The ALICE Electromagnetic Calorimeter (EMCAL): its status and physics capabilities

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ALICE Collaboration

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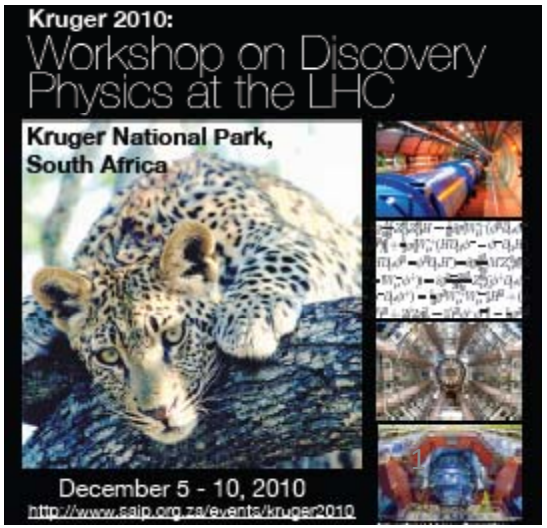
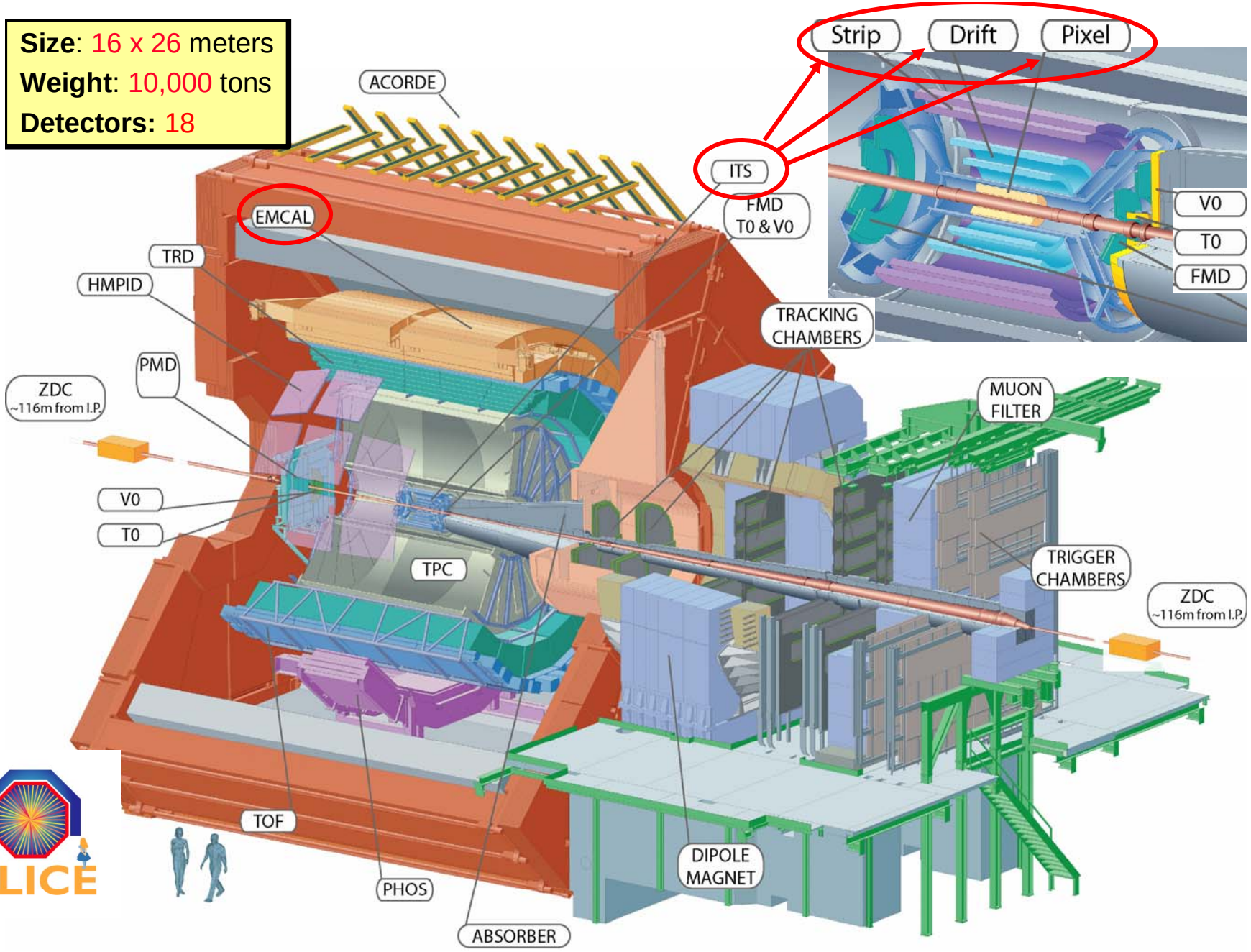


Workshop on Discovery Physics at the LHC
Kruger National Park, South Africa, December 5-10, 2010

Size: 16 x 26 meters
Weight: 10,000 tons
Detectors: 18

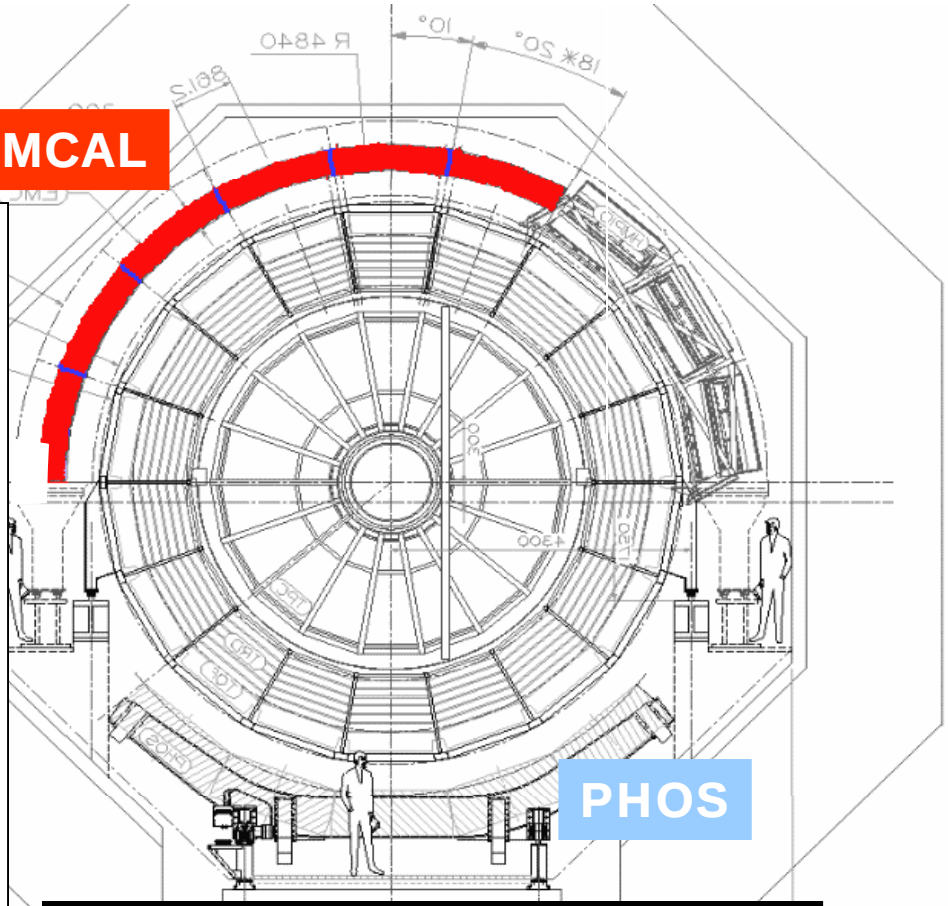


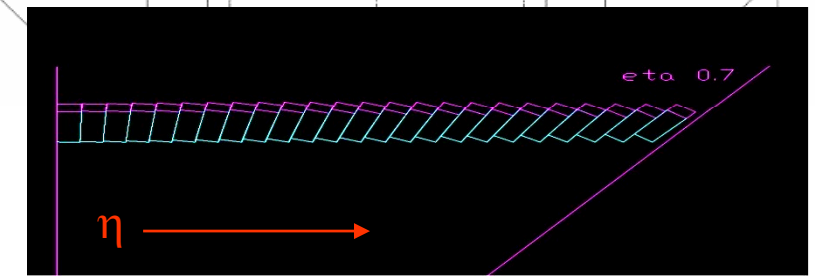
1. EMCAL: Location in ALICE and Characteristics

To do **jet** (quenching) **physics**:
- large coverage
- good granularity

EMCAL
— located **inside** the L3 solenoidal magnet
— **sampling** calorimeter: 20.1 X_0
— **sandwich**, 1.44 mm Pb/1.76 mm Scint
final geometry when installation completed
- $-0.7 < \eta < 0.7$
- $\Delta\Phi = 100°$
- small Φ gaps (~ 3 cm) aligned w/ TPC gaps

— sampling fraction 1/10.5
— density 5.86 g/cm^3
— R_M = 3.20 cm; X_0 = 12.3 mm
— Scintillator = Polystyrene (BASF143E + 1.5% pTP + 0.04% POPOP)
—10 super-modules in total
— granularity: **11520 towers**
tower size: $\Delta\eta \times \Delta\phi$ ~ 0.0143×0.0143
— σ_E/E ~ 10%
— installed back to back with PHOS





Module Parts

Containment: 88 parts

1) Back (holes: 144 thru for fibers + springs + mech. support), 1
2) Compression (holes: 144 thru for fibers + springs), 1
3) Front Plate (holes: 144 thru for fibers + springs + mech. support), 1
4) 5) Plungers (10)
6) Belleville washers (75)

Tensioning and Isolation: 40 parts

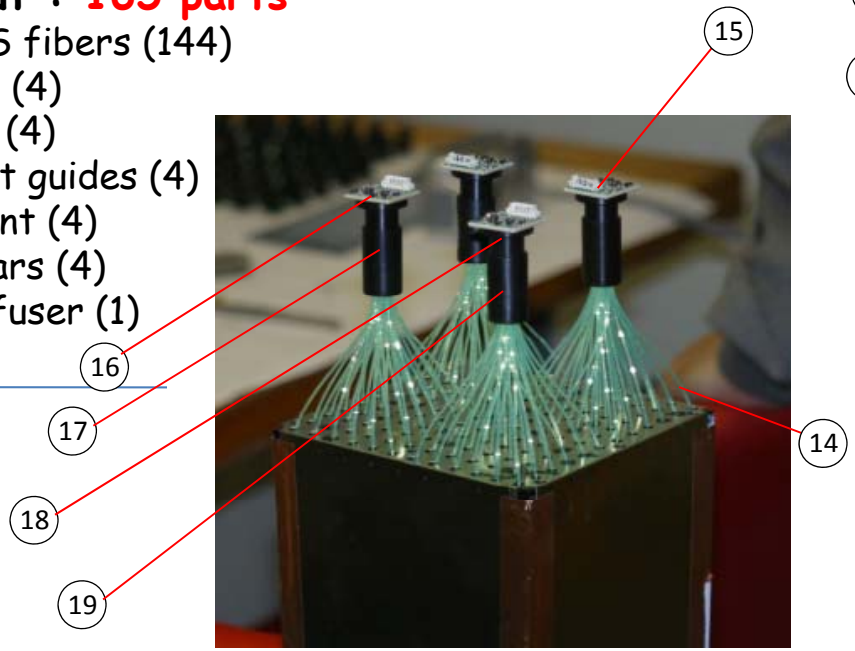
7) Stainless steel straps (4)
8) Screws (24)
9) Flanges (8)
10) Light tight stickers (4)

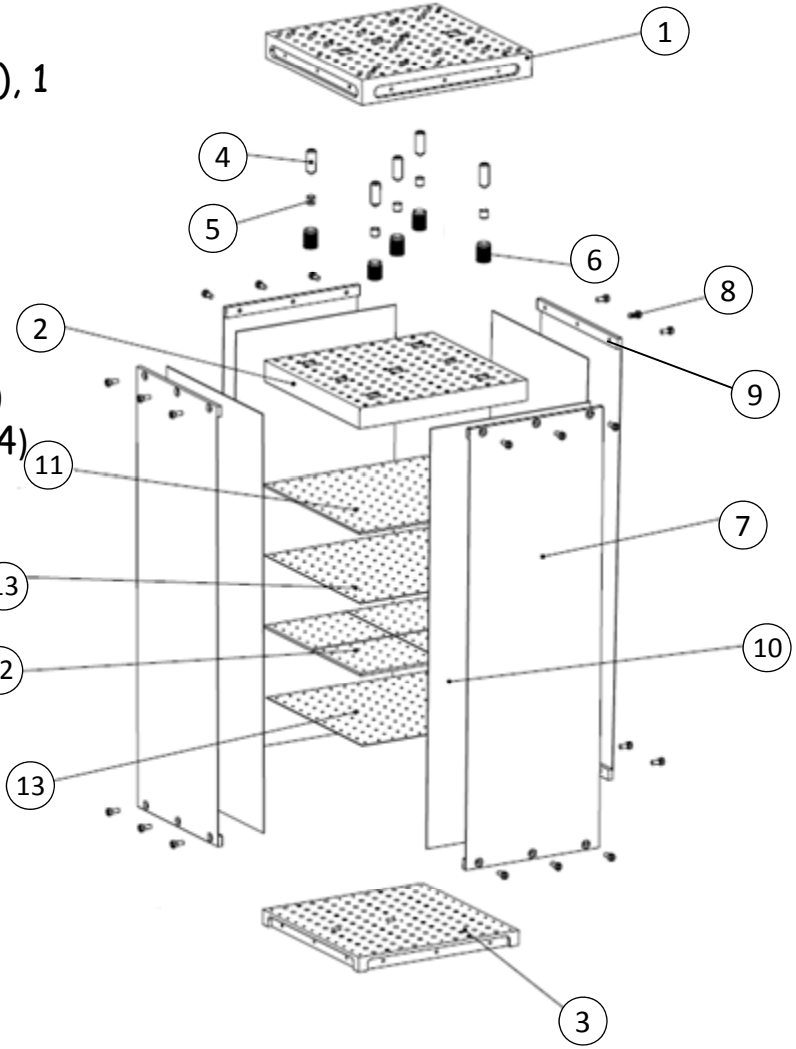
Sandwich: 538 parts

11) Lead tiles (76)
12) Scintillator tiles (308)
13) Bond paper sheets (154)

