Jet Physics at the LHC with the ALICE Detector

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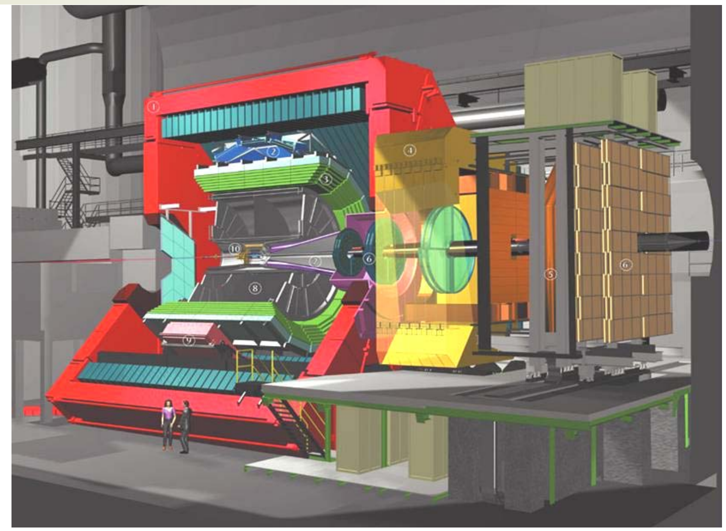
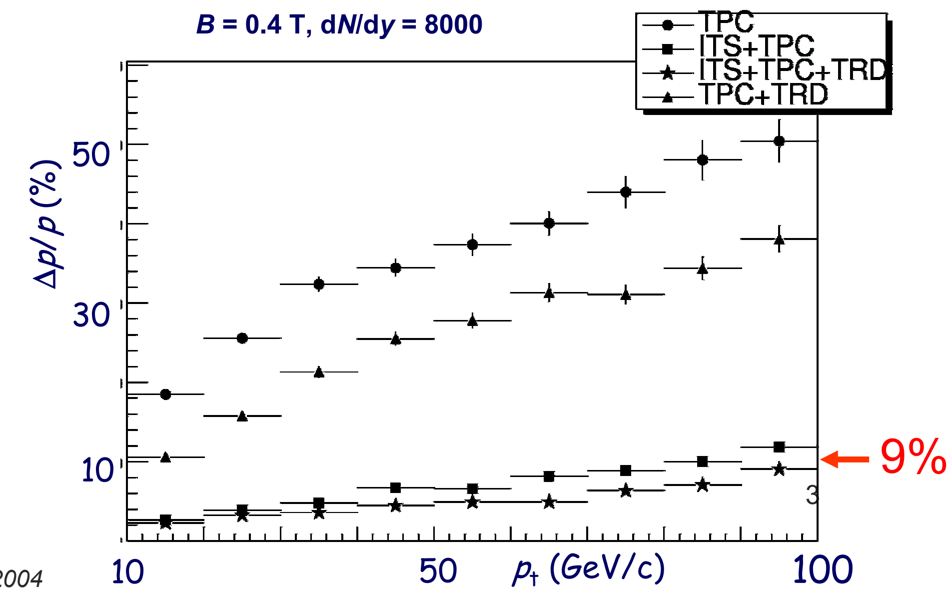
Outline

- ALICE in short
- Motivation for jet physics at the LHC
- ALICE needs an electromagnetic calorimeter (EMCAL)
- Low-p_T capabilities are essential for complete jet measurements in AA
- Shower MC including in-medium radiation is needed to constrain medium parameters

ALICE the LHC experiment dedicated to HI physics

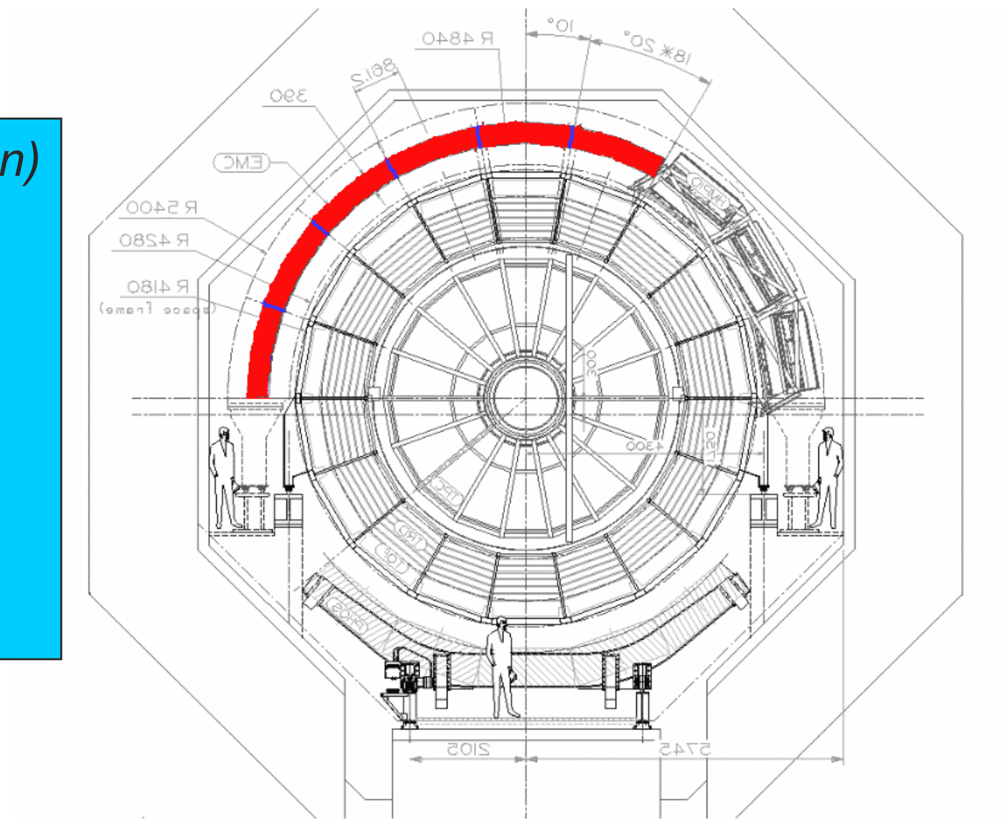


- In the central part of the experiment, $|\eta| < 0.9$, ALICE will measure event-by-event the inclusive distribution and correlation of a wide range of flavor identified particles, whose momenta and masses are of the order of the typical energy scale involved ($T \sim \Lambda_{QCD} \sim 200$ MeV).
- But ALICE has also almost all important high-p_T capabilities
  - High p_T charged hadrons
  - Muons
  - Electrons
  - Secondary vertex capabilities (charm, beauty)
  - Photons
- Electromagnetic calorimeter proposed.



