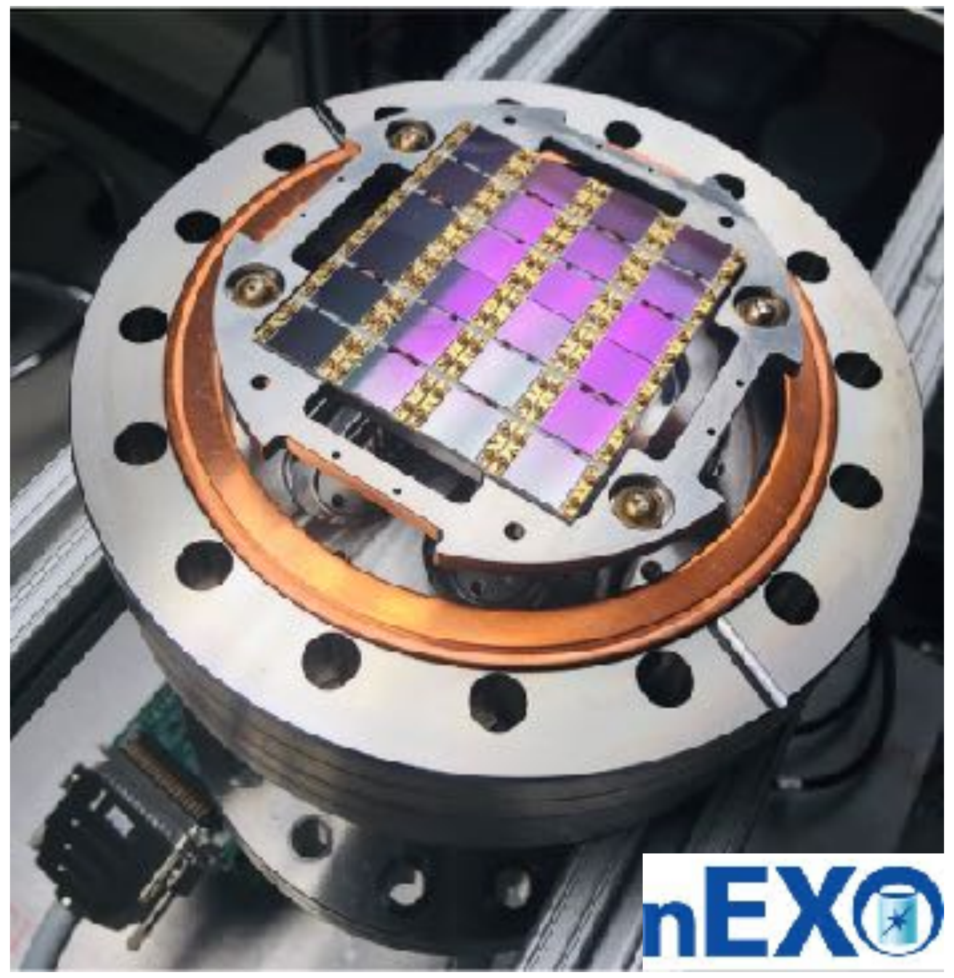
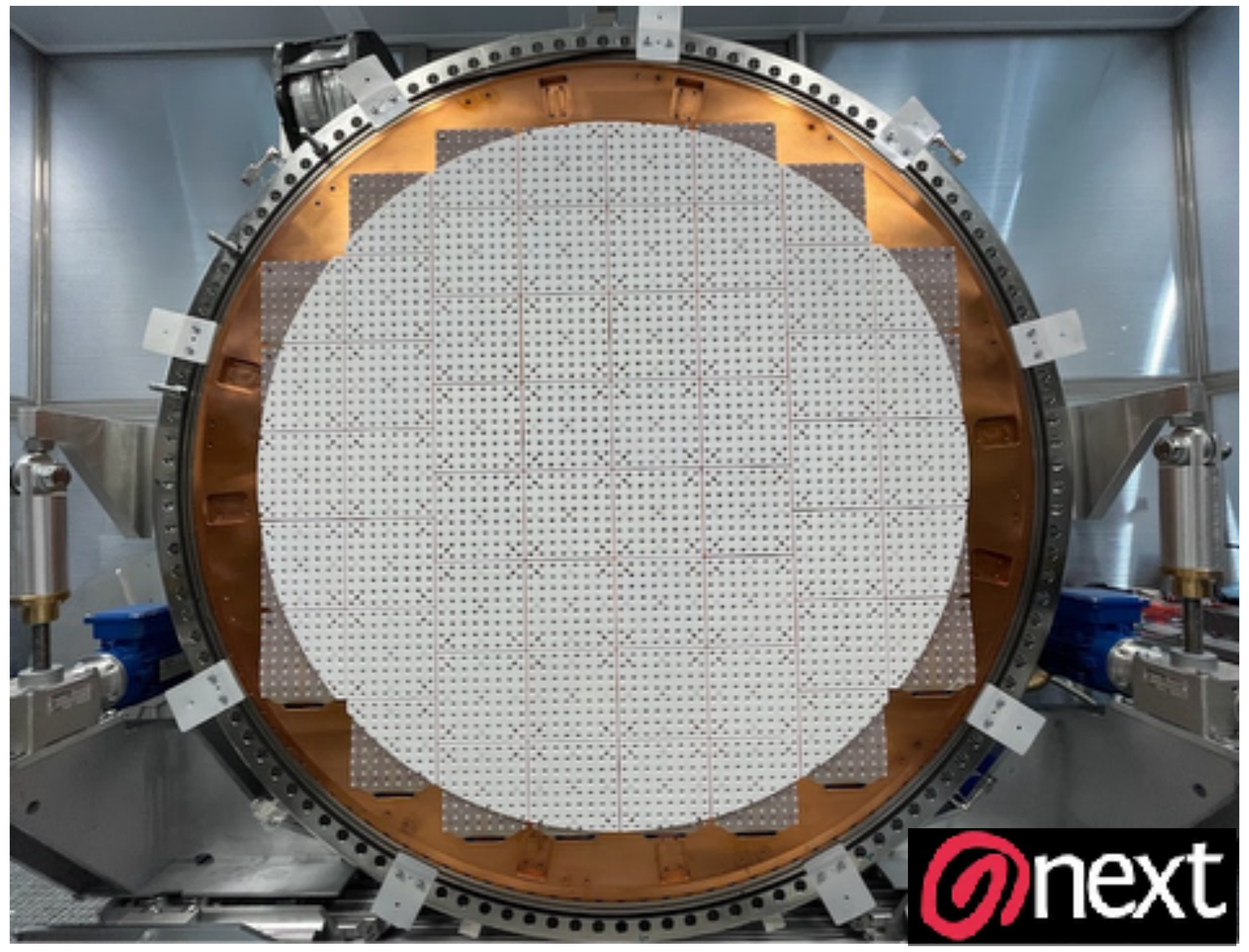
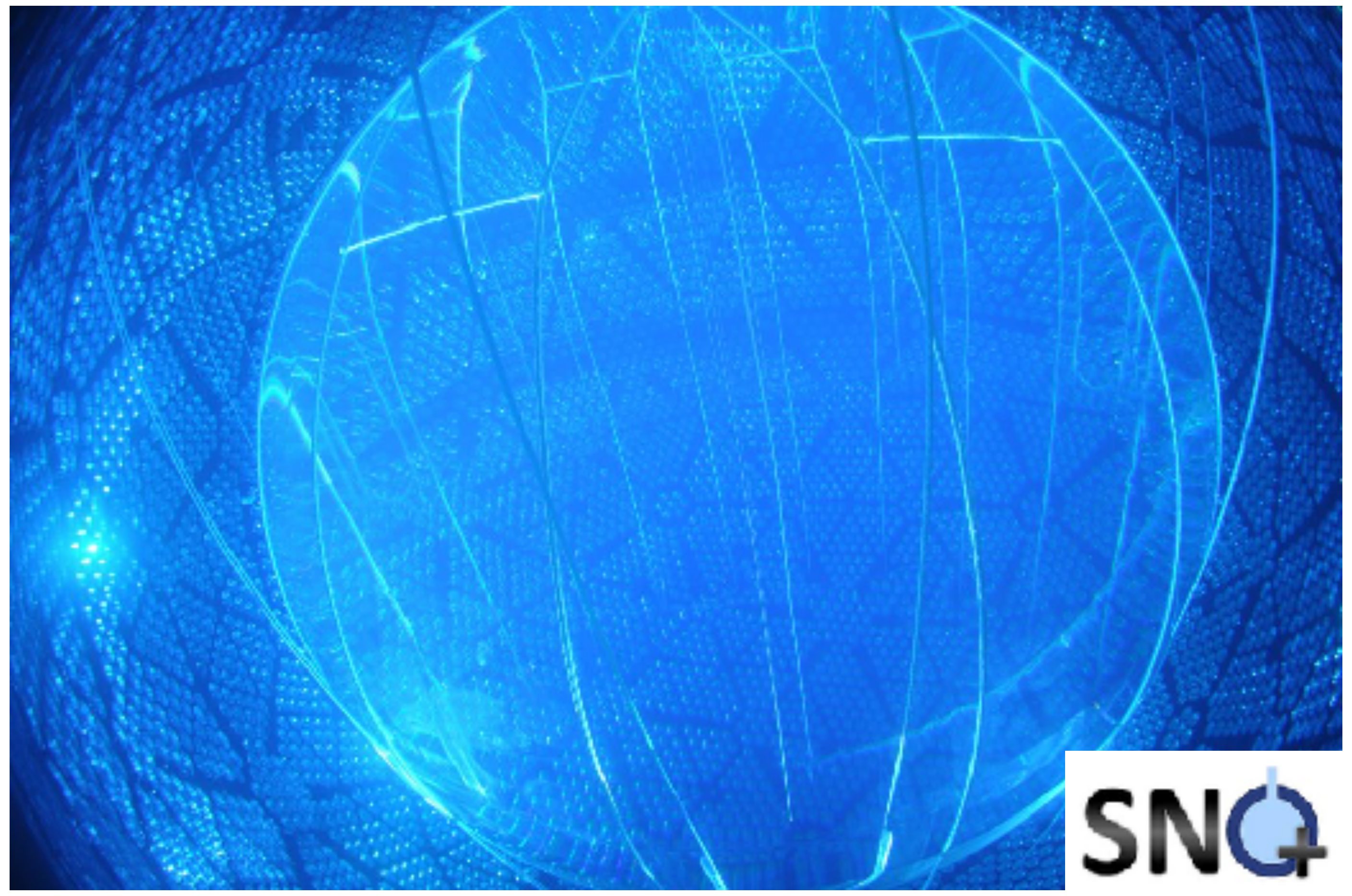
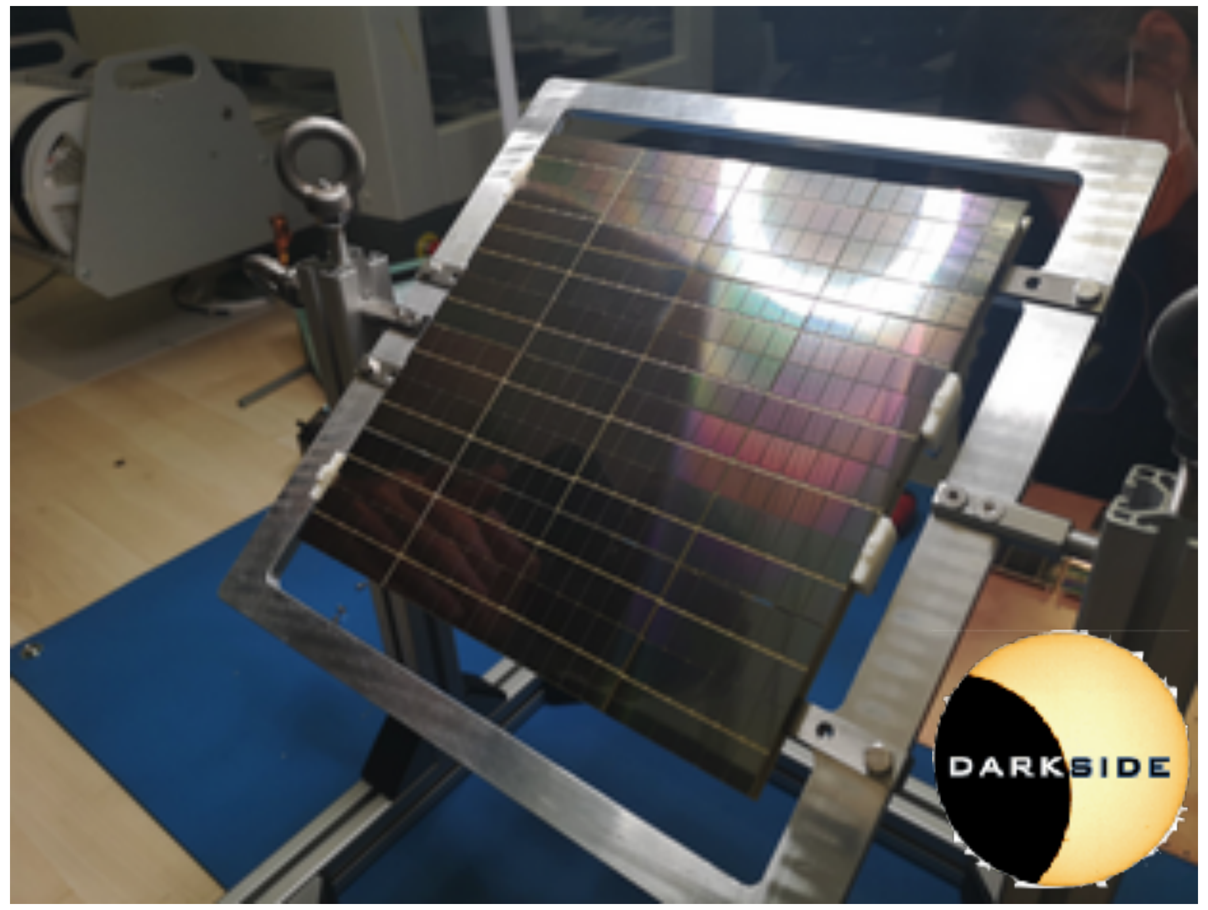








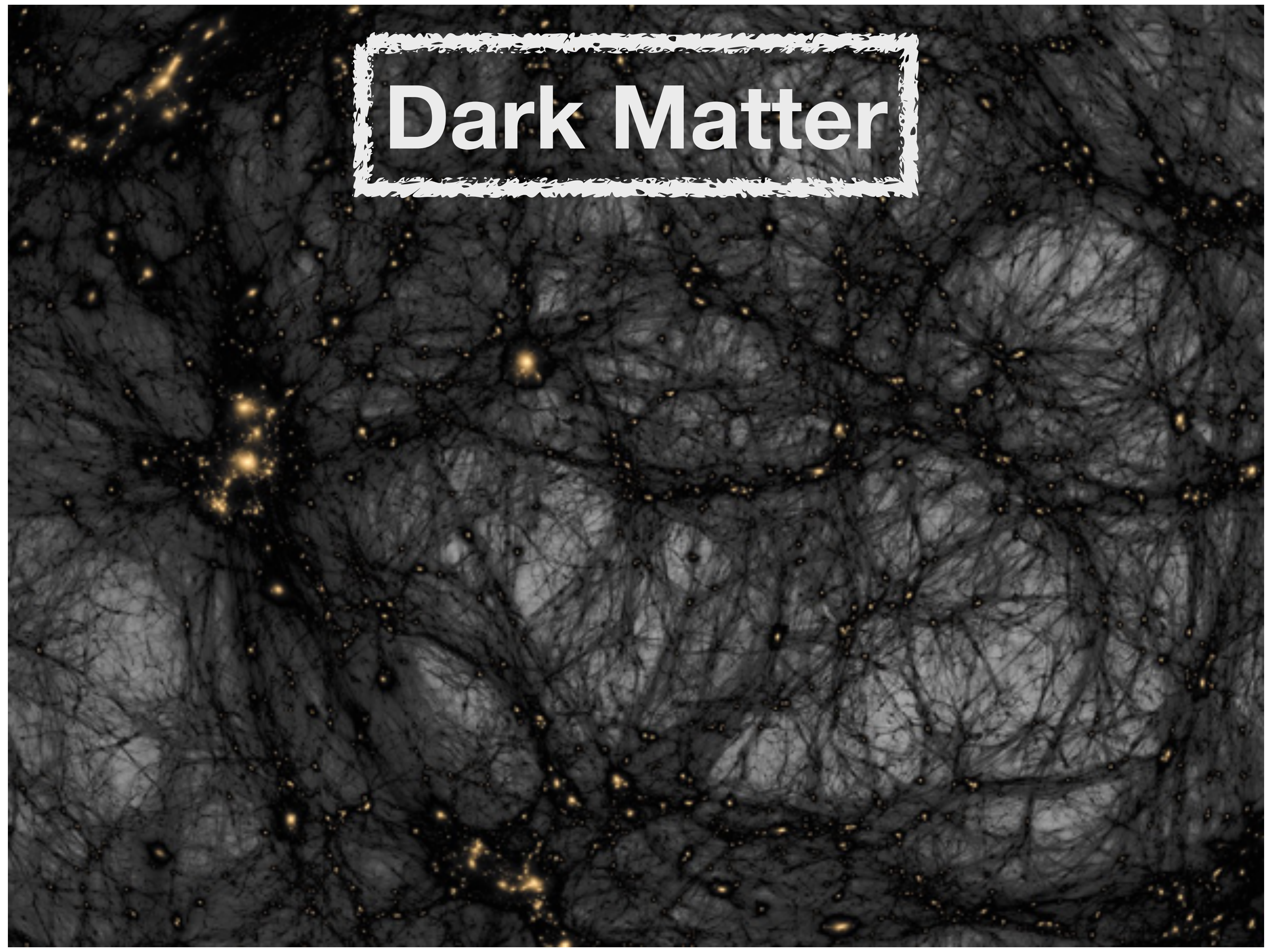
Light detection in neutrino and dark matter (liquid) detectors

