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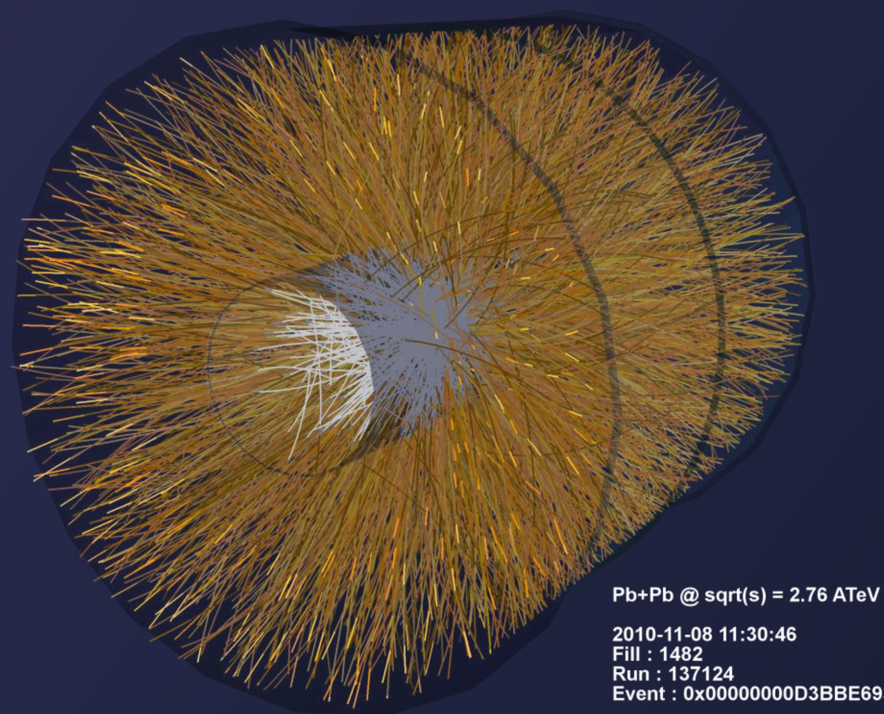
Fast Embedding of Jets in Heavy-Ion Collisions for Background Studies with ALICE



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BMBF Forschungsschwerpunkt ALICE Experiment 201

6th Int. Workshop High-p_T Physics at LHC
Utrecht, April 5th 2011

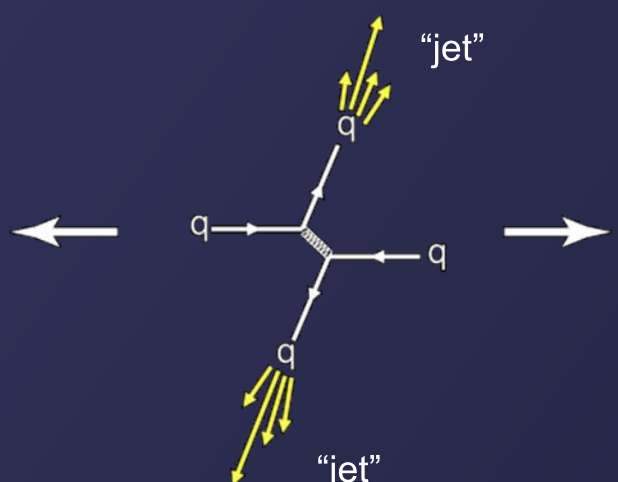
Outline

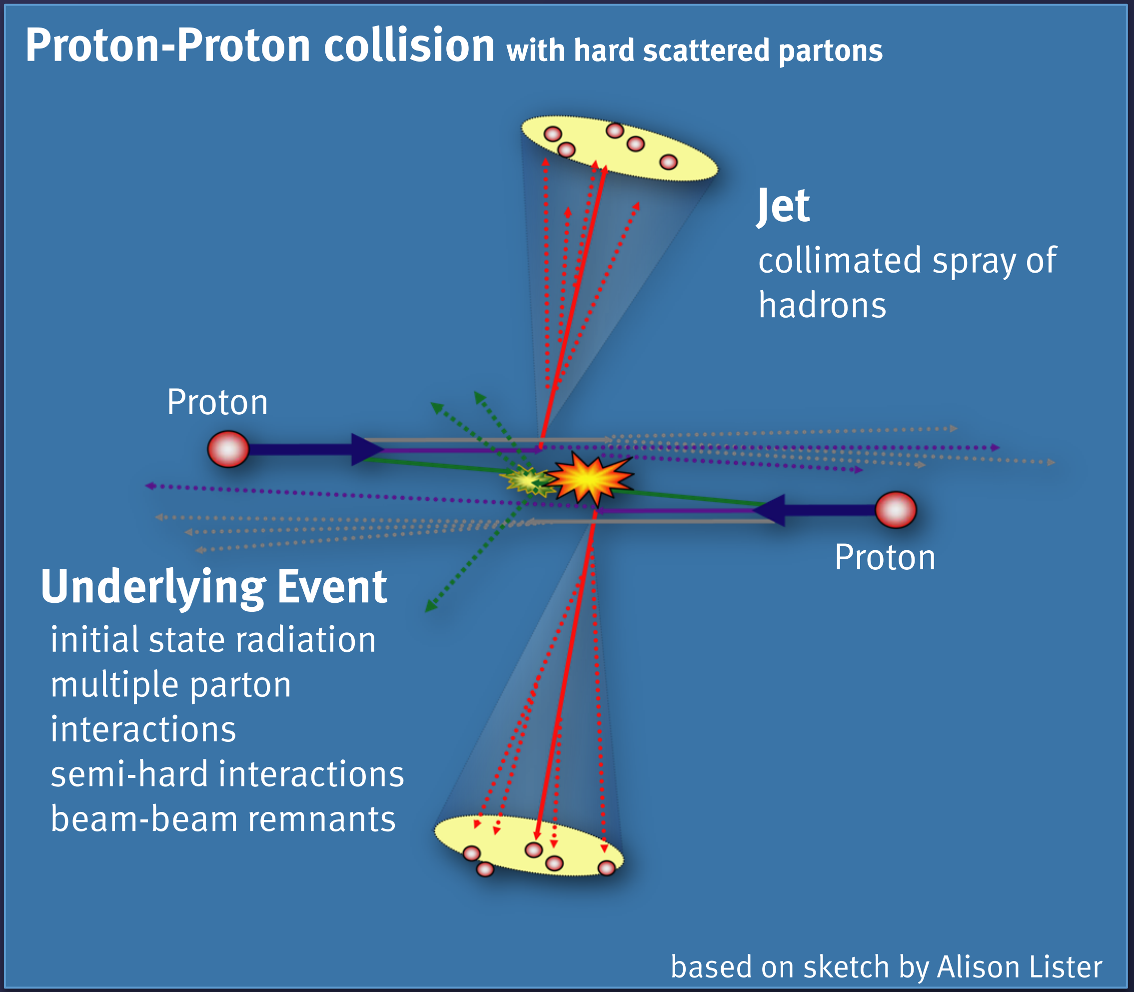
- Introduction to Jets
- ALICE
- Jets in ALICE
    - Jet Algorithms
- Jets
    - in p+p Collisions
    - in Pb+Pb Collisions
- Background in HI Events
    - Background Fluctuations
    - Fast Embedding
    - Random Cones
- Conclusion and Outlook

Introduction to Jets

- parton scattering with large Q^2
- quarks / gluons achieve a high transverse momentum
- due to confinement it results in a spray of observable hadrons (with high p_T)

hard scattered partons





NB: for A+A multiple nucleon-nucleon collisions, strong increase of underlying event

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A Large Ion Collider Experiment

ALICE EXPERIMENT

Electro Magnetic Calorimeter (EMCal)

Time-of-Flight (TOF)

