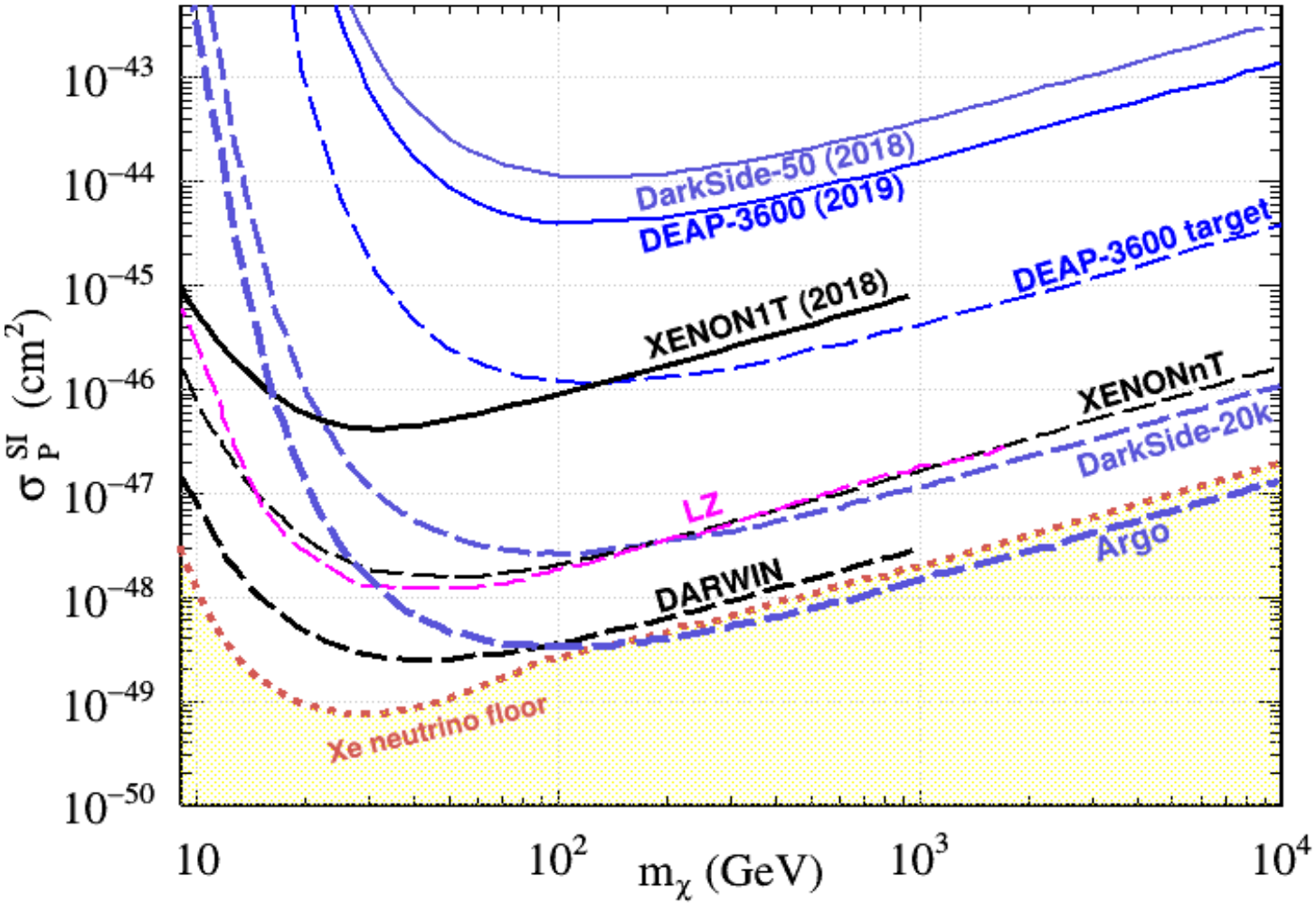
Direct Detection of Dark Matter with Liquid Argon

Chris Jillings for the Global Argon Dark Matter Collaboration

Overview

- The near-term future for DEAP-3600
  - Hardware upgrades, why they are important, and what we will learn
- The mid-term future: DarkSide-20k
  - A mostly Canadian-centric view
- The long-term future: ARGO
  - A multi-hundred tonne detector at SNOLAB

Liquid Argon is a valuable dark matter detector to and beyond the neutrino fog.



