DarkSide-20k Veto: construction and characterization

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on behalf of the DarkSide-20k Collaboration

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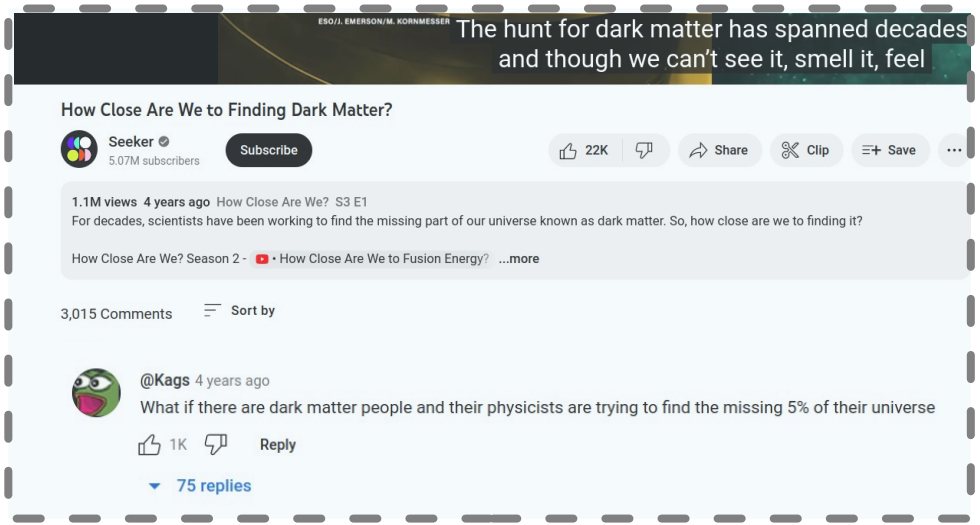
LIDINE 2023

Madrid, Spain

22 September, 2024

Outline

- DarkSide-20k
- Signal and background mitigation
- Neutron Veto
- Veto Photo Detection Modules
- Production
- Characterization and QA/QC



DarkSide-20k @ LIDINE23

Monitoring 39Ar Background for DarkSide-20k with DArTinArDM

Assessing the purity of the underground argon in terms of Ar-39 is crucial to ensure the successful operation of DarkSide-20k (DS-20k), a next-generation dark matter detector under construction by the Global Argon Dark Matter Collaboration

Daniel Díaz Mairena (CIEMAT)
20 September 2023 11:25

Estimation of Ar-37 activation and decay rate in DarkSide-50 experiment

The DarkSide-50 (DS-50) experiment uses underground argon (UAr) as a target for the detection of WIMPs, one of the prime candidates for dark matter searches. During the transportation from Colorado (US) to Gran Sasso (Italy) cosmic ray inte

Iftikhar Ahmad (ASTROCENT), Vallivilayil John Teena (GSSI)
21 September 2023 08:15

Neutron tagging with Gd-loaded PMMA

DarkSide-20k is a direct dark matter search experiment, that looks for Weakly Interacting Massive Particle (WIMP) events. The detector is based on an ultrapure liquid Argon double-phase Time Projection Chamber, which will be located at Labo

Alessio Caminata (INFN-Genoa)
20 September 2023 10:15

The DarkSide-20k underground argon procurement chain

The DarkSide-20k experiment searches for dark matter by looking for interactions of WIMPs in a 50 tonnes target of liquid argon using double-phase time projection chamber technology. The key component of the experiment is low radioactivity

Valentina Cocco (Universita' e INFN Cagliari, Italy)
20 September 2023 11:10

The DarkSide 20k Experiment

The DarkSide-20k experiment represents the present goal of the Global Argon Dark Matter Collaboration program. Bringing together the success of the DarkSide-50 detector and the experience gained on large volume membrane cryostats developed

Andrea Zani
20 September 2023 09:00

Analysis of S1 Triplet Component in Darkside-50 Experiment

Dark matter (DM), which constitutes five-sixths of all matter, is hypothesized to be a weakly interacting non-baryonic particle, created in the early stages of cosmic evolution. There are several experiments that aim for the detection of DM

Clea Sunny (AstroCeNT, CAMK PAN)
20 September 2023 15:30

Study of low-energy nuclear recoils in liquid argon with the ReD experiment

Liquid Argon (LAr) Time Projection Chambers (TPC) operating in double-phase detect the nuclear recoils (NR) possibly caused by the elastic scattering of dark matter WIMP particles via light signals from both scintillation and ionization pro

Noemi Pino (University of Catania, INFN Sezione di Catania)
21 September 2023 08:00

Study of cosmogenic activation above ground of Argon for DarkSide-20k

The use of large amounts of low-radioactivity Argon is envisaged in the context of different projects related to rare event searches like the direct detection of dark matter or neutrino studies. Material activation due to exposure to cosmic

Susana Cebrian (Universidad de Zaragoza)
20 September 2023 11:40

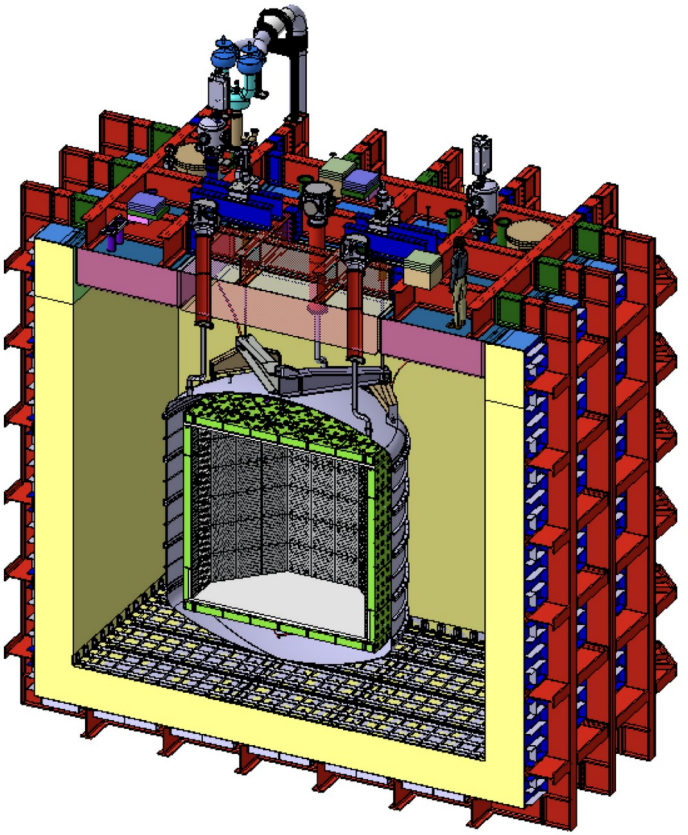
Ar37 source production for low-energy calibration

The search for light dark matter (<10 GeV/c^2) has become increasingly important, since no conclusive evidence has been found in the higher dark matter (DM) mass region. In order to explore this light mass range, it is necessary to accura

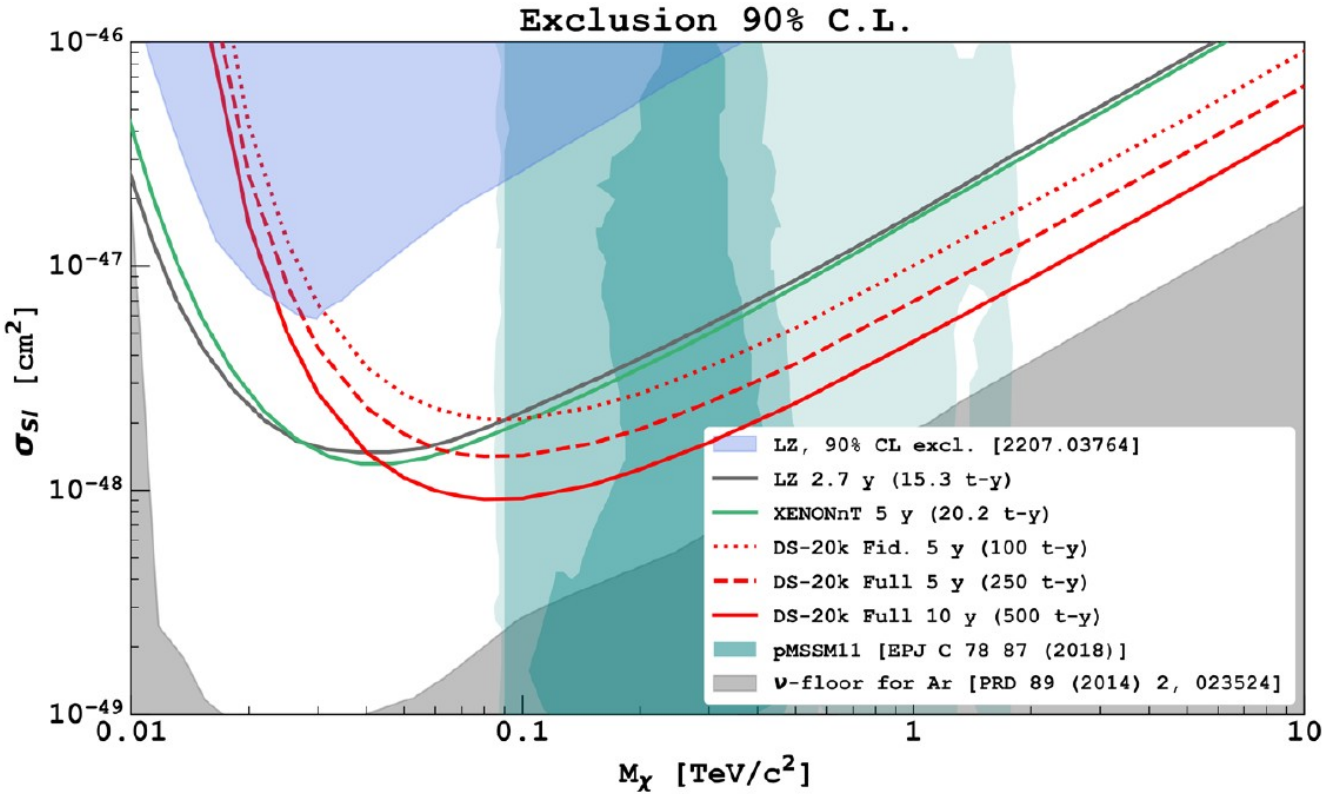
Paules Zakhary (AstroCeNT, CAMK, PAN)
22 September 2023 13:15

DarkSide-20k

- Next generation LAr detector for direct detection of DM
- Global Argon Dark Matter Collaboration
- Underground in LNGS (Italy)
- Dual-phase TPC containing 50 t of underground Argon, instrumented with 21 m^2 of SiPM-based light detectors
- 0.1 background events in ROI [30-100 keV_{NR}] in 200 t·year exposure



DarkSide-20k: projected sensitivity



WIMP-nucleon scattering cross section:

6.3×10^{-48} cm^2 for 90% CL exc.

