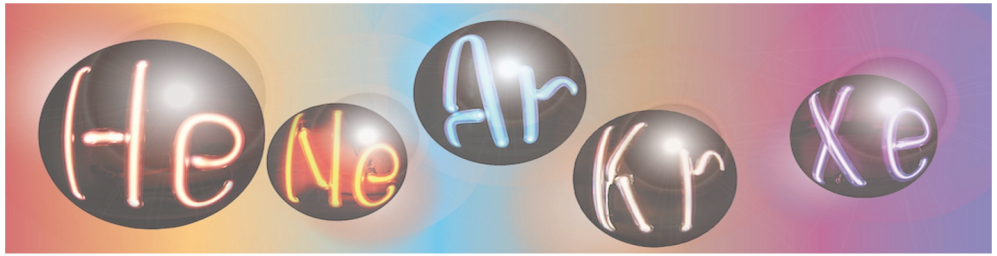
Production and Characterization of Veto Photon-Detection Units for the DarkSide-20k Experiment

- **Maria Cecilia Queiroga Bazetto**
- On behalf of the DarkSide-20k collaboration

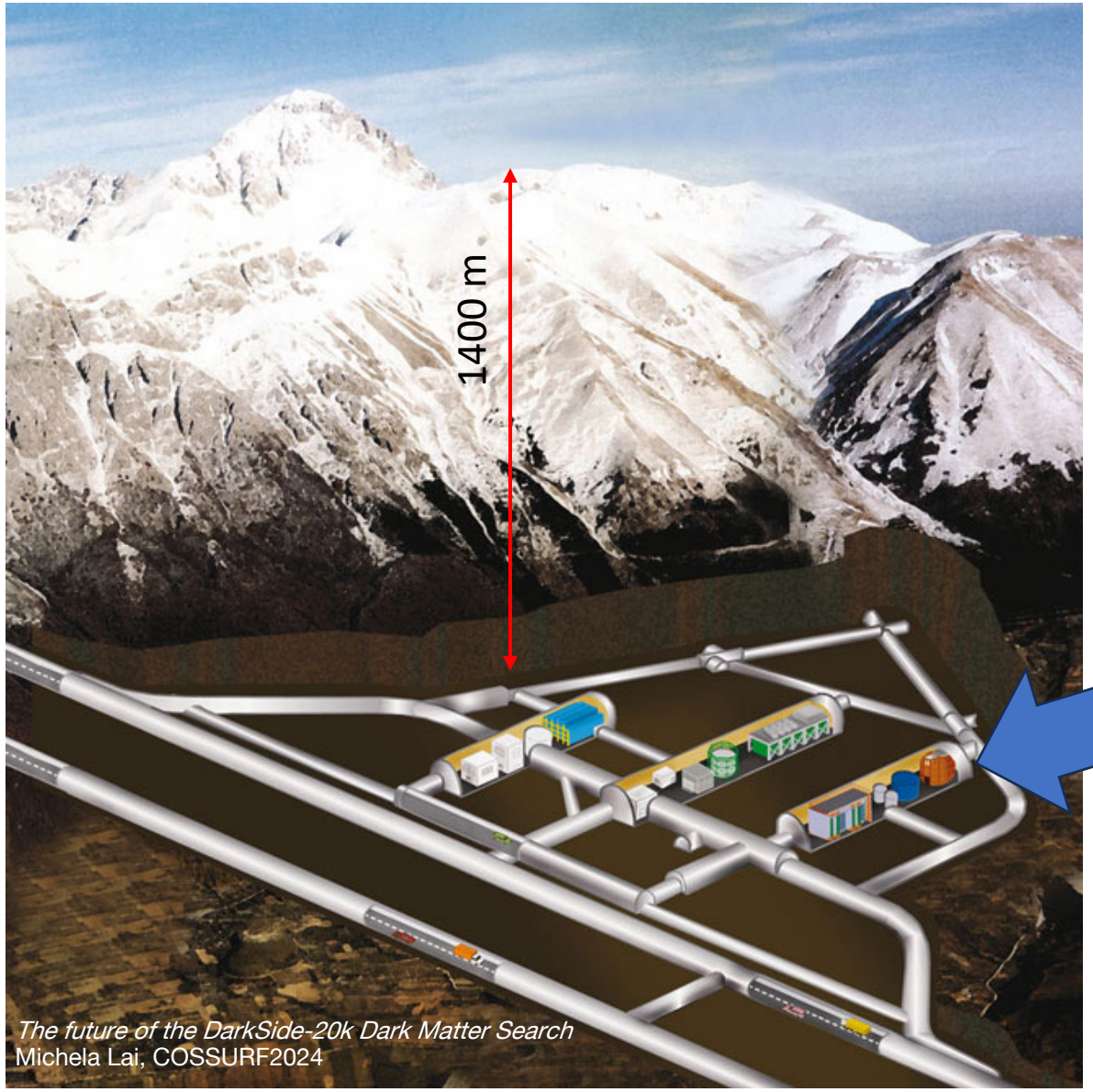
- LIDINE 2024 - Light Detection In Noble Elements
- 26-29 August 2024



Outline

- Experiment overview
- Production flow
- vTile
- vPDU

DarkSide-20k



The future of the DarkSide-20k Dark Matter Search
Michela Lai, COSSURF2024

- Dark Matter (DM) direct detection experiment currently under construction at LNGS
- **WIMP** as a promising dark matter candidate

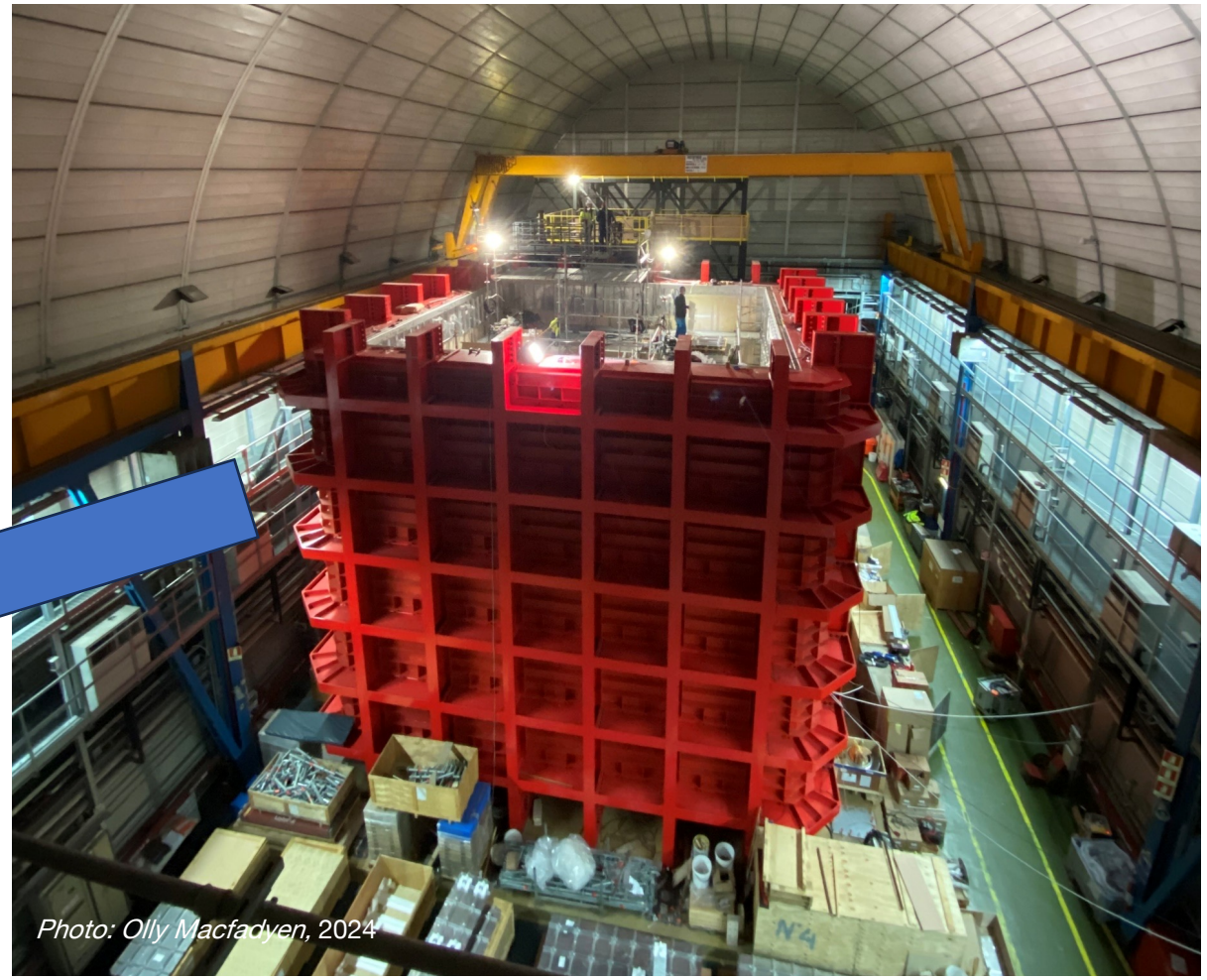
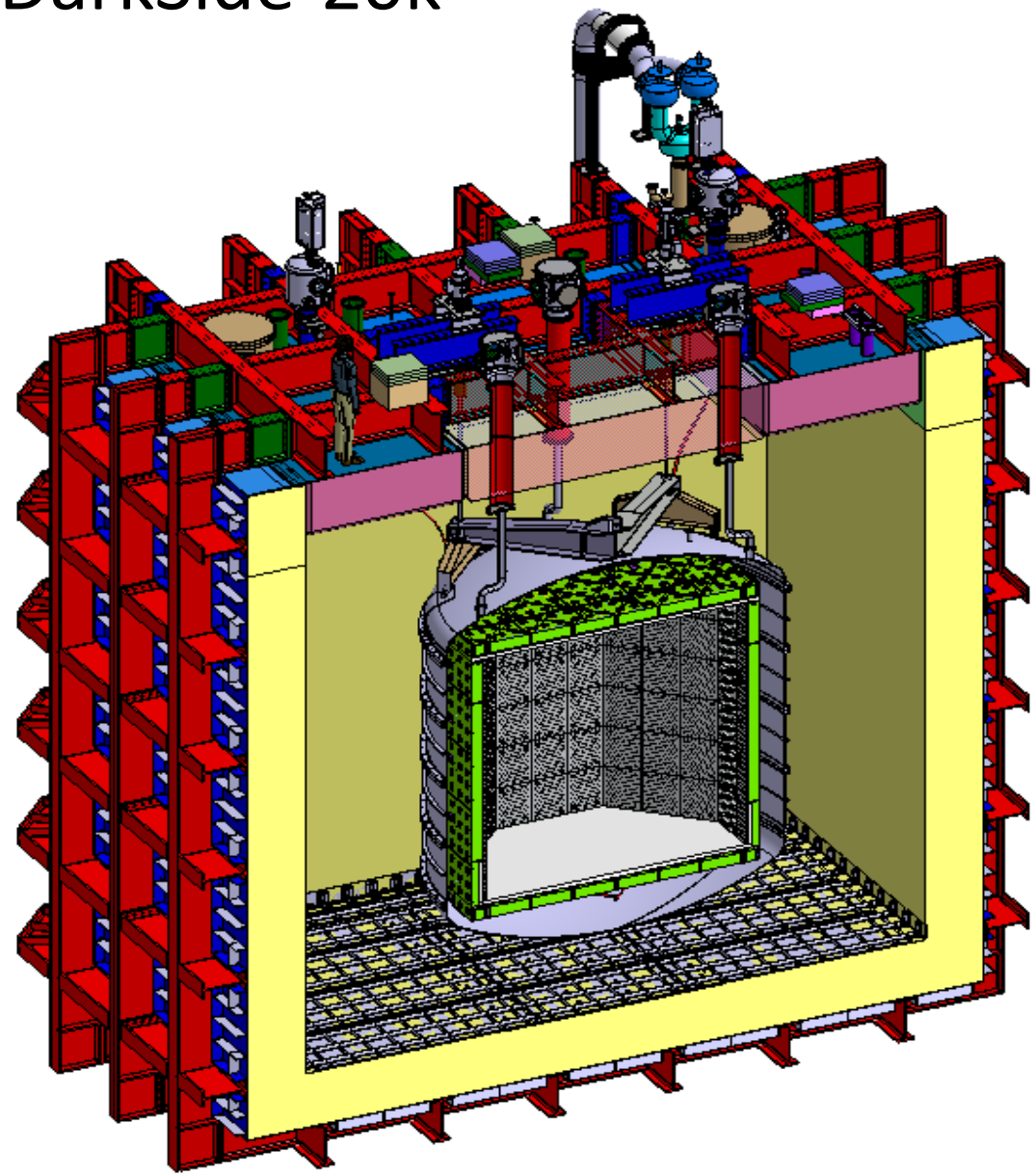


