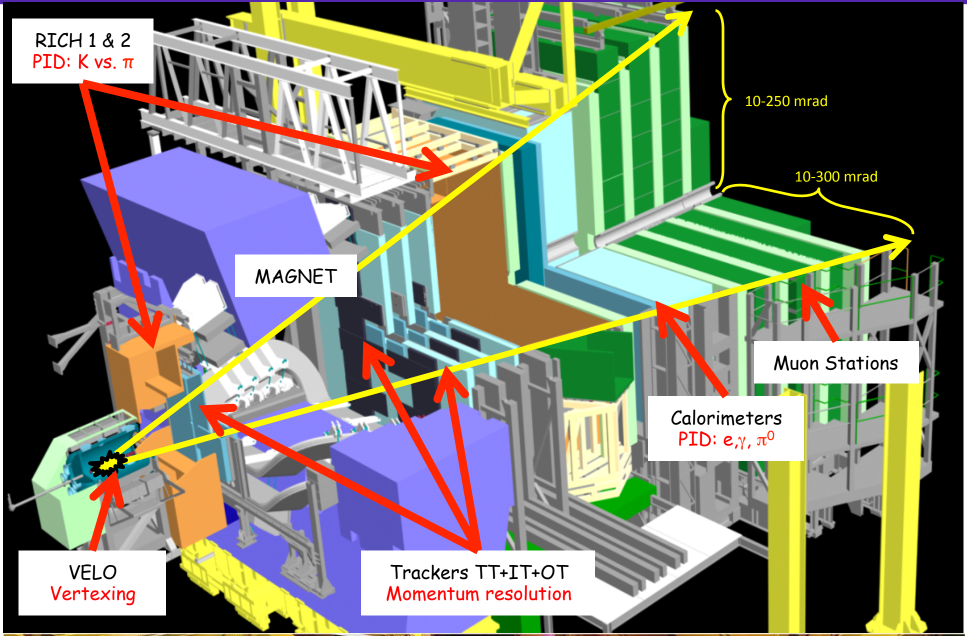
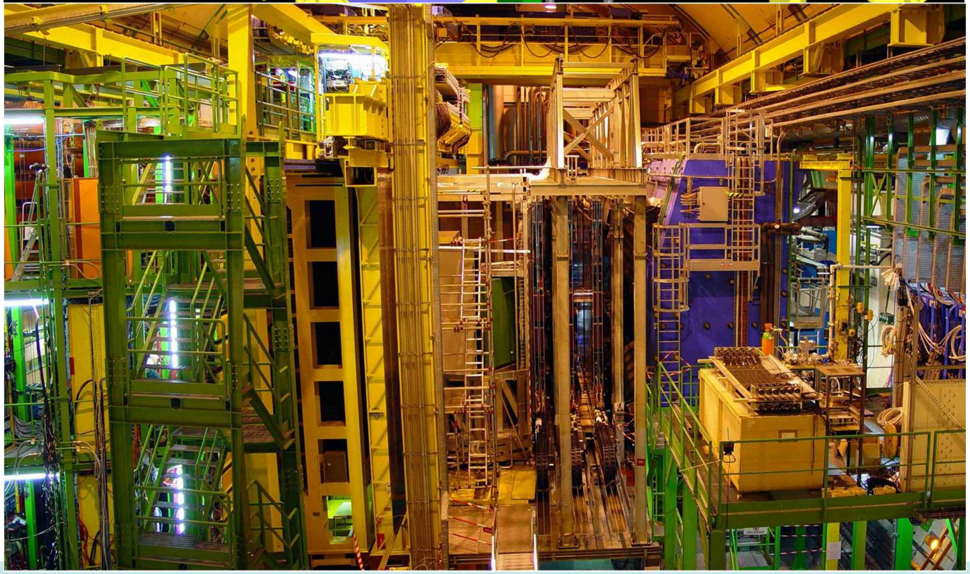
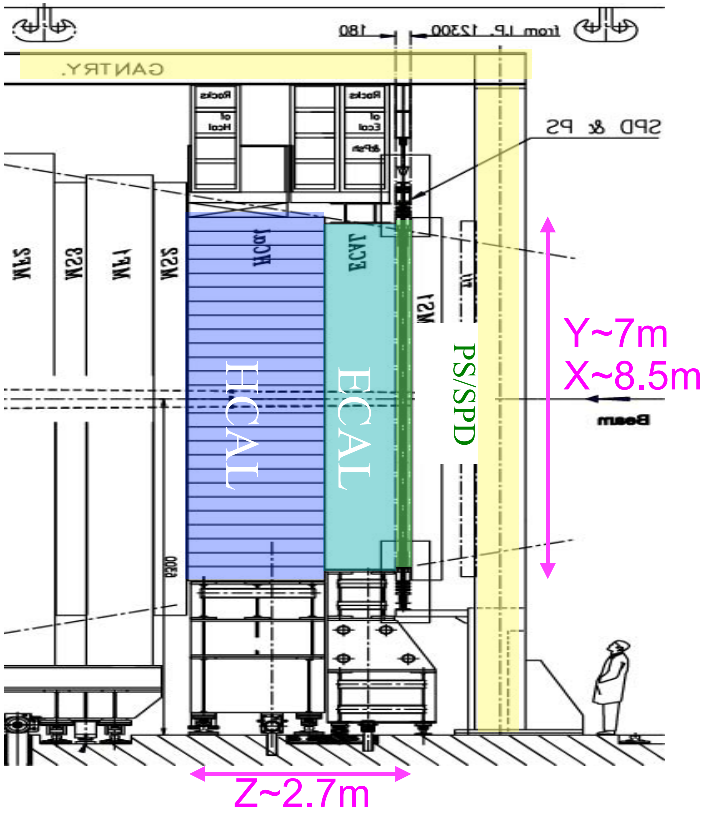
Performance of the LHCb calorimeters
during the period 2010-2012

Xavier Vilasís-Cardona

LHCb Calorimeters





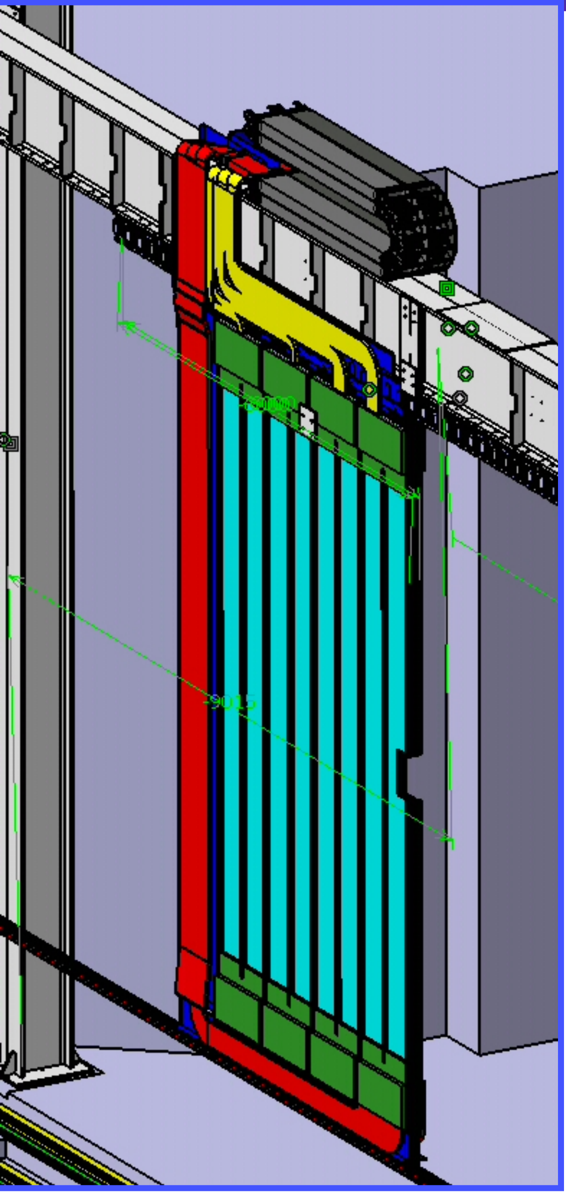


- Preshower (PS)/Scintillator Pad Detector (SPD)
- Electromagnetic Calorimeter (ECAL)
- Hadronic Calorimeter (HCAL)

Purpose of LHCb calorimeters

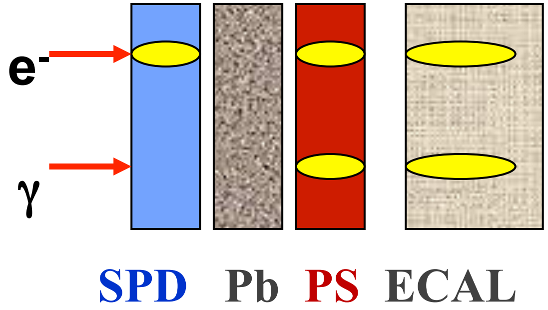
- Preshower (PS) and Scintillator Pad Detector (SPD):
  - PID for L0 electron and photon trigger
  - electron, photon/pion separation by PS
  - photon/MIP separation by SPD
  - charged multiplicity veto by SPD
- Electromagnetic Calorimeter (ECAL):
  - E_t of electrons, photons and π^0 for L0 trigger (e.g. $B \rightarrow J/\Psi$ Ks, $B \rightarrow K^*\gamma$)
  - reconstruction of π^0 and prompt γ offline
  - particle ID
- Hadron Calorimeter (HCAL):
  - E_t of hadrons for L0 trigger (e.g. $B \rightarrow \pi\,\pi$, $B \rightarrow D_s K$)
  - particle ID

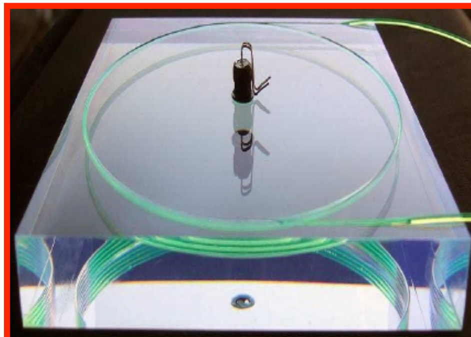
PS and SPD

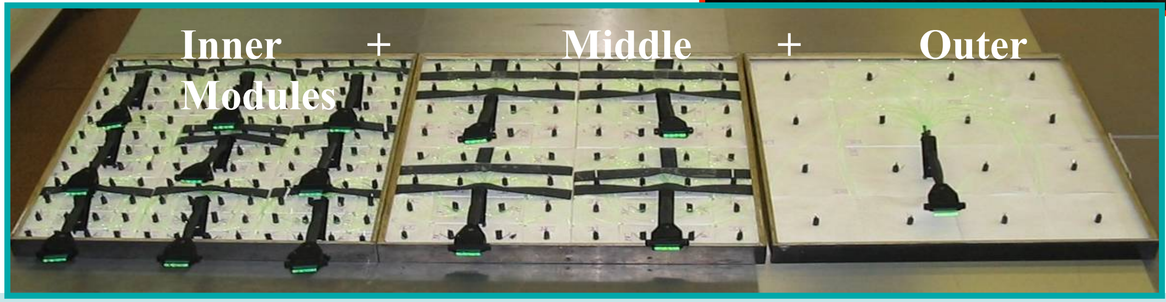


- Scintillator blocs with coiled WLS fiber
- Geometry projective with ECAL: 3 zones
- MAPMT Hamamatsu 5900 M64
- 6016+6016 Cells

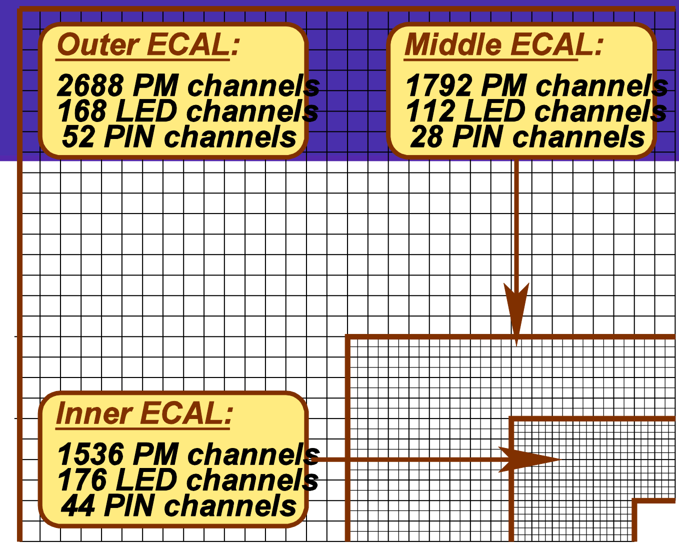
JINST 3 S08005 (2008)







ECAL

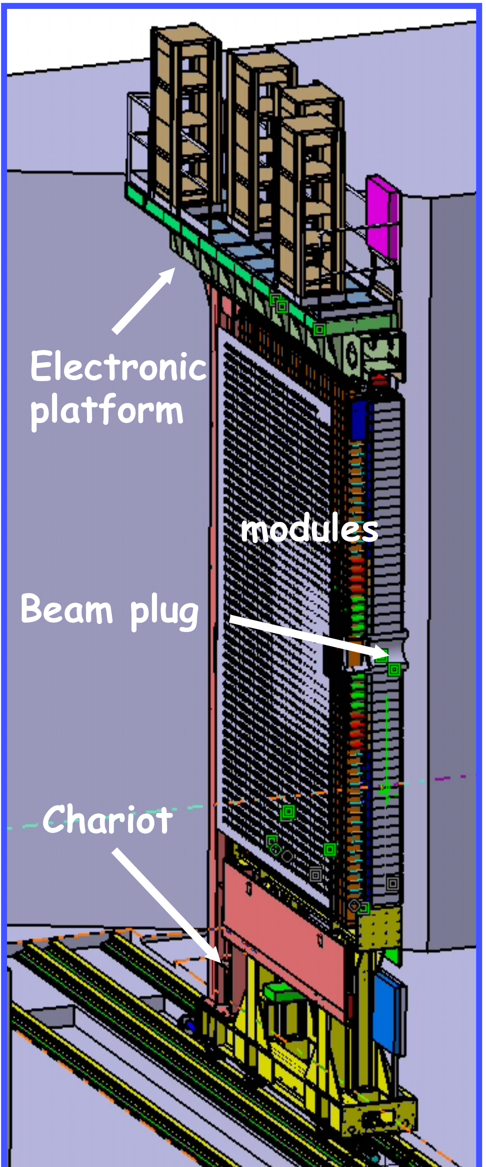


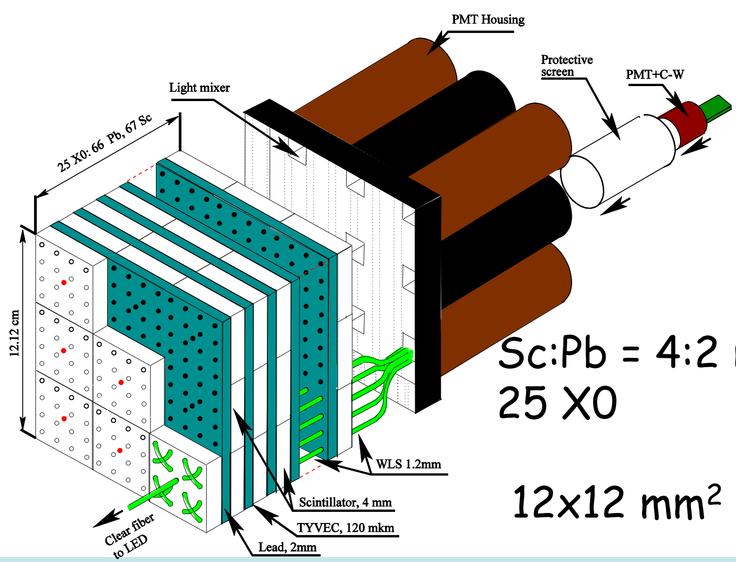
- Shashlik
- PMT readout

  Hamamatsu R7899-20
- Energy resolution

  $\sigma(E)/E = 0.085 \pm 0.01/ E \oplus 0.008 \oplus 0.003 * x/E$
- 6016 cells

JINST 3 S08005 (2008)