Readout : 165 parts

14) WLS fibers (144)
15) APD (4)
16) CSP (4)
17) Light guides (4)
18) Mount (4)
19) Collars (4)
20) Diffuser (1)



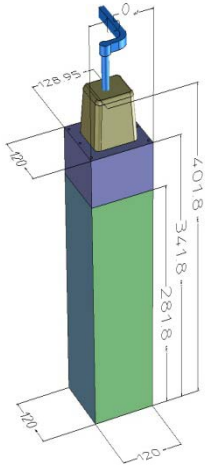


TOTAL components: 20

TOTAL parts: 831

Plus cabling, GMS and mech. supports

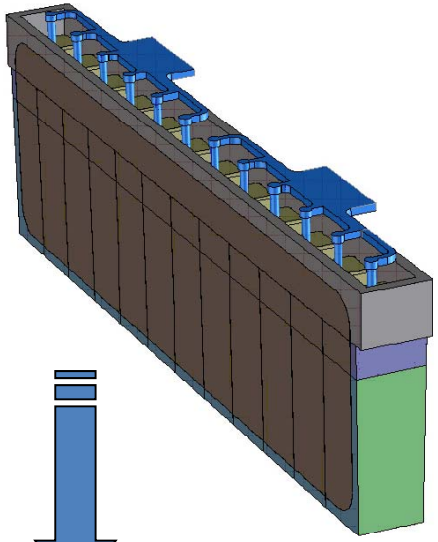
The EMCAL Modular Structure



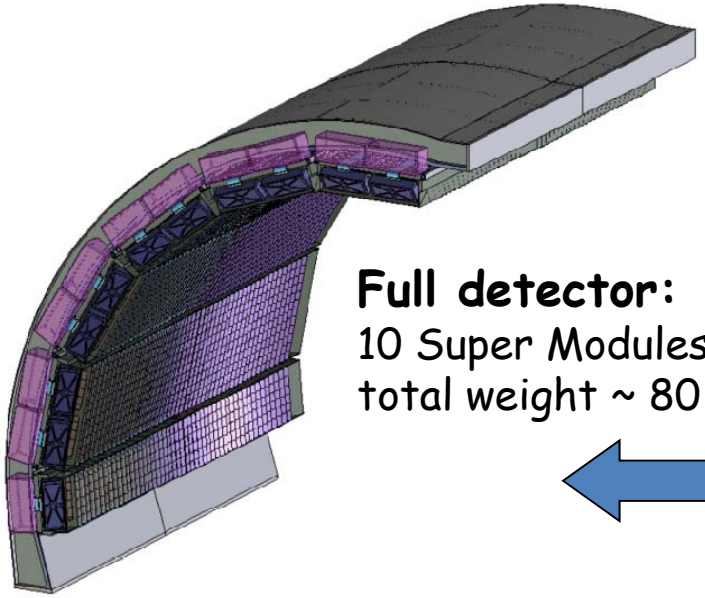
One Module

12 modules (4 for Prototypes)

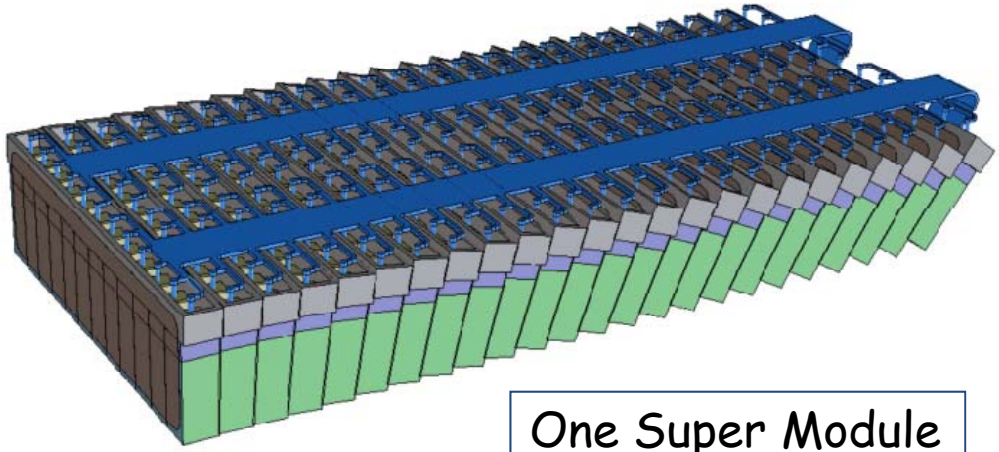
One FULL Strip Module



- 1 Module = 26.7 kg
- 1 Strip Module = 324 kg
- 1 Super-Module =288 modules ~ 7.7 tons



Full detector:
10 Super Modules,
total weight ~ 80 tons

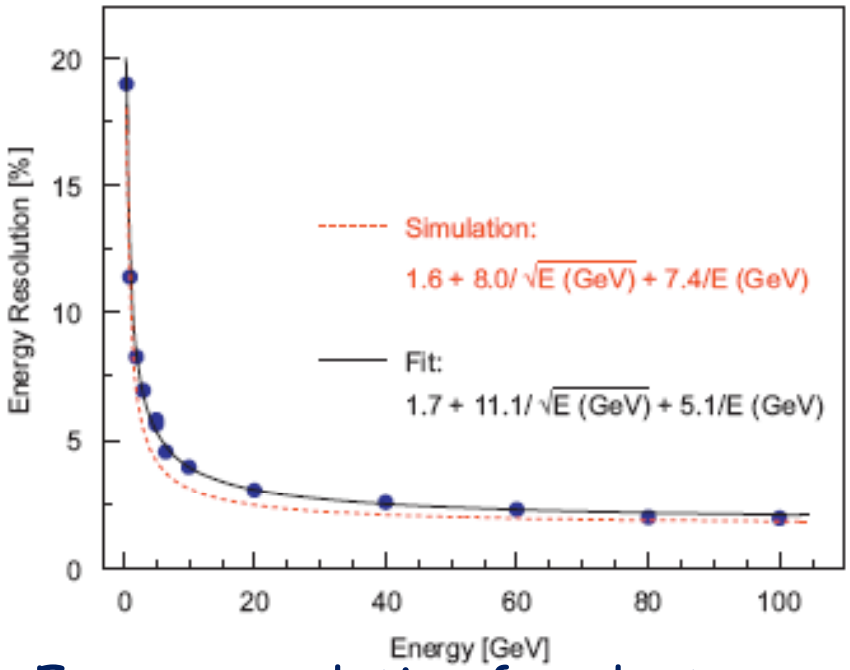


One Super Module

2. Results from test beams

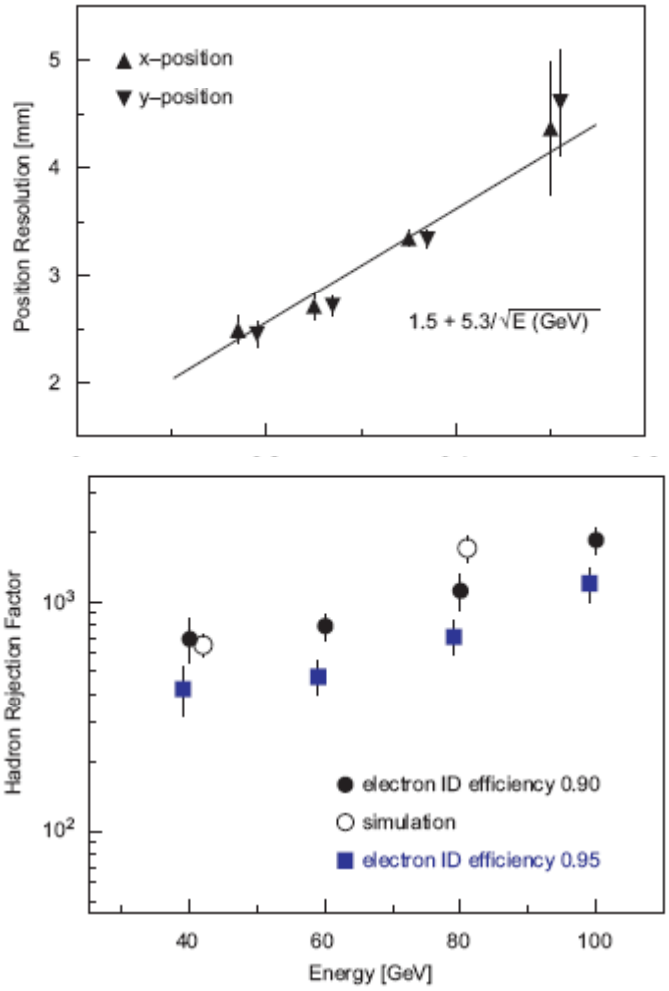
EMCAL prototypes (4 modules x 4 strips) under test beams:

FNAL, November 2005 & SPS + PS, September – October 2007



Energy resolution for electrons as a function of the incident beam momentum:

$$\sigma(E)/E = 1.7 + 11/\sqrt{E} + 5.1/E$$



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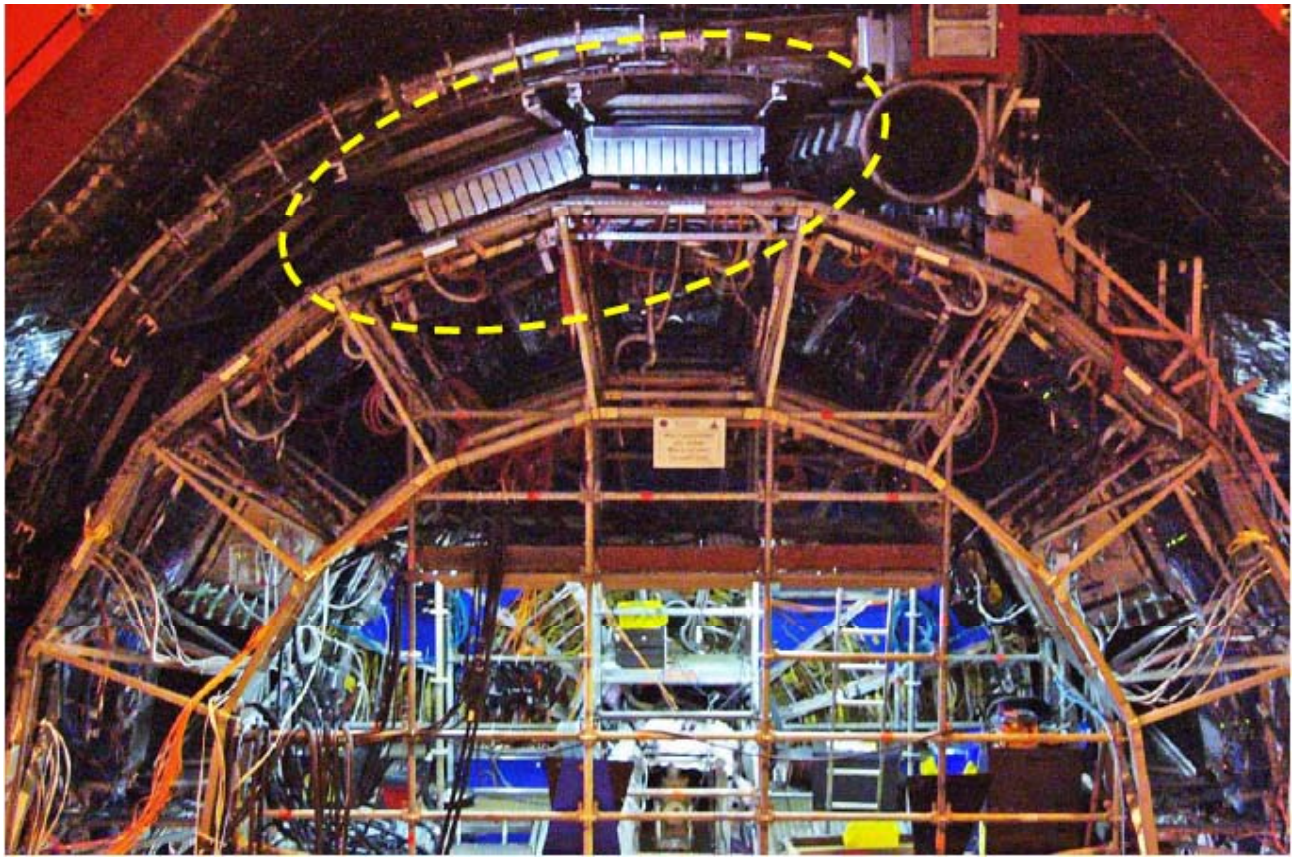
3. EMCAL Status

