The LHCb VELO Upgrade

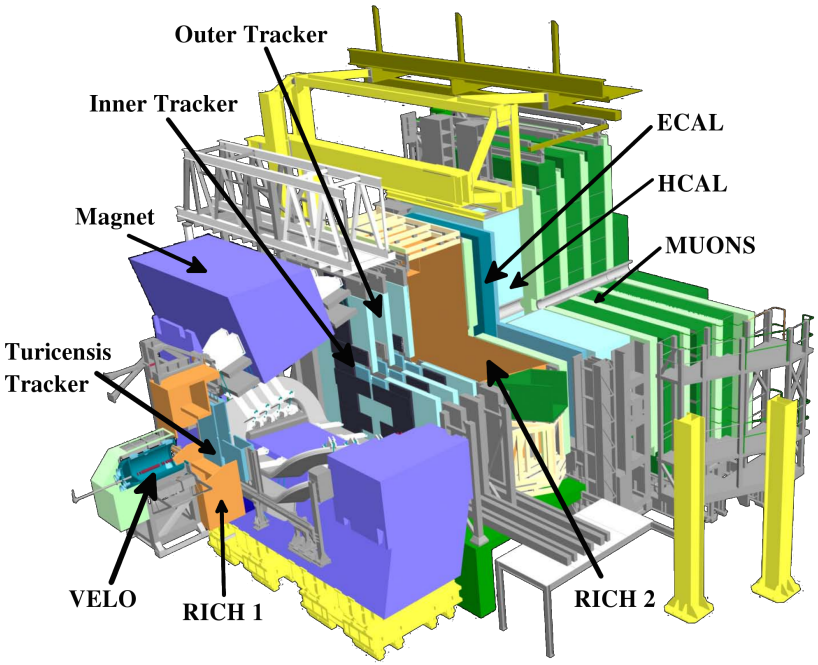
A. Dosil Suárez
(On behalf of **the LHCb collaboration**)

2012 Nuclear Science Symposium, Medical Imaging Conference &
Workshop on Room-Temperature Semiconductor X-Ray
and Gamma-Ray Detectors
29th October - 3rd November, 2012
Anaheim, California

