The LHCb Detector and Triggers

BEACH 2006

2-8 July 2006
University of Lancaster (UK)

Fabio Metlica
(Bristol University)
On behalf of the LHCb Collaboration

Introduction
Detector and Trigger
Expected Offline Performance
Summary
Introduction

**LHCb: dedicated 2nd generation B physics precision experiment at LHC**

- study CP violation (precise determination of the CKM parameters)
- search rare B decays

**B meson system:**
- CPV expected to occur in many different decay channels
- ideal to test SM predictions and search for new physics

Aim to **over-constrain** the Unitarity Triangles ⇒ any inconsistencies are hint of new physics.

See talks by:
- P. Koppenburg, LHC semileptonic and radioactive rare B decays program
- M. Musy, Potential for precise Unitarity Triangle angles measurements in LHC
- V. Obratsov, LHCb – beyond the baseline
LHCb: b production

LHCb: single arm forward spectrometer (1.9 < η < 4.9)

• **pp collisions at \( \sqrt{s} = 14 \text{ TeV} \)
  - 25 ns bunch crossing
  - large cross section \( \sigma_{b\bar{b}} \sim 500 \text{ µb}, \sigma_{\text{inelastic}} \sim 80 \text{mb} \)

![bb correlation](image)

• **\( b\bar{b} \) hadrons are produced in a forward cone, correlated**
  - single arm (cost and space reduction)

• **Copious source of B-hadrons ⇒ high statistics**
  - \( B_u, B_d, B_s, B_c, b \)-baryons
  - expect \( \sim 10^{12} b\bar{b} \) pairs/year

• **Run at lower luminosity \( \mathcal{L} \sim 2 \times 10^{32} \text{cm}^{-2}\text{s}^{-1} \)**
  (LHC design \( \mathcal{L} = 10^{34} \text{cm}^{-2}\text{s}^{-1} \))
  - mostly single inelastic interactions
  - simpler event reconstruction
  - limit radiation damage
  - available form the start
  - 2 fb\(^{-1}\)/year(10\(^7\) s) nominal
LHCb Detector Schematic

Requirements for B physics:
- good vertexing
- good tracking
- efficient particle ID (π/K separation)
- efficient trigger for leptonic/hadronic B decays

VELO: Vertex Locator
TT, T1, T2, T3: Tracking stations
RICH1-2: Ring Imaging Cherenkov detectors
SPD/PS: Scintillating Pad Detector, Preshower
ECAL, HCAL: Calorimeters
M1–M5: Muon stations

~10 mrad < θ < 300 mrad  bending plane (x-z)
~10 mrad < θ < 250 mrad  non-bending plane (y-z)
Measurement of track coordinates close to interaction region

- **21 stations:**
  - each station 2 pairs of Si half-discs: $r, \phi$ measurement
  - positioned along beam line axis
  - 300 $\mu$m thick Si sensors
  - 35-100 $\mu$m pitch
  - operated at -5 degrees (C02 cooling)

- **Pile Up System:** two $r$-disks placed upstream to reject multiple interaction events (L0 trigger)
VELO-Vertex Locator

Sensitive area ~ 8mm of the LHC beam
- two retractable halves
- Si disks housed in secondary vacuum (Roman Pot) separated from beampipe vacuum by Al RF foil (250 μm)
- 3 cm retraction during injection

Commissioned in testbeam 2006
Final installation 2007
RICH: Ring Imaging Cherenkov Detectors

Charged particle identification in 2-100 GeV/c range: two RICH detectors, 3 radiators

**RICH1**
- **mirrors**: spherical (light-weight carbon fiber) and planar (glass)
- **radiator**: aerogel $\Rightarrow$ ~2-10 GeV/c
  C4F10 gas $\Rightarrow$ ~10-65 GeV/c
- **magnetic shielding**: shield photon detectors stray B-field
  funnels B-field for tracking
- **wide acceptance**: 25-300 mrad (bending plane)
- Installation completed by ~March07

