DarkSide 20k

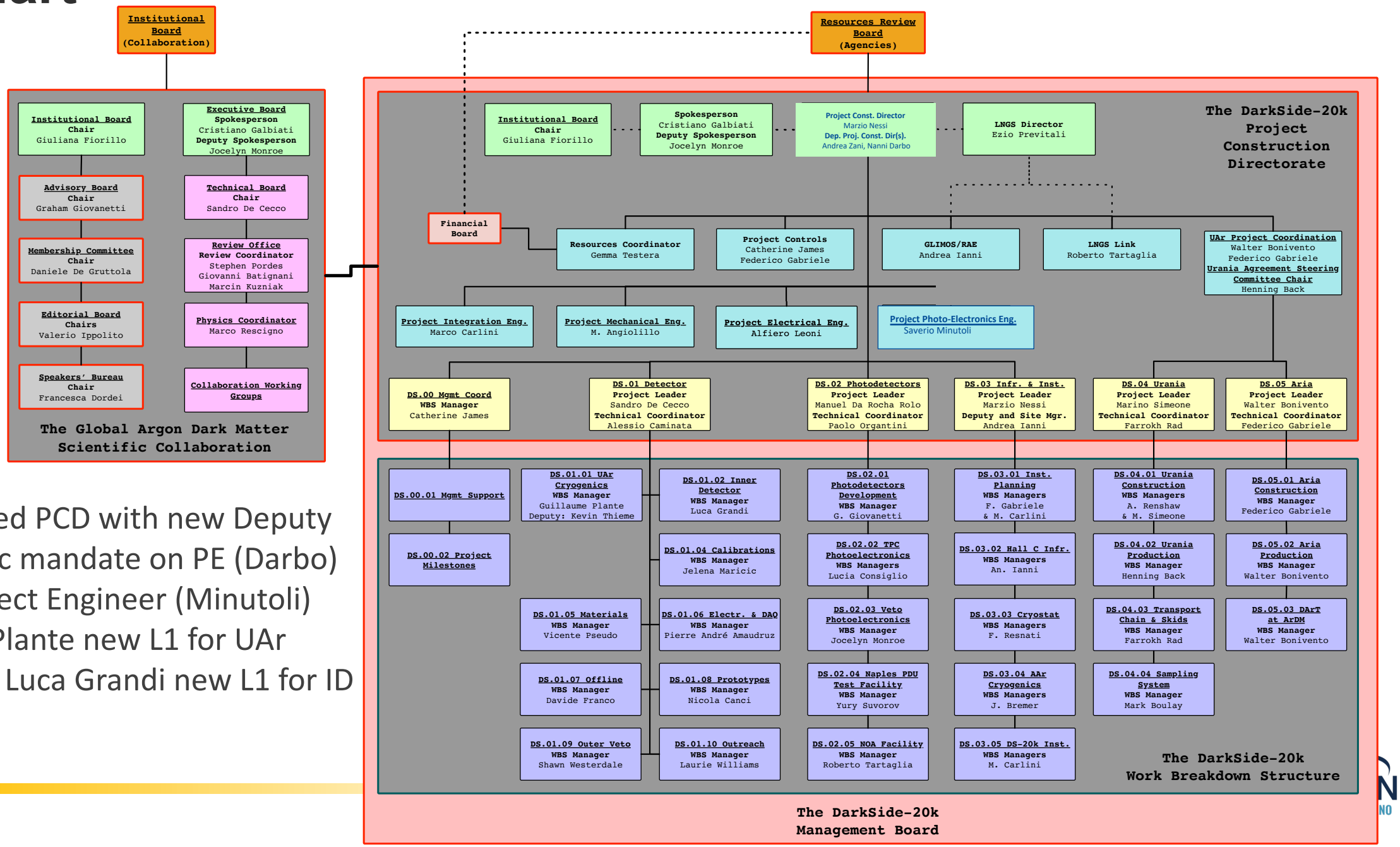
LX meeting of the LNGS Scientific Committee

16-17 October 2023

Andrea Zani, INFN Milano, reporting on the DarkSide 20k experiment

Constructions advancement since last SC

Org Chart



- Strengthened PCD with new Deputy with specific mandate on PE (Darbo) and PE Project Engineer (Minutoli)
- Guillaume Plante new L1 for UAr Cryogenics, Luca Grandi new L1 for ID

DarkSide TDR Review Committee

- Started regular meeting pattern, defined after Jan. 2023 meeting
  - 1 yearly in-depth review
  - 1 light review 6 months apart
  - Quarterly milestones reports (Two already submitted, third one is due tomorrow)
  - Informal meetings, or formal breakout sessions, with subsystems as needed
  - Zoom sessions to describe delivery of documentation
  - Synchronize with DS Collaboration meetings, if possible.

