



# ALICE

## Jet Quenching Plans and Needs

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# ALICE Detector Systems for Jet and $\gamma$ -Identification

## ■ ITS+TPC+(TOF, TRD)

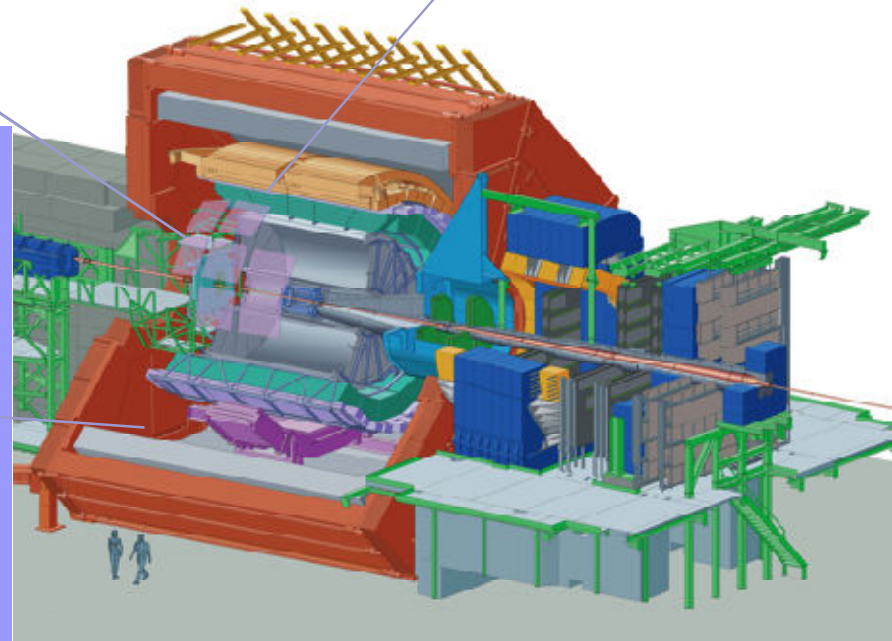
- Charged particles  $|\eta| < 0.9$
- Excellent momentum resolution up to 100 GeV/c ( $\Delta p/p < 6\%$ )
- Tracking down to 100 MeV/c
- Excellent Particle ID and heavy flavor tagging

## ■ EMCal

- Energy from neutral particles
- Pb-scintillator, 13k towers
- $\Delta\phi = 107^\circ$ ,  $|\eta| < 0.7$
- *Energy resolution*  $\sim 10\%/\sqrt{E_\gamma}$
- Trigger capabilities

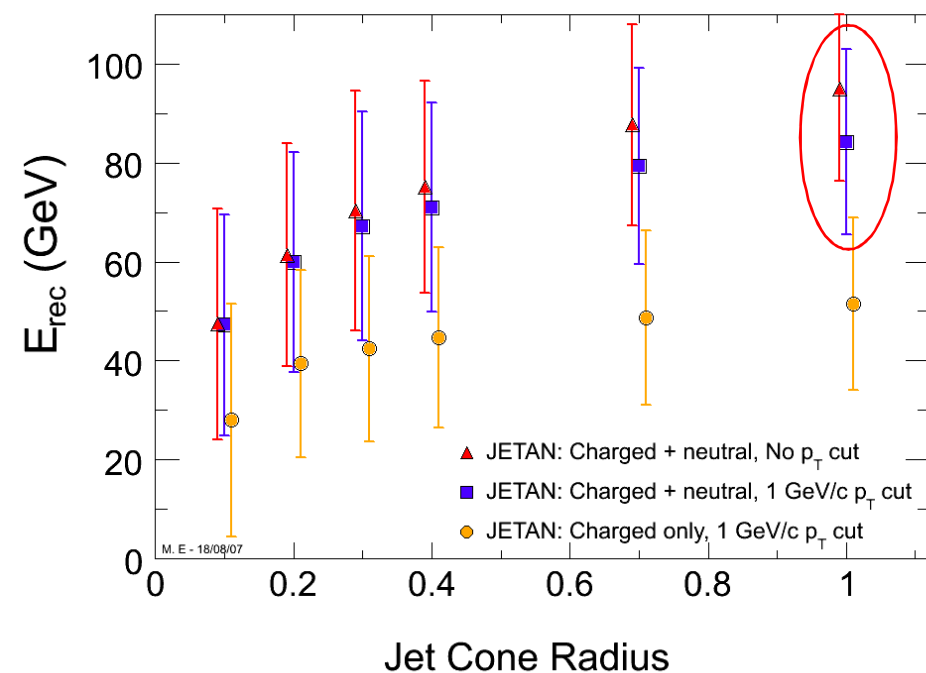
## ■ PHOS

- High resolution electromagnetic spectrometer (PbWO<sub>4</sub> crystals)
- $\gamma$ -Trigger
- $|\eta| < 0.12$
- $220^\circ < \phi < 320^\circ$
- Energy resolution:  $\Delta E_\gamma/E_\gamma = 3\%/\sqrt{E_\gamma}$
- Position resolution:  $\Delta x/x = 23\%/\sqrt{E_\gamma}$