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

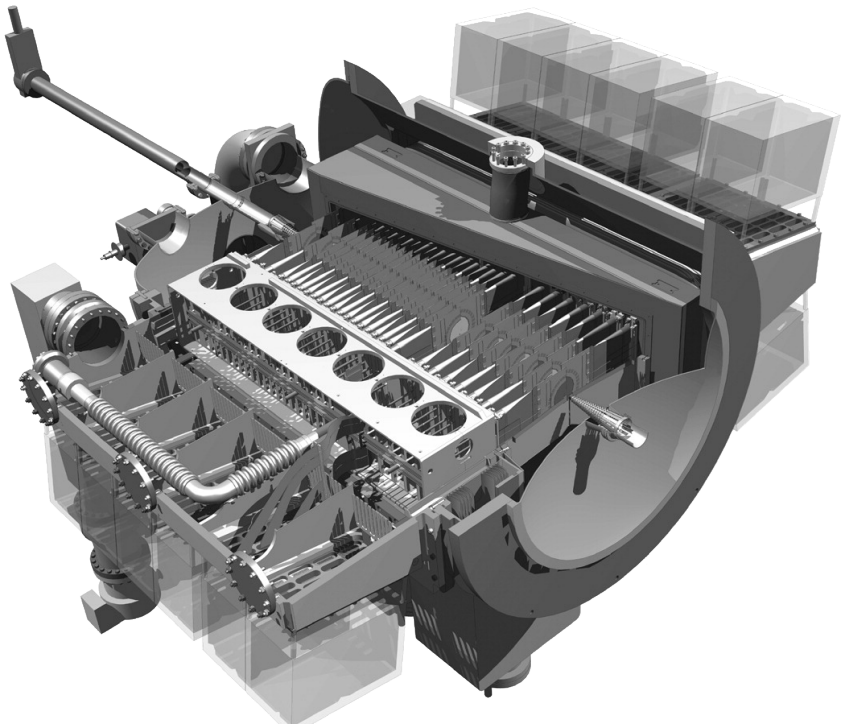


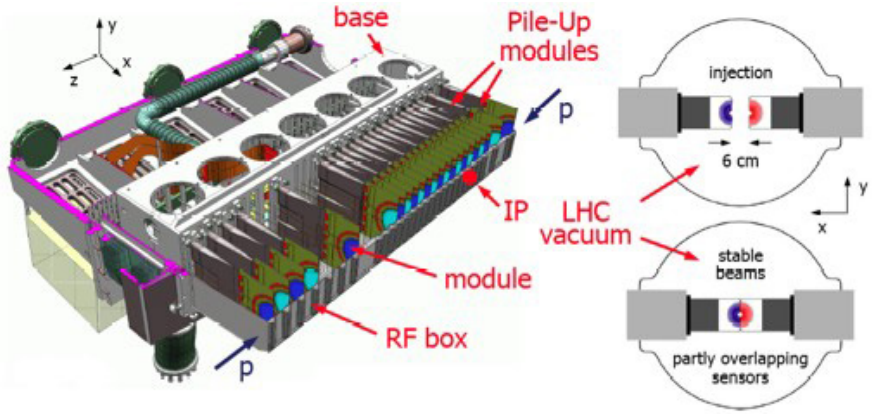
- Excellent vertex, momentum and particle identification
- Design luminosity lower than the LHC can deliver.
  - → Built for $\mathcal{L} = 2 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ at 25 ns spacing, with an average of μ=0.4 interactions per bunch crossing
  - → Running at a $\mathcal{L} = 4 \times 10^{32}\text{cm}^{-2}\text{s}^{-1}$ at 50 ns spacing with μ=1.4
  - → Has recorded 1.1 fb^{-1} in 2011 and 1.63 fb^{-1} so far in 2012

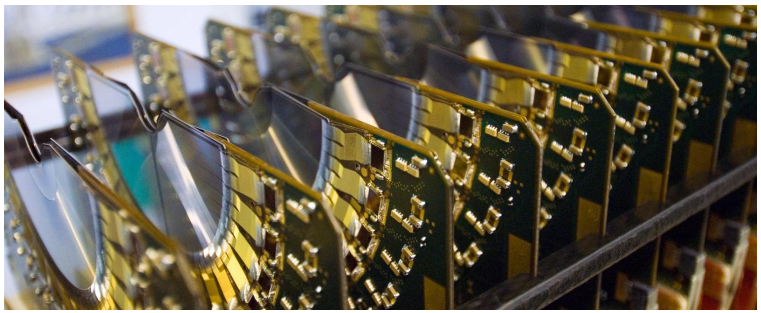
- Running at higher luminosity does not improve hadronic event yield due to trigger bottleneck

