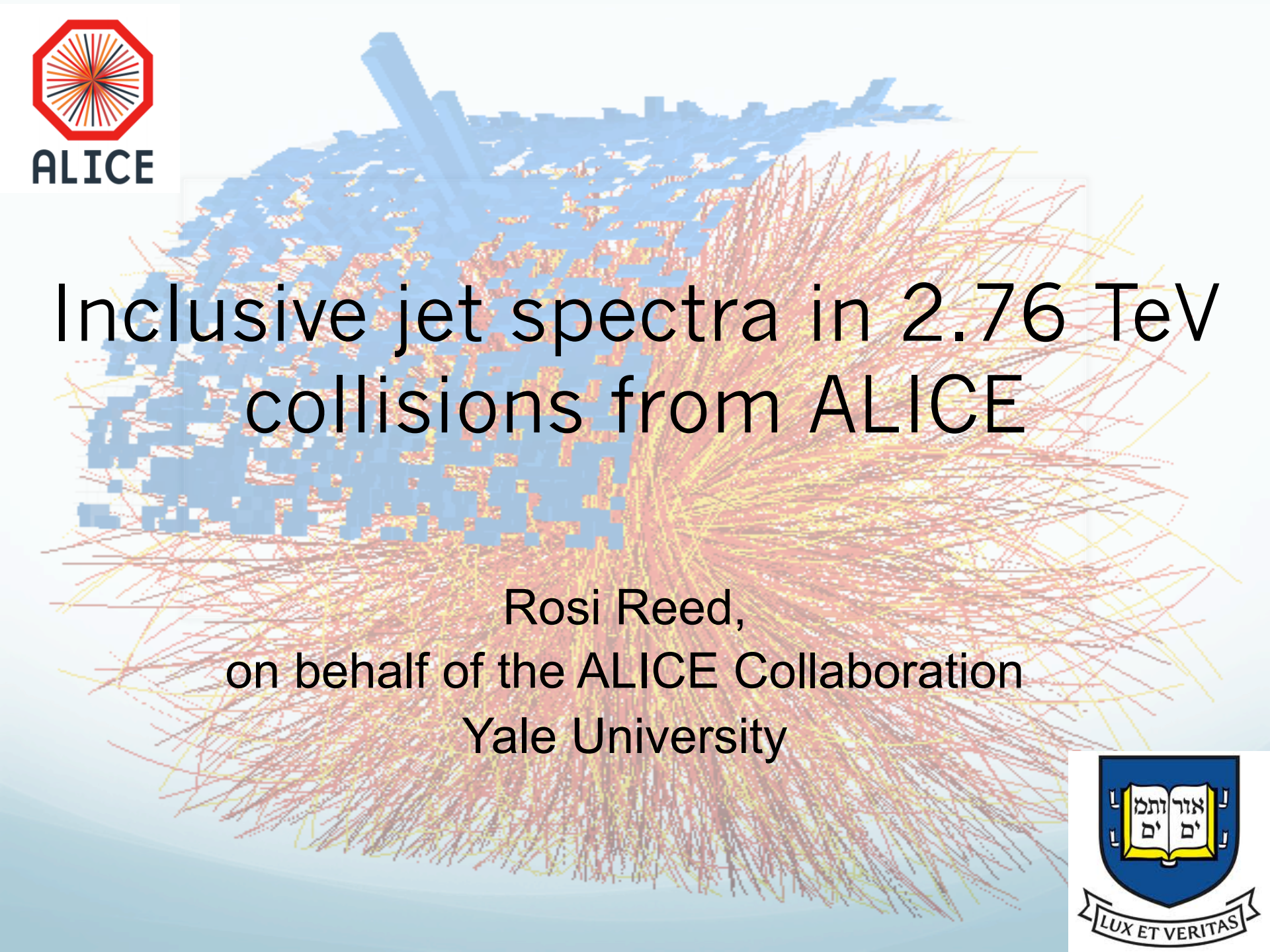


Inclusive jet spectra in 2.76 TeV collisions from ALICE

Rosi Reed,
on behalf of the ALICE Collaboration
Yale University

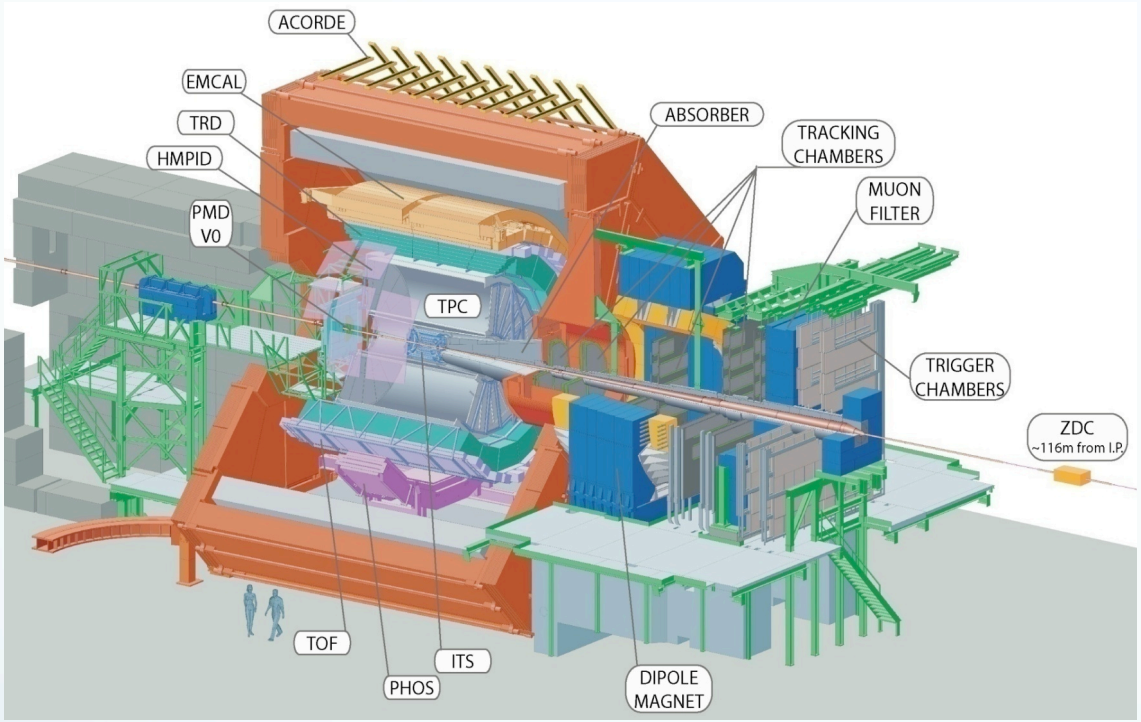
Jets in Heavy-Ion Collisions

- Jets make an ideal probe of the medium
  - Partons from hard scattering are produced early
  - Propagating parton is modified by the QCD medium
  - Observation of jet quenching indicates modification
- Experimental challenges
  - Need to remove underlying event contribution
  - Jet $p_{\mathrm{T}} = p_{\mathrm{T}}^{rec} - \rho A$
    - A = Jet area
    - ρ = Underlying event momentum density
    - p_{T}^{rec} = Jet p_{T} from jet finder

ALICE Jets at $\sqrt{s}$ = 2.76 TeV

- Inclusive jet cross section in pp $\sqrt{s}$ = 2.76 TeV
  - Important reference for Pb-Pb measurements
  - Test of pQCD calculations
  - Minimum-bias: 0.4 nb^{-1}
  - EMCal trigger: 4x4 towers, 3 GeV threshold: 11 nb^{-1}
- Pb-Pb charged jets
  - 15M events from 2010 Pb-Pb run
  - Uniform $\eta - \Phi$ acceptance: $|\eta| < 0.9$ $0 < \Phi < 2\pi$
  - Neutral energy missing

