First Year Of Running Of The LHCb Calorimeter System

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on behalf of the LHCb collaboration

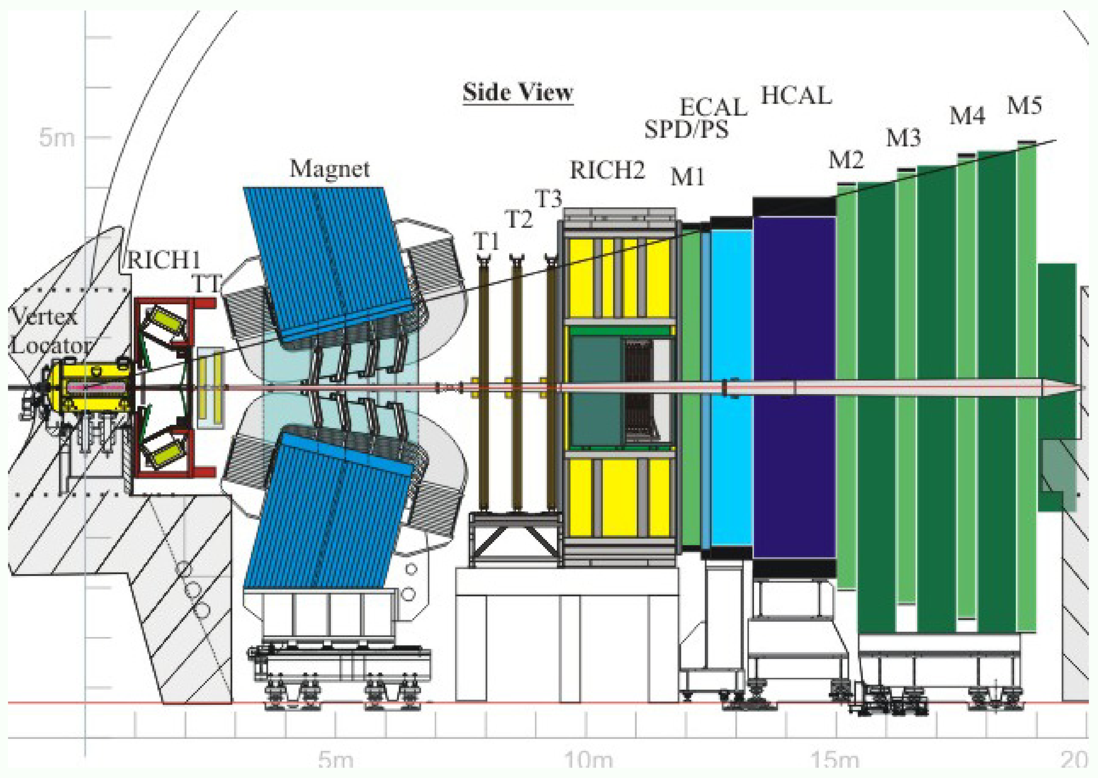
LHCb is a dedicated *b* physics experiment at LHC devoted to the precision study of CP violation and rare decays.

The calorimeter system is intended to provide:

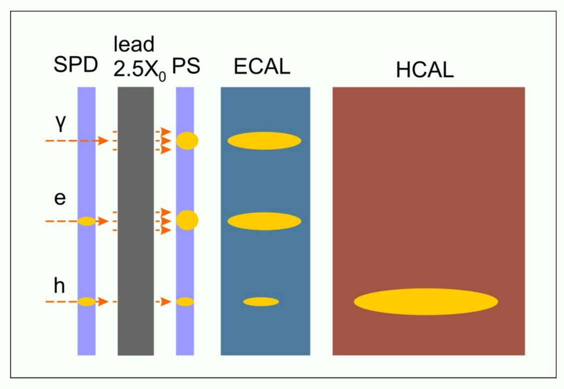
- ✓ L0 trigger on high p_T particles (4 μs for decision);
- ✓ energy measurement and particle identification for hadrons, electrons and photons.

Its data are used in important physics analyses:

- radiative decays B→K*γ, B_S→φγ, …;
- decays with π^0/η: B→πππ^0, J/ψη, D^0→Kππ^0, …;
- decays with electrons: B→K*e⁺e⁻…



The LHCb calorimeter system covers the area of ~7x8.5 m^2. It has classical structure with an electromagnetic (ECAL) and hadronic (HCAL) calorimeters. The ECAL is preceded by the Scintillating Pad detector (SPD) and Pre-Shower (PS) – two planes of scintillating pads, with 15 mm thick lead converter plane between them. SPD provides neutral / charged separation, while PS contributes to electromagnetic shower identification.



