Production of the DarkSide-20k photo-detectors

G. Rogers

University of Birmingham

On behalf of the DarkSide-20k collaboration

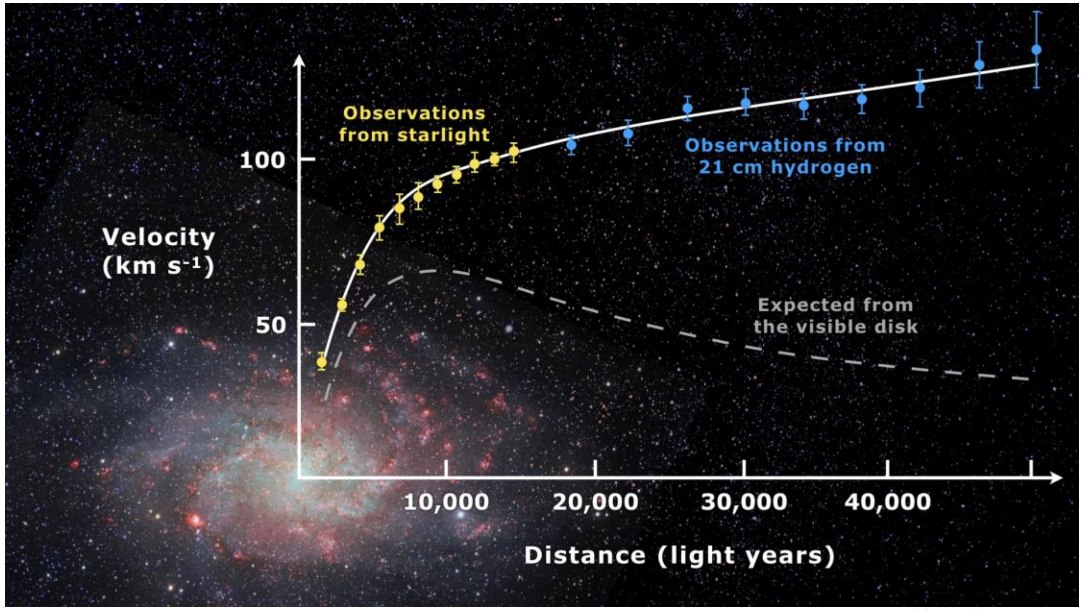
16th Pisa Meeting on Advanced Detectors

30/05/2024

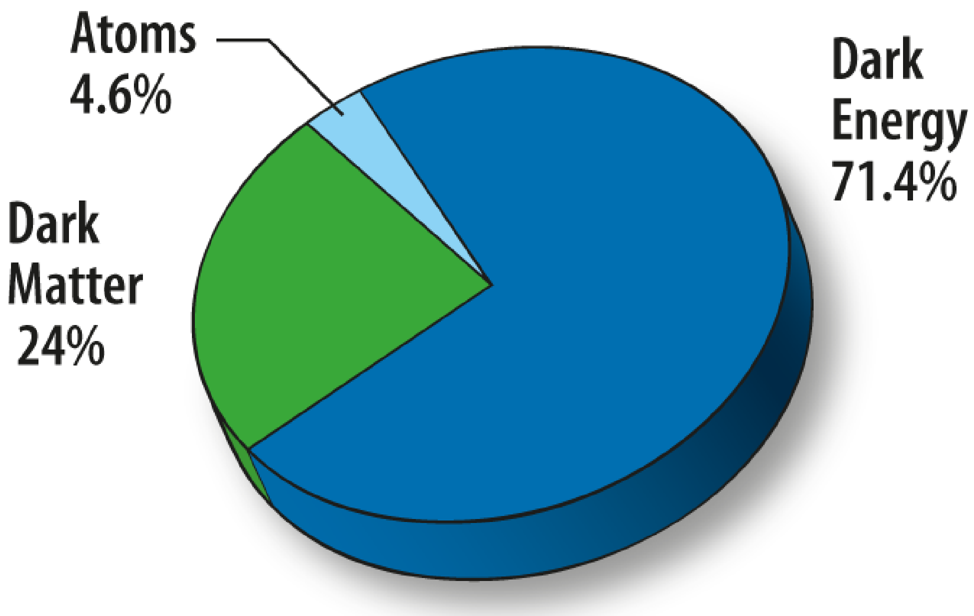
Image of LNGS

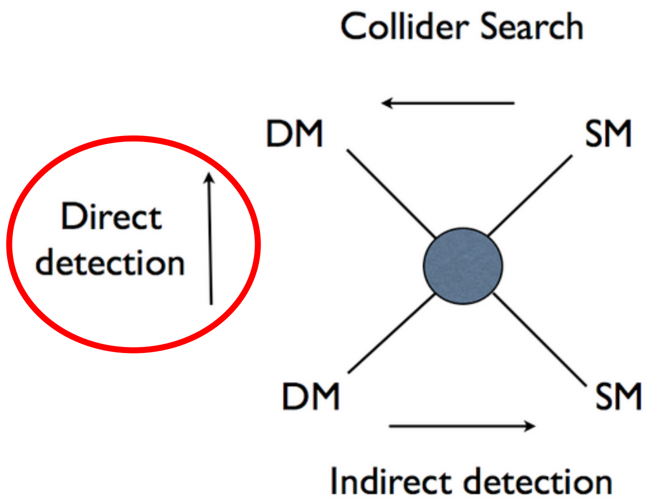
Evidence for Dark Matter

- Dark matter observed from its gravitational influence, including
  - Rotational curves
  - Gravitational lensing
  - CMBR
- The nature of dark matter is still unknown
- The **WIMP** is a promising dark matter candidate



Wiki - Mario De Leo

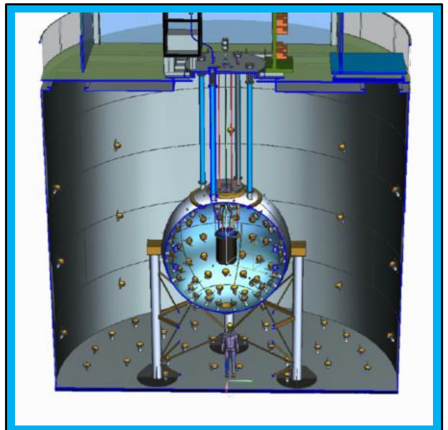




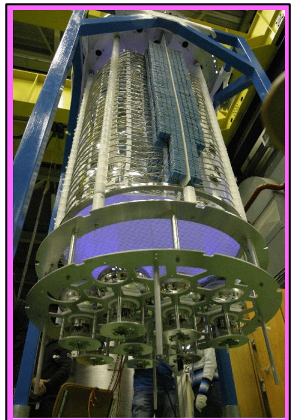
The Global Argon Dark Matter Collaboration

MiniCLEAN: SNOLAB

June 2023 DarkSide-20k collaboration meeting - LNGS



DarkSide-50: LNGS



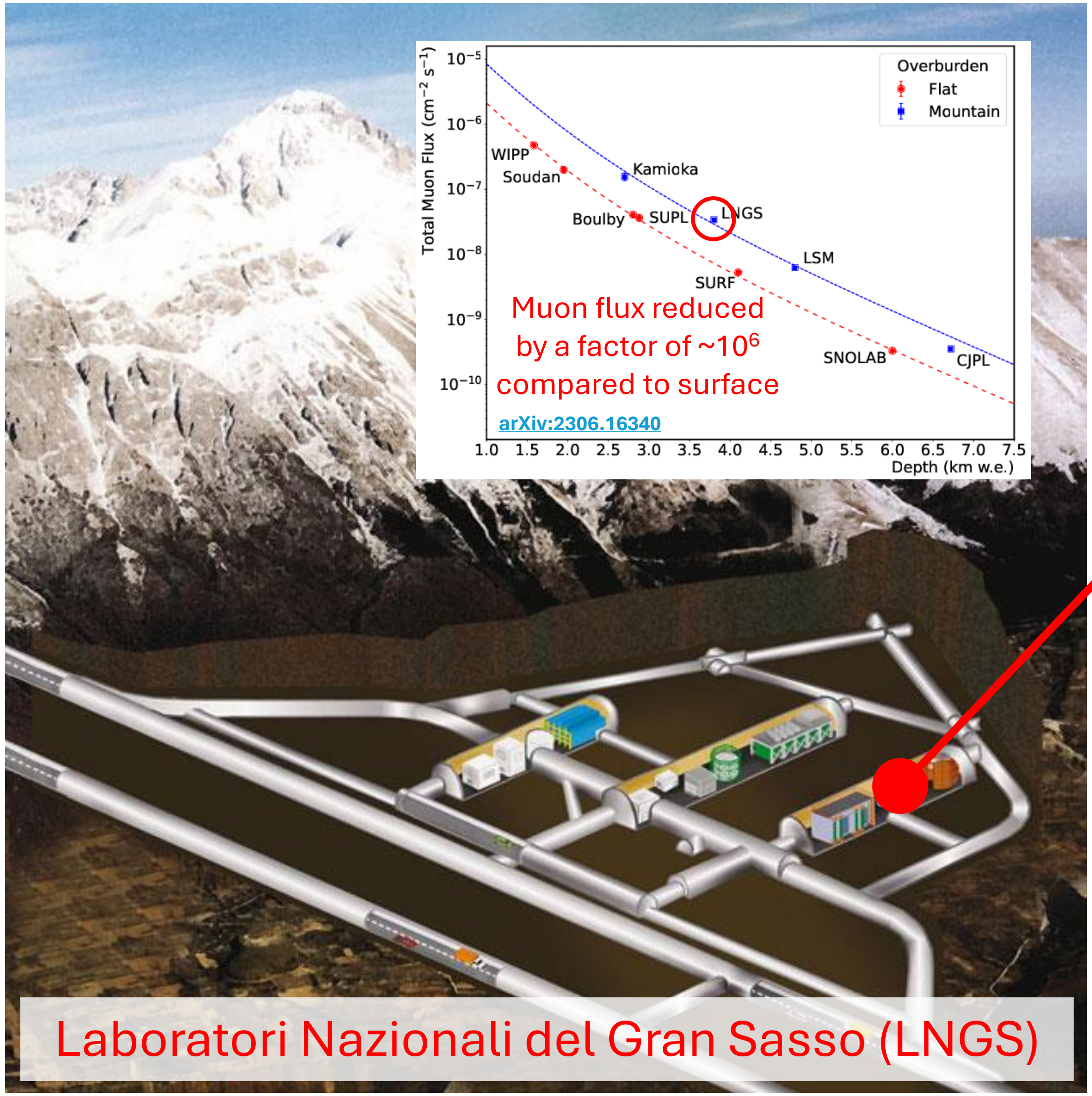
ArDM: Canfranc

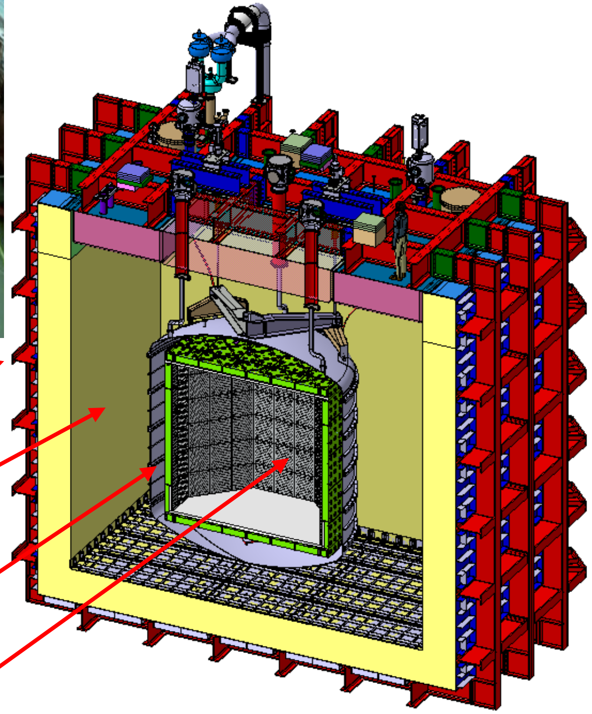
- Combined expertise from four LAr experiments
- Over 400 collaborators from over 100 institutions worldwide

Immediate goal: DarkSide-20k

DEAP-3600: SNOLAB

DarkSide-20k





Membrane ProtoDUNE-like cryostat

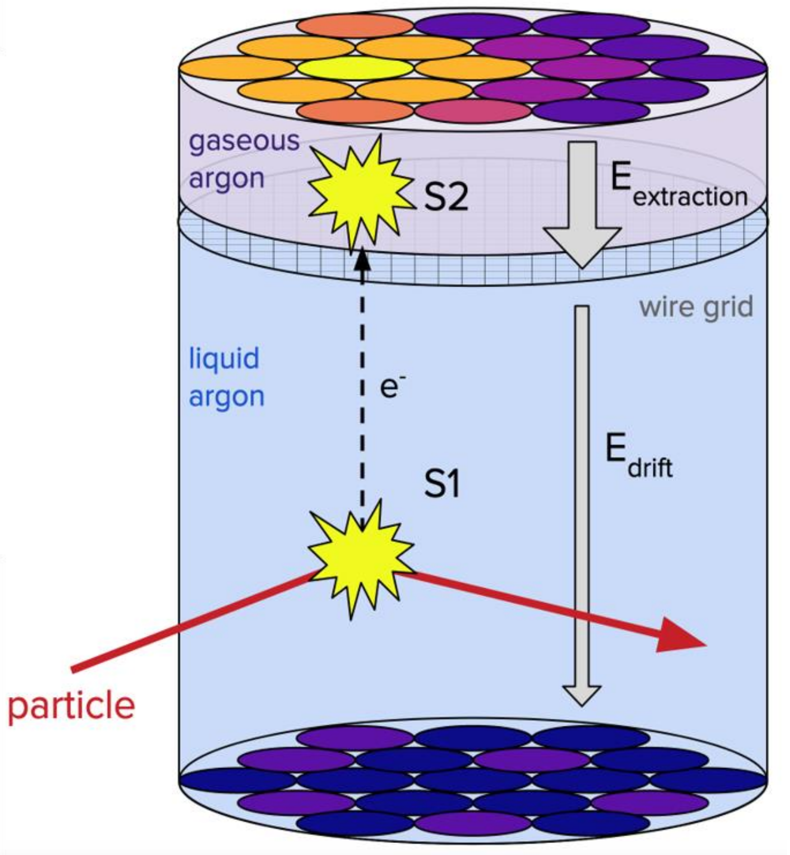
700t atmospheric argon muon veto

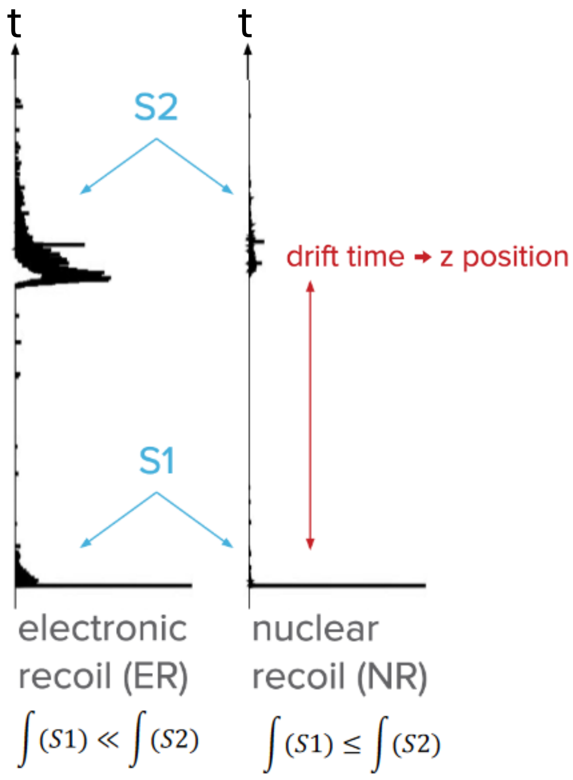
35t underground argon (UAr) neutron veto

