Measurements of the inclusive jet cross-section and jet fragmentation in pp collisions with the ALICE experiment at the LHC

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Outline

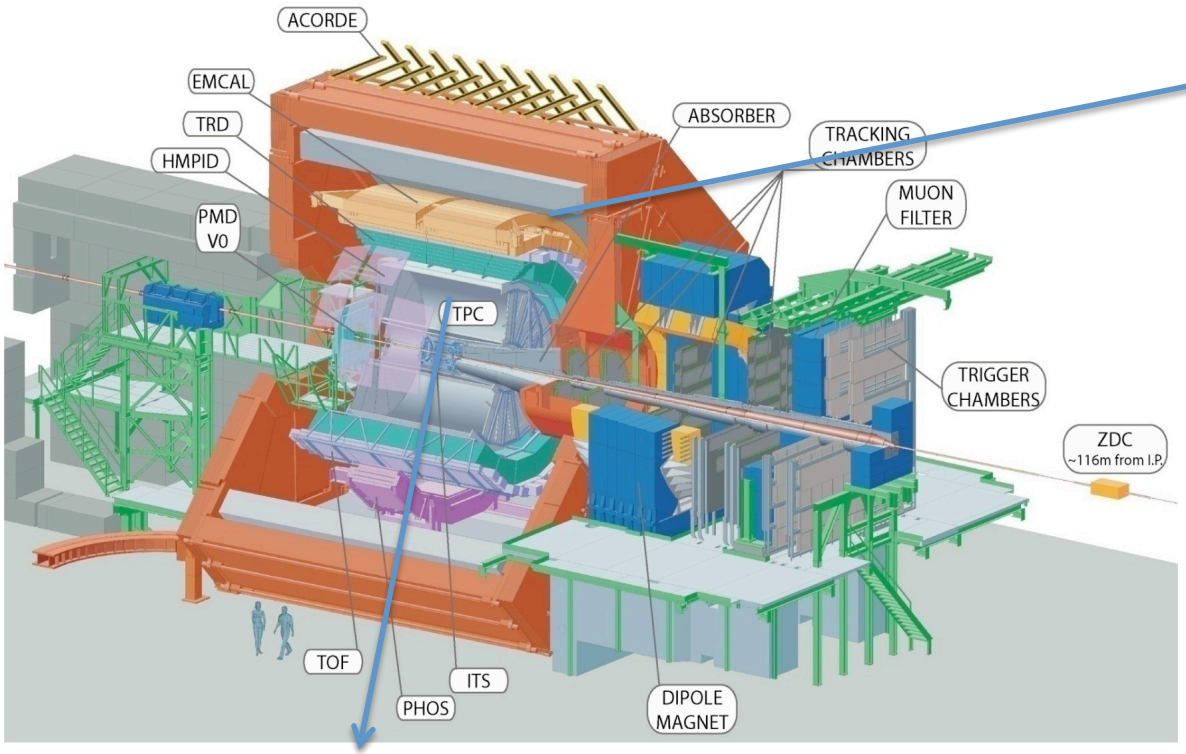
- Motivation
- ALICE detector
- Inclusive jet cross-section in pp $\sqrt{s}$ = 2.76 TeV
  - Analysis roadmap
  - Comparison to theory
- Charged jet fragmentation in pp $\sqrt{s}$ = 7 TeV
  - Momentum distribution of charged particles inside of jet cone
- Summary

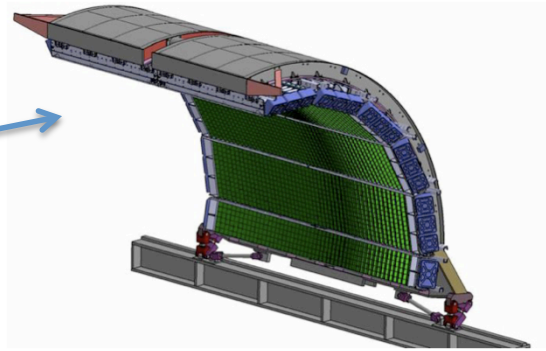
Motivation

- Inclusive jet cross-section in pp $\sqrt{s}$ = 2.76 TeV
  - Important reference for Pb-Pb measurements at the same $\sqrt{s_{NN}}$ = 2.76 TeV
  - Test of pQCD calculations at a new $\sqrt{s}$
- Charged jet fragmentation in pp $\sqrt{s}$ = 7 TeV
  - Baseline for modification of the jet profile in Pb-Pb

ALICE approach to jet measurements:

Measure almost all jet constituents individually (contrast calorimeter-only based measurements)





- EMCal is a Pb-scintillator sampling calorimeter which covers:
  $|\eta| < 0.7$, $1.4 < \phi < \pi$
- 11520 towers with each covers
  $\Delta\eta \sim 0.014$, $\Delta\phi \sim 0.014$

