CMS ECAL Cosmic Calibration

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On behalf of the CMS ECAL collaboration

Compact Muon Soleniod (CMS)

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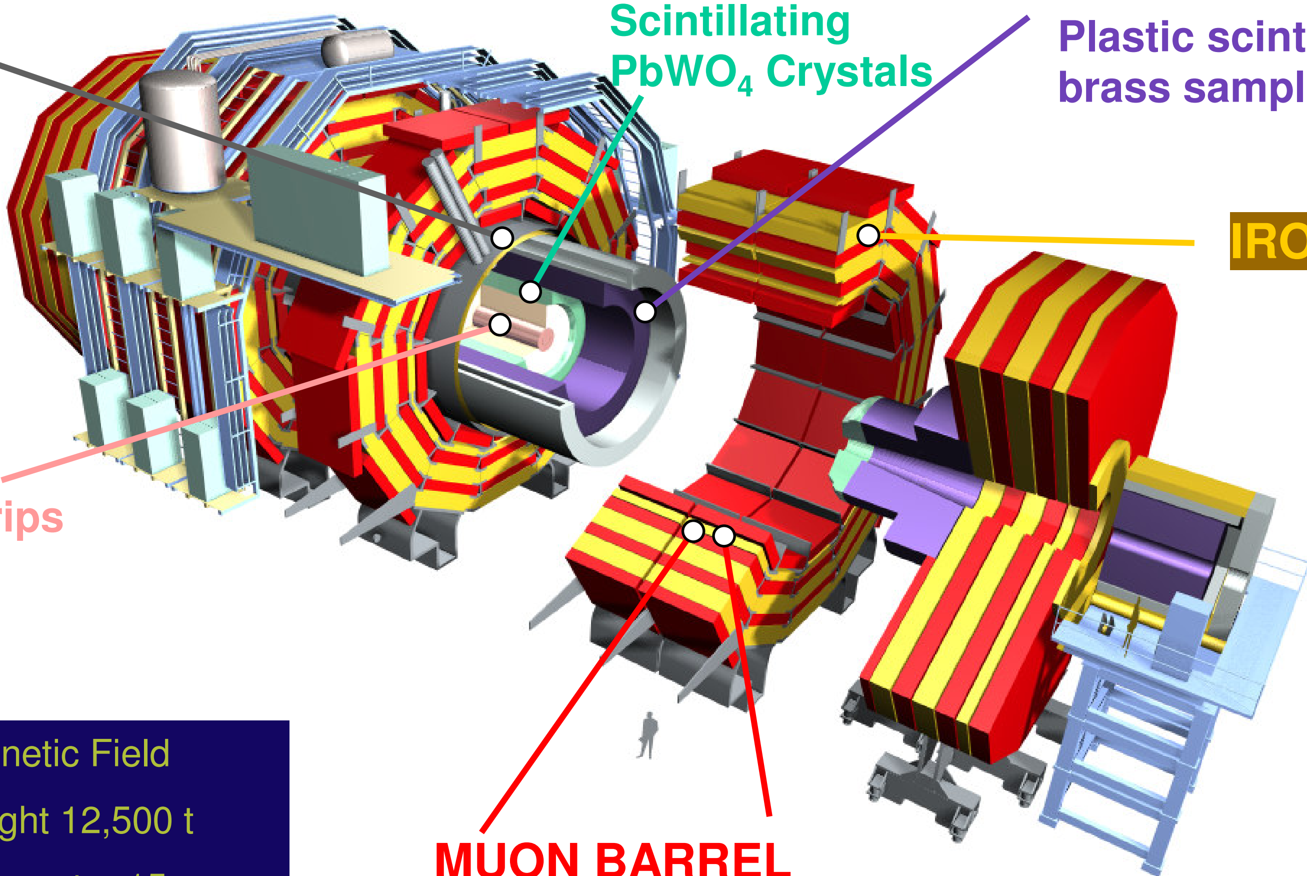


