Universiteit Utrecht

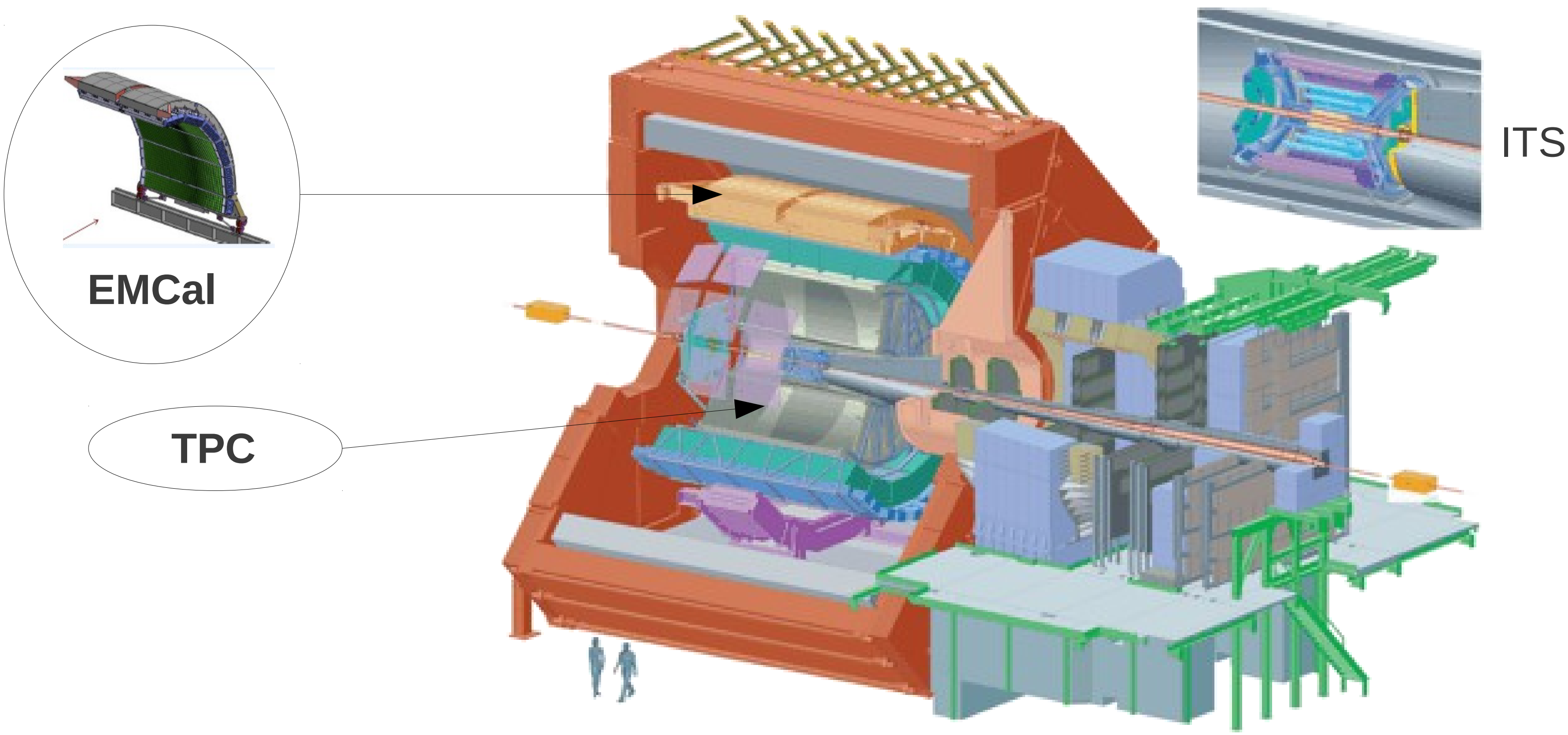
Jets in ALICE

Marta Verweij
for the ALICE collaboration

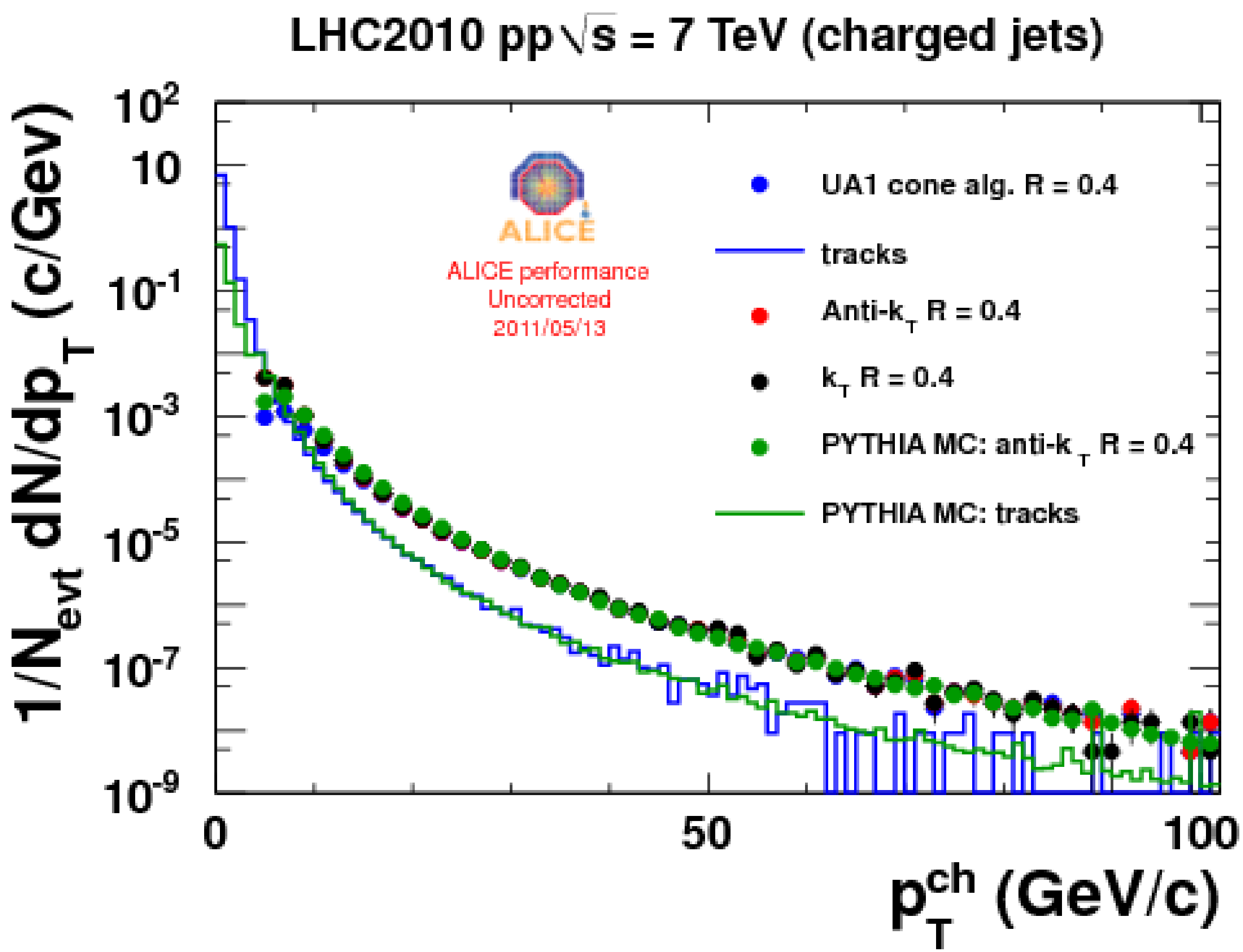
High-p_T Probes of High-Density QCD at the LHC 2011
Ecole Polytechnique, Palaiseau

Jet analysis with ALICE

- 2009/2010: Jet reconstruction with charged particles:
  - Central tracking system: Time Projection Chamber (TPC)
- 2011: Fully installed EMCal (10/10 modules) → full jets
  - Neutral particle measurements: Electromagnetic Calorimeter (EMCal)



Charged Jet reconstruction in pp

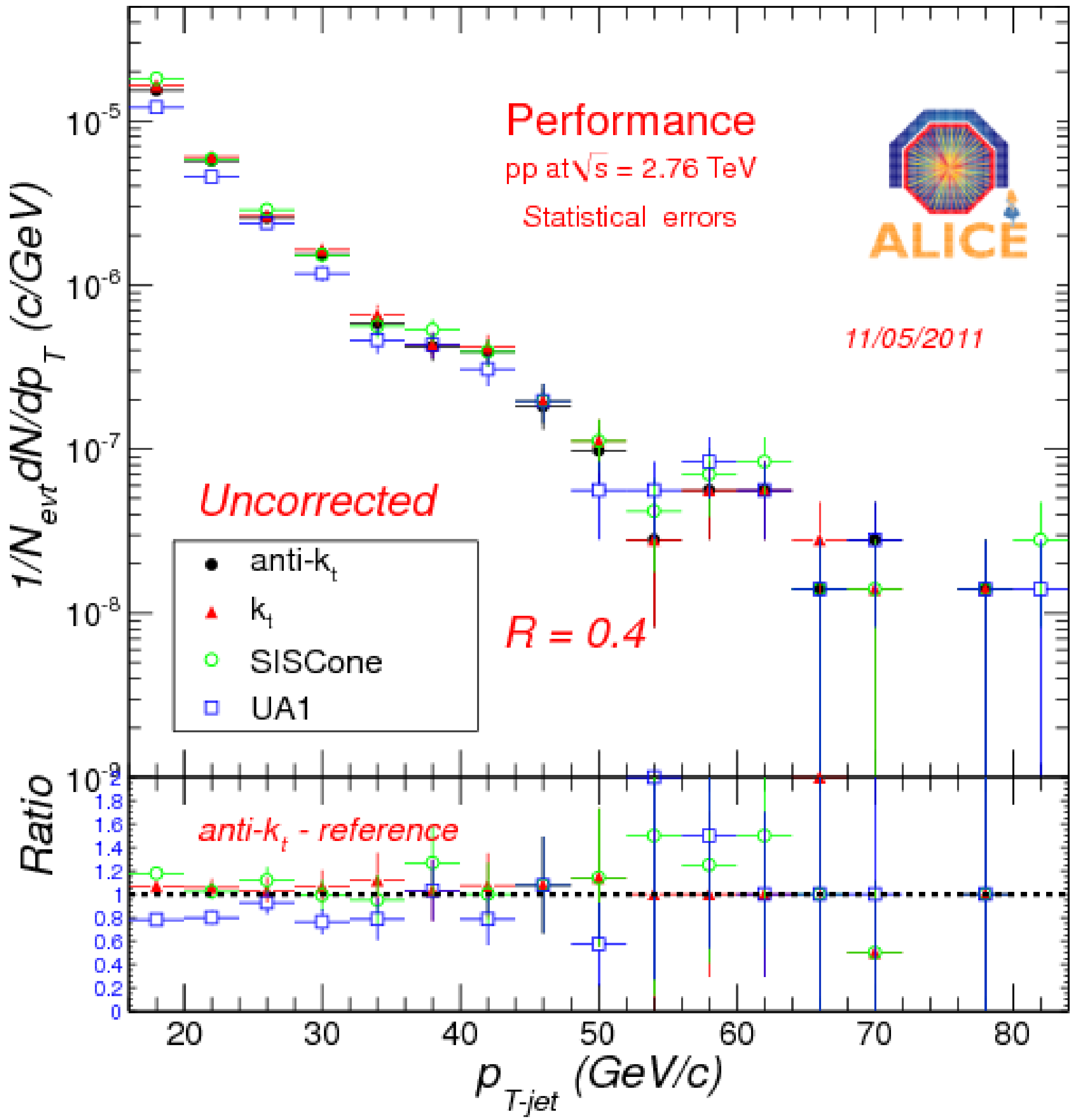


pp @ 7 TeV

- Tracks:
  full azimuth
  $|\eta| < 0.9$
  $p_T > 0.15$ GeV/c
- Jets:
  full azimuth
  $|\eta| < 0.5$