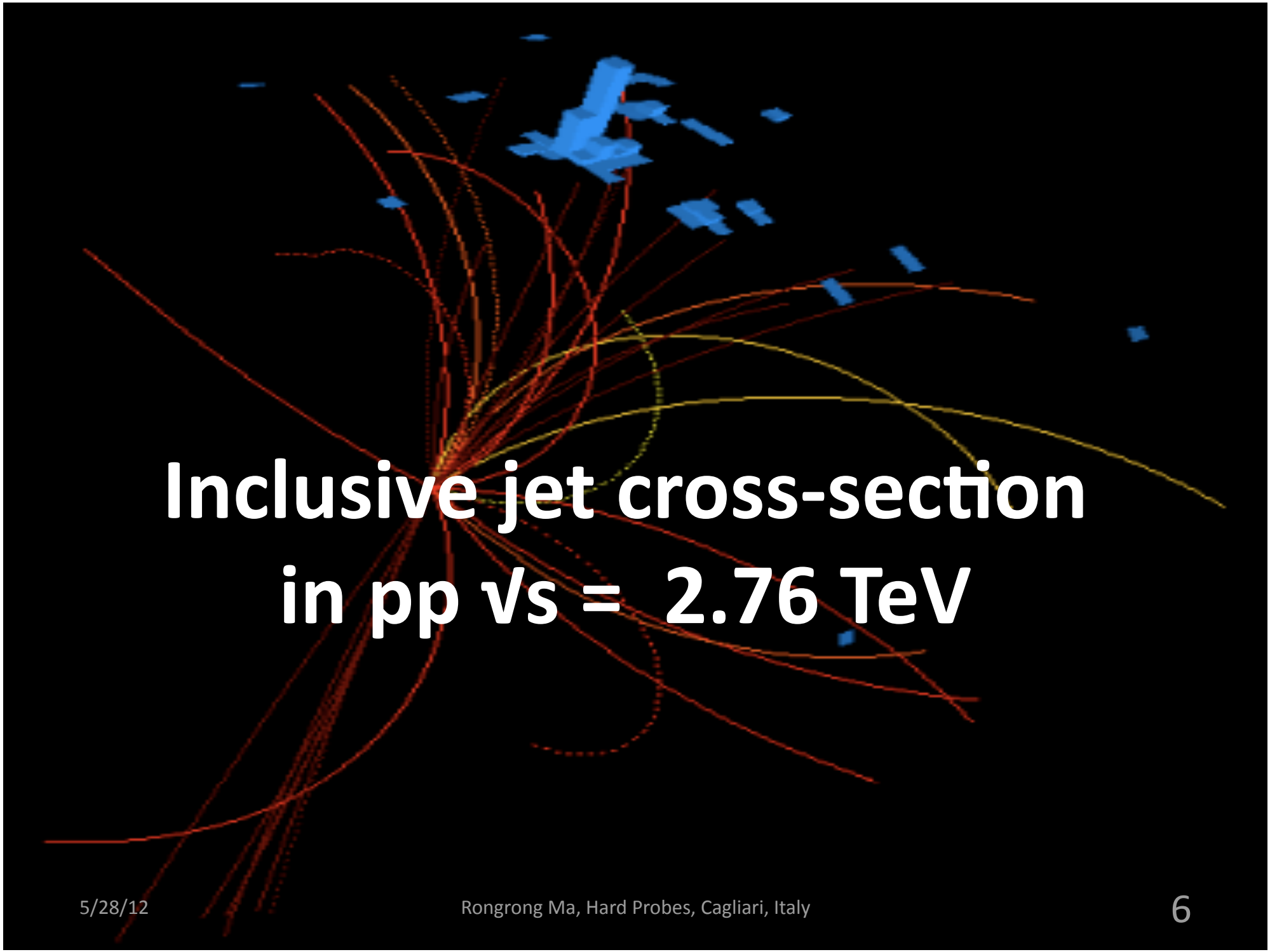
Tracking: $|\eta| < 0.9$, $0<\phi<2\pi$
TPC: gas detector
ITS: silicon detector

→ ***Charged constituents*** → **JET** ← ***Neutral constituents***

Dataset and Triggers

- pp $\sqrt{s}$ = 2.76 TeV
  - Run in March 2011
  - Minimum-bias: 0.4 nb^{-1}
  - **EMCal-L0 trigger**: 4x4 towers with 3 GeV threshold: 11 nb^{-1}

- pp $\sqrt{s}$ = 7 TeV
  - Run in 2010
  - Minimum-bias: 4.5 nb^{-1}

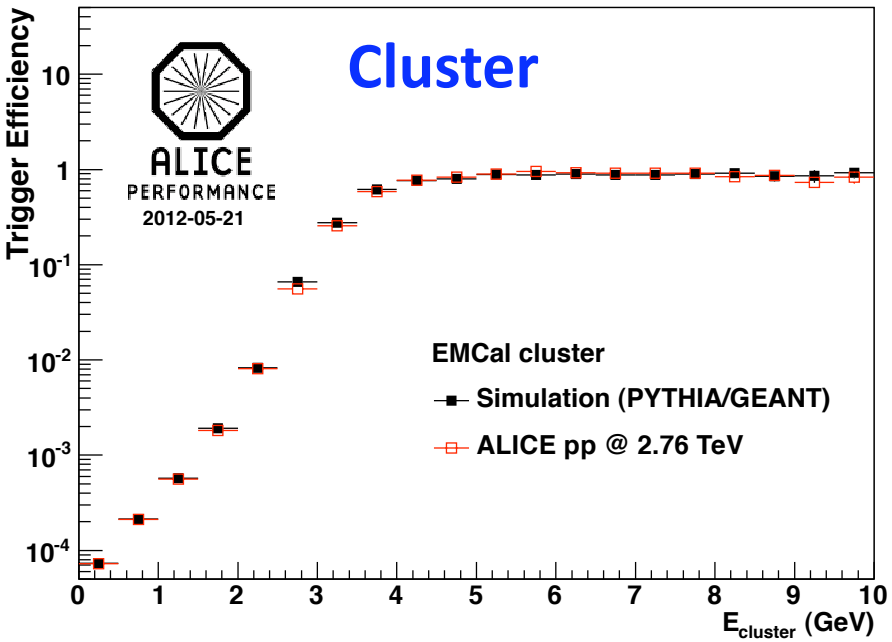


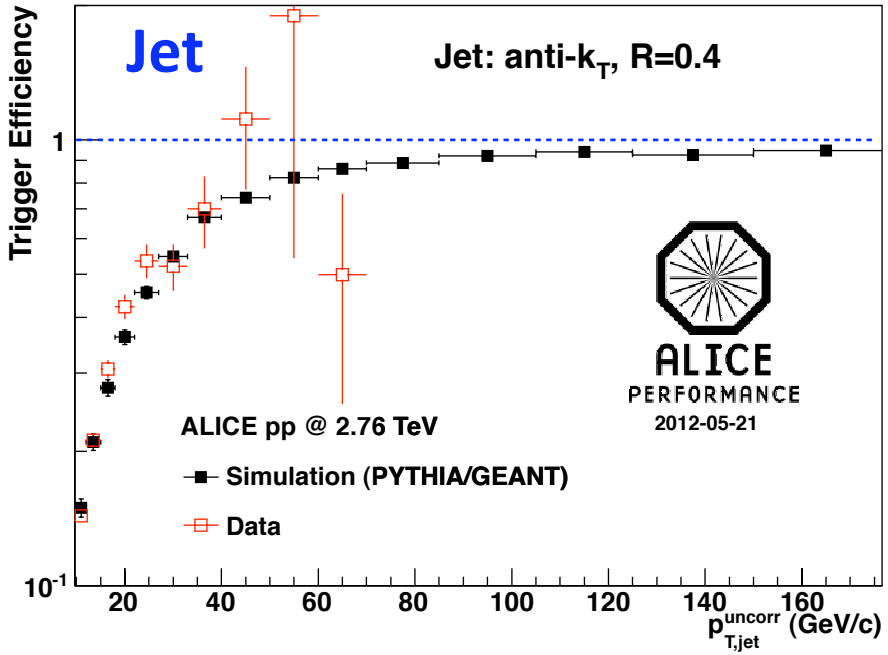
Inclusive jet cross-section in pp $\sqrt{s}$ = 2.76 TeV

