DarkSide-20k 26 m² SiPM Detectors: Production and Characterisation

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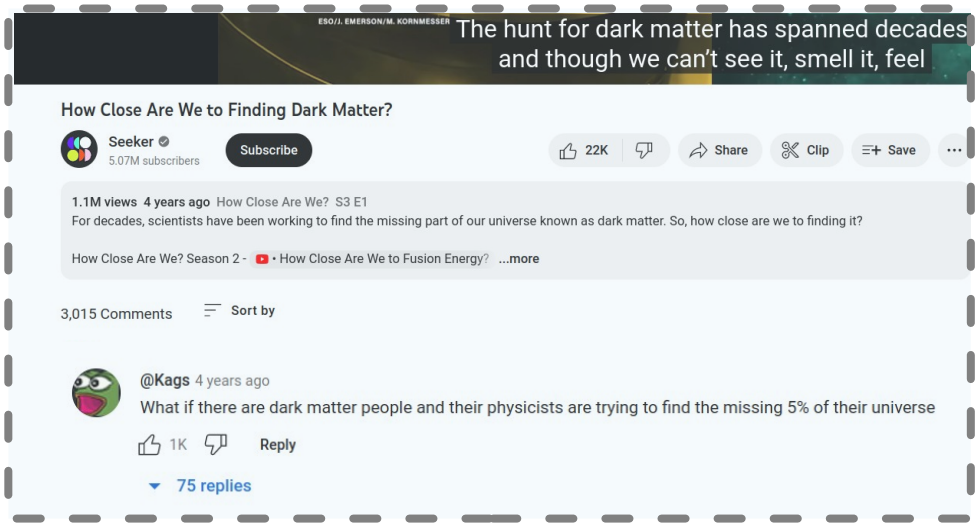
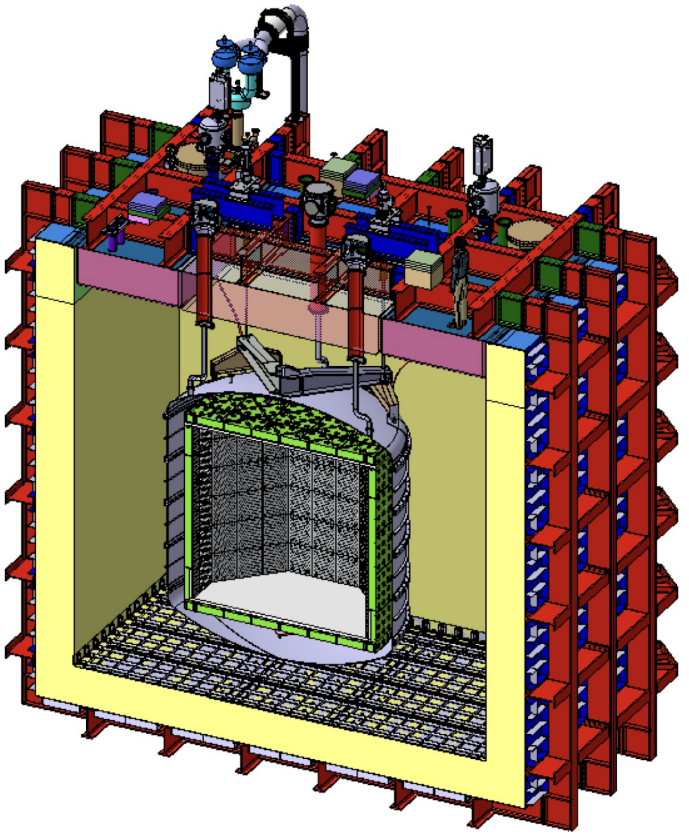
Outline

- DarkSide-20k introduction
- Signal and background mitigation
- Neutron Veto
- Photo Detector Units
- Production for TPC and Veto
- Characterisation and QA/QC

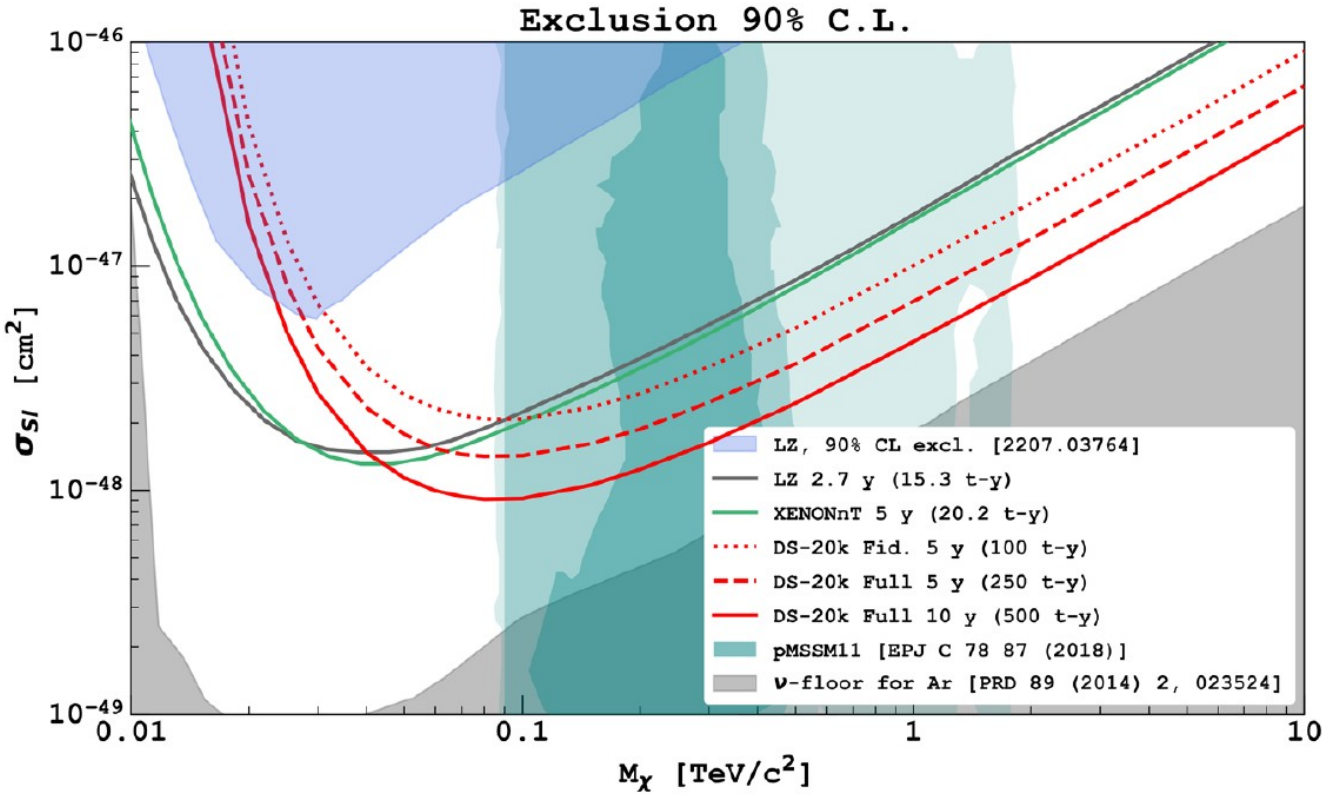


DarkSide-20k

- 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
- 0.21 background events in ROI [30-100 keV_{NR}] in 200 t·year exposure



DarkSide-20k: projected sensitivity



WIMP-nucleon scattering cross section:

