EM calorimeter for e+e- collider – 250 GeV

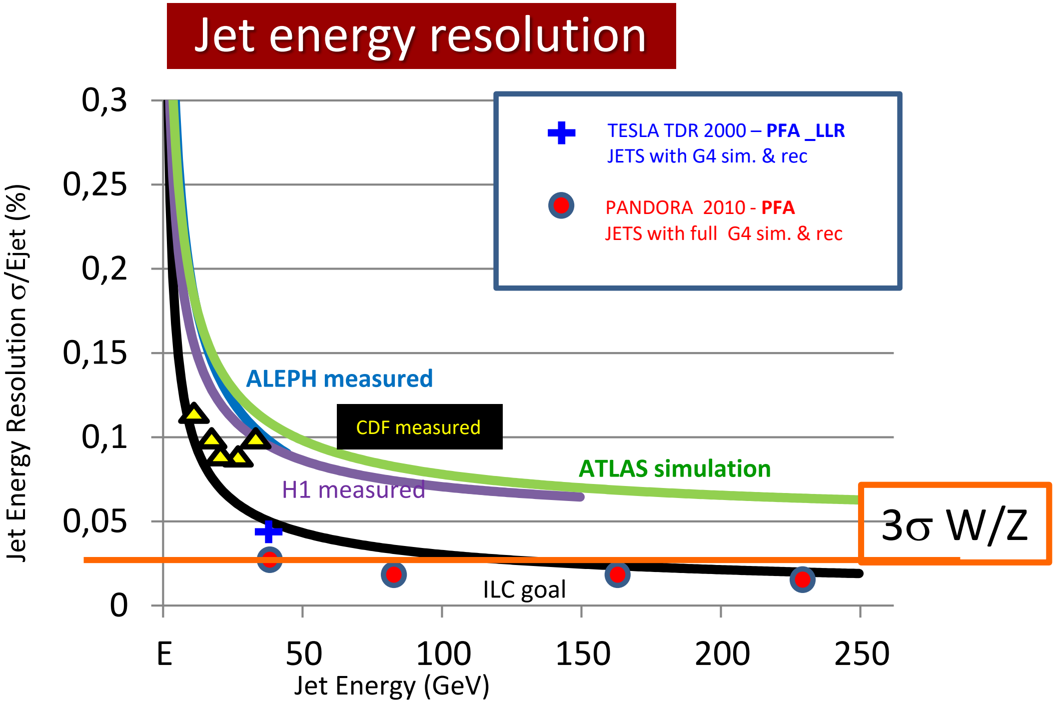
Jean-Claude Brient*

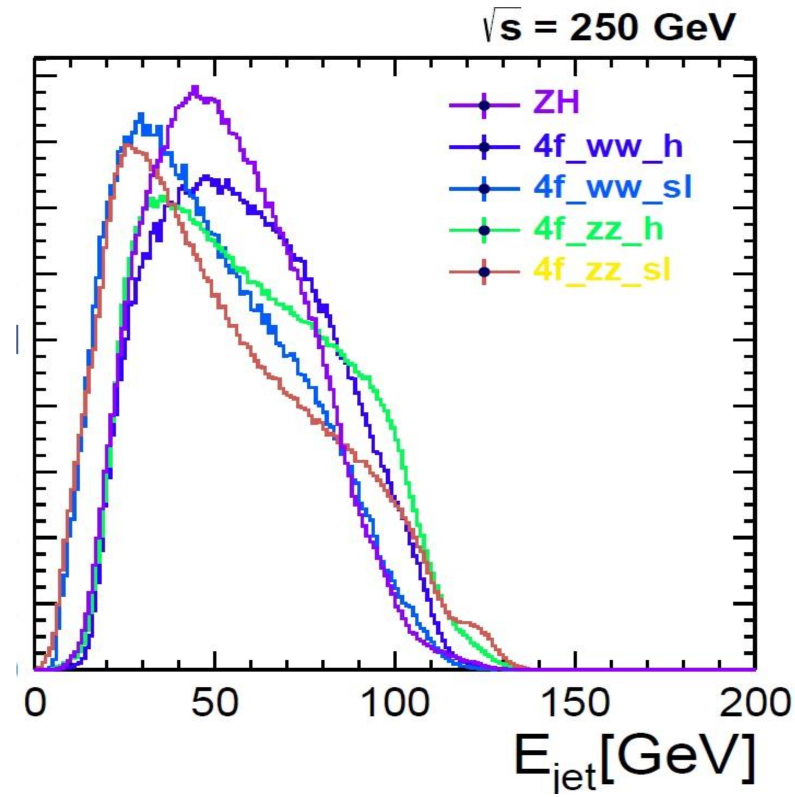
Laboratoire Leprince-Ringuet
Ecole Polytechnique – CNRS
Palaiseau

* co-convener for ECAL-ILD and former spokesperson of CALICE

e+e- collider at 250 GeV … to do what ? HIGGS FACTORY

- Study of e^+e^- physics from Z to 250 GeV
- ZH, ZZ, WW ,etc…
- BEST use of luminosity : Tag the boson through 2 jets decays
- tau polarization (Higgs CP violation, AFB(pol) …)



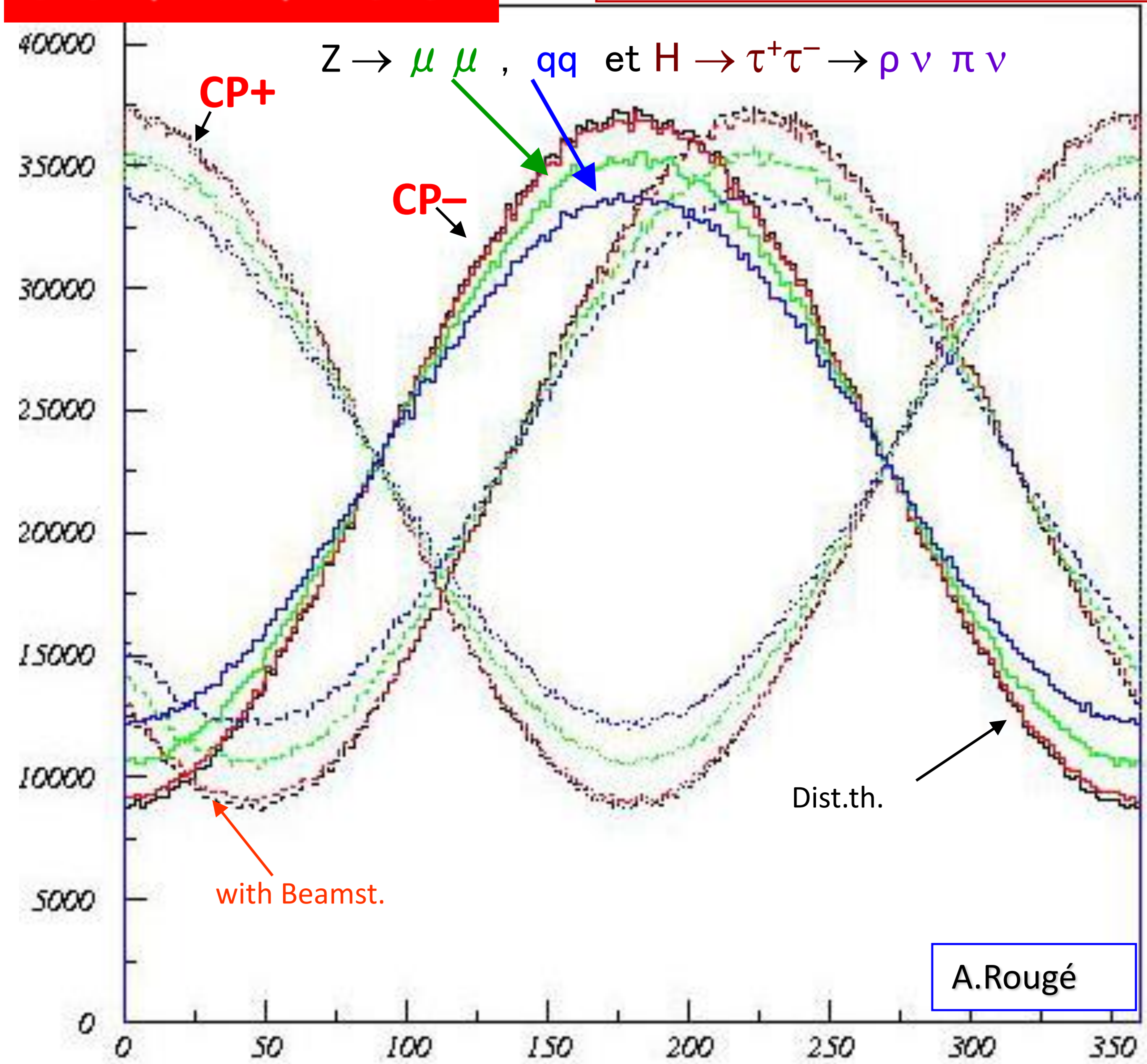


CEPC same conclusion than ILC …. Use of PFA >>>> Ultragranular calorimeter <u>inside coil</u> ("a la CMS")…. (in memory of ATLAS pb with PFA)

