Il Calorimetro Elettromagnetico di CMS

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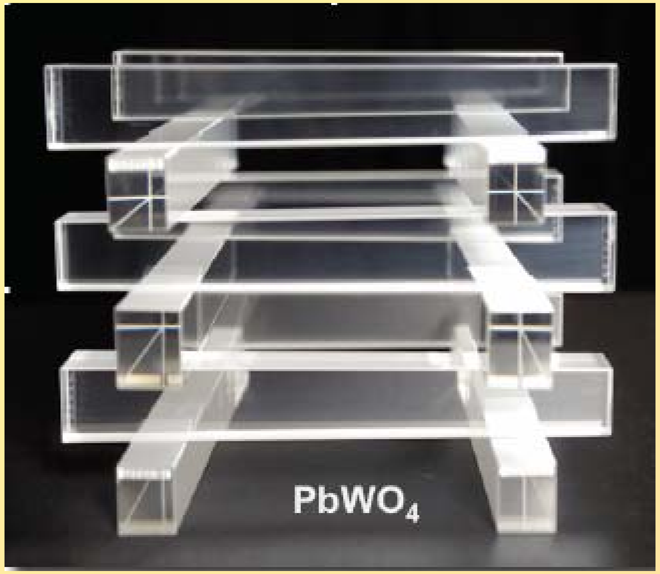
Outline

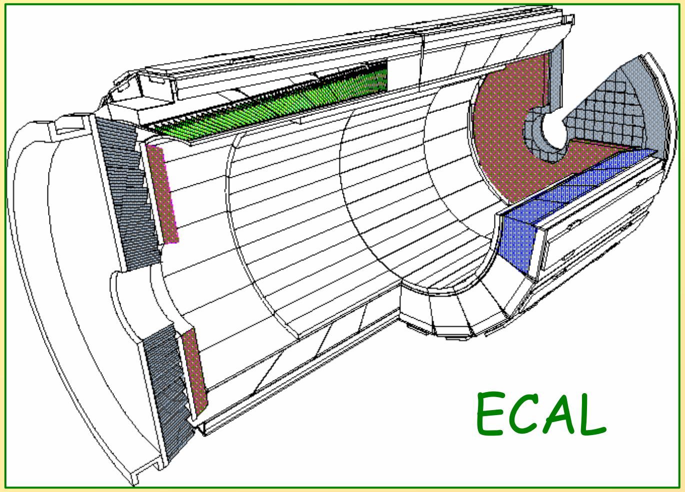
- Caratteristiche del calorimetro
- Stato della costruzione
- Precalibrazione del calorimetro
- Strategie di calibrazione in situ
- Ricostruzione degli elettroni



Partecipazione INFN (Roma, Milano e Torino):
costruzione e test moduli del calorimetro, produzione e test schede elettronica, sistema di raffreddamento, sistema High Voltage per APD, struttura meccanica, ECAL database, precalibrazione, analisi e simulazione Test Beam, produzione Montecarlo, calibrazione in situ, analisi canali SM Higgs e BSM.

ECAL Introduction

- Homogenous calorimeter
- Lead Tungstate Crystals $PbWO_4$
- Solenoidal Magnetic Field: 4 Tesla



Parameter	Barrel	Endcap
η coverage	$\|\eta\| < 1.48$	$1.48 < \|\eta\| < 3.0$
Granularity ($\Delta\eta\times\Delta\phi$)	0.0175×0.0175	varies in η
Crystal Dims. (cm^3)	$2.18\times2.18\times23$	$2.85\times2.85\times22$
Depth in X_0	25.8	24.7 (+3X_0)
No. of crystals	61,200	14,950
Crystal Volume (m^3)	8.14	3.04
Photodetector	APDs	VPTs
Modularity	36 supermodules	4 Dees

Crystal Producers: Bogoroditsk (Russia), Shanghai Institute of Ceramics (Cina)

Construction Regional Centers: CERN (lab 27) and INFN/ENEA - Rome

Crystal choice

	NaI(Tl)	BaF_2	CsI(Tl)	CsI	CeF_3	BGO	PWO	
ρ	3.67	4.88	4.53	4.53	6.16	7.13	8.26	g/cm^3
X0	2.59	2.05	1.85	1.85	1.68	1.12	0.89	cm
RM	4.5	3.4	3.8	3.8	2.6	2.4	2.2	cm
τ	250	0.8/620	1000	20	30	300	15	ns
λp	410	220/310	565	310	310/340	480	420	nm
n (λp)	1.85	1.56	1.80	1.80	1.68	2.15	2.29	
LY	100%	15%	85%	7%	5%	10%	0.2%	%NaI

Typical light yield of NaI ~ 40000 γ/MeV

Characteristics

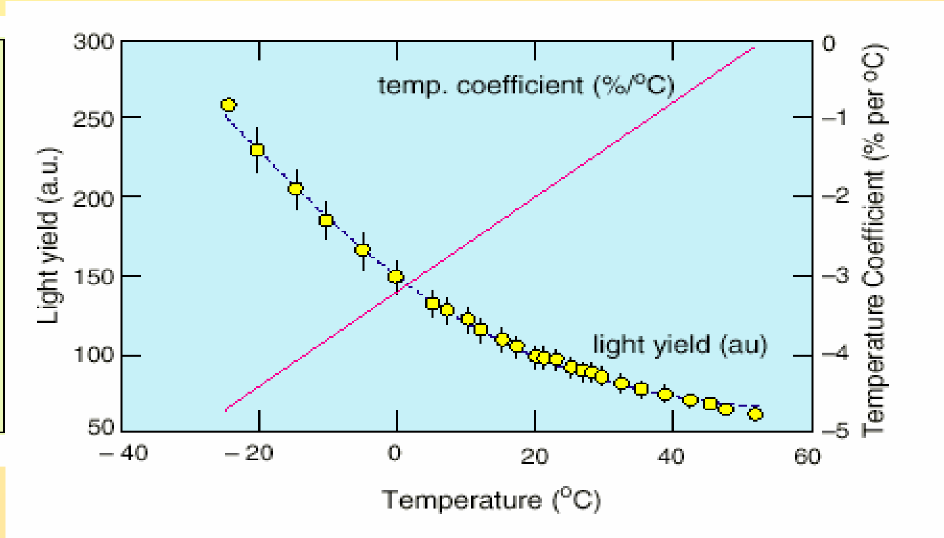
☺

- Fast scintillation
- Small X_0 and R_m
- Radiation hardness
- Relatively easy to grow

