The LHCb Detector and Triggers

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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** $\Rightarrow$ 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 ($1.9 < \eta < 4.9$)

- pp collisions at $\sqrt{s} = 14$ TeV**

- 25 ns bunch crossing
- large cross section $\sigma_{b\bar{b}} \sim 500 \mu\text{b}$, $\sigma_{inelastic} \sim 80\text{mb}$

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

- Copious source of B-hadrons $\Rightarrow$ 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 from the start
- $2 \text{ fb}^{-1} / \text{year} (10^7 \text{ s})$ nominal

LHCb Detector Schematic

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

$\sim 10 \text{ mrad} < \theta < 300 \text{ mrad}$ bending plane (x-z)
 $\sim 10 \text{ mrad} < \theta < 250 \text{ mrad}$ non-bending plane (y-z)

VELO-Vertex Locator

Measurement of track coordinates close to interaction region

- 21 stations:**

- each station 2 pairs of Si half-discs: r, ϕ measurement
- positioned along beam line axis
- 300 μm thick Si sensors
- 35-100 μm pitch
- operated at -5 degrees (CO₂ cooling)

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

VELO-Vertex Locator

RF boxes

VELO TANK at IP8

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 ~March 07

RICH1

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

RICH2

RICH2

hybrid photon detectors (HPD) : $\lambda \sim 200\text{-}600\text{ nm}$

HPD

Si array of 1024 pixels
2.5mmx2.5mm granularity
~500 HPD

HPD Column

ring image ~30k events
 N_2 radiator

Polar angle vs. momentum $B_d^0 \rightarrow \pi^+ \pi^-$

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 $+5^\circ, -5^\circ$

Trigger Tracker

- 4 Si μ -strip planes
- 500 μ m Si, pitch 183 μ m, up to 37 cm long strips
- operated at $\sim 5^\circ\text{C}$

TT detector half

Silicon ladders

Magnet

- Warm dipole magnet
- $\int B dL = 4 \text{ Tm}$
- B field regularly reversed
- Installed and commissioned
- Field map completed

Fe yoke (1.45 kt)

Al coil ($2 \times 25 \text{ t}$)

Tracking

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

Inner Tracker:

- Si sensors
- Si μ -strip, pitch 198 μ m, lengths up to 22 cm
- Thickness: 320 μ m and 410 μ m

Outer Tracker

- Kapton/Al straw tubes (5 mm * 4.7 m)
- Ar-CO₂ gas

OT production completed
 IT, TT chambers in production

OT half station

OT straw tube module

Calorimeters

Energy measurement and e, γ, π^0 , hadron identification

3 subdetectors

- **SPD/PS**: 2 planes of scintillating pads with $2X_0$ Pb wall in between (e, γ separation)
- **ECAL**: Pb-scintillator Shashlik ($25 X_0, 1.1\lambda_I$)
- **HCAL**: Fe-scintillator tile ($5.6 \lambda_I$)

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

Calorimeters

HCAL

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

HCAL structure

HCAL Module

ECAL modules

ECAL

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

- ECAL: $\sigma(E)/E \sim 10\%/\sqrt{E} \oplus 1.5\%$
- HCAL: $\sigma(E)/E \sim 80\%/\sqrt{E} \oplus 10\%$
- $\varepsilon(e \rightarrow e) \sim 95\%$, $\varepsilon(\pi \rightarrow e) \sim 0.7\%$

ECAL, HCAL installed
SPD/PS installation summer 2006

Muon System

High Pt Muon triggering (LO) and Muon identification

- 5 muon stations
- 1380 MWPC
- 24 Triple-GEMS in M1 inner part were high rate ($>100\text{kHz/cm}^2$)
- 3 iron muon filters

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

Muon filter installed
 Muon chambers completed by end 2006
 Installation completed $\sim$ April 2007

Select interesting B-meson decays

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

Require selective and efficient trigger

B-meson signatures:

- leptons, hadrons with large P_t
- secondary vertices
- tracks with large impact parameter

Trigger: Two levels

Level 0

- reduce rate from 40MHz (bunch crossing) to 1MHz
- fixed latency 4 μ s
- 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, γ , π^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

L0 Trigger

L0 Efficiency:

- ~50% for hadronic channels
- ~90% for μ channels
- ~70% for radiative channels

HLT Trigger

- 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: $\sim 8 \mu\text{m}$ (x,y)
 $\sim 44 \mu\text{m}$ (z)

Long tracks (from VELO to T stations):

- Efficiency: $\sim 94\%$ ($p > 10 \text{ GeV/c}$)
- Ghost rate: $\sim 3\%$ ($p_T > 0.5 \text{ GeV/c}$)
- Momentum resolution: $\sim 0.4\%$
- Impact parameter resolution: $\sim 40 \mu\text{m}$

Expected Particle ID

- Efficient (K, π) separation with RICH

K, π id efficiency $\sim 90\%$
 K, π misidentification $< 10\%$

- With ECAL and Muon e, μ id efficiency $\sim 95\%$, π misID $\sim 1\%$

Expected Neutral Reconstruction

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

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

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.
- LO 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.