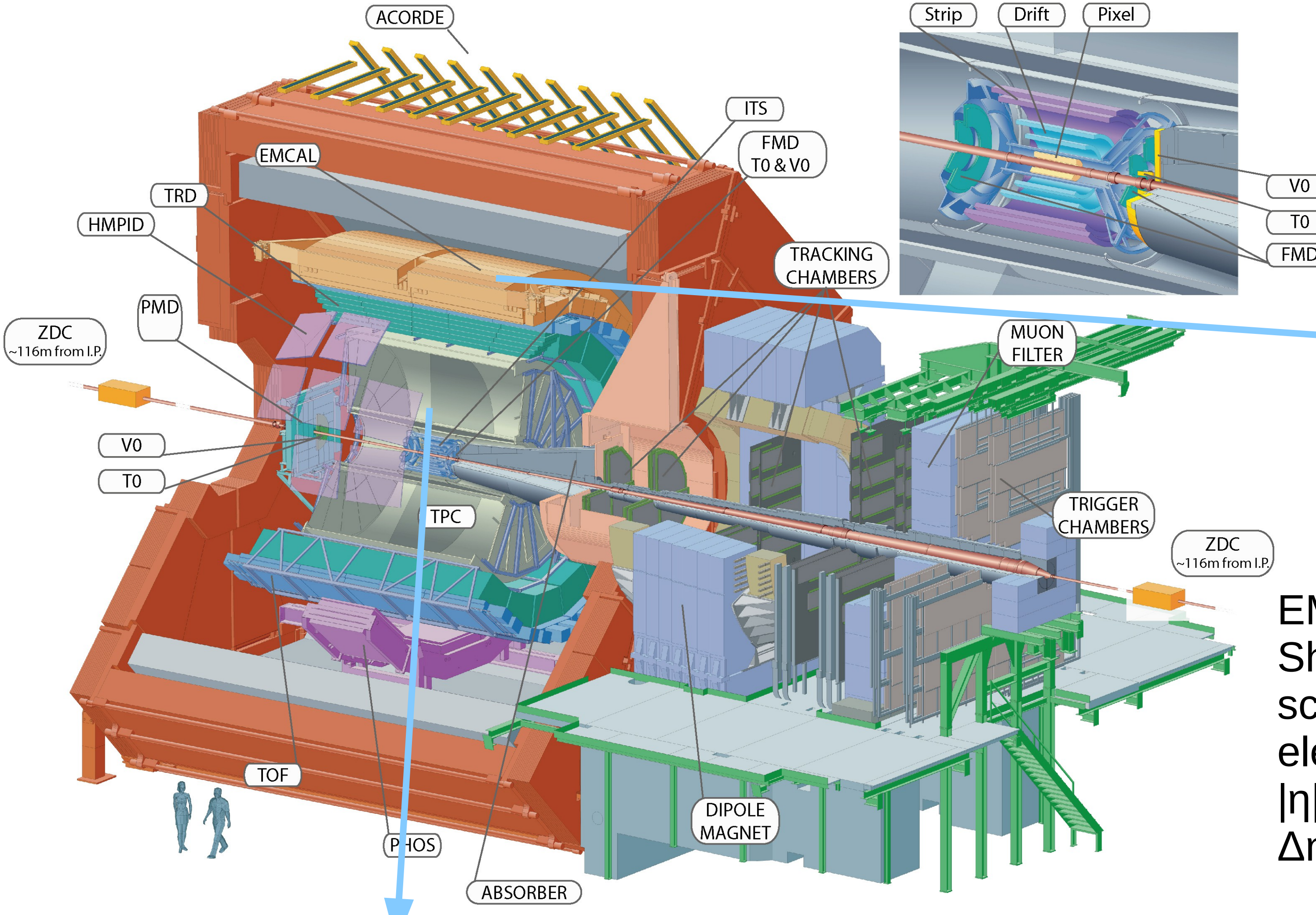
- Motivation
- "Full" (charged + neutral) jets in pp
  - Correction for charged particle contamination
  - Triggering
  - pp jet cross-section and structure
- Jets in Pb-Pb
  - Background
  - Unfolding
  - Cross-section, structure, R_{AA}

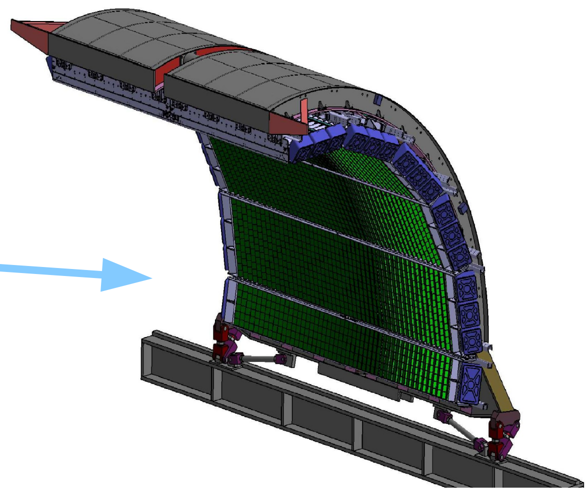
Jets

- Jets originate from the hard scattering of partons
  - Fragment and hadronize into a spray of particles
- The spray (initial parton) is recovered using jet algorithms
  - Resulting jets depend on algorithm choice and constituent cuts
- Tests of PDFs, fragmentation and pQCD hard scattering



The ALICE detector





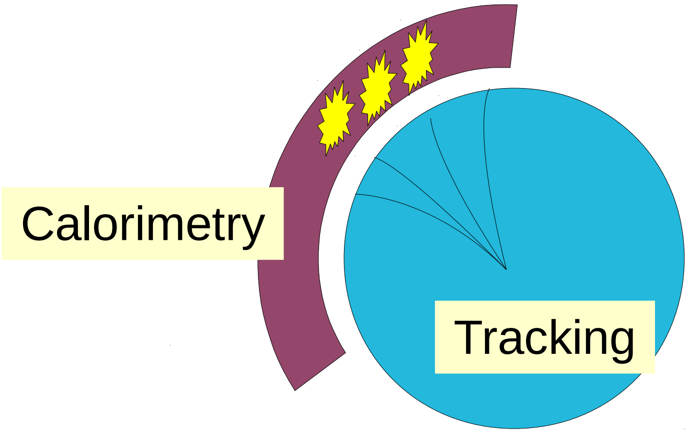
EMCal:
Shashlik Pb/organic scintillator sampling electromagnetic calorimeter
$|\eta| < 0.7$; $1.4 < \Phi < \pi$
$\Delta\eta \sim \Delta\Phi \sim 0.014$

TPC + ITS (silicon) tracking
$|\eta| < 0.9$; $0 < \Phi < 2\pi$

→ Charged constituents (tracks) → **JET** ← Neutral constituents (clusters, *optional*)

Data sets and jet reconstruction

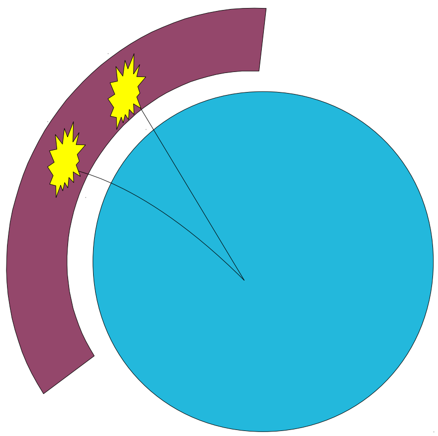
- Data
  - pp $\sqrt{s}$ = 2.76 TeV
  - Pb–Pb $\sqrt{s_{NN}}$ = 2.76 TeV
  - p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV
- Jets
  - Charged tracks (ITS+TPC) and clusters from EMCal (full jets only)
  - Anti-k_T algorithm for signal jets, k_T for background
  - Jets fully contained in acceptance
  - R = 0.2 – 0.6

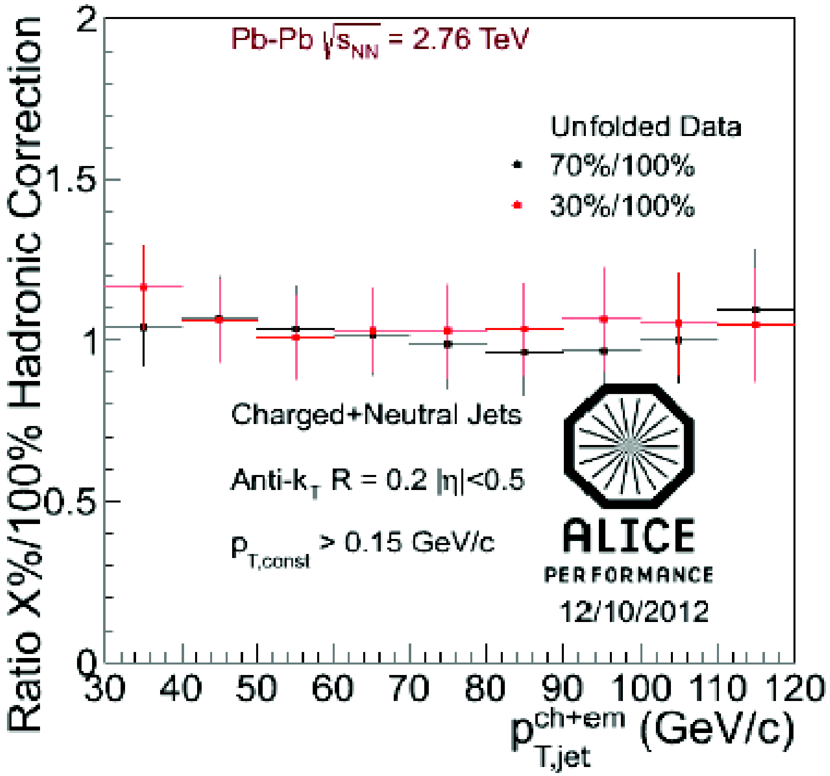


Correction for charged particle contamination

- Charged particles deposit energy in EMCal
- Need to avoid double counting of the momenta
- Tracks are matched to clusters and up to 100% (f = 1) of their momenta is subtracted from the cluster energy
- $E^{corr}_{cluster} = E^{orig}_{cluster} - f \cdot \sum E_{track}$

