INSTITUTO GALEGO DE FÍSICA DE ALTAS ENERXÍAS IGFAE

LHCb

LHCb-VELO Upgrade II and LumiTracker – mechanics, cooling and electronics

Bhagyashree Pagare

On behalf of the LHCb collaboration,
IGFAE, University of Santiago de Compostela, Spain

TIPP 2.2.2026, Mumbai, India

ये है Bombay मेरी जाँ

**Most of the slides are inspired from VELO U2 workshop 2025, Santiago de Compostela*

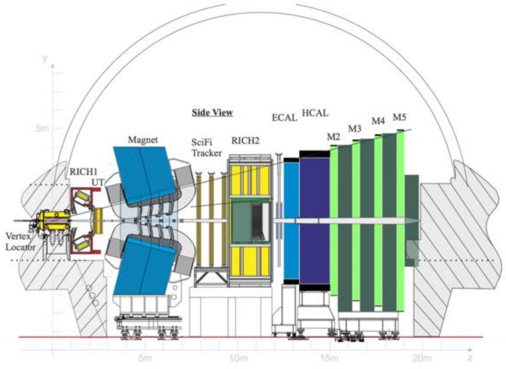
USC Universidade de Santiago de Compostela · Ministerio de Ciencia, Innovación y Universidades · Agencia Estatal de Investigación · Excelencia María de Maeztu 2024-2030 · Xunta de Galicia · Rede CIGUS Centros de investigación do Sistema Universitario de Galicia · Cofinanciado por la Unión Europea · Fondos Europeos

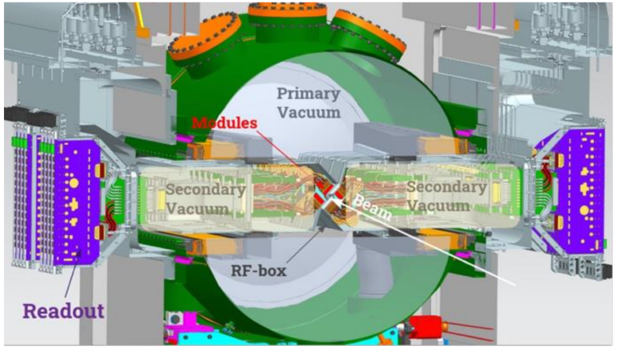
What is VELO – why so special ???

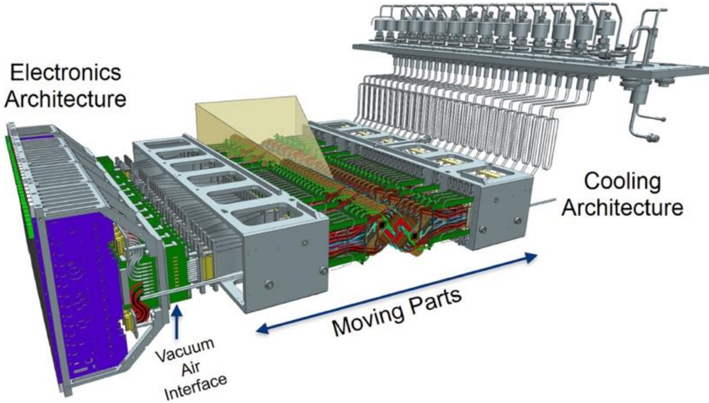
Welcome Drink

- Vertex detector close to the interaction point.
- Provides precise measurements of track positions close to the interaction point.
- 2 halves A and C side. Requires to be retracted during LHC injection.
- Operating in UHV environment. Considering LHC primary vacuum. Separated with RF foil.
- High and non-uniform radiation.

