

Dark matter search with liquid argon detectors

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Group Leader

“Silicon Photomultiplier Systems for Astroparticle Physics and Medical Physics”

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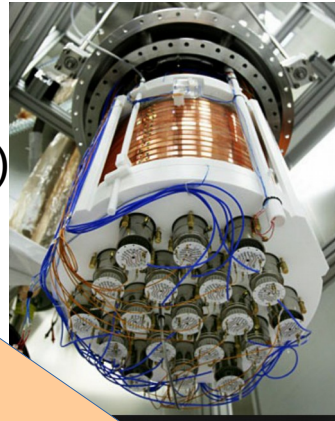
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 952480

LAr-based dark matter detectors

2010

10 kg

DarkSide-50
(50 kg, LNGS)



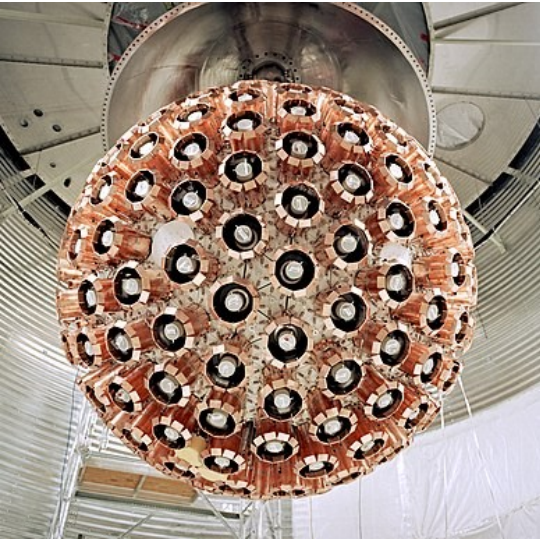
100 kg

ArDM (1t, LSC)

- More than 300 scientists from 15 countries and 60 institutions
- Officially supported by underground labs: LNGS, LSC, and SNOLAB

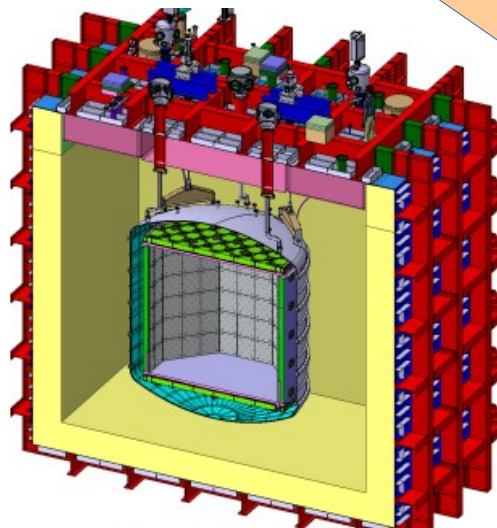
1000 kg

DEAP-3600 (3.3t, SNOLAB)



2015

Global Argon Dark Matter Collaboration formed



2020

DarkSide-20k
(50t, LNGS)