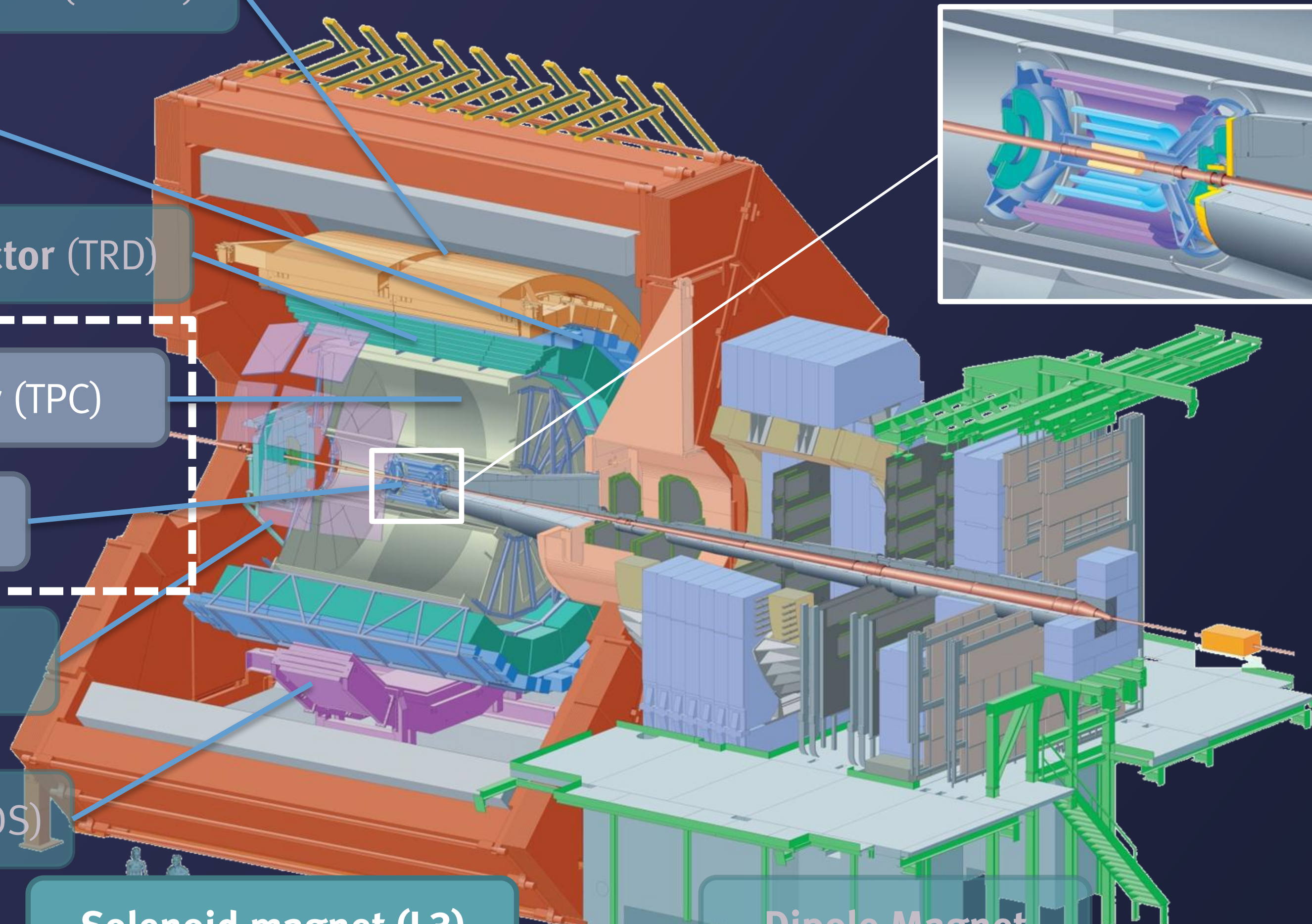
Transition Radiation Detector (TRD)

Time Projection Chamber (TPC)

Inner Tracking System (ITS)

High Momentum Particle Identification (HMPID)

Photon Spectrometer (PHOS)



Solenoid magnet (L3)

Dipole Magnet

Central barrel

Forward Muon Arm

list of detectors not complete

Jets in ALICE

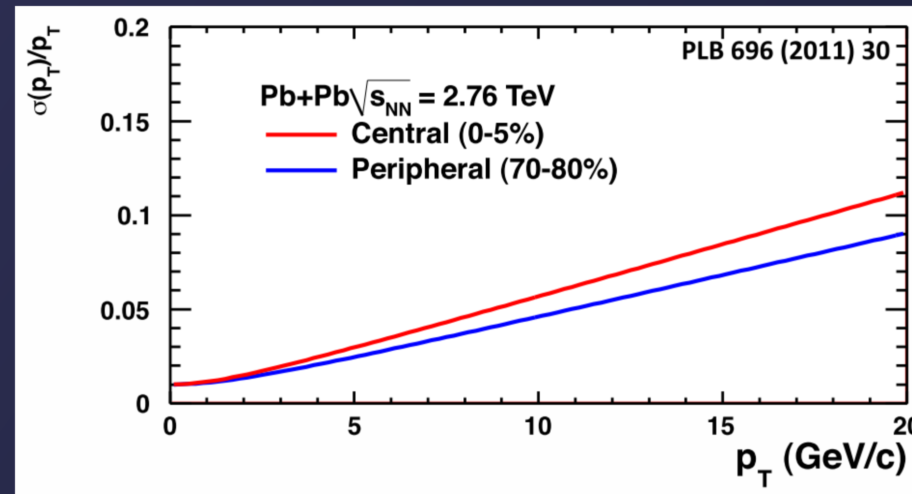
- central tracking detectors
  → tracking acceptance $|\eta| < 0.9$, full azimuth (ϕ)
- charged particles → shift of reconstructed jet energy
- good momentum resolution from very low up to high p_T

- event selection: minimum bias
- vertex cut: $|z_{vertex}| < 8.0$ cm

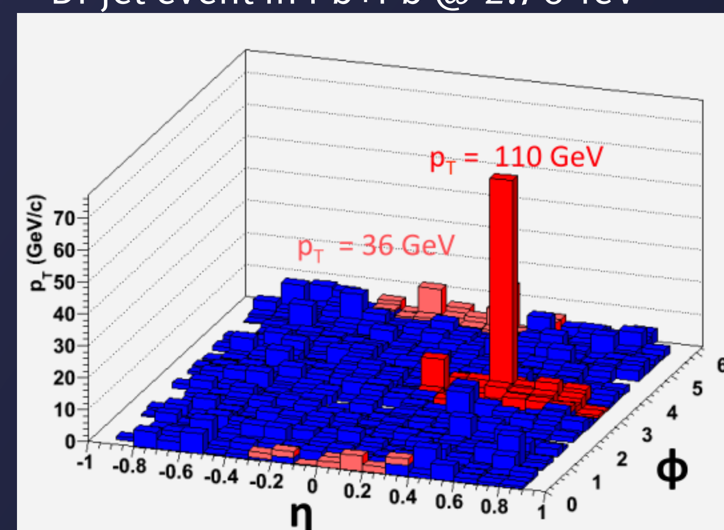
- track cuts (→ uniform detection efficiency!)
  - TPC only tracks
  - minimum number of clusters: $N_{cls} > 70$
  - constrained to SPD vertex
  - $p_T > 150$ MeV/c

- anti-k_T clusterizer*
  - R = 0.4
    → jet acceptance $|\eta| < 0.5$

- k_T algorithm for background estimation



Di-jet event in Pb+Pb @ 2.76 TeV



*) FastJet package: Phys. Lett. B641 (2006) [hep-ph/0512210]

Jet Finder Algorithms

- jet finder reconstruction algorithms:
  link between spray of reconstructed hadrons and the original parton

two basic types of jet algorithms:

1. **cone algorithm** (e.g. HIJA based on UA1)
   - requires a seed particle above p_T threshold*
   - fixed cone size*
   - calculates jet axis and energy from tracks inside cone
   - some iterations, while jet cone moves
   - ○ alternative: seed-less algorithm (e.g. SISCone)

*) original, not in general

2. **sequential recombination clusterizer** (e.g. FastJet anti-k_T)
   - combines nearby particles with similar momentum to quasi-particles
     - calculates ‘distance’ d_{ij} and d_{iB}
     - merges particles with smallest d_{ij}
     - if d_{iB} is smallest it defines quasi-particles as jet
   - several iterations until termination condition has defined all quasi-particles as jets
   - parameter D, similar to cone radius ($R \approx D$)