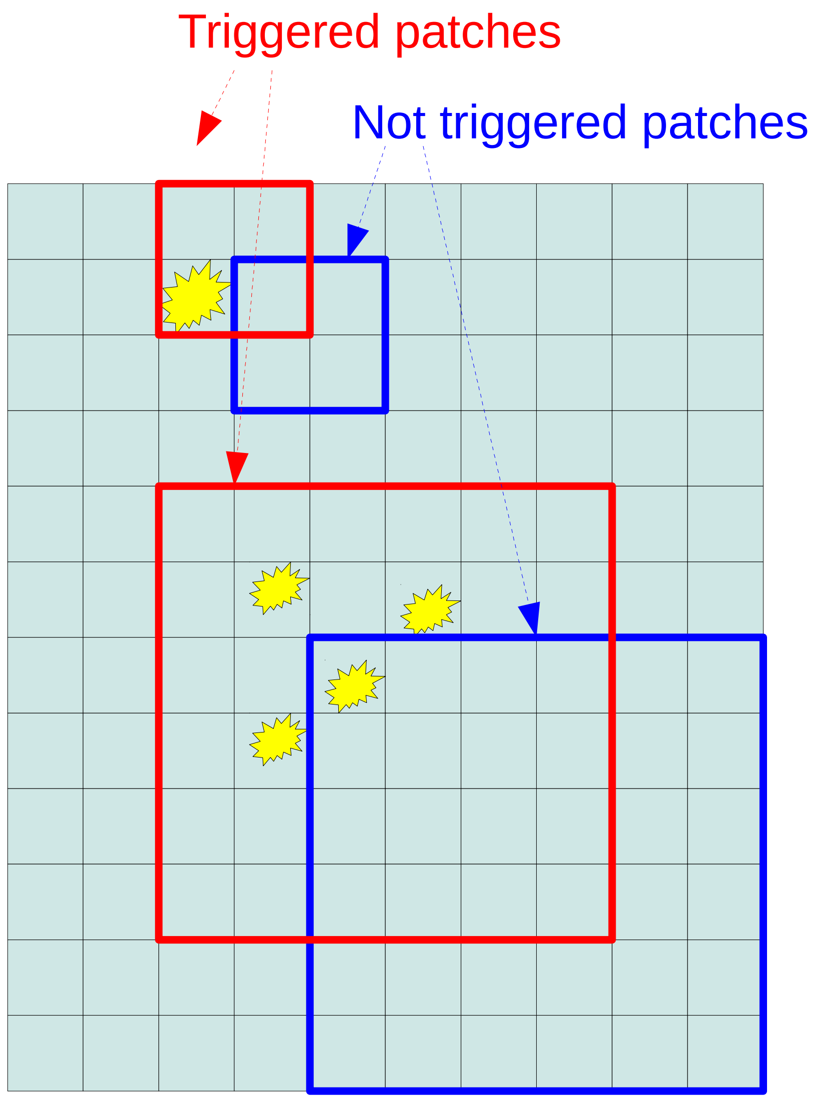
  $E^{corr}_{cluster} \geq 0$





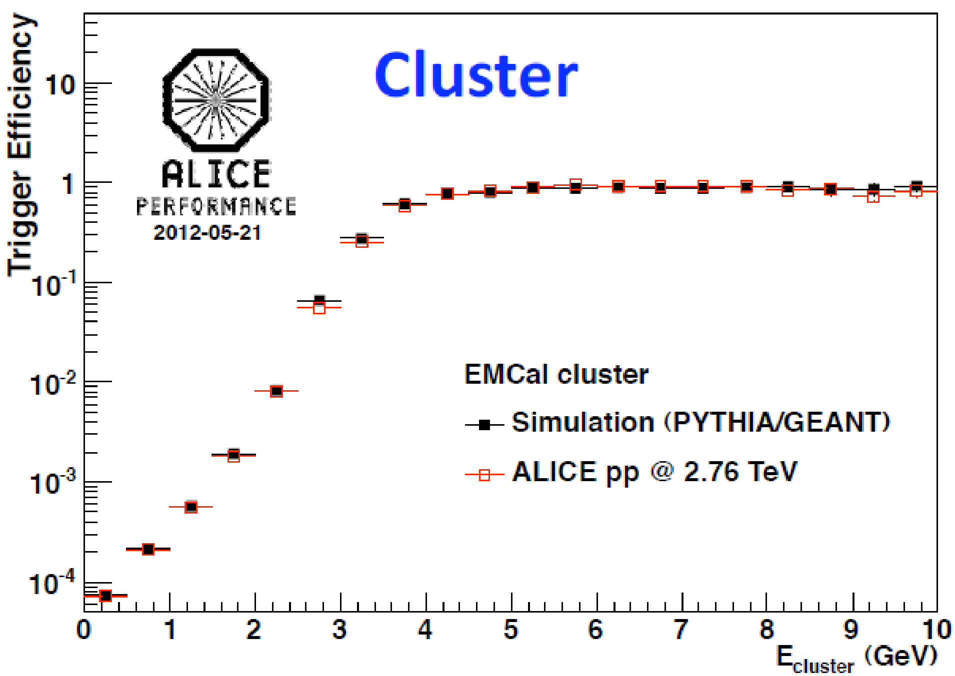
EMCal triggers

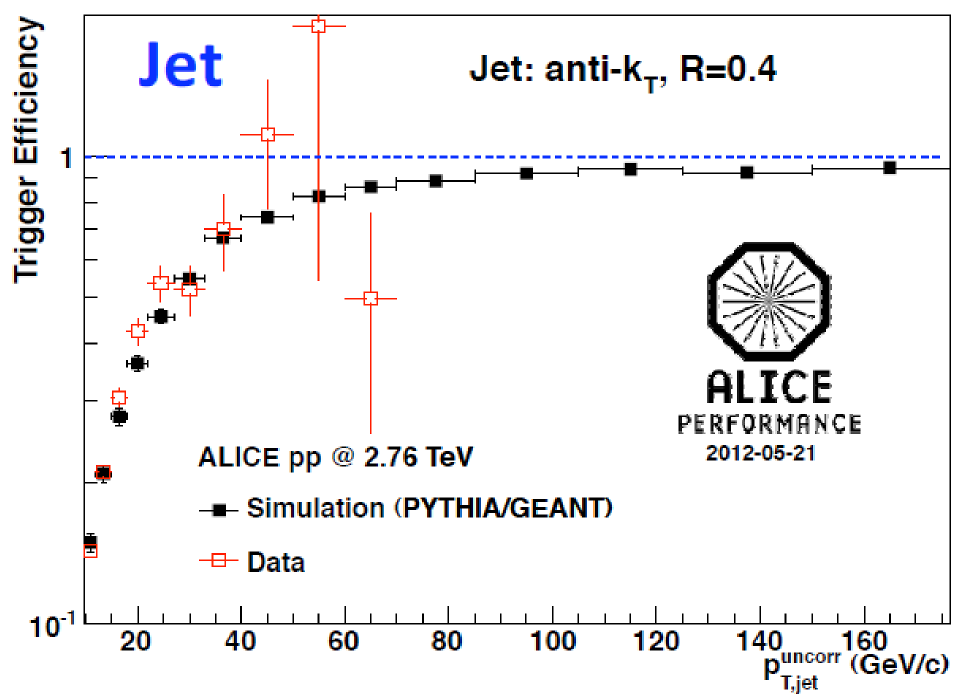
- EMCal triggers on integrated energy deposits in a given area
- Triggers are formed by sliding window algorithms of different granularity and steps
- L0 (600ns), 4x4 towers
- L1 (~5μs), 4x4 towers without FEE HW borders
- L1 (~5μs), 32x32 towers, jet trigger



Trigger bias and efficiency in pp

- Trigger selects high-energy jets
- The trigger bias needs to be understood and corrected in the cross-section measurement
- Studied using full MC simulation, good agreement with data

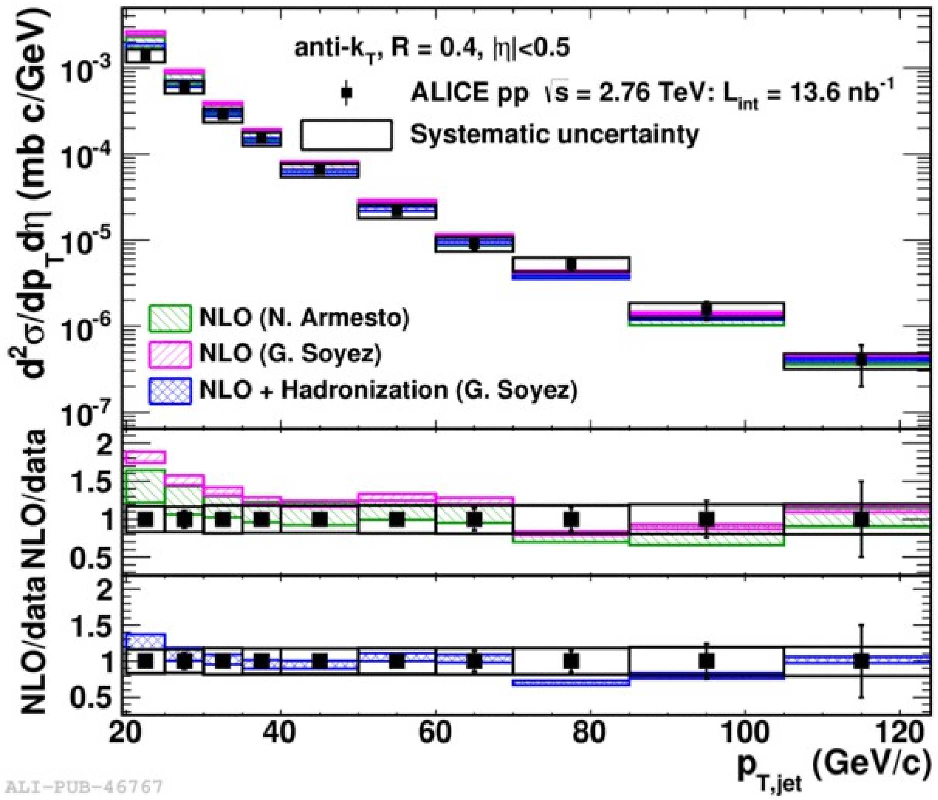


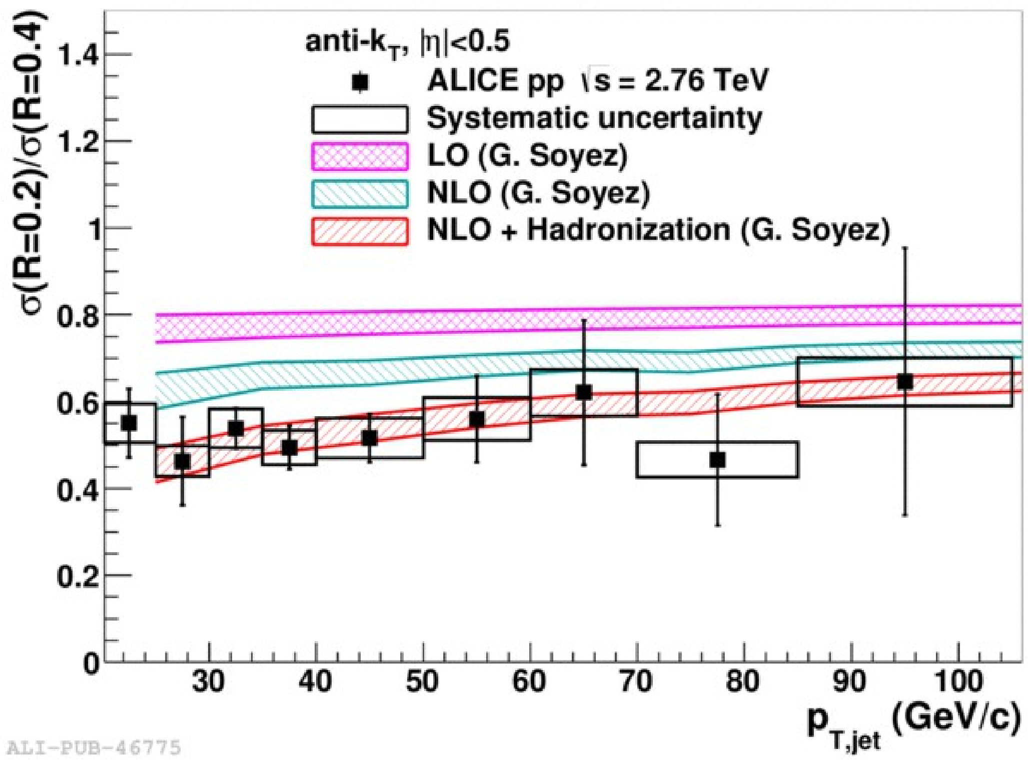


Jet cross-section and structure in pp

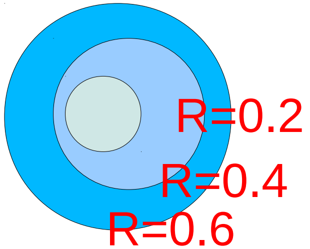
- Inclusive jet cross section and structure

R = 0.4





- Good agreement with NLO + hadronization



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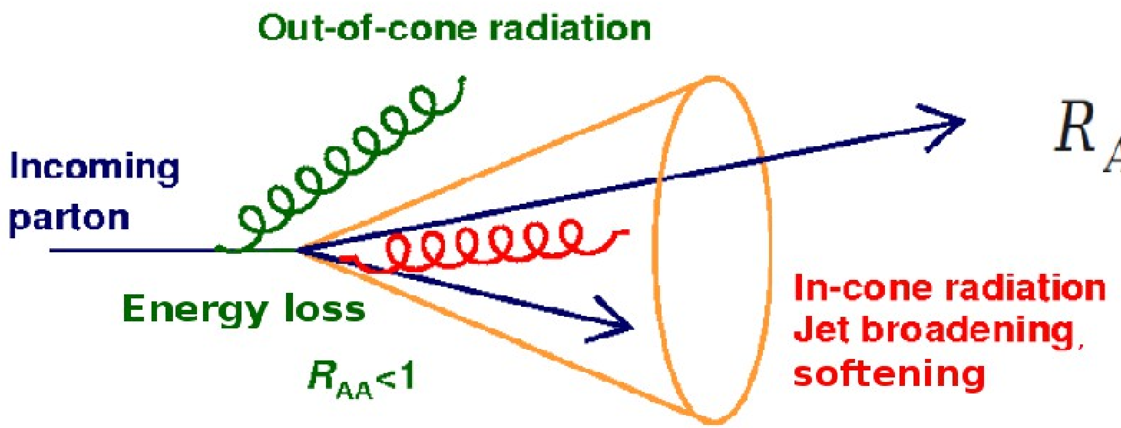
Jets in medium

