Photon/pi0 - hadron correlations in ALICE at LHC

1. Motivation
2. Feasibility study
3. Preliminary results
4. Summary

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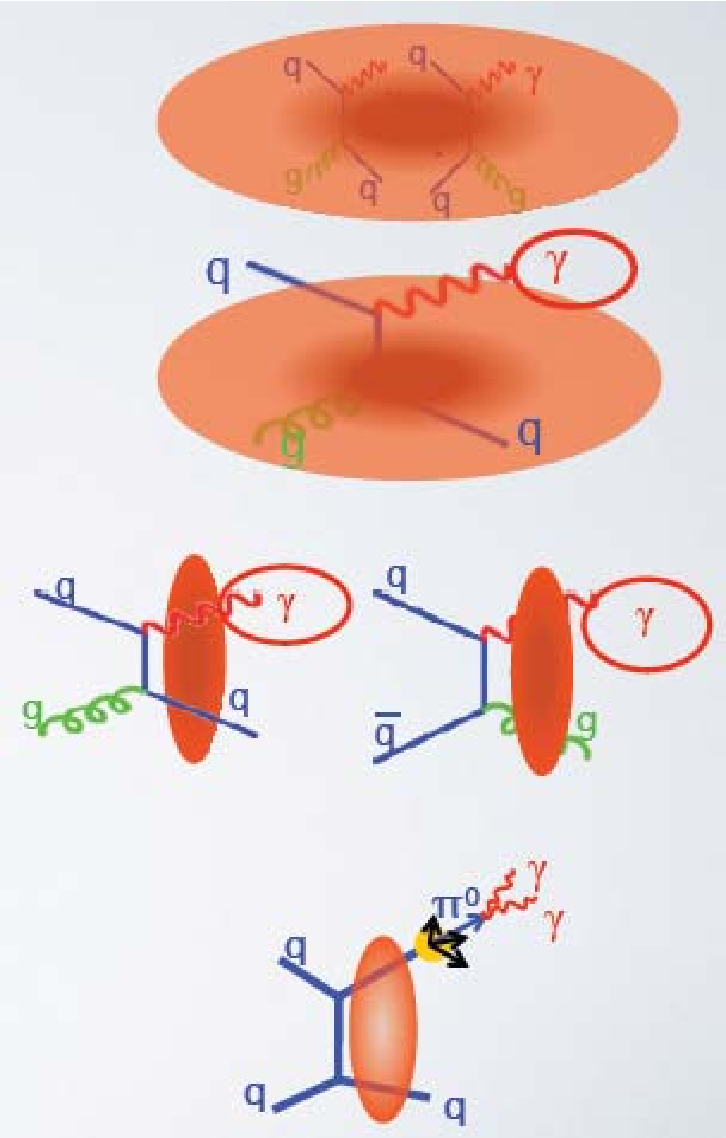
Photons: an “universal” probe of QGP

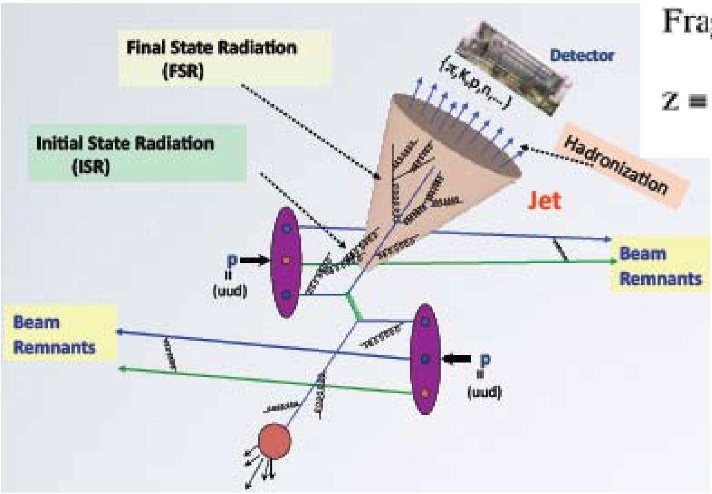
- Temperature : thermal photons radiated from the medium
- Chemical composition : semi hard photons produced by hard partonic interaction with the hot medium (bremsstrahlung and conversion)
- Reference for the hard process : prompt photons are not interacting with the medium
- Jet structure and quenching : decay photon



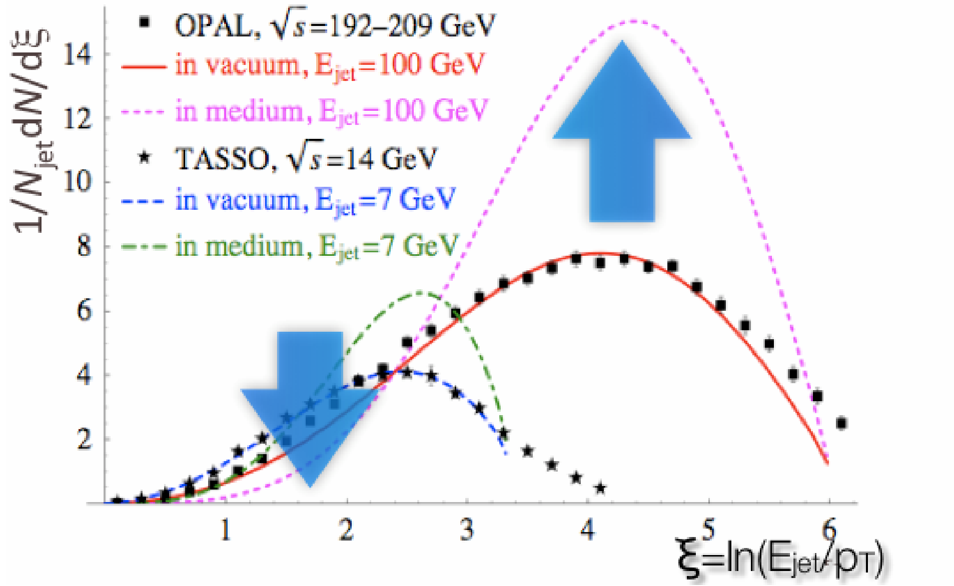
Jets: a special hard probe of QGP

Borghini and Wiedemann, hep-ph/0506218

$R_{cone} = \sqrt{(\Delta\phi^2 + \Delta\eta^2)}$



Fragmentation: $z = \frac{p_{hadron}}{p_{parton}}$



Jet - QGP interaction:

hard scattered partons loose energy by radiating soft gluons, which frag-ment as low pT hadrons in the final state

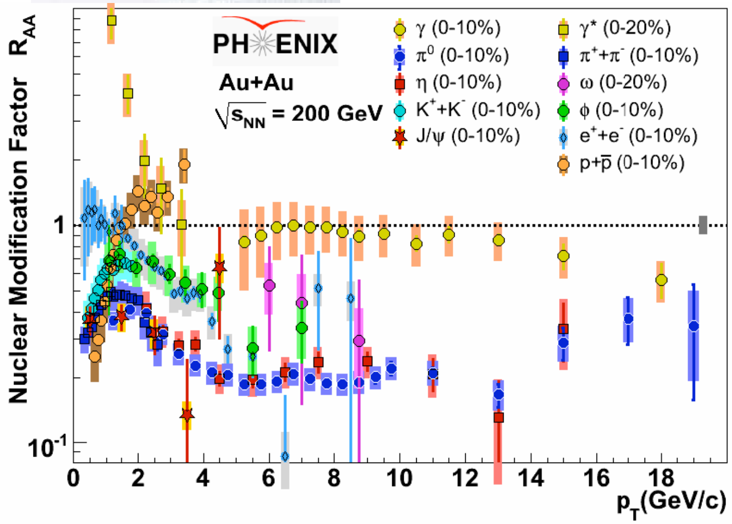
- cause the modification on the fragmentation function and jet shape

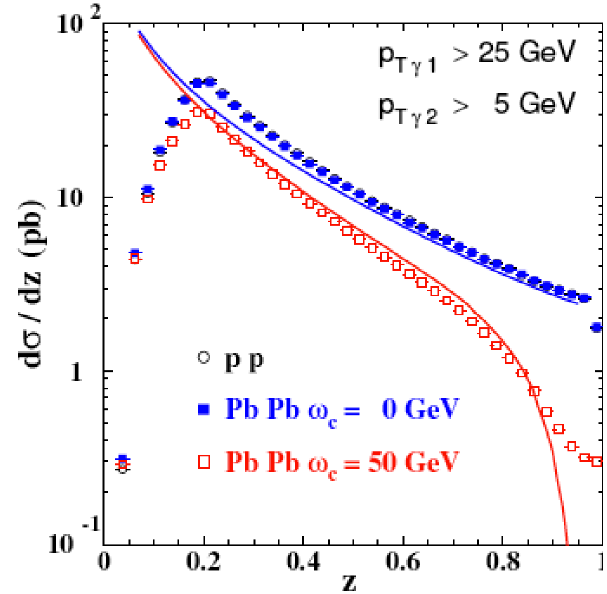
Experimentally, look for

- suppression at low ξ;
- Enhancement at high ξ;
- Jet broadening & radiation out of cone;
- Increase of di-jet acoplanarity

γ +Jet : the "Golden" channel

$$R_{AA} = \frac{1}{N_{AA}} \frac{d\sigma_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$





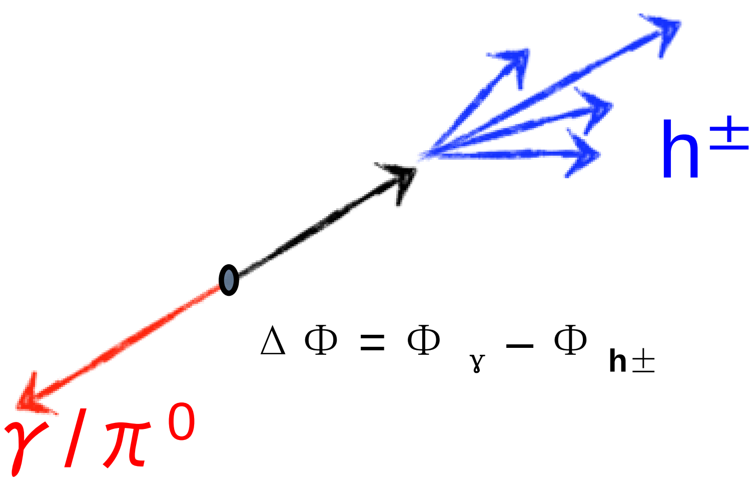
F. Arleo, J. Phys. G: Nucl. Part. Phys. 34(8), S1037 (2007)

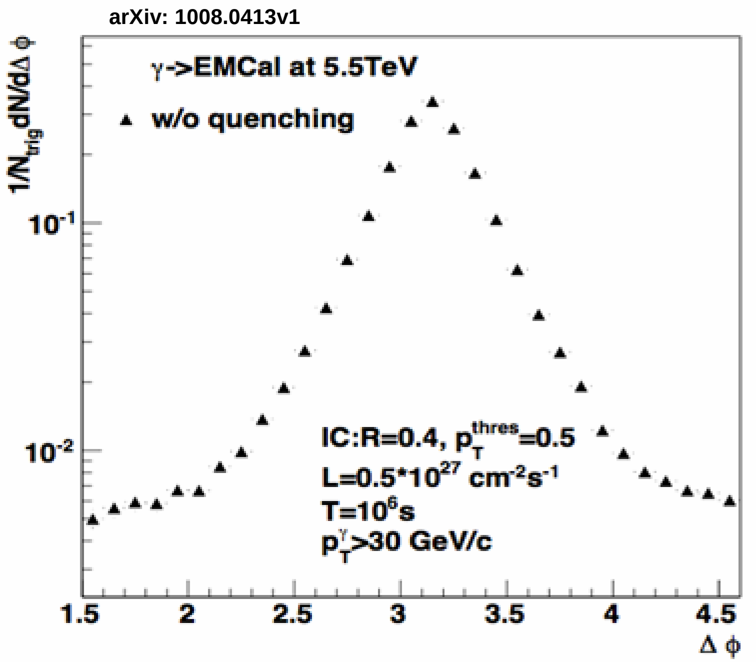
- γ - tagged jet opposite to the direct photon: $E_\gamma \sim E_{jet}$ – the photon 4-momentum remains unchanged while traversing the medium and sets the reference of the hard process