Installion of 2 SMs in ALICE in March 2009 and 2 SMs in July 2009

3. EMCAL Status

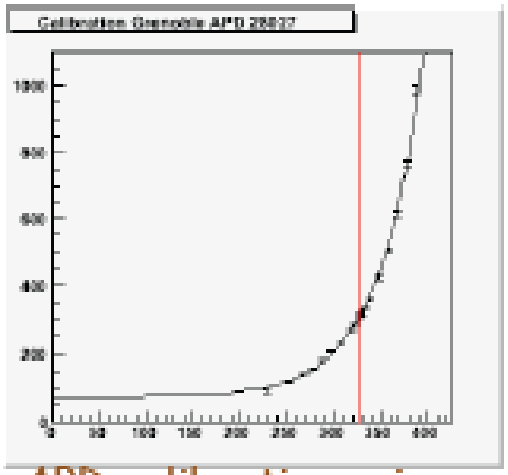


EMCAL Collaboration
= USA + Europe
(France and Italy)

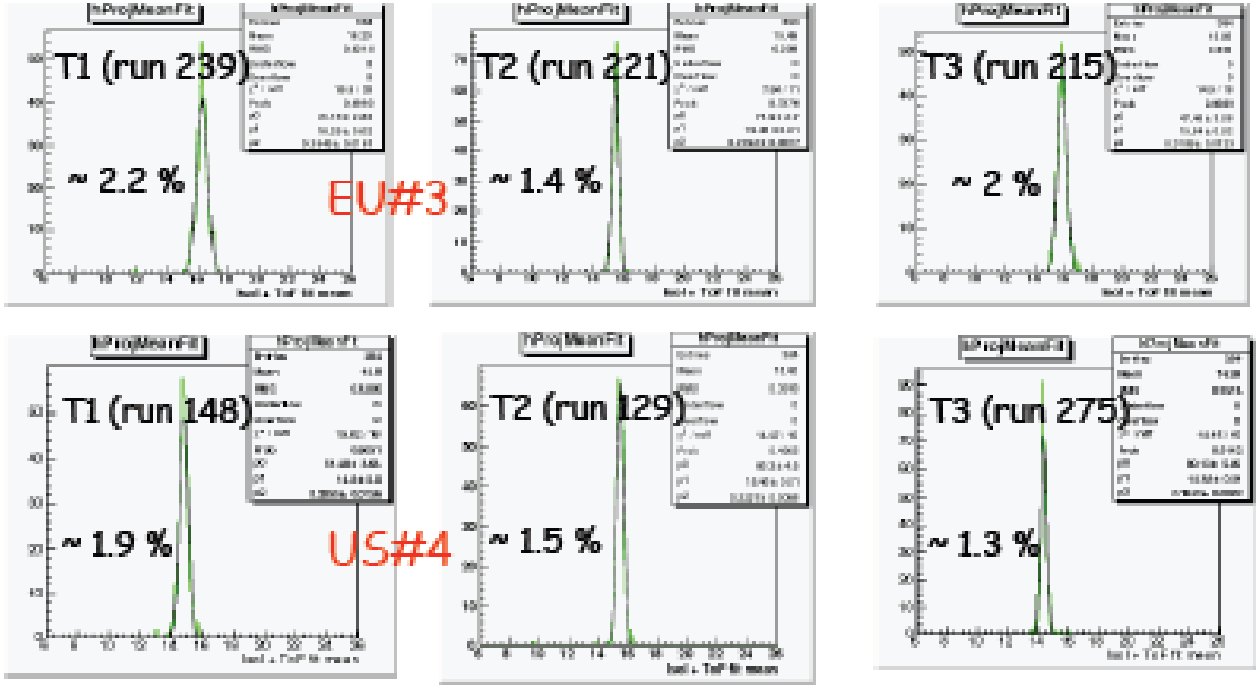
4 SMs installed in ALICE (2 in March and 2 in July 2009), operational and taking data

installed coverage: $\Delta\eta = 1.4$; $\Delta\phi = 40°$

3. EMCAL Status



APD calibration using LED running

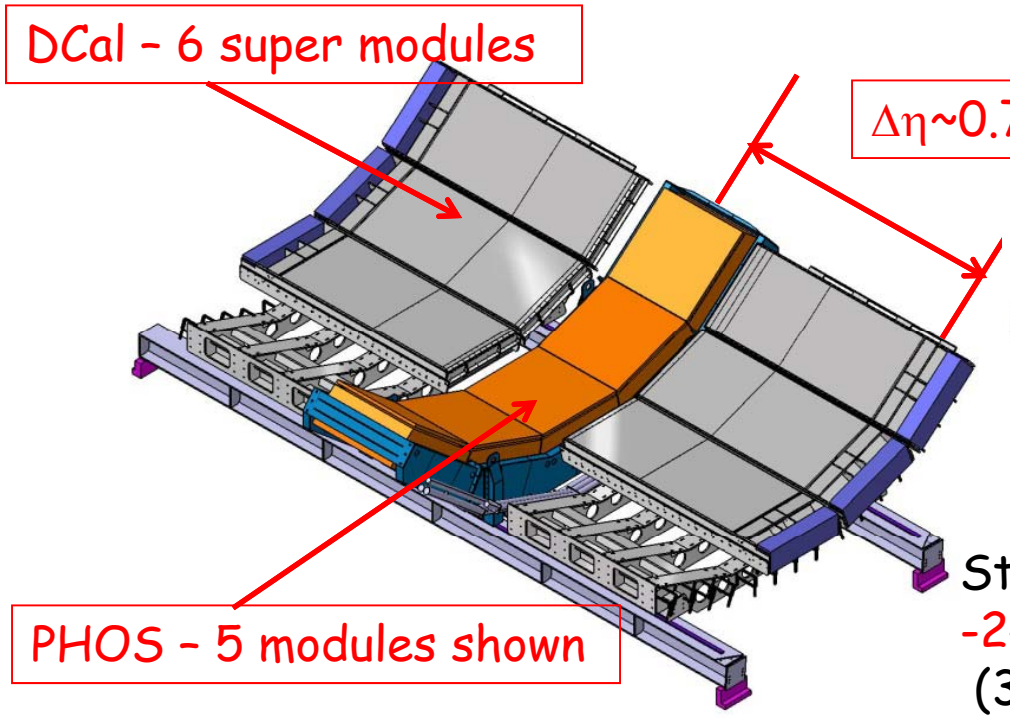


- Assembly of EMCAL completed in summer 2010
- 5 SMs ready and calibrated
- 1 SM under testing/calibration, to be completed in next days
- Cosmic calibration will be completed soon

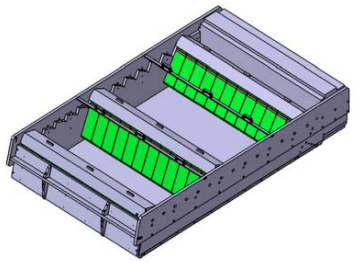
6 SMs will be installed in ALICE in January, full EMCAL during 2011 data taking

4. EMCAL extension: DCAL

Despite EMCal being the last ALICE detector proposed, approved assembled, and (still partially) installed ....the first upgrade approved (by November 2009) by the ALICE collaboration is ..... an extension of EMCal
→ DCal back to back with EMCal for jet-jet and γ-jet physics

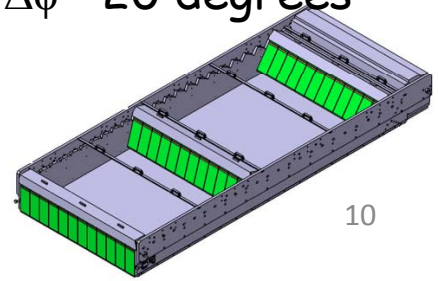


DCAL modules:
Same technology of EMCal
Shorter SM (2/3 of EMCal SM)

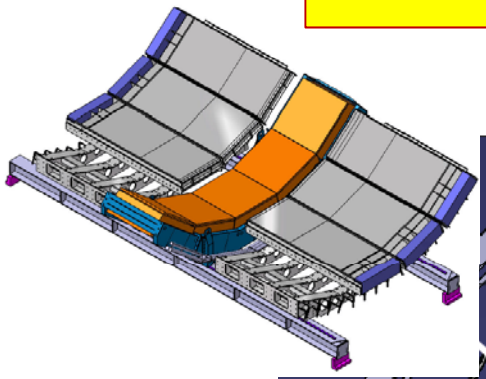


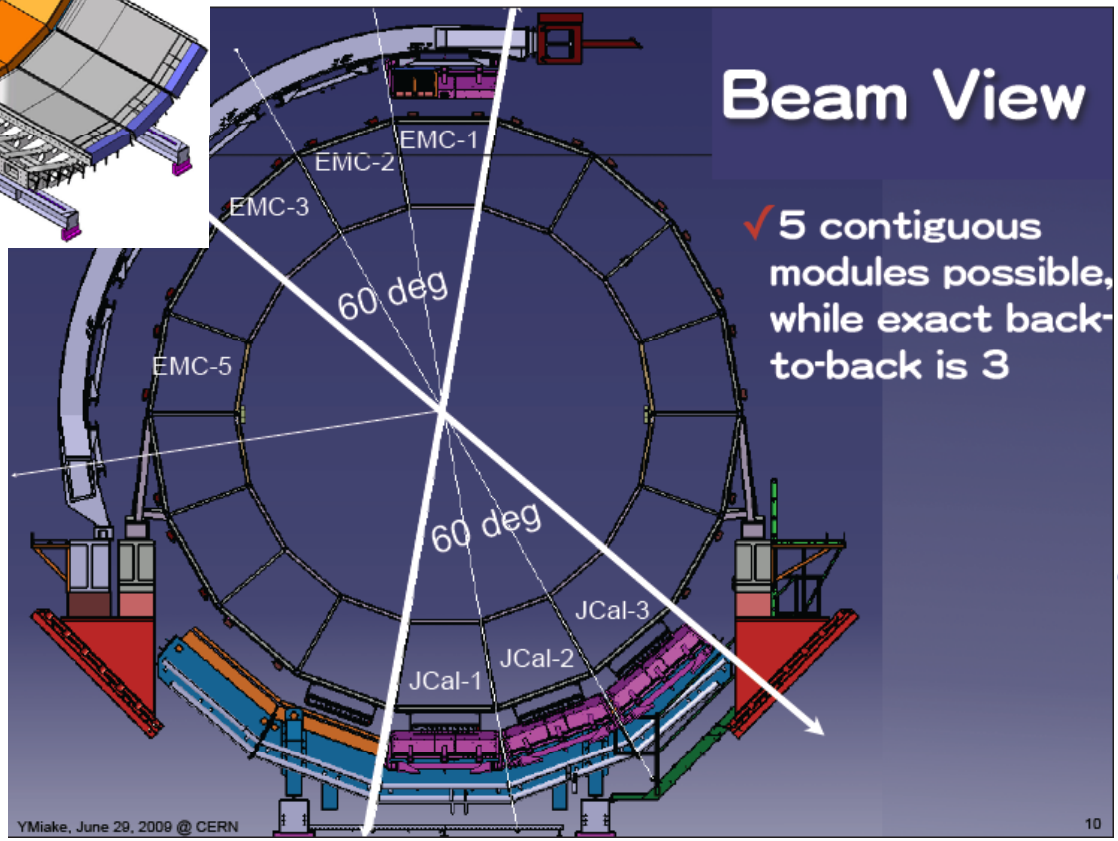
Shortened DCal SM
-16 strip modules
(2 shown)
- Installed η= 0 to ~0.7 (including PHOS)
- $\Delta\phi$ ~20 degrees

Standard EMCal SM
-24 strip modules
(3 shown)



4. EMCAL extension: DCAL





DCAL Collaboration
= EMCAL Collab.
+ China (Wuhan)
+ Japan (Tsukuba)

Focus on γ/π^0/jet-jet correlations

Assembly of DCAL modules started in summer 2010, more than 300 modules already assembled (> 1.5 SM)
Assembly expected to be completed before summer 2011, ready to be installed for 2012 runs

5. EMCAL Performance plots

- Inclusive spectrum of π^0 production in pp collisions at 900 GeV and 7 TeV in mid-rapidity and p_T range from 0.3-0.5 to 20-30 GeV/c

- Measure inclusive spectrum of η and other neutral mesons production in pp collisions at 7 TeV in p_T range from 3-5 to 15-20 GeV/c

