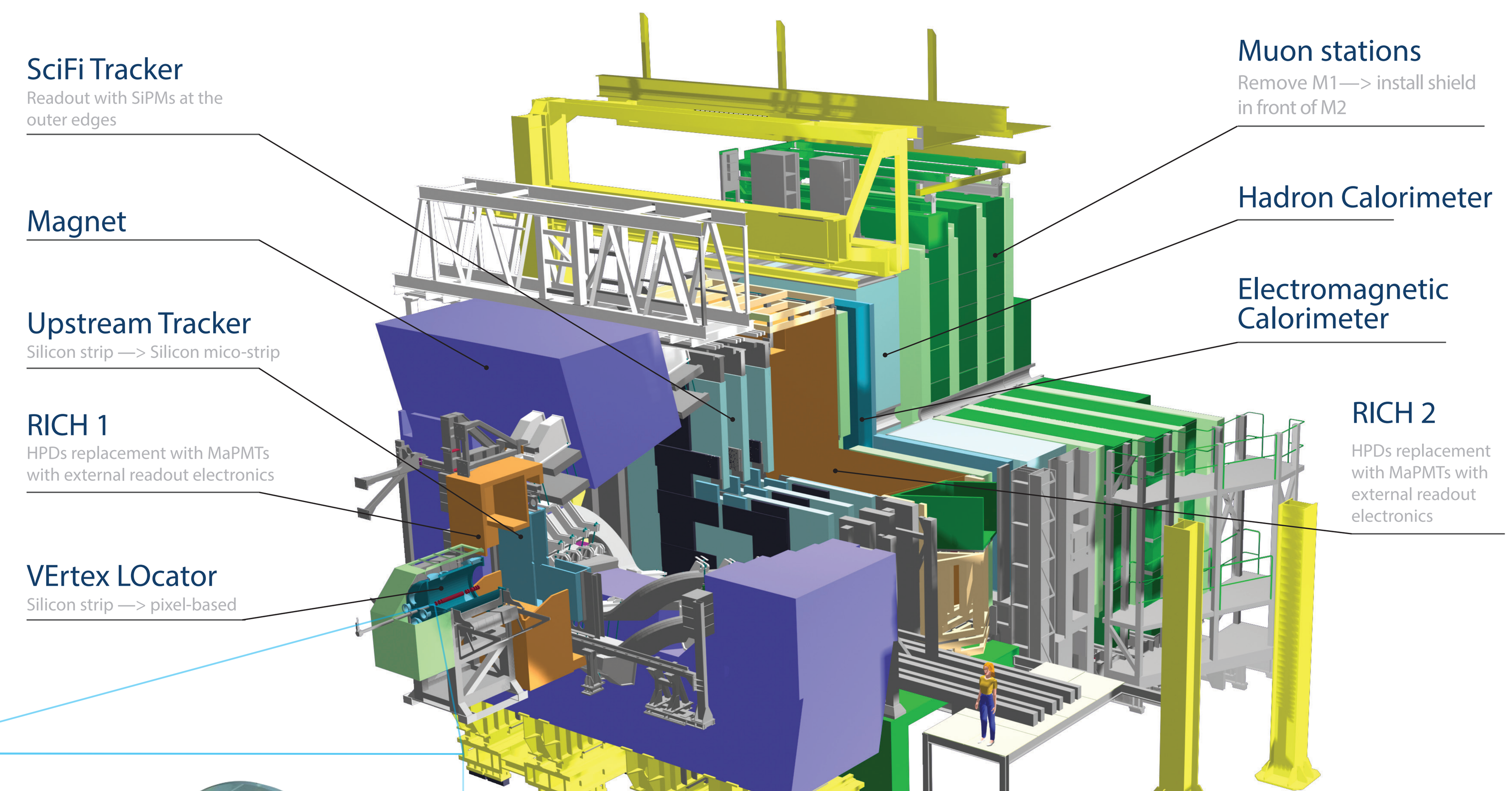
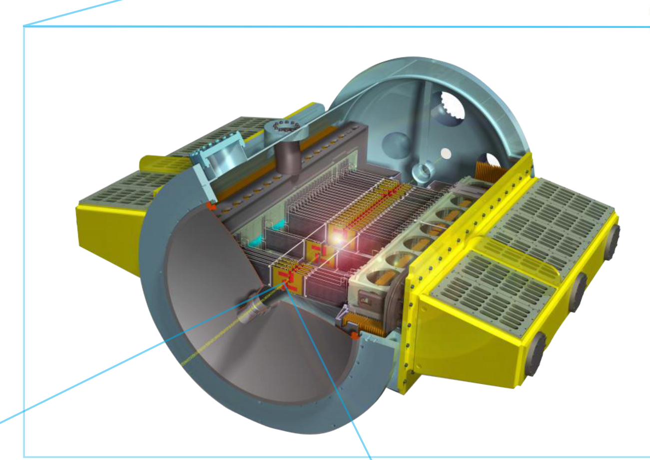
Bartłomiej Rachwał on behalf of the LHCb collaboration | 1-5 April 2019 | INFN National Laboratory of Legnaro, Italy