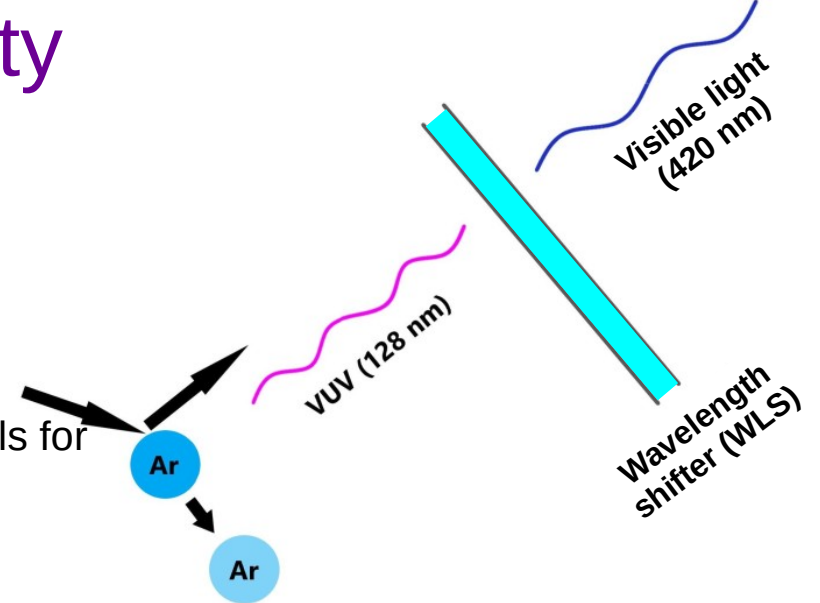
100000 kg

Argo: 400 t

Our specialty

• Light collection

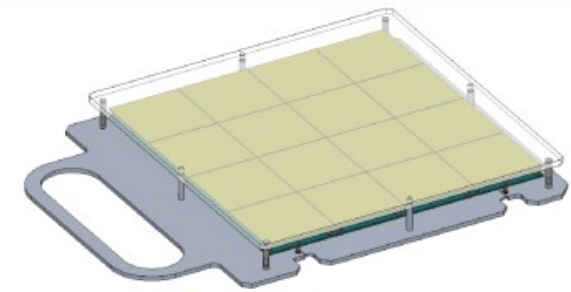
- Wavelength shifter (WLS) materials
 - Liquid argon scintillates at 128 nm (VUV)
 - Proposed new scalable materials
 - Developed concept for new wavelength shifting materials for background mitigation
- Reflector and optics configuration/optimization



• ... and light detection

- SiPM: new cutting edge devices, DarkSide-20k is the first experiment to use them on that scale
- Collaboration with DarkSide-20k:

Veto SiPM system: analysis, testing and development



20cm x 20cm SiPM array

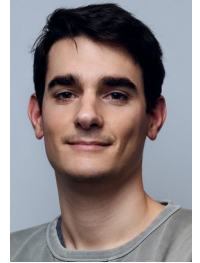
• Main collaborations:

- Direct search for dark matter with liquid argon detectors:
 - **DEAP-3600** (running at SNOLAB, Canada)
 - **DarkSide-20k** (under construction in Italy)
 - **ARGO** (conceptual phase)
- Synergies: DUNE (via **CERN Neutrino Platform**), **KM3NeT** (with APC Paris)

**Global
Argon
Dark
Matter
Collaboration**

Group 1 profile

- Group members:
 - **Leader** Marcin Kuźniak
 - **PhD students:**
 - Sarthak Choudhary ([soon to graduate](#))
 - Pulse shape discrimination analysis + light collection optimization
 - Iftikhar Ahmad ([defense this Friday](#))
 - SiPM testing for DarkSide-20k
 - Theo Hugues (cotutelle with APC Paris, [graduated in March](#))
 - DEAP-3600 physics data analysis
 - Annual modulation analysis for DarkSide-50
 - **Postdocs:**
 - Michał Olszewski
 - Monte Carlo simulations
 - DEAP-3600 WIMP data analysis
 - **MSCA Fellow:** Andre Cortez
 - **Support from technicians and an engineer**
- Access to electronics, chemistry and cryogenic (cleanroom) lab at CEZAMAT
- Cooperation agreement with the University of Warsaw, Chemistry Department



Grants and leadership roles

Ongoing

- M. Kuźniak, 2.1 MPLN/ 3 yr, *Search for dark matter with liquid argon detectors*, **OPUS, NCN**
- L. Roszkowski, Horizon Europe Teaming, 15 MEur/6 years (as a team member)
- A. Cortez, *"innovative SStructures for improvEd Light colLEction in ARgon-based TPCs"*, **MSCA Postdoctoral Fellowship, European Commission** (as supervisor)

Submitted proposals:

- SNSF MAPS with University of Zurich, CIFRA Bucharest and Jagiellonian University, **under evaluation**
- M-ERA.NET3 with Universite de Bordeaux, Univ. Jaume I de Castelon (Spain), Warsaw University of Technology and Nanoxo sp. z o.o. (rejected)
- FNP MAB FENG (as a leader, rejected)
- FNP MAB FENG (as a group leader, rejected)

Chosen leadership roles:

- APPEC Scientific Advisory Committee member
- DarkSide-20k review office member
- DRD2 collaboration work package leader
- LIDINE conference International Scientific Committee