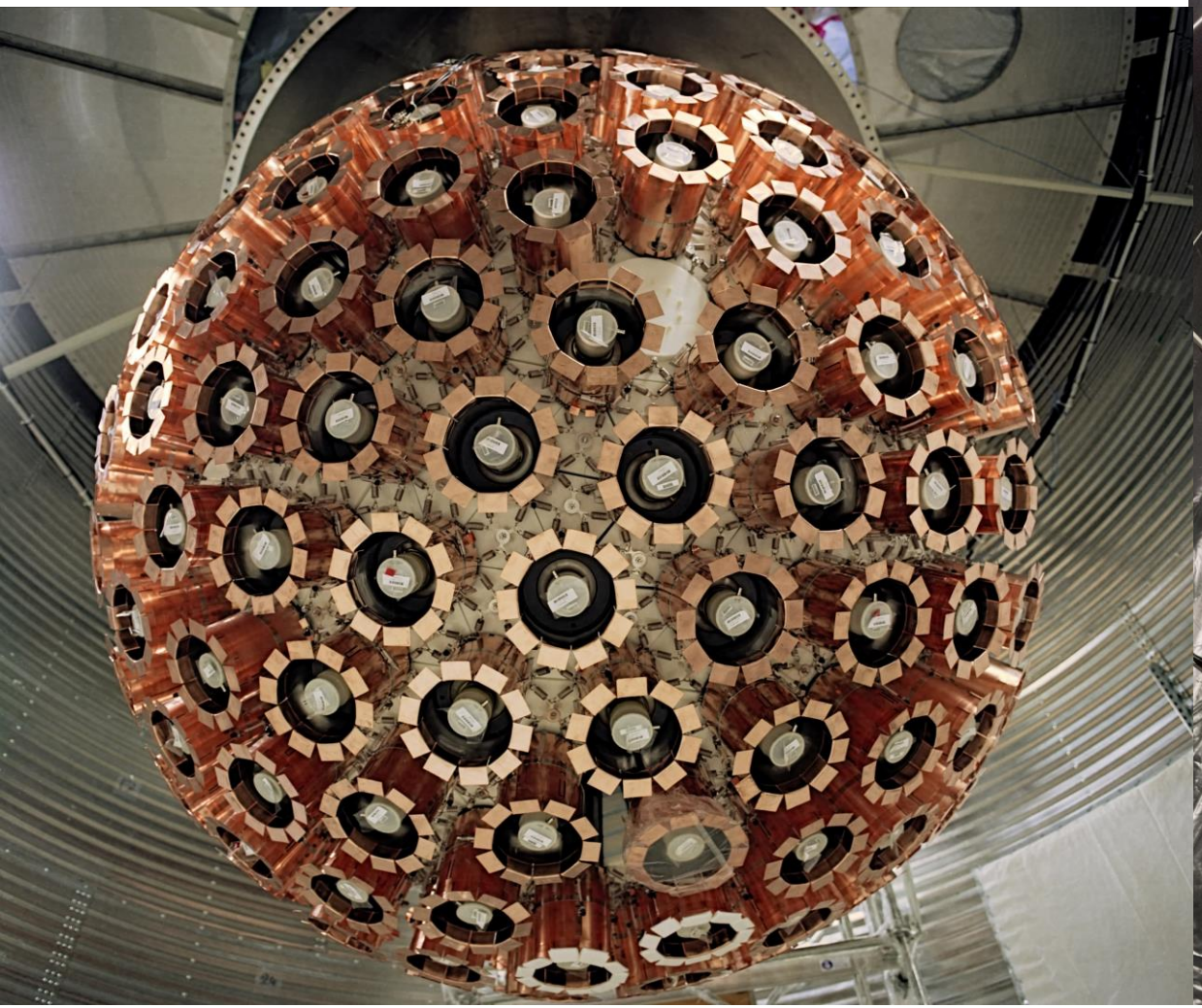
Scalable

High light yield

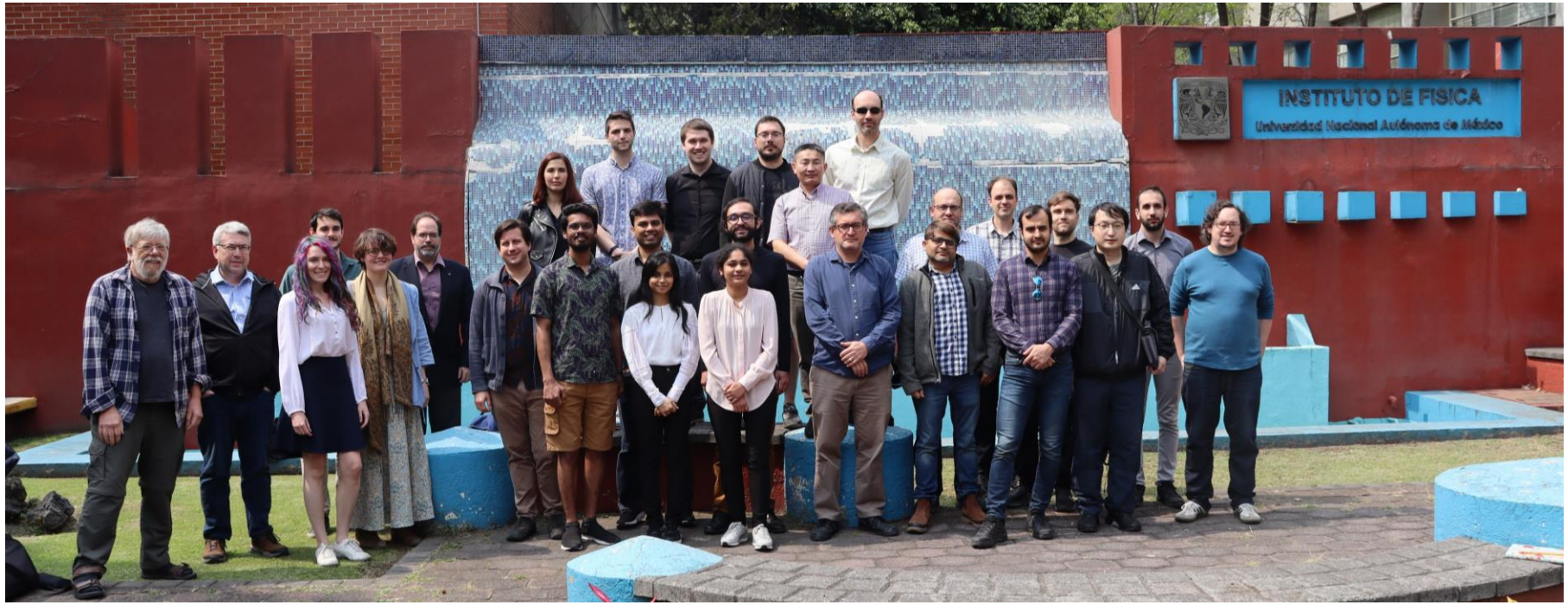
Excellent radiopurity

Single phase or a Time Projection Chamber

DEAP-3600
Near-term future



The DEAP-3600 Collaboration

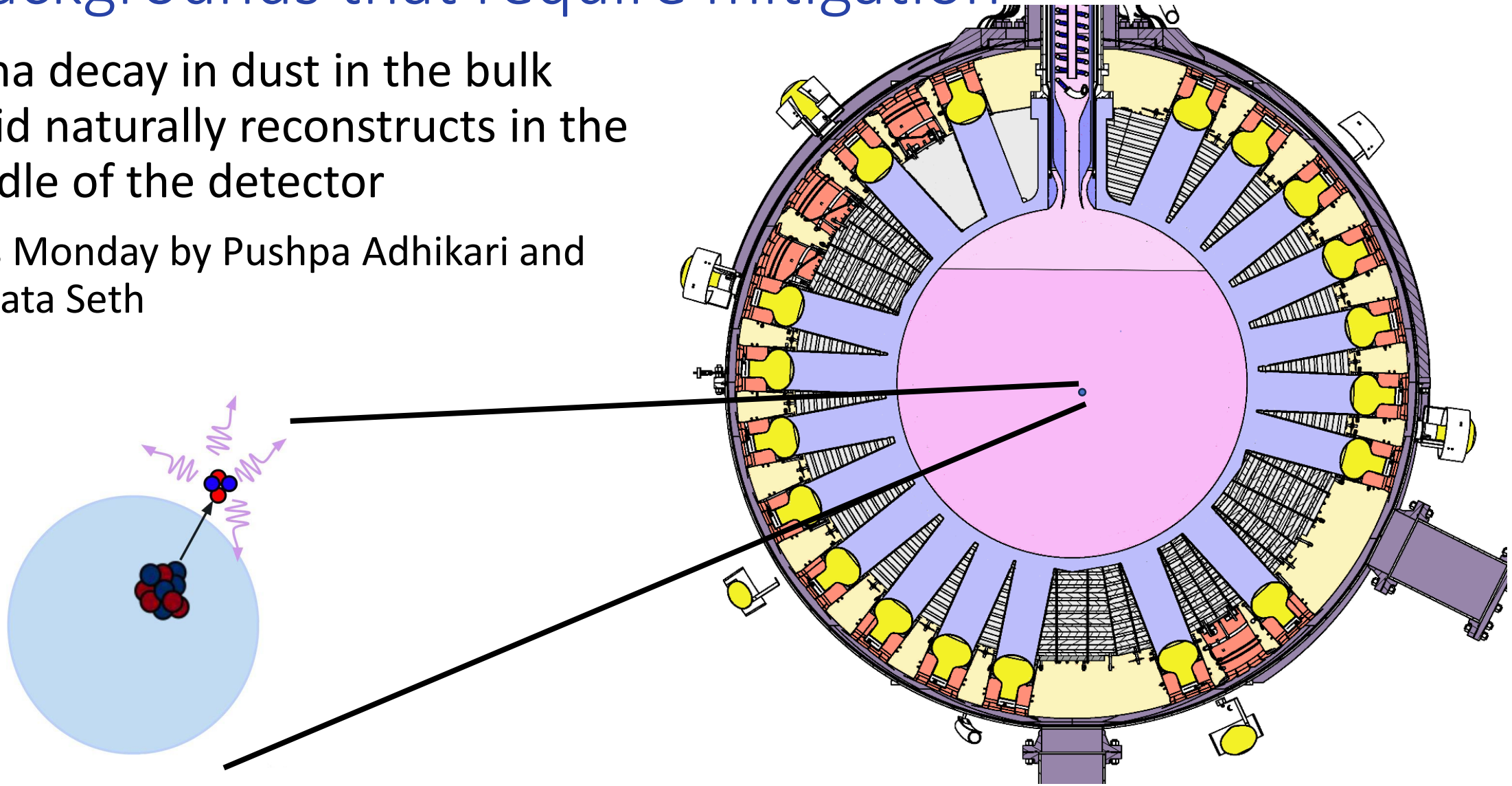


University of Alberta
Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens
Carleton University
UC Riverside
University of Sussex
Particle Physics
Rutherford Appleton Laboratory
Gobierno de España
Ministerio de Ciencia, Innovación y Universidades
Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas
Laurentian University
Université Laurentienne
Princeton University
Royal Holloway University of London
Technical University of Munich
INFN
Istituto Nazionale di Fisica Nucleare
National Research Center "Kurchatov Institute"
IF
Instituto de Física
Queen's University
SNOLAB
TRIUMF

DEAP-3600 background model contains dust alpha backgrounds that require mitigation

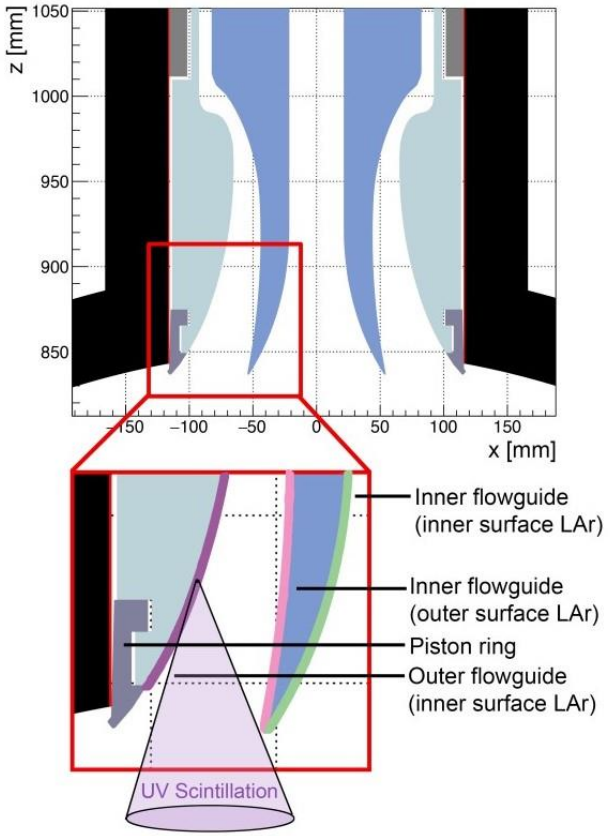
Alpha decay in dust in the bulk liquid naturally reconstructs in the middle of the detector