https://iopscience.iop.org/article/10.1088/1748-0221/19/05/P05065

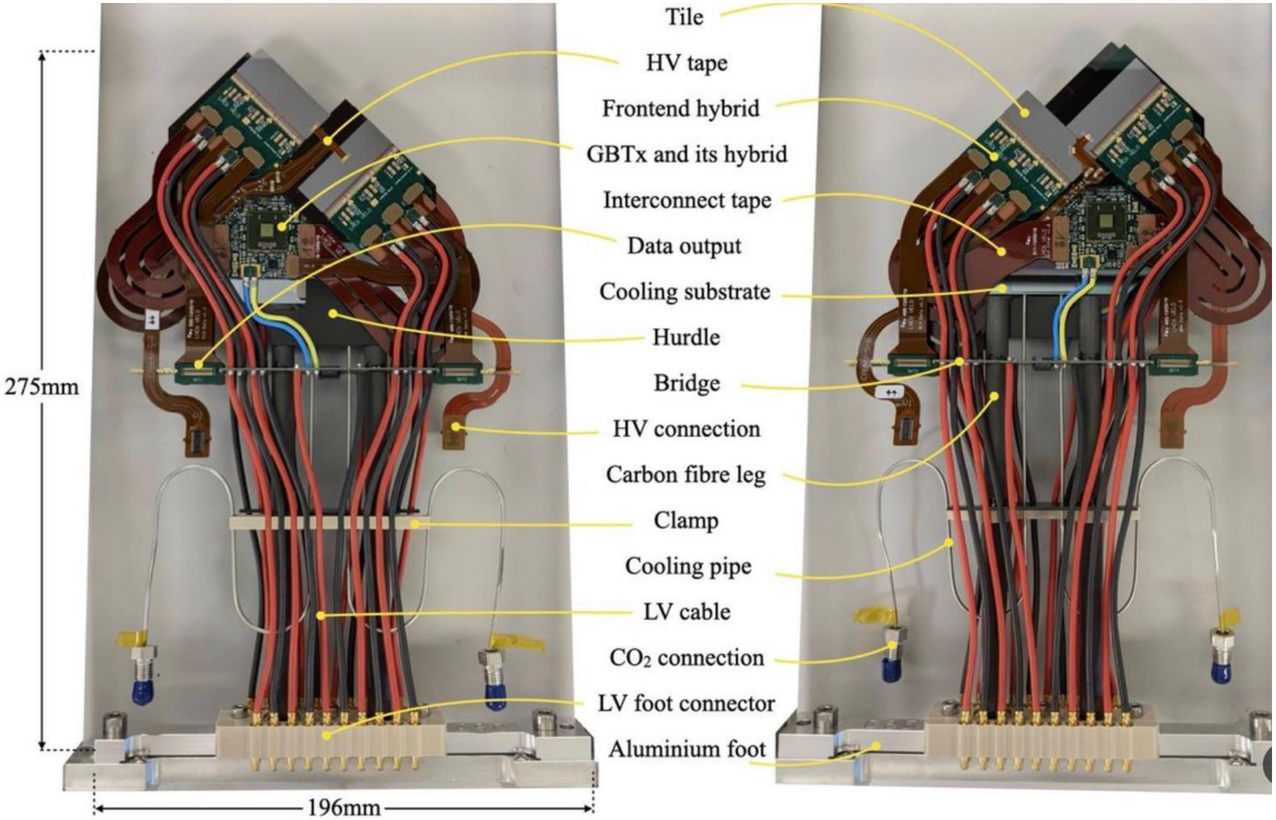






Module design

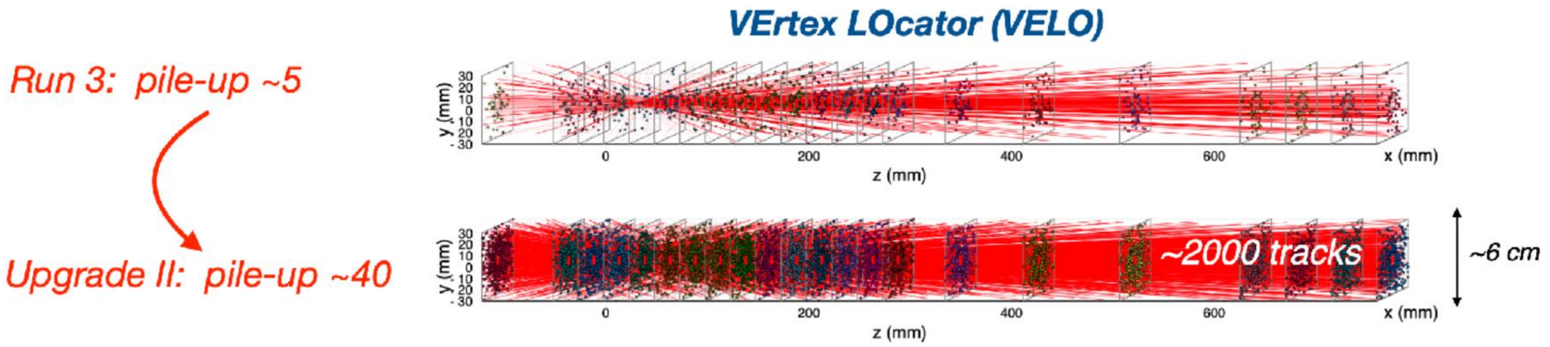
[2024 JINST 19 P06023]



Evolution of the detectors because....

arXiv:2208.05403

- U2 target is to cope with the high mu, while keeping/improving the U1 performances.
- Timing is required to reconstruct the events, but spatial resolution is what we do physics with.
- Sensors and readout ASICs must be redesigned and more tightly synchronized.
- Electronics need to handle enormous data rates (tens of Tb/s).
- This affects mechanical layouts, cooling, power distribution, and data transmission, all of which interact with the physical design of the VELO and its support structures.