Papers and conferences

- 1) *Constraints on directionality effect of nuclear recoils in a liquid argon time projection chamber, DarkSide-20k Collaboration et al., 2024, EPJC., 84, 24*
- 2) *Study of low-energy nuclear recoils in liquid argon with the ReD experiment, Pino, N. et al, 2024, JInst, 19, C04054*
- 3) ***Development of wavelength-shifting PEN foils for next generation experiments, Kuźniak, M. et al, 2024, JInst, 19, C05017***
- 4) ***Cryogenic setup for the characterization of wavelength-shifting materials for noble element radiation detectors, Choudhary, S. et al, 2024, JInst, 19, C05019***
- 5) ***Long-term temporal stability of the DarkSide-50 dark matter detector, Agnes, P. et al, 2024, JInst, 19, P05057***
- 6) *A new hybrid gadolinium nanoparticles-loaded polymeric material for neutron detection in rare event searches, Acerbi, F. et al, 2024, JInst, 19, P09021*
- 7) ***Search for dark matter annual modulation with DarkSide-50, Agnes, P. et al, 2024, PhRvD, 110, 102006***
- 8) ***FAT-GEMs: (field assisted) transparent gaseous-electroluminescence multipliers, Leardini, S. et al, 2024, Frontiers in Detector Science and Technology, 2, 1***
- 9) *DUNE Phase II: scientific opportunities, detector concepts, technological solutions, Abed Abud, A. et al, 2024, JInst, 19, P12005*
- 10) *Characterization of low-energy argon recoils with the ReD experiment, Ahmad, I. et al, 2024, Proceedings of Science, 441, 52*
- 11) ***Status of direct detection searches of heavy dark matter, Kuźniak, M., 2024, Proceedings of Science, 441, 18***
- 12) *DarkSide-20k sensitivity to light dark matter particles, The DarkSide-20k Collaboration, 2024, CmPhy, 7, 422*

- **Conference presentations**

- LIDINE 2024 (Sao Paulo)
- MESON 2024 (Kraków), invited review talk
- LRT 2024 – Low Radioactivity Techniques (Kraków), poster

- **Other presentations**

- Łukasiewicz Research Network – Institute for Industrial Chemistry Seminar,
- IFJ PAN Colloquium

Wavelength shifting reflector test

- Jointly with TUM, Uni Zurich, NIKHEF, Uni Edinburgh and CERN
 - Groups from LEGEND, DUNE and DarkSide-20k
- Most promising combination of reflector (ESR) and PEN identified with tabletop measurements (Zurich, TUM, Astrocent)
- Large scale LAr test completed at CERN to demonstrate light yield **stability** over 2 weeks long run