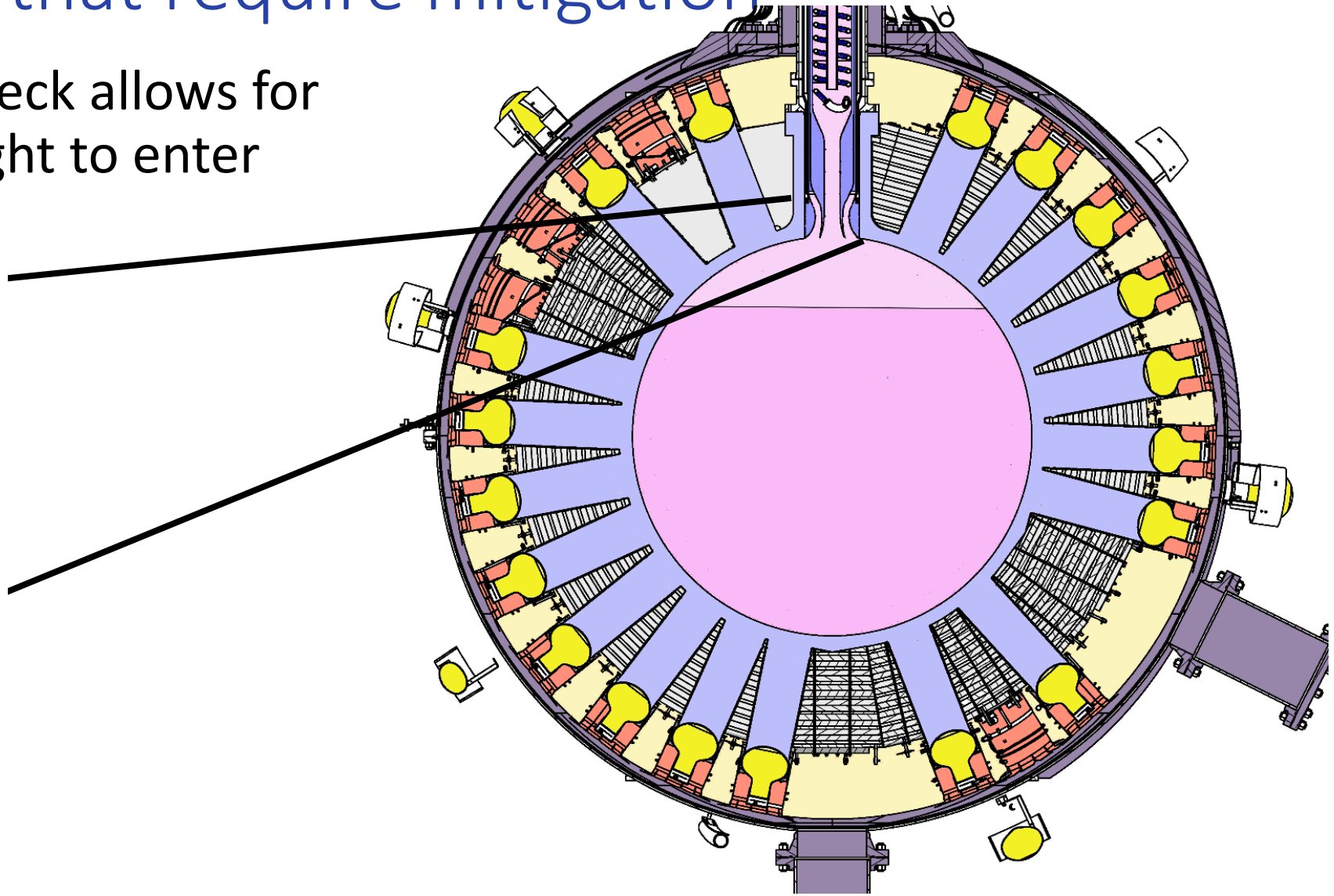
Talks Monday by Pushpa Adhikari and Susnata Seth



DEAP-3600 background model contains two alpha backgrounds that require mitigation

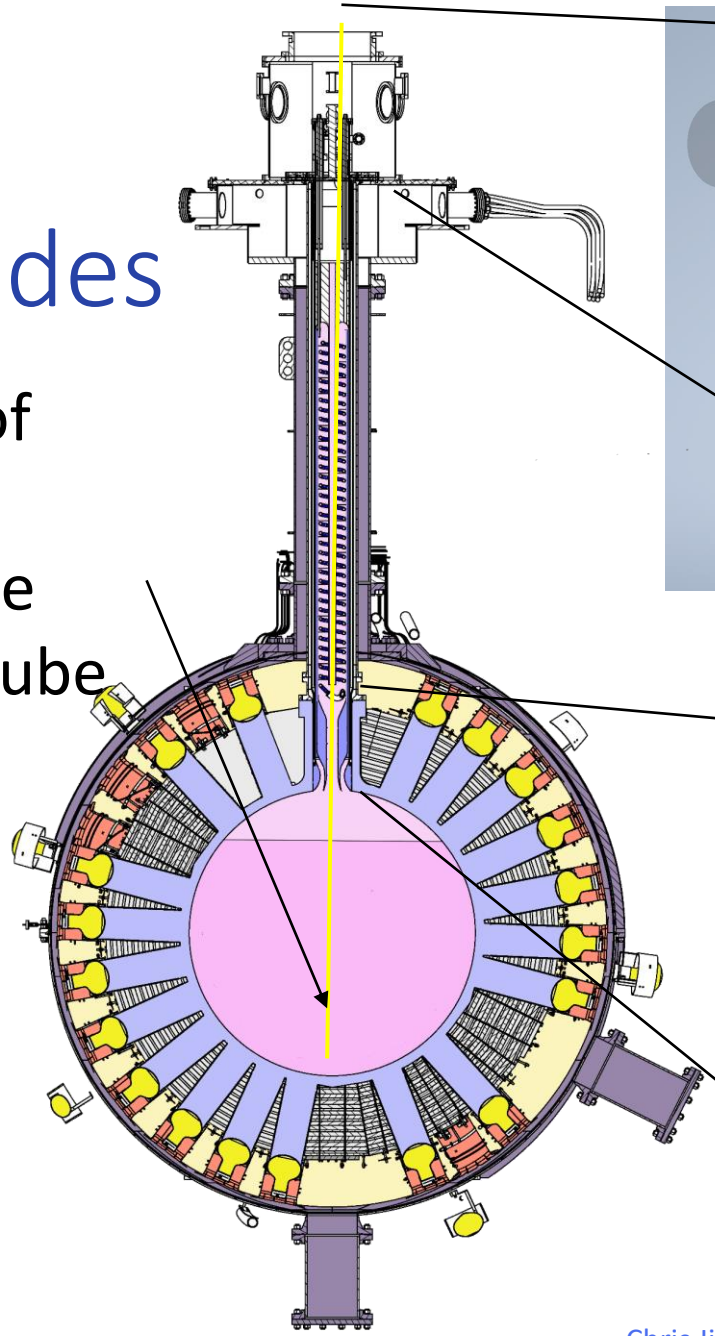
Alpha decay in the neck allows for a small fraction of light to enter the main detector

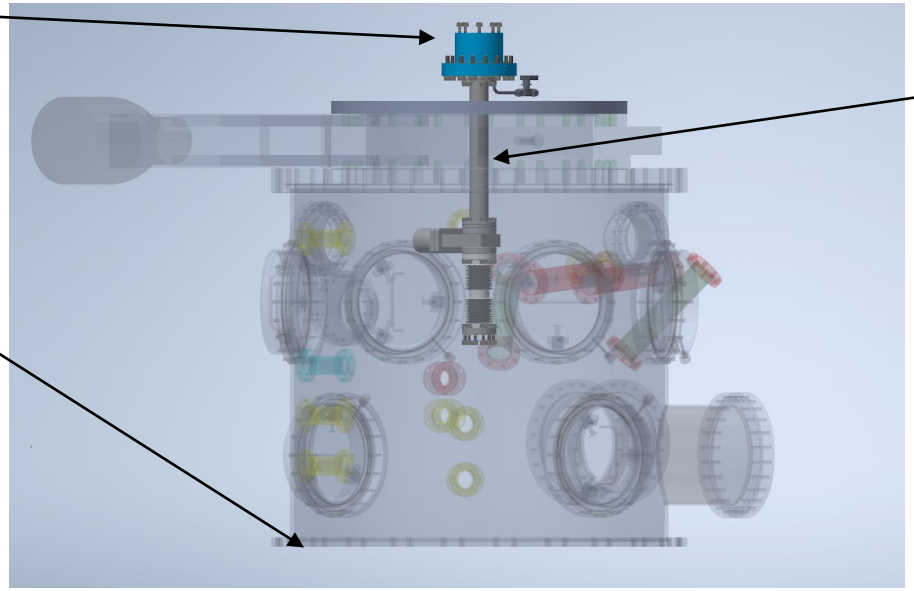




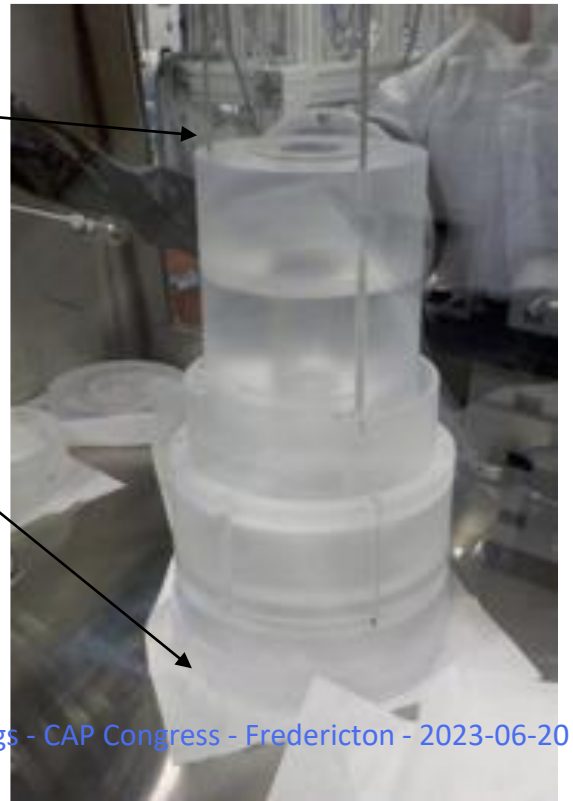
Upgrades

Position of deployed particulate removal tube





New radon-tight deployment system for particulate removal/external cooling



Replacement acrylic flowguide assembly made in Rn-clean room and coated with pyrene-doped polystyrene

All Work at Universities Delivered

Queen's U: Studies of pyrene at low temperatures.

https://doi.org/10.1088/1748-0221/16/12/P12029

Veto PMT replacement.