BEYOND JET(S). EW physics with tau

CP violation, Higgs sector

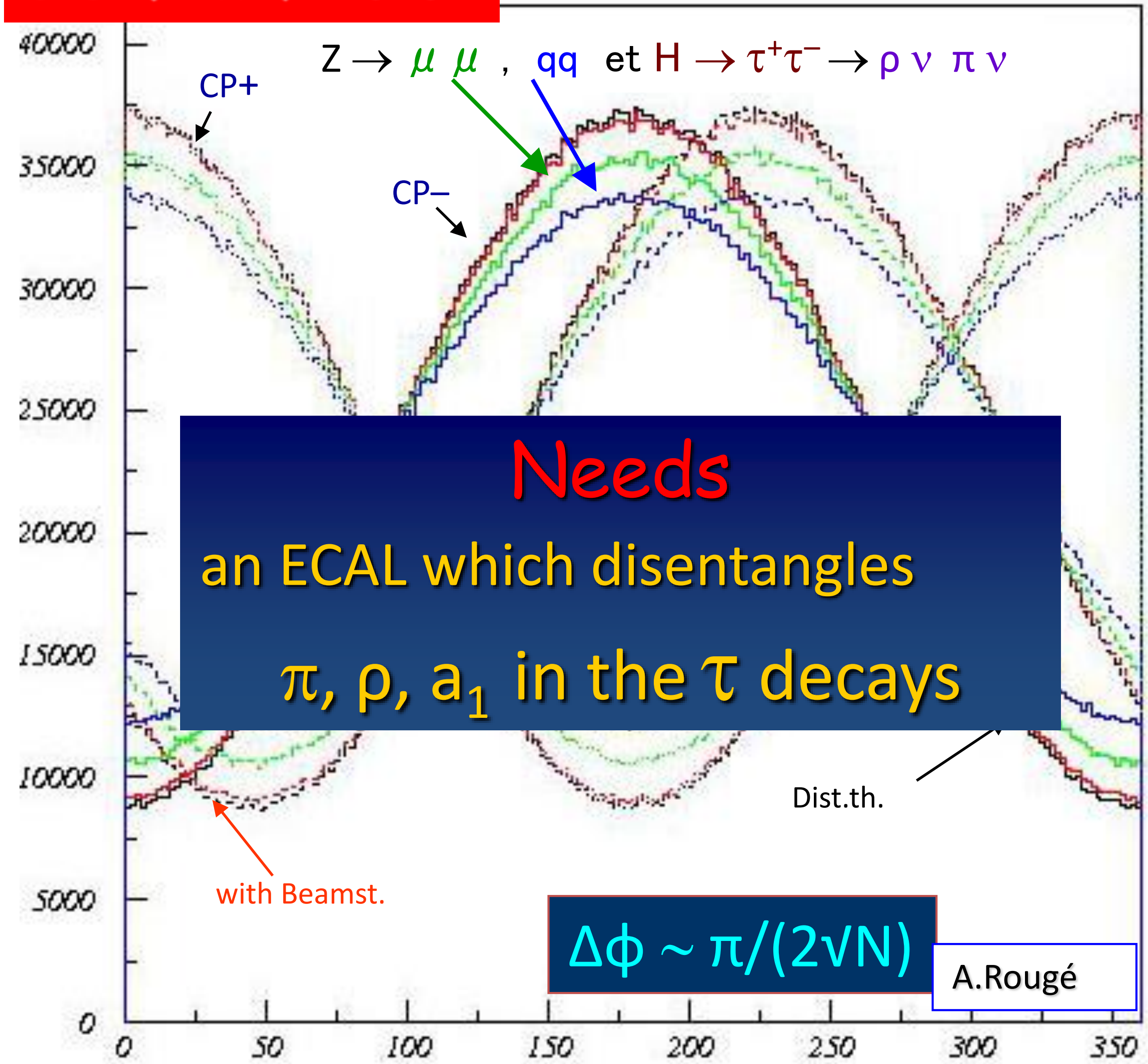
$e^+e^- \rightarrow ZH \rightarrow Z\tau^+\tau^-$



CP angle analyser

CP violation, Higgs sector

$e^+e^- \rightarrow ZH \rightarrow Z\,\tau^+\tau^-$



Needs

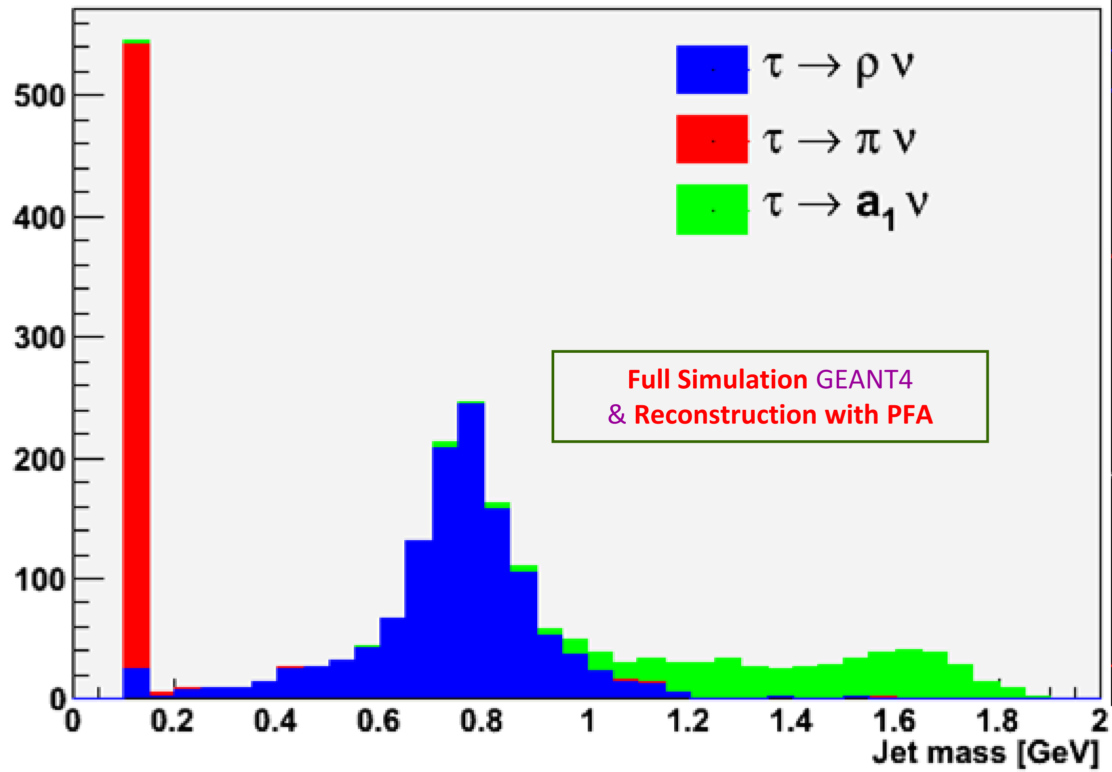
an ECAL which disentangles

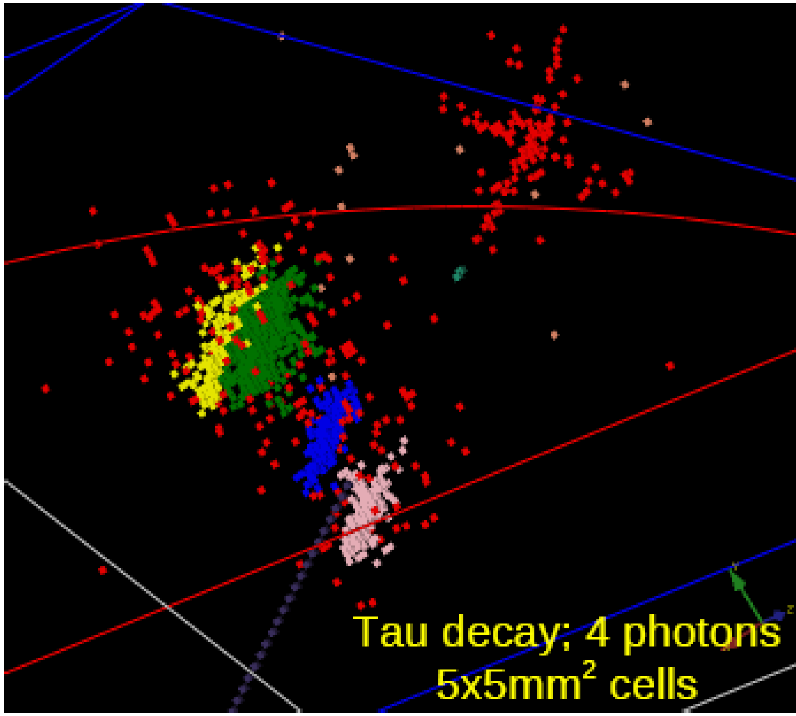
π, ρ, a_1 in the τ decays

$\Delta\phi \sim \pi/(2\sqrt{N})$

Thanks you to granularity and segmentation !!

