UNIVERSITY OF LIVERPOOL

LHCb

The LHCb VELO upgrade

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PSD12: The 12th international conference on position sensitive detectors

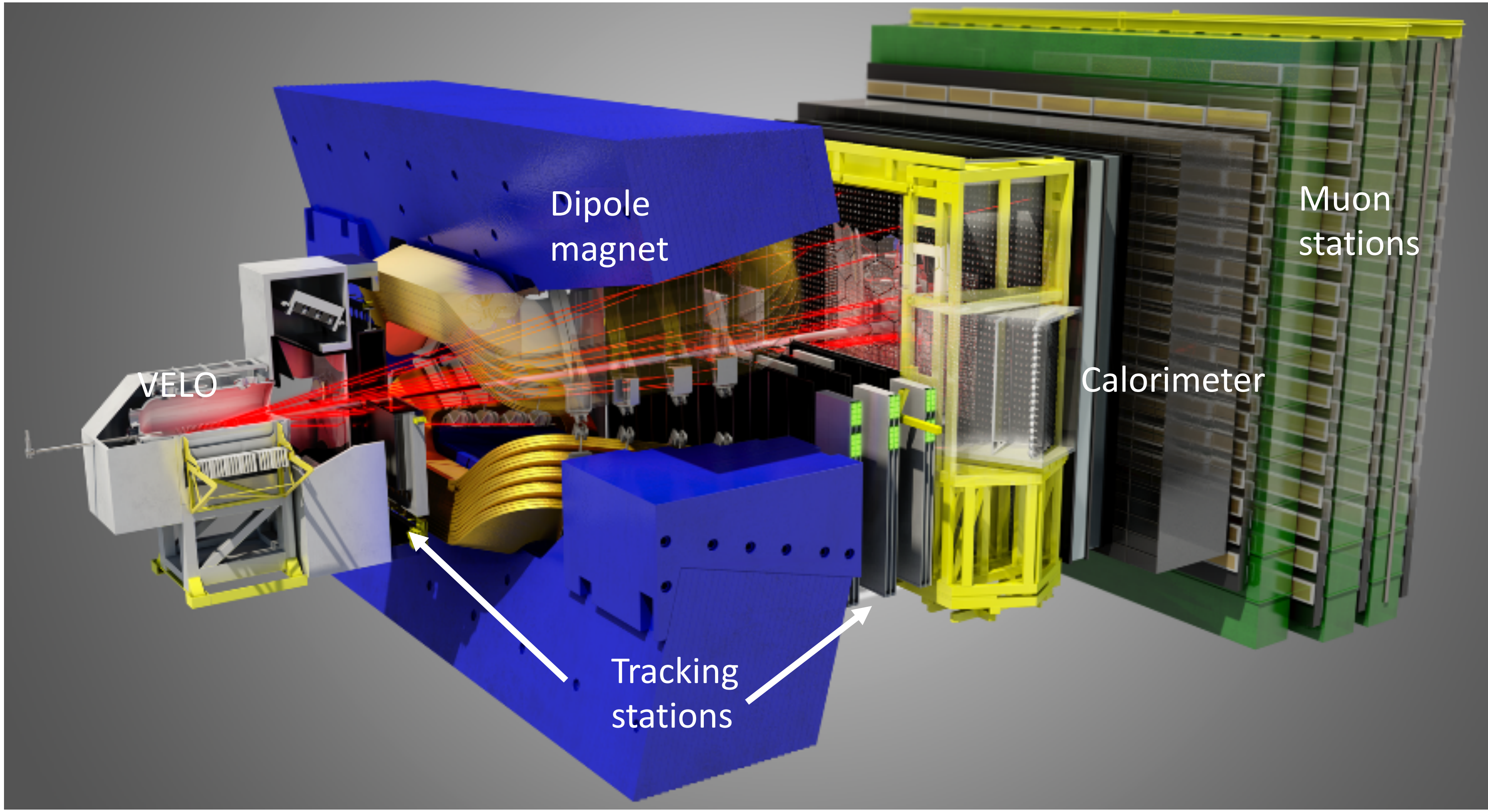
September 12th -17th 2021

Previous LHCb Detector

•The Large Hadron Collider beauty (LHCb) is one of the 4 major experiments at LHC at CERN.

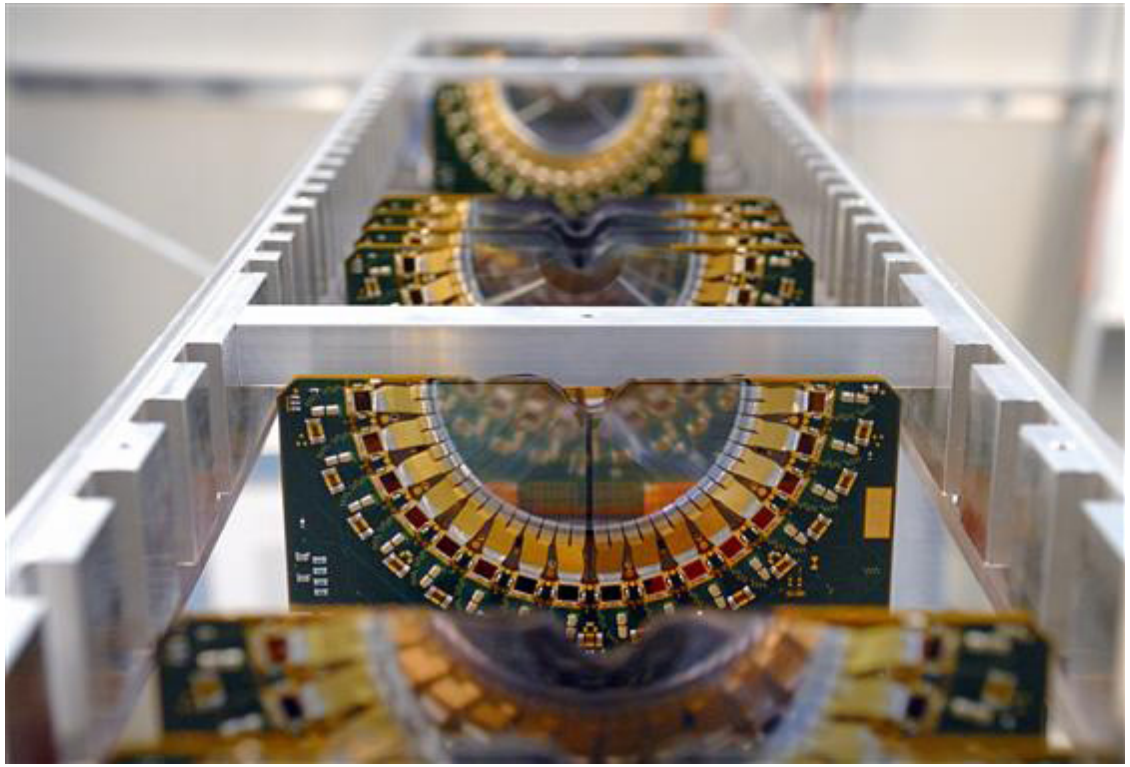
•The detector is a single arm forward spectrometer operating at one of the interaction points of the LHC.

• Its main purpose is to study CP violation, rare decays and more, focusing on b- and c-hadron decays.



Previous VELO Detector

- Responsible for vertex and track reconstruction.
- 42 modules operated in vacuum.
- Silicon strip sensors surrounding the interaction point.
- CO_2 cooling through a series of cooling blocks attached to the base of the module substrate.
- Retractable halves - active region 8mm from beam.
- Radiation Hard - innermost region 1.3×10^{14} n_{eq}/cm^2/year.
- Total power dissipated is ~16.5W/module.

