CERN Detector Seminar

8 February 2013

Overview of the LHCb calorimeter detectors

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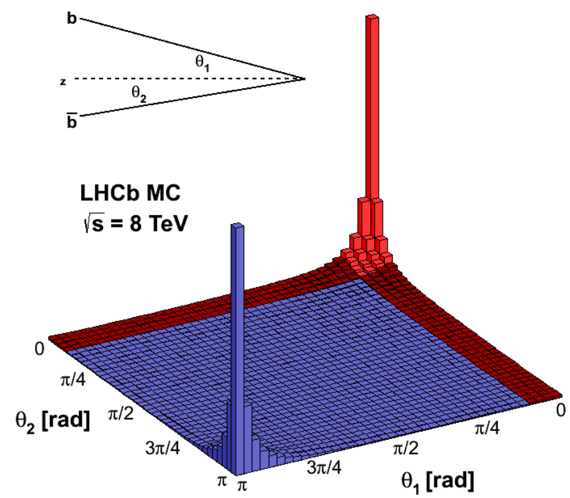
Heavy Flavours @ LHC

- LHC is a B- and D-mesons super factory:
  - Large $b\bar{b}$ cross section (~250 µb – 500 µb @ $\sqrt{s}$=7 – 14 TeV):
    - LHCb measurement @ 7 TeV *[PLB 694 (2010) 209]*:
      - ~ 280 µb (~75 ± 14 µb in LHCb acceptance)
    - $\sigma_{c\bar{c}}$ is 20 times larger! *[LHCb-CONF-2010-013]* $\sigma(pp \rightarrow c\bar{c}X)$ = ~6 mb
      - LHCb acceptance / 1 fb^{-1}:
        - ~10^{11} b decays [all species produced, B^0,B^+,B_S, Λ_b,..]
    - b-hadrons produced at low angle
      - Spreading predominantly in the narrow cone around the beam
    - High rate of background events:
      - $\sigma_{vis.\ Inel.}$ ~ 60 mb at $\sqrt{s}$ =7 TeV
      - 1/200 event contains a b quark, typical interesting BR < 10^{-3}

TRIGGER!

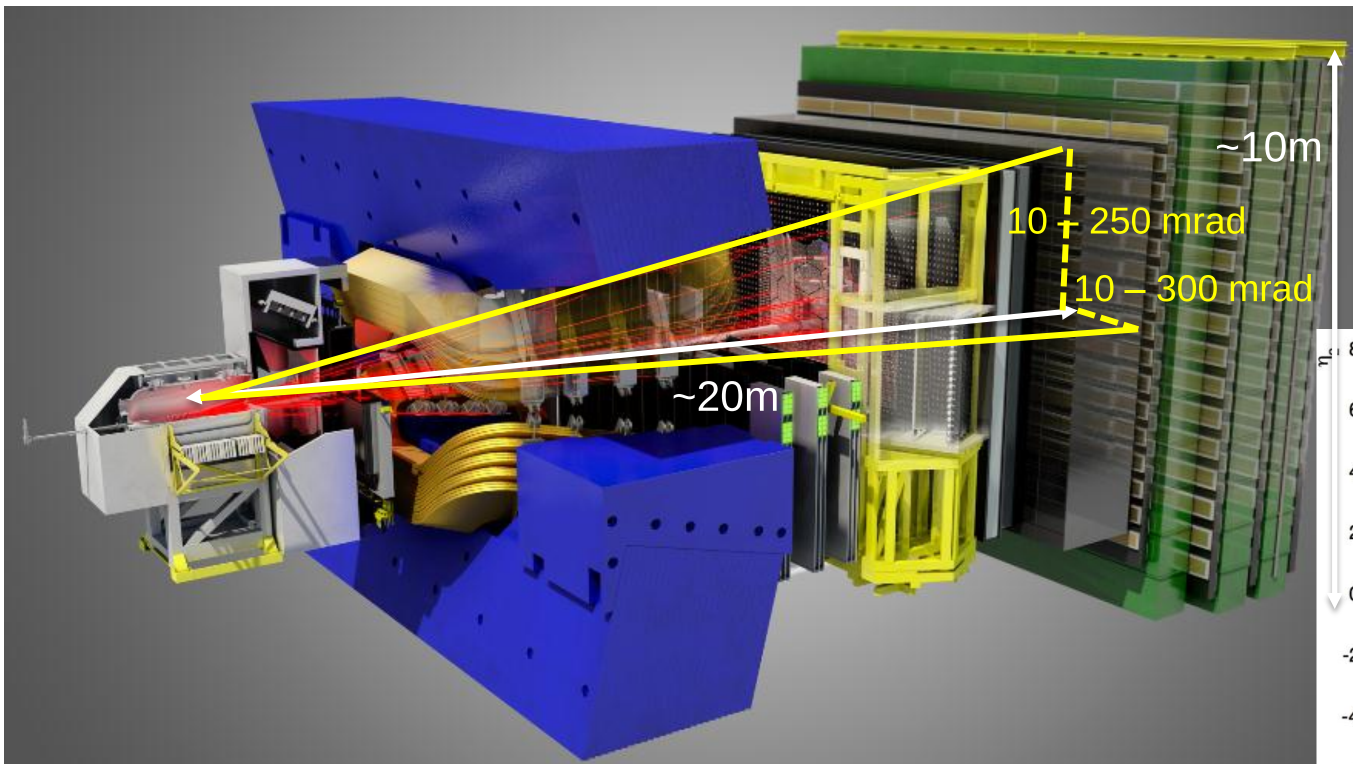


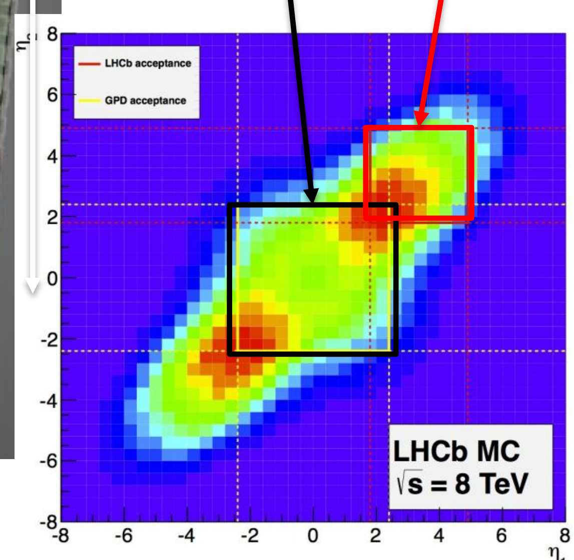
Outline

- The LHCb detector
- The LHCb calorimeters
- Commissioning & operation
  - Calibration
  - Stability
- Performances
- Conclusion

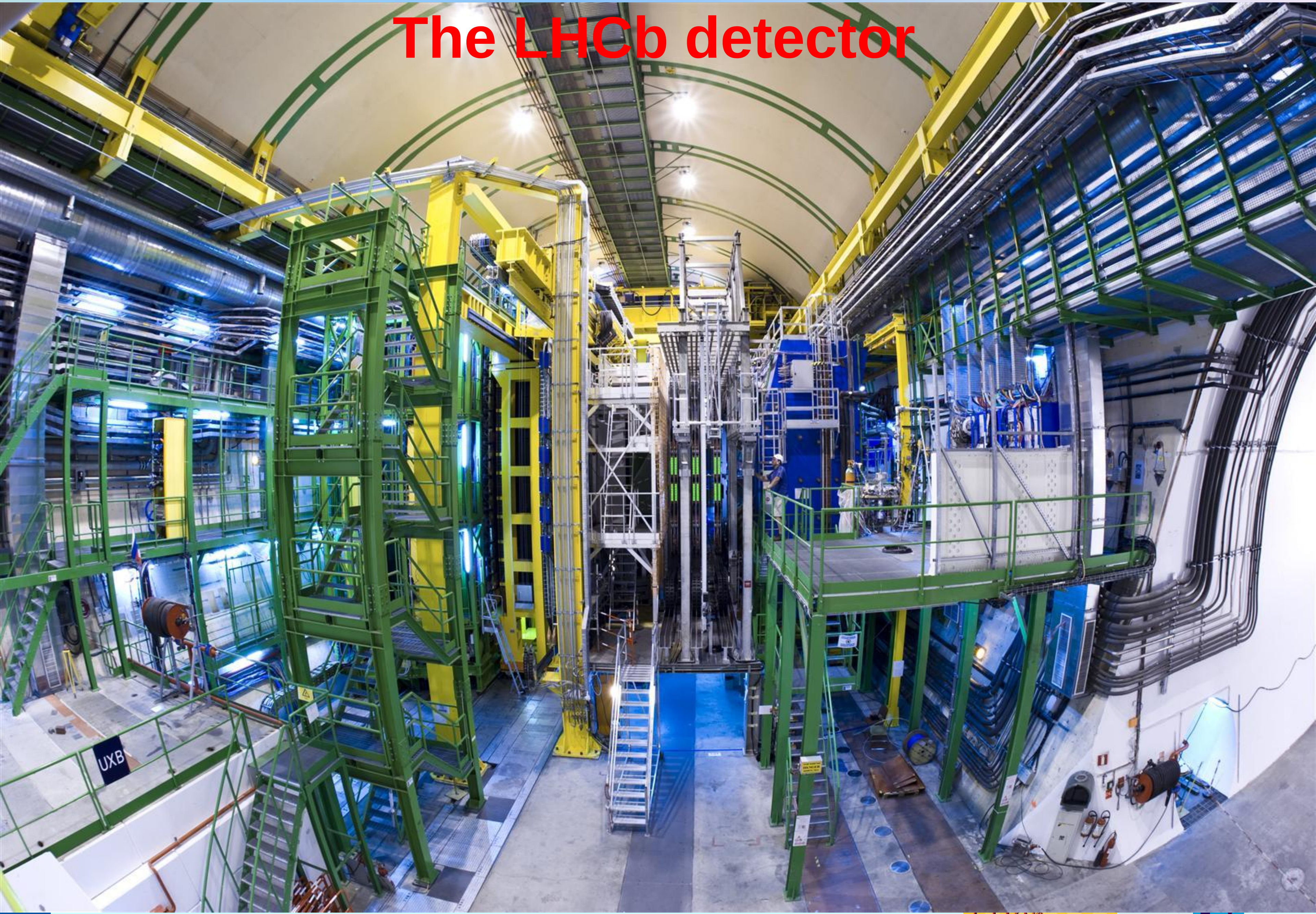
The LHCb detector

- A single-arm forward spectrometer:
  - Covers ~4% of the solid angle, but captures ~30% of the heavy quark production cross-section

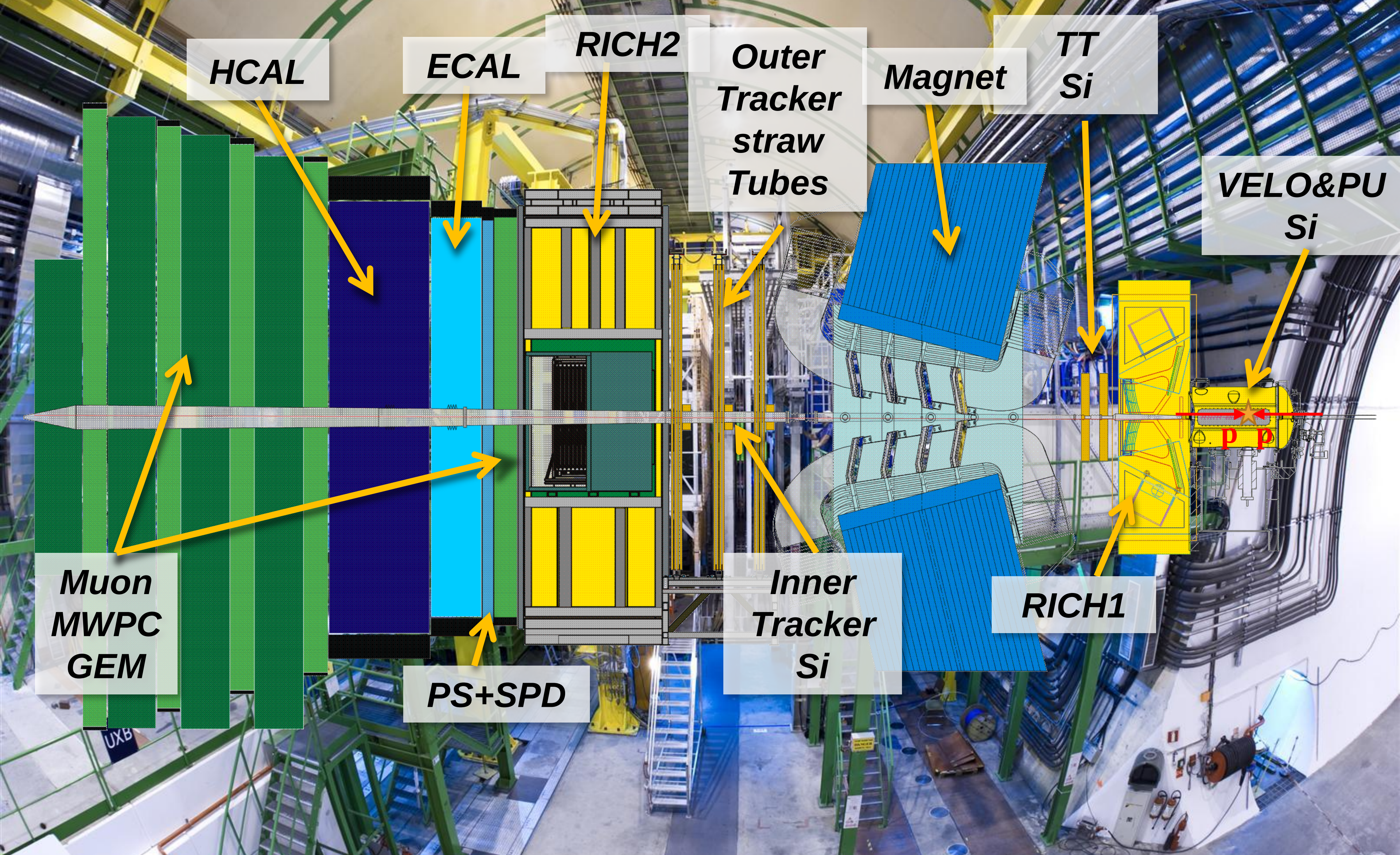




The LHCb detector

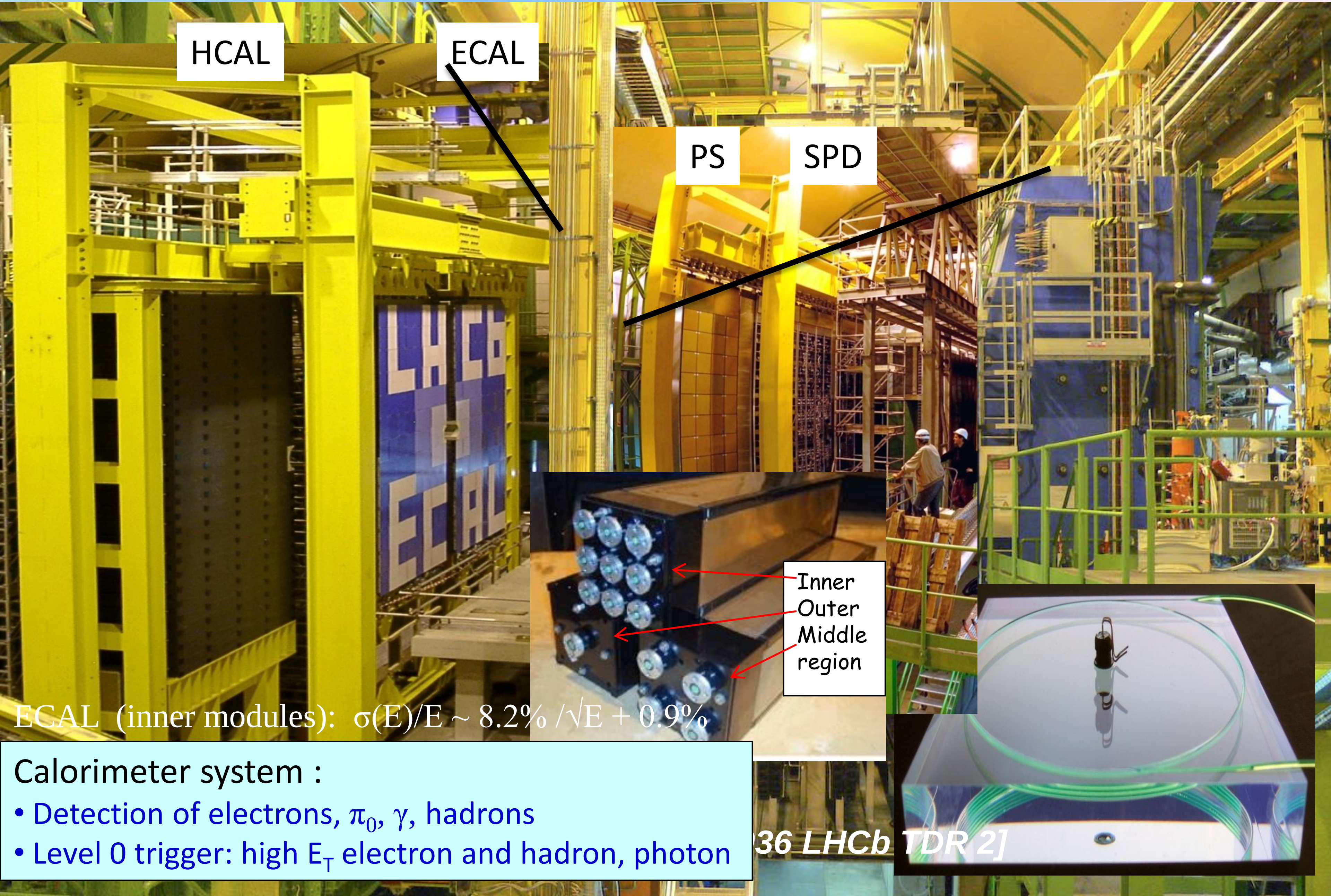


The LHCb detector



[The LHCb Detector at the LHC, JINST 3 (2008) S08005]

The LHCb calorimeters

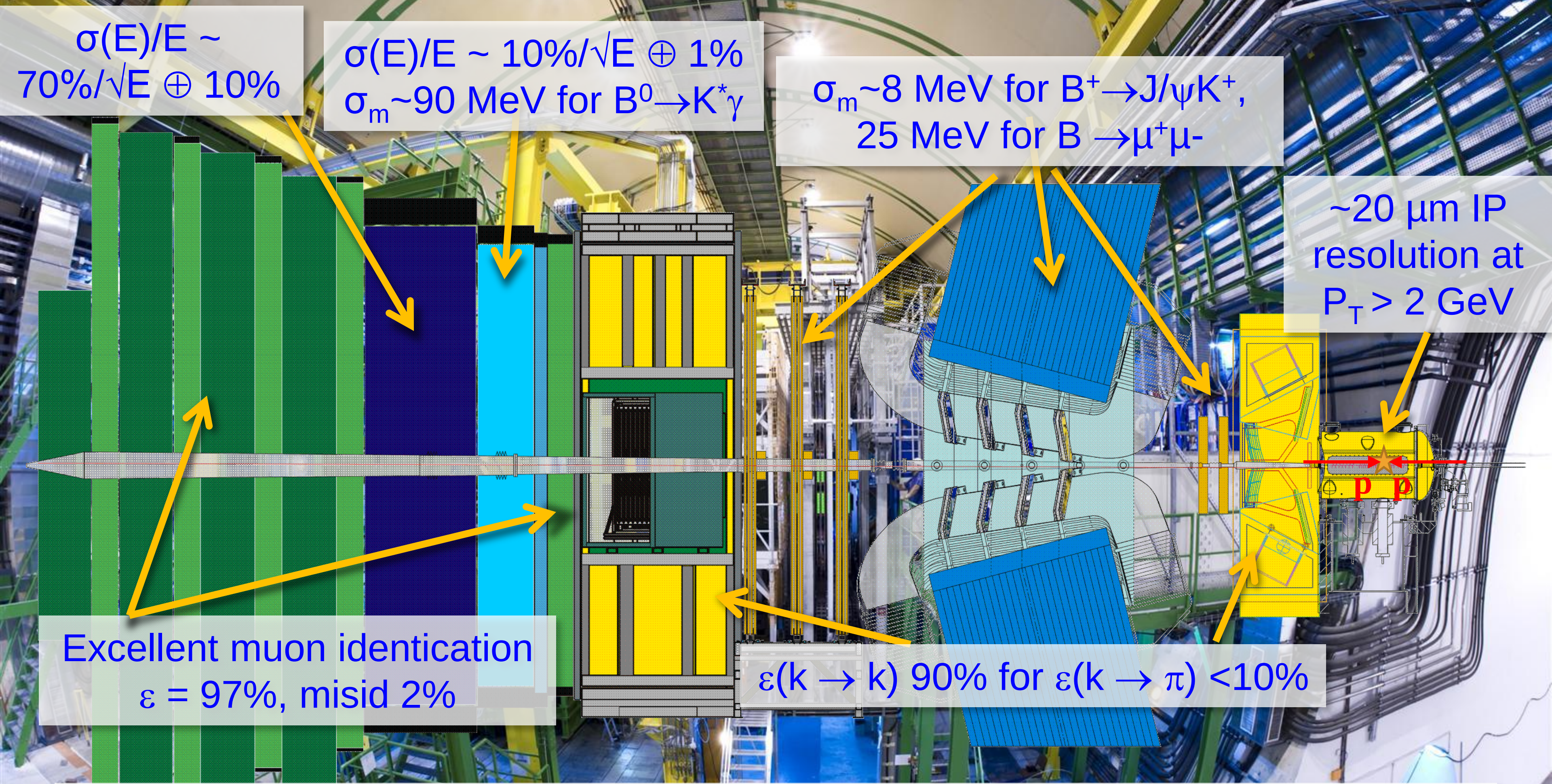


ECAL (inner modules): $\sigma(E)/E \sim 8.2\% / \sqrt{E} + 0.9\%$

Calorimeter system :

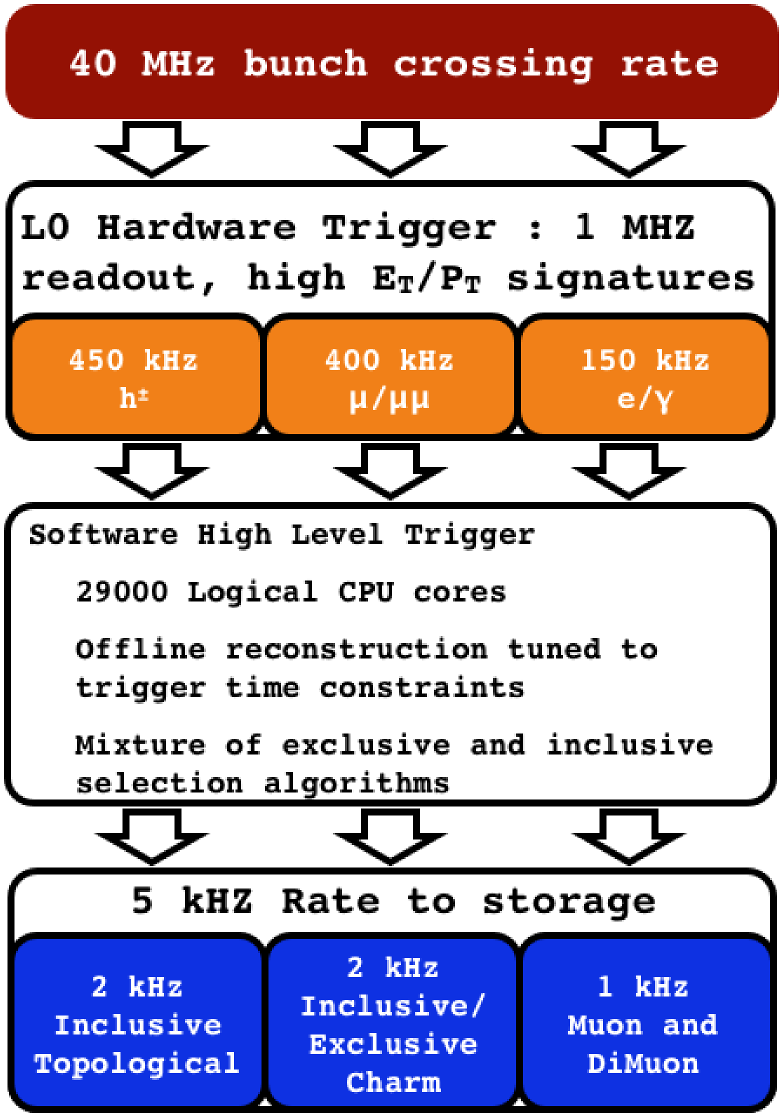
- Detection of electrons, π_0, γ, hadrons
- Level 0 trigger: high E_T electron and hadron, photon

The LHCb detector



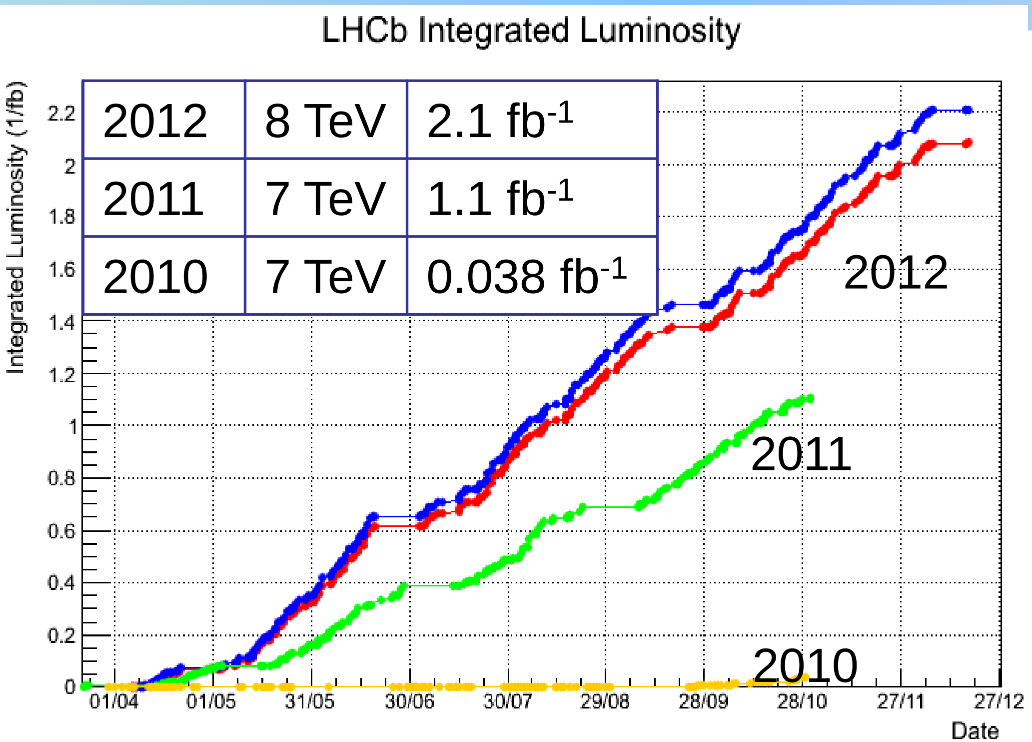
- ❖ Great Vertex Resolution! Primary/secondary separation, proper time resolution.
- ❖ Excellent momentum and mass resolution.
- ❖ Outstanding PID (K-π) and μ reconstruction.
- ❖ Dedicated Trigger system for B and C!