Photo: Olly Macfadyen, 2024

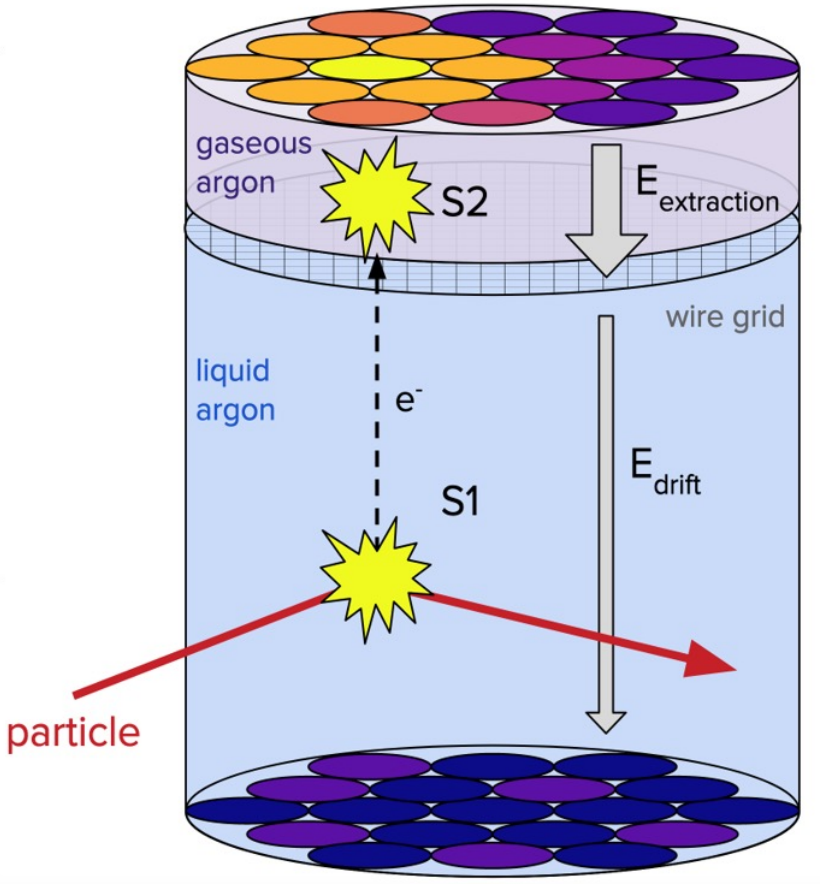
DarkSide-20k

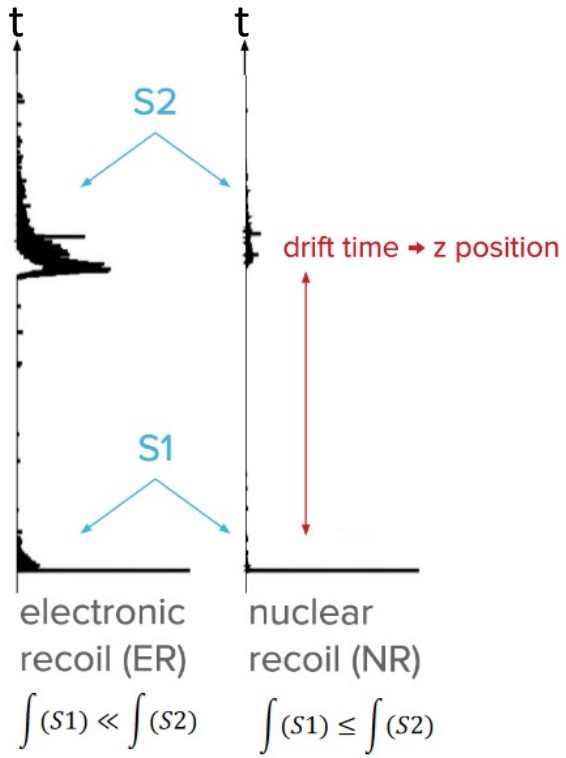


- ProtoDUNE-like cryostat
- ~700t of atmospheric argon (AAr) (muon veto)
- ~35t of underground argon (UAr) (neutron veto)
- ~50t UAr dual-phase TPC (20t fiducial)
- Instrumented with silicon photomultipliers (SiPMs)
- Detects signals in the visible range
- Detect WIMP with masses around 1TeV

Operations expected to start in early 2028

Argon TPC



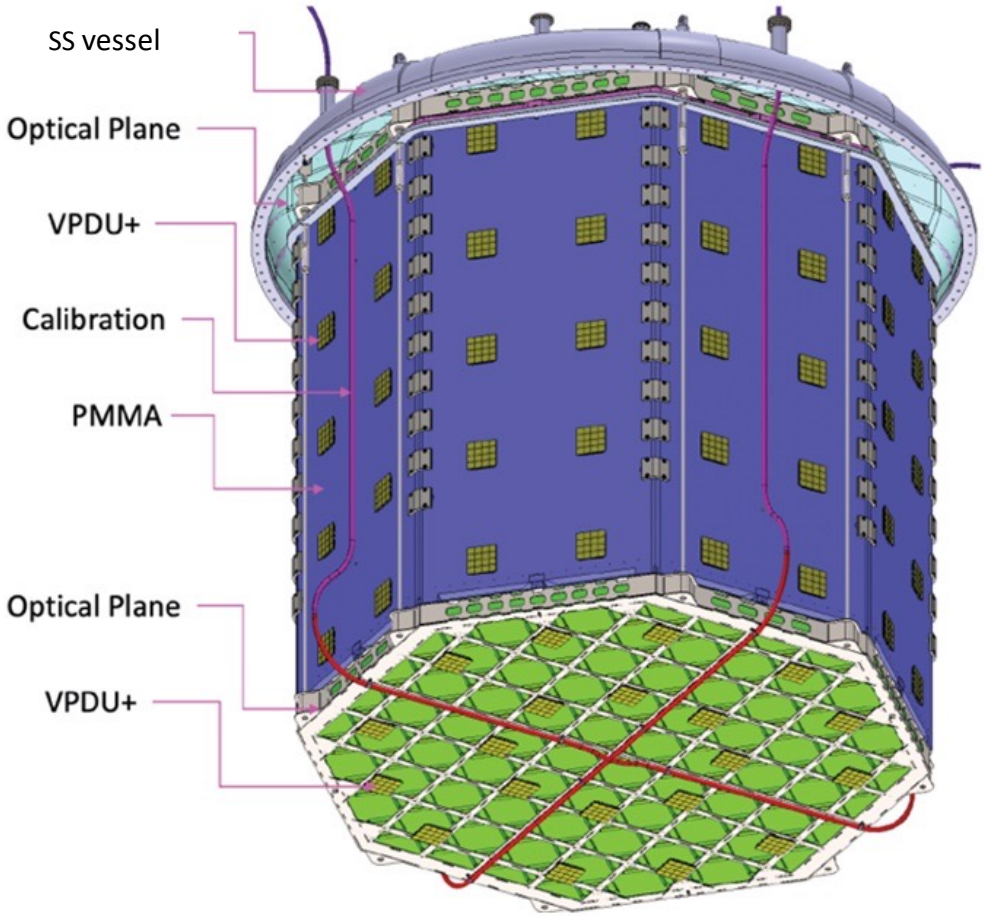


- Dual-phase Argon TPC with a small gas layer at the top
- Why Argon?
  - Good scintillator
  - Easy to purify
  - Transparent to own scintillation
  - Scalable
  - High ionization
  - Strong ER discrimination via pulse shape
- TPC is shielded by a “Neutron Veto” designed to capture neutrons before they reach the TPC

Detection mechanism - WIMP elastically scattering argon nucleus producing
scintillation photons (S1) - reconstructs the x-y coordinates and the energy of the event
ionization electrons (S2) - drift velocity and the time difference between S1 and S2, reveals the z coordinate

Background Mitigation

Goal: Operate in a free instrumental background of less than 0.1 neutron-WIMP-like events in a total exposure of 200t.y



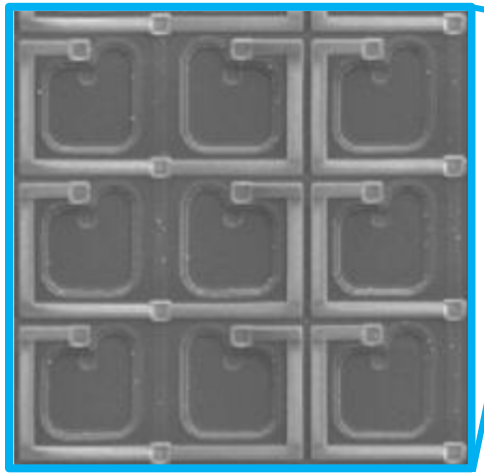
Adapted from; Direct Detection of Dark Matter with DarkSide-20k, Paolo Agnes, 2023 https://doi.org/10.1051/epjconf/202328006003

Sources of background:
-> radiogenic neutrons (α, n)
-> 39Ar (β-emitter) and gamma

To suppress the background => achieve expected WIMP sensitivity:

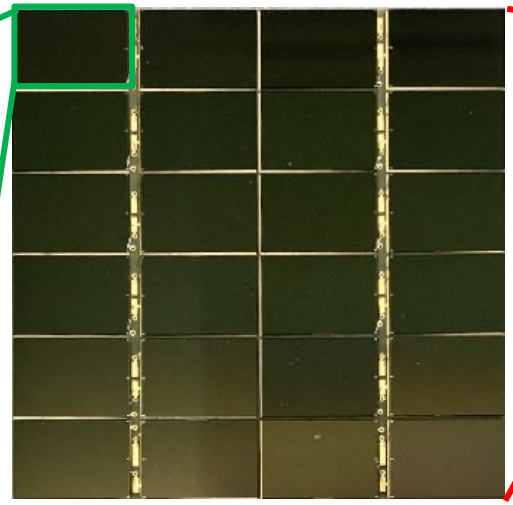
- stringent material selection and radiopurity control
- **the use of minimally-radioactive UAr**
- an neutron veto
- a large area light detector based on SiPM technology
- pulse shape discrimination
- plastic shielding around the vessel
- underground location

Photo-detectors

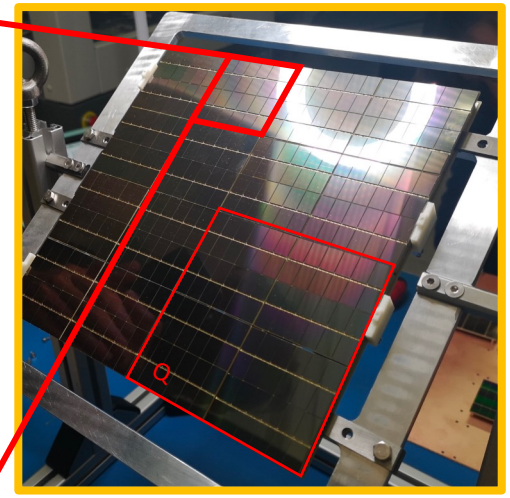


SPAD: 25 µm^2

SiPM: 12x8 mm
(NUV-HD-Cryo SiPMs from FBK)



vTile: 5x5 cm



vPDU: 20x20 cm

Largest single read-out SiPM array!

