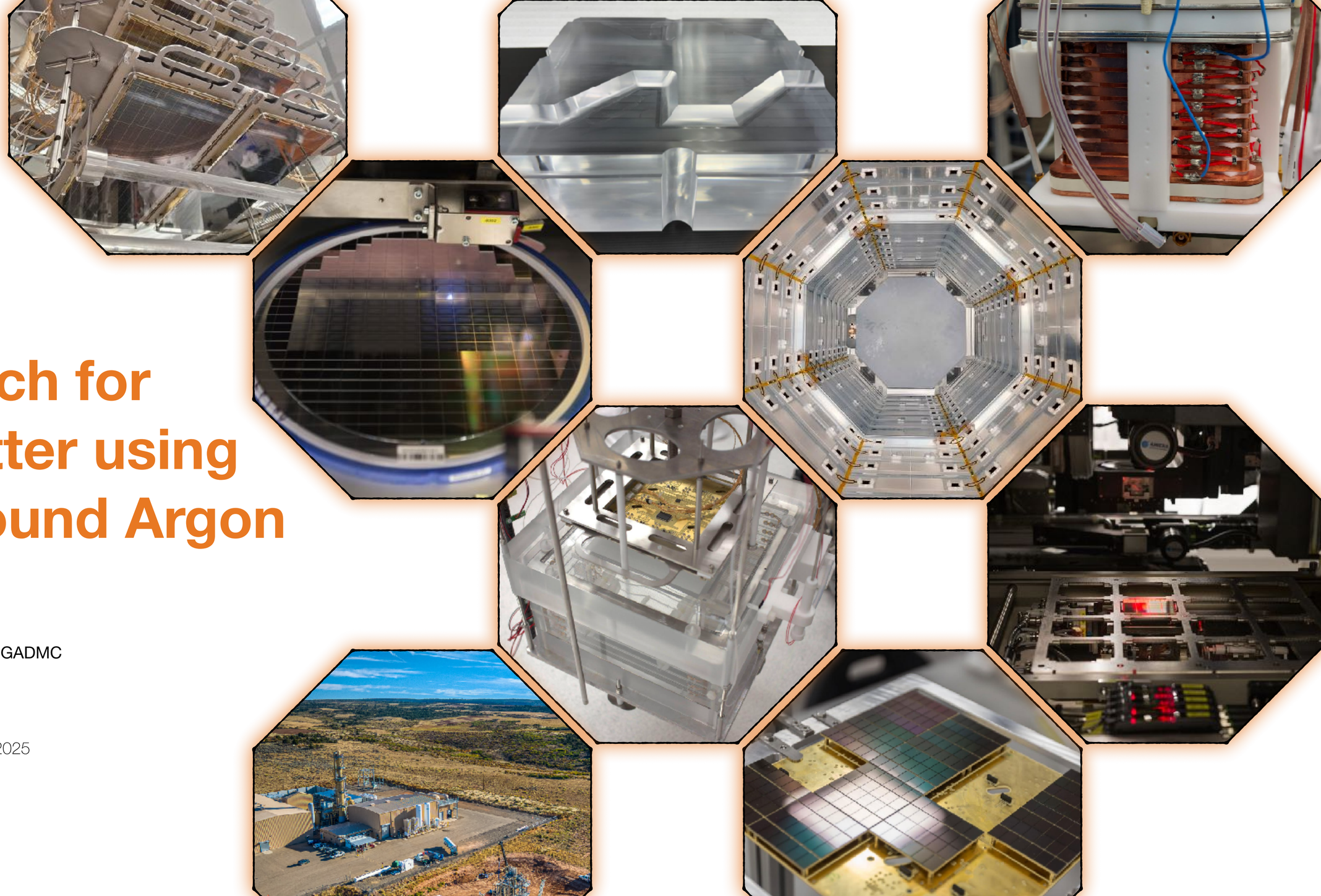

The Search for Dark Matter using Underground Argon

Ako Jamil on behalf of the GADMC

Princeton University

October 21, 2025

Light Detection in Noble Elements 2025

Hong Kong

Evidence for Dark Matter (DM) at All Scales

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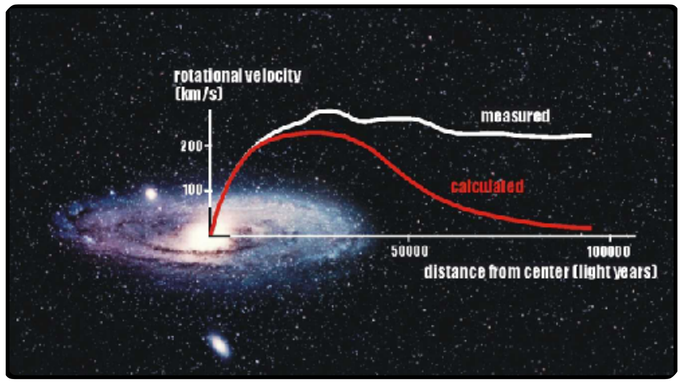
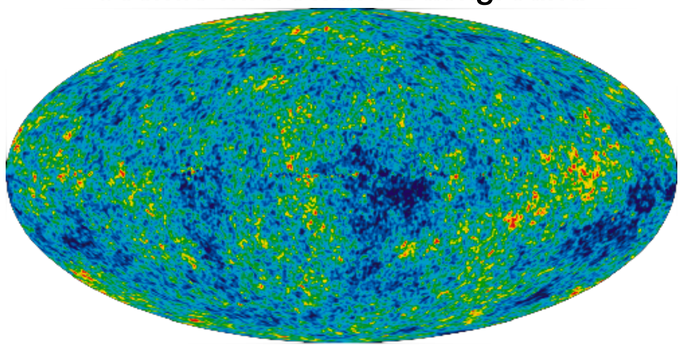
- Numerous cosmological evidence for the existence of DM
  - *Galactic rotation curves*
  - *Clusters of galaxies*
  - *Early and late cosmology (CMB, LSS)*
  - *Big Bang Nucleosynthesis*
  - *…*

Rotation curves of stars



Colliding galaxy clusters

Cosmic Microwave Background



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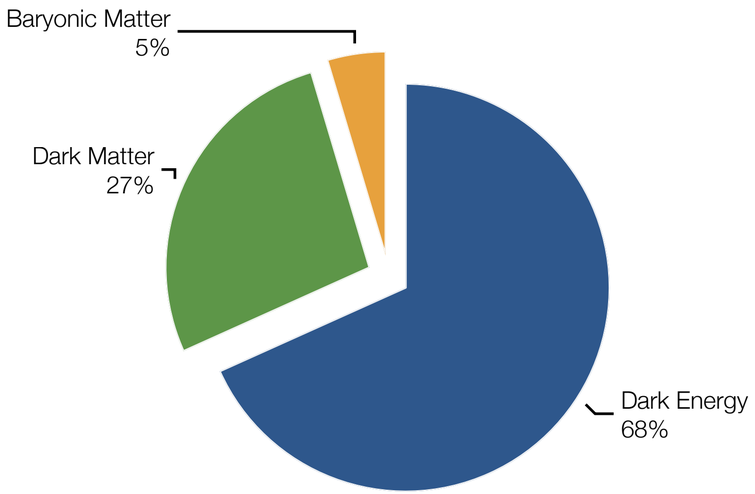
  - *…*

- What we know so far
  - *Long-lived*
  - *Electrically neutral*
  - *Gravitationally interacting*
  - *“Particle-like”*
  - *Non-baryonic*



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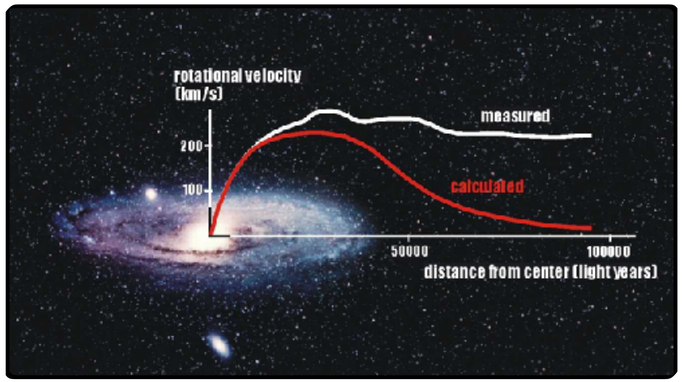

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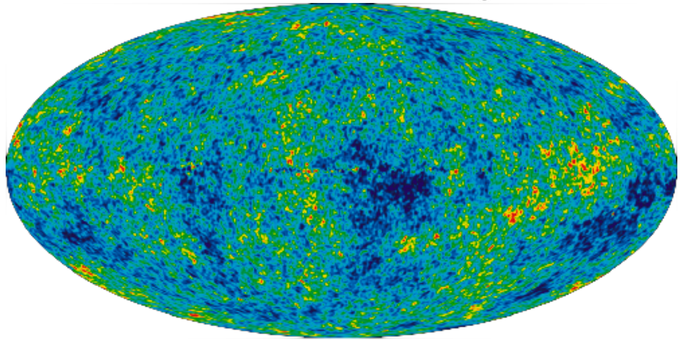
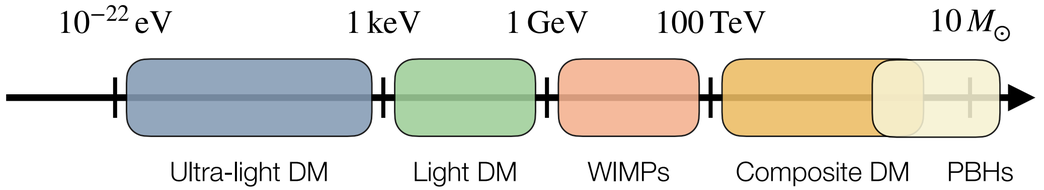


Where do we look?

- Many models consistent with observations exist
  - *WIMPs and axions among popular candidates*



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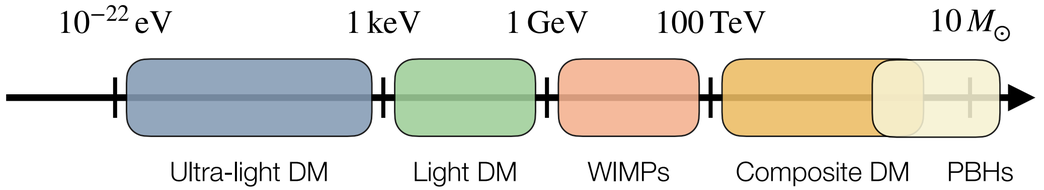

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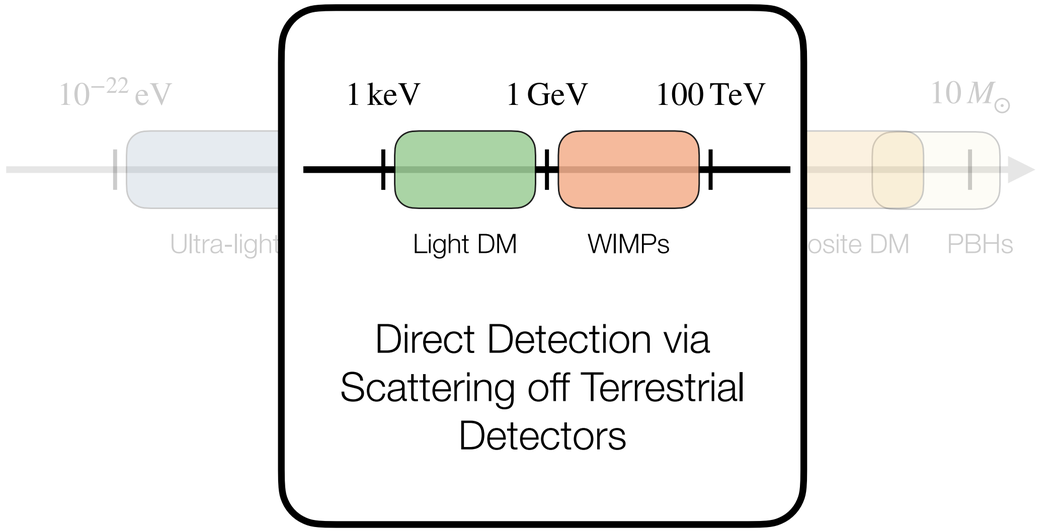
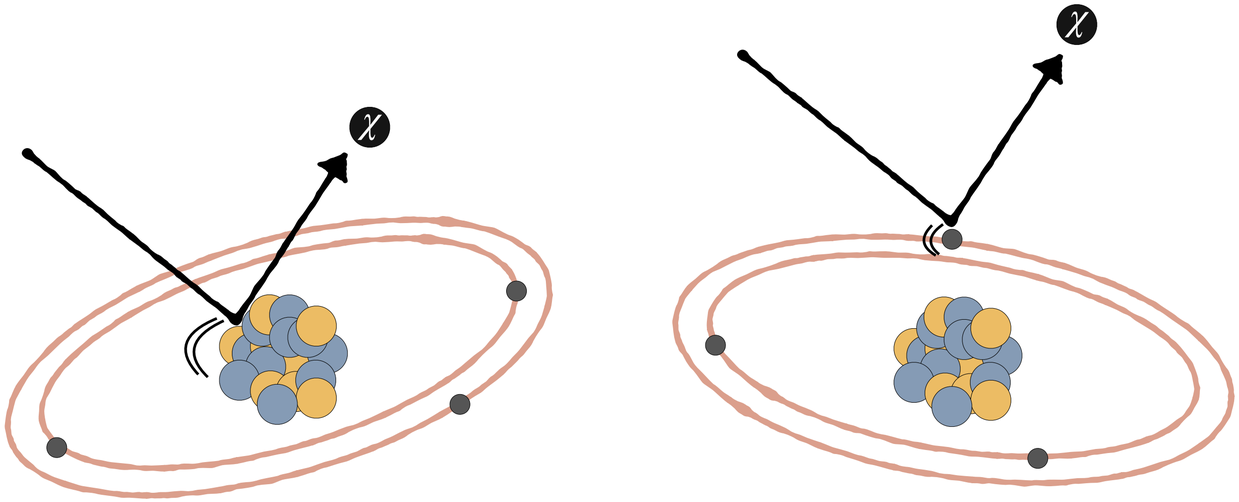


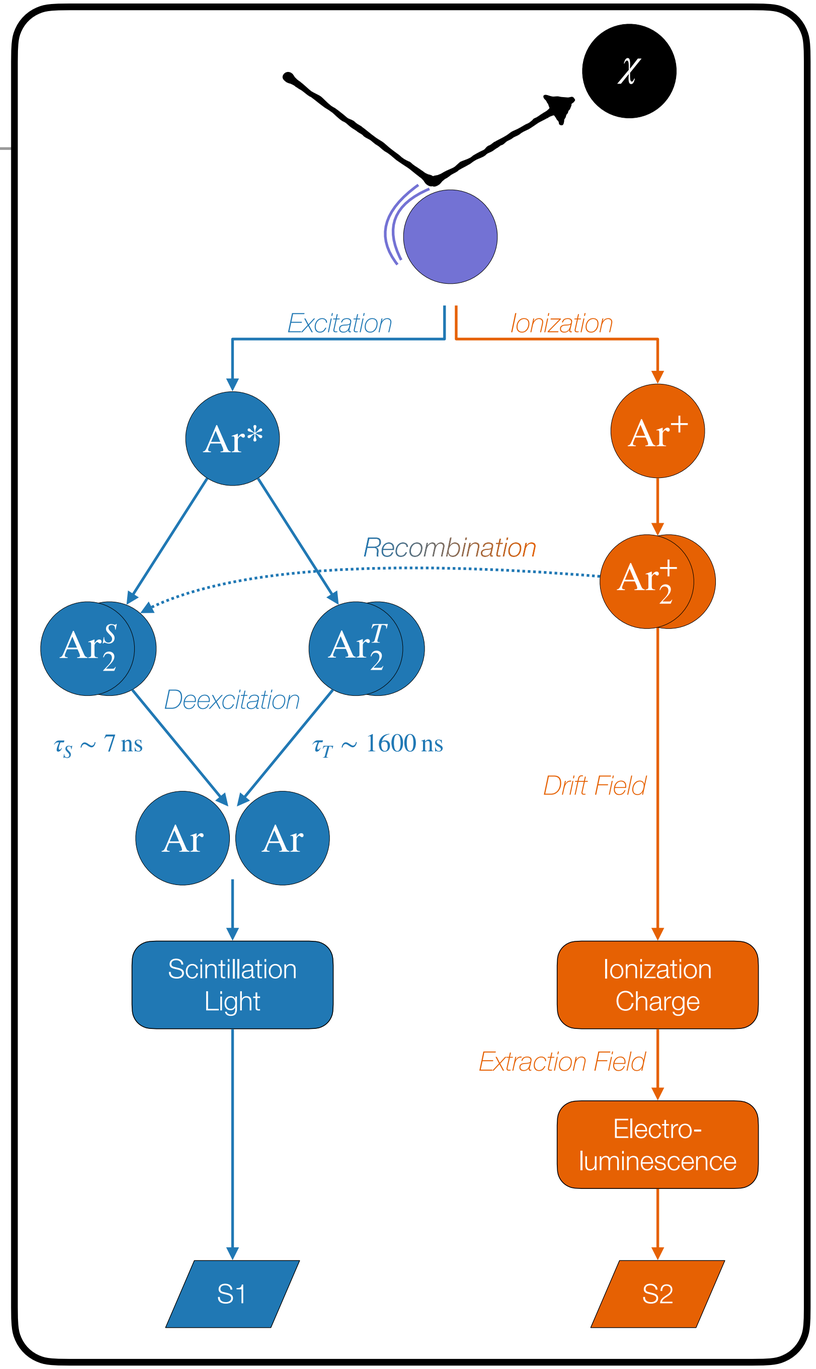


Nuclear Recoil (NR)

Electronic Recoil (ER)

Liquid Argon as Target Material

- Liquid Argon (LAr) properties
  - *Scalable to very, very large detector volumes → large exposure*
  - *Easy purification for both electro-negative and radioactive contamination → high purity*
  - *Provide good self-shielding capabilities → low background*
  - *Colder temperatures (easier Rn removal) → low background*
  - *Powerful background rejection techniques by measuring charge and light → background rejection*
- Emission of VUV scintillation light
  - *Requires wavelength-shifting material* $128\,\mathrm{nm} \rightarrow 420\mathrm{nm}$
- Presence of cosmogenically activated $^{39}\mathrm{Ar}$
  - *Pulse Shape Discrimination (DEAP-3600)*
  - *Underground-sourced argon (DarkSide-50)*