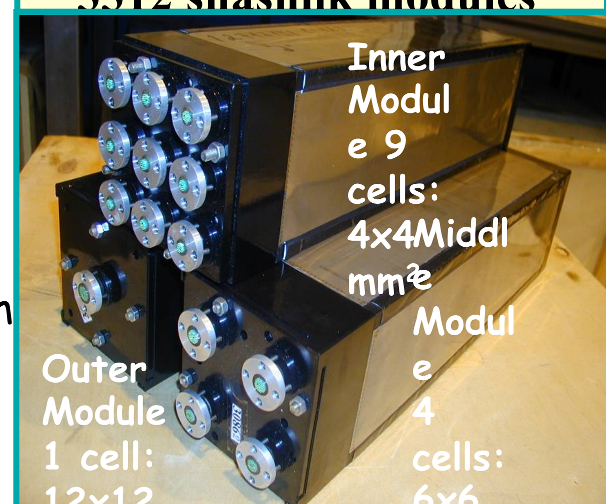




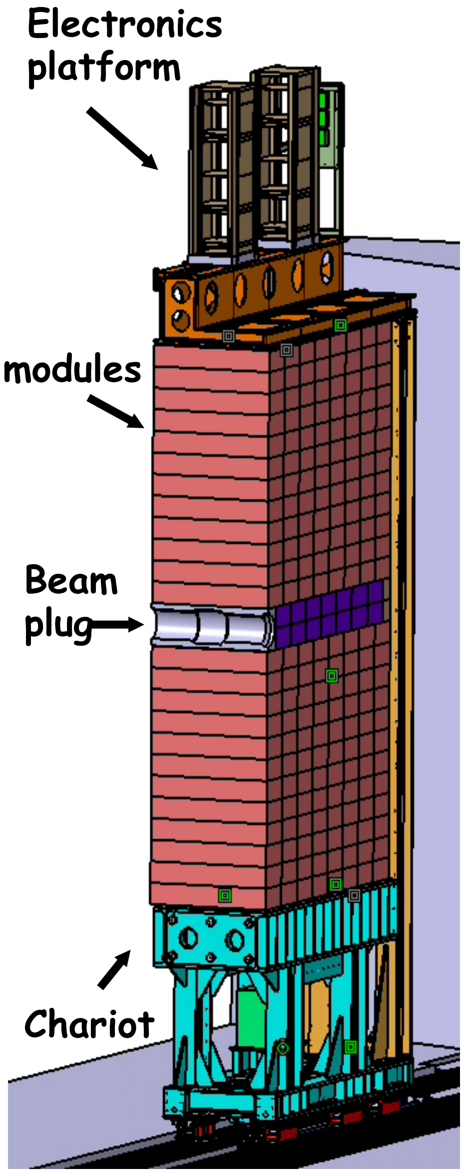
Sc:Pb = 4:2 mm
25 X0

$12x12\ mm^2$

3312 shashlik modules



HCAL



- Tile structure

JINST 3 S08005 (2008)

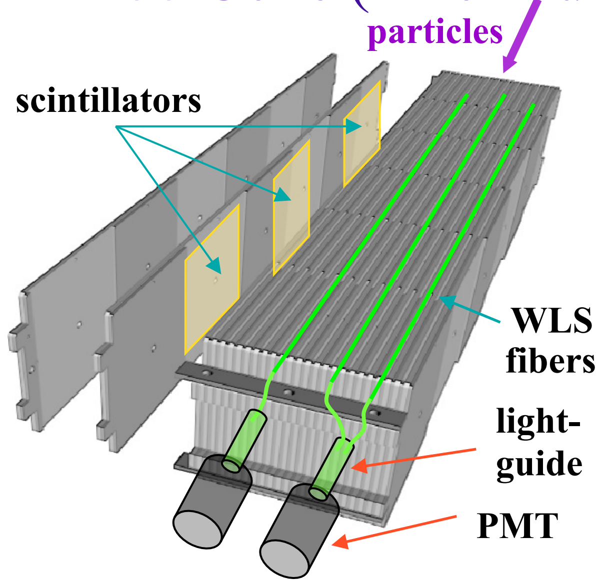
- PMT readout

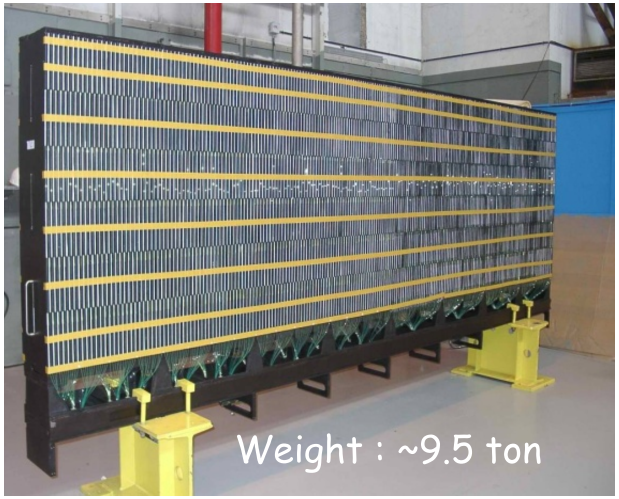
  Hamamatsu R7899-20

- Energy resolution

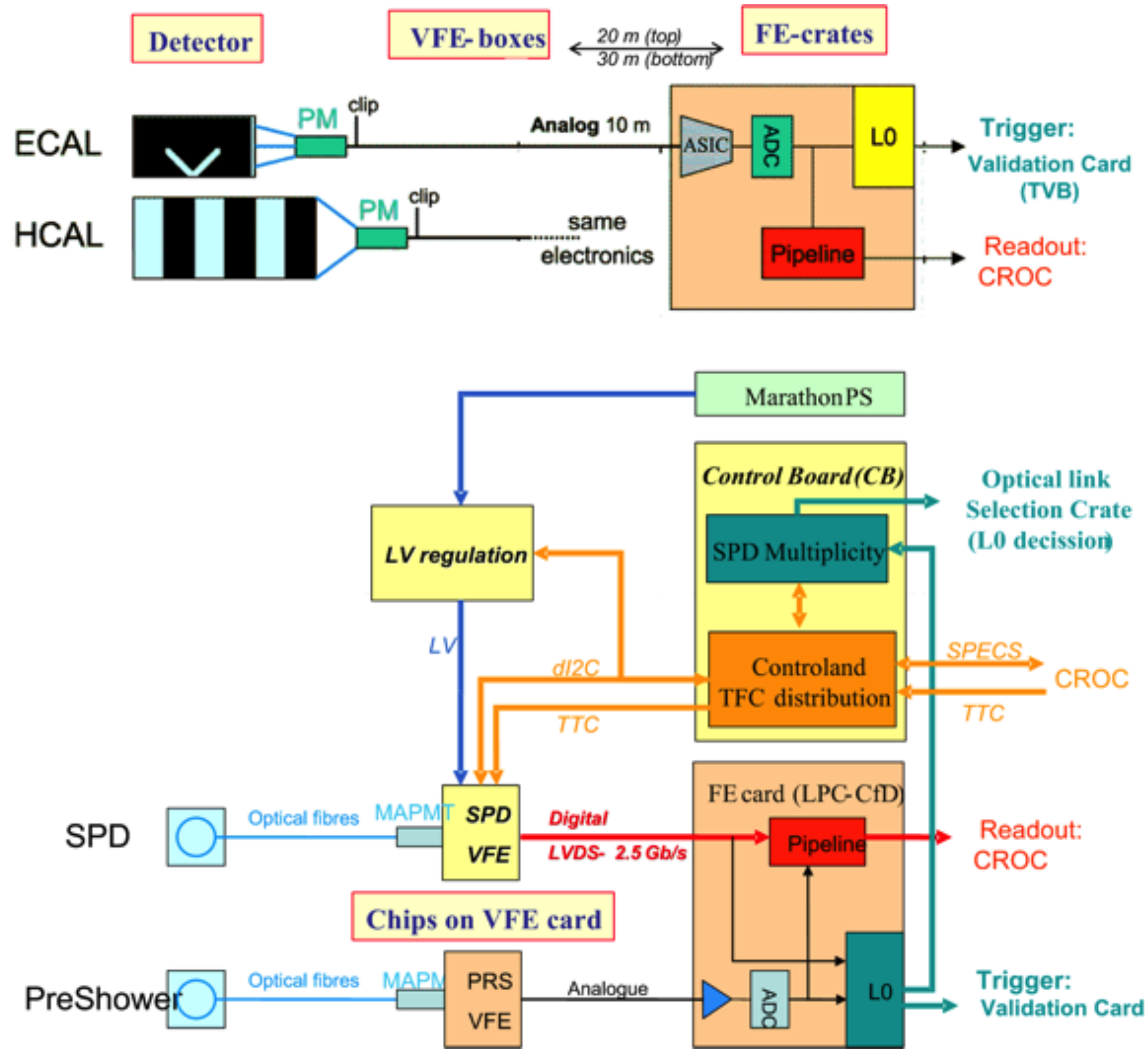
$\surd\sigma(E)/E = (0.69 \pm 0.05)/ E \oplus (0.09 \pm 0.02)$

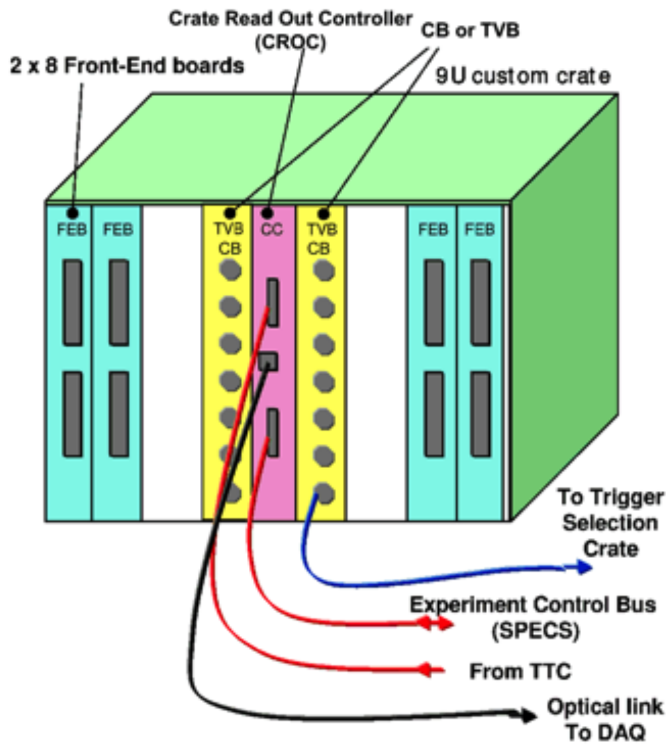
- 1488 Cells (inner-outer)





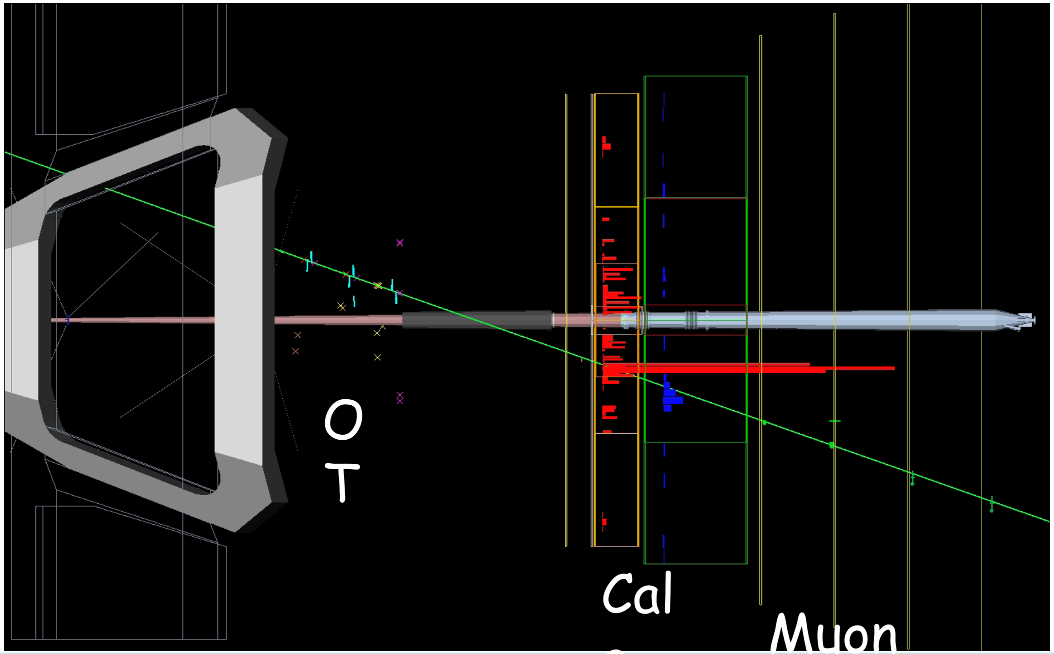
Front End Electronics





Installation and Commissioning

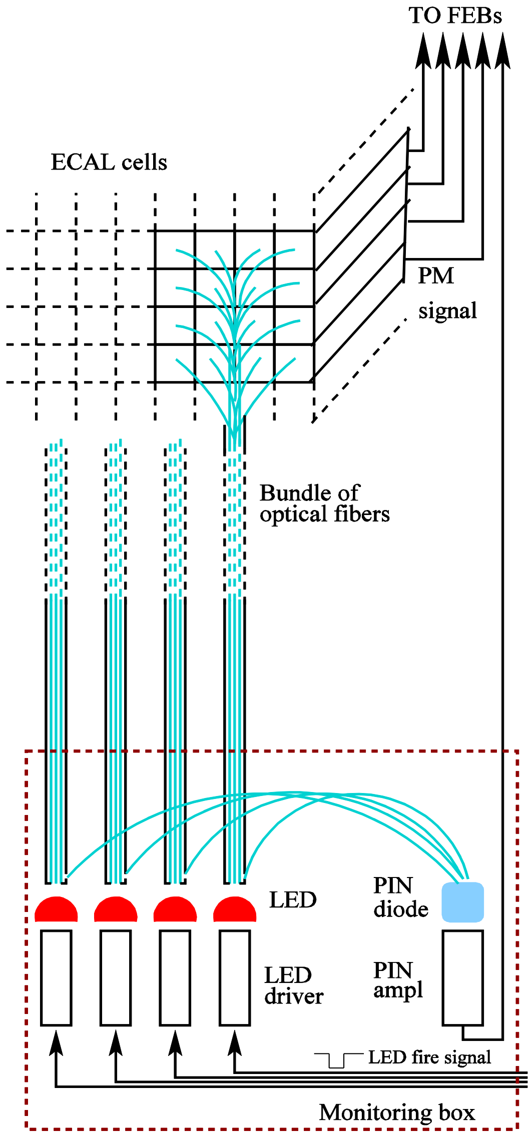
- Installation from 2004-2008
- Commissioning 2005-2009
- First cosmic seen January 2008
- Commissioning using built in monitoring tools, cosmics and splash events.