   - k_T: $p = 1$ ← convenient for background
   - anti-k_T: $p = -1$ ← convenient for jets

$$d_{ij} = \min\left(p_{T,i}^{2p}, p_{T,j}^{2p}\right) \frac{\Delta R_{ij}^2}{D^2}$$

$$d_{iB} = p_{T,i}^{2p}$$

p+p Collisions

p+p collisions

- give a ‘clean’ sample of jets (underlying event is small)
- allow to understand the
  - detector response
  - jet finder characteristics
  - other uncertainties and systematics

start with raw jet spectrum in p+p

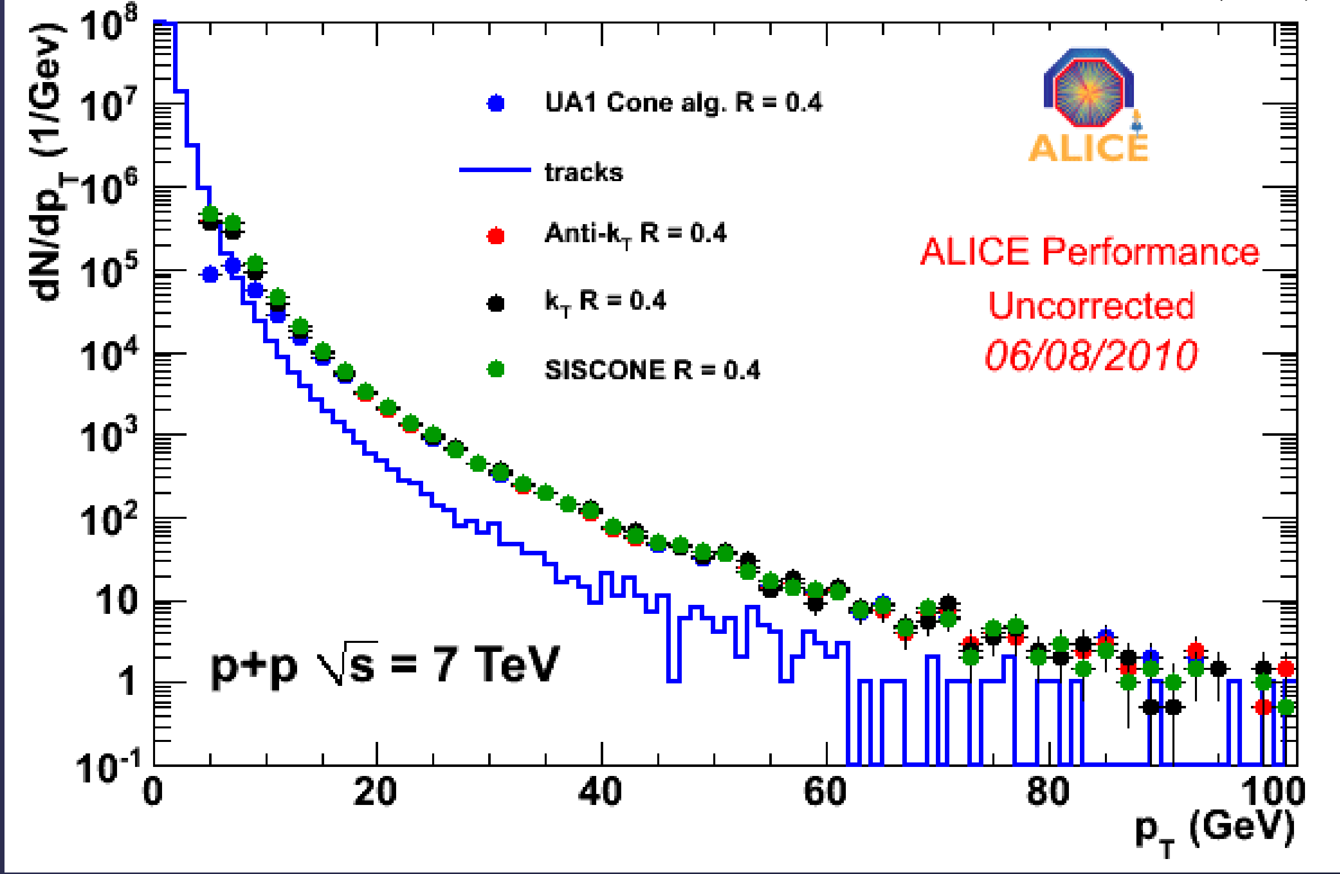
- track quality cuts applied, aimed for high-p_T → after detailed studies
- correct spectrum by unfolding for
  - smearing in p_T: due to track momentum resolution
  - shift in p_T: due to charged tracks only and tracking efficiency
  - yield of reconstructed jets: fake jets / cosmics, tracking efficiency

- characteristics of jet finder algorithm
  - cone size
  - combination scheme

Jets in p+p Collisions

raw charged jet spectrum from p+p collisions at $\sqrt{s} = 7$ TeV

~ 33% of full statistics (2010)



- uncorrected jet spectrum, needs to be unfolded

➢ good agreement between different jet finders above 20 GeV/c

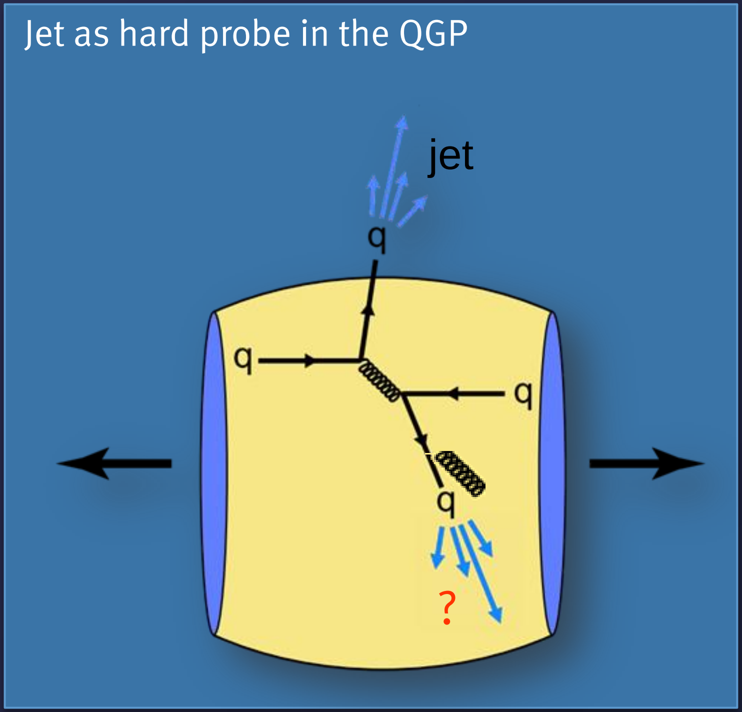
Jets in Pb+Pb Collisions

Motiviation

- use hard scattered partons as hard probes
- scattered partons interact with the Quark-Gluon Plasma (before fragmentation)
  - for high-p_T tracks → R_{AA}
  - jets: modification of jet structure → e.g. momentum distribution in jets

Challenge

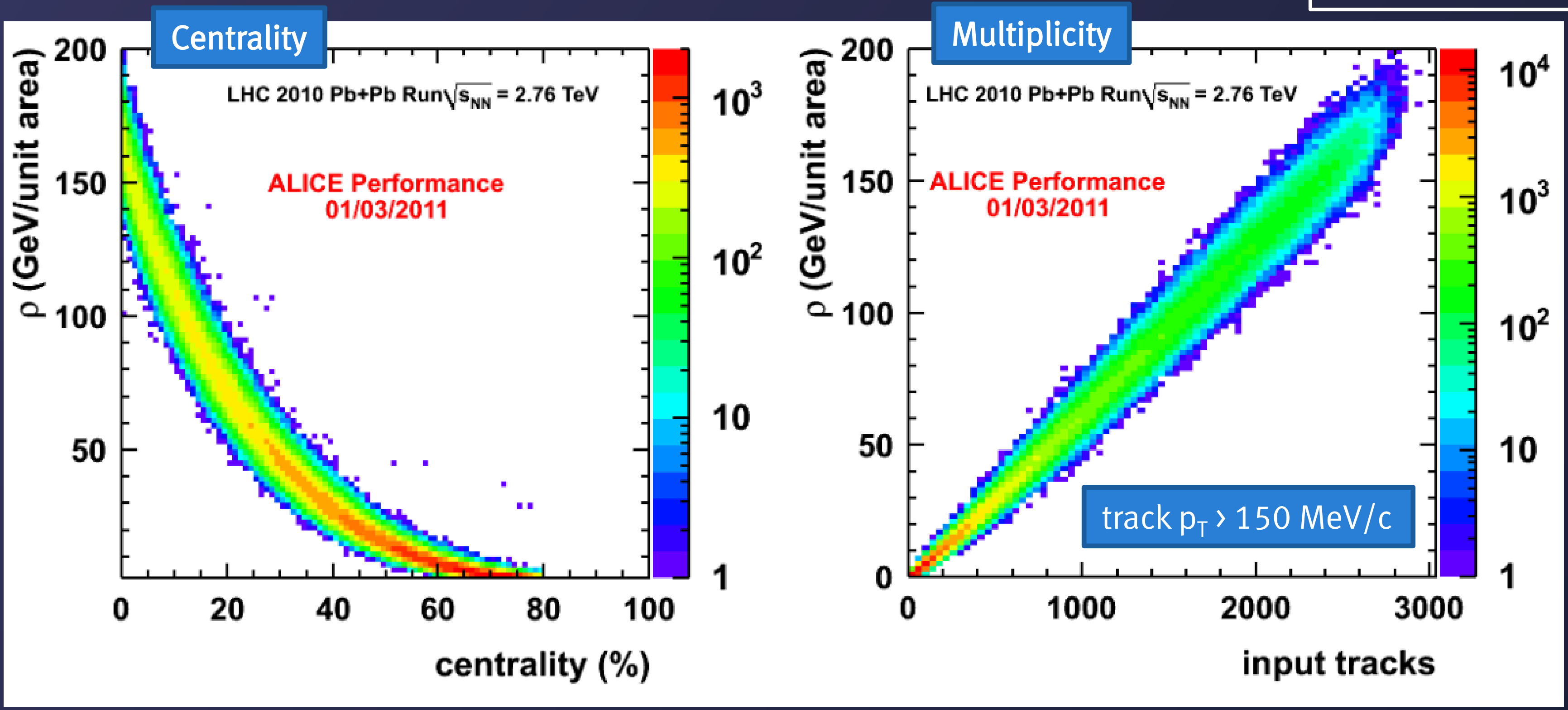
- underlying event (increases with nb. of participants)
- background subtraction
- region-to-region fluctuations (mainly Poissonian)