Single Photon Avalanche Diode (SPAD)

- Semiconductor sensors based on p-n junction
- Reverse biased above breakdown
- Operated in Geiger mode (signal amplification)

Silicon Photo Multiplier (SiPM)

- Designed in collaboration with FONDAZIONE BRUNO KESSLER
- ~94,900 SPADs/SiPM
- Cryogenically stable
- Low voltage operation
- Good single photon resolution

veto Tile (vTile)

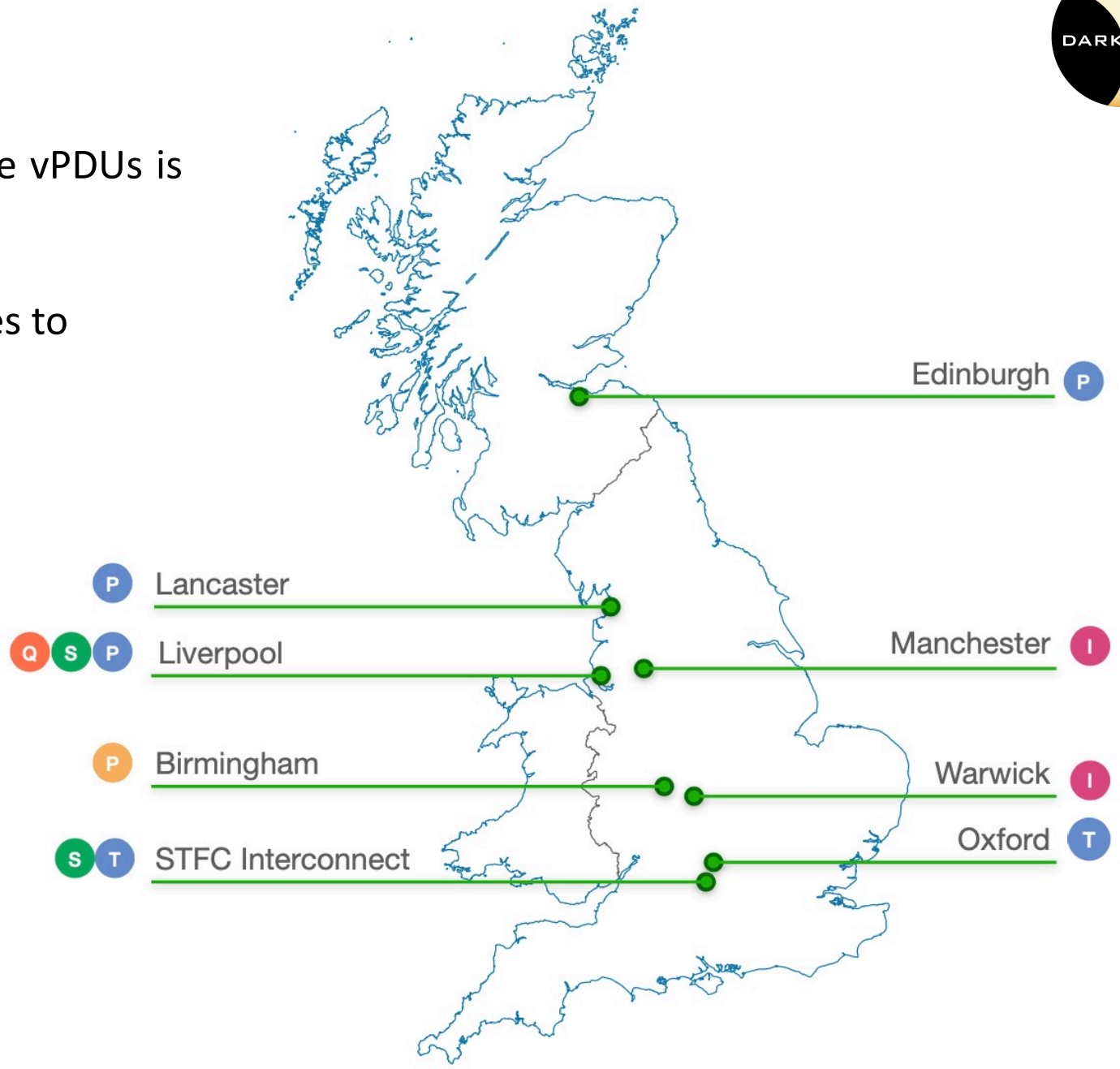
- 24 SiPMs mounted on Arlon 55N substrate with readout electronics on the backside

veto PDU (vPDU)

- 16 vTiles assembled onto Arlon 55N motherboard (MB)
- Provides signal and power to the vtiles
- Summed into quadrants: 4 readout channels/vPDU
- Low power consumption

UK consortium members

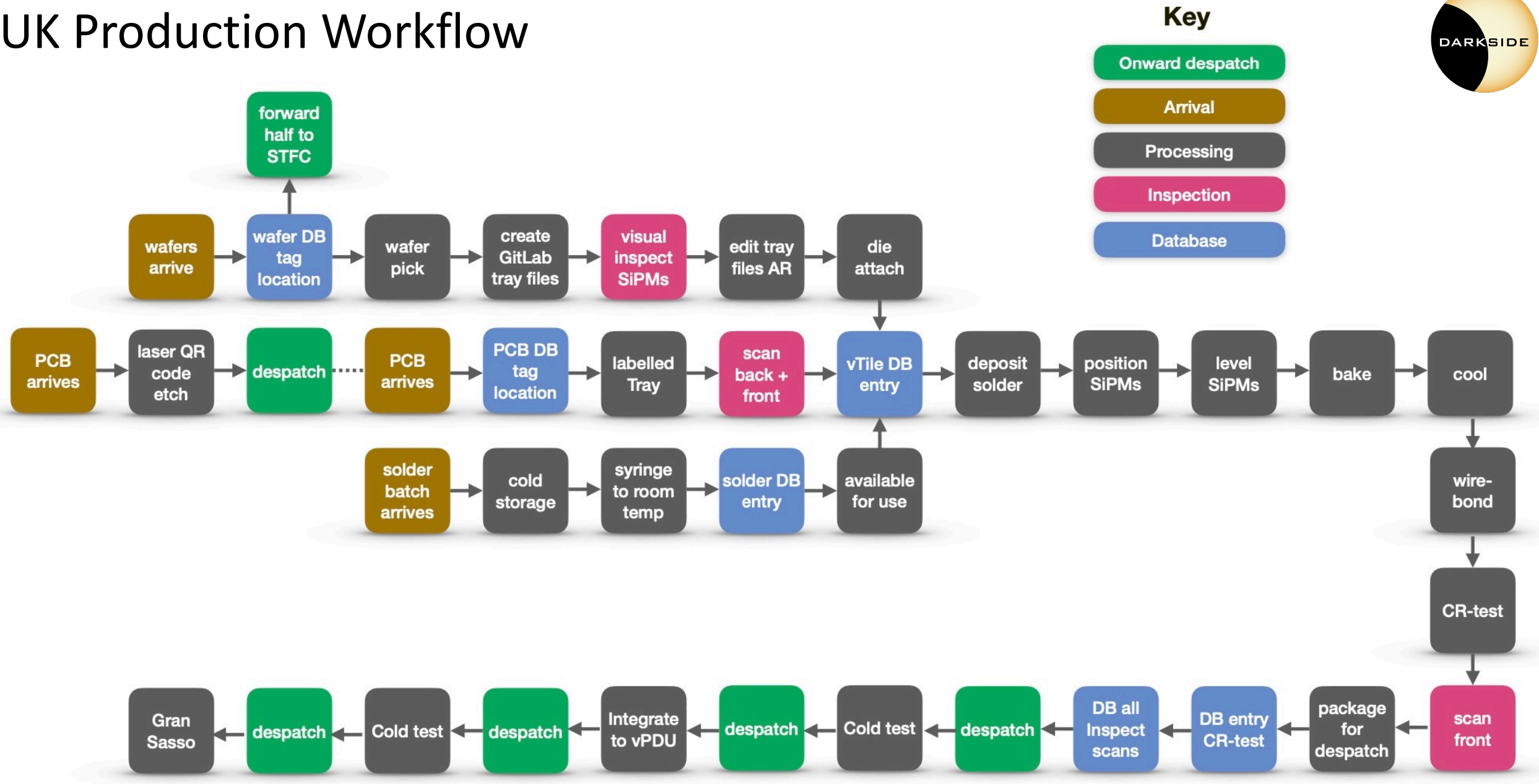
- The construction, testing and delivery of the vPDUs is splitted by UK institutes
- Some activities are duplicated at various sites to ensure redundancy and capacity



Key

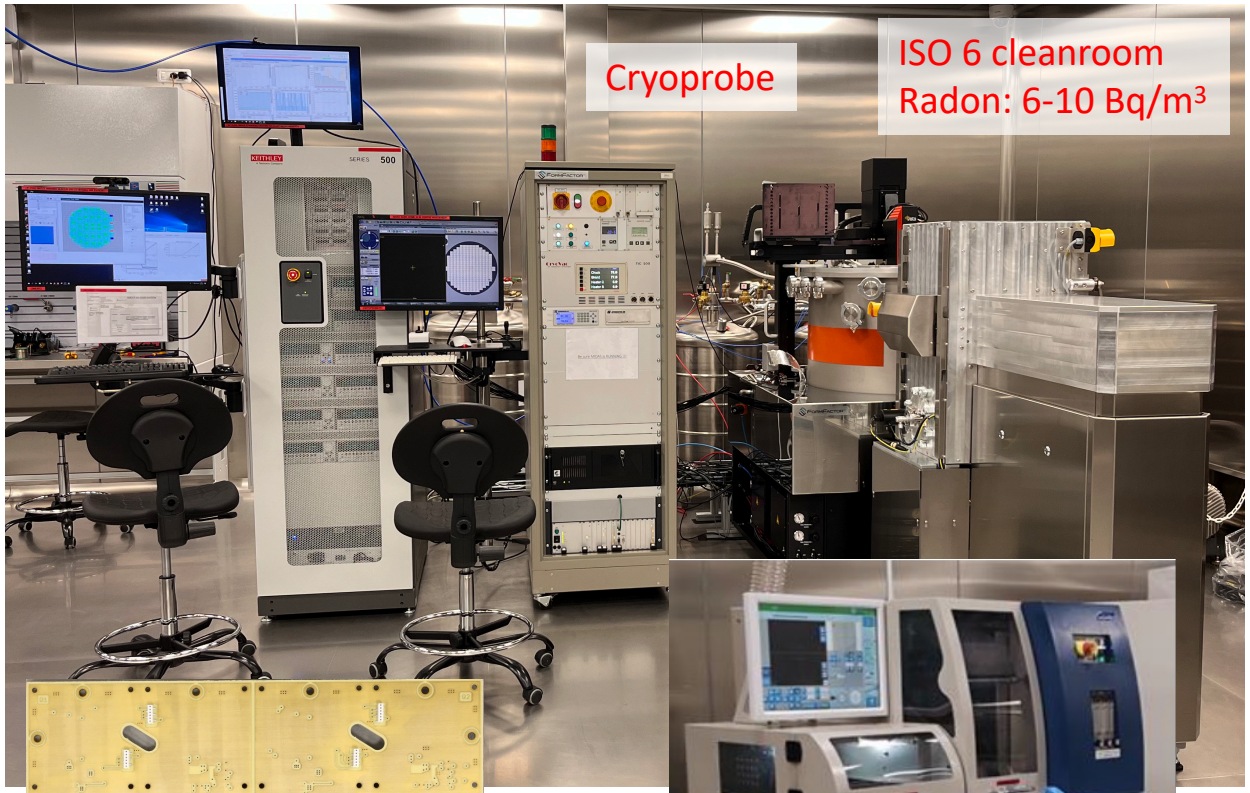
- Q QR code etching
- P PCB population
- S SiPM die attach + wire bonding
- T vTile cold test
- I Integration (vPDU) and warm test
- P vPDU cold test

