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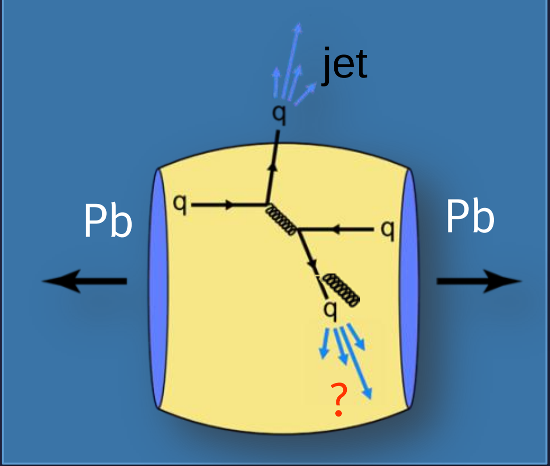
Jet Reconstruction and the Evolution of Background Effects
in Pb-Pb Collisions Measured with the ALICE Experiment

Jet as hard probe in the QGP



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for the **ALICE Collaboration**

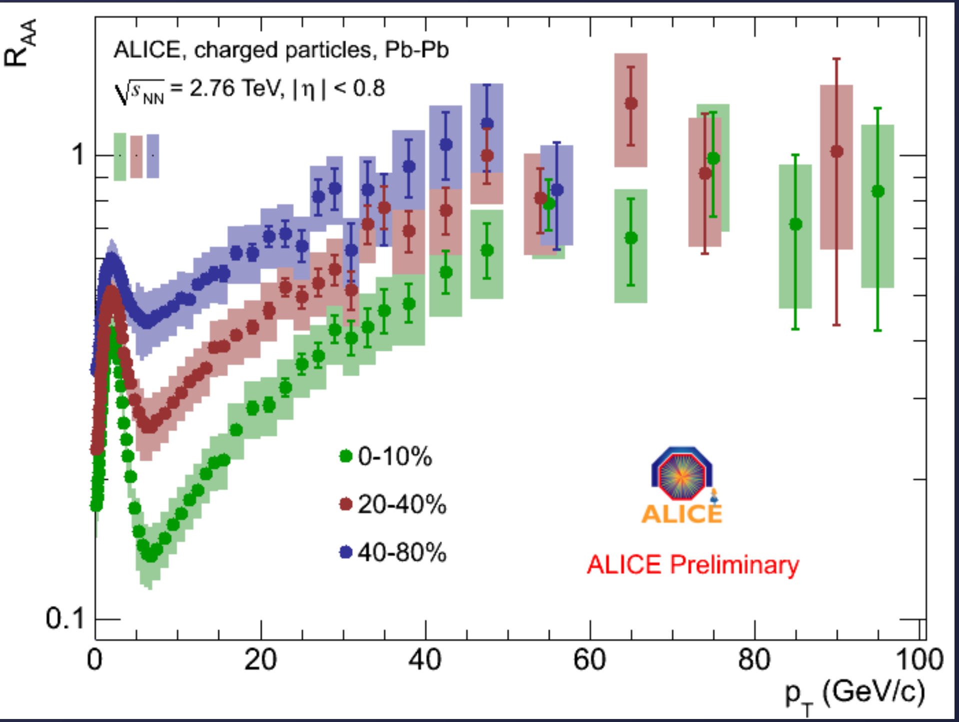
Physics at LHC
Perugia, June 5th-11th 2011

Motivation

Jets

- ‘jet quenching’ at RHIC and LHC
  - single track R_{AA}
  - energy loss of initial hard scattered partons

- jets in pp: closely related to parton properties
- Pb-Pb: access to medium modified parton fragmentation process



Background in HIC

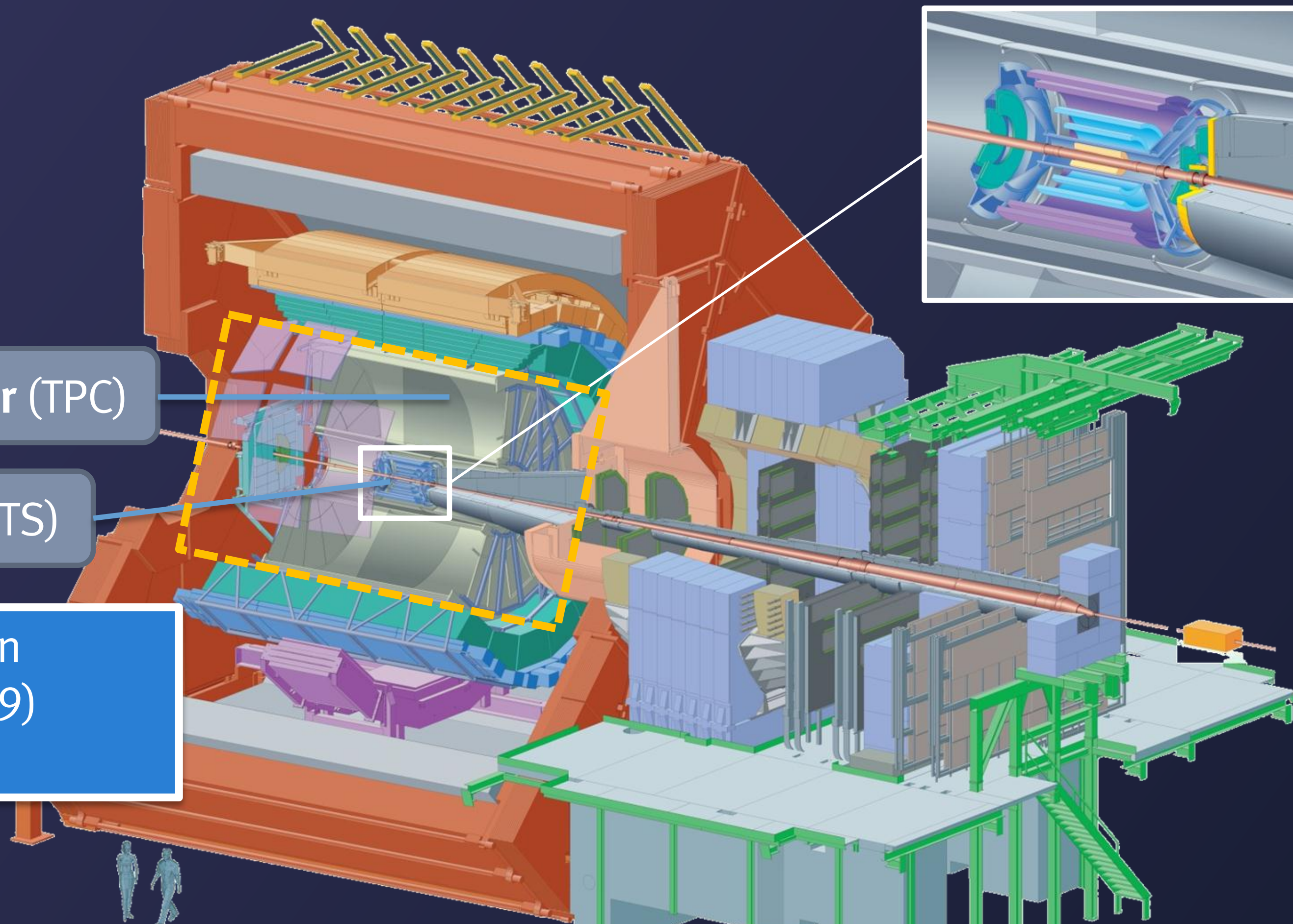
- low-p_T region most sensitive to medium
- large impact of underlying event at jet reconstruction
- essential to understand for interpretation of jet observables, e.g.
  - recently measured di-jet imbalances at LHC
  - fragmentation process → jet structure

nuclear modification factor:

$$R_{AA}(p_T) = \frac{(1/N_{evt}^{AA})}{\langle N_{coll}\rangle\,(1/N_{evt}^{pp})}\;\frac{d^2N_{ch}^{AA}/d\eta dp_T}{d^2N_{ch}^{pp}/d\eta dp_T}$$