- Measure the jet fragmentation: $z = p_T^{hadron} / E_\gamma$

γ + jet correlation (1)

- Exploit 2→2 hard processes with a photon or a π^0 in the final state to study the QCD medium:
  - in pp collisions, understand and characterize the probe: measure the transverse momentum at parton level (intrinsic, IR, FSR/NLO) from azimuthal $\gamma / \pi^0 - h^{\pm}$ correlations, —> hard partonic fragmention function (FF)

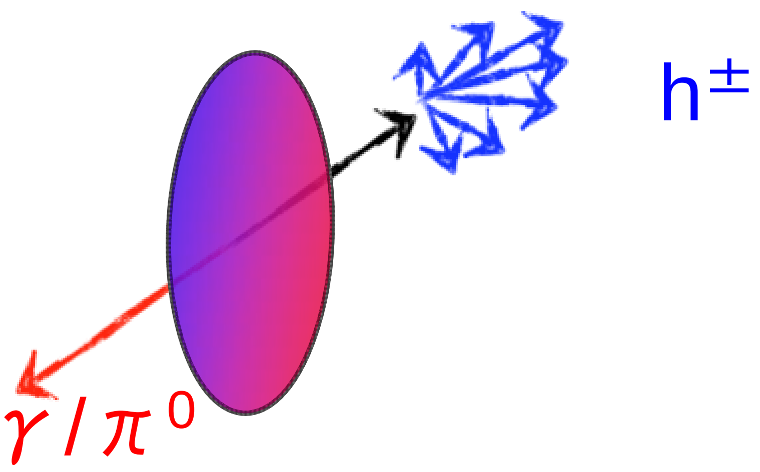




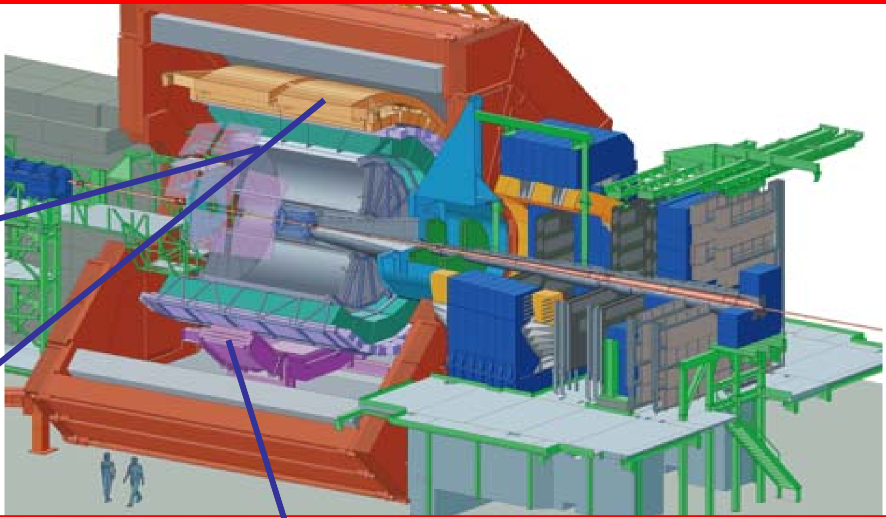
$\Delta\Phi = \Phi_{\gamma} - \Phi_{h\pm}$

γ + jet correlation (2)

- Exploit 2→2 hard processes with a photon or a π^0 in the final state to study the QCD medium:
  - —in A-A collisions, measure the modifications inferred by the created QCD medium on the final state of the jets: transverse momentum kick, modified partonic FF(or CF)



ALICE capability on charged particle and photon identifications



- **ITS+TPC+TOF+TRD+HMPID**
  - 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
  - Mass resolution: σ_π~3.3 MeV

- **EMCal**
  - Lead-scintillator sampling EMCal, 13k towers of $\Delta\eta \times \Delta\phi = 0.014 \times 0.014$
  - $\Delta\phi = 107°$, $|\eta| < 0.7$,
  - Energy resolution ~10%/ $\sqrt{E}$
  - Mass resolution: σ_π ~ 16 MeV
  - High pt triggers: γ, π^0, e
  - pt measured up to ~250 GeV/c

- **PHOS**
  - High resolution photon spectrometer (PbWO$_4$ crystals 56x64x5): $\Delta E/E$~3%/*E*
  - $|\eta| < 0.12$, $220° < \phi < 320°$
  - Energy and position resolution (E in GeV):

$$\frac{\Delta E}{E} = \sqrt{\frac{a^2}{E^2} + \frac{b^2}{E} + c^2}, (a = 0.03, b = 0.03, c = 0.01)$$

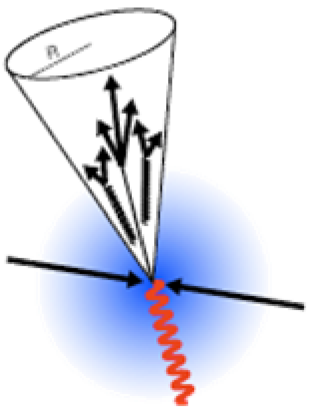
  -

$$\Delta x = \frac{A}{\sqrt{E}} + B, (A = 3.26\,mm, B = 0.44\,mm)$$

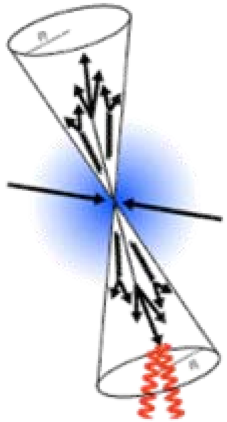
  - Mass resolution: σ_π ~ 4.7 MeV
  - high pt trigger : γ, π^0, e
  - pt from ~100MeV/c to ~100 GeV/c

Strategy of correlation measurements

- Reconstruct and identify trigger particles (request leading) in calorimeters (PHOS and EMCal) with invariant mass + shower shape + isolation cut， → p_T^{ch} , p_T^{clu} , $p_T^{\pi^\circ}$



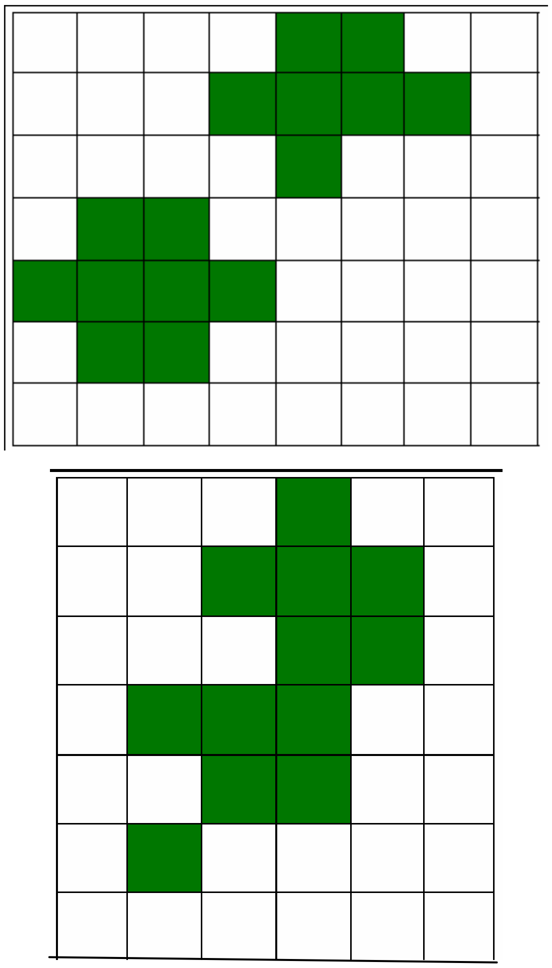
- Reconstruct charged tracks in CTS → p_T^h
- Establish azimuthal correlation between triggers and charged hadrons:
  $\Delta\Phi = \Phi^h - \Phi^{clu,\pi^\circ,\gamma}$ → (extract) k_T
- Construct the correlation function (CF) variable (x_E) by correlating hadrons opposite to the trigger particles
  → $x_E = (-p_T^h \cdot p_T^\gamma)/|p_T^\gamma|^2$, $\Delta\Phi = \pi$



- Subtract background
  — decay and fragmentation photons
  — soft hadrons from underlying event

Photon identification

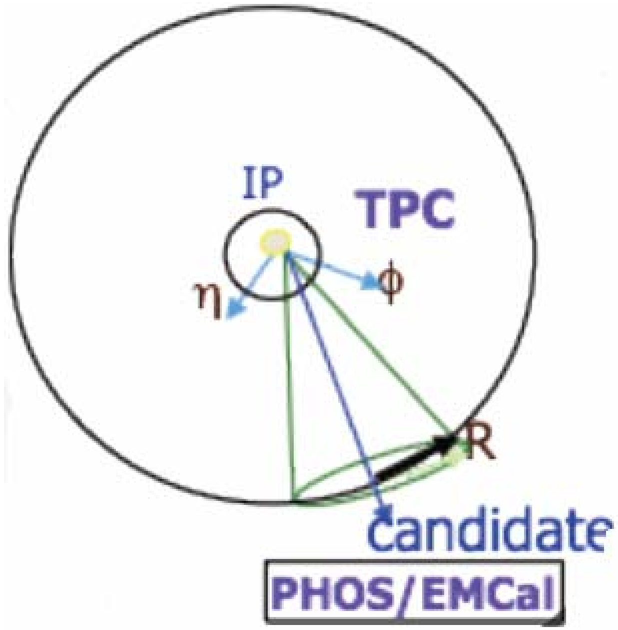
- Photons are detected as clusters of cells in the calorimeters
  - clusters originated mainly from π^0 decay photons (95%)
  - at low π^0 energy, a cluster originates from a single photon
  - at higher energy (E_{π^0}~ 25 GeV in PHOS and ~8 GeV in EMCAL), the 2 decay photons merge into a single cluster
    ➜ shower shape analysis



High energy photon identification: isolation slection (IS)

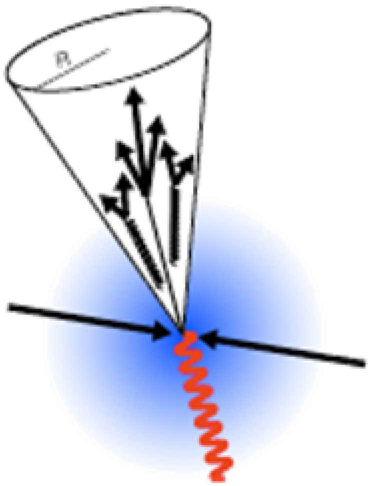
- Enrich the sample of isolated (direct) photon
- Study the hadronic (charged only) activity around the detected cluster
- 3 parameters:
  — **R** is the size of the cone
  — ε is a fraction of the cluster energy
  — p_T^{thres} is the energy from UE
- The cluster with energy $E_{cluster}$ is isolated if