<https://arxiv.org/abs/2411.17934>

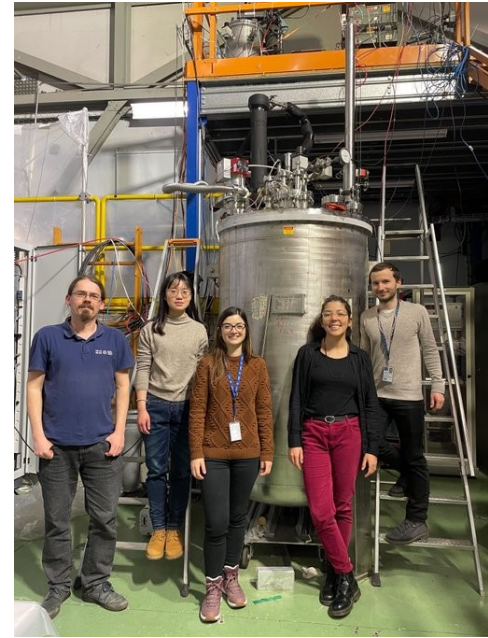
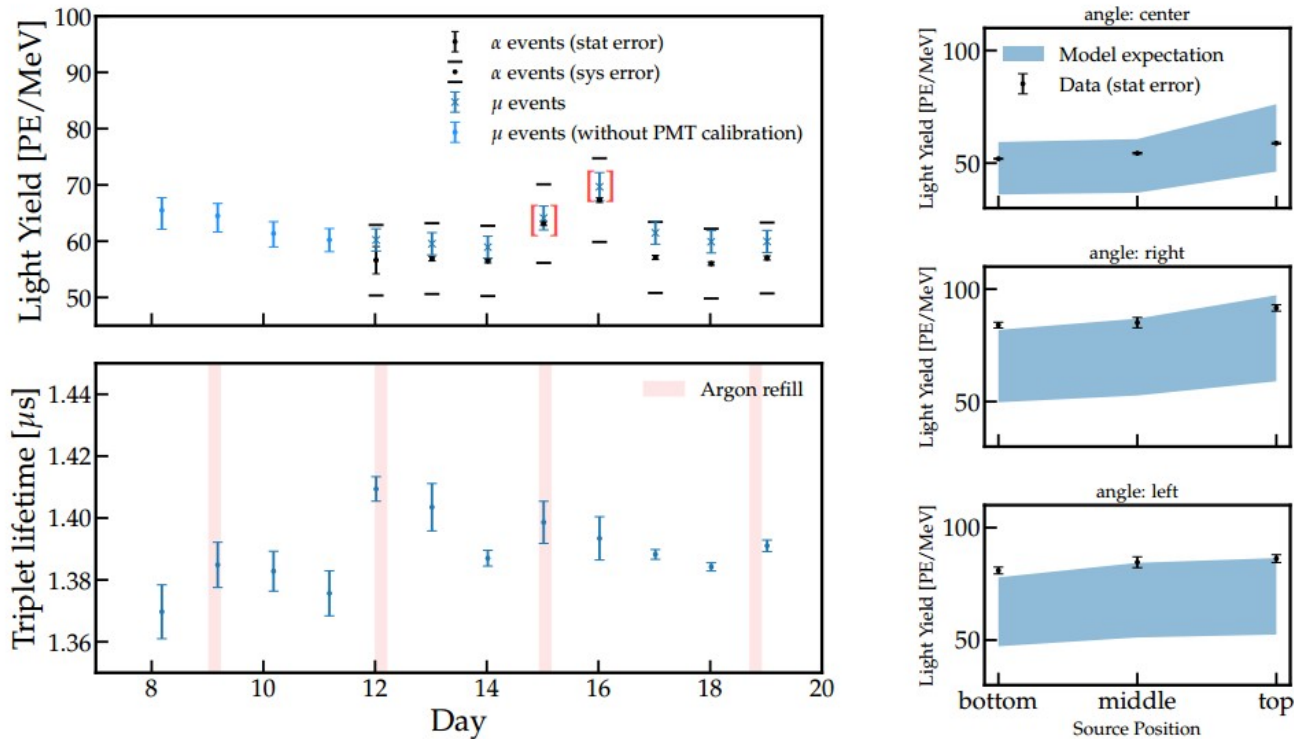


Figure 6: (left) Evolution of LY (after correcting for triplet lifetime variation) and the triplet lifetime. Data points in brackets were taken during periods of high noise rates. (right) Measured LY and the MC model expectation for different α source positions.

Dark matter annual modulation limit

Phys. Rev. D 110, 102006 (2024)

Masato Kimura + T. Hugues PhD thesis work

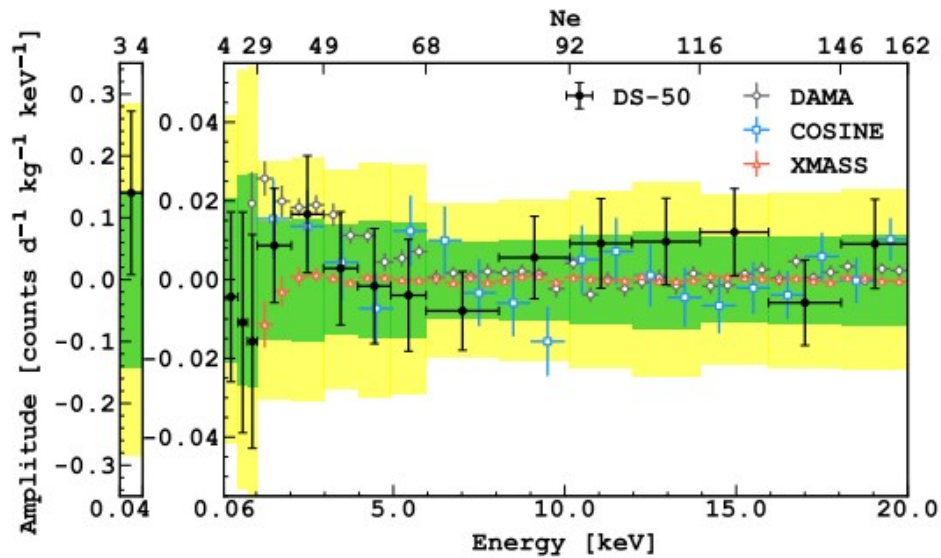


FIG. 4. Best fit amplitude of the modulation signal as a function of N_e . The green and yellow bands represent the expected 1σ and 2σ statistical fluctuations derived by background-only Monte Carlo samples. Also shown are the results from DAMA/LIBRA [3], COSINE-100 [17], and XMASS [13].

