THE DARKSIDE-20K VETO READOUT SYSTEM: construction and characterisation

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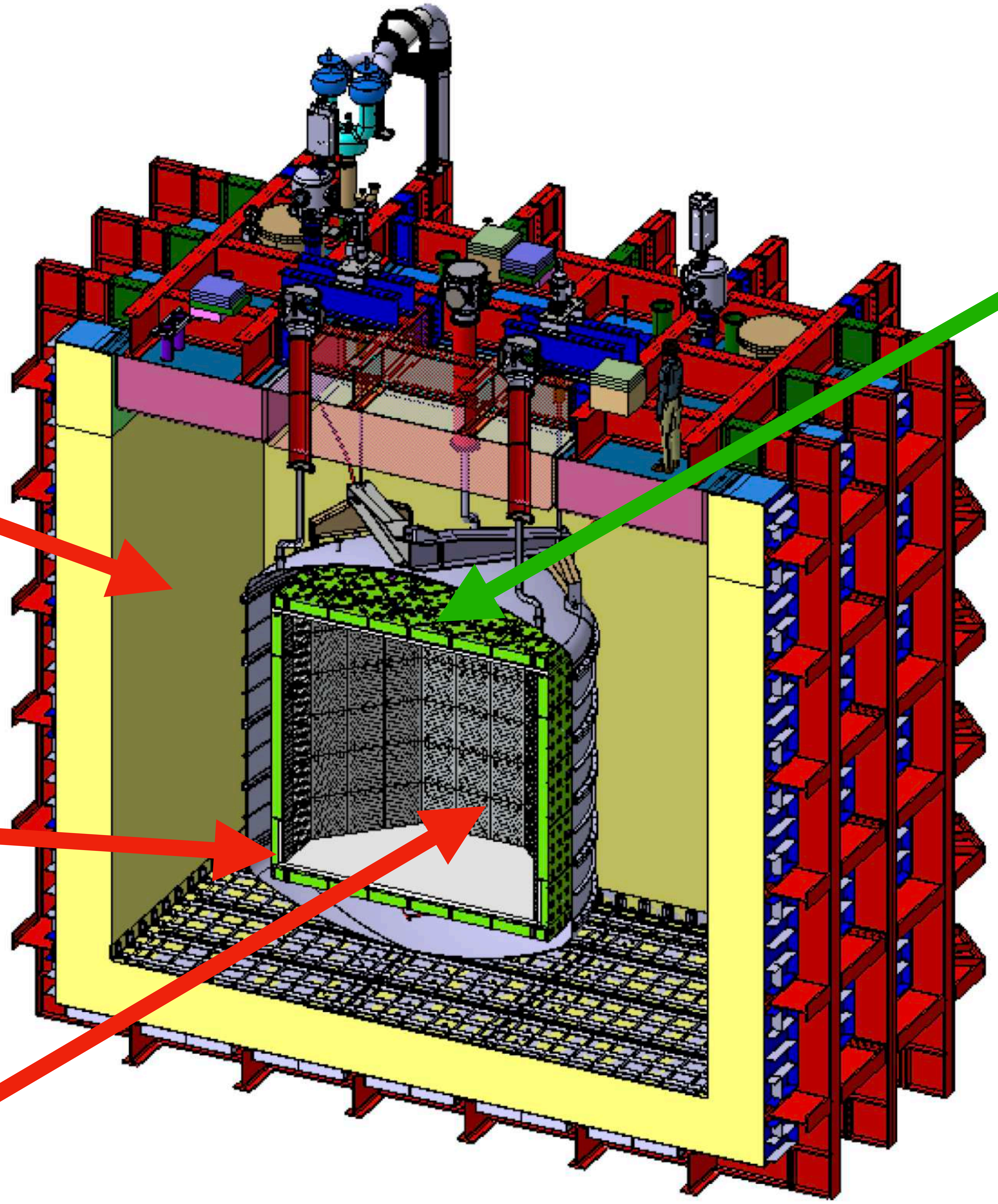
DARKSIDE-20k

Outer cryostat filled with 600 tonnes of Atmospheric Argon (AAr) acts as cosmogenic veto

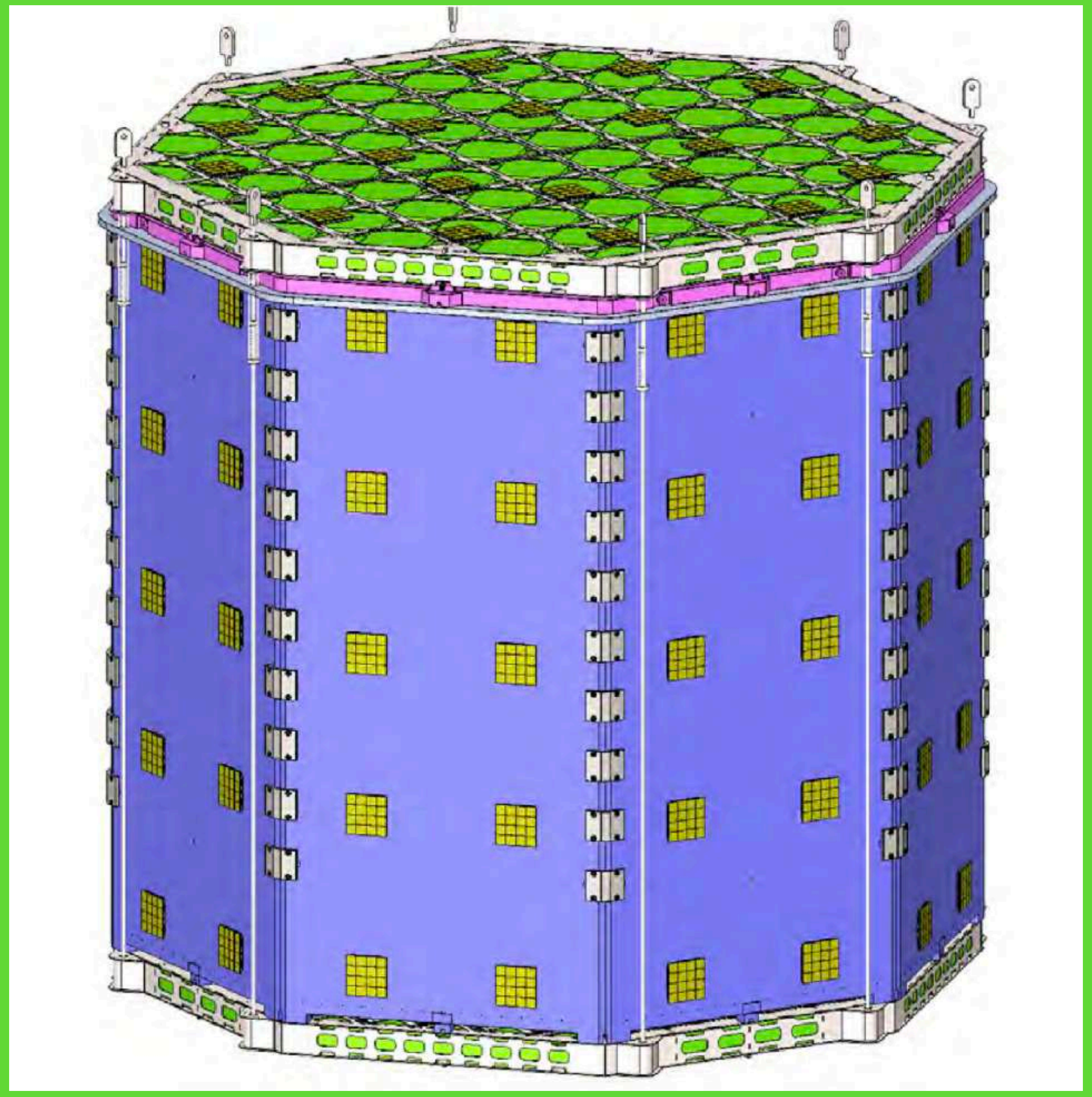
SS vessel

Dual phase time projection Chamber (TPC) filled with 50 tonnes of UAr

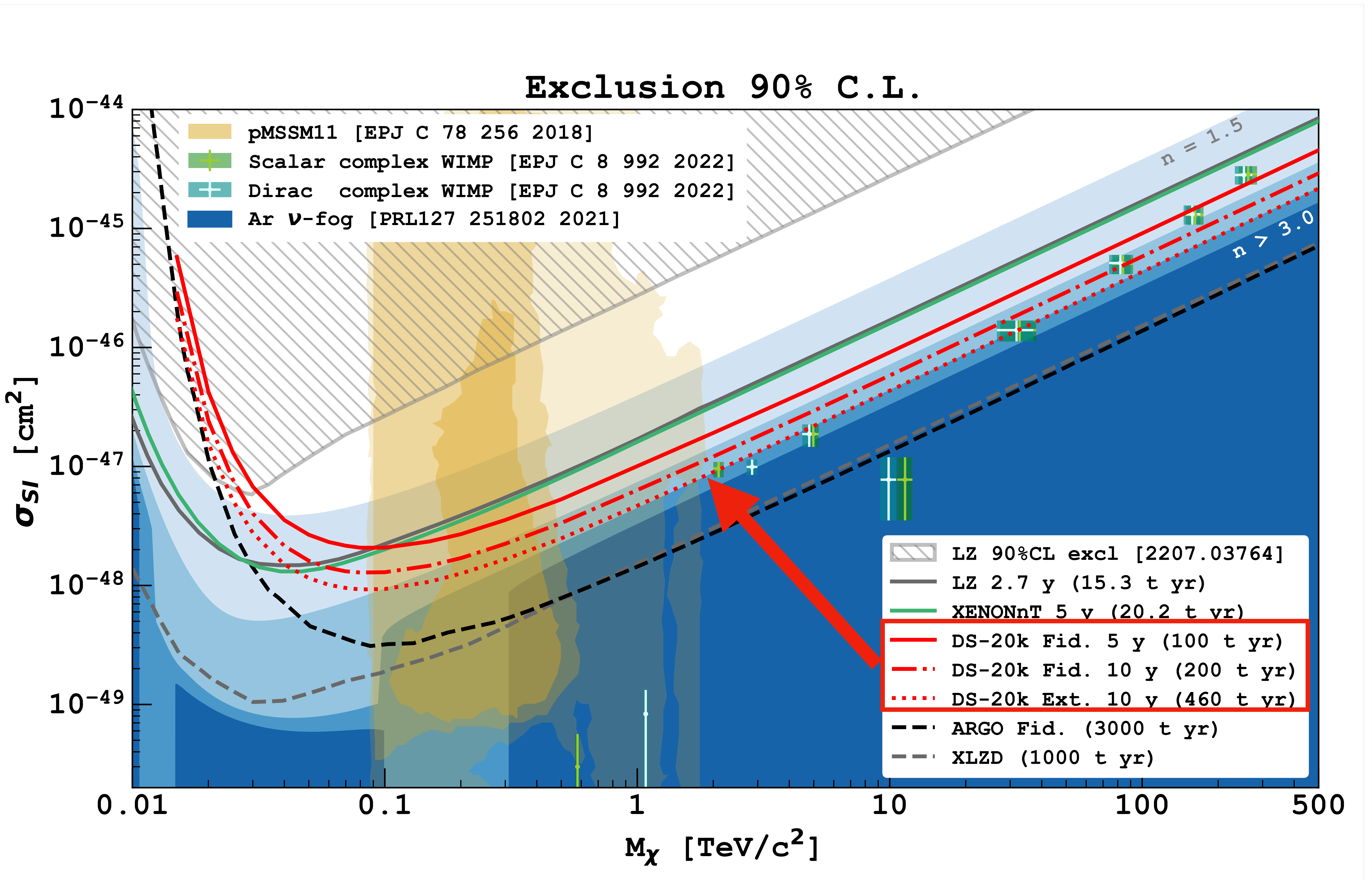


See more in previous talk on DS-20k
By Yi Wang

Gd-PMMA acts as neutron Veto surrounded by 35 tonnes of Underground Argon equipped with Silicon photomultiplier (SiPMs) Array as readout system



DARKSIDE-20K: DARK MATTER SENSITIVITY

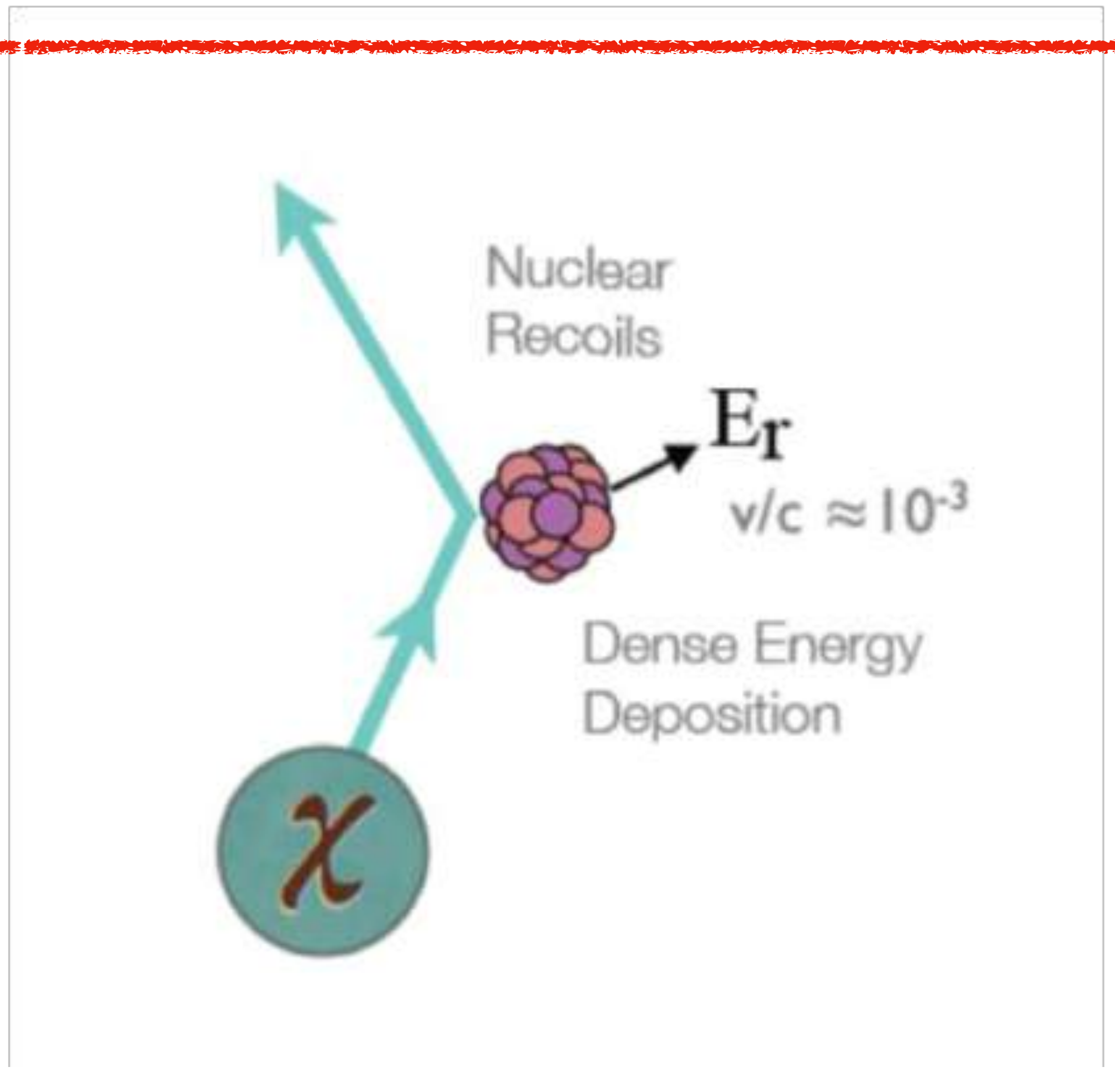


- Sensitivity to high mass WIMP-nucleon scattering cross section of 7.4 x 10-48 cm² for a 1 TeV/c² WIMP for a total exposure of 200 ton-years
- Total background events after all cuts: < 0.1 neutron WIMP-like events in a total exposure of 200 ton-years

See more in previous talk on DS-20k By Yi Wang

WIMP SIGNAL & BACKGROUND

WIMP SIGNAL



- Single nuclear recoil
- Energy recoil between 1 and 100 keV

BACKGROUND

Background source	Mitigation strategy
39Ar β decay	Use Underground Argon + pulse shape discrimination
γ from rock and γ,e from material	Pulse shape discrimination Selection material
Radiogenic neutron (α,n) reaction in detector material	Material screening & selection Definition of Fiducial volume in the TPC **Veto to reject neutron signal**
Surface contamination due Rn progeny	Surface cleaning Reduce the number of surfaces Installation of Rn abated system
Muon induced background	Cosmogenic veto
Neutrino coherent scatter	Irreducible