# Rec. Energy and Resolution (rel. to $R = 1$ )

p+p@14 TeV

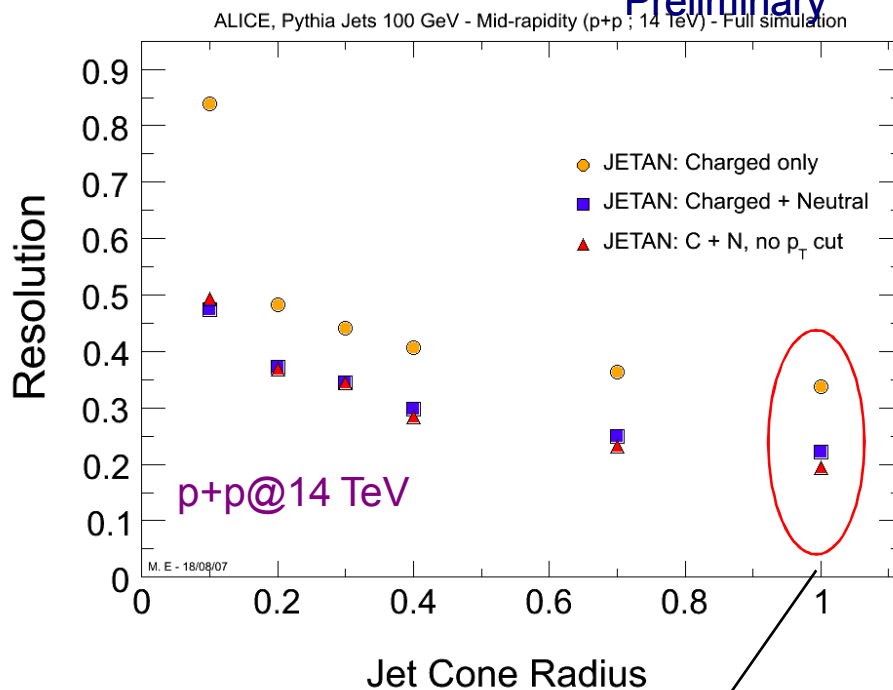


$E_{rec}$  = mean energy inside a cone of radius  $R$

Resolution =  $RMS/E_{rec}$

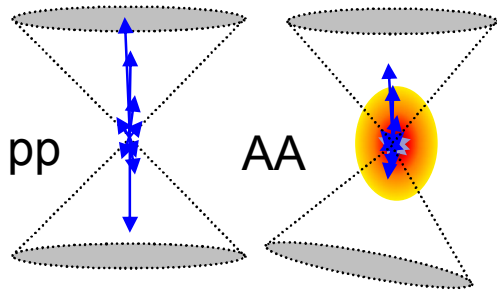
M. Estienne (2009)

Preliminary



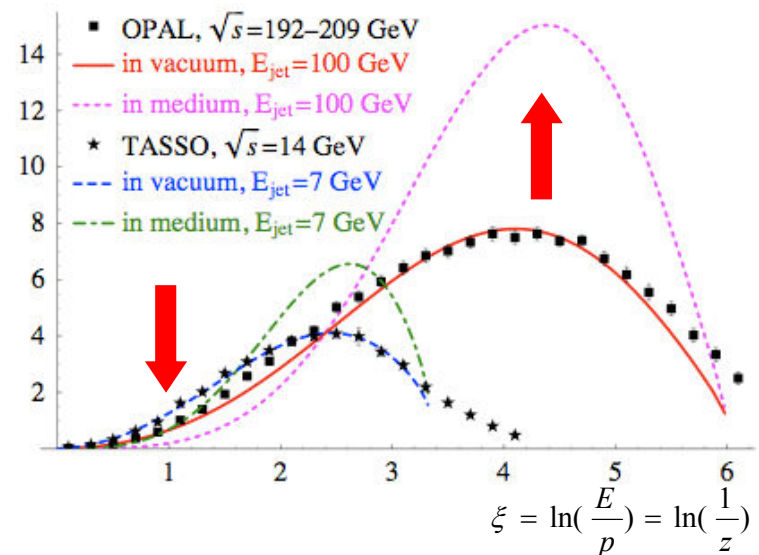
Charged-to-neutral fluctuations  
Fluctuations of  $K^0_{L,n}$  -fraction  
Acceptance

# Modification Jet Structure



Simplistically:  $\text{Jet}(E) \rightarrow \text{Jet}(E - \Delta E) + \text{soft gluons}(\Delta E)$

Borghini, Wiedemann, hep-ph/0506218



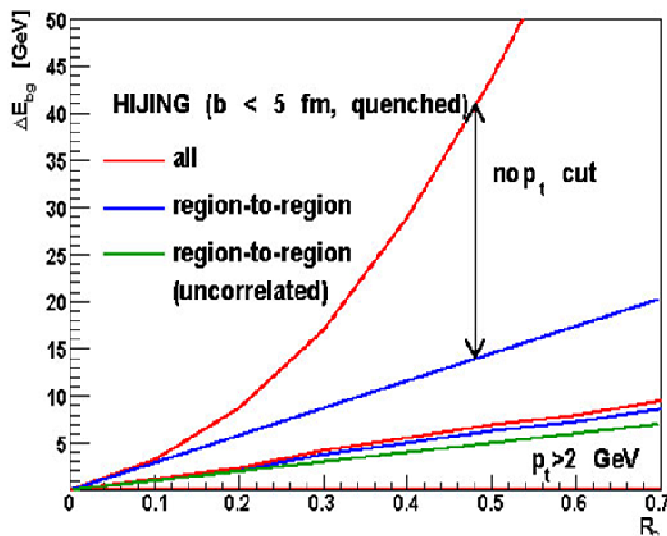
- Decrease of leading particle  $p_T$  (**energy loss**)
- Increase of number of low momentum particles (**radiated energy**)
- Increase of  $p_T$  relative to jet axis ( $j_T$ )
  - Broadening of the jet
  - Out of cone radiation (**decrease of jet rate**)
- Increased di-jet energy imbalance and acoplanarity.

# Analysis strategy will focus on ...

- Effects from background of the Underlying Event (UE)
  - Most important difference between jet physics in pp and AA collisions
    - Background effects jet reconstruction (energy, direction) and jets structure analysis (low- $p_T$ , high  $R$ )
    - There are 0<sup>th</sup>, 1<sup>st</sup> and 2<sup>nd</sup> order background effects
- Possible strong modification of the jet shape
  - Out of cone radiation