Background in HI Events

- ρ measures the momentum of the background in an area (in η-ϕ plane): p_T/A
- estimation of ρ: event-by-event with k_T clusterizer, $\boldsymbol{\rho = \mathrm{median}(p_T^i/A_{jet}^i)}$, except two hardest jets

Jet with R=0.4 has an area of 0.5

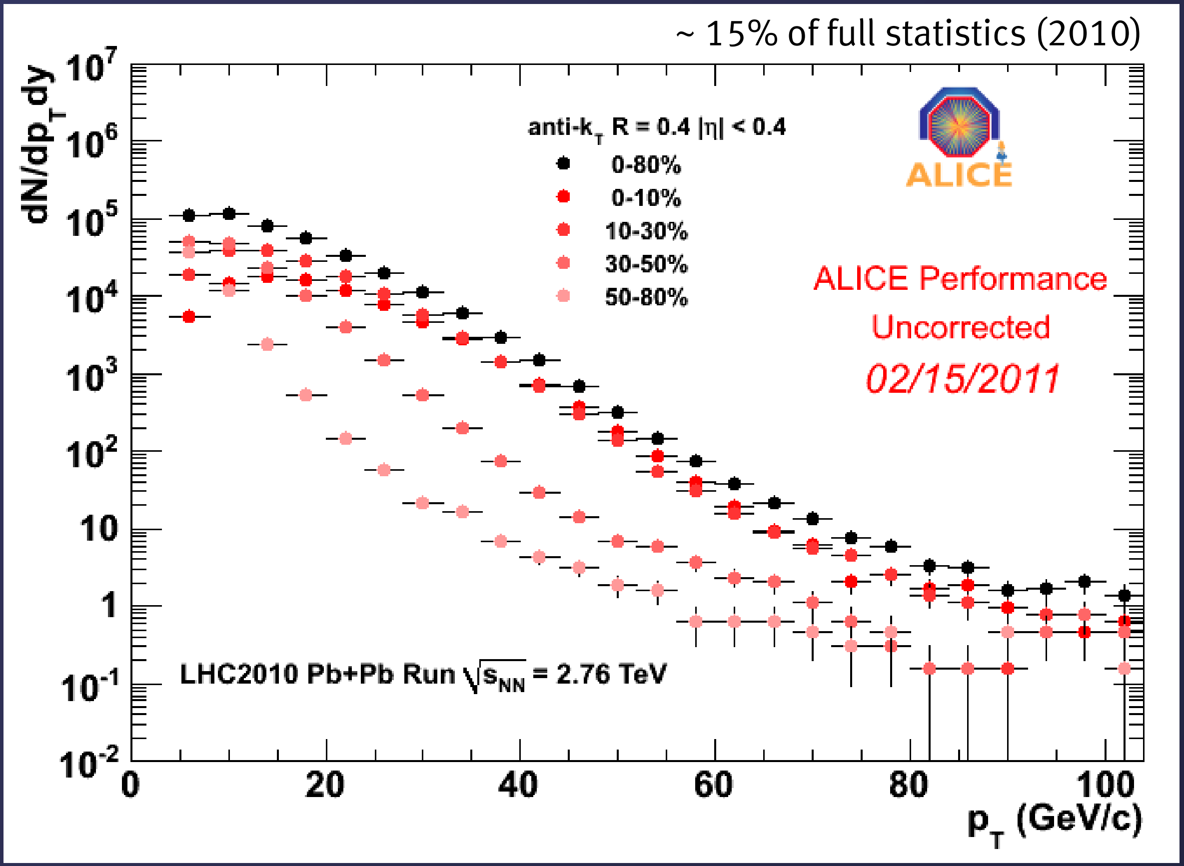


$$p_{T,jet} = p_{T,jet}^{rec} - \rho \times A_{jet} \pm \sigma \times \sqrt{A_{jet}}$$

A_{jet} : jet area
σ: background fluctuations

Jets in Pb+Pb Collisions

raw charged jet spectrum from Pb+Pb collisions @ 2.76 TeV
- in different centralities



- leading jets
- **background subtracted**
- ~ 15% of full statistics (2010)

– track acceptance $|\eta| < 0.8$
– jet acceptance $|\eta| < 0.4$

- not corrected for
  - background fluctuations
  - tracking efficiency and resolution
  - neutral energy fraction
  - fake jets / cosmics

- will be unfolded

➢ tools for jet reconstruction incl. background subtraction in place
➢ detailed knowledge of background fluctuations essential

Fast Embedding

Method:

- embed a known probe: single high-p_T track or full p+p jet event (real or MC)
- into a HI event (mainly soft background)

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

A_{jet} : jet area

$\rho = \mathrm{median}(\mathrm{p_T}/A_{jet})$

$p_{T,jet}^{probe}$: transverse momentum of embedded probe (e.g. jet or single track)

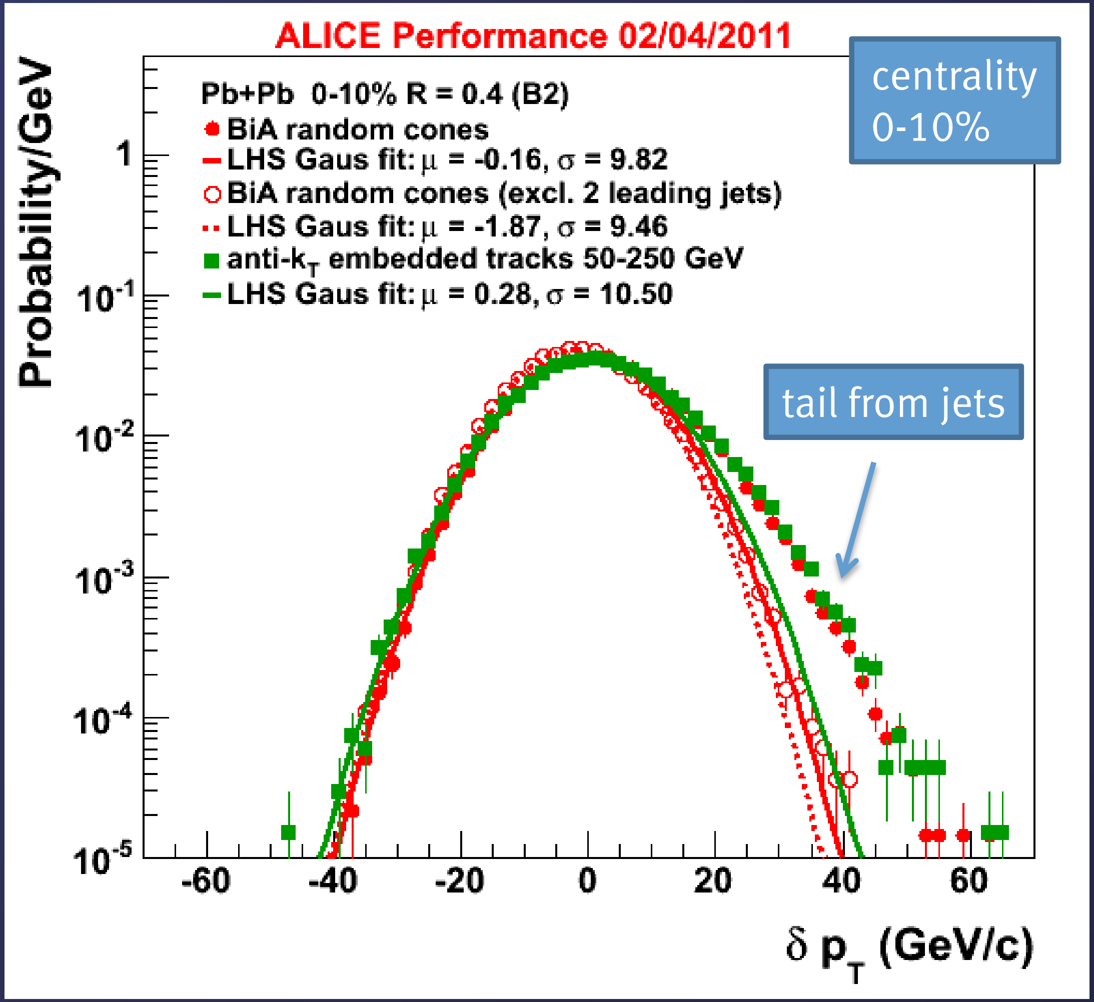
Aim:

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

Fast Embedding (cont'd)

- compare reconstructed jets of
  - embedded probe (e.g. jet) → probe jet
  - embedded probe + HI event → rec. jet
- matching condition:
  - start with probe jet with highest momentum
  - look for (max.) 4 closest rec. jets to the probe jet
  - (allow max. distance, e.g. 0.3)
  - calculate the fraction of momentum (based on tracks) which is found in the rec. jets from the probe jet
  - jets with largest fraction match, require at least 50%
  - both jets need to be in jet acceptance ($|\eta| < 0.4$ for following studies)

Background Fluctuations



embedded tracks

- single tracks embedded
- randomized over full eta-phi acceptance ($|\eta|<0.4$)
- flat p_T distribution (50 – 250 GeV/c)
- flat centrality distribution

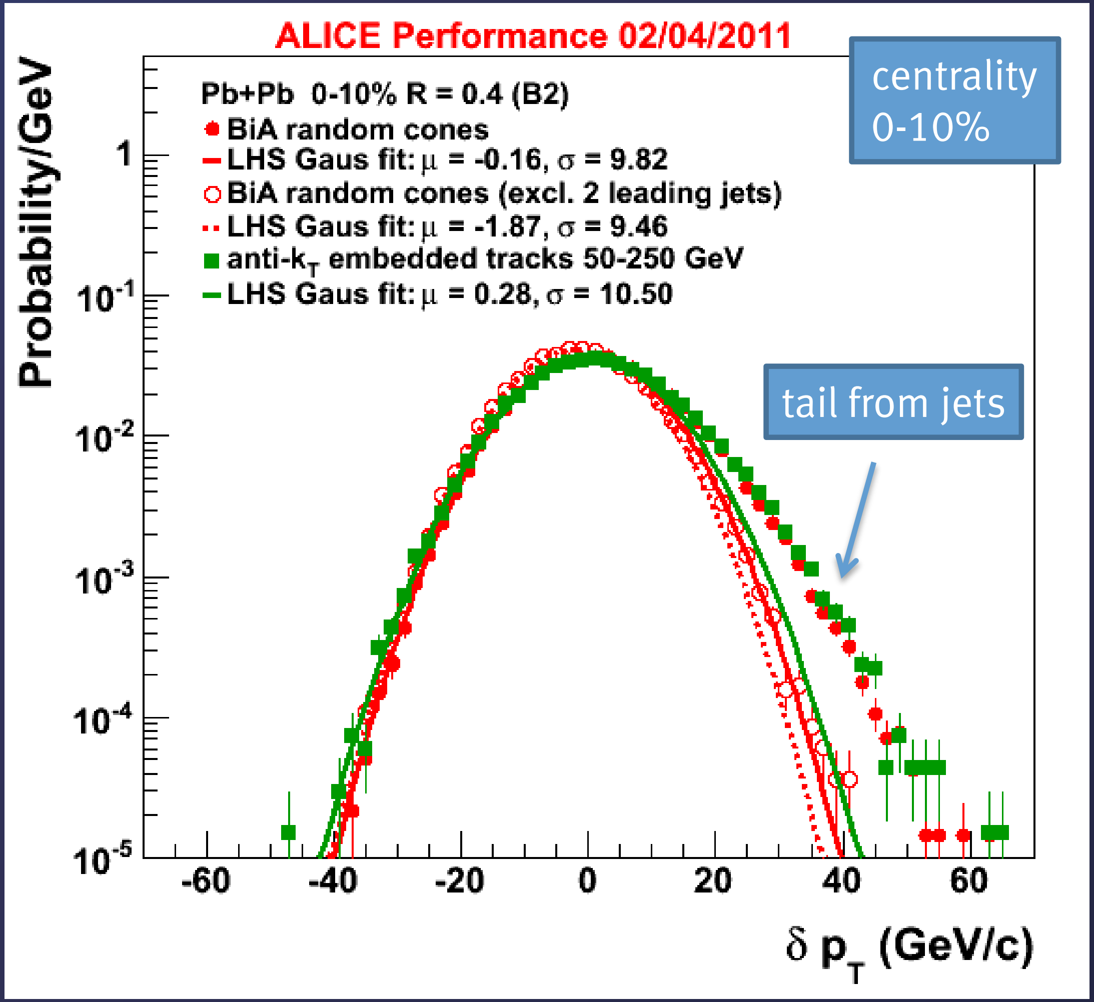
LHS Gaus fit

- iterative
- fit range: $[\mu - 3\sigma, \mu + 0.5\sigma]$
- start with [-999.,999.]
- terminate condition: shift of $\mu < 0.1$, max. 20 iterations

- mean around 0 → background subtraction works
- background fluctuation $\pm\sigma \approx 10$ GeV/c

- full embedded jets show similar results

Background Fluctuations (cont'd)



- mean around 0 → background subtraction works
- background fluctuation $\pm\sigma \approx 10$ GeV/c

- full embedded jets show similar results

random cones

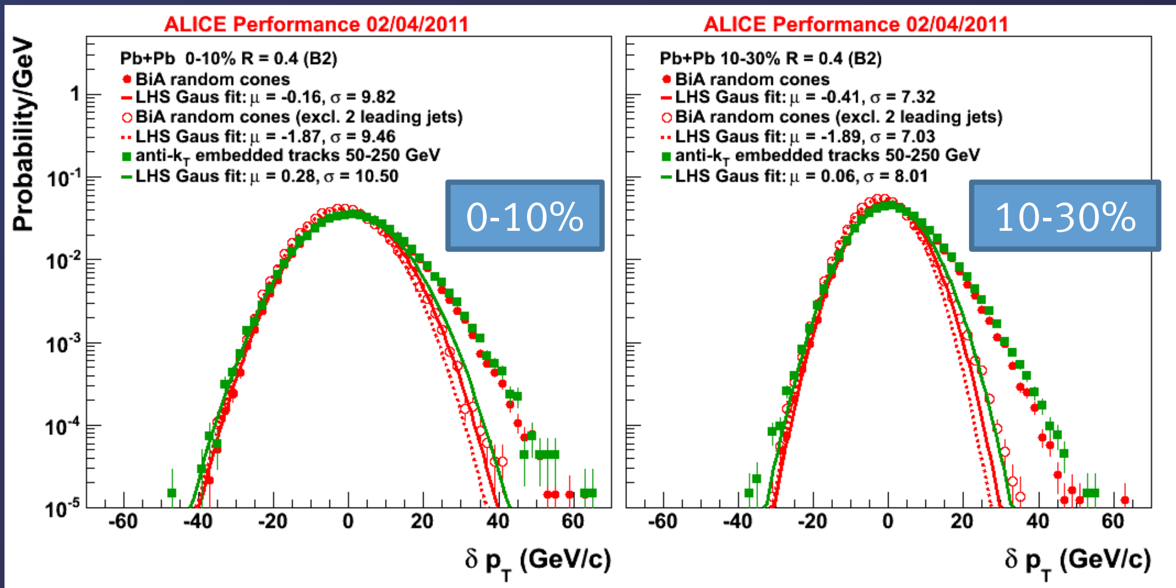
- alternative method for background studies
- place randomly cones with fixed area

