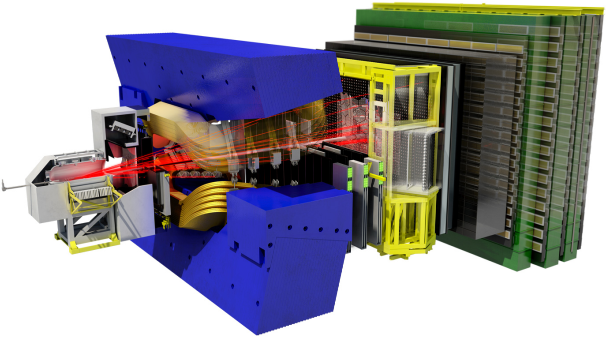
The LHCb Detector Upgrade

H. Schindler on behalf of the LHCb collaboration

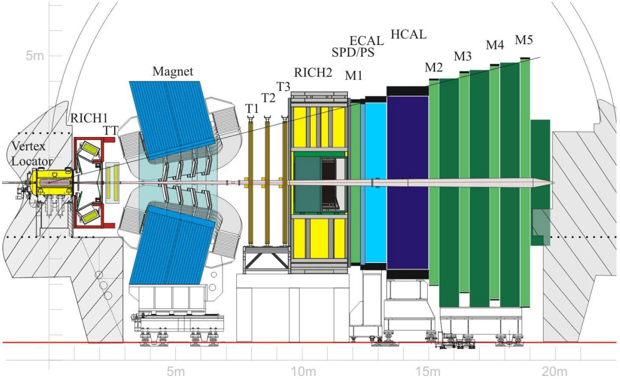
Vienna Conference on Instrumentation 2013



LHCb

In a Nutshell

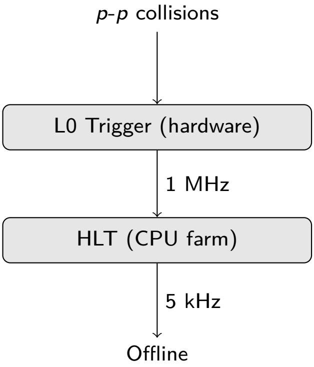
- LHCb is an LHC experiment designed for heavy quark flavour physics.
- The detector is a single-arm forward spectrometer, covering $2 < \eta < 5$.
- Tracking system consists of Vertex Locator (VELO), followed by one tracking station upstream and three stations downstream of 4 Tm dipole magnet.
- Particle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



Present Trigger

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, γ

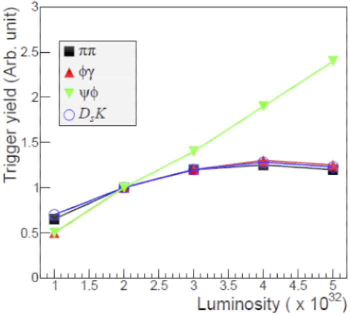
High Level Trigger

- 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
- HLT2
  - full reconstruction
  - combination of inclusive and exclusive selections

LHCb Upgrade

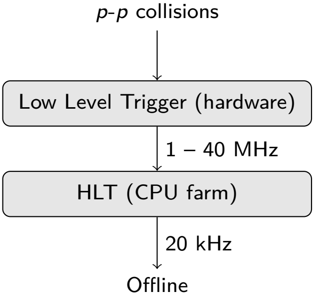
Why Upgrading?

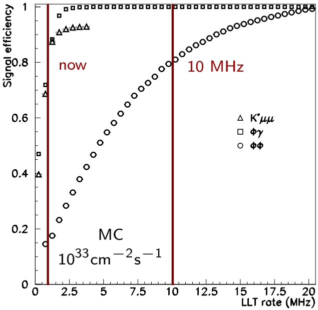
- The experiment is performing well ($\rightarrow$ talk by F. Dettori), operating in 2012 at $\mathcal{L} = 4 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ (twice design luminosity) corresponding to $\sim 2\ \text{fb}^{-1}$ per year.
- Going to higher luminosity is inhibited by 1 MHz detector readout rate 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.





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

LHCb Upgrade

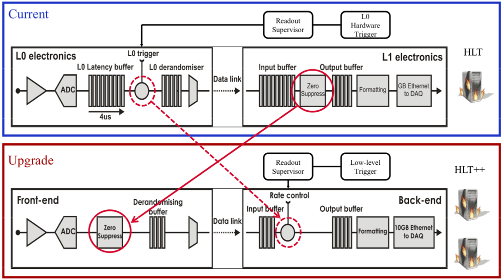
LHCb Upgrade and LHC

- 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

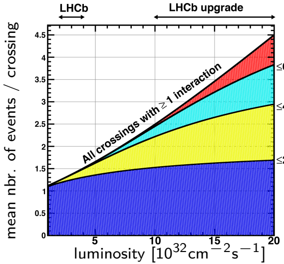


Consequences of Readout Scheme

- 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



Vertex Locator

Current Detector

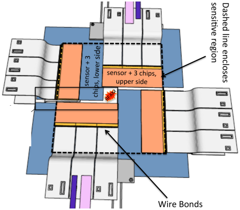
- Present VELO ($\rightarrow$ talk by S. de Capua) consists of 21 stations of R and ϕ measuring microstrip sensors along z.
- Detector operates in vacuum. Left and right halves can be moved into/out of the beam.