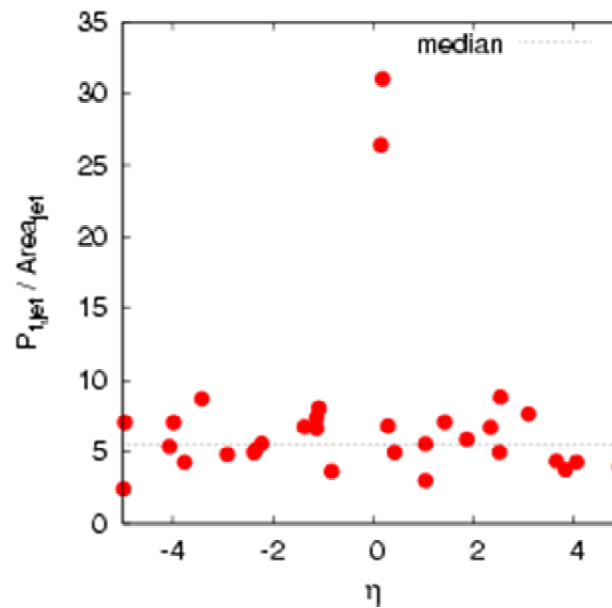
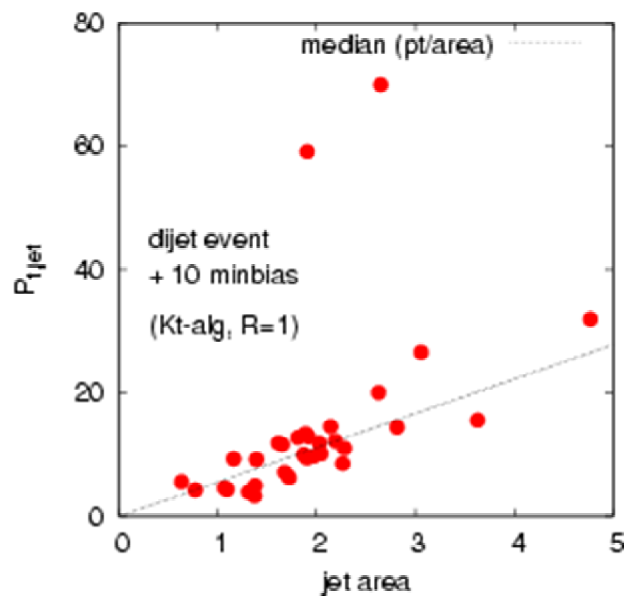
# 0<sup>th</sup> order background effects

- Estimation of background (UE) energy within jet cone
  - Has to be subtracted event-by-event (jet-by-jet)
- Contribution of particles from the UE to jet structure observables
  - Estimated from UE outside jet cones



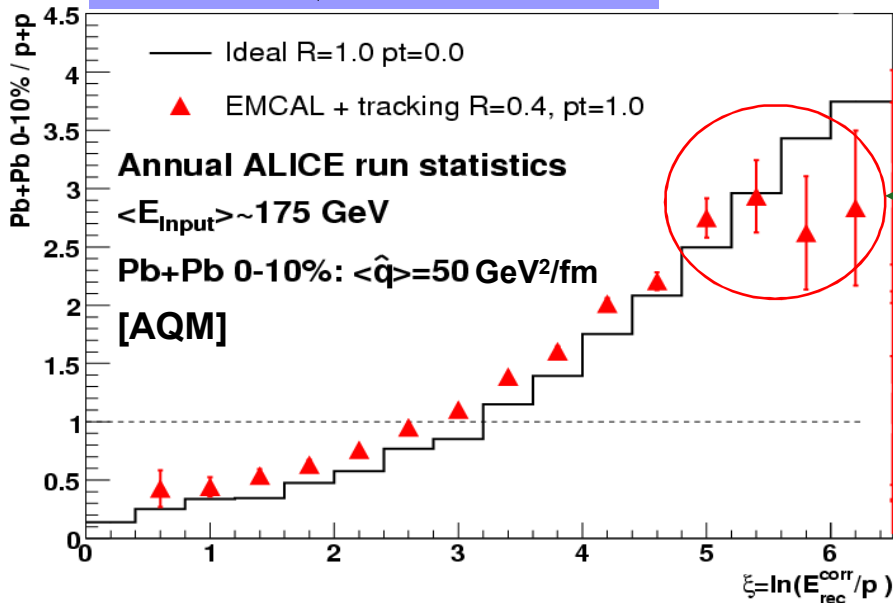
# 0<sup>th</sup> order background effects

- Cone algorithms with fixed cone size
  - Background energy from random cones outside the jet areas. Subtraction at each iteration.
- Algorithms with variable cone size (sequential recombination algorithms)
  - Jet area has to be determined for each jet (M. Cacciari et al.)
    - Concept of active and passive areas

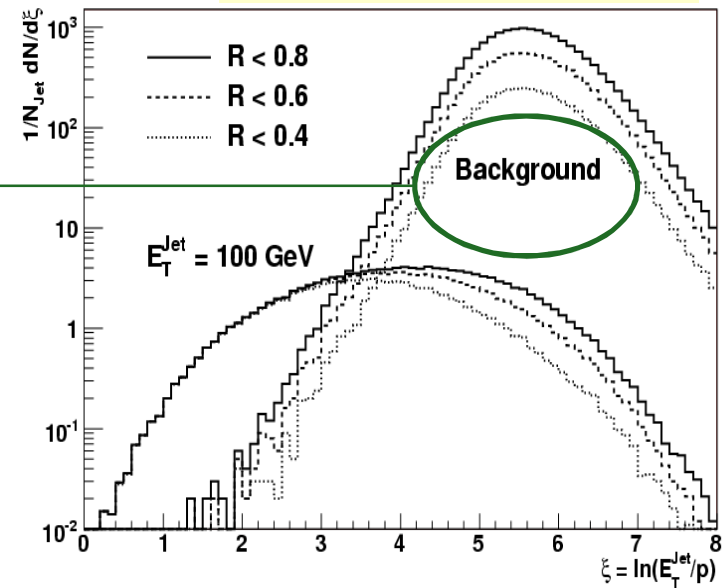


# Background and Fragmentation Function

$$R_{AA}(\xi) = \frac{1/N_{jet}^{AA} dN^{AA} / d\xi}{1/N_{jet}^{pp} dN^{pp} / d\xi}$$