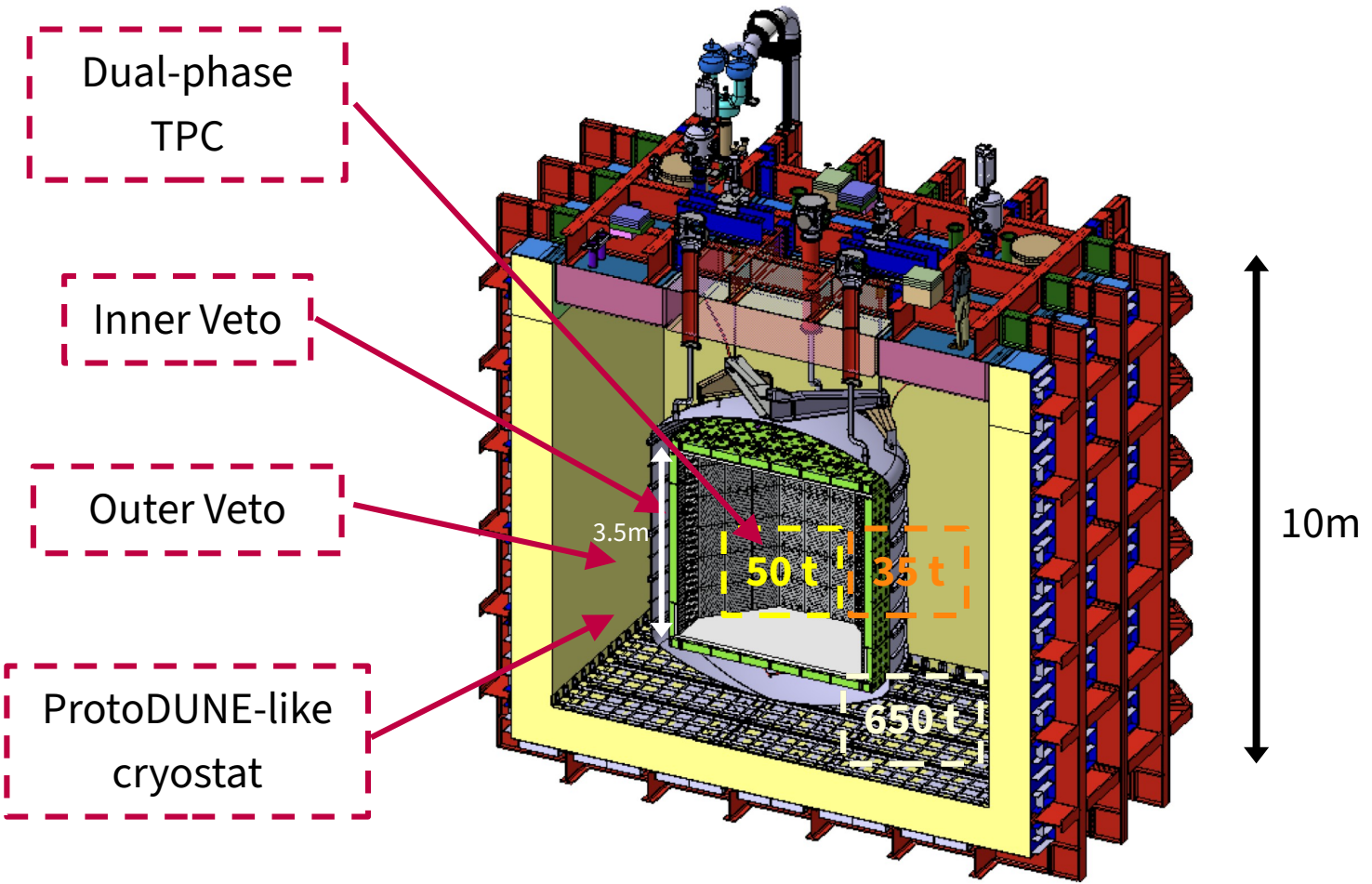
6.3 x 10^{-48} cm^2 for 90% CL exc.

2.1 x 10^{-47} for 5σ discovery

1 TeV/c^2 WIMP

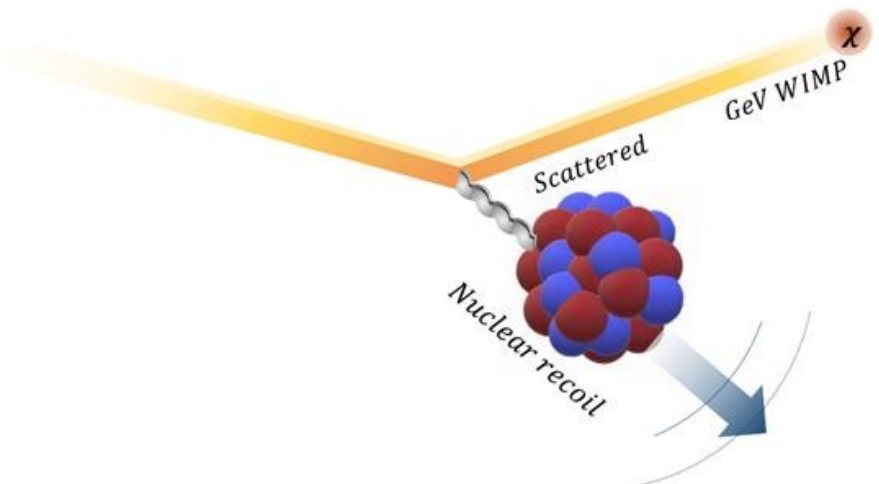
for 200 t·years in the f.v.

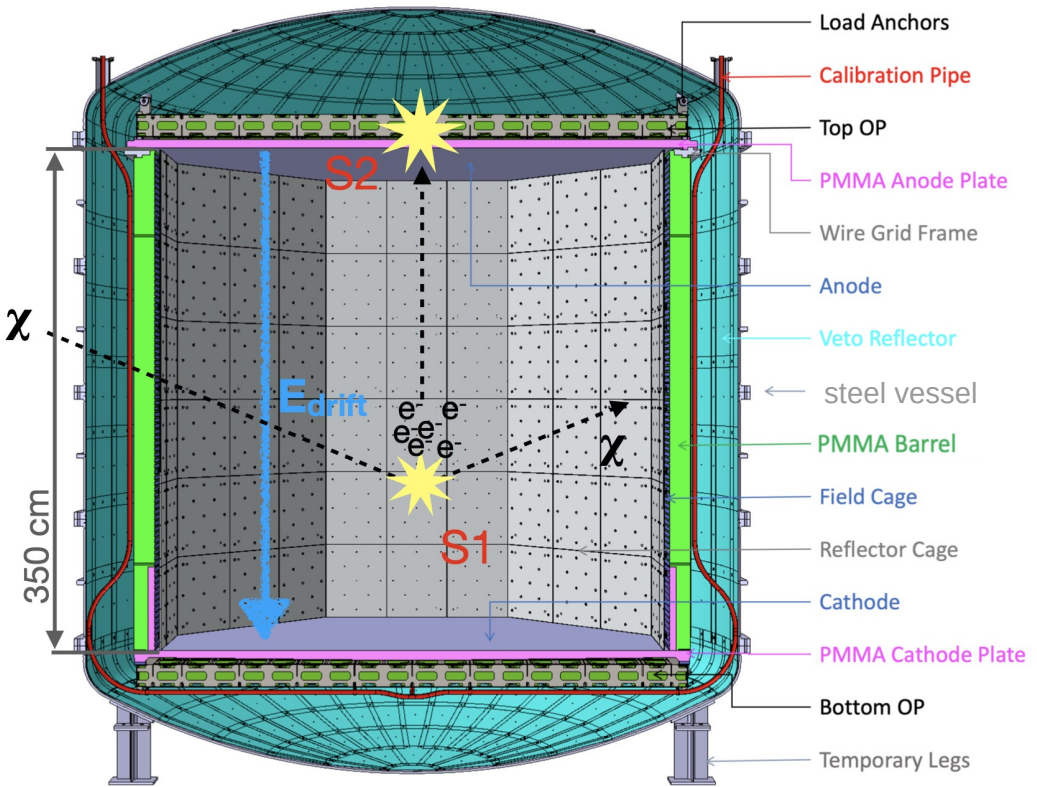
DarkSide-20k



Signal and background

- Nuclear recoil energy: 1-100 keV (sub-keV at low mass for S2 only)
- Detect light from the prompt (S1) and delayed (S2) signals