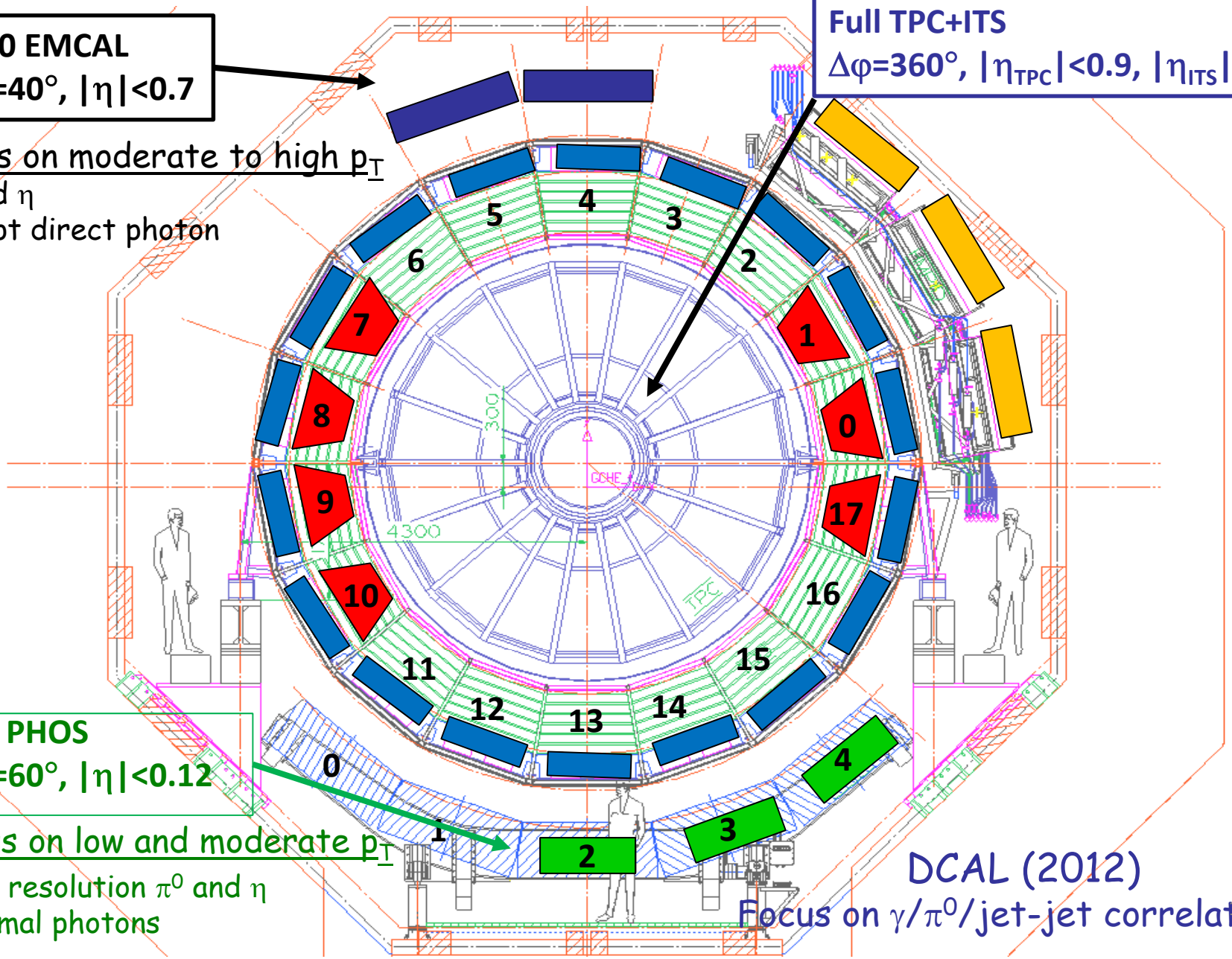
- Physics:
  - Constrain pQCD and non perturbative aspects of QCD
  - Provide reference spectrum for Pb-Pb collisions at 2.76 TeV

ALICE setup for 2010

4/10 EMCAL
$\Delta\varphi$=40°, $|\eta|$<0.7

Focus on moderate to high p_T
π^0 and η
prompt direct photon
jet

Full TPC+ITS
$\Delta\varphi$=360°, $|\eta_{TPC}|$<0.9, $|\eta_{ITS}|$<1.2



3/5 PHOS
$\Delta\varphi$=60°, $|\eta|$<0.12

Focus on low and moderate p_T
High resolution π^0 and η
Thermal photons

DCAL (2012)
Focus on γ/π^0/jet-jet correlations

Neutral meson measurement in ALICE

- ALICE provides 3 independent ways to identify π^0 and η mesons through invariant mass analysis of photon pairs and external conversion electrons:
  - h -> $\gamma\,\gamma$ (both on PHOS or EMCAL)
  - h -> $\gamma\,\gamma$
    $\hookrightarrow$ e^+e^- (CTS, PHOS or EMCAL)
  - h-> $\gamma\,\gamma$
    $\hookrightarrow$ e^+e^- $\qquad$ $\hookrightarrow$ e^+e^- (CTS)

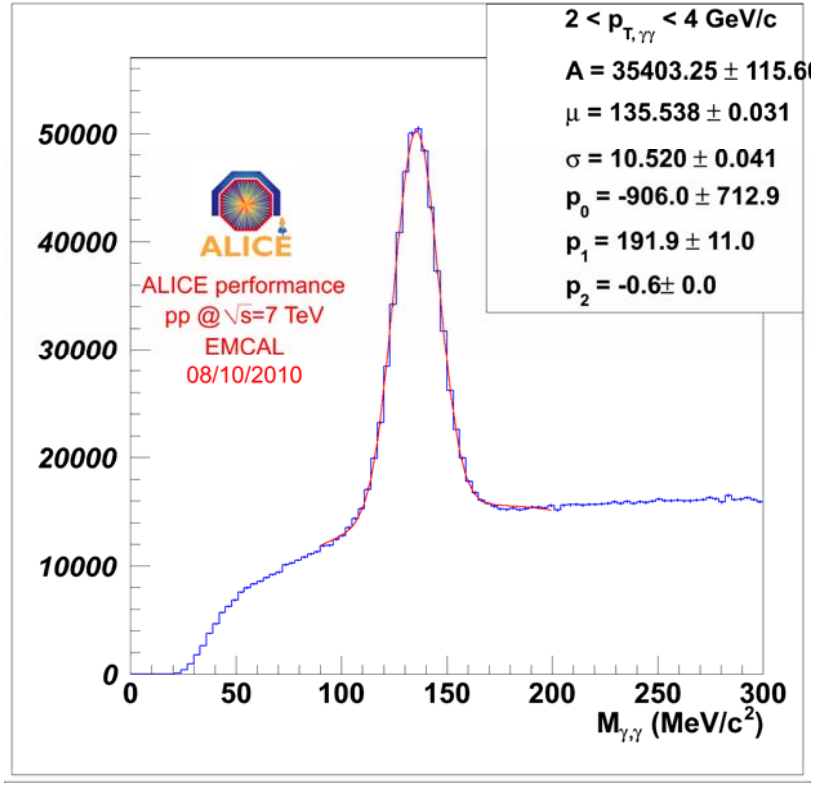
CTS = Central Tracking System

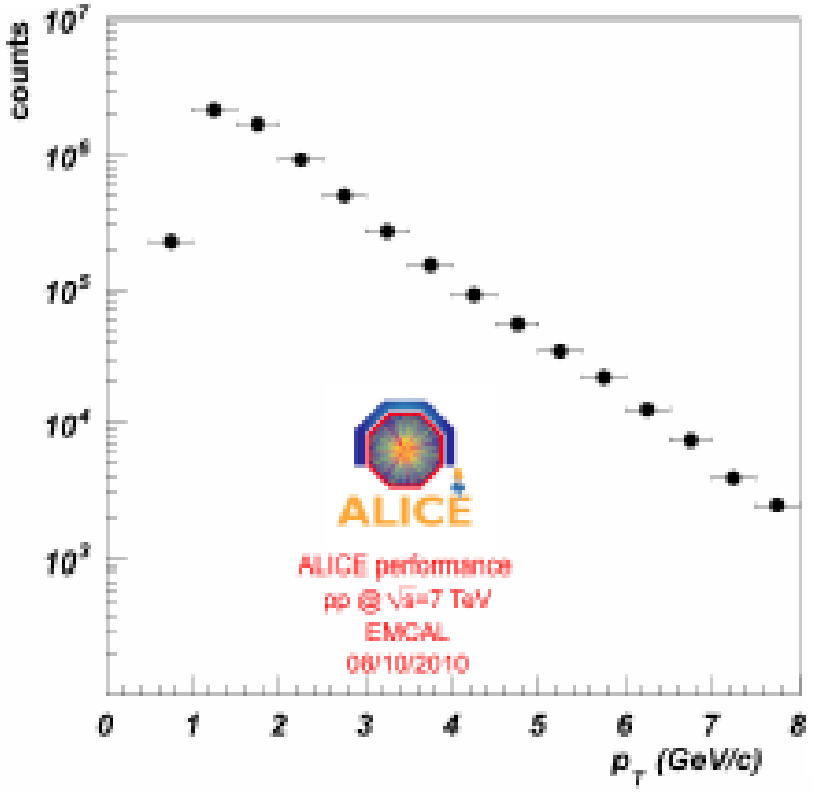
- Method of 2 γ invariant mass analysis works for γ registered in EMCAL up to p_T~15 GeV/c

π^0, η direct photon spectra

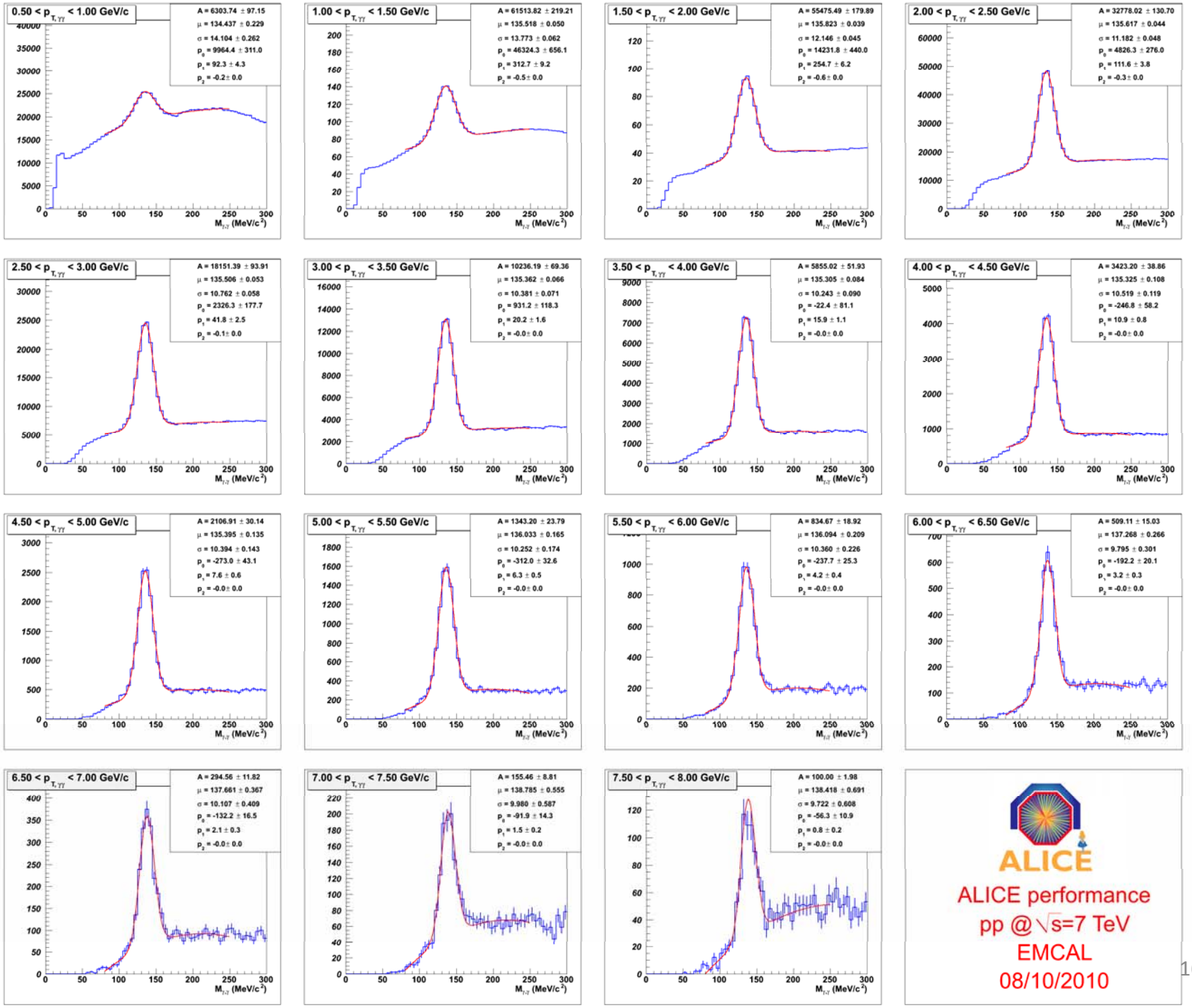
h -> $\gamma+\gamma$
π^0

- pp @ 7 TeV, LHC10e pass, 180 Mevents
- cluster selection: $N_{cell}=2$, $E_{cl}>0.5$ GeV