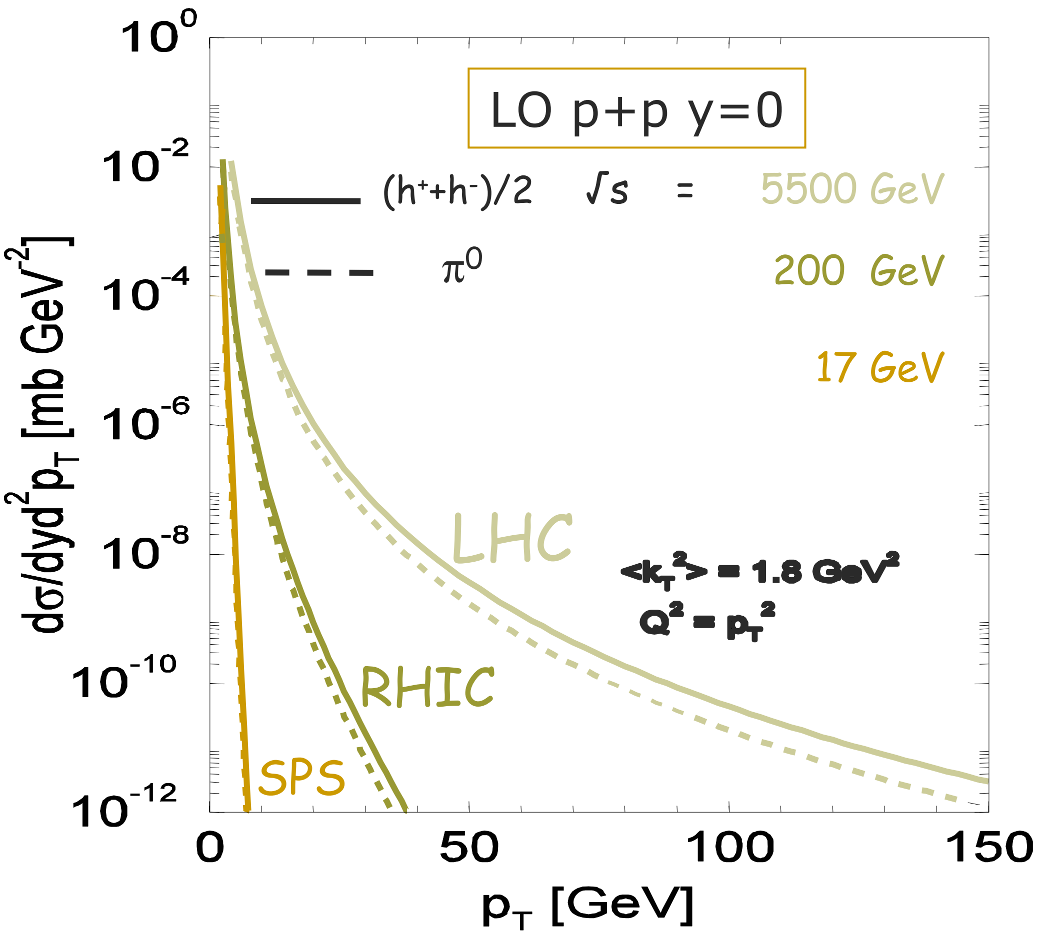
Proposed ALICE EMCAL

- *EM Sampling Calorimeter (STAR Design)*
- *Pb-scintillator linear response*
  - $-0.7 < \eta < 0.7$
  - $\pi/3 < \Phi < \pi$
- *12 super-modules*
- **19152** *towers*
- *Energy resolution ~15%/√E*



Unique at the LHC

- Medium and low-p_T
  - Dominated by hard processes
  - Several Jets E_T < 20 GeV / central PbPb collision
- At high-p_T
  - Jet rates are high at energies at which ALICE can reconstruct jets over the background of the underlying event.

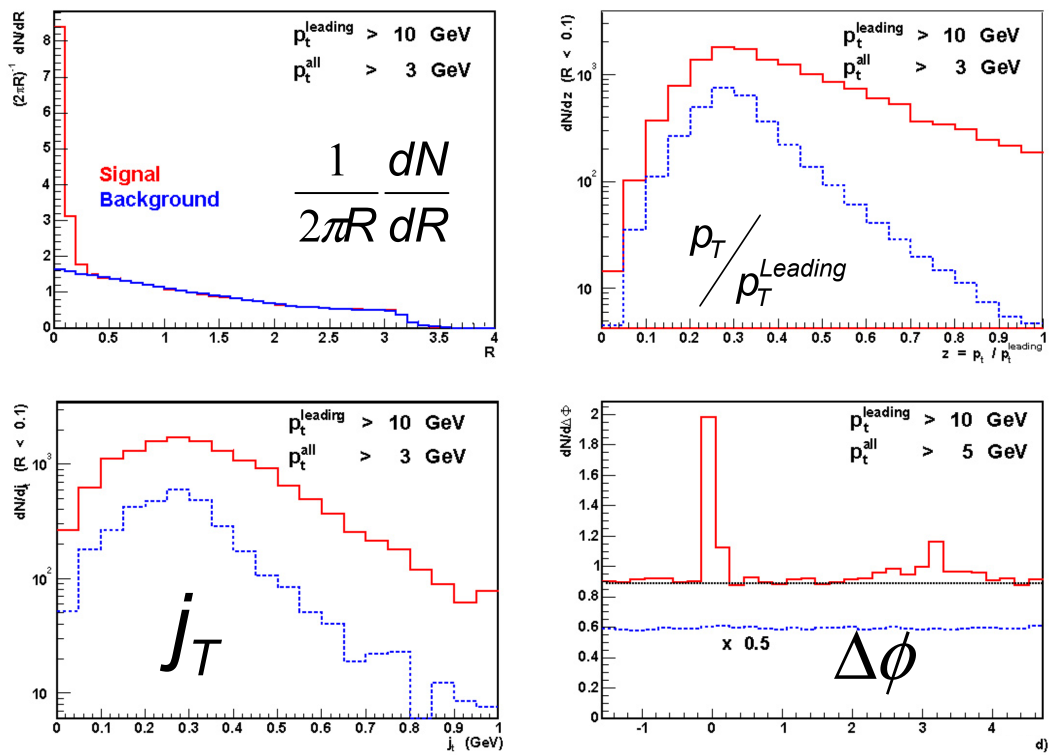


Leading hadrons studies

- Nuclear modification factor pattern very different at LHC:
  - Final state interactions (radiative & collisional energy loss) dominate over nuclear effects (shadowing+Cronin).
- Measurement of suppression pattern of leading partons remains experimentally the most straightforward observable for jet-tomography analysis.
- Correlation studies *à la* RHIC

Leading Particle Correlations

- Remember ~50 Jets E_T < 10 GeV overlapping in ALICE acceptance
- For high enough p_T^{trig} and p_T^{assoc} cuts correlations a visible (HIJING study)
- Real life (RHIC) much richer than expected
- Look for the unexpected.