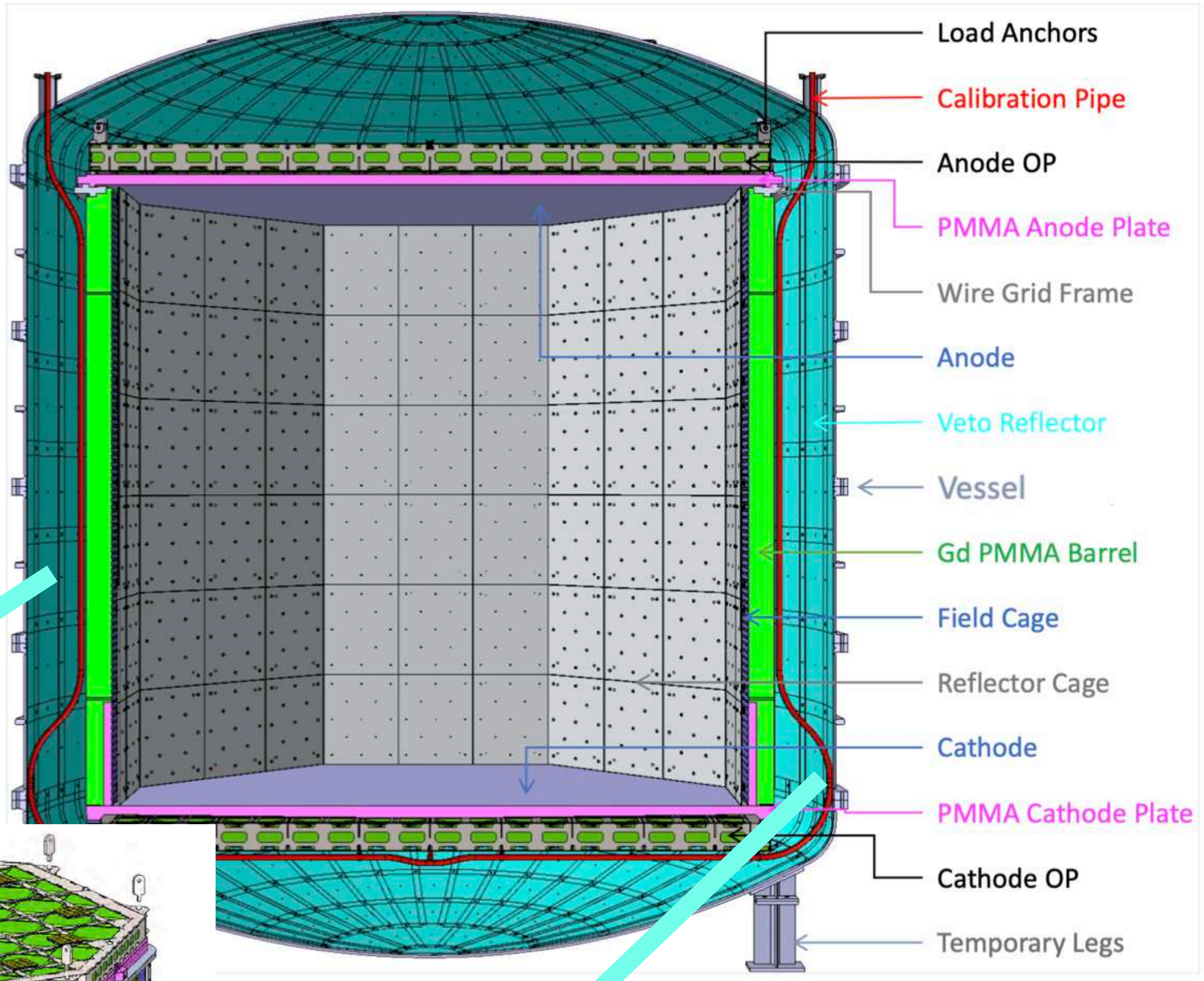
NEUTRON VETO: TPC+veto integrated system

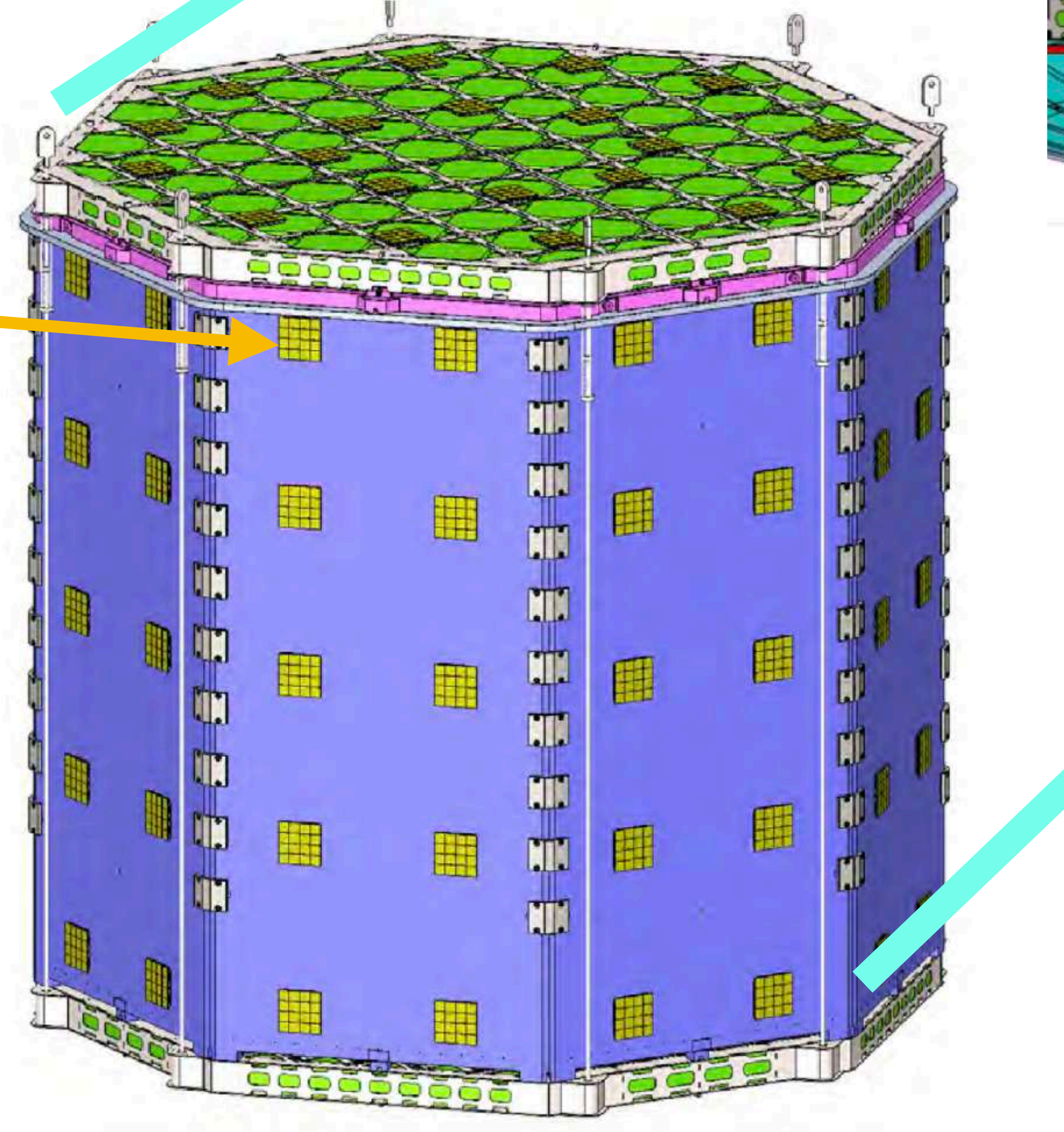
- Novel technology: TPC+veto integrated system -> Gd-PMMA (11.2 tons needed) around TPC to capture neutrons (4π coverage)

- Readout: SiPM arrays, assembled in veto photodetector units (vPDU) around TPC wall for light detection -> 120 vPDU in total

- **Reflector+ PEN** for light collection optimisation

- Enclosed in a SS vessel filled with 35 tons of underground Argon

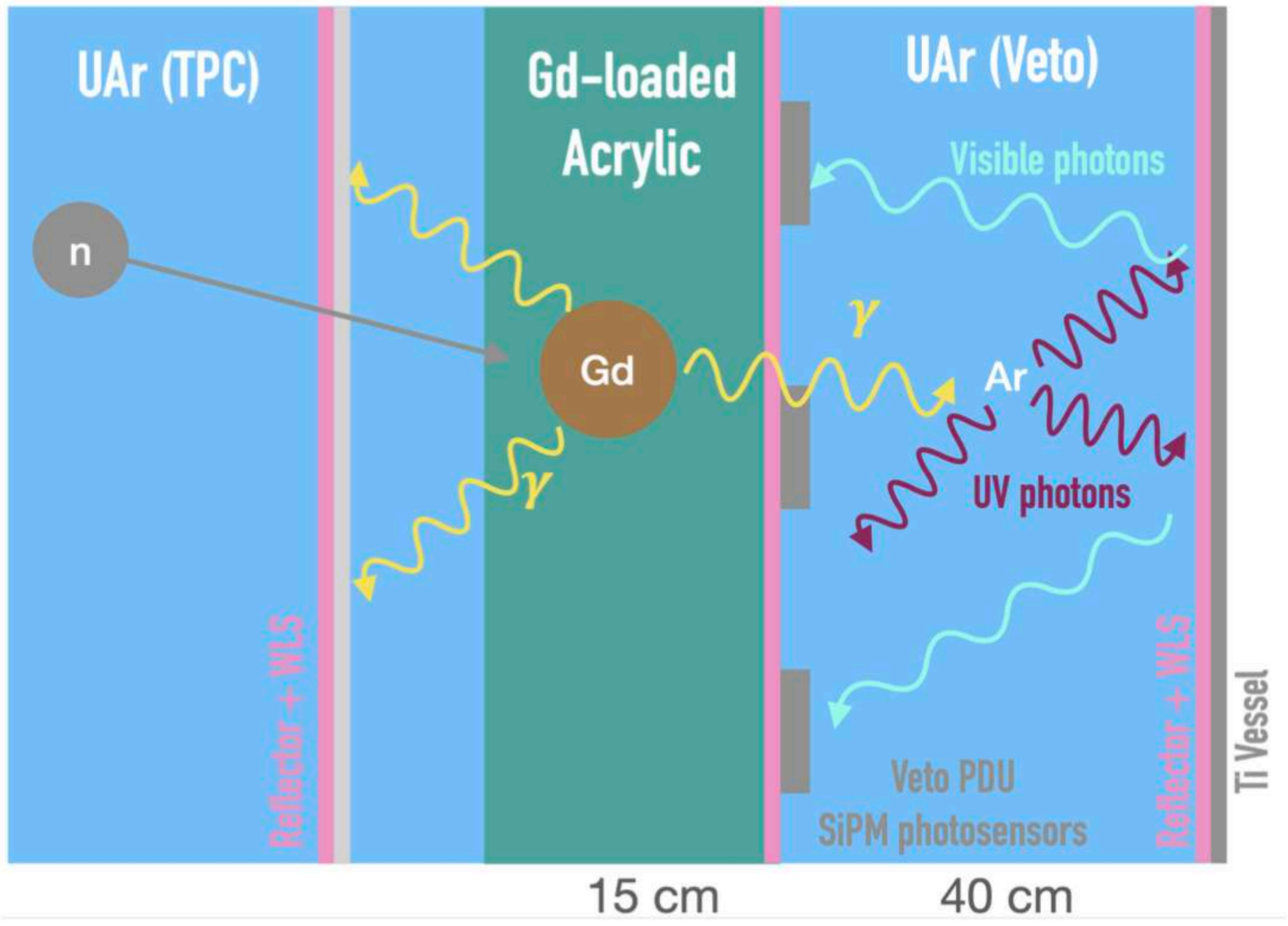


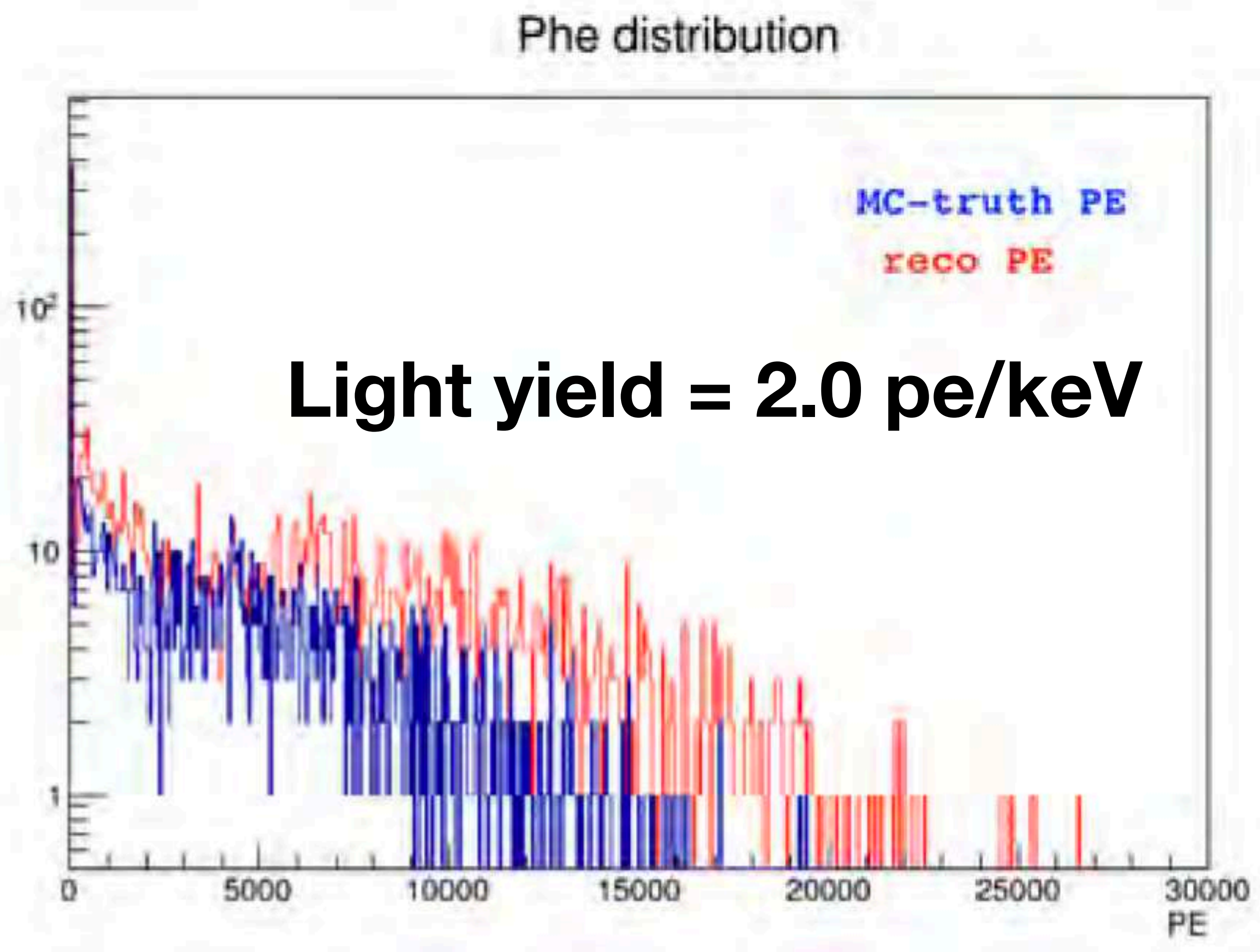


NEUTRON TAGGING

- Gd-PMMA is highly efficient at moderating and then capturing neutrons
- Gd-PMMA 15 cm thick
- Gd concentration chosen to have neutron capture on Gd dominates w.r.t capture on H
- Neutron capture on Gd produced a gammas cascade with a energy of 8 MeV

- **Neutron identification**:
  - Single NR
  - Energy in ER: 7.5< E_{ER}< 50 keVee
  - R-z position cuts —> FV = 20 tons
  - Energy deposit in ER in the TPC > **50 keV OR** energy deposit in UAr veto > **200 keV**
  - TPC-veto window of 800 µs





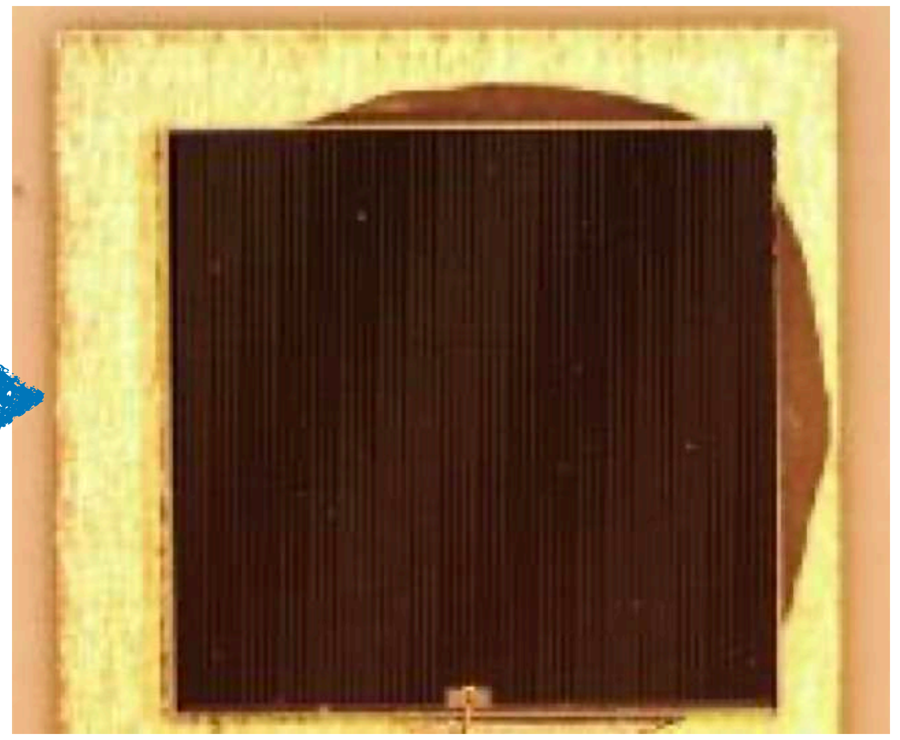
Neutron background after veto cuts:
< 0.1 event
in the full exposure of 200 tons x years
-> satisfies DarkSide-20k requirement

VETO PHOTO DETECTION MODULE (vPDU)

SPADs

SPADs - Single Photon Avalanche Diodes: semiconductor devices based on a p-n junction, reverse biased well above breakdown voltage (operating in Gieger mode).

