LHCb Vertex Locator Upgrade

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on behalf of the LHCb collaboration

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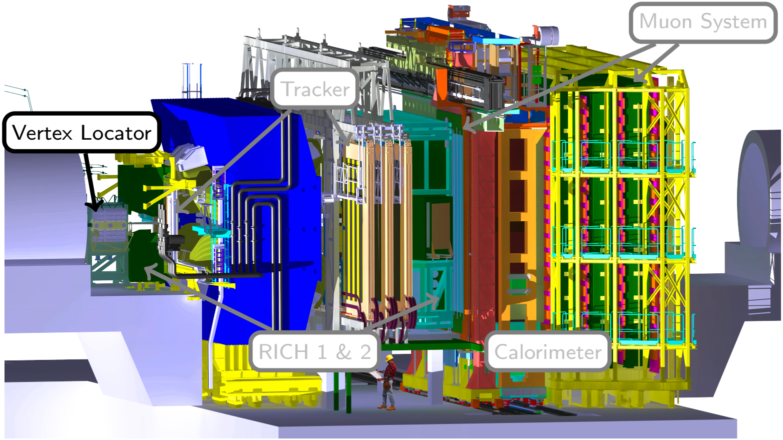
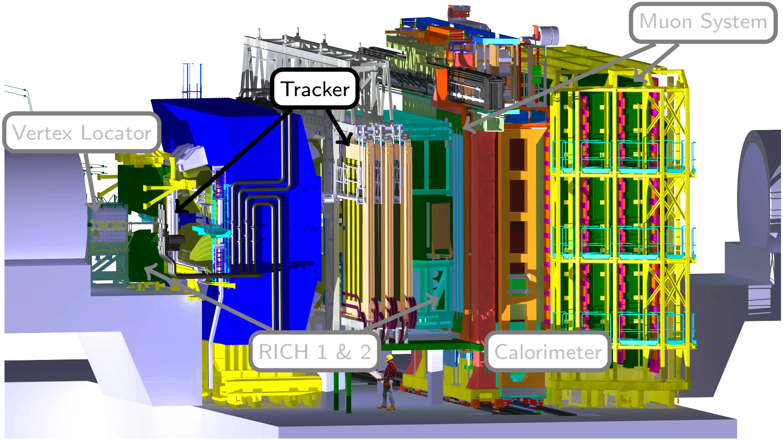
LHCb Upgrade

- LHCb detector is planned to be upgraded to 40 MHz readout with a flexible, entirely software-based trigger ($\rightarrow$ talk by V. Gligorov).
- The experiment is currently running at a luminosity of $\mathcal{L} = 4 \times 10^{32}$ cm^{-2} s^{-1} (at $\sqrt{s} = 8$ TeV) with 50 ns bunch separation.
- Sub-detectors being replaced are designed to be able to operate at a luminosity of $\mathcal{L} = 2 \times 10^{33}$ cm^{-2} s^{-1} (at $\sqrt{s} = 14$ TeV) with 25 ns bunch separation.
- Installation is foreseen for Long Shutdown 2 (LS2) of LHC in 2018.
- Upgraded experiment is expected to collect 50 fb^{-1} of data (5 fb^{-1} per year).
- Ongoing R&D programme to evaluate different technology options for sub-detectors

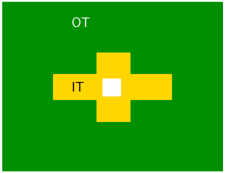


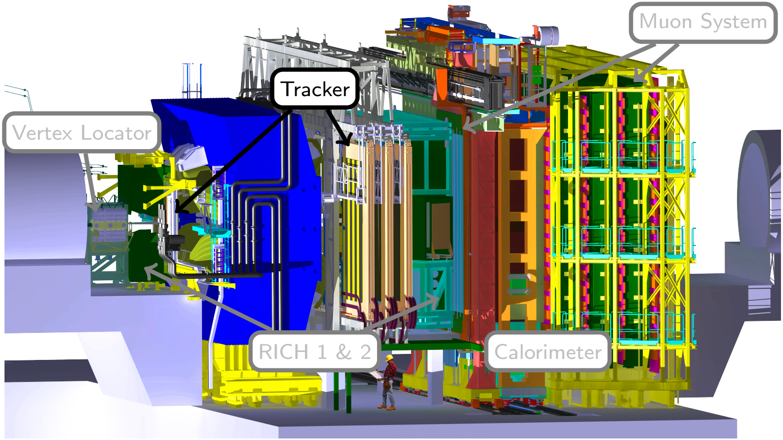
Muon System
Tracker
Vertex Locator
RICH 1 & 2
Calorimeter



