7th International Conference on
New Developments In Photodetection
Tours, France, June 30th to July 4th **2014**
NDIP

First years of running for the LHCb calorimeter system

NDIP 2014

June 30th – July 4th, 2014

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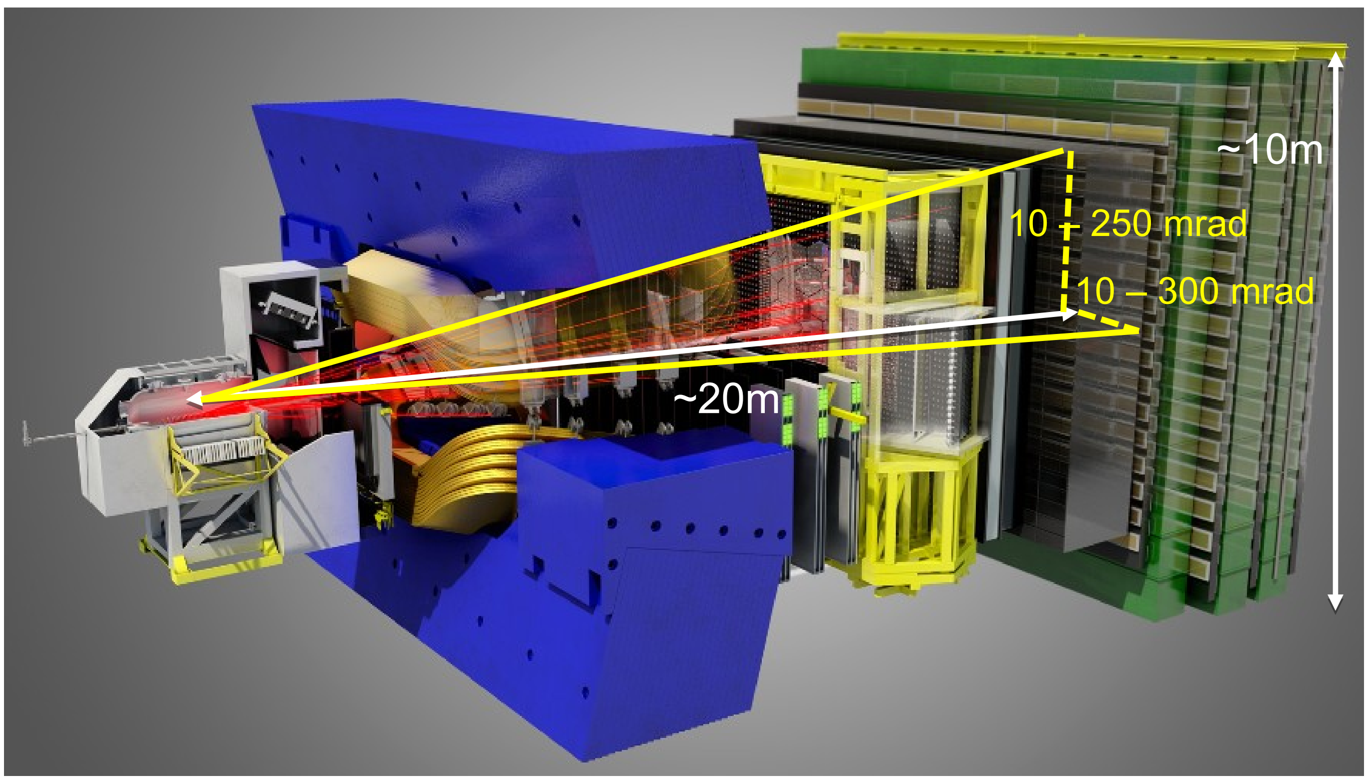
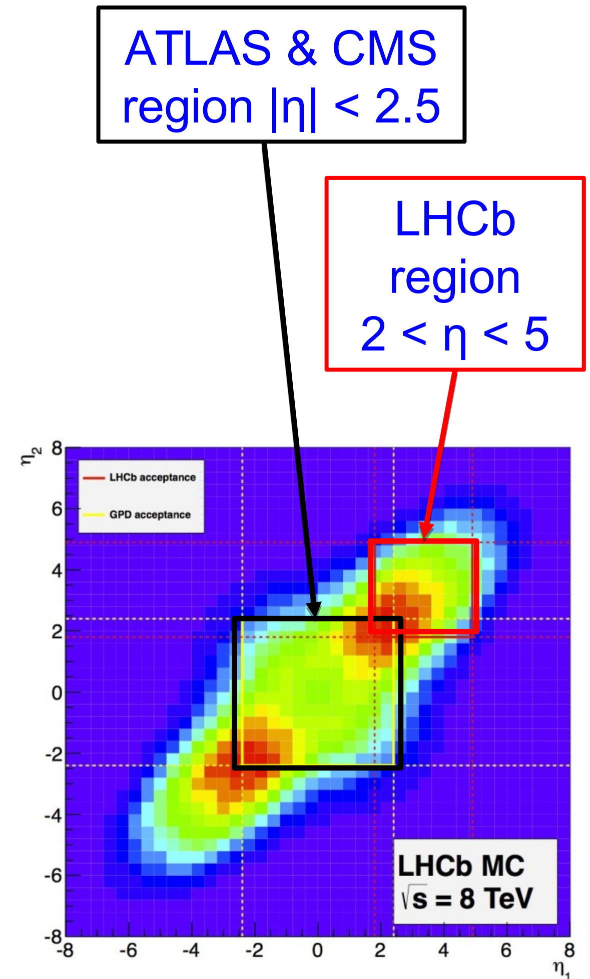
On behalf of the LHCb collaboration

NDIP

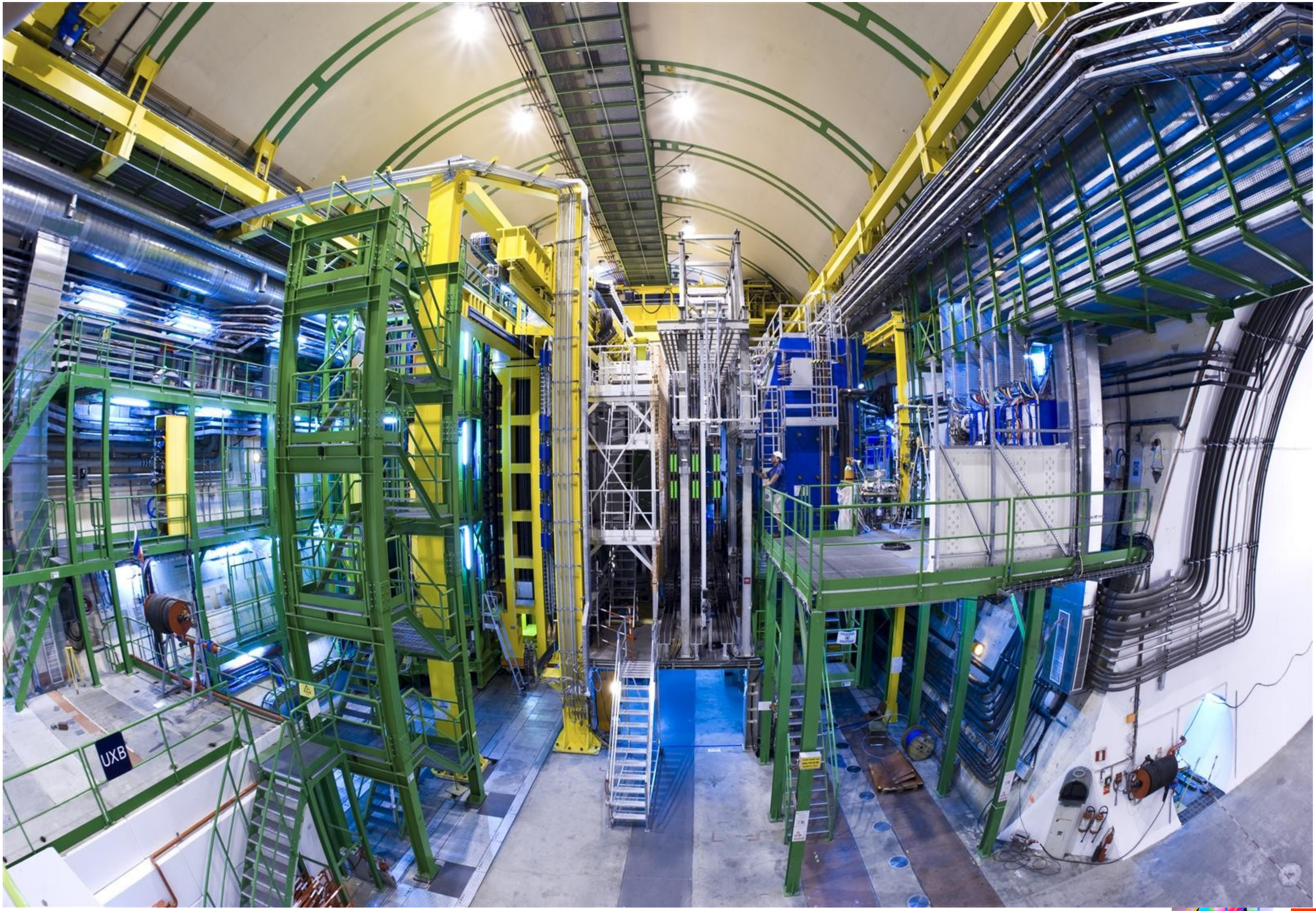
The LHCb detector

- Precision measurements in the beauty and charm quark sectors
  - Study of CP violation, rare decays
  - discovery of new states, indirect search for new physics beyond the standard model
- LHCb is a single-arm spectrometer
  - 4% of the solid angle
  - 30% of the heavy quarks cross-section production at LHC

