VELO Upgrade

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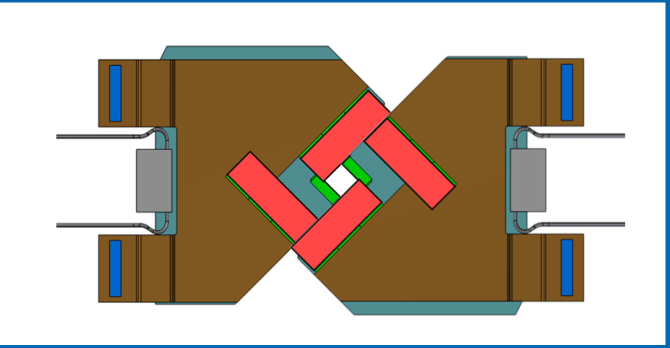
(Nikhef, Amsterdam)
on behalf of the LHCb VELO group



- LHCb: present limits and future extensions
- Current VELO
- VELO Upgrade: technology choices, predicted performance
- Planning and summary

Introduction

Physics objectives of LHCb:
Quest for New Physics via measurements of CP violation and rare decays of beauty and charm particles.

LHCb runs at a constant luminosity of 4×10^{32} $cm^{-2}s^{-1}$.

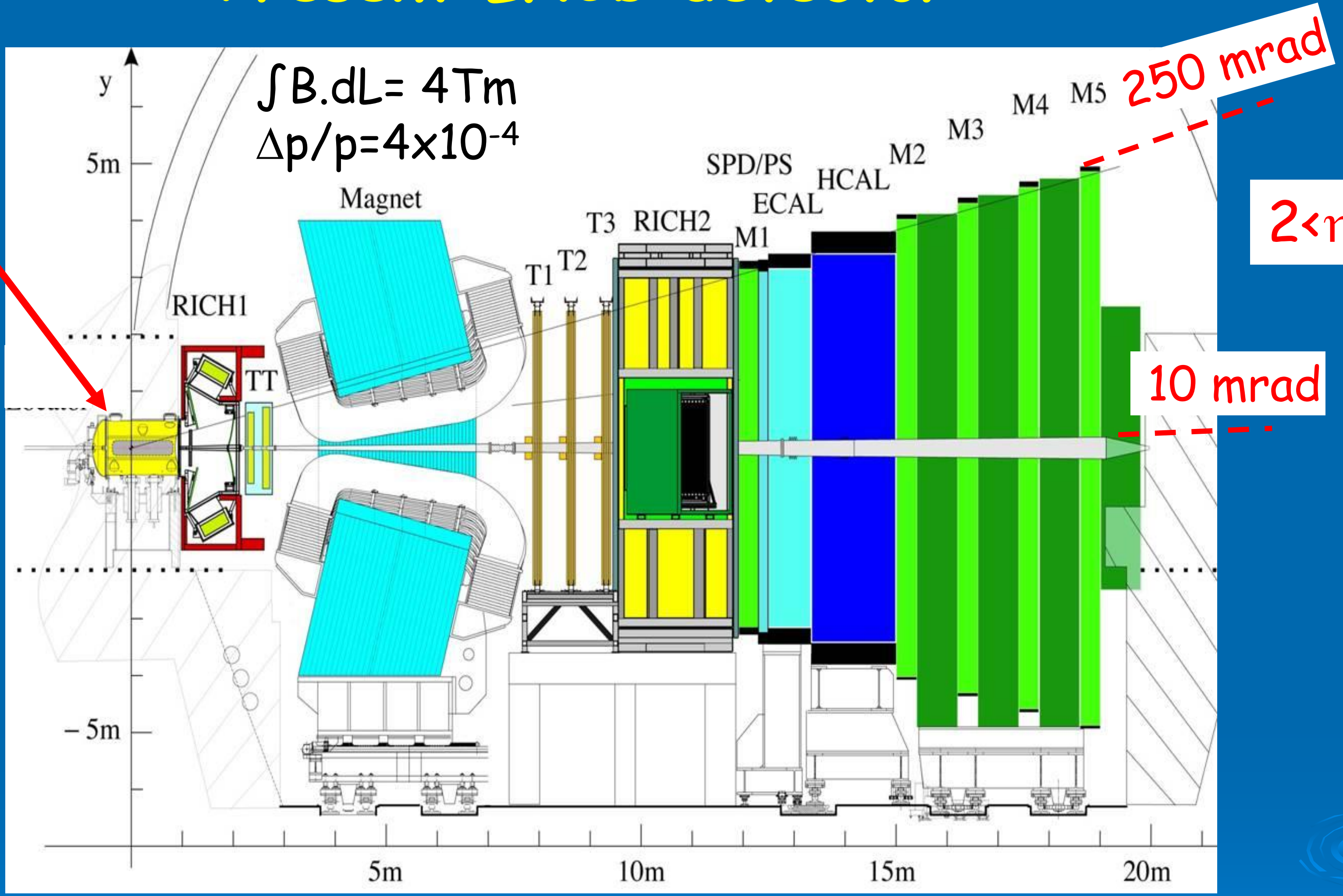
By mid 2018, i.e. at the end of Run II, $\int L.dt$ will be ~7 fb^{-1}.

So continuing on the same footing beyond LS2 is not efficient.
→ Upgrade of the LHCb detector during the 18 months of LS2.

- Limitations of the present detector.
- Solution chosen for the Upgrade.

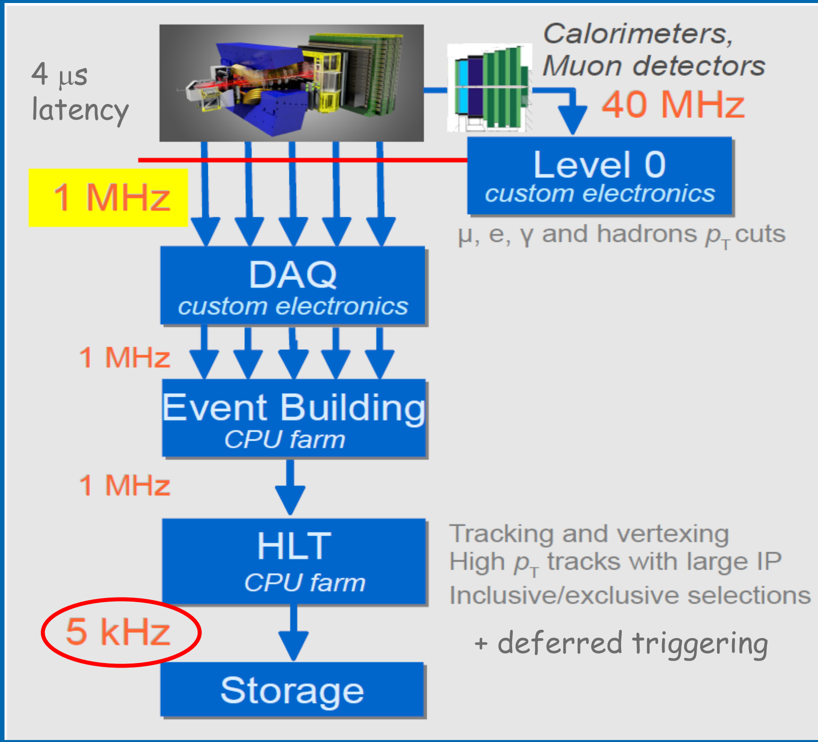
Present LHCb detector

IP inside the VELO



LHCb features excellent vertex and momentum resolution, particle ID and a flexible trigger.