$\langle N_{coll}\rangle$: nb. of binary nucleon-nucleon collisions

A Large Ion Collider Experiment



2010+: jet reconstruction
- charged tracks ($|\eta|<0.9$)
- jets R=0.4, $|\eta|<0.5$

more about ALICE: see talk by J.P. Wessels

A Large Ion Collider Experiment

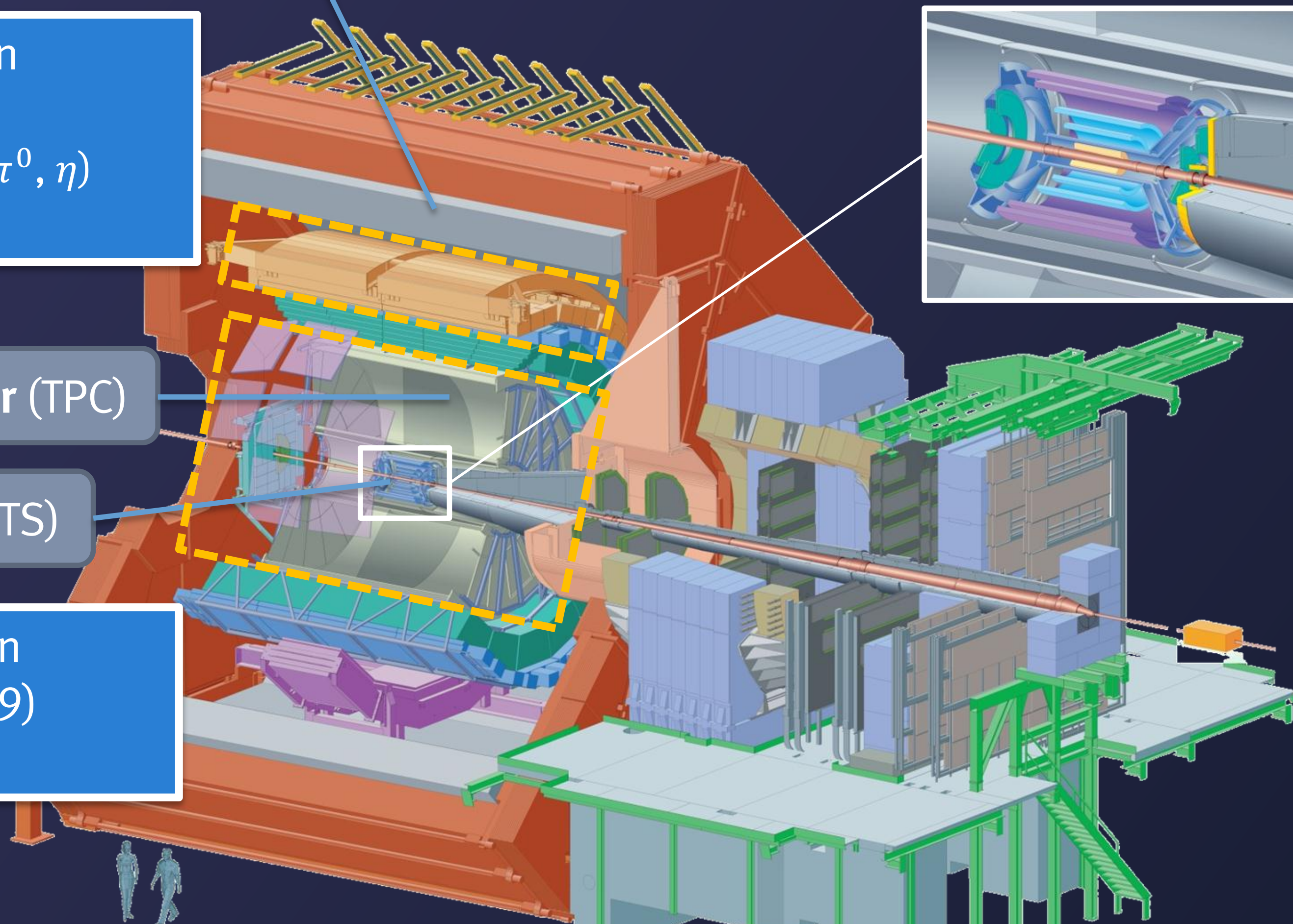
Electro Magnetic Calorimeter (EMCal)

2011+: jet reconstruction
- EMCal complete
- charged+neutral (i.e. π^0, η) ($|\eta|$<0.7)

Time Projection Chamber (TPC)

Inner Tracking System (ITS)

2010+: jet reconstruction
- charged tracks ($|\eta|$<0.9)
- jets R=0.4, $|\eta|$<0.5



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Jet Reconstruction in pp@7 TeV

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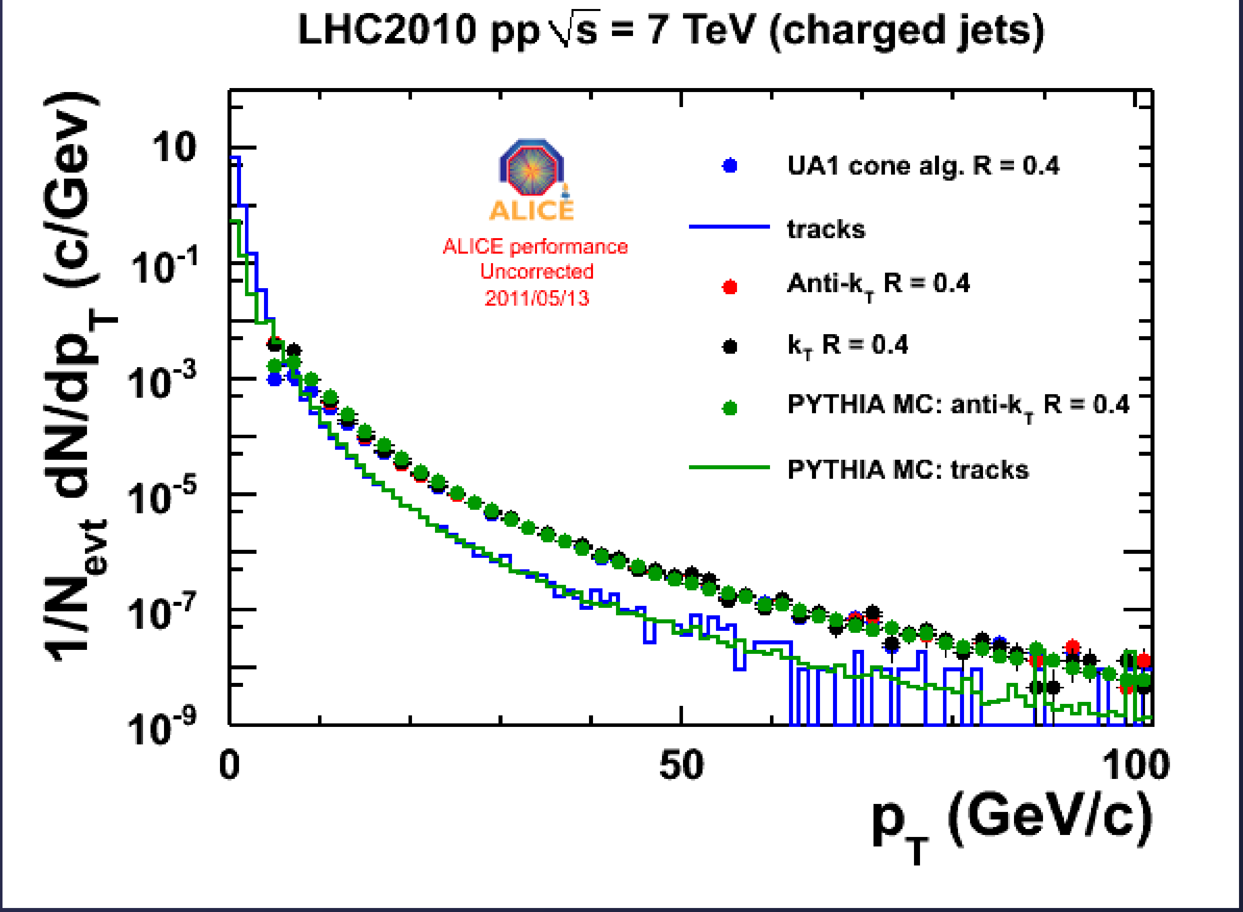
focus on

- sequential recombination algorithms
  - FastJet *(Phys. Lett. B 641 (2006) 57)*
  - **anti-k_T**: jet finding
  - **k_T**: background density (in Pb-Pb)
  - radius parameter R=0.4

- clustering on particle level
  - low momentum cut off: p_T › 150 MeV/c

Aim:

- minimize bias on hard fragmentation
- measure detailed structure of jets
- classify background sources



