LHCb detector status and upgrade

- General overview
- Status of the various components
- Global performance
- Upgrade guidelines
LHCb is studying beauty (and charm)
- At LHC, the production is peaked forward/backward
- The detector is a single arm spectrometer
  - Both b go together forward (or backward)
  - Acceptance $2 < \eta < 5$
- The b meson / baryon is boosted
  - It flies a several millimetres before decaying
  - This is the signature for selecting events

General detector layout
- The vertex detector is a key component
- Dipole magnet, and tracking stations after, to measure accurately the momentum
- Particle identification by 2 RICH detectors, electromagnetic and hadronic calorimeters, and a muon system
Velo

◆ **84 silicon micro strip sensors**
  - 44 mm radius
  - R or Phi geometry

◆ **Open and closes for each fill**
  - Centred around the current beam position
    - It doesn’t move during a fill
  - Mechanically reproducible to ~ 5 µm

*Average distance between right-side PV and left-side PV*

![Diagram of Velo sensors and mechanical components]
Impact parameter resolution is essential

- Very good resolution
  - \(~20\ \mu\text{m at high Pt}\)
    - This means over 2 GeV…

- Slightly better in MC
  - Work in progress to understand it
  - Material description suspected

- Primary vertex resolution excellent
  - \(~16\ \mu\text{m in x,y, ~76\ \mu\text{m in z (20 tracks)}\)

Radiation damage

- Starts to be visible in dark current
- It behaves as expected
- Doesn’t affect data quality.
Tracking system

- **One station (TT) before the magnet**
  - Si strips, 4 layers

- **Dipole magnet**
  - $\int Bdl = \sim 4$ Tm; polarity switched regularly

- **3 stations after the magnet**
  - Si strips in centre (IT), straw tubes outside (OT)
  - 4 layers per station $x-u-v-x$, (5 degree stereo angle)

- **Tracking efficiency over 96%**
  - For tracks traversing the whole detector, over 5 GeV momentum
RICH

- **Particle identification from 2 to ~100 GeV**
  - 2 RICH, 3 radiators
  - Readout by HPD
    - ~500, 1024 channels
    - High efficiency
    - Very low noise
    - 10-20 replaced each year

- **Particle ID performance**
  - ~95% efficiency for 5% contamination
    - Averaged over B daughter tracks
  - Well described by simulation
Calorimeters

◆ **ECAL made of shashlik blocks**
  - Lead - scintillator stack
  - ~6000 channels, readout by PMT
  - ~10% / $\sqrt{E} + 1%$

◆ **HCAL: scintillating tiles in iron**
  - ~1500 channels, same readout and electronics as ECAL
  - ~70% / $\sqrt{E} + 9%$
  - Mainly used for trigger

◆ **PreShower and SPD**
  - same geometry as ECAL
  - Scintillator tiles readout by MAPMT
  - Identify electron/photon, used in L0 trigger
Muon system

- 5 stations interleaved with iron walls
  - First station before the calorimeters
  - Projective geometry
    - Allows it to be used in the L0 trigger
  - Muon identification performance
    - ~97% efficiency for 3% miss-ID.
Trigger

- **L0 hardware trigger, custom electronics**
  - High Pt local cluster in HCAL (3.6 GeV) or ECAL (2.6 GeV)
  - High Pt muon (1.4 GeV) or di-muon
  - Accept rate limited to 1 MHz, latency < 4 µs

- **HLT software trigger, 30,000 copies on 1500 nodes**
  - HLT1 mainly a topological trigger:
    - At least one track with Pt > 1.6 GeV and impact parameter > 100 µm
    - Accepts around 50 kHz
  - HLT2 selects by physics channel, inclusive or exclusive
    - Full track reconstruction but no particle-id.
  - 25% of the input events are deferred, i.e. stored on disk and processed during inter-fills!
  - Total accept rate around 5 kHz.
Luminosity

◆ **LHCb was designed for single collision crossings**
  - Worries of ambiguities to assign the B to the proper primary vertex
    - We even intended to reject multiple interaction at level 0 trigger…
  - Design luminosity $2 \times 10^{32}\text{ cm}^{-2}\text{ s}^{-1}$ for $\sim 2700$ colliding bunches