- Jet finding with charged tracks in pp well understood

Charged Jet reconstruction in pp

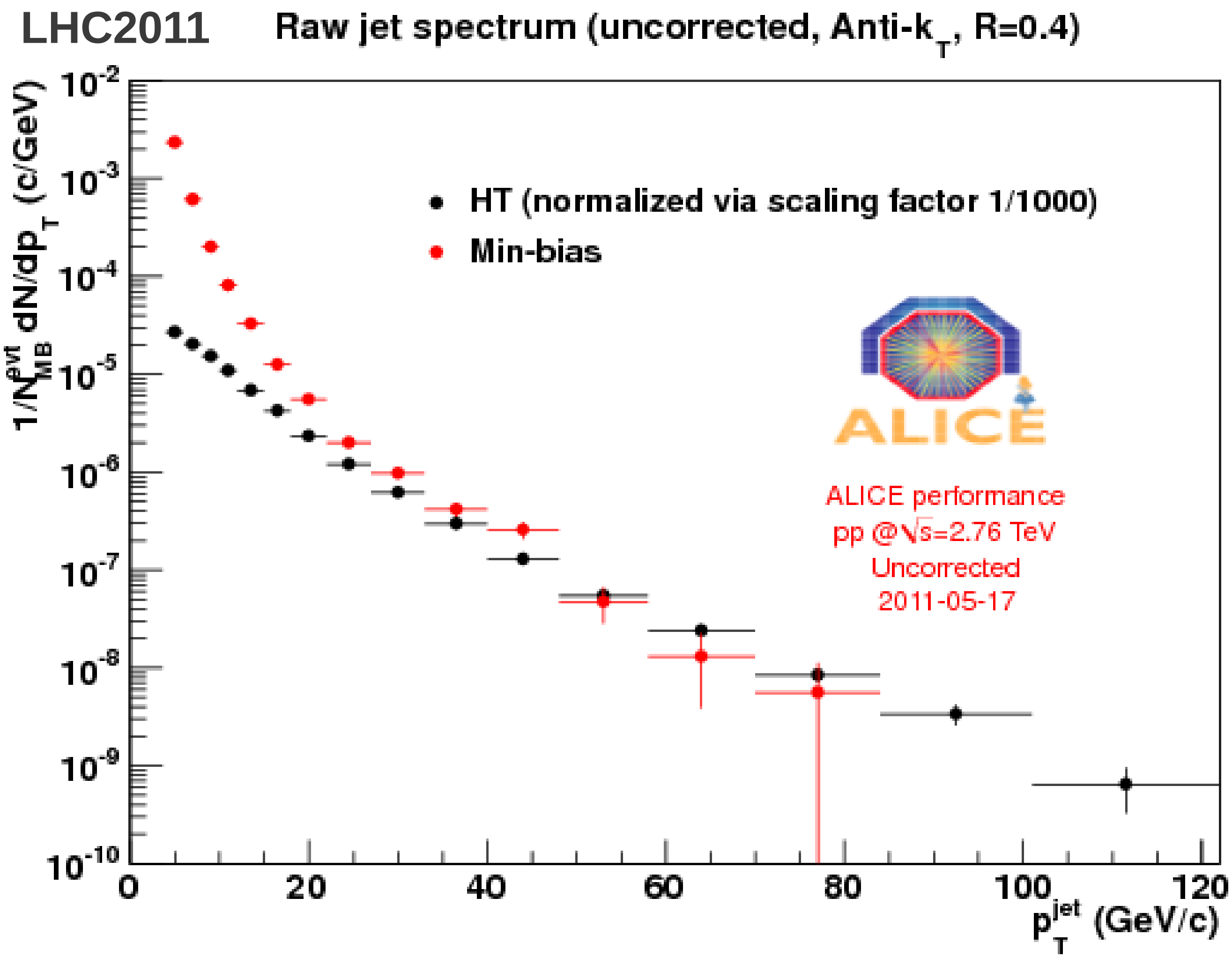


Reference run
pp @ 2.76 TeV

- Tracks:
  full azimuth
  $|\eta| < 0.9$
  $p_T > 0.15$ GeV/c
- Jets:
  full azimuth
  $|\eta| < 0.5$

- Jet finding with charged tracks in pp well understood

Full Jet reconstruction in pp



Reference run pp @ 2.76 TeV

- EMCal + TPC
  - Clusters + Tracks
- EMCal acceptance: $|\eta| < 0.7$; $1.4 < \phi < \pi$
- Jet acceptance: $|\eta| < 0.3$; $1.8 < \phi < 2.7$
- Uncorrected for charged particle shower

- High-tower trigger enhances jet yield at high p_T
- In progress: measurement inclusive differential jet cross-section

Jets in Heavy Ion Collisions

- At early stage in the collision hard scattered parton is produced
- Parton traverses hot medium created in a Heavy Ion collision
- Due to interaction of the jet with the medium, the jet is modified:
  Jet Quenching
- The amount of medium-induced gluon radiation depends on the coupling

Experimental challenge in HI collisions:
Separate jet signal from large soft background originating from bulk

Jet Reconstruction

- ALICE uses sequential recombination algorithms from FastJet package [Phys Lett B 641 (2006) 57]:
  - anti-k_T for signal (stable area)
  - k_T to estimate background density
  - Boost invariant p_T recombination scheme
  - Transverse momentum track cut-off $p_T > 0.15$ GeV/c
- Charged jet reconstruction with tracks reconstructed in the TPC:
  - High precision on particle level
  - Uniform η-φ acceptance
  - Neutral energy missing, eg. π^0, n, γ

Jets in PbPb: background

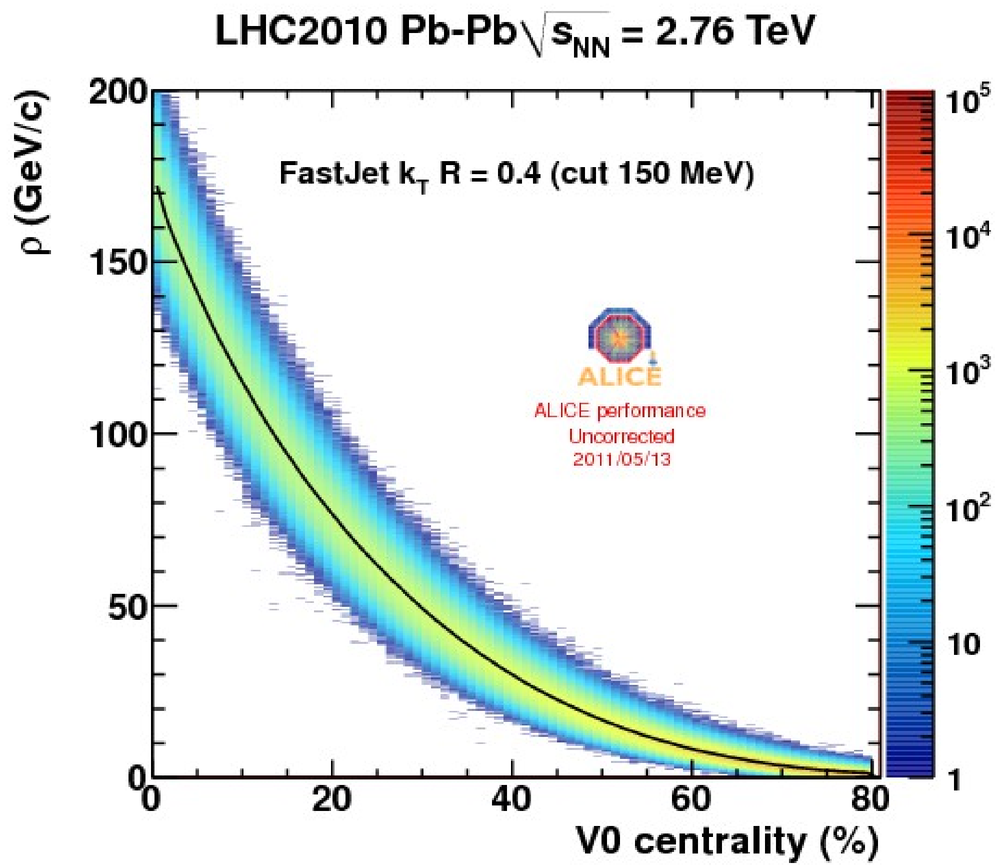
- 2 step procedure to correct for UE contaminating the jet:
  - Subtraction of background density ρ event-by-event:
    event clustered with k_T algorithm to calculate ρ

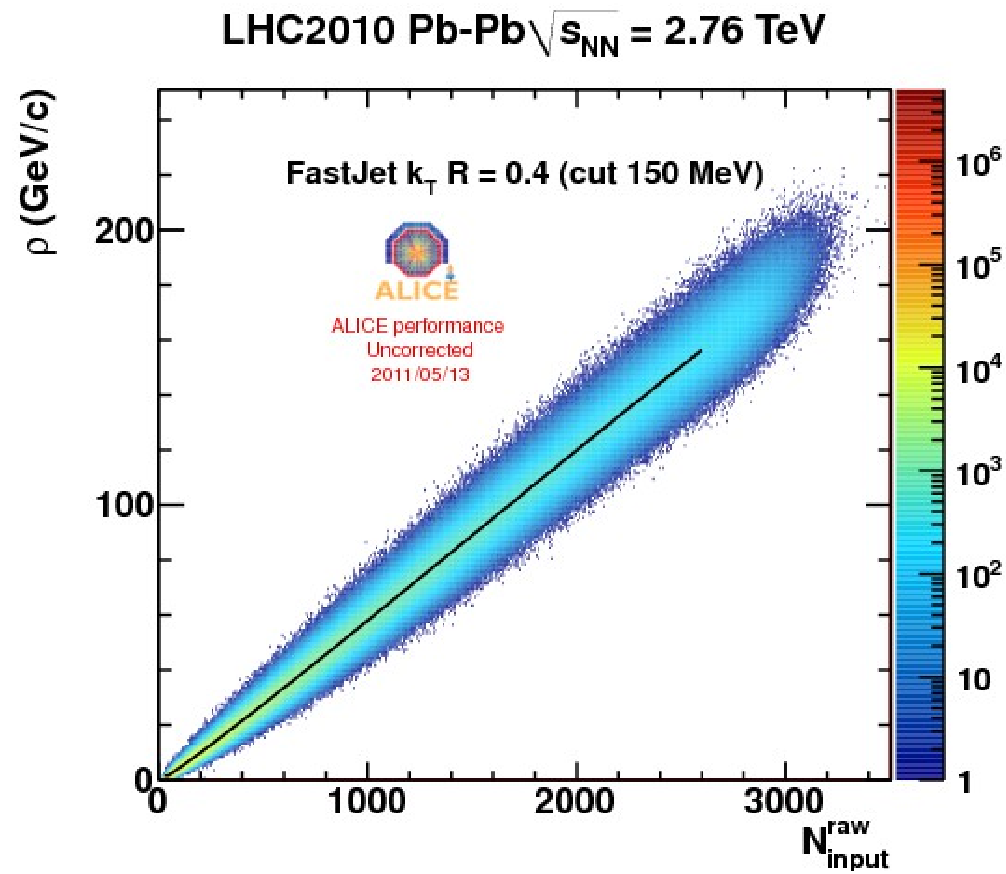
$$\rho = median\left(\frac{p_T^{jet,i}}{A_i^{jet}}\right)$$

    excluding the 2 leading clusters.
    In case of a dense and homogeneous background each clusters has momentum density ρ. Otherwise → jet energy irresolution.

