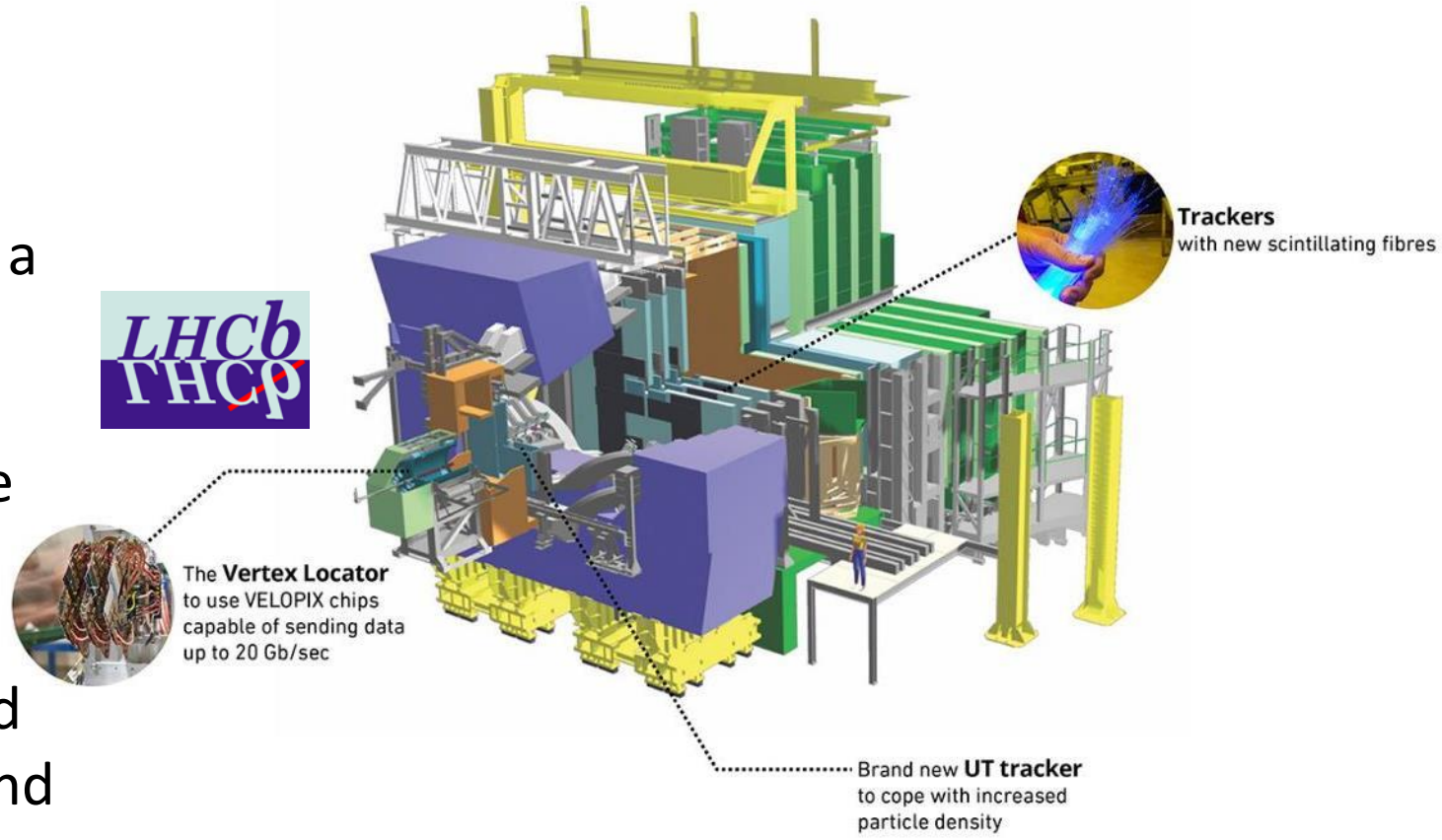
LHCb VELO upgrade

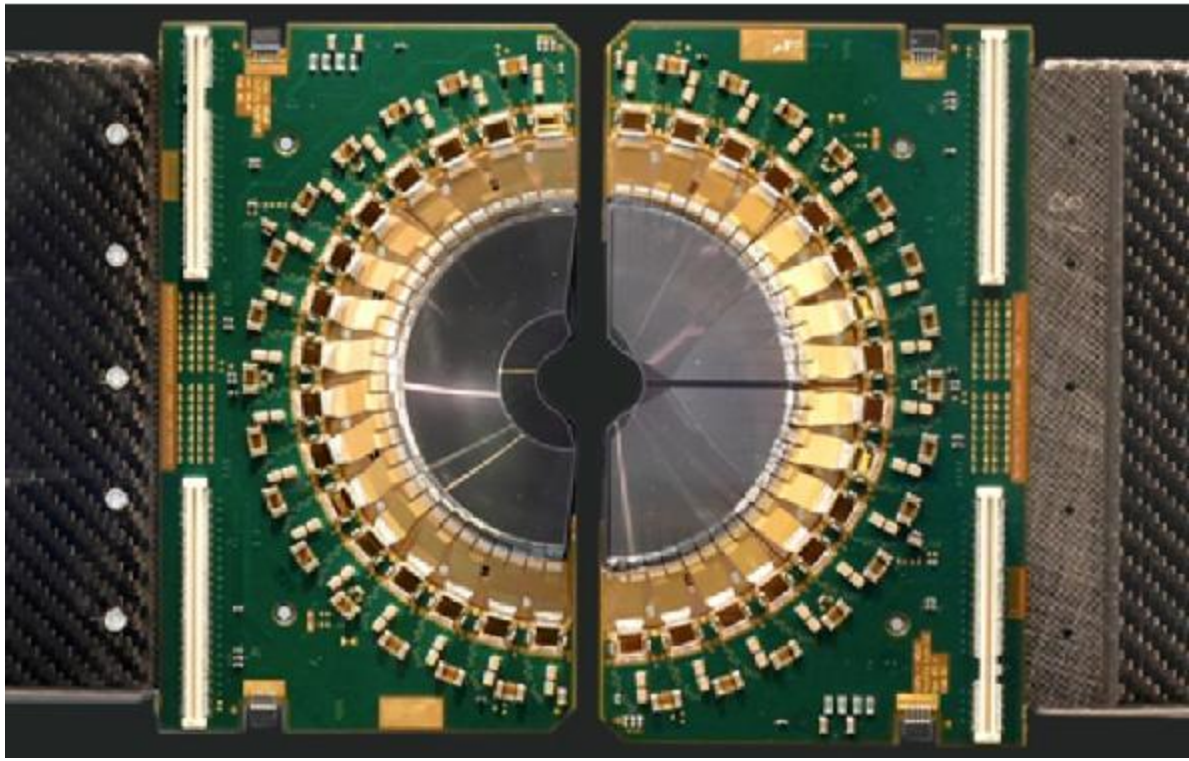
After the success of the Run 1 and 2 LHCb programmes it is time to install a better detector

This is the story of the upgrade to the VErtex LOcator

The second half of which was shipped to CERN on the 27th of March 2022 and installed last week, commissioning is ongoing



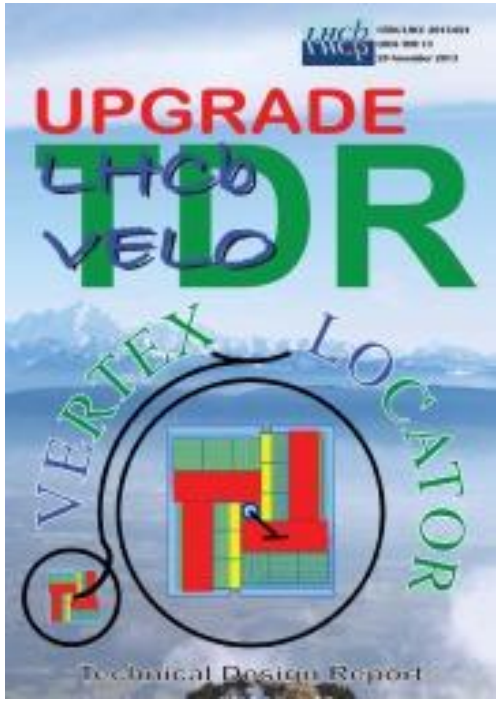
What was the VELO?



- When LHCb was designed during the LEP era (1990 to 2000) it was clear for the b-physics sensitivity a vertex detector with unique properties was required
  - Sensitive areas close to the pp interactions
  - Excellent spatial resolution
  - Very low materiel before the first measurement
  - Very high radiation tolerance
- The team at Liverpool designed, built, tested and delivered the VELO detector (twice!) which exceeded all of the requirements
  - This is not the story of that detector, this is the story of the next one

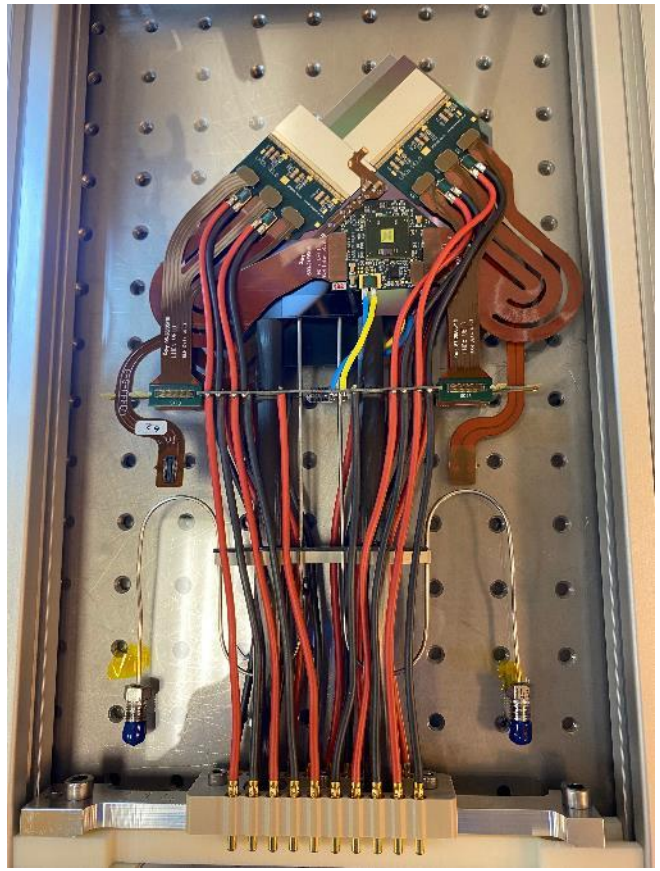
What does the upgrade detector have to do?