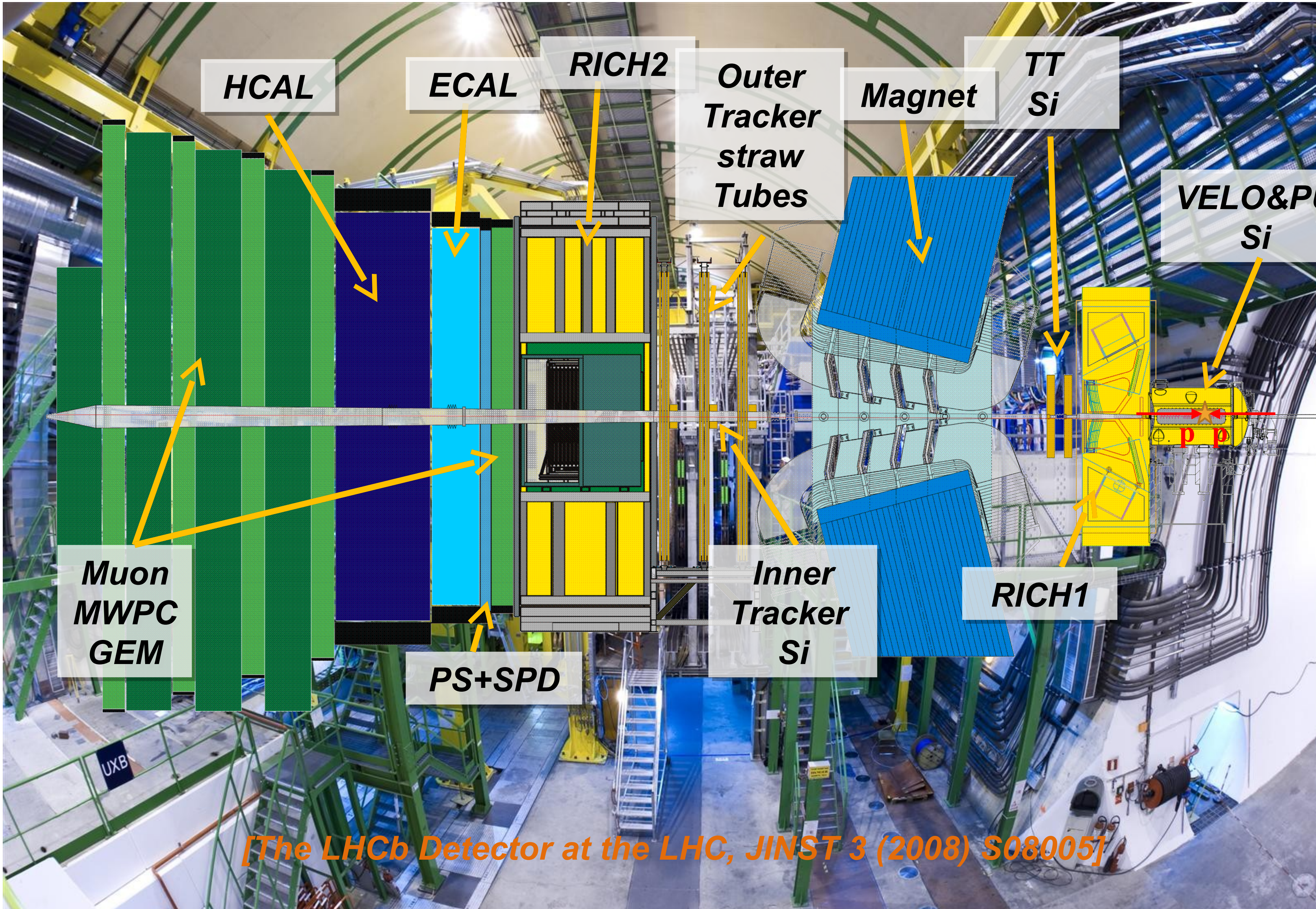




The LHCb detector



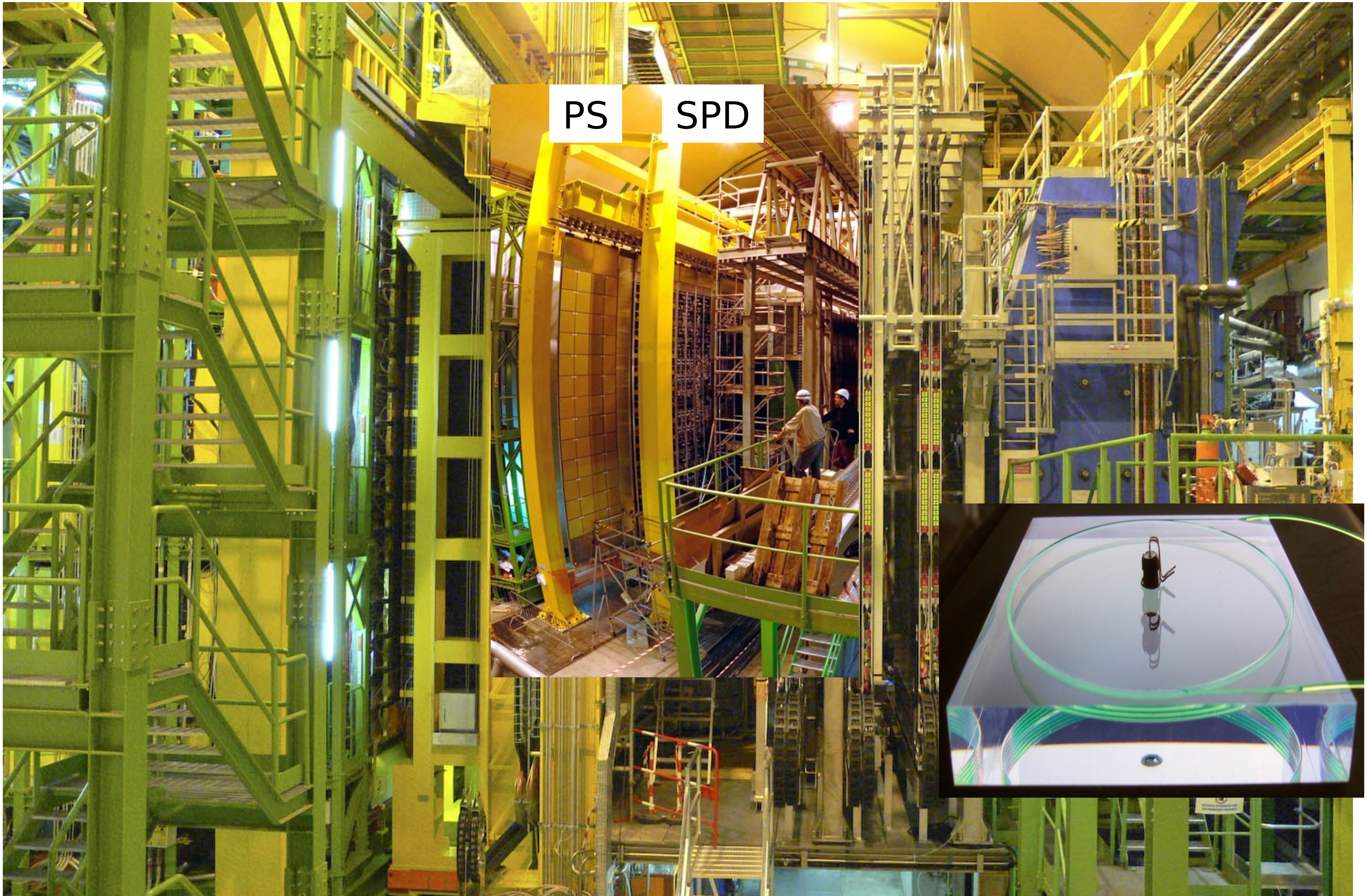
The LHCb detector



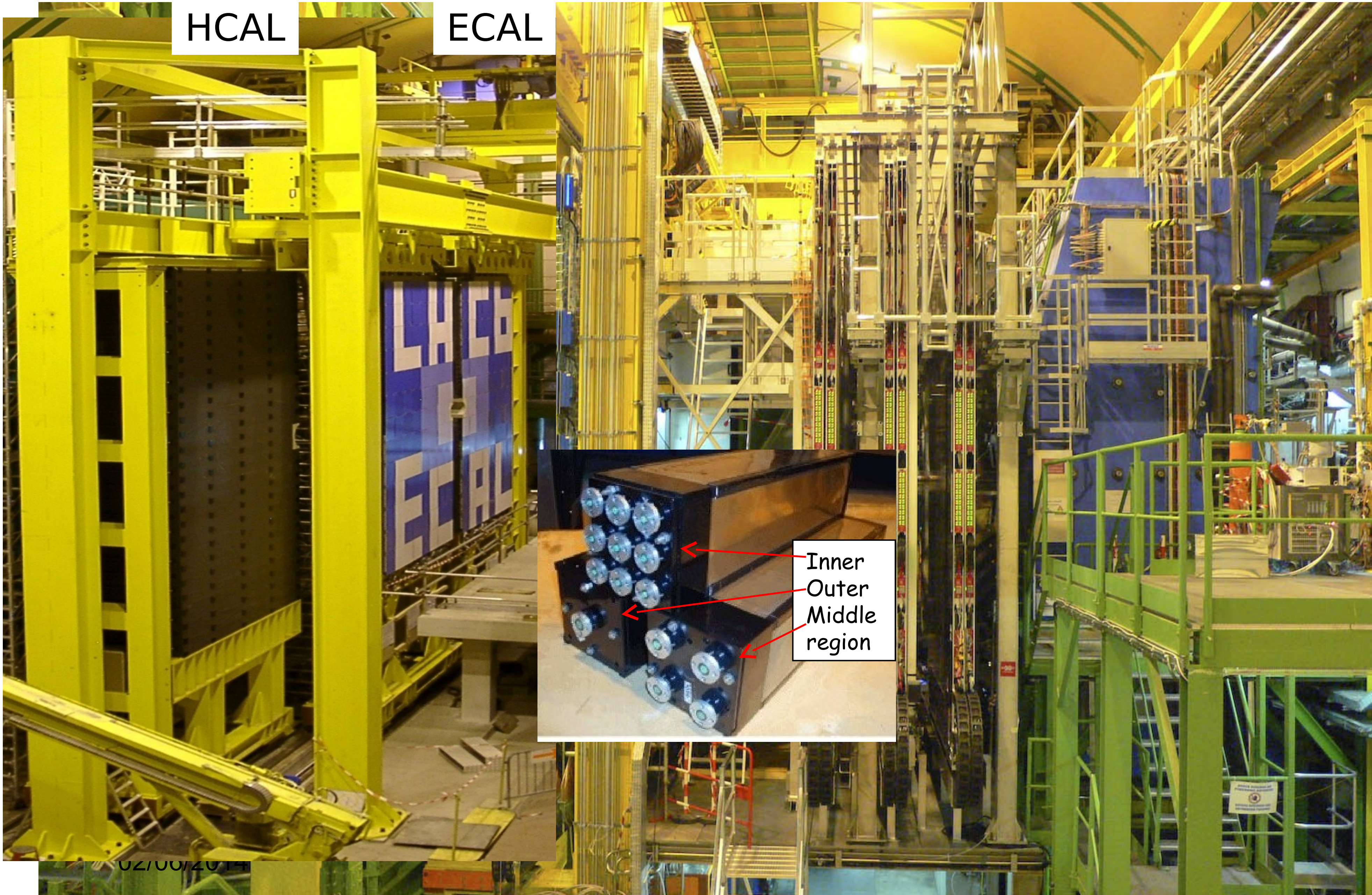
The calorimeter system

[JINST 3 (2008) S08005,
LHCb calorimeters", TDR, CERN/LHCC/2000-0036 LHCb TDR 2]

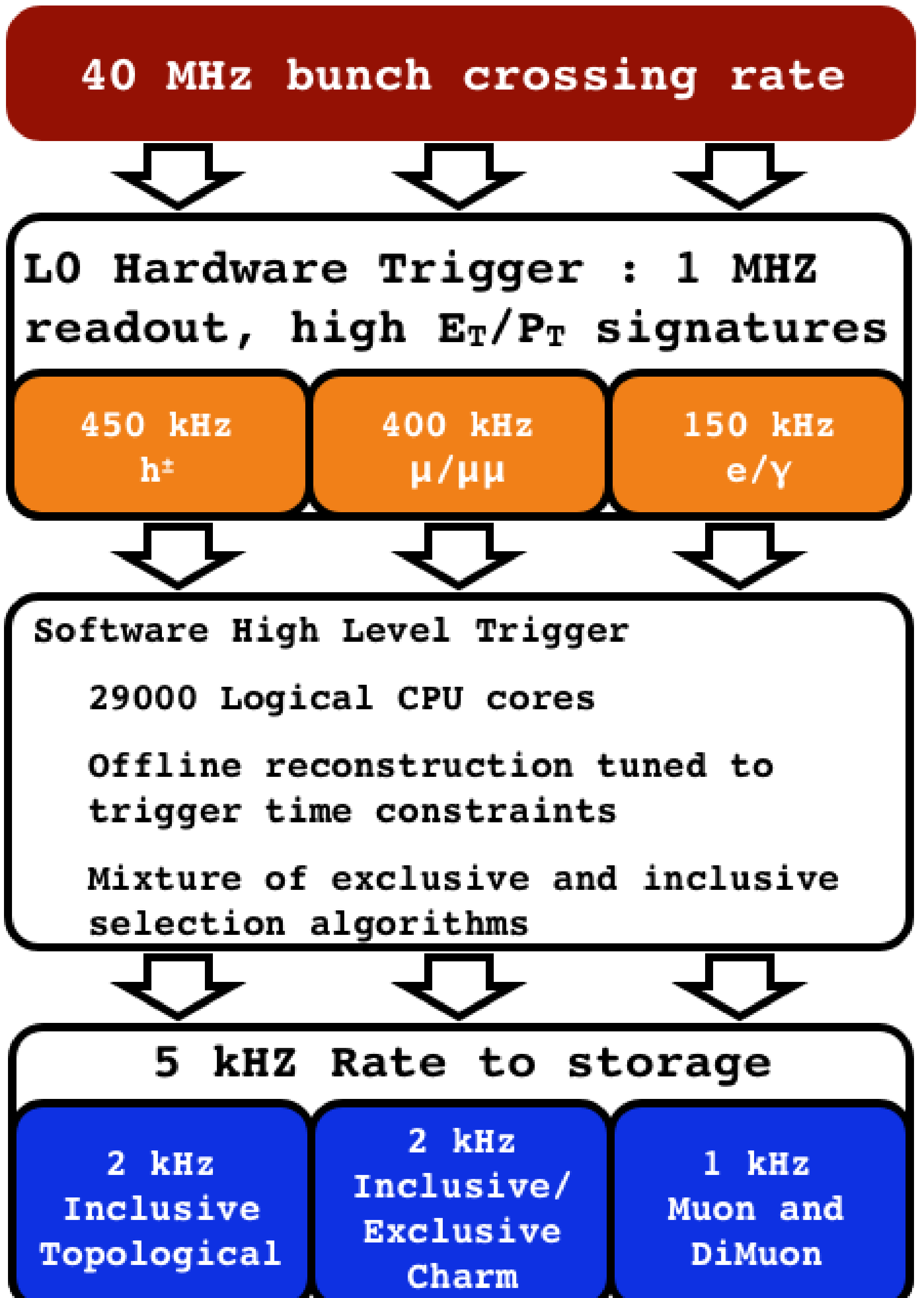
The calorimeter system: SPD, PS



The calorimeter system: ECAL, HCAL

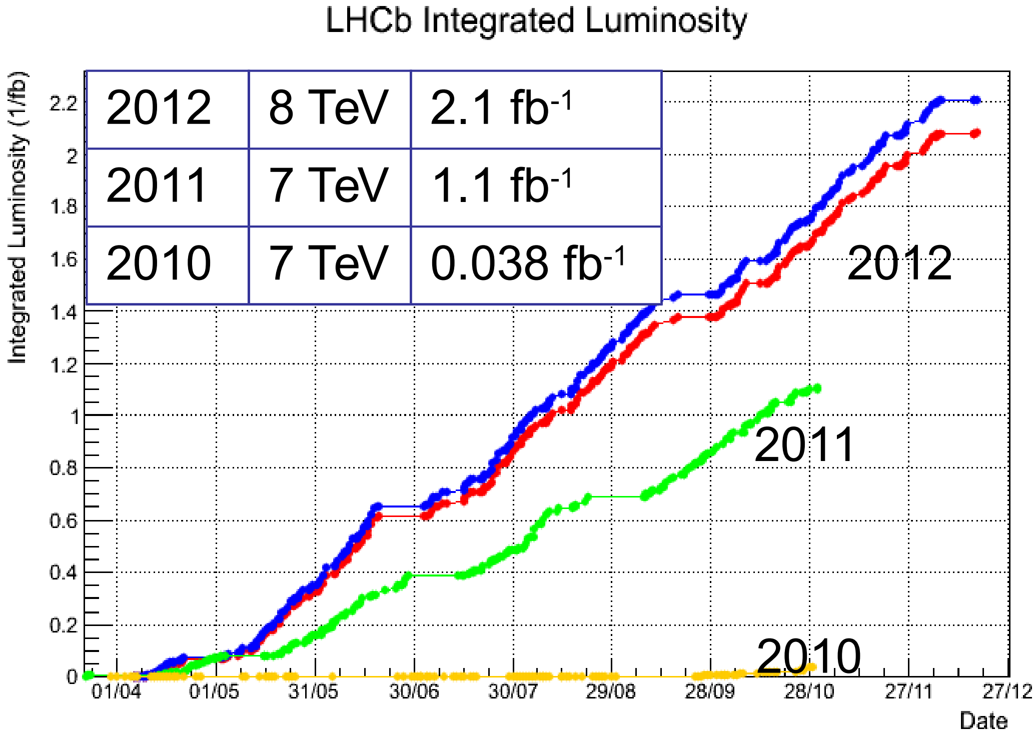


LHCb trigger

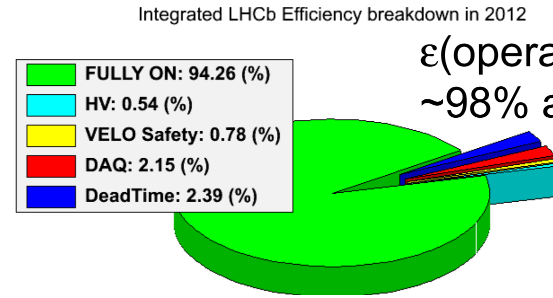


- L0 trigger
  - first level trigger of LHCb
  - 4μs latency at 40MHz
  - Apply selection cuts
    - Et(γ/e) > 2.7 GeV
    - Et(h) > 3.6 GeV
    - Pt(μ) > 1.4 GeV
- HLT : software trigger
  - 300k tasks in parallel
  - More than 1500 nodes
- Storage : 5kHz
- Combined efficiency
  - 90% for muon channels
  - 30% for multi-hadronic final states

LHCb operation



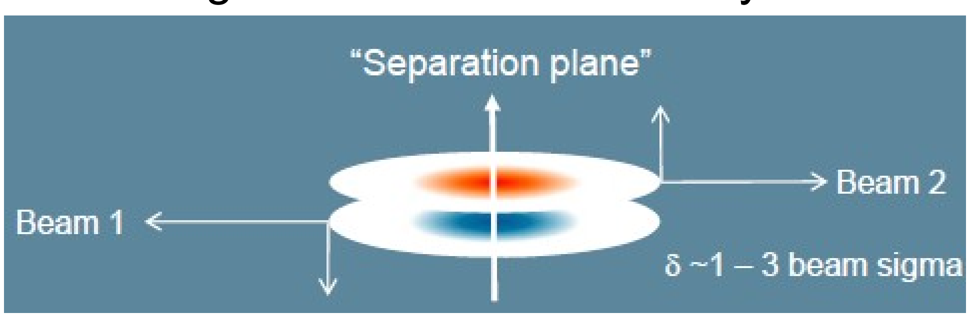
2012	8 TeV	2.1 fb^{-1}
2011	7 TeV	1.1 fb^{-1}
2010	7 TeV	0.038 fb^{-1}

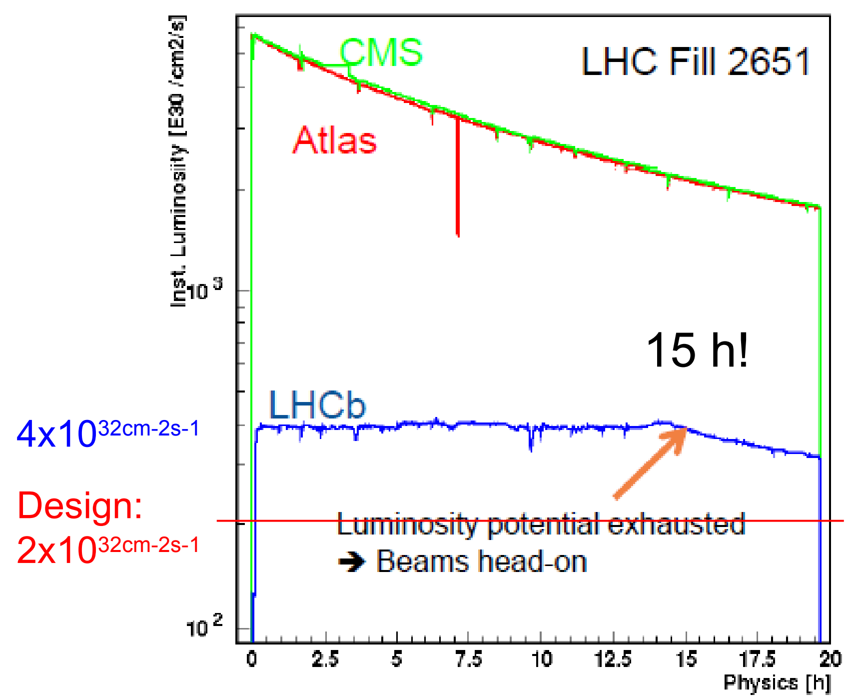


ε(operation)>94%
~98% are good data!

