The LHCb Detector Upgrade

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**In a Nutshell**

- LHCb is an LHC experiment designed for heavy quark flavour physics.
- The detector is a single-arm forward spectrometer, covering $2 < \eta < 5$.
- Tracking system consists of Vertex Locator (VELO), followed by one tracking station upstream and three stations downstream of 4 Tm dipole magnet.
- Particle identification provided by two RICH detectors, calorimeters and muon system.
**Readout**

- Calorimeter and muon stations provide 40 MHz input to L0 trigger.
- All other detectors are read out at 1 MHz.

**L0 Trigger**

- Selection based on $p_T$ and $E_T$ cuts
- 450 kHz $h^\pm$ / 400 kHz $\mu, \mu\mu$ / 150 kHz $e, \gamma$

**High Level Trigger**

1. **HLT1**
   - Reconstruct VELO tracks and primary vertices
   - Select events with at least one track matching $p$, $p_T$, impact parameter, and track quality cuts
   - $\sim 30$ kHz output rate

2. **HLT2**
   - Full reconstruction
   - Combination of inclusive and exclusive selections
Why Upgrading?

- The experiment is performing well (→ talk by F. Dettori), operating in 2012 at $\mathcal{L} = 4 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ (twice design luminosity) corresponding to $\sim 2\text{ fb}^{-1}$ per year.
- Going to higher luminosity is inhibited by 1 MHz detector readout rate in combination with limited discriminating power of L0 hardware trigger (saturation of trigger yield for hadronic channels).

Upgrade Strategy

- Read out whole detector at every bunch-crossing.
- Move to fully software-based trigger.
Trigger Upgrade

\( p-p \) collisions

\[ \rightarrow \]

Low Level Trigger (hardware)

\( 1 - 40 \text{ MHz} \)

\[ \rightarrow \]

HLT (CPU farm)

\( 20 \text{ kHz} \)

\[ \rightarrow \]

Offline

LLT

- similar to existing L0 trigger
- throttle input to HLT depending on size of CPU farm

High Level Trigger

- tight time-budget
- HLT is guiding factor for detector design
- use of hardware “accelerators” (e.g. GPUs) being investigated

\[ \text{Signal efficiency} \]

\[ \text{MC} \quad 10^{33} \text{ cm}^{-2}\text{s}^{-1} \]

\[ \text{now} \quad 10 \text{ MHz} \]
LHCb Upgrade and LHC

- Target luminosity is $\mathcal{L} = 1 - 2 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$.
- Key requirement is 25 ns bunch spacing.
- Sub-detectors being replaced are designed to be able to operate at a luminosity of $\mathcal{L} = 2 \times 10^{33}\,\text{cm}^{-2}\text{s}^{-1}$.
- Installation is planned for Long Shutdown 2 of LHC in 2018/19.
- Upgraded experiment is expected to collect 50 fb$^{-1}$ over 10 years.

Physics Motivation

- Perform precision measurements of $CP$ asymmetries and search for physics beyond the Standard Model through indirect effects of new states.
- Expected statistical sensitivities become comparable to theoretical uncertainties.
- Enhanced trigger flexibility allows expansion of physics programme $\rightarrow$ general-purpose experiment in forward region.
LHCb Upgrade

Consequences of Readout Scheme

- Front-end electronics need to be replaced (or modified).
- Silicon detectors (and RICH HPDs) need to be replaced due to embedded electronics.

Challenges for Detectors

- 40 MHz readout, data rates
- radiation tolerance
- occupancies
- pileup
- material budget
Current Detector

- Present VELO (talk by S. de Capua) consists of 21 stations of $R$ and $\phi$ measuring microstrip sensors along $z$.
- Detector operates in vacuum. Left and right halves can be moved into/out of the beam.

Upgrade Option 1: Pixels

- ASIC derived from Timepix/Medipix family (55 $\mu$m pitch)
- sensor R&D focussing on planar silicon sensors

Upgrade Option 2: Strips

- sensors conceptually similar to existing VELO (R/$\phi$ layout)
- finer pitch and segmentation, reduced thickness and inner radius
**Vertex Locator**

**Radiation Environment**
- Irradiation profile is strongly non-uniform.
- Expected fluence after 50 fb$^{-1}$ at current inner sensor radius $\sim 4 \times 10^{15} n_{eq} \text{cm}^{-2}$.

**Aperture**
- Primary (beam) and secondary (VELO) vacuum are separated by thin Al box (“RF foil”).
- Inner radius of RF foil could be reduced from 5.5 mm to 3.5 mm.

**Performance Considerations**
- Reconstruction efficiency, speed and ghost rate are crucial for HLT performance.
  - Simulations predict excellent pattern recognition performance for pixels (ghost rate $\lesssim 1\%$).
- Impact parameter resolution depends on
  - single hit resolution,
  - distance to interaction point ($\rightarrow$ reduce inner radius),
  - material (favours strip option).
### Cooling

- Sensors need to be kept at $\lesssim -20^\circ$ C.
- As for current detector, evaporative CO$_2$ cooling will be used but module interface needs redesign.
  - Micro-channels would be attractive solution for both pixels and strips.
  - Other concepts (diamond, TPG, carbon foam substrates) also being explored.

