# The LHCb VELO Upgrade

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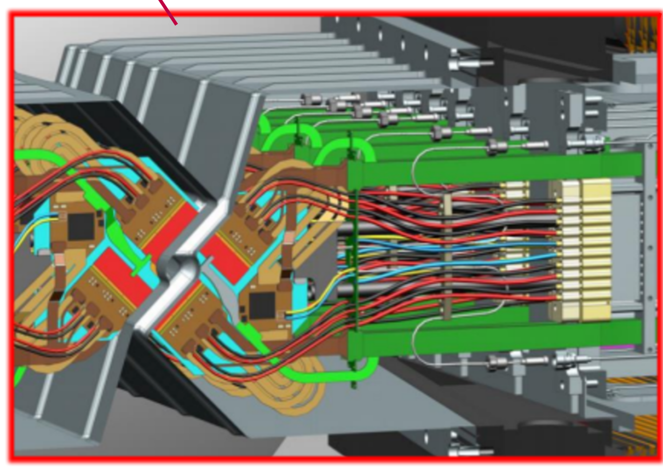
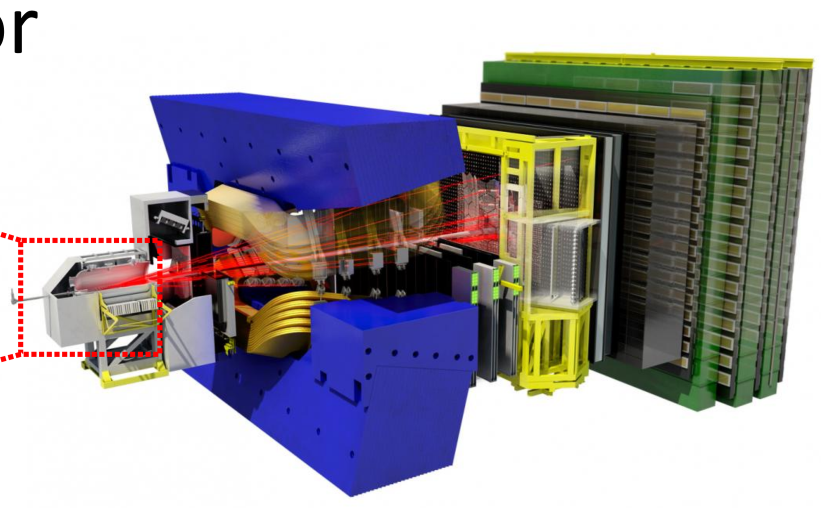
On behalf of the LHCb collaboration
The University of Manchester

## LHCb Detector

RF box enclosure
- Single aluminium alloy part
- Separates beam and module vacua

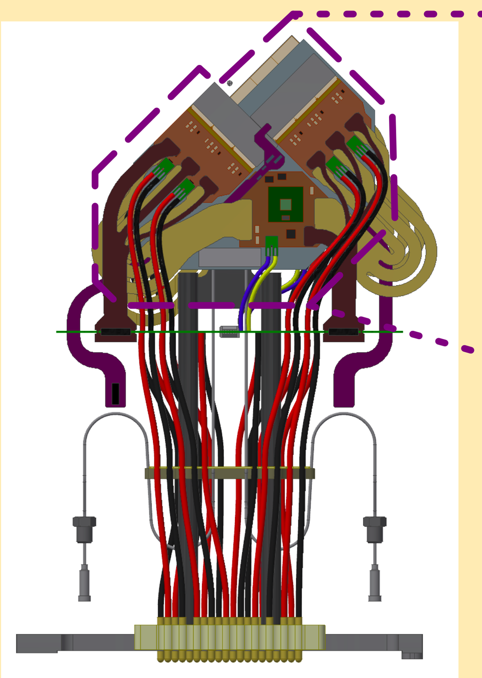
VELO upgrade [2]:
- 52 double-sided modules divided in 2 retractable halves
- 5.1 mm close to the beam when closed
- 4 Tiles (pixel sensor + ASICs) per module
  - 3 ASICs (VeloPix) per Tile
    - 256x256 Pixel per ASIC, 55 × 55 μm² pixels

