The LHCb VELO upgrade

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on behalf of the LHCb Velo group

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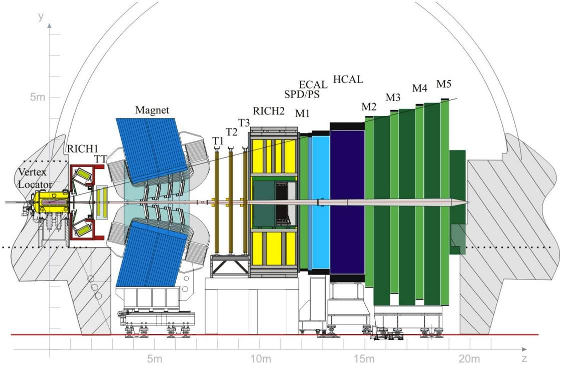
LHCb characteristics

- Single arm spectrometer
- Luminosity 4×10^{32} cm^{-2} s^{-1}
- Integrated luminosity of 8 fb^{-1} by end of Run 2
- Collision rate reduced from 40 to 1.1 MHz using a hardware trigger

Check also talk from S. de Capua on the *Performance of and Radiation Damage Effects in the LHCb Vertex Locator* today at 17:00.



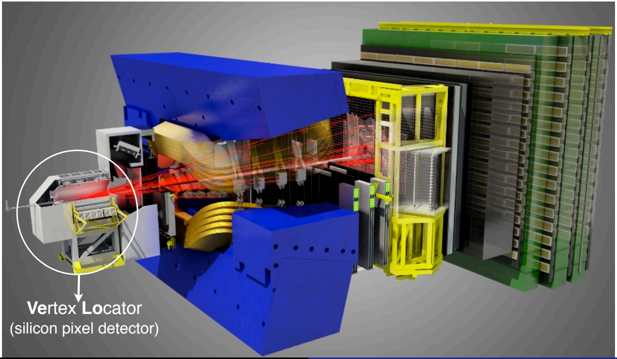
Reasons to upgrade

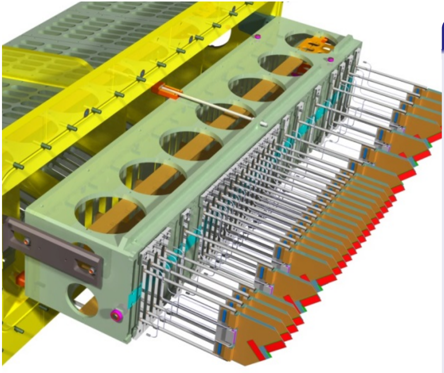
- A factor 5 higher luminosity (2×10^{33} cm^{-2} s^{-1})
- Capable of accumulating 50 fb^{-1}

Features of the upgrade

- Full software trigger at 40 MHz
- Increased yield by a factor 10 (depending on the channel)
- Installation by 2018

$\Rightarrow$ Upgrade of all subdetectors





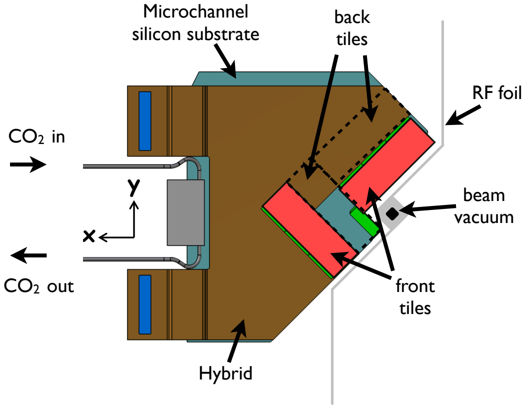
One of the retractable halves

Main features of Vertex Locator upgrade

- strips $\rightarrow$ pixels
- VeloPix ASIC with a 200 μm thick sensor
- 52 modules divided in two retractable halves
- Edge of detector closer to beam (8.2 mm $\rightarrow$ 5.1 mm)
- Microchannel cooling of modules with two-phase CO_2
- Expected reconstruction efficiency $> 99\%$ at upgrade beam conditions
- Detector is in secondary vacuum separated from beam vacuum by a 250 μm thick RF foil