- Submitted documentation to baseline project in Jan./Feb. 2023
  - Baseline schedule, costbook, design
  - Some design changes since then -> baseline change request process in place

- Submitted documentation update following June 2023 meeting

Interactions with LNGS

- Weekly meetings with Director and Coordination Office
- Almost daily (in-)formal interactions with Coordination Office Personnel

- Electrical power requirements
- Water/air cooling for equipment
- Hall C layout
- LN2 cooling for operations – under discussion
- Safety/work regulations for all activities (cryostat erection, mock-up installation, AAr cryogenics tender)
- Quantitative Risk Analysis to be performed – process started sending documents to an external company
- … (many more)

Detector design - I

Octagonal shape dual phase argon TPC:

- Active(Fiducial) UAr mass: 49.7(20.2) tonnes;
- Inner Neutron veto, active UAr mass: 32 tonnes.

Drift field: 200 V/cm; Extraction field: > 2.8 kV/cm;

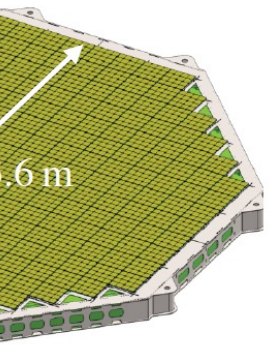
Cathode @ -73.38 kV. Gas pocket thickness: 7.0±0.5 mm.

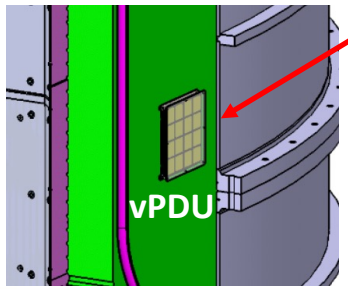
Structurally made in Acrylic: pure (anode/cathode) or 1% Gd-doped (side walls, for n-moderation)