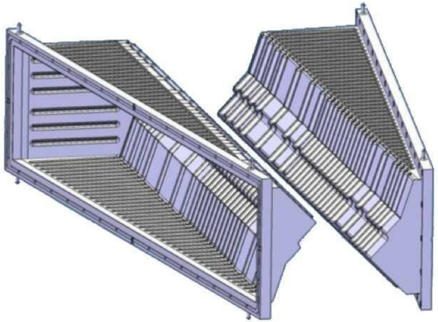
Main course 1 - Mechanics

Low Material RF shield + Vacuum

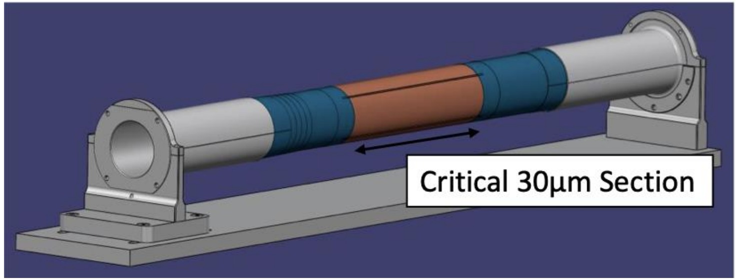
- Moving from VELO UI corrugated design towards cylindrical RF shield :
  - Low material better performance
  - Mechanical challenge, less rigid
  - Composite design in development with ultra-low material critical section or hybrid corrugated design
- Major challenge from maintaining secondary VELO vacuum
  - Thinner material increases risk
  - Alternatively, opt for mixed-vacuum, carbon fibre mesh can meet RF requirements
  - But all components must be vacuum safe .

VELO U2 workshop 2026

U1

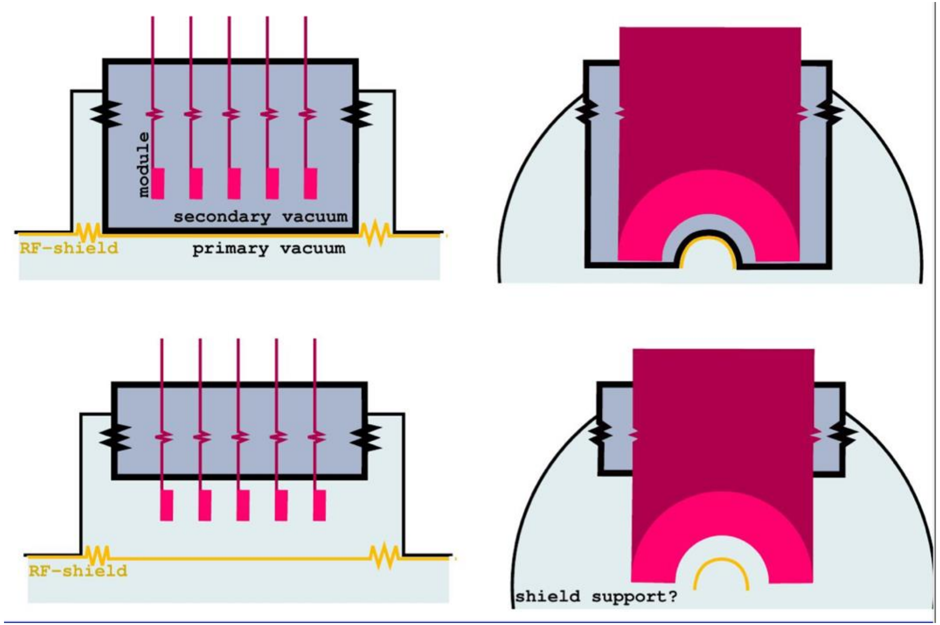


U2



The RF shield

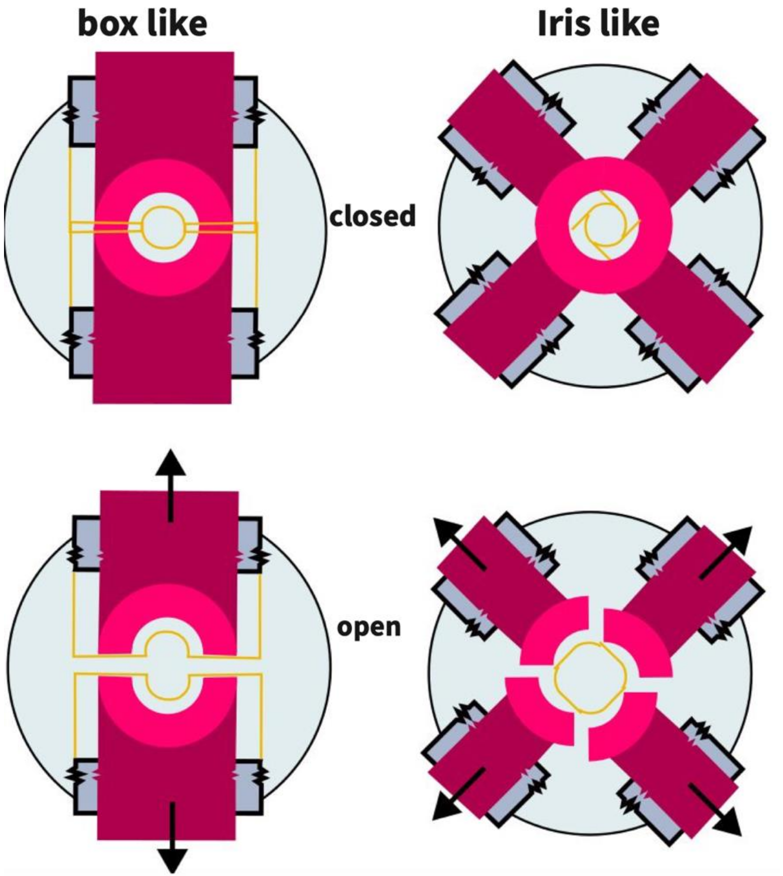
- Combined RF-shield and Vacuum barrier adds to the mechanical constraints
  - Requires to hold balancing (+/- 10mbar)
  - Lifting this requirement means the sensors live in vacuum => primary/secondary vacuum barrier in the module
  - Maximise track precision and reduce material budget due to RF foil interaction.



