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First Years of Running for the LHCb Calorimeter System

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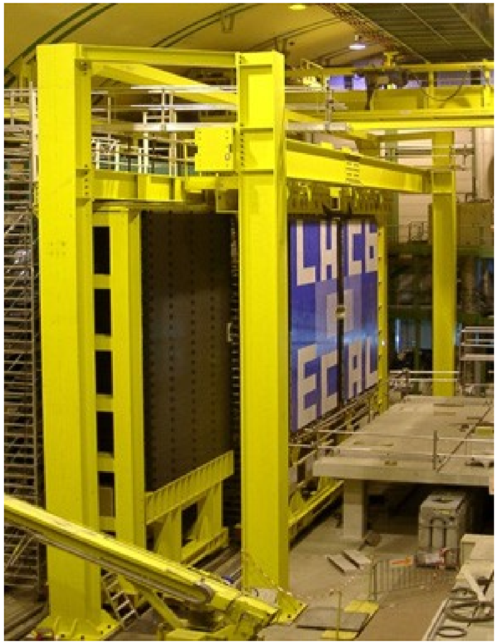
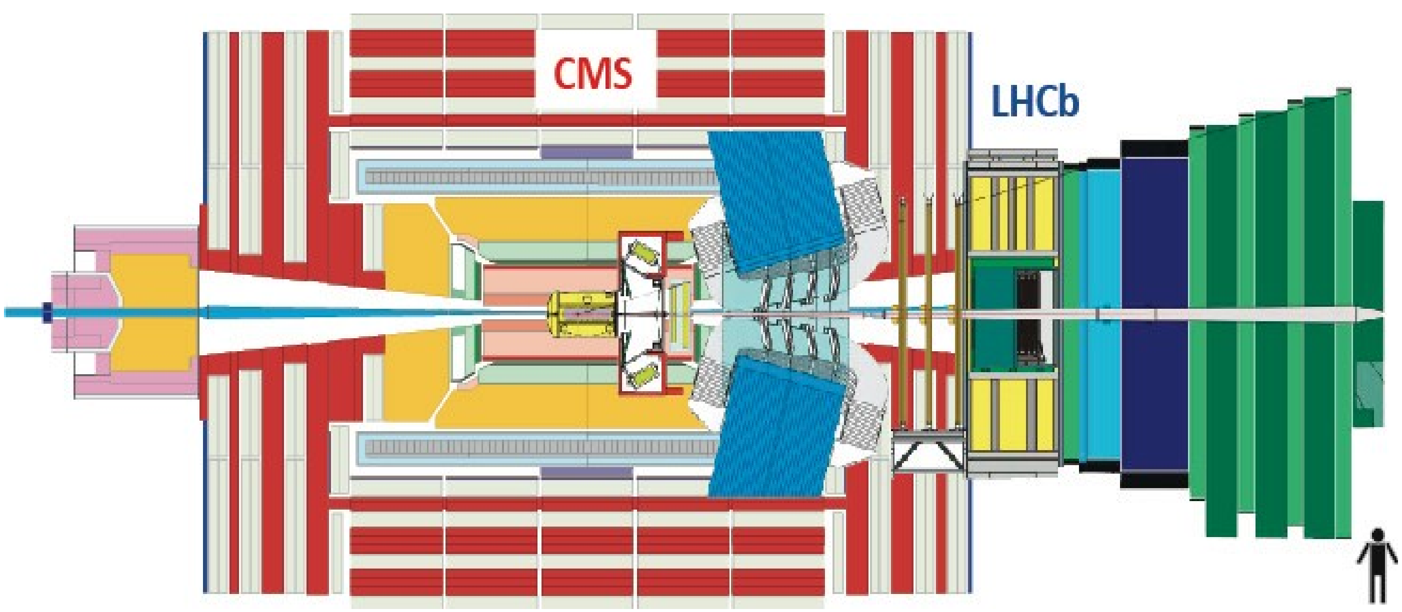
On behalf of the LHCb collaboration

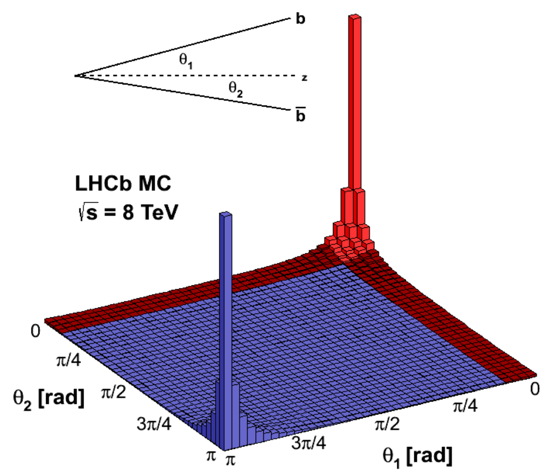


The LHCb Detector

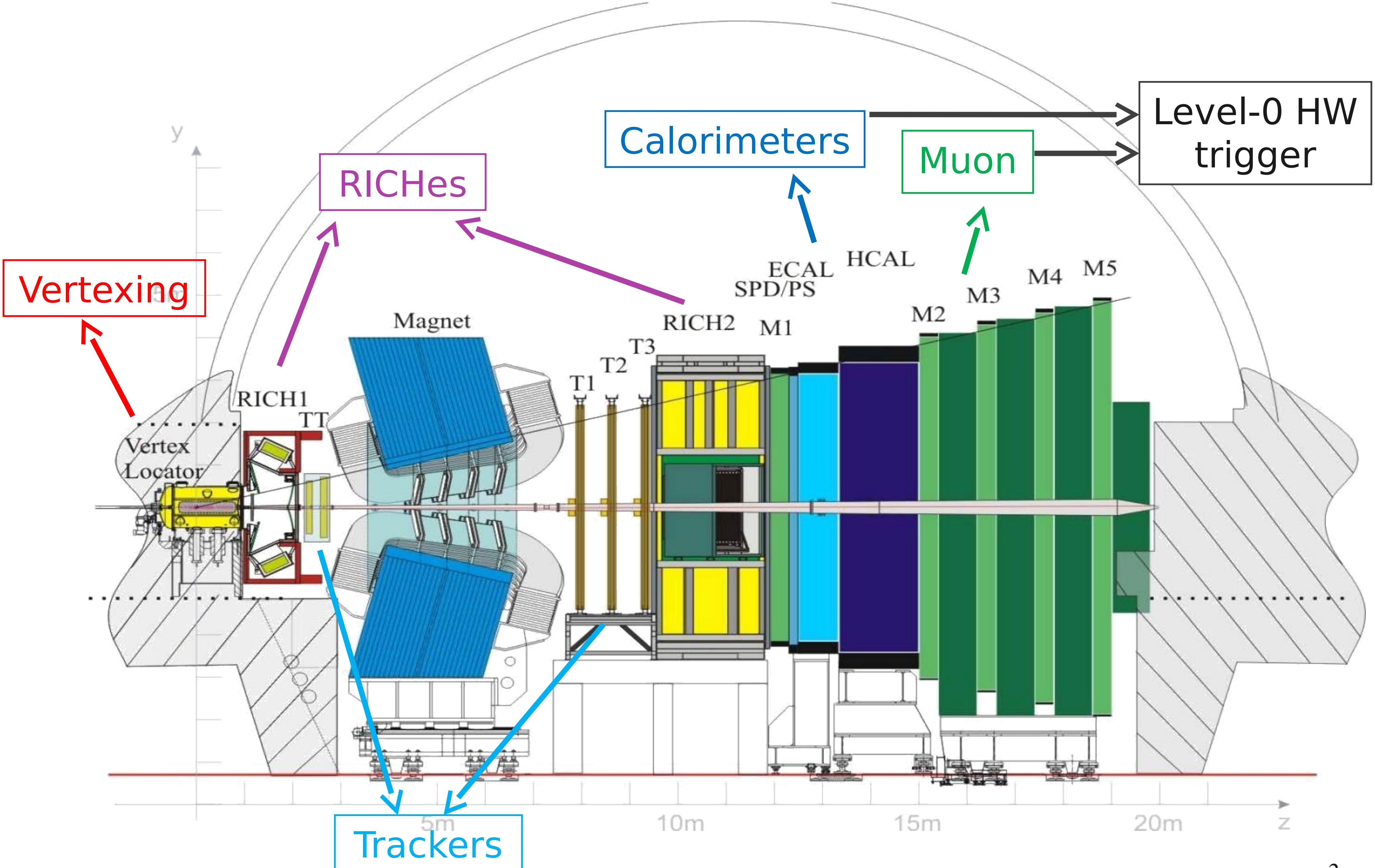
- LHCb is a Forward General-Purpose Detector at the LHC:
  - Single-arm forward spectrometer with unique coverage in pseudorapidity: $2 < \eta < 5$ (4% of solid angle)
  - Catching 25 % of $b\bar{b}$ quark pairs
  - Precision measurements in beauty and charm sectors