50t UAr dual-phase TPC

Operations expected to start in late 2026

Dual-phase Argon TPC





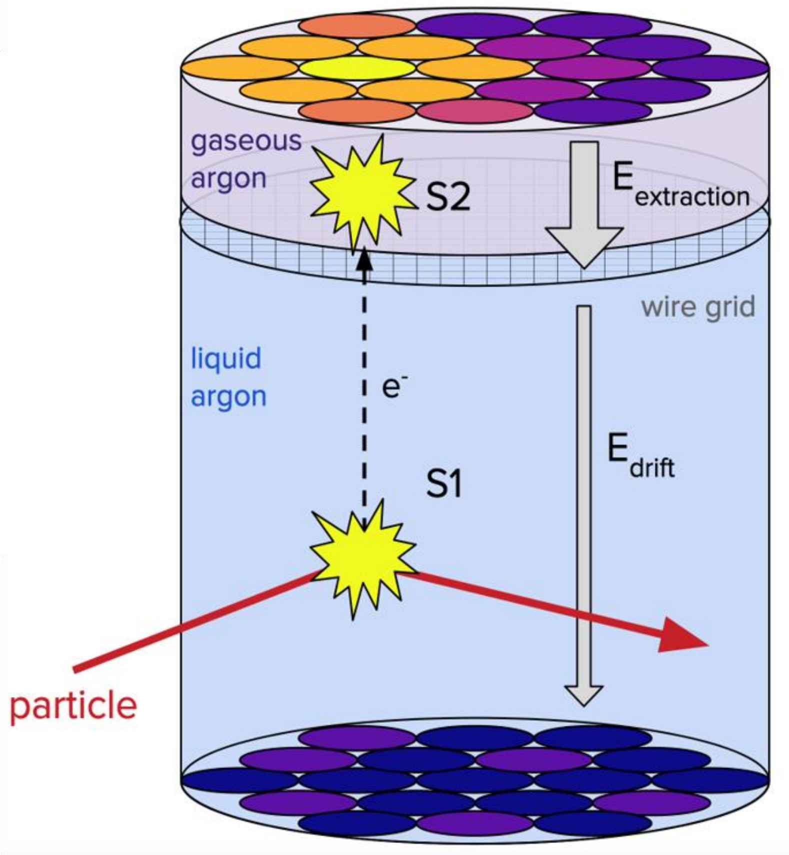
S1: Prompt scintillation

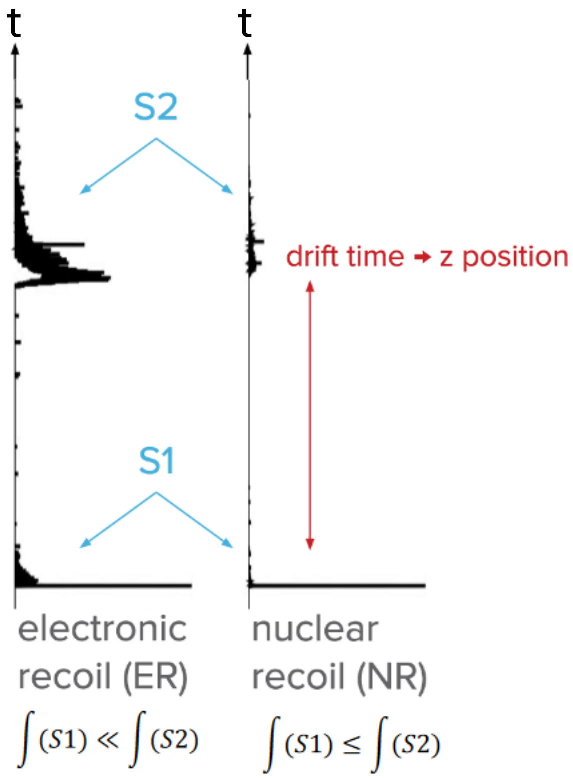
S2: Ionization (position reconstruction)

Why argon?

- Easy to purify
- Transparent to own scintillation
- Scalable
- High ionization, good scintillator
- Strong ER discrimination via pulse shape

Dual-phase Argon TPC

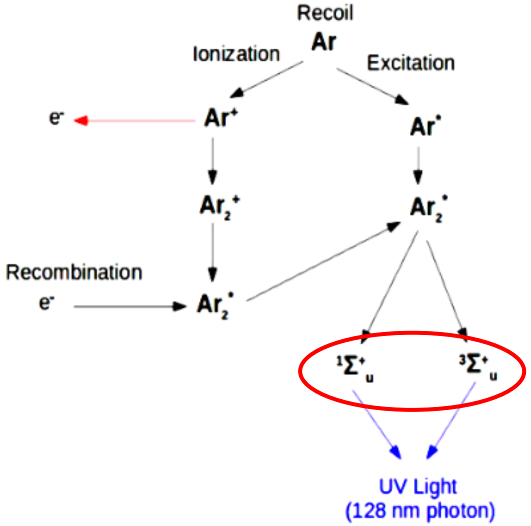




S1: Prompt scintillation

S2: Ionization (position reconstruction)

ER/NR discrimination



ER/NR different ionisation densities

↓

Different excitation fraction of singlet/triplet states

↓

Decay time: single (~7 ns), triplet (~1.5 μs)

↓

Use fraction of prompt light to discriminate between ER/NR

Why argon?

- Easy to purify
- Transparent to own scintillation
- Scalable
- High ionization, good scintillator
- Strong ER discrimination via pulse shape

Dual-phase Argon TPC

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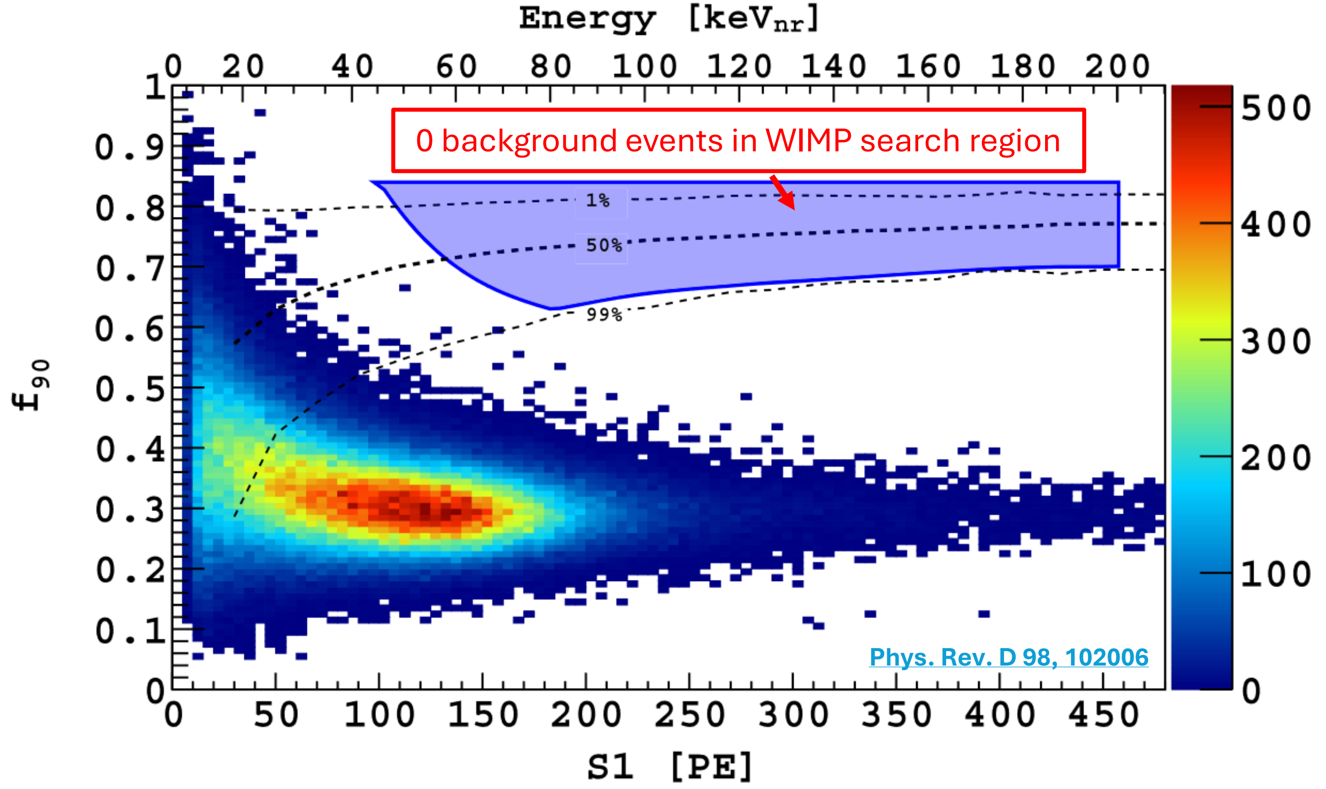
ER rejection power demonstrated by DarkSide-50



ER rejection of 2.4 x 10^8 for 44-89 keV$_{ee}$ energy range

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s

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Why

- Easy
- Tran
- Scal
- High
- Strong ER discrimination via pulse shape

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Background Mitigation

Goal: To be instrumentally background-free over 200 t·yr exposure

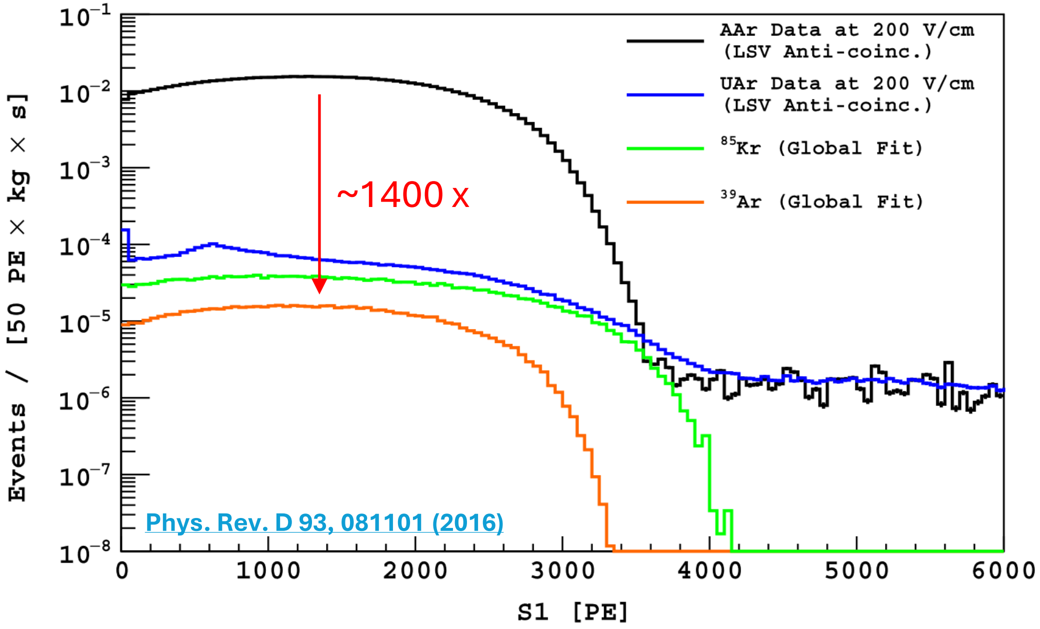
Primary sources of background

- Electron Recoils
- Nuclear Recoils

Material Selection & Assay

- Strict material selection
- Extensive material assay campaign
- Assay facilities at institutions worldwide

Underground Argon

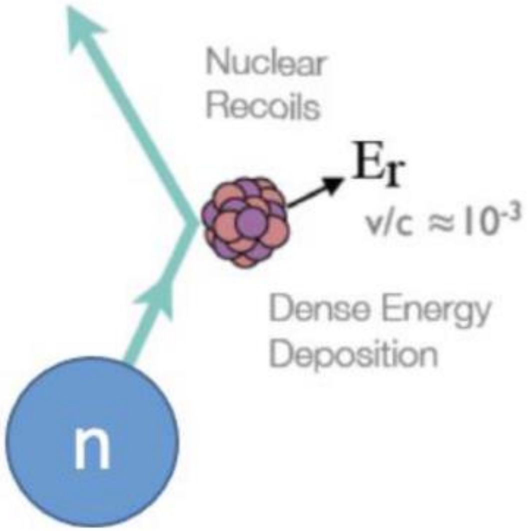


- ^{39}Ar is a radioactive isotope found in AAr
- UAr extracted from CO_2 well in Colorado
- Purified in dedicated distillation column in Sardinia
- DArT in Canfranc measures ^{39}Ar depletion factor

^{39}Ar depletion factor: ~1400x

Background Mitigation: Nuclear Recoil

Goal: To be instrumentally background-free over 200 t·yr exposure



Background Mitigation: Nuclear Recoil

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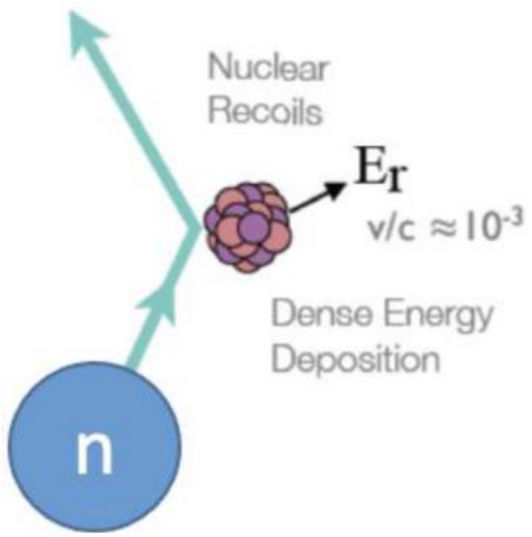
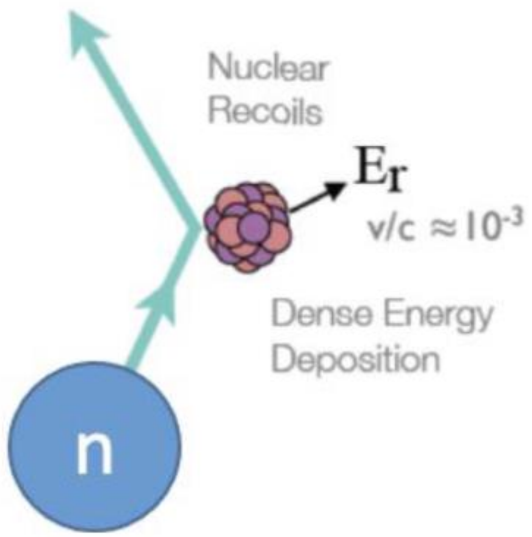


