CMS ECAL Calibration Strategy

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What is *Calibration* ?

To profit from the intrinsic ECAL performance (measured in TestBeam) we have to:

equalize crystals response
(*inter-calibration*)

$$\left(\frac{\sigma}{E}\right)^2 = \left(\frac{2.9\%}{\sqrt{E}}\right)^2 + \left(\frac{125(MeV)}{E}\right)^2 + (0.30\%)^2$$

constant term increased by calib. errors

Raw channel-to-channel response variation:

Barrel:	variation of scintillation light	r.m.s. ~ 13%
Endcaps:	VPT signal yield	r.m.s. ~ 25%

What is calibration?

Crystals Pulse Amplitudes in a clustering algorithm → ***Calibration*** → Particle's Energy

$$E_{e,\gamma} = G \times \mathcal{F} \times \sum_{i}^{\text{Cluster}} c_i \times A_i,$$

- G: absolute energy scale
- $\mathcal{F}$: algorithmic corrections (particle type, momentum, position & clustering algo)
  Account for energy losses due to containment variations or electron radiation in the Tracker material
- c_i: inter-calibration constants
- A_i: amplitudes

G, F, c factors should/must be determined by the Calibration procedure, aiming for the most accurate energy measurement for electrons & photons.

Calibration Roadmap

Before Data taking:

Crystals in TestBeam

Lab measurements

see R. Paramatti talk

Cosmics

see G. Franzoni talk

During Data taking (in-situ):

Min-bias / Level-1 jet triggers

$Z \to e^+e^-$

Isolated electrons ($W \to e\nu$)

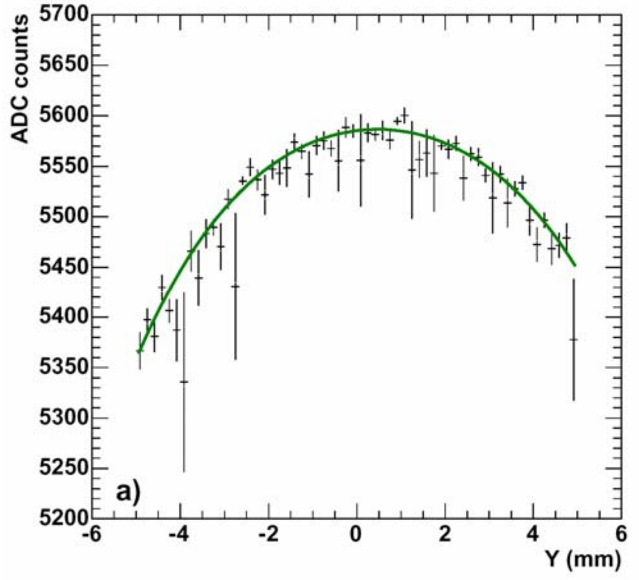
$\pi^0, \eta \to \gamma\gamma$, $Z \to \mu\mu\gamma$

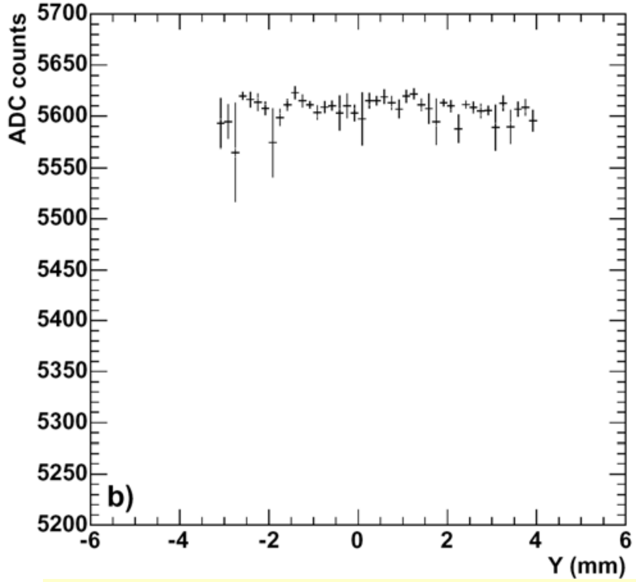
Crystals response must be stable in time.
Complications:

- Radiation exposure changes crystals transparency (formation of color centers and subs. annealing).
  Crystal transparency is measured every 20 min by injecting laser pulses.
  see A. Bornheim talk

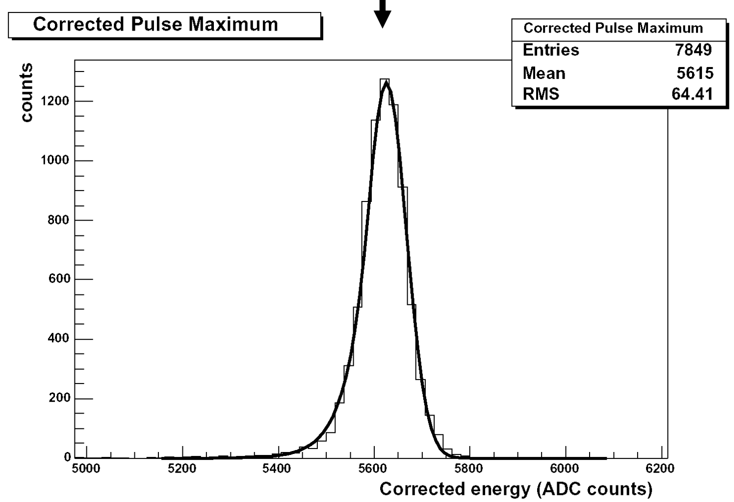
- Temperature variations affect APDs and crystals.
  Cooling system:
  keeps temperature stable in time ($\Delta T \sim 0.05^0$C) and uniform within Supermodule ($\Delta T \sim 0.2\ ^0$C)