Input to jet finder

- **Charged tracks** measured in the tracking system above 150 MeV/c
- **EMCal clusters** -> EM or hadronic showers
  - *Hadronic correction to EMCal energy*
    - Charged particles also deposit energy in EMCal
    - Match track-cluster and subtract track momentum from the associated cluster. ($E_{subtracted}$>0)
    - Correction for multiple particles in cluster: <5% (via simulation)
- **Jet reconstruction:** FASTJET package
  - anti-k_T algorithm
  - Boost-invariant recombination scheme (jets have zero mass)
  - R=0.2, 0.4
  - Fiducial cut in EMCal acceptance and $z_{leading} < 0.98$

EMCal-L0 trigger bias: data vs simulation



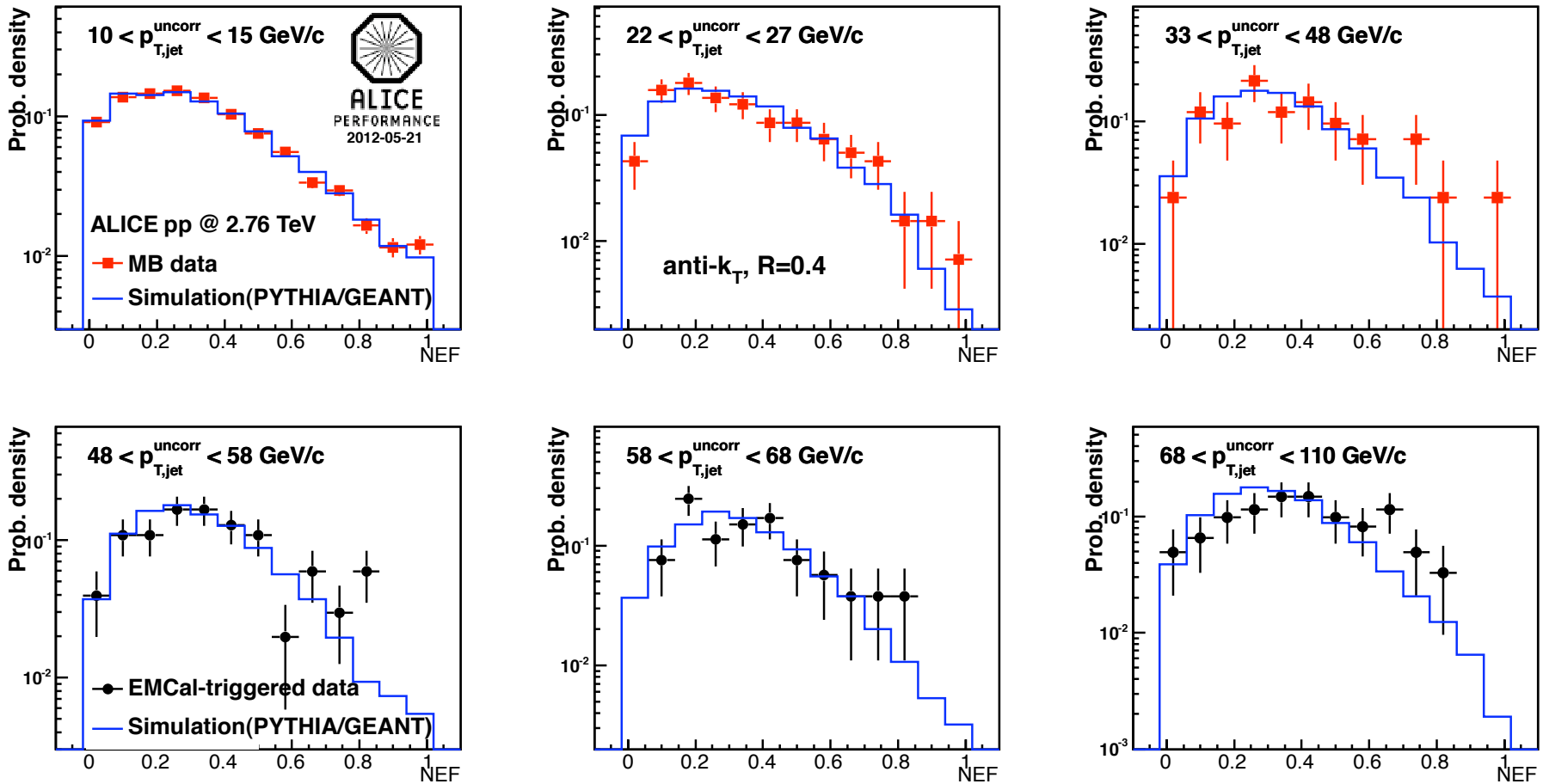


- Need to correct trigger bias on jet population to extract cross-section
- Left: trigger efficiency for EMCal clusters (trigger object) -> Good agreement of data + simulation over 4 orders of magnitude
- Right: trigger efficiency for reconstructed jets -> agreement within statistical precision of Minimum-bias data -> assign 10% systematic uncertainty