- exclude leading jets
  → tail on RHS suppressed

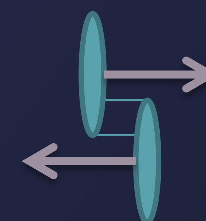
- different methods help to understand tail on RHS

$$\delta pT = p_{T,jet}^{rndm} - \rho \times A_{jet}$$

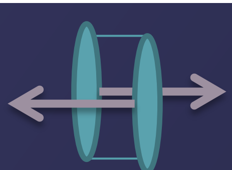
Centrality Dependence

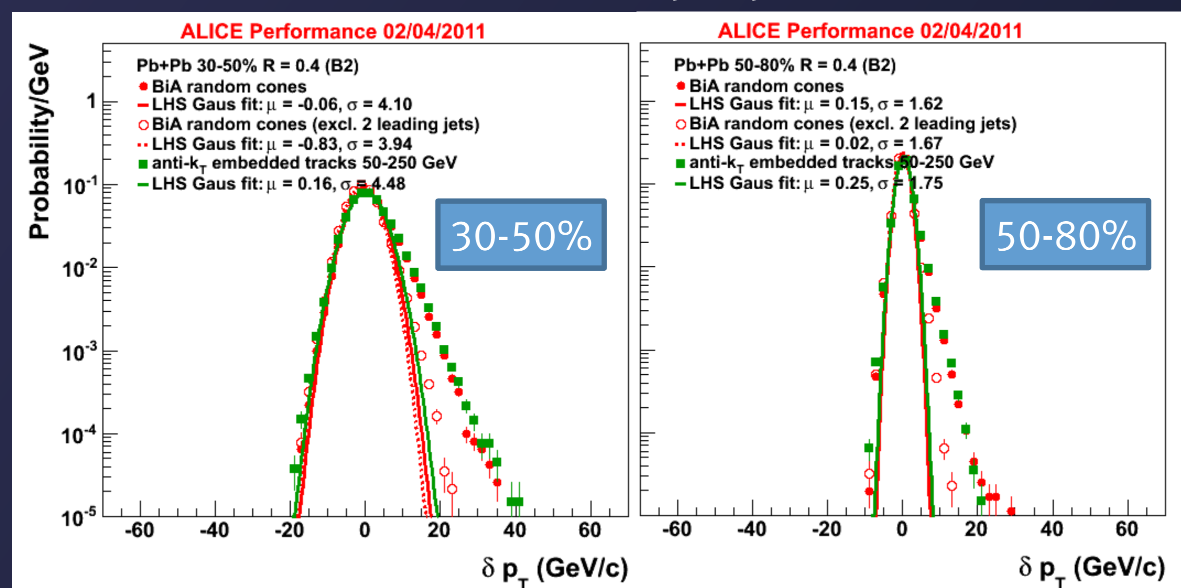


- background fluctuation decreases from central to peripheral events



central ←------------------------------→ peripheral



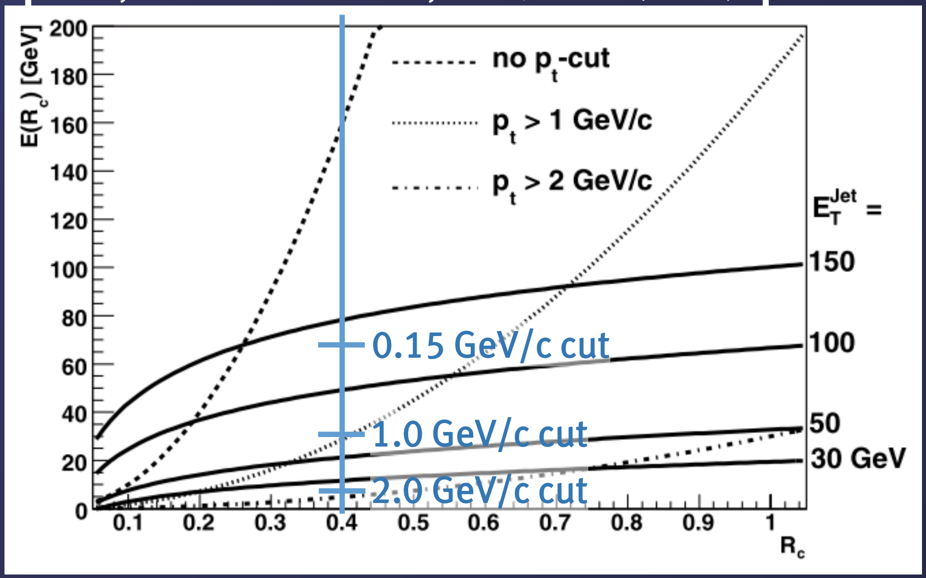


- background subtraction is independent from background (mean of the fit around 0)

Different Track-p_T Cuts

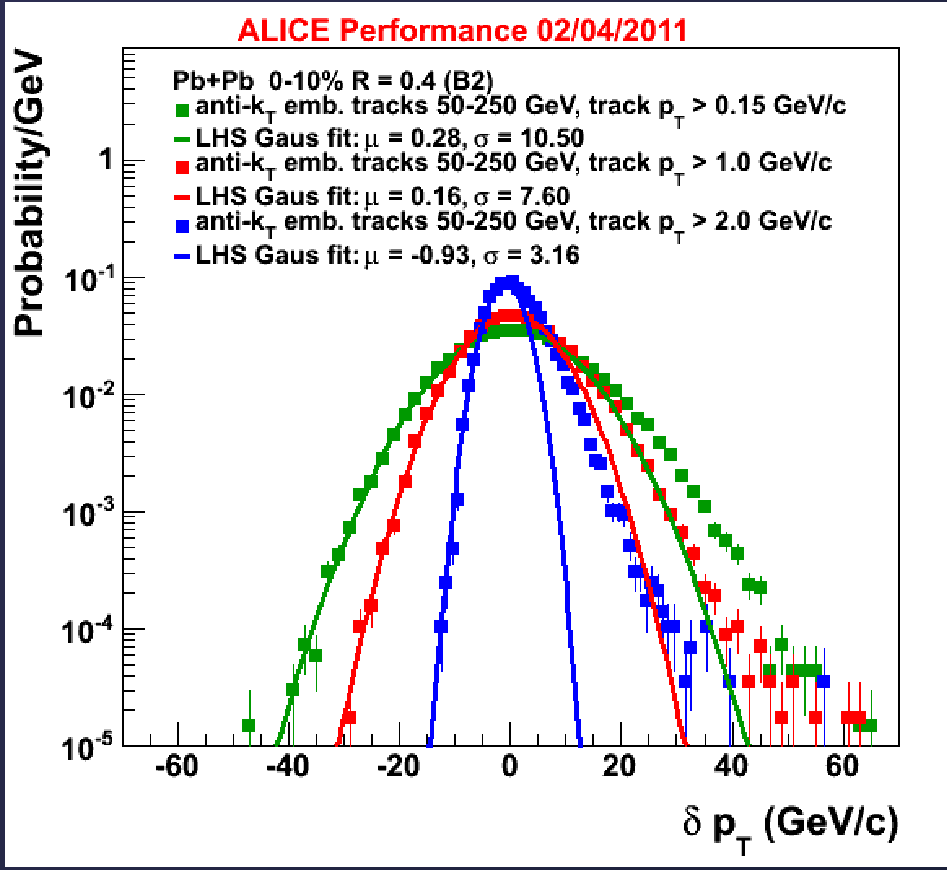
influence of track-p_T cuts on “measured” background

ALICE Physics Performance Report II
J. Phys. G: Nucl. Part. Phys. 32, 1295 (2006)



background HIJING quenched for b ‹ 5 fm

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

Different Track-p_T Cuts

influence of track-p_T cuts on “measured” background

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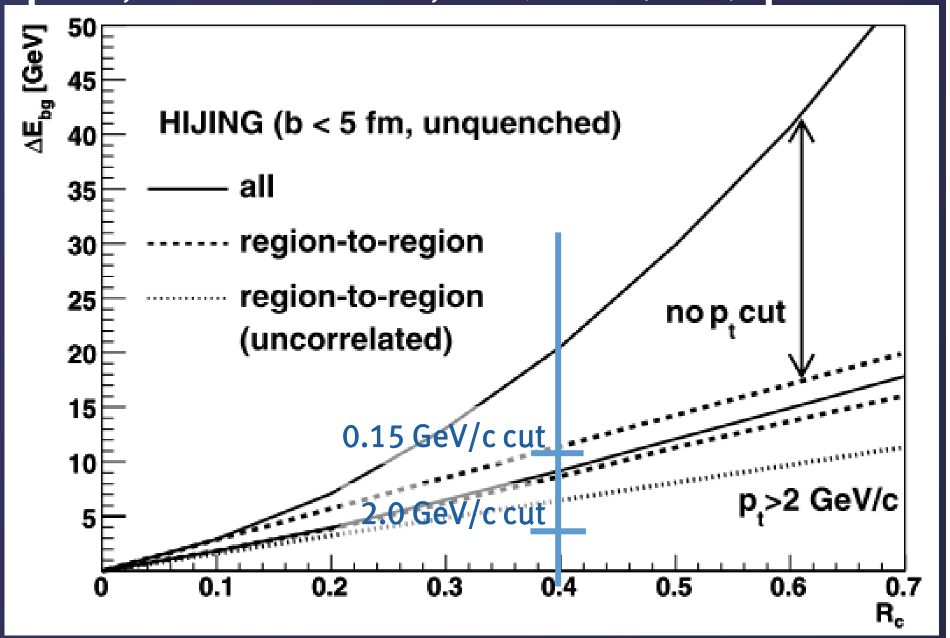

