Calorimetry in ALICE at LHC

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for the ALICE Collaboration

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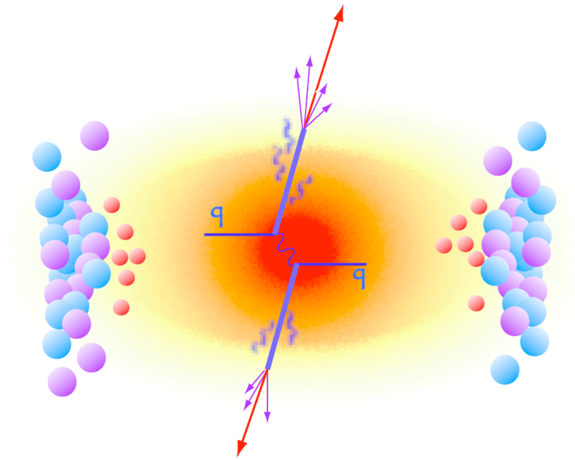
Outline

1. **Electromagnetic Calorimeters in ALICE**
   - ALICE Experiment
   - PHOS
   - EMCal
   - Performance (2009-2013)
2. **Upgrade during LHC long shutdown (2013-2014)**
   - EMCal extension (DCal), PHOS upgrade
   - SRU readout upgrade (EMCal/DCal, PHOS)
3. **Future plan**
   - Forward Calorimeter (FoCal)
4. **Summary**

1. Electromagnetic Calorimeters in ALICE

ALICE Physics Program and Hard Processes



Physics Goal of ALICE:

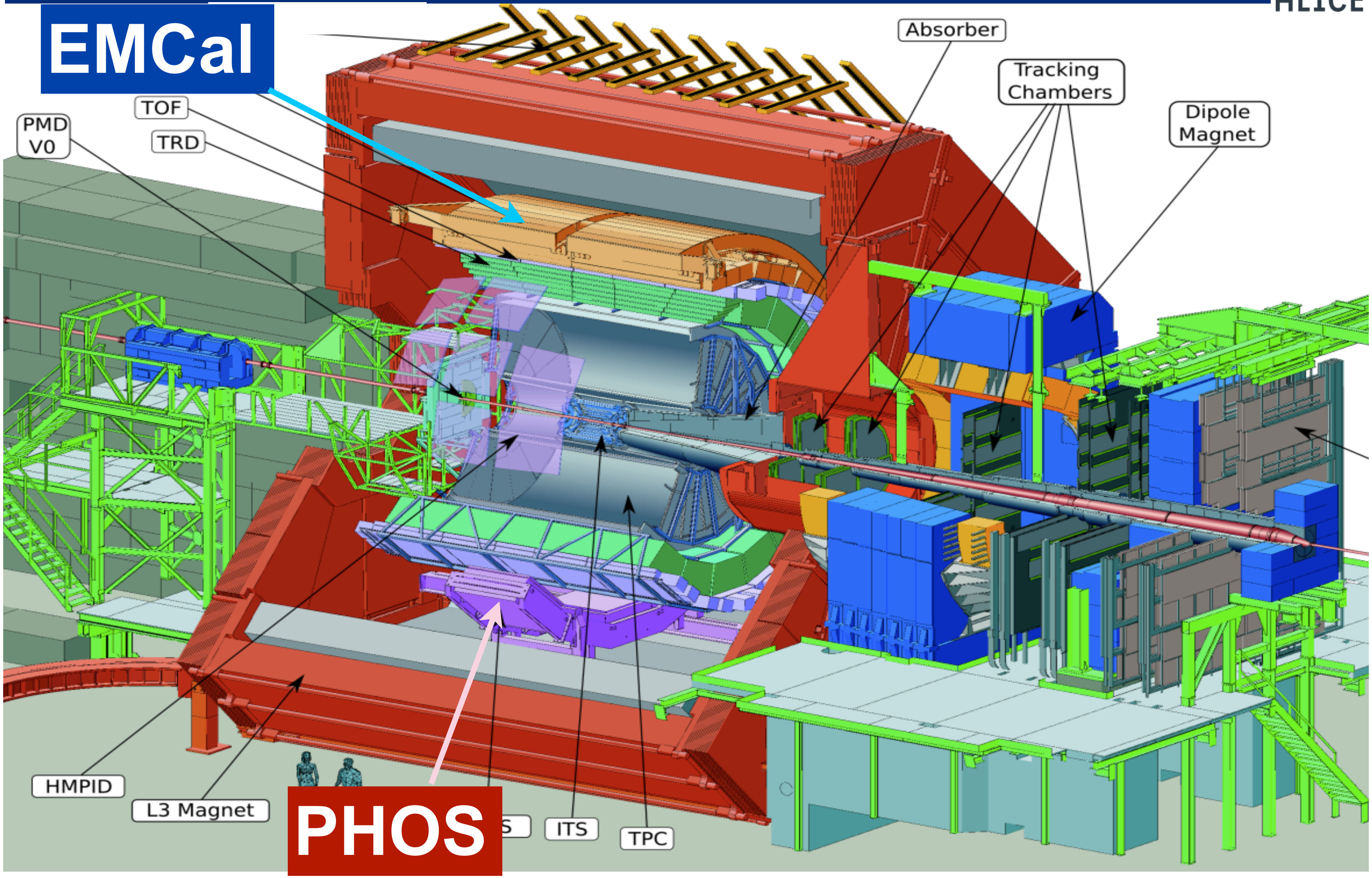
To study/ characterize the properties of hot, dense, de-confined matter ("Quark Gluon Plasma", QGP) as produced on a "macroscopic" scale in central Pb+Pb collisions at the LHC.

- **Initial temperature of matter:**
  - Thermal γ radiation from QGP
- **Parton energy loss in QGP (jet quenching):**
  - Probe the "stopping power" of the medium
  - dE/dx for partons in QGP

➡ **Requires EM calorimetry**

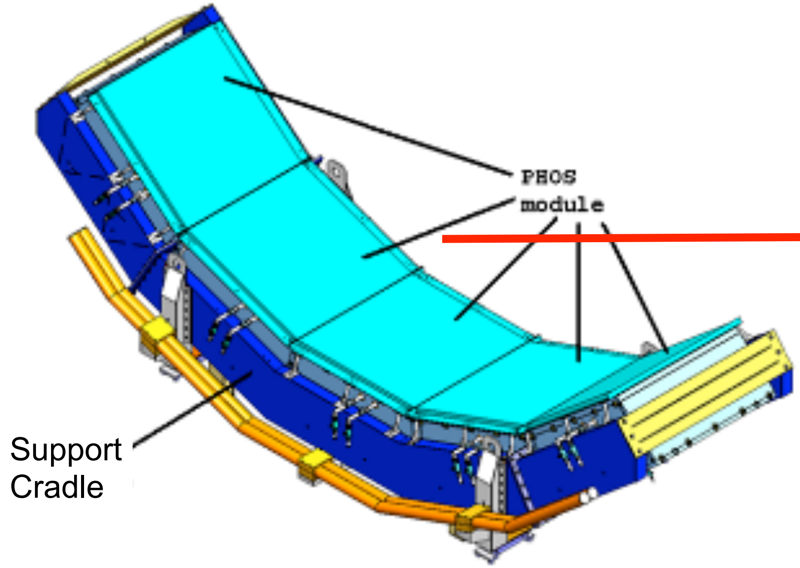
- Measure EM energy to provide total jet energy (or recoil γ)
- Provide jet (or γ) trigger
- Thermal γ, π^0.

The ALICE Experiment

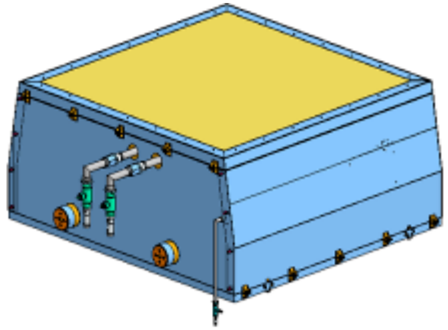


The ALICE Photon Spectrometer (PHOS)

Design goal: To measure π^0's and thermal photons (Initial T)



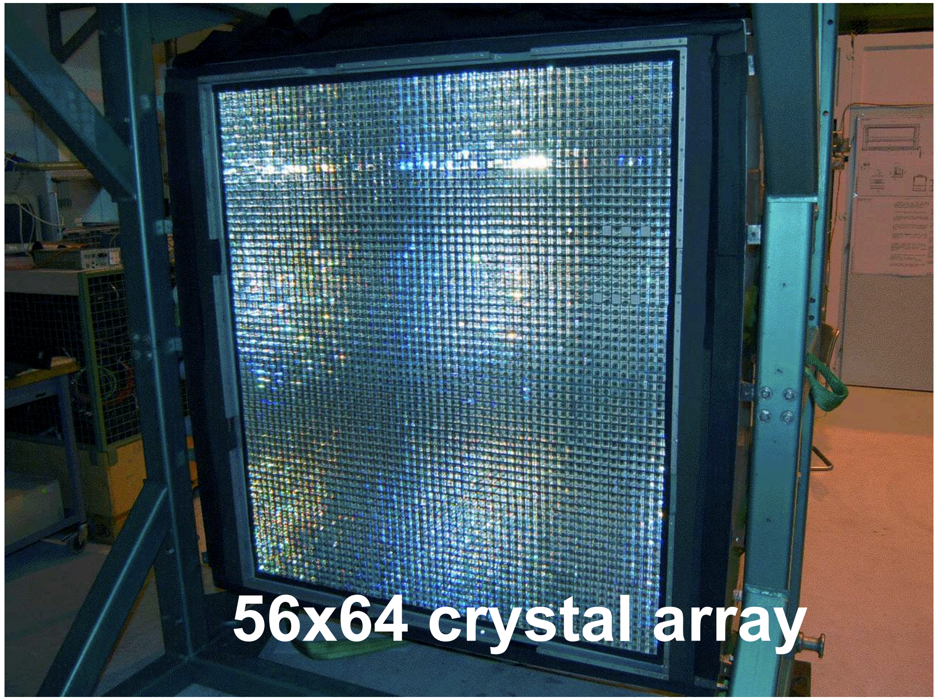
- 3 of 5 Super-Modules installed (Run-1)



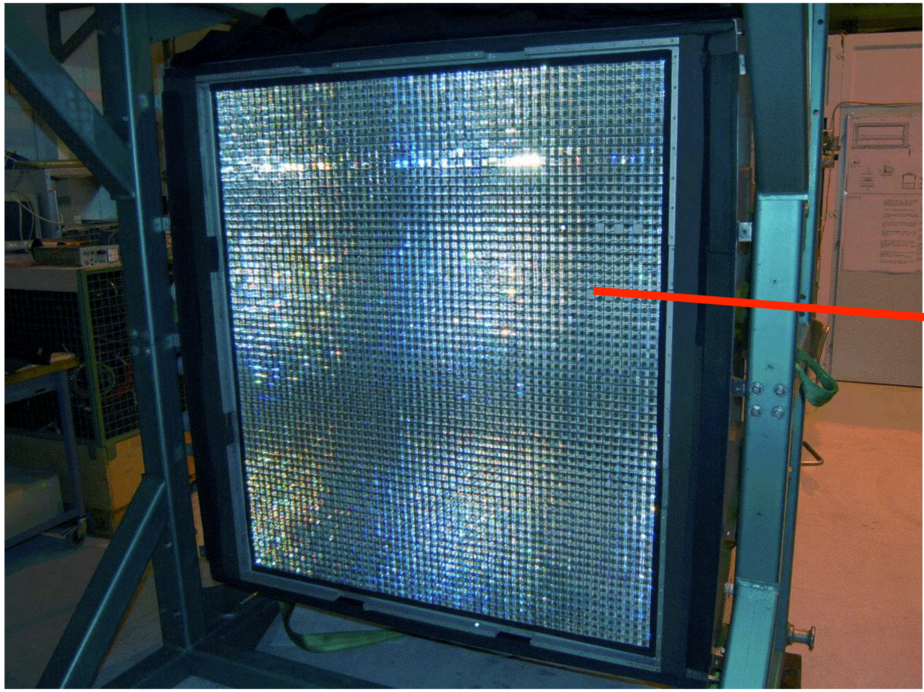
PHOS Super Modules

$PbWO_4$ crystals

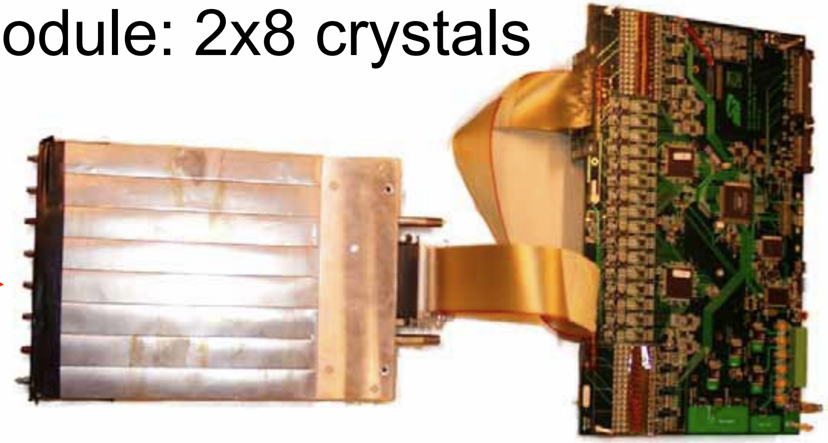
- APD Photosensor
- Crystals at -25^o C → ~triple LY
- 10,752 crystals installed
- At 4.6m from IR.
- $\Delta\eta$ = 0.24, $\Delta\phi$ = 60^o (100^o)
- Full-scale Energy: 100 GeV