**RICH2**
- **mirrors**: glass (spherical + planar)
- **radiator**: CF4 gas
- **momentum range**: ~15-100 GeV/c
- **smaller acceptance**: 15-120 mrad (bending plane)
- Installation completed by end 2006
Hybrid photon detectors (HPD): $\lambda \approx 200-600$ nm

- Si array of 1024 pixels
- 2.5mm x 2.5mm granularity
- ~500 HPD

HPD Column

Ring image ~30k events

N$_2$ radiator
Tracking

Find charged particle tracks and measure momentum: VELO + 4 tracking stations

4 Tracking stations (TT,T1,T2,T3)
- 2 outer layers: vertical strips
- 2 inner layers: rotated by stereo angle +5°, -5°

Trigger Tracker
- 4 Si μ-strip planes
- 500μm Si, pitch 183μm, up to 37 cm long strips
- operated at ~5°C

Magnet
- Warm dipole magnet
- $\int B dL = 4 T m$
- B field regularly reversed
- Installed and commissioned
- Field map completed
Tracking

High track occupancy close to beampipe
Area: IT~2%, OT~98%
Tracks: IT~20%, OT~80%

Inner Tracker:
- Si sensors
- Si $\mu$-strip, pitch $198\mu m$, lengths up to $22 \text{ cm}_x$
- Thickness: 320$\mu m$ and 410$\mu m$

Outer Tracker
- Kapton/Al straw tubes ($5 \text{ mm} \times 4.7 \text{ m}$)
- Ar-CO$_2$ gas

OT production completed
IT, TT chambers in production

OT half station
OT straw tube module
Calorimeters

Energy measurement and e, γ, π⁰, hadron identification

3 subdetectors
- **SPD/PS**: 2 planes of scintillating pads with 2X₀ Pb wall in between (e, γ separation)
- **ECAL**: Pb-scintillator Shashlik (25 X₀, 1.1λ₁)
- **HCAL**: Fe-scintillator tile (5.6 λ₁)

Light collection: WLS fibers to PM; MaPMT for SPD/PS
Contributes to L0 trigger

**SPD/PS**: 16 super modules, each consisting of 26 modules mounted in two columns
ECAL, HCAL installed
SPD/PS installation summer 2006

ECAL:
- $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1.5\%$
- $\varepsilon(e \rightarrow e) \sim 95\%$, $\varepsilon(\pi \rightarrow e) \sim 0.7\%$

HCAL:
- $\sigma(E)/E \sim 80\%/\sqrt{E} \oplus 10\%$
- $\varepsilon(e \rightarrow e) \sim 95\%$, $\varepsilon(\pi \rightarrow e) \sim 0.7\%$

HCAL structure
- 52 modules
- Each half: 26 stacked modules
- Each module: 8 sub modules

HCAL Module

ECAL modules

ECAL
- ~3300 modules, stacked ~6m high
- 3 module types of different segmentation

ECAL module assembly
Pb-scintillator Shashlik
Muon System

High Pt Muon triggering (L0) and Muon identification

- 5 muon stations
  - 1380 MWPC
  - 24 Triple-GEMS in M1 inner part were high rate (>100kHz/cm²)
- 3 iron muon filters

Muon Identification efficiency ~94%
Pion misidentification ~1.5%
\[ \delta p/p \sim 20\% \] for b-decays

Muon filter installed
Muon chambers completed by end 2006
Installation completed ~April 2007
Select interesting B-meson decays

- large background/signal ratio $\sigma_{\text{inelastic}} / \sigma_{b \bar{b}} \sim 160$
- small branching ratios (<10^{-3})
- limited detector acceptance

Require selective and efficient trigger

B-meson signatures:
- leptons, hadrons with large Pt
- secondary vertices
- tracks with large impact parameter
**Trigger: Two levels**

### Level 0
- Reduce rate from 40MHz (bunch crossing) to 1MHz
- Fixed latency 4μs
- Hardware trigger
- Custom electronics