Indistinguishable from WIMP

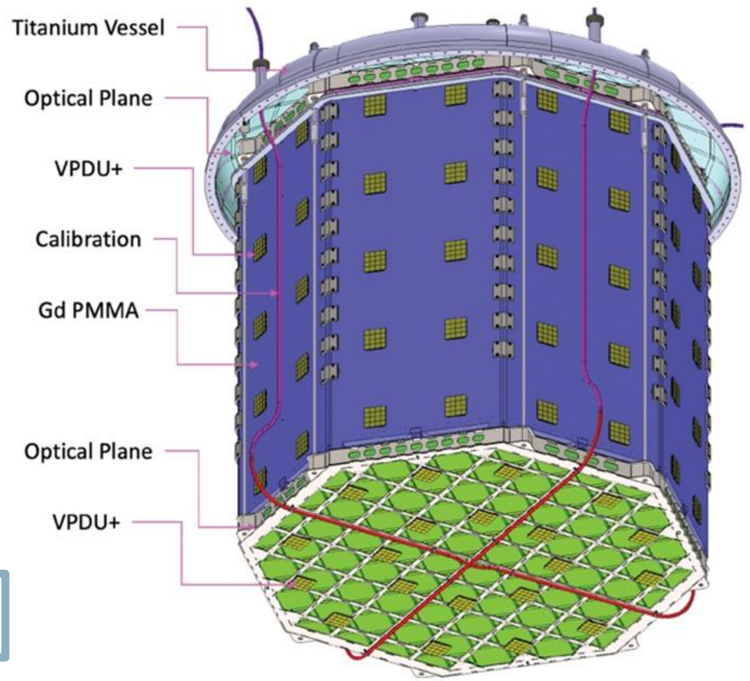
Background Mitigation: Nuclear Recoil

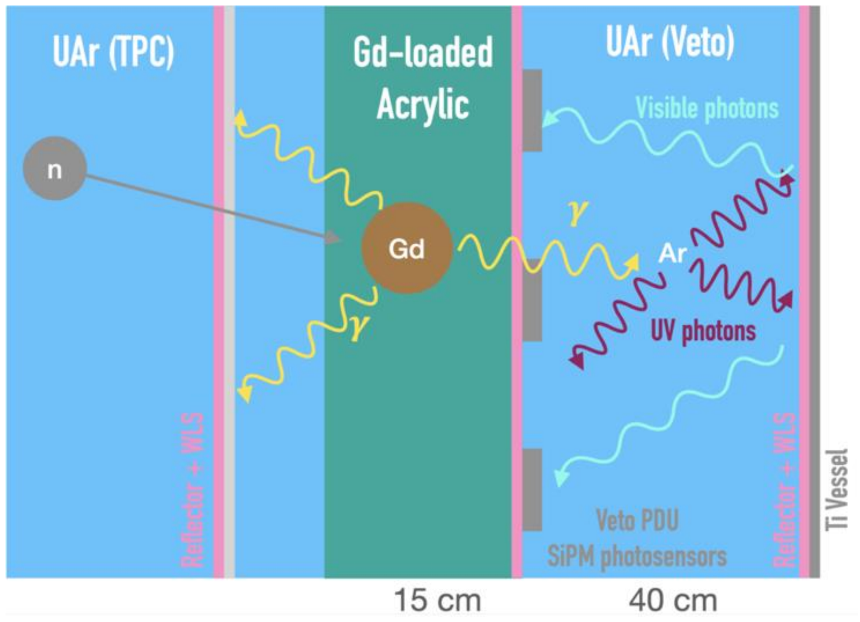
Goal: To be instrumentally background-free over 200 t·yr exposure



Indistinguishable from WIMP

Neutron Veto

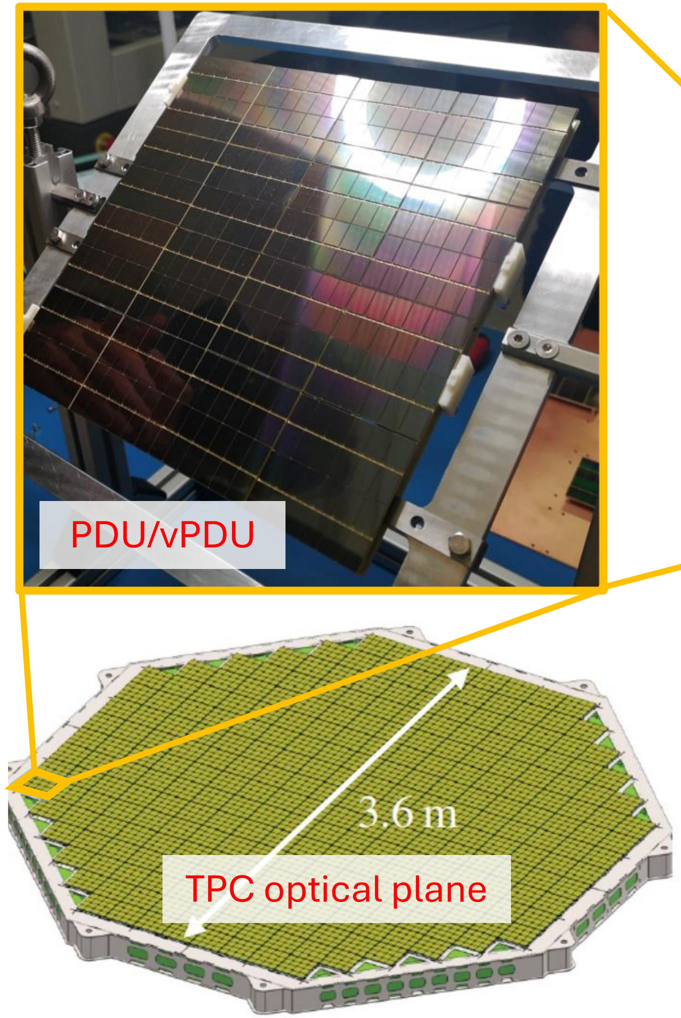




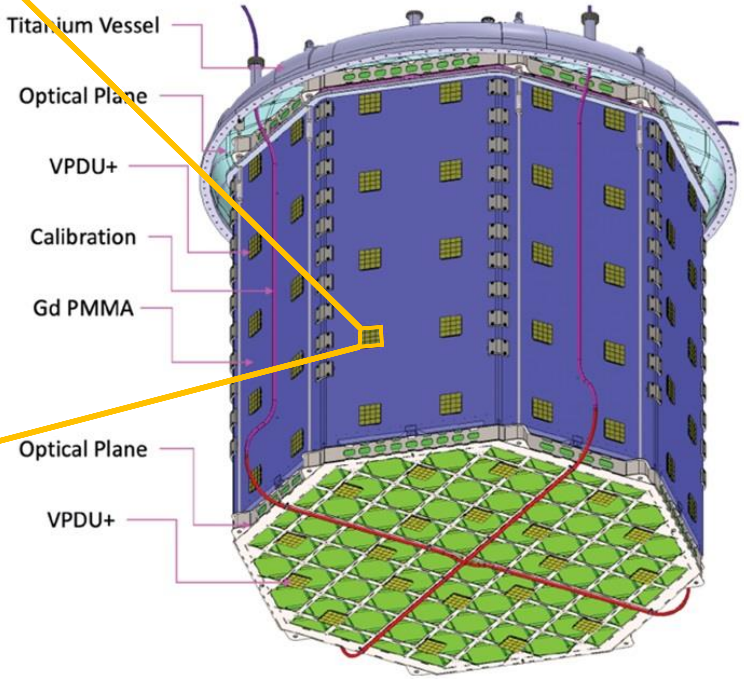
Neutrons tagged by coincidence detection in TPC and veto

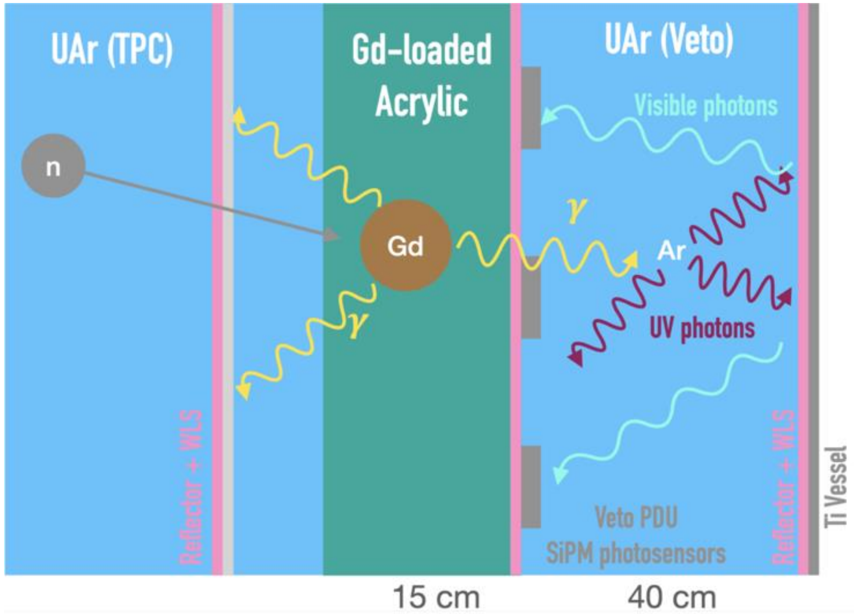
Background Mitigation: Nuclear Recoil

Goal: To be instrumentally background-free over 200 t·yr exposure



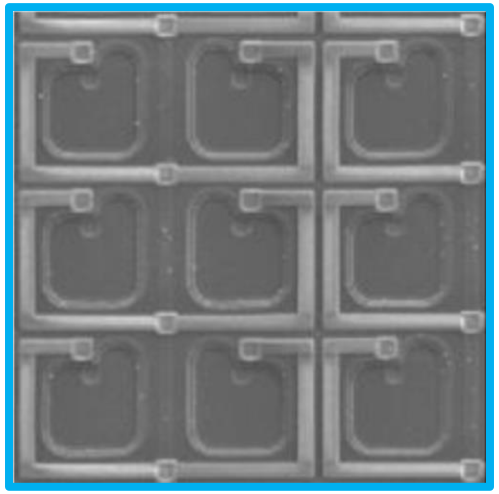
Neutron Veto





Neutrons tagged by coincidence detection in TPC and veto

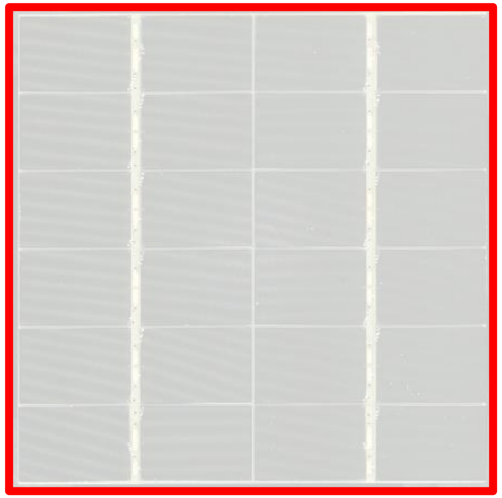
Large area SiPM photo-detectors



Single Photon Avalanche Diode (SPAD): 25 μm^2

SiPM: 1 cm^2

x24



Tile/vTile: 5x5 cm^2

x16

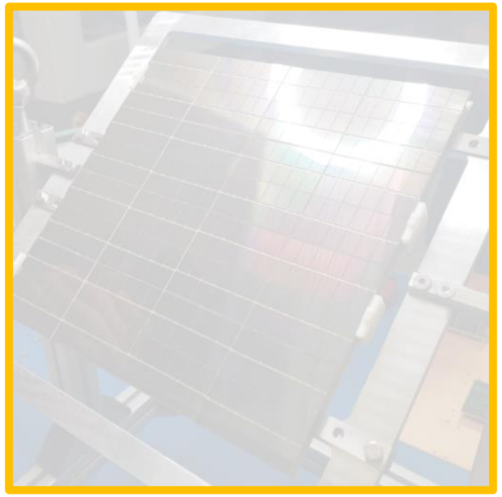
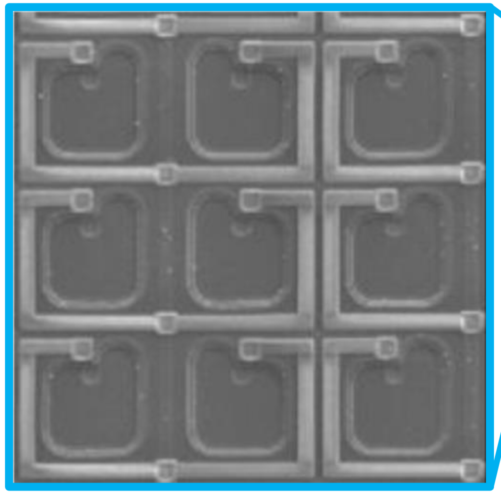


Photo Detection Unit (PDU/vPDU): 20x20 cm^2

SPAD

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

Large area SiPM photo-detectors



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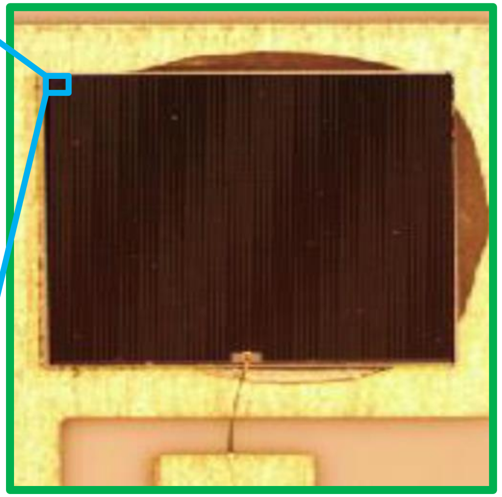

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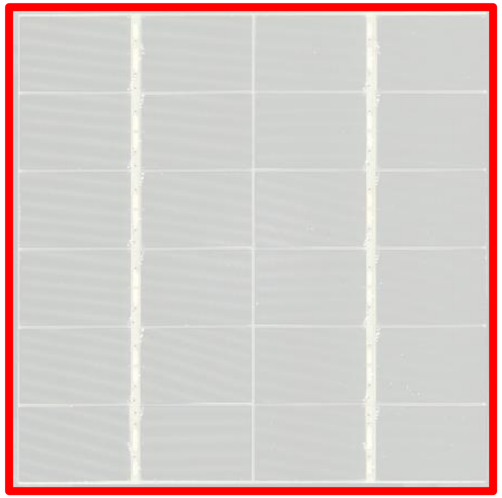