Present trigger and DAQ



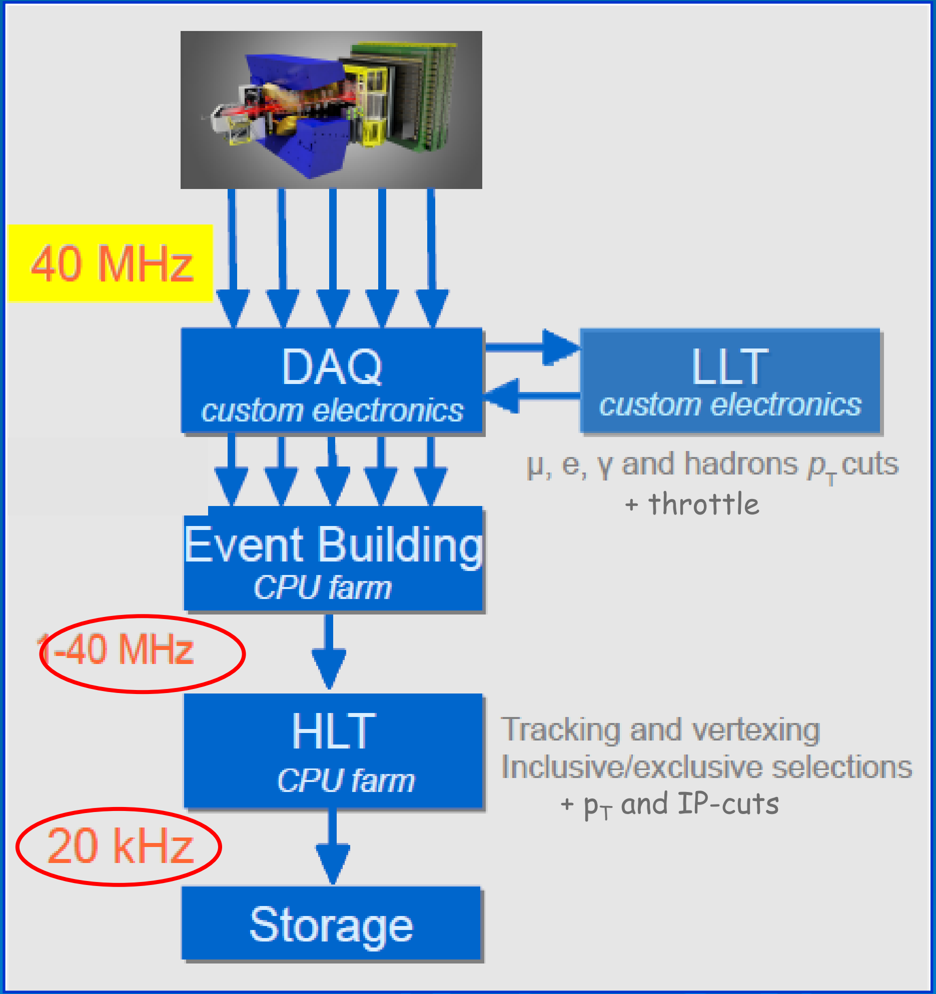
Due to the 1 MHz Level0 limit an increase of the luminosity alone would not be effective due to the need to cut harder on hadron E_t, to prevent saturation of the trigger by hadronic channels.

LHCb Upgrade:
Trigger-less system, read out the whole detector at 40 MHz, implement the trigger in software.

→ replace all frontend electronics + increase farm capacity.

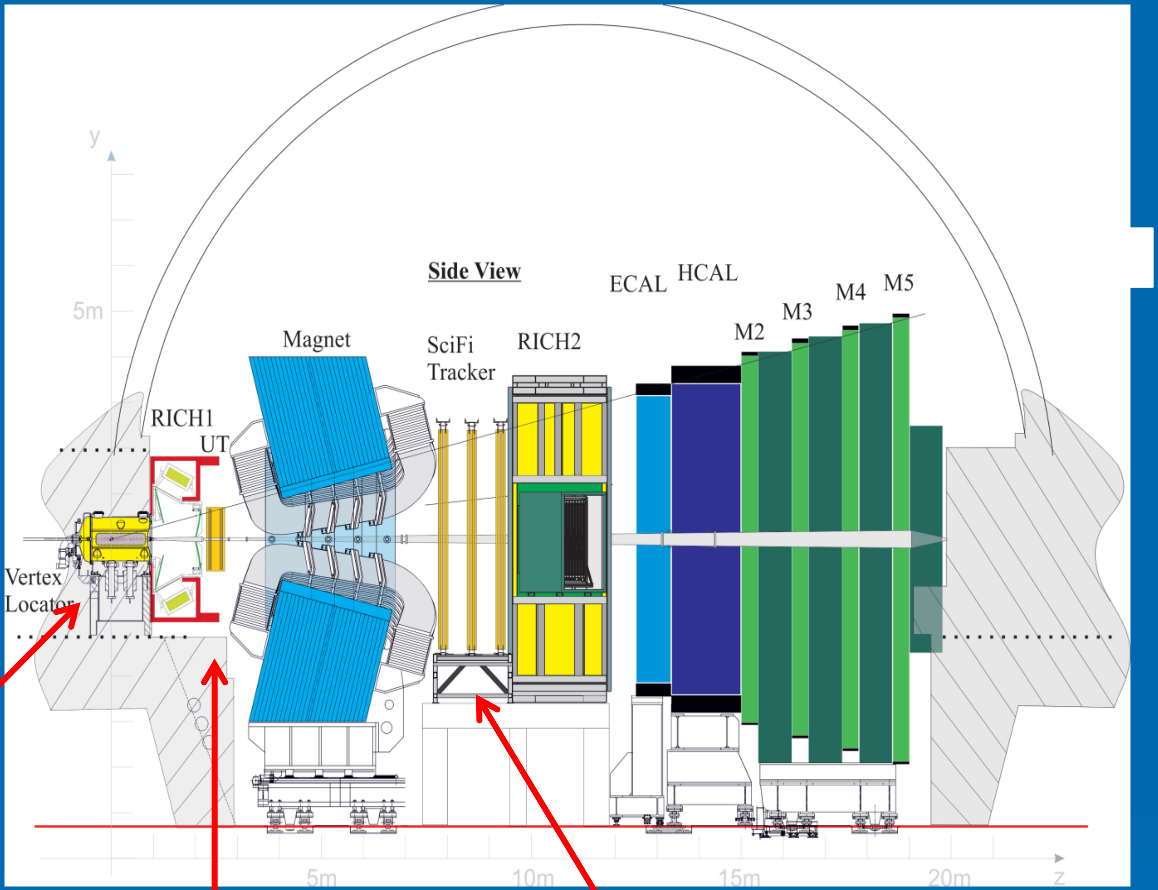
Run at five times higher luminosity: 2×10^{33} $cm^{-2}s^{-1}$ (μ=5.2).

→ ≈order of magnitude increase in yield between pre and post Upgrade.



Upgraded LHCb detector

Three completely new sub-detectors + replacement of the frontend electronics of the rest.



pixel vertex detector (VELO)

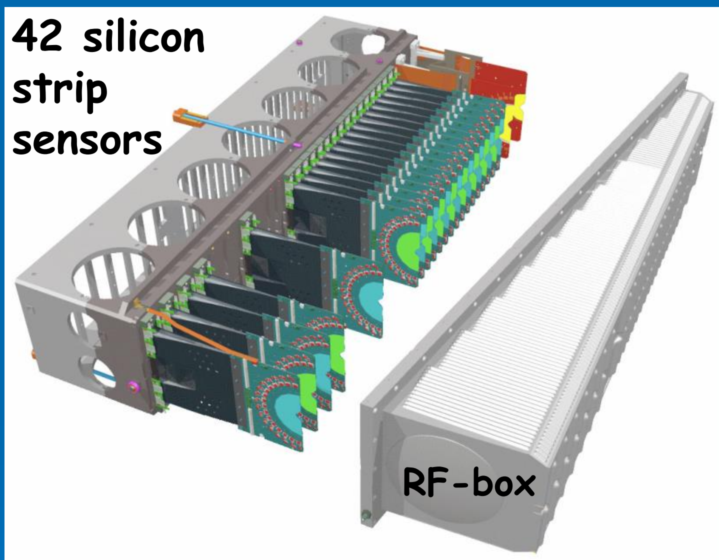
silicon strip tracker (UT)