Invariant Mass from τ decays





	Jet mass < 0.2	Jet mass in 0.2-1.1	Jet mass >1.1
$\tau \to \pi\nu$	90.2 %	1.7 %	8.1 %
$\tau \to \rho\nu$	1.7 %	87.3 %	7.4%
$\tau \to a_1\nu$	0.6 %	7.4 %	92.0 %

CEPC would have 2 IPs experiments → BOTH detectors must have similar performances !!

A Cross Check is ESSENTIAL

All PFA studies are based on reconstruction program of simulated events with G4 (plus realistic digitization) !!
But, never tested in full size experiment
(CMS use a kind of EFLOW…. Due to the absence of long. Seg.)

Realistic ?

1 - take **CALICE** prototype TEST BEAM DATA.

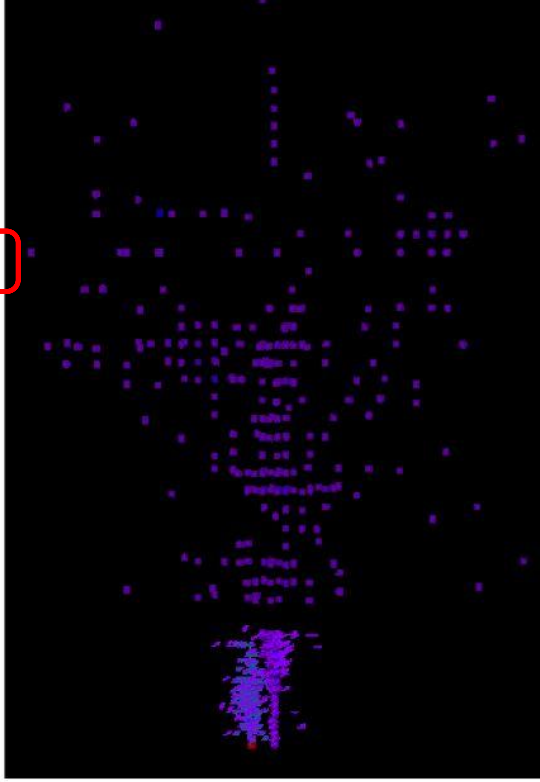
2 - Superimpose TB interaction at several distance and energy

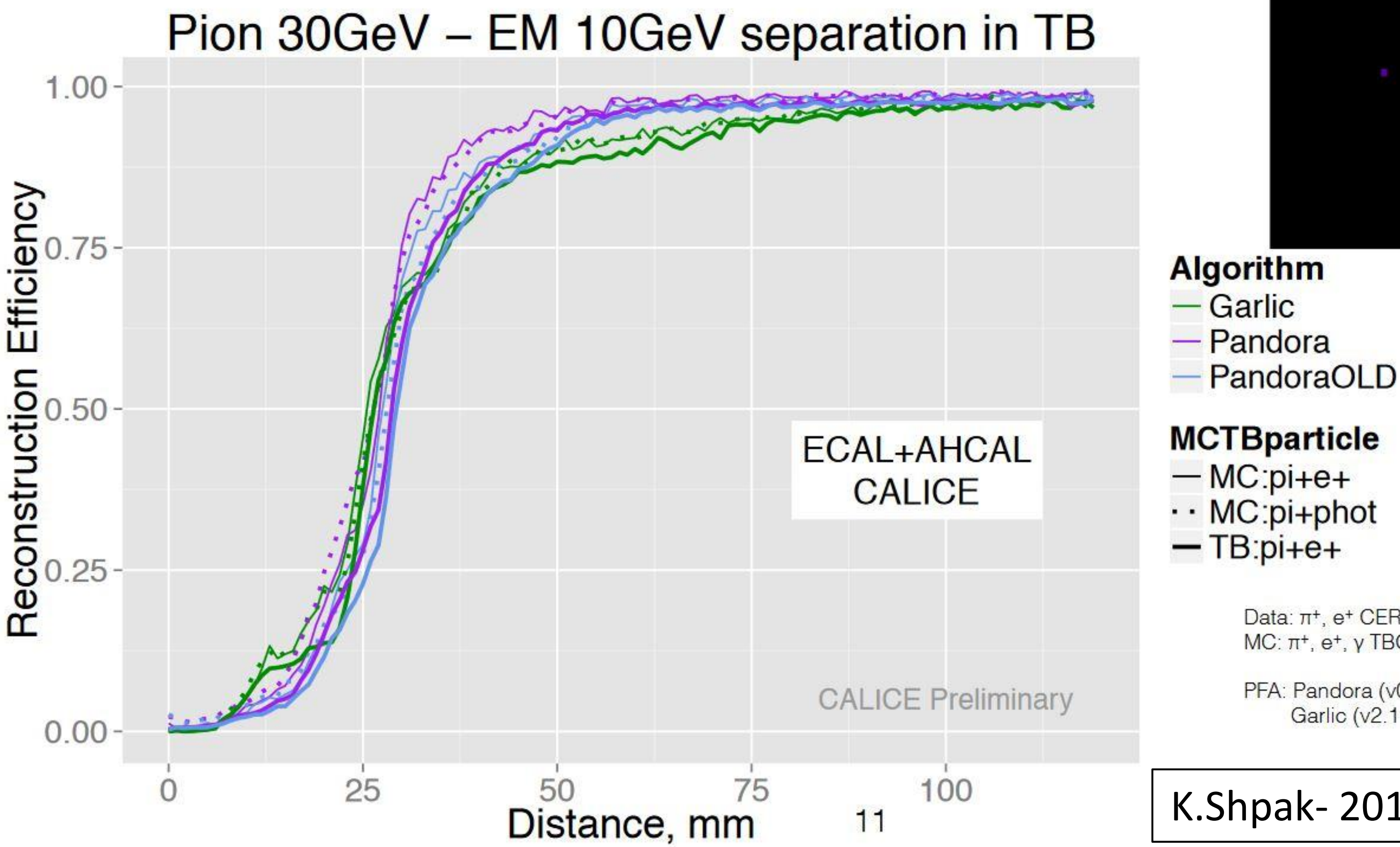
3 - Compare performances on Data and Simulation for
Several reconstruction programs and several
Hadronic interaction models in Geant4

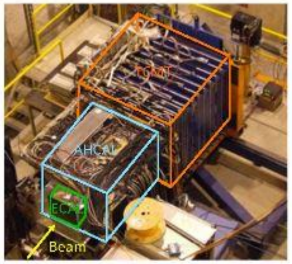
Hadron-EM separation: 30+10 GeV
$\pi^+ - e^+$ (TB+MC), $\pi^+ - \gamma$ (MC)

Probability to reconstruct exactly one γ & one π^+ for Pandora or one γ for Garlic (which does not reconstruct hadrons), Arbor not used for AHCAL.

Good agreement between TB and MC.







Data: π^+, e^+ CERN'07, ECAL+AHCAL
MC: π^+, e^+, γ TBCERN0807_p0709

PFA: Pandora (v00-14 & v02-04)
Garlic (v2.11), only ECAL

K.Shpak- 2017

CALICE Calorimeter for ILC

ULTRAGRANULAR CALORIMETER

Requirements

a) Calibration of O(100) millions channels and signal stability (small syst. uncert. needs same response for all collisions)

b) Capability to make zero suppress "in-situ" (we don't want to read empty pixel)

c) Keep S/N ≥ 8-10 at MIP level and coherent noise under control (limitation of the DAQ and it is not interesting to store noisy pixels)

d) Multiplexing for the quantity of signal line out (we don't want to have 100M cables)

e) Power and thermal management due to large number of channels (we don't want to burn our electronics readout)

f) KEEP the COST UNDER CONTROL (we want an affordable cost)

One set of answers

a) Choose stable device (silicon) or control & monitor the signal stability (Scint. or Micromegas)

b) ADC& digital memory in readout chip, close to active layer. Read memories continuously WITH S/N > 8

c) i.e. Silicon PIN diodes …. AC/DC coupling , ground loop … (see later)