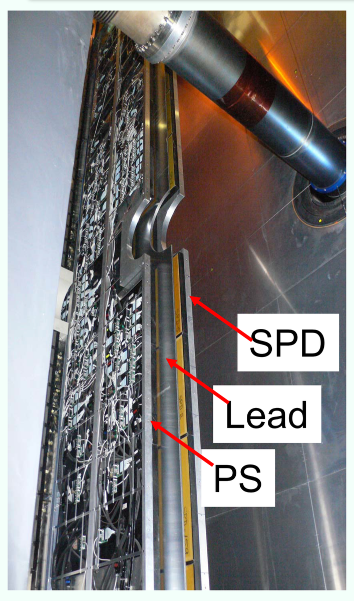
The LHCb calorimeter system layout

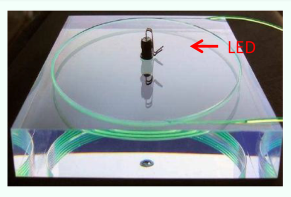
Common requirements: radiation hardness up to ~1-2 Mrad; fast response (LHC bunch clock 25 ns).

In all the four subdetectors the light produced in scintillator tiles is captured by wave-length shifting fibers, and transported towards photomultipliers.

All the subdetectors are equipped with LED monitoring system; in addition, HCAL has embedded radioactive source (^{137}Cs) calibration system.

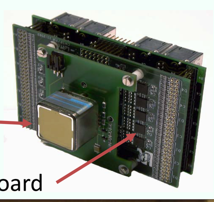
PS / SPD design

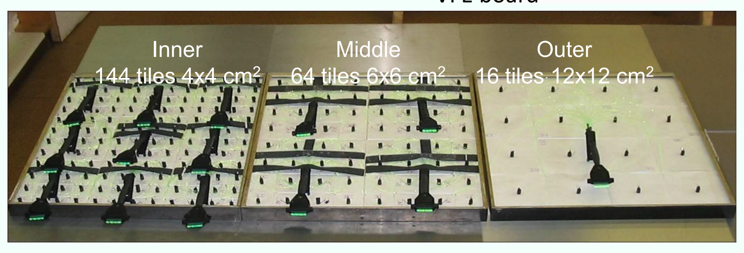




The scintillator tiles are 15 mm thick. The light is captured and re-emitted by WLS fiber (3.5 loops) glued in a deep groove machined at the surface of the tile.

Multi Anode PMT: 64 channels 2x2 mm²



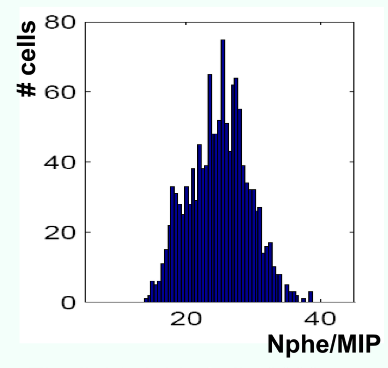


The scintillation light is captured by WLS fibers glued into the tiles, and transported via clear fibers to 64-channel HAMAMATSU multi-anode PMT R7600-00-M64MOD.

Segmentation: 3 zones, Inner (tile size 4x4 cm^2), Middle (6x6 cm^2) and Outer (12x12 cm^2)

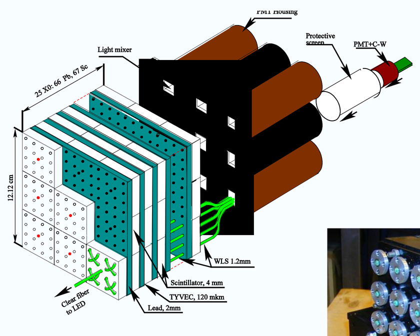
Size ~(7.7 x 6.3) m^2, 2 x 6016 cells

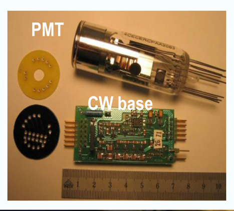
Readout electronics:
Very Front End (VFE) board : dead-timeless charge integrator(25 ns)
Front End (FE) board: digitization, 10 bit ADC for PS, threshold discrimination for SPD.