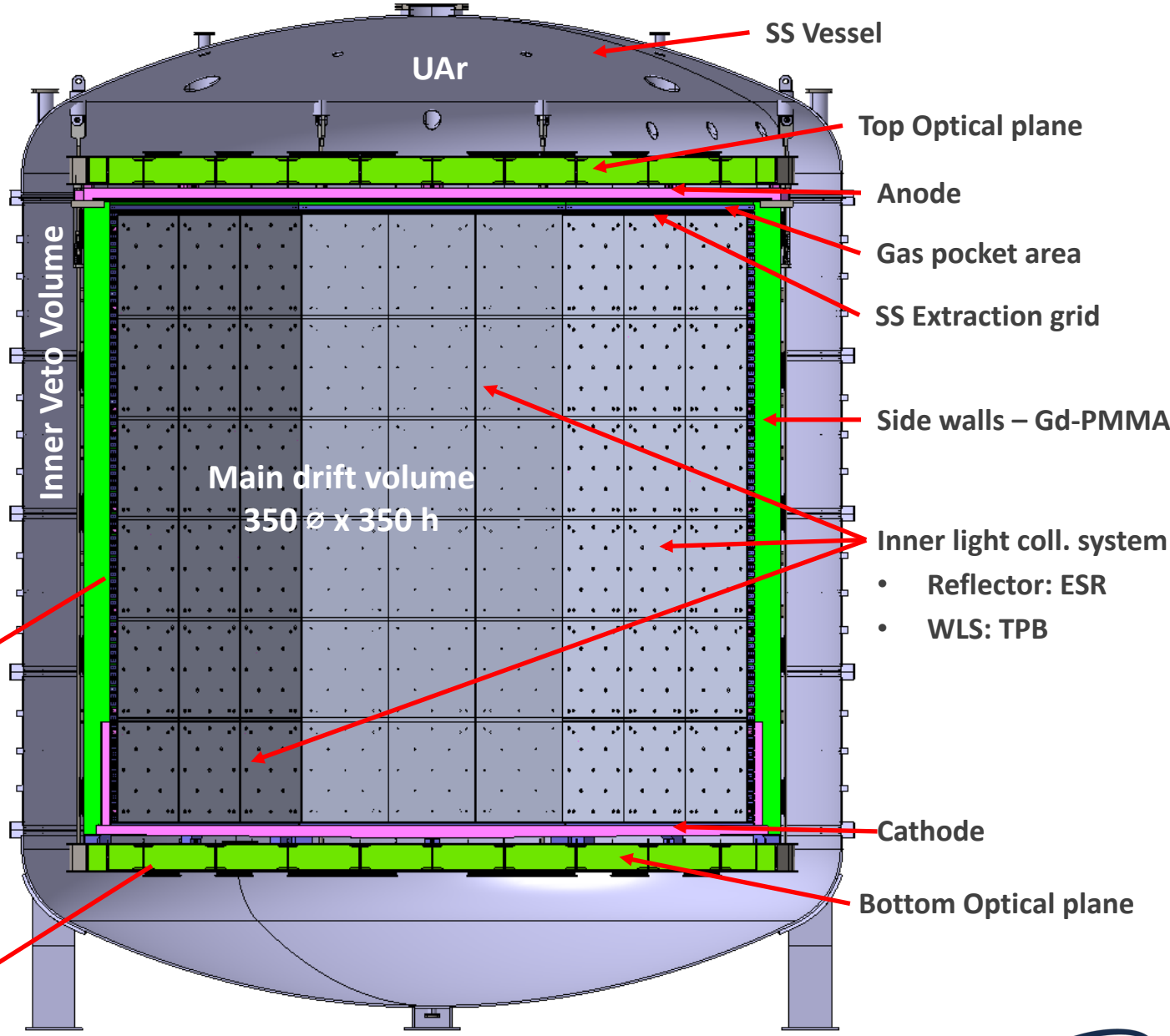
E-field definition: Conductive polymer (Clevios™) coating on anode, cathode and field cage rings;

Readout based on SiPMs

- TPC: 264 Photon Detection Units (PDU)/optical plane
- r/o channel size: 10x10 cm^2