Upgrade Option 1: Pixels

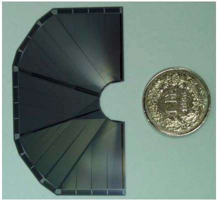
- ASIC derived from Timepix/Medipix family (55 μm pitch)
- sensor R&D focussing on planar silicon sensors

Upgrade Option 2: Strips

- sensors conceptually similar to existing VELO (R/ϕ layout)
- finer pitch and segmentation, reduced thickness and inner radius



pixel module layout

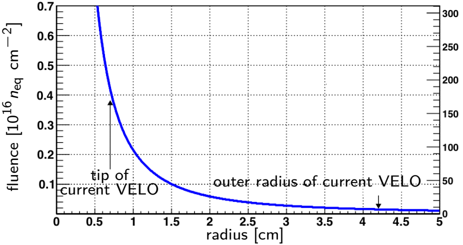


prototype strip sensor

Vertex Locator

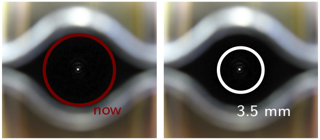
Radiation Environment

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



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).

Vertex Locator

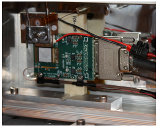
Cooling

- 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.

micro-channel prototype

Sensors

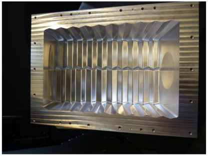
- Radiation hardness is critical issue.
- Extensive testbeam programme for pixel sensor characterisation (different vendors, guard ring designs, irradiation levels).



irrad. slim-edge sensor on Medipix3 (testbeam setup)

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.

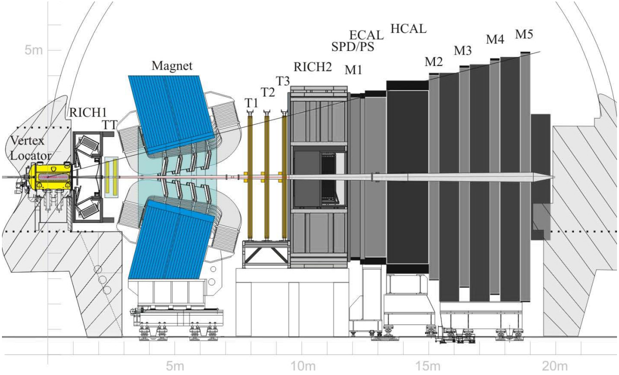


L shaped foil prototype

Tracker

Current Detector

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

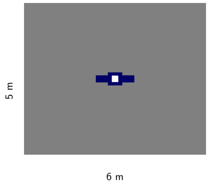


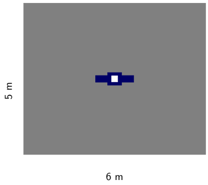
Tracker

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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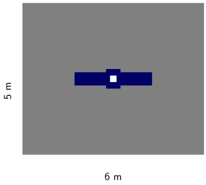

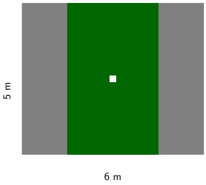

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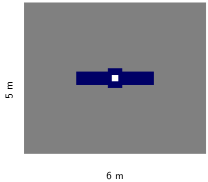
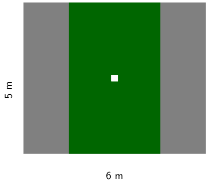
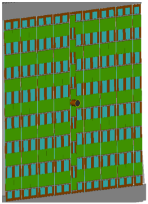
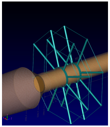




Upstream Tracker

- 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.