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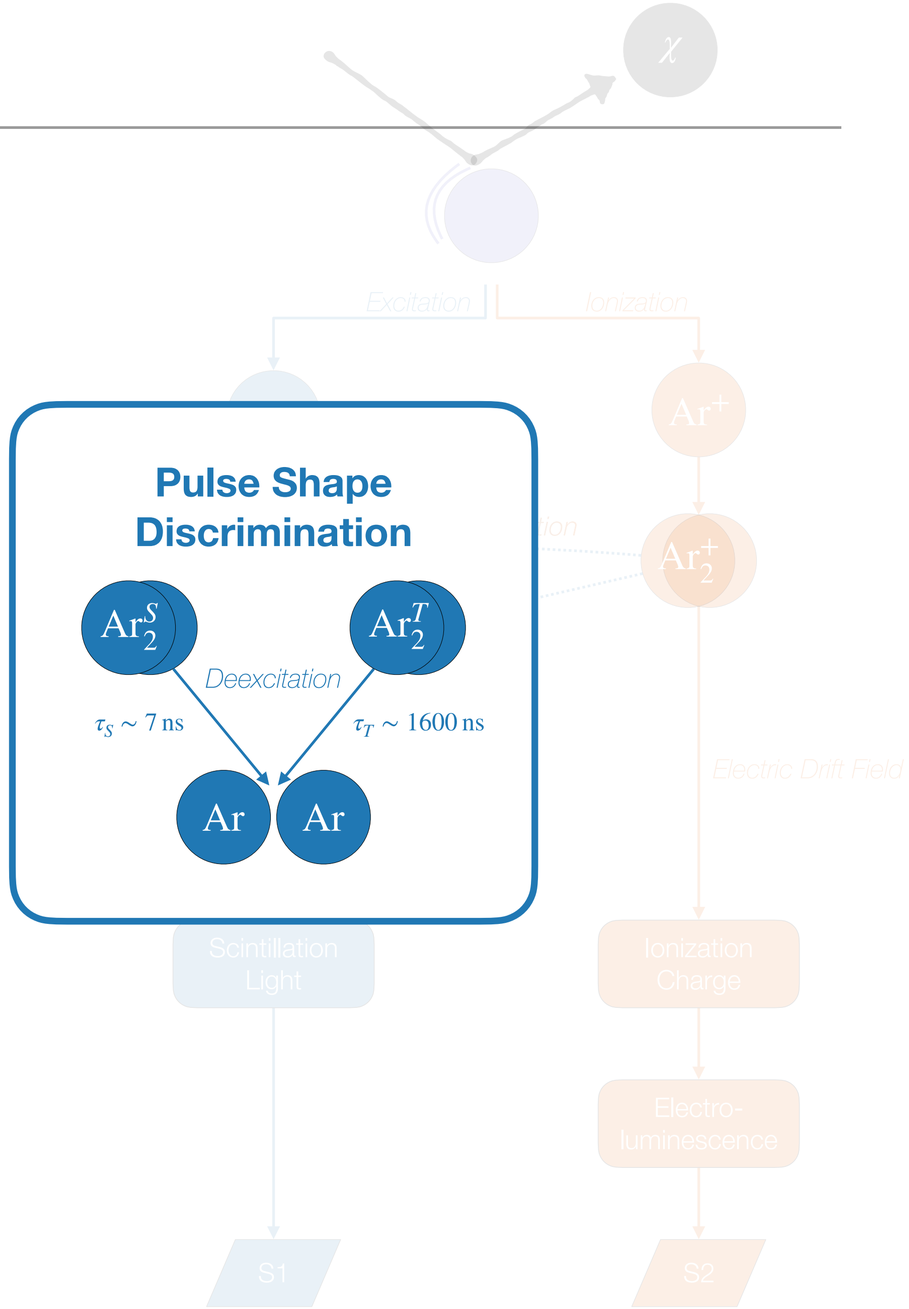


Pulse Shape Discrimination

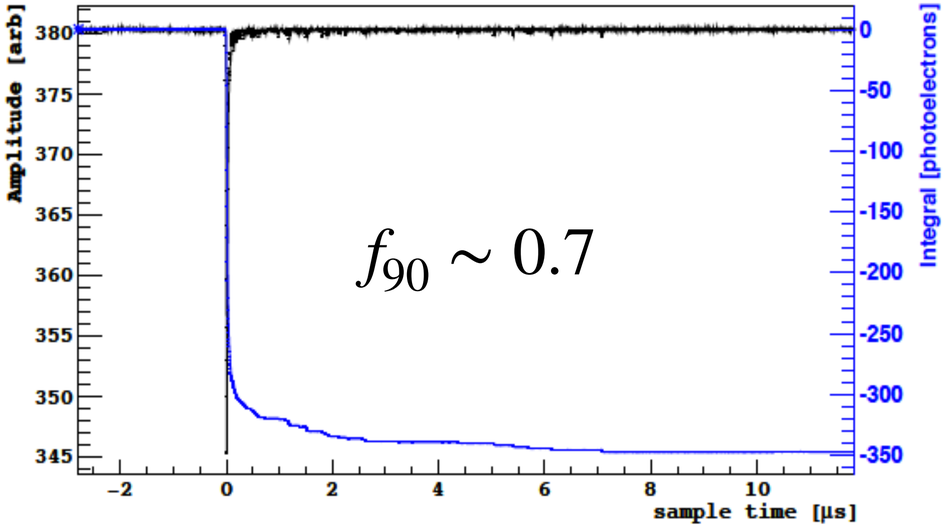
- The population of Singlet ($\tau_S \sim 7\,\mathrm{ns}$) vs Triplet ($\tau_T \sim 1600\,\mathrm{ns}$) states is particle dependent
  - *Nuclear Recoil* (NR) *(*n, α, χ*): preferably Singlet*
  - *Electronic Recoil* (ER) *(*β, γ*): preferably Triplet*

- Effective observable to discriminate based on the prompt light signal

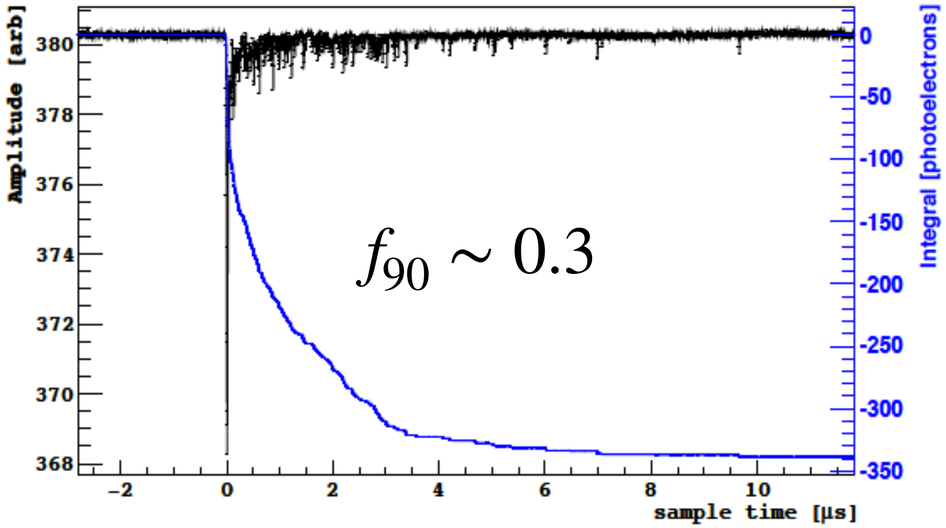
$$f_{90} = \frac{\int_0^{90} A(t)dt}{\int A(t)dt}$$

Needs to be optimized for a given detector

Nuclear Recoil Event

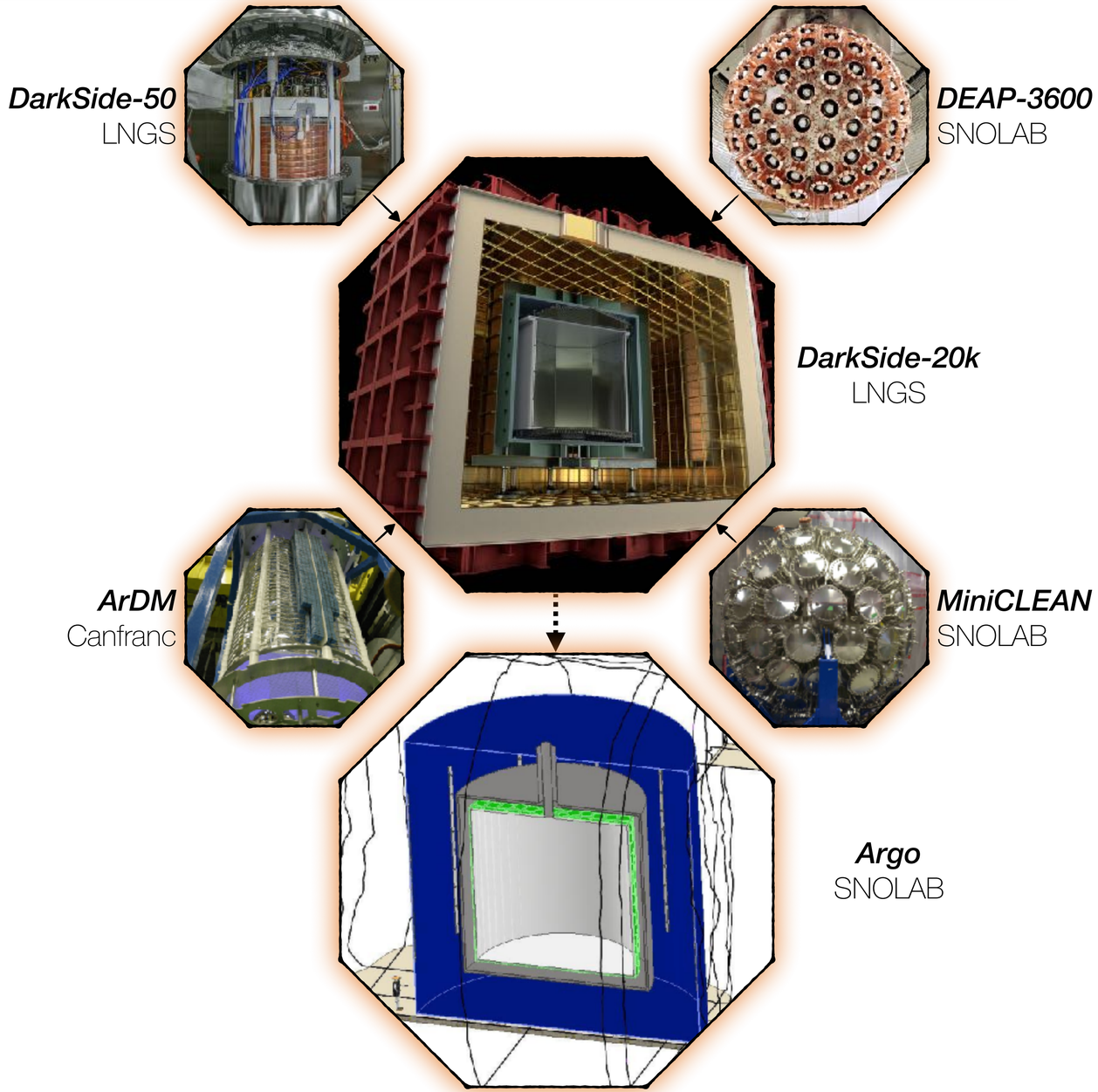


Electron Recoil Event



Global Argon Dark Matter Collaboration

- Combined expertise from 4 LAr experiments
  - *Over 400 collaborators*
  - *100 different institutes*
- Goal
  - *Build the ultimate LAr Detector*
  - *Explore DM to the neutrino floor and beyond*
  - *Extremely low instrumental background*
- A sequential, two-step program
  - *DarkSide-20k (*$200\,t \cdot yr$ *fiducial)*
  - *Argo (*$3000\,t \cdot yr$ *fiducial)*

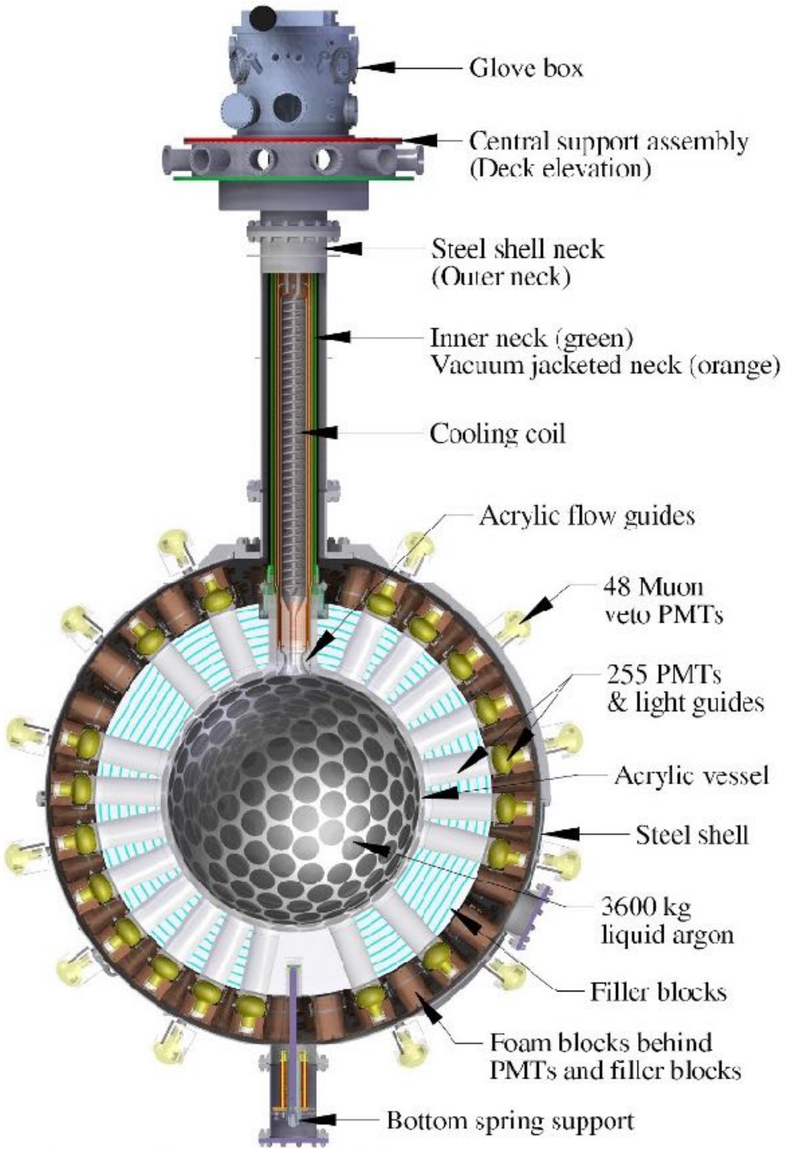


DEAP-3600 Overview

Dark matter **E**xperiment using **A**rgon **P**ulse-shape discrimination

With input from Susnata Seth

- Largest operating liquid-argon DM detector
  - *Single-phase LAr detector with* $3600\,kg$ *of LAAr*
  - *Spherical acrylic vessel instrumented with 255 PMTs*
  - *Located at SNOLAB*
- Key achievements
  - *World-leading PSD performance*
  - *Providing the best limit for above* $30\,GeV$ *WIMPs with argon*
  - *Leading sensitivity to superheavy, multi-scattering dark matter*
- Main ongoing analyses
  - *WIMP search with improved background model and Profile Likelihood Ratio method (3yr dataset)*
  - *Solar neutrino absorption in* ^{40}Ar
  - *Muon flux measurement at SNOLAB*
- Hardware upgrades completed
  - *Reduce challenging alpha backgrounds in the neck*
  - *Aiming for a background-free sensitivity at* $10^{-46}cm^2$ *level*
  - *Detector refilled with LAr and currently taking data*



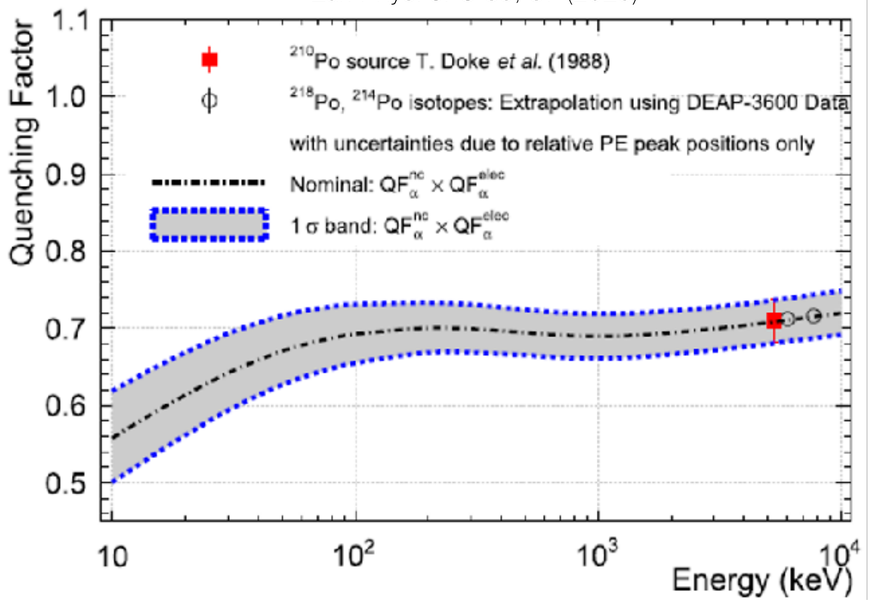
DEAP-3600 Recent Results

Dark matter Experiment using Argon Pulse-shape discrimination

With input from Susnata Seth

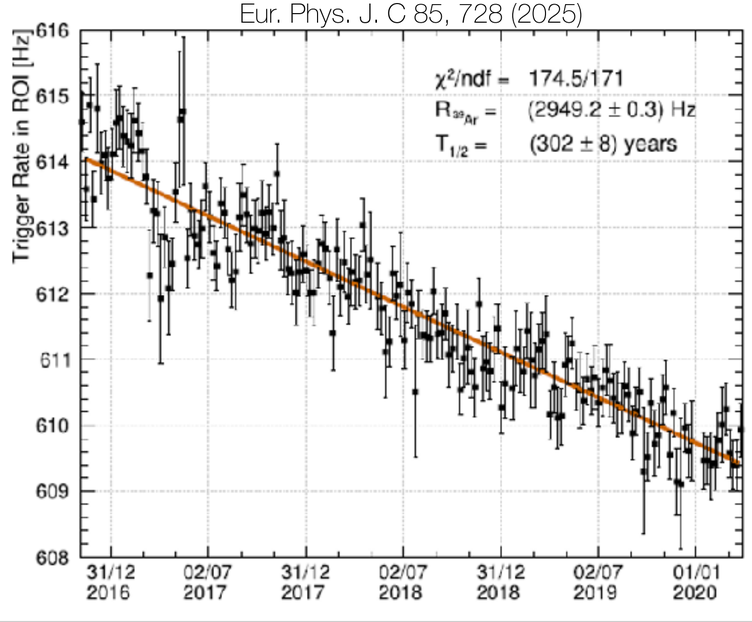
Relative Measurement and Extrapolation of the Scintillation Quenching Factor of α-Particles in Liquid Argon using DEAP-3600 Data