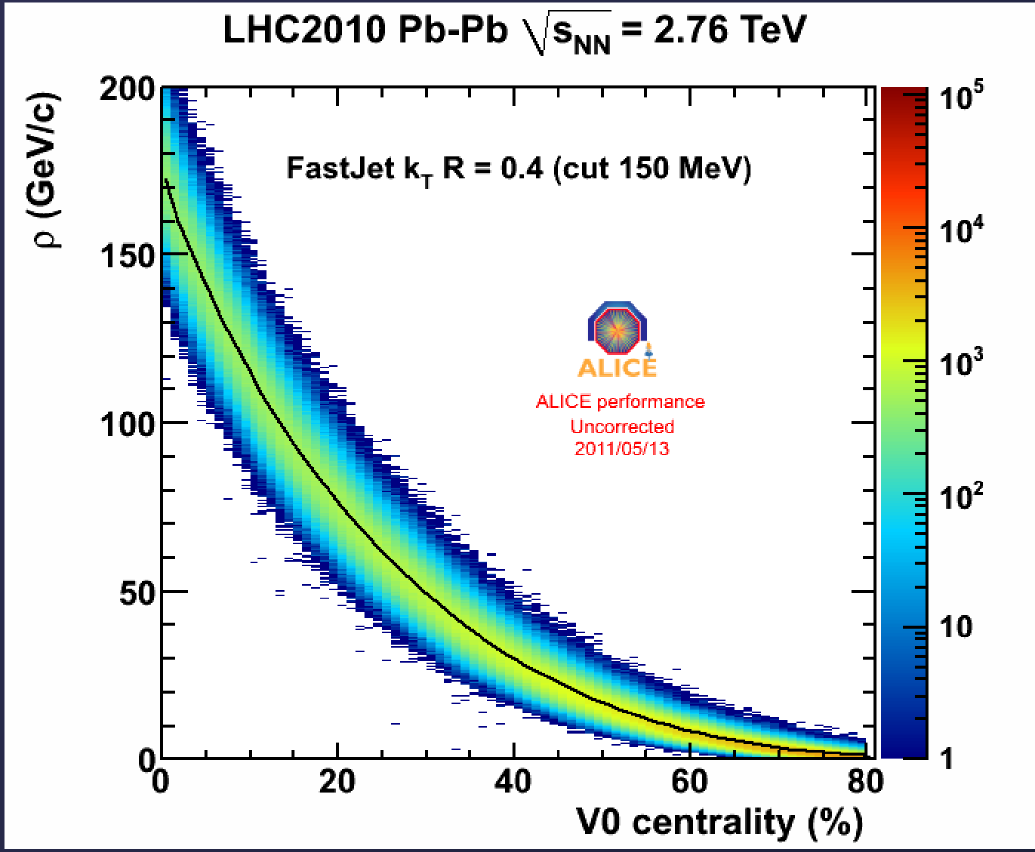
- good agreement between different jet finders for p_T › 20 GeV
- reproduced in full simulation (jets and tracks)
- jet reconstruction in pp collisions looks promising

Background Subtraction

- ρ: background density p_T/A
- estimation of ρ:
  - event-by-event
  - k_T clusterizer, $|\eta|<0.5$
  - $\rho = \mathrm{median}[p_T^i / A_{jet}^i]$

    exclude two hardest jets
- typical size $R = 0.4$: $A_{jet} \approx 0.5$

  → 50 – 100 GeV/c background for 0-10%



Strong change within central bin.

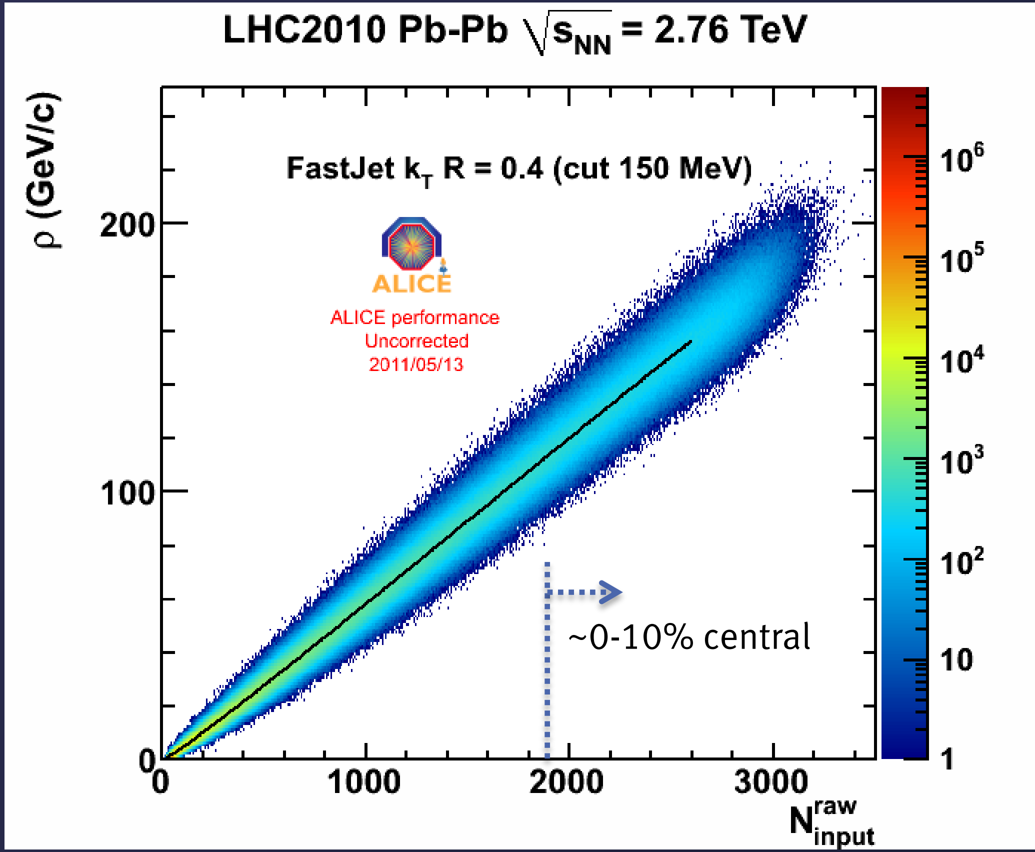
$$p_{T,jet} = p_{T,jet}^{rec} - \rho \times A_{jet} \pm \delta p_{T,bckg}$$

A_{jet} : jet area
$\delta p_{T,bckg}$: background fluctuations

Background Subtraction

- ρ: background density p_T/A
- estimation of ρ:
  - event-by-event
  - k_T clusterizer, $|\eta|<0.5$
  - $\boldsymbol{\rho = \mathrm{median}[p_T^i / A_{jet}^i]}$

    exclude two hardest jets
- background scales with event multiplicity: $\rho \approx N\langle p_T \rangle$
- region-to-region fluctuations $\pm\delta p_T$:
  - spread of ρ in given multiplicity bin
  - needs unfolding



Linear correlation with input raw multiplicity.

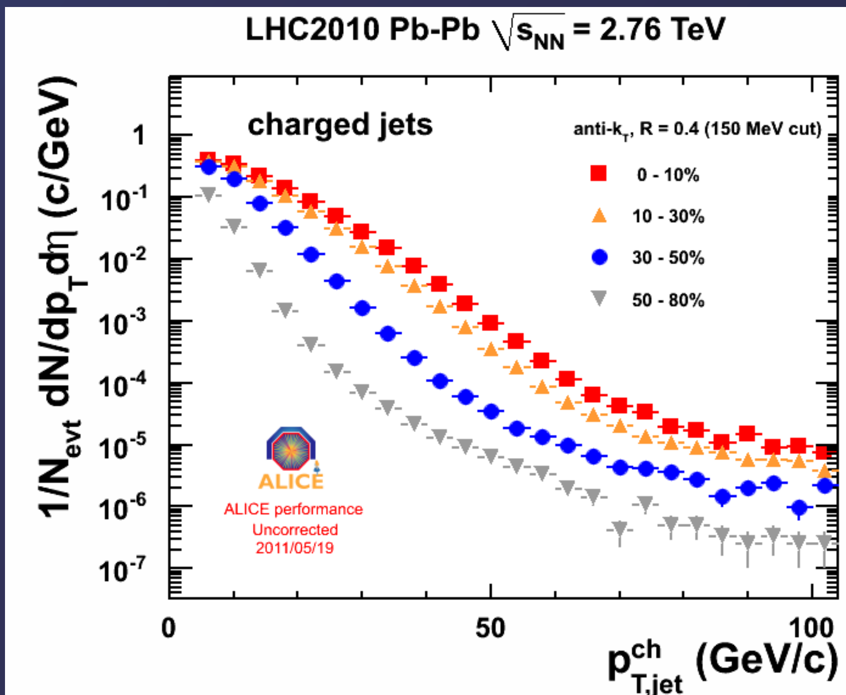
$$p_{T,jet} = p_{T,jet}^{rec} - \rho \times A_{jet} \pm \delta p_{T,bckg}$$