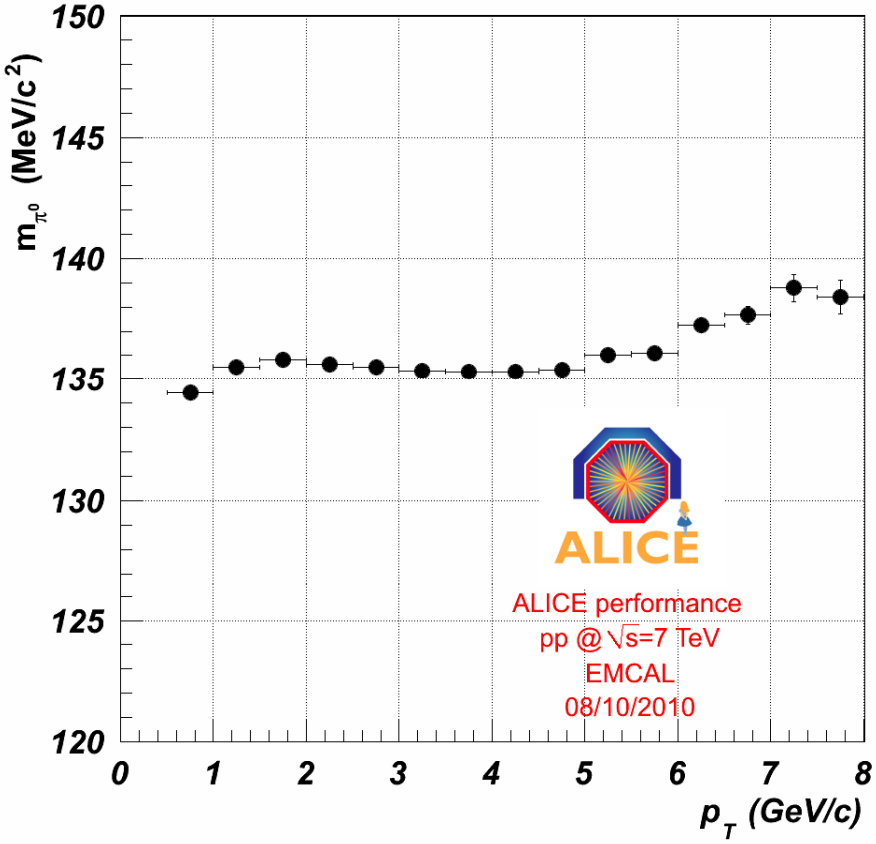


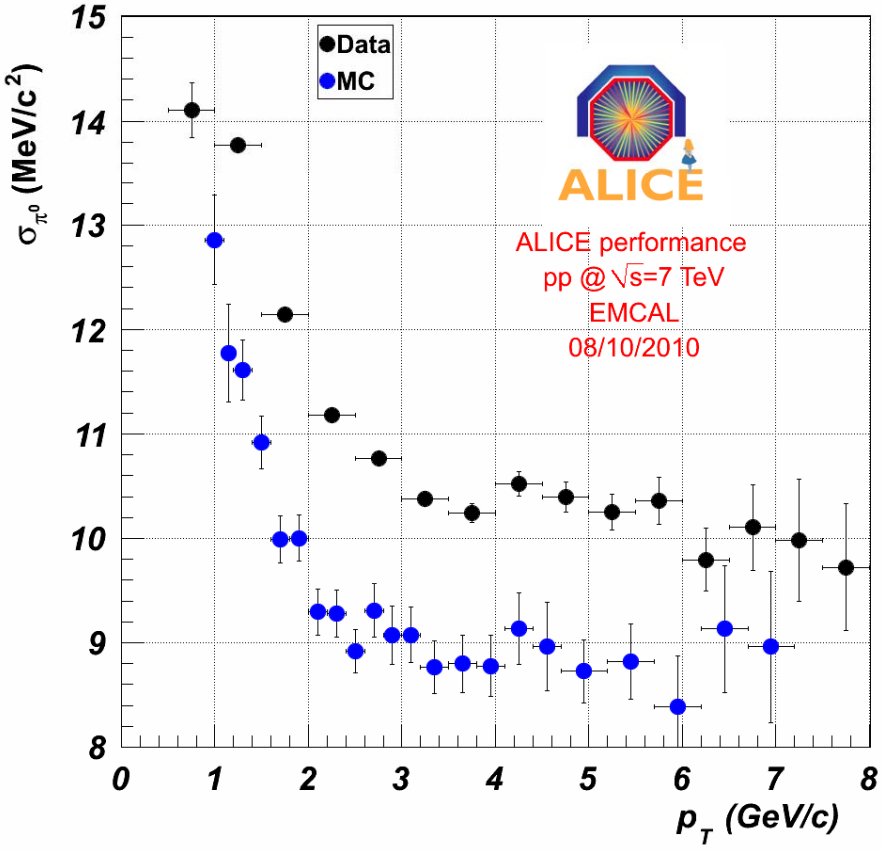
p_T reach ~10 GeV/c due to size of cells and clusterized used
Fit = Gauss + Polynomial 2nd order


0.50 < p_T,γγ < 1.00 GeV/c
A = 6303.74 ± 97.15
μ = 134.437 ± 0.229
σ = 14.104 ± 0.262
p0 = 9964.4 ± 311.0
p1 = 92.3 ± 4.3
p2 = -0.2± 0.0
1.00 < p_T,γγ < 1.50 GeV/c
A = 61513.82 ± 219.21
μ = 135.518 ± 0.050
σ = 13.773 ± 0.062
p0 = 46324.3 ± 656.1
p1 = 312.7 ± 9.2
p2 = -0.5± 0.0
1.50 < p_T,γγ < 2.00 GeV/c
A = 55475.49 ± 179.89
μ = 135.823 ± 0.039
σ = 12.146 ± 0.045
p0 = 14231.8 ± 440.0
p1 = 254.7 ± 6.2
p2 = -0.6± 0.0
2.00 < p_T,γγ < 2.50 GeV/c
A = 32778.02 ± 130.70
μ = 135.617 ± 0.044
σ = 11.182 ± 0.048
p0 = 4826.3 ± 276.0
p1 = 111.6 ± 3.8
p2 = -0.3± 0.0
2.50 < p_T,γγ < 3.00 GeV/c
A = 18151.39 ± 93.91
μ = 135.506 ± 0.053
σ = 10.762 ± 0.058
p0 = 2326.3 ± 177.7
p1 = 41.8 ± 2.5
p2 = -0.1± 0.0
3.00 < p_T,γγ < 3.50 GeV/c
A = 10236.19 ± 69.36
μ = 135.362 ± 0.066
σ = 10.381 ± 0.071
p0 = 931.2 ± 118.3
p1 = 20.2 ± 1.6
p2 = -0.0± 0.0
3.50 < p_T,γγ < 4.00 GeV/c
A = 5855.02 ± 51.93
μ = 135.305 ± 0.084
σ = 10.243 ± 0.090
p0 = -22.4 ± 81.1
p1 = 15.9 ± 1.1
p2 = -0.0± 0.0
4.00 < p_T,γγ < 4.50 GeV/c
A = 3423.20 ± 38.86
μ = 135.325 ± 0.108
σ = 10.519 ± 0.119
p0 = -246.8 ± 58.2
p1 = 10.9 ± 0.8
p2 = -0.0± 0.0
4.50 < p_T,γγ < 5.00 GeV/c
A = 2106.91 ± 30.14
μ = 135.395 ± 0.135
σ = 10.394 ± 0.143
p0 = -273.0 ± 43.1
p1 = 7.6 ± 0.6
p2 = -0.0± 0.0
5.00 < p_T,γγ < 5.50 GeV/c
A = 1343.20 ± 23.79
μ = 136.033 ± 0.165
σ = 10.252 ± 0.174
p0 = -312.0 ± 32.6
p1 = 6.3 ± 0.5
p2 = -0.0± 0.0
5.50 < p_T,γγ < 6.00 GeV/c
A = 834.67 ± 18.92
μ = 136.094 ± 0.209
σ = 10.360 ± 0.226
p0 = -237.7 ± 25.3
p1 = 4.2 ± 0.4
p2 = -0.0± 0.0
6.00 < p_T,γγ < 6.50 GeV/c
A = 509.11 ± 15.03
μ = 137.268 ± 0.266
σ = 9.795 ± 0.301
p0 = -192.2 ± 20.1
p1 = 3.2 ± 0.3
p2 = -0.0± 0.0
6.50 < p_T,γγ < 7.00 GeV/c
A = 294.56 ± 11.82
μ = 137.661 ± 0.367
σ = 10.107 ± 0.409
p0 = -132.2 ± 16.5
p1 = 2.1 ± 0.3
p2 = -0.0± 0.0
7.00 < p_T,γγ < 7.50 GeV/c
A = 155.46 ± 8.81
μ = 138.785 ± 0.555
σ = 9.980 ± 0.587
p0 = -91.9 ± 14.3
p1 = 1.5 ± 0.2
p2 = -0.0± 0.0
7.50 < p_T,γγ < 8.00 GeV/c
A = 100.00 ± 1.98
μ = 138.418 ± 0.691
σ = 9.722 ± 0.608
p0 = -56.3 ± 10.9
p1 = 0.8 ± 0.2
p2 = -0.0± 0.0
M_γ-γ (MeV/c²)
ALICE
ALICE performance
pp @ √s=7 TeV
EMCAL
08/10/2010

h -> γ+γ

π^0





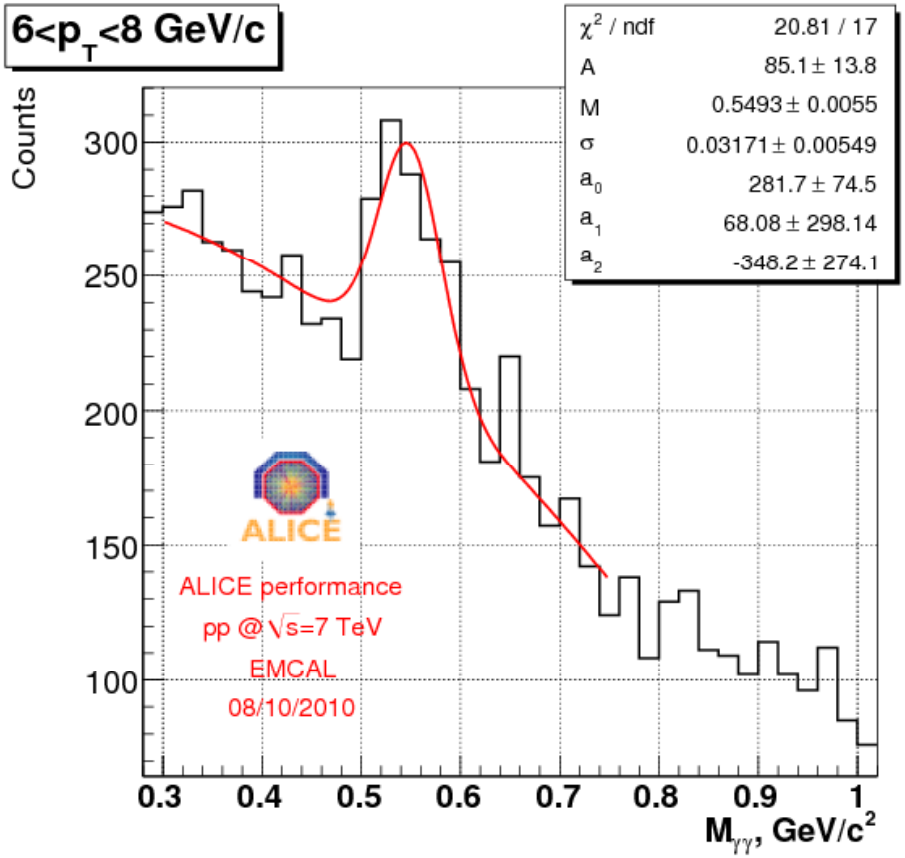
- Good linearity before clusters start to merge (~5GeV/c)
- Non final calibration results in non-optimal resolution