Jets at ALICE



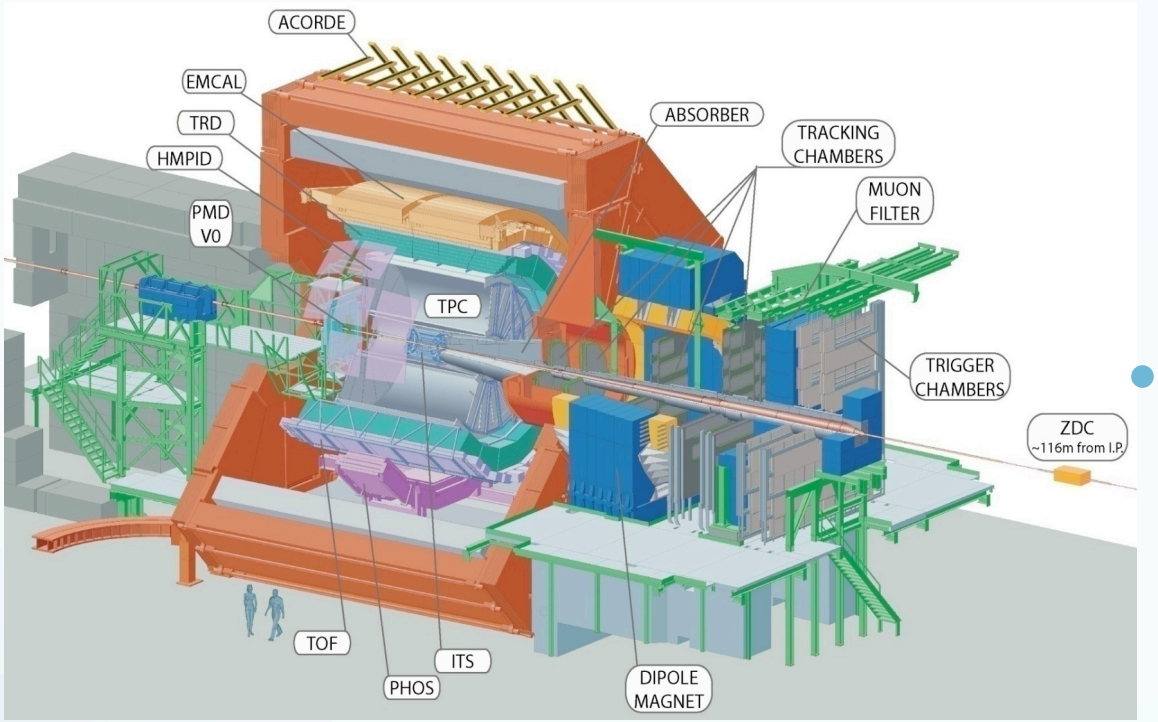
Tracking: $|\eta| < 0.9$, $0 < \Phi < 2\pi$

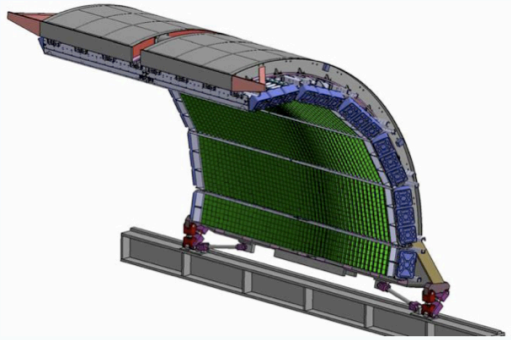
TPC: gas detector

ITS: silicon detector

→ *Charged constituents* → **JET**

Jets at ALICE





- EMCal is a Pb-scintillator sampling calorimeter which covers:
  - $|\eta| < 0.7$, $1.4 < \phi < \pi$
  - tower $\Delta\eta \sim 0.014, \Delta\varphi \sim 0.014$

Charged hadronic correction prevents double counting

Tracking: $|\eta| < 0.9$, $0 < \Phi < 2\pi$
TPC: gas detector
ITS: silicon detector

→ *Charged constituents* →

JET

← *Neutral constituents*

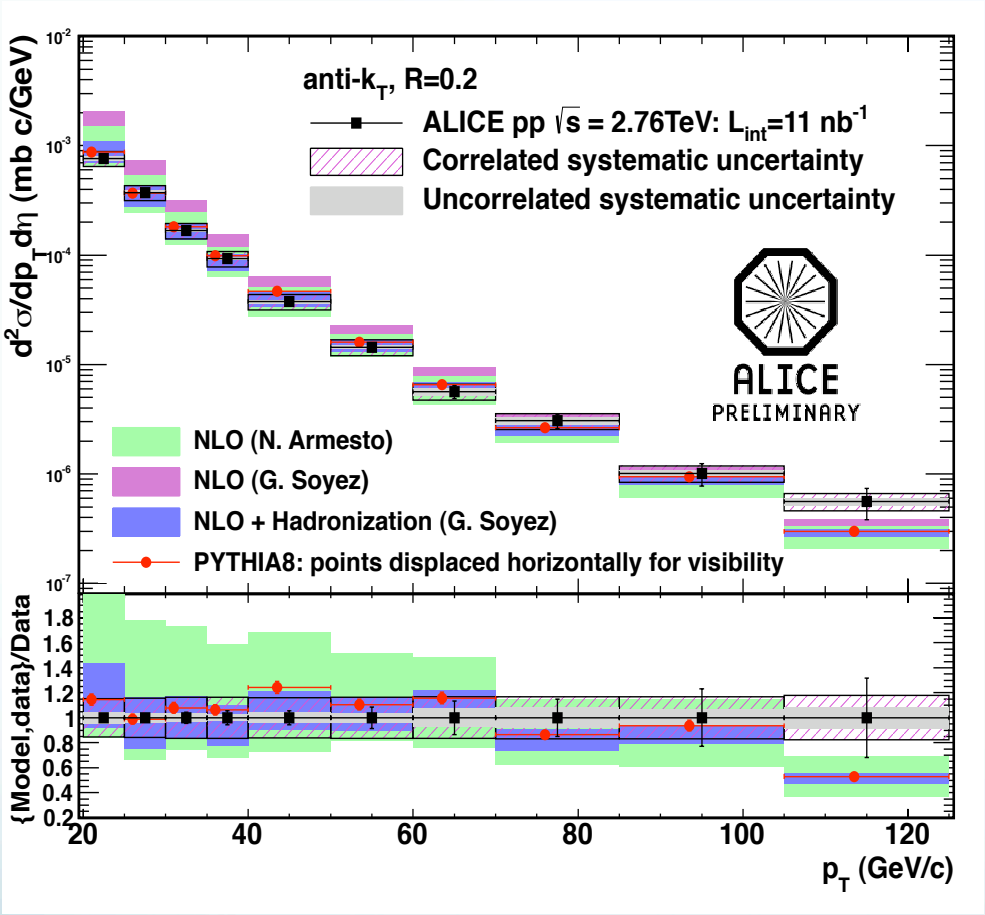
Jet Reconstruction

- Input to the Jet Finder
  - Assumed to be massless
  - Charged tracks with p_T > 150 MeV/c (pp, Pb-Pb)
  - EMCal clusters with E_T > 150 MeV after hadronic correction: (pp)
    - $E_{cluster}^{cor} = E_{cluster}^{orig} - f\sum p^{matched}, \quad E_{cluster}^{cor} \geq 0$
    - For pp analysis f = 100%
- Jets reconstructed using FastJet package
  - R = 0.2, 0.3, 0.4
  - Anti-k_T for signal jets (pp, Pb-Pb)
  - k_T for ρ calculation (Pb-Pb)
  - EMCal jets: Fiducial cut requires jet fully contained in the EMCal acceptance (pp)

Detector Effects - pp

- Bin-by-bin technique
  - Compare simulated the cross sections before and after Detector response
  - Use uncorrected spectrum in data as weighting function
- *Shift of jet energy scale ~ 20-25%*
  - Unmeasured neutrons and K^0_L's: compare proton and kaon spectra to data; PYTHIA vs HERWIG
  - Tracking inefficiency: track quality in data vs simulation
  - 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