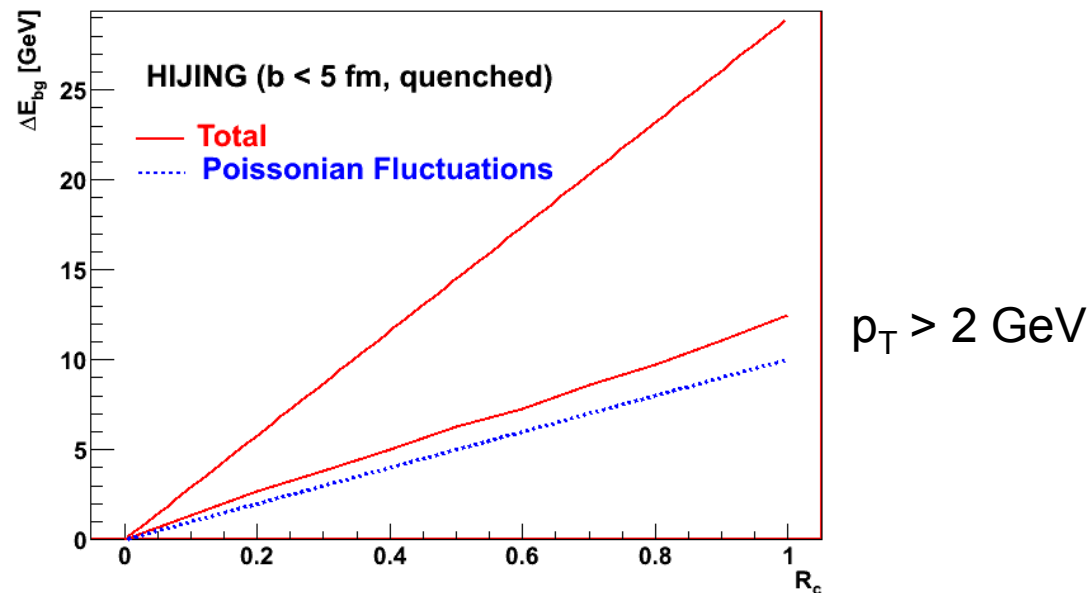


$$\sqrt{S + B + 0.002B}$$



# 1<sup>st</sup> order Background effects

- Only the mean background energy can be subtracted. We are left with the fluctuations. Depend on jet area and  $p_T$ -cut (pedestal subtraction)



# 1<sup>st</sup> order Background effects

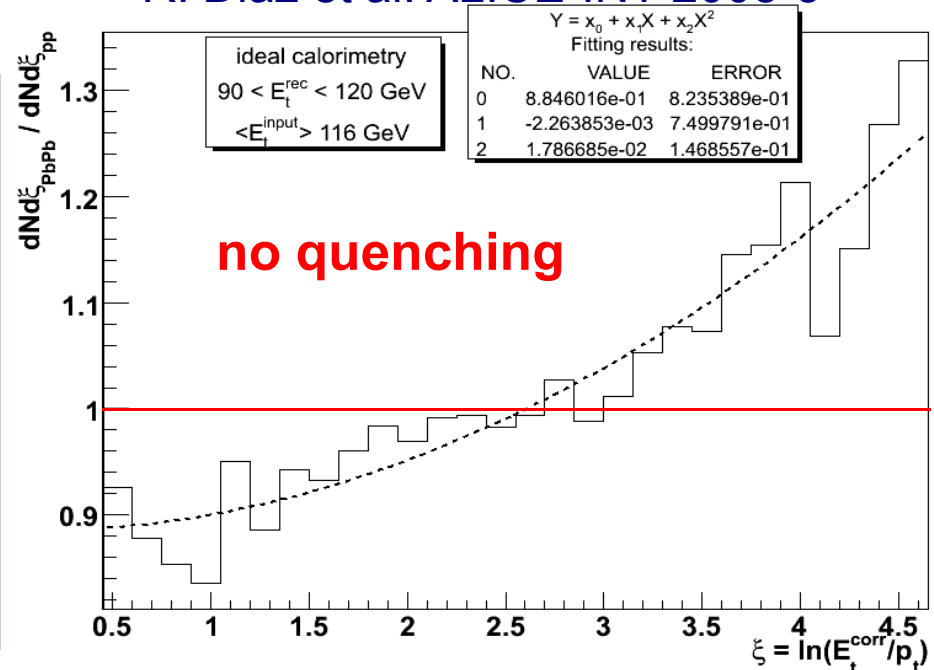
- Jet spectrum has to be de-convoluted using the shape of the background energy distribution (see PHENIX, STAR)
- In low energy region “pure” fluctuations dominate (fake jets) and have to be subtracted. From data we have to find out whether these fake jets are
  - Superpositions of uncorrelated particles (STAR)
  - “ of uncorrelated mini-jets (ATLAS)

# 1<sup>st</sup> order Background effects

- Affect also jet structure observables

- Jet reconstruction pre-selects jets with larger than average soft UE contribution (production spectrum bias). Needs correction.

