The Upgrade of LHCb VELO

Paweł Kopciewicz on behalf of the VELO group

15th Topical Seminar on Innovative Particle and Radiation Detectors , 14-17 October 2019
Siena, Italy

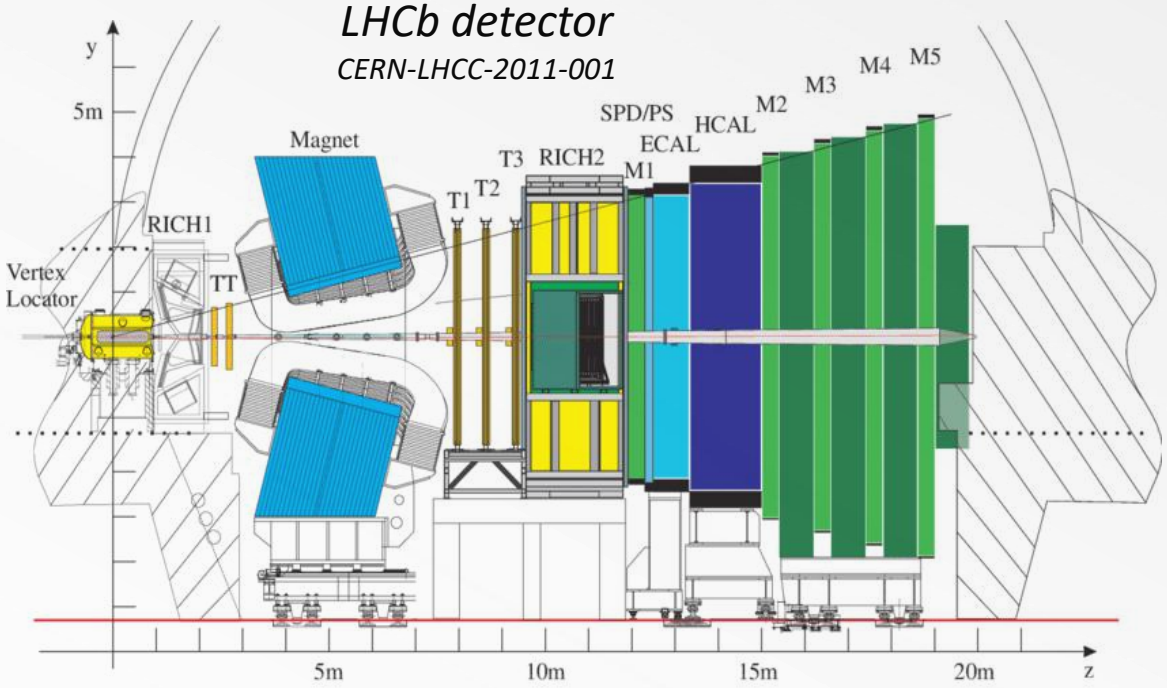
LHCb experiment

- Operating at LHC, specialized in searching for **New Physics** (Physics beyond the Standard Model)
- Forward single-arm spectrometer with a very precise tracking system CERN-LHCC-2011-001

LHCb upgrades and plans

- **Upgrade I (2019-2020)** to triggerless read-out at 40 MHz and increased instantaneous luminosity to $2\times10^{-33}cm^{-2}s^{-1}$ CERN-LHCC-2014-016
- **Upgrade II (2030)** High Luminosity HL-LHC era, increased luminosity to $1\text{-}2\times10^{-34}cm^{-2}s^{-1}$ CERN-LHCC-2017-003

LHCb detector
CERN-LHCC-2011-001

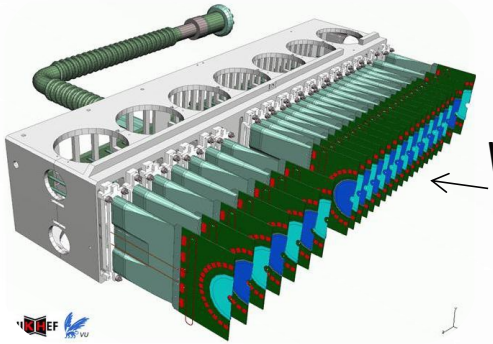


Detector VELO CERN-LHCC-2001-0011

- Vertex Locator (VELO) is a detector located closest to the beam intersection region and takes vital part in vertexing and track reconstruction

How's it been so far?