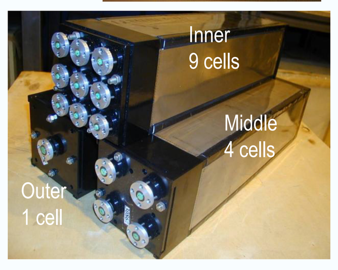


The light yield of all 12032 cells was measured on cosmics at production tests: ~ 25+-12 ph.el. / MIP

ECAL design







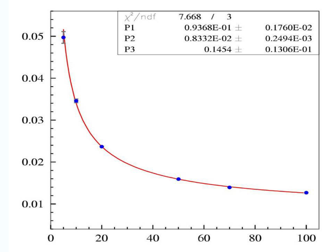
Shashlik technology

- 4 mm thick scintillator tiles and 2 mm thick lead plates, ~25 X_0 (1.1 λ_I);
- Moliere radius ~ 35 mm;
- modules 121.2 x 121.2 mm2;

Segmentation: 3 zones → 3 module types, Inner (9 cells per module), Middle (4), Outer (1). Total of 3312 modules, 6016 cells, (7.7 x 6.3) m^2.

Light readout: PMT R-7899-20, HAMAMATSU. An individual HV supply (Cockcroft-Walton circuit) at each PMT.

Readout electronics: dead-timeless charge integrator(25 ns), flash ADC 12 bit.



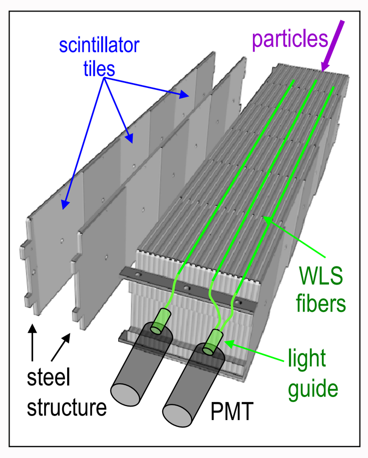
Average performance figures from beam test (there is slight difference between zones):

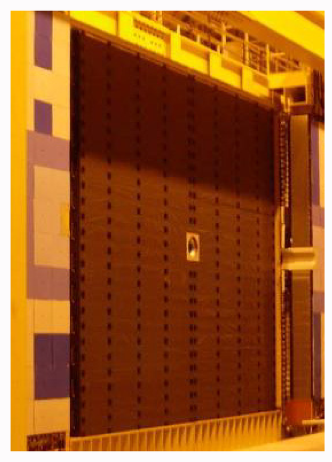
Light yield: ~ 3000 ph.el. / GeV

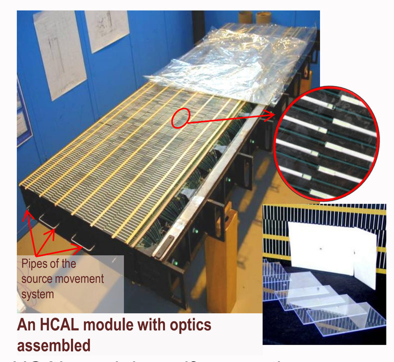
Energy resolution:

$$\frac{\sigma_E}{E} = \frac{(8 \div 10)\%}{\sqrt{E(GeV)}} \oplus 0.9\%$$

HCAL design







HCAL module: self-supporting structure containing either 16 outer or 8 outer + 32 inner cells. HCAL consists of 52 modules, 9.5 tons each.

Tilecal technology (originally developed for ATLAS): iron/scintillator structure arranged parallel to the beam direction. The volume ratio Sc:Fe ~ 3:16.

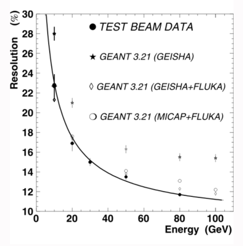
Instrumented depth: 1.2 m, 6 tile rows, ~5.6λ_I

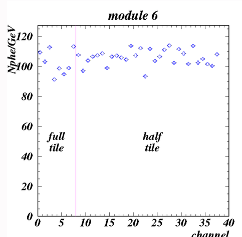
Segmentation: 2 zones, Inner (cells 13x13 cm^2), Outer (26x26 cm^2).
Total of 1488 cells, ~(8.3 x 6.7) m^2, 500 tons.