- Important physics analyses in the LHCb core program are calorimeter-related:
  - Radiative decays: $B_d \to K^{*0}\gamma$, $B_s \to \phi\gamma$
  - Decays involving neutral pion, eta: $B_d \to \pi^+\pi^-\pi^0$, $J/\psi\ \eta^{(')}$, $D^0 \to K^-\pi^+\pi^0$
  - Or electrons: $B_d \to K^{*0}e^+e^-$



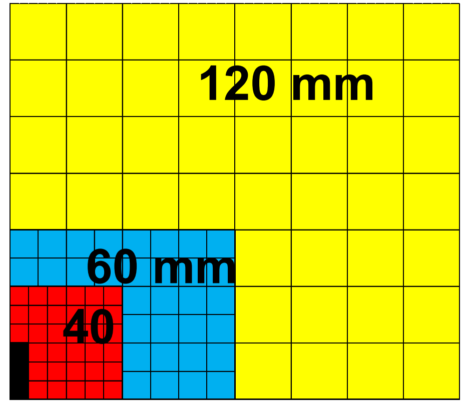


The LHCb Detector

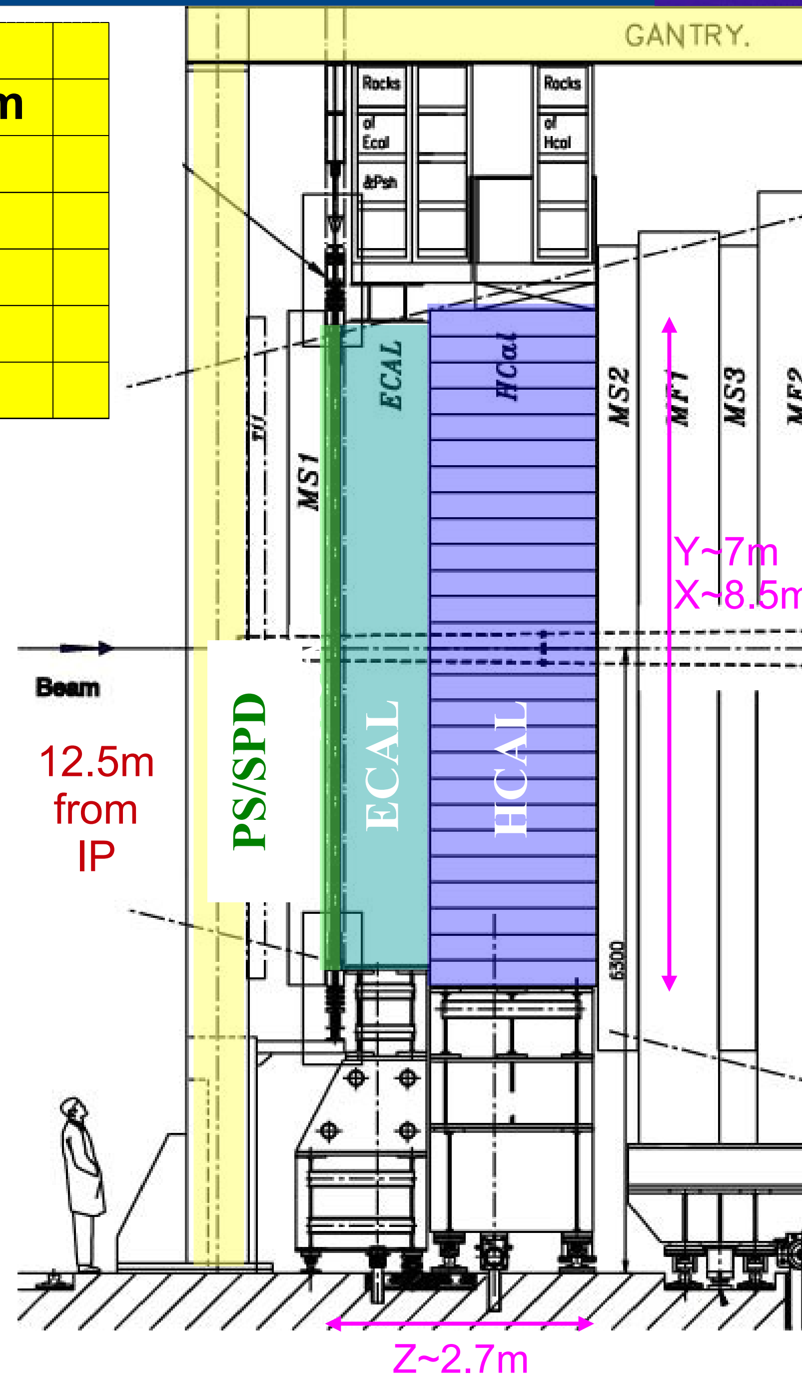


The LHCb Calorimeter System

- Four sub-detectors:
  - SPD, PS, ECAL: 6016 cells
    - 3 zones 4x4; 6x6 and 12x12 cm^2
  - HCAL: 1488 cells
    - 13x13 and 26x26 cm^2

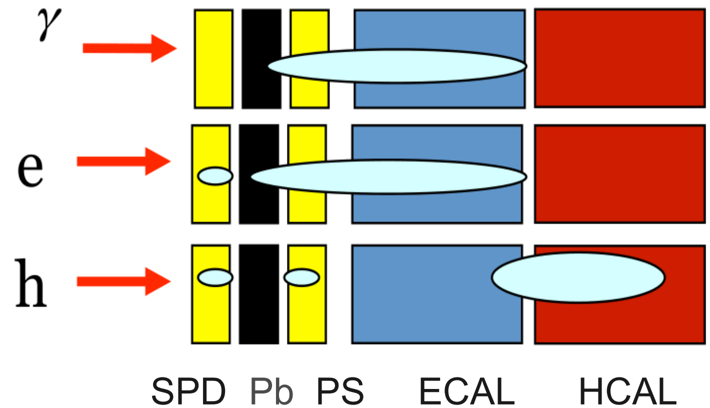


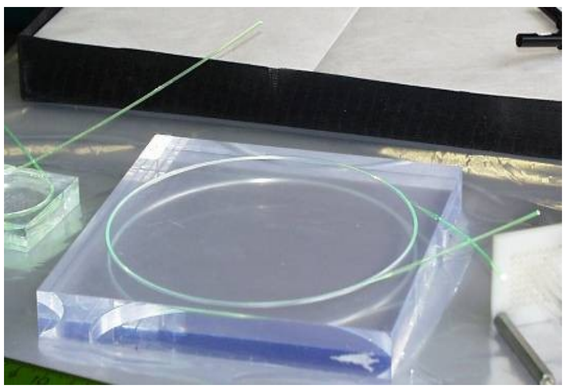
- Based on scintillators/WLS technique, light readout by PMTs
- Equipped with LED-based monitoring system (ECAL/HCAL)
  - Collected at a 50 Hz level outside of the bunch-crossing zones during data taking
- Provides:
  - L0 trigger on high-E_T $e^{\pm}/\gamma/\pi^0/h$
  - Precise energy measurement of $e^{\pm}$ and γ
  - Particle Identification: $e^{\pm}/\gamma/h$; contributes to μ ID (HCAL)