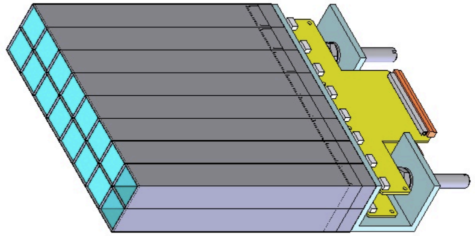


The ALICE Photon Spectrometer (PHOS)



Module: 2x8 crystals





100μm Stainless steel honeycomb

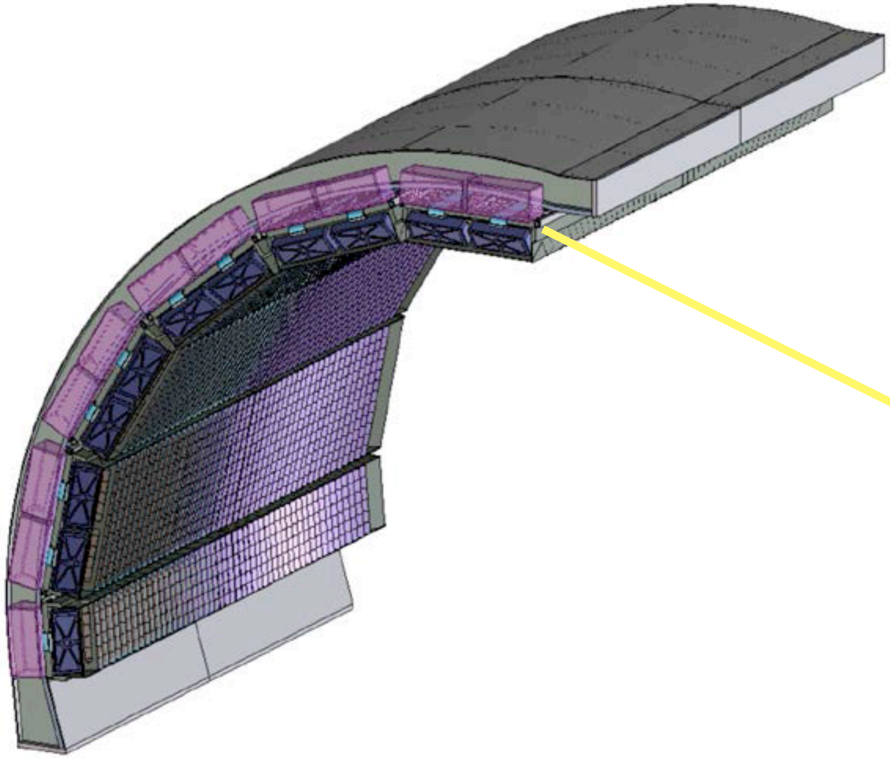
$PbWO_4$ crystals 2.2 x 2.2 x 18 cm

- 20 X_0
- APD + Preamp on crystal
- Crystals at -25 ^oC
- $\Delta\eta = 0.24$, $\Delta\phi = 60^o$ (100^o)

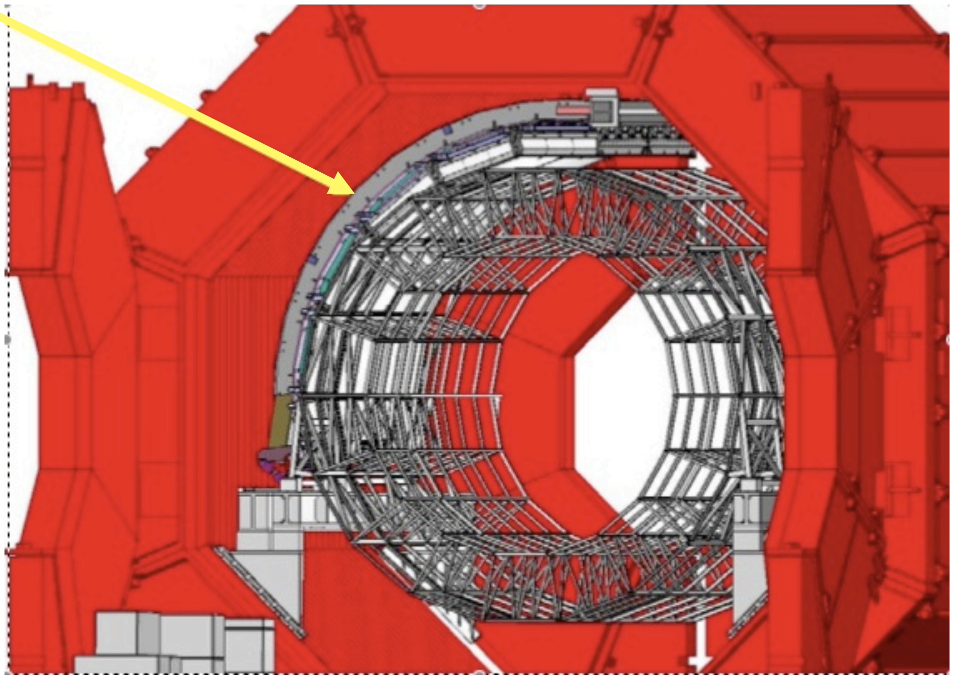
High resolution, low occupancy, but limited acceptance.

The Electromagnetic Calorimeter (EMCal)

Large acceptance with moderate resolution and occupancy.



- A late addition to ALICE
- Funding approval: Feb. 2008

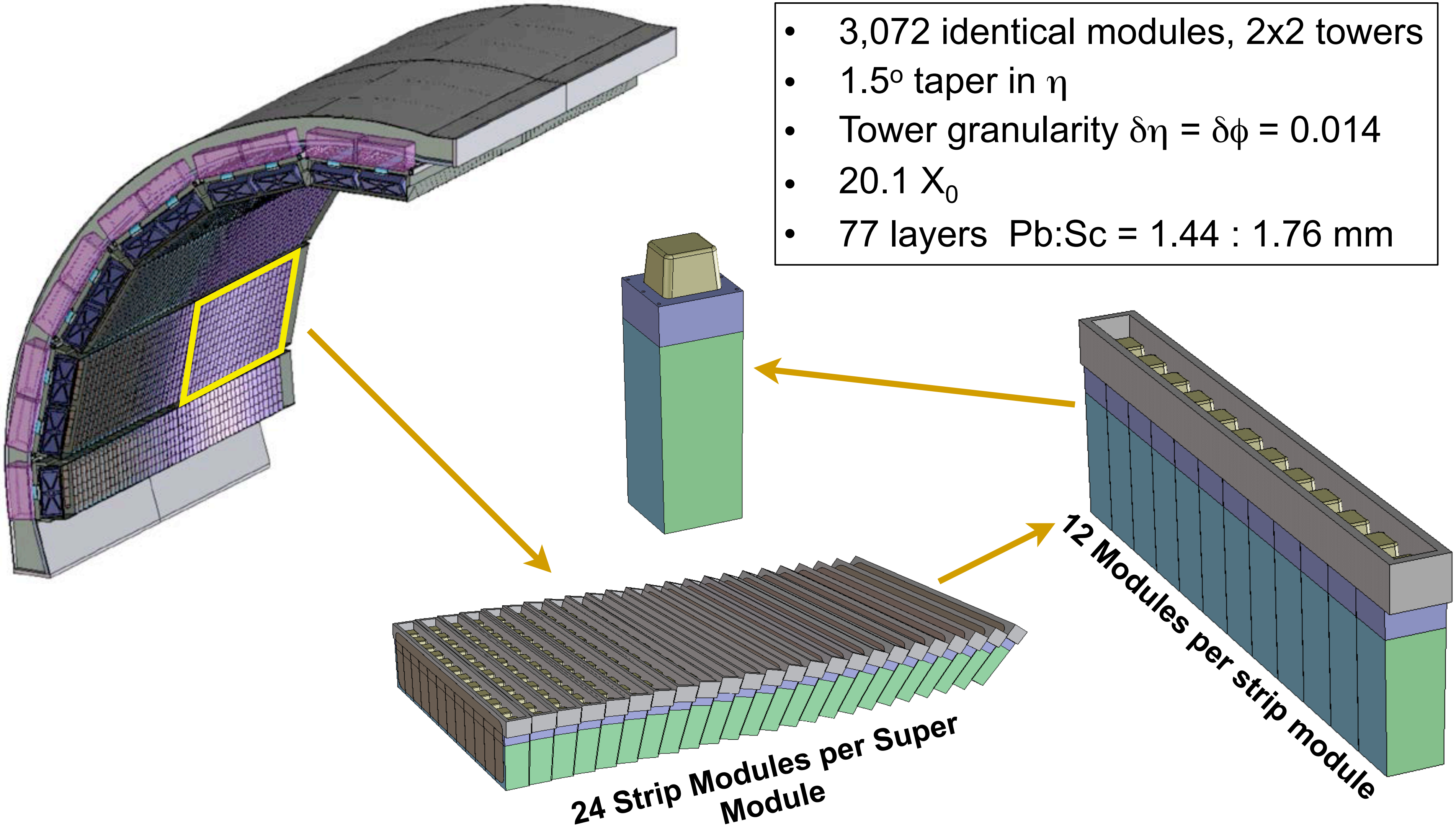


Lead-Scintillator Sampling Calorimeter
$\Delta\eta$ = 1.4, $\Delta\phi$ =107°

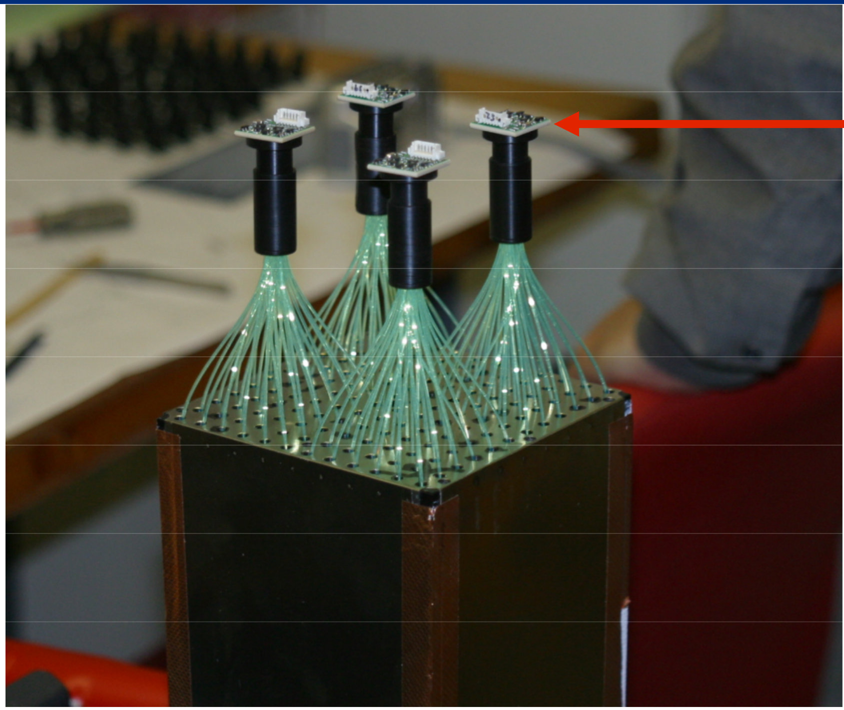
Shashlik Geometry, APD Photosensor
12,288 Towers

EMCal Assembly

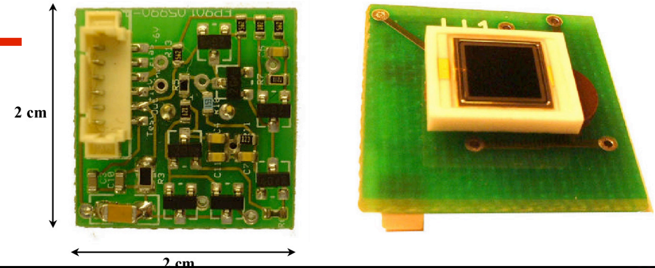
- 3,072 identical modules, 2x2 towers
- 1.5^{o} taper in η
- Tower granularity $\delta\eta = \delta\phi = 0.014$
- 20.1 X_0
- 77 layers Pb:Sc = 1.44 : 1.76 mm