Upgrade of Tracker stations

- outer region (straw tubes): replace electronics
- inner region (currently silicon strips):
  - enlarged silicon strip Inner Tracker (IT)
  - scintillating fibres Central Tracker (CT)
- Trigger Tracker (before magnet): new silicon strip detector





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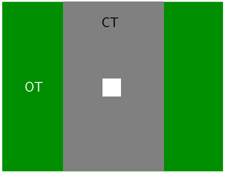
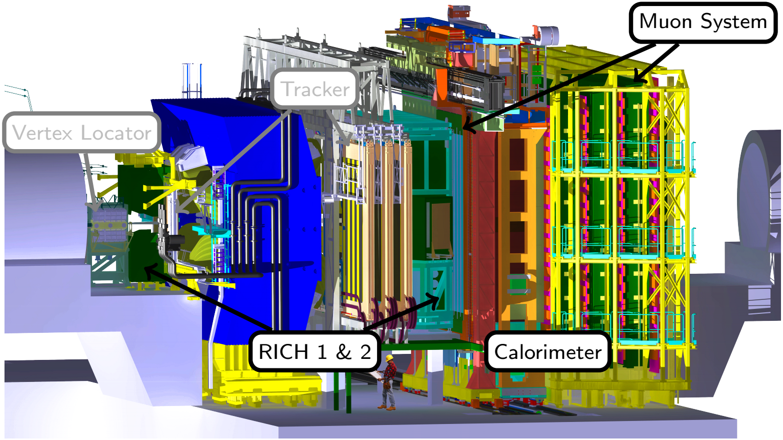




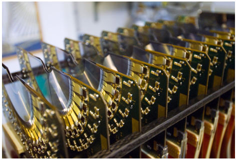
Upgrade of particle identification detectors

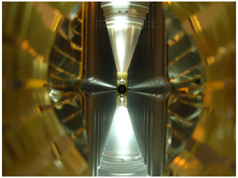
- RICH: replace photon detector and electronics
- Calorimeter: replace readout electronics

Vertex Locator (VELO)

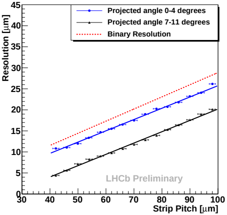
Current VELO (→ poster by D. Dossett)

- 21 stations of R and ϕ measuring microstrip sensors (300 μm n-on-n) along z
- operates in secondary vacuum (separated from beam vacuum by RF foil)
- left and right halves can be moved into and out of the beam
- hit resolution down to 4 μm (at 40 μm pitch)

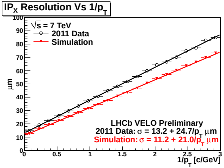




view along z inside VELO as seen by the beam



single hit resolution



impact parameter resolution

VELO Upgrade

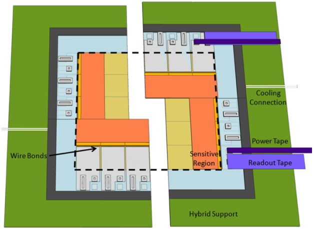
- For the upgrade, the sensors, electronics, modules, and RF foil need to be replaced.
- The existing vacuum tank and cooling plant can be re-used.
- Two options are currently being explored:
  - hybrid pixel detectors,
  - strip sensors with finer granularity.
- Technology choice to be taken in second half of 2013.