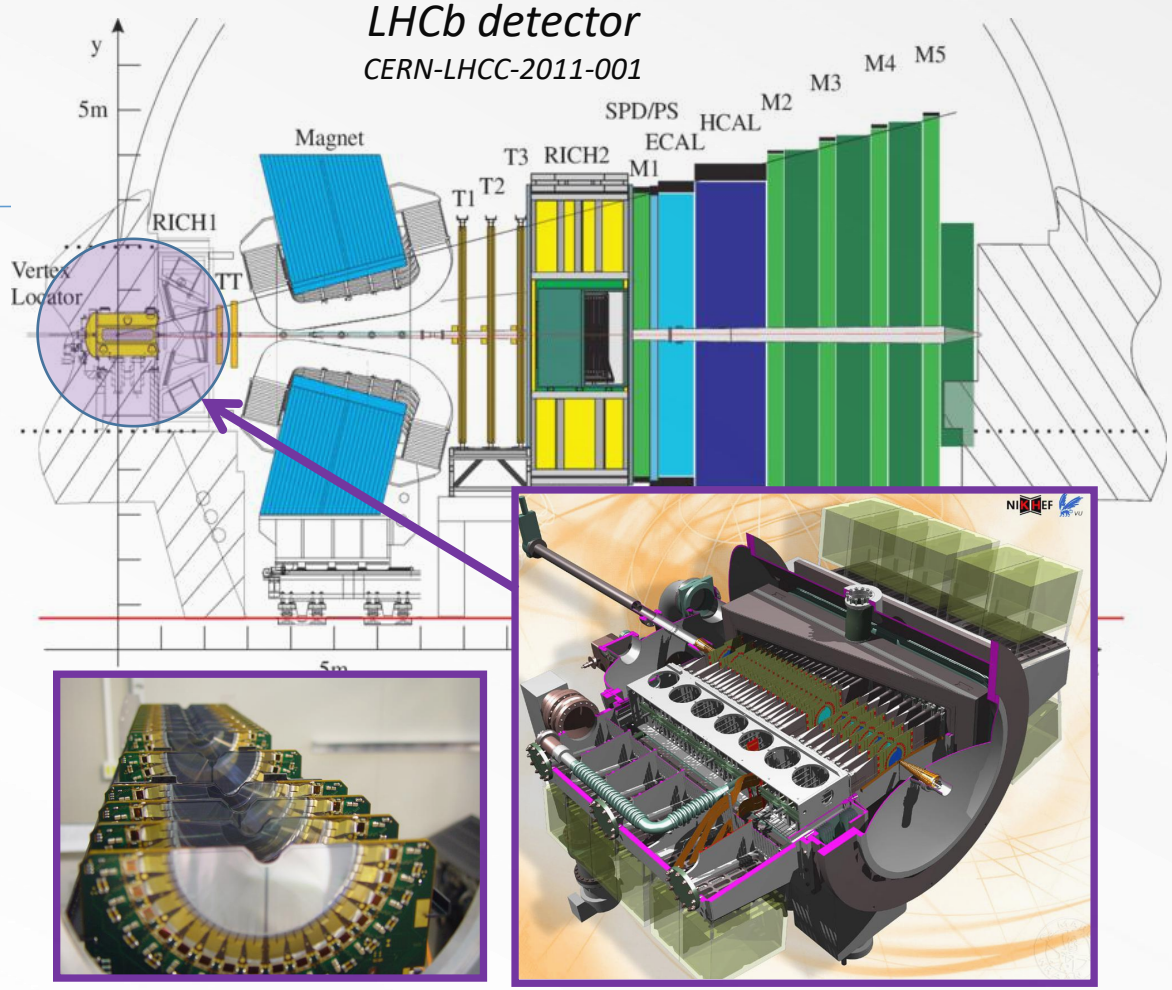
- During Run I and Run II data taking periods vertex detector with planar micro-strip sensors (until end of Run II, December 2018)



Vertex Locator's right halve

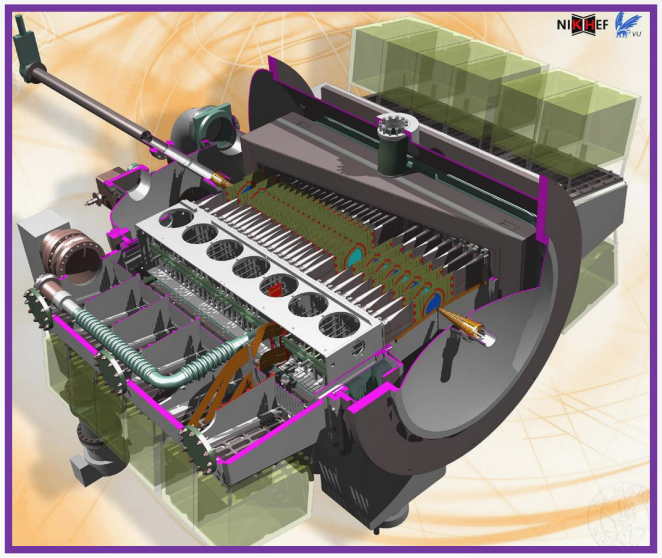
- Consistsed of **42 semi-circular modules**, each equipped with two 300 µm thick silicon strip sensors, measuring R and Φ coordinates.

LHCb detector
CERN-LHCC-2011-001

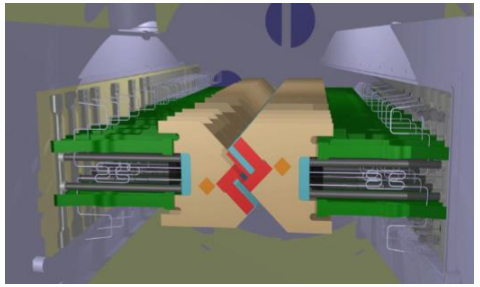


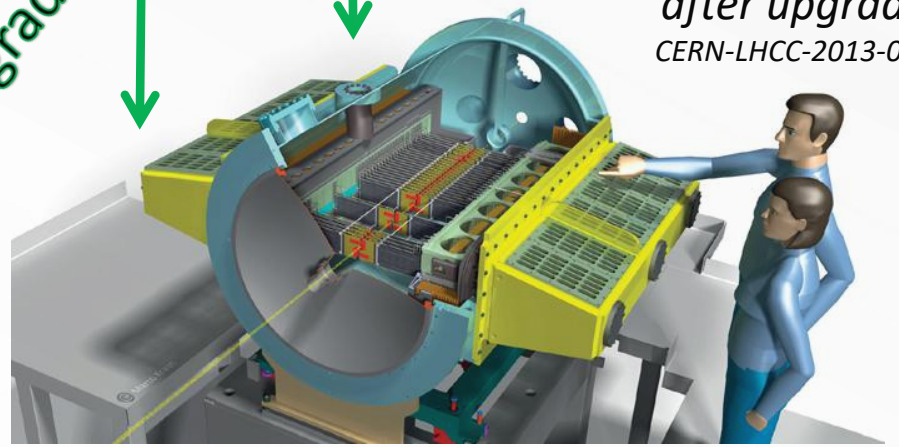
VELO Upgrade I CERN-LHCC-2014-016

- Extensive modernization of VELO is the part of the LHCb Upgrade I, adjusting it to the full 40 MHz read-out and higher luminosity
- From silicon **strip detector** to silicon **pixel detector**
  - **Improved** spatial resolution
  - Radiation tolerant up to 10^{16} n_{eq}/cm^2
  - **New front-end** electronics
  - Noise-free operation and high reduction of the fake events
  - **Faster** reconstruction algorithm
- Substantially thinner RF-foil, reduced material budget
- Efficient micro-channel cooling