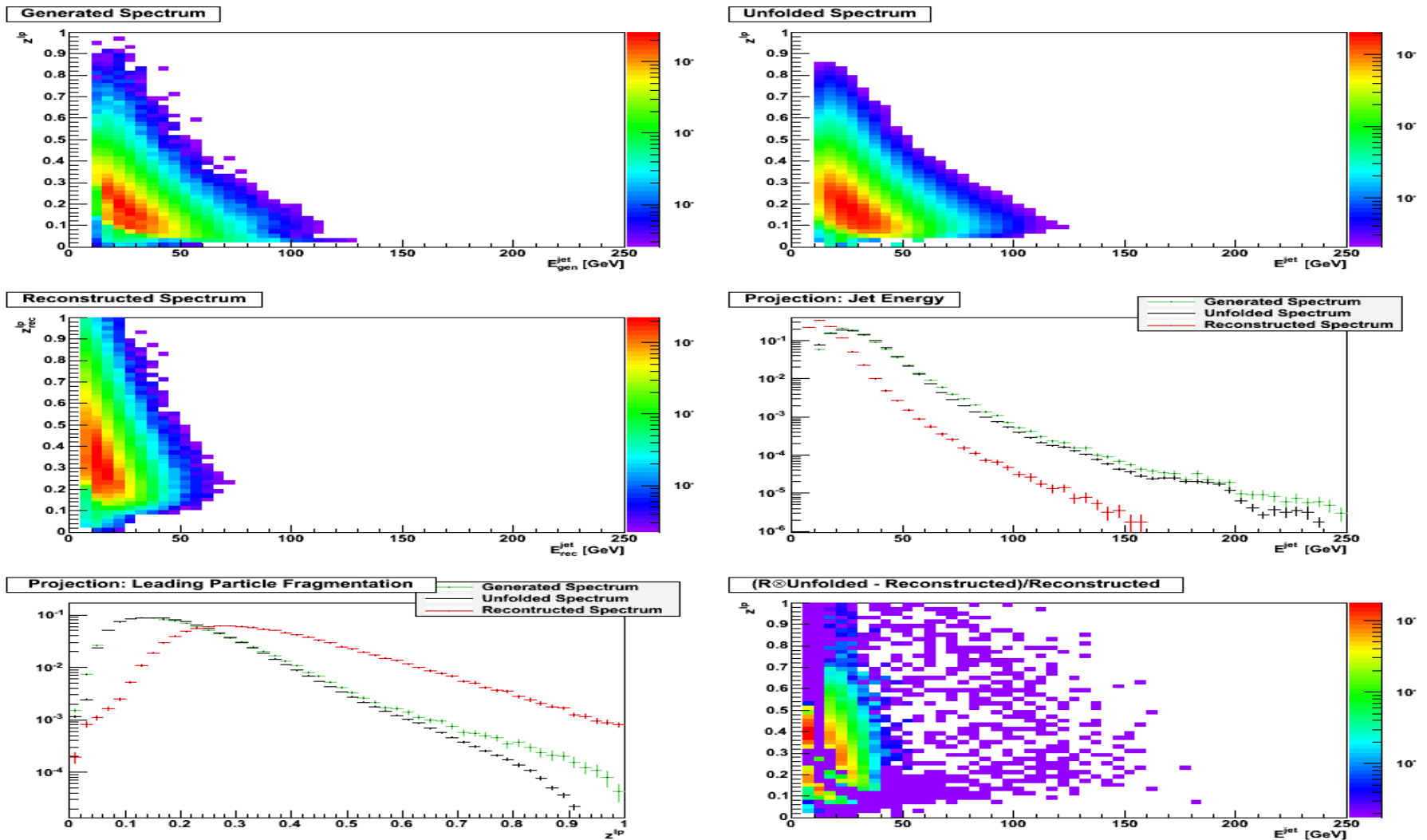
R. Diaz et al. ALICE-INT-2008-5



... possibly using combined de-convolution of energy spectrum and FF (under study)

# 2D Unfolding Example

(here for charged to neutral fluctuations)

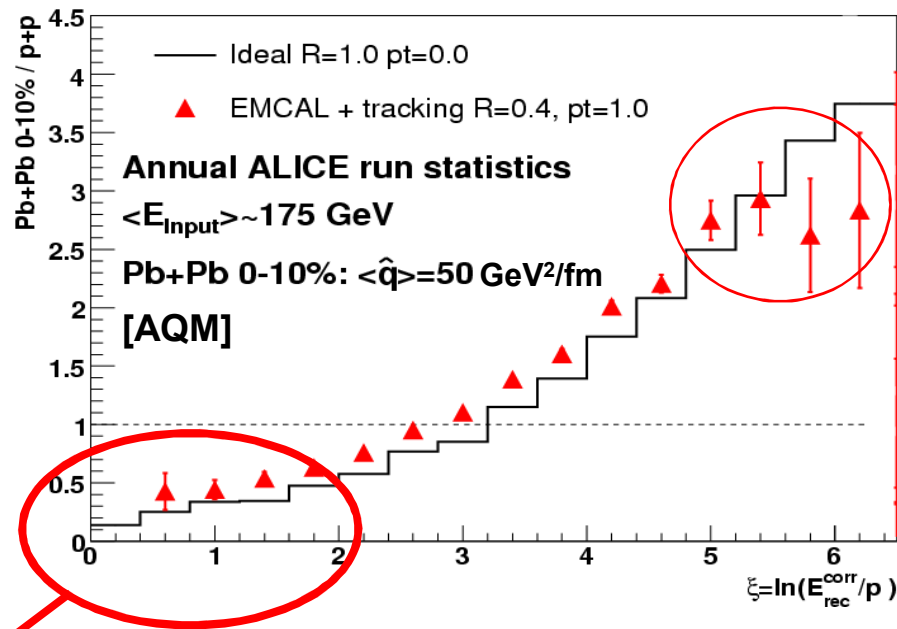




## 2<sup>nd</sup> Order UE Effects

- Result of jet reconstruction is not a simple linear superposition of background fluctuations and the physical jet. Jet finder prefers positive background fluctuations.
- Systematics has to be studied using different jet reconstruction algorithms.

# 2<sup>nd</sup> order UE Effects



But also:

Jets that fragment into particles with high  $z$  have a jet shape different from the average jet (more collimated).

They are differently affected by the background.

Bias due to UE even for jets of fixed input energy.

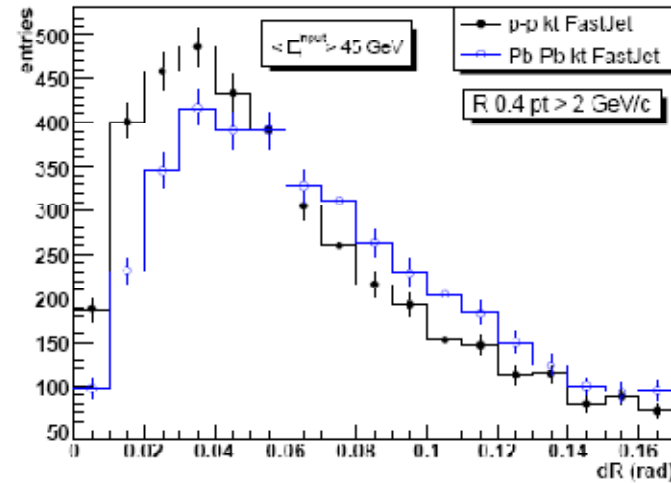


Figure 7: Differences between the jet axis and the centroid reconstructed in pp and Pb-Pb (Run II and III) for jets with 45 GeV, using  $k_t$  algorithm.

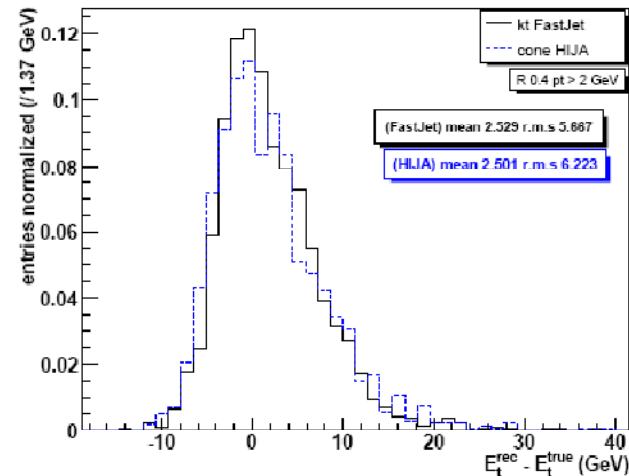


Figure 8: Difference between the reconstructed and the true jet energy within the reconstructed area for jet of 45 GeV using cone and  $k_t$ -algorithms in a ideal calorimetry detector response.