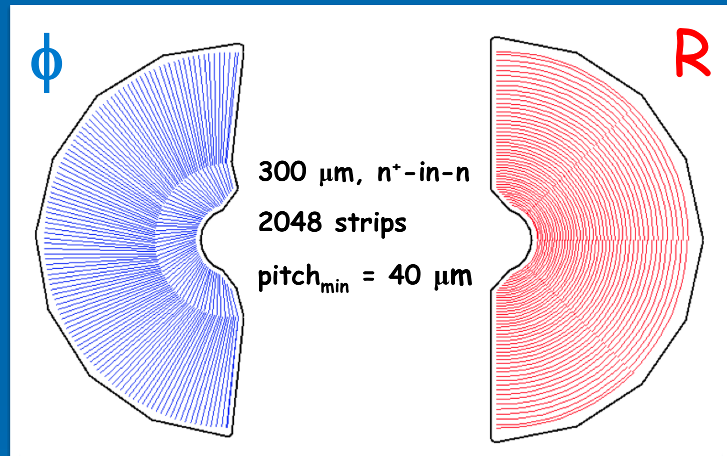
scintillating fiber tracker (SciFi)

Current VELO

VELO surrounds the luminous region at IP8.
Its main task is to measure primary and secondary vertices, and to provide tracking information for the rest of the LHCb detector.

- Vacuum tank with two detector halves with 21 pairs of Rϕ silicon strip sensors.





bi-phase CO_2

- Halves are surrounded by RF-boxes and opened 29 mm during Injection and Ramp, then centered around the luminous region once Stable Beams $\rightarrow$ first active strip at 8.2 mm.

For the Upgrade change from strips to pixels, because of more robust track reconstruction performance in terms of efficiency, ghost rate, and CPU time required for pattern recognition in the HLT.

VELO Upgrade ingredients:

- move sensors closer to the beams,
- new pixel detector: readout chip and sensor,
- novel cooling technique with microchannels,
- module design,
- data transmission,
- thinner RF-boxes.

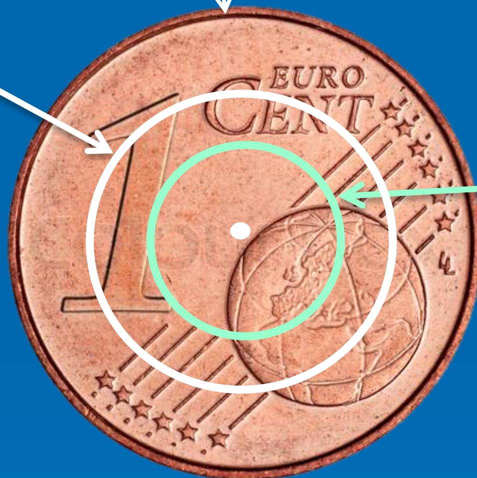
Moving sensors closer to the beams

$$\sigma_{IP}^2 \approx r_1^2 \left(\frac{13.6\ \mathrm{MeV}}{c\, p_T}\right)^2 \frac{x}{X_0} + \frac{r_2^2\sigma_1^2 + r_1^2\sigma_2^2}{\Delta_{12}^2 \tan^2\theta}$$

IP-resolution benefits from minimal material and closer proximity of sensors to the luminous region.

R=8 mm

Inner radius of current RF-box is 5.5 mm, first strip @ 8.2 mm.

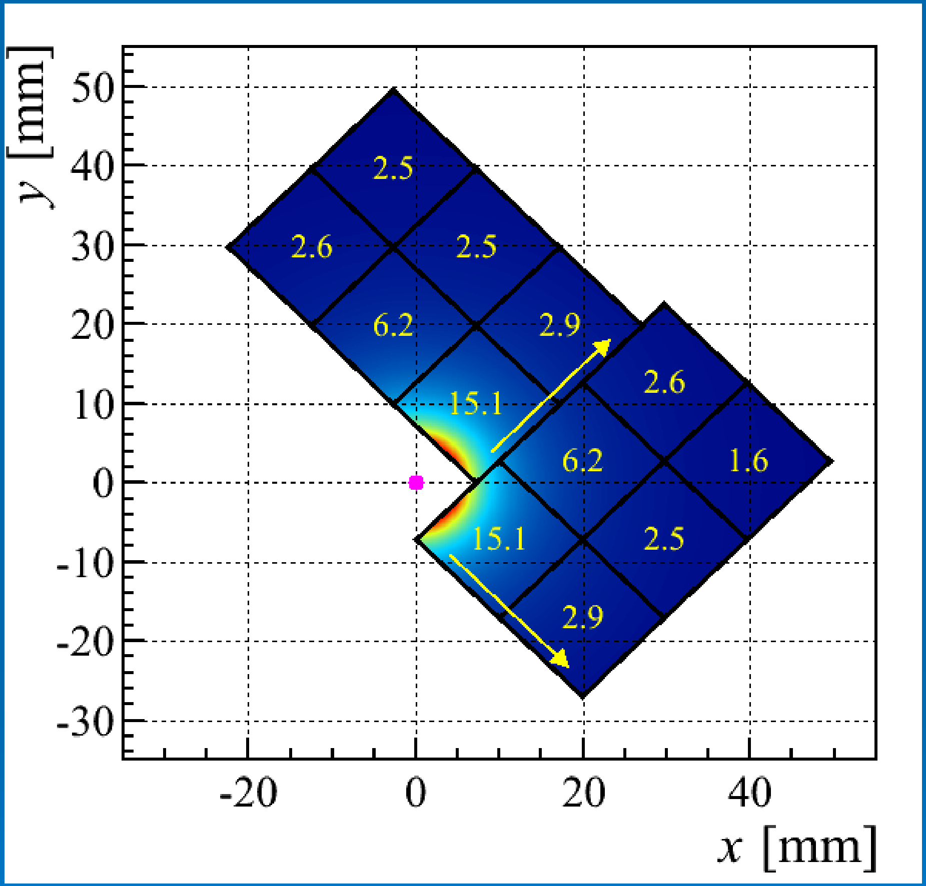


Inner radius of Upgrade RF-box: 3.5 mm, first pixel @ 5.1 mm.

→ factor 12 increase in track rate and radiation damage at the tip.
Need to design a new readout chip: VeloPix.

Data rates and VeloPix chip

data rate per ASIC [Gb/s]



See talk of Tuomas Poikela Wednesday @10h10

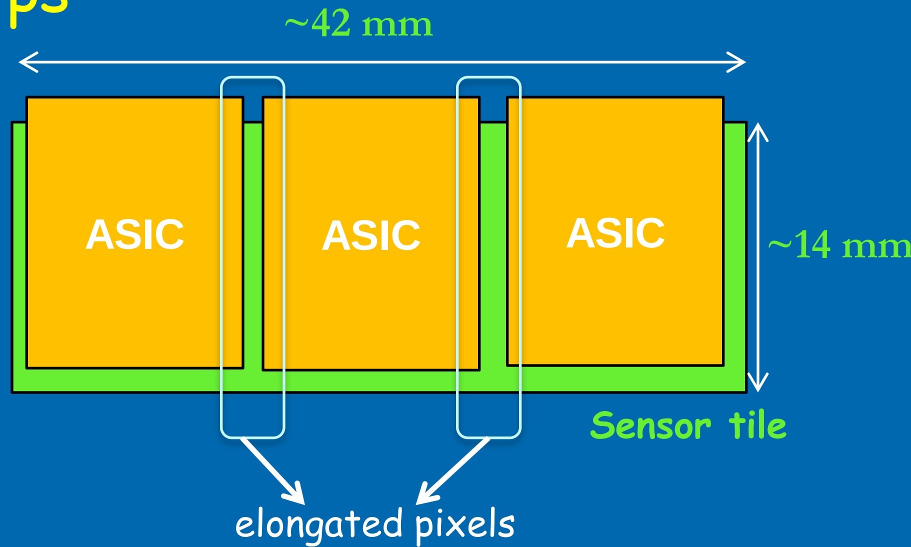
- successor of Timepix3
- 256x256 pixels of 55x55μm^2
- active area 14x14 mm^2