LHCb trigger

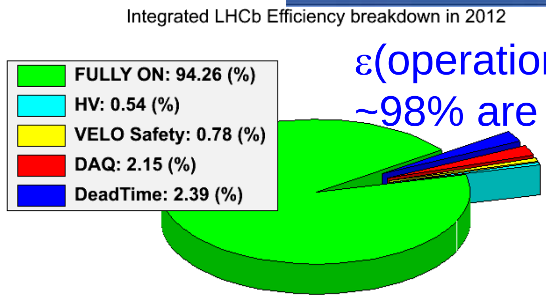


- Level-0 trigger: hardware
  - 4 μs latency @ 40MHz
  - "Moderate" E_T/p_T threshold:
    - *Typically*
      - *$E_T(e/\gamma)>2.7$ GeV*
      - *$E_T(h)>3.6$ GeV*
      - *$p_T(\mu)>1.4$ GeV/c*
- HLT trigger: software
  - ~30000 tasks in parallel on ~1500 nodes
- Storage rate: 5 kHz
- Combined efficiency (L0+HLT):
  - ~90 % for di-muon channels
  - ~30 % for multi-body hadronic final states

LHCb operation



2012	8 TeV	2.1 fb^{-1}
2011	7 TeV	1.1 fb^{-1}
2010	7 TeV	0.038 fb^{-1}

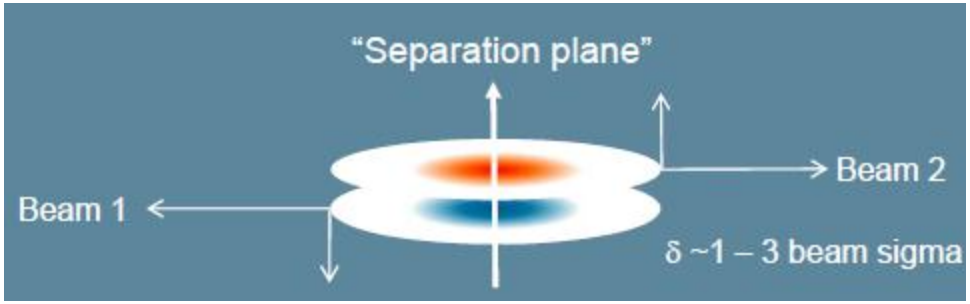


ε(operation)>94%

~98% are good data!

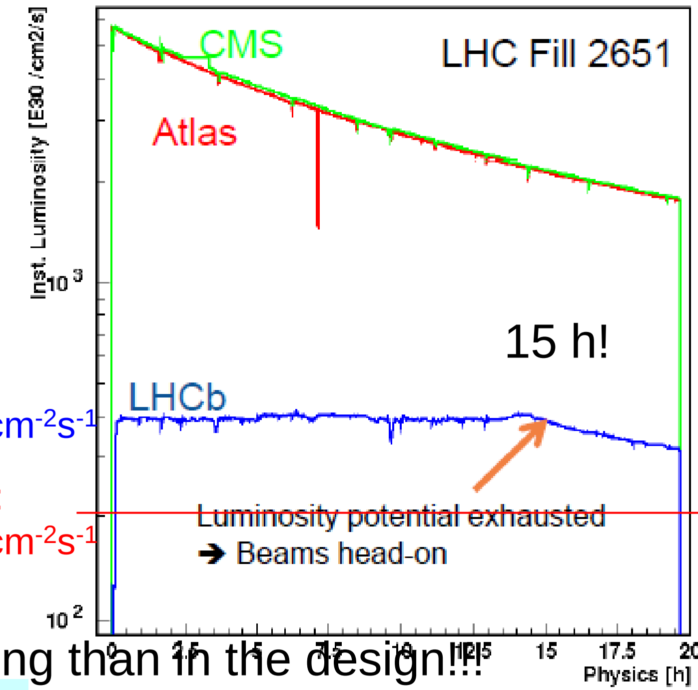
Detectors all with >~99% active channels

Semi-continuous (automatic) adjustment of offset of colliding beams allows luminosity to be *levelled*



$4\times10^{32}cm^{-2}s^{-1}$

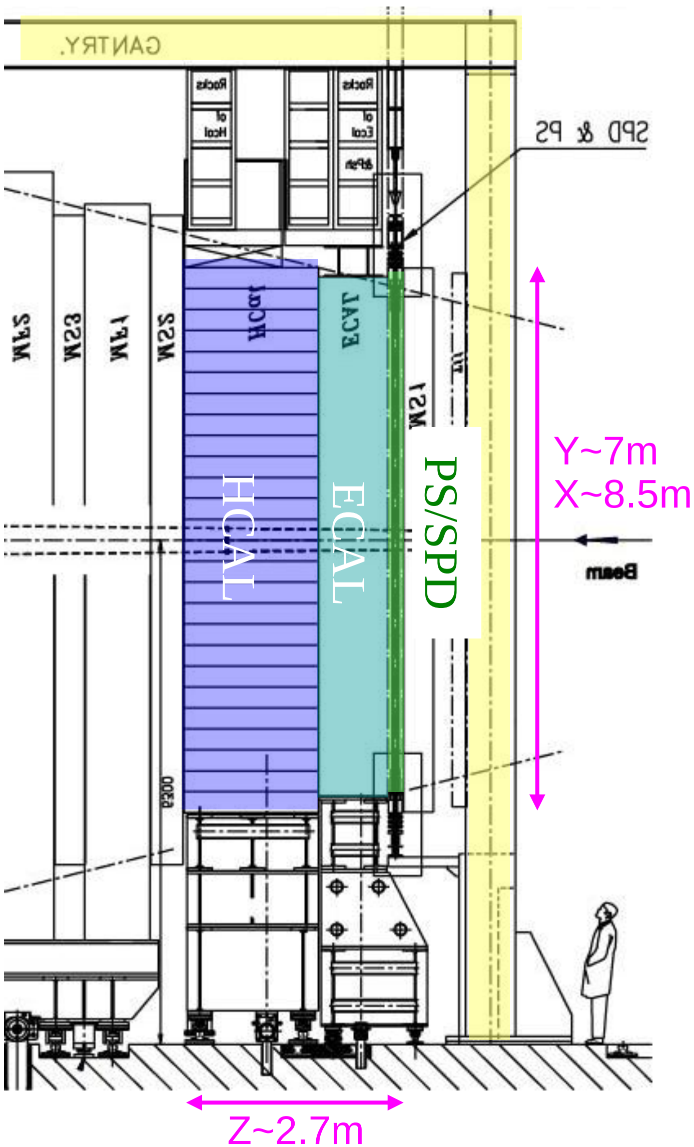
Design: $2\times10^{32}cm^{-2}s^{-1}$



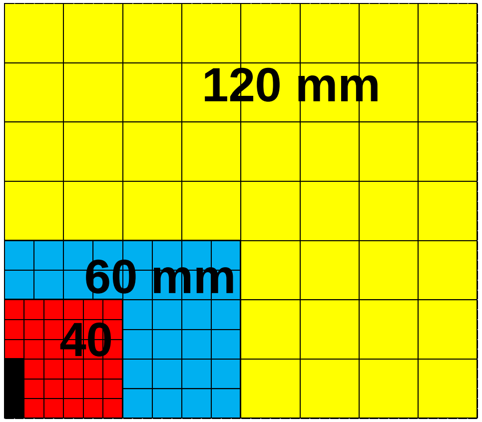
4 times more collisions per crossing than in the design!!!

THE LHCB CALORIMETERS

LHCb Calorimeter System

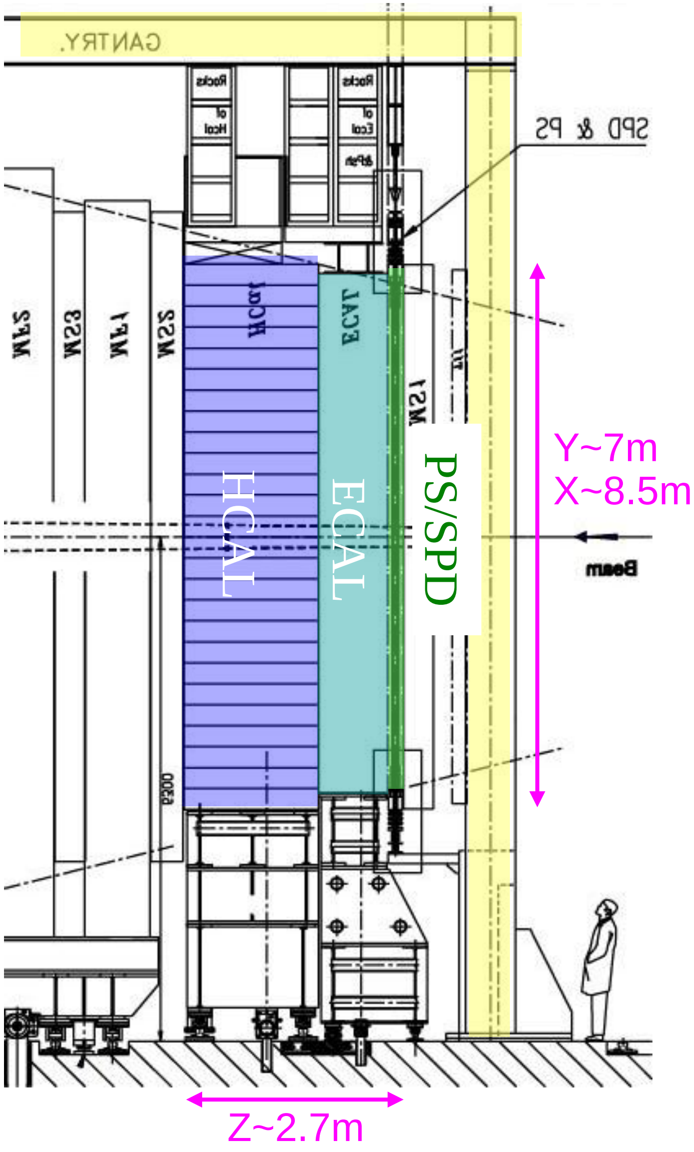


- 40 MHz trigger on energetic e, π^0, γ, h
- Distance to i.p. ~13 m
- Solid angle coverage 300x250 mrad
- Four sub-detectors: SPD,PS,ECAL,HCAL
  - Independently retractable halves
- Granularity:
  - SPD, PS, ECAL:
    - 6016 cells: 3 zones 4x4; 6x6 and 12x12 cm^2



  - HCAL: 1488 cells: 13x13 and 26x26 cm^2

LHCb Calorimeter System



- 40 MHz trigger on energetic e, π^0, γ, h
- Distance to i.p. ~13 m
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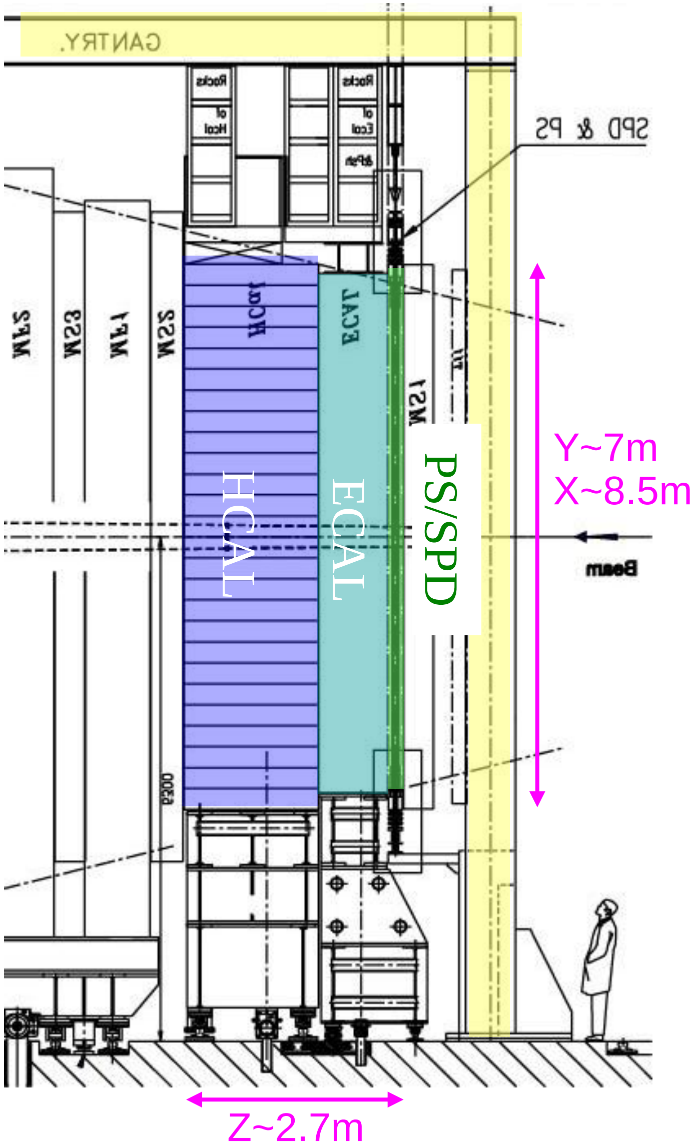
  - Independently retractable halves
- Granularity:
  - SPD, PS, ECAL:
    - 6016 cells: 3 zones 4x4; 6x6 and 12x12 cm^2
  - HCAL: 1488 cells: 13x13 and 26x26 cm^2
- Detection
  - Sandwich of scintillator/lead (iron for HCAL)
  - WLS fibres are used to collect the light read out thanks to photomultipliers (PMT)
    - Multianode PMT (64) for SPD & PS
  - Cost effective

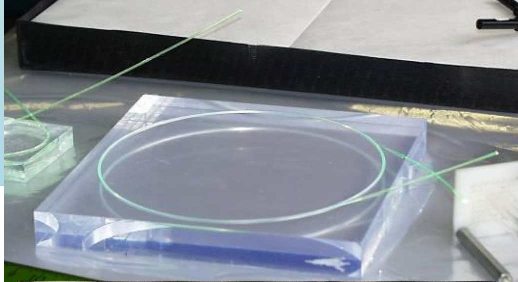
SPD & PS

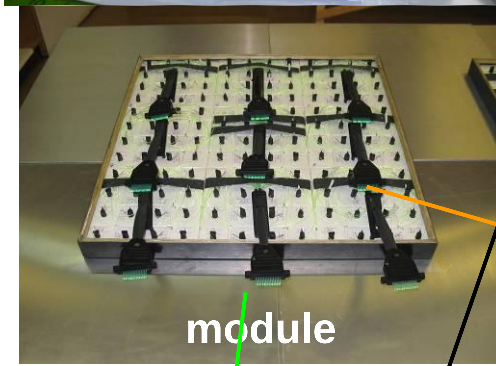


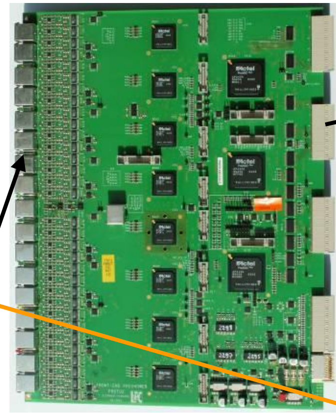
- Scintillator Pad Detector (SPD) and Preshower (PS) :
  - Particle ID for L0 electron and photon trigger
  - electron, photon/pion separation by PS
  - photon/MIP separation by SPD
  - Charged multiplicity by SPD
  - Scintillator Pad – 2.5X_0 lead – Scintillator Pad
    - 15/15/15 mm thick;
    - WLS fibres are used to collect the light

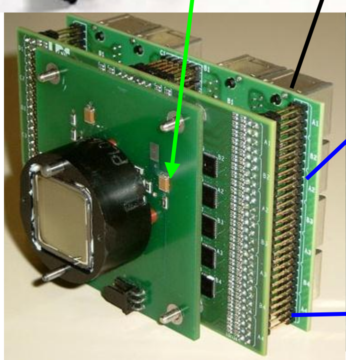
The Preshower

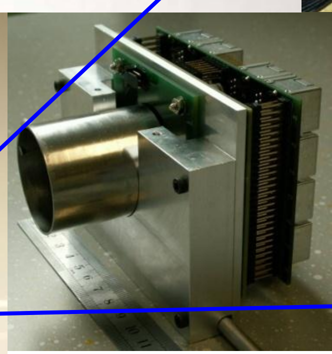
6016 cells
5x100 boards

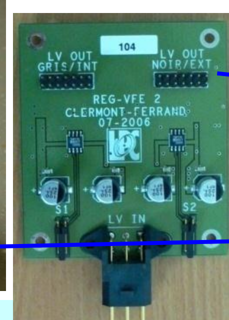


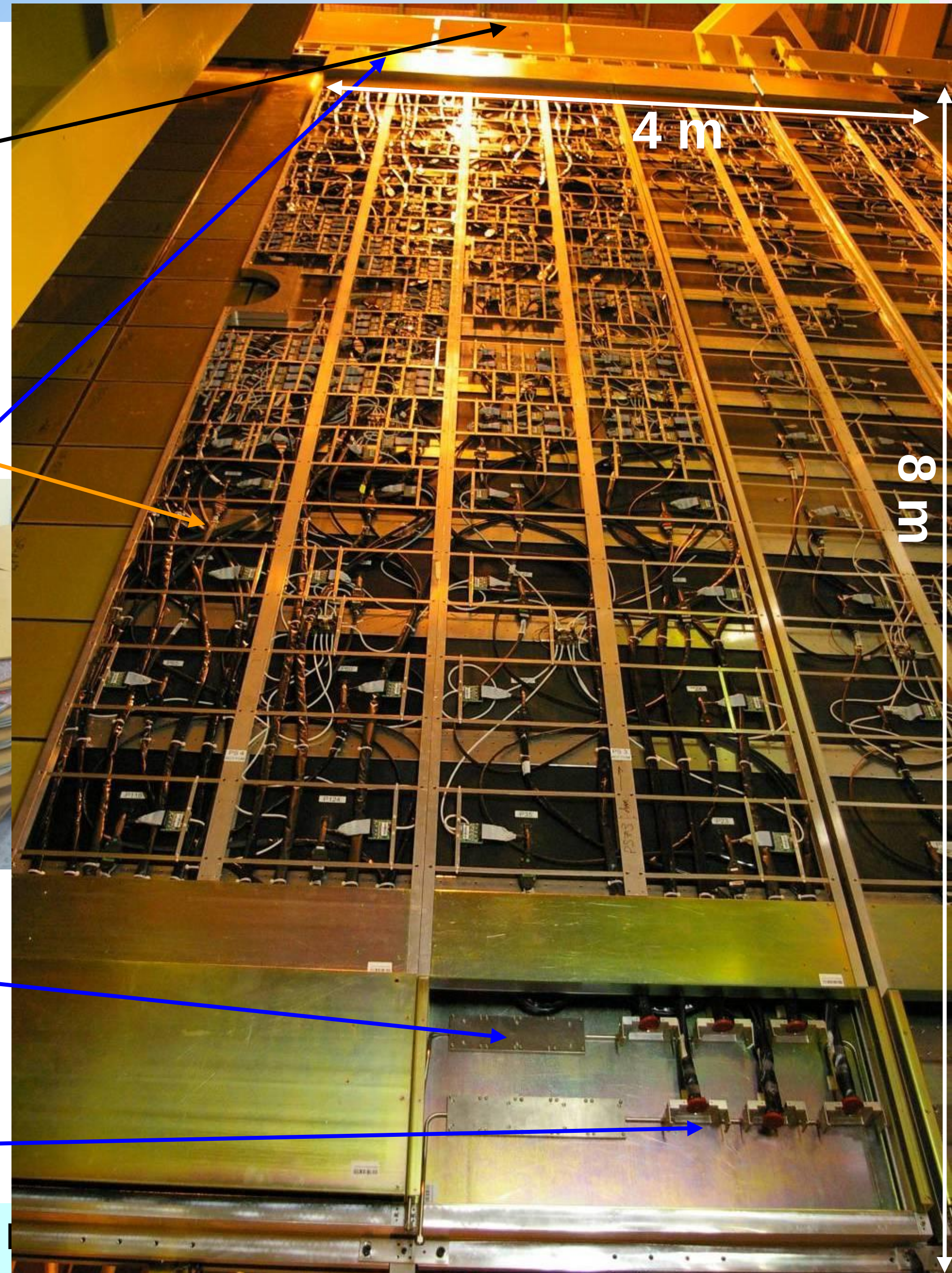






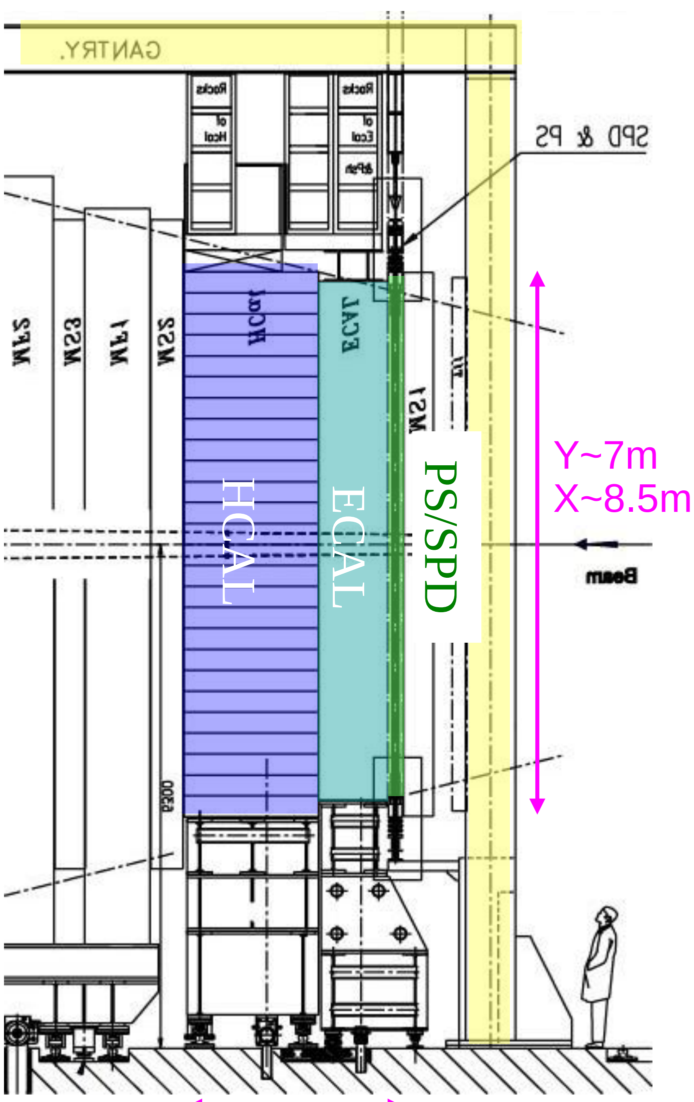






+ Services

ECAL

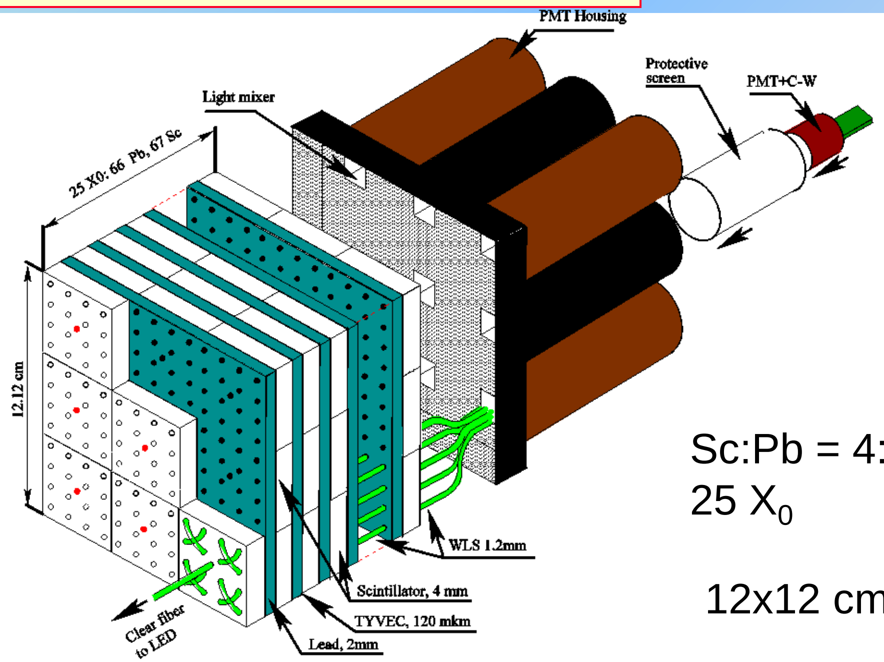


- Electromagnetic Calorimeter (ECAL):
  - E_T of electrons, photons and π^0 for L0 trigger ($B_d \rightarrow K^* ee$, $B^0 \rightarrow K^* \gamma$, etc.)
  - Reconstruction of π^0 and prompt γ offline
  - Particle ID

  - 66 layers of 2mm Pb/ 4mm scintillator
  - Light collected through WLS fibres bunch
    - Moliere radius: 3.5 cm
    - Longitudinal size: $25X_0$, 1.1 λ_I,
    - Dynamic range: 10 ÷ 12 GeV of transverse energy (E(max, GeV)=7 + 10 /sin(θ))
    - Energy resolution (beam tests)
      $\sigma(E)/E = (8 \div 10)\% / \sqrt{E} \oplus 0.9\%$

