Universiteit Utrecht

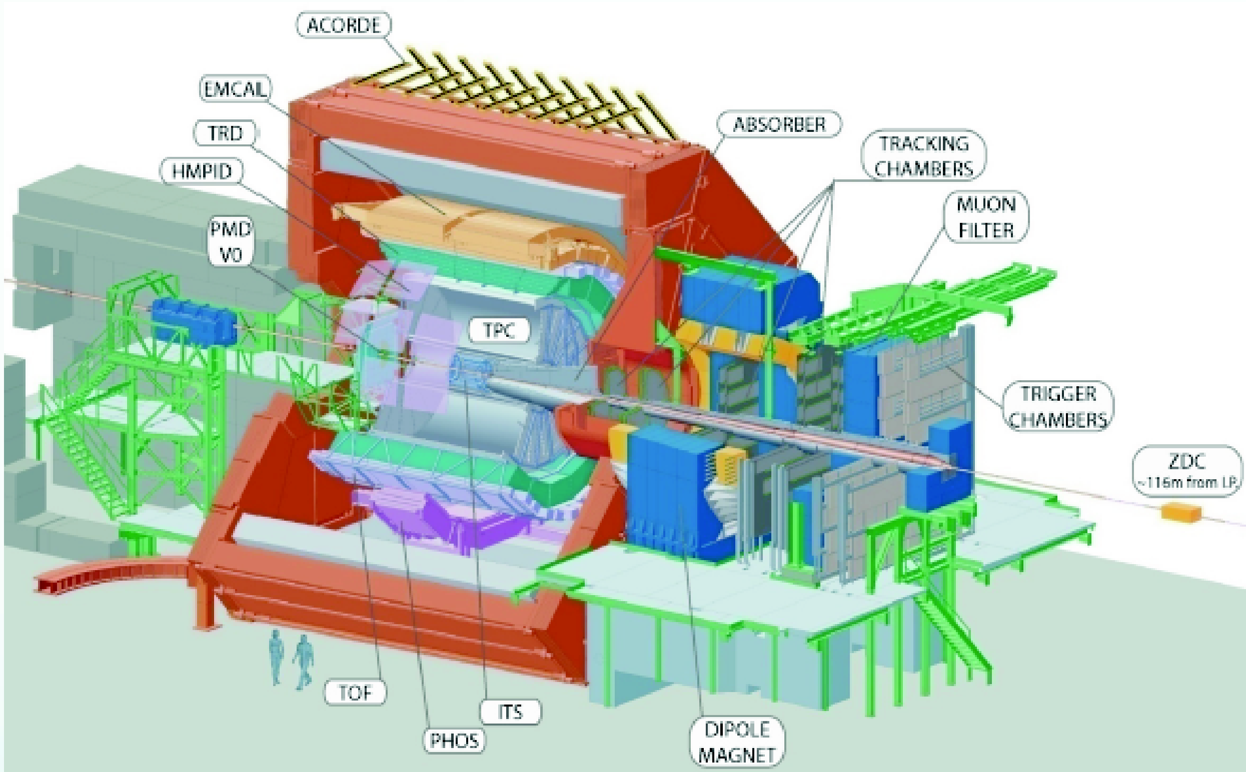
ALICE

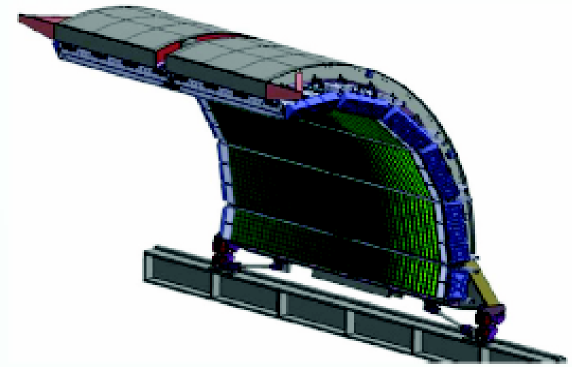
Jet Reconstruction and Corrections in ALICE

Marta Verweij
for the ALICE collaboration

Jet Quenching Workshop, CERN
the interface between theory and experiment
February 2013

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*

Slide from Rosi's presentation yesterday

Jet Reconstruction

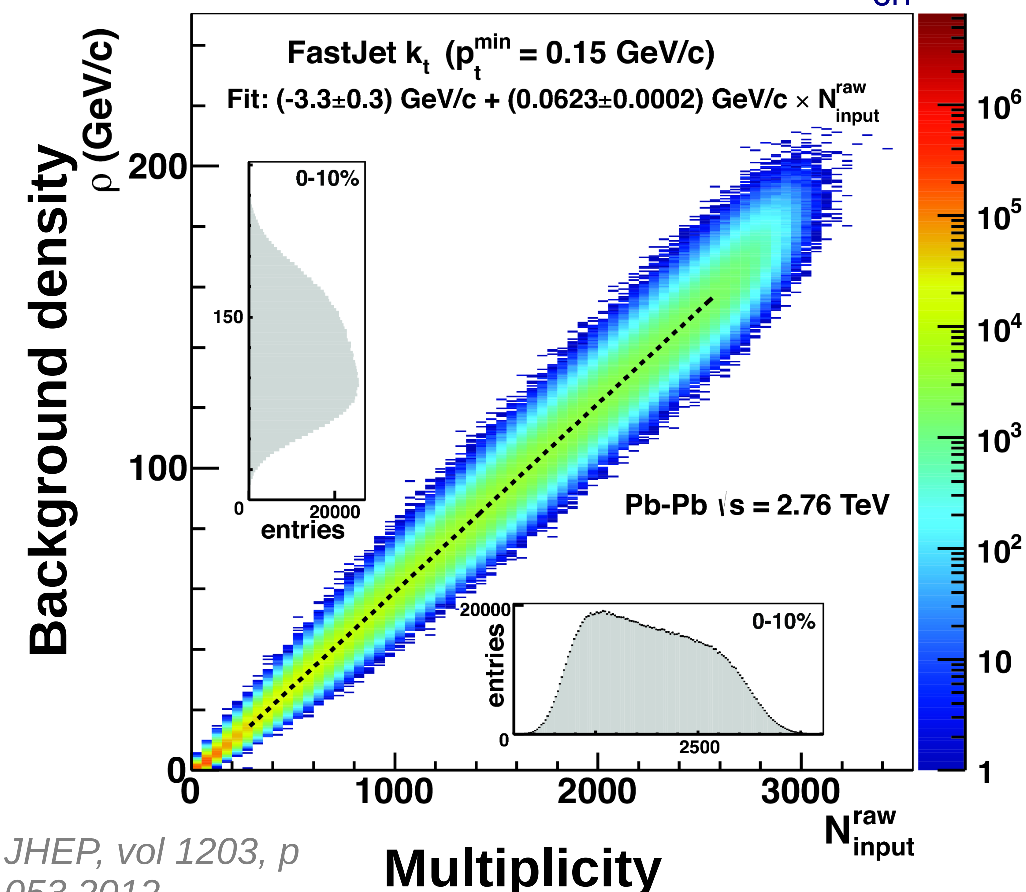
- Jet reconstruction with charged tracks reconstructed in tracking detectors (ITS + TPC) + neutral energy in EmCal:
  - High precision on particle level
  - Uniform η-φ acceptance:
    - Tracking: $|\eta|<0.9$ $0<\varphi<2\pi$
    - EmCal: $|\eta|<0.7$ $1.4<\varphi<\pi$
- ALICE uses sequential recombination algorithms from FastJet package:
  - Charged tracks: **p_T > 150 MeV/c;** EmCal clusters: E_T>300 MeV/c
  - anti-k_T for signal (stable area)
  - k_T to estimate background density
  - Boost invariant p_T recombination scheme (sets jet mass to zero)

Raw vs corrected jet

- What we measure:
  - p_T of a jet which is clustered by a jet algorithm (anti-k_T)
  - hard jets + fakes on top of a soft background
    p_T resolution of jets affected by detector effects
- What we want to measure:
  - jets which originate from the shower of a highly energetic parton
  - Independent of detector effects and background fluctuations
- Corrections:
  - Average background → jet-by-jet
  - Background fluctuations & Fake jets } Unfolding
  - Detector Effects } Unfolding

Event Background

Charged background density ρ_{ch}



JHEP, vol 1203, p 053 2012

- Event-by-event background calculation – FastJet method
- p_T density ρ: median of k_T clusters excluding 2 leading clusters

$$\rho = median\left(\frac{p_T^{jet,i}}{A_i^{jet}}\right)$$

- Background density scales with event multiplicity: $\rho \sim N \langle p_T \rangle$

Subtract average background from each jet event-by-event

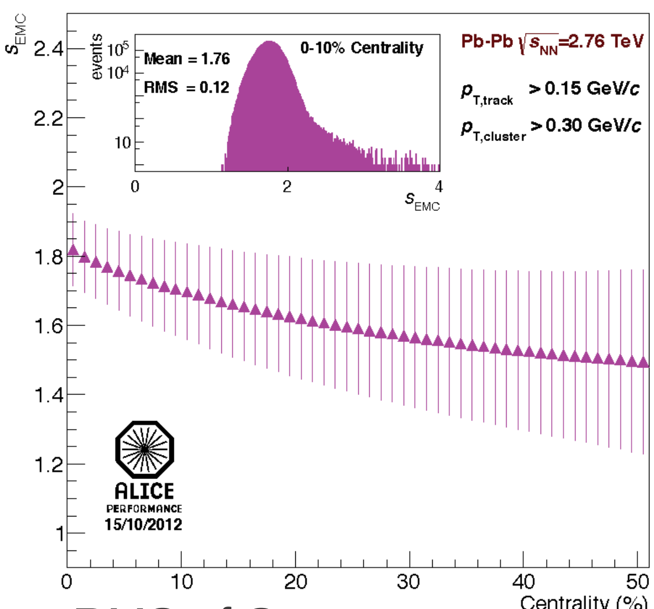
$$p_{T,j}^{sub} = p_{T,j} - \rho A_j$$

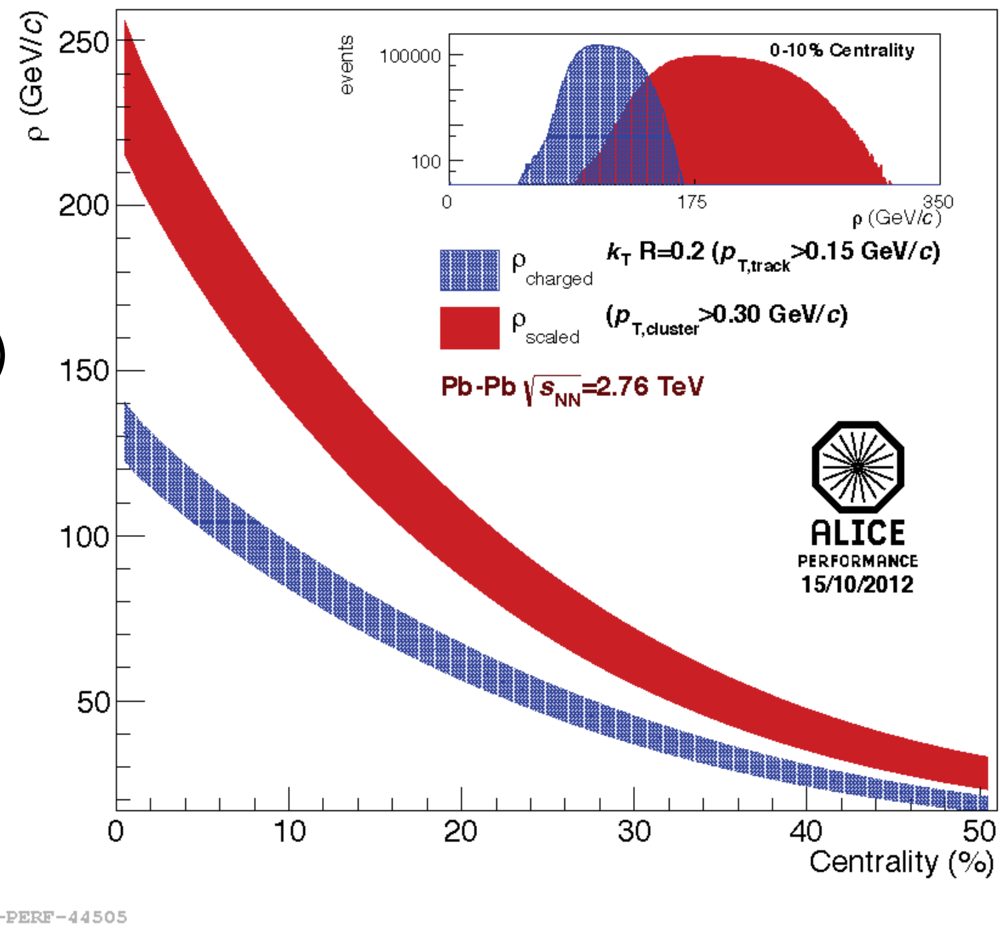
Event Background II

- Full jets: ρ measured with charged tracks and scaled up to charged+neutral

$$\rho_{ch+em} = \rho_{ch} \times s_{EMC}$$

- s_{EMC} from data: (EmCal+TPC density)/(TPC density)



