First Year of Running of the LHCb Calorimeter System

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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 $\sim 50$ GeV
  - Good decay time resolution
  - Good background rejection

Calorimeter-related important physics analysis:
- Radiative decays: $B_d \rightarrow K^*\gamma$, $B_s \rightarrow \phi\gamma$
- Decays involving neutral pions, $\eta: B_d \rightarrow \pi^+\pi^-\pi^0$, $J/\psi \; \eta$, $D^0 \rightarrow K^-\pi^+\pi^0$
- Or electrons: $B_d \rightarrow K^*e^+e^-$
The LHCb detector

Tracking Stations:
- p of charged particles

Calorimeters:
- PID: e, γ, π^0

VELO:
- primary vertex
- impact parameter
- displaced vertex

Muon System

RICHES:
- PID: K, π separation

PileUp System

Trigger Tracker:
- p for trigger and K_s reco

June 11st, 2011

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Running conditions

- LHC delivers $\sqrt{s}=7$ TeV pp collisions
- The machine performances improve rapidly
  - Get to more than 1000 bunches colliding at LHCb IP
  - Instantaneous luminosity is now $3 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$ (1.5 x design)
  - Average visible pp interaction per crossing $\mathcal{O}(2)$
- 37.5 pb$^{-1}$ collected in 2010
- 2011 recorded luminosity $\sim 200$pb$^{-1}$
  - Aim at 1fb$^{-1}$ by the end of this year
Overview of the calorimeter system

Requirements:

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

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

ECAL
Shashlik (Pb-scint.) 6016 cells

HCAL
Tiles (Iron-scint.) 1488 cells

Front-end Crates
Power Supply

Front-end Crates
Power Supply
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

Essentially same method for SPD/PS

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

**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 $\pi^0$ 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 $\pi^0$ peak
  - Iterative procedure by $\pi^0$ mass peak fitting
    - Find the coefficient which would move the measurement closer to the nominal mass
    - Accumulate $\pi^0$ contributing to each cell
  - ~2% precision

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

Energy deposit

Absolute calibration iterations

Channel gain corrections (Eflow)
- Radioactive source scan
  - Performed every 1 to 2 months
    - $^{137}\text{Cs}$ source runs allowed an intercalibration < 3 %
  - Cross-check from Eflow method

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Photon PID

- Photon PID based on probability density functions
  - Track – ECAL cluster position anti-coincidence
  - ECAL shower shape
  - PS energy
- Neutral pion selection
  - $\text{CL}(\gamma)>0.8$
  - $\text{Pt}(\gamma)>650\text{MeV/c}$
- Typical neutral pion resolution
  - $\pi^0 \rightarrow \gamma\gamma : 7.2 +/\ 0.1 \text{MeV/c}^2$
  - $\pi^0 \rightarrow \gamma(\text{ee}) : 8.2 +/\ 0.1 \text{MeV/c}^2$
  - $\pi^0 \rightarrow (\text{ee})(\text{ee}) : 9.5 +/\ 0.1 \text{MeV/c}^2$

![Graphs showing photon PID](image)

- 0 conversion
- 1 conversion
- 2 conversions
Electron PID

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

Signal:
$M(e^+e^-) < 50$ MeV

Background:
$\pm 25$ MeV around $D^0$ peak

No "signal" behavior
Electron PID : performances

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

Combined Calo Delta Log –Likelihood

Mis_ID rate ~4% for electron eff 90%

Fake rate vs efficiency

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Radiative decays of B mesons

- Radiative $b \rightarrow q\gamma$ 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

- $B^0 \rightarrow K^* (K\pi) \gamma$ is observed
  - $\text{Br}(B^0 \rightarrow K^* \gamma) = (43.3 \pm 1.5) \times 10^{-6}$
  - Production rate in LHCb
    - $(6.1 \pm 0.7) B^0 \rightarrow K^* (K\pi) \gamma / \text{pb}^{-1}$  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 $B_s \rightarrow \phi(KK) \gamma$
  - First observed by Belle: $\text{Br}(B_s \rightarrow \phi\gamma) = (57^{+21}_{-18}) \times 10^{-6}$

Belle PRL100,121801, 2008

Babar, Belle, Cleo – HFAG 2010

$B^0 \rightarrow K^* \gamma$

$(0.68 \pm 0.14) / \text{pb}^{-1}$

O(700) in 2011
Relative $\chi_c$ production at LHC

- Heavy quarkonia is still a challenging problem for QCD
  - Bound charmonium states described by non-perturbative models
  - Ratio of $\chi_{c1}$ vs $\chi_{c2}$ BR is a key ingredient
  - $\chi_c$ reconstructed as $J/\psi \gamma$
- Photons id. by a likelihood method
Calorimeter and more generally LHCb running have been excessively successful

- Very aggressive 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

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
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 $E_t$ 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 $\lambda_i$
  - 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:
    $E_{\text{max}} = 7 + 10/\sin(\theta)$ GeV
HCAL design

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

- Is a large array of ~ 50m²
- 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 cm²
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 m²
  - 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