- Jets are important probes of the medium that the parton passes through
  - Parton interacts strongly with the medium
  - Parton loses energy due to induced gluon radiation
- Removing the soft background contribution to the jets is an experimental challenge
- p-Pb collisions allow us to probe cold nuclear matter effects

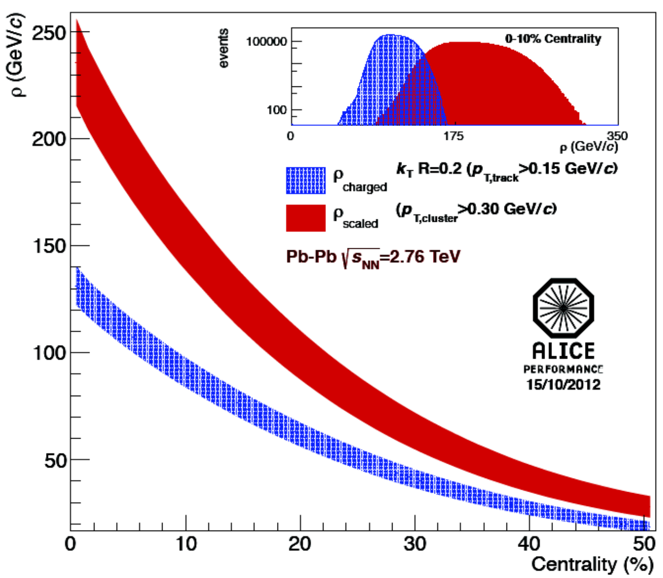


$$R_{AA} = \frac{\sigma_{pp}^{inel}}{\langle N_{coll} \rangle} \frac{d^2 N_{AA} / dp_T d\eta}{d^2 \sigma_{pp} / dp_T d\eta}$$

Underlying event

- Event-by-event subtraction
- $\rho_{charged}$ calculated using k_T jets p_T/A
- ρ_{scaled} is scaled from $\rho_{charged}$

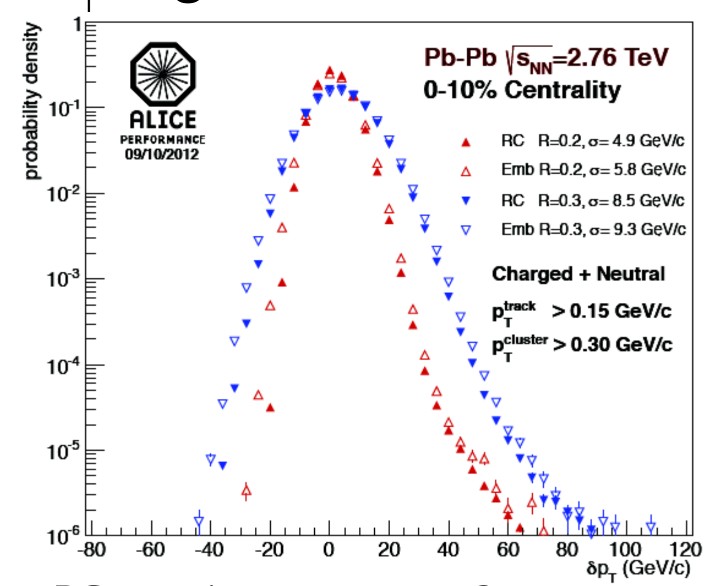
arXiv:1207.2392



$$\rho_{scaled} = s_{emc} \cdot \rho_{charged} = s_{emc} \cdot median\left(\frac{p_T^{k_T\,jet}}{A^{k_T\,jet}}\right)$$

s_{emc} scale in between charged and full jets

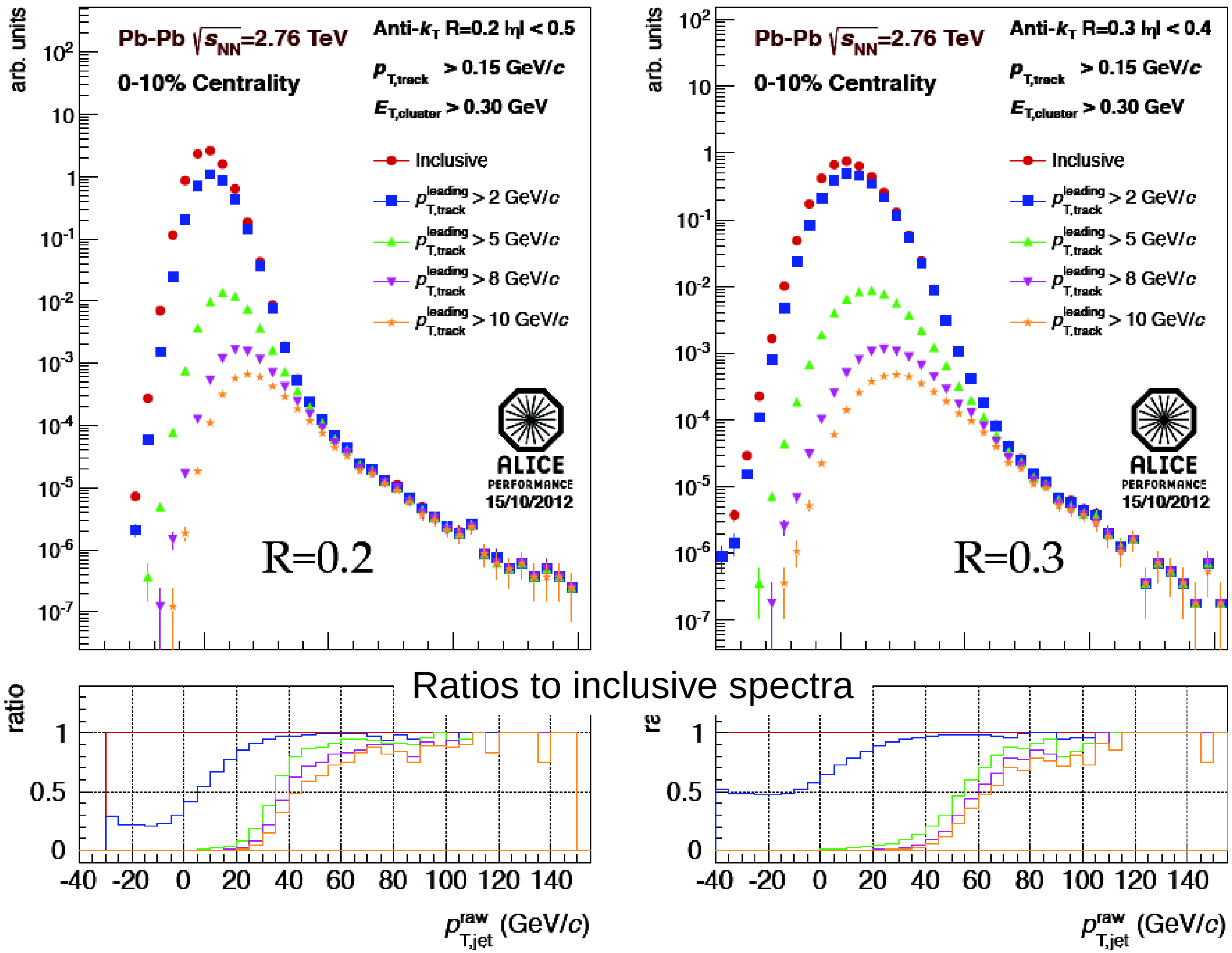
- Within-event fluctuations determined by
  - Random cones
  - Embedded track with anti-k_T algorithm



$$\delta_{p_T}^{RC} = p_{T\,rec}^{jet} - \rho \cdot \pi R^2$$

$$\delta_{p_T}^{emb} = p_{T\,rec}^{jet} - \rho \cdot A^{Anti-k_T\,jet} - p_T^{emb\,probe}$$

Leading particle bias

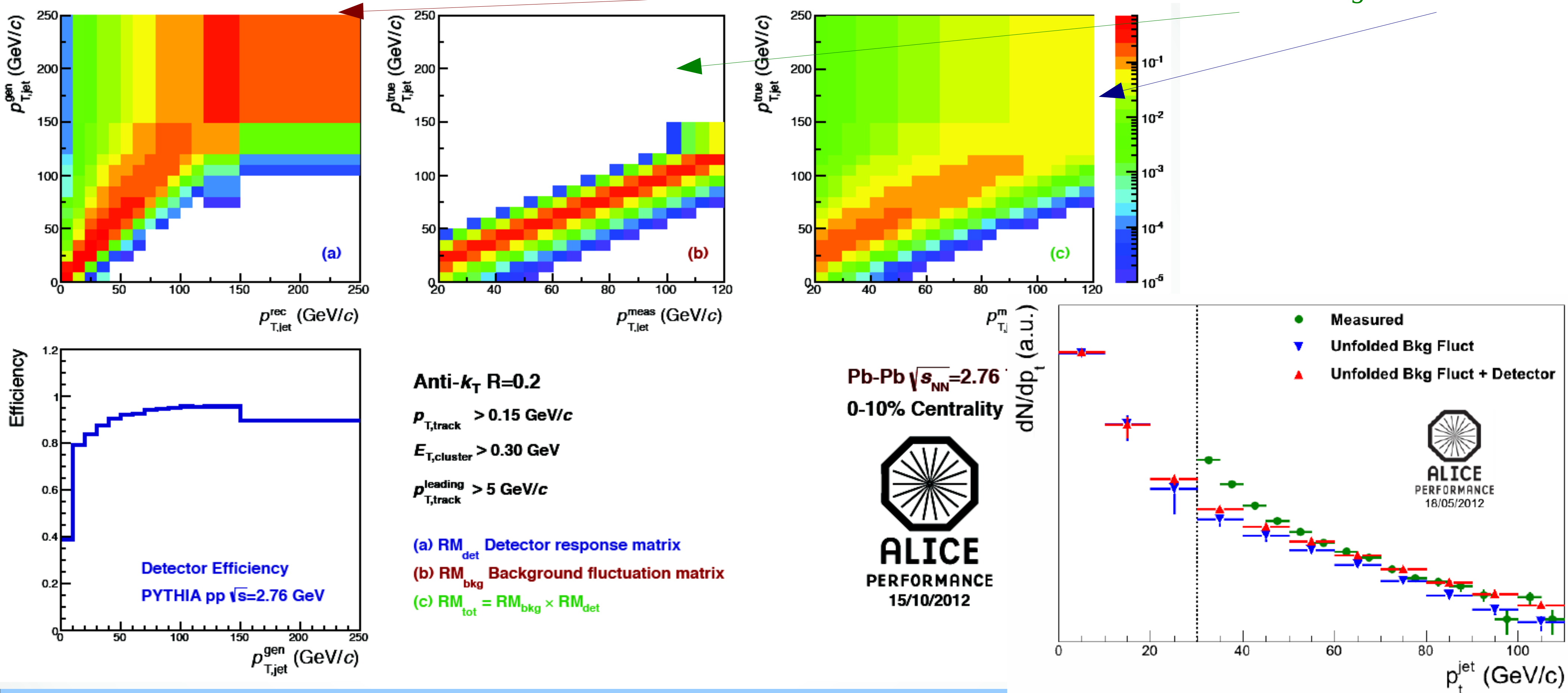


- Offline requirement of a high-p_T jet constituent
- The bias allows the removal of combinatorial jets, made of soft particles
- 5 GeV/c track required in analysis