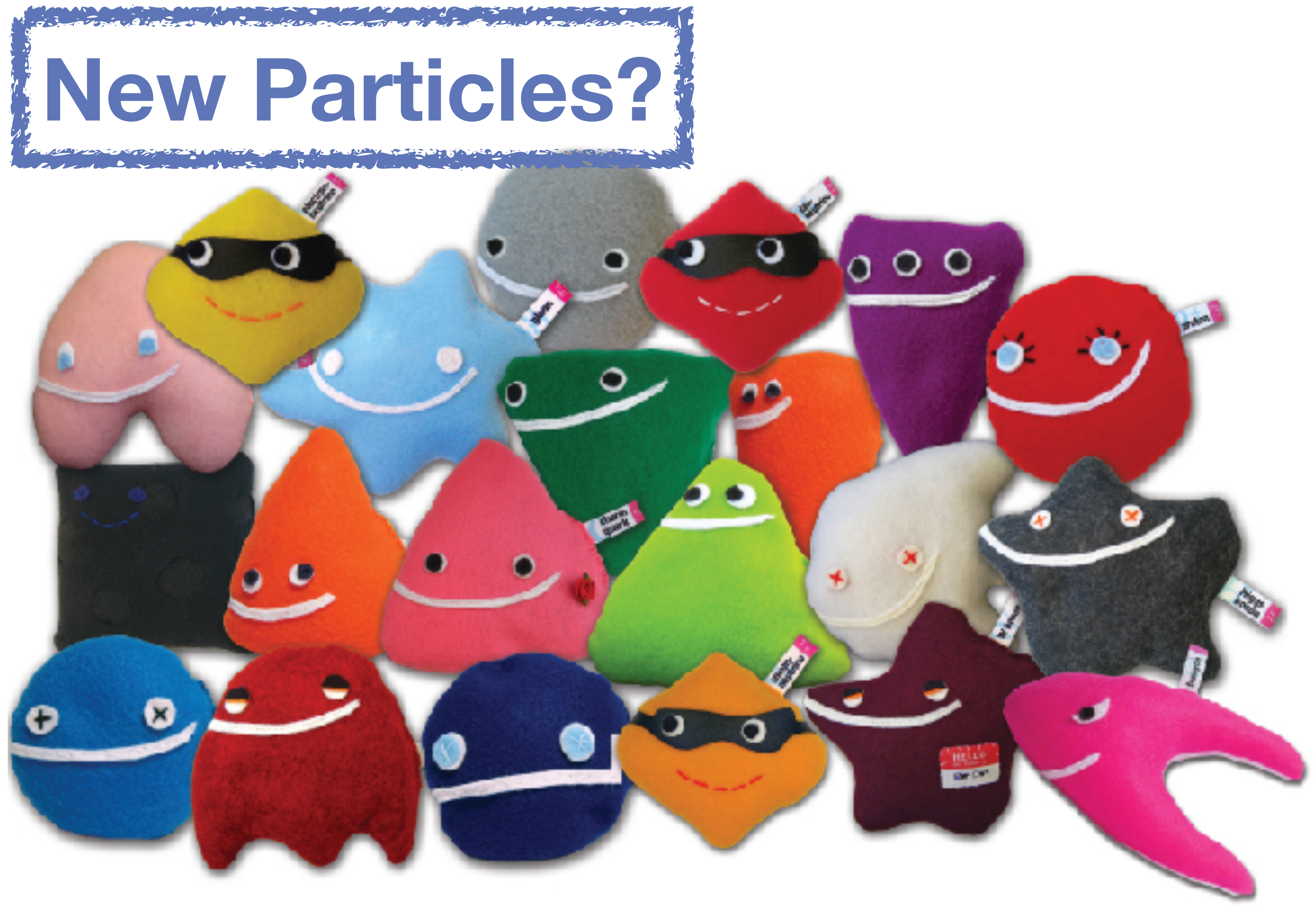
Roxanne Guénette

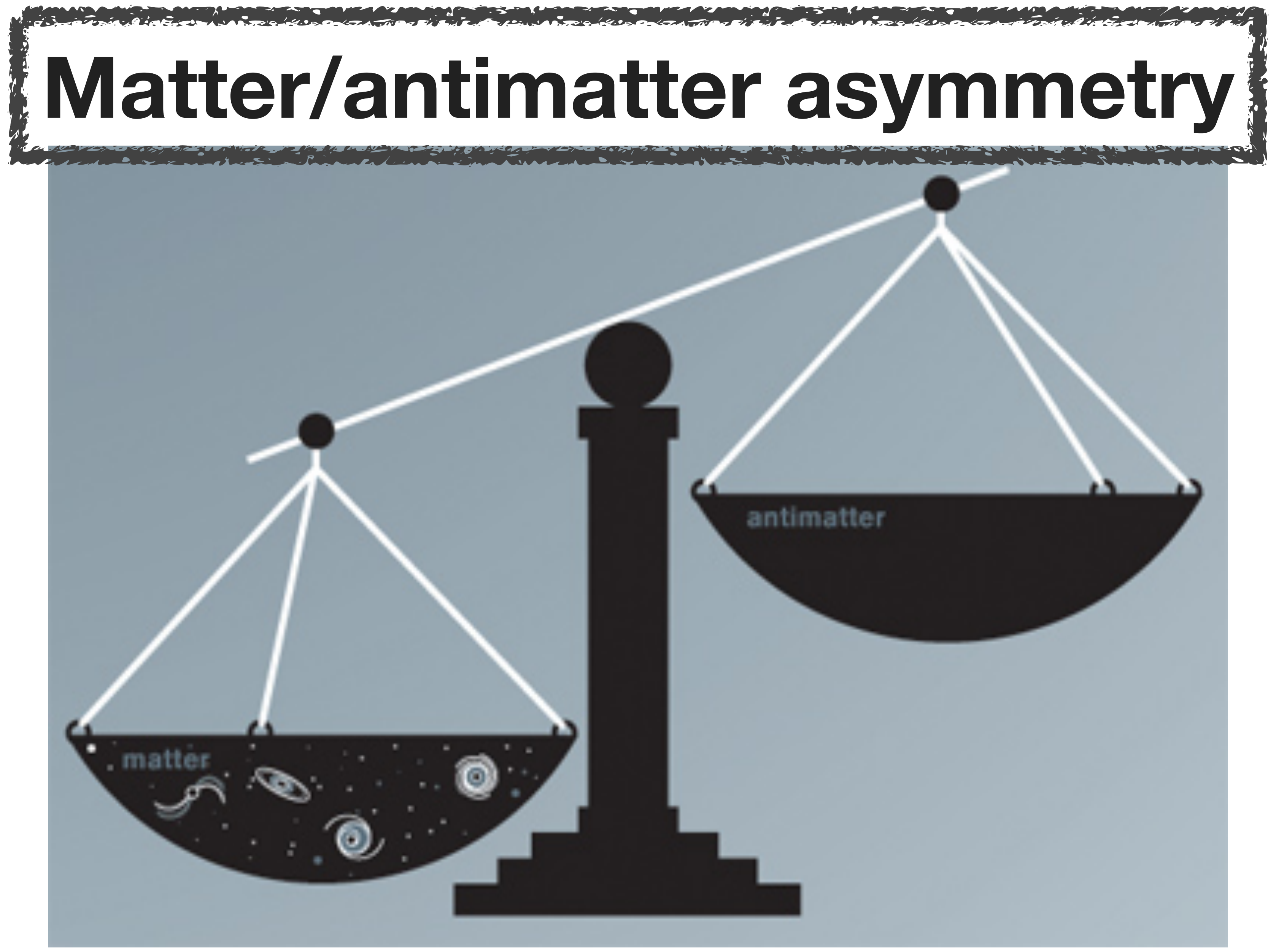
MANCHESTER 1824
The University of Manchester

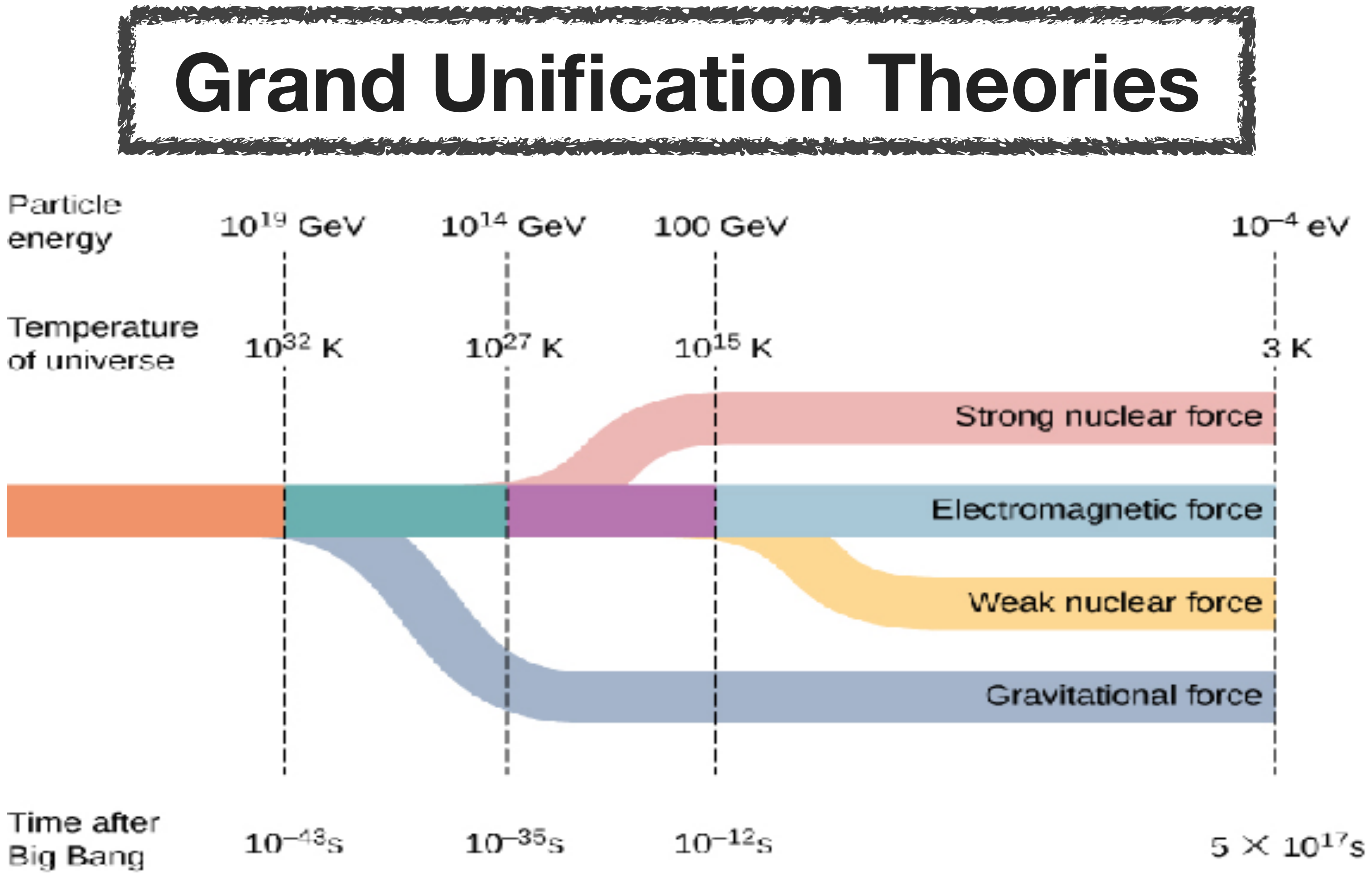
6th International Workshop on New Photon-Detectors
20 November 2024