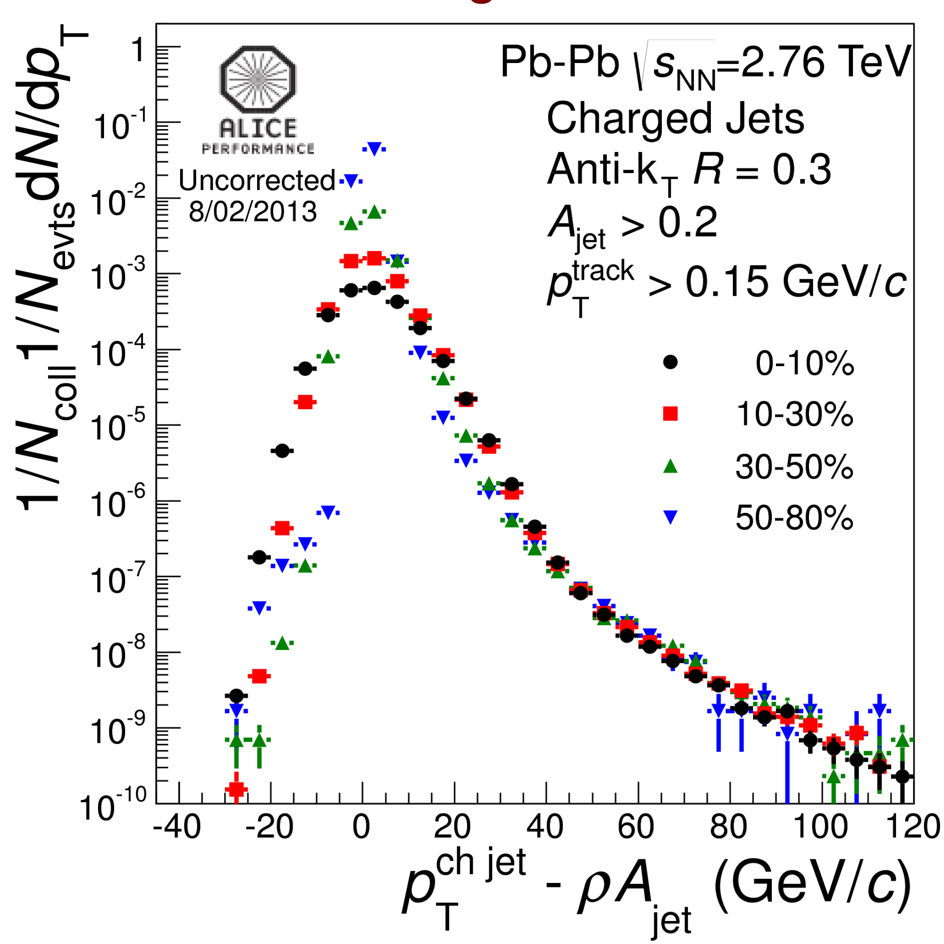


Error bars are RMS of S_{EMC}

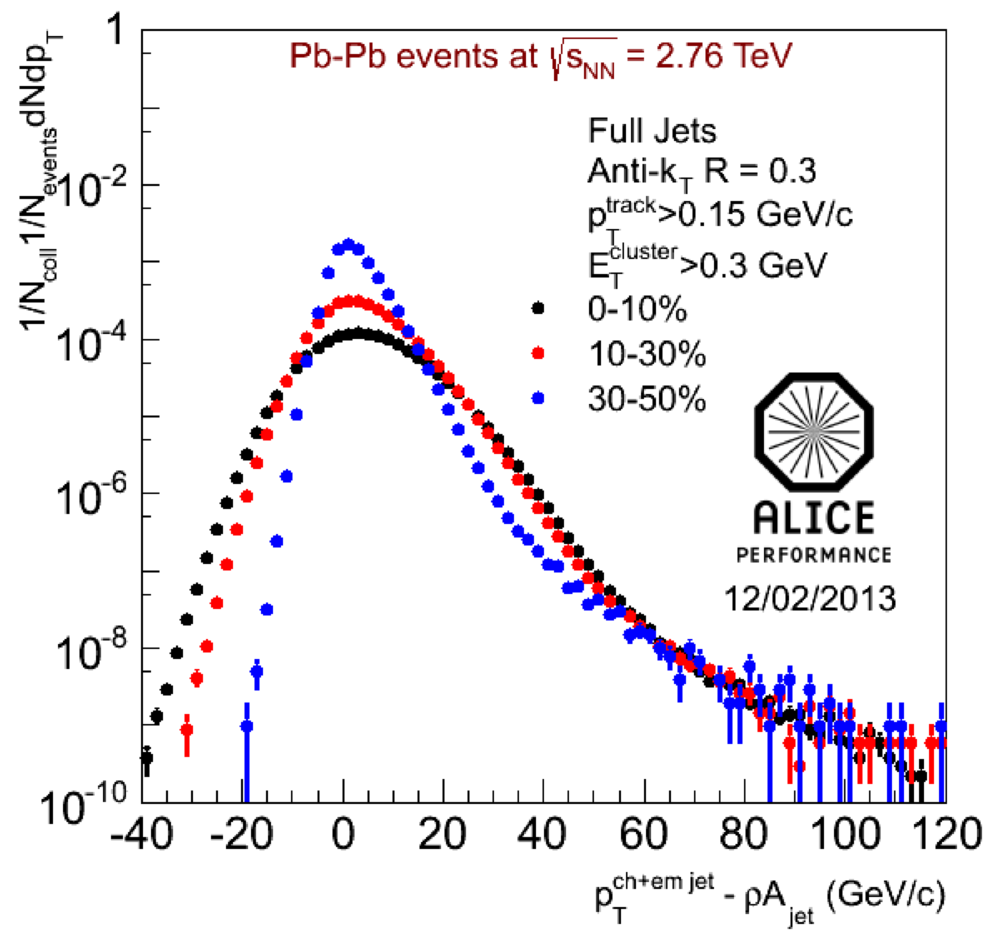
Raw Jet Spectrum

- Jet spectrum of jets after background subtraction
- Local variation of ρ → large distortion in background subtracted jet spectrum

Charged Jets



Full Jets

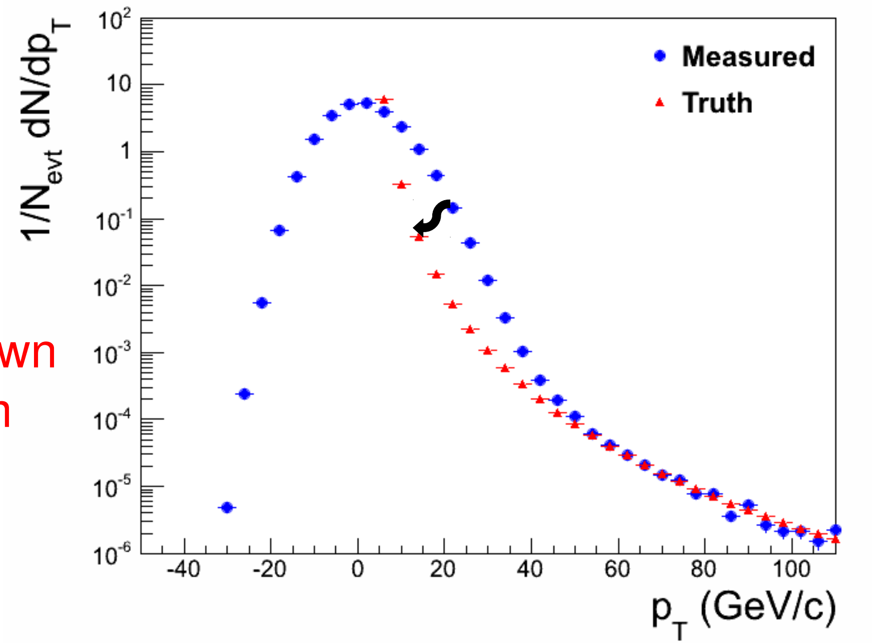


Unfolding

- Problem to solve:

$$\mathbf{M_m = G_{m,t} \cdot T'_t}$$

Measured jet spectrum — Response matrix — 'true' unknown jet spectrum



- Response matrix encodes effect of detector and background
- ill-posed problem, cannot invert response matrix
- Regularized unfolding
- Used unfolding methods:
  - χ^2 minimization of refolded and measured spectrum
  - SVD
  - Bayesian

Response Matrix

Background Fluctuations

$$M_m = G_{m,d} \cdot D_d$$

Detector Effects

$$D_d = G_{d,t} \cdot T_t$$

Determined separately

$$M_m = G_{m,d} \cdot G_{d,t} \cdot T_t = G_{m,t} \cdot T_t$$

Merged into one combined response matrix ($G_{m,t}$)
→ used for unfolding

Detector Effects

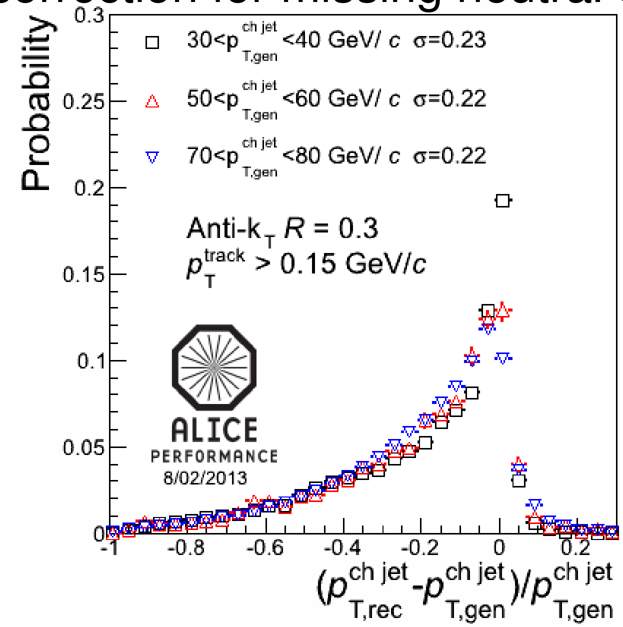
Particle level jets
Anti-k_T jets reconstructed from particles produced by PYTHIA (charged or charged+neutral)

Detector level jets
Anti-k_T jets reconstructed from tracks after detector simulation PYTHIA

Detector level jets affected by: tracking efficiency and momentum resolution
Geometrical Matching between **particle** level and **detector** level jets gives detector response

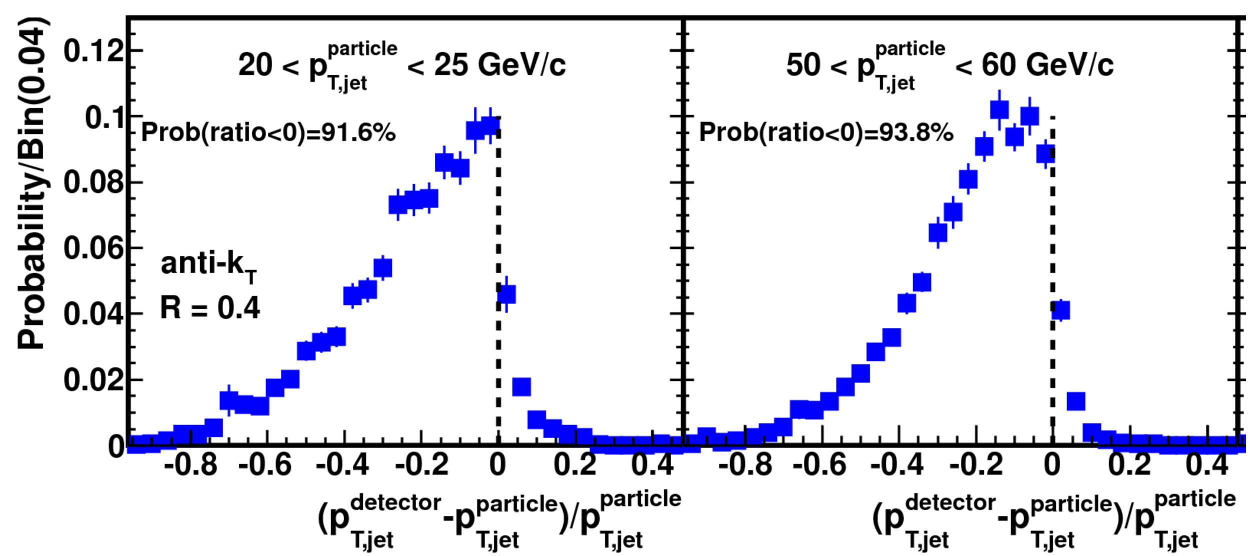
Charged Jets

No correction for missing neutral energy



Full Jets

arXiv:1301.3475



Background Fluctuations

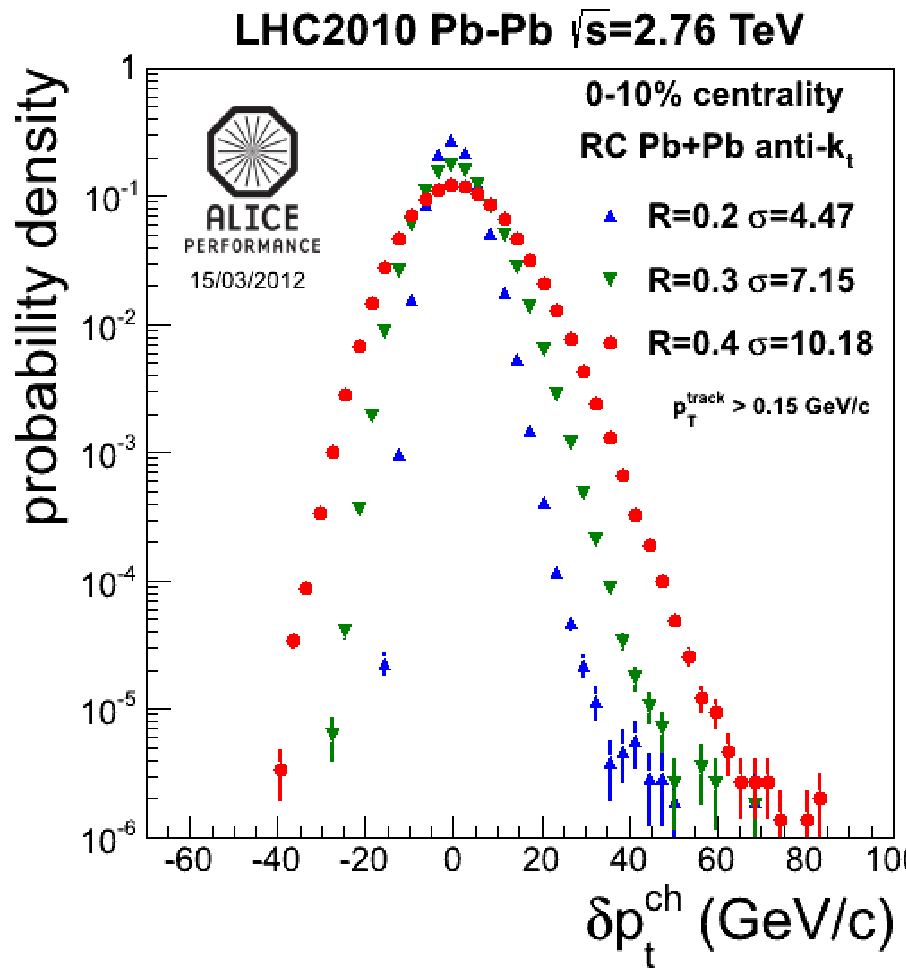
Background varies from region-to-region:

- statistical fluctuations
- collective effects

Data driven method to quantify background fluctuations:
Random cone and high p_T probe embedding in Pb-Pb events

$$\delta p_{\mathrm{T}} = p_{\mathrm{T,jet}}^{\mathrm{rec}} - \rho A - p_{\mathrm{T}}^{\mathrm{probe}}$$