Inclusive pp Cross Section



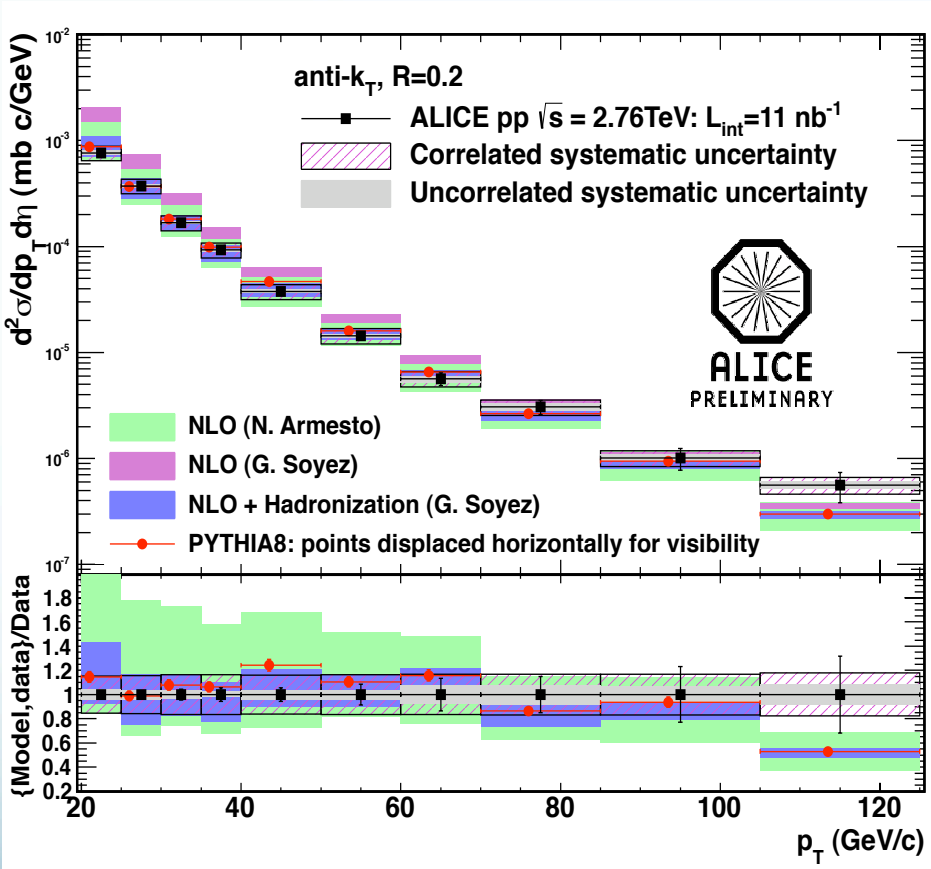
- Green and magenta bands: NLO on Parton level
- Blue band: NLO + hadronization
- Red points: PYTHIA8. Shifted horizontally for visibility
- f_{hadcor} = 100%, R = 0.2, p_T c, E_T > 150 MeV

Good agreement between data and NLO calculations as well as PYTHIA8 prediction within both experimental and theoretical uncertainties