The Big Questions of Particle Physics



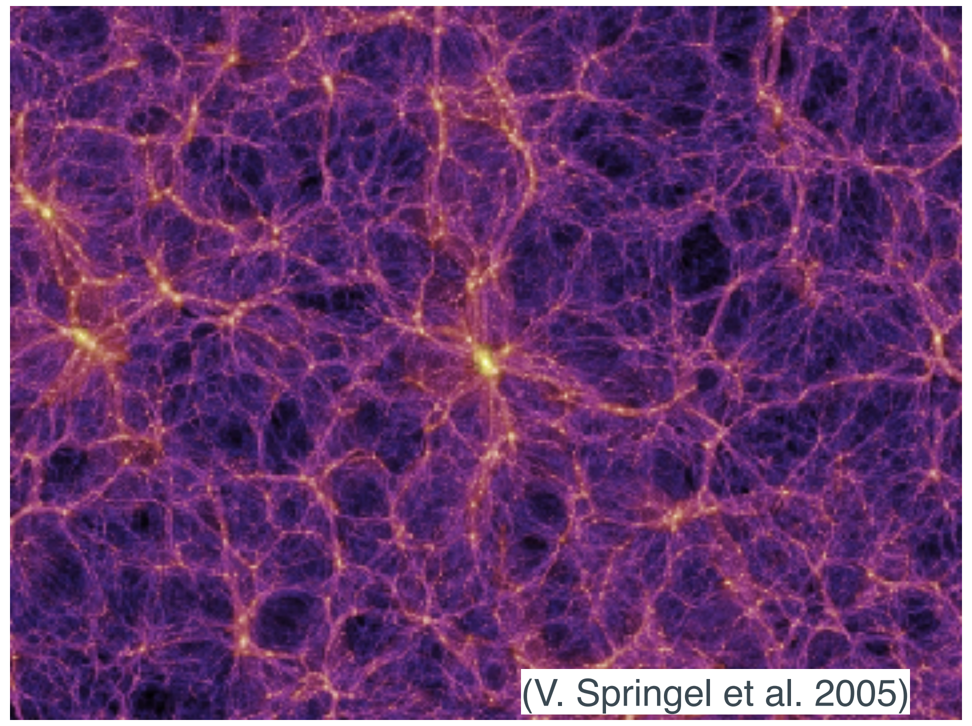


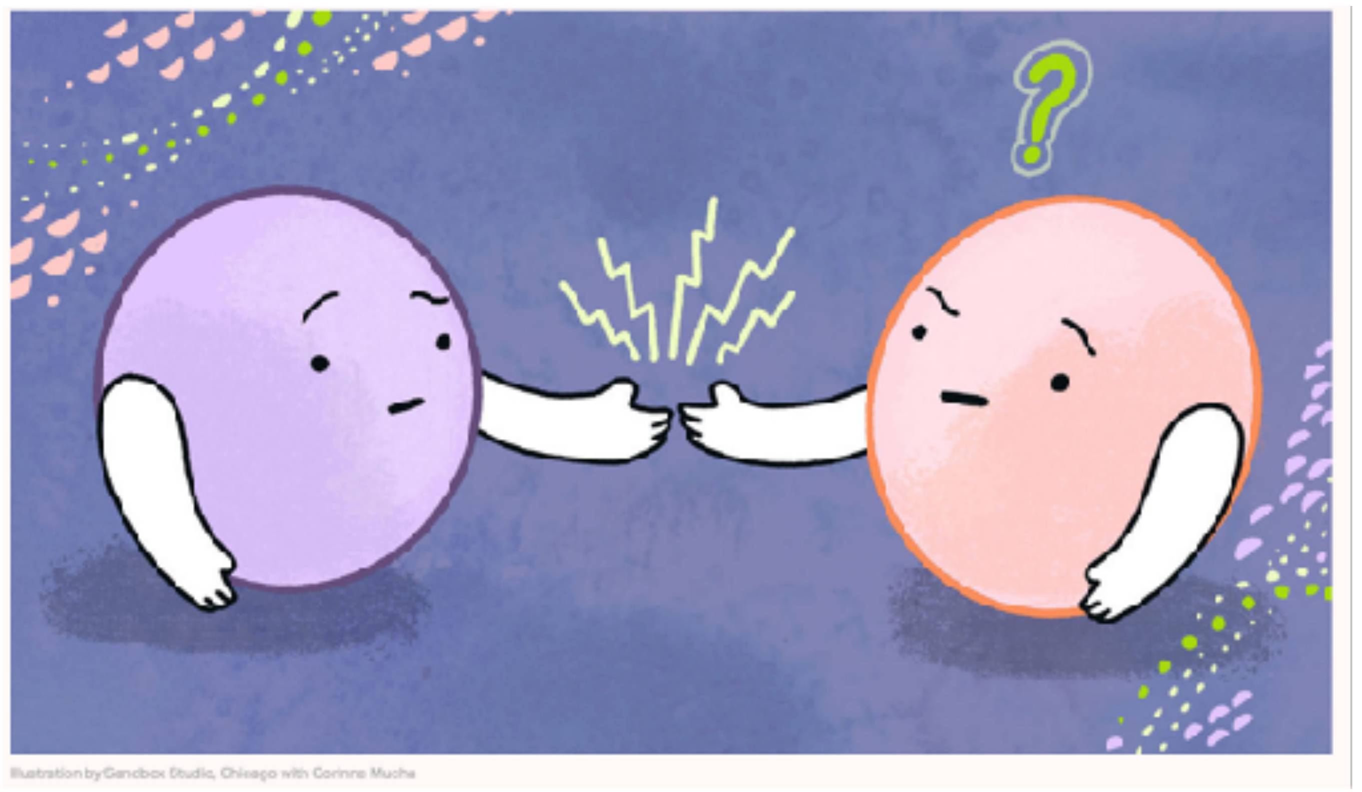


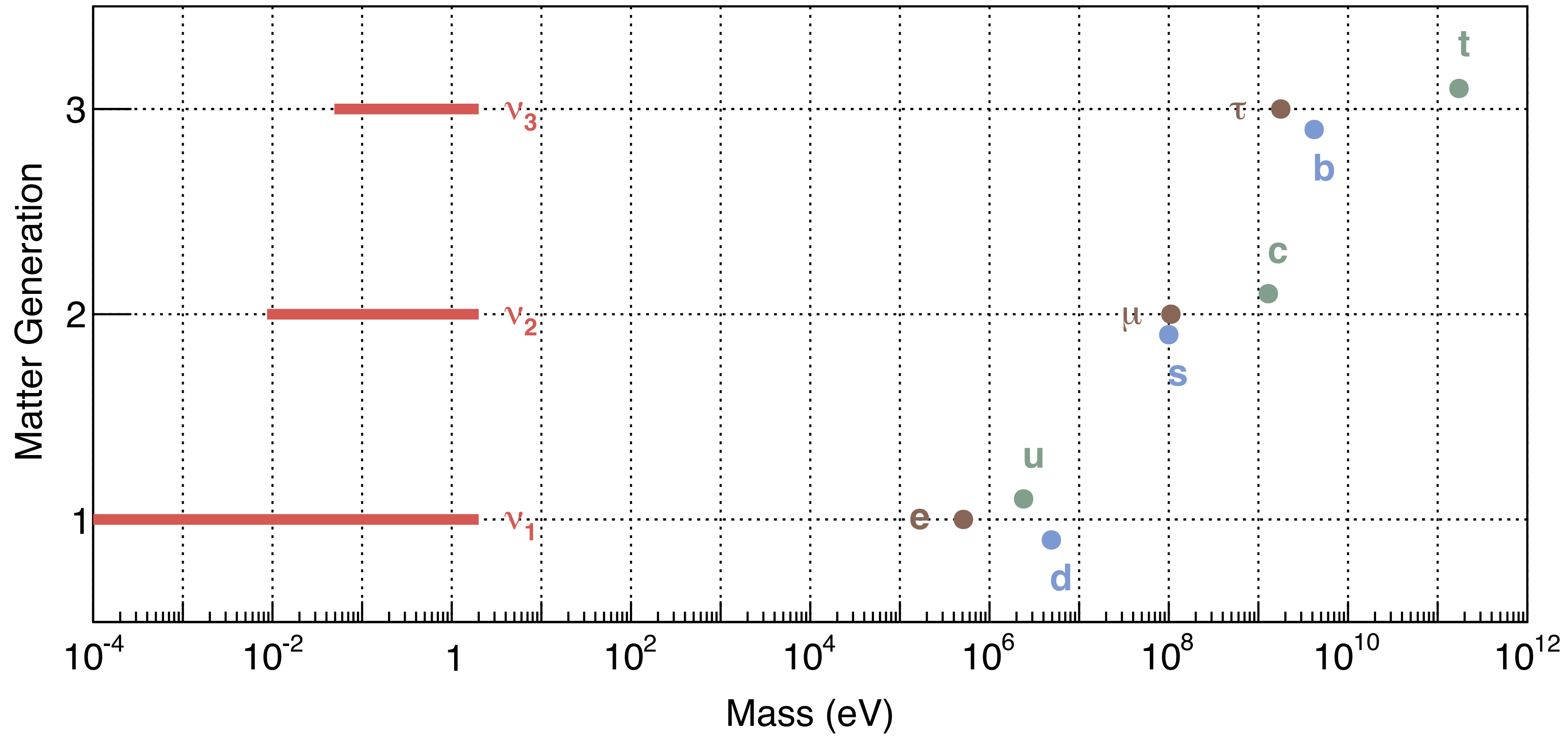


Dark Matter and Neutrinos

- What is Dark Matter?
- What is the nature of neutrinos?
- What is the mass of neutrinos?
- What is the neutrino mass ordering?
- Do neutrinos violate CP?
- Are there sterile neutrinos?







Dark Matter and Neutrinos

- What is Dark Matter? → **Direct searches**
- What is the nature of neutrinos? → **$0\nu\beta\beta$ searches**
- What is the mass of neutrinos? → **End point of β decays**
- What is the neutrino mass ordering?
- Do neutrinos violate CP?
- Are there sterile neutrinos?

→ **Neutrino oscillation**

Dark Matter and Neutrinos

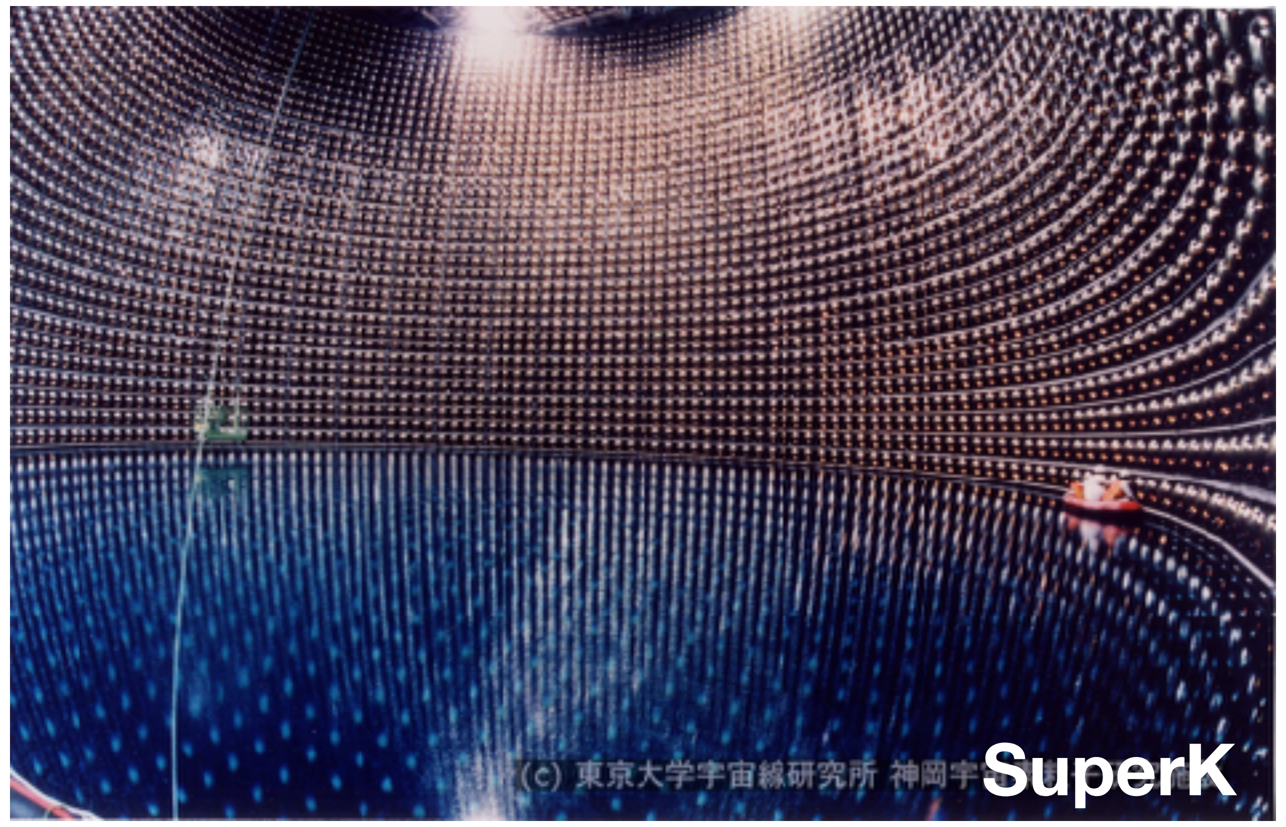
- What is Dark Matter?
- What is the nature of neutrinos?
- What is the mass of neutrinos?
- What is the neutrino mass ordering?
- Do neutrinos violate CP?
- Are there sterile neutrinos?

Large Liquid Detectors!

Liquid detector technologies

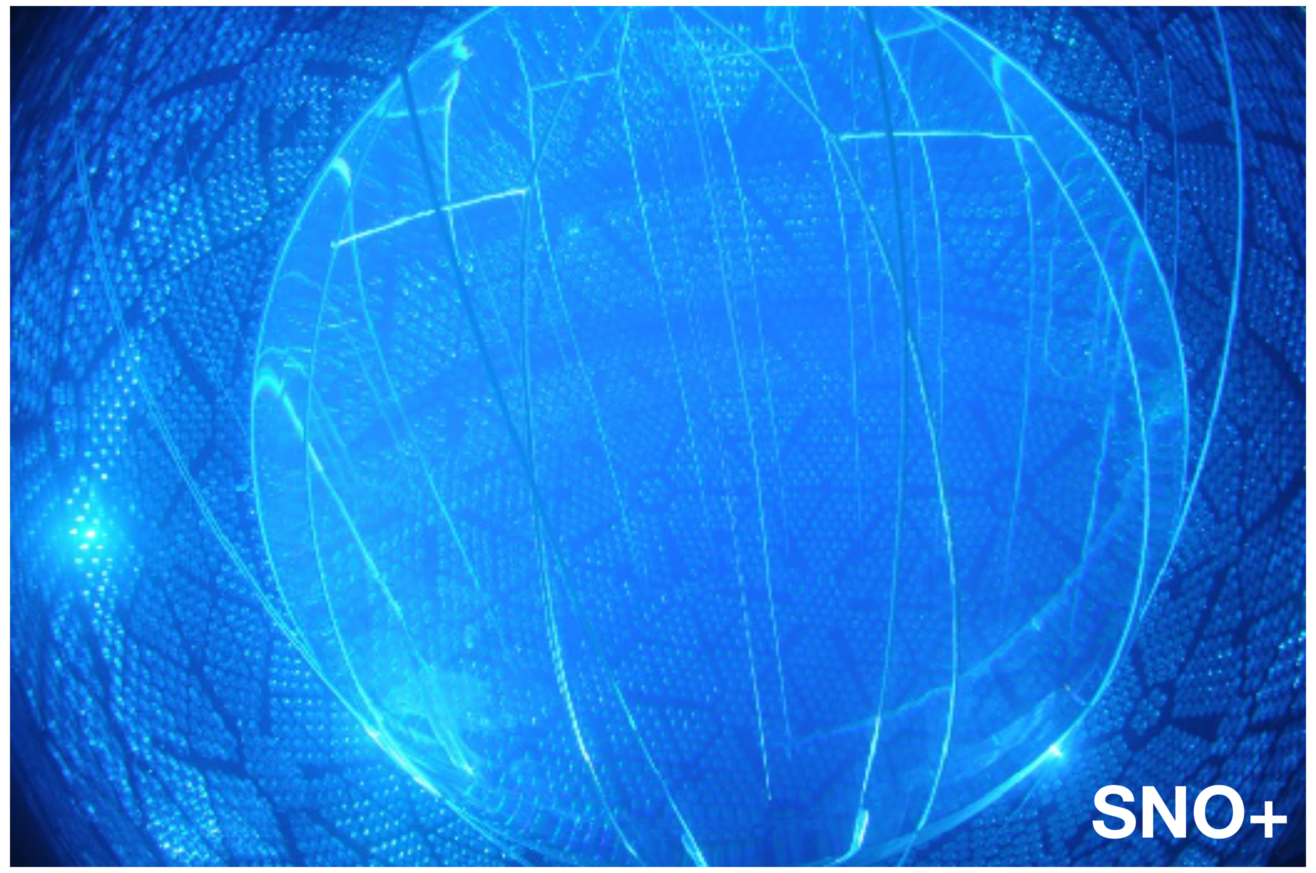
Water Cherenkov

- Established technology
- Cherenkov light
- Large-area photon detectors with some granularity (multiPMTs)
- Gd doping to increase sensitivity to neutrons