Detector effects correction

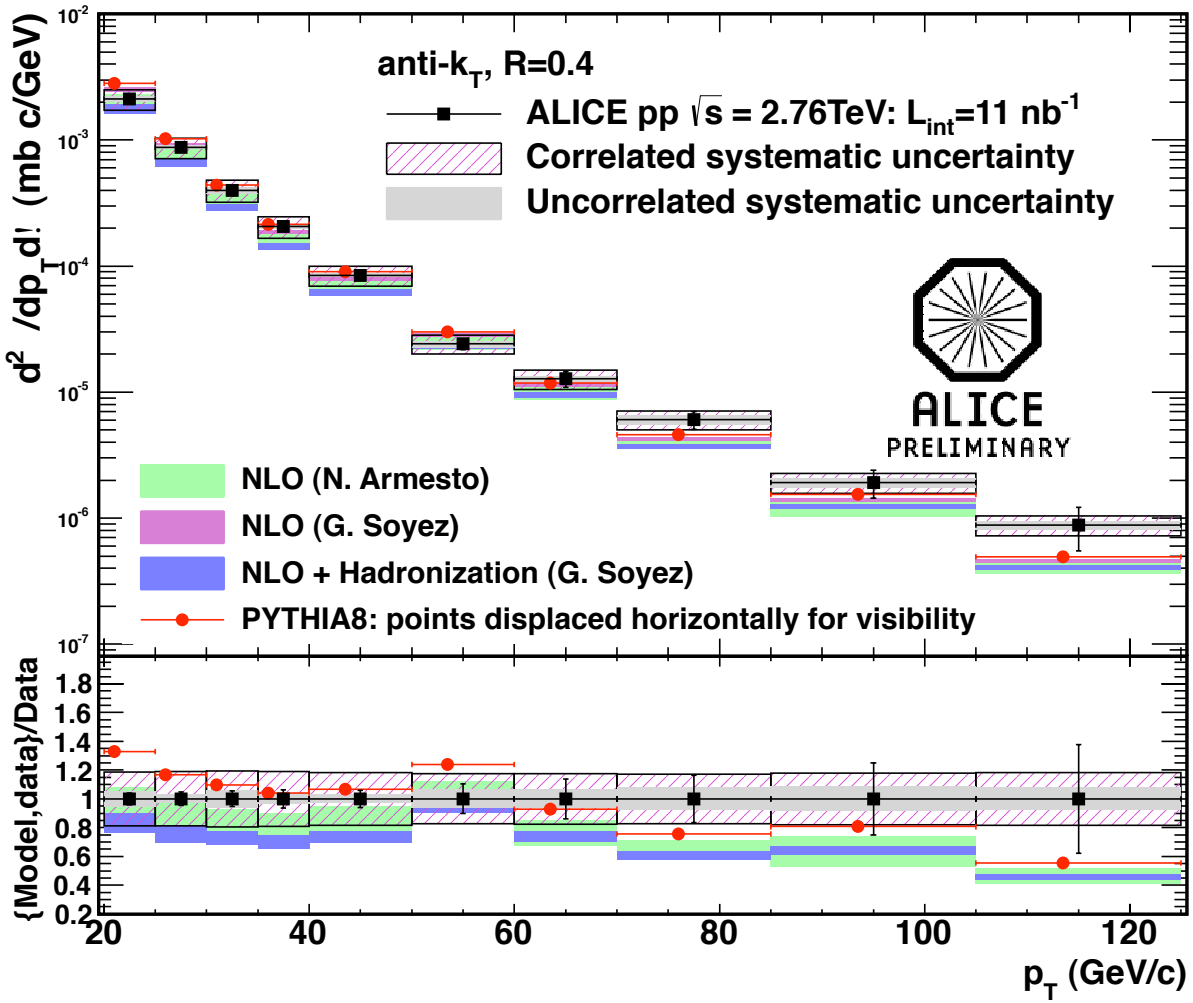
- Bin-by-bin technique
  - Determined by comparing the cross-section on the Particle level to the Detector level in simulation
  - Use uncorrected spectrum in data as weight function
- *Shift of jet energy scale ~ 20-25%*
  - Unmeasured neutrons and K^0_L's: compare proton and kaon spectra to data; PYTHIA 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

Jet Neutral Energy Fraction: data vs simulation



- 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*

Inclusive jet cross-section in pp √s = 2.76 TeV (R=0.4)