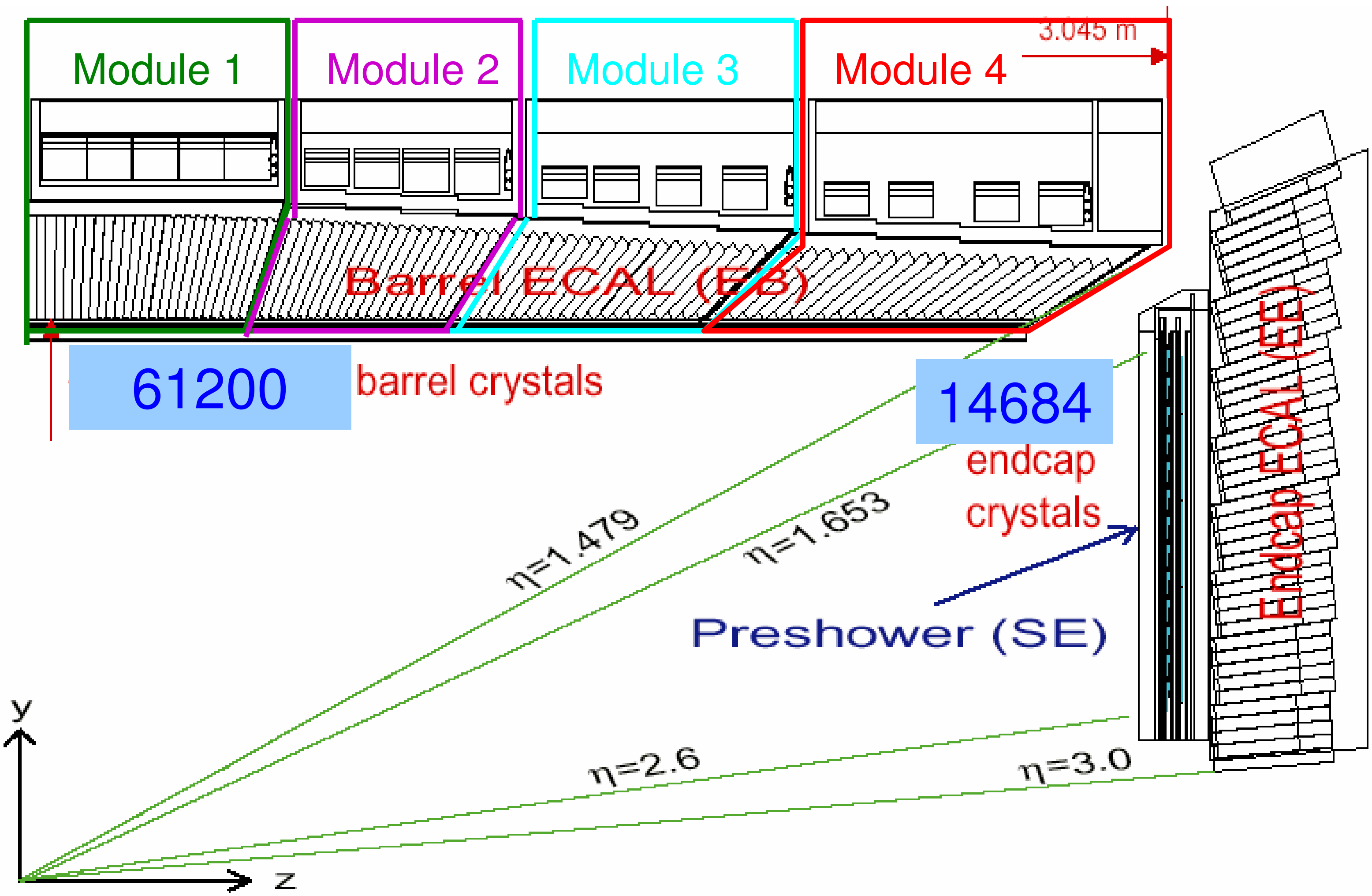
4 T magnetic Field

Total Weight 12,500 t

Overall Diameter 15m

Overall Length 21.6m

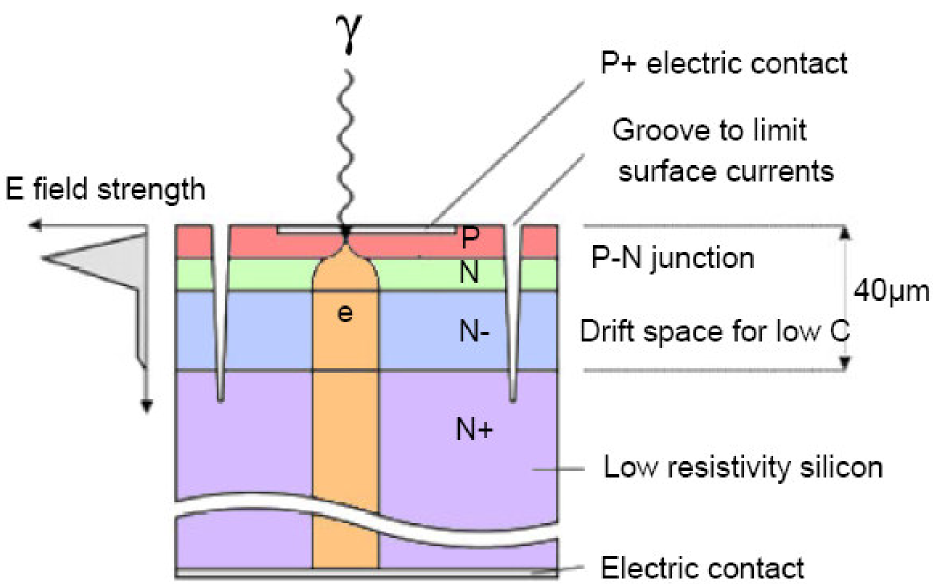
ECAL

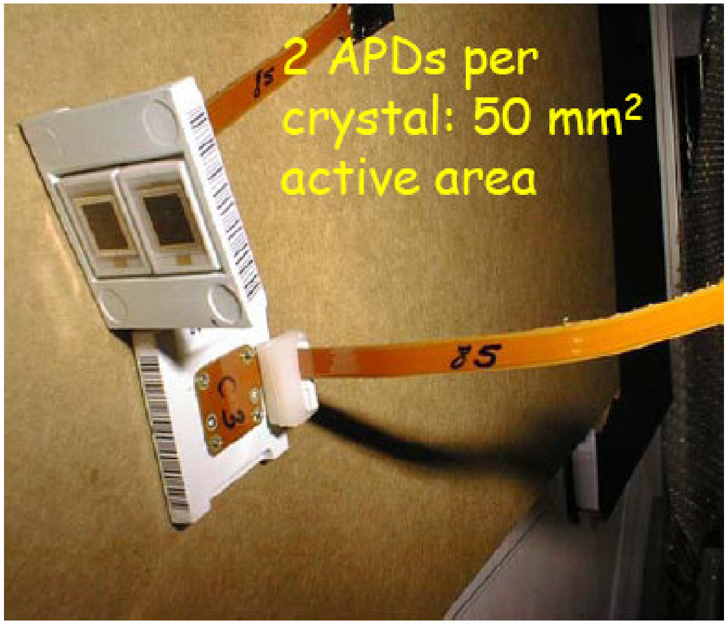

Module 1
Module 2
Module 3
Module 4
3.045 m
Barrel ECAL (EB)
61200
barrel crystals
14684
endcap
crystals
Endcap ECAL (EE)
Preshower (SE)
η=1.479
η=1.653
η=2.6
η=3.0
y
z

PbWO4 Crystals

- Lead Tungstate Crystals
  - Moliére radius 2.2cm
  - Radiation Length 0.89cm
  - Scintillation decay time 80% at 35ns
  - Been shown to be radiation resistant
  - Low LY compared to other commonly used crystals (CsI BGO …)
  - $-1.9\%/^{o}C$ temp dependence
- Lead Tungstate Crystals in CMS (Barrel)
  - "Average size", $2.4 \times 2.4 cm^2$ and 23cm in length
  - 34 Different crystal shapes
  - 25.8 X_o
  - 36 Supermodules make up the barrel calorimeter
    - Each Supermodule has 1700 crystals

ECAL Barrel Optical Readout





- Two 5x5 mm^2 APD's/crystal
- Gain – 50
- QE – 75% @ 420 nm
- Temp sensitivity – -2.4%/^{o}C

≈ 4.5 photo-electrons/MeV

122400 Total APD's

Very Linear Devices

ECAL Inter-calibration Goals

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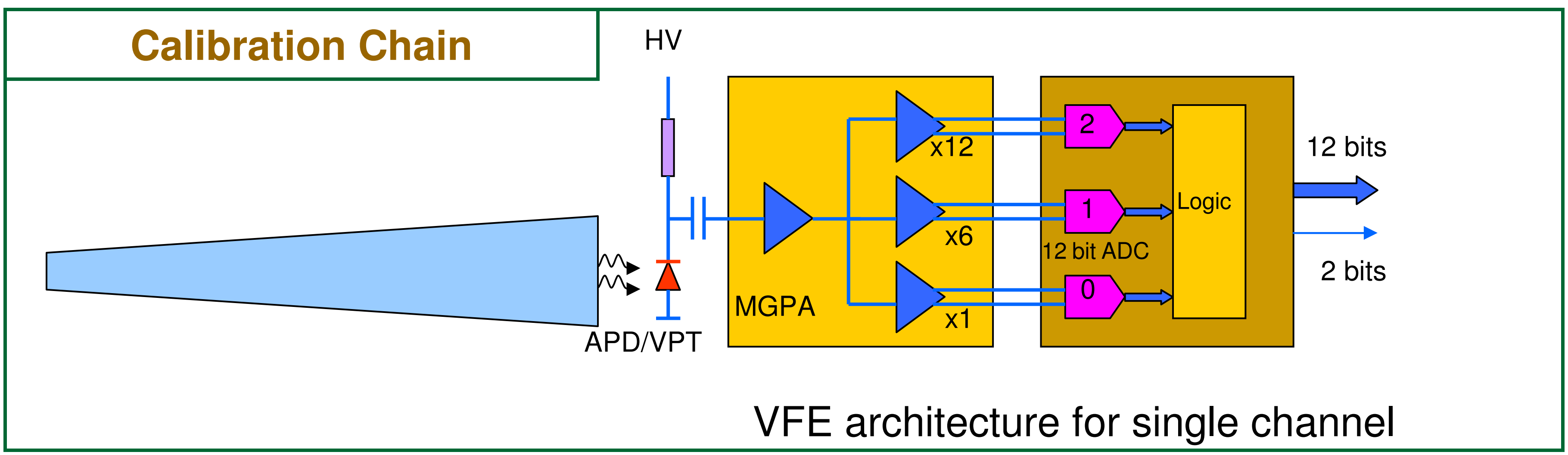
- Energy Resolution $(\sigma_E / E)^2 = (a / \sqrt{E})^2 + (b / E)^2 + c^2$
- Goal : constant term "c" < 0.5% $\rightarrow$ $\sigma/E < 0.5\%$ (For High Energies)
- *In-situ* Calibrations
  - $Z \rightarrow e^+e^-$ ~1 day 1% (with ϕ ring inter-calibration)
  - $W^\pm \rightarrow e^\pm\nu$ ~2 months E/p from Tracker
  - $\pi^0 \rightarrow \gamma\gamma$, $\eta^0 \rightarrow \gamma\gamma$, etc.
- Initial inter–calibrations
  - LY ~4%
  - Cosmics ~2%
  - Test Beam ~0.3% (Not available for all SM's)
- Reason for pre–calibration
  - Uniform detector response at startup