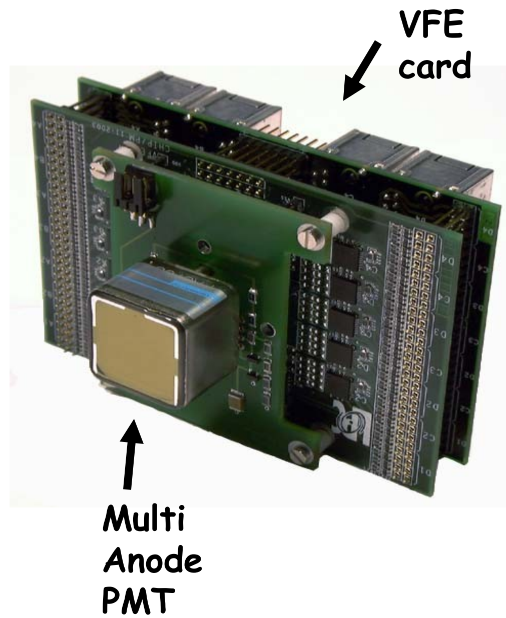


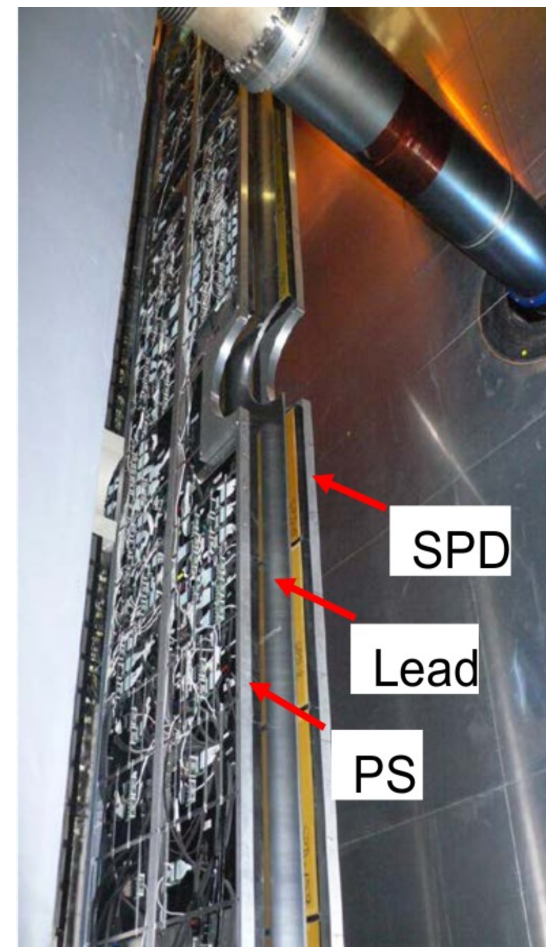
Scintillator Pad and Preshower Detectors

- Scintillator Pad Detector (SPD) and Preshower (PS):
  - Particle ID for electron and photon L0 trigger
    - PS: electron, photon/pion separation
    - SPD: photon/MIP separation
  - Charged multiplicity by SPD









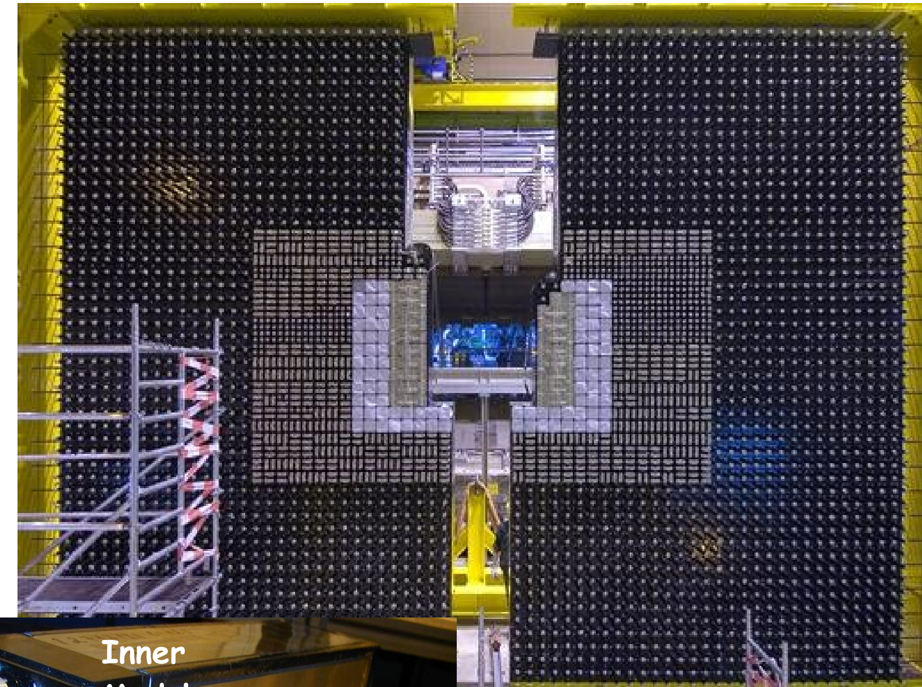
- Scintillator Pad – $2.5X_0$ lead – Scintillator Pad:
  - 15/15/15 mm thick
  - Signal read by 64-channel MAPMT
  - Average light yield: ~20 p.e/MIP
  - PS: 10 bit readout – dynamic range: 0.1-100 MIPs
  - SPD: 1 bit readout – track counter

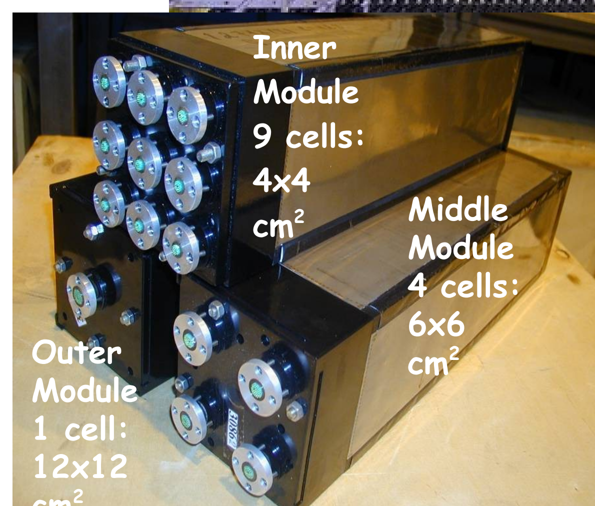
Electromagnetic Calorimeter

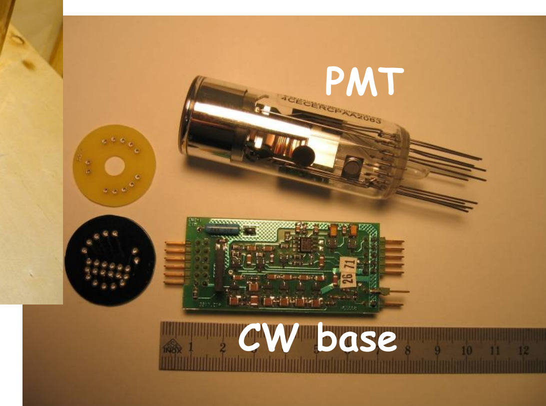
- Electromagnetic Calorimeter (ECAL):
  - E_T of $e^{\pm}$, γ and π^0 for L0 trigger

    ($B_d \rightarrow K^* ee$, $B_d \rightarrow K^* \gamma$, etc.)
  - Reconstruction of π^0 and prompt γ offline
  - Particle ID

- Shashlik technology:
  - 66 layers of 2mm Pb/ 4mm scintillator
  - Moliere radius: 3.5 cm
  - Longitudinal size: $25X_0$, 1.1 λ_I
  - Average light yield: ~3000 p.e/GeV
  - Dynamic range: uniform E_T up to 10-12 GeV
  - Energy resolution (beam tests):
    - $\sigma(E)/E = (8 - 10)\% / \sqrt{E} \oplus 0.9\%$

