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Innovative Particle and Radiation Detectors (IPRD06)
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the CMS ECAL *in situ* inter-calibration

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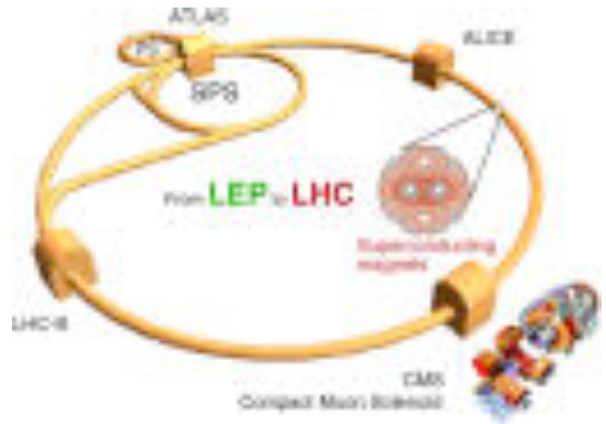
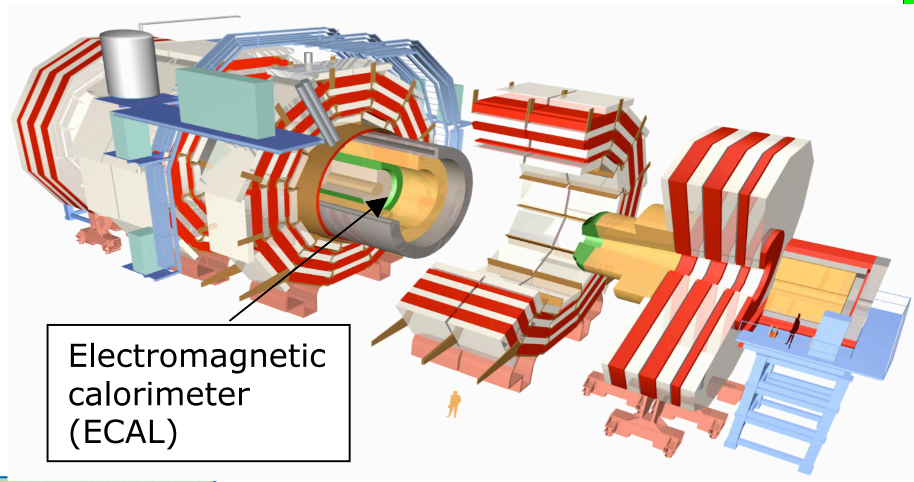
outline

- a quick introduction to CMS and ECAL
- the ECAL calibration: issues, needs, protocols
- the *in situ* calibration techniques envisaged
- conclusions