Reconstructed jet p_T | **Background subtraction** | **Embedded probe p_T**



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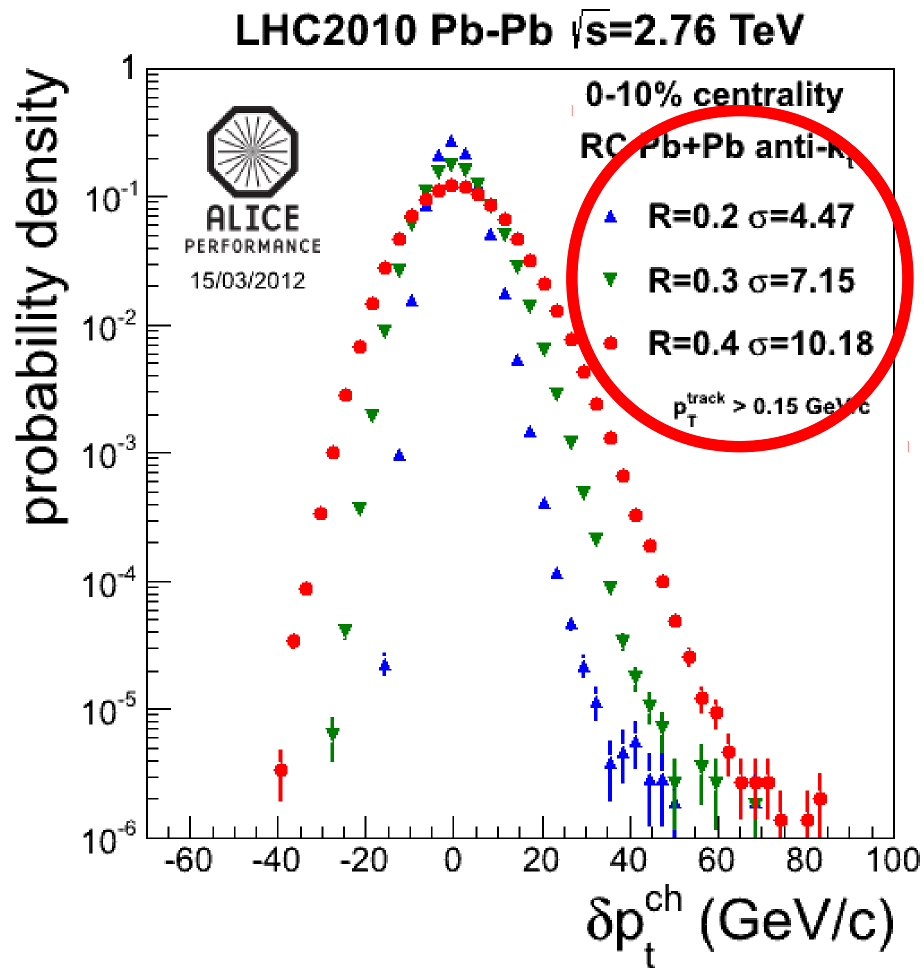


Size of fluctuation depends on particle multiplicity in jet cone:
σ(δp_T,*R*=0.3) > σ(δp_T,*R*=0.2) and **σ(δp_T,*central*) > σ(δp_T,*peripheral*)**

Background Fluctuations II

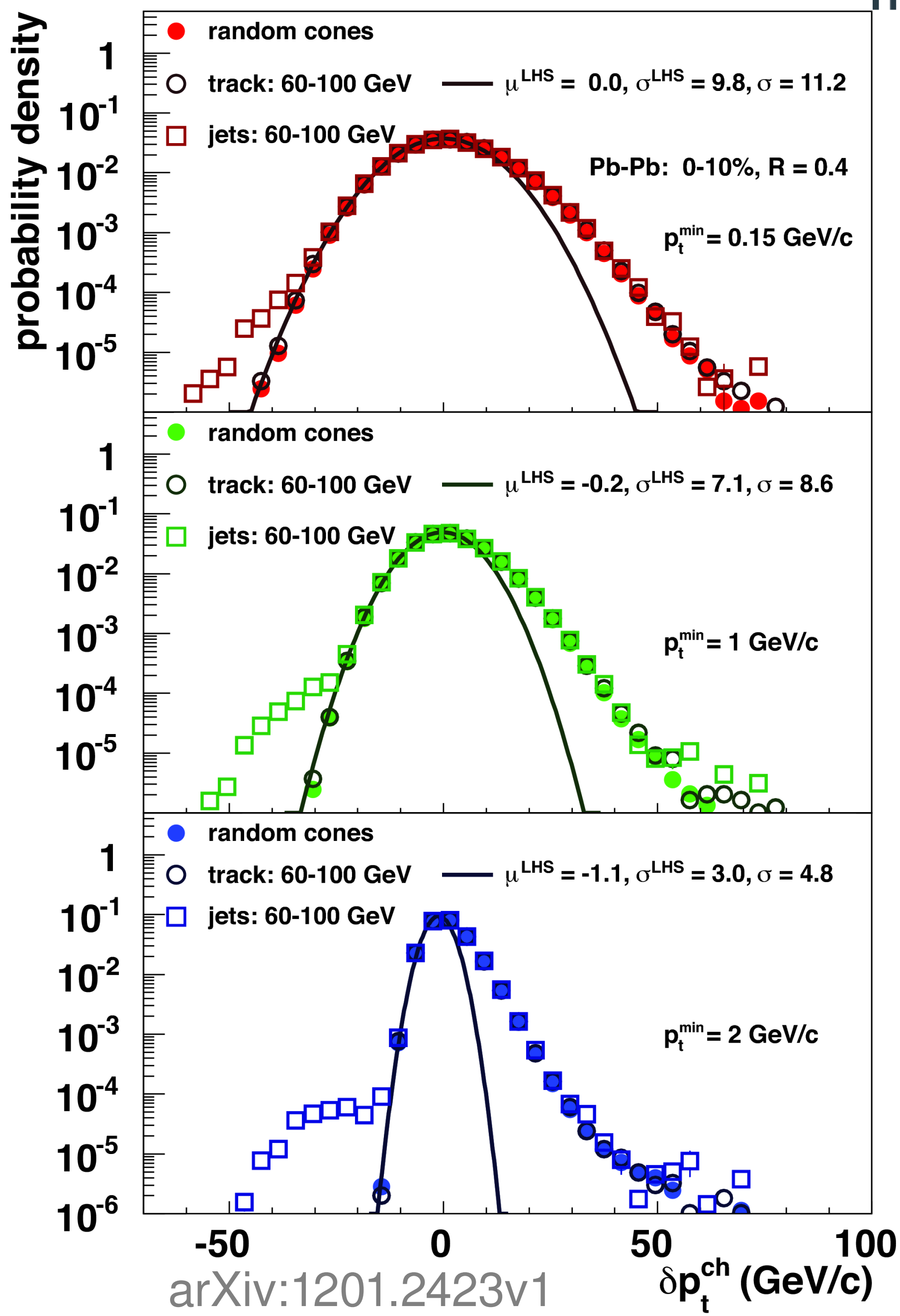
Comparison of Probes

Random Cones
Single Tracks
Pythia jets

- No dependence on fragmentation pattern observed
    - Small back-reaction effect

Minimum p_T constituents

- Fluctuations reduced by increasing minimum particle p_T

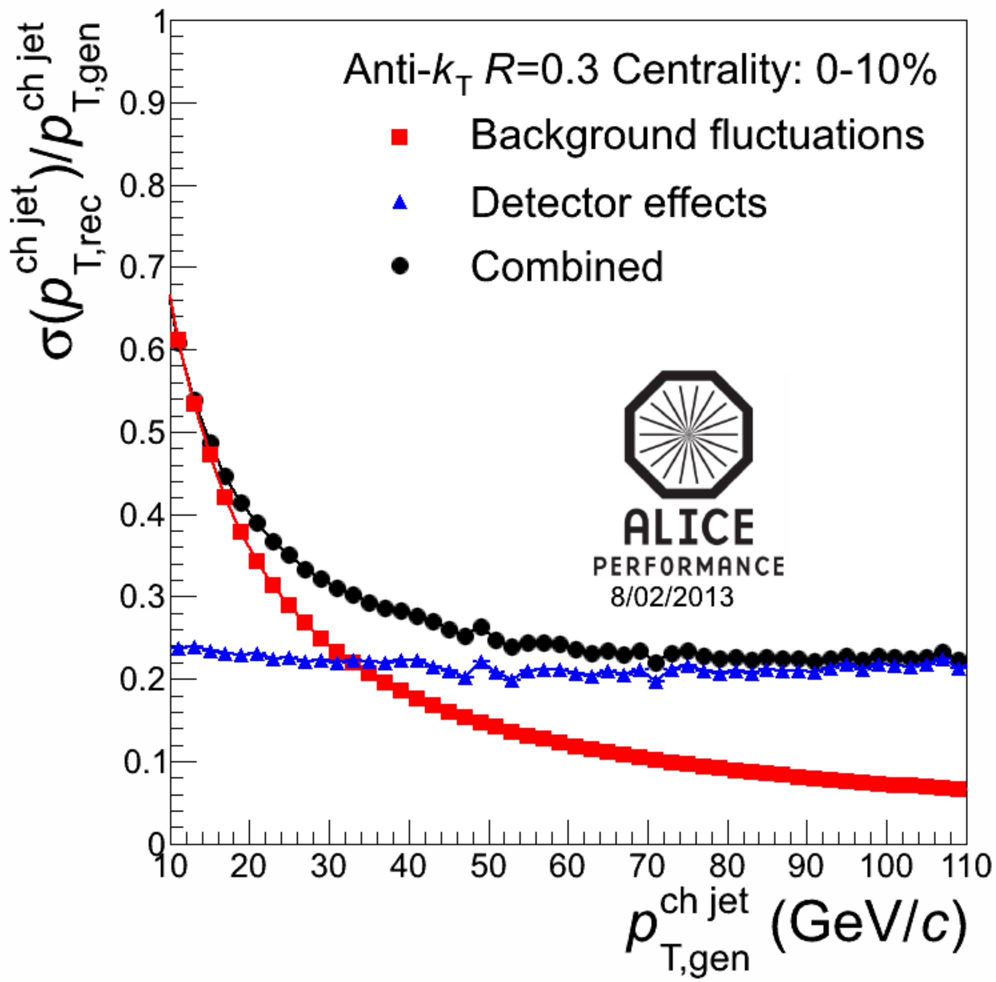


arXiv:1201.2423v1

Jet p_T resolution

- Detector effects and Background Fluctuations: Partially compensating effects
  - At low p_T background fluctuations dominate
  - At high p_T detector effects dominate
- Correction done all at once via unfolding

Charged Jet Response



What is a jet in HI?

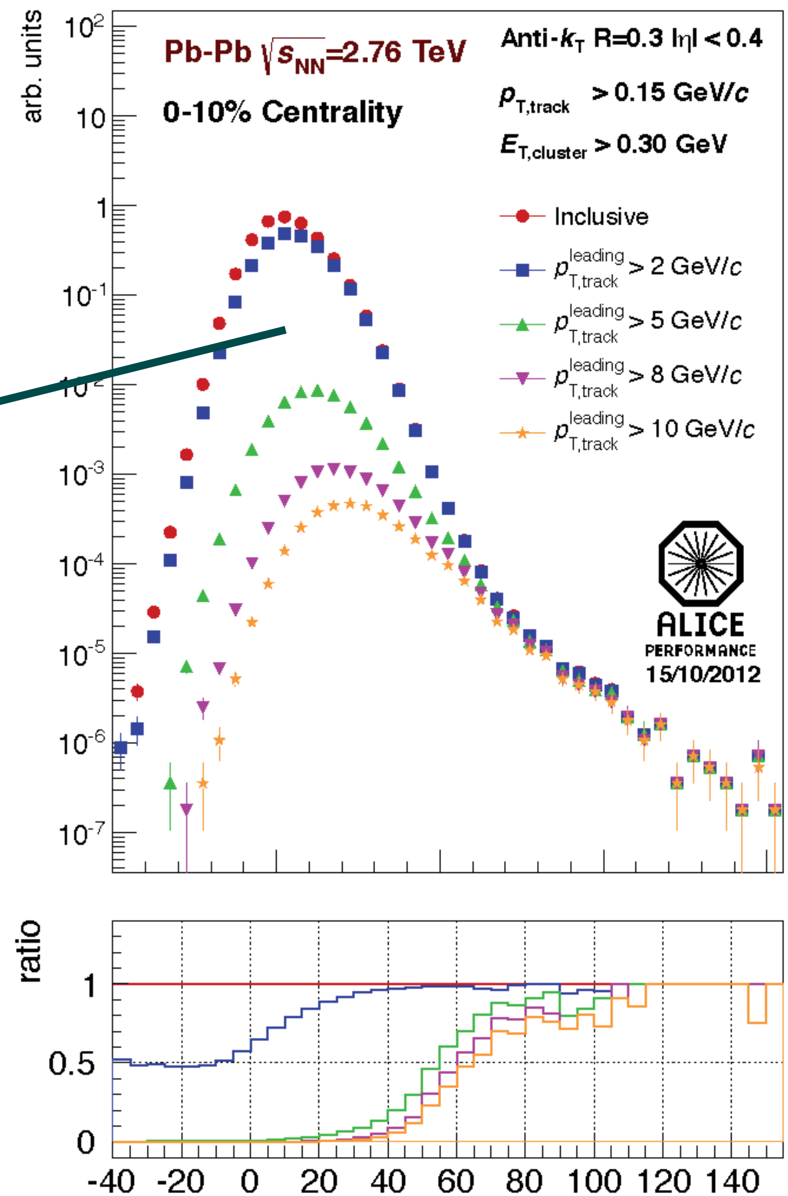
- Not possible to distinguish if jet originates from hard process of combinatorial clusters → matter of definition
- Even in pp: 2 GeV cluster a jet? 5 GeV? 10 GeV?
- In heavy-ion collisions: low p_T jets appear at high p_T
  - Very high p_T: jet clearly visible – unknown which constituent from background and hard jet
  - Intermediate p_T: mix of combinatorial and hard clusters
  - Very low p_T: dominated by combinatorial clusters

ALICE approach

- Inclusive spectra: unfold only considering jets above a certain p_T, select jets with a high p_T constituent
- Recoil spectra: trigger recoil jets, subtract combinatorial jets, unfold

