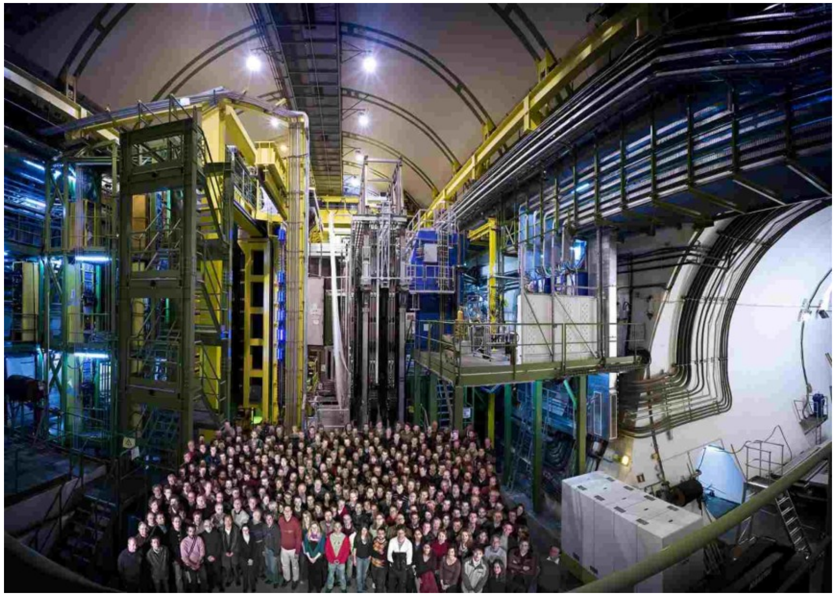
First Year of Running of the LHCb Calorimeter System



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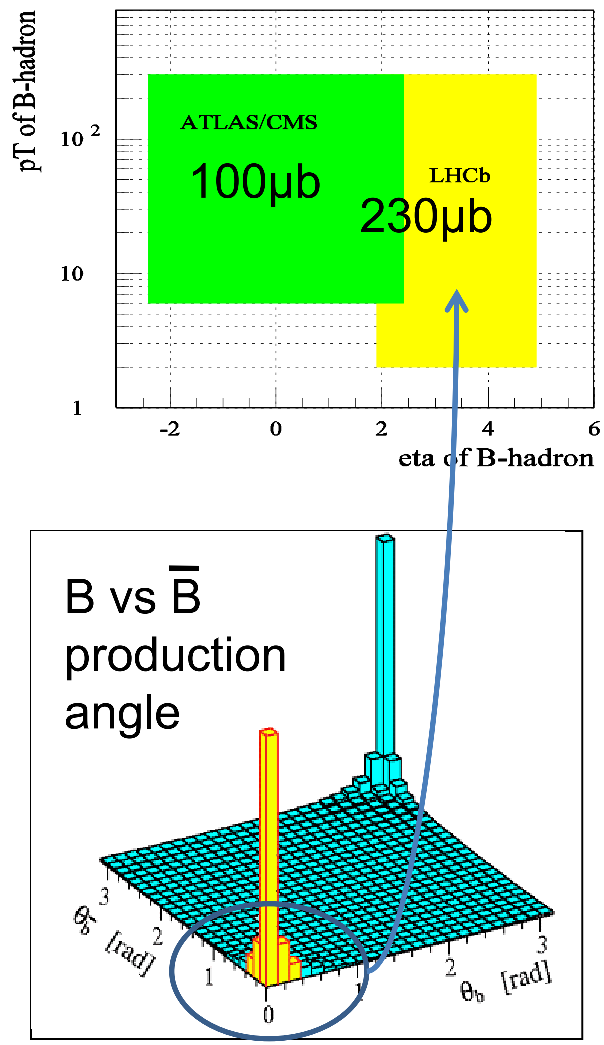
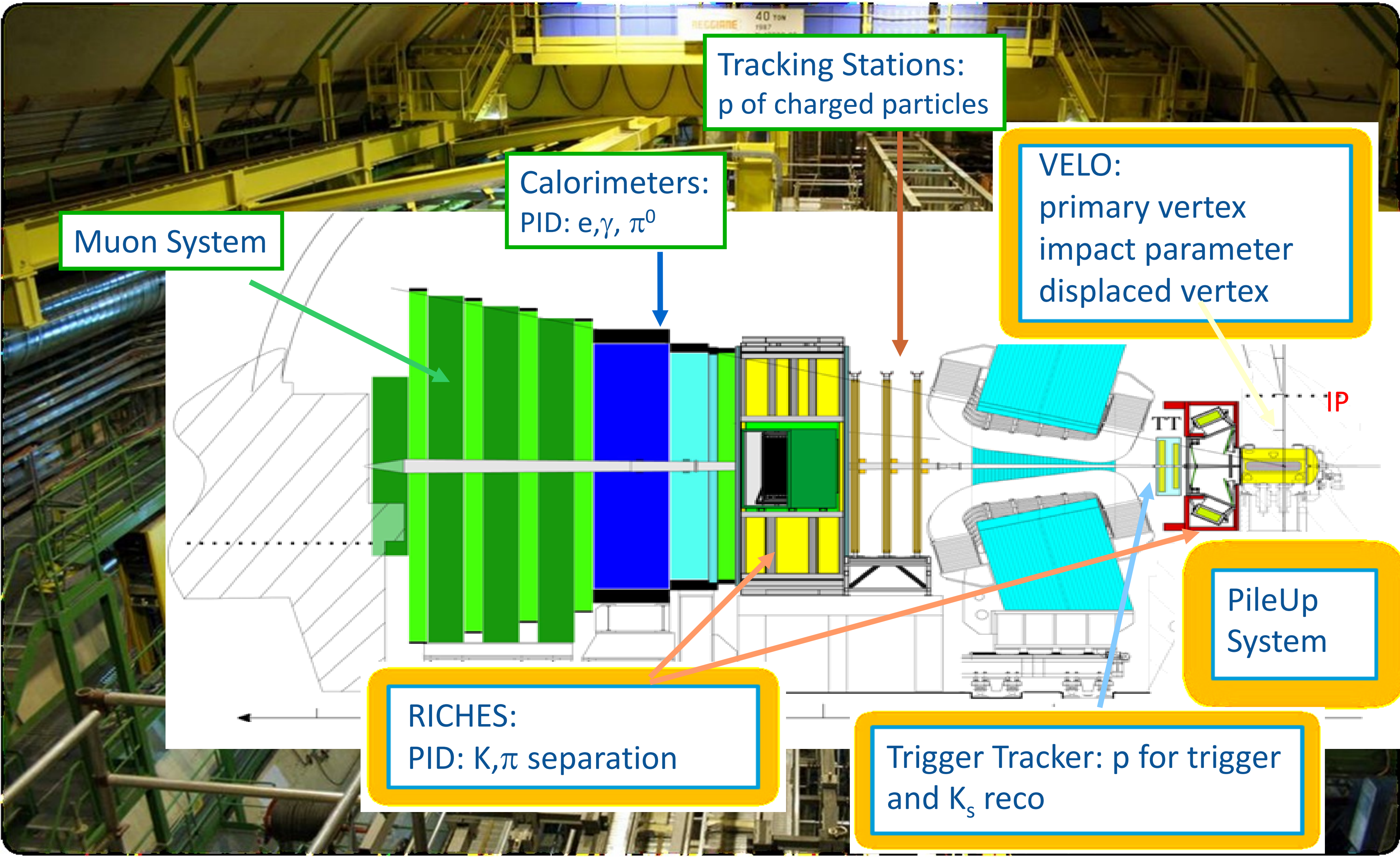
Orsay, France

Introduction

- LHCb is the dedicated b physics experiment at the LHC devoted to the precision study of CP violation and rare decays
- The purpose of LHCb is
  - Extend B physics results obtained in B-factories and the Tevatron
  - Search for new physics in a complementary way to ATLAS/CMS
- LHCb benefits from
  - A large $b\bar{b}$ cross-section in the forward region
    - Pseudo-rapidity range $1.9<\eta<4.9$
  - B hadrons are both likely to be in the forward acceptance
  - B have a momentum ~ 50 GeV
    - Good decay time resolution
    - Good background rejection
- Calorimeter-related important physics analysis :
  - Radiative decays : $B_d \to K^*\gamma$, $B_s \to \phi\gamma$
  - Decays involving neutral pions, η : $B_d \to \pi^+\pi^-\pi^0$, $J/\psi\ \eta$, $D^0 \to K^-\pi^+\pi^0$
  - or electrons : $B_d \to K^* e^+ e^-$