  - Background fluctuations around ρ due to inhomogeneous structure of events. Quantified by embedding high p_T probes on top of the measured PbPb events.

Event Background

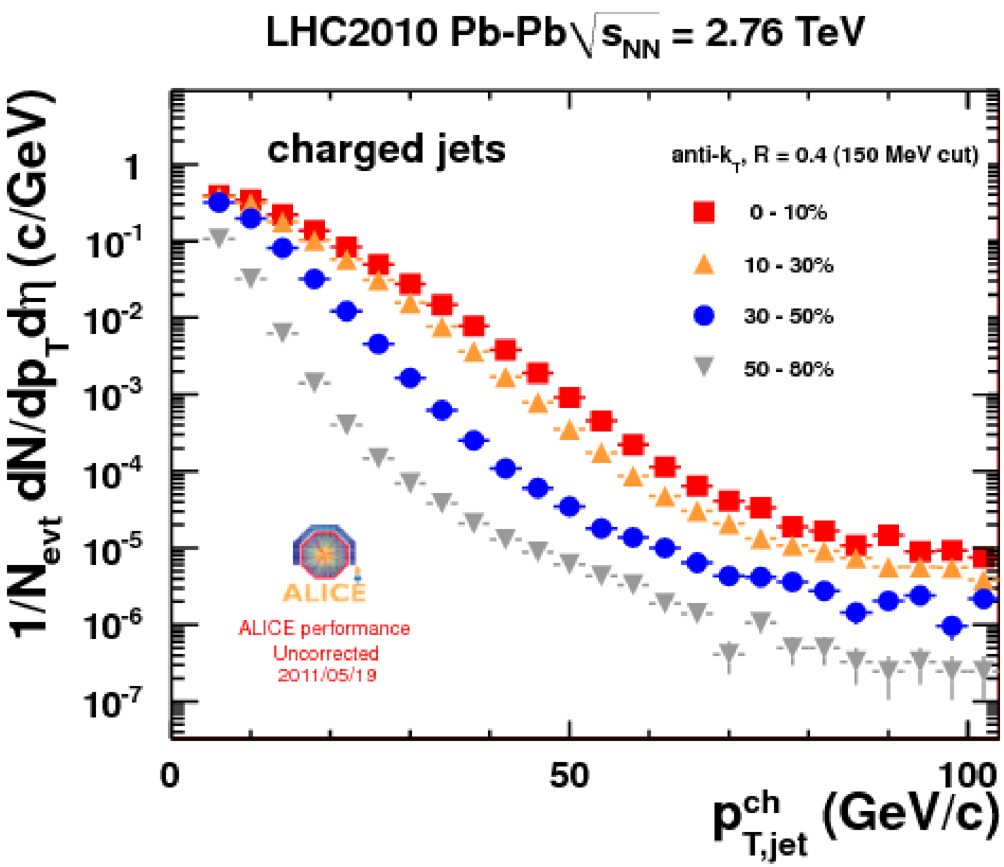




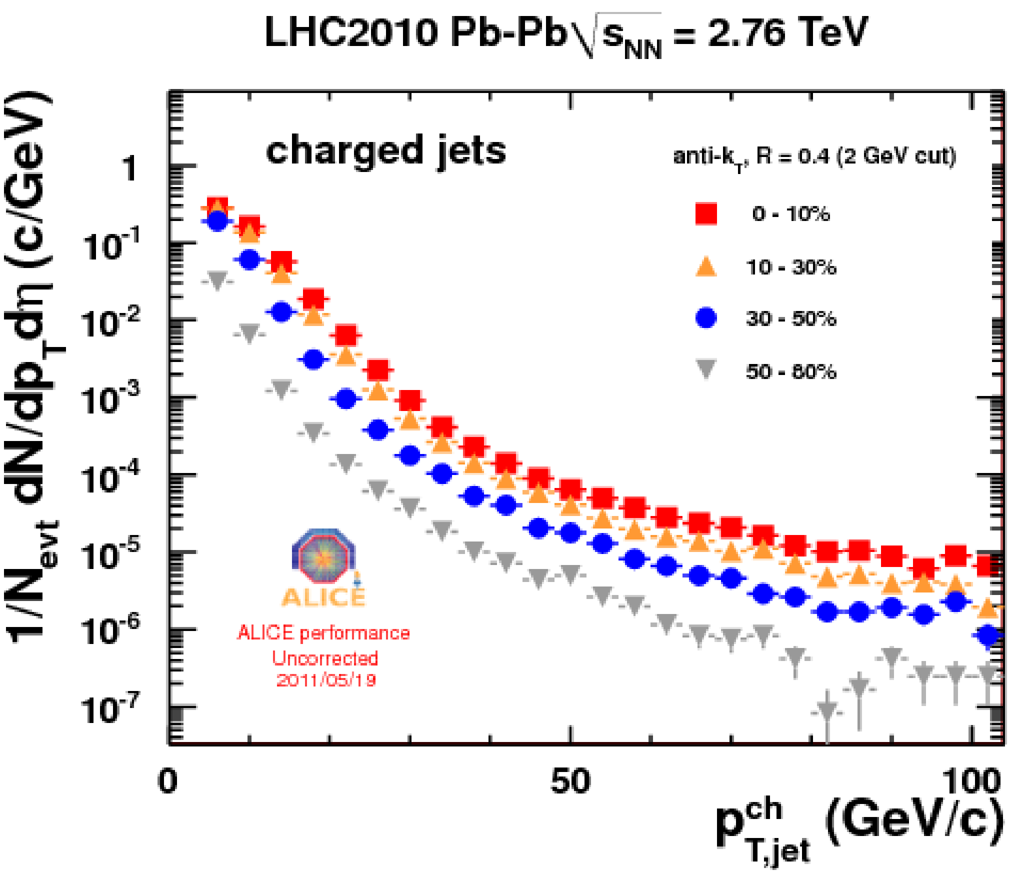
- Background scales with event multiplicity: $\rho \sim N \langle p_T \rangle$
- For 0-10% centrality, $\langle \rho \rangle \sim 140$ GeV/area
  → contamination of 70 GeV/c in cone of R = 0.4
- Fluctuations are spread of ρ in given multiplicity bin

Uncorrected Jet Spectra

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



$p_{T,track}$ > 2 GeV/c



- Average background subtraction: event-by-event
- p_T<80 GeV/c: Large fluctuations in measured jet energy

Background Fluctuations

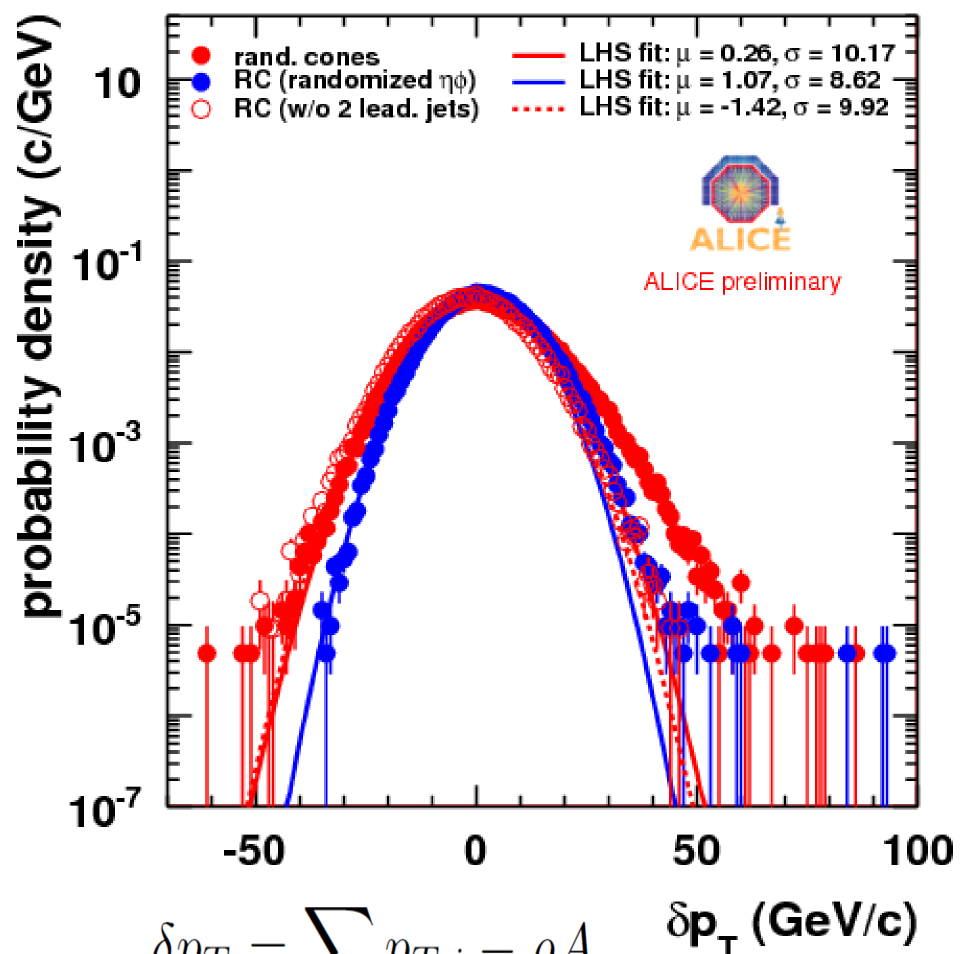
- Background fluctuations estimated by studying the response of embedded high p_T probe in heavy ion event.
- Data driven approach to estimate influence of background fluctuations on jet reconstruction.
- We embed different kind of probes:
  - Random cones
  - Single tracks
  - Jets from full detector simulation pp @ 2.76 TeV
- Response is quantified by comparing the reconstructed jet to the embedded jet:

$$\delta_{p_T} = p_{T,jet}^{rec} - \rho A - p_T^{probe}$$

Random cones

- Non-overlapping cones of fixed area placed randomly within HI event. 3 types of events:
  - Measured event
  - Measured event without 2 leading jets
  - Randomized event in η-φ
- Fluctuations centered around 0 → quality check for background subtraction.
- RC with and w/o leading jets similar for $\delta p_T < 0$
- RC w/o 2 leading jets and RC randomized event similar for $\delta p_T > 0$