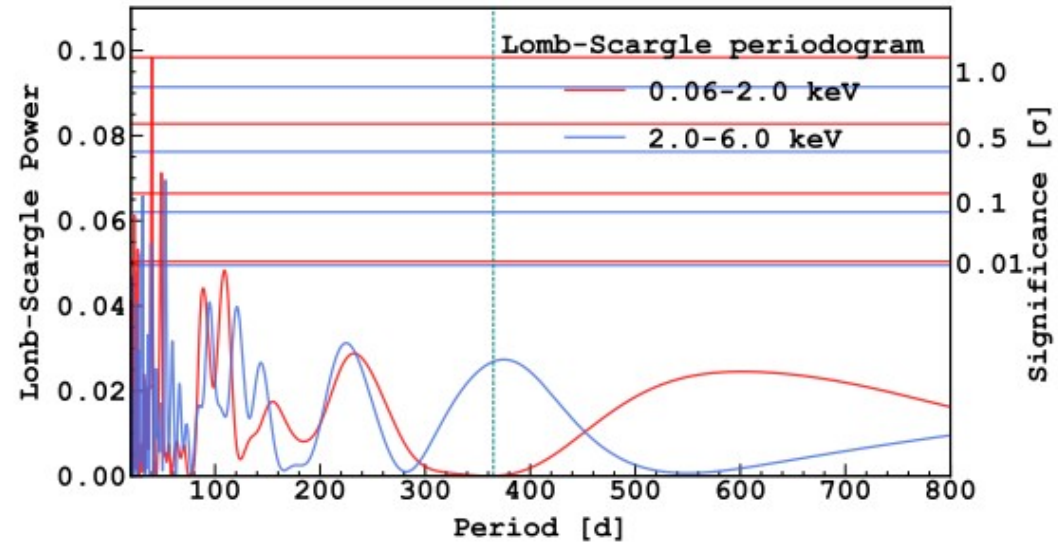


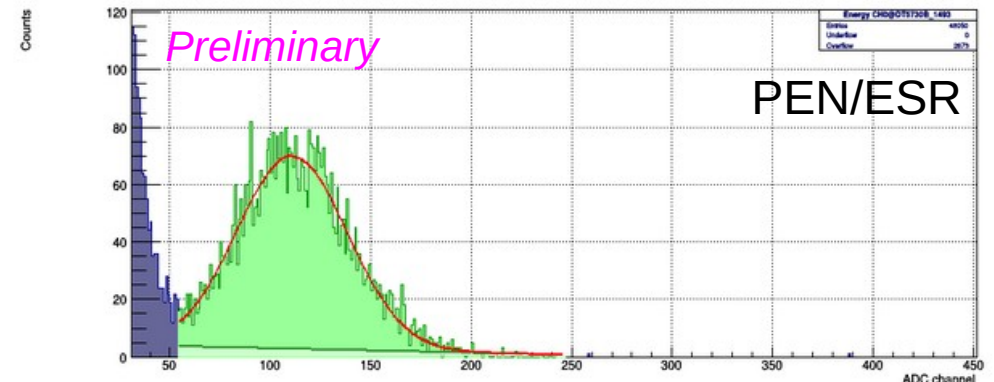
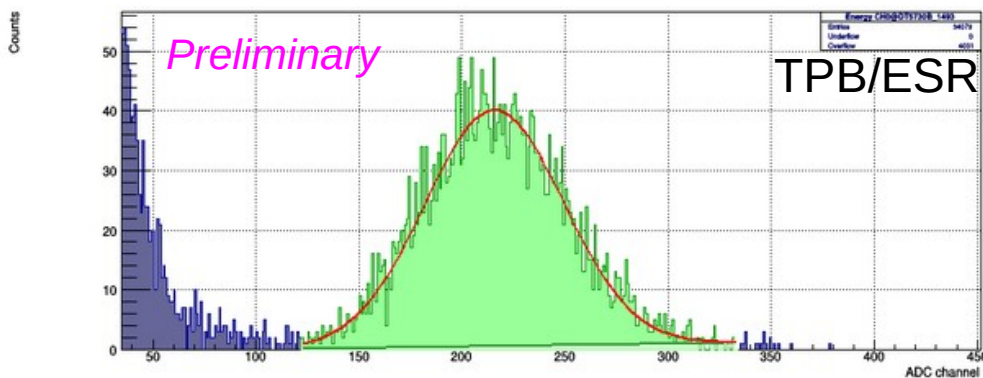
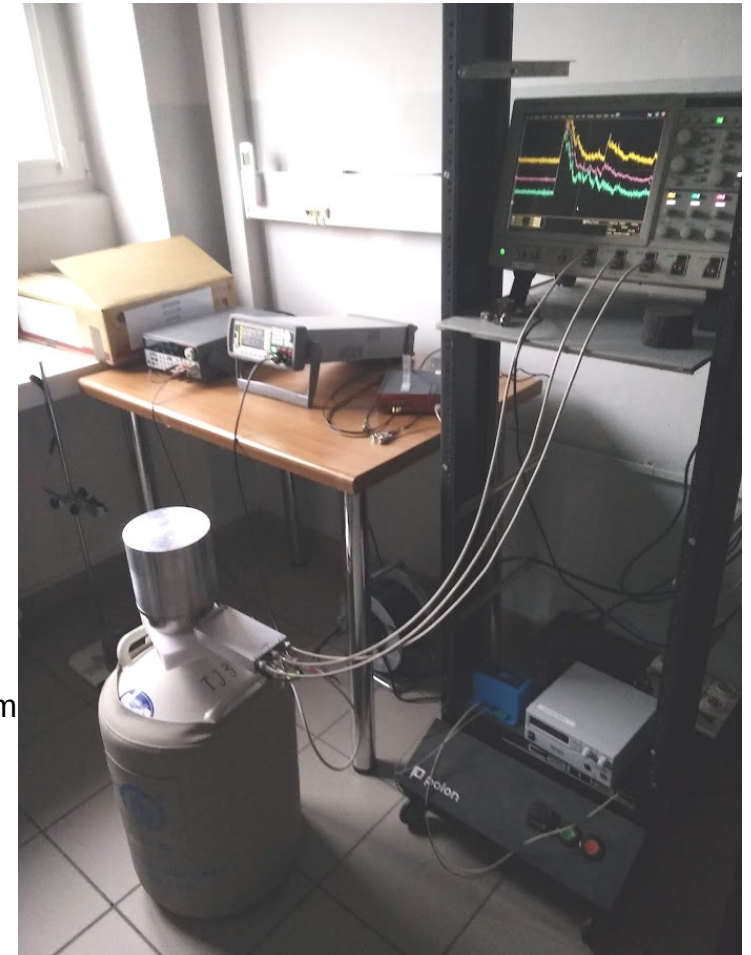
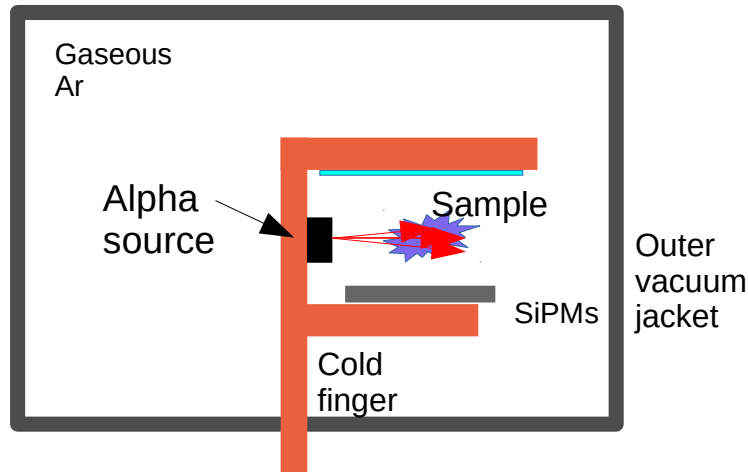
FIG. 5. Observed sinusoidal signal strengths from the Lomb-Scargle periodogram as a function of its period. The horizontal lines represent the 0.1σ , 0.5σ , and 1.0σ false alarm probability from the Bootstrap method for each range. The vertical dashed line corresponds to the period of 1 yr.