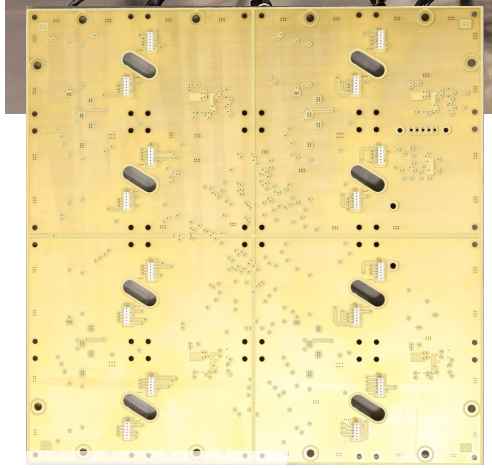
UK Production Workflow



Particle Physics Annual Meeting, Alan Taylor, 2024, https://indico.ph.liv.ac.uk/event/1628/

vPDU - Stage 0



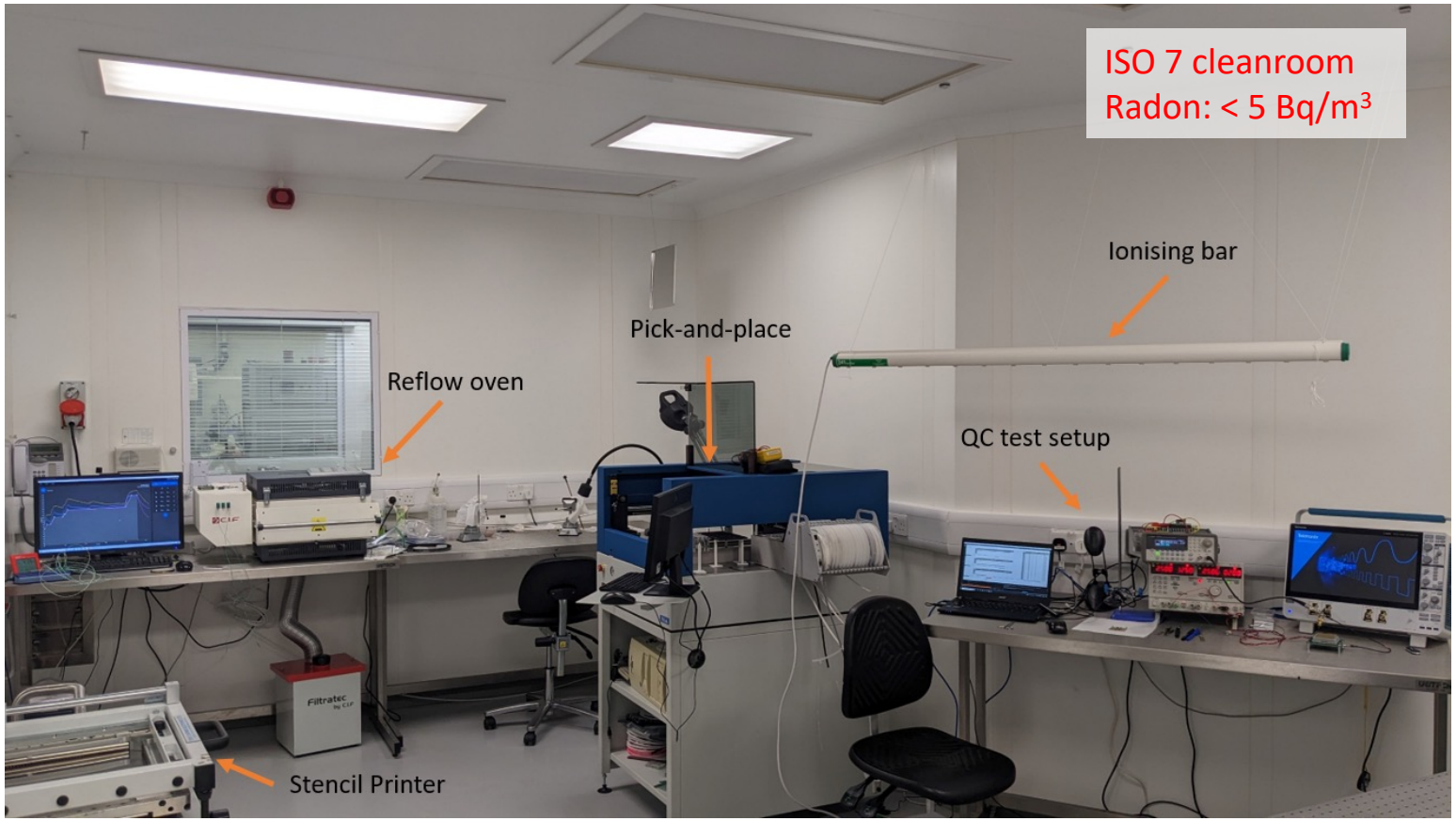


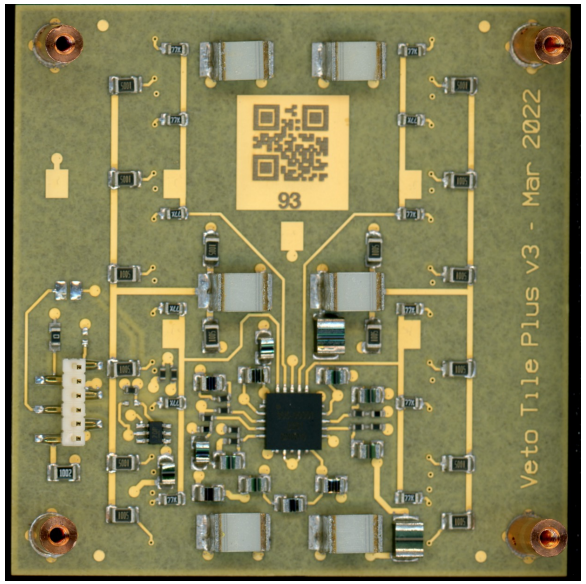
Motherboard

- Some steps in the vPDU production chain are performed by several INFN groups
- Development, test and production of the custom ASIC (amplifier)
- Design of the vtile boards and prototyping
- SiPM wafer characterisation at cryogenic temperature and dicing (Nuova Officina Assergi – NOA/LNGS)
- Design, test and production of the motherboards
- Some initial complementary vPDu test

vPDU - Stage 1

Readout electronics population: University of Birmingham





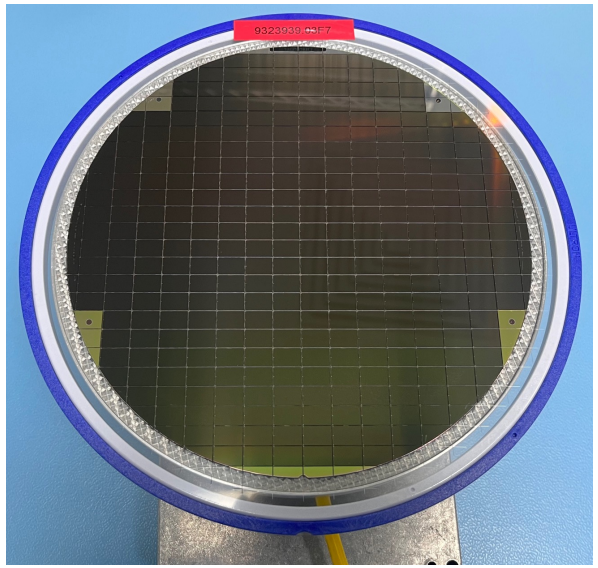
Quality control criteria

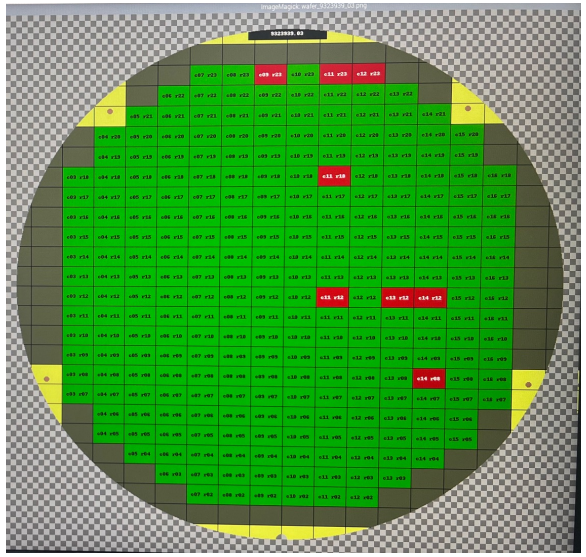
- Visual inspection
- Nominal response to injected pulse
- Nominal power consumption

- Industry standard method: Apply solder paste, pick and place, reflow and test

vPDU - Stage 2

Wafer pick and SiPM inspection: University of Liverpool and STFC Interconnect

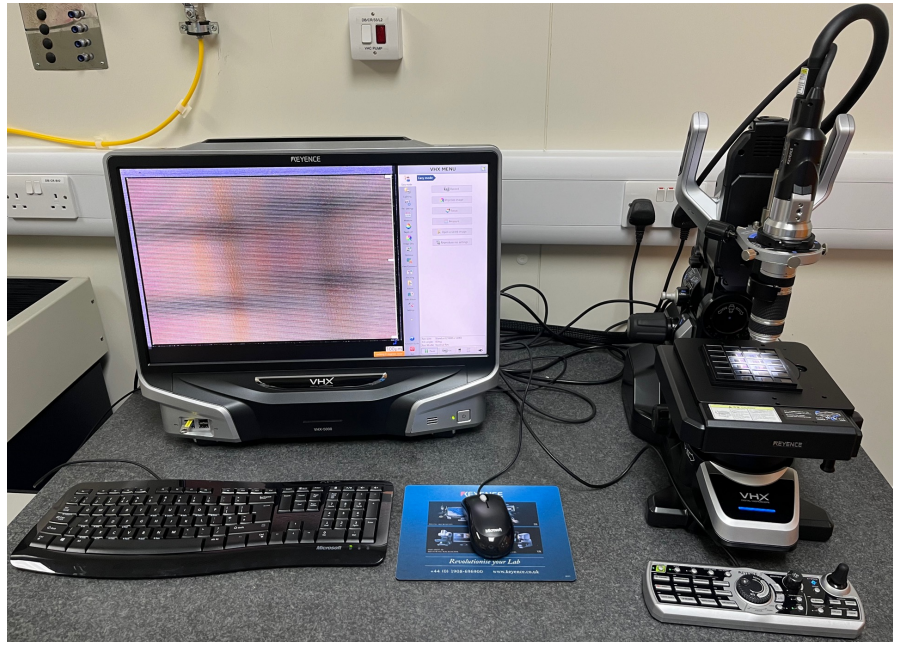




- Wafers after cryoprobing along with a map identifying good/bad dies are separated into trays