Before Data taking: Crystals in TestBeam





Corrections in both lateral dimensions



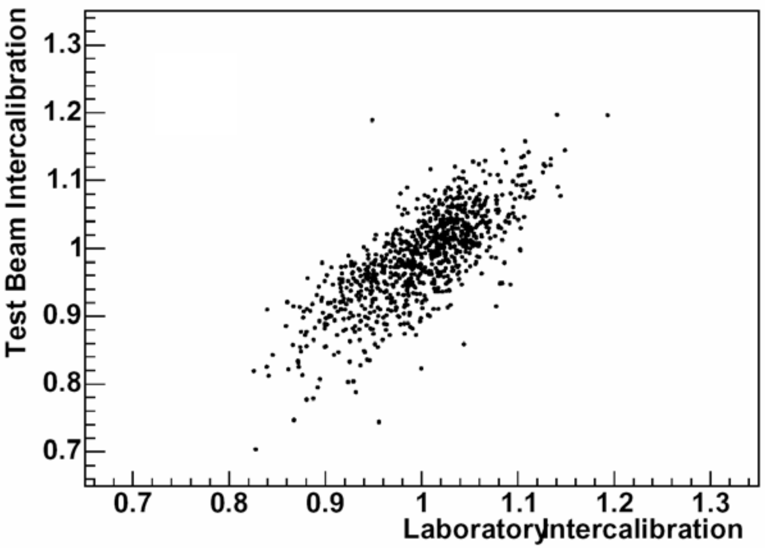
Electron beam and trigger have a lateral spread similar to the lateral size of the crystal.

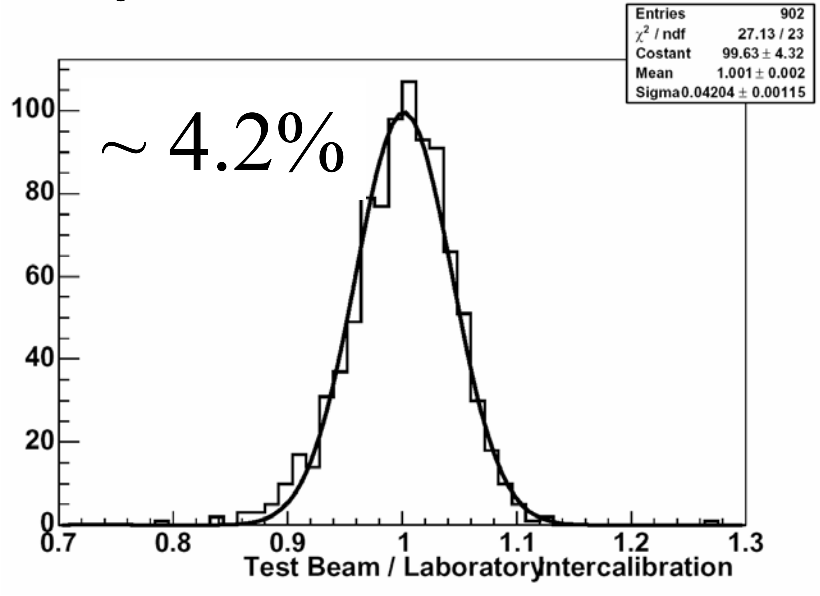
Correct the reconstructed energy dependence on the impact position of the electron.

Relative Calibration factor: $\alpha_i = \frac{\text{Mean}_i}{\text{Mean}_{ref}}$

No time for all ECAL supermodules

Before Data taking: Crystals in the LAB





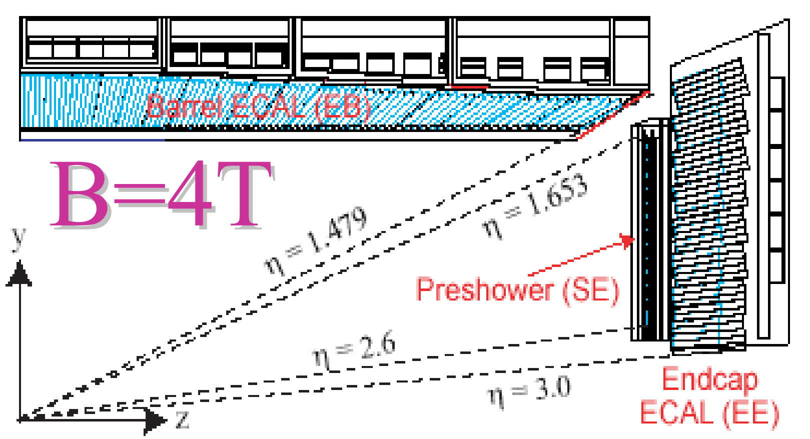
Regional centers : CERN, INFN-ENEA Casaccia

Radioactive source : ^{60}Co with γ at 1.2 MeV

Comparison with TestBeam : 4.2% inter-calibration precision.