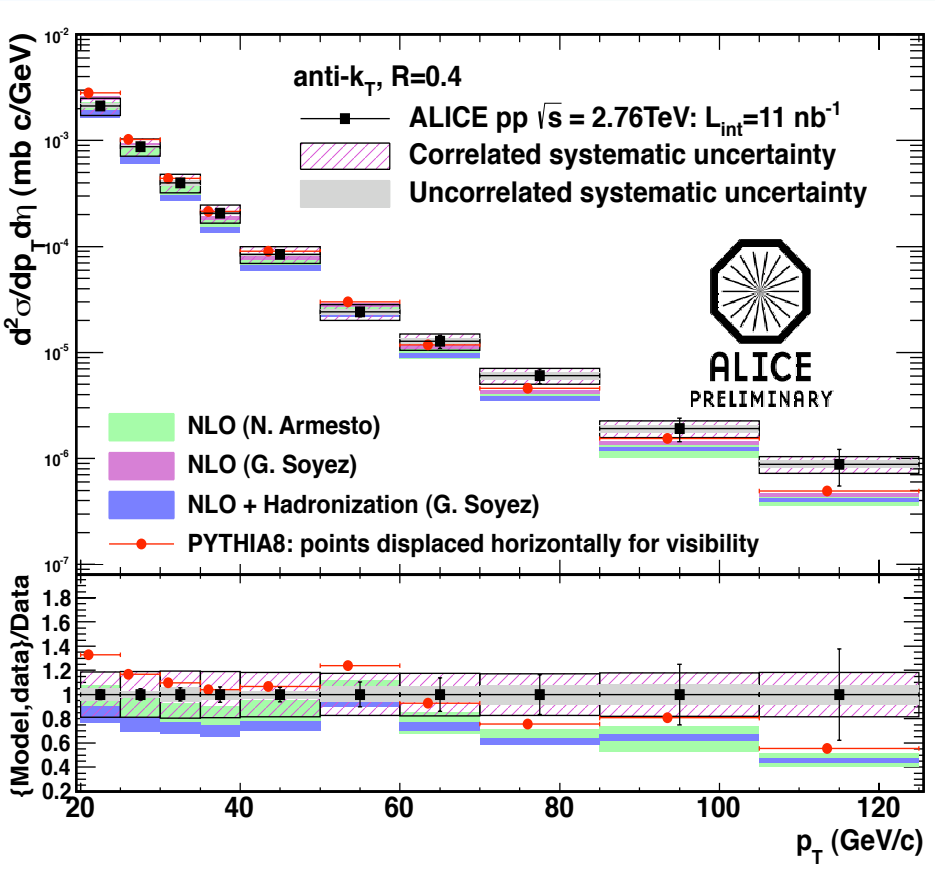
See Rongrong Ma's Poster #35

Inclusive pp Cross Section

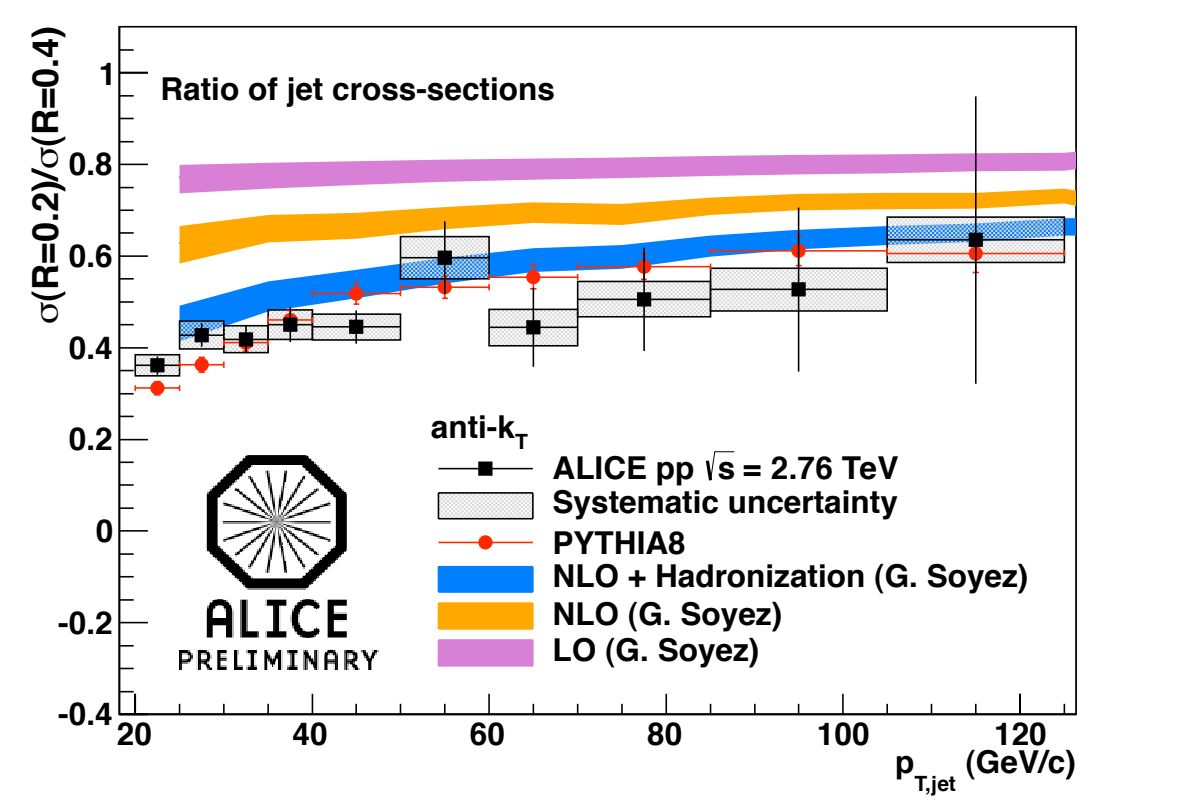
R=0.2



R=0.4



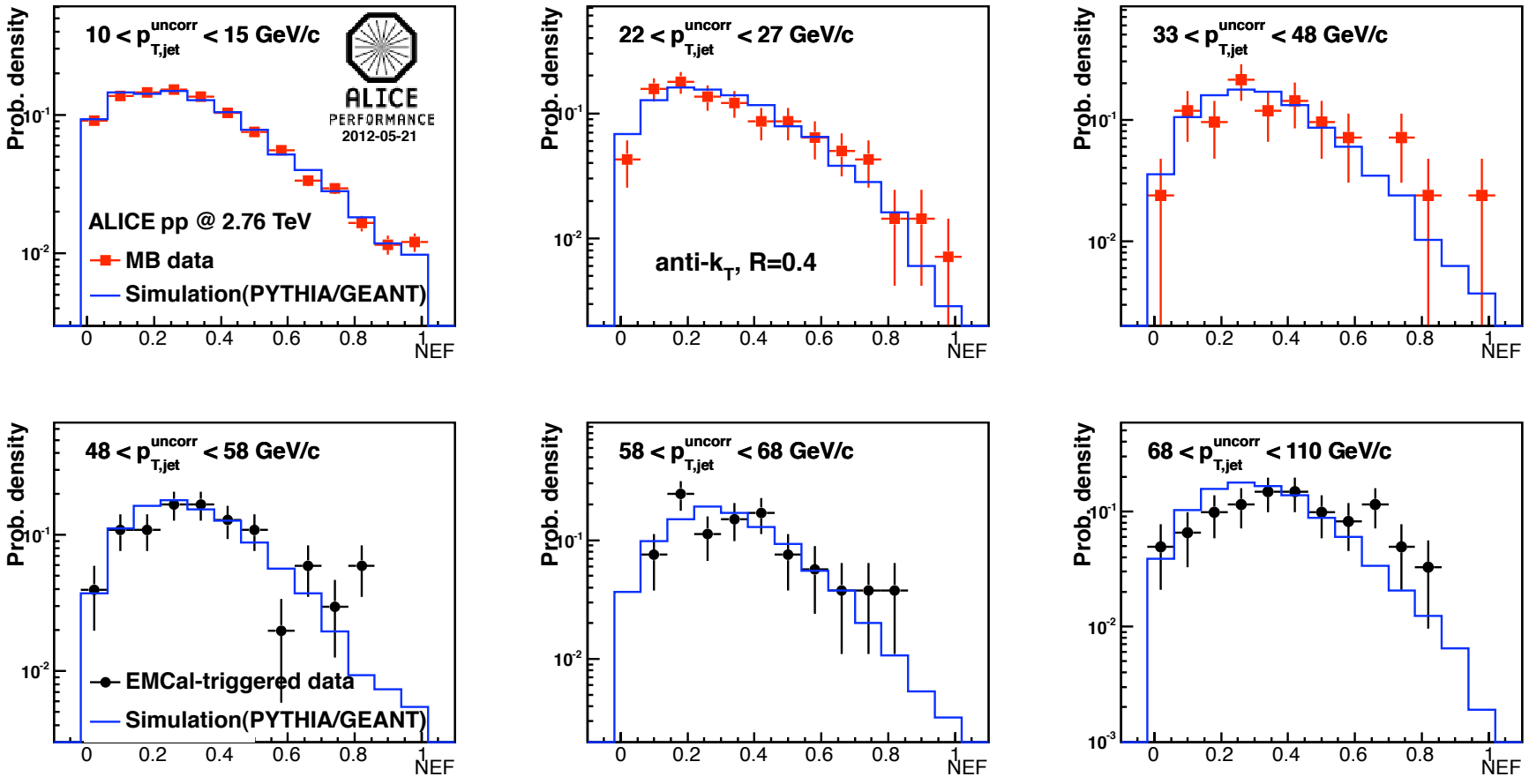
Ratio of Jet Cross Sections
R=0.2/R=0.4



- NLO ratio is equivalent to ratio of cross sections calculated at NNLO
- **Good agreement between data and NLO+hadronization[1]** within experimental and theoretical uncertainties

[1] G. Soyez, Phys.Lett. B698 (2011) 59

Neutral Energy Fraction

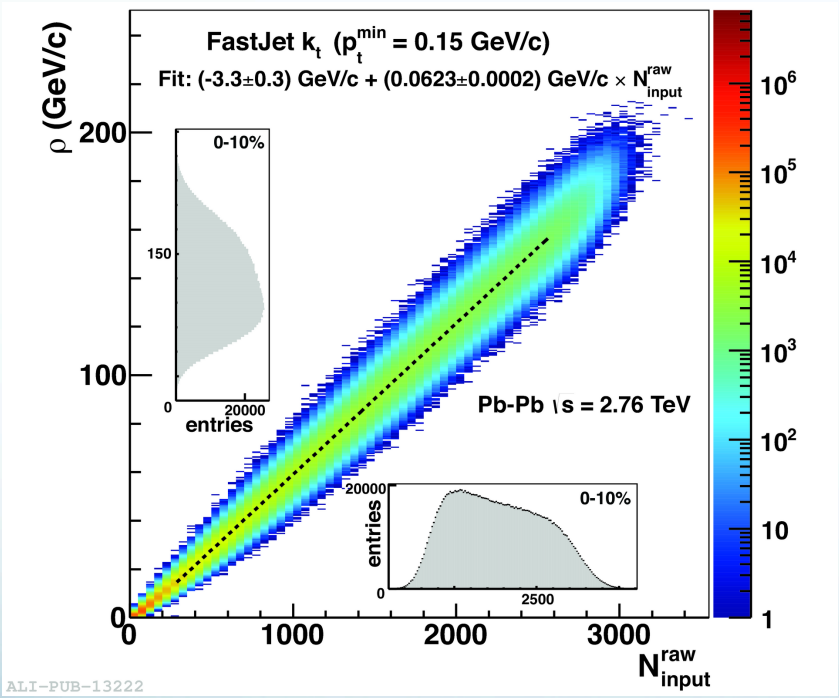


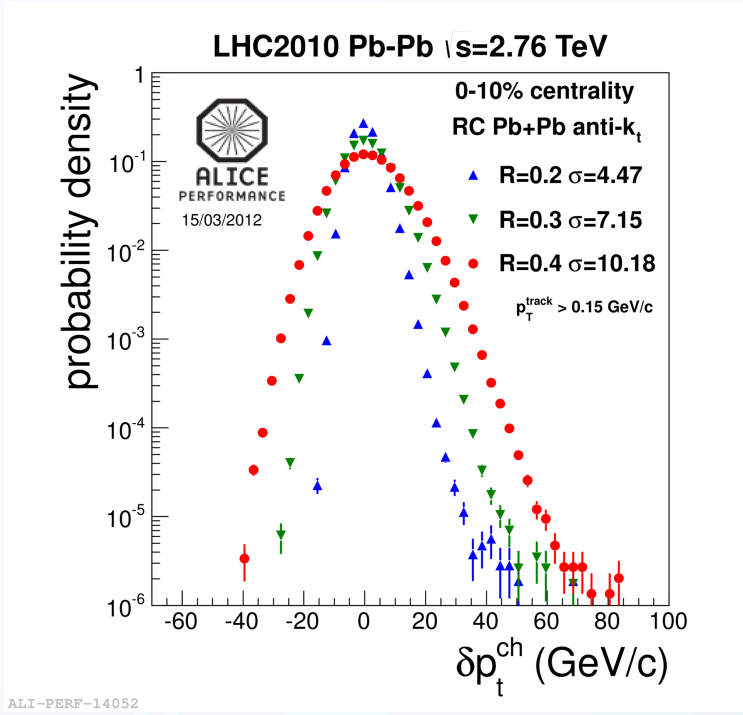
- Compare the neutral energy fraction (NEF) distribution between data and Detector Level simulation in different jet p_T bins
- *Good agreement within the statistical precision*

