Performance of radiopure large-area SiPM arrays for DarkSide-20k

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on behalf of the DarkSide collaboration

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Low Radioactivity Techniques
Krakow

Presentation outline

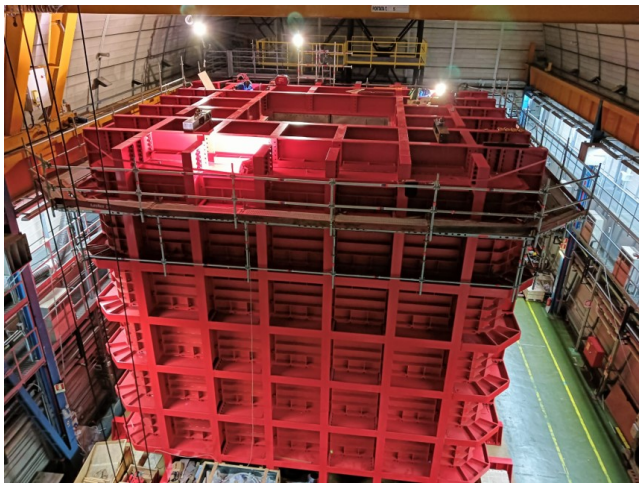
1. Material assay for DS-20k photoelectronics
   - DS-20k overview
   - radiopurity requirements
   - material assay(s)
2. Nuova Officina Assergi (NOA)
   - built on purpose
   - radon abatement system
3. NOA bagging procedures
   - silicon wafer shipping
   - DS-20k photo detection unit
4. Detector performance
   - is it possible to build a good photodetector although radiopurity requirements?

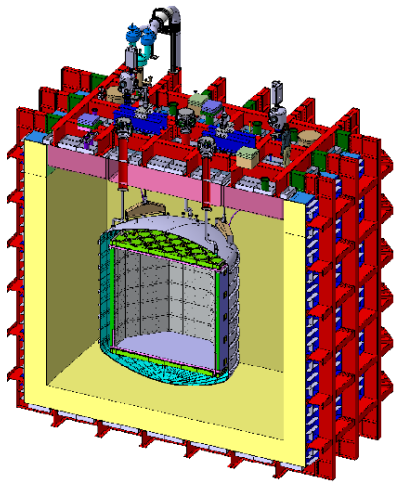
The DarkSide-20k (DS-20k) experiment

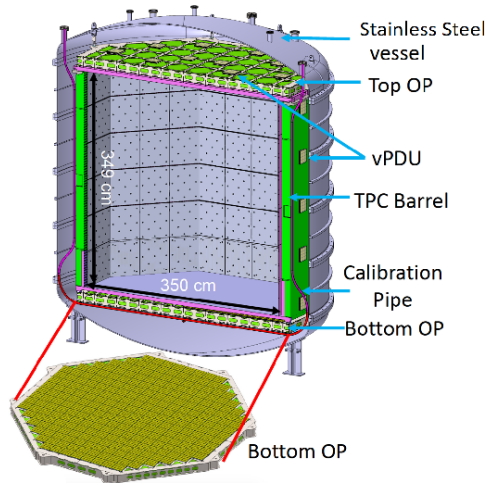
Direct dark matter search experiment under construction at Laboratori Nazionali del Gran Sasso (LNGS), Italy

Active volume filled with liquid argon from underground (specific activity down to 0.7 mBq/kg)

Readout of TPC light signals by 21 m^2 of SiPM arrays in two optical planes. Inner veto equipped with 5 m^2 of similar SiPM photodetectors.