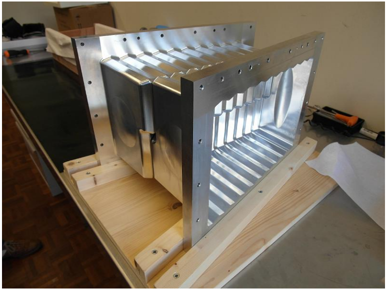
Module description

- All module components made of silicon
  $\Rightarrow$ minimal mismatch in thermal expansion coefficient
- 2 tiles mounted on each side
- 3 chips in a row bump-bonded to a single sensor form a tile

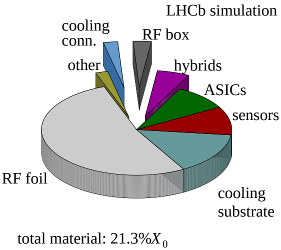


Box with corrugated foil

- Separates beam vacuum from secondary vacuum
- Shields modules from beam interference
- Guides mirror currents
- Milled to a thickness of $\sim$250 µm from a solid block of AlMg4.5
- Further thinning by chemical etching is being investigated
- Particles may traverse the foil multiple times: main contribution to material budget



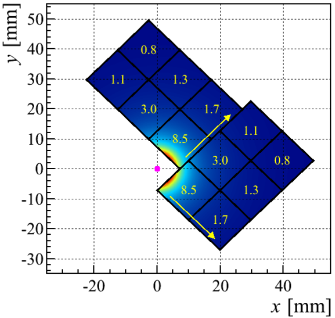
RF box and foil



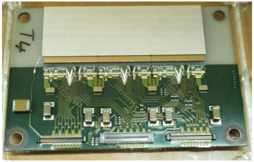
Sensor characteristics

- 200 µm thick
  (exploring other thicknesses too)
- 400-450 µm wide guard rings
- n-on-p (n-on-n)
- Vendors
  - Micron
  - Hamamatsu
- Radiation hard up to $\sim 10^{16}\ n_{eq}/cm^2$
- Non-homogeneous irradiation (factor 40 difference from hottest to coolest point)

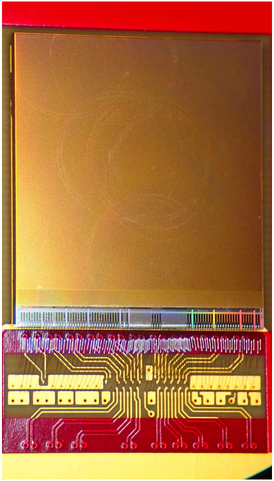
First prototype sensors arrived recently.
Lab & beam tests are ongoing.



Number of tracks / chip / bunch crossing.



Picture of a 3 × 1 tiles on a hybrid board.

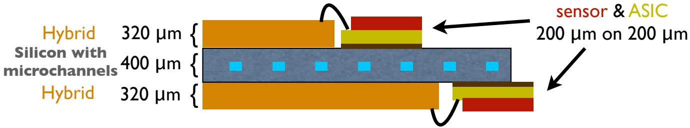


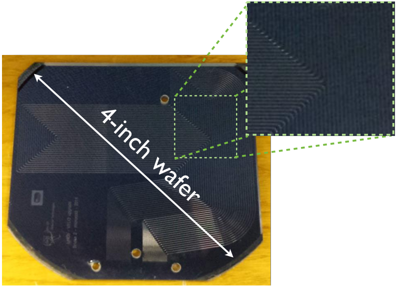
Picture of Timepix3 chip, predecessor of VeloPix.

VeloPix - a pixel ASIC for Velo

- based on Timepix3
- 256 x 256 square pixels of 55 µm size
- 130 nm CMOS technology
- measures
  - Position (x, y)
  - Time of Arrival with 25 ns resolution
- Peak hit rate 900 MHits/s per ASIC
- Radiation hard up to 400 Mrad
- Zero suppressed data driven readout

Cooling





“Snake” sample on a Si-Pyrex prototype plate

Microchannels in silicon substrate

- 400 μm thick silicon substrate
- 19 parallel microchannels of 200 μm width & increasing depth up to 120 μm
- Pressure up to $\sim$65 bar at room temperature, system will be qualified to 170 bar
- Cooling requirement: > 3 W/ASIC, > 36 W/module
- From a 6$\times$4 cm^2 Si-pyrex prototype 12.9 W of power can be removed