Unfolding

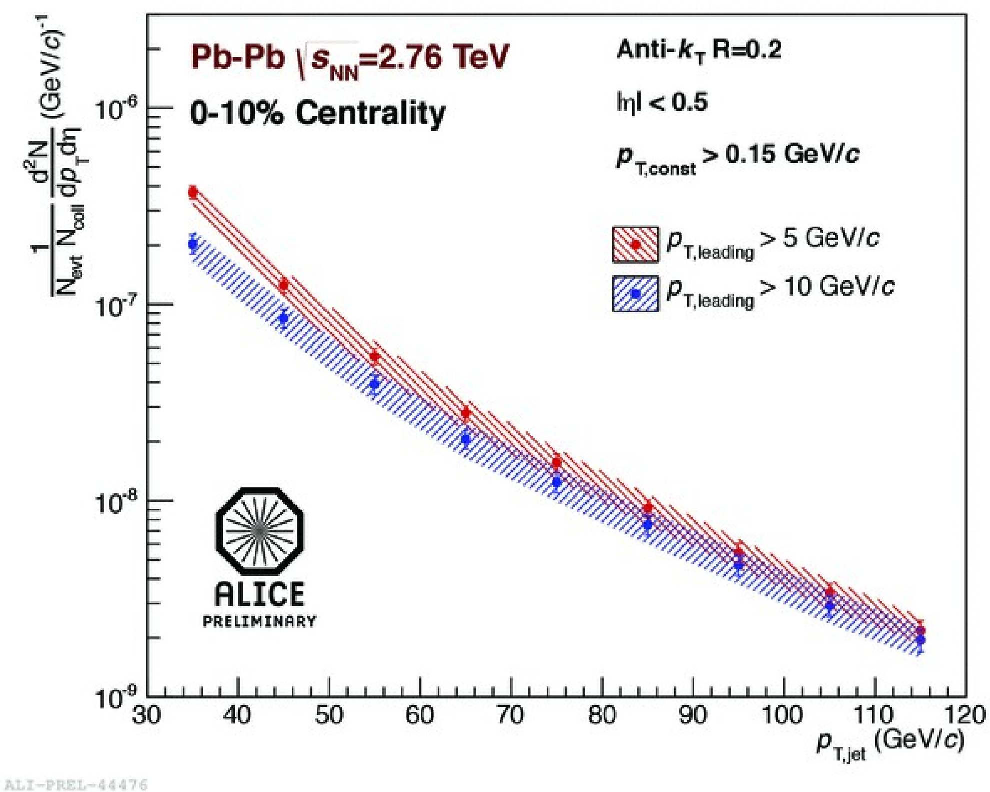
- Unfolding used to obtain true jet spectrum
- Bayesian, SVD (Singular Value Decomposition) or χ^2 minimization methods used

$$RM_{detector} \cdot RM_{bkg} = RM_{total}$$

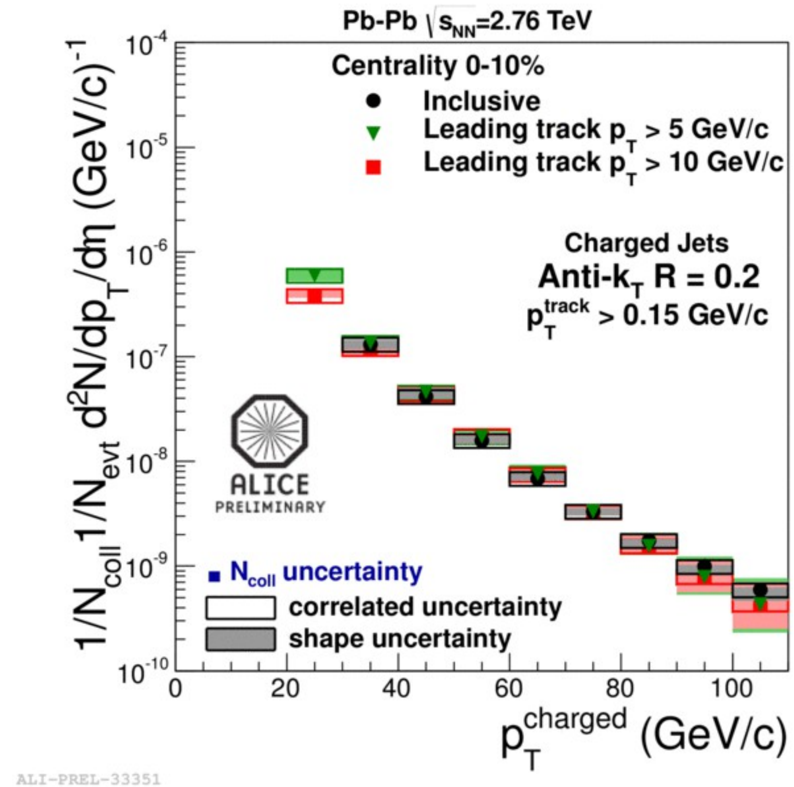


Pb-Pb jets

Full jets



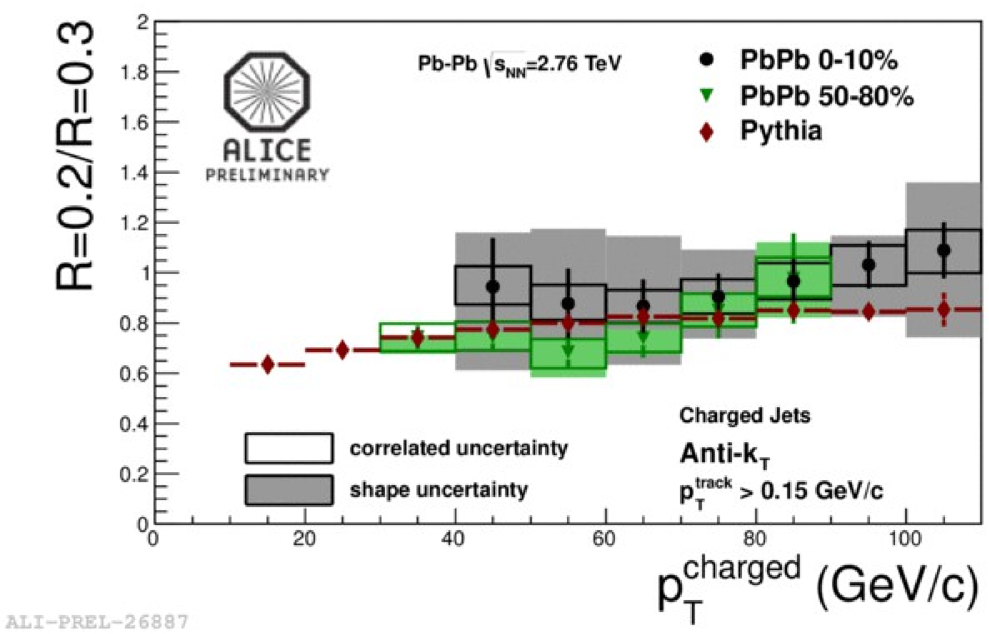
Charged jets

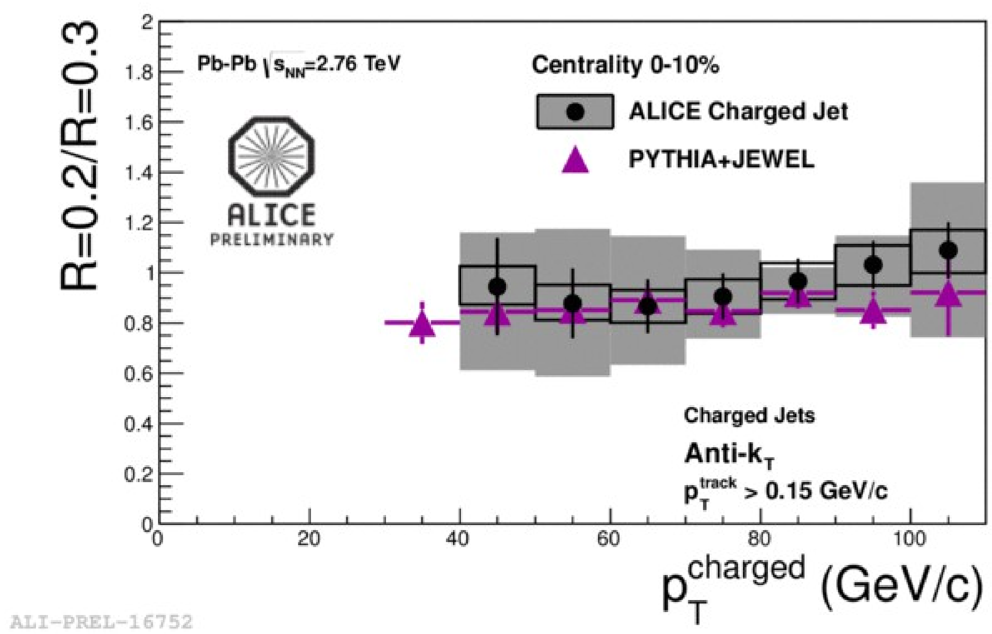


- Leading particle bias, central events 0-10%, R = 0.2
- Charged jets are not corrected for the neutral part

Pb-Pb jet structure

- No significant jet broadening within the uncertainties for charged jet ratio R 0.2 / 0.3
- Good agreement with Pythia + JEWEL
- From inclusive spectra with no leading track bias

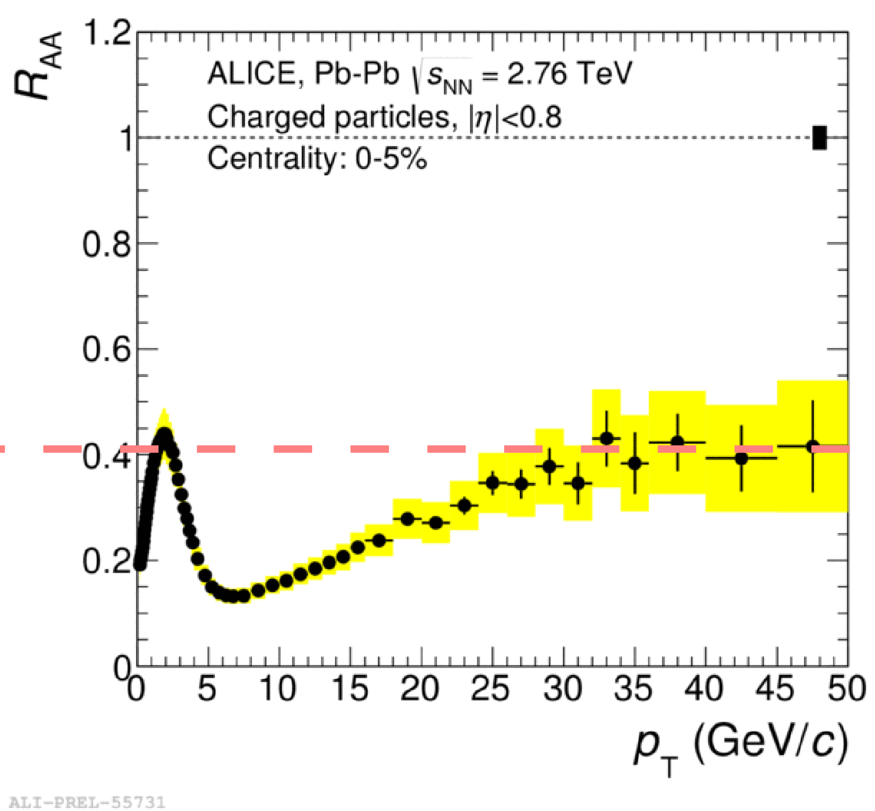




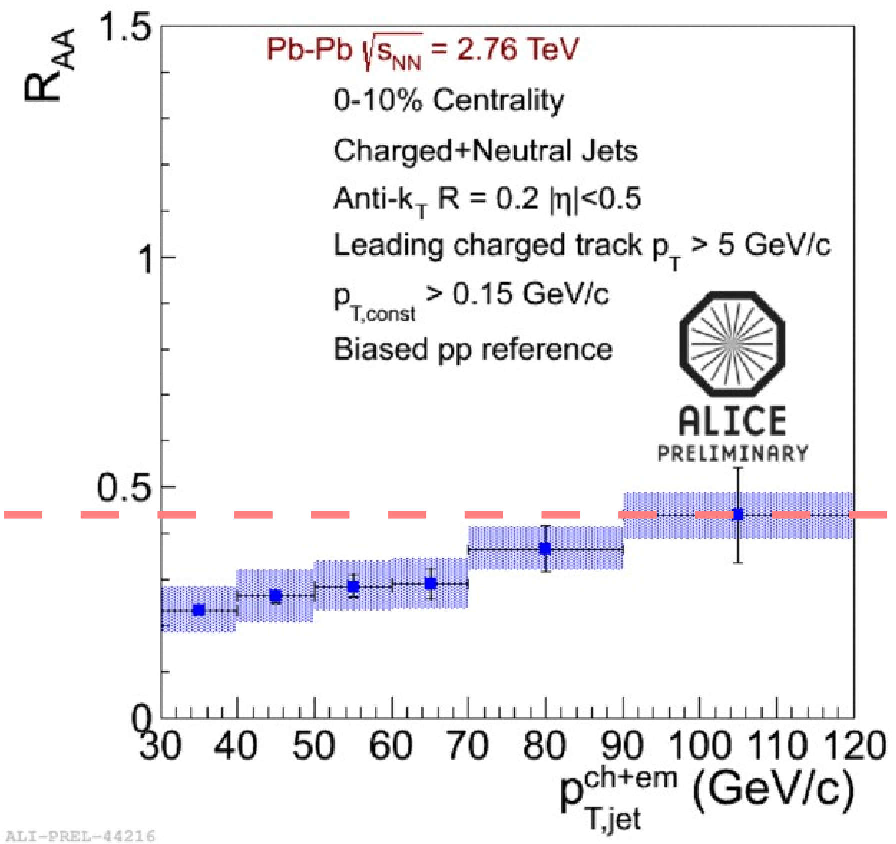
Jet vs hadron R_{AA}

- Similar R_{AA} value for most central collisions for jets and charged hadrons at high-p_T ~ 0.4