HIJING Simulation

PbPb b=0-5 fm

$\Delta\phi$

Background estimated from random combinations

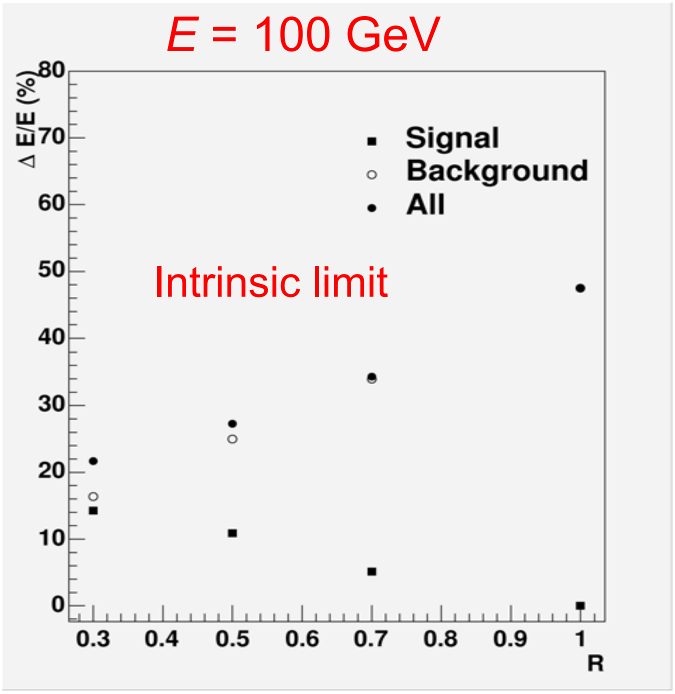
Why analysis with reconstructed jets ?

- Analysis of reconstructed jets allows us to measure the original parton 4-momentum and the jet structure (longitudinal and transverse). From this analysis a higher sensitivity to the medium parameters (transport coefficient) is expected.
  - In the ideal case (oversimplified)
    - Jet as an entity (parton hadron duality) stays unchanged
    - Map out observables as a function of parton energy
    - Move away from the trigger bias (low ΔE, high z, ...) inherent to leading particle correlation studies
- Caveat: The additional energy from the underlying event forces the use of reduced cone sizes for jet reconstruction ($R < 0.7$) this locates jet reconstruction in Pb-Pb collisions at the LHC in between full jet reconstruction like in pp and leading particle studies.

What are the conditions for measuring jets in central PbPb collisions at the LHC ?

- Central PbPb Collisions at $\sqrt{s}$=5.5 TeV
  - dN_{ch}/dy = 2000-8000
  - $dE_T/d\eta$ ~ 1.5-6 TeV
  - Energy in $R = \sqrt{(\Delta\eta^2+\Delta\phi^2)} < 0.$: 0.4 -1.5 TeV
- Problem for jet reconstruction
  - Identification: for large cone sizes jets don't stick out of the background
  - Energy resolution: Background fluctuations comparable to jet energy
- Solution:
  - Smaller cone sizes
    - $E \sim R^2$
    - $\Delta E \sim R$
  - p_T-Cut
    - $\Delta E > \sqrt{N(p_T)}\ \sqrt{(\Delta p_T^2+\langle p_T\rangle^2)}$
    - Less efficient than one would naively think
- The price to pay:
  - Reduced measured energy ($E\downarrow$)
  - Increased fluctuations ("out-of-cone"-fluctuations) ($\Delta E\uparrow$)
  - $\Delta E/E\ \uparrow$