Upgrade I



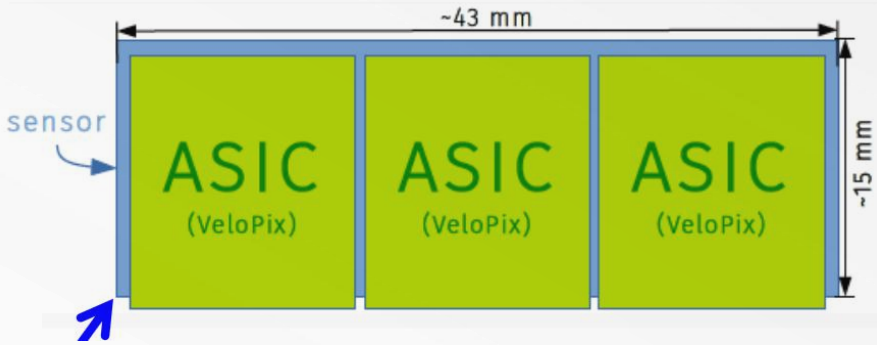


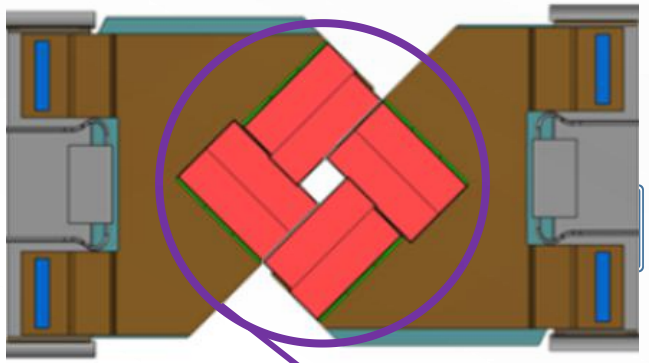
Visualisation of VELO after upgrade
CERN-LHCC-2013-021

New Sensor/ASIC

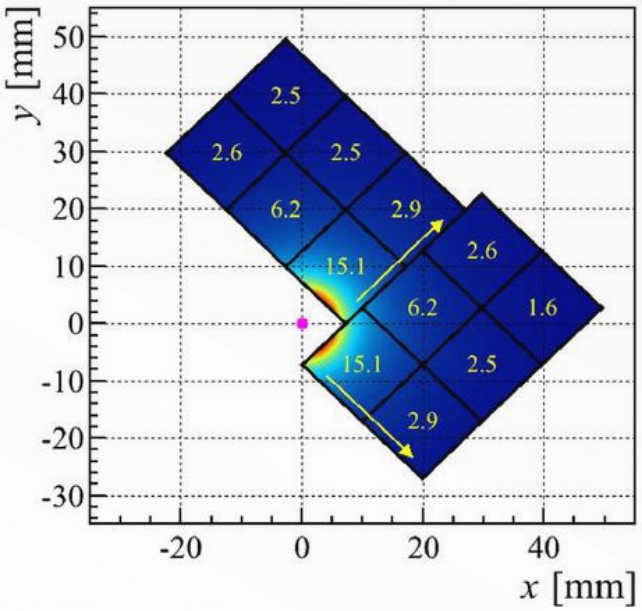
- **The Velopix** is a readout front-end chip of the new VELO detector
- Made in **pixel technology** (256x256 pixels per ASIC)
- There will be **624 ASICs** in the whole detector, which turns into over 40 millions of pixels in total
- Non-uniform particle fluence, data driven up to 15 Gbit/s wihtin the innermost region of the detector
- Pixels closer to the beam than strips in old VELO