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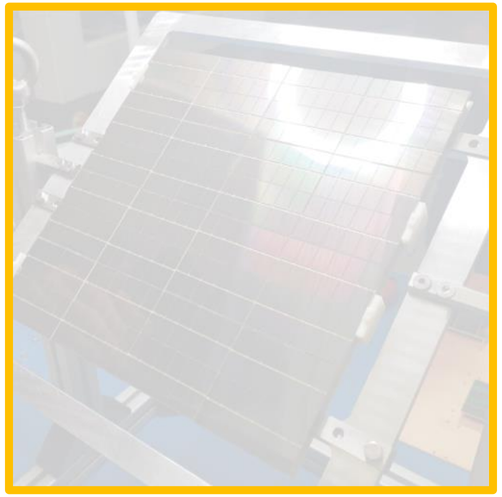
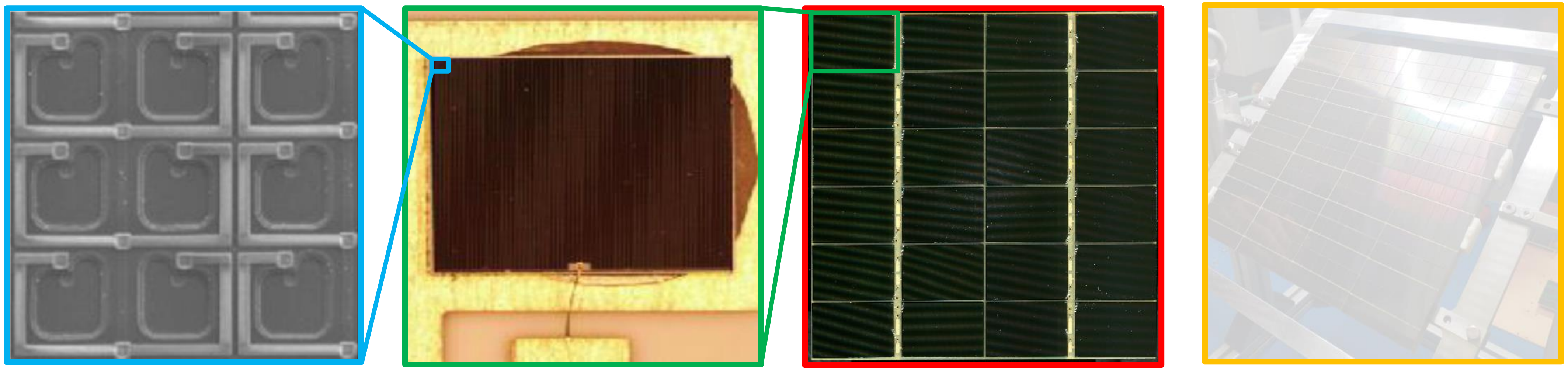


Photo Detection Unit (PDU/vPDU): 20x20 cm^2

SiPM

- Designed in collaboration with Fondazione Bruno Kessler (FBK)
- ~94,900 SPAD's/SiPM
- Used in TPC and Veto
- Cryogenically stable
- Low voltage operation
- Low material budget
- Good single photon resolution

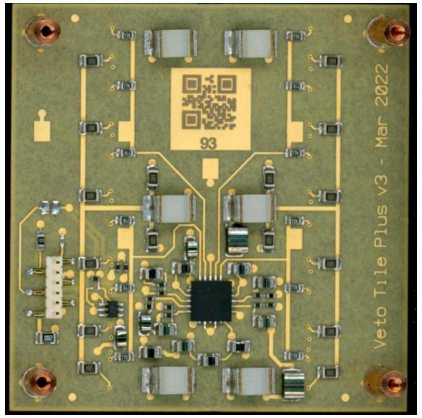
Large area SiPM photo-detectors



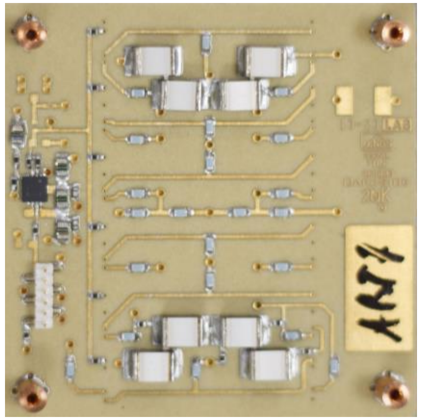
Single Photon Avalanche Diode (SPAD): 25 μm^2 | SiPM: 1 cm^2 | x24 | Tile/vTile: 5x5 cm^2 | x16 | Photo Detection Unit (PDU/vPDU): 20x20 cm^2

Tile and veto Tile (vTile)

- 24 SiPMs mounted on Arlon 55N substrate with readout electronics on the backside
- TPC and veto have different electronics and SiPM summing scheme

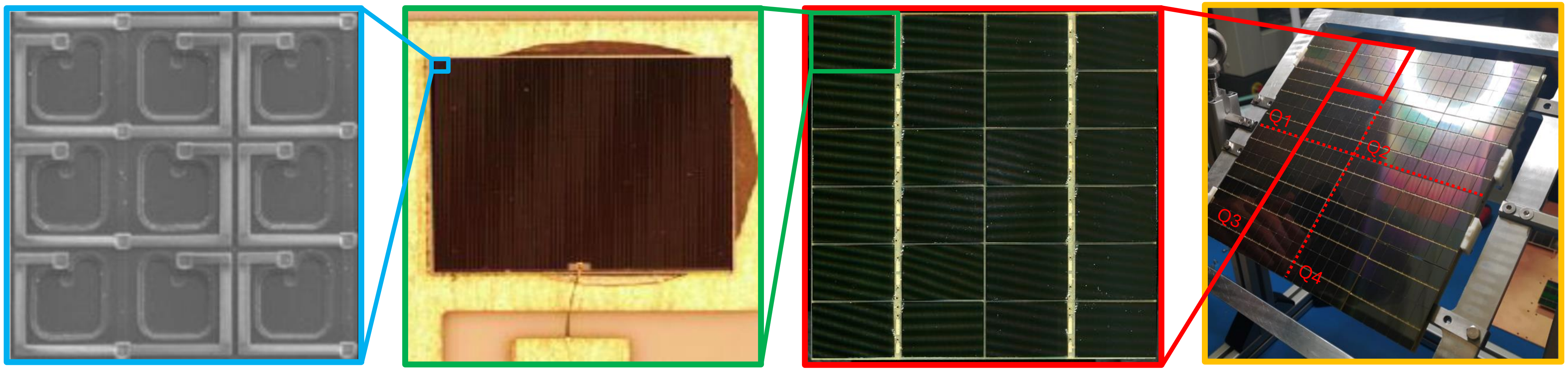


vTile backside



TPC Tile backside

Large area SiPM photo-detectors

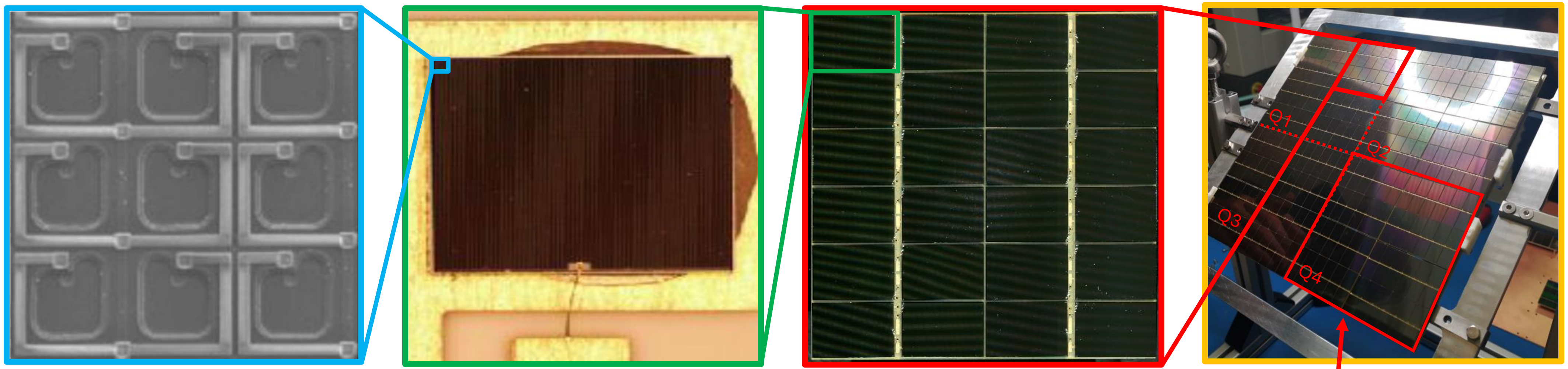


Single Photon Avalanche Diode (SPAD): 25 μm^2 | SiPM: 1 cm^2 | x24 | Tile/vTile: 5x5 cm^2 | x16 | Photo Detection Unit (PDU/vPDU): 20x20 cm^2

PDU and veto PDU (vPDU)

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

Large area SiPM photo-detectors



Single Photon Avalanche Diode (SPAD): 25 μm^2

SiPM: 1 cm^2

x24

Tile/vTile: 5x5 cm^2

x16

Photo Detection Unit (PDU/vPDU): 20x20 cm^2

PDU and veto PDU (vPDU)

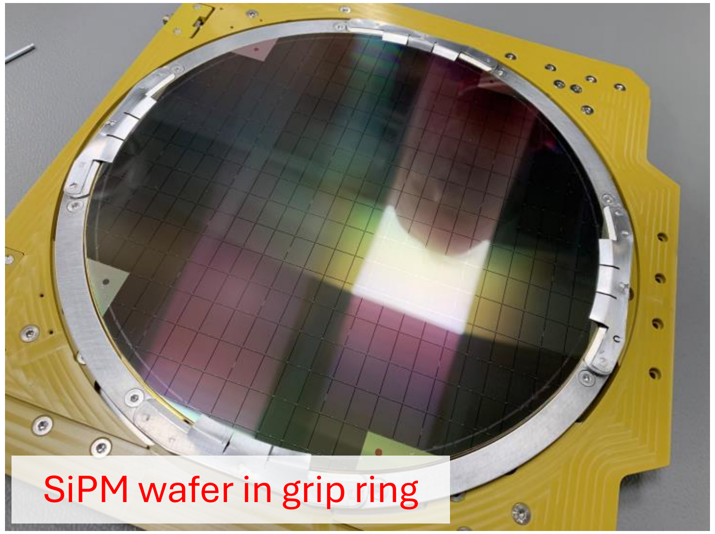
- 16 Tiles assembled onto Arlon 55N motherboard (MB)
- Provides signal and power to the tiles
- Summed into quadrants: 4 readout channels/PDU
- Low power consumption

Largest single read-out SiPM array!

Cryoprobe at NOA

Nuova Officina Assergi (NOA)

- ISO 6 clean room at LNGS
- SiPM wafer characterisation
- Location of TPC PDU production
- Rn monitoring: 6-10 Bq/m^3

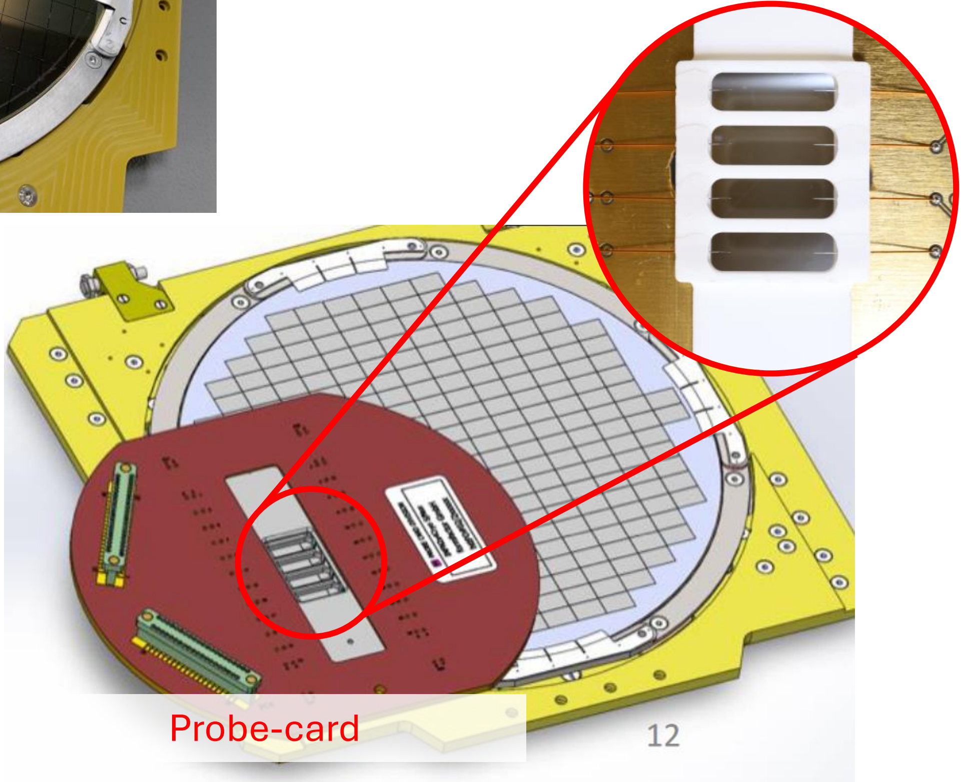


SiPM wafer in grip ring

- 200 mm diameter
- 550 μm thick
- 264 SiPMs

Cryoprobe at NOA

- Characterising SiPMs at cryogenic temperature



Probe-card

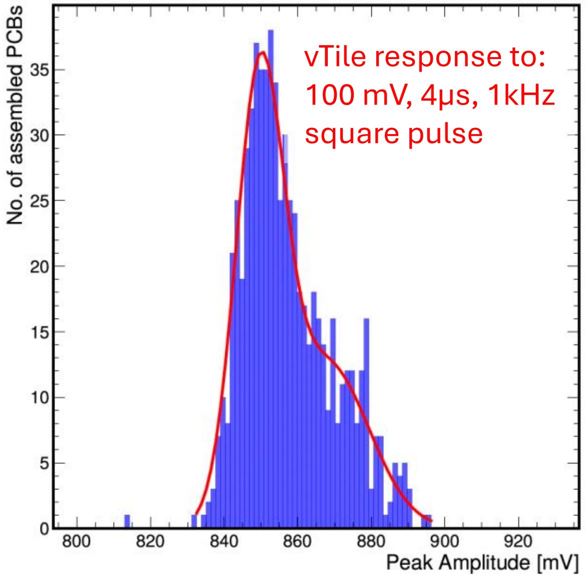
- 2x4 needles for anode contact

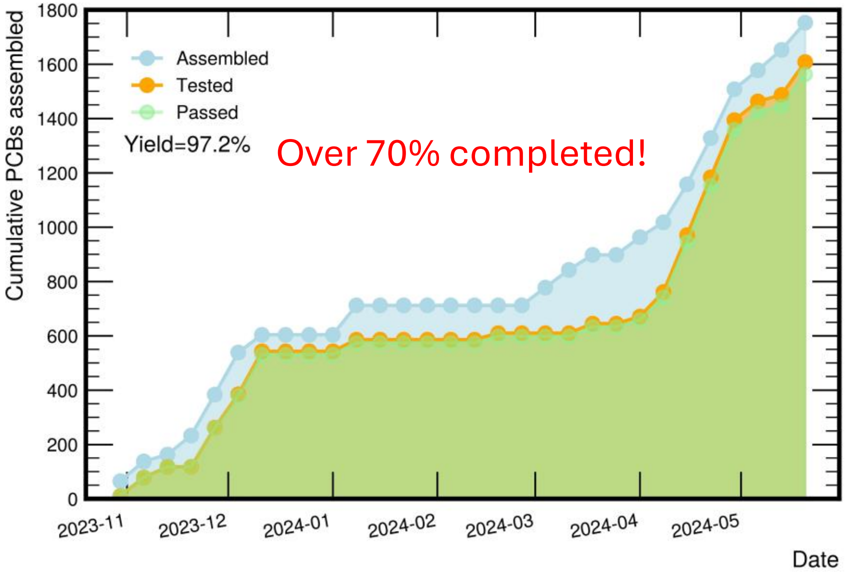
Veto photo-detector production – Stage 1