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

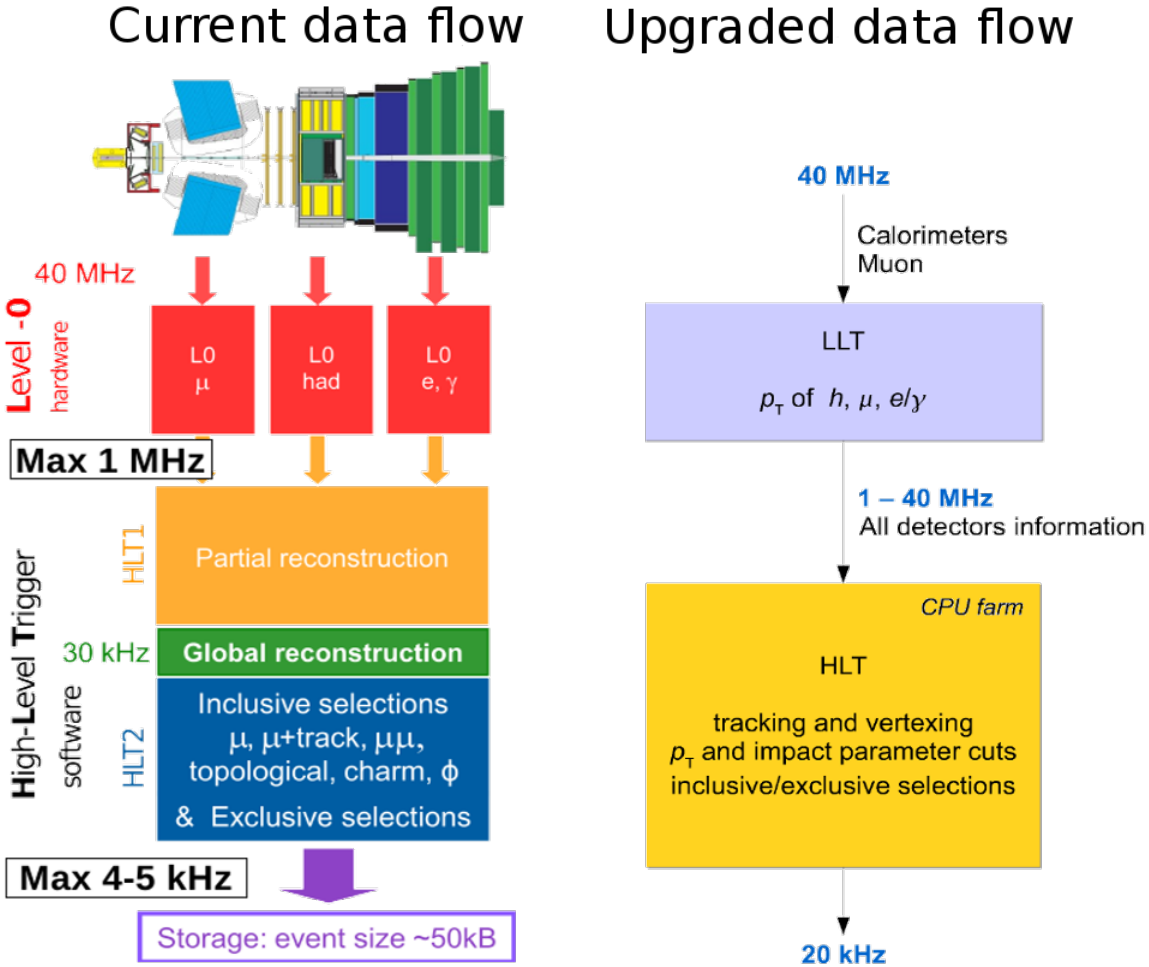






More information in C. Farinelli's talk: *Performance of the LHCb VELO* and J. Harrison's talk: *VELO Radiation Damage*

LHCb upgrade



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

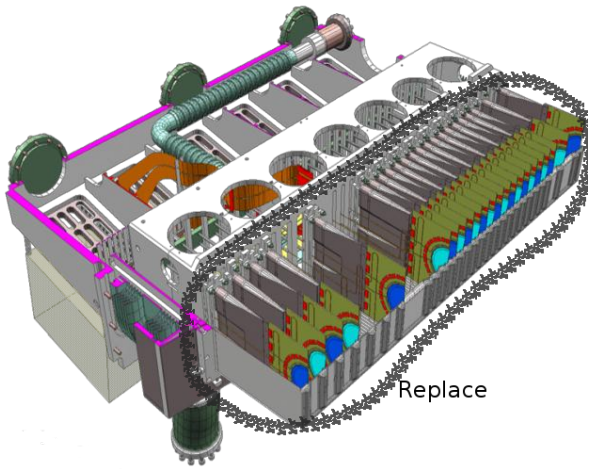
Apart from the increase in luminosity and trigger rate, we expect an increment of approx. a factor 10 and 20 in the muonic and hadronic channels yield respectively.

More information in C. Faerber's talk: *The LHCb Detector Upgrade*

VELO upgrade

Requirements and challenges

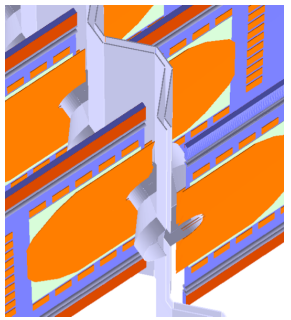
- Data-driven readout at 40 MHz. $>$2 Tbit/s from whole VELO
- Radiation tolerance. Higly non-uniform radiation: $4.8 \times r^{-1.9}$ hits event^{-1}cm^{-2}
- Keep/improve performance
- Increase granularity to allow operation at $\mathcal{L} \geq 2 \times 10^{33}$cm^{-2}s^{-1}



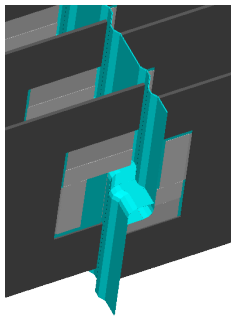
- Sensors, electronics, modules and RF foil need to be replaced.
- Vacuum tank, cooling plant and motion system will be re-used.

- Two options under investigation:
  - → Pixel detector based on TimePix family of chips
  - → Strip detector following similar philosophy to existing design