- 130 nm CMOS
- rad-hard to 400 Mrad
- binary readout
- VELO total (peak) data rate: 1.9 (2.9) Tb/s.
- Thermal budget: 3 W/chip

- Highly non-uniform radiation pattern

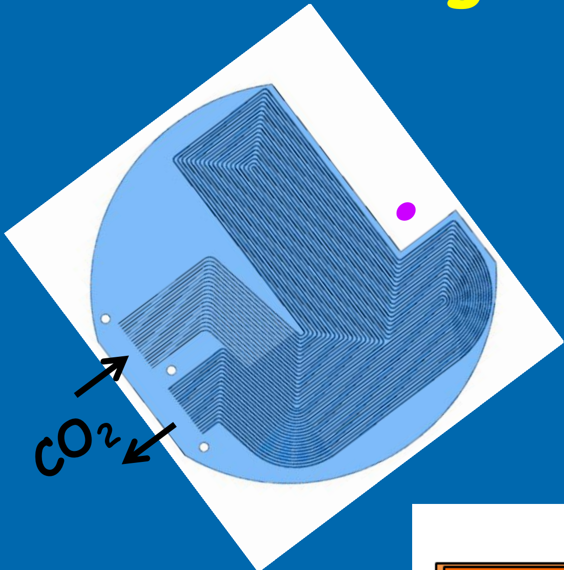
Pixel sensors

- Layout: one sensor covers three chips
  - 450/600 μm guard ring designs,
  - 200 μm thickness,
  - radiation tolerant up to 50 fb^{-1}: 8×10^{15} $1MeVn_{eq}cm^{-2}$ @ tip, factor 45 less at the outer edge,
  - HV tolerant up to 1000 V,
  - n^+-in-p or n^+-in-n,
  - bump bond 200 μm thick ASICs on 200 μm thick sensors

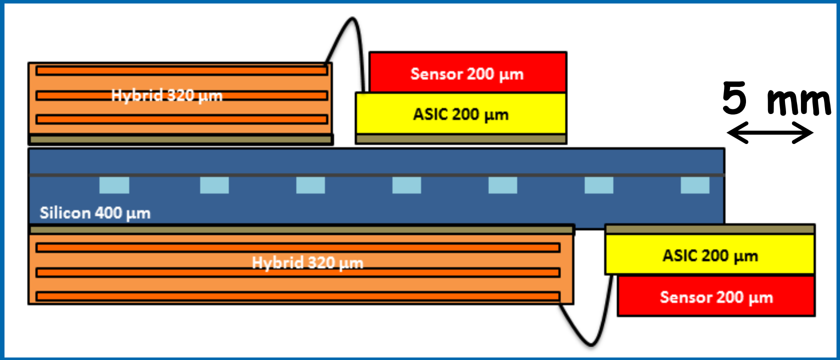


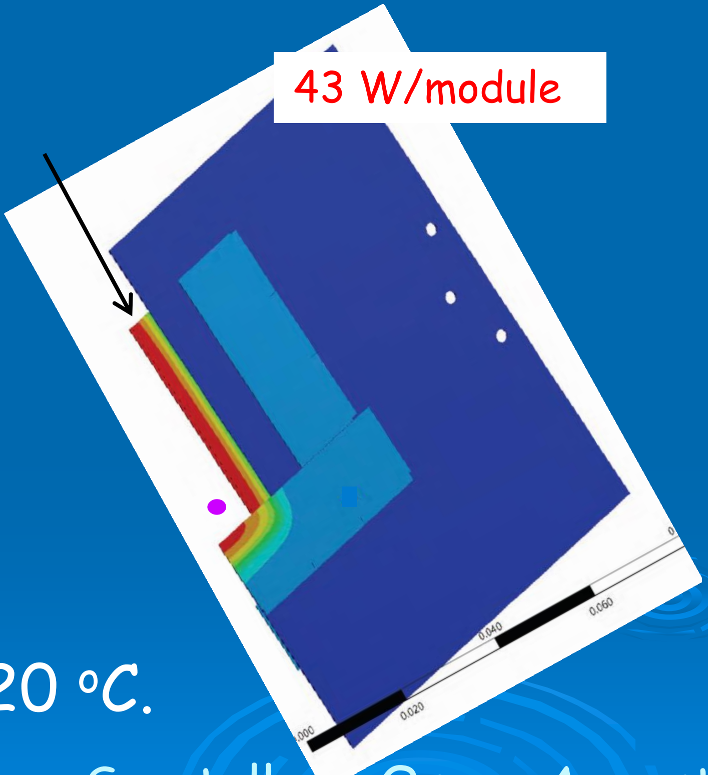
- Two vendors producing prototypes: Hamamatsu and Micron
- R&D program: irradiation and test beam campaigns to study radiation hardness and performance.
- A new beam telescope with TPx3 chips is recently commissioned: 2 μm pointing resolution and capable of handling 10^7 tracks/s.

Cooling with silicon microchannel substrate



400 μm thick silicon substrate with 19 parallel μ-channels (200 μm x 120 μm at 700 μm pitch) for evaporative CO_2 cooling.
After etching, the two wafers are bonded in a hydrophobic process.



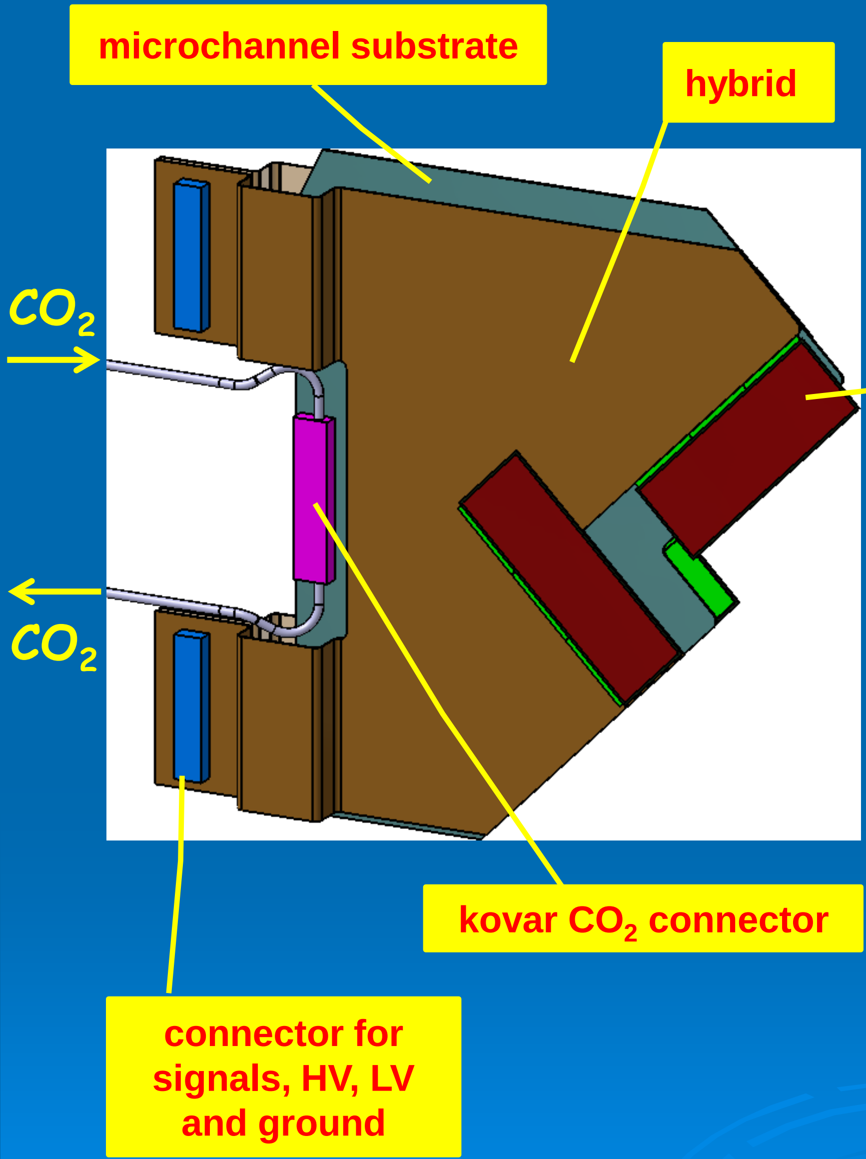


Sensors protrude the substrate at the edge by 5 mm. → Threat: thermal runaway.
Solution: keep sensor temperature below -20 °C.