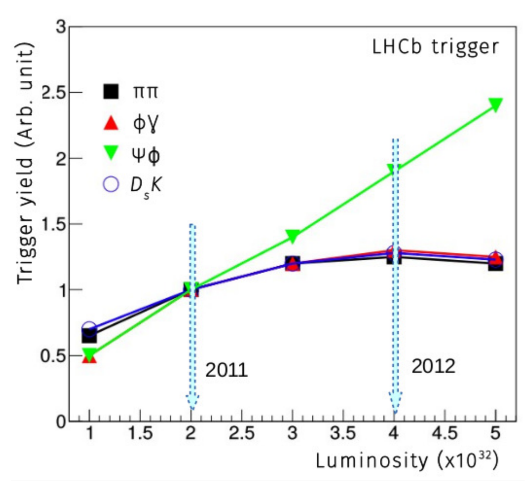
The LHCb VELO Upgrade - sensor R&D with the Timepix3 Telescope

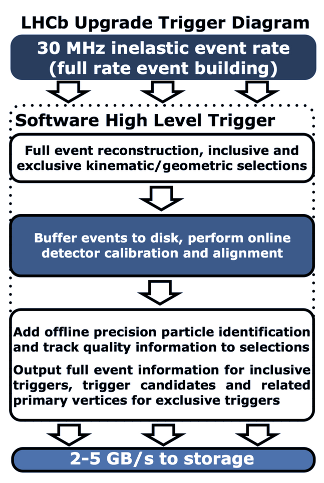
Upgraded LHCb detector





Upgrade motivation

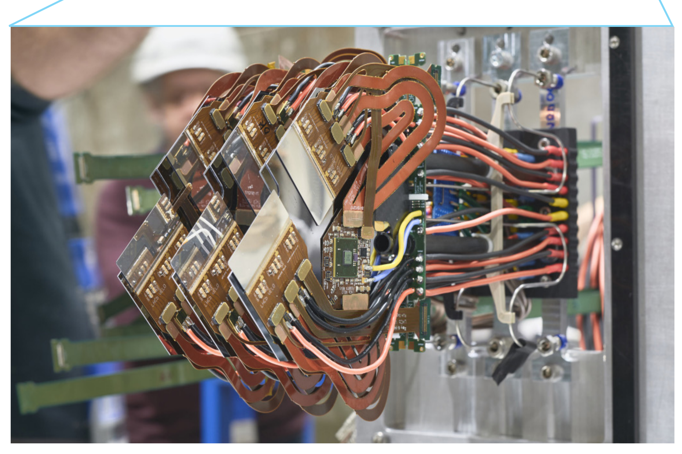




Precision of many physics measur-e-ments at LHCb will be statistically limi-ted at end of Run 2 | Boost statistic with increased L(4×10^{32} $\to 2\times10^{33}$)$cm^{-2}\,s^{-1}$ | 25 fb^{-1} expected in Run 3 | But many hadronic channels saturate due to ener-gy cuts in the trigger | Remove hardware trigger | $1MHz \to 40\ MHz$ readout rate with software trigger only | Data taking in Run 3 starting 2021 [1].

VELO functionality

- Detector surrounding the proton-proton interaction region
- Integrated in the LHC vacuum system
- Halves retractable during the beam injection and setting
- Excellent hit and geometry impact parameter resolution

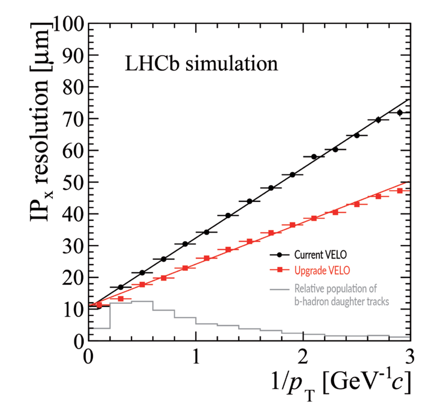


VeloPix: the pixel ASIC. CERN © 2018.