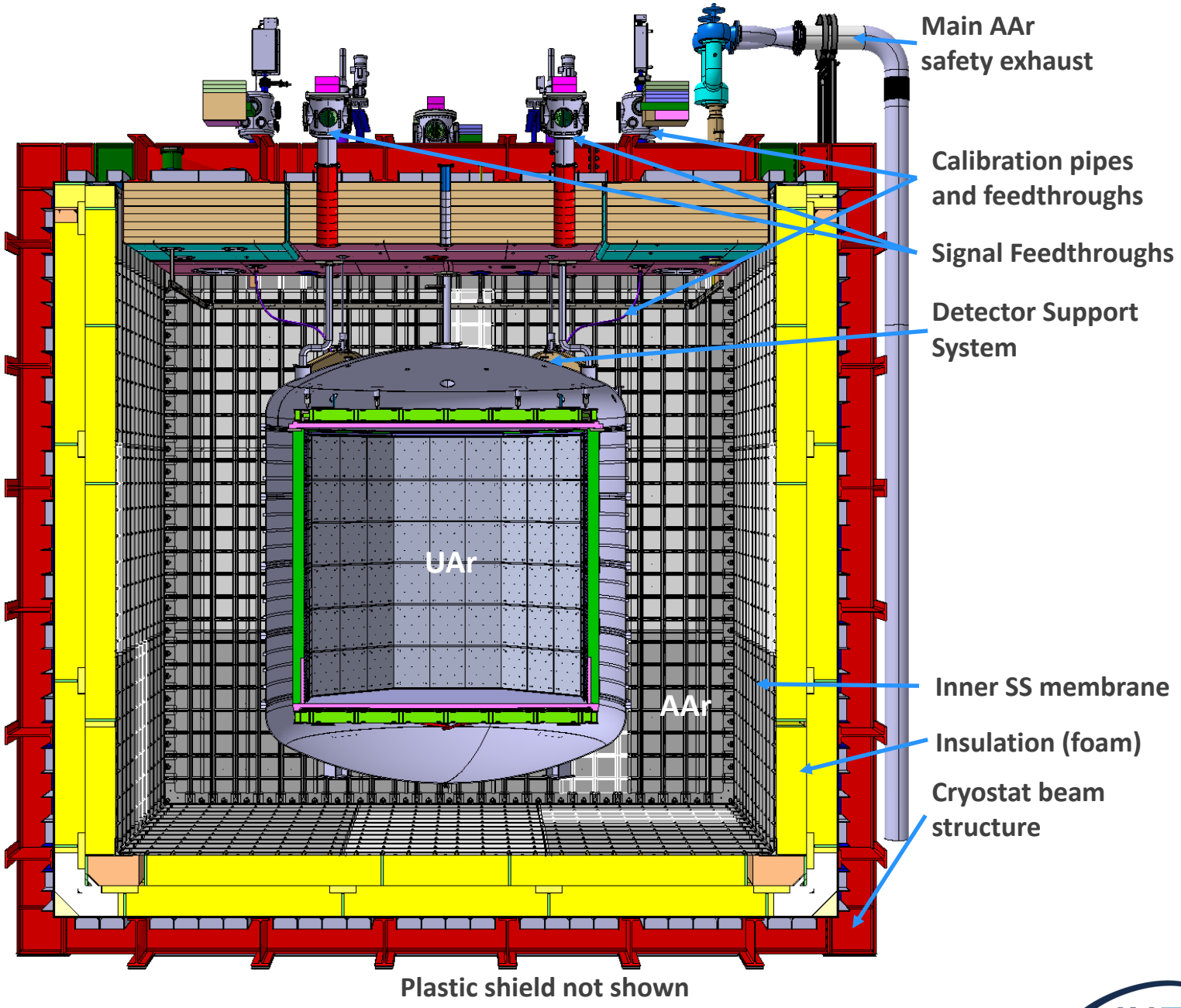






Detector design - II

- Integrated TPC & Inner Veto within SS vessel & UAr
- ~5-10 cm plastic shielding around SS vessel (moderation of n from cryostat, LNGS Hall C)
- Outer muon veto
  - 32 vPDUs
  - Installed on the outside of the plastic shielding
- DUNE-like membrane cryostat filled with AAr