Eur. Phys. J. C 85, 87 (2025)



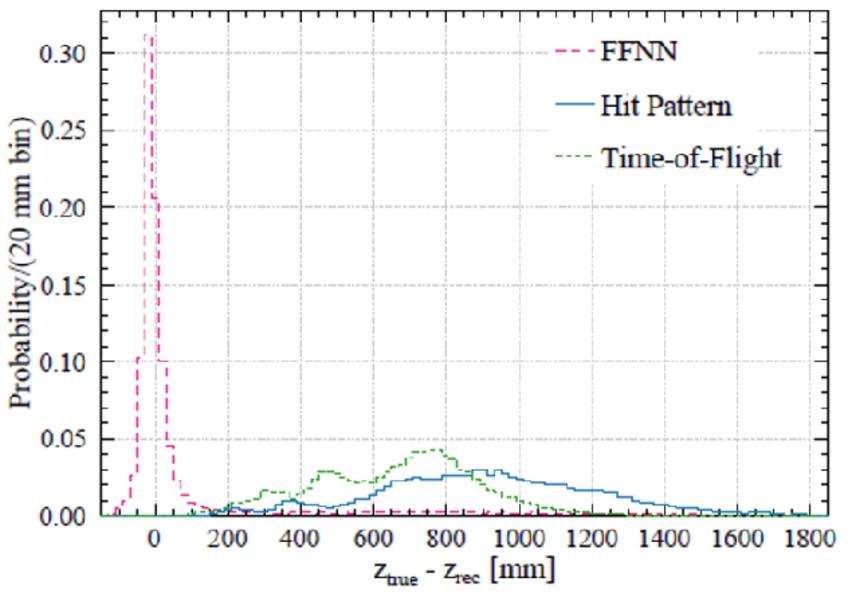
Direct Measurement of the ^{39}Ar Half-life from 3.4 Years of Data with the DEAP-3600 Detector

Eur. Phys. J. C 85, 728 (2025)



Position Reconstruction in the DEAP-3600 Dark Matter Search Experiment

2025 JINST 20 P07012



Updates on the DEAP-3600 experiment and steps towards the ARGO experiment

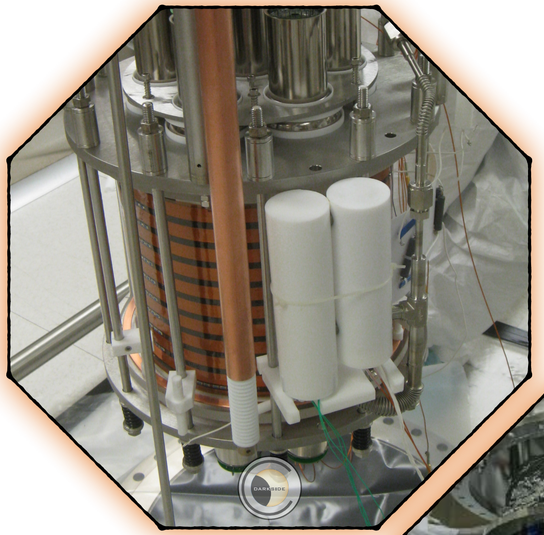
Tuesday, October 21

Susnata Seth

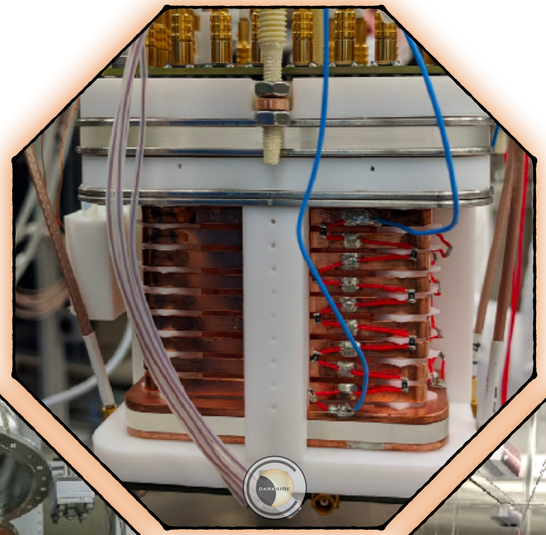
https://indico.ihep.ac.cn/event/24964/contributions/194837/

The DarkSide Program

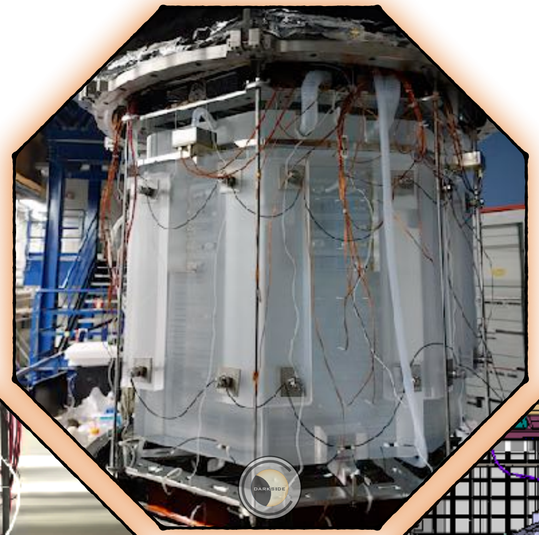
DS-10
2010



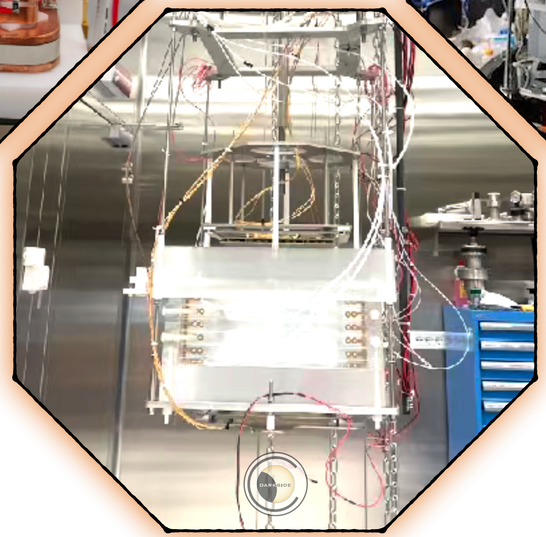
DS-ReD
2017-2025



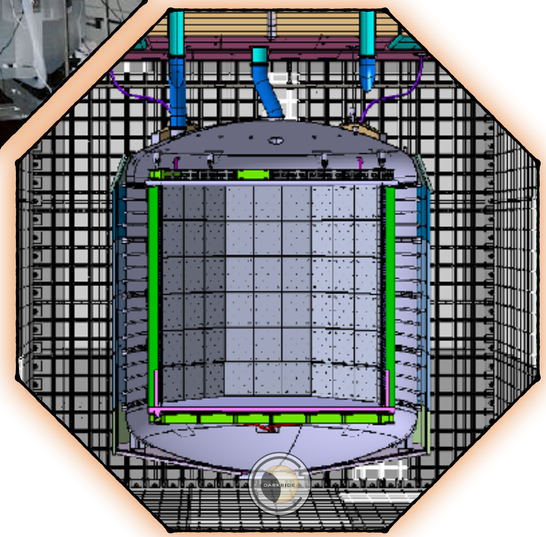
DS-Mockup
2025



DS-50
2013-2020



DS-Proto-0
2024-2025



DS-20k
2027-

The DarkSide Program

DS-10
2010

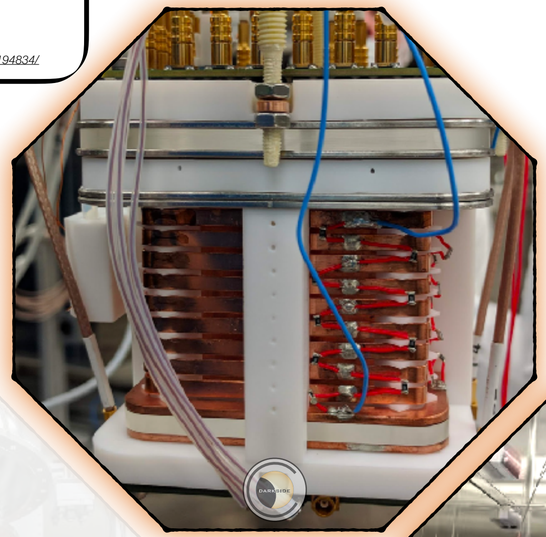
Characterization of argon recoils at the keV scale with ReD and ReD+

Tuesday, October 21

Luciano Pandola

https://indico.ihep.ac.cn/event/24964/contributions/194834/

DS-ReD
2017-2025



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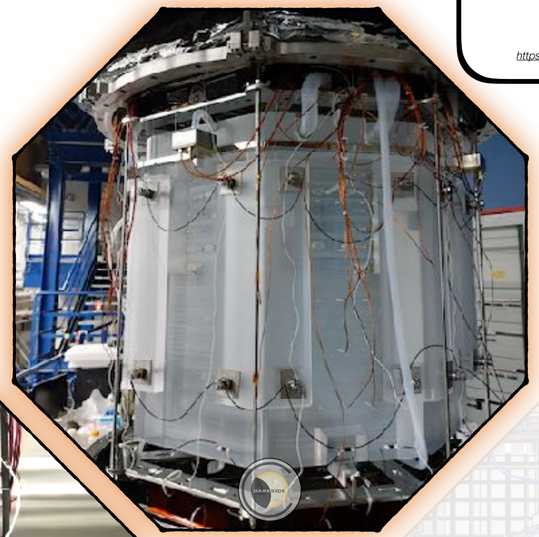
2025



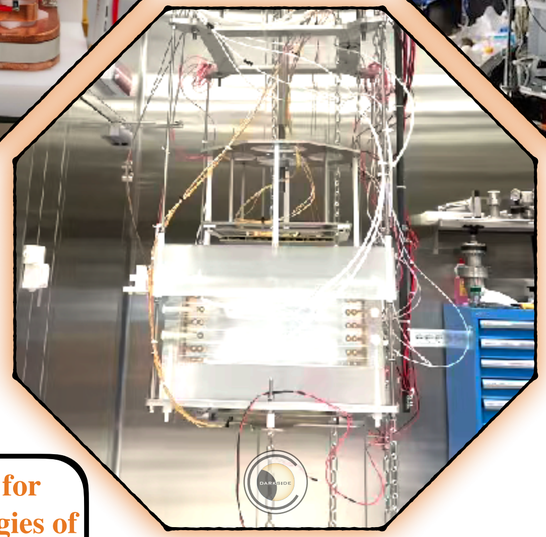
A Tonne-scale Demonstrator for the DarkSide-20k Inner Detector at LNGS

Tuesday, October 21

Paolo Salomone

https://indico.ihep.ac.cn/event/24964/contributions/196480/

DS-50
2013-2020



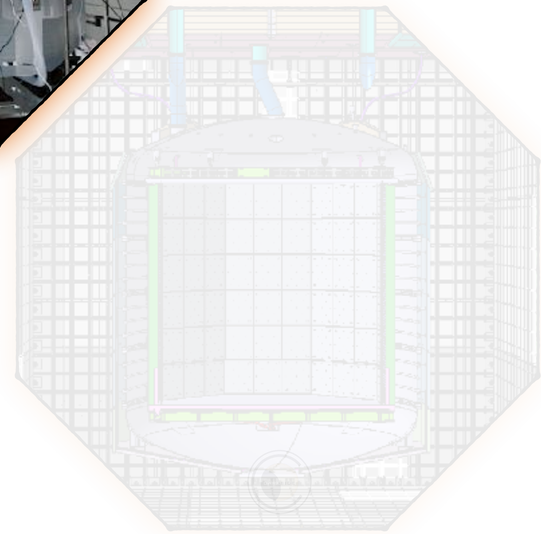
Proto-0: a prototype for validating key technologies of the DS-20k experiment

Tuesday, October 21

Giuseppe Matteucci

https://indico.ihep.ac.cn/event/24964/contributions/196481/

DS-Proto-0
2024-2025



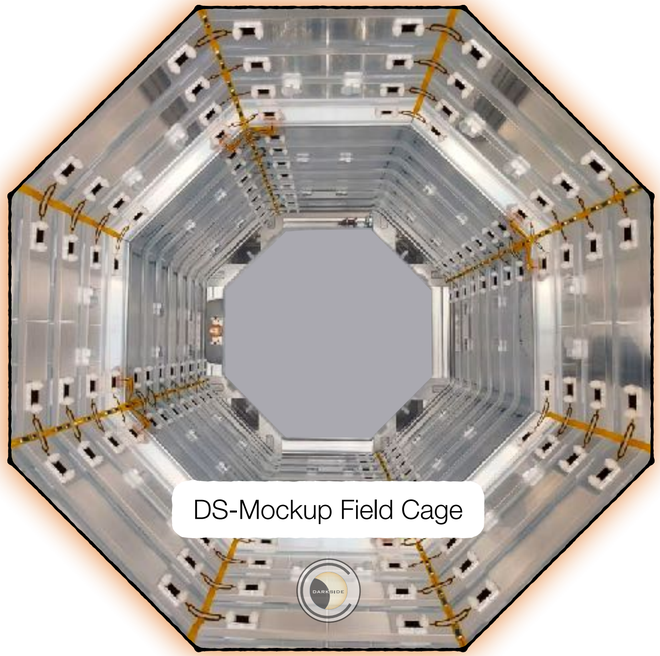
DS-20k
2027-

Key Technologies for DarkSide-20k

Underground Argon (UAr)

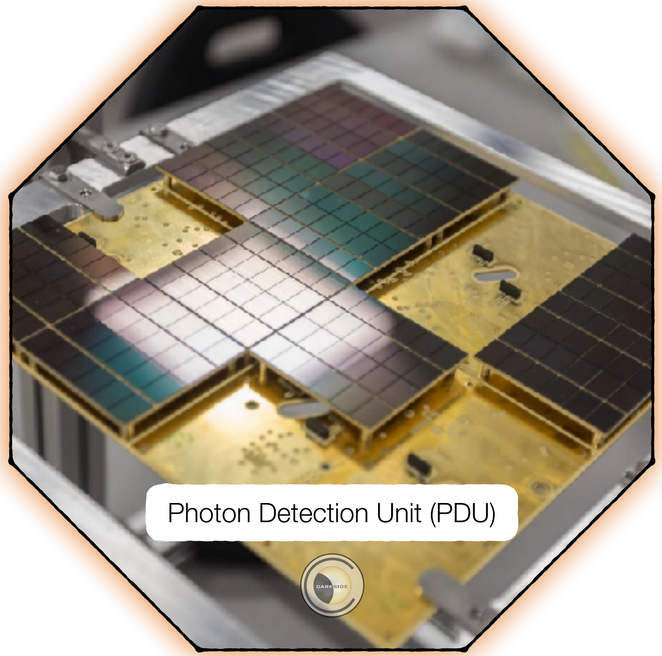
A detector medium with a reduction factor of ~ 1400 in $^{39}\mathrm{Ar}$ compared to atmospheric argon

PMMA TPC



Transparent low-radioactivity PMMA TPC with conductive Clevios$^{\mathrm{TM}}$-coated surfaces as electrodes

Silicon Photomultiplier (SiPM)



Large-area ($\sim 25\ \mathrm{m}^2$), low-noise, low-radioactivity SiPM arrays

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- **Production in Colorado, USA**
  - *Industrial-scale extraction plant*
  - *Extraction rate of* $(250 - 330)\,kg/day$
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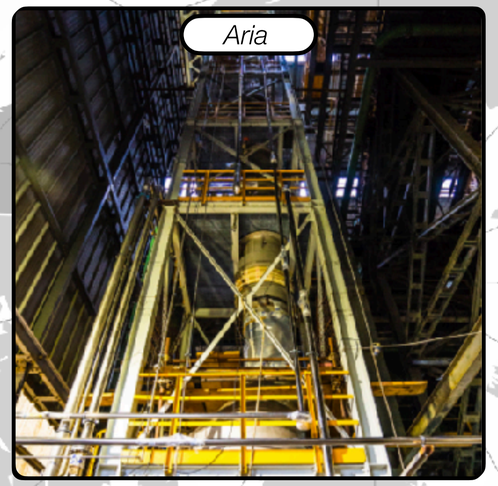