Charged Jets in Pb-Pb

- 2 important aspects of the underlying event (UE)
  - Within-event fluctuations
  - Average background

JHEP, vol 1203, p 053 2012





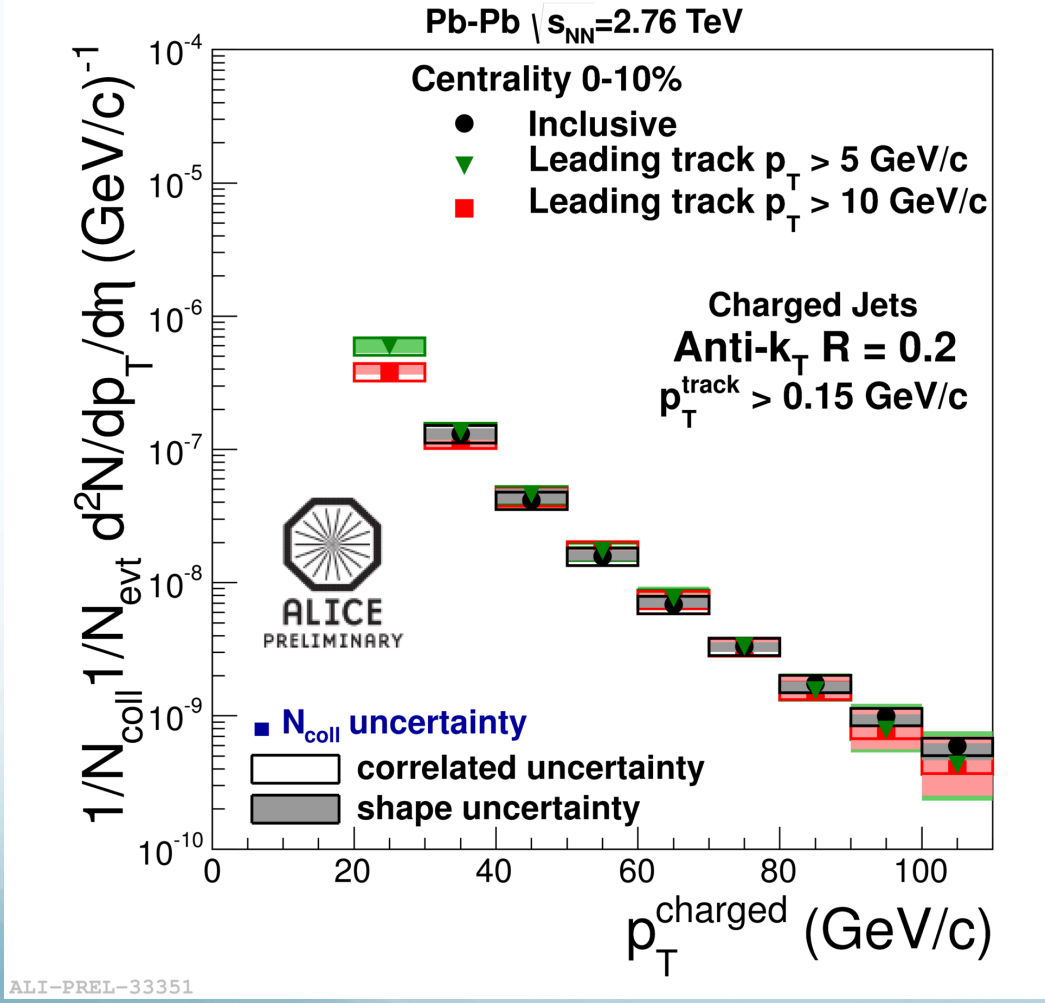
$$\rho_{ch} = \text{median}\left(\frac{p_T^{k_T\,jet}}{A^{k_T\,jet}}\right)$$

- Effect of UE on jets
  - Multiplicity/flow
  - Dependent on R
  - Constituent cut

Detector and Background Effects

- Unfold measured spectrum to obtain true spectrum
  - Effects are combined in response matrix
    - Background ➔ data driven
    - Detector Effects ➔ simulation
  - χ^2 minimization routine
- Leading track bias removes combinatorial jets
  - Important for charged + neutral Pb-Pb analysis since background fluctuations are larger than in charged only
  - Can cause a fragmentation bias which we can observe in charged only analysis

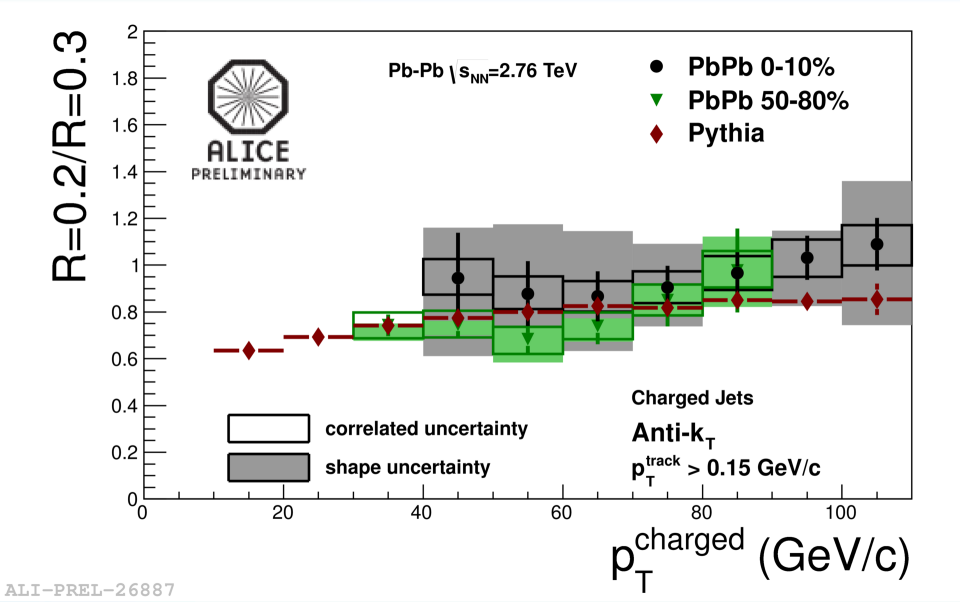
Charged Jet Spectra in Pb-Pb 0-10%



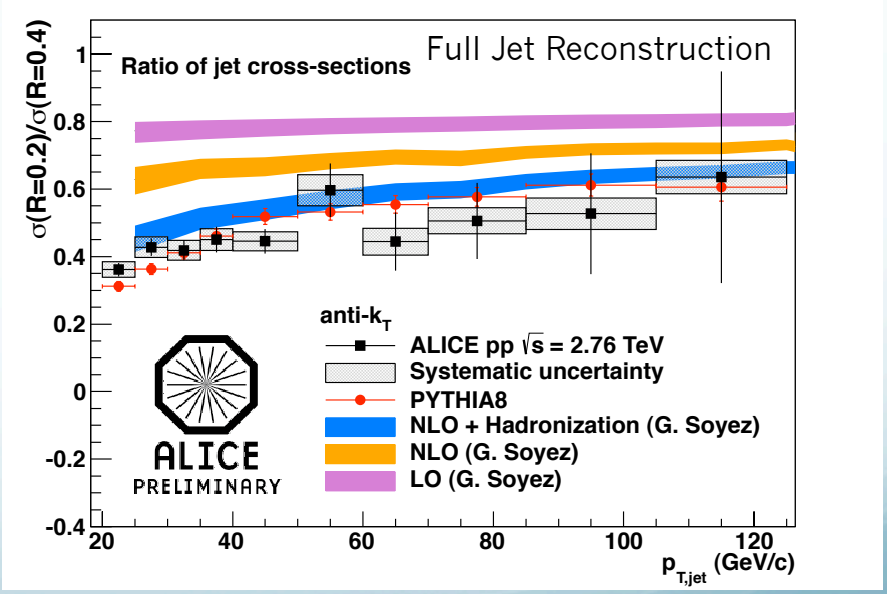
- Leading track requirement facilitates unfolding to a lower jet p_T compared to inclusive results
- Does not have a large effect on the spectra with p_T > 30 GeV/c