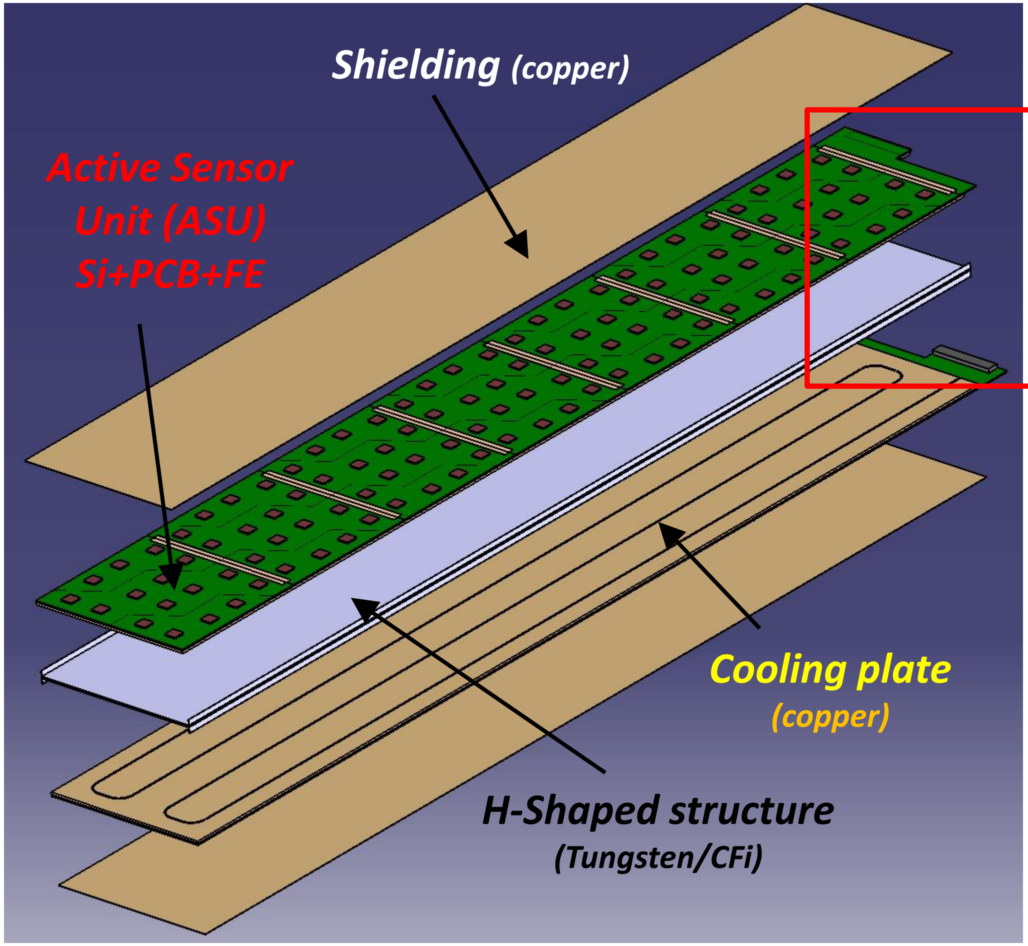
d) Large number of Channels/VFE ASIC… (KPIX, SKIROC), but only few readout line

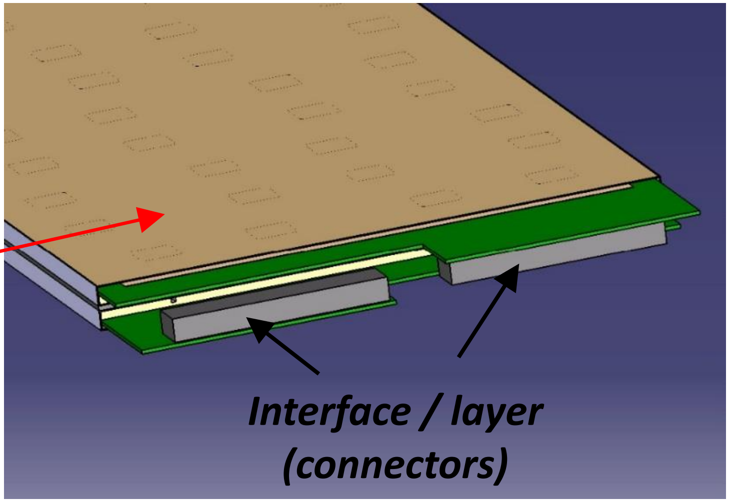
e) reduced the number of channels → the power to dissipate (see later)

f) Reduce the overall surface or use lower cost active device (Micromegas, scintillator)

BUT warning versus point a) and c) . 10 years contacts with producers, defining wafers design which reduce the cost

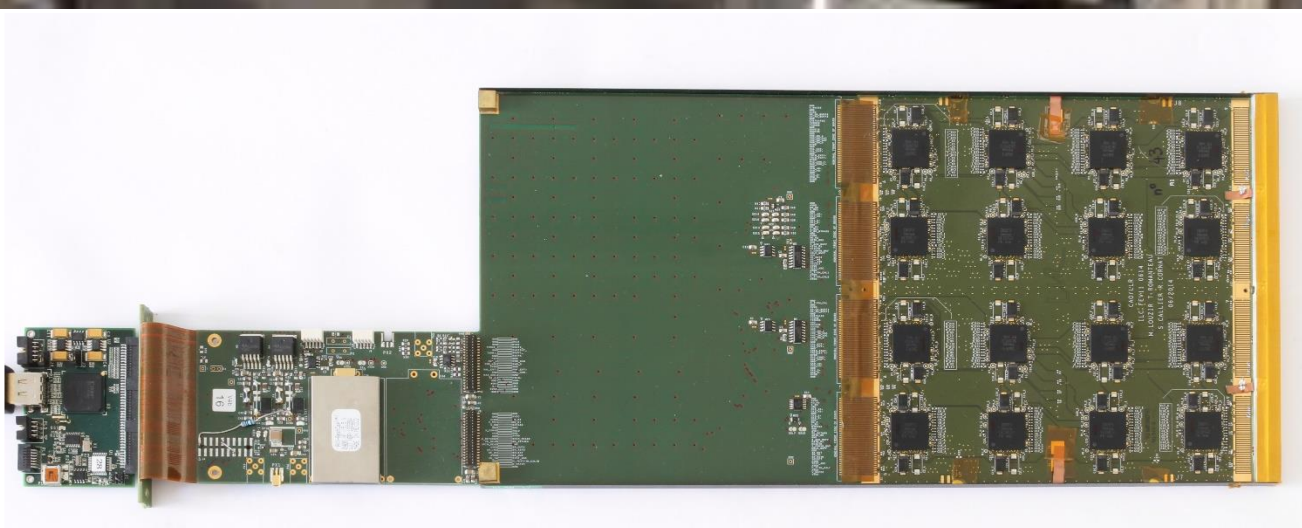
Detector SLAB (exploded view)





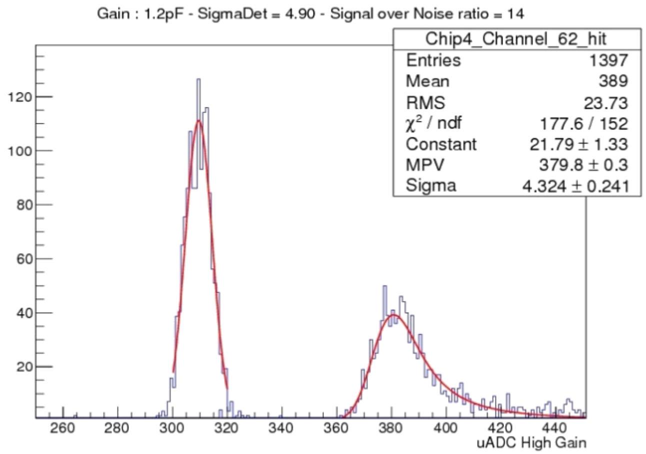
Electronics VFE INSIDE

Module 10 layers
@DESY Test Beam
(electron 1-6 GeV)