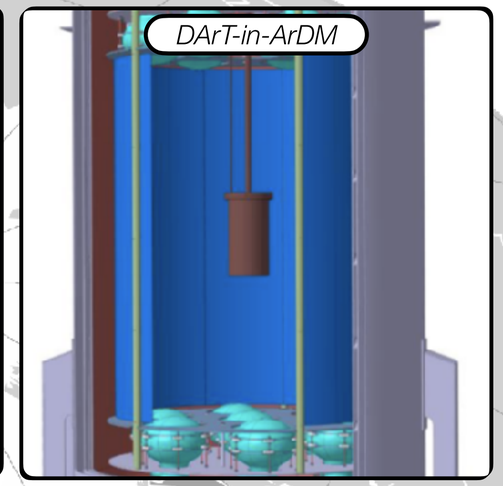

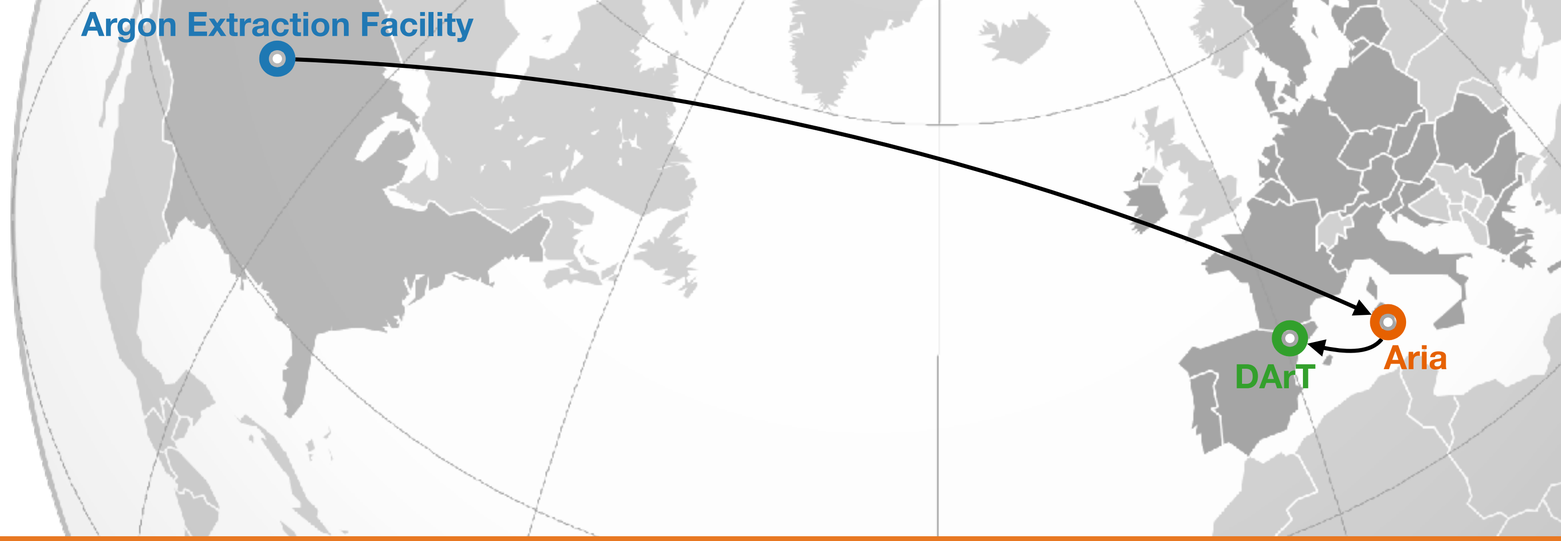

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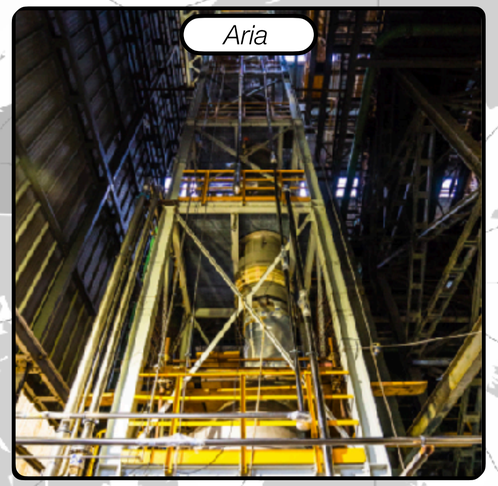

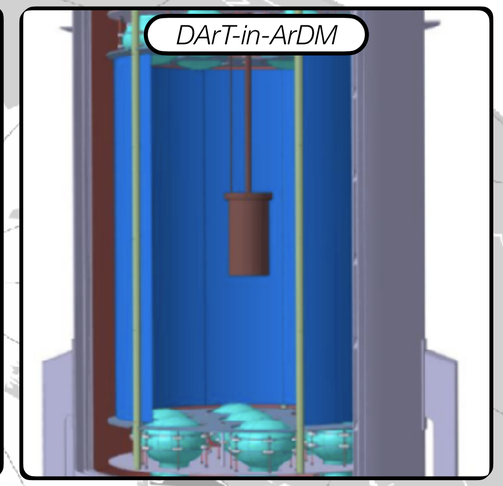

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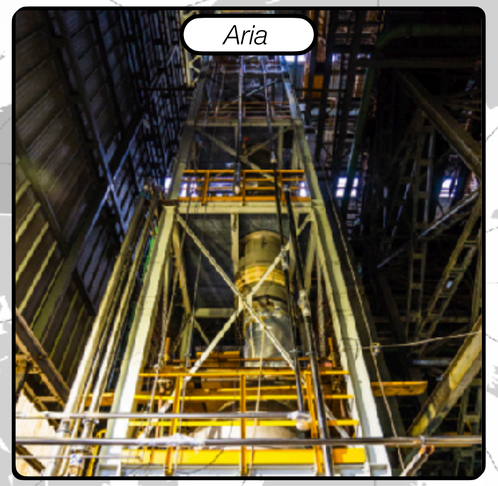
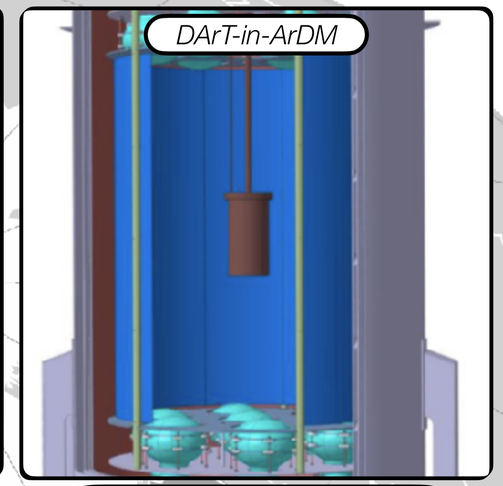


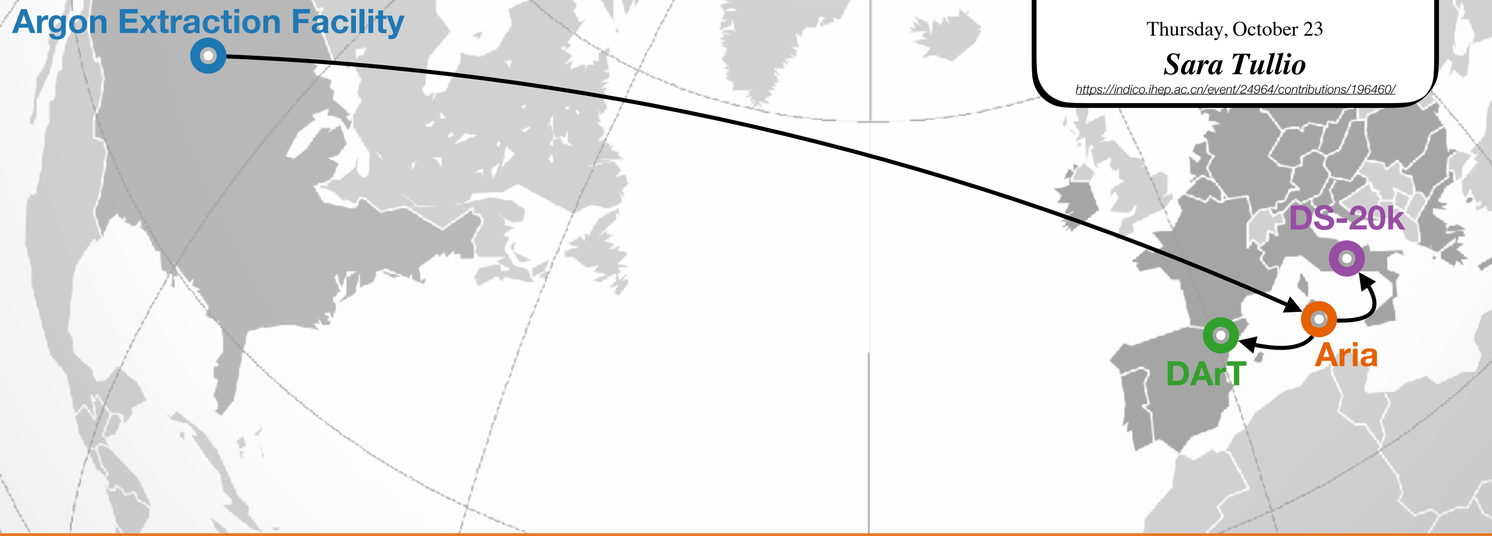


DArT-in-ArDM: A Dedicated Detector for 39Ar Characterization in UAr

Thursday, October 23

Sara Tullio

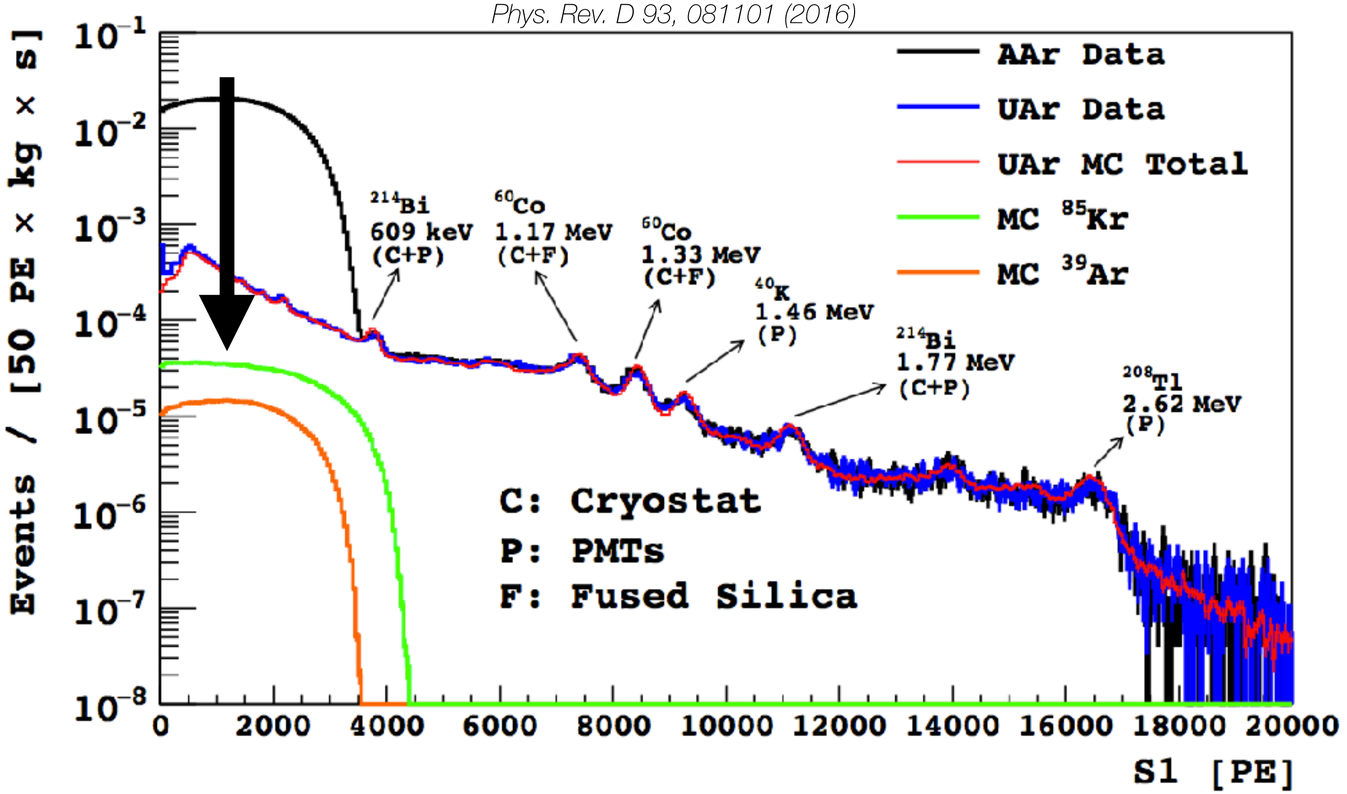
https://indico.ihep.ac.cn/event/24964/contributions/196460/



UAr in DarkSide-50

- $^{39}\mathrm{Ar}$ activity sets the detection threshold at low energies
  - *where pulse shape discrimination is less effective*
- Deployed $157\,\mathrm{kg}$ UAr in 2015
- $^{39}\mathrm{Ar}$ reduction factor of ~ 1400
  - *Intrinsic depletion factor in UAr is likely higher*

Phys. Rev. D 93, 081101 (2016)

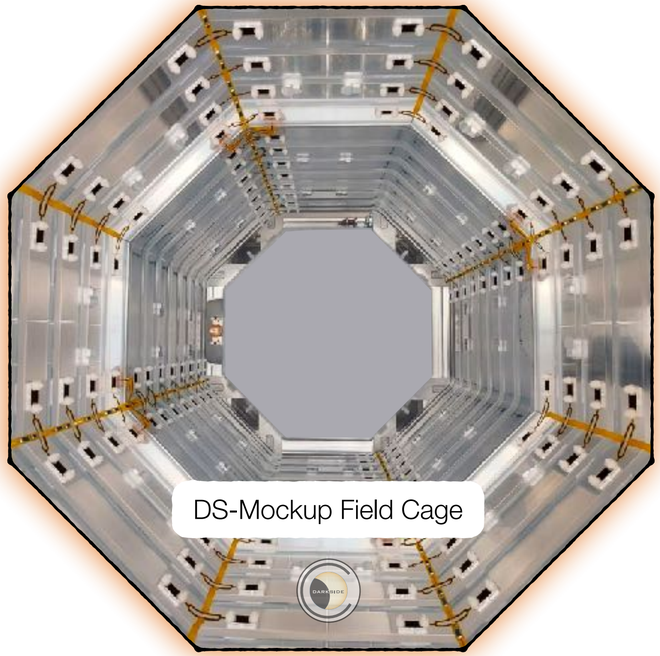


Key Technologies for DarkSide-20k

Underground Argon (UAr)

A detector medium with a reduction factor of ~ 1400 in ^{39}Ar compared to atmospheric argon

PMMA TPC



Transparent low-radioactivity PMMA TPC with conductive Clevios™-coated surfaces as electrodes

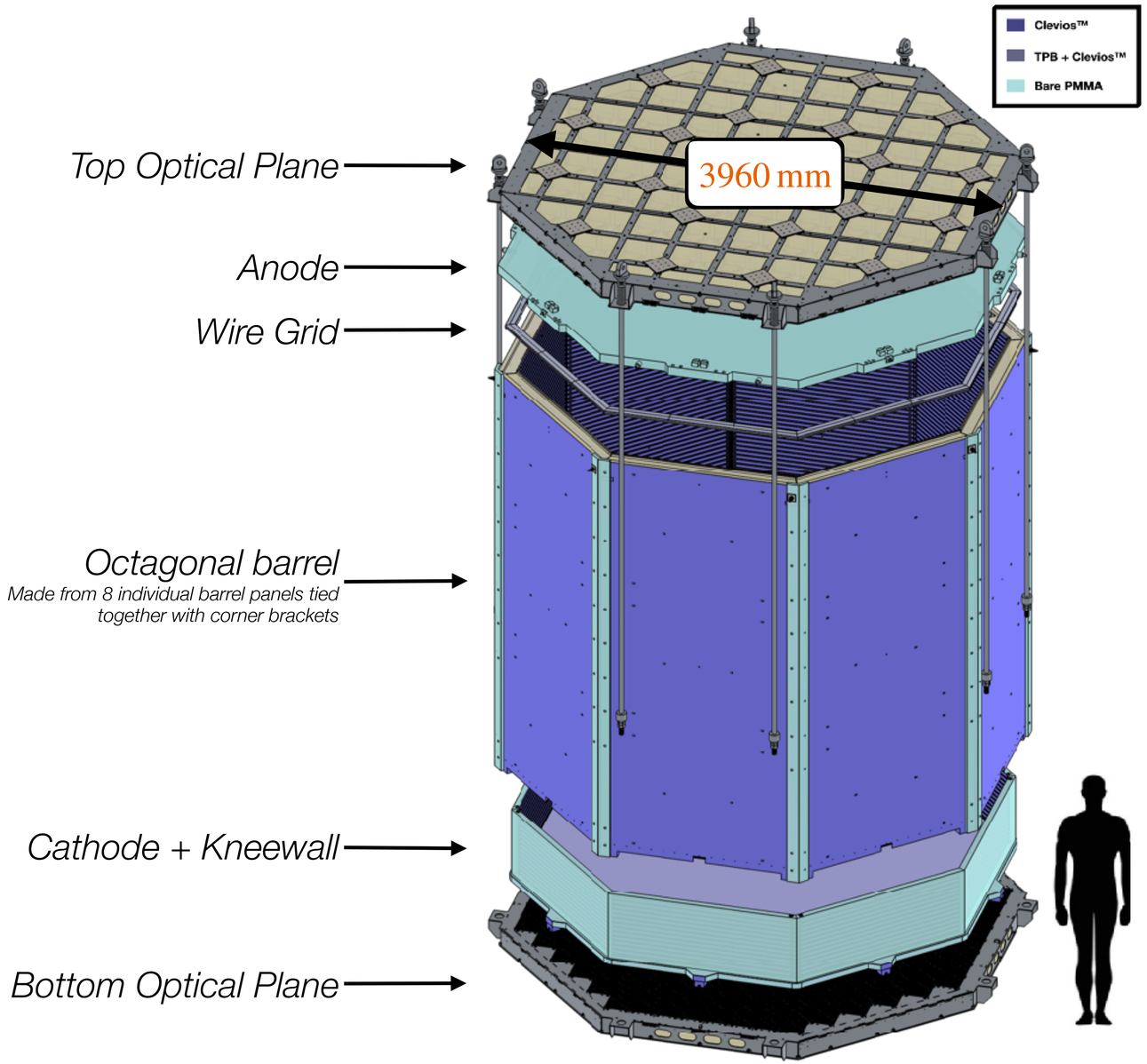
Silicon Photomultiplier (SiPM)

Large-area ($\sim 25\ m^2$), low-noise, low-radioactivity SiPM arrays

The DarkSide-20k Inner Detector

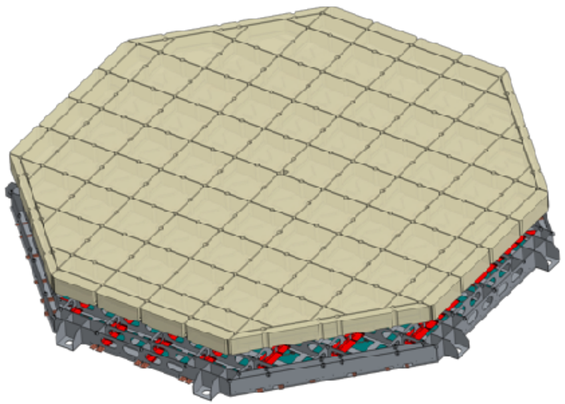
- Octagonal vessel made from ultra-pure PMMA
  - *Operated as a dual-phase time projection chamber (TPC) filled with* $\mathit{low\ radioactivity\ underground\ argon}$
  - *Active (fiducial) mass of* $49.7\,t\ (20.2\,t)$
  - *Drift length of* $3480\,mm$
- Two optical planes with 528 light readout channels each (total of $20\,m^2$ of light sensors + $5\,m^2$ in inner veto)
  - *Light wavelength-shifted via TPB from* $128\,nm$ *to* $420\,nm$
  - *Visible light reflected by foils of Enhanced Specular Reflector (ESR)*
- Drift field of $200\,V/cm$
  - $(V_{Cathode} \approx -75\,kV)$