☹

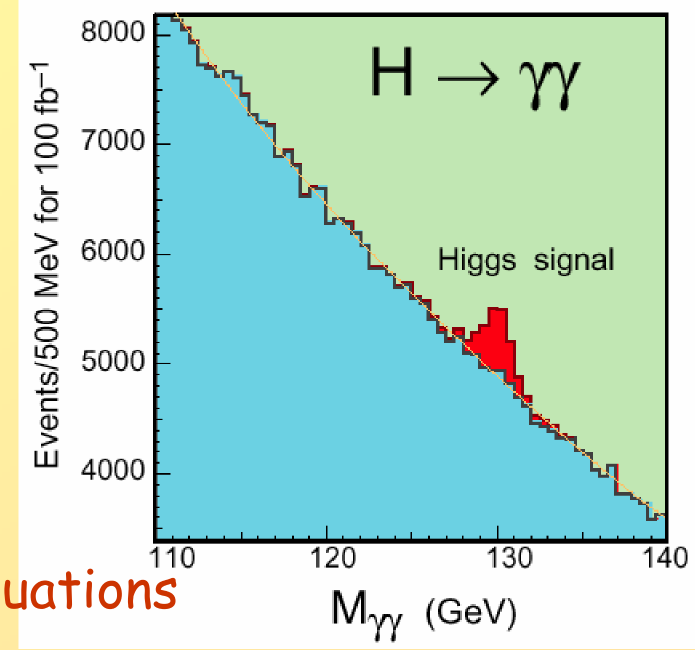
- Low Light Yield
- High index of refraction
- Strong LY dependance on T

Parameter		Value
Radiation length	cm	0.89
Moliere radius	cm	2.2
Hardness	Moh	4
Refractive index		2.3
Peak emission	nm	440
% of light in 25 ns		80%
Light yield (23 cm)	γ/MeV	100



Energy Resolution (1)

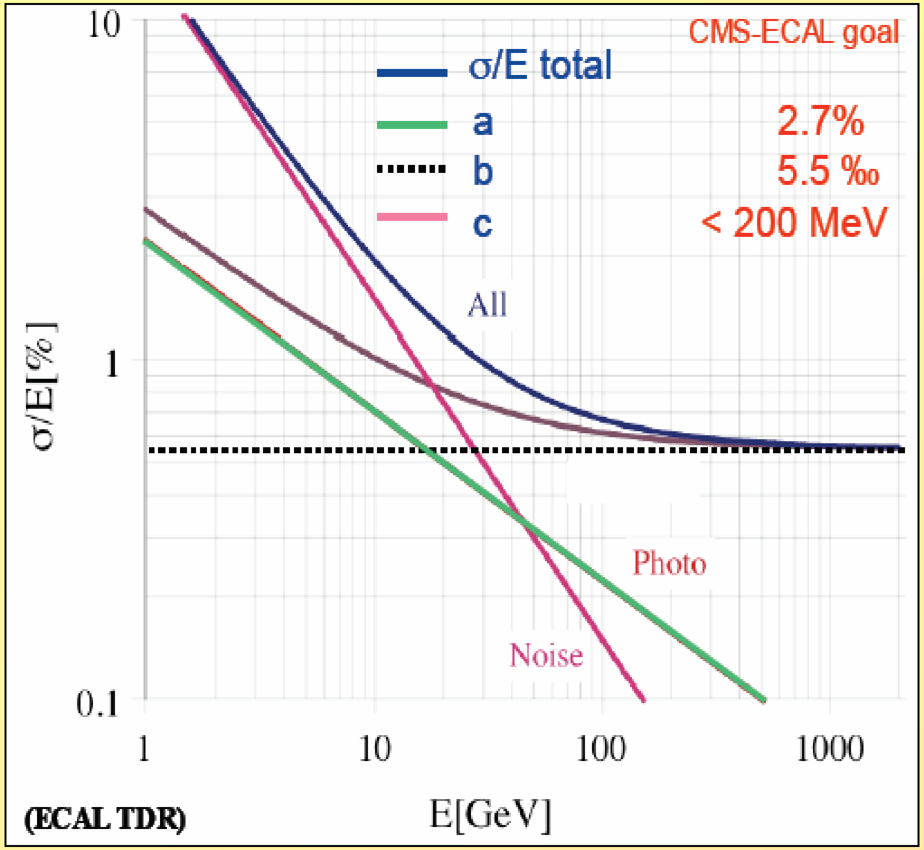
The discovery potential of an intermediate mass Higgs boson via the two photon decay channel is strongly dependent on the energy resolution.



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

- a: stochastic term from Poisson-like fluctuations
  - sampling contribution (natural advantage of homogenous calorimeters)
- b: constant term
  - dangerous limitation to high energy resolution
  - important contribution from intercalibration constants
- c: noise term from electronic and pile-up
  - relevant at low energy

Energy Resolution (2)



Stochastic Term

- photostatistics contibution:
  - light yield
  - geometrical efficiency of the photodetector
  - photocatode quantum efficiency
- electron current multiplication in APDs
- lateral containment of the shower

Energy Resolution (3)

Constant Term contributions:

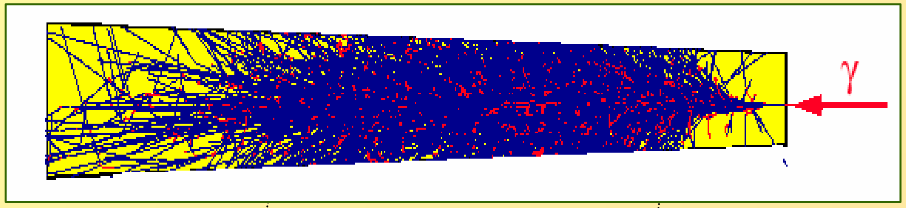
- leakage (front, rear, dead material)
  CMS full shower simulation < 0.2 %
- temperature stabilization < 0.1 °C
  (dLY/dT = -2.0%/°C @ 18°C ; dM/dT ~ -2.3 %/°C)
- APD bias stabilization (±20 mV / 400 V)
  (dM/dV = 3%/V)
- light collection uniformity (next slide)
- intercalibration by light injection monitor and physics signals