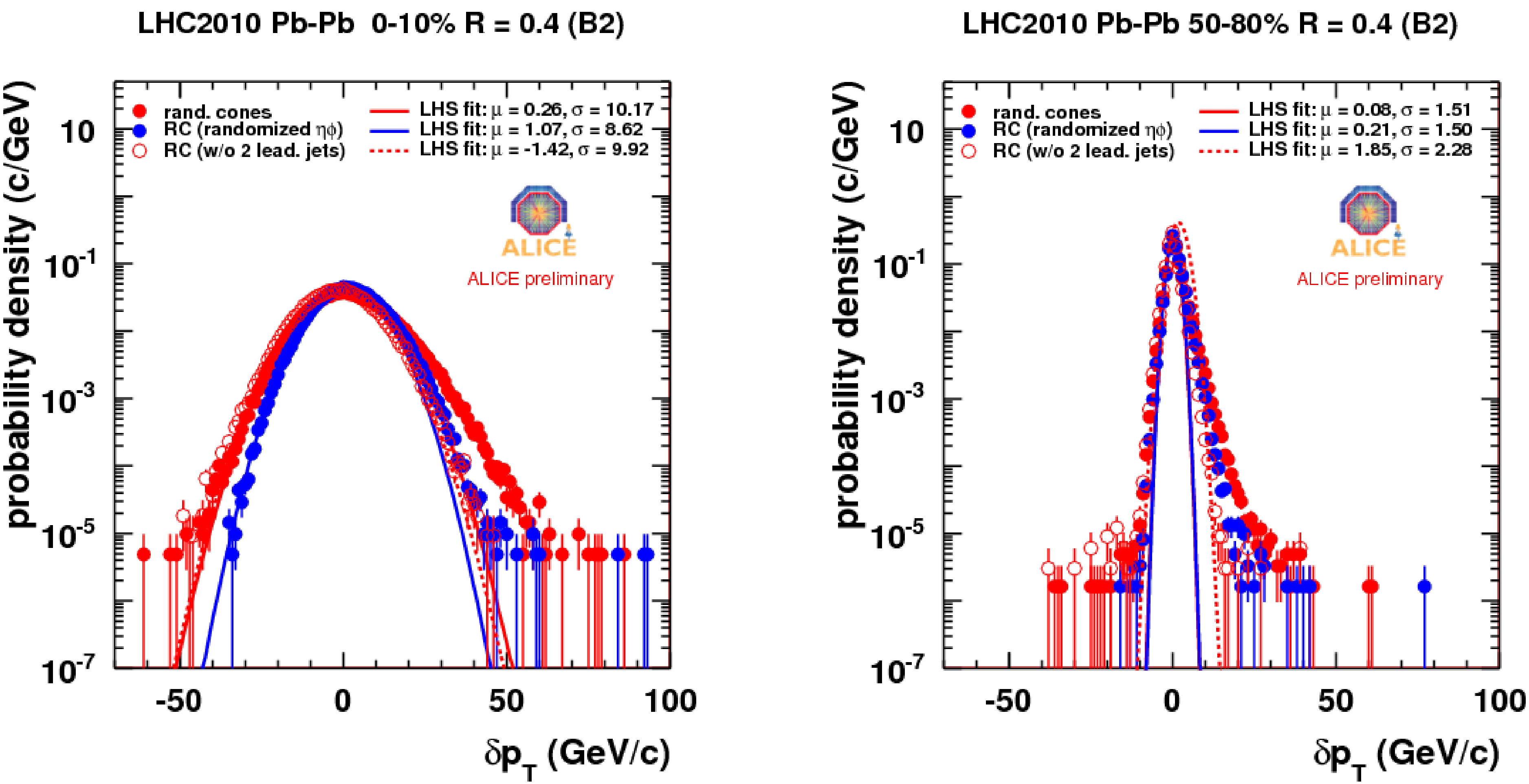
LHC2010 Pb-Pb 0-10% R = 0.4 (B2)



$$\delta p_T = \sum_i p_{T,i} - \rho A$$

Sum of all particles in cone

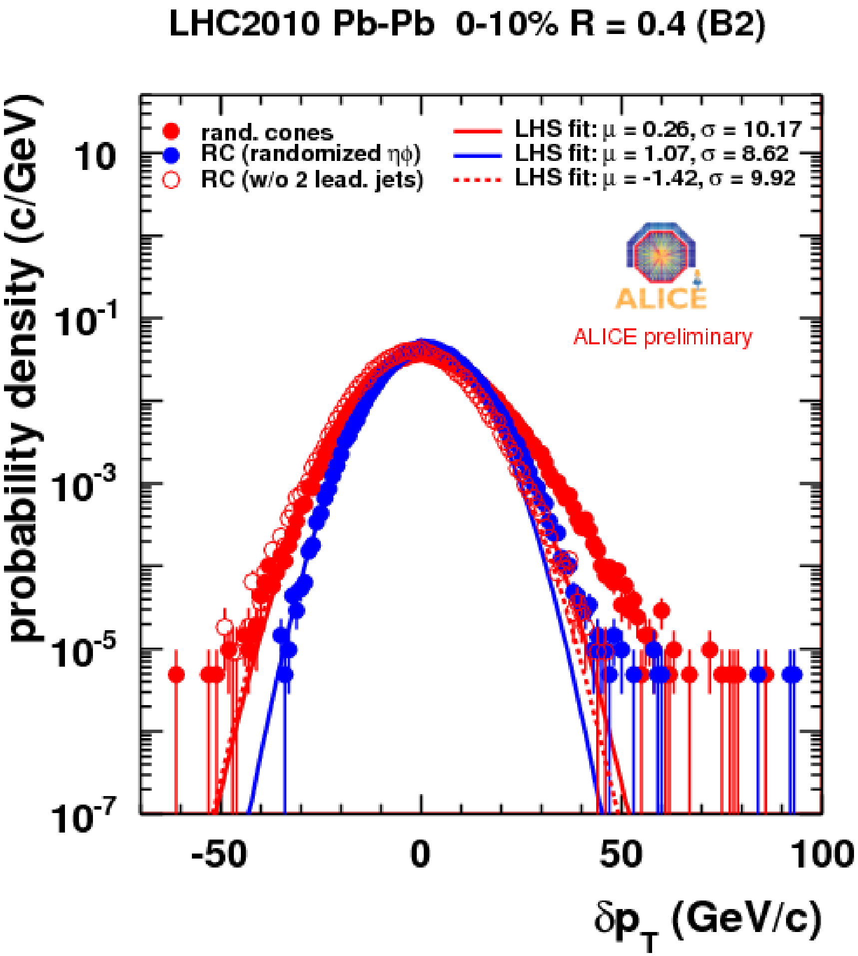
Random cones

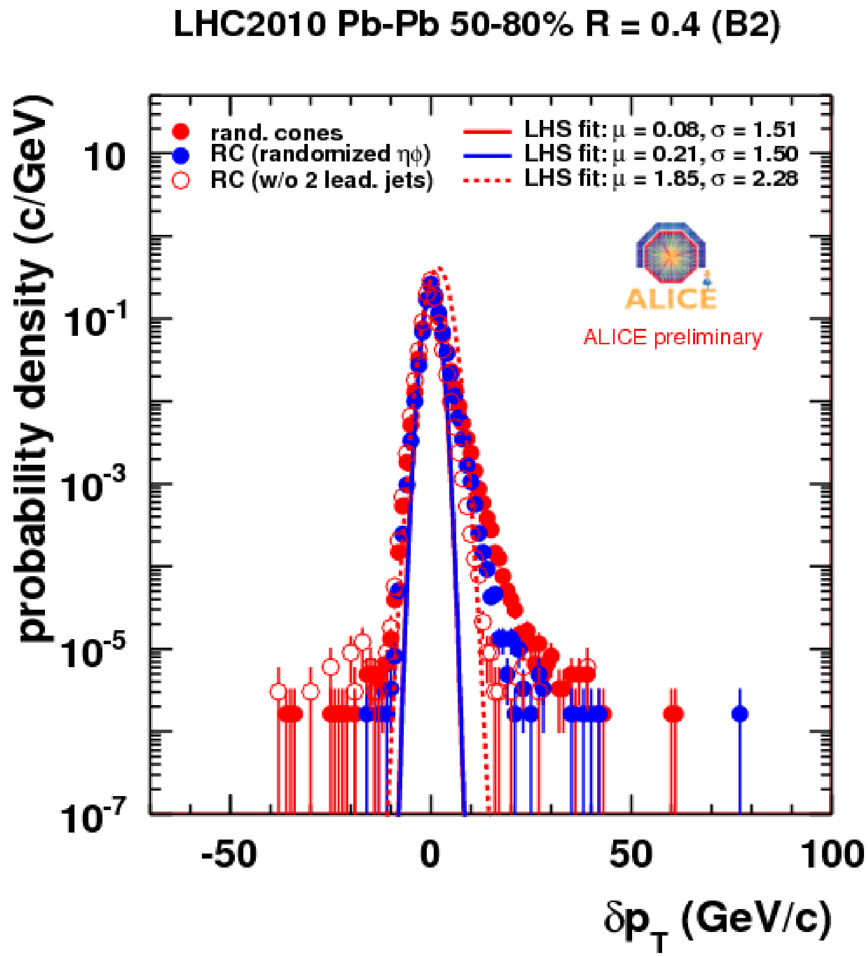


- Left-Hand-Side ($\delta p_T < 0$) of response:

  Correlated region-to-region fluctuations.
  Characterized by iterative Gaussian fit to estimate fluctuation (width).
  Background fluctuation smaller for more peripheral events.