1 layer

First Test Beam for scalable prototype at DESY - 2012



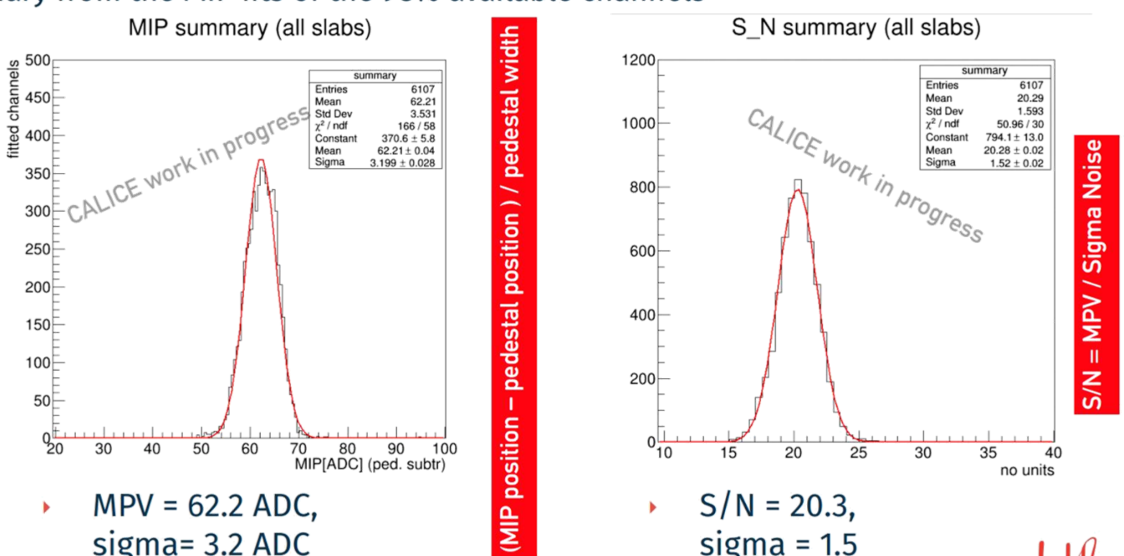
ONE LAYER

S/N ~ 14

MIP CALIBRATION RESULTS

CALICE ECAL SiW Test Beam at DESY - 2017

- Summary from the MIP fits of the 98% available channels

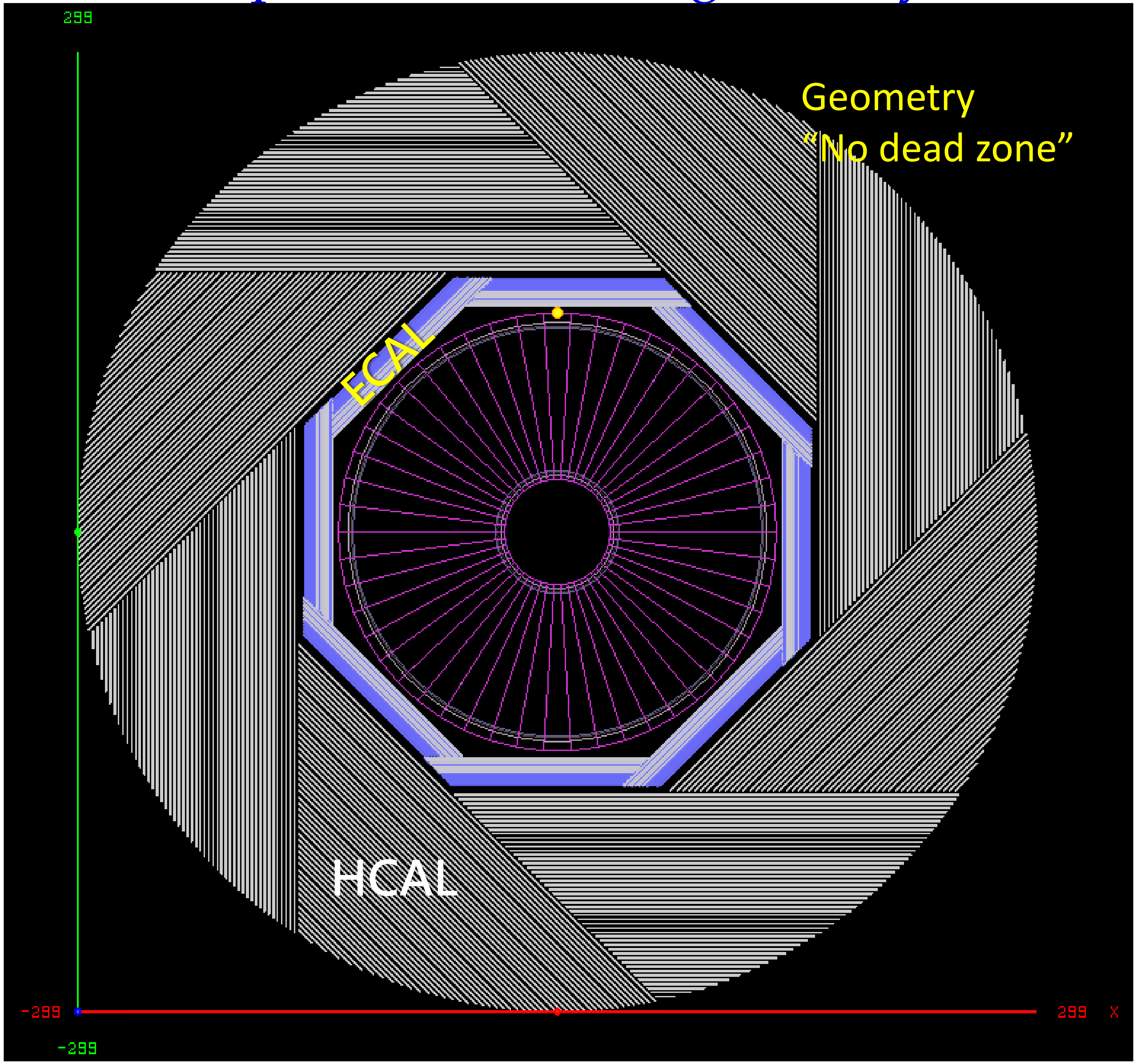


10 LAYERS

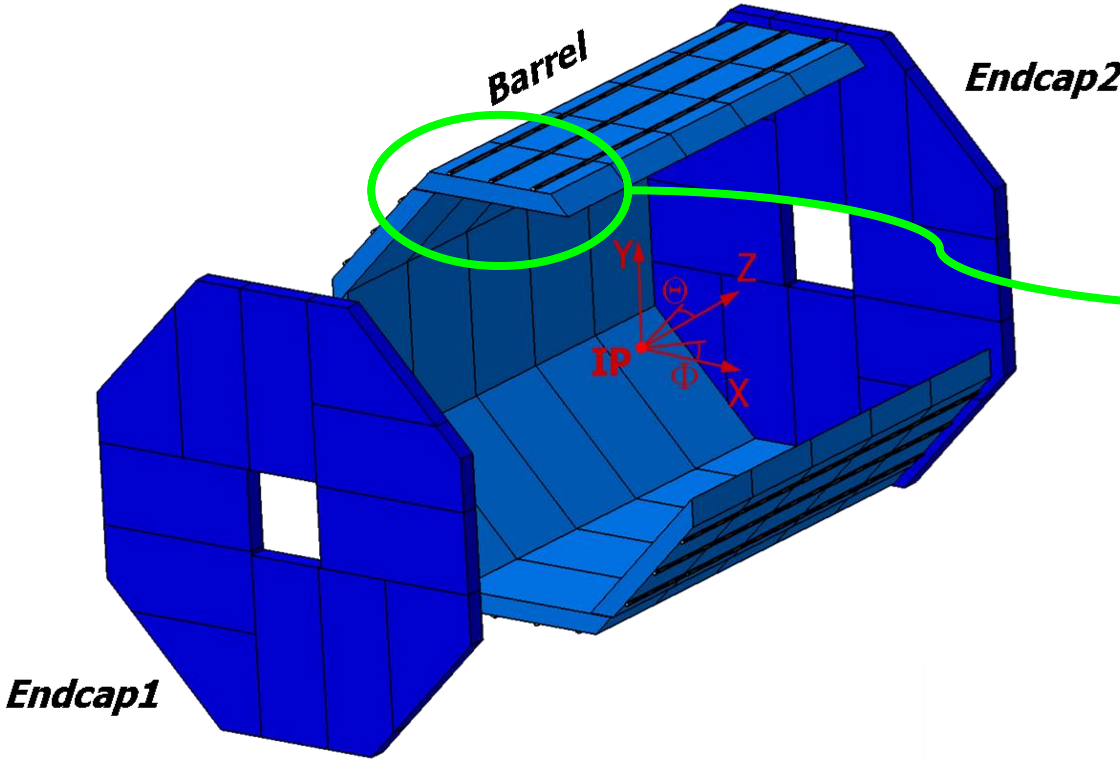
S/N ~ 20

- MPV = 62.2 ADC, sigma= 3.2 ADC (dispersion of 5.1 %)
- S/N = 20.3, sigma = 1.5 (7.4 % dispersion)

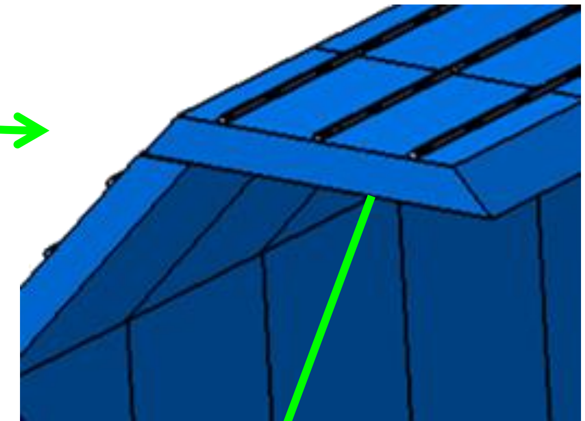
A possible detector geometry

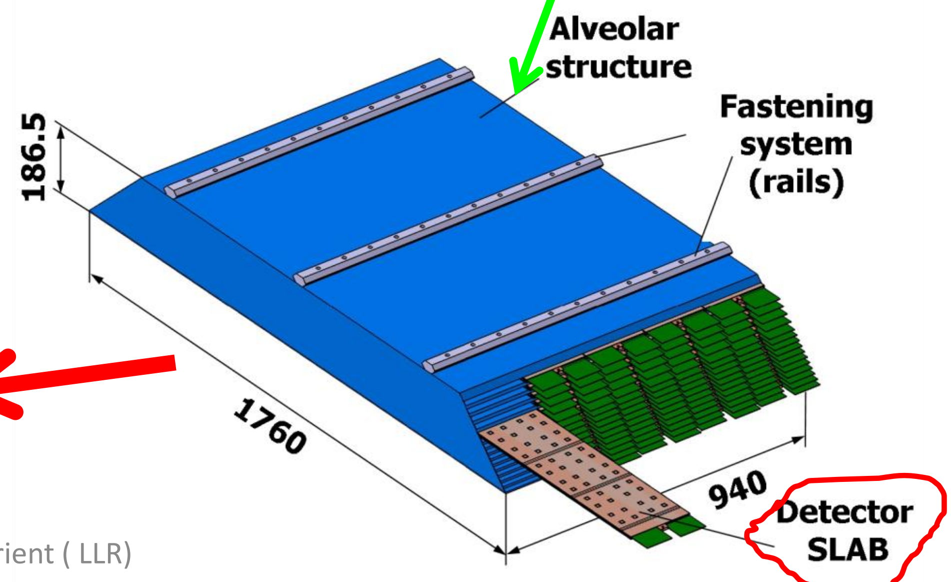


ECAL GEOMETRY



No DEAD ZONE !!!