Alberta: Low background machining of flow guides.

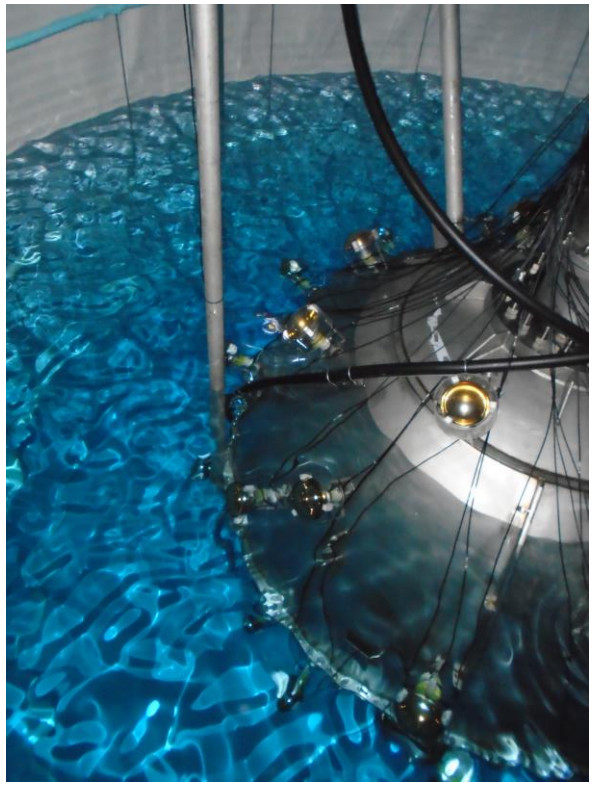
Design/assembly of external system.

Carleton: Development of pyrene coating.

Applications of coatings.

Engineering design.

Project Management.



Fluorescence of pyrene-doped polystyrene films from room temperature down to 4 K for wavelength-shifting applications

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Abstract: In liquid argon-based particle detectors, slow wavelength shifters (WLSs) could be used alongside the common, nanosecond scale, WLS tetraphenyl butadiene (TPB) for background mitigation purposes. At room temperature, pyrene has a moderate fluorescence light yield (LY) and a time constant of the order of hundreds of nanoseconds. In this work, four pyrene-doped polystyrene films with various purities and concentrations were characterized in terms of LY and decay time constants in a range of temperature between 4 K and 300 K under ultraviolet excitation. These films were found to have a LY between 35 and 50% of that of evaporated TPB. All light yields increase when cooling down, while the decays slow down. At room temperature, we observed that pyrene purity is strongly correlated with emission lifetime: highest obtainable purity samples were dominated by decays with emission time constants of ~ 250–280 ns, and lower purity samples were dominated by an ~ 80 ns component. One sample was investigated further to better understand the monomer and excimer emissions of pyrene. The excimer-over-monomer intensity ratio decreases when the temperature goes down, with the monomer emission dominating below ~ 87 K.

The hardware upgrades will allow us to reach DEAP-3600 design sensitivity, allow us to verify the DEAP background model, and allow us to have a “zero background” data set.

1. Dust removal
    1. Liquid recirculation from detector
    2. Improved filtration on process systems
2. Elimination of neck events
    1. Scintillating coatings to tag neck alphas with PSD
    2. Possible external cooling to allow neck to stay warm
3. Replace faulty VETO PMTs
4. Many maintenance/process improvements

Data Taking – third fill in early 2024

- Mimic second fill parameters
- Use work from second fill to automate analysis, do sideband searches, monitor rates, explore PSD with new neck coatings
- Longer term: consider using DEAP-3600 to assay underground argon for Ar-42.

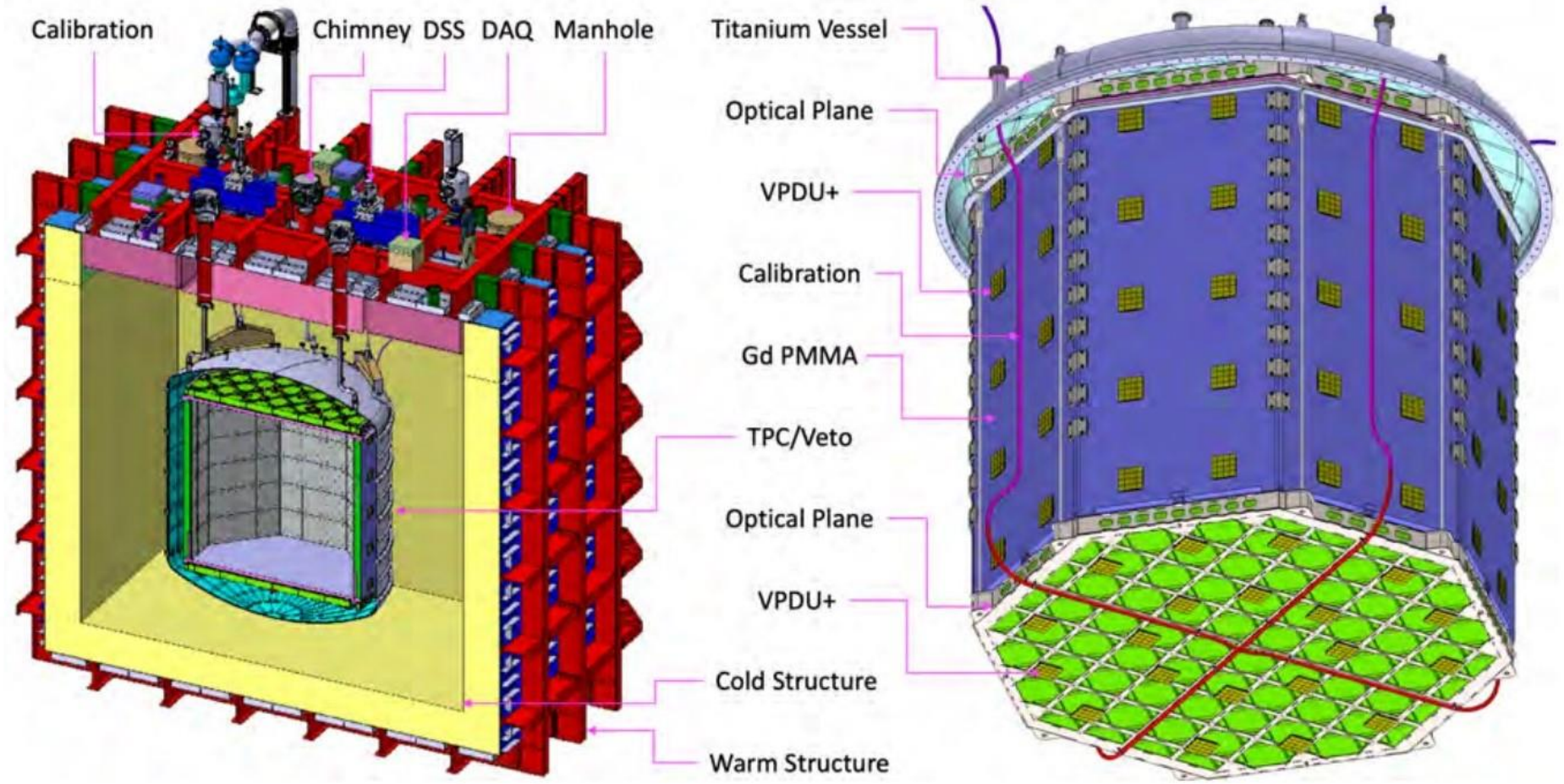
Global Argon Dark Matter Collaboration

400 scientists
14 countries

Tackle the next two generations of experiments.

DarkSide-20k in construction at LNGS

Technical design report submitted to INFN / LNGS – publication version in preparation.



A TPC design with 20-tonnes fiducial mass has been submitted to INFN.

(Publication version in preparation.)