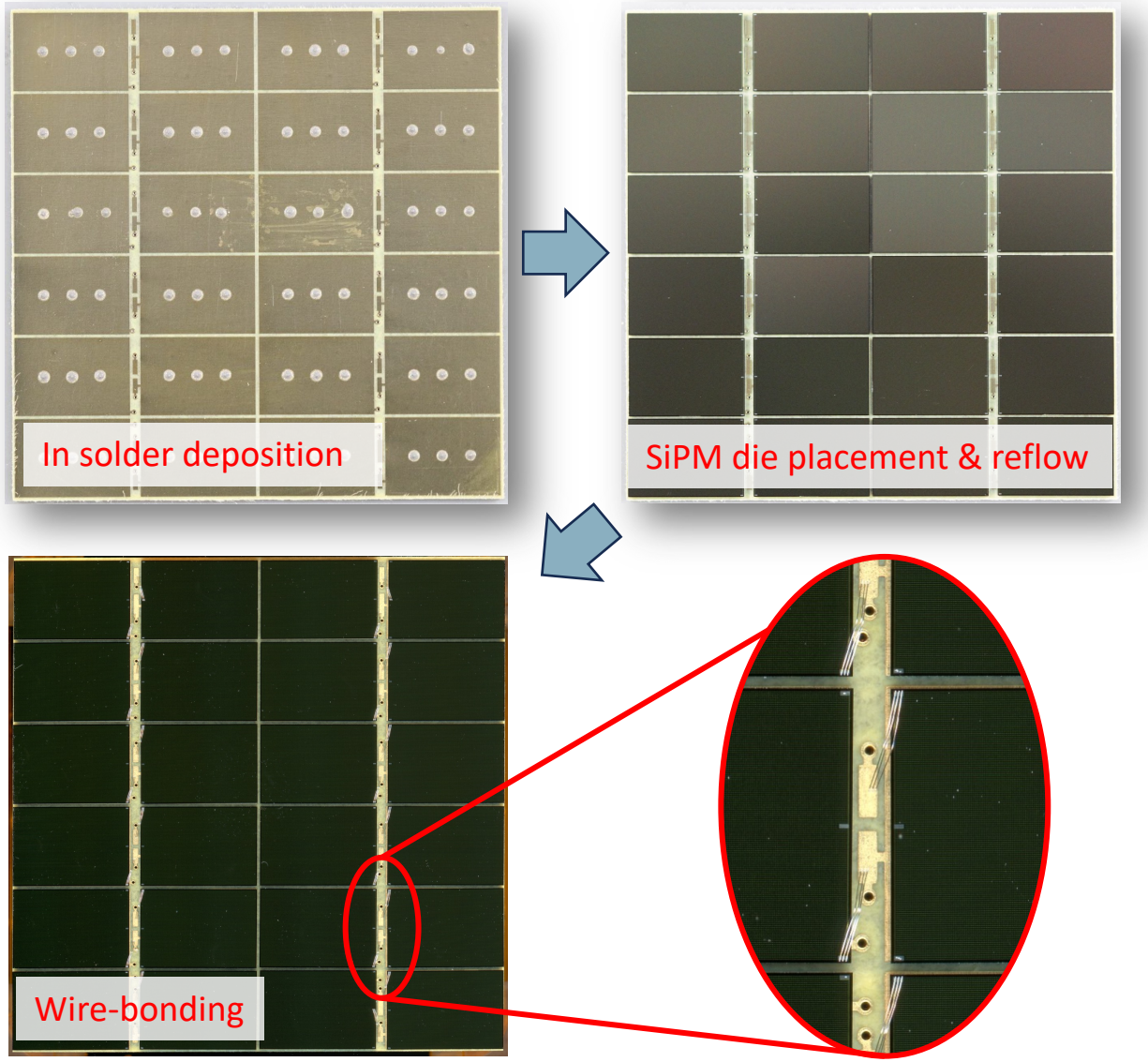
Quality control criteria

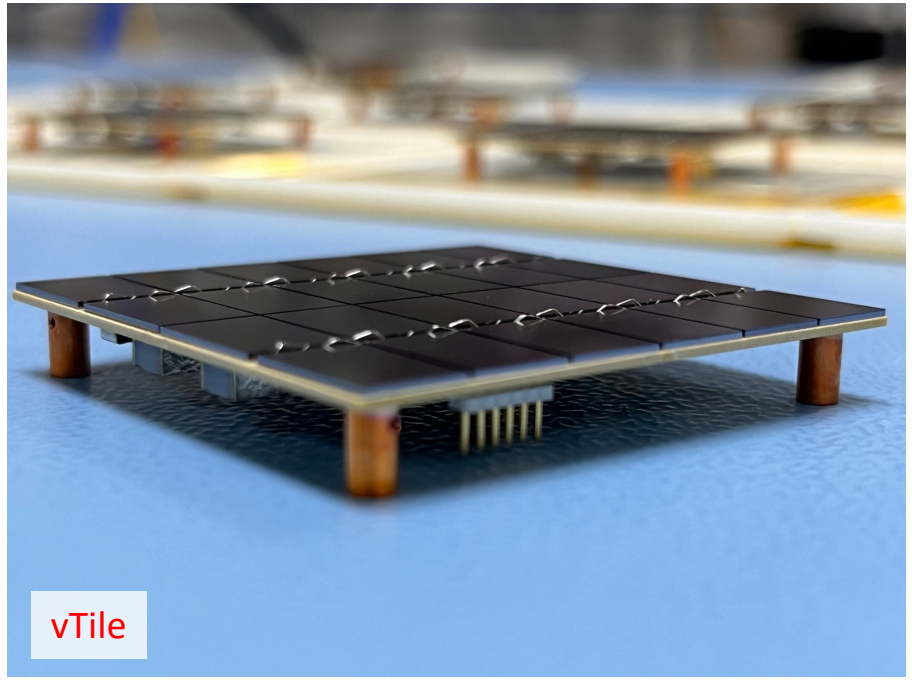
- Visual inspection of individually SiPM die



vPDU - Stage 2

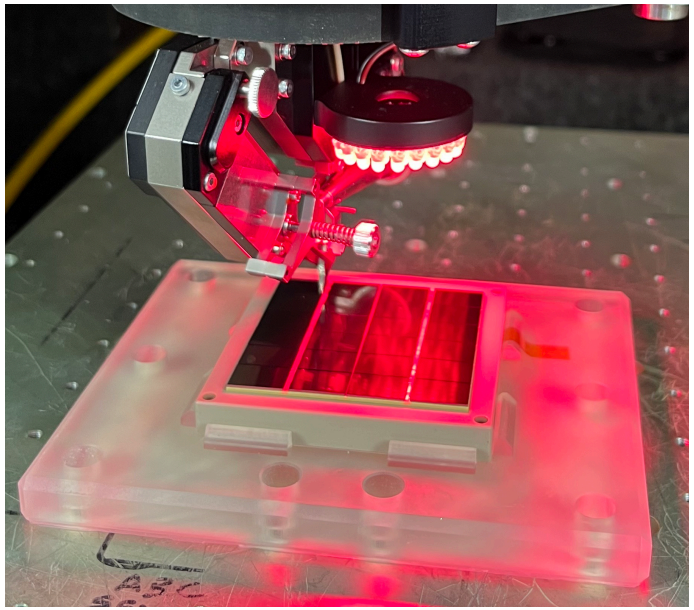
SiPM die attach and wire-bond: University of Liverpool and STFC Interconnect