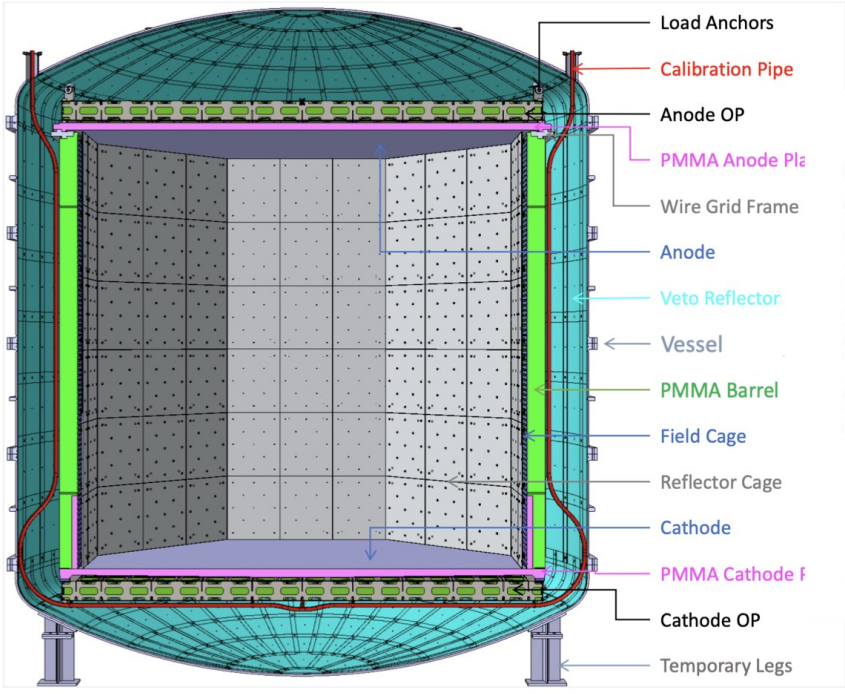


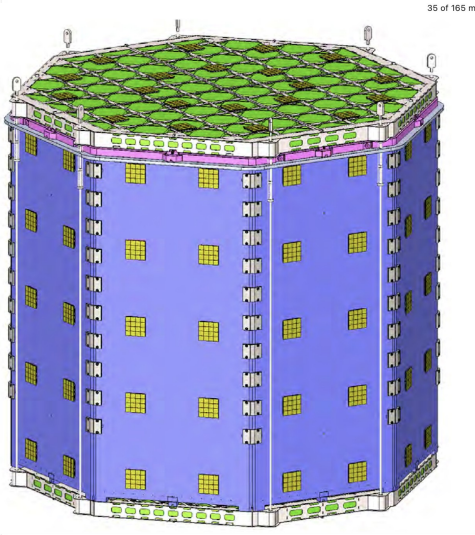
Signal and **background**

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
- PMMA shell
- SiPM arrays: 120 vPDU
- Reflector + WLS (PEN)
- SS vessel:
  - 35 t Underground argon (UAr)

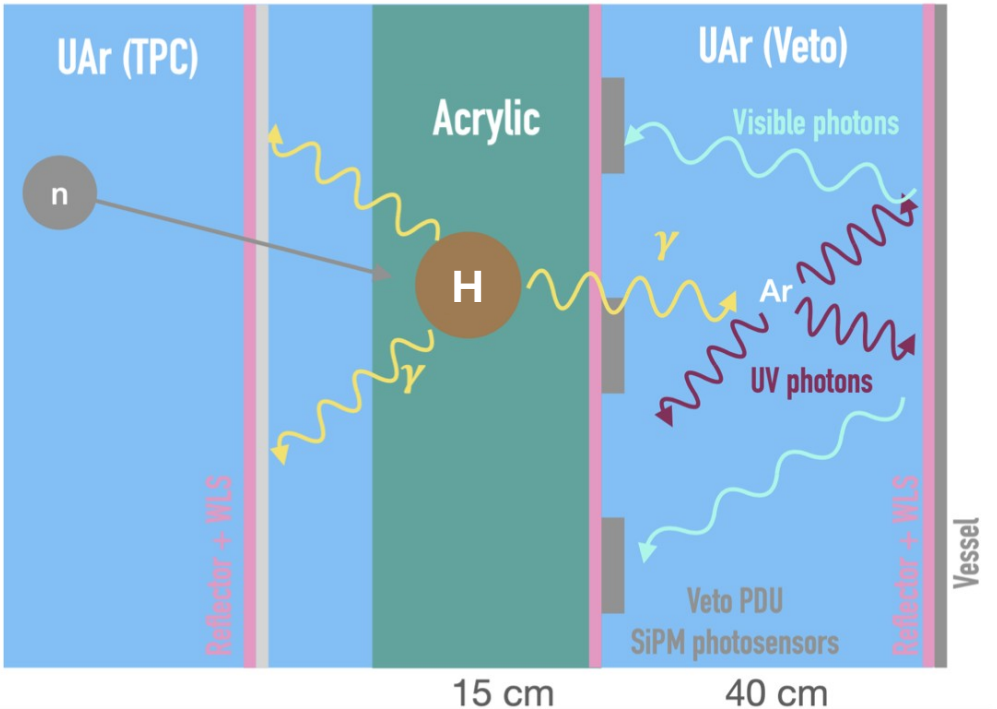




Neutron tagging

- PMMA as **neutron moderator**
- MeV gamma cascades from **neutron capture** in H and ^{40}Ar
- Gamma producing secondary electrons causing **UV scintillation → WLS → visible photons**
- 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