Requirements and Challenges

- data-driven readout at 40 MHz
- radiation tolerance
- keep/improve performance

Pixel Option

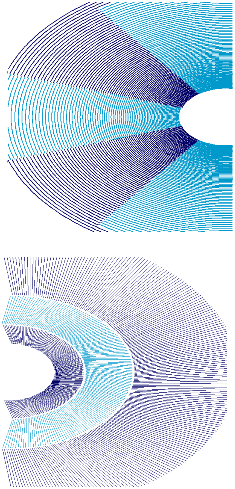
- based on Velopix ASIC (successor of Timepix3)
  55 μm $\times$ 55 μm pixel size, 256 $\times$ 256 matrix
  - simultaneous measurement of time-over-threshold (ToT) and time-of-arrival (ToA)
  - peaking time < 25 ns, timewalk < 25 ns
  - hit rate up to 500 MHz
  - submission planned for second half of 2013
- L-shaped half modules with two blocks of 6 chips
- sensor R&D focussing on planar Si sensors
- alternative sensor technologies:
  - diamond sensors,
  - 3D sensors



“straw-man” pixel module layout

Strip Option

- conceptually similar to existing detector (R/ϕ geometry)
- increased number of strips, reduced pitch and strip length, lighter (200 μm)
- improved routing line layout
- variable pitch designed for $\approx$ same occupancy per strip
- new strip chip being developed (synergy with other silicon detectors)
  - on-chip common mode suppression, zero suppression, and clustering
  - ADC stage has been submitted, submission of final chip expected for end of 2013
- sensor prototypes from two manufacturers are being produced, first one to arrive next month



layout of R and ϕ prototype sensors (every 5^{th} strip drawn)

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

	strips (128 channel ASIC)	pixels	
number of ASICs per module	40	12	
number of modules	42	52	
total number of ASICs	1680	624	
cluster size	1.6	2.2	
number of clusters / module / 25 s	52.6	25.8	
bits / cluster	42.2	52.3	
hottest chip output rate [Gbit / s]	1.4	12.2	⚠
coolest chip output rate [Gbit / s]	1.4	1.5	
total data rate [Gbit / s]	2352	2823	

- strip solution has less modules but two sensors (R, ϕ) per module
- Velopix groups pixels to 4×4 super-pixels $\rightarrow \approx 30\%$ bandwidth reduction

Performance Aspects

Impact Parameter Resolution

IP resolution depends on

- single hit resolution
- distance to interaction point
  - minimize guard ring width ($< 500\ \mu$m)
  - move closer to beam?
    $\rightarrow$ limitations due to data rates, fluence, beam size/stability, ... to be understood
- material
  - reduce material per module (sensor thickness, thinning of pixel chips, hybrid design)
  - optimize number of stations (without sacrificing efficiency)
  - reduce RF foil thickness and optimize shape

Track Reconstruction

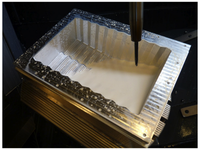
- Preliminary studies for pixel option show
  - processing time of ≈ 1 ms per event,
  - ghost rate $< 1\%$,
  - efficiency $> 99.5\%$.
- Performance of strip solution to be evaluated.

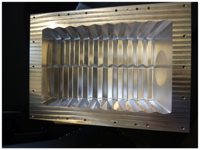
Detailed simulations with realistic material description and data processing chain are critical to arrive at a conclusion pixels vs. strips.

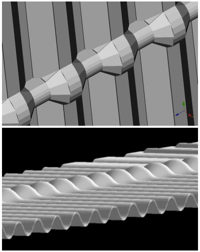
RF Foil

Manufacturing

- R&D on milling technique (milling out of one box)
- L-shape prototype has been produced







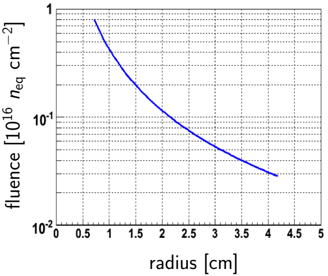
Simulation

- complex shape of foil is time-consuming to model using standard LHCb geometry description (XML)
- possible approach providing fast turn-around for optimizing foil layout: export CAD drawing to GDML format, can be loaded directly into Gauss simulation framework