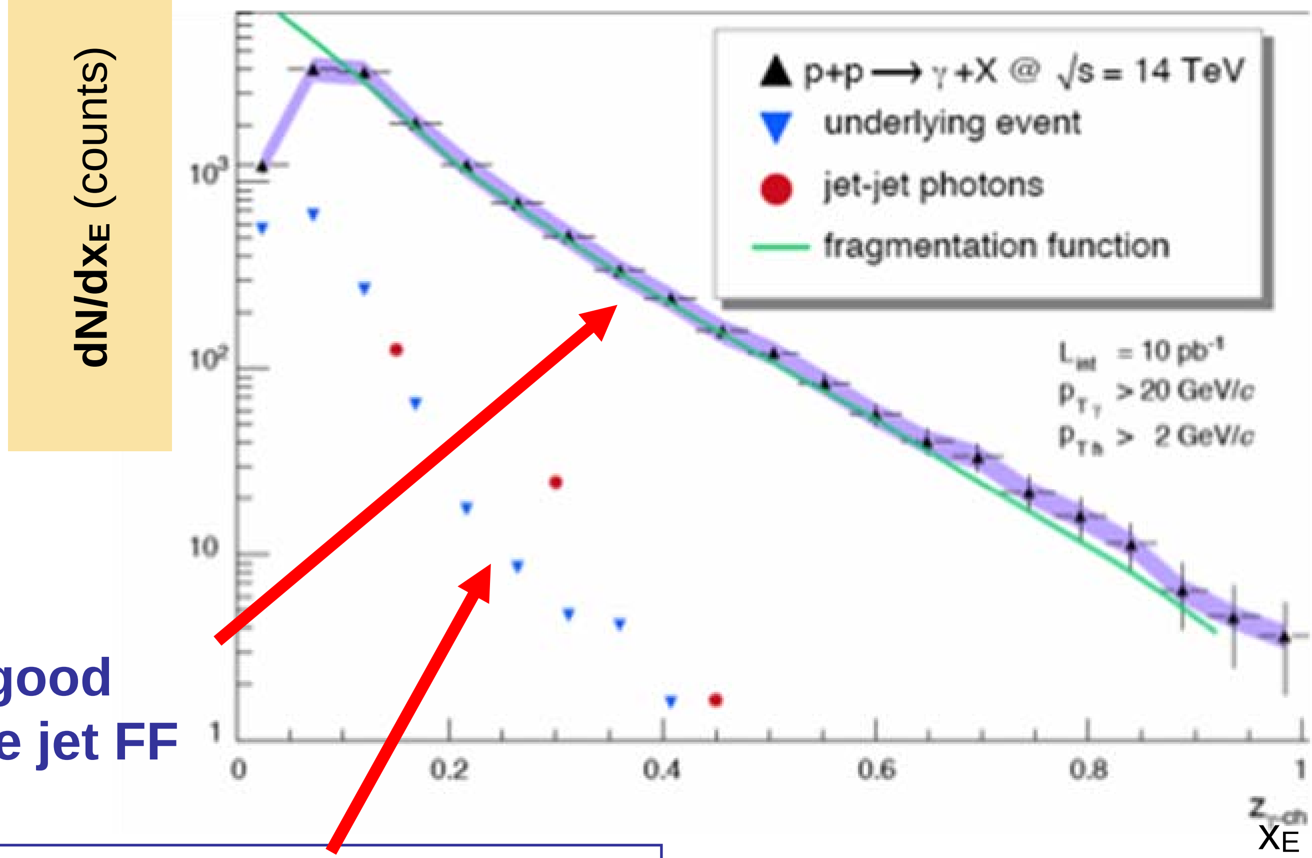
$$\Sigma_{cone}\, p_T^{h\pm} < Max(\varepsilon \times E_{cluster},\, p_T^{cluster})$$



Feasibility study of CF in pp at 14TeV with PHOS

Y.X.Mao et al, Euro. Phys. J. C (2008) 57, QM2008 poster





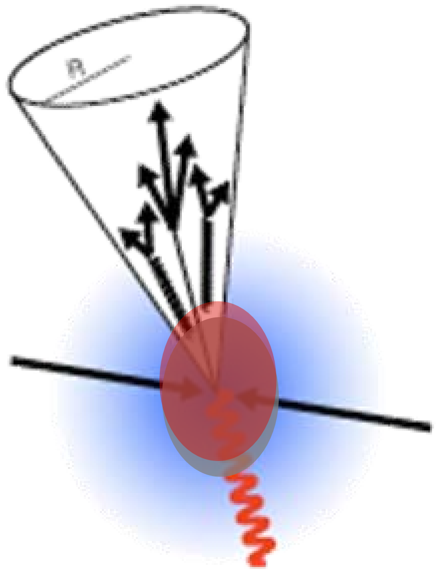
The signal: a good description of the jet FF

The background: quite well under control

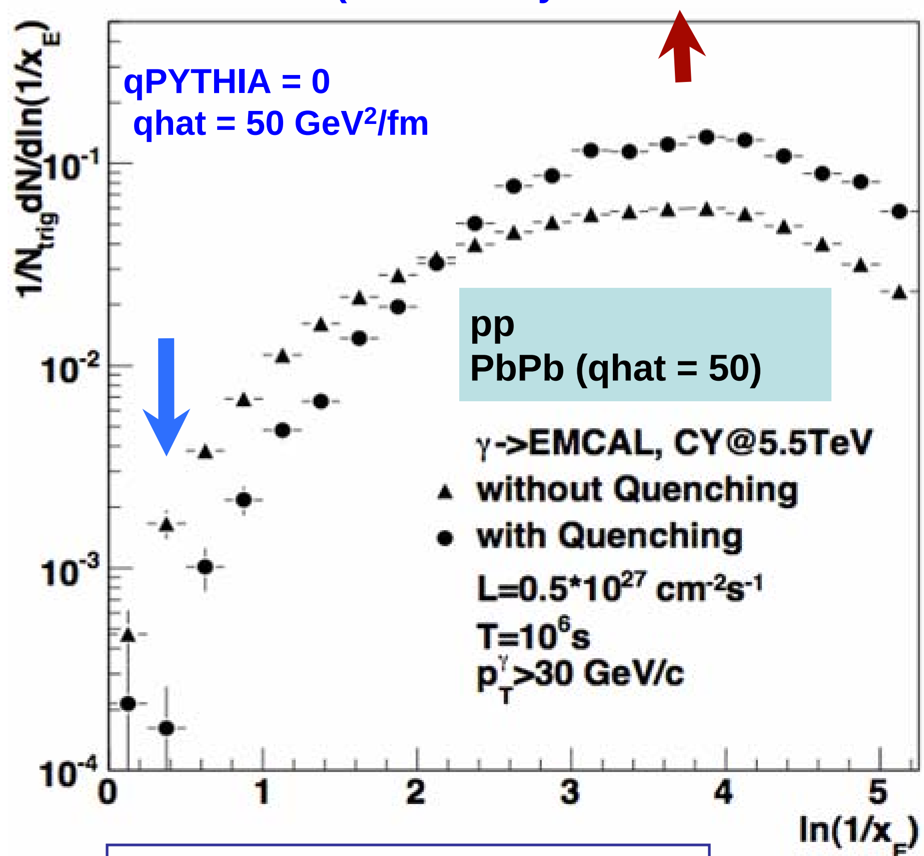
$X_E = -p_T^h \cdot p_T^{\gamma} / |p_T^{\gamma}|^2$

Feasibility study of CF in p-p and Pb-Pb at 5.5 TeV with EMCal

γ – hadron correlation provide a sensitive measurement of medium effects modifying the jet structure



arXiv: 1008.0413v1 (EMCAL Physics Performance Report)



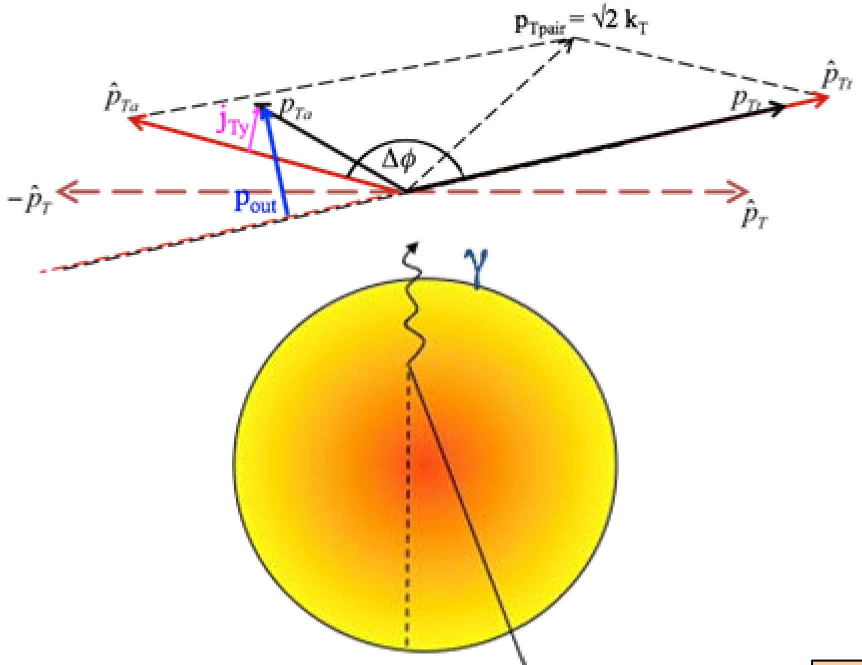
The modification of the signal by the medium is well measurable

↓ jet quenching

↑ gluon radiation

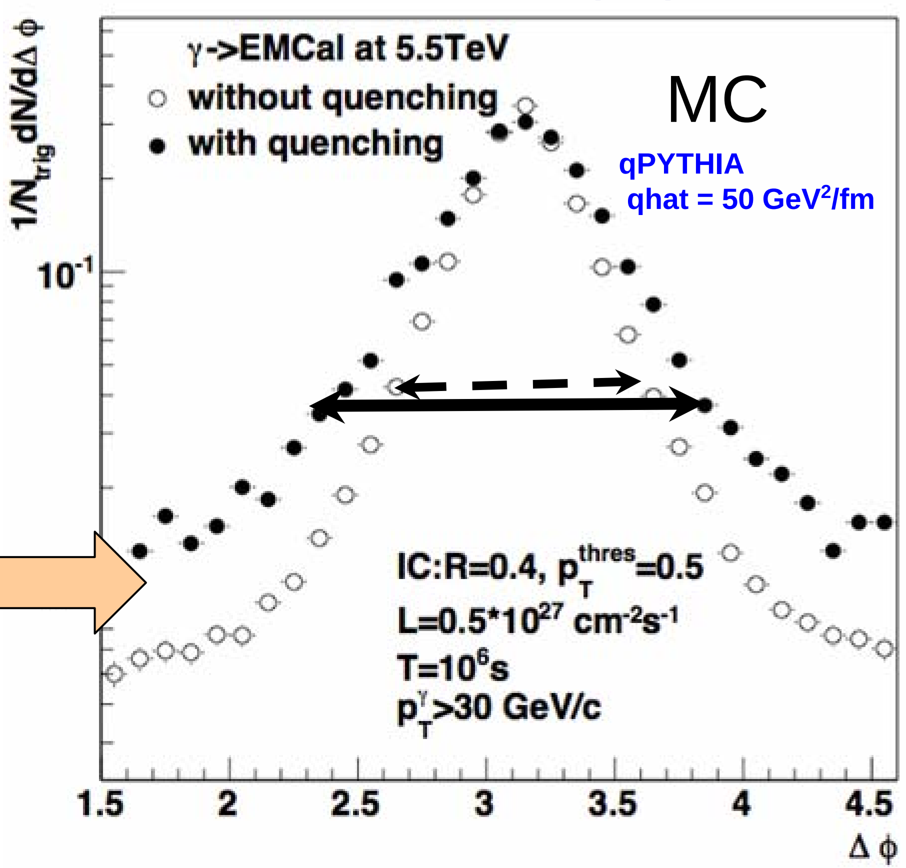
$X_E = -p_T^h \cdot p_T^{\gamma} / |p_T^{\gamma}|^2$

