The LHCb VELO Upgrade

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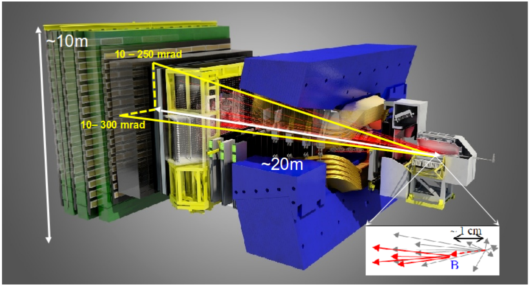
Taller de Altas Energías (TAE)
15^{th} - 28^{rd} September, 2013
Benasque

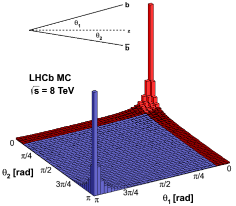
Outline

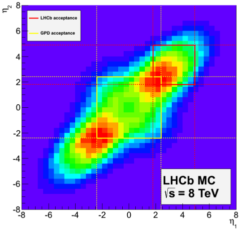
The LHCb experiment

LHCb is a forward spectrometer designed to study flavor physics exploiting the enormous production cross sections of heavy hadrons at the LHC

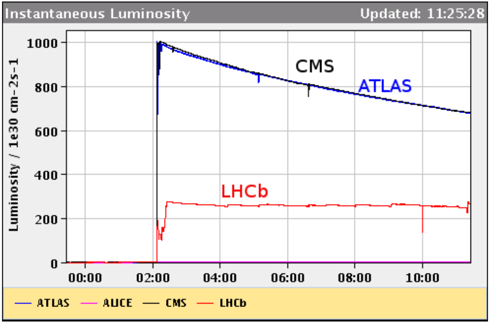


- Excellent vertex, momentum and particle identification
- $2 < \eta < 5$
- 40% of heavy quark production x-section with 4% of solid angle



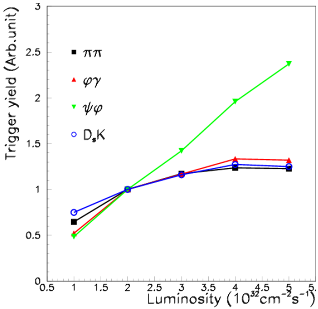


The LHCb experiment



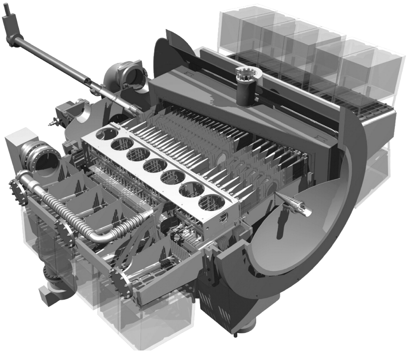
- Design luminosity lower than the LHC can deliver.
  - → Built for $\mathcal{L} = 2 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ at 25 ns spacing, with an average of μ=0.4 interactions per bunch crossing
  - → Running at a $\mathcal{L} = 4 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ at 50 ns spacing with μ=1.4
  - → Has recorded 1.1 fb^{-1} in 2011 and 2 fb^{-1} in 2012

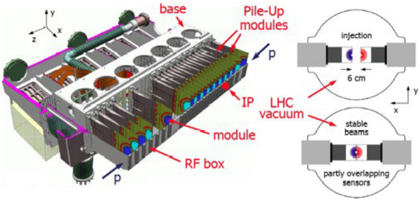
- Running at higher luminosity does not improve hadronic event yield due to trigger bottleneck

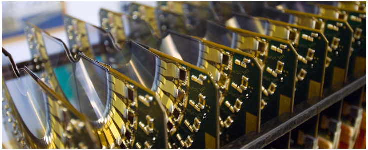


The Vertex Locator (VELO)

- Silicon strip detector surrounding the interaction point
- 88 silicon n^{+}-on-n sensors, 300 μm thick, R-ϕ design
- Located only 8 mm from the beams
- Enclosed into a separated vacuum box (RF Foil)
- Halves are separated for beams injection
- 1 MHz trigger rate
- Bi-phase CO_2 cooling system