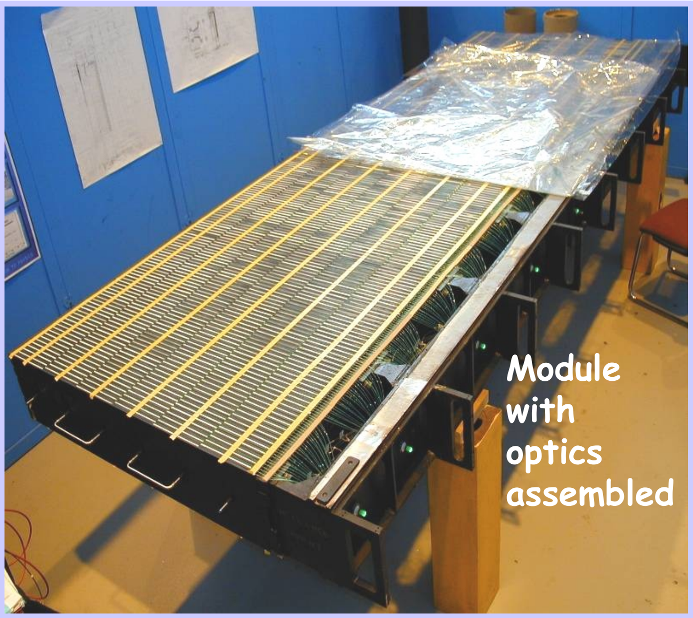


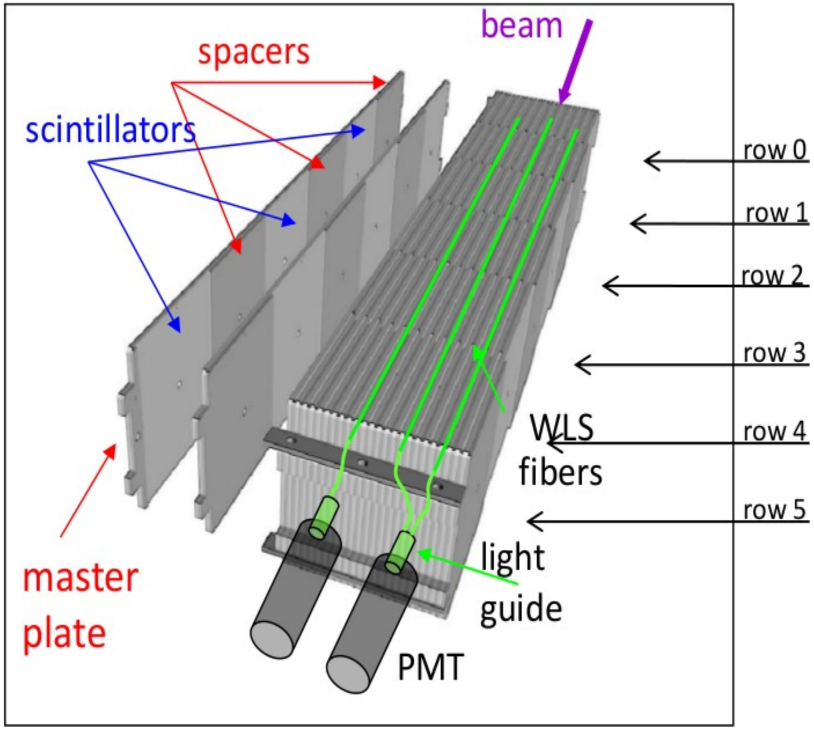




Hadronic Calorimeter

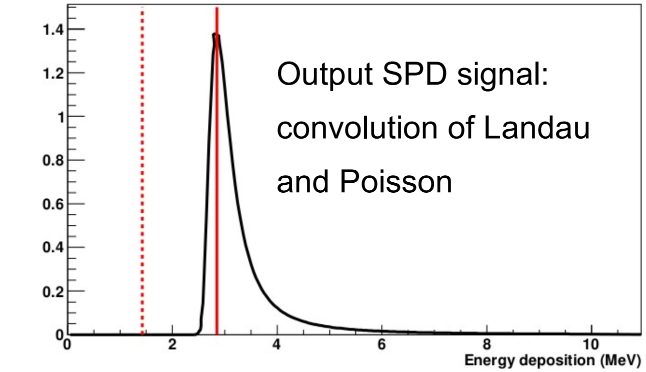
- Hadronic Calorimeter (HCAL):
  - E_T of hadrons, ΣE_T for L0 trigger (~ 500 kHz out of ~1 MHz)
- TileCal technology (originally developed for ATLAS)
  - Interleaving Sc tiles and iron plates parallel to the beam axis
  - Volume ratio: Fe:Sc = 5.58:1
  - Longitudinal size: 5.6 λ_I
    - Mostly used as a trigger device!
  - Average light yield: ~105 p.e/GeV
  - Dynamic range: uniform E_T up to 15 GeV (in 2012: 30 GeV)
  - Energy resolution (beam tests)
    - $\sigma(E)/E = (69\pm5)\% / \sqrt{E} \oplus (9\pm2)\%$

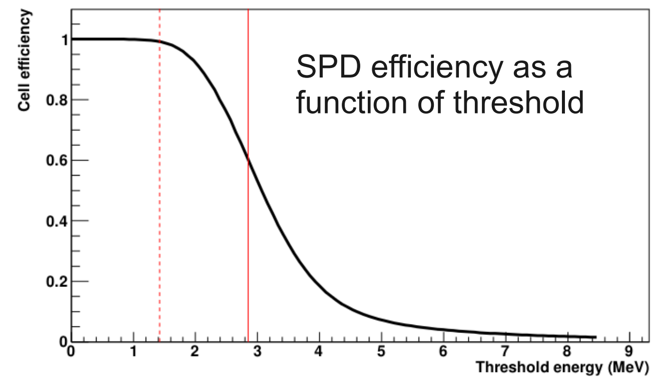




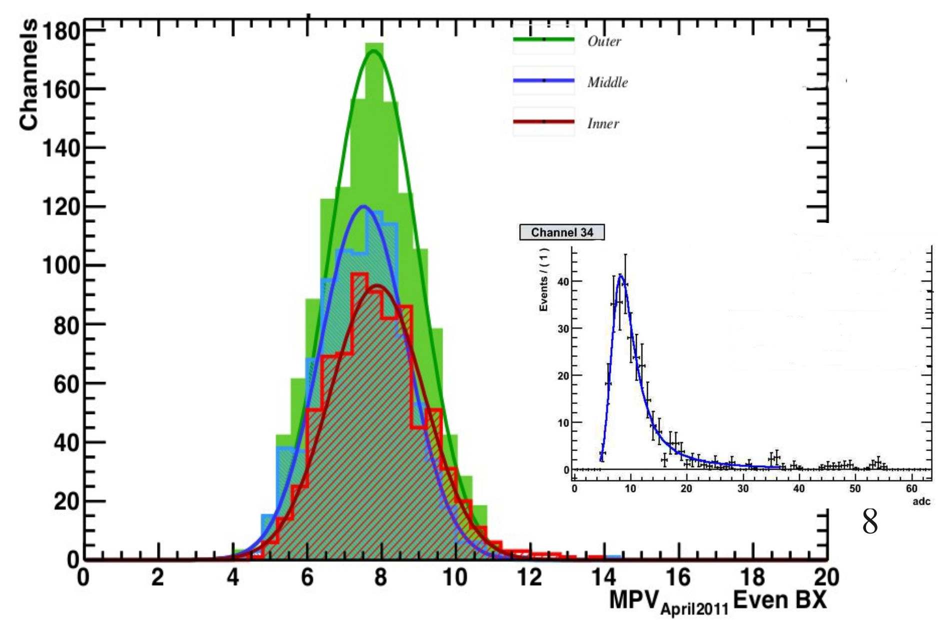
Calibration of PS and SPD

- SPD: **[LHCb-PUB-2011-024]**
  - Binary detector: no straight MIP calibration
  - Collect data at different thresholds, get efficiency to MIP and compare to theoretical expectation
  - Provide a resolution in the MIP position smaller than 5%