Detectors all with >~99% active channels

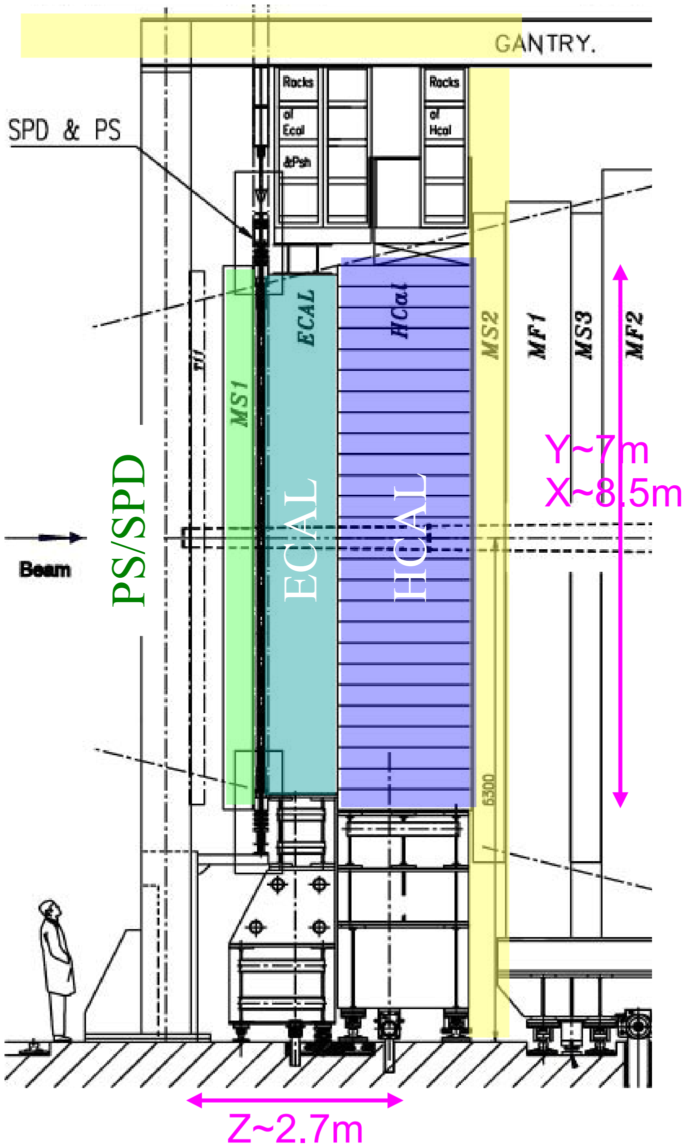
Semi-continuous (automatic) adjustment of offset of colliding beams allows luminosity to be *levelled*





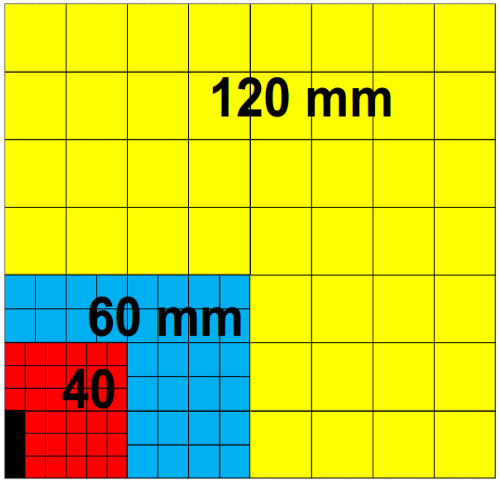
4 times more collisions per crossing than in the design

Calorimeter system geometry

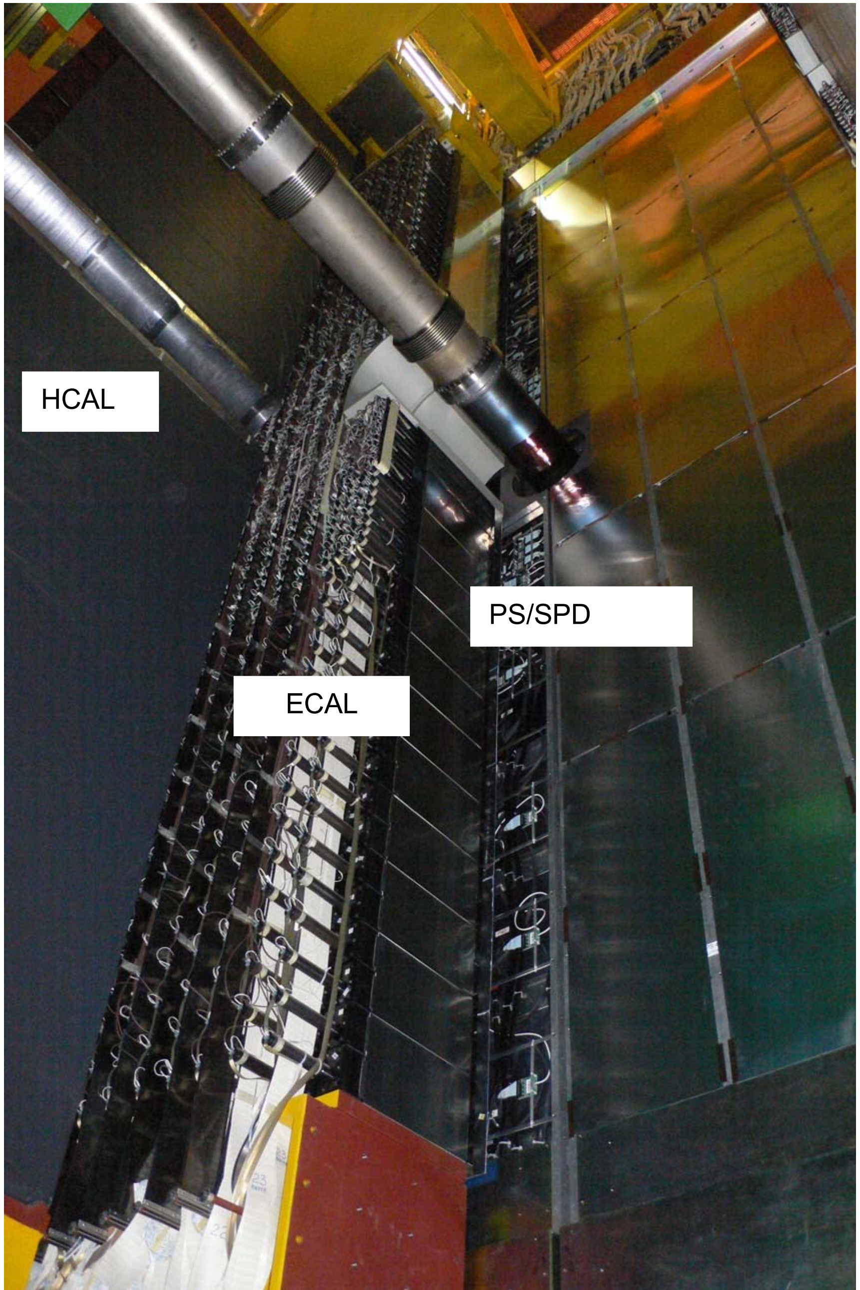


02/06/2014

- 40MHz trigger on energetic e, π^0, γ, h
- Distance to IP ~13m
- Solid angle coverage 300 x 250mrad
- Four sub-detectors:
  - SPD, PS, ECAL, HCAL
- Independently retractable halves
- Granularity :
  - SPD, PS, ECAL : 6016 cells with 3 sizes
    - 4x4, 6x6, 12x12 cm^2 (2 zones for HCAL)

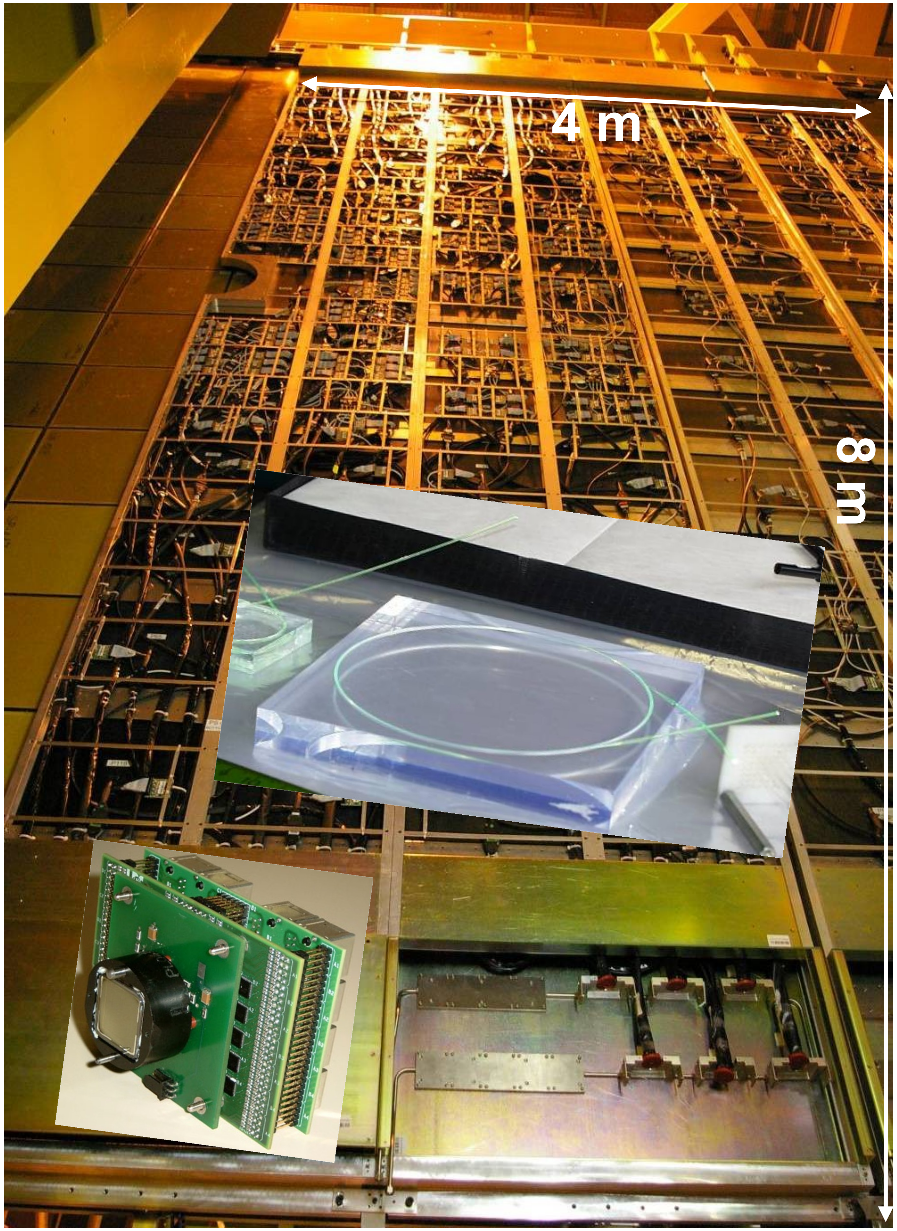


Calorimeter system



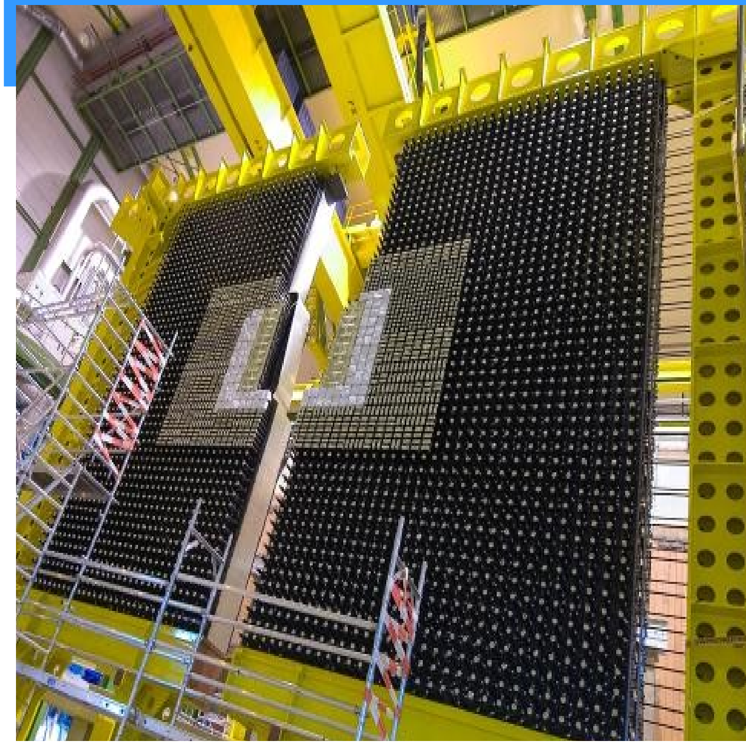
- 40MHz trigger on energetic e π^0, γ, h
- Distance to IP ~13m
- Solid angle coverage 300x250mrad
- Four sub-detectors: SPD, PRS, ECAL, HCAL
- Independently retractable halfes
- Granularity :
  - PRS, ECAL, HCAL : 6016 cells with 3 sizeS
    - 4x4, 6x6, 12x12 cm^2
- Detection
  - Sandwich of scintillator/lead (iron for HCAL)
  - WLS are used to collect the light and to propagate it to photomultipliers
    - MAPMT for the SPD/PS