ECAL

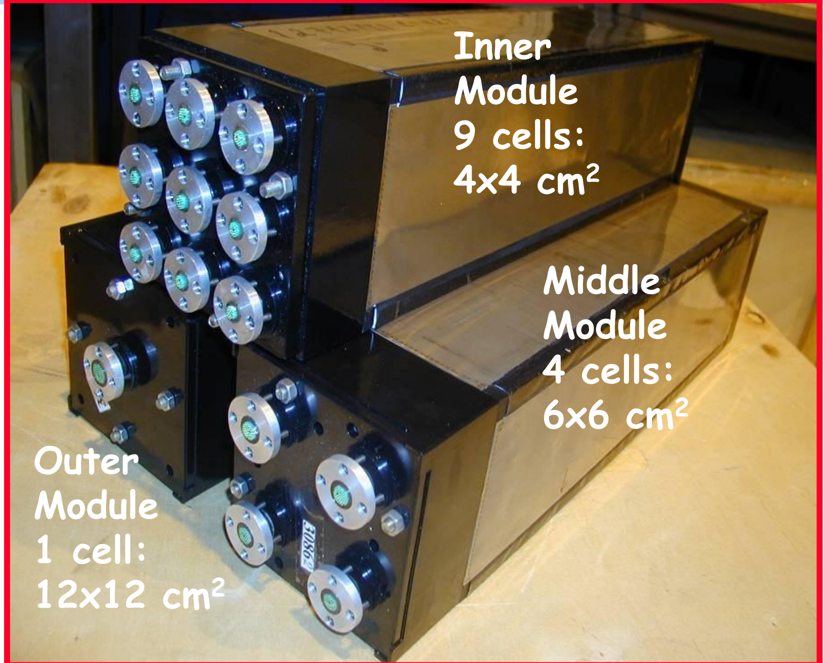
ECAL Shashlik modules



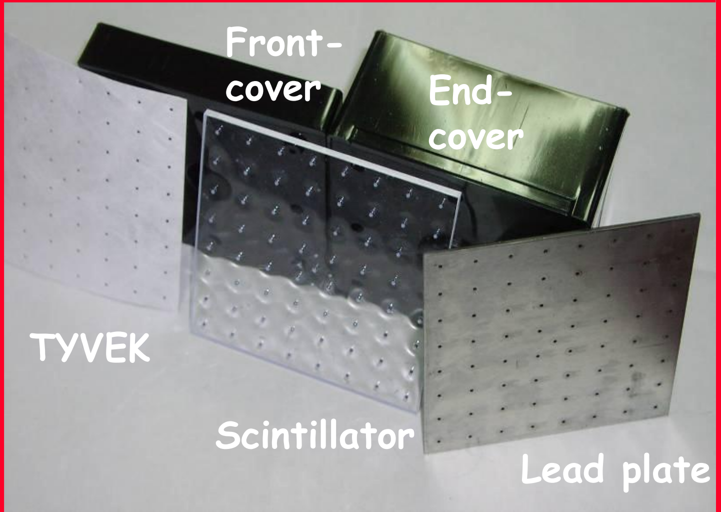
Sc:Pb = 4:2 mm
25 X_0

12x12 cm^2

3312 shashlik modules with 25 X_0 Pb

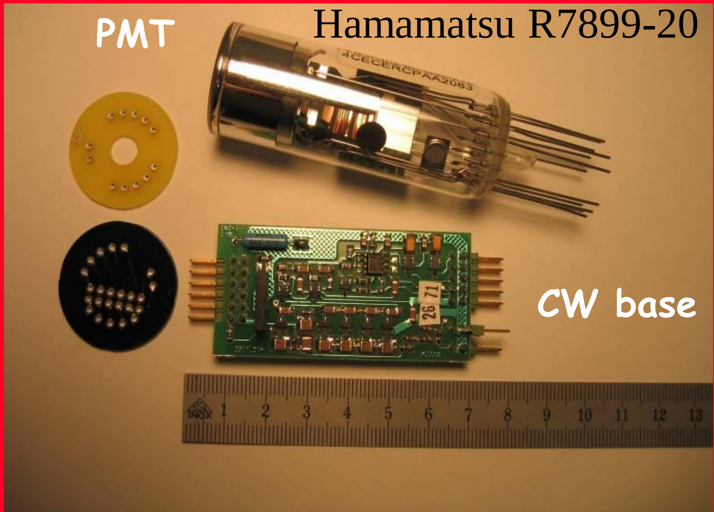


Scintillators, lead-plates, covers

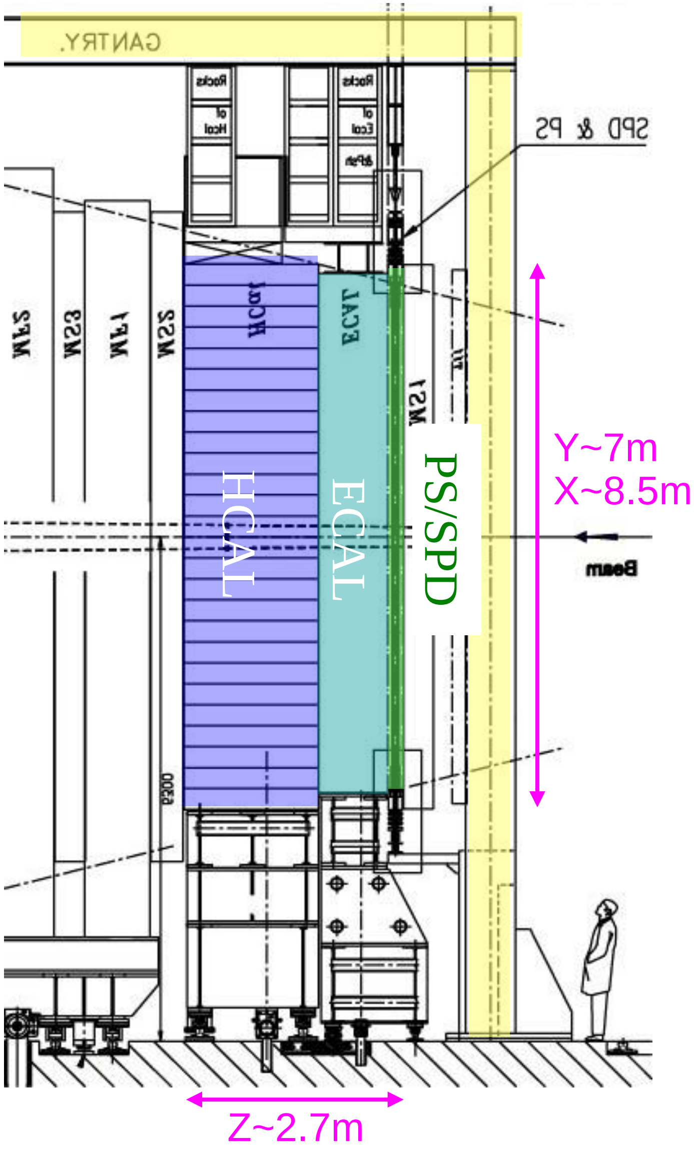


Fibres with loops

PMT and CW base



HCAL



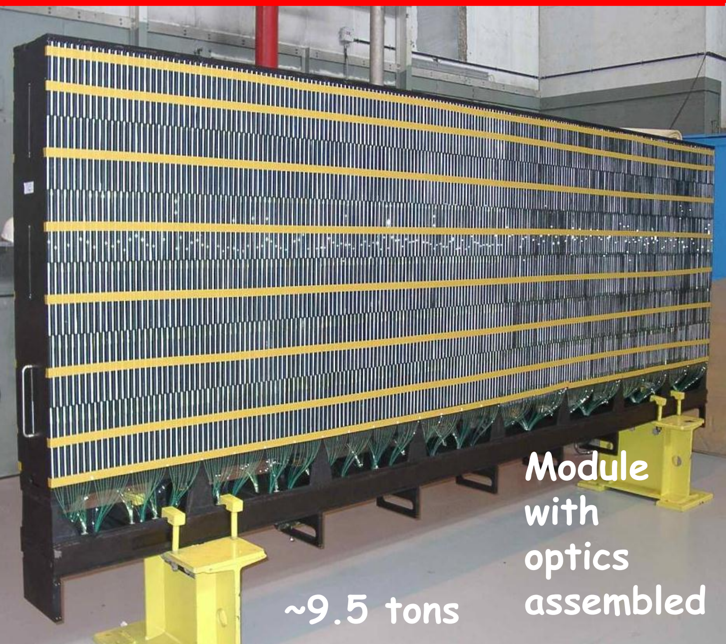
- Hadronic Calorimeter (HCAL):
  - E_T of hadrons, ΣE_T for L0 trigger
    - ~ 500 kHz (out of ~1 MHz)
  - 26x2 horizontal modules
    - The same design as in ATLAS TileCal
    - interleaving Sc tiles and iron plates parallel to the beam axis. Volume ratio Fe:Sc = 5.58:1
    - Longitudinal size: 5.6 λ_I
      - Mostly used as a trigger device!
    - Dynamic range: 15 GeV of E_T (now 30 GeV)
    - Energy resolution (beam tests)

      $\sigma(E)/E = (69 \pm 5)\% / \sqrt{E} \oplus (9 \pm 2)\%$

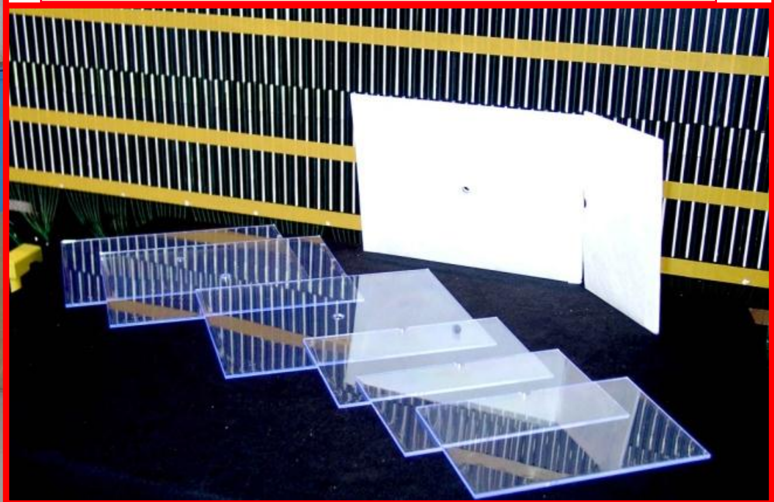
      moderate resolution is sufficient

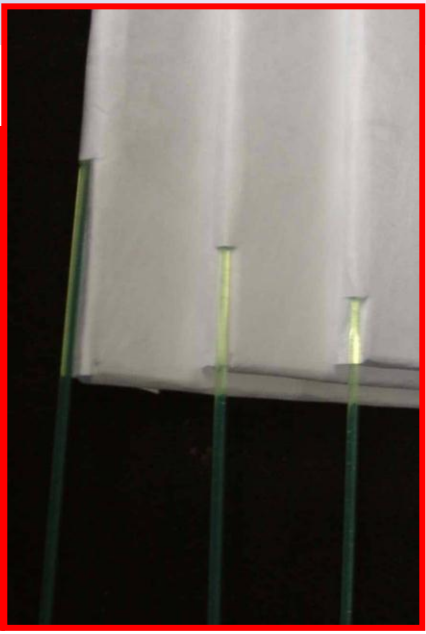
HCAL

52 modules with longitudinal tiles

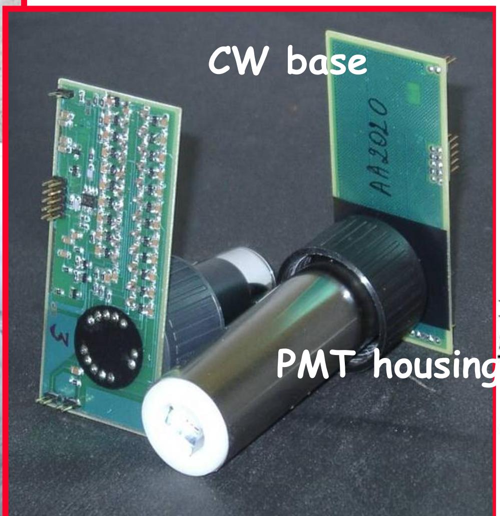


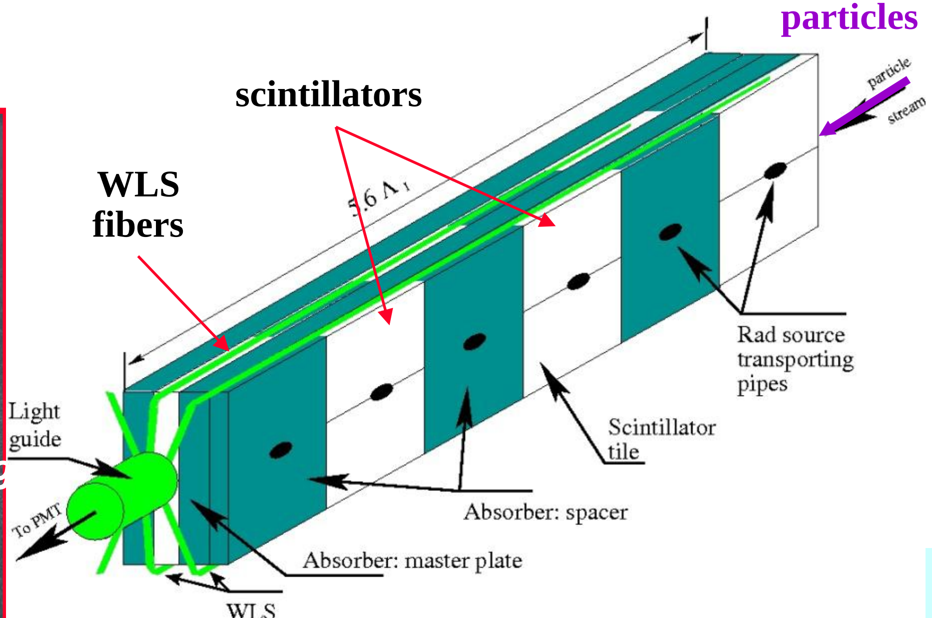
HCAL tile-cal modules





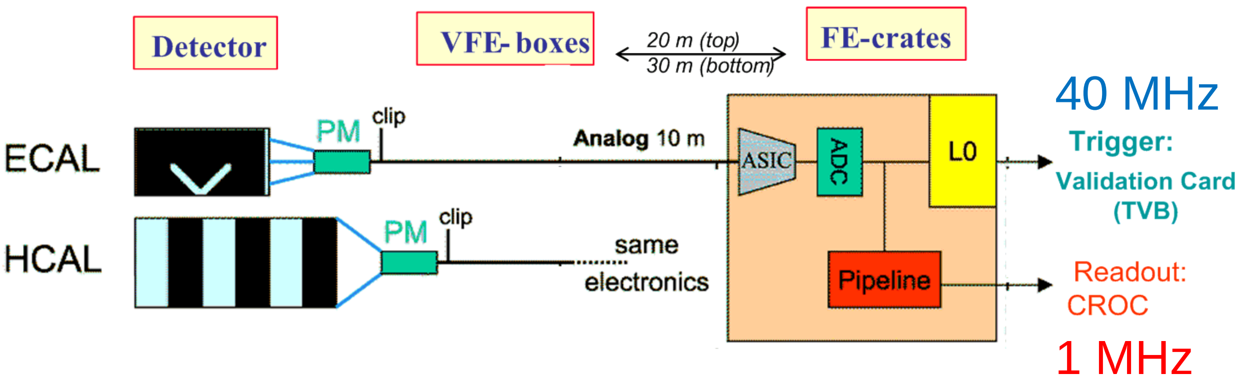
6mm master, 4mm spacer / 3mm scintillator