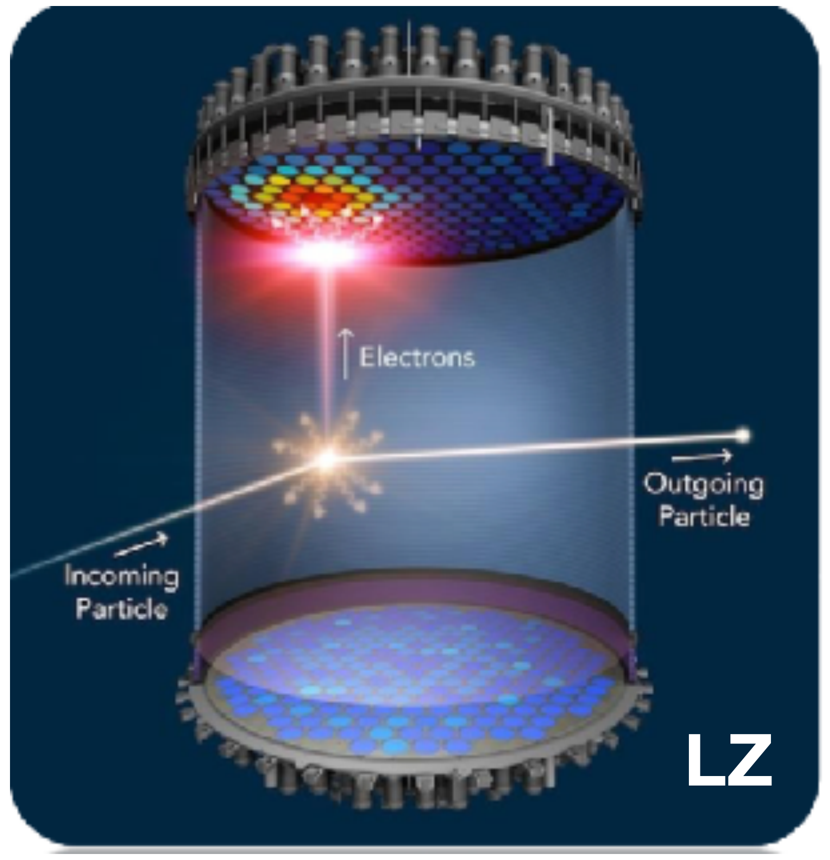
Liquid Scintillators

- Established technology
- Scintillation light (visible)
- Hybrid development for dual (Cherenkov + scintillation)
- Isotope loading (0νββ)



Noble Elements

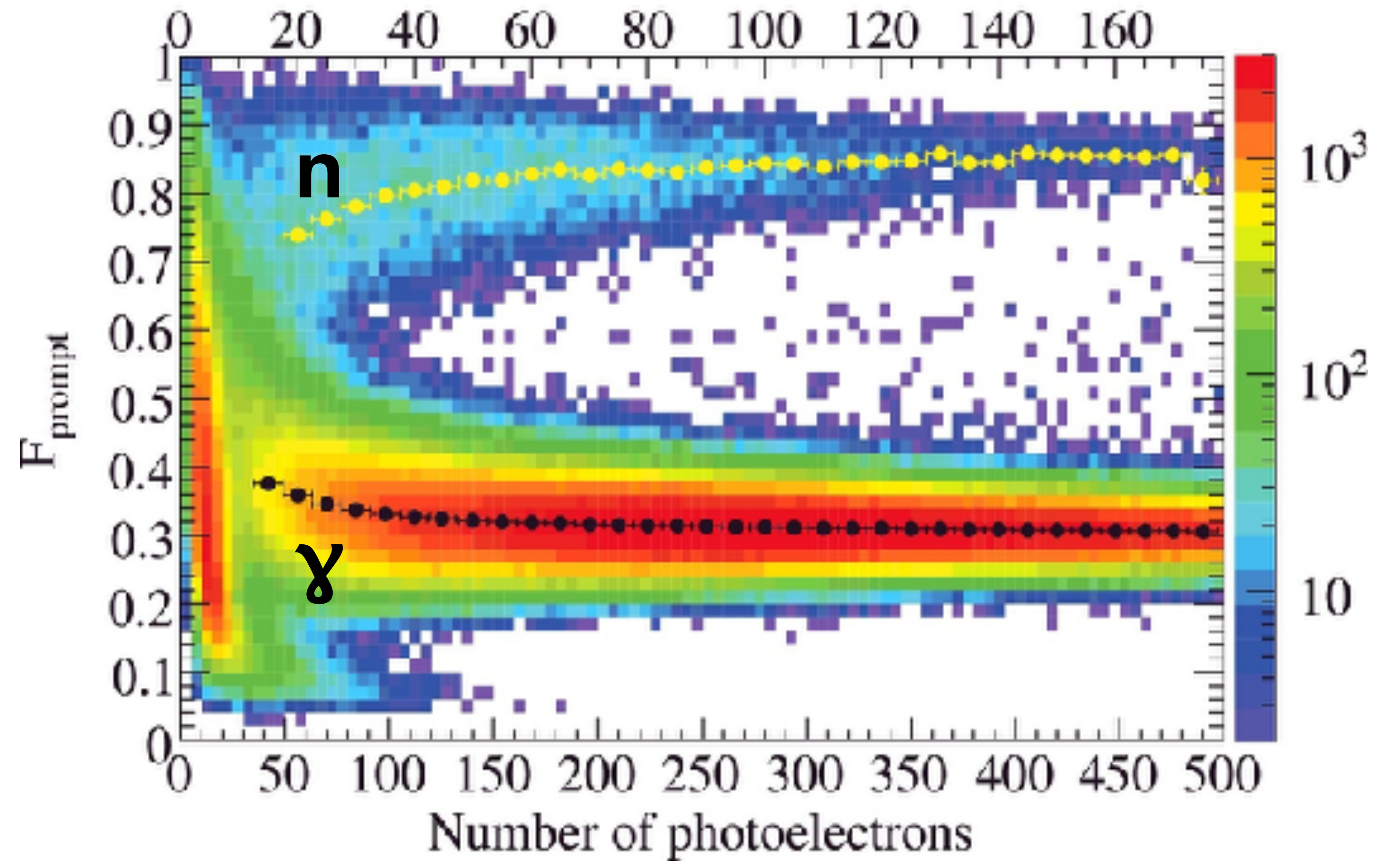
- More recent technology
- Mostly Ar & Xe
- VUV scintillation light (Ar:128nm, Xe:175nm)
- Energy deposition shared between light (scintillation), charge (ionization) and heat (phonons)

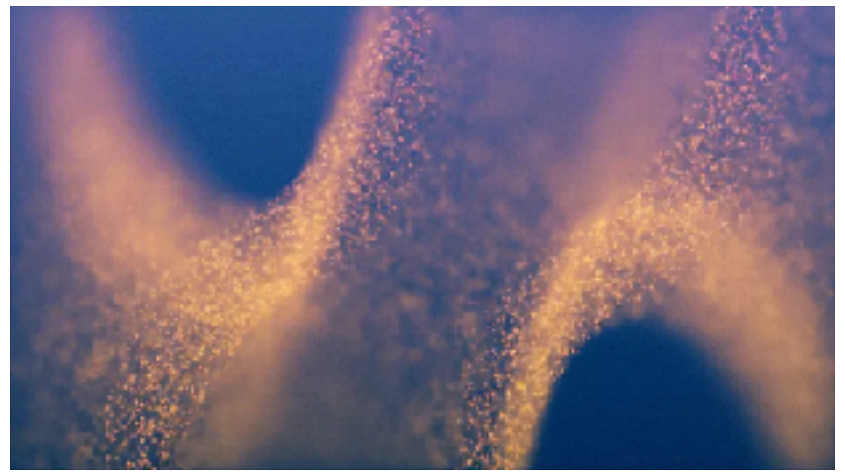


Light in detectors

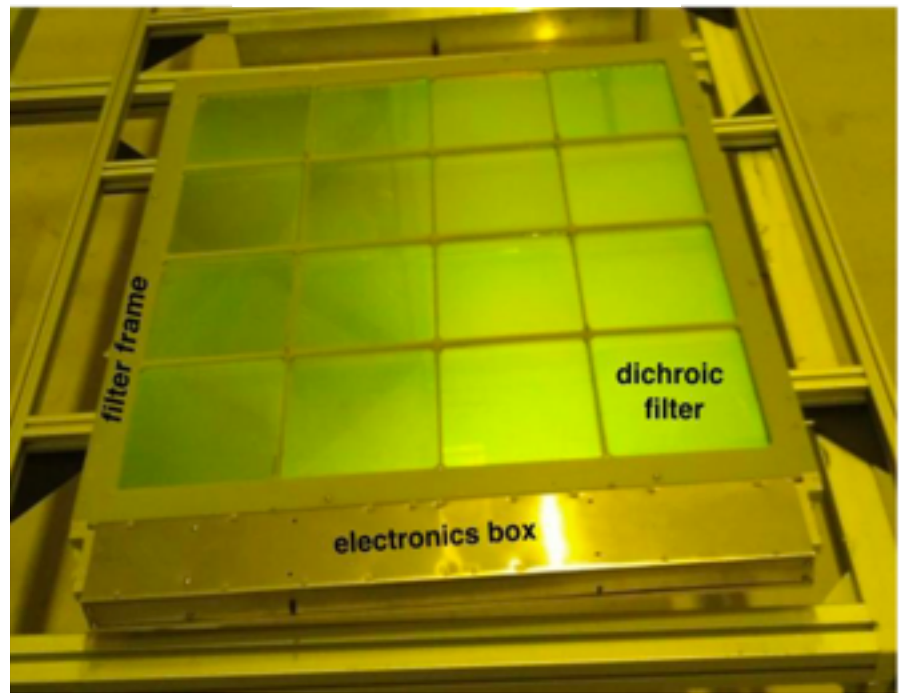
- Light is produced in detectors by charged particle energy deposition
- Light signals allow to reconstruct: time of arrival, energy of particles, types of particles, particle direction…
- To reconstruct all the light information we need to:
  - ➡ Understand the light production mechanisms
  - ➡ Understand and model light propagation
  - ➡ Collect & Detect light

PSD (DEAP-1)

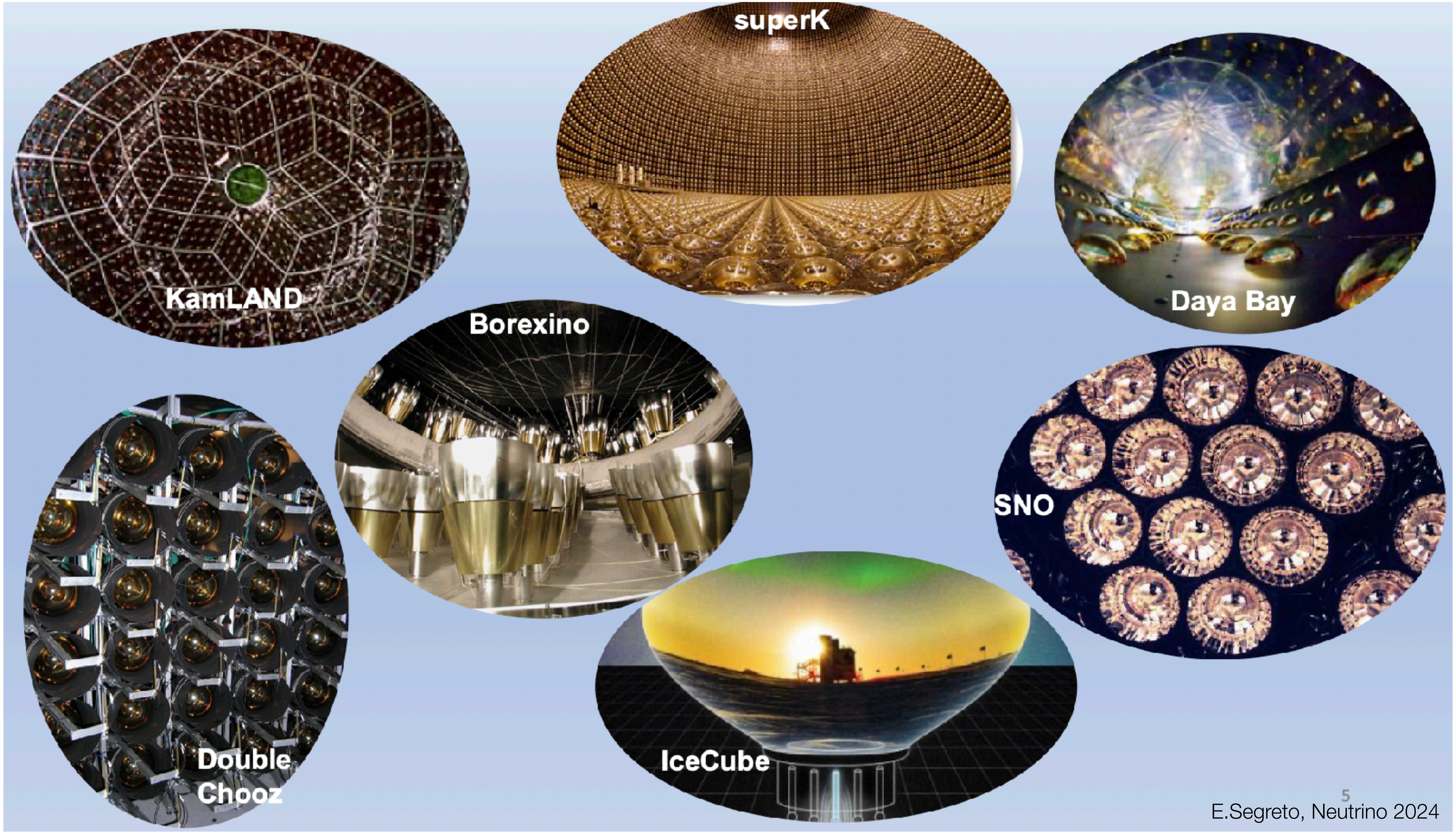




X-ARAPUCA



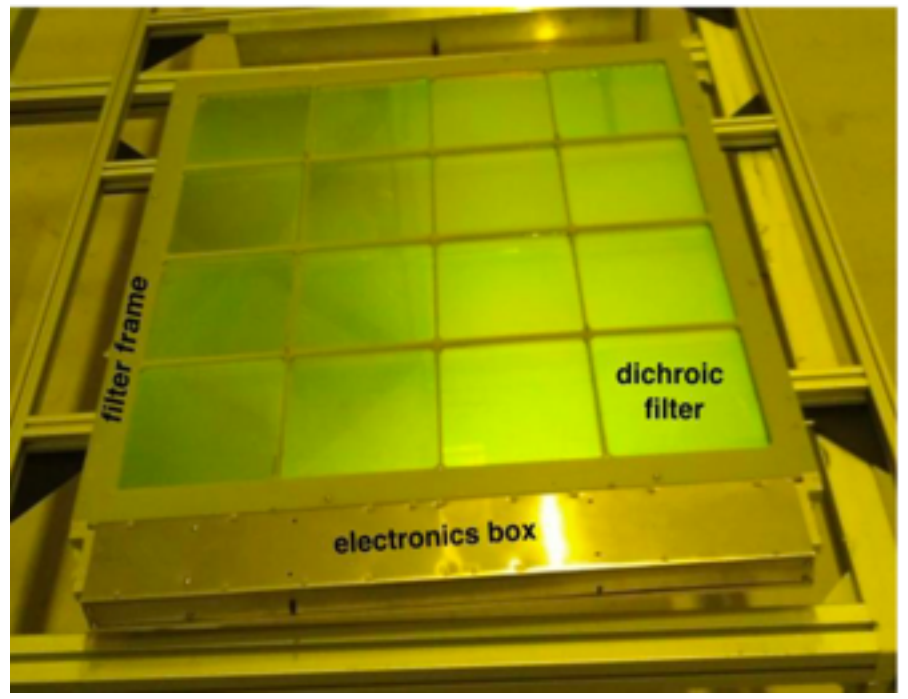
PMTs and Neutrinos (non exhaustive list)