Charged hadrons

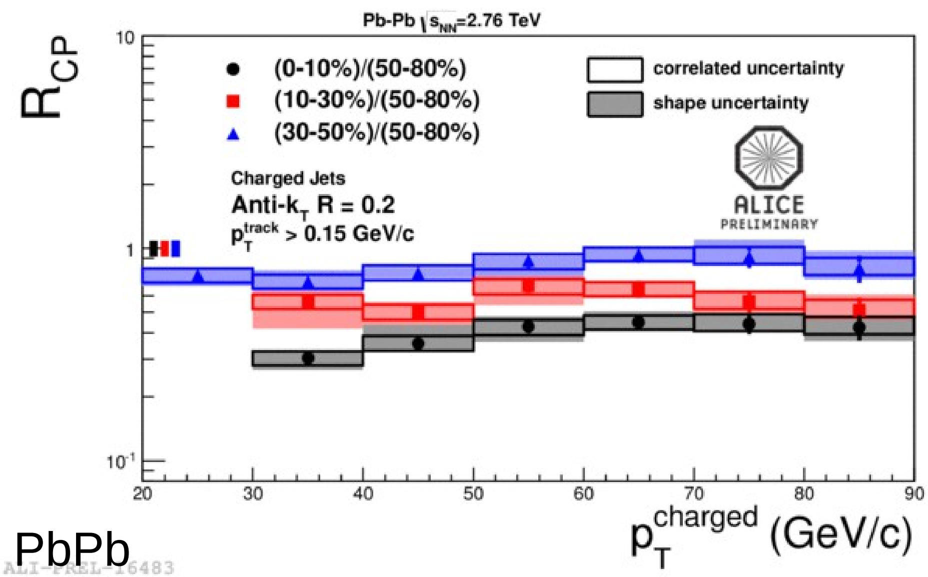


Full jets

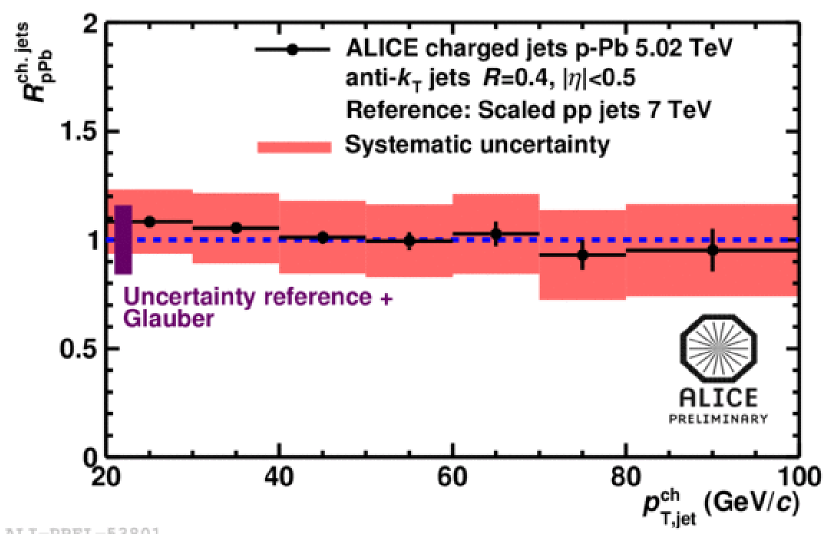


Other results...

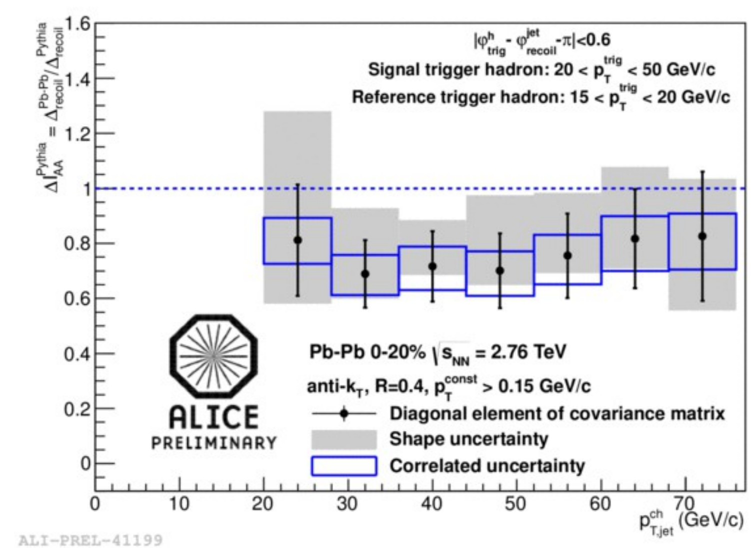
- See M. Ploskon's talk from Tuesday
- More information R_{pPb} and R_{CP} available (R_{pPb} ~ 1)



p-Pb



PbPb



Conclusion

- Charged and full (charged+neutral) jet spectra were analyzed in several collision systems collected by the ALICE experiment

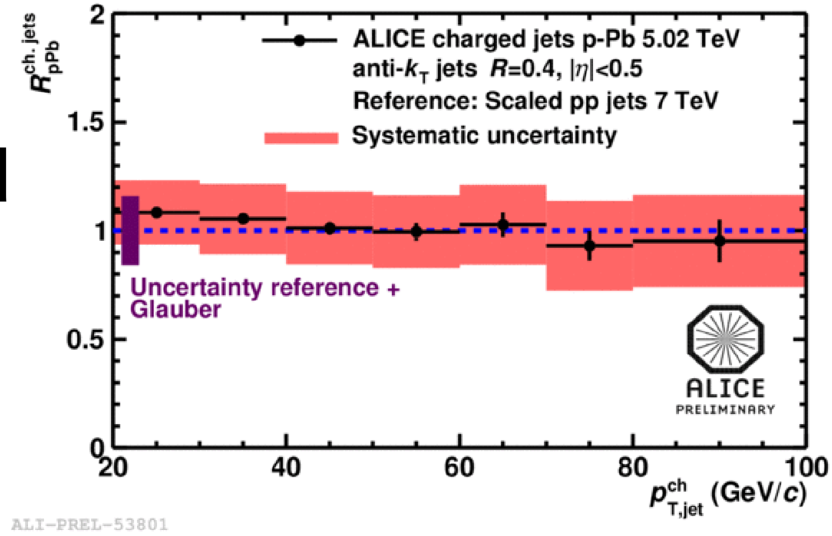
- Jet structure measured in pp collisions is well described with NLO + hadronization model
- Full jet R_{AA} from the 10% most central events is comparable with charged hadrons R_{AA} in high-p_T
- Within uncertainties there is no observation of jet broadening between R = 0.2 and 0.3 due to in-cone radiation

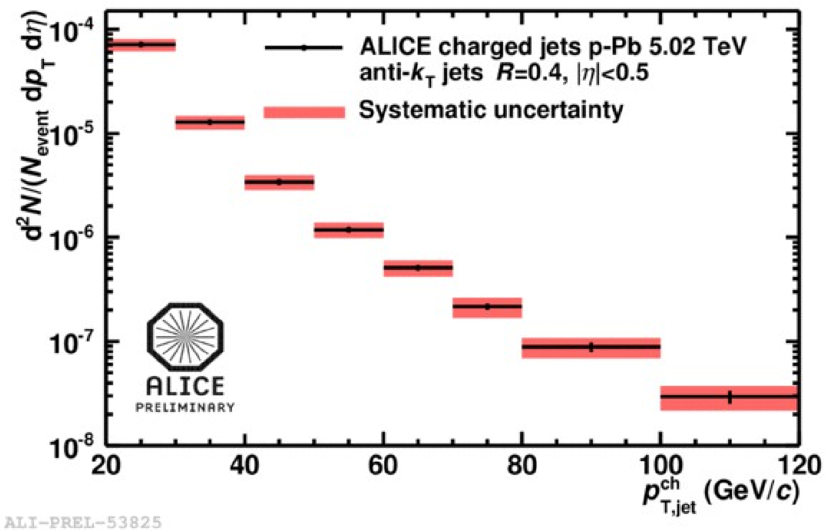
Backup

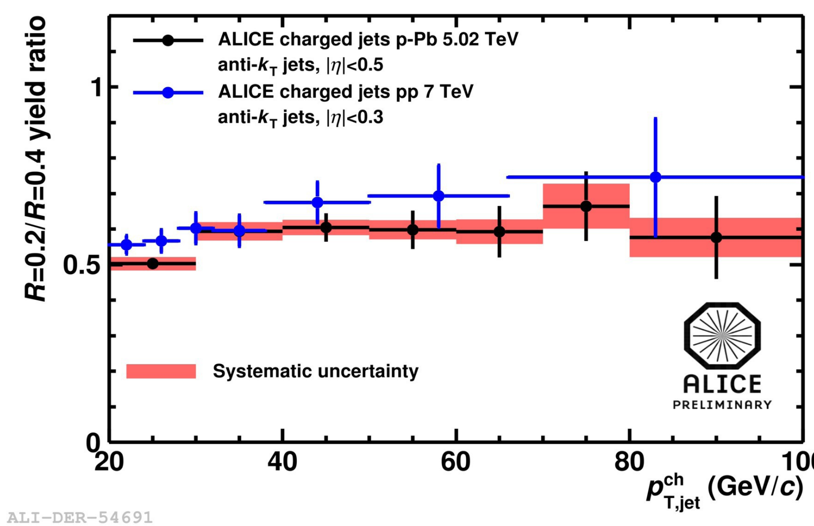
Cold nuclear matter, p-Pb

- Charged jets
- No suppression observed
- Scaled pp 7 TeV spectra used as a reference (slide 26)

$$N_{5\ \mathrm{TeV}} = N_{7\ \mathrm{TeV}} \cdot \frac{N_{5\ \mathrm{TeVMC}}}{N_{7\ \mathrm{TeVMC}}},$$

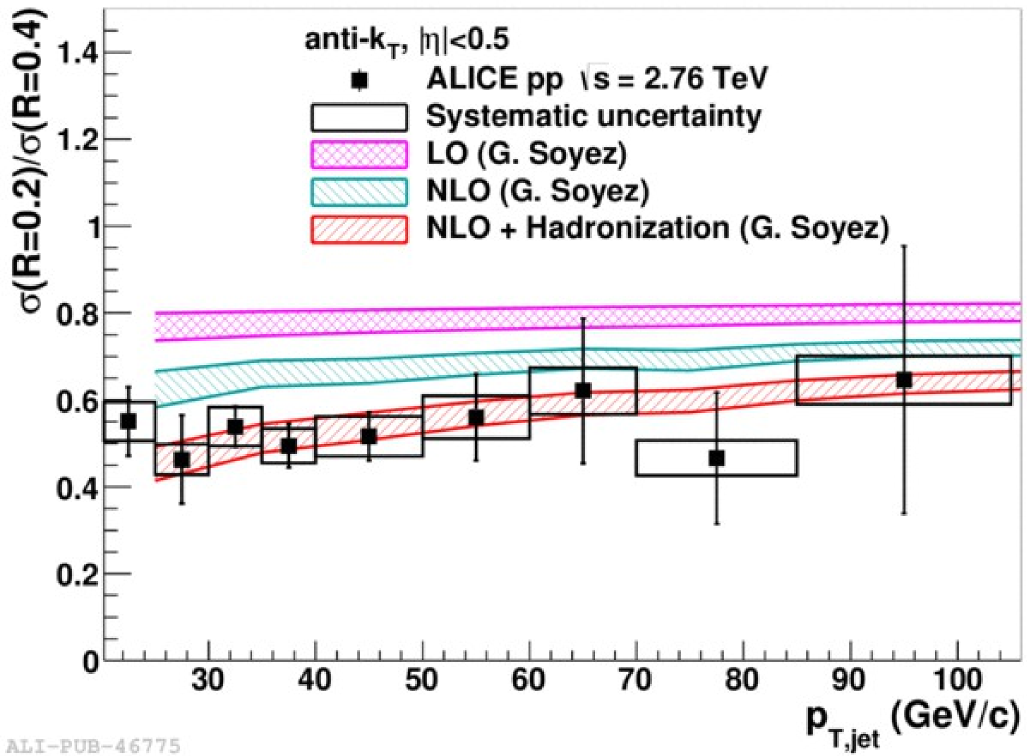


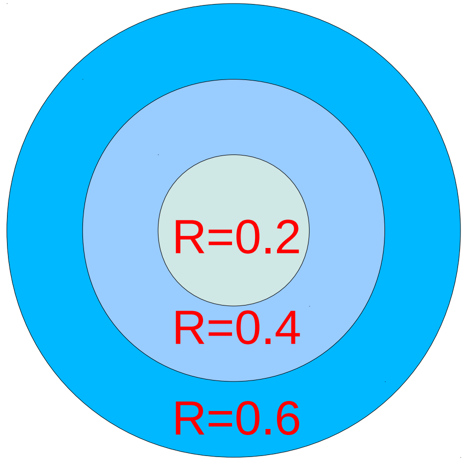




p-p jet structure

- Jet collimation increases weakly with p_T
- Good agreements with NLO + hadronization within uncertainties