- Everything the old detector did but better
  - Better track position resolution
  - Better radiation tolerance
  - Better pattern recognition
  - Faster readout, 30MHz up from 1MHz
  - Designed, optimised, built, delivered and operated in a much shorter time scale
  - Fit into the existing mechanics



CERN-LHCC-2013-021

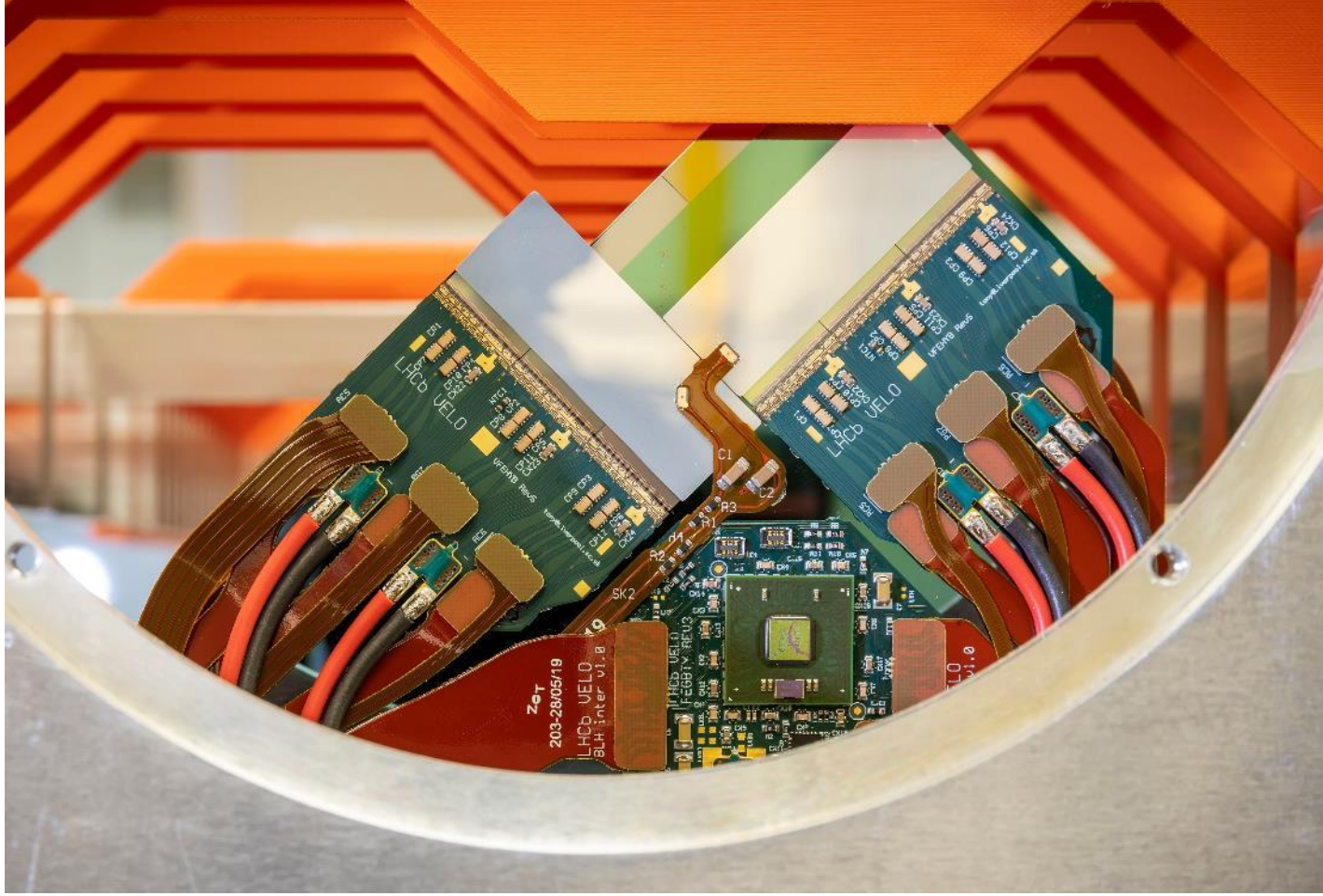
- So we started again and designed a new detector that would meet all of those requirements



Module M107 on arrival at Liverpool 13th September 2021

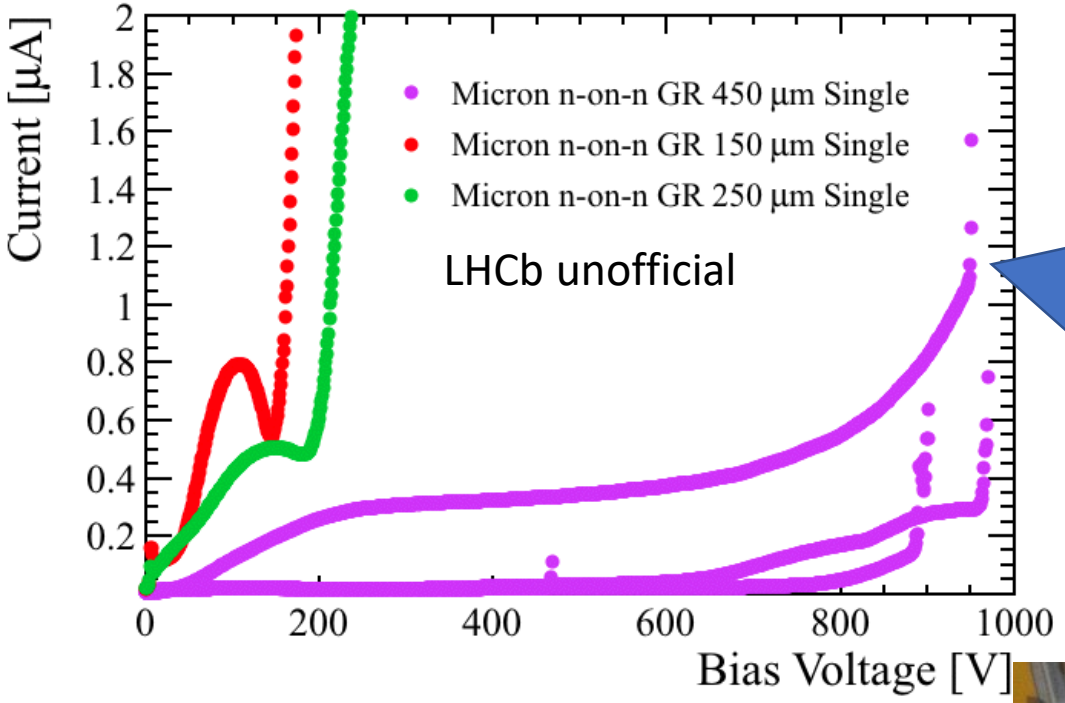
Velo Pixel detector

- The big changes were pixels not strips: mostly for pattern recognition reasons
- 41 million $55 \times 55\ \mu m$ pixels in 208 sensors each $200 \mu m$ thick
- 4 sensors per module (two on each side)
- Starting 5mm from the beams
- Using a thinner RF foil
- Support structure is $500 \mu m$ silicon wafer with $200 \times 150 \mu m$ liquid CO_2 channels in for cooling
- The $45°$ offset optimises the average material seen by the tracks

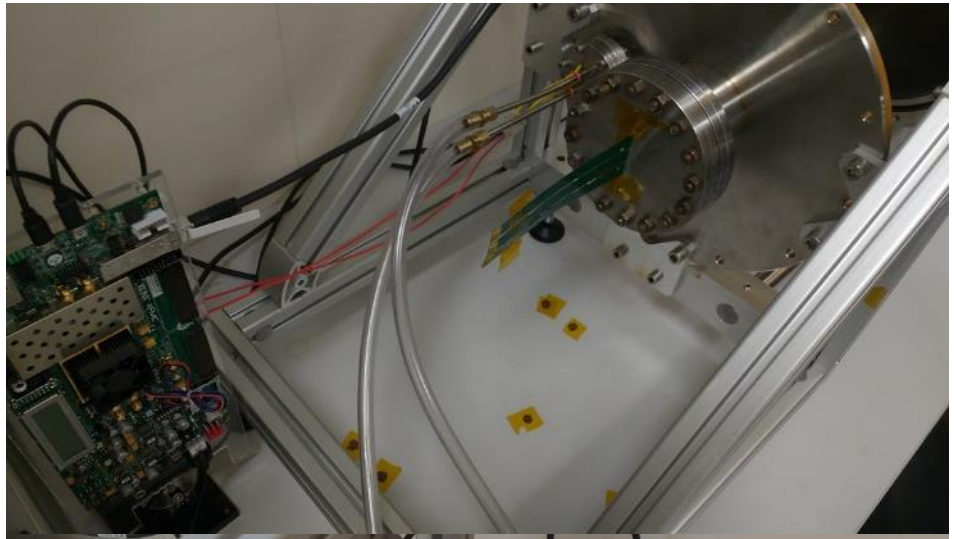


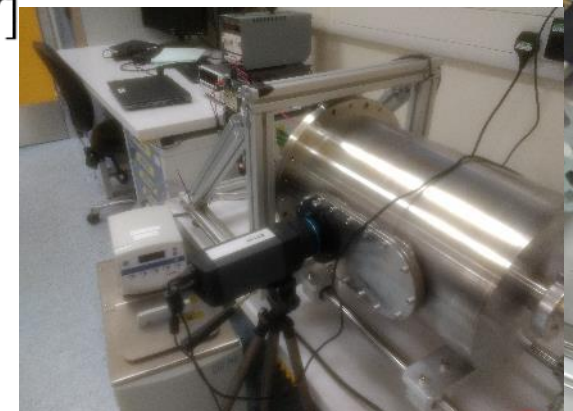
Images courtesy of McCoy-Wynne

Lots of results from test beams and development of sensors and chips (Vinicius)