VELO U2 workshop 2026

RF shield

- Box like :
  - 2 flanges
  - More material in the wings
  - Current corrugated foil but with different materials
- Iris like
  - >= 4 flanges
  - Less material overall(?)
  - Likely lower impedance when open
  - Curving foil with support
  - Needs module to be inside.
- Performance to be checked in simulation using radiation length



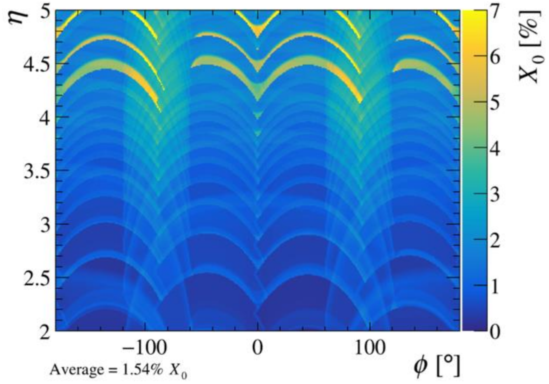
Scans of radiation lengths

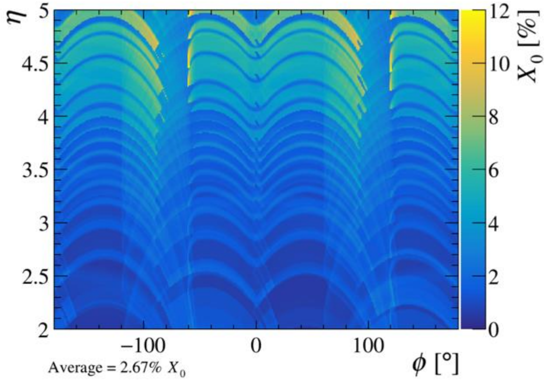
Before 1st hit

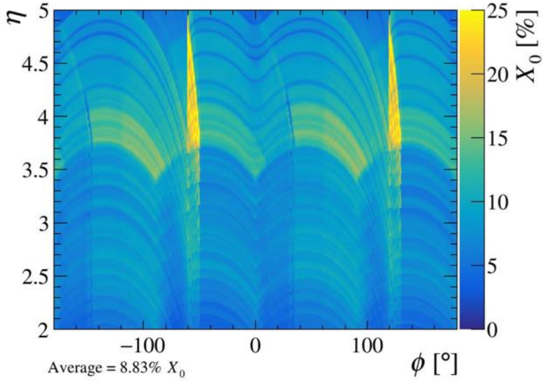
Before 2nd hit

Before last hit

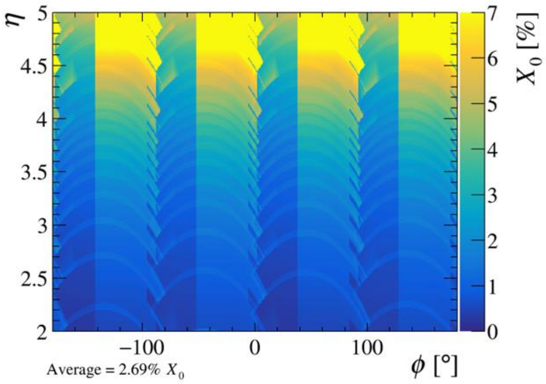
Box

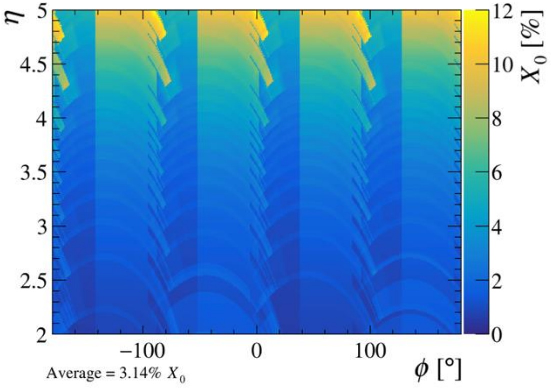


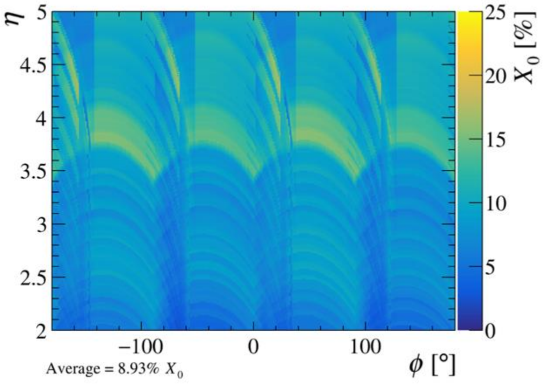




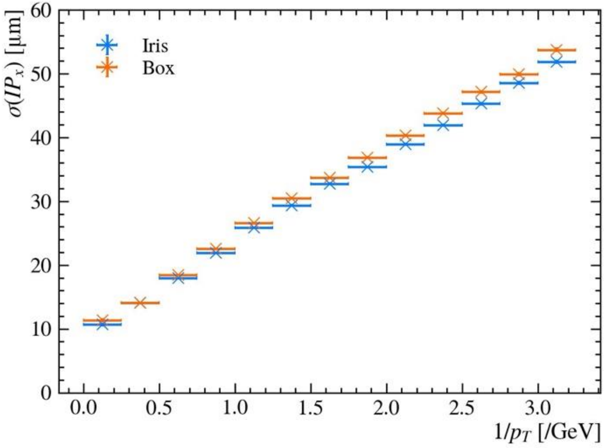
Iris



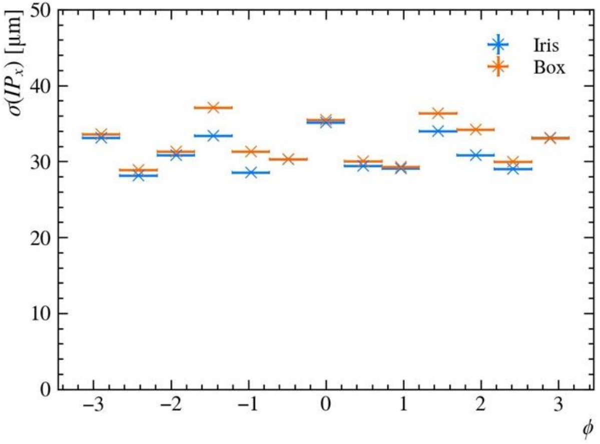