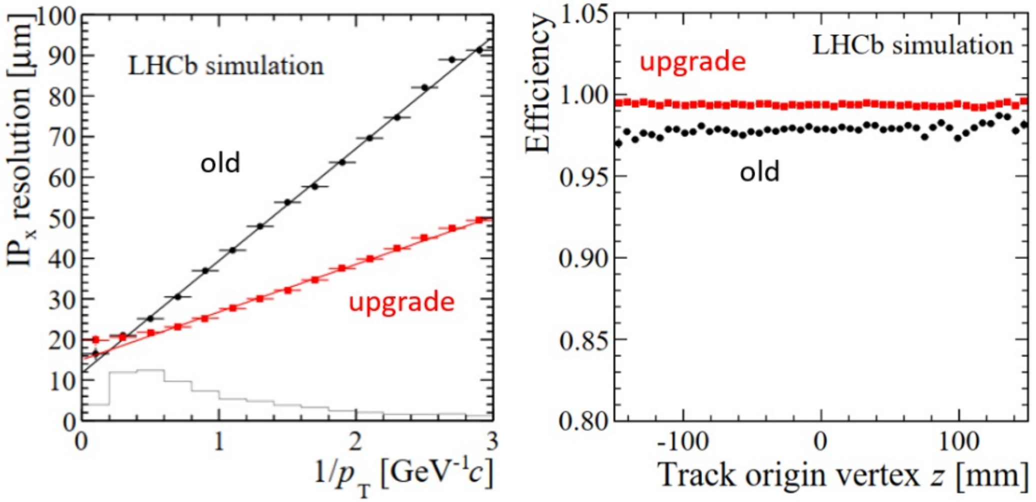


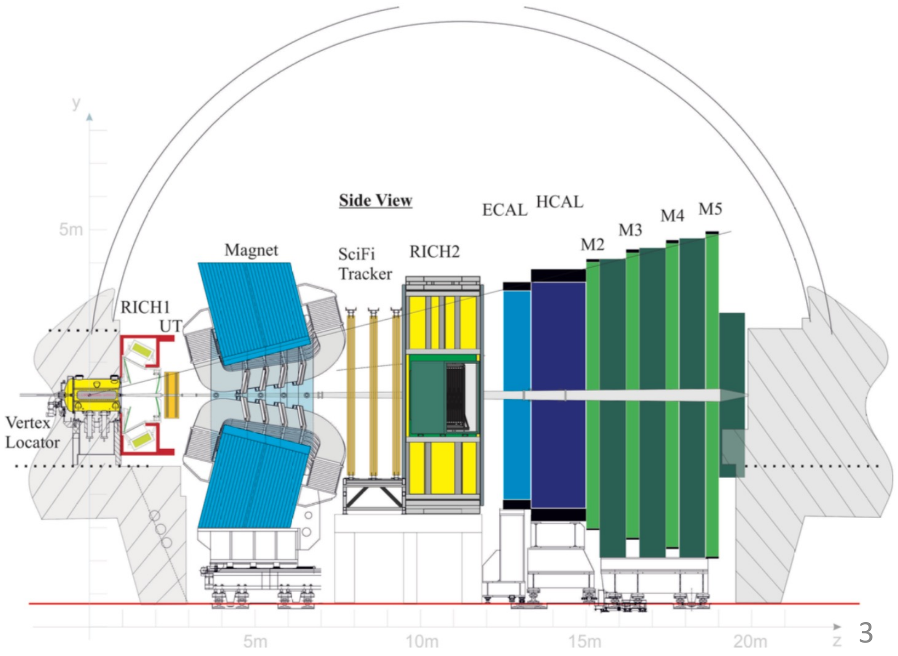
VELO Closed
Stable Beams

VELO Open

Motivation For Upgrade

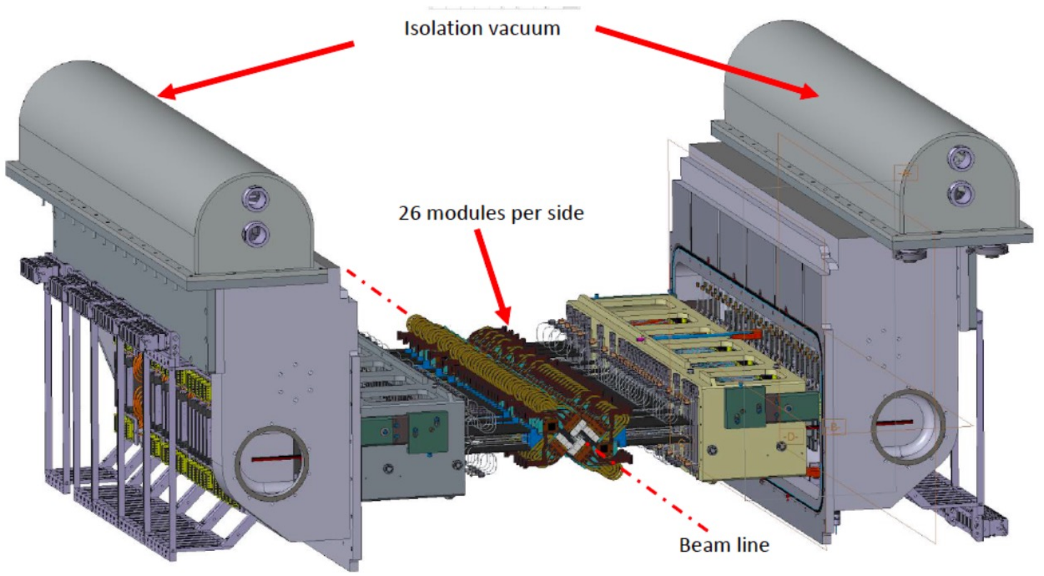
- Precision of many physics measurements at LHCb will be statistically limited at end of Run II.
- But many hadronic channels saturate due to energy cuts in the hardware trigger therefore remove this trigger.
- Software trigger only
- 1MHz→40MHz readout rate
- Boost statistics with increased luminosity
  $4x10^{32}cm^{-2}s^{-1} \rightarrow 2x10^{33}\ cm^{-2}s^{-1}$
- $50\ fb^{-1}$ expected in Run III and IV
- Data taking in Run III starting 2022



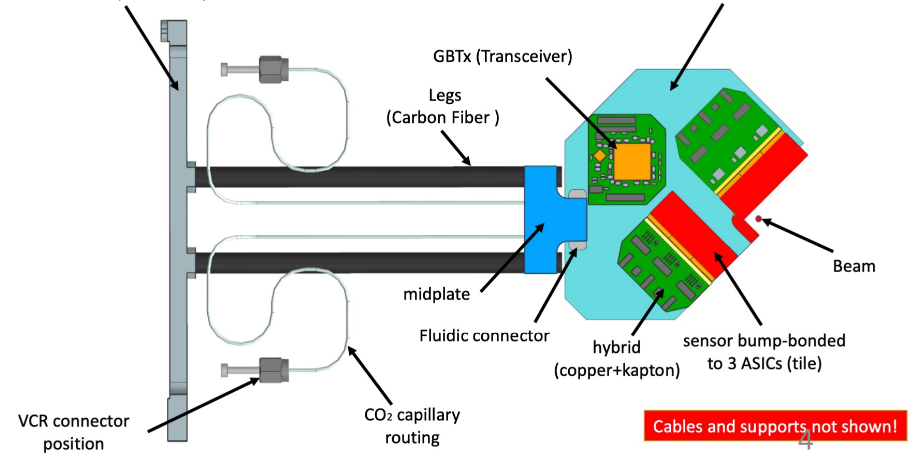


VELO Upgrade

- Part of an experimental wide upgrade to all detectors.
- Better particle recognition (pixels compared to strips).
- Better IP resolution.
- New ASIC VeloPix.
- New silicon substrate containing microchannel evaporative CO_2 cooling.

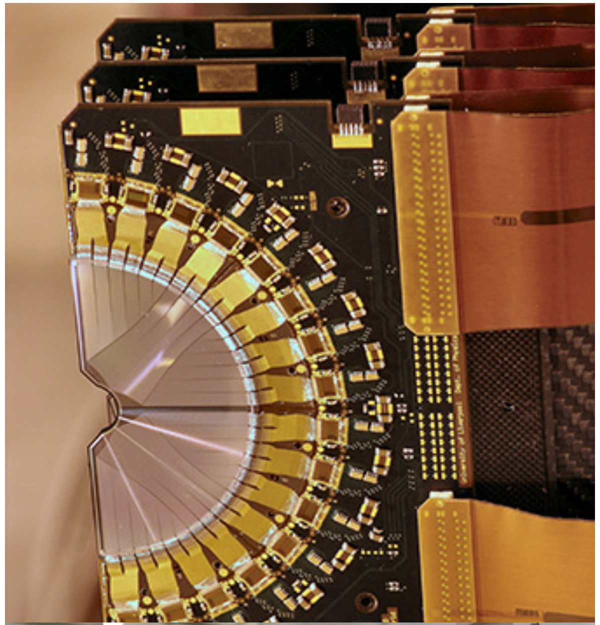


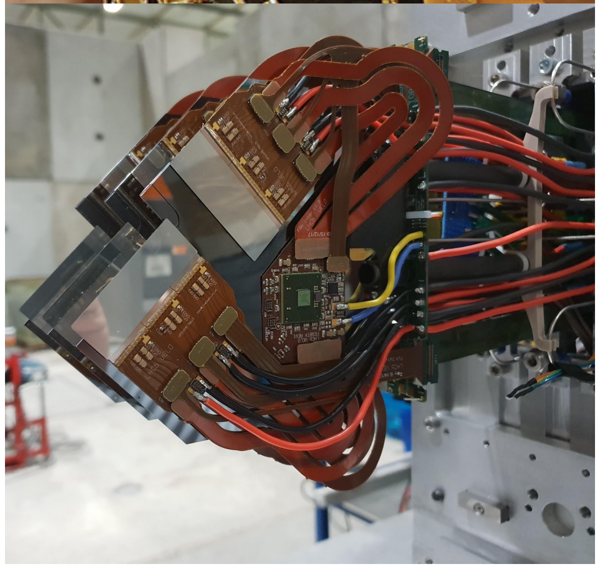
New module design



VELO Upgrade

Feature	Previous VELO	VELO upgrade
Number of modules	42	52
sensors	R and Ø strips 172,032 strips 300 μm thick 40-100 μm pitch	Pixels 41 million pixels 200 μm thick 55 μm pitch
Distance from beam	8.2 mm	5.1 mm
Luminosity	$4x10^{32}cm^{-2}s^{-1}$	$2x10^{33}\ cm^{-2}s^{-1}$
Maximum fluence	$4.3x10^{14}1Mev\ n_{eq}cm^{-2}$	$8x10^{15}1Mev\ n_{eq}cm^{-2}$
HV tolerance	500V	1000V
ASIC readout rate	1 MHz	40 MHz
Total data rate	150 Gb/sec	2.8 Tb/s
Operating temperature	-8°C	-20°C
Power consumption	~0.8kW	~1.6 kW





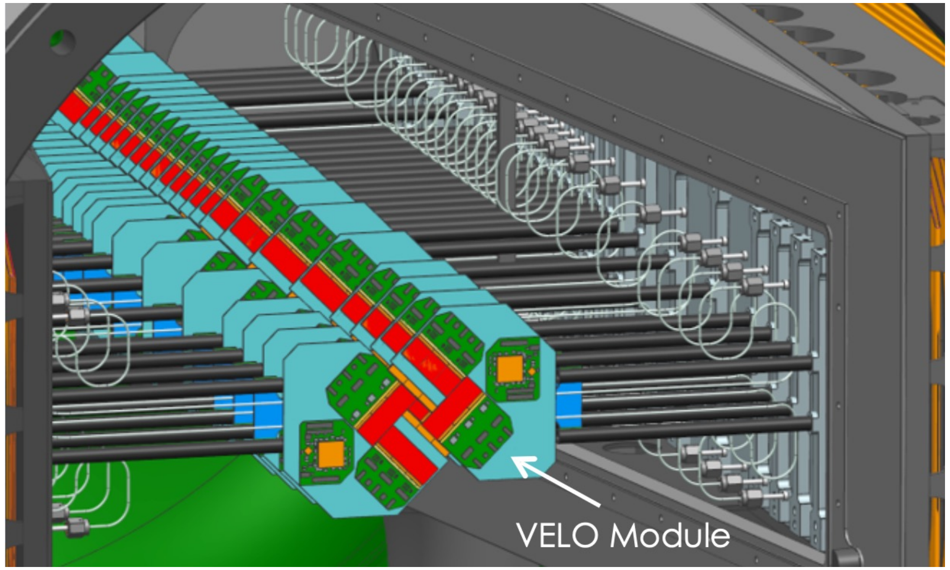
Module Electronics

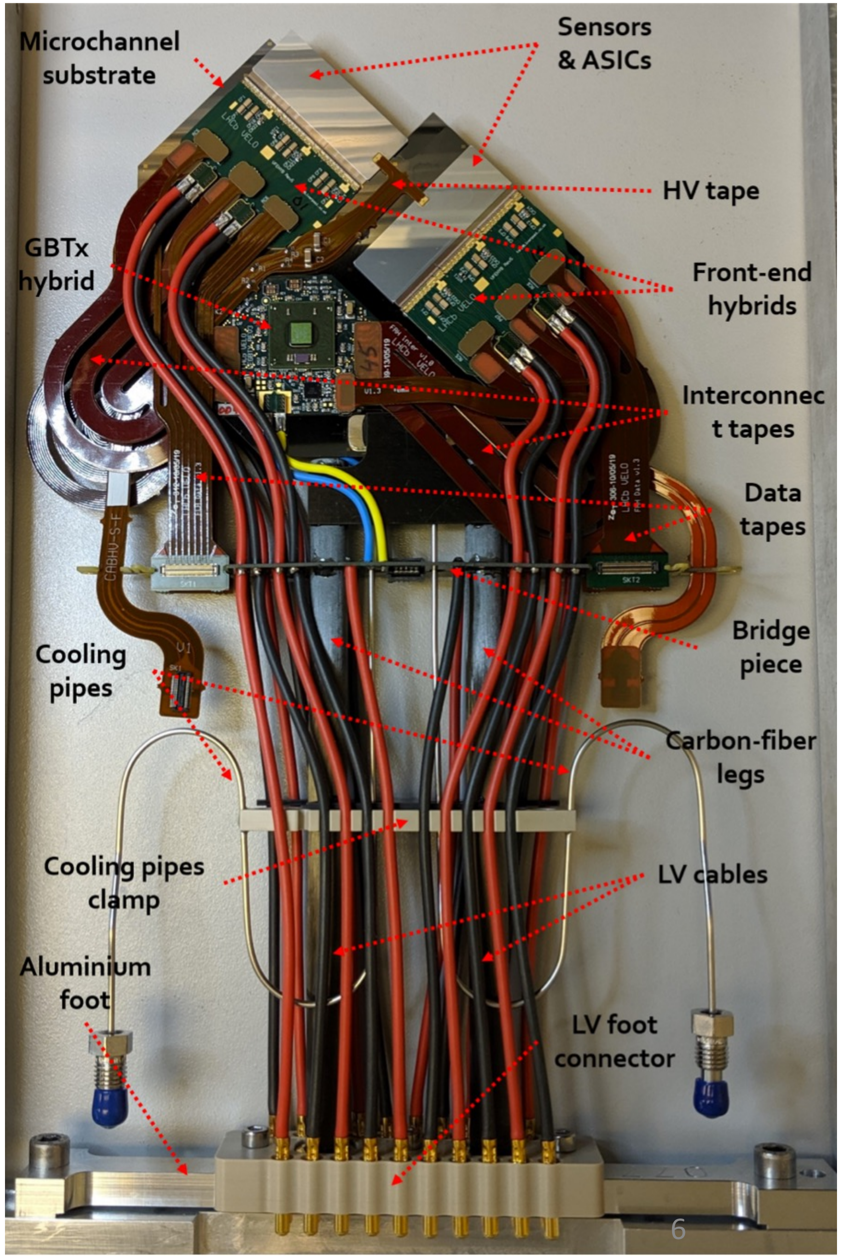
Sensors

- 4 n-on-p silicon sensors per module (thickness 200 µm)
- Sensor is bump-bonded to 3 VeloPix ASICs
- The sensors closest to the beam have a 5 mm overhang from the substrate, to minimise material.