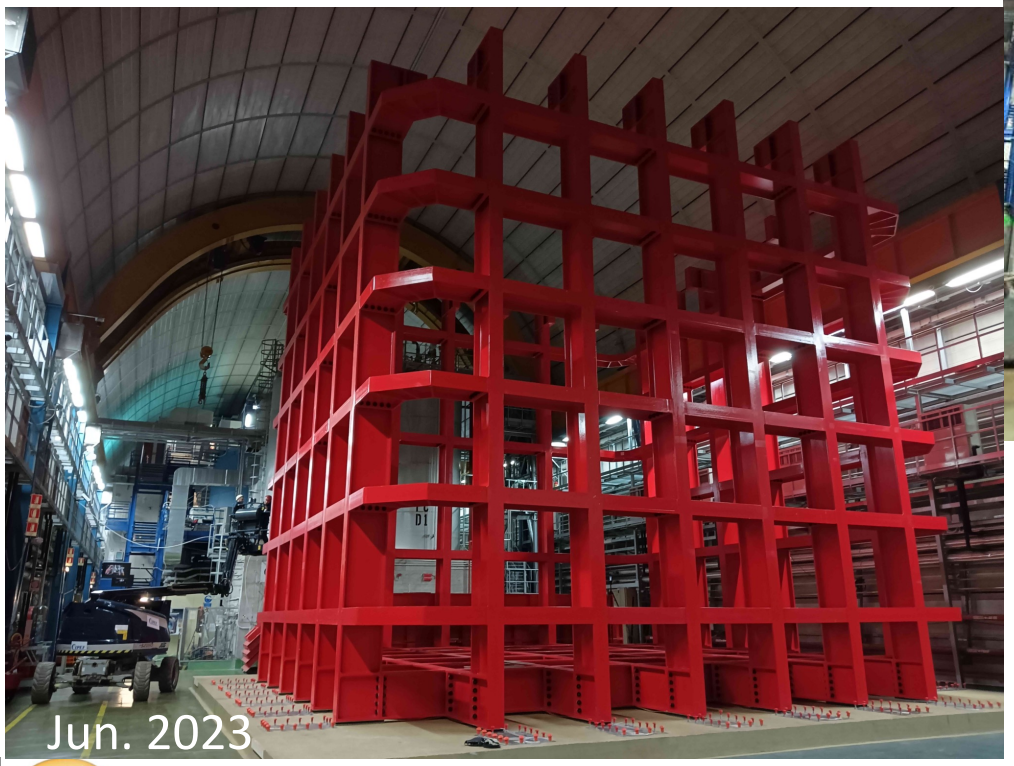


Cryostat construction

- Concrete base: poured in late 2022, resin layer in Jan. 2023
- Beam structure (load-bearing): 4 weeks construction in May 2023
- External membrane: installation & welding, Jun-Oct 2023
- “Cold part”: insulation & internal membrane: Nov 2023 – Feb 2024

- Top caps: roof is divided in 5 pieces, that are separately produced, in all their components.
  - Production completed by end 2023
  - Then, shipment to LNGS; test installation; removal, to make space for clean room installation