Carbon fiber –Tungsten structure with Alveola
to slide in the active layers.

ECAL

Thermal dissipation

level of granularity can be afforded without powerpulsing (like at ILC) ?

- For physics, the smaller is the best (it continue to improve largely even for S_{Pixel}<<Rm)
  BUT for the electronics cost and cooling , … there is some limits

- Readout every 25 ns; no power pulsing
  readout frequency versus ILC x **14** (350 ns to 25 ns)
  conso/cell = 2.8 mW (Analogic part SKIROC2 without PP) +
  2,1 mW (=0,15 x**14** for digital part with readout every 25ns)

  = 5mW …. Propose to use 10 mW/channel (including a safety factor of 2)

- From CMS upgrade project-**HGCAL** , active cooling system can be stabilized in temperature
  for about 100W/layer, with fluid running in tube inside cooper plate (Rm not so good than ILC… but)

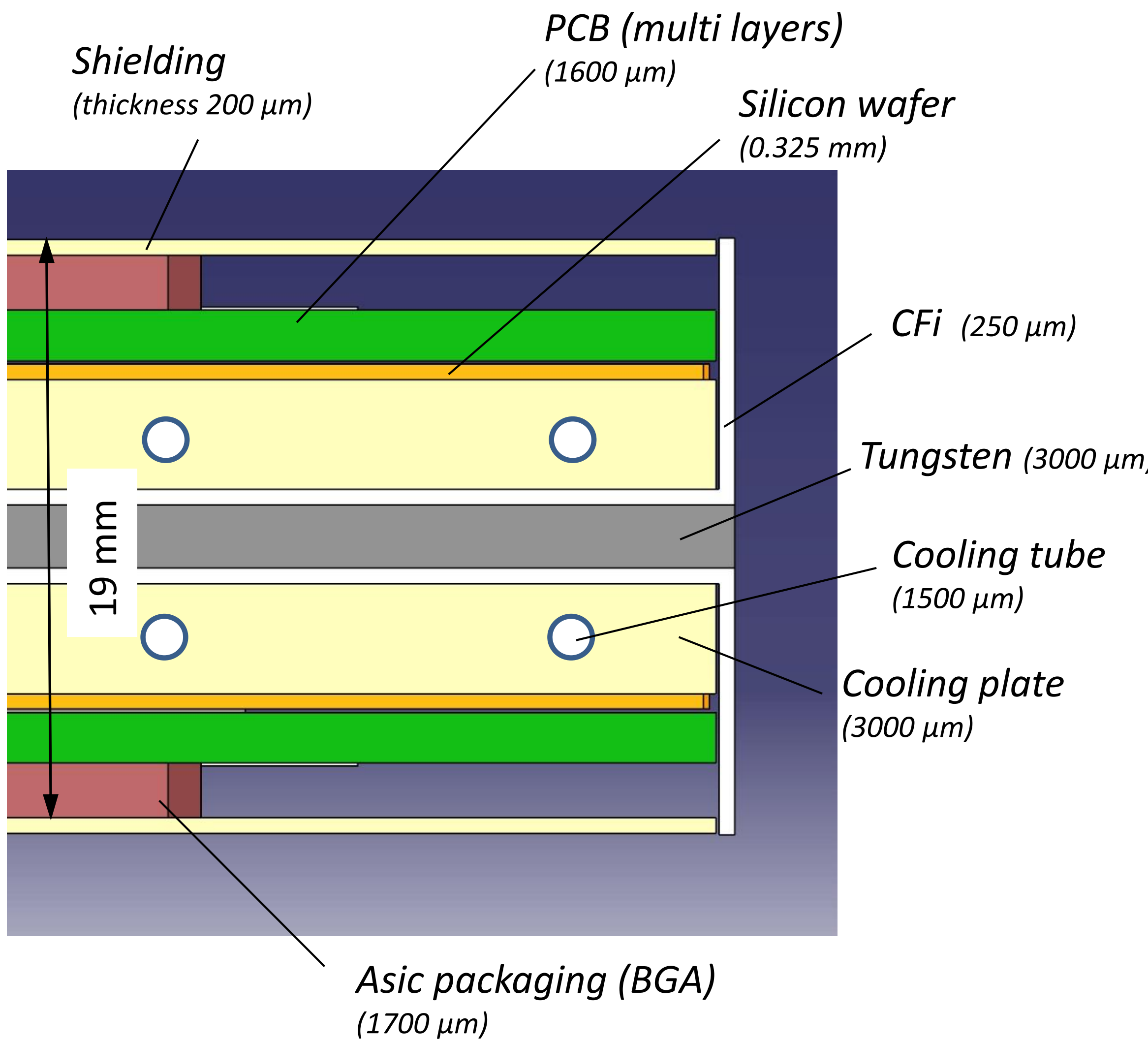
Taking into account the chosen layer size (= 150x20 cm²) and the 100W,
The cooling can afford pixel size of about 0.6x0.6 cm² !!! We have it

Possible cross section of the ECAL with active cooling (based on CMS study for HGCAL)

About 8.7 mm/layer

R_M^{eff}= 2.4 cm(2cm in CALICE-ILD)
Total thickness for 23 X0, 30 layers is 26 cm.

Pessimistic version since in 2017, PCB is 1200 and VFE packaged is 800



3 remarks to conclude

High granularity **ECAL** (longitudinal segmentation and small lateral size) gives you for free (almost free … TOT in ASICS or LGAD diodes)

- BX-ID for neutral (about few ps per shower… limitation from jitter on clock distr.)
- A particle ID for charged tracks (about 5-10 ps , with TOF)

Efficient cost optimization is in progress

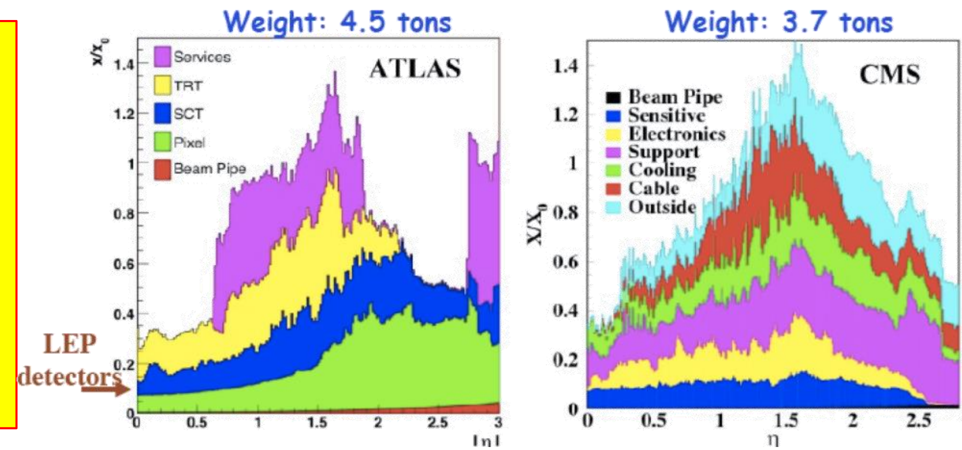
Optimisation with the number of Layers, the silicon thickness, a better use of the silicon ingot, the internal radius of the ECAL, etc … about 40% reduction is expected by cost experts with modest impacts on performances (G4 full simulation.. Published in JINST)