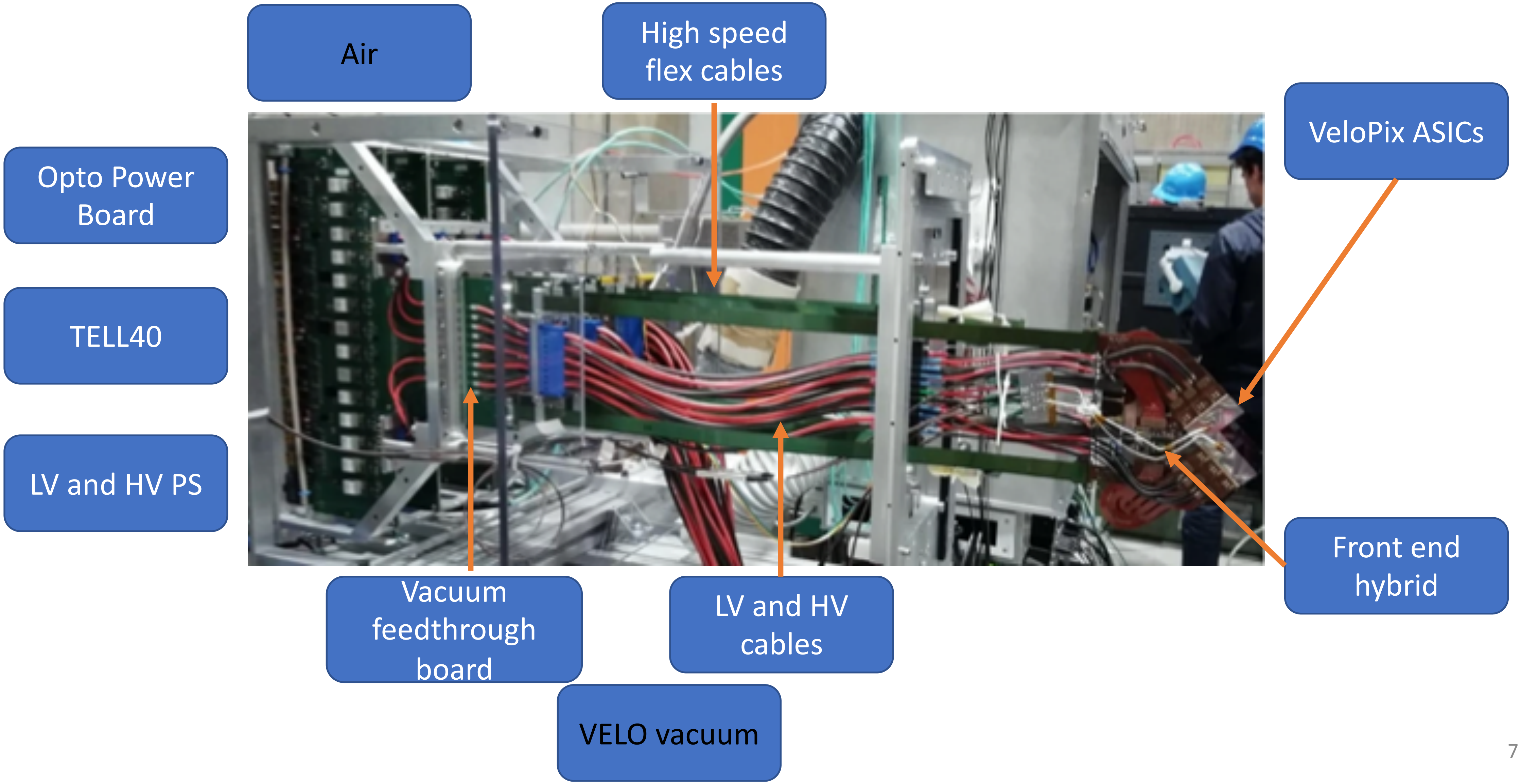
VeloPix ASICs

- 256x256 pixels, with a size of 55 µm × 55 µm
- Data driven readout
- Up to 800 Mhits/s/ASIC
- Power consumption up to 1.5 W/cm^2
- Radiation hardness
- Highly non-uniform irradiation



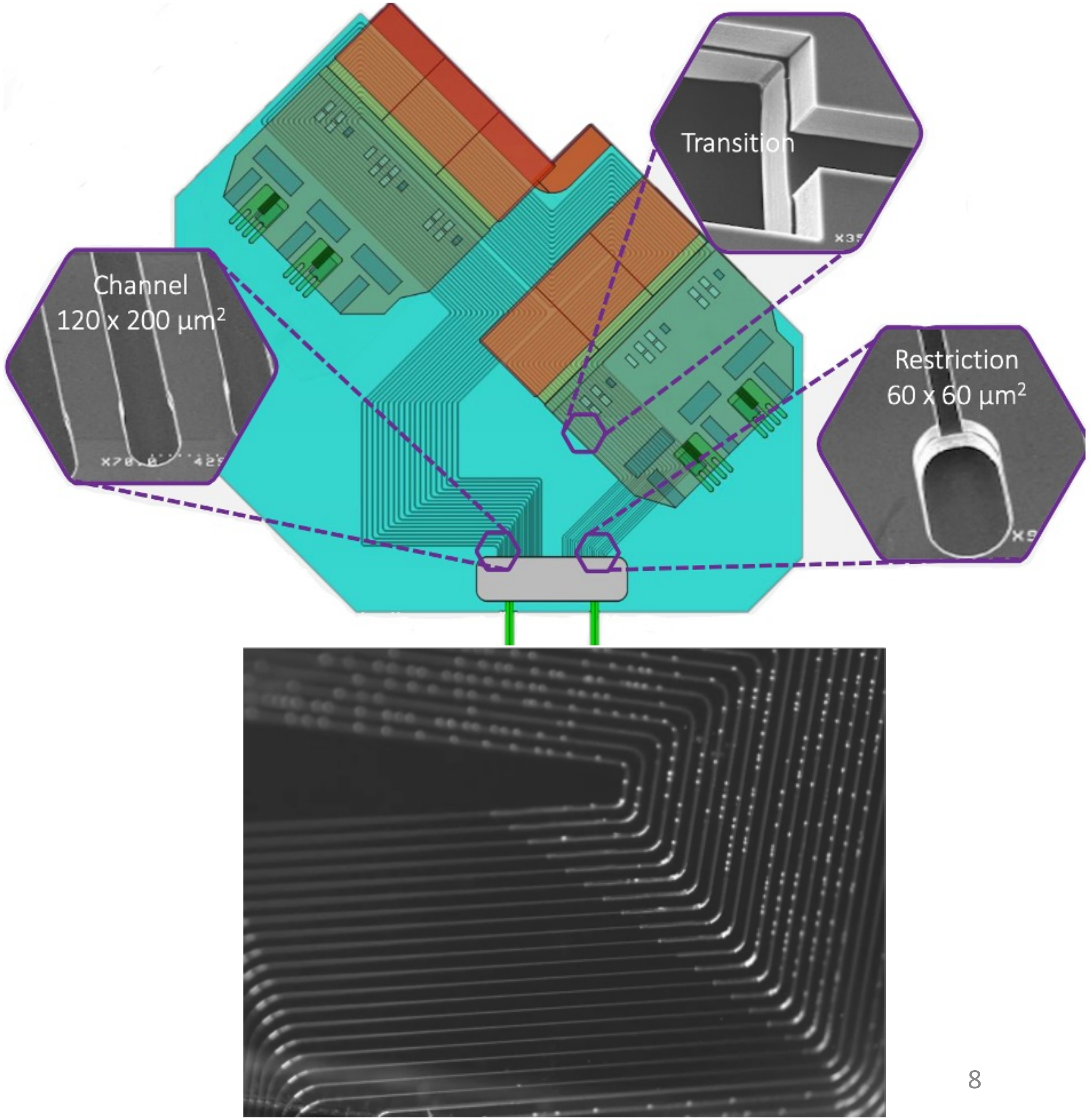


Readout Chain



Module Cooling

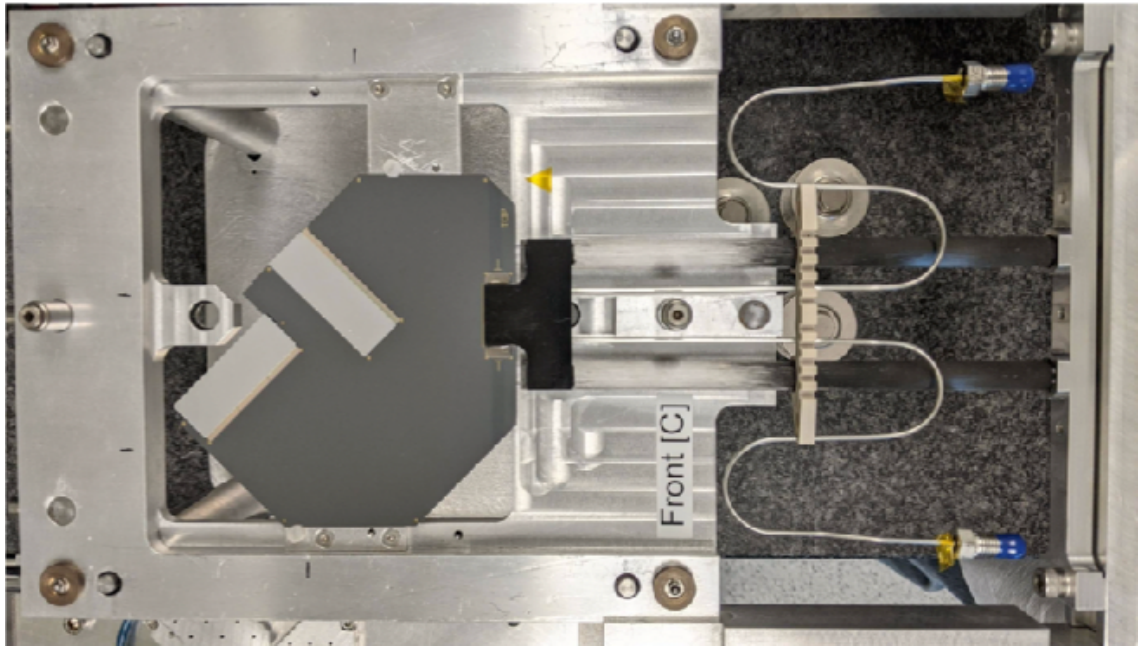
- Microchannel evaporative CO_2 cooling.
- Sensor temperature < -20 °C (CO_2 at -30 °C).
- Designed to cool a load of up to 30W from each module.
- Narrow restrictions at the entrance 60 µm x 60 µm (40 mm long).
- Main channels 120 µm x200 µm microchannels in silicon substrate (~260 mm in average).
- The sudden increase in cross section between the restriction and the main channels triggers the boiling.