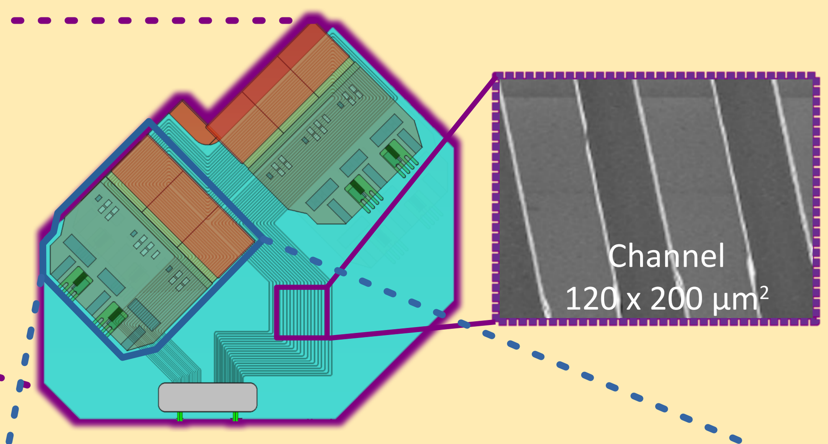


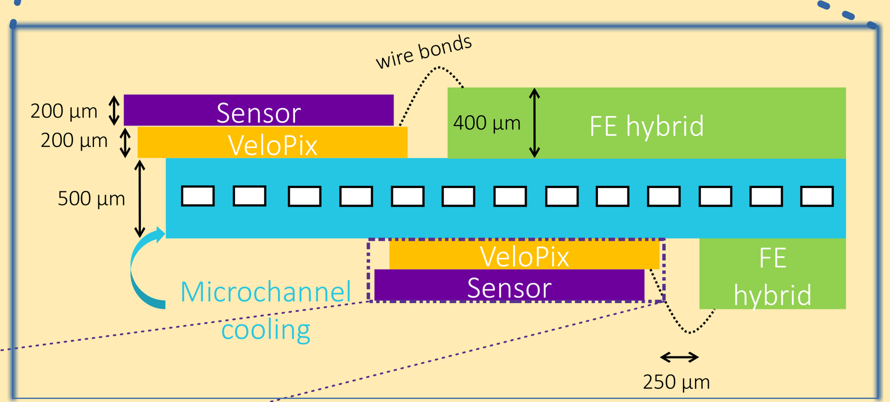


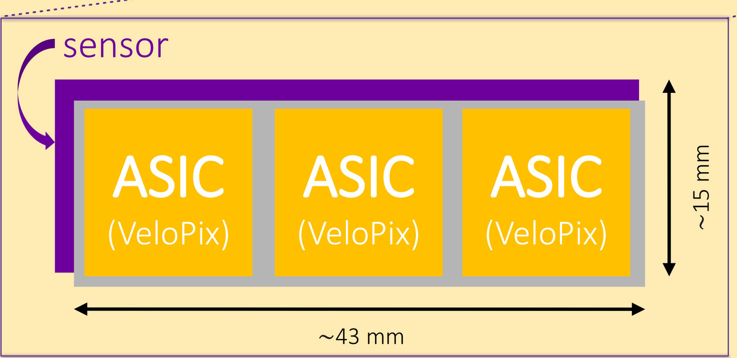
- Single arm forward spectrometer [1]
- Focus on *b* and *c* hadron physics
- Reliance on secondary vertices reconstruction
  - VErtex LOcator (VELO) plays a crucial role