Combinatorial Jets

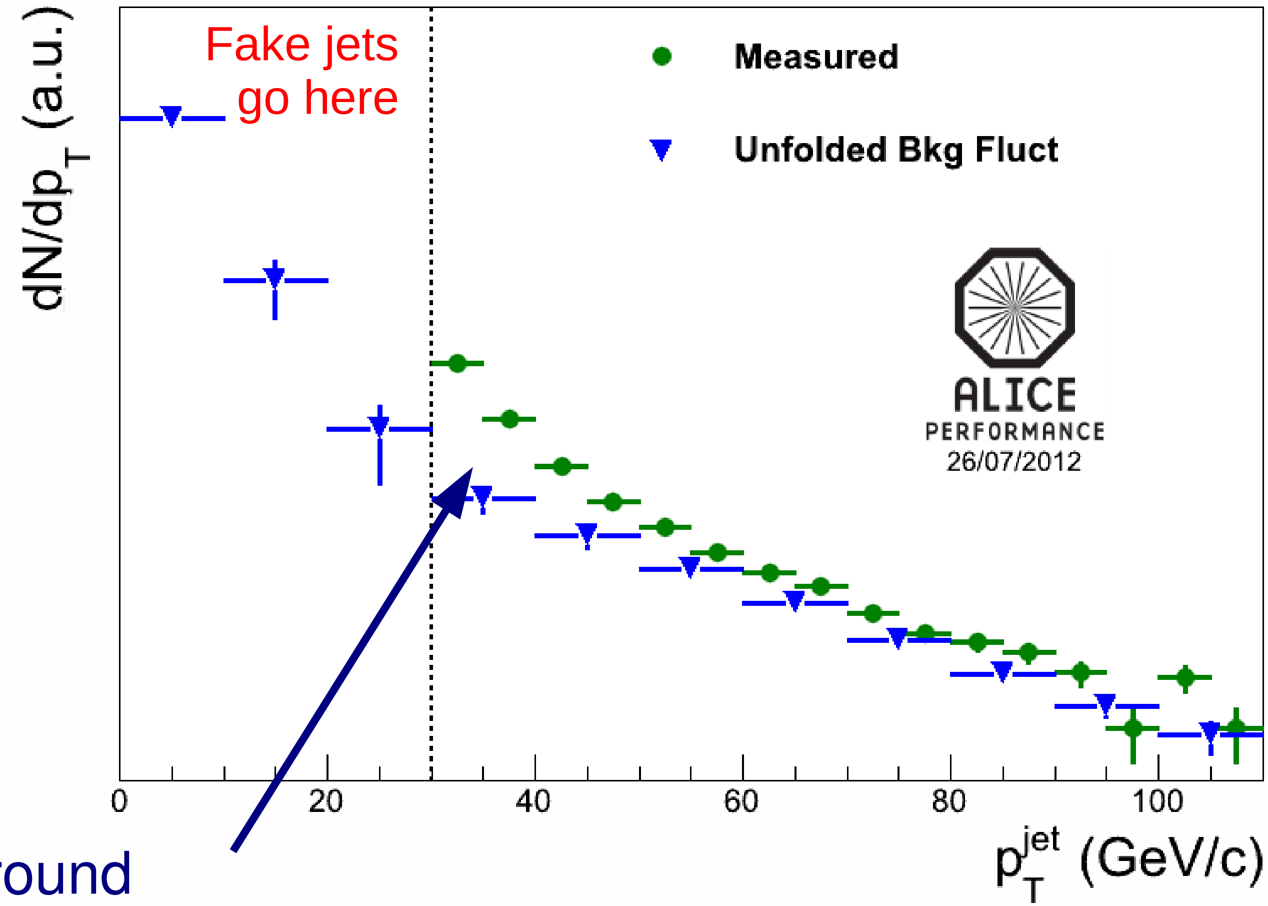
- Combinatorial jets: clusters which do not originate from a hard process.
- Bump at zero: combinatorial jets Transition to 'real' is grey area
- Combinatorials reduced by selecting jets with a leading track of p_T > 5, 8, 10 GeV/*c*. Selection after jet finding.
  However, fragmentation bias
- ~ 60-80 GeV hard jets start to dominate



Full Jets

Unfolding Strategy

Raw jet spectra need to be corrected for background fluctuations



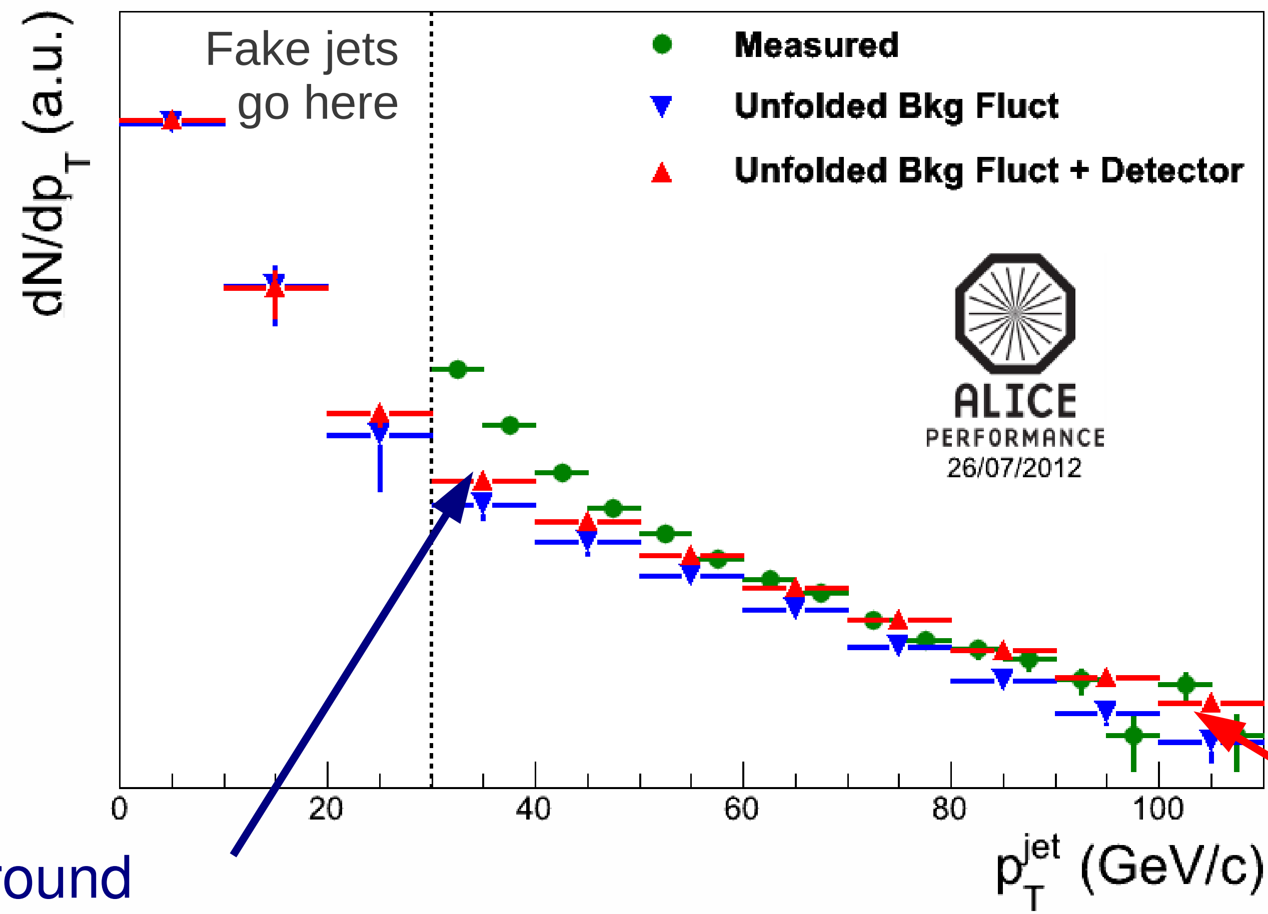
Background fluctuations shift low p_T jets to high p_T

Combinatorial jets suppressed with minimum p_T cut on measured spectrum

Feed in from low p_T: unfolded spectrum starts at p_T=0 GeV/c

Unfolding Strategy

Raw jet spectra need to be corrected for background fluctuations and detector effects.



Combinatorial jets suppressed with minimum p_T cut on measured spectrum

Feed in from low p_T: unfolded spectrum starts at p_T=0 GeV/c

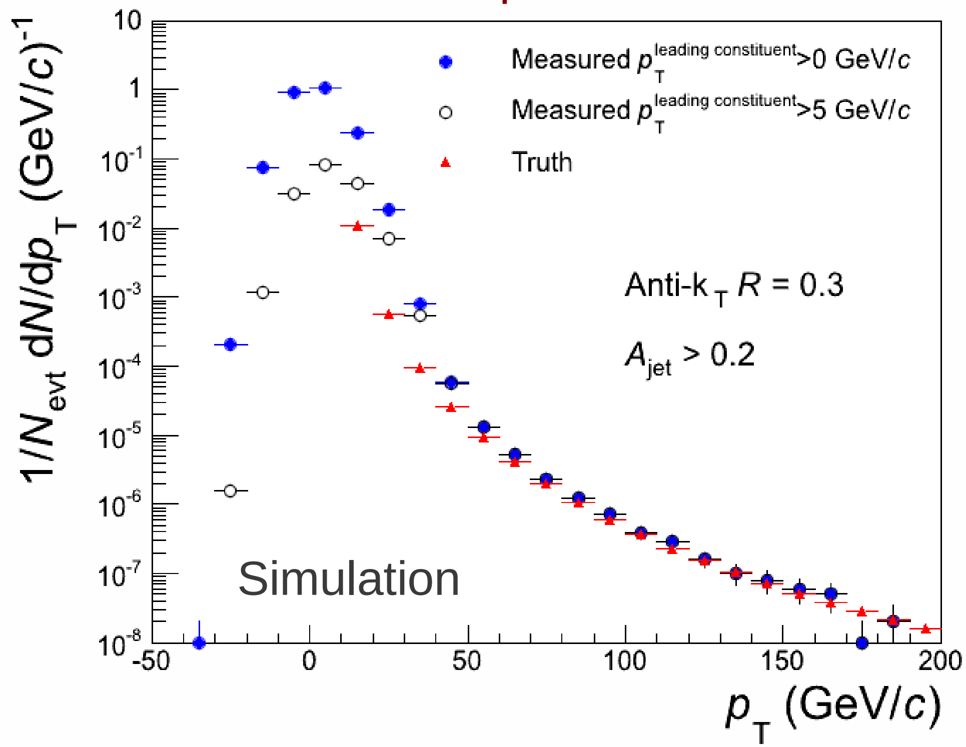
Background fluctuations shift low p_T jets to high p_T

Detector effects shifts jets to lower p_T

Unfolding Validation

- LBNL background model: background fluctuations + fake jets
- Model is tuned to reproduce general features of ALICE data:
  - Soft component: Boltzmann distribution $\langle p_T \rangle$=670 MeV/c
  - Hard jet component: power law (p_T^{-5})
- Multiplicity, mean p_T and RMS soft+hard particle distribution as in ALICE charged particle measurement for central Pb-Pb collisions
- Unfold measured spectrum in model and compare to truth

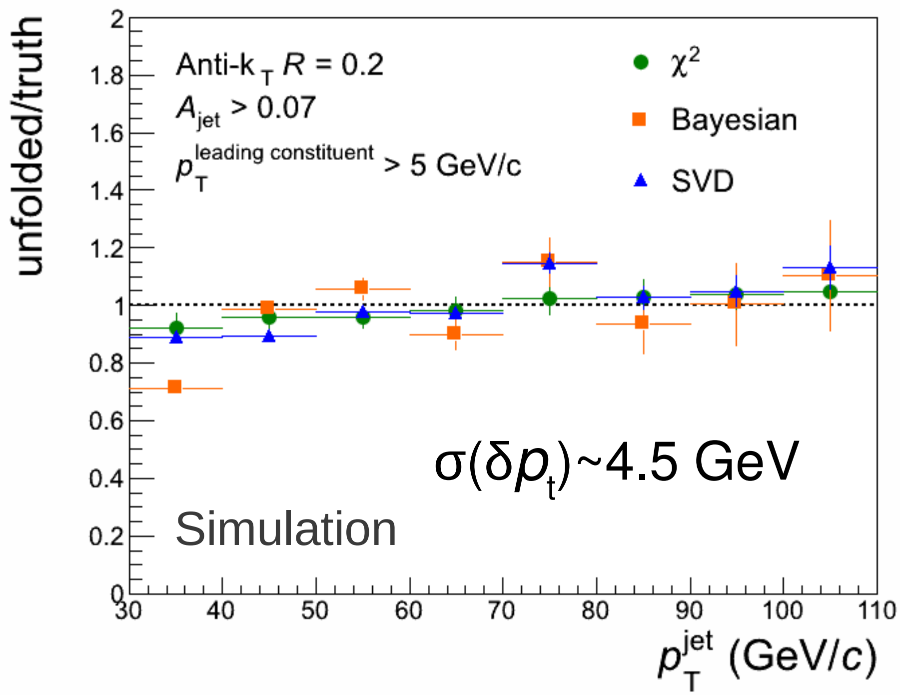
Raw Jet Spectra in model

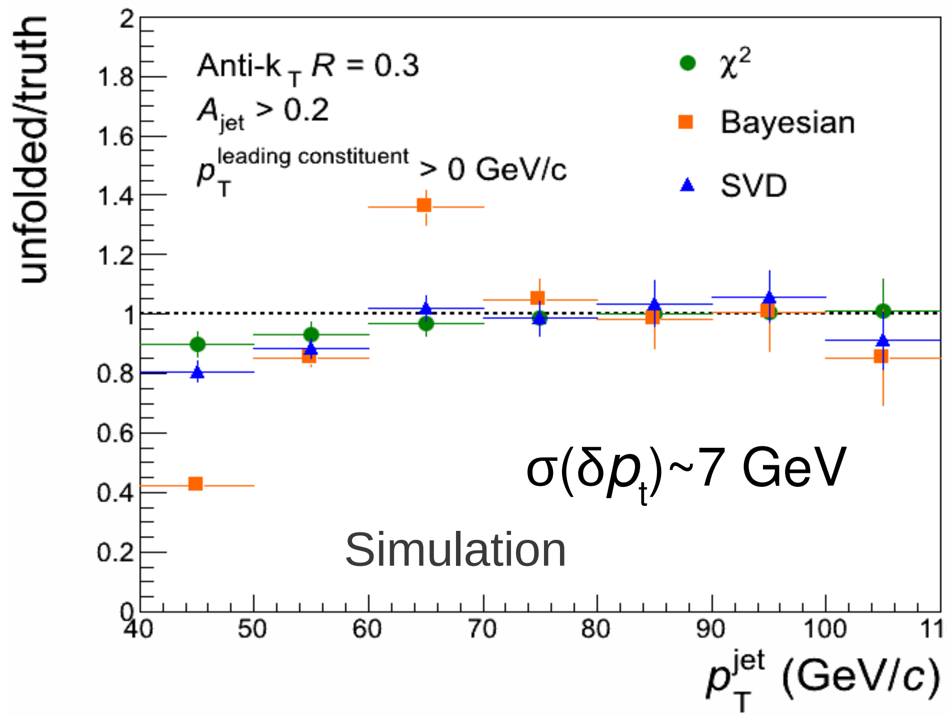


LBL Background Model:
arXiv:1208.1518

Unfolding Validation II

- Unfolding done with 3 algorithms (prior is measured spectrum)
- Comparison of unfolded spectrum to the true jet spectrum