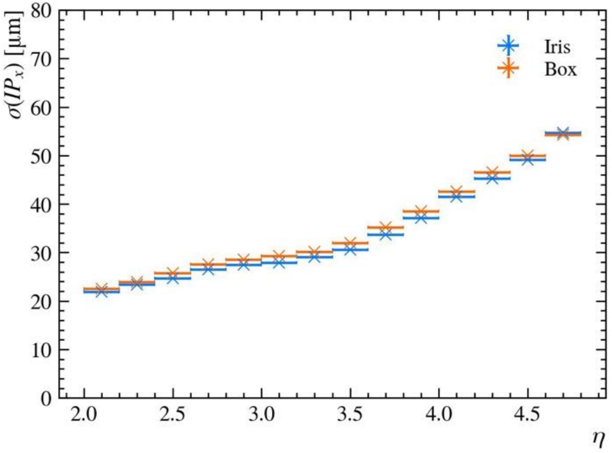


Performance



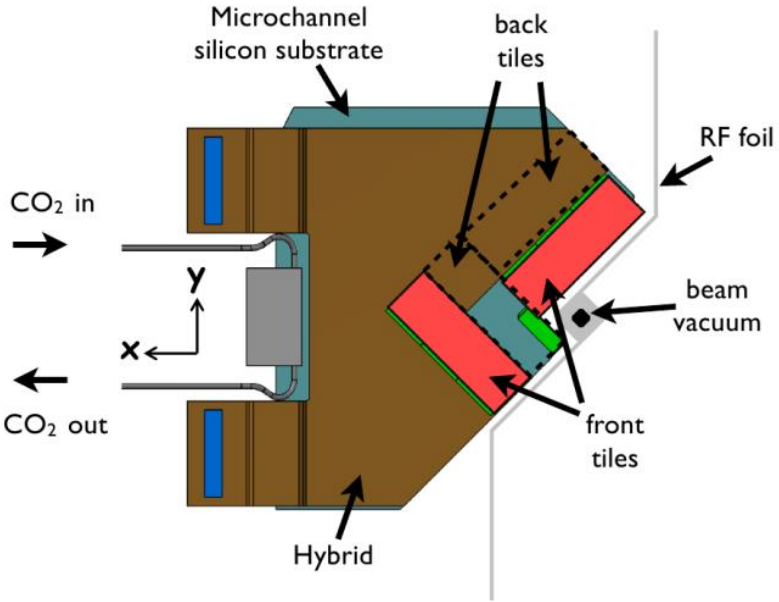
Some preliminary studies





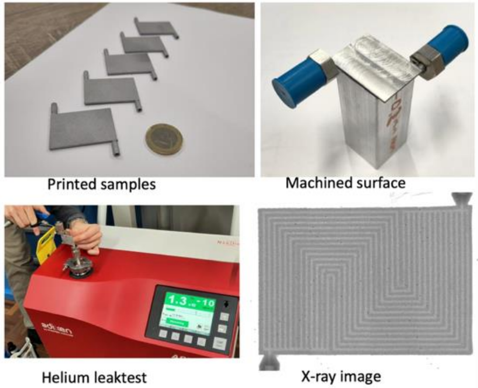
Main course 2 – Cooling and Sensors

The LHCb VELO upgrade



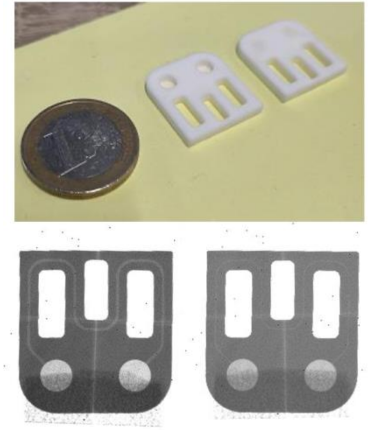
Possible cooling options

- 3D printed Aluminium : AlSi10Mg
  - High radiation length, high thermal conductivity, high CTE
  - Si 0.5% X0 equivalent thickness : tAL = 0.47mm
  - Size: 40mm x 27mm x 1.5mm
  - 11 parallel channels size 0.8 x 0.5mm
  - Wall thickness: 0.5mm
  - Less production time and cheap cost for 3D printing



VELO U2 workshop 2026

- 3D printed Ceramics
  - High radiation length, high thermal conductivity, CTE close to silicon
  - Si 0.5% X0 equivalent thickness: tAlN = 0.45 mm, tAl2O3 = 0.37 mm