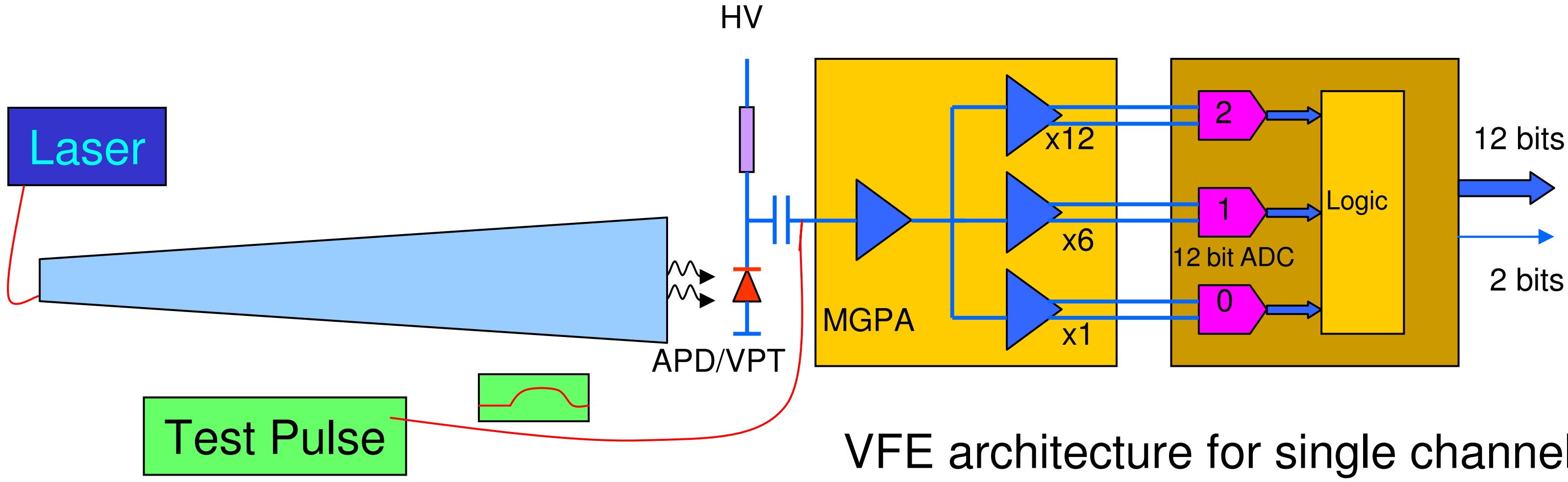
Calibration Chain

- Crystal Energy $\rightarrow$ ADC count
  - Crystal optical response
  - APD Gain
  - Amplifier Gain
  - ADC 12bit Out



Performance Checks

- Cross Checks
  - Test Pulse (after APD)
    - Compared to previous test pulses
  - Laser allows for self referencing
    - Compare one laser run to another



VFE architecture for single channel

Laboratory Inter-Calibration

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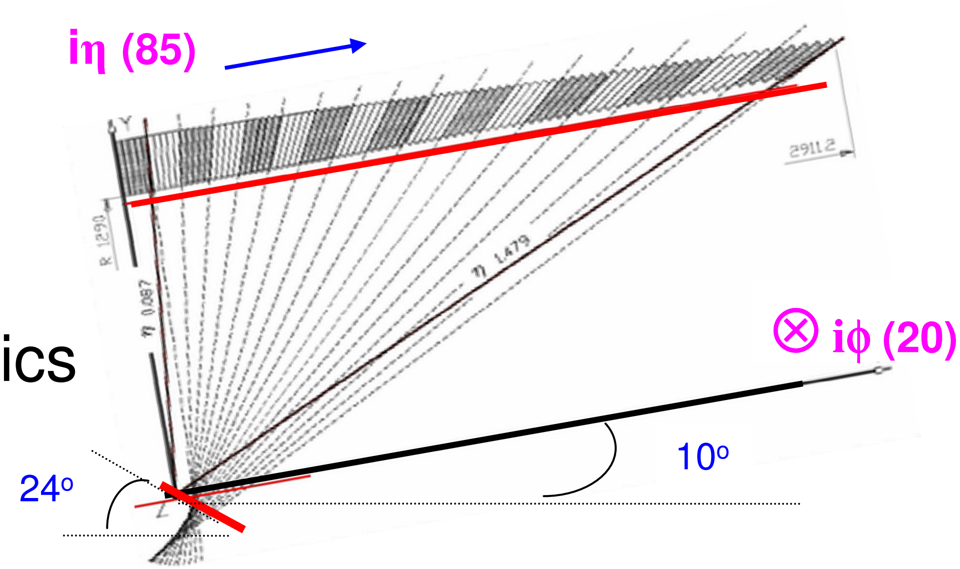
- Two current methods to LY measurements (Basically Quality Checks) automated
  - 1. Direct LY along crystal ^{60}Co
    - ~1.2 MeV source
  - 2. Transmission through crystals longitudinally at 360nm
- Combined Laboratory constants
  - Laboratory measurements are combined; LY, APD gain, the preamp.
  - Result of a ~4.0% agreement compared to testbeam calibration constants
    - Comparing ~1.2 MeV Source to 120 GeV testbeam!

Cosmic Ray Muons

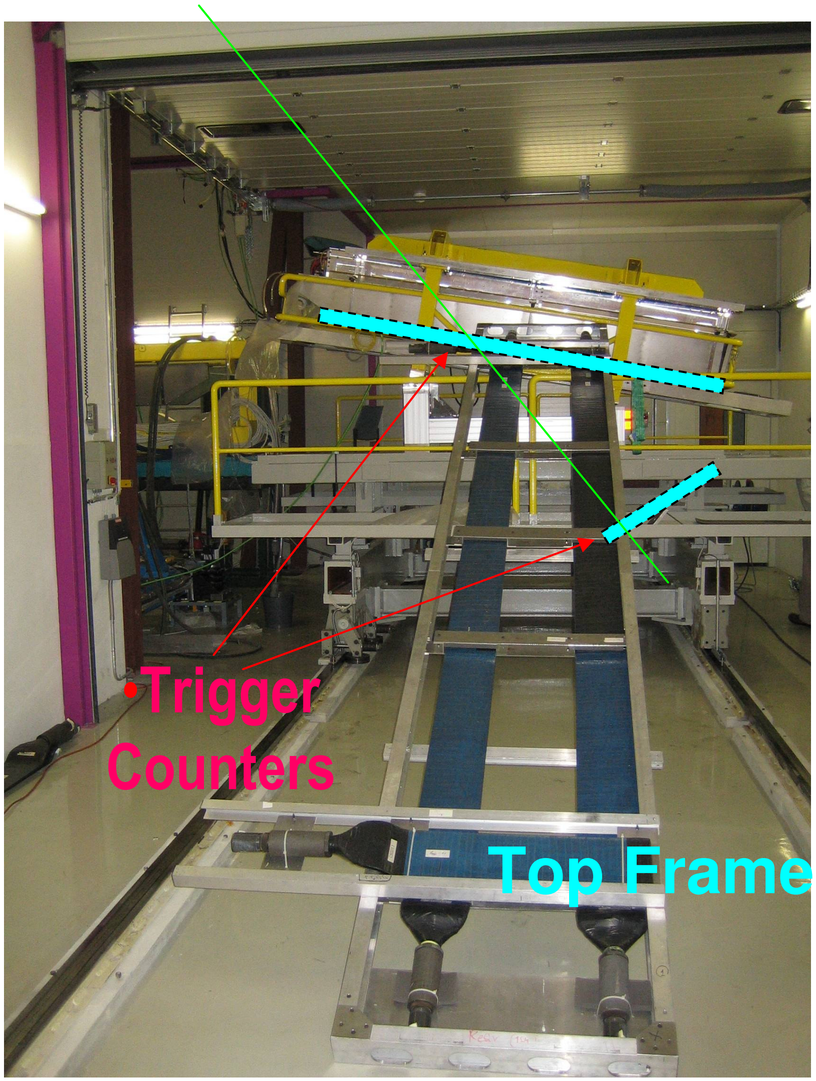
- Cosmic ray muons deposit ~11 MeV/cm in $PbWO_4$ crystals
- A through going muon will deposit ~250 MeV in a 23cm crystal
- APD gain was increased factor of 4 to get away from the ~38 MeV electronics noise. Actual gain ratio is found with laser. Also to improve the neighbor veto.
- 1 ADC count ~9 MeV
- Goal
  - Improve measurement for all 61,200 barrel crystals with full readout chain
  - Excellent way to run each SM ~10 days as a final “burn-in” step