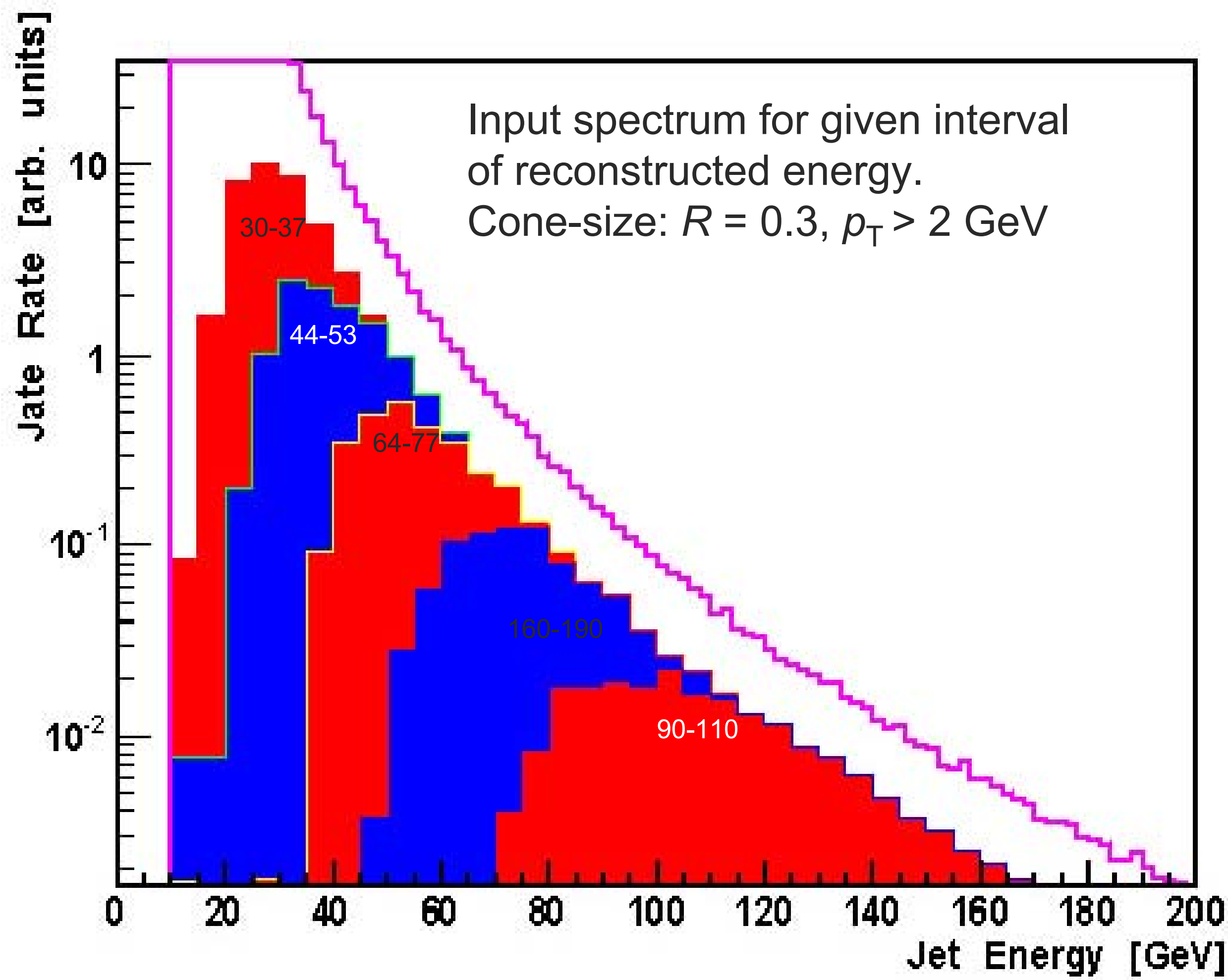
dN/dy = 4000



Jet energy resolution using charged particles

Charged/neutral fluctuations dominate:

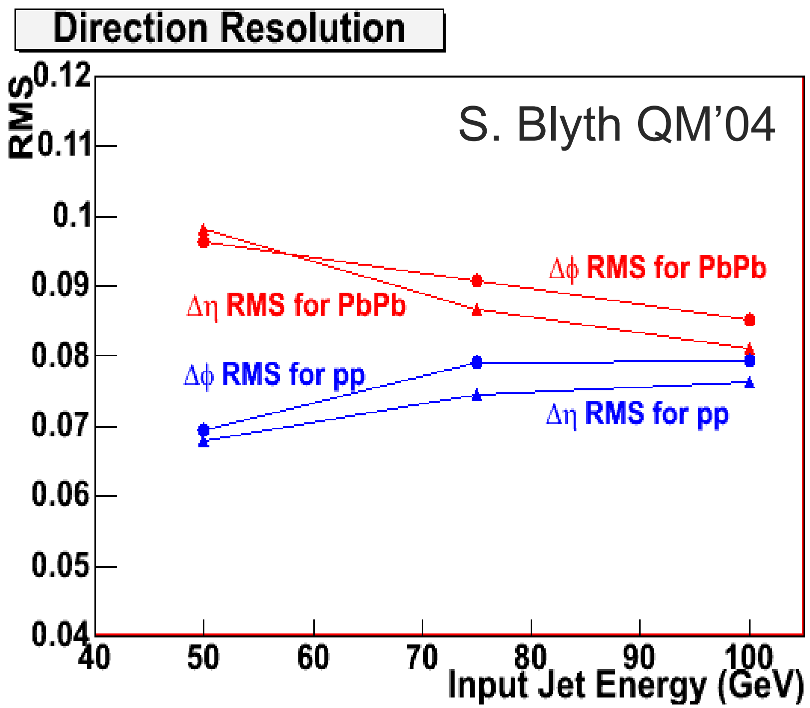
***ΔE/E* > 50%**

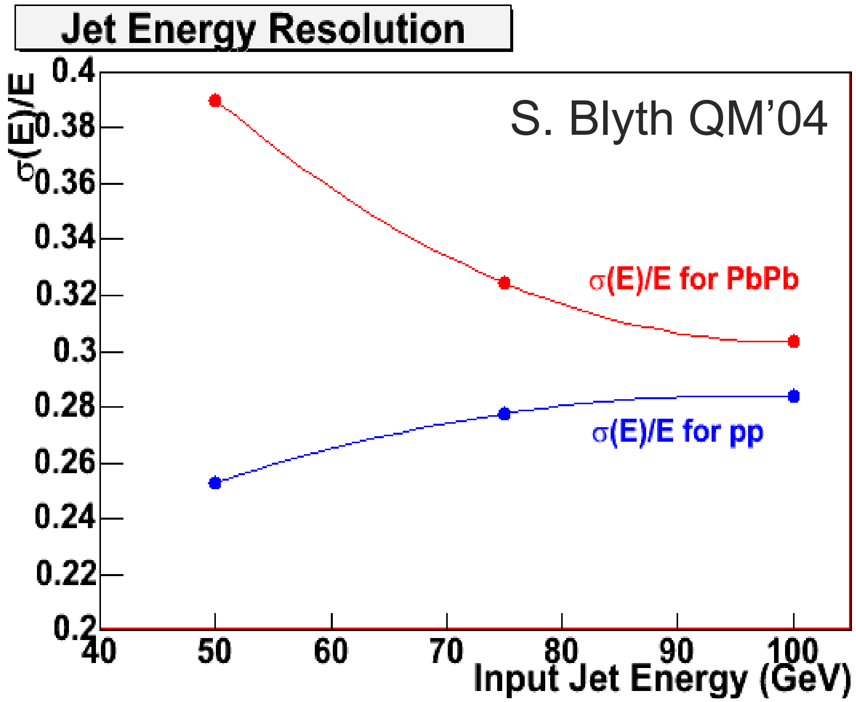


(R<1 = parton energy)

EMCAL
Directional and Energy Resolution

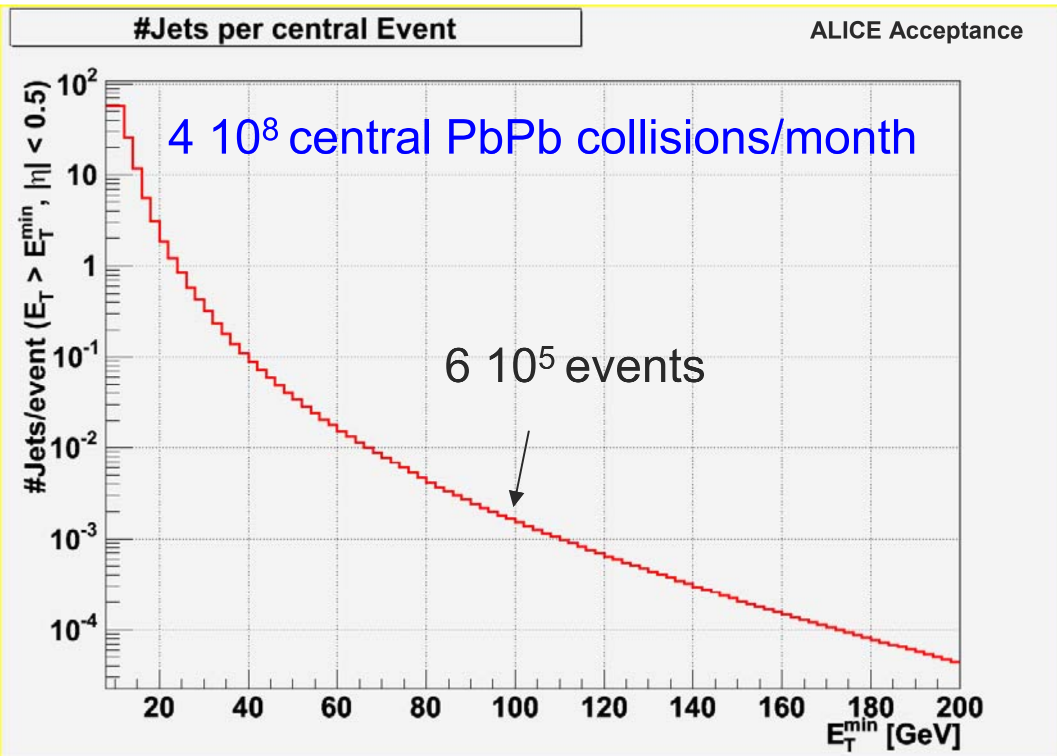
- •Modified UA1 cone algorithm
- •Uses combination of tracking and calorimeter information
- •Cone Radius: *R* = 0.3, Seed 4.6 GeV, Minimum Jet energy 14 GeV
- •Background HIJING PbPb *b* = 0-5 fm