- PS:
  - Calibration factor is extracted from the position of MIP peak in each cell
    - ~5% precision achieved
  - Cross-check with Energy flow method:
    - Smoothing by averaging over neighbor channels
    - ~4 % precision

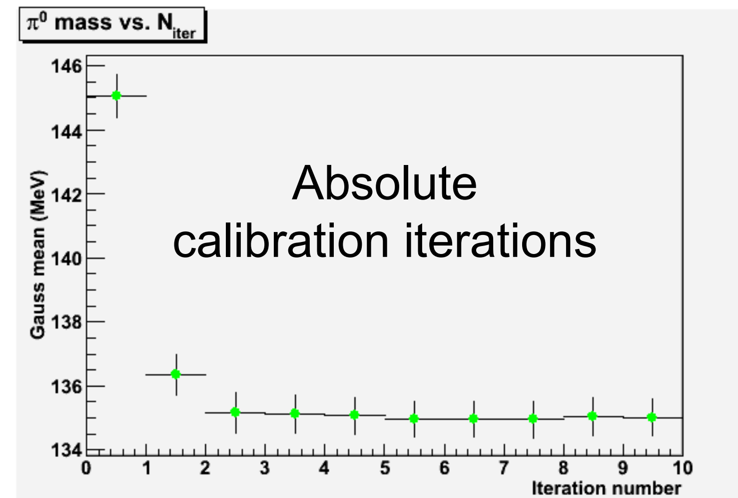


Calibration of ECAL

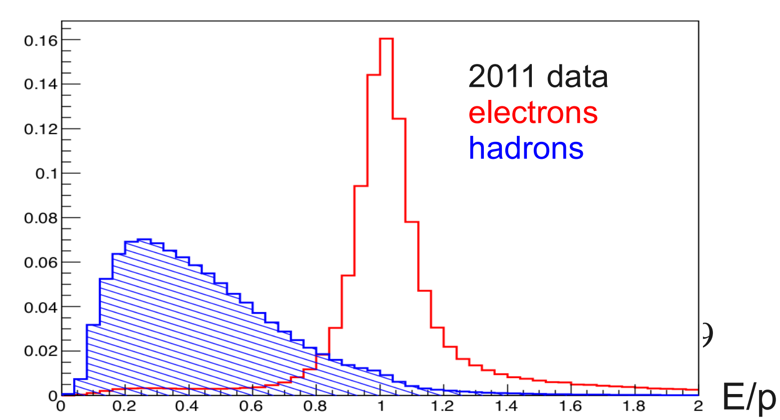
- ECAL pre-calibration done before 2009 data taking
  - At the 8% level and based on the absolute gain from LED pulse photostatistics

- Fast relative inter-calibration on collision data using an energy flow method
  - Smoothing by averaging over neighbor channels
  - ~4% precision level

- Fine absolute calibration using reconstructed π^0 peak
  - Iterative procedure by π^0 mass peak fitting
    - Find the coefficient which would move the measurement closer to the nominal mass
    - Accumulate π^0 contributing to each cell
  - ~2% precision level (π^0 mass resolution: 8 MeV/c^2)

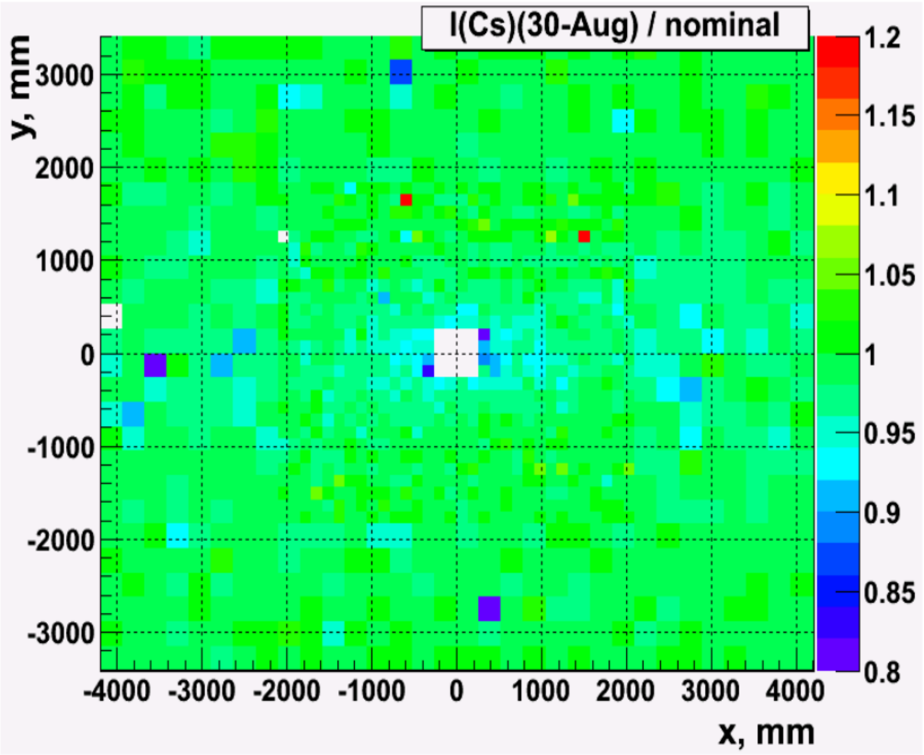


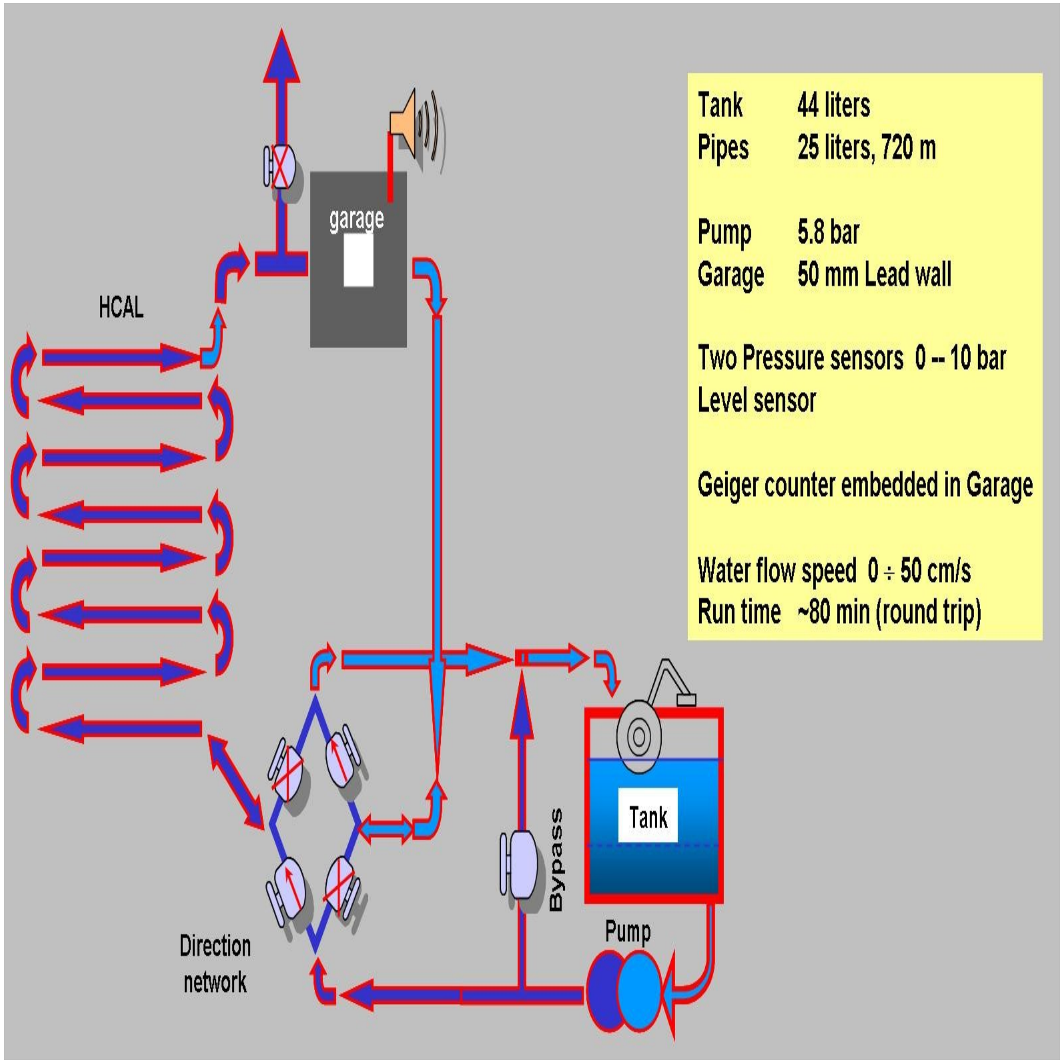
- Calibration with electrons:
  - Compare the electron momentum measured in the tracking system with its energy measured by the ECAL and PS



