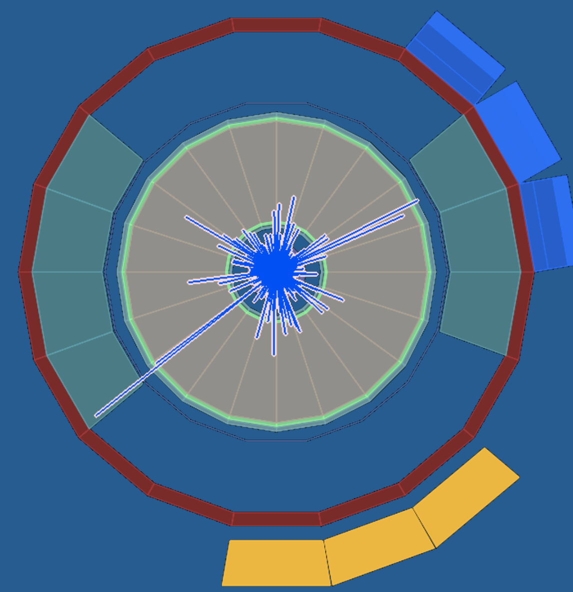
Jet Reconstruction and Jet Background Classification with the ALICE-Experiment in Pb+Pb collisions at the LHC

Quark Matter 2011

Annecy

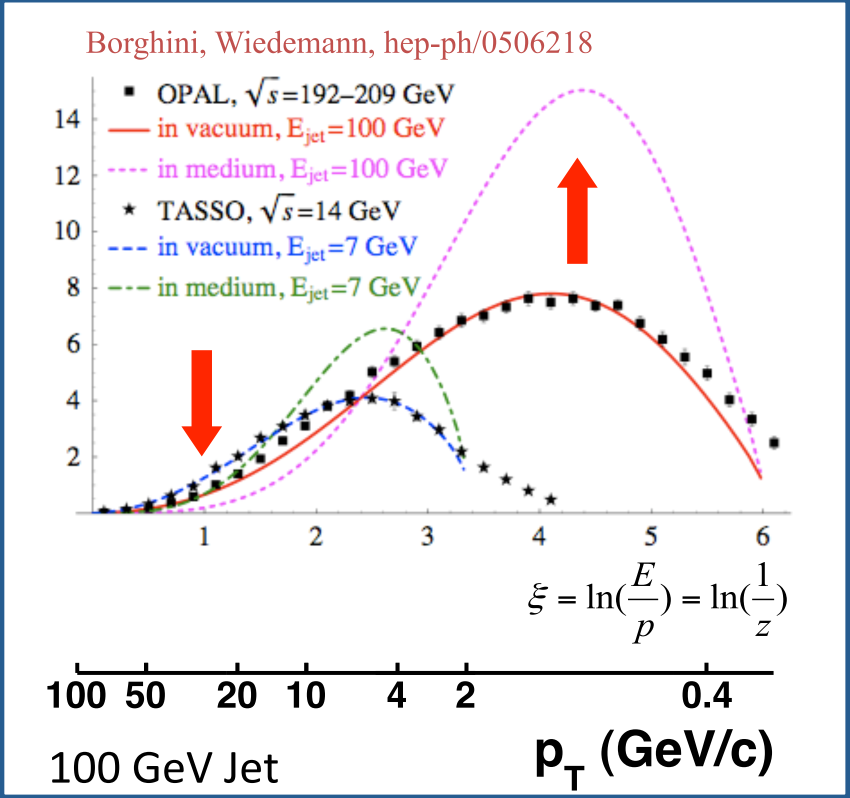


Christian Klein-Bösing
for the ALICE Collaboration

EMMI

Motivation

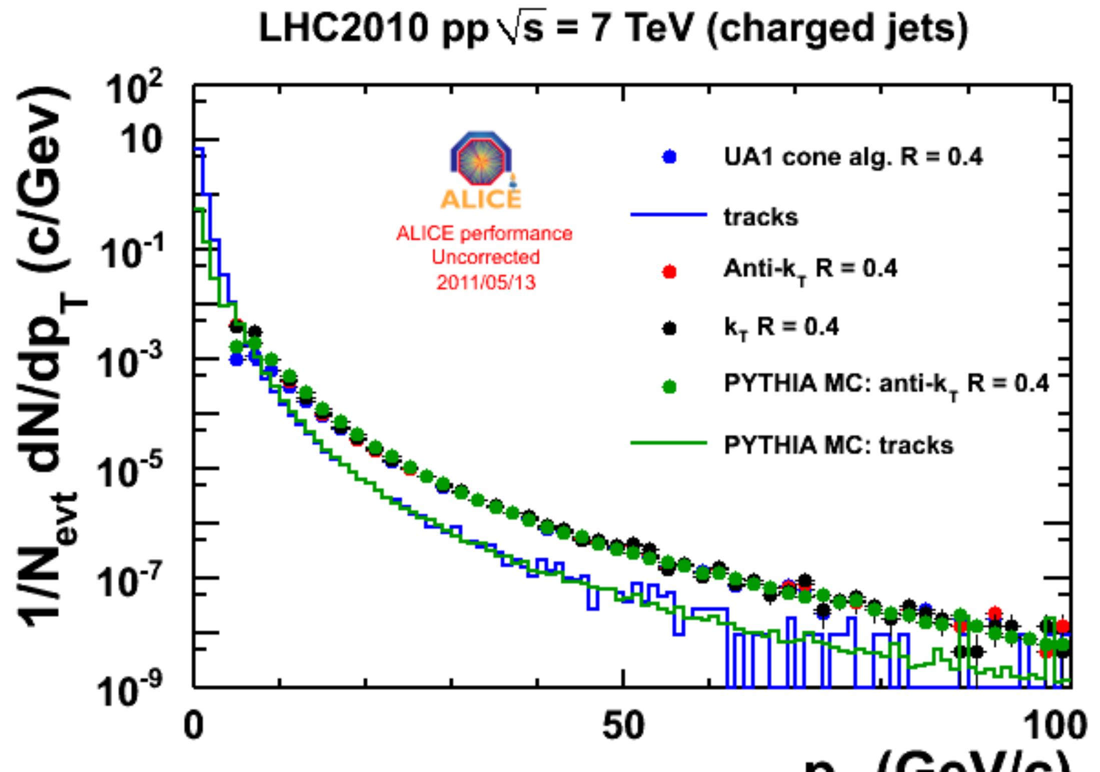
- Jets in pp closely related to parton properties
  - Reduced bias compared to single particle jet-like properties
- In Pb-Pb jets provide more direct access to medium modified parton fragmentation process
  - Change of transverse and longitudinal jet structure
  - Is it there at all? Or do jets simply heat system?



- Essential for interpretation of jet observables, discern
  - medium influence on partons
  - and **underlying event** influence on jet reconstruction

Jet Reconstruction in pp with ALICE

- **2009/2010**
  - pp @ 0.9 and 7 TeV
  - Pb-Pb @ 2.76 TeV
  - Based on charged tracks $|\eta| < 0.9$
  - $|\eta_{jet}| < 0.5$
- **2011**
  - pp @ 2.76 and 7 TeV
  - Fully installed EMCAL
  - Charged + neutral

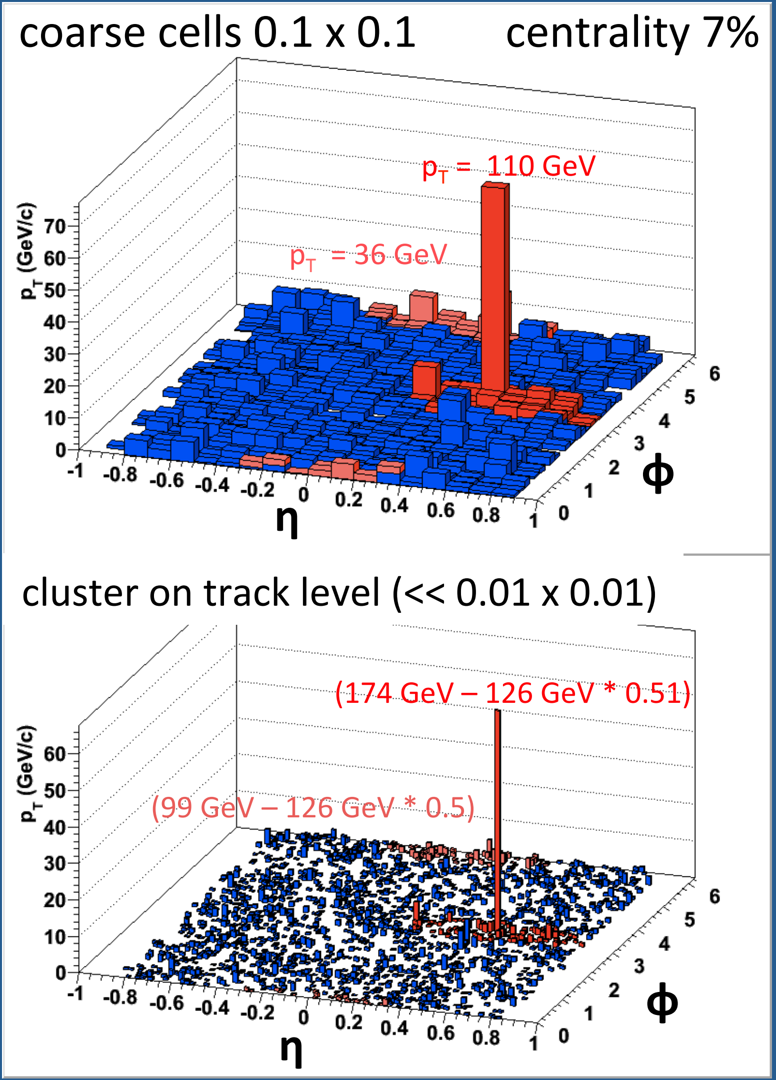


2.76 TeV Posters Thursday:
Rongrong Ma board #35 and Sidhart Prasad board #23

Jet finding with charged tracks in pp well understood.
All jet finders agree for p_T > 20 GeV, reproduced in full simulation

Jet Finding in Pb-Pb with ALICE

- **Focus on sequential recombination**
  - FastJet (Phys. Lett. B **641** (2006) 57)
  - k_T: background density
  - anti-k_T: stable area, signal jets
- Clustering on particle level
  - ALICE TPC: high precision, uniform ηϕ-efficiency
- Low momentum cut off **(150 MeV)**
- Stronger affected by fluctuations



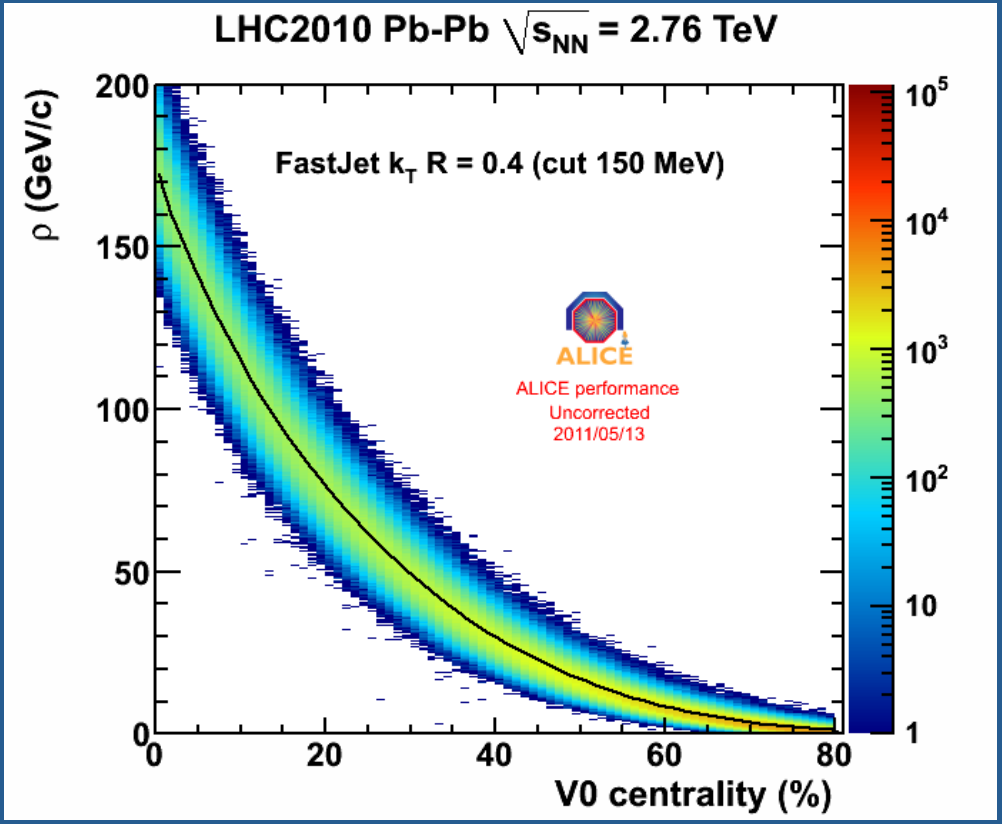
ALICE:
Minimize bias on hard fragmentation/unquenched.
Resolve the detailed structure of jets and jet background sources.