SiPMs: 8 mm x 12 mm

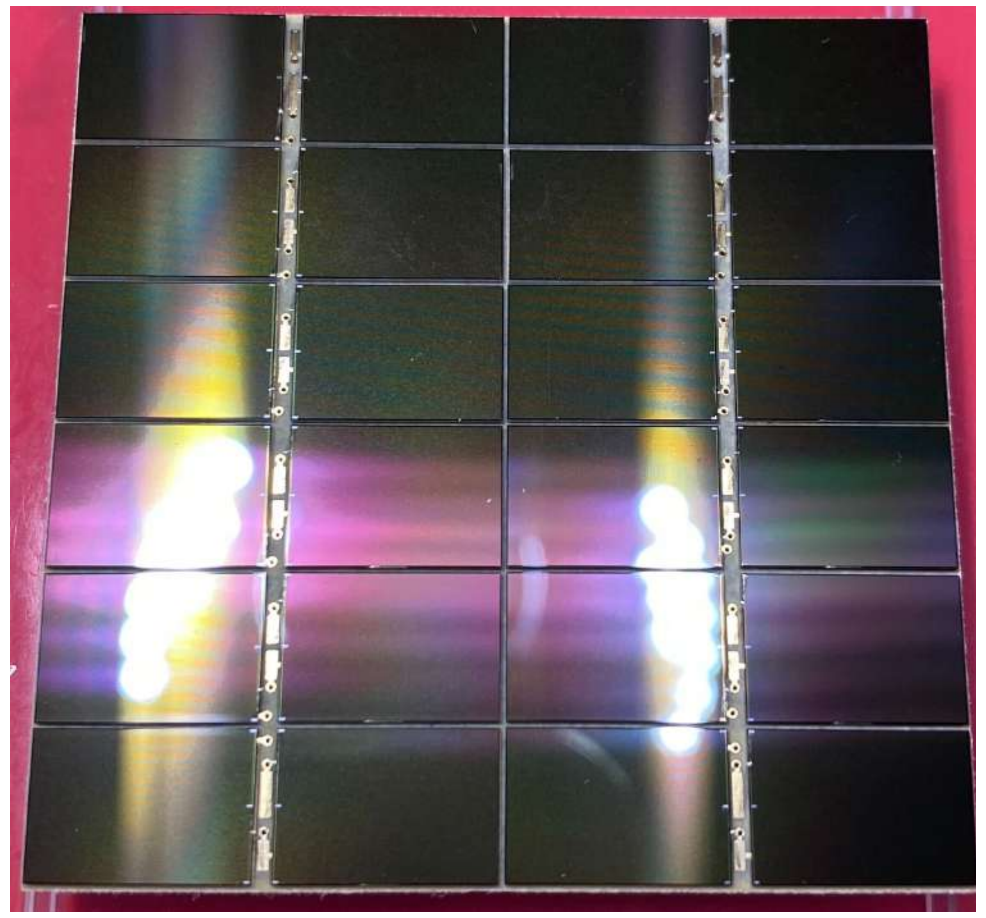


SiPMs - Silicon Photomulplier:
A single SiPM consists of around 94,900 SPADs.

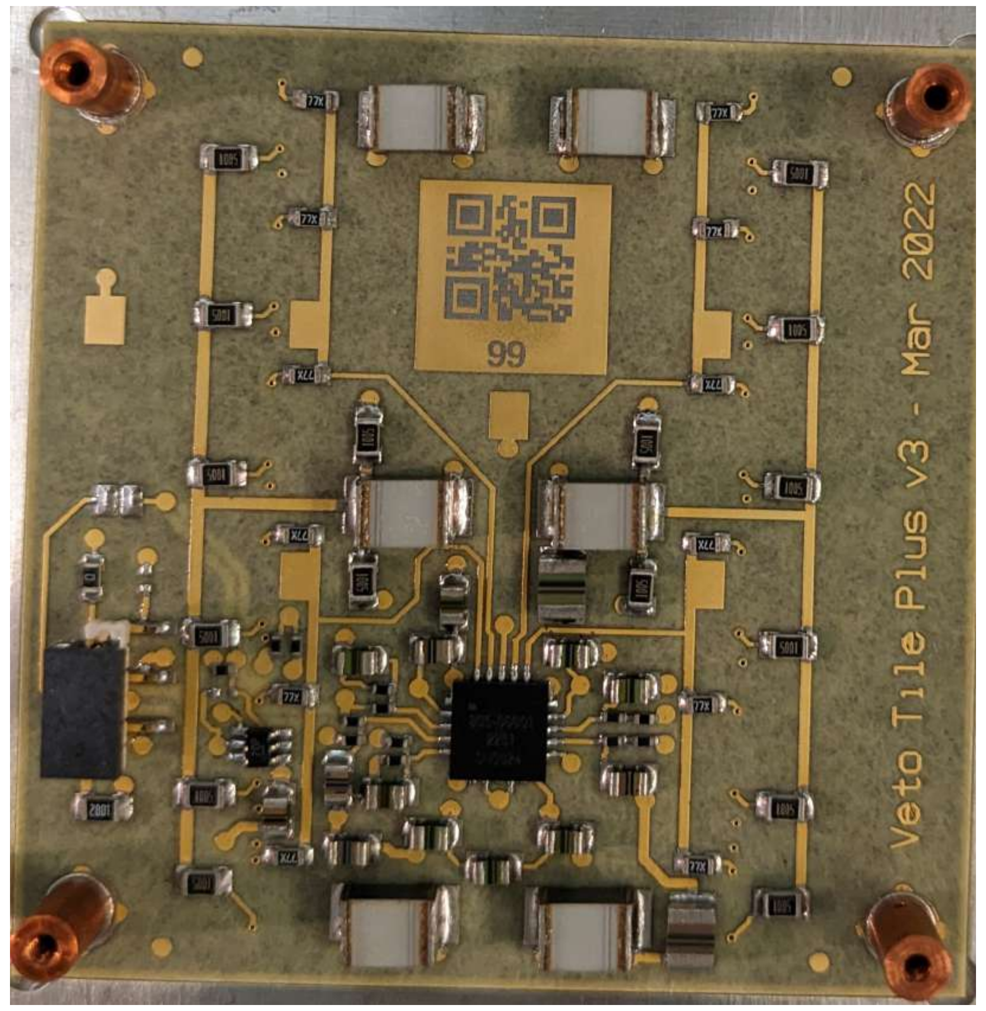
single printed circuit (PCB)

- Side 1: array of 24 SiPMs For a total size of 25 cm², The signals of all SiPMs are Summed
- Side 2: front-end electronics for Signal amplifier -> ASIC

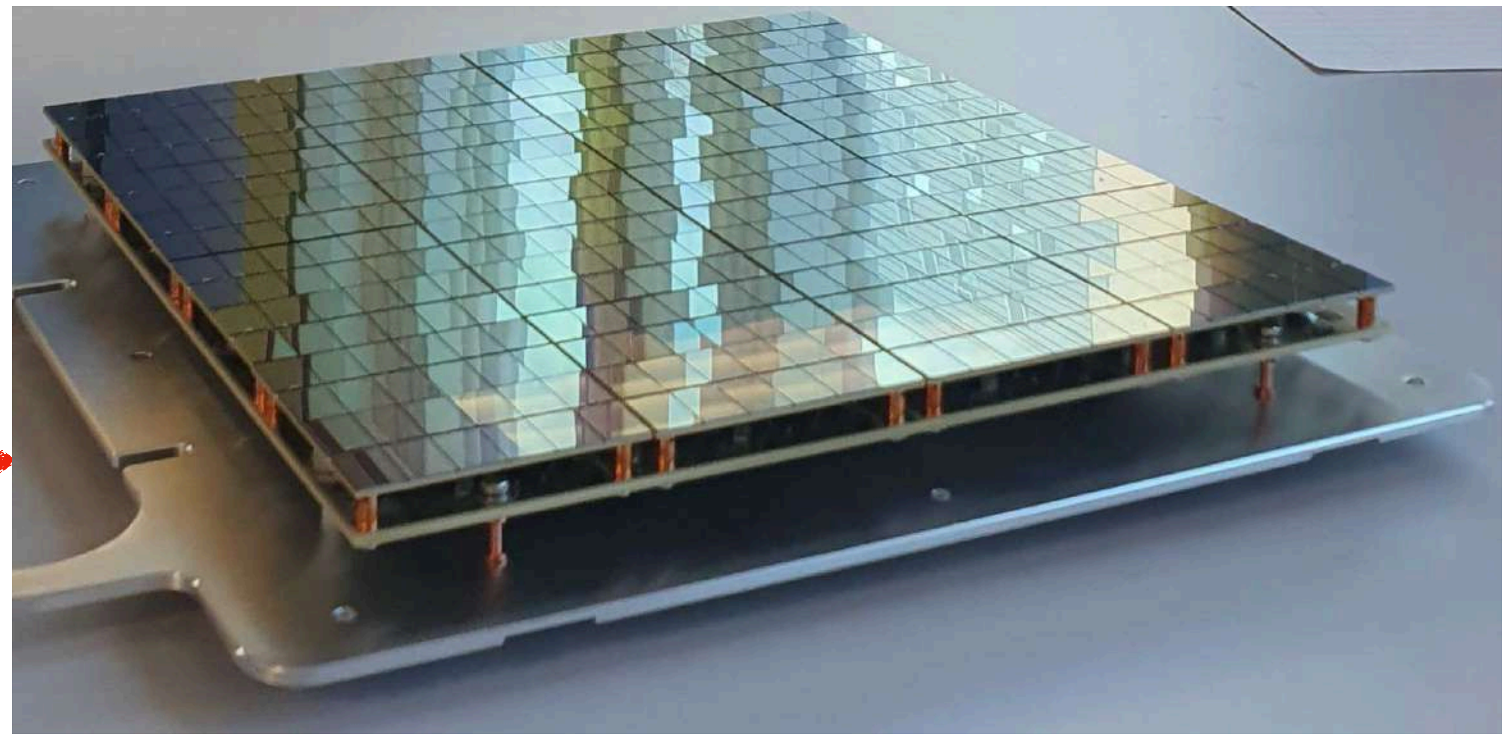
Tile side 1: 24 SIPMs



Tile Side 2: front-end electronics



vPDU



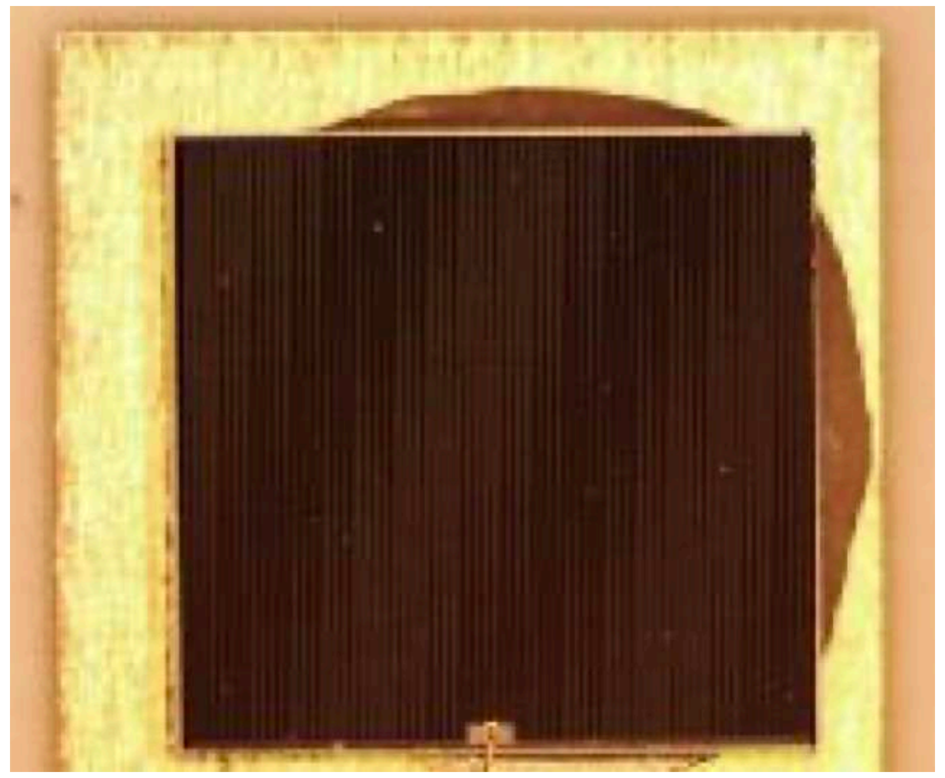
- 16 SiPM array “Tiles” for total area of 400 cm²
- 1 large PCB for control signal, biasing each tile, and signal conditioning
- Signals from 4 tiles are summed together, i.e. 4 tiles correspond to 1 DAQ channel
- 4 channels per vPDU

DARKSIDE SIPM REQUIREMENTS

From PhotoMulplier (PMT)

To

Silicon Photomulplier (SiPM)



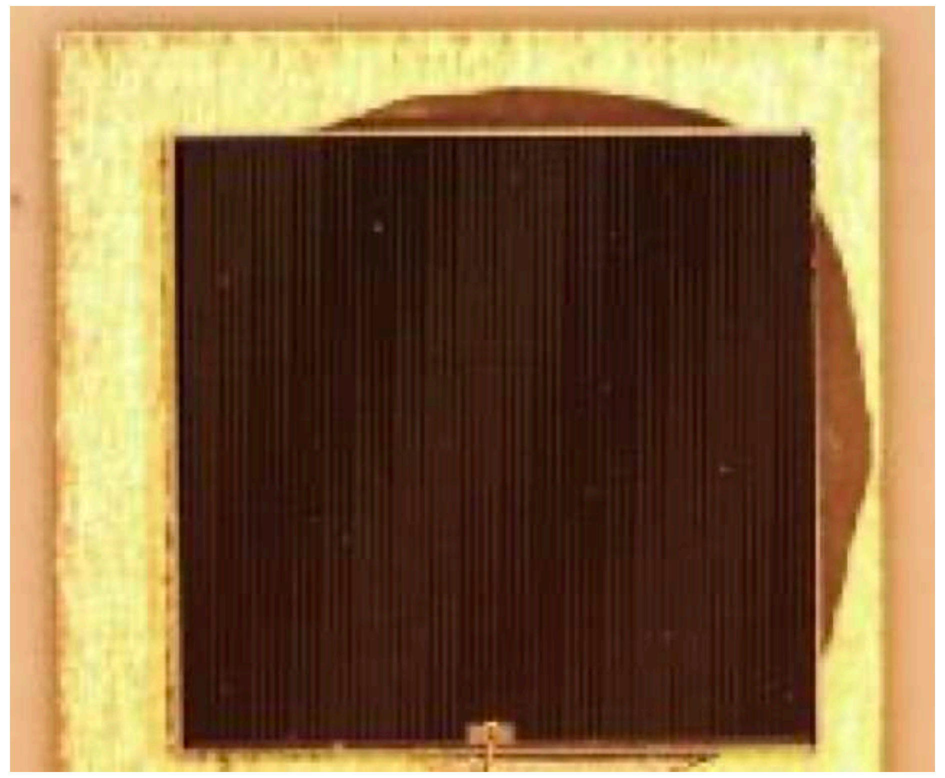
Quantity	Requirement
Breakdown voltage	26.8 +/- 0.2 V
SiPM response - recharge time	300 - 600 ns
Single Photoelectron (SPE) spectra	distinct PE
Gain	stable gain
Signal to noise ratio (SNR)	> 8
Dark count rate (DCR)	< 0.01 Hz/mm^2 (7 Vov) < 0.1 Hz/mm^2 (9 Vov)
Internal cross talk (CT) probability	< 33 % (7 Vov) < 50 % (9 Vov)
Afterpulsing (AP) probability	< 10 %

DARKSIDE SIPM REQUIREMENTS

From PhotoMulplier (PMT)

To

Silicon Photomulplier (SiPM)



Why SiPMs

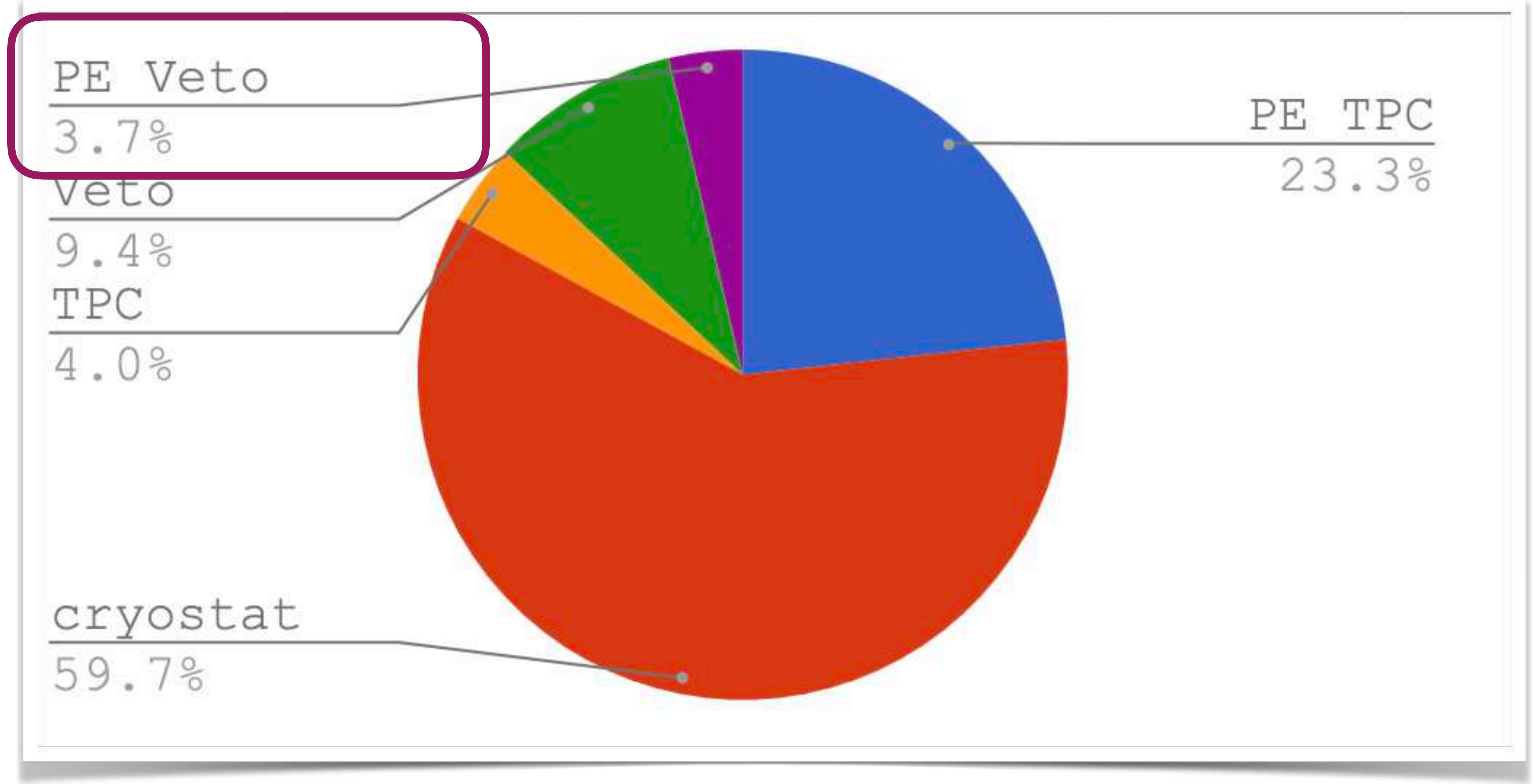
- Cryogenic temperature stability
- Better single photon resolution
- **Higher photo-detection efficiency**
- Low voltage operation
- **Radio-purity an order of magnitude lower than PMTs**
- Lower cost per area

vPDU: radio-purity control

- Stringent radio-purity control and material selection
- Each component for vPDU has been assayed trough ICPMS/BeGe
- Assay of final populated board to qualify assembly process -> *no additional contamination introduced*
- **vPDU contributes to the 3.7% of the total neutron background budget**