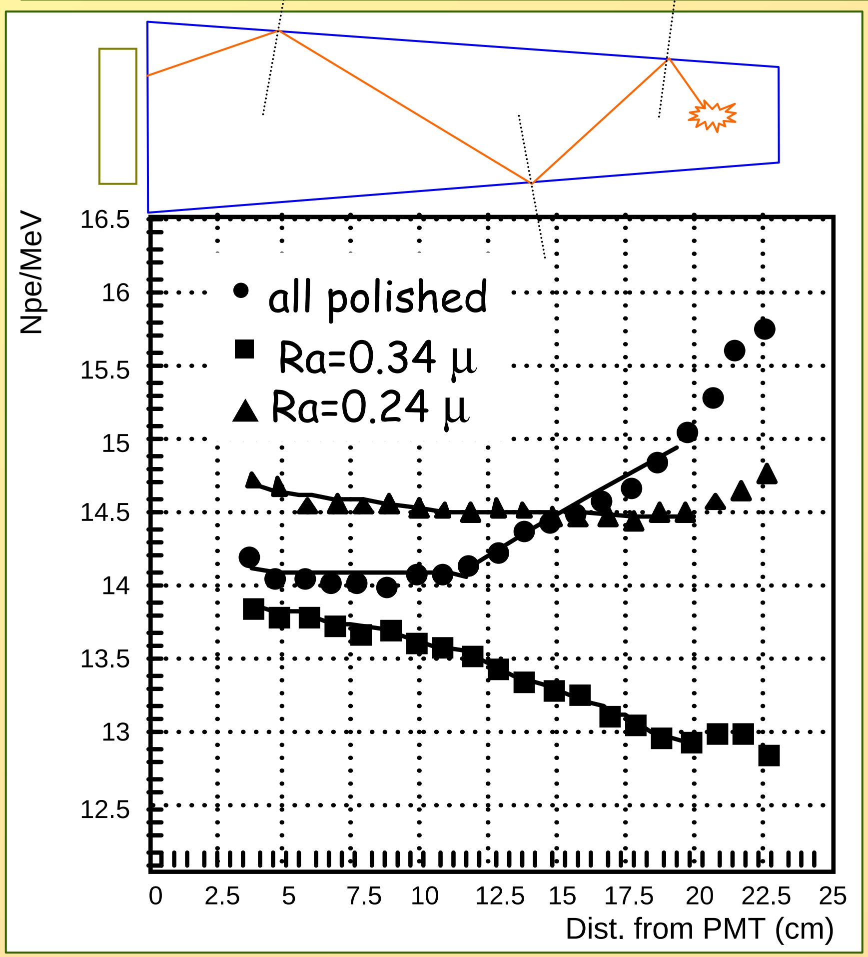
Total constant term $C \approx 0.5\ \%$

Light Collection Uniformity

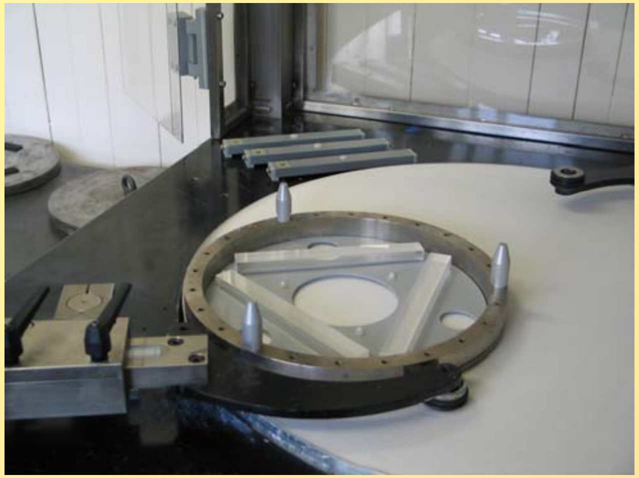
- A non uniformity of the light collection in the shower max region may significantly contribute to the constant term in the energy resolution.

- Uniformity can be controlled by depolishing one lateral face with a given roughness



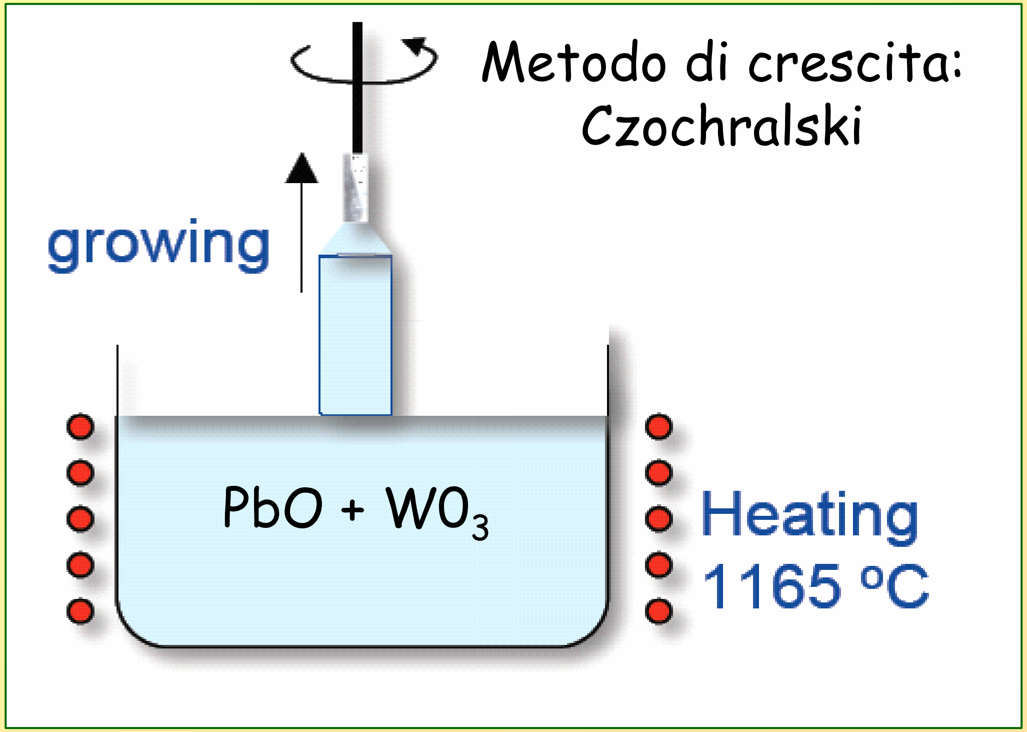


Uniformity treatment



Construction (1)

- Crystal R&D phase (1995-1998)
- 6000 crystal preproduction (1998-2000)
- Crystal production:
  2001-2006 Barrel
  2006-2007 Endcap