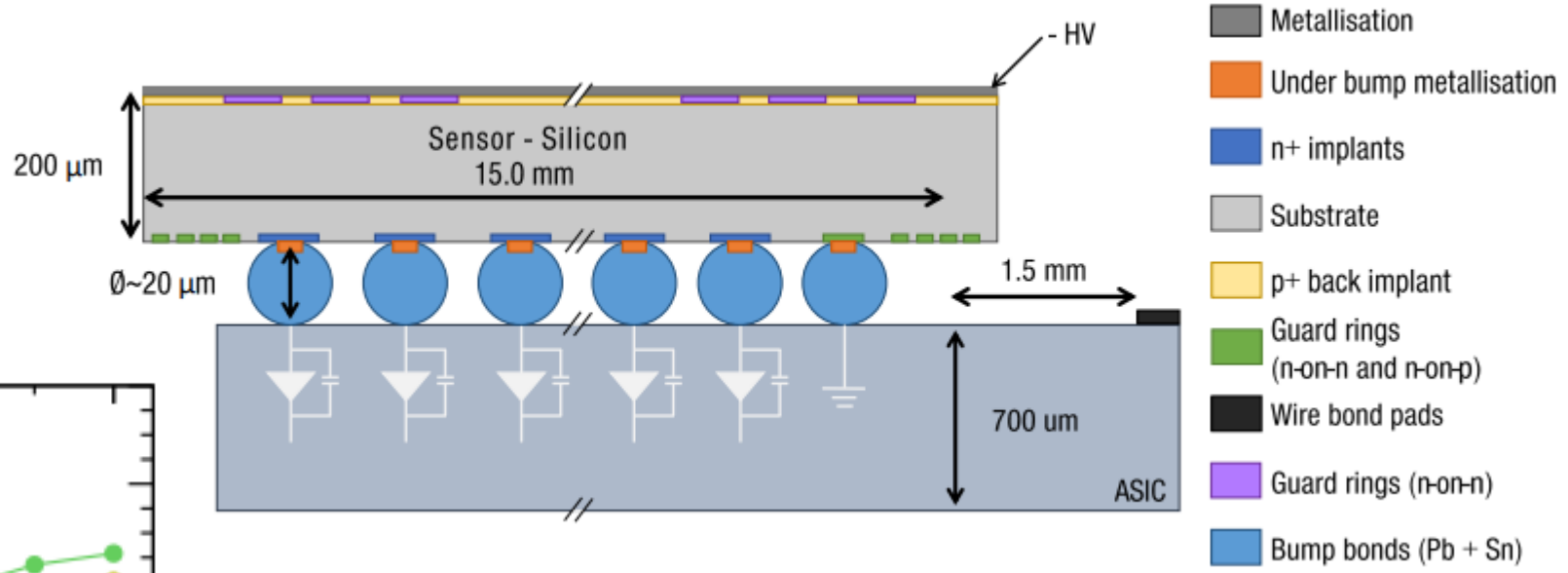
Unsuitable sensors tested (n-in-n not a viable technology for the upgrade)

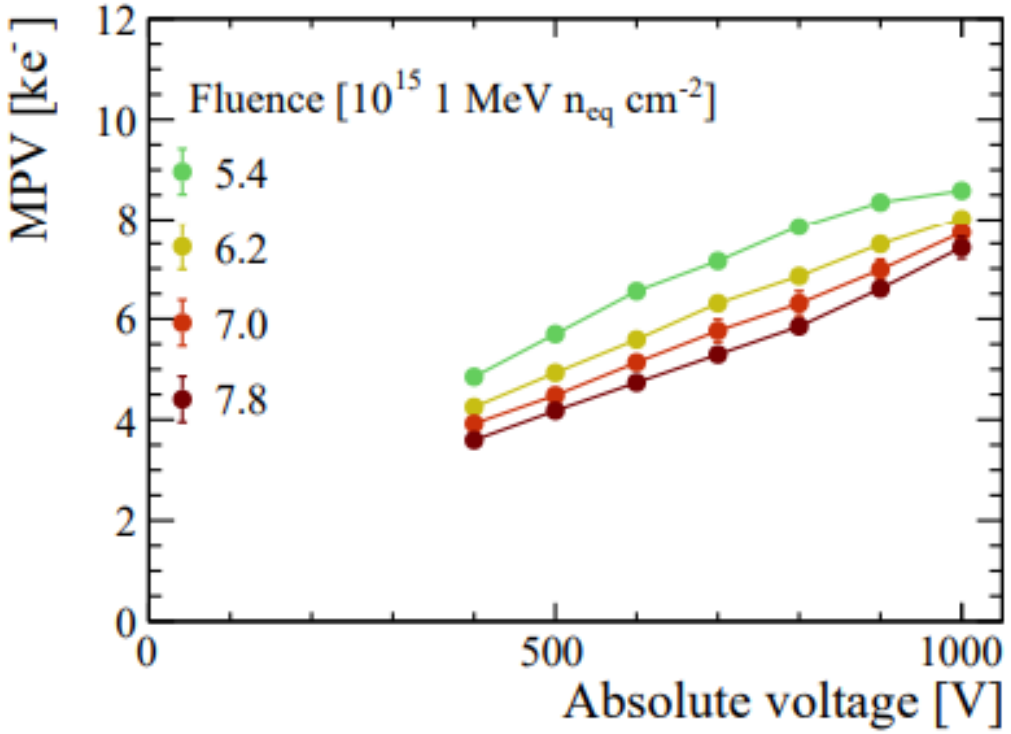




Tests done at CERN and in the Liverpool Vacuum tank

Final Radiation tolerant silicon





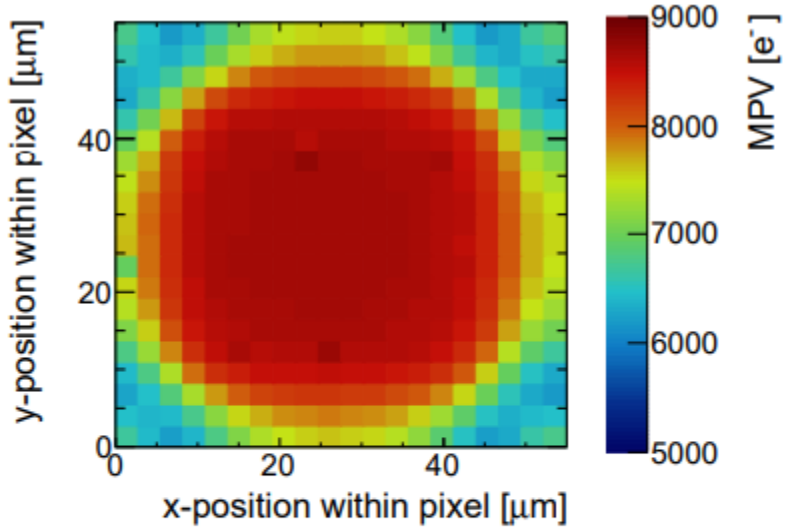


Figure 10. The MPV of the cluster charge distribution within a pixel for S8 at 1000 V after irradiation at IRRAD. Only clusters in the region of the sensor exposed to fluences in the range 7.3 to 7.9×10^{15} 1 MeV n_{eq} cm^{-2} are selected.

