The Upgrade of LHCb VELO

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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 $2 \times 10^{33} \text{cm}^{-2} \text{s}^{-1}$ [CERN-LHCC-2014-016]
- **Upgrade II (2030)** High Luminosity HL-LHC era, increased luminosity to $1-2 \times 10^{34} \text{cm}^{-2} \text{s}^{-1}$ [CERN-LHCC-2017-003]
Detector VELO

- 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).

- Consistsed of **42 semi-circular modules**, each equipped with two 300 μm thick silicon strip sensors, measuring R and Φ coordinates.
Extensive modernization of VELO is the part of the LHCb Upgrade I, adjusting it to the full 40 MHz readout 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

**Visualisation of VELO after upgrade**
CERN-LHCC-2013-021
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 within the innermost region of the detector

Pixels closer to the beam than strips in old VELO

8 sensors (24 ASICs) on a single station

Velopix triplet

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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 \(-25^\circ C\) 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 substrates (substrates 500 μm thick, with 120x200 μm micro-channels)
Modules summary

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

- Velopix triplets
- Micro-channel panel
- LV and data cables
- Cooling
  - Two-phase CO₂
  - Using micro-channels

- Substrate platform
- 19 micro-channels
- Connected with cooling pipes
- Power supply
- Sensor read-out
- LV cables, substrate 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 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**!
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
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)
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
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This is not over yet - look at my poster about LHCb VELO Upgrade II