Strip modules

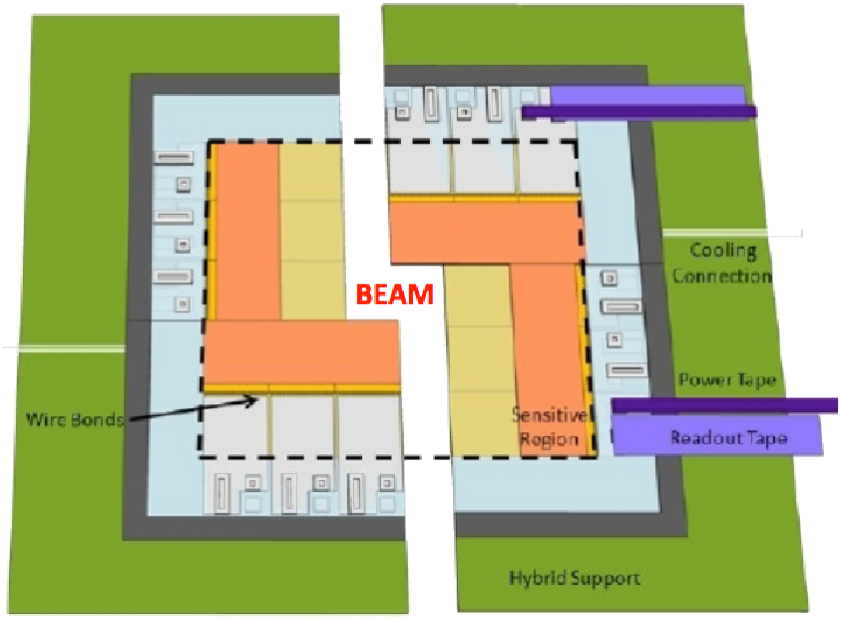


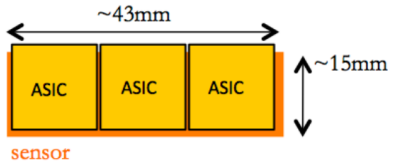
Pixel modules

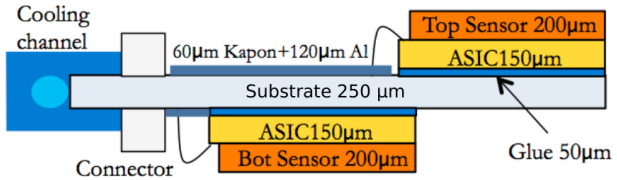


Pixel option

- 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 $\leq$7.5 mm from the beam center
- sensor R&D focussing on planar Si sensors
- alternative sensor technologies:
  - → 3D sensors
  - → diamond sensors

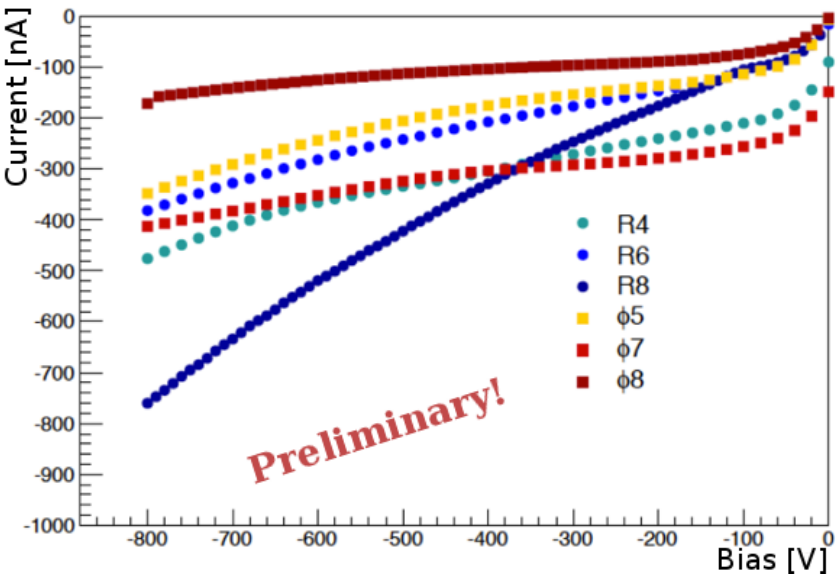




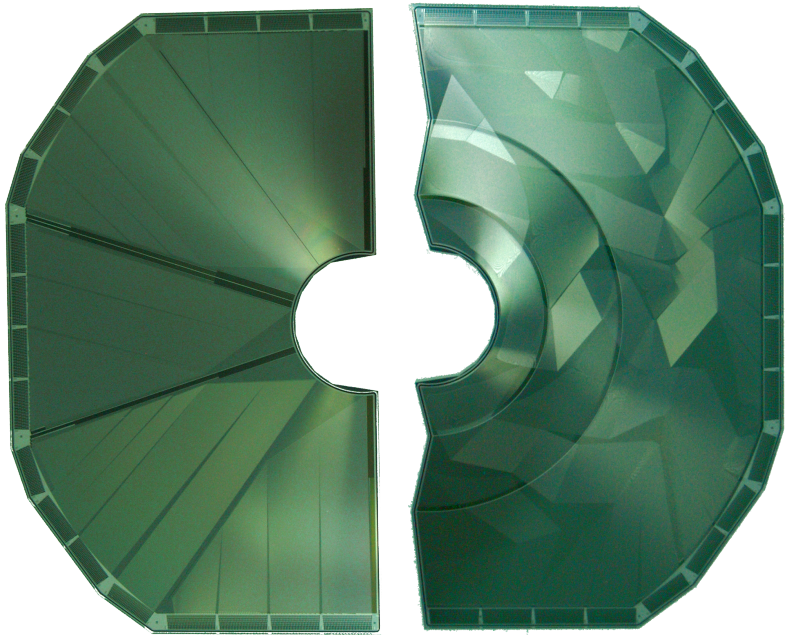


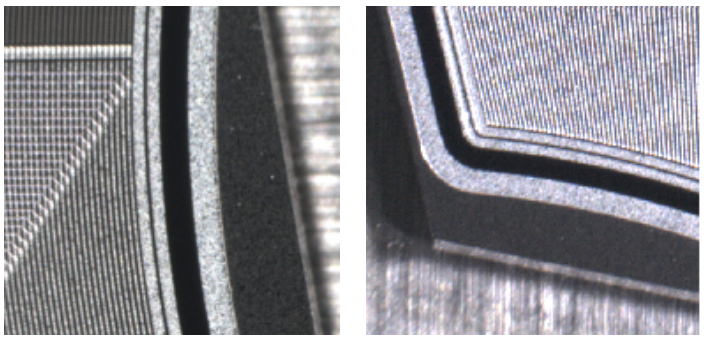
Strip option

- 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
- To be tested in coming test beams
- new strip chip being developed (synergy with other LHCb silicon detectors)
  - $\rightarrow$ on-chip common mode suppression, zero suppression, and clustering



