The LHCb upgrade

Burkhard Schmidt for the LHCb Collaboration

Outline:

• Present LHCb detector and trigger
• LHCb upgrade – main drivers
• Overview of the sub-detector modifications
• Conclusions
Forward spectrometer designed to exploit huge $\sigma_{bb}$ at the LHC
Detector shows excellent performance
- see talk of M. v. Beuzekom this morning

LHCb physics goals:
- Search for New Physics via CP asymmetries and rare decays
- Collect $\sim 5$ fb$^{-1}$ at $L \sim 3 \times 10^{32} \text{cm}^{-2}\text{s}^{-1}$ over 5 years before 2$^{nd}$ LHC long shutdown in 2018
Search for New Physics at LHCb

Two classes of measurements:

**Exploration:**
- Focus on decay modes or observables a priori very sensitive to New Physics, but which have not been accessible to previous experiments.

**Precision studies:**
- Measurement of known parameters with improved sensitivity, to allow for more precise comparisons with theory.

As new exploration topics appear, existing studies migrate to precision studies.

**Present LHCb detector**
- collect $\sim 5 \text{ fb}^{-1}$ with $L \sim 3 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$
- Exploration example:
  - search for $B_s \rightarrow \mu\mu$ down to SM value
- Precision studies:
  - Measure CKM angle $\gamma$ to $3-4^\circ$ to permit meaningful CKM tests

**Upgraded LHCb Detector**
- collect $> 50 \text{ fb}^{-1}$ with $L \sim 1 \times 10^{33}\text{cm}^{-2}\text{s}^{-1}$
- Precision studies:
  - Measure $\text{BR}(B_s \rightarrow \mu\mu)$ to precision of $\sim 10\%$ (assuming SM value)
- Exploration example:
  - Search for $B^0 \rightarrow \mu\mu$
LHCb goals with the upgrade:

- Quark flavour physics main component, but expand physics program to include:
  - Lepton flavour physics
  - Electroweak physics
  - Exotic searches
- General purpose detector in the forward region with 40 MHz readout and a full software trigger.
LHCb Trigger – limitations

- Final states with muons
  → Linear gain

- Hadronic final states
  → Yield flattens out
  → Must raise \( p_T \) cut to stay within 1 MHz readout limit

- To profit of a luminosity of \( 10^{33}\text{cm}^{-2}\text{s}^{-1} \), information has to be introduced that is more discriminating than \( E_T \).

Upgrade strategy:
40MHz readout rate
Fully software trigger
20kHz output rate
LHCb design operation:
- \( \mathcal{L} \approx 2 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \) with 25ns bunch spacing
  - Average pile-up \( \sim 0.4 \)

LHCb Upgrade:
- \( \mathcal{L} \approx 1 \times 10^{33} \text{ cm}^{-2}\text{s}^{-1} \) with 25ns bunch spacing
  - Average pile-up \( \sim 2.1 \)

Present LHCb operation:
- \( \mathcal{L} \approx 3 \times 10^{32} \text{ cm}^{-2}\text{s}^{-1} \) with 50ns bunch spacing
  - (LHC has up to 1380 bunches per beam)
  - Average pile-up of 1.2 - 2.5 has been successfully used
VELO Upgrade

Challenges: Data rates $<\text{rate}_{\text{max}}>$ = 200MHz cm$^{-2}$
Irradiations$_{\text{max}}$ = $5 \times 10^{15}$ 1 MeV n$_{\text{eq}}$cm$^{-2}$
Low material budget

Two options:
- **Pixel detector**: VELOPIX based on TimePix
  - 55 μm x 55 μm pixel size
  → Advantageous for pattern recognition
- **Strip detector**: based on proven design
  - reduced strip pitch 30 μm
  → Better IP-resolution performance

R&D ongoing
- Module layout and mechanics
- Sensor options:
  - Planar Si, 3D, Diamond
- CO$_2$ cooling
- FE - electronics
- RF-foil of vacuum box
Current IT and TT Si-strip detectors must be replaced:

- 1 MHz Readout electronics integrated

Two technologies:

- Silicon strips:
  - Current technology
  - Development of a rad-hard FE chip @ 40MHz

- 250 μm Scintillating Fiber Tracker
  - Fibers coupled to a Silicon Photo-Multiplier
  - SiPM radiation tolerance under study
  - R/O ASIC for SiPM under investigation
Main Tracker upgrade: OT