Exploded View of DS-20k Inner Detector 3D Model

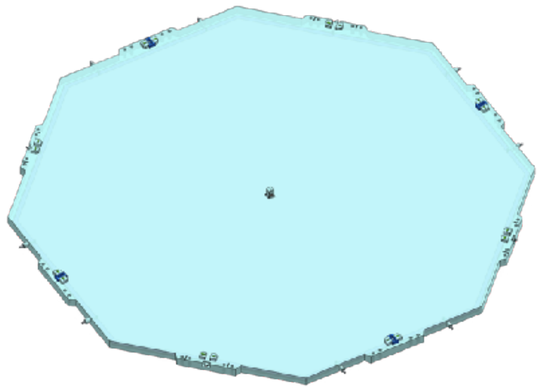


PMMA Time Projection Chamber

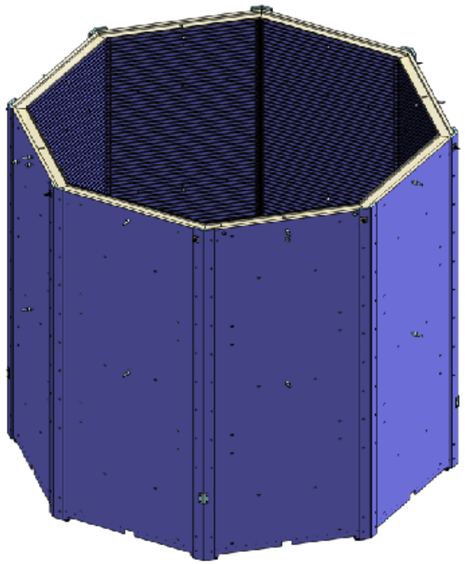
- Many pieces of the DarkSide-20k are made from PMMA
  - *Neutron capture on* ^{1}H
  - *Transparent to visible light*



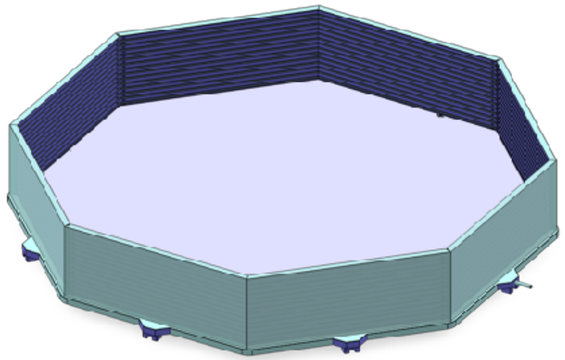
PMMA Blocks
inside Optical Planes (Top and Bottom)



PMMA Anode



PMMA Barrel



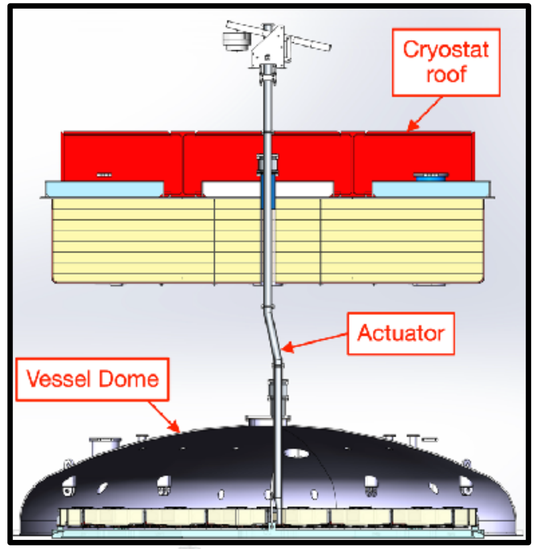
PMMA Cathode/Kneewall

PMMA Time Projection Chamber

Spatial uniformity of S2-response requires the bottom surface of the anode window to be planar, stationary, parallel and 7 mm above the liquid argon surface, and parallel to the grid wires.

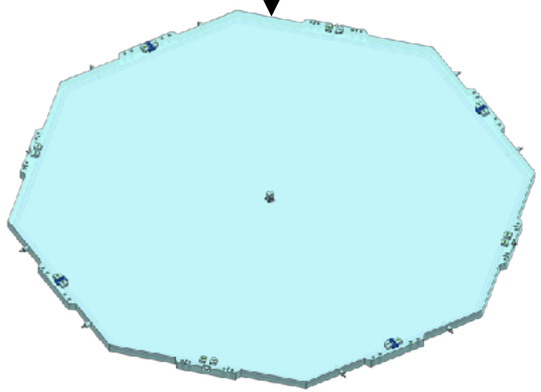
➡**Optimal S2 gain:**
flatness across the **whole anode/grid system** to be **within 0.5 mm** coupled with **S2 (x,y) calibrations**.

➡**Optimal S2 resolution:**
surface flatness across **distances of order 20 cm** to be **within 0.1 mm**.



Anode Adjustment System to Counteract Creep of Anode due to Gravity

PMMA Blocks inside Optical Planes (Top and Bottom)

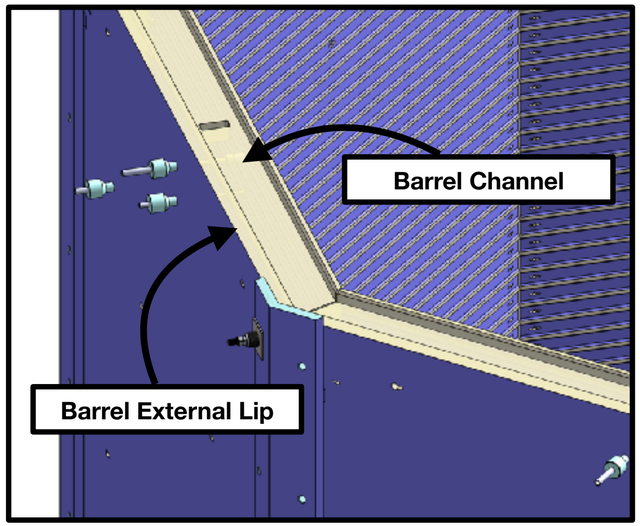


PMMA Anode

PMMA Barrel

PMMA Cathode/Kneewall

PMMA Time Projection Chamber



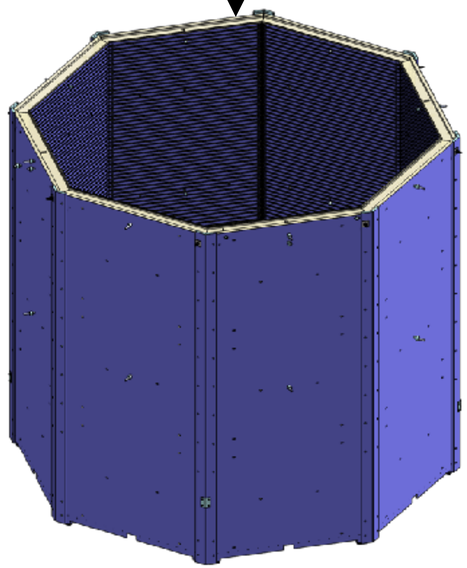
Aiming to **0.1 mm flatness requirement** on:

- **external lip** of barrel (where the anode rests);
- barrel **channel** (where the wire-grid frame rests).

➡ developed a barrel-assembly procedure and anchoring scheme aiming to **enable alignment** of panel top features within **0.1 mm**

PMMA Blocks inside Optical Planes (Top and Bottom)

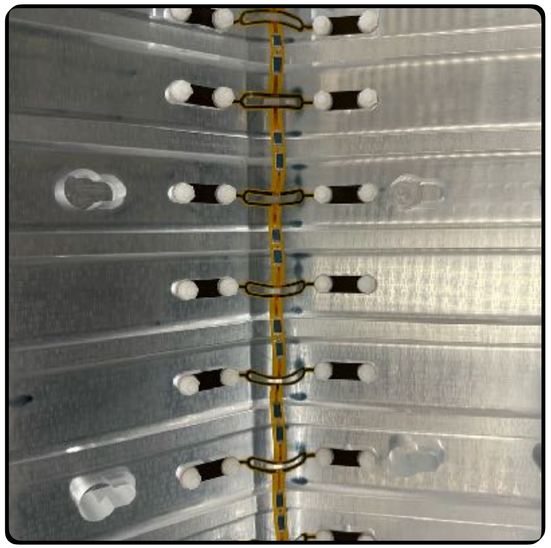
PMMA Anode



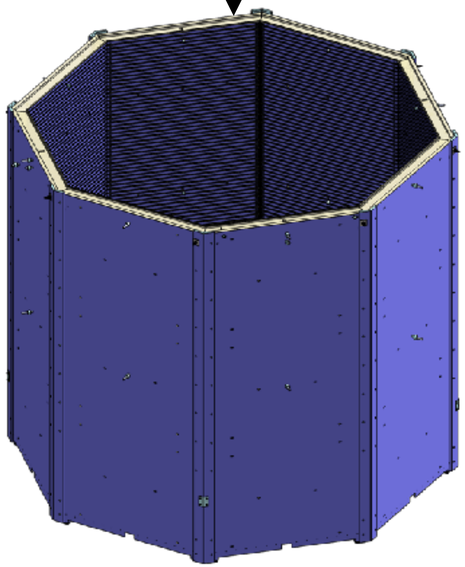
PMMA Barrel

PMMA Cathode/Kneewall

PMMA Time Projection Chamber



Field shaping rings are kept at a degrading voltage via ***4 redundant Resistor Chains*** i.e. voltage dividers on a flexible caption PCB.



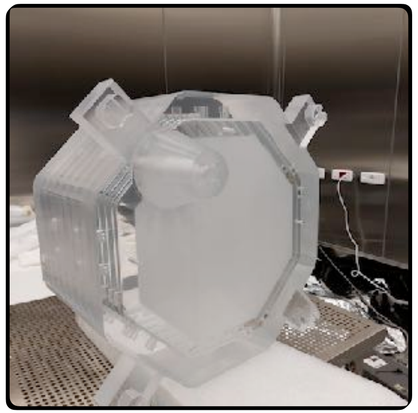
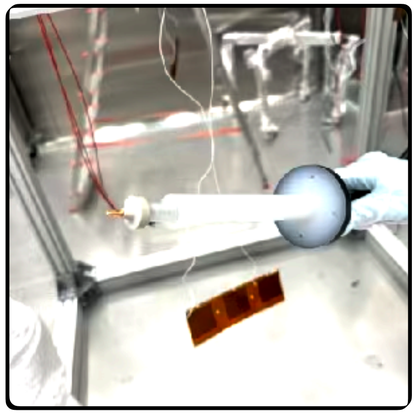
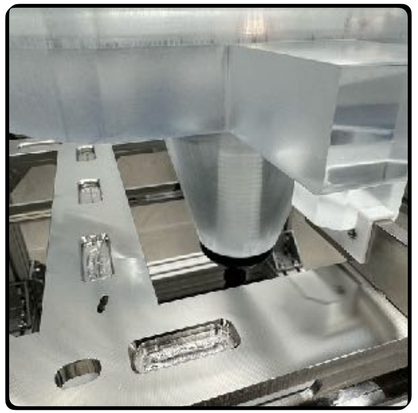
PMMA Barrel

PMMA Blocks inside Optical Planes (Top and Bottom)

PMMA Anode

PMMA Cathode/Kneewall

PMMA Time Projection Chamber


A conducting PE HV cable delivers the high voltage to the Clevios™-coated cathode surface ;

- ➡ penetrating the Argon volume through a warm feedthrough on the roof of the cryostat.

A stress cone located below the cathode

- ➡ a plug terminating the cable
- ➡ a PMMA cone bonded on the outer face
- ➡ a copper “mushroom” contacting the inner Clevios™-coated cathode surface.

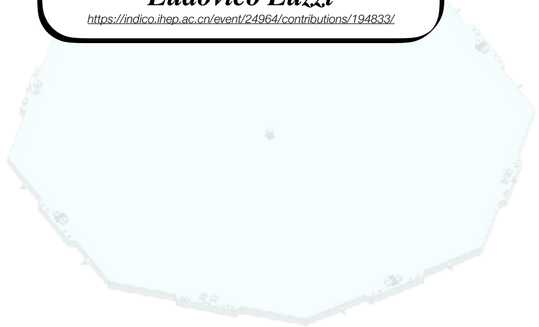
HV Performance Testing in LAr of the PMMA Cathode Connection for DS-20k

Wednesday, October 22

Ludovico Luzzi

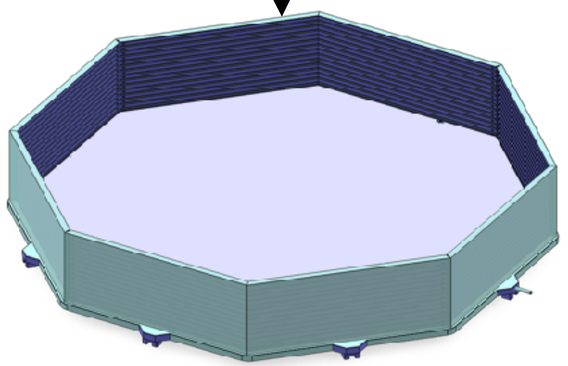
https://indico.ihep.ac.cn/event/24964/contributions/194833/

PMMA Blocks inside Optical Planes (Top and Bottom)



PMMA Anode

PMMA Barrel

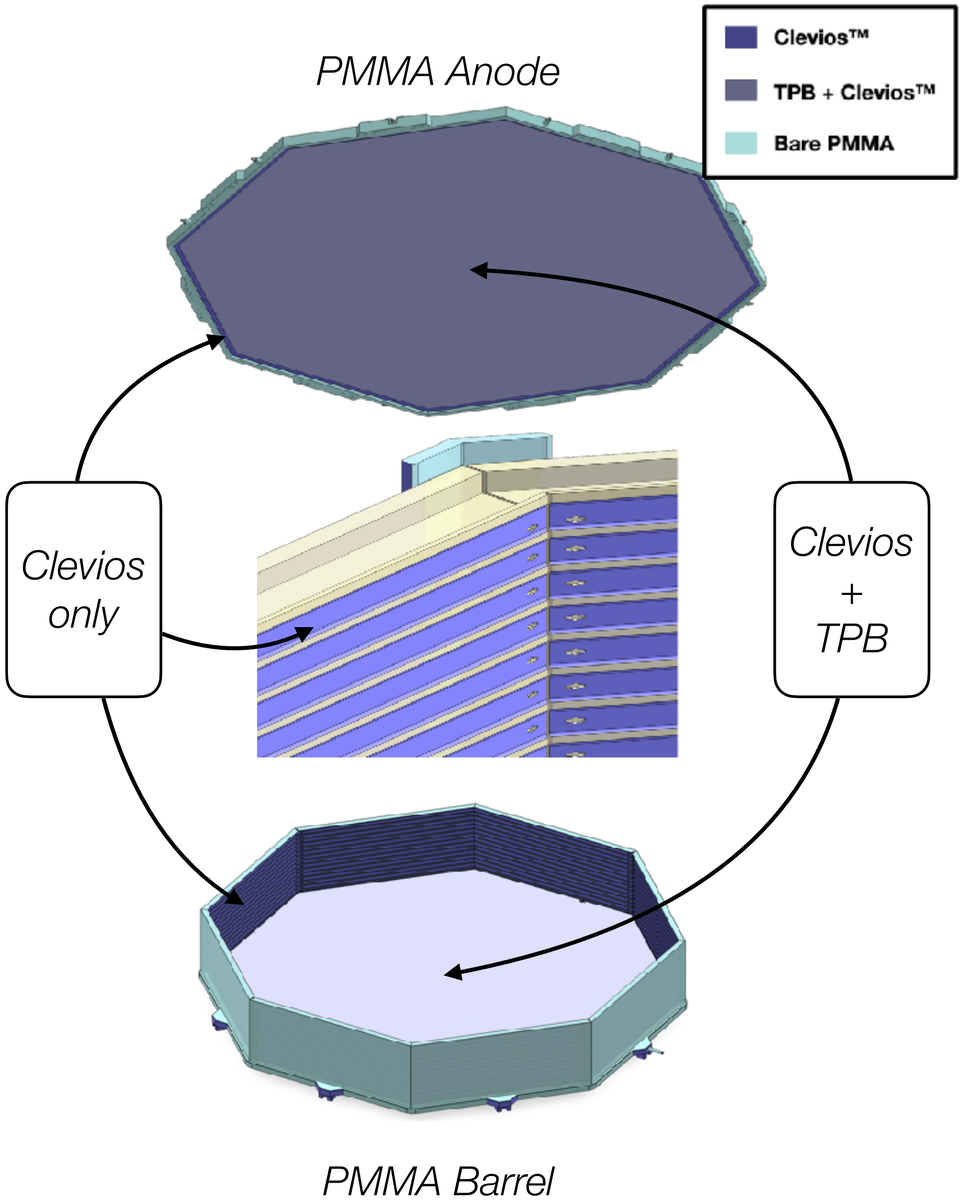


PMMA Cathode/Kneewall

Clevios and TPB Coatings

- Clevios™-coated PMMA surfaces as electrodes
  - ➡ *Conductive polymer*
  - *Inward-facing cathode window at potential* $(V_C \approx -75\,\mathrm{kV})$
  - *Inward-facing anode window* $(V_A = 0\,\mathrm{V})$
  - *Inward-facing strips on the barrel at potential*
  - *Outward-facing PMMA surfaces will be grounded*

- TPB coating for wavelength shifting
  - *Inward-facing cathode window (Clevios+TPB)*
  - *Inward-facing anode window (Clevios+TPB)*
  - *Reflector assembly around barrel (ESR+TPB)*