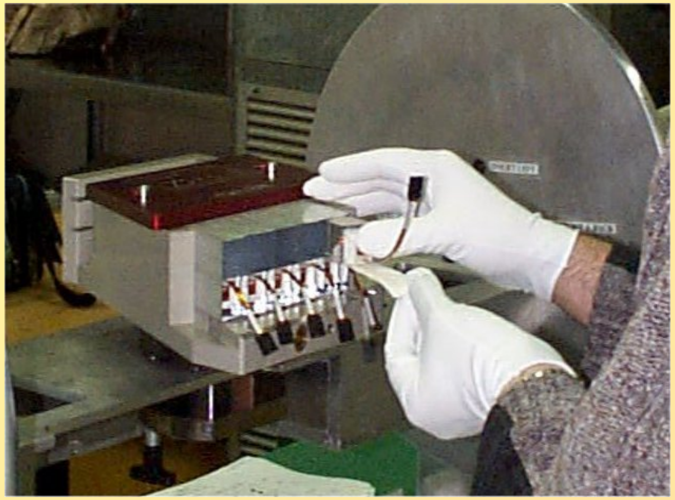


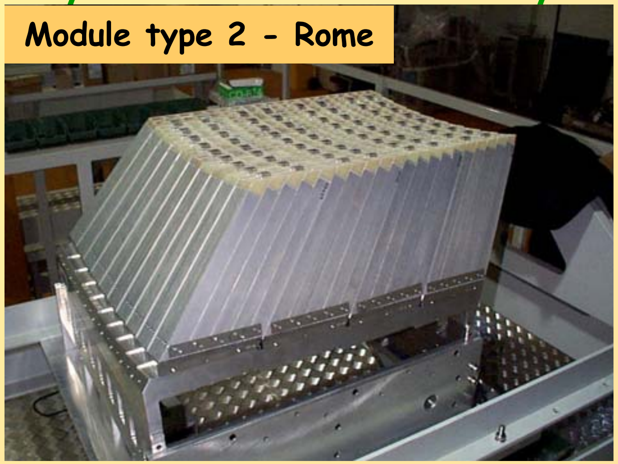
BARREL ingot

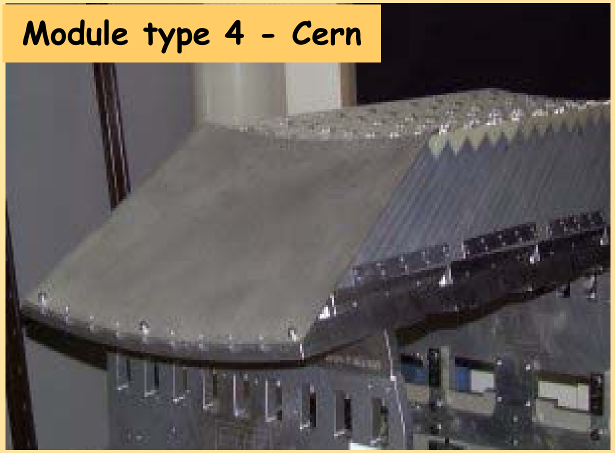
Construction (2)

CERN (lab 27) and INFN/ENEA (Casaccia) Regional Centers:

- Automatic measurements of:
  crystal dimensions, trasmission, light yield and uniformity
- Submodule assembly (10 crystals)
- Module assembly (40-50 submodules)



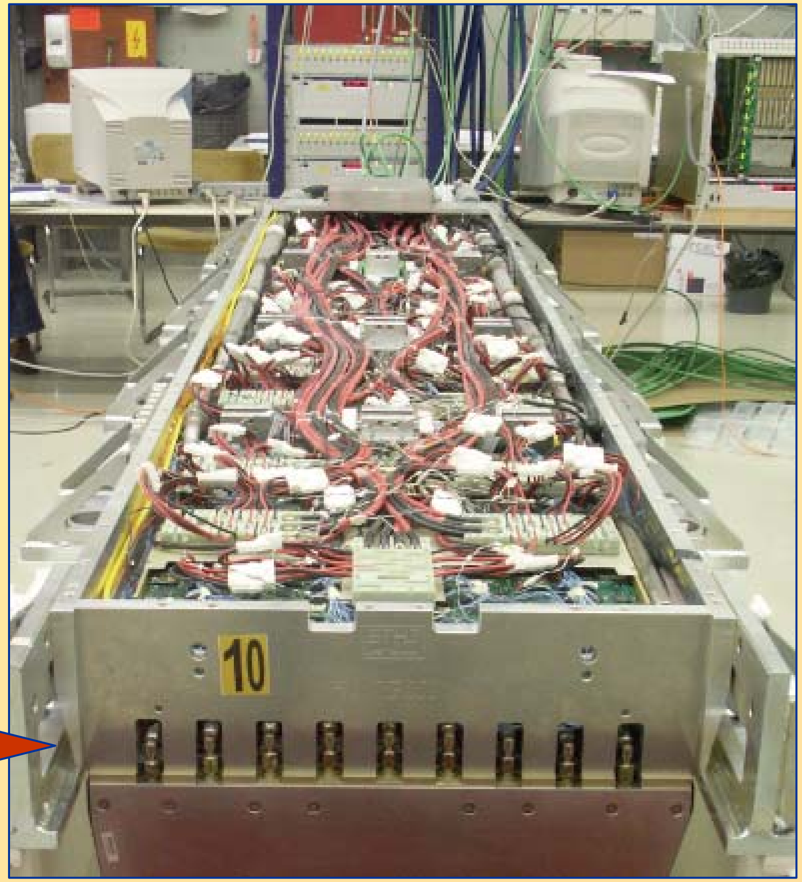

Module type 2 - Rome


Module type 4 - Cern

Construction (3)

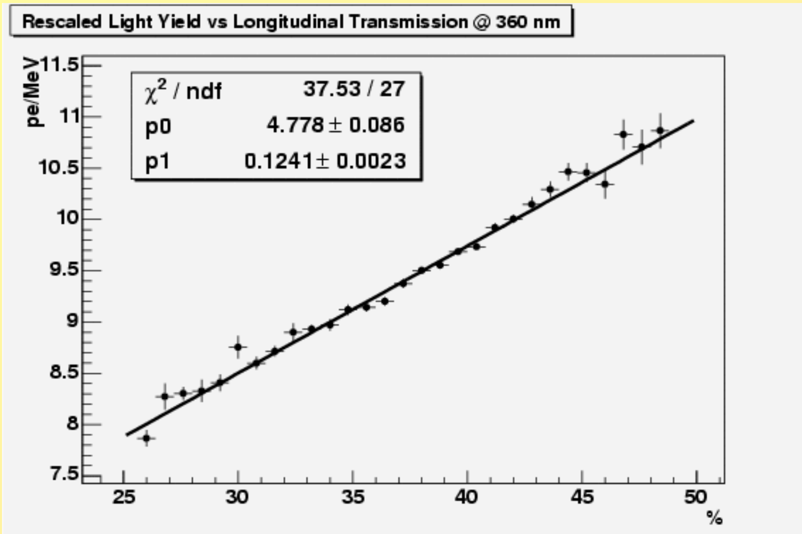
1 SuperModule = 4 Modules
= 1700 xtals + 3400 APDs +
68 TriggerTowers + 34 HV channels + …

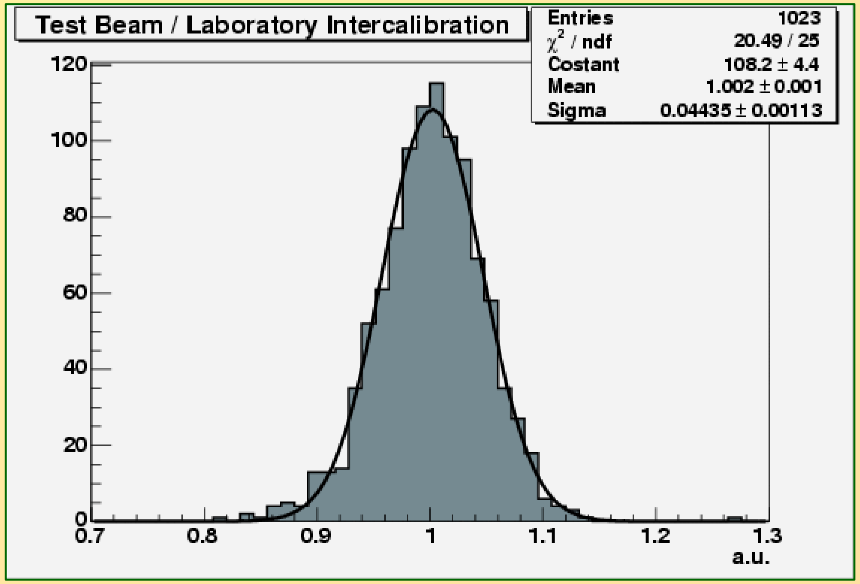
- Up to now, more than half of the barrel modules have been assembled.
- Foreseen rate: one SuperModule per month (= real rate)
- The electronic chain is assembled and tested at Cern (Prevessin)



Precalibration (1)

- Crystal measurements performed in the Regional Centers allow to precalibrate the electromagnetic calorimeter to a precision level of about 4%.
- A useful correlation between Light Yield and Longitudinal Transmission has been observed. It helps to improve the precalibration at the startup.