→ 0.21 events in ROI [30-200 keV$_{NR}$] for 200 t·y



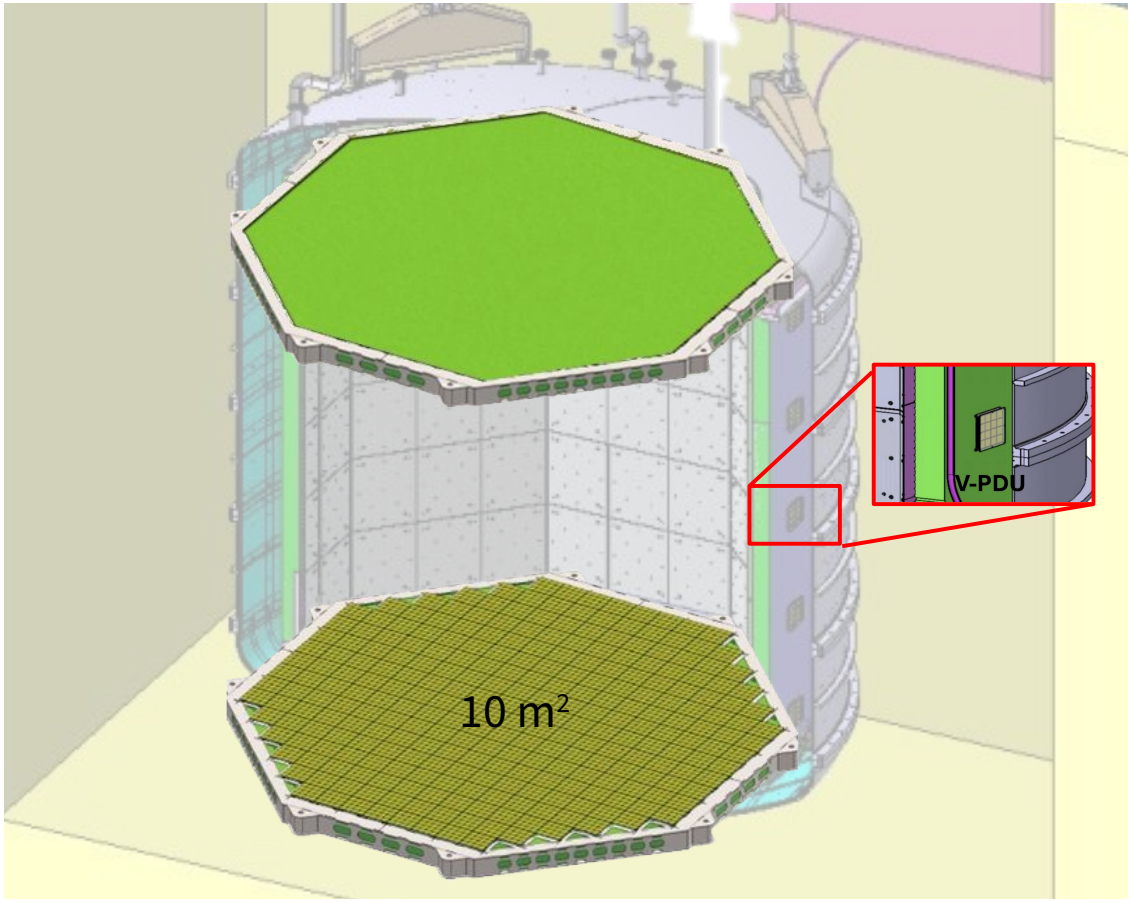
Silicon Photo Multipliers

- **Move from PMTs to SiPMs**
- **Advantages**:
  - Cryogenic temperature stability
  - Better single photon resolution
  - High photo-detection efficiency
  - Low voltage operation
  - Radiopurity
  - Low cost per area
- **Disadvantages**:
  - Small cells size

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 %

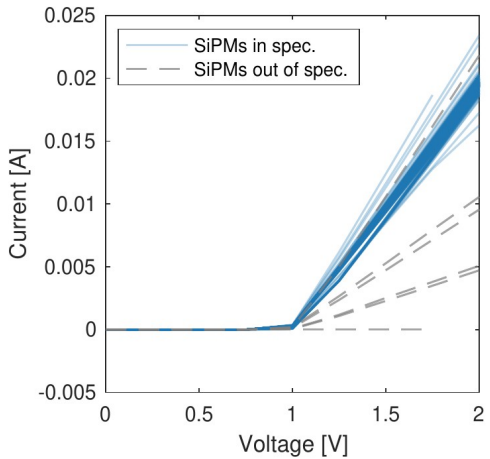
Photoelectronics in DarkSide-20k

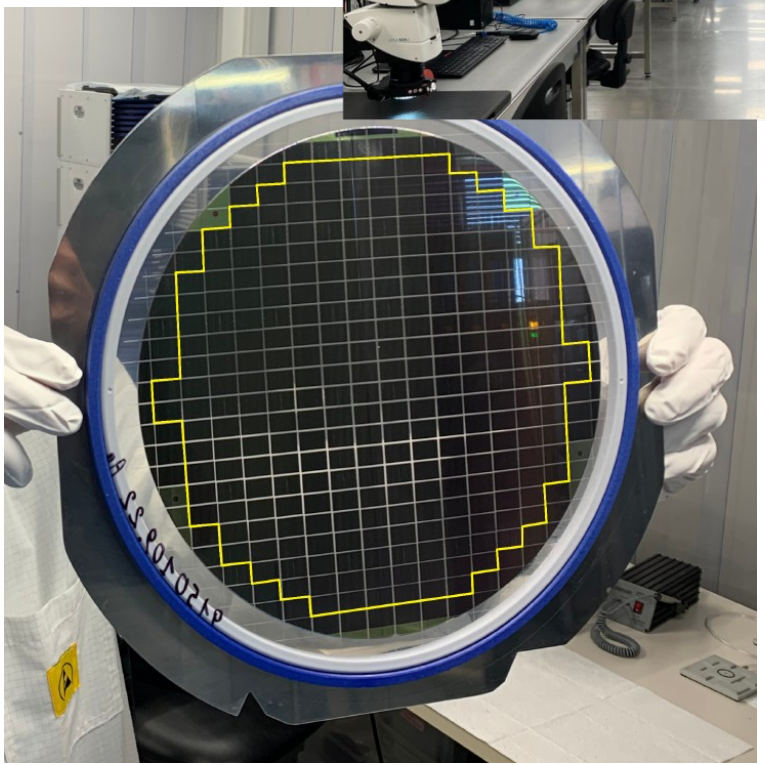
- **TPC**:
  - two optical planes
  - 21 m^2 in total
  - full coverage of SiPMs
  - 528 PDUs: 2112 channels
- **Vetoes**:
  - inner veto: 120 vPDUs, 480 channels
  - outer veto: 30 vPDUs, 120 channels



SiPMs

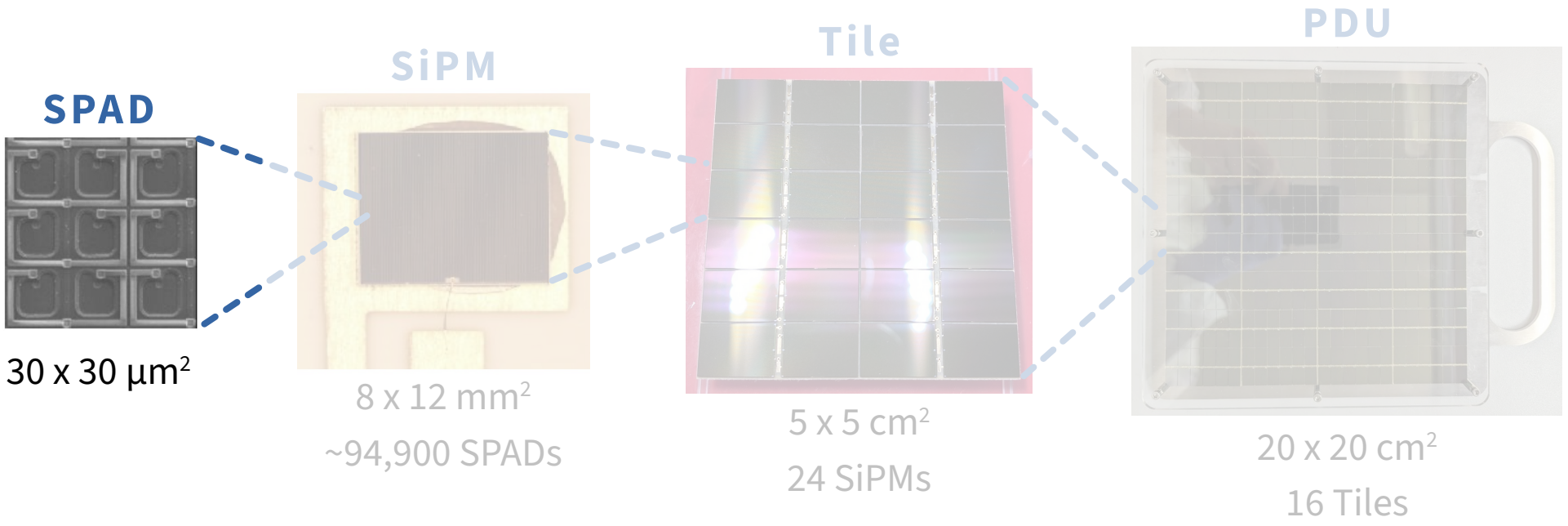
- Cryogenic SiPM technology developed by FBK (Italy)
- NOA (Assegi, Italy)
  - Cryoprobed each SiPM
  - 1400 tested wafers