Comparison between sum of each components vs final populated board

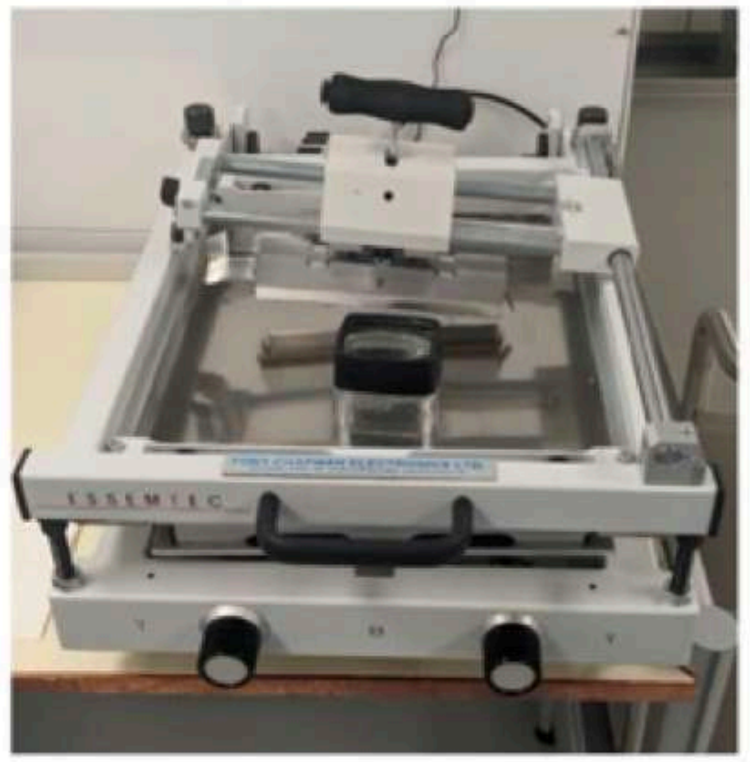
	From summing [Bq]	From assay [Bq]
Uup	2.2E+00	2.3E+00
Umid	1.2E+00	1.3E+00
Ulow	5.8E+01	**8.4E+01**
Th232	1.3E+00	1.1E+00
Ur-235	1.6E-01	1.1E-01
K40	1.4E+01	1.3E+01



UK FACILITIES: PCB production

PCB production @Birmigham

Application of Solder paste using stencil printer



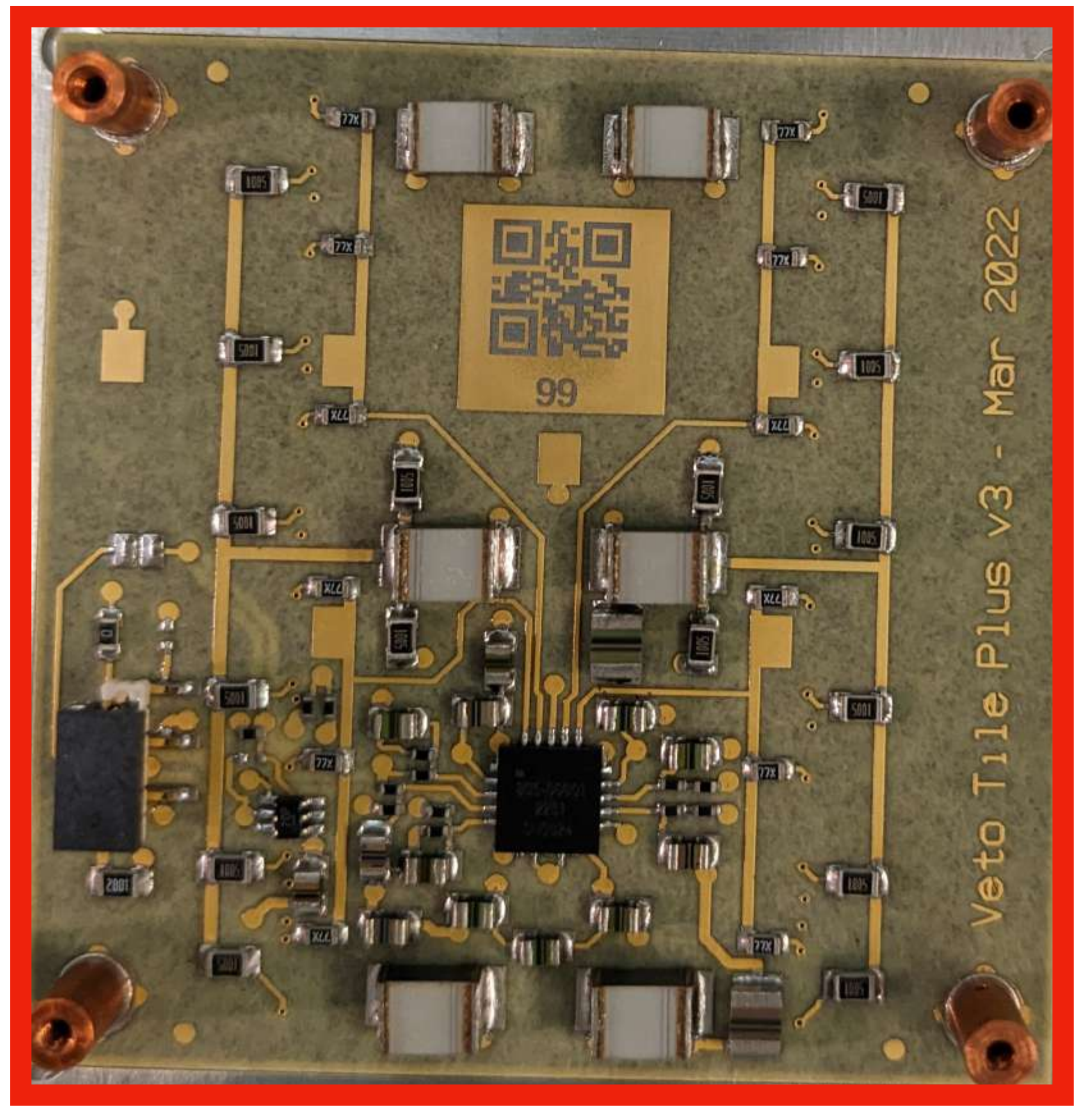
ESSEMTEC SP-002 Manual
Stencil printer
Solder paste: CHIPQUIK

Pick and Place machine – PCBs to come as 4x3 sheet

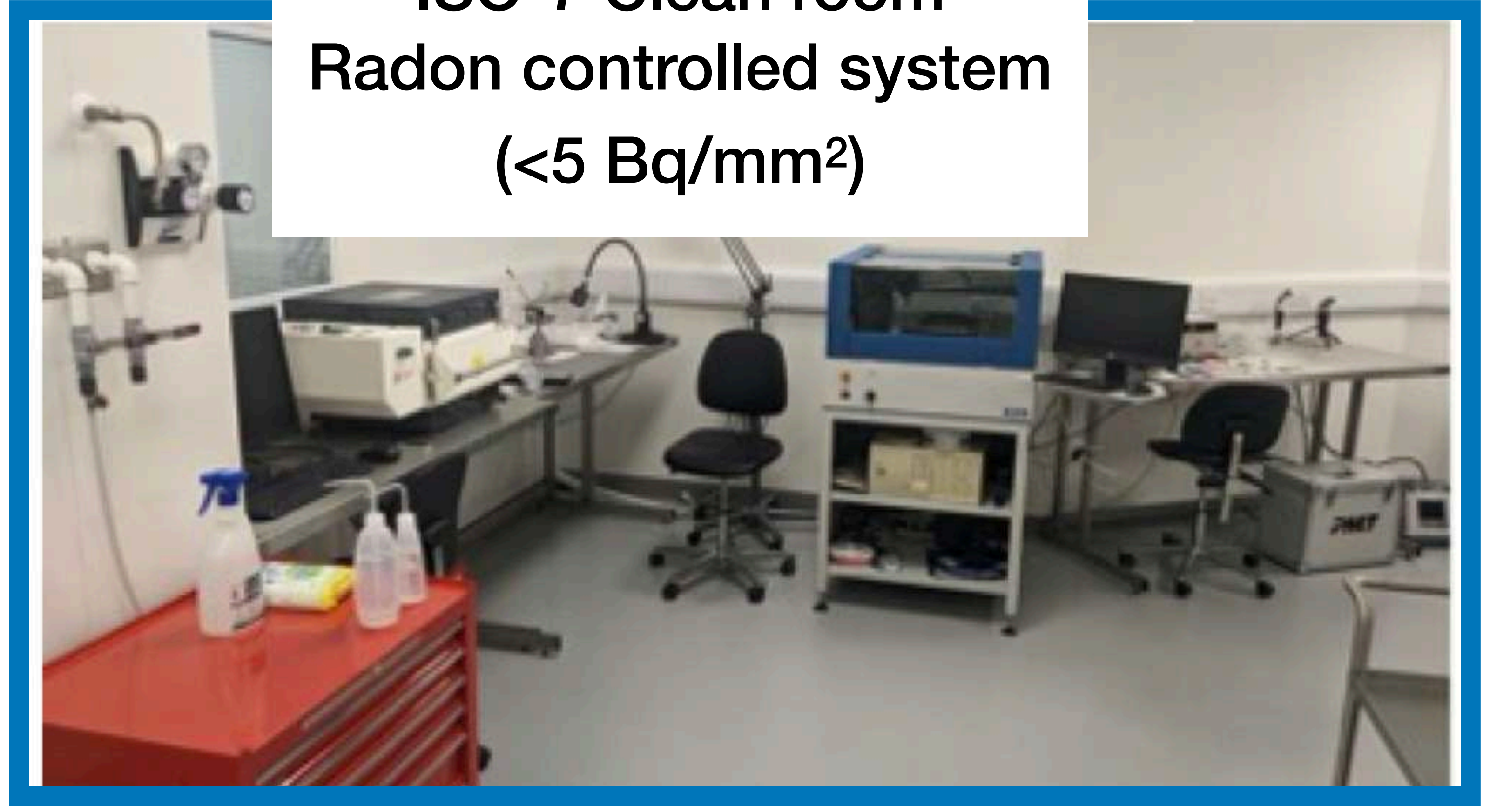
MECHATRONICA M60 pick and place

New Reflow oven:
3 temperature probes
5 minutes at 150°C
1 minute at 200 °C

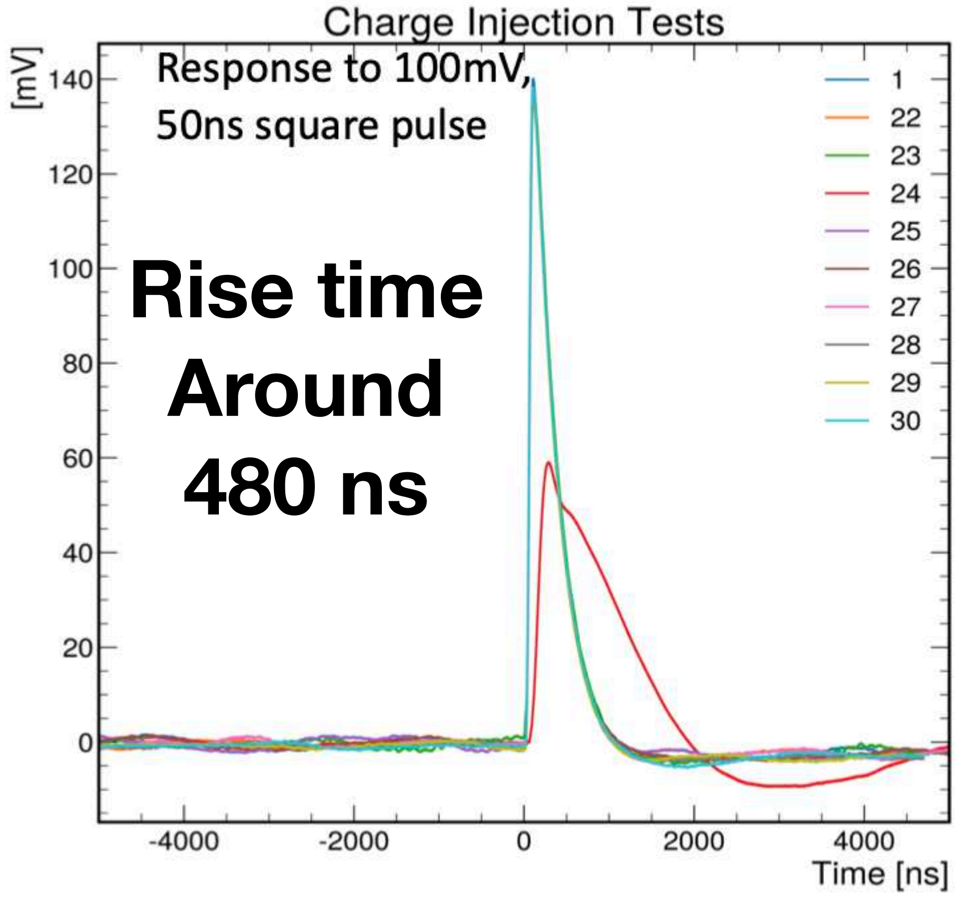
C.I.F FT05 advanced forced convection oven



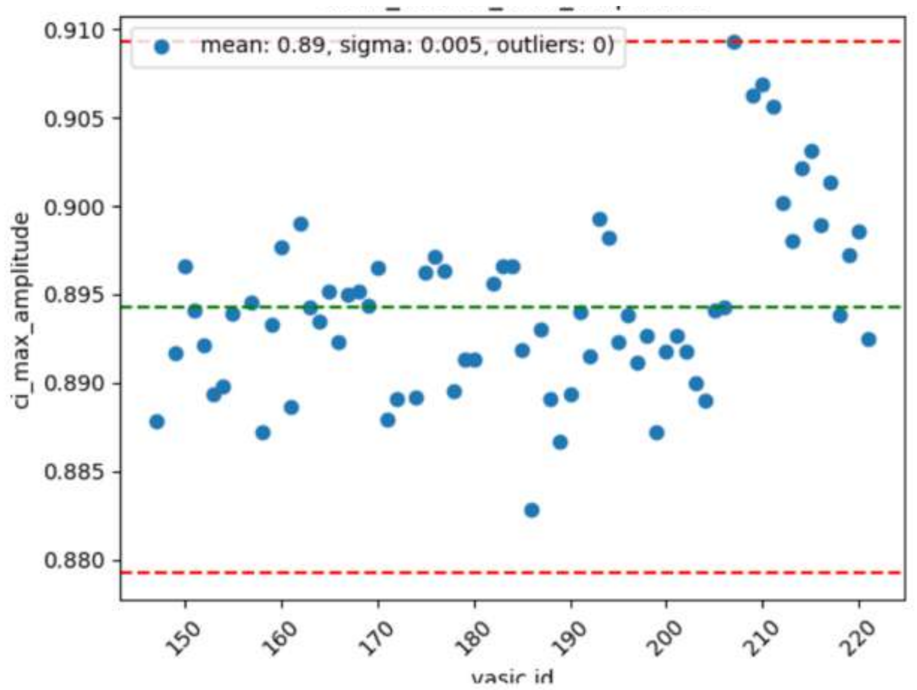
ISO-7 Clean room
Radon controlled system
(<5 Bq/mm^2)