Impact Parameter resolution

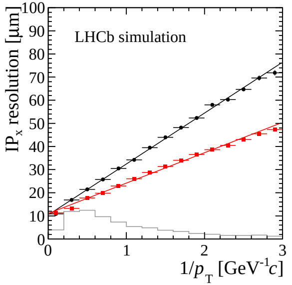
- Distance between extrapolated particle trajectory and its primary vertex is a signature of a B meson decay.

$$\sigma_{IP}^2 \approx \sigma_{MS}^2 + \sigma_{extrapolation}^2$$

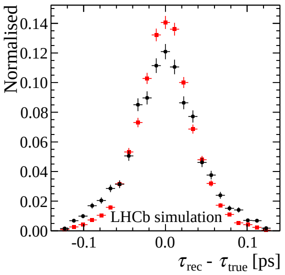
Decay time resolution

- Dilution on the amplitude of a B meson oscillation depends on the decay time resolution σ_t

$$D = e^{\left(-\frac{1}{2}\Delta m_s^2 \sigma_t^2\right)}$$



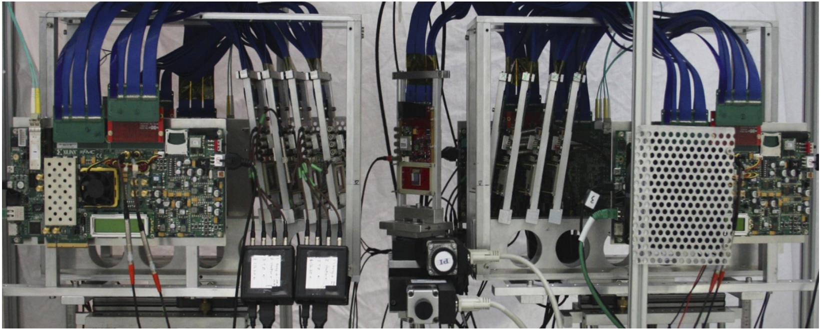
Impact Parameter resolution: Current Velo (black) and Upgraded Velo (red)



Decay time resolution: Current Velo (black) and Upgraded Velo (red)

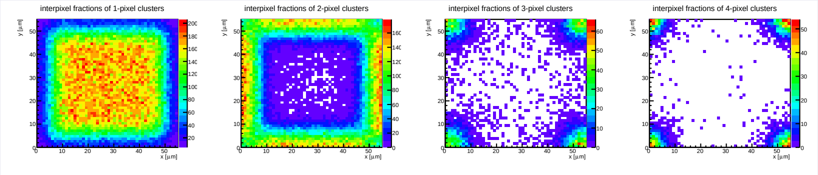
Timepix3 telescope

- 8 Timepix3 detectors divided in 2 arms
- Active area of $\sim$ 2 cm^2
- Pointing resolution $<$ 2 µm for a 180 GeV beam
- Reconstruct up to 10 million tracks/s
- Extensive testbeams in PS & SPS at CERN

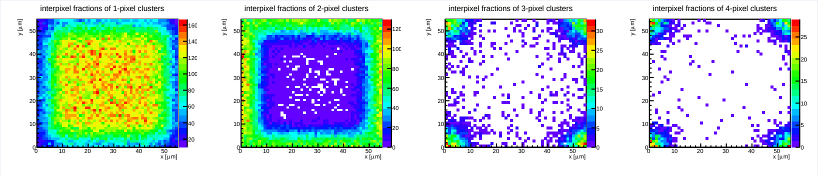


200 µm thick Hamamatsu sensor on a Timepix3 chip bump-bonded by Advacam

- Interpixel fractions of 1,2,3 and 4 pixel clusters (sensor perpendicular to the beam)

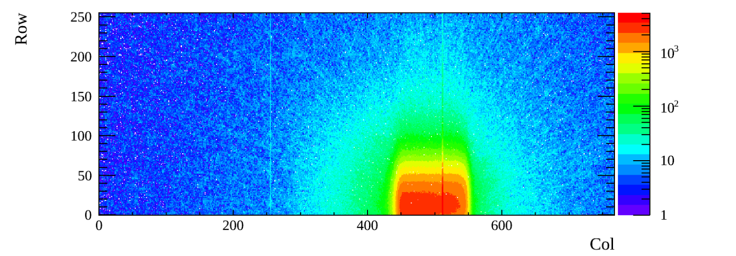


Bias voltage: -100 V (close to depletion voltage)



Bias voltage: -500 V (over depleted)

200 µm thick Hamamatsu 3×1 tile on 3 Timepix3 chips bump-bonded by Advacam



Hit map of a 3 × 1 tile in a 180 GeV beam (data from testbeams in late October).