HPK sensors

Selected after extensive development and testbeams

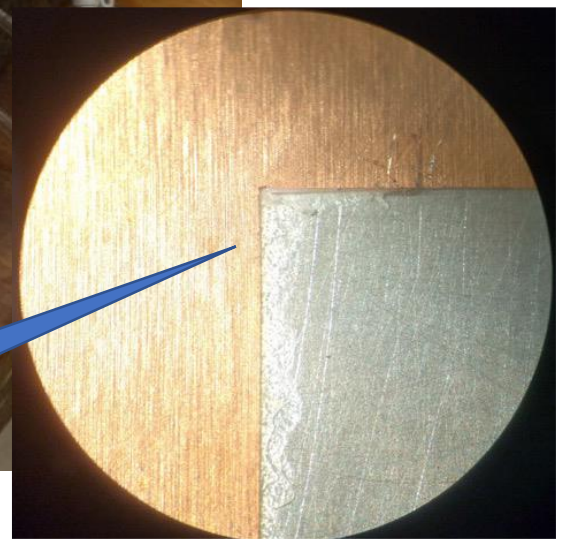
2021 JINST 16 P02029

Sensor testing: Vinicius, Tom and Karlis

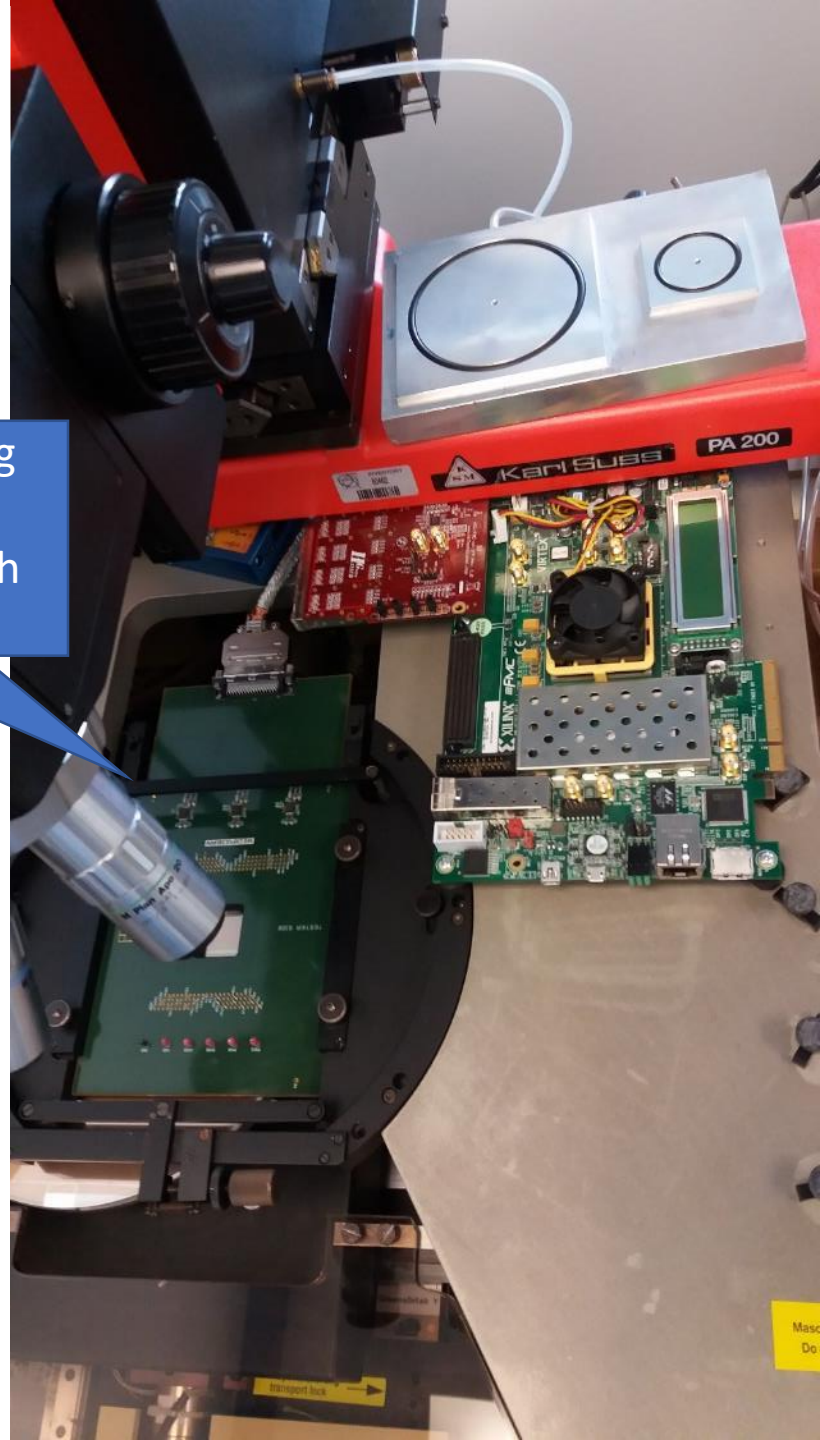
Vacuum jig for ten triplets for probing

Vacuum hood for IV curves

Probe card for testing each VeloPix
3 bumped under each triplet senor



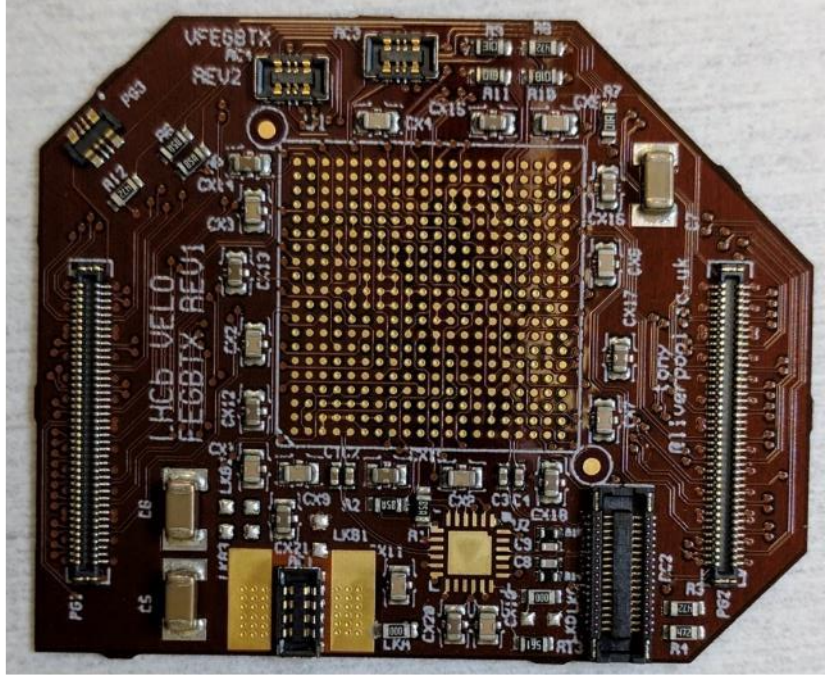
With stencil for alignment

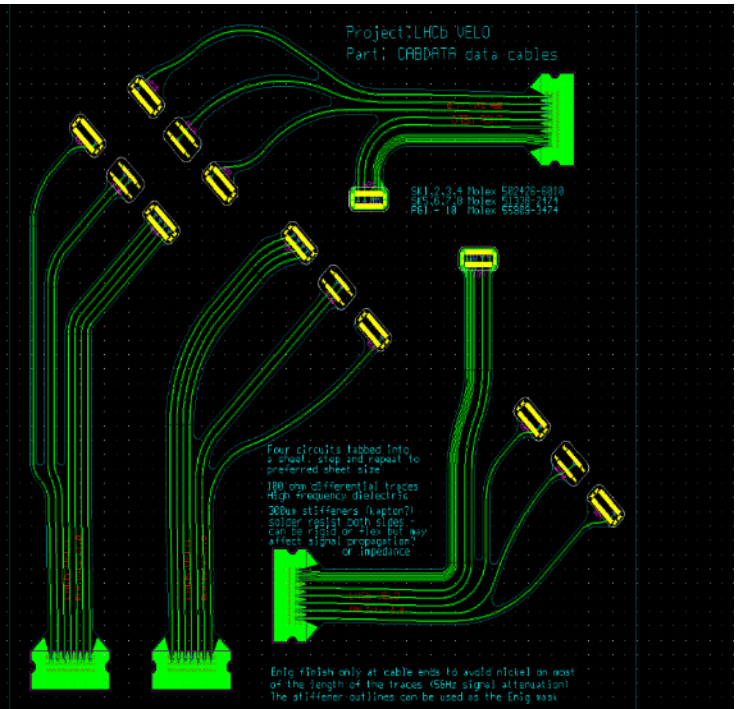


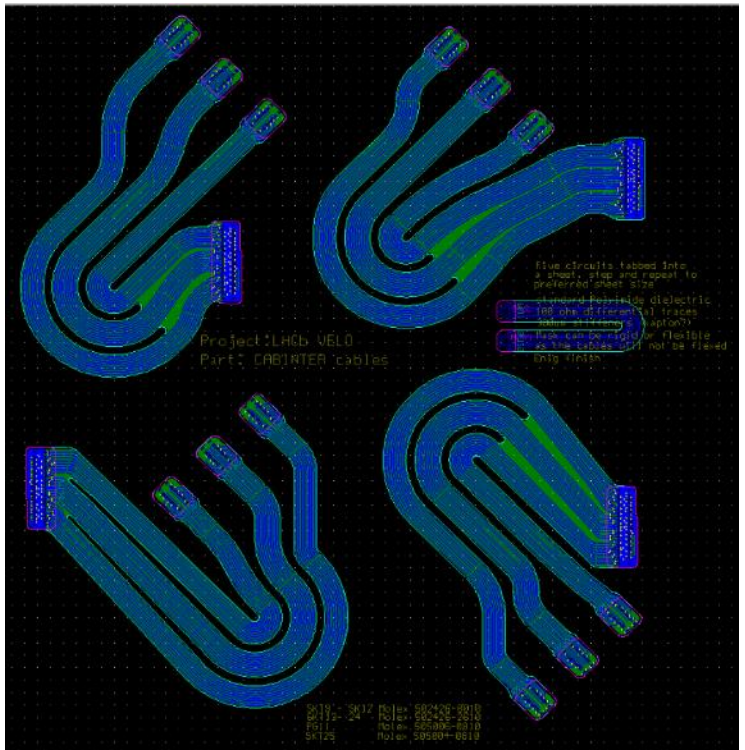
Liverpool tested all of the triplets, to automate testing jig is flat to 25μm and within 40μm in x/y to allow needle card probing

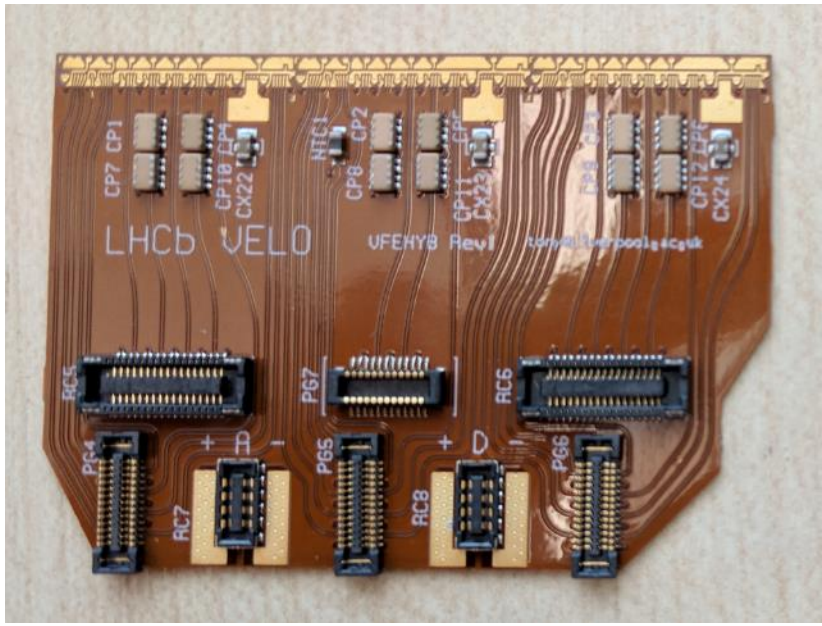
Electrical pathways

- Tony Smith designed the separate hybrids for each sensor, the central GBTX and the interconnect cables, power and readout links