A_{jet} : jet area

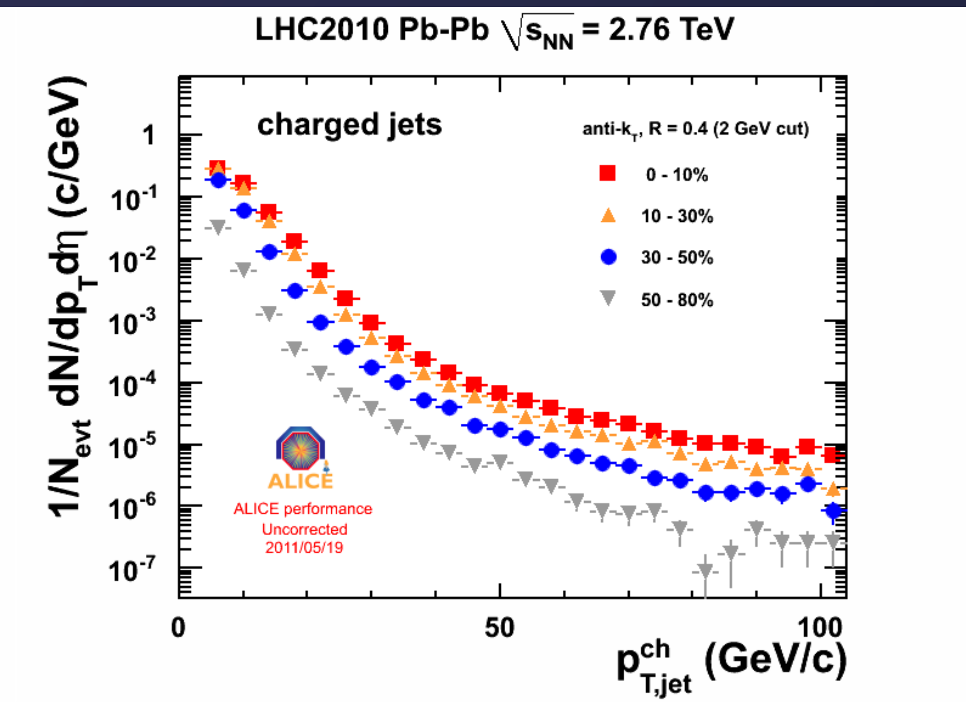
$\delta p_{T,bckg}$: background fluctuations

Jet Reconstruction in Pb-Pb

p_T track cut-off 0.15 GeV/c



p_T track cut-off 2 GeV/c



$$p^{ch}_{T,jet} = p^{rec}_{T,jet} - \rho \times A_{jet}$$

- average background corrected (event-by-event)
- large impact of background fluctuations for jet $p_T < 80$ GeV/c

Background Fluctuations

- embed well defined probes into real Pb-Pb events
- background fluctuations measured as residuals:

$$\delta p_T = p_{T,jet}^{rec} - \rho \times A_{jet} - p_{T,(jet)}^{probe}$$

Probes:

bias and back-reaction increase

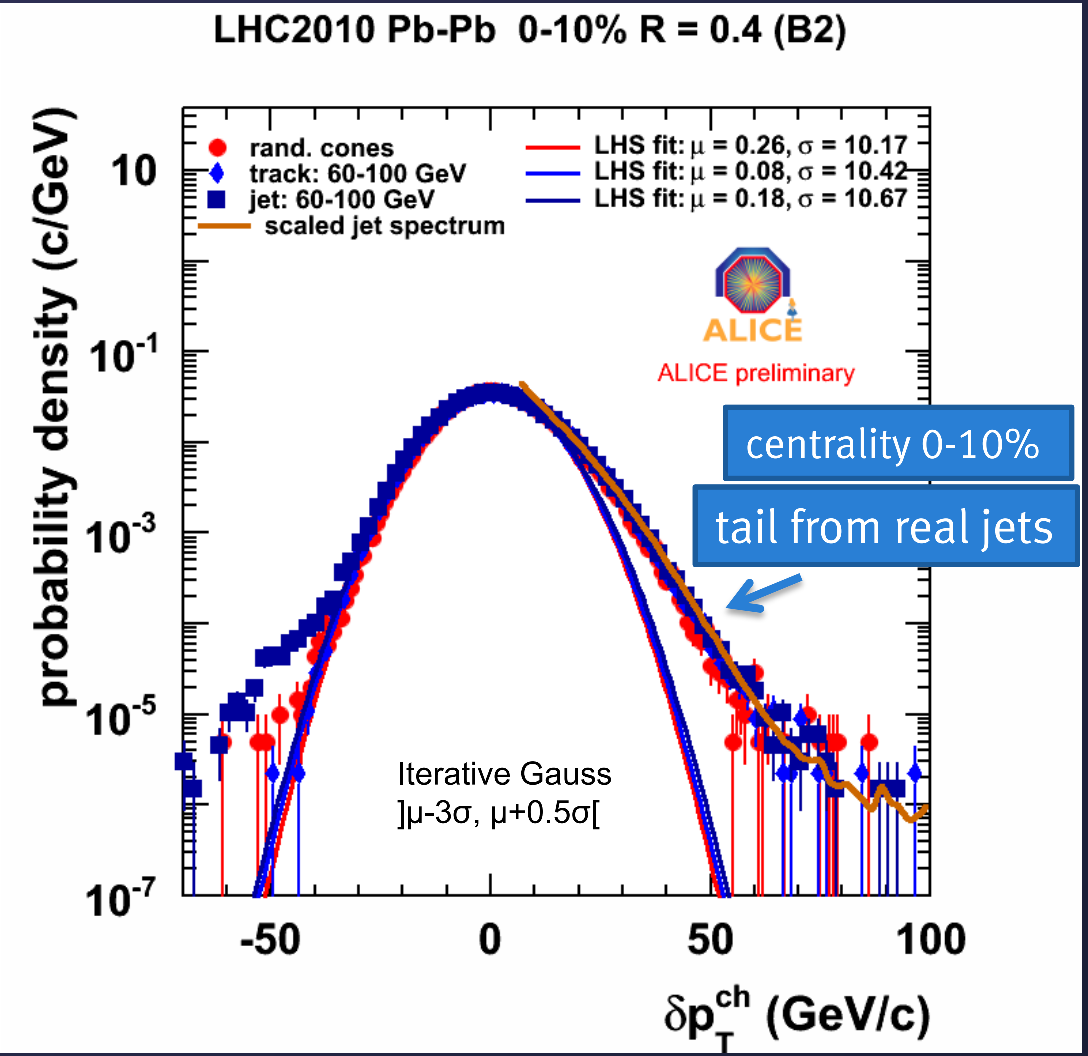
- random cones
  - fixed cone size
  - randomly placed in full jet acceptance
- single tracks
  - high-p_T seed
  - delta probe for jet finder
- pp jet events
  - real or PYTHIA+GEANT
- quenched jets
  - QPYTHIA and PYQUEN

Aim:

- study the influence of the background on the reconstruction observables of the jet
- verify the performance of the background subtraction methods ($\rho \times A_{jet}$)

Compare Different Probes (cent.)

- random cones
  - $\delta p_T = p_T^{rndm} - \rho \times A_{jet}$
  - p_T^{rndm}: $\sum p_T$ in RC with R=0.4
- embedded single high-p_T tracks
  - flat p_T distribution 60-100 GeV/c
- embedded pp jet events @ 2.76 GeV
  - full simulation (PYTHIA+GEANT)
  - p_T hard 117-156 GeV/c
- overlaid jet spectrum
  - scaled to 20 GeV/c
- Iterative Gaussian fit:
  - LHS only
    - insensitive to tail due to jet on RHS
    - region-to-region fluctuations (uncorrelated & correlated)
  - lower limit on total fluctuations



$$\delta p_T = p_{T,jet}^{rec} - \rho \times A_{jet} - p_{T,(jet)}^{probe}$$

Compare Different Probes (cent.)