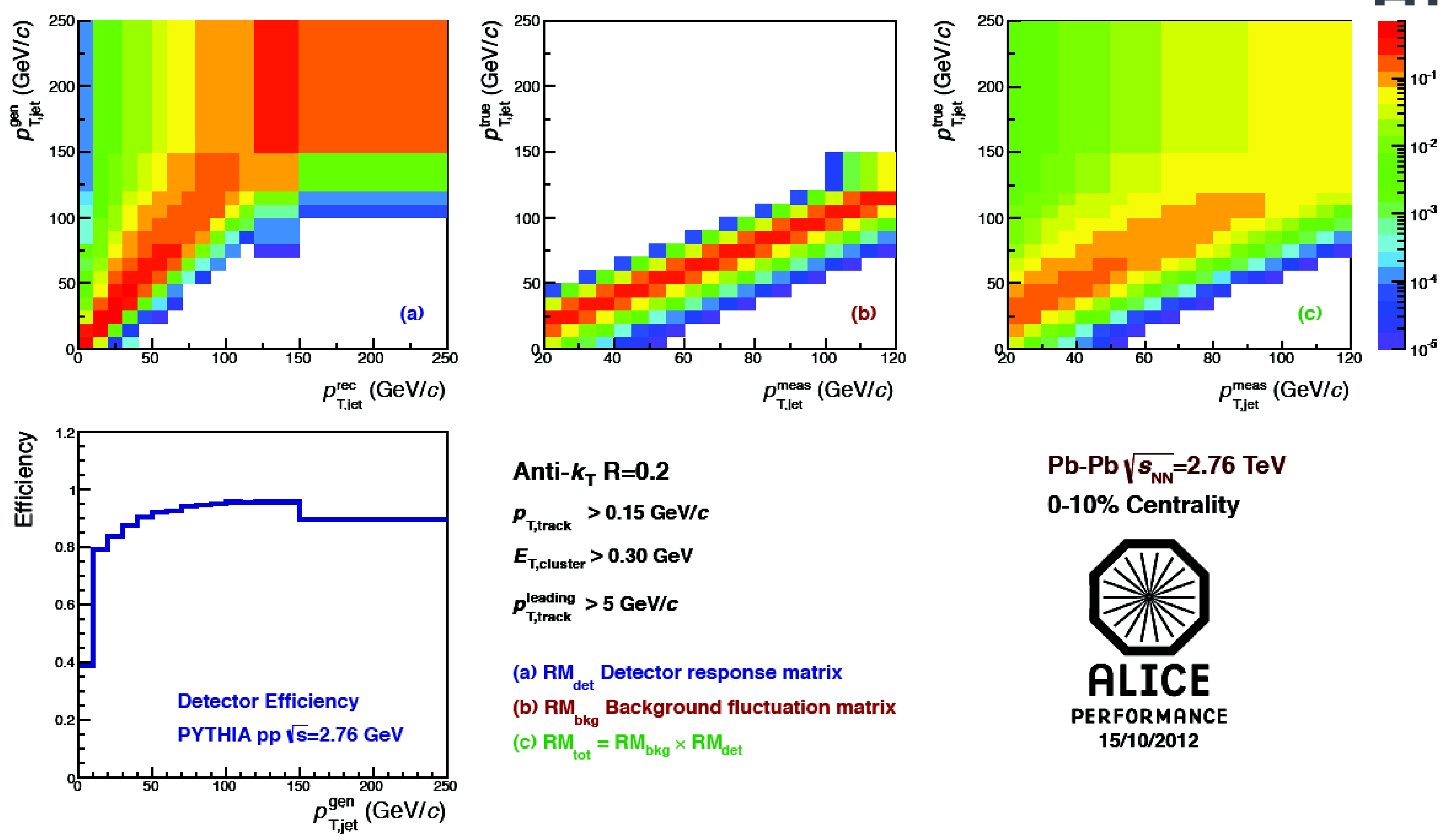
Geometrical ratio 0.2/0.4 = 0.25

G. Soyez, "A simple description of jet cross-section ratios", Phys.Lett. B698 (2011) 59

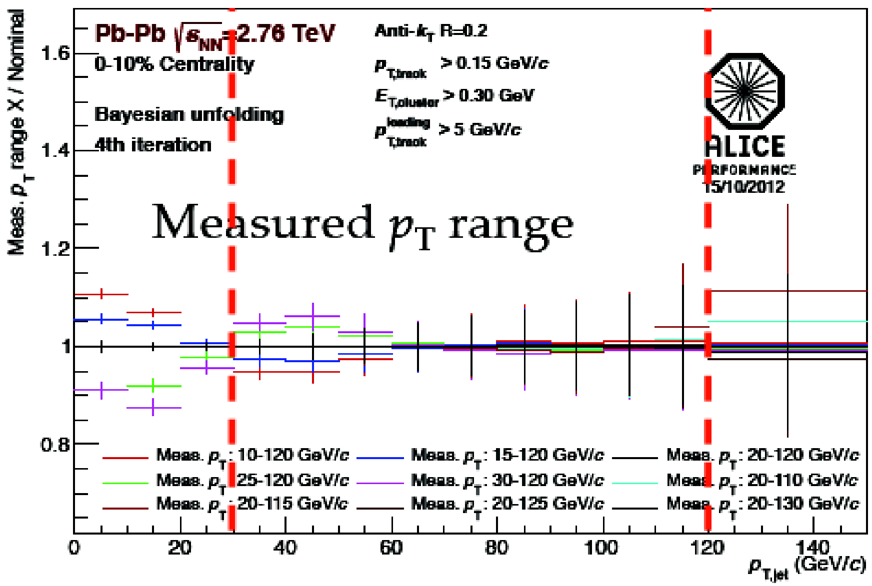
Detector effects

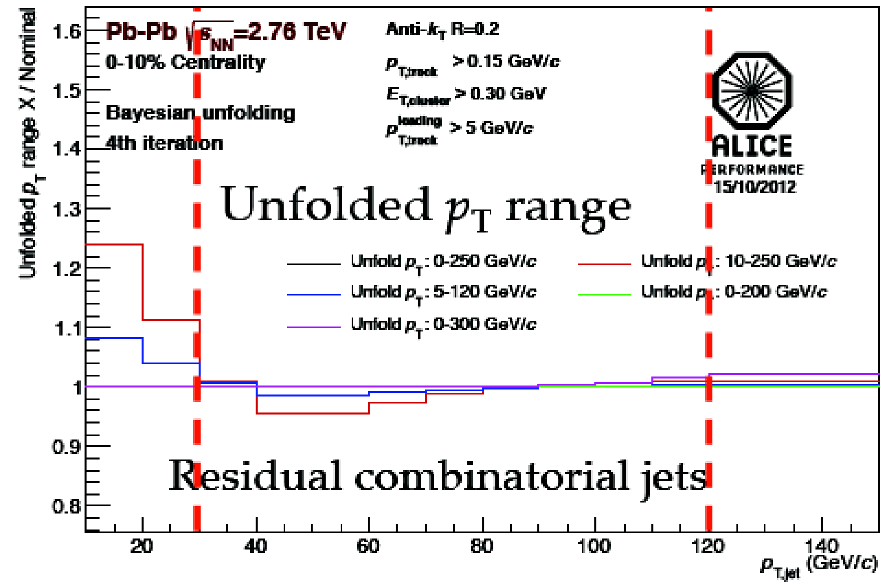
- Bin-by-bin technique
  - Compare the MC cross-section before and after the detector response
  - Use uncorrected spectrum in data as weighting function
- *Shift of jet energy scale ~ 20-25%*
  - Unmeasured neutrons and K^0_Ls : compare proton and kaon spectra to data; PYTHIA vs HERWIG
  - Tracking inefficiency: track quality in data vs MC
  - Residual hadronic correction for EMCal: data-driven check
  - JES uncertainty ~ 4%
- *Jet energy resolution ~ 18%*
  - Detector resolution: data-driven check + test beam
  - Fluctuations (e-by-e) in correction of jet energy scale