## R. Diaz et al. ALICE-INT-2008-5

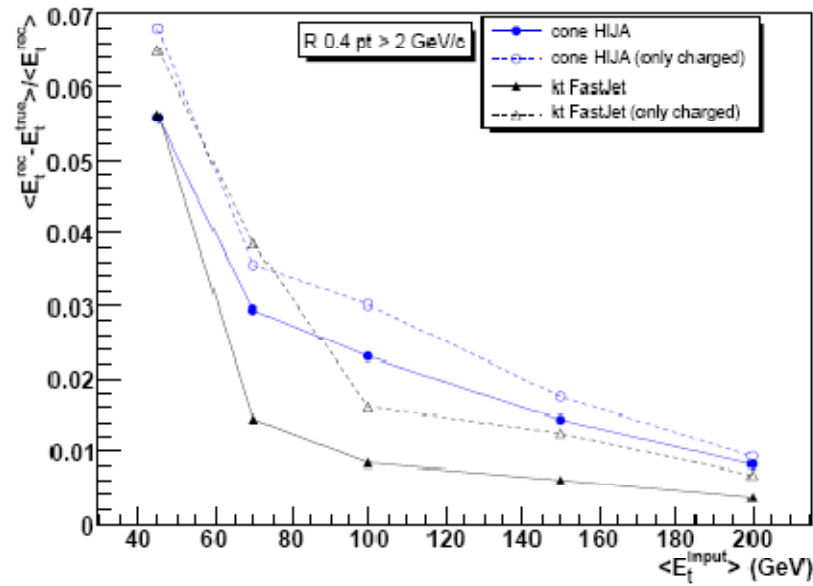


Figure 10: Average fraction of background in the reconstructed energy as function of the input energy of the jets, using  $k_t$  and cone algorithms in the reconstruction.

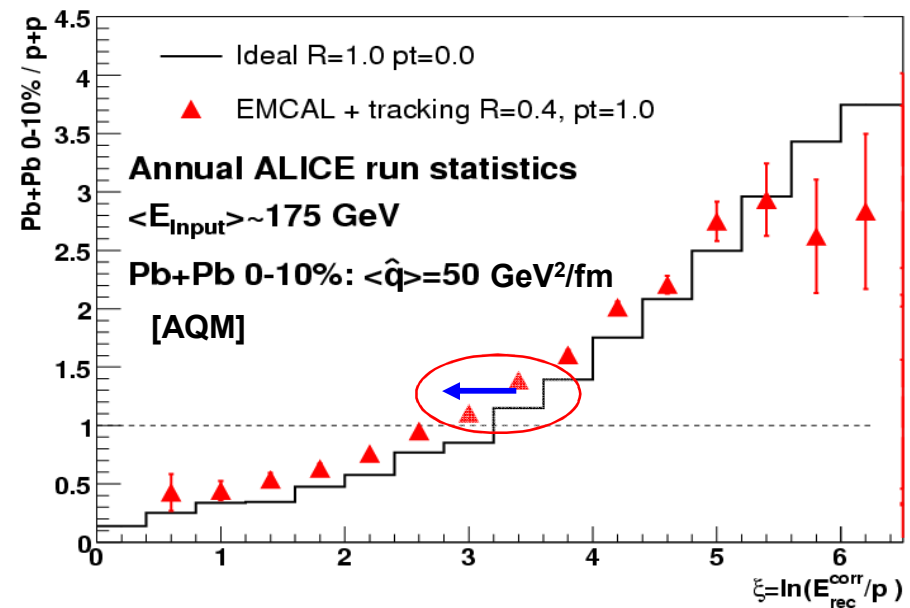


# Analysis Strategy UE Background:

- 0<sup>th</sup>-order correction: Jet-by-jet UE Energy Subtraction
- 1<sup>st</sup>-order correction:
  - Subtraction of the fake-jet spectrum
  - Unfolding of jet energy spectrum and FF using estimated UE Energy spectrum in jet area.
  - Determine smearing function for each energy bin in which jet structure will be studied.
- 2<sup>nd</sup>-order correction: study residual systematics of back-reaction of the background to the jet reconstruction.
  - Correct measured jet structure

# Effects of out-of-cone radiation

- Robust signal but underestimation of jet energy biases  $\xi$  to lower values.
  - Depends on cone size  $R$  and  $p_T$  cut



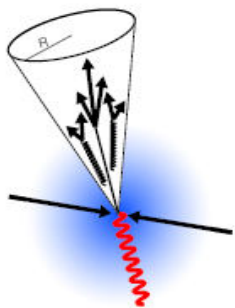


# Analysis Strategy:

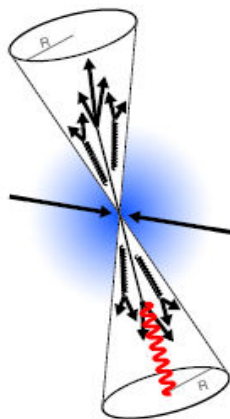
## Out of cone radiation

- Measure  $R_{AA}^{\text{Jet}}(E_T)$ , Jet shape and FF
- Under ideal conditions (no background) these measurements should over-constrain the fragmentation model. If inconsistent, better understanding of background systematic is needed.
  - Learn from PHENIX and STAR experience
- Improve MC (effective) model. Assess BG systematics again.

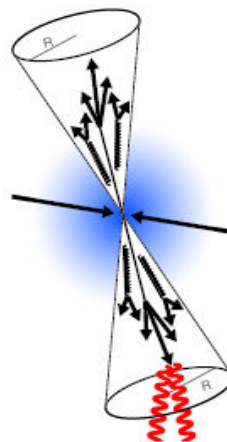
# $\gamma$ -Jet Correlations



Prompt photon



Fragmentation photon



Decay photon

Direct  $\gamma$  are likely to be produced isolated. Two parameters define  $\gamma$  isolation:

**Cone size  $R$**

**$p_T$  threshold**, candidate isolated if:

No particle in cone with  $p_T > p_T^{\text{thres}}$   
or

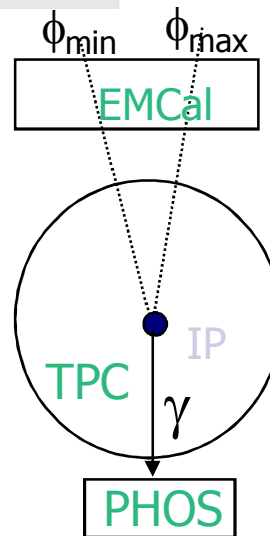
$p_T$  sum in cone,  $\Sigma p_T < \Sigma p_T^{\text{thres}}$