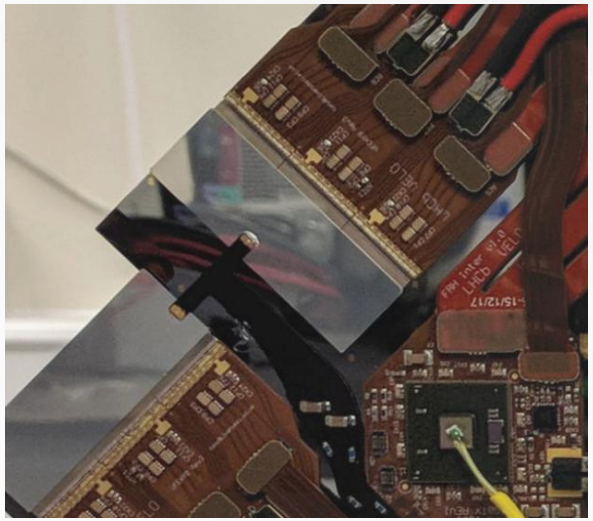
Velopix triplet





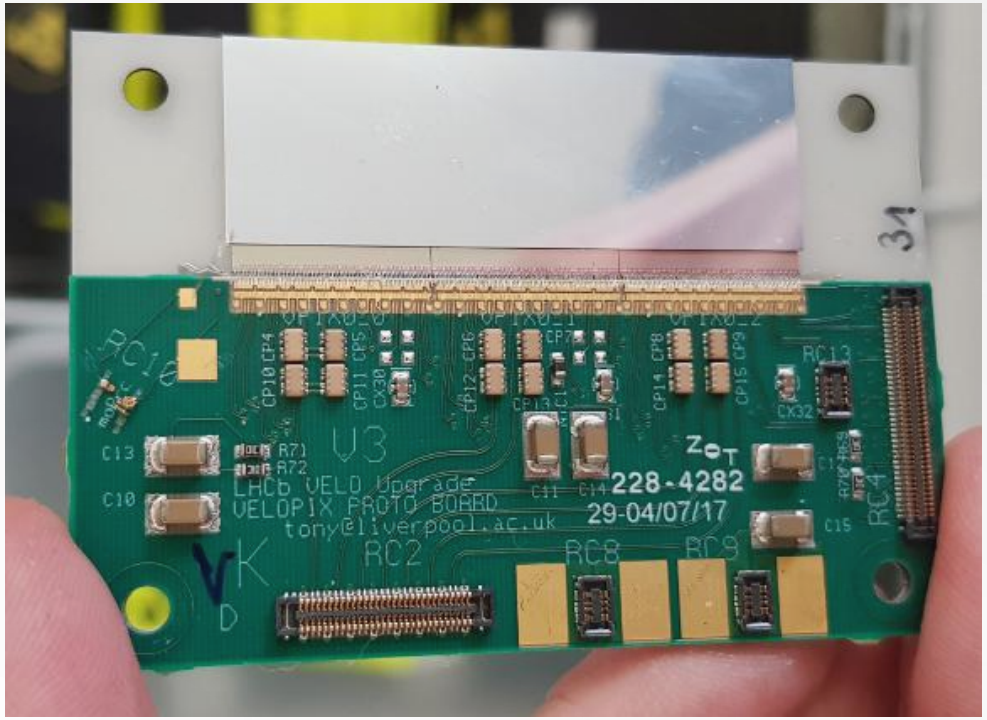
8 sensors (24 ASICs) on a single station





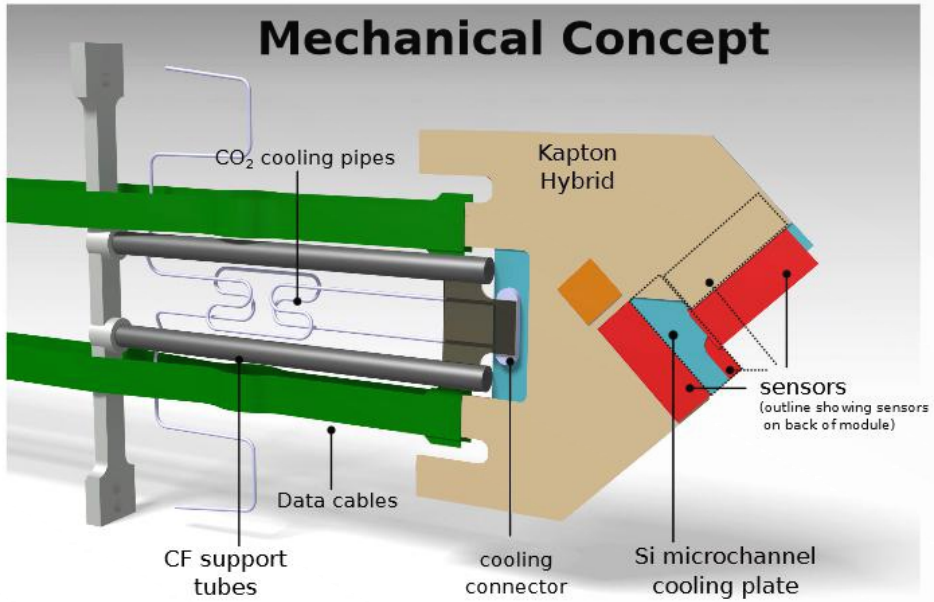
Sensor/ASIC specification

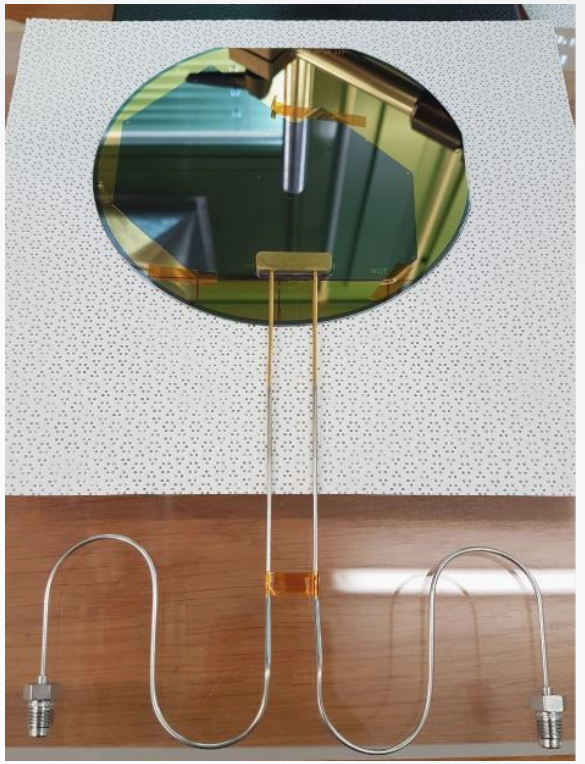
- Silicon **pixels 55 µm x 55 µm**, grouped in logical structures called superpixels (2x4 pixels)
- ASIC based on Timepix3 (Medipix) chip
- **TSMC 130 nm CMOS** technology
- Bump-bonded 3 Velopix ASICs to a single sensor
- **Triggerless binary readout (40 MHz)**, timing resolution 25 ns
- Radiation hardness of **400 Mrad**
- Maximal data rate of 20.48 Gb/s