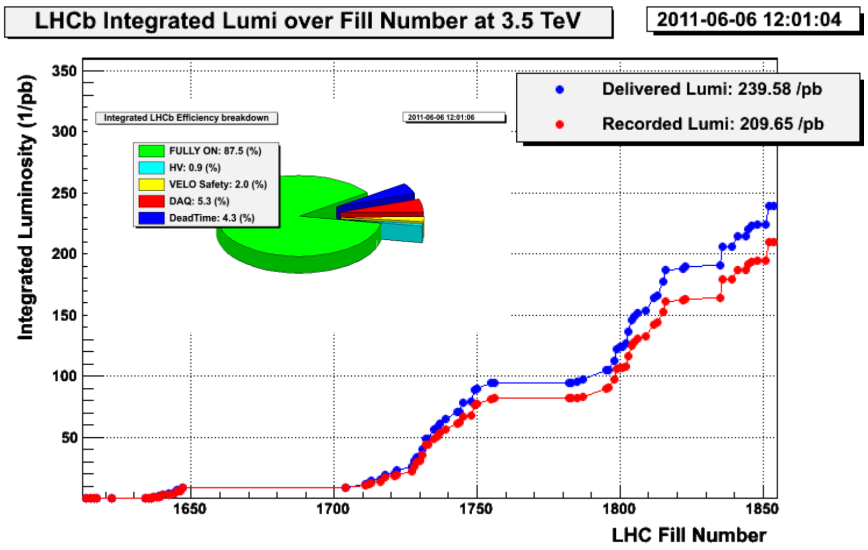


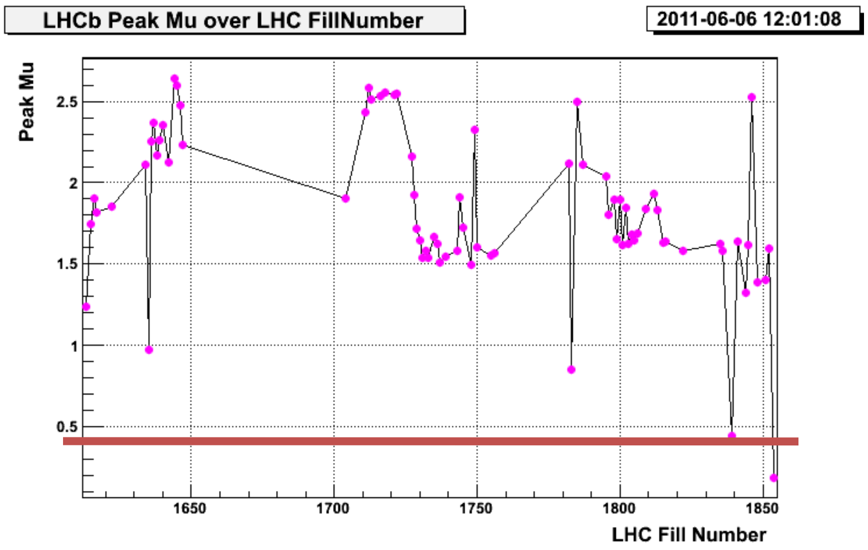
The LHCb detector



Running conditions

- LHC delivers √s=7 TeV pp collisions
- The machine performances improve rapidly
  - Get to more than 1000 bunches colliding at LHCb IP
  - Instantaneous luminosity is now $3x10^{32}cm^{-2}s^{-1}$ (1.5 x design)
  - Average visible pp interaction per crossing O(2)
- 37.5 pb^{-1} collected in 2010
- 2011 recorded luminosity ~ $200pb^{-1}$
  - Aim at $1fb^{-1}$ by the end of this year





Overview of the calorimeter system

- Requirements:
  - Energy / Position measurements
  - Identification of hadrons, electrons, γ, π^0
  - L0 Trigger input (SPD/PRS/ECAL/HCAL):
    - High sensitivity
    - Fast response (40MHz)
  - No electronics pile-up (25 ns shaping)

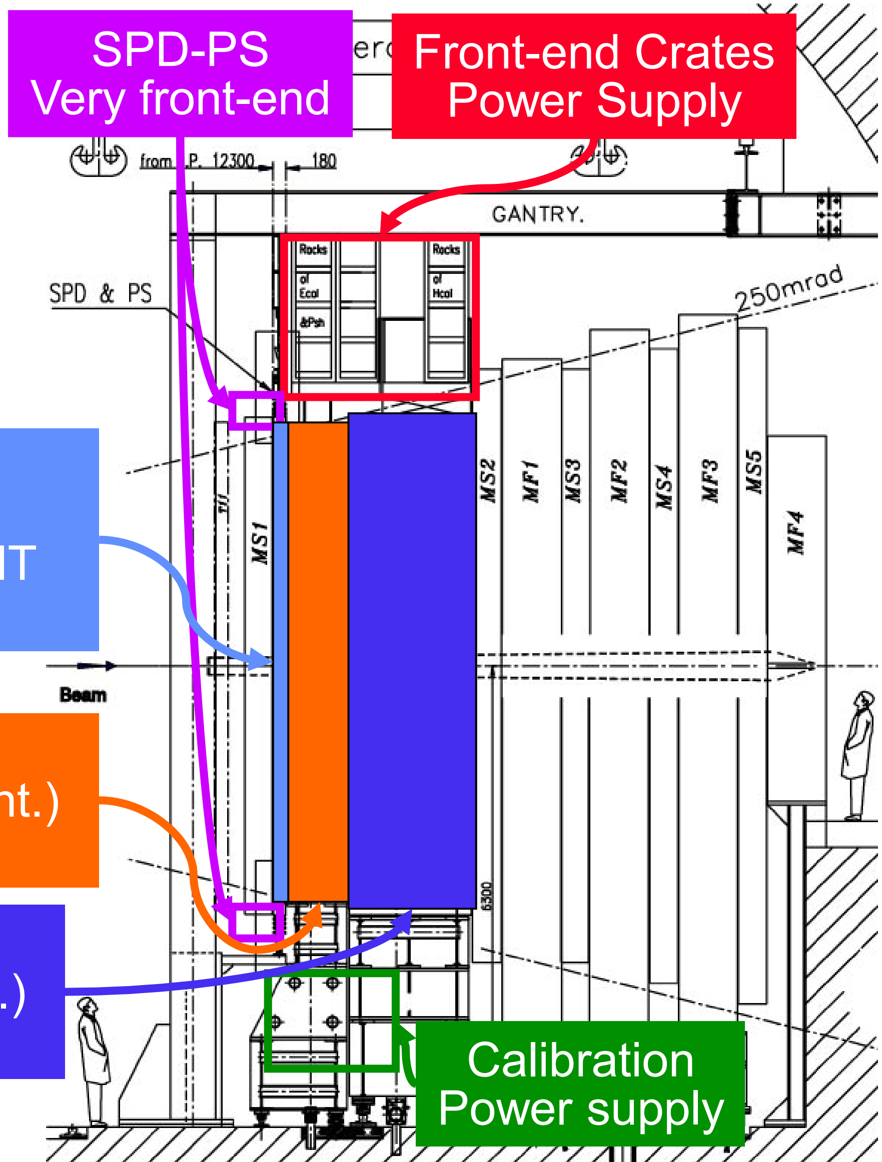
Front-end partly common
same crates

Scintillating Pad Det (SPD)
Preshower (PS)
Scint. Pad + Fibres+ MAPMT
6016 cells each

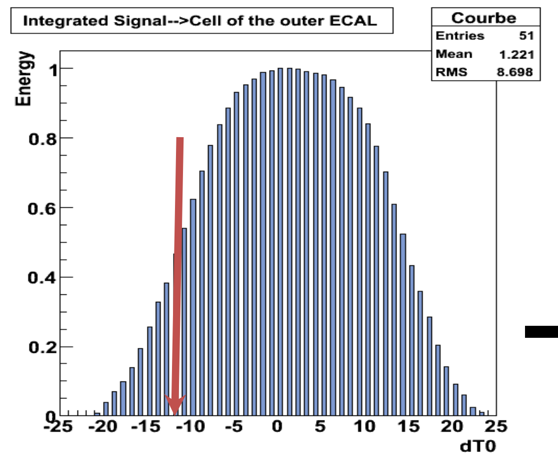
same electronics
same crates

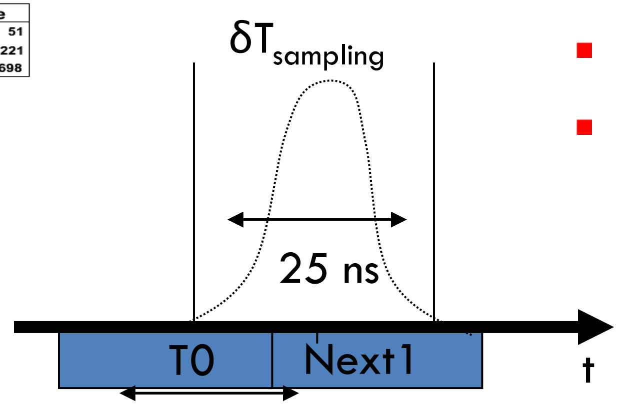
ECAL
Shashlik (Pb-scint.)
6016 cells

HCAL
Tiles (Iron-scint.)
1488 cells



ECAL / HCAL time alignment with particles

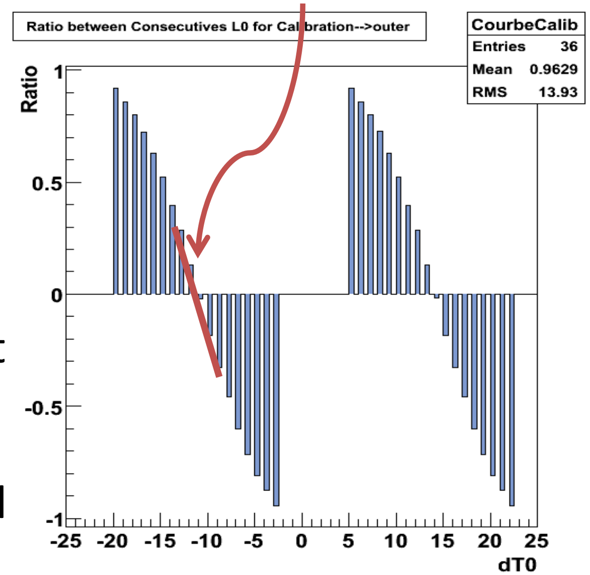




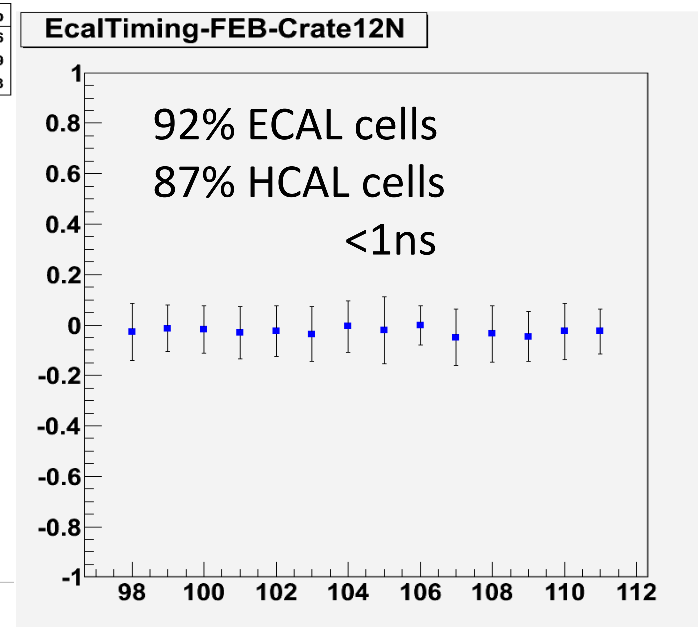
- Pulse shape precisely known
- LHCb DAQ may be configured to perform the acquisition of successive events around the « true » collision

$$R = -0.121\, dT + 1.52$$

- Half-detector shifted by 12.5 ns
  - Best timing sensitivity
  - Precise time alignment from calculation of asymmetries between current and next signal amplitude
  - Original shift removed