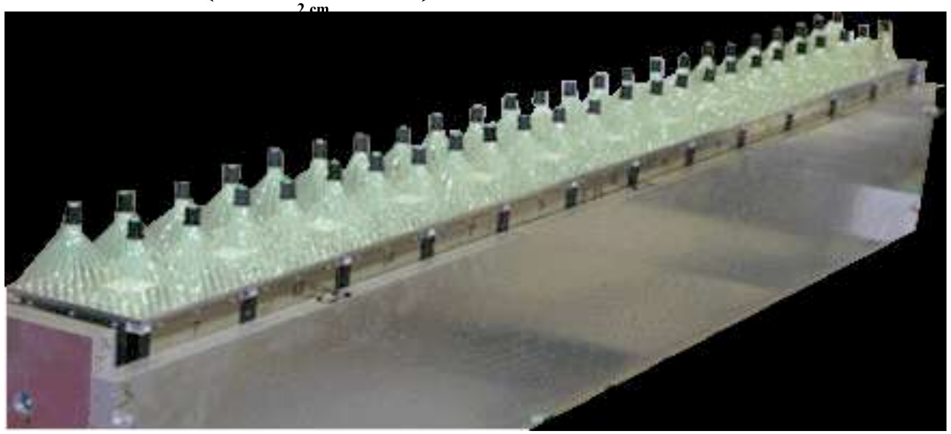


EMCal Readout



Preamplifier + APD



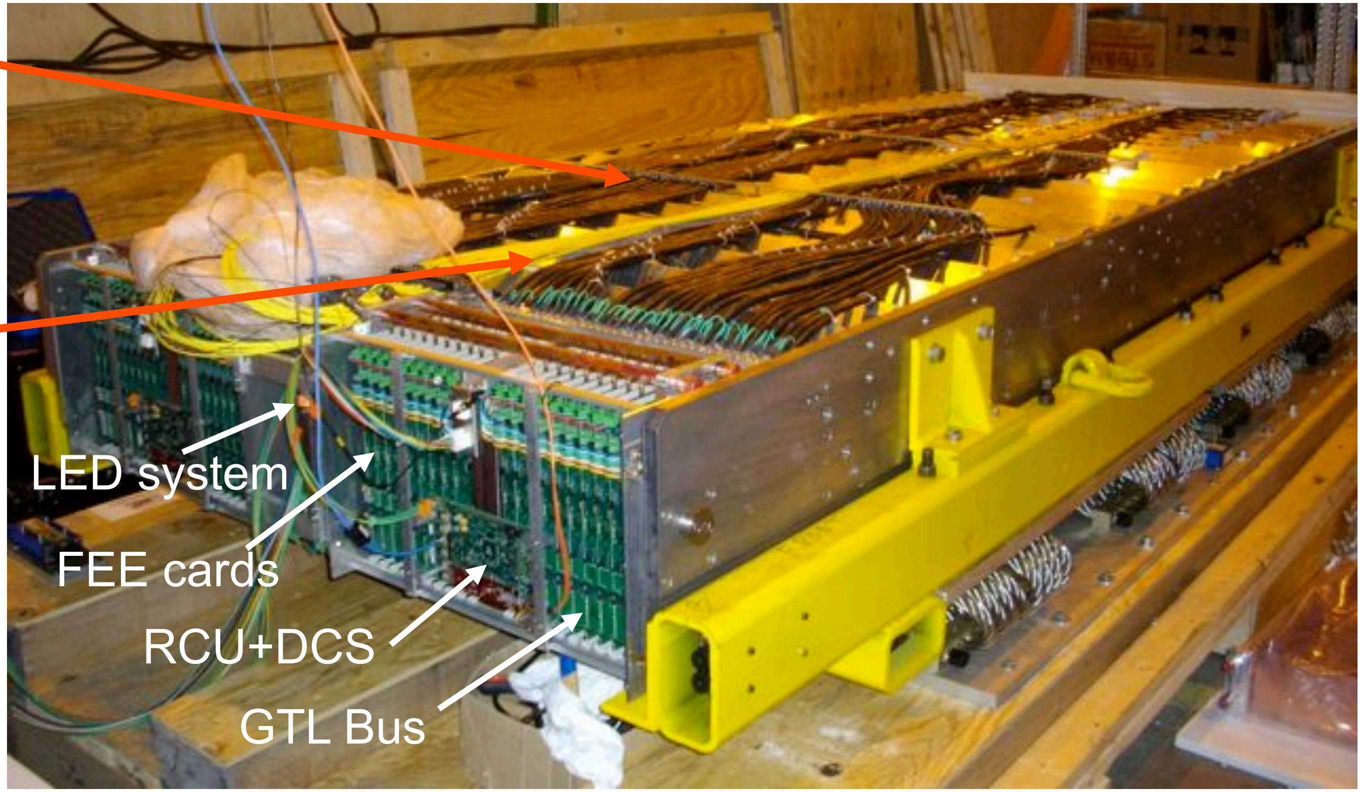


- 4 x (6x6 cm^2) towers/module
- WLS fiber readout on 1cm grid
- 5x5 mm^2 Hamamatsu and Perkin Elmer APDs
- ~4.5 photo-electrons/MeV at gain M=1
- Operated at nominal gain M=30
- Full-scale Energy = 250 GeV

EMCal SM Readout Assembly and Readout

- Signal Cables
  - 16 towers each

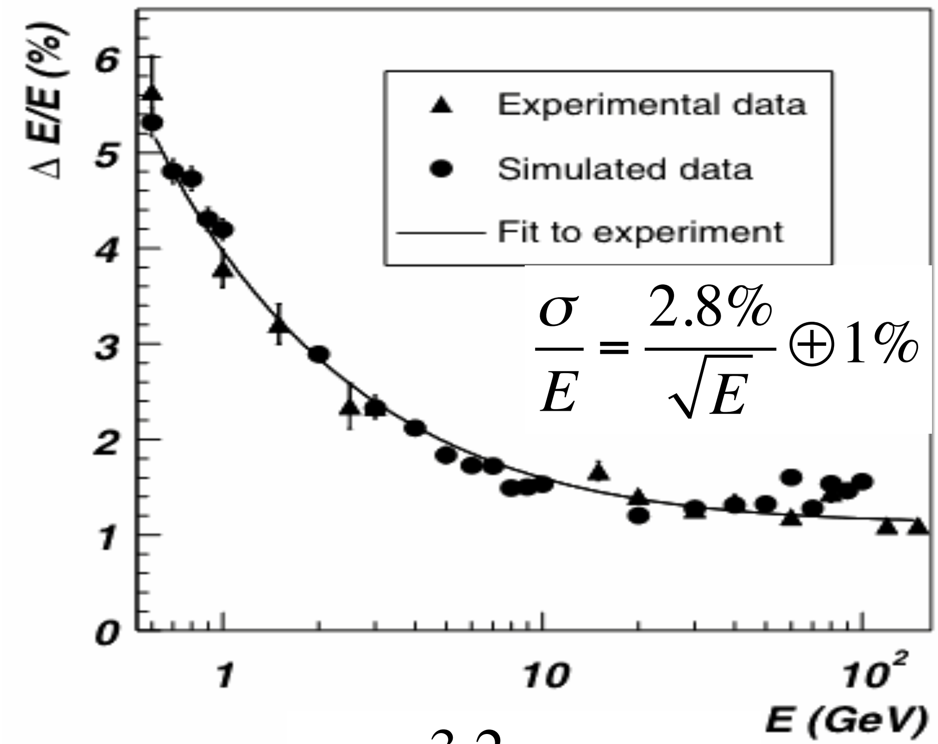
LED fibers
(monitoring)



- 2 FEE crates per SM
  - 36 + 1 FEE cards + 3 TRU (Trigger Region Unit) per SM
- 1 Readout+Detector Control Unit (RCU(Readout Control Unit) +DCS) per FEE crate
  - Control via ethernet. Readout via fiber optic (ALICE DDL standard)
  - 2 GTL Readout/Control Bus per FEE crate

EMCal/PHOS Performance

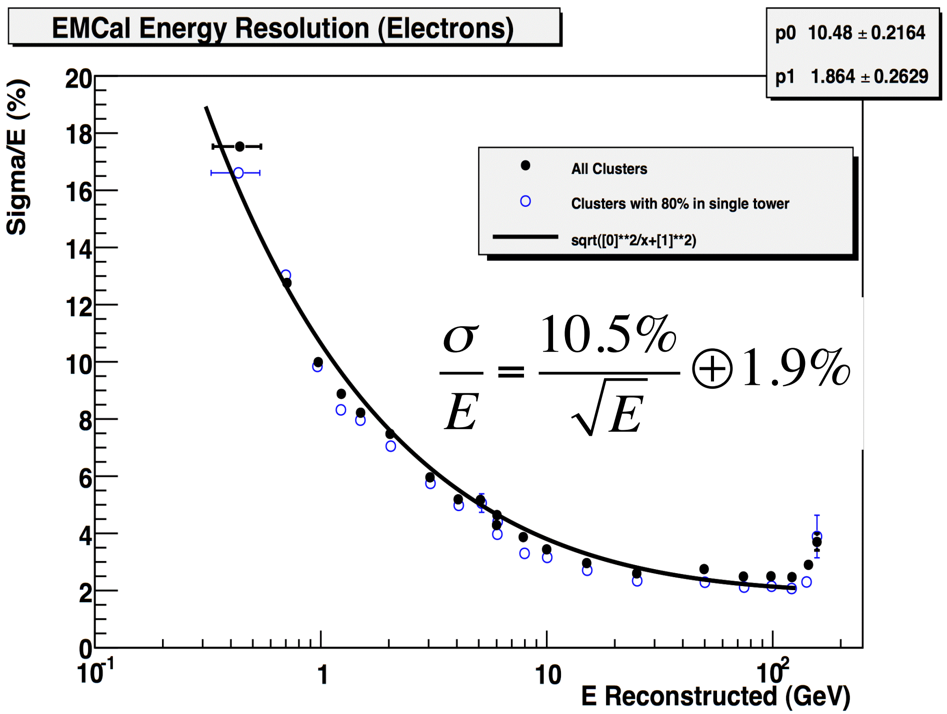
PHOS



$$\frac{\sigma}{E} = \frac{2.8\%}{\sqrt{E}} \oplus 1\%$$

$$\sigma_x = \frac{3.2}{\sqrt{E}} \oplus 0.7mm$$

EMCal

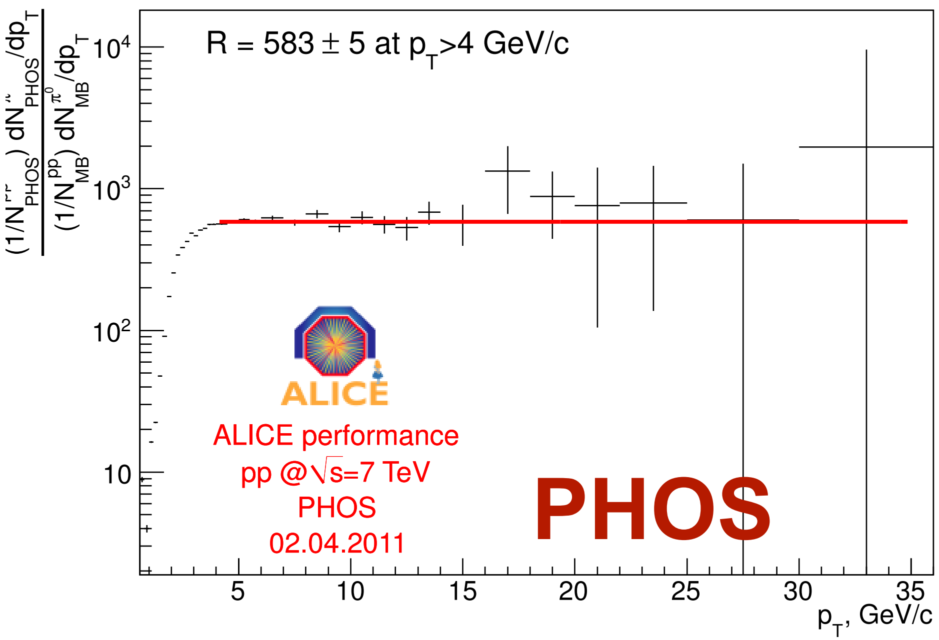


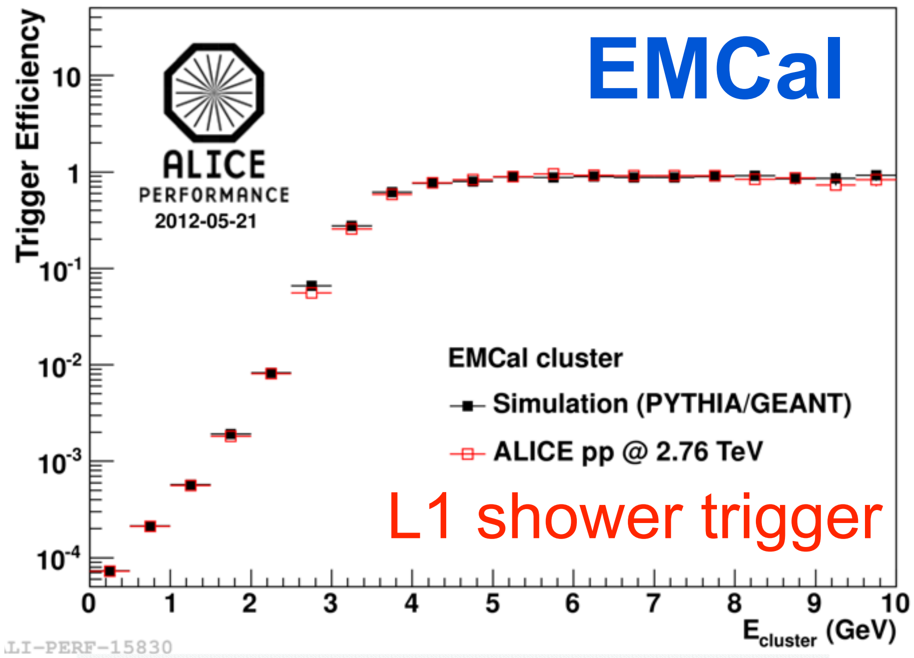
$$\frac{\sigma}{E} = \frac{10.5\%}{\sqrt{E}} \oplus 1.9\%$$