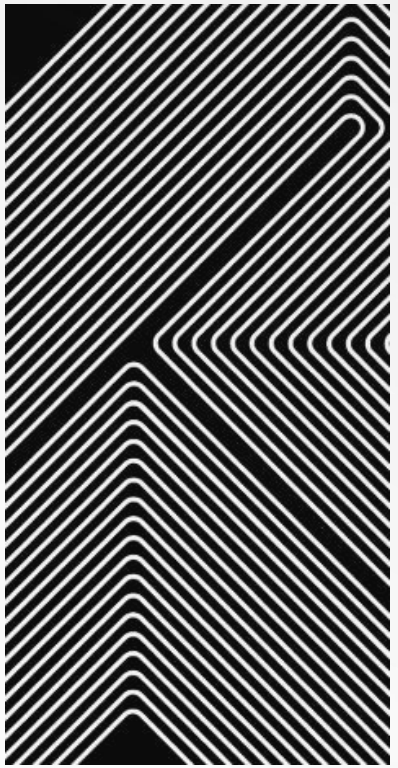
Cooling

- Primary source of heat are Velopix chips
- Sensors must be kept at **-25°C during operation** in order to minimise the thermal runaway likelihood and limit the radiation damage impact on sensor's performance
- **Two-phase CO_2** cooling in **micro-channel subtrates** (subtrates 500 µm thick, with 120x200 µm micro-channels)



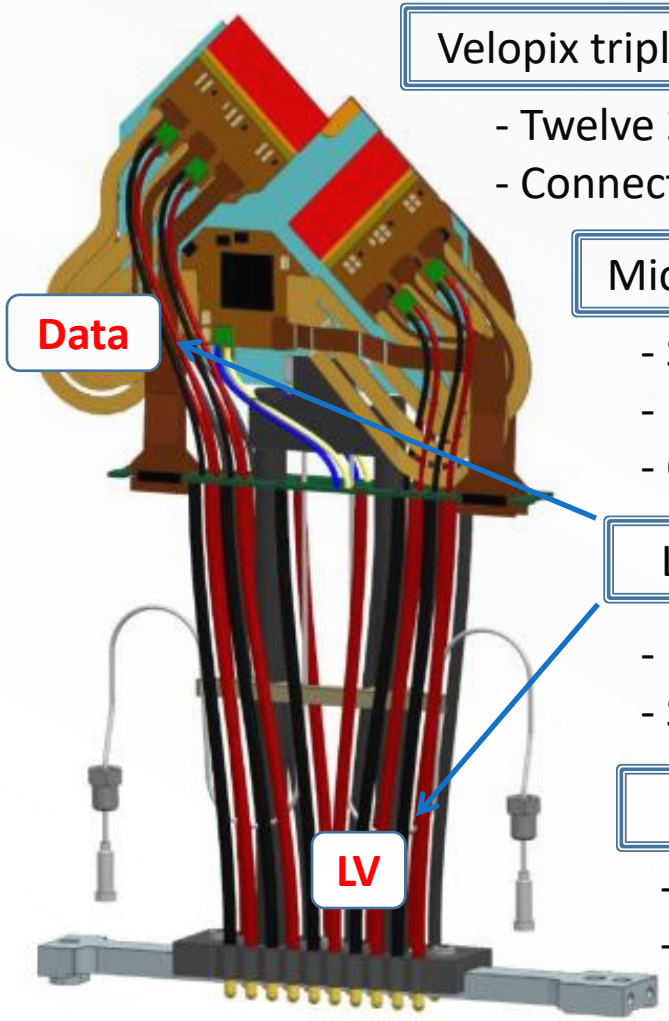


Soldered panel, cooling pipes are connected to micro-channel subtrate



Micro-channels in magnification

Modules summary



Velopix triplets

- Twelve 256x256 ASICs on the module
- Connected with the GBTx board

Micro-channel panel

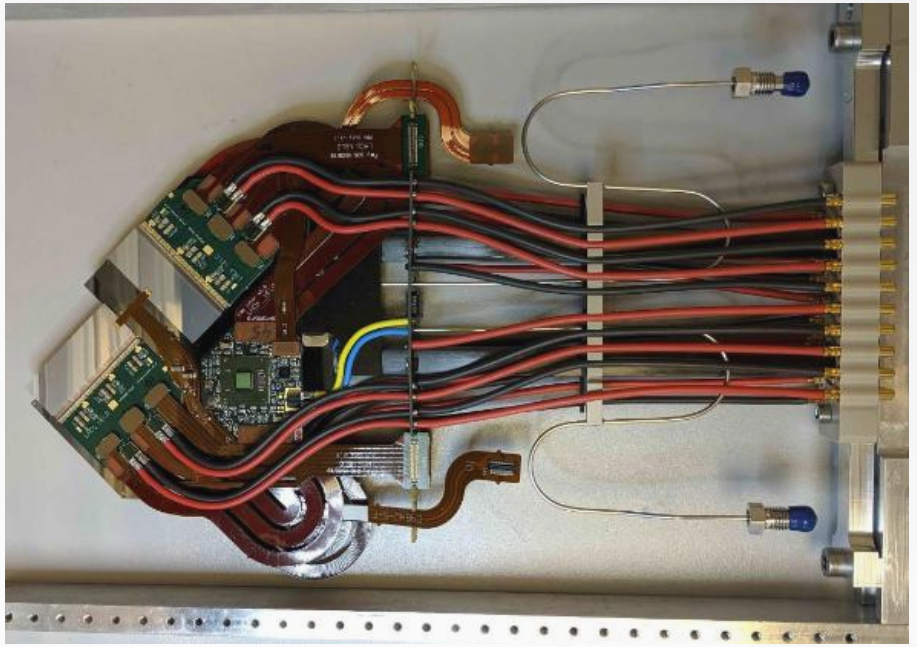
- Subtrate platform
- 19 micro-channels
- Connected with cooling pipes