R-Type ϕ-Type



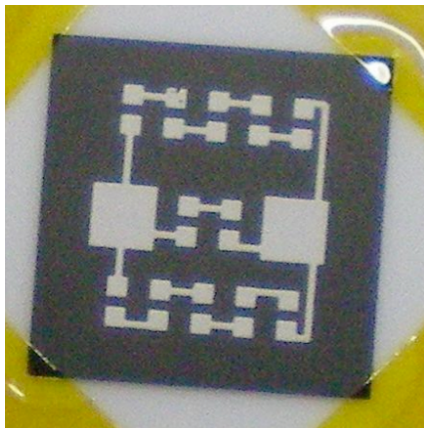


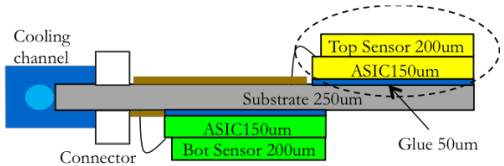
Strip sensors made by Hamamatsu

Cooling

Metallised diamond substrate

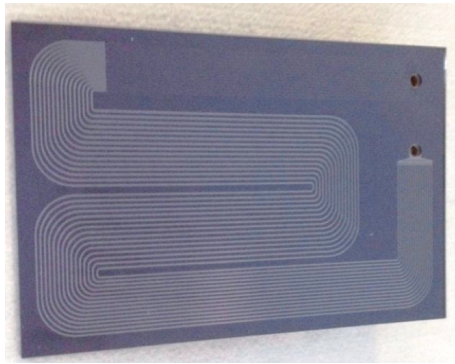
- Thermally is highly conductive
- Electrically is highly resistive
- Traces for chip IO deposited with thermally activated silver paste

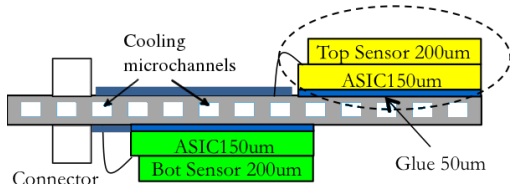




Microchannel cooling option

- Build $\sim 200\ \mu m \times 70\ \mu m$ channels etched onto silicon
- The layout can be customized according to cooling needs
- Same coefficient of expansion than ASIC
- Several prototypes already produced and working in lab environment





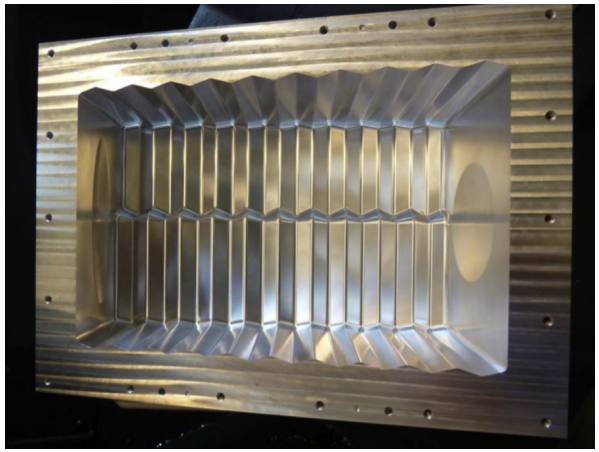
Aim to re-use current CO_2 cooling plant