◆ **We found that higher collision rate was OK**
  - We now run at $4 \times 10^{32}\text{ cm}^{-2}\text{ s}^{-1}$ with only 1262 colliding bunches
    - 50 ns separation between bunches, 25 ns nominal and from 2015.
    - This means 4 times more collisions per crossing than in the design
    - The average number of visible collisions per crossing is $\sim 1.8$
      - Higher occupancy in the detector
      - More challenging for the trigger, see later
  - The luminosity is kept constant thanks to the ‘luminosity levelling’
    - The beam separation is adjusted a few times per hour to maintain the luminosity constant.
    - Routine operation since 2011
**PROTON PHYSICS: STABLE BEAMS**

| Energy: 4000 GeV | \( I(B1): \) 1.39e+14 | \( I(B2): \) 1.46e+14 |

**FBCT Intensity and Beam Energy**

**Instantaneous Luminosity**

**Comments (29–Oct–2012 08:43:19)**

We keep this fill a bit longer as MKI8 temperature is still well above the injection interlock level.

Next: VdM scans in IP5 to start at ~8:30

**BIS status and SMP flags**

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<tr>
<th>Link Status of Beam Permits</th>
<th>B1</th>
<th>B2</th>
</tr>
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<tr>
<td>Global Beam Permit</td>
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<td>Beam Presence</td>
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<tr>
<td>Moveable Devices Allowed In Stable Beams</td>
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</table>

**AFS:** 50ns_1374_1368_0_1262_144bp12inj

**PM Status B1:** ENABLED

**PM Status B2:** ENABLED
Luminosity is frequently adjusted (±3% around target value)
Global performance

Data taking is very efficient

- Minor losses due to HV not OK, or Velo not in working position
- 2.4% dead time, due to some hardware devices
- “DAQ” is in fact a lot of short stops to give a “kick” to some systems

Integrated LHCb Efficiency breakdown in 2012

- FULLY ON: 94.49 (%)
- HV: 0.25 (%)
- VELO Safety: 0.77 (%)
- DAQ: 2.22 (%)
- DeadTime: 2.37 (%)

HCP 2012 : LHCb detector status and upgrade

12 November 2012
**Reconstruction performance**

**Momentum resolution excellent**

- From 0.4% at 5 GeV to 0.6% at 100 GeV/c
- Important ingredient to study narrow states
- Momentum scale OK, checked by comparing the mass of B mesons to the PDG values.

\[ J/\Psi \rightarrow \mu\mu : \sigma \approx 15 \text{ MeV}/c^2 \]
\[ \Upsilon(1S) \rightarrow \mu\mu : \sigma \approx 54 \text{ MeV}/c^2 \]
\[ B_S \rightarrow J/\Psi \Phi : \sigma \approx 8 \text{ MeV}/c^2 \]
**PID is working nicely**

- Important to disentangle various decays

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- $B^0 \rightarrow K^+\pi^-$
- $B^0 \rightarrow \pi^+\pi^-$
- $B^0_s \rightarrow K^-K^+$
- $B^0_s \rightarrow \pi^+K^-$
- $\Lambda^0_b \rightarrow pK^-$
- $\Lambda^0_b \rightarrow p\pi^-$
- $B \rightarrow 3$-body
- Comb. bkg

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- $B^0 \rightarrow K\pi$
- $B^0 \rightarrow \pi\pi$
- $B^0_s \rightarrow KK$
- $\Lambda^0_b \rightarrow p\pi$
- $\Lambda^0_b \rightarrow pK$
- $B^0 \rightarrow \pi\pi\pi$
- $B^0 \rightarrow \pi\pi\pi$
- $B^0_s \rightarrow KK$
Integrated luminosity

🔹 Well on track for over 2 pb-1 this year!

LHCb Integrated Luminosity in 2011 and 2012

- Delivered in 2012 (4 TeV): 1.741 /fb
- Recorded in 2012 (4 TeV): 1.645 /fb
- Recorded in 2011 (3.5 TeV): 1.107 /fb
◆ The current main limitation is the LO trigger

- Rate limited to 1 MHz (in practice ~950 kHz) due to the readout time of the front-end
  - 36 clock cycles -> 900 ns
- The main hadronic trigger is based on HCAL clusters
  - Threshold is high, to decrease the rate to ~700 kHz
  - About half the interesting B decays are lost.