Marta Verweij's Poster #34

Jet Structure



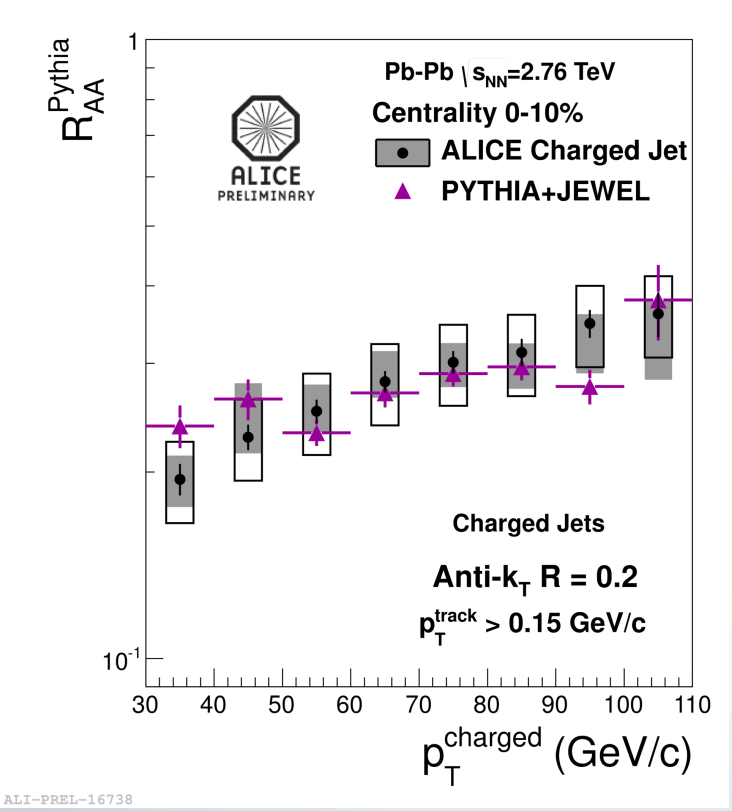
- R=0.2/R=0.3 is consistent with vacuum jets
  - In both central and peripheral collisions!

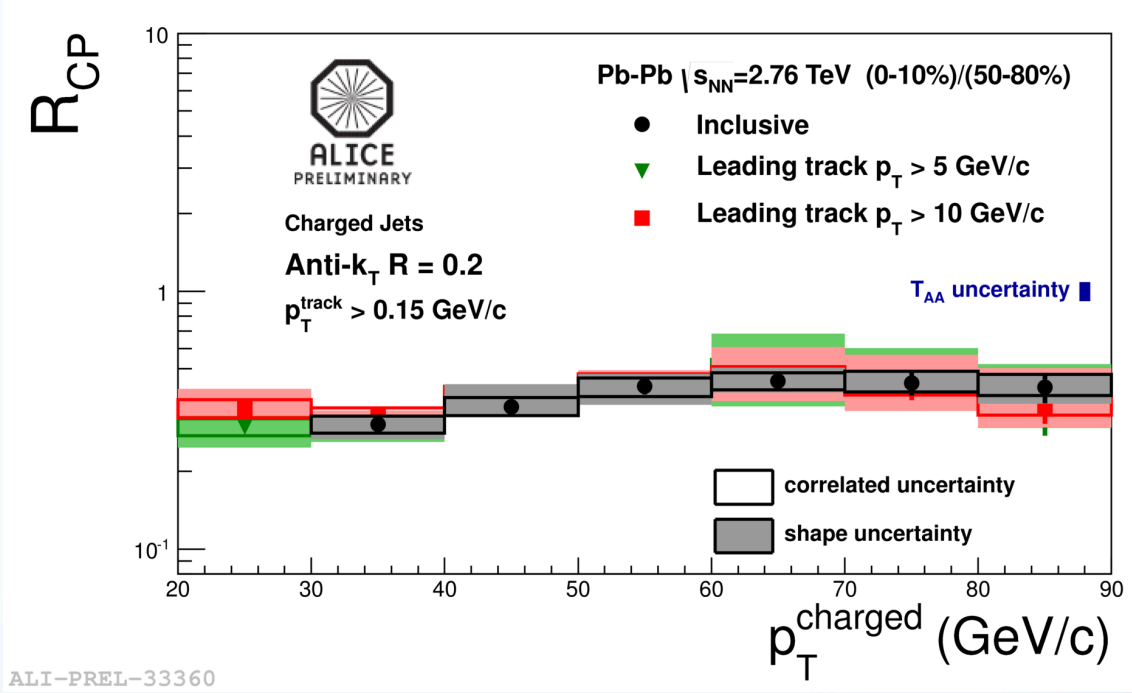


- Charged Pb-Pb results show consistency with PYTHIA
  - pp shows PYTHIA simulates vacuum fragmentation well

Jet Quenching Charged Jets in Pb-Pb

JEWEL : (Zapp, Krauss, Wiedemann arXiv:1111.6838)

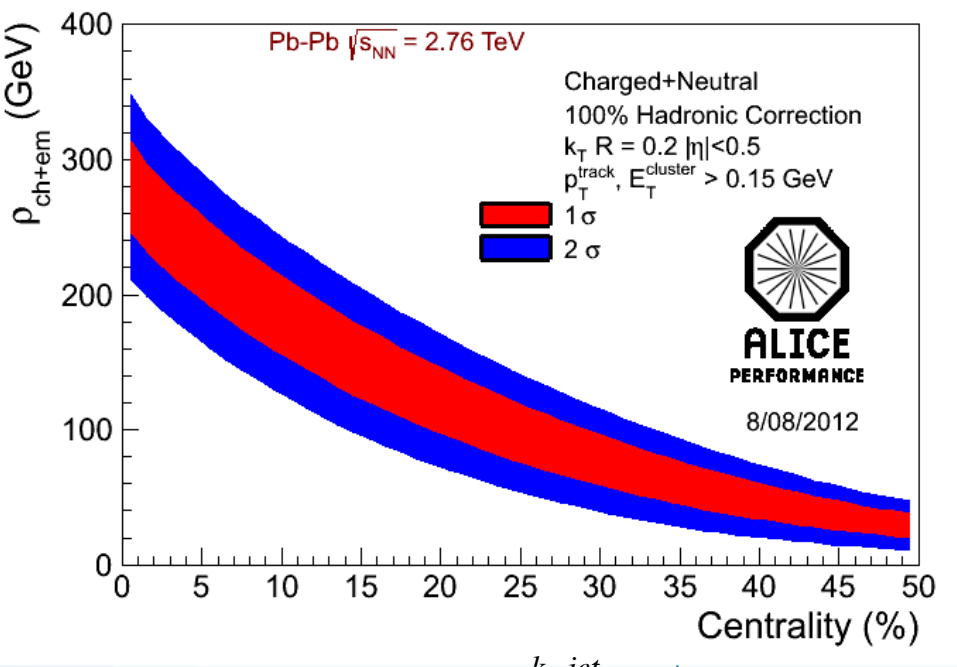


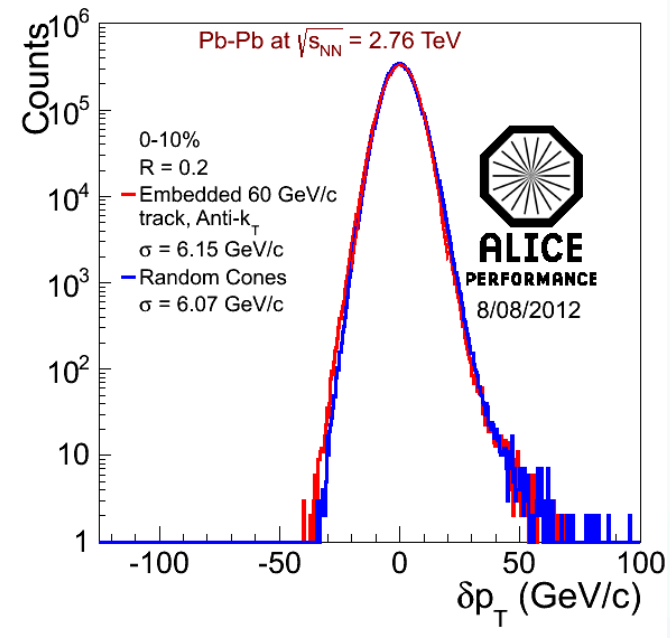


JEWEL MC: radiative+eleastic energy loss

- Charged jets show suppression with PYTHIA reference (R_{AA}) and from peripheral to central (R_{CP})