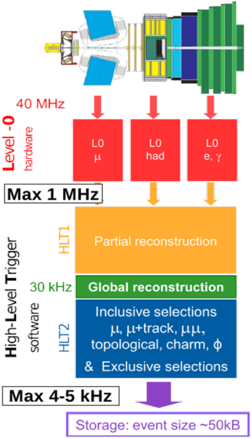




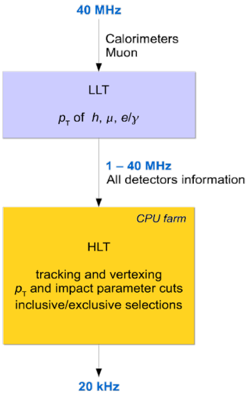


LHCb upgrade

Current data flow



Upgraded data flow



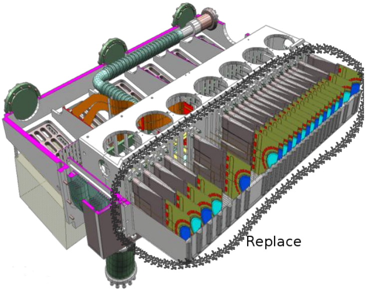
- Remove Hardware trigger. Use software-only trigger
- 1 to 40 MHz trigger rate
- Output rate from 5 to 20 kHz
- Increase luminosity to $\geq 2 \times 10^{33} \text{cm}^{-2}\text{s}^{-1}$

Apart from the increase in luminosity and trigger rate, we expect an increment of approx. a factor 10 and 20 in the muonic and hadronic channels yield respectively.

VELO upgrade

Requirements and challenges

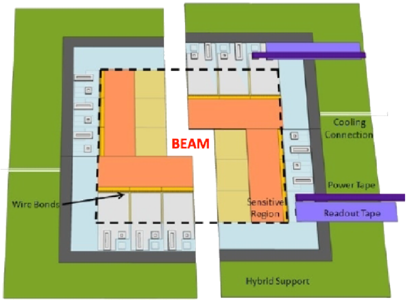
- Data-driven readout at 40 MHz. >2 Tbit/s from whole VELO
- Radiation tolerance. Higly non-uniform radiation: $4.8 \times r^{-1.9}$ hits event^{-1}cm^{-2}
- Keep/improve performance
- Increase granularity to allow operation at $\mathcal{L} \geq 2 \times 10^{33}$cm^{-2}s^{-1}

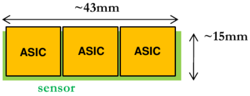


- Sensors, electronics, modules and RF foil need to be replaced.
- Vacuum tank, cooling plant and motion system will be re-used.

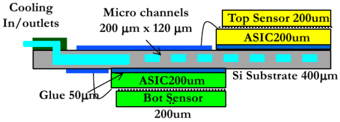
Modules

- based on Velopix ASIC (successor of Timepix3) 55 μm x 55 μm pixel size, 256 x 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. (Above 12 Gbit/s)
  - → submission planned for early 2014
- L-shaped half modules with two blocks of 6 chips
- Closest pixel is at 5.1 mm from the beam center
- Geometrical efficiency > 99 % for R < 10 mm



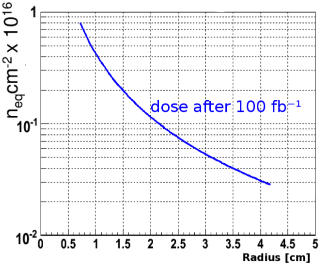


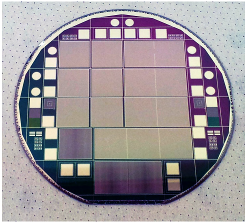
- Cooling:
  - → Novel method: evaporate CO_2 via micro-channels etched in Si substrate
  - → Bring the cooling power where you need it, using least material
  - → No CTE difference (Si on Si)



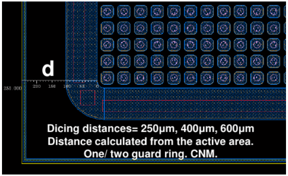
Silicon sensors

- Planar silicon, n-in-n or n-in-p to be decided
- Tile for 3 VeloPix chips: ∼43 x 14 mm, thickness 200 μm
- 55 μm x 55 μm pixel size
- Non homogeneous irradiation sets constraints on guard ring design
  - → factor ∼40 difference in fluence from tip to far corner
  - → bias voltage at end on life ∼1000 Volts for tip
  - → guard ring width ∼400 μm