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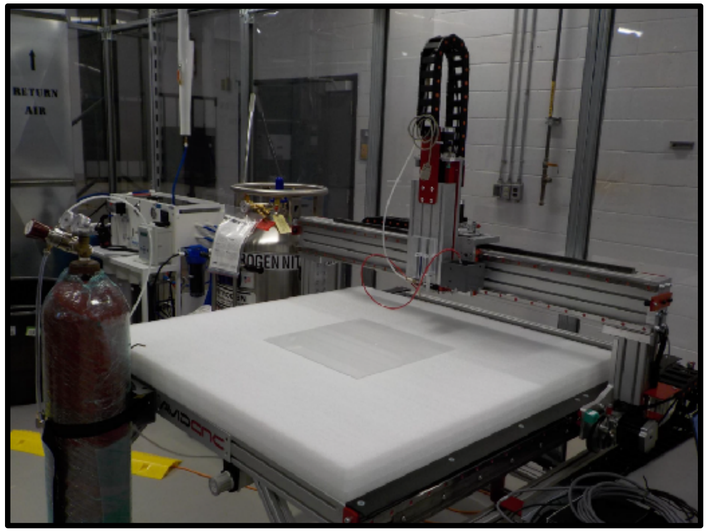
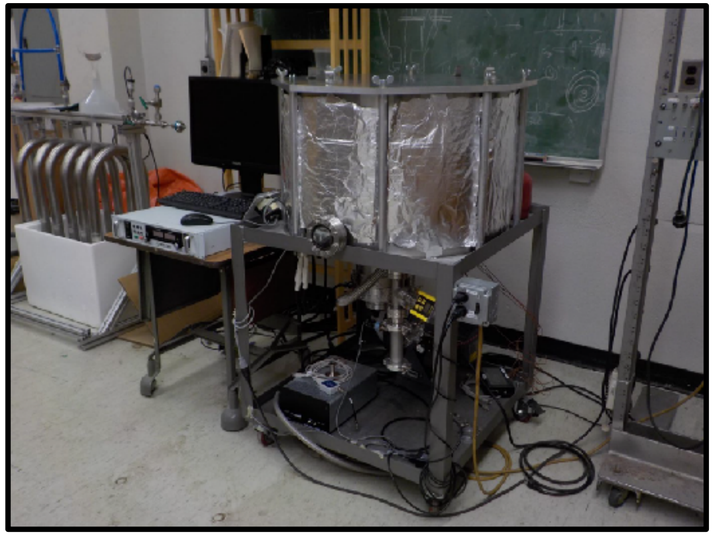
- Fully exercised for the DS-Mockup demonstrator

CNC Table for Clevios Spray Coating



TPB Evaporation Chamber



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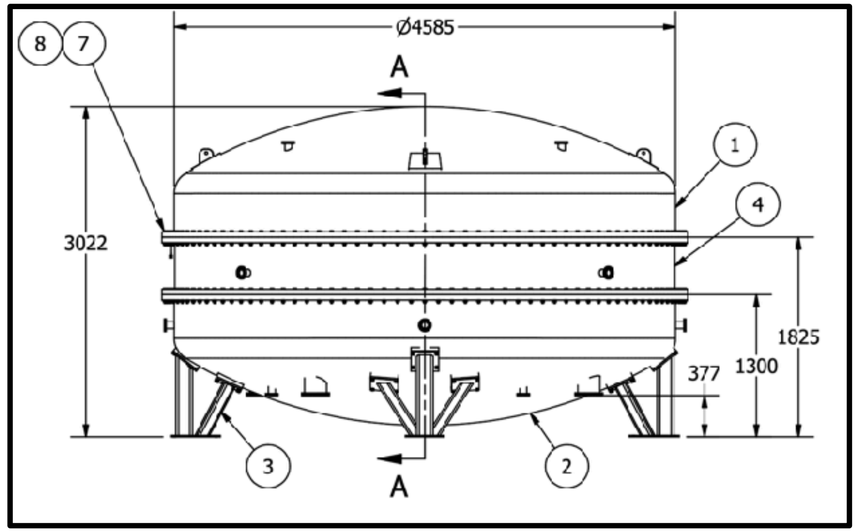
  - *Reflector assembly around barrel (ESR+TPB)*

- Fully exercised for the DS-Mockup demonstrator

- Scaling it up for DS-20k



DS-20k Evaporation Chamber

DS-Mockup

- Integration exercise at the tonne-scale
  - *PMMA barrel assembly and flatness of the top surface to within* $\sim 100\,\mu\mathrm{m}$
  - *Thermal cycling of conductive* Clevios$^{\mathrm{TM}}$*-coated PMMA TPC*
  - *High-voltage (HV) delivery up to* $V_C \sim -100\,\mathrm{kV}$
  - *Power requirements for gas pocket generation*

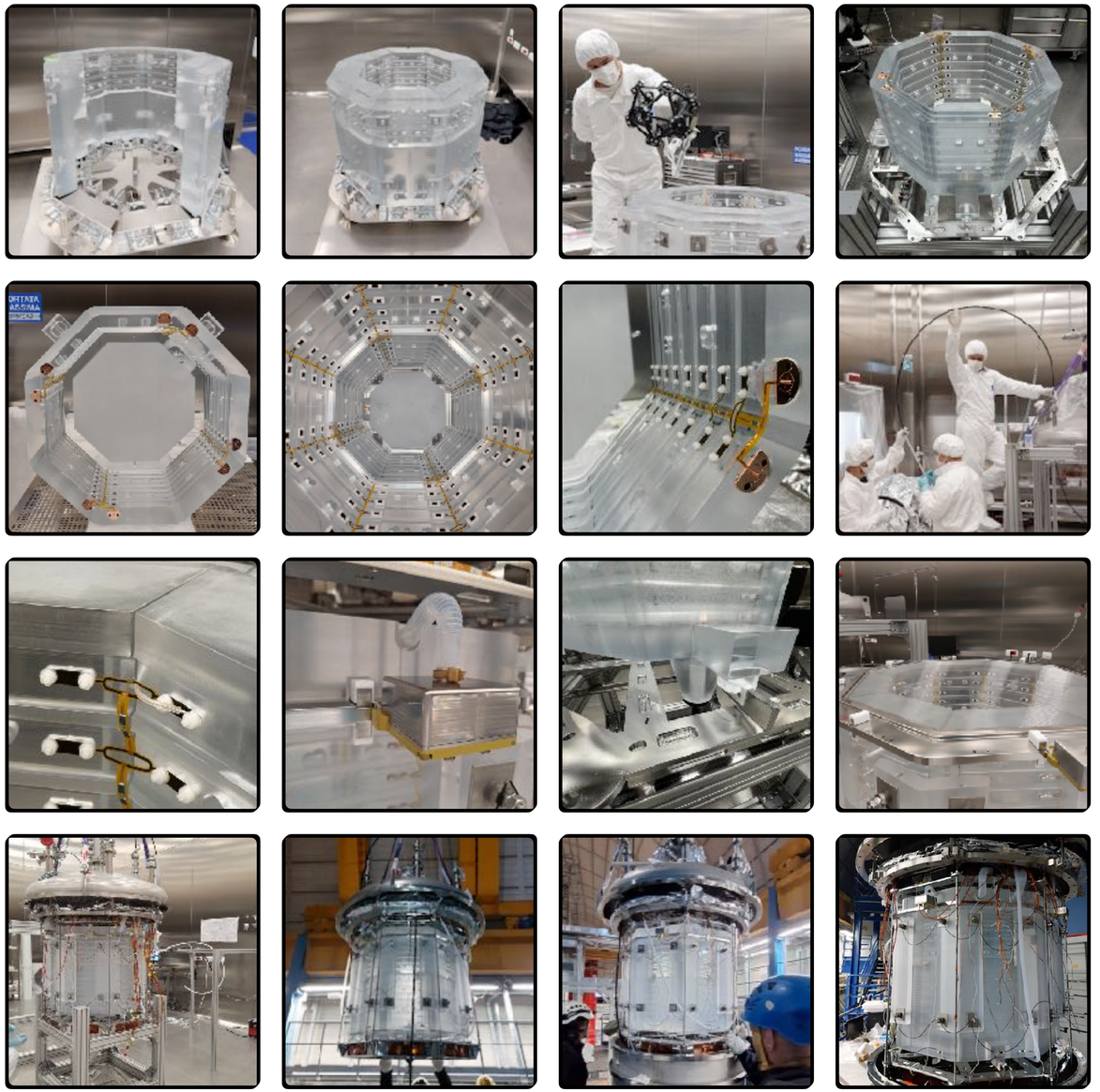
- Multiple runs over the last 2 years with important technical results
  - ➡ *Benchmarking of the UAr cryogenic system*
    2025 JINST 20 P02016
  - ➡ *A Tonne-Scale Demonstrator for the DarkSide-20k Inner Detector*
    in preparation

A Tonne-scale Demonstrator for the DarkSide-20k Inner Detector at LNGS

Tuesday, October 21

Paolo Salomone

https://indico.ihep.ac.cn/event/24964/contributions/196480/



The DarkSide-20k Cryostat

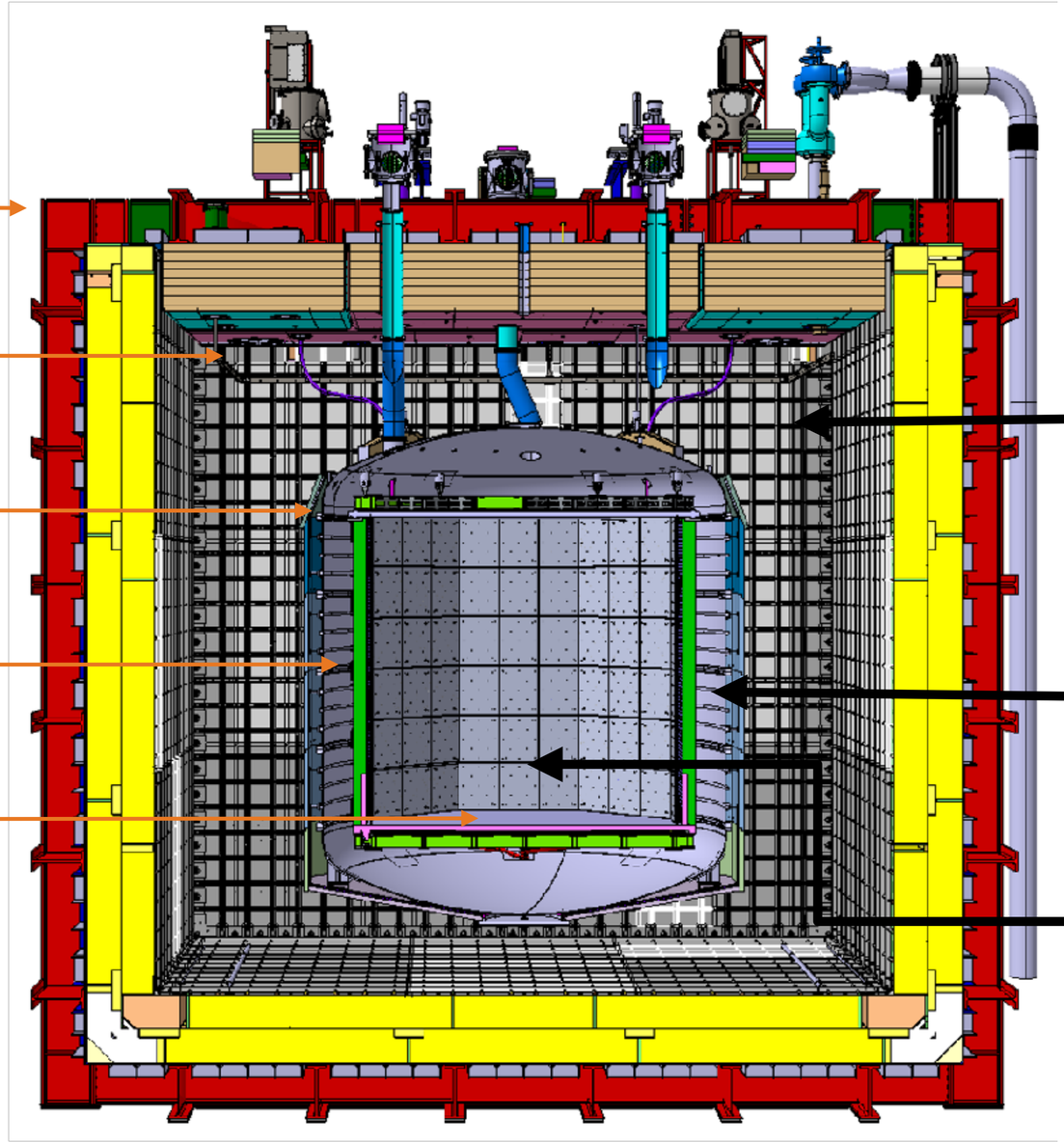
ProtoDUNE-like Membrane Cryostat

Atmospheric Argon Outer Veto ~650 tons

Stainless Steel Cryostat

Underground Argon Inner Veto ~32 tons

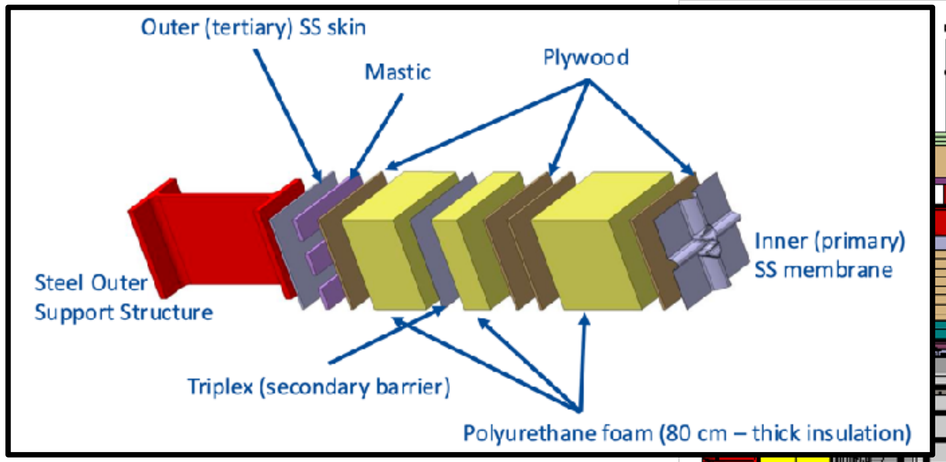
Underground Argon TPC ~51 tons



DarkSide-20k consists of three nested detectors:

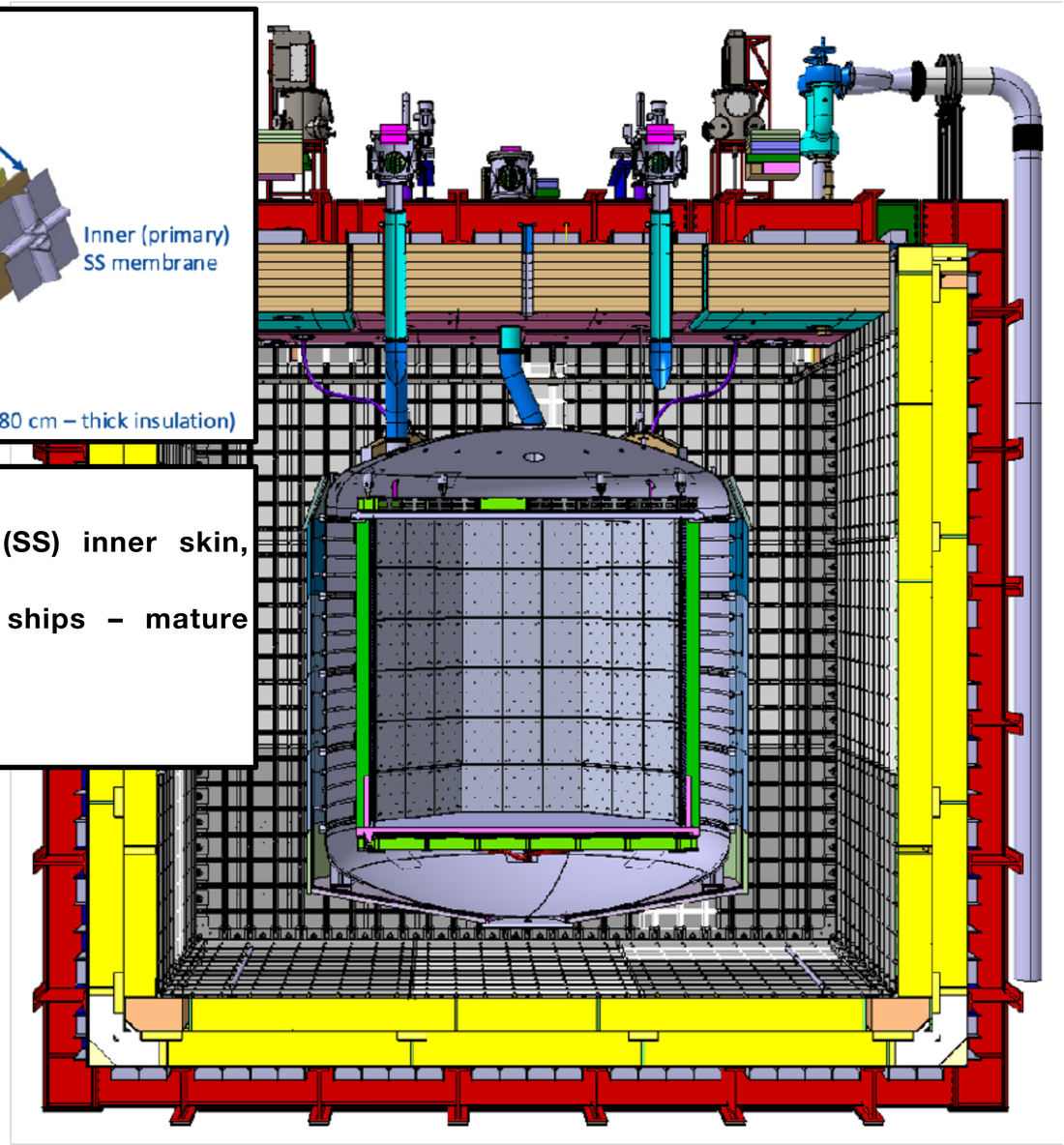
- The **Outer Veto (OV)**, which is filled with AAr and designed to catch cosmogenic neutrons by detecting the primary muon
- The **Inner Veto (IV)**, which uses UAr to tag radiogenic neutrons by detecting gammas from their capture
- The **Dual-Phase UAr TPC**