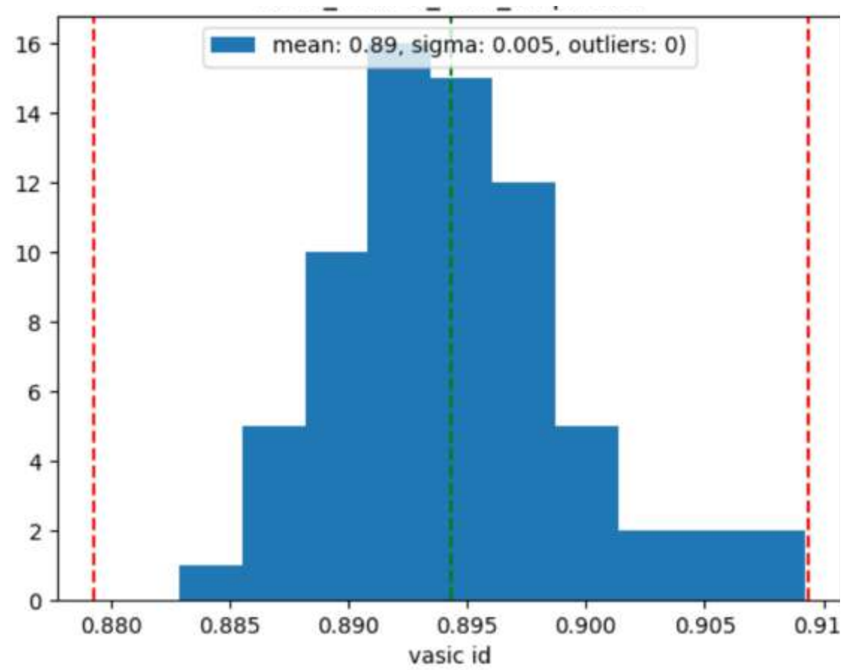


Accumulating Statistics to define QA/QC acceptance criteria



Amplitude distribution



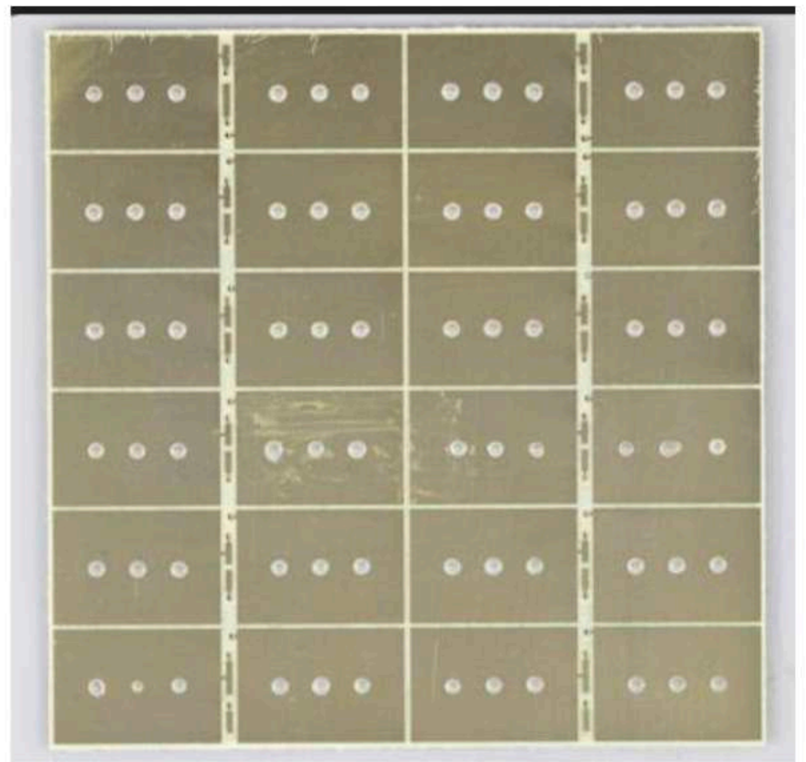


Amplitude around 880 mV

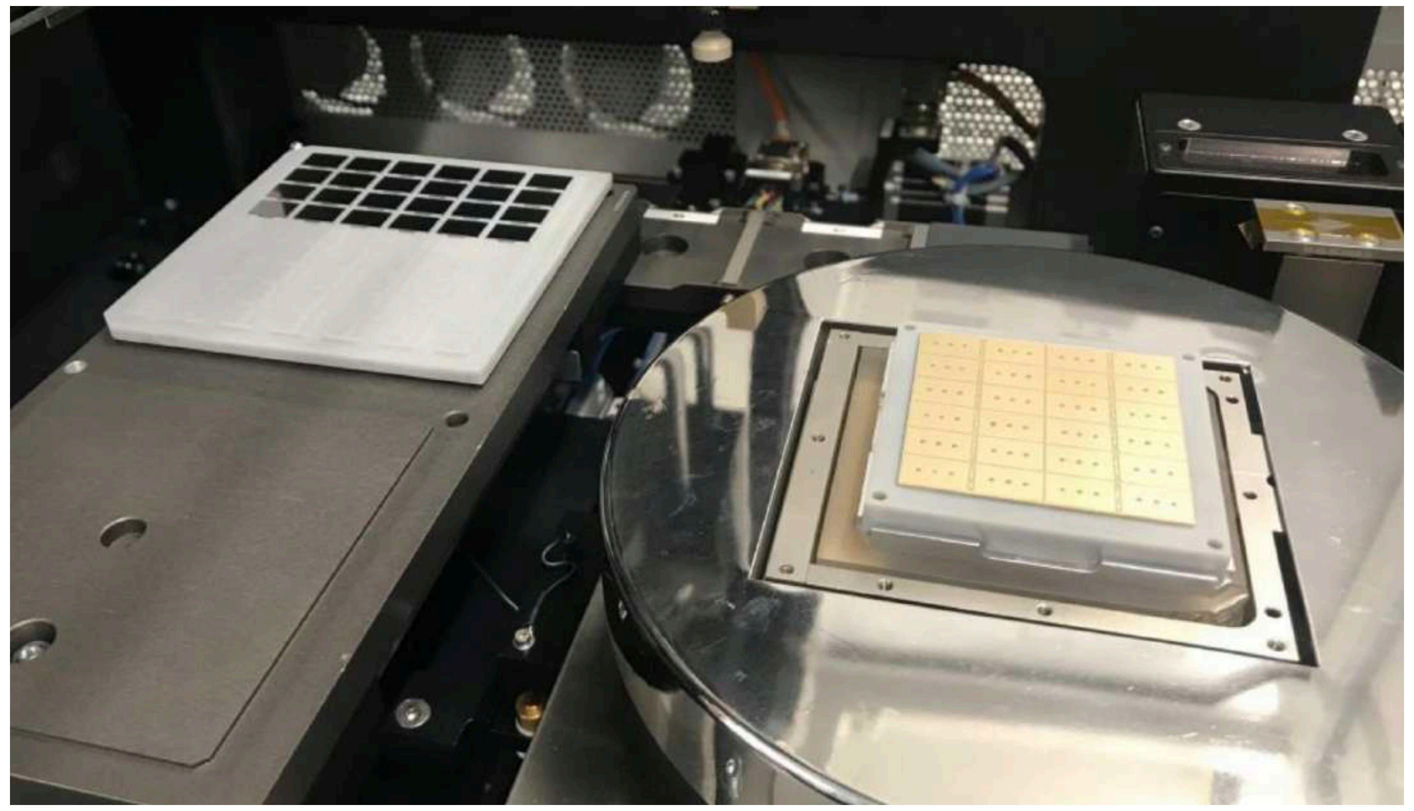
UK FACILITIES: Tile assembly @STFC interconnect