Random cones





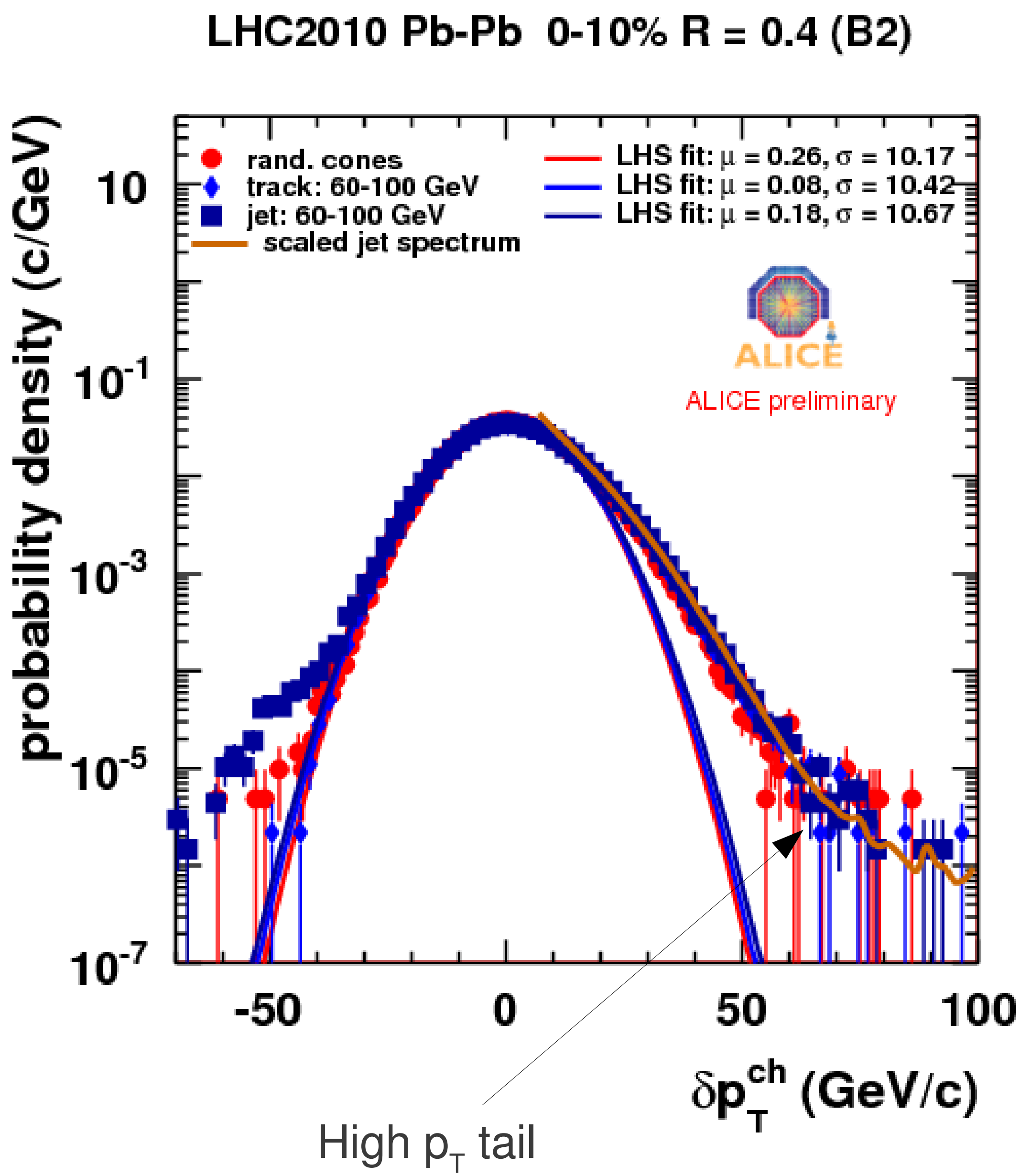
- Right-Hand-Side ($\delta p_T > 0$):

  Suppression of tail: removal of jet signal

Comparison of probes

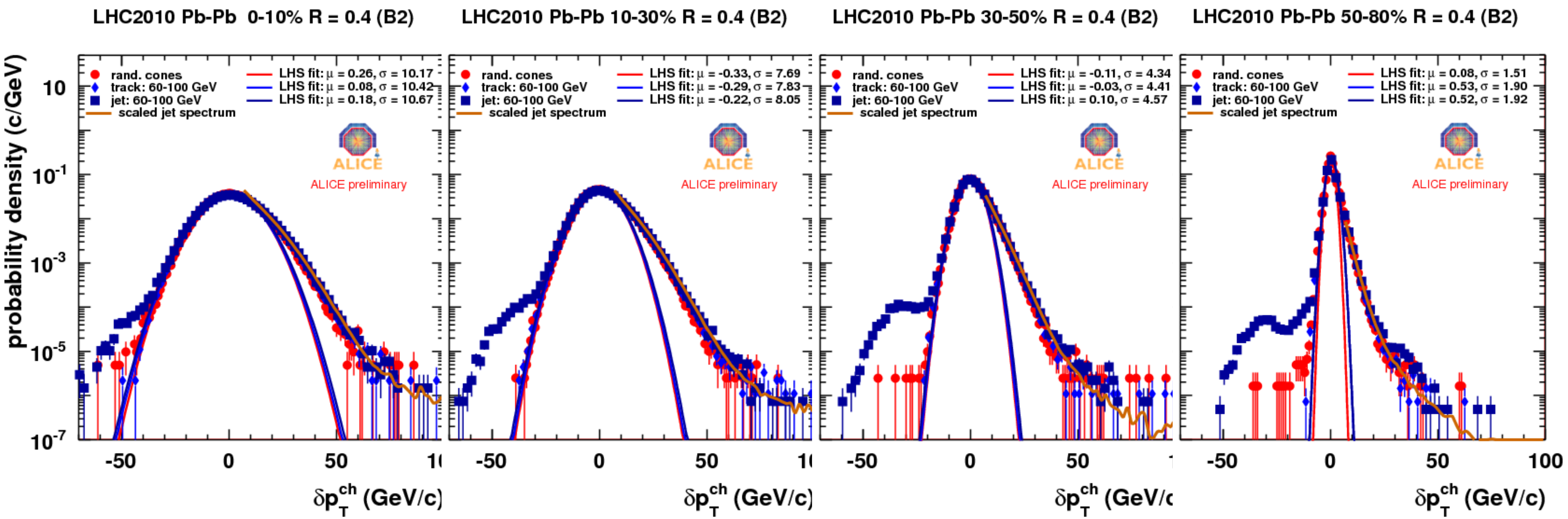
Random Cones
Single Tracks
Pythia jets

- Fluctuations independent of type of probe
- Background correction should not depend on fragmentation pattern since this is an unknown
- High p_T tail same shape as jet spectrum
  - Challenging for unfolding



Comparison of probes

central → peripheral

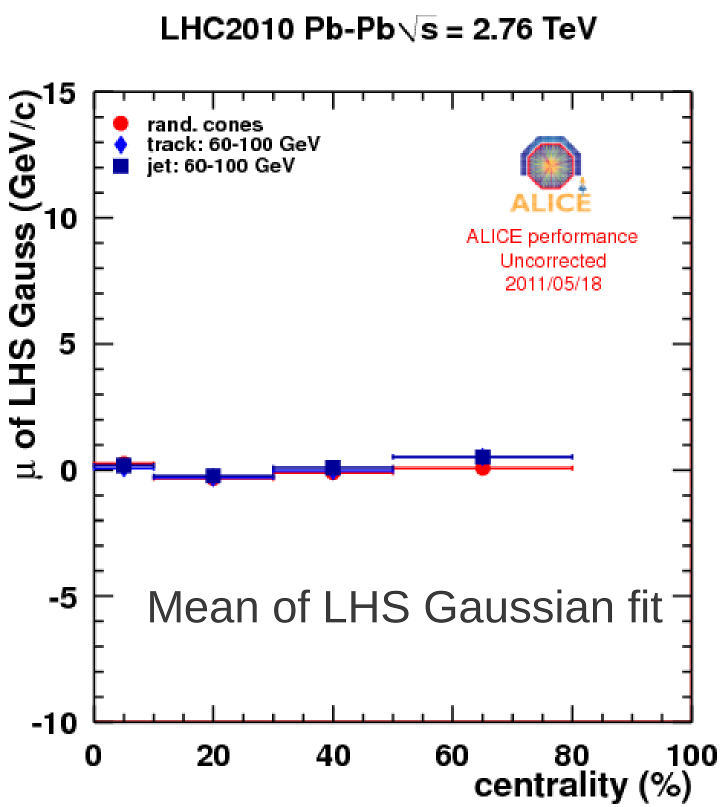


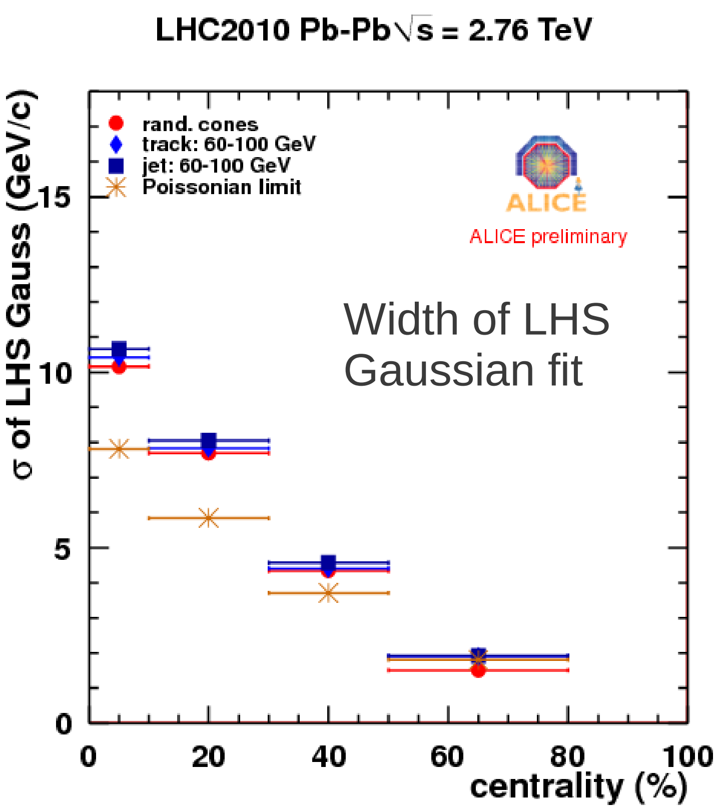
- Broad response + high p_T tail challenging for unfolding