Background Subtraction:

$$p_{T,jet} = p_{T,jet}^{rec} - \rho \times A_{jet} \pm \sigma \times \sqrt{A_{jet}}$$

- ρ: Median of p_T/area, determined event by event via k_T clustering
  - Here k_T clusters $|\eta| < 0.5$, excluding two leading clusters
  - Advantage: Robust statistical measure
- σ: background fluctuation needs unfolding

- Typical size for R = 0.4: A ≈ 0.5
  - 50 – 100 GeV/c background for 0-10%



Strong change within central bin.

Background Subtraction:

$$p_{T,jet} = p_{T,jet}^{rec} - \rho \times A_{jet} \pm \sigma \times \sqrt{A_{jet}}$$

- ρ: Median of p_T/area, determined event by event via k_T clustering
  - Here k_T clusters $|\eta| < 0.5$, excluding two leading clusters
  - Advantage: Robust statistical measure
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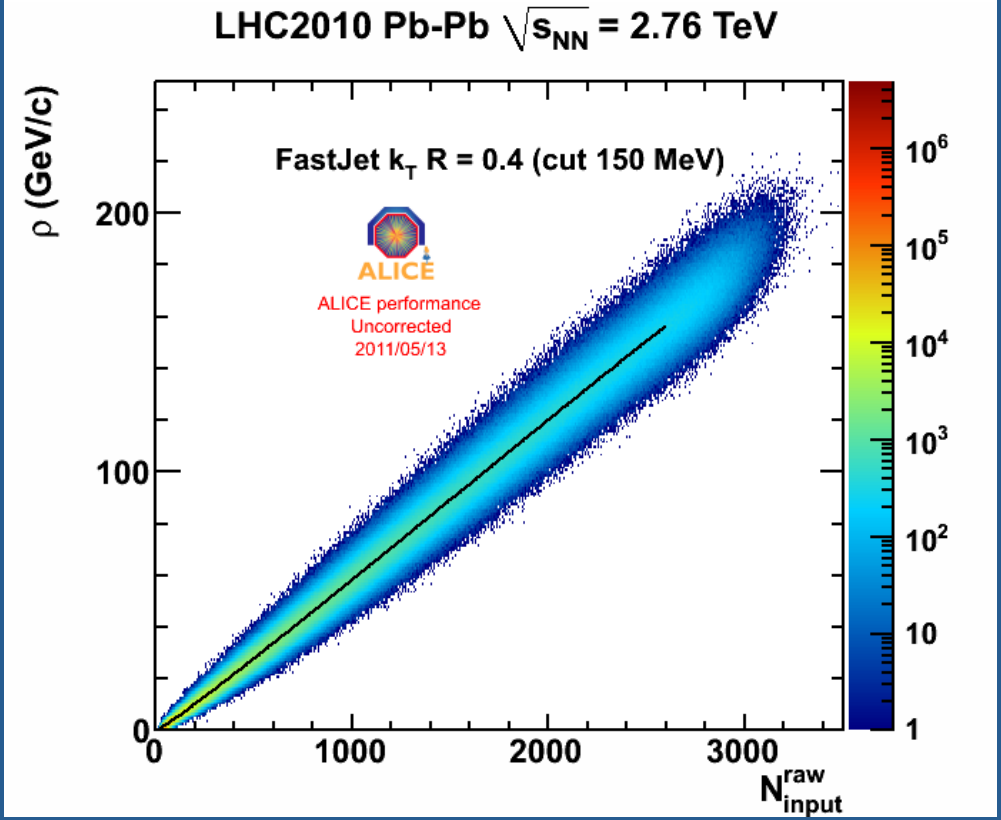
- Natural connection of ρ to event properties/ characteristics of p_T spectrum
  - $\rho \approx N \langle p_T \rangle$

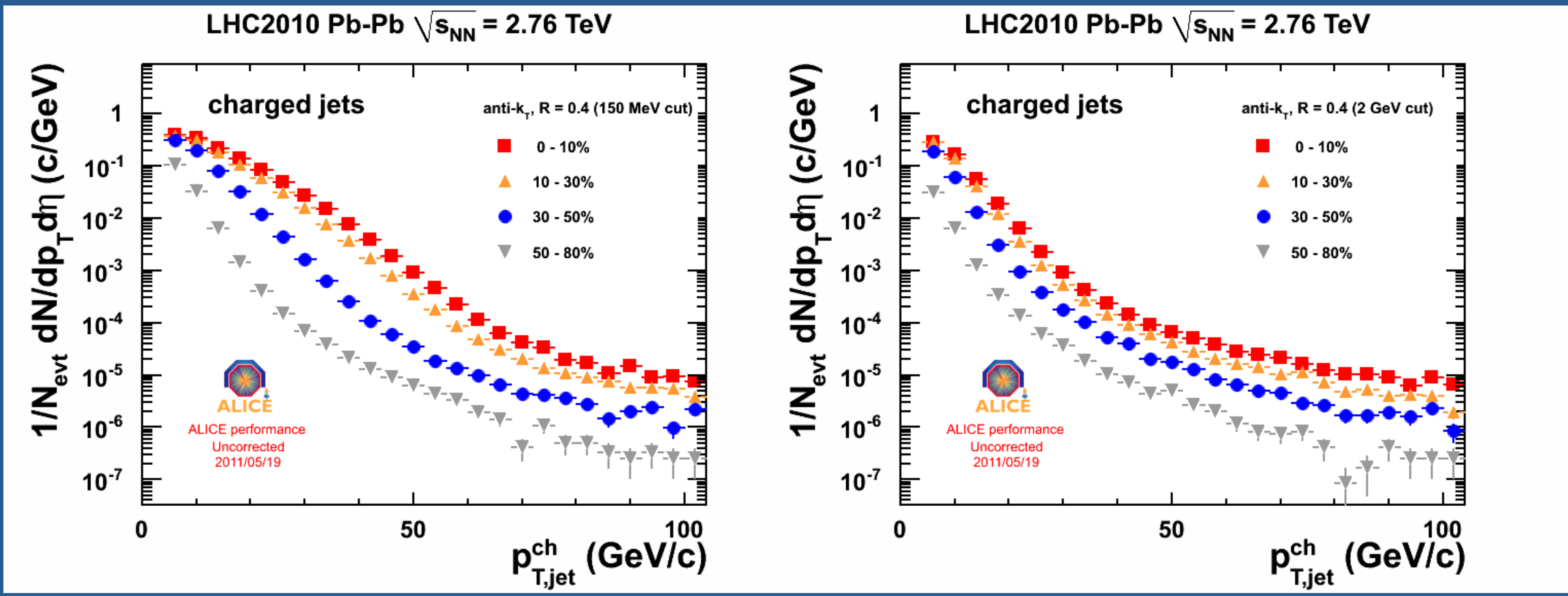


Linear correlation with input raw multiplicity.

Raw Charged Jet Spectra Below 100 GEV

Jets with low p_T track cut-off (150 MeV/c)

Jets with high p_T track cut-off (2 GeV/c)



$$\mathbf{p^{rec}_{T,jet}} - \rho \times \mathbf{A}$$

Spectral shape strongly affected by fluctuations for low p_T cut off.
Trade-off between bias from background fluctuation and bias on fragmentation.

Quantification of Background Fluctuations

- Residuals of well defined probes put into real Pb-Pb events

$$\delta \mathbf{p_T} = \mathbf{p_{T,rec}} - \mathbf{A} \cdot \rho - \mathbf{p_{T,probe}}$$

- Probes:
  - Random cones (Fixed area!)
    - Using full jet acceptance (< 0.5)
    - Excluding area around 2 leading jets (D > 1.0)
    - In randomized event
  - Embedded single particles
    - Delta probe for jet finding (high p_T seed, robust area)
  - Embedded jets from full detector simulation p+p @ 2.76 TeV (PYTHIA+GEANT)
  - Embedded quenched jets

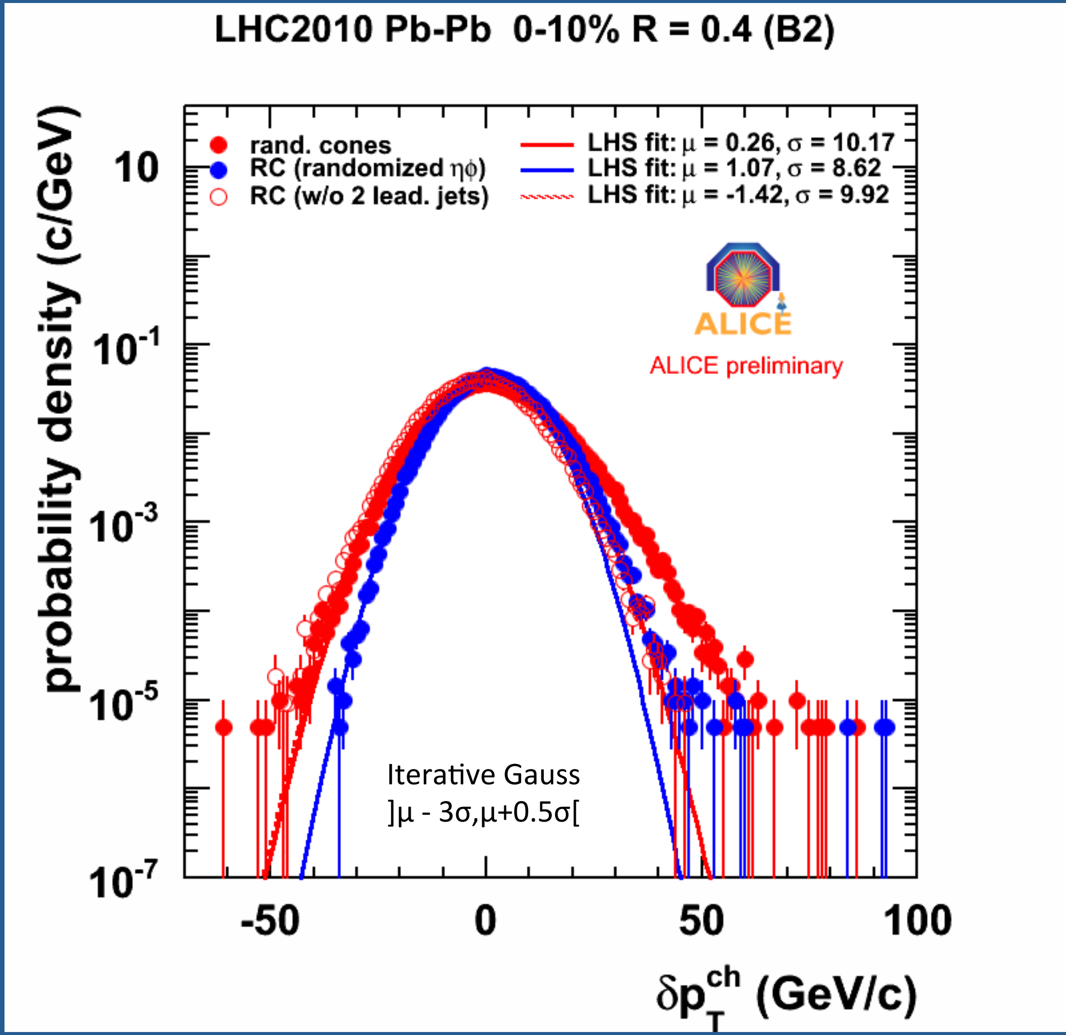
no bias, no back-reaction

↓

largest bias,
largest back-reaction

Different methods to test specific influences of background, i.e. event properties vs. jet finder specific back-reaction.