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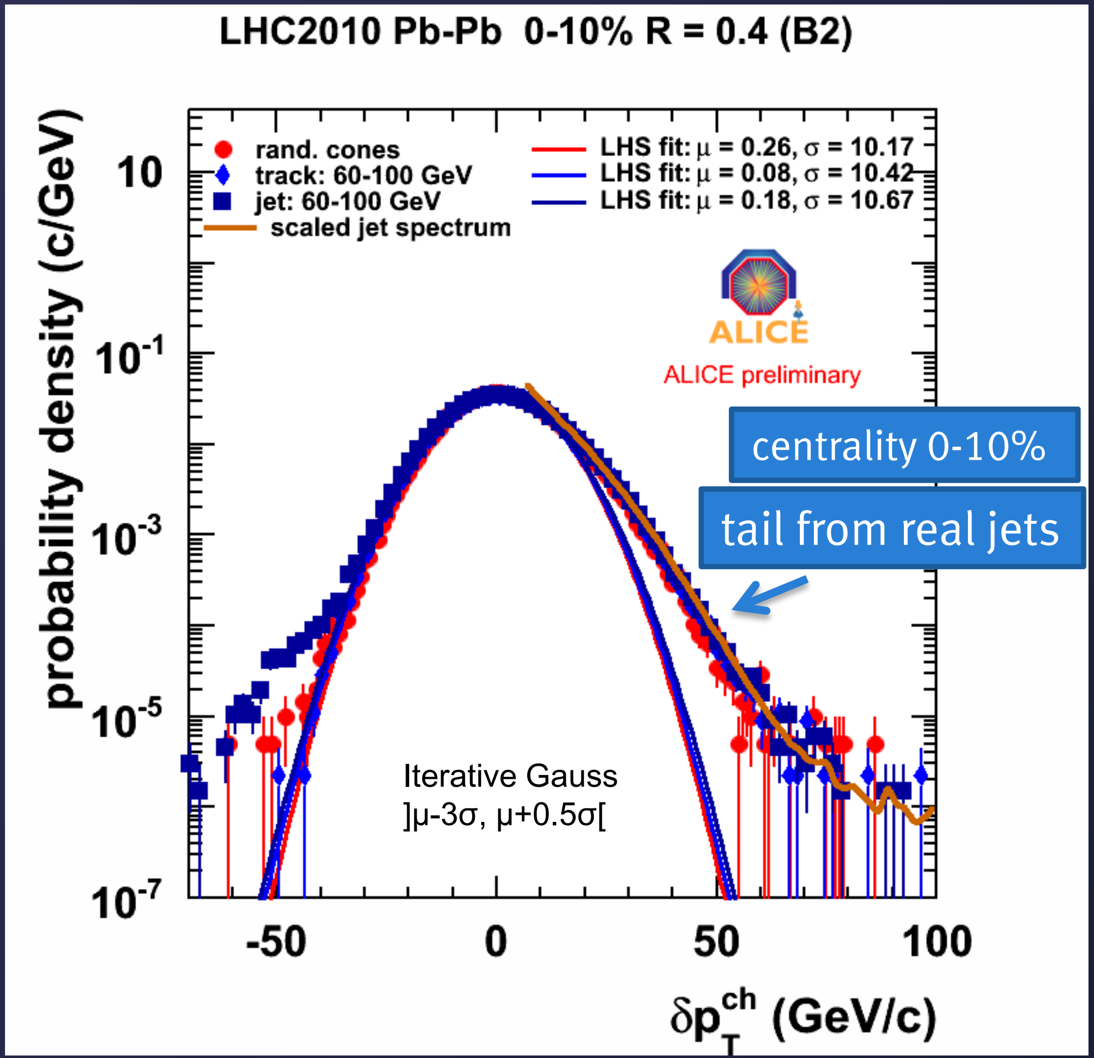

$$\delta p_T = p_{T,jet}^{rec} - \rho \times A_{jet} - p_{T,(jet)}^{probe}$$

Very good agreement between all methods.

- $\sigma \approx 10 - 11$ GeV/c (for 0-10%)
- $\mu \approx 0$ GeV/c

→ **background subtraction works** (for unbiased jet population)

- shape of jet spectrum similar

→ **challenge for unfolding**

Compare Different Probes (periph.)

- random cones
  - $\delta p_T = p_T^{rndm} - \rho \times A_{jet}$
  - p_T^{rndm}: $\sum p_T$ in RC with R=0.4
- embedded single high-p_T tracks
  - flat p_T distribution 60-100 GeV/c
- embedded pp jet events @ 2.76 GeV
  - full simulation (PYTHIA+GEANT)
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- overlaid jet spectrum
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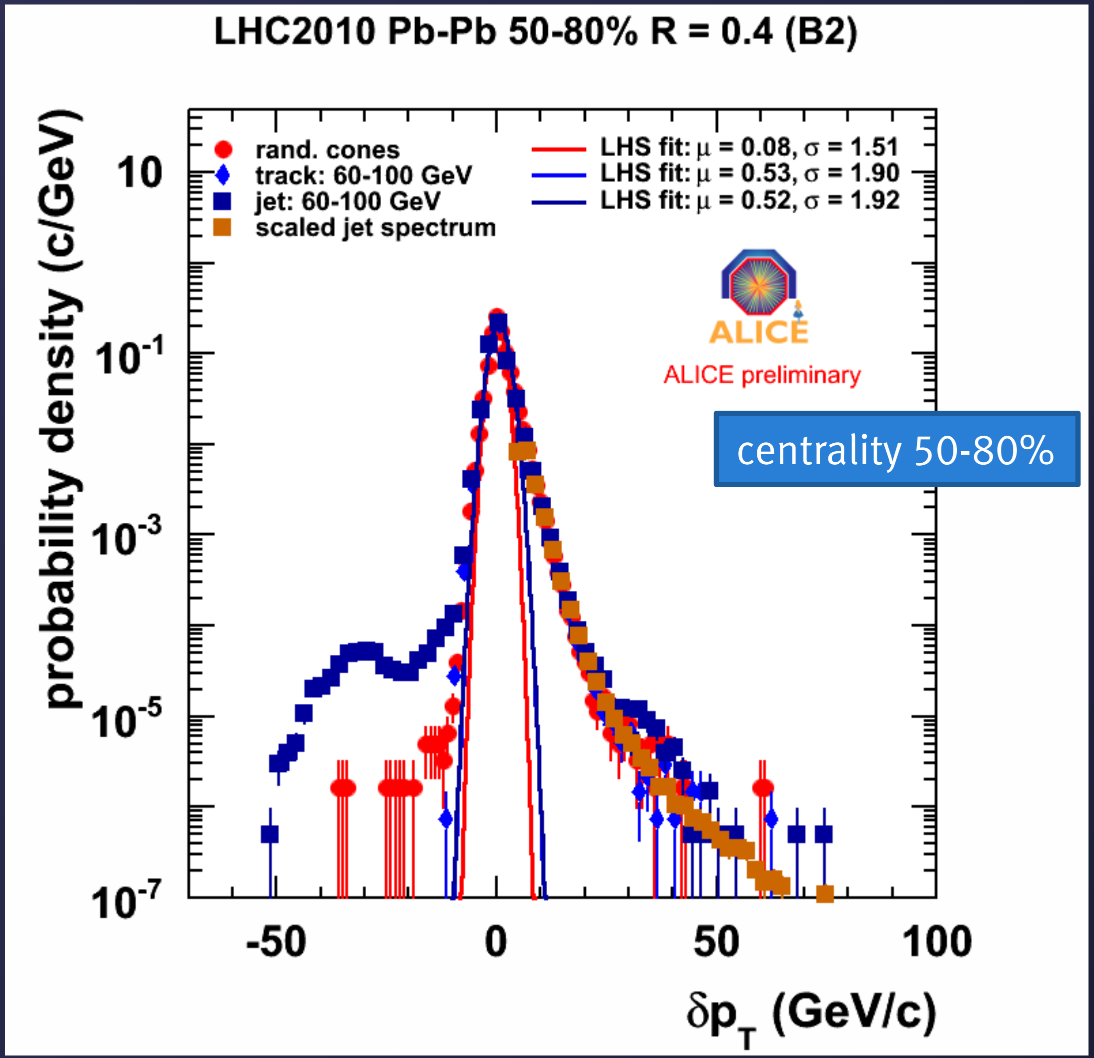


increase of non-Gaussian contribution

Very good agreement between all methods.