Details in R. Paramatti talk

Detector Details



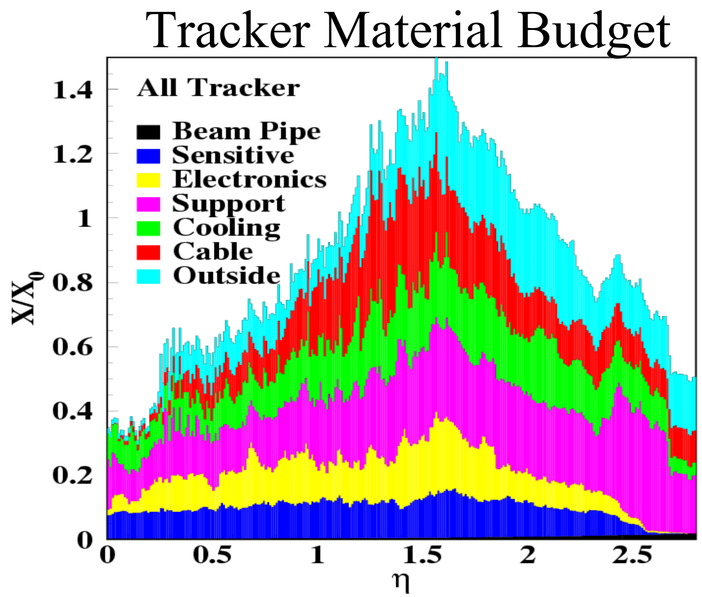
Tracker material :

electrons loose energy via Bremsstrahlung

photons convert

4T solenoidal B field :

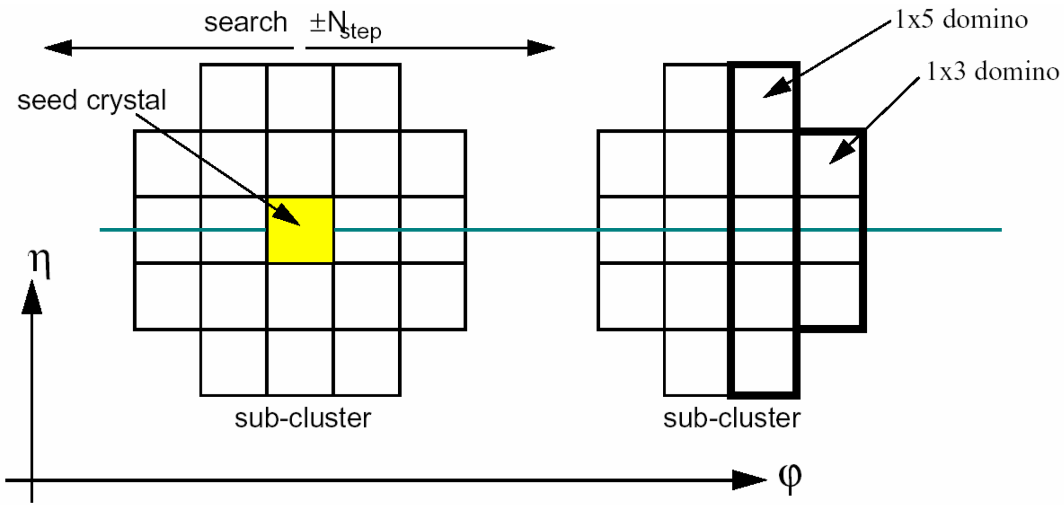
Electrons bend ⇒ radiated energy spread in φ

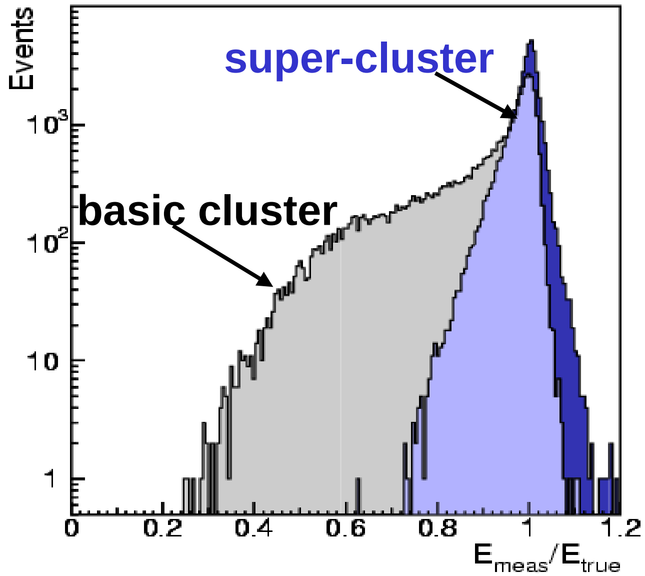


impact on the energy resolution for electrons and photons.

***In-situ* calibration of ECAL will be a challenge!**

Energy Reconstruction





Electrons:

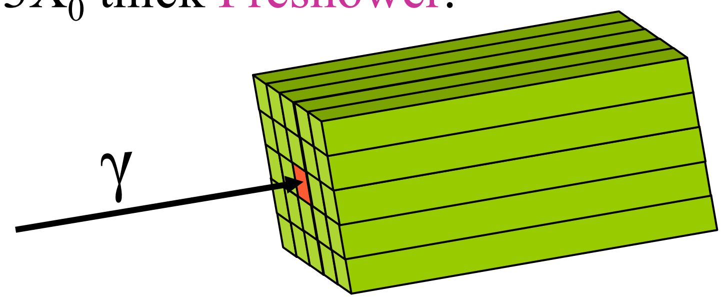
4T B field : Electrons bend ⇒ radiated energy reaching ECAL is spread in φ.

The spread energy is clustered by building a cluster of clusters, a supercluster.

In the Endcaps, add also the energy deposited in the ~3X_0 thick Preshower.