## ■ Dominant processes in pp

- $g + q \rightarrow \gamma + q$  (Compton)
- $q + q \rightarrow \gamma + g$  (Annihilation)

## ■ $\gamma$ -jet correlations

- $E_\gamma \approx E_{\text{jet}}$
- Opposite direction
- Direct photons are not perturbed by the medium

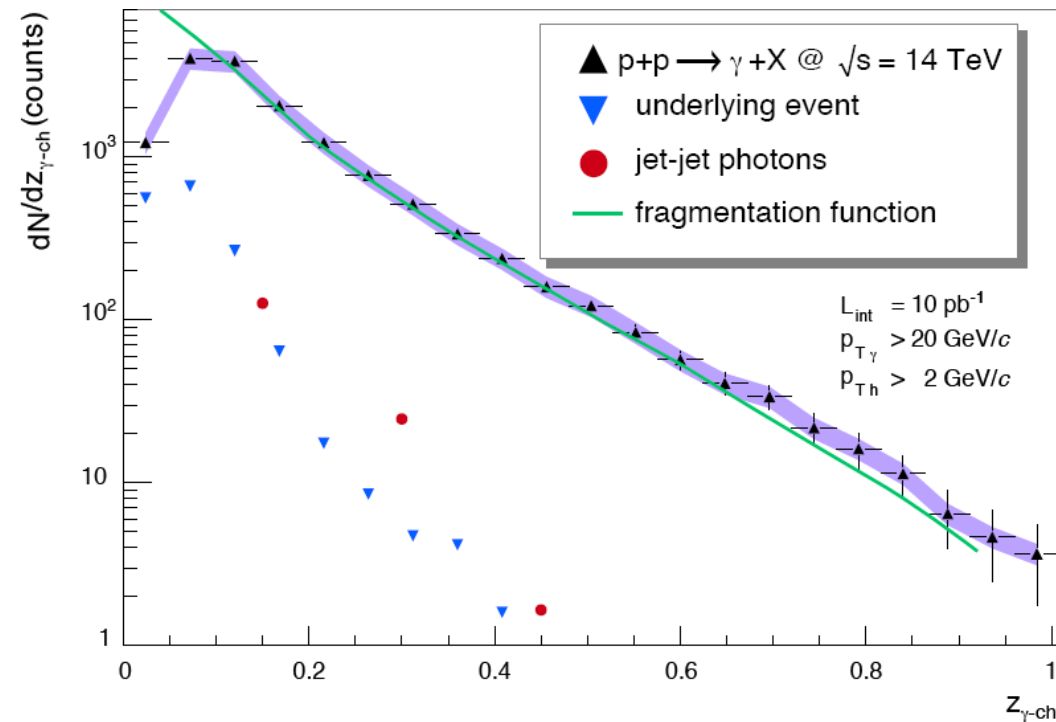


## ■ $\gamma$ Identification

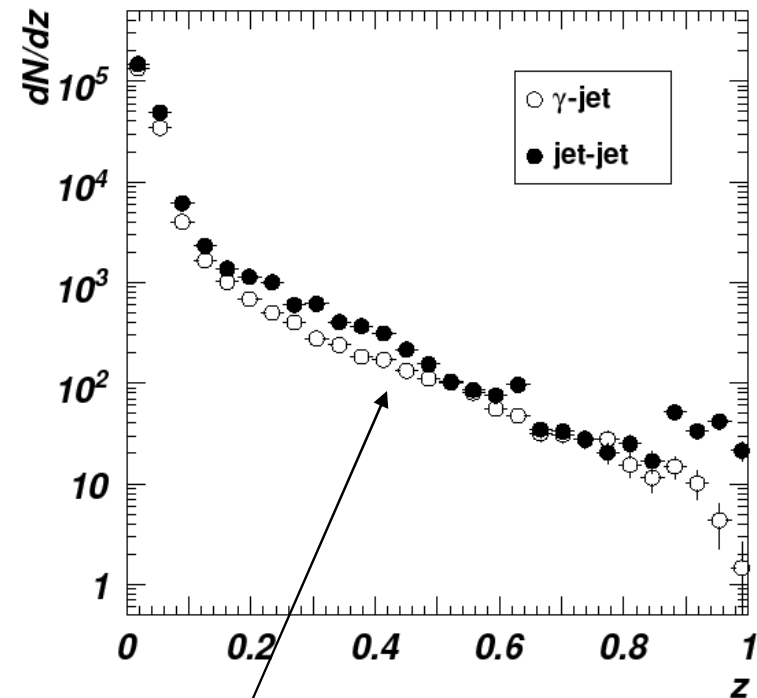
- Time of flight
- Charged particle veto
- Shower shape