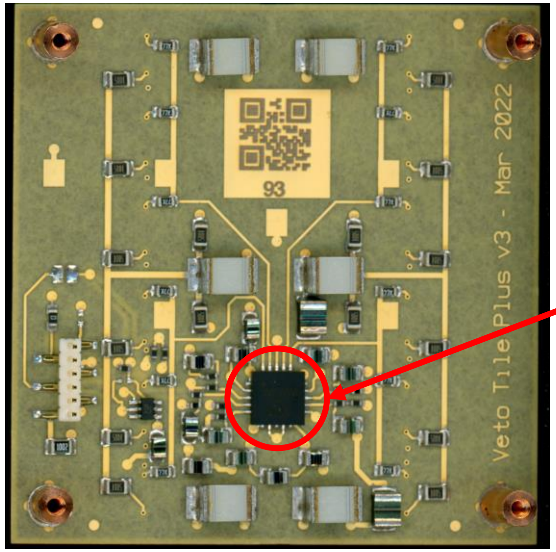
Readout electronics population: University of Birmingham

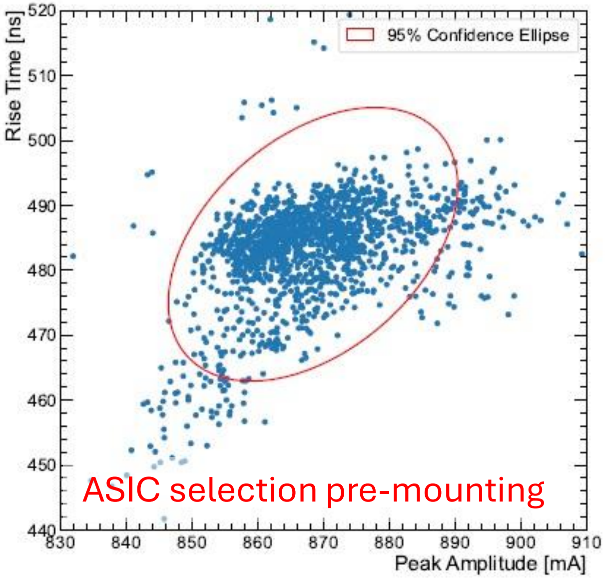
Quality control criteria

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







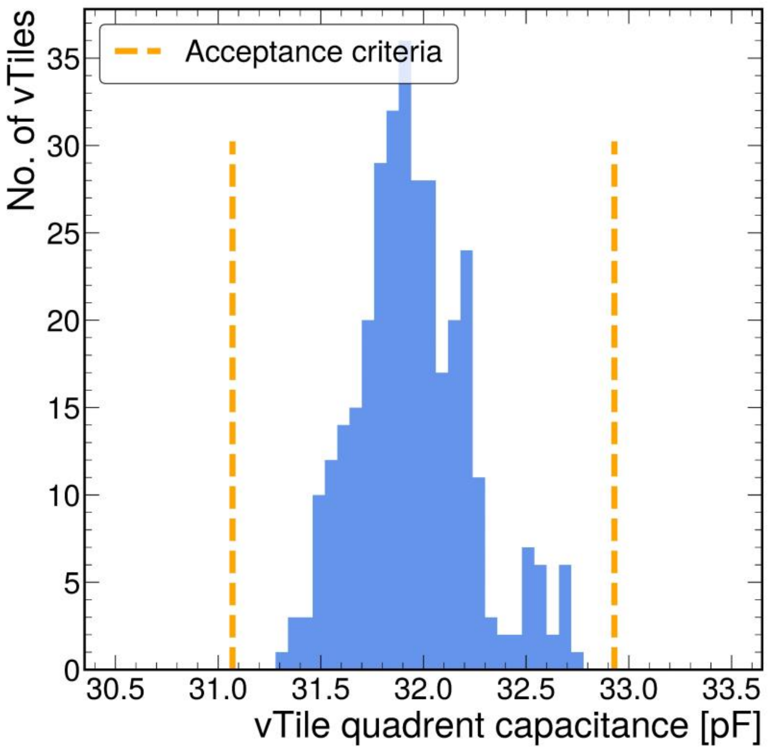


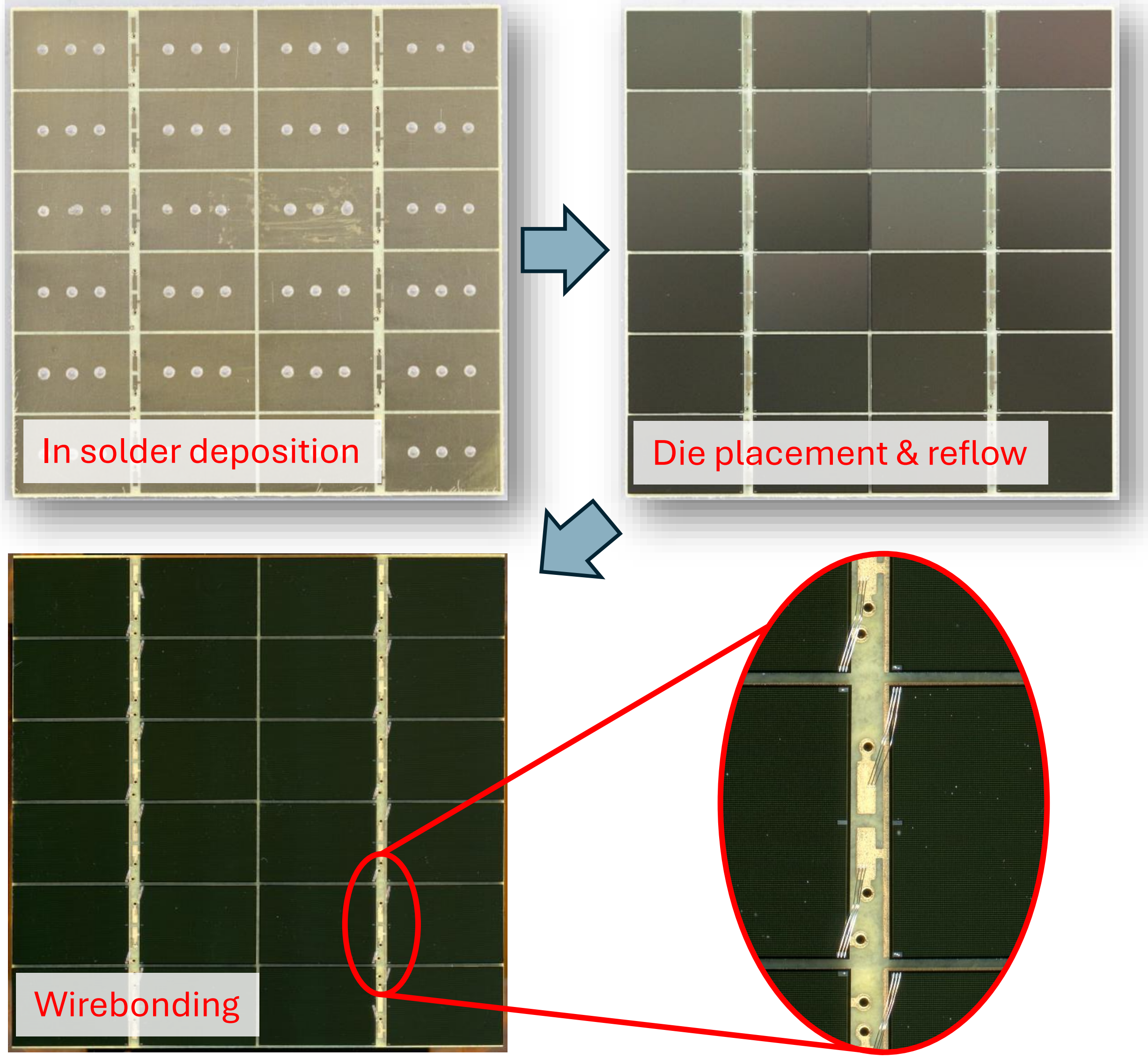
Veto photo-detector production – Stage 2

SiPM die attach and wirebond: University of Liverpool and STFC interconnect

Quality control criteria

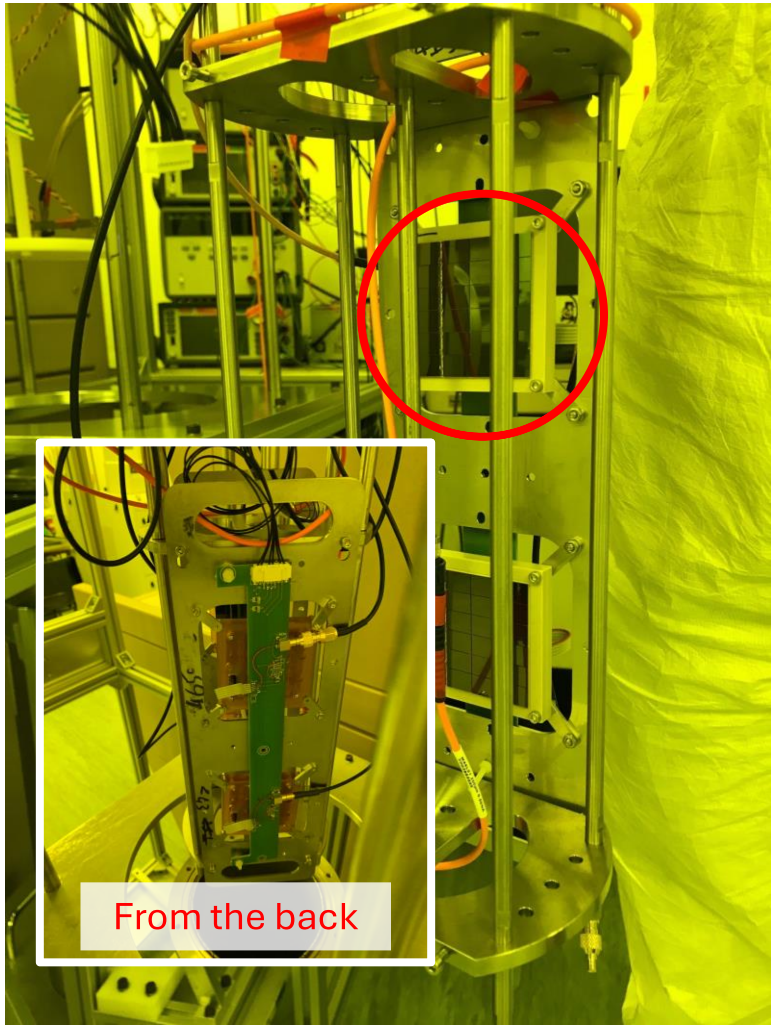
- Visual inspection of SiPM die
- Nominal quadrant capacitance and resistance
- Visual inspection of vTile

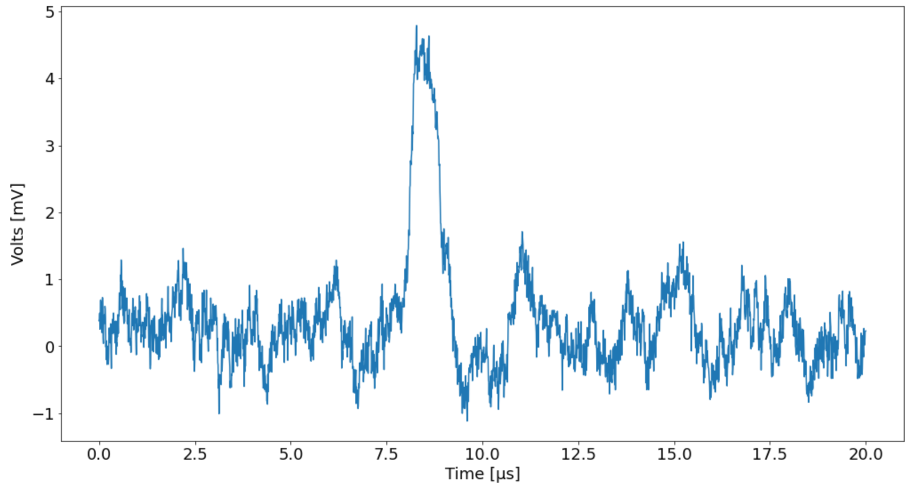


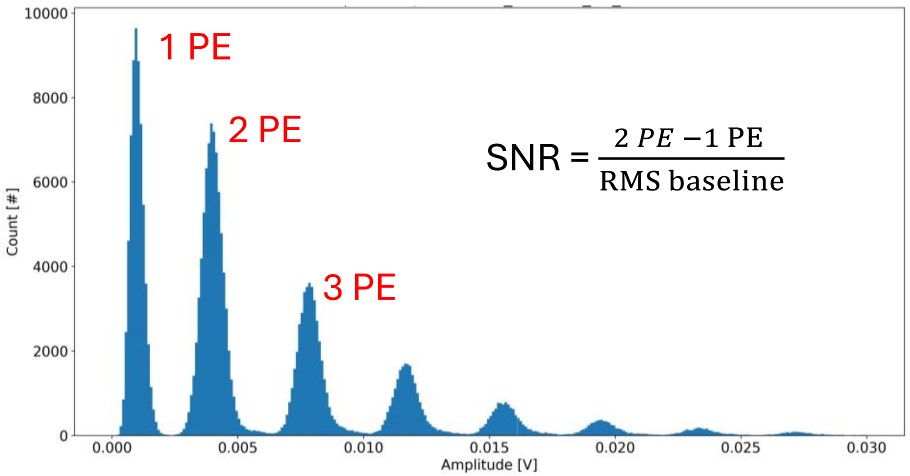


Veto photo-detector production – Stage 3

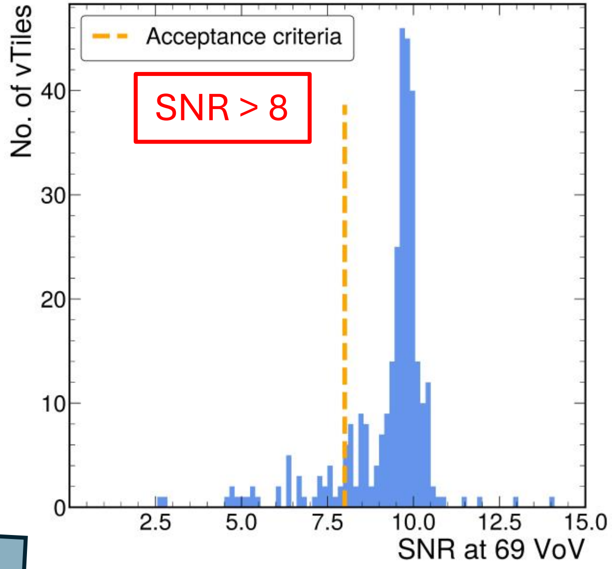
Single vTile testing – University of Oxford and STFC interconnect