Will use underground argon and Silicon PMs for light detection

Canadian Contributions to DarkSide-20k

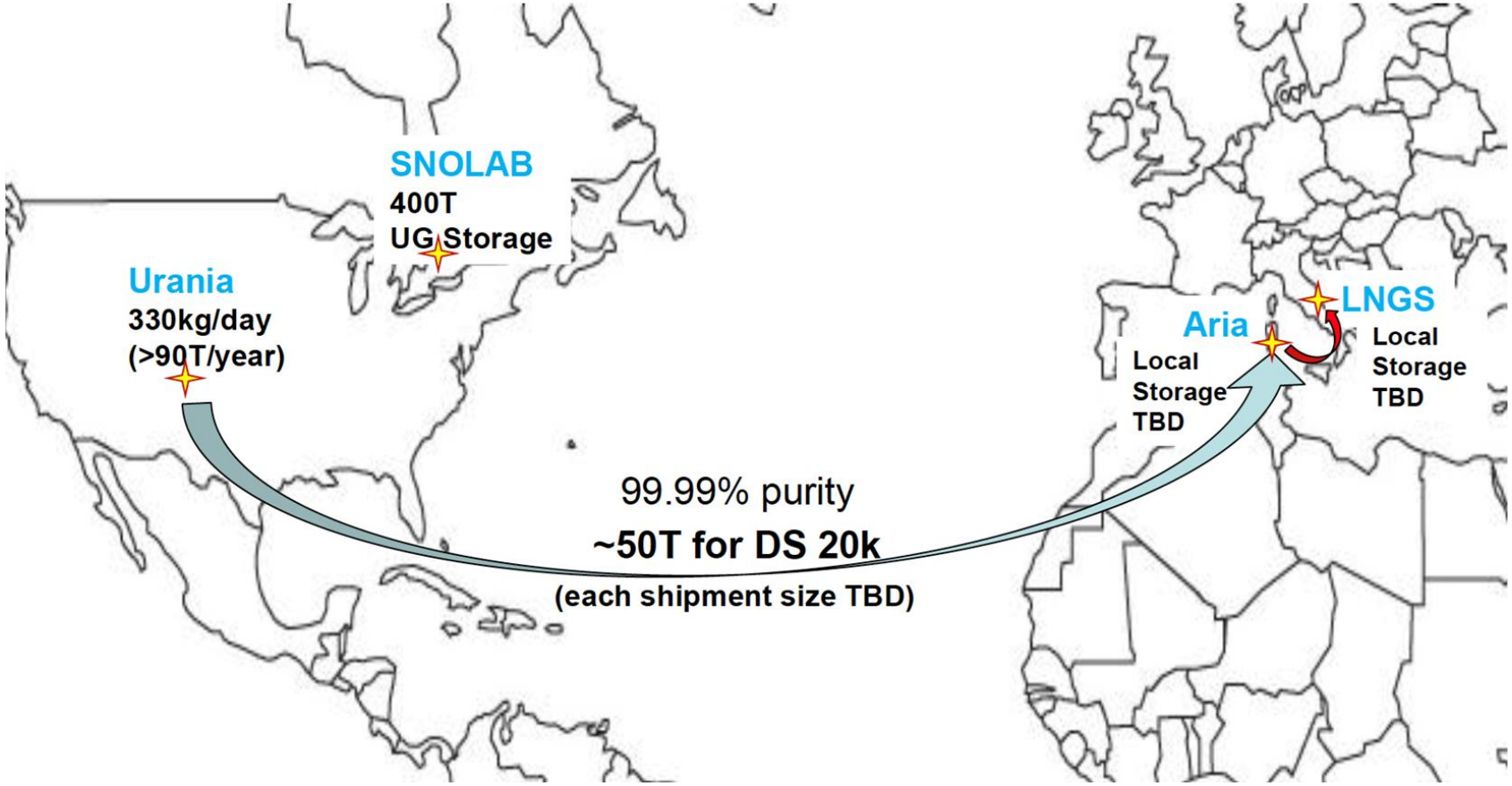
- Low radioactivity underground Argon
  extraction, transport, and assay
- Data Acquisition (MIDAS system)
- Acrylic TPC design and construction
- Surface coatings – talk Monday by Bansari Vyas
- Silicon PM testing
- Calibration deployment system
- Material assay
- Studies of surface backgrounds

Underground argon will come from the Urania facility in Colorado and be shipped to the Aria facility in Sardinia where it will be purified for deployment in DS-20k.

DarkSide 50 demonstrated >1400 reduction factor in [A(Ar-39)] https://doi.org/10.1103/PhysRevD.95.069901

DArT sampling detector at Canfranc can measure [A(Ar-39)] at depletion factor of 1400 with 7% accuracy and 14000 with 40% accuracy in 1 week. https://doi.org/10.1088/1748-0221/15/02/P02024

Preparation for 400 tonnes storage underground at SNOLAB and with a sampling detector, Ar2D2.

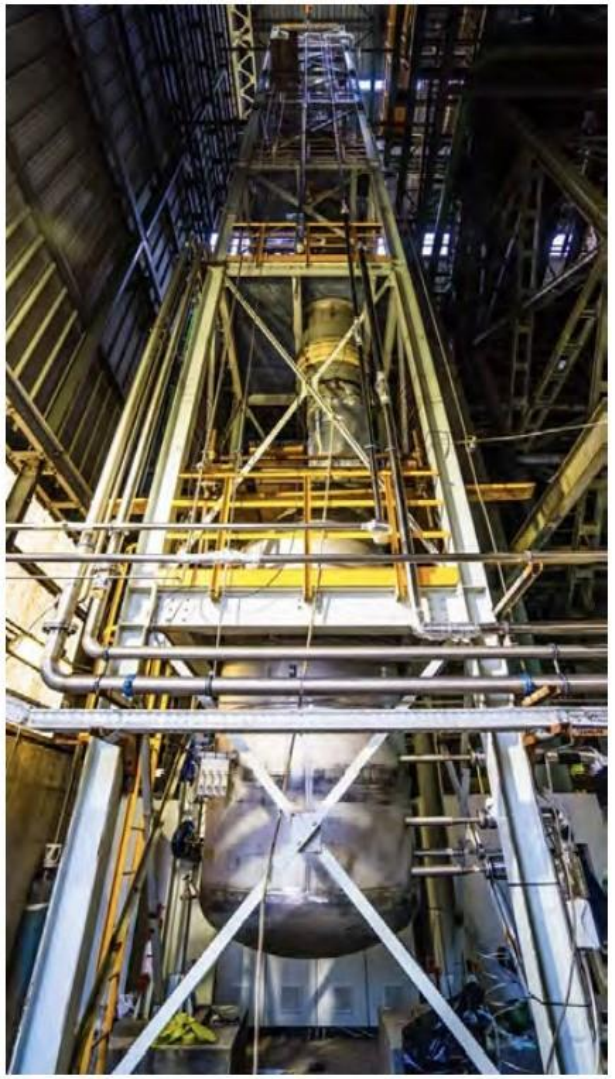


Aria will have a 350m tall distillation column capable of isotopic separation.

The 22m prototype passed nitrogen commissioning and isotopic separation tests.

https://doi.org/10.1140/epjc/s10052-021-09121-9
https://arxiv.org/abs/2301.09639

Some structural steel is being replaced at Aria site before full-scale installation can begin.



Column before deployment

The LEGEND collaboration has formally joined the underground argon effort

- LEGEND-1000 will need underground argon to control the background from K-42, the progeny of Ar-42.
- (See talk in DNP session June 21 at 15:45)

- A joint funding proposal is being submitted to the NSF this summer.

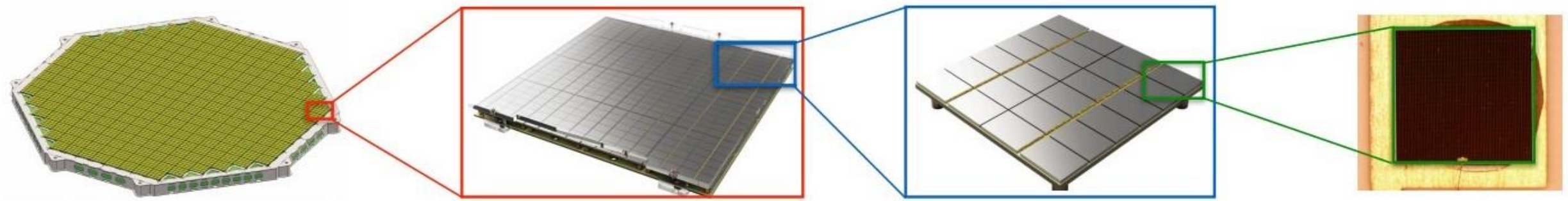
Silicon Photomultipliers

Silicon photomultipliers by Fondazione Bruno Kessler, model NUV-HD-CRYO

Meet all requirements on photodetection efficiency, low noise at liquid argon temp.

Talk presented in this symposium by Simon Viel on exciting work with SiPMs for future experiments

Note: components for photodetection modules, and complete assemblies, meet radiopurity requirements.