Need 2.5 kW CO_2 cooling power @ -35 °C.

See talk of Oscar Augusto Thursday @14h00

VELO pixel module

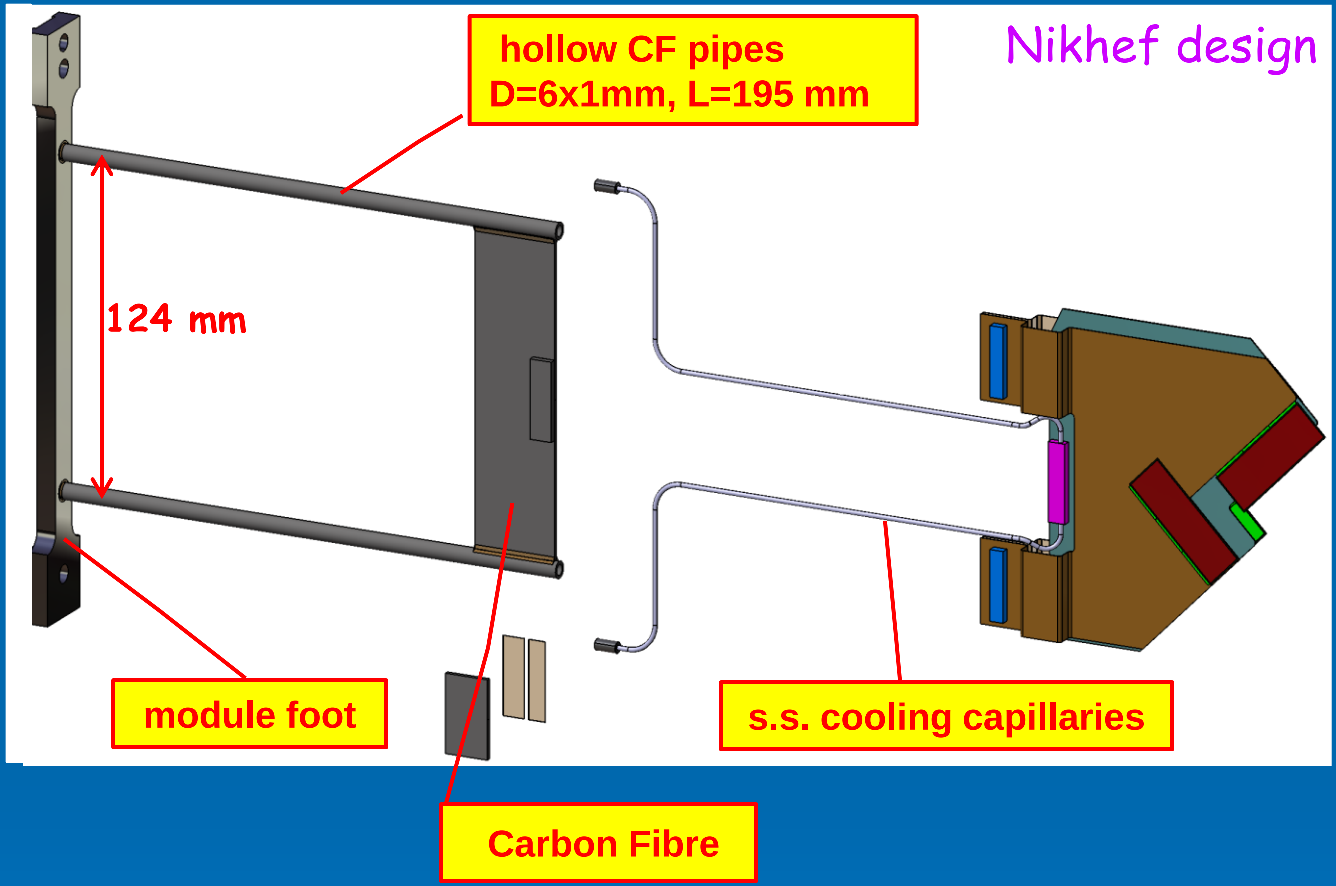


Per module:
4 pixel sensors (14x42 mm^2), each bump bonded to 3 VeloPix chips.

Each detector half:
26 double-sided modules.

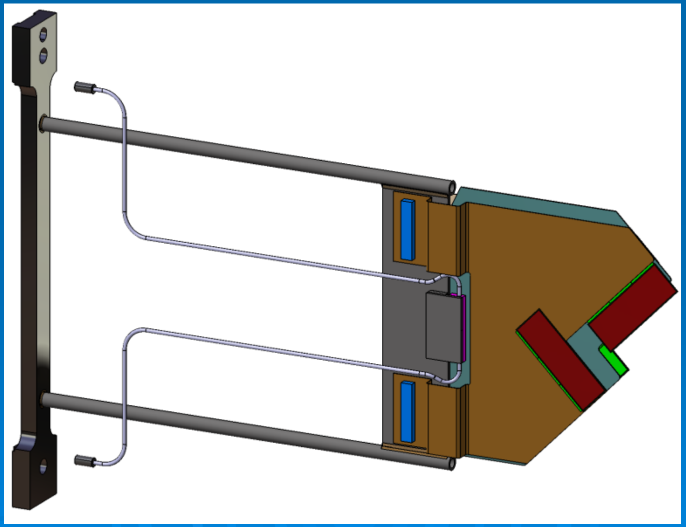
In total:
40.9 M pixels in 1243 cm^2 silicon
(=2 mid-plus tennis rackets = 1xA3).