ISO7 CR
Radon level
3.3 Bq/m3

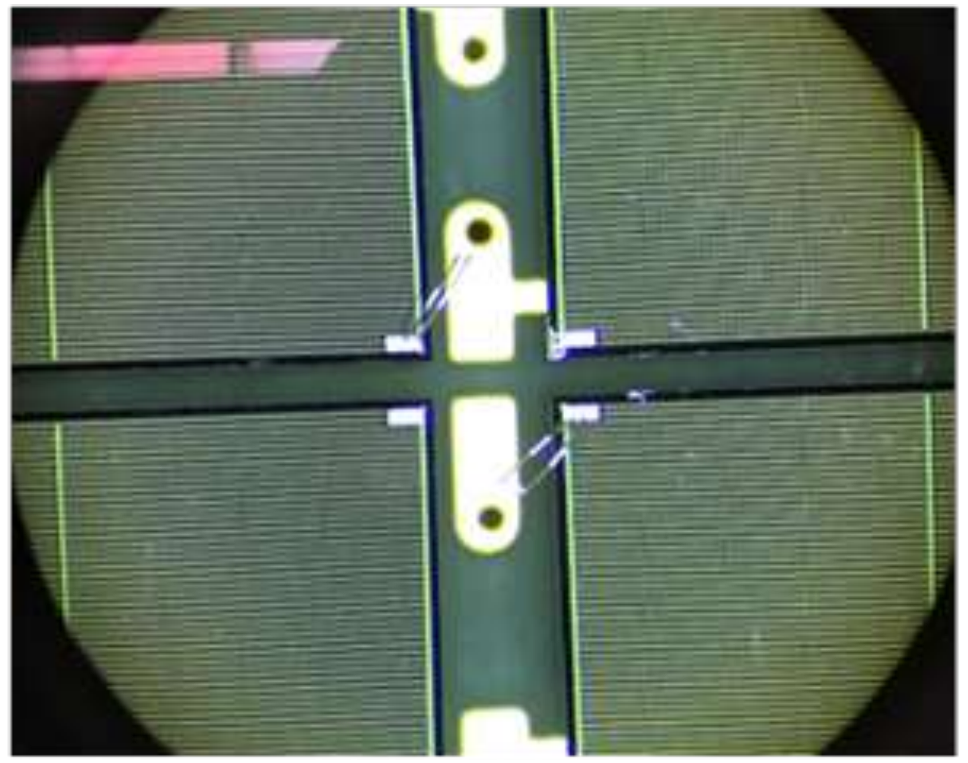
Glue dispense



Die attach



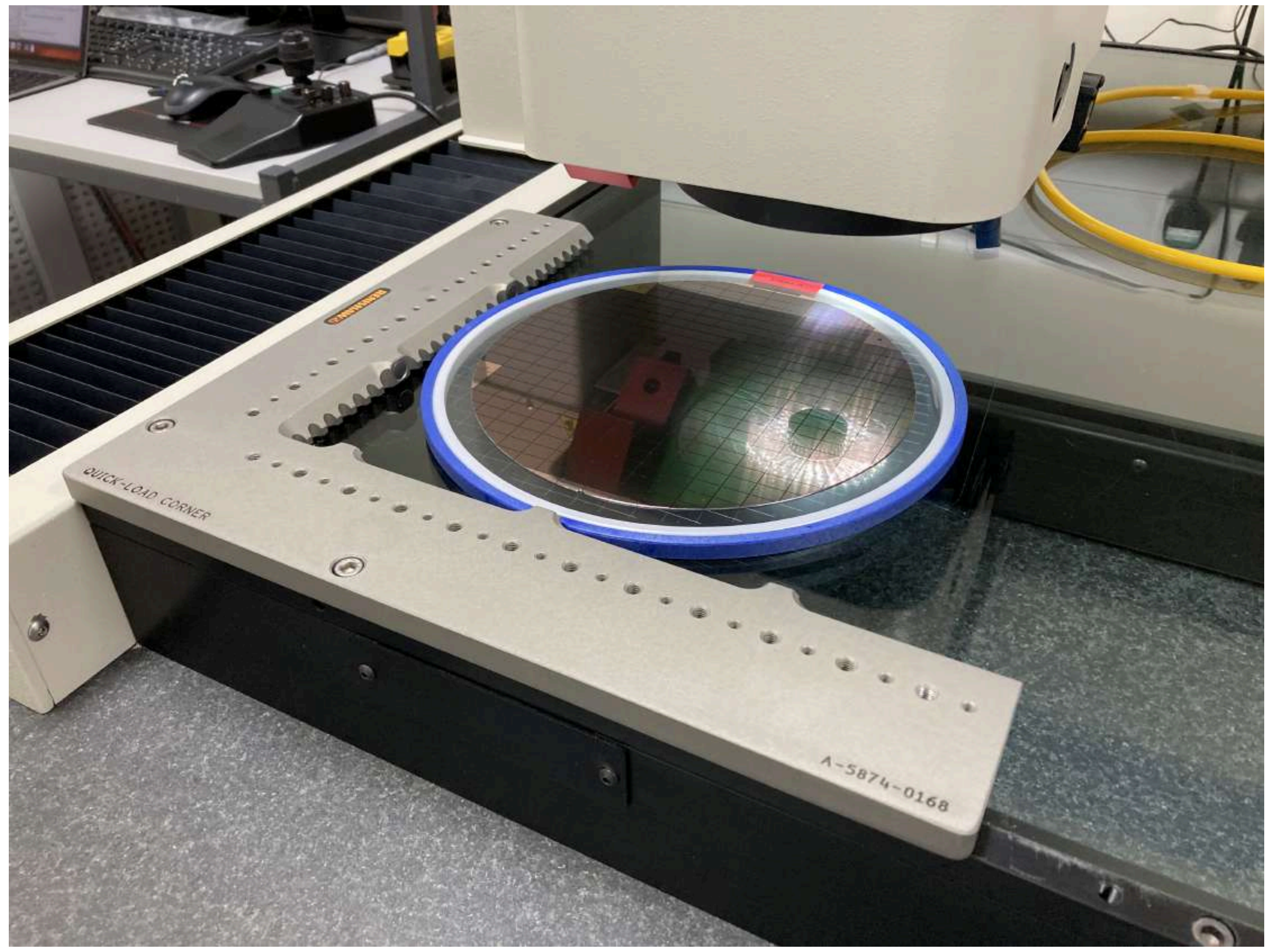
Wire Bonding



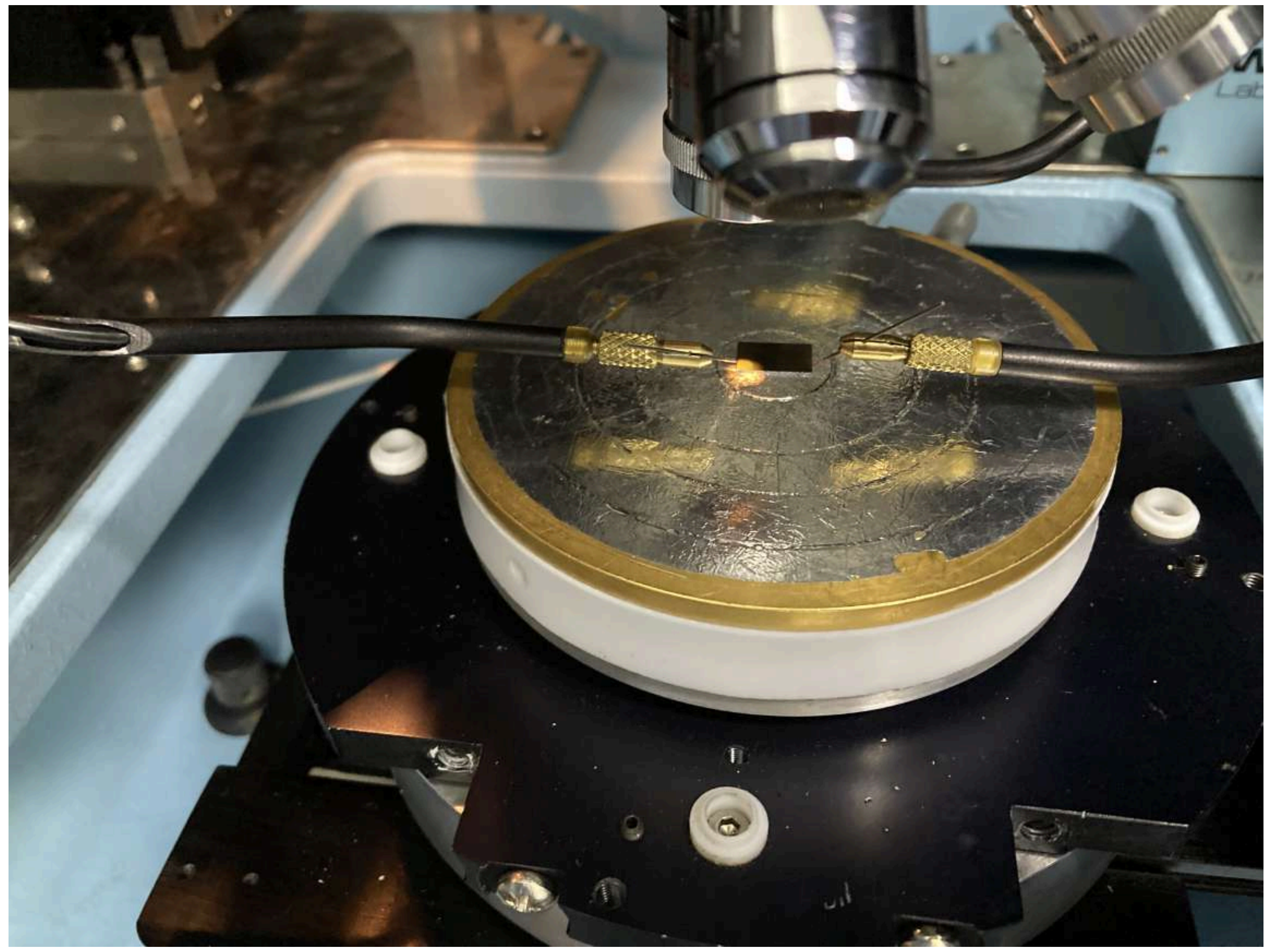
UK FACILITIES: Tile assembly @Liverpool

ISO7 CR
Radon level < 1.1 Bq/m3

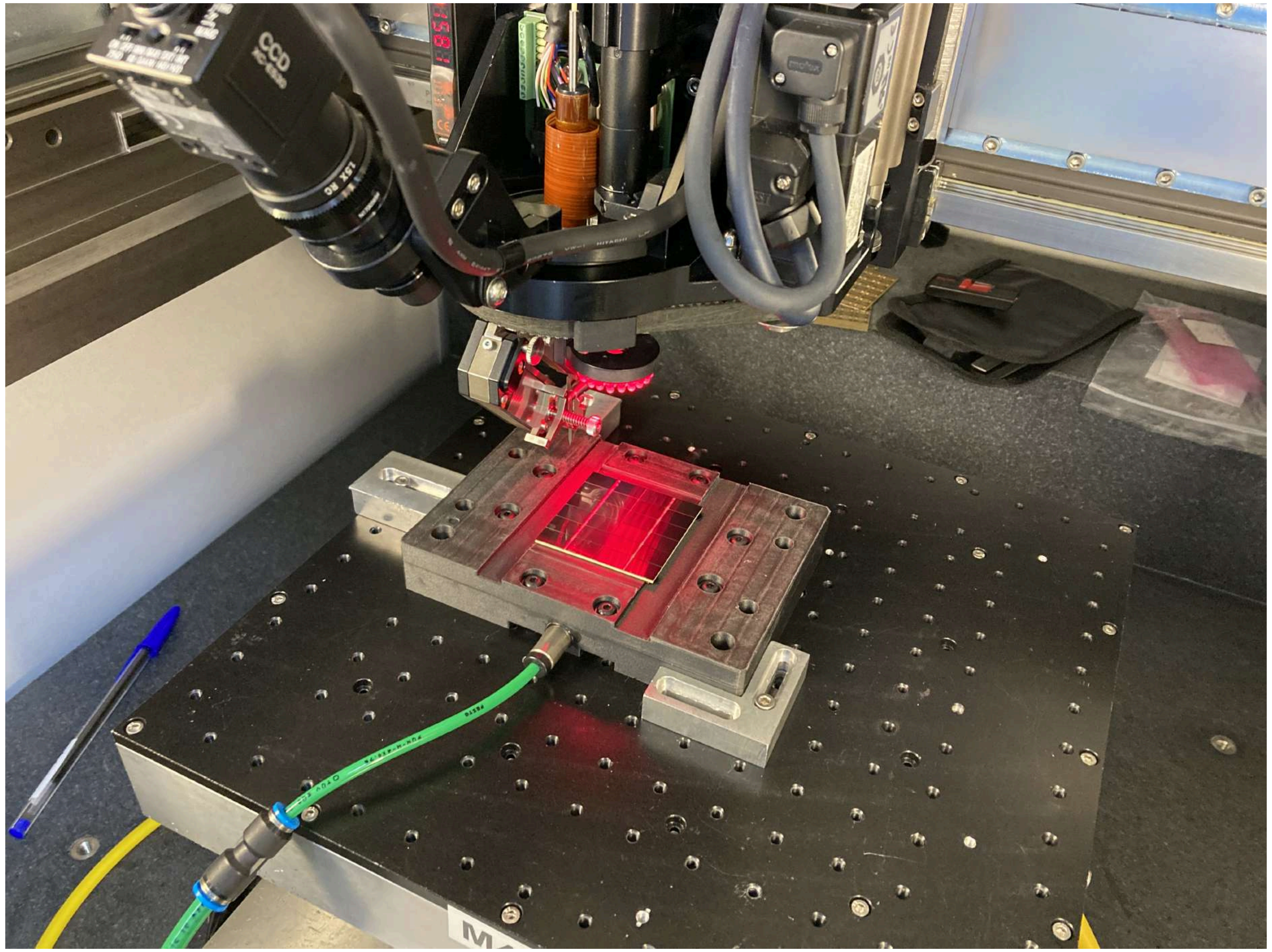
SiPMs Wafers inspection



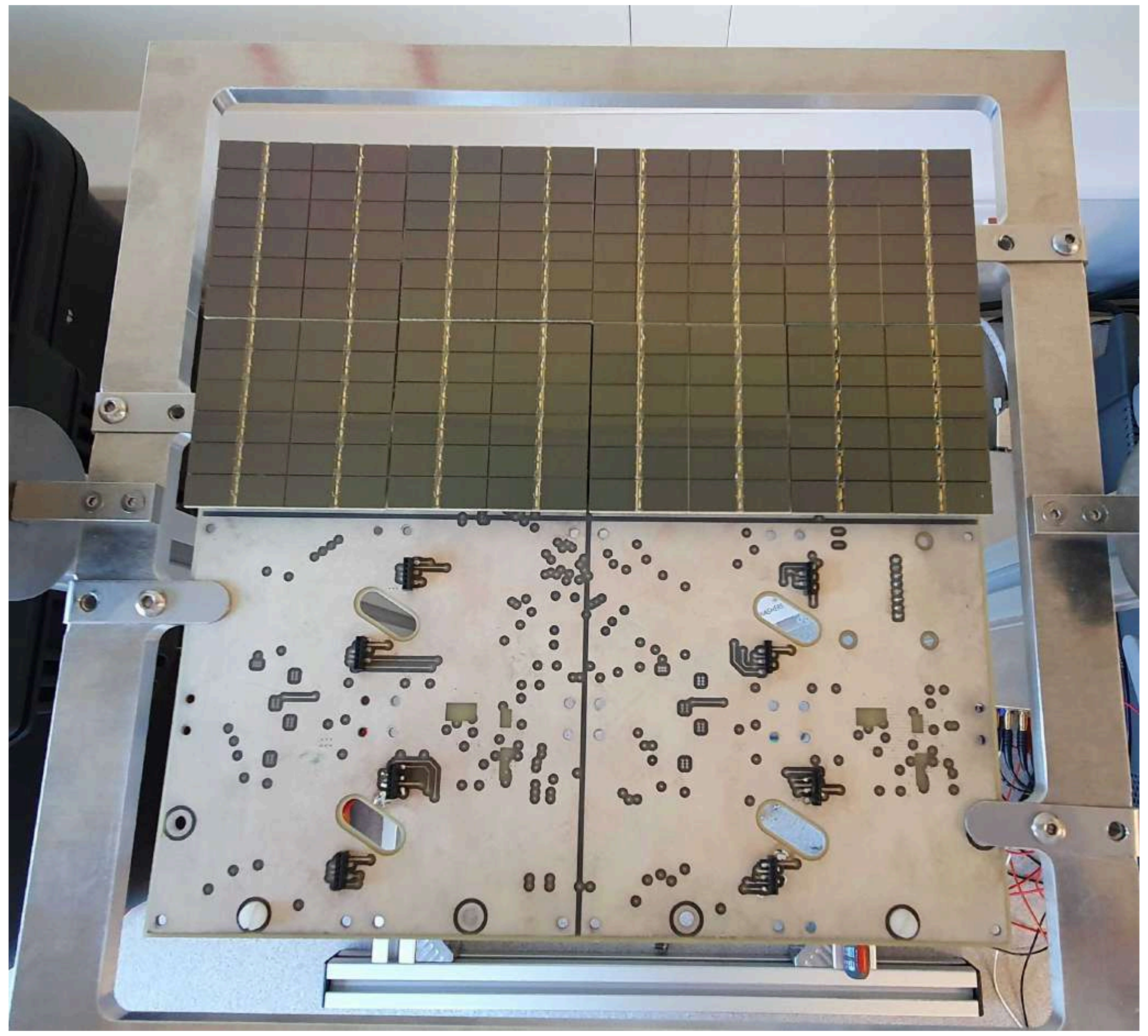
SiPMs IV measurement

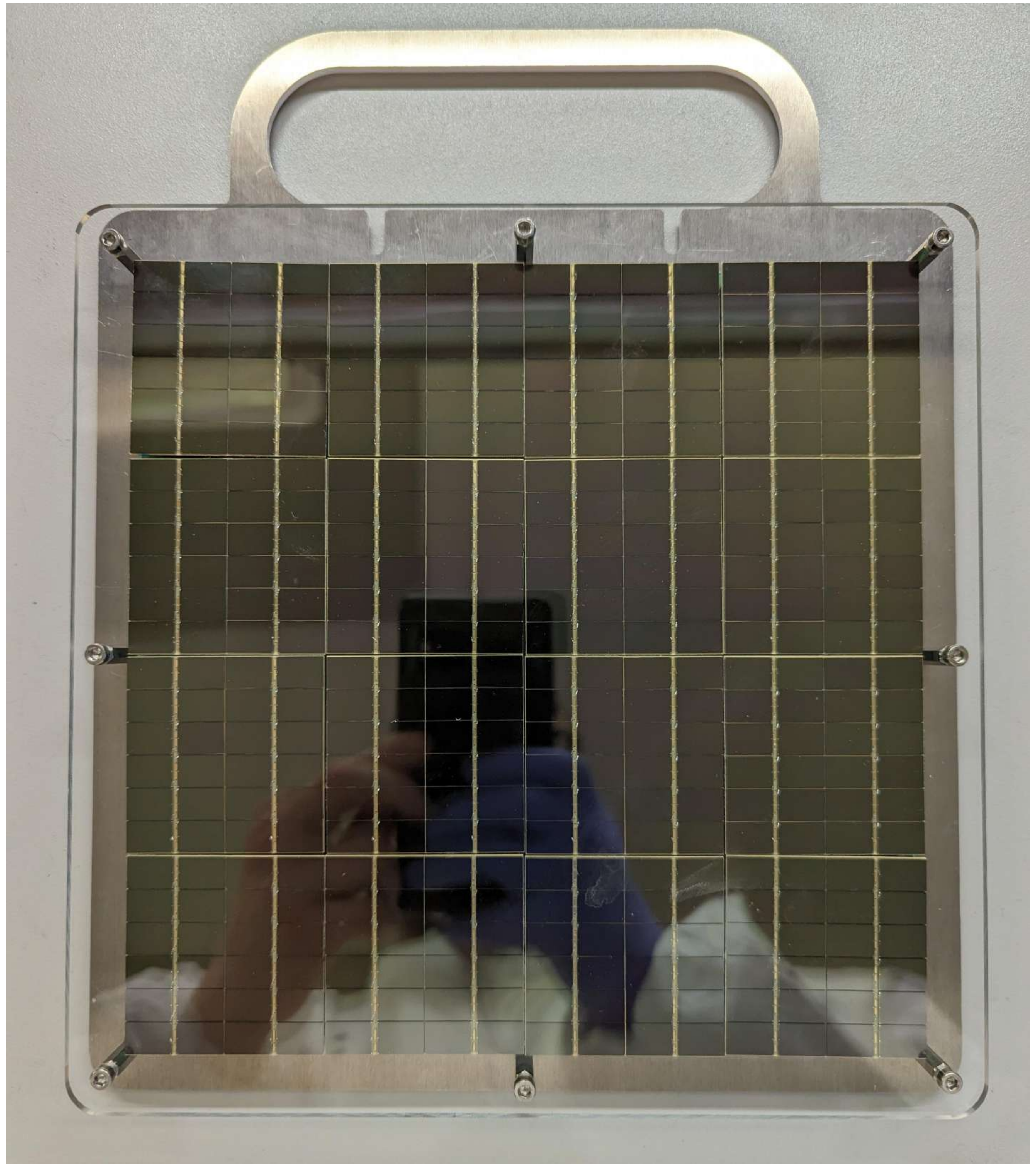


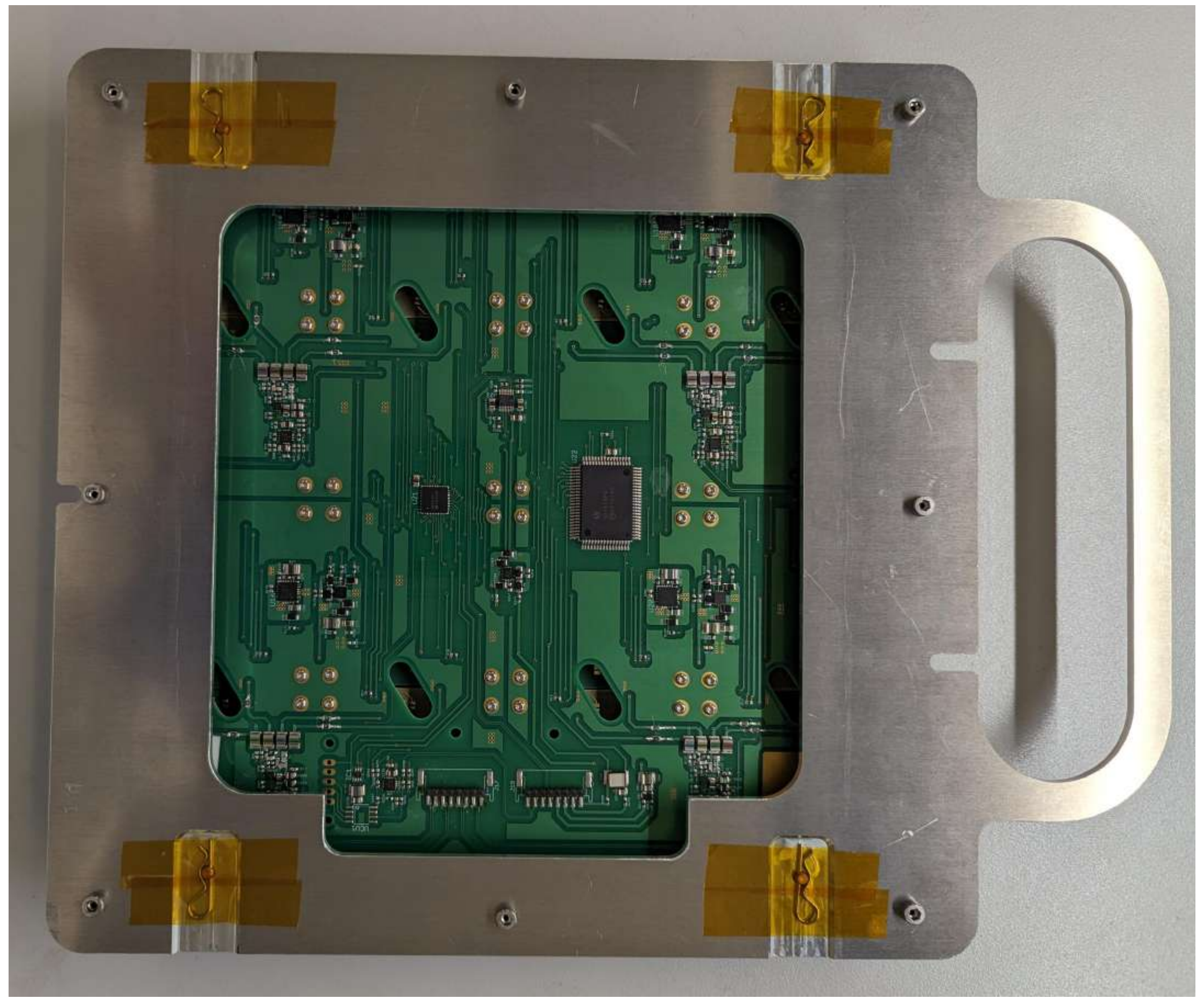
Wire Bonding a vTile



UK FACILITIES: PDU assembly @Manchester