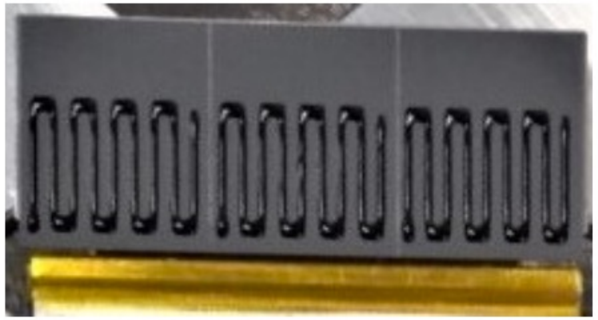


Module Production

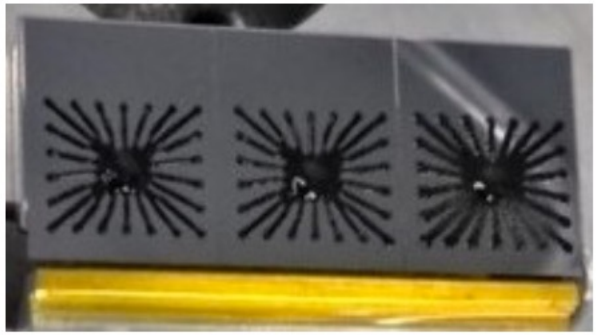
Module production taking place at both Nikhef and the University of Manchester.

- At first, the bare module consisting of aluminium foot, carbon fibre legs, mid- plate and the cooling substrate is constructed.
- Tile glueing: To achieve the best cooling performance delivered to all VeloPixes, a thin uniform layer of glue has to be deposited.
- Tests of gluing pattern to optimize tile glueing procedure. Using Stycast 2850FT with catalyst 9, targeting a 80µm thick uniform layer.





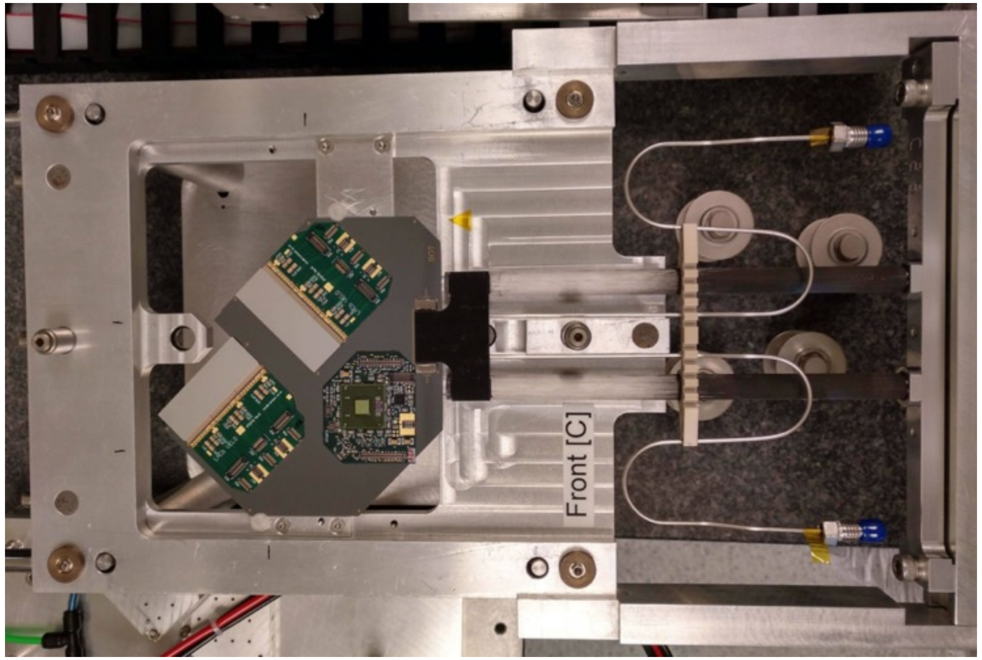
(a) Snake pattern.

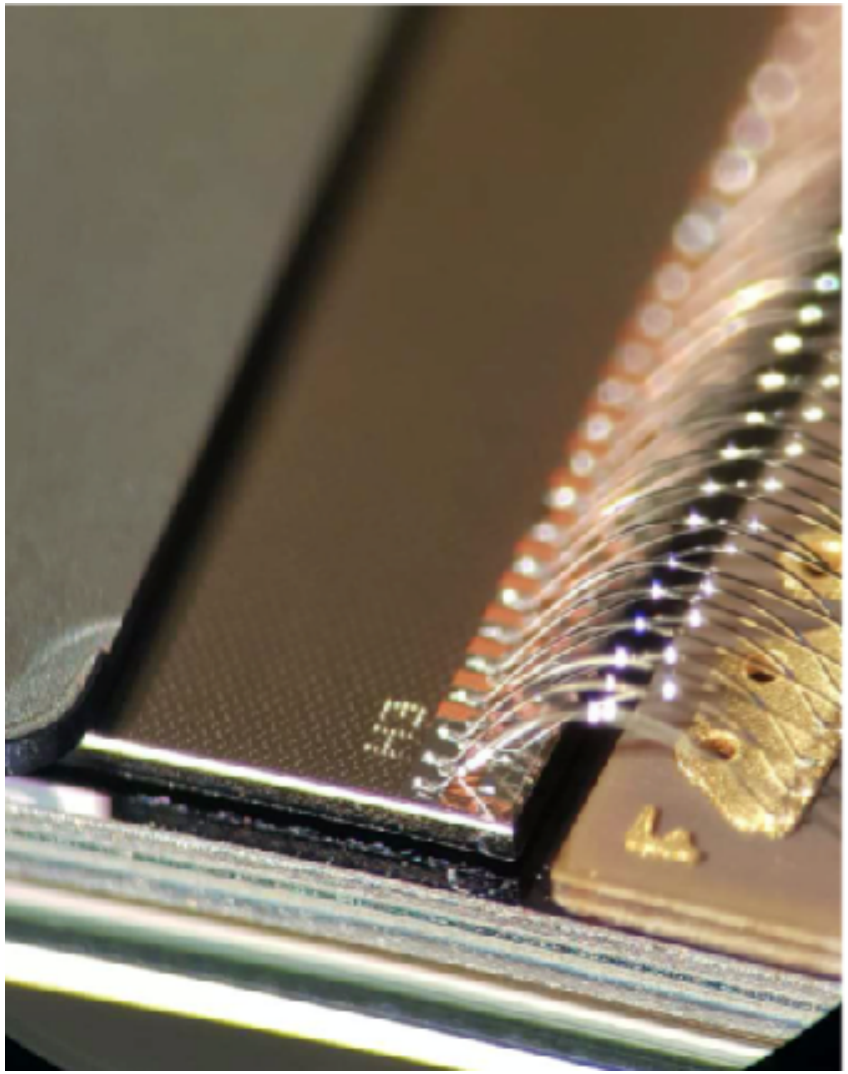


(b) Star pattern.

Module Production

- The hybrid ASICs attached using a standard loctite glue, HV tapes using a drop of Araldite 2020.
- Wire bonding ASICs to hybrid: Each of the 4 tiles must be wire bonded to its associated hybrid circuit, with a total of 420 bonds per tile. The procedure is done separately for the two sides, connection of ASICs to the front-end hybrids and HV tapes to the sensor surface in one go.
- Attach all the LV cables and data tapes for powering and module readout

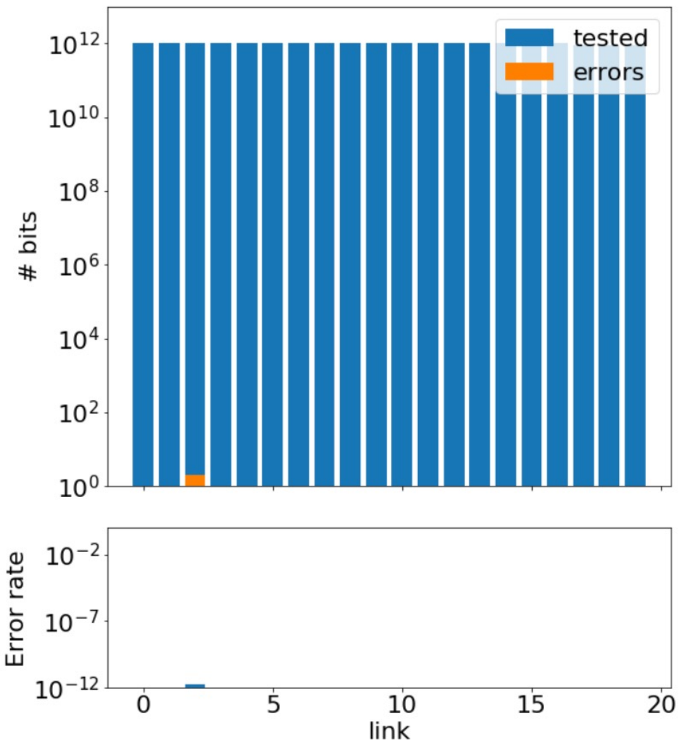


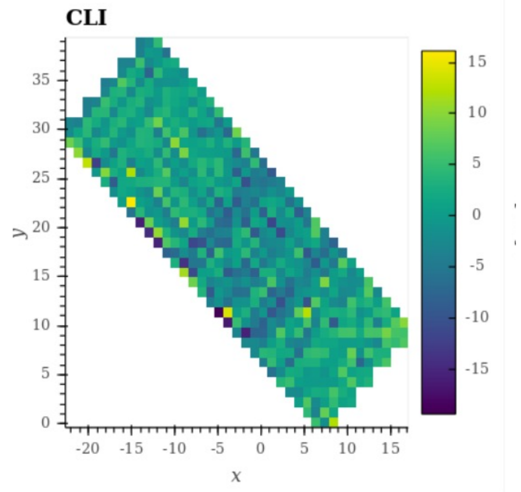


Module Testing

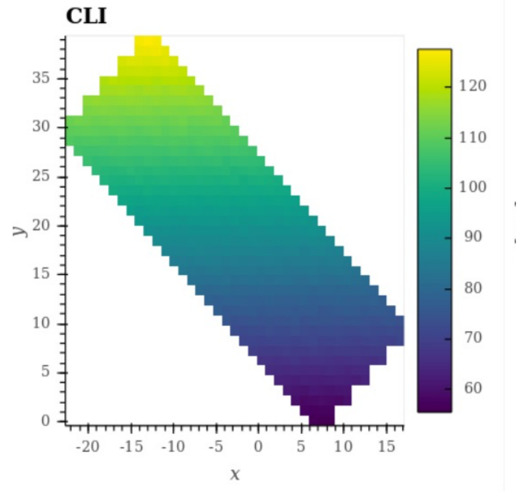
After assembly every module goes through extensive QA testing

- Mechanical performance
  - IV curves
  - *Displacement test*
  - *Thermal cycling*
  - *Thermal performance*
- *Communication test*
  - *TFC (timing and fast control)*
  - *Equalization*
  - *PRBS (pseudo-random bit stream)*
- *Metrology*
  - *Cooling substrate flatness*
  - *Glue layer thickness and tile flatness*
  - *Tile position*
  - *Pull test*