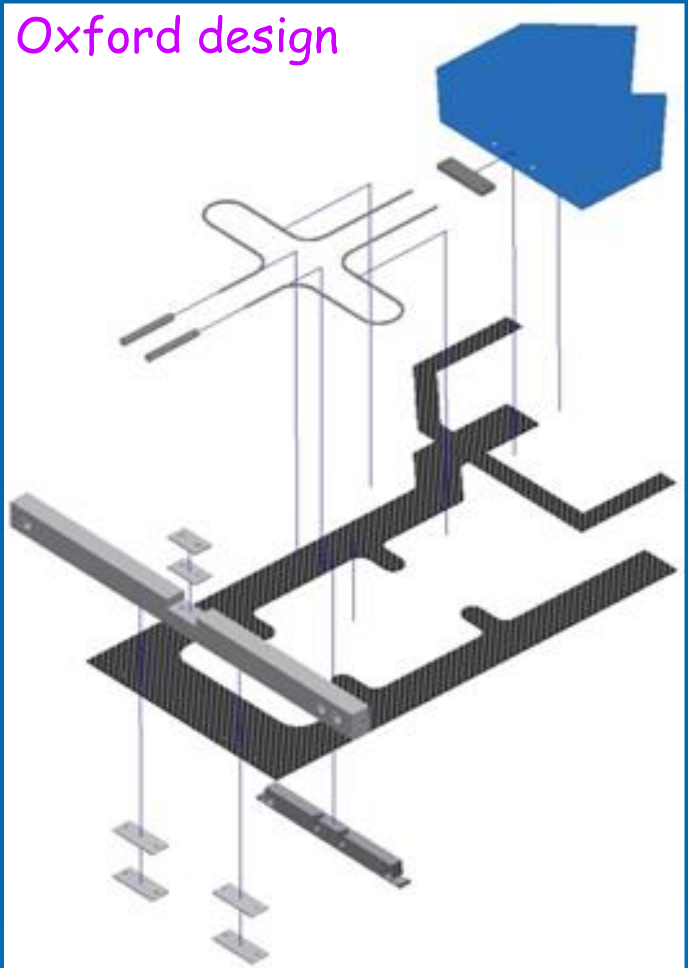
VeloPix module designs



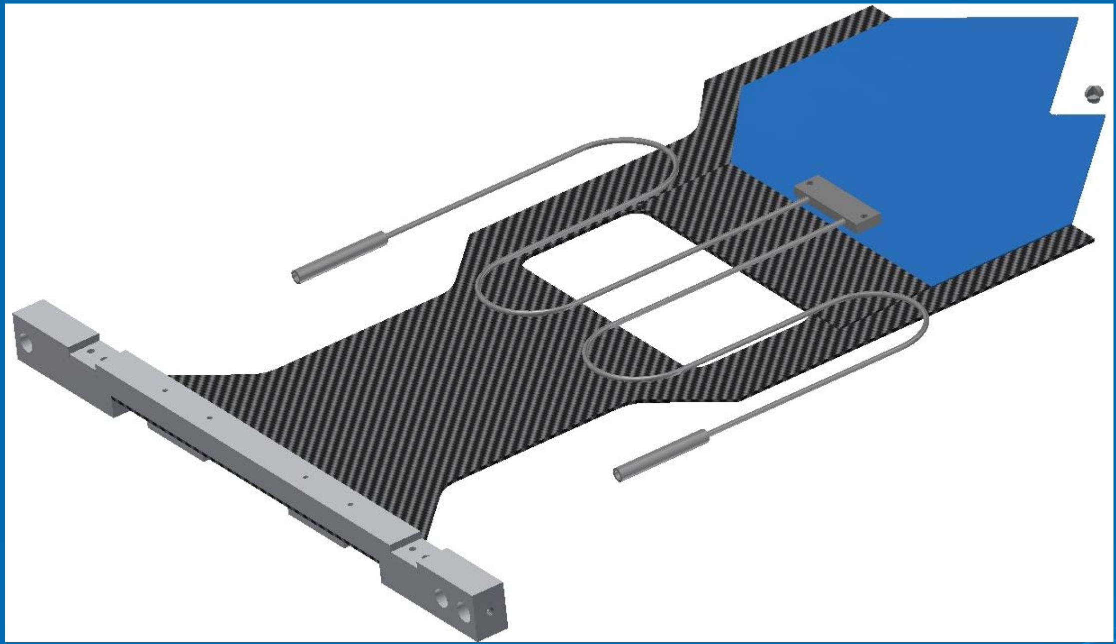
2*8 +17= 34 g of Carbon Fibre.

Glue the CF structure on the kovar CO_2 connector → minimal stress on delicate substrate.



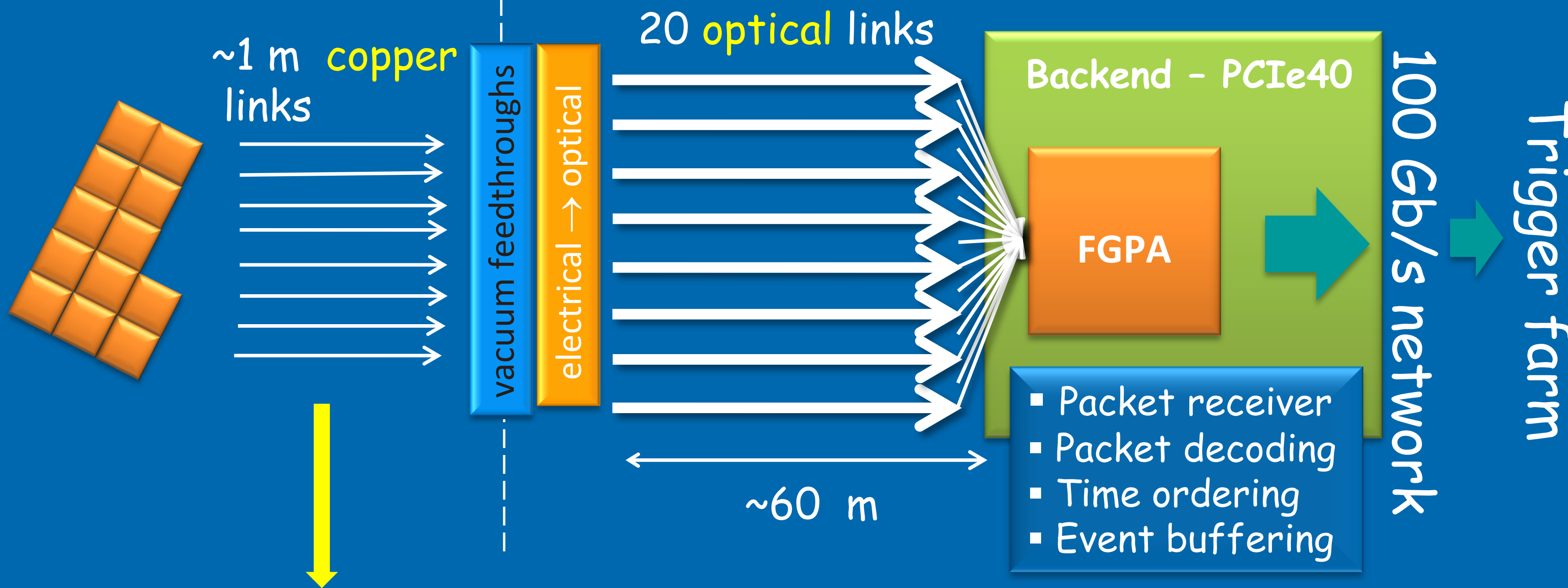


Glue substrate on a 1 mm thick carbon fibre frame, and then on another one.

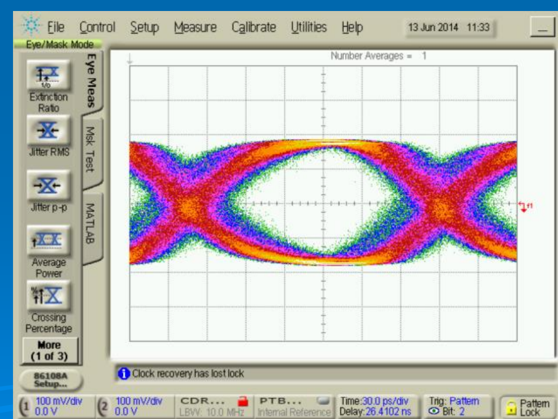


Both module prototypes will be tested on their mechanical stability.
Metrology measurements planned while cooling down to -30°C.

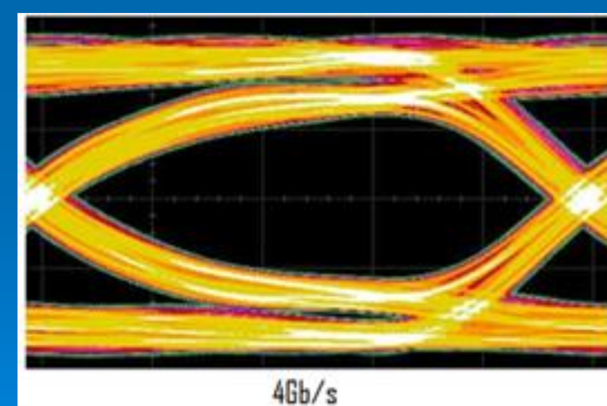
Data transmission



- Radhard, low outgassing, flexible
- Dupont Pyralux AP-plus 'kapton'
- Eye diagrams of serialising and transmission look promising for 0.5 -1 m of cable, but mechanically rigid.