Feasibility study of azimuthal angle distribution w/o and with quenching in PbPb at 5.5 TeV



$$\langle \Delta q_T^2 \rangle = \int dy \hat{q}(y, E)$$

arXiv: 1008.0413v1 (EMCAL Physics Performance Report)

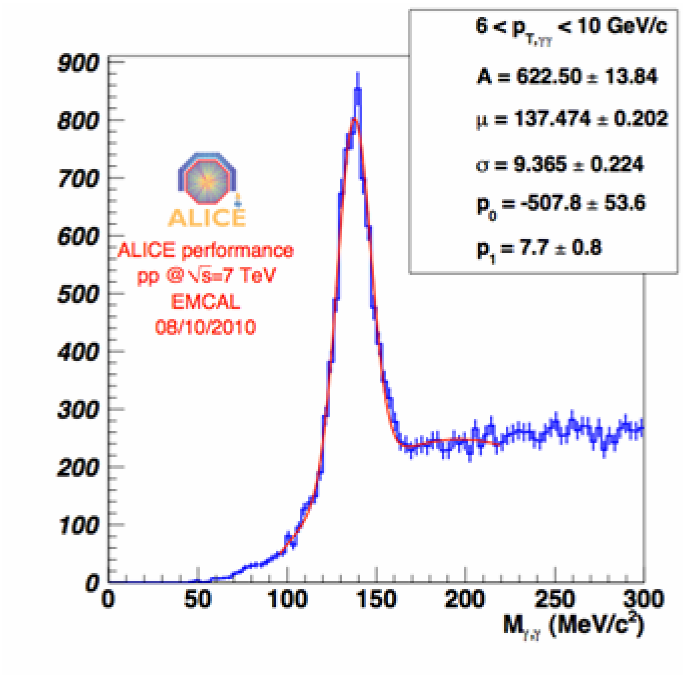


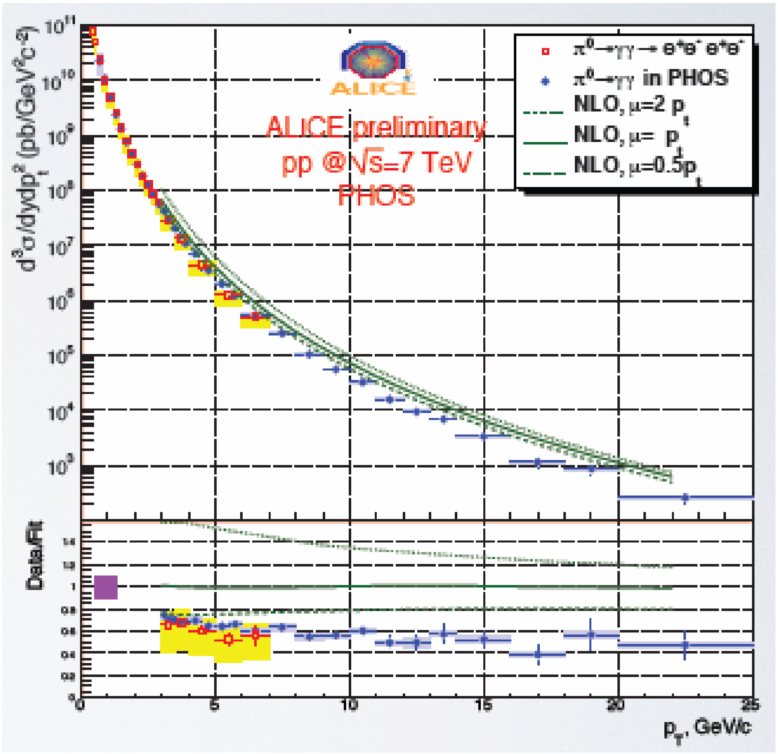
The k_T broaden effect is possible to be observed, a challenge

π^0 identification in pp at 7 TeV

- low energy π 0 produces two separated clusters

➜ Invariant mass analysis



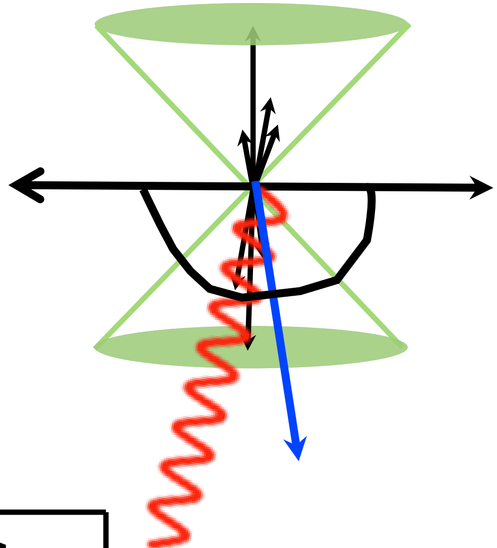


- high energy π_0 (E $_{\pi^\circ}$ ~25 GeV in PHOS and ~8 GeV in EMCAL) the 2 decay photons merge into a single cluster

➜ shower shape analysis

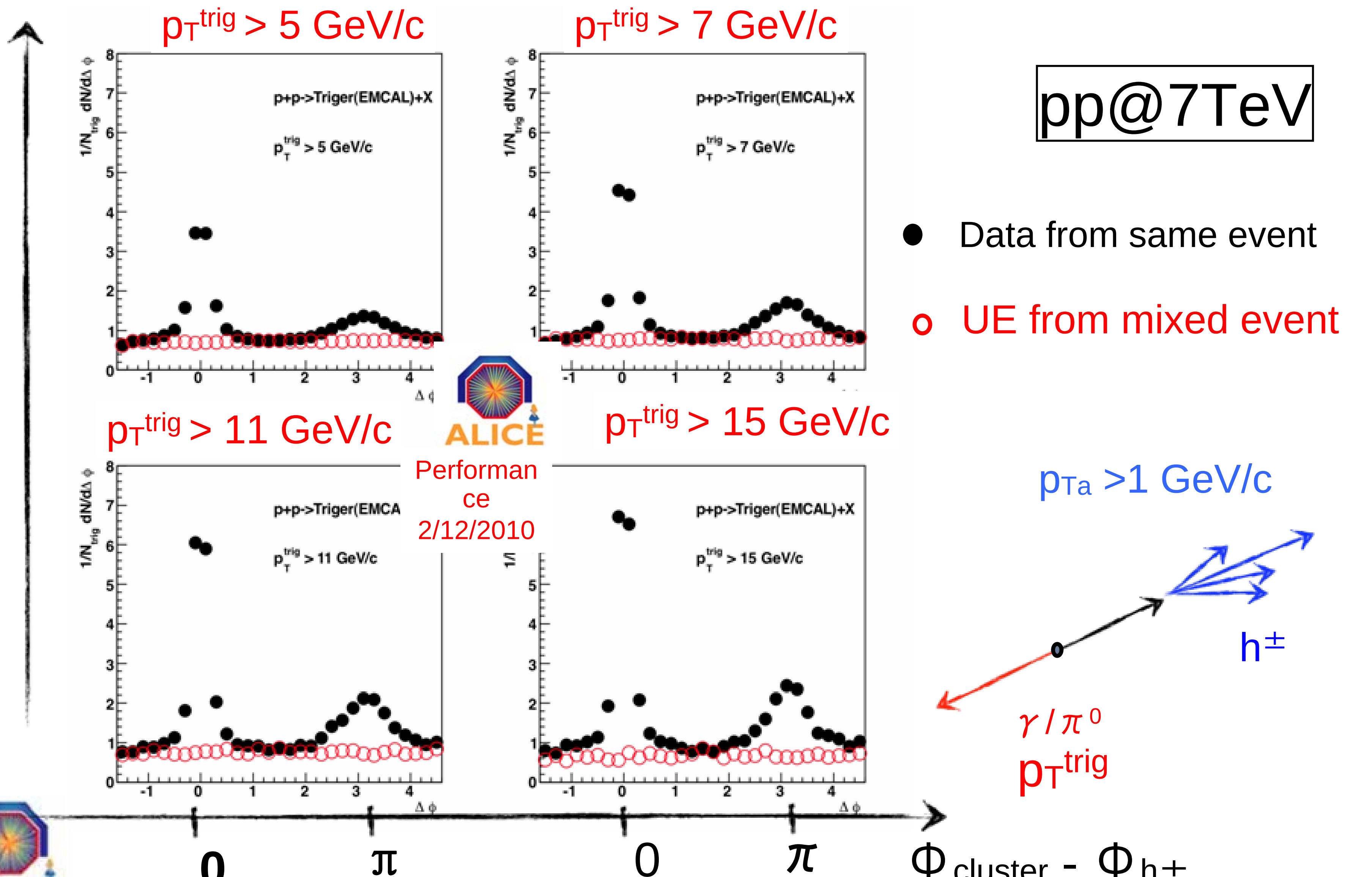
Trigger selection

- Charged trigger (tracks):
  - $p_T(ch) = Max(p_{T\_}track)\,|_{-\pi/2}^{\pi/2}$
- Neutral trigger (cluster, π^0):
  - $E(ne) = Max(E_{cluster}, p_{T,track})|_{-\pi/2}^{\pi/2}$

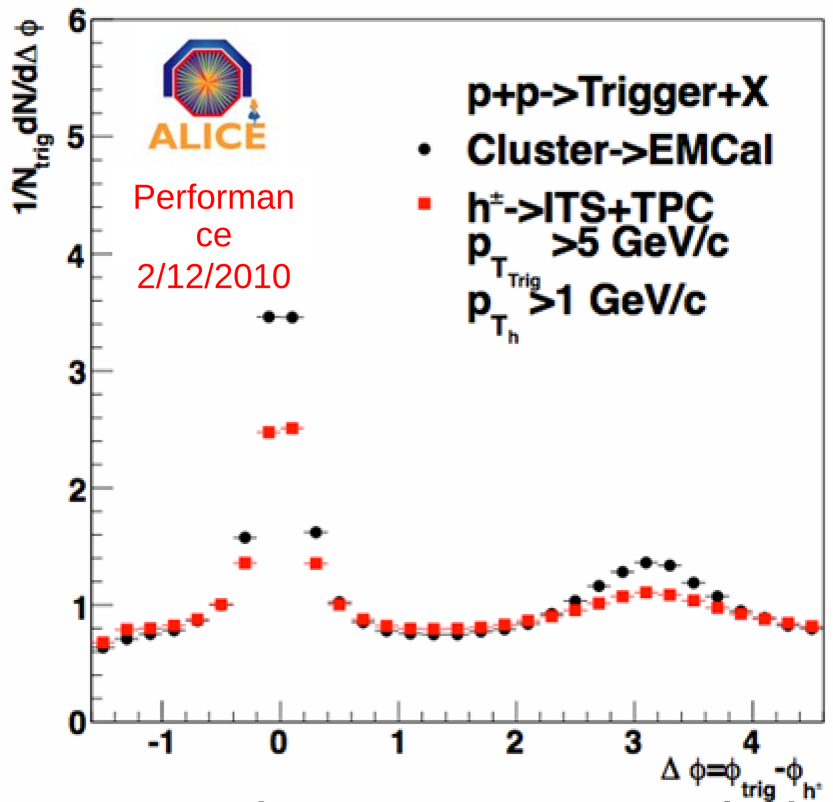


N_{trig} (N_{evt}~160M)	p_T > 5GeV/c	p_T > 7GeV/c	p_T > 15GeV/c
Cluster EMC	25993	10171	1291
Cluster PHOS	2288	623	69
Charged CTS	2,50E+06	1,10E+06	402189
π^0 EMC	254	30	0
π^0 PHOS	48	24	0