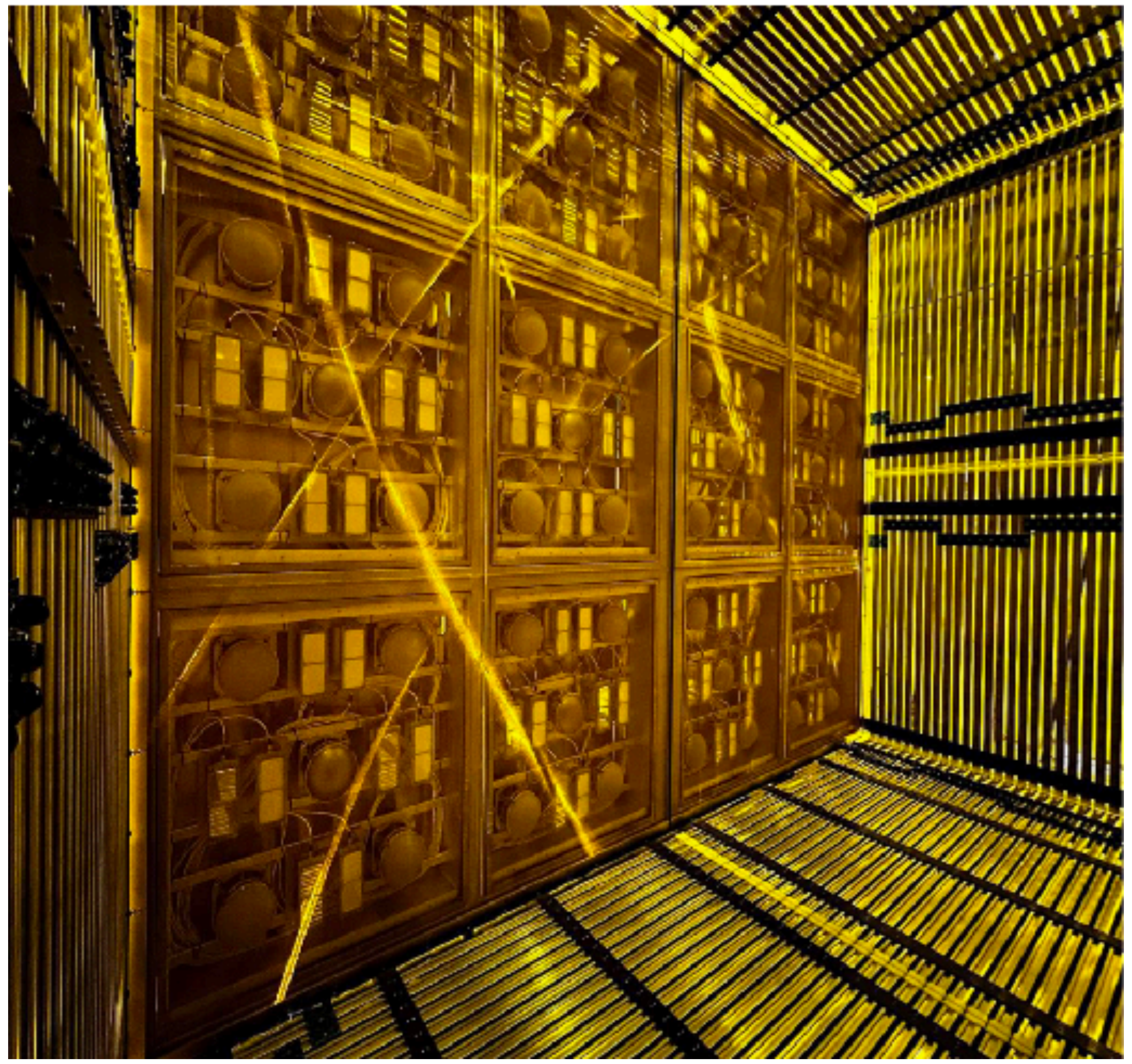
E.Segreto, Neutrino 2024

SiPMs and Neutrinos (non exhaustive list)

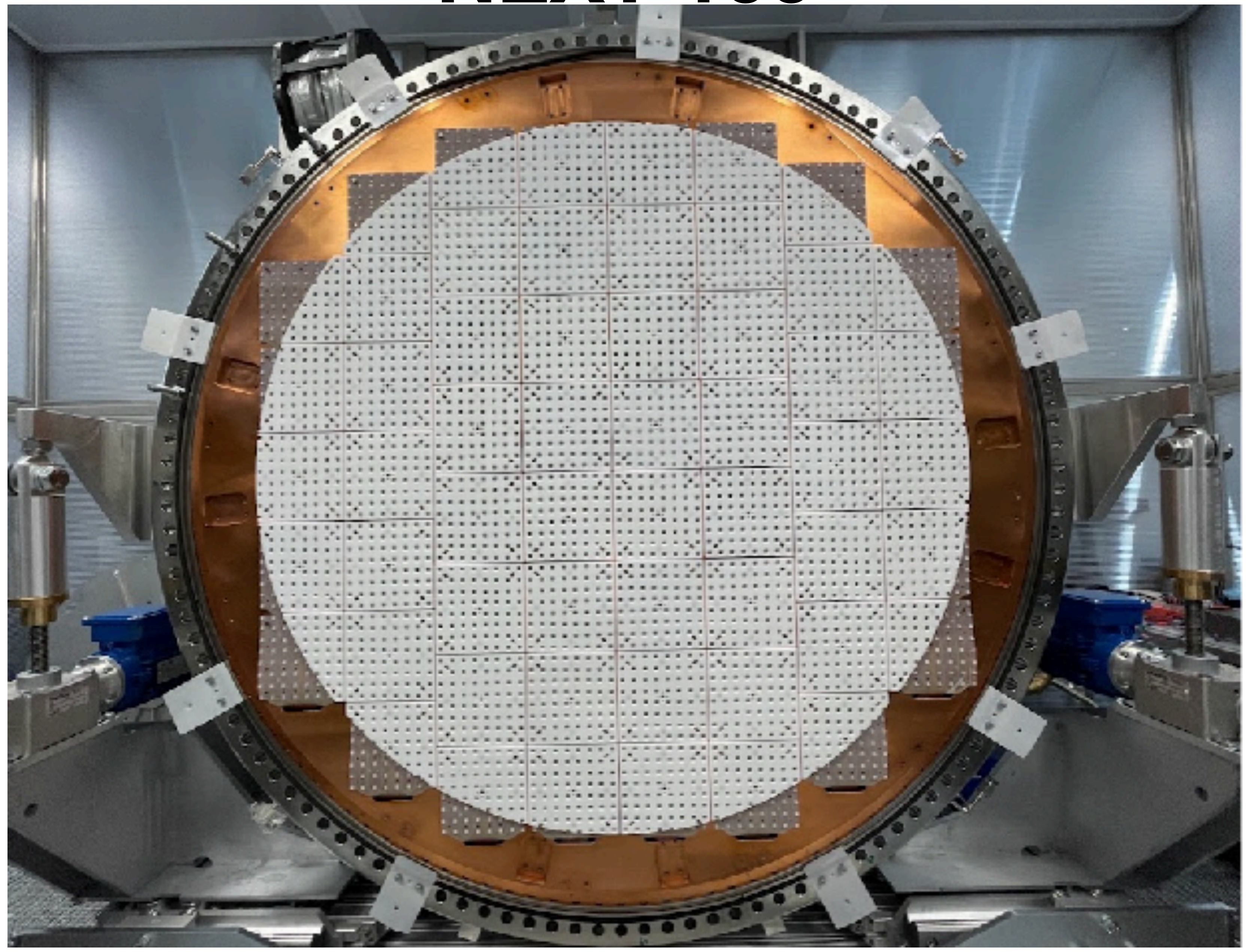
X-ARAPUCA



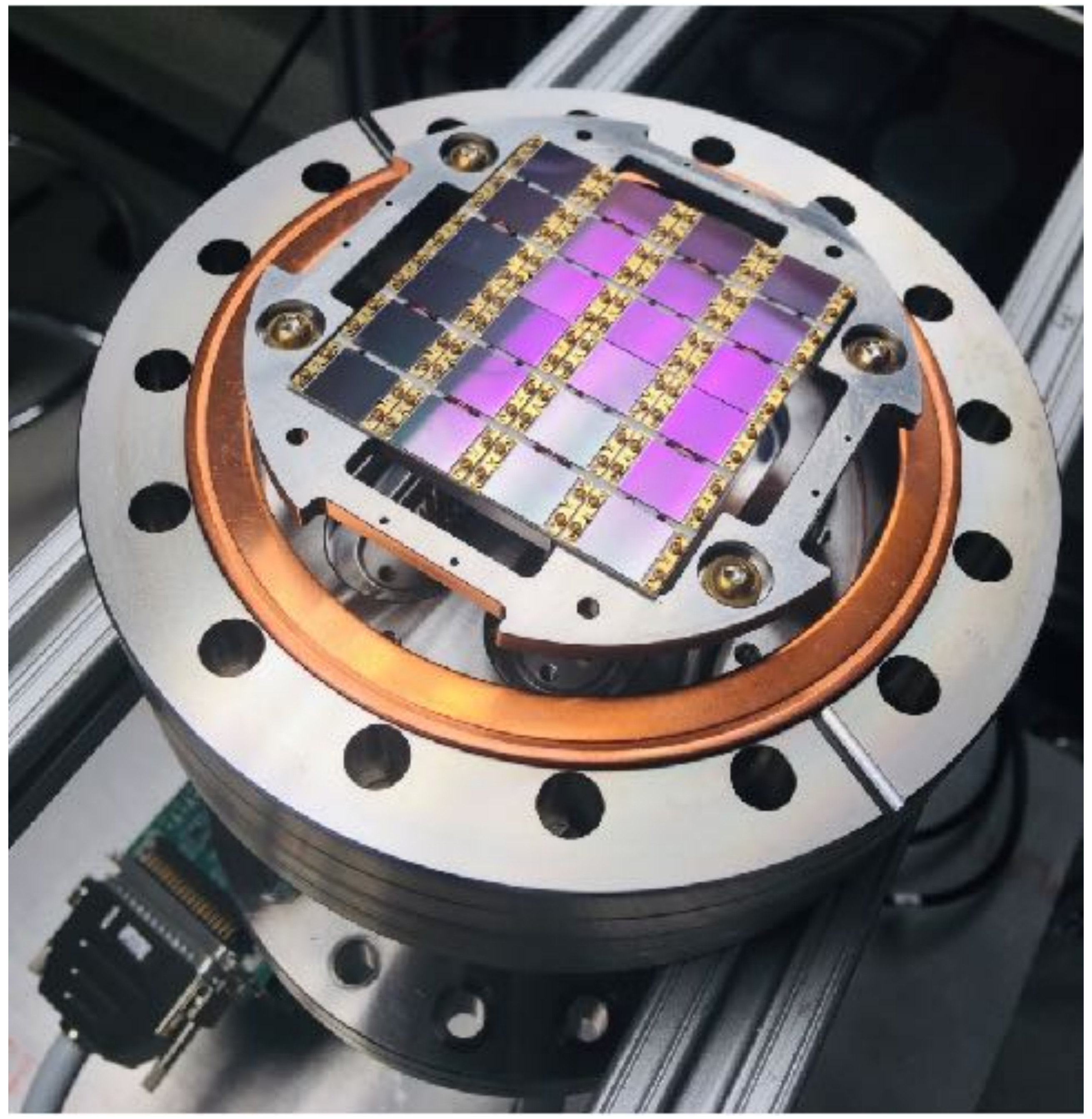
SBND



NEXT-100

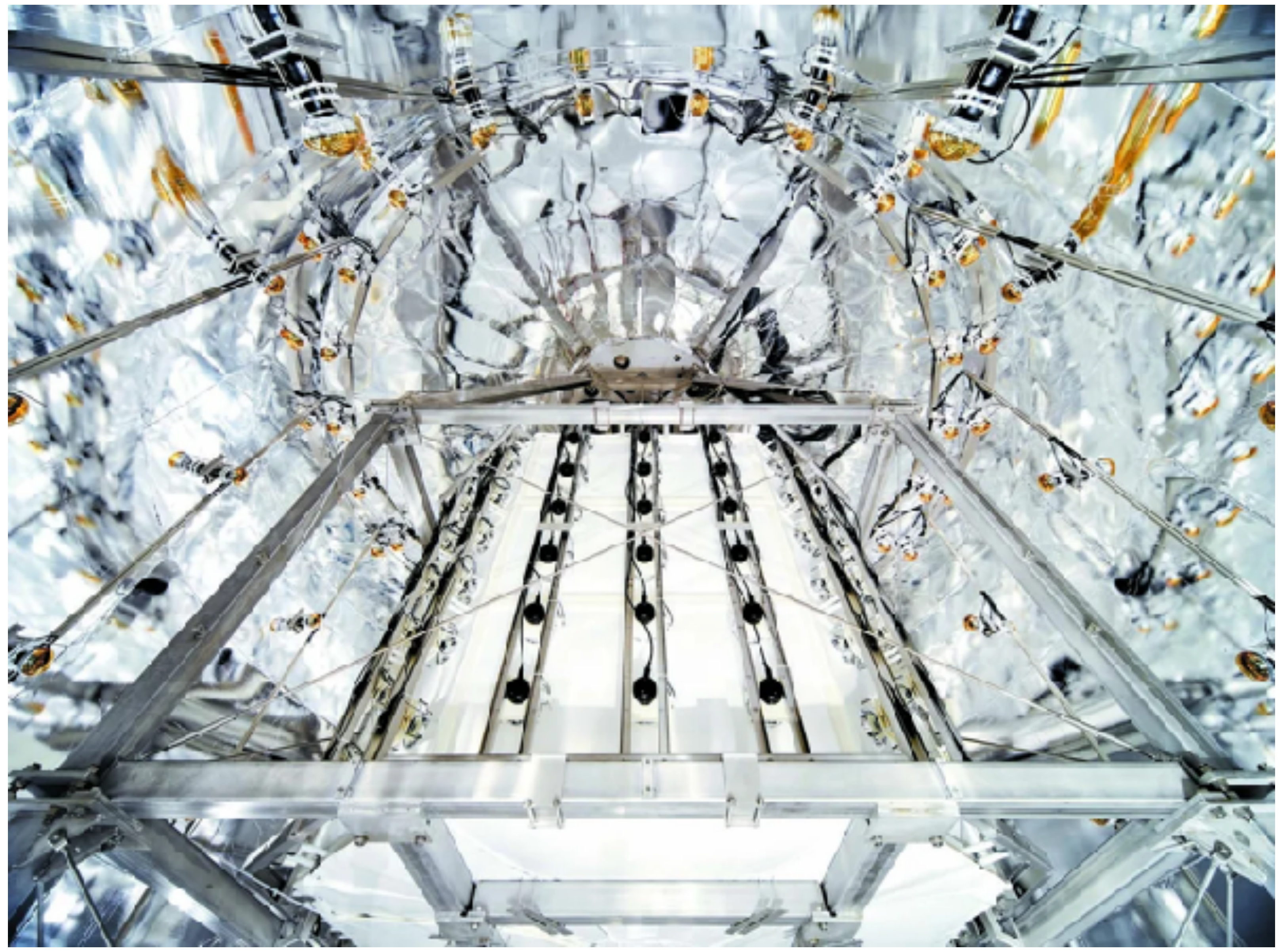


nEXO SiPM tile



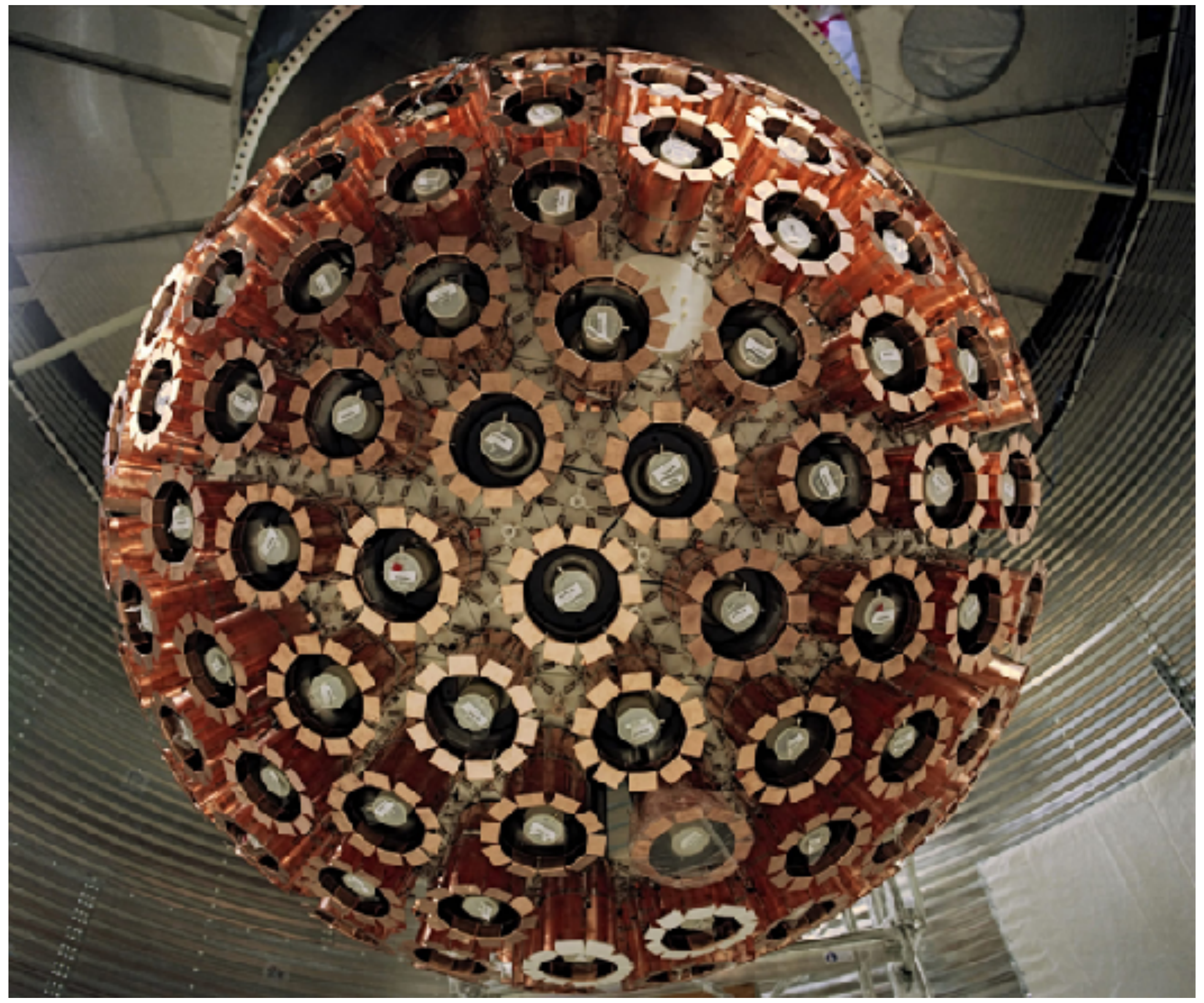
PMTs and Dark Matter (non exhaustive list)