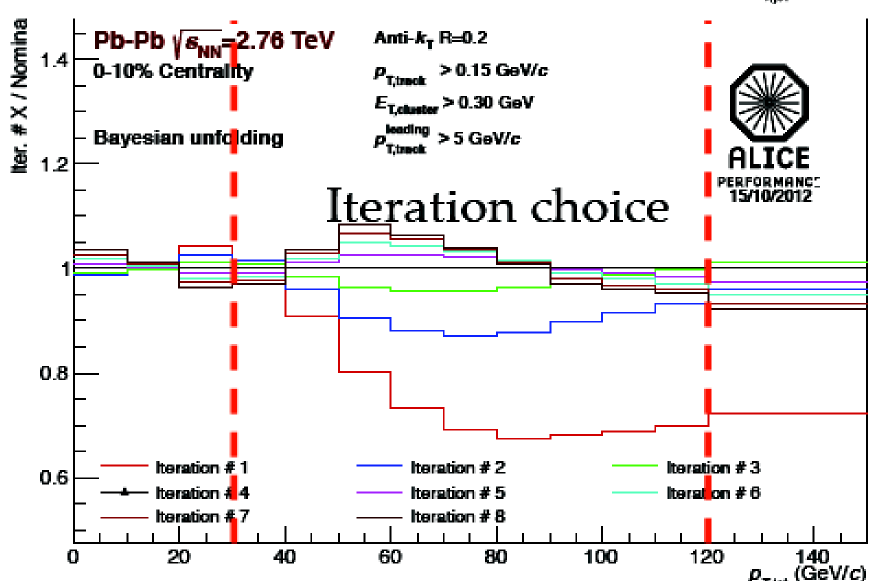
Response matrix

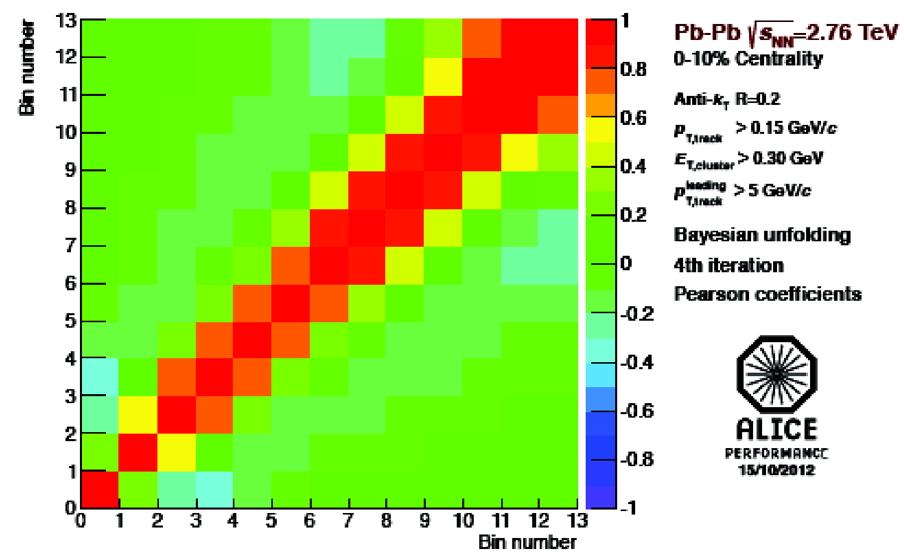


Bayesian unfolding

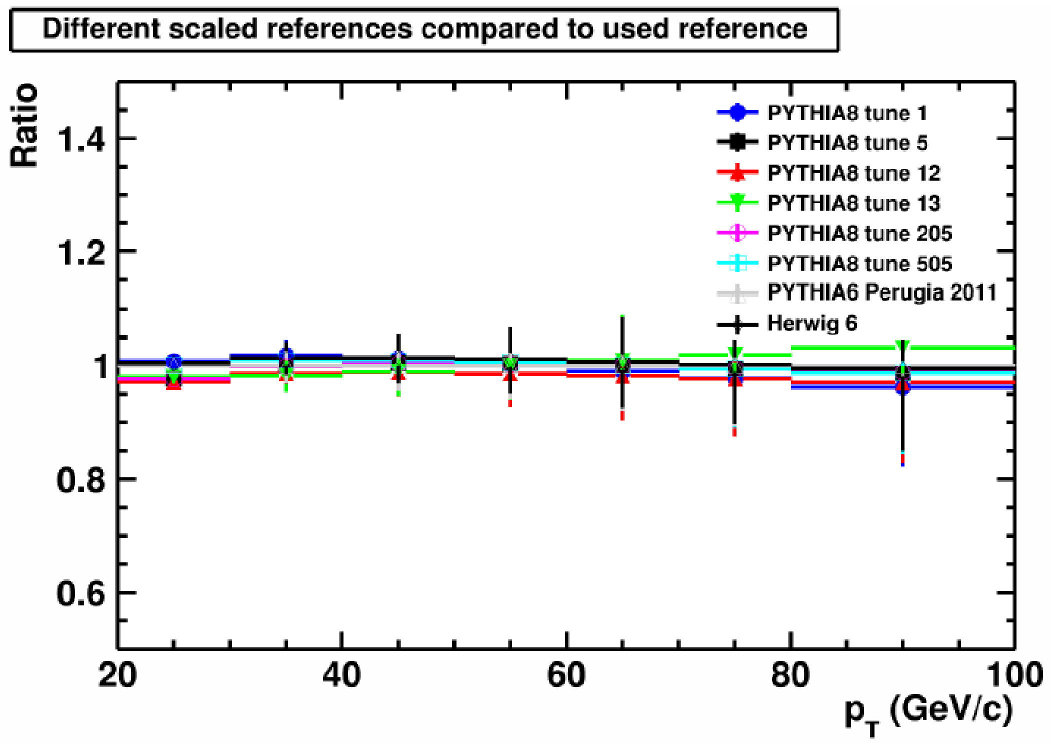




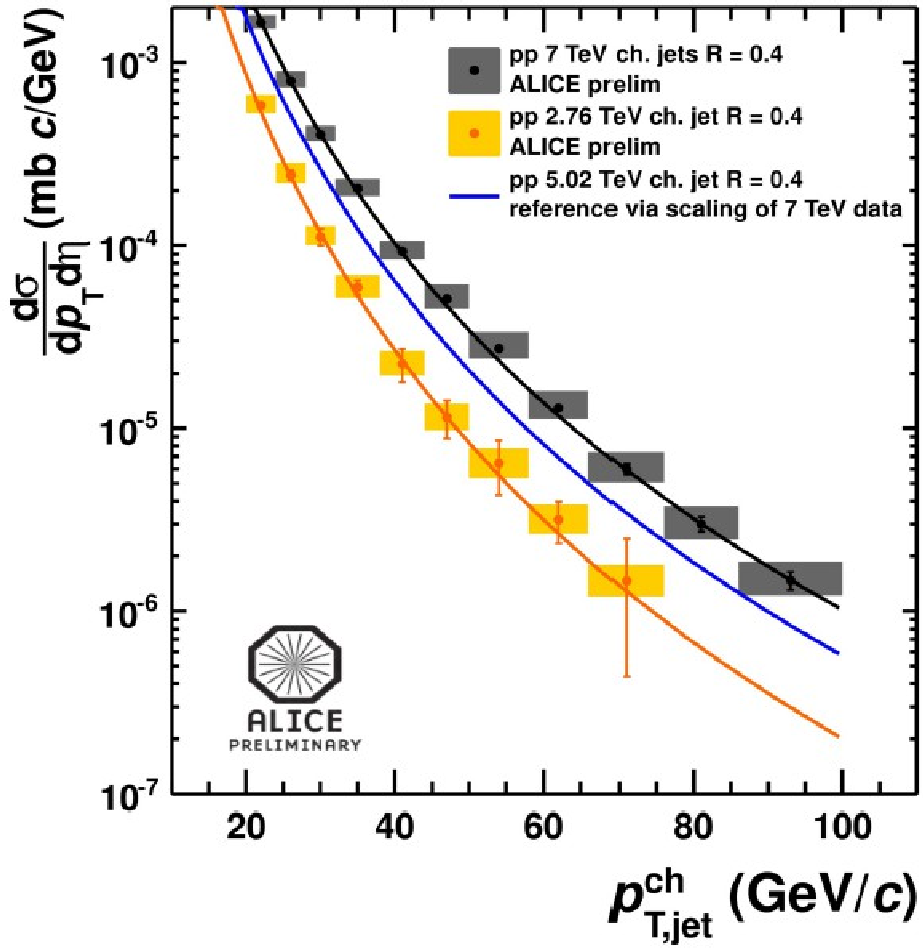




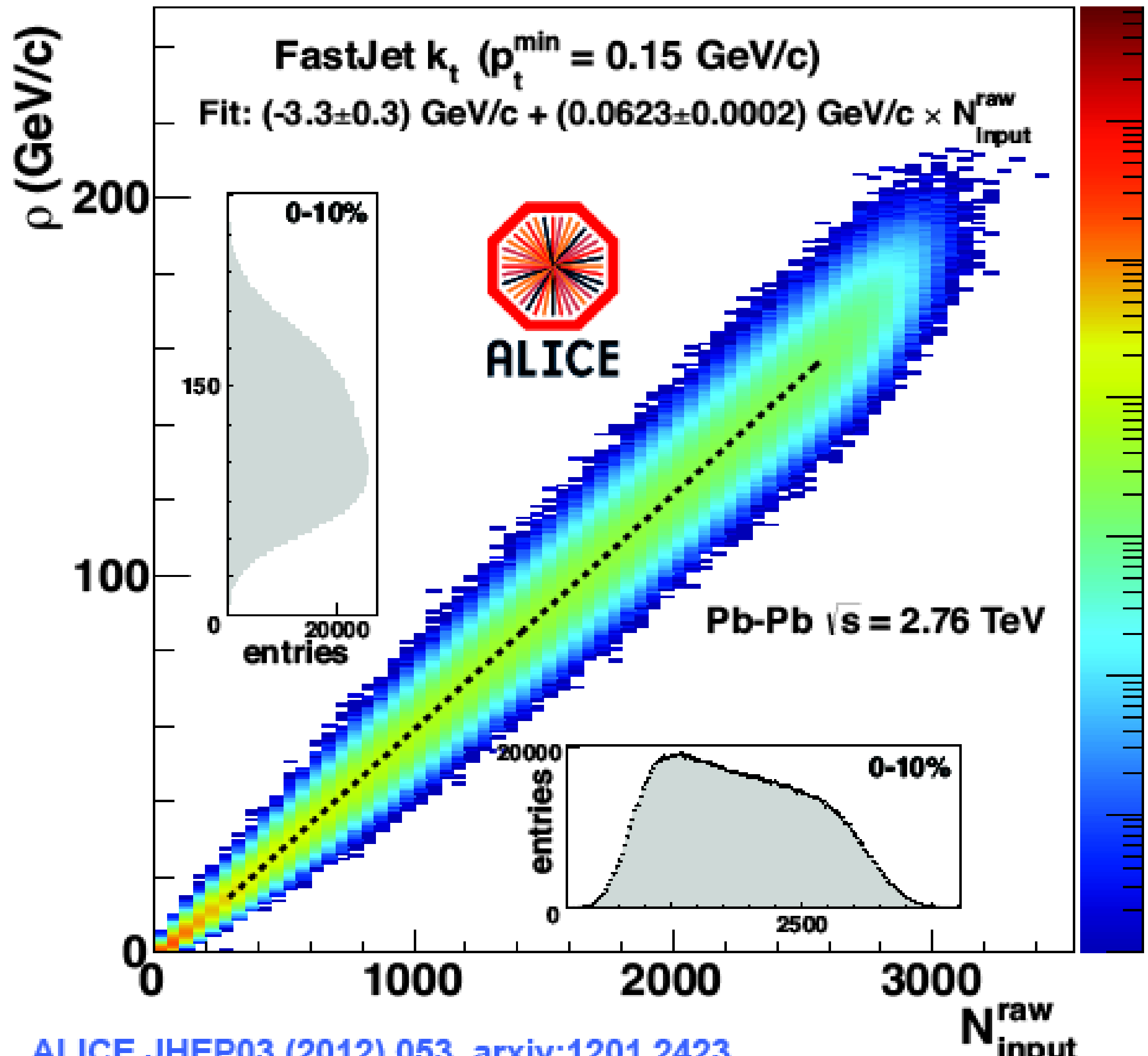
pp reference for pPb



pp scaled reference

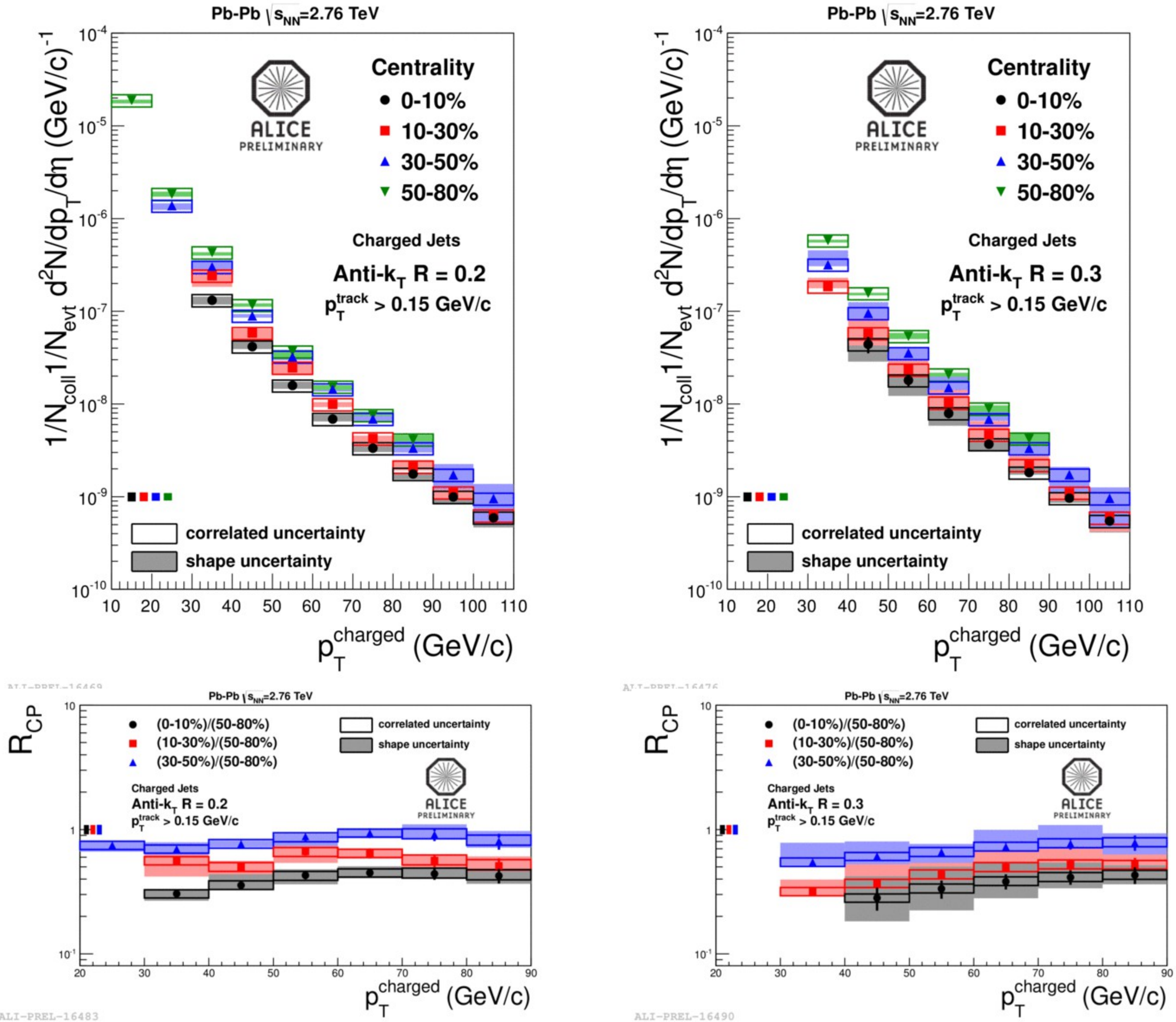


Background MC



ALICE JHEP03 (2012) 053, arxiv:1201.2423

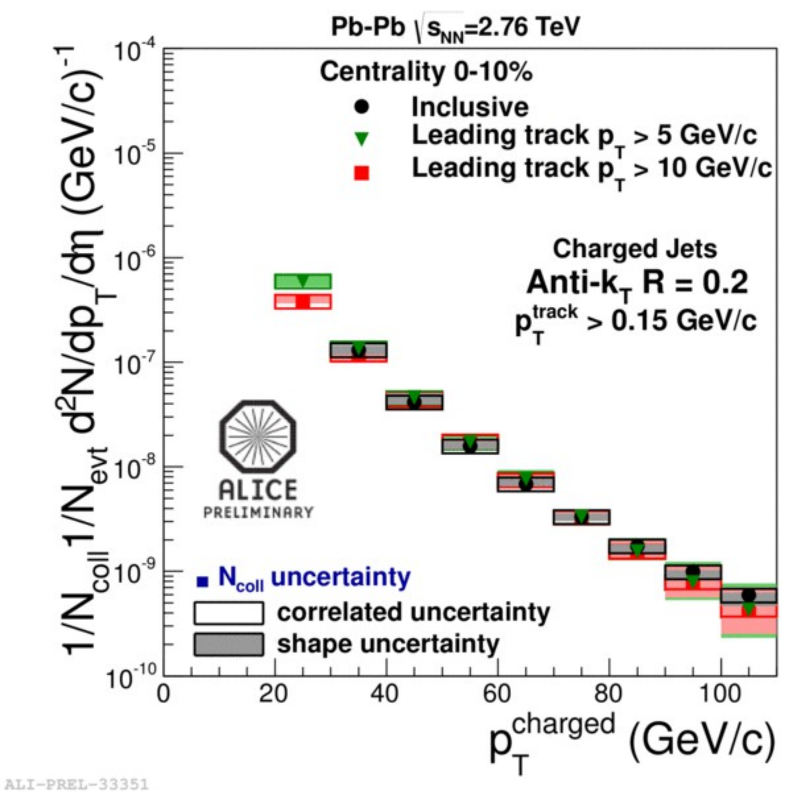
Pb-Pb, charged jets

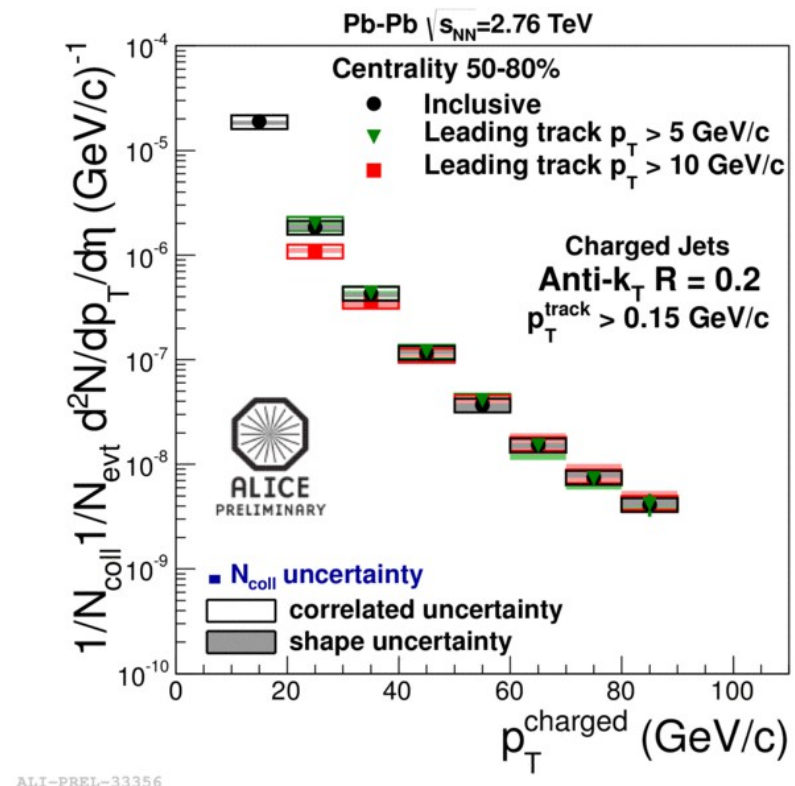


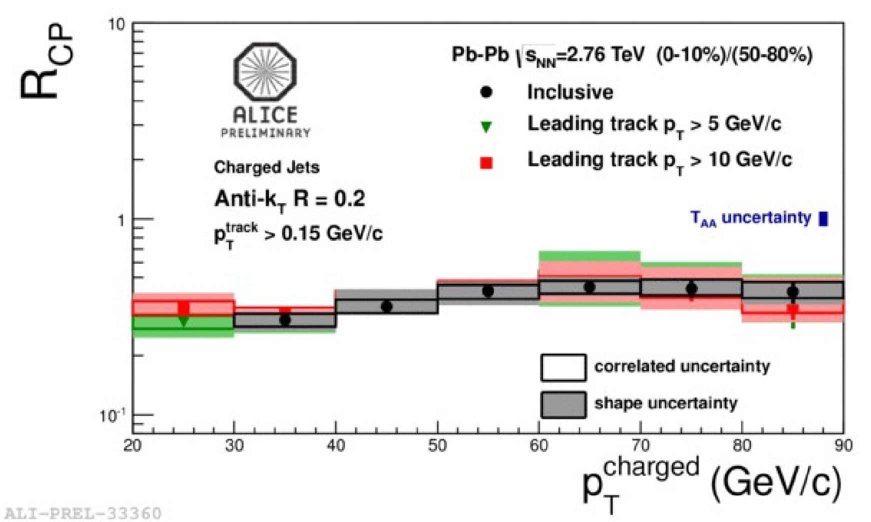
Two jet cone variables:
0.2, 0.3