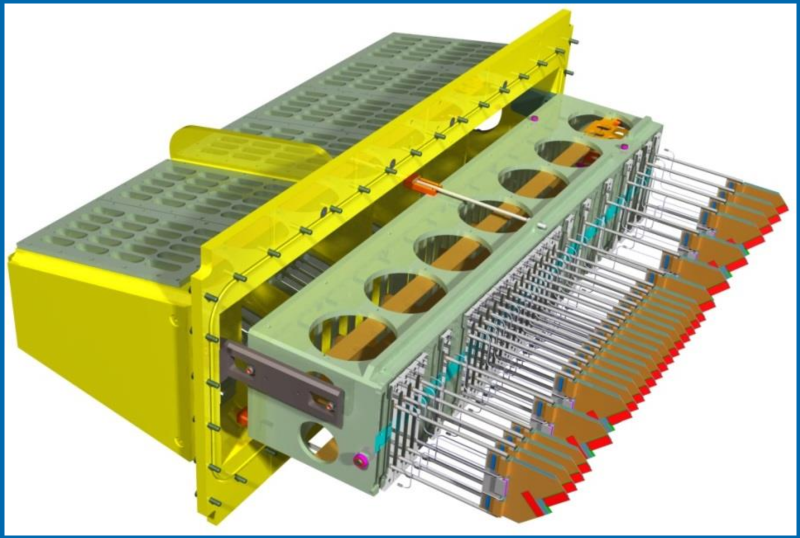


serialiser



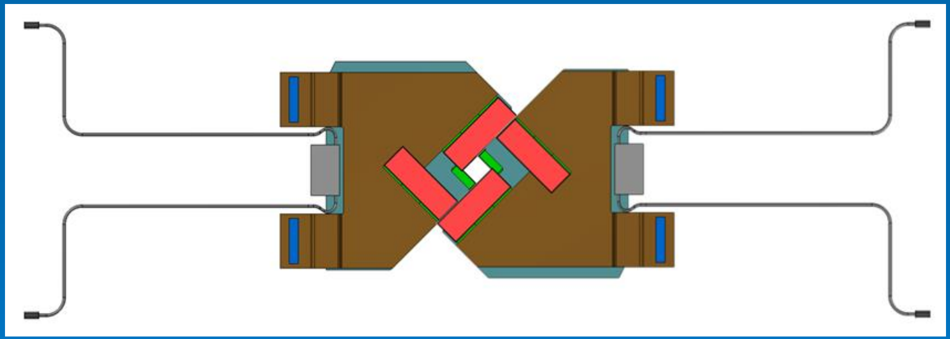
100 cm copper cable

Detector half

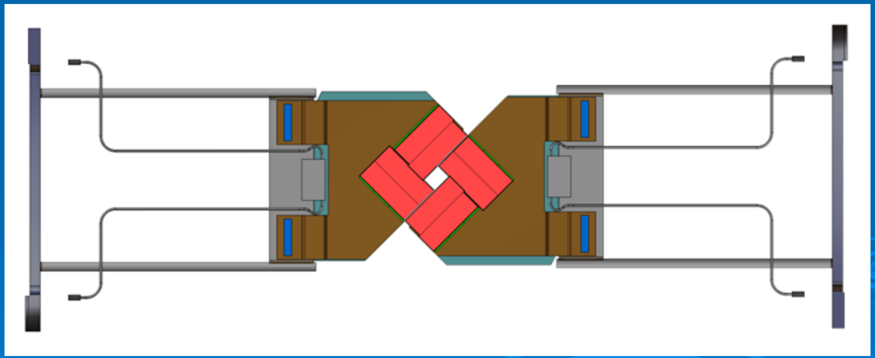


Module pitch:
N*25 mm

VELO halves closed



front view

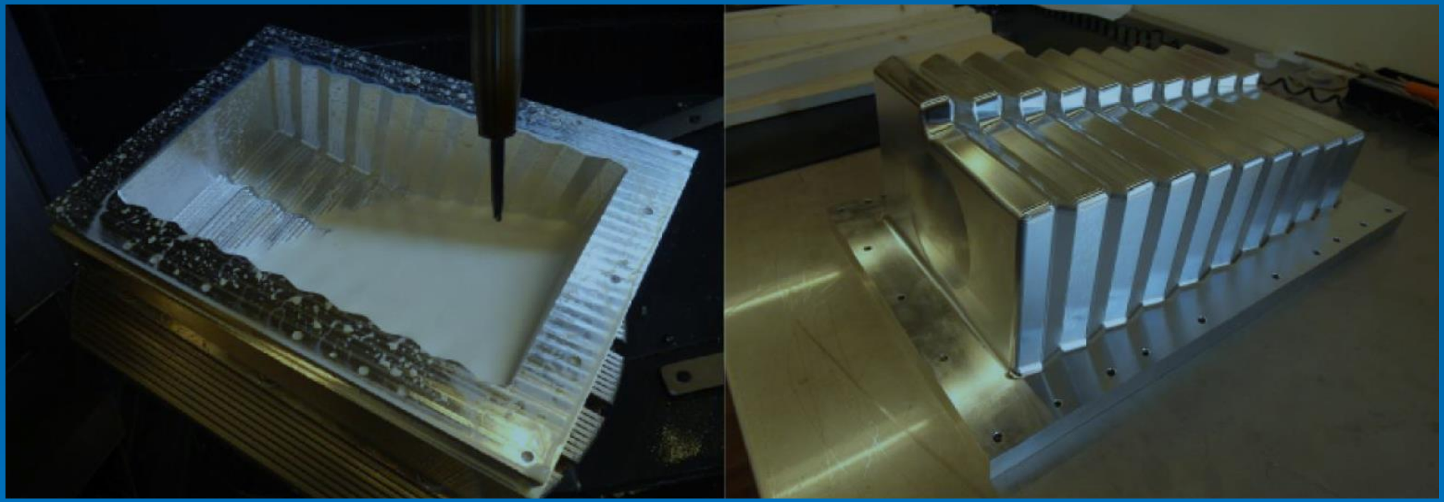


projected view of sensors

RF-box

Construct corrugated RF-box (@ 0.7 mm from the sensors) by milling a solid block of AlMg4.5 down to 250 μm (or less):

- possibillity to vary locally the thickness,
- important because on average many times traversed,
- higher mechanical precision expected,
- easier weldable configuration possible.

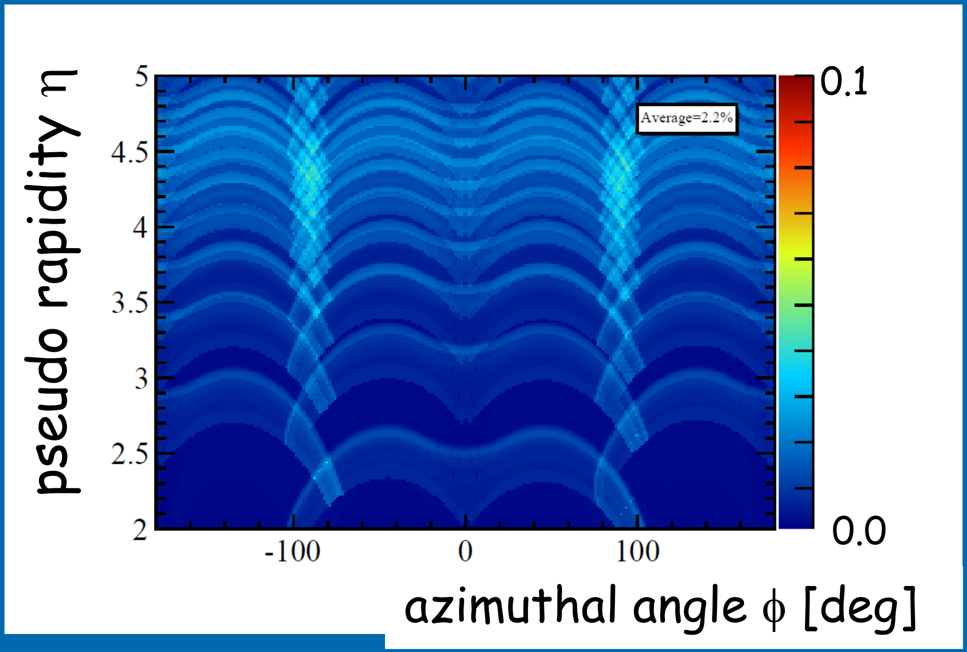


Prototype RF-box: 1/4 of full length.