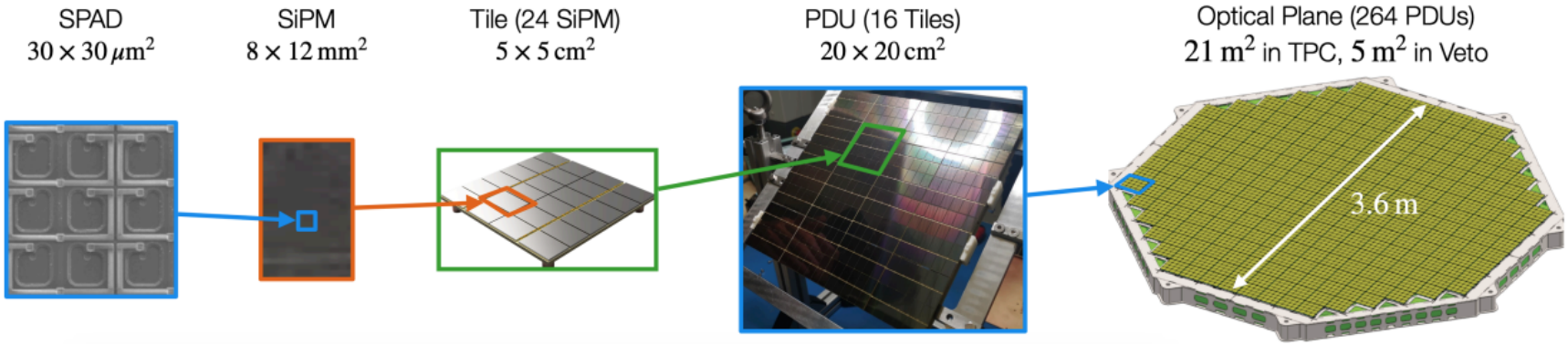


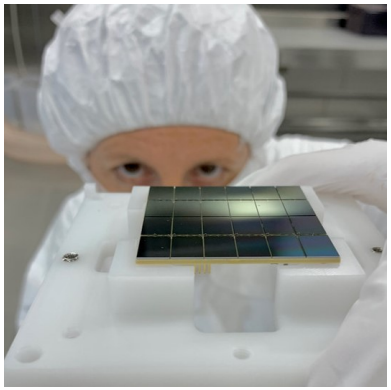




Aim to probe spin-independent WIMP-nucleus cross section down to $6.3 \cdot 10^{-48}\,\mathrm{cm}^2$ (90% CL) for $m_\chi = 1\,\mathrm{TeV/c^2}$

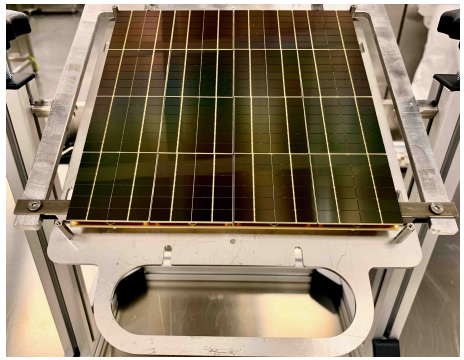
DS-20k photoelectronics





Unprecedented technological effort
to group cm^2 SiPMs in m^2 optical planes

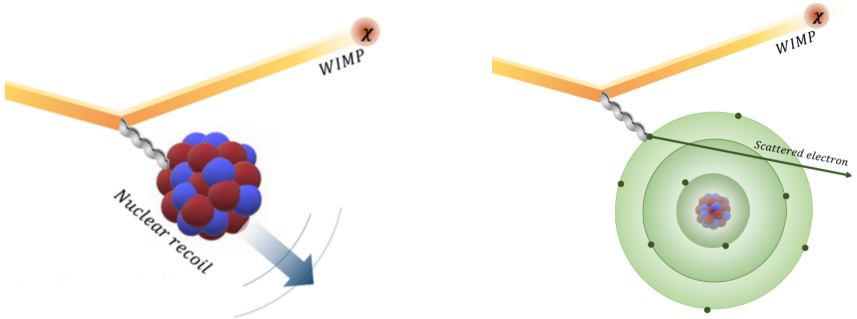
Low total activity on a very large surface
$\Longrightarrow$ very small specific activity



DS-20k background

Two main background sources in liquid argon:

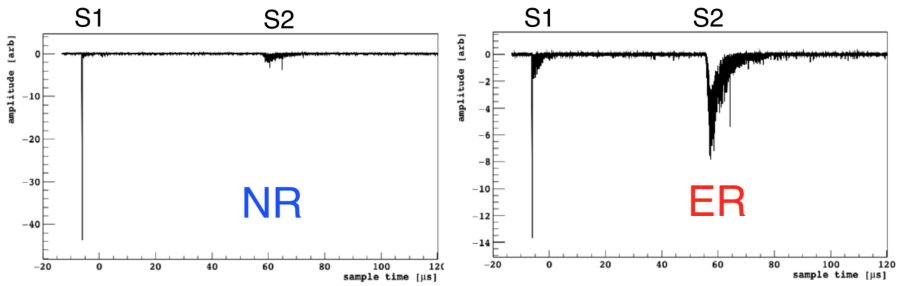
- electron recoil (ER): γ, e^-
  clear signature in liquid argon
- nuclear recoil (NR): n, CEνNS, (α, n)
  same signature of expected WIMP scattering