Structure for $\delta p_T < 0$ discussed on slide 19 & 20

Comparison of probes

Trending vs Centrality





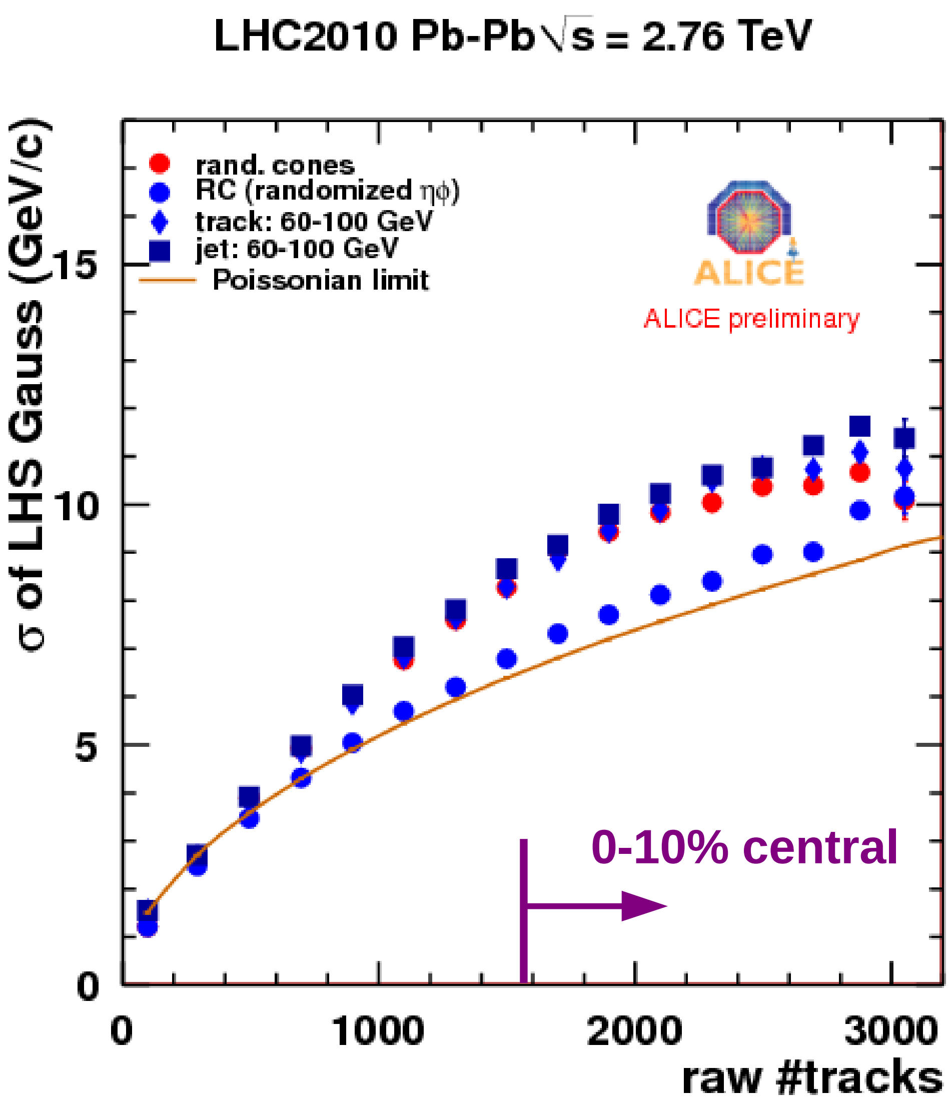
Stable background subtraction.
Poissonian limit: if background consists of independently emitted particles.
Observed fluctuations larger than Poissonian limit. *M. Tannenbaum PLB 498 2001*

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

$\langle p_T \rangle$ and N from raw p_T spectrum

Comparison of probes

Trending vs Multiplicity

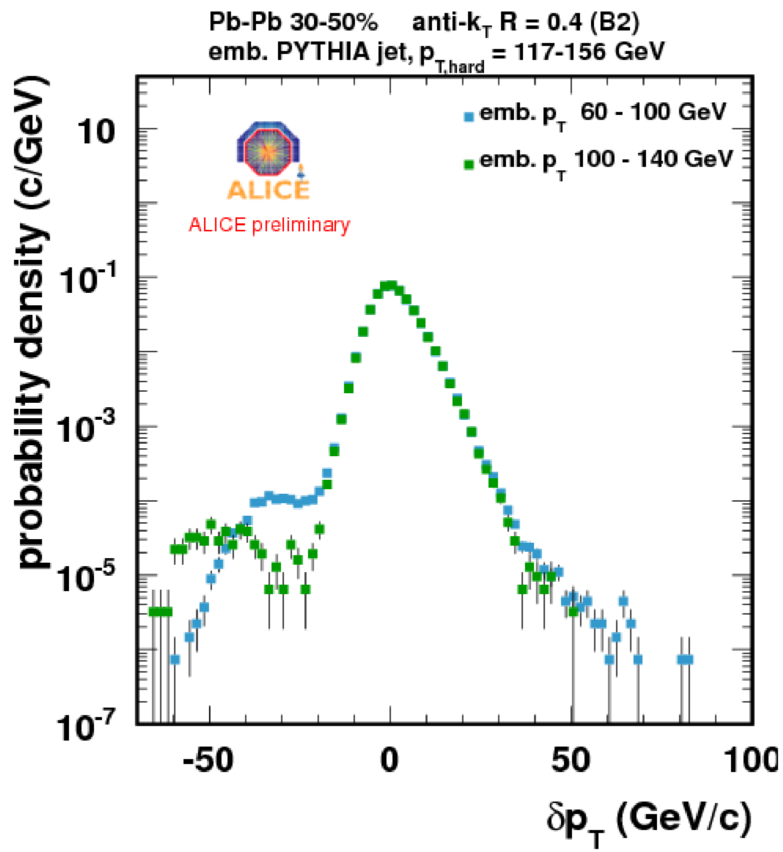


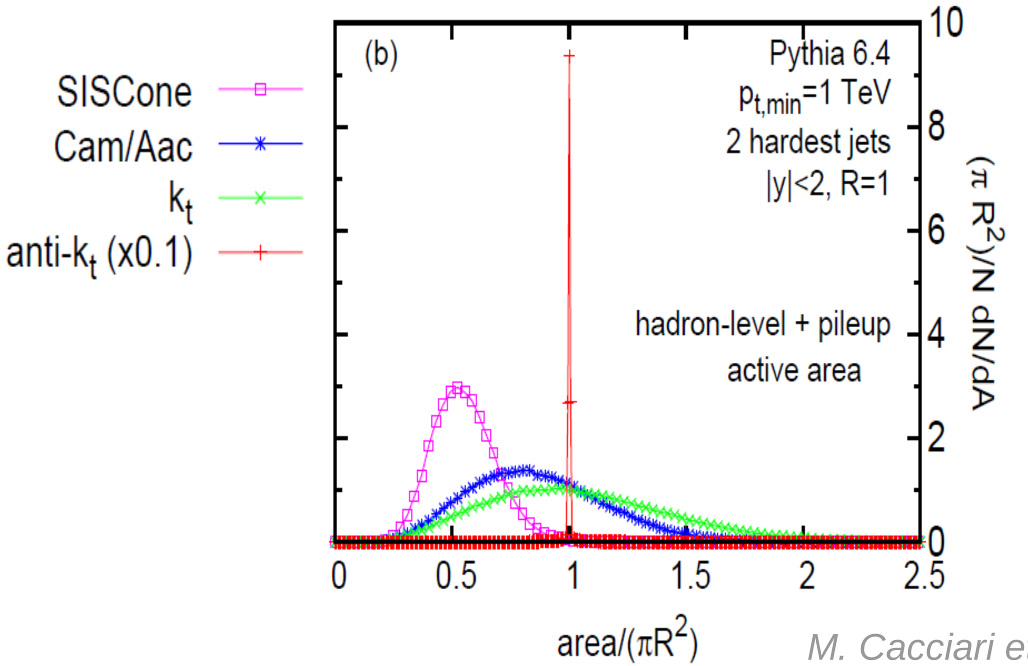
- Large variation of fluctuations within 0-10% centrality bin → ~ 70%
- Randomized events approach Poissonian limit.
  (ρ calculated from real event)

Back reaction

- $\delta p_T < 0$ tail from jet splitting

  Anti-k_T: most jets have area = πR^2 = 0.503 for R=0.4
  Rare fragmentation patterns with hard perturbative radiation → large area.
  Jet consists of two hard particles ($k_{T,1} \sim k_{T,2}$) within distance R → final jet is union of 3 cones: 2 around the leading particles and 1 at the center of the jet.





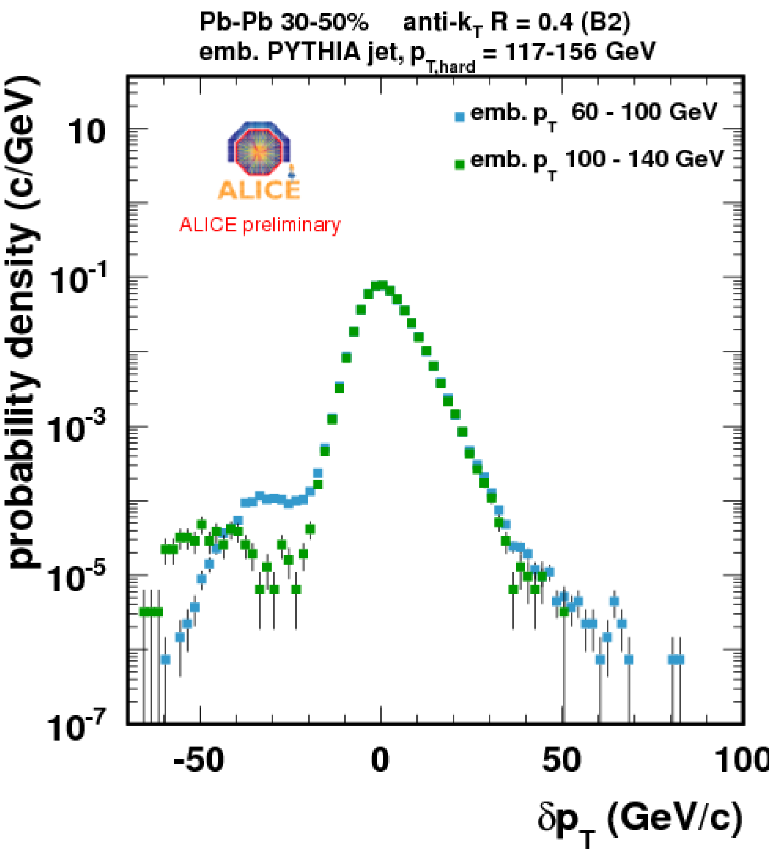
M. Cacciari et al JHEP04(2008)063

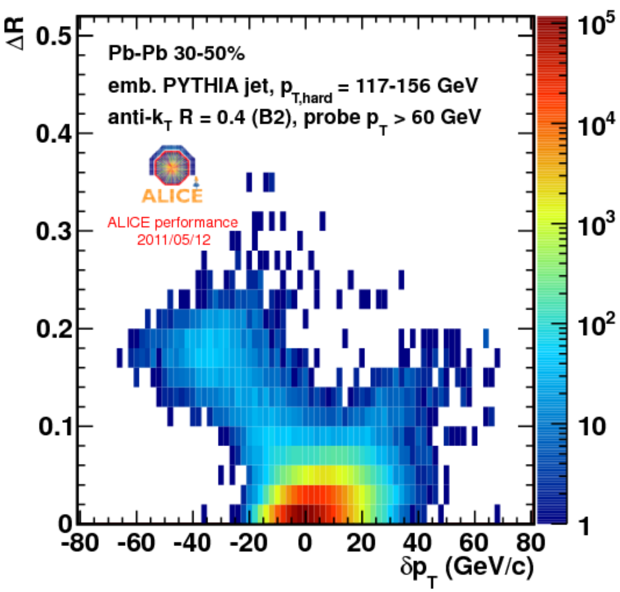
Back reaction

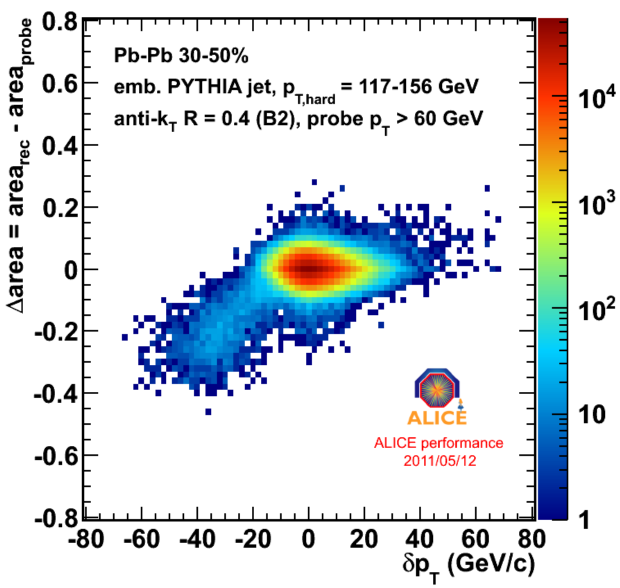
- $\delta p_T < 0$ tail from jet splitting

  Anti-k_T: most jets have area = πR^2 = 0.503 for R=0.4
  Rare fragmentation patterns with hard perturbative radiation → large area.
  Jet consists of two hard particles ($k_{T,1} \sim k_{T,2}$) within distance R → final jet is union of 3 cones: 2 around the leading particles and 1 at the center of the jet.