LV and data cables

- Power supply
- Sensor read-out

Cooling

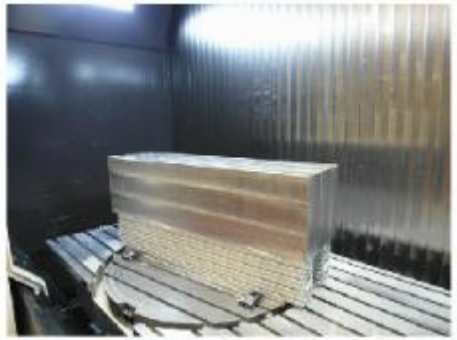
- Two-phase CO_2
- Using micro-channels

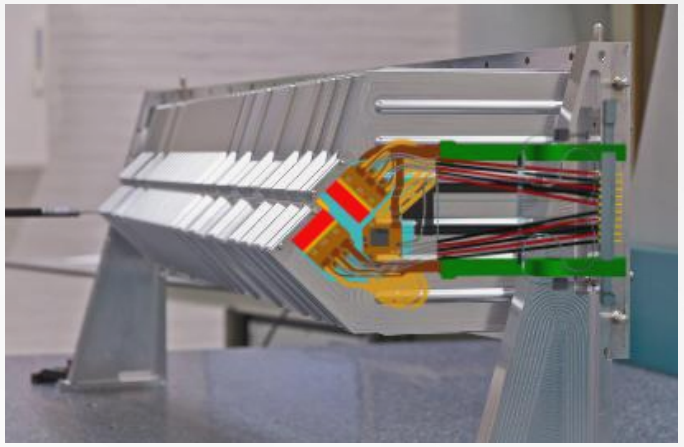


Constructed module with ASICs, LV cables, subtrate panel and cooling pipes

RF foil

- Separating primary (LHC beam) and secondary vacuum (VELO sensors)
- Foil as thin as possible (500 µm at planning, 150 µm eventually)
- Milled from solid aluminium blocks (whole process took around of 6 months):



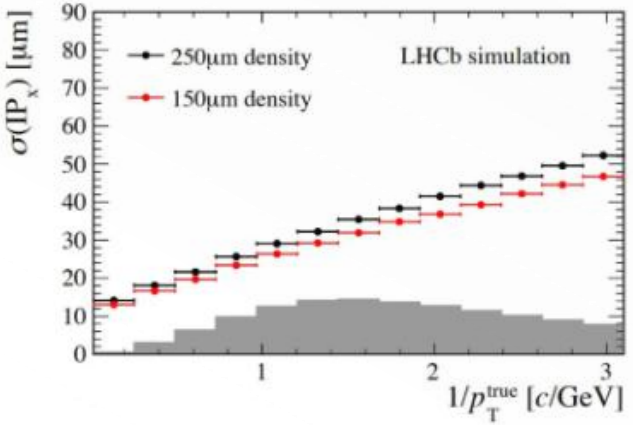


- RF foil has several other properties, such as dealing with beam wakefields or guiding the beam currents

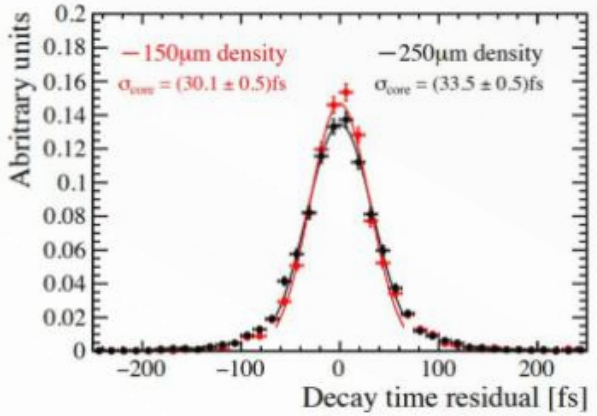
A frame from a youtube video movie:
https://www.youtube.com/watch?v=EqG5J7rro6s

Etching the RF foil

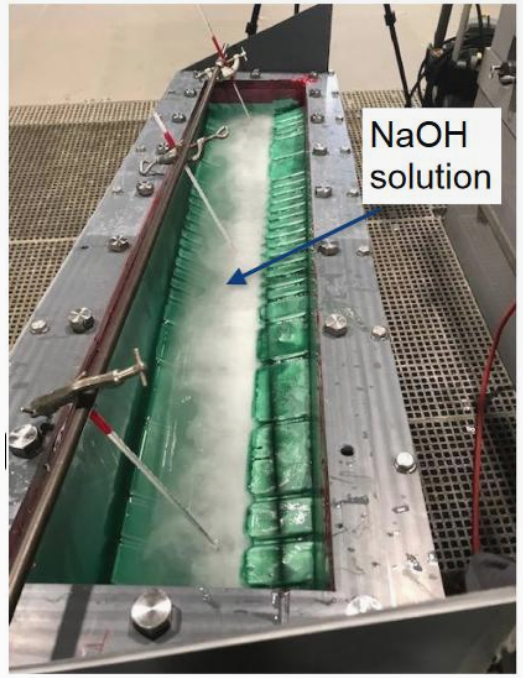
- **Thickness decrease to 150µm** is going to be achieved using etching process
- Whole procedure is complex and is done step-by-step
- **Removing 40% of the foil** (from 250µm to 150µm) should benefit physics performance, among others estimated **10% better decay time** resolution!