- $\sigma \approx 10 - 11$ GeV/c (for 0-10%)
- $\mu \approx 0$ GeV/c

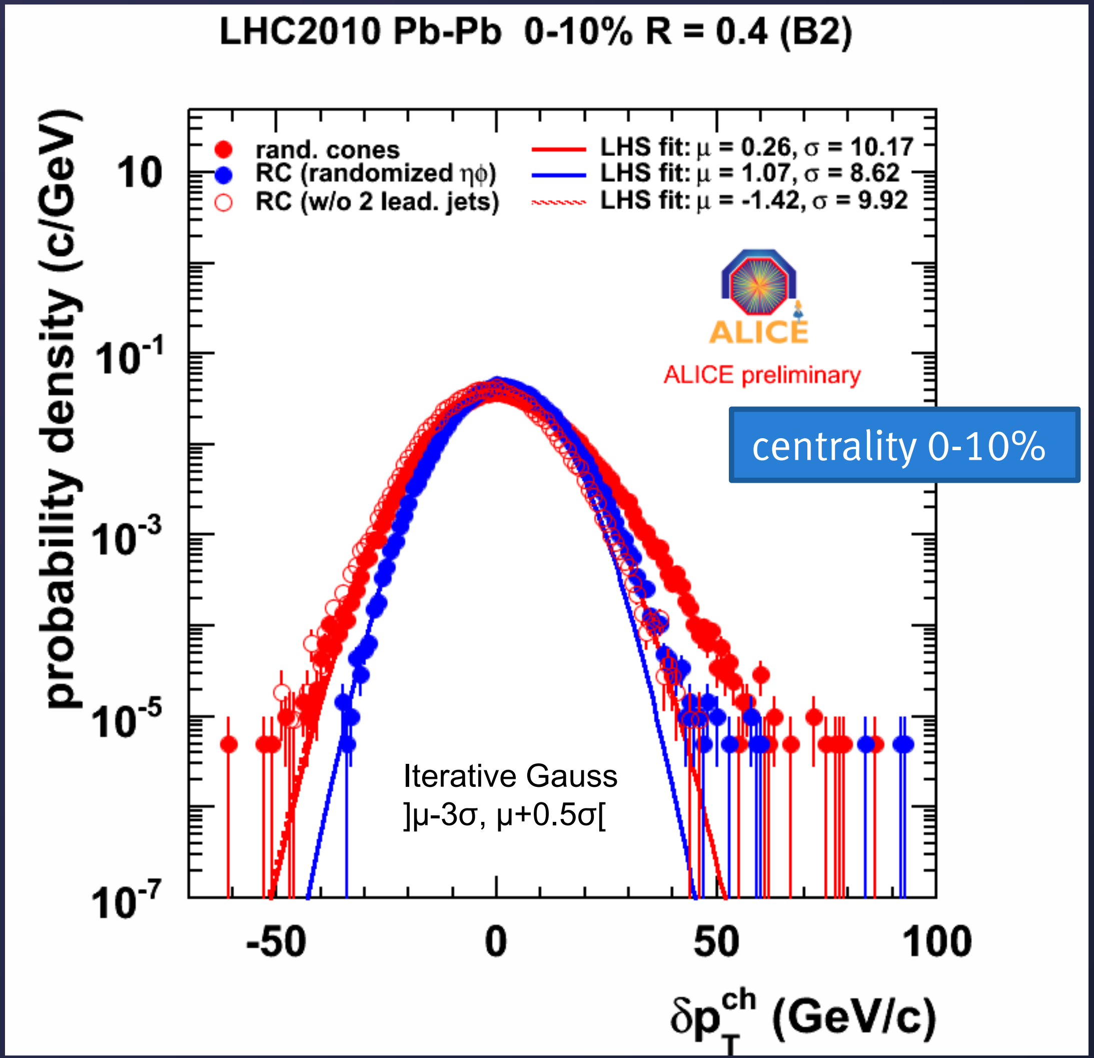
→ **background subtraction works** (for unbiased jet population)

- shape of jet spectrum similar

→ **challenge for unfolding**

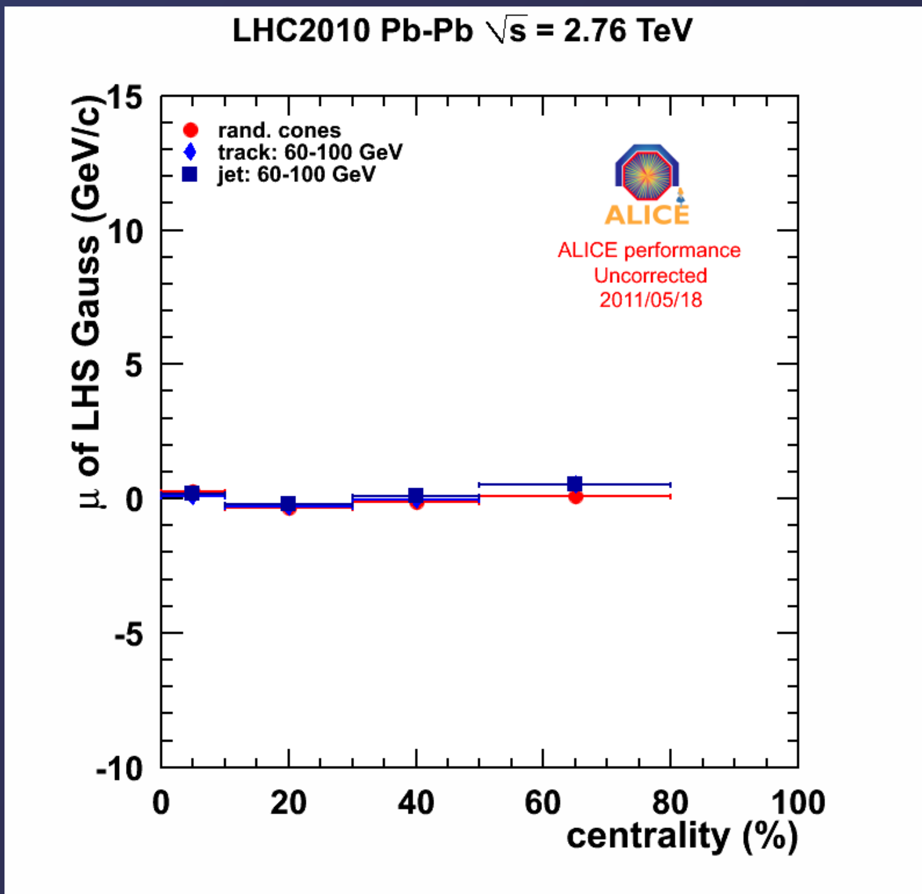
Random Cones

- random cones
  - $\delta p_T = p_T^{rndm} - \rho \times A_{jet}$
  - p_T^{rndm}: $\sum p_T$ in RC with R=0.4
- additional options:
  1. in randomized events
  2. exclude area around 2 hardest jets (D › 1.0)
- RHS tail:
  - smaller for randomized events
  - smaller w/o leading jets
  - → jet origin
- LHS tail:
  - insensitive to jet removal
  - → correlated region-to-region fluctuations