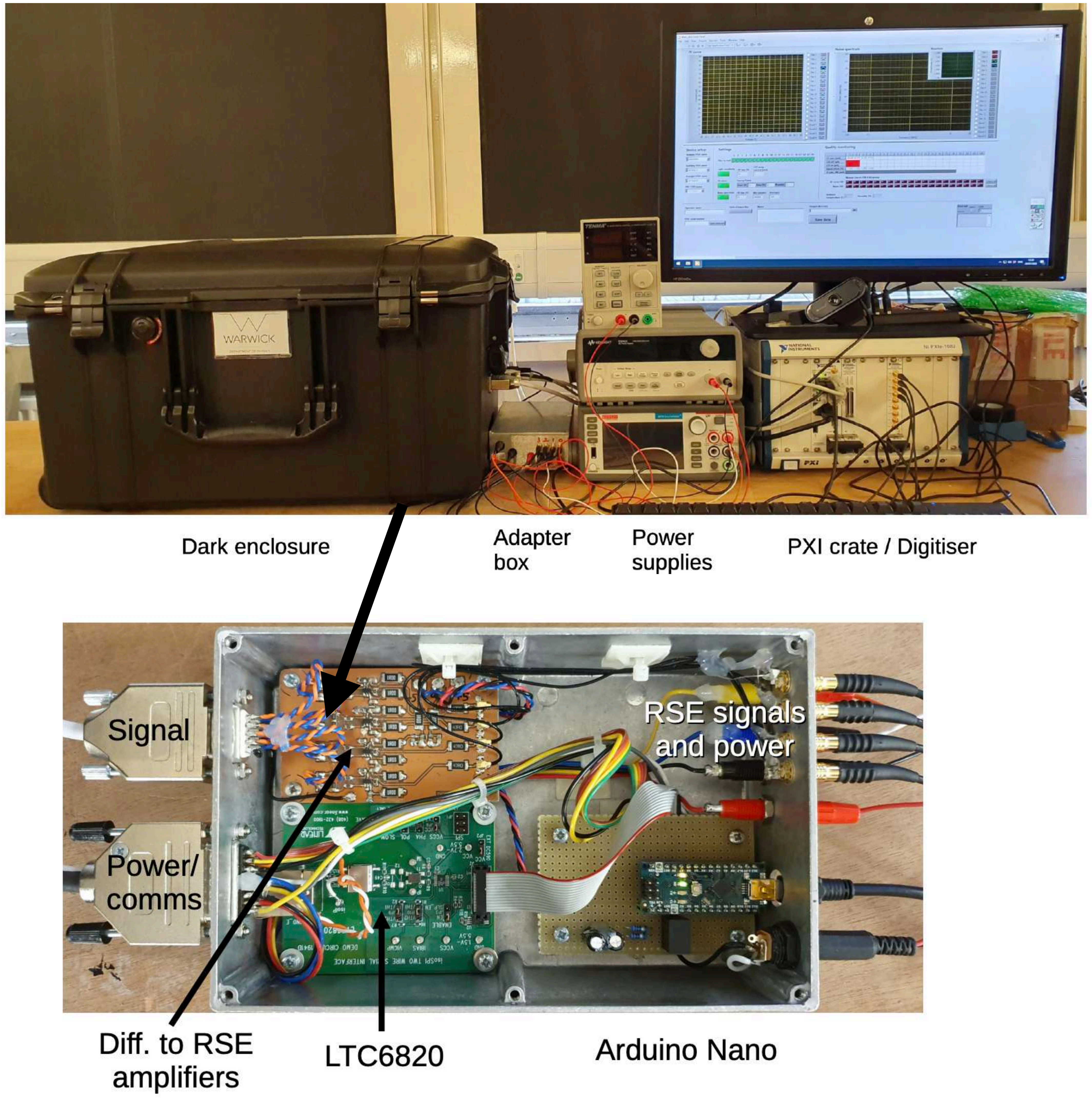




first three vPDUs assembled

vPDU TEST FACILITIES

Warwick WARM testing setup @Manchester



Cold testing setup @Liverpool

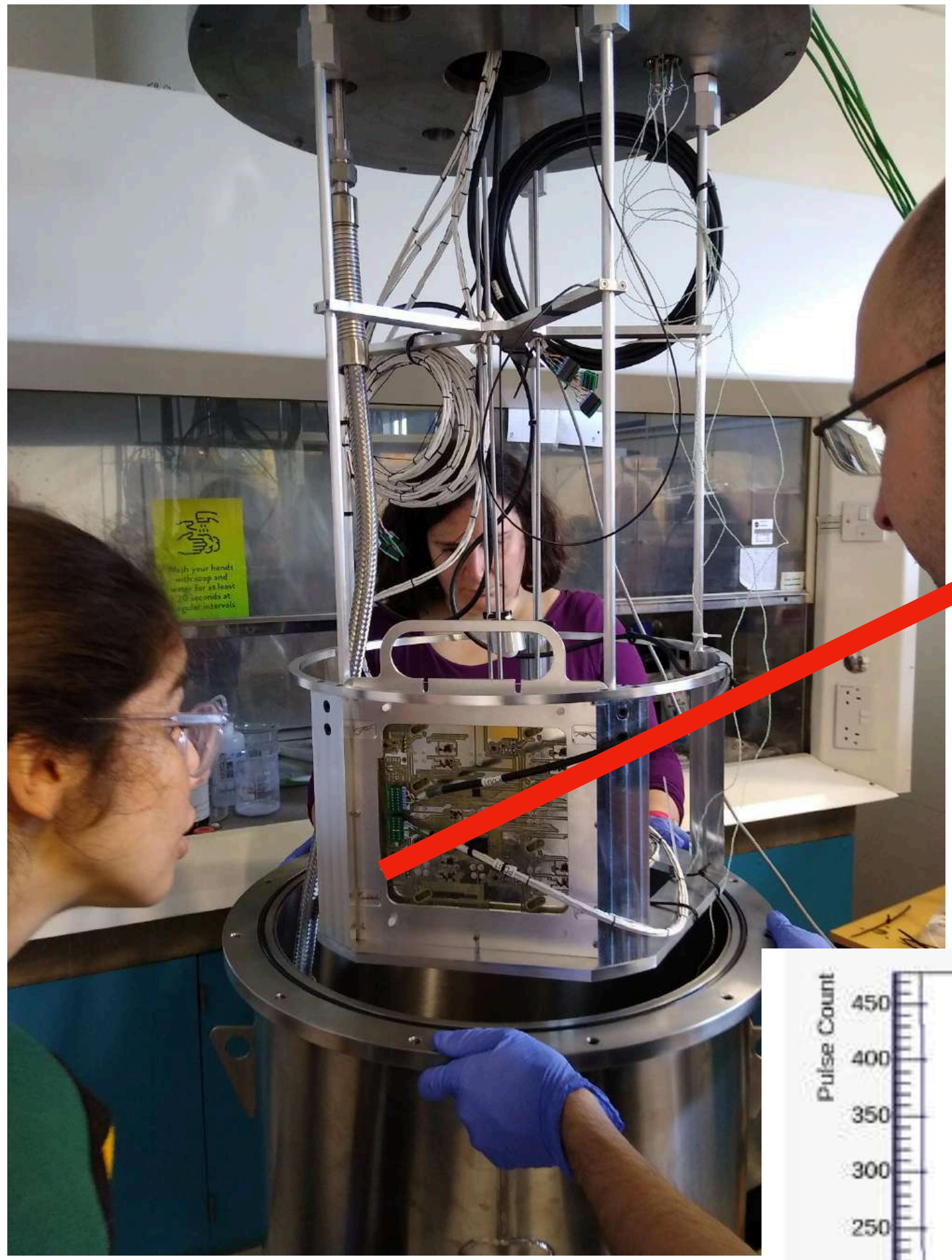
PHAIDRA

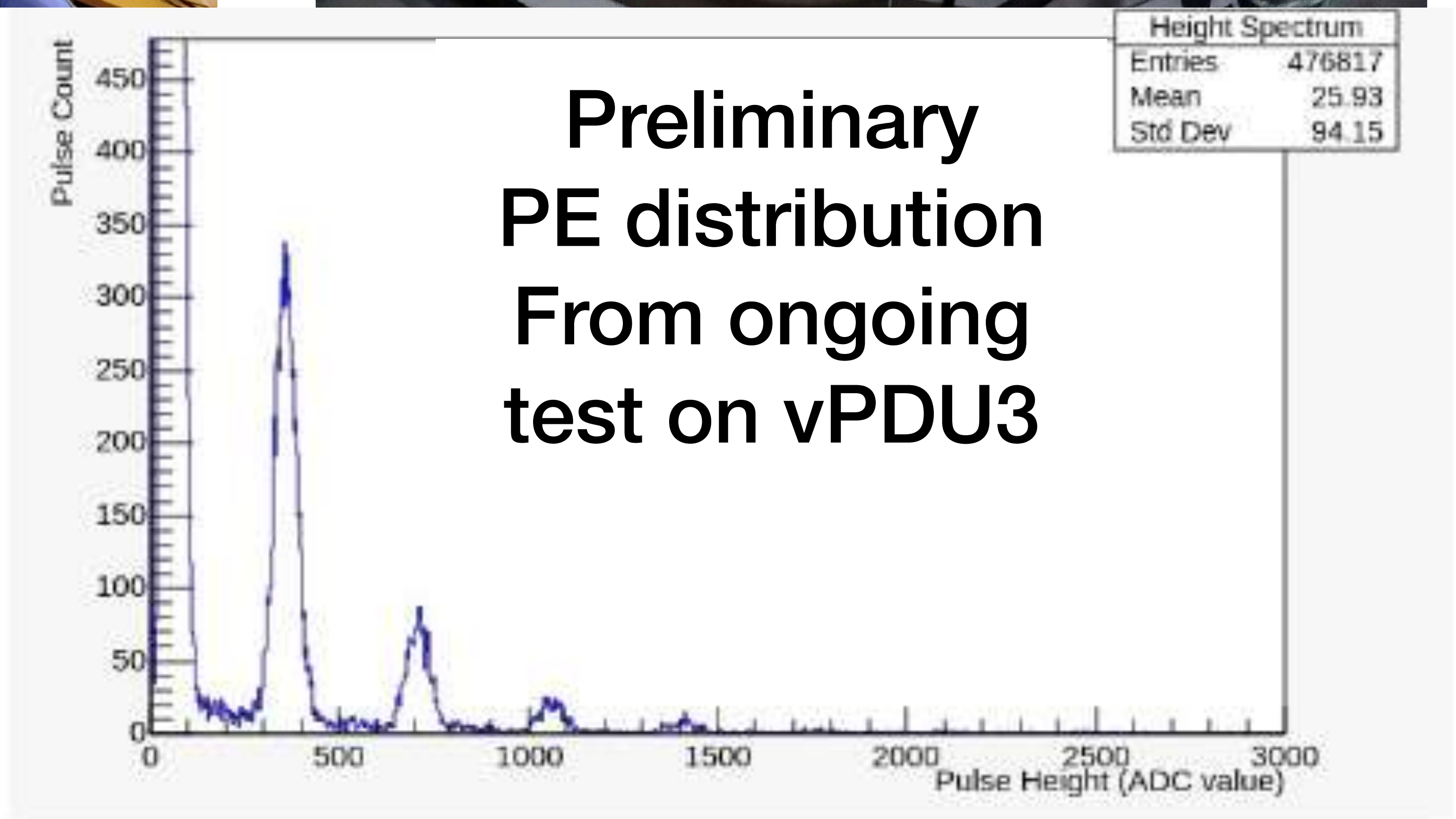
- Cold test in Liquid Nitrogen
- PDU testing starting in summer
- Ready for tile production testing: 10/time

vPDU TEST FACILITIES (2)

smaller cold test setups @Edinburgh

Host 4 tile/time



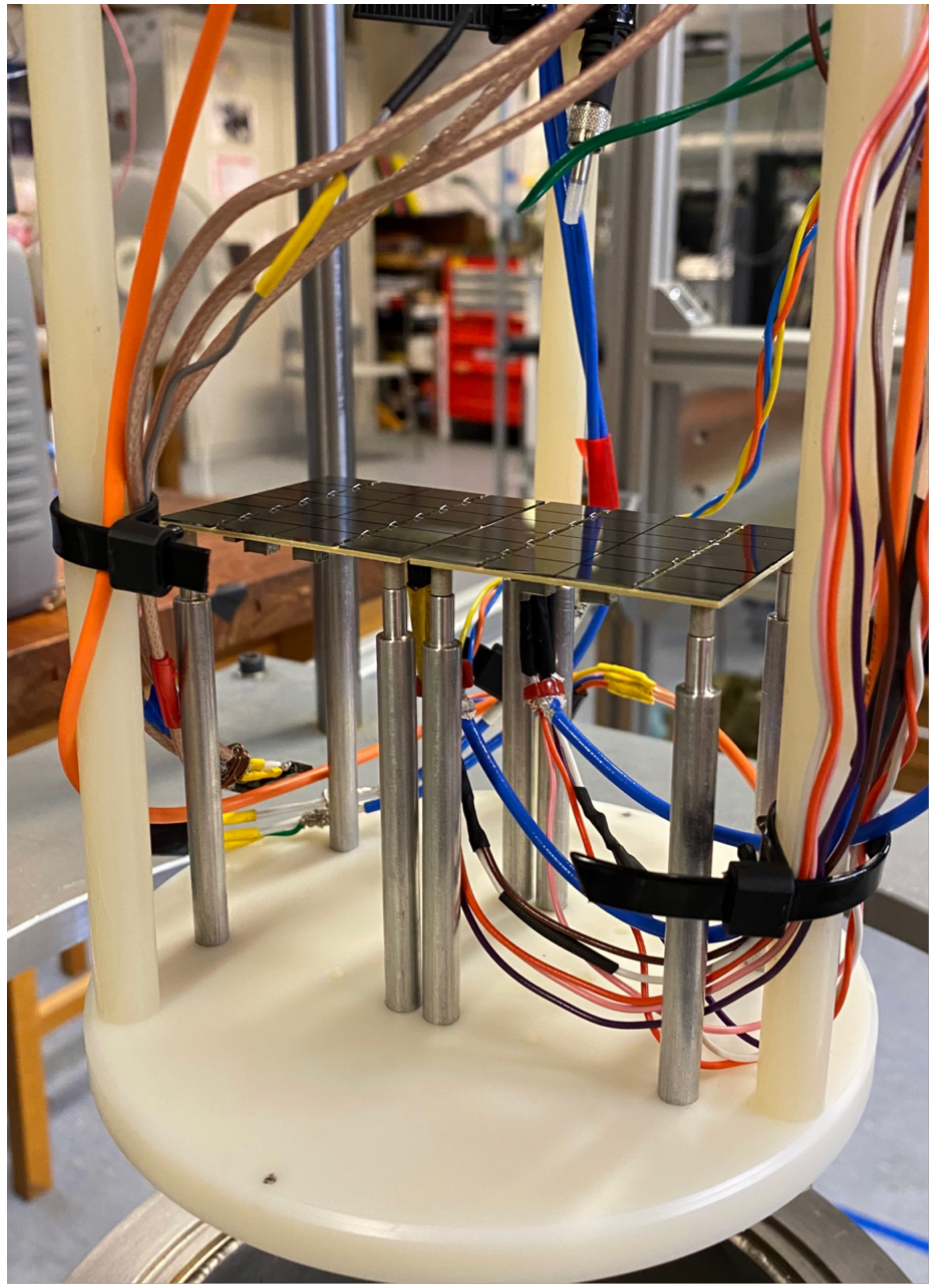


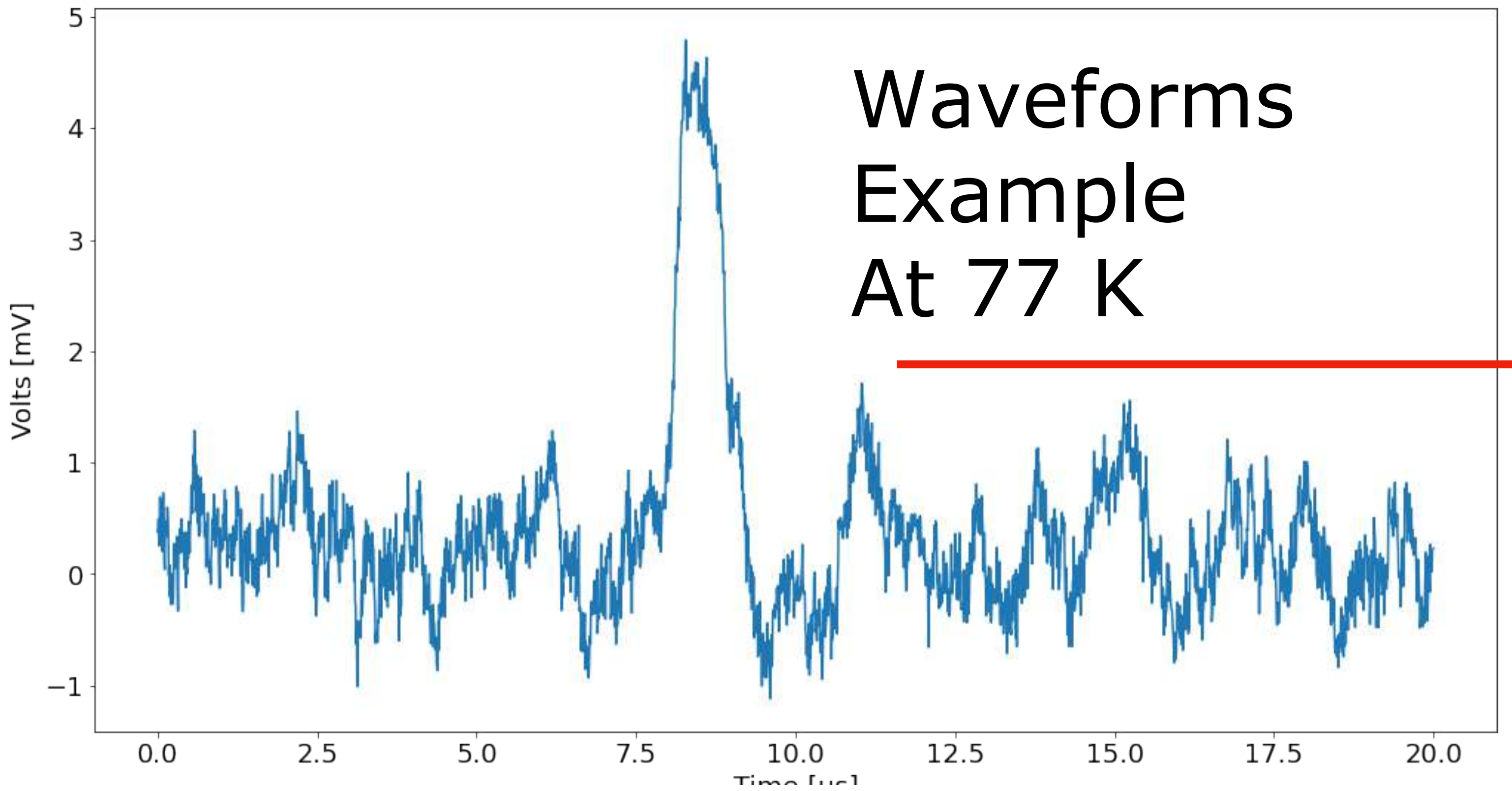
Preliminary
PE distribution
From ongoing
test on vPDU3