Calibration of HCAL

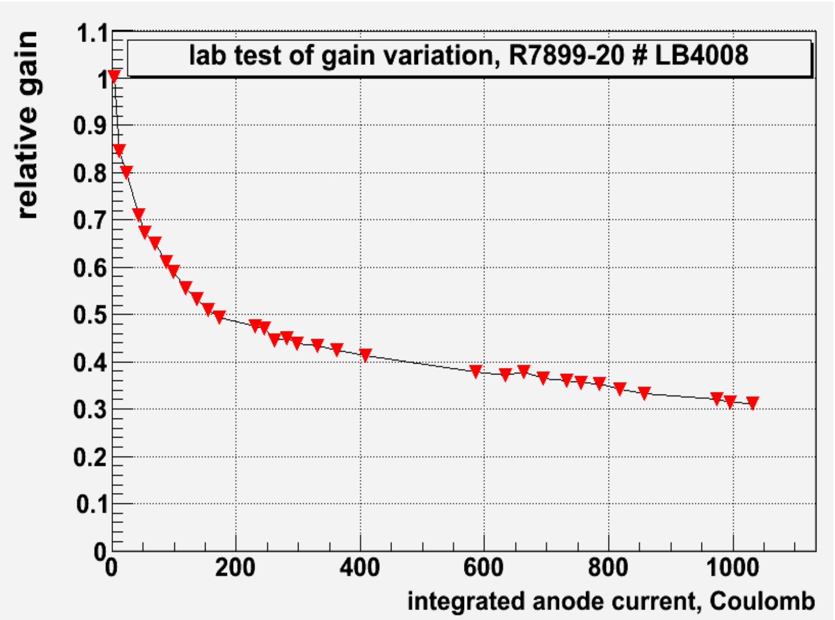
- Radioactive source scan (two 10 mCi ^{137}Cs)
  - Performed every 1 to 2 months
  - Precision: ~5% (design of HCAL)
- Cross-check with energy flow method



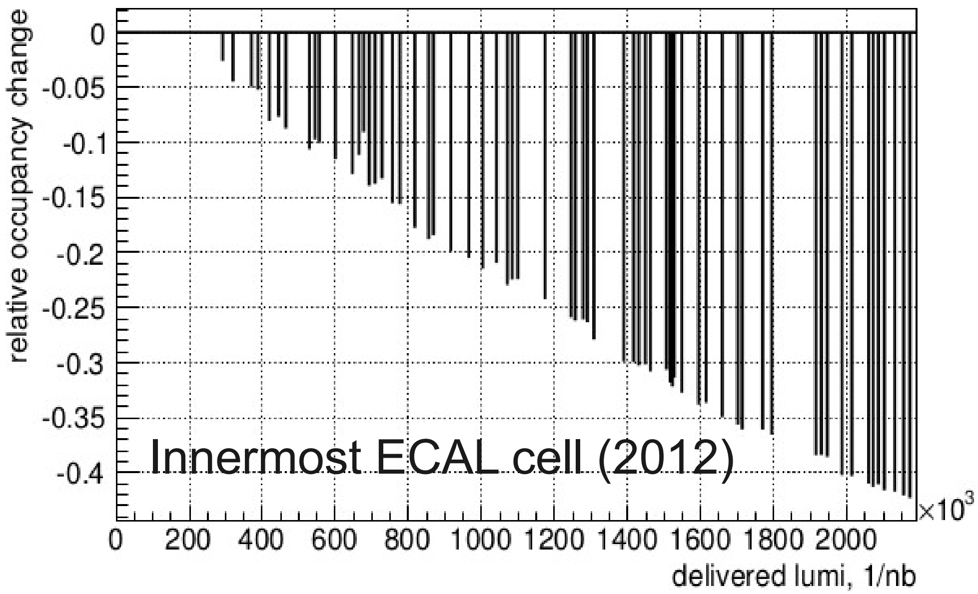


Aging

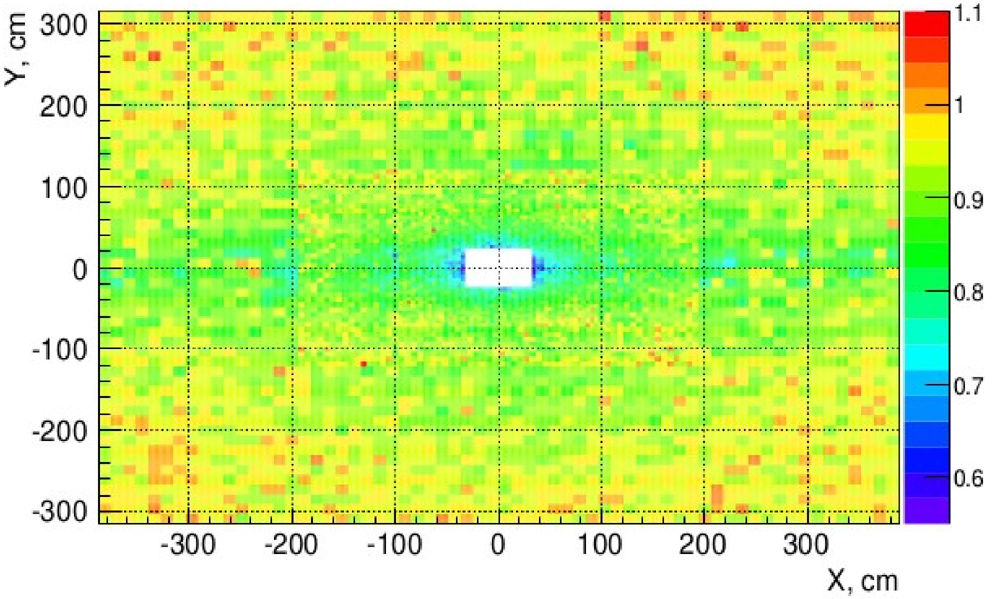
- Two major sources:
  - Radiation damage of scintillator tiles and WLS fibers
  - PMT degradation with the integrated current
- ECAL:
  - 20 C (2011) + 37 C (2012)
- HCAL:
  - 2011: up to 100 C
  - 2012: gain reduced by 2