### HLT (High Level Trigger)
- Reduce rate from 1MHz to ~2kHz
- Full detector info available
- Software trigger
- CPU farm (~1800 nodes)
- Latency dependant on number of CPUs
L0 Trigger

- **Pile-up system**
  - reject events with multiple interactions per bunch crossing

- **Calorimeter trigger (high $E_T$ clusters)**
  - find and select (h, e, $\gamma$, $\pi^0$) candidates with highest $E_T$ in ECAL/HCAL

- **Muon Trigger (high $P_T$ muons)**
  - select 2 muons with the highest $P_T$ in each quadrant

**Decision Unit**

- trigger conditions evaluated
- L0 decision formed

Latency ~1μs
L0 Trigger

LO Efficiency:
~50% for hadronic channels
~90% for \( \mu \) channels
~70% for radiative channels
Use all detector info.

Starting point is the L0 decision.

4 alleys:
- Alley chosen depends on L0
- Alleys are independent
- Alleys produce a summary (monitoring):
  - Decision
  - Type of trigger
  - Quantities used
  - Reconstructed objects
- Each alley consists of 3 main steps:
  - Level-0 trigger confirmation
  - Fast rejection using reconstructed quantities
  - Alley-dependent trigger algorithm

Inclusive selection:
- Systematic studies
- Inclusive B or D*

Exclusive selection:
- Reconstructed B decays

HLT Output Rates:
- Exclusive B ~200Hz (core physics)
- D* ~300Hz (PID eff., D decays)
- Dimuon ~600Hz (tracking, $\Delta \Gamma$)
- Inclusive $b \rightarrow \mu$ ~900Hz (trigger eff., data mining)
Expected Tracking Performance

Primary vertex resolution:
- $\sim 8 \mu m$ (x,y)
- $\sim 44 \mu m$ (z)

Long tracks (from VELO to T stations):
- Efficiency: $\sim 94\%$ ($p > 10$ GeV/c)
- Ghost rate: $\sim 3\%$ ($p_T > 0.5$ GeV/c)
- Momentum resolution: $\sim 0.4\%$
- Impact parameter resolution: $\sim 40 \mu m$

Proper time resolution
- $\sigma_t \sim 40$ fs

$B_s \rightarrow D_s \pi$
- $\sigma_t = 33 \pm 1$ fs (69\%)
- $\sigma_t = 67 \pm 3$ fs

$\Delta p/p \sim 0.35\% - 0.55\%$

P spectrum of B tracks

1/P$_T$ spectrum of B tracks

$\sigma(IP) = 14 \mu m + 35 \mu m/P_T$
Expected Particle ID

• Efficient \((K,\pi)\) separation with RICH
  
  - \(K,\pi\) id efficiency \(\sim 90\%\)
  - \(K,\pi\) misidentification <10%

• With ECAL and Muon
  
  - \(e,\mu\) id efficiency \(\sim 95\%\)
  - \(\pi\) misID \(\sim 1\%\)
Expected Neutral Reconstruction

- $\pi^0 \sim 50\%$ reconstruction efficiency ($B^0 \rightarrow \pi^+\pi^-\pi^0$)
  - use CALO clusters not associated to tracks
  - reconstruct $\pi^0$ from two separate clusters (resolved) or single merged cluster (use cluster shape)

- $K_S \rightarrow \pi^+\pi^-$ reconstruction efficiency $\sim 75\%$ if decay in VELO, lower otherwise.

![Graph showing $p_T(\pi^0)$ vs. Efficiency (%)]
Summary

- LHCb detector is a dedicated B-physics experiment.
  - precise vertexing and tracking
  - excellent PID
  - excellent proper time resolution
  - efficient and selective trigger

- Construction and installation of the subdetectors is progressing on schedule.

- L0 trigger hardware is under construction and the commissioning is in early 2007, while the HLT trigger is in its final stage of development.

- LHCb will be ready for the LHC pilot run second half 2007.

- Aim to get physics results early from the LHC.