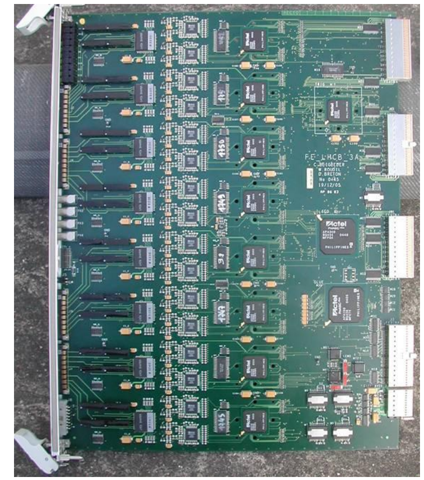




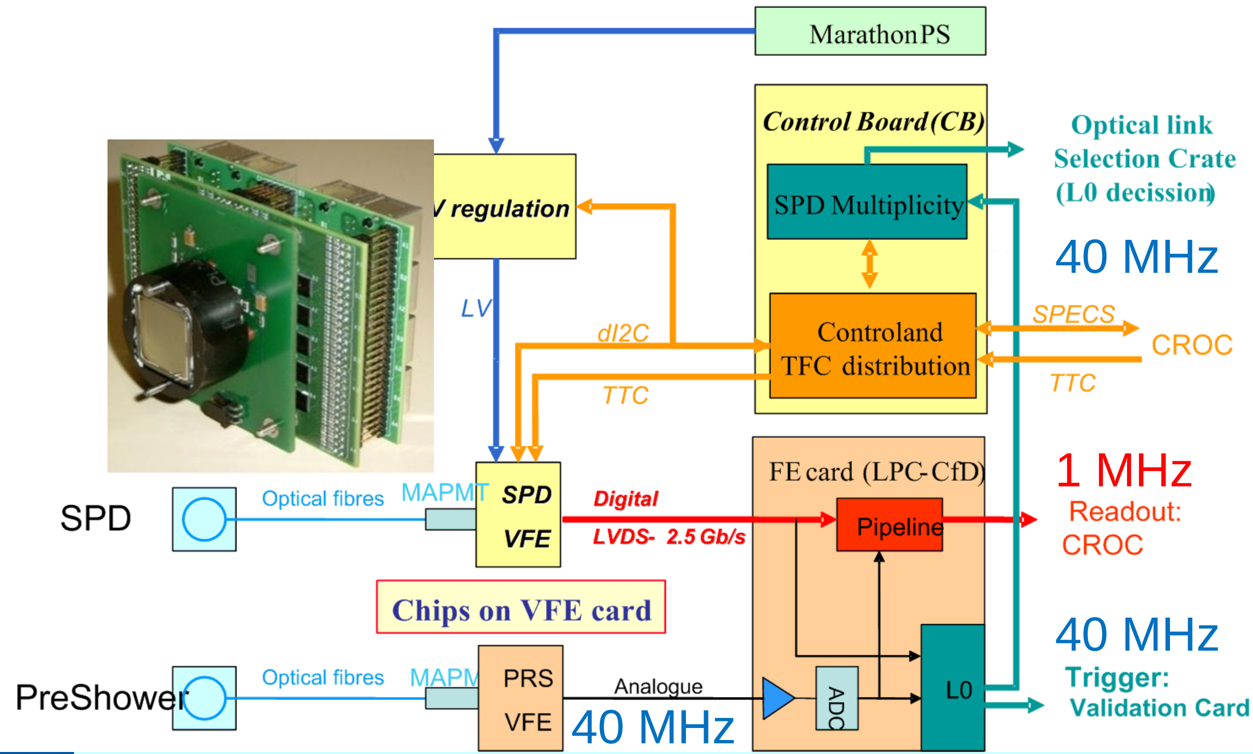
The readout system

192 ECAL FEB
54 HCAL FEB
12-bit ADC





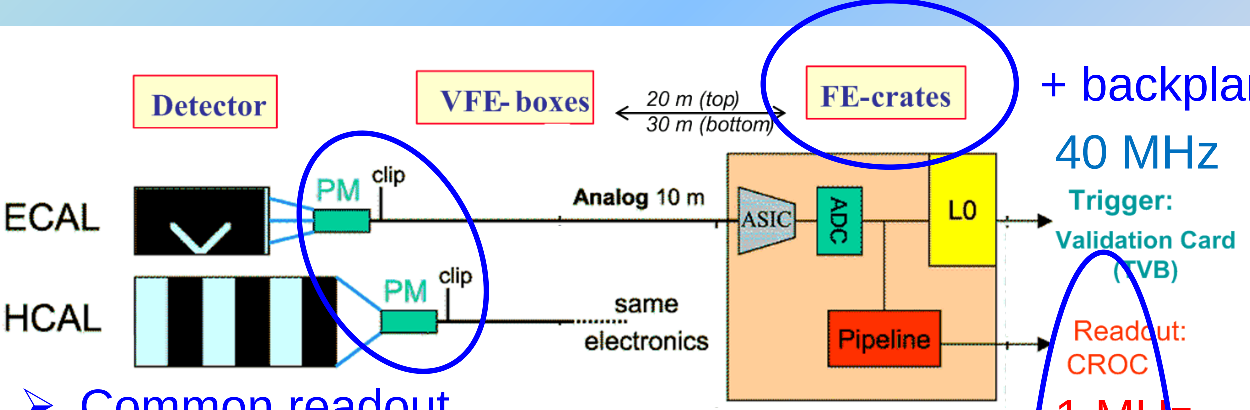
32 channels

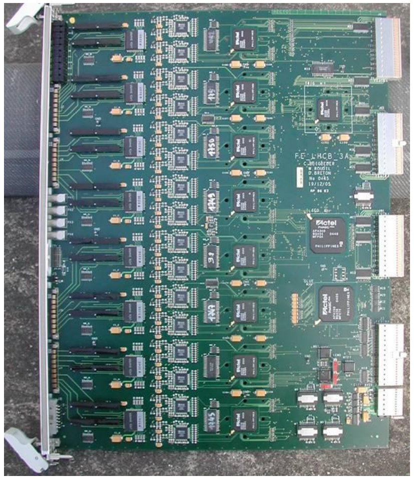


100 PS/SPD FEB
10-bit ADC

64 channels

The readout system

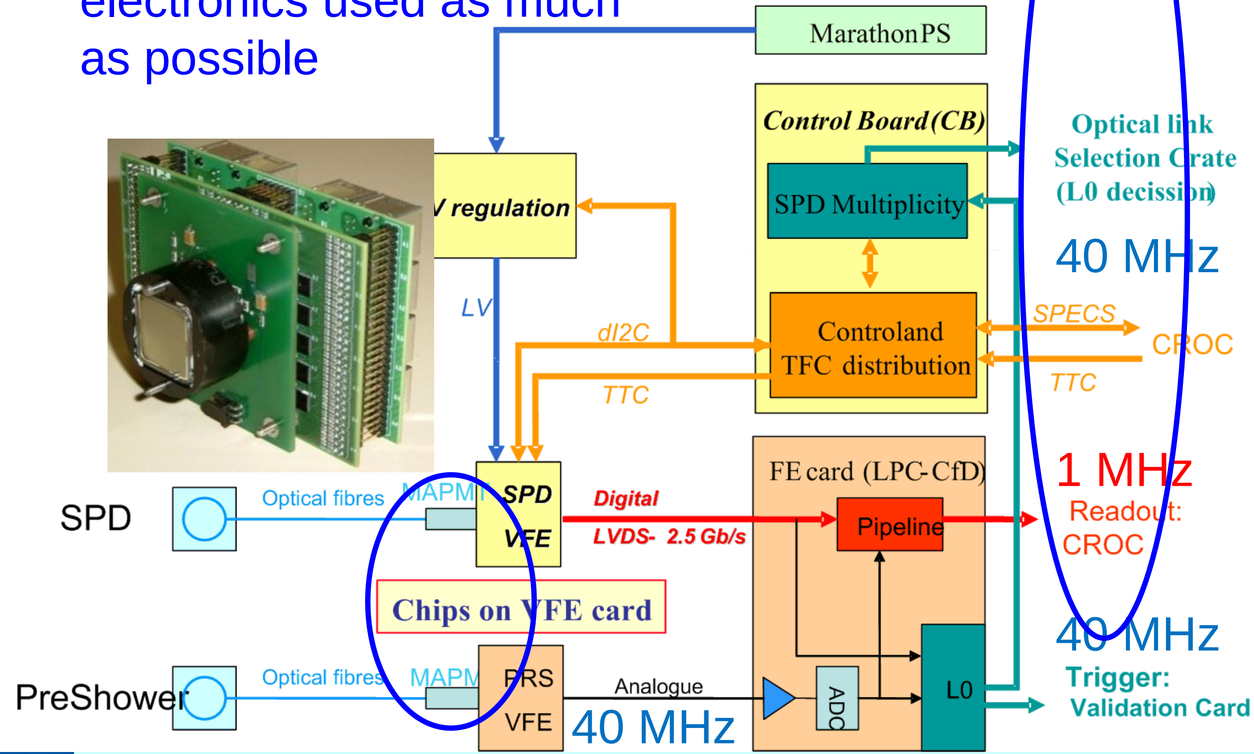




192 ECAL FEB
54 HCAL FEB
12-bit ADC

32 channels

- Common readout electronics used as much as possible



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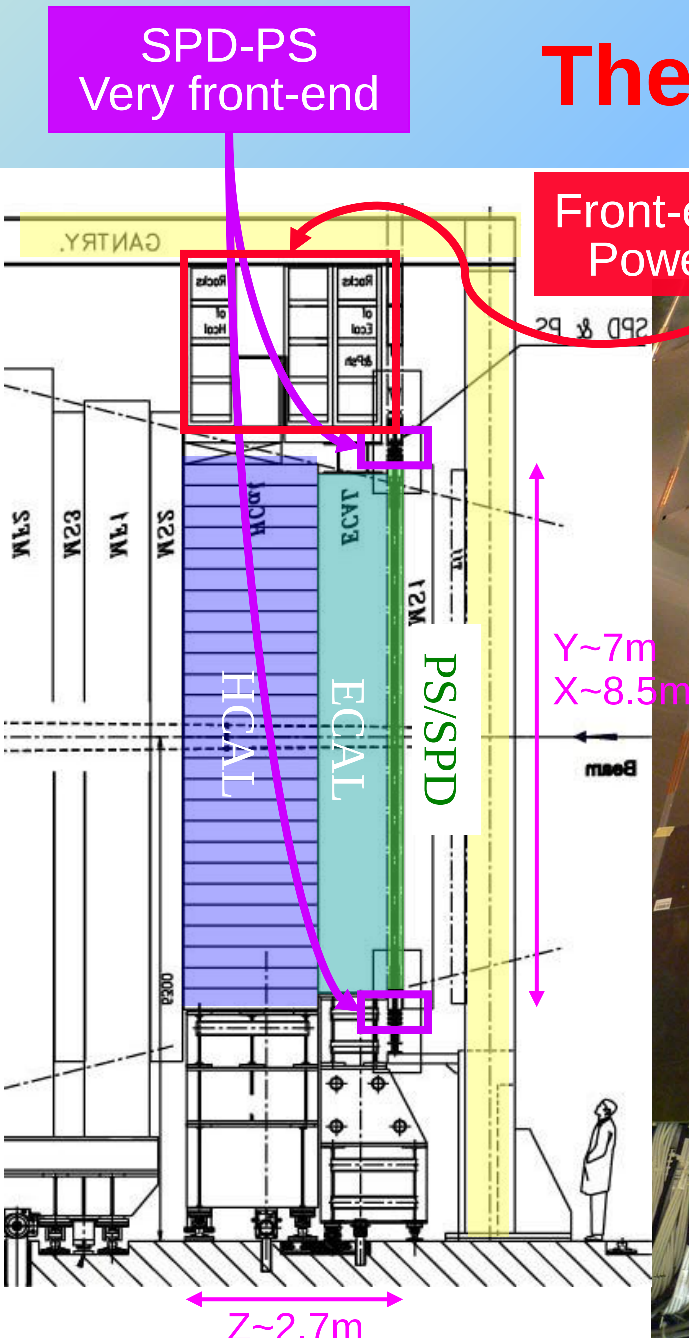
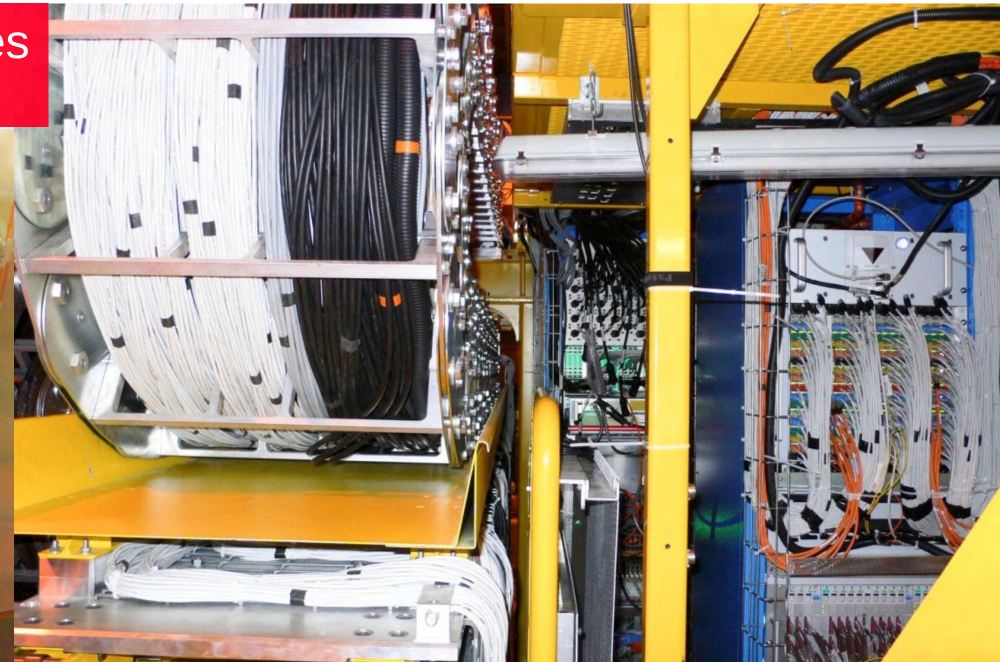
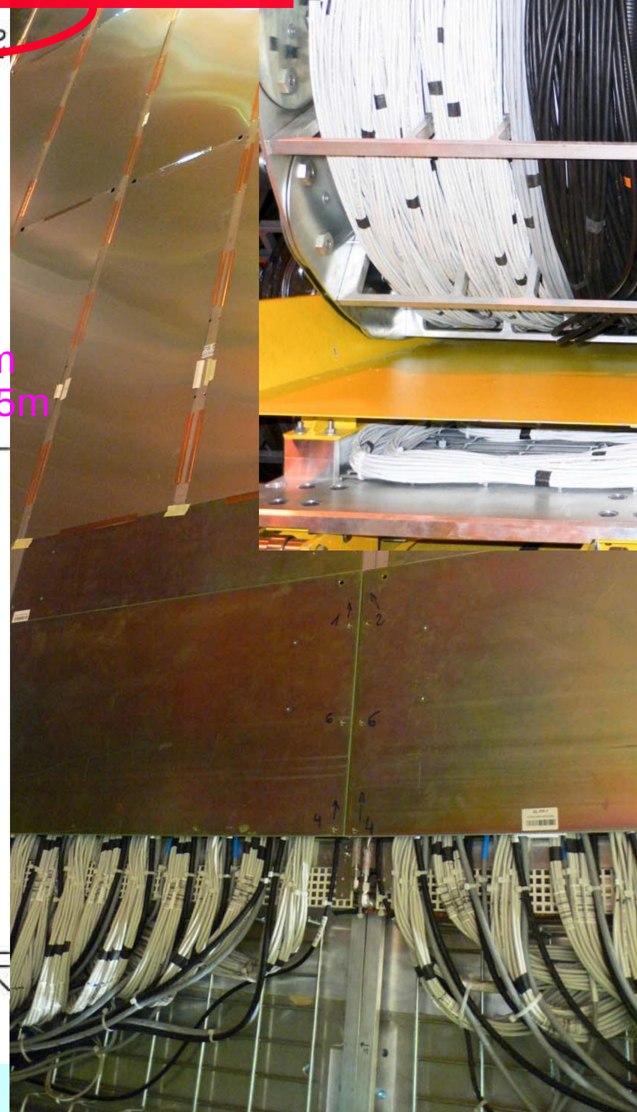
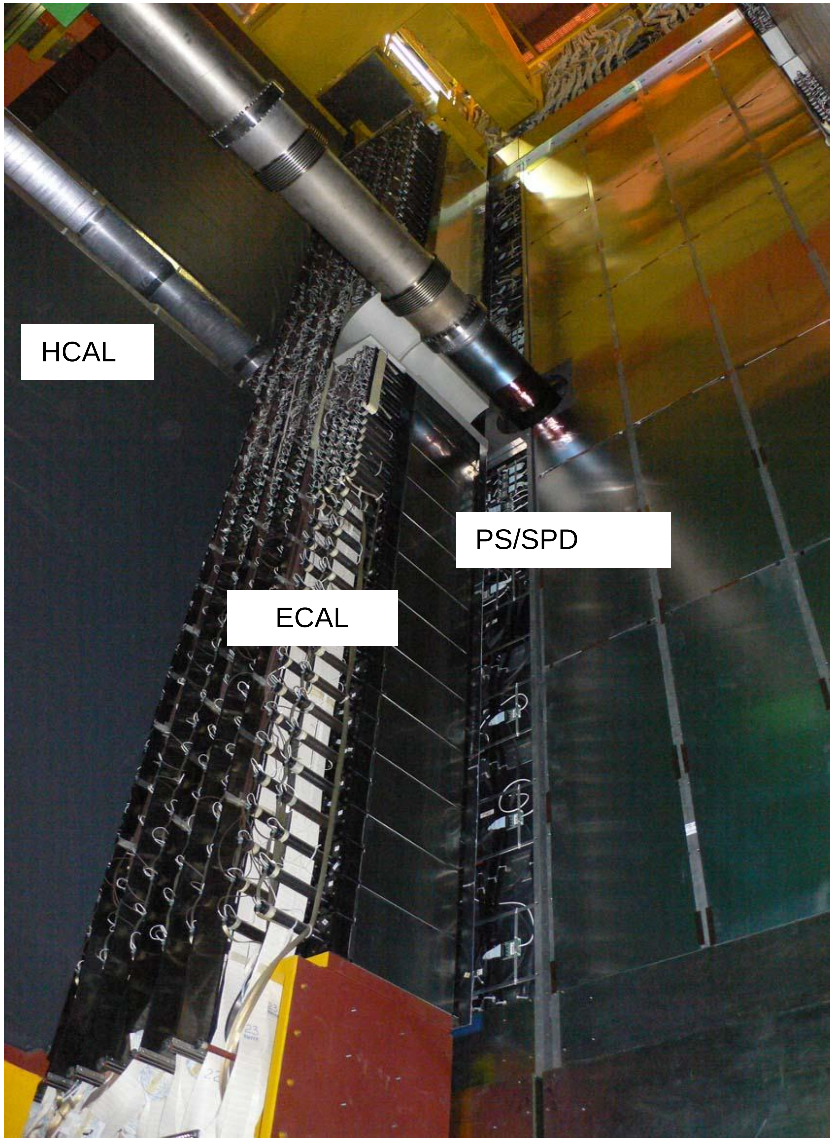






- In a same rack:
  - 1 PS crate
  - 2 ECAL crates
- ECAL/HCAL platforms moving with the detector
- Each ½ detector can be moved independly

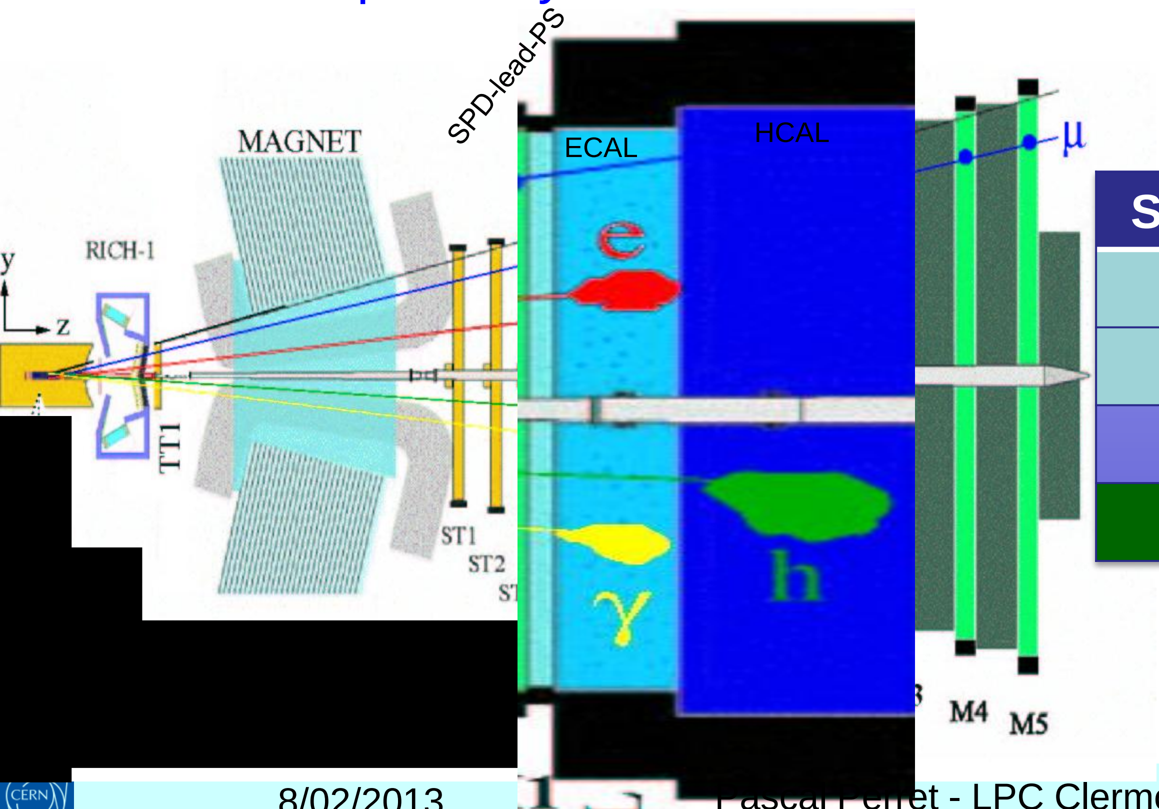
LHCb Calorimeter System



- Used to measure energy and to identify e, γ, π^0, h
  - at the fast Level-0 trigger (@40 MHz) to identify high E_T particles that could sign a B decay:
    - SPD/PS/ECAL/HCAL in coincidence

Electromagnetic Clusters

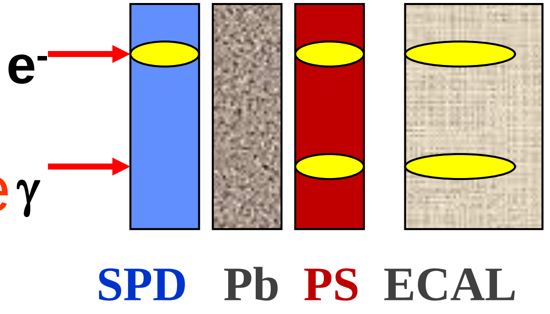
- Electromagnetic particles will deposit their energy inside ECAL
  - The energy deposit in PS is added (offline)
- Most of the energy contained in a quartet of cells
  - Cell size of inner part close to the "Moliere" radius:
- SPD & PS validate the charged and EM nature of incoming particle, respectively



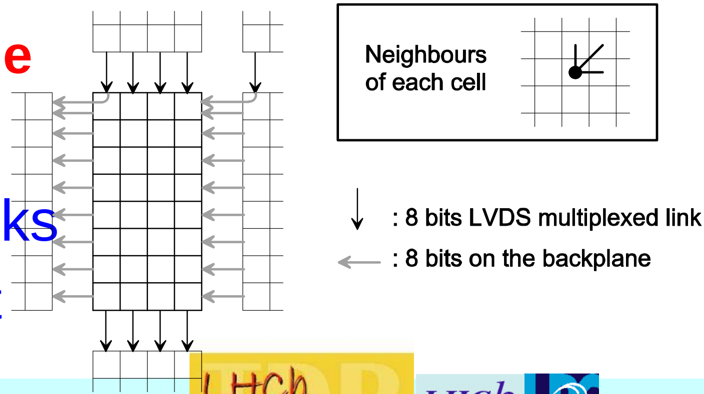
SPD	PS	ECAL	HCAL	
1	1	1	0	**e**
0	1	1	0	**γ**
1	0	0	1	**h**
1	0	0	0	**μ**

L0 CALO: Cluster Algorithm

- Detect a local high E_T cluster in ECAL (or HCAL)
  - Cluster = 2x2 cells
  - ECAL:
    - Validation by PS/SPD (same geometry) to get e and γ candidates
  - HCAL :
    - Add the ECAL E_T in front if available

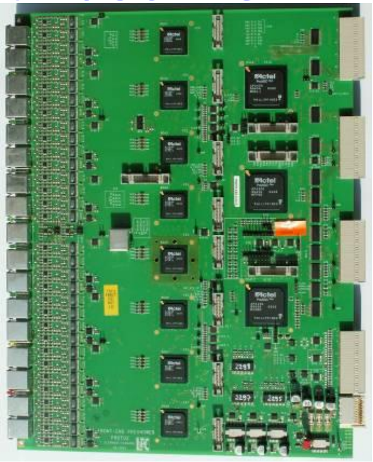


- Synchronous processing, integrated in the FE card to minimise the connections
  - Only the highest E_T candidate is searched for
    - Select locally as much as possible
    - **Access to neighbours is the key issue**
  - Easy on the same board
  - Dedicated backplane for most of the links
    - Short (2-10 m) LVDS cables for the rest



Hardware implementation

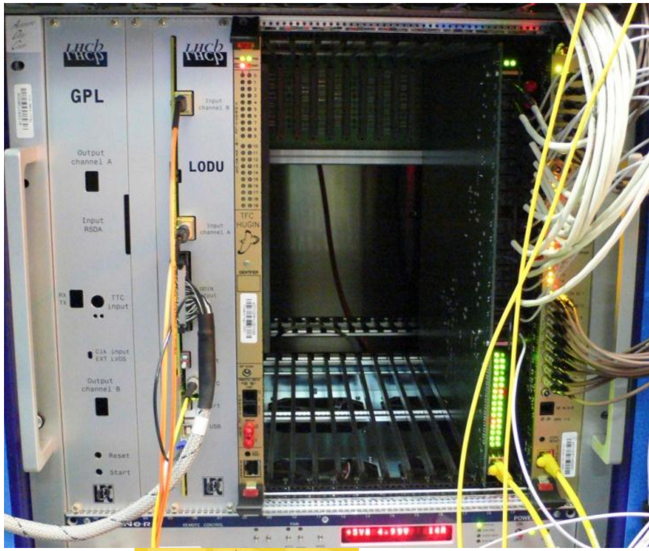
- Mostly on top of the calorimeter
  - Radiation (<10 Gy/year) and SEU impose to use anti-fuse PGA and triple voting techniques
- First step is integrated in the FE cards
  - Calorimeter FE card for cluster search
  - Preshower FE card for access to SPD/Preshower
    - Only one extra PGA on each card
  - Dedicated backplane for as many links as possible



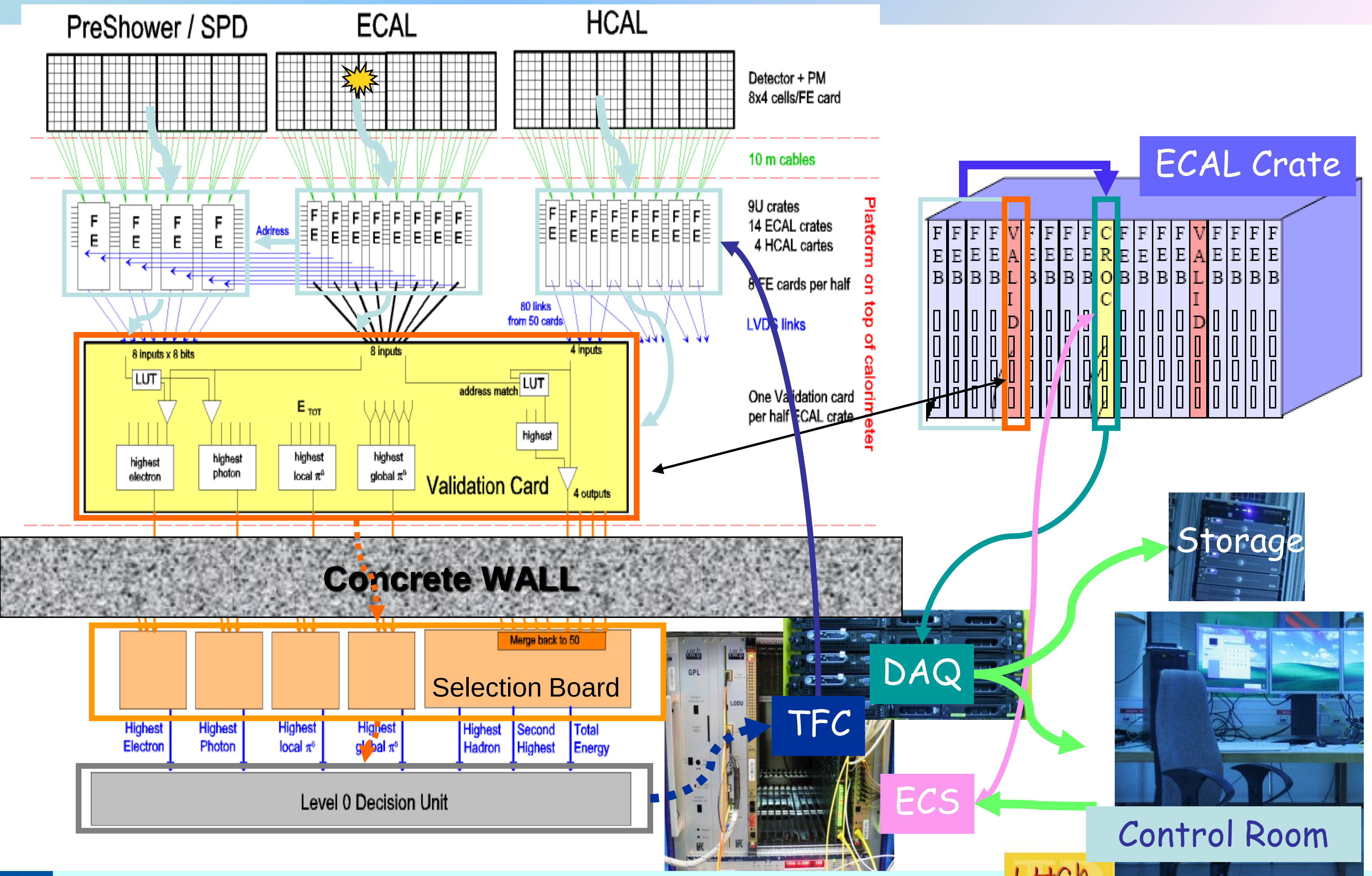
- Two Validation cards in each ECAL crate
  - To combine the various information, and reduce the number of candidates *(ECAL+HCAL sum done, the highest sum sent to the SB)*
  - 28 cards needed
- About 200 optical links
  - To send the candidates for final processing in the barracks

Hardware implementation

- Selection Crate for final selection
  - Outputs only the best candidate (highest E_T) in each category
    - Electron, photon, π^0, hadron
  - Provide also global variables
    - *Total SPD multiplicity, to reject dirty events*
    - *Total E_T, to reject empty crossing (no interaction) that may be triggered by halo muon*
  - Eight identical boards needed, seven quantities sent to L0DU
- Level-0 Decision Unit (L0DU)
    - Apply thresholds on highest E_T and p_T
    - Combine information
    - Send decision to Time Fast Control (TFC)
    - Send data to HLT and DAQ
- Fully synchronous system
    - Latency under control: 4 µs allowed



Hardware implementation

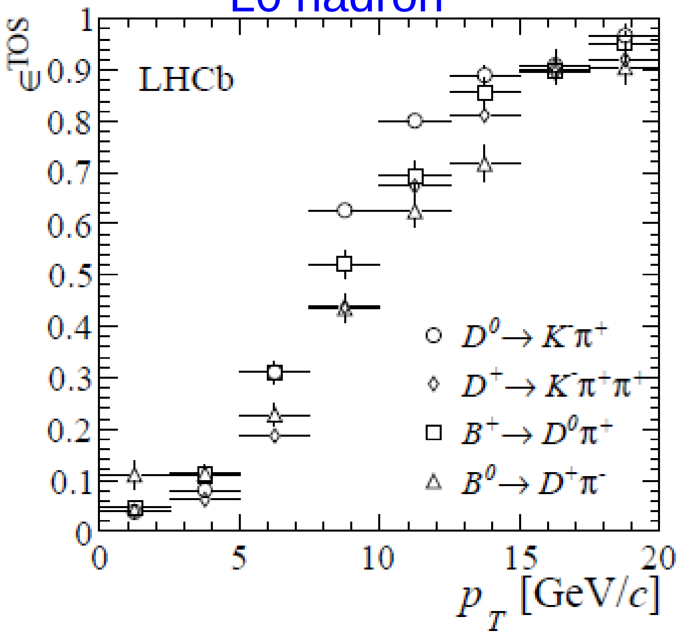


L0 CALO performances

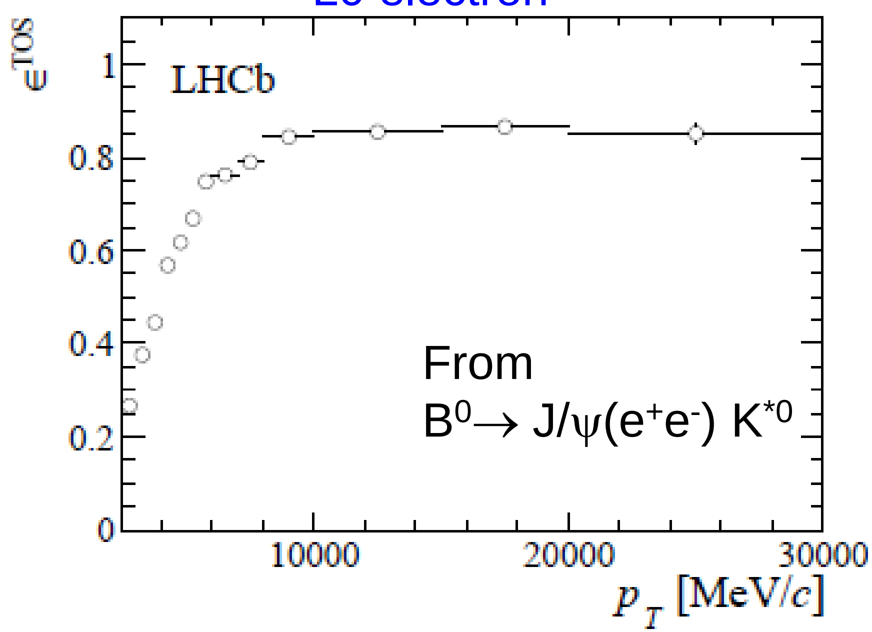
- Main L0 lines and rates used in 2011 (Σ=870 kHz): *[arXiv:1211.3055]*

L0 lines	Threshold	SPD mult.	Rate
L0Hadron	E_T>3.5 GeV	<600	405 kHz
L0Electron	E_T>2.5 GeV	<600	160 kHz
L0Photon	E_T>2.5 GeV	<600	80 kHz
L0Muon	p_T>1.48 GeV/c	<600	340 kHz
L0DiMuon	>1.30 GeV/c	<900	75 kHz