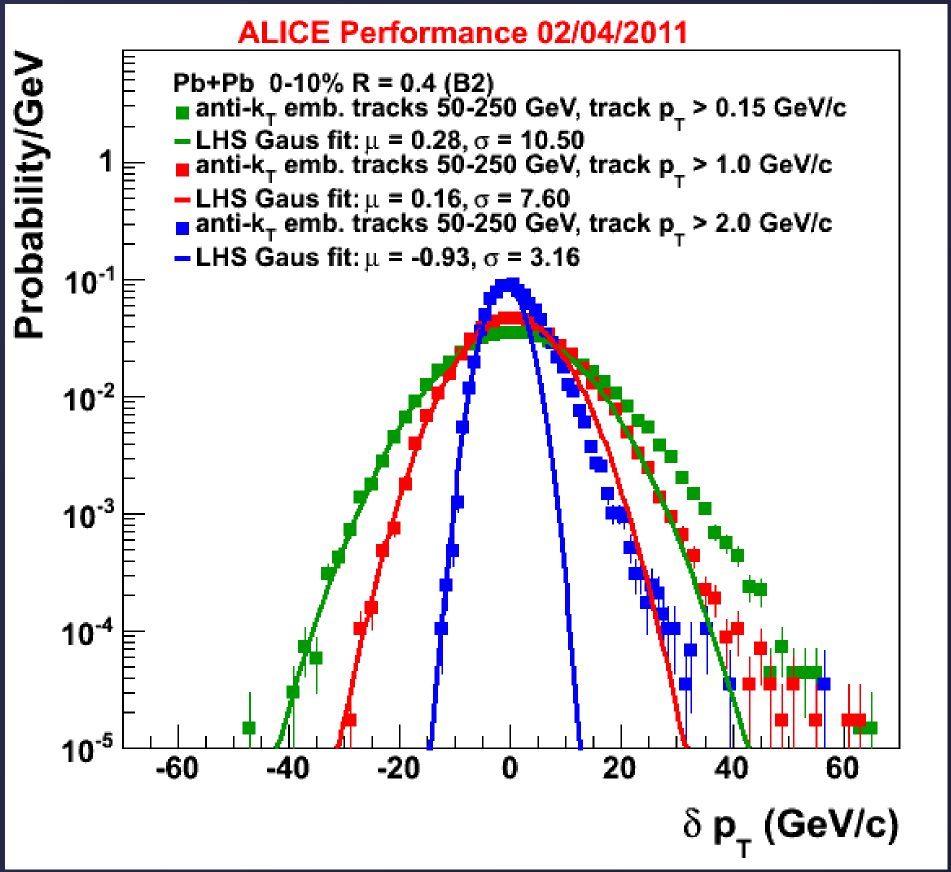

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- reduction of soft background by track p_T cut also visible in background fluctuations
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Conclusion & Outlook

Conclusion

- tools for jet reconstruction incl. background subtraction in place
- underlying event in Pb+Pb is large (50 – 100 GeV/c for typ. jet area in centrality 0-10%)
- use fast embedding and random cones for background studies
- background subtraction works independent from amount of background
- background fluctuations about 10 GeV/c (0-10% most central events, lowest p_T cut)

Outlook

- embed quenched jets
- background fluctuation as function of multiplicity (fluctuation)
- final parameterization of
  - fluctuations and
  - tail on RHS

  → unfolding and physics statement

- important for all jet studies to understand the background fluctuations
- jet reconstruction tools basis for lots of impressive studies (e.g. momentum distribution in jets)

Thank you for your attention!

... and many thanks to the ALICE jet group

Thanks to
specified "background" people:
Jochen Klein
Christian Klein-Bösing
Leticia Cunqueiro Mendez
Marta Verweij

Backup

Collision Centrality

- estimate centrality of collision with V0 detector
- V0 detector:
  - two arrays of 32 scintillator tiles
  - 2.8 < |η| < 5.1, -3.7 < |η| < -1.7

PRL 106, 032301 (2011)
arXiv:1012.1657v2

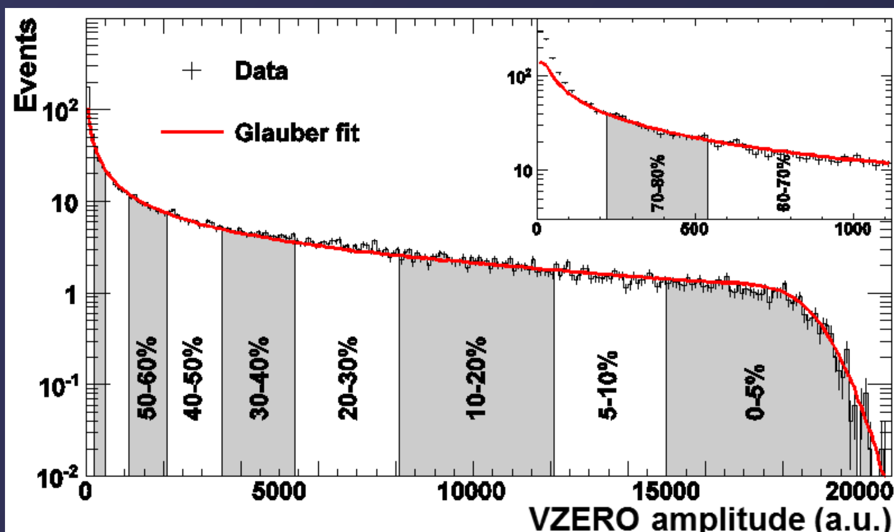
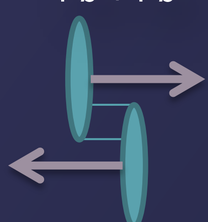


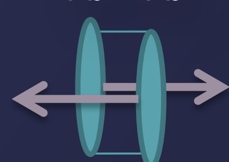
TABLE I. $dN_{ch}/d\eta$ and $(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$ values measured in $|\eta| < 0.5$ for nine centrality classes. The $\langle N_{part}\rangle$ obtained with the Glauber model are given.

Centrality	$dN_{ch}/d\eta$	$\langle N_{part}\rangle$	$(dN_{ch}/d\eta)/(\langle N_{part}\rangle/2)$
0%–5%	1601 ± 60	382.8 ± 3.1	8.4 ± 0.3
5%–10%	1294 ± 49	329.7 ± 4.6	7.9 ± 0.3
10%–20%	966 ± 37	260.5 ± 4.4	7.4 ± 0.3
20%–30%	649 ± 23	186.4 ± 3.9	7.0 ± 0.3
30%–40%	426 ± 15	128.9 ± 3.3	6.6 ± 0.3
40%–50%	261 ± 9	85.0 ± 2.6	6.1 ± 0.3
50%–60%	149 ± 6	52.8 ± 2.0	5.7 ± 0.3
60%–70%	76 ± 4	30.0 ± 1.3	5.1 ± 0.3
70%–80%	35 ± 2	15.8 ± 0.6	4.4 ± 0.4