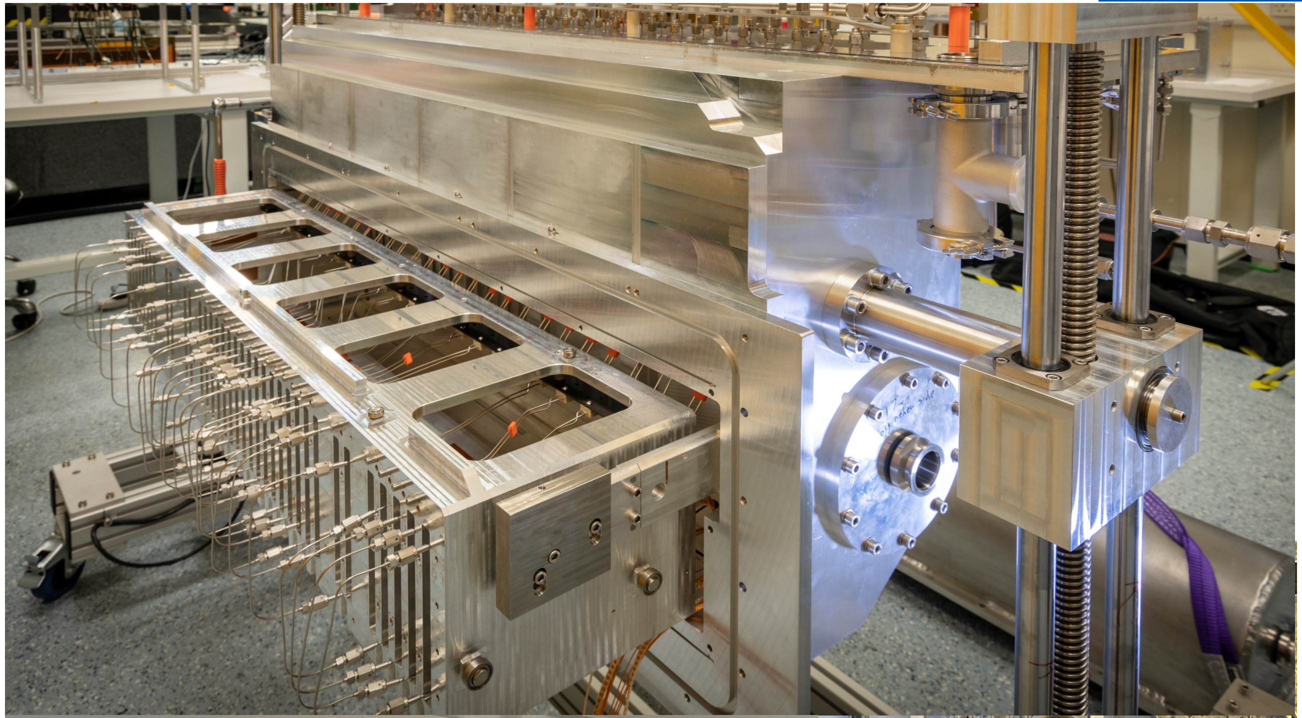
(a) Tile flatness.

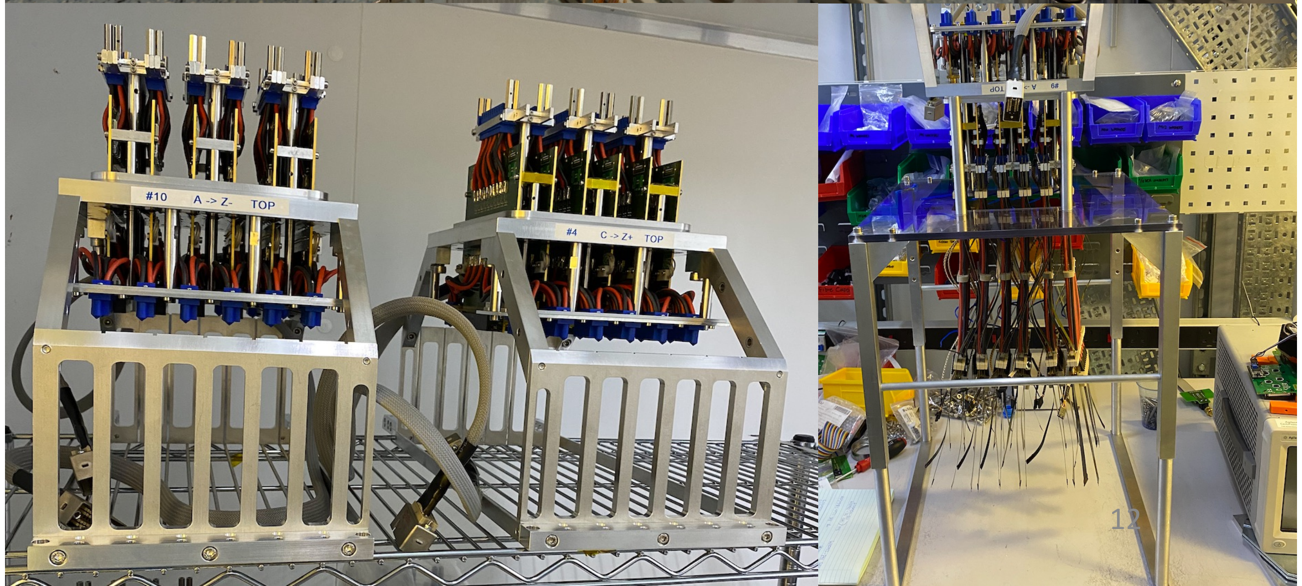


(b) Glue layer thickness.

VELO Assembly

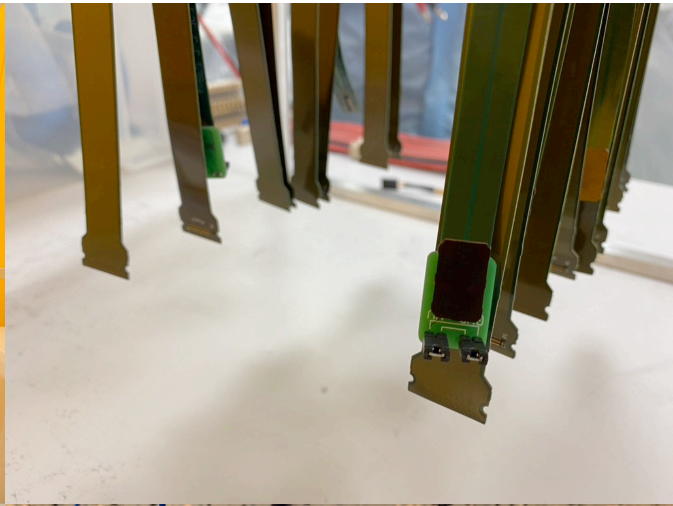
- All modules to be shipped to the University of Liverpool where both VELO halves are assembled and shipped to CERN.
- Assembly of all power and data readout infrastructure for connecting modules.
- Mounting of modules, qualification, performance checks and metrology.

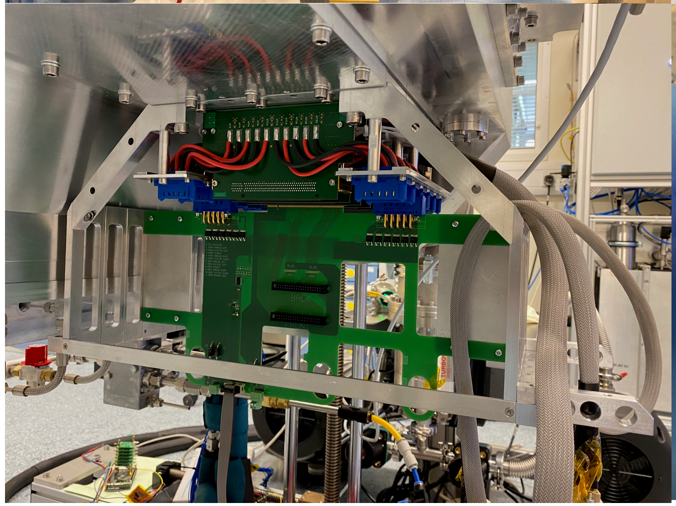


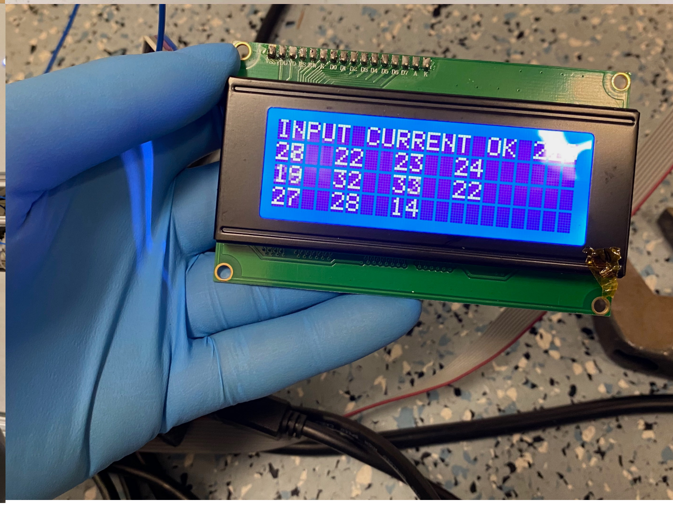


VELO Assembly

- Extremely delicate work
- Quality control is carried out for every power and data channel for all 26 modules per VELO half:
  - Data cable time domain reflectometry
  - HV connection tests
  - LV resistance tests
  - PT100 resistance tests
- Entered into a database that records the position of each item and tracks all tests and actions performed on each item.