Light readout: HAMAMATSU R-7899-20, same as ECAL

Performance from the beam test:

- energy resolution $\frac{\sigma}{E} = \frac{(69 \pm 5)\%}{\sqrt{E}} \oplus (9 \pm 2)\%$
- light yield 105±10 ph.el. / GeV

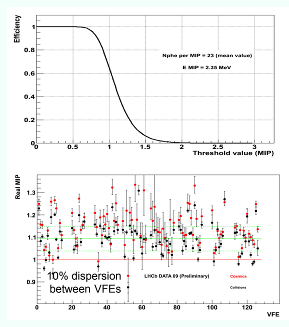




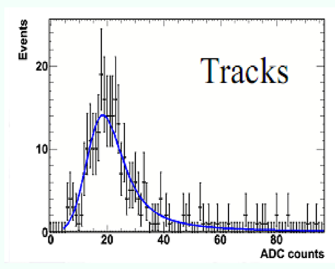
Readout electronics: same as for ECAL.

PS / SPD calibration

The SPD detector gives binary information ("yes/no"). The nominal threshold corresponds to ~0.7 MIP.
The calibration is performed via threshold scan, either with beam or on cosmics (~10% precision). Good agreement between the two.



The PS detector signal is digitized by 10-bit ADC; nominal sensitivity is set to ~ 300 MeV max.
The inter-calibration of cells is based on the position of the MIP peak.

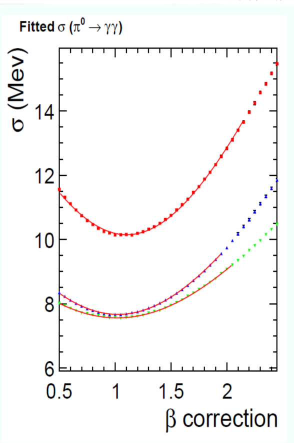


The absolute normalization scale ("β-factor") is necessary for the PS correction to ECAL energy measurements. The EM shower energy is

$$E_{EM} = \alpha E_{ECAL} + \beta E_{PS}$$

, both α and β being dependent on the shower position and origin (e⁻ or γ). The default values of β obtained from MC are ~ 8.8.

The correction is determined in ECAL + PS calibration by minimizing the π^0 width. The event samples are π^0 decays with converted or non-converted photons.

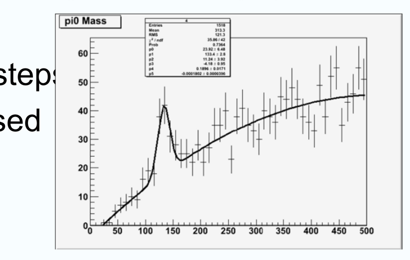


ECAL calibration

The nominal sensitivity of ECAL cells is set depending on their (x,y) position: $E^{max}(\theta)$=(7+10/sin(θ)) GeV.

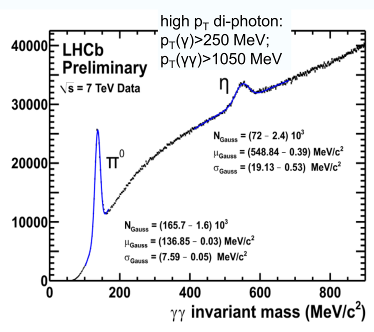
The ECAL calibration was performed in several steps:

1. Pre-calibration before the startup of LHC. Based on PMT gain measurement with LED monitoring system; precision of ~8%. *Clear π^0 signal was observed right after the LHC startup.*



2. Improve inter-calibration with "energy flow" method: for each cell the correction factor is derived from comparison of its average energy deposit per event to that in neighboring cells. Does not require high statistics (~1 M events), was performed shortly after the LHC startup. Precision of ~4-5%.

3. Fine calibration using position of the π^0 peak. For each cell the $M_{\gamma\gamma}$ distribution is filled for γγ pairs with centre of one of γ's cluster at this cell. The correction factor for a cell is determined from the deviation of fitted π^0 mass from the PDG value. Only a subsample of clusters with low energy deposition in PS (<10 MeV) is used at this step. The procedure is iterative, 5-6 iterations. To calibrate all cells, ~100M events is needed.



Performed regularly, ~1-2% precision.

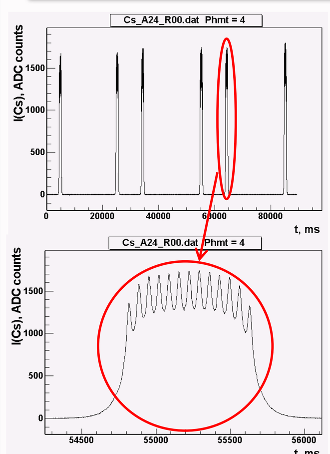
4. Preshower energy correction determination ("β-factor"), from simultaneous calibration of ECAL and PS.