Pb + Pb

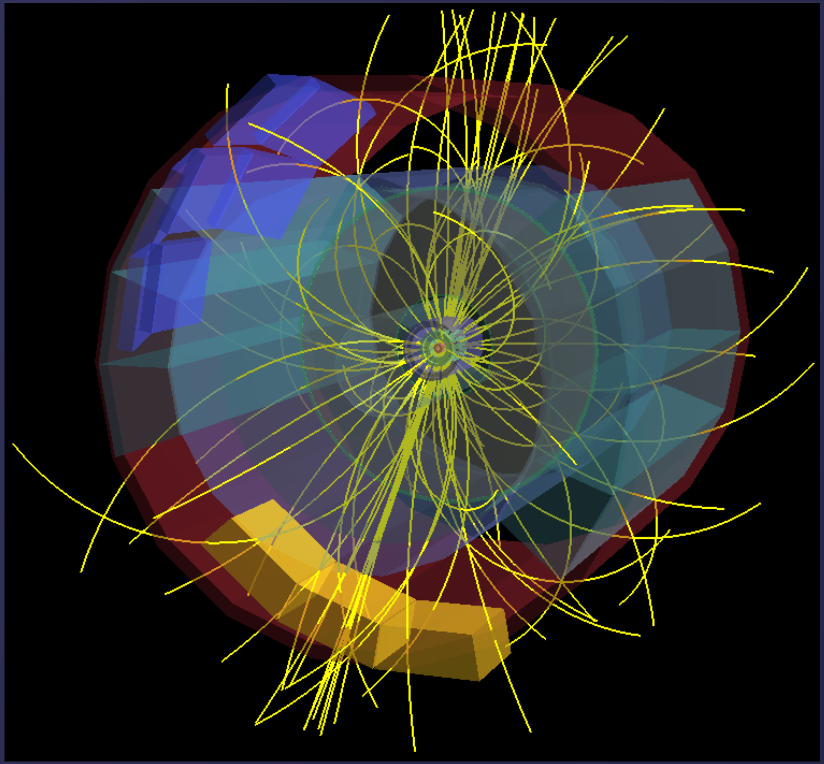


Pb + Pb

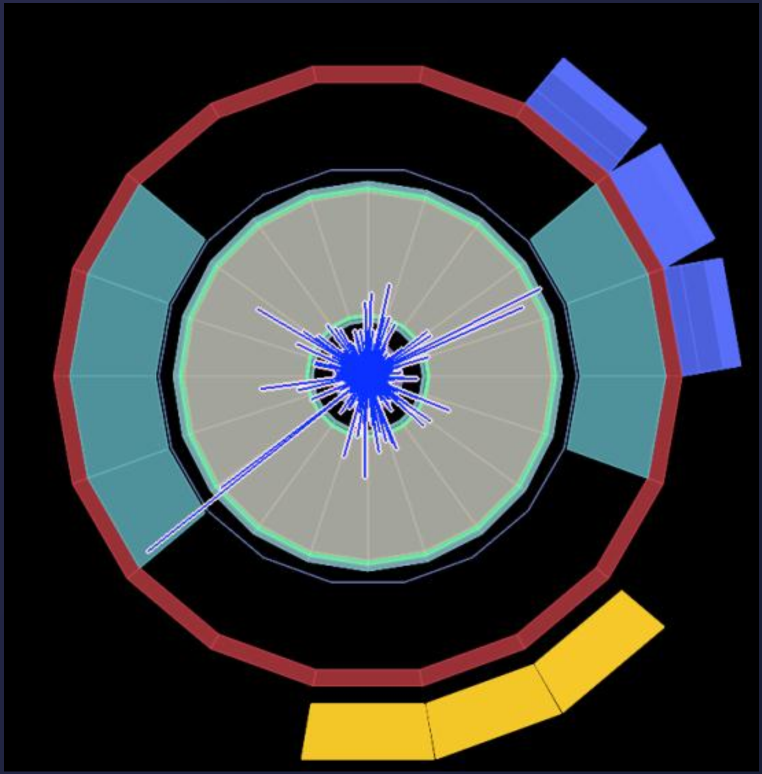


peripheral 50-80% ⟷ central 0-10%

jet event in p+p @ 7 TeV



Pb+Pb @ 2.76 TeV
jet1 51.5 GeV/c
jet2 50.0 GeV/c
after background subtraction



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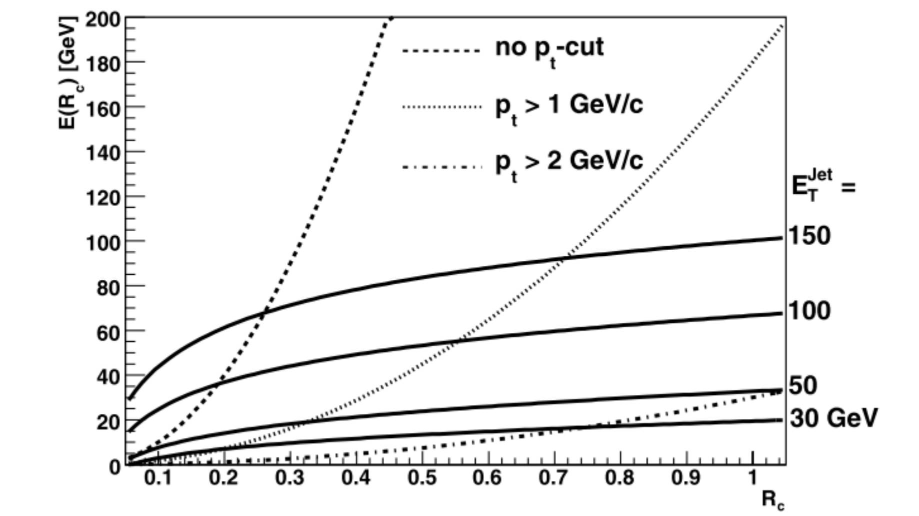

Figure 6.371. Charged jet energy within a cone of radius R_c (full lines) compared to the energy of the underlying event for different transverse momentum thresholds (dashed lines). The background energy has been calculated using HIJING quenched with $b < 5$ fm.

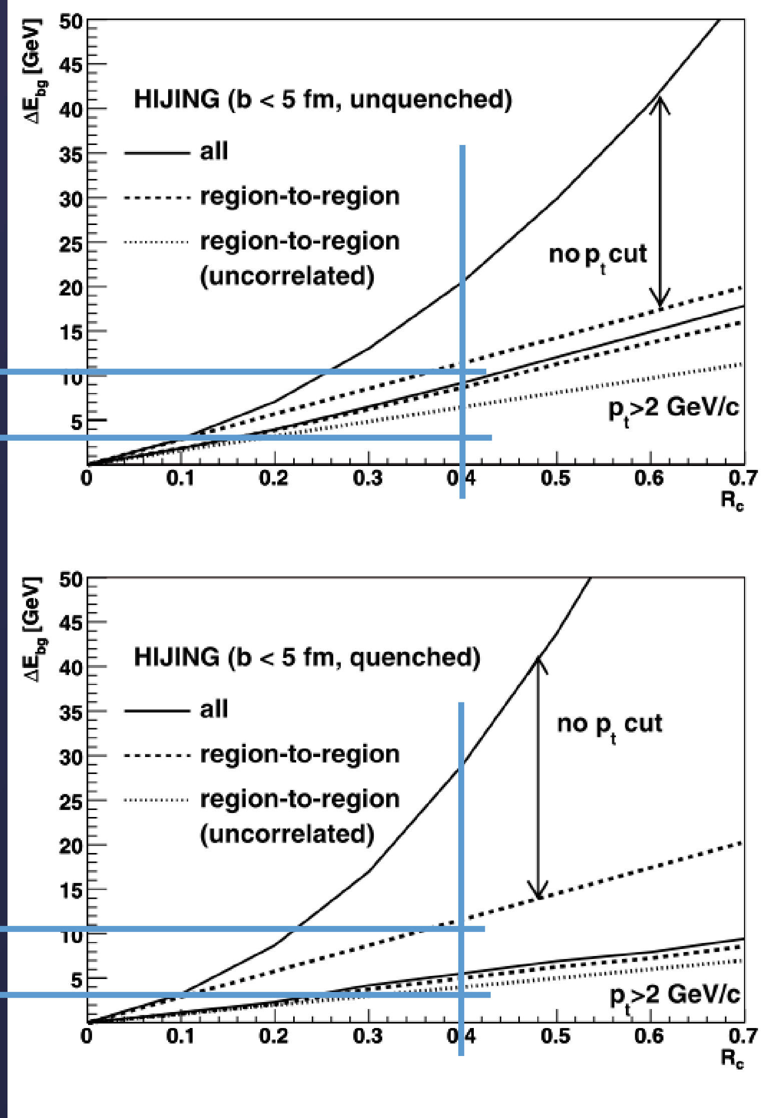

Figure 6.373. Different contributions to the background fluctuations as a function of the cone size R_c for the 10% most central Pb–Pb collisions simulated with HIJING unquenched (upper) and quenched (lower).