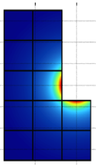
At the innermost part (7 mm from beam line), the sensors are expected to accumulate (after 100 fb^{-1})

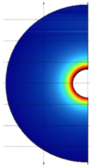
- a dose of $\approx$ 370 MRad,
- and a fluence of $\approx 8 \times 10^{15}$ n_{eq} cm^{-2}

S/N ratio after irradiation is a critical issue for strip option



- The dose profile is highly non-uniform
  - consequences for biasing (bias sensor of each chip individually?)
  - implies non-uniform heat-dissipation profile $\rightarrow$ consequences for cooling



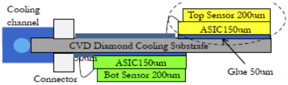


Cooling

- The cooling concept (two-phase CO_2 cooling) of the current VELO will be kept.
- Two main solutions for module cooling are being explored.

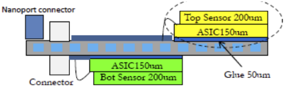
Baseline Solution

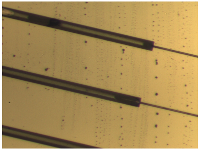
- CVD diamond support + TPG block
- R&D on diamond metallisation



Micro-Channel Cooling

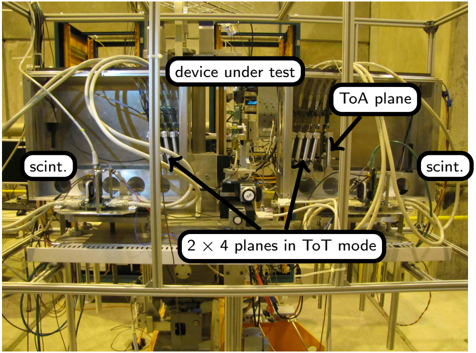
- attractive solution (particularly for pixel option) due to
  - low material budget,
  - possibility to adapt channel layout to heat dissipation profile.
- however: $\approx$ 60 bar pressure under chips





Timepix Telescope

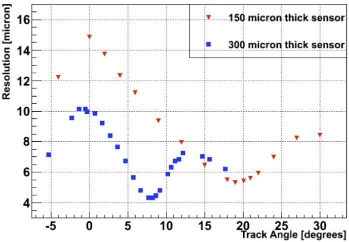
- constructed for LHCb upgrade (joint-venture with Medipix collaboration), described in NIMA **661**, 31-49
- Timepix assemblies (with 300 μm sensors) used as telescope planes
- device under test can be moved/rotated and cooled (portable CO_2 cooling plant)
- available to external users within the framework of AIDA WP 9.3

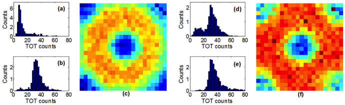


Performance Characteristics

- pointing error $\approx 2\ \mu$m (with 180 GeV/c π beam)
- track time-stamping with ≈ 1 ns resolution
- >15 kHz track rate

Testbeam Programme





JINST **6**, P05002

2012 Testbeam Campaign

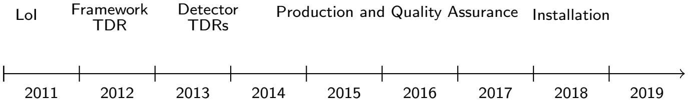
Focus on

- sensor performance after irradiation (Medipix3 assemblies)
- evaluation of guard-ring designs, edge efficiencies
- prototype strip module

Outlook

- Timepix3 chip expected to become available beginning of next year
  $\rightarrow$ build Timepix3 telescope
- frame-based readout $\rightarrow$ data-driven readout

Summary



LHCb Upgrade

Upgrade requires

- replacement of front-end electronics,
- re-building/replacing VELO, silicon tracker, and RICH photon detector.

VELO Upgrade

R&D in several areas to develop a detector which is

- radiation tolerant (ASIC and sensor),
- light,
- capable of 40 MHz readout at $\mathcal{L} = 2 \times 10^{33}$ cm^{-2} s^{-1},
- features high resolution and fast and efficient pattern recognition.