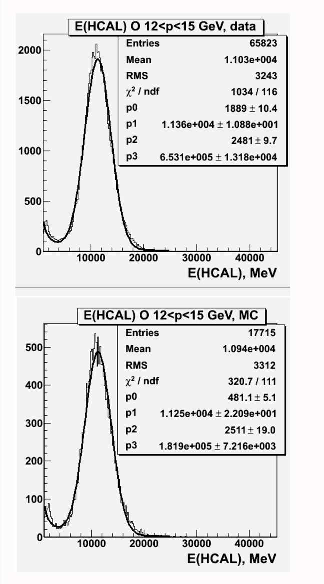
Photon reconstruction performance

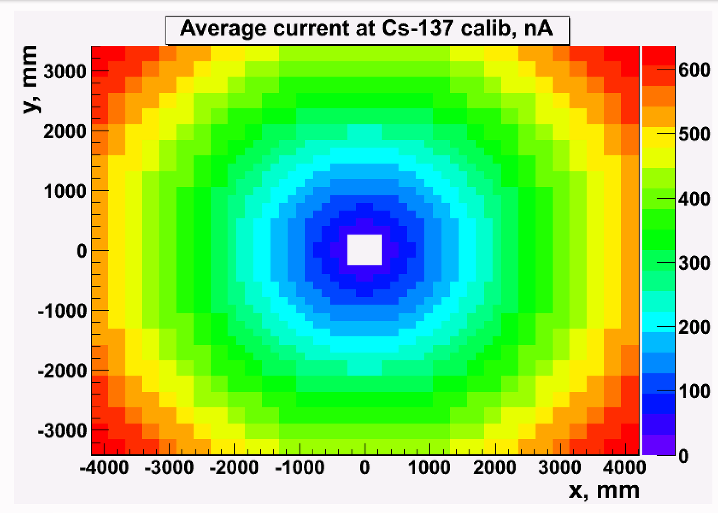
π^0 peak width in modes with 0, 1, 2 converted (→e⁺e⁻) photons:

- π^0→γγ : 7.2 MeV/c^2;
- π^0→γ(ee)γ : 8.2 MeV/c^2;
- π^0→γ(ee)γ(ee) : 9.5 MeV/c^2;

HCAL calibration







Like in ECAL, the HCAL cells' nominal sensitivities are position-dependent: $E^{max}(\theta)$ = 15 GeV/sin(θ).

The calibration with ^{137}Cs source is done every 1-2 month.

The capsule with source passes consecutively through the centers of each of the 6 tile rows of a module in the direction perpendicular to the tiles. The anode current of each PMT is measured with a dedicated "integrator" board ~500 times per second.

The response of each individual tile can be determined from analysis of $I_{Cs}(t)$. The average current of all the tiles of a cell is proportional to the cell's sensitivity to hadrons; precision is 3-4% RMS.

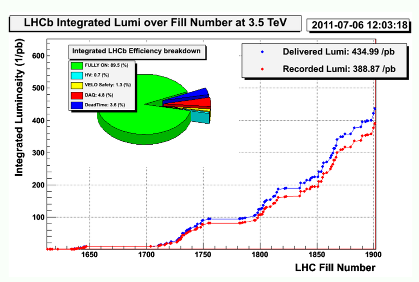
The absolute scale was determined at beam tests before the LHC startup, and then verified with data.

Calorimeter system operation in 2011

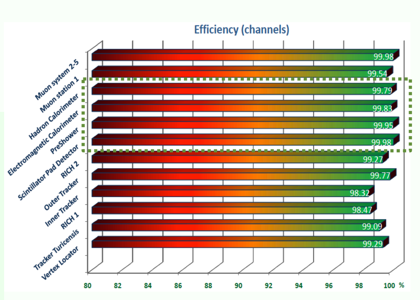
LHC is running now at √s=7 TeV gradually improving its performance. LHCb running conditions are already far above the design values:

- instantaneous luminosity at LHCb ~ 3-4·10^{32} $cm^{-2}s^{-1}$: (1.5-2) x design value
- average number of interactions per event ~ 2 (~ 1.6x);

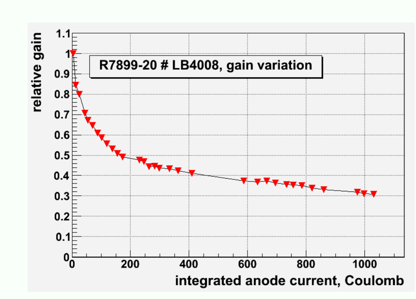
Integrated luminosity of ~400 pb^{-1} already collected, ~1 fb^{-1} expected by the end of 2011.