$$\text{SNR} = \frac{2\,PE - 1\,\text{PE}}{\text{RMS baseline}}$$

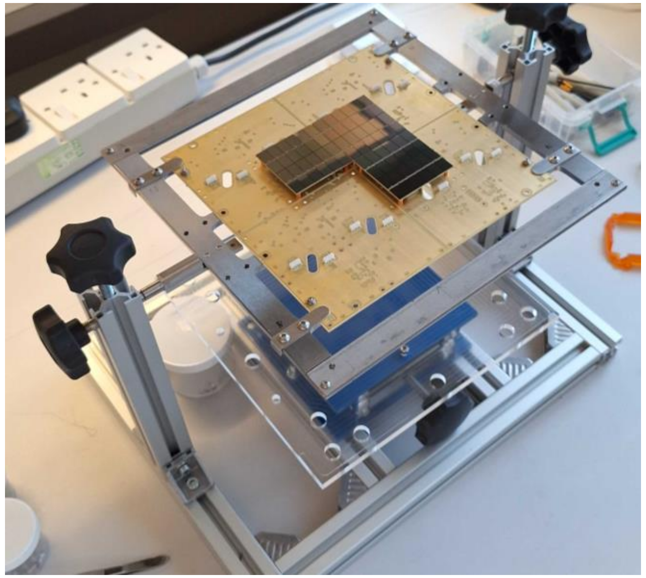


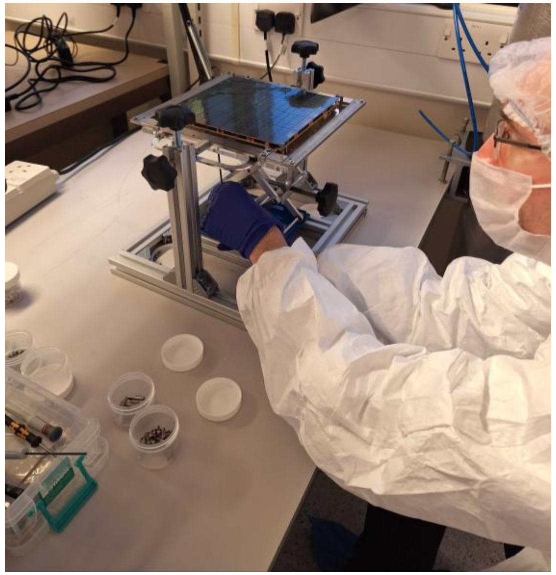
Quality control criteria

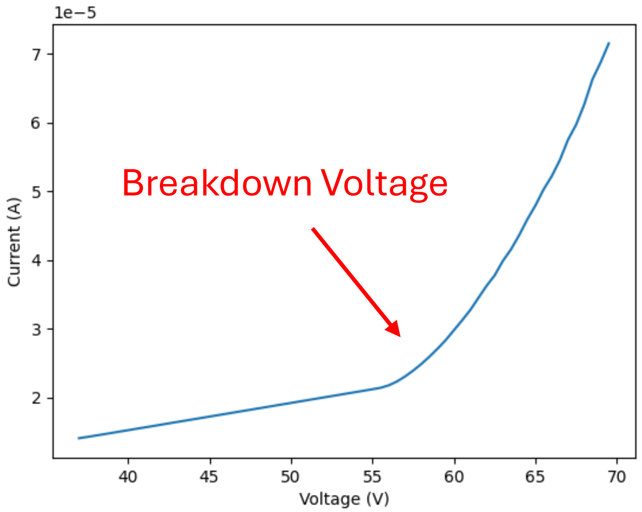
- SNR > 8
- Distinct PE spectrum
- Nominal breakdown voltage ~ 55V

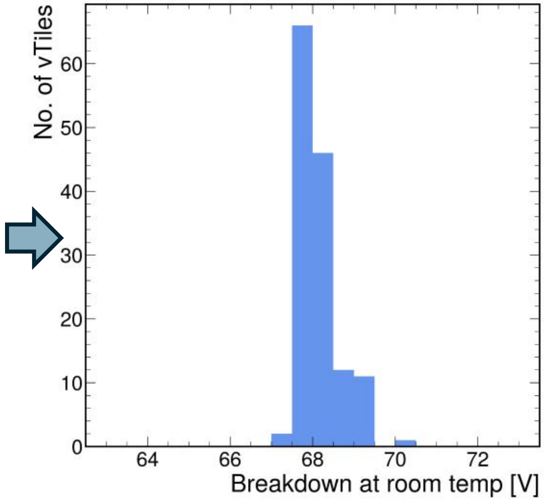
Veto photo-detector production – Stage 4

vPDU assembly and warm test – University of Manchester and University of Warwick



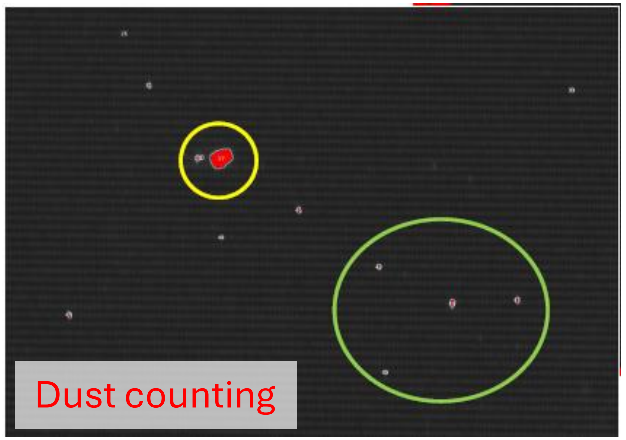






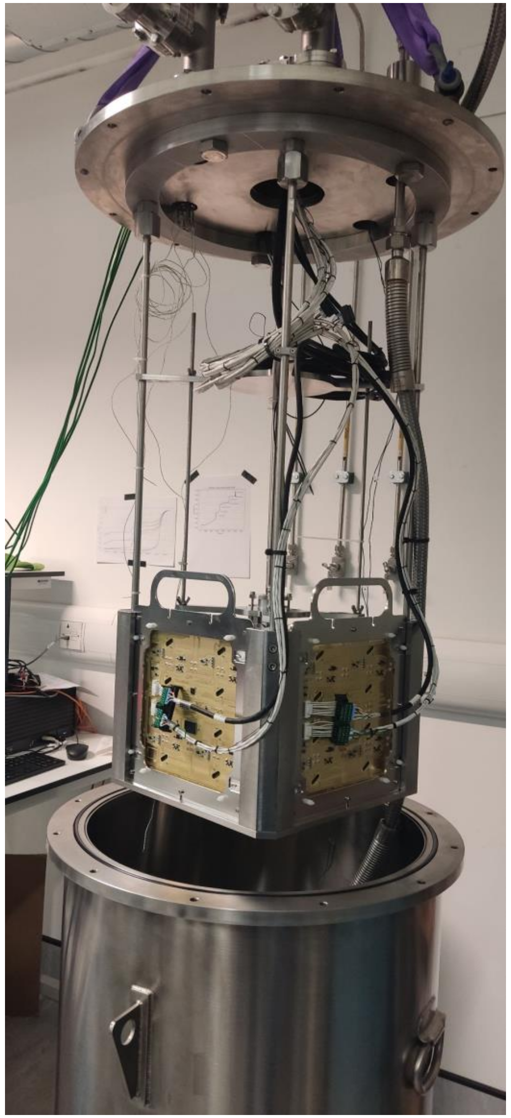
Quality control criteria

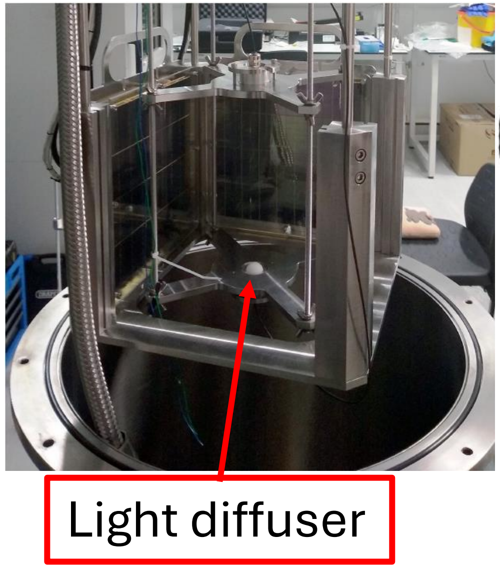
- Visual inspection
- Automated dust counting
- Electrical characterisation at room temperature

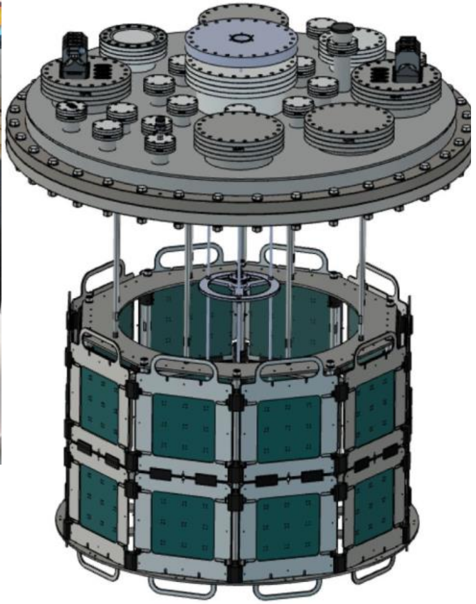


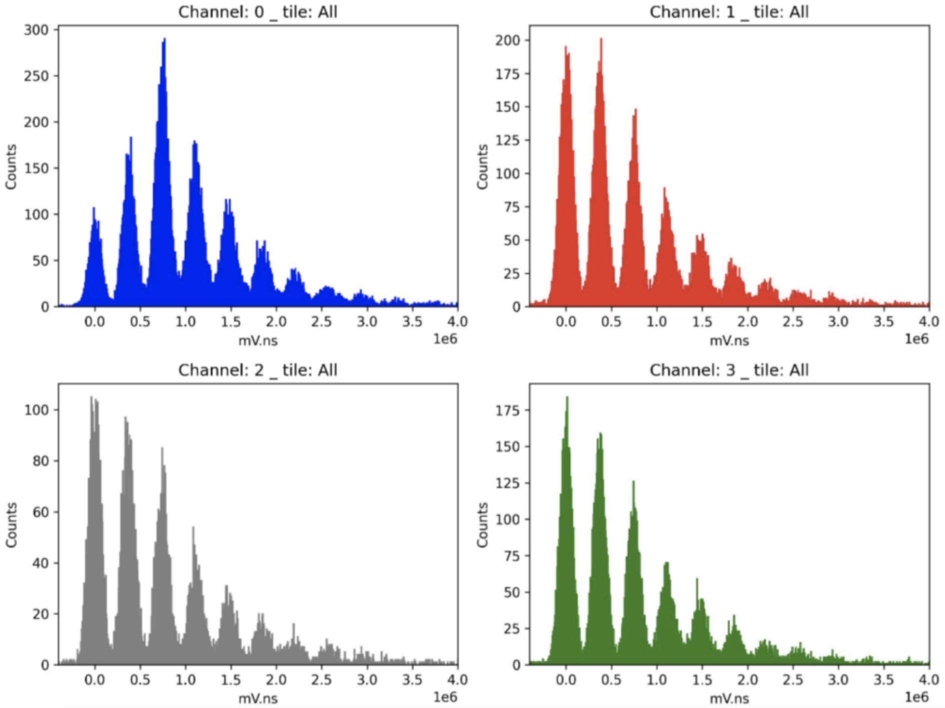
Veto photo-detector production – Stage 5

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









- Positioned in ring facing inwards towards a light source
- Lowered into LN dewar
- Capacity for 33 vPDUs/cooldown between all sites
- Each quadrant of each vPDU is electrically characterised

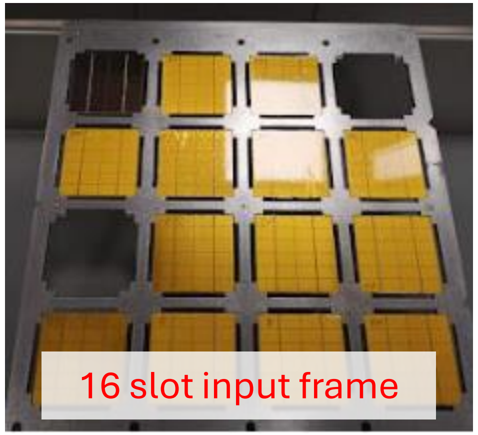
Example vPDU PE spectrum per quadrant

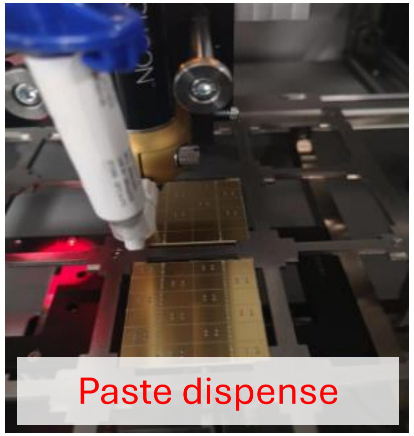
Quality control criteria

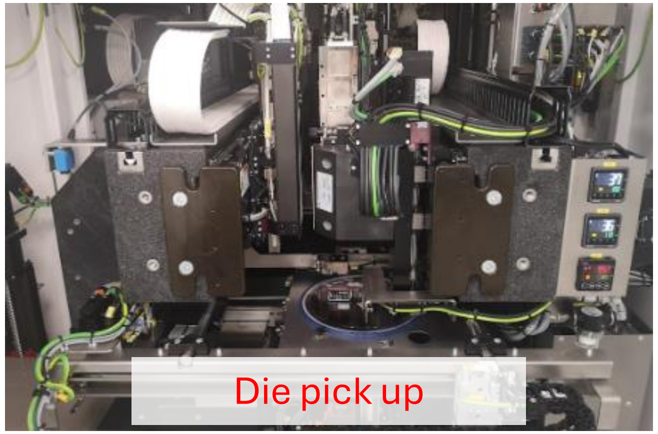
- SNR > 5
- Distinct PE spectrum
- Nominal breakdown voltage ~ 55V

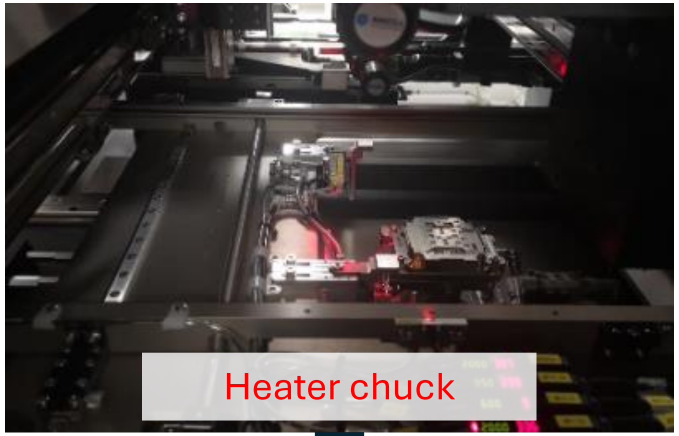
TPC PDU Production at NOA

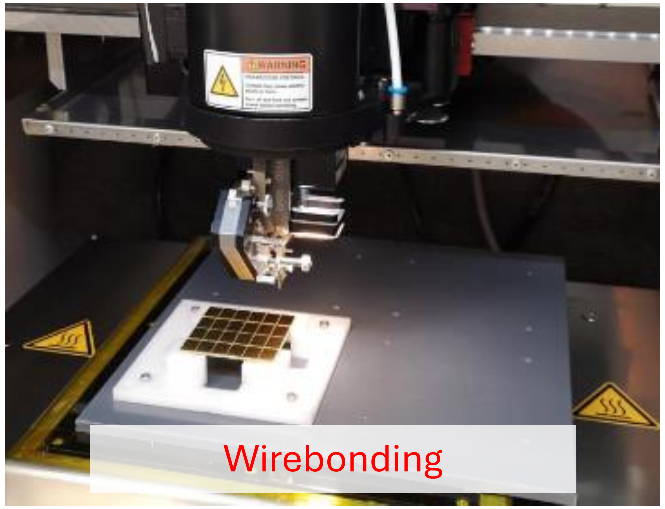
- TPC Tile readout electronics assembled in an external company, tested at NOA
- SiPM mounting takes place at NOA
- Process very similar to vPDU production