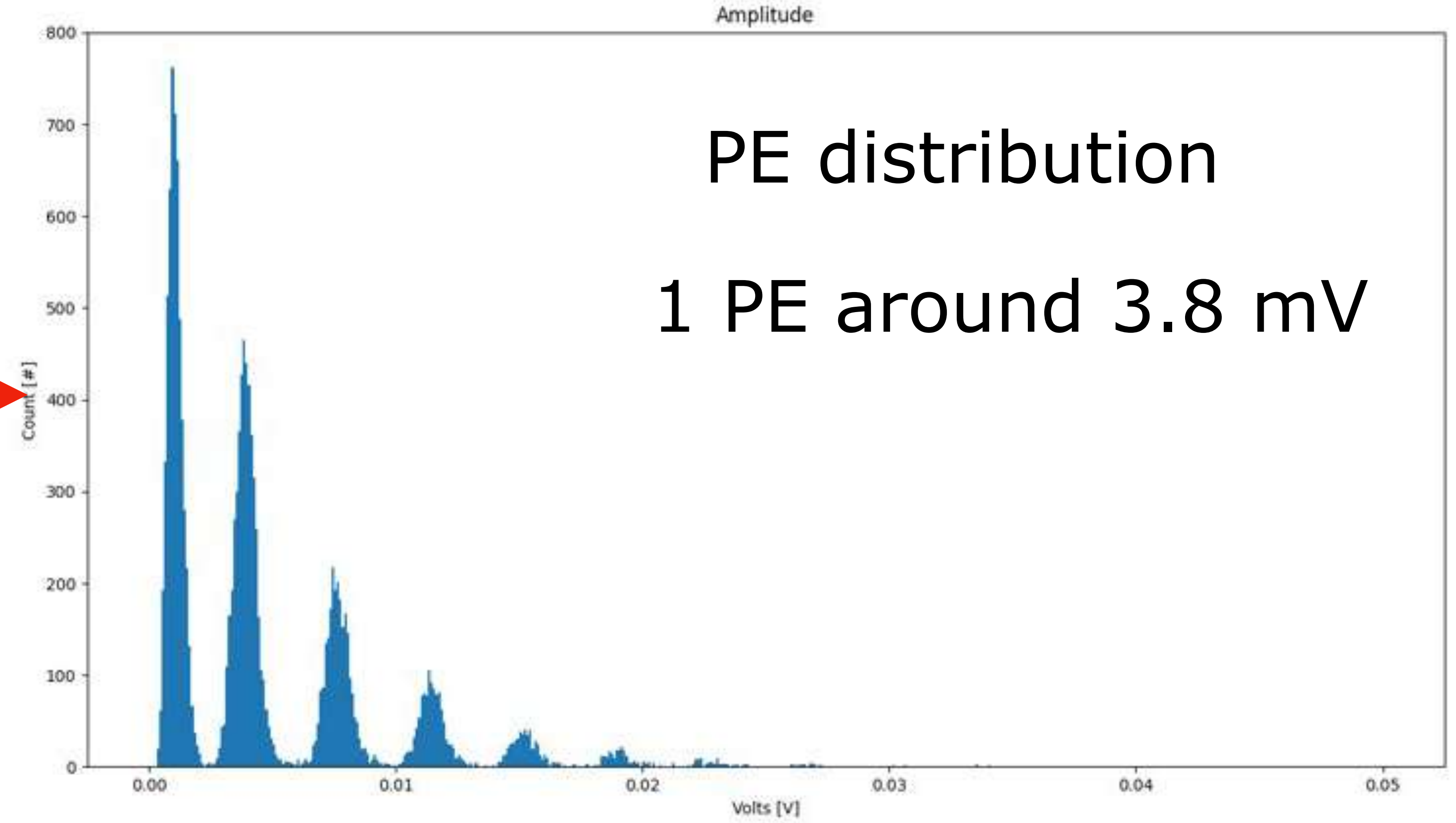
Other two facilities under development
@Lancaster, @Astrocent

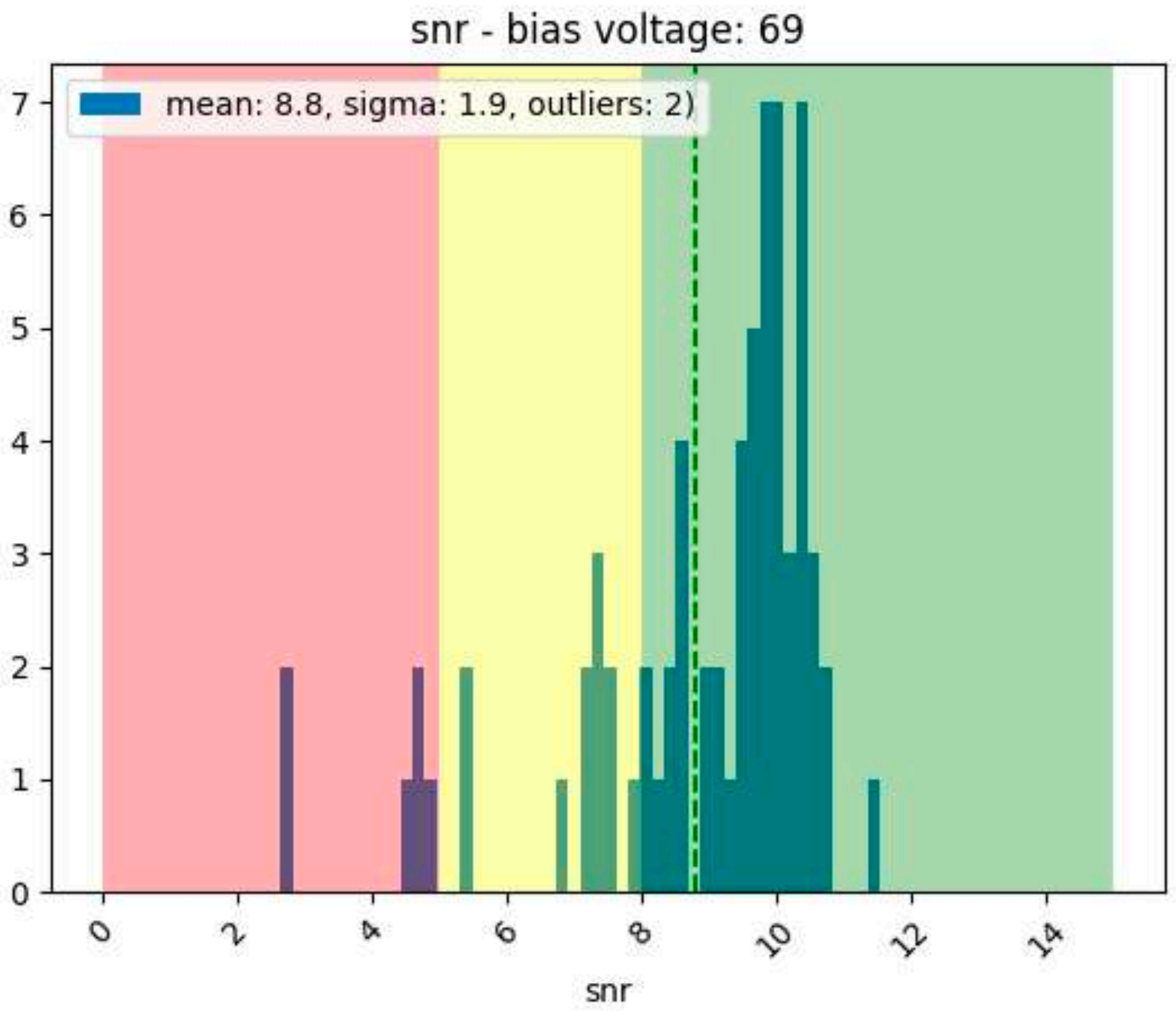
vTILE TESTING

Tile testing @RHUL
In liquid nitrogen









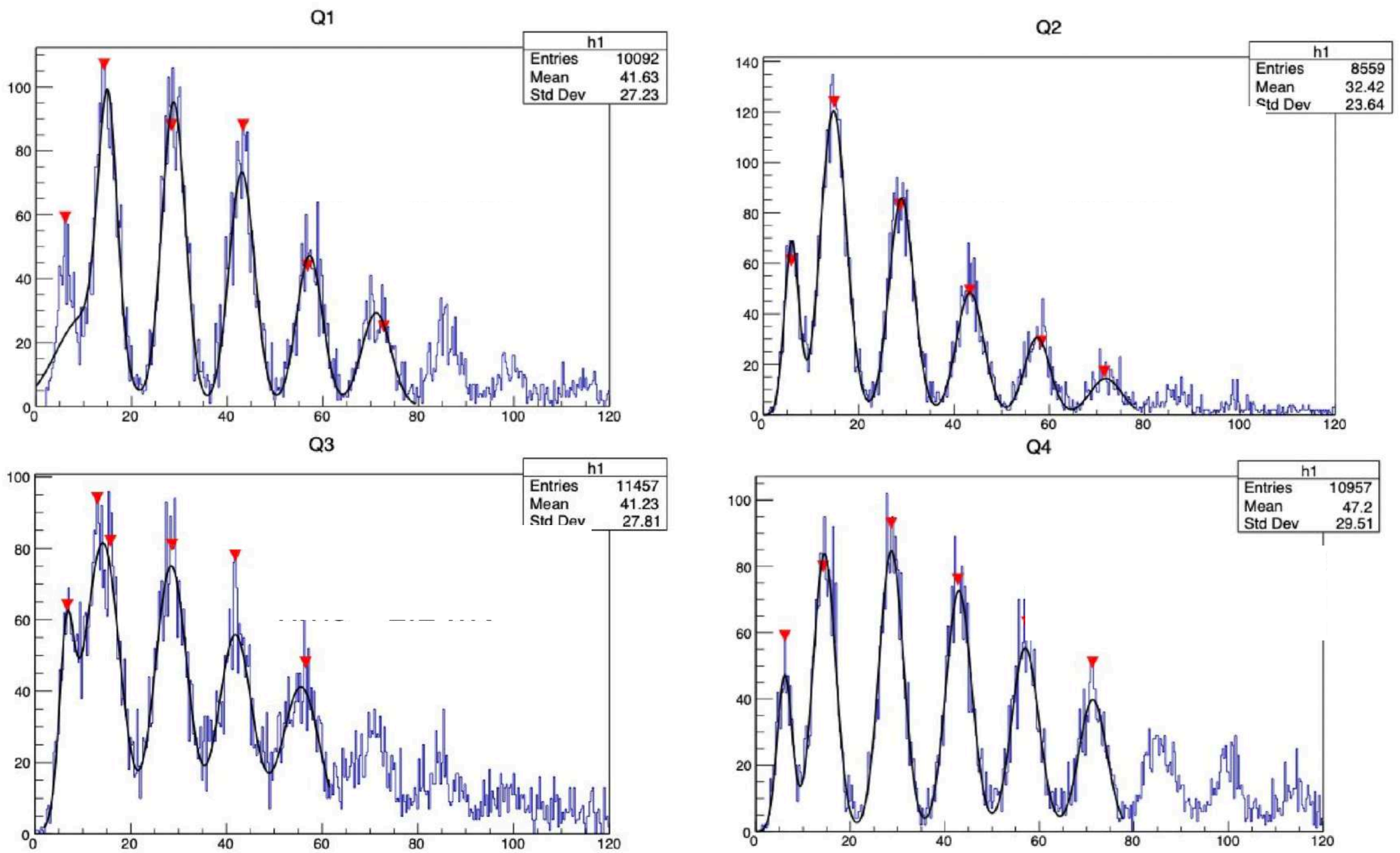
$$\textbf{SNR} = \frac{\textbf{1 PE amplitude}}{\textbf{RMS baseline}}$$

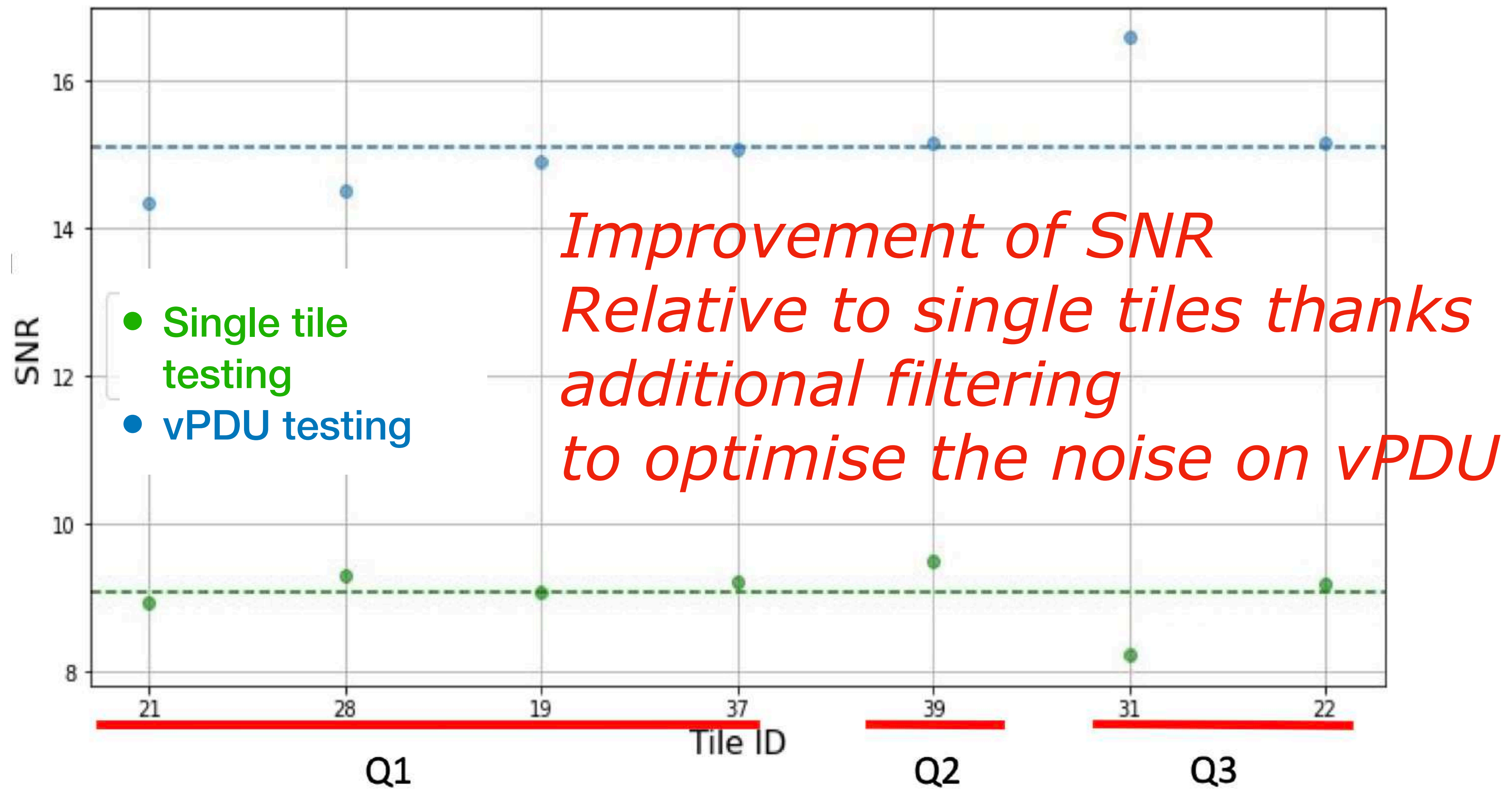
- *Improvement on test stand to optimise throughput*
- *Accumulating statistics to define QA/QC acceptance:* ***SNR > 8***

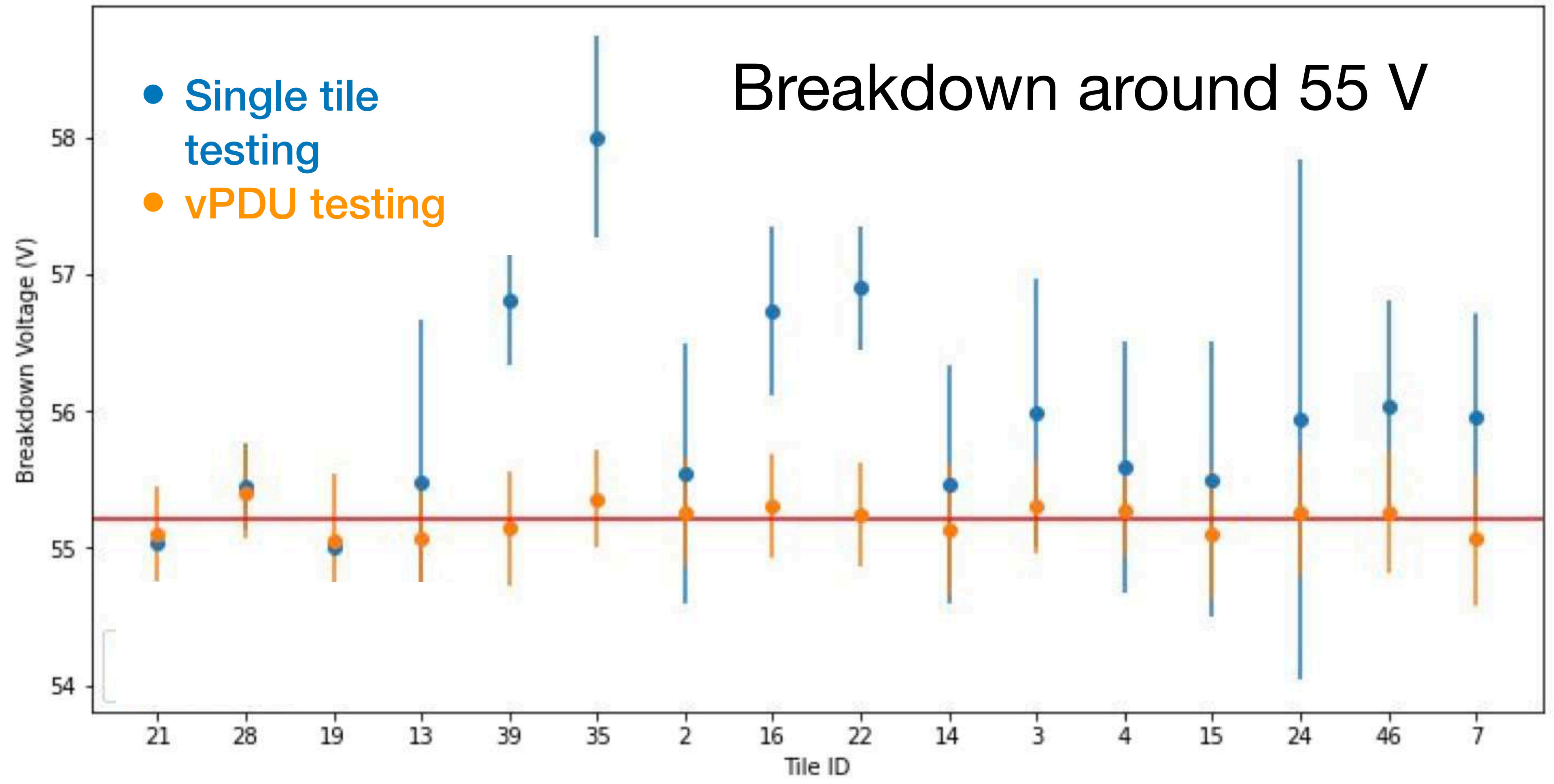
vPDU testing

Preliminary

PE distribution per quadrant = sum of 4 tiles = 10 cm x 10 cm area!
1 PE around 14 mV







Conclusion & outlook

- Veto detector is the key to achieving <0.1 instrumental background to dark matter search!

- Assembled and tested the first three vPDUs, vPDUs meet specifications!

- UK production facilities ready for full vPDU production and testing

- vPDU production complete within 2024