L0 hadron

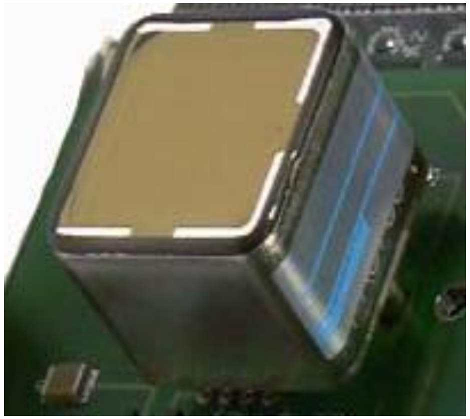


L0 electron

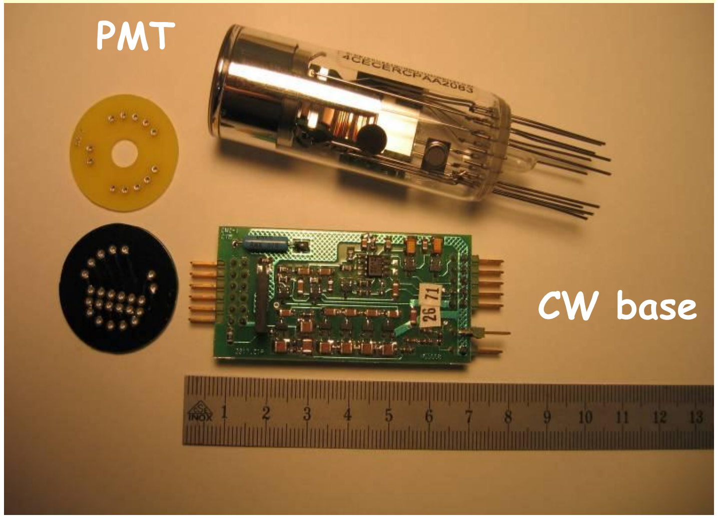


Photodetectors

- SPD/PS
  - 64-anodes PMT (Hamamatsu R7600)
    - Pixel size: 2x2 mm^2
  - Average light yield: ~20 p.e. /MIP
  - SPD: Mean HV~560V
  - PS: Mean HV~530V
- ECAL/HCAL
  - Hamamatsu R7899-20
  - ECAL
    - Average light yield:~3000 p.e./GeV
    - Mean HV ~760V
  - HCAL
    - Average light yield:~105 p.e./GeV
    - Mean HV ~1100V

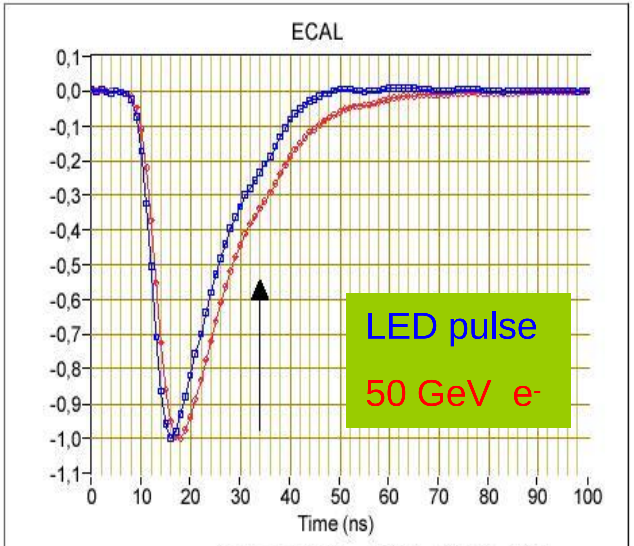


PMT and CW base



LED monitoring system

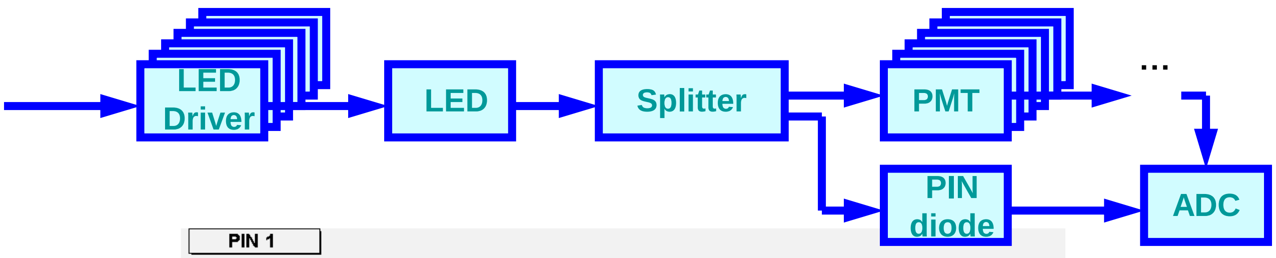
- Aim:
  - Check readout channels serviceability
  - Control the stability of r/o chains
- ECAL:
  - Small pulse duration and dispersion of amplitude
  - Adjustable pulse rate and amount of light
  - Emulate e/m particles in full “physics” region
  - Gain control to better than 1% accuracy
  - Control only electronics chain
    - supply LED light directly to the PMT
  - Use empty bunches for running monitoring system

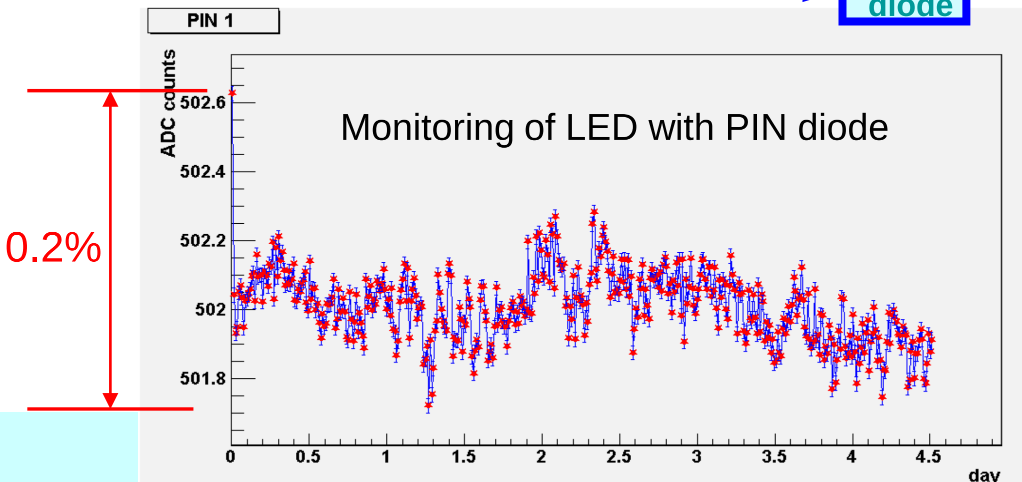


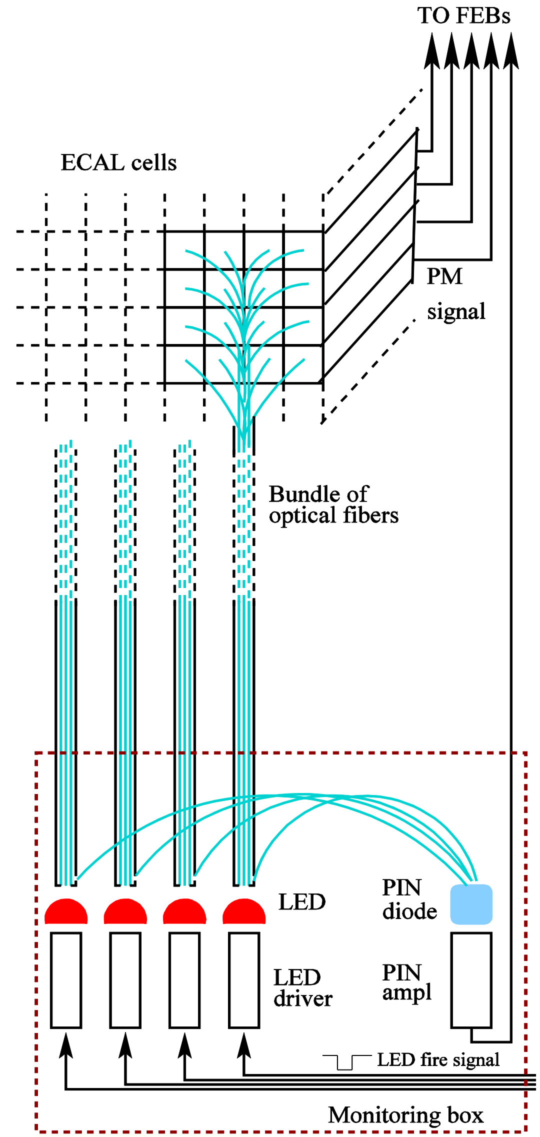
	Amplitude	rise time	fall time	Largeur	delay
LED pulse	-1,0000	5,10	20,66	13,62	11,96
50GeV electrons	-1,0000	5,58	25,04	15,74	12,71

LED monitoring system

- ECAL:
  - 512 LED drivers & LEDs & splitters & fiber-bundles
    - 1 LED illuminates a group of channels
      - 9 in the Inner, 16 in the Middle/Outer sections
  - Stability of LEDs themselves is traced by PIN photodiodes: 64 PIN-diodes

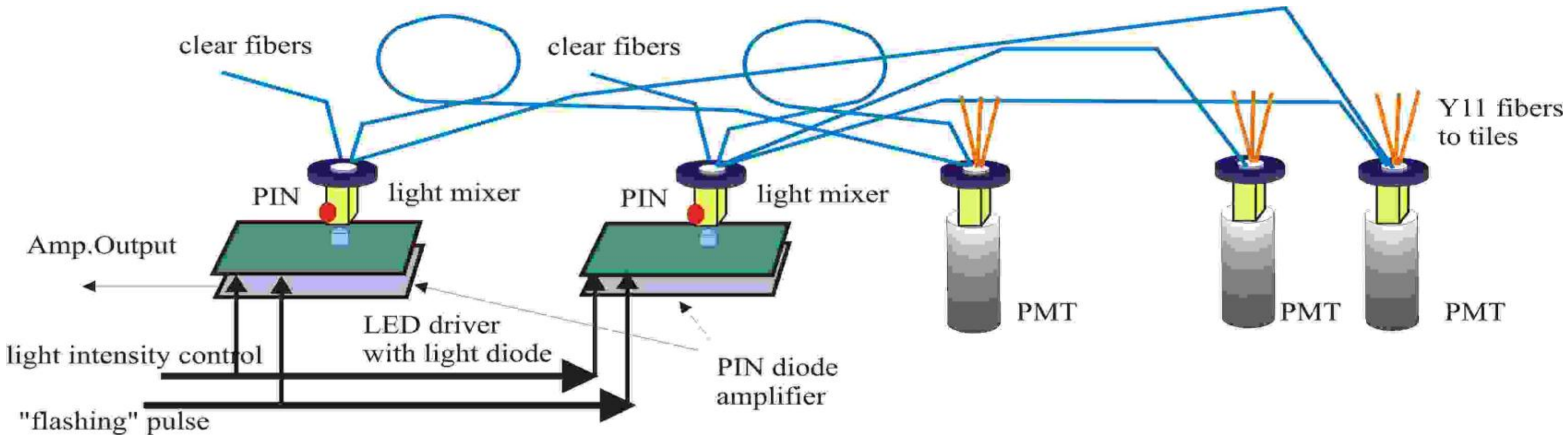




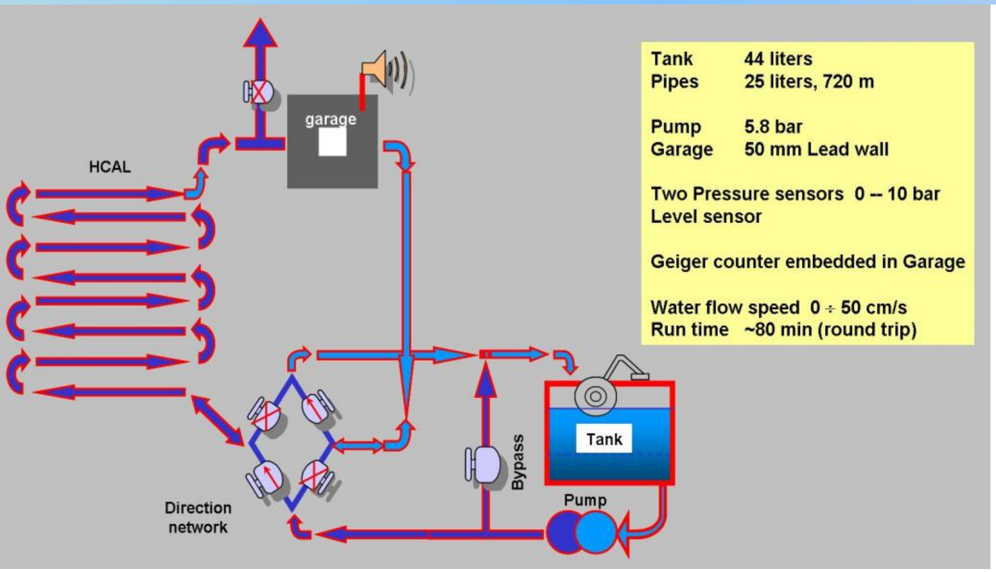


LED monitoring system

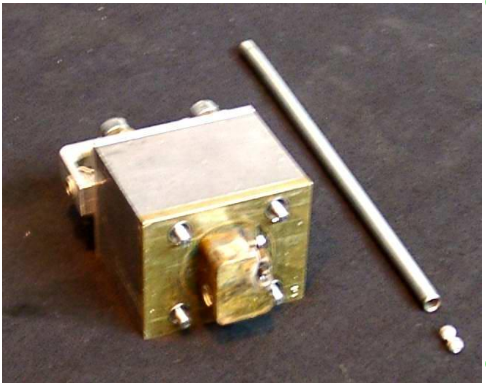
- HCAL
  - Two independent LEDs per module
    - Blue LEDs (WU-14-750BC)
  - Adjustable LED pulse amplitude
  - Monitoring PIN photodiode at each LED in order to account for LED instability
  - Light distribution with clear fibers of same length



Calibration system of HCAL



- Two ~ 10 mCi ^{137}Cs source used:
  - 1 per each detector half
  - Driven by hydraulic system
  - Similar to the ATLAS TileCal one
- Each source propagates consecutively through 26 HCAL modules with an average velocity of about 20–40 cm/s.



- System of dedicated integrators measures PM anode currents every 5 ms
  - Boards installed at the back of the HCAL nearby PMTs.
  - Readout via the slow control bus (SPECS)
    - Currents in HCAL cells are continuously monitored during physics data taking
- Absolute normalization ~10%, dominated by the uncertainty in the source activity
- Cell to cell intercalibration better than 4%
- Calibration done regularly

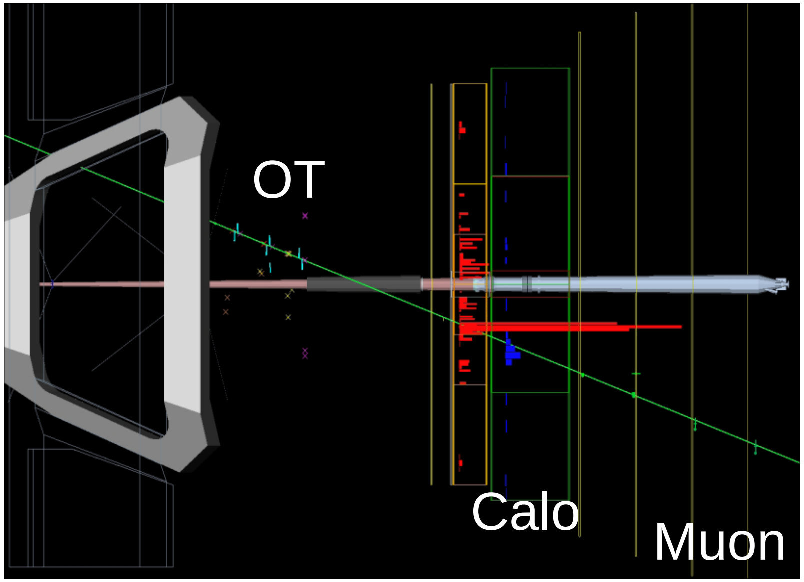
COMMISSIONING & OPERATION

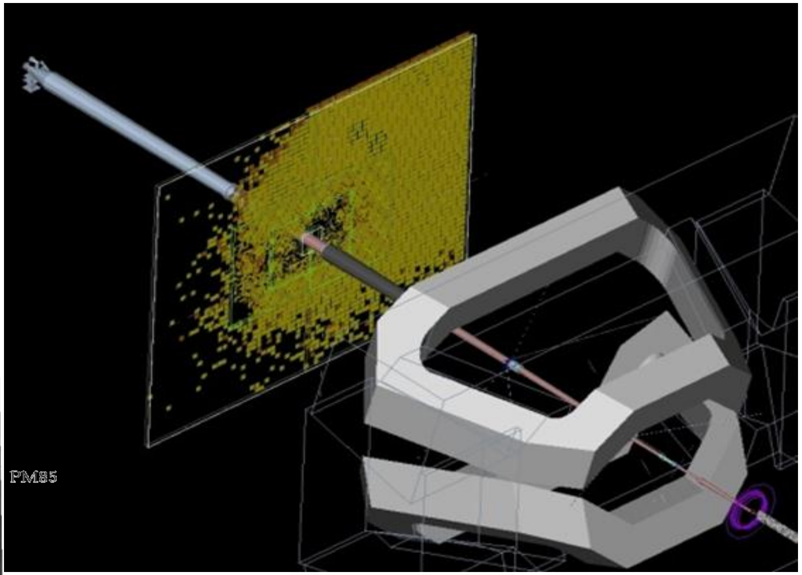
Commissioning & Operation

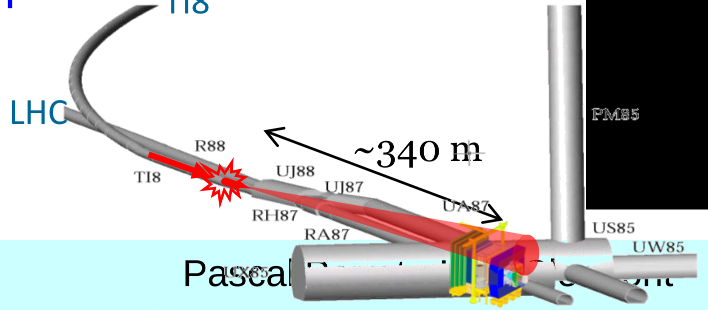
- Major issues
  - Time alignment
    - Internal alignment of each detector (individual channels)
    - Relative alignment of the calorimeter subdetectors with each other
    - Absolute alignment with LHCb and accelerator cycle
  - Calibration
    - Absolute calibration of detector response on the level of individual cells
  - Stability
    - Monitoring of the stability of calorimeters with LED / PIN systems
      - Done in parallel with data taking:
      - LEDs are fired synchronously with one of “empty” bunches with frequency ~50 Hz

Commissioning & Operation

- The tools
  - LED system + Cs source for HCAL
  - Cosmic rays
    - Few Hz of “horizontal” cosmic tracks: O(M) events
    - Cosmics come from top
      - Slope gives direction, and then time-of-flight corrections
  - LHC injection events
    - Transfer line External beam Dump (TED)
      - Shots every 48 seconds
        - ~10 particles/cm^2
  - Collisions







Time alignment

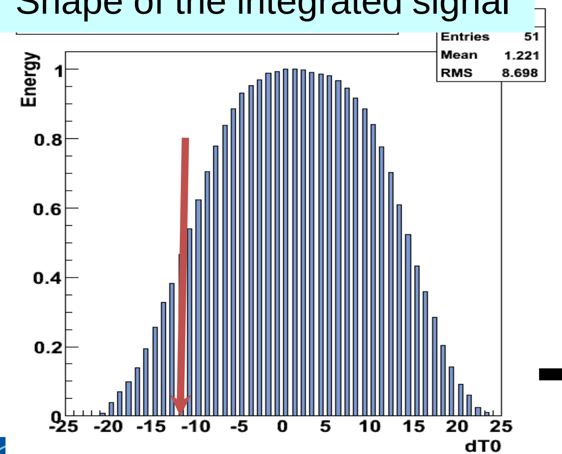
- ECAL/HCAL (essentially same method for SPD/PS)
  - Pulse shape known

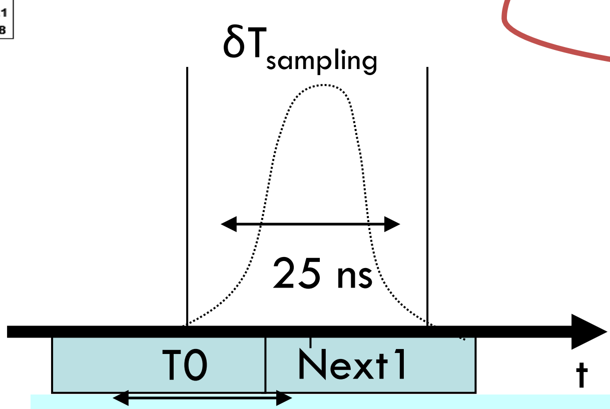
    [JINST 7 (2012) P08020]
  - LHCb DAQ may be configured to perform the acquisition of up to 7 successive events around the collision (TAE)
  - Extract time of crossing particle from Asymmetry between current and next signal amplitude
    - Best timing sensitivity obtained when half-detector shifted by 12.5 ns
  - Precision achieved <1 ns

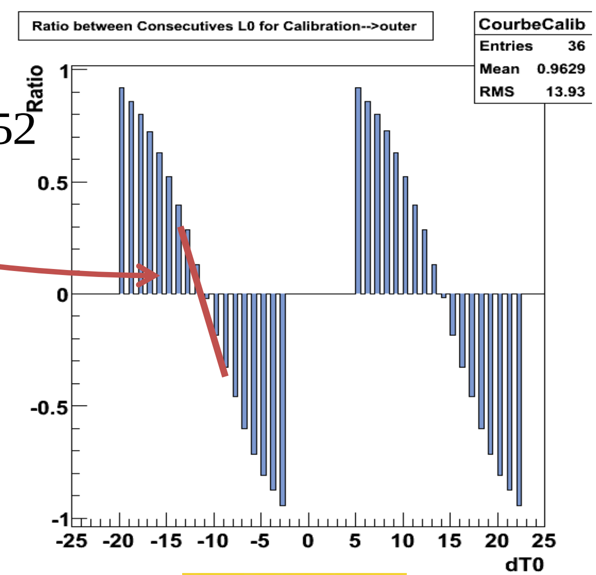
$$Rj = \frac{\sum_i^{Nevt} E_{ij}(Current) - \sum_i^{Nevt} E_{ij}(Next)}{\sum_i^{Nevt} E_{ij}(Current) + \sum_i^{Nevt} E_{ij}(Next)}$$

$$R = -0.121 dT + 1.52$$

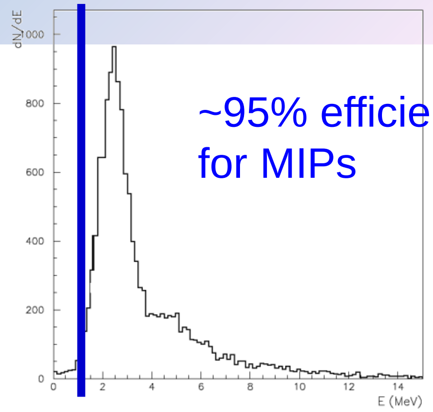
Shape of the integrated signal







Calibration

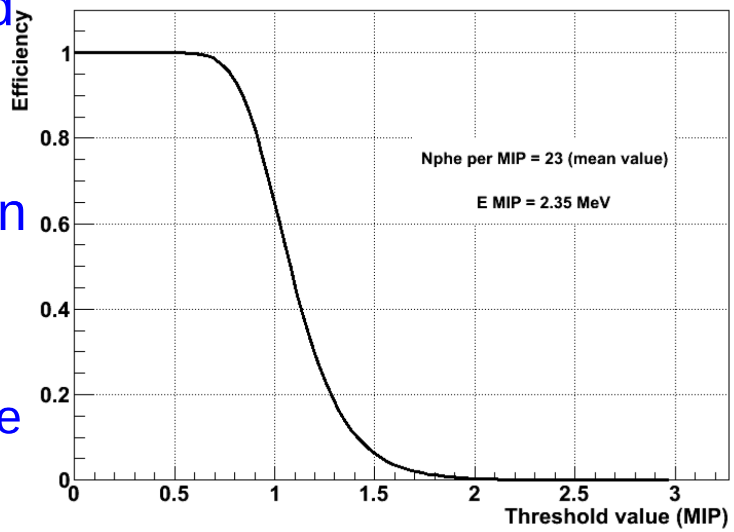


- SPD/PS
  - SPD: threshold set at ~0.5 MIP
  - PS: MIP signal set at ~10 ADC count
  - Fit the MIP signal and look for efficiencies
- ECAL/HCAL
  - HV are set so that the PMT response is the same over the entire detector for the same E_T
    - $E_T = E \sin\theta$ where θ is the angle between the beam and the line from the collision point to the position of the cell.
      - *$E_T \neq p_T$ for charged tracks because of the bending of the magnet, and the relation between E_T and p_T depends on the charge of the track and on the magnet polarity*.
  - ECAL: LED system, Fit π^0 mass, E/p for electrons, etc.
  - HCAL: LED system, Radioactive ^{137}Cs source, E/p hadrons, etc.
- Two places to adjust the calibration:
  - Gain of the PMT,
  - Constants in the electronics.

SPD/PS calibration

- Performed first with cosmic rays then with collisions
  - SPD
    - Binary detector: no straight MIP calibration
    - Collect data at different thresholds and get efficiency to MIP by comparing with theoretical value
    - Provide a resolution in the MIP position smaller than 5%
      - limited by electronics

        (Electronic resolution for setting the value of the threshold value is 5% of E_{MIP})
      - ~10% achieved with cosmics



$$\varepsilon = \frac{\text{number of SPD hits}}{\text{number of tracks pointing at SPD cell}}$$

Theoretical efficiency

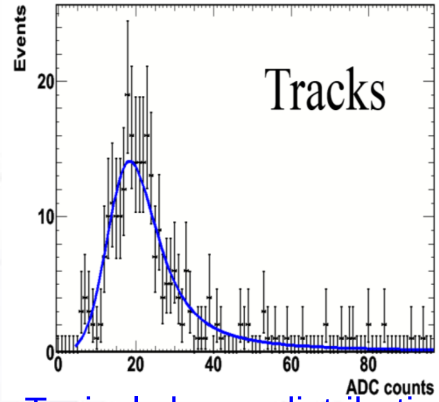
ε = Landau x Poisson

Energy loss

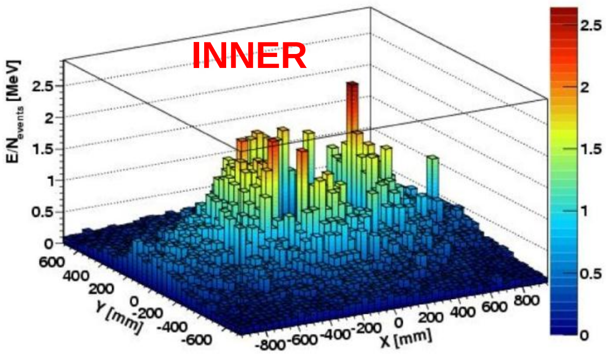
Fluctuations of nphe at photocathode.