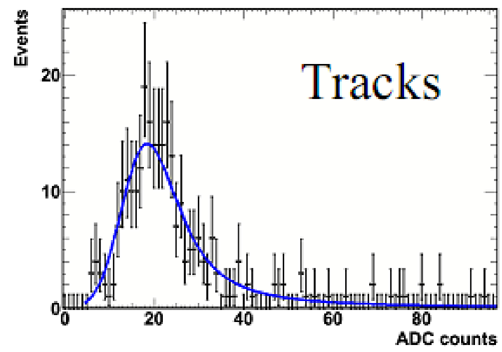
$$Rj = \frac{\sum_{i}^{Nevt} E_{ij}(Current) - \sum_{i}^{Nevt} E_{ij}(Next)}{\sum_{i}^{Nevt} E_{ij}(Current) + \sum_{i}^{Nevt} E_{ij}(Next)}$$



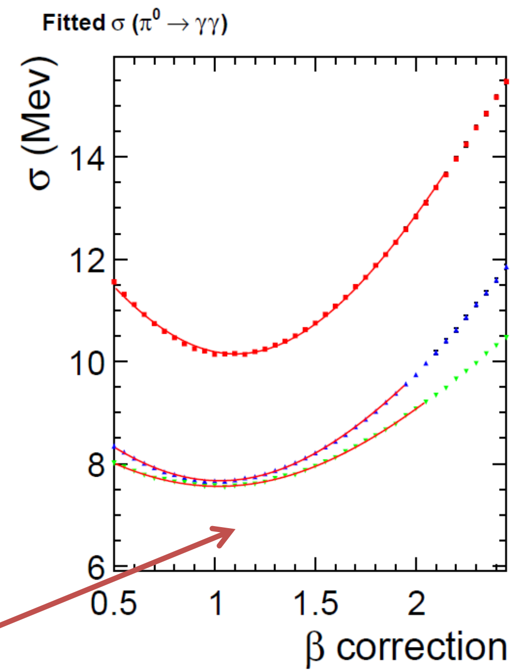
- Essentially same method for SPD/PS

PS/SPD calibration

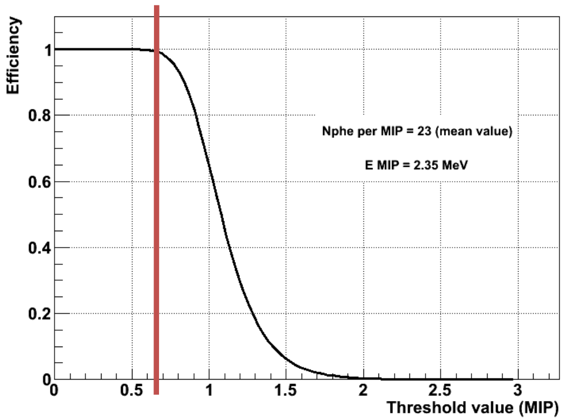
- Preshower
  - inter-calibration based on MIP position
    - Individual channel measurement (~5% precision)



    - Cross-check with Energy flow method (next slide)
  - Absolute calibration from π^0 width minimisation

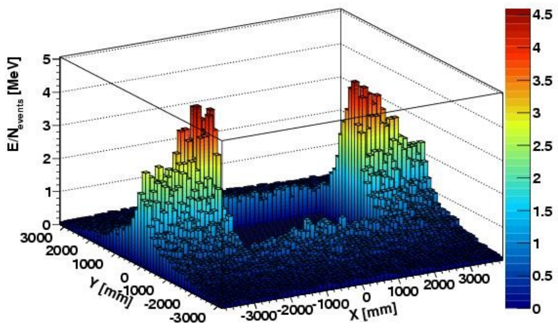


- SPD calibration
  - Binary detector : no straight MIP calibration
  - Collect data at different thresholds and get efficiency to MIP
  - 10% inter-calibration achieved

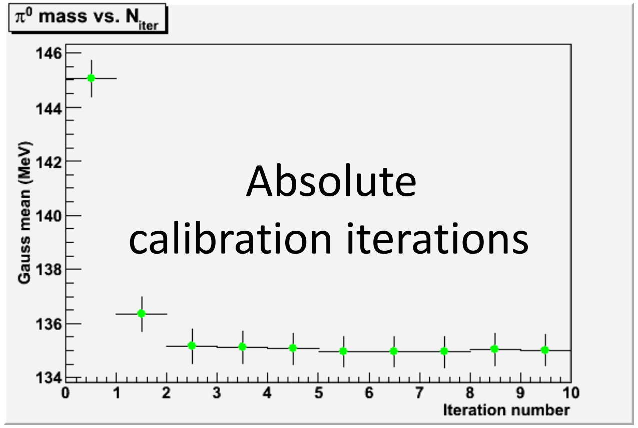


ECAL calibration

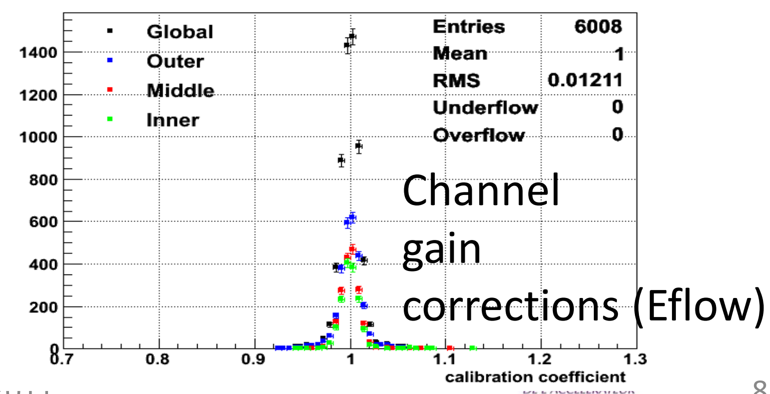
- ECAL pre-calibration done before data taking
  - At the 8% level and based on absolute gain from LED pulse photostatistics
- Relative inter-calibration on collision data using an energy flow method
  - Smoothing of the local energy deposit
    - Average over neighbour channels
  - ~4% precision level
- 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



Energy deposit

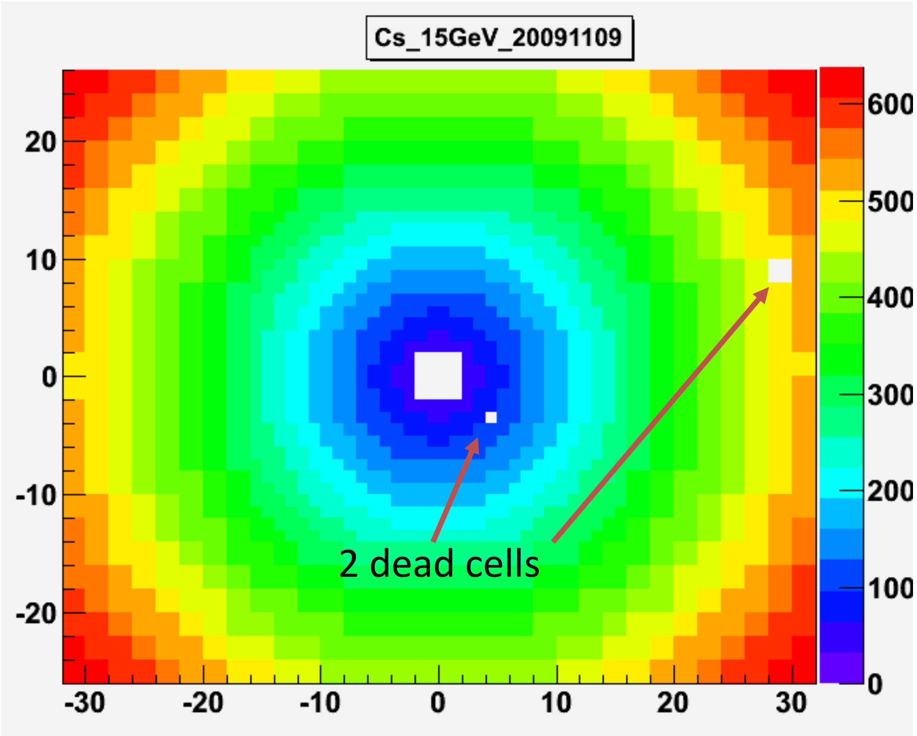


- EFlow applied again to correct for border effects
  - Precision < 1.5 %

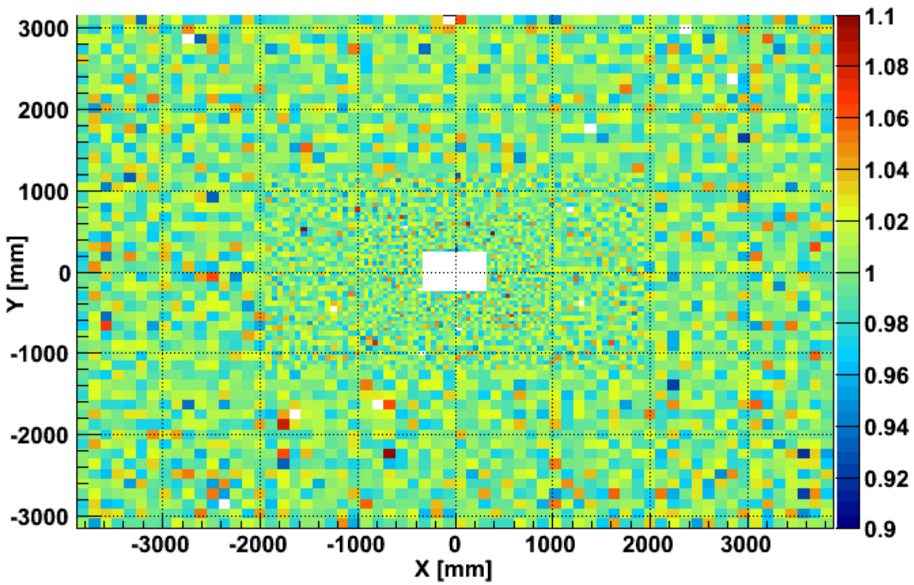


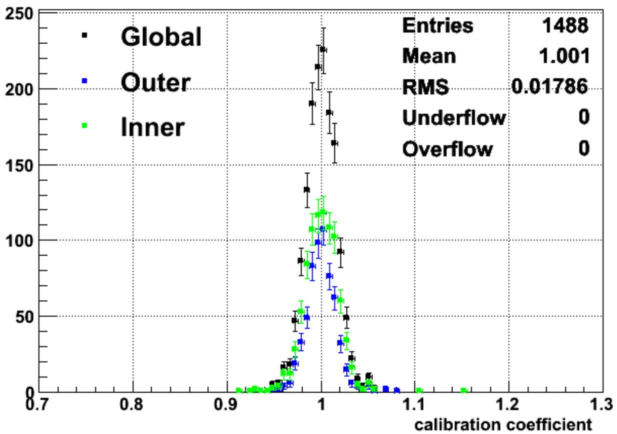
HCAL calibration

- Radioactive source scan
- Performed every 1 to 2 months
  - ^{137}Cs source runs allowed an intercalibration < 3 %