Impact on data acquisition:

- electron recoil $\Longrightarrow$ pile-up
  Expected rate in the TPC: 85 Hz
- nuclear recoil $\Longrightarrow$ irreducible background in the WIMP search region of interest

  Expected irreducible background after final analysis cuts:
  3.8 events in 10 years
  (3.5 neutrinos + 0.3 neutrons)



Material assay

Features:

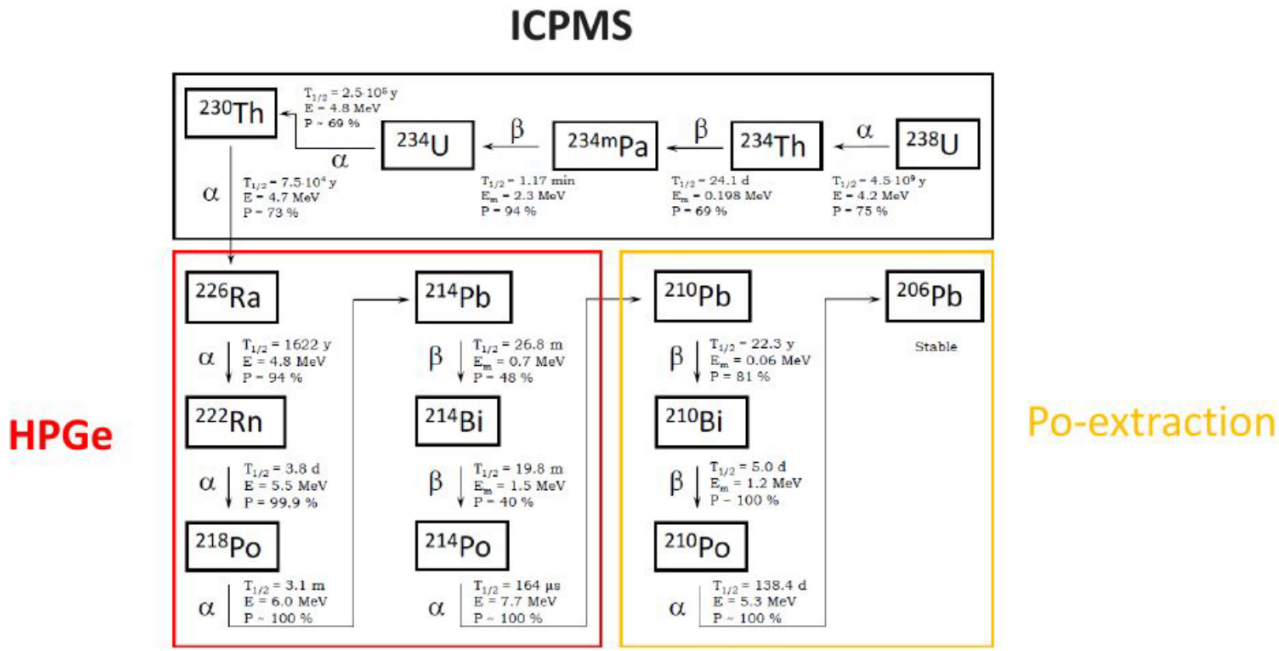
- carried out by a dedicated working group of the DarkSide collaboration
- characterization of all photodetector components
- storage of results in a common database
- estimation of the impact of contaminations in DS-20k
- definition of cleaning procedures

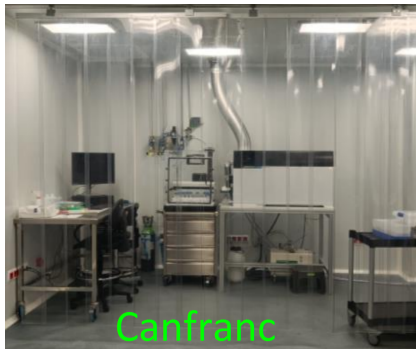
Realization:
joint effort of LNGS (Italy), Canfranc and Ciemat (Spain), Boulby (UK), Jagiellonian University (Poland), SNOLAB (Canada) and Temple University (USA)