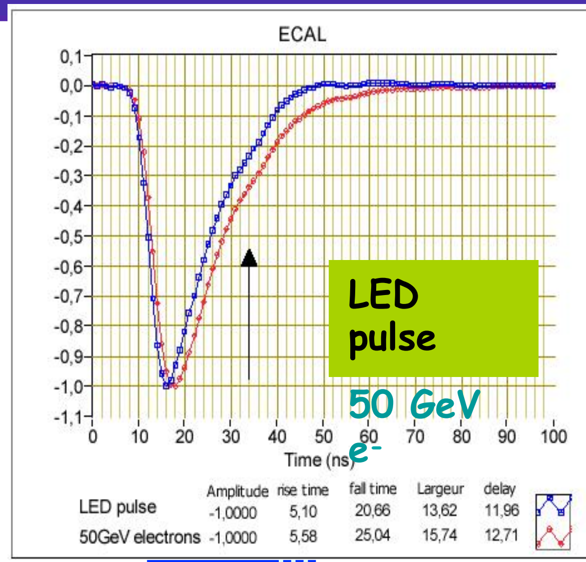


Calibration and Monitoring

- Calibration strategies
  - PS / SPD
    - Fit the MIP signal and look for efficiencies
  - ECAL
    - Initial adjustment
    - Energy Flow
    - Fit π^0 mass
    - E/p for electrons
  - HCAL
    - Built in ^{137}Cs source
- Detectors include built in LED system for monitoring detector stability

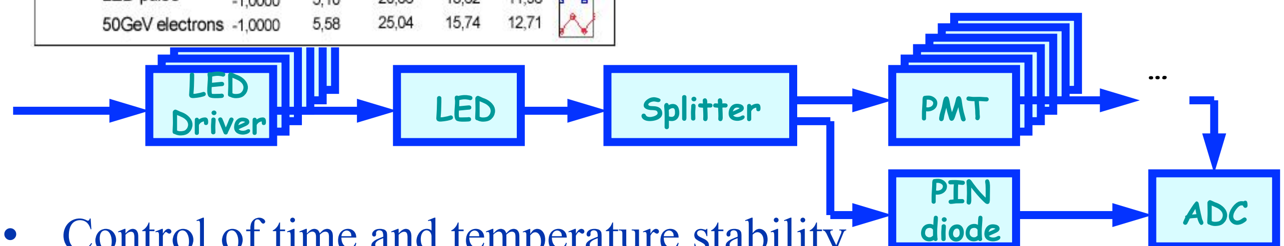
LED monitoring system of XCAL





ECAL

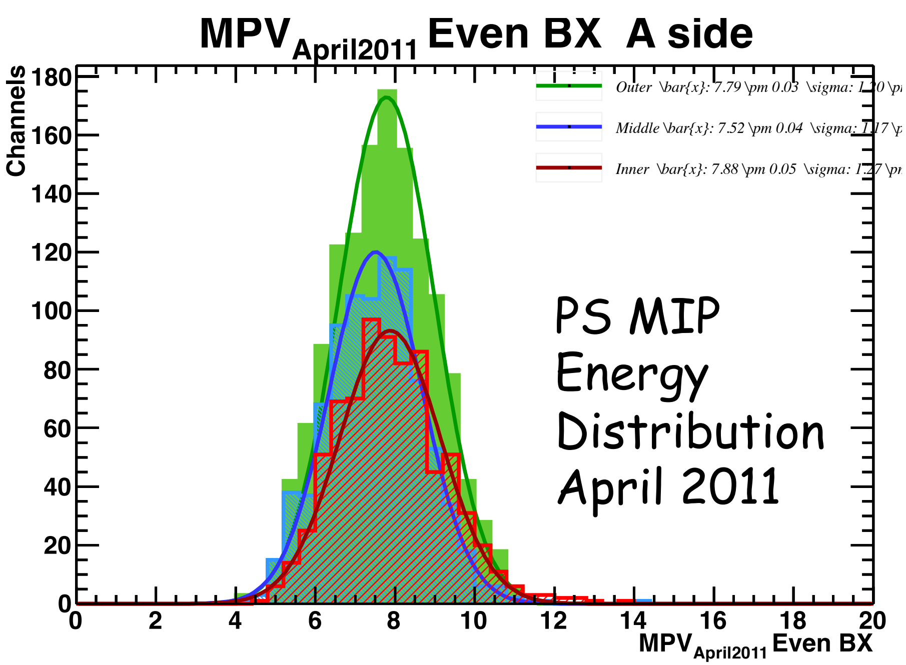
- 512 LED drivers & LEDs & splitters & fiber-bundles
- 64 PIN-diodes

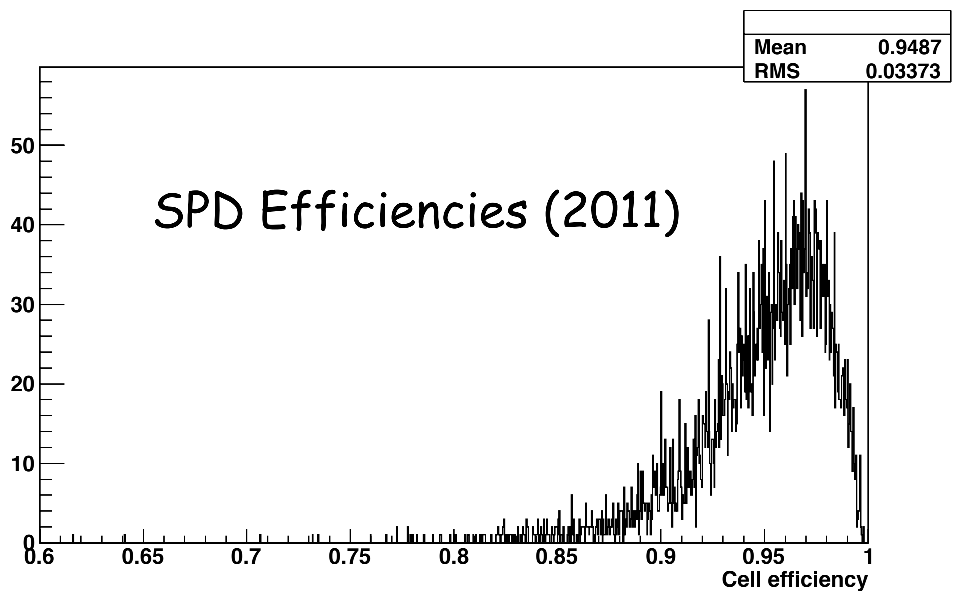


- Control of time and temperature stability
- Small pulse duration and dispersion of amplitude
- Adjustable pulse rate and amount of light
- Emulate e/m particles in full "physics" region
- Gain control to better than 1% accuracy
- Control only electronics chain→ supply LED light directly to the PMT
- Use empty bunches for running monitoring system

PS-SPD

- Tracks pointing to given PS/SPD cell are extrapolated
- PS: MIP signal is fitted and fixed to a given number of ADC counts
- SPD: signal is checked for existing tracks



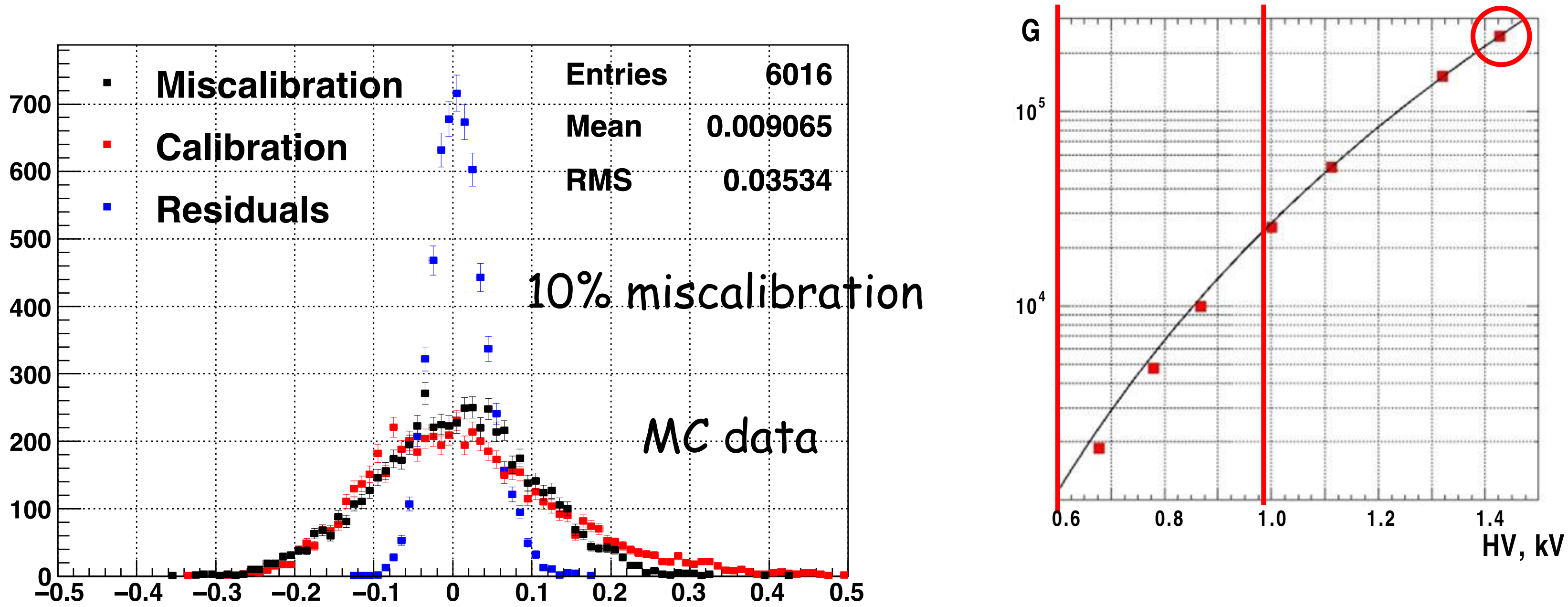


ECAL – Initial calibration + Energy Flow

- Initial Calibration (relative width of π^0 peak, 10%)

$$ADC_{\max} = E_{\max}\, e\, k \frac{Y\, G_{\mathrm{nominal}}}{s_{\mathrm{ADC}}}$$

- Energy Flow
  - Equalize the energy flow over 3x3 cell blocks



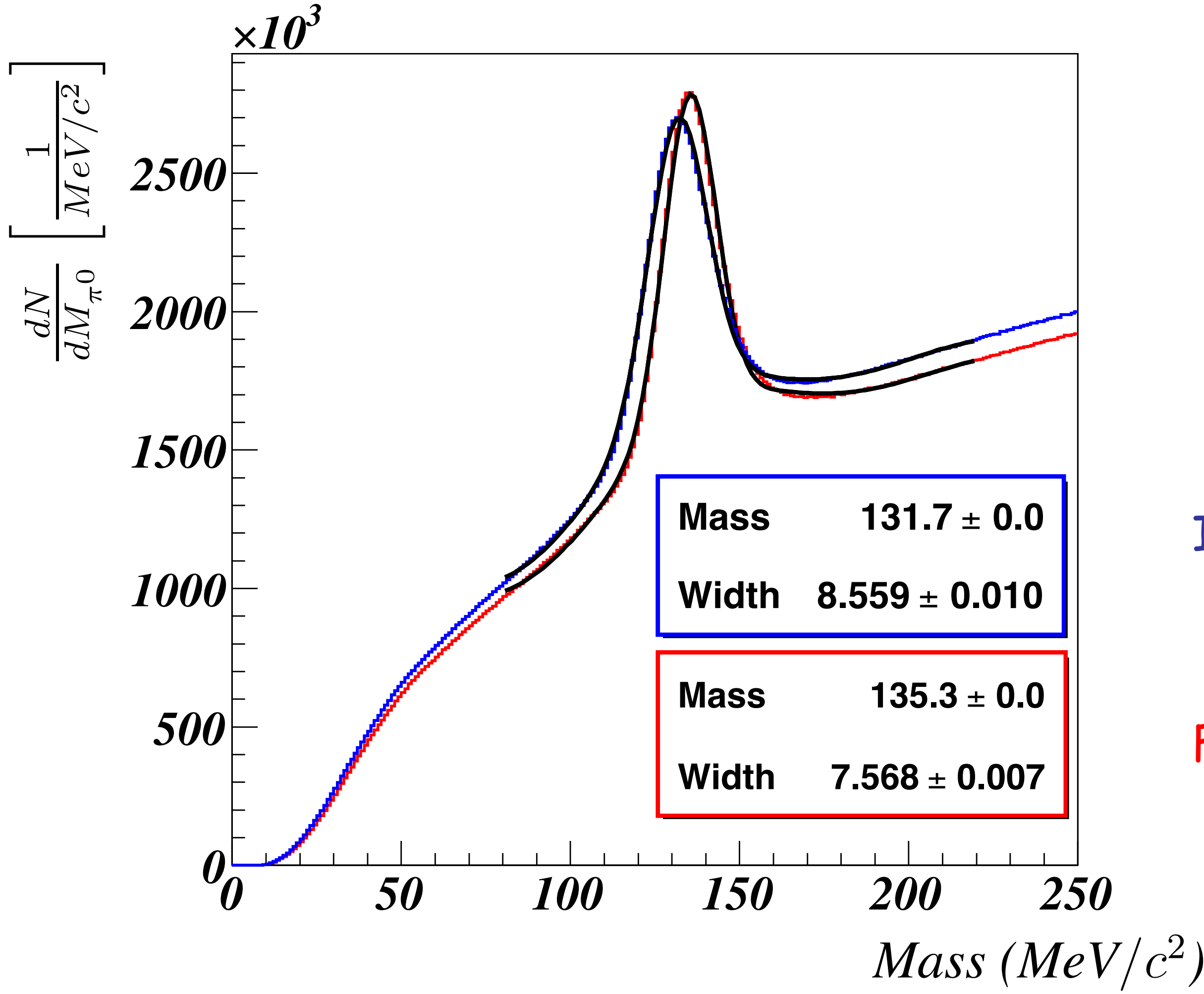
ECAL – Fine Calibration

- Currently absolute calibration based on the
  'Mass distribution fit' method

  (O.Igonkina et al. HERA-B 00-103)
- Fit π^0 mass from 2 photon signals in ECAL
- Iterative procedure
  - Select photons (3x3 clusters) and fix seed (central) cell.
  - For each cell
  - Compute di-photon invariant mass
  - Fit π^0 mass distribution
  - Correct calibration of seed cells
  - Restart until stable