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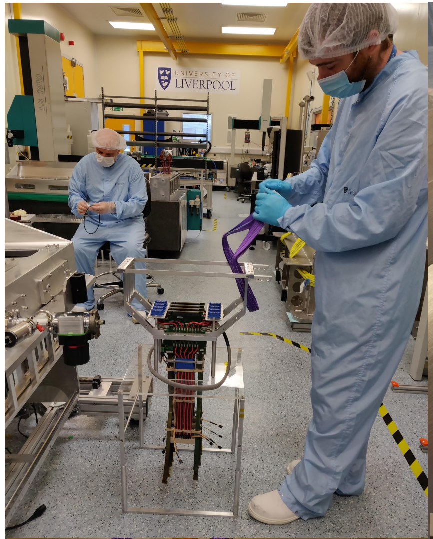
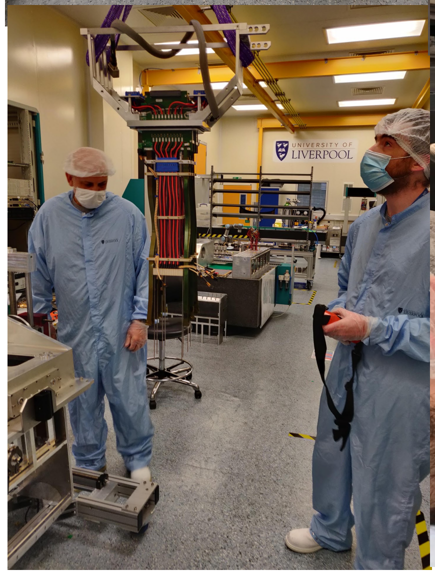
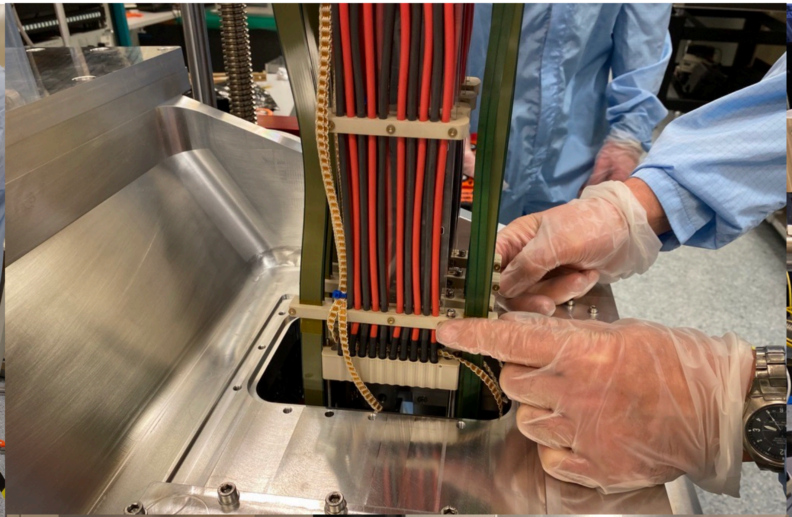
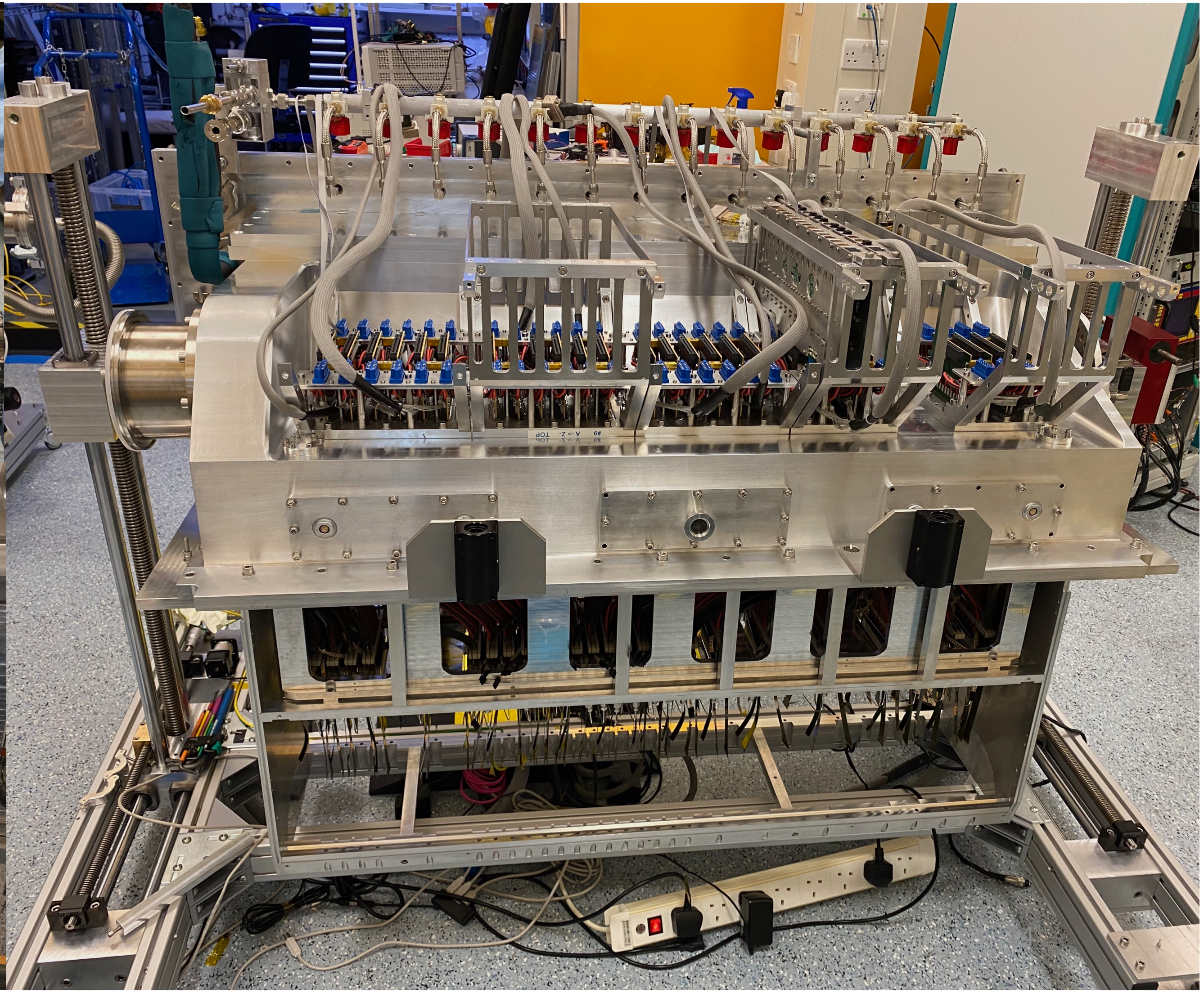
Flange Installation