SPD/PS calibration

- Performed first with cosmic rays then with collisions
  - PS
    - Use any reconstructed track which extrapolation hits the Preshower
    - MIP signal is fitted (Landau⊗Gauss) and fixed to a given number of ADC counts
      - ~5% precision level
    - Cross-check with Energy flow method
      - Smoothing of the local energy deposit
      - Average over neighbour channels
      - ~4% precision level



Typical charge distribution for extrapolated tracks



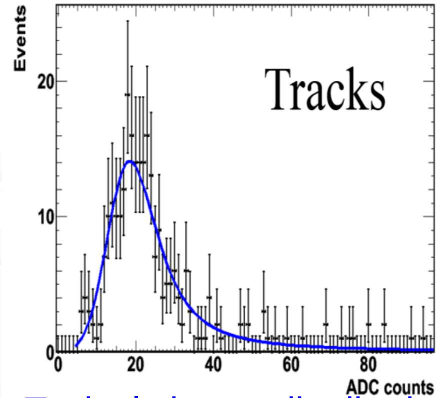
SPD/PS calibration

- Performed first with cosmic rays then with collisions
  - PS
    - Use any reconstructed track which extrapolation hits the Preshower
    - MIP signal is fitted (Landau⊗Gauss) and fixed to a given number of ADC counts
      - ~5% precision level
    - Cross-check with Energy flow method
      - Smoothing of the local energy deposit
      - Average over neighbour channels
      - ~4% precision level
    - Absolute calibration from π^0 width minimisation (or electron)

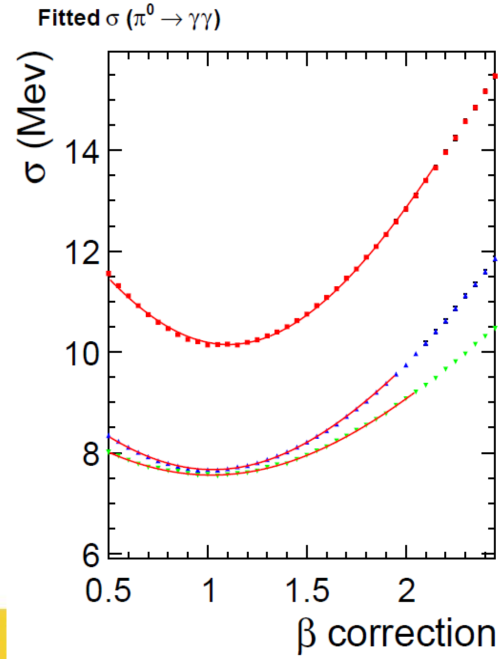
$$E_{rec} = \alpha\, E_{cluster} + \beta\, E_{ps}$$

(depends on barycenter position inside the cluster and inside the module)

Preshower correction (determination for e, γ)



Typical charge distribution for extrapolated tracks

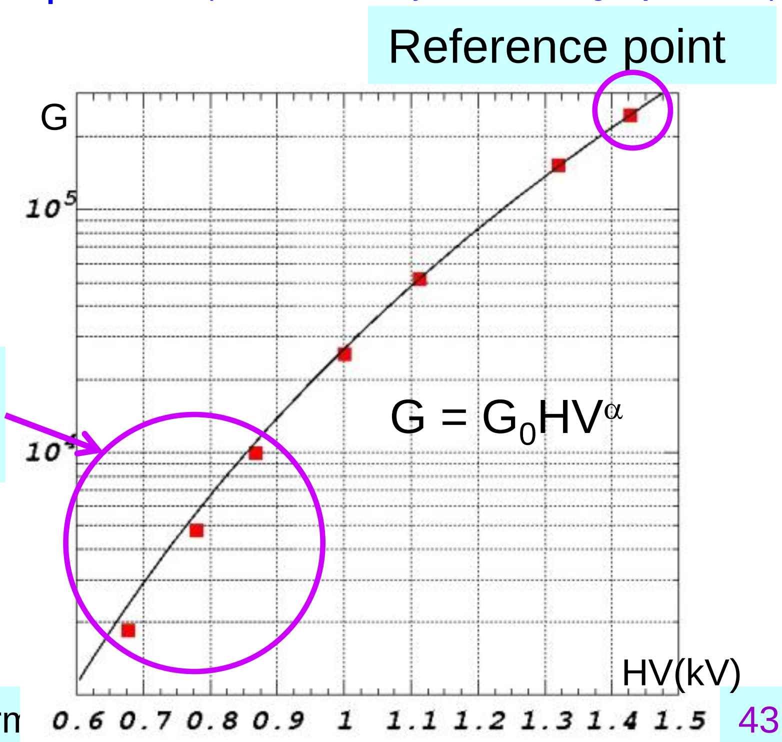


ECAL calibration

- Pre-calibration with the LED monitoring system
  - Performed in 2 steps:
    - Measurement of absolute value of G in the reference point
      - Width of the distribution of PM responses on LED is defined by photostatistics ~√Np.e.

      $G = К * (\sigma(LED)^2 - \sigma(pedestal)^2) / (A(LED) – A(pedestal))$

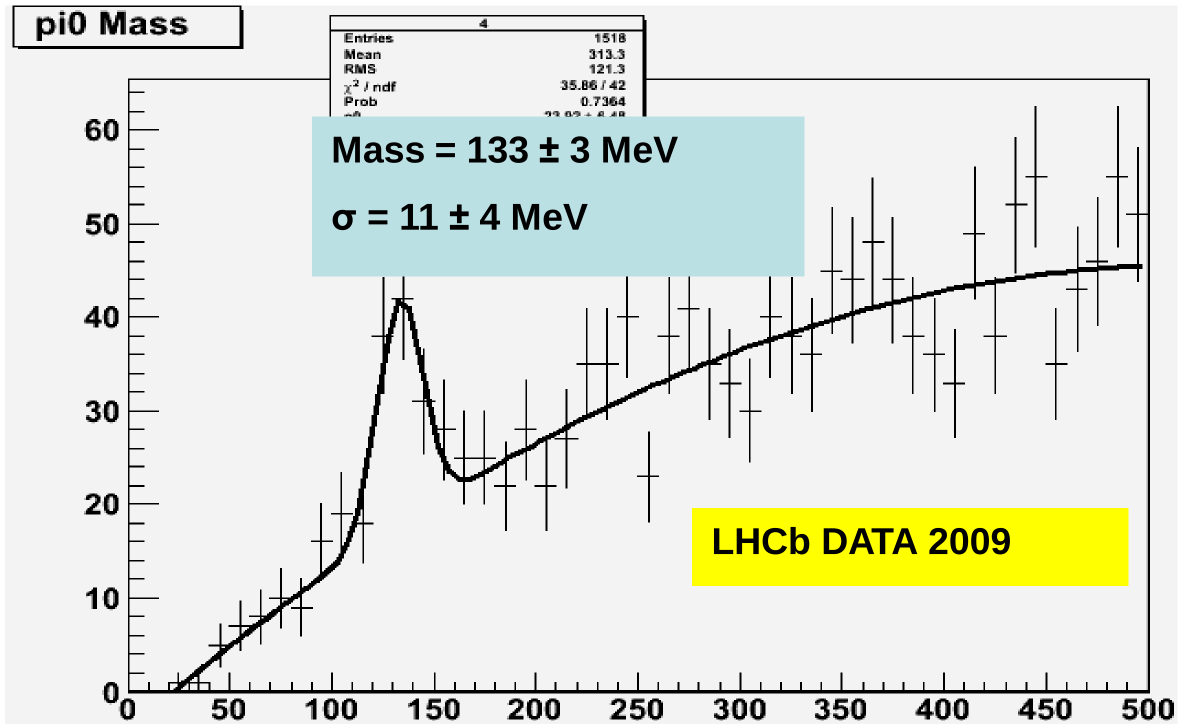
      К – parameter, defined by hardware properties (ADC sensitivity, modules light yield, etc)
    - Measurement of the normalized dependence G(HV) with respect to the reference point:
      - according to the change of PM response



  - Intercalibration of ~6% at start

ECAL calibration

- Clear observation of $\pi^0 \rightarrow \gamma\,\gamma$ signal immediately after the LHC startup in the end of 2009



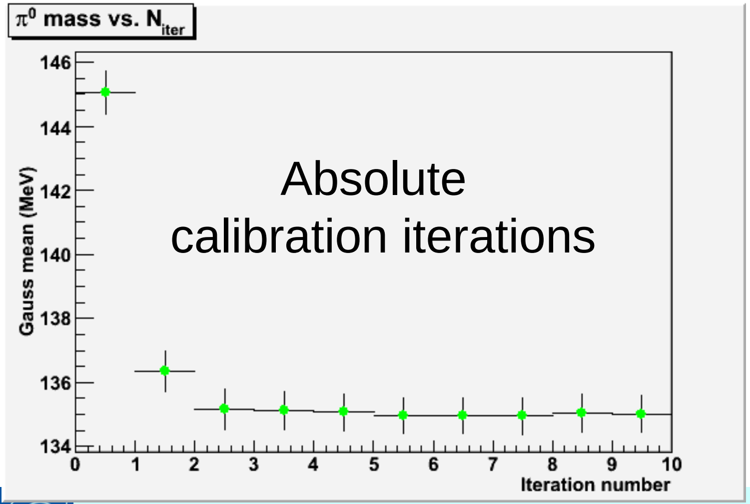
Di-photon invariant mass distribution, MeV/c²

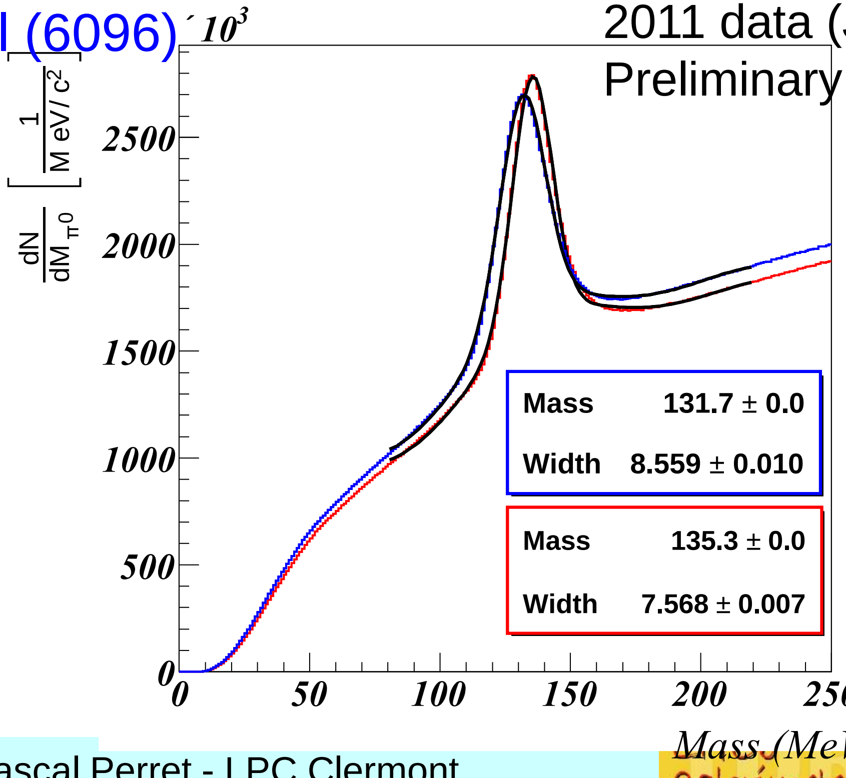
π^0 calo-standalone selection:

- E_T (γ) > 200 MeV
- (no track veto)
- E_{PS} >10 MeV && no-SPD

ECAL calibration

- Absolute calibration using reconstructed π^0 peak
  - Iterative procedure by π^0 mass peak fitting
    - Select photons (3x3 clusters) and fix seed (central) cell
      - Compute di-photon invariant mass
      - Find the coefficient which would move the measured mass closer to the π^0 nominal one: $\lambda = M_{nom}/M_{meas}$ = 135 MeV / M_{meas}
    - Repeat for each cell (6096)
    - Iterate until stable
  - ~1-2% precision





π^0 selection cuts:
- No SPD hit
- $p_T(\gamma)$>300 MeV
- E_{PS}<10 MeV (only ECAL calibration)
- $p_T(\pi^0)$>800 MeV

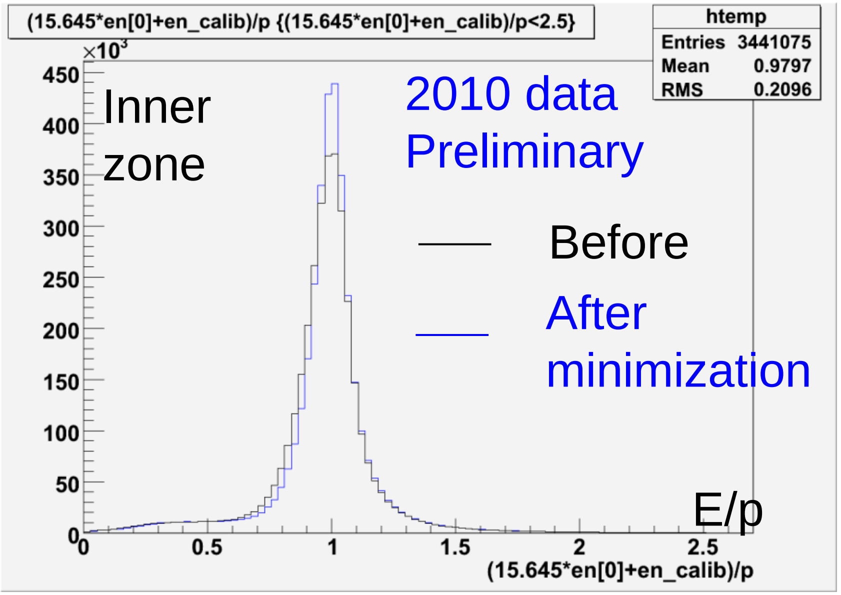
Initial calibration value

Final calibration value

ECAL calibration

- Calibration with electrons
  - Isolated electrons
    - Defined pure electron samples with the RICH detectors
    - No charged tracks within circle with R = 30 cm at ECAL entrance
    - Comparison of the total energy of the charged cluster in ECAL (+ PS) to the momentum of tracks for electron-candidates
      - Minimization of

$$\chi^2 = \sum_n \left[\left(\frac{\alpha \cdot E_{prs} + \sum_j k_j E_j^n}{p^n} - 1 \right)^2 \times \frac{1}{\sum_j k_j E_j^n} \right]$$

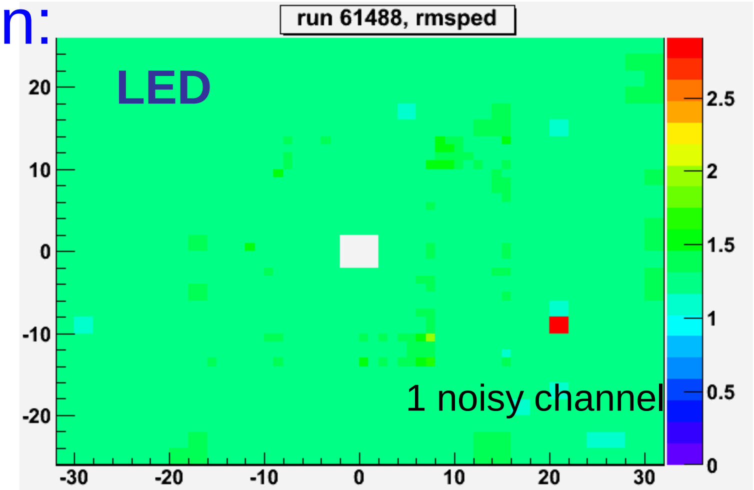


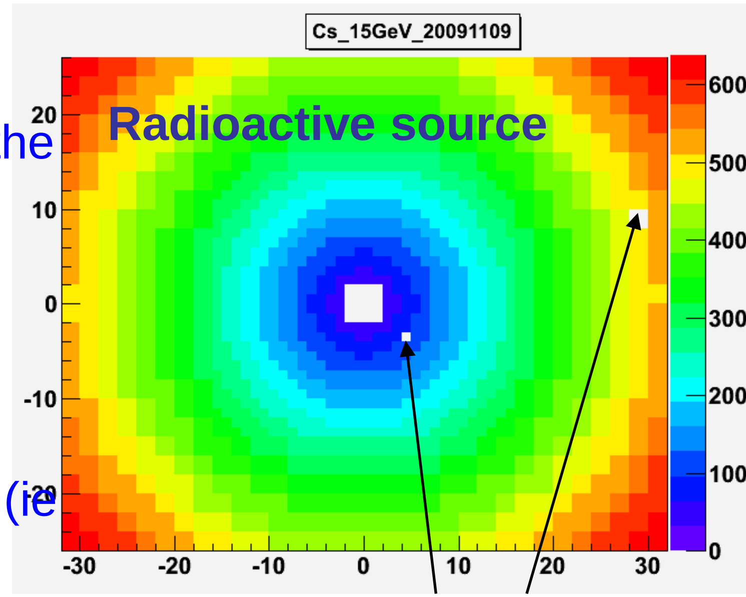
Where:

- N: total number of tracks (e-candidates),
- M: number of cells in ECAL cluster from i-th track,
- EPRS: the energy deposited in Preshower detector,
- α: weight factor for Preshower energy deposition,
- p_i : momentum of i-th track,
- k_j : j-th element of the vector k of calibration coefficients,
- E_{ij} : energy deposition in j-th cell of ECAL cluster from i-th track,
- σ_i : energy resolution of ECAL for current track.

HCAL calibration

- 3 steps to ensure correction calibration:
  - LED system
    - This gives the relative variation of the PMT
  - Cs source
    - Allows the absolute calibration of the scintillator response
  - Monte Carlo simulation
    - The missing step is the knowledge of the complete module response (Iron + scintillator + all materiel in front of the HCAL) to particles
    - The ratio « Measured energy in the scintillator/Energy of the particle when produced » is taken from Monte Carlo (ie Geant4), for pions.
  - ~5% precision (design of the HCAL)

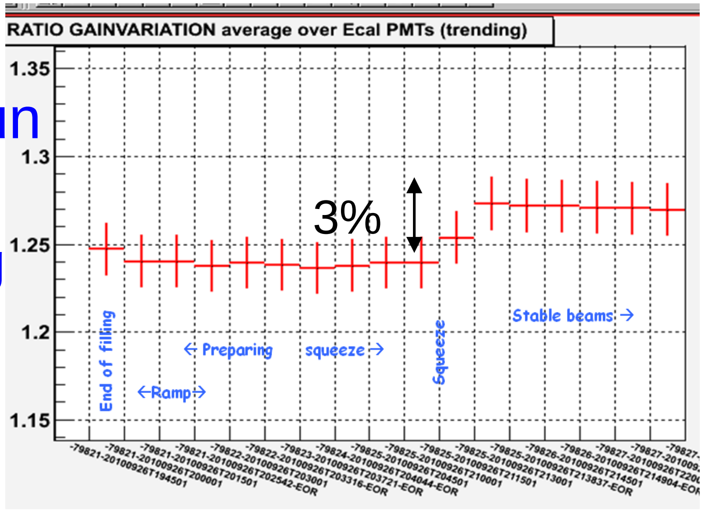


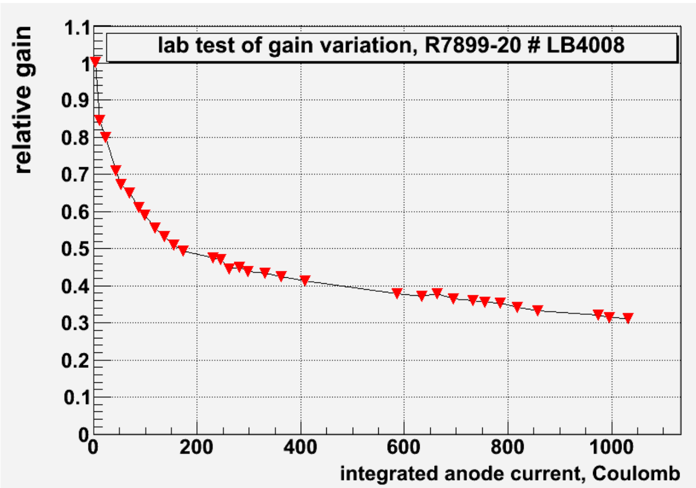


2 dead cells

Stability

- ◆ Unstability: PMT
  - Rate effects: but reproduced at each run
    - Addition of an extra 11 kHz of periodic triggers for ECAL & HCAL LED flashing
- ◆ Ageing
  - Combination of several effects:
    - PMT ageing as a function of the integrated current (PMT dynode)
      - Depends upon cell size and location
    - Scintillator ageing due to radiations
      - Plastic tiles become less and less transparent
      - Proportional to particule flux (neutral + charged)
  - These are well known unavoidable effects …

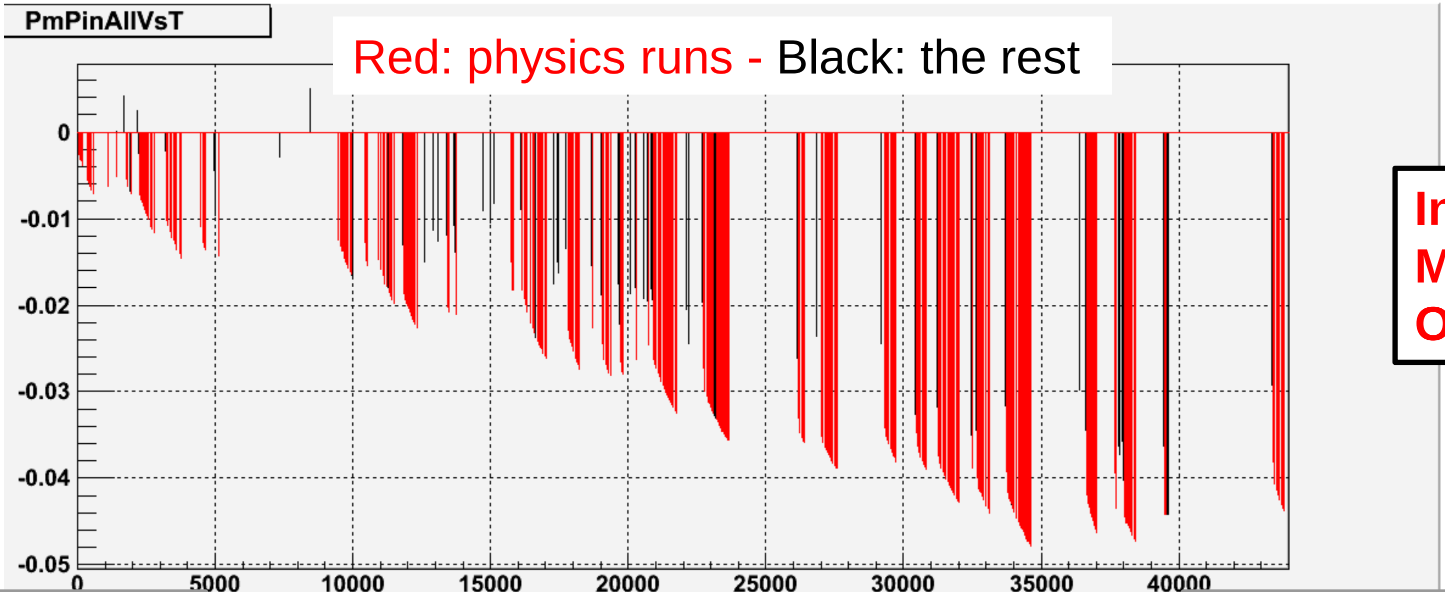




ECAL ageing

- LED monitoring system can be used to follow ECAL ageing
  - Comparison of LED response (PIN corrected) for different fills:

Average relative PmToPin change with respect to 1st run (fill 1799)

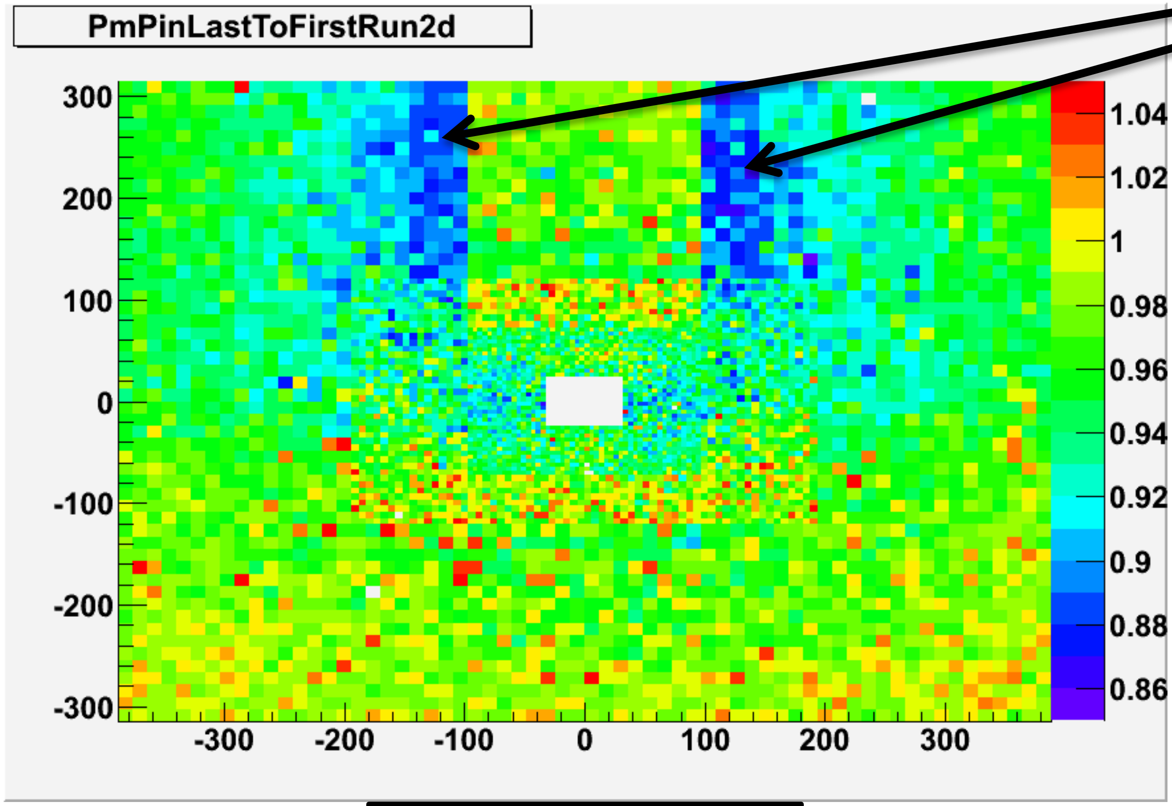


Inner: up to 5.7%
Middle: up to 3.8%
Outer: up to 4.1 %

#92035	Time, minutes. One point per run	#93995
1799		1883
21/5/11	~300 pb^{-1}	**21/6/11**