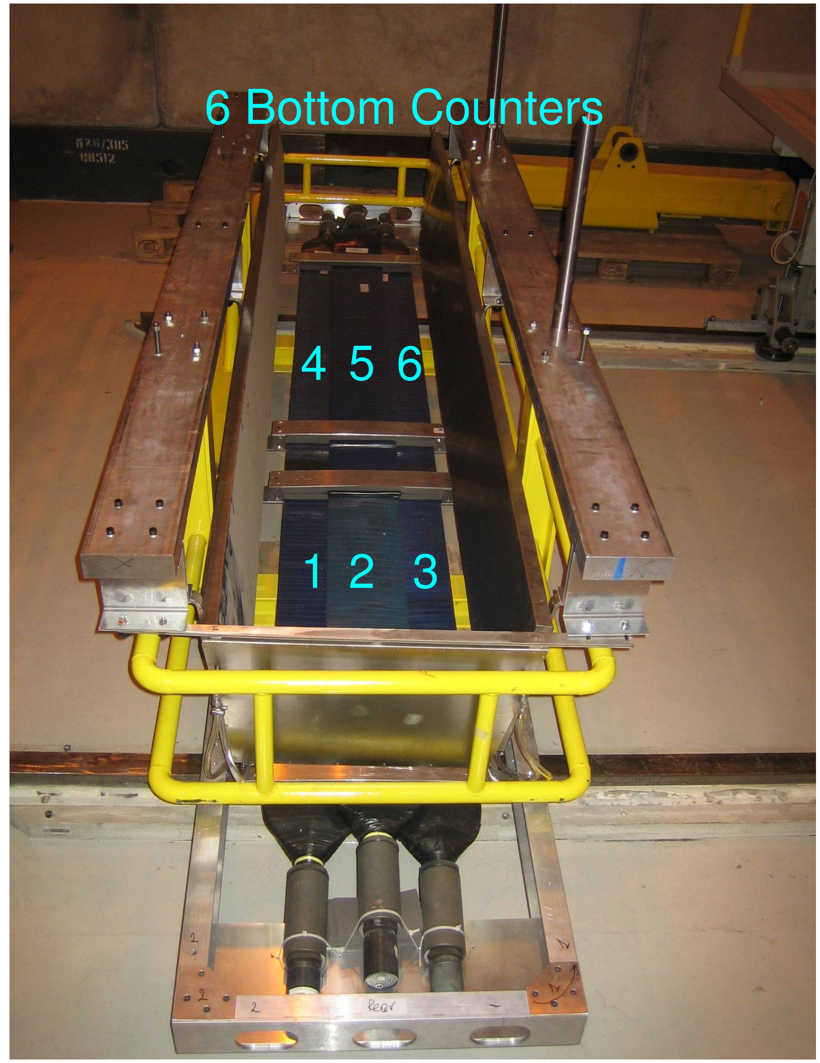
Cosmic Muon Trigger

- The trigger is a coincidence of one of 6 plastic scintillator counters spread over the bottom of the Super-Module with another counter placed near the interaction point.
- Trigger is designed as to select muons that are through-going. In this situation the amount of deposited energy is most well determined.
- 85x20 iηxiϕ grid
- One SM has more than 34 Million Triggers
- Most have 4-7 M
- 23 SM's have been calibrated with cosmics



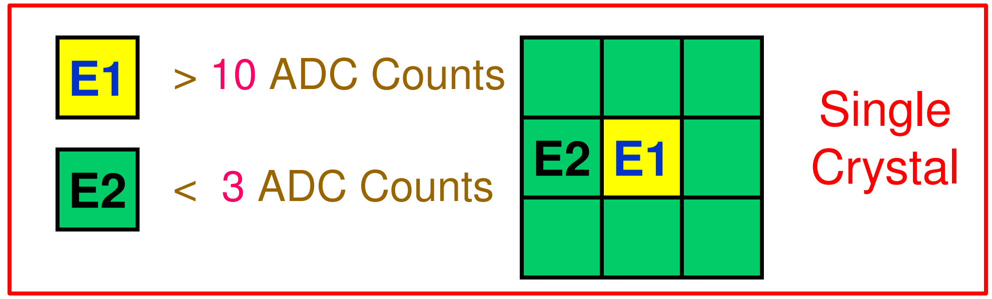
Cosmic Trigger Setup

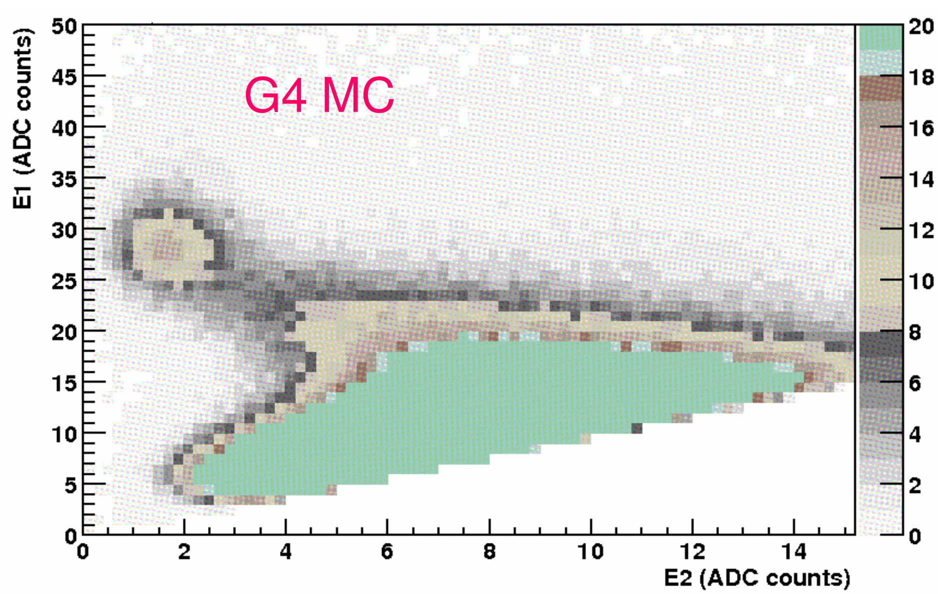


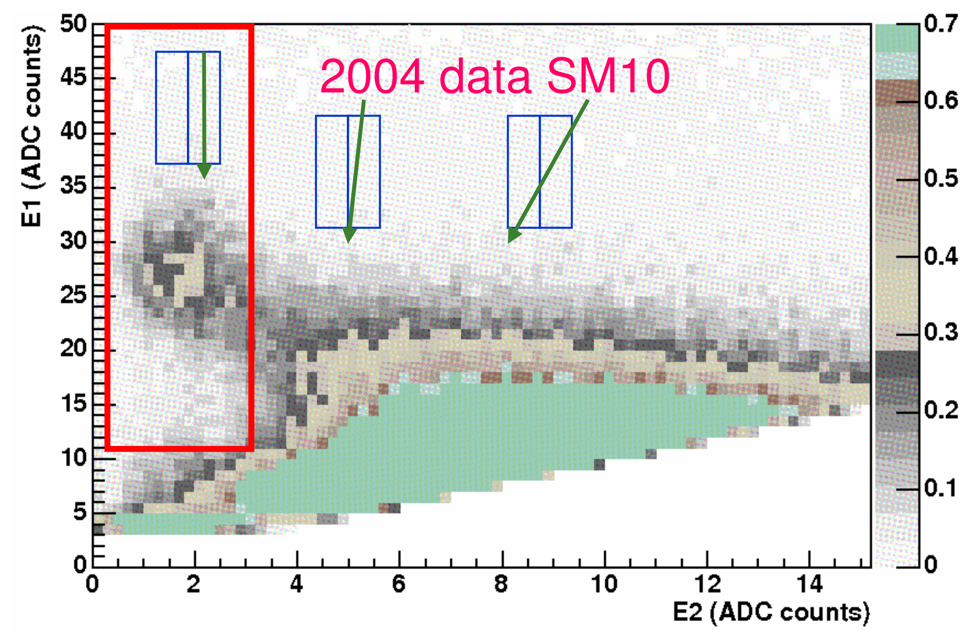


Crystal Selection

- E1 is the Energy of the Maximal crystal
- E2 is the energy of the next highest crystal around the max
- RED marks selection