LHCb

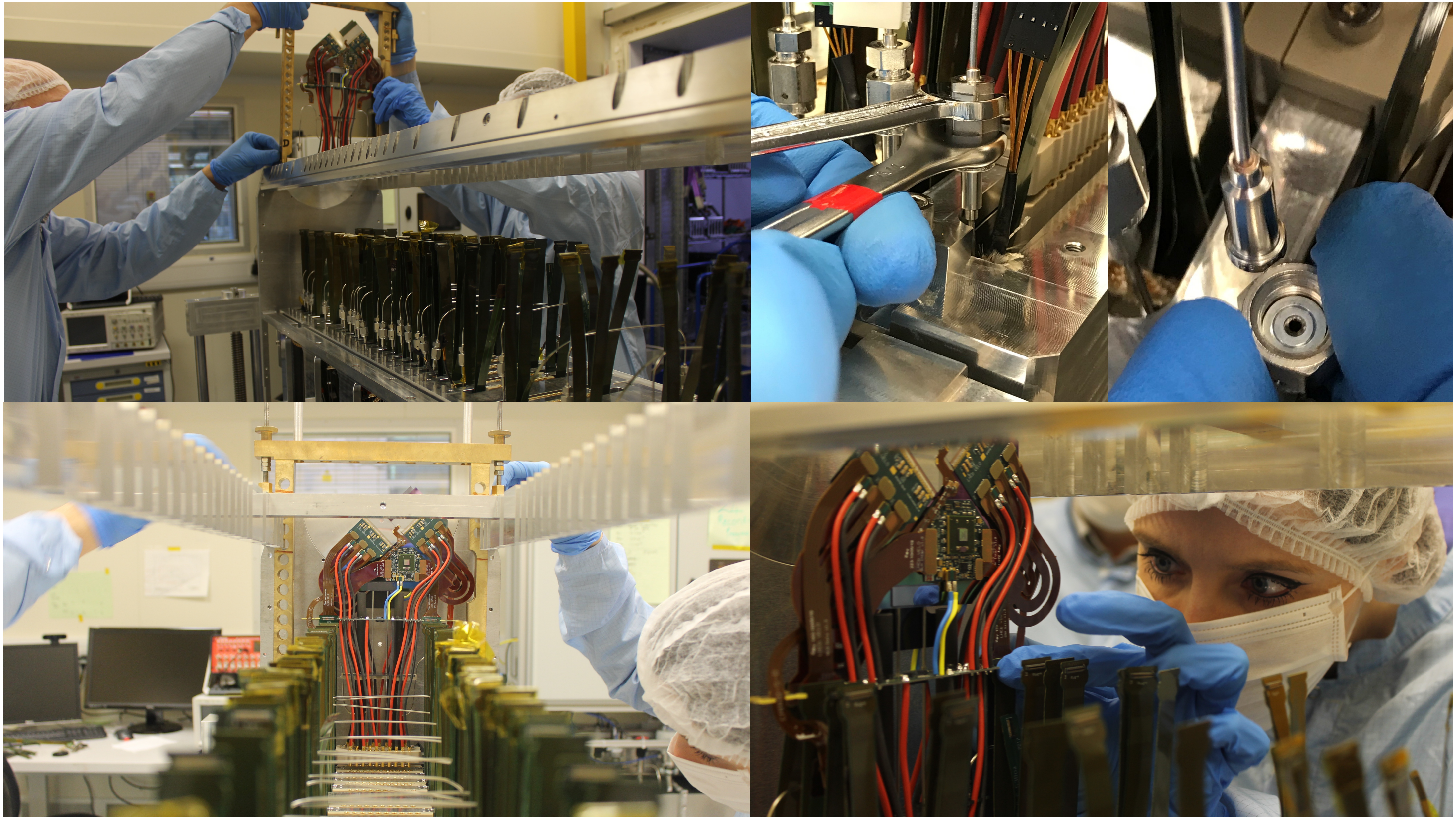




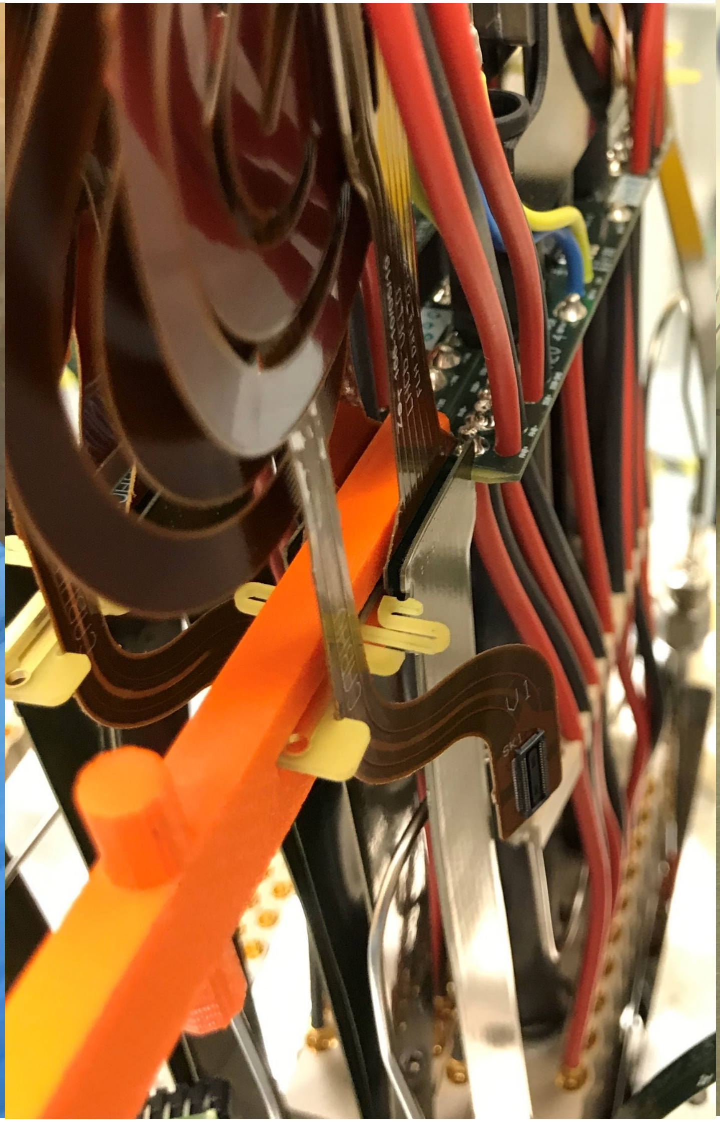


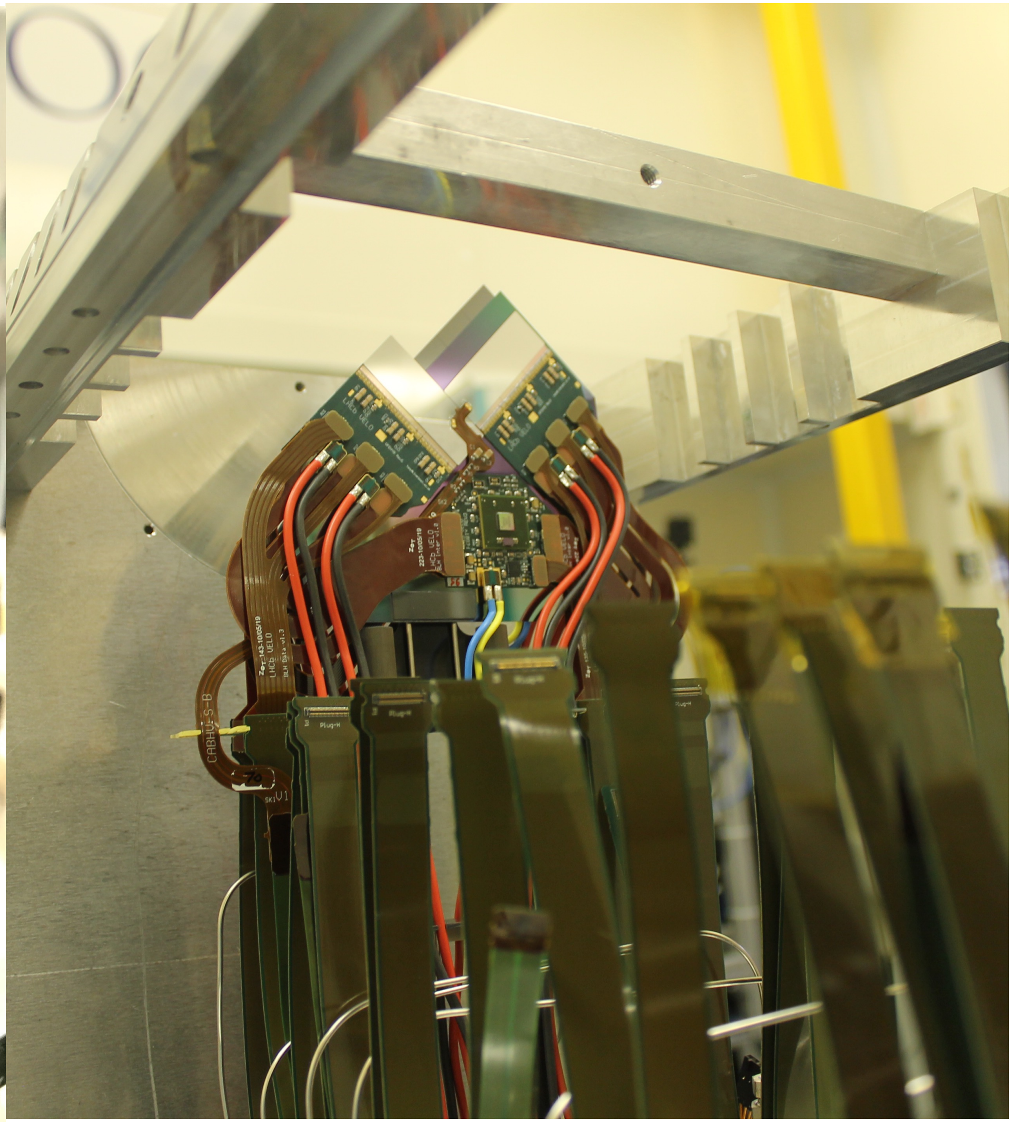


First Module Insertion



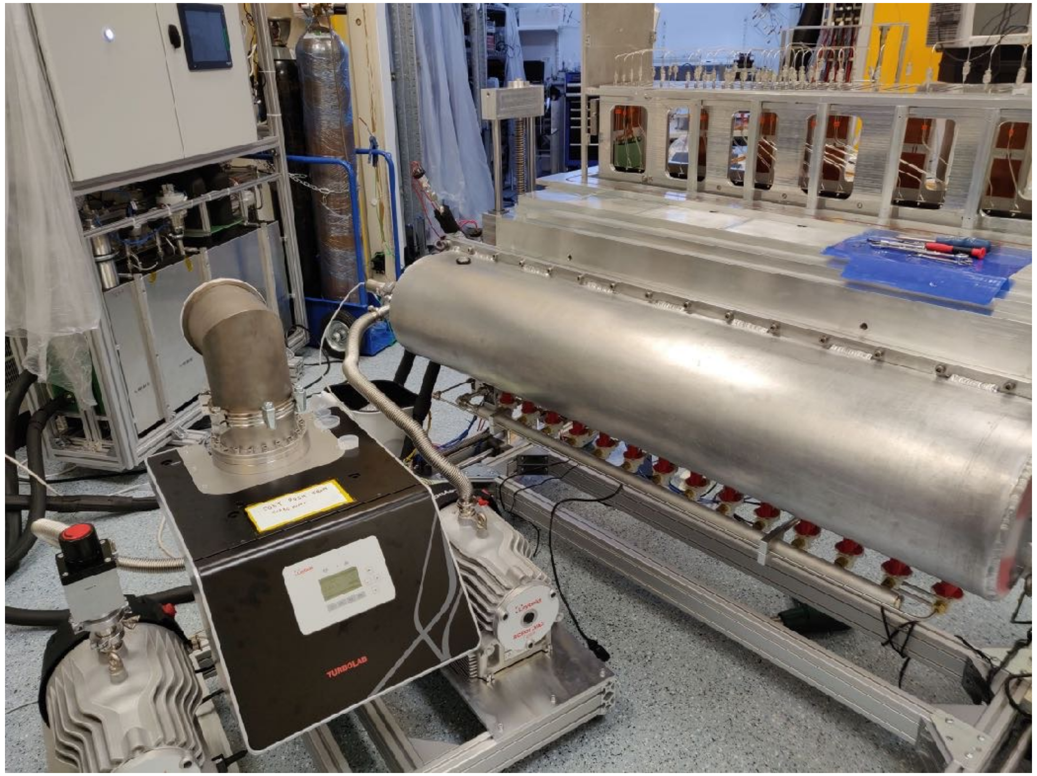
First Module Insertion



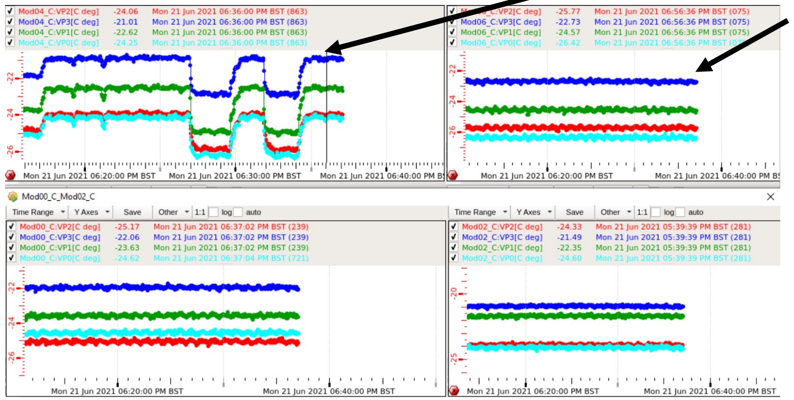


Cooling Commissioning

- Ensure all 4 modules on both the shortest and longest loops boil in the correct place at the same time.
- Make sure this can be done at the nominal flow.



-30ºC operation

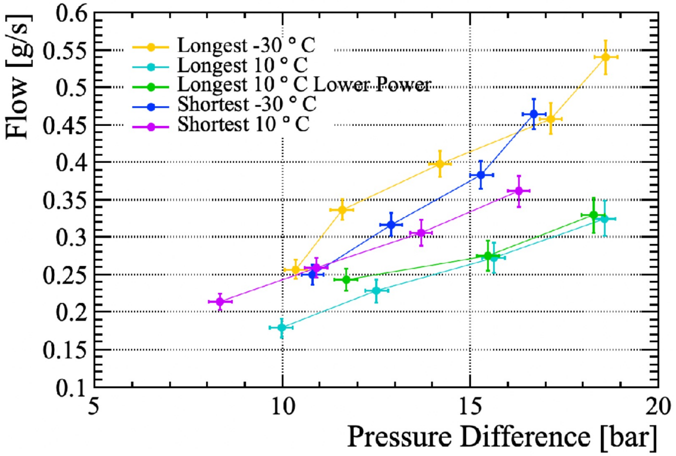


Power cycle of one module doesn't affect others

Power cycling all modules, stable operation through out.

All cooling loops independent.

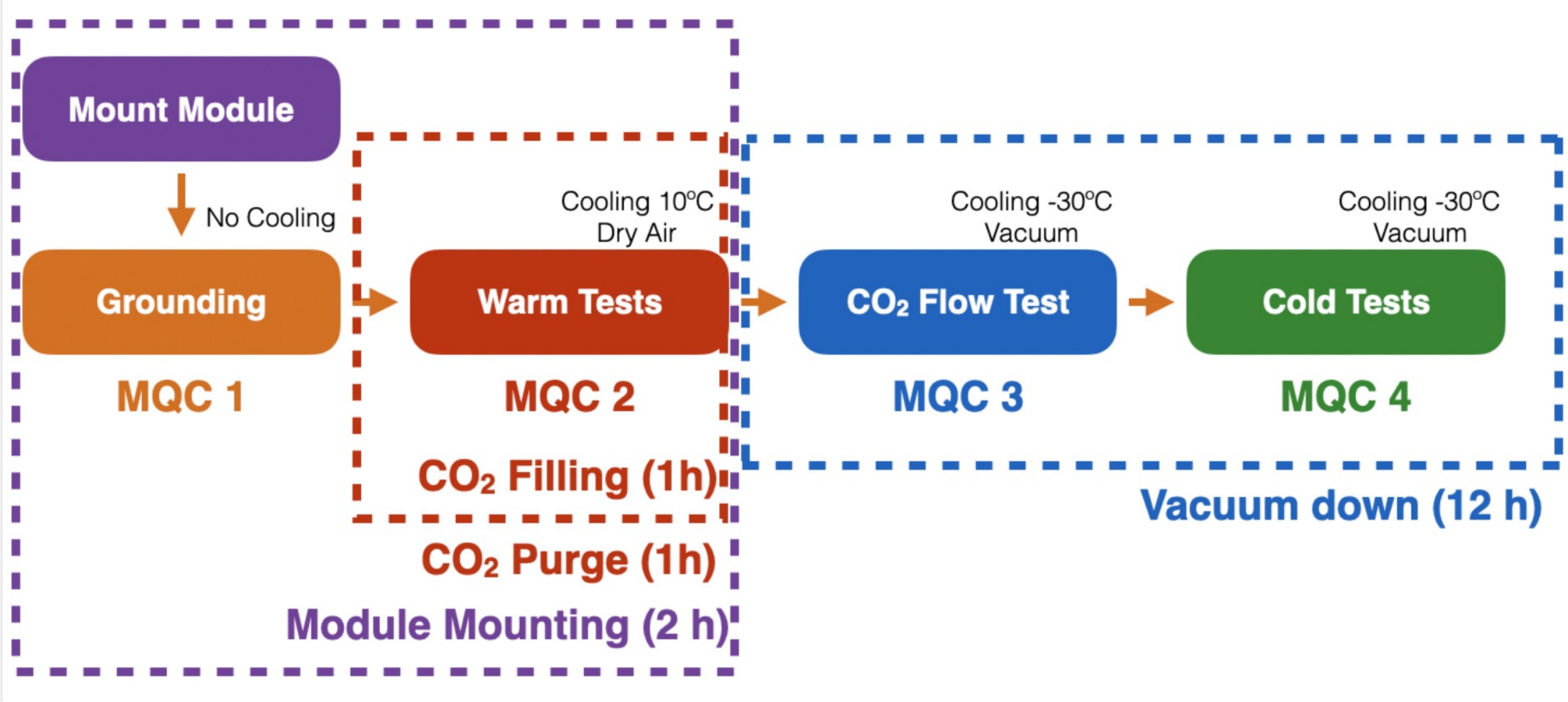
Shortest and Longest Loop



-30º slightly less restrictive.