Sensor wafer with variable guard ring designs
(Tiles 2-1 and 3-1. CNM)

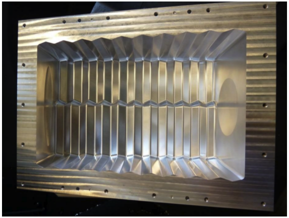


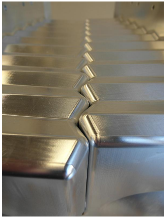
RF foil

The RF foil is a *de facto* beam pipe

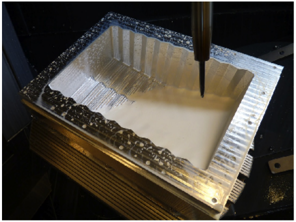
Severe requirements:

- Vacuum tight ($< 10^{-9}$ mbar l/s)
- Radiation hard
- Low mass but rigid to prevent deflection onto the sensors or pinhole leaks
- Good electrical conductivity to mirror beam currents and shield against RF noise pick-up in FE electronics
- Thermally stable and conductive (heat load from the beam)





Material and fabrication:

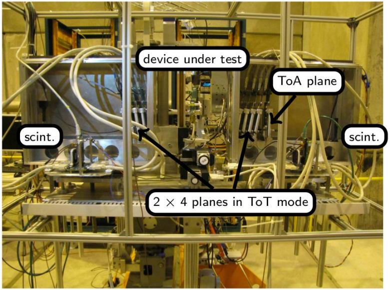


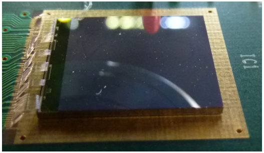
- Mill foil from solid Al alloy block
- By 5-axis milling head
- Achieve 300 μm thickness
- More flexibility to change shape than made by pressing method

Test beam

TimePix telescope

- Constructed for LHCb upgrade
- Timepix assemblies (with 300 μm sensors) used as telescope planes (8 ToT + 1 ToA)
- device under test can be moved/rotated and cooled (portable CO_2 cooling plant)
- Resolution at the DUT plane $\leq 2\mu$m (with 180 GeV/c π beam)
- Track time-stamping with
  - $\rightarrow$ $\approx$ 1 ns resolution
  - $\rightarrow$ $\approx$ 3-12 kHz track rate
- available to external users within the framework of AIDA WP 9.3





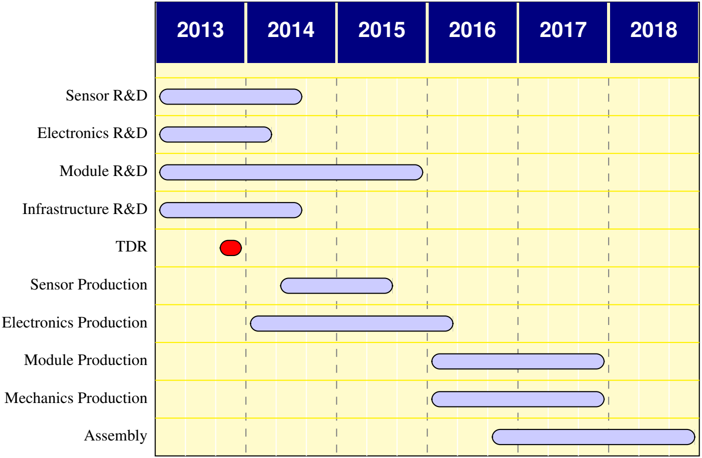
Focus on

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

Schedule

LoI: CERN-LHCC-2011-001

FTDR: CERN-LHCC-2012-007



... to be installed in LHC Long Shutdown 2, in 2018-2019

Conclusions

The requirements for the LHCb VELO upgrade are very demanding:

- Luminosity will be increased by a factor ≥ 10
- Trigger readout will be increased by a factor of 40
- Keep or improve the performance of the current VELO

R&D effort is underway:

- Vertex Locator will consist of planar silicon pixels, 55 x 55 μm^2
- Evaporative CO2 cooling in Silicon micro-channel substrate
- Material budget reduction in elements placed in the acceptance (modules, RF-Foil)
- Intense testbeam program to study: sensor technologies, radiation hardness, cooling schemes and readout electronics

Installation during long shutdown 2 in 2018