  See M. Cacciari et al JHEP04(2008)063

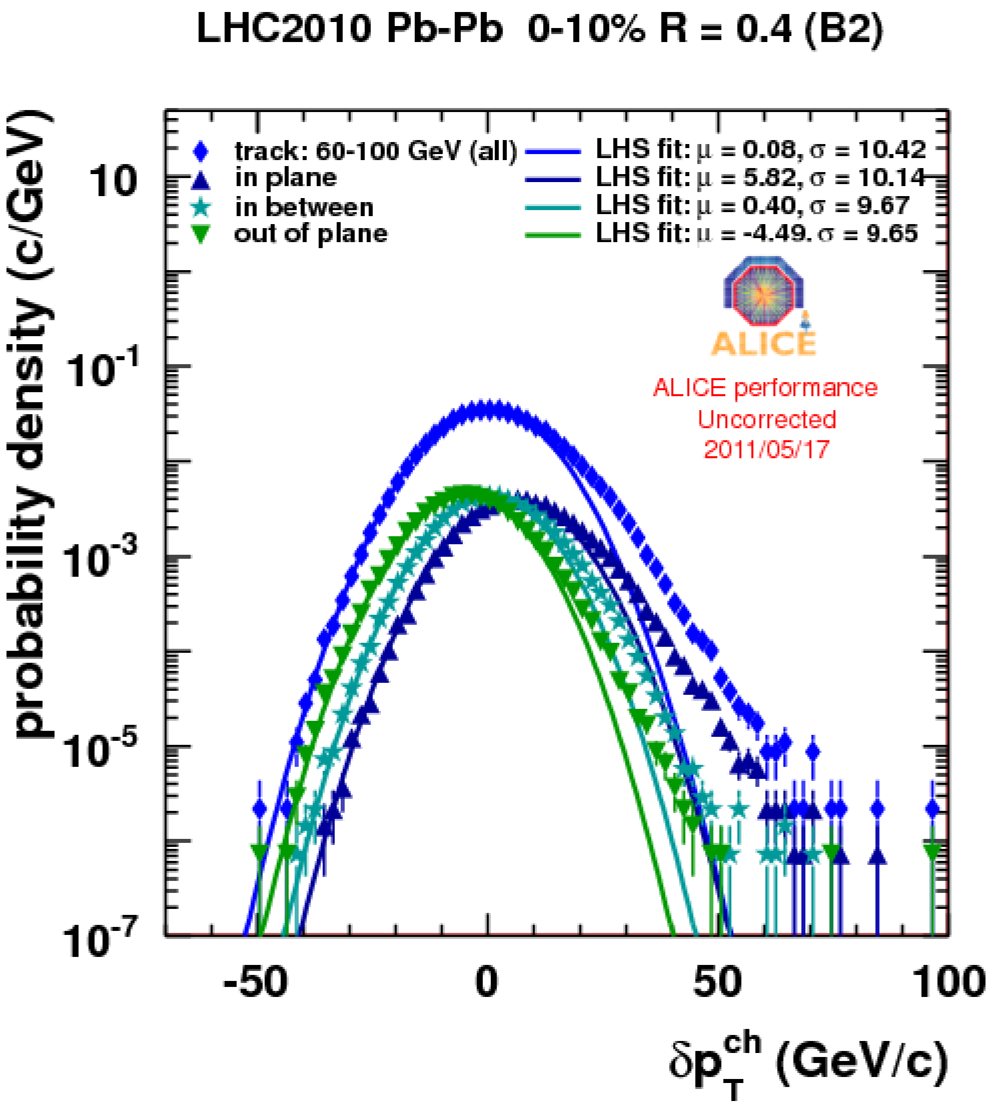




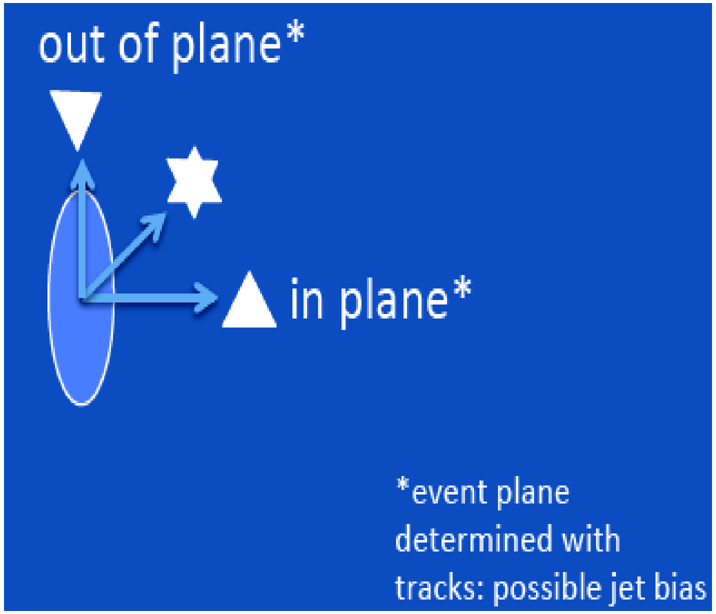


HI background leads to splitting into normal sized jets with large negative δp_T and a change in the jet axis

Fluctuations vs Event Plane



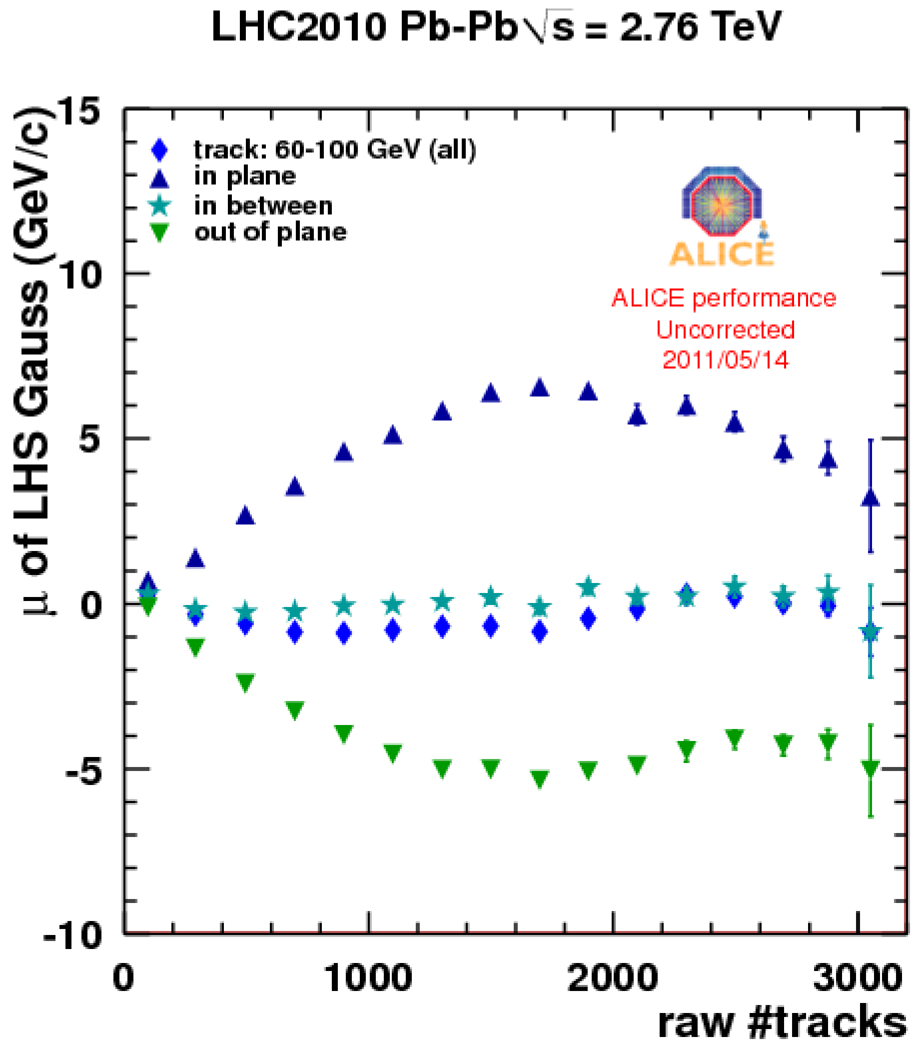
Goal: estimate influence of region-to-region fluctuations of correlated background.