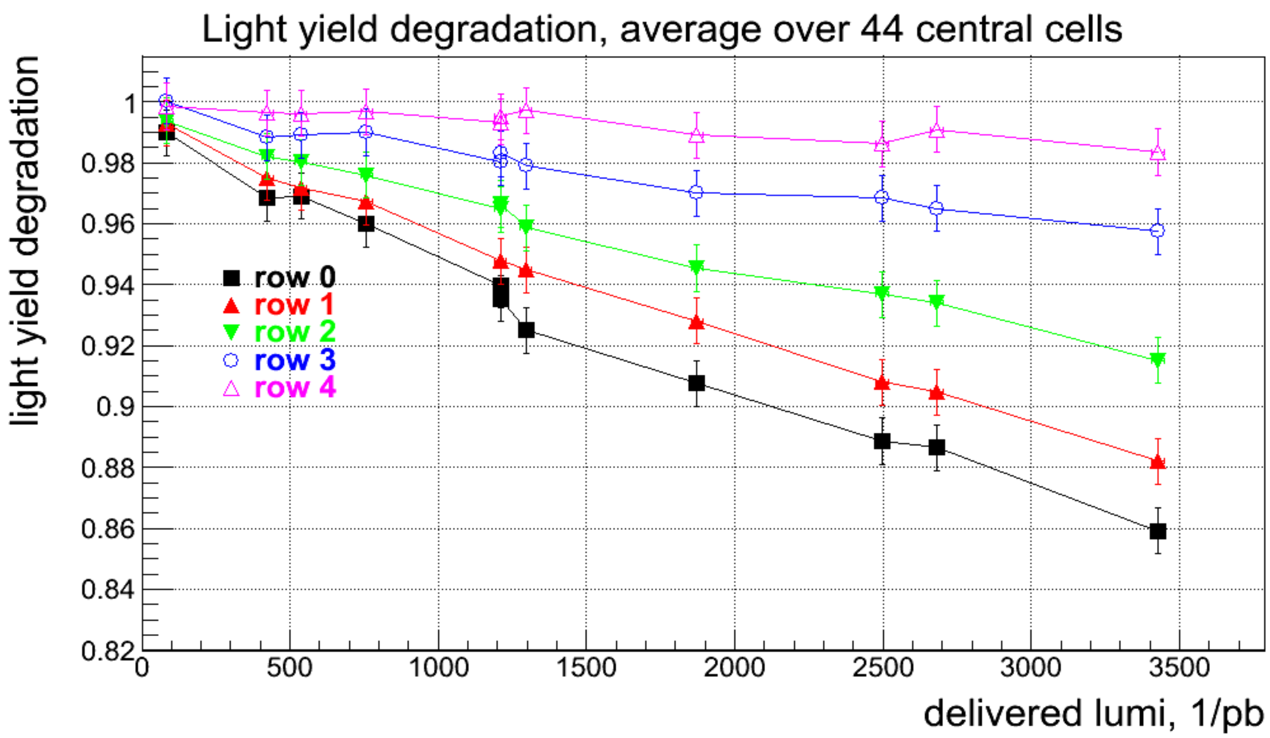
- ECAL: up to 40% for the most irradiated cells

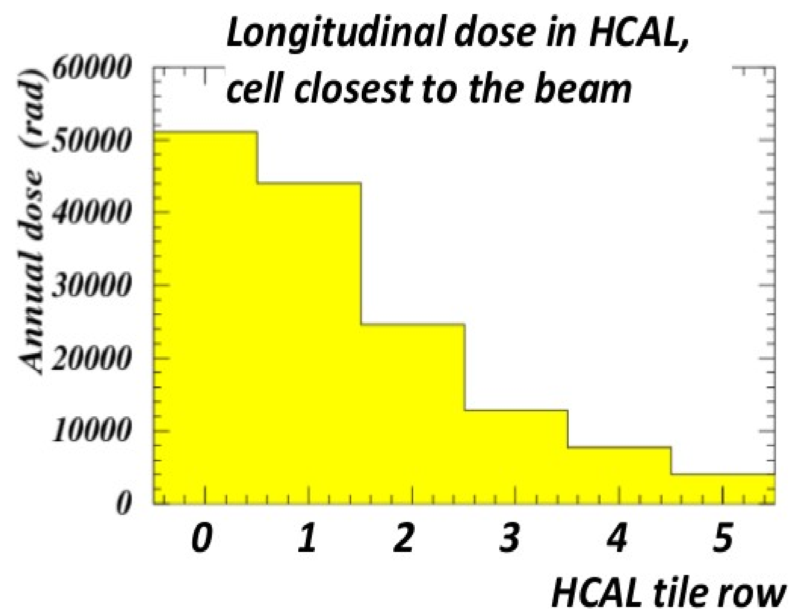


ECAL: Dec/May 2012 ratio



Aging





- Longitudinal dose in HCAL (cells closest to beam):
  - Radiation damage of tiles and fibers (checked directly with radioactive source)
  - Most affected tiles are in the plane closest to IP (row 0)
- Compensation of aging effects:
  - Regular calibrations
  - PMT HV changes

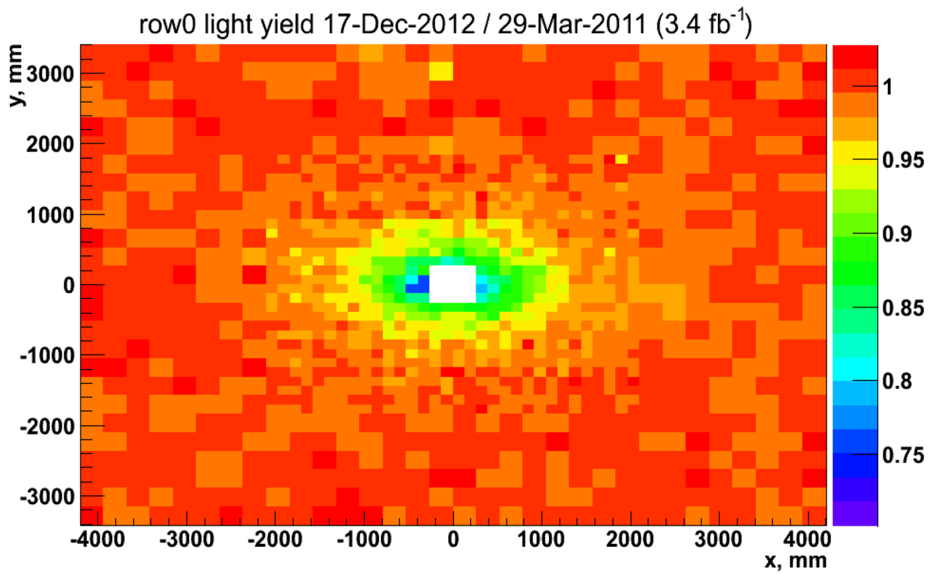
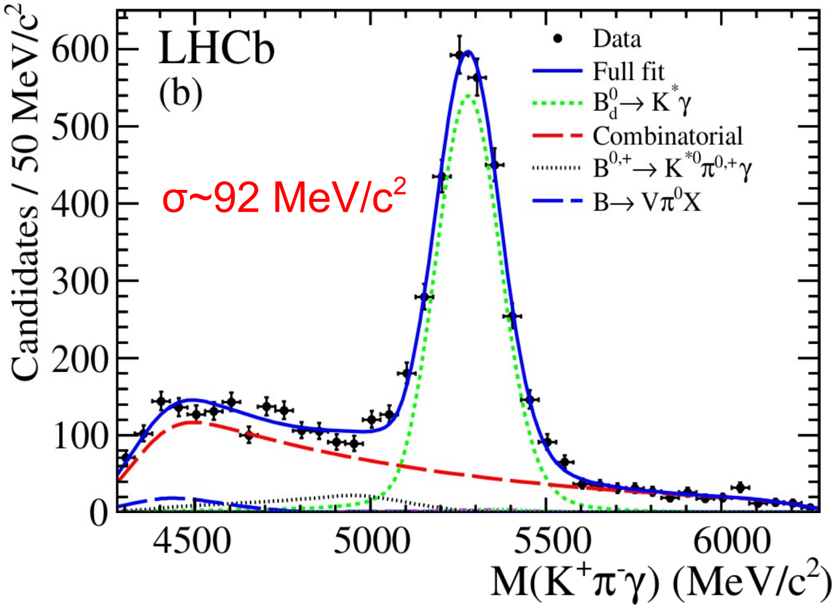


Illustration of Performances

- High energy photon: $B^0 \rightarrow K^{*0}\,\gamma$

L=1.0 fb^{-1} [NP B 867 (2013) 1]