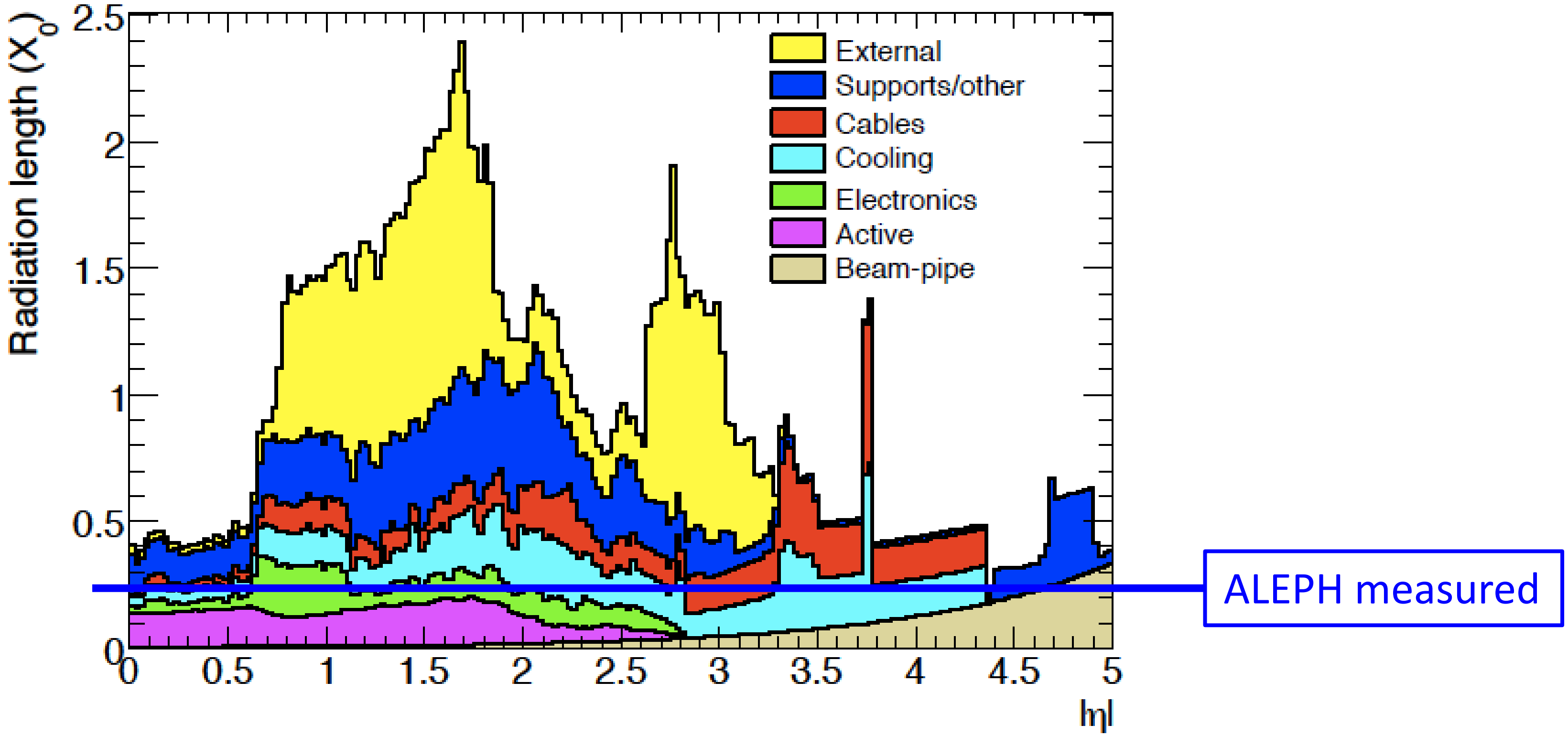
The preliminary cost estimate is NOW at the level of 90% of CMS-ECAL

Please don't forget !!

Optimising for a fantastic Vertex and Tracker … and Forgetting the calorimeters

Amount of material in ATLAS and CMS inner trackers





CONCLUSION

Which **ECAL** for e+e- circular collider at 250 GeV

- Ultra granular calorimeter , optimized for PFA, would do the job at CEPC (including EW physics with tau , i.e. Higgs CP violation studies)

- Thermal simulation and VFE .. an active cooling , "a la CMS" would be sufficient

- Large luminosity and large number of pixels leads to a MANDATORY S/N>8 at MIP

Silicon –tungsten seems a good choice

A personal remark….

CEPC means high lumi. e+e- ….. Small statistical errors ….

→ It is mandatory to have small syst. errors from detector (it is our responsibility)

→ Recommendation **: BEGIN NOW to think about systematics** …..

Near and mid-term future

Full prototype with about 20 layers at the end of 2018 ..
- Test Beam (Data taking and analysis) 2019-2020

and

- Going from ILC type to CEPC type
  (new ideas welcome and one real bi-layer to be put in TB)

- Going from prototype to "full scalable" (2m length layer)

- Interact with industry for optimized production and cost (tungsten, silicon, etc…)

Transfer knowledge to students about ultra-granular calorimeter
(there is specific problems to this type of device…. Ask for to CMS ☺/☹)
Important to learn about with real hardware device

All Chinese groups are/will be welcome
brient@llr.in2p3.fr

BACKUP

Scintillator or silicon ?

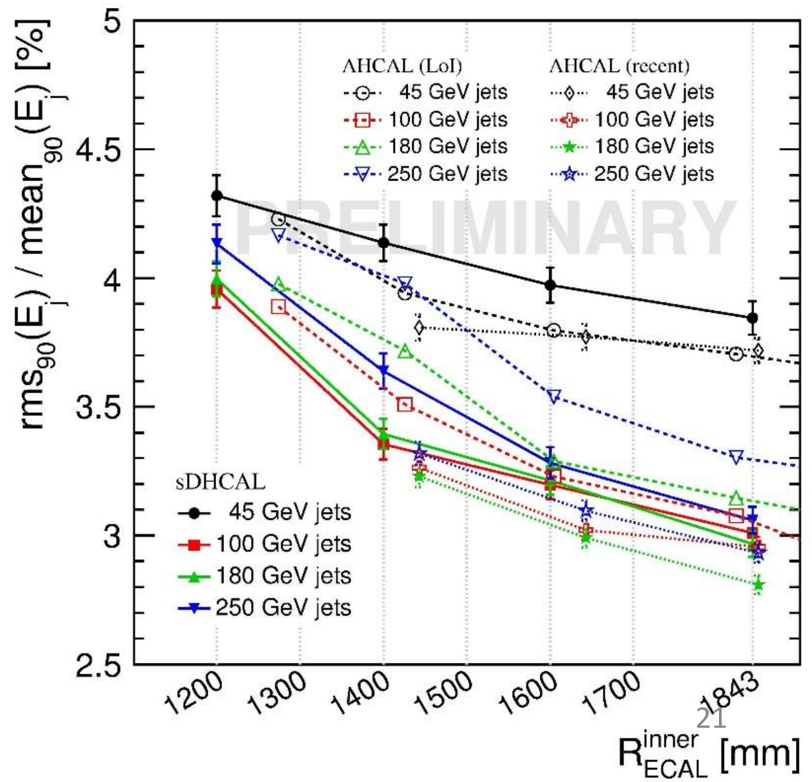
- Stability
- Capability to go down to 0.5x0.5 cm²
- Good S/N at MIP level
- VERY good uniformity (guarding vs uniformity in strip or tile)
- Cost …

Today price is about **2.0-3.0 €/cm²** for silicon PIN diodes
If you include the scintillator, fibers, monitoring system and SiPM
the price is marginally different from silicon PIN

HOWEVER, about the overall detector cost
It depends of the ECAL barrel radius and length.
For the same physics(jet, tau, etc..) performances, a smaller detector with smaller pixel could do the job

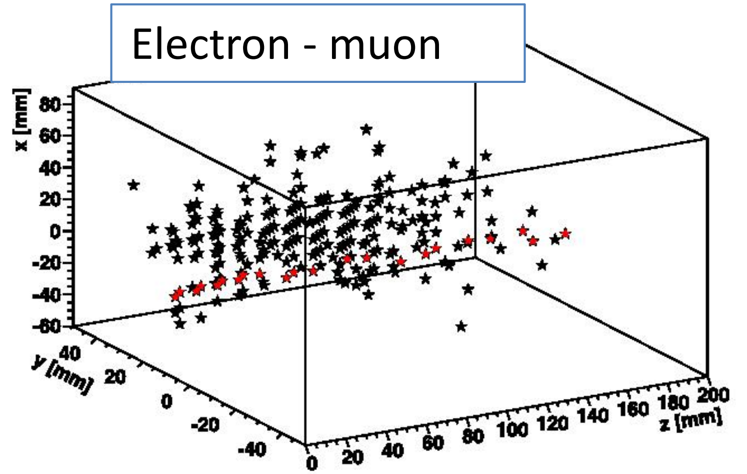
Smaller detector ⇒
smaller cavern, smaller Yoke, smaller return yoke, etc… **COST !!**

