Status of the LHCb experiment

Outline

- Introduction to the LHCb experiment
- The LHCb detector
- Calibration of the VELO detector
- Performance with the first collision data
- Summary

On behalf of the LHCb collaboration
Introduction to LHCb
Why the LHCb detector was built?

LHCb is a dedicated experiment to study B physics at the LHC

- search for New Physics (indirect)
- rare decays
- complementary to ATLAS/CMS experiments (direct searches)

Main detector requirements

- Efficient trigger for both hadronic and leptonic final states
- Excellent vertex finding and tracking efficiency
- Outstanding Particle Identification

Primary vertex: many tracks ~50

B decay vertices: a few tracks

100 µm to 10 mm

Tomasz Szumlak (University of Glasgow)
Epiphany 2010, 06-09 Jan 2010, Krakow, Poland
Physics prospects

- $b \to s$ transitions: far from having full picture, space for NP effects
- Flavour physics observables have sensitivity to new particles at high mass scales via their virtual effects in loop diagrams:

- Loop diagrams are sensitive to New Physics effects (heavy particles)
- Limits come from both experiment (measurement precision) and theoretical uncertainties (not CM energy)
- Heavy flavour physics can provide reliable hints before direct observation of new particles is made

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The LHCb is a forward spectrometer, angular acceptance 15 - 300 (250) mrad or in other ‘pseudo-rapidity language’ η 1.9 - 4.9

A forward spectrometer is sufficient for the physics since produced \( bb \) pairs are strongly correlated and forward peaked.

For the designed LHC machine energy of 14 TeV extrapolated cross-section (PYTHIA) is about 500 μb this is equivalent to \( 10^{12} \) \( bb \) pairs per year (access to all b-hadrons)

But..., \( \sigma_{bb}/\sigma_{Tot} \approx 10^{-2} \), in addition the most interesting events have tiny BR.

Luminosity limited to \( \sim 2 \times 10^{32} \) cm\(^{-2} \) s\(^{-1} \) (to maximise the prob. of single int. per x-ing), 2fb\(^{-1} \) per nominal year (10\(^7 \) s)
The LHCb collaboration

~700 members
15 countries
52 institutes
The LHCb detector
The LHCb detector

Conductor: Aluminium
Integrated field: 4 Tm (10m)
Peak field: 1.1 T
Weight: 1600 tons
Power: 4.2 MW
Velo tracks: Used to find primary vertex.
Long tracks: Used for most physics studies: B decay products.
T tracks: Improve RICH2 performance.
Upstream tracks: Improve RICH1 performance, moderate p estimate.
Downstream tracks: Enhance $K_S$ finding.

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• Two RICH detectors are needed to cover angular and momentum acceptance
• The RICH detectors allow ($\pi$ - $K$) Identification from ~2 to 100 GeV

Good $\pi$-$K$ separation in 2-100 GeV/c range
• Low momentum:
  - Tagging kaons
• High momentum
  - Clean separation of $B_{d,s} \rightarrow hh$ modes
LHCb Trigger System

<table>
<thead>
<tr>
<th>Trigger</th>
<th>had</th>
<th>μ</th>
<th>μμ</th>
<th>e⁺</th>
<th>γ</th>
<th>π⁰</th>
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<td>p_T&gt; (GeV)</td>
<td>3.5</td>
<td>1.3</td>
<td>&gt;1.5</td>
<td>2.6</td>
<td>2.3</td>
<td>4.5</td>
</tr>
</tbody>
</table>

High Level Trigger (C++ application)
Event Filter Farm with up to 1000 16-core nodes

HLT1: Check LO candidate with more complete info (tracking), adding impact parameter

HLT2: global event reconstruction + selections.

Trigger is crucial as σ_{bb} is less than 1% of total inelastic cross section and B decays of interest typically have BR < 10⁻⁵
Calibration of the VELO detector
• Involved procedure
• Critical for the physics performance of the experiment
• Will try to explain it using VELO detector as an example
• Only selected topics - not enough time for too many details
**VELO – VErtex LOcator**

- Detector halves retractable (by 30mm) from interaction region before LHC is filled (to allow for beam excursions before injection and ramping)
- 21 tracking stations
- Unique R-Φ geometry, 40-100μm pitch, 300μm thick
- Optimized for
  - tracking of particles originating from beam-beam interactions
  - fast online 2D (R-z) tracking
  - fast offline 3D tracking in two steps (R-z then Φ)
- 3cm separation
- RF foil
- Interaction point
- Pile-up veto (R-sensors)
Before physics analysis we need to understand our detector

Learning how to use VELO is a good example of what needs to be done

I will introduce briefly the following topics:

• Processing parameters setting and verification
• Clusterisation (zero-suppression)
• Time alignment
• Resolution
Calibration Data stream needed to optimize processing

Non-zero suppressed data taken in so-called round-robin scheme during physics

Run emulation of TELL1 board processing off-line to optimise algorithm performance

6 algorithms
~ $10^6$ parameters
Bit perfect emulation of FPGA performance

Parameters used for readout board fixed in emulation

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Clusterisation (hit reconstruction) has profound impact on the quality of the physics - depends completely on the Tell1 processing parameters.

Noise hits considerably suppressed.
Time alignment affects directly the quality of the data (S/N, Spillover)

Tuning the front-end sampling time (time when the charge is stored in the front-end pipeline)

Collision data must be used (need to have particles crossing the detector)

Each sensor needs to be adjusted separately:
- time of flight
- cable length
Impact parameter resolution strongly depends on the hit resolution.