  - Outer dimensions: 20mm x 20mm x 2.5mm

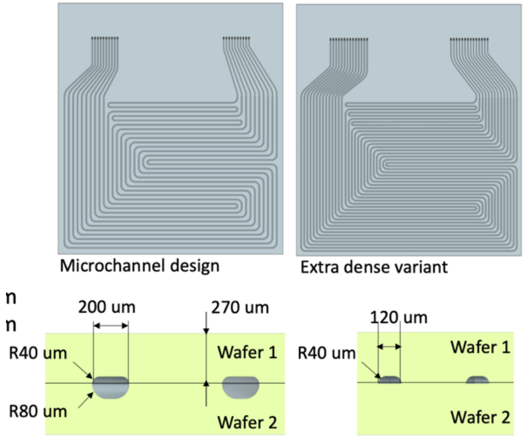


X-ray: □0,37 mm channels

X-ray: □0,2 mm channels

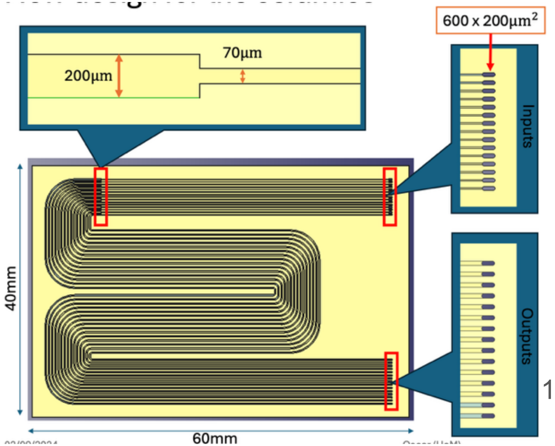
Possible cooling options

- Borosilicate glass
  - High radiation length, low thermal conductivity, low CTE
  - Microchannel design
    - 10 x Channels: 200um x 120um
    - Pitch: 1000um
    - Restriction: 120um x 40um
  - Variant – Extra dense
    - 14 Channel: 200um x 120um
    - Pitch: 700um



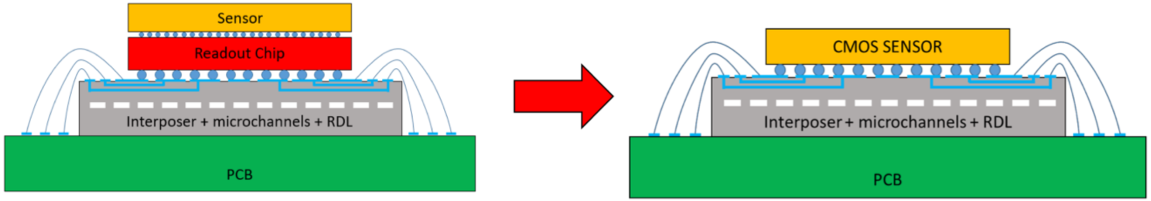
VELO U2 workshop 2026

- Ceramic microchannels
  - Robustness and reliability
  - Possible to embed conductive layers in between ceramics layers and metalize the surface
  - Potential to integrate electronics or high conductivity elements
  - Mechanically robust and compatible with UHV