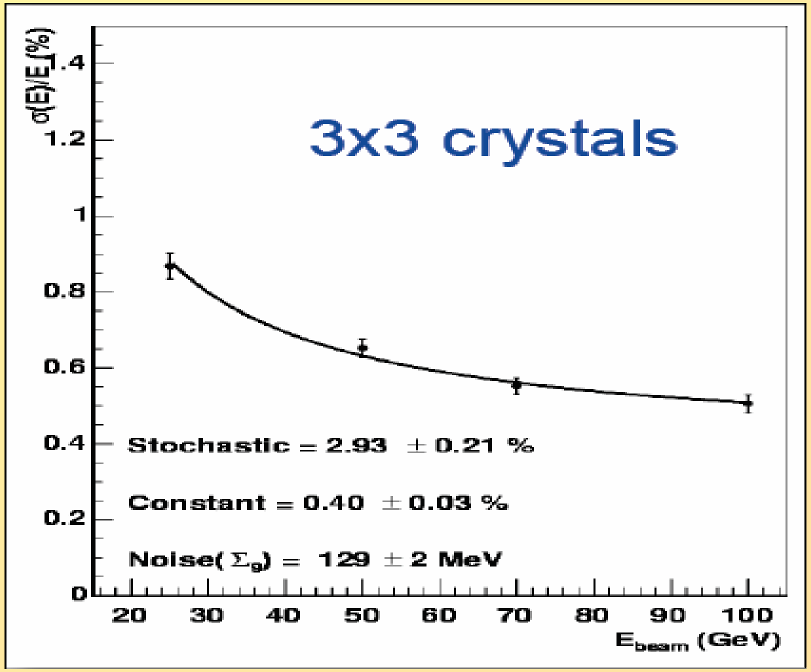




Precalibration (2)

Calibration with Cern-SPS electron beams in the last three years

Goals:
- ✓ electronics: noise
- ✓ cooling: T stability
- ✓ High Voltage: V stability
- ✓ Laser: stability and performance in the irradiation phase
- ✓ Energy resolution
- ✓ Precalibration precision < 0.5%

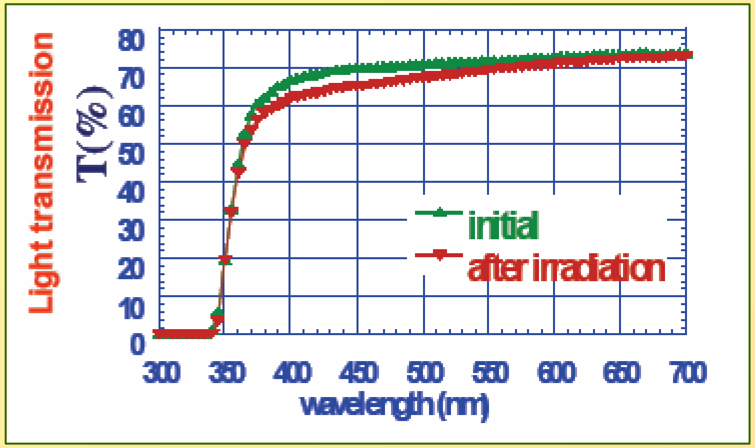


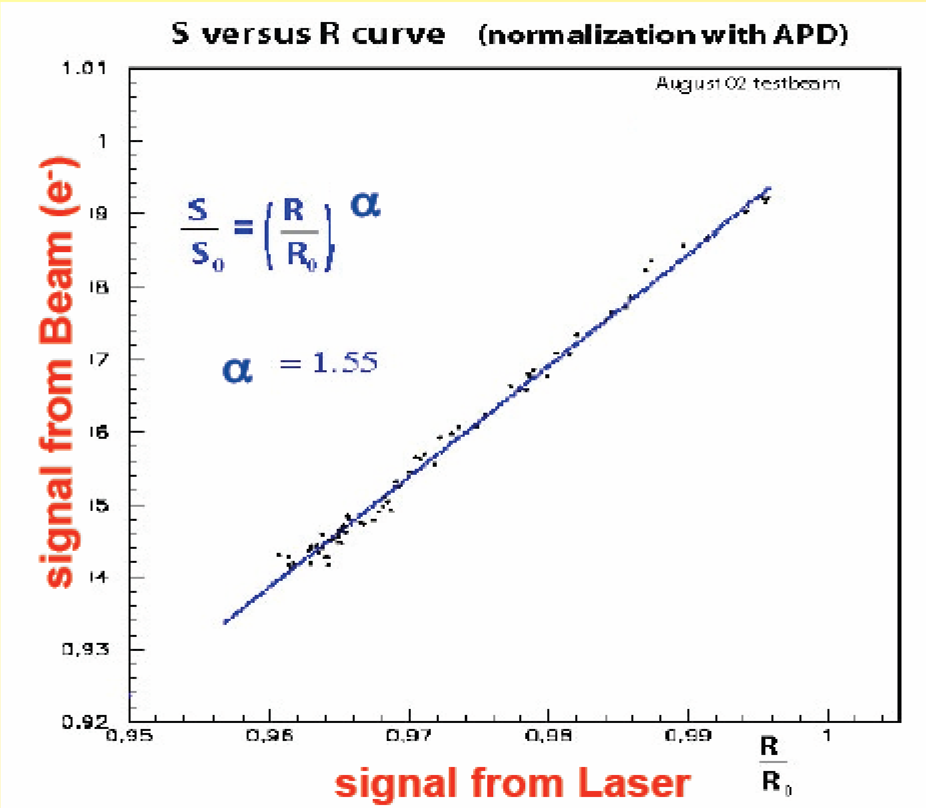
- Few other SuperModules could be probably tested and calibrated in the 2006 test beam @ Cern.
- This year a cosmic run will start. The aim is to reach a precalibration level of 3% with a rate of two SuperModules per month.

Laser Monitoring

Electromagnetic radiation produces a damage:

- crystal trasparency is reduced
- scintillation mechanism is not affected





The relation between XL response to electrons (S/S_0) and response to laser (R/R_0) varies in the same way during recovery and irradiation phases.

Insitu Calibration (1)

In-situ calibration with physics events: this is the main tool to reduce the constant term to the design goal of 0.5%.