## Microchannel substrate





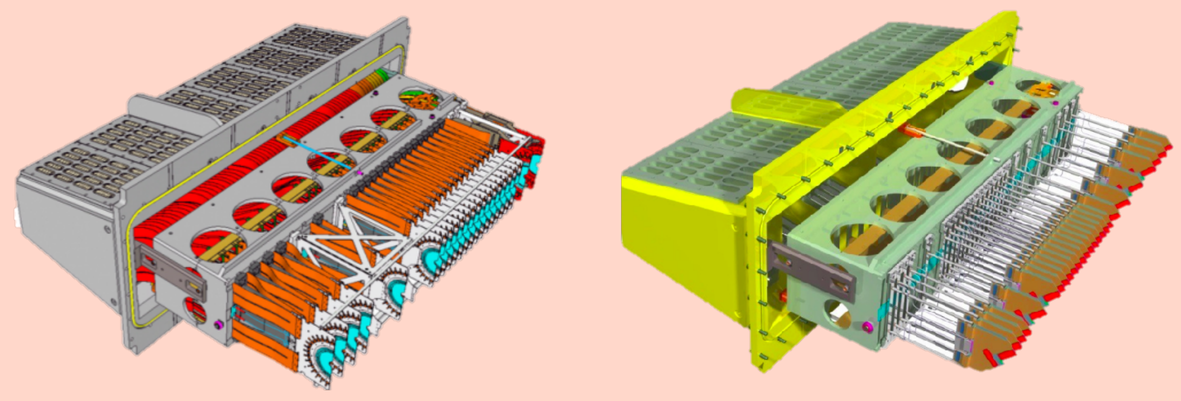




Electronics sandwich
- Tile: sensor + 3 bump bonded ASICs
- Tile & Front End (FE) hybrids glued to microchannel substrate
  - Heat dissipation through glue interface
- ASICs wire bonded to FE hybrids

VELO Upgrade:
- Higher precision
- Faster readout
- Closer to beam
- Higher radiation hardness

Microchannel silicon substrate:
- Provides structural support & cooling
  - 19 microchannel etched in the substrate
    - 140/240 μm from the chips
  - Uniform heat dissipation via evaporative $CO_2$ [3]
  - Dissipate up to 30W per module
  - Low budget material

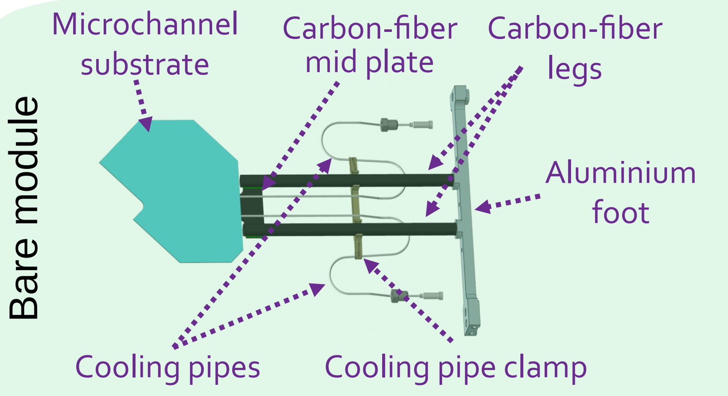
## OLD vs NEW



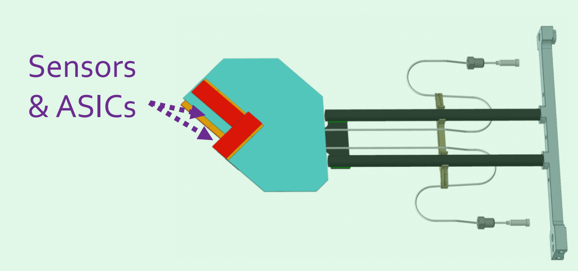
| Feature | VELO | VELO Upgrade |
| --- | --- | --- |
| Readout channels | strips, ~0.2 M | pixels, ~41 M |
| Readout rate | 1 MHz, triggered | 40 MHz, data-driven |
| Beam distance | 8.2 mm | 5.1 mm |
| Fluence | $4 \times 10^{14}$ 1 MeV neq cm$^{-2}$ | $8 \times 10^{15}$ 1 MeV neq cm$^{-2}$ |

Assembly Steps:
- Assembly @ Manchester & Nikhef
- Bare module
- Tile glueing
- Hybrid Gluing
- Tapes & cables