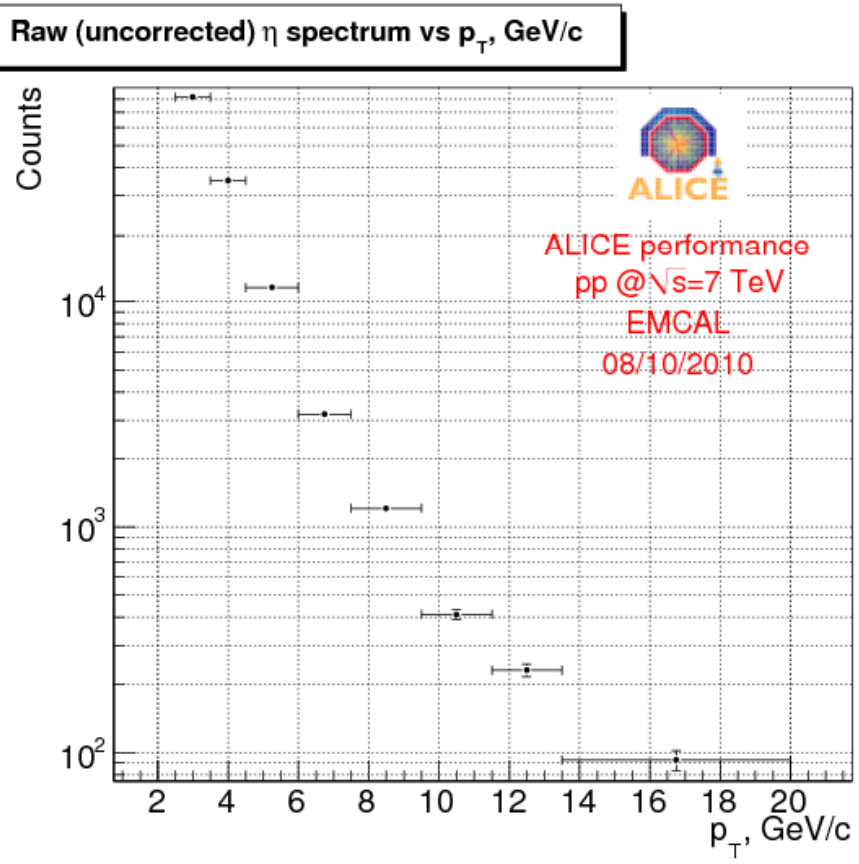
Working in progress for better tuning

h -> γ+γ

η

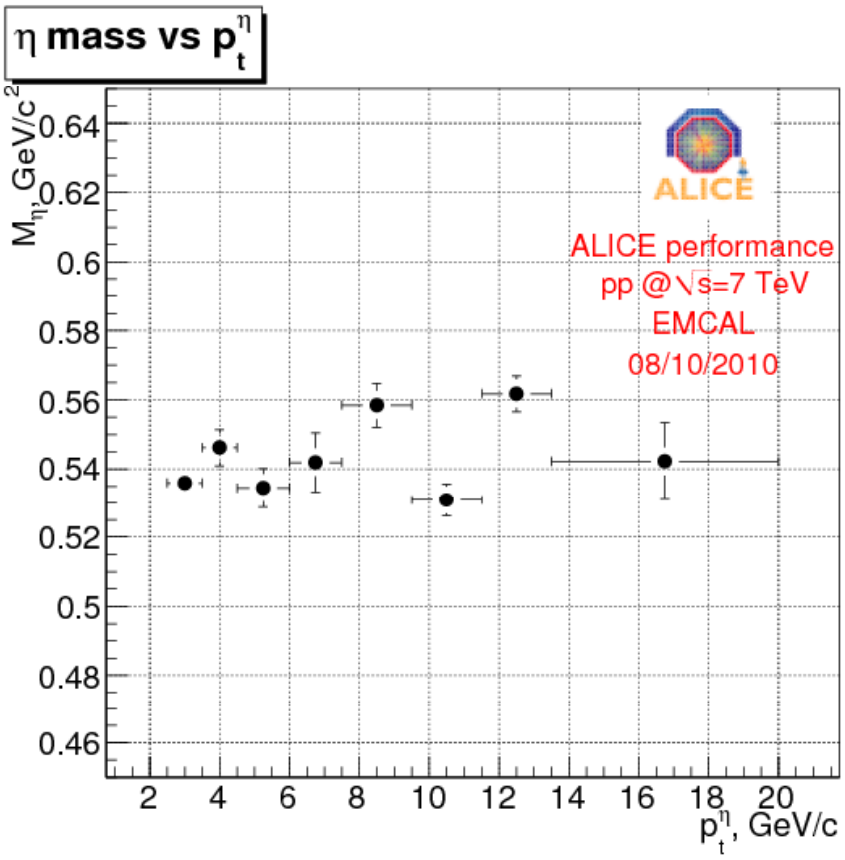
- pp @ 7 TeV, LHC10e pass, 180 Mevents
- cluster selection: $N_{cell}=2$, $E_{cl}>0.3$ GeV

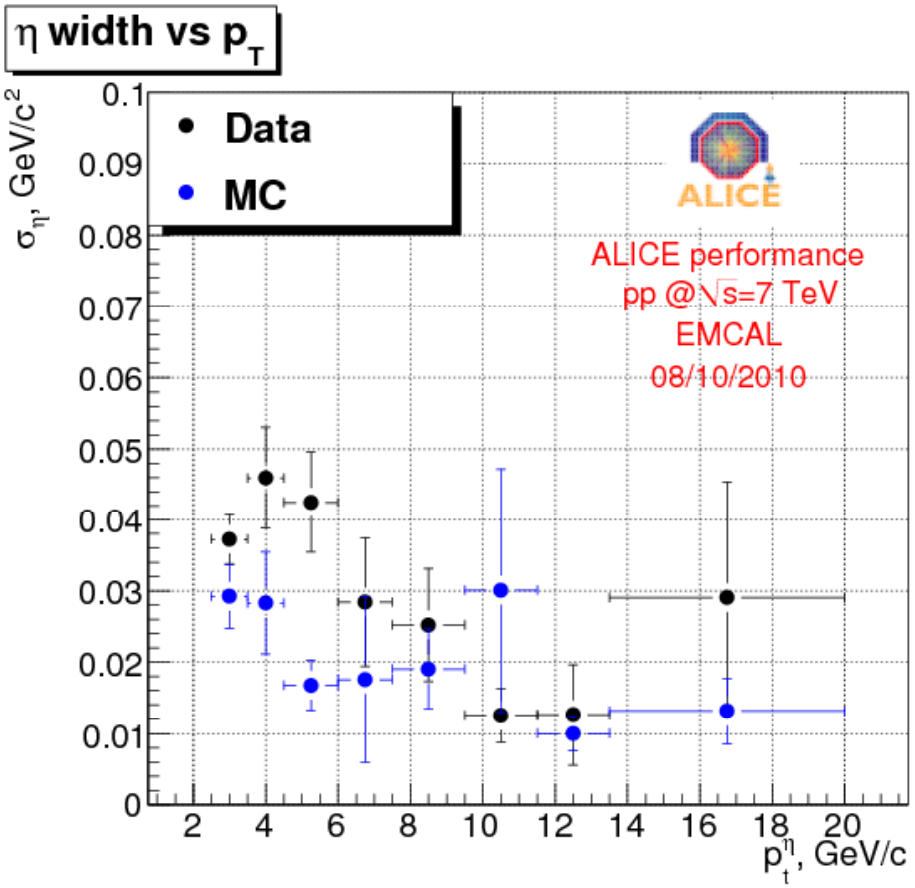




h-> γ+γ

η





EMCAL able to measure η mesons in the range $2<p_T<20$ GeV/c

6. EMCAL Physics Capabilities

EMCal extends the scope of the ALICE experiment for jet quenching :

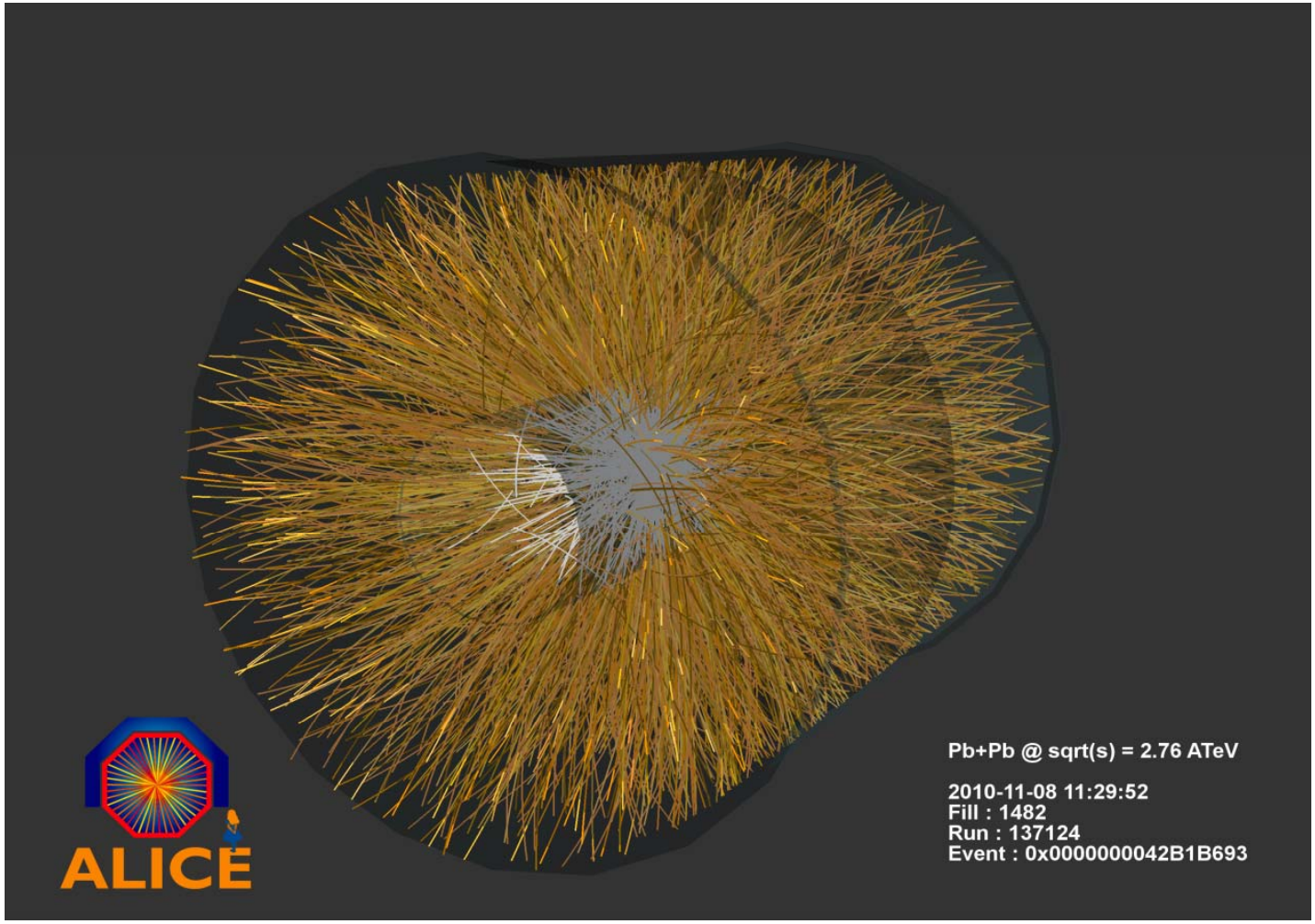
- EMCal provides a fast, efficient trigger for high p_T jets, γ (π^0), electrons
  $\Rightarrow$ recorded yields enhanced by factor ~10-60

	L^{max} ($cm^{-2}s^{-1}$)	interaction rate	max rate to tape	EMCal enhancement	
				e,γ,π^0	jet
Pb+Pb	1.0×10^{27}	8 kHz	100 Hz	14	10
Ar+Ar	0.6×10^{29}	130 kHz	500 Hz	44	31
O+O	2.0×10^{29}	220 kHz	500 Hz	75	53
p+p	5.0×10^{30}	200 kHz	500 Hz	68	48

- EMCal markedly improves jet reconstruction through measurement of e.m. fraction of jet energy with less bias

- EMCal provides good γ/π^0 discrimination, augmenting ALICE direct photon capabilities at high p_T

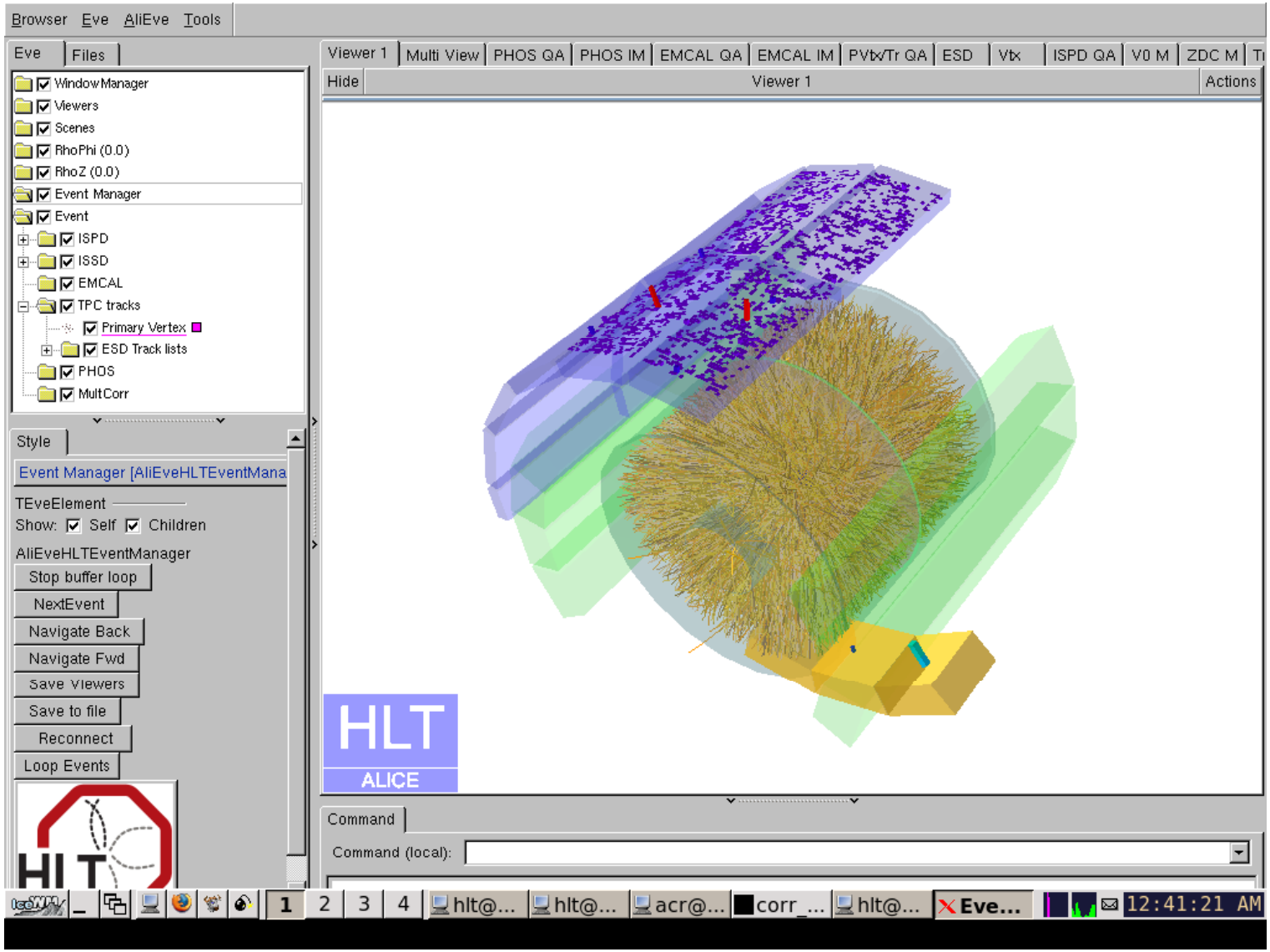
- EMCal provides good electron/hadron discrimination, augmenting and extending to high p_T the ALICE capabilities for heavy quark jet quenching measurements



Monday Nov. 18th @ 11:20 LHC declared
"Stable beam with ions" Pb-Pb @ 2.76 TeV

EMCAL ready .....