Green and magenta bands: NLO on Parton level

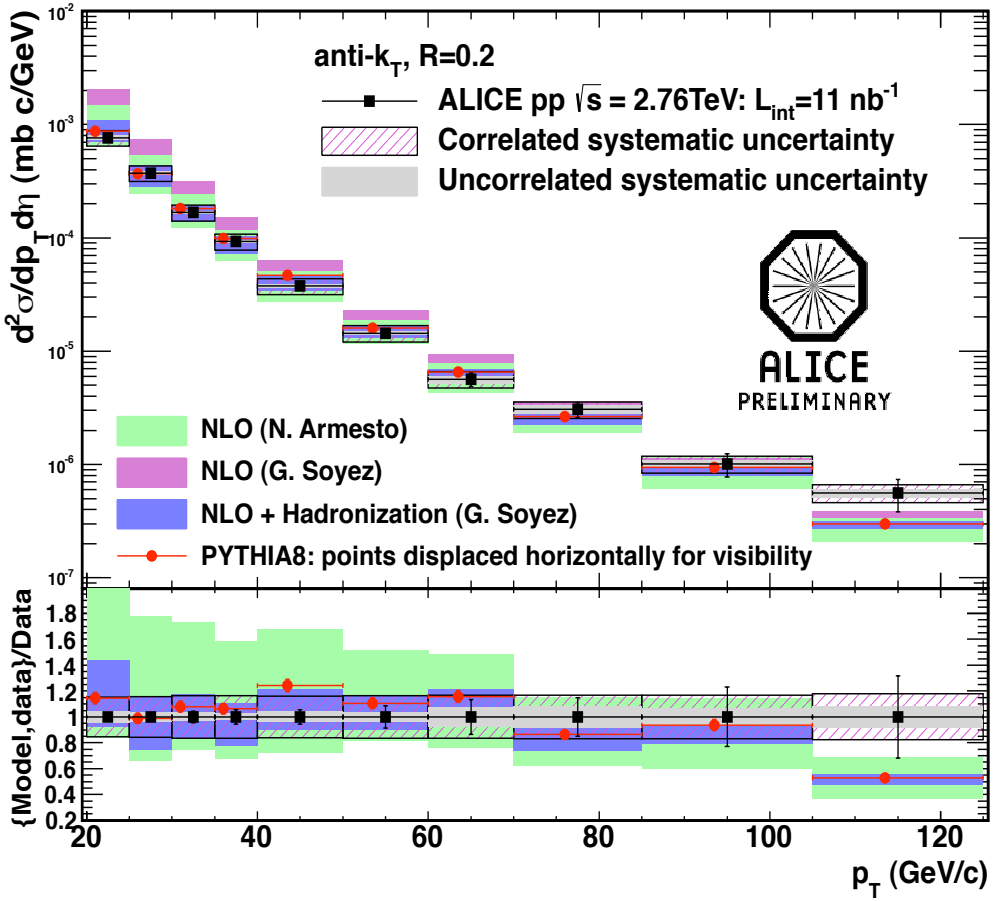
Blue band: NLO + hadronization

Red points: Pythia8. Shifted horizontally for visibility

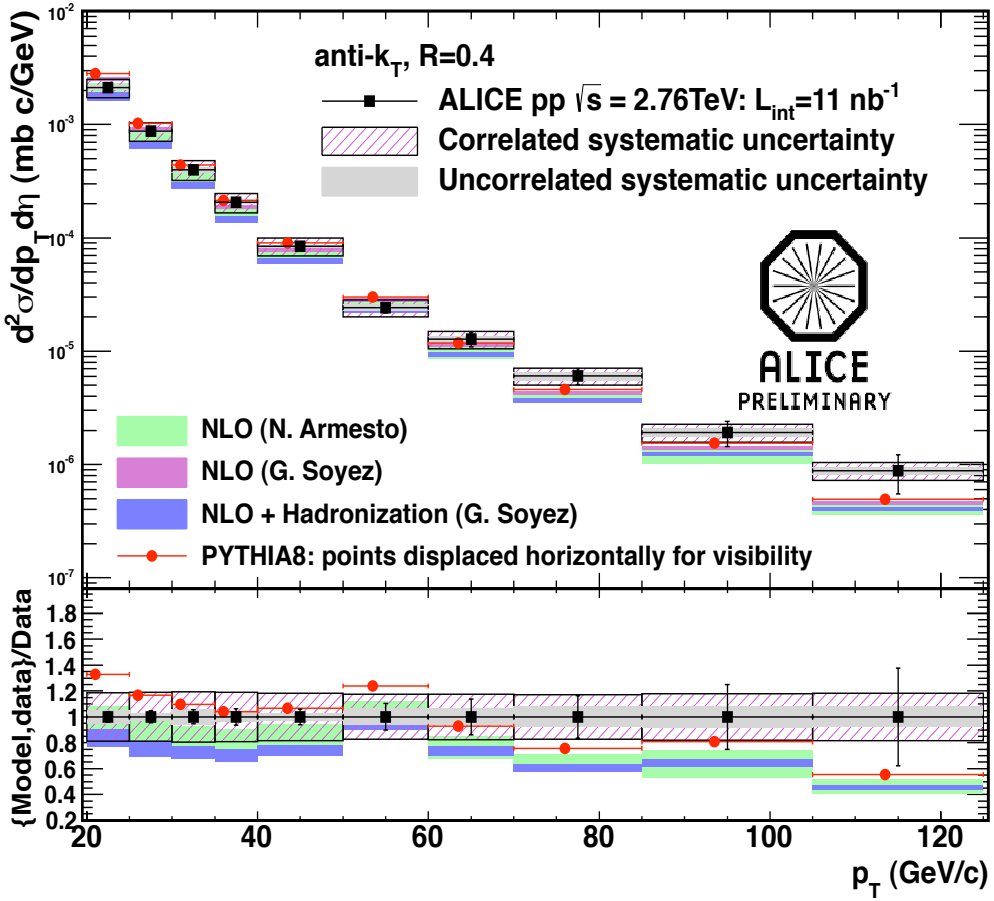
Good agreement between data and NLO calculations as well as Pythia8 prediction within both experimental and theoretical uncertainties