ECAL: LED

- Changes are more pronounced in inner section but …

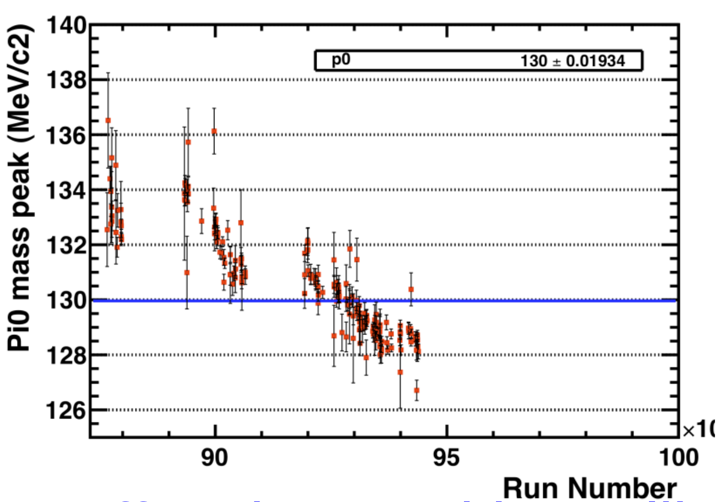


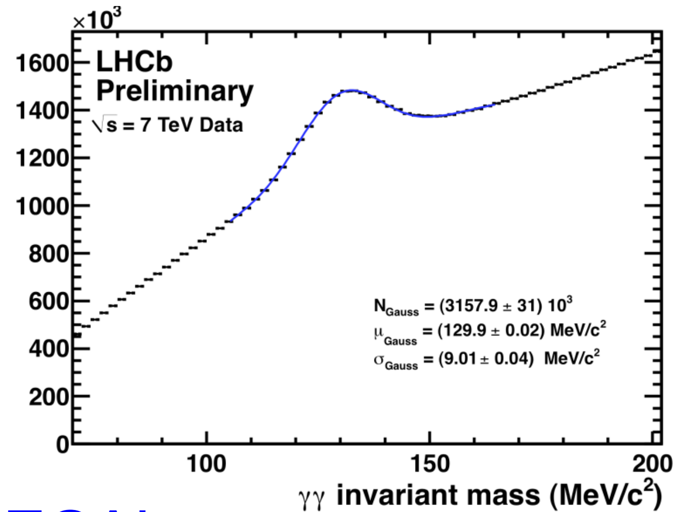
PmToPin(93995)
/PmToPin(92035)

- Degradation of clear fibers due to radiation damage
- The ECAL LED monitoring system cannot be used to monitor (simply!) ECAL ageing…

ECAL ageing

- π^0 mass as a function of time (recorded luminosity)

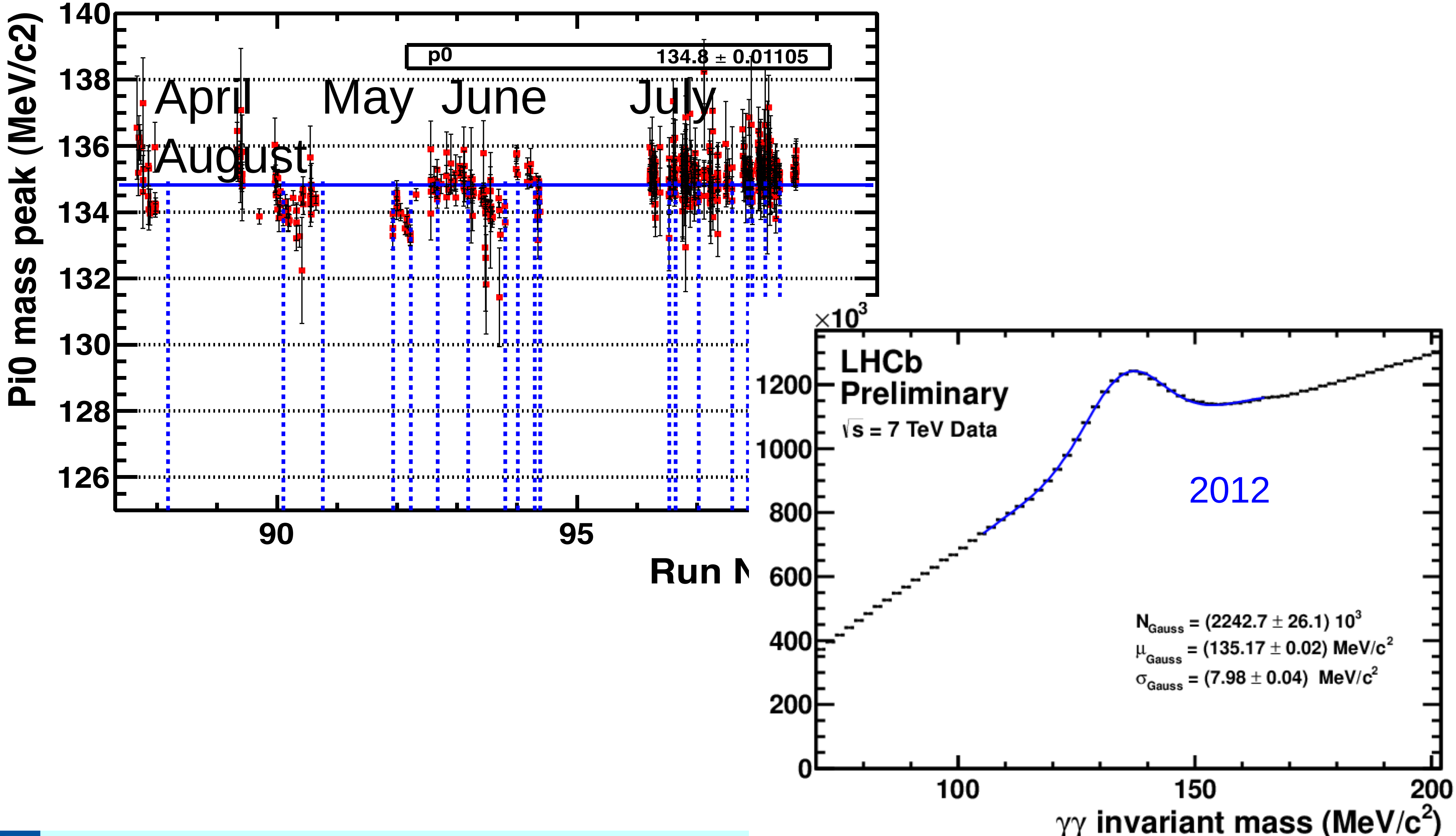




- The effect is cured by calibrating ECAL:
  - Using π^0 and adjusting its mass for each ECAL on a short period of data taking
  - On top of π^0 calibration data trending coefficients are applied:
    - Extracted from E/p for electrons from conversion selected with RichDllE and loose electron id.
    - In 9 small zones over ECAL
    - For every ~20-40/pb intervals over the year

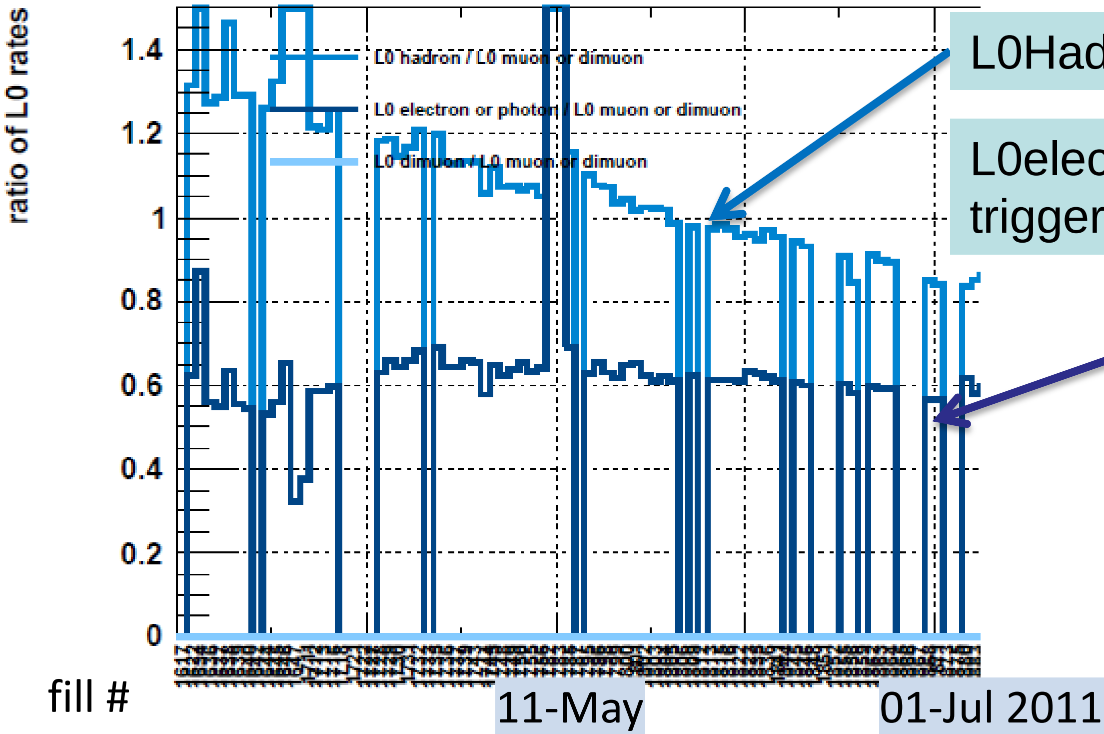
ECAL ageing

- After calibration (preliminary, 2011 data):



HCAL ageing

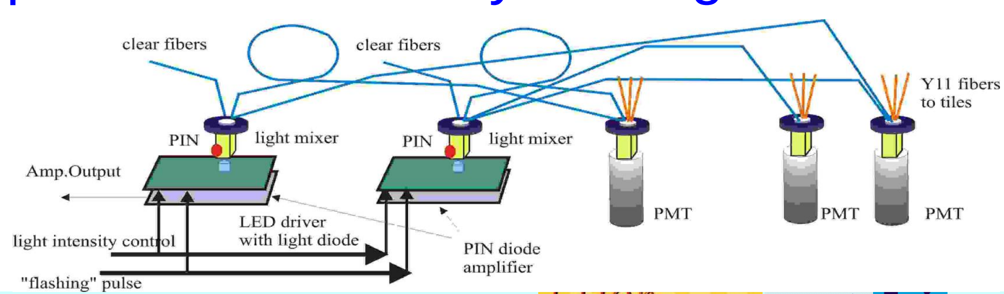
- The L0 trigger rate (L0 hadron) is affected by HCAL ageing:



L0Hadron/L0muon-dimuon trigger rate

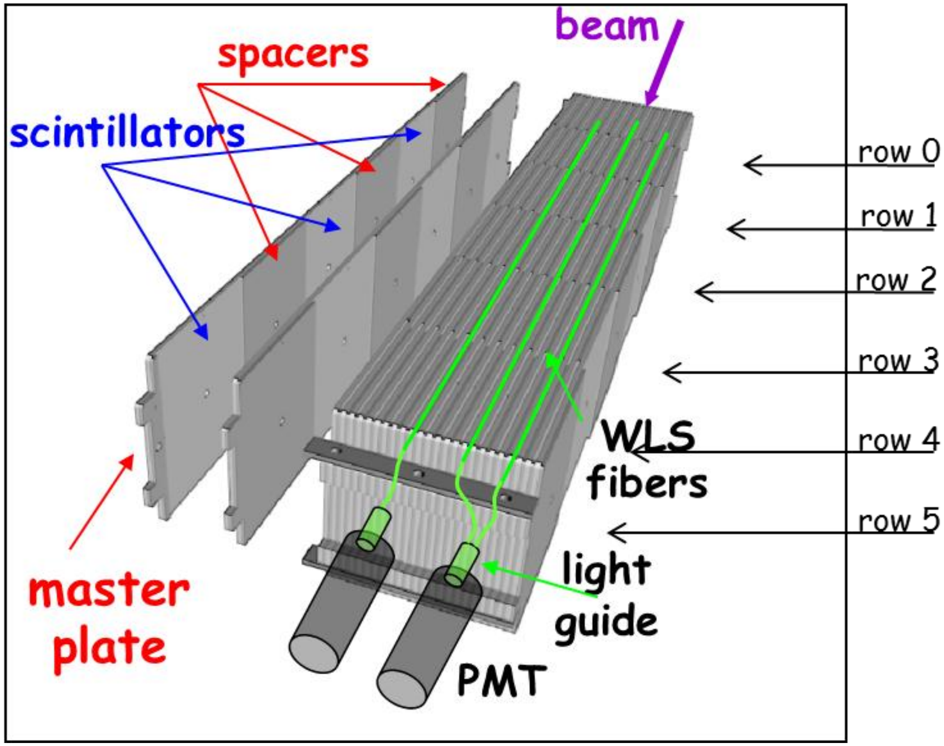
L0electron/photon / L0muon-dimuon trigger rate

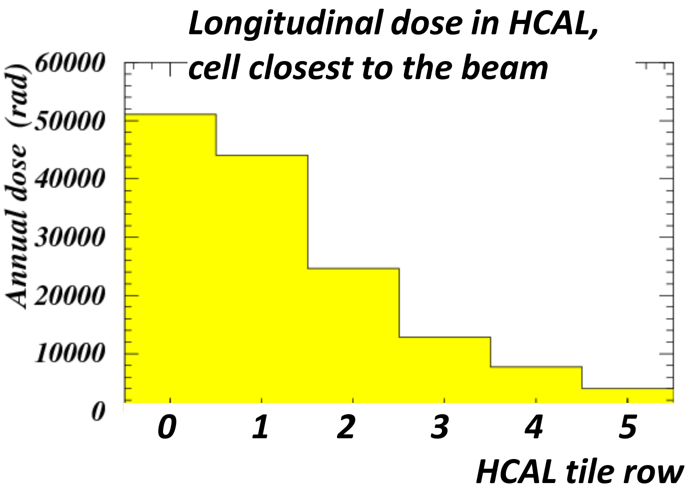
- Corrections have to be applied to restore it by making use of:
  - Cs source
  - LED monitoring sytem
    - Not affected by ageing (fibers at HCAL back!)



HCAL ageing

- ^{137}Cs source
  - Allow to separate the light yield degradation from the PMT gain loss
  - Radiation damage of tiles and fibers

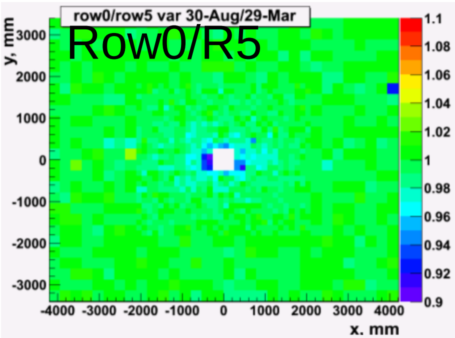


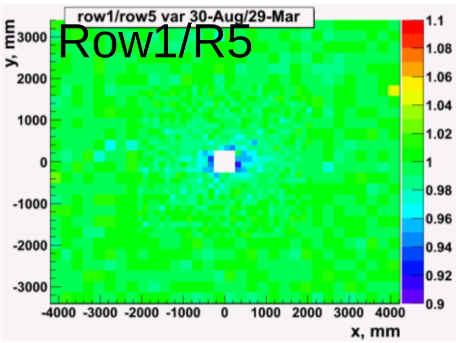


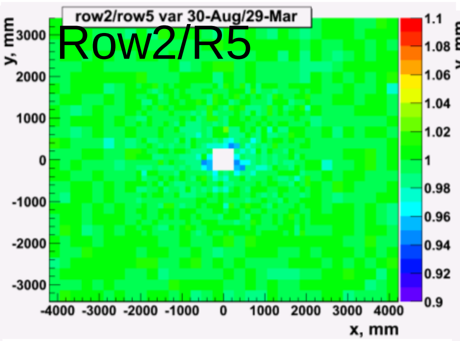
The hadronic shower maximum lays ~ within the tile row 0; the dose in the row 5 is much less. Radiation damage of scintillator tiles and fibers can therefore manifest itself as a decrease of relative response of upstream rows (0, 1) with respect to row 5.

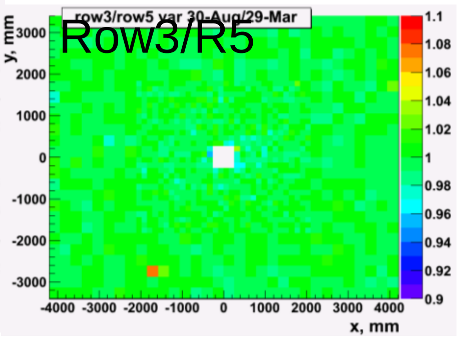
HCAL ageing

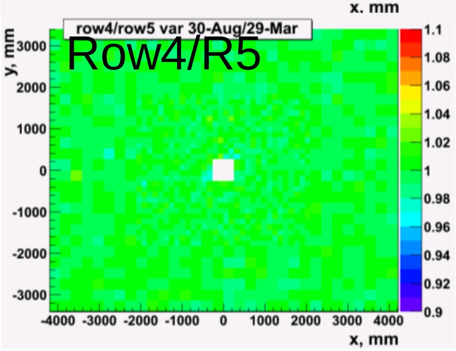
- Radiation damage of tiles and fibers
  - 30-Aug vs 29-Mar (758 pb^{-1})



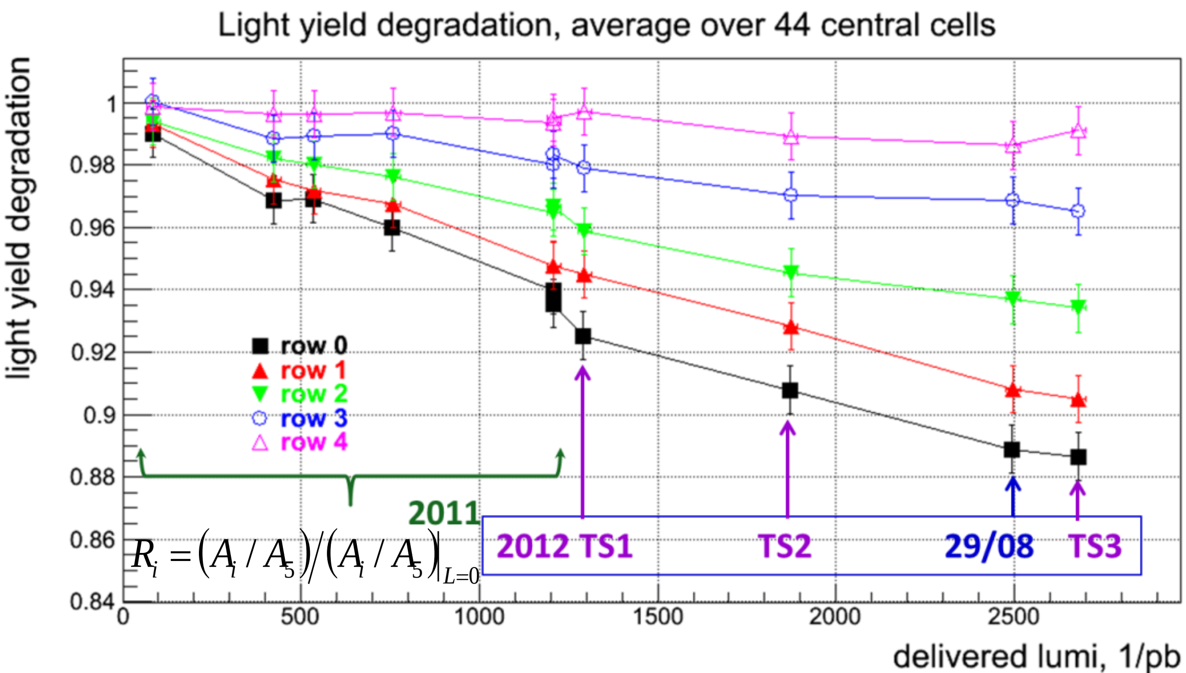








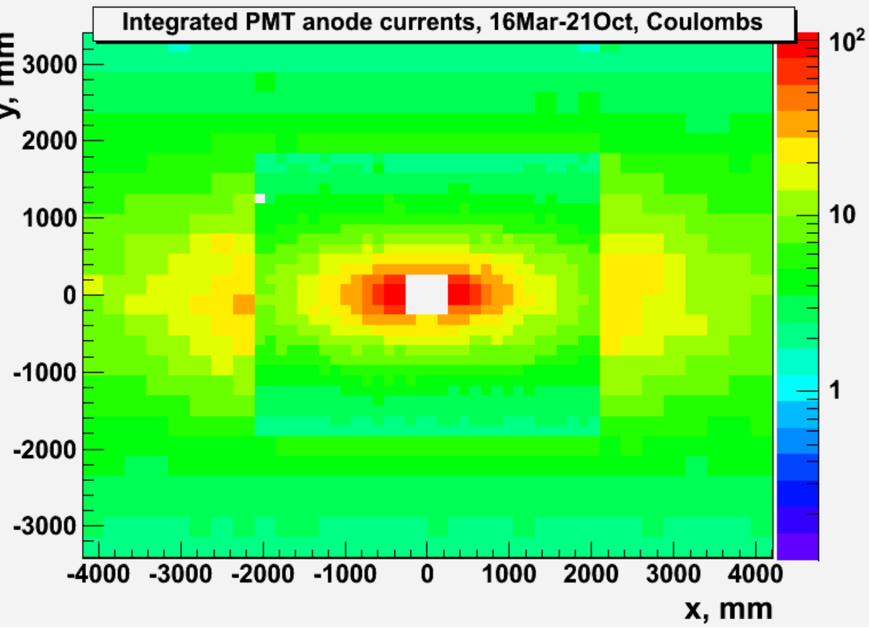
Further decrease in the centre

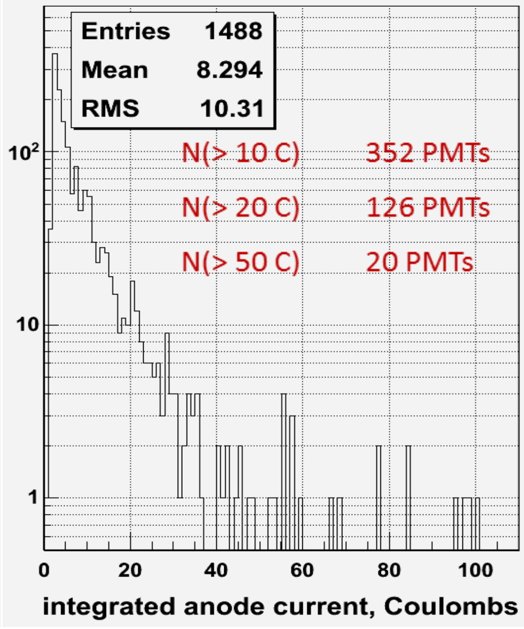


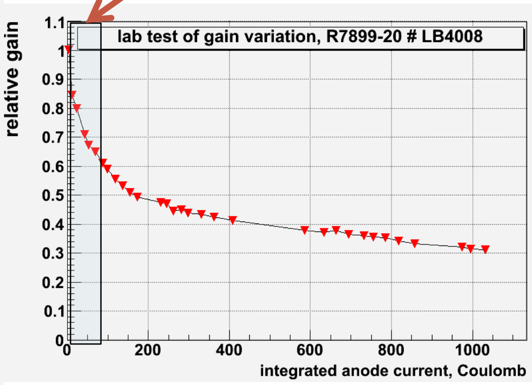
At low doses, it develops ~linearly in time

HCAL ageing

- PMT ageing
  - The anode currents of the HCAL PMTs are continuously monitored with integrators of the source calibration system
  - In 2011, at $L=3.5\cdot10^{32}/cm^2/s$, PMT anode current was significant, up to 35μA in the HCAL centre. The integrated anode currents are up to 100C



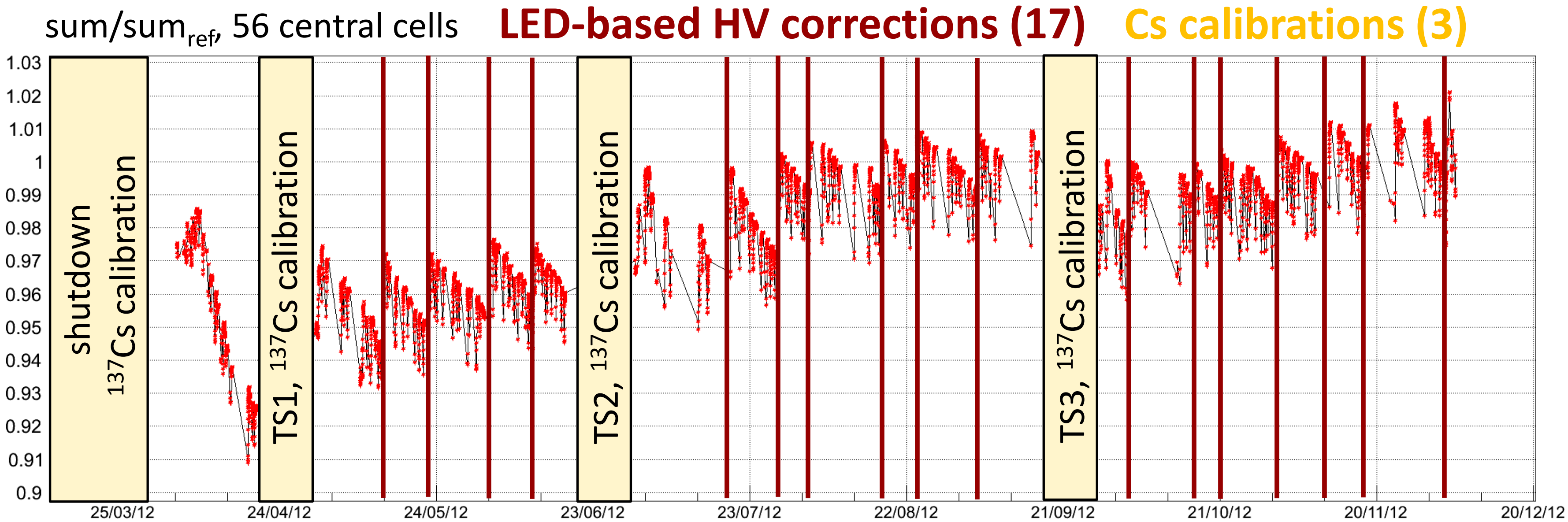




  - x5 times more current than for ECAL
  - In 2012, the PMT gain has been reduced by a factor 2 to reduce the ageing rate