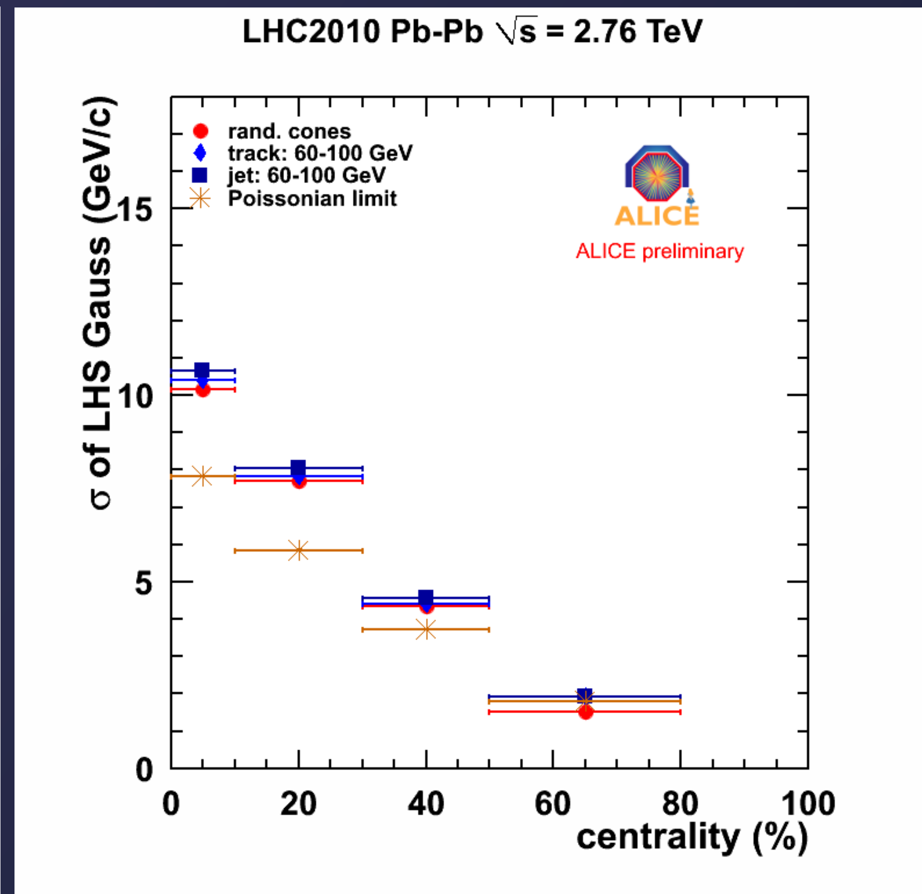


Evolution with Centrality

Mean of Gaussian fit



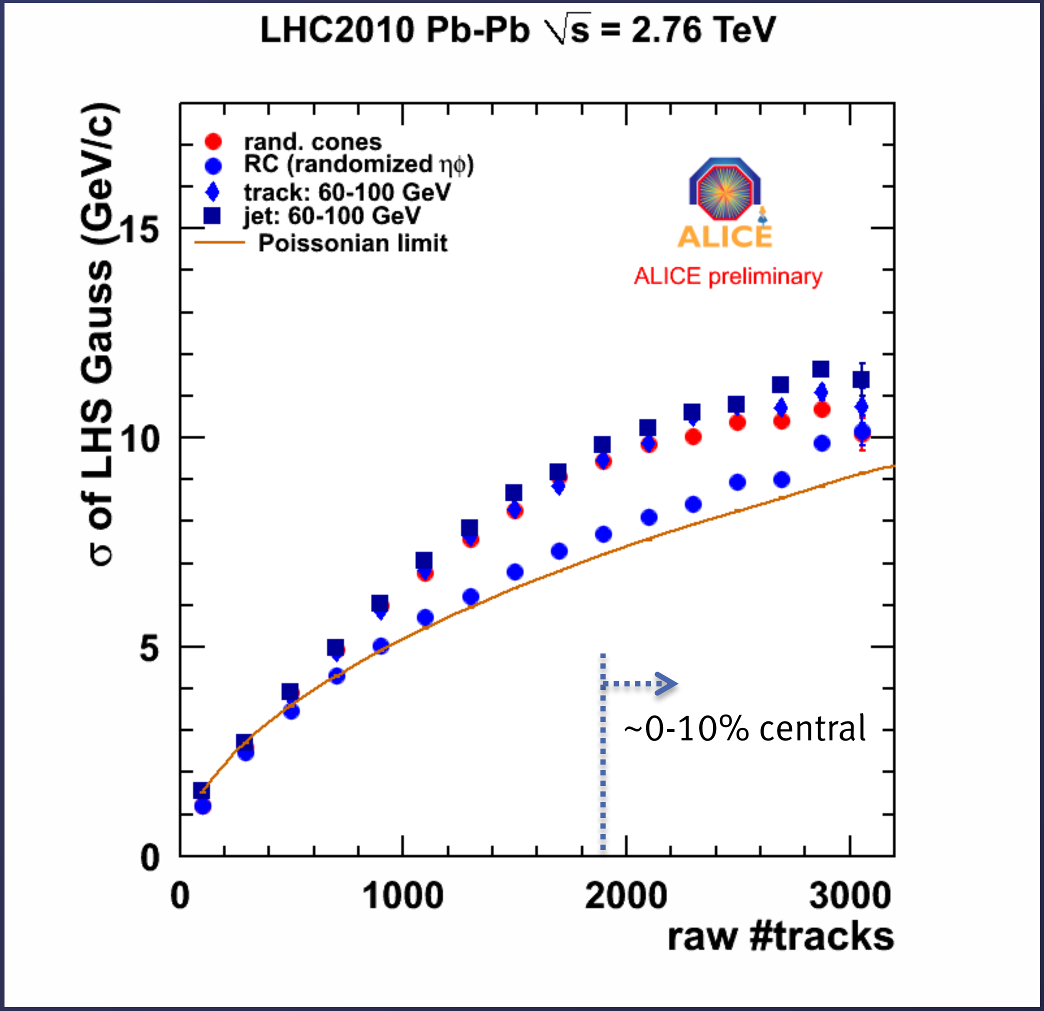
Width of Gaussian fit

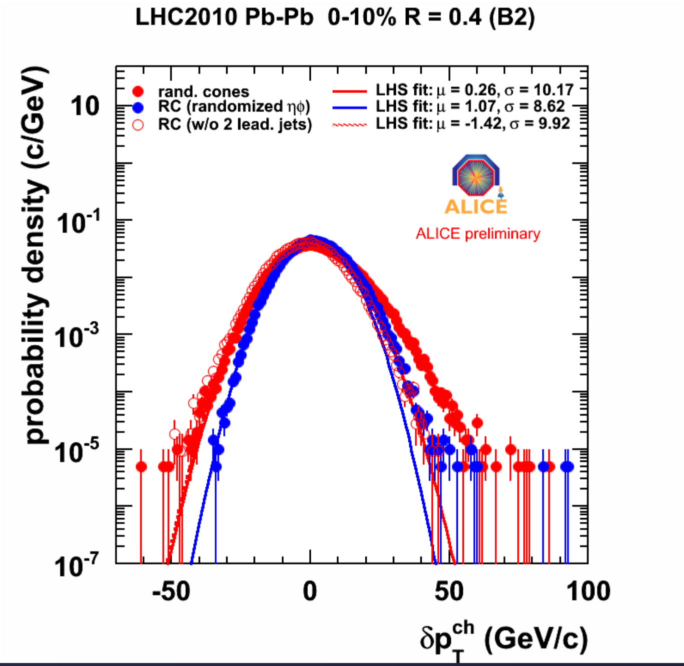


Poissonian limit: $RMS(\delta p_T) = \sqrt{N} \times \sqrt{\langle p_T \rangle^2 + RMS(p_T)^2}$

- stable background subtraction
- correlated contributions in fluctuations (> Poissonian limit, except for peripheral)

Evolution with Multiplicity

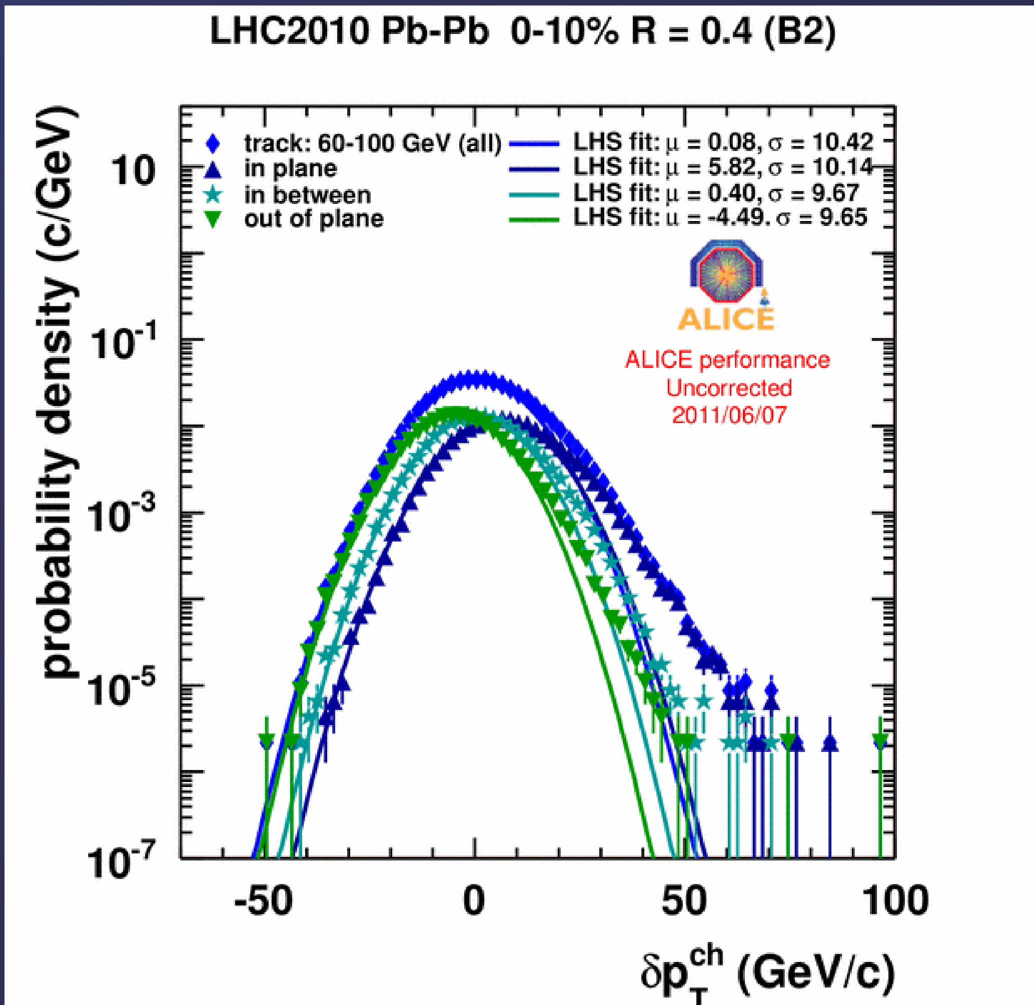




Poissonian limit: $RMS(\delta p_T) = \sqrt{N} \times \sqrt{\langle p_T \rangle^2 + RMS(p_T)^2}$