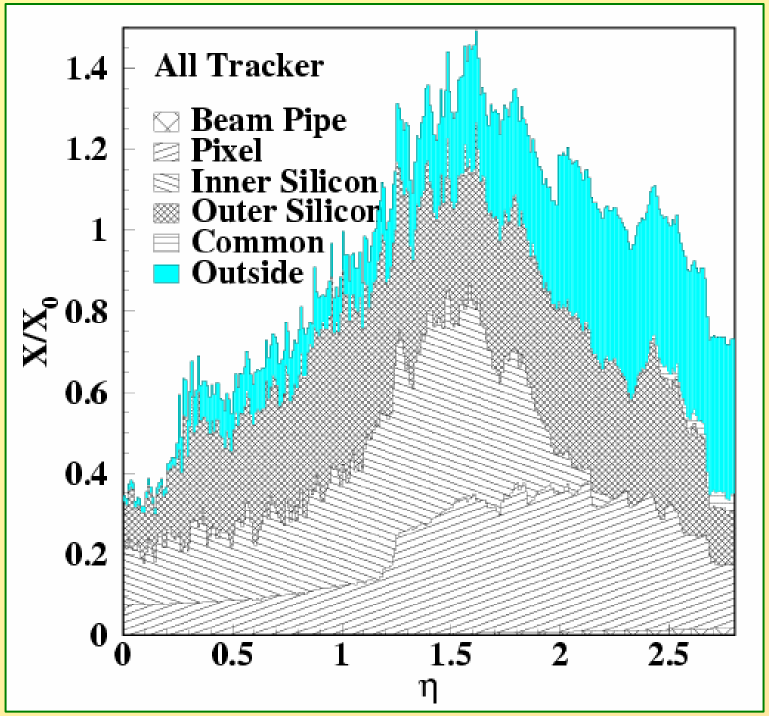
- At the beginning of detector operation -> fast intercalibration method based on the ϕ symmetry in minimum bias events.
- Energetic electrons from $Z \rightarrow e^+ e^-$ decay -> intercalibration of different regions and absolute energy scale setting.
- Once the Tracker fully functional -> intercalibration of individual crystals with E/p measurement ($W \rightarrow e\nu$ events).

TRACKER MATERIAL:

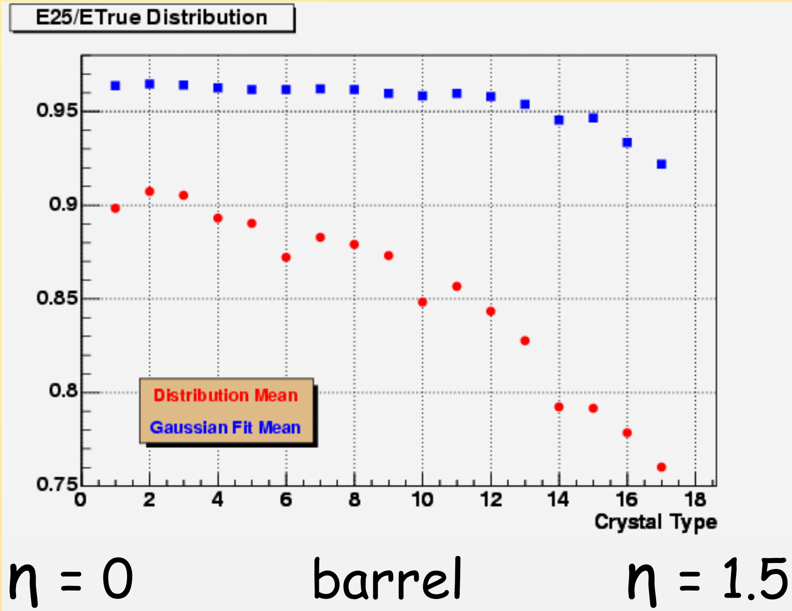
the amount of material (~ 1 X_0) between interaction point and ECAL is the main difficulty in performing calibration.

Tracker Material

- Complex tracking system + frames + cooling + cables and services
- Around one radiation lenght between the interaction point and the electromagnetic calorimeter !
- Bremsstrahlung and photon conversion (big non-gaussian tails in physical distributions)



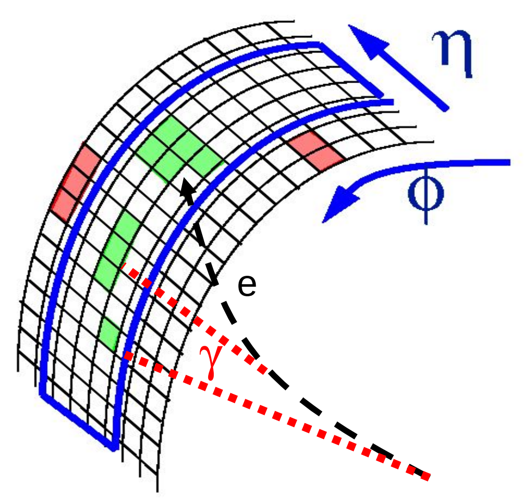
E25/E_True: Mean and Gaussian Peak



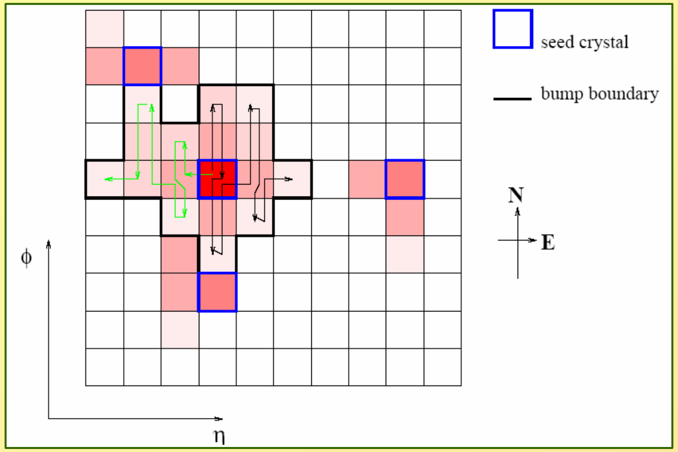
Electron Reconstruction

The electron cluster is spread by Bremsstrahlung (mainly in ϕ)

- Too little recostructed cluster: not full containment of brem. photons
- Too big recostructed cluster: noise, pile-up

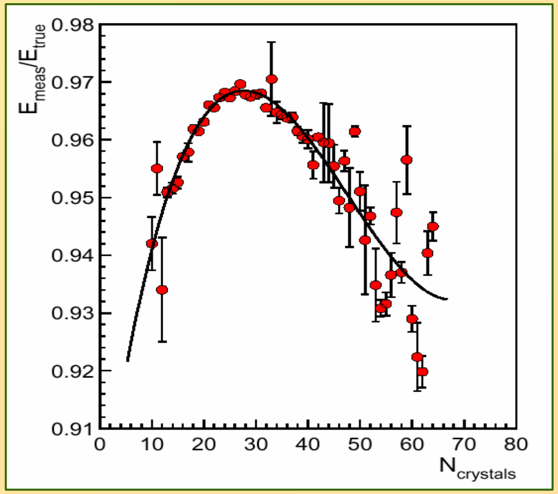


SuperCluster = clustering with dynamic algos.