Current tracker works already with upgrade pile-up level spill-over for 25ns bunch-spacing not yet tested

OT straw detector remains for the outer part

- Detector aging in hot area is under investigation
- Consider module replacements with 1mm Scintillating Fiber Tracker in hottest region
- Replace straw tracker TDC chip by 40 MHz version
• Retain RICH-1 and RICH-2 detectors
• Replace Photo-detectors
  - At present: Pixel HPDs with 1 MHz R/O chip integrated
  - Readout for the upgrade: MaPMTs & R/O with 40 MHz custom ASIC

MaPMTs (Hamamatsu):

R7600 vs R11265:
• 8x8 pixels, 2.0x2.0 mm², 2.3 mm pitch (2.9 mm)
• 18.1x18.1 mm² active area (23.5x23.5 mm²)
• CE (simulation): 80% (90%)
• Fractional coverage: 50% (80%)

Prototyping using 40 MHz Maroc-3 R/O chip
• Gain compensation
• Binary output
Add Time of Flight detector based on a 1 cm quartz plate, for the identification of $p<10$ GeV hadrons (replacing Aerogel) combined with DIRC technology:

- **TORCH** = Time Of internally Reflected CHerencov light
- reconstruct photon flight time and direction in specially designed standoff box
- Measure ToF of tracks with $\sim 15$ ps ($\sim 70$ ps per photon)

→ could be installed later than 2018
Calorimeter and Muon System

- **ECAL and HCAL are maintained**
  - Keep all modules & PMTs
  - Reduce the PMTs gain by a factor 5
- **PS and SPD will be removed**
  - $e/\gamma$ / hadron separation in HLT with the whole detector info
- **New FEE to compensate for lower gain and to allow 40 MHz readout**

- **Muon detectors are already read out at 40 MHz in the present L0 trigger**
  - Front-end electronics can be kept
  - Remove detector M1
    - muon ID LLT and HLT
    - room for TORCH
  - **MWPC aging**:  
    - Expect up to 0.7 C/cm on wires for 50 fb$^{-1}$ in hottest region
    - tested up to 0.44 C/cm with no loss of performance
    - 1C/cm is considered as an upper limit for safe operation of MWPCs
TELL40: Common Back-End readout module:

- Modular mezzanine-based approach
- Format under investigation:
  - Advanced-TCA motherboard
- Tests of high-speed links on proto-board:
  - 12-way Optical I/Os, GBT compatible
- Transmission to the DAQ using 10 Gb Ethernet

ACTEL Flash FPGA for front-end modules

- Advantages over ASICs:
  - re-programmable, faster development time.
- Can they survive the radiation?
- Irradiation program started (on A3PE1500)
  - Preliminary results: up to 30 krad ok
The schedule

2010-2012
LHC data taking at 7TeV
Ramping up to a few \(10^{33}\)

Long shutdown 1
2013-2014

2015-2017
LHC data taking up to 14 TeV
Ramping up to design luminosity

Long shutdown 2
2017-2018

2019-2021
LHC data taking at design energy and luminosity

Long shutdown 3
Towards HL-LHC

2011 – 2013:
- Carry out Detector R&D for the upgrade
- Prepare TDRs
- Secure funding

2014 – 2017:
- Construction of detector components
  VELO, IT/TI, RICH

2017 – 2018:
- Installation and commissioning of the upgraded detector

2019 onwards:
- Data-taking with the fully upgraded LHCb detector
Conclusions

- **LHCb has a firm plan to upgrade by 2018:**
  - Readout entire detector at 40 MHz with a fully software-based trigger
  - Enormous samples of exclusive b- and c- decays, particularly in the B_s sector
  - Independent of the LHC luminosity upgrade.

- **Upgrade LOI submitted to the LHCC in March 2011**
  - LHCC considers “the physics case compelling” and the 40 MHz readout as the right upgrade strategy.
  - LHCC encouraged LHCb to prepare a TDR as soon as possible.

- **Given its forward geometry, its excellent tracking and PID capabilities and the foreseen flexible software-based trigger, the upgraded LHCb detector**
  - is an ideal detector for the next generation of flavour physics experiments
  - provides unique and complementary possibilities for New Physics studies beyond flavour.