Azimuthal correlation



Charged versus cluster trigger



pp@7TeV

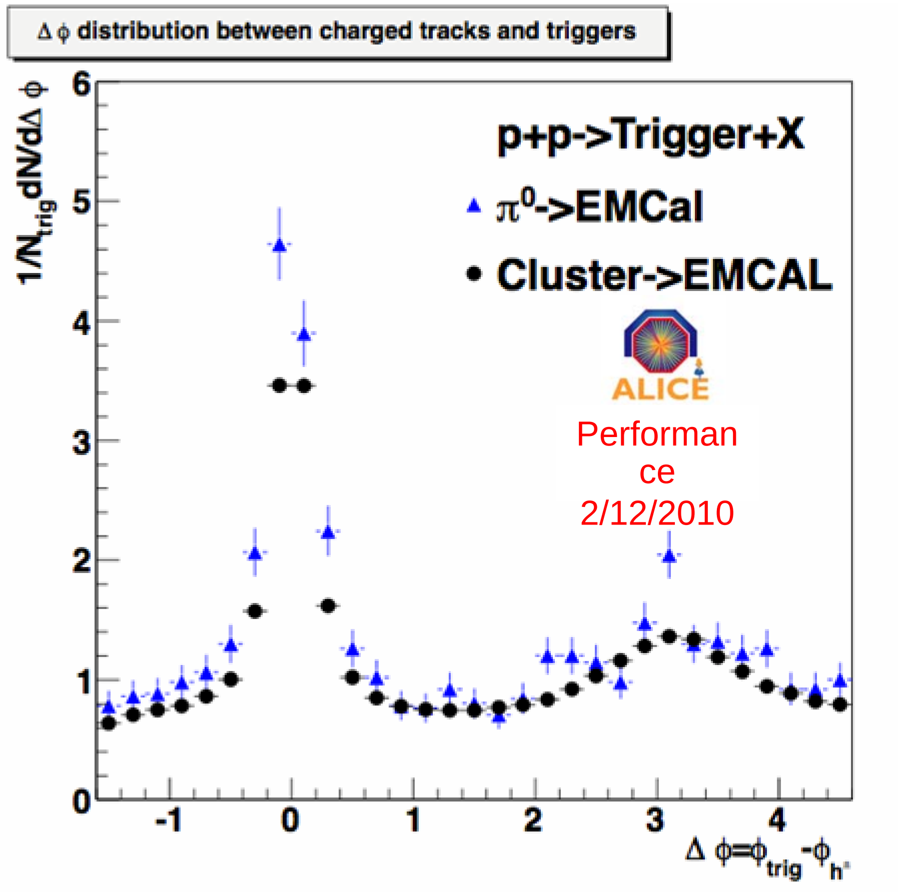
- data trigger cluster in EMCAL
- ■ data trigger charged

$p_T^{trig} > 5$ GeV/c

$p_{Ta} > 1$ GeV/c

- The stronger correlation results from the selection of the leading in EMCAL : the leading among clusters and charged in the same hemisphere
- The charged leading is only the leading among charged

Cluster versus π^0 trigger



pp@7TeV

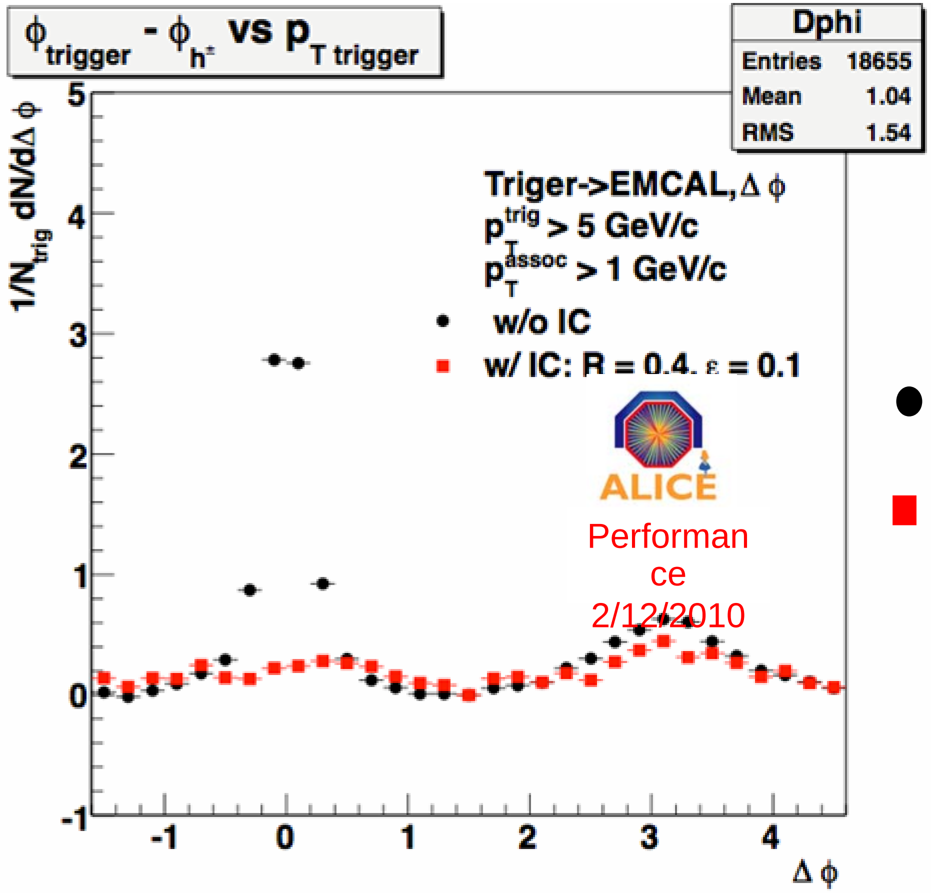
- ●data trigger cluster in EMCAL
- ▲data trigger π^0 in EMCAL

$p_T^{trig} > 5$ GeV/c

$p_{Ta} > 1$ GeV/c

- Within the limited statistics, the cluster trigger is a good approximation of the π^0 trigger

Isolated cluster trigger



pp@7TeV UE subtracted

- ● data trigger cluster in EMCAL
- ■ data isolated trigger cluster in EMCAL

$p_T^{trig} > 5$ GeV/c

$p_{Ta} > 1$ GeV/c

- Isolation suppresses near side correlation by construction
- Away side correlation subsists: direct photon or z~1 fragmentation π^0 candidates

Conclusion

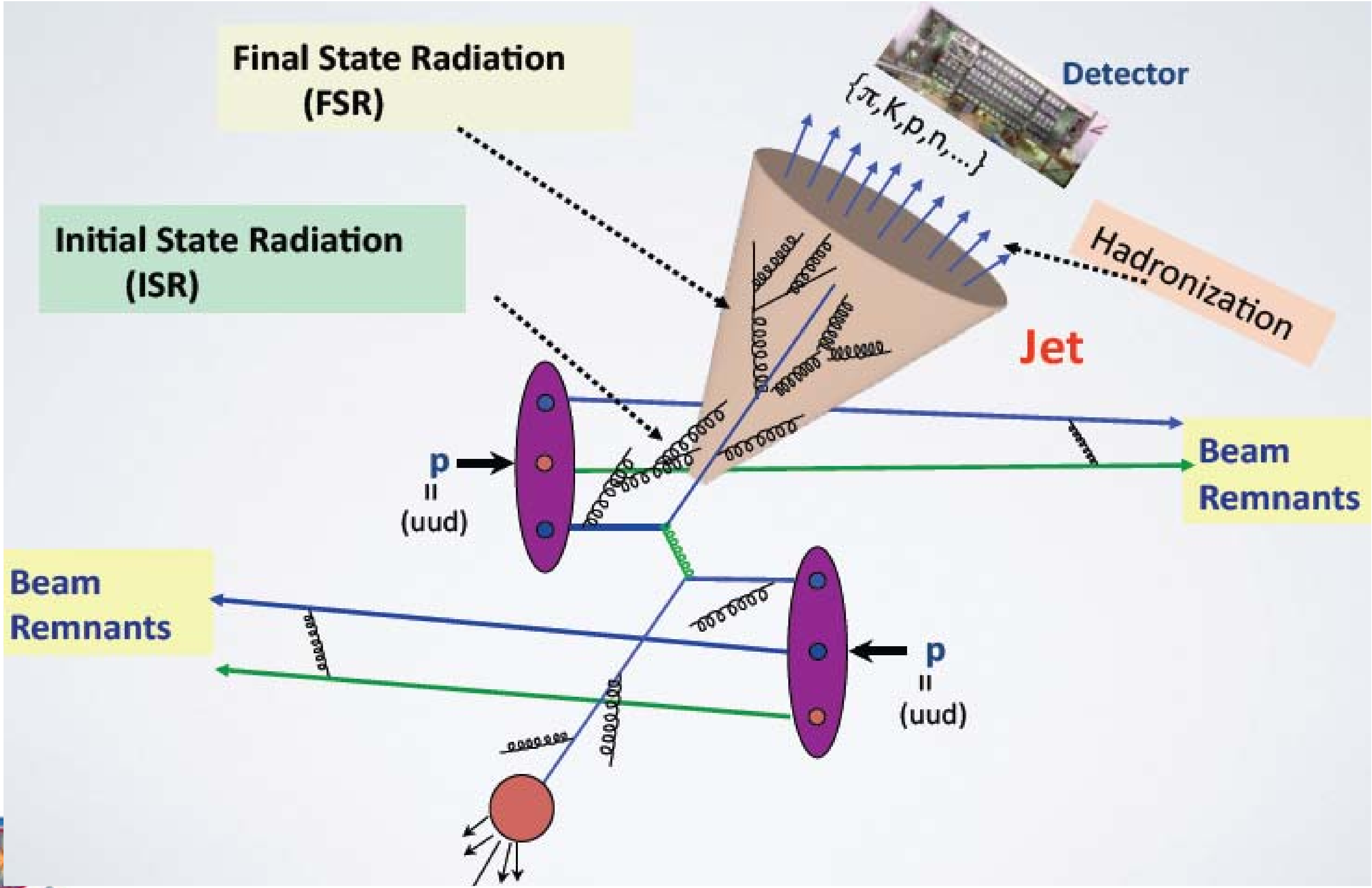
- The studies of the ALICE detector performance on CF have been presented
- Preliminary results on γ (pi0) - hadron correlations of pp data are obtained
- The Pb-Pb data analysis is on going