Need for Triggering

Copious production ...



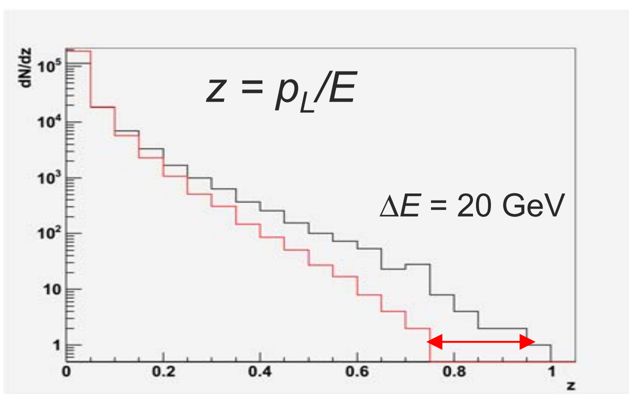
Yellow report + Pythia + ALICE acceptance

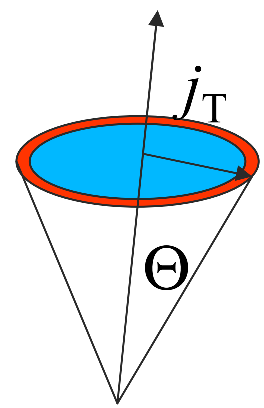
On tape ...

- Minimum Bias $E_T > 100$ GeV
  - 1.5 10^6 jets/month produced
  - No trigger: 10^4 jets on tape
  - **Need Trigger !**
- High Level Trigger using charged tracks under study
- EMCAL essential to reduce the input rate to HLT and to reduce trigger bias.

Some thoughts on how to measure jet quenching at the LHC ...

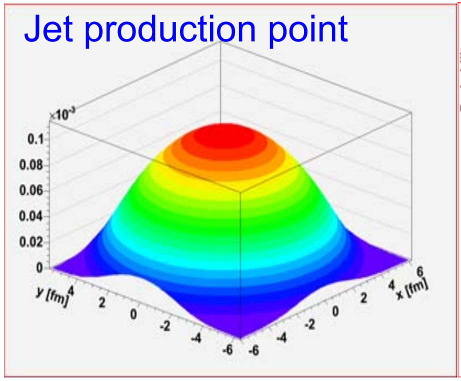
- .... or, how close are we to the ideal case
  - Measure unquenched parton energy by measuring the jet energy.
  - Determine energy loss and transverse heating by measuring the fragmentation function and j_T spectra.

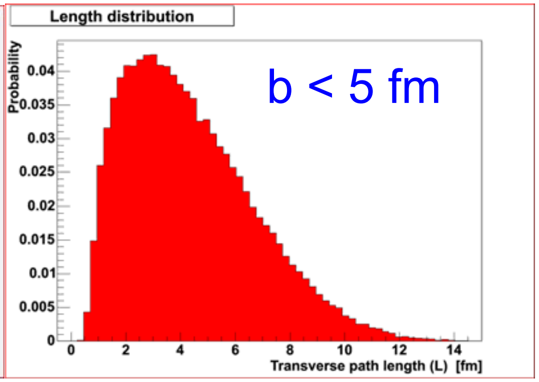




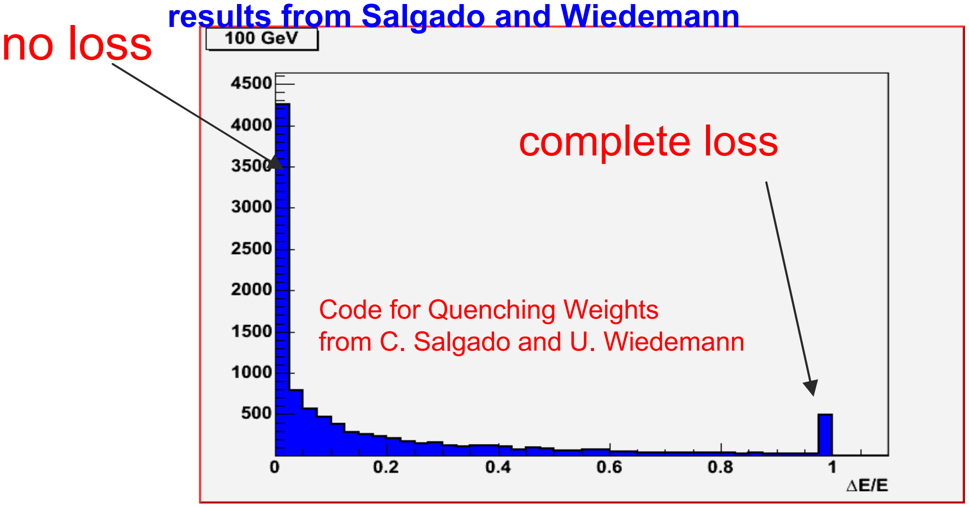
Energy loss measurement

- No trivial relation between energy loss and jet observables
  - Intrinsic to the system
    - Path length is not constant
  - Intrinsic to the physics
    - Finite probability to have no loss or on the contary complete loss
  - Reduced cone size
    - Out-of-cone fluctuations and radiation
- Need shower MC combining consistently parton shower evolution and in-medium gluon radiation.