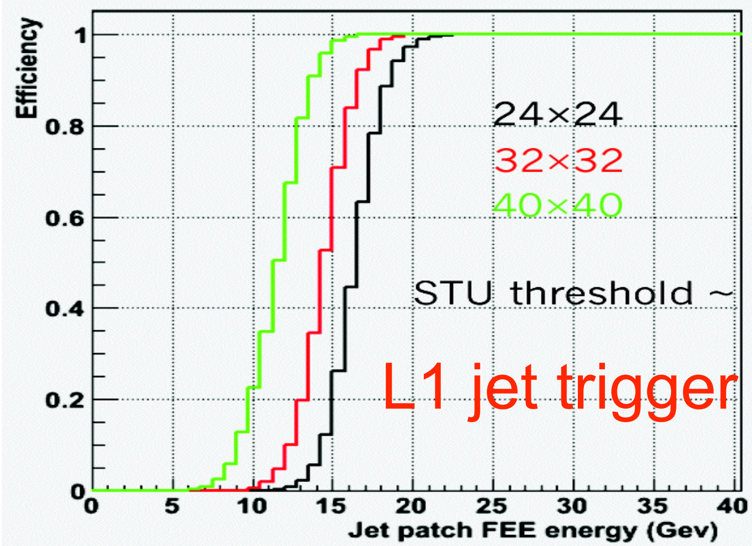
$$\sigma_x = \frac{5.3}{\sqrt{E}} \oplus 1.5mm$$

- Both calorimeters have had extensive beam tests at the CERN PS
- Important for detailed response description in Monte Carlo simulation

L0 and L1 Trigger efficiencies



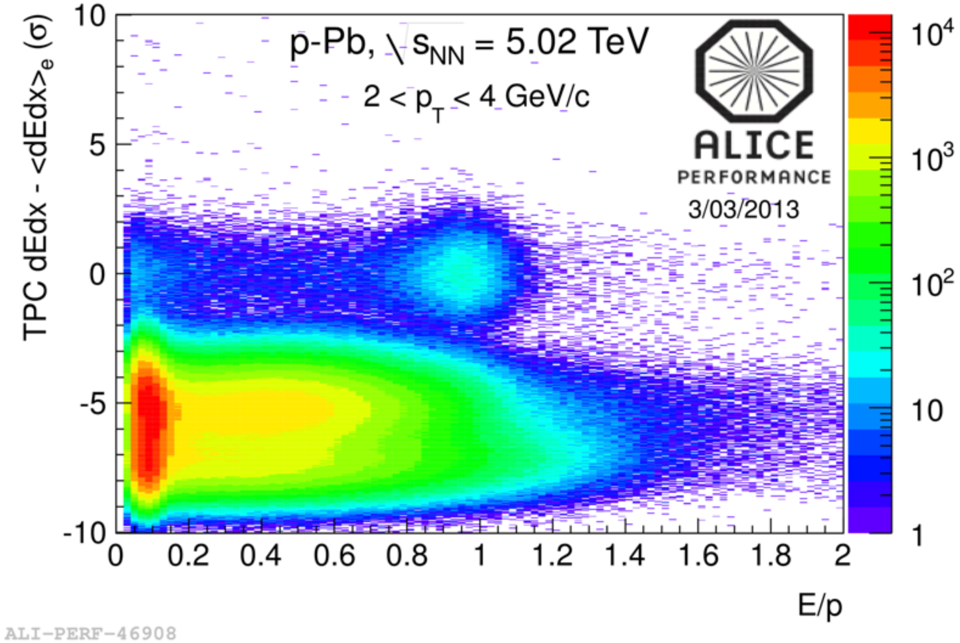


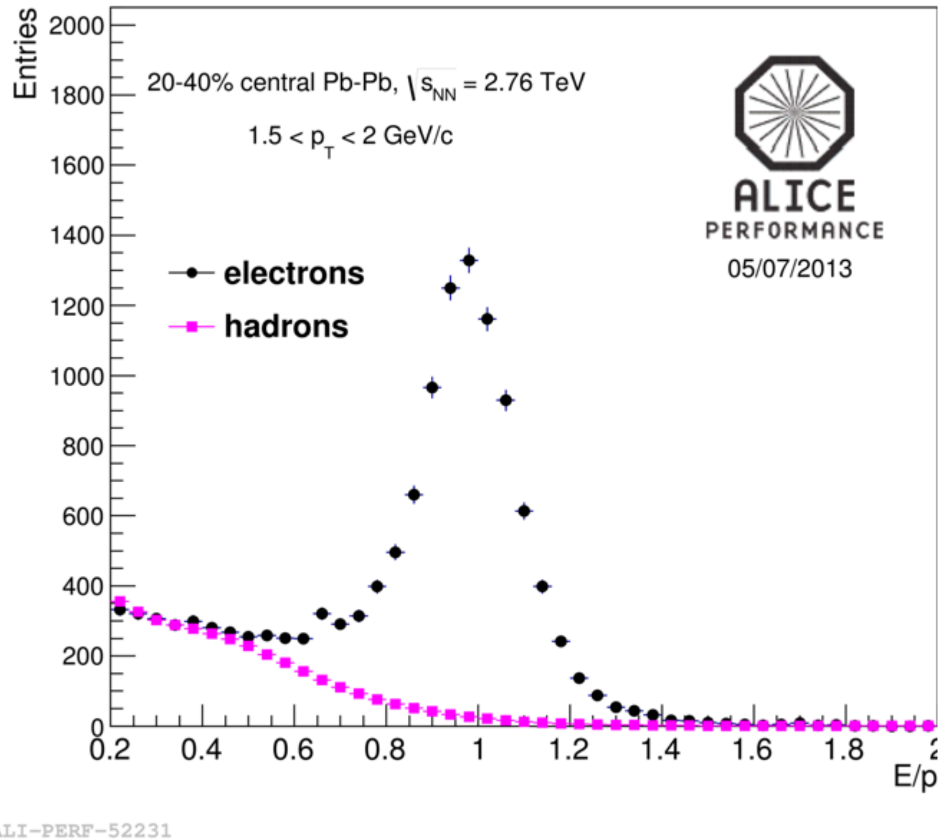


- Calorimeter triggers have been in operation during LHC 2011 p+p 7 TeV run period with rejection factors of ~x3000

E/p response (EMCal)

EMCal

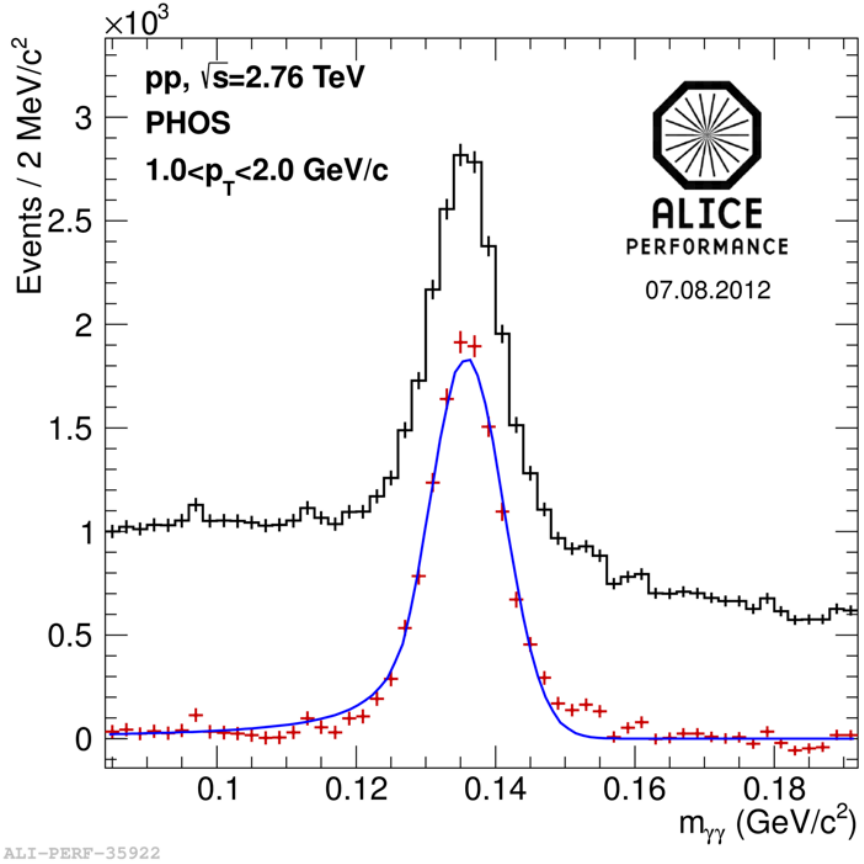




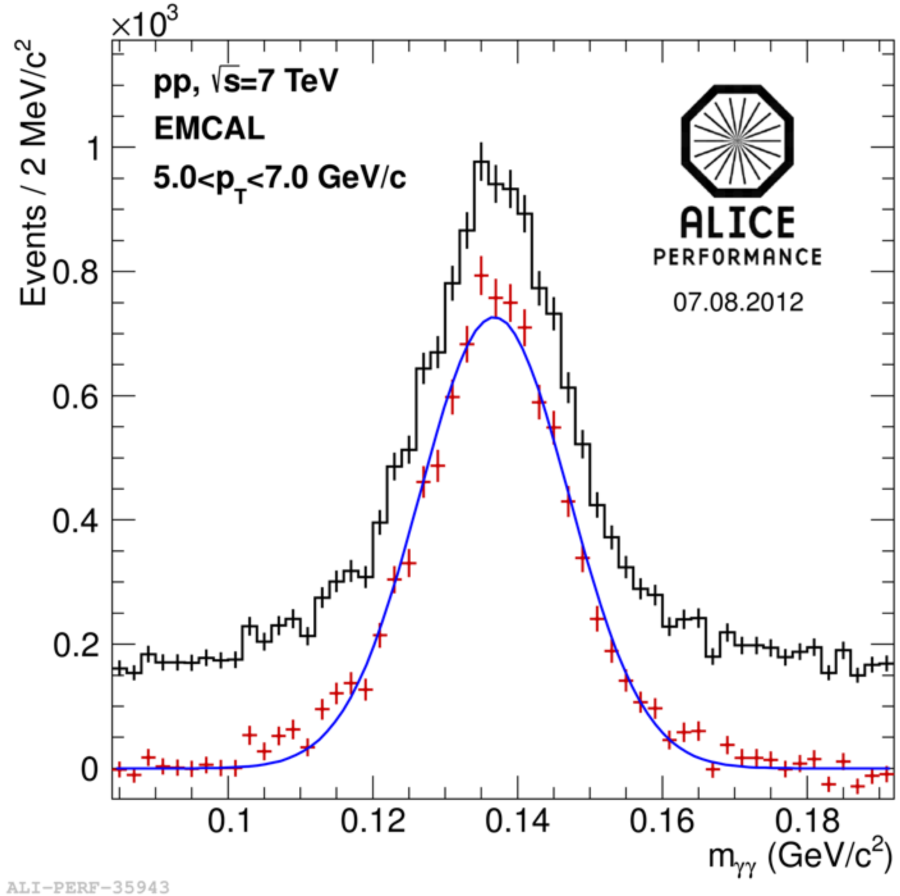
- Seen clear E/p peak (p-Pb, 5.02 TeV), and demonstrated clear discrimination between hadrons and electrons.