- Cross-check from Eflow method

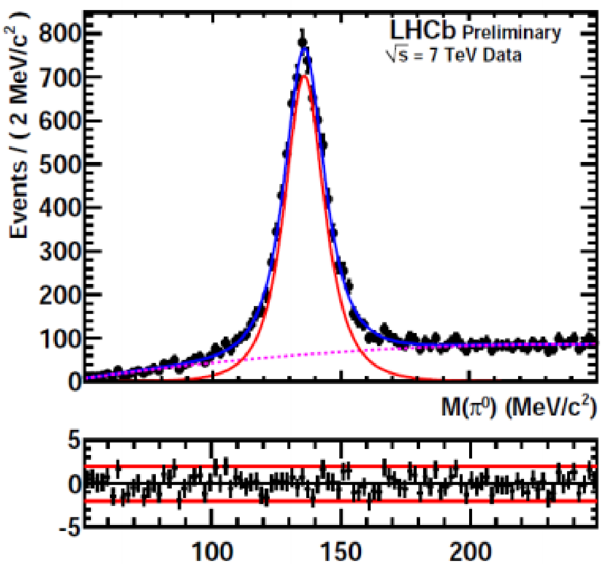




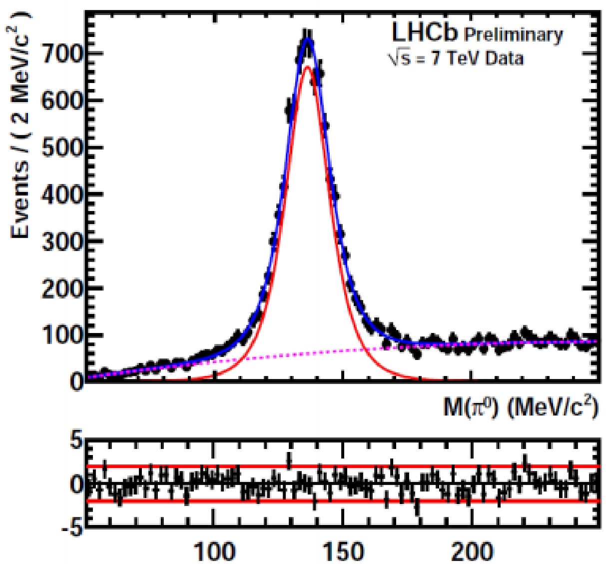
Photon PID

- Photon PID based on probability density functions
  - Track – ECAL cluster position anti-coincidence
  - ECAL shower shape
  - PS energy
- Neutral pion selection
  - CL(γ)>0.8
  - Pt(γ)>650MeV/c

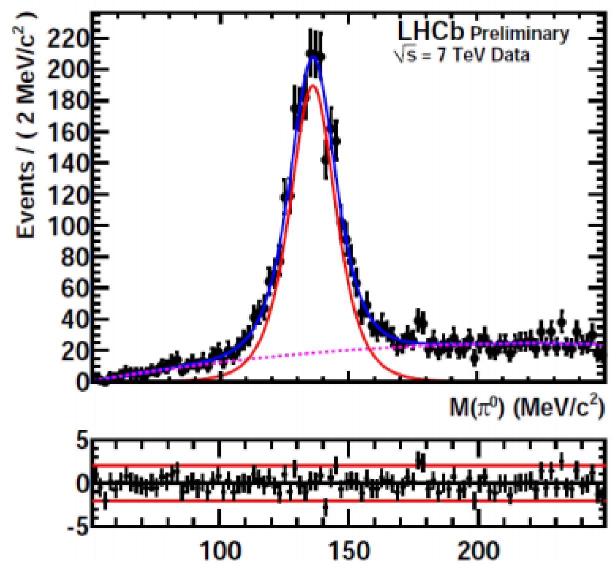
- Typical neutral pion resolution
  - $\pi^0 \to \gamma\gamma$: 7.2 +/- 0.1 MeV/c^2
  - $\pi^0 \to \gamma(ee)$: 8.2 +/- 0.1 MeV/c^2
  - $\pi^0 \to (ee)(ee)$: 9.5 +/- 0.1 MeV/c^2



0 conversion



1 conversion

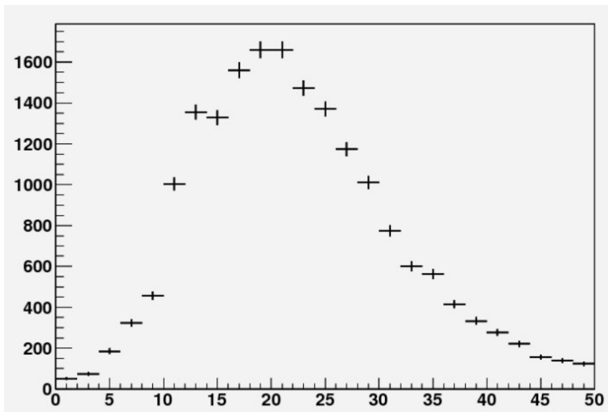


2 conversions

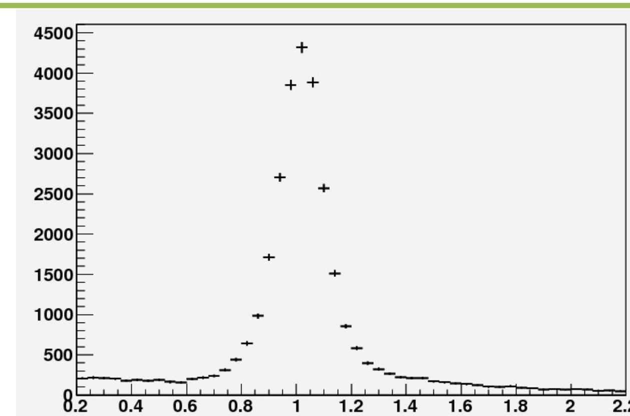
Electron PID

- Based on difference between likehood of the electron (sig) and background hypo.
  - Fully based on data distributions
    - Signal : electrons/positrons from γ conversions
    - Background : hadrons from $D^0 \rightarrow K\pi$