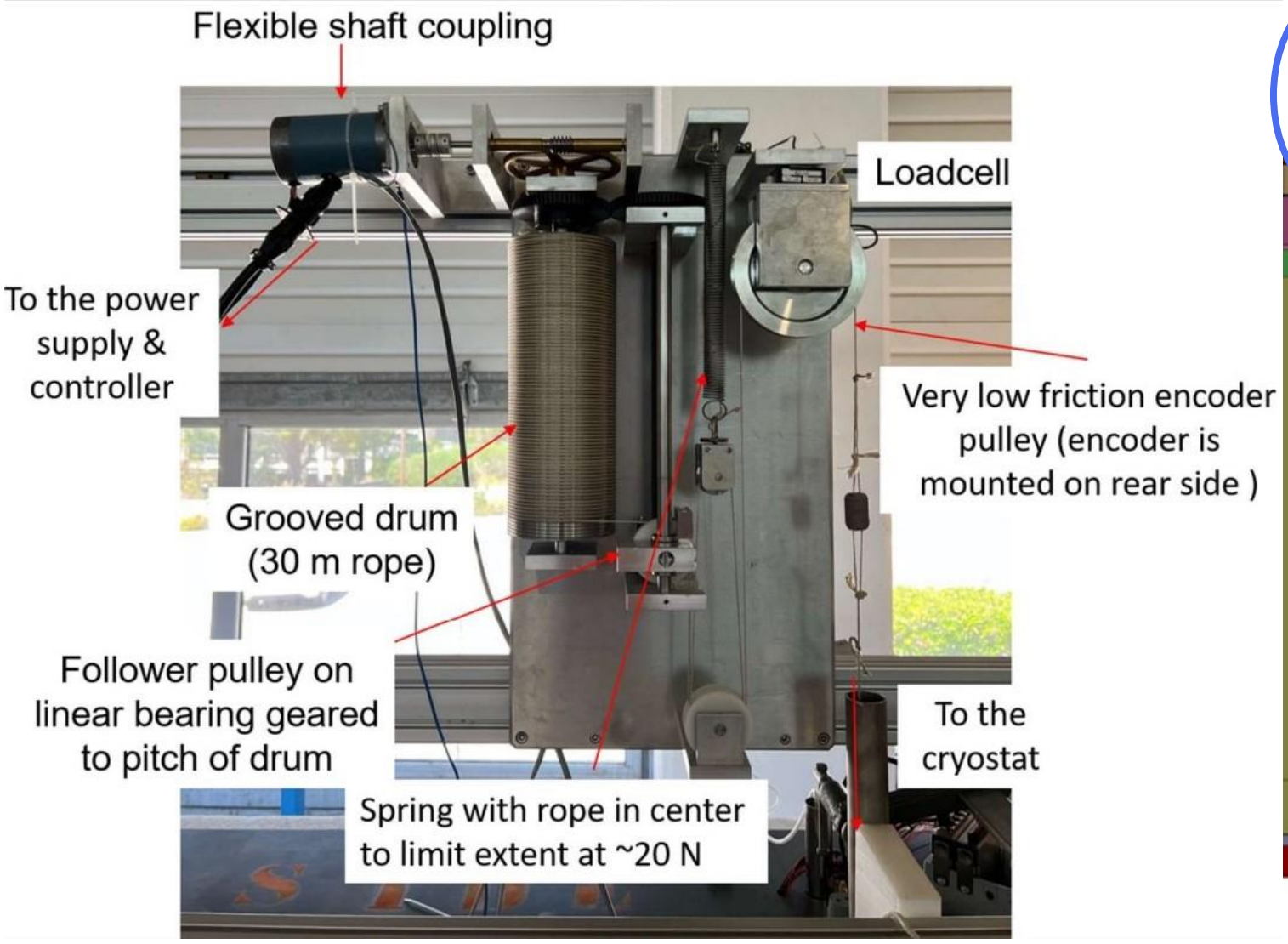
TPC optical plane ($\sim 21\ \mathrm{m}^2$)
525 PDUs

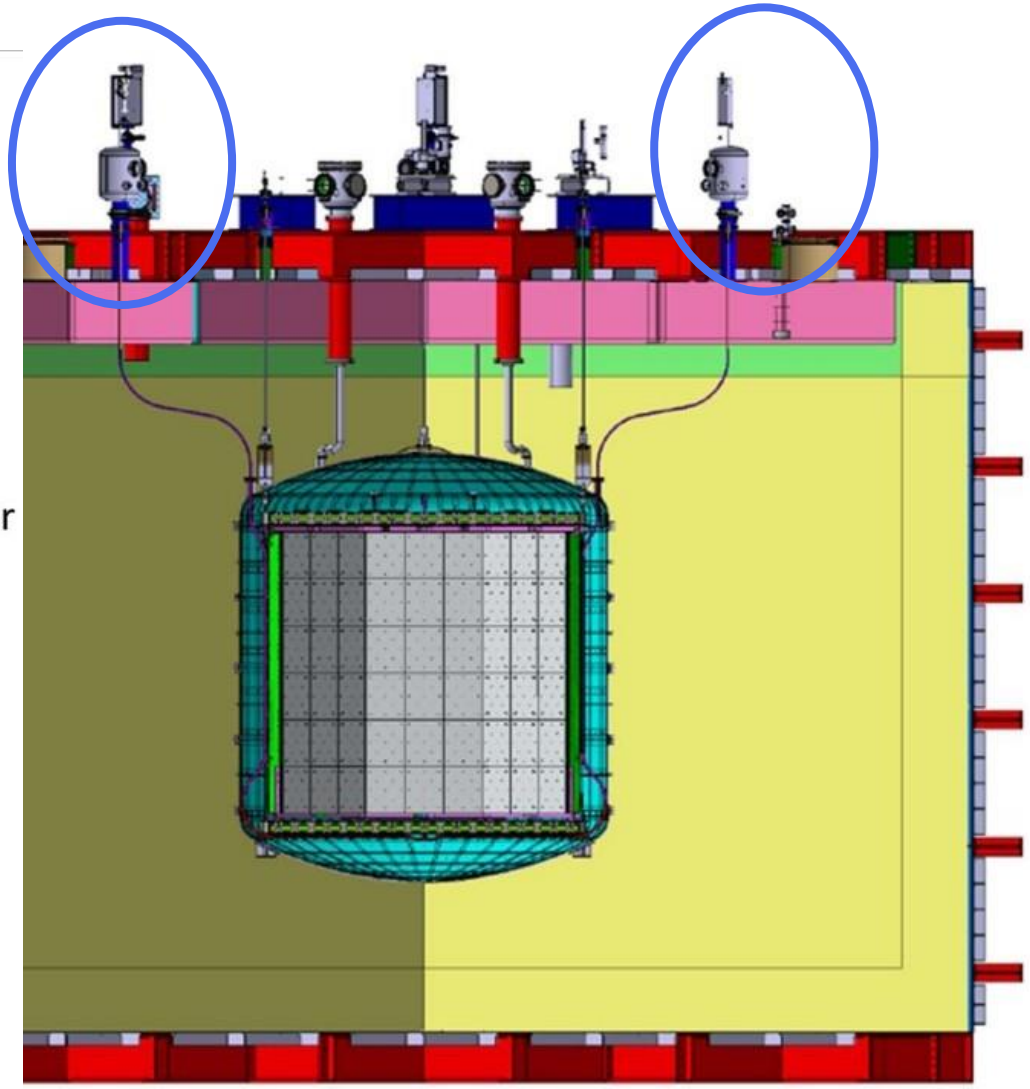
Photo-detection unit
16 tiles arranged into 4 channels

Tile / photo-detector module
24 SiPMs + signal amplifier

SiPM ($\sim 1\ \mathrm{cm}^2$)