2.1×10^{-47} for 5σ

1 TeV/c^2 WIPM

for 200 t·years in the f.v.

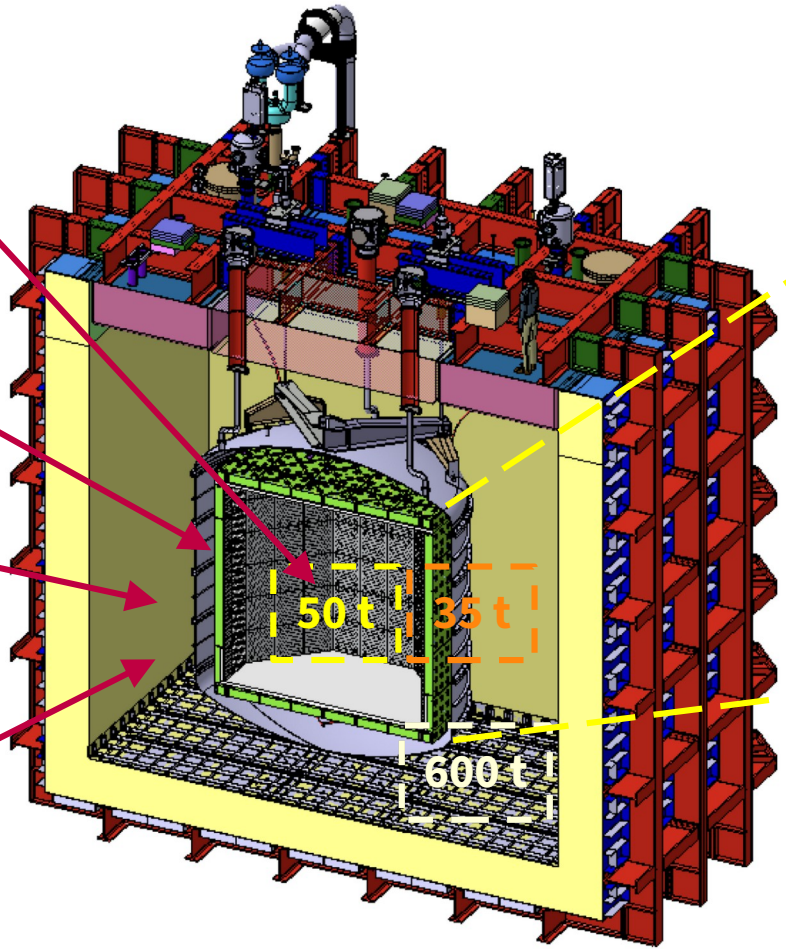
DarkSide-20k

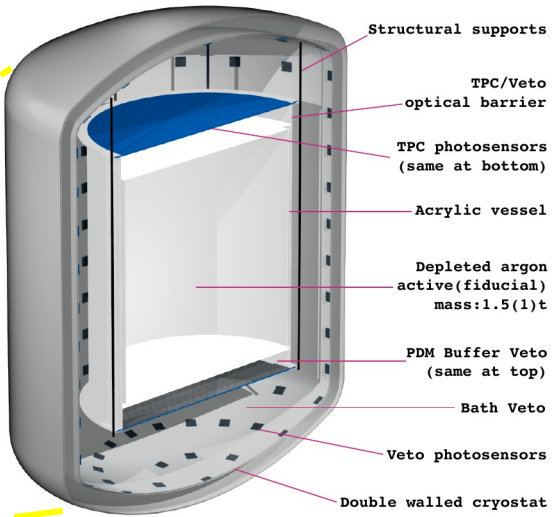
Dual-phase TPC

Inner Veto

Outer Veto

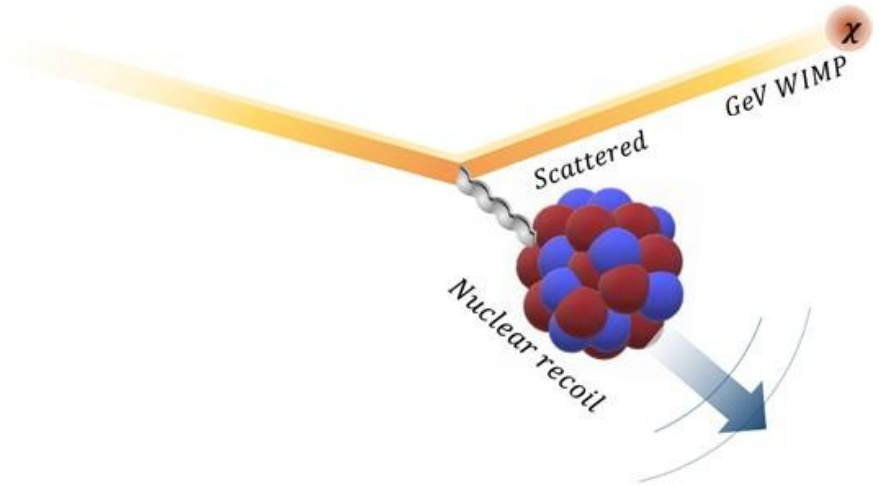
ProtoDUNE-like cryostat

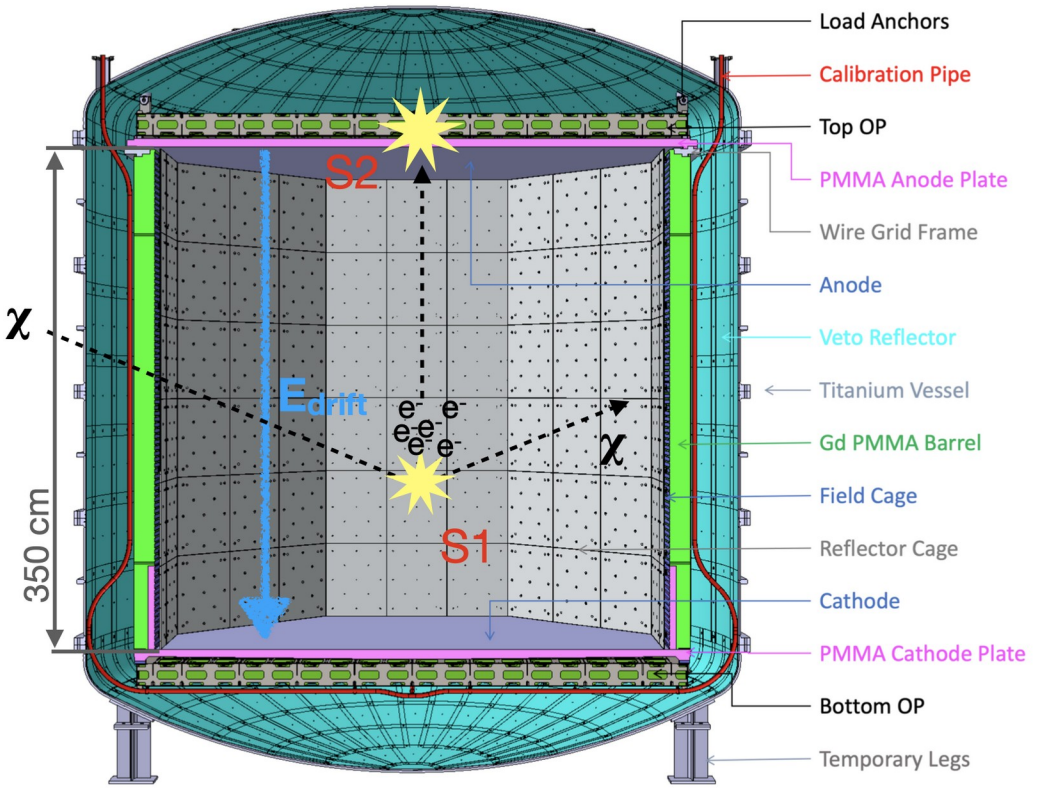




Signal and background

- Nuclear recoil energy: 1-100 keV



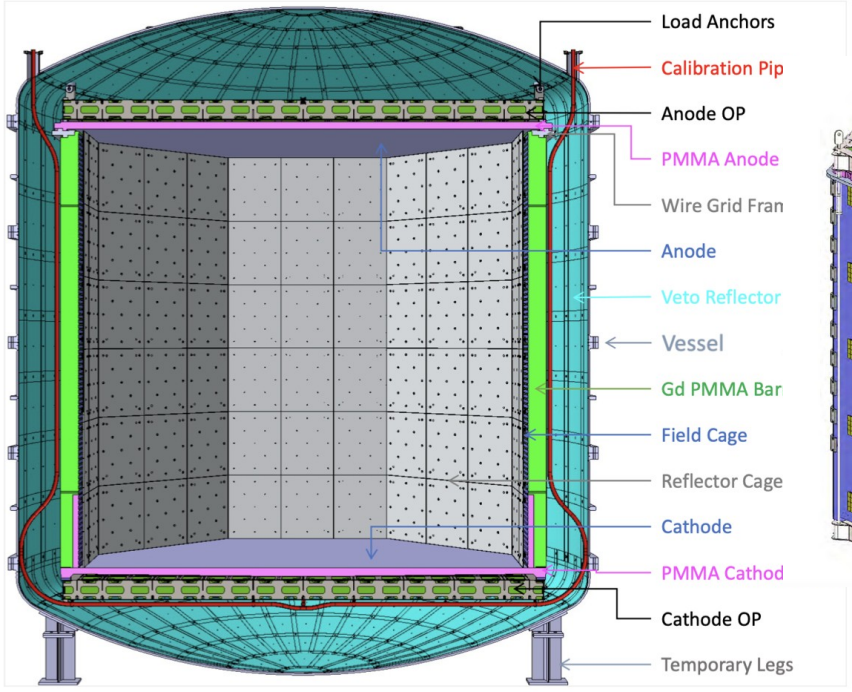


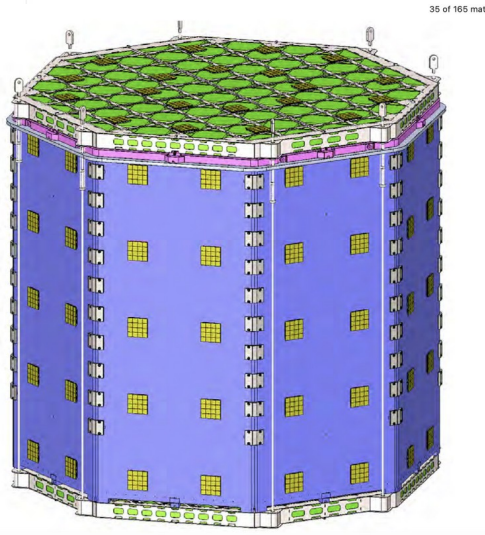
Signal and **background**

Source	Mitigation
β decay from Ar-39	Underground Argon + pulse shape discrimination
γ from rocks and e,γ from materials	Pulse shape discrimination, material screening and selection
Radiogenic neutrons, mostly (α,n)	• Material screening and selection • Definition of TPC fiducial volume • Rejection from **neutron veto**
Surface contamination from Radon decays	• Reduction of surfaces • Surface cleaning • Radon abatement system
Muon induced background	Cosmogenic veto
Neutrino coherent scattering	*Irreducible*

Neutron Veto

- TPC + Inner Veto
- Gd-PMMA
- SiPM arrays: > 120 vPDU
- Reflector + WLS (PEN)
- SS vessel:
  - 35 t Underground Argon (UAr)

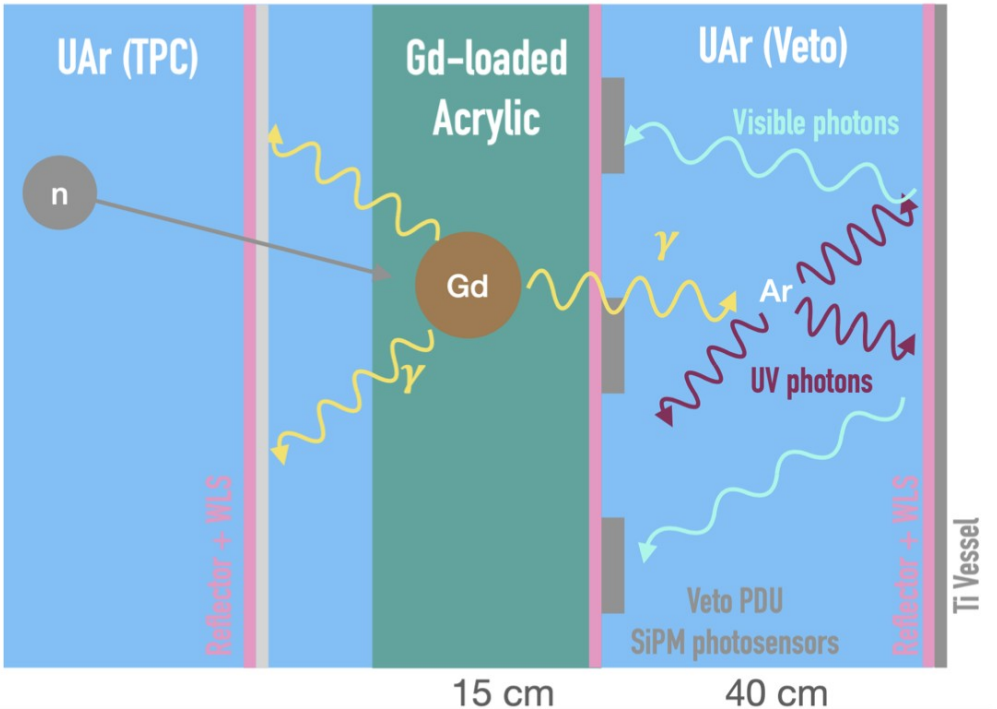




Neutron tagging

- Gd-PMMA as neutron moderator
- 8 MeV **gamma cascade from neutron capture**
- Identification
  - Single Nuclear Recoil (NR)
  - 7.5 keV < Electron Recoil energy < 50 keV
  - R-z fiducial cut
  - ER in TPC > 50 keV *or*
  - Energy deposit in UAr veto > 200 keV
  - TPC-Veto window of 800 µs

→ 0.1 events in ROI [30-200 keV_{NR}] for 200 t·y

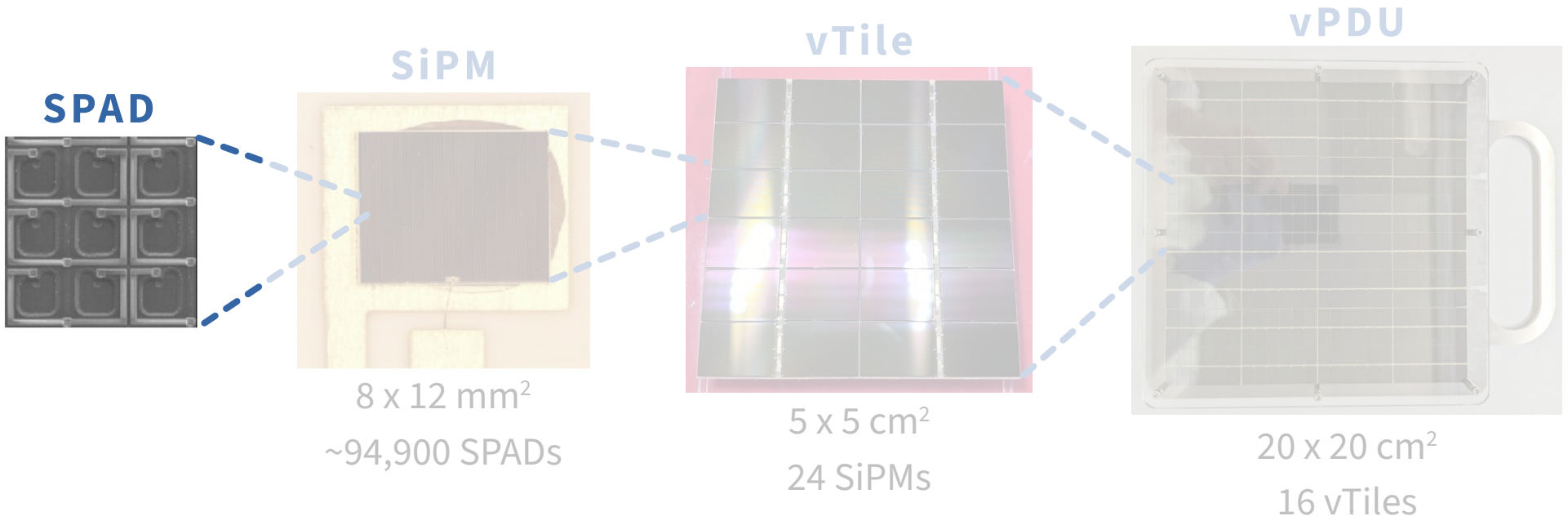


Silicon Photo Multipliers

- **Move from PMT to SiPM**
- **Advantages**:
  - Cryogenic temperature stability
  - Better single photon resolution
  - High photo-detection efficiency
  - Low voltage operation
  - Radiopurity
  - Low cost per area
- **Disadvantages**:
  - Small cells size
  - High Dark Count Rate (DCR)

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 %

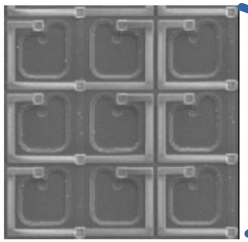
Veto Photon Detection Module



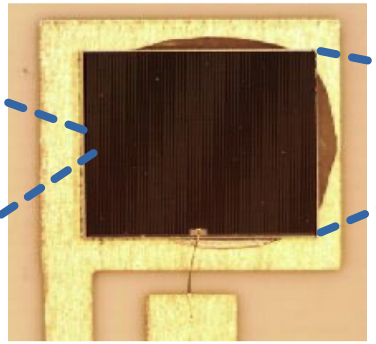
- **Single Photon Avalanche Diode**
  - Semiconductor devices based on a p-n junction
  - Reverse biased well above breakdown voltage
  - Operating in Geiger mode