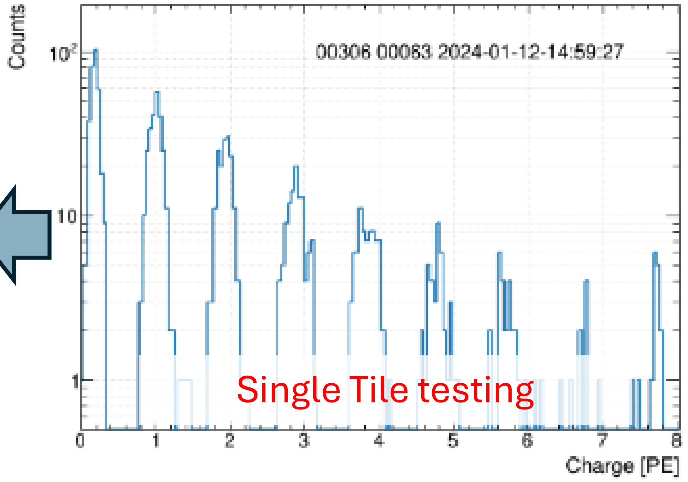


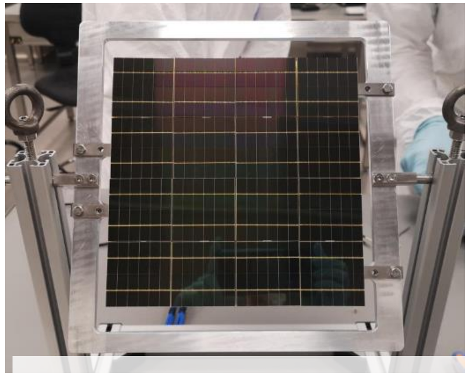






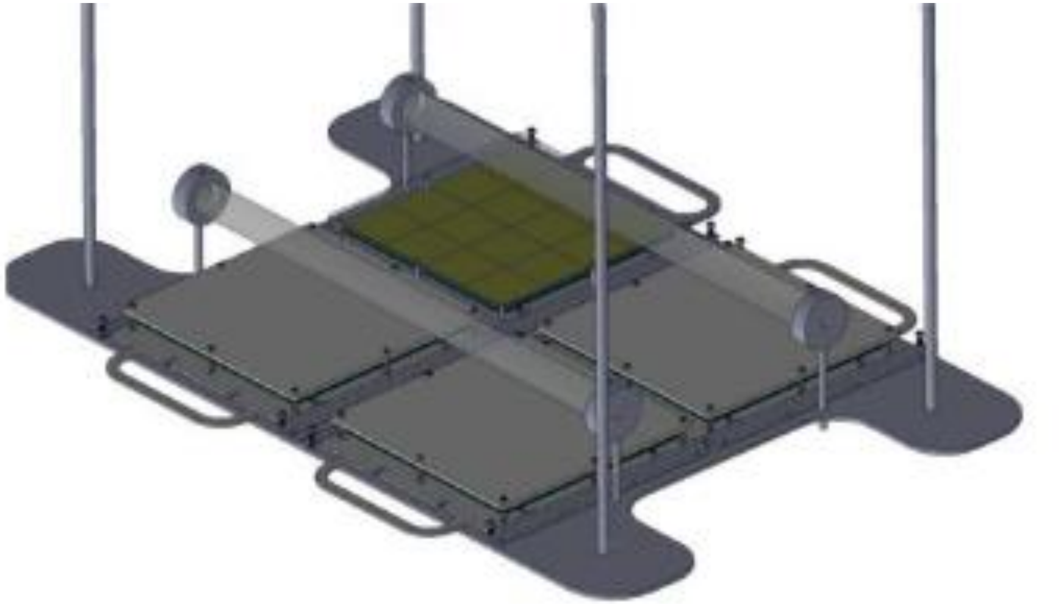





PDU assembly

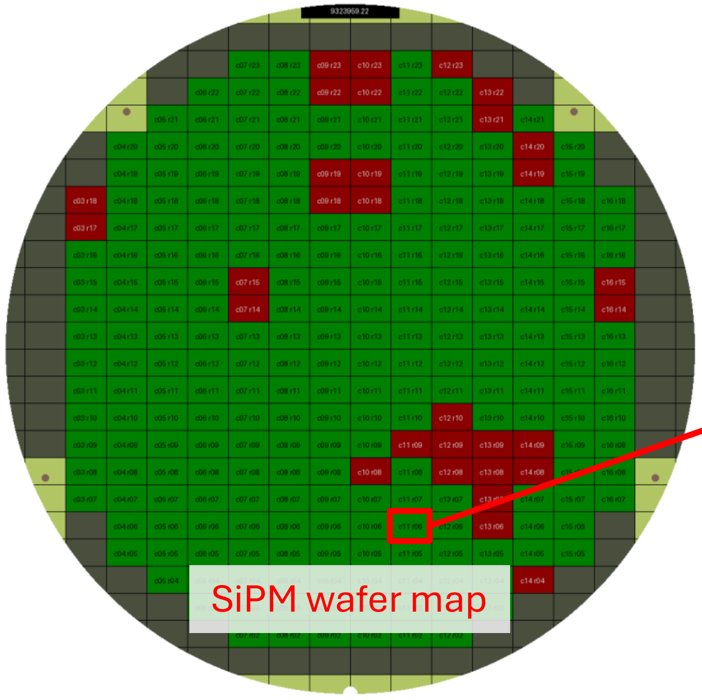
PDU testing in Napoli

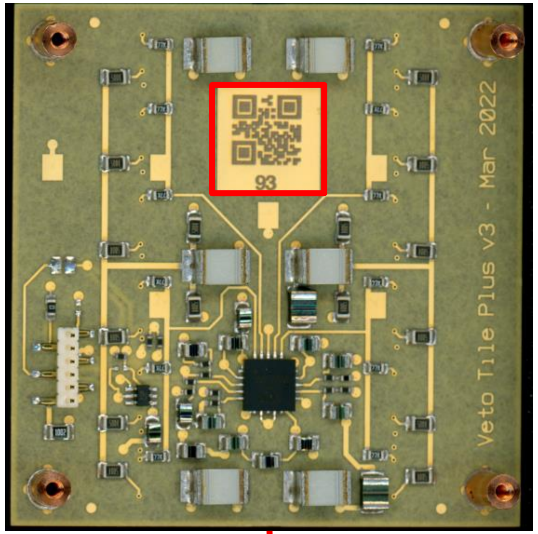
- ISO 6 cleanroom
- PDU characterisation at LN temperature
- Four-layer mechanical structure each layer holding 4 PDUs

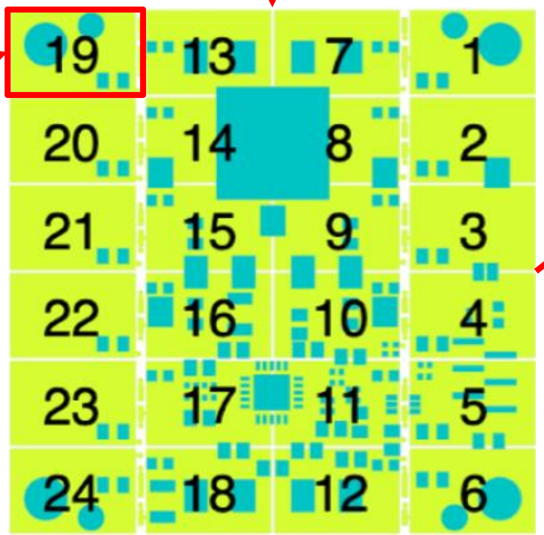


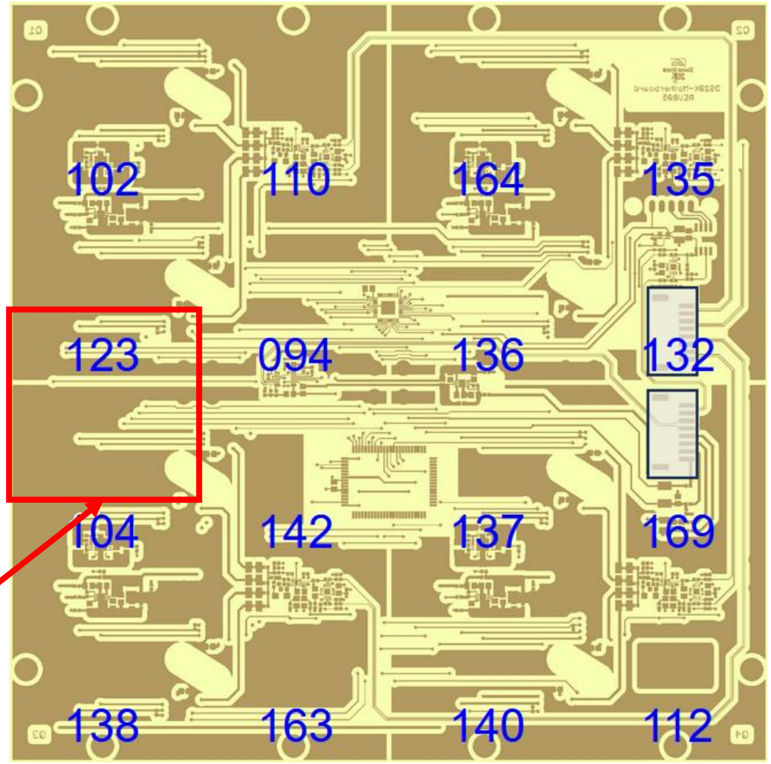
Production Database

- Object tracking via QR codes or wafer position
- Central storage of all test results
- Track production progress
- Monitor quality assurance metrics







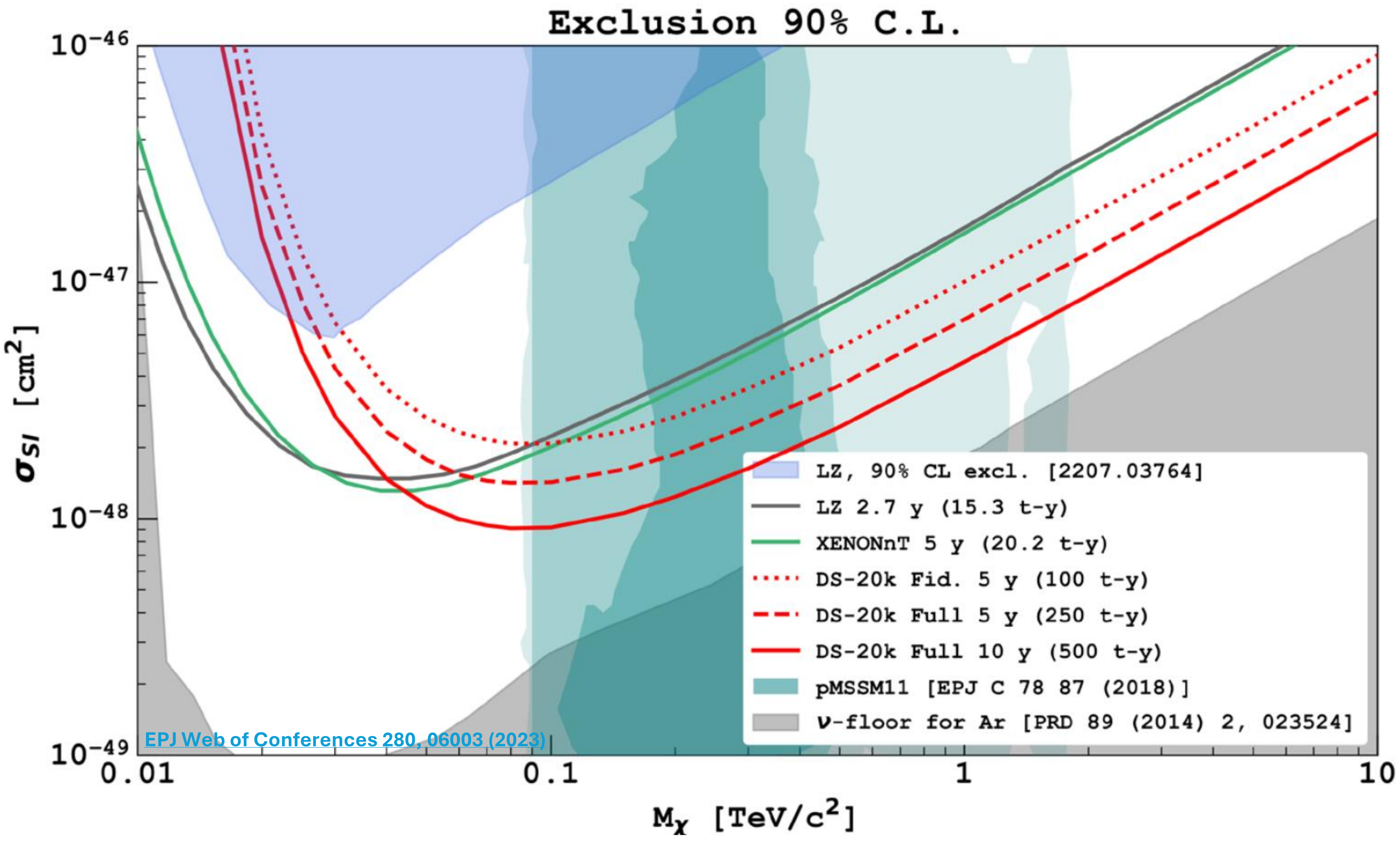


Ability to trace to original components

Physics Reach

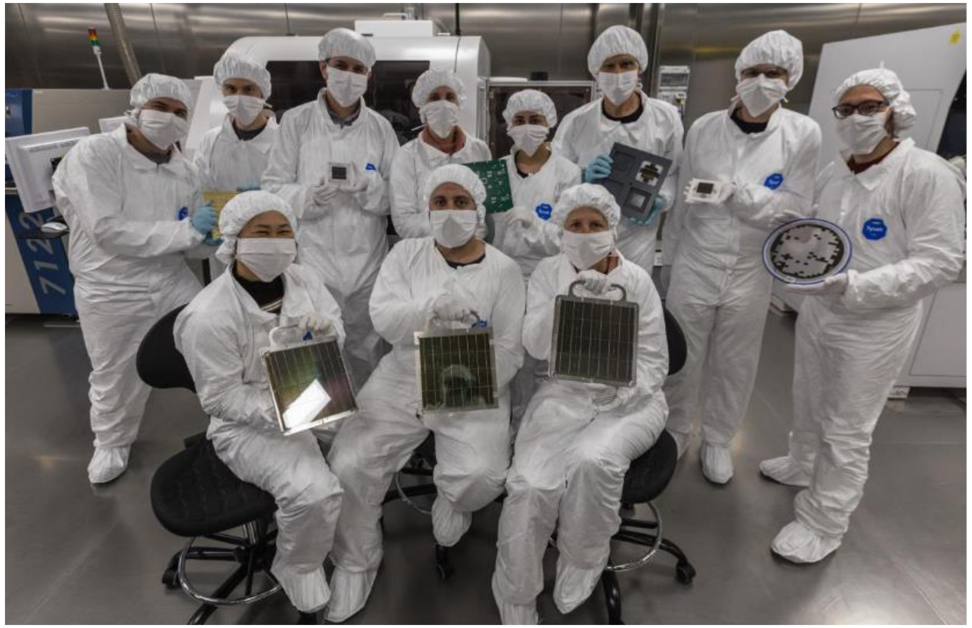
- Total background events after all cuts: < 0.1 neutron WIMP like events in total exposure of 200 t·yr
- The present projection - based on a 10 yr run, giving a fiducial volume exposure of 200 t·yr is 6.3×10^{-48} cm^2 for 90% C.L. exclusion and 2.1×10^{-47} for 5σ discovery for 1 TeV/c^2 WIMP.