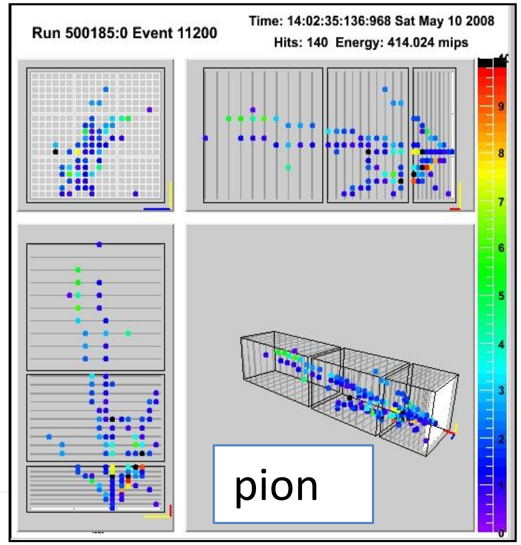
CONCLUSION

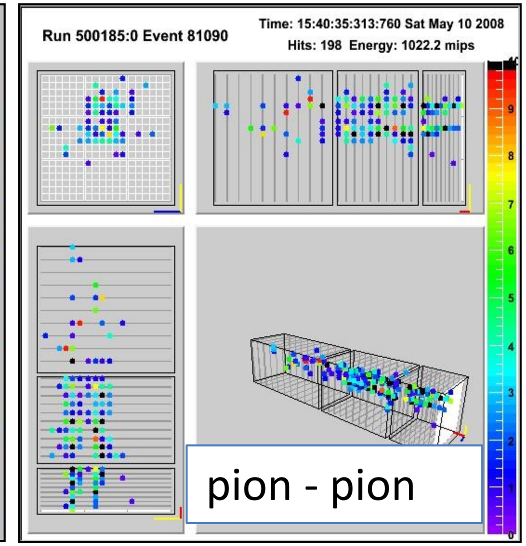


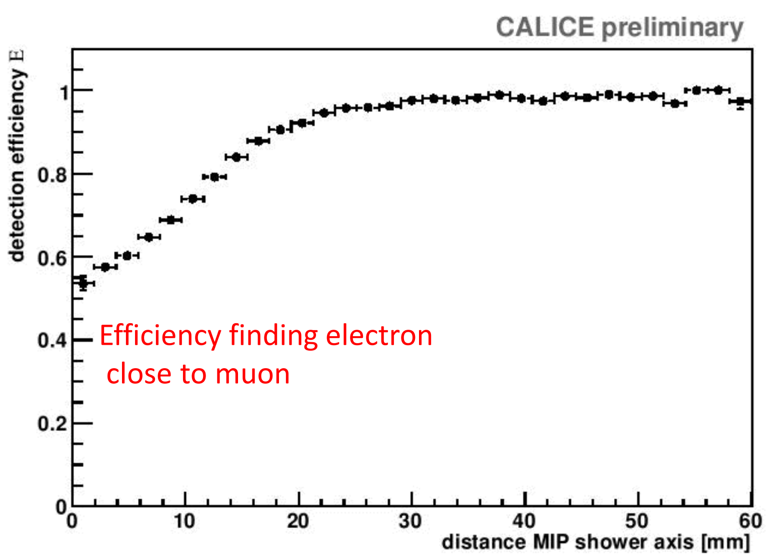
Small pixels, small radius, small coil …
OR
Larger pixels (scintillator), larger radius …
SID , ILD ===== same detector cost

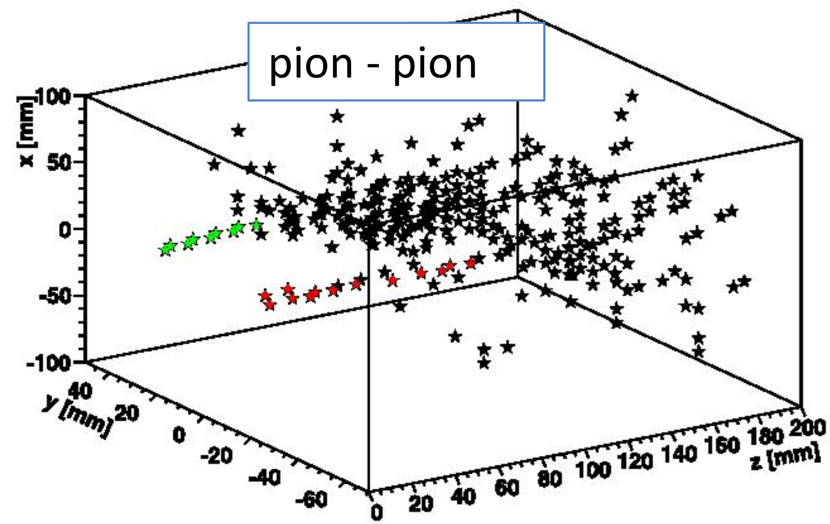
The tests of the camera



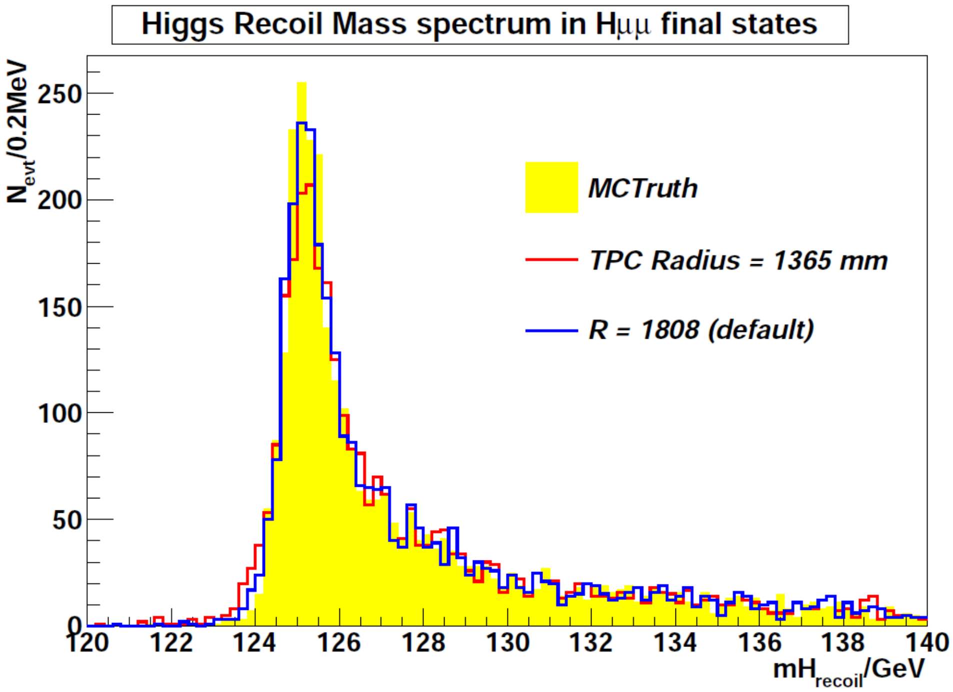


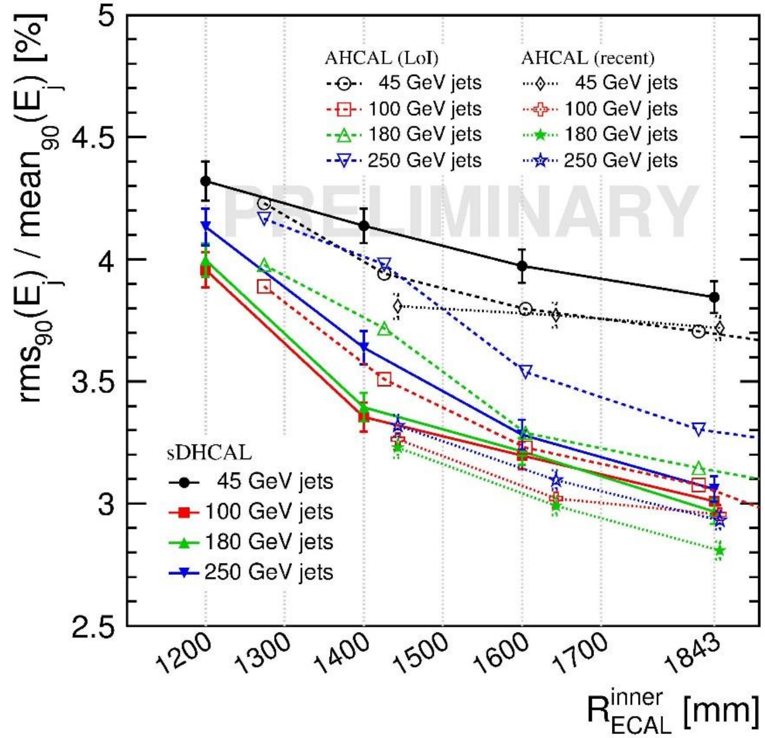






Quantitative test has been published by CALICE (test of PANDORA PFA with TB data)


Higgs Recoil Mass spectrum in Hμμ final states
N_evt/0.2MeV
MCTruth
TPC Radius = 1365 mm
R = 1808 (default)
mH_recoil/GeV


AHCAL (LoI)
45 GeV jets
100 GeV jets
180 GeV jets
250 GeV jets
AHCAL (recent)
45 GeV jets
100 GeV jets
180 GeV jets
250 GeV jets
PRELIMINARY
sDHCAL
45 GeV jets
100 GeV jets
180 GeV jets
250 GeV jets
rms90(Ej) / mean90(Ej) [%]
R_ECAL^inner [mm]

Front of ECAL – Shower start