Invariant mass spectra in p+p: π^0

PHOS

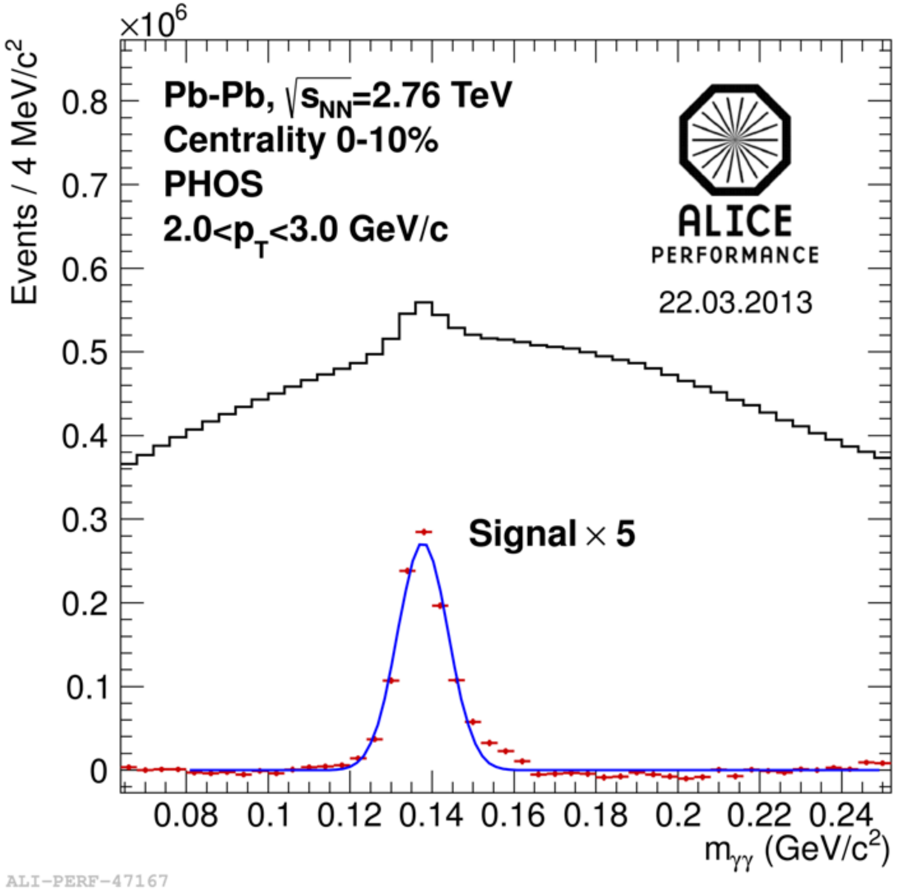


EMCal

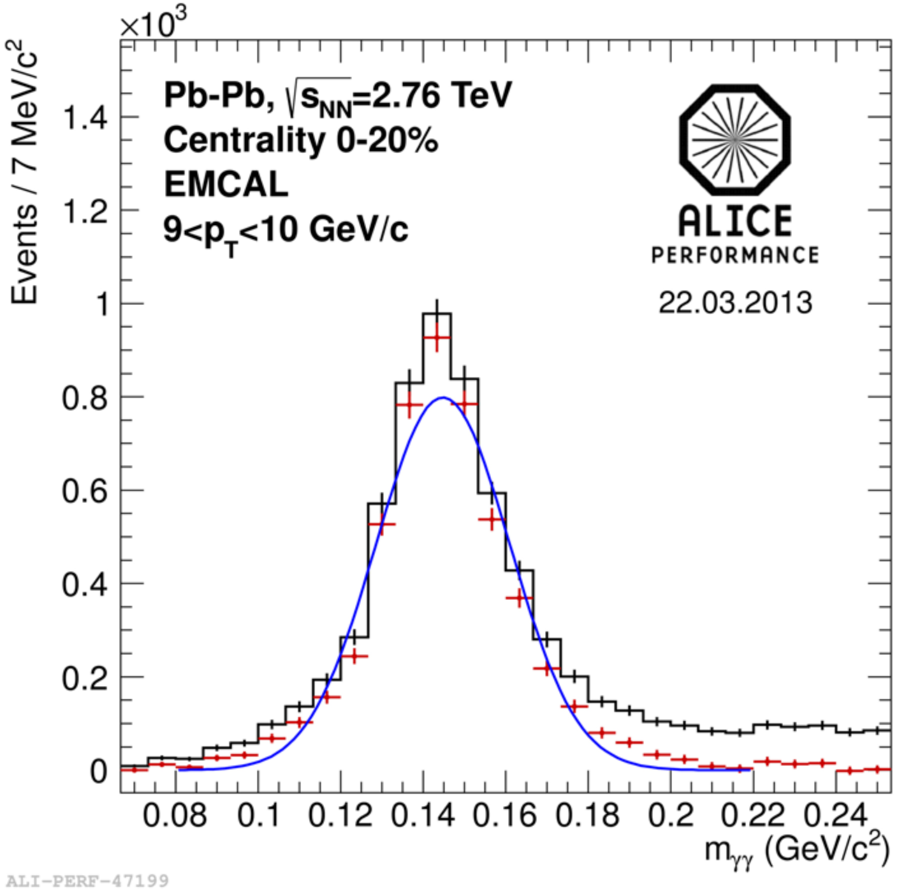


Invariant mass spectra in Pb+Pb (central): π^0

PHOS

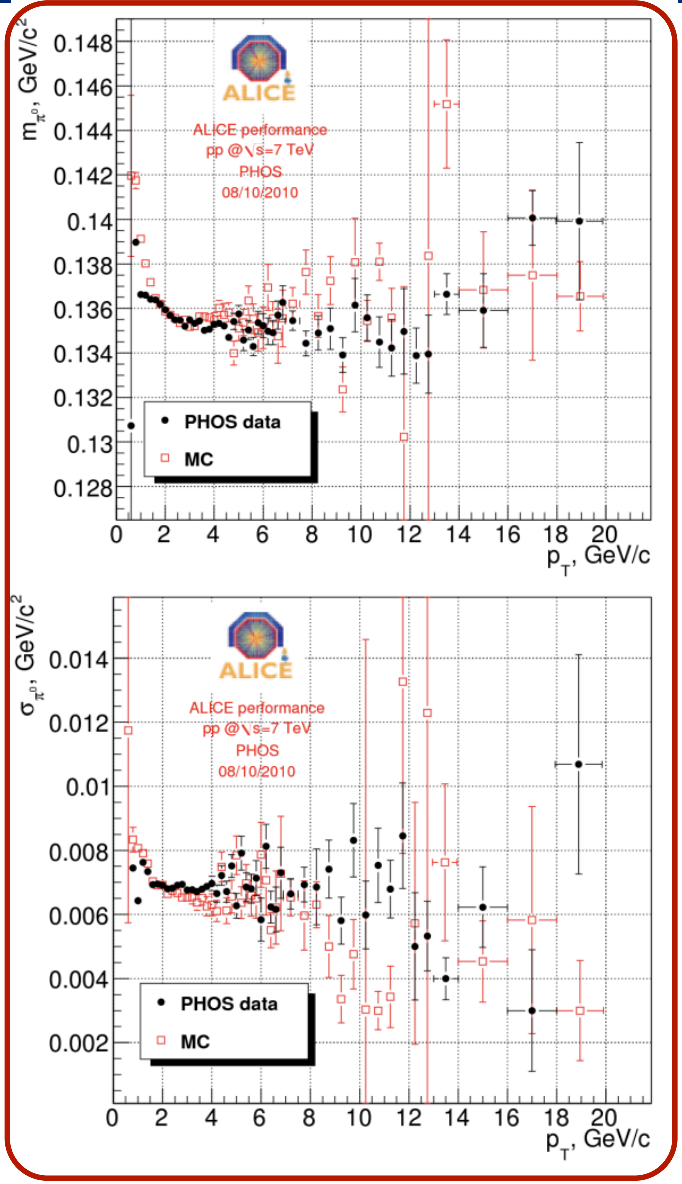


EMCal

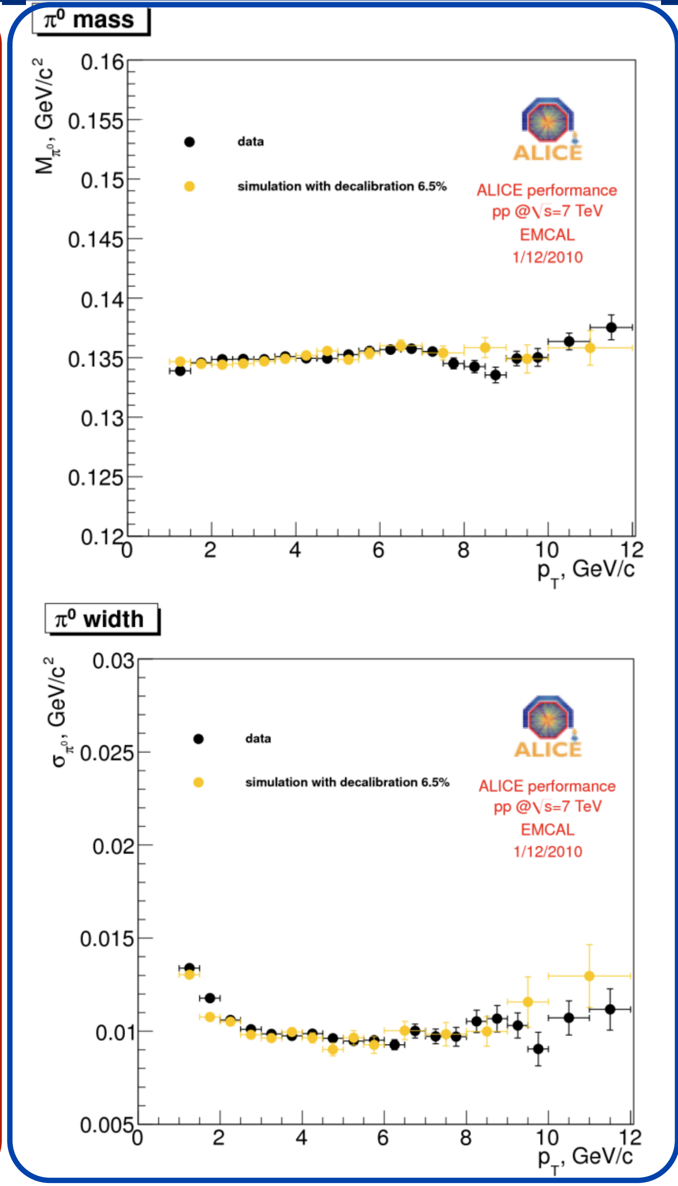


Mean and width of π^0 mass peak (p+p)