SNO-style motor & pulley for calibration deployment



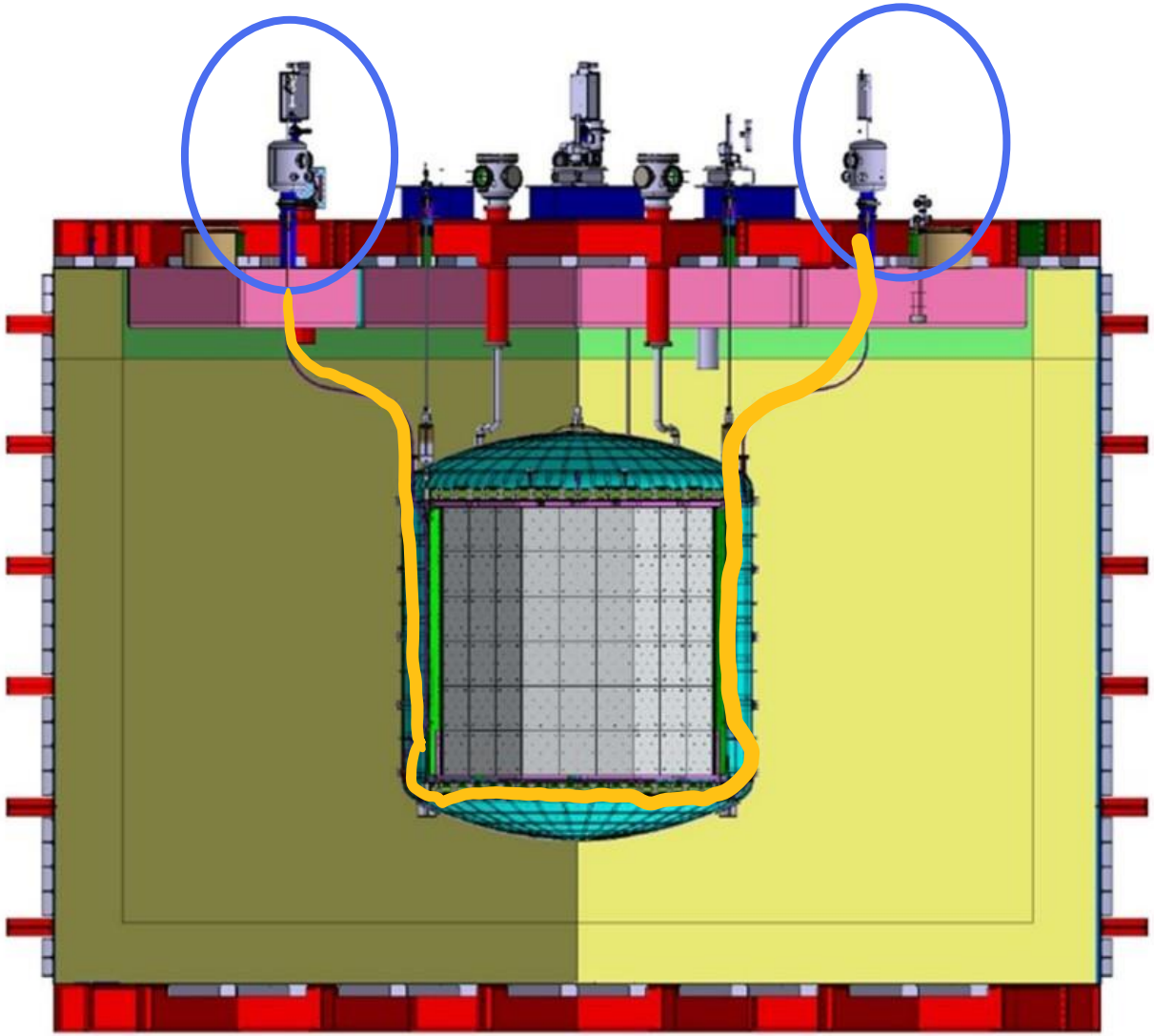


SNO-style motor pulley for calibration deployment

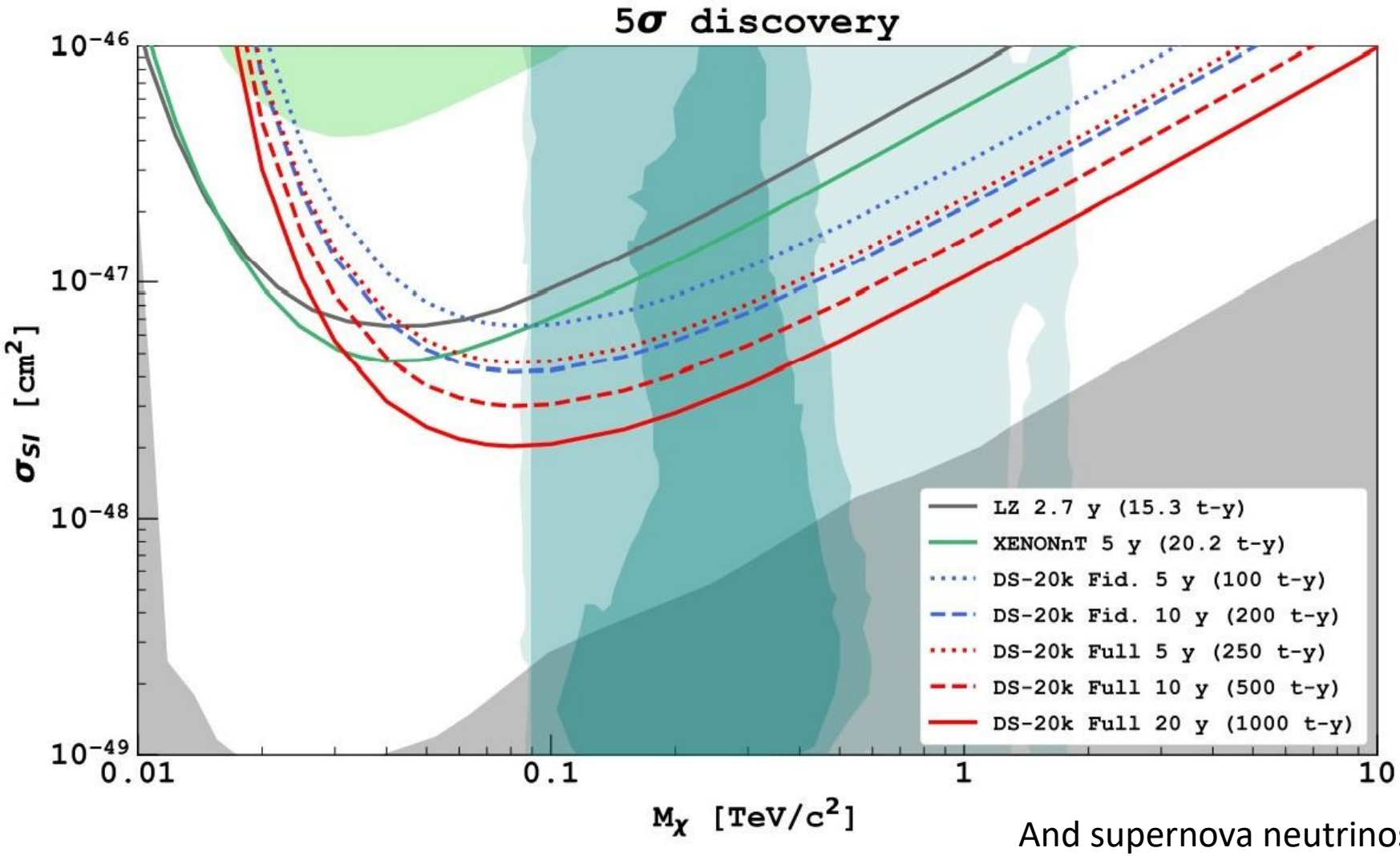
Control code expanded to work in mode of keeping two ends of a rope in tension. Friction modeled. (Source deployed in tube highlighted yellow.)

Initial cryo-tests passed.

Extensive cryo-testing to start this month.