Signal :
M(ee)<50MeV

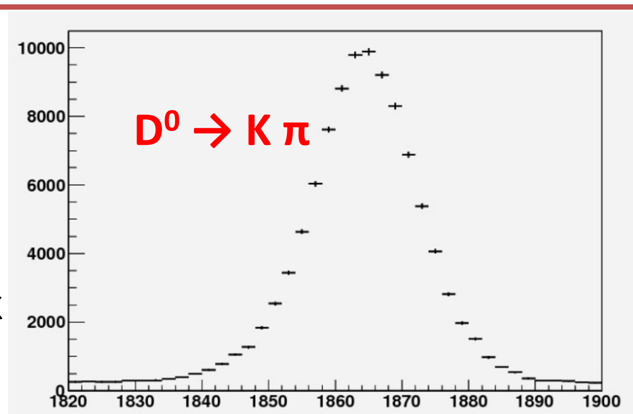


$M(e^+e^-)$, MeV/c^2

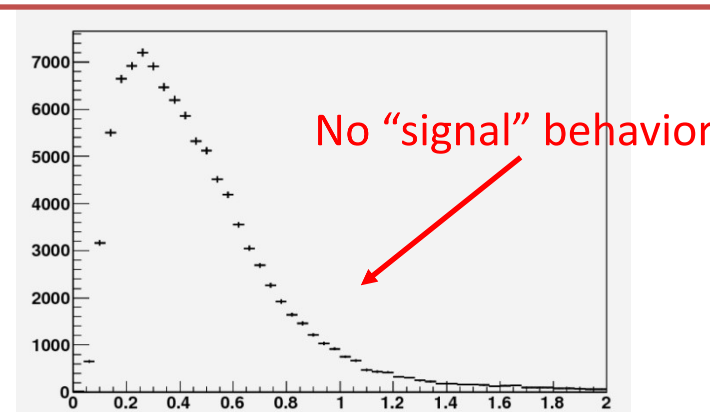


energy/momentum ratio

Background :
+/-25 MeV
around D0 peak

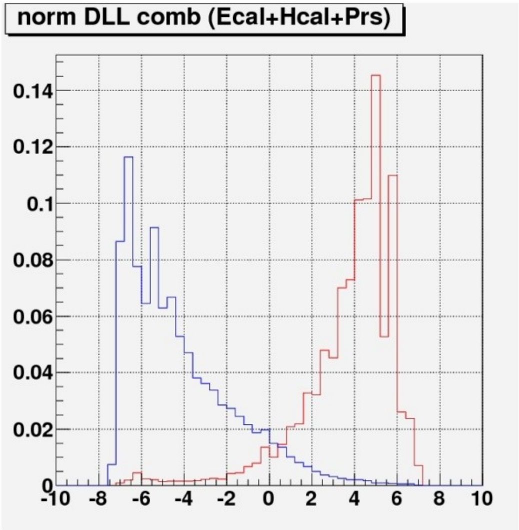


M(Kπ), MeV/c^2

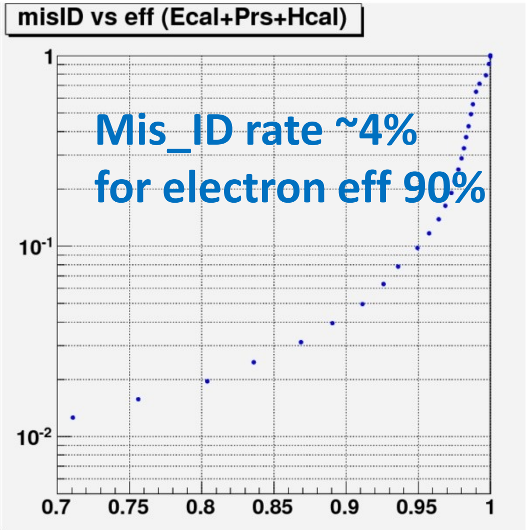


energy/momentum ratio

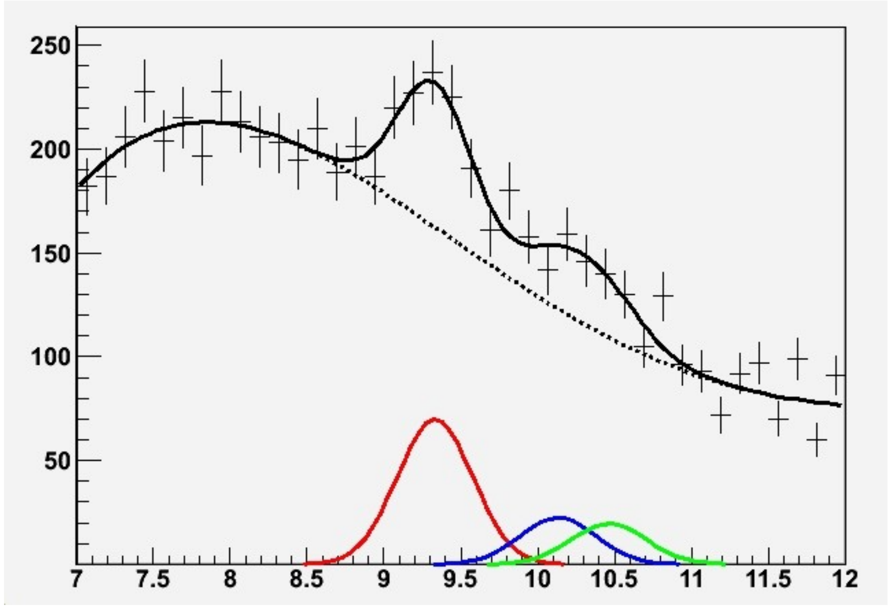
Electron PID : performances



Combined Calo Delta Log –Likelihood



fake rate vs efficiency



M(e+e-), GeV/c^2

- 2D probability density functions built on real data :
  - Energy versus
    - Track – ECAL cluster matching
    - E_{PS}
    - E_{HCAL}
- Reconstruction of the states
  - ϒ(1S), ϒ(2S) and ϒ(3S)

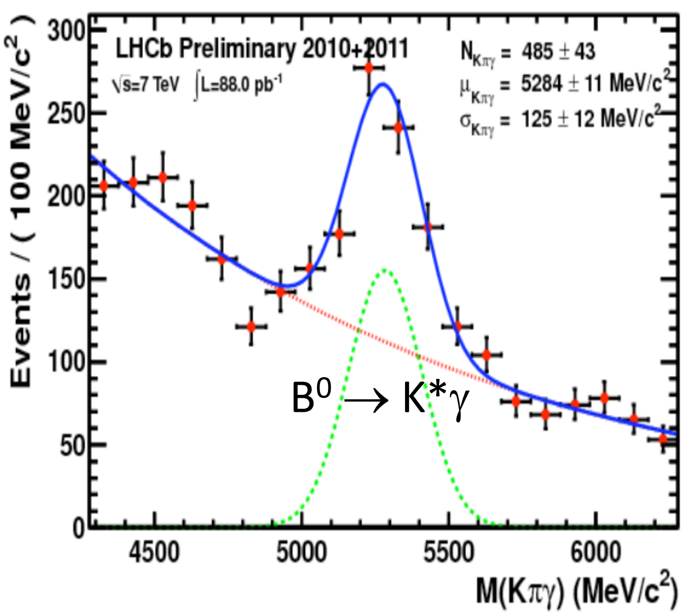
Radiative decays of B mesons

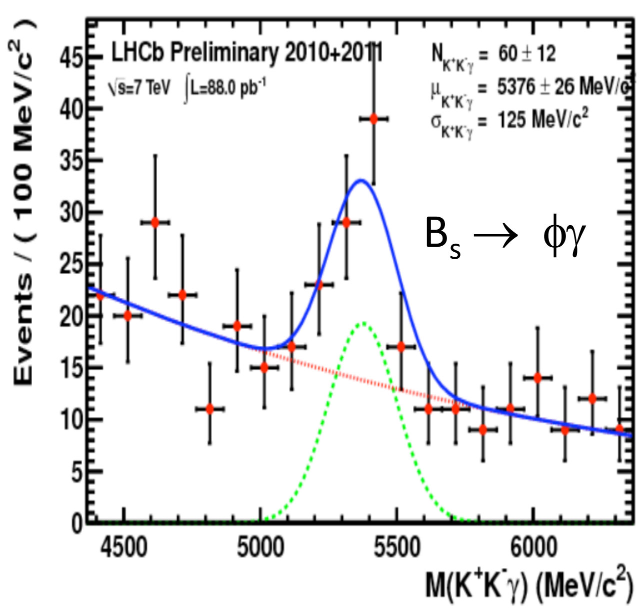
- Radiative $b \to q\gamma$ FCNC penguin (q=d, s)
  - BR and asymmetry of exclusive modes give a direct constraint on UT
  - Right-handed photon is suppressed by m_q/m_b within Standard Model
- $B^0 \to K^* (K\pi)\, \gamma$ is observed
  - $Br(B^0 \to K^* \gamma) = (43.3 \pm 1.5) \times 10^{-6}$

Babar, Belle, Cleo – HFAG 2010

  - Production rate in LHCb
    - $(6.1 \pm 0.7)\ B^0 \to K^* (K\pi)\, \gamma\ /pb^{-1}$ Expect O(6k) by the end of 2011
    - Direct asymmetry measurement by the end of the year $A_{cp}(K^* \gamma)<1\%$ in SM
- Evidence for $B_s \to \phi(KK)\, \gamma$
  - First observed by Belle : $Br(B_s \to \phi\gamma)=(57^{+21}_{-18}) \times 10^{-6}$

Belle PRL100,121801, 2008

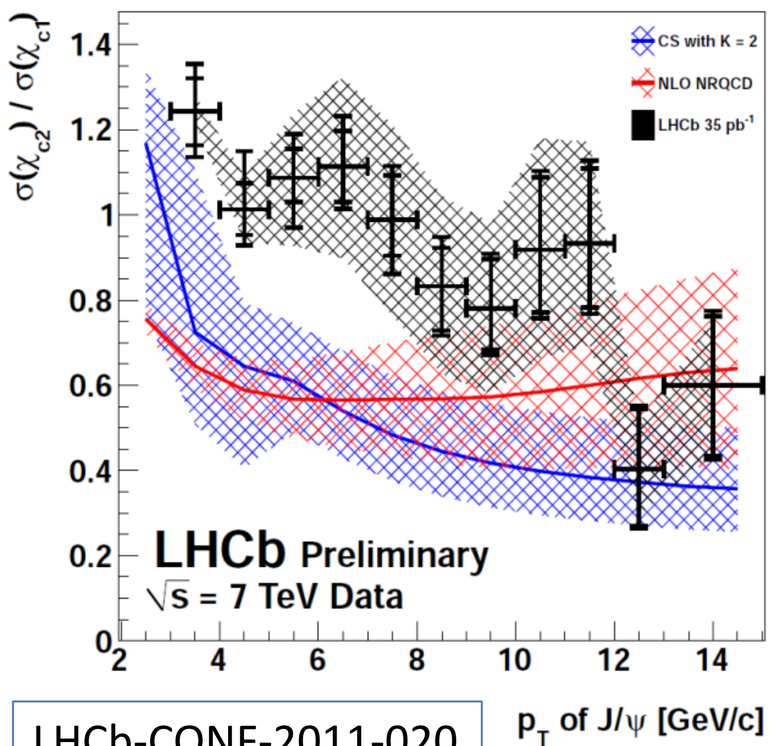


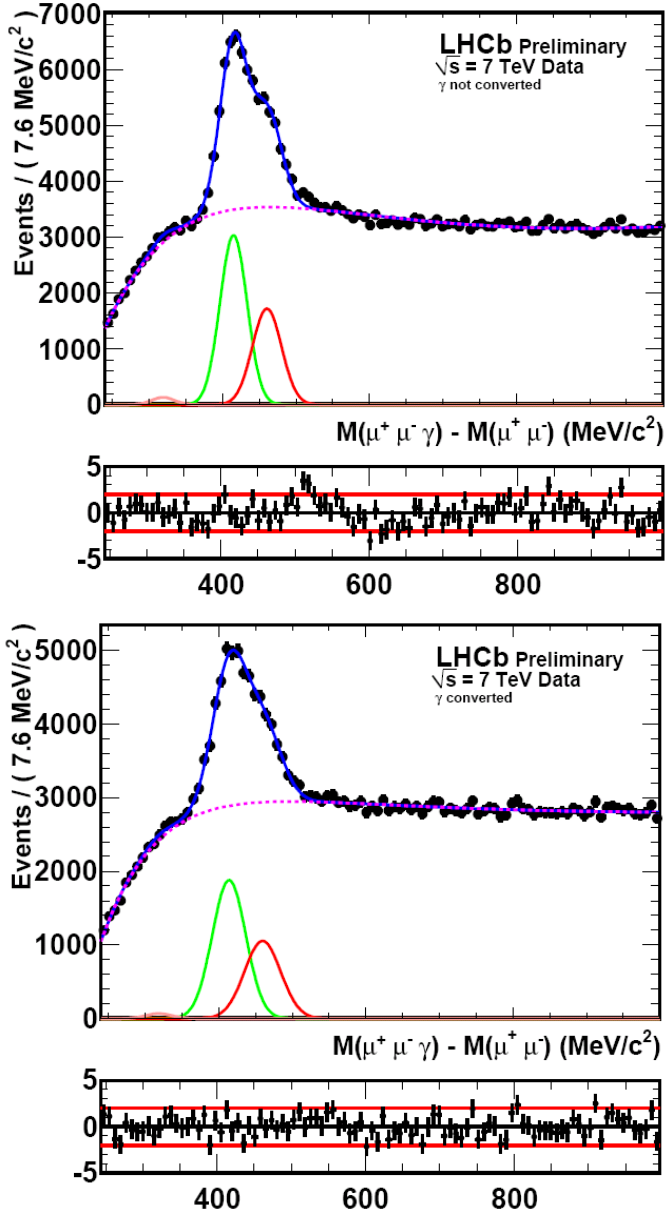


$(0.68 \pm 0.14)\ /pb^{-1}$
O(700) in 2011

Relative χ_c production at LHC

- Heavy quarkonia is still a challenging problem for QCD
  - Bound charmonium states described by non perturbative models
  - Ratio of χ_{c1} vs χ_{c2} BR is a key ingredient
  - χ_c reconstructed as $J/\psi\ \gamma$
- Photons id. by a likelihood method