Veto Photon Detection Module

SPAD



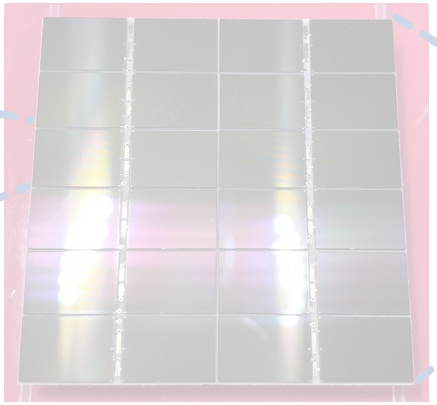
SiPM



8 x 12 mm^2

~94,900 SPADs

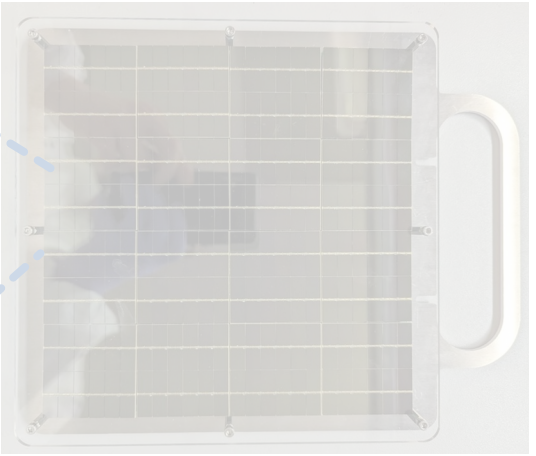
vTile



5 x 5 cm^2

24 SiPMs

vPDU

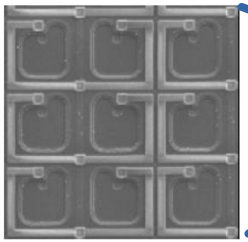


20 x 20 cm^2

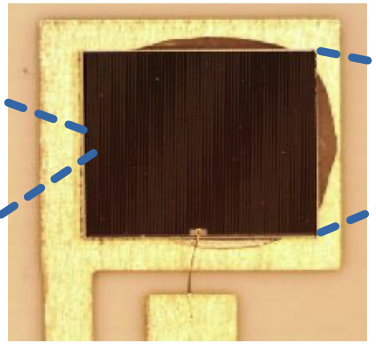
16 vTiles

Veto Photon Detection Module

SPAD



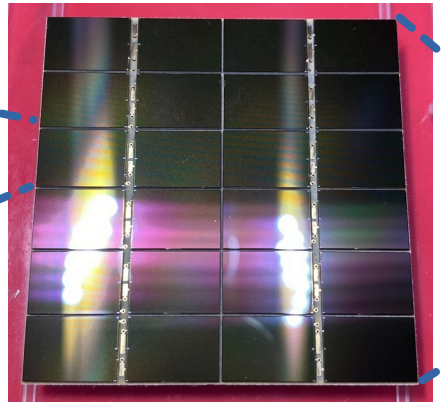
SiPM



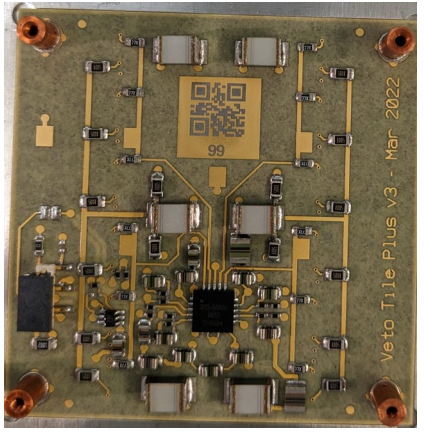
8 x 12 mm^2

~94,900 SPADs

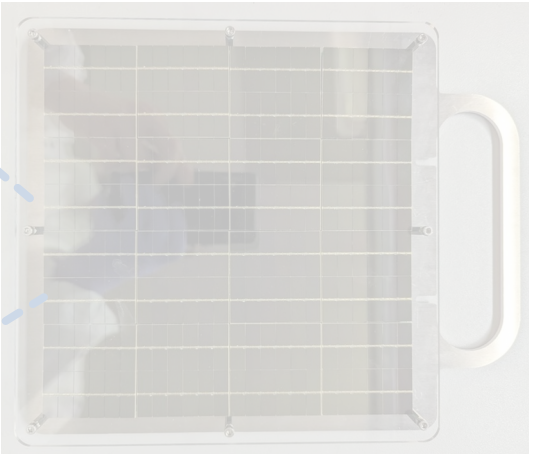
vTile



5 x 5 cm^2



vPDU

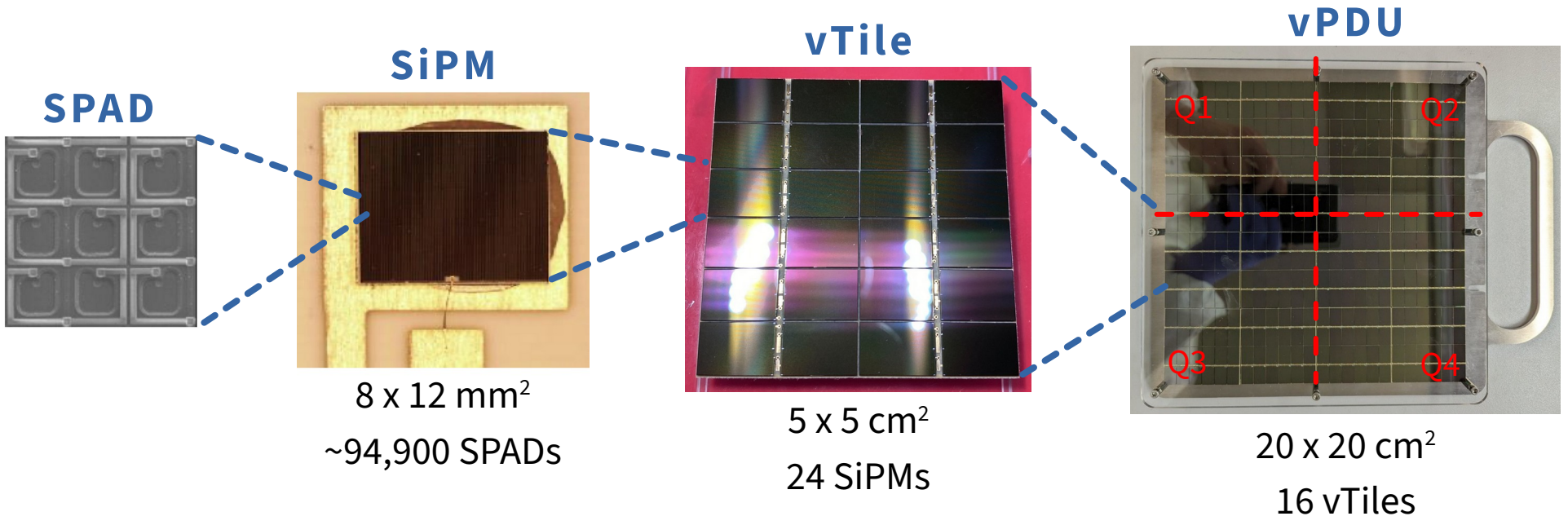


20 x 20 cm^2

16 vTiles

- **Veto Tile**
  - 24 SiPM signals summed
  - Backside: front end readout ASIC developed by the Collaboration

Veto Photon Detection Module

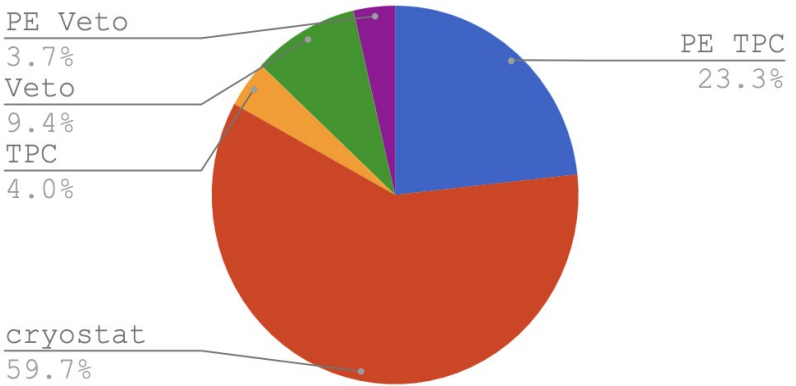


- **Veto Photo Detection Unit**
  - Backside: Single Motherboard PCB
  - Single vTile bias
  - 4 Quadrants: 4 channels summing 4 vTiles

Radiopurity

- Stringent material selection
- Radio purity-control
- Assay of components and final boards

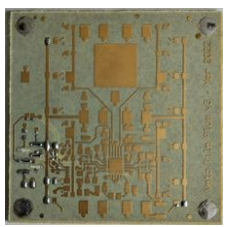
- Production and tests in clean environment