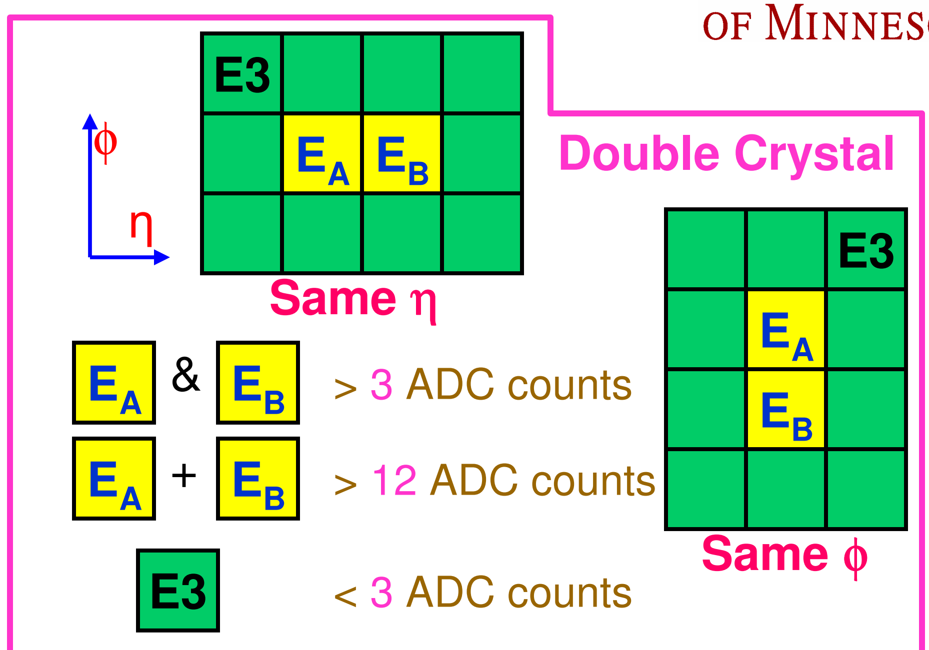


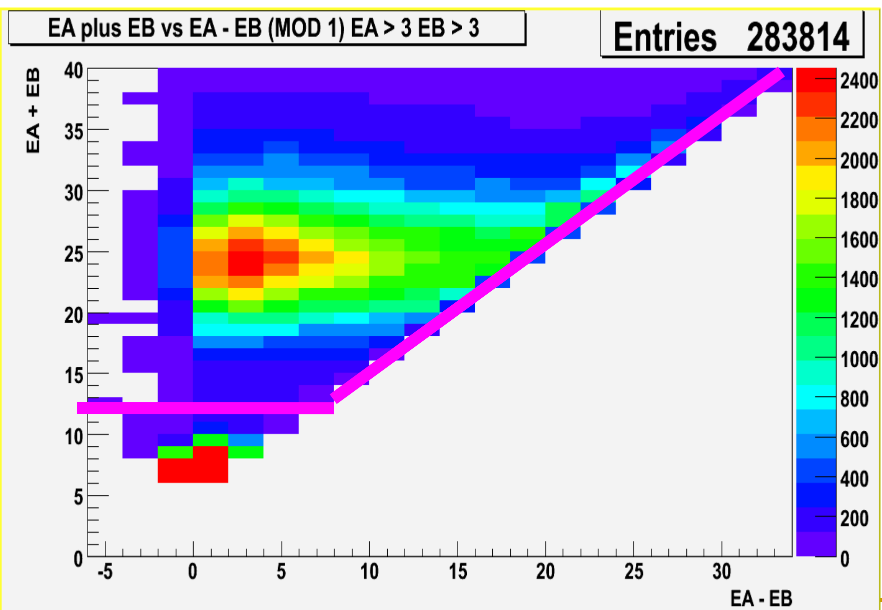


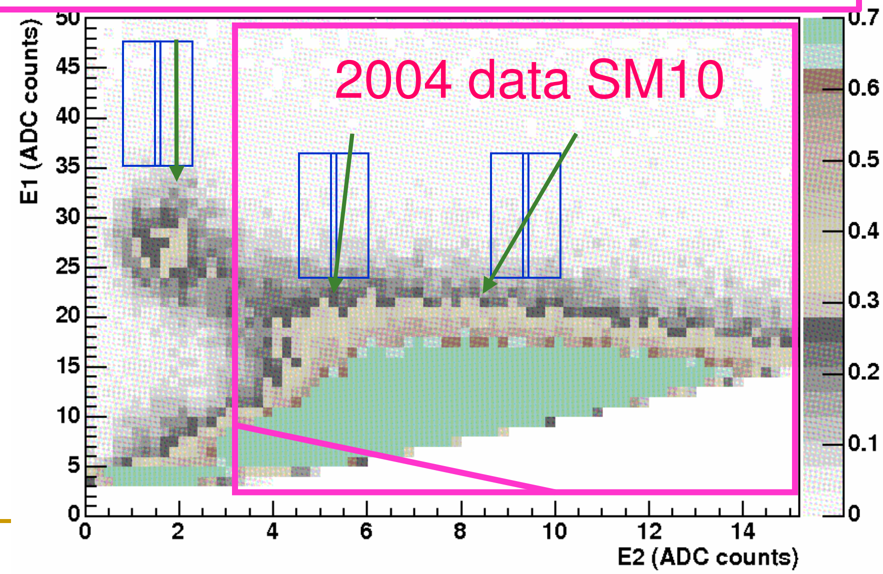


Crystal Selection

- E_A is the Energy of the Maximal crystal
- E_B is the energy of the next highest crystal around the max
- E3 refers to all other surrounding crystals
- Magenta marks selection