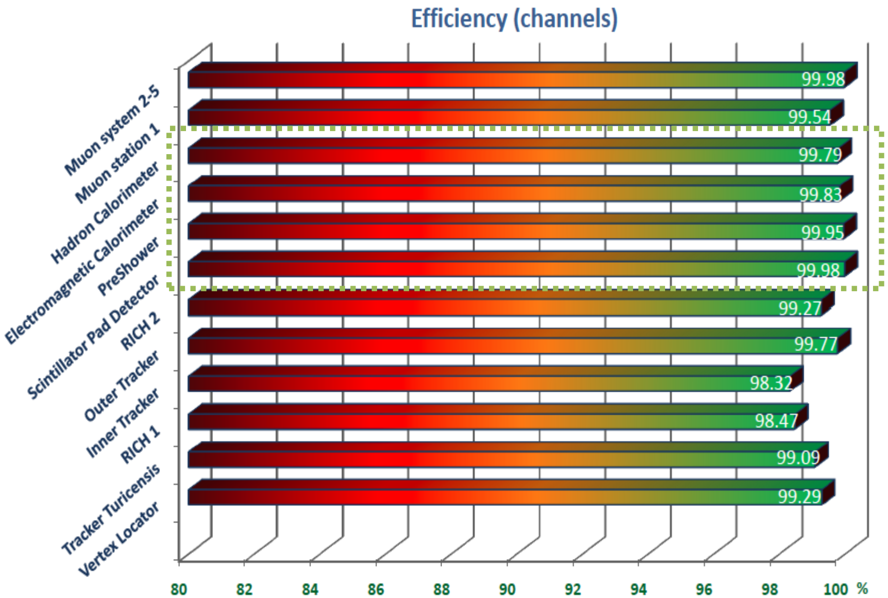




LHCb-CONF-2011-020

Summary

- Calorimeter and more generally LHCb running have been excessively successful
  - Very agressive running conditions (pile-up)
    - Purpose : accumulate a large statistics
    - Pile-up far above nominal design
    - Reconstruction is not heavily affected
  - Already a large statistics recorded
    - 37pb^{-1} recorded in 2010
    - >210 pb^{-1} at present for 2011
      - Hope for 1 fb^{-1} this year



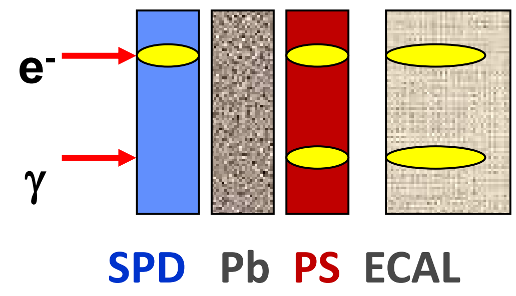
Detector efficiency in 2010

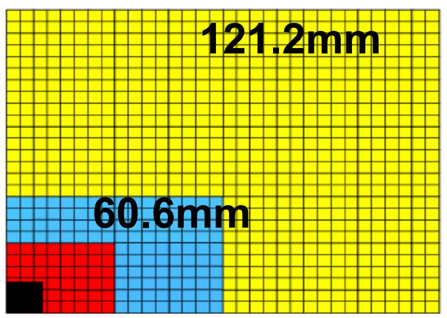
- LHCb is already competing with Tevatron in some areas
  - Calorimeter is contributing to this achievement
- Long programme over several years to explore the full potential of physics beyond the standard model
- Calorimeter upgrade group is already very active,
  - Presentation by Abraham Gallas Torreira
  - Poster from Carlos Abellan Beteta

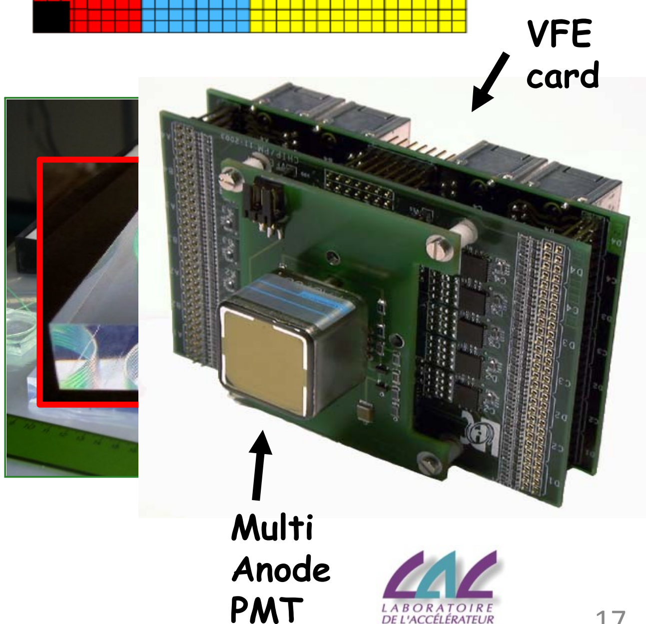
Backup

SPD – PS design

- PS : electron/pion separation
- SPD : photon/mip separation
- Both are part of the first trigger LEVEL (40MHz)
- Design :
  - 2.5 X^0 lead converter sandwiched between two scintillator planes (pads)
  - 3 granularity zones
    - ~ 6000 channels
    - Notice : 3 same zones for ECAL
      - Projective Calorimeters
    - Fast response (L0)
    - ECAL finds local Et maxima
      - SPD/PRS determines nature of energy deposit
  - Signal read by MAPMT
    - PS Dynamic range :
      - 0 – 100Mips
    - Resolution : 10 bits (PS) – 1 bit (SPD)