Cryostat construction

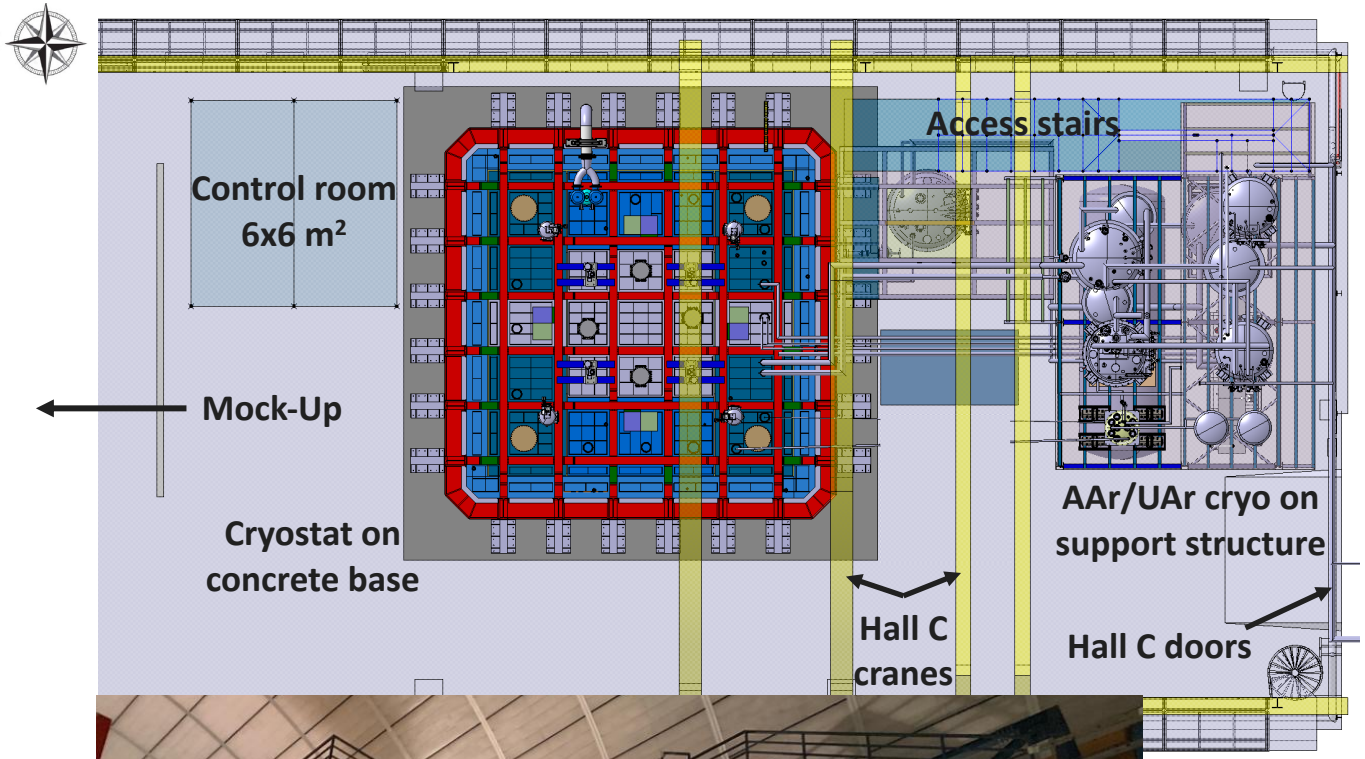


Hall C infrastructures

- **Access stairs** – installed through 28/09 – 06/10 2023
- **Cryogenics Support structure** – to be installed starting mid-October for 3-4 weeks
- **Brackets** – in production; to be installed before year's end
- **Protego valve cover frame** - to be procured, possibly starting in November

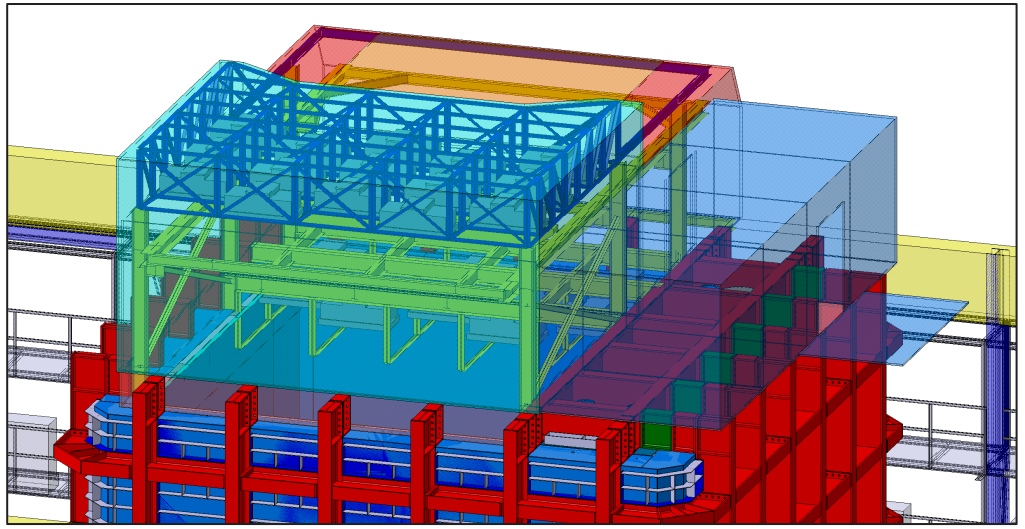
- **Control Room**: gathering technical specifications to share with the lab.
- LNGS will take care of designing and installing the building and plan (with us) connection to lab services (electrical, water/air cooling, ethernet)