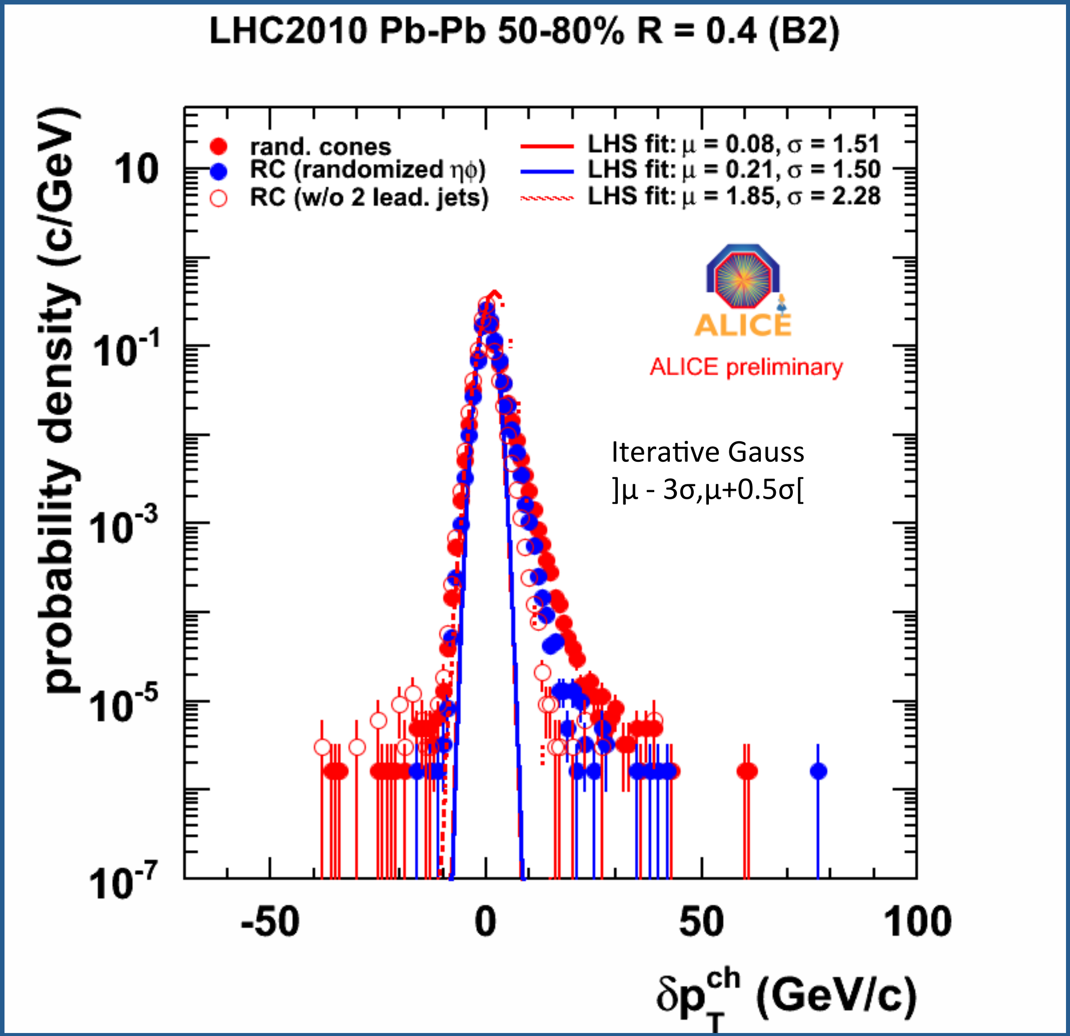
Random Cones (0-10%)



- $\Sigma\ p_T$ in random cone R = 0.4
- Right hand side tail
  - Smaller for randomized ηϕ
  - Smaller when leading jets are excluded
- Left hand side tail
  - Insensitive to jet removal
- Iterative Gaussian fit:
  - Measure of width of LHS only
  - Lower limit on total fluctuation
  - Visualize non Gaussian fluctuations

Right side: Jet origin
Left side: Correlated region-to-region fluctuations

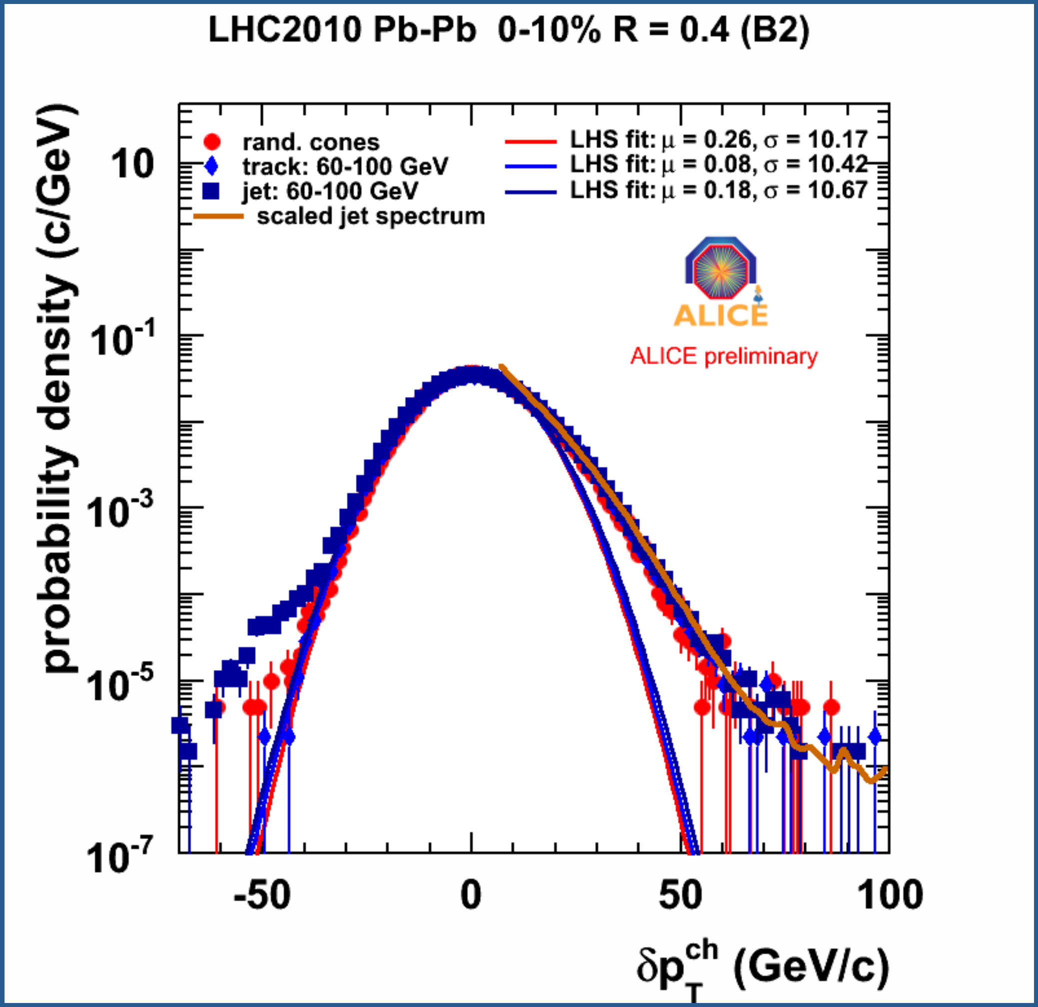
Random Cones (50-80%)



- Iterative Gauss lower limit for all region-to-region fluctuations
- Non Gaussian contribution for lower multiplicities and due to shape of p_T spectrum
  - Other measures:
    - RMS
    - Quartile ranges (robust statistics)

Right side: Jet origin
Left side: Region-to-region fluctuations

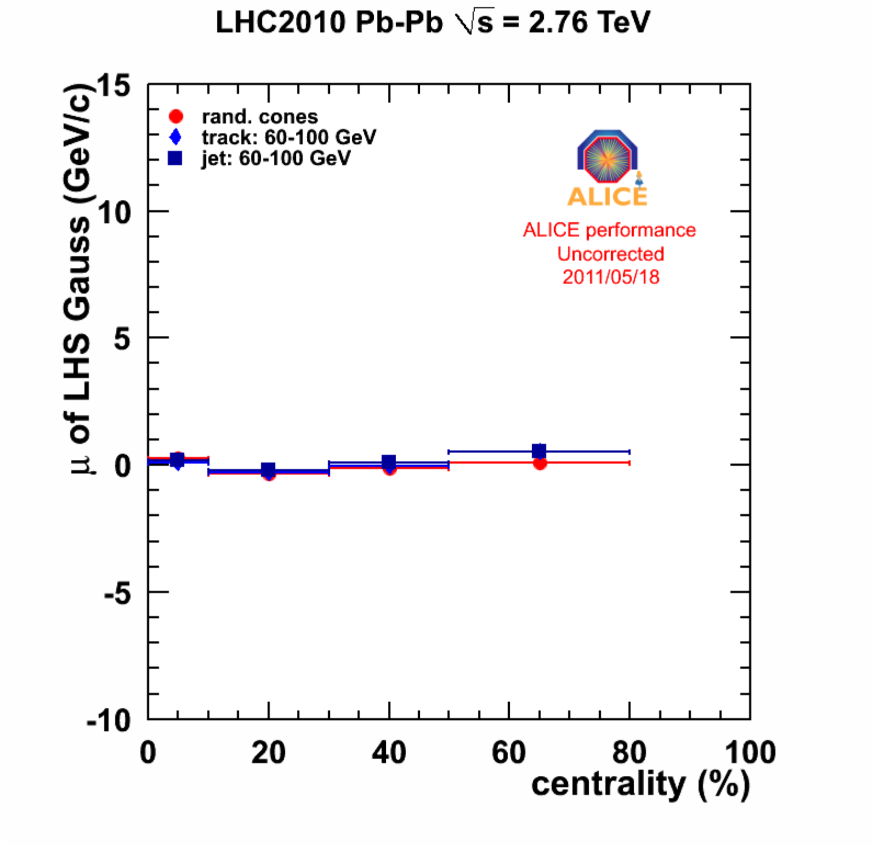
Comparing Different Probes (0-10%)

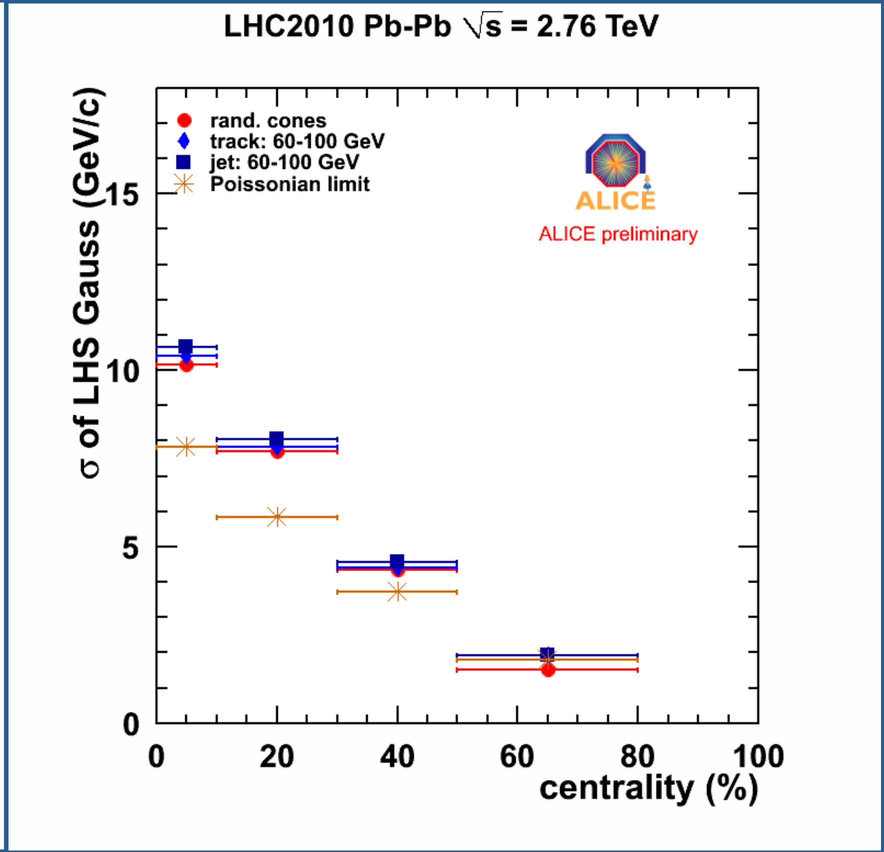


- Random cones
- Embedding of single high p_T tracks
- Embedding of fully simulated PYTHIA jets
- Jet spectrum scaled to 20 GeV
  - Like embedding $p_T \approx 0$ probe
  - Shows little separation of jet signal below 100 GeV

General agreement between all methods,
Background subtraction works: $\mu \approx 0$
Shape of "jet" spectrum similar.