To be upgraded [1]

Detector Channels	R/O Electronics	DAQ
80%	100%	100%

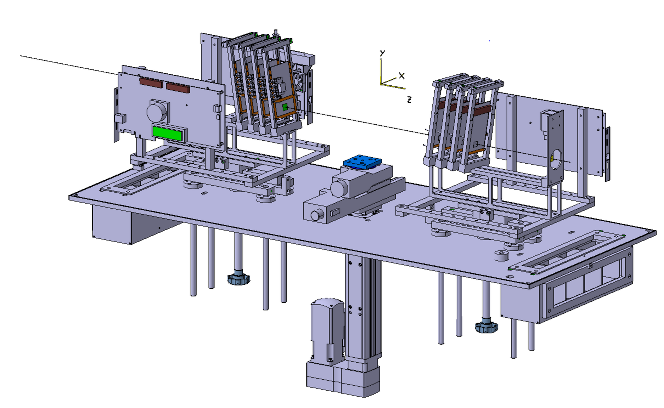
Pixel detector [2]



- Better/more robust pattern recognition and alignment performance (compared to strips)
- Improved spatial and impact parameter resolution
- Closer to beam (8.1 →5.1)mm
- Approx. 10 times more fluence than the current design ~$10^{16}\ n_{eq}/cm^2$

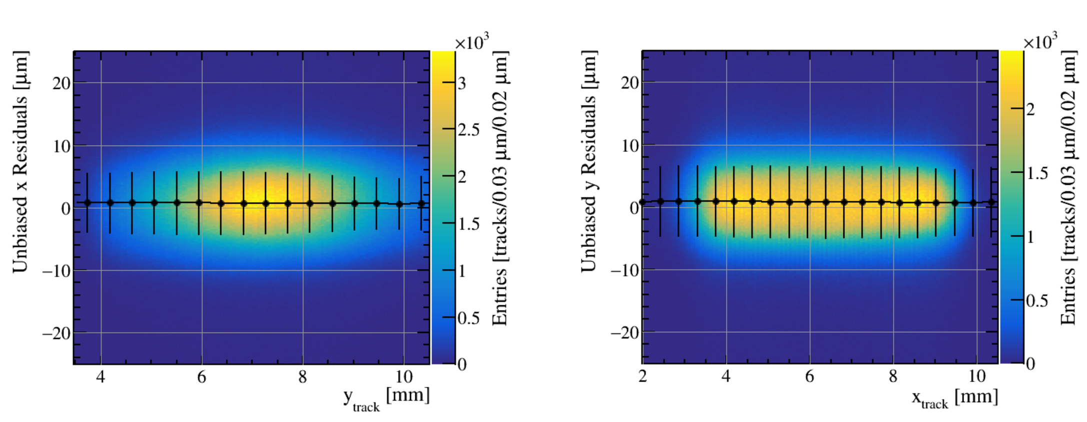
Timepix3 telescope performance

The Timepix3 telescope is a high rate, data-driven beam telescope originally built to test the prototype sensors for the LHCb VELO upgrade, but also employed by other users due to its excellent performance. It provides a fast and robust pattern recognition and track reconstruction.



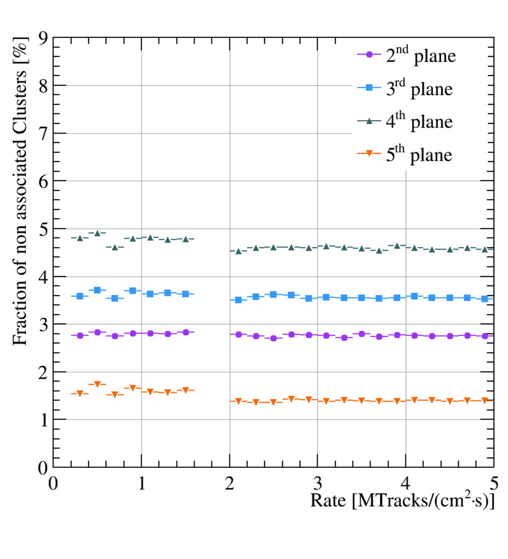
Left: Photograph of the Timepix3 telescope. CERN © 2018. Right: Mechanical design of the Timepix3 telescope, with the coordinate system displayed at the top. The telescope stations are mounted on two retractable arms around a central stage. The central stage is reserved for studies on DUTs; it provides translations in x and y as well as rotations about the y axis [4].