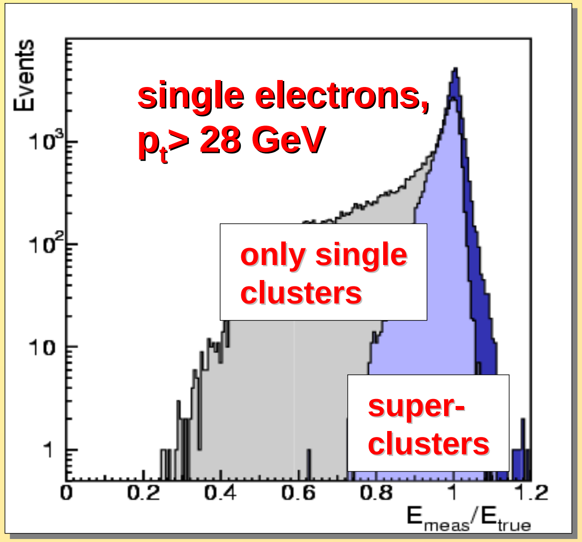
more brem./conversions = bigger SC dimension

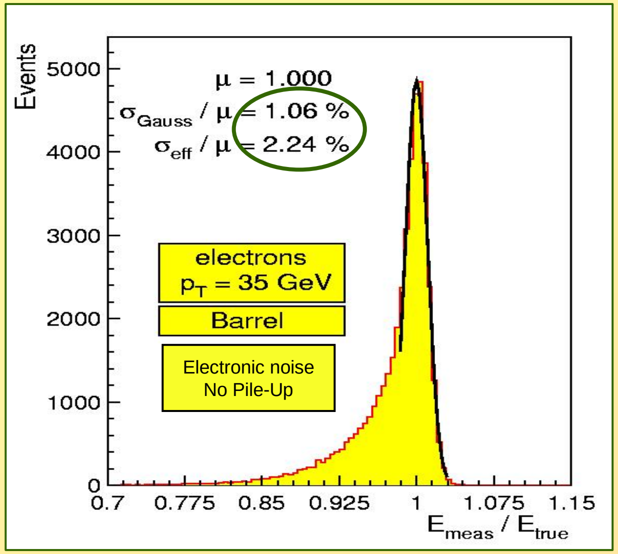
SC Energy and Position are used in High Level Trigger

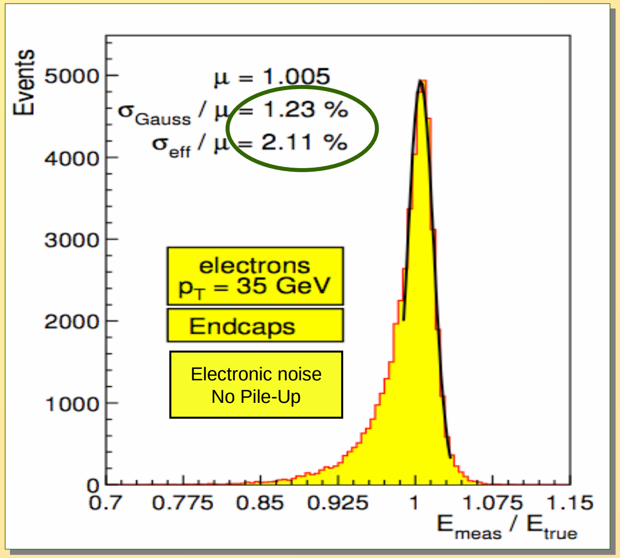


Electron Reconstruction (2)

This dynamic algorithm reduces non gaussian tails more than a fixed dimension algorithm (e.g. nxn crystals cluster).
SuperCluster is optimized for HLT threshold energies.
Considering low energy electron (≈ 10 GeV), tracker momentum helps to improve energy measurements. Work in progress.







To be compared with intrinsic calorimeter resolution < 0.9%

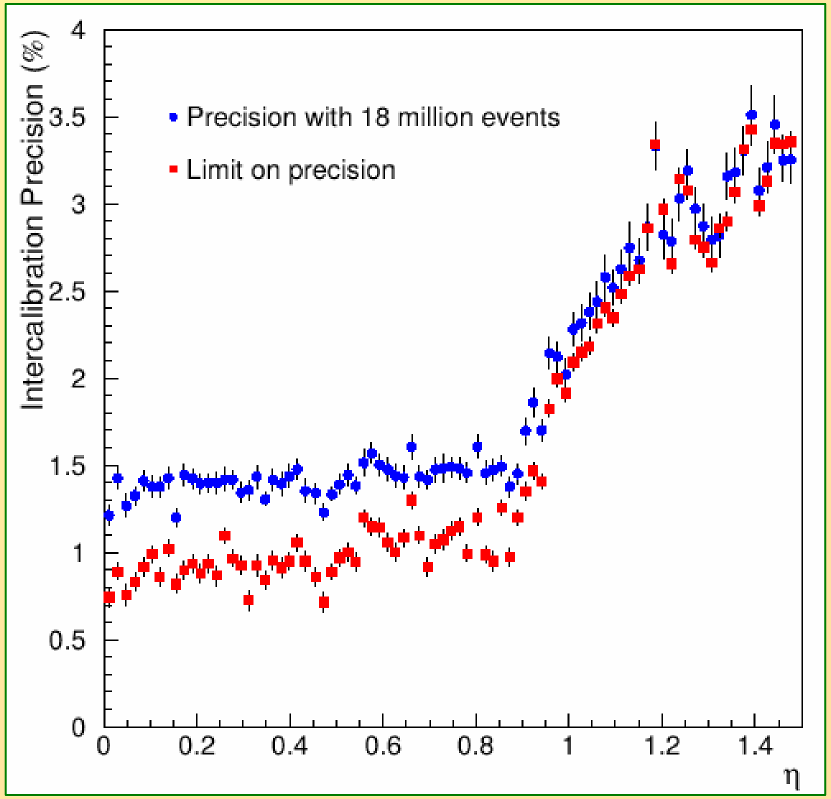
Insitu Calibration (2)

φ symmetry

Assumption: the total transverse energy deposited from a large number of events should be the same for all crystals at fixed η

Aim: reduce the number of intercalibration constants at the startup: from 61200 (crystals) to 170 (rings) in the barrel.

Studies with fully simulated Montecarlo give a precision of 1.3% - 3.5%, in case of limited knowledge of φ inhomogeneity.