Charged Background Evolution with Centrality

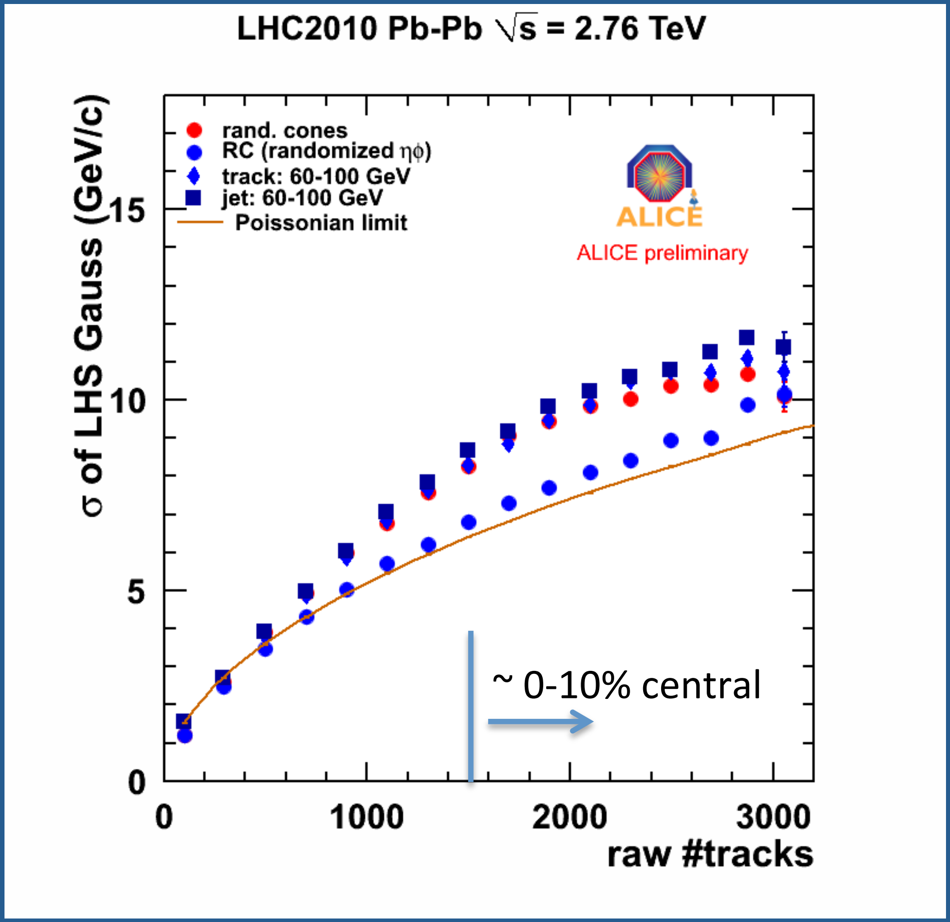




Stable background subtraction, fluctuations larger than pure Poissonian limits:

$$\mathrm{RMS}(\delta p_T) = \sqrt{N} \cdot \sqrt{\langle p_T \rangle^2 + \mathrm{RMS}(p_T)^2}$$

Charged Background Fluctuations Evolution with Multiplicity



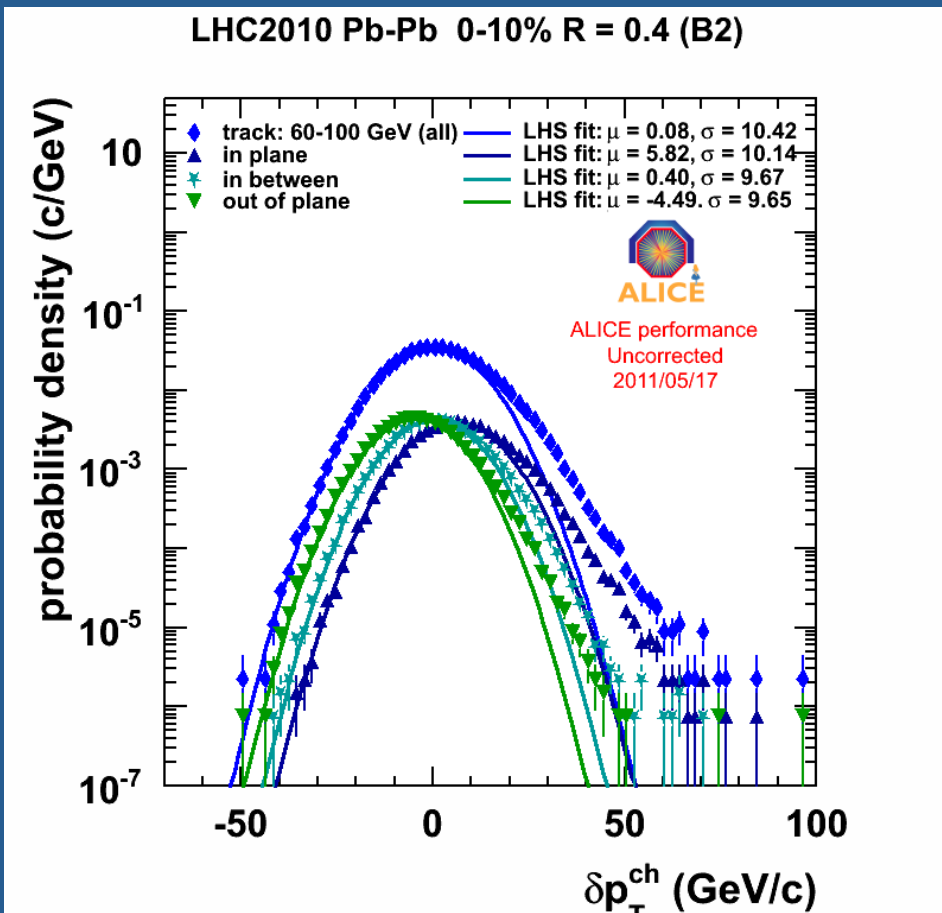
Randomized events approach limit (N.B. rho taken from real event).

Expected increase with raw number of inputtracks, almost 70% in 0-10% centrality

Poissonian limits from raw p_T spectrum

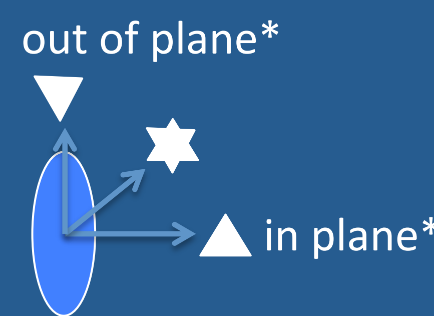
Efficiency corrected (Ideal detection):
Larger <N>, change in <p_T> and RMS(p_T)
➔ 8% increase in fluctuations, but also improved jet signal

Event Plane Dependent Jet Background



Event wise ρ estimate does not account for region-to-region correlated soft background:

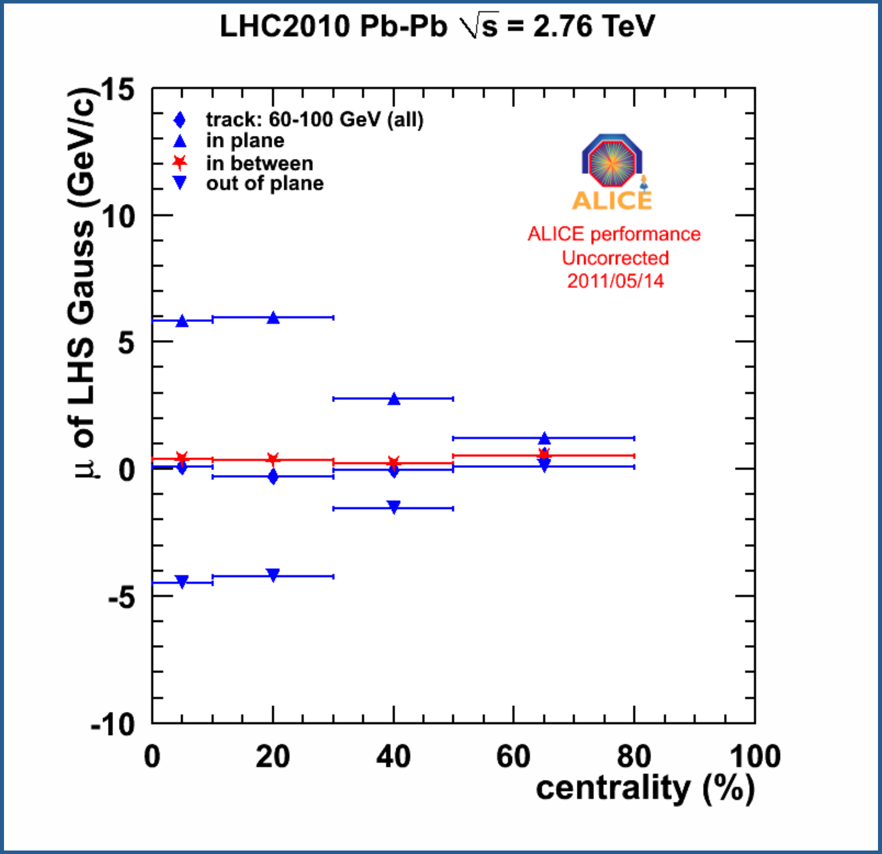
- Change of N and $<p_T>$, i.e.due to collective flow
- Essential to study path-length dependence of jet quenching.

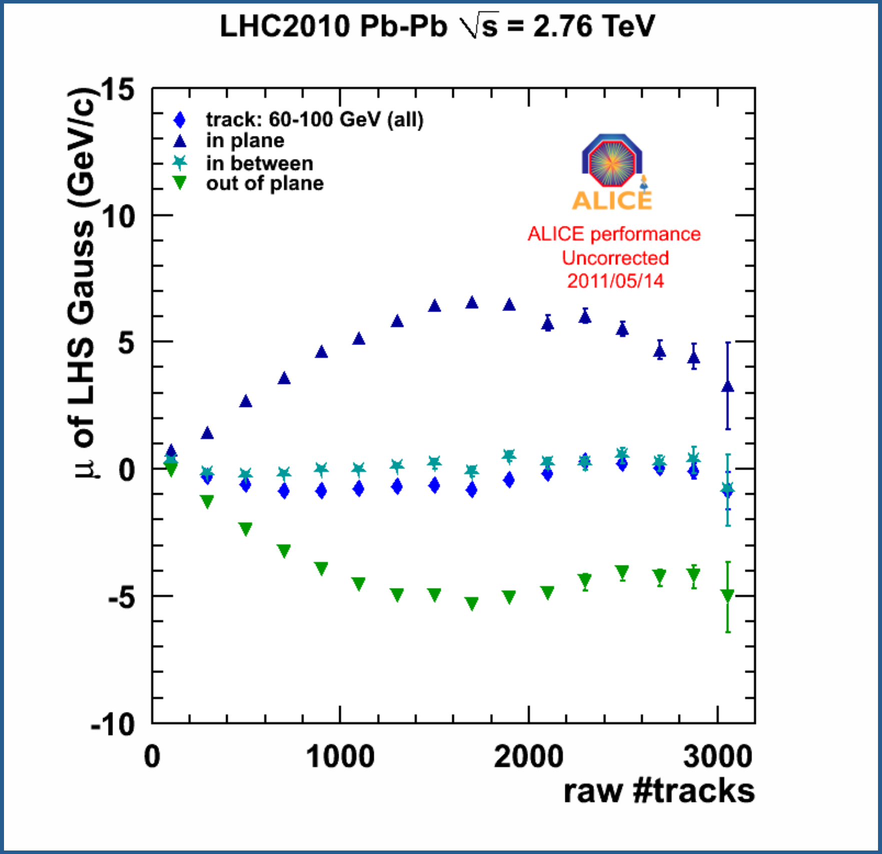


*event plane determined with tracks: possible jet bias

Significant shift of background jet energy scale, depending on orientation to event plane. One source of broadening.