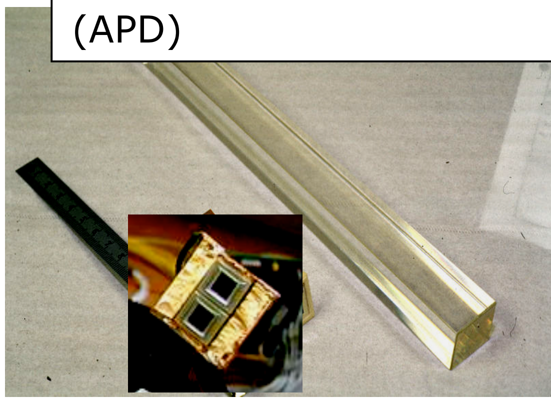
LHC, CMS and ECAL

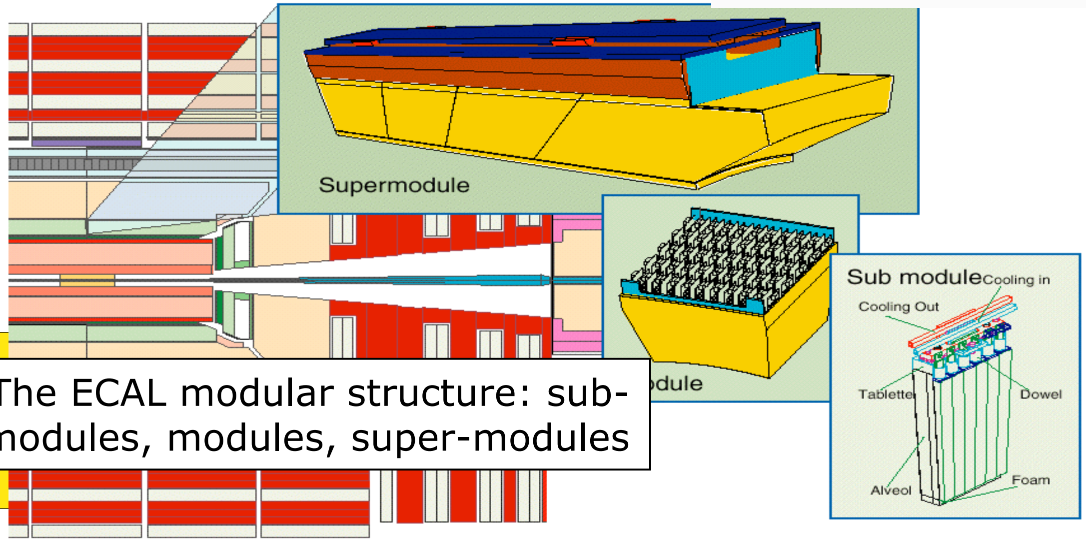




Electromagnetic calorimeter (ECAL)

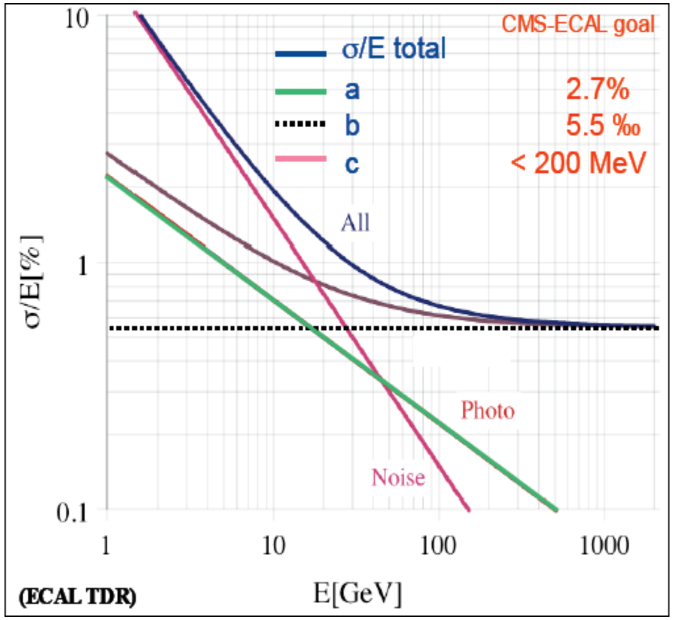
A crystal and an Avalanche PhotoDiode (APD)





The ECAL modular structure: sub-modules, modules, super-modules

ECAL energetic resolution



energetic resolution: stochastic term (a), noise term (c) and constant term (b)

$$\frac{\sigma(E)}{E} = \frac{a}{\sqrt{E}} \oplus b \oplus \frac{c}{E}$$

CMS goal: b ~ 0.5%

The constant term will be dominated by the calibration precision

the ECAL calibration

- main sources of mis-calibration: **crystals light yield** (barrel, 10%) and **VPT response** (endcaps, 25%)
- dependance on **the algorithm used** for the reconstruction (3x3, 5x5, SC) and on the **reconstructed object** (e,γ)
- the **reference benchmarks**: $H \to \gamma\gamma$ e $H \to ZZ^{(*)} \to 2e^+2e^-$
- two phases: **the inter-calibration** and the **determination of an absolute scale**

$$E_j^{calib} = E_j^{raw} c_j$$

single crystal inter-calibration

The reconstructed energy for physics objects (e,γ) depends on the one deposited in the single crystals (E_j^{raw}), inter-calibrated (k_j), converted in GeV (G), corrected for possible geometrical factors (F(η)) and clustering ones (F(N))

$$E_{e,\gamma} = F(N_{xtl}) \times F(\eta) \times G_{conv} \times \sum_{j \in clust} \left(c_j E_j^{raw} \right)$$

the calibration protocols

- a **complete set of procedures** starting from the very beginning of the ECAL construction is put in place to calibrate the detector