LZ



XENON

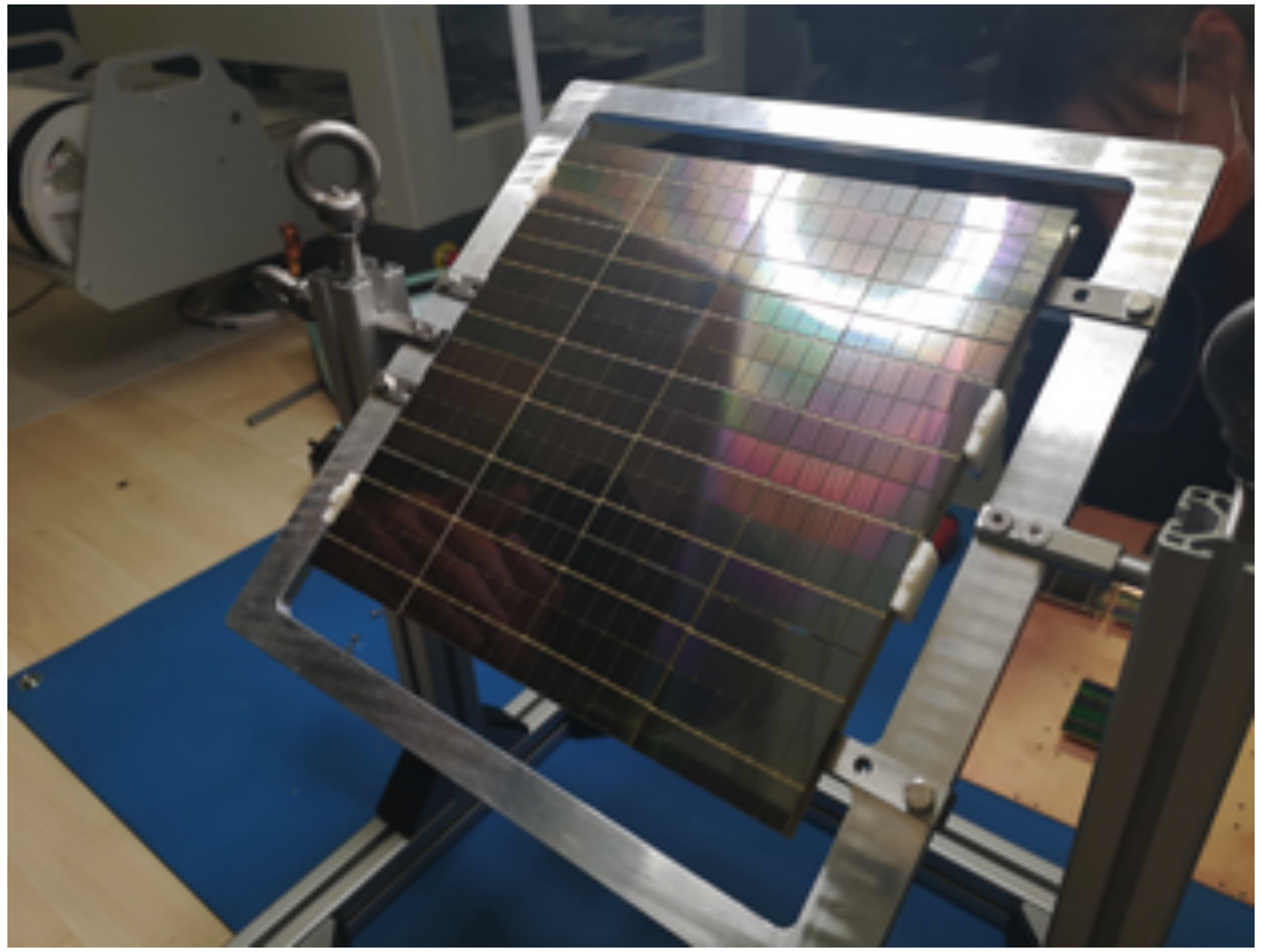
DEAP-3600



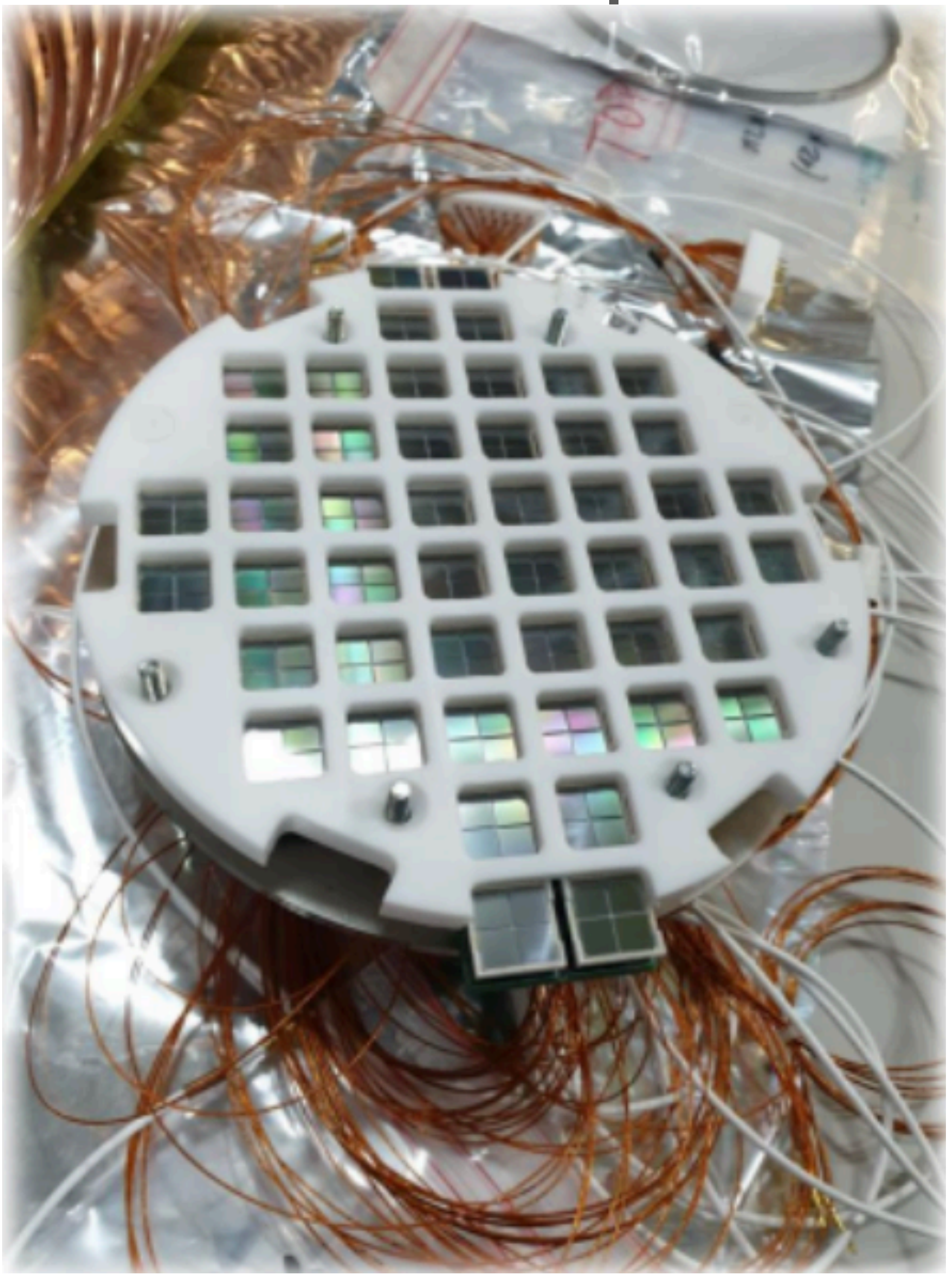
DarkSide-50

SiPMs and Dark Matter (non exhaustive list)

DarkSide-20k SiPM tile



Xenoscope



Physics needs for the future

Neutrinos

- **Push Energy thresholds down** to ~1MeV to enhance oscillation physics, supernovae νs study, to enable solar νs …
- **Unambiguous readout**
- **Scalability**

Dark Matter

- **Push Energy thresholds down** to 1 meV/10 eV/1 keV to enable low mass DM/1 GeV DM/WIMPs
- **Reduce background rates**
- **Scalability**

$0\nu\beta\beta$

- **Improve Energy Resolution** to sub-% FWHM
- **Reduce background rates**
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0νββ

- **Improve Energy Resolution** to sub-% FWHM
- **Reduce background rates**
- **Scalability**

Improving light readout can address all of these!

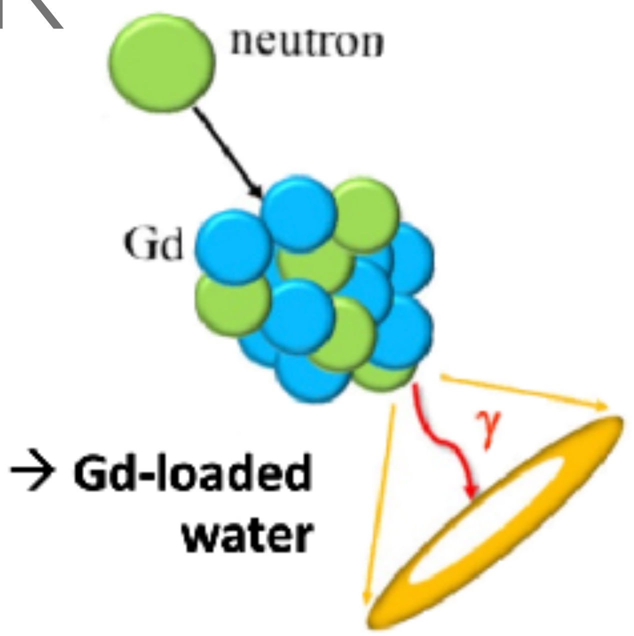
Current Goals (non exhaustive list)

Water Cherenkov

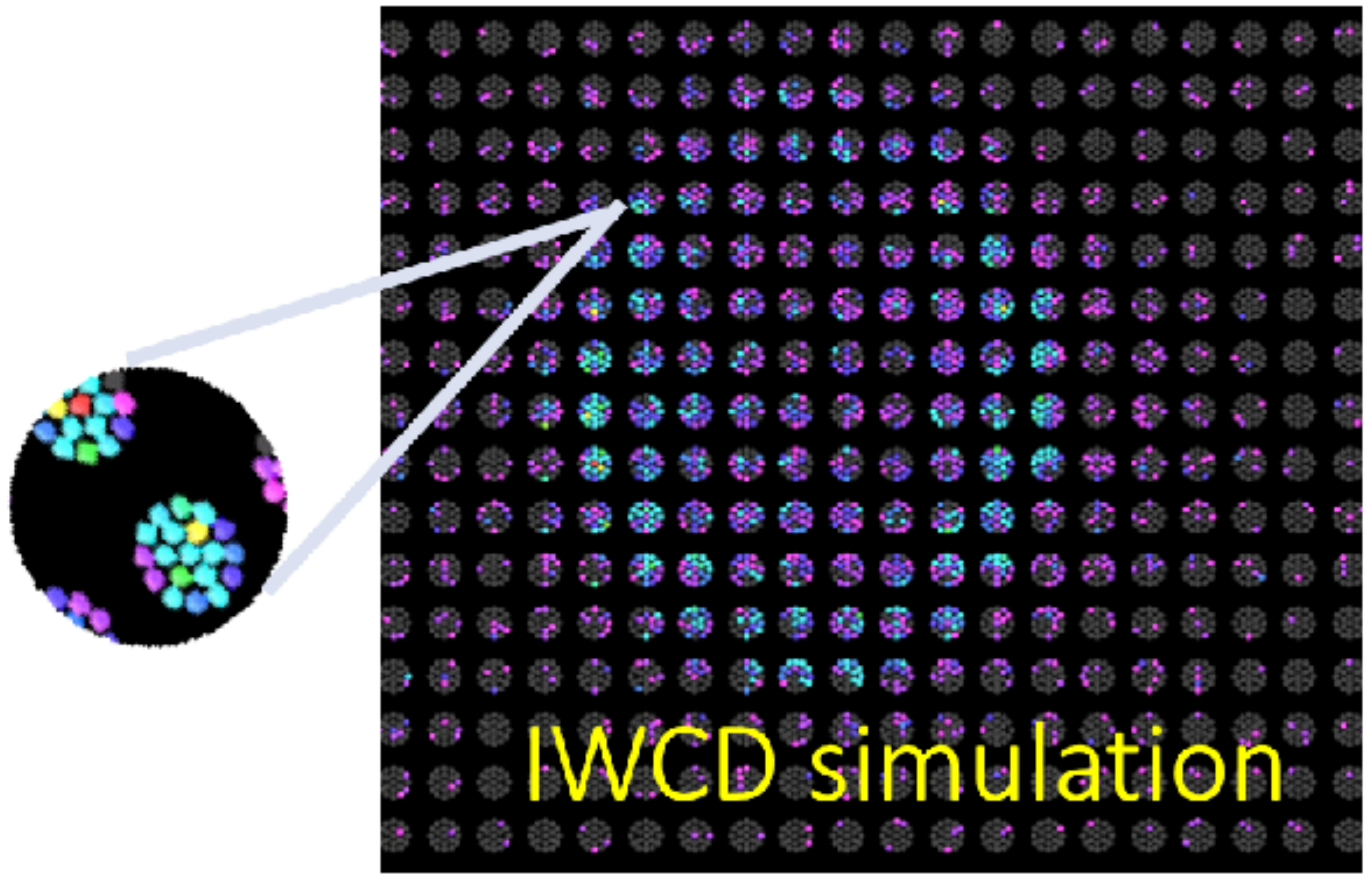
- Mainly targeted at neutrino physics:

➡ **Neutrino oscillation**: HyperK

- Gd-doping (>0.1 %)
- Purification and recovery



HyperK



➡ **Neutrino astronomy**:

KM3Net

TRIDENT

Current Goals (non exhaustive list)