Photons:

Energy contained in a fixed array of crystals (5x5)



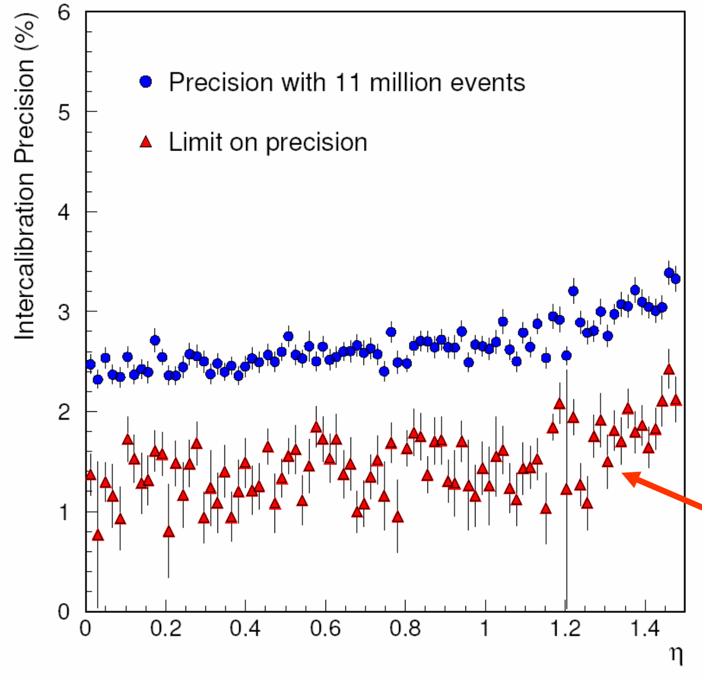
Algorithmic Energy Corrections for e & γ :

Different sources of variation in the clustered energy need to be corrected.

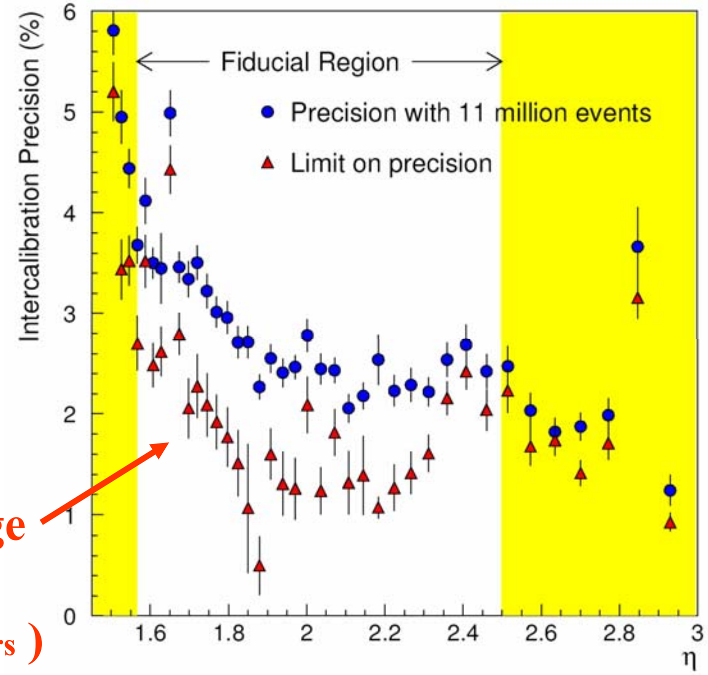
Tuning algorithmic corrections is necessary in the complete calibration process.

In-situ: φ-uniformity method

BARREL



ENDCAPS



11 million
Level-1 jet trigger events

Precision limits assuming no knowledge of tracker material
(~10h , 1kHz L-1 single jet triggers)

Idea: φ-uniformity of deposited energy in crystals at constant η

Limitations : non-uniformities in φ

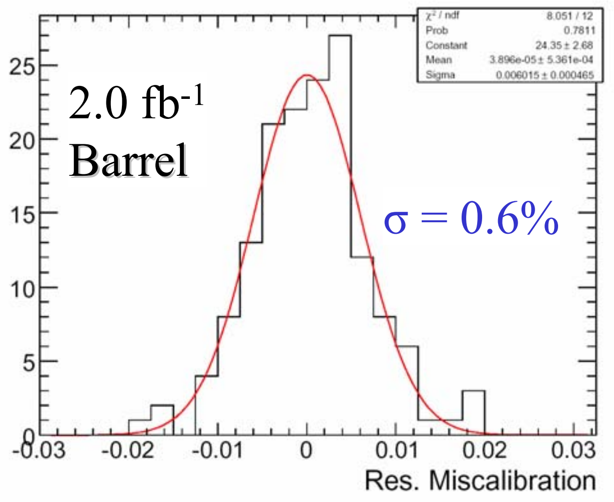
- in-homogeneity of tracker material
- geometrical asymmetries

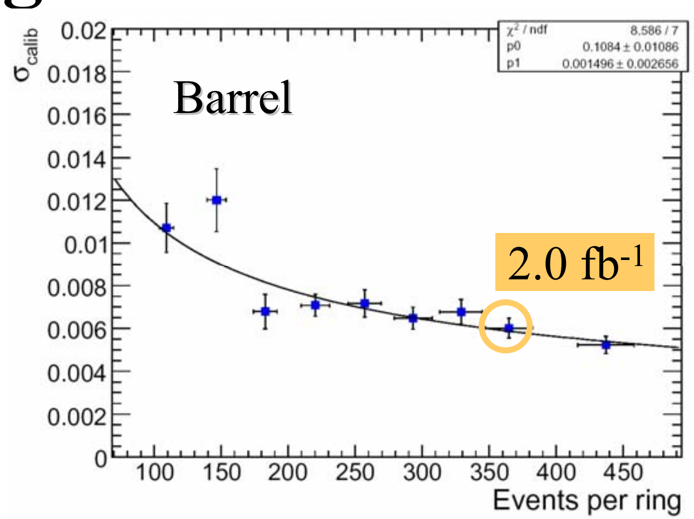
Used: Min-bias / Level-1 jet trigger events

Method: Compare $<E_T>_{CRYSTAL}$ with $<E_T>_{RING}$.