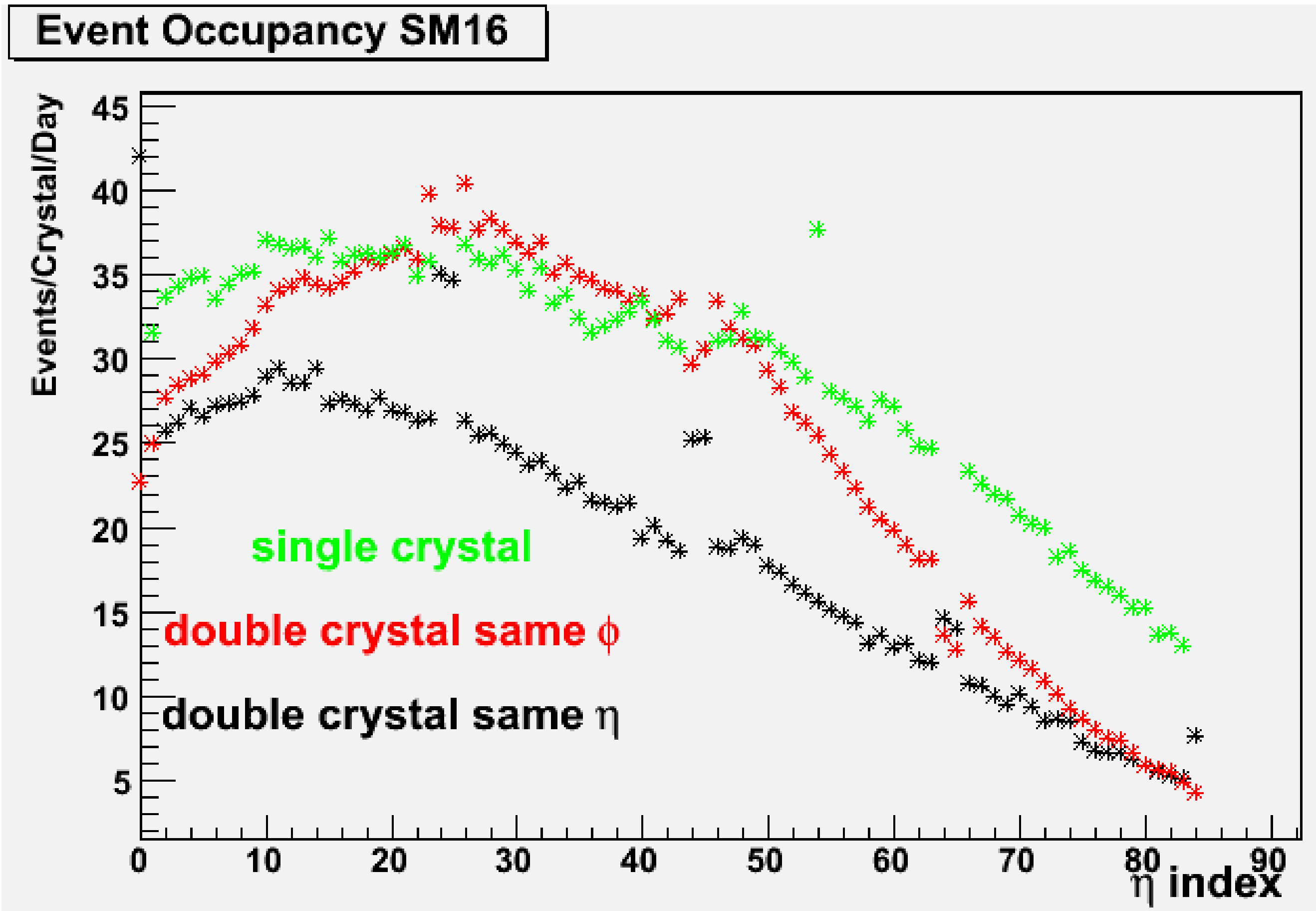




Useful Events

Of the triggers

Single ~10% Same eta ~6.8% Same phi ~8.6%



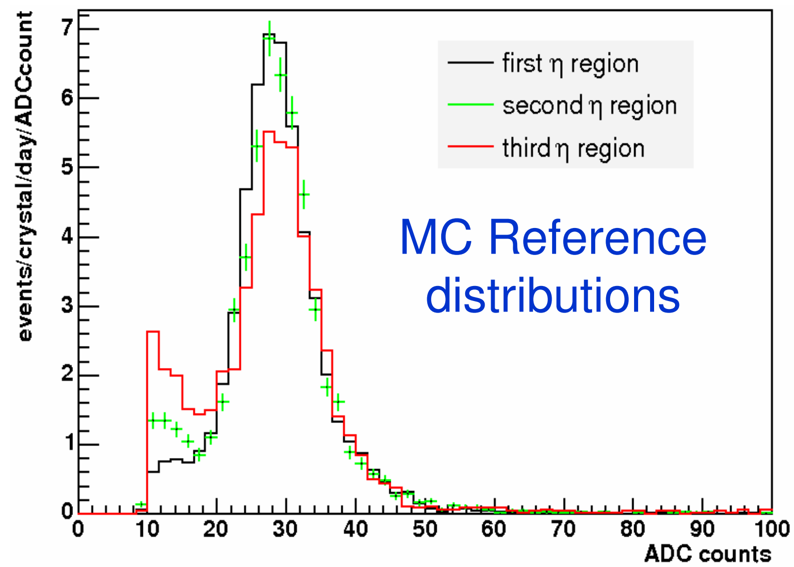
~500,000 Triggers/Day
~10 Days

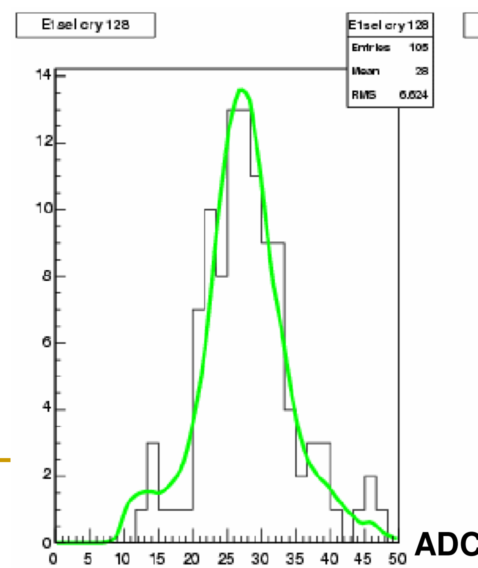
~25% of the triggers combined!

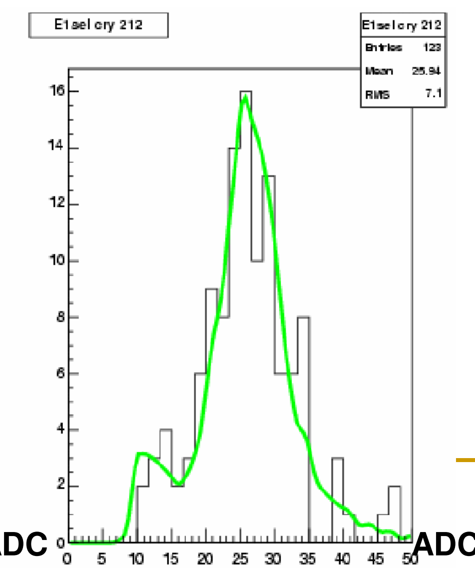
Single Crystal Method

- Pulse-height distributions of the crystal of highest energy deposited (E1) are made for each crystal
- Pulse-height distributions are also generated from MC information.
  - 17 different η dependent MC energy distributions are created.
- The constant is then found by adjusting the pulse-height to MC with an unbinned maximum likelihood method.
  - Factor: Relative Scale = Calibration constant

$$\mathcal{L} = \prod_i pdf\left(c \cdot E_i\right)$$







Two Crystal Method (Matrix Inversion)

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- Energy = Sum of both crystals
- Define a χ^2
- Minimize the χ^2 for each constant
- Fill Matrix event by event
- Invert
- **Only Input is the mean of the MC distributions**
- 17 Monte Carlo (MC) E1+E2 reference distributions are made
  - The mean is extracted from each within the selection range
- Reference distributions are created for special cases.
  - Module Borders
  - ϕ edges
  - η edges

$$E_{Total} = \Sigma c_i E_i$$

$$\chi^2 = \sum_{Events} \frac{(E_{True} - \sum c_i E_i)^2}{\sigma_E^2}$$

$$R_j = \sum_{Events} \frac{E_{True} E_j}{\sigma_E^2} \qquad A_{ij} = \sum_{Events} \frac{E_i E_j}{\sigma_E^2}$$

$$R_j = \sum_i c_i A_{ij}$$

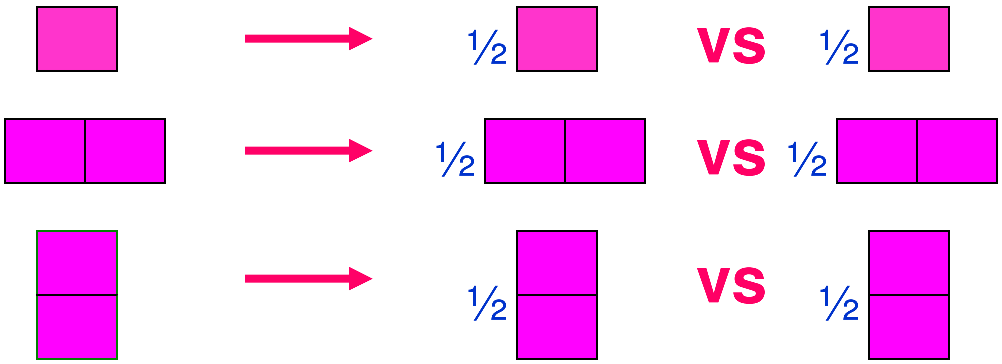
$$c = R \times A^{-1}$$

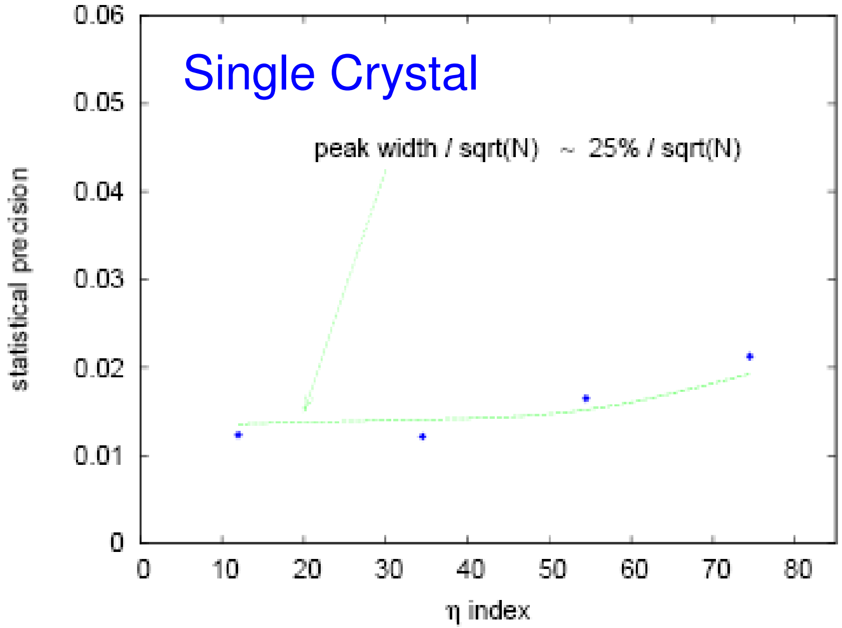
Calibration Schema

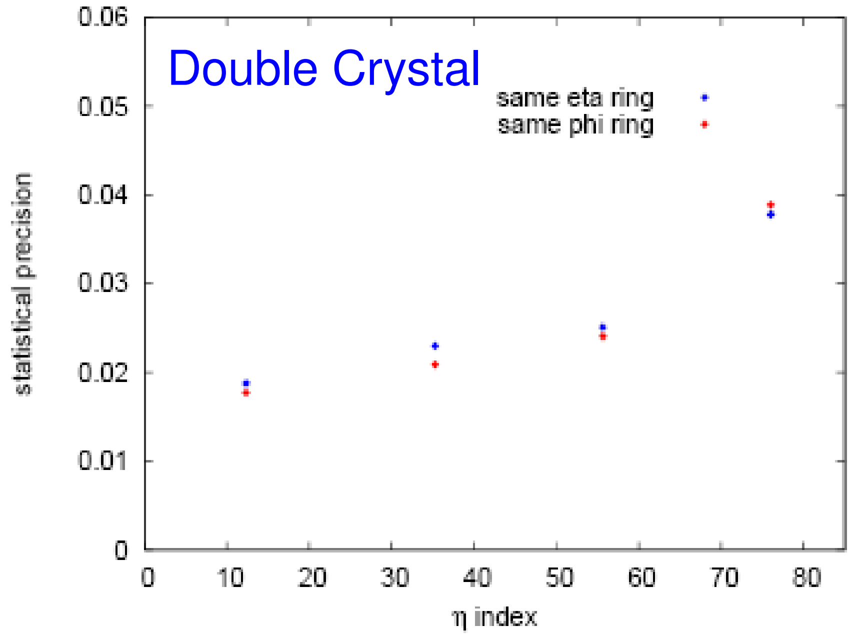
- 36 SM's
- 10 will have electron testbeam calibration
- Use the beam inter-calibration constants to build reference distributions for the cosmic data
- Use these cosmic reference distributions in place of MC
- Validate method by comparing inter-calibration constants obtained with test beam and with cosmics for different SM's.
  - **Difference → precision**
- Then use cosmic ray data to obtain inter-calibration constants for remainder of SM's.