π^0 *mass*

Mass distribution fit algorithm 2011 data (june)

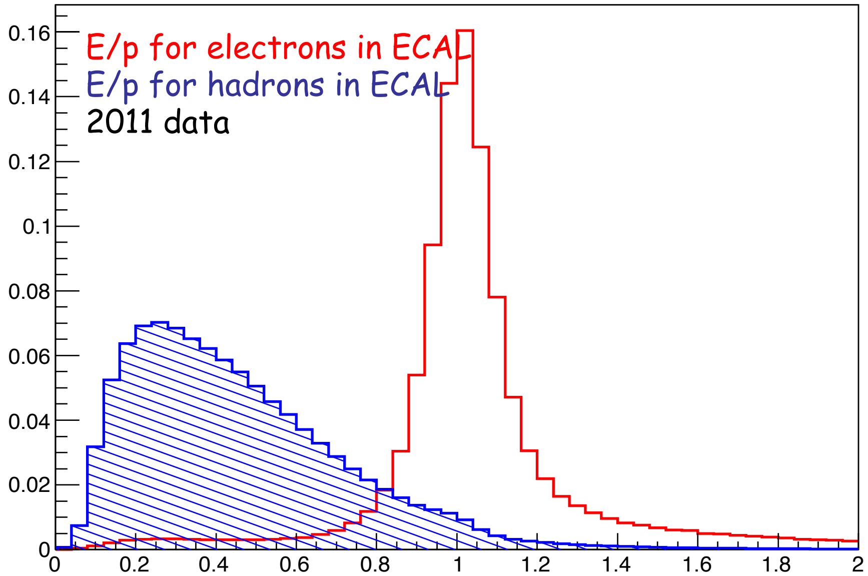


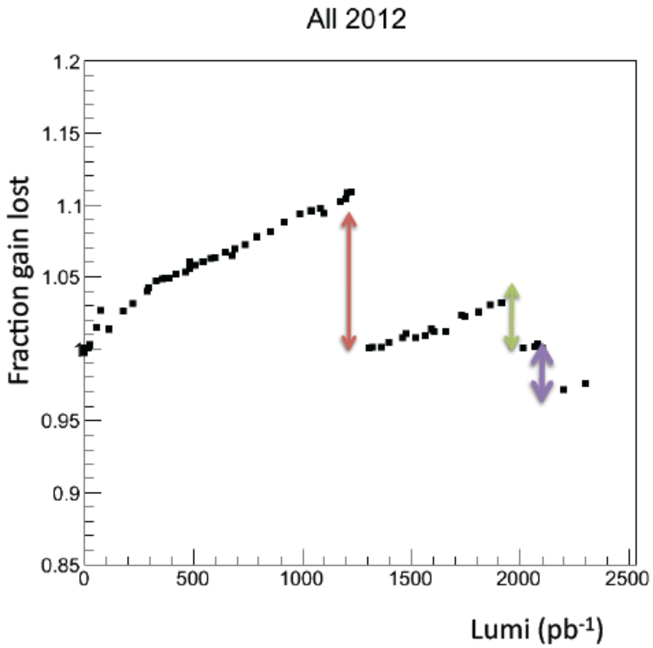
Initial calibration value

Final calibration value
About 6% error

E/p

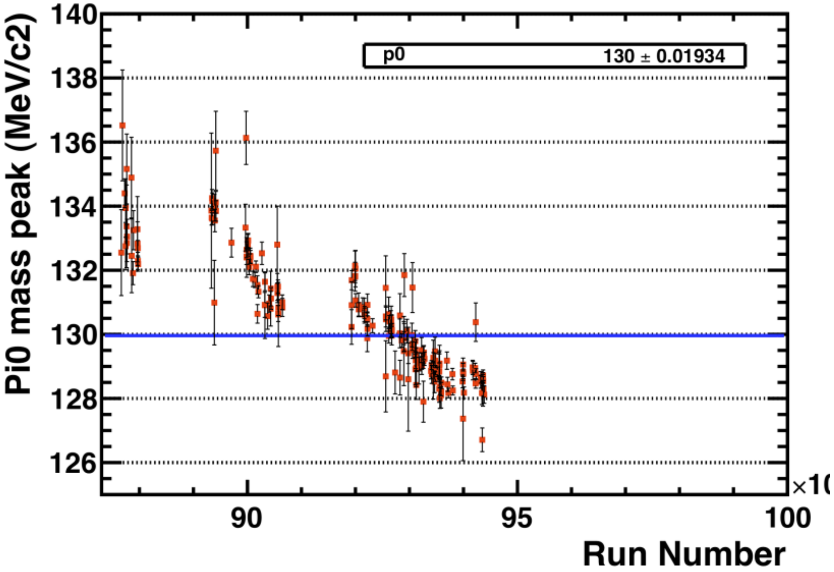
- Another method to monitor or correct the ECAL cell calibration is through electron E/p
- Electrons are identified by estimation of the momentum of the extrapolated of tracks and energy of the matching clusters.
- Used to monitor ageing.

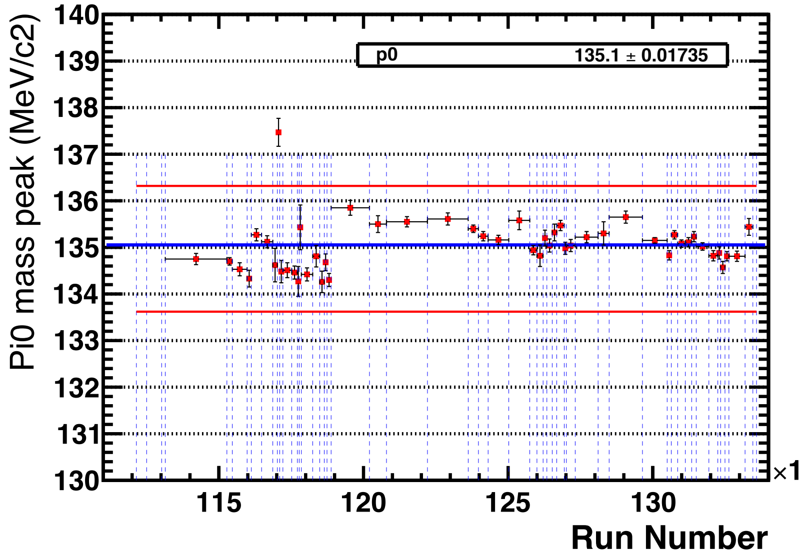




Ageing on ECAL

– π^0 mass variation as a function of time (luminosity) observed:





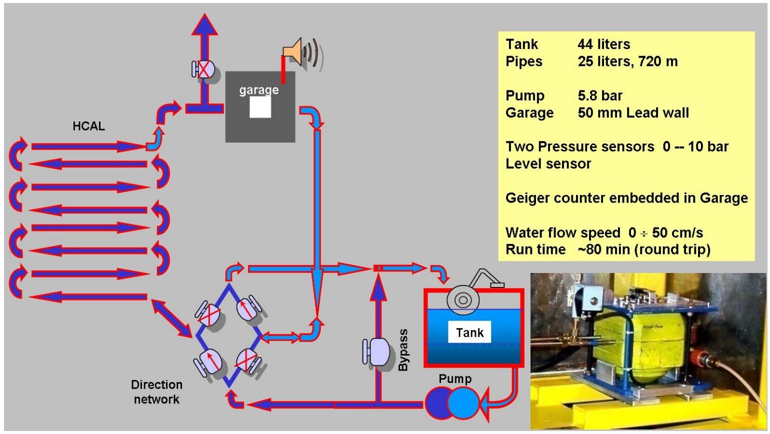
– Optical fibres of ECAL LED monitoring system are also affected

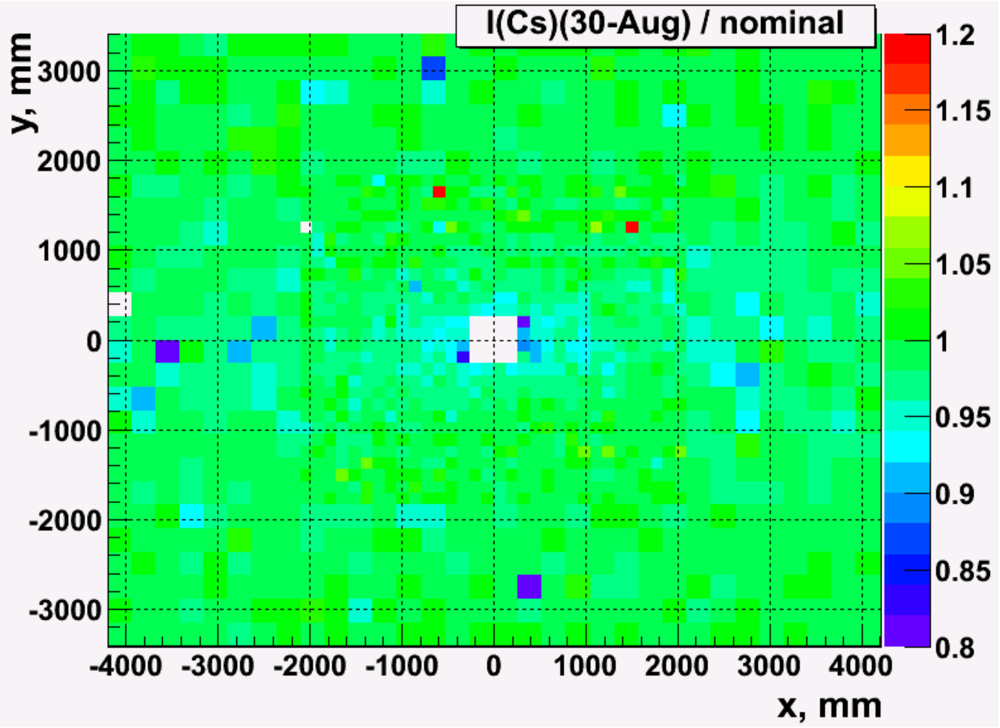
– The effect is cured by calibrating ECAL:

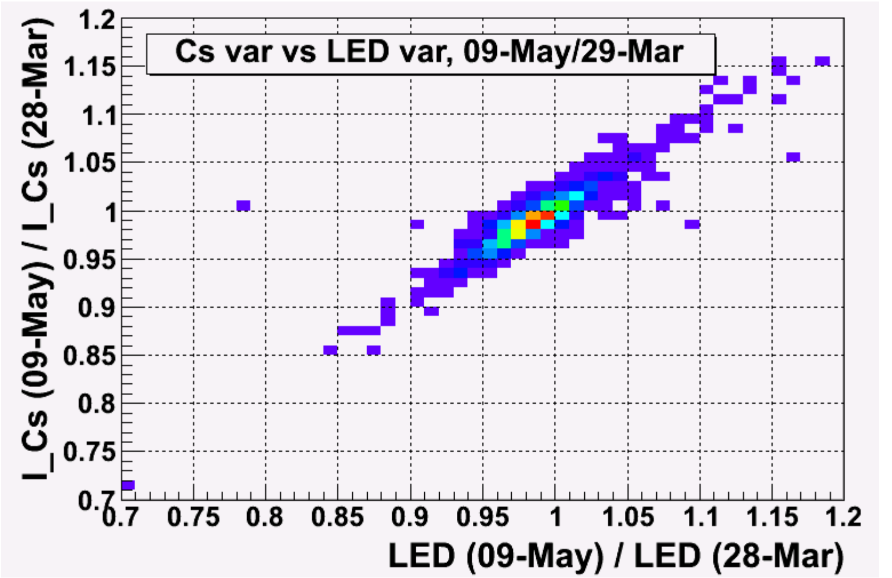
- Apply fine calibration of each ECAL cell using π^0 and adjusting its mass on a short period of data taking
- On top of fine-calibrated data trending coefficients are applied:
  – π^0 statistic not high enough to follow closely the changes
  – Make use of photon conversion and look at E/p

HCAL Calibration

- HCAL absolute Calibration
  - Based on ^{137}Cs source scans performed during technical stops
  - LEDs used to monitor.