Scintillating Pad Detector - Preshower



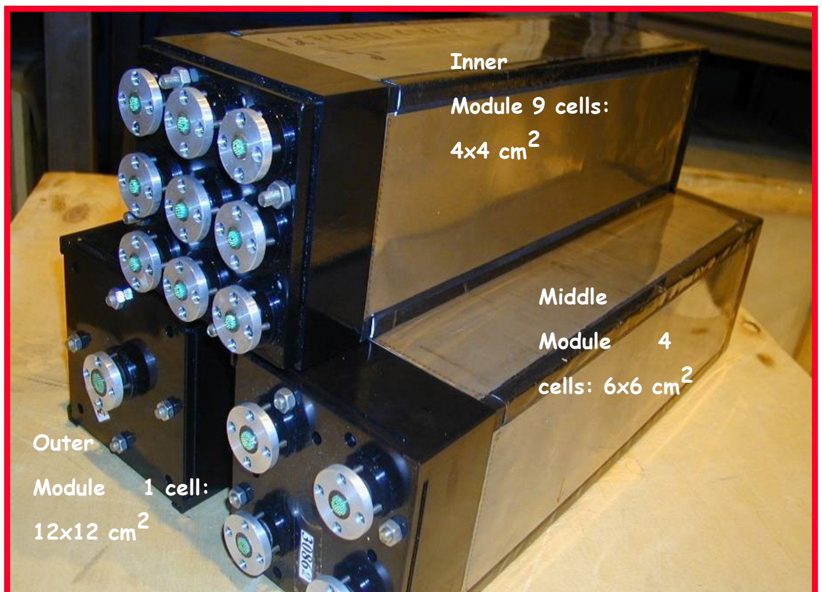
- Scintillator pads
  - 2.5 X_0 lead
  - 15mm thick
  - Light collected by WLS
- Signal read by 64 channel MAPMT
- Average light yield
  - 20 pe/mip
- SPD
  - 1 bit
- PS
  - 10 bits
  - Dynamic range 0 - 100mip

ECAL



- Electromagnetic calorimeter
  - 66 layers
    - 2mm Pb, 4mm scintillator
  - Light collected by WLS
  - Moliere radius ~ 3.5cm
  - Longitudinal size
    - 25 X_0
    - 1.1 λ_I
  - Average light yield :
    - 3000 pe/GeV
  - Dynamic range ~12 GeV (Et)
  - Energy resolution (test beam)

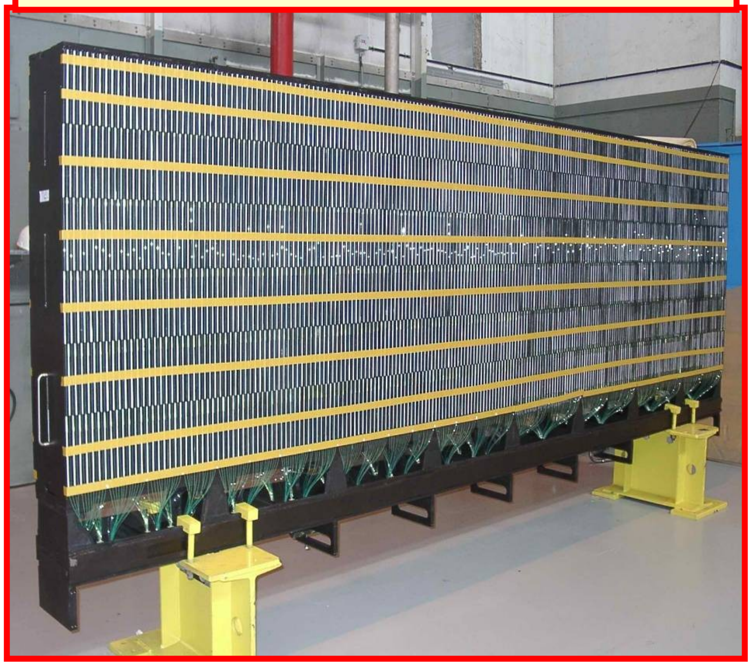
$$\frac{\sigma(E)}{E} = \frac{10\,\%}{\sqrt{E}} \oplus 0.9\,\%$$



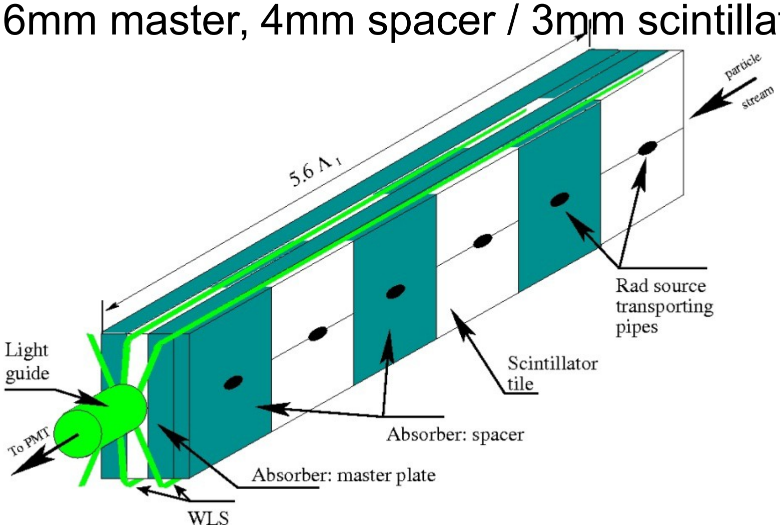
3312 shashlik modules with 25 X_0 Pb

HCAL

52 modules with longitudinal tiles



6mm master, 4mm spacer / 3mm scintillator



- Hadronic calorimeter
  - 26x2 modules
  - Interleaved scintillator and iron plates
  - Parallel to the beam axis
  - Volume ratio
    - Fe:Sc = 5.58:1
  - Longitudinal size
    - 5.6 λ_I
  - Average light yield ~ 105pe/GeV
  - Dynamic range ~15 / 30 GeV
  - Energy resolution (test beam)

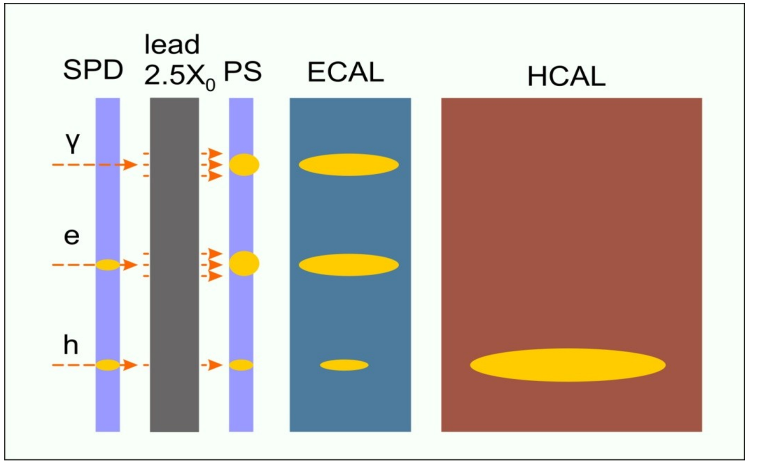
$$\frac{\sigma(E)}{E} = \frac{(69 \pm 5)\%}{\sqrt{E}} \oplus (0 \pm 2)\%$$

Calorimeter particle identification

- PS / SPD for L0 electron/photon trigger
  - Electron/photon separation from SPD
  - Photon/mip separation PS
  - Charge multiplicity given by the SPD

SPD/PS/ECAL/HCAL
in coincidence

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



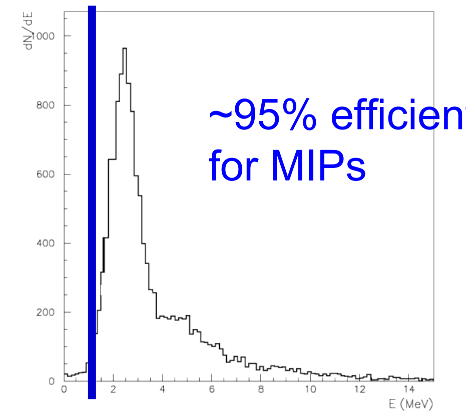
- ECAL
  - Et of electrons, photons, π^0 for L0 trigger
  - Offline reconstruction of π^0 and photons
  - Particle identification

- HCAL
  - Et of hadrons for L0, ∑Et for L0 trigger

    (~ 500 MHz out of the 1MHz bandwidth of the L0)

Calibration : SPD

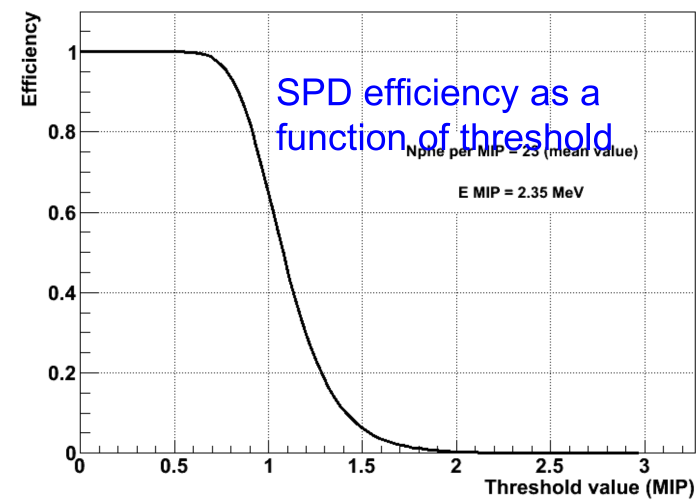
- SPD (LHCb-PUB-2011-24)
  - Threshold set at 0.5 mip
  - Binary detector
    - No straight mip calibration
    - Tracks are extrapolated to the SPD
    - Collect data at different thresholds
      - Get mip efficiency by comparing with theoretical value



$$\epsilon = Landau \times Poisson$$

Energy loss

Fluctuations of the npe at the photocathode

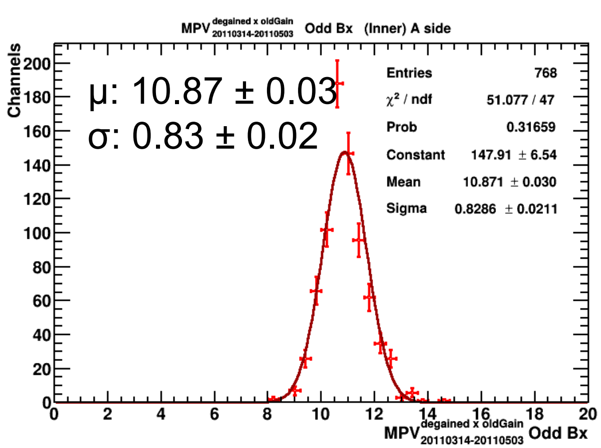


$$\epsilon = \frac{\#\, of\ SPD\, hits}{\#\, tracks \rightarrow SPD}$$

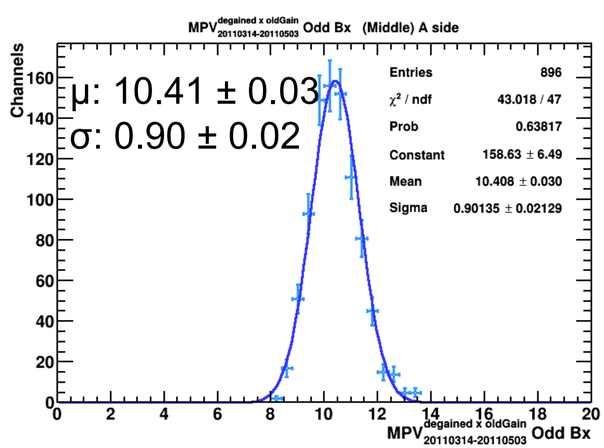
Precision on the mip position better than 5%

Calibration : Preshower

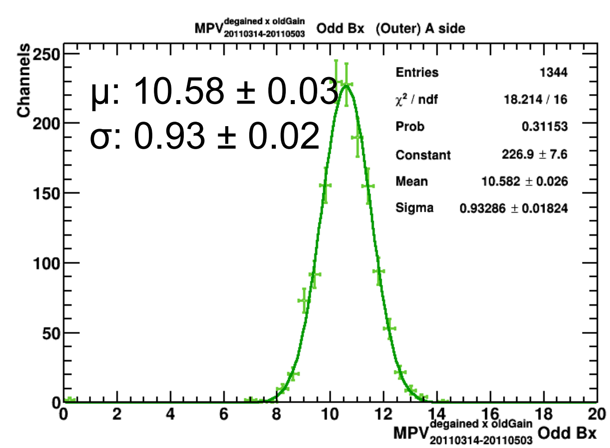
- Preshower
  - Mip signal set at ~10 ADC counts (~1mip)
    - Use extrapolation of the tracks to the PS
    - Mip signal is fitted (Landau ⊗ Gauss for statistical resolution) and fixed to a given number of photoelectrons
      - 5% precision level