Charged+Neutral Background Determination





$$\rho_{ch+em} = \text{median}\left(\frac{p_T^{k_T\,jet}}{A^{k_T\,jet}}\right)$$

- $\rho_{ch+em} > \rho_{ch}$
- $\sigma_{ch+em}\,\delta p_T > \sigma_{ch}\,\delta p_T$
  - 6.1 vs 4.5 GeV/c

- Fluctuation size characterized by δp_T
  - Embedded particle

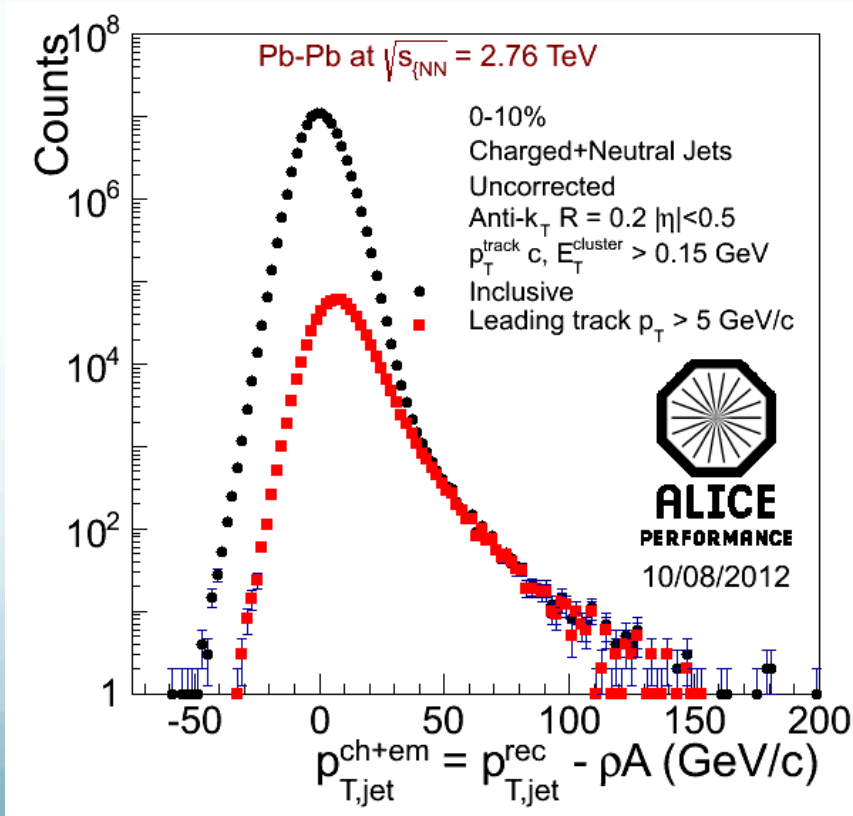
$$\delta_{pT} = p_T^{rec} - \rho_{ch+em} A^{\text{Anti-}k_T} - p_T^{emb}$$

  - Random Cones

$$\delta_{pT} = p_T^{rec} - \rho_{ch+em}\pi R^2$$

Conclusions and Outlook

- Report on fully reconstructed jet cross section for pp $\sqrt{s}$ = 2.76 TeV R = 0.2, 0.4
  - The measured cross sections agree well with theory
  - The ratio agrees well with NLO+hadronization
  - Important reference
- Charged jet analysis in Pb-Pb collisions
  - Strong jet suppression in central events
  - No signs of modified jet structure observed in ratio R=0.2/R=0.3
- Charged+neutral background fully characterized in Pb-Pb

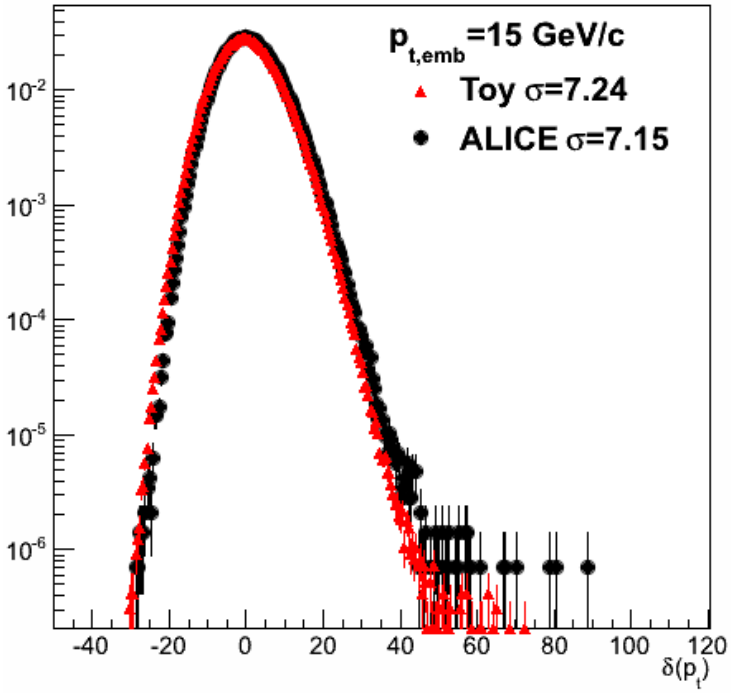


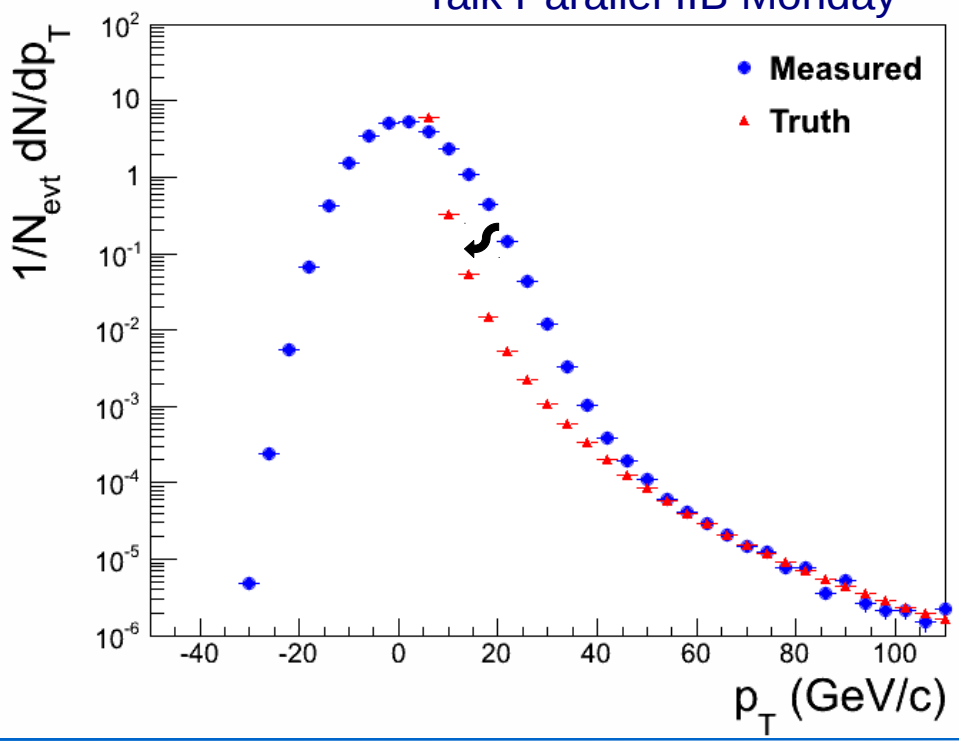
Back-up

Unfolding the background

- Need to **unfold** measured jet spectrum to obtain 'real' jet spectrum (Truth)
- Low p_t jets are dominated by random collections of particles → background jets. These appear up to very high p_t.