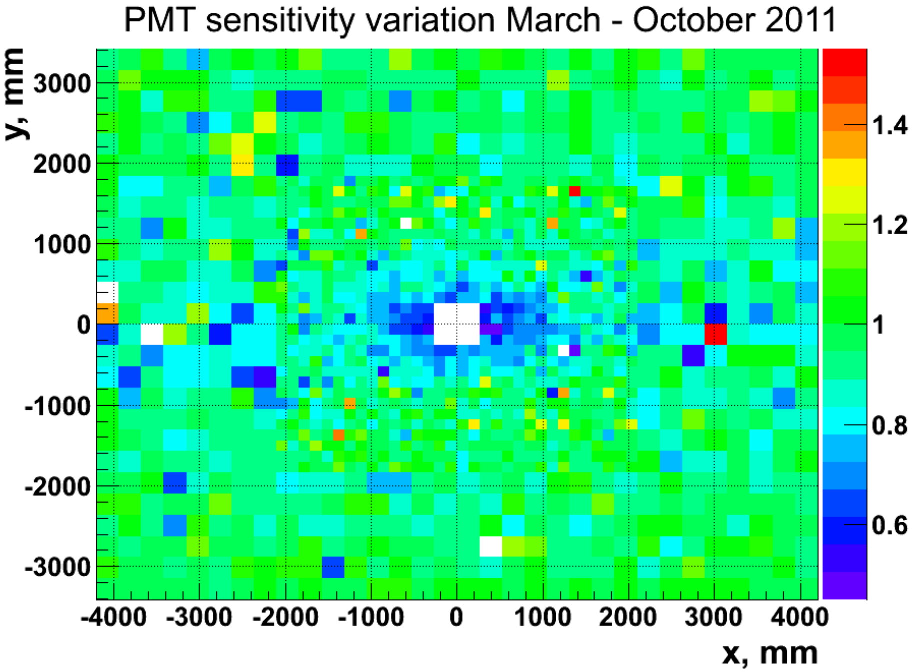




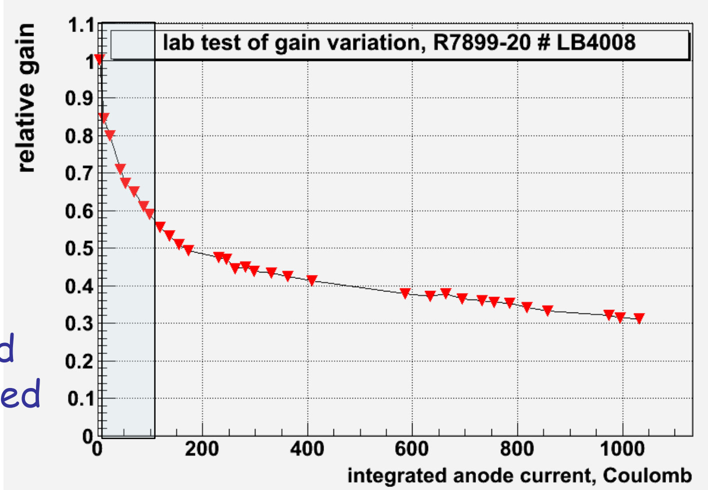


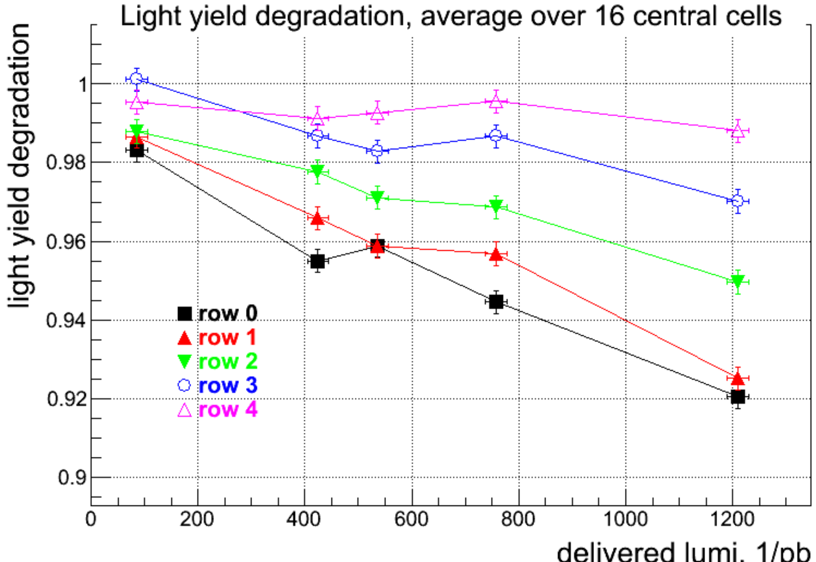
Ageing on HCAL (both on detector and PMT)

The "PMT sensitivity variation" is the PMT gain variation reduced to the initial (March 2011) HV, calculated from the calibration coefficients.



PMT gain Loss expected With cumulated charge





Can be corrected by

Modifying PMT gain (HV)

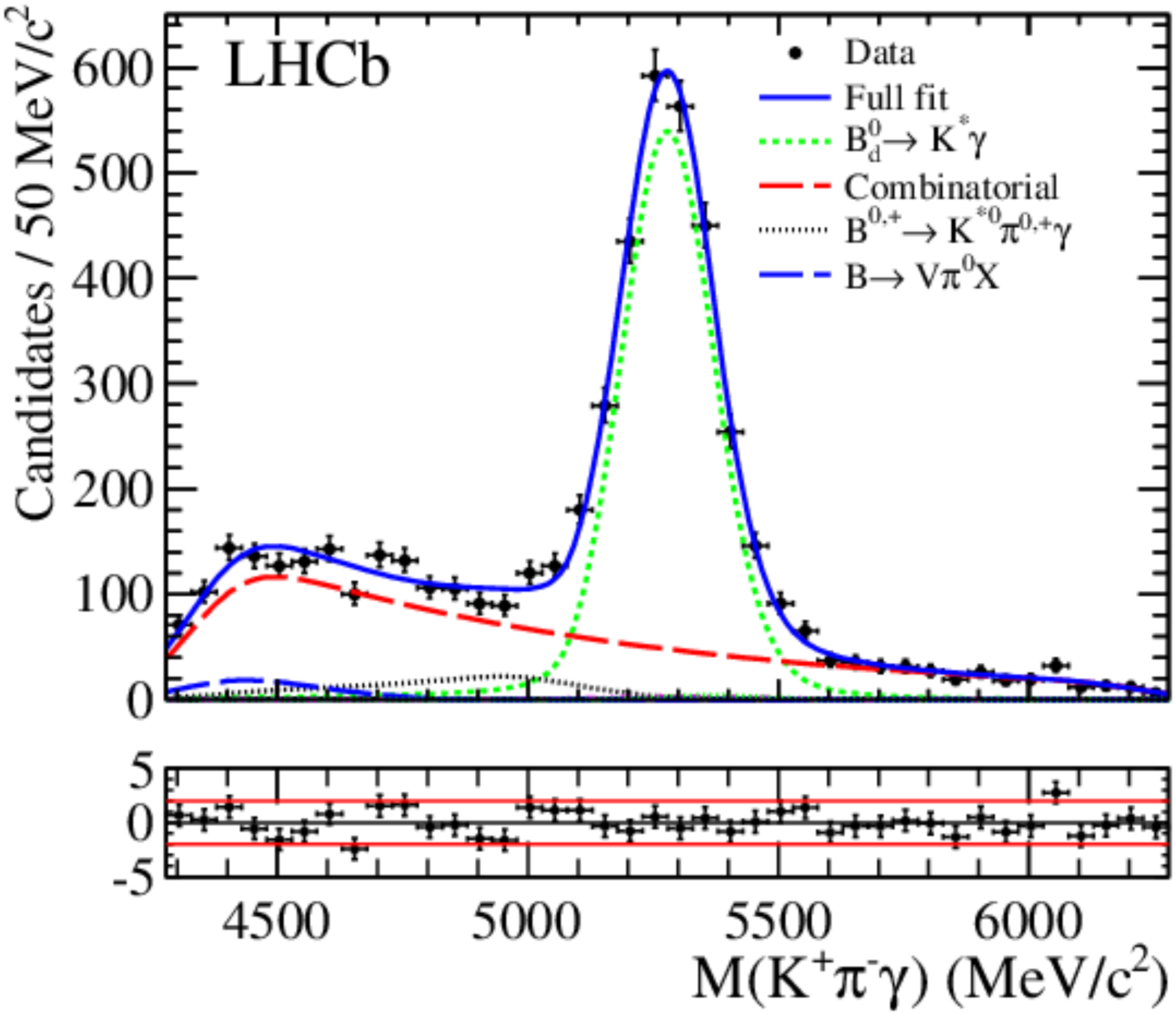
Calibration

Cs source runs + LED

Scintillator rows in the tile get affected depending on their depth

Photon Reconstruction

$$B_d^0 \rightarrow K^{0*}\gamma \qquad \mathcal{L} = 1.0\text{fb}^{-1}$$



- Clusters : 3x3 cells
  - Barycenter,
  - Energy
  - Spread

$$\chi^2_{2D}(\vec{p}) = (\vec{p}_{tr} - \vec{p})^T \mathcal{C}_{tr}^{-1}(\vec{p}_{tr} - \vec{p}) + (\vec{p}_{cl} - \vec{p})^T \mathcal{S}_{cl}^{-1}(\vec{p}_{cl} - \vec{p})$$

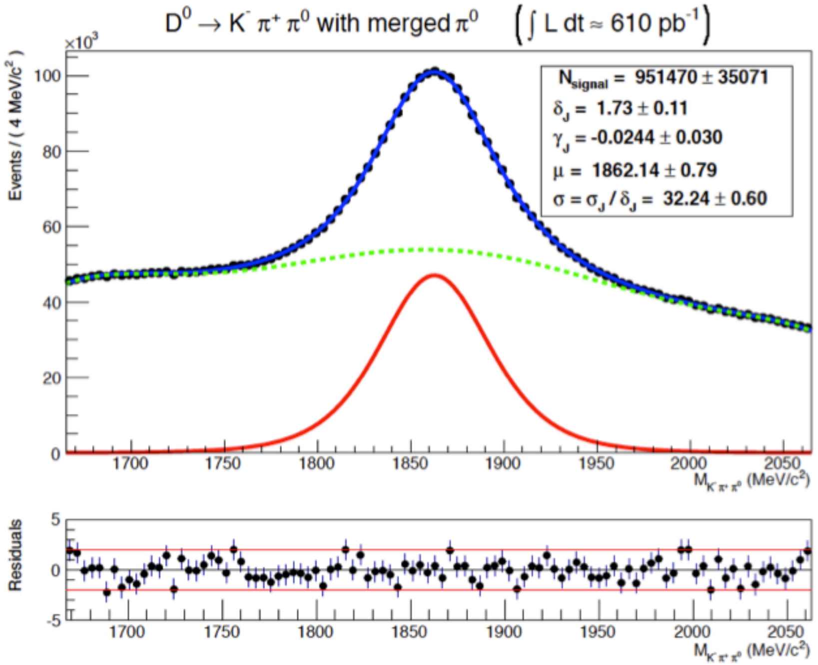
- Match fitted tracks to discard charged particles

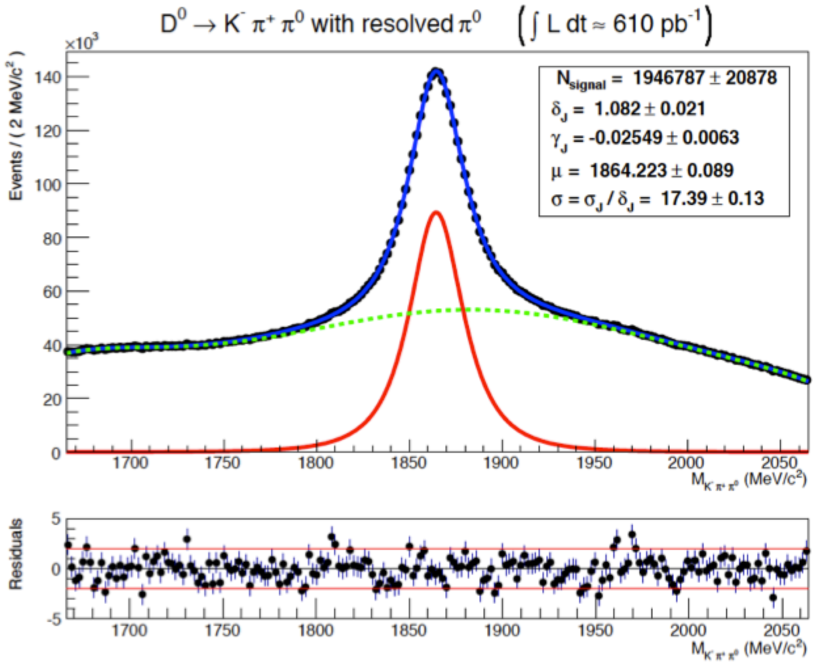
$$E_c = \alpha\varepsilon_{cl} + \beta\varepsilon_{PS}$$

- Mass resolution : $100\text{MeV}/c^2$

π^0 reconstruction

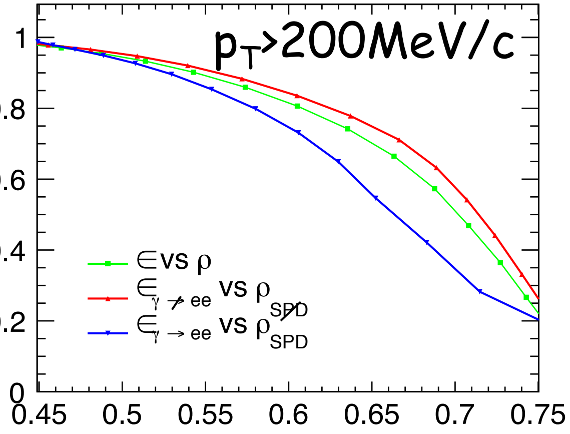
- Neutral π^0
  - Low energy : resolved pair of γ – mass resolution : 8 MeV/c^2
  - High energy (p_T>2GeV/c): overlapped γ clusters – iterative algorithm to separate in two subclusters – mass resolution : 20 MeV/c^2

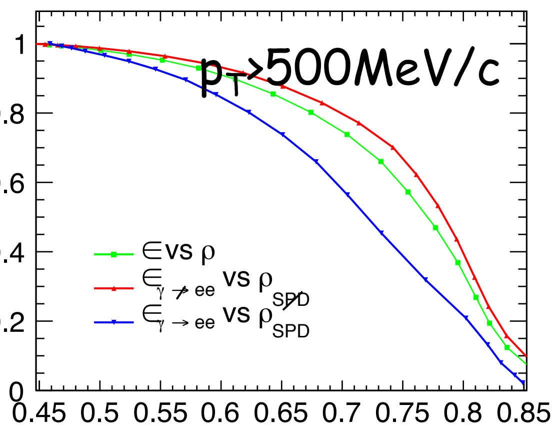




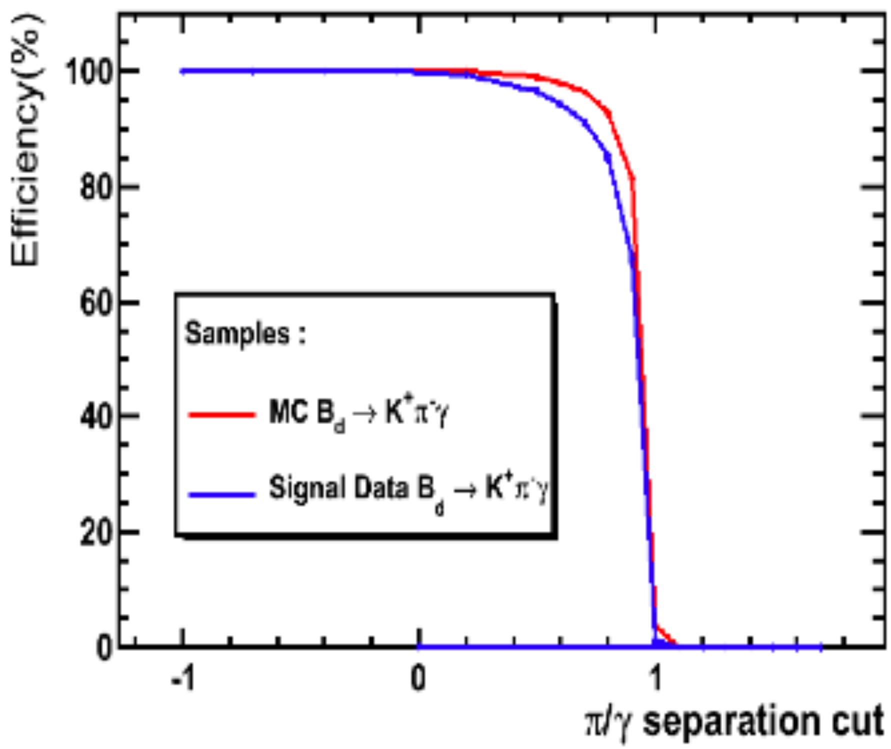
Photon identification and merged π^0

- Photon Hypothesis uses
  - PS cells in front of ECAL cells energy, Ratio of energy (central cell/cluster), X^2_{2D}