PHOS



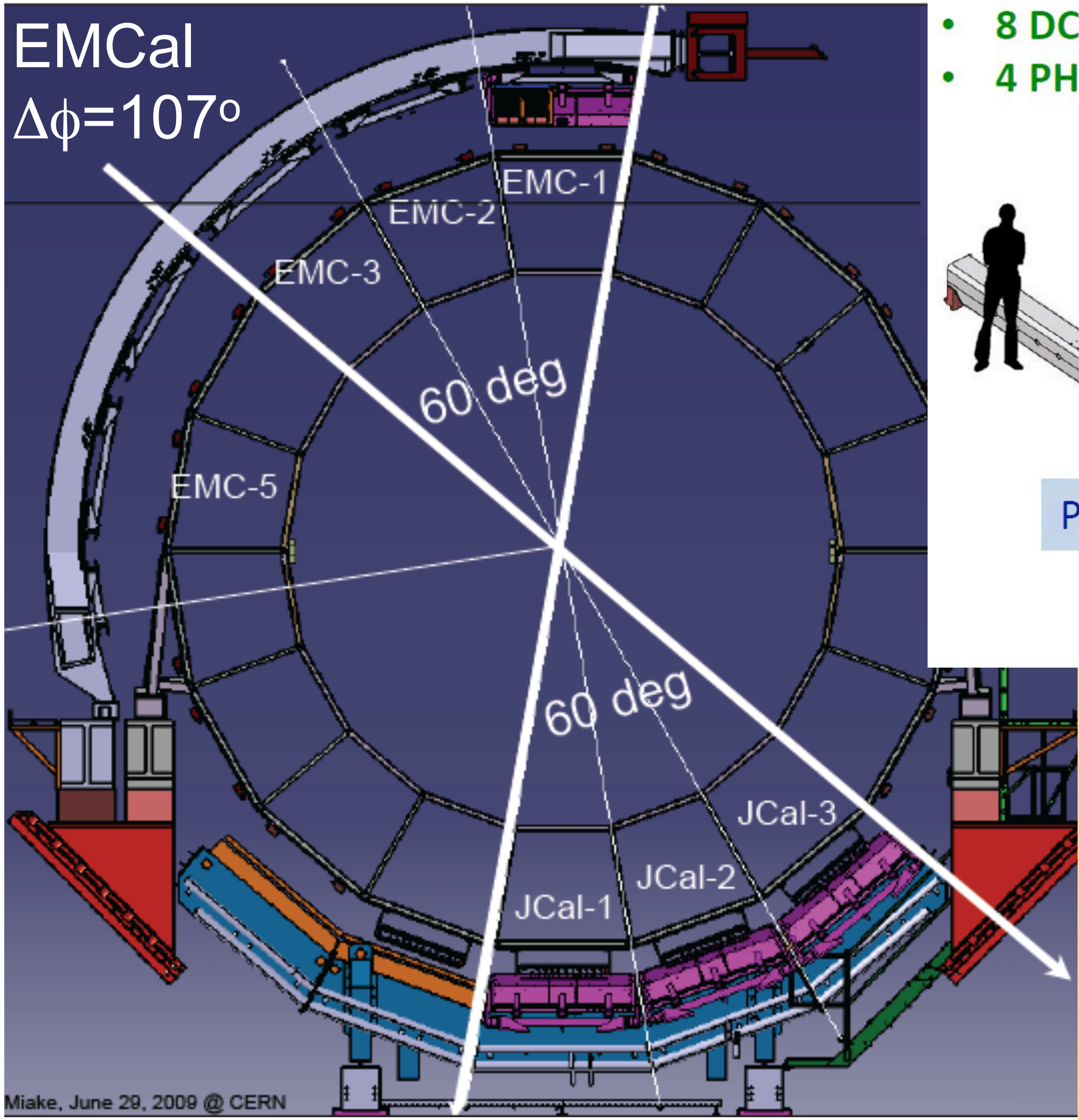
EMCal



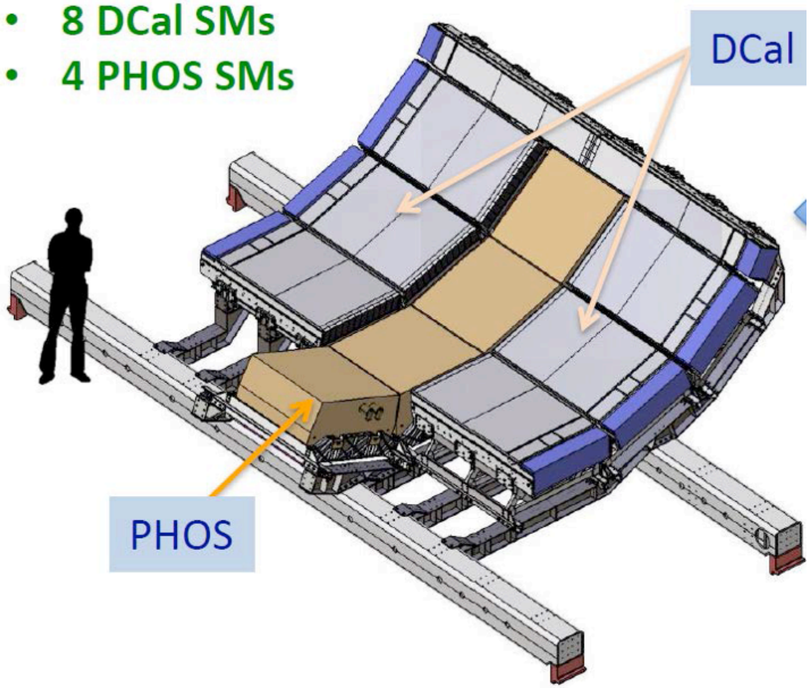
Good agreement with simulation

2. Upgrade during LHC long shutdown (2013-2014)

EMCal Extension/Upgrade (DCal)



- 8 DCal SMs
- 4 PHOS SMs



DCal (**D**i-jet **Cal**orimeter):

Same modules as the EMCAL, shorter SuperModules in η.
Including PHOS, acceptance is $\Delta\eta=1.4$, $\Delta\phi=67°$
Enhance di-jet yield (w/ jet trigger)
To be completed installation in 2013-2014 shutdown.

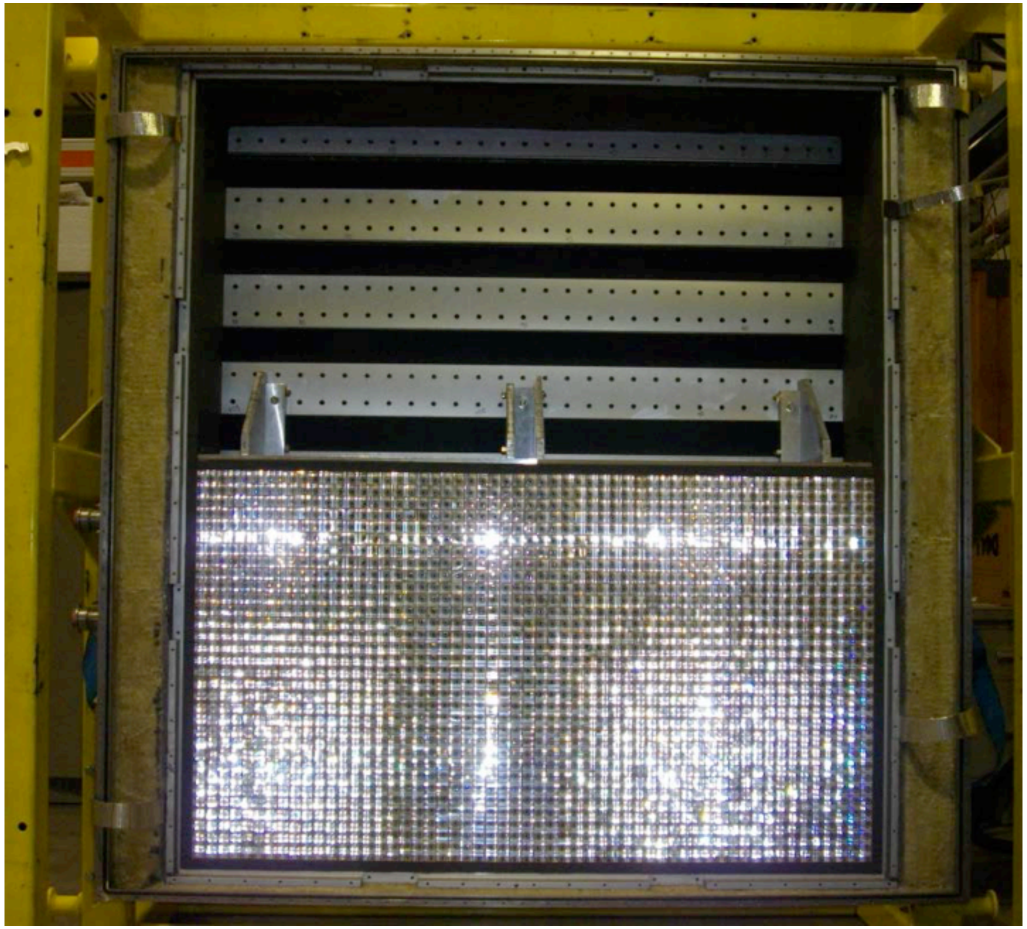
DCal installation (2013 - 2014)

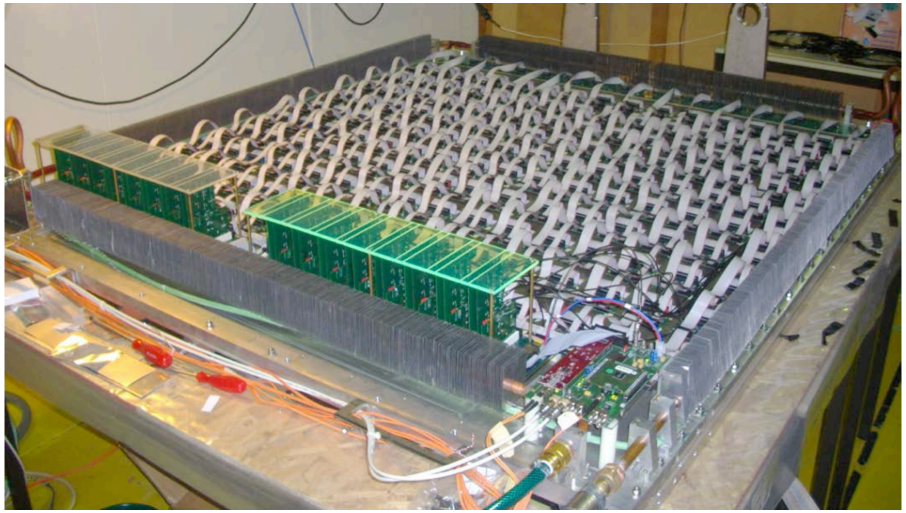
DCal SM in ALICE surface before installation (Sep. 2013 @ CERN, P2)

DCal C-side installation (2013 fall)

- 3 sectors of full DCal SMs, and 1 sector of 1/3 SMs
- C-side sectors installed in fall 2013, A-side to be installed in fall 2014
- L0 and L1 trigger geometry reconfiguration in on-going.
- DCal + PHOS common jet trigger is also under development.

PHOS new module and CPV for Run-2

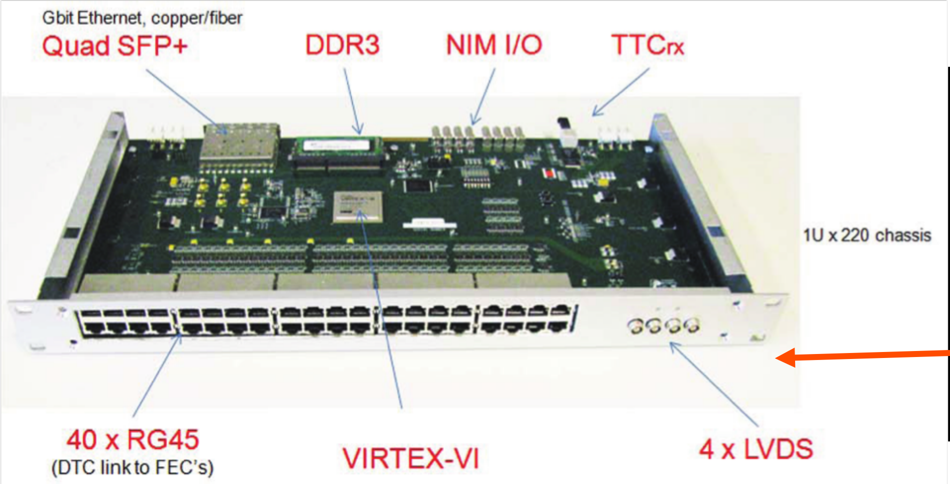


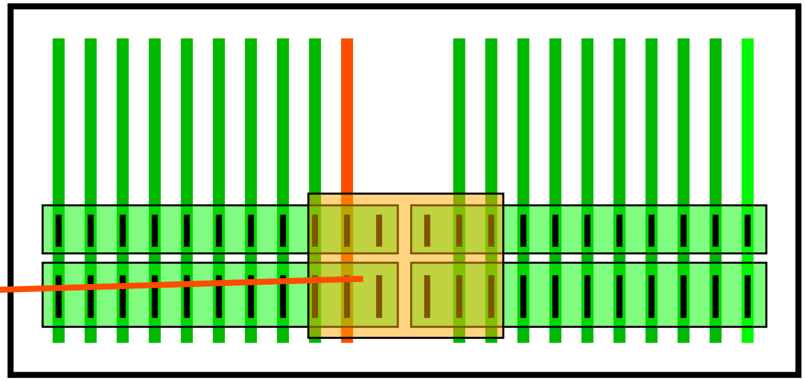


CPV for PHOS

- Added new PHOS 1SM (50% coverage of 1 SM = 1,792 crystals).
- For Run2, PHOS will have 3½ modules with azimuthal coverage $\Delta\varphi=70^{\circ}$.
- Charged Particle Veto (CPV) will be installed in front of one PHOS SM.

