Performance of the LHCb detector during the LHC proton runs 2010-2012

Francesco Dettori

Nikhef

13th Vienna Conference on Instrumentation
Vienna, February 11-15/2012
Outline

• LHCb experiment and detector
• Trigger
• Tracking and vertexing
• Particle identification and neutrals
• Ageing

Focus on some aspects.
See also:
Stefano De Capua - Performance and Radiation Damage Effects in the LHCb Vertex Locator
Mark Tobin - The LHCb Silicon Tracker
Heinric Schindler - The LHCb detector upgrade
The LHCb experiment

**LHC**
- *pp* collisions at 7-8 TeV
- Large *b*-quark production in the forward region
- Full *b*-hadrons spectrum

**Studies**
- CP Violation
- CKM matrix tests
- Rare decays

**LHCb**
- Specialized B-physics experiment
- Forward single arm spectrometer
- Acceptance: $2 < \eta < 5$
- $\mathcal{L} = 3 - 4 \cdot 10^{32} \text{cm}^{-2}\text{s}^{-1}$
- $\int \mathcal{L} = 3.3 \text{fb}^{-1} \Rightarrow 10^{12} \text{b}\bar{b}$ pairs
The LHCb experiment

813 members
16 countries
59 institutes
(July 1, 2012)
The LHCb detector
Operating conditions in the data taking 2010-2012

- Instantaneous luminosity double the design one
- $\sqrt{s} = 0.9, 7, 8$ TeV
- 50ns bunch spacing
- Larger pile-up not compromised performances
- Luminosity levelling
Trigger

40 MHz bunch crossing rate

L0 Hardware Trigger: 1 MHz readout, high $E_T/P_T$ signatures

- 450 kHz $h^+$
- 400 kHz $\mu/\mu\mu$
- 150 kHz $e/\gamma$

Software High Level Trigger

- 29000 Logical CPU cores
- Offline reconstruction tuned to trigger time constraints
- Mixture of exclusive and inclusive selection algorithms

5 kHz Rate to storage

- 2 kHz Inclusive Topological
- 2 kHz Inclusive/Exclusive Charm
- 1 kHz Muon and DiMuon

**$B^+ \rightarrow J/\psi(\rightarrow \mu\mu)K$**

- L0Muon
- L0DiMuon

$\varepsilon_{TOS}$ vs $p_T$ [MeV/c]

$\varepsilon_{TOS}$ vs $\tau$ [ps]

**HLT2**

Topological trigger versus B lifetime
Deferred High Level Trigger

- Increase L0 rate beyond HLT farm capacity
- Overflow to farm node disks (1 petaByte in total)
- Defer HLT processing to LHC intfill time
Tracking

- Dipole magnet
- VELO, TT and IT: Silicon detectors
  ⇒ See M. Tobin and S. De Capua talks
- Outer Tracker
Outer Tracker

- Straw-tube drift chambers
- 3 stations, 4 layers per station
- Stereo geometry \((y, 5^\circ, -5^\circ, y)\)
- \(\text{Ar (70\%), } CO_2 (28.5\%), O_2 (1.5\%)\)
Greatest Hits
Hit efficiency and resolution

Performance measured with tracks on data:

- Removing the hits of the probed layer
- Searching for hits in track extrapolation

OT single cell efficiency profile

OT unbiased hit residual

\[
\mu = -1 \mu m \\
\sigma = 211 \mu m
\]
Track finding efficiency

Efficiency measured with tag and probe method in $J/\psi \rightarrow \mu^+ \mu^-$

![Graph showing efficiency](image)

CERN-LHCb-PUB-2011-025

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Vertexing

Primary vertex resolution:
- Estimate from splitting tracks into two samples
- Decreases with the number of tracks
- For $N = 25$ $\sigma_{xy} \sim 13\mu m$, $\sigma_z \sim 70\mu m$

IP Resolution:
- Crucial to separate B decays from PV
- Depends on $p_T$

![Impact parameter (\(\mu m\))](image)

- Decay time fundamental for time-dependent CP asymmetries
Momentum and mass resolutions

\[ \sigma_{\mu\mu} = 15 \text{ MeV}/c^2 \text{ for } J/\psi \]

\[ 1.7 \text{ GeV}/c^2 \text{ for } Z^0 \]

Mass bias of the order of 1 per mill from the \( J/\psi \) to the \( Z^0 \)
Tracking highlights

hep-ex/1302.1072
Particle identification and neutrals

- RICH
- Calorimeters
- Muon
**Ring Imaging Cherenkov Detectors (RICH)**

Similar structure:
- Spherical + Flat mirrors
- HPD readout with encapsulated FEE

Different conditions:

<table>
<thead>
<tr>
<th>RICH1</th>
<th>RICH2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiator</td>
<td>Aerogel/C_{4}F_{10}</td>
</tr>
<tr>
<td>Momentum (GeV/c)</td>
<td>2-40</td>
</tr>
<tr>
<td>Acceptance (mrad)</td>
<td>25-300</td>
</tr>
</tbody>
</table>

Can't you see the rings?