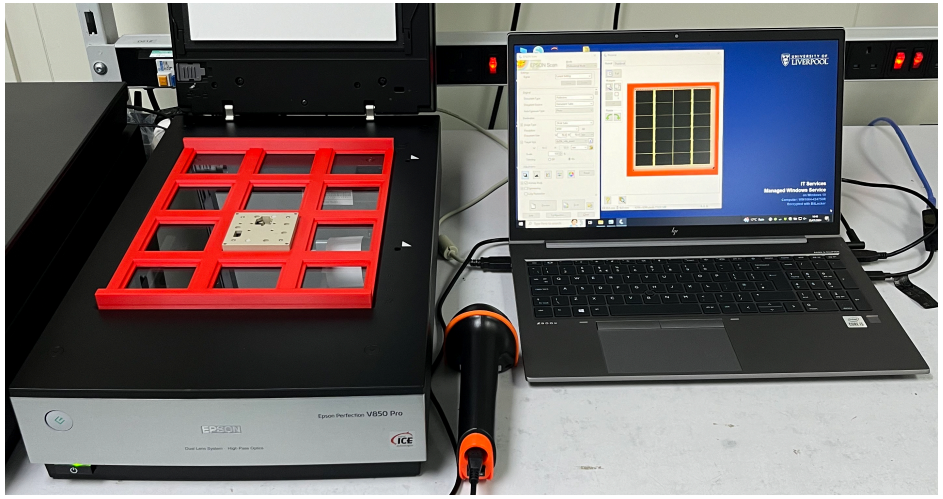
vPDU - Stage 2

SiPM die attach and wire-bond: University of Liverpool and STFC Interconnect



Wire-bonding

CR-test



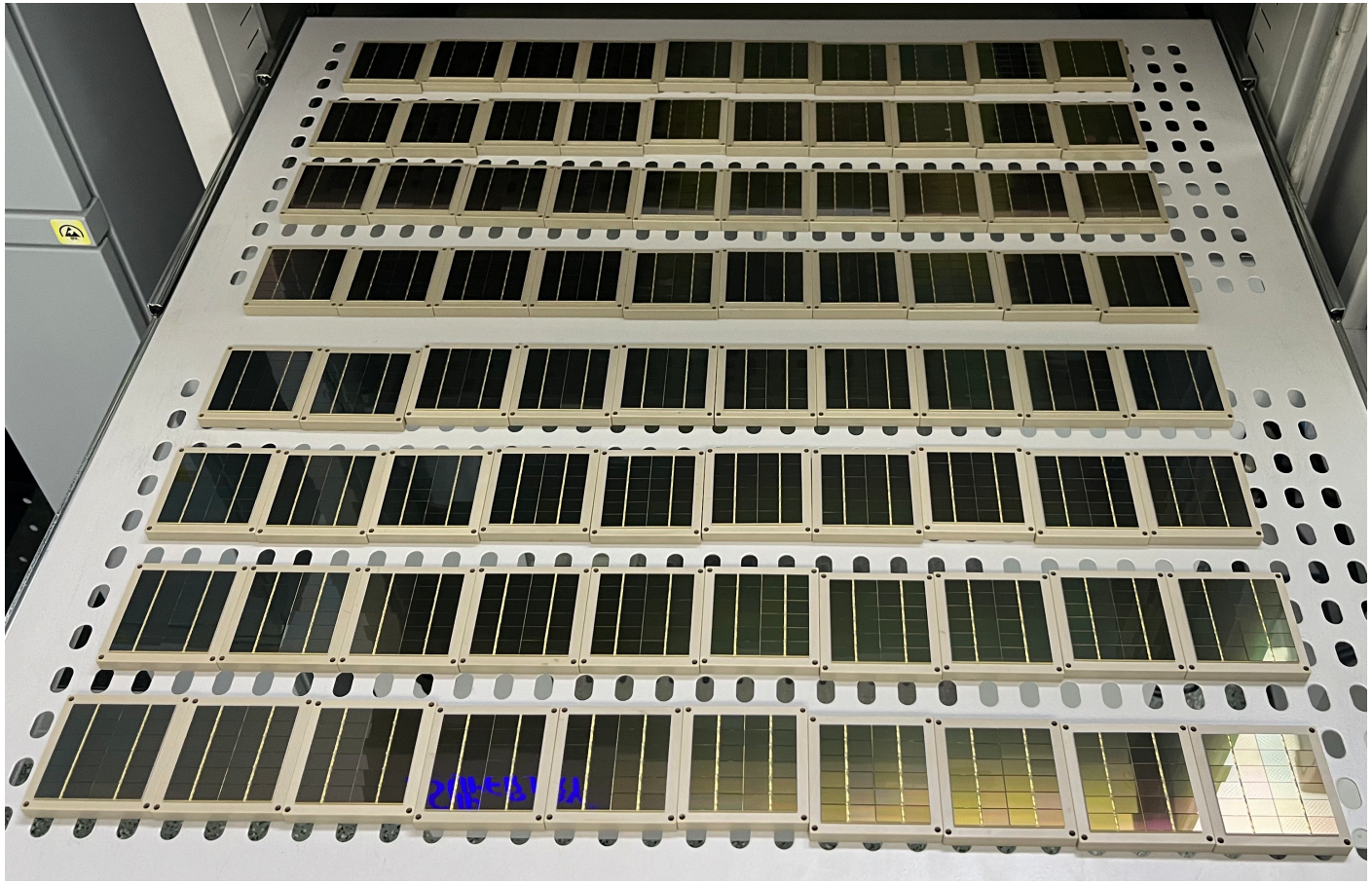
Outgoing Scan

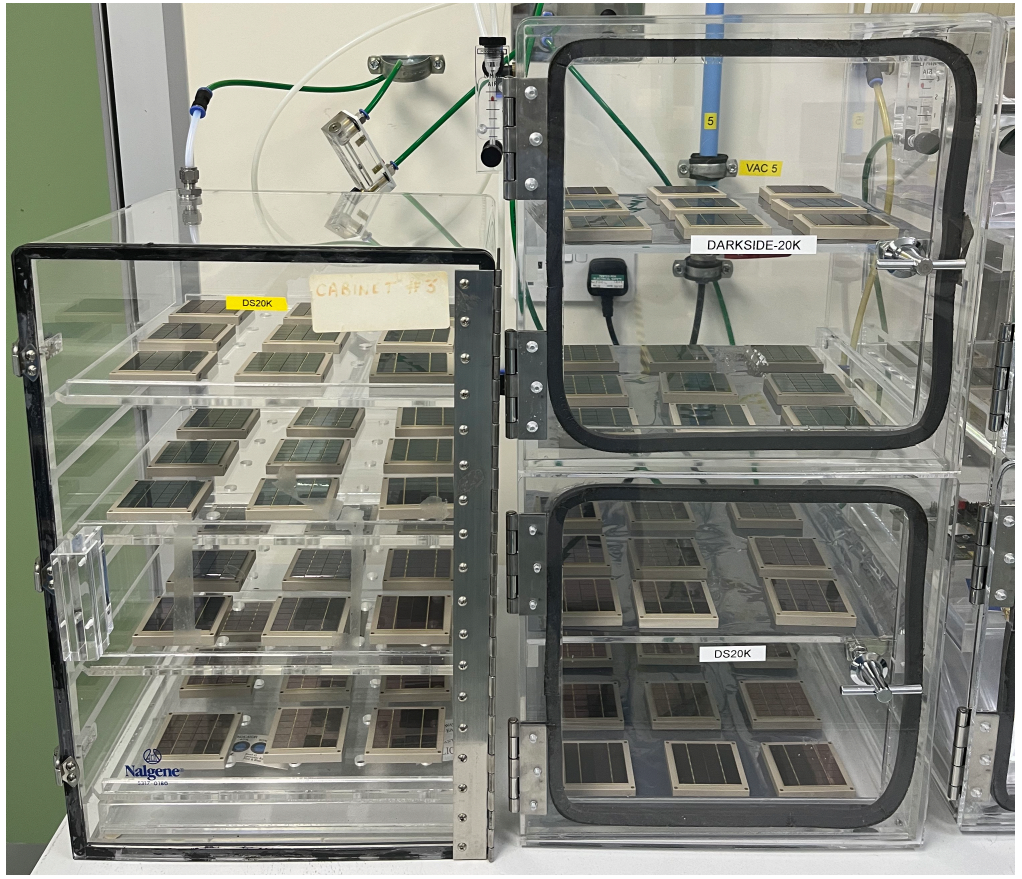
Quality control criteria

- Quadrant C and R is measured and compared with nominal
- Visual inspection of vTile

Storage

Devices always stored in nitrogen cabinets



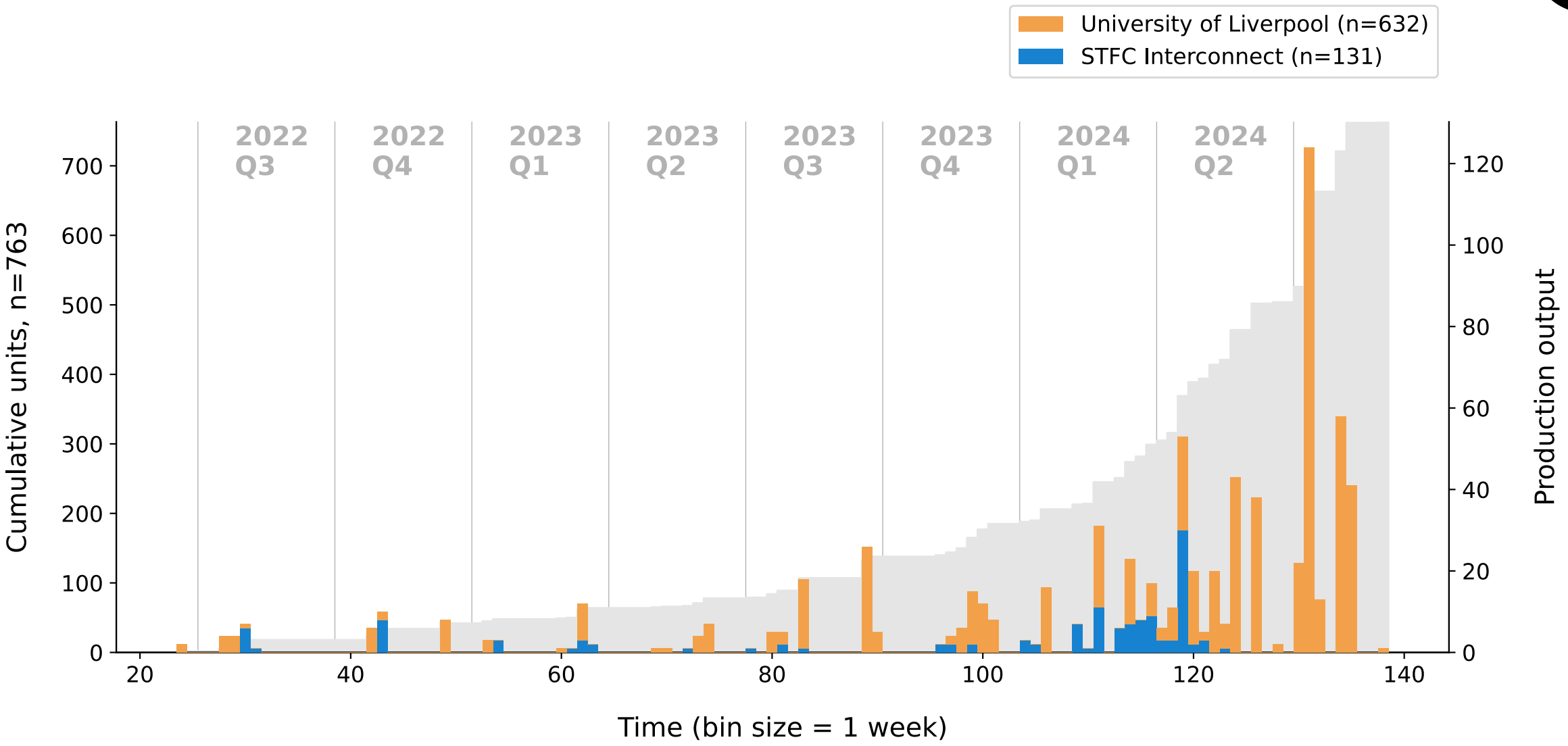


Packaging and Shipping

4 process carriers / shipping carriers
2 shipping carriers / pack

1st sealed in ESD bag
2nd, 3rd placed in a plastic bag + desiccant + moisture monitoring strip