Event Plane Dependent Background: Evolution of Mean

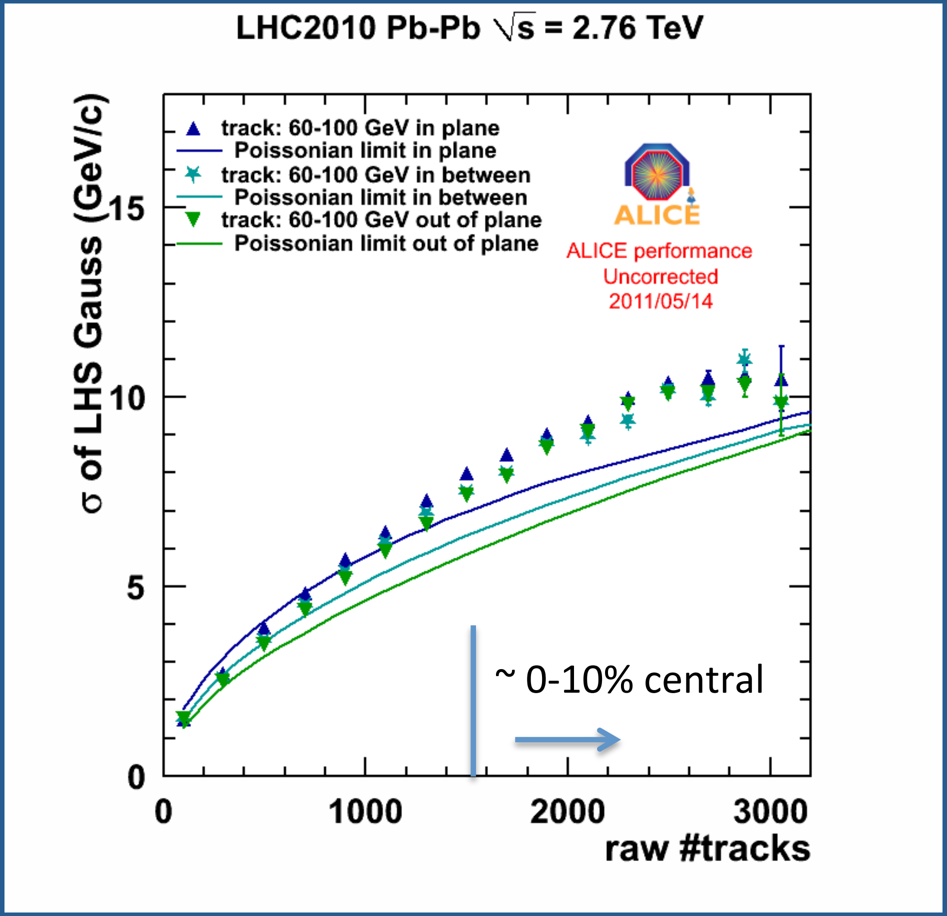




Large change inbackground subtracted jet energy scale.

N.B: Effect scales with ≈ $v_2 * \Sigma p_T$, hence still important for central collisions.

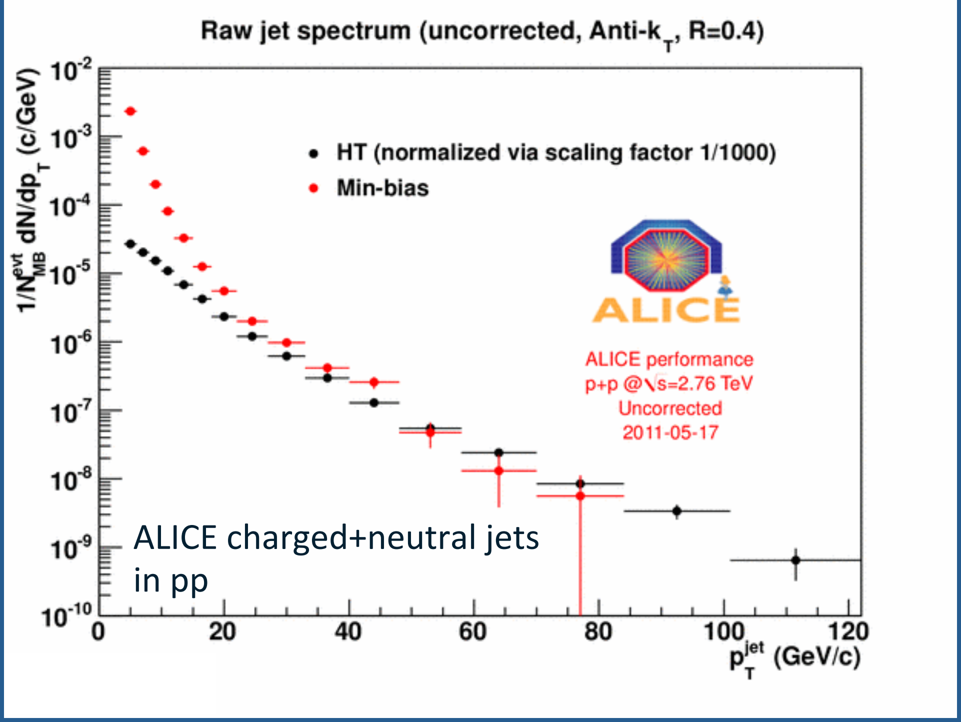
Event Plane Dependence: Evolution of Width



Width reduced compared to inclusive fluctuation, similar for all EP bins, ordering explained by change of <p_T>, <N>. (additionally washed out by size of jet).

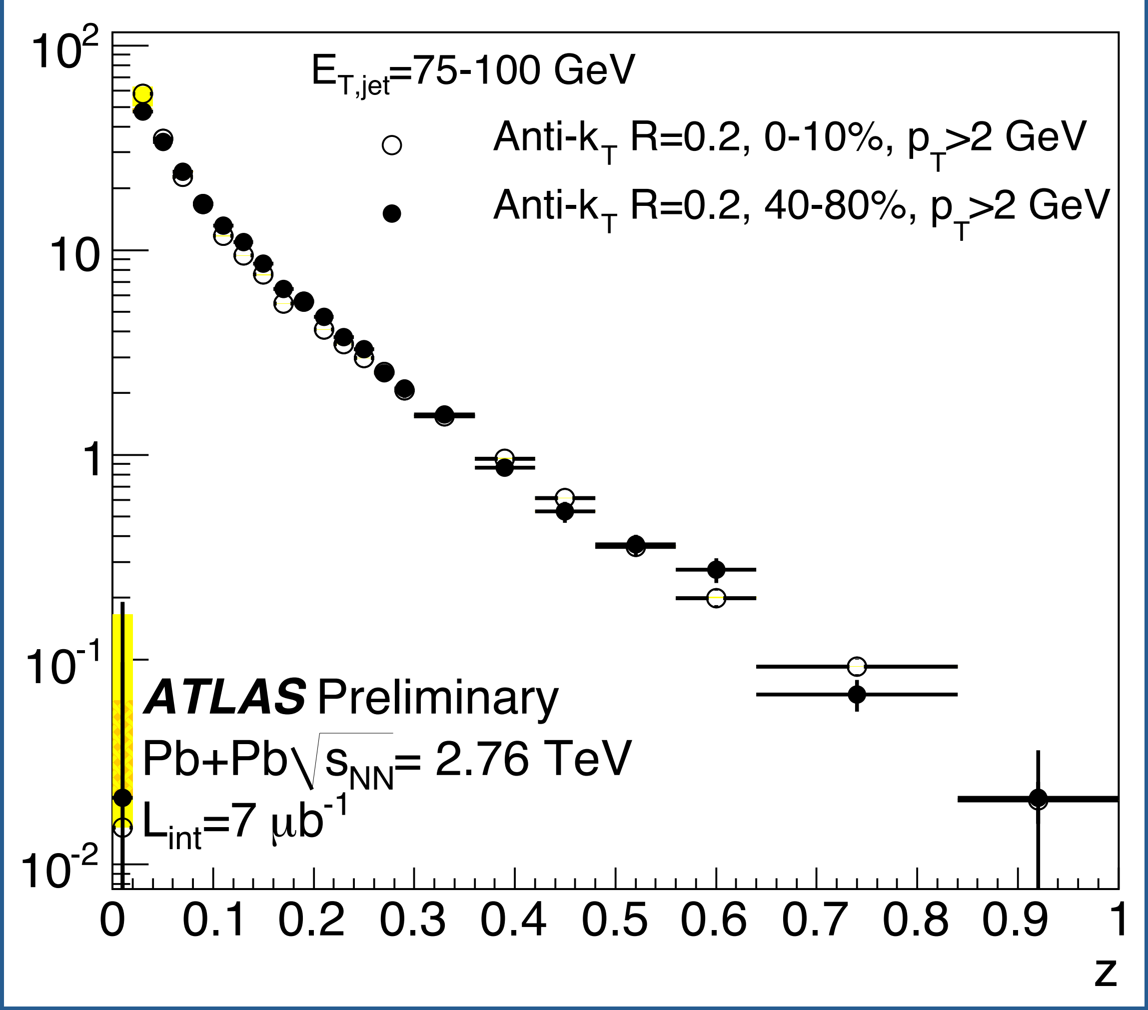
Summary and Outlook

- Understanding of jet background and its fluctuation essential for understanding of jet modification in heavy ion collisions
  - Direct impact e.g. on jet asymmetry (See e.g. Cacciari et. al arxiv:1101.2878) and understanding of energy dissipation
- First detailed assessment of (charged) background fluctuations in Pb-Pb collisions at the LHC
  - Gaussian width of fluctuation > 10 GeV/c in central PbPb
  - Non-Gaussian tail of fluctuations challenging for unfolding
- Region-to-region correlations change the background energy scale
  - Basis for improved jet background resolution
  - Important for path-length dependent jet measurement
- Next: Unfolded charged jet spectra in Pb-Pb for low jet p_T
- pp reference at 2.76 TeV with full calorimetry