Impact parameter: ~ 10%



Decay time resolution: ~ 10%

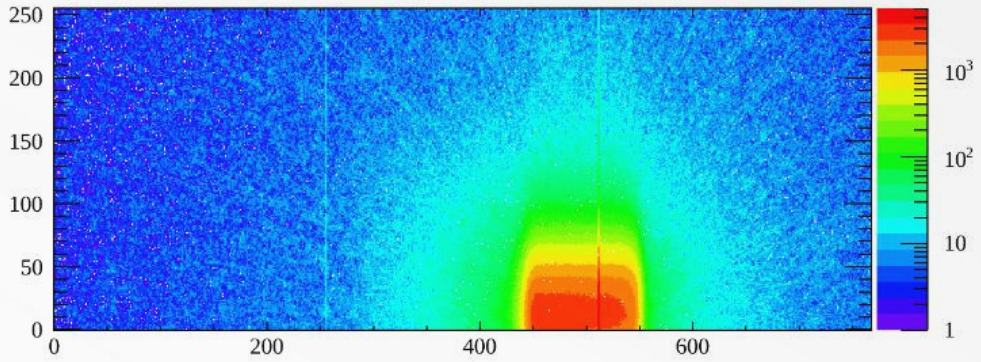


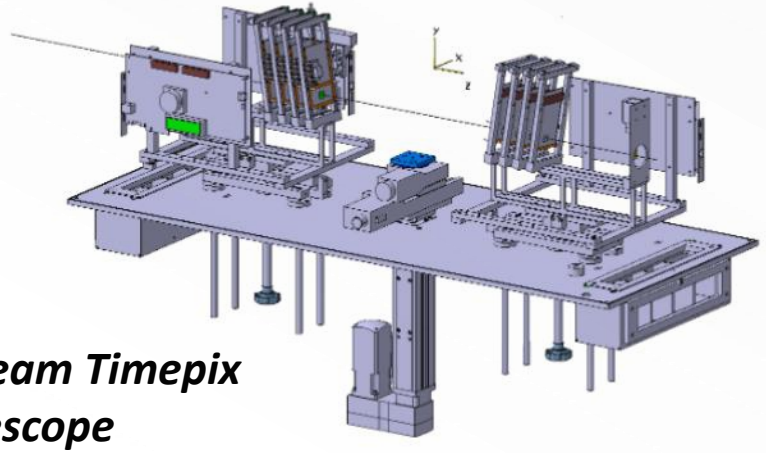
Etching the foil (green color comes from the paint)

Sensor testing at SPS testbeam

- Velopix has been widely tested under lab conditions and at the **testbeam** (SPS)
- Steering and calibration tool written in **WinCC OA** (Siemens Open Architecture)
- It includes **spatial resolution tests** at different angles, Time over Threshold (ToT) studies and a bunch of other things related to sensor's performance.

Timepix triplet at the testbeam

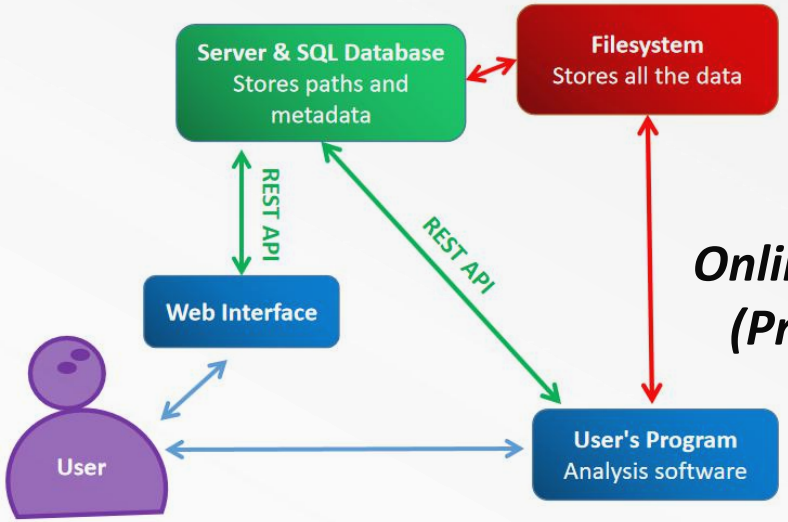




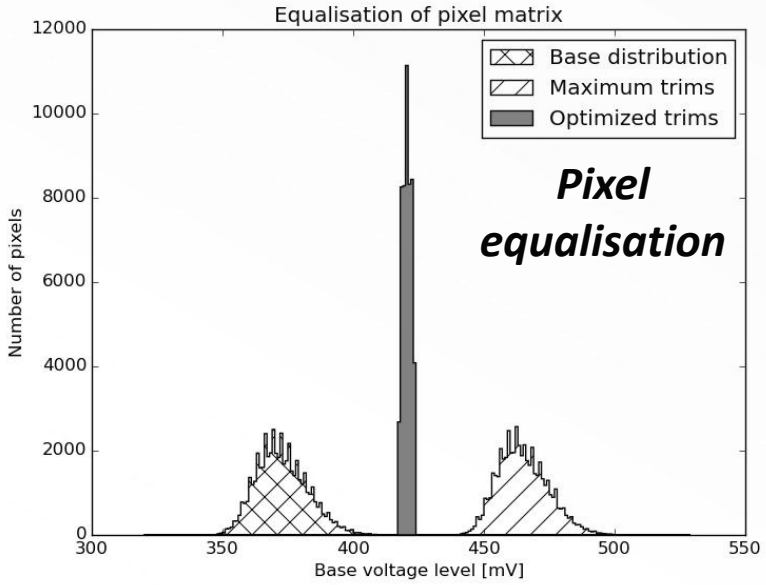
SPS Testbeam Timepix telescope

Sensor calibration & online monitoring

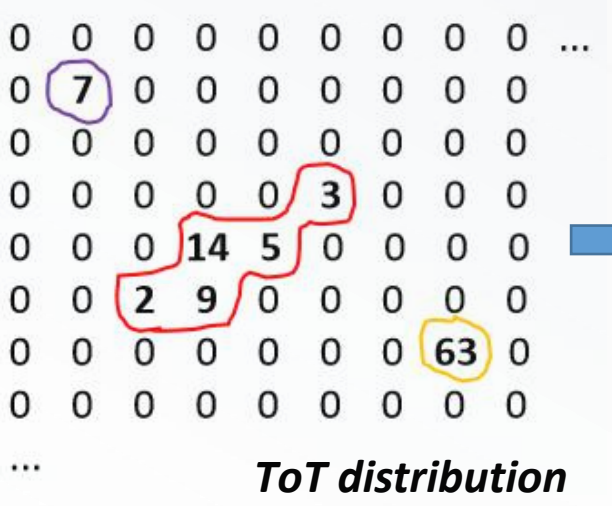
- More emphasis on **sensor calibration and monitoring**
- As at the testbeam, calibration tool written in **WinCC OA** (Siemens Open Architecture)
- **Monitoring tool** will be implemented in Python 3.4 under the name **Vetra++**