Assay sites

Different sites contribute to photoelectronics assay with different techniques to identify different stages of ^{238}U decay chain

- LNGS: ICP-MS and HPGe
- Canfranc: ICP-MS and HPGe
- Boulby: HPGe
- U. Jagiellonian: Po radiochemical separation
- SNOLAB: HPGe
- CIEMAT: ICP-MS
- Temple university: HPGe

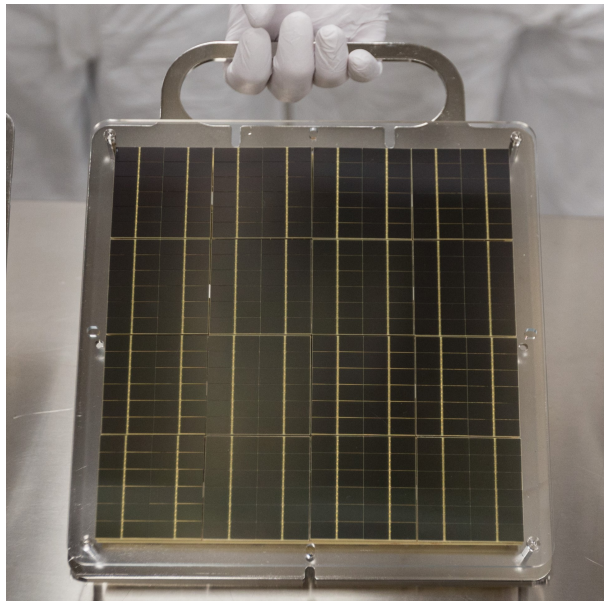




Tile and PDU activity

Photo Detection Unit (PDU) assay (ongoing):

- Tile assay
  - SiPMs (finished)
  - electronics substrate
    - Arlon 55NT (finished)
  - electronics components
    - e.g. PEN-PPS capacitors
  - soldering paste
    - In-Sn for SiPMs
    - Sn-Bi for electronics
  - connectors
    - nylon 66 (finished)
  - copper pillars
- Motherboard assay
  - electronics components
  - soldering paste
  - PCB
  - connectors
- PDU handling
  - stainless steel handler
  - pins, screw, clips, nuts...
  - acrylic cover



veto Tiles assay finished

Parent	Combined Specific Activity mBq/unit
U238_E	1.2 ± 0.6
U238_L	0.9 ± 0.1
Pb210	62.6 ± 4.2
Th232_E	0.4 ± 0.2
Th232_L	< 0.5
K40	5.1 ± 1.9
Co60	< 0.1

Expected TPC activity from photoelectronics (preliminary): about 30 Hz

Credits: D. Santone, DS-20k collaboration meeting

Nuova Officina Assergi (NOA)

ISO 6 clean room built in LNGS to assemble DS-20k TPC's photodetectors
(but available for other future experiments)

Professional tools for silicon packaging and test of assembled detectors

Availability of a dry cabinet to store hygroscopic material

Radon contamination at level of 3-10 $\mathrm{Bq/m^3}$ measured with certified environmental sensors

Plan to add a Rn abatement system (under technical and financial investigation)

NOA particulate level

CR3 air particle concentration (counts/liter)

	0,3 µm	0,5 µm	1,0 µm
CryoProbe	3.6963	1.3420	0.4002
Wire Bonder	0.1883	0.0235	0.0
Frame Mounter	0.2825	0.0942	0.0
PDU Assembly	0.0235	0.0	0.0
ISO5 MAX concentration limit	10.2	3.52	0.83
ISO6 MAX concentration limit	102	35.2	8.32

June 2024

Anti-Rn bagging procedure

Activation performed in Aix-Marseille

Measurement of surface activity carried out in Jagiellonian University

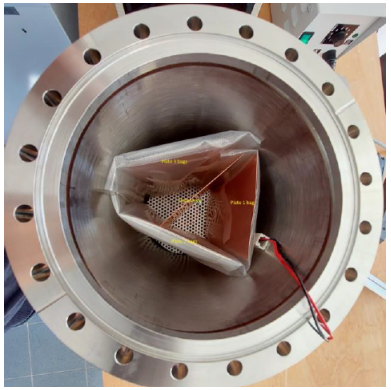
Screening from environmental ^{222}Rn with plastic bags