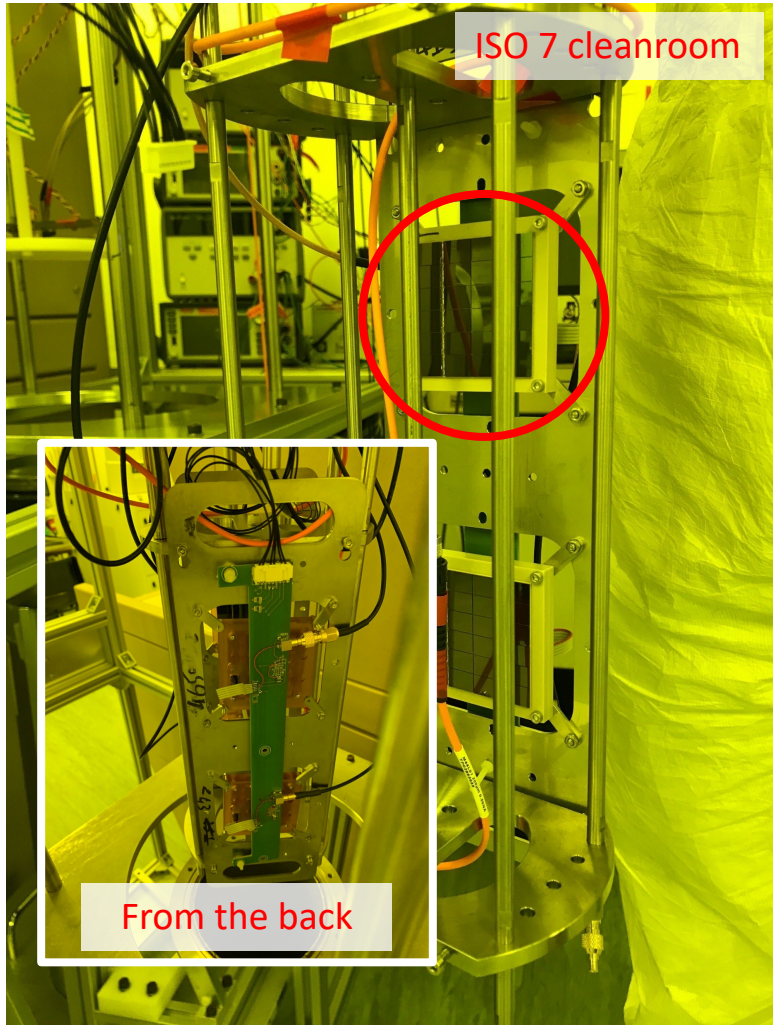
vTile Production Status

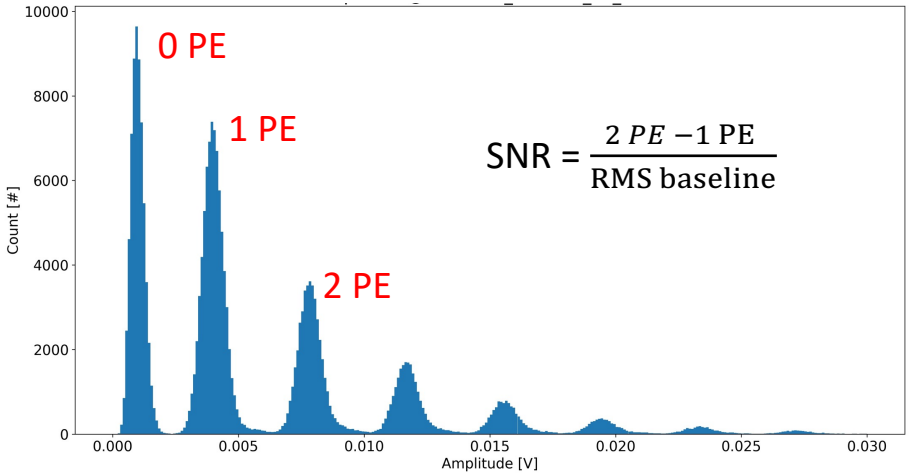


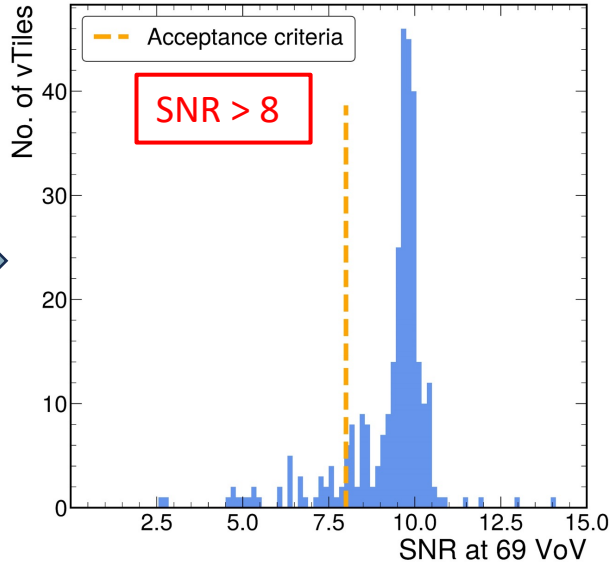
Data from 2024 08 26; data updated every 24 hours:
https://hep.lancs.ac.uk/~pfranchini/DarkSide/production.html

vPDU - Stage 3

Single vTile cold test: University of Oxford and STFC Interconnect







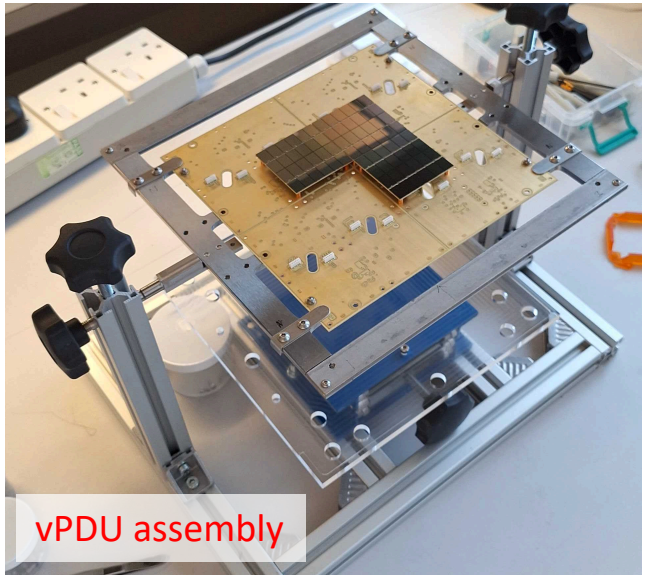
- Single vTiles tested at LN temperatures
- Tested with laser to look for a good photo-electron spectrum
- Other metrics also recorded
- Good vTiles are assembled onto vMB

Quality control criteria

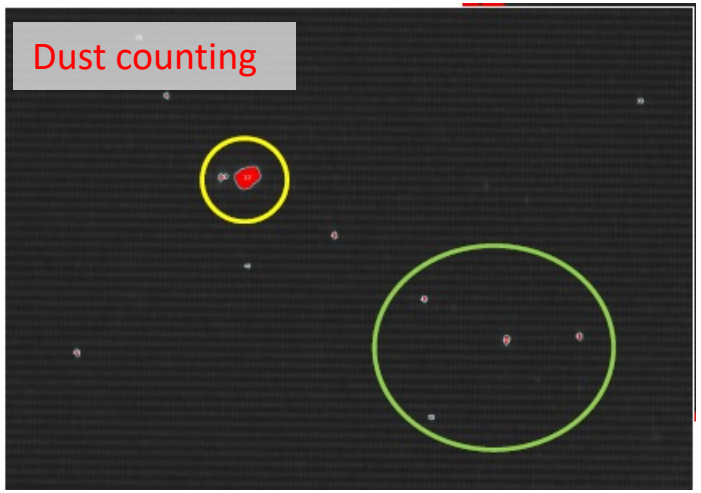
- SNR > 8
- Distinct PE spectrum
- Nominal breakdown voltage ~ 55V

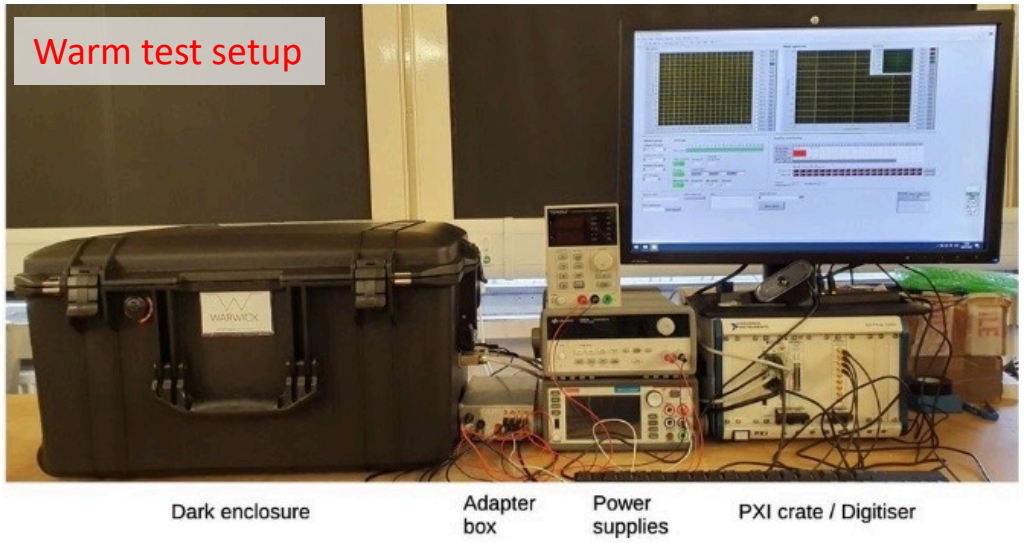
vPDU - Stage 4

vPDU assembly and warm test: University of Manchester and Warwick



- PDUs are warm tested comparing their noise spectra and key SiPM characteristics to nominal values
- Dust is also controlled with automated software
- PDUs are secured onto a stainless steel handler with a protective acrylic cover over the fragile SiPMs and wirebonds



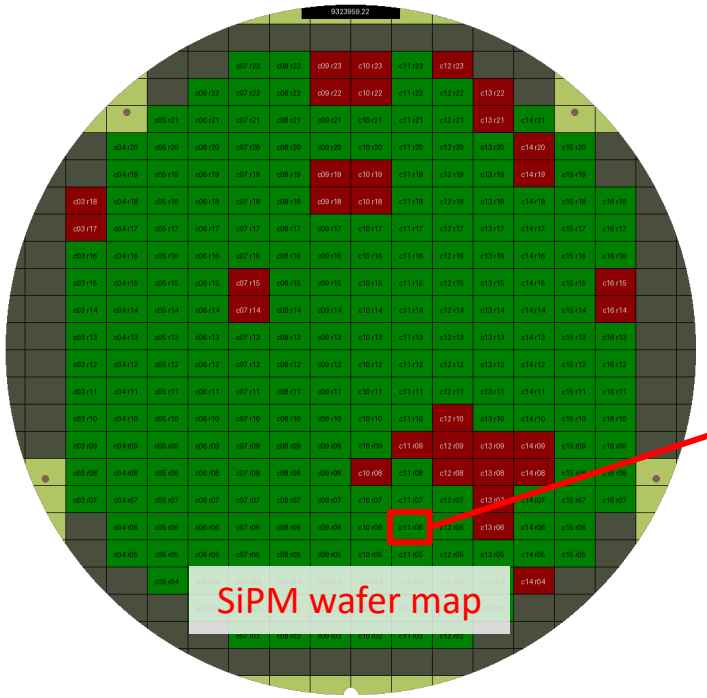


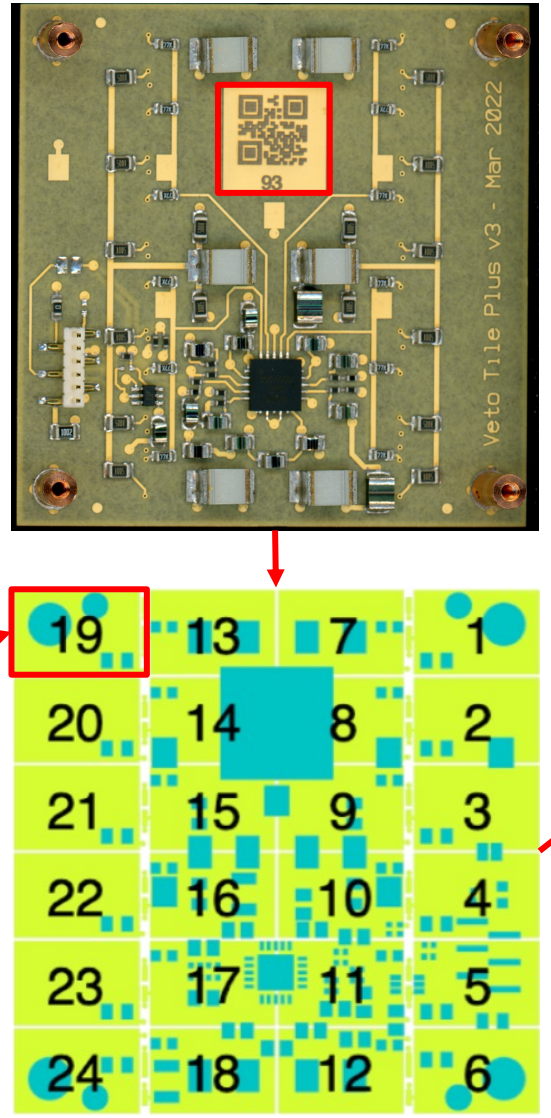
Quality control criteria

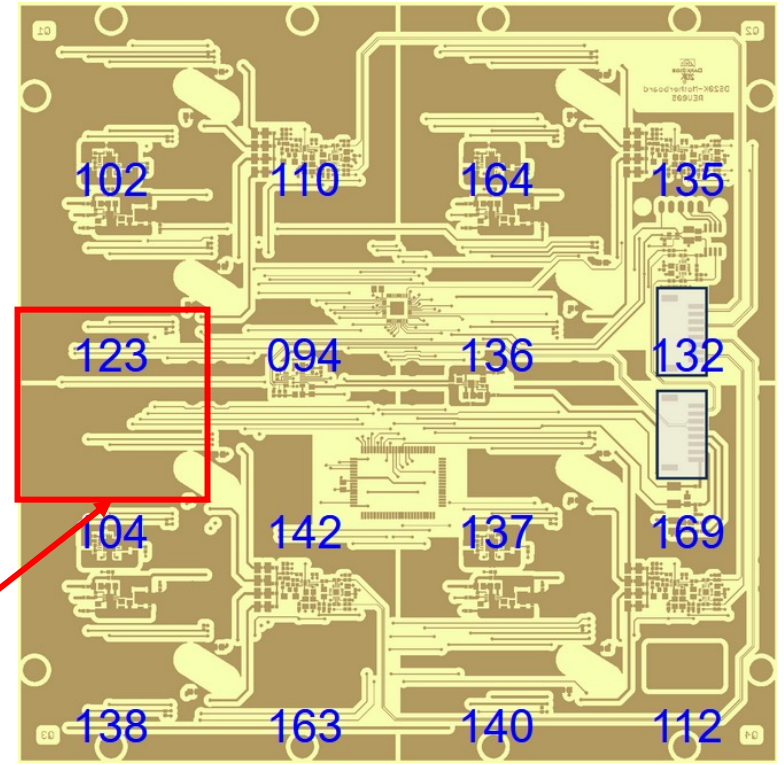
- Visual inspection
- Automated dust counting
- Electrical characterisation at room temperature