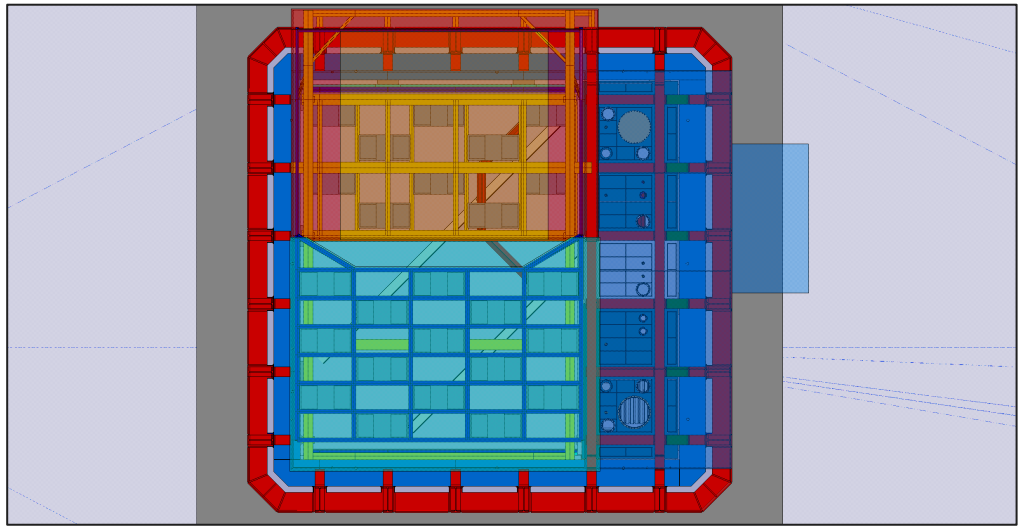
- **Clean room** …

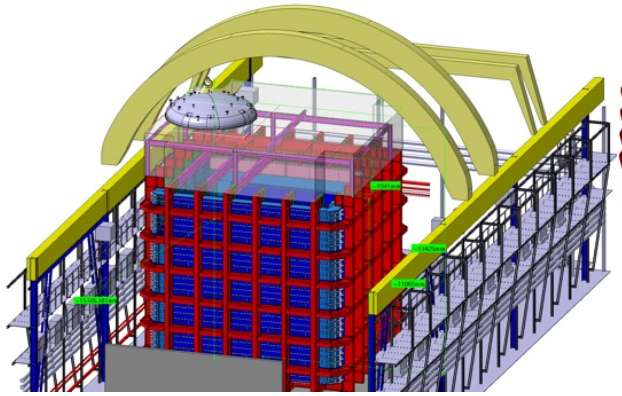


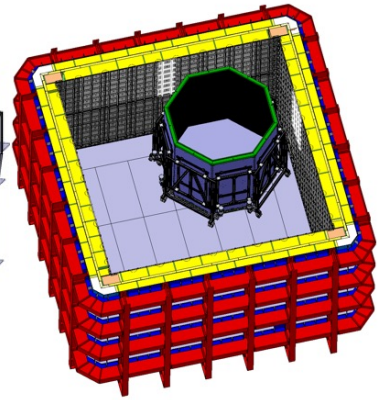
New clean room for detector ass.ly

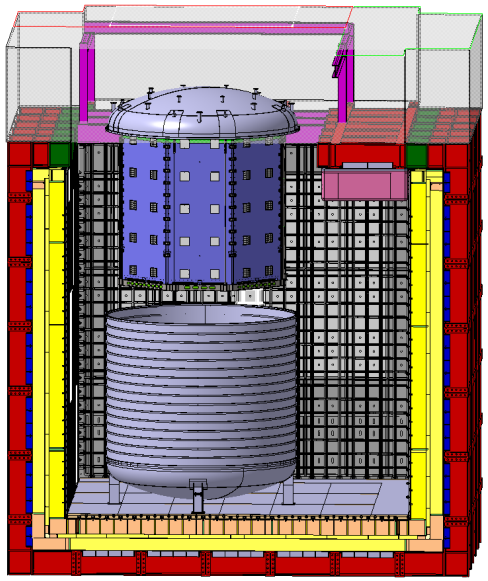
- Clean room: new design under way, to accommodate new detector assembly strategy – within cryostat
- New clean room will feature: metallic false floor; antechambers for pieces introduction and personnel entrance; dedicated 3 t crane, for piece manipulation; Rn-abated air; filtering system to ensure ISO 6 standards
- Design under way, along with storyboard of new detector assembly strategy.











Underground Argon extraction & storage

UAr extraction

- The Urania plant delivery to the US has been completed.
- Civil engineering site construction design completed by AECOM (Houston)
- The Collaboration is going through the process of completing the procurement plan for the civil engineering site construction (Last public hearing with Dolores county officials **today**)
- Construction of the sitework package should start immediately afterwards; prospected cost within NSF budget
- Plant installation to start at the end of Spring 2024. INFN/Polaris involvement in this phase under internal discussion.