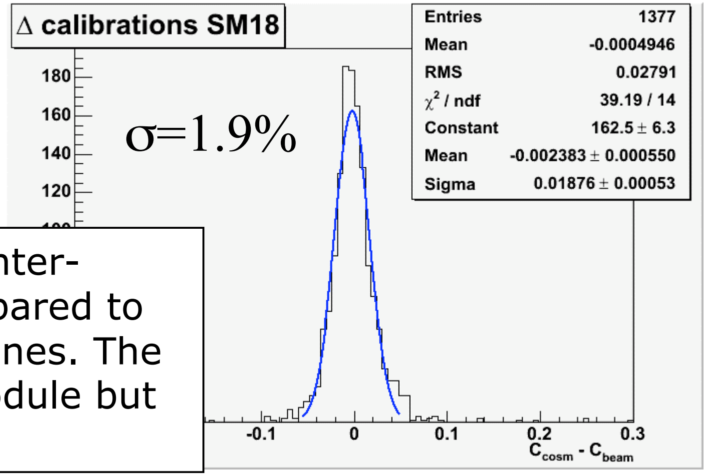
the pre-calibration:
- laboratory measurements of crystals optical properties (4%)
- test-beam measurements with known energy electrons (permill)
- cosmic rays measurements (2%)

the *in situ* calibration:
- exploit the φ symmetry to inter-calibrate single rings of crystals
- inter-calibrate different rings and find the energy scale by reconstructing the $Z \rightarrow e^+e^-$ mass peak
- use the E/p ratio for isolated electrons (from $W^\pm \rightarrow e^\pm \nu$) to inter-calibrate
- profit of the $\pi^0 \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$ channels at low energy

NO NEED FOR MC IN ALL THE CHAIN

the starting point

- all the crystals will be characterized by their **optical properties** (4%)
- the **cosmics inter-calibration** will be performed on all the super-modules of the barrel (2%)
- some super-modules of the barrel will be inter-calibrated **during the test-beam**:
  - **overall inter-calibration** at the level of permill
  - well known behaviour to be used as a reference for **cross checks and validation of the in-situ algorithms**
- the main problem that has to be faced is the **amount of material in front of the ECAL**



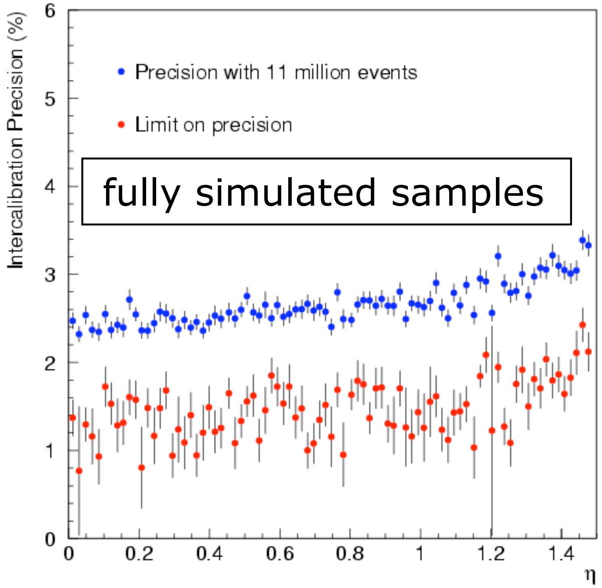
SM18 cosmics inter-calibration compared to the test-beam ones. The whole super-module but the borders.