Thanks

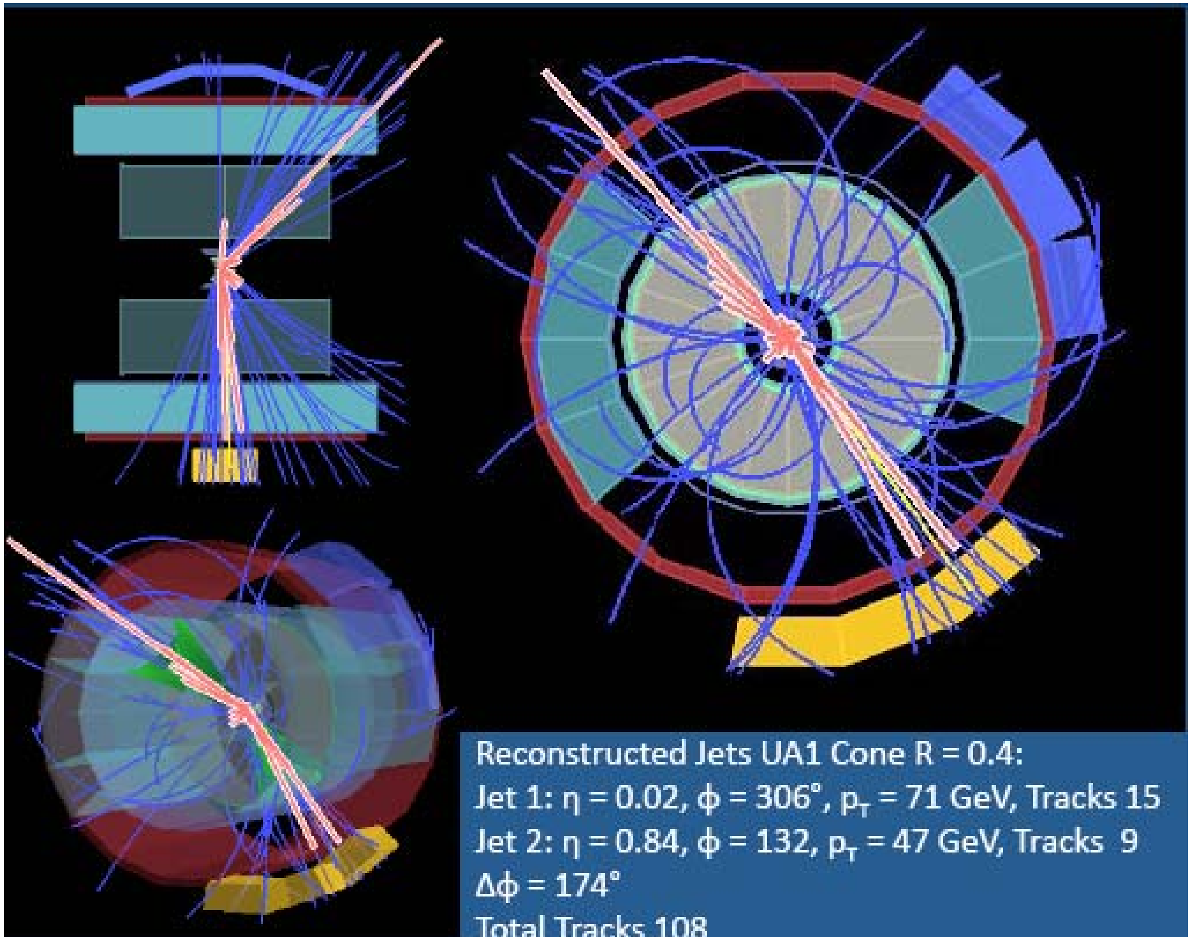
Specially to: Y. Kharlov, Z.-B. Yin, C. Klein-Bosing M. Estienne, A. Morsch and ALICE/PWG4, PHOS and EMCal teams

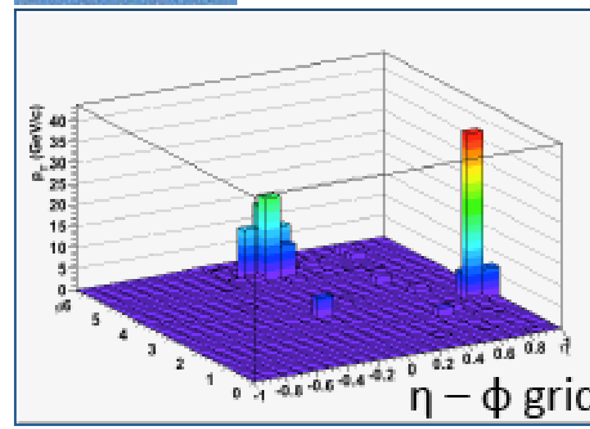
Back up

Jets: QGP hard probe



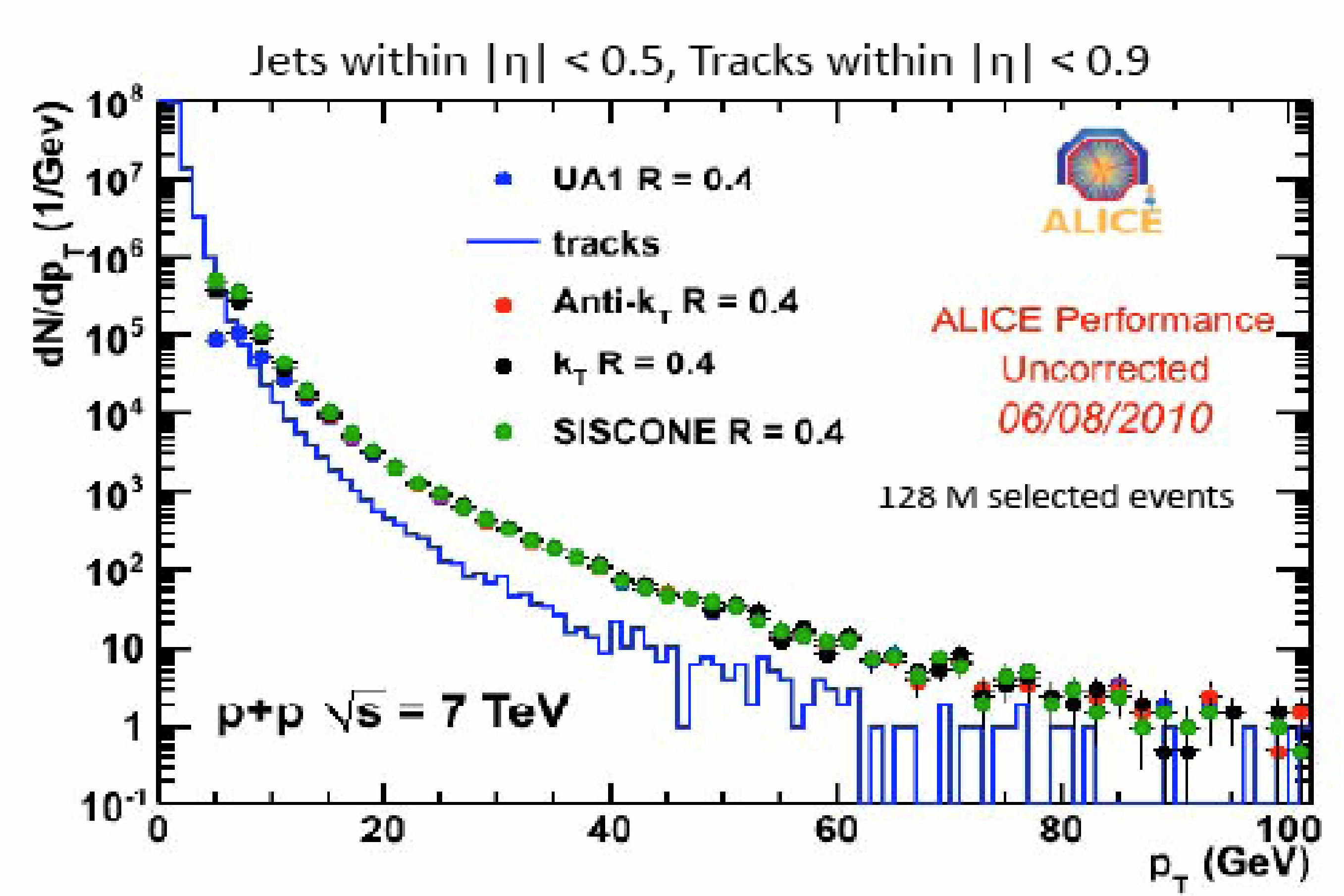
Di-jets in ALICE from p-p at 7 TeV





Christian Klein-Bosing, WISH 2010

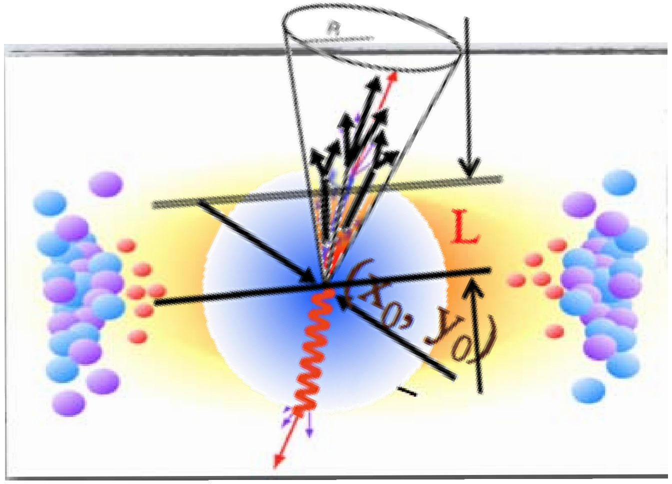
Raw minimum bias Jet spectrum in pp at 7 TeV