INNER



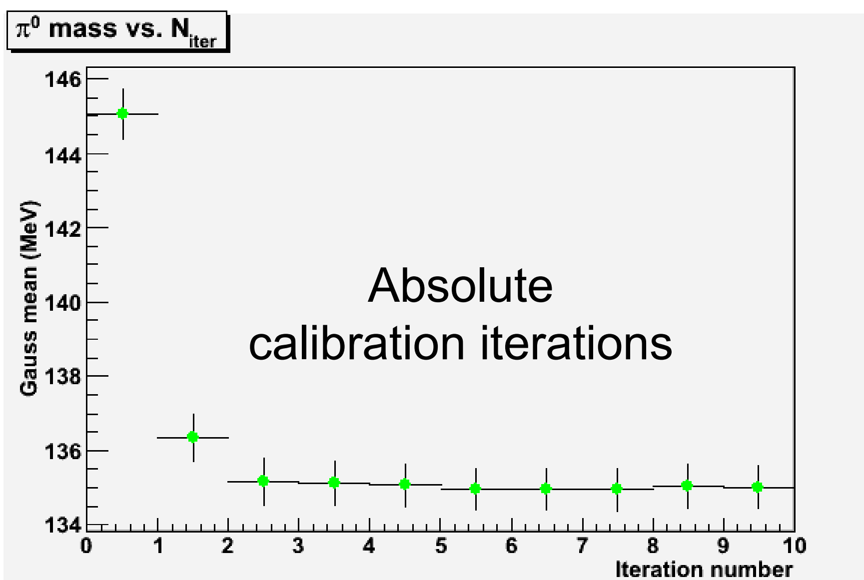
MIDDLE

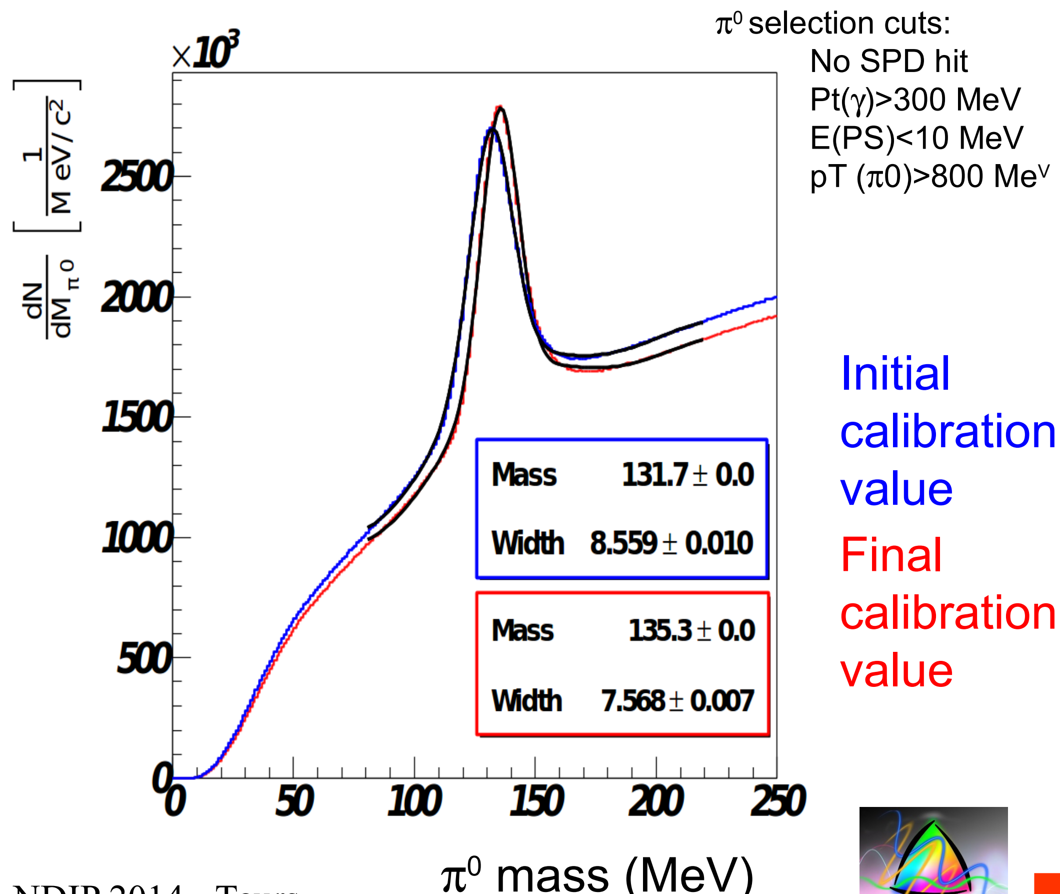


OUTER

Calibration : ECAL

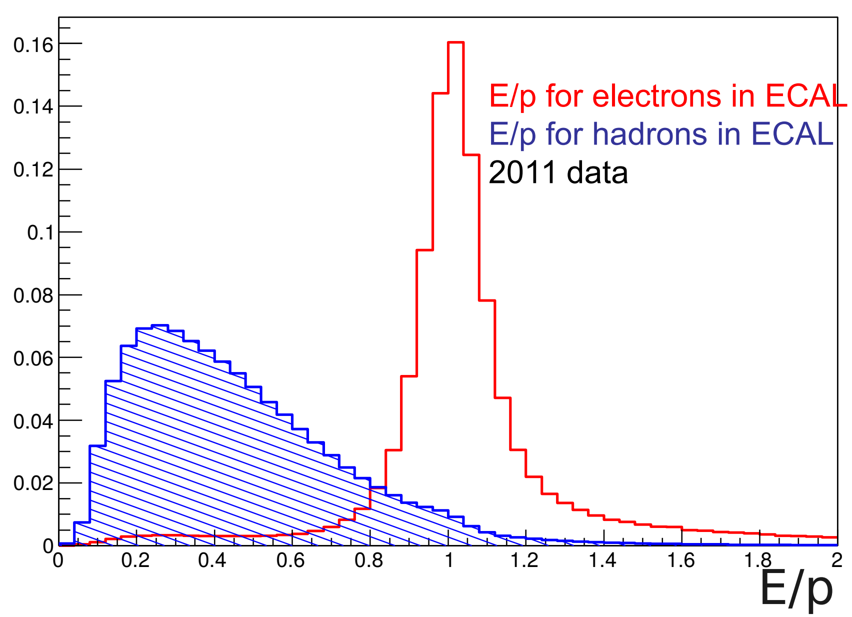
- Fine calibration using reconstructed π^0
  - Iterative procedure based on the π^0 mass fit
  - Find the calibration coeff that moves the π^0 mass close to the theoretical value
    - $\lambda = m_{th}/m_{rec}$ → one coefficient per cell (more than 6000 cells)
- ~1% precision reached
  - 100 million events needed (200pb^{-1}, 1 month)

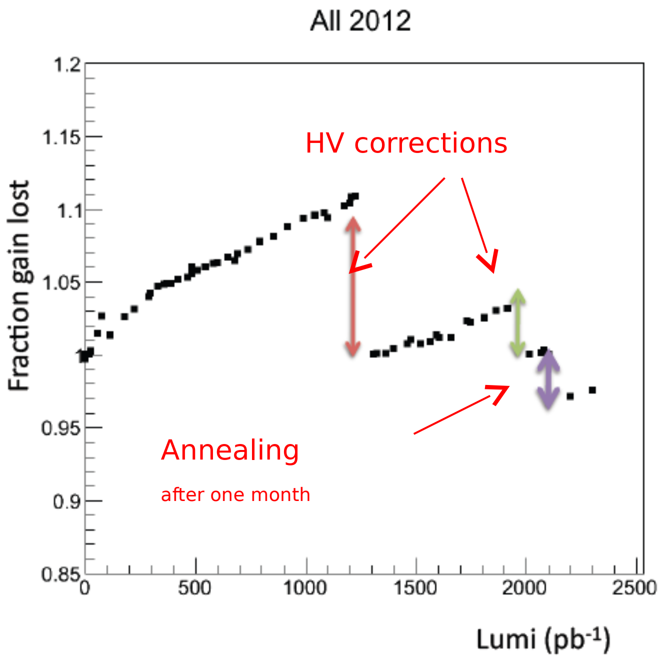




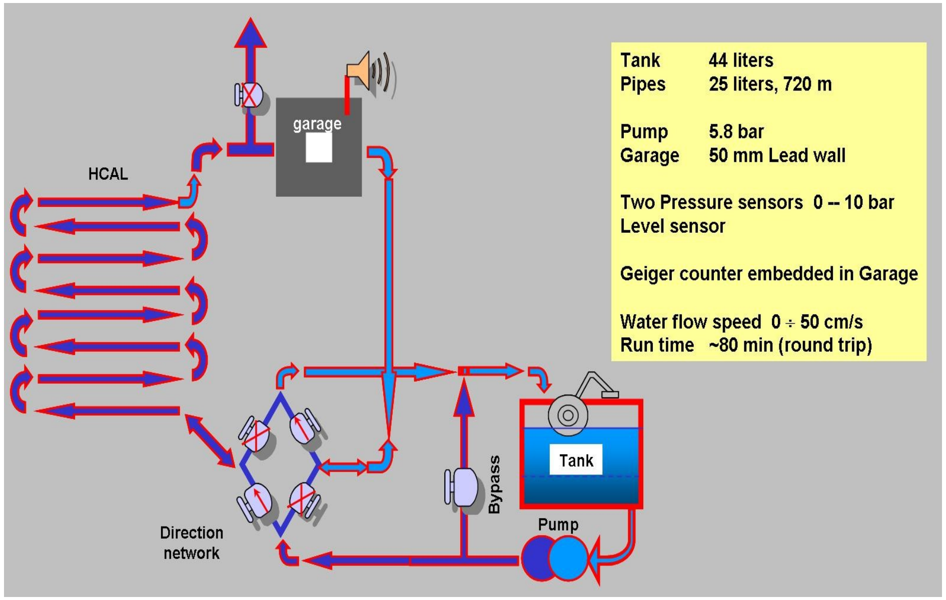
Calibration : ECAL

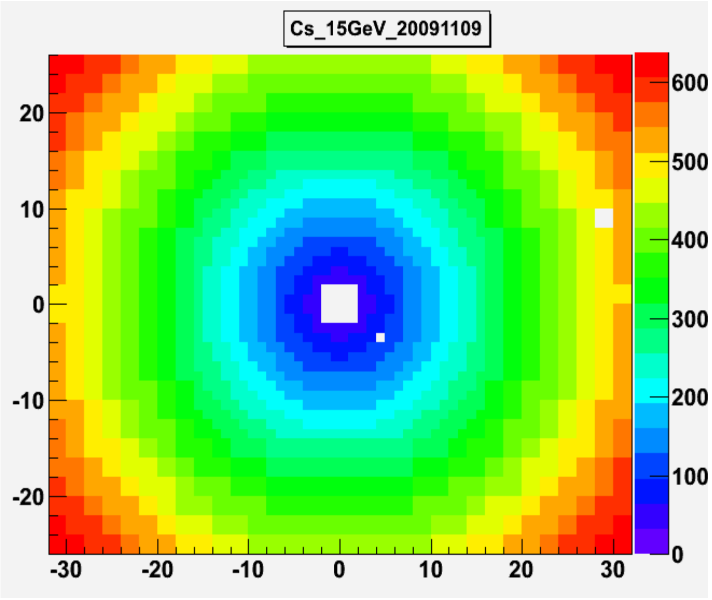
- ECAL calibration with electrons
  - Comparison of the electron momentum from the tracking with its energy measured in the ECAL and PS (electrons from conversions selected with RICH PID)
  - Also used to monitor the ageing and applying trend corrections every 40pb^{-1}





Calibration : HCAL



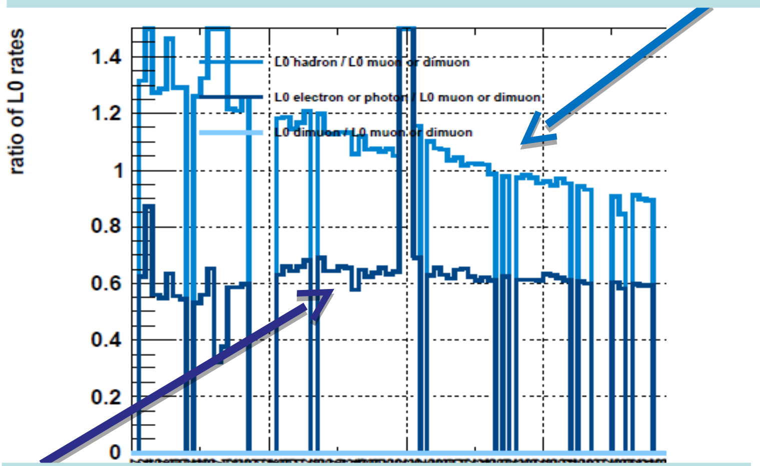


- Cs^{137} source
  - 1 source per half (10mCi)
  - Driven by an hydraulic system
  - Each source travels at 20-40cm/s through 26 modules
  - Dedicated integrators measure the anode current every 5ms
    - Absolute normalisation ~10%
    - Cell to cell calibration ~4%
    - Done during technical stops
- LED system
  - Control HCAL response
  - During data taking

Detector ageing

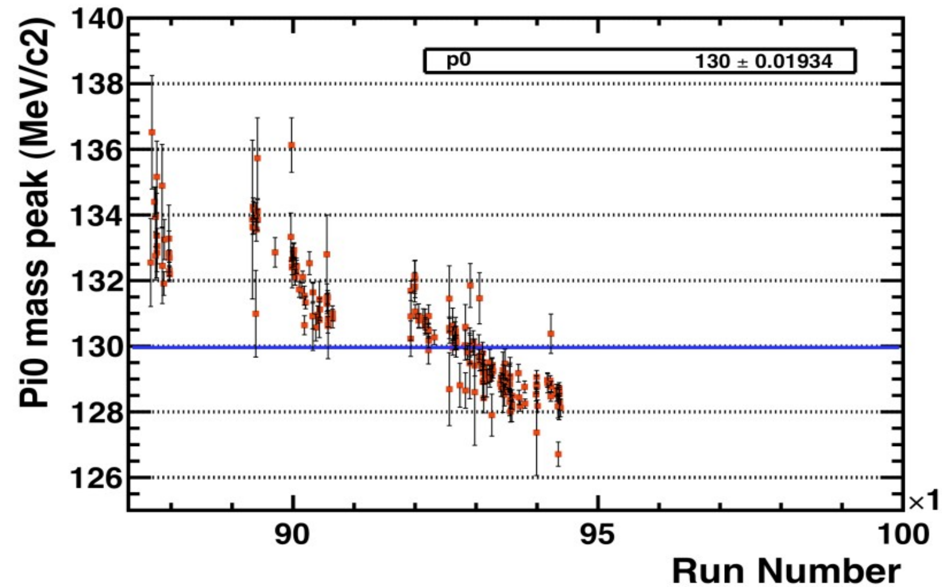
- Combination of several effects
  - Scintillator ageing due to radiations (~0.25Mrad/y)
    - Plastic tiles are less transparents
    - Proportional to the particle flux
  - PMT ageing as a function of the integrated current
    - Depends on cell size and position

L0Hadron/L0muon-dimuon trigger rate



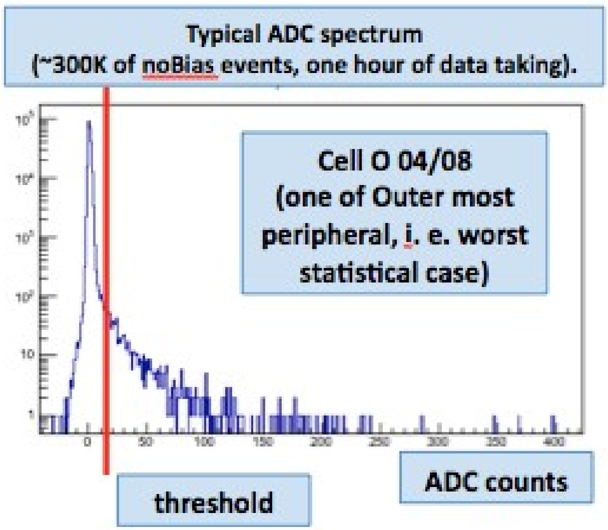
L0electron/photon / L0muon-dimuon trigger rate