Test stand @ AstroCeNT for quality control

- DarkSide-20k to use ~300 m² of PEN as the WLS in the veto
- Recently successfully commissioned an alpha-excited gaseous Ar cell with a cryogenic stage for PEN WLS quality control

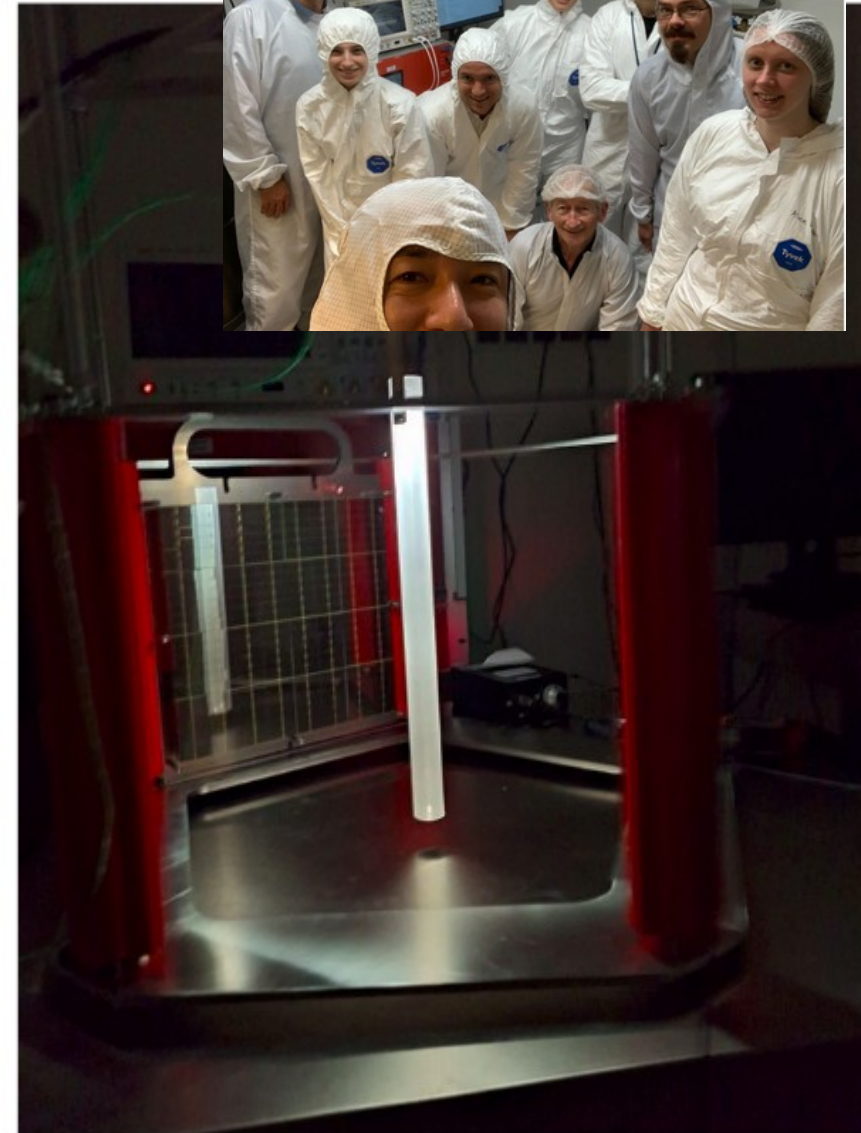
Next steps:

- QC for DarkSide-20k
- New materials
- Add a nanosecond-pulsed VUV source
- Gaseous TPC configuration



DS-20k veto SiPM module testing

Iftikhar Ahmad PhD thesis work



- ISO-7 class cleanroom in CEZAMAT laboratory
- Allows tests of 5 (10) units per cooldown
- CAEN power supplies and VX2740 digitizer

Summary

- ★ Much time last year devoted to project development and proposal writing
- ★ Two fully functional cryogenic test facilities at the cleanroom lab
- ★ Good quality results from ongoing experimental test campaigns for DarkSide-20k and from the tests at CERN
- ★ Published leading dark matter annual modulation limit from DarkSide-50