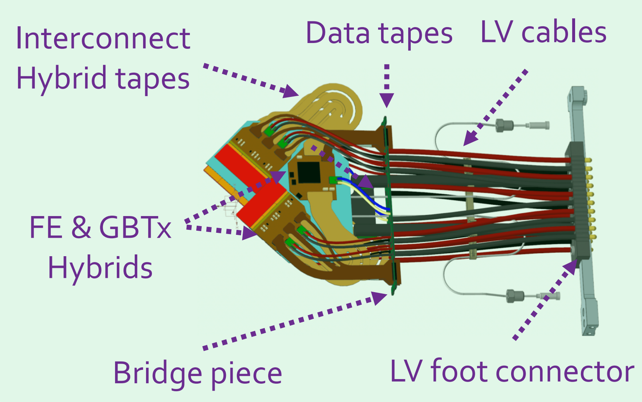
Bare module



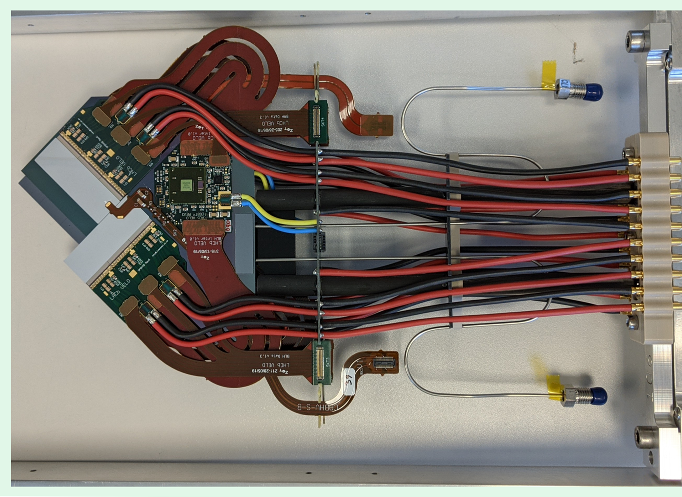

Tile glueing




Hybrids + Tapes & Cables




Completed Module



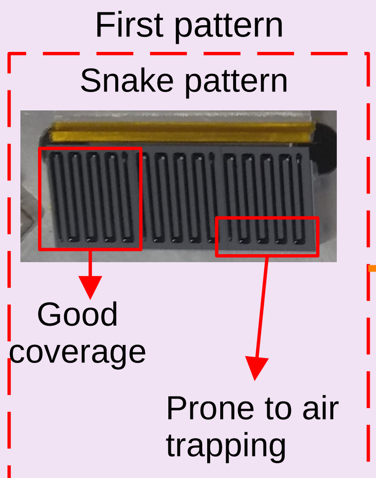
## Glue interface crucial for heat dissipation & mechanical soundness

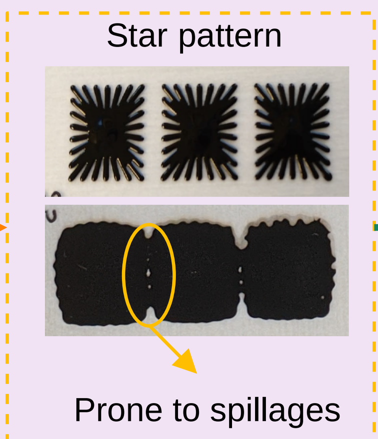

Choice: Stycast 2850FT with catalyst 23LV
- Good thermal conductivity: 1.1 W/mK
- Radiation hard, good ageing properties
- Cons: hygroscopic catalyst → Heat treatment to remove humidity

### Pattern R&D

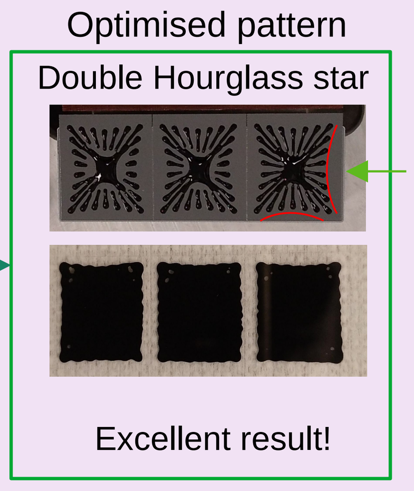
Glue Target parameters
- Thickness: 80 μm → good heat transfer and thermal stress absorption
- Evenness: ±40 μm → uniform glue layer == uniform heat dissipation
- Coverage: 70% of the ASIC
- No air bubbles trapping when pressing down (air expansion in vacuum+heat)
- Avoid splillage in-between ASICs → cause electronic noise