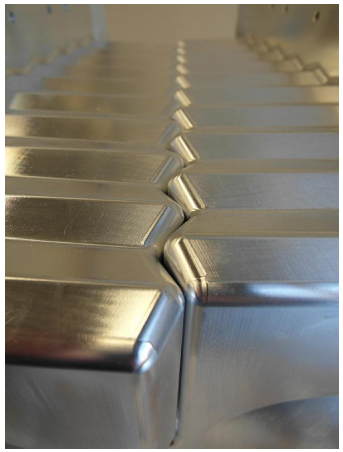
RF foil

The RF foil is a *de facto* beam pipe

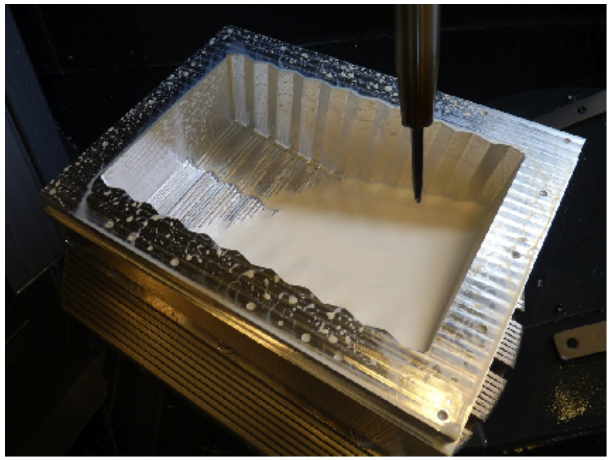
Severe requirements:

- 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:

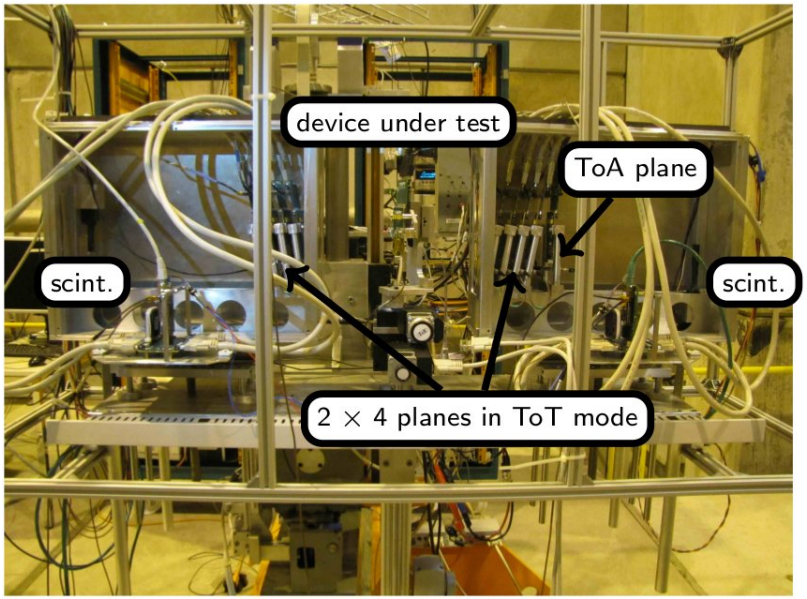


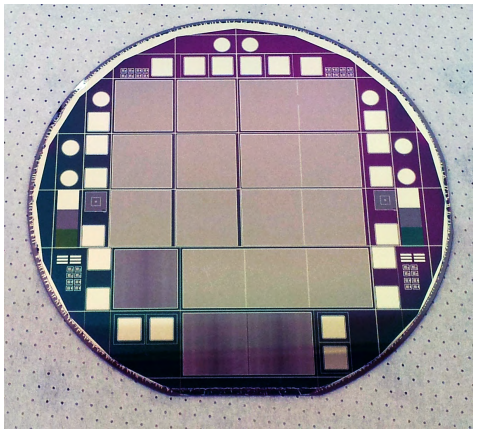
- Mill foil from solid Al alloy block
- By 5-axis milling head
- Achieve 200-350 μm thickness
- More flexibility to change shape than made by pressing method