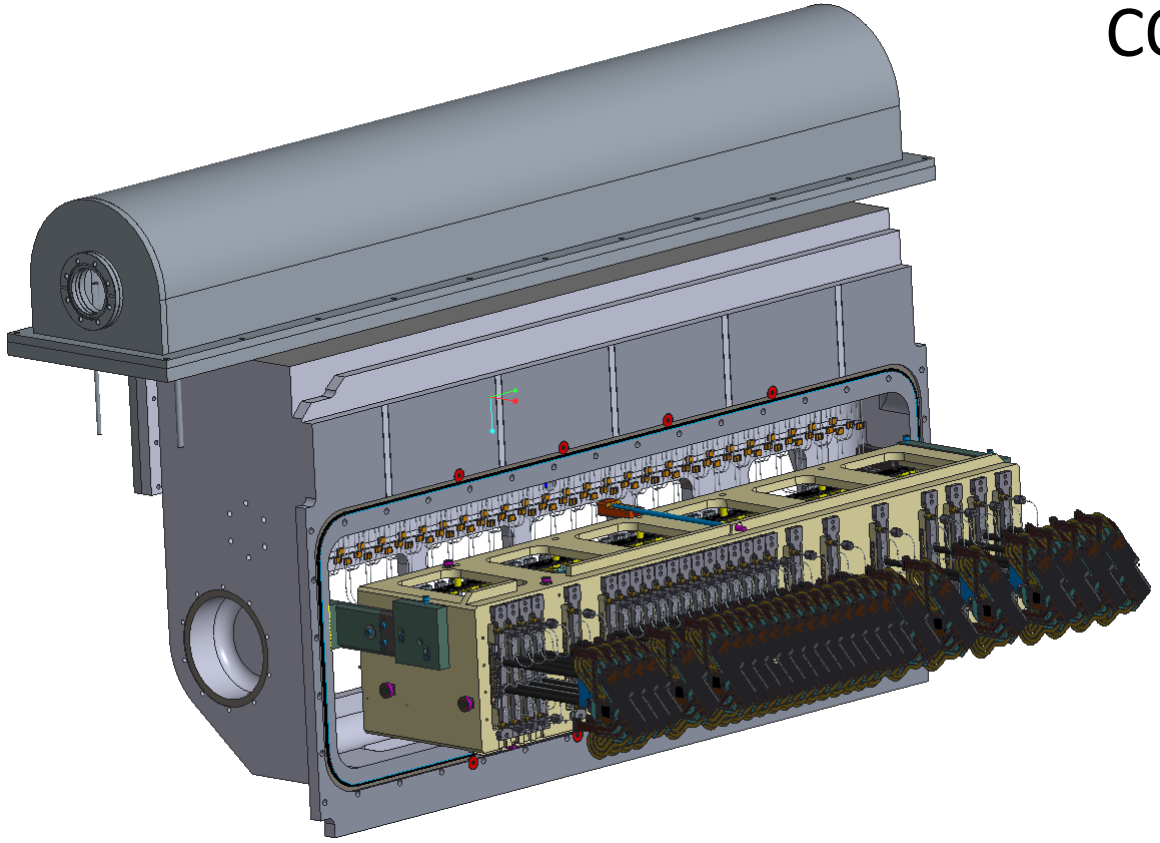




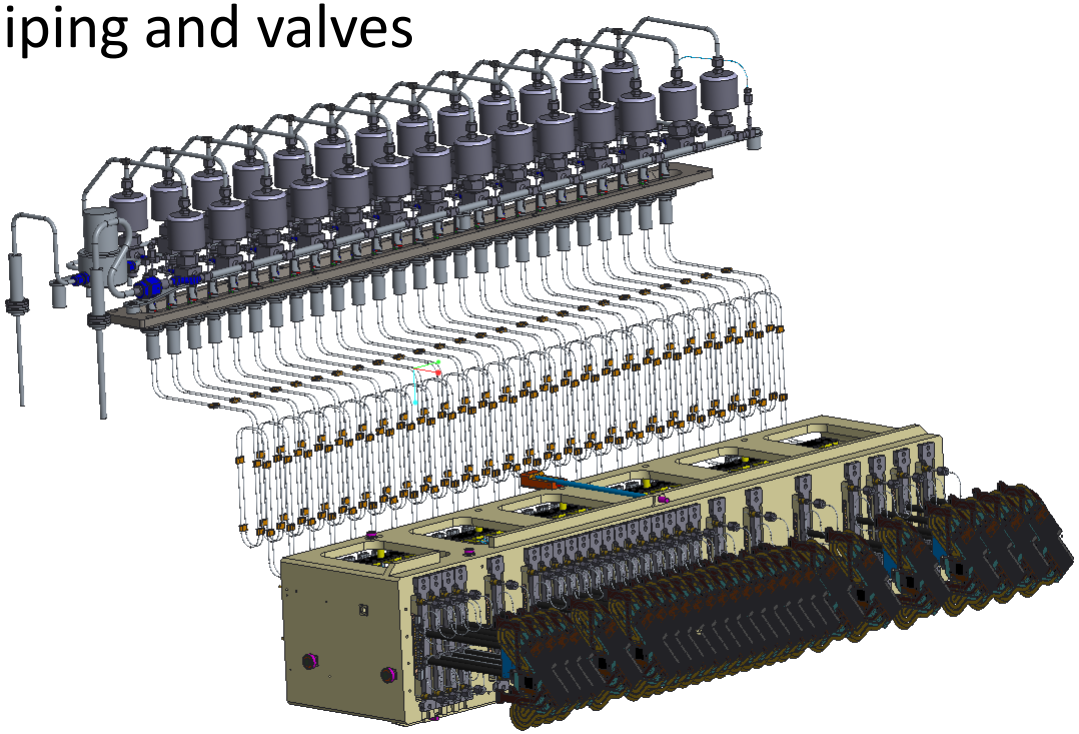
Mechanics and cooling prototypes: Kieran Bridges and John Carroll

2017 “flat pack prototype”