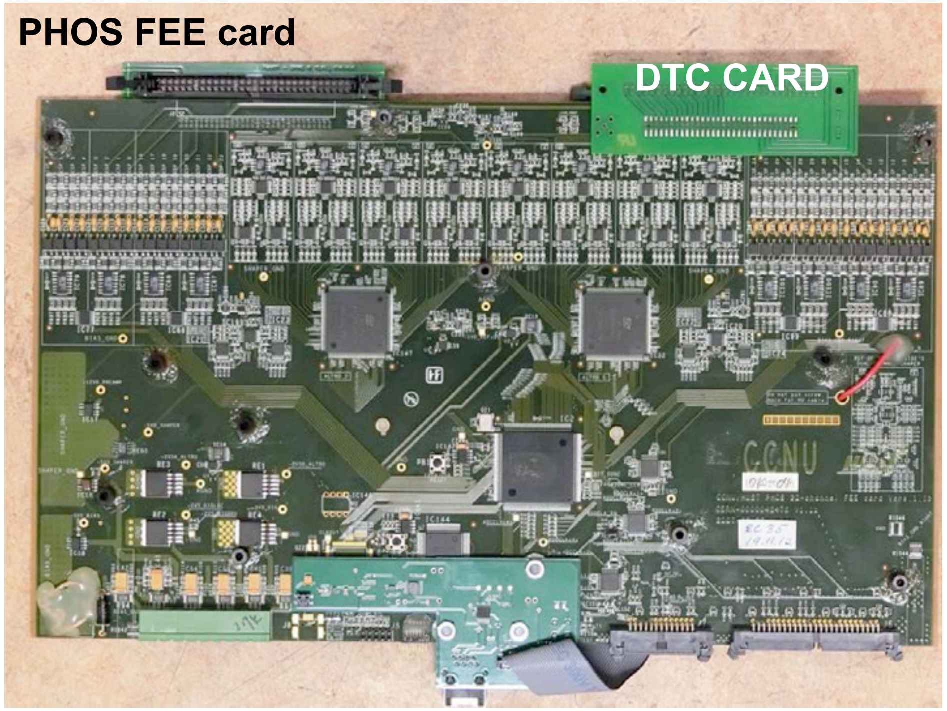
FEE Upgrade: RCU/GTL bus ⇒ point-to-point SRU

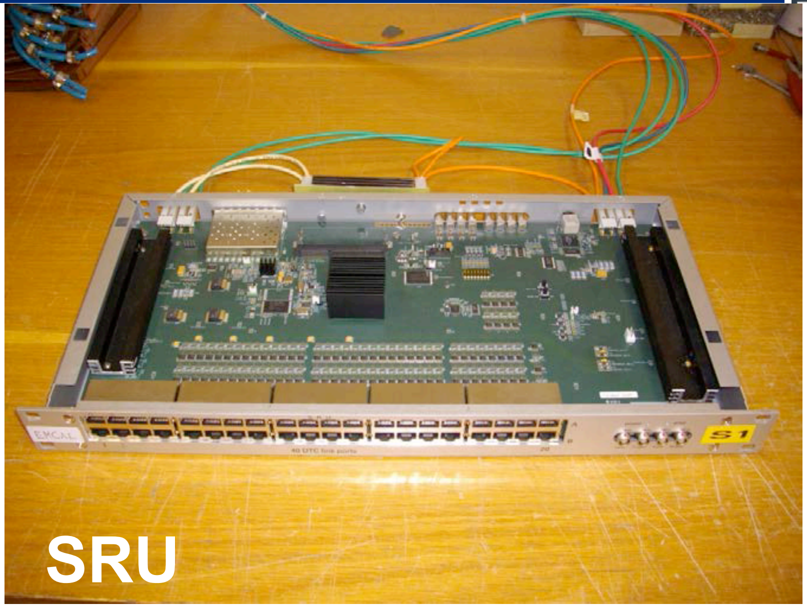




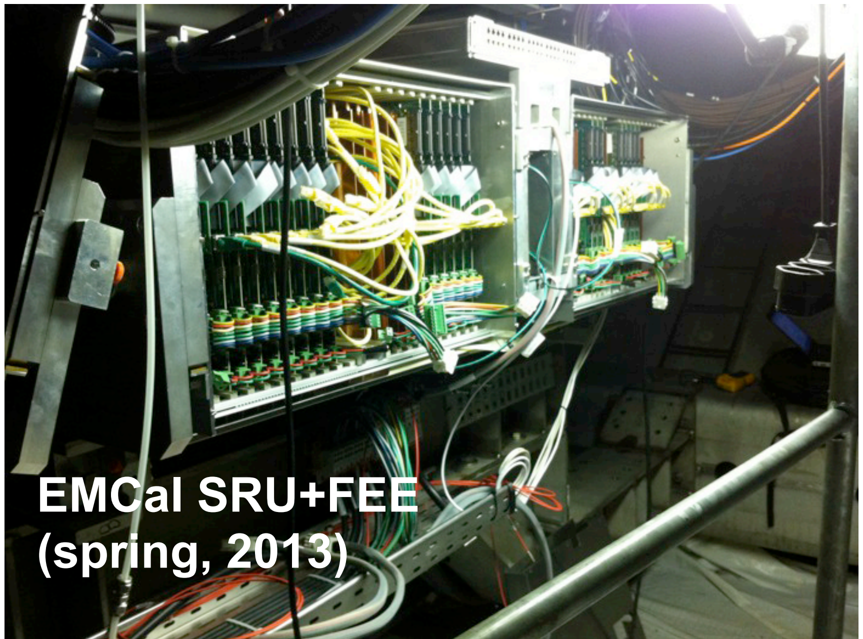
- Replace 2 (RCU+DCS+SIU) + 4 GTL Bus with single SRU mod.
  - Developed by CERN-RD51.
  - Replace serial readout of 10 cards/GTL bus with parallel readout of all FEE boards
    - Minimum readout speed ~30μs (set by ALTROs in FEE)
  - FEE-SRU communication via DTC LVDS serial link
  - SRU-LDC communication via ALICE DDL protocol (or Gigabit ethernet)
    - Compatible with existing DDL readout – fibers/RORC
- **Results:** SRU readout allowed to achieve 20-50 times shorter readout time with respect to RCU readout in Run-1.
  - e.g.) PHOS readout time was 900 us (Run-1) -> up to 25 us by SRU.

Current status of SRU in PHOS/EMCal/DCal





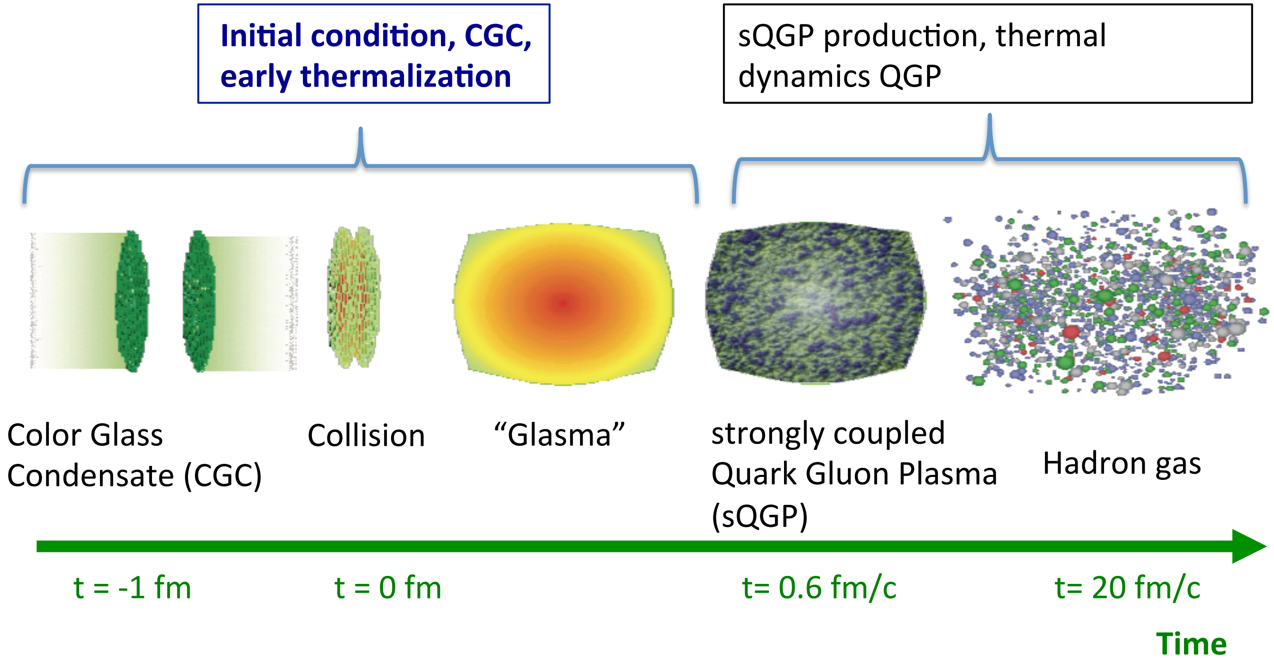
- **PHOS:**
  - upgraded all FEE boards (~430).
  - New SRU and FEE F/W is now being commissioned together w/ EMCal/DCal.
- **EMCal/DCal:**
  - SRU switching over done (2013, spring)
  - SRUs for all of EMCal + installed part of DCal (C-side)



3. Future upgrade plan:

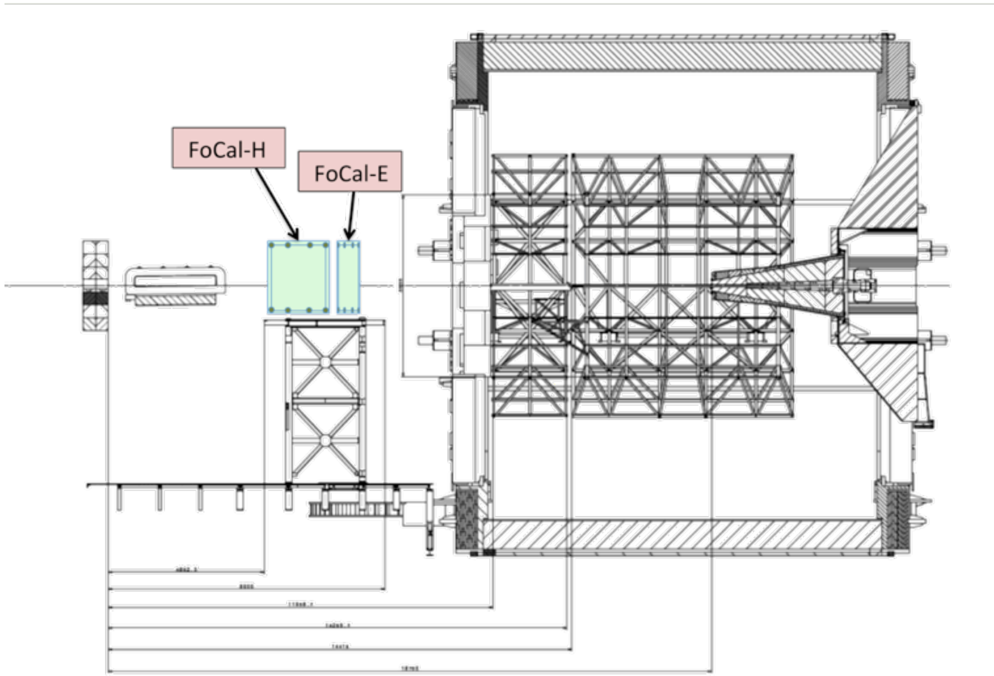
Direct photon measurements at forward rapidity region at LHC

Physics of photon measurements at forward η @ LHC



- Results from d-Au (RHIC), p-Pb (LHC) collisions, there are some indications of **Color Glass Condensate (CGC)** formation, but not conclusive.
- Main observables so far by hadrons, which include final state interaction.
- **Experimental challenge**: essential to make a measurement at forward direction by a cleaner probe, such as **direct photons**.
  - ➡ Larger kinematic reach in saturation region at LHC.
  - ➡ CGC vs. Glauber initial condition
    - → key to understand the early thermalization of QGP.

Forward Calorimeter (FoCal) in ALICE

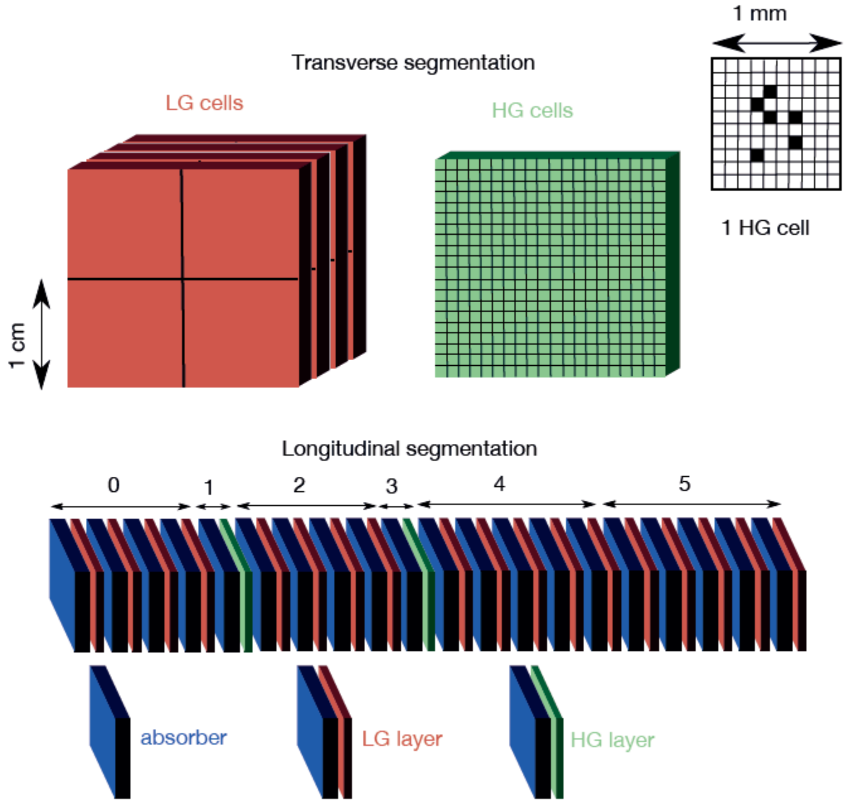


•Electromagnetic calorimeter for γ and π^0 measurement, with Hadron Calorimeter.