EMCAL HLT



One of the first Pb-Pb collisions @ 2.76 TeV from ALICE High Level Trigger display

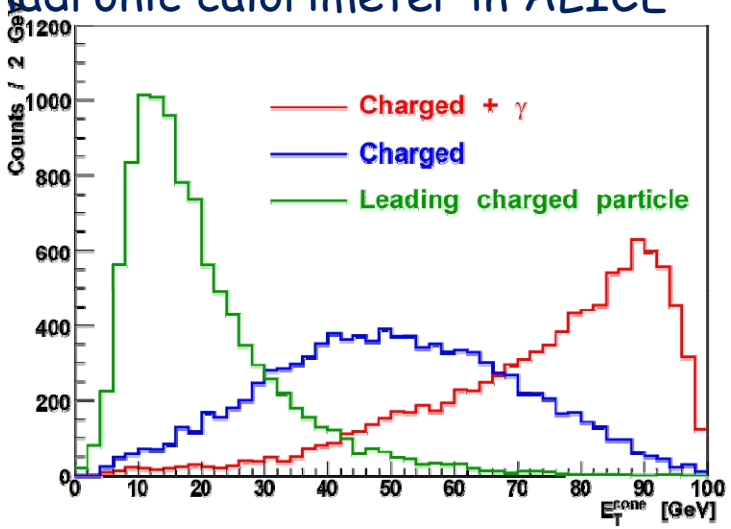
EMCAL able to run with the rest of ALICE

EMCAL: last detector installed, short time for developing HLT

⇒ very good starting point!!!

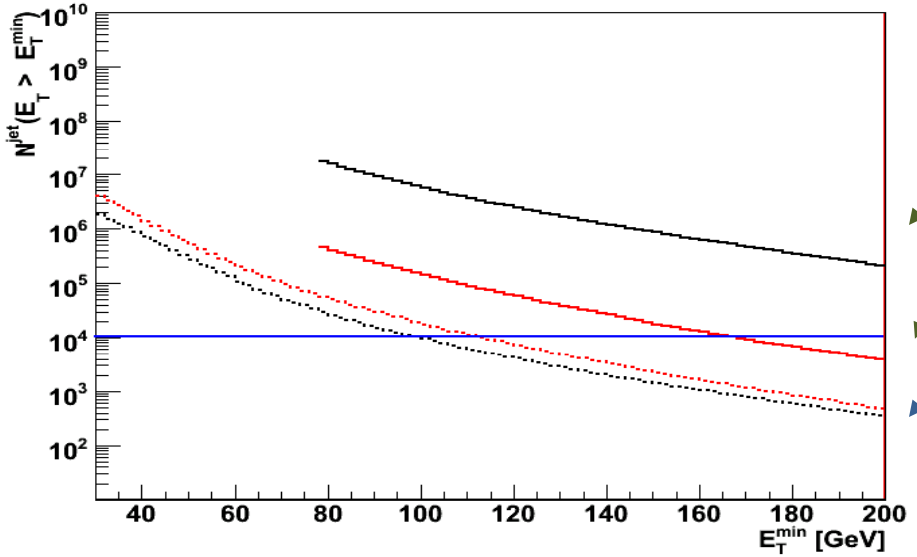
EMCAL for Jet reconstruction

Typical jet reconstruction : combination of e.m and hadronic calorimeters, but no hadronic calorimeter in ALICE



- Hadronic energy: charged tracks (TPC/ITS)
- Electromagnetic energy: EMCal
- Corrections:
  - unmeasured hadrons (n, K^0_L,…) (<10%)
  - hadronic energy (25%) in EMCal

Possibility to measure the neutral components of the jets

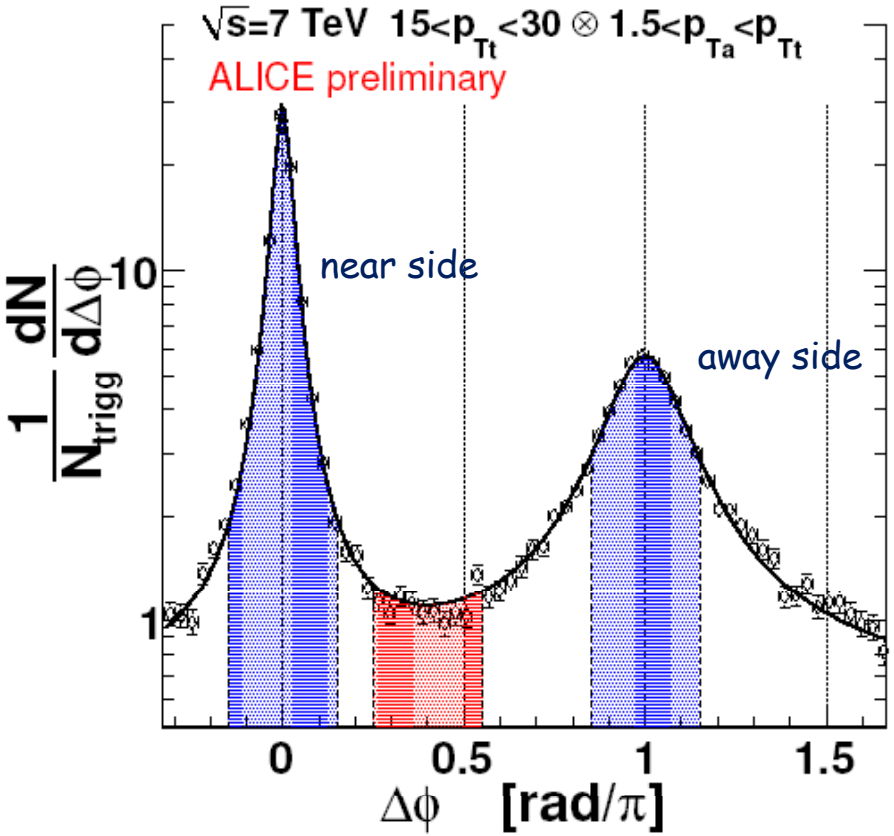


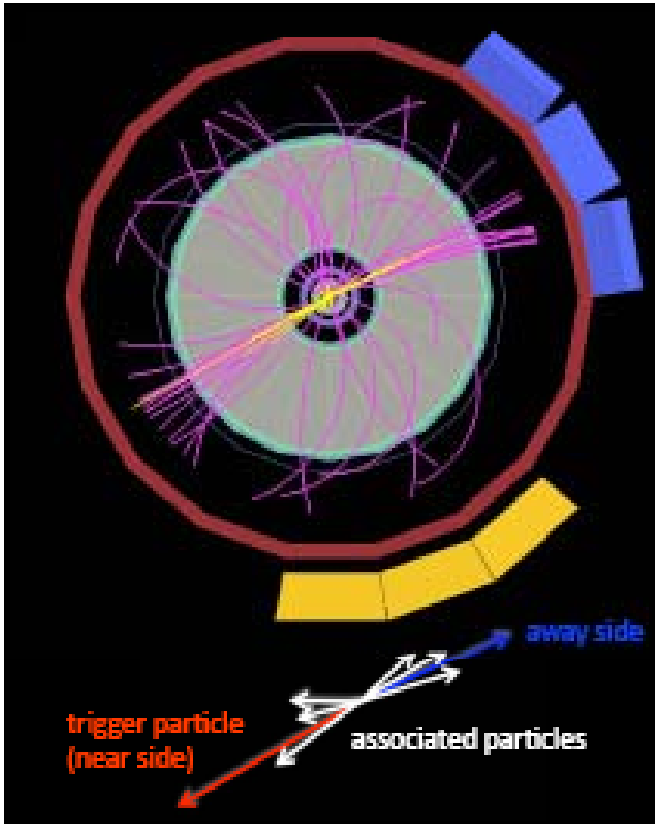
Track + Calo

Charged only

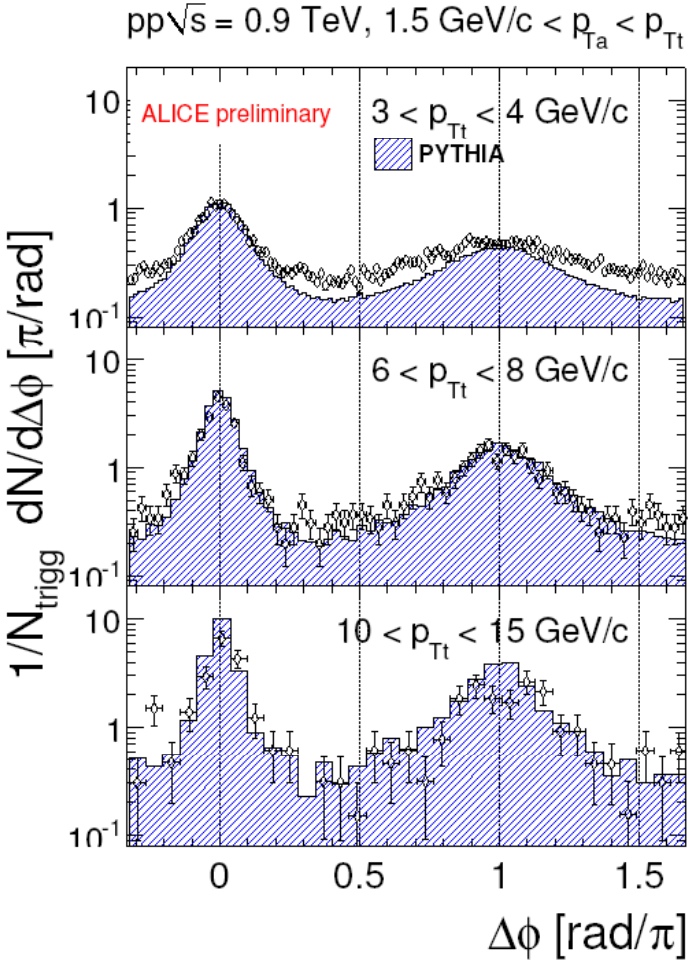
	Charged	Charged + neutral
RMS [GeV]	21	15
E_{cone}/E_T	0.50	0.77
Efficiency	67%	80%

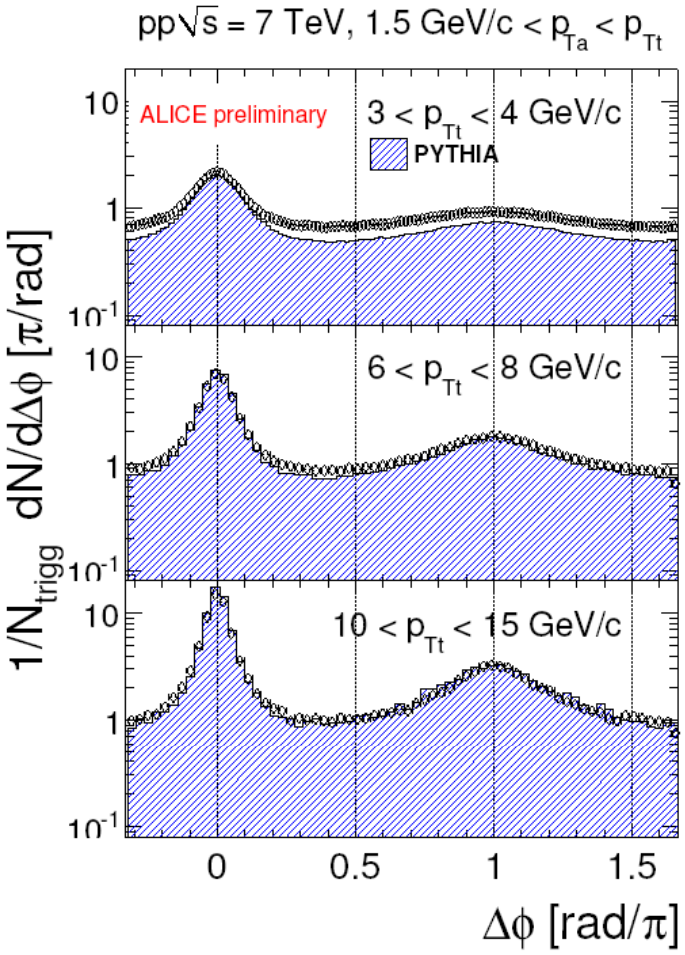
Particle correlation ⟹ access to jet properties in kinematical regions where full jet recontruction is difficult