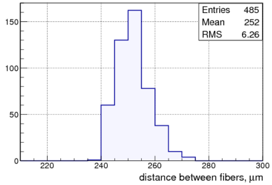


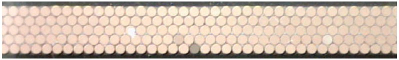


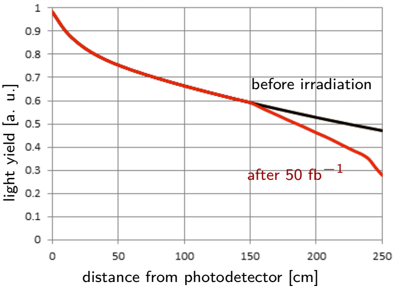
Fibre Tracker

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, ~ 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

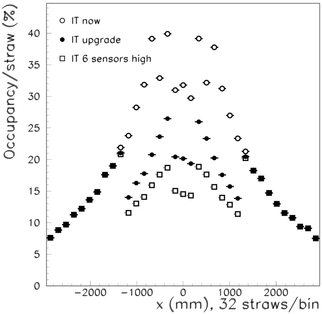
- Four-fold increase of Inner Tracker area reduces straw tube occupancy to $< 25\%$.
- Further occupancy reduction possible by
  - minimization of IT material (reduce OT hits from secondaries in IT)
  - faster gas in OT.

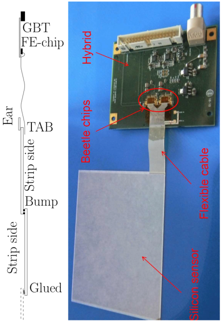
Low-Mass Module R&D

- Separation of FE electronics from sensors using thin flex cable (thermal insulation).
- Prototype for convective air cooling
- Daisy-chaining of silicon sensors

Electronics

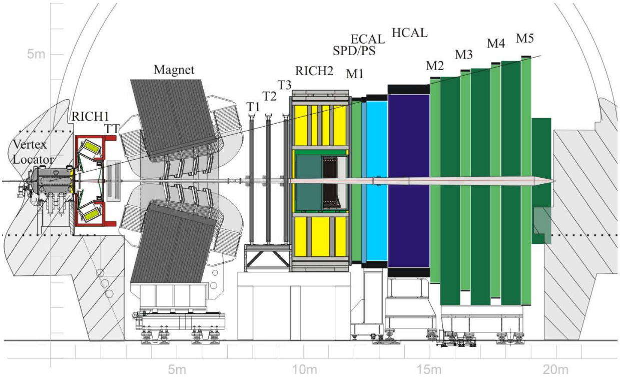
- New strip chip with on-chip zero-suppression and common-mode correction being developed.
- Synergy with upstream tracker and VELO (strip option).





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_4F_{10} in RICH2).



Particle Identification

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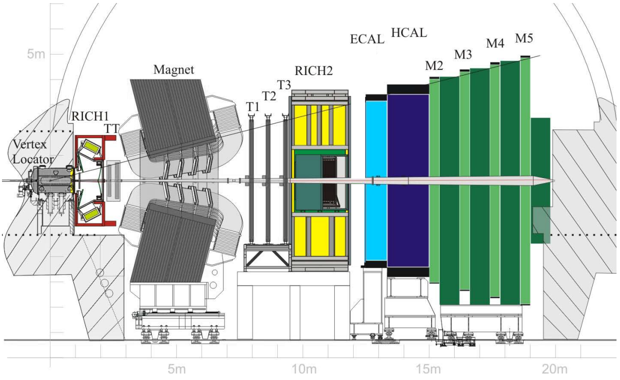
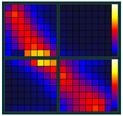


RICH

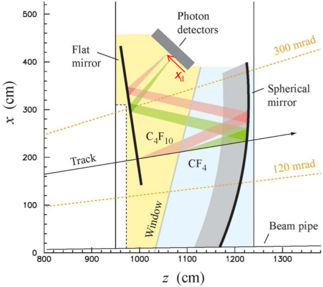
Photon Detectors

- 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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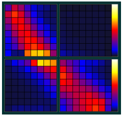

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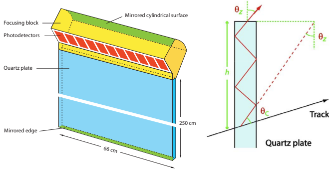
TORCH

- Idea: time-of-flight measurement using Cherenkov photons from 1 cm thick quartz plate to enhance PID at < 10 GeV$/c$.
- Required time resolution: ~ 15 ps per track.
- Not part of baseline for 2018, but subject of active R&D programme.



Calorimeter and Muon Systems

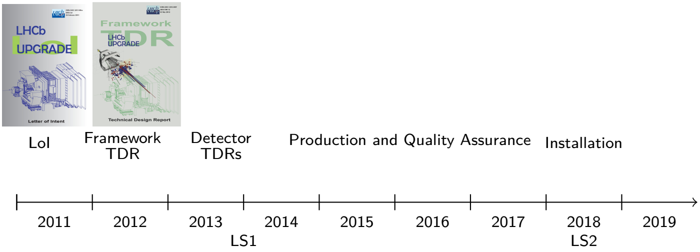
Modifications for $\mathcal{L} = 1 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

- 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.

Summary

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
- *Implications of LHCb measurements and future prospects*, CERN-PH-EP-2012-334

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*