- increase with raw number of input tracks (Poissonian limit $\propto \sqrt{N}$)
- Poissonian limits from raw p_T spectrum
- correlated contribution in fluctuations
- randomized events approach limit (N.B. ρ calculated from real event)

Correlation with Event Plane

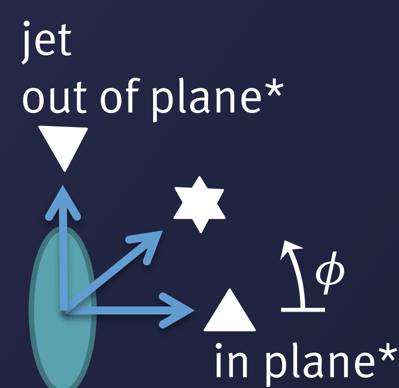


$$\delta p_T = p^{rec}_{T,jet} - \rho \times A_{jet} - p^{probe}_{T,(jet)}$$

- some correlated region-to-region fluctuations, not taken into account via global ρ estimation:
  - collective flow: ϕ-dependent change in N and $\langle p_T \rangle$
  - under-/overestimation of background
  - results in a significant shift of residuals

One source of broadening.

Essential to study path-length dependence of jet quenching.



* possible jet bias:
- event plane determined with raw tracks ($|\eta|<0.9$)
- weighted with p_T, $p_T > 2$ GeV/c: weighted with 2

EP Dependence with Multiplicity

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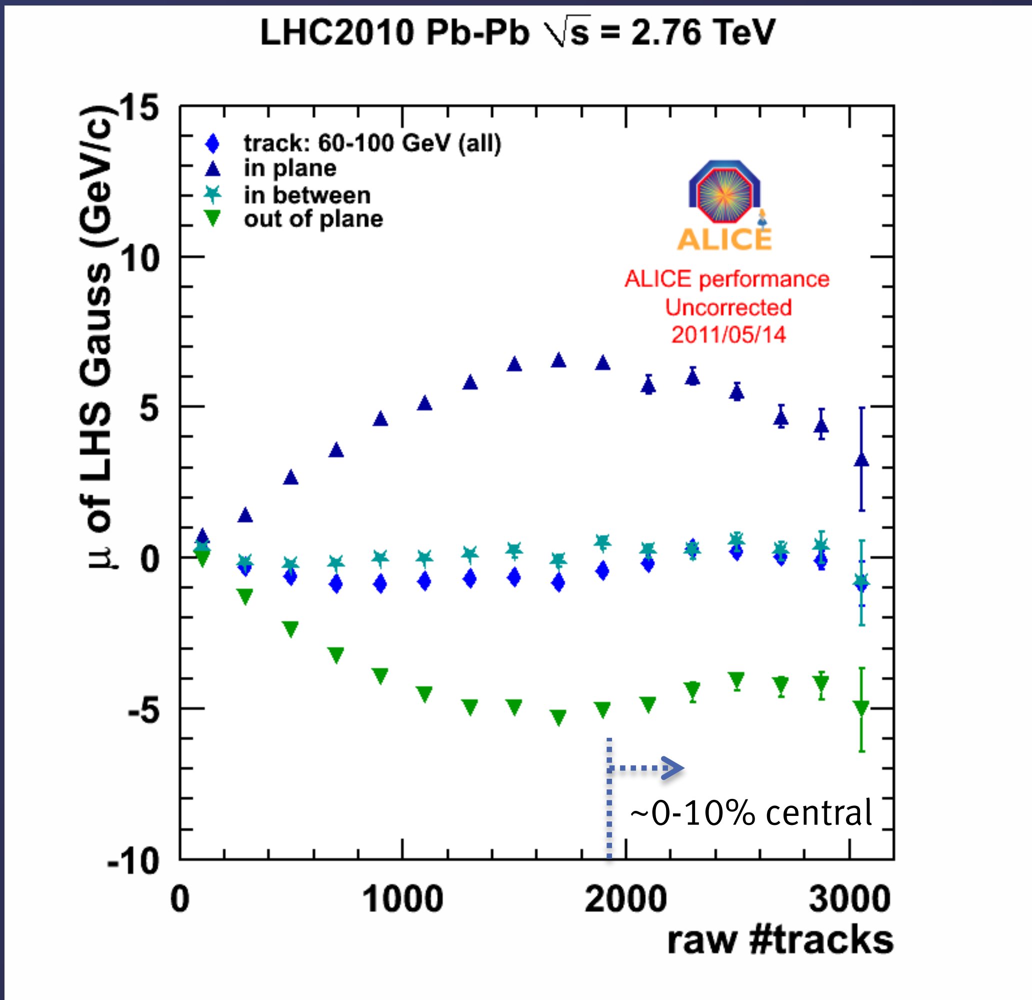
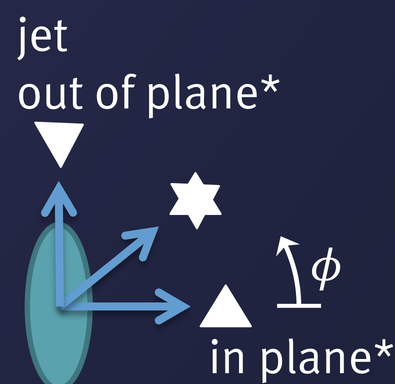
Mean of Gaussian fit



- some correlated region-to-region fluctuations, not taken into account via global ρ estimation:
  - collective flow: ϕ-dependent change in N and $\langle p_T \rangle$
  - under-/overestimation of background
  - results in a significant shift of residuals
- effect scales with $\sim v_2 \cdot \sum p_T$
- hence still important for central collisions



* possible jet bias:

- event plane determined with raw tracks (|η|<0.9)
- weighted with p_T, p_T > 2 GeV/c: weighted with 2

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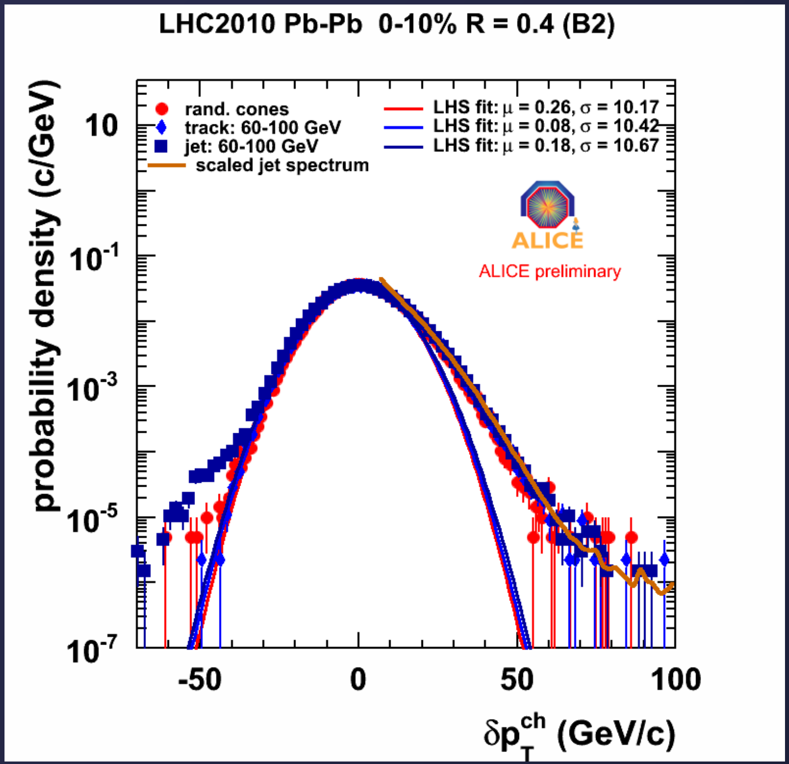
Summary

- "low"-p_T jets < 80 GeV/c in HIC strongly affected by background fluctuations
  - in 10% most central events: Gaussian width of fluctuations ≈ 10 GeV/c
  - understanding of background and its fluctuations essential in this energy region

- existence of region-to-region correlations:
  - due to collective flow
  - also present in central events
  - scope for improved jet background resolution



Outlook

- embedded quenched jets
  - input from strongly biased probe

- unfolded charged jet spectra in Pb-Pb
  - challenge due to similar shape of jet spectrum and non-Gaussian tail

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Thank you for your attention!