Inclusive jet cross-section in pp √s = 2.76 TeV

R=0.2

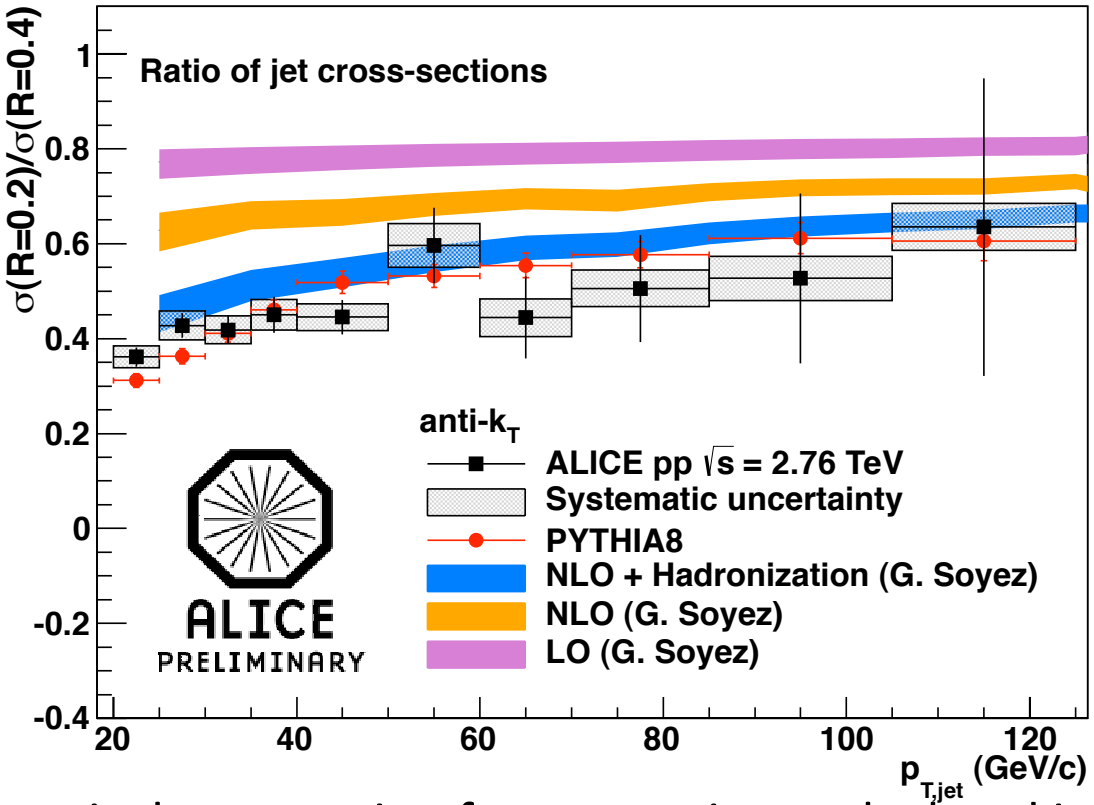


R=0.4



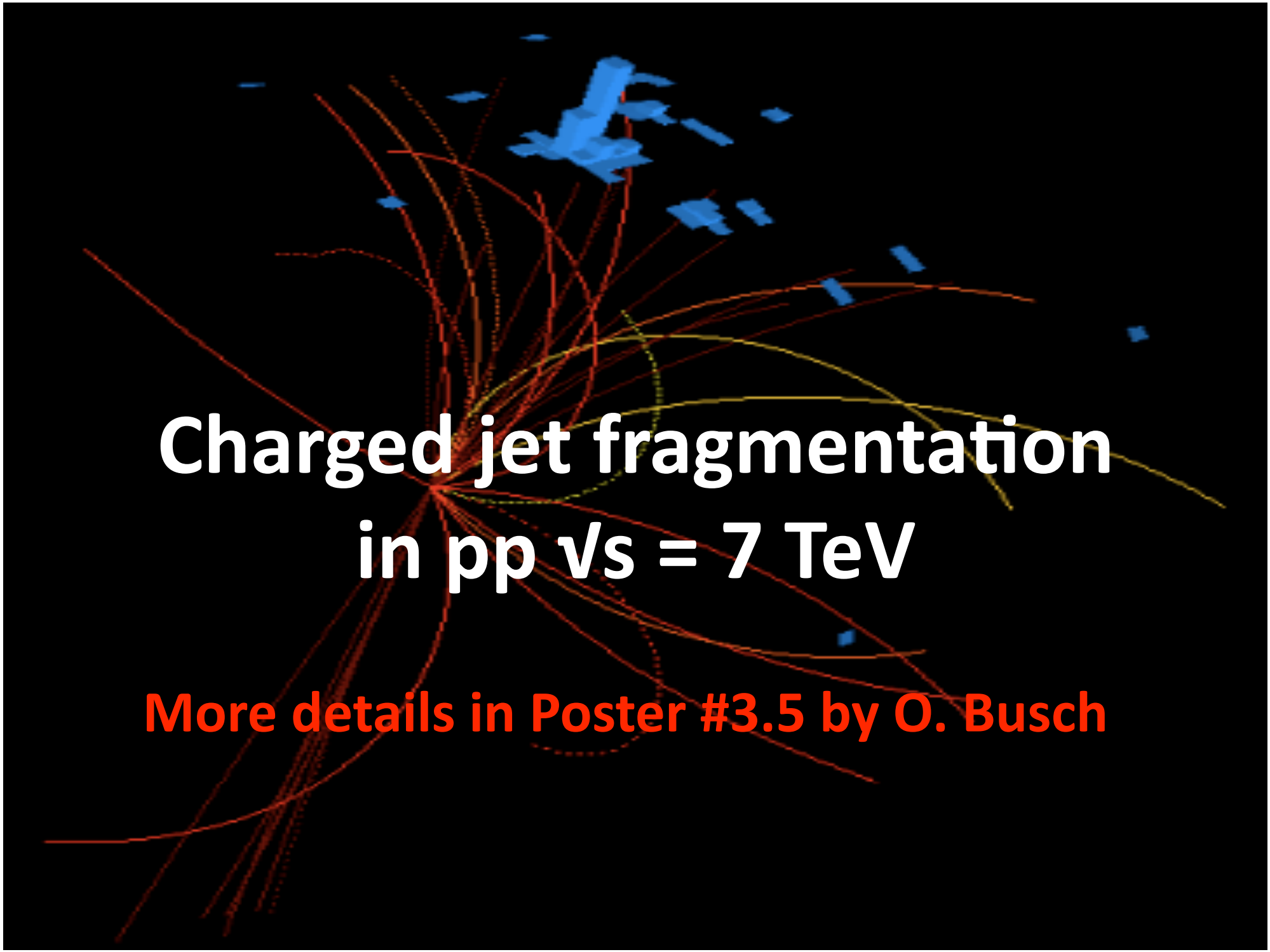
Ratio of jet cross-sections R=0.2/R=0.4

Probe of jet structure



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

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



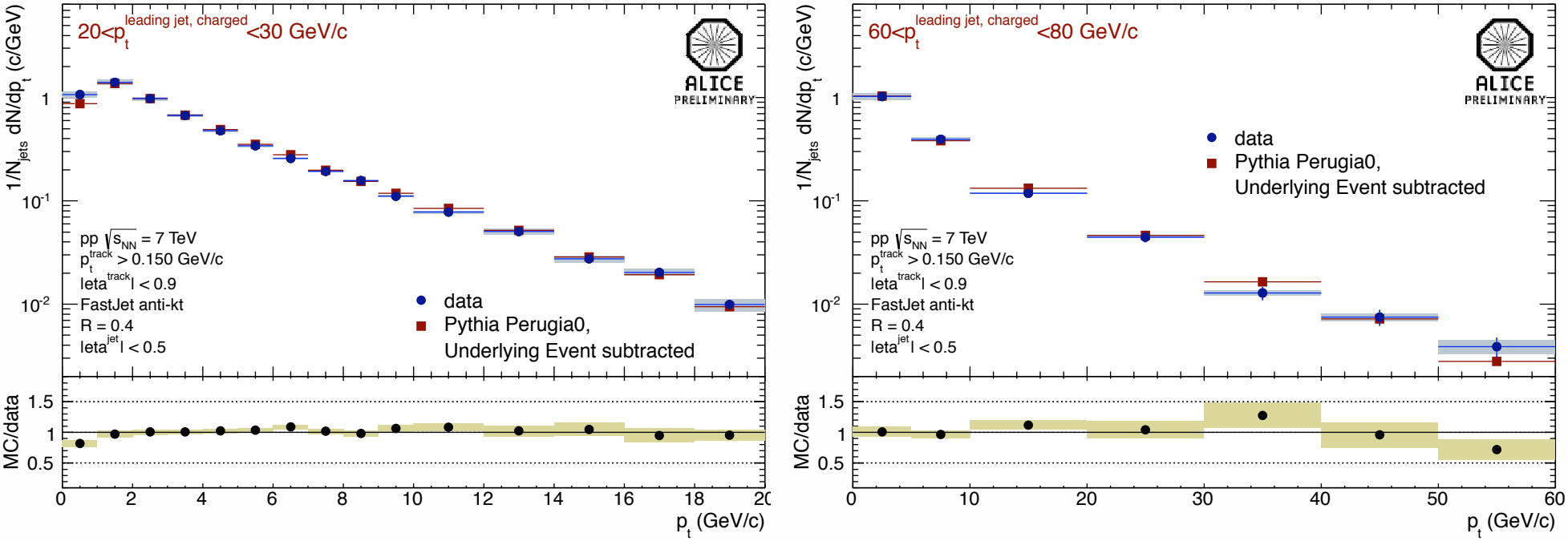
Charged jet fragmentation in pp √s = 7 TeV