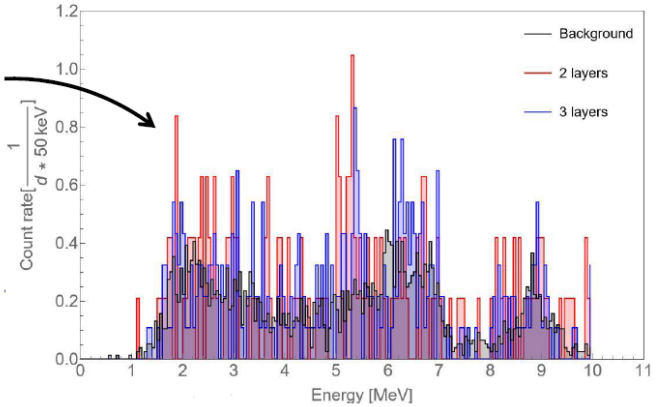
- samples: clean Cu plates
- contaminant: ^{222}Rn source (0.4-$0.8\,\mathrm{MBq/m^3}$)
- Cu plates in single, double and triple bagging
- reference sample without bags

Result: ^{222}Rn suppression ≥ 146 with 2 bags
Negligible improvement (for DS-20k purposes) with 3 bags

$\Downarrow$

Triple bagging (2 + 1 spare) is now the standard DS-20k storage and shipping procedure for small to medium size objects





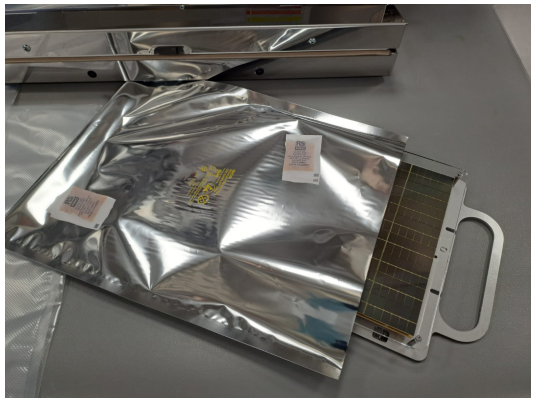
Credits: M. Czuback, DS-20k collaboration meeting

Example: shipping of silicon wafers inserted in their protective case and surrounded by 2 anti-Rn bags

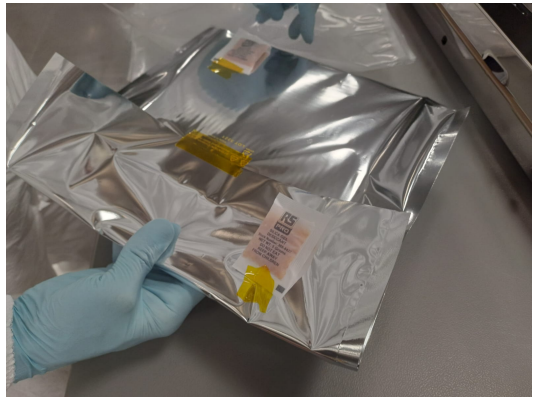
PDU bagging procedure

from NOA to Naples (and viceversa)