First pattern



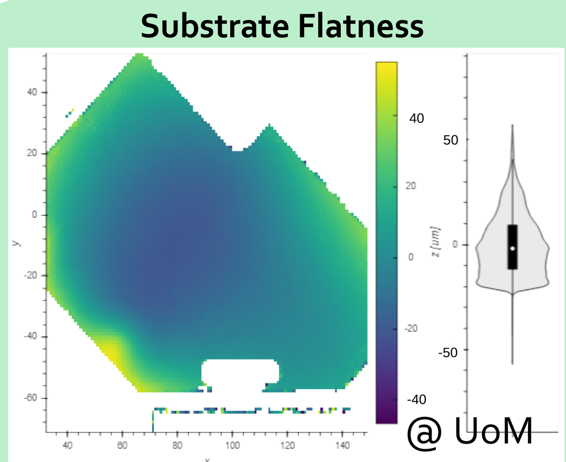



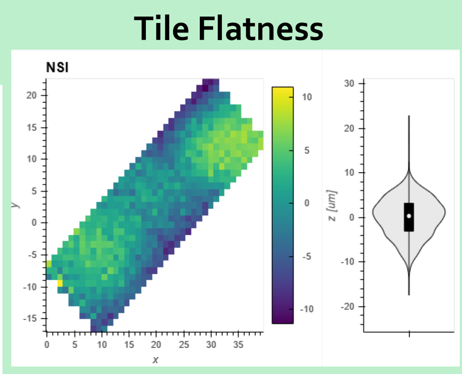

Optimised pattern



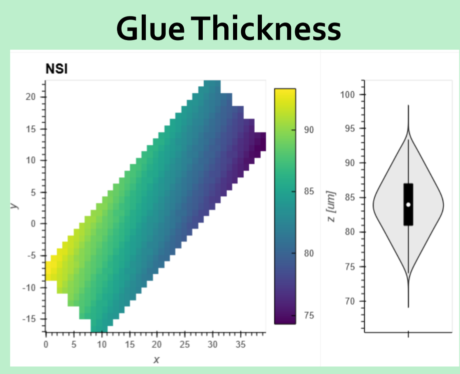

Add bowing on both sides

Metrology:
- Performed after each assembly step
- Assign grading



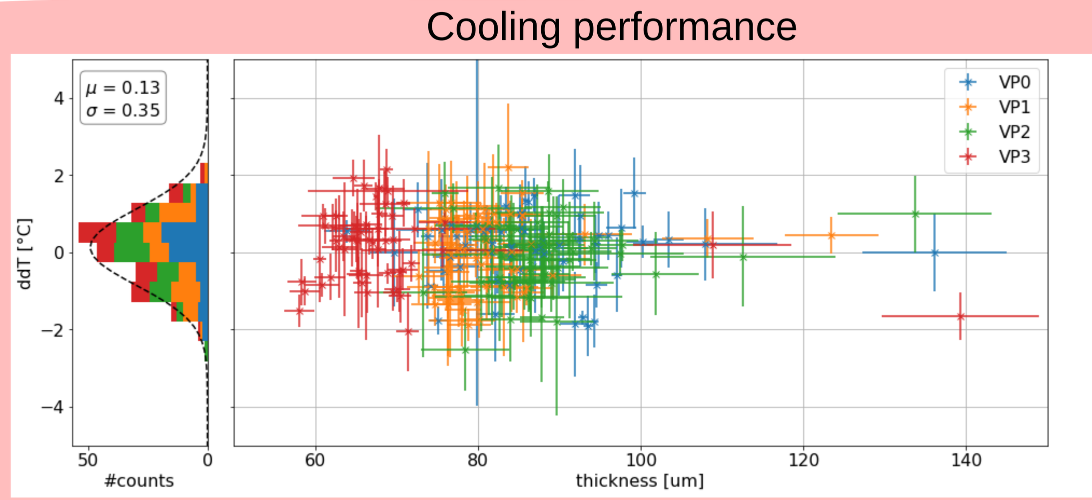



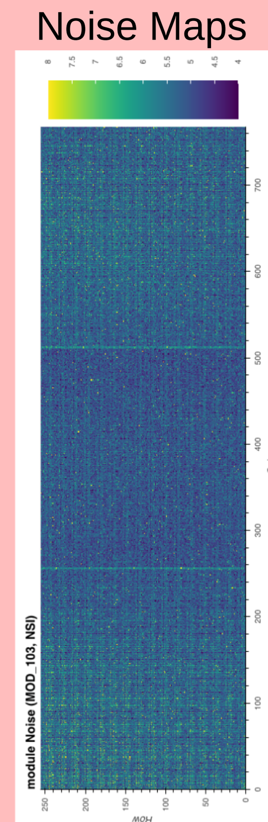

Grades (mean ± 2 · stdev)
- A (±30 μm)
- B (±60 μm)
- C (±120 μm)
- F (outside)




Grades (mean ± 2 · stdev)
- A (+40 μm, +120 μm)
- B (+20 μm, +160 μm)
- C (+0 μm, +200 μm)
- F (outside)

Validate modules:
- Apply vacuum @ -30°C
- Simulate operation conditions
- Test electrical performance
- Test thermal performance