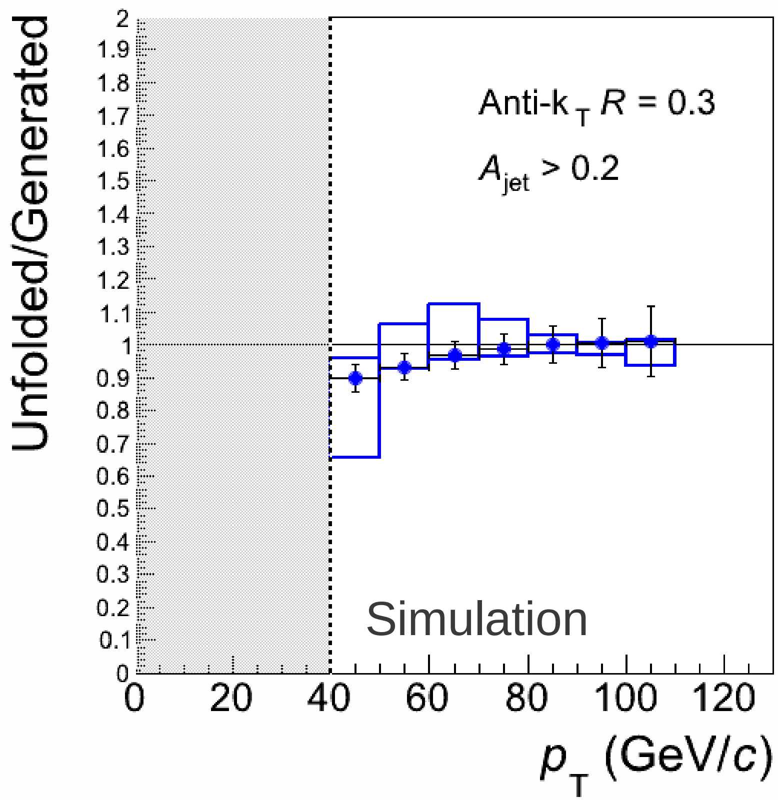


SVD and χ^2: efficient unfolding of combinatorial jets
Bayesian: not stable with a large number of combinatorial jets

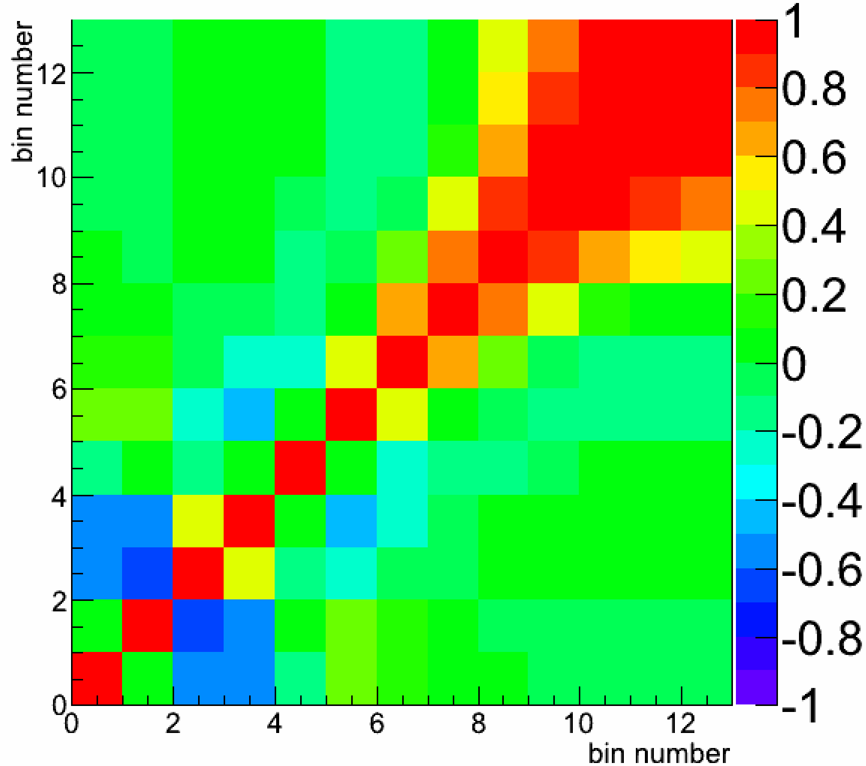
Systematics χ^2 method

Systematic unfolding uncertainty evaluated by varying:

- Unfolding p_T ranges
- Regularization
- Prior
- δp_T distribution



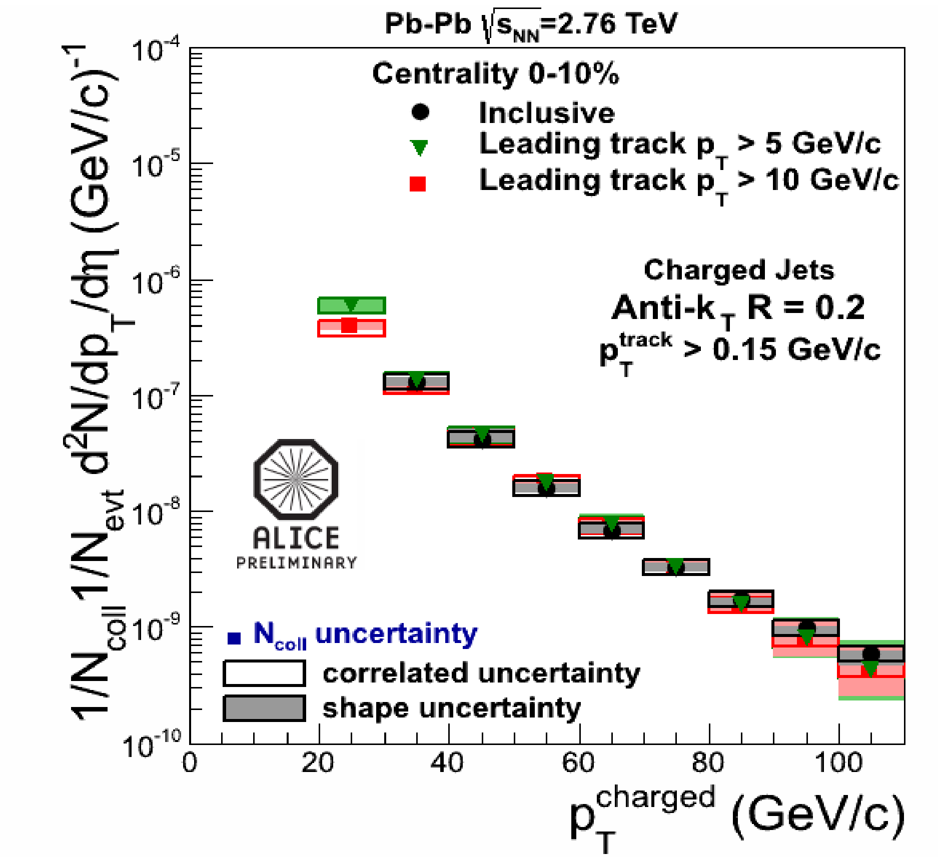
Pearson coefficients:
Correlation between bins



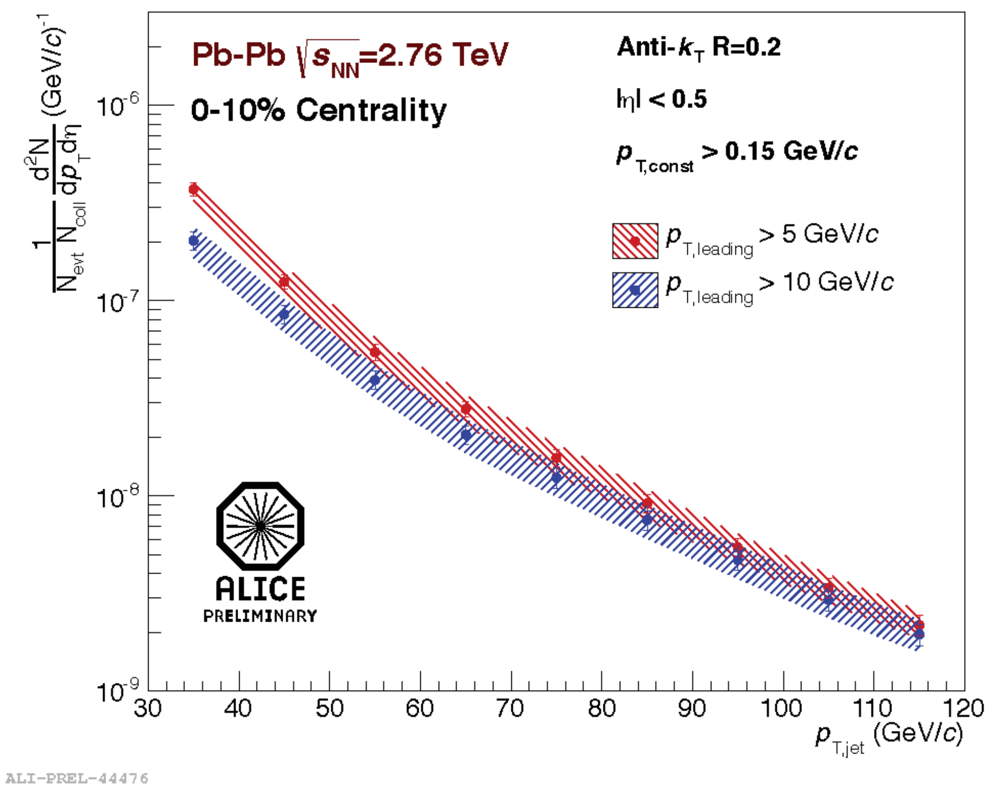
Figures from background model

Unfolded Jet Spectra

Charged Jets



Full Jets



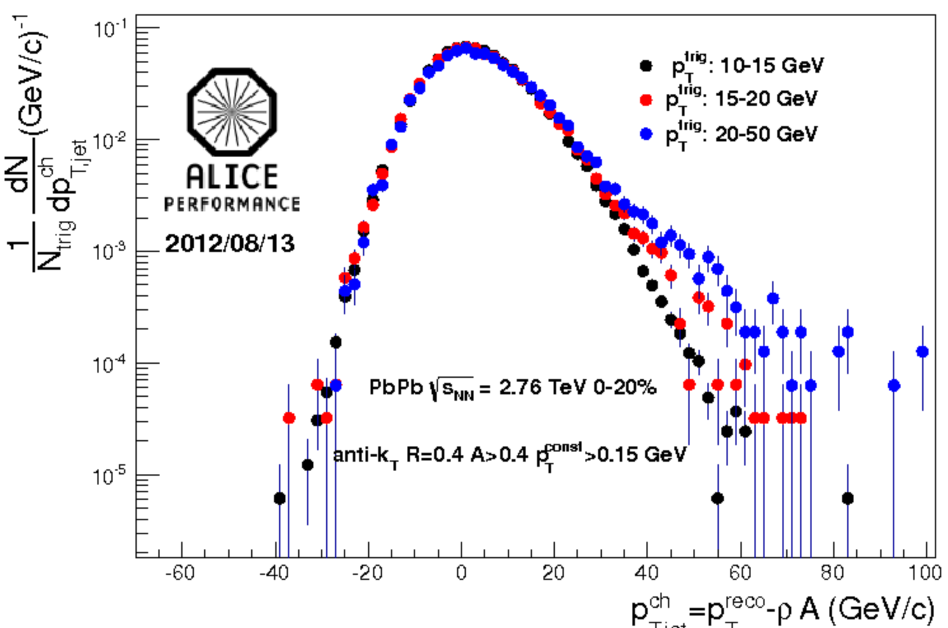
Fragmentation bias due to leading hadron selection agrees with PYTHIA and pp

Systematic uncertainties from unfolding and detector effects
Leading hadron bias introduces correlation with flow modulation → larger average background → small effect and taken into account in response matrix

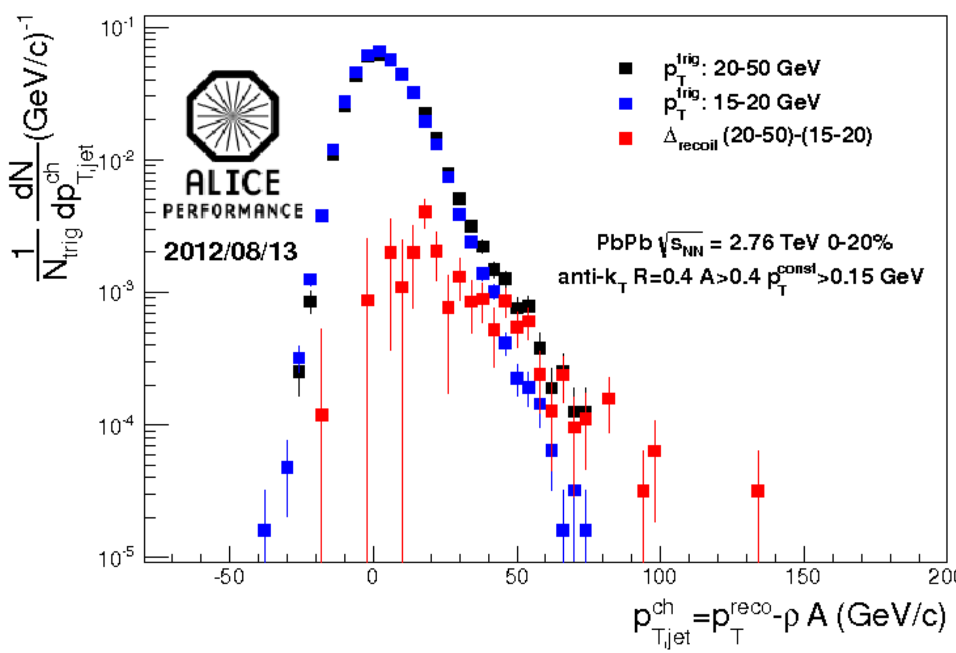
Recoil Jets

$$\Delta_{\mathrm{recoil}}\left(p_{\mathrm{T,Jet}}^{\mathrm{ch}}\right)=\frac{1}{N_{\mathrm{trig}}}\frac{\mathrm{d}N\left(p_{\mathrm{T,Jet}}^{\mathrm{ch}};p_{\mathrm{T}}^{\mathrm{min}},p_{\mathrm{T}}^{\mathrm{max}}\right)}{\mathrm{d}p_{\mathrm{T,Jet}}^{\mathrm{ch}}}-\frac{1}{N_{\mathrm{trig,ref}}}\frac{\mathrm{d}N\left(p_{\mathrm{T,Jet}}^{\mathrm{ch}};p_{\mathrm{T,ref}}^{\mathrm{min}},p_{\mathrm{T,ref}}^{\mathrm{max}}\right)}{\mathrm{d}p_{\mathrm{T,Jet}}^{\mathrm{ch}}}$$