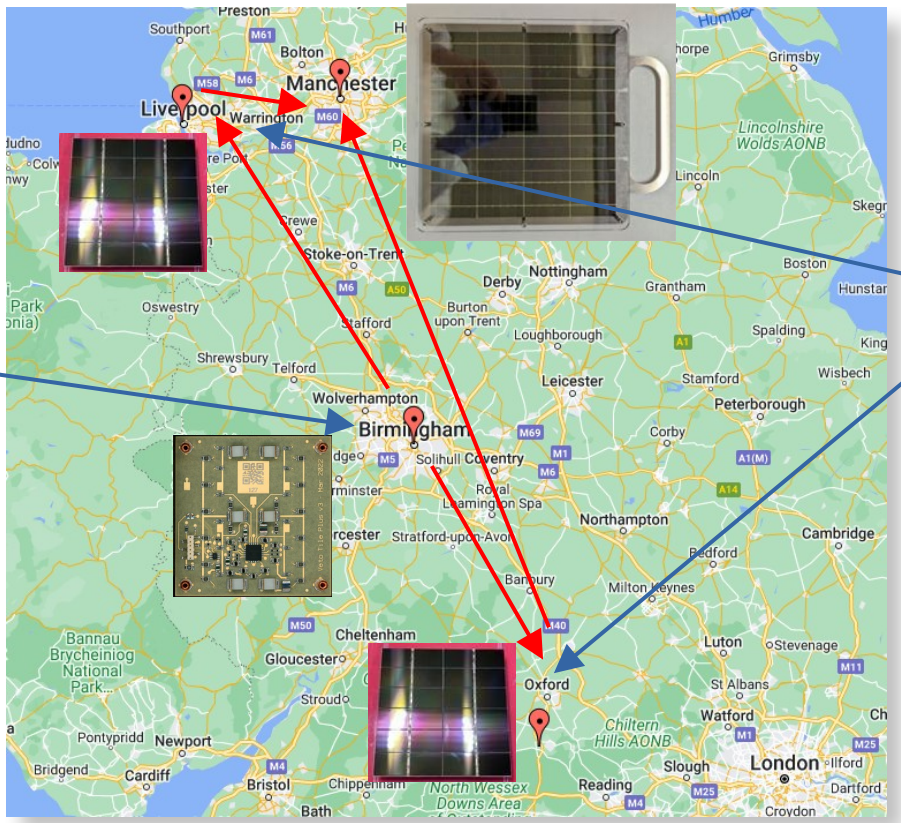


	From summing [Bq]	From assay [Bq]
Uup	2.2E+00	2.3E+00
Umid	1.2E+00	1.3E+00
Ulow	5.8E+01	**8.4E+01**
Th232	1.3E+00	1.1E+00
Ur-235	1.6E-01	1.1E-01
K40	1.4E+01	1.3E+01

UK production

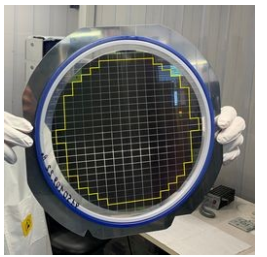
STEVENAGE CIRCUITS
ADVANCED PCB MANUFACTURE





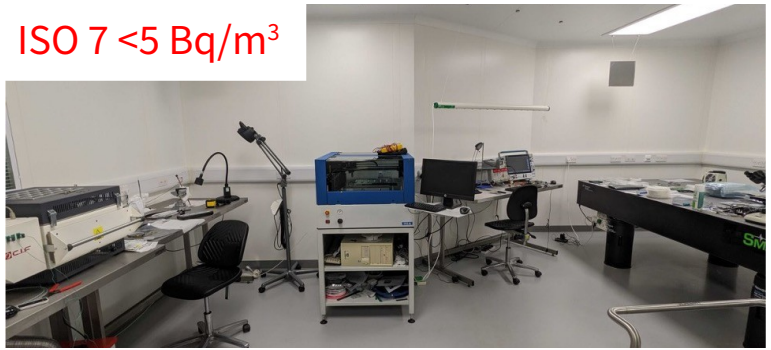
INFN Laboratori Nazionali del Gran Sasso

NOA (LNGS)

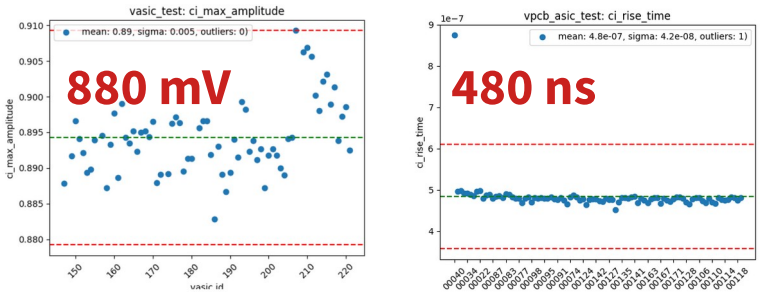


PCB production: Birmingham

ISO 7 <5 Bq/m^3



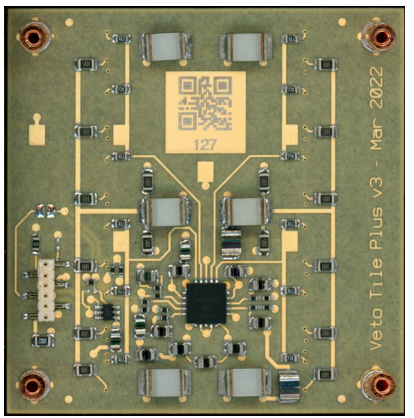
Charge injection tests:



Stencil for solder paste

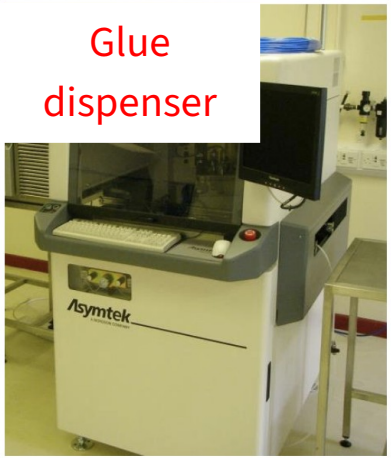
Pick and place

Reflow oven



vTile assembly: STFC Interconnect

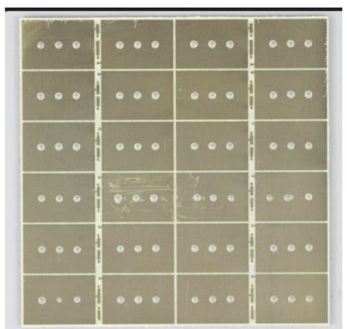
Glue dispenser

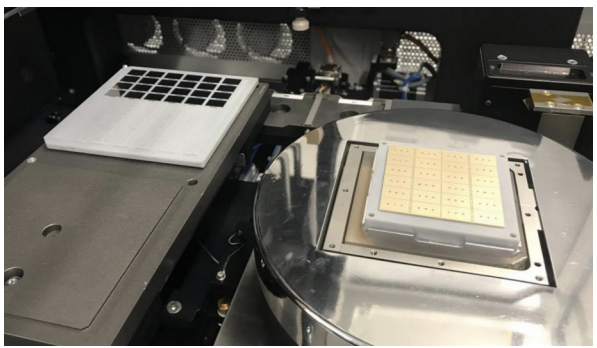


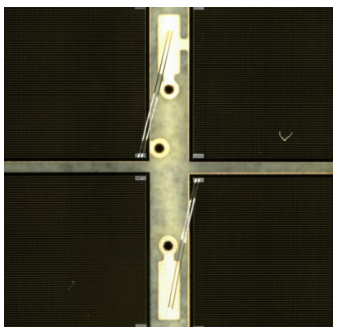
Die attach

Wire bonding

ISO 7: 3.3 Bq/m^3



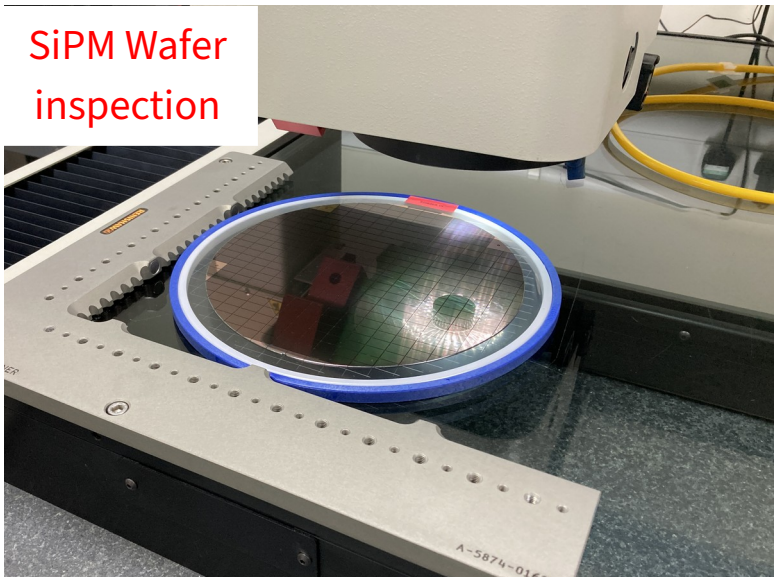




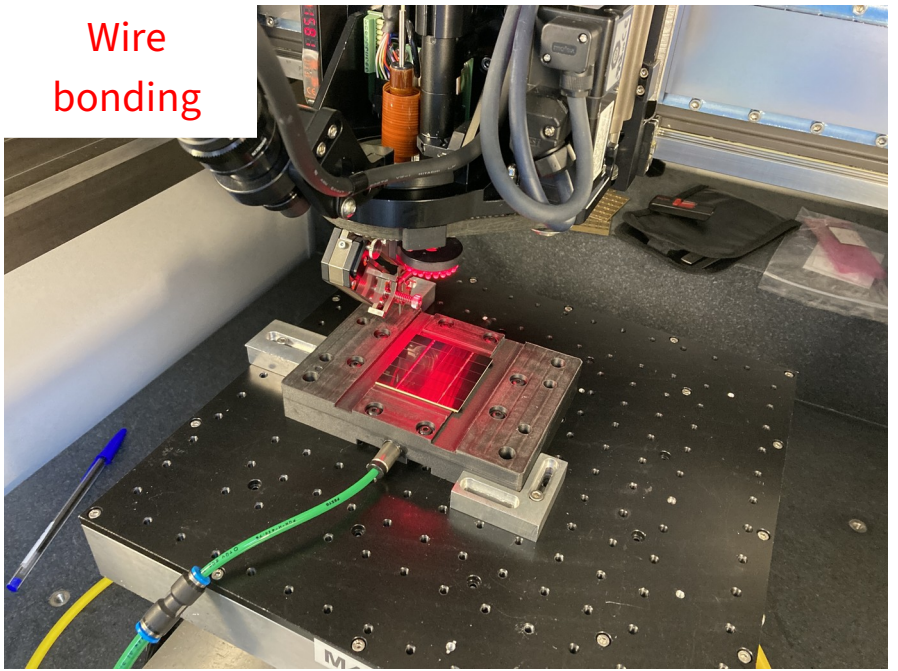
vTile assembly: Liverpool

ISO 7 <1.1 Bq/m^3

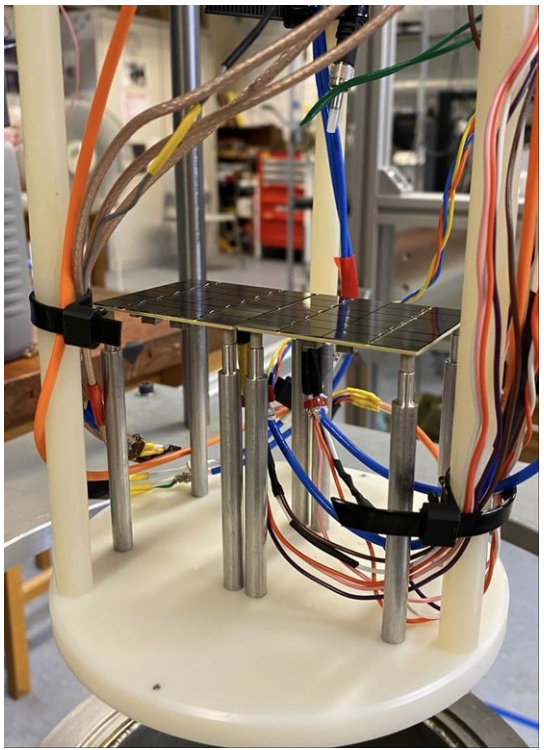
SiPM Wafer inspection

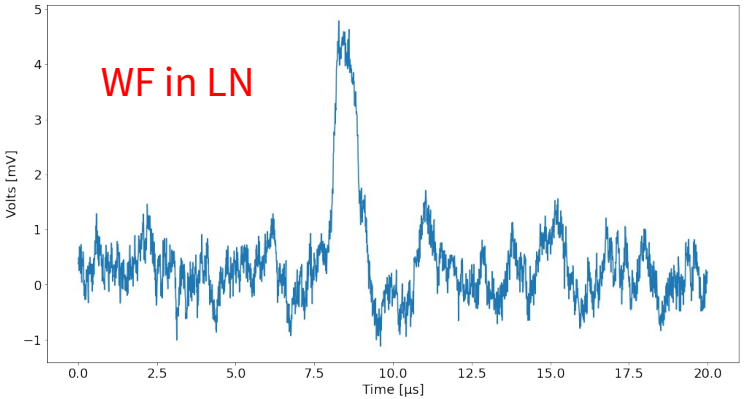


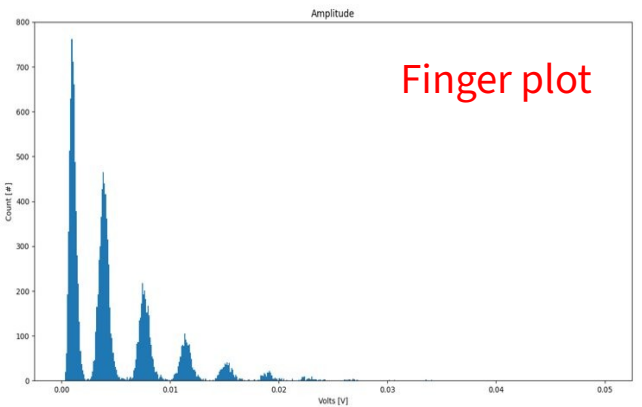
Wire bonding

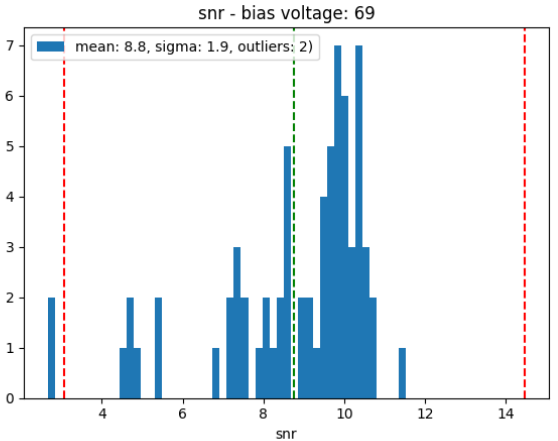


vTile cold test: RHUL





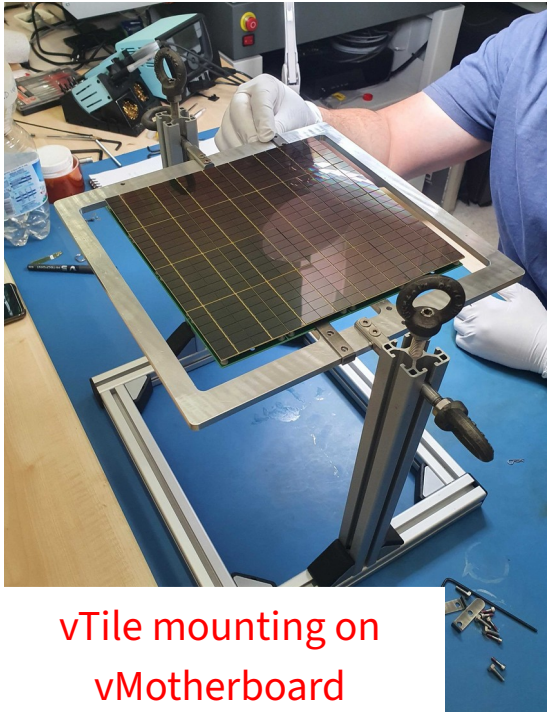




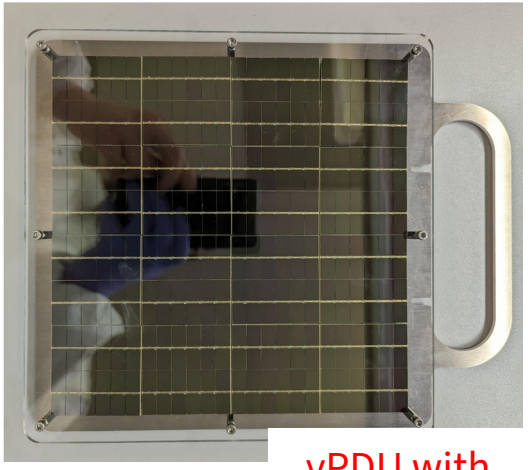
$$SNR = \frac{1\,PE\ amplitude}{baseline\ RMS}$$