Quality assurance and quality control of the SiPM production for the DarkSide-20k dark matter experiment Eur. Phys. J. C 85, 534 (2025)

Photo Detector Units

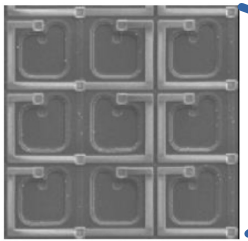


Single Photon Avalanche Diode

- Semiconductor devices based on a p-n junction
- Reverse biased well above breakdown voltage
- Operating in Geiger mode

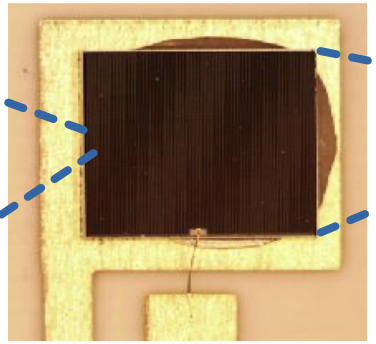
Photo Detector Units

SPAD



30 x 30 µm^2

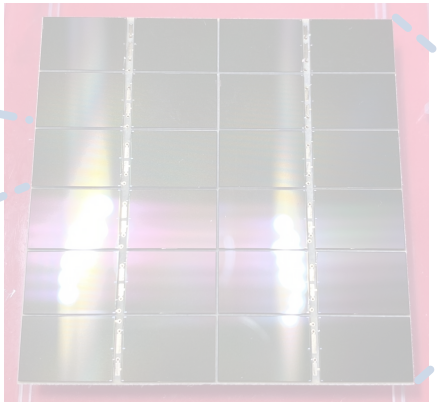
SiPM



8 x 12 mm^2

~94,900 SPADs

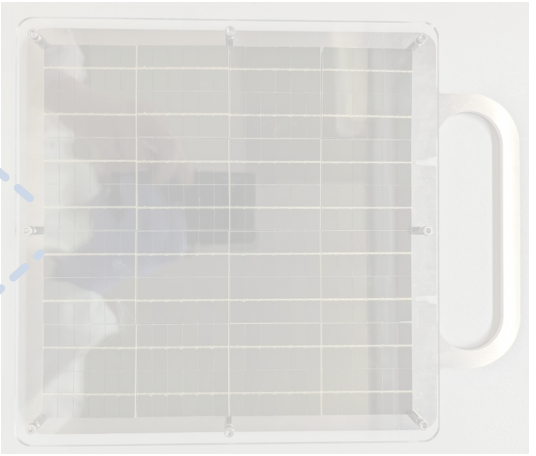
Tile



5 x 5 cm^2

24 SiPMs

PDU

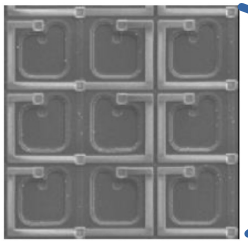


20 x 20 cm^2

16 Tiles

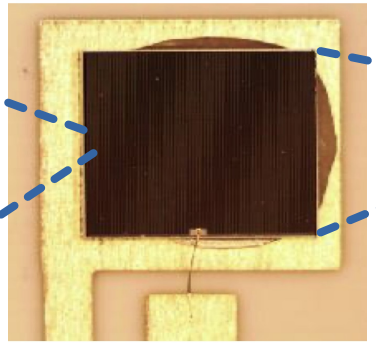
Photo Detector Units

SPAD



30 x 30 µm^2

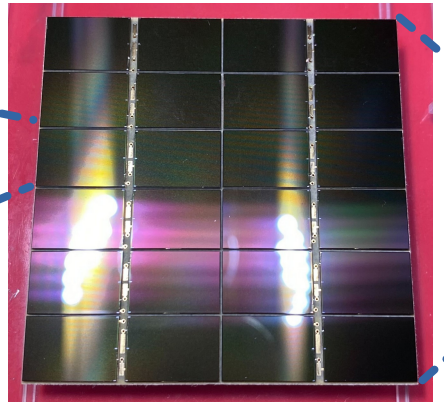
SiPM



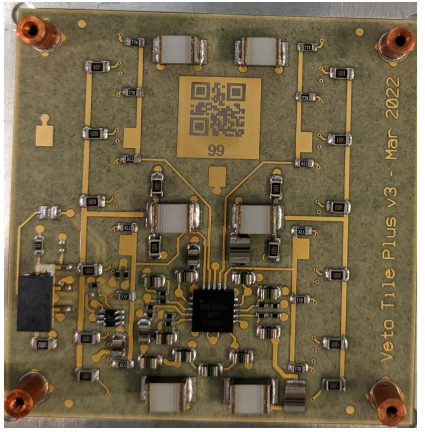
8 x 12 mm^2

~94,900 SPADs

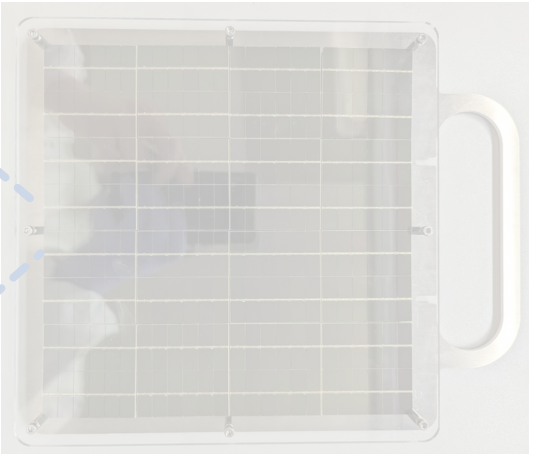
Tile



5 x 5 cm^2



PDU



20 x 20 cm^2

16 Tiles

Tile

- 24 SiPM signals summed
- Backside: front end readout amplification developed by the DS-20k collaboration