The DarkSide-20k Cryostat

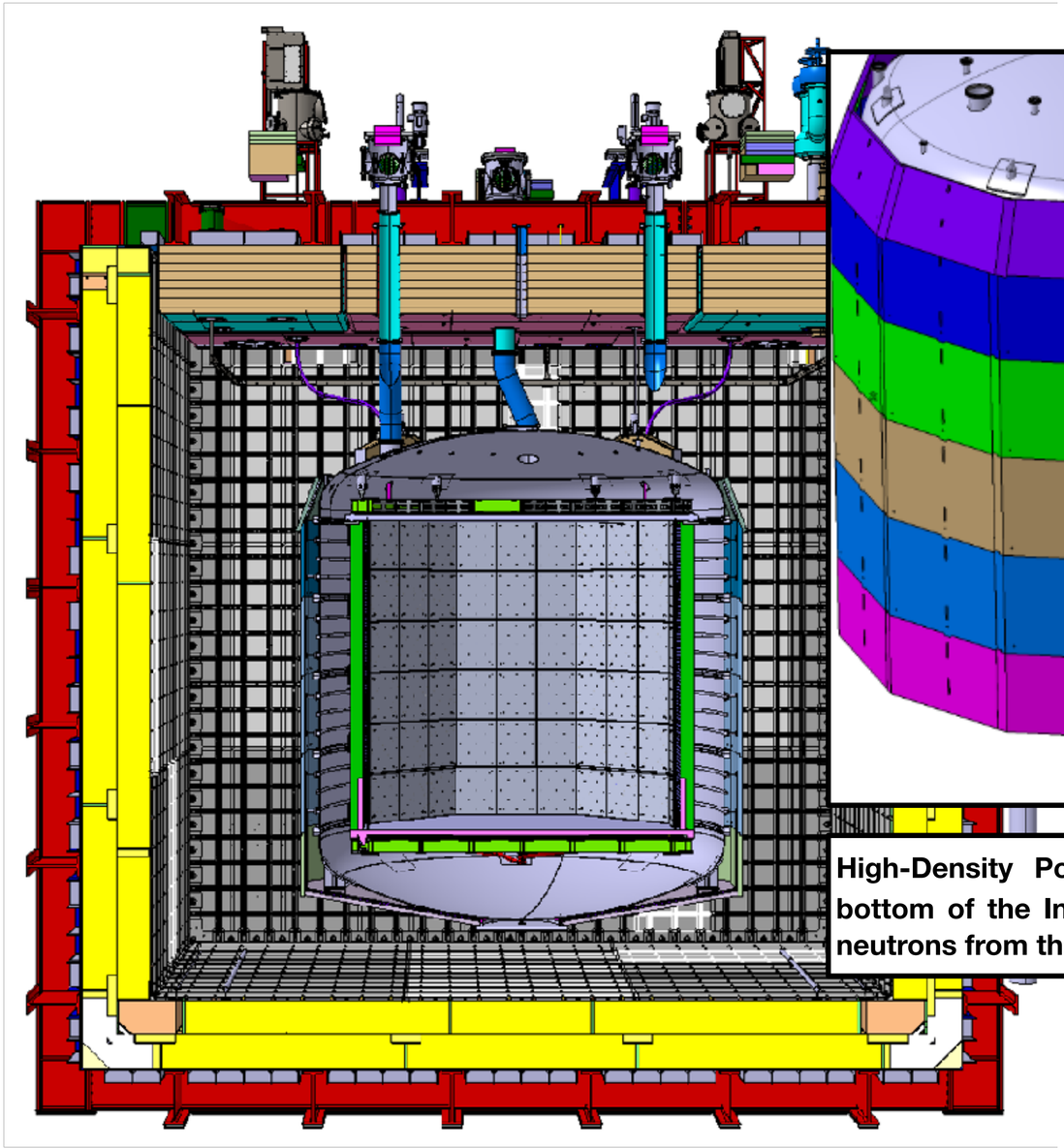


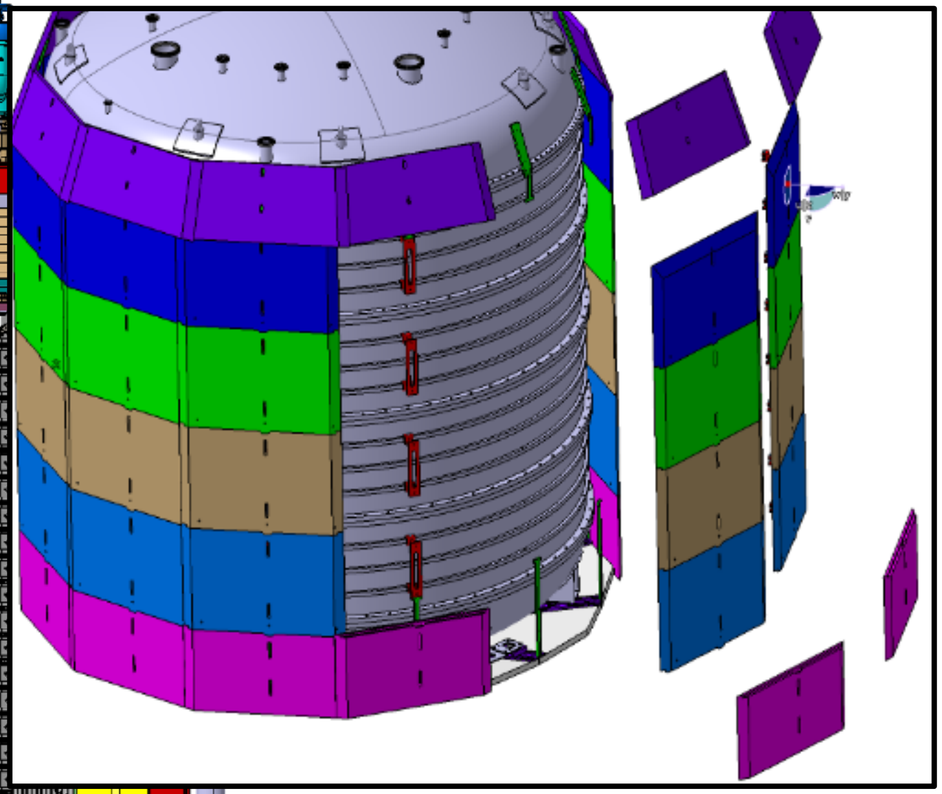
Membrane cryostats

- **elastic, 1.2 mm thick stainless steel (SS) inner skin, accommodates cryogenic shrinking**
- **used on liquid natural gas transport ships – mature technology;**
- **No need for vacuum (argon purge)**
- **Few months of construction time**



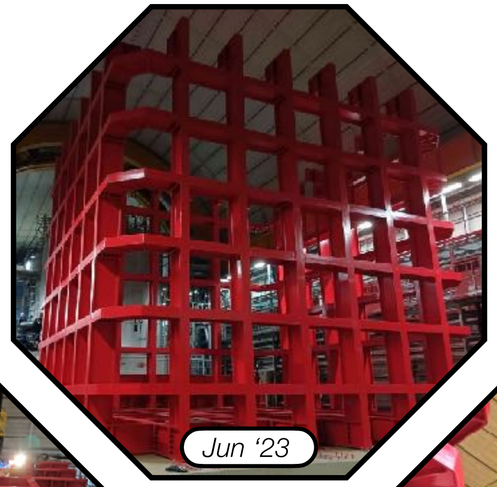
The DarkSide-20k Cryostat

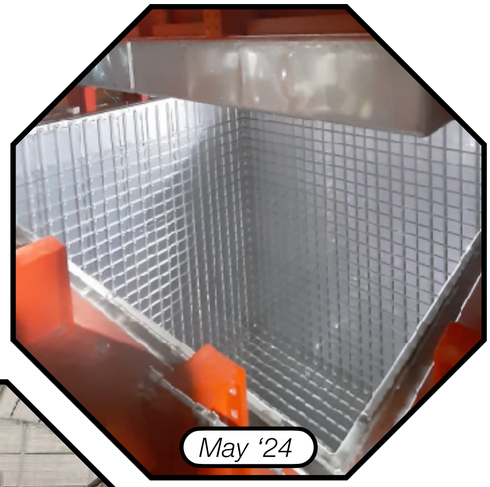


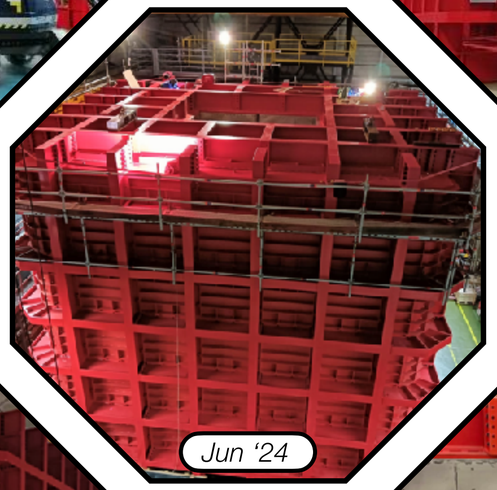


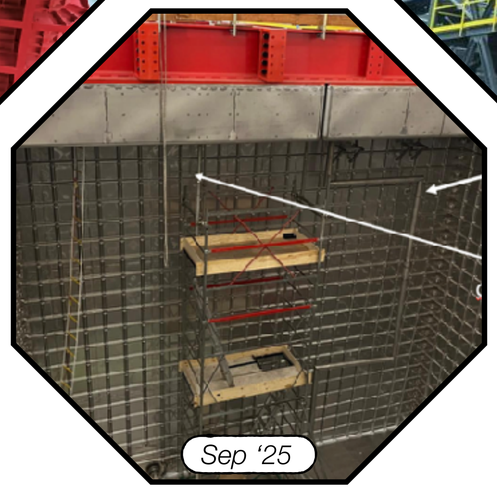
High-Density Polyethylene (HDPE) surrounds the sides and bottom of the Inner Detector vessel and shields against (α, n) neutrons from the membrane cryostat and Hall C.

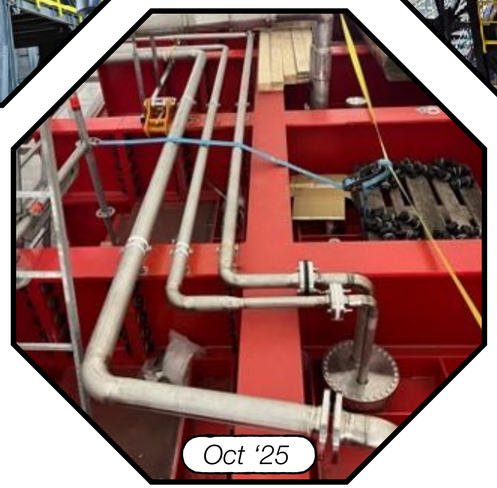
Status of Construction at LNGS











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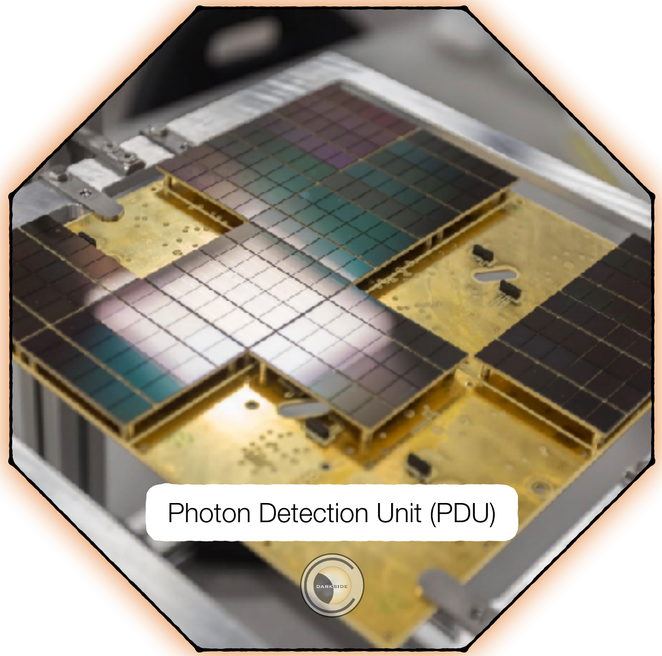
Silicon Photomultiplier (SiPM)



Large-area ($\sim 25\ \mathrm{m}^2$), low-noise, low-radioactivity SiPM arrays

Low-radioactivity, high-efficiency SiPM Development

- Developed with Fondazione Bruno Kessler (FBK)
  - *Photon detection efficiency:* $> 40\,\%$ *at 77K*
  - *SNR > 8 (TPC PDU)*
-

PDU packaging and assembly at Nuova Officina Assergi (NOA) at LNGS

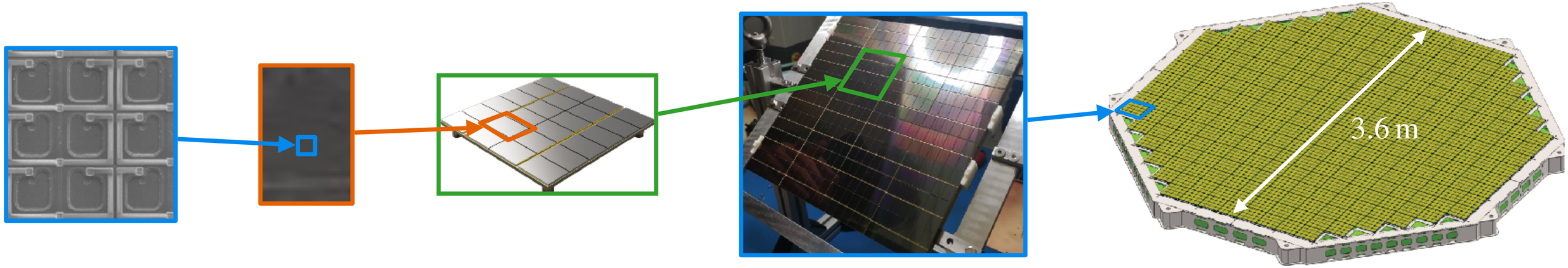
SPAD
$30 \times 30\,\mu\mathrm{m}^2$

SiPM
$8 \times 12\,\mathrm{mm}^2$

Tile (24 SiPM)
$5 \times 5\,\mathrm{cm}^2$

PDU (16 Tiles)
$20 \times 20\,\mathrm{cm}^2$

Optical Plane (264 PDUs)
$21\,\mathrm{m}^2$ in TPC, $5\,\mathrm{m}^2$ in Veto



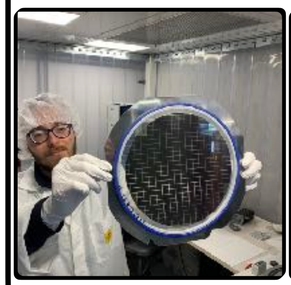
DarkSide Collaboration: "Cryogenic Characterization of FBK RGB-HD SiPMs", JINST 12 P09030 (2017)

SiPM Production and Testing

Nuova Officina Assergi

LNGS, Italy

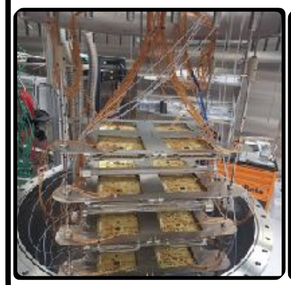
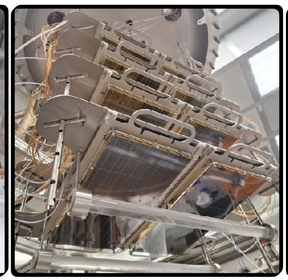
- ISO-6 class with $420\,\mathrm{m}^2$
- CR3: Production facility for TPC PDUs
- CR2: Optical plane assembly area




PDU Test Facility

Naples, Italy

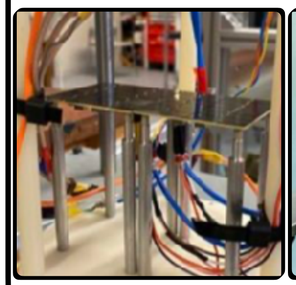
- Testing facility for TPC PDUs
- $800\,\mathrm{L}$ cryostat with LN2
- 16 PDU capacity
- TPC prototype setup

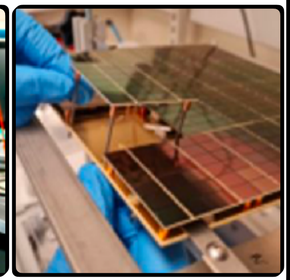




vPDU Test Facilities

United Kingdom, Poland

- Production and testing pipeline across DS-20k institutions in the UK and Poland
- **All vPDUs already produced!**





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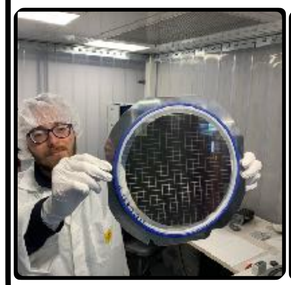
Nuova Officina Assergi

LNGS, Italy

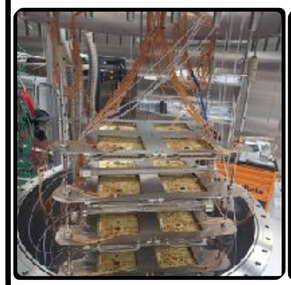
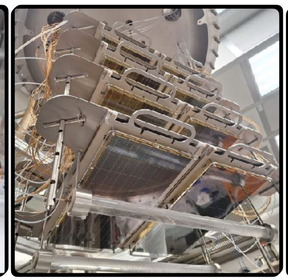
- ISO-6 class with $420\,\mathrm{m}^2$
- CR3: Production facility for TPC PDUs
- CR2: Optical plane assembly area




PDU Test Facility

Naples, Italy

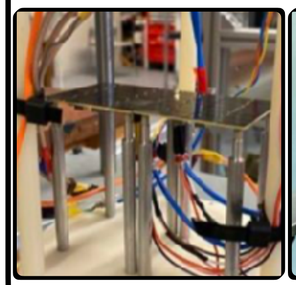
- Testing facility for TPC PDUs
- $800\,\mathrm{L}$ cryostat with LN2
- 16 PDU capacity
- TPC prototype setup

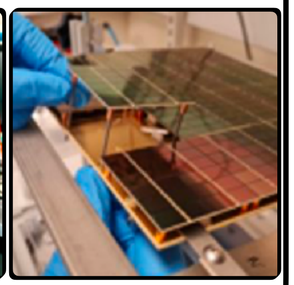




vPDU Test Facilities

United Kingdom, Poland

- Production and testing pipeline across DS-20k institutions in the UK and Poland
- **All vPDUs already produced!**