- Hadron-triggered semi-inclusive recoil jet distribution
- No fake jets in Δ_{recoil} and no hard fragmentation bias
- Can go to larger *R* and lower p_T (w.r.t. Inclusive spectrum)
- Unfolding for background fluctuations and detector effects → same response as for inclusive analysis



ALI-PERF-41382



ALI-PERF-41389

Summary

- ALICE measures jets with constituents p_T>150 MeV/c
  - Average HI background is subtracted event-by-event
  - Background fluctuations, combinatorics and detector effects are corrected by unfolding

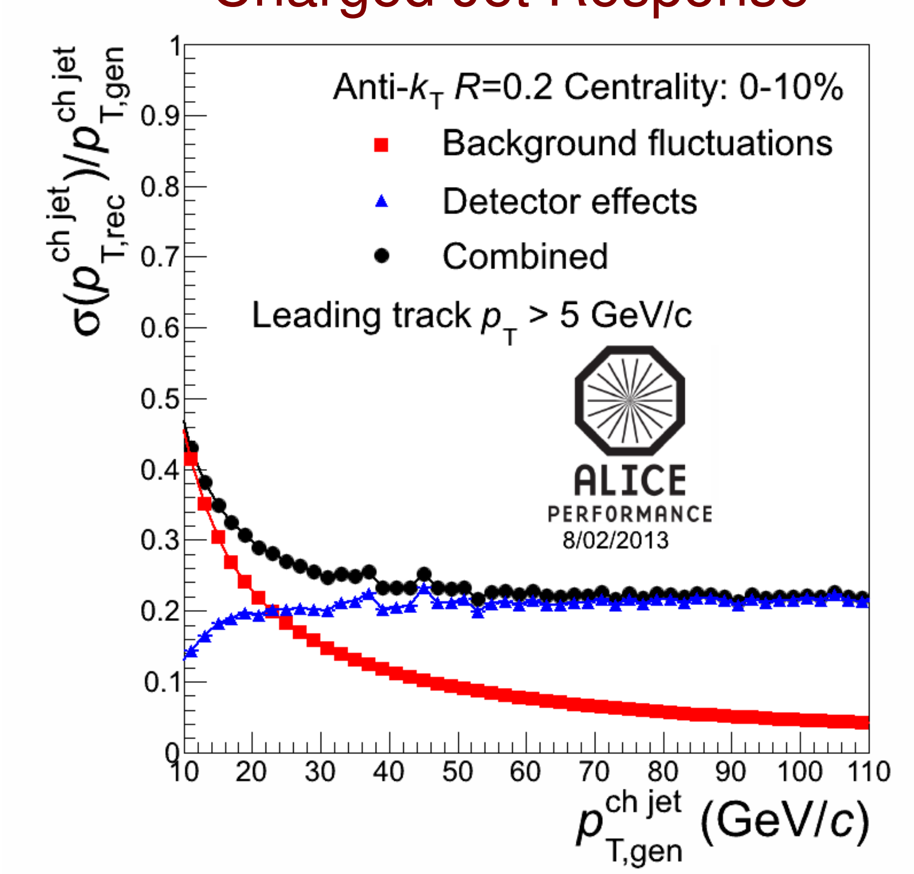
- Unfolded jet spectra (inclusive and recoil) as independent as possible from background and detector effects
  → should be able to compare with jet quenching MC without background effects
  - incorporating background in the model only needed for specific studies/scenarios: strong correlated effects in background

backup

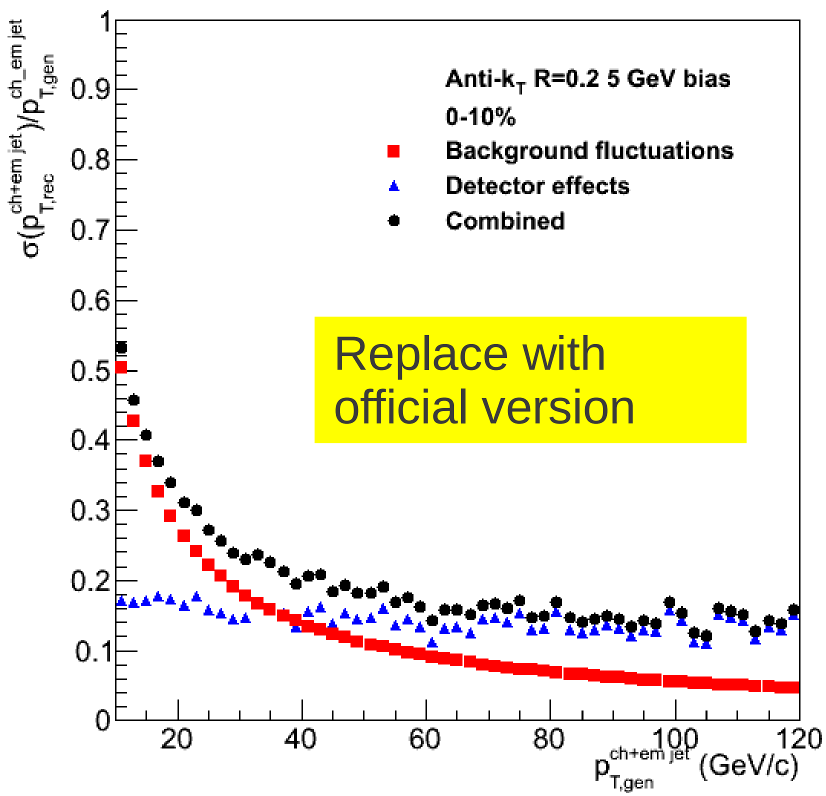
Jet p_T resolution ch vs full

- Detector effects and Background Fluctuations: Partially compensating effects
- Correction done at once via unfolding

Charged Jet Response



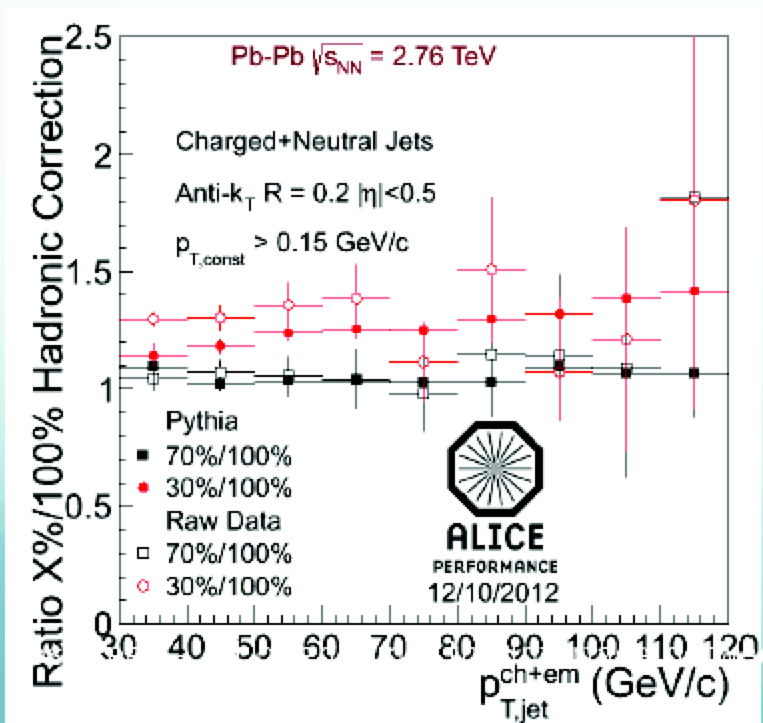
Full Jet Response



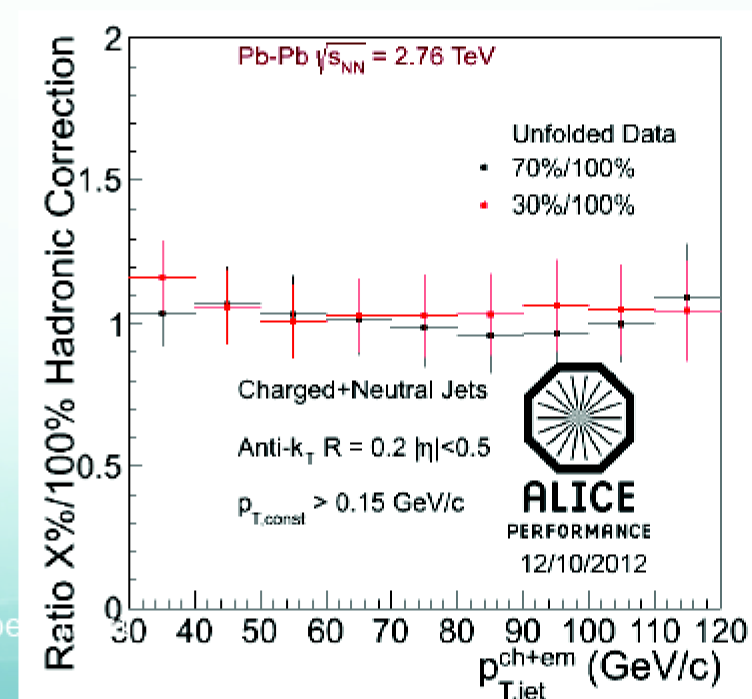
Hadronic Correction

- We need to correct the double counting of charged energy deposited in EMCal
  - Energy deposition is a statistical process
  - Corrected in unfolding

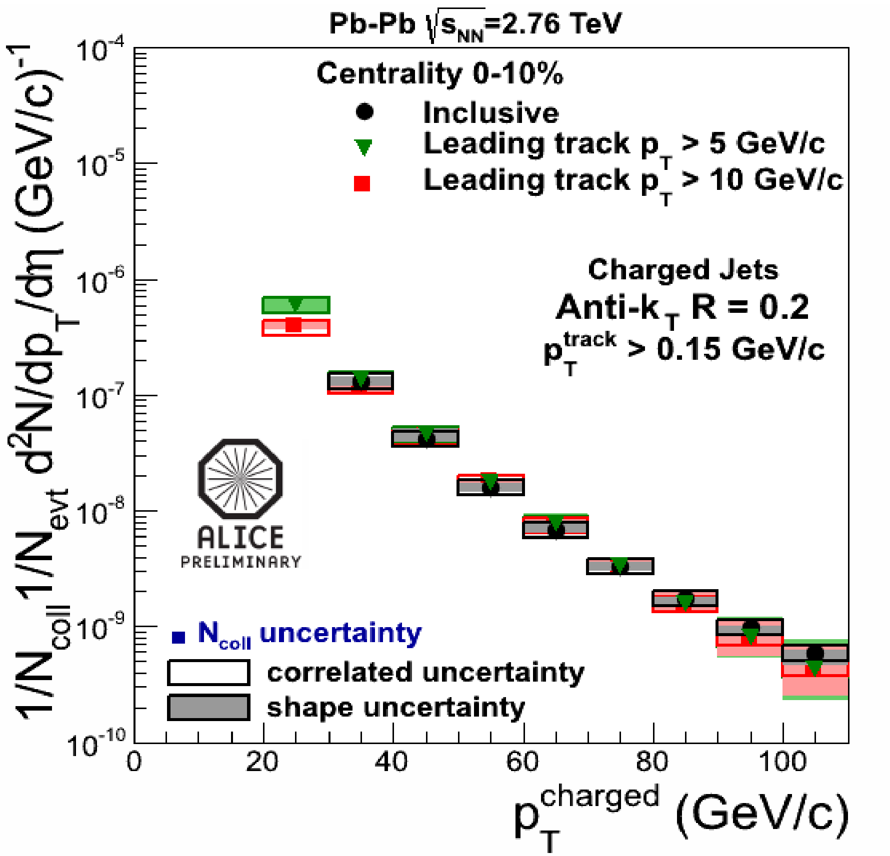
- Charged tracks matched to clusters and clusters are corrected by: $E^{cor}_{cluster} = E^{orig}_{cluster} - f \sum p^{matched}, \quad E^{cor}_{cluster} \geq 0$