Insitu Calibration (3)

$Z \rightarrow e^+ e^-$

- The rings can rapidly be intercalibrated using $Z \rightarrow e^+e^-$ without tracker momentum measurements, using reconstruction of the invariant mass
- A large fraction of events allows to intercalibrate the endcaps with respect to the barrel
- The $Z \rightarrow e^+e^-$ rate is ~ 1 Hz (almost flat in η)

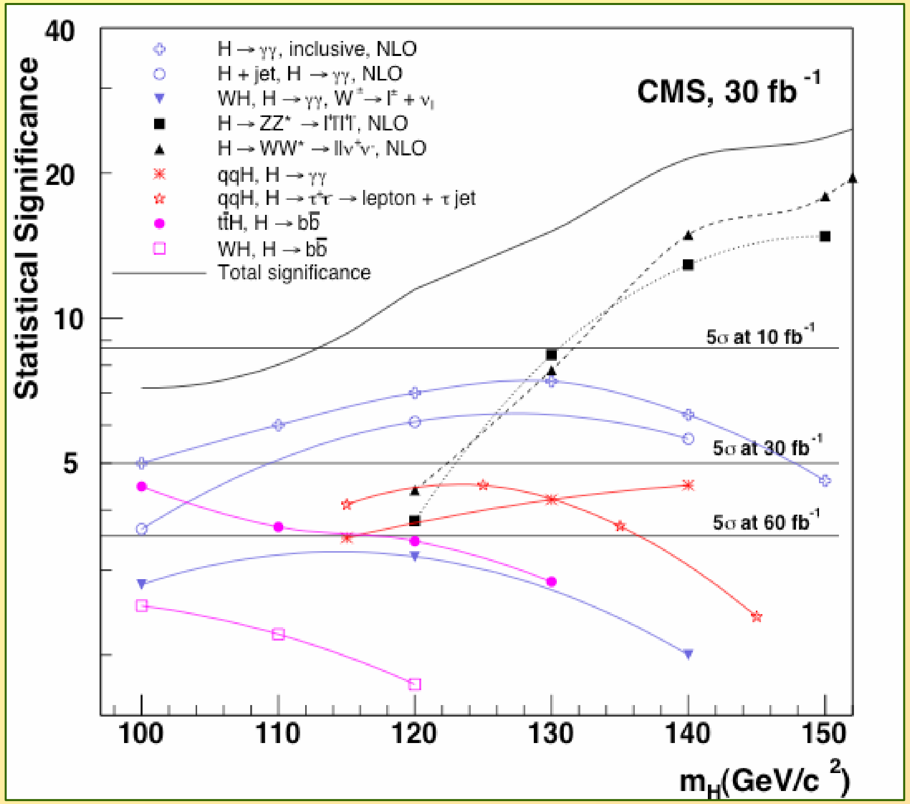
$W \rightarrow e\,\nu$

- The electron shower involves many crystals -> algorithm to unscramble individually the calibration constants.
- The $W \rightarrow e\nu$ rate is ~ 10 Hz.
- In a couple of months at 2*10^{33} cm^{-2} s^{-1}, exploiting the full tracker information will allow to reach 0.5% resolution.

New calibration studies on low energy photons ($\pi \rightarrow \gamma\gamma$ and $\eta \rightarrow \gamma\gamma$). Mainly during the startup phase.

Conclusioni

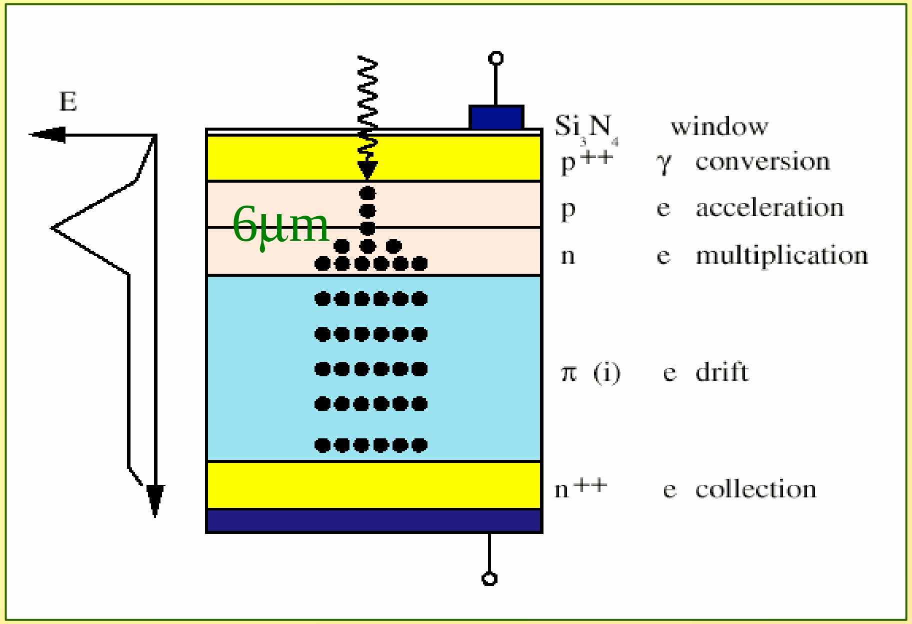
Stiamo lavorando per…

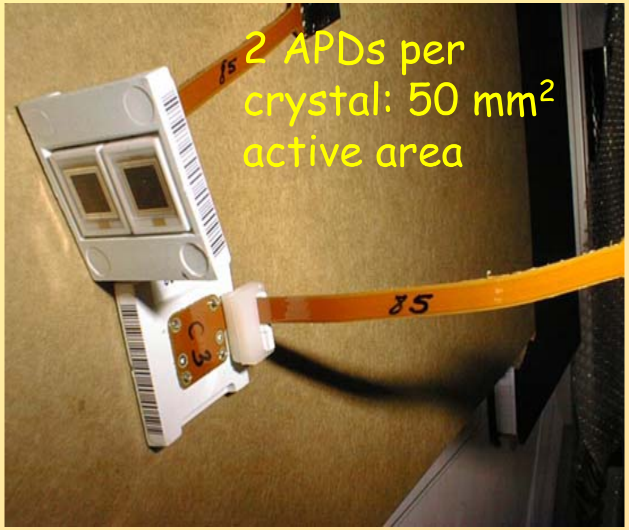


Backup slides

Avalanche Photo Diodes

Due to low light yield, need photodetector with intrinsic gain.
Radiation hard and insensitive to magnetic field (4T)





- Internal gain: M=50 @ HV ≈ 380 V
- Good match to PWO scintillation spectrum (Q.E. ≈ 75% @ 430 nm)
- Strong sensitivity of gain to Voltage and Temperature variations: good stability needed

High Level Trigger

	$2x10^{33}cm^{-2}s^{-1}$			$10^{34}cm^{-2}s^{-1}$		
	Signal	**Background**	**Total**	**Signal**	**Background**	**Total**
Single electron	$W \to e\nu$: 10Hz	$\pi^{\pm}/\pi^0$ overlap: 5Hz π^0 conversions: 10Hz $b/c \to e$: 8Hz	33Hz	$W \to e\nu$: 35Hz	$\pi^{\pm}/\pi^0$ overlap: 15Hz π^0 conversions: 19Hz $b/c \to e$: 6Hz	75Hz
Double electron	$Z \to ee$: 1Hz	~0	1Hz	$Z \to ee$: 4Hz	~0	4Hz
Single photon	2Hz	2Hz	4Hz	4Hz	3Hz	7Hz
Double photon	~0	5Hz	5Hz	~0	8Hz	8Hz
TOTAL:			43Hz			94Hz

Angular Resolution

- Energy-weighted mean position of crystals in the cluster with 2 corrections:
  - Longitudinal center of gravity of the shower because the crystals do not exactly point to the nominal interaction vertex.
  - Weighted mean using the logarithm in the cluster (not in the SuperCluster !)