Statistical Precision

- Each of the 3 data sets are divided in half
  - Odd vs. Even events
  - $\sigma_{stat} = \sigma_{odd\ vs.\ even}/2$







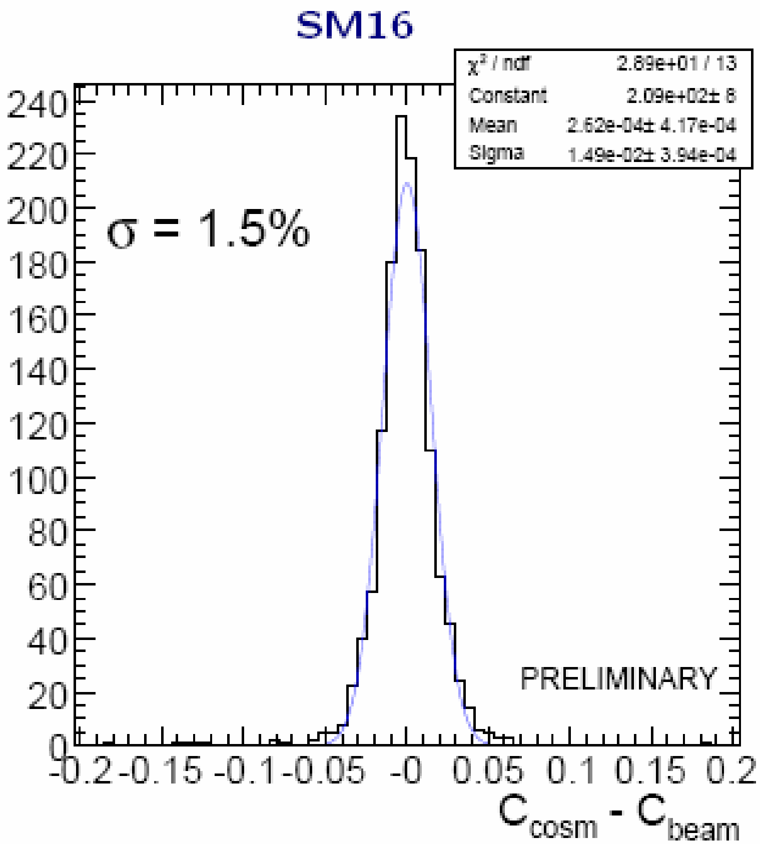
Test Beam data

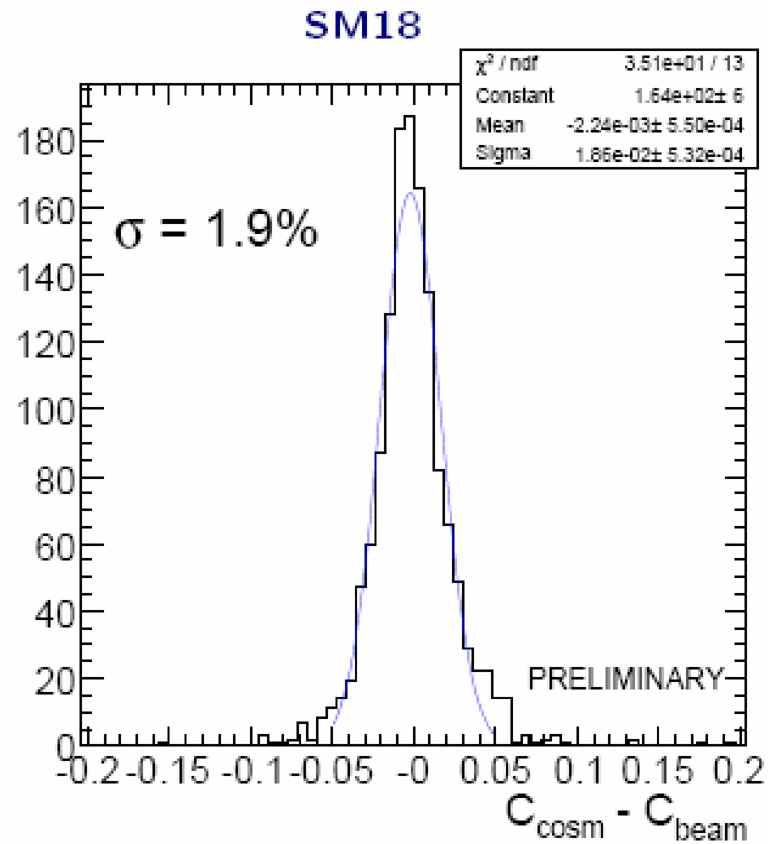
- ECAL setup employs full CMS geometry and electronics setup
- Using electron beam with energy of 120 GeV
- Preliminaries available for two supermodules
- Used SM16 to build references
- Validate them with SM18
- Combine the datasets according to the statistical uncertainties

$$C_{comb}^{\;i} = \frac{\dfrac{C^i_{Single}}{\sigma^2{}_{Single}(\eta)} + \dfrac{C^i_{i\eta}}{\sigma^2{}_{i\eta}(\eta)} + \dfrac{C^i_{i\varphi}}{\sigma^2{}_{i\varphi}(\eta)}}{\dfrac{1}{\sigma^2{}_{Single}(\eta)} + \dfrac{1}{\sigma^2{}_{i\eta}(\eta)} + \dfrac{1}{\sigma^2{}_{i\varphi}(\eta)}}$$