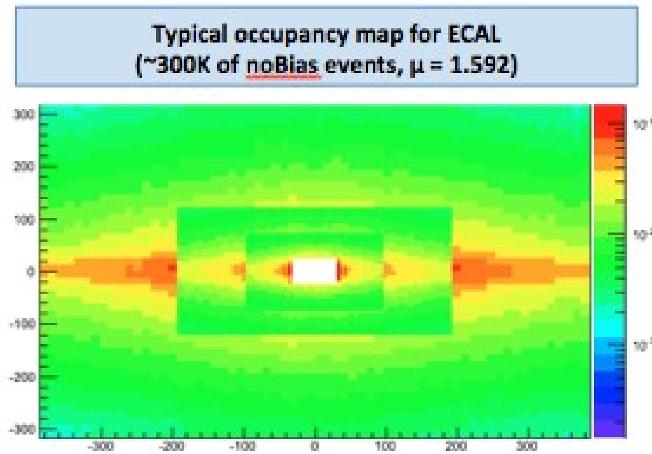
π^0 mass as a function of time (luminosity)

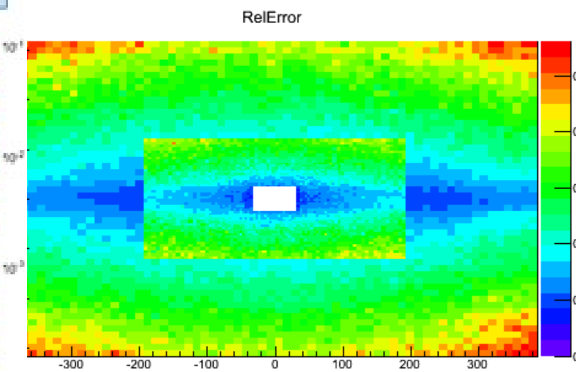


Towards an automatic calibration

- Plan is to have a fully automatic calibration for run 2
  - Based on LED and RAW occupancy





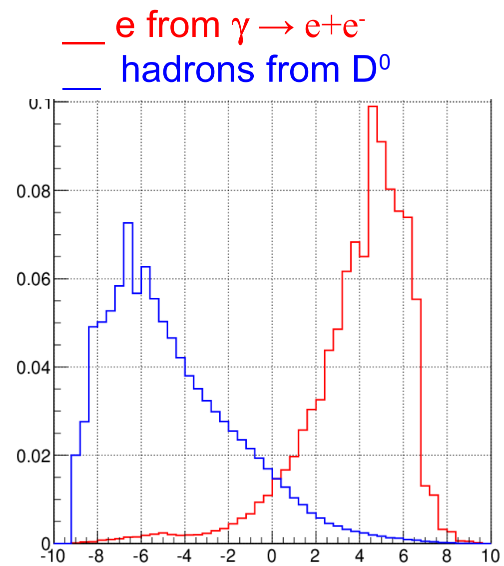


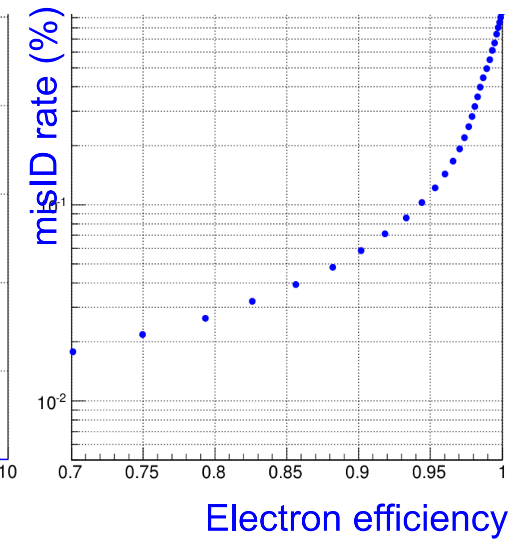
OCC = Nentries(adc_reading > threshold) / Nentries

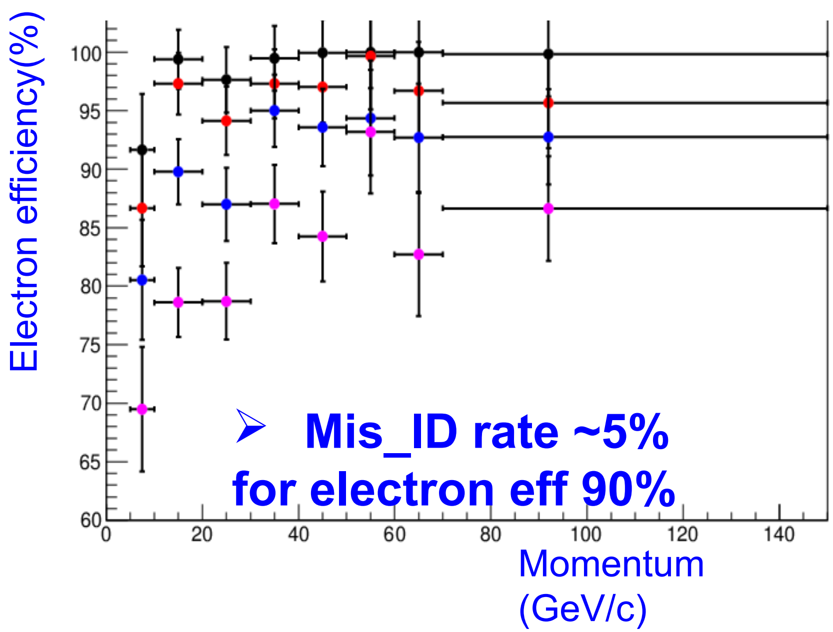
Precision reached with
1 hour data taking

- Promising method : reach 1% precision
  - Test on 2012 data sample for PS, ECAL and HCAL
  - Adjust PMT gain for each fill
  - Stable trigger

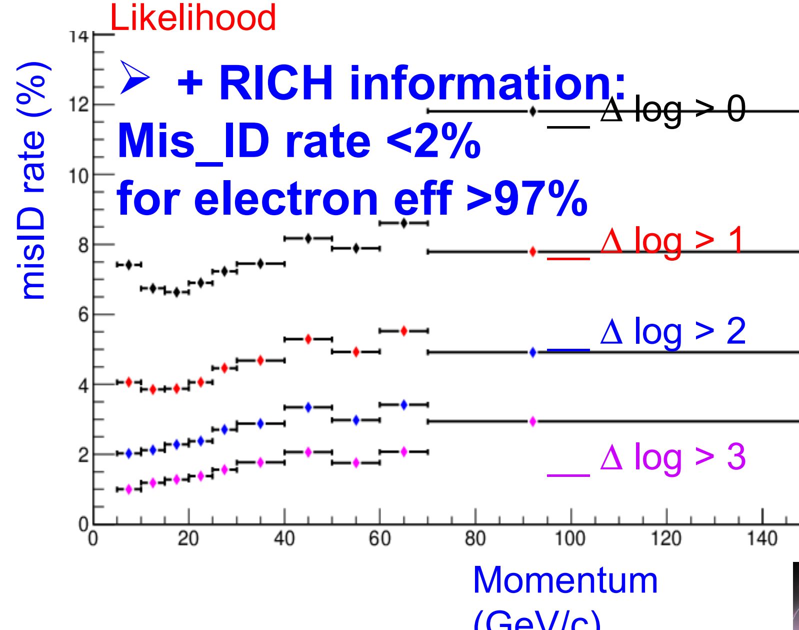
- Likelihood difference for the signal (electron) and background hypothesis
  - Based on data distributions
    - Signal : electrons from conversions
    - Backgrounds: hadrons from $D^0 \to K\pi$







Combined Calo Delta Log – Likelihood

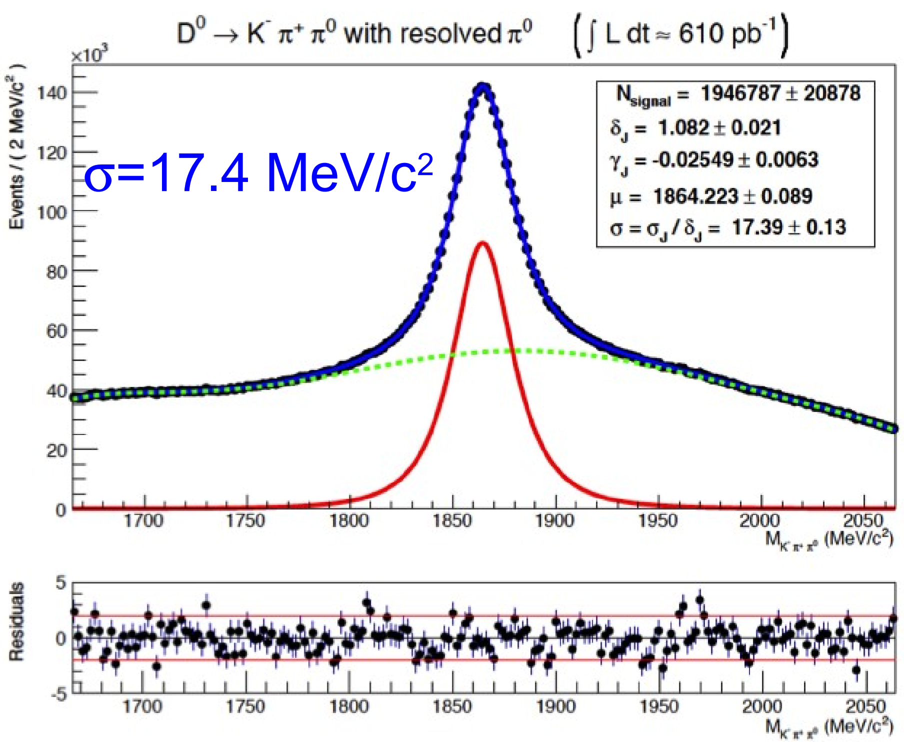


From $B^+ \to J/\psi K$

π^0 reconstruction

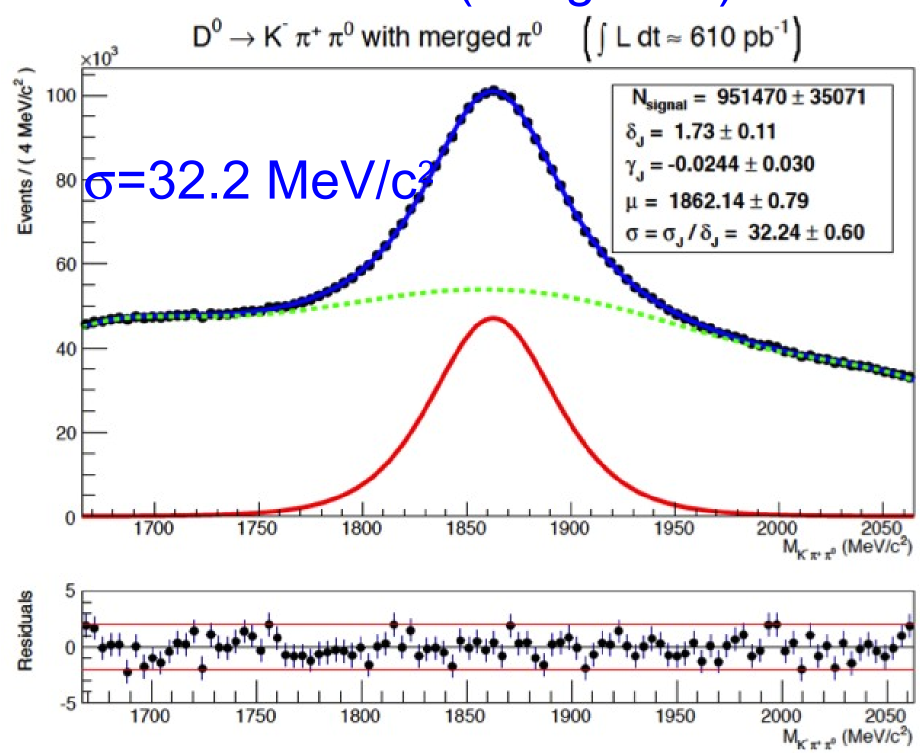
- Low energy pions: resolved as a photon pair – σ~8 MeV
- Above 2.5 GeV (Pt), reconstructed as merged photons

$D0 \rightarrow K^+\pi^-\pi^0$ (resolved π^0)



Resolved pair of well separated photons

$D^0 \rightarrow K^+\pi^-\pi^0$ (merged π^0)

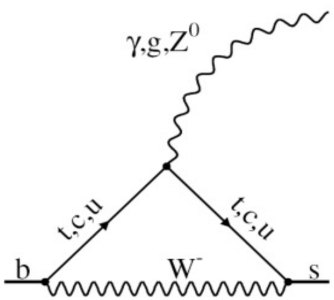


Photons that cannot be resolved as a pair of clusters within ECAL granularity

Radiative decays

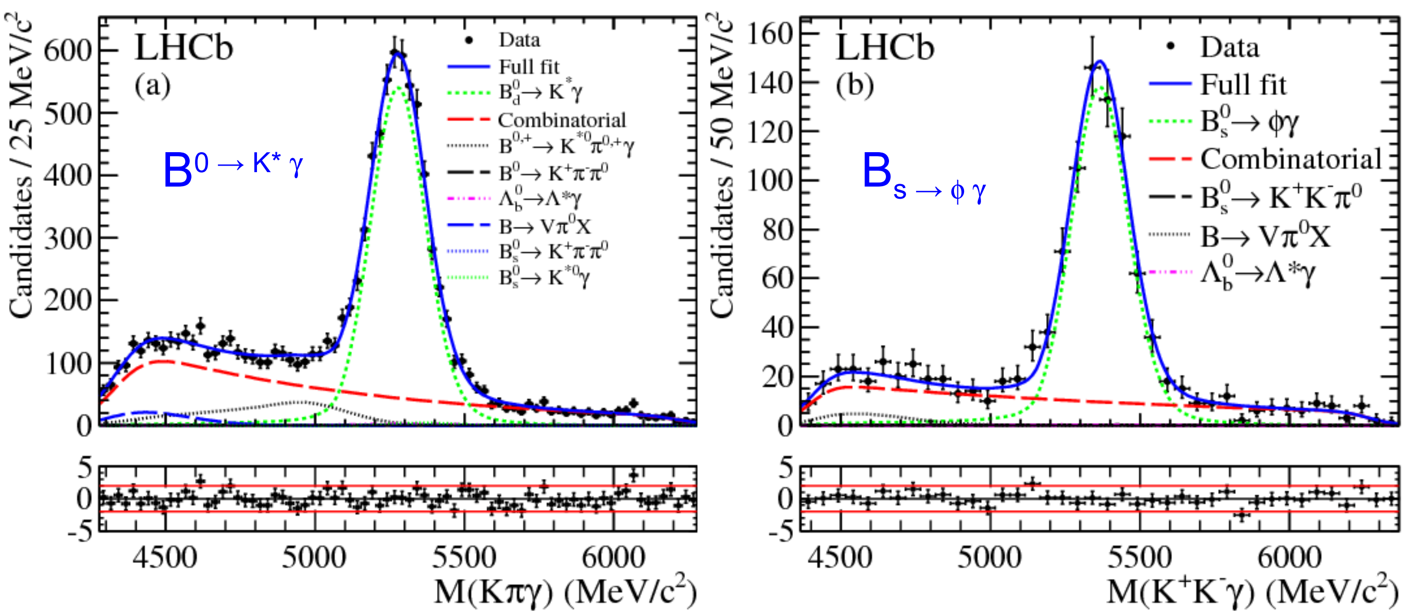
Radiative $b \rightarrow s\,\gamma$ FCNC decay, penguin diagram:

- Important candidate to identify new physics at LHC (BR measurement)
- Asymmetry give a direct constraint on the CP violation



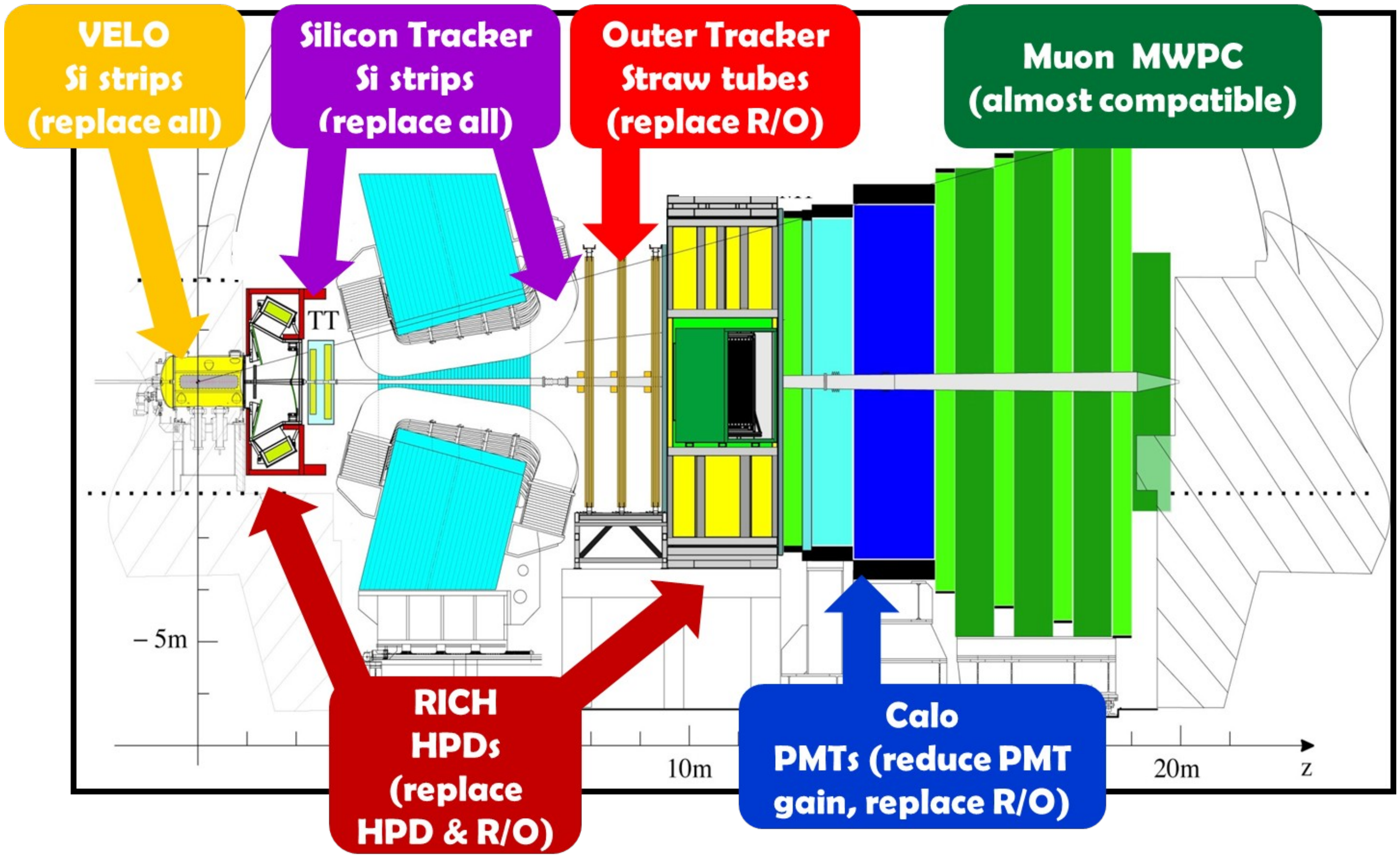
- BR predictions suffer from high uncertainties (hadronic form factor)
  - $B^0 \rightarrow K^*\gamma = (4.3 \pm 1.4) \times 10^{-5}$; $B_s \rightarrow \varphi\gamma = (4.3 \pm 1.4) \times 10^{-5}$

    $\rightarrow$ R(BR) = $1.23 \pm 0.06 \pm 0.04 \pm 0.10$(fs/fd) [Th: 1.0 ± 0.2]
- LHCb measures precisely ratio of BR and asymetries
  - $1fb^{-1}$ [NP B 867(2012)1]
    - $N(B^0 \rightarrow K^*\gamma) = 5279 \pm 93$; $N(B_s \rightarrow \varphi\gamma) = 691 \pm 36$ $\rightarrow$ BR($B_s \rightarrow \phi\gamma$) = $(3.5 \pm 0.4) \times 10^{-5}$
    - $A_{CP}(B^0 \rightarrow K^*\gamma) = (0.8 \pm 1.7 \pm 0.9)$ % [Th: (-0.61 ± 0.43)%]
  - World best measurement



Invariant mass resolution: ~92 MeV/c²

LHCb Upgrade



- The sub-detectors should be able to sustain $2 \times 10^{33} cm^{-2} s^{-1}$ at 14 TeV
- Full software trigger
  - The calorimeter electronics will send data to a large PC farm @ 40MHz
  - Reduction of the gain of the PMT to keep them alive (compensated in the FEB)
- LHCb upgrade PID TDR: CERN/LHCC 2013-022

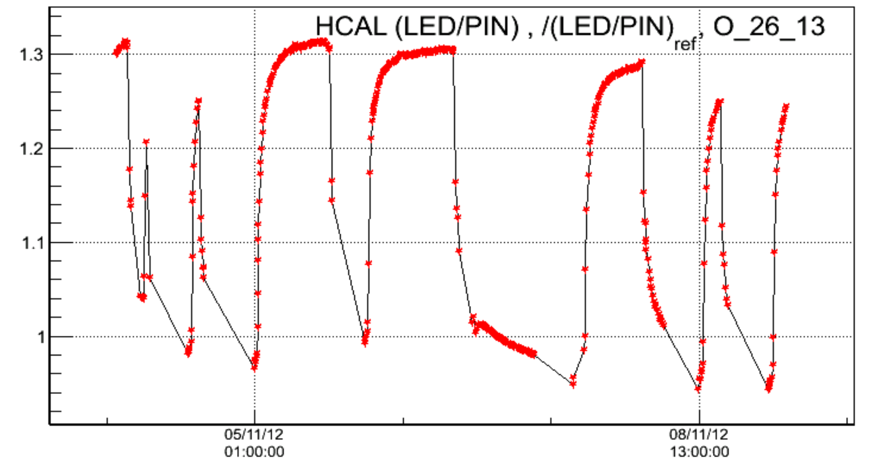
Conclusion

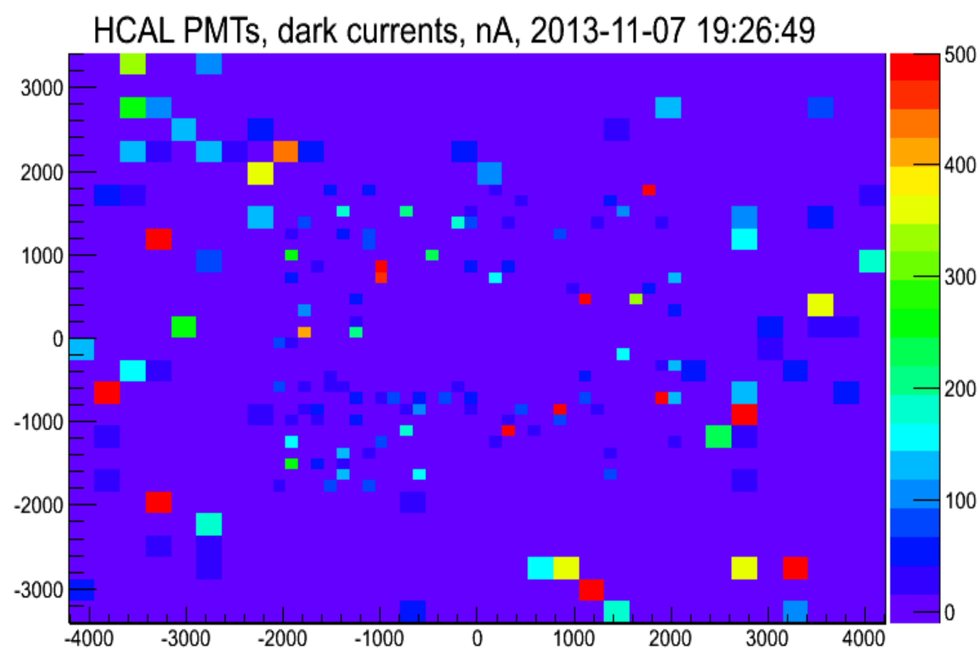
- The LHCb calorimeters are running smoothly
  - $O(10^{-3})$ dead channels
- Good performances
  - Key role on the trigger :
    - Hadrons, electrons, photons channels
  - Important measurements
    - $b \to s\gamma$ decay type, γ polarisation
    - $B^0 \to K^* \gamma$, $B_s \to \varphi \gamma$
    - χ_c states production at LHC ($\chi_c \to J/\psi\ \gamma$)
- Significant ageing effects (PMT, scintillator) → expected
  - Automation of PMT HV adjustment procedure
- Calorimeter part of the LHCb upgrade program (2019)

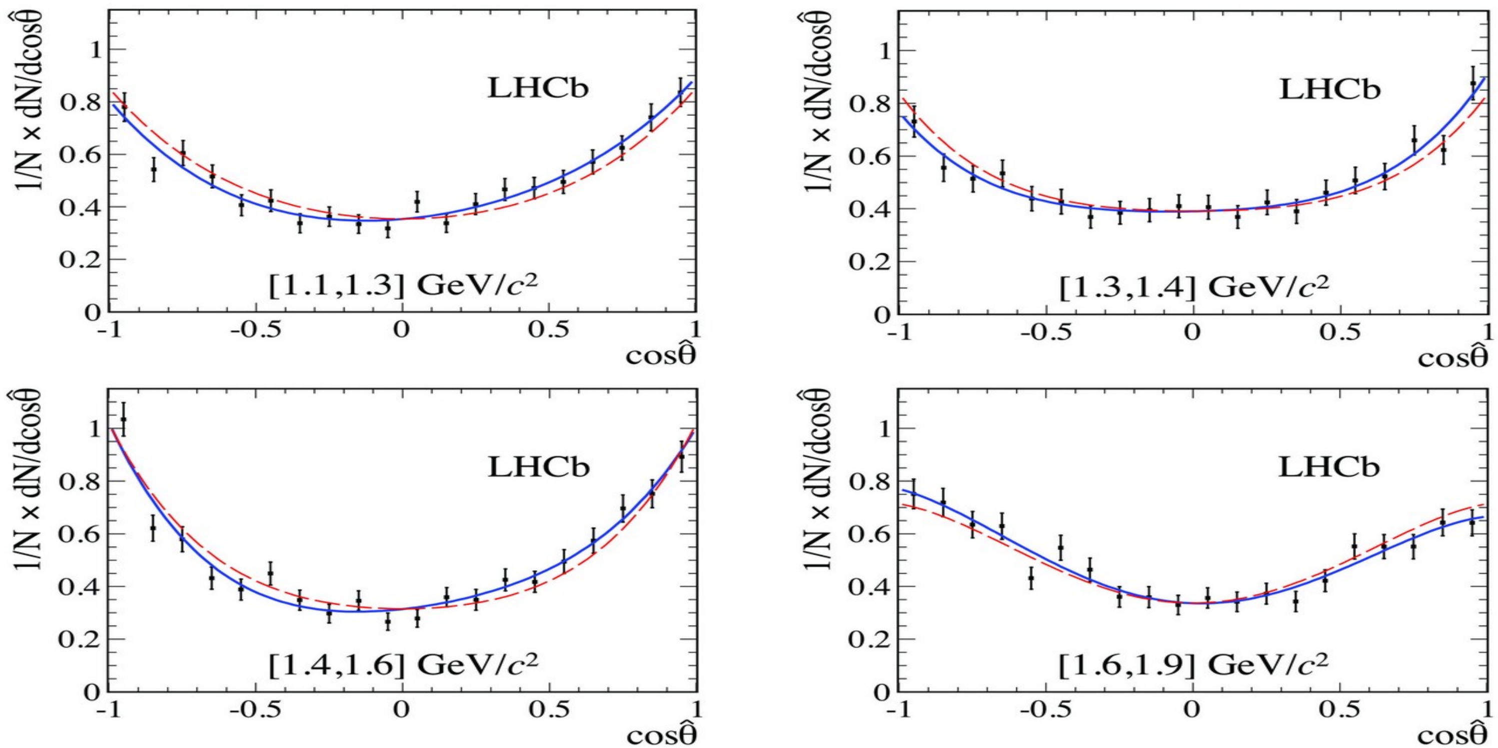
Thank You !