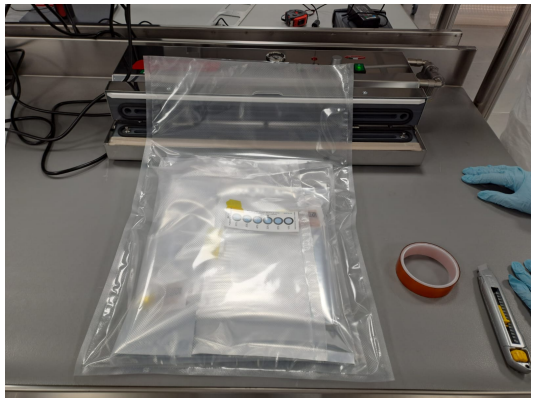
1) PDU inserted in an antistatic bag



2) Humidity dryers are attached to the antistatic bag after closure



3) The package is double sealed in anti-radon plastic bags



4) The envelope is finally placed in a protective case for its travel

Some cleaning procedures

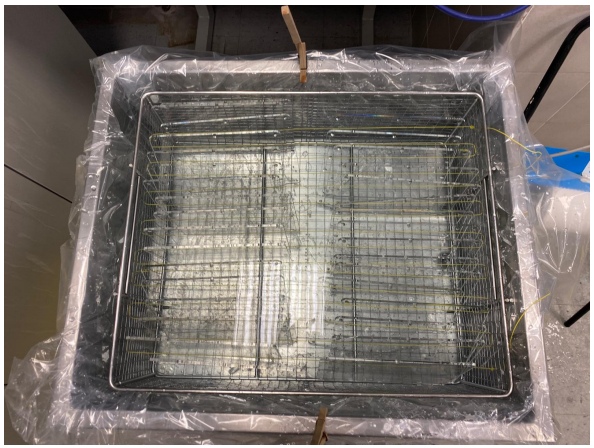
Items to clean in Laboratori Nazionali di Legnaro (LNL):

- Tile's copper pillars $\longrightarrow$ electropolishing, plasma cleaning and etching (more details in O.Azzolini's presentation of yesterday afternoon)

Items to clean in LNGS:

- stainless steel handler and acrylic cover $\longrightarrow$ ultrasonic bath with 2% nitric acid
- handler screws, pins, etc... $\longrightarrow$ ultrasonic bath and etching (to be defined)

Hundreds of large-size pieces already cleaned in a week
thanks to LNGS chemistry service and our summer shifters

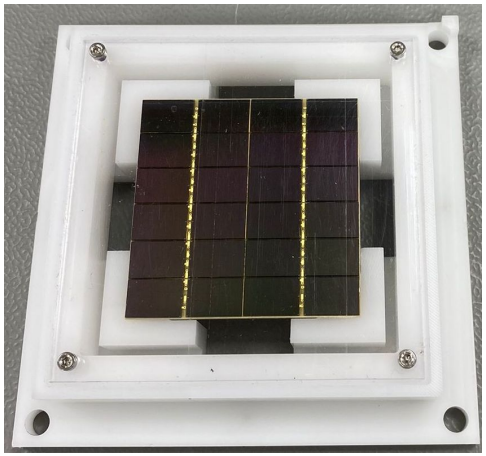


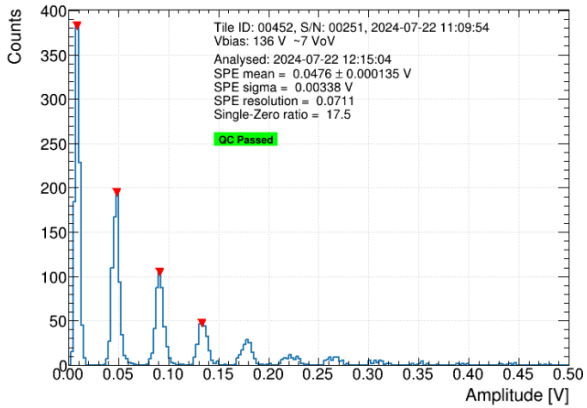
Performance of DS-20k SiPM arrays

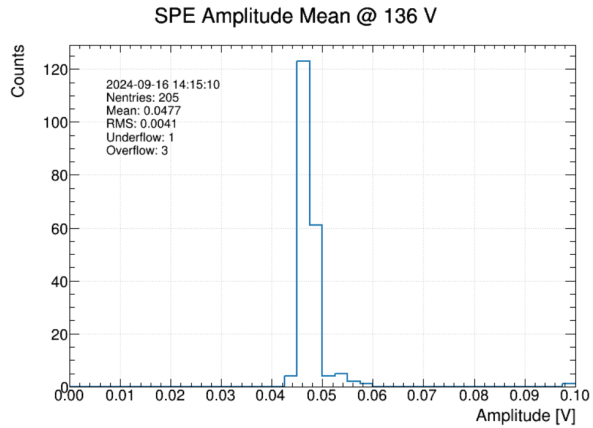
Excellent photon counting and good parameters stability across our pre-production of about 200 Tiles.