Photo Detector Units

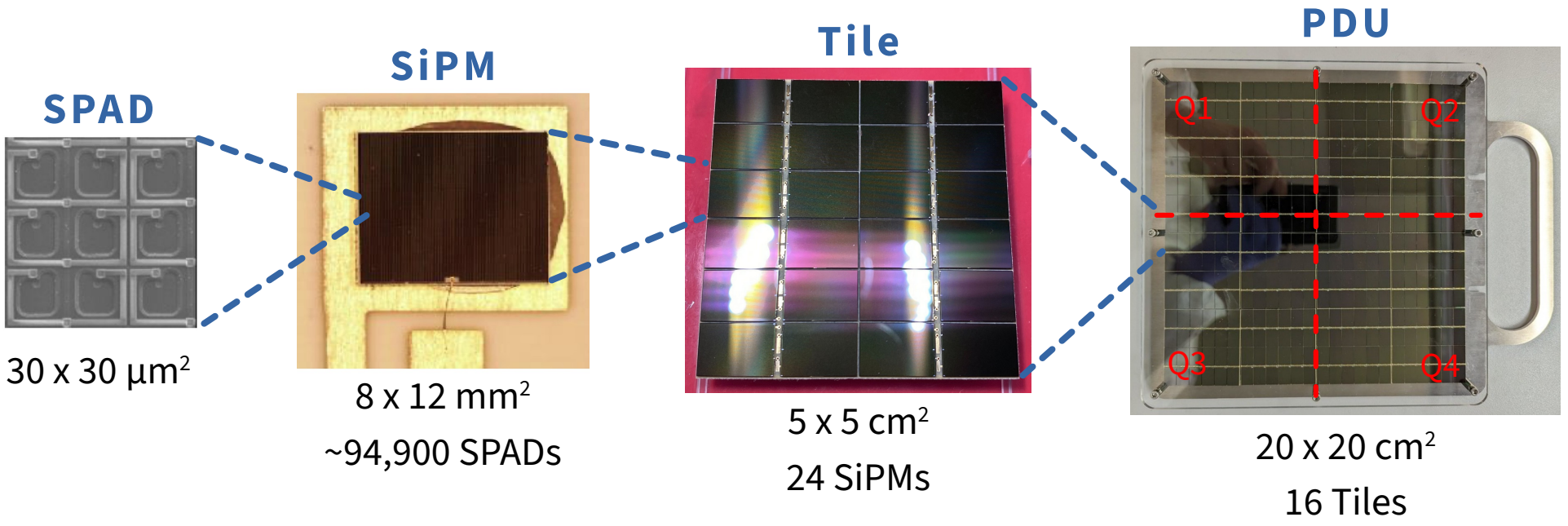


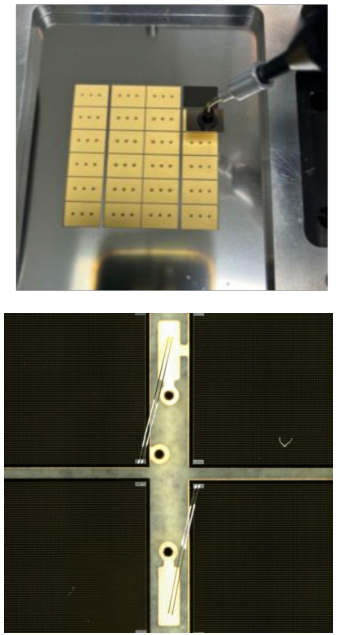
Photo Detection Unit

- Backside: Single Motherboard PCB
- Single Tile bias and amplification
- 4 Quadrants: 4 channels summing 4 Tiles

Veto PDU production: UK

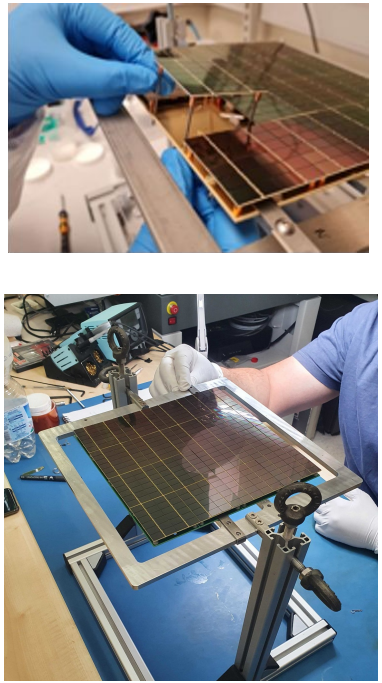
PCB population in Birmingham

SiPM die attach and wire bonding in Liverpool and STFC Interconnect

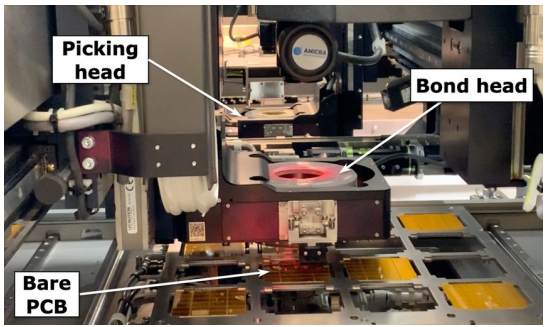


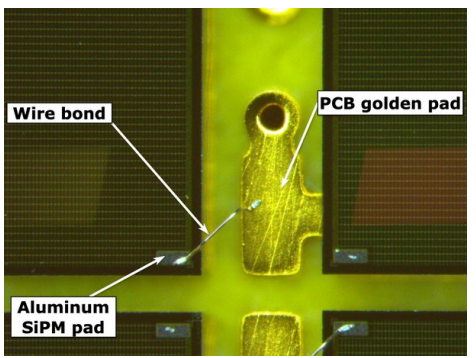
vTile testing in Oxford and STFC Interconnect

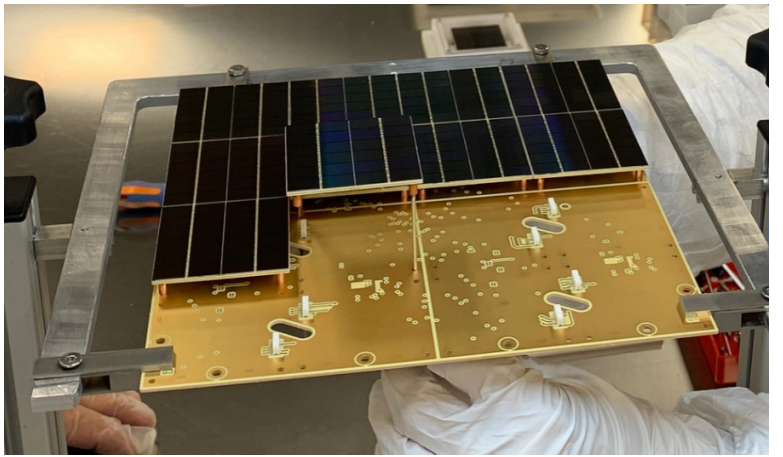
vPDU assembly in Manchester and Warwick



TPC PDU production: NOA



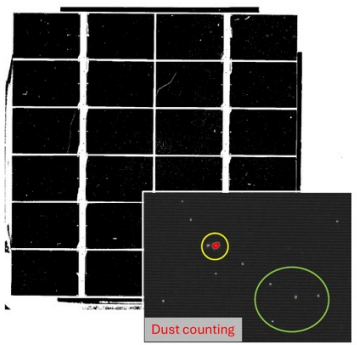


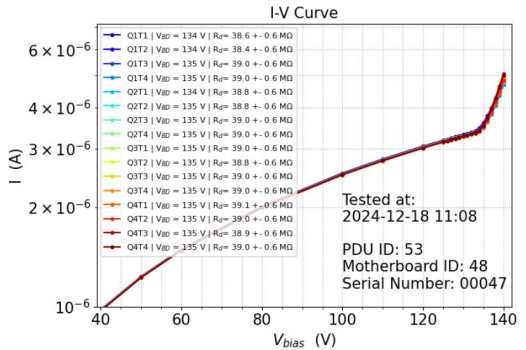


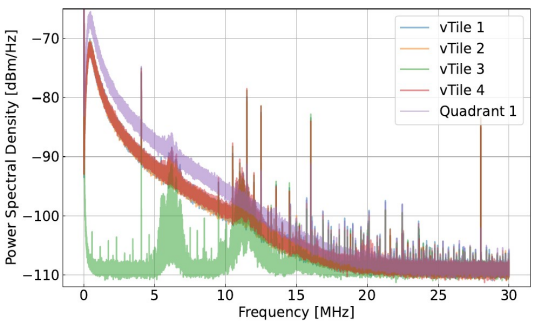
Production, Quality Assurance and Quality Control of the SiPM Tiles for the DarkSide-20k Time Projection Chamber
arXiv:2507.07226
(accepted by EPJ-C)