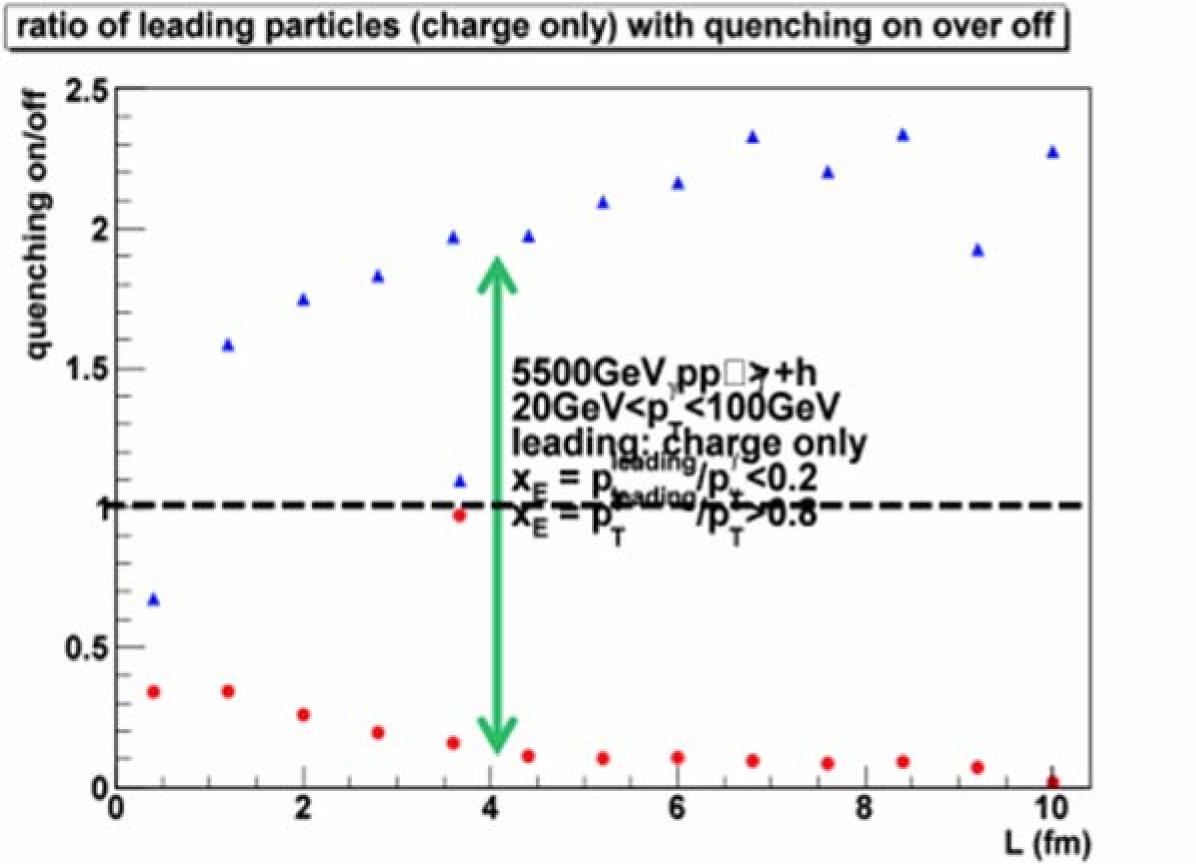


Jet spectrum with charged particles safely reconstructed to 70 GeV

Christian Klein-Bosing, WISH 2010

Tomography with leading particles in medium



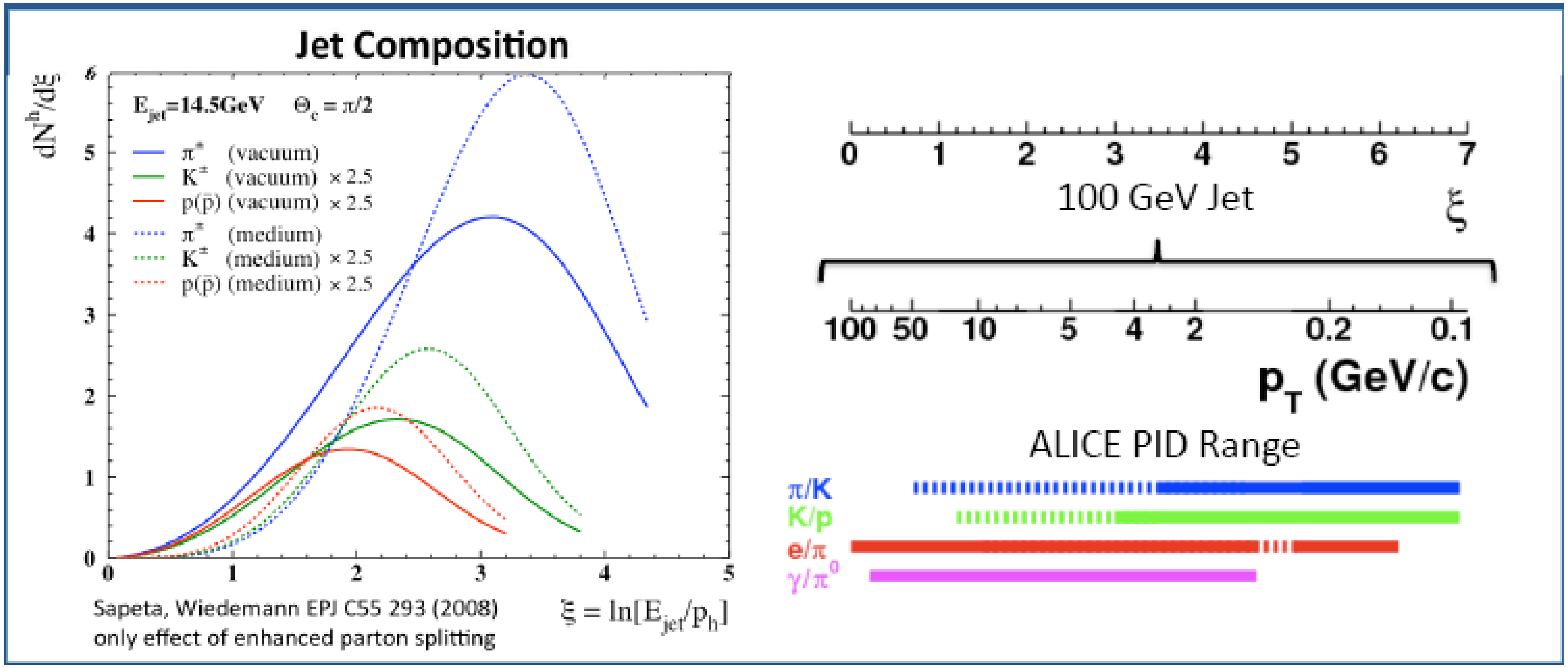


- XE < 0.2 volume emission shows gluon radiation increasing with L

- XE > 0.8 surface emission shows jet quenching increasing with L

Jet PID composition

Composition can be affected by recombination, and color flow of the parton shower

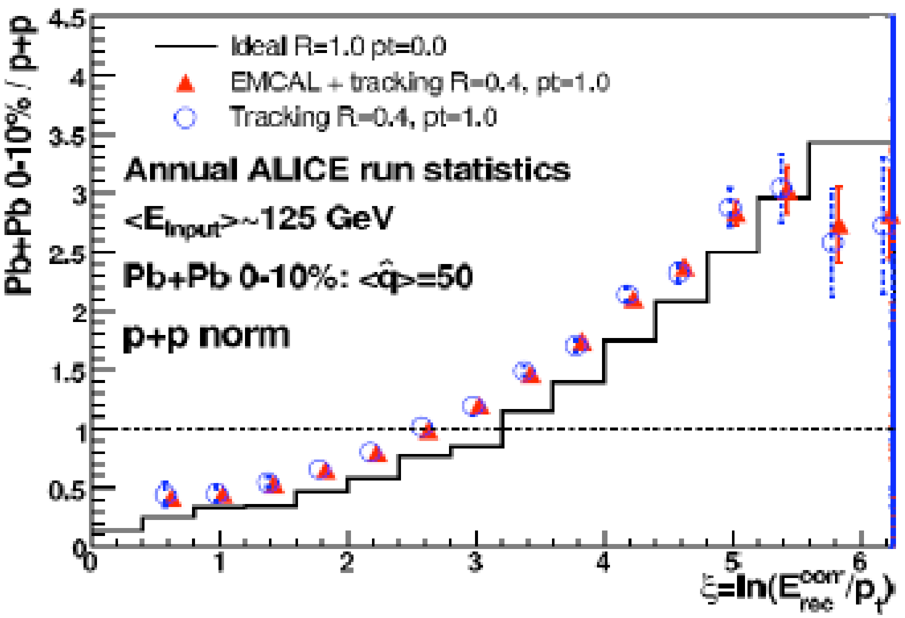


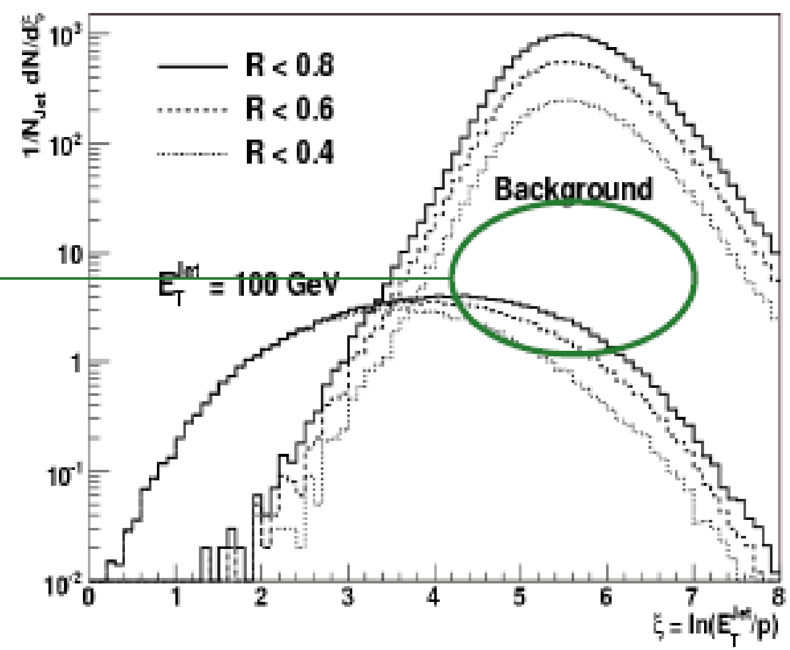
Christian Klein-Bosing at Pragure 08-2010

R_{AA} (ξ) and soft underlying events

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

In A-A, the high multiplicity soft backgrounds hide the medium induced soft jet-particles enhancement

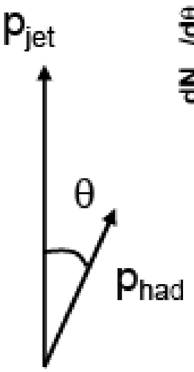


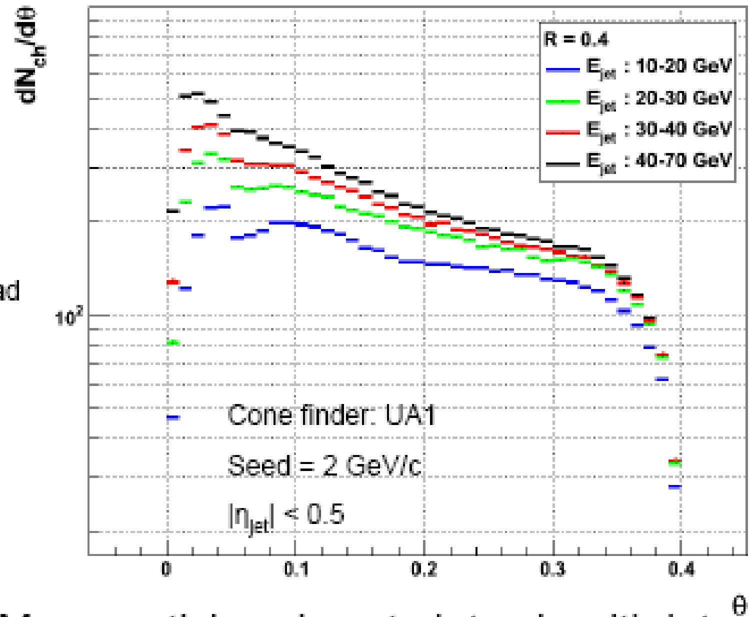


Christian Klein-Boring at Pragure 08 2010

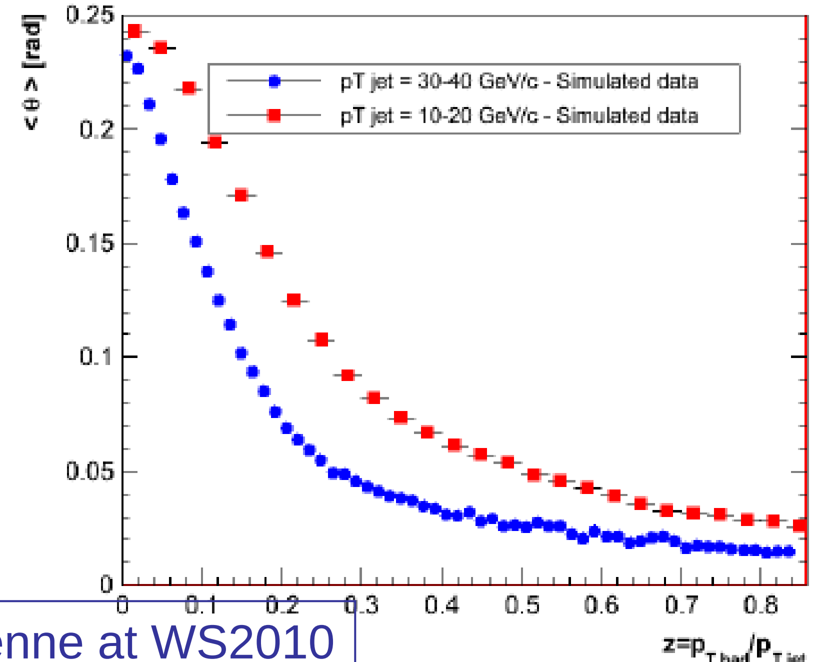
θ distribution of charged particles in cones

θ = 3D angle between jet axis and particle momentum.