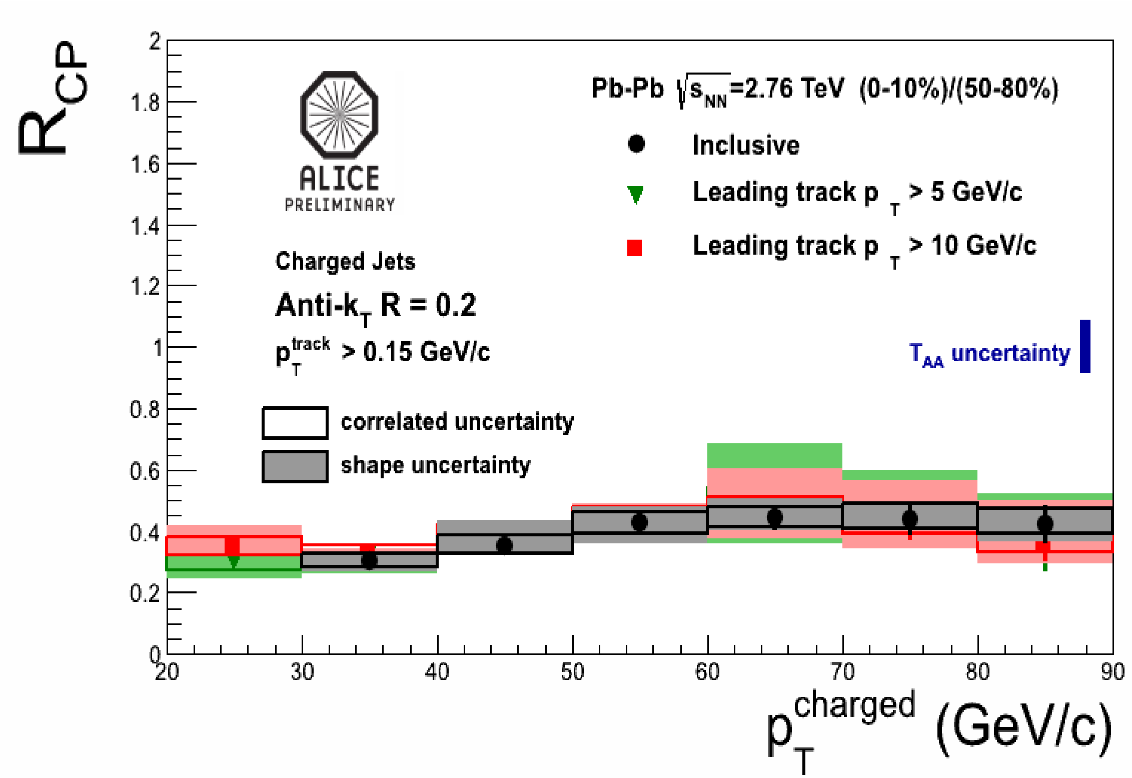


Unfolding



Jet Suppression



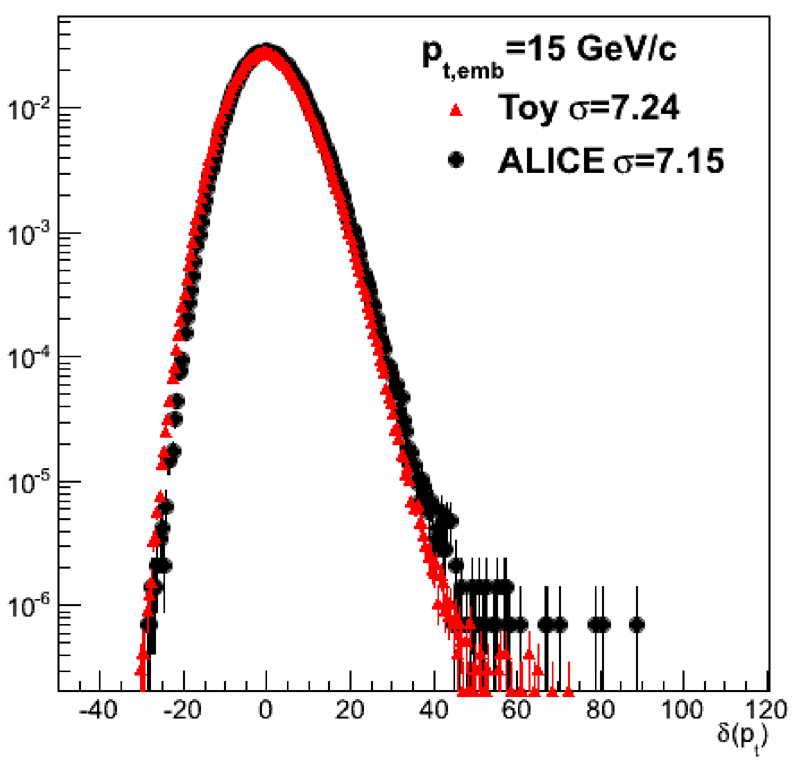


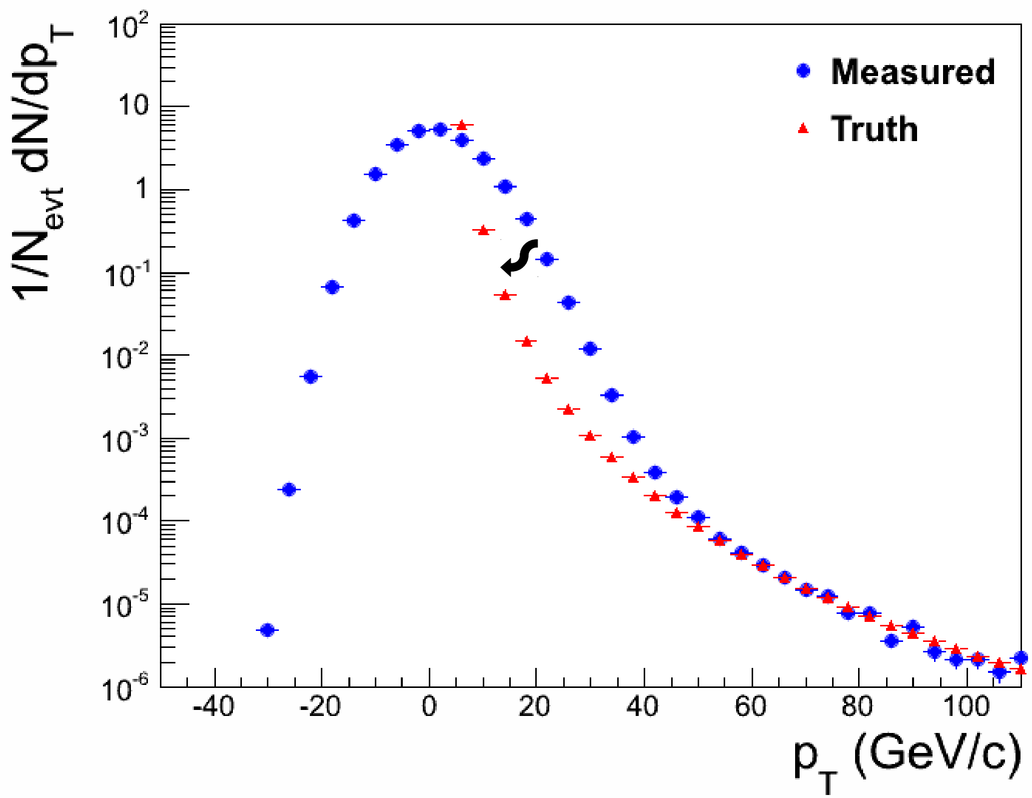
Corrected jet spectra: Leading track requirement → fragmentation bias at low p_T

Strong jet suppression observed. Fragmentation bias the same for central and peripheral events.

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.

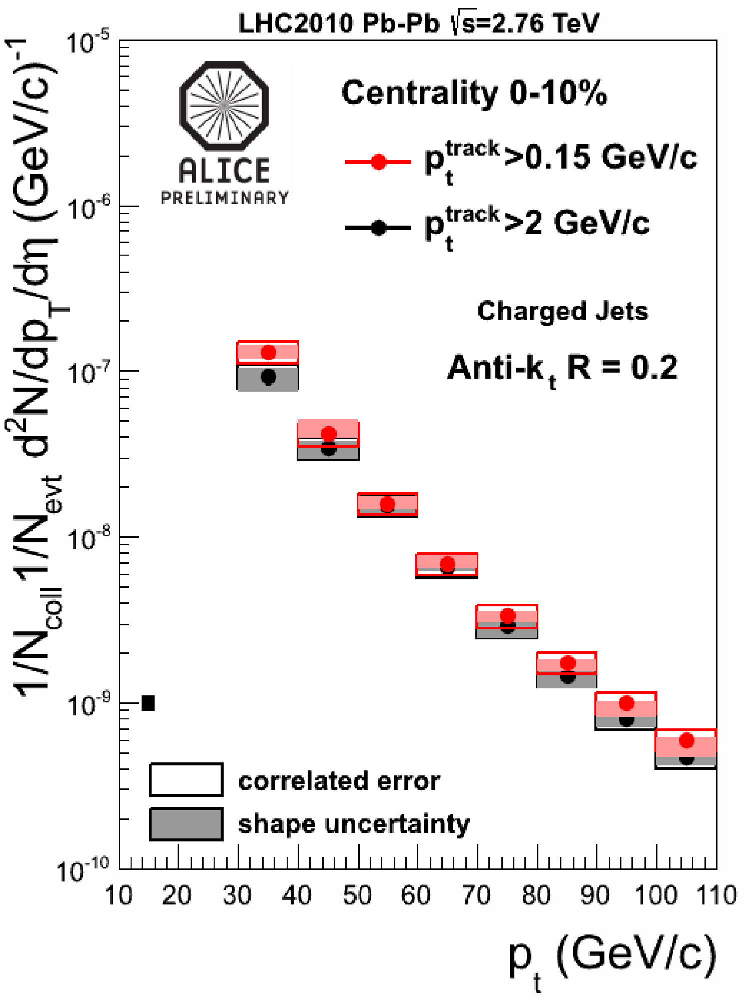


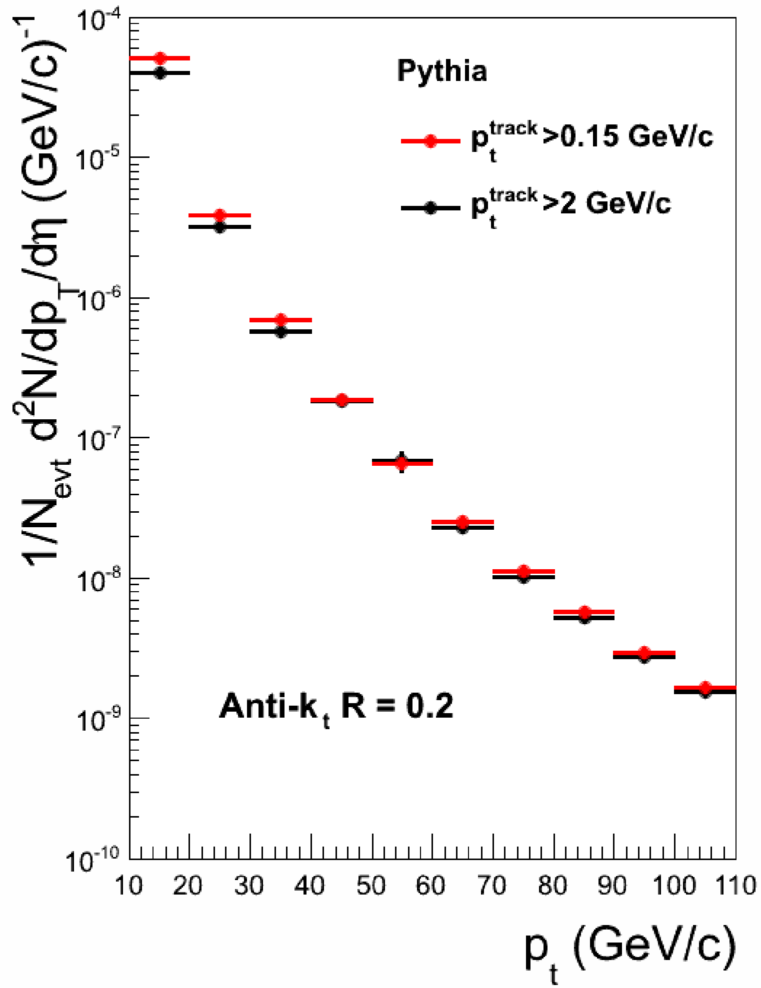


Jet Constituents

Spectra corrected for detector level effects for particles with $p_t > p_{t,min,track}$

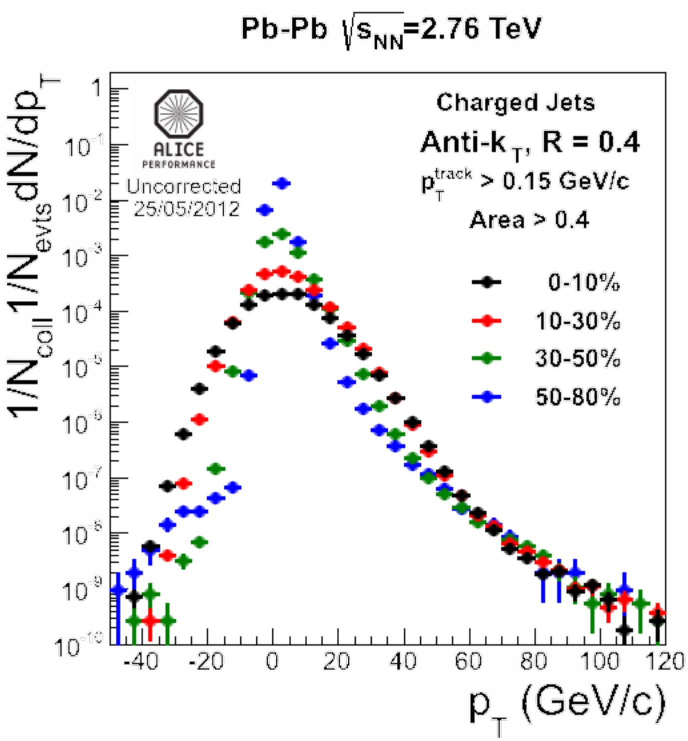
R=0.2: PbPb very similar to Pythia → shift of spectrum in pt for PbPb and Pythia. Not many soft particles in small cone of R=0.2.