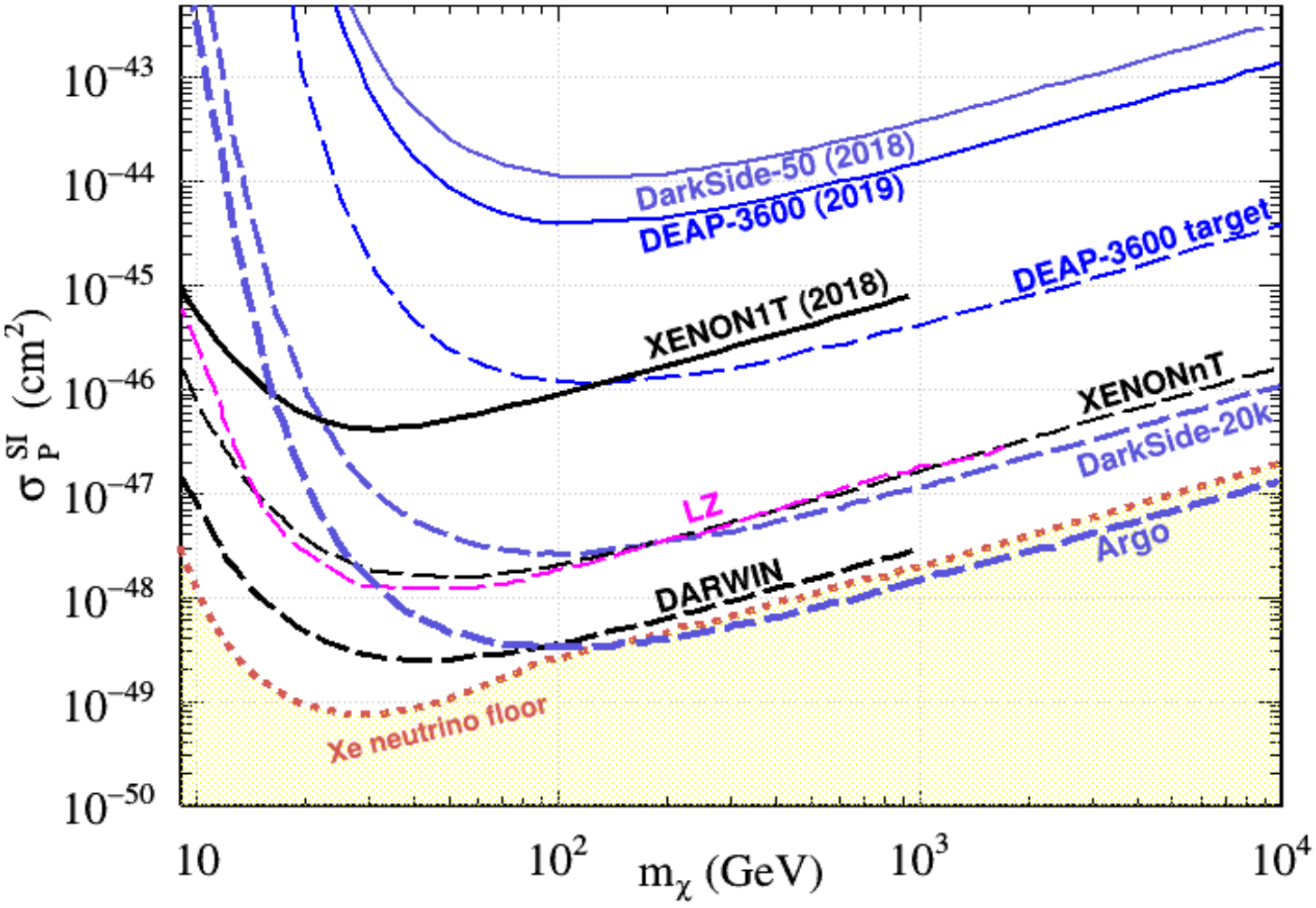


5 sigma discovery space



And supernova neutrinos too!
https://doi.org/10.1088/1475-7516/2021/03/043

ARGO



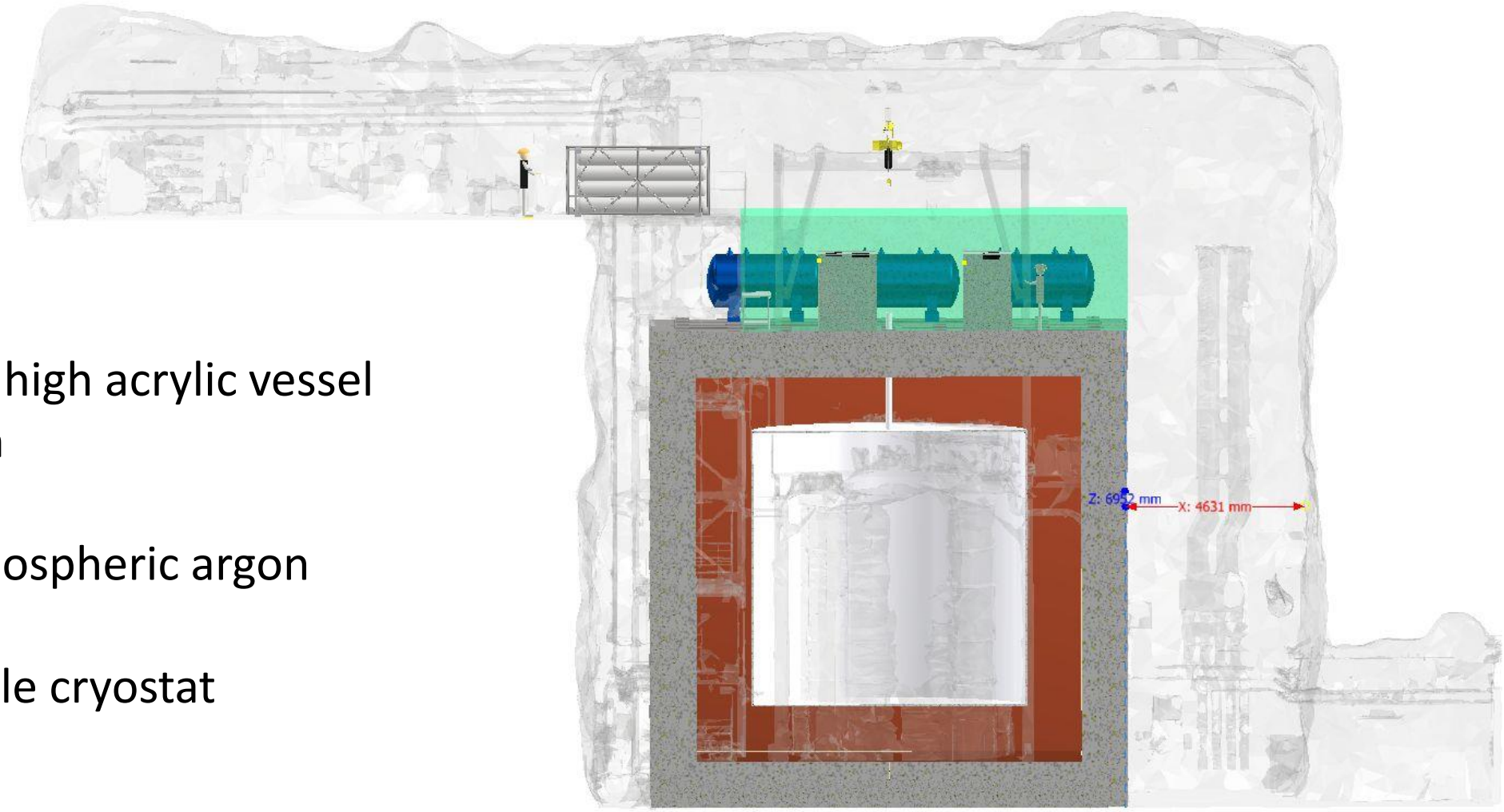
A multi hundred tonne detector with SNOLAB the preferred site.

Canadian groups are working on a single-phase design with 400 t underground argon.

> 200m^2 of SiPM

Event ID with some reconstruction at DAQ level

ARGO would fit in the SNOLAB Cube Hall



7 m diameter x 7m high acrylic vessel underground argon

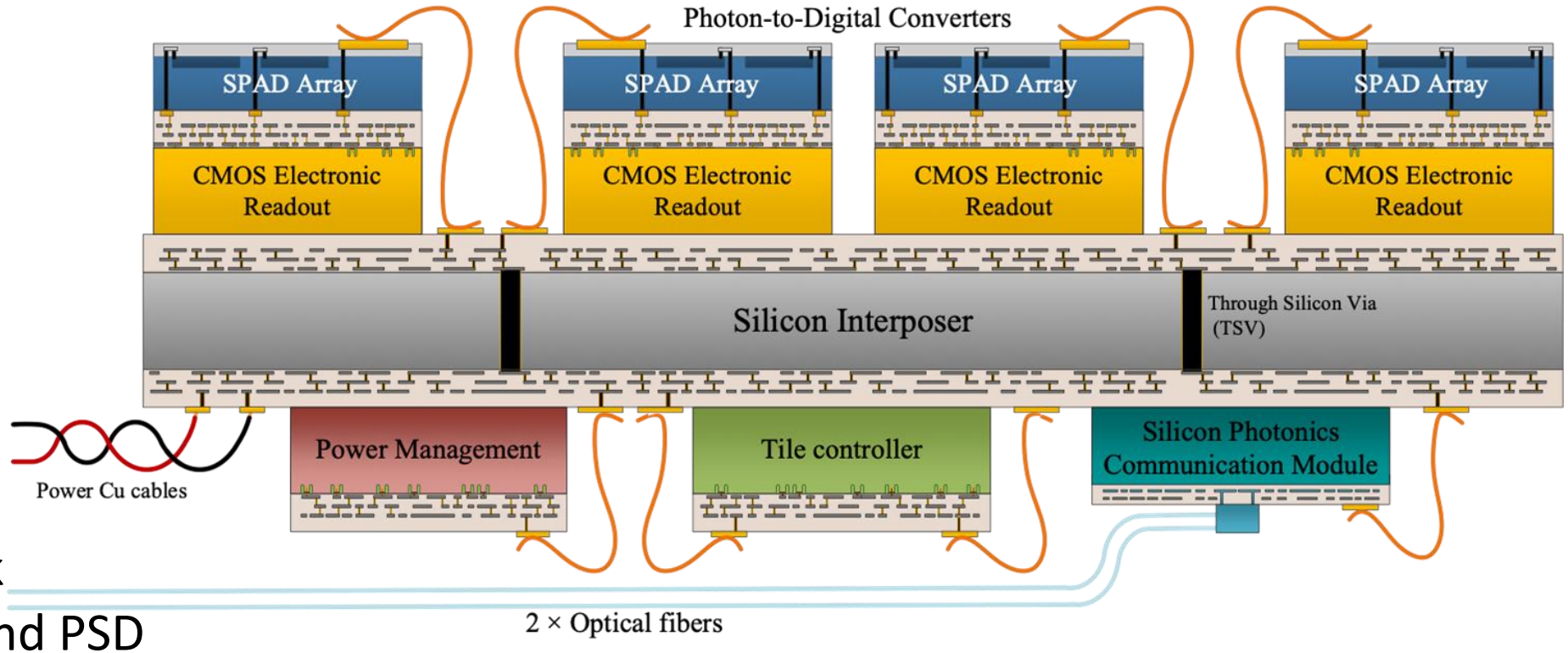
Surrounded by atmospheric argon

In a Proto-Dune style cryostat

Silicon Photodetector R&D for ARGO

Development of photon-to-digital converters (aka “3D SiPMs”) led by U Sherbrooke.

CFI IF 2017, 2020, and 2023



See Michael Perry’s talk Monday about SiPMs and PSD

Develop Conceptual Design for Single Phase ARGO

- Background budget
  - Neutrons
  - Cosmogenics
  - EM rejection (Pulse shape discrimination in argon will work!)
- Optical model
  - Rayleigh scattering is important.
- Photon-to-digital converter specifications
- Sensitivity projections
- Neutrino studies - See talk by Emma Ellingwood, Wednesday at 16:15 for a discussion of neutrinos in DEAP-3600.

ARGO is large enough to require photon hit times in event reconstruction algorithms

Resolution of hit-time algorithms proportional to time resolution of system.

Resolution of hit-pattern algorithms depends is a fraction of the detector size.

ARGO is large enough that time response is better.

<u>Rayleigh scattering is important</u>

- Depends on the isothermal compressibility which depends on temperature.
- For DEAP-3600: Rayleigh scattering length between 85 and 100 cm
- This is small on the scale of ARGO (7 m)

This is taken into account in development of position reconstruction and PSD models.

DEAP-3600 hardware upgrades will inform future detector designs.

DarkSide-20k construction at LNGS is underway and Canadian groups are making important contributions.

A design for ARGO is advancing towards seployment at SNOLAB in the 2030s.

A wide and exciting science program awaits!