Hood with secondary and tertiary vacuum enclosures



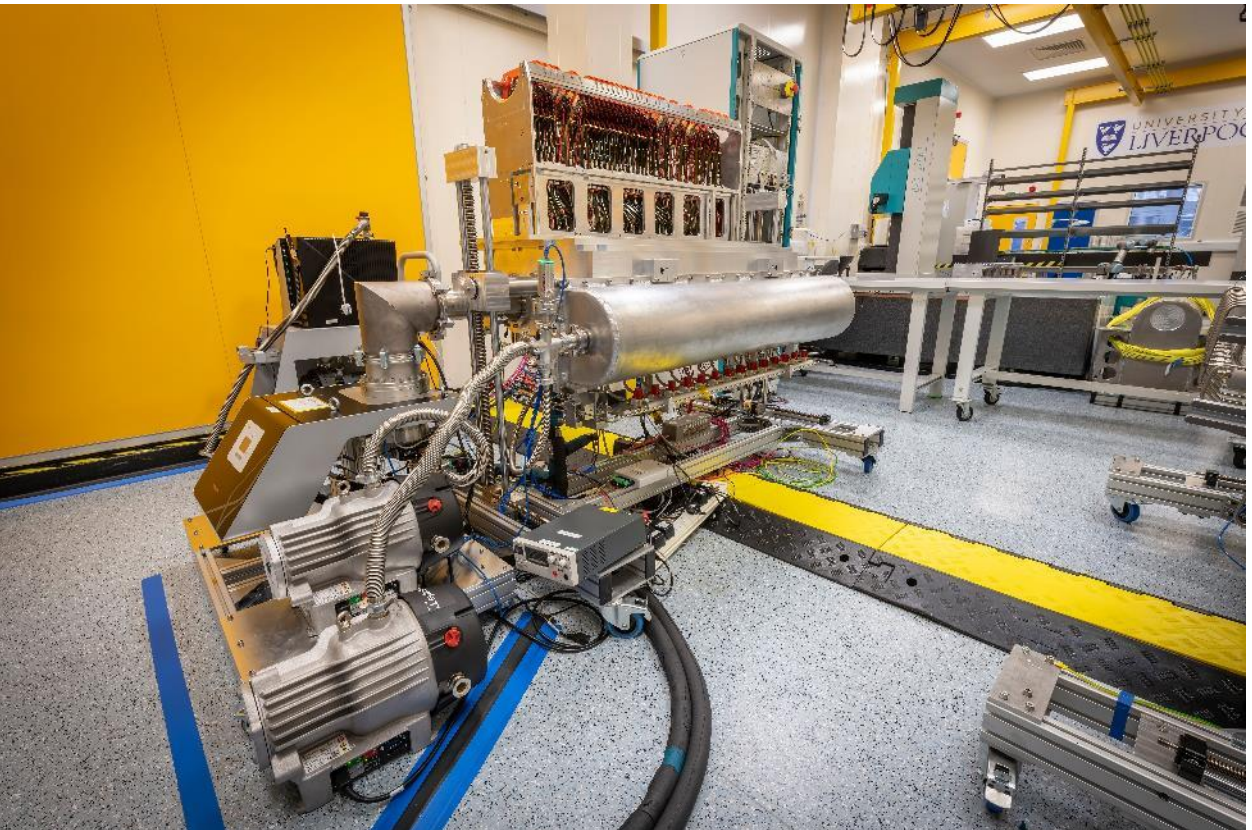
CO_2 piping and valves

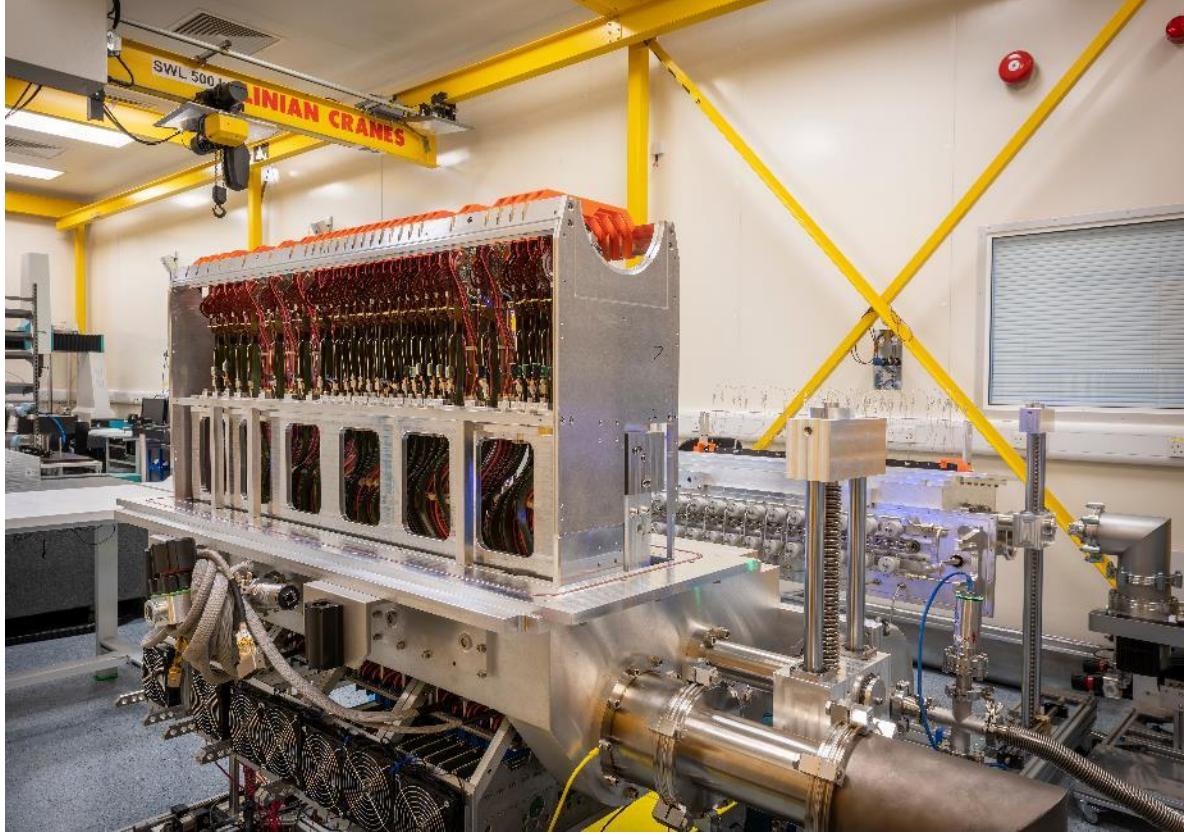


Needed to prove we could access and assemble all of the components

Final assembly

In 2021 we started assembling the two halves, with Kieran, Tabitha and Vinicius leading the clean room teams



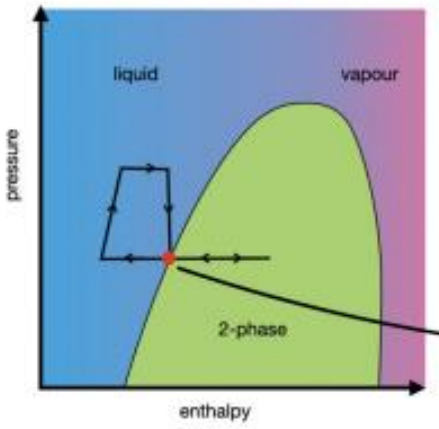


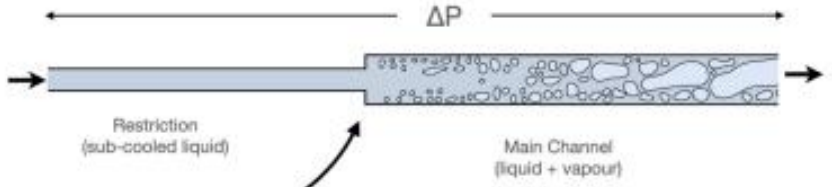
This is the completed C side in our clean room

Tests on the cooling system pressure and vacuum were performed

Cooling & Leak testing

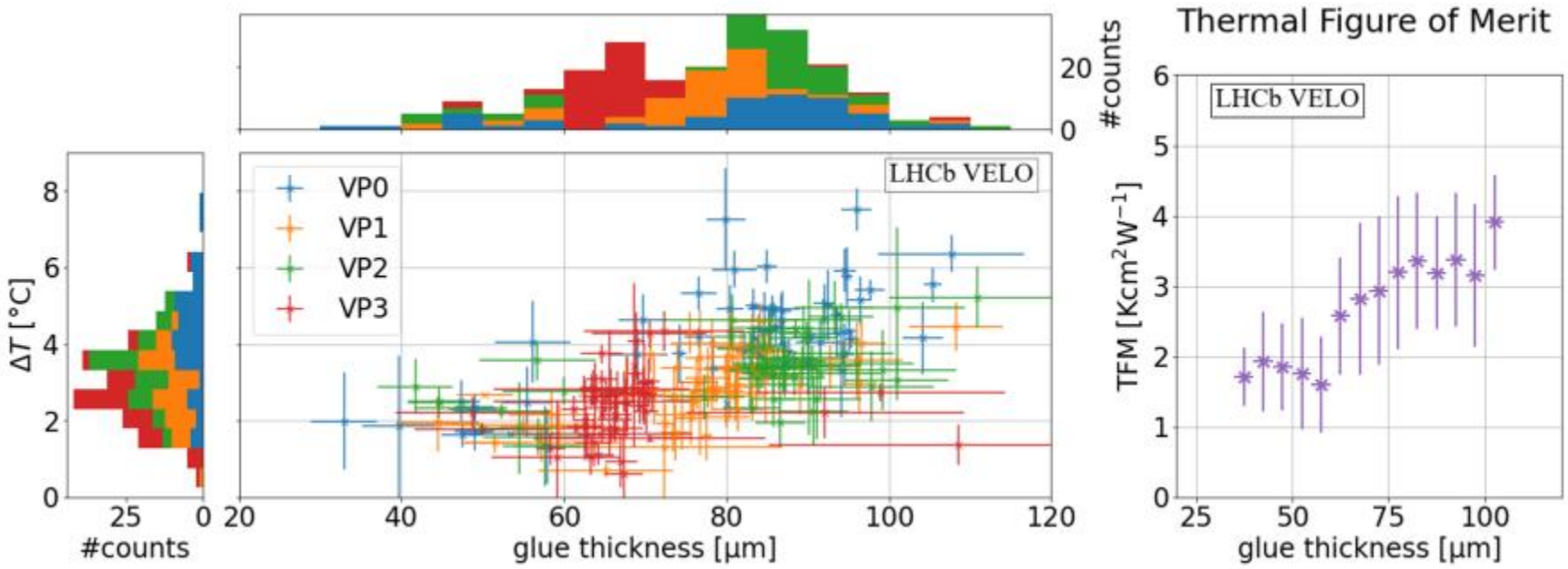
- Cooling loops are running liquid CO_2 which evaporates in microchannels
- 0.5mm silicon plate made of two silicon wafers, one with $150 \times 200\ \mu m$ channels etched
- Use up to 80 bar of Helium and helium sniffer on the vacuum pumps
- VCR connectors use thin metal washers pinched between knife edges
  - Several needed replacing
- We have an excellent He leak tester available to rent/buy if you need it





Thermal Figure of Merit

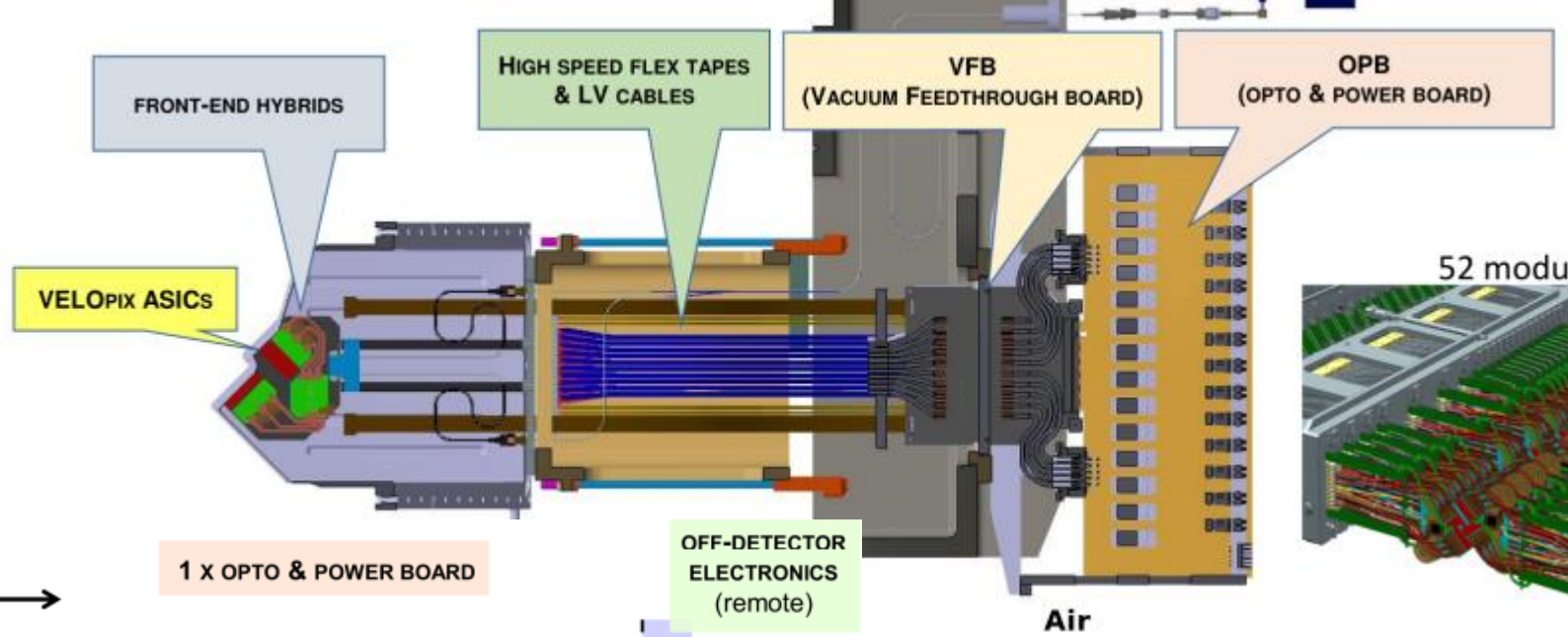
- Result is a detector with a Thermal Figure of Merit of $3 - 4\ K\ cm^2 W^{-1}$
  - Previous best at LHC was ATLAS IBL of $13\ K\ cm^2 W^{-1}$