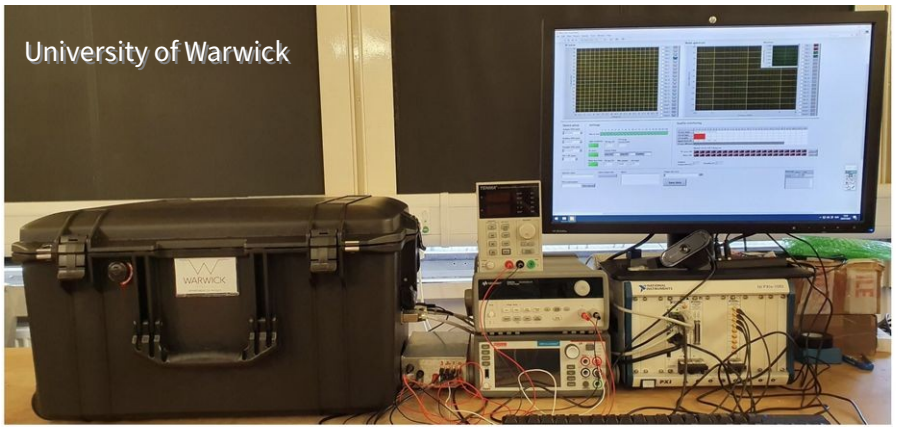
Preliminary tests “at warm”

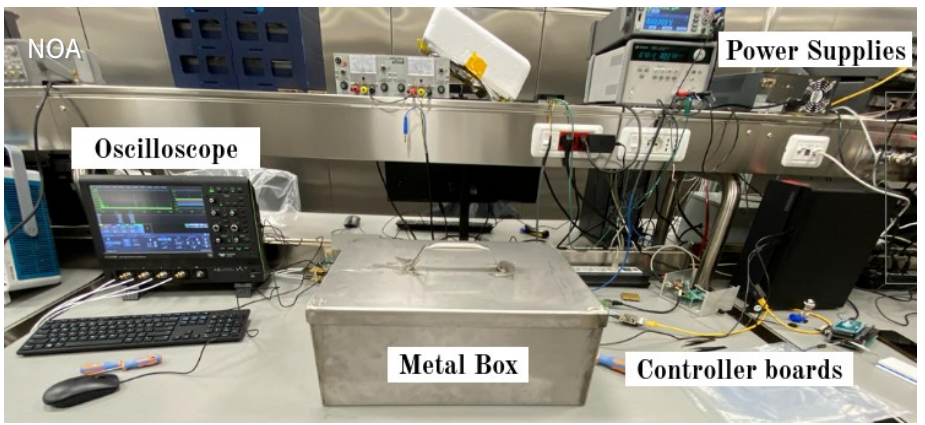
- Performed on each (v)PDU quadrant/tile
- Visual inspection and dust count
- IV curves
- Noise FFTs





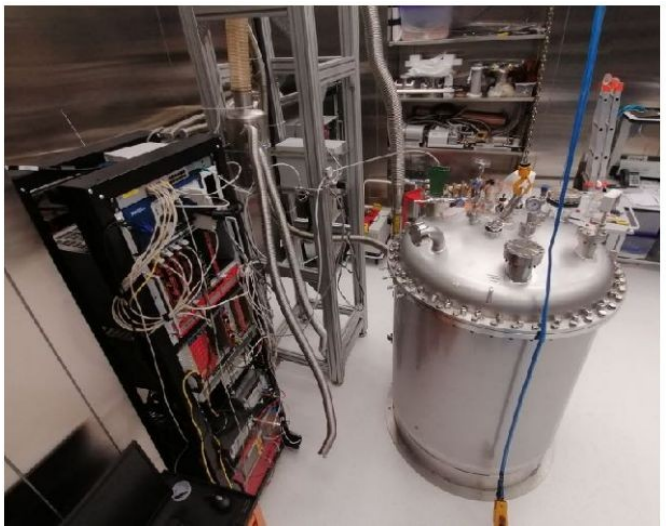


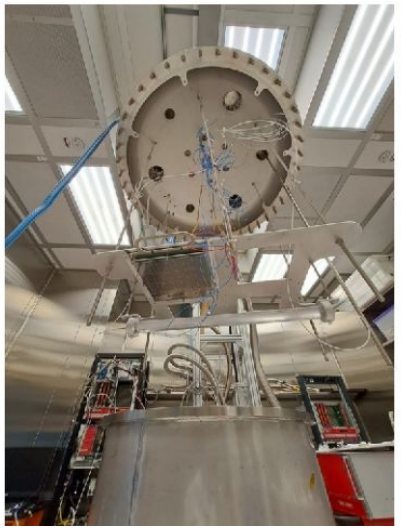




Cryogenic testing for PDUs

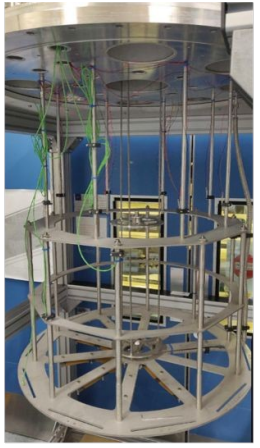
- PDU Testing Facility in INFN-Napoli (Italy)
- 16 PDUs capacity
- 2 CAEN VX2740 digitisers





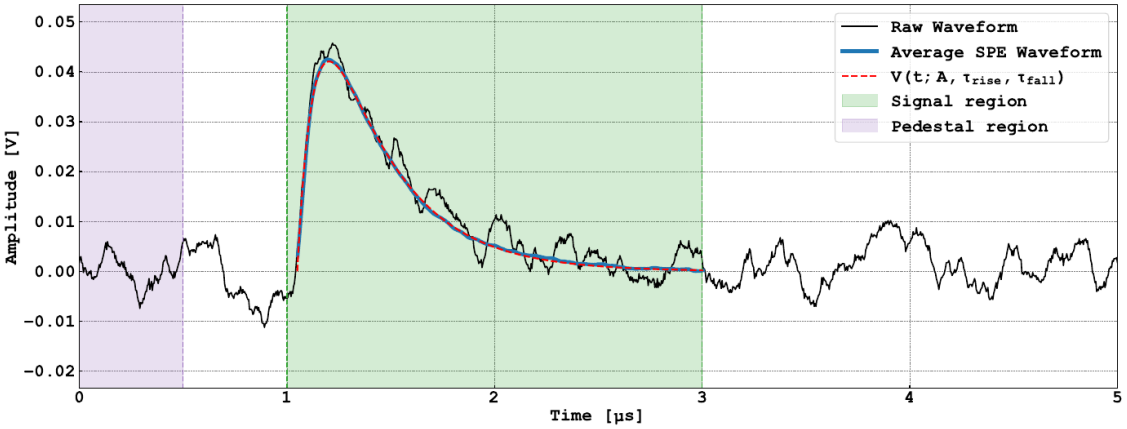
Cryogenic testing for vPDUs

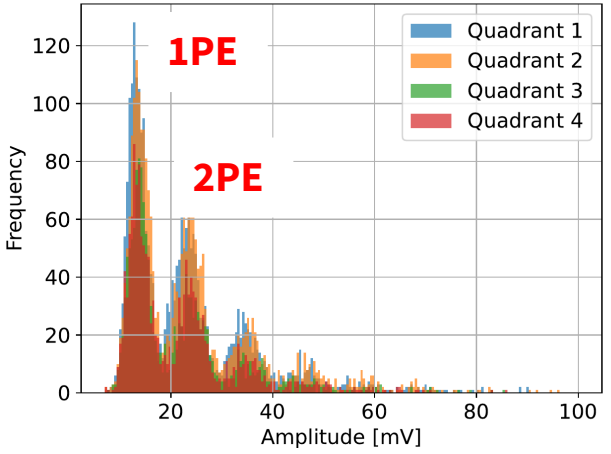
- Test facilities: Edinburgh, Liverpool and AstroCeNT (Poland)
- 30 vPDUs capacity in total
- Equivalent testing setups (PSUs, digitisers, DAQ)
- Tests in liquid nitrogen and argon