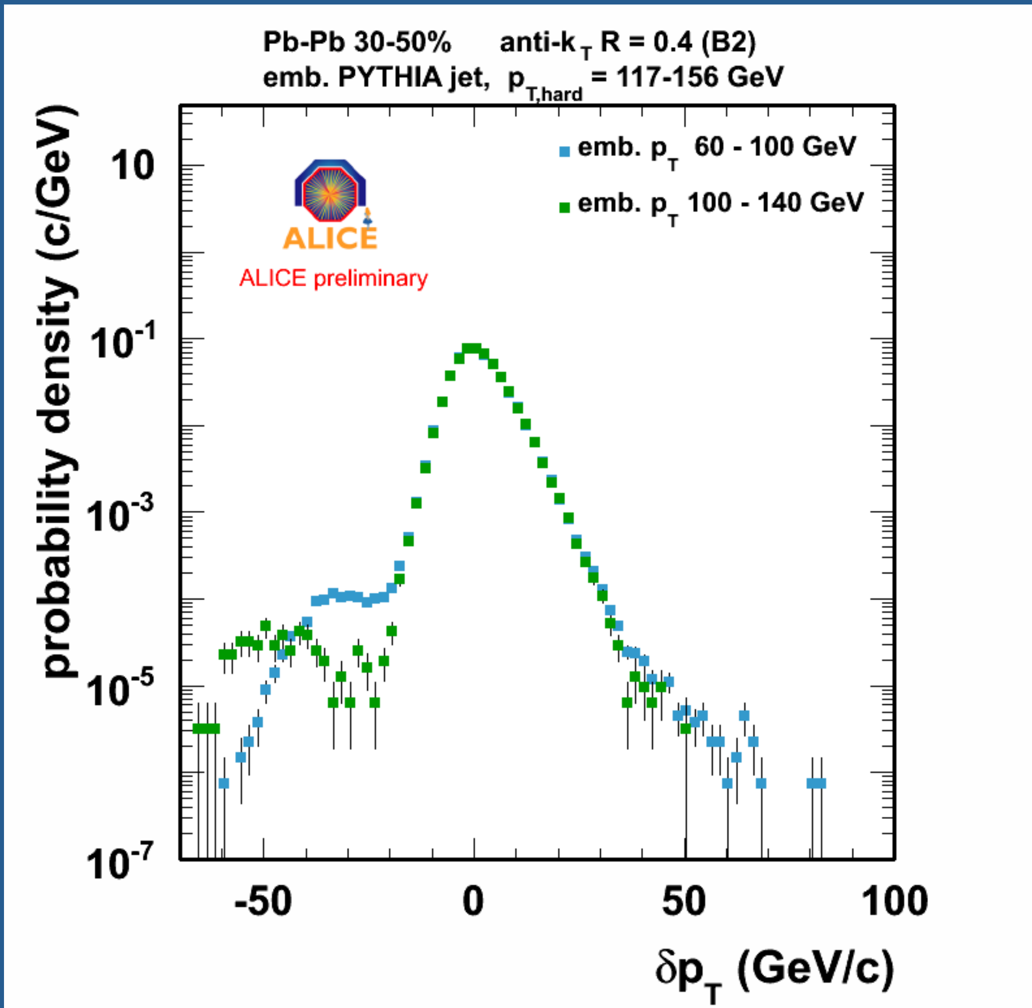


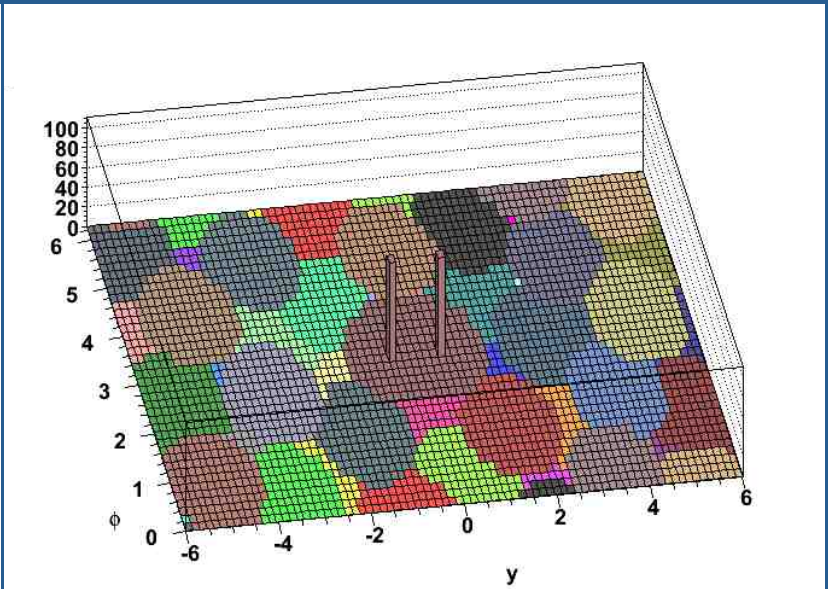
BACKUP

Backup: ATLAS Fragmentation



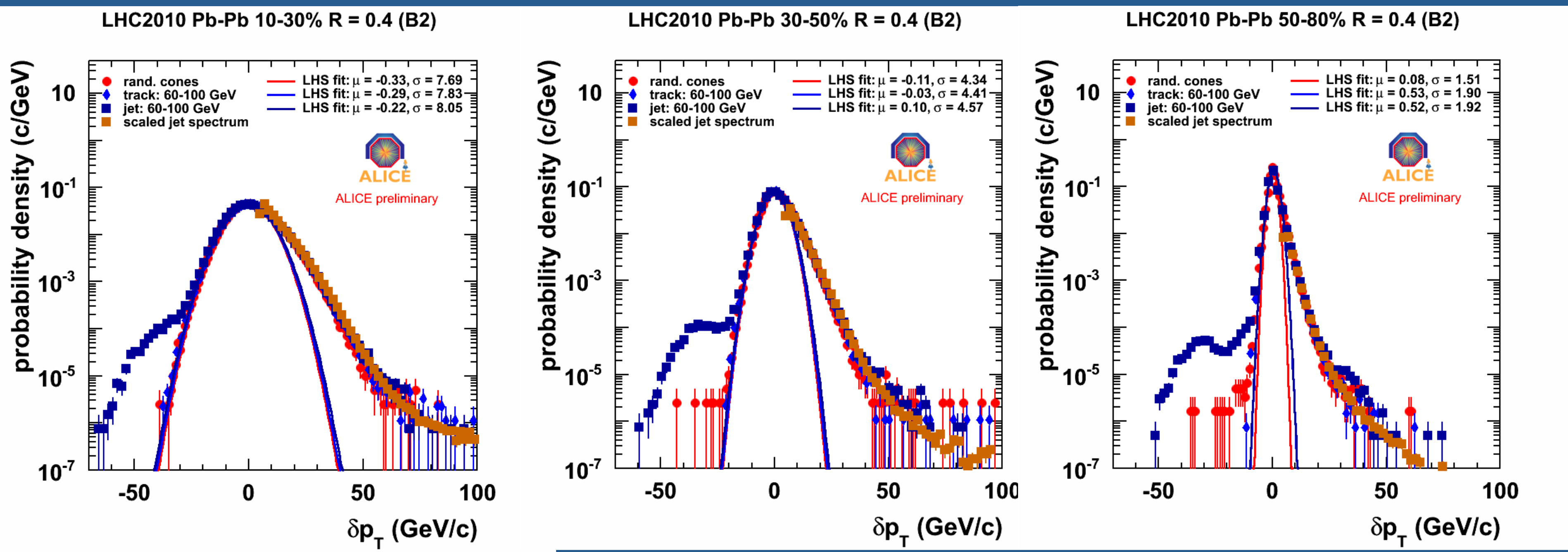
Backup: p_T Dependence Jet Embedding





Effect in jet embedding depends on embedded jet p_T.
Global width unaffected.

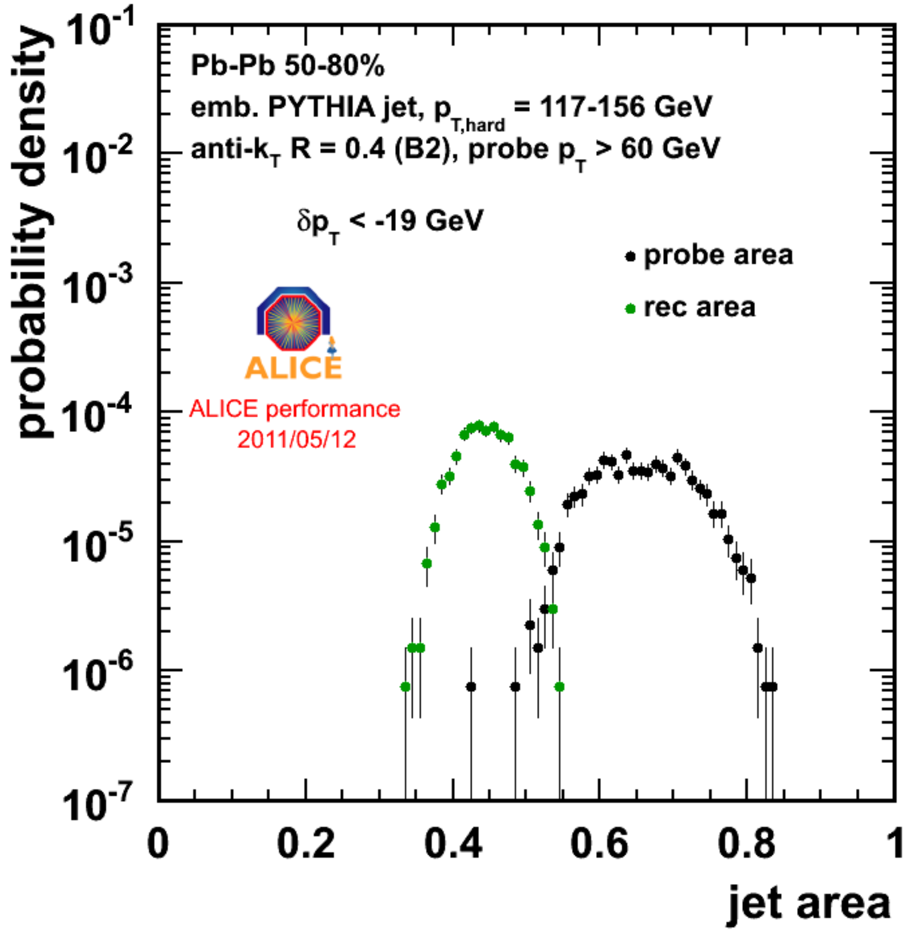
Backup: Different Probes vs. Centrality:

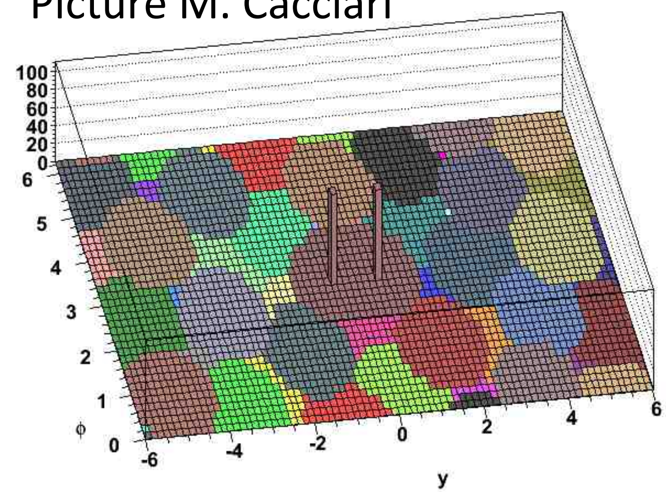


Right side tail shape similar to jet finding output.

LHS: Bump developing in jet embedding: Back reaction.

Reason: Large Jets in p+p

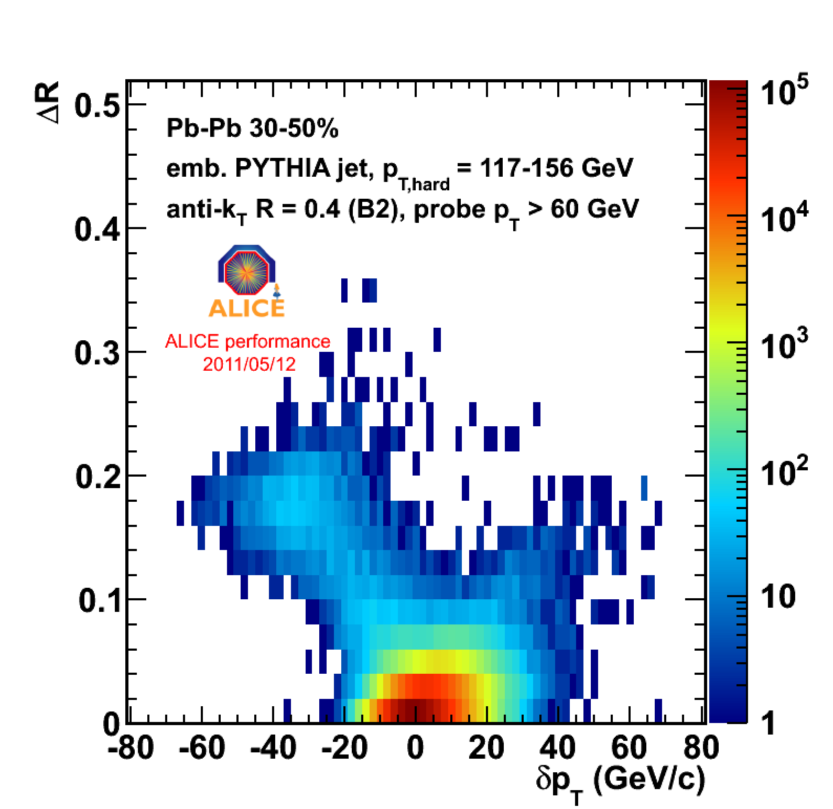


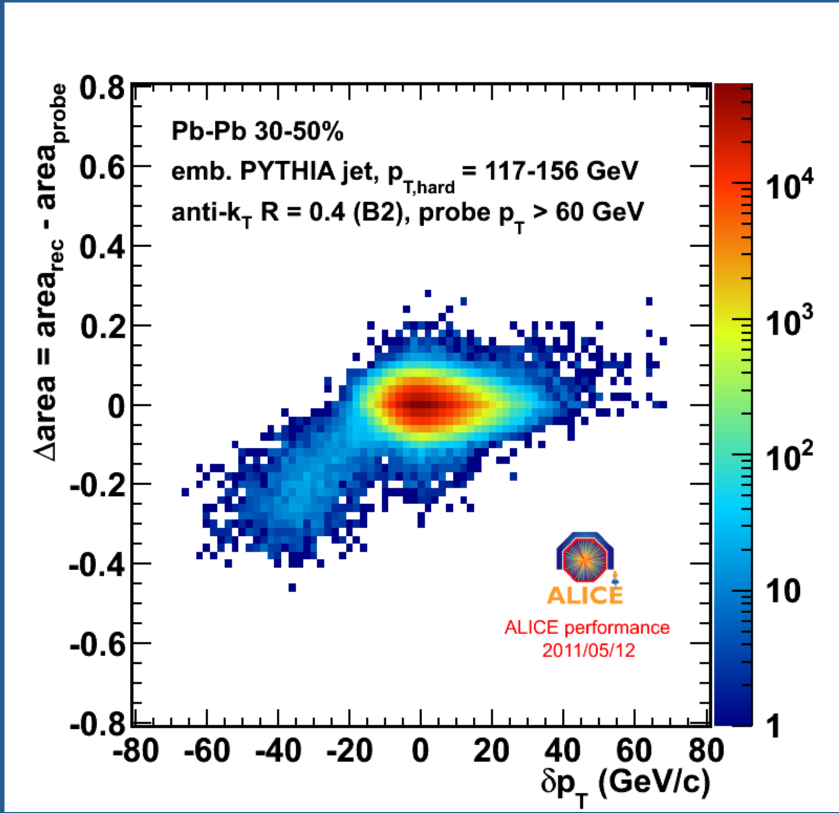


- Rare case in p+p: jet with 2 hard radiated particles at distance ≈ D
  - Cones around 2 similar seeds can merge (Salam et. al. arxiv 0802.1189)

Heavy ion background leads to splitting into regular sized objects: Back reaction.