Since the beginning of the LHC operation, the LHCb experiment, and in particular its calorimeter system, is running successfully and meets its design parameters. The very heavy conditions of running in 2011 does not affect much neither detector running nor data (reconstruction) quality.



For the calorimeter system operation at high luminosity, one can mention higher rate of PMT gain variation, as a consequence of work at higher anode currents → accounted for by detector calibrations.

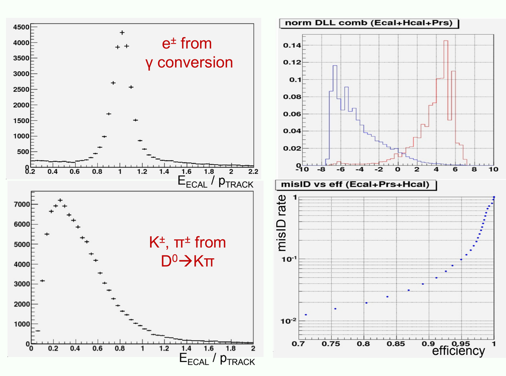


Particle identification with calorimeters

Electron ID. Combined likelihood fully based on real data distributions. Clean reference samples are available in data:

- pure electron/positron sample: photon conversion γ→e⁺e⁻;
- pure hadron sample: decay D0→Kπ

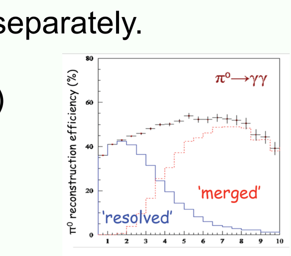
Performance on data:
~4% misidentification rate at 90% efficiency

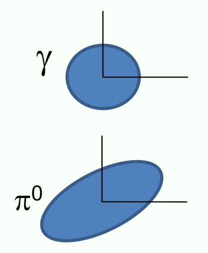


Photon ID. Based on the following observables:

- energy deposition in PRS;
- track matching χ^2 (there should be no track pointing to the Calo cluster)
- clusters with and without SPD hits in front are treated separately.

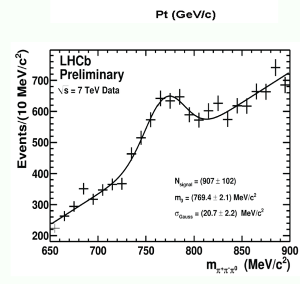
Photon / merged π^0 separation. At high pT (>3 GeV/c) ECAL energy depositions of both γ's from π^0 decay merge into a single cluster. The γ/π^0 separation is an important pre-requisite for radiative decay studies.
The separation is based on cluster shape variables.





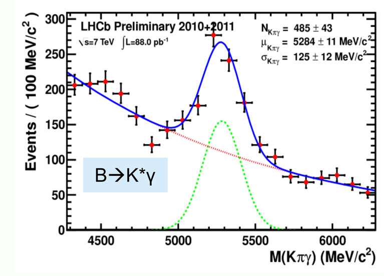
merged π^0 separation performance (for B_S→φγ, B→K*γ)

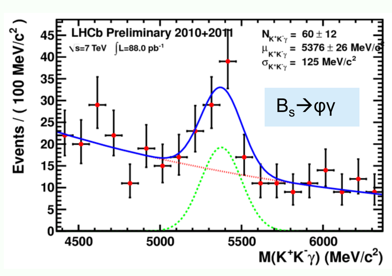
zone	ε, %	misID, %
Inner	90	14
Middle	91	6
outer	91	7



ω→π⁺π⁻π^0 with merged π^0.

Physics with LHCb calorimeters





Radiative decays of *B*-mesons

- proceed via radiative b→(s,d)γ FCNC penguin;
- BR and asymmetries in exclusive modes give a direct constraint on UT;
- right-handed photons suppressed in SM → CP asymmetry in B_S→φγ sensitive to New Physics contribution;
- expect O(6000) B→K*γ and O(700) B_S→φγ events by the end of 2011

Heavy quarkonia production is still a challenging problem for QCD. Measurement of the production cross section of various χ_c spin states, χ_{c0}, χ_{c1}, χ_{c2}, at LHC energy gives an important input for various QCD models.