◆ Basic upgrade strategy: Remove the LO trigger

- Readout the events at 40 MHz
- Implement a fast software trigger to select events based on their topology
  - Gain a factor 2 in efficiency on hadronic channels
  - Improve the detectors to provide a fast reconstruction
Consequence

◆ All front-end electronics has to be redone
  - Change in output rate requirement
    - No more pipe-line or buffers locally
    - A lot more optical links, of a newer generation
  - Rebuild the detectors with embedded front-end chips
    - Silicon strip detectors, i.e. Velo, TT, IT
    - RICH photo-detectors (front-end chip inside the HPD)

◆ Target luminosity
  - Similar value of pile up ($\mu=2$) but twice the number of bunches
  - Initial target: $10 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$, i.e. 2.5 times the current value
    - Factor $\sim 10$ in the yield of hadronic channels (14 / 7 TeV helps)
  - Foresee to run at $20 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ and prepare the detectors for it.
New detectors

*Two options for the Velo*

- Upgraded micro strip detector
  - Similar overall geometry, 20% more channels per sensor, smaller pitch and thickness

- Pixel detector
  - 53 x 53 µm² cells
  - ~780 k channels per module
  - 50 modules
  - → 40 millions pixels…
Proposed layout of the Pixel detector
Tracking stations

◆ **TT similar but improved**

- Better coverage by overlapping sensors and getting closer to the beam pipe
- Less material with thinner sensors.
**Main tracking stations (after magnet)**

- **Two options for the T stations**
  - Similar to the current detector, with an increased Inner Tracker
    - Outer Tracker straw tubes are sensitive to spill-over from the previous and next crossings, as the drift time is around 40 ns.
      - This will be the case with 25 ns crossing period.
    - Increasing IT will decrease the occupancy in OT by a factor~2, to reach similar levels as the current ones.
    - IT made thinner and lighter
      - 4 times more channels
Scintillating fibres

- 2.5 m long fibres, 5 layers of 0.25 mm diameter
- Readout by SiPM with readout cells 0.25 x 1.32 mm
- Similar geometry as now (reuse of supports)
  - 3 stations, 4 layers each
  - But less material in acceptance
- R&D ongoing to validate this option
  - Radiation hardness of SiPM
    - Need dedicated shielding, low temperature…
    - Noise reduction by cluster shape analysis in front end
  - Accuracy of the fibre mechanics
    - Need to keep the fibre straight to ~50 µm and flat to ~200 µm over 2.5 m!
RICH

◆ Replace the HPD by MAPMT

◆ Remove the aerogel radiator
  ■ Limited use in a very dense environment
  ■ Decrease dead material.

◆ Studies on-going to improve the optics
  ■ Reduce the number of MAPMT (cost…)
  ■ Better resolution
  ■ Less magnetic field to be shielded where the MAPMT will be

◆ More fancy proposal also investigated
  ■ TORCH detector (time of flight with quartz bars to ~15 ps, for low momentum particles) for ~2020
Calorimeter and muon

**No major change needed**
- The electronics of the calorimeter should be remade, but will stay very similar, only the output stage will change
- M1 will be removed as we don’t need a L0Muon any longer
- The muon electronics will stay as is, as for the L0Muon the readout works already at 40 MHz.

**Possible improvements**
- The central part of M2 may become GEM instead of MWPC
  - Handles more rate
- Electronics may be re-implemented to be safe at $20 \times 10^{32}$ cm$^{-2}$ s$^{-1}$
  - Dead time due to long signals
Olivier Callot

Trigger

◆ Suppress the L0
  ■ In fact one can keep it at the beginning as a “Low Level Trigger” to minimize the load on the CPU farm
    ● But no longer limited to 1 MHz

◆ Implement a very fast software trigger
  ■ 30 MHz input implies that every millisecond requires 30,000 copies of the code running in parallel
  ■ Tune the detector (and readout) to be fast
    ● Pixel seems better than strips for the Velo
    ● Fibre Tracker seems better than IT + OT
  ■ Investigate new trends in computing
    ● GPU, large number of core, …
  ■ We need a factor 30 compared to the current system!
    ● We expect ~10 from the computing industry…
    ● We need to find a factor 3 in our code!
Summary

◆ **LHCb is performing very well in difficult conditions**
  - Four times more luminosity per crossing than in the design
  - All detectors over 99% operational
  - Resolutions in position and momentum conform to expectations

◆ **High statistics available, a lot of results expected**
  - Many already published, see Burkhard’s talk just after this.
    - And a special talk by Johannes after
    - See also parallel sessions: Tom (SUSY), Andrea (QCD), Kurt (EW), Johannes, Mika, Stefania, and Angelo (Heavy Flavour)
  - Expect than 2012 will give more than twice 2011 statistics...
    - And we will continue to take data at the same rate from 2015

◆ **The upgrade program is progressing**
  - Get up to 20 times more hadronic events per second!
  - Challenging, but realistic
Thanks you for your attention ...

LHCb detector
And collaboration
... and for the occasion to visit Japan
Saturday morning at Yamanakako lake