Change in Jet Area and Direction

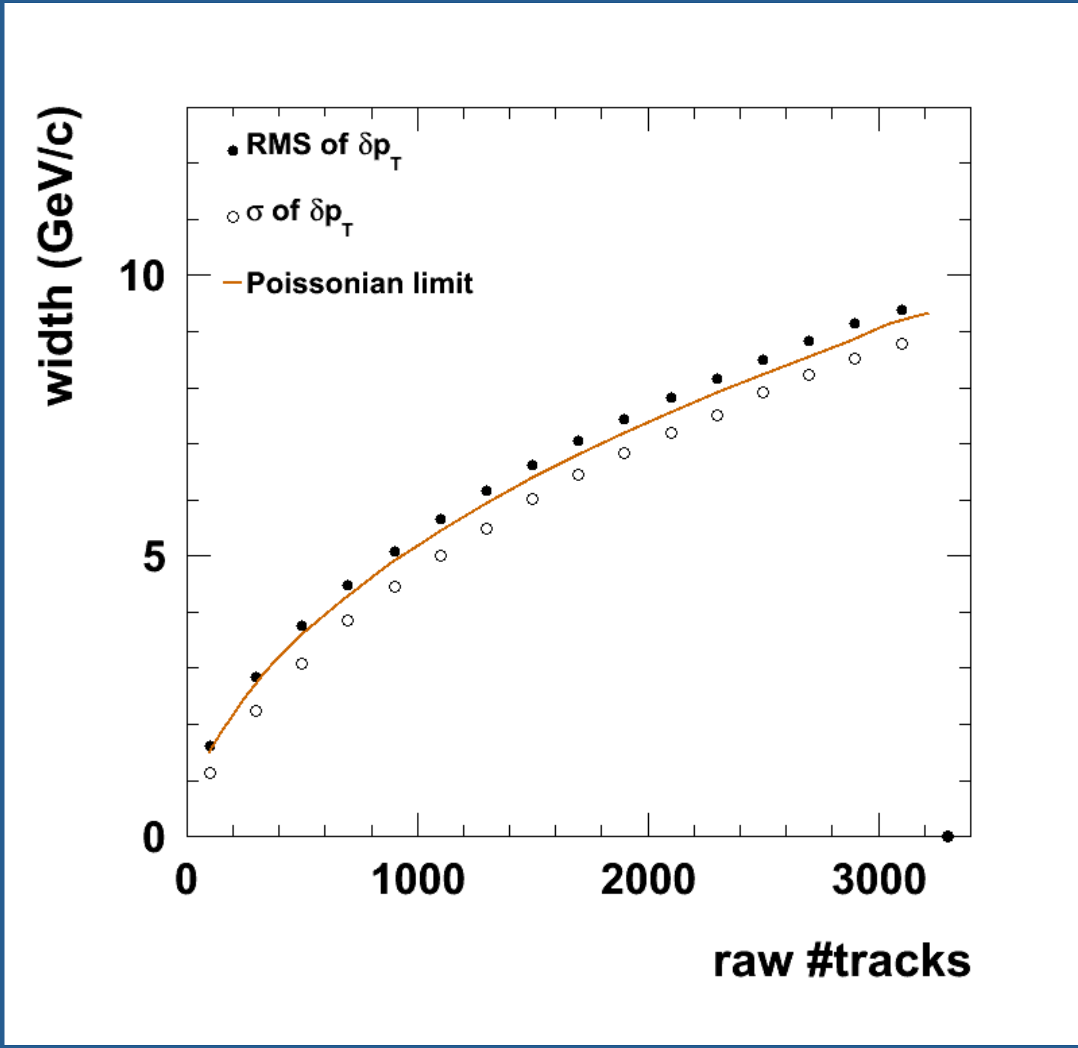




Rare fragmentation pattern and anti-k_T treatment of two similar seed particles at distance ~R leads to too large p+p jets which are split in the presence of heavy ion background.

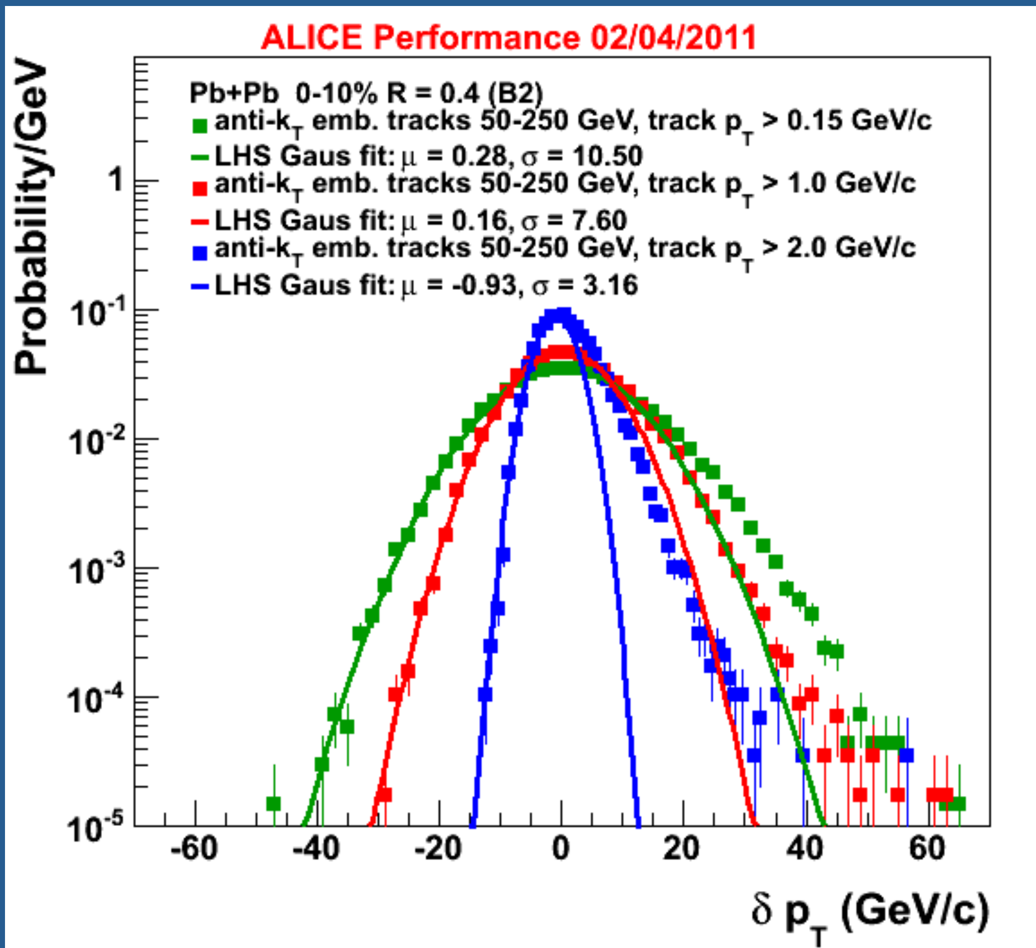
Large changes in area of embedded jets:
Caused be splitting, seen a of jet axis

RMS vs Gaussian Fit



Points from Poissonian multiplicity fluctuation in cone with R = 0.4 + sampling of p_T distribution.
Average event p_T per unit area subtracted.

Backup: Different Track p_T Cuts (0-10%)



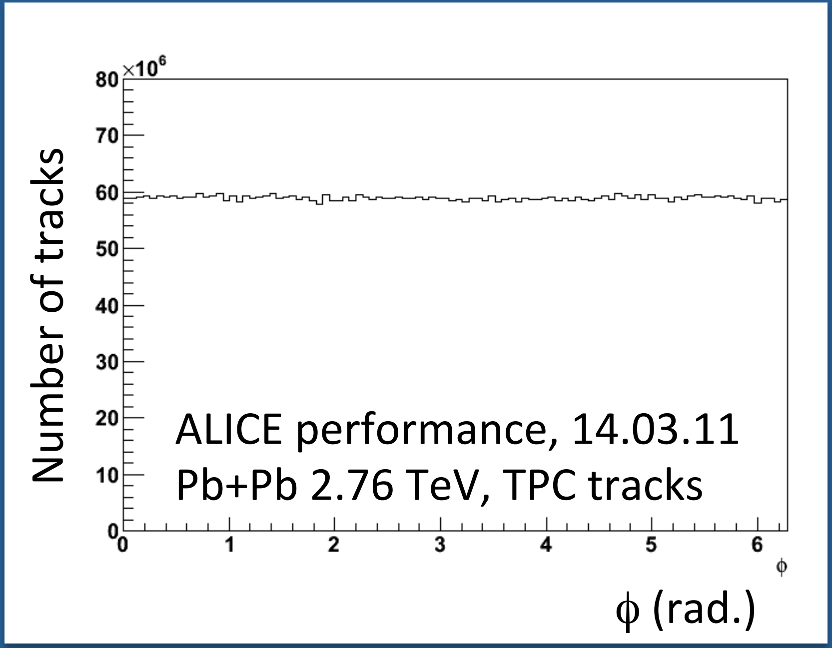
track p_T cut	average ρ
0.15 GeV/c	136 GeV/c
1.0 GeV/c	61 GeV/c
2.0 GeV/c	13 GeV/c

- reduction of soft background by track p_T cut also visible in background fluctuations
- methods work also with high-p_T cut off (μ close to 0)
- Tail more pronounced

influence of track-p_T cuts on "measured" background

Track Selection

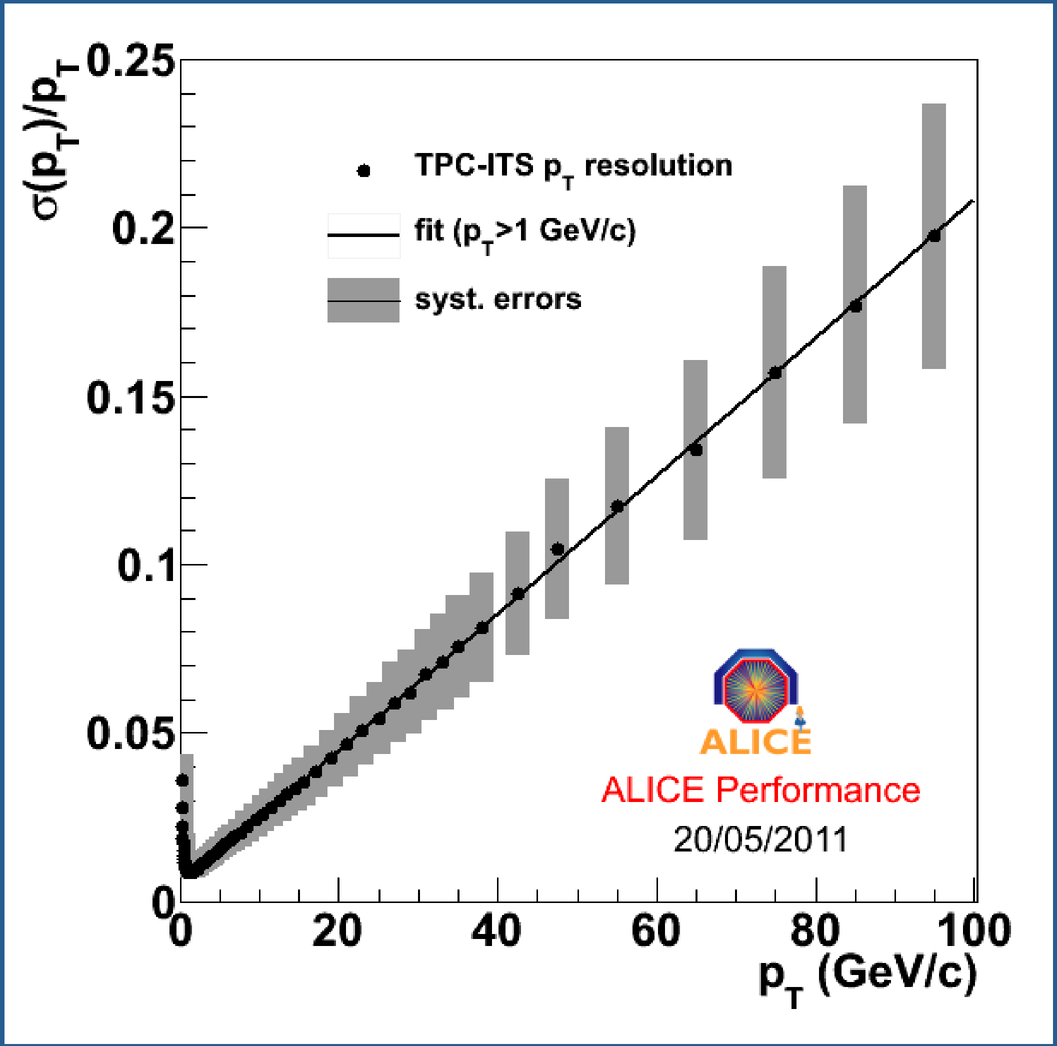
- TPC SA+vtxSPD
  - TPC only track parameters
  - constrained to SPD vertex
- Advantage:
  - Maximum uniformity in η-ϕ
  - Improved momentum resolution compared to TPC SA, but worse that ITS+TPC
  - Essential for:
    - Correlation studies, Di-Jets
    - Unbiased background estimates