NOA's Tiles features at $T = 77\,\mathrm{K}$:

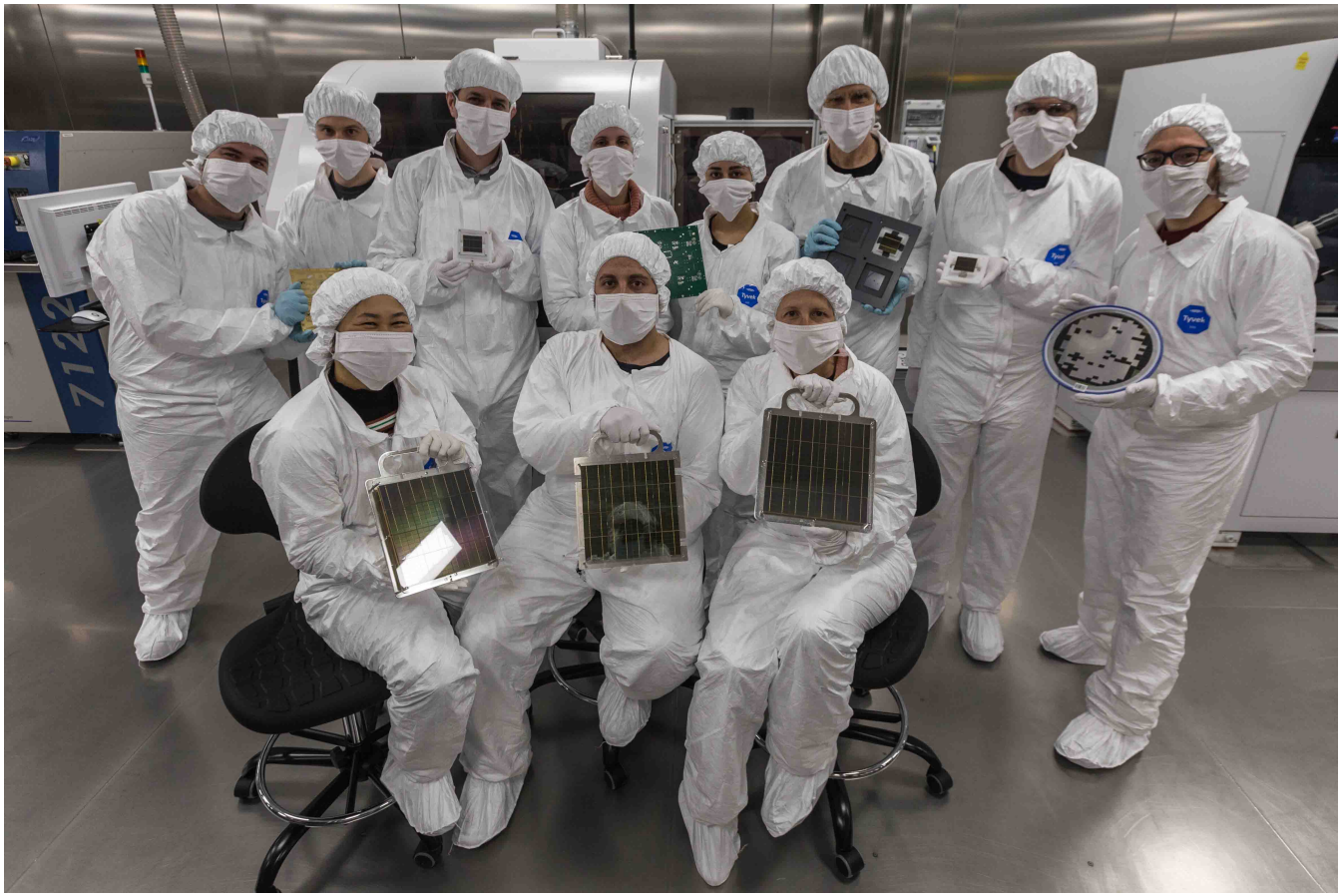
- Photon Detection Efficiency (PDE) $> 40\%$ at $\lambda \sim 420\,\mathrm{nm}$
- Breakdown Voltage $V_{BD} = 108 \pm 1\,\mathrm{V}$
- Dark Count Rate (DCR) at 7 VoV: $\mathcal{O}(10^{-2}\,\mathrm{Hz/mm^2})$
- Signal to noise ratio > 15 at 7 VoV







The NOA team



Thank you for the attention!