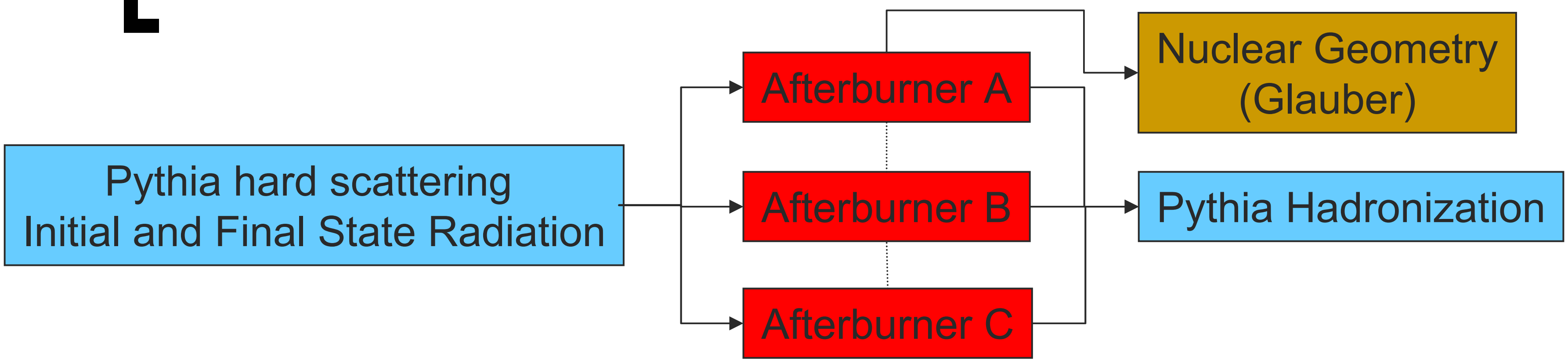




"Bremsstrahlung" Spectrum exemplified using results from Salgado and Wiedemann



Toy Models

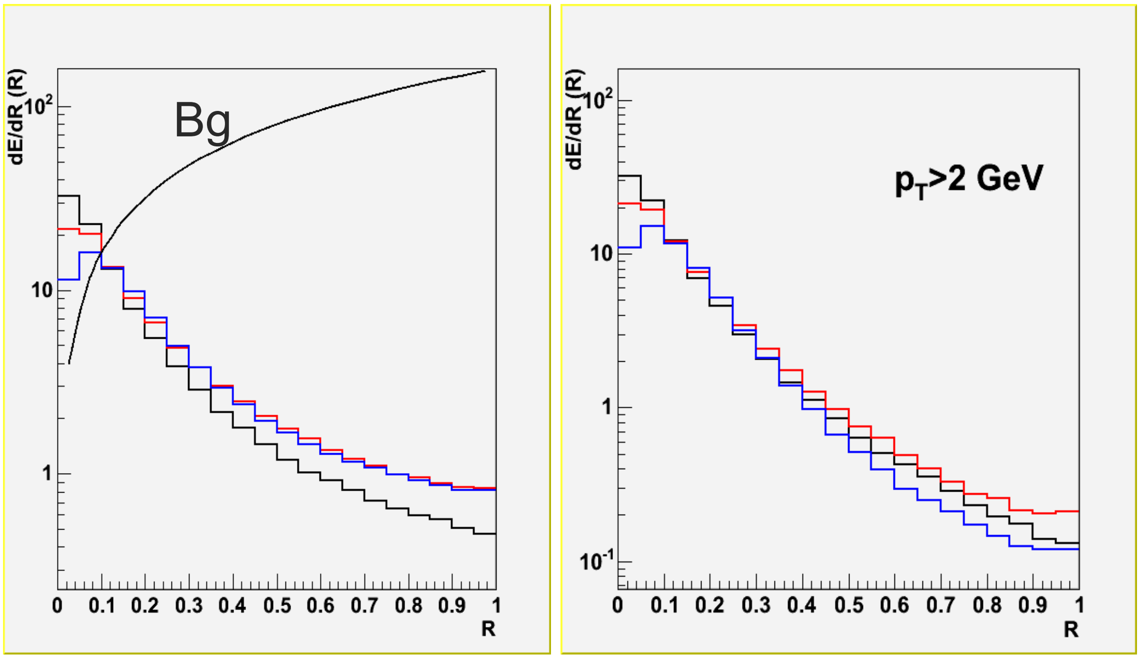


Jet (E) → Jet (E-ΔE) + n gluons (“Mini Jets”)

- **Two extreme approaches**
  - Quenching of the final jet system and radiation of 1-5 gluons. (AliPythia::Quench + Salgado/Wiedemann - Quenching weights with q = 1.5 GeV^2/fm)
  - Quenching of all final state partons and radiation of many (~40) gluons (I. Lokhtin: Pyquen)*
- **Can we learn something from these toy MCs ?**

)*I.P. Lokhtin et al., Eur. Phys. J C16 (2000) 527-536
I.P.Lokhtin et al., e-print hep-ph/0406038
http://lokhtin.home.cern.ch/lokhtin/pyquen/

Importance of low-p_T capabilities



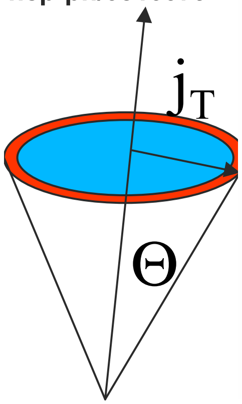
Unquenched
Quenched (AliPythia)
Quenched (Pyquen)

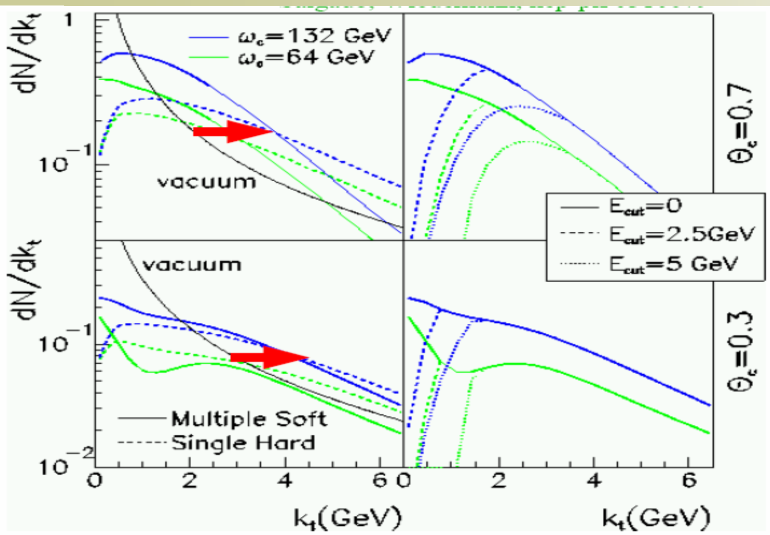
Note: $\sin \Theta = j_T/p_l$
Theory predicts increase of j_T and decrease of p_l !