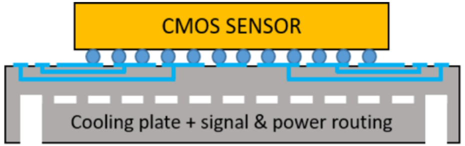
Possible cooling options

- Silicon microchannels
- Heterogeneous integration: microchannels embedded in functional silicon interposers with integrated signal and power routing
  - Combining the cooling capabilities with the electrical connection of the CMOS detector
    - For signal and power routing -> Redistribution Layer (RDL)



  - Also interposer for mechanical support: “All.silicon” ladder

VELO U2 workshop 2026



In the end final choice will be made on cooling performance and thermal stability

3D sensors for VELO U2

Advantages

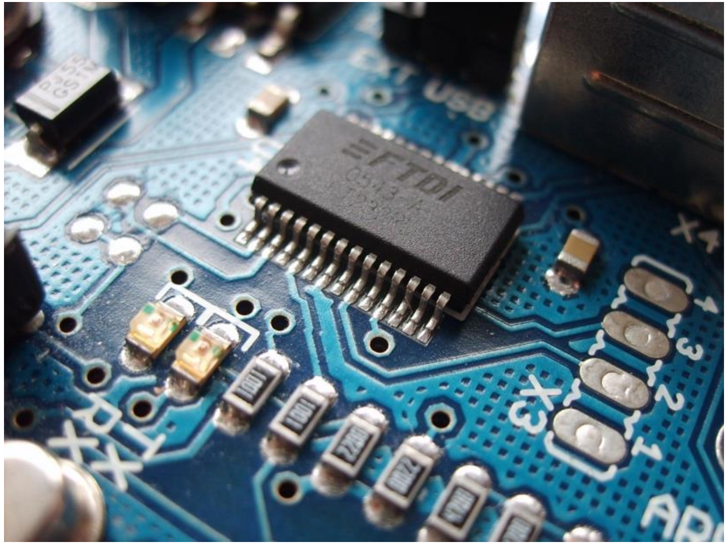
- Low depletion voltage (low power diss.)
- Excellent radiation hardness (>=10^16 neq/cm2)
- Tolerant to high bias even in non-irradiated zones
- Short charge collection distance:
  - Fast response rise
  - Less trapping probability after irradiation
- Goals
  - <=50ps timing and >=99% efficiency
  - Low capacitance and ASIC compatibility
- Lateral charge drift -> cell “shielding” effect:
  - Lower charge sharing
  - Low sensitivity to magnetic field

Disadvantages

- Non uniform spatial response (electrodes and low field regions)
- Higher capacitance with respect to planar (around 3-5x for 200um thickness)
- Complicated technology (cost, yield)