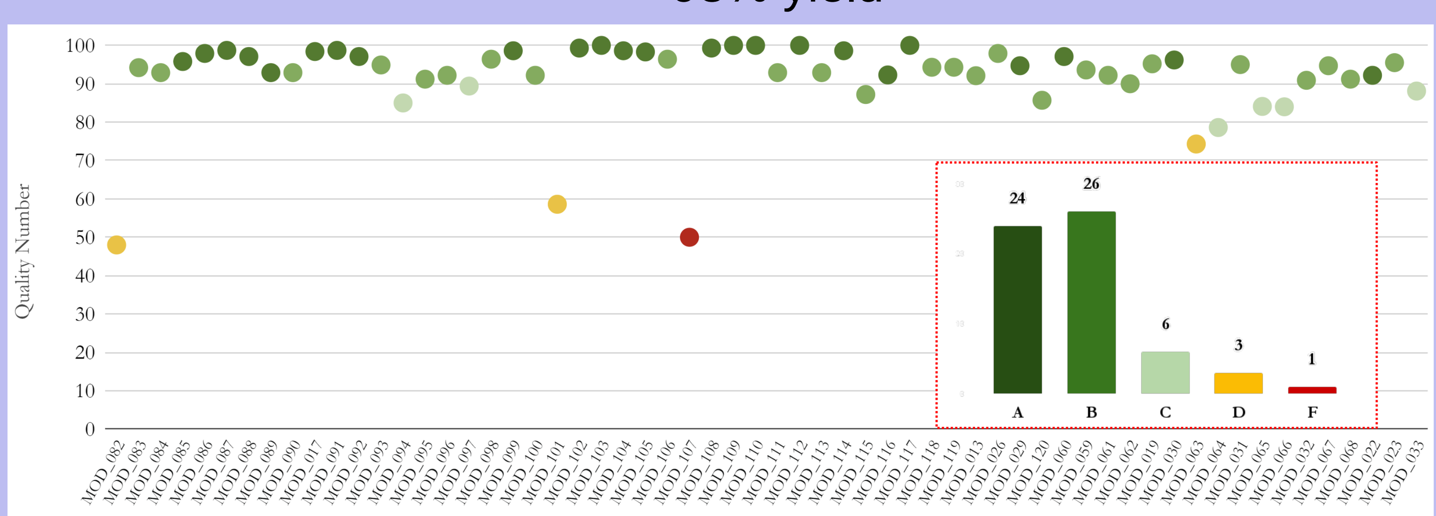




## Assembly Campaign

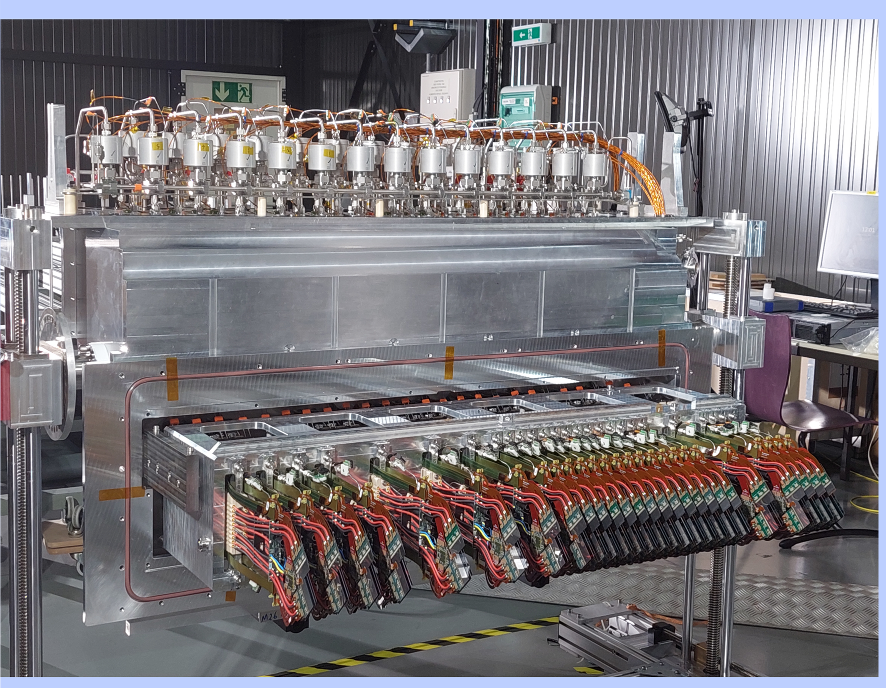
- 60 modules produced
- 56 detector quality (>99% eff: A,B,C grade)
- > 93% yield




## VELO Assembly @ Liverpool

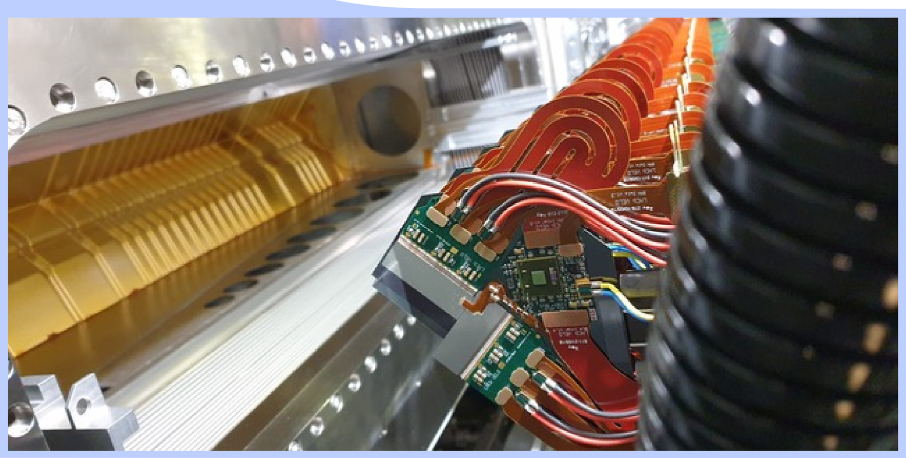
- Electrical performance re-validated after installation onto the VELO base
- Simultaneously test 26 modules (full half!) for cooling and leak tightness
- Check modules alignment

## Full Detector Commissioning @ CERN



- Check leak tightness again
- Run "warm" tests:
  - Bit Error rate, HV, LV
- Test temperature sensors
- Metrology

Full detector successfully installed!



## References

[1] Int. J. Mod. Phys. A 30, 1530022 (2015)
[2] LHCB-TDR-013
[3] A Nomerotski et al 2013 JINST 8 P04004