# Fragmentation function

pp



PbPb



Jet-Leading Hadron correlations are equally usefull

# Other issues: cone size

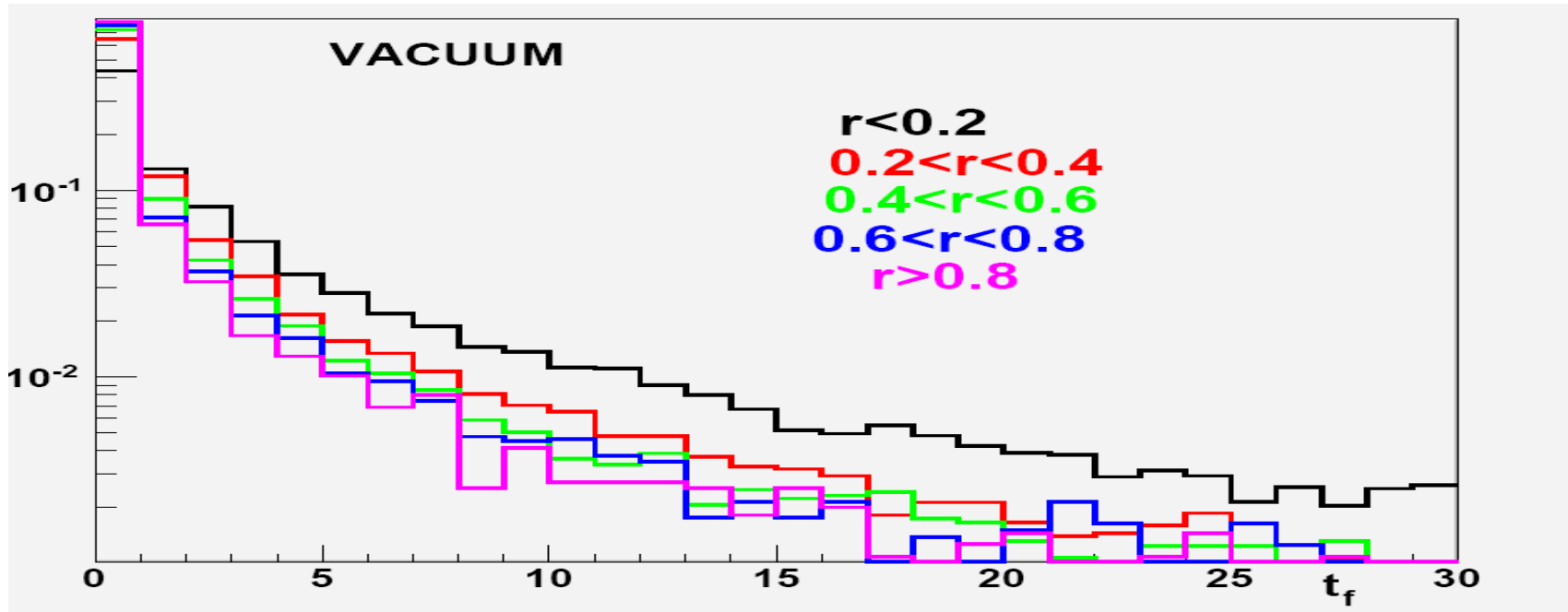
- Optimal cone size (resolution parameter)
  - Background energy vs out-of-cone fluctuations
  - Fluctuations maybe not relevant for single jets, but produce di-jet energy imbalance and  $k_T$  in LO
  - In this context, is it really true that “A jet does not exist until the reconstruction algorithm has been defined” ?

# Other issues: path length and formation time dependence of quenching

- Measure jet structure modification dependence on distance to reaction plane
- New idea: Jet Chronography
  - $R$ -dependence of quenching probes parton formation time ( $t_F \sim 1/(R j_T)$ )

# QPYTHIA:

## Space-time evolution of the shower

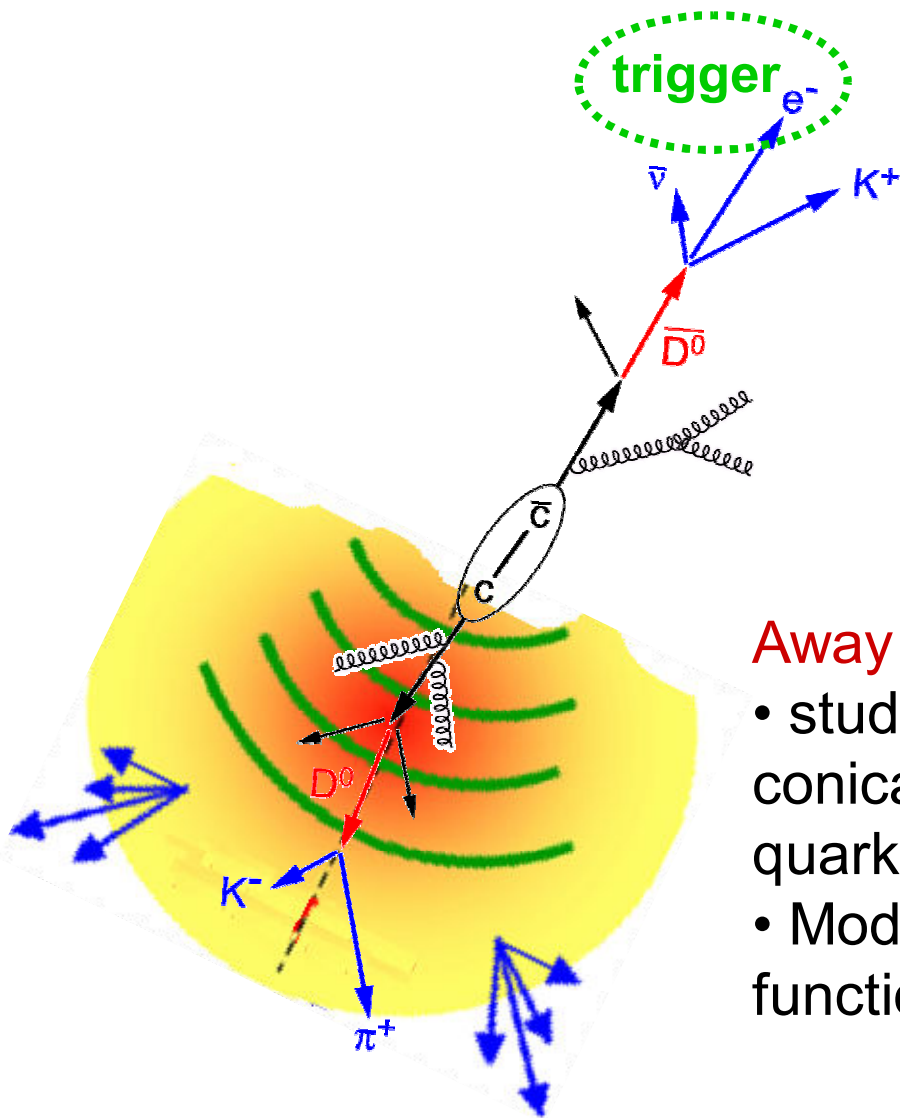




# Heavy Flavor Quenching

- We will measure  $D^0$  spectrum down to  $p_T = 0$
- In addition flavor (c,b) tagging using e-D back-to-back charge correlation.

# Heavy-flavour particle correlations



## Near side ( $\Delta\Phi = 0$ ):

- study D/B decay contribution to single electrons
- correlations width depends on decay kinematics, not on the production dynamics

## Away side ( $\Delta\Phi = \pi$ ):

- study in-medium D/B energy loss - conical emission as observed for light quark hadrons?
- Modification of the fragmentation function

*Differentiate between charm and bottom quark energy loss*

# Needs

- Analysis should not rely on model prediction or specific MC. However, observables are non-trivially correlated (in particular due to the presence of the background from UE). Some guidance from full MC implementations is needed to develop the analysis strategy. Full means
  - Interactions of partons with the medium
    - Modification of the FF and jet shape
    - Modification of the hadro-chemistry
    - Flavor dependent effects
    - Dijet acoplanarity
    - Consistent space time evolution of the shower
  - Underlying event