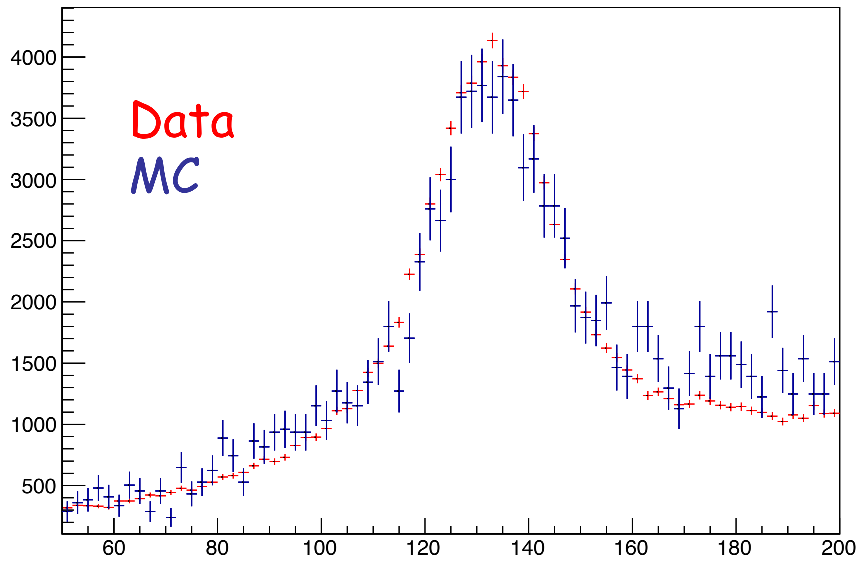
- Separating merged π^0 from γ
  - Uses cluster shape
  - MLP
  - Trained on simulation
  - Checked on data B and D decays



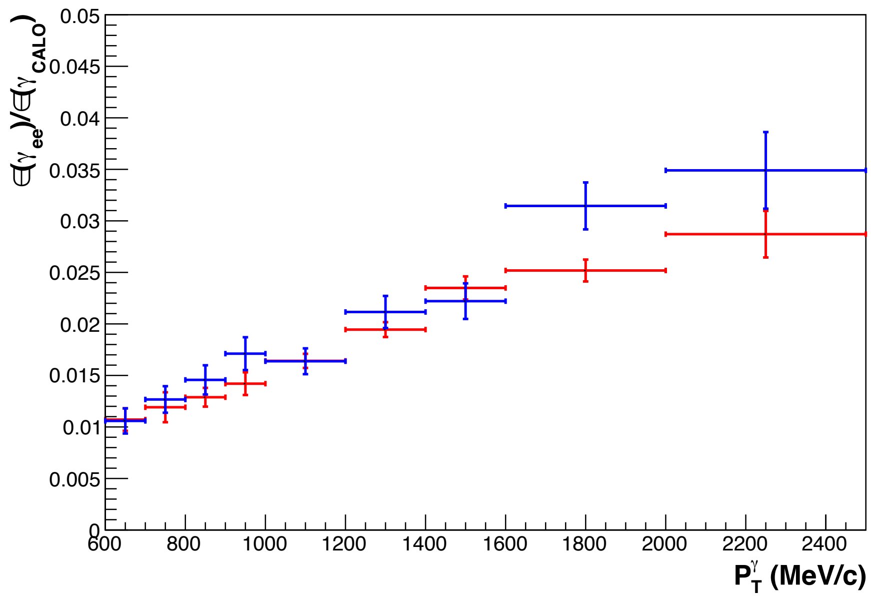
Converted Photon Reconstruction

- Converted photons produce a pair (ee)
- Correct for e bremsstrahlung
  - Bremsstrahlung candidate : neutral energy deposition with $X_2 < 300$ from a charged track.

$$\pi^0 \to \gamma(\to ee)\gamma_{\mathrm{CALO}}$$

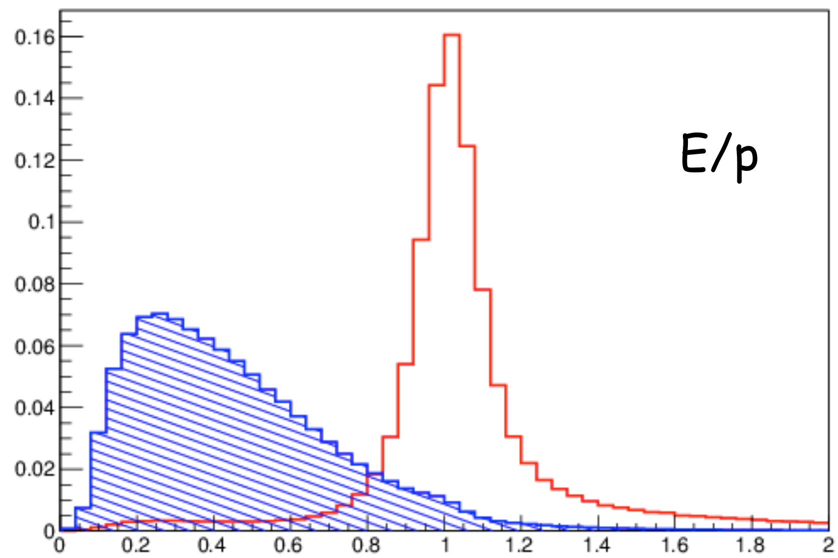


$$\epsilon(\gamma \to ee)/\epsilon(\gamma_{CALO})$$

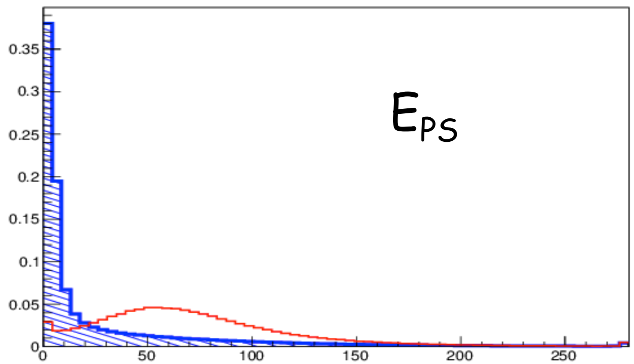


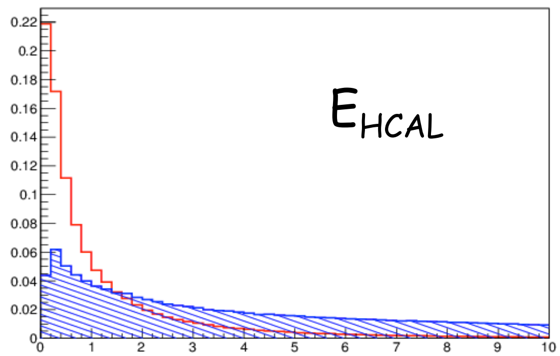
Electron Identification

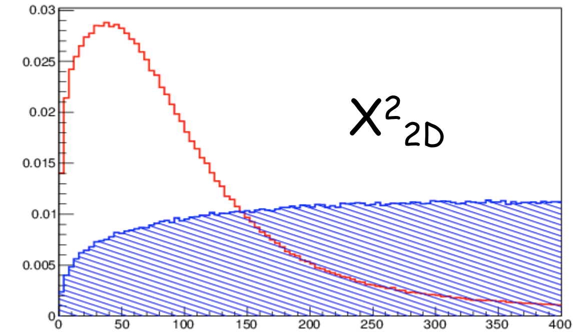
- Build reference histograms
  - use converted γ reconstructed from events triggered by muon detector
  - Hadron background made of **π** and K from D^0 decays
  - Use 340 pb^{-1} from 2011 data
- Histograms built for PS, ECAL and HCAL
- Identification is based on E/p refined using X^2_{2D} and also E_{PS} and E_{HCAL}



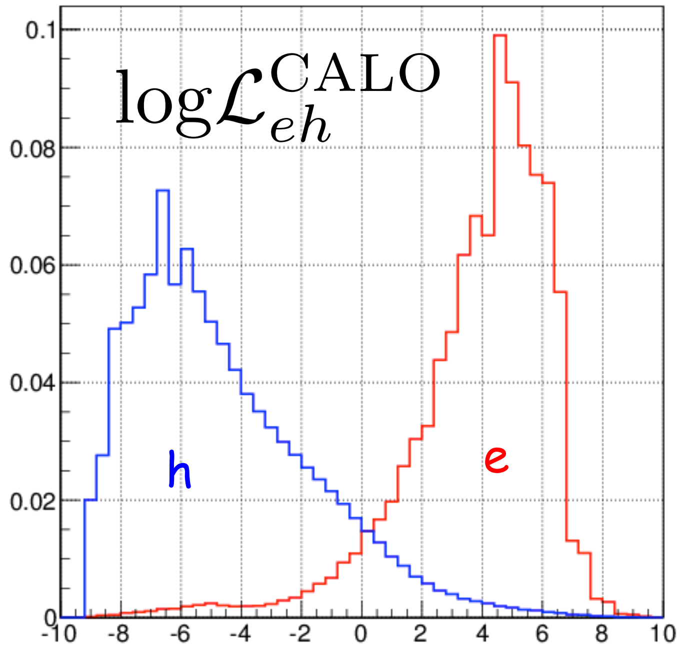
$$\mathcal{L}_{eh}^{\mathrm{CALO}} = \mathcal{L}_{eh}^{\mathrm{ECAL}} \mathcal{L}_{eh}^{\mathrm{HCAL}} \mathcal{L}_{eh}^{\mathrm{PS}}$$

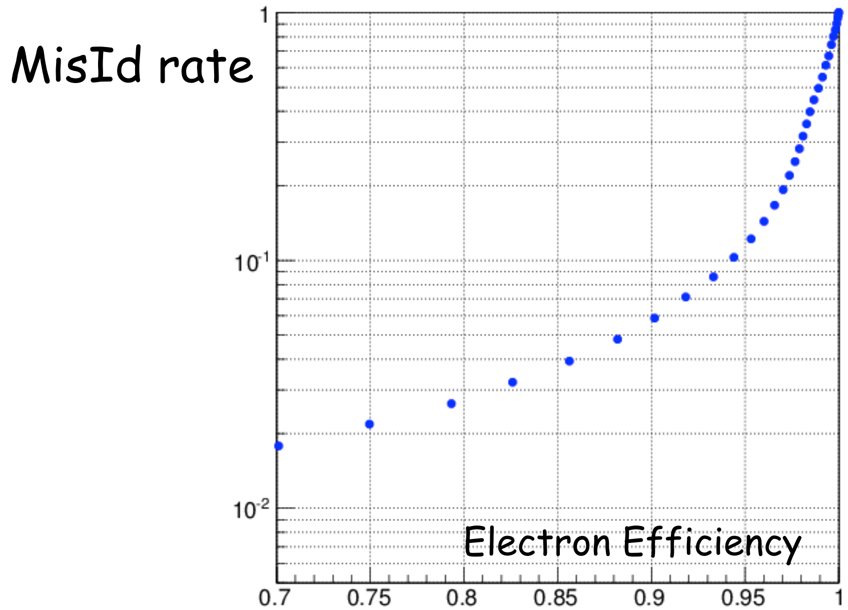






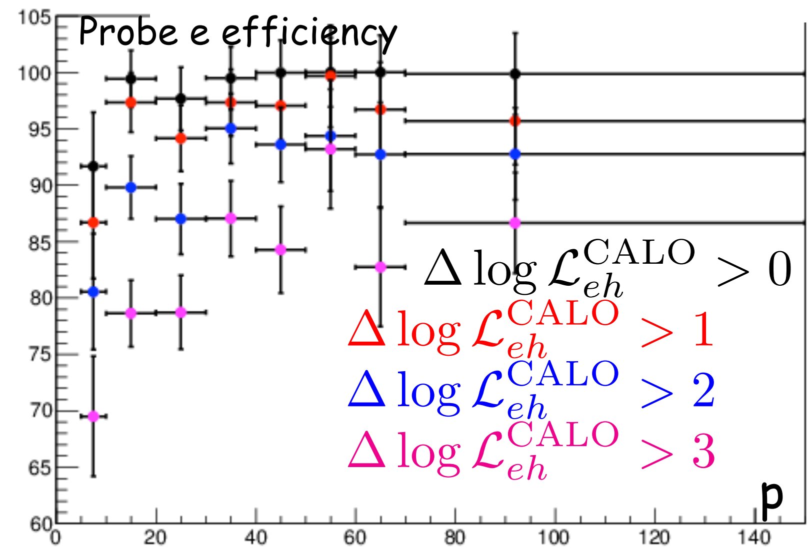
Combined Performance of electron identification