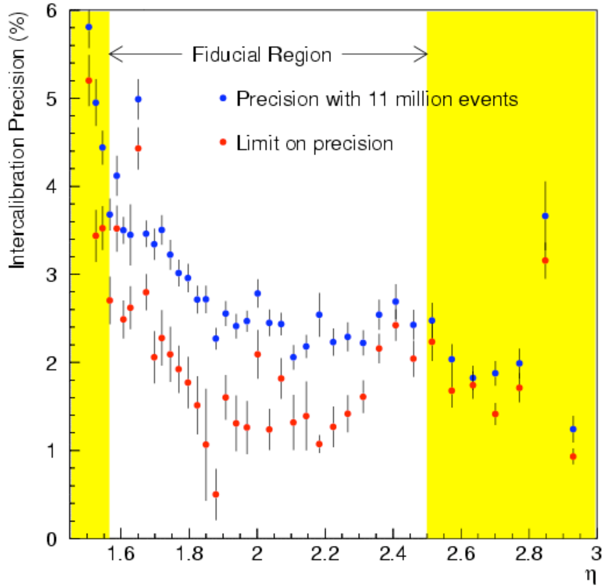
the φ symmetry inter-calibration

- inter-calibrate the crystals in an η–constant ring by exploiting the φ **symmetry of the deposited energy** — jet either minimum bias events
- **quick initial inter-calibration**
- to be used together with **an other technique** to inter-calibrate the rings among themselves ($Z \rightarrow e^+e^-$)
- the precision is **limited by the knowledge of the tracker material distribution** along φ

precision attainable with 11M events (•) and limit on the precision (•), versus η

few days





CMS NOTE 2004/007

the Z→ee inter-calibration

- Force the **reconstruction of M_Z** event by event to determine the inter-calibration coefficients
- **multiple iterations of the algorithm** on the available dataset to let the inter-calibration coefficients to converge
- independent of the tracker measurements: can be used **from the beginning of the data taking**
- **inter-calibration of rings at fixed η**, already calibrated internally (or determination of **algorithmic corrections** for the energetic reconstruction ($F(\eta)$))
- measurement of the **absolute scale** of ECAL

CMS NOTE 2006/039

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

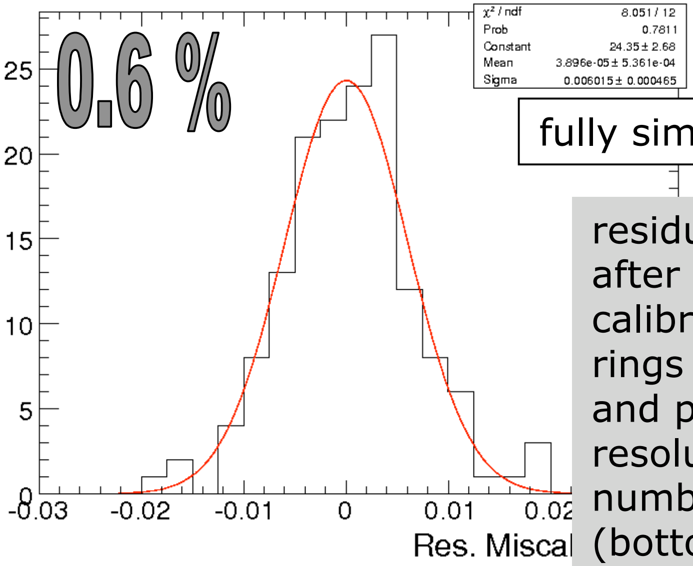
inter-calibration coefficient derived from a single event

the inter-calibration coeff. are a weighted mean over the whole dataset

$$\epsilon_j = \frac{\sum_{event\ i} w^i_j \cdot \epsilon^i}{\sum_{event\ i} w^i_j}$$