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





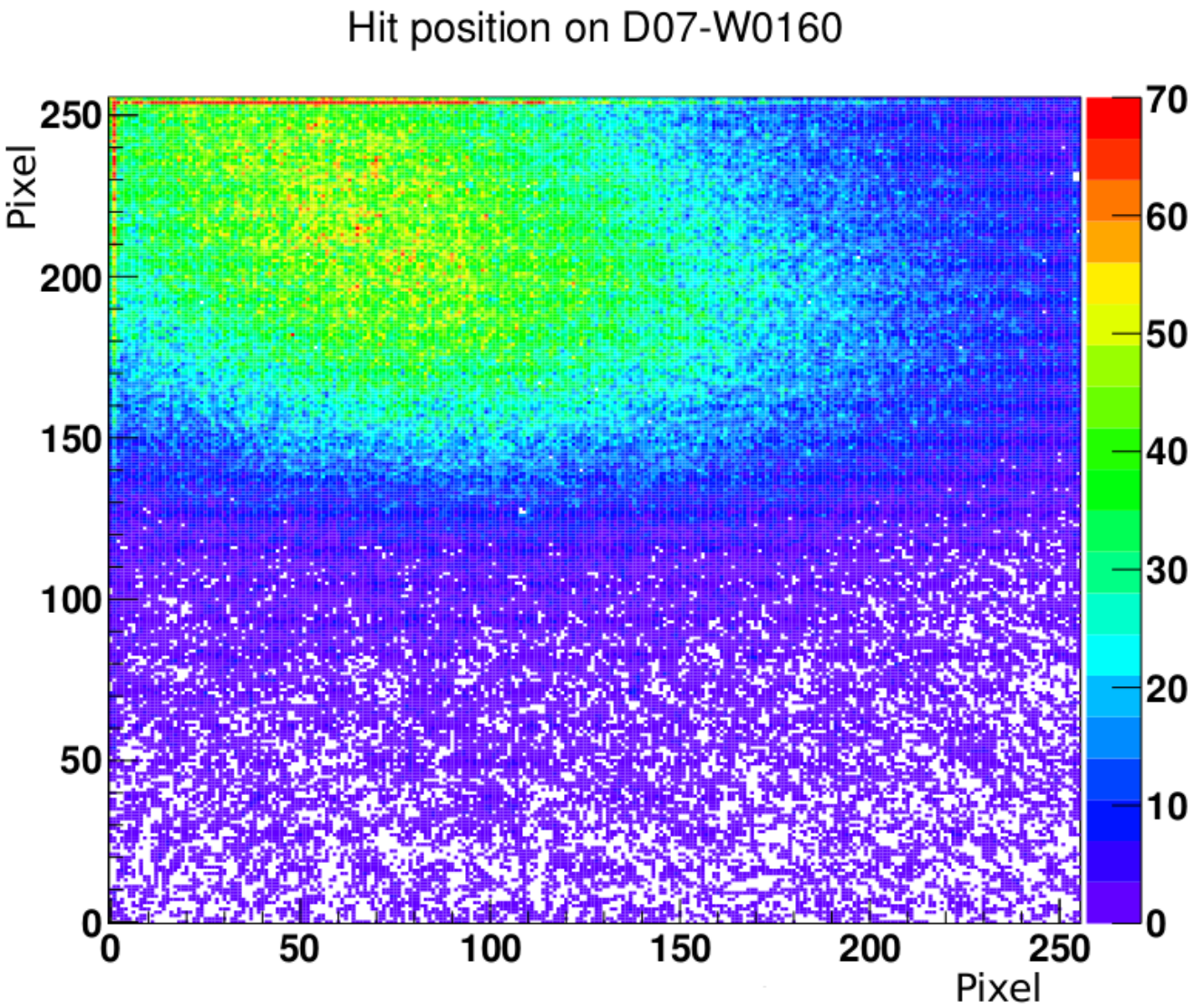
Sensor wafer with variable guard ring designs (Tiles 2-1 and 3-1. CNM)

Focus on

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

Test beam

Results

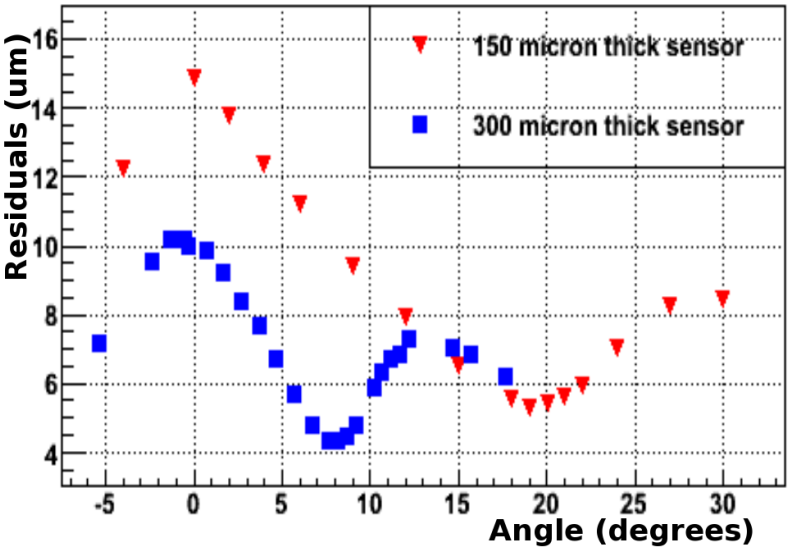


- 150 μm
- n-on-n
- edgeless

Test beam

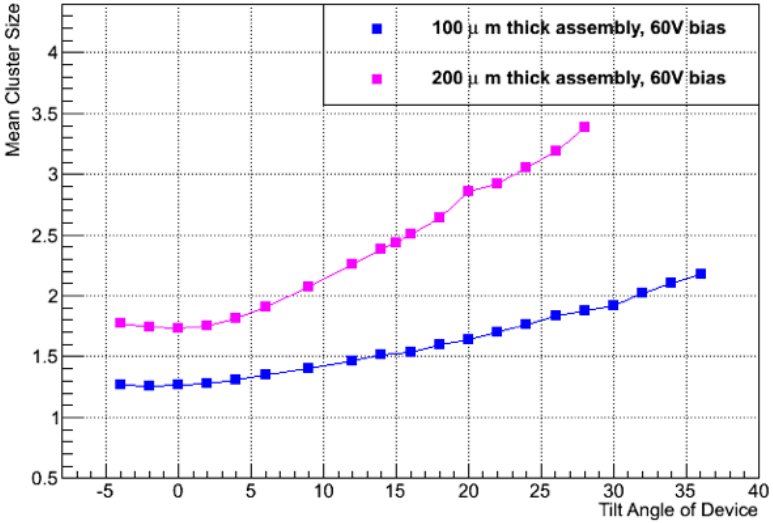
Results

CNM TimePix assemblies for LHCb



K. Akiba et al. "Charged Particle Tracking with the Timepix ASIC", Nucl. Instr. and Meth. A. NIMA53849, doi: 10.1016/j.nima.2011.09.021.