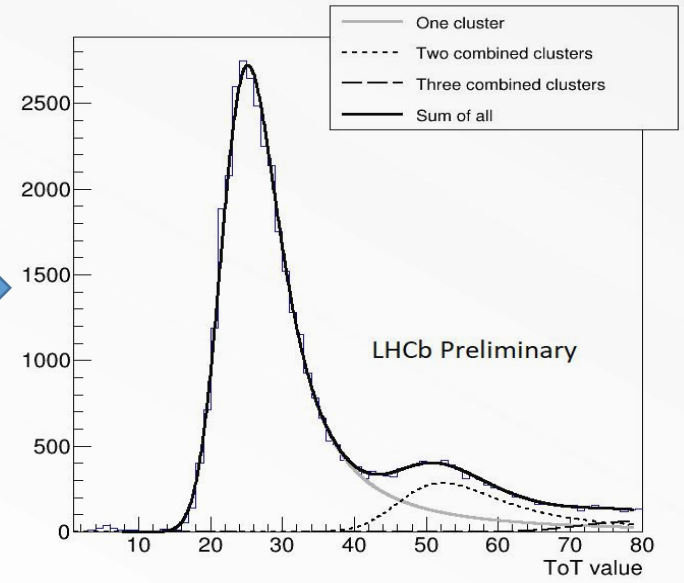
Online database (Preliminary)



Pixel equalisation

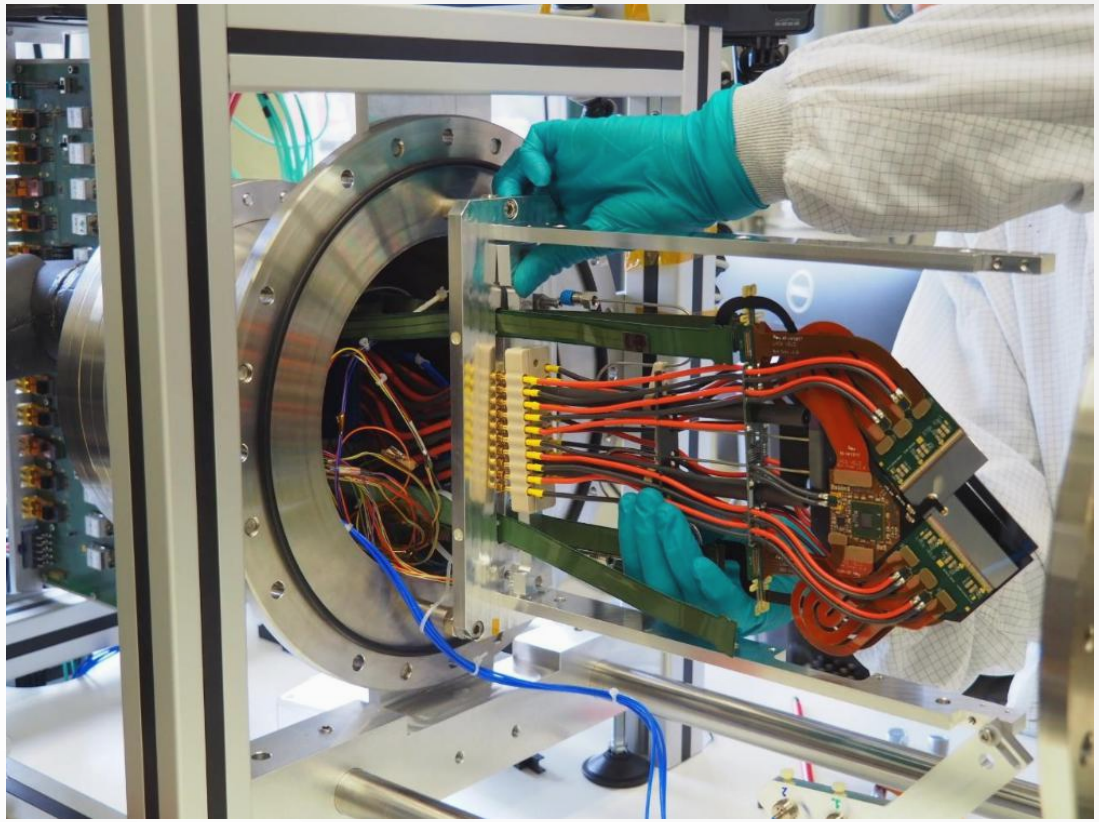


ToT distribution



Status summary

- **Module production** in progress
  - 120% of needed modules in April 2020
- **Cooling** in advanced stage of production
  - More than 17 soldered panels for now, production approximately 4-5 per week)
- **Foil** production almost complete (shipping)
- **Software**
  - **Calibration** working in WinCC, though it needs some improvements
  - **Monitoring and online database**; ongoing work, need to define the final data protocols and decoders



Status summary

- **Module production** in progress
  - 120% of needed modules in April 2020
- **Cooling** in advanced stage of production
  - More than 17 soldered panels for now, production at approximately 4-5 per week)
- **Foil** production almost complete (shipping)
- **Software**
  - Alignment working algorithm out, though it needs some improvements
  - **Monitoring and online database**; ongoing work, need to define the final data protocols and decoders

This is not over yet - look at my poster about LHCb VELO Upgrade II