Reasonable agreement between the preliminary results and the simulation.
Performance with the first collision data
Very first data: 23 November 2009, No B-field

\[<m> = (133 \pm 3) \text{ MeV/c}^2\]
(perfect agreement with the PDG value)

\[\sigma = (11 \pm 4) \text{ MeV/c}^2\]

Now \(\pi^0\) peak can be routinely monitored on-line:

\[M_{\gamma\gamma} (\text{MeV/c}^2)\]

LHCb data (preliminary)

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Tracking without VELO

Tracking detectors were well calibrated at the start-up!

\[ M(K_S) = 496.9 \pm 0.3 \text{ MeV}/c^2 \]
\[ \sigma = 11.0 \pm 0.4 \text{ MeV}/c^2 \]

\[ M(K_S^{PDG}) = 497.7 \text{ MeV}/c^2 \]

\[ M(\Lambda) = 1115.6 \pm 0.2 \text{ MeV}/c^2 \]
\[ \sigma = 3.1 \pm 0.2 \text{ MeV}/c^2 \]

\[ M(\Lambda^{PDG}) = 1115.7 \text{ MeV}/c^2 \]
Using full tracking power, including VELO

\[ M(K_S) = 497.3 \pm 0.2 \text{ MeV}/c^2 \]
\[ \sigma = 4.3 \pm 0.1 \text{ MeV}/c^2 \]
\[ M(K_S^{PDG}) = 497.7 \text{ MeV}/c^2 \]

\[ M(\Lambda) = 1115.6 \pm 0.1 \text{ MeV}/c^2 \]
\[ \sigma = 1.4 \pm 0.1 \text{ MeV}/c^2 \]
\[ M(\Lambda^{PDG}) = 1115.7 \text{ MeV}/c^2 \]

Accuracy will be further improved after complete alignment

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VELO can not be fully closed at $\sqrt{s} = 900$ GeV (LHC is projected for a nominal energy of 7TeV per beam) each side is 15 mm away from the nominal position.

VELO moved in and out routinely; Kept 30 mm away during injection.

**Measured dimensions of the luminous region:**

$s_X \approx s_Y \approx 0.3$ mm

$s_Z \approx 40$ mm
Summary
The LHCb detector is ready for the data in 2010

The calibration data taken in December 2009 allowed to perform both hardware and software tests

Detector performance with the early collision data is very promising

Can measure the shape of proton beams - direct luminosity measurement possible with precision ~5 - 10 % (after a nominal year of data taking)

We are ready for some real physics this year!
Physics priorities for 2010 (200 pb\(^{-1}\))

- Calibration and min. bias physics: \(10^8\) evts., \(K_s \rightarrow \pi\pi\) and \(\Lambda \rightarrow \pi\pi\)
- PID and momentum calibration (\(J/\psi\) trigger on single \(\mu\) and \(p_T\) cut)
- \(J/\psi\) physics and production x-sections (~1.5 pb\(^{-1}\)) - differential x-section for prompt \(J/\psi\), and \(b\)-\(\bar{b}\) production x-section
- Commissioning the analysis in the hadronic modes: study \(D \rightarrow hh\) channels
- Charm physics (> 20 pb\(^{-1}\)) - LHCb can overtake Belle statistics with just few pb\(^{-1}\) of data
- With a data sample of 200 pb\(^{-1}\) LHCb should be able to improve the Tevatron sensitivity for \(BR(B_s \rightarrow \mu\mu)\) and the phase \(\Phi_s\)

If there is NP LHCb should be able to see it next year!

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Epiphany 2010, 06–09 Jan 2010, Krakow, Poland
Backup
Average # of tracks in bb events:
34 VELO tracks,
33 long tracks,
19 T tracks,
6 upstream tracks
14 downstream tracks
Total 106 reconstructed tracks

20-50 hits assigned to each long tracks.
98.7% assigned correctly.
Data processing

VELO front-end

TELL1 board

Raw cluster buffer

Reconstruction

Hit Processing board - TELL1, FPGA based

Main goal - suppress the data (factor ~ 200)

From non-zero suppressed (2048 /sensor)

To zero suppressed (clusters only)

Technically it is a farm of parallel stream processors

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**Occupancy** extremely important - needs to be monitored constantly

Noisy (dead) channels may cause many problems during hit reconstruction phase

**Agreement between data and simulation astonishing!**
δp/p = 0.38 - 0.55 %
Resolution dominated by the multiple scattering effect

σ_{IP} = 14 μm + 35 μm/p
Error dominated by material before first measurement

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Vertexing

\[ \sigma = 168 \, \mu m \]

Proper time - \( \tau = \frac{L m_B}{p_B c} \)
dominated by B vtx resolution

\[ \sigma_T \approx 40 \, fs \]

\[ \sigma_{M(B)} \approx 14 \, MeV \]

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Inject Xe gas \((10^{-7}\ \text{torr})\) into VELO region.

Reconstruct beam - gas interaction vertices

Must have

- Vertex resolution in X/Y \(<\) beam sizes
- Dependence on X/Y (gas density, efficiency, ...) must be small or well known.
- Ability to distinguish beam1-gas beam2-gas and beam1-beam2 interaction.