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RICH performances

Cherenkov angle resolution of 1.62 (0.68) mrad for $C_4F_{10}$ ($CF_4$) in agreement with simulations. Aerogel resolution is worse than expected probably due to $C_4F_{10}$ contamination.

hep-ex/1211.6759
**RICH performances**

Calibrated with pure particle samples:

\[ K_S^0 \rightarrow \pi^+\pi^- , \quad \Lambda^0 \rightarrow p\pi^- , \]

\[ D^{*+} \rightarrow D^0(K^-\pi^+)\pi^+ , \quad B \rightarrow \pi\pi \text{ No PID} \]

- **LHCb (b)\rightarrow K^\pi\llbracket (7 \text{ TeV Datas})

- **LHCb \sqrt{s} = 7 \text{ TeV Data}**

- **Kaon ID Efficiency**

- **Pion Mis-ID Efficiency**

- **No. Tracks in Event**

- **hep-ex/1211.6759**

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Calorimeters

- Scintillating Pad Detector / Pre-Shower
- ECAL - Shashlik calorimeter
- HCAL - Sampling calorimeter

- Scintillation light read by PMT
- Projective segmentation
- $\sigma(E)/E \sim 9\%/\sqrt{E} \oplus 0.8\%$ (ECAL)
- $\sigma(E)/E \sim 69\%/\sqrt{E} \oplus 9\%$ (HCAL)
Calorimeters performance
Calibration and neutrals reconstruction

Monitoring and calibration:

- LED systems on empty bunches
- SPD: threshold scan
- PS: MIP signals from track extrapolations
- ECAL: $\pi^0$ mass iterative calibration
- $E/p$ from pure electrons
- HCAL: built-in $^{137}$Cs source

$m_{\pi^0}$ calibration

$D^0 \rightarrow K^- \pi^+ \pi^0$ with resolved $\pi^0$

$\sigma_m \sim 8\text{MeV}/c^2$

$D^0 \rightarrow K^- \pi^+ \pi^0$ with merged $\pi^0$

$\sigma_m \sim 20\text{MeV}/c^2$
Muon detector

MWPC for M2-M5 and M1 outer region
- Four gaps in OR per station
- \( \text{Ar : CO}_2 : \text{CF}_4 = 40 : 55 : 5 \)

Triple-GEM detectors for M1 inner region
- Pairs of modules in OR

Perfect rate scaling with luminosity

Timing efficiencies well beyond design requirements.
Muon detection

- Tracks extrapolated to the muon chambers
- Very high hit efficiency (> 99%) everywhere except some triple-GEM detectors

★ High muon ID efficiency with low mis-ID
★ Limited by decays in flight
Particle identification highlights

\[ B \rightarrow h h \text{ No PID} \]

\[ B \rightarrow \pi \pi \text{ with PID} \]

\[ B \rightarrow K K \text{ with PID} \]

\[ B^0 \rightarrow K^*\gamma \text{ rare decay} \]

\[ B^+_S \rightarrow \mu \mu \text{ evidence} \]

\[ K^0_S \rightarrow \mu \mu \text{ search} \]

J. High Energy Phys. 01 (2013) 090
Ageing and radiation damage

Outer Tracker

- Periodic $^{90}\text{Sr}$ scans
- Monitoring with threshold scans during $pp$ collisions
- No visible sign of ageing so far
- Actually LHC can cure some current losses
Ageing and radiation damage (2)

Ageing on calorimeters

- Carefully monitored with LED - Cs source calibration
- ECAL cross-checked with $\pi^0$ mass
- Scintillators ageing modeled
- HCAL automatic PMT HV adjustment for each fill

\[
\frac{\sum I_i}{\sum I^\text{ref}_i}
\]

Before calibration

After calibration

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Performance of the LHCb detector...
Conclusions

- LHCb performed well in harsh conditions
- 2010-2012 data taking collected $3.3 \ fb^{-1}$ at different energies
- Performance of the subdetectors close to design
- Excellent physics output
- Ageing well
Additional material
Alignment

VELO:
- Survey before installation
- Track and vertex based alignments
- Monitoring crucial for a moving detector

Tracking system alignment:
- TT, IT, OT aligned to the VELO
- Alignment with tracks. Important constraints from tracks traversing sensors assembled together.
- Curvature bias constrained by $J/\psi \rightarrow \mu^+ \mu^-$ and $D^0 \rightarrow K^- \pi^+$ masses
Greatest Hits Vol. 2
Hit resolution

<table>
<thead>
<tr>
<th>VELO</th>
<th>[4,25] μm</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT</td>
<td>60 μm</td>
</tr>
<tr>
<td>IT</td>
<td>50 μm</td>
</tr>
<tr>
<td>OT</td>
<td>210 μm</td>
</tr>
</tbody>
</table>

- Biased resolution even better