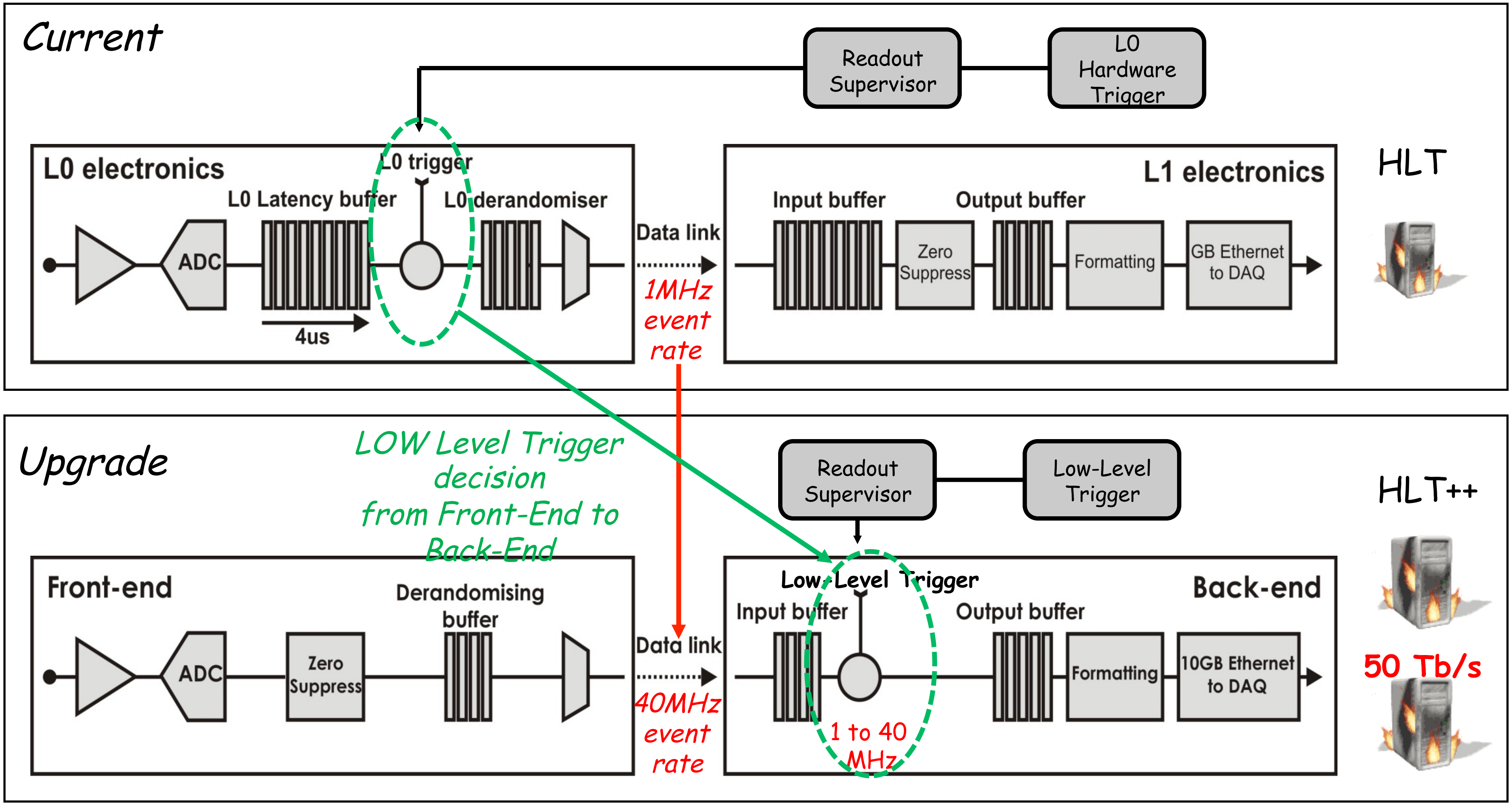


Tag and probe method using e from

$$B^{\pm} \to J/\psi(e^{+}e^{-})K^{\pm}$$



LHCb Upgrade Architecture



Upgrade

- Increased luminosity
- New features
- PS and SPD shall be eliminated (they mainly contribute to L0 trigger)
- DAQ @ 40MHz
  - Change in the readout electronics
- Lower PMT gain
  - Higher luminosity
  - Ageing
- New electronics under development
- TDR under review

Conclusions

- LHCb calorimeters fully functional
- Ageing observed
  - Frequent calibrations
- Good performances in γ and e identification.
- Upgrade
  - Leave ECAL-HCAL
  - Software trigger
  - New DAQ electronics

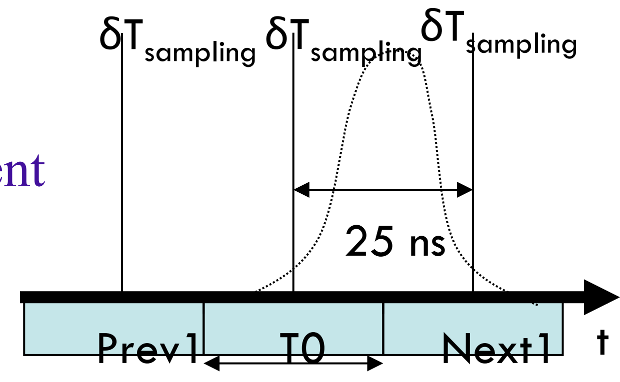
Performance of the LHCb calorimeters
during the period 2010-2012

Xavier Vilasís-Cardona

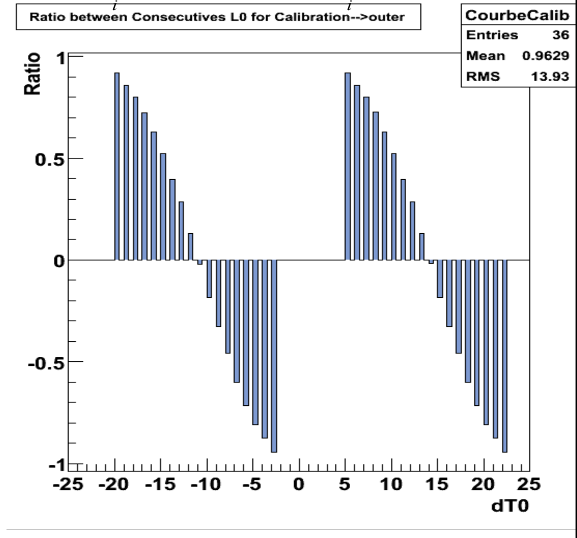
BACKUP

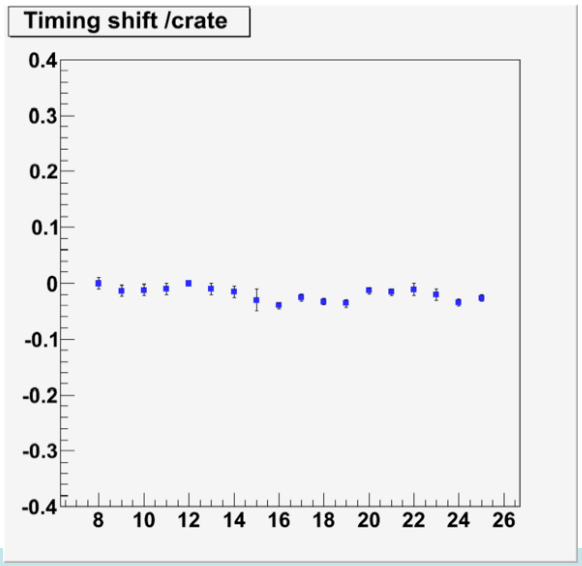
Time Alignment

- DAQ feature: Time Alignment Events
- Equalise an a-priori delay from theoretical values
- Adjust BXID so that an event is mainly seen on Current
- Adjust integration time t0
  - Select the pair of BX with maximum signal
    - Prev1/Current vs. Current/Next1
  - Compute the asymetry **R**
- All XCAL channels adjust within **1ns**



$$Rj = \frac{\sum_i^{Nevt} E_{ij}(Current) - \sum_i^{Nevt} E_{ij}(Next)}{\sum_i^{Nevt} E_{ij}(Current) + \sum_i^{Nevt} E_{ij}(Next)}$$

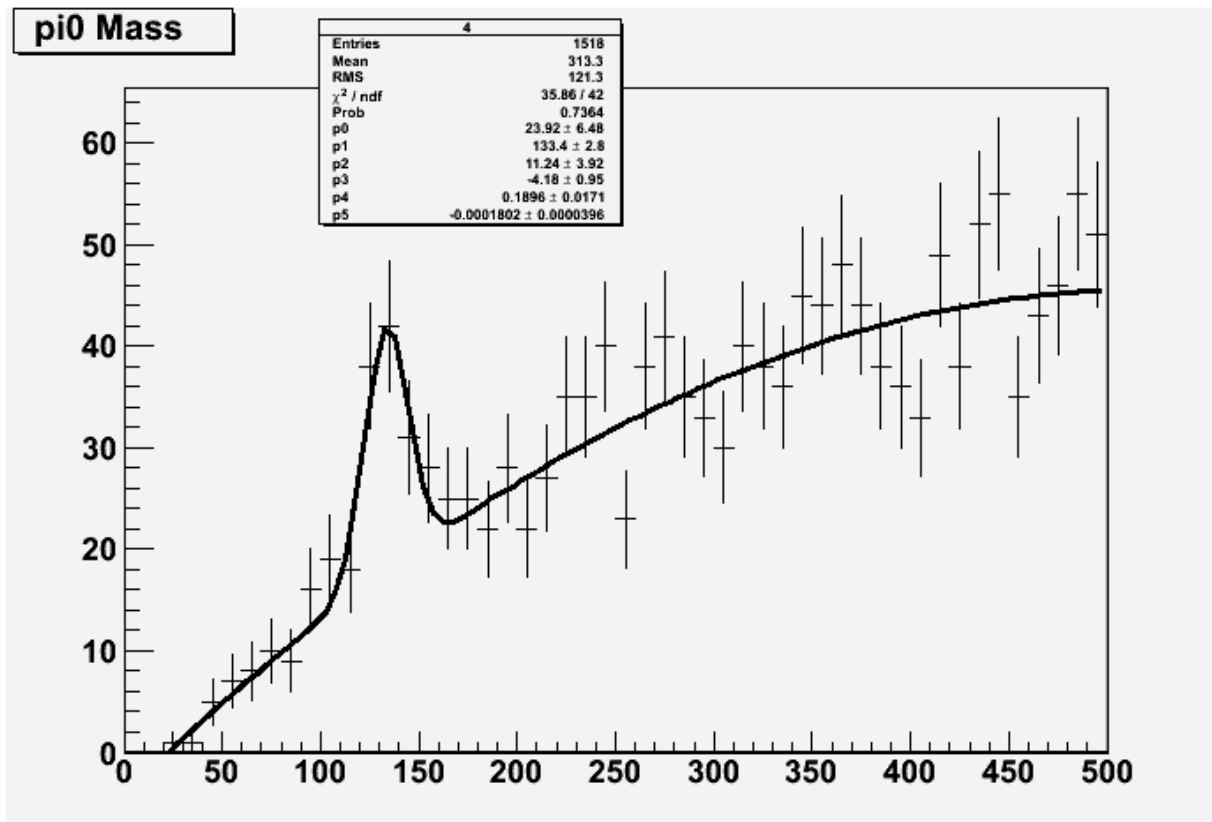




First π^0 fit – Nov 2009

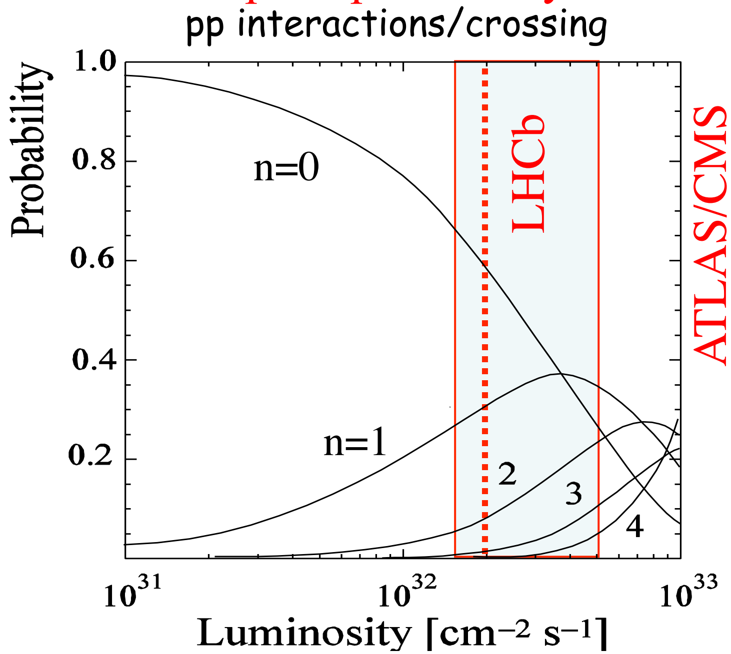
- Initial calibration was performed by setting a uniform ADC count value per transverse energy unit.
- This calibration allowed to fit the π^0 peak in NOV2009