VTT edgeless Timepix assemblies for LHCb

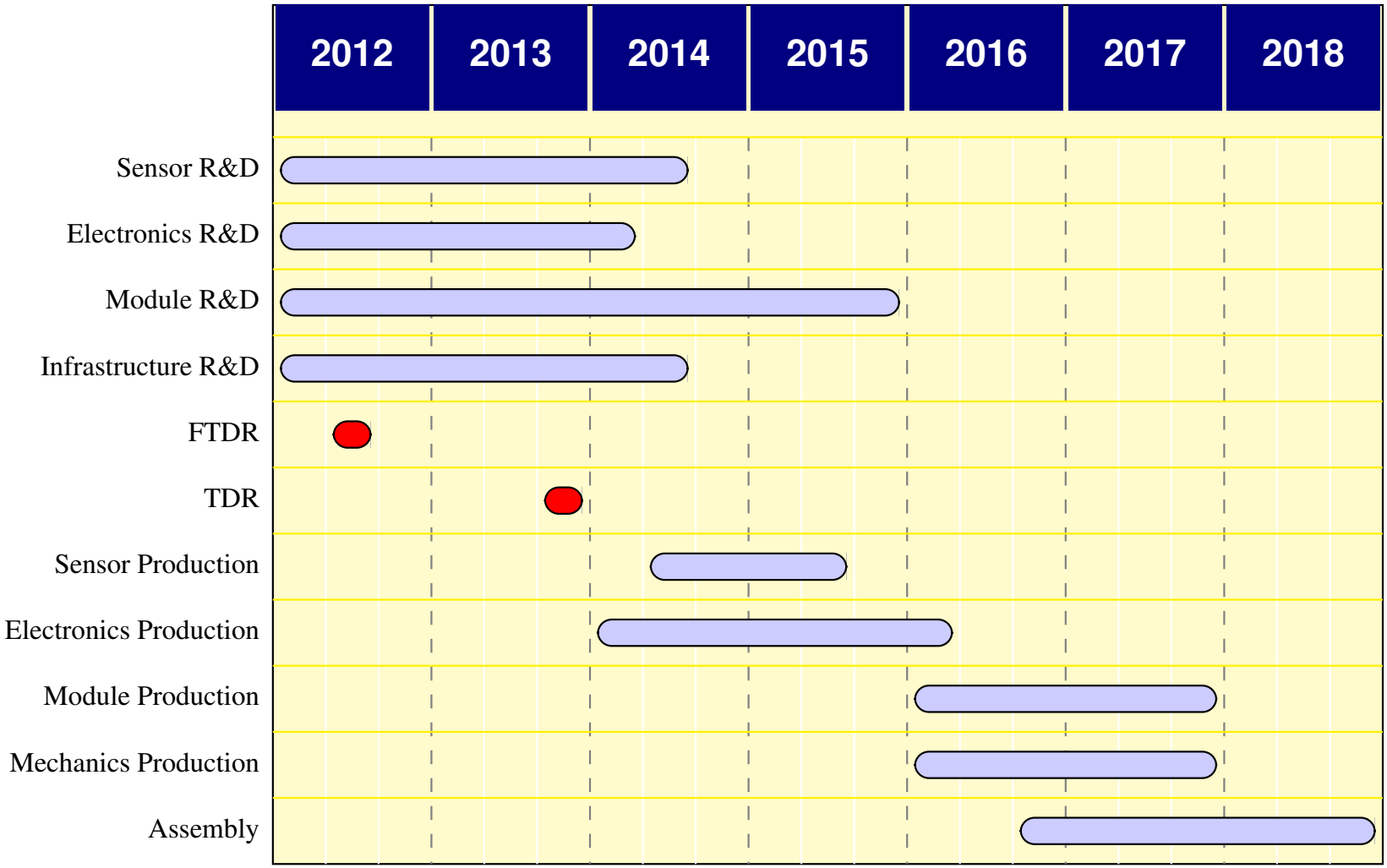


Cluster width distribution for edgeless sensors

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:

- For modules, pixel and strip detector options are being developed in parallel
- Cooling solutions like metallised diamond or microchannel also being investigated
- 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

Have a magical day!

Work on going...