Inter-calibration of η rings:
$Z \rightarrow e^+e^-$, $Z \rightarrow \mu^+\mu^-\gamma$, isolated electrons

In-situ: using $Z \to e^+e^-$





Method:
Z mass constraint

Use cases:
- Inter-calibrate crystals in ECAL regions
- Inter-calibrate ECAL regions (i.e.rings in φ-symmetry method)
- Set the absolute energy scale
- Tune algorithmic corrections for electron reconstruction

Events Selection: Low brem electrons.

Algorithm:
Iterative (~10-15), constants are obtained from the peak of ε^i distribution.

$$\bar{\epsilon}^i = \frac{1}{2} \cdot \left[\left(\frac{M^i_{inv}}{M_Z} \right)^2 - 1 \right]$$

Results:
Assuming 5% mis-calibration between the rings and 2% mis-calibration between the crystals within a ring

↓ *Statistics: **2.0 fb^{-1}***

0.6% ring inter-calibration precision

In-situ: using isolated electrons

Target: **0.5%** calibration precession

Sources: $W \to e\nu$ (10Hz HLT @ $2\text{x}10^{33}\text{cm}^{-2}\text{s}^{-1}$),
$Z \to e^+e^-$ (2Hz HLT @ $2\text{x}10^{33}\text{cm}^{-2}\text{s}^{-1}$),
$J/\Psi \to e^+e^-$, $b/c \to e$, …

Method: E / P <width minimization>

ECAL

$$E = \sum^{5x5} c_i E_i$$

TRACKER
electron momentum

Event Selection:
We need a narrow E/P ⇒ Low brem $e^{\pm}$
Variables related to electron bremsstrahlung :
ECAL (S_{3x3}/S_{5x5})
TRACKER (track valid hits, χ^2/n.d.f., P_{out}/P_{in})
Efficiency after HLT: 20-40% Barrel ,
10-30% Endcaps

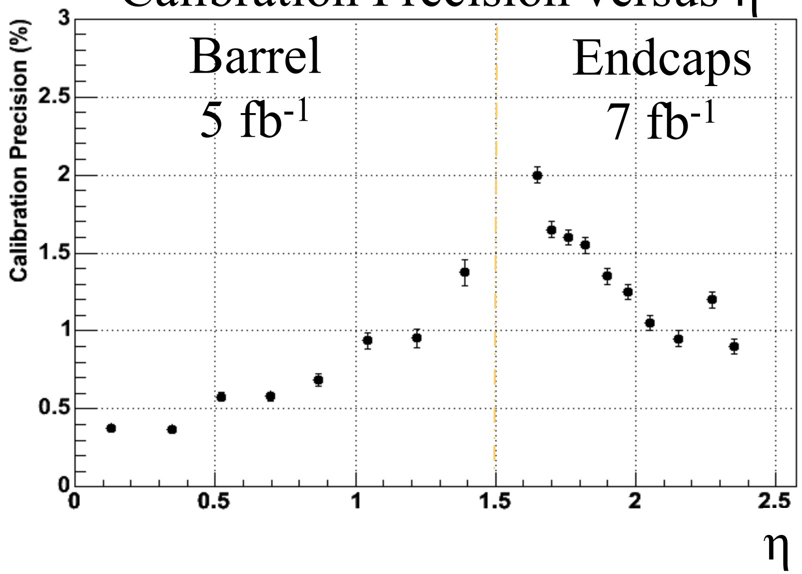
Background: S/B~8
(isol. electrons from W/QCD)
Part of it might be useful ($b/c \to e$).

Calibration Constants extraction Techniques:
- L3/LEP iterative (~20 iterations),
- matrix inversion

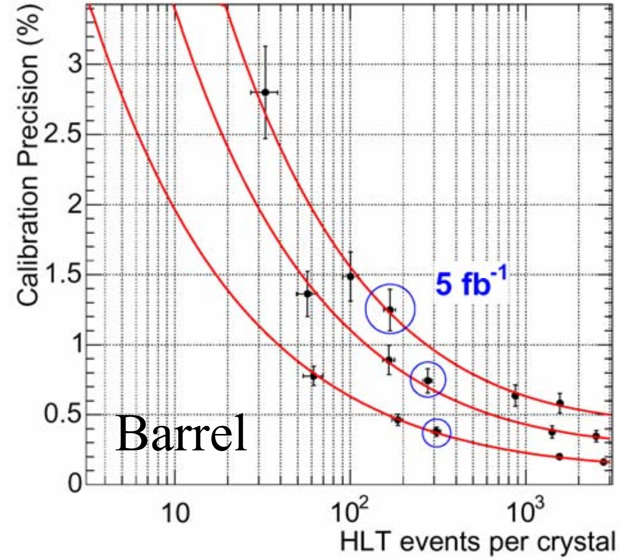
Calibration Steps
- Calibrate crystals in small η-φ regions
- Calibrate regions between themselves using tighter electron selection, $Z \to e^+e^-$, $Z \to \mu^+\mu^-\gamma$