HCAL ageing

- HCAL HV corrections
  - Results of Cs calibrations at TS is used as a starting point, then LED-based corrections



- Precision of corrections is limited by:
  - annealing during TS (and faster ageing afterwards)
  - A model to account for plastic ageing has been used >August 2012
    - uncertainty in the “plastic ageing” prediction – non linearity, annealing

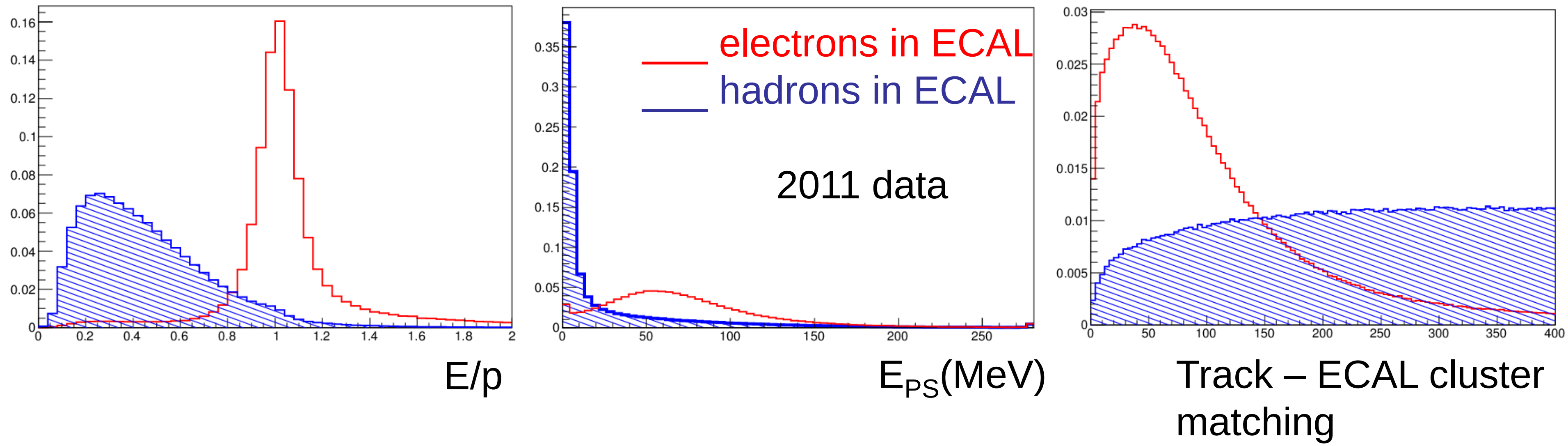
PERFORMANCES

Neutral clusters

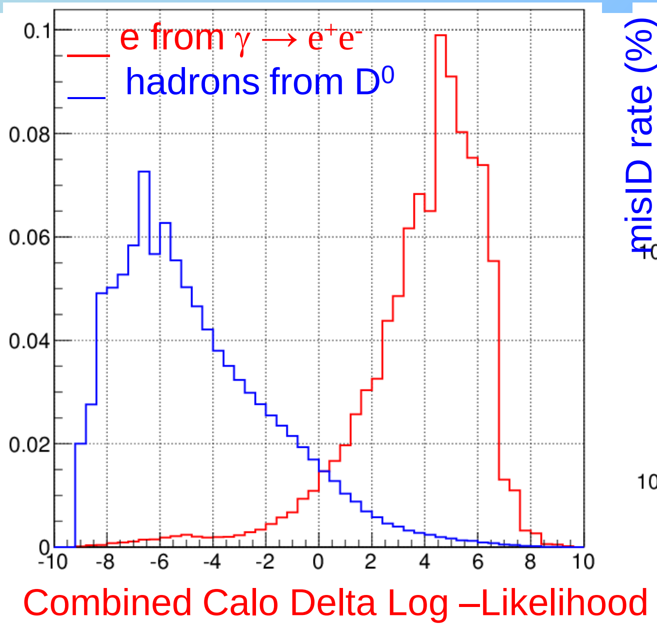
- Energy deposits in ECAL cells are clusterized applying a 3x3 cell pattern around local maxima
  - Photon PID based on probability density functions
    - Track – ECAL cluster anti-coincidence
    - ECAL shower shape
    - PS energy
  - Neutral pions
    - Mostly reconstructed as a resolved pair of well separated photons
      - Mass resolution of ~8 MeV/c^2 (low transverse energy π^0)
    - For high energy π^0 (p_T > 2 GeV/c):
      - A large fraction of the pairs of photons cannot be resolved as a pair of clusters within ECAL granularity: merged π^0
        - *Specific procedure: consists in spliting each single Ecal clusters into two interleaved 3x3 subclusters built around the two highest deposits of the original cluster. Iterative procedure for the sharing of the energy of the common cells based on the expected transversal shape of photon showers.*
      - Mass resolution of ~20 MeV/c^2

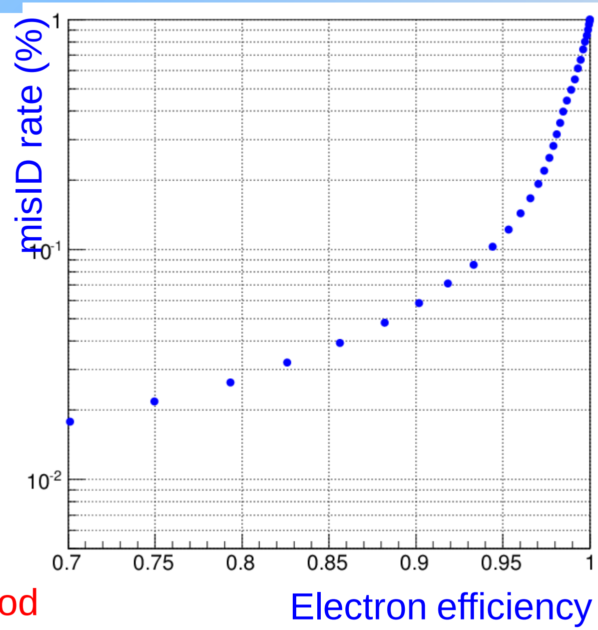
Electron PID

- Based on difference between likehood of the signal (electron) and background
  - Fully based on data distributions
    - Signal : electrons/positrons from γ conversions
    - Background : hadrons from $D^0 \to K\pi$
  - Some discriminant variables:

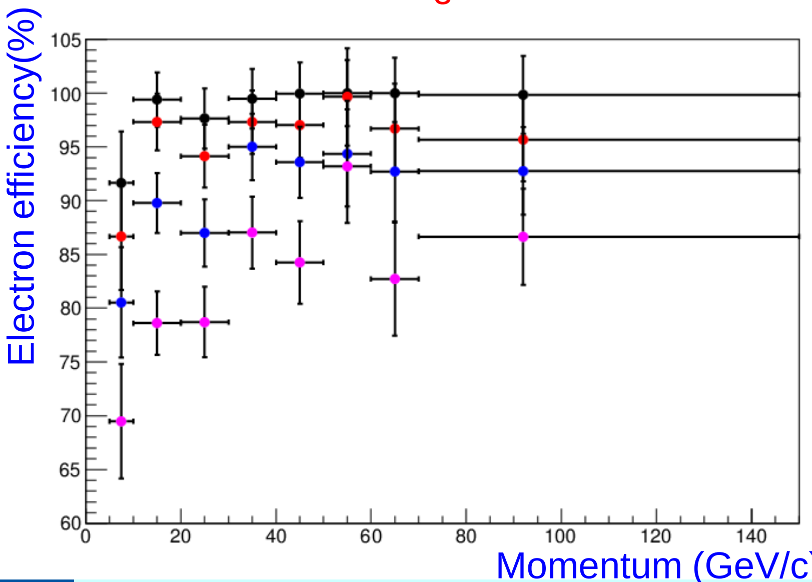


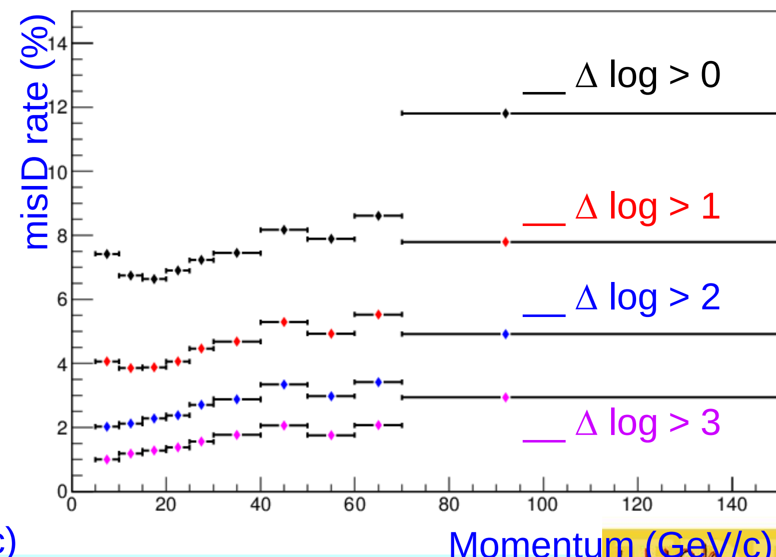
Electron PID: performances





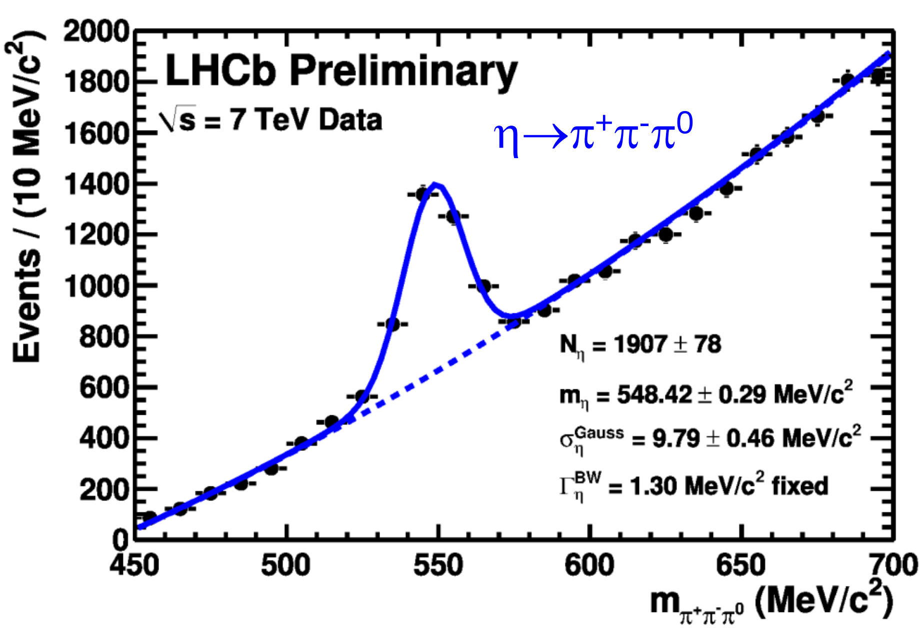
- **Mis_ID rate ~5% for electron eff 90%**
- **+ RICH information: Mis_ID rate <2% for electron eff >97%**

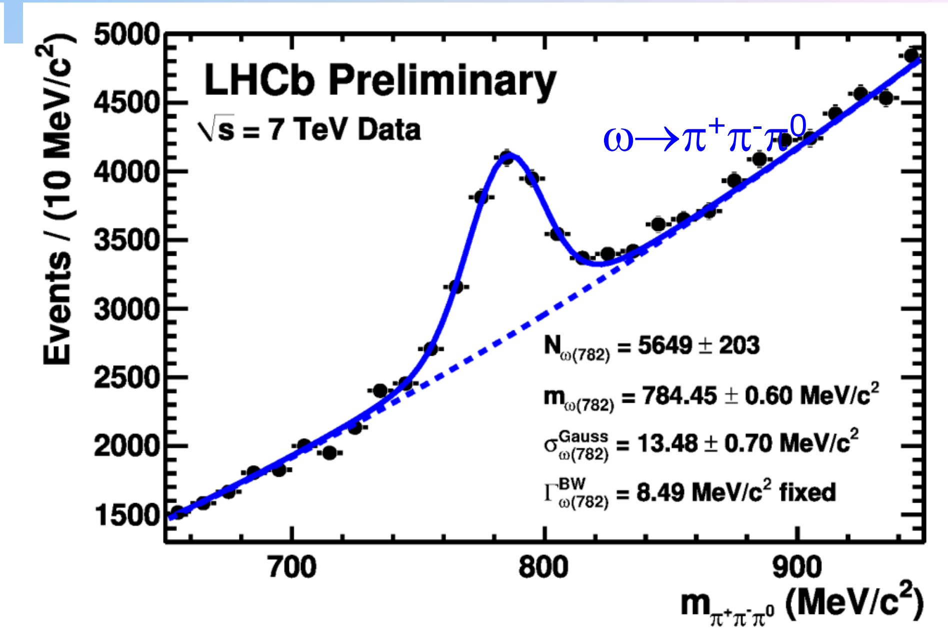


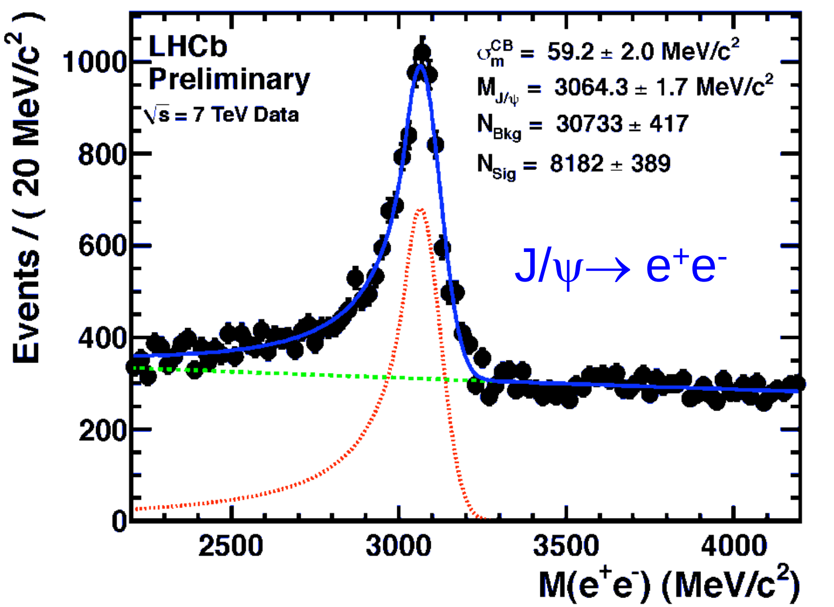


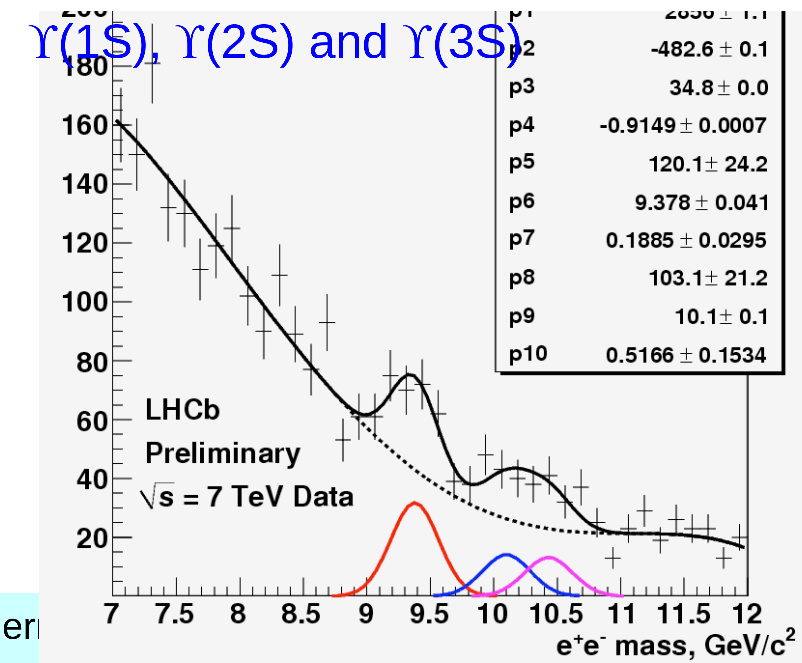
From $B^+ \to J/\psi\ K$

Some first displays: 2010 data



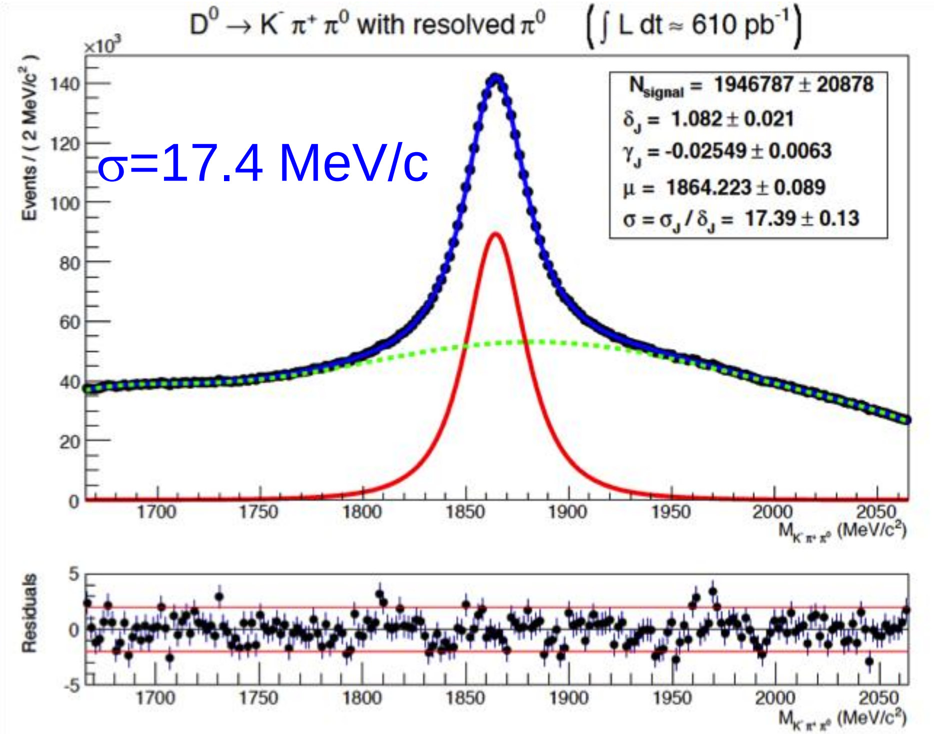




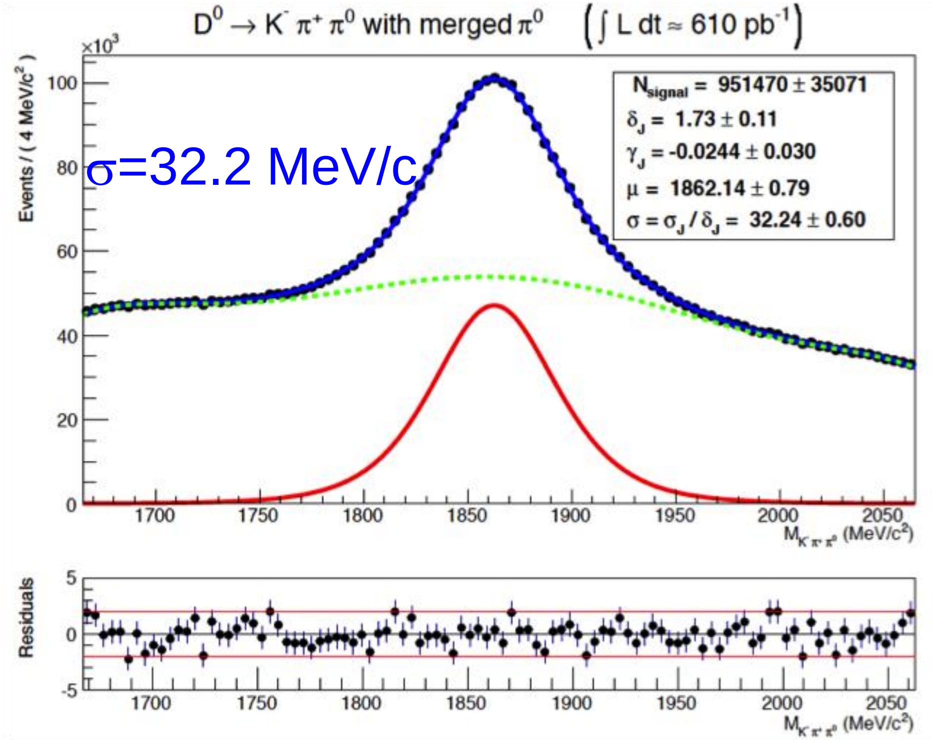


2011 data

$D^0 \to K^+\pi^-\pi^0$ (resolved π^0)

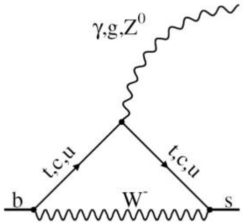


$D^0 \to K^+\pi^-\pi^0$ (merged π^0)



Radiative decays

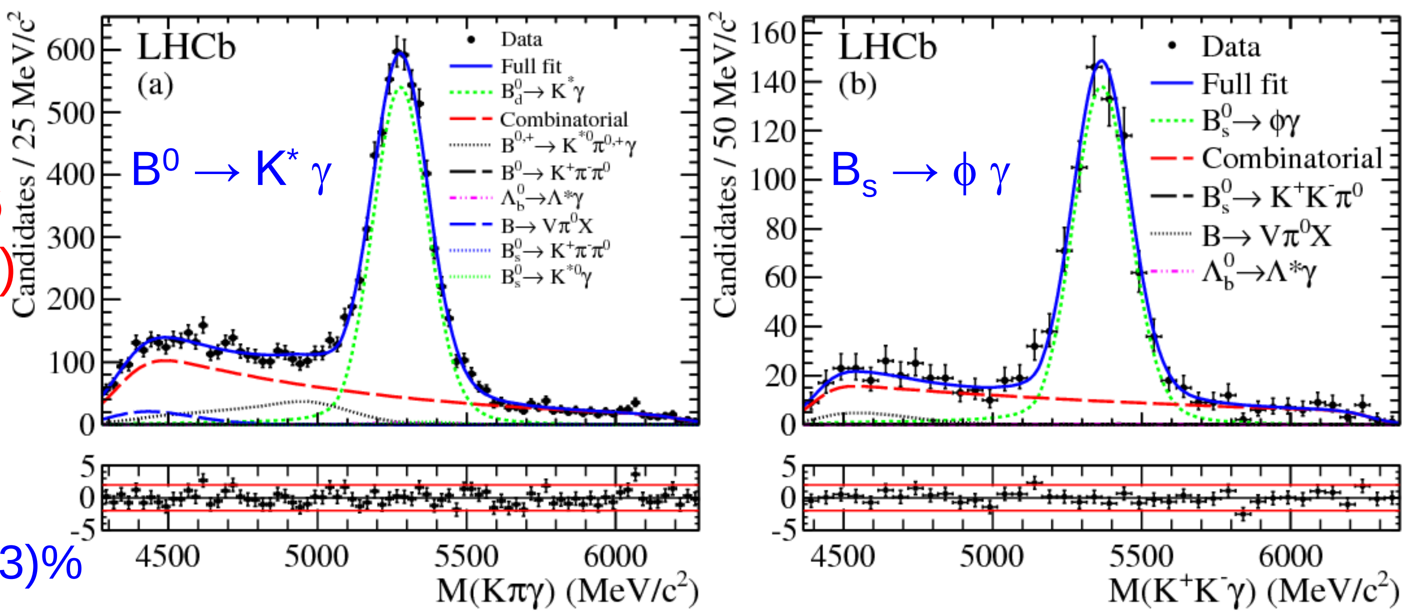
- Theory



  - Predictions for BR suffer from large uncertainties from hadronic form factors
    - $B^0 \to K^* \gamma = (4.3 \pm 1.4) \times 10^{-5}$; $B_s \to \varphi \gamma = (4.3 \pm 1.4) \times 10^{-5}$
  - Ratio of BR and direct CP asymmetries are better known
- LHCb measurements (1 fb^{-1}) *[NP B 867 (2012) 1]*

$N_{B0 \to K^* \gamma} = 5279 \pm 93$
$N_{Bs \to \varphi \gamma} = 691 \pm 36$

- $R_{BR} = 1.23 \pm 0.06 \pm 0.04 \pm 0.10(f_s/f_d)$
  - Th: 1.0 ± 0.2
- $A_{CP}(B^0 \to K^* \gamma) = (0.8 \pm 1.7 \pm 0.9)\%$
  - Th: $(-0.61 \pm 0.43)\%$
- WB measurements



Invariant mass resolution: ~92 MeV/c^2

$BR(B_s \to \phi \gamma) = (3.5 \pm 0.4) \times 10^{-5}$

- No sizeable deviation from SM

CONCLUSION

Summary & Conclusion

- **The calorimeters are running smoothly!**
  - All channels operational but 72 SPD channels (over 6016)
    - 1 VFE electronics (64) + 1 ASIC (8) problems: will be fixed during LS1
- **and performing well:**
  - Trigger capabilities: hadron, electron, photon
    - Key role in the trigger system:
  - Energy resolution
    - Important measurements: $b \rightarrow s \gamma$ ($B^0 \rightarrow K^* \gamma$, $B_s \rightarrow \phi \gamma$), etc.
- Significant ageing (PMT, scintillators) … as expected
  - Under control thanks to “frequent calibrations”
  - Some improvements expected during LS1:
    - Installation of rad hard (quartz) fibers for the ECAL LED system
    - Development of ageing models to predict/correct the effects
    - Automatization of HV PMT adjustment procedures after each fill

THANK YOU!