Production Database

- Object tracking via QR codes
- Central storage of all test results
- Track production progress
- Monitor quality assurance parameters



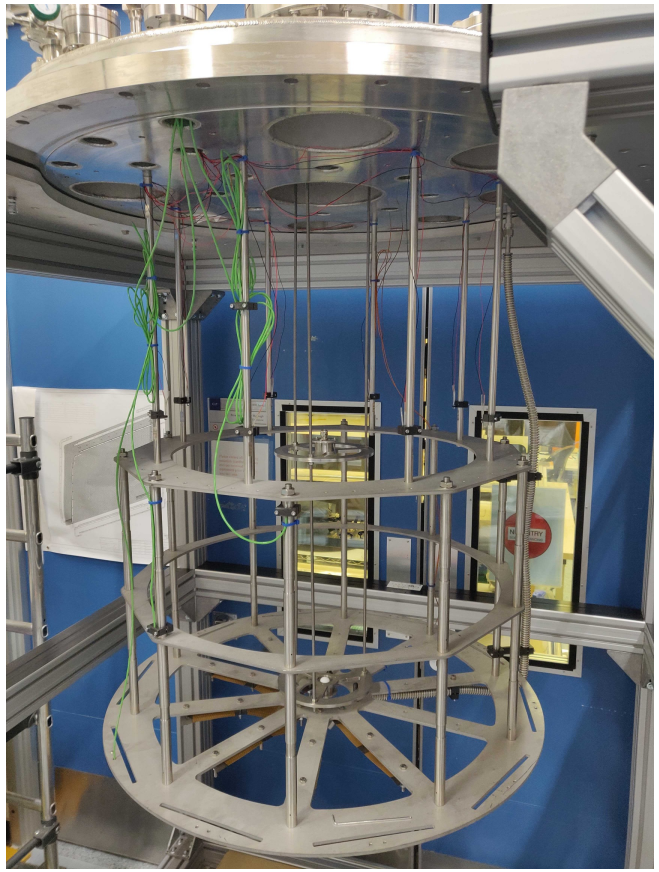




Ability to trace to original components

vPDU - Stage 5

vPDU cold test: University of Edinburgh, University of Lancaster, University of Liverpool & AstroCeNT



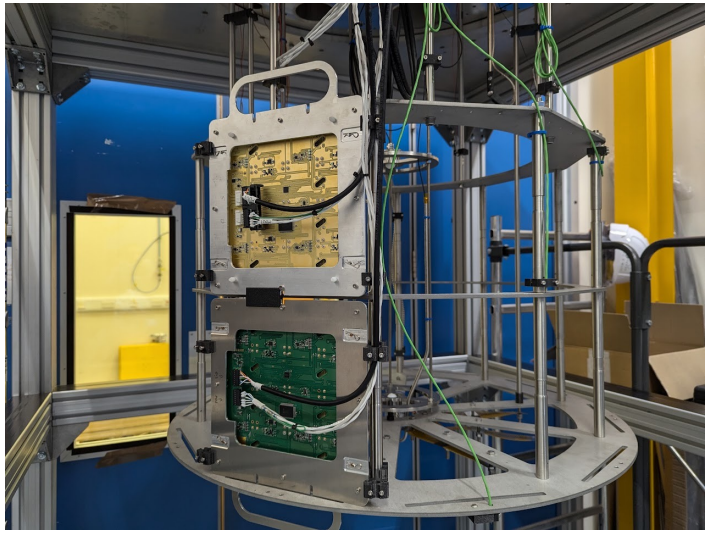
Photos: Sudikshan Ravinthiran

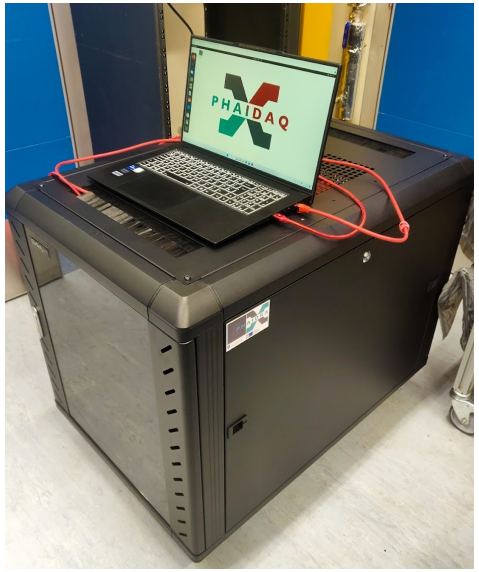
- Each test stand has the capability for multiple PDU/cooldown
- PHAIDRA is the large cryostat (600 L) capable to test simultaneously 16 vPDUs
- Cryogenic operation soon
- Edinburgh and AstroCent already have successfully cooled down vPDUs in smaller cryostats capable up to 4 PDUs

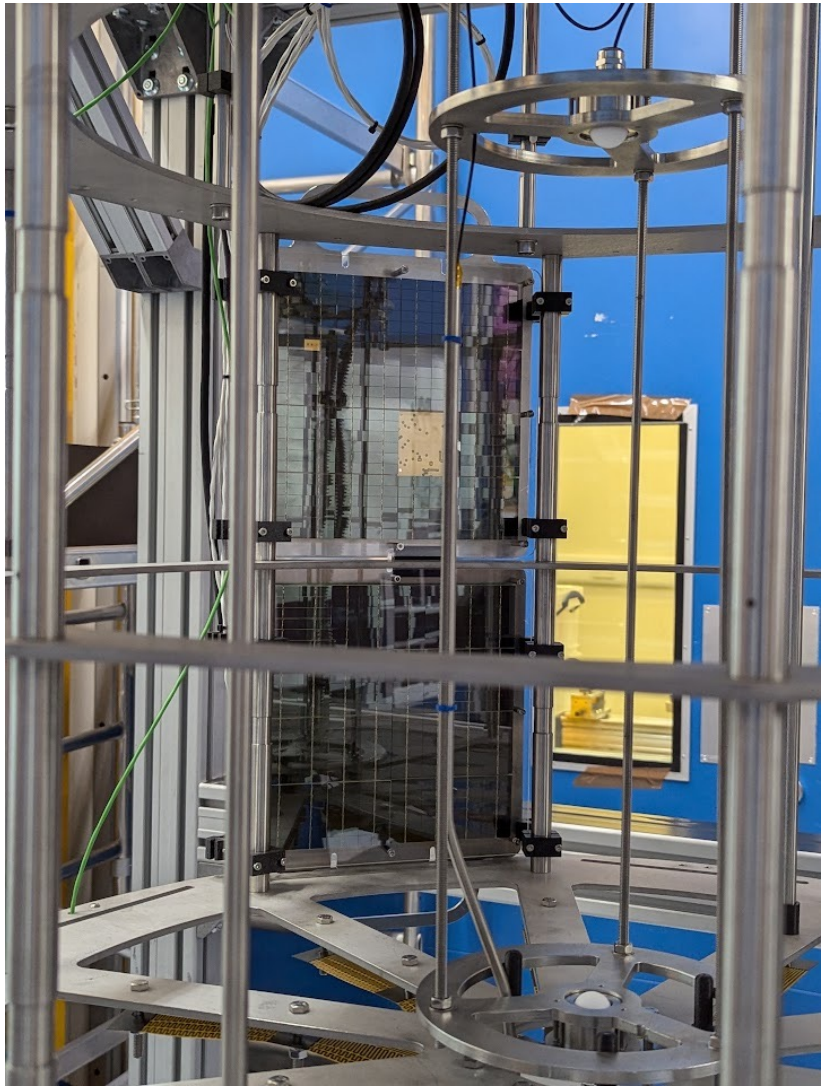
vPDU - Stage 5

vPDU cold test: University of Edinburgh, University of Lancaster, University of Liverpool & AstroCeNT

- vPDU2 & vPDU3 recently installed
- LV and HV were tested from PHAIDAQ to power both vPDUs
- The first measurements are under analysis







Photos: Sudikshan Ravinthiran

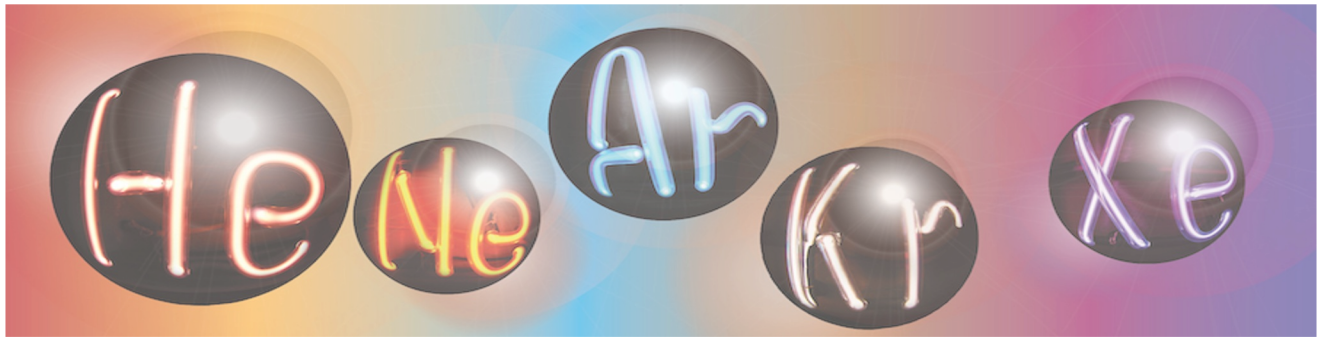
Conclusions and Outlooks

- Production of DarkSide-20k is well underway
- DarkSide-20k utilises many state-of-the-art technologies:
  - Novel cryogenic large area SiPM arrays
  - Underground Ar
- DarkSide-20k has innovated in production and testing methods for SiPM technologies
- Veto detector is key to achieve the required instrumental background
- Facilities producing (UK) and testing (UK and Polish)
- vPDUs already tested meet the requirements
- vPDU production intended to be completed in 2025

Acknowledgments

UNIVERSITY OF LIVERPOOL

Physics Department
Particle Physics



Being in a physics world is always a mix of emotions…

Thank you!!!

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