In-situ: using isolated electrons

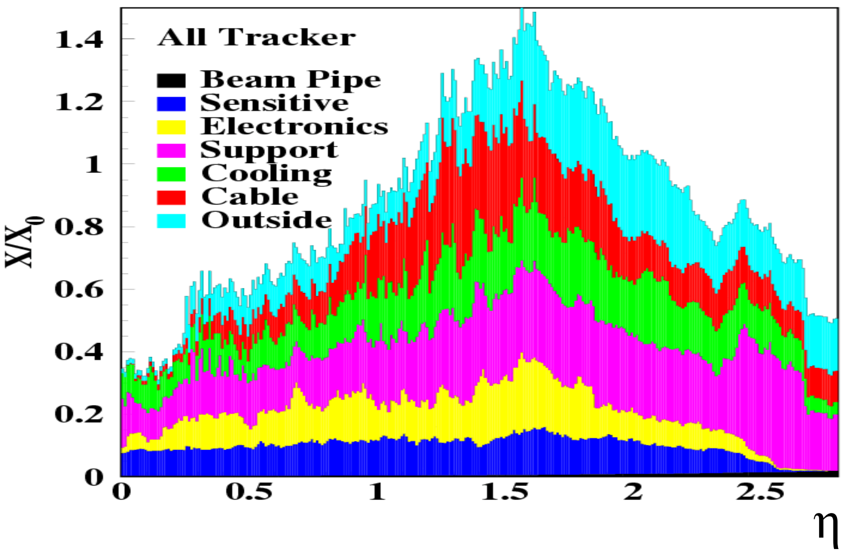
Calibration Precision versus η



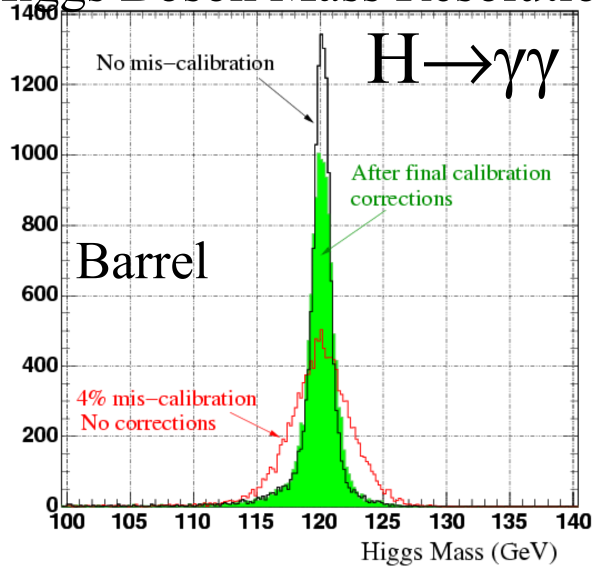
Precision versus Statistics



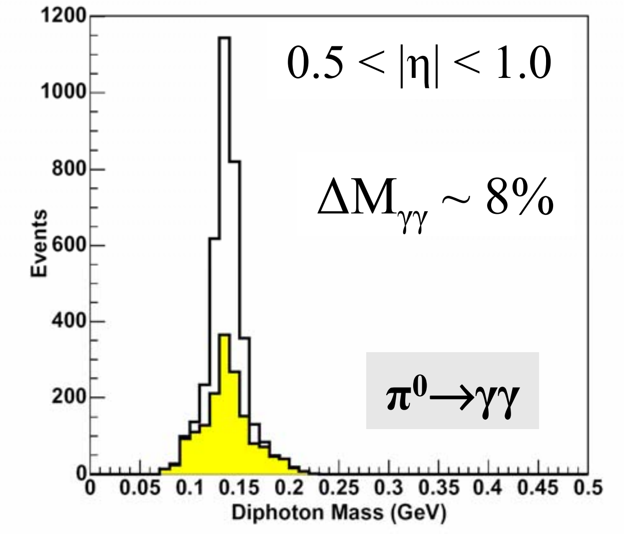
Tracker Material Budget



Higgs Boson Mass Resolution



In-situ: $\pi^0 \to \gamma\gamma$, $\eta \to \gamma\gamma$



Method:
Mass constraint for crystal inter-calibration.

Unconverted photons are in-sensitive of the tracker material

Selection : shower shape cuts per γ, small γ opening angles (60-90mm)

$\pi^0 \to \gamma\gamma$:

"Common" π^0s; can be found in L1 e/m triggers (source: jets or pileup events)

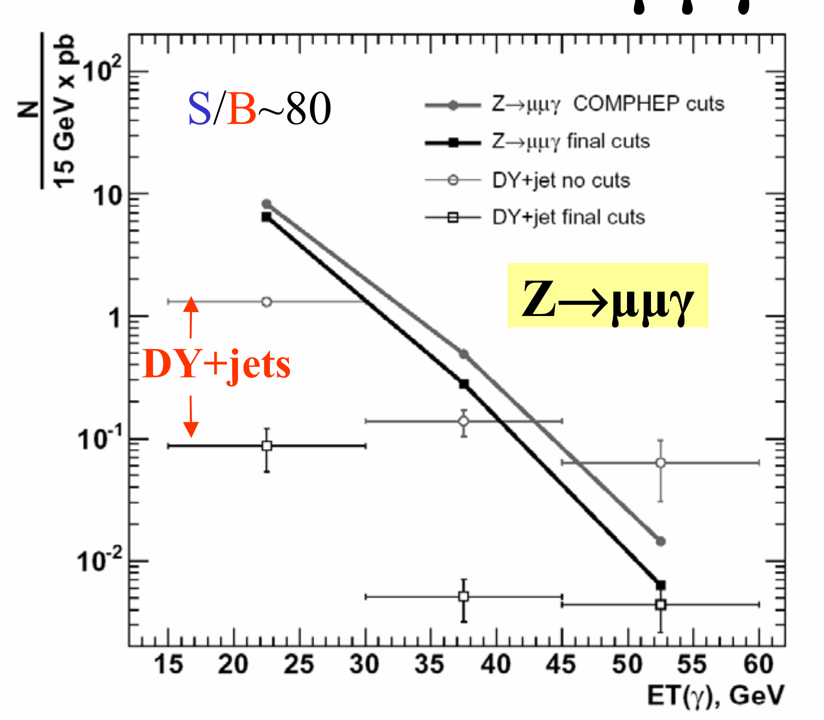
Efficiency ~ **1.4%**
Level-1 rate : **25kHz**
} ~**2days** ⇒ **1K** ev./crystal ⇒ ~ **0.5%** stat. inter-calibr. precision