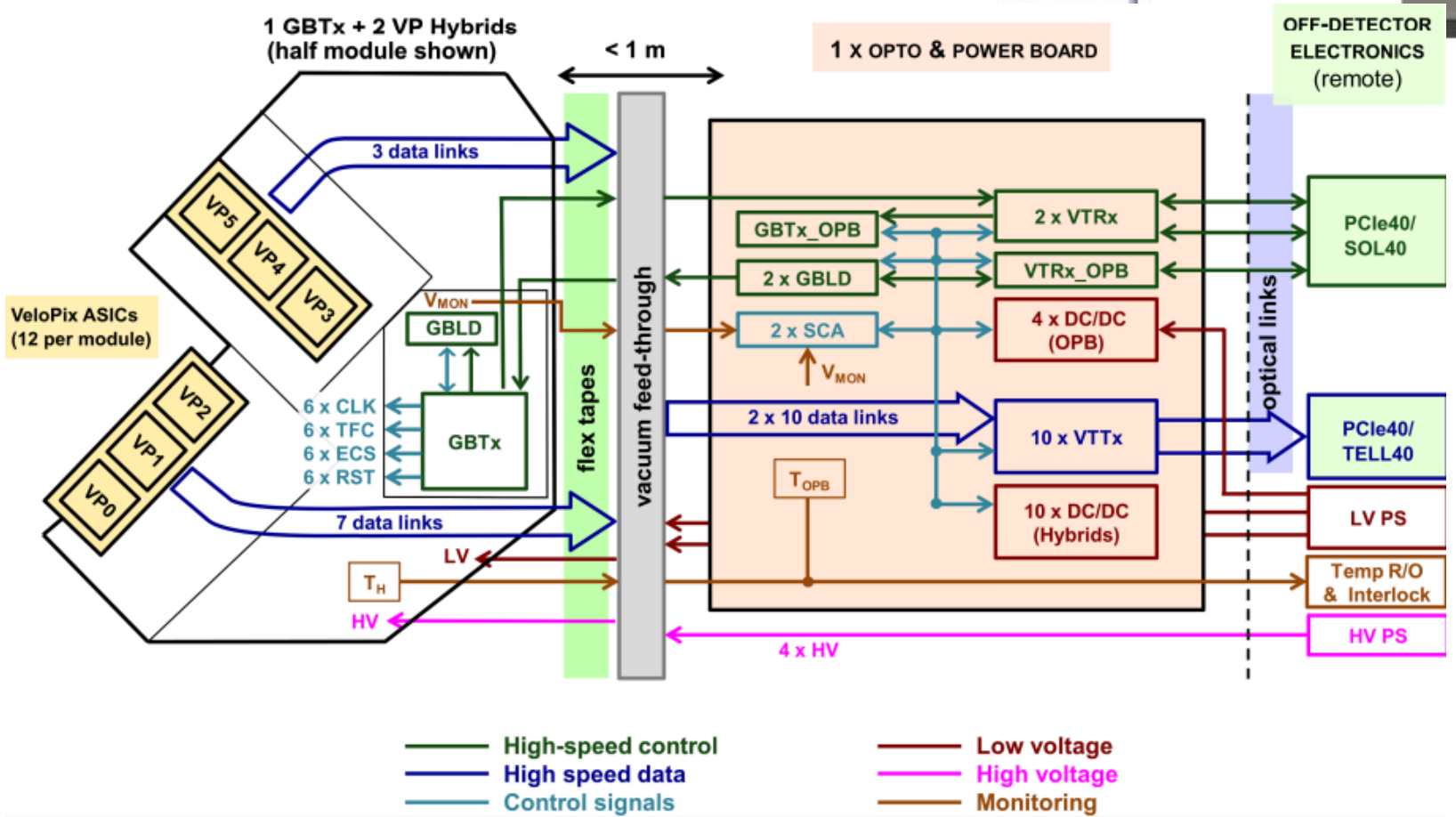


- Cooling performance measured with $C0_2$ input & output flow, pressure and temperature at Liverpool (glue thickness measured at production sites)

https://doi.org/10.48550/arXiv.2112.12763

Readout chain



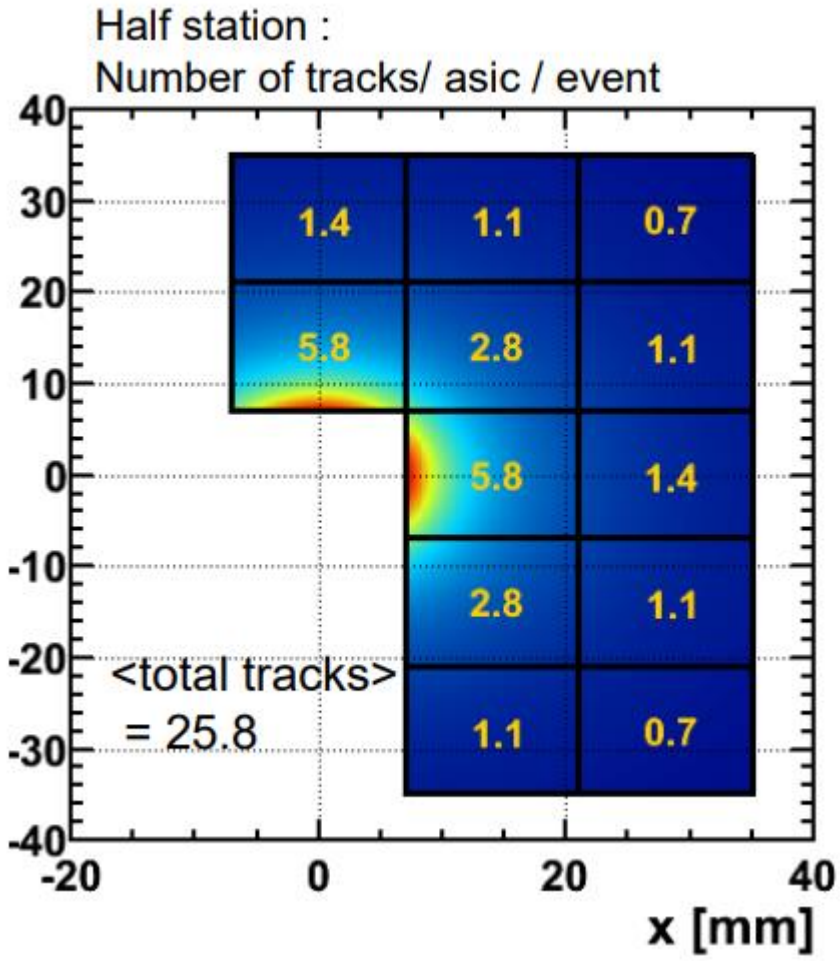


Full 40 MHz sampling and data pipelines passing Tb/s with clustering on the detector

Karol lead the effort to design and implement the readout system

Tests done by Tom and others to validate the software and data loss at extreme occupancies