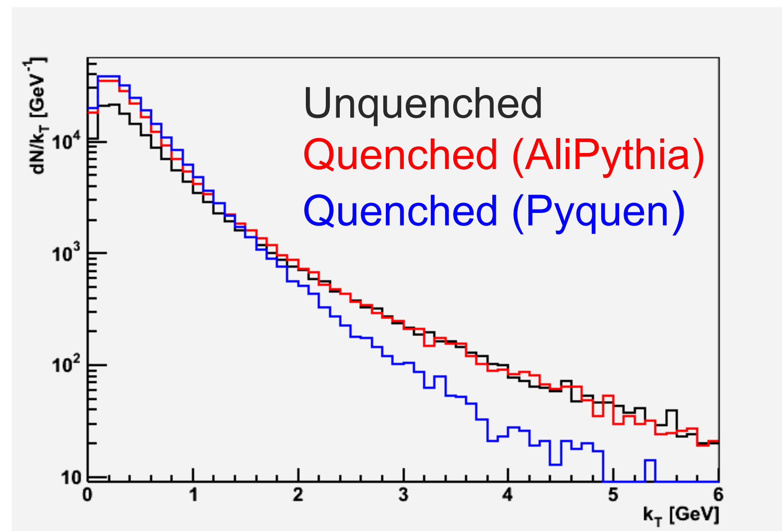
- Low-p_T capabilities are essential
  - To measure the phase space distribution of radiated energy
  - To reduce the bias on the measured jet energy
- However, this implies also high *R* and a compromise between background fluctuation and energy bias has to be found
- Jet shapes will be measured inclusively

Transverse Heating and high j_T suppression

Salgado, Wiedemann, hep-ph/0310079





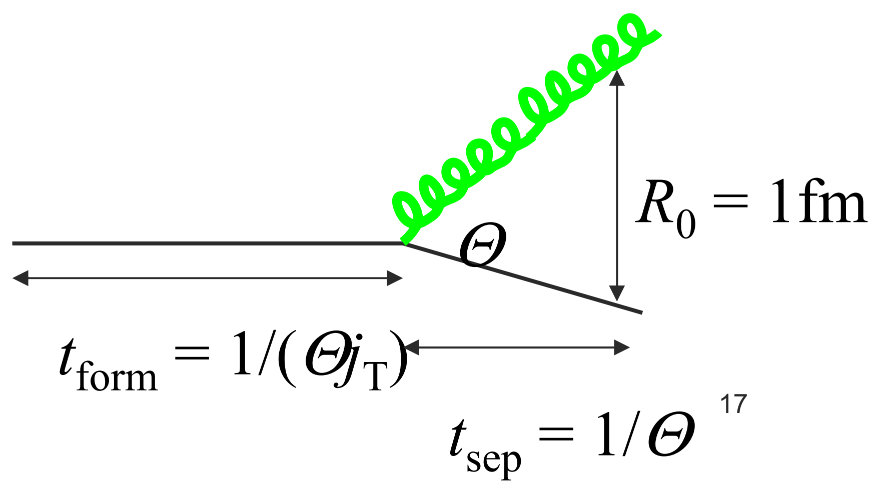


Look for

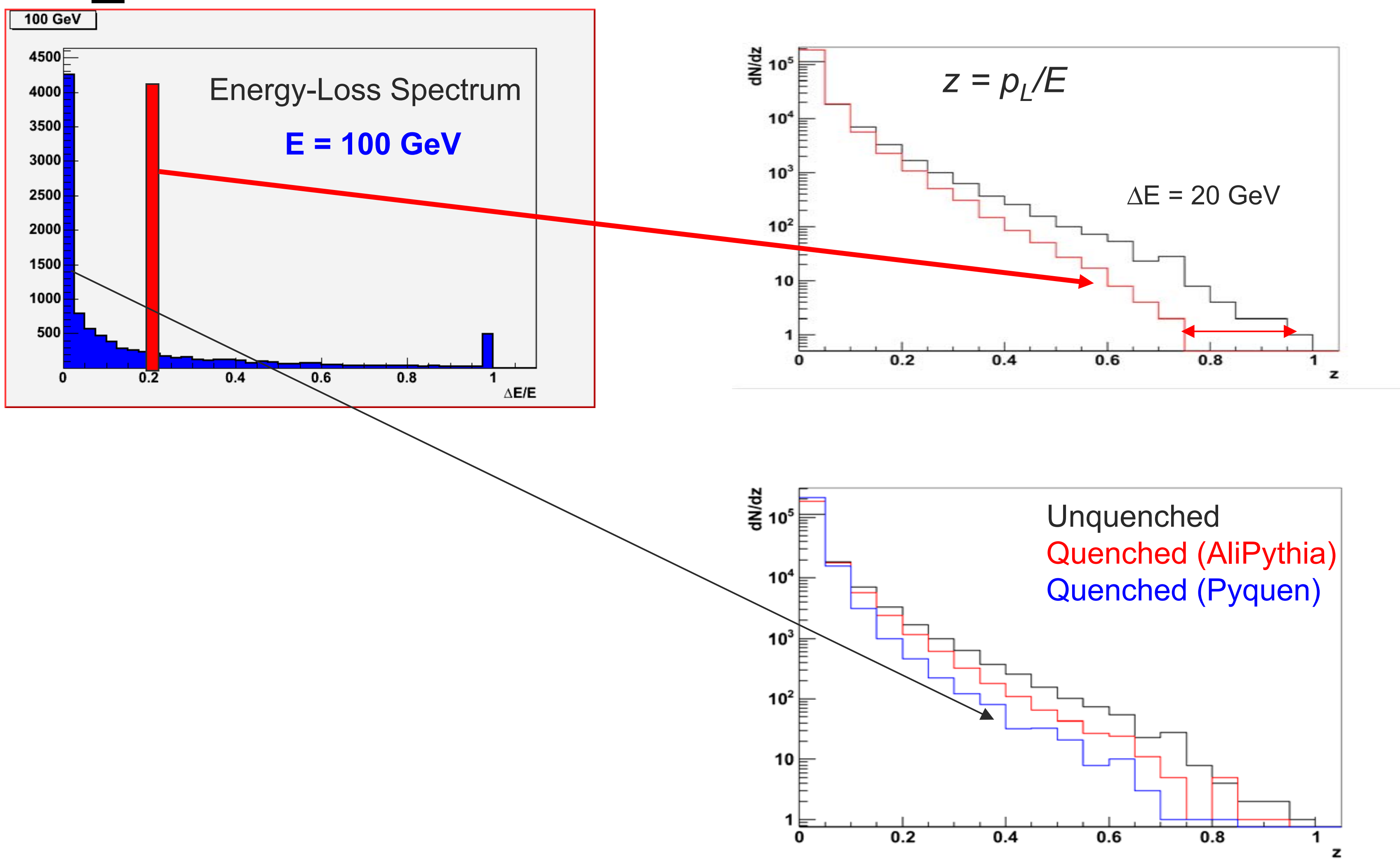
- Increase of mean j_T (tranverse heating)

but also

- Suppressions of hard gluons from final state radiation.