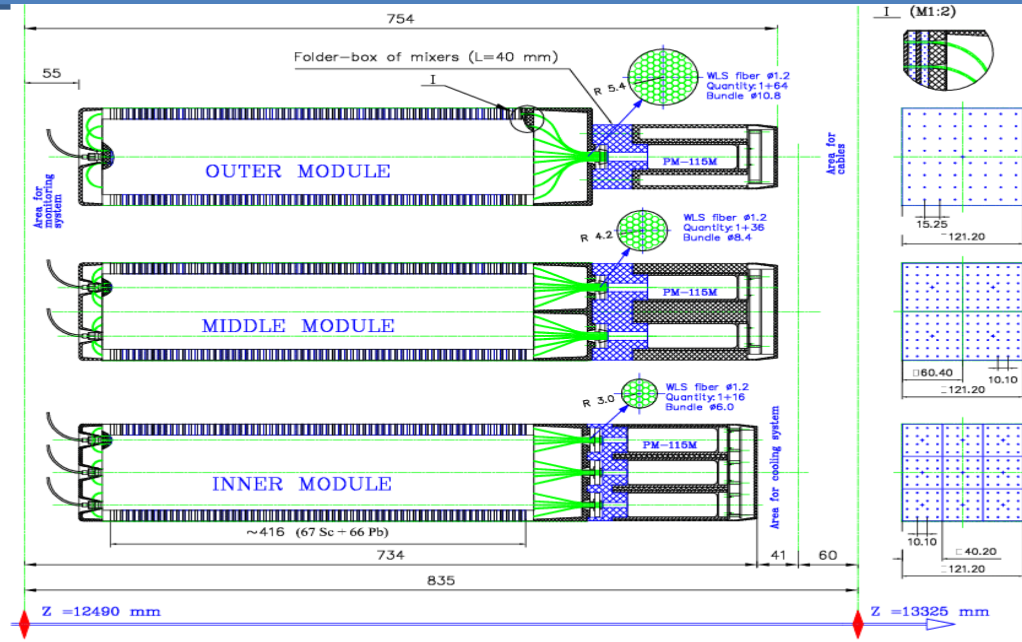


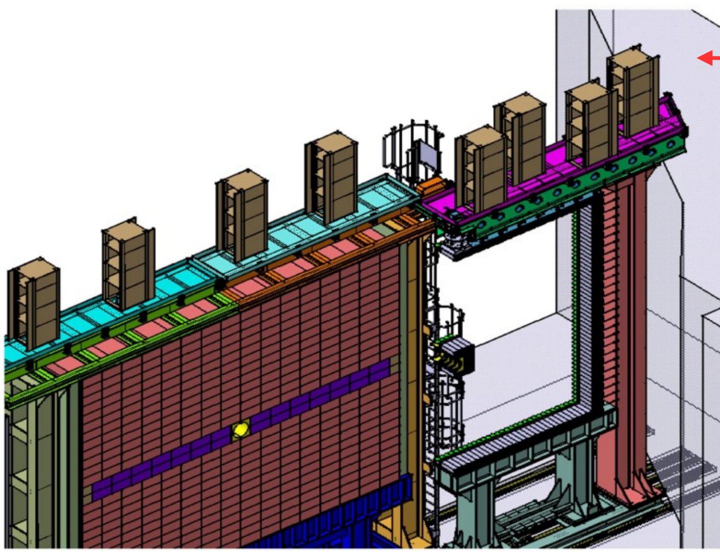




ECAL design

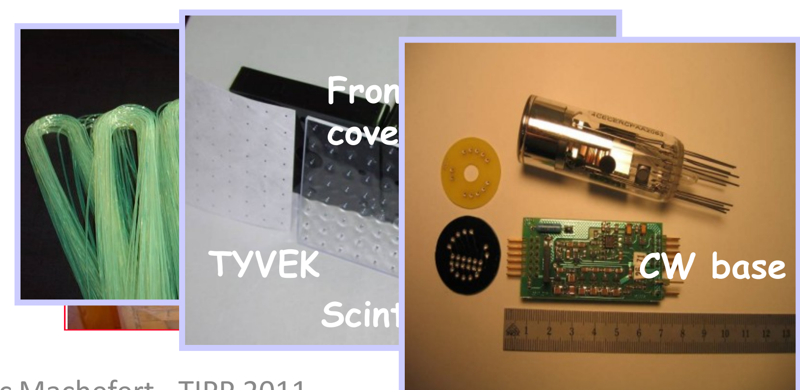
- Shashlik technology
  - Radiation resistance
  - Fast response
  - No spill over
  - Variable segmentation
  - 66 layers of 2mm Pb / 4mm scintillator
    - 25 X^0, 1.1 λ_I
  - WLS fibres transport signal to PMT





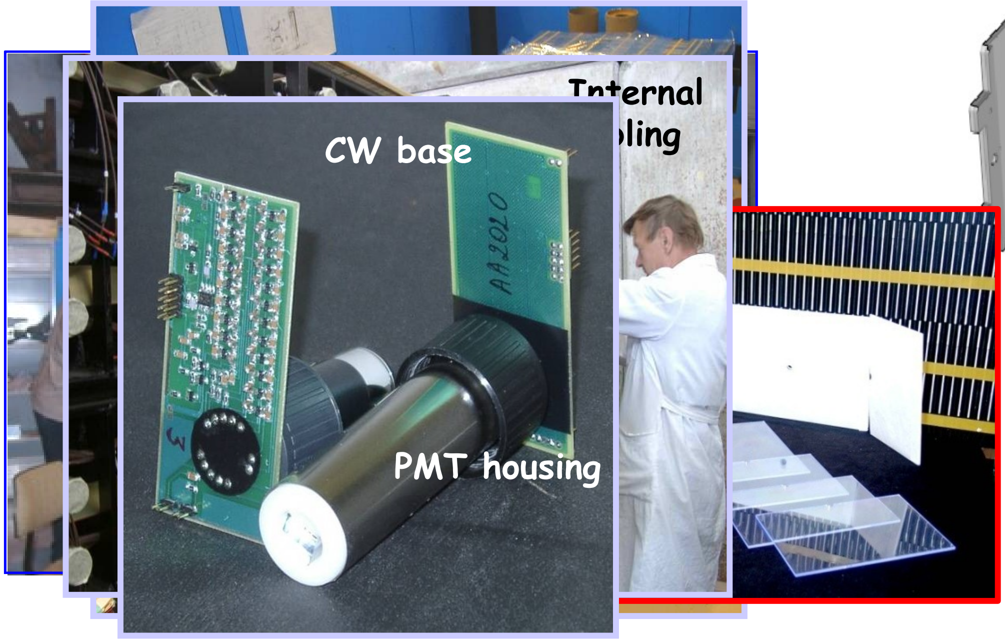
- ECAL front-end / L0 electronics
  - Common with HCAL (see below)
  - Installed on top of sub-detectors (200 rad/y)
  - ECAL dynamic range follows transverse energy rule:

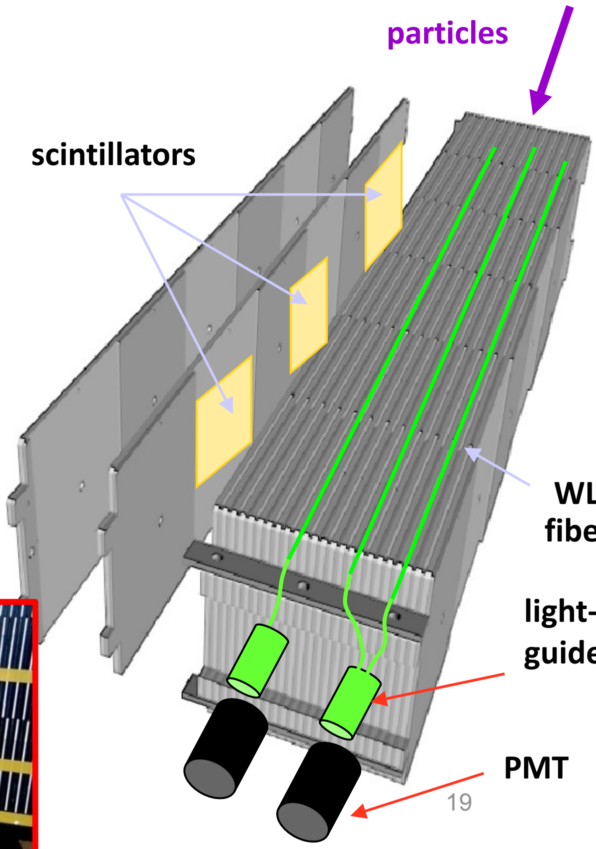
    E(max)=7 + 10/sin(θ) GeV



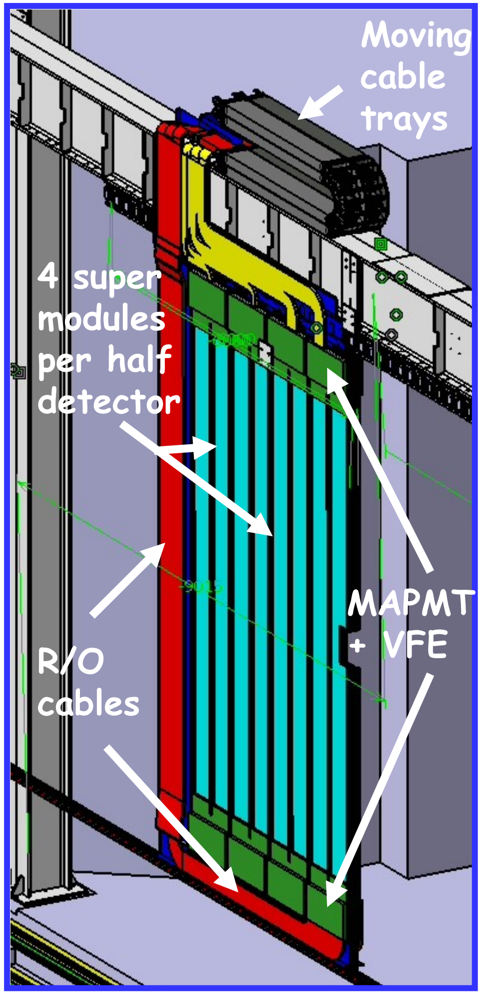
HCAL design

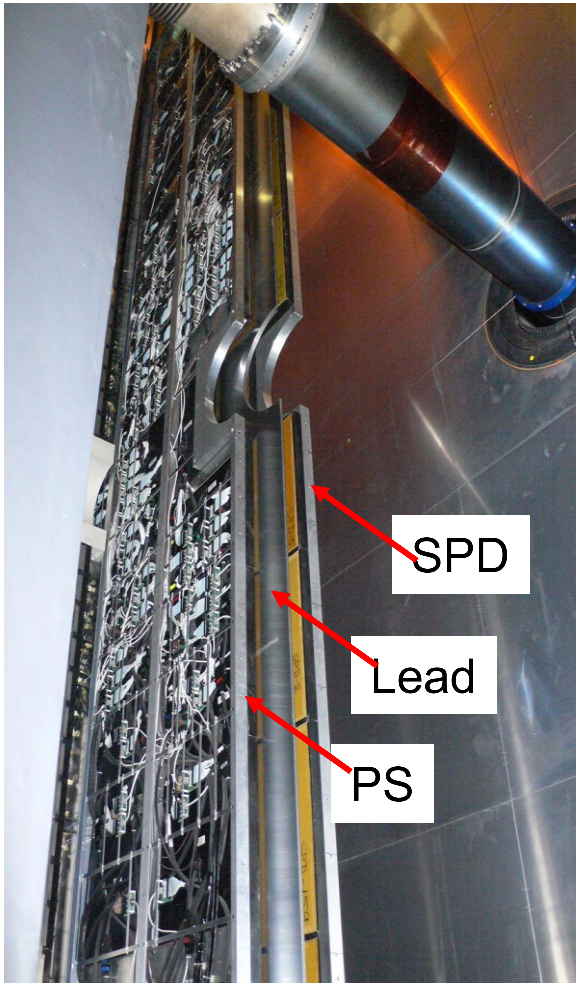
- HCAL is made of 52 tile modules
  - Iron and scintillator tiles
    - 6mm master, 4mm spacer / 3mm scintillator
    - 5.6 λ_I
  - 2 segmentations (1488 channels)
  - Signal propagates with WLS fibres to PMT