Possible optimalisations: local thinning by chemical etching or start with a block of AlBeMet (→gain factor 2.0 in X_0).

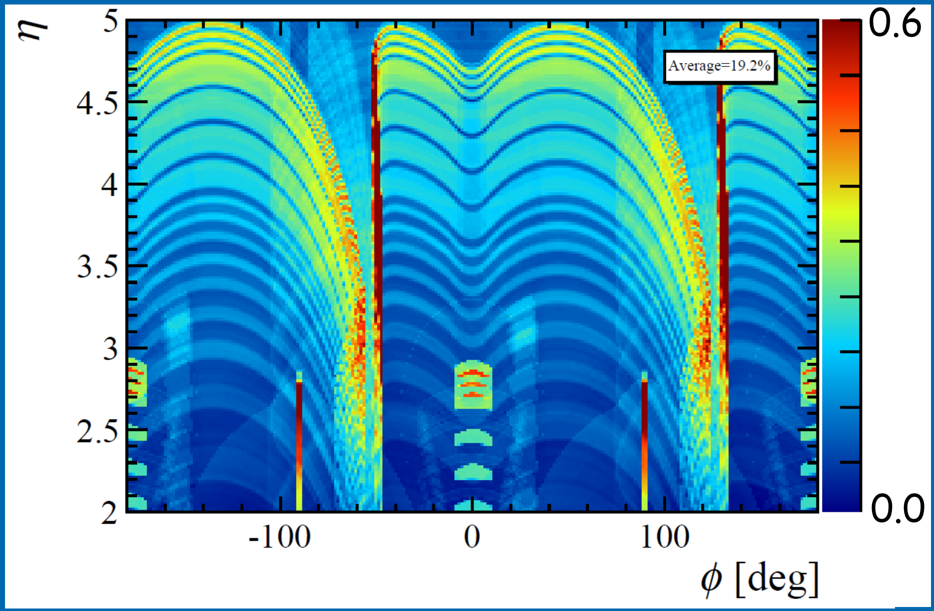
Material budget

Before first hit



Average : 0.022 X_0

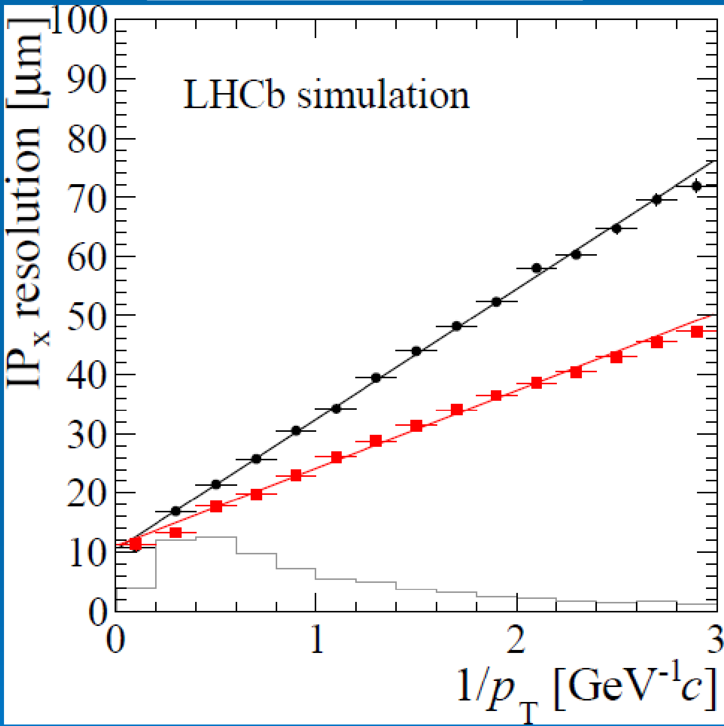
Total VELO



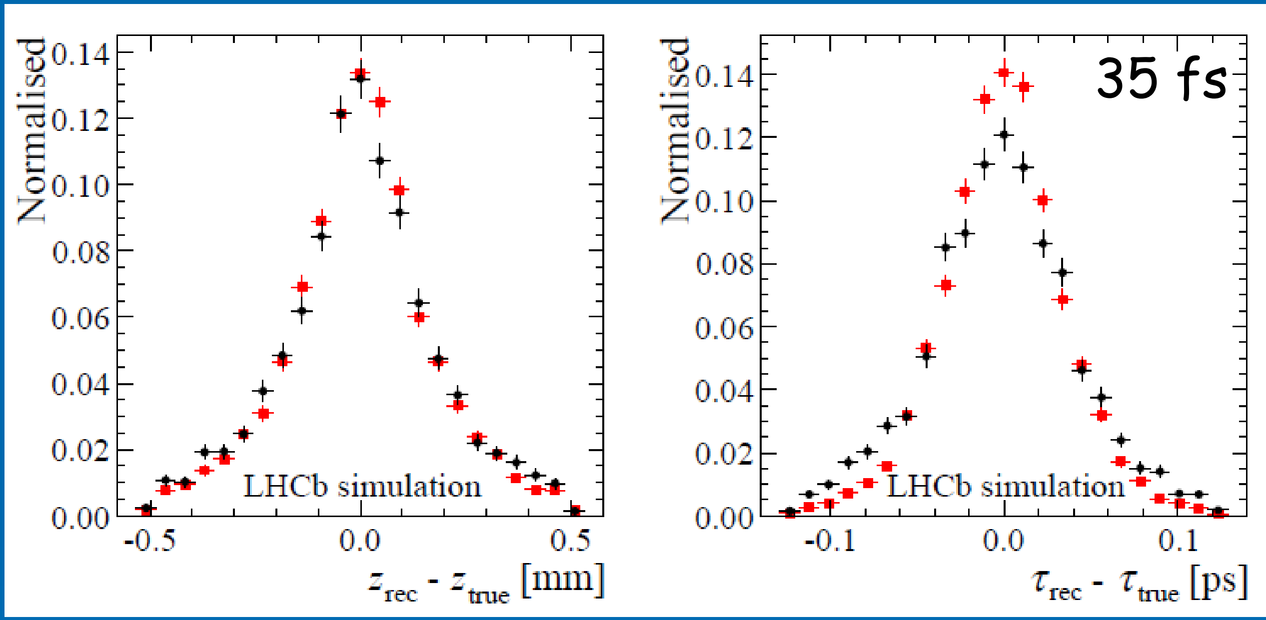
Average: 0.192 X_0

Comparison of simulated physics performance of present VELO versus VELO Upgrade

. present VELO
. Upgrade



Impact parameter resolution in *x*



Uncertainty in the *z*-position of the B vertex.

Decay time resolution of $B^0 \rightarrow K^{*0}\mu^+\mu^-$

Planning

- MoUs will be signed shortly,
- List of milestones, Engineering Design Reviews and Production Readiness Reviews is being updated.

Should all converge to deinstallation of the current VELO after the end of Run II (Q3 2018) and subsequent installation of the VELO pixel detector.

Summary

- LHCb is performing very well, but after LS2 the statistical error will only go down slowly.
- Upgrade the detector to 40 MHz readout, a software trigger with full event info and 20 kHz event storage.
- Run at 5x higher luminosity such that ~ an order of magnitude gain in signal rate.
- VELO becomes a pixel detector with a new high-speed ASIC, minimal material, especially the RF-foil, and a novel microchannel cooling technique.
- Various R&D and prototyping projects are ongoing.
- Installation in VELO tank foreseen for 2019 during LS2.