HCAL ageing effect

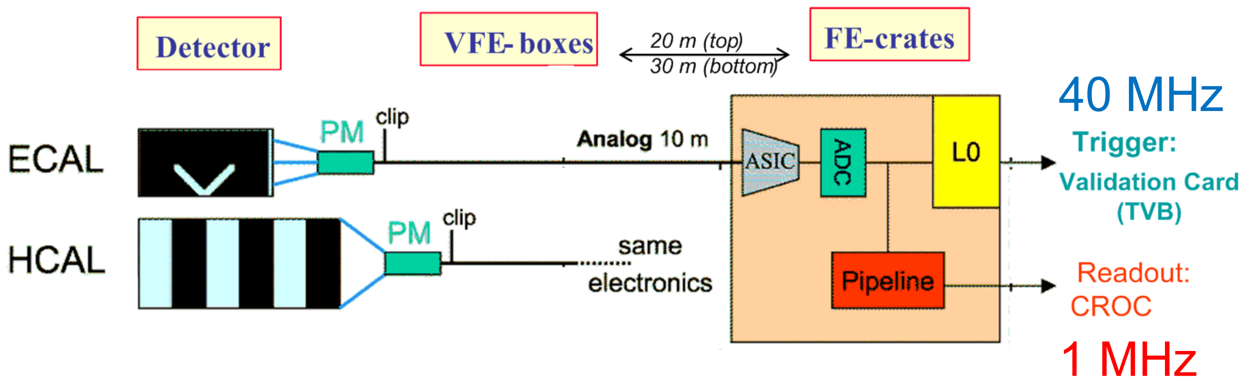
- Degradation of a significant number of HCAL PMT
  - ~ 15% (only affect the HCAL)
- Three types of problems :
  - Significant rate effect
    - up to +5 … +30 %
  - Dark current appears
  - Degradation of the gain
- The effects are correlated
- No correlation with the occupancy



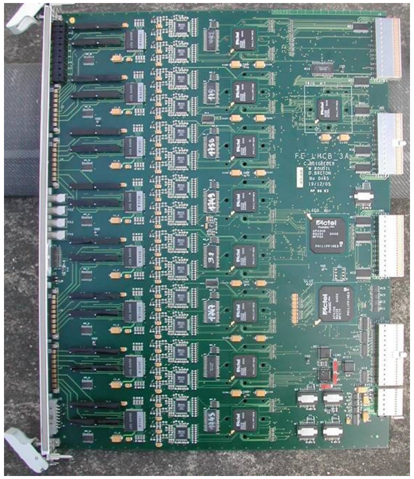



LHCb
[1.1,1.3] GeV/c^2
LHCb
[1.3,1.4] GeV/c^2
LHCb
[1.4,1.6] GeV/c^2
LHCb
[1.6,1.9] GeV/c^2
$1/N \times dN/d\cos\hat{\theta}$
$\cos\hat{\theta}$

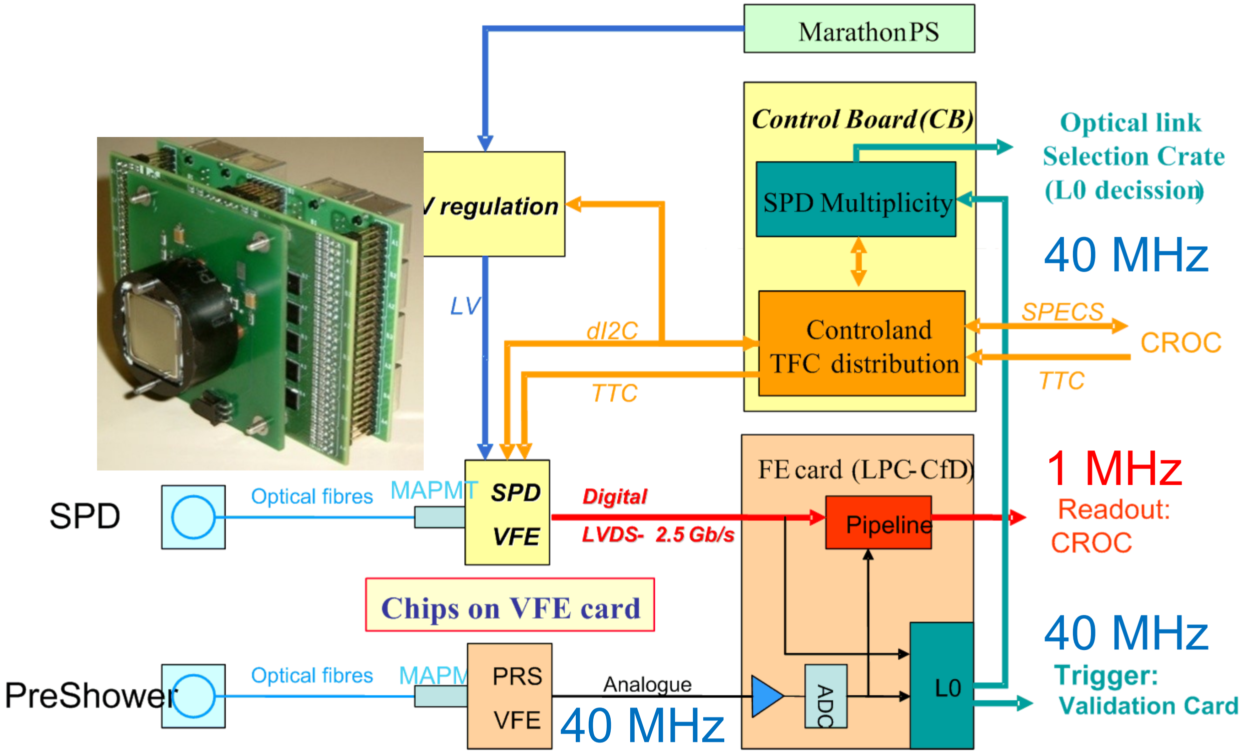
Readout of the (MA)PMT



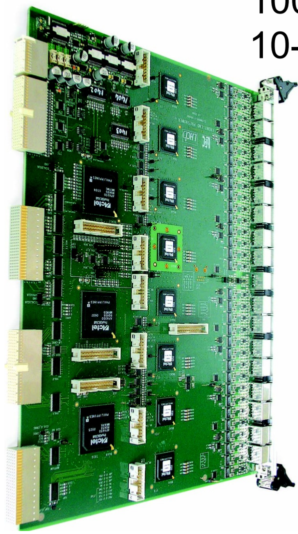
192 ECAL FEB
54 HCAL FEB
12-bit ADC



32 channels



100 PS/SPD FEB
10-bit ADC

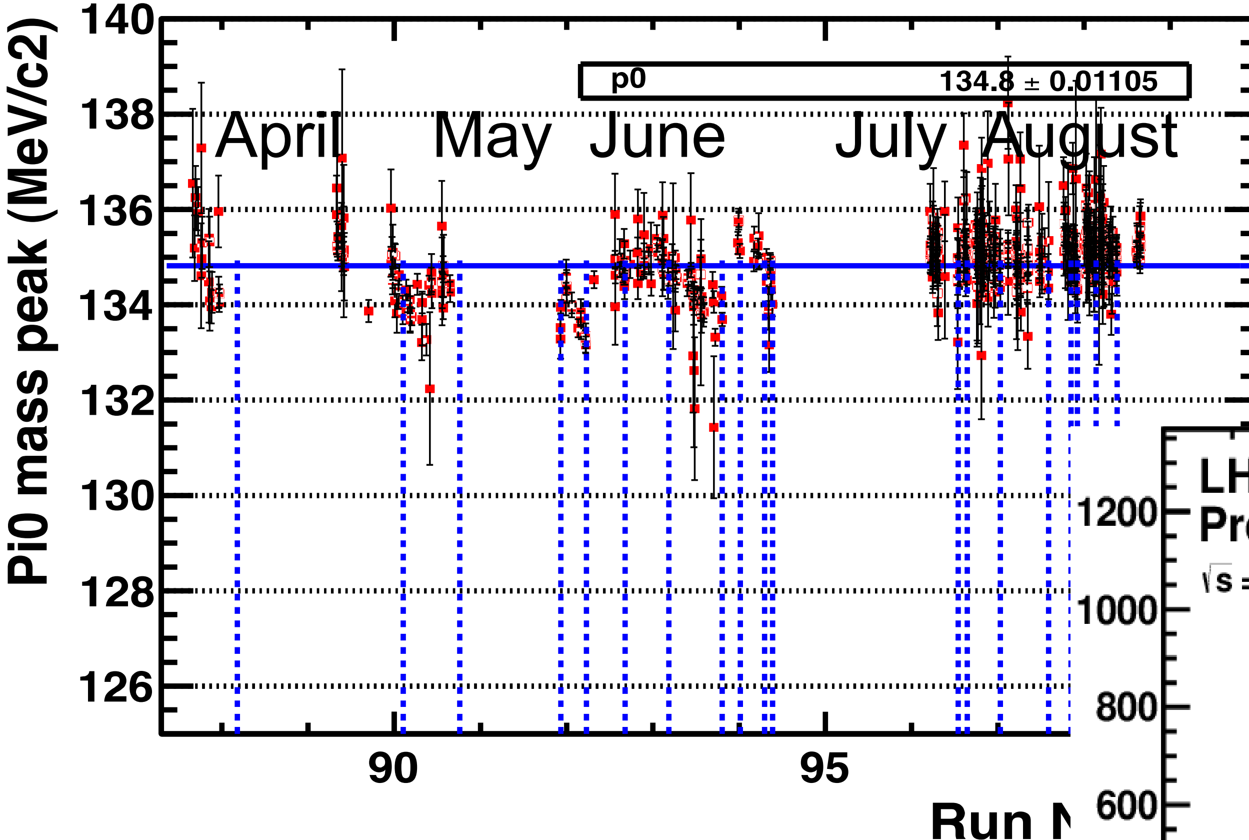


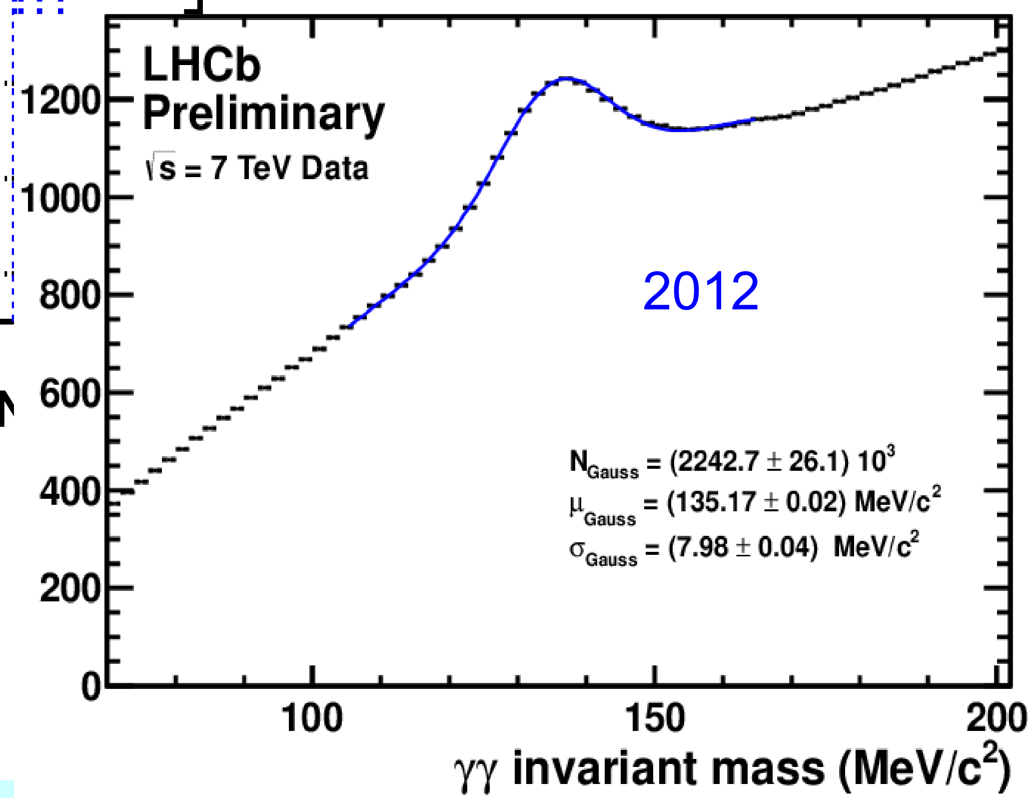
64 channels

02/06/2014

ECAL ageing

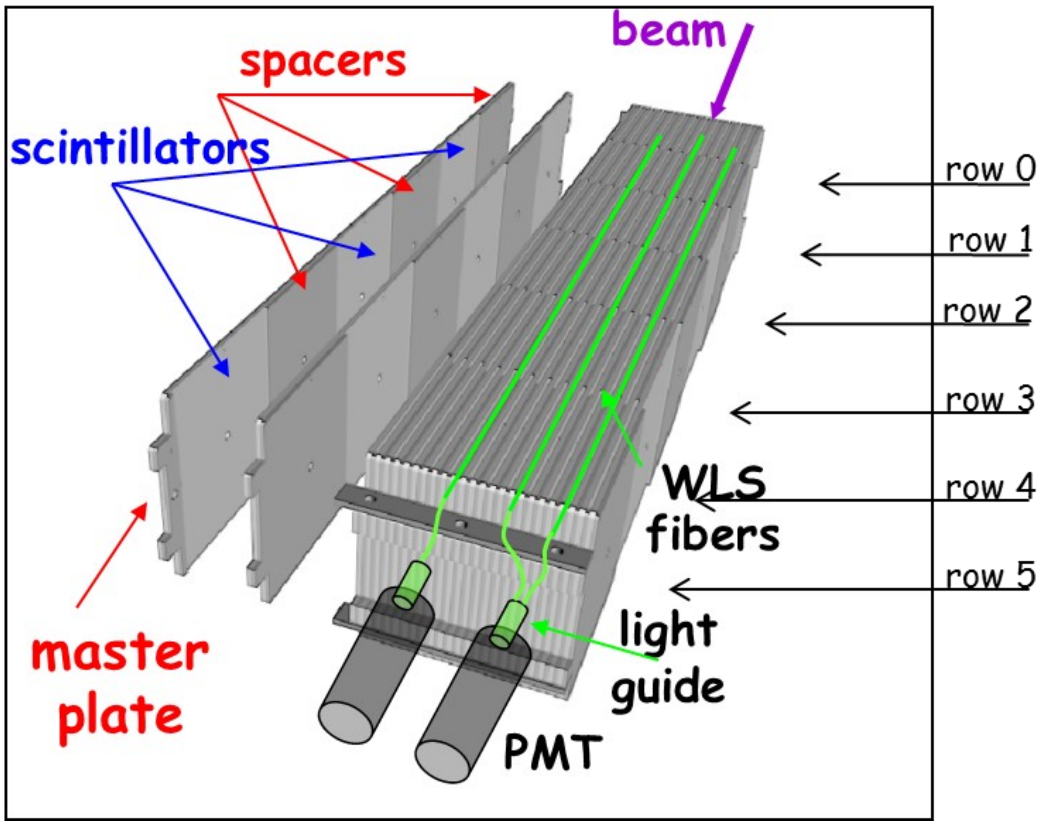
- After calibration (preliminary, 2011 data):

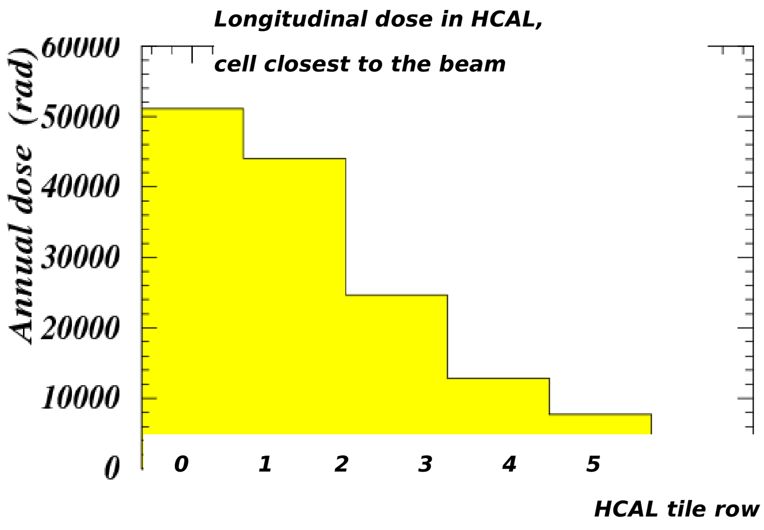




HCAL ageing

- 137Cs 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.