PE Activities for DS-20k at NOA: Production, Tile-Testing, and Assembly

Wednesday, October 22

Devidutta Gahan

https://indico.ihep.ac.cn/event/24964/contributions/196502/

Characterization of DarkSide-20k Photodetector Units

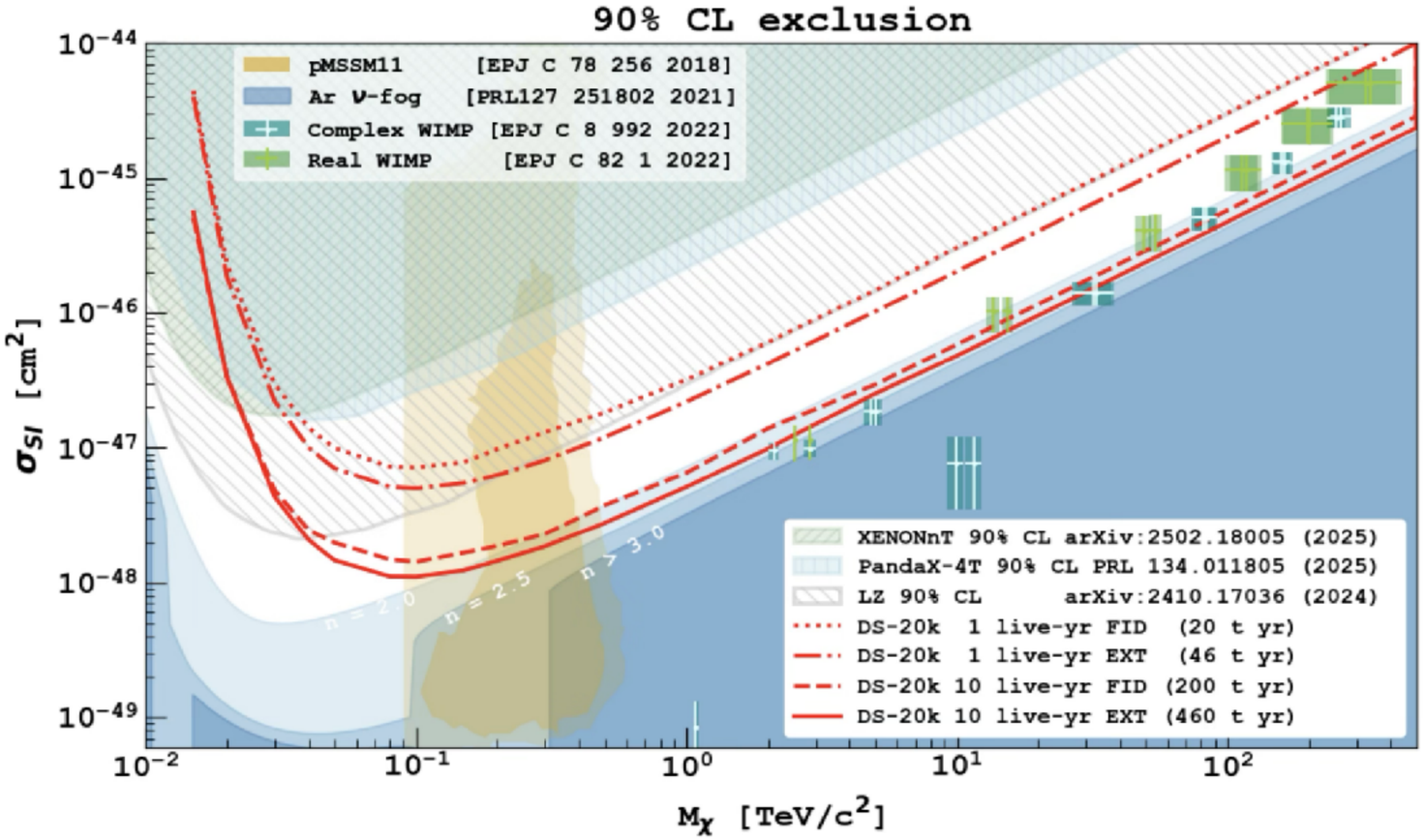
Wednesday, October 22

Dmitrii Rudik

https://indico.ihep.ac.cn/event/24964/contributions/196500/

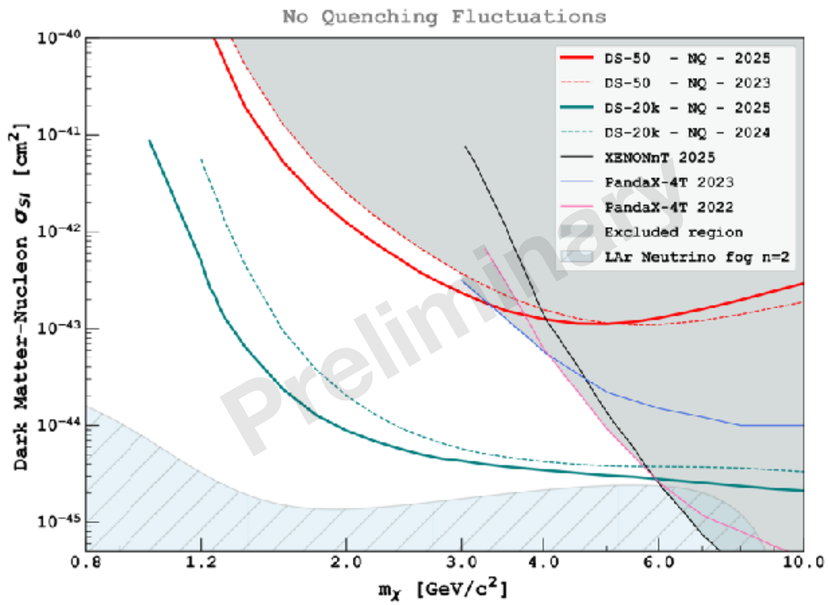
DarkSide-20k Sensitivity — High Mass

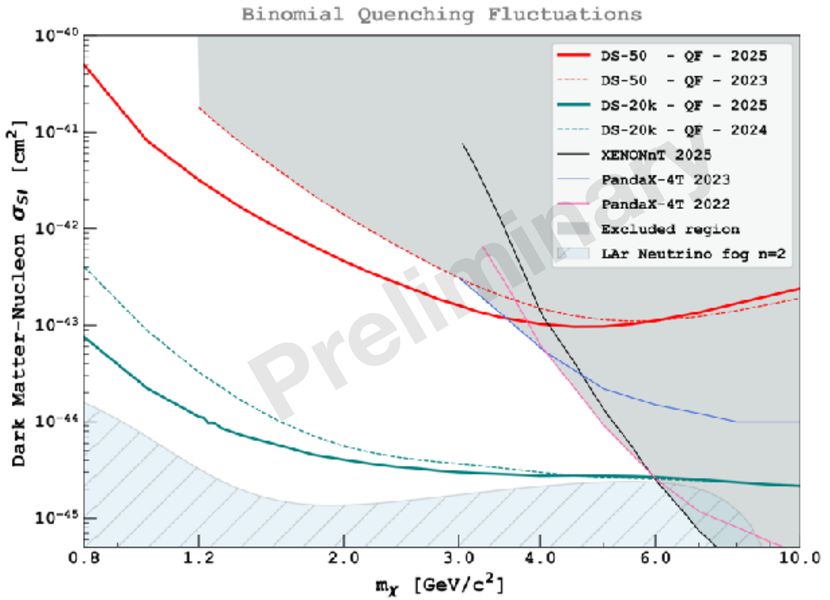
- Fiducial volume
  - *Low instrumental background rate*
  - ***< 0.3 events in ROI (30-200 keVnr) with 200 t-yr exposure***
- Extended volume
  - *Almost full active mass is used*
  - *background dominated by radiogenic neutrons from photo-sensors and experimental Hall*



DarkSide-20k Sensitivity — Low Mass

- Using S2 (ionization signal) only
- Detailed background study, information from DarkSide-50 data
- New data for nuclear recoil response at low energies from the ReD experiment
  - *Recasting DarkSide-50: new best limit below 3.5 GeV / c2*
  - *Enhanced potential of DarkSide-20k in the low-mass range*





Characterization of argon recoils at the keV scale with ReD and ReD+

Tuesday, October 21

Luciano Pandola

https://indico.ihep.ac.cn/event/24964/contributions/194834/

Improved ionization response model of LAr within the DarkSide programme

Tuesday, October 21

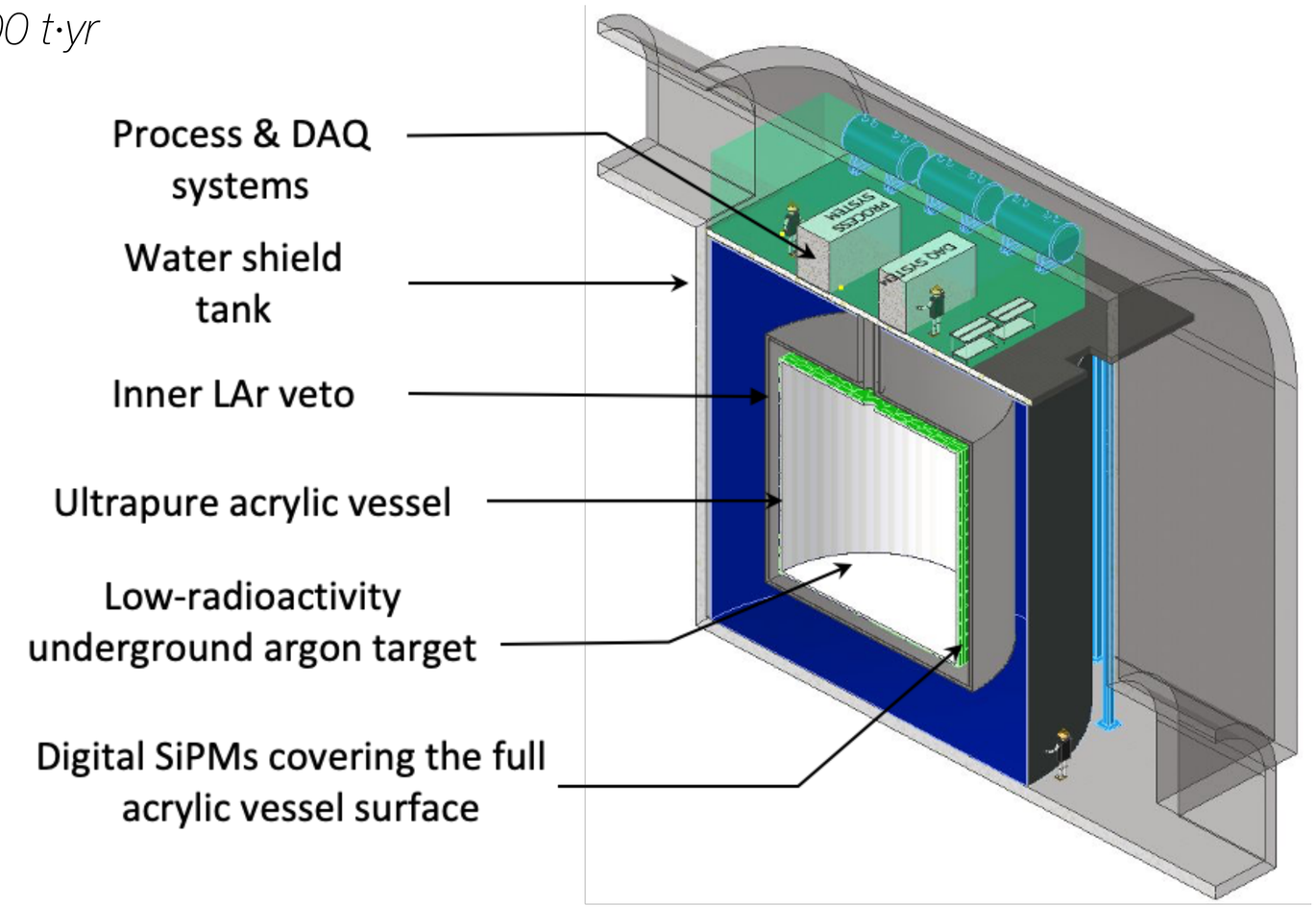
Davide Franco

https://indico.ihep.ac.cn/event/24964/contributions/197371/

The ARGO Experiment at SNOLAB

With input from Asish Moharana

- Detector Overview
  - *Target mass of 400 t of UAr (300 t fiducial; ~3000 t·yr exposure)*
  - *~250 m^2 of pixelated digital SiPM readout.*
  - *Planned in SNOLAB Cube Hall (Gateway-1a approved in 2025)*
- Physics Goals
  - *leading sensitivity to heavy WIMPs*
  - *extending deep into the neutrino fog*
  - *solar and supernova neutrinos*
- Timeline
  - *ARGOlite prototype: 2028–2030*
  - *Full-scale design by 2031*



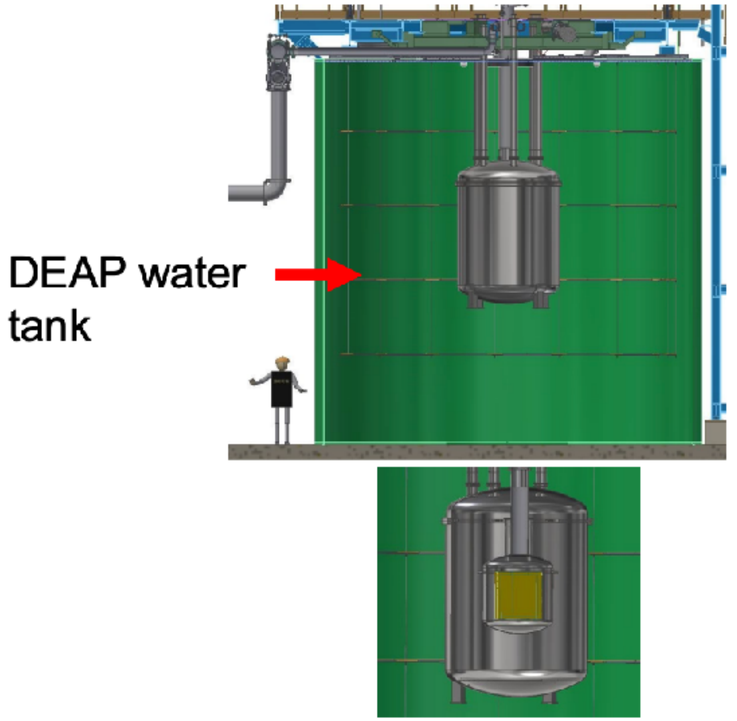
R&D Towards Argo

With input from Asish Moharana

- Key Technologies
  - *Digital SiPMs: pixelated arrays with ns-scale timing and spatial granularity → enable precise event localization and strong background rejection*
  - *ARGOlite prototype: 2 m^2 digital SiPM array in DEAP-3600 shield tank to validate PSD (10^{-9} ER rejection) and surface-α rejection (10^{-7}).*
  - *Smart DAQ system: FPGA-based edge computing for real-time filtering and ML-driven data reduction.*

- Software development
  - *Optical modeling: realistic Monte Carlo of SPAD-level photon detection and optical crosstalk tracking.*
  - *Detailed neutron simulations: target of demonstrating < 1 neutron event leakage into WIMP ROI in 10 live-years.*
  - *Event reconstruction algorithms:*
    - ➡ *Position reconstruction with time/charge fitters.*
    - ➡ *Machine learning techniques for complex signals.*

ARGOlite in the DEAP shield tank at SNOLAB



Optical modeling of pixelated digital SiPMs for ARGO

Thursday, October 23

Asish Moharana

https://indico.ihep.ac.cn/event/24964/contributions/194844/

Summary

- Argon-based searches for DM are a scalable technology to the kton scale

- The GADMC is heavily investing in key technologies
  - *Low-radioactivity underground argon*
  - *Large-Area Silicon Photomultiplier*
  - *Ultra-Pure PMMA*

- Achieving very low instrumental backgrounds is realistic
  - *will allow to expand the reach beyond heavy WIMPs*

- The construction of DS-20k is progressing well!

GADMC Talks at LIDINE 2025

Updates on the DEAP-3600 experiment and steps towards the ARGO experiment

Tuesday, October 21

Susnata Seth

https://indico.ihep.ac.cn/event/24964/contributions/194837/

Characterization of argon recoils at the keV scale with ReD and ReD+

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The DarkSide-20k Dark Matter Detector: Physics Goals and Data Acquisition

Tuesday, October 21

Marek Walczak

https://indico.ihep.ac.cn/event/24964/contributions/194831/

Proto-0: a prototype for validating key technologies of the DS-20k experiment

Tuesday, October 21

Giuseppe Matteucci

https://indico.ihep.ac.cn/event/24964/contributions/196481/

A Tonne-scale Demonstrator for the DarkSide-20k Inner Detector at LNGS

Tuesday, October 21

Paolo Salomone

https://indico.ihep.ac.cn/event/24964/contributions/196480/

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HV Performance Testing in LAr of the PMMA Cathode Connection for DS-20k

Wednesday, October 22

Ludovico Luzzi

https://indico.ihep.ac.cn/event/24964/contributions/194833/

DArT-in-ArDM: A Dedicated Detector for 39Ar Characterization in UAr

Thursday, October 23

Sara Tullio

https://indico.ihep.ac.cn/event/24964/contributions/196460/

Optical modeling of pixelated digital SiPMs for ARGO

Thursday, October 23

Asish Moharana

https://indico.ihep.ac.cn/event/24964/contributions/194844/

United States

- Augustana University
- University of Houston
- Umass Amherst
- Columbia University
- Temple University
- The University of Chicago
- Princeton University
- UC Riverside
- UC Davis
- Virginia Tech
- Fort Lewis College
- University of Hawai'i
- PNNL
- Williams College
- University of Washington

United Kingdom

- University of Oxford
- The University of Manchester
- University of Liverpool
- University of Birmingham
- University of Warwick
- Royal Holloway Uni. of London
- Rutherford Appleton Lab.
- University of Edinburgh
- Lancaster University

Italy

- INFN LNGS
- INFN LNL
- INFN LNS
- Roma Tre University
- Uni. of Naples Federico II
- INFN Napoli
- Fondazione Bruno Kessler
- INFN Sezione di Roma
- University of Genova
- University of Cagliari
- INFN Catania
- Università of Catania
- INFN Cagliari
- University of Bologna
- INFN Bologna
- University of L'Aquila
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- University of Pisa
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- Kore University of Enna
- Polytechnic Uni. of Turin
- University of Milan
- Polytechnic Uni. of Milan

Canada

- University of Alberta
- Carleton University
- Queen's University
- TRIUMF
- Université de Sherbrooke
- SNOLAB
- Laurentian University
- McDonald Institue

Germany

- University of Hamburg
- JGU Mainz

Brazil

- Universidade de São Paulo

France

- Aix-Marseille University
- AstroParticule et Cosmologie

Switzer-land

- ETH Zurich

The DARKSIDE-20k Collaboration

Poland

- AstroCeNT
- Jagiellonian University
- Warsaw Univ. of Technology

China

- IHEP
- University of the CAS

Russia

- Belgorod Nat. Research Univ.
- Joint Inst. for Nucl. Research
- St. Petersburg Nucl. Phy. Inst.
- Mendeleev University
- Budker Inst. of Nucl. Phys.
- Moscow State University
- Kurchatov Institute

Spain

- CIEMAT
- Universidad de Zaragoza

Bonus Slides