More details in Poster #3.5 by O. Busch

Analysis setup

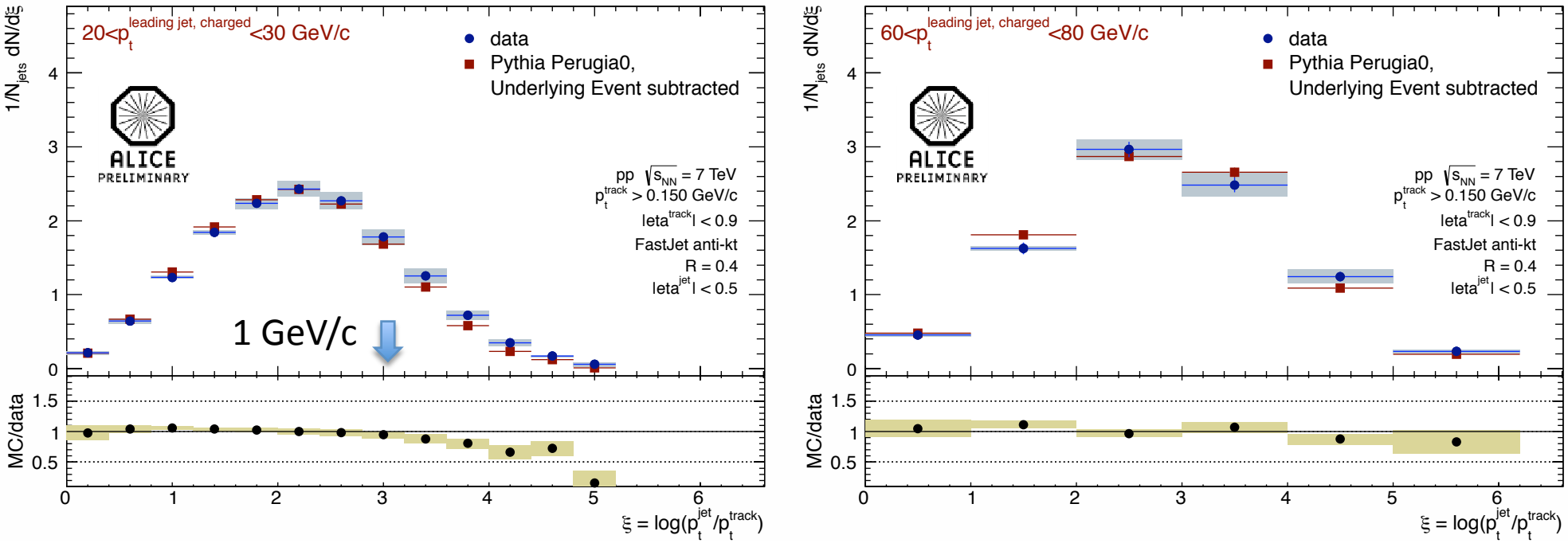
- Only **charged tracks** above 150 MeV/c are fed into jet finder
- *Jet reconstruction*
  - anti-k_T with R=0.4. Fiducial cut of $|\eta| < 0.5$
- Use the leading jet in each event and collect all the charged tracks in cone of 0.4 around the jet axis
- Jet fragmentation variables:
  - **p_T distribution** of the charged tracks in the jet cone
  - Scaled momentum distribution: **$dN/d\xi$, $\xi = \ln(p_T^{jet}/p_T^{track})$**
- Corrections
  - Underlying event from initial state radiation, beam remnants, etc: *use track density perpendicular to the jet cone*
  - Secondaries from weak decays, conversions, etc: *use simulation*
  - Detector effects of tracking efficiency and tracking resolution: *use simulation -> bin-by-bin technique*

Charged jets: p_T distribution of charged particles



- Pythia (Perugia0) agrees well with data above 1 GeV/c
  - Agreement improved after underlying event subtraction

Charged jets: dN/dξ distribution of charged particles



- "Hump-backed plateau" structure
- Particle yield (area under the dN/dξ distributions) increases as jet p_T increases

Summary

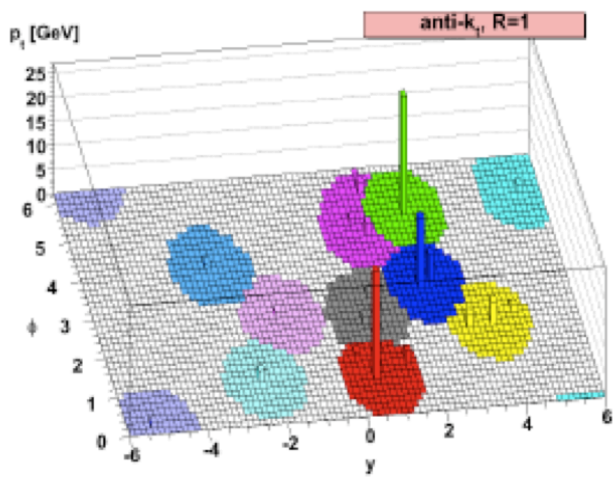
- **First measurement of jet cross-section for pp √s = 2.76 TeV**
  - The measured cross-sections with two different radii are in agreement with NLO+hadronization calculation as well as PYTHIA8 prediction within uncertainties
  - The ratio of the cross-sections agrees well with NLO +hadronization
- **Measurement of charged jet fragmentation in pp √s = 7 TeV**
  - PYTHIA agrees well with data above 1 GeV/c
  - Next: comparison to theory (e.g. MLLA)
- Important reference for upcoming heavy ion jet results.

- *Thanks to N. Armesto and G. Soyez for providing the theoretical calculations.*