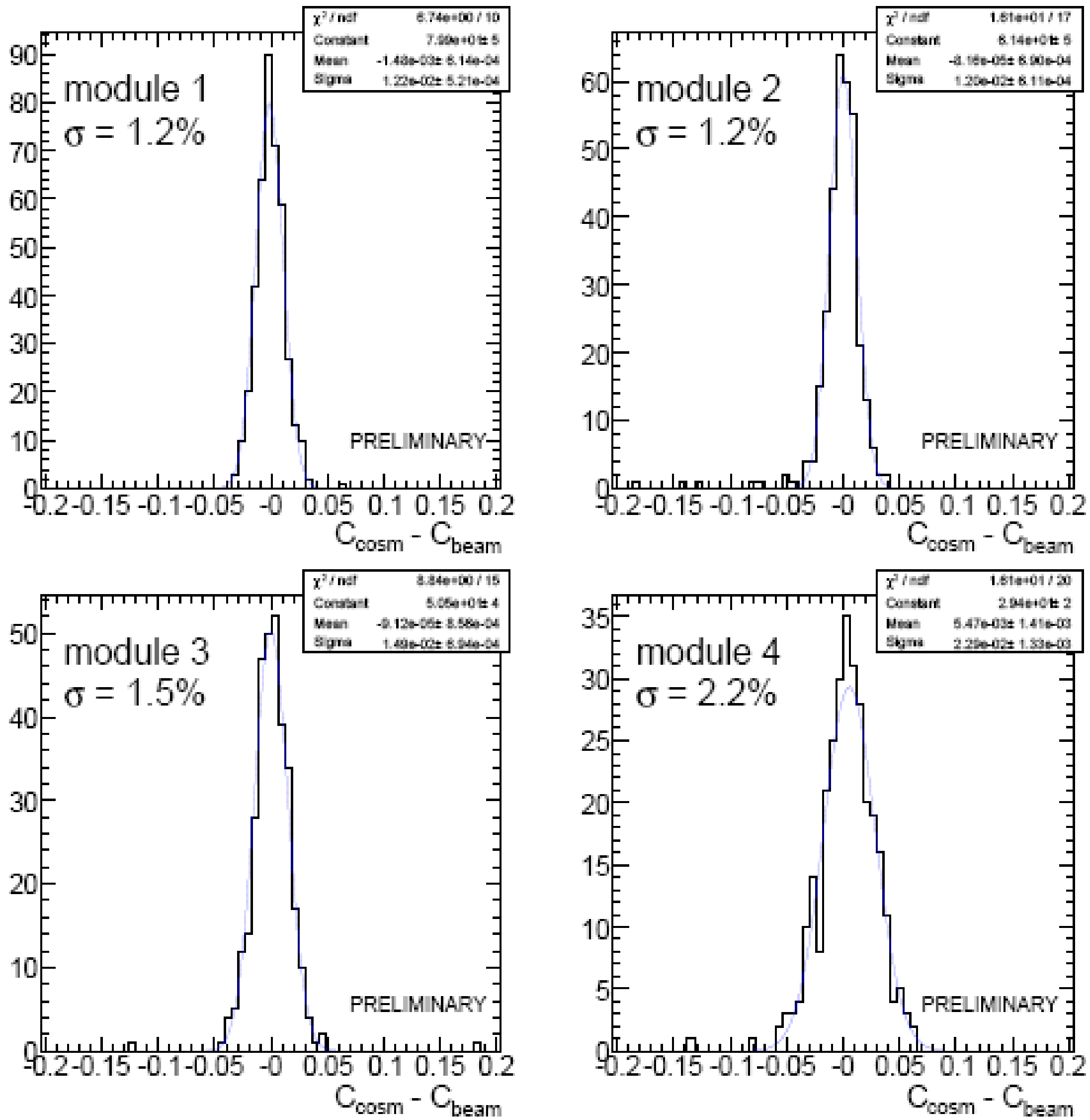
Test-Beam Comparison

- Good to 1.5% in SM16 and 1.9% in SM18
- Ignoring edges and module borders





SM16 TB Comparison by module



Future

- Combined results with all beam calibrated SM's
  - Evaluate systematic uncertainties.
- Including beam data to check for differences between muons and electrons signals
- More than 23 SM's have collected cosmic data. All are now expected to collect cosmic data.
- SM installation starting soon

Conclusion

- 5 million triggers (10 days), provides a statistically accuracy of 2% or better
- Testbeam comparisons show an average agreement over an entire SM of less than 2%
- Cosmic ray muons will provide the most accurate inter-calibrations that will be available to all barrel crystals at CMS startup
- Using the ~250 MeV cosmic signal we can predict to 2% the calibration constants found at 120 GeV.

→ Uniform energy response between all crystals

References

- LY
  - L. M. Barone *et al.* “Correlation between Light Yield and Longitudinal Transmission in PbWO4 crystals and impact on the precision of the crystal intercalibration.” CMS RN 2004-005 http://cmsdoc.cern.ch/documents/04/rn04_005.pdf
  - F. Cavallari *et al.* “Improvement on PbWO4 Crystal Intercalibration Precision from Light Yield Measurements at the INFN-ENEA Regional Center” CMS RN 2004-003 http://cmsdoc.cern.ch/documents/04/rn04_003.pdf
  - F. Cavallari *et al.* “Relative Light Yield comparison between laboratory and testbeam data for CMS ECAL PbWO4 crystals” CMS RN 2004-002 http://cmsdoc.cern.ch/documents/04/rn04_002.pdf
  - E. Auffray et al. “SPECIFICATIONS FOR LEAD TUNGSTATE CRYSTALS PREPRODUCTION” CMS Note 1998-038 http://cmsdoc.cern.ch/documents/04/rn98_038.pdf
- Cosmic
  - M. Bonesini *et al.* “Inter-calibration of the CMS electromagnetic calorimeter with cosmic rays before installation” CMS NOTE 2005/023
  - W. Bertl *et al.* “Feasibility of Intercalibration of CMS ECAL Supermodules with Cosmic Rays” CMS NOTE 2004/036
  - K. Deiters *et al.* “Test of the Feasibility of Pre-intercalibration of ECAL Supermodules with Cosmic Rays” CMS IN 2004/023
- General
  - CMS Collaboration, *CMS Technical Proposal*, CERN/LHCC 94-38
  - CMS Collaboration, *The Electromagnetic Calorimeter Project TDR*, CERN/LHCC 97-33
  - Particle Data Handbook and references therein

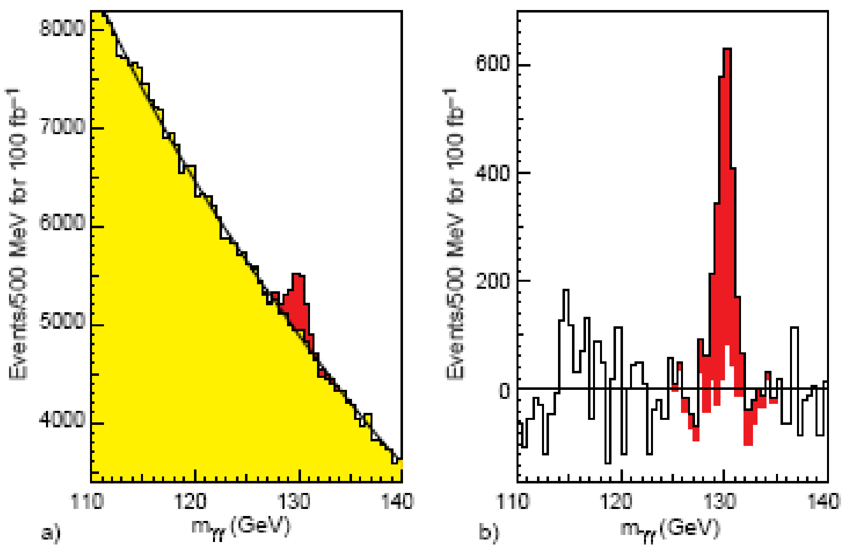
Extras

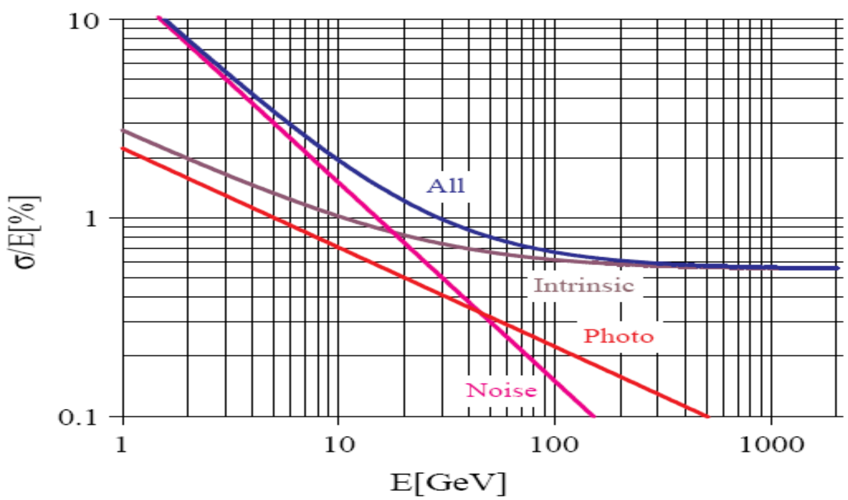
ECAL: Higgs $\rightarrow \gamma\gamma$

- The reconstructed mass the the Higgs depends on the Energy of both photons as well as the angle between the two.
- The error of the photon energy is very important

$$m_{\gamma\gamma}^2 = 2E_{\gamma 1}E_{\gamma 2}(1-\cos\theta_{\gamma 1,\gamma 2})$$

$$\frac{\sigma_{m_{\gamma\gamma}}}{m_{\gamma\gamma}} = \frac{1}{2}\left[\frac{\sigma_{E_{\gamma 1}}}{E_{\gamma 1}} \oplus \frac{\sigma_{E_{\gamma 2}}}{E_{\gamma 2}} \oplus \frac{\sigma_{\theta_{\gamma\gamma}}}{\tan(\theta_{\gamma\gamma}/2)}\right]$$





Term	% expected	σ_E for 100GeV
a	2.7%/√E	270 MeV
c	155 MeV in E_T	265 + 355 MeV
b	0.5%	500 MeV

Selection MC

Selection from MC