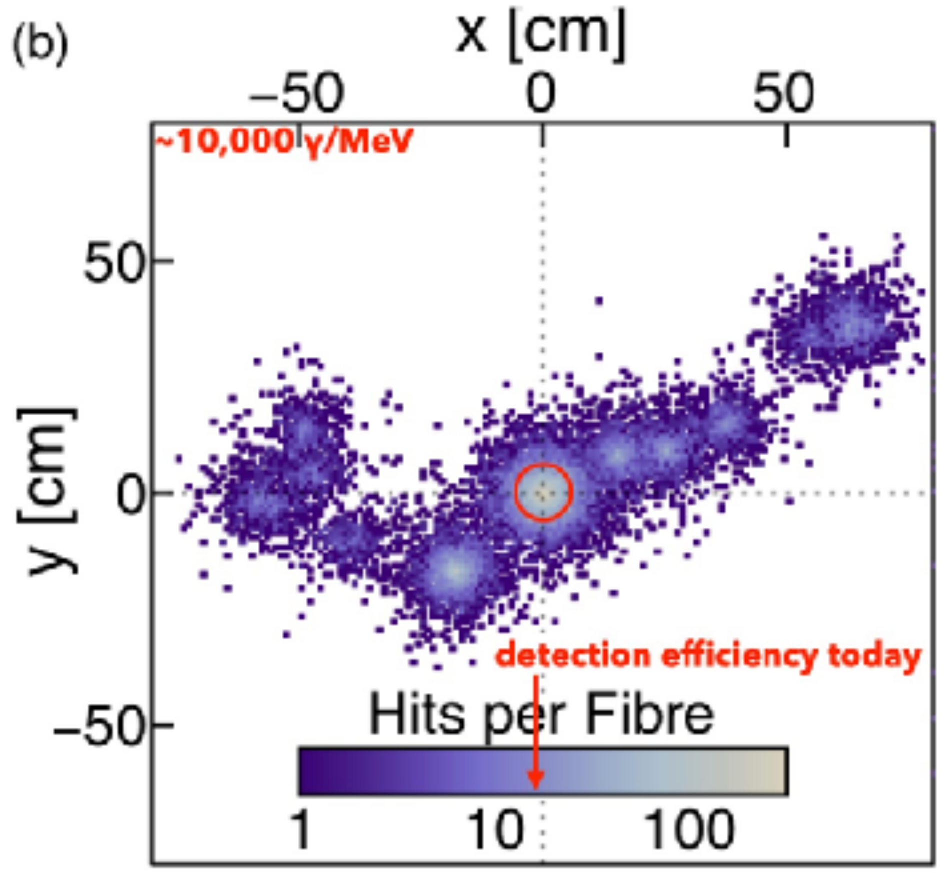
Liquid Scintillators

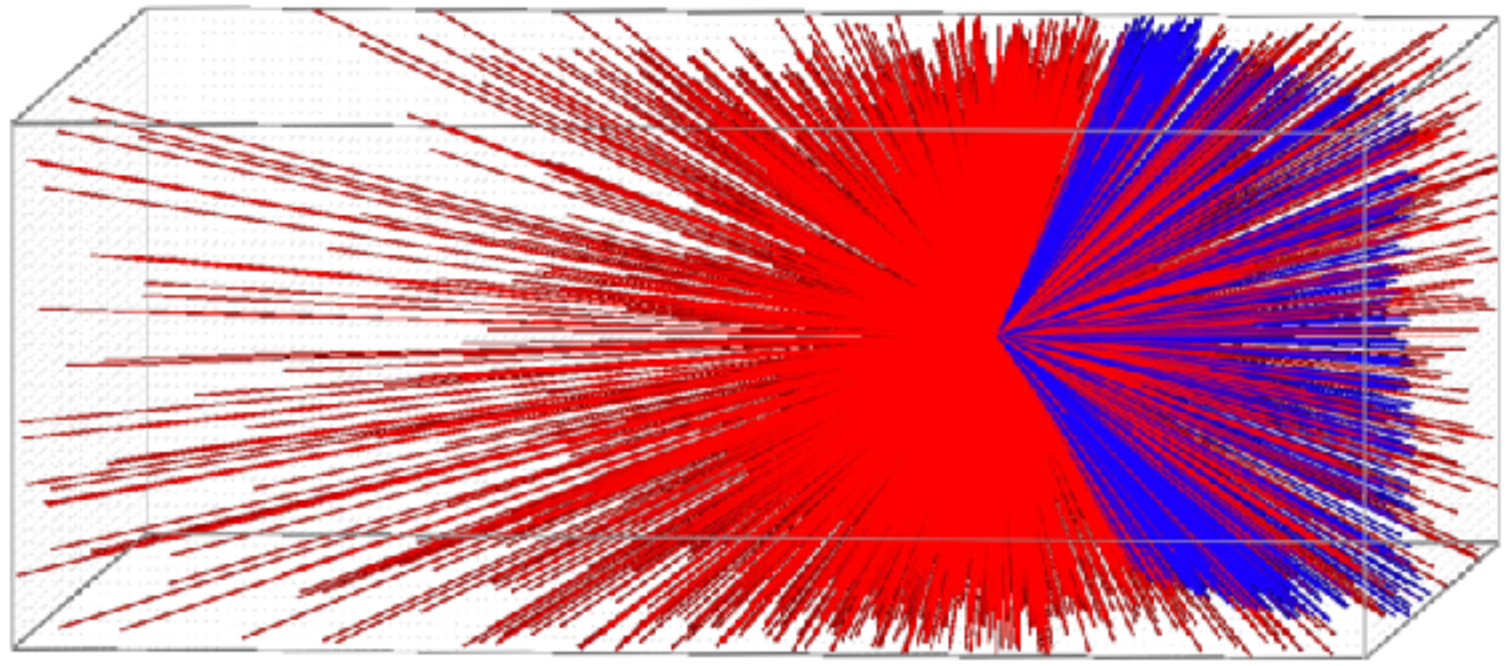
- Mainly targeted at neutrino physics:

➡ **Neutrino studies**: Hybrid LS, opaque LS
- Demonstration of novel LS
- Understanding of light propagation
- Demonstration at (ton)scale
- Gd-loading

➡ **0νββ**: Te loading
- Increasing loading (Te, Xe)

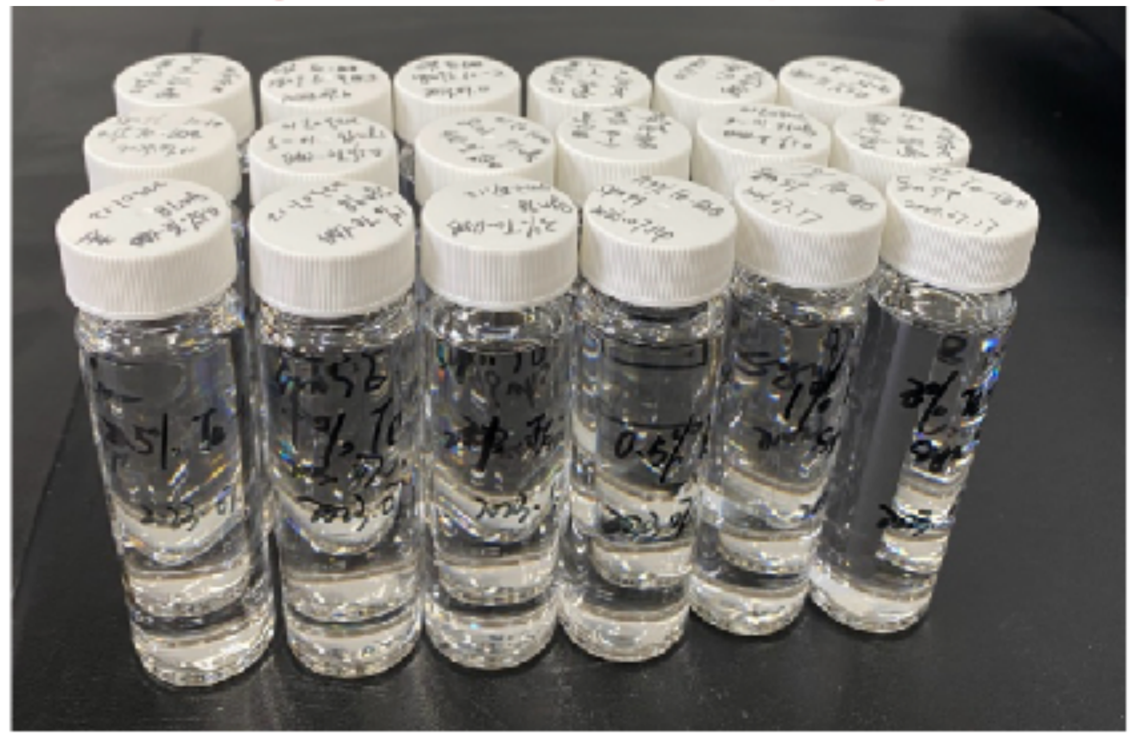
→ opaque scintillators



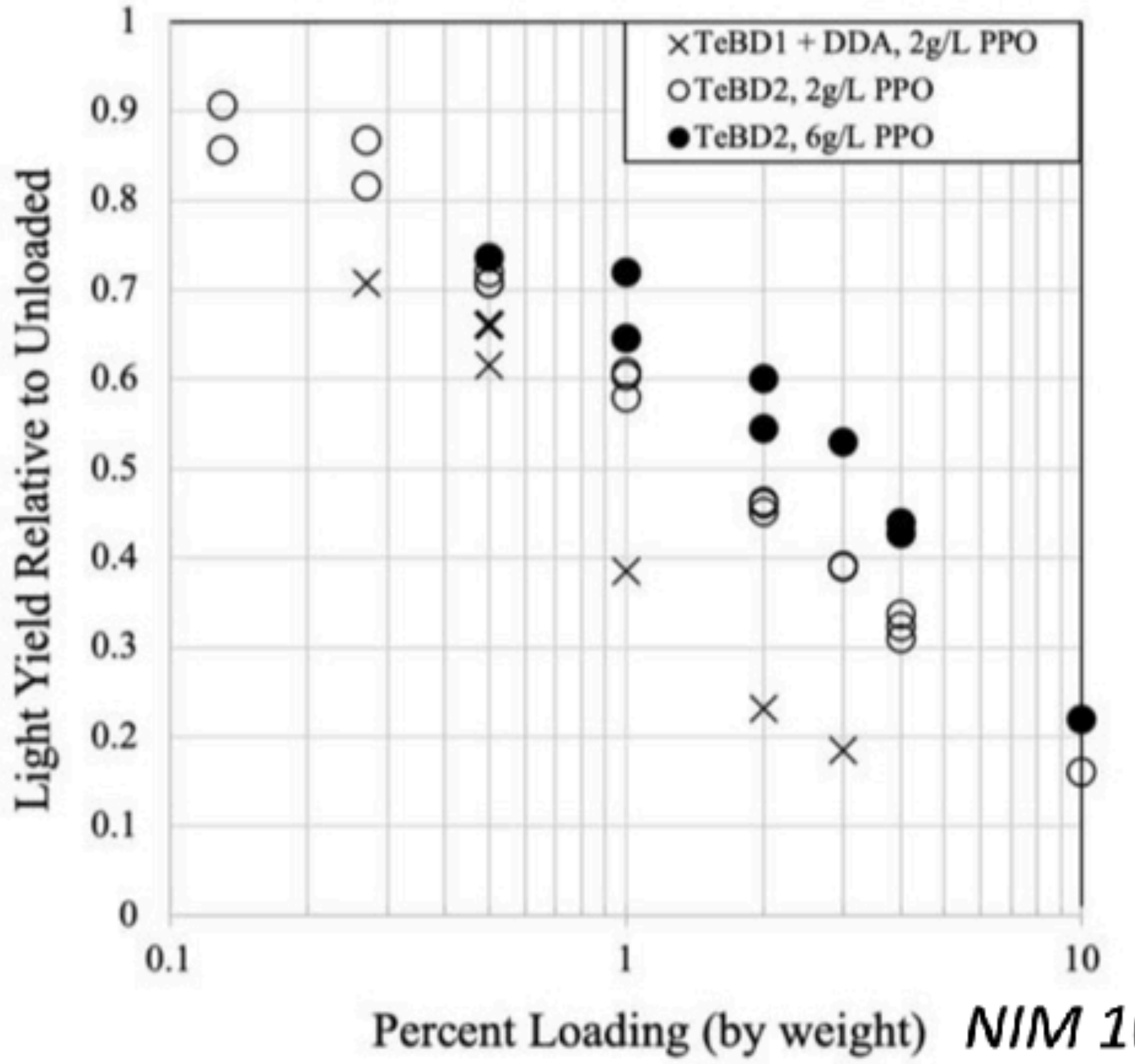


→ hybrid scintillators

Te-LS samples @ IHEP (Yayun Ding)



Light yield vs. Te-loading



NIM 1051 168204 (2023)

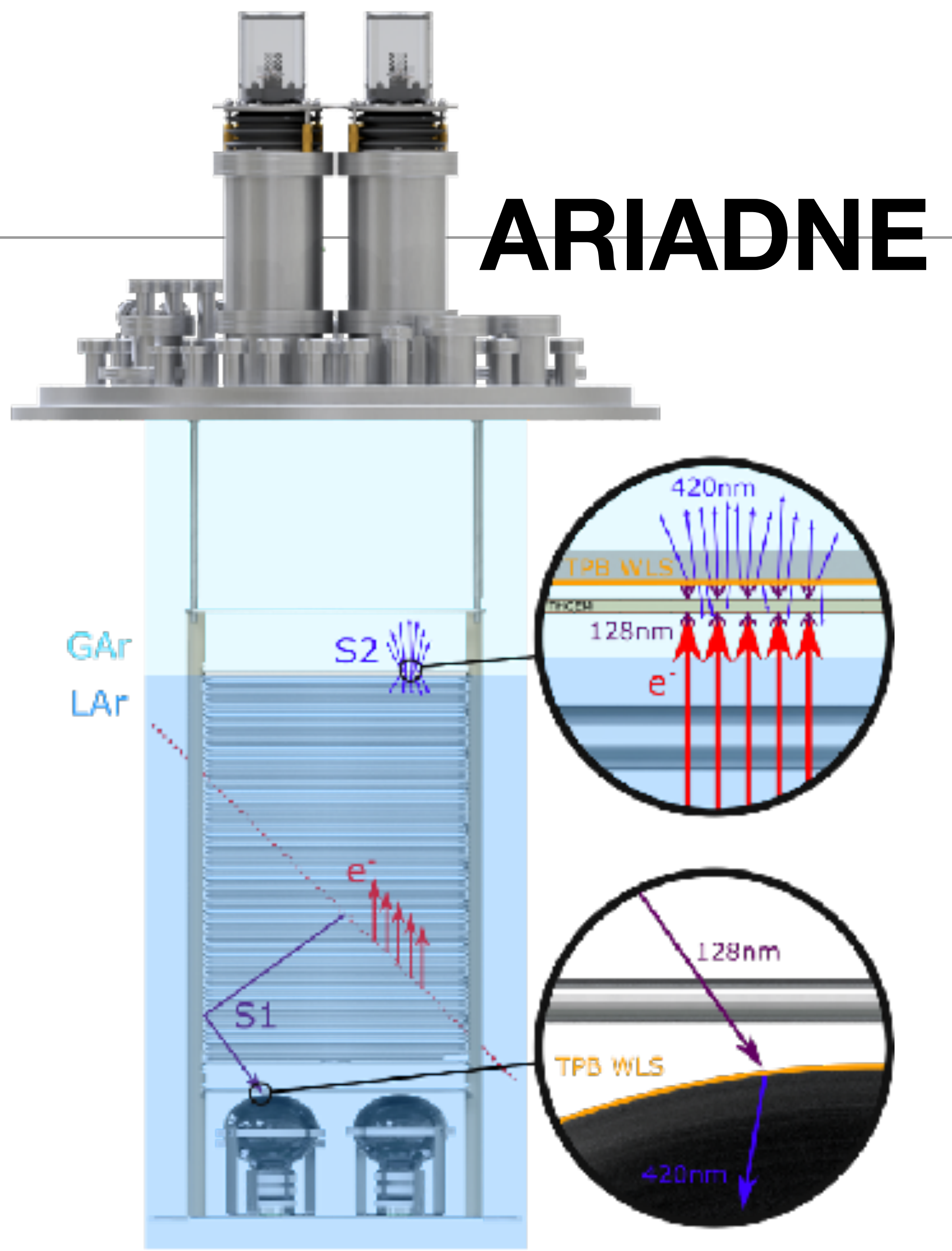
Current Goals (non exhaustive list)