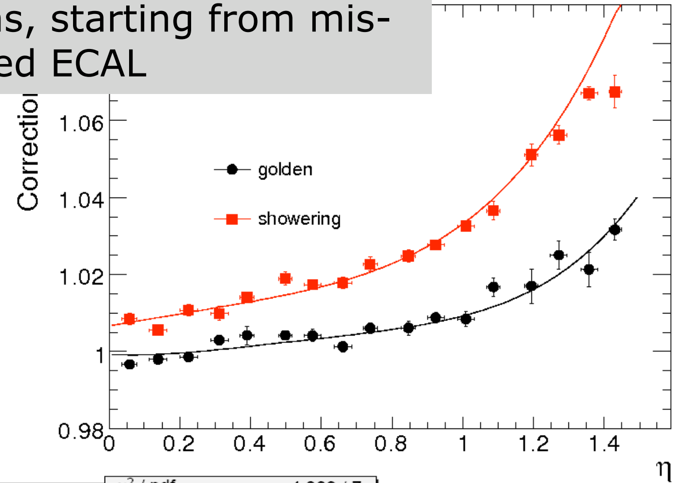
Z→ee Montecarlo studies

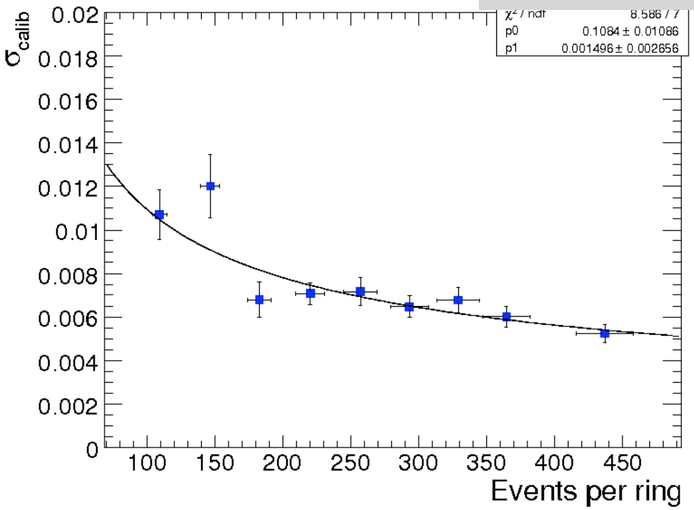
fully simulated samples

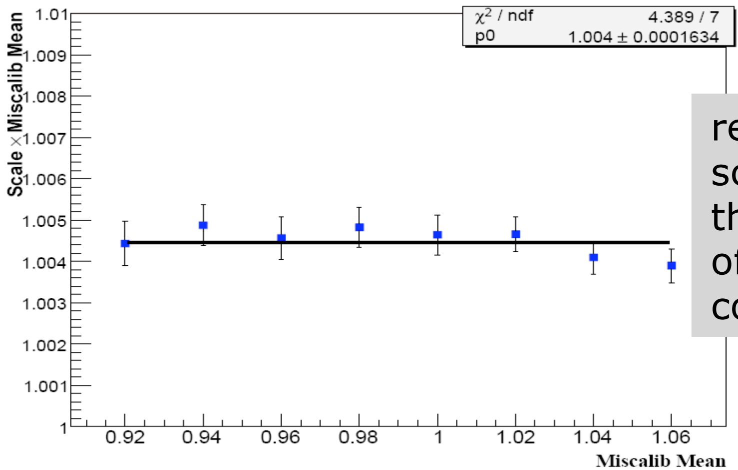


residuals distribution after the inter-calibration of different rings — 2 fb^{-1} — (top) and plot of the resolution versus the number of events (bottom)

determination of algorithmic corrections, for different categories of reconstructed electrons, starting from mis-calibrated ECAL







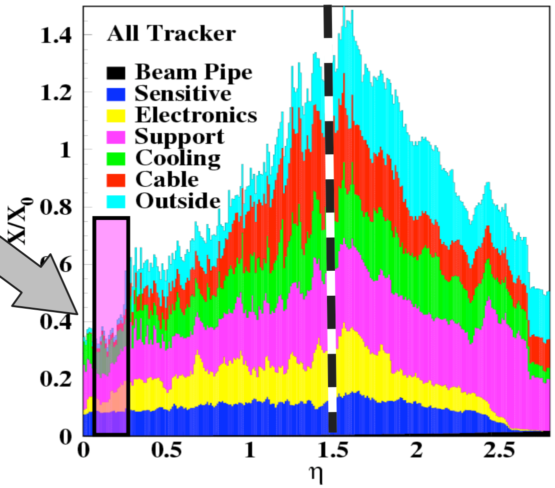
residuals of the scale factors after the re-alignment of the calibration coefficients

the isolated electrons technique

- **compare the electron momentum as reconstructed by the tracker to the energy reconstructed by ECAL**
- the **tracker has to be aligned**: not applicable from the beginning of the data taking
- based on the **minimization of: $\langle E_{25} - p_{tk} \rangle$**
- **three different implementations** give the same results
- **inter-calibration of ECAL regions** has been produced (10x10 in the barrel)
- the **intra-calibration of the regions** is under study