SNR > 8

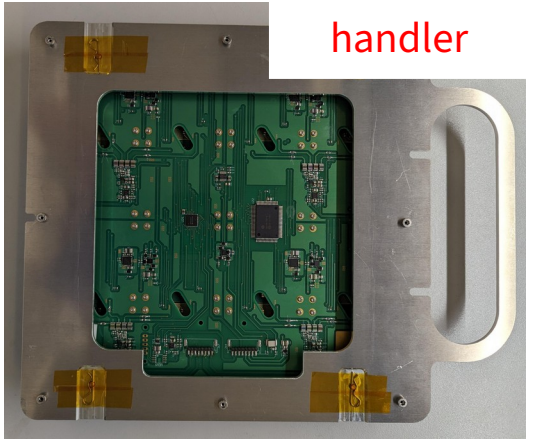
vPDU assembly: Manchester



vTile mounting on vMotherboard



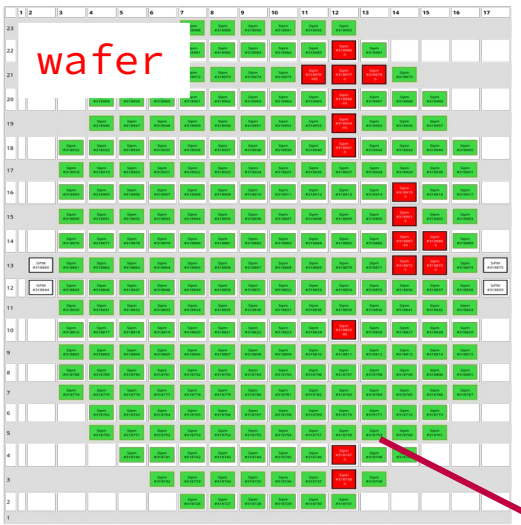
vPDU with handler

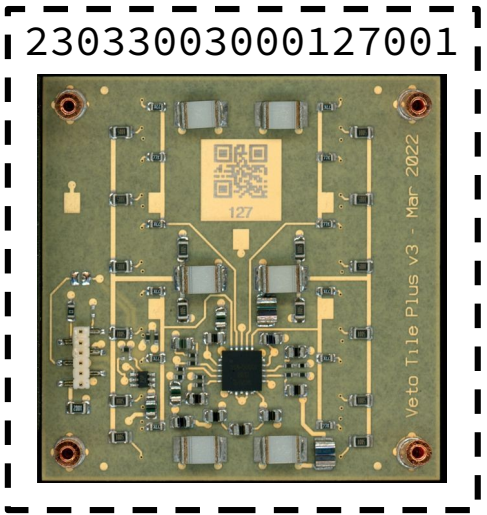


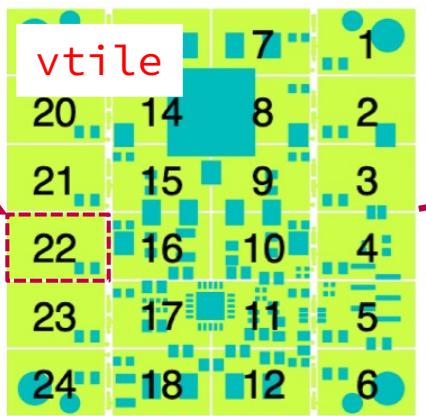
3 vPDUs currently assembled and tested

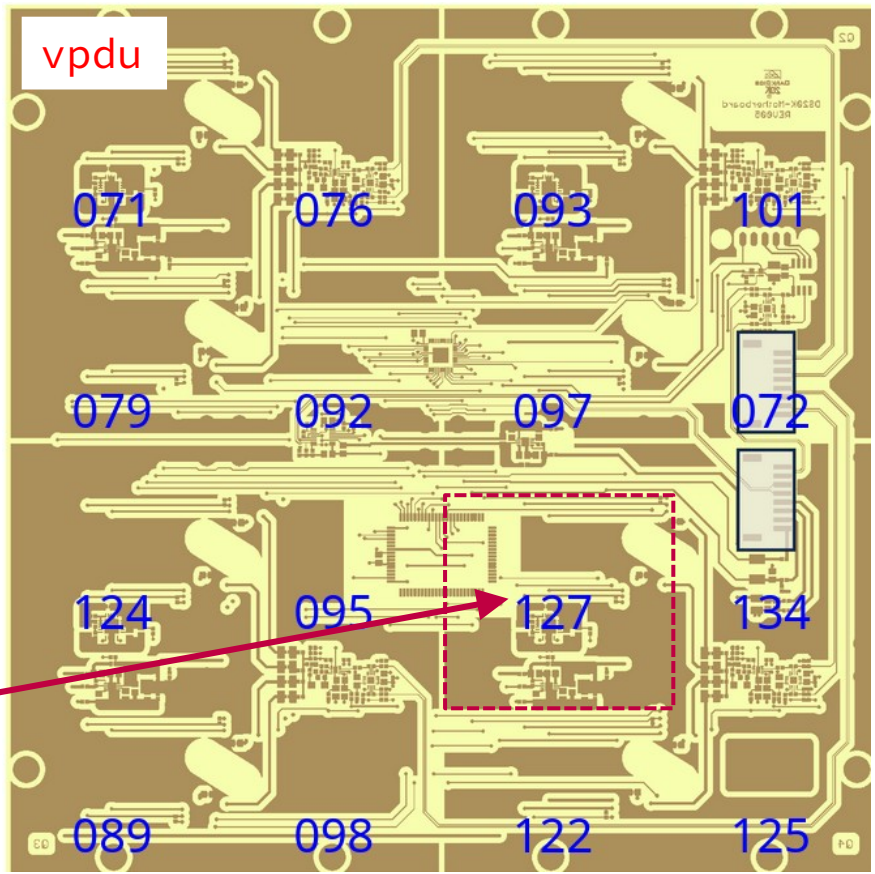
4th vPDU in progress

Production DataBase

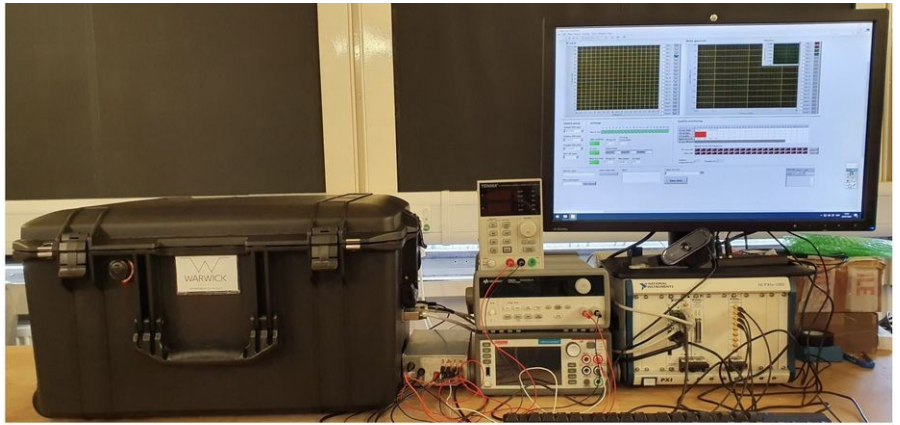


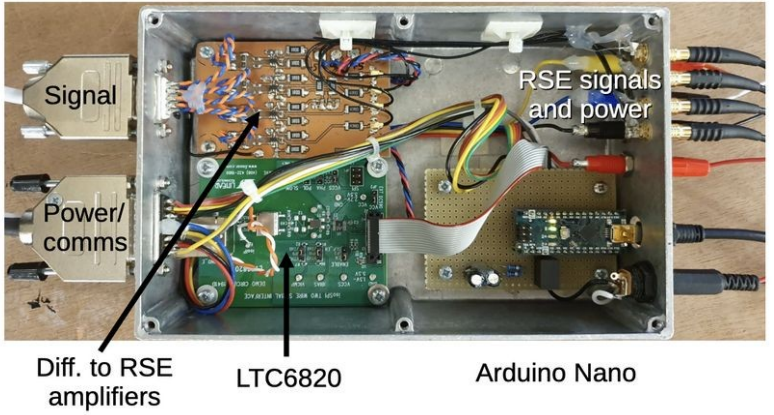


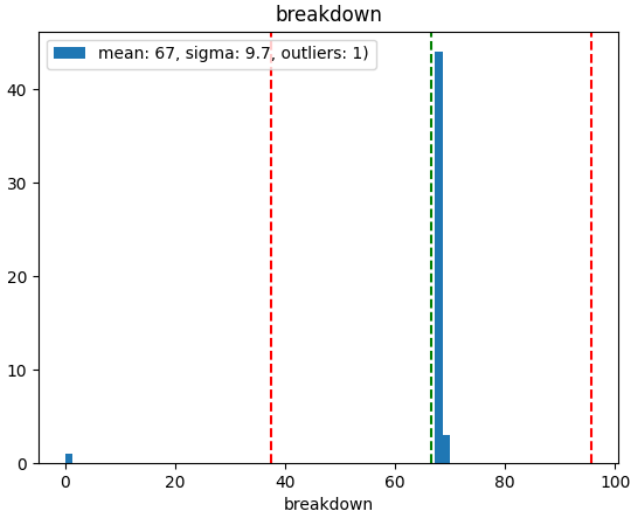




vPDU warm test: Manchester & Warwick

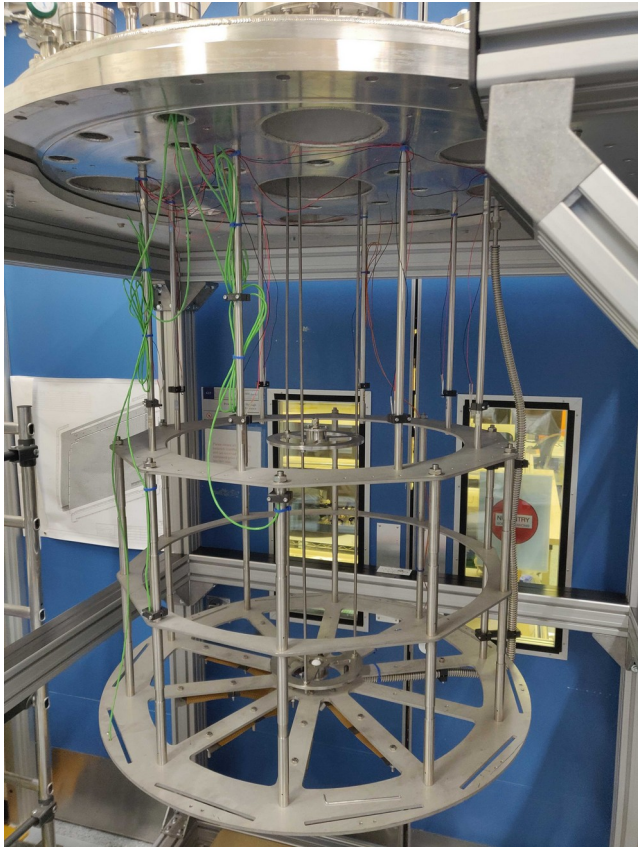






Breakdown @ warm

vPDU cold test: Liverpool



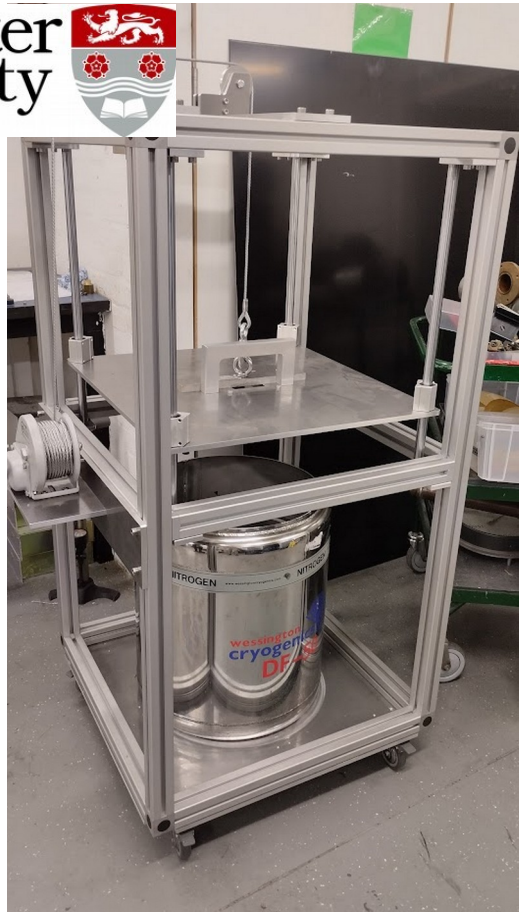
Largest Liquid Nitrogen test stand

Test capability:
10 vPDUs/time

UNIVERSITY OF LIVERPOOL

vPDU cold test: Lancaster and Astrocent

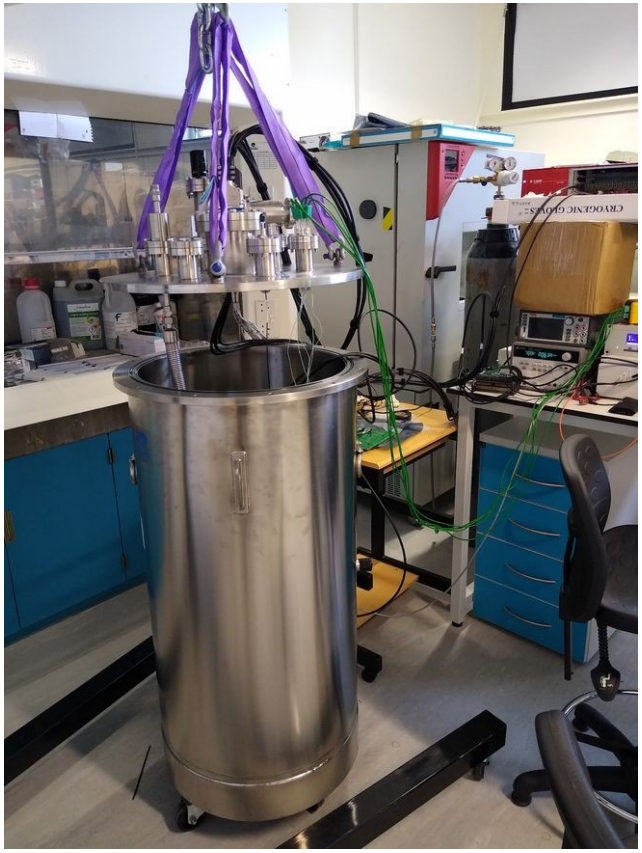
Lancaster University

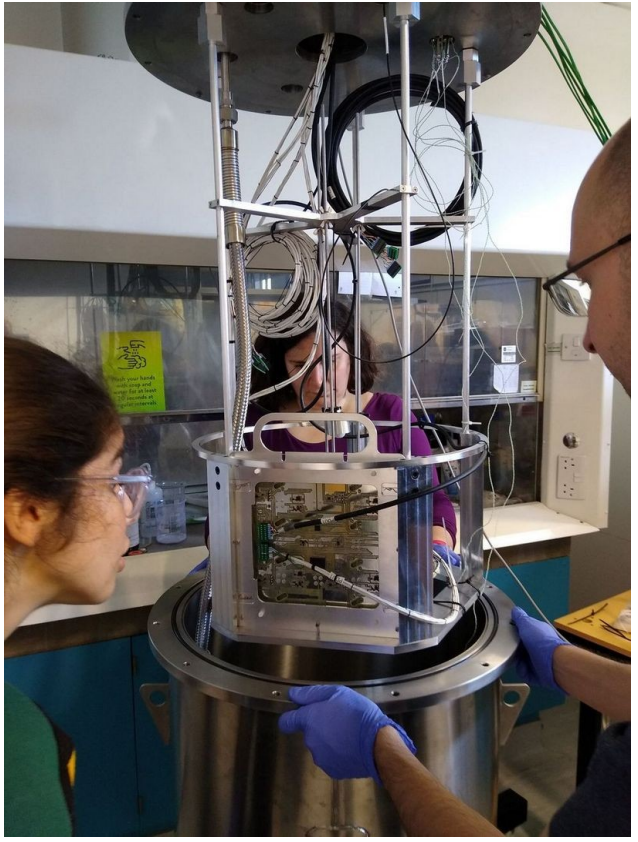


ASTROCENT

Testing capability up to 5 vPDUs/time each (with possibility to extend to 10)