Background vs Event Plane

Mean

- In plane:
  background underestimated
- Out of plane:
  background overestimated
- Local ρ different for in and out of plane.
- Effect scales with $v_2 * \Sigma p_T$

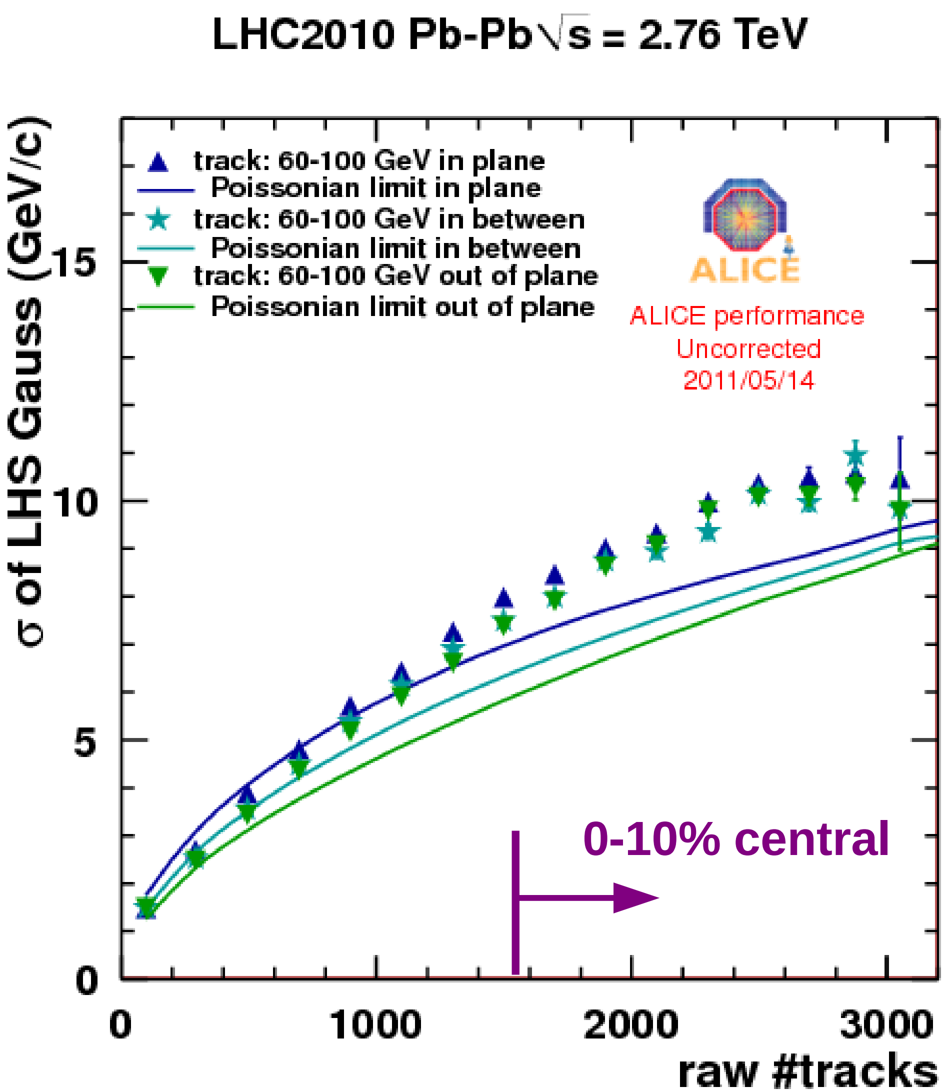


Broadening of fluctuations due to:
Shift in background energy scale as function of EP

Fluctuations vs Event Plane

Width

- Smaller fluctuations compared to inclusive.
- Less variation of ρ within a given event plane bin:
  - change in mean p_T and mean multiplicity



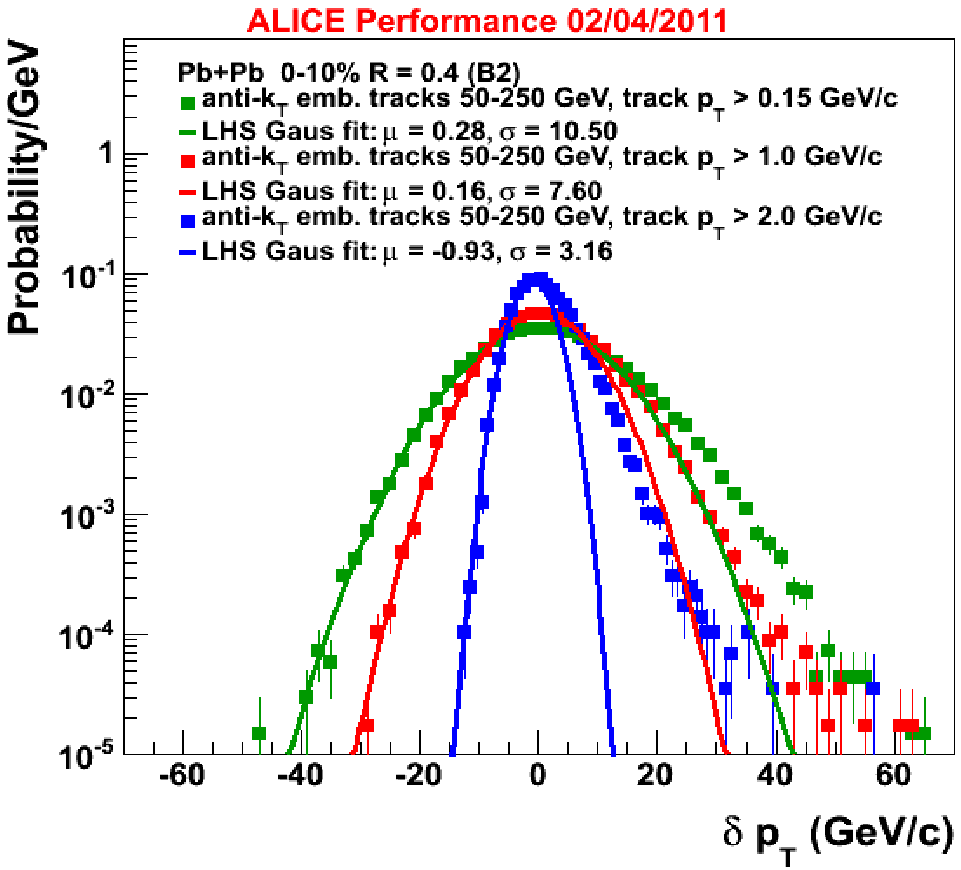
Summary and Outlook

- Background fluctuations largest uncertainty for inclusive jet cross section in HIC.
  - Same level of background fluctuations for different fragmentation patterns.
  - Collective effects (v_2) broaden background fluctuations
  - Gaussian width of fluctuation > 10 GeV/c for central collisions
  - A challenge for unfolding

- Next for ALICE jet analysis:
  - Unfolded charged jet spectra in PbPb with 2010 data
  - 2011: fully installed EMCal → full jet reconstruction
  - Intrajets, correlations, ...

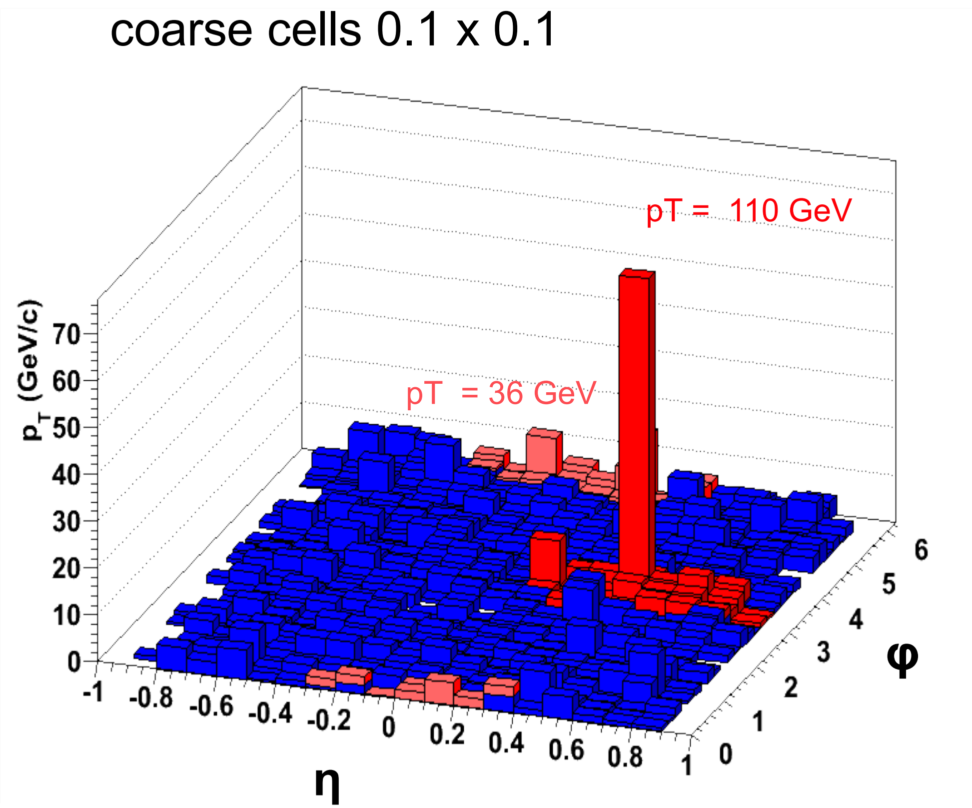
backup

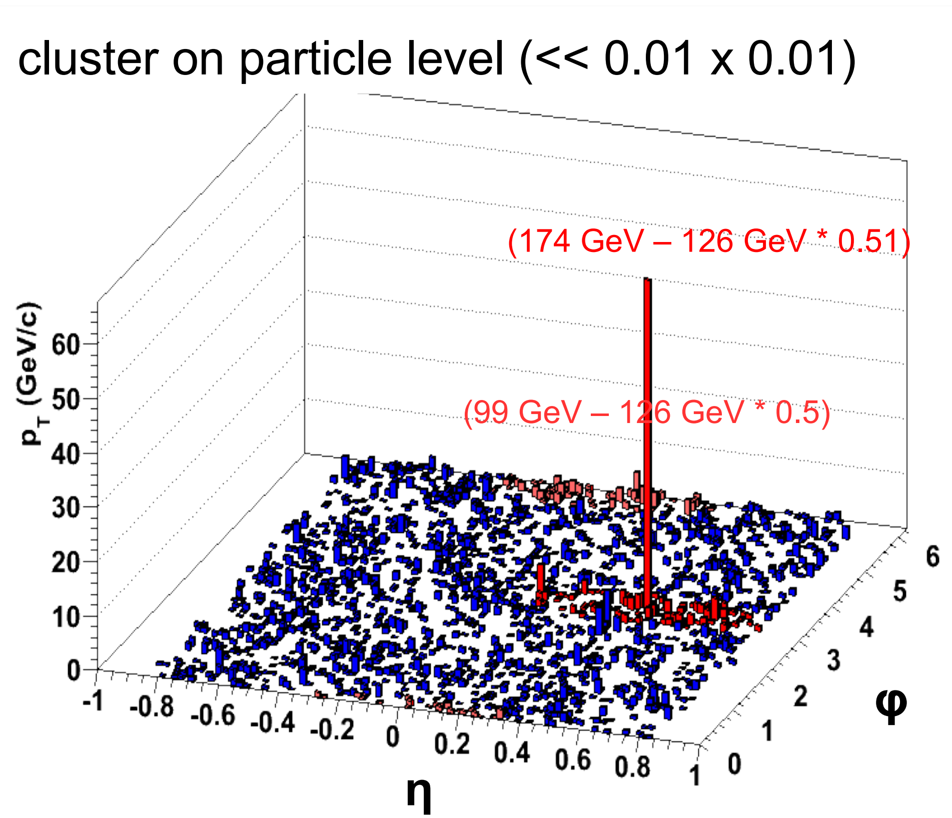
σ_{Jet} vs track p_T cut



Reduction of background fluctuations as function of track p_T cut.

Course cells vs particles





Jet embedding

- Embed jet in event
- Get N closest reconstructed jets around position of embedded jet (we chose N=4)
- Calculate embedded energy fraction of each closest jet
  - Embedded energy fraction:

$$f = \frac{\Sigma_i p_{T,emb}^{part,i}}{p_{T,emb}^{jet}}$$

- Reconstructed jet (of the N closest) with largest fraction is defined as match to embedded jet
- Require embedded energy fraction > 0.5

EMCal High Tower trigger