$\eta \to \gamma\gamma$:

Much lower rate after background suppression
Better mass resolution ~ 3%

… they seem promising … still under study …

In situ: $Z \to \mu\mu\gamma$



- Inter-calibrate ECAL regions
- Set absolute energy scale
- Tune algorithmic cluster corrections

Significant rate; Little Background;

Selection: $40 < M_{\mu\mu} < 80$, $\Delta R_{\mu,\gamma} < 0.8$, $15 < E_T^{\gamma} < 30$, $87 < M_{\mu\mu\gamma} < 95$

For $1 fb^{-1}$ ⇒ 1 γ / crystal ⇒ calibrate 10-crystal wide rings with 0.1% stat. precision.

… still under study …

Conclusions

We have to inter-calibrate 75848 ECAL crystal.
Target: 0.5% inter-calibration accuracy through out ECAL.

Before DATA taking:

- TestBeam (not all SuperModules)
- Laboratory Measurements (^{60}Co , all crystals) : ~4.0%
- Cosmic muons : ~3%

***In-situ*:**

- φ-symmetry (jets/min-bias events): 2-3% in couple of hours
- Isolated electrons ($W \to e\nu$, $Z \to e^+e^-$,..) : ~ 0.6% with 10 fb^{-1}
- $\pi^0, \eta \to \gamma\gamma$: very promising but still under study

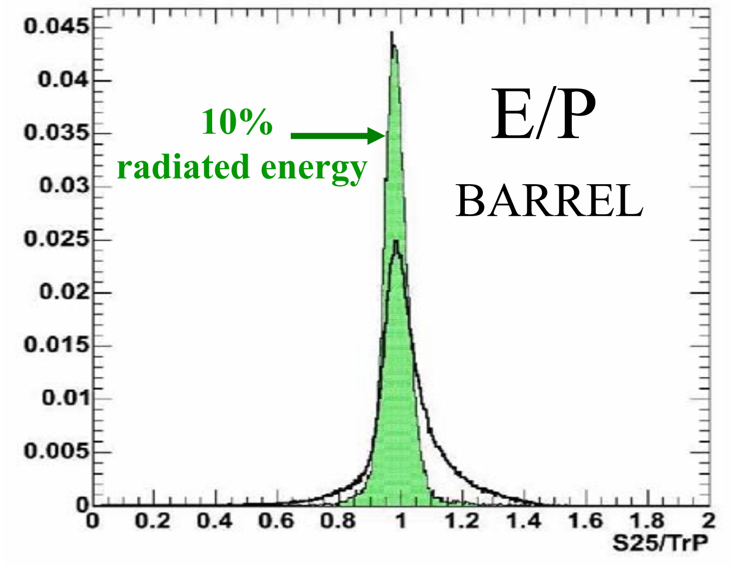
Absolute Energy Scale
ECAL region inter-calibration
Tune algorithmic cluster corrections
} $Z \to e^+e^-$, $Z \to \mu^+\mu^-\gamma$

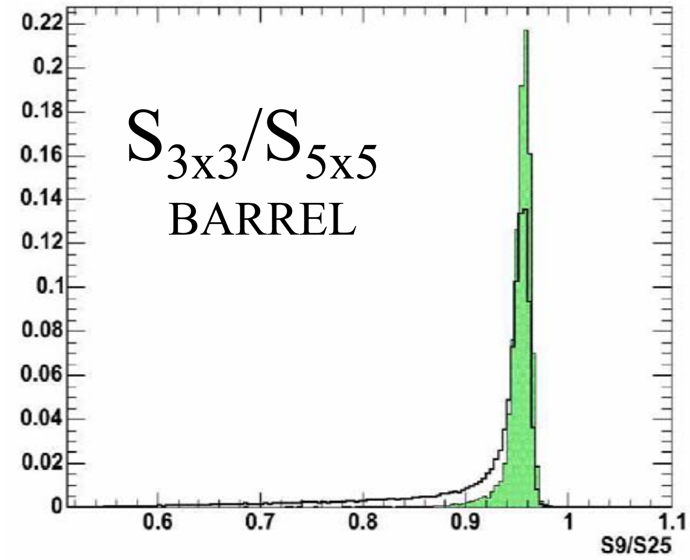
Calibration Strategy aims to:

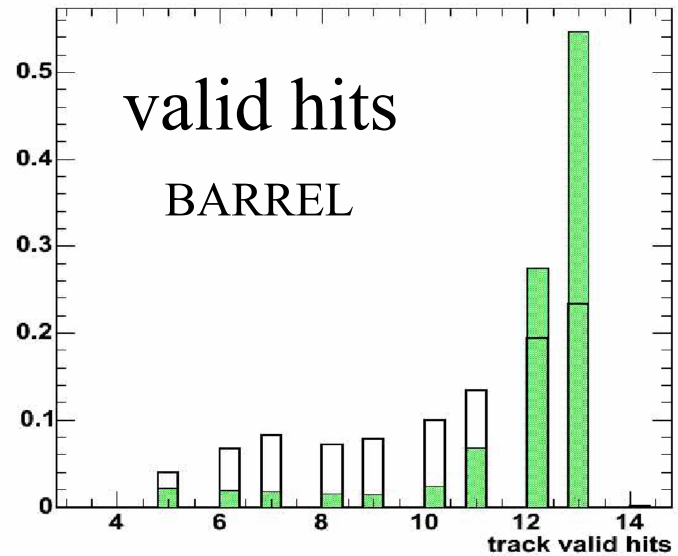
achieve the most accurate energy measurement for electrons & photons that will lead us to fast and clean discoveries.