### Sensors

- Radiation hardness is critical issue.
- Extensive testbeam programme for pixel sensor characterisation (different vendors, guard ring designs, irradiation levels).

### RF Foil

- RF foil constitutes $\sim 40\%$ of present VELO material budget $\rightarrow$ can it be made thinner?
- Prototype using new manufacturing technique (milling out of one box) produced.
- Improved modelling in simulation.
Current Detector

- Upstream station (TT) and inner regions (close to beam pipe) of downstream stations (IT) are silicon strip detectors (→ talk by M. Tobin).
- Outer region of downstream stations instrumented by straw tubes (OT).
- Main problem in upgrade scenario is high occupancy (≳ 40%) of straw tubes in central region.
Downstream Tracking Stations

Two technology options are currently being investigated.

1. **new silicon strip detector with larger coverage**
   - in combination with shorter straw tubes in central region

2. **replacement of straw tubes (in central region) by scintillating fibres**
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Tracker

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**Upstream Tracker**

- Technology: silicon strip sensors with
  - reduced thickness, finer segmentation, improved coverage
- R&D so far focussed on mechanics
  - cooling, material minimization, beampipe interface
- Simulation studies
  - optimise global pattern recognition, ghost rejection and trigger performance.
Fibre Tracker

Concept

- Active element: five layers of 2.5 m long scintillating fibres (250 µm diameter).
  - Multi-clad blue emitting fibre chosen as baseline.
- Readout at fibre ends by silicon photo-multipliers (outside acceptance).
- Expected performance: \( \sim 60 - 100 \) µm spatial resolution, \( \sim 15 \) photoelectrons / mip
- Main challenges: radiation damage, noise cluster rate, mechanical precision

Radiation Hardness

- Ongoing programme to characterise irradiated fibres and SiPMs up to dose/fluence at 50 fb\(^{-1}\).
- SiPMs need to be operated cold.
Silicon Tracker

**Occupancy**
- Four-fold increase of Inner Tracker area reduces straw tube occupancy to < 25%.
- Further occupancy reduction possible by
  - minimization of IT material (reduce OT hits from secondaries in IT)
  - faster gas in OT.

**Low-Mass Module R&D**
- Separation of FE electronics from sensors using thin flex cable (thermal insulation).
- Prototype for convective air cooling
- Daisy-chaining of silicon sensors

**Electronics**
- New strip chip with on-chip zero-suppression and common-mode correction being developed.
- Synergy with upstream tracker and VELO (strip option).
Less is More

- First muon station (M1) as well as preshower (PS) and scintillating pad detector (SPD) will be removed due to reduced role in upgrade trigger scheme.
- Due to occupancy, aerogel radiator in RICH1 will be removed (leaving CF$_4$ in RICH1 and C$_4$F$_{10}$ in RICH2).
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Photon Detectors

- R&D focussed on MaPMTs, potential candidate is Hamamatsu R11265.
- Custom readout ASIC (CLARO) being developed (alternative option: Maroc-3).

Operation at $\mathcal{L} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

- Preliminary simulation results indicate high occupancy in RICH1 ($\gtrsim 30\%$).
- Several ideas to cope with occupancy problem are being discussed, e.g.
  - new optics to spread out the rings,
  - remove RICH1 and adapt RICH2 to encompass two radiator gases.
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TORCH

- Idea: time-of-flight measurement using Cherenkov photons from 1 cm thick quartz plate to enhance PID at \(< 10 \text{ GeV/c} \).
- Required time resolution: \( \sim 15 \text{ ps per track} \).
- Not part of baseline for 2018, but subject of active R&D programme.
Modifications for $\mathcal{L} = 1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

- Muon front-end electronics are almost compatible.
- Tolerable aging and rate effects (e.g. space charge) in Muon MWPCs.
- CALO PMTs need to be operated at reduced HV $\rightarrow$ development of new front-end electronics with higher amplifier gain.

Higher Luminosity

- Ongoing studies to evaluate performance at $\mathcal{L} = 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$.
- Central ECAL modules (probably) need to be replaced.
- Rate capability of muon chambers close to beam pipe would need to be improved.
  - reduction of pad size or alternative technologies (e.g. GEMs)
  - additional shielding
Roadmap

Milestones

- Letter of Intent submitted in 2011 and endorsed by LHCC.
- Follow-up document (Framework TDR) submitted in 2012 and endorsed by LHCC.
- Sub-detector Technical Design Reports to follow in 2013.
LHCb Upgrade

- LHCb will be upgraded in 2018 to exploit higher luminosity with better efficiency.
- This is achieved by triggerless readout and software-based trigger.
- Detector R&D programme is in full swing.
- Key challenges are
  - 40 MHz readout,
  - radiation tolerance,
  - robust and fast reconstruction,
  - material budget.
- Key technology choices to be taken in next months for
  - VELO (pixels or microstrips),
  - tracking stations (silicon strips or scintillating fibres), and
  - RICH.
More Information

- Letter of Intent for the LHCb Upgrade, CERN-LHCC-2011-001
- Framework TDR for the LHCb Upgrade, CERN-LHCC-2012-007

Other LHCb Talks

- F. Dettori, Performance of the LHCb detector during the LHC proton runs 2010 – 2012
- S. de Capua, Performance and Radiation Damage Effects in the LHCb Vertex Locator
- M. Tobin, The LHCb Silicon Tracker