CMS NOTE 2006/021

precision 0.4% reached soon



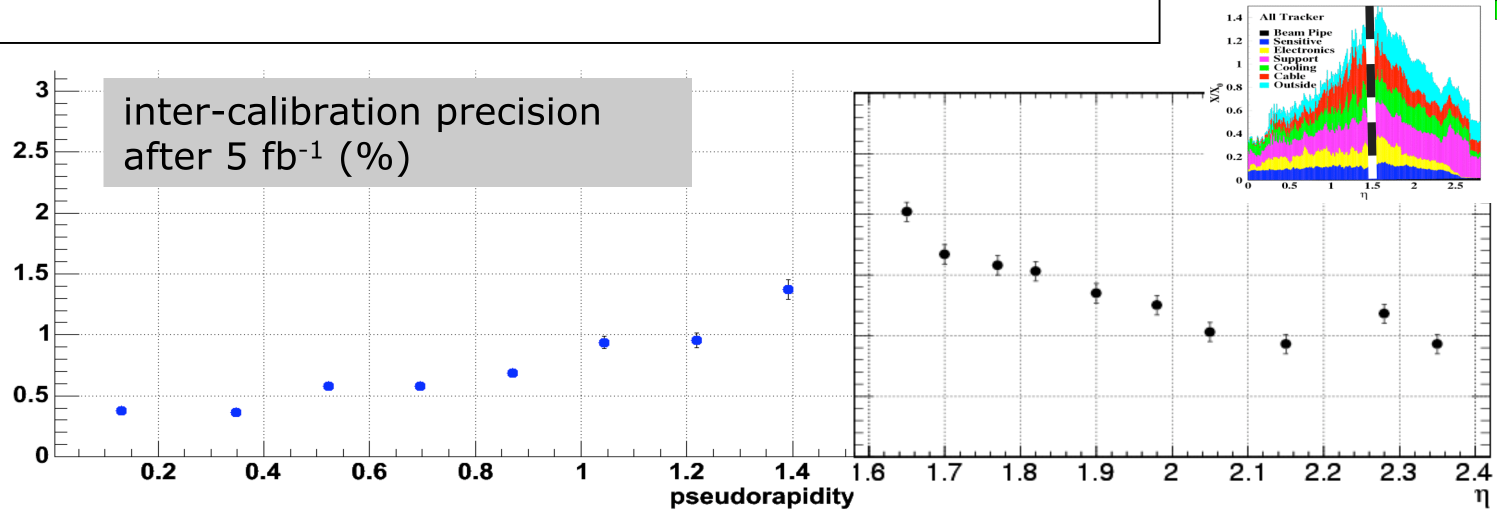
very good results in the central region (low η), at high η the resolution is affected by the tracker material budget, because of the bremsstrahlung