Reached nominal flow @ -30ºC around 15-16 bar

Mounted Module Testing



Module Quality Control (MQC)1: Grounding

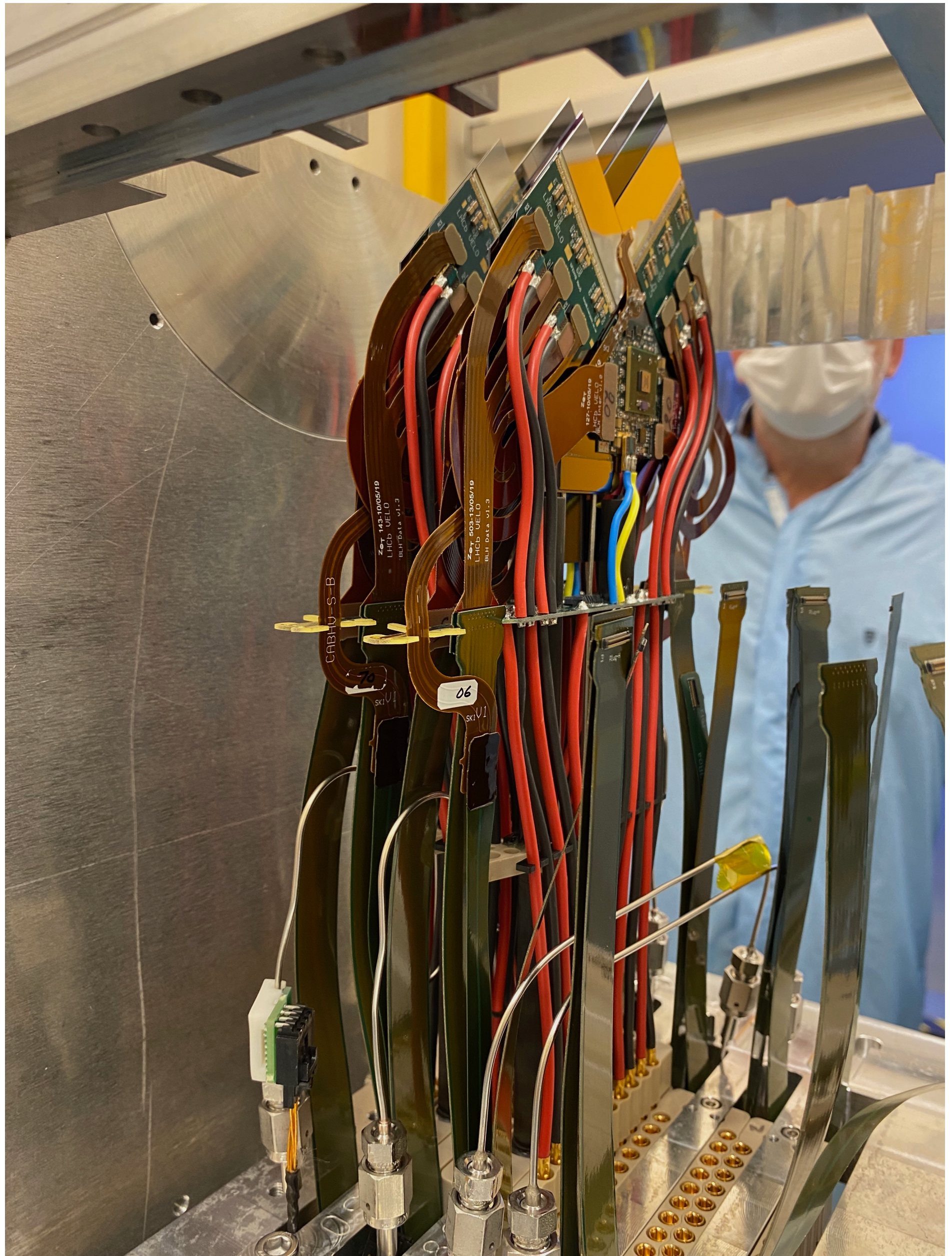
MQC2.1: VPX comm
MQC2.2: TFC check
MQC2.3: PRBS testing
MQC2.4: IV curve

MQC3: Cooling performance and stability test

MQC2.1: VPX comm
MQC2.2: TFC check
MQC2.3: PRBS testing
MQC2.4:Equalisation
MQC2.5: IV curve

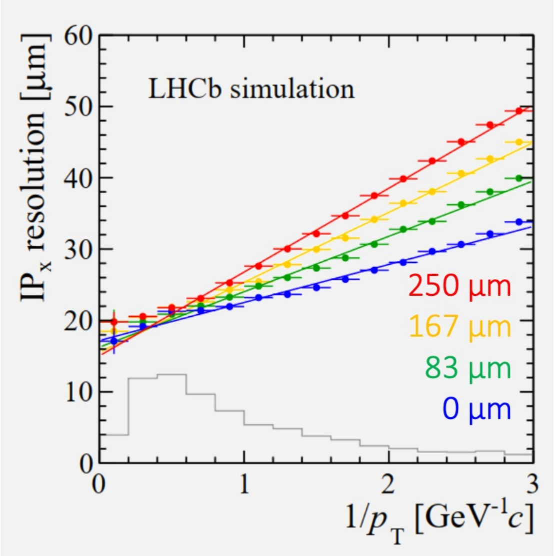
Summary Page

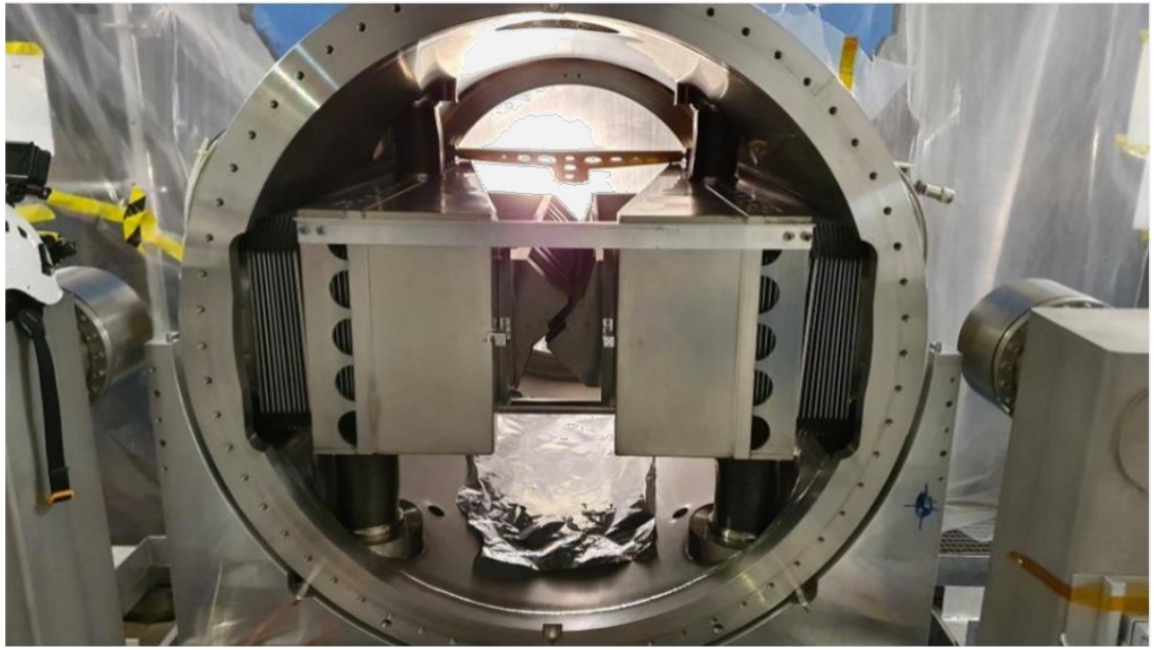
- C-side flanges all installed and passed QA testing
- First two modules installed.
- Aim to have the first VELO half (C-side) to be completed and delivered to CERN by the end of October
- Second VELO half (A-side) to be completed by the end of the year.

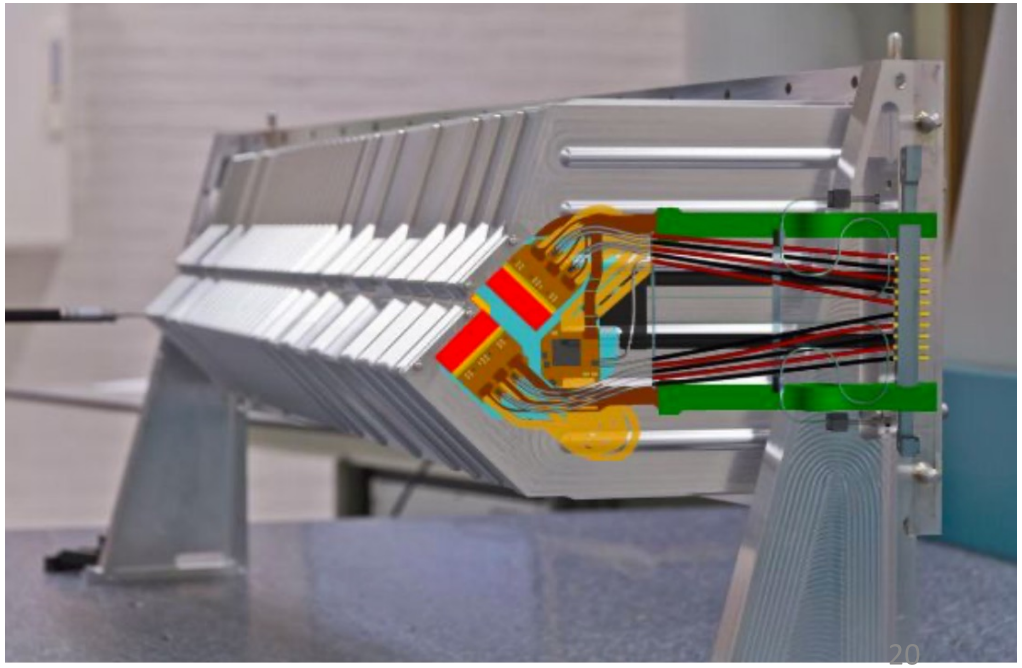


RF Foil

- Modules will be housed in a secondary vacuum separated from the primary LHC vacuum by a thin RF aluminium foil.
- Vacuum tight.
- Must withstand variation of pressure ~10 mbar.
- Must withstands heavy irradiation.
- Light (~200 µm thickness at its thinnest part closest to the beam) , using a combination of milling and chemical etching techniques.







Module Transport

- First VELO half (C-side) to be shipped to CERN end of October
- Transport frame fully constructed
- Van hired for dummy transport tests
- Will perform dummy transport first to check the vibration levels during regular transport, and perform stress test to check level of shocks that may be experienced
- Monitoring of transport will be performed using Monilog Sensor Network