- $\eta \rightarrow \gamma\gamma$

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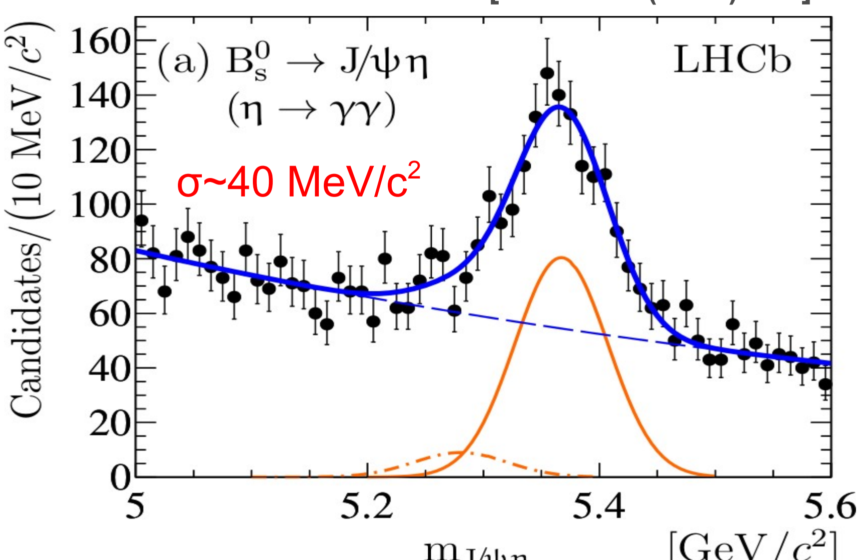
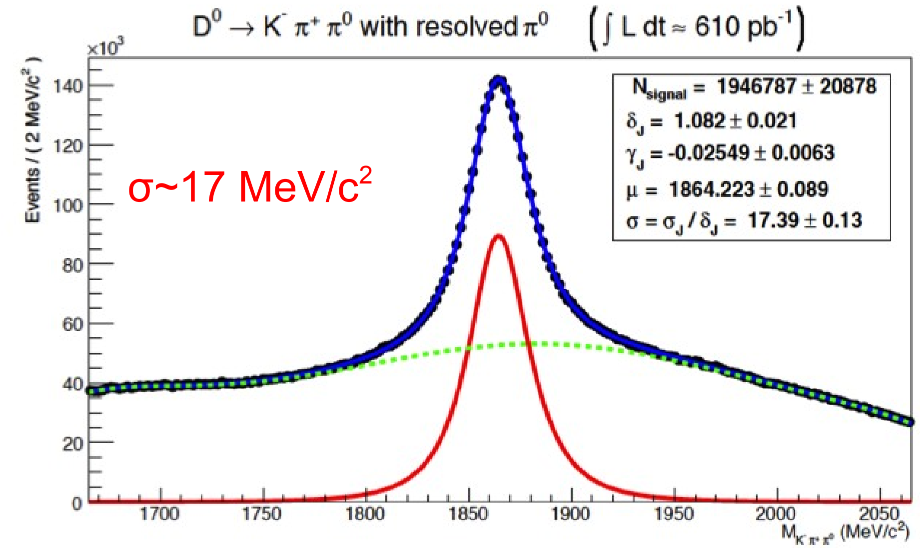
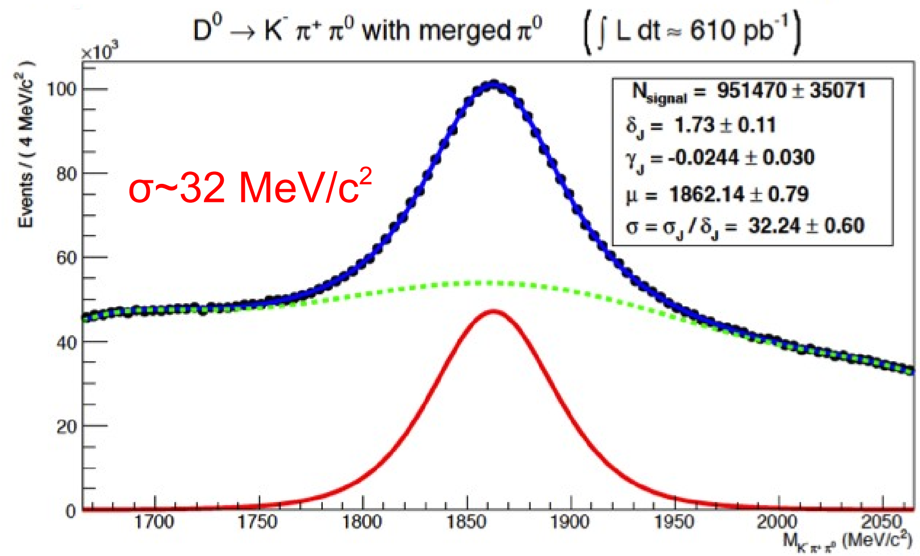


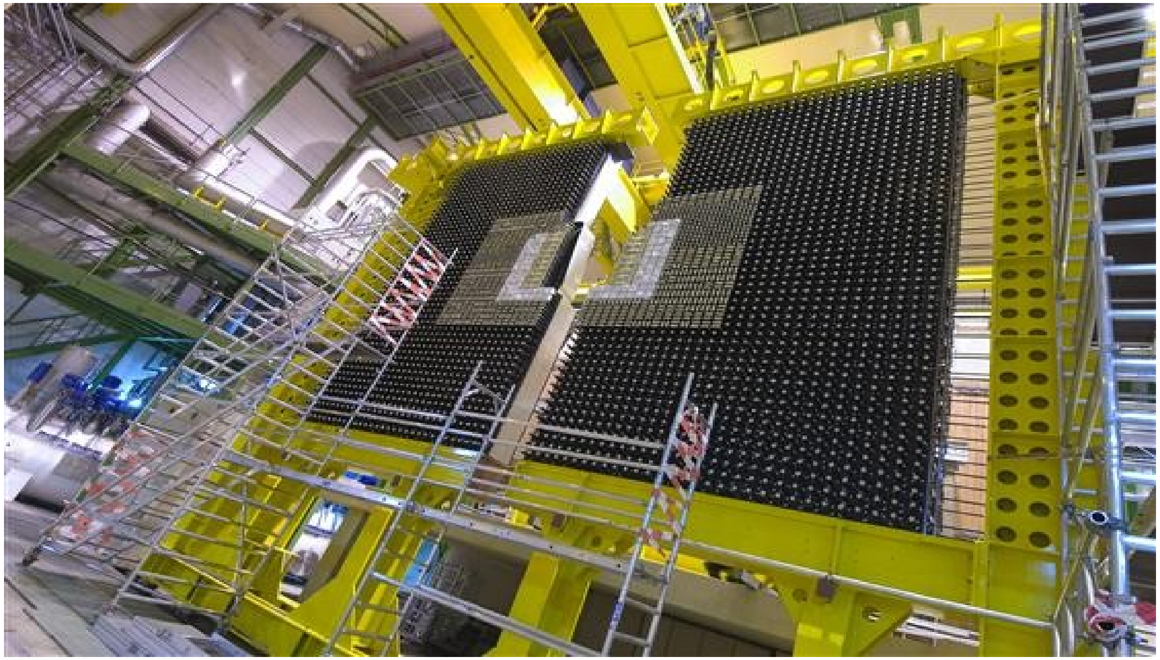
- Neutral pion: $D^0 \rightarrow K^-\,\pi^+\,\pi^0$





Conclusion

- LHCb calorimeters fully functional:
  - Smoothly operating over the entire period of data taking
- Performing well:
  - L0 trigger
  - Physics results:
    - Radiative decays: $B \rightarrow V\gamma$
    - D0 decays with π^0
    - χ_c, J/psi $\eta^{(')}$, etc.



- Aging observed (PMT, scintillators):
  - Frequent calibrations:
    - PMT HV adjustment (ECAL/HCAL)
    - Calibration coefficients used in reconstruction software
  - Fast online procedure producing set of relative correction factors for each long fills (development ongoing)

Backup

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