Laser calibration “at cold”

- Liquid nitrogen characterisations on
  - single tiles
  - integrated tiles
  - full quadrants
- Injected laser light
- Waveforms → peakfinder
- Baseline RMS
- Finger plots



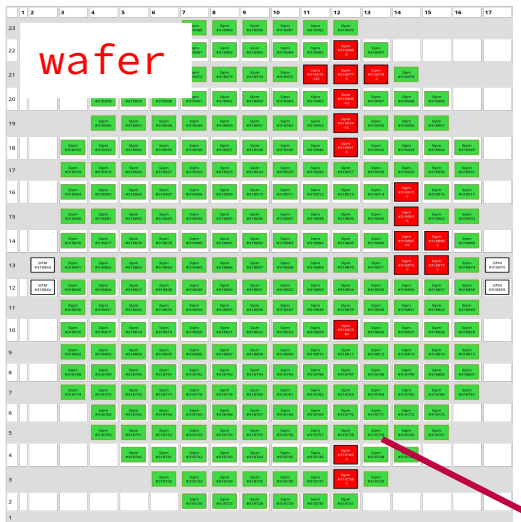


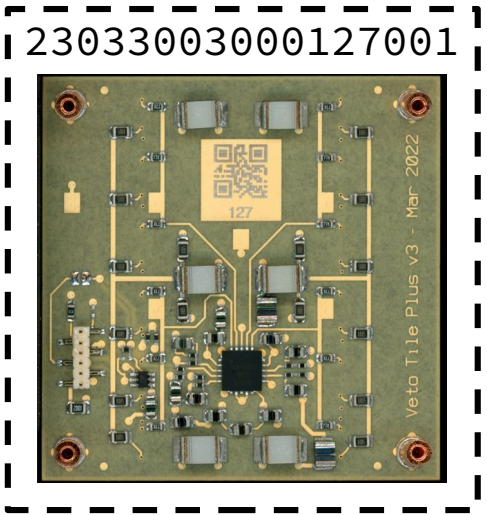
1 PE ~ 13 mV

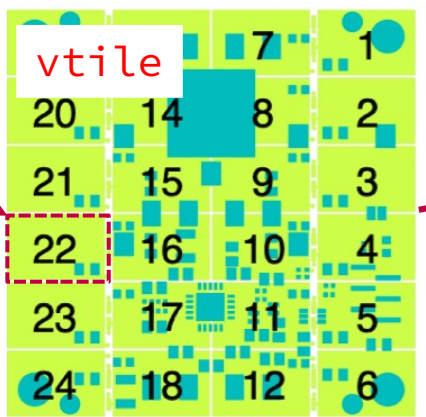
TPC: SNR > 6

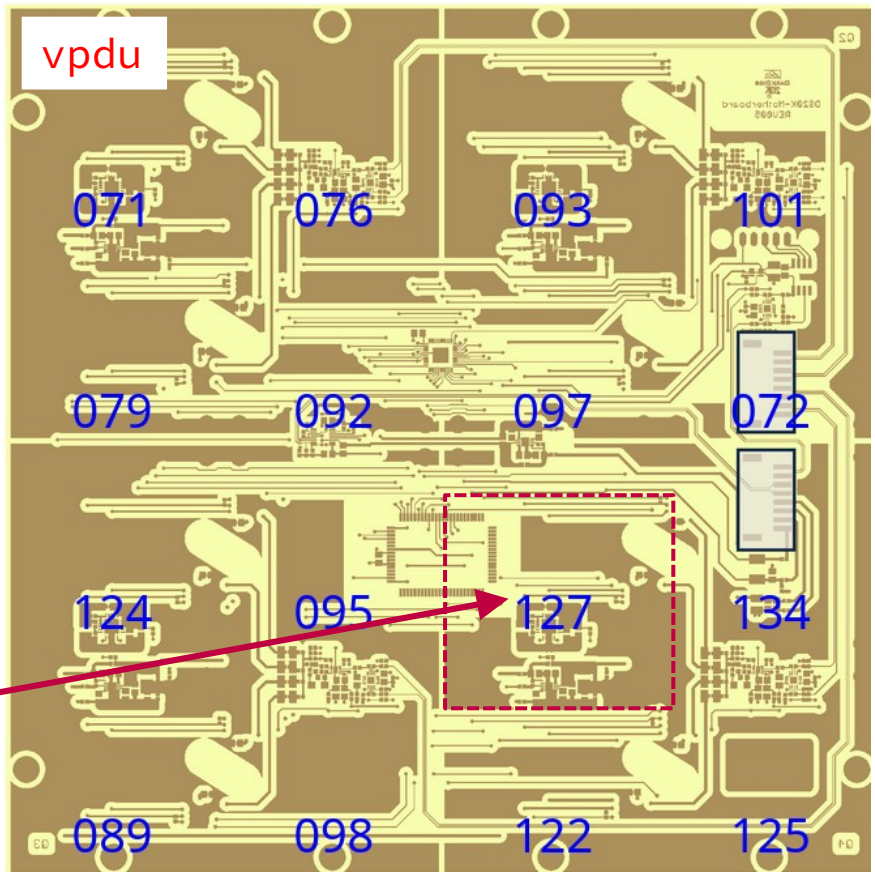
Veto: SNR > 4

Production Database



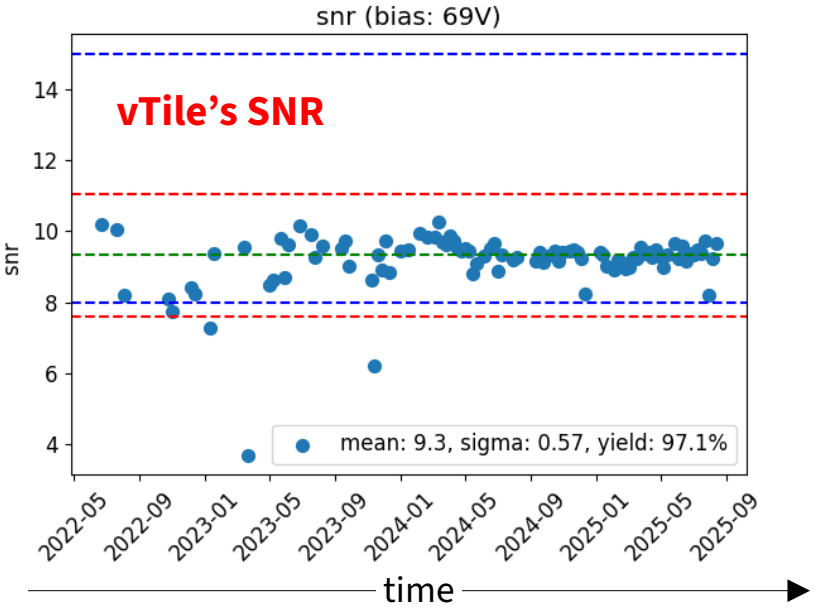






QA/QC for tiles and pdus

- Baseline analysis from all the test stands, e.g.
  - Breakdown, Signal-to-noise Ratio (SNR), Dark Count Rate, Correlated Delayed Avalanches, Mean After Pulsing, Direct Cross Talk Probability
- Assess the full production chain over time
  - maintain good production yield
  - spot production problems at an early stage
- Assign quality grades
  - uniform detector
  - single photo-electron resolution
- Identify tiles replacements



Conclusions and Outlook

- **Veto PDU production:** 100% completed ✅ - 50% tested 🚀
- **TPC PDU production:** 25% completed🚀 - 20% tested 🚀

- **Photoelectronics to be completed in 2026 and integrated in Q1 of 2027**
  … using a (co)robot arm…

Thanks! Questions?