Spatial resolution

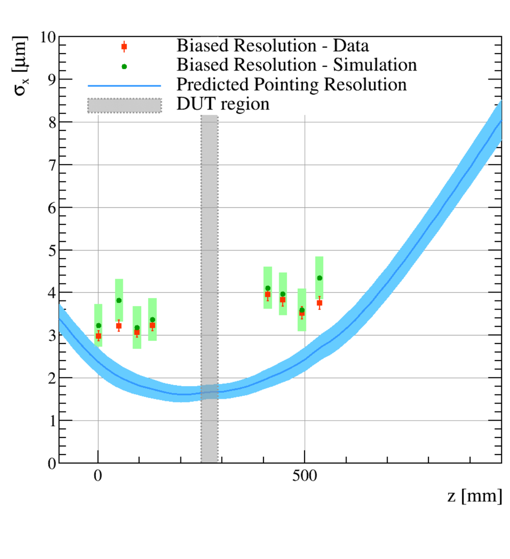


Spatial resolution
Unbiased x residuals as a function of track position in x and y direction for a telescope plane [4].
CERN © 2018.

High rate



Pointing resolution



High rate
Fraction of clusters non assiciated to tracks as a function of the particle rate for the telescope planes [4].
CERN © 2018

Pointing resolution
Predicted pointing resolution (blue band) as a function of the position along the beam axis. The pink region indicates the DUT position. The biased resolution from simulation and data are indicated by green and red markers, respectively [4].
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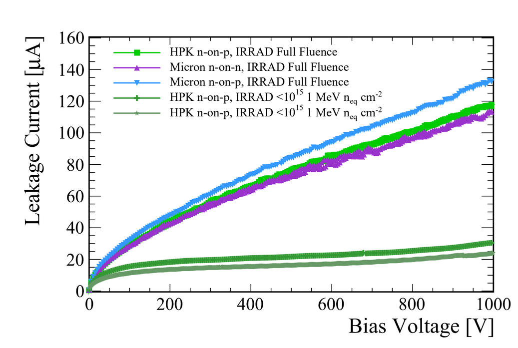
- The simultaneous ToT and ToA measurements of the Timepix3 offers a fast, simple and robust pattern recognition and track reconstruction.
- The use of a charge-weighted clustering algorithm and a track-based alignment procedure provide residuals of the order of 4 μm for each telescope plane.
- The pointing resolution at the DUT position, in the centre of the telescope, is determined to be 1.69±0.16 μm.
- A time resolution of 350 ps is achieved for reconstructed tracks traversing eight telescope planes.
- No deterioration of the telescope performance has been observed to a rate of 5 MHz/cm².

Sensor characterization

The sensors have been tested more than 30 different assemblies have been tested with beam with the aid of the Timepix3 telescope in order to assess the best candidate for the VELO upgrade. Two different manufacturers, Hamamatsu (HPK) and Micron, provided sensors of different bulk types (n-on-p and n-on-n), thickness,implant width and guard ring size. The prototypes tested can be distinguished in three families, whose characteristics are summarised in table below.

Vendor	Type	Thickness	GR size	Implant width
HPK	n-on-p	200 μm	450 μm	39,35 μm
Micron	n-on-p	200 μm	450 μm	36 μm
Micron	n-on-n	150 μm	450,250 μm	36 μm

HV tollerance



The leakage current as a function of the bias voltage for sensors irradiated at a fluence < 10^{15}1MeV n_{eq}/cm^2 at a temperature of -22°C (the two green lines that show lower leakage current) and at full fluence at the temperature of -34°C.
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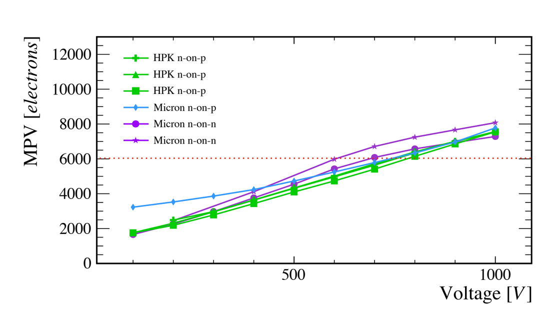
Charge collection