Strong suppression for central collisions

Pb-Pb, charged jets







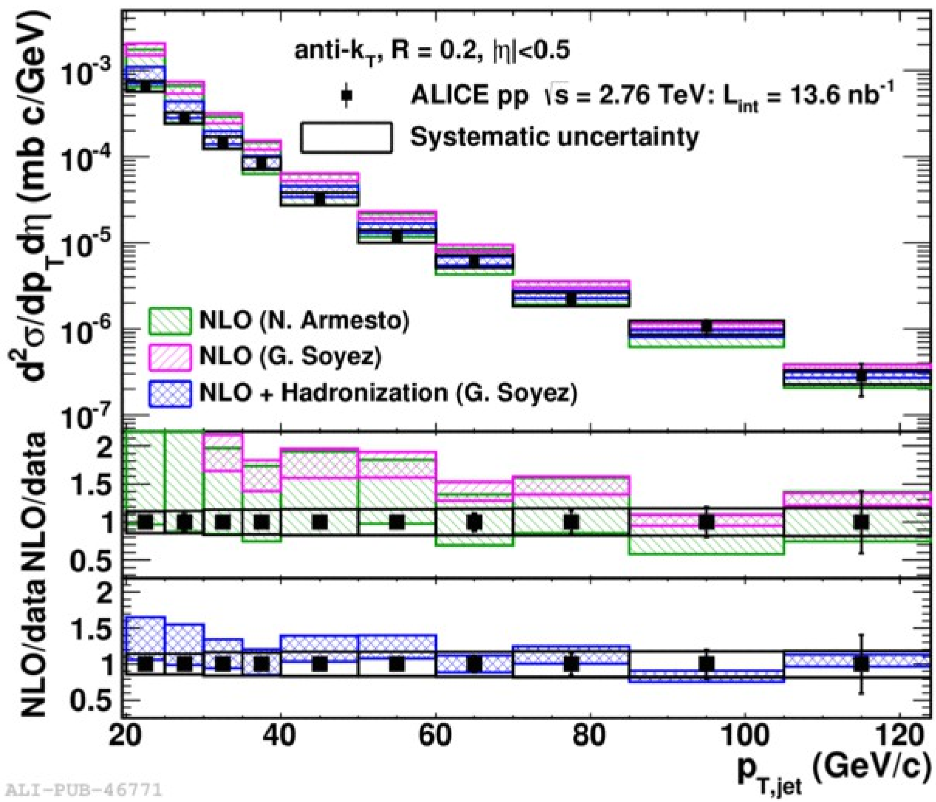
Leading particle trigger

Strong suppression for jets.
Not dependent on p_T

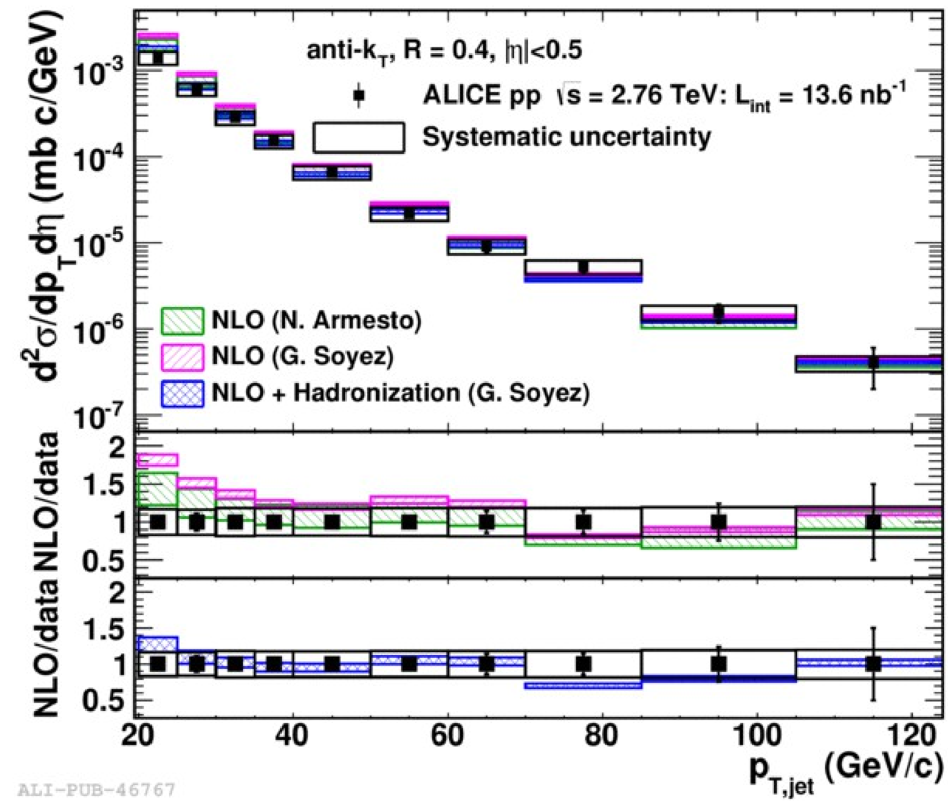
QCD vacuum p-p baseline

- Inclusive jet cross section

R = 0.2



R = 0.4



- Good agreement with NLO + hadronization

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$$d_{ij} = min\left(k_{Ti}^{p}, k_{Tj}^{p}\right)\frac{R_{ij}^{2}}{R^{2}}$$

$$R_{ij}^{2} = (\eta_i - \eta_j)^2 + (\varphi_i - \varphi_j)^2$$

$$d_{iB} = k_{Ti}^{p}$$

k_T: p = 2   Anti-k_T: p = -2