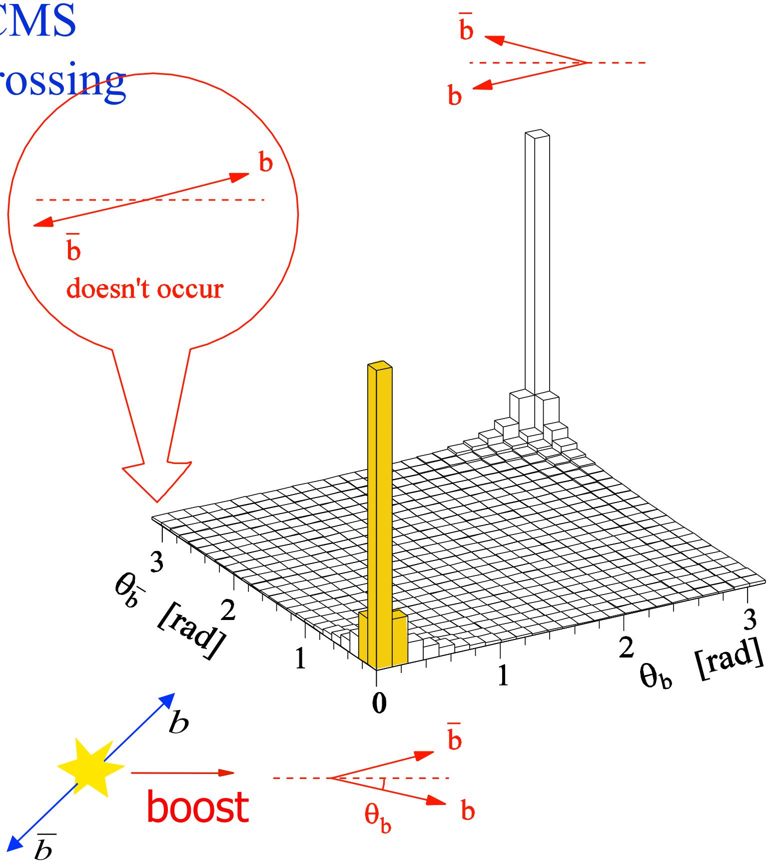
M=133 ± 3 MeV/c2,
with σ = 11 ± 4



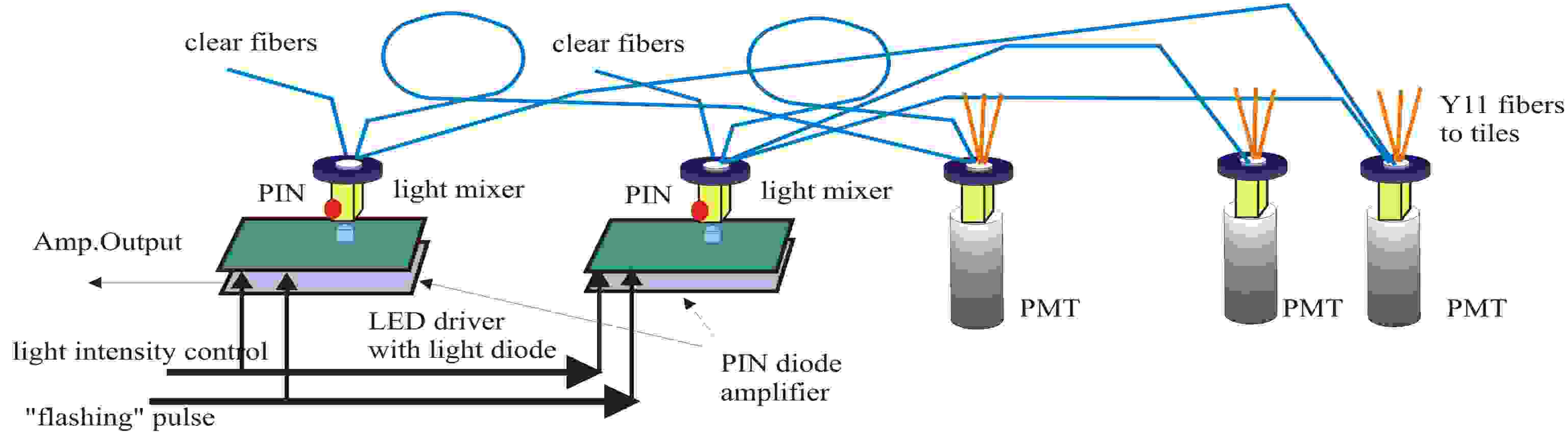
B production in LHCb

- $\bar{b}$ and b quarks are produced in pairs
- bb production is correlated and sharply peaked forward-backward
- LHCb single-arm forward spectrometer : θ~15-300 mrad (rapidity range: 4.9>η>1.9)
- Cross section of bb production in LHCb acceptance: $\sigma_{bb} \sim 230\ \mu b$
- LHCb limits luminosity to few $10^{32} cm^{-2}s^{-1}$ instead of $10^{34} cm^{-2}s^{-1}$ by not focusing the beam as much as ATLAS and CMS
- Maximizes probability of a single interaction per crossing
- Design luminosity from start-up of LHC
- ~ 10^{12} bb pairs produced/year in LHCb acceptance

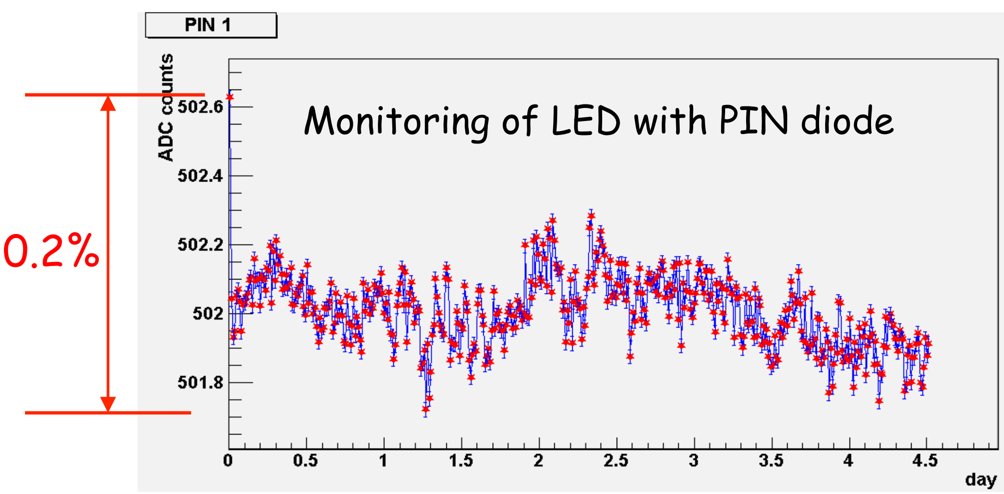




LED monitoring system of HCAL

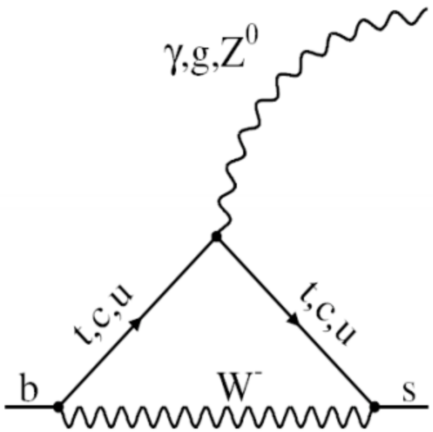


- blue LEDs (WU-14-750BC)
- two independent LEDs per module
- adjustable LED pulse amplitude
- monitoring PIN photodiode at each LED in order to account for LED instability
- light distribution with clear fibers of same length
- timing of the LED flashing pulse adjustable with 1 ns step



Radiative decays $b \rightarrow q\gamma$

- Radiative $b \rightarrow (d, s)\gamma$, one-loop penguin transition, sensitive to NP.

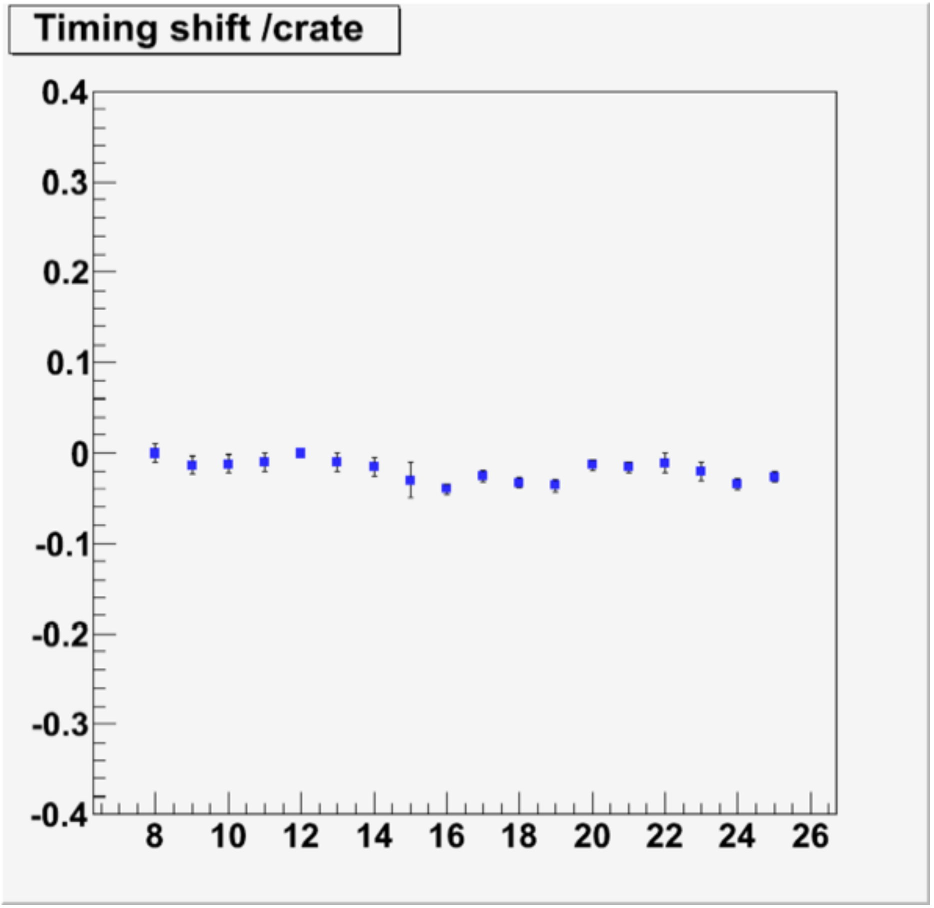


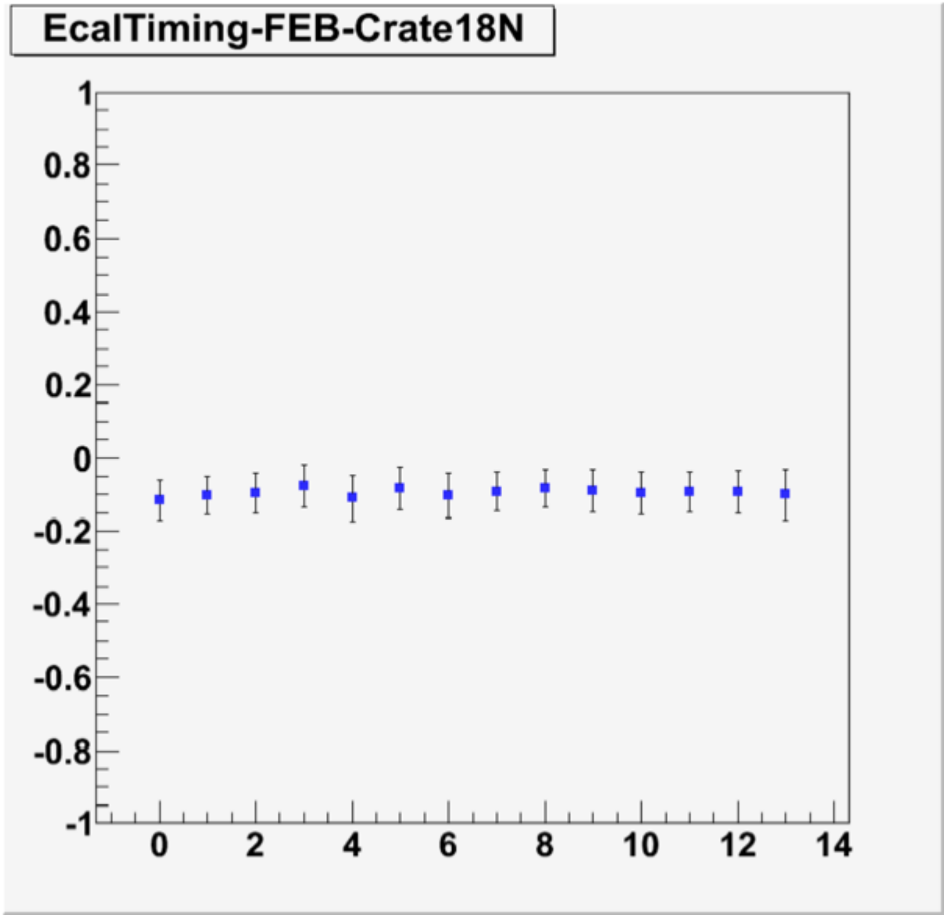
NP may introduce sizeable effects on the dynamics of the transitions, through contributions of new particles inside the loops

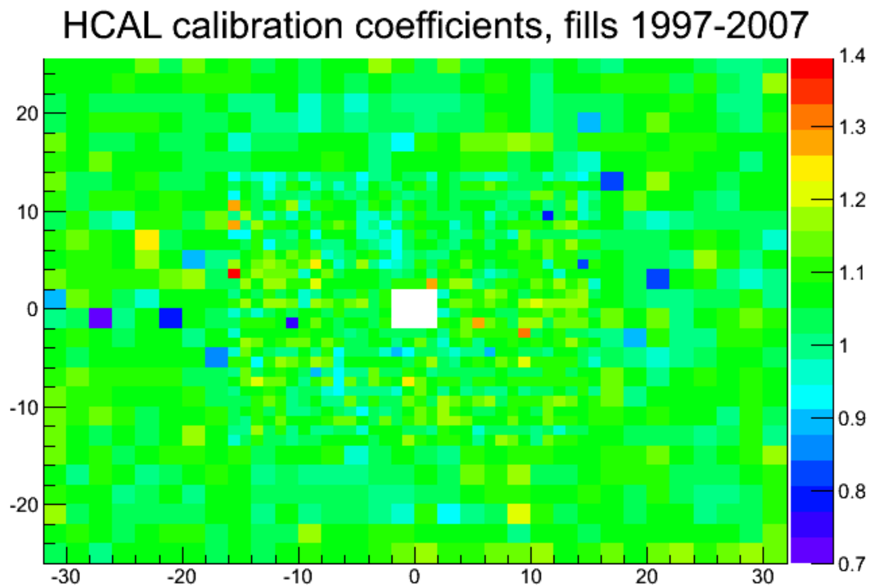
- Theoretically clean FCNC transition & experimentally accessible.
- Many observables: branching fractions (BR), CP asymmetries (A_{CP}), isospin asymmetry, helicity structure of the photon.

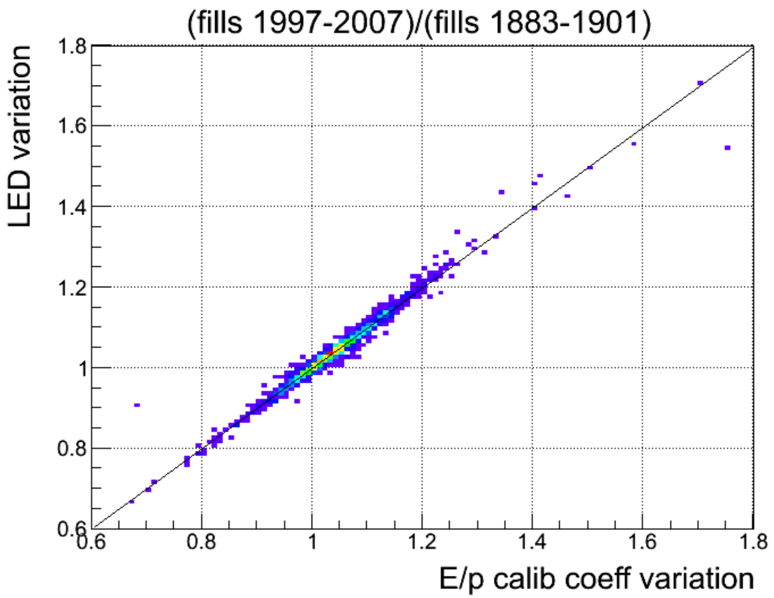
Time Alignment results-ECAL

- All XCAL channels adjusted within 1 ns.









If the offline accounting for the HCAL ageing will be found necessary, one can use the E/p based calibration on hadron tracks (for the moment, available per fill, up to fill #2007, Aug-2011).

The E/p calibration gives absolute scale and calibrates the whole signal chain, accounting also for the spread of FEB sensitivities.

Here: correlation of ratio of E/p-based calibration coefficients for fill ranges 1883-1901 and 1997-2007 (~5 weeks in between) and LED amplitude change for the same period. This validates the use of the LED corrections at least for short time scale.