The Most Probable Value (MPV) of the charge distribution is shown as a function of the bias voltage for sensors uniformly neutron irradiated to full fluence at JSI.
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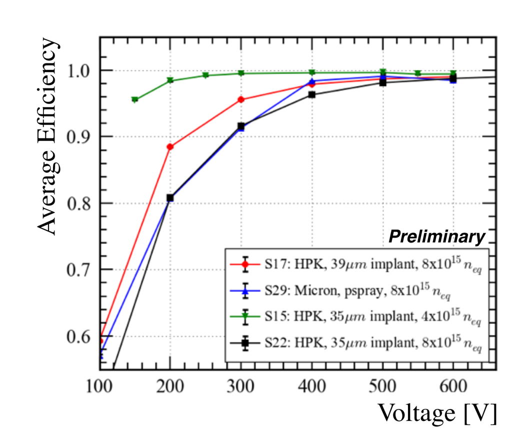
Efficiency



Average efficiency over the sensor as a function of bias voltage for sensors uniformly irradiated at JSI.
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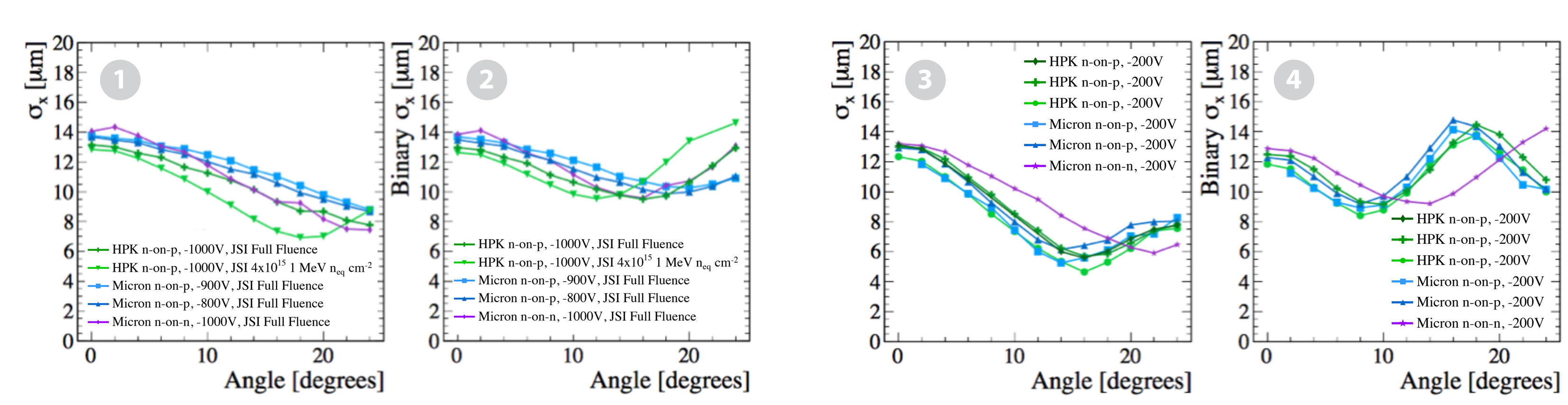
Resolution



Resolution in x direction as a function of the track angle for non irradiated sensors (1,2) and uniformly neutron irradiated sensors at JSI (3,4), in analog (1,3) readout and binary (2,4) readout mode. CERN © 2018.

References

[1] I. Bediaga et al., "Framework TDR for the LHCb Upgrade: Technical Design Report," Tech. Rep. CERN LHCC-2012-007. LHCb-TDR-12, Apr 2012. [Online]. Available: https://cds.cern.ch/record/1443882

[2] LHCb Collaboration, "LHCb VELO Upgrade Technical Design Report," Tech. Rep. CERN LHCC-2013-021. LHCB-TDR-013, Nov 2013. [Online]. Available: https://cds.cern.ch/record/1624070

[3] T. Poikela et al., "VeloPix: the pixel ASIC for the LHCb upgrade," JINST, vol. 10, no. 01, p. C01057, 2015.

[4] Kazu Akiba, et al. „LHCb VELO Timepix3 Telescope", arXiv:1902.09755 [physics.ins-det]