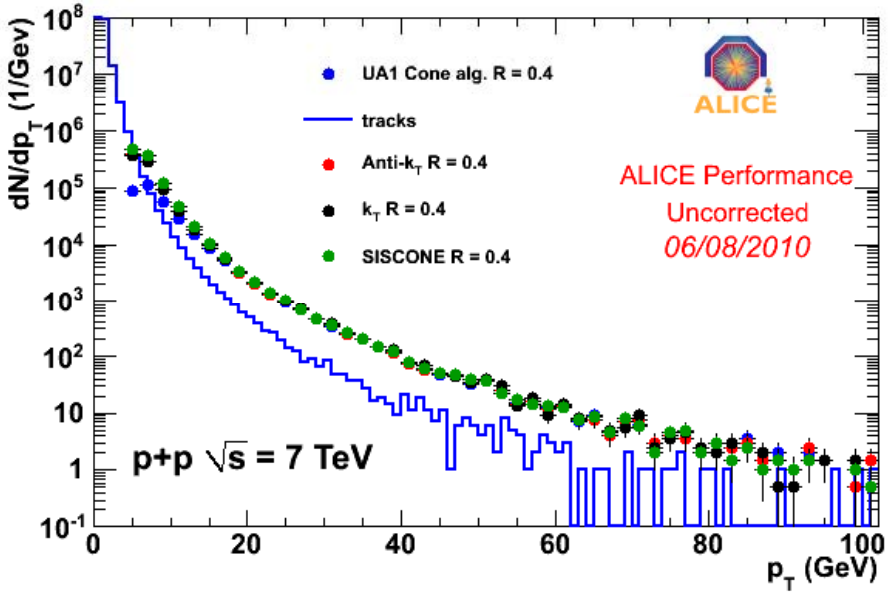


Angular Correlation Functions at 0.9 and 7 TeV





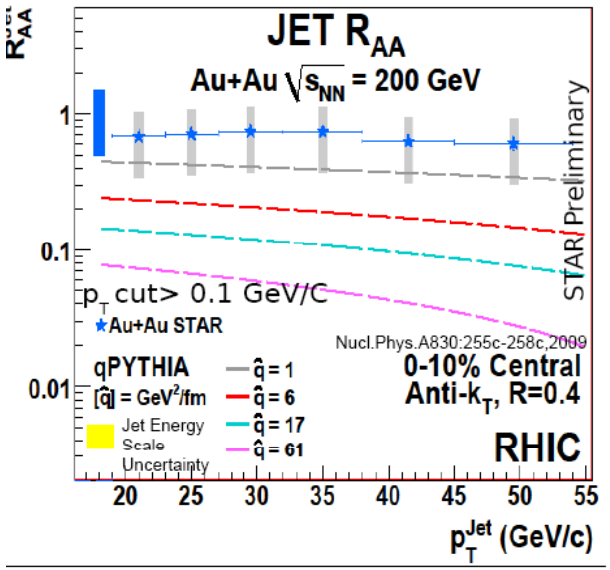
provide access to jet-like properties down to low p_T (mini-jets)

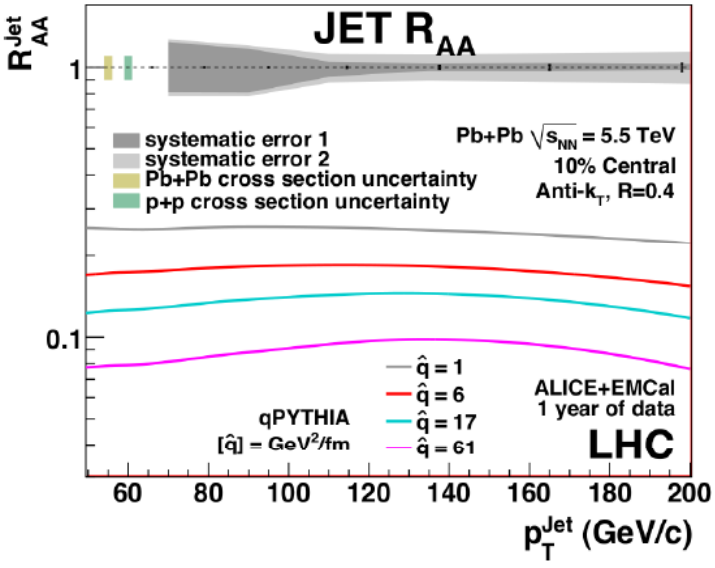


Jet reconstructed in ALICE with different algorithms (different sensitivity to background and different background subtraction scheme)

Good agreement for all jet finders

To test for Pb-Pb





Expected performance of ALICE jet measurement in 1 year Pb-Pb data taking with EMCAL

Comparison with RHIC Au-Au

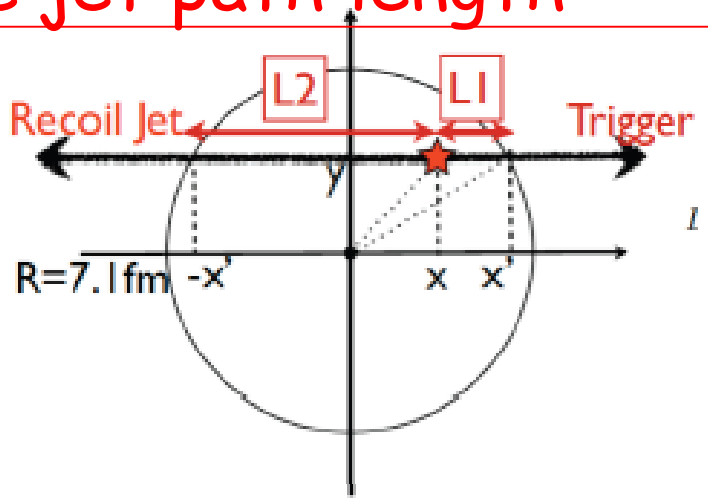
Much higher collision energy at LHC

Full EMCAL will enhance ALICE's capabilities for jet measurements

Jet quenching measurement with DCAL: controlled variation of the jet path length

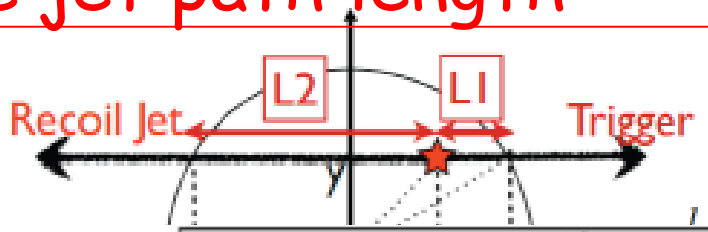
Triggering on high p_T hadron provides a unique bias of the jet recoiling azimuthally opposite:

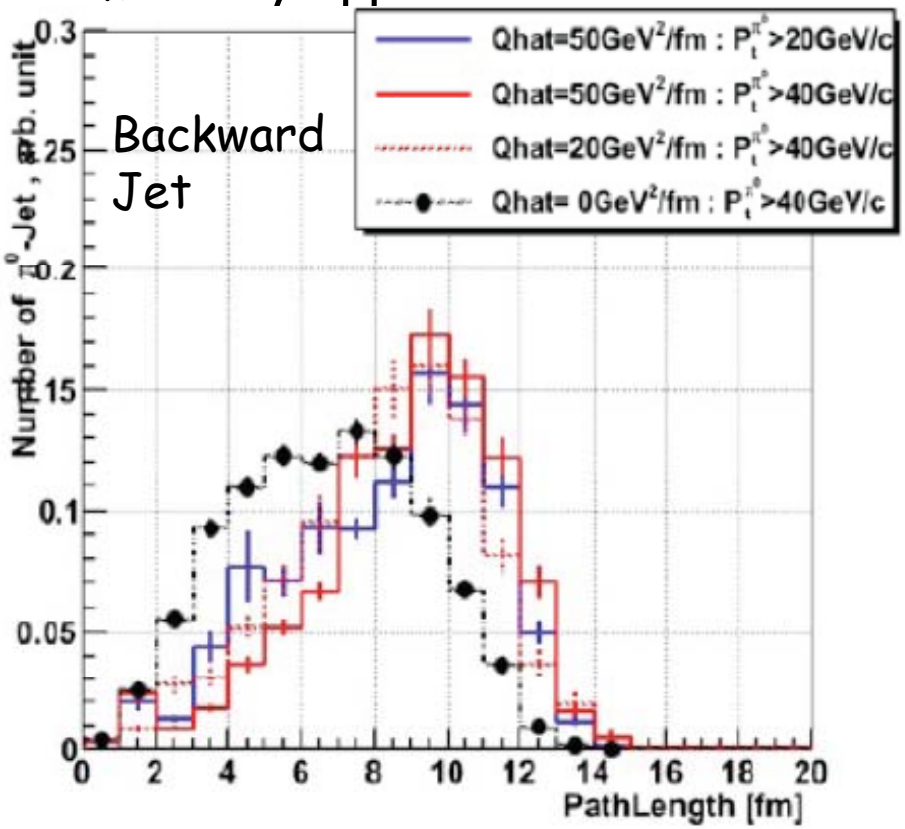
the hadron trigger arises from jet mainly generated near the surface (L1), thereby maximizing the path length of the recoiling jet in matter (L2).

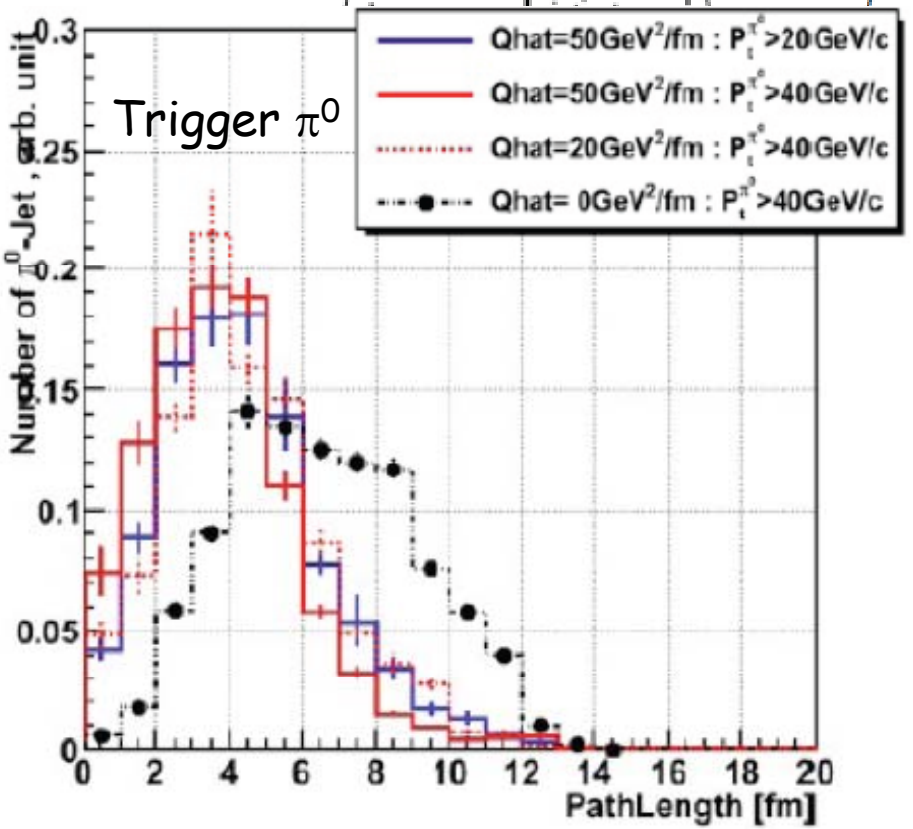


Jet quenching measurement with DCAL: controlled variation of the jet path length

Triggering on high p_T hadron provides a unique bias of the jet recoiling azimuthally opposite:







- Marked bias of several fm is seen for both jets.
- Triggering on high $P_T^{\pi 0}$ maximizes the path length of the recoiling jet in the matter
- Small dependence on Qhat and $P_T^{\pi 0}$ if these quantities are large enough→ geometric bias can be calculated reliably.

7. Summary

- First 4 EMCAL SMs installed in 2009 and taking data
- 6 SMs will be installed in January 2011, EMCAL completed
- EMCAL upgrade: DCAL completion for γ-jet and jet-jet physics, work already started, shutdown needed (2011)

- EMCAL performance plots from data taking shown
- After analysis of all statistics in 7 TeV pp run (~800 Mevents) $\longrightarrow$ π^0 spectrum measured up to 30 GeV/c, η up to 20 GeV/c
- Great physics capabilities: possibility of full reconstruction of jets, measuring the neutral components
- DCAL installation for 2012 runs will allow back-to-back hadron-jet, jet-jet and γ-jet correlations
- Runs with Pb-Pb started on Nov. 2010, EMCAL working fine