PYTHIA full simulation: p+p collisions at 10 TeV



Magali Estienne at WS2010

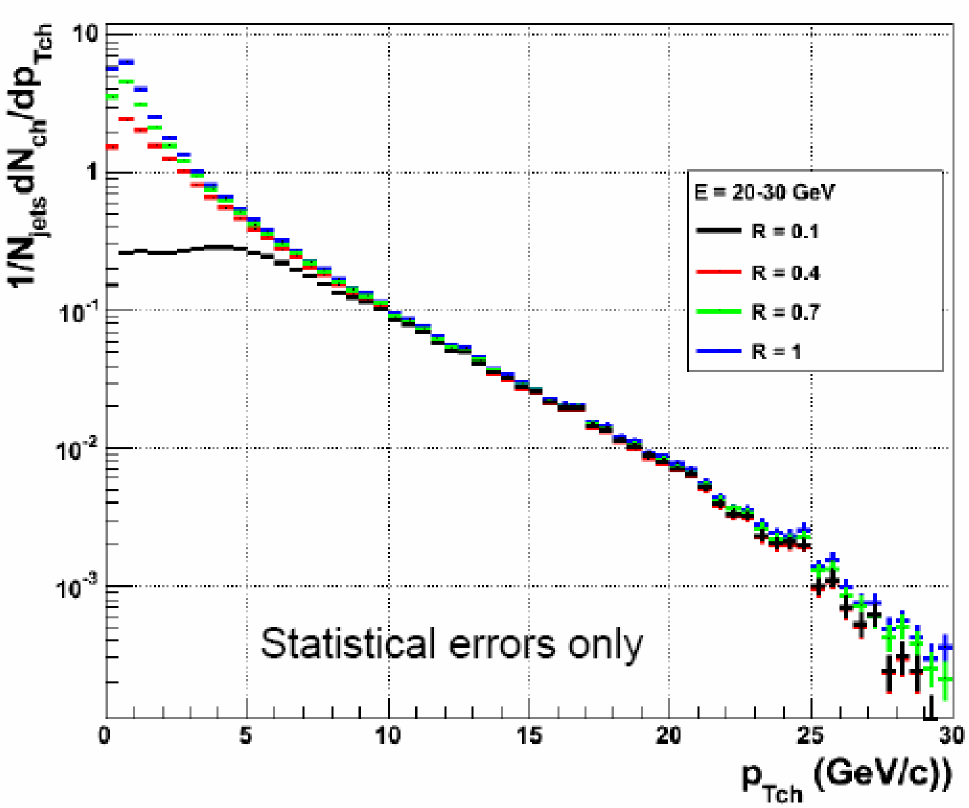
- More particles close to jet axis with jet energy increasing.
- Softer emission at larger angles.
- With jet energy increasing, more particles at small angles over the full p_T range ?

Caveat: no background subtraction and track efficiency correction

- <θ> for high momentum jets below <θ> of low momentum jets.
- Support the idea of collimation !

Expected p_T distribution of charged particles in jets

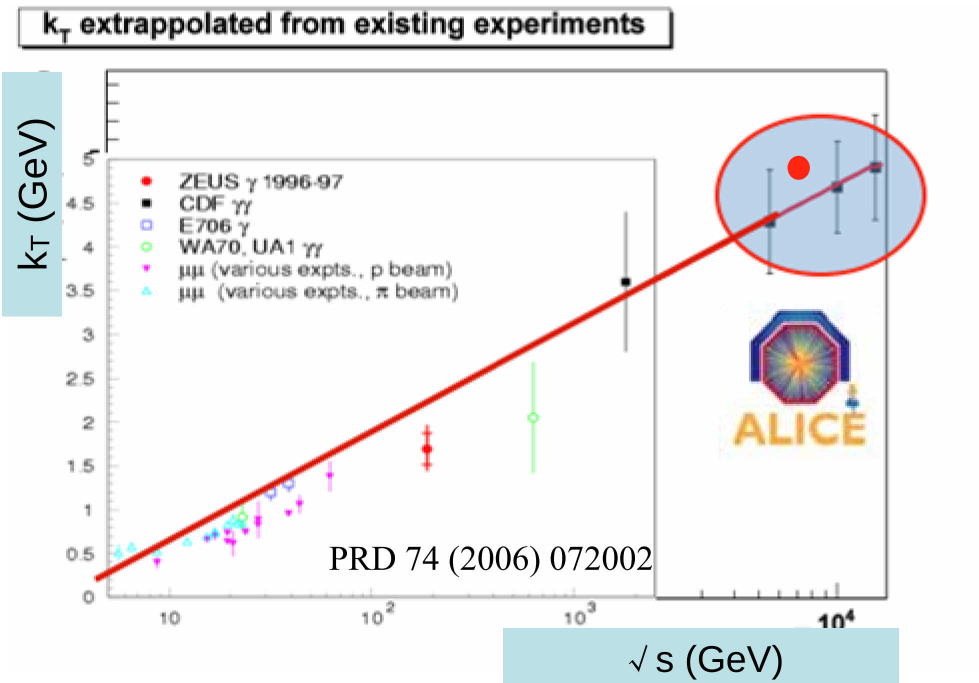
With Phythia full simulation : p+p collisions at 10 TeV



- **Leading particles are recovered at all angles and they are near the jet axis**
- **More low pt particles are recovered at large angles**
- **Low pt particles emitted at small angles**
- **more backgrounds enter the cone**

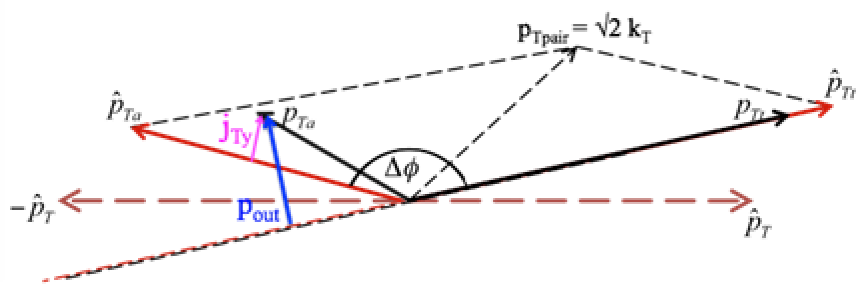
Magali Estienne at WS2010

k_T estimation at LHC



First k_T measurement by di-hadron correlation in ALICE:

$$\sqrt{\langle k_T^2 \rangle} = 4.9 \pm 0.1 \text{ GeV/c}$$



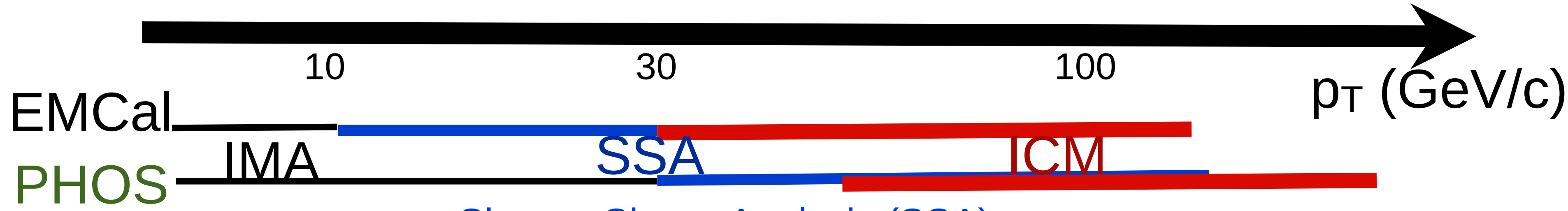
extrapolation to √s=0.9 TeV: $\langle k_T \rangle = 3.2 \pm 0.4$ GeV/c, $\langle p_T \rangle_{pair} \approx 4.5 \pm 0.5$ GeV/c

extrapolation to √s=7 TeV: $\langle k_T \rangle = 4.5 \pm 0.5$ GeV/c, $\langle p_T \rangle_{pair} \approx 6.3 \pm 0.7$ GeV/c

extrapolation to √s=10 TeV: $\langle k_T \rangle = 4.7 \pm 0.5$ GeV/c, $\langle p_T \rangle_{pair} \approx 6.6 \pm 0.7$ GeV/c

extrapolation to √s=14 TeV: $\langle k_T \rangle = 4.9 \pm 0.6$ GeV/c, $\langle p_T \rangle_{pair} \approx 6.9 \pm 0.9$ GeV/c

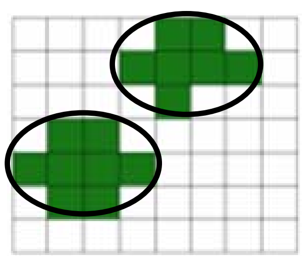
Particle identification in calorimeters

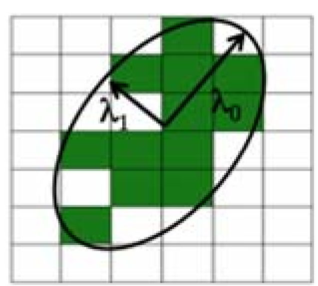


Invariant Mass Analysis (IMA) (γ , π^0, η , ω ...)
=>well separated clusters

Shower Shape Analysis (SSA)
(γ /e, π 0, hadrons, ...)
=>merged clusters not spherical: $\lambda 0$ / $\lambda 1$ =1 ?

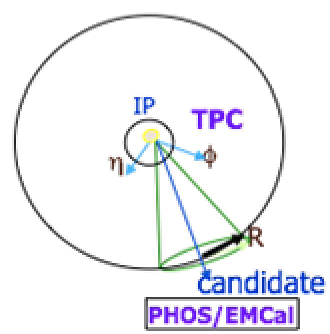
Isolation Cut Method (ICM)
(γ , e, π^0)
=>two clusters from π^0 are merged

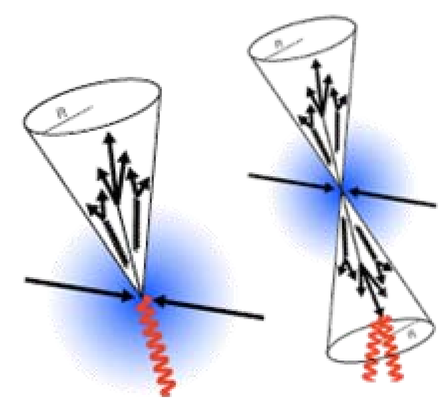




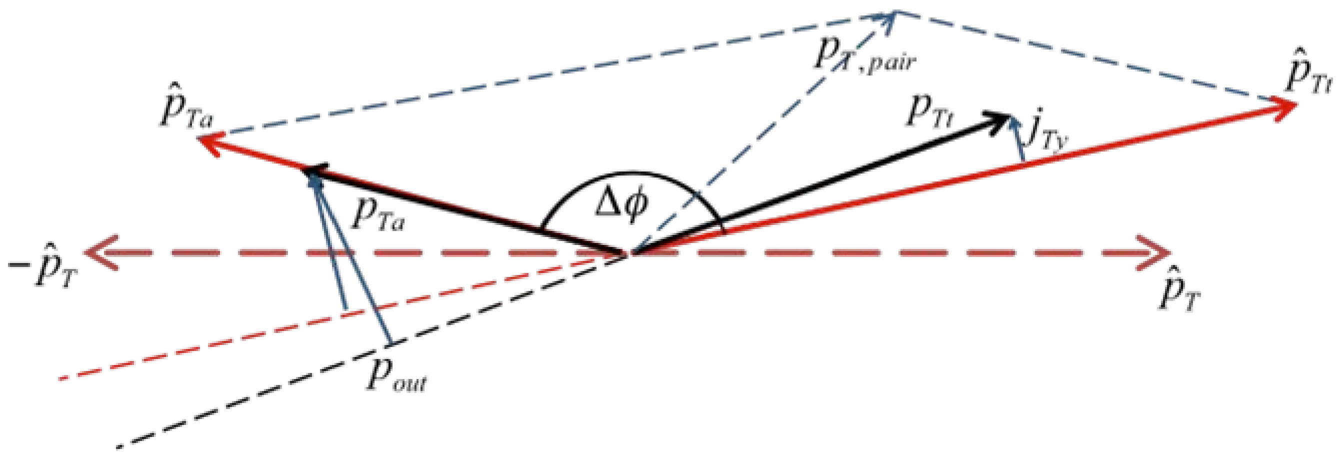
Isolated if:

- no particle in cone with $p_T > p_T^{thres}$
- p_T sum in cone, $\Sigma p_T < \Sigma p_T^{thres}$





k_T definition



- Two partons (with hat) back to back in CM
- At an angle in lab frame due to **Magali Estienne** k_T
- Fragment into final hadrons (no hat)
- $\langle k_T \rangle = \langle p_T \rangle_{pair} / \ 2$