• At $z \approx 8$m (outside magnet) $3.3 < \eta < 5.3$

Main challenge: **separate γ/π^0** at high energy
- Need small Molière radius, high-granularity read-out
- Si-W calorimeter, granularity ≈ 1mm²

FoCal-E Strawman Design



- **Si/W** sandwich calorimeter layer structure:
  - W absorbers (thickness $1X_0$)+ Si sensors
- Longitudinal segmentation:
  - 4 segments low granularity (LG)
  - 2 segments high granularity (HG)

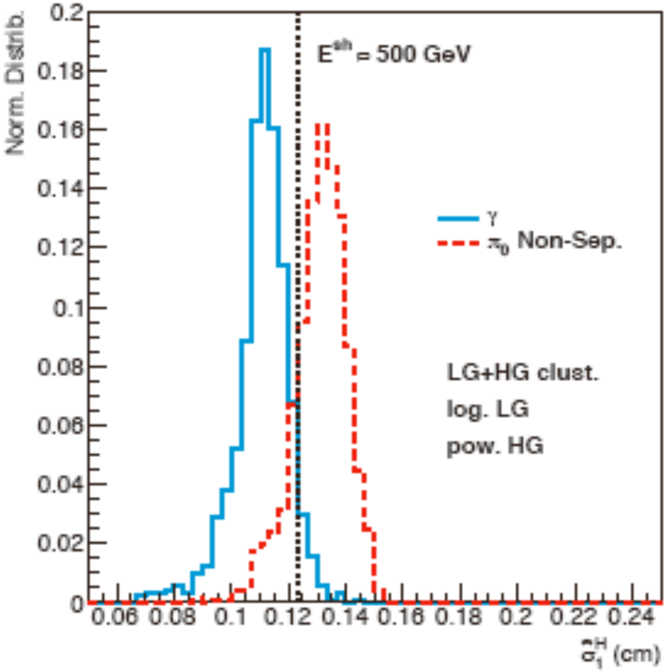
- **LG segments**
  - 4 (or 5) layers
  - Si-pad with analog readout
  - cell size 1 x 1 cm^2
  - longitudinally summed

- **HG segments**
  - single layer
  - CMOS-pixel (MAPS*)
  - pixel size ≈ 25 x 25 μm^2
  - digitally summed in 1mm^2 cells

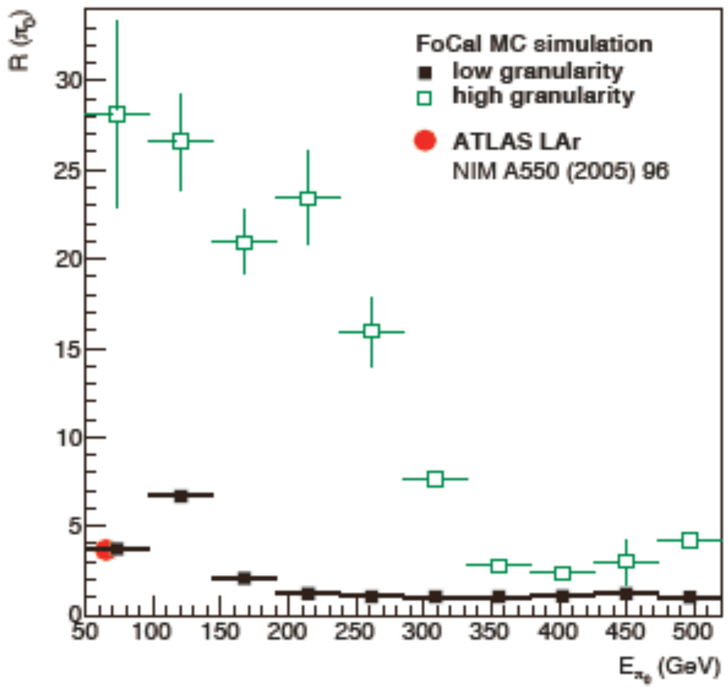
*MAPS = Monolithic Active Pixel Sensor (cm)

Detector Performance

lateral shower width
for γ and merged π^0



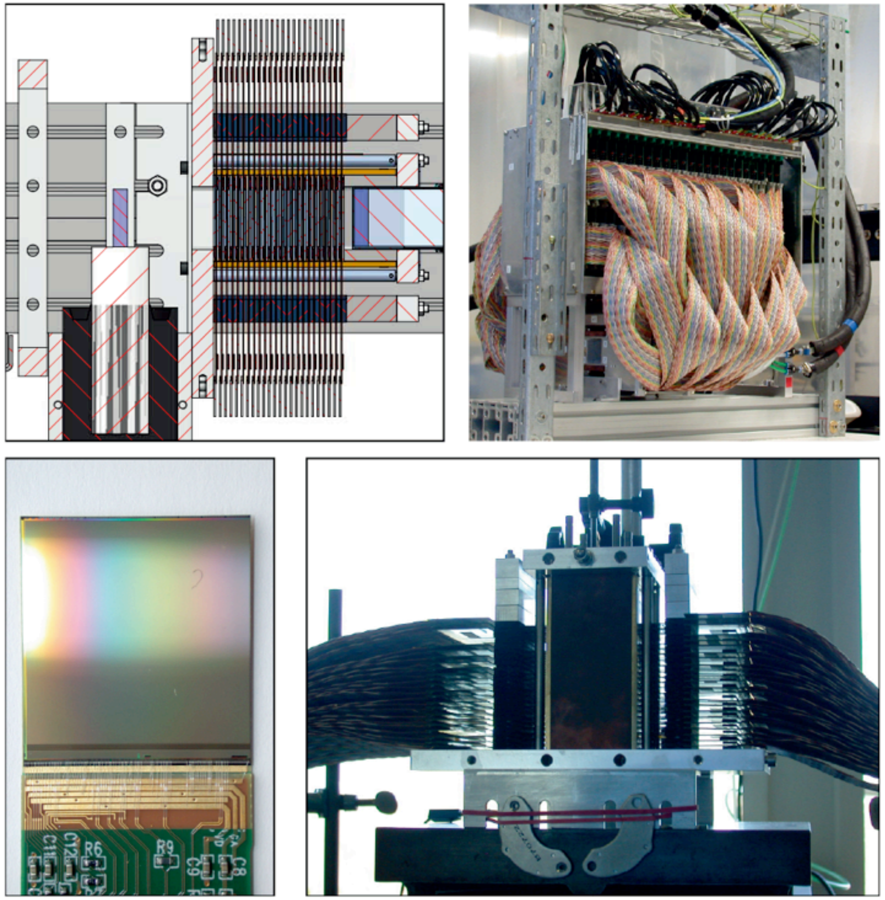
pion rejection factor



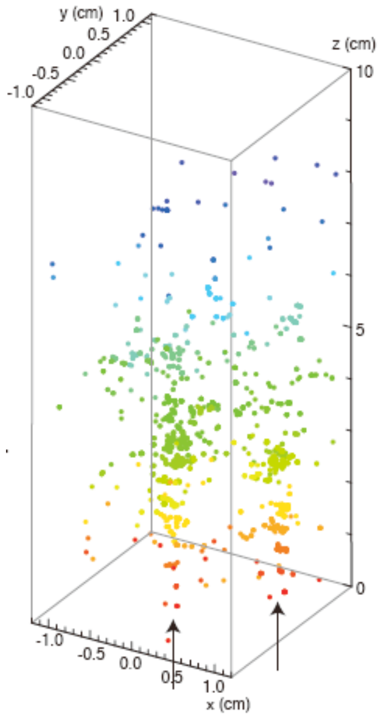
- Reasonable energy resolution, extremely good two-shower separation with HG segments
- → efficient pion rejection (e.g. via shower shape analysis)

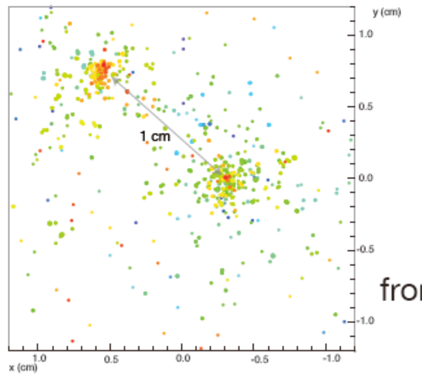
High Granularity (HG) Prototype, MAPS

MAPS prototype



- 4x4 cm² cross section, 28 X_0 depth
- 24 layers: W absorber + 4 MAPS each
- MIMOSA PHASE 2 chip (IPHC Strasbourg)
  - 30 µm pixels
  - 640 µs integration time
  (needs upgrade – too slow for experiment)
- 39 M pixels total
- Test with beams at DESY, CERN PS, SPS

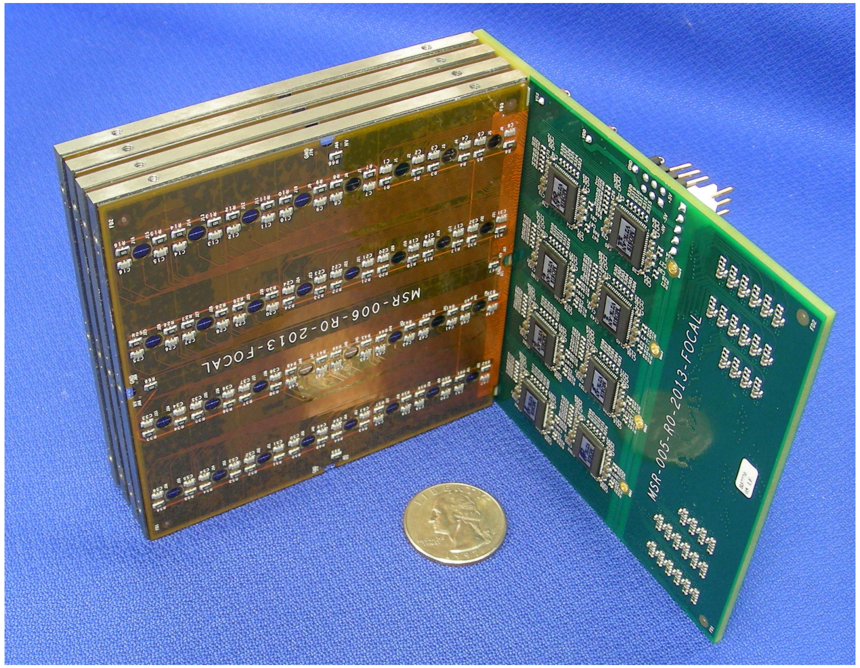




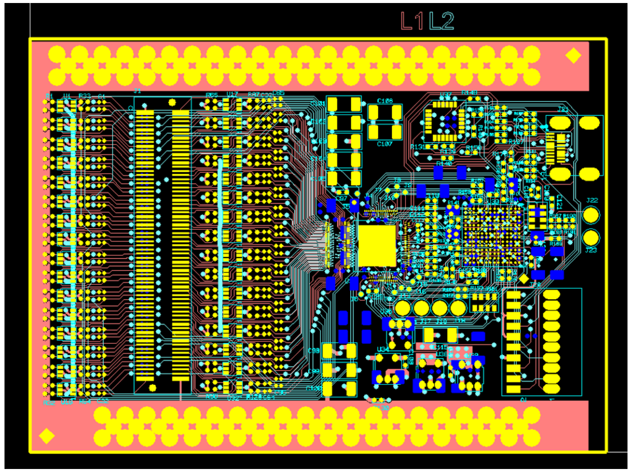
front view

Event Display:
measurement (DESY) of pile-up of two 5.4 GeV electrons, demonstrates two-shower separation capabilities

Low Granularity (LG) Prototype, PAD



- **First LG (PAD) prototype (ORNL).**
  - Si-pad with analog readout.
  - cell size 1x1 cm^2
  - longitudinally summed
- **4 tungsten plates are interleaved with silicon pad sensor layers.**
  - ORNL ASICs are located on summing board on side of module.
  - Readout by RD-51 readout system
    - APV25 hybrid/ Beetle hybrid



Beetle hybrid

PLAN

- The integrated system of FoCal-E (HG + LG) will be tested at PS (Sep. 2014) and SPS (Nov. 2014).
- LoI is under preparation, will be submitted in summer 2014 to ALICE.

4. Summary

- **Complimentary EM Calorimeters in ALICE:**
  - **PHOS**: high resolution, low occupancy, limited acceptance, with emphasis to measure low p_T π^0's and thermal photons
  - **EMCal**: Moderate resolution and occupancy, large acceptance with emphasis to measure Jets
  - Run-1 performance:
    - PHOS and EMCal have been working as design.
- **Upgrades during LS1 (2013-2014):**
  - **DCal**, PHOS upgrades, SRU readout upgrade
- **Future upgrade in Forward region:**
  - **FoCal**: direct direct photons to determine the initial condition of QGP, crucial to understand QGP properties.