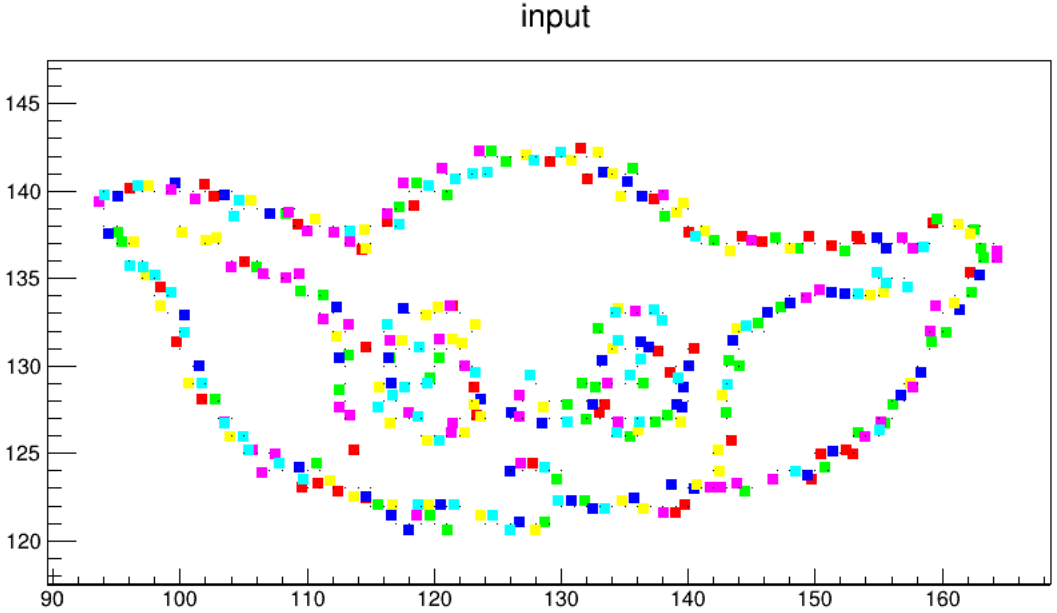
Full data readout

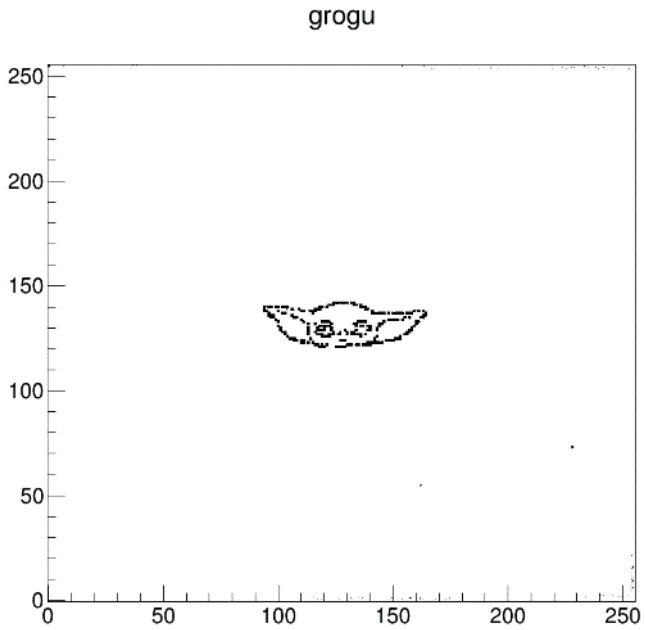


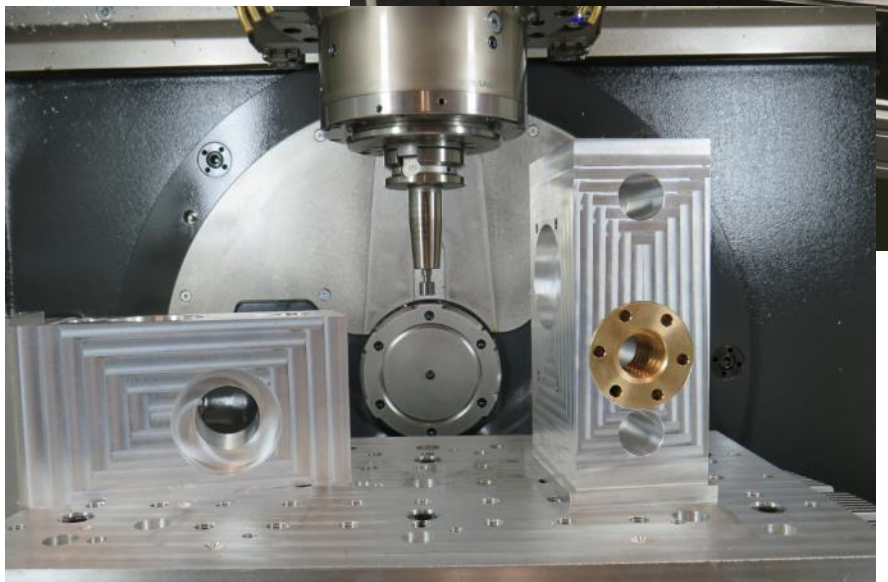
Full data rate (left)

First full chain tests patterns input and readout (right)

Development moving at pace to continue the readout integration







Workshop team: enormous thanks to them all

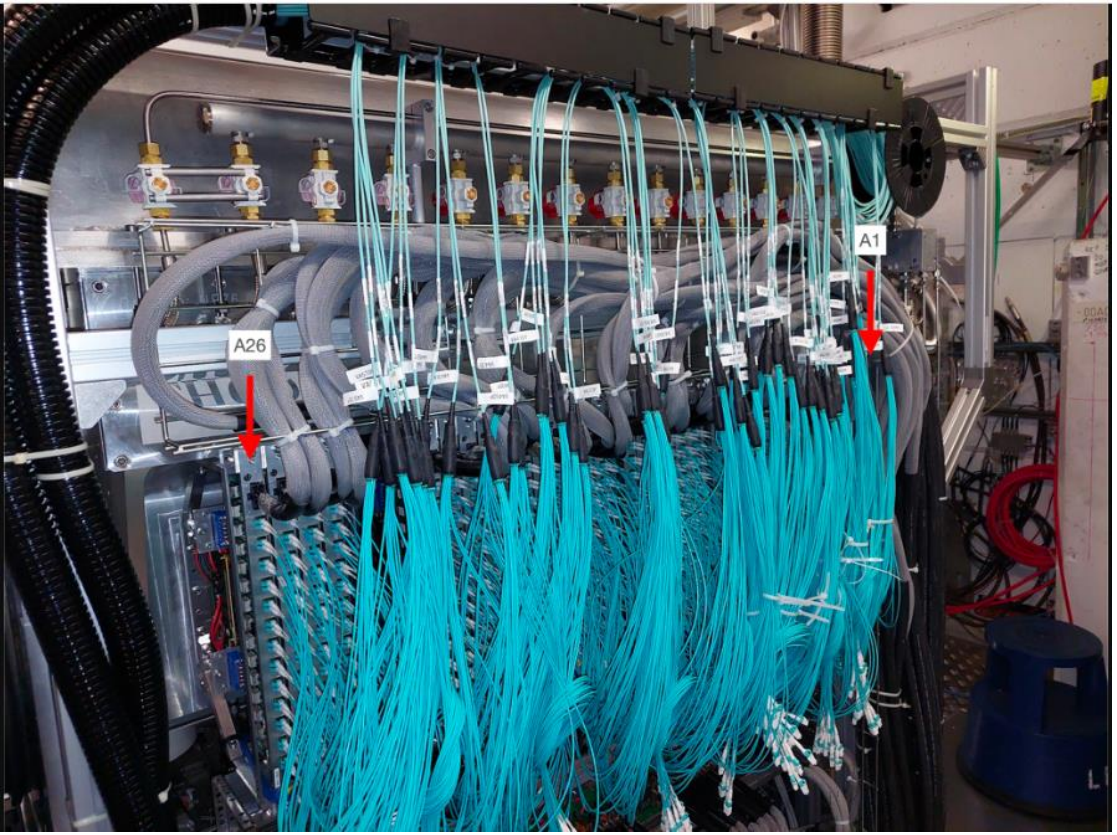
List of people involved: Alphabetical

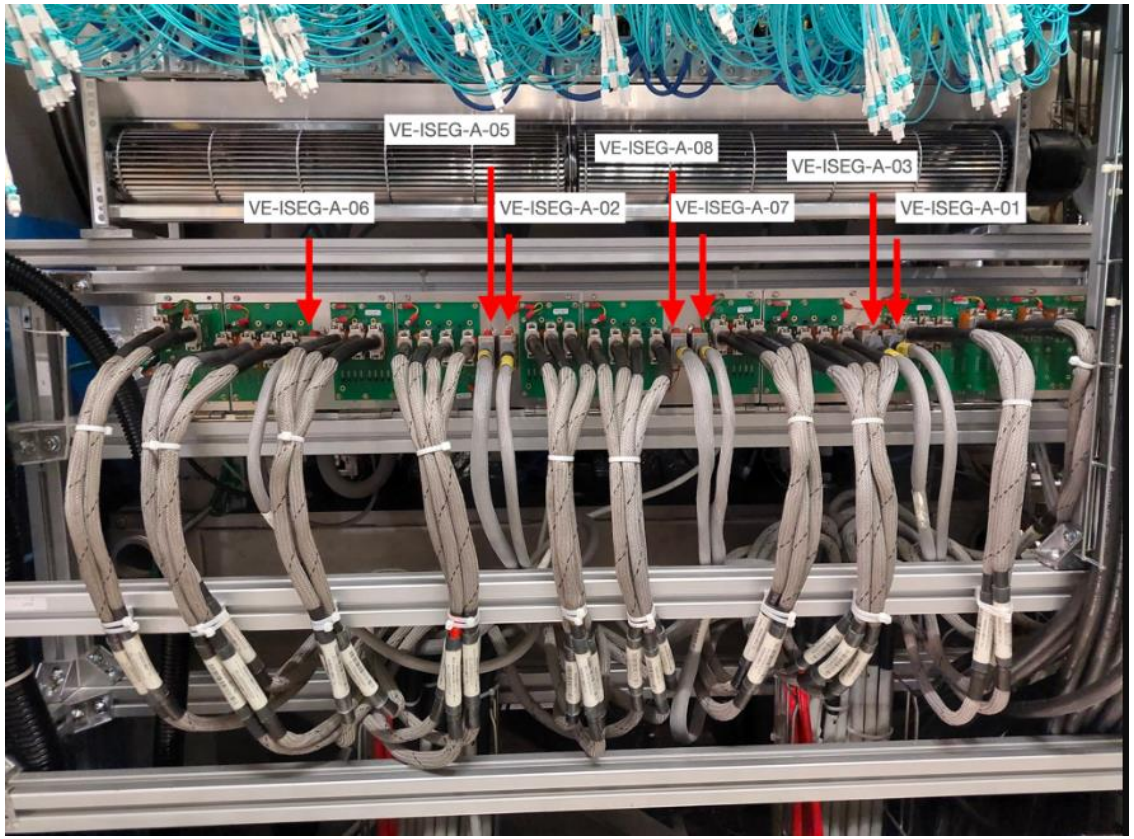
(apologies to anyone I've forgotten)

- Kieran Bridges
  - Mechanical Engineering design of the structures and detector construction
- Themis Bowcock
  - UK project management, initial designs
- John Carroll
  - Mechanical Engineering design of the structures and detector construction, vacuum system design
- Gianluigi Casse
  - Sensor development
- Francesco Dettori
  - Upgrade studies
- Karlis Dreimanis
  - Sensor testing, construction DB design and development
- Stephen Farry

  Transport shock logs and clean room video timelapse
- Vinicius Franco Lima
  - Testbeams, sensor measurements; and final construction and measurements
- Tabitha Halewood-Leagas
  - Construction and measurements
- Karol Hennessey
  - Readout design and programming
- David Hutchcroft
  - Simulation and reconstruction development, trigger software
- Kurt Rinnert
  - Construction DB and software development, especially use of GPU for the trigger
- Eduardo Rodrigues
  - Data analysis and reconstruction for the upgrade, DPA project leader
- Tara Shears
  - Project management and admin
- Tony Smith
  - Electrical Engineering design of hybrids, cabling and readouts

Next is commissioning and then Physics!





Images of cabling LV and HV for the A-side from last Friday

Thanks for listening, any questions?