Noble Elements

- Mainly targeted at neutrino physics:

➡ **Neutrino studies**: kilo-ton scale LAr

- Amplification, combined charge-light
- Microphysics (MeV-GeV)
- Xe doping



➡ **0νββ**: ton-scale LXe

- Microphysics (MeV)
- Xe procurement

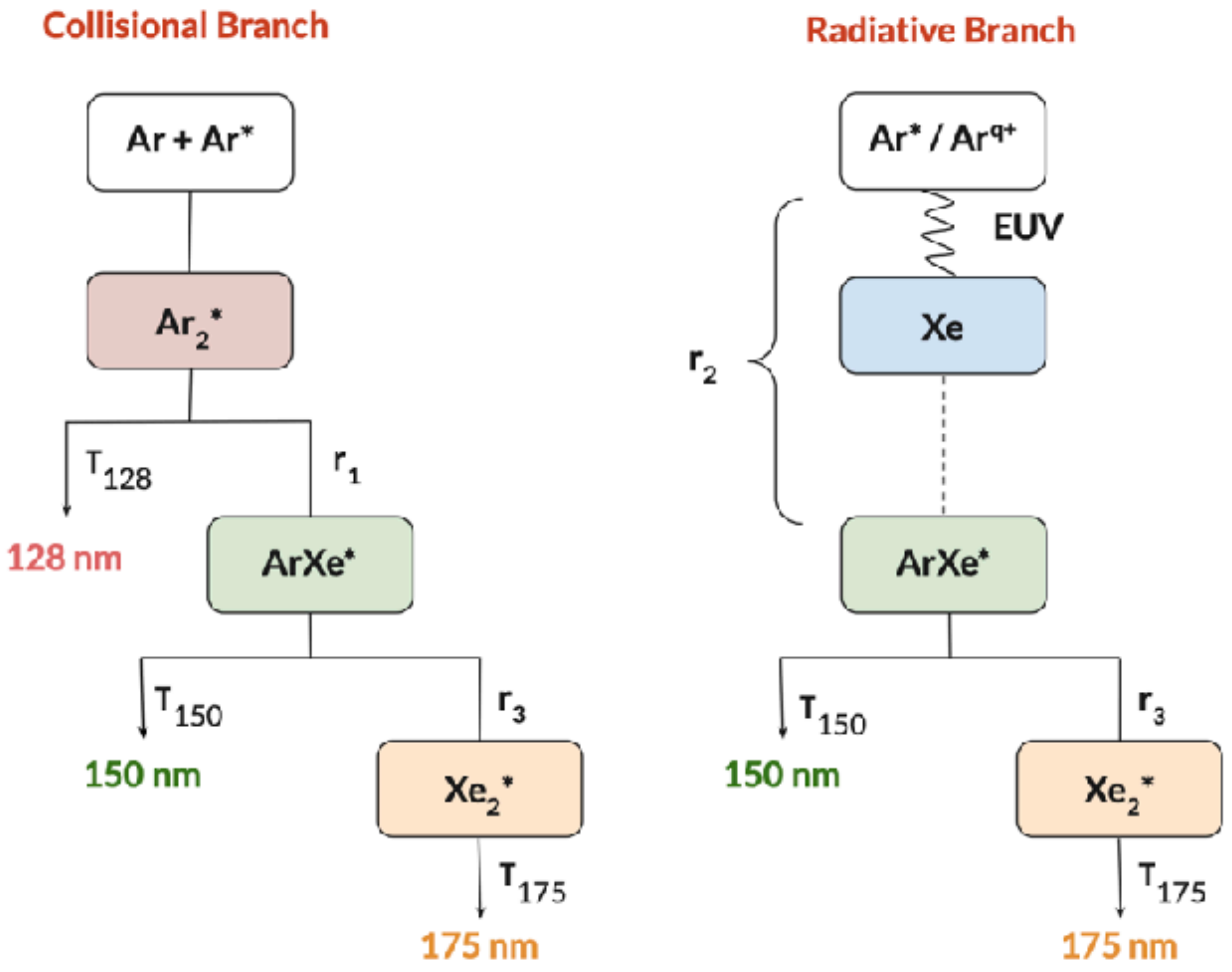
Linde Air Separation Unit in Hungary

➡ **Dark Matter**: (50-100) ton-scale LXe and LAr

- Microphysics (keV) & light transport
- UAr procurement, purification

EUV scintillation from xe-doped LAr

P.Agnes et al., X-ArT : https://arxiv.org/abs/2410.22863



Targeted detector R&D

- DRD2 Collaboration: R&D for Liquid Detectors

WP1 Charge Readout	WP2 Light Readout	WP3 Target Properties	WP4 Scaling-up Challenges
1.1 Pixels & charge+light	2.1 Increased sensor quantum efficiency	3.1 Target properties and isotope loading of LS & WC	4.1 Radiopurity & background mitigation
1.2 Charge-to-light, electroluminescence & amplification	2.2 Higher efficiency WLS and collection	3.2 Target properties and isotope loading of noble elements	4.2 Detector and target procurement/production & purification
Ion detection	Improved sensors for LS & WC		4.3 Large-area readouts
			Material properties

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Ion detection	Improved sensors for LS & WC		4.3 Large-area readouts
			Material properties

All relates to light!

WP2.1: Increased sensor quantum efficiency **Task Leaders: Paolo Agnes & Miguel Garcia Peris**

- Targeted at **VUV** only (and for cryogenic operations) → Clear synergy with DRD4

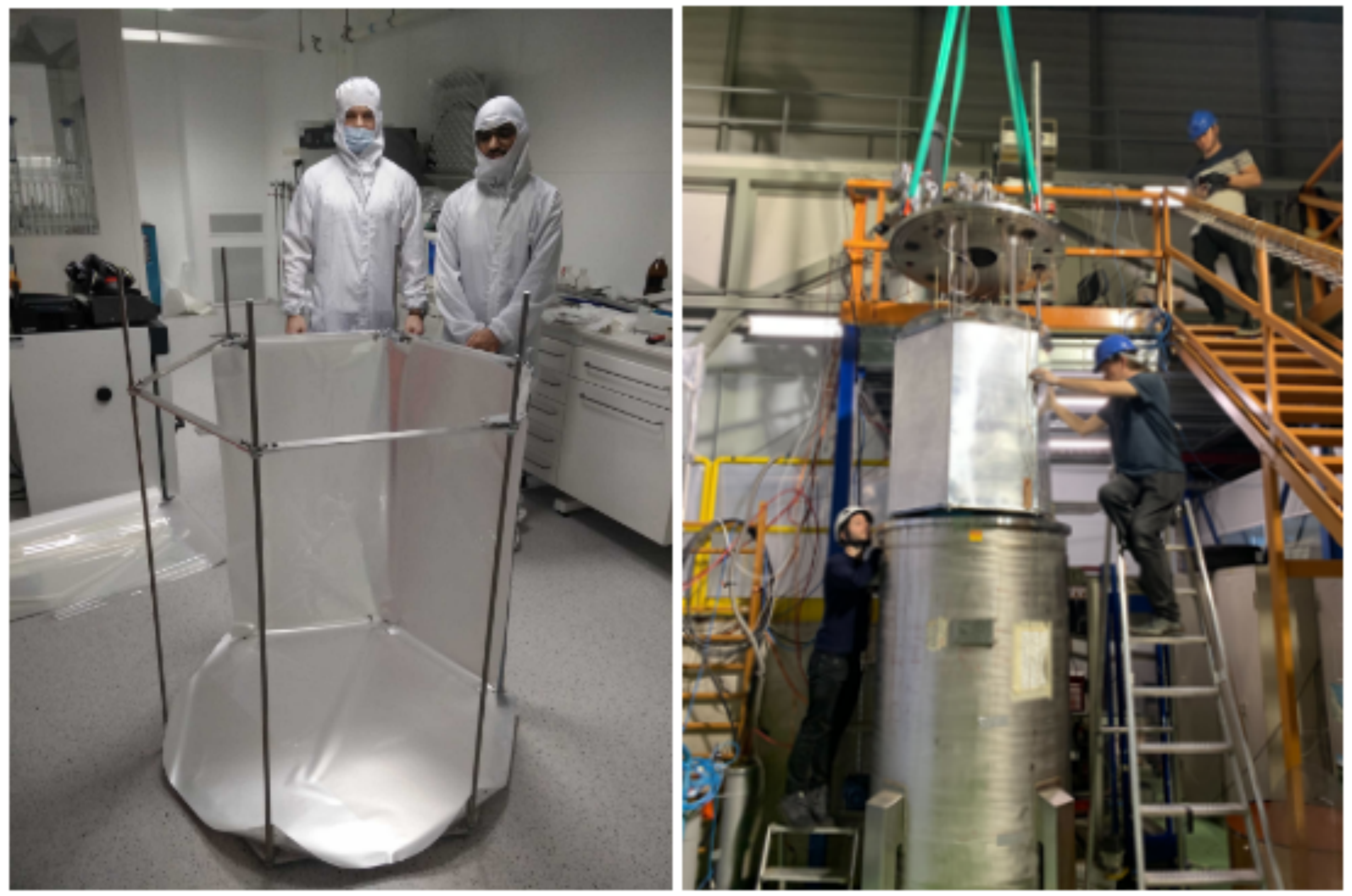
	Goal	Description
D2.1	Sensor development for VUV sensitivity	Development* and characterization of organic photosensors, coatings and passivation methods and of SPAD geometry for VUV detection
D2.2	Prototype SPAD arrays	Prototypes and characterization of new SPAD arrays for 3D-integrated FSI and BSI, analog BSI and monolithic arrays
D2.3	Report on VUV-optimized sensor	Report on the performance of new VUV-optimised sensors in term of PDE, noise and application to rare-event searches

*** At Manchester, we will start testing 2D material coatings (e.g. graphene), potential collaboration possible!**

WP2.2: Higher efficiency WLS and collection

	Title	Description
D2.4	Report on optimised WLS	Report on optimised WLS (VUV to visible) and evaporation systems
D2.5	Design report on light collection	Design report on VUV light collection in noble elements and light readout for liquid scintillators

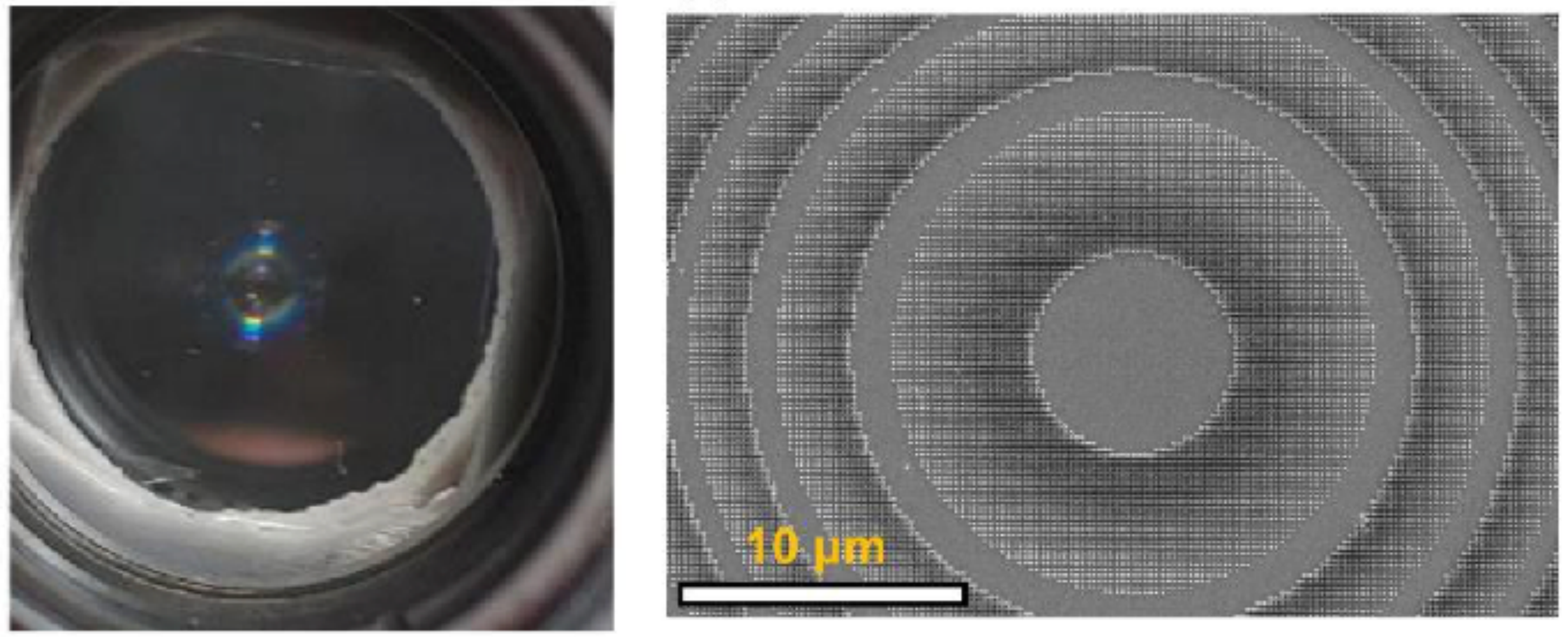
Large-scale PEN WLS test at CERN



Led by Astrocent, CERN, U. Edinburgh, U. Hawaii, Nikhef, TUM, Uni. Zurich

Contact Marcin Kuzniak (Astrocent)

VUV metalenses as light collectors



A. Martins, T. Contreras, C. Stanford, M. Tuzi, J. M. Albo, C. O. Escobar, A. Para, A. Kish, J.-S. Park, T. F. Krauss, R. Guenette, (2024), High efficiency glass-based VUV metasurfaces, arXiv:2401.11315, submitted to ACS Nano.

A. Martins, A. F. da Mota, C. Stanford, T. Contreras, J. Martin-Albo, A. Kish, C. Escobar, A. Para, R. Guenette, (2023), Simple strategy for simulation of large area of axially symmetric metasurfaces, arXiv:2310.19121, accepted by JOSAB.

T. Contreras, A. Martins, C. Stanford, C. O. Escobar, R. Guenette, M. stancari, J. Martin-Albo, B. Lawrence-Sanderson, A. Para, A. Kish, F. Kellerer, (2023), A Method To Characterize Metalenses For Light Collection Applications, JINST 18 09, T09004.

A.A. Loya Villalpando, J. Martín-Albo, W.T. Chen, R. Guenette, C. Lego, J.S. Park2 and F. Capasso, (2020), Improving the light collection efficiency of silicon photomultipliers through the use of metalenses, JINST 15 P11021.

WP 3: Target Properties

Water Cherenkov

- Increase of the Gd-concentration in water
- Synthesize nanoparticles-based water liquid scintillator and water-based nanocrystal liquid scintillators

Liquid Scintillators

- Development of slow WbLS with alternative fluors and quantum dots, and isotope loading in WbLS
- New class of slow WbLS, build demonstrator of WbLS purification
- Development of improved microphysics model for organic liquid scintillators
- Demonstration of ββ isotope loading in scintillators on several % level
- …

Noble Elements

- LAr/LXe nuclear recoil quenching and its fluctuation down to sub-keV region
- LAr/LXe ionisation response to electron recoil/nuclear recoils vs electric field
- Low-energy calibration techniques
- Impact of contaminants on noble liquid responses
- Energy transfer and response in Xe-doped LAr
- …

Summary

- Light detection is central to all neutrino and dark matter detectors
- Future generations would significantly benefit from increased and improved light detection
- Wide R&D activities already underway
- DRD2 collaboration aims to bring together the R&D community to strengthen the different R&D programs and to provide a platform for scientific exchange

Consider joining DRD2!

Email Roxanne Guenette (roxanne.guenette@manchester.ac.uk
and/or Giuliana Fiorillo (giuliana.fiorillo@na.infn.it)