vPDU cold test: Edinburgh

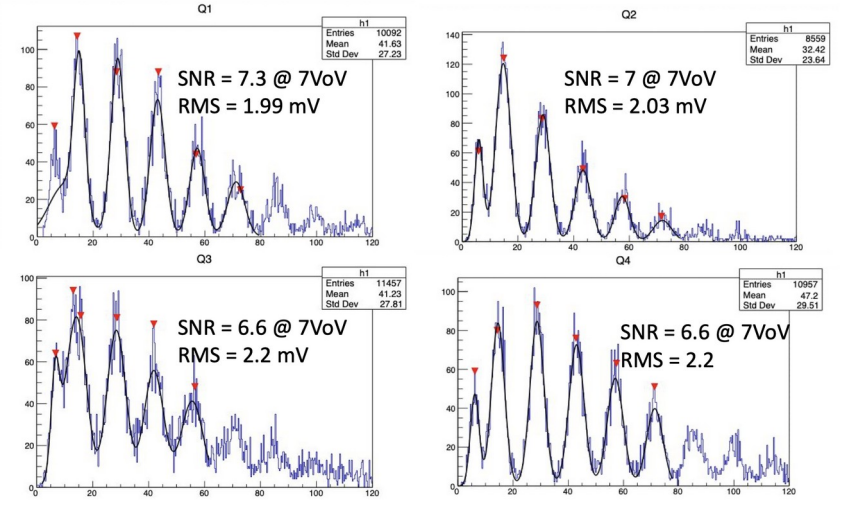


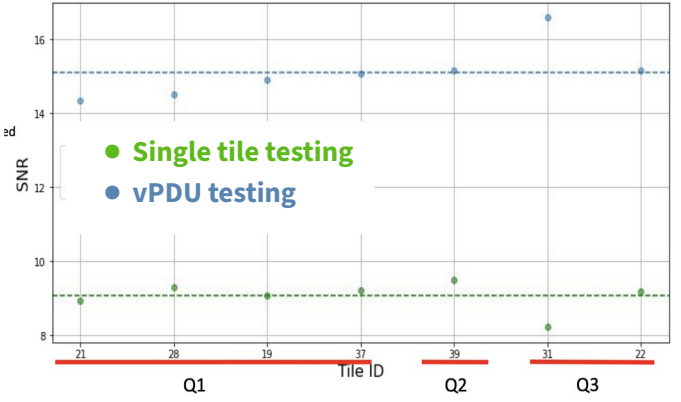


vPDU cold test: Edinburgh

- Single vTile and Quadrant tests
- 4 quadrants (4 channels) = 4 vTiles each

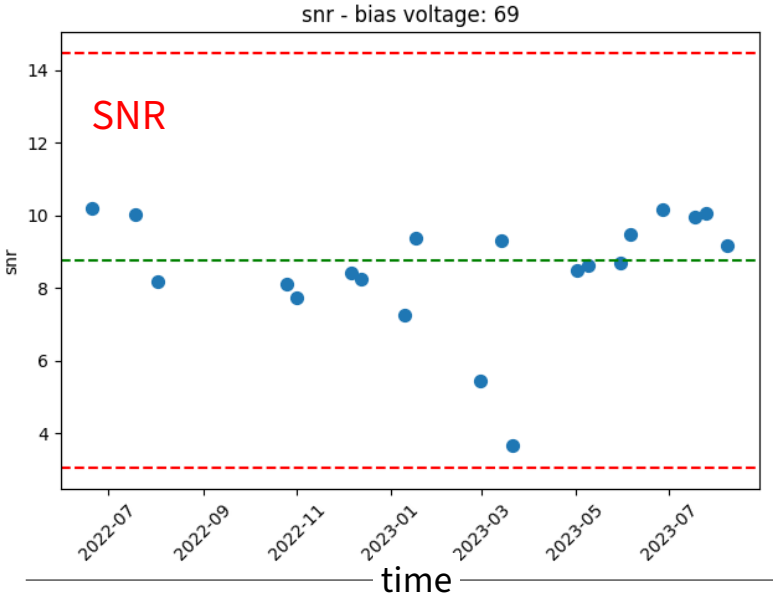
- 1 PE at 14 mV
- Higher SNR because of better filtering





QA/QC

- "Veto Passport" to have a baseline analysis from all the test stands
  - Breakdown, Signal-to-noise Ratio (SNR), Dark Count Rate (DCR), Correlated Delayed Avalanches (CDA), Mean After Pulsing (APA), Direct Cross Talk Probability (DICT)
- Assess the full production chain over time
- Assign quality grades
- Maintain good production yield
- Spot production problems at an early stage



Conclusions and Outlook

- **Veto detector is key to achieve the required instrumental background**

- UK and Polish facilities ready for production and testing
- Analysis distributed infrastructure in place
- First vPDUs meet the requirements

- **vPDU production to be completed in 2024**