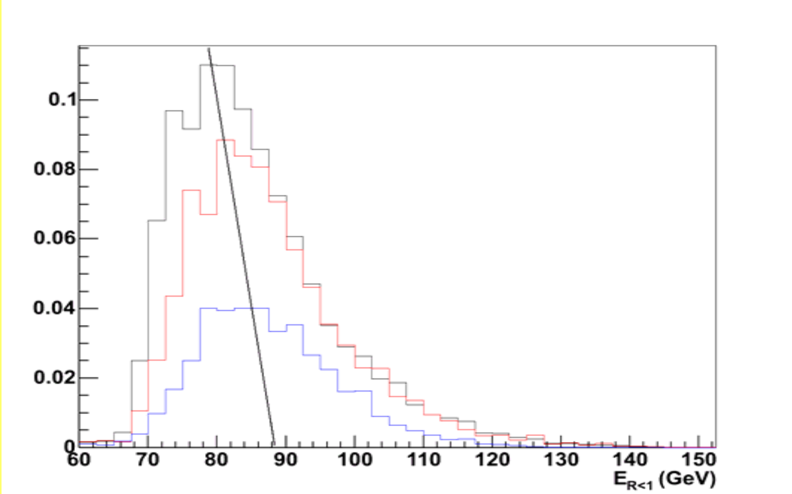


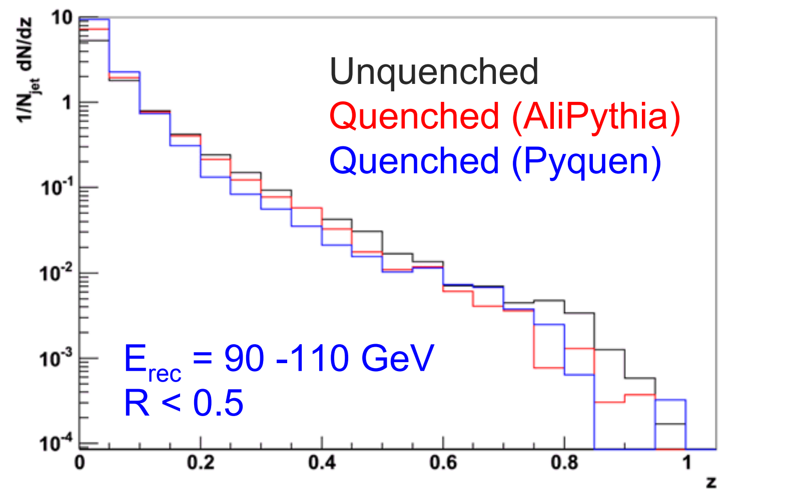
Interpreting Fragmentation Functions



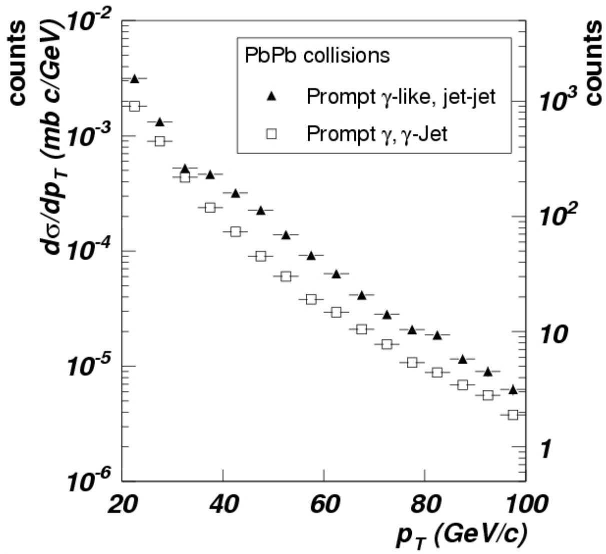
Out of cone radiation

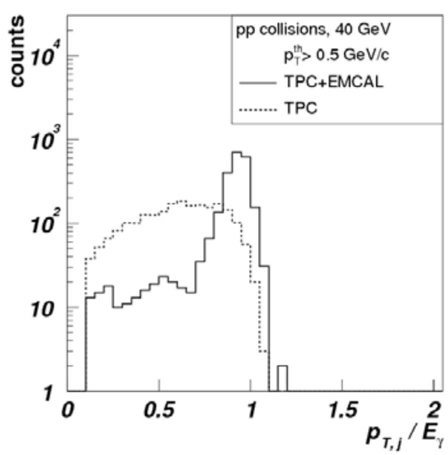
- Consequence of out-of-cone radiation
  - At fixed parton energy: Energy (E_c) in reduced cone decreases $z = p_L/E_c$ increases
  - At fixed reconstructed energy: bias towards higher parton energies: p_L and consequently z increase.
  - Softening of fragmentation function is partially masked.
  - Larger cone sizes and low-p_T measurements are favorable.





γ-Jet Correlations





- Advantage: Strong Correlation between γ and Jet Energy allows unbiased measurement of fragmentation function
- Caveat: low rate
- Interesting for p_T> 20 GeV bridging between the energies accessible through correlation studies to identified jets.
- Needs EMCAL to reject π^0 contamination.

Conclusions

- Copious production of jets in PbPb collisions at the LHC
  - < 20 GeV many overlapping jets/event
    - Inclusive leading particle correlation
  - > 100 GeV Triggering necessary
- Background conditions require jet identification in reduced cone $R < 0.3$-0.5
- ALICE needs calorimetry (EMC) for triggering and jet reconstruction
- Signals for jet quenching in jet structure observables (j_T, fragmentation function, jet-shape)
  - One observable is not enough, in particular jet-shapes have to be understood (out of cone radiation)
  - Radiated energy is observed in low-p_T particles.
    - Good low-p_T tracking capabilities are needed
  - Interpretation of data requires MC combining consistently in medium energy loss and parton showers