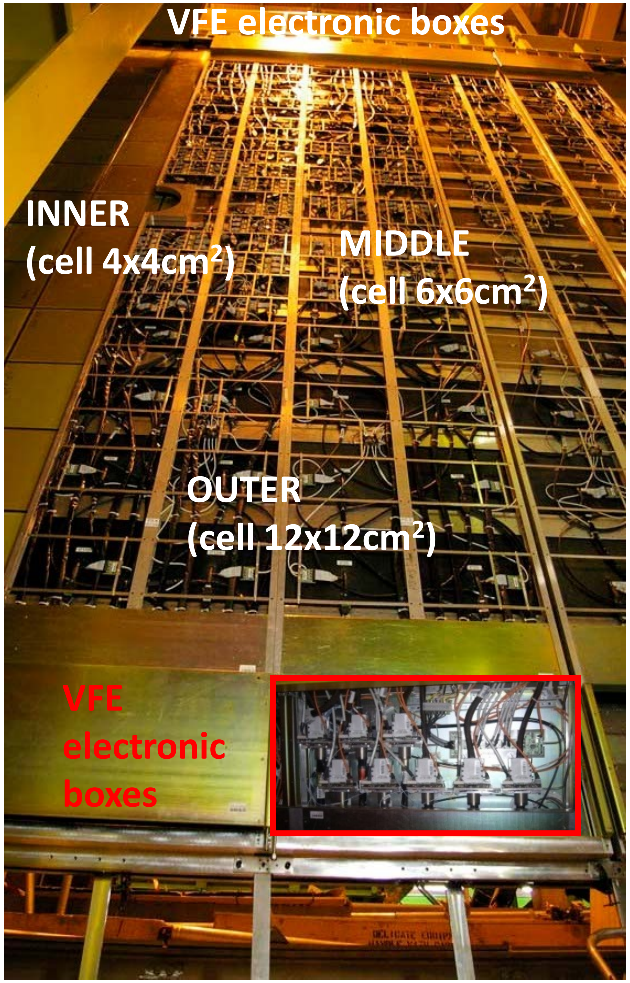




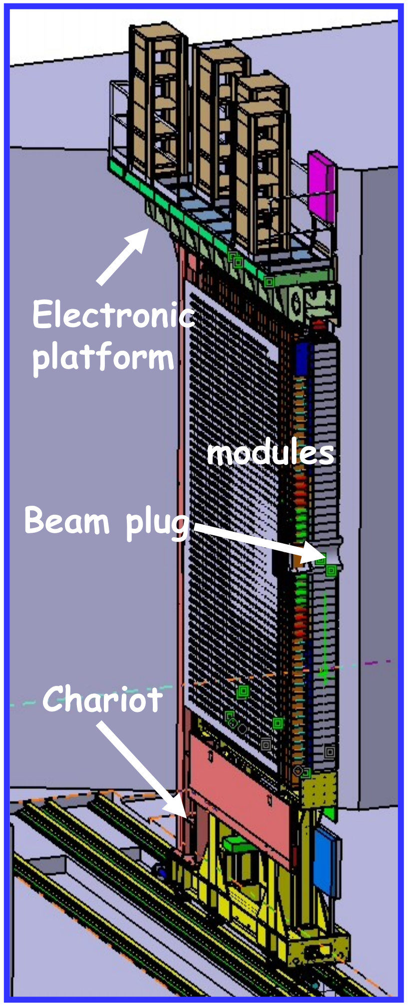
PS – SPD Geometry and Structure

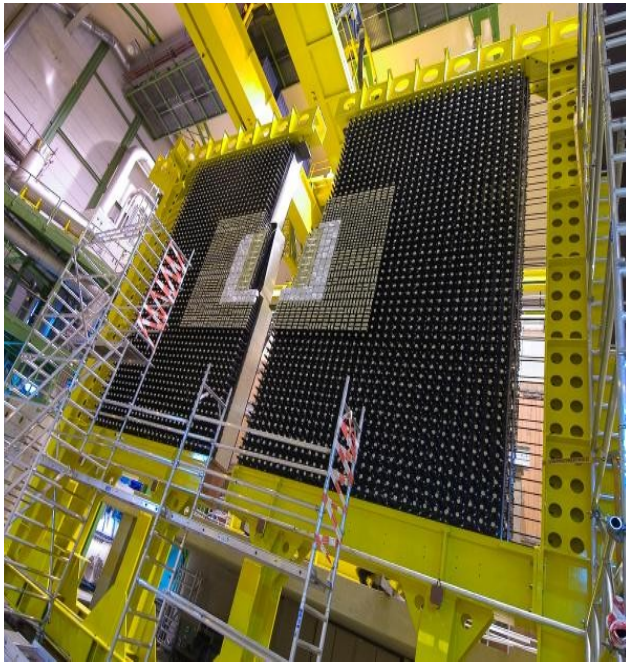


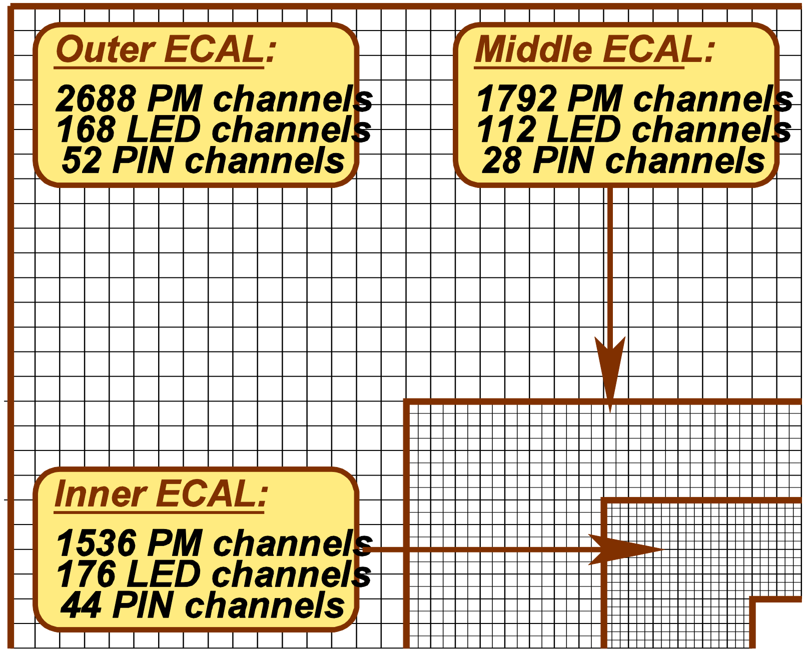




ECAL Geometry and Structure

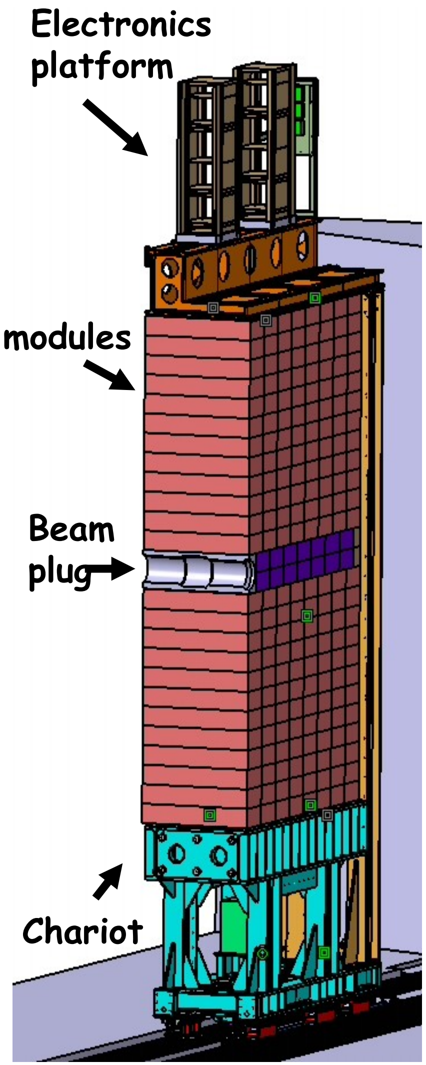


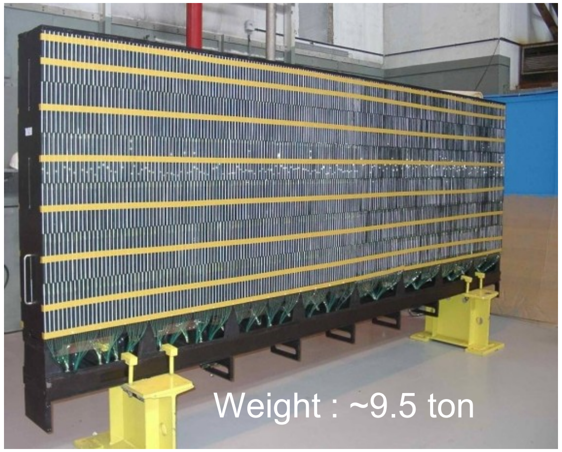


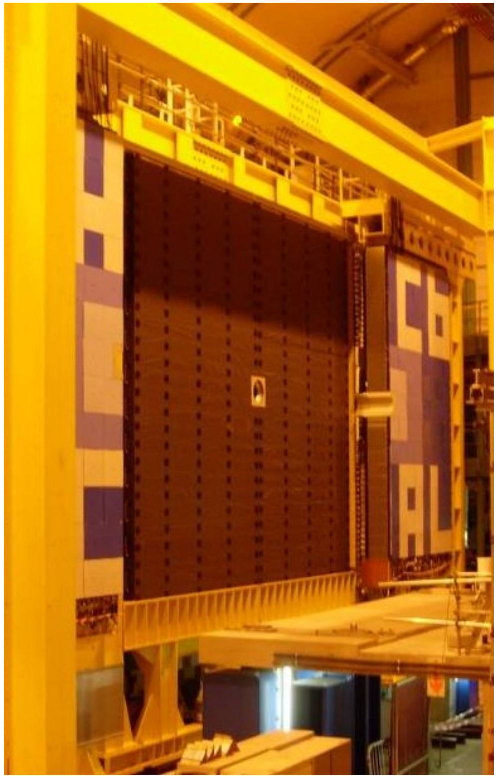


- ECAL
  - Is a large array of ~ $50m^2$
  - Is a modular wall-like structure of 7.8m x 6.3 m
  - has 3312 modules and 6016 channels
  - weights 80 tons
  - Is made of 2 independant halves
    - Ease detector maintenance
  - 3 sections (inner, middle, outer) of 4x4, 6x6, 12x12 cm^2

HCAL Geometry and Structure







- HCAL is made of tile modules
  - two independently retractable halves each consisting of 26 modules stacked on a movable platform
  - size of active area: 8.4 x 6.8 m^2
  - instrumented depth: 120 cm
  - cell size:
    - outer zone 262 x 262 mm2
    - inner zone 131 x 131 mm2
  - 1488 cells (608 outer + 880 inner)
  - LED based Monitoring System
  - built-in 137Cs calibration system for *in situ* calibration

First Level Trigger