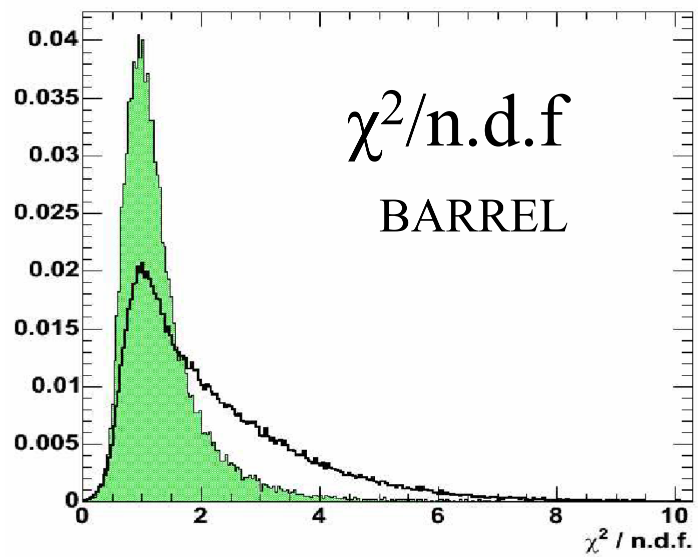
BACKUP

In-situ: using isolated electrons

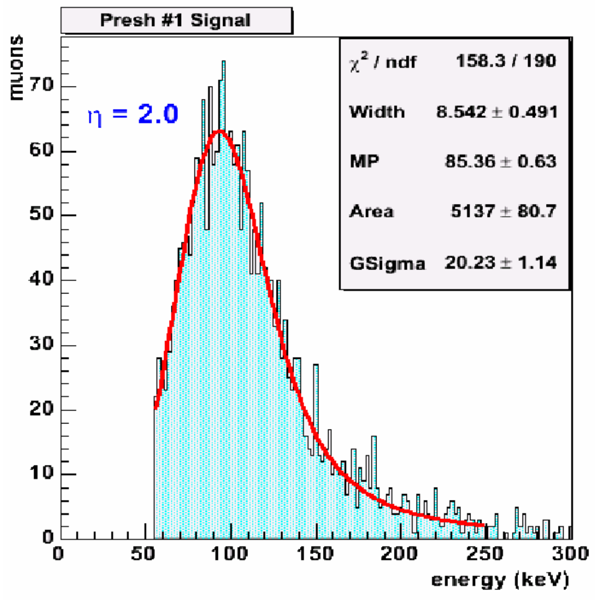


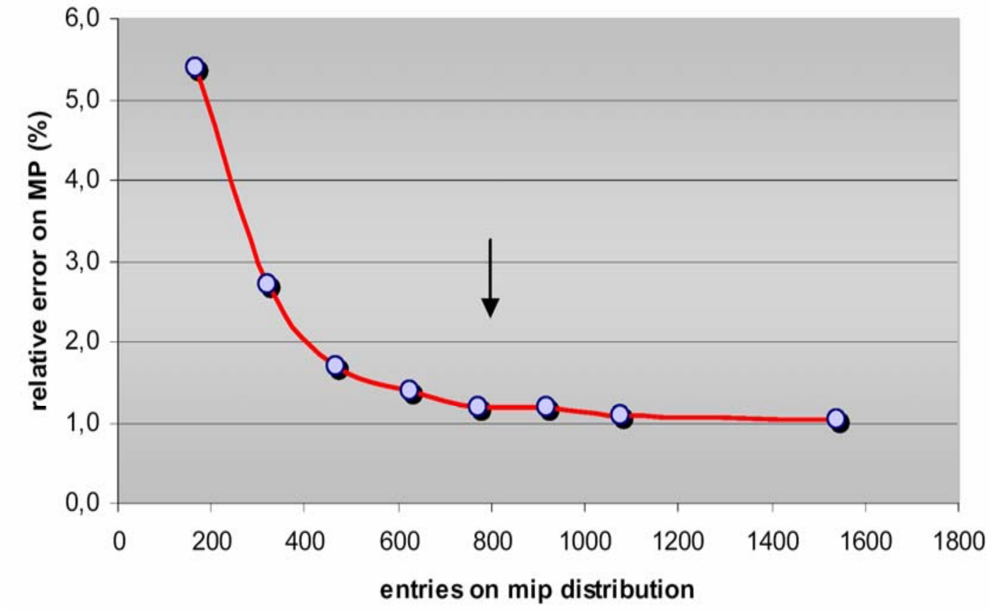






In situ: Preshower





Response variation:
- **sensor thickness (1% r.m.s.)**
- **gain uniformity (5% r.m.s.)**

Dynamic range: 1-400 MIPS equivalent

Absolute MIP scale :

Use 1 MIP @ High Gain ⇒ suitable S/N

Cosmic μ (4GeV) ⇒ Absolute MIP scale ~ **10 h**

Sensor-to-sensor inter-calibration

- *In-situ* $\mu^{\pm},\pi^{\pm}$ (jets/pile-up) ⇒ **1%** in **1 week**
- Use ICC (front-end) to inter-calibrate High/Low Gains
- ICC calibration in **few hours** (between LHC fills)