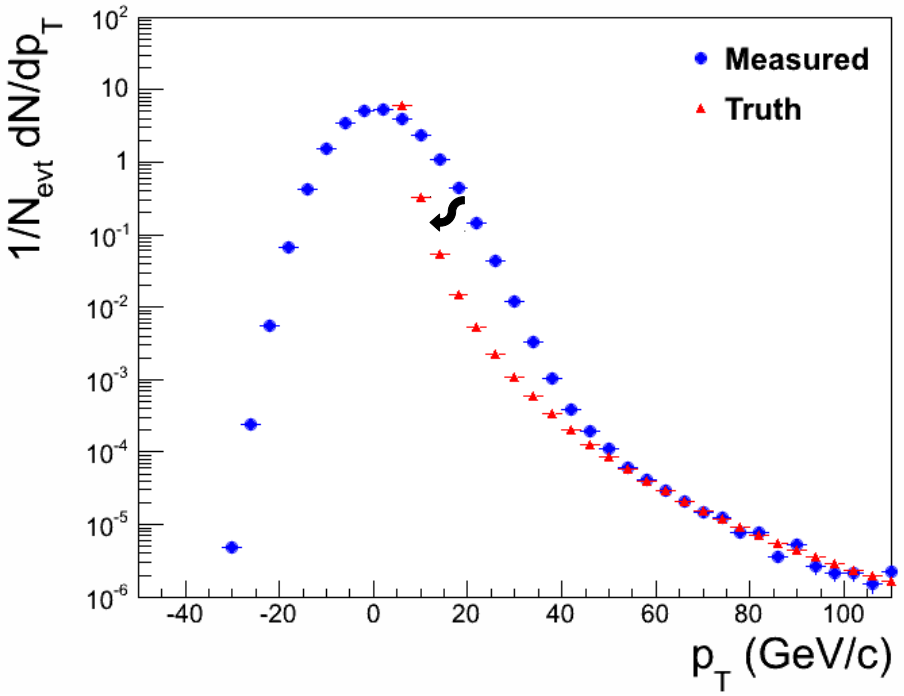
Toy model G. Barros et al.
Talk Parallel IIB Monday





Unfolding the background

- Need to **unfold** measured jet spectrum to obtain 'real' jet spectrum (Truth)
- Refolded = unfolded jet spectrum smeared with background fluctuations



Assume:

$$\left.\frac{dN}{dp_T}\right|_{meas} = P(\delta p_T) \otimes \left.\frac{dN}{dp_T}\right|_{jet}$$

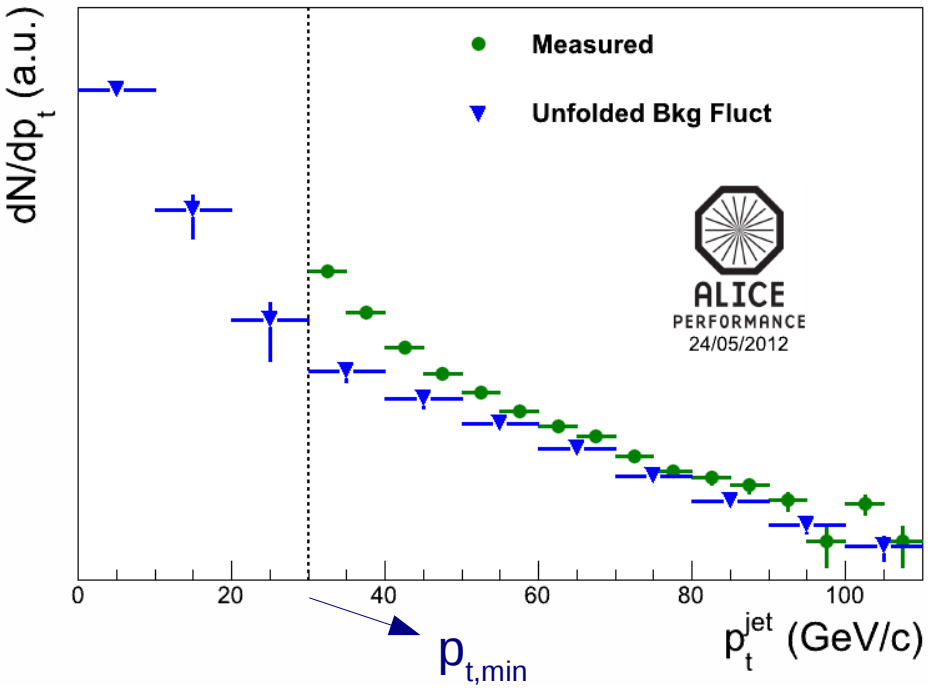
Unfolding done with χ^2 minimization

$$\chi^2 = \sum_{refolded} \left(\frac{y_{refolded} - y_{measured}}{\sigma_{measured}} \right)^2 + \beta \sum_{unfolded} \left(\frac{d^2 log\, y_{unfolded}}{d\, log\, p_t^2} \right)^2$$

χ^2-term *Regularization/penalty*

Unfolding: p_t ranges & systematics

- Measured spectrum: $p_{t,min}$ – $p_{t,max}$
  - $p_{t,min}$ ~ 5σ(δp_t) → Suppression of background jets. Estimated from various toy model studies
- Feed in from low p_t
  - Unfolded starts at p_t=0 GeV/c
- Feed in from high p_t



Systematic uncertainty from unfolding procedure
'Shape uncertainty'

Main contributions

- Regularization strength
- p_t cut-off in measured spectrum
- Feed in of low p_t bins in unfolded spectrum

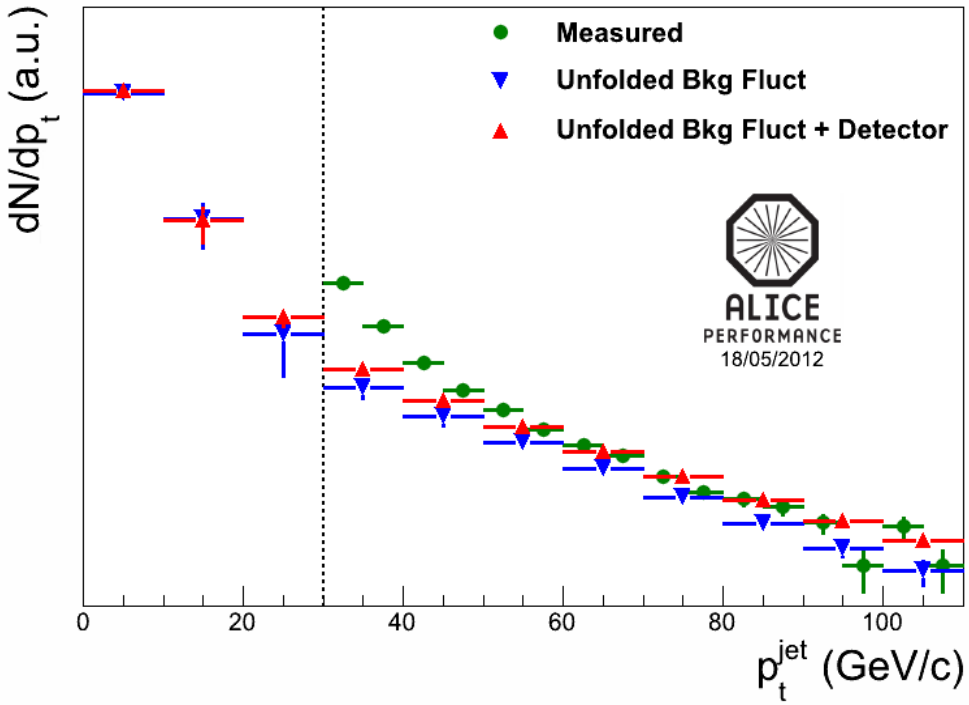
Including detector effects

Response matrix includes background fluctuations and detector effects (tracking efficiency and track p_t resolution).

No correction for missing neutral particles

Truth $\xrightarrow{RM_{det}}$ D $\xrightarrow{RM_{\delta pt}}$ Measured

D=jet spectrum after detector effects



$$M = RM_{\delta p_t} \cdot RM_{det} \cdot T$$

p_t^{jet}<60 GeV/c:

Dominant correction from background fluctuations