See talk by Morag Williams

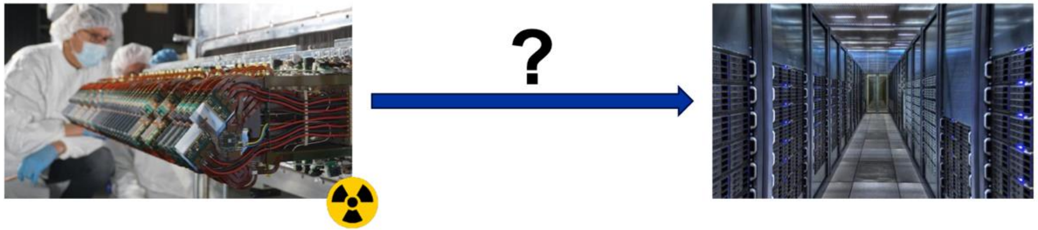
Main course 3 – Electronics

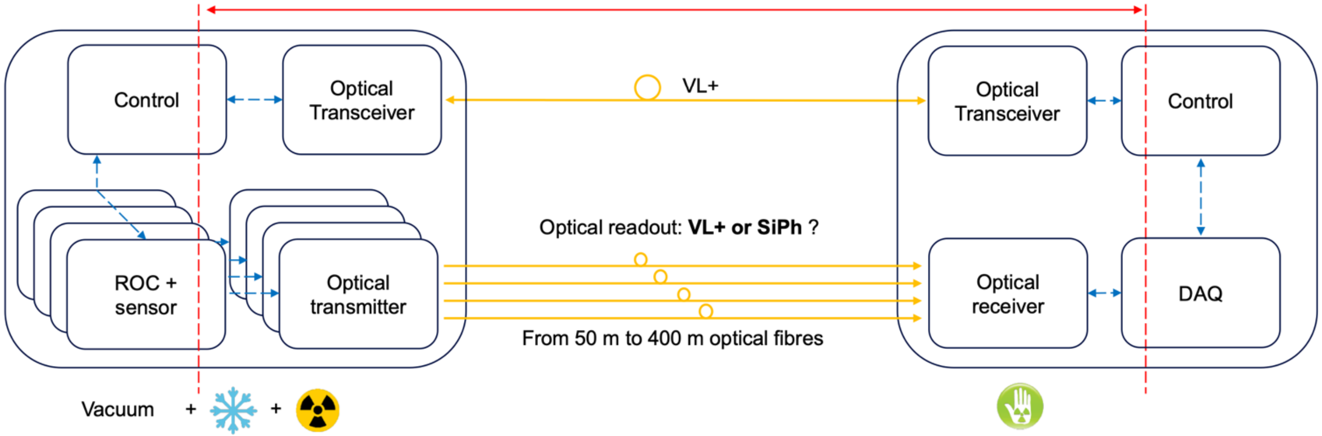


Data Readout

From detector…

… to back end





VELO U2 workshop 2026

- Fibre optic link between fron-end and back-end
- Control and timing using the Versatile Link + (VTRx+) and lpGBT
- Detector readout based on VTRx+ or Silicon Photonics (SiPh) optical transmitter

Silicon Photonics

- Photonic Integrated Circuits (PICs)
  - Chiplet fabricated using CMOS process
  - Fiber couplers, optical waveguides, modulators, photodiodes
  - Radiation tolerant
- Wavelength division multiplexing (WDM)
  - Lane (optical channel) : 25 Gbps
  - Fibre : 100 Gbps
- Laser sits outside of radiation environment
  - Wavelength 1300 nm
  - Transparent window for silicon
- Low power / Low mass

Versatile Link PLUS

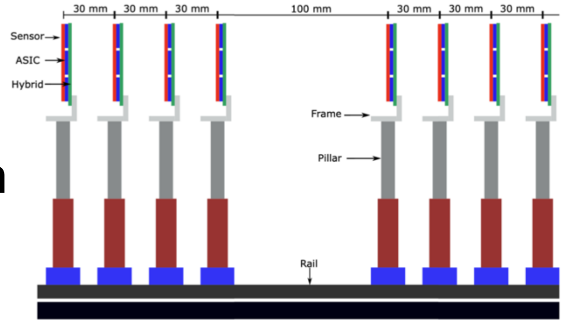
- A bi-directional optical transveiver for optical links
  - Discrete opto-electronic components
  - Radiation tolerant,
  - low mass, low power.
- No WDM. Single wavelength
  - ~10Gbps
  - One lane per fibre
- Laser integrated inside
  - ~1310 nm
- Modules need to be kept in secondary vacuum.

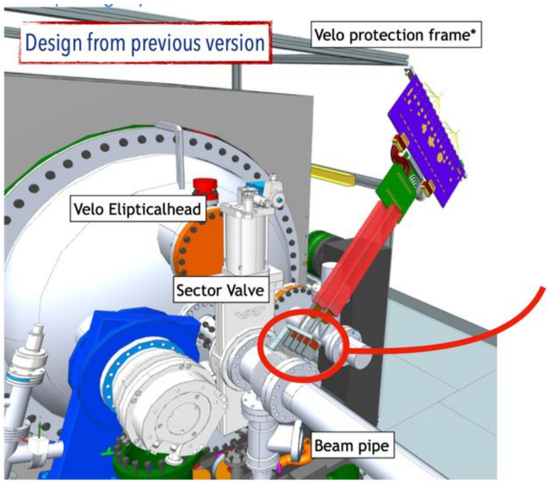
Main course 4 – LumiTracker and ALADDIN

LumiTracker --- based on VELO U2 developments

- Mini-telescope upstream of VELO
- Based on track counting
- 6-8 hybrid silicon planes arranged in two arms
- Planes layout optimised for tracks from luminous region
- Rotation around z between 30-60 degrees for better mechanical integration
- Full length around 35cm
- Provide real-time luminosity measurement per bunch
  - Beneficial that its always closed
  - Similar precision as VELO
- Integration into the LHCb global event stream
- Luminous region monitoring
- ALADDIN experiment – project under study based on VELO U2 developments. – Aims to measure the dipole moments of charmed baryons.

VELO U2 workshop 2026





The Desert : Summary and a look into the future

- Different RF geometries are being looked at
  - Box-like and Iris-like
- Different cooling options are being studied
  - Silicon microchannels, 3D aluminium, 3D ceramics, Ceramic microchannel, Borosilicate glass.
- Fibre-link options were discussed
  - Silicon photonics and VTRx
- Prototypes like LumiTracker and experiment like ALLADIN are being pursued