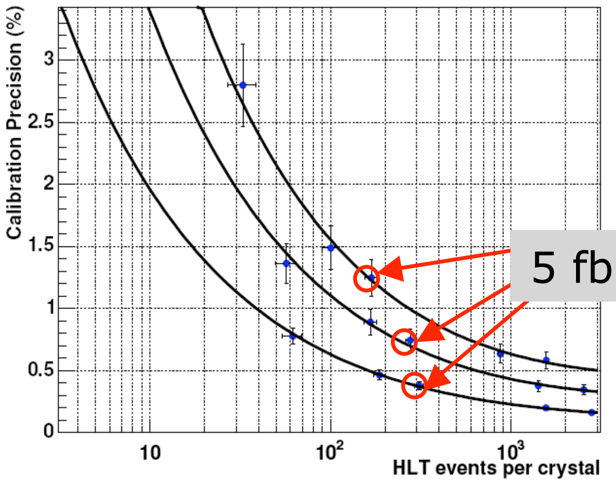
isolated e: Montecarlo studies

barrel

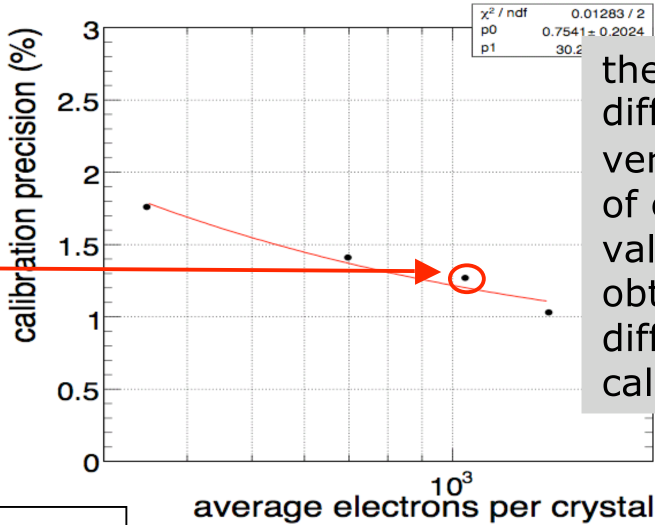
endcap

inter-calibration precision after 5 fb^{-1} (%)





5 fb^{-1}



the precision, in different η regions, versus the number of events. The values have been obtained with 50 different mis-calibration sets

fully simulated samples

inter-calibrating with photons

- other techniques are under study for the *in situ* calibration
- make use of the physics **channels** $\eta \rightarrow \gamma\gamma$ $\pi^0 \rightarrow \gamma\gamma$
- these procedures will provide an excellent **monitoring for the inter-calibration coefficients**
- the inter-calibration coefficients will be **calculated with photons**, that show a slightly different shower development (i.e. shower start) in the crystals than electrons

first tests of the algorithms

- the **test-beam data (ongoing)** are used to test the calibration techniques
- the chi2 minimization techniques (matrix of crystals) are **validated against the well known test-beam procedure** (single crystals) based on the crystal maximum containment
- the analyses performed so far give already **very good results**
- the absence of any materials in front of the detector allows careful studies of possible **systematic effects** when varying the η position of the crystals
- results from the test-beam will be a powerful instrument to **validate and interpolate the calibrations during the data taking**

ECAL test-beam setup for the super-module holding and displacement

conclusions

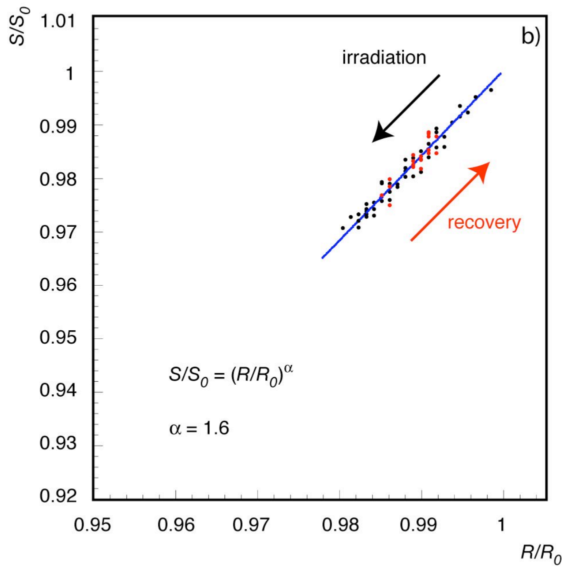
- the **CMS ECAL will play a fundamental role** in the CSM program (e.g. search for the Higgs boson in the golden channel $H \rightarrow \gamma\gamma$)
- to exploit its Physics reaches, the detector has to be **calibrated with a precision at the level of 5 permill**
- a **detailed set of protocols** has been implemented to be applied both before and during the data taking
- starting from the results of the pre-calibration, the algorithms designed for the *in situ* calibration will **guarantee the required precision**
- both Montecarlo studies and the test-beam data analysis **validate the procedures envisaged**

backup slides

the laser monitoring

- the crystals have been designed to let the dose at LHC **affect only their transparency**
- such short time scale variations will be followed by means of **a laser system, injecting light in each crystal**
- **the loss in transparency is followed** by blue light, while an infra-red light is used as a reference
- the **precision, stability and reproducibility** of the system measurements have been proved during several test-beam campaigns

response to electrons (S/S_0) versus response to laser light (R/R_0) during controlled irradiation and recovery at 2002 test-beam



CMS CR 2005/001