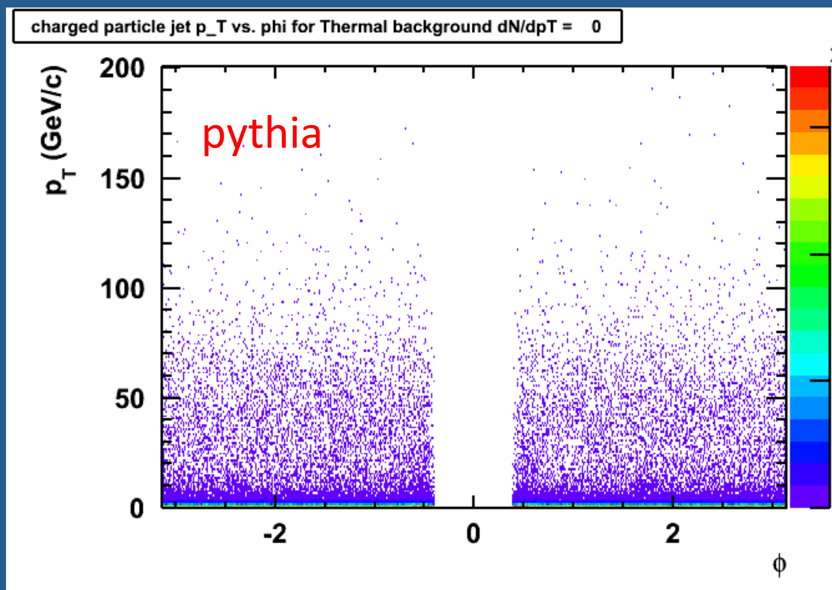
p_T Resolution ITS+TPC Tracking

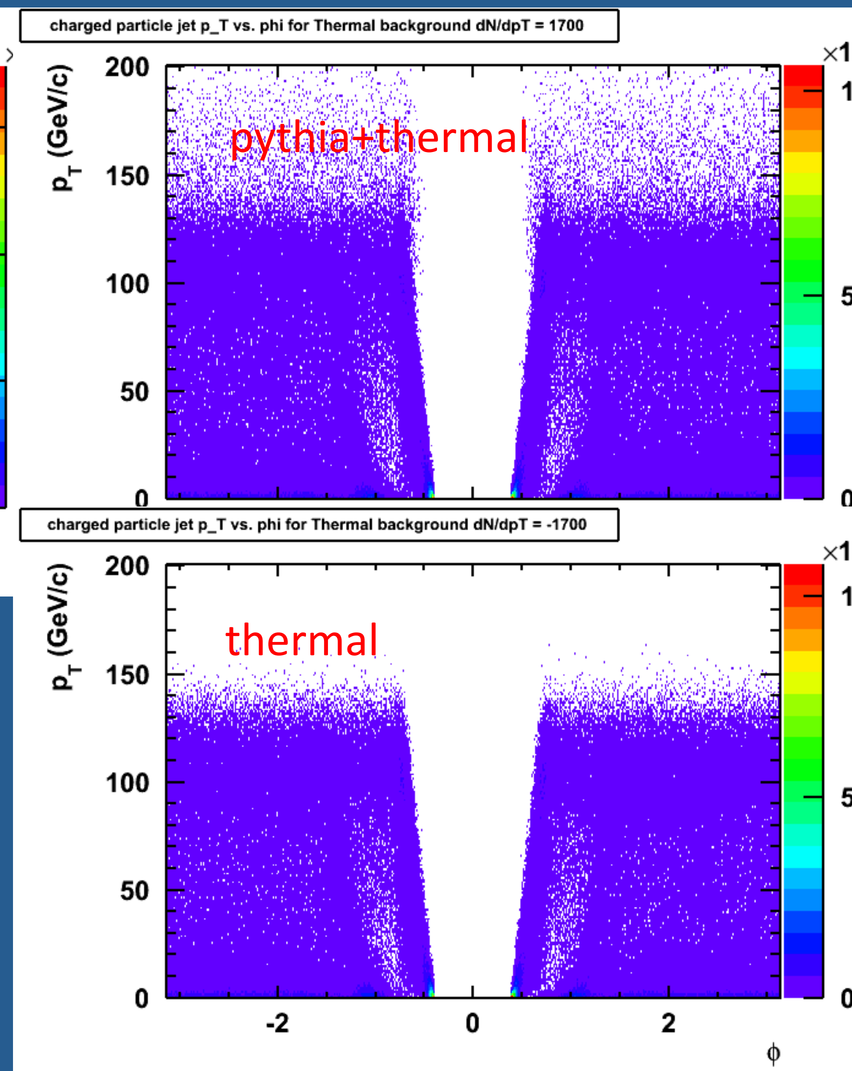
Factor 2 improvement soon

Background studies used
TPC tracks constrained to ITS-Vertex
(Maximum ϕ uniformity, worse resolution at high p_T)



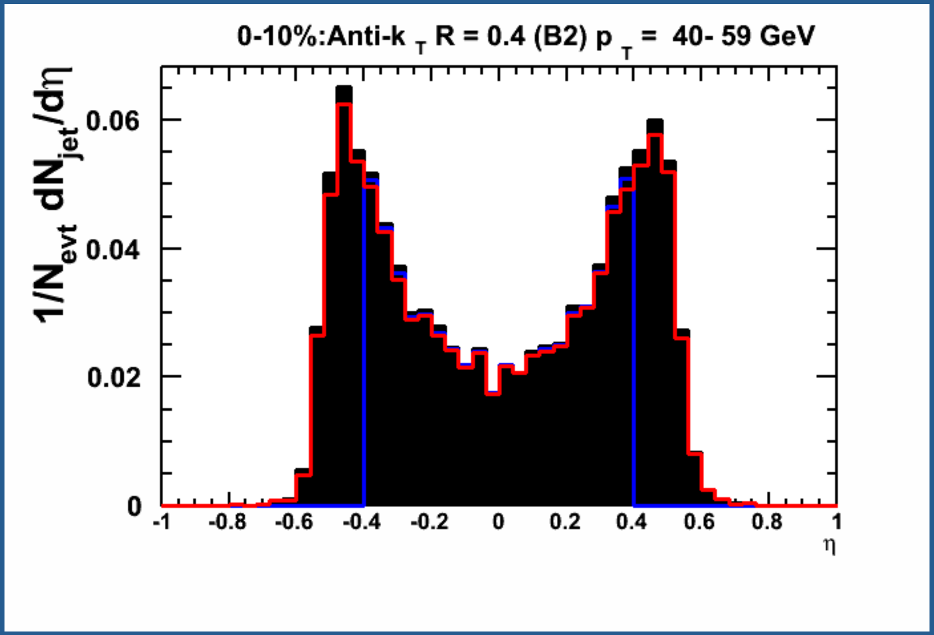
Backup: ϕ Distribution Toy MC with ϕ-Hole





Similar behavior as in η, hence not an effect of non-boost invariant variables.

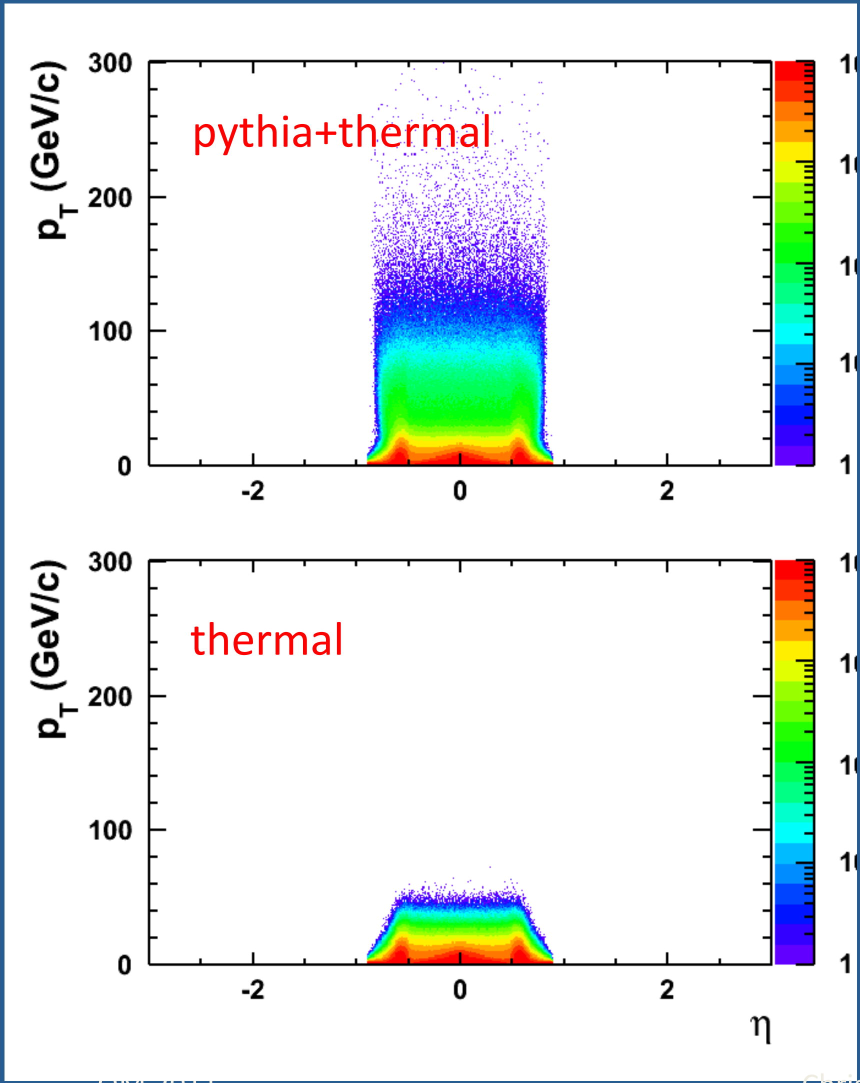
Backup: Background influence on jet η Distribution in Pb+Pb

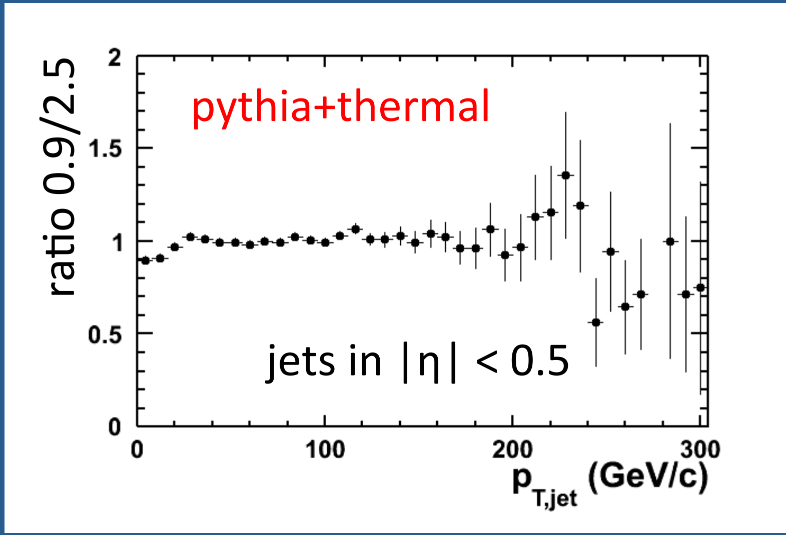


Does the effect vanish when background no longer dominates. What is the influence on the yield in |η| < 0.4

- Structure in η at edge of acceptance
  - becomes weaker with increasing jet p_T but lacks statistics
  - Becomes weaker in more peripheral events
  - Also present in randomized HI event
- Toy MC for tests in larger acceptance

After Background Subtraction





Residual structures visible, dominant at low p_T.
No Effect on the yield beyond ≈ 30 GeV for the signal + thermal.