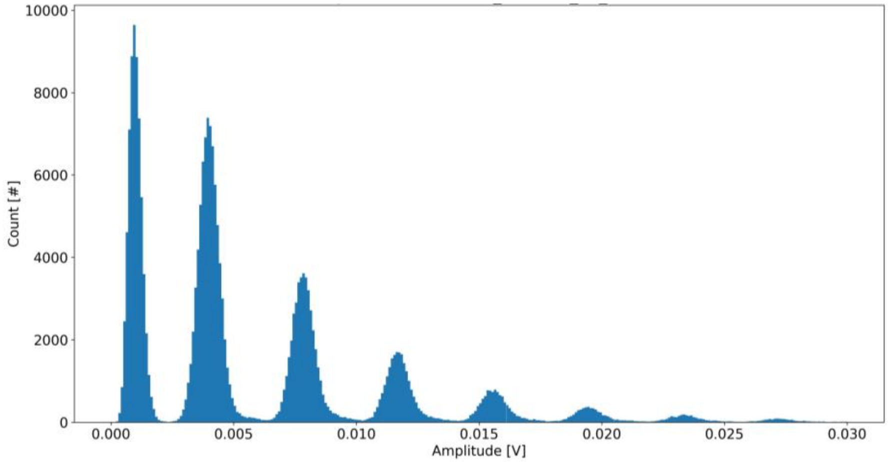
World leading sensitivity!

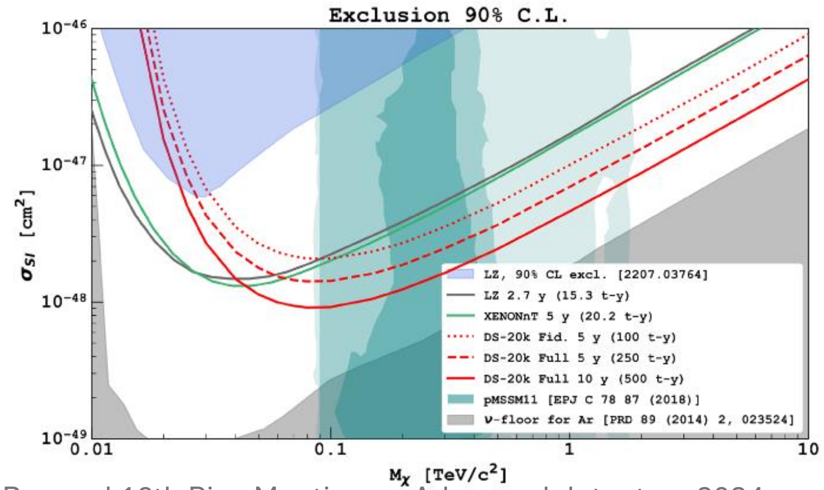


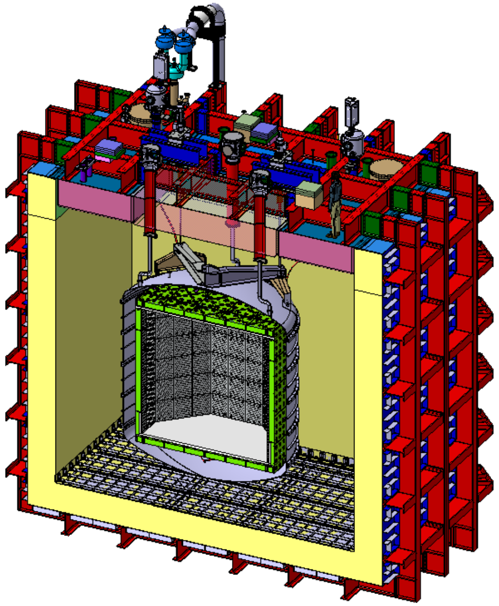
Conclusions and outlook

- Production of DarkSide-20k is well underway
- DarkSide-20k utilises many state-of-the-art technologies:
  - Novel cryogenic large area SiPM arrays
  - Underground Ar
  - Gd-PMMA
- DarkSide-20k has innovated in production and testing methods for SiPM technologies
- DarkSide-20k is set to lead the search for WIMPs!



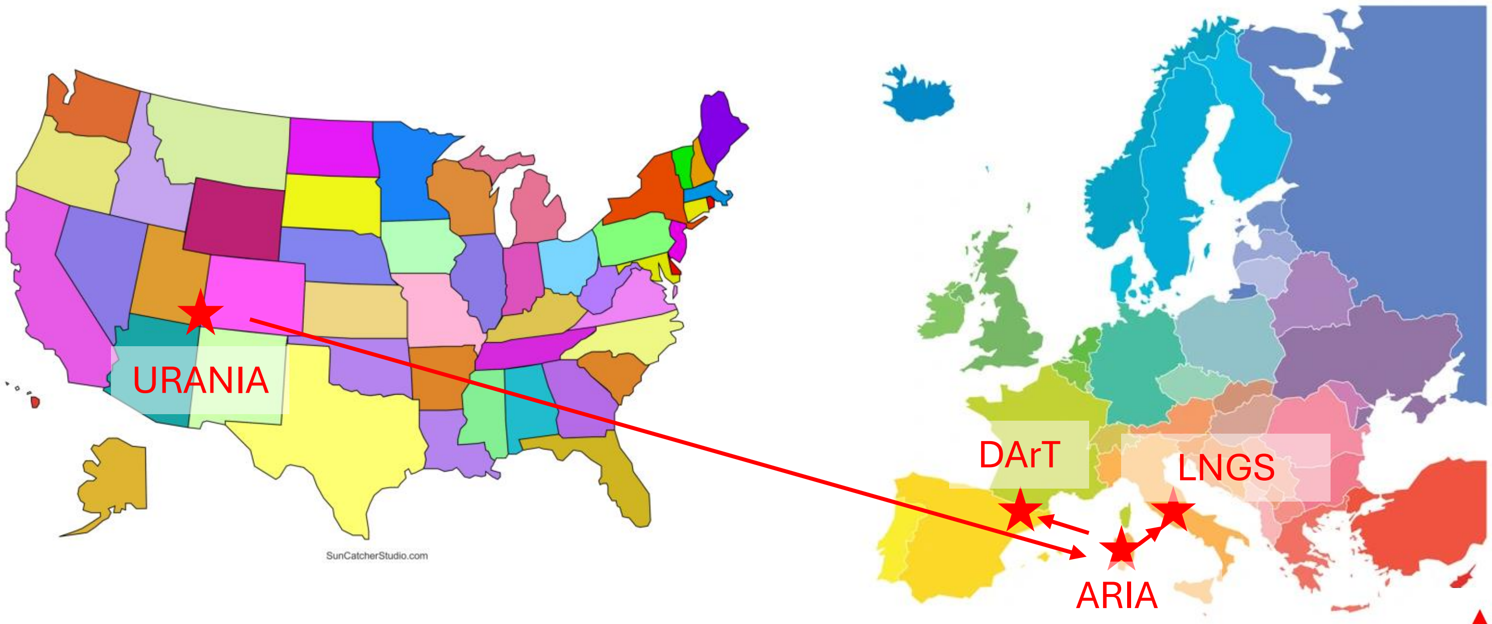






Backup Slides

Underground Argon



DArT (Radiopure assay)

- Located in the ArDM experiment at Canfranc lab
- Single-phase detector to measure ^{39}Ar depletion factor

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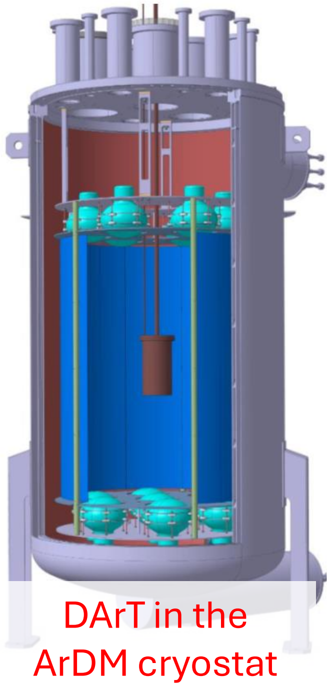

URANIA (Extraction)

- UAr extraction plant in Colorado, USA
- Located in CO_2 well
- 250-330 kg/day
- 99.99% pure

ARIA (Purification)

- 350m cryogenic distillation column in Sardinia
- 99.999% pure

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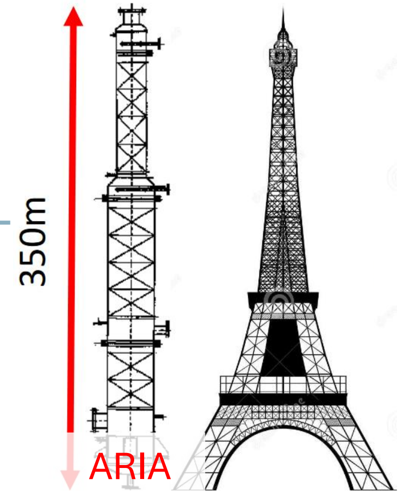
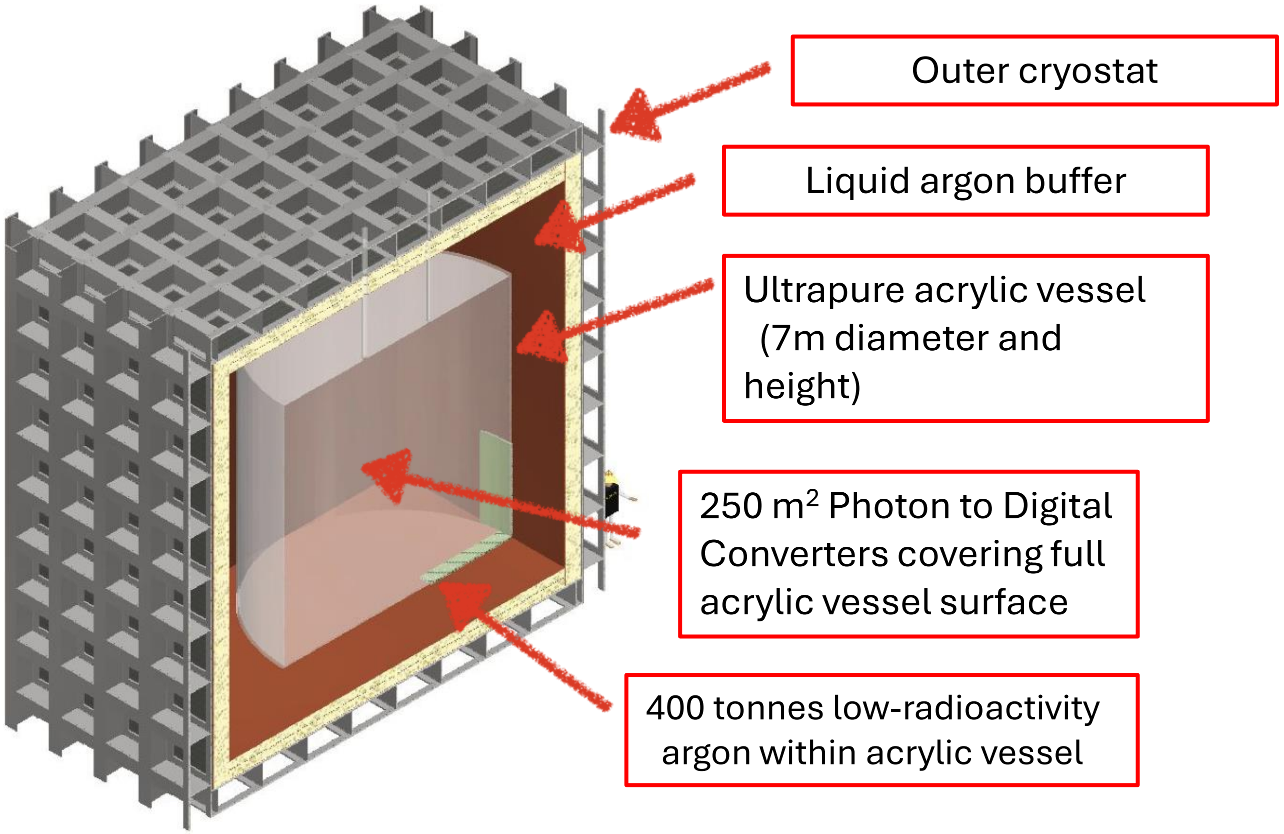


DarkSide low mass and Argo

ARGO

- 3000 t·yr exposure
- 2030s +
- Focused on high mass dark matter



DarkSide-LowMass

- 1 t·yr exposure
- Low mass focus

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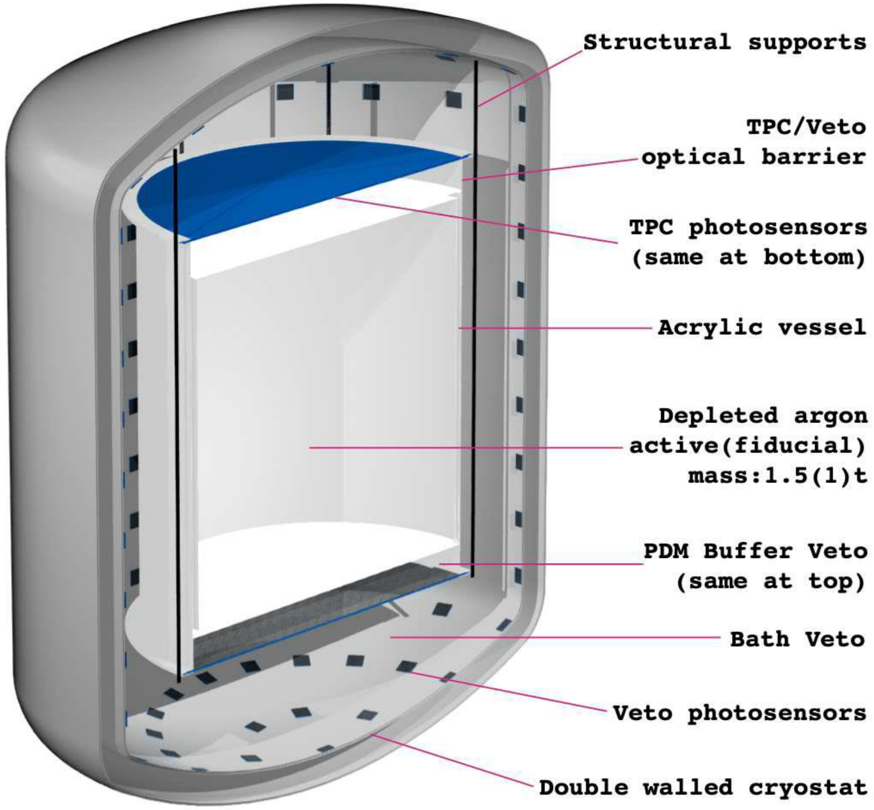
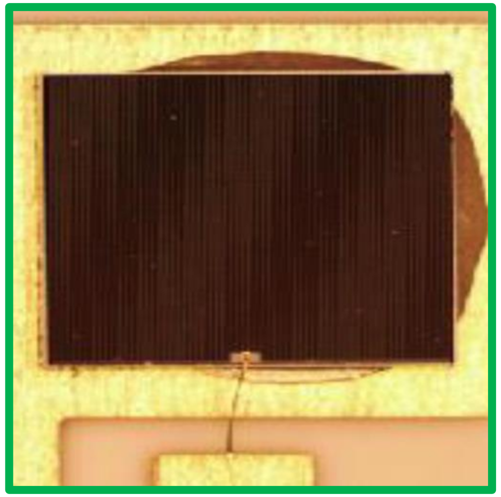


SiPM specifications



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