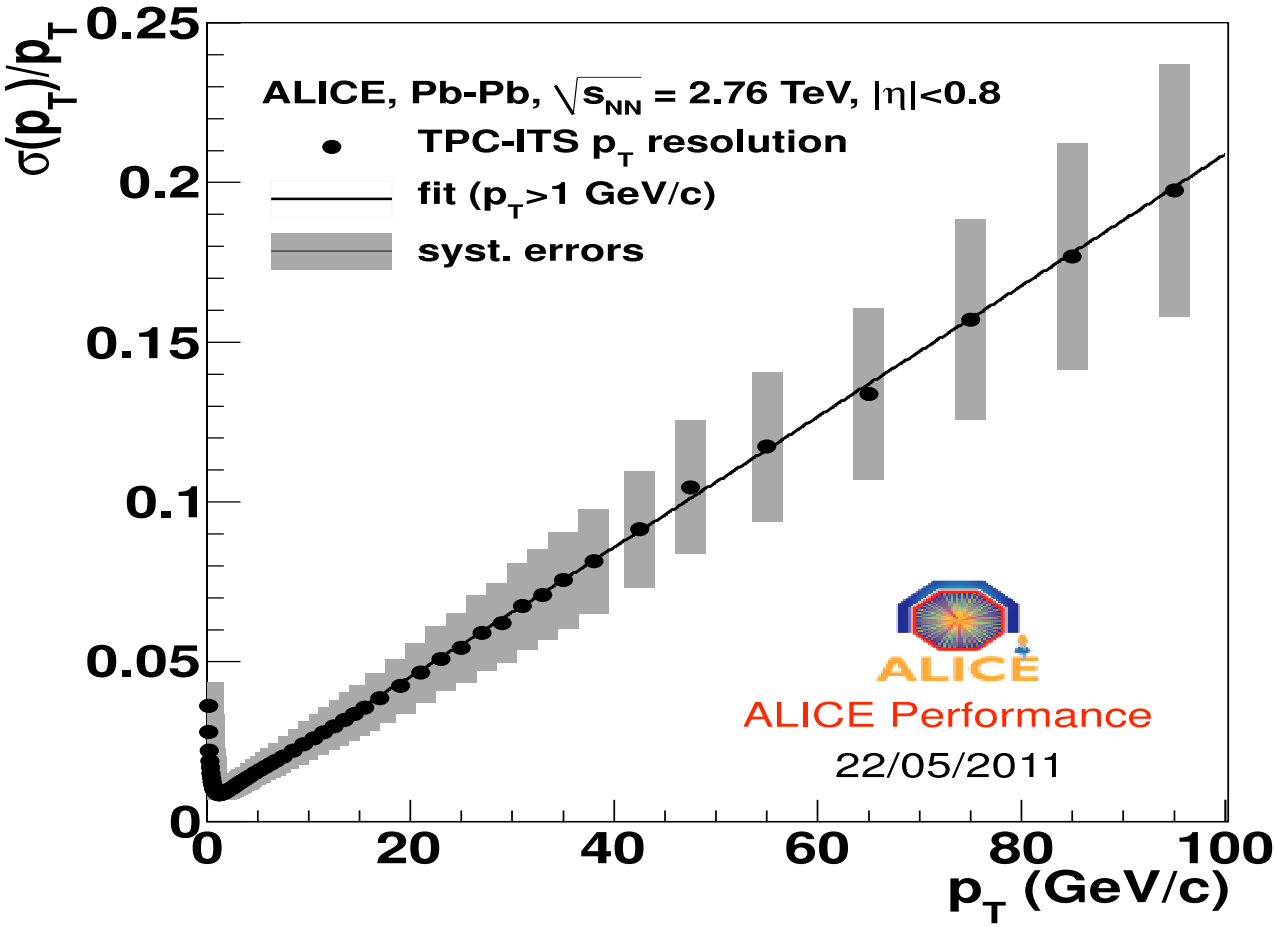
Backup

Jet reconstruction

- Full jet reconstruction collects all the hadrons originate from the parent parton
  - Enables reconstruction of the initial parton scattering kinematics
  - Enables a direct study of the jet-quenching, compared to the hadronic variables, such as R_{AA}, di-hadron correlation, etc.
- Challenge: enormous background in HI collisions
  - LHC 2.76TeV Pb+Pb: ~100 GeV/unit area
- Jet reconstruction algorithm: anti-k_T
  - Starts from high-p_T particles
  - Sequentially combines all the particles into jets
  - Insensitive to soft and collinear radiation



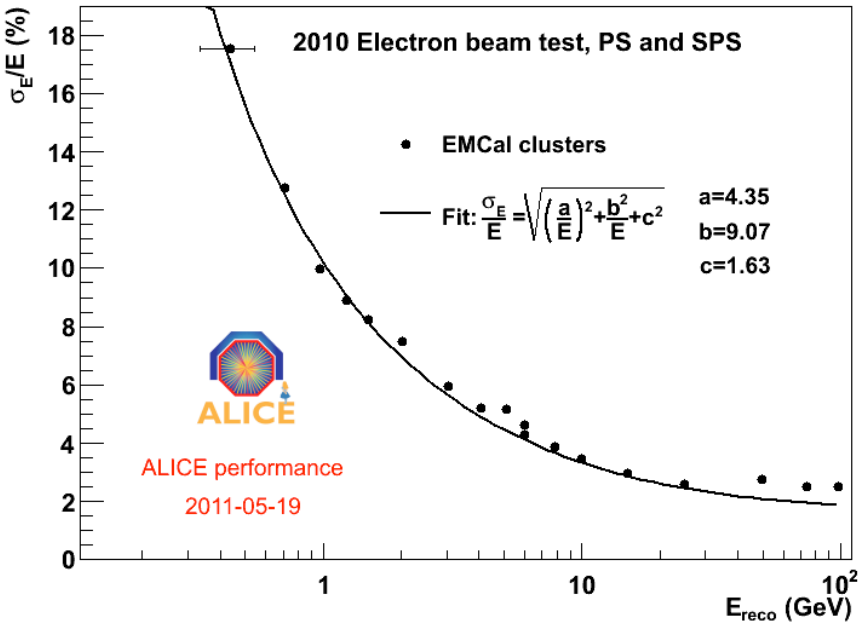
Charged track p_T resolution

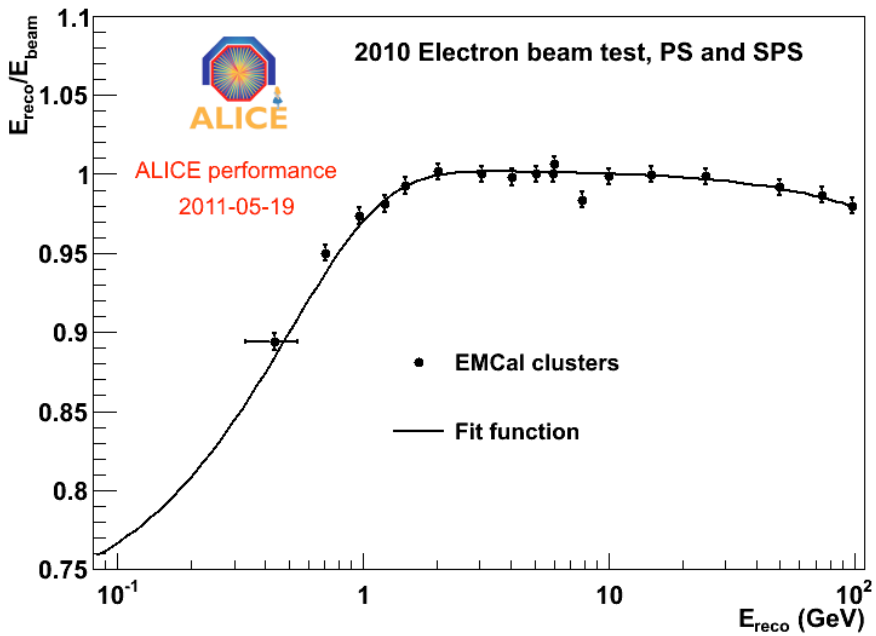


Jet Energy Scale

- *Shift of jet energy scale ~ 20-25%*
  - Unmeasured energy of neutrons and K^0_L
    - **Measured spectra of protons and Kaons are conssitent with simulation**
    - Compare PYTHIA vs HERWIG: < 1% uncertainty on JES
  - Tracking inefficiency
    - Track quality in data vs simulation by varying track cuts.
      5% uncertainty on tracking efficiency -> 2-3% uncertainty on JES
  - Residual hadronic correction for EMCal
    - Data-driven check: <1% uncertainty on JES
- JES uncertainty: ~4%

EMCal resolution and non-linearity





- Left plot: relative energy resolution. For cluster E > 5 GeV, $\sigma_E/E < 5\%$
- Right plot: non-linearity is small for cluster with 2 < E < 100 GeV
- Used to tune simulation

Bin-by-bin correction

$$C_{MC}(p_T^{low}, p_T^{hi}) = \frac{\int_{p_T^{low}}^{p_T^{hi}} dp_T \frac{dF_{measure}^{uncorr}}{dp_T} \frac{d\sigma_{MC}^{Particle} / dp_T}{d\sigma_{MC}^{Detector} / dp_T}}{\int_{p_T^{low}}^{p_T^{hi}} dp_T \frac{dF_{measure}^{uncorr}}{dp_T}}$$