Data available

- Efficiency measurements
- Bias voltage & angle scans
- High rate tests
  (up to 80 Mhits/s)

Further tests

- Examination of irradiated tiles both in lab & in testbeams
- HV tolerance testing (before/ after irradiation)
- First assemblies irradiated now & planned to be tested in beam next week

Summary

- LHCb will have to cope with 5$\times$ higher luminosity and 100$\times$ more data
  - Move to software trigger and data driven readout
- Upgrade of the Vertex Locator is ongoing
  - All silicon module
  - A new pixel ASIC: VeloPix
  - Microchannel cooling
  - Highly non homogeneous illumination with a maximum fluence of $8\ \times 10^{15}\ n_{\text{eq}}/\text{cm}^2$
- Very active testbeam program for sensor & ASIC characterisation
  - Telescope with Timepix3 (predecessor to VeloPix)
  - First sensors exposed to beam, data analysis ongoing

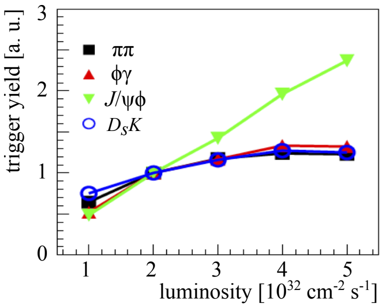
Outlook

- Extensive irradiation programme of sensors already started
- First version of VeloPix ASIC and prototype module expected mid 2015
- Module production scheduled for 2016
- Installation in 2018

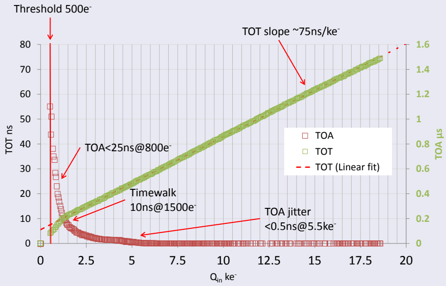
back up slides

Fully software based event selection

- Higher luminosity results in saturation of signal yield for hadronic channels

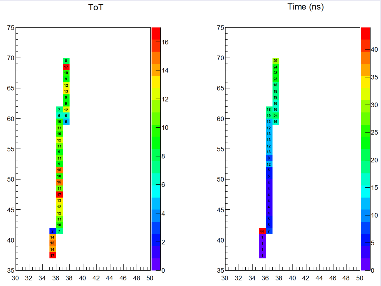


Timewalk and ToT linearity



- measurements done using testpulses

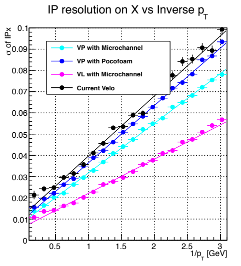
Cosmic rays through sensor



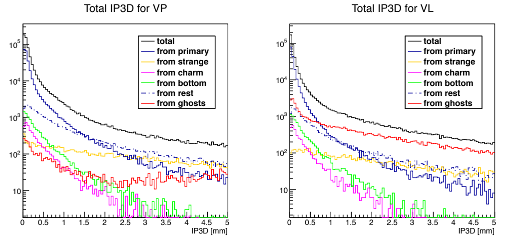
- 300 µm thick silicon p-on-n sensor

figures taken from Massimiliano De Gaspari's talk in TIPP 2014

Impact parameter for different Upgrade scenarios



Ghost rates for different Upgrade scenarios



IP formula

$$\sigma^2_{IP_Y} = \underbrace{\frac{\sigma_0^2}{(z_2 - z_1)^2}\left[(z_1 - z_{PV})^2 + (z_2 - z_{PV})^2\right]}_{\text{extrapolation term}} + \underbrace{\theta_0^2 (z_1 - z_{PV})^2}_{\text{MCS term}}$$

becomes

$$\sigma^2_{IP_Y} = \frac{\sigma_0^2}{(z_2 - z_1)^2}\left[(z_1 - z_{PV})^2 + (z_2 - z_{PV})^2\right] + \frac{1}{p_T^2}\left(\frac{13.6\ \text{MeV}}{\beta\, c}\, q\, \sqrt{x/X_0}\ [1 + 0.038 ln(x/X_0)]\right)^2 (y_1 - y_{PV})^2$$