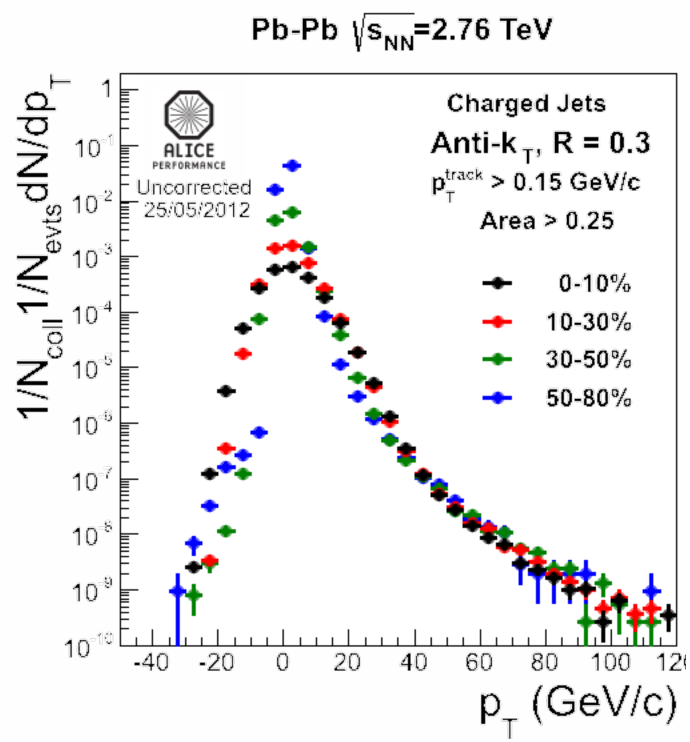
Uncorrected Jet Spectra

R=0.4



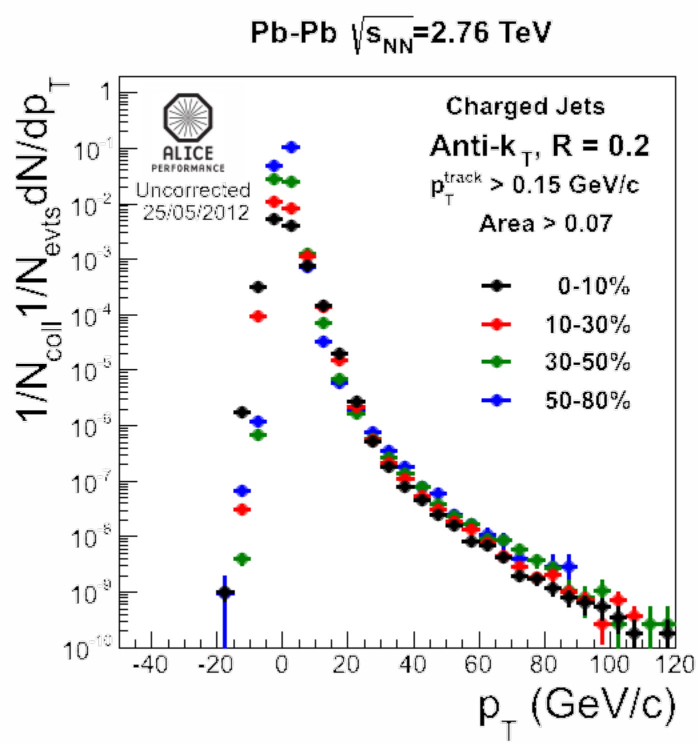
σ(δpt)~11 GeV

R=0.3



σ(δpt)~7 GeV

R=0.2



σ(δpt)~4.5 GeV

σ(δpt) values for central events

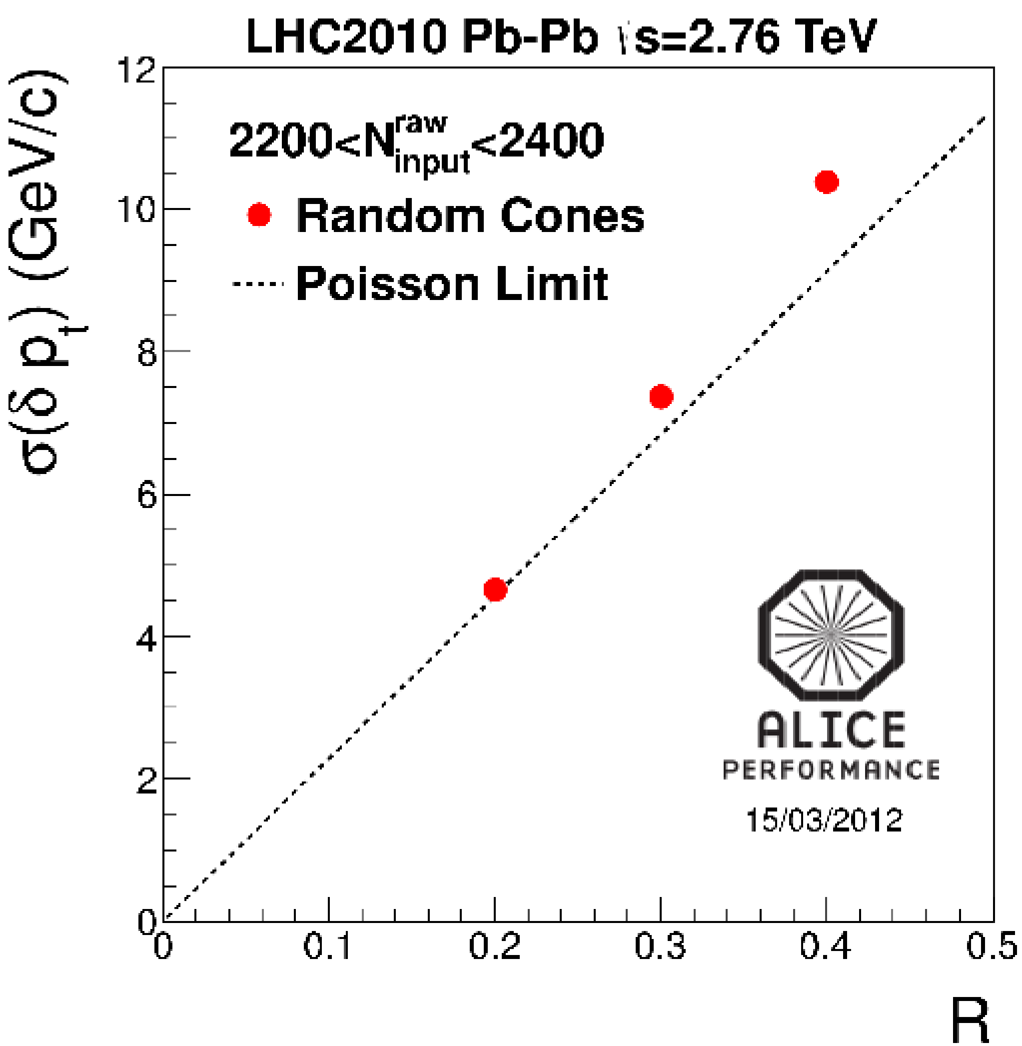
$p_{t,track}$ > 0.15 GeV/c

Smaller Jets → Less Background Fluctuations

Area dependence

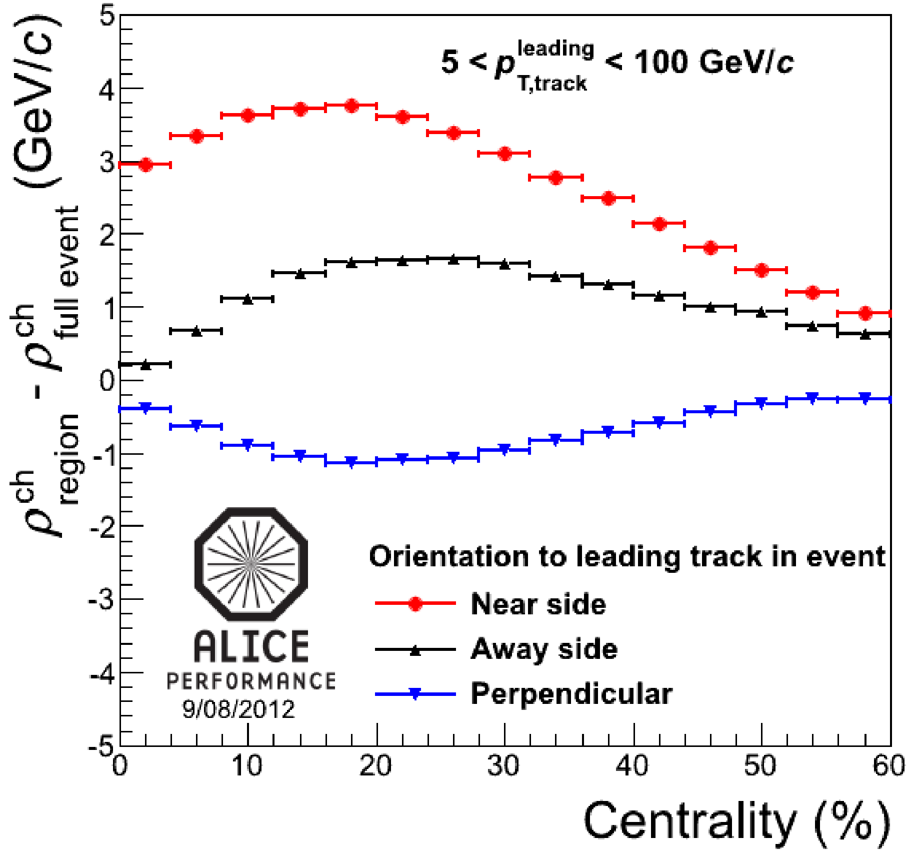
- Multiplicity bin typical for 10% most central events
- Reduced background fluctuations for smaller jet areas
- $$\sigma(\delta p_t) = \sqrt{N_A \cdot \sigma^2(p_t) + N_A \cdot \langle p_t \rangle^2}.$$
- Measured $\sigma(\delta p_T)$ larger than naive expectation from only statistical fluctuations

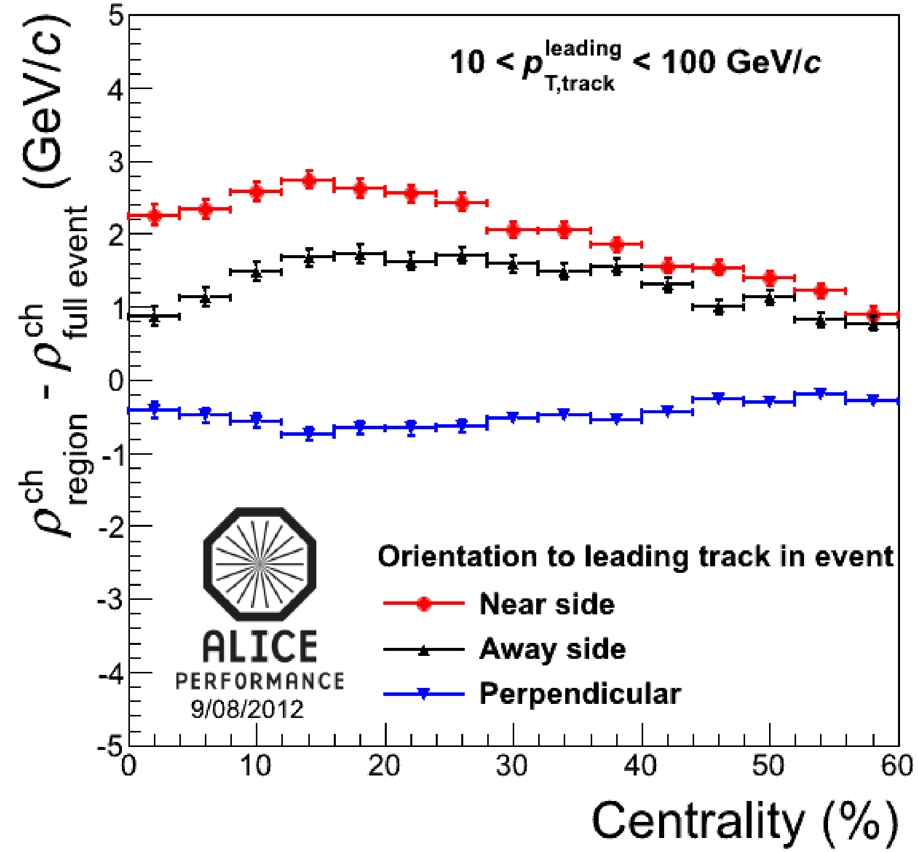
  → flow and hard jets



Flow effect on biased jets

Flow bias: high p_T hadron correlated to event and participant plane. Background density per unit area below jet is larger.
Magnitude of bias on inclusive jet spectra depends on p_T of trigger.

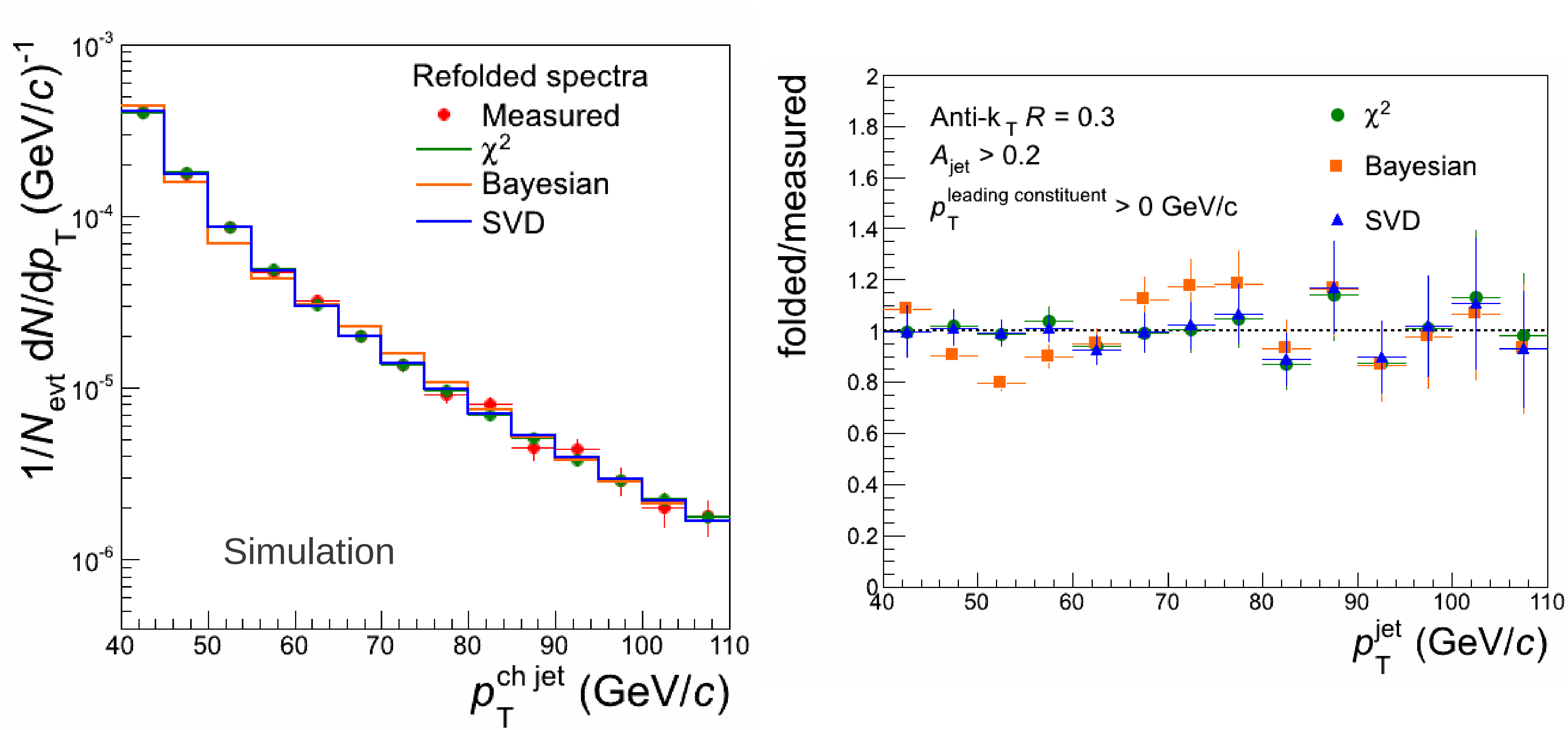




Hadron triggered jet spectra are corrected for the flow bias.

Unfolding Validation III

- Refolded spectra in background model



SVD and χ^2: refolded consistent with 'measurement'

Bayesian: due to large number of combinatorial jets fluctuating around measured