UAr transport/storage

- UAr storage/transport strategy changed, from gas to liquid phase - Due to Canadian grant for high-pressure transport skids turned down
- Collaboration is defining a new proposal based on passive-insulation ISO tanks (15 t of UAr each). Risk of UAr loss increased but still acceptable. This solution can fit within the CFI budget
- Once the new proposal is considered finalized by the Collaboration, it will be shared immediately with LNGS for the review of the environmental, authorization and logistical aspects. A Change Control Procedure has been triggered for the change in the storage and shipping system, and it will be managed within the rules established in the PE/MP.

UAr distillation and measurement

ARIA

- The refurbishment of the mine headframe (“castello minerario”), was put in stand-by in the second half of July, due to a personnel change in the Iglesias office of the “Soprintendenza ai Beni Culturali”, and it is expected to resume in October 2023.
- New “Accordo di Programma” (AdP) with INFN and ARIA foundation signed by Regione Sardegna (RAS) President on July 20, 2023. INFN signed the AdP at the end of July. This provides funds and a legal framework to complete the project
- Seruci0 commissioning with argon: results published in EPJC

DArTinArDM @ LSC (Spain)

- Refurbishment of the ArDM detector with the single-phase setup completed
- Commissioning of the DART detector tests in a test cryostat ongoing: Argon-39 beta decay spectrum with atmospheric argon has been observed well above background.
- Three gas bottles of UAr from DarkSide 50 were transported from LNGS to LSC to enable the first DART measurements with reduced Argon-39 levels.
- Waiting from LSC Director to send text of MOU with DarkSide-20k for operations

PhotoElectronics: NOA updates

CryoProbe

- **Wafer characterization from Feb. to July 2023: tested 15% of wafers, with >90% yield**
- Tests suspended mid-March due to a mechanical problem on the first probe card (PC), caused by a malfunction of the cryoprobe software. Contractor has assumed responsibility. Restarted in April.
- Late June - Operations stopped because second PC failed. Issues detected with needles touching. PC1 received back at the end of June but we observed strong aplanarity of the card.
- Both PCs sent back to company for investigation. They proposed to change the design: 2x12 → 2x4 needles. **No major impact on test time. INFN accepted**
- Second PC shipped back to LNGS last week (02/10).
- Maintenance with company engineer on site planned for mid-October but postponed due to travel issues. Wafer measurements will resume after this
- For production wafers, we started way ahead of time, out of the critical path

Wire Bonder

- 20-22 June Set up & training completed
- Machine is operational - Process validation to be started

PhotoElectronics: NOA updates

Flip Chip Bonder

- Installed and set up during March 2023. Training complete
- Software devoted to the quality control and database archiving is approaching the final release.
- Shutdown in July 2023 due to detection of faint markings on tested SiPMs (done by the machine). Tools reworked at the company, and a technician should come this week. Packaging activity will be resumed after the test and cross-validation of the tools.

Procurements

- The INFN tender for radio-pure printed circuit boards (PCBs) for all the motherboards (TPC and Veto) and tiles of the TPC has been assigned.
- The bulk of the most critical components have been partially received. The remaining quantities will be delivered between December 2023 and February 2024.

PE: Inner Veto & test facilities

- Assembly of vPDUs will take place in the laboratories of the UK Institutions, with front-end amplifier based on a custom ASIC developed, tested and purchased by INFN.
- The current delivery date from Alter Technologies of the packaged ASICs is now estimated to be Oct. 12.
- The ASIC production and packaging gates the start of the veto photosensor production in the UK; 6 months of delay were accumulated in the procurement process.

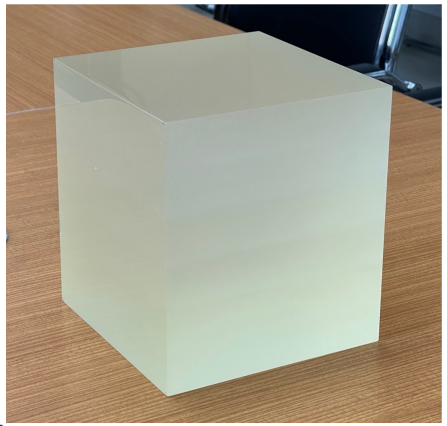
- The Naples test facility is up & running
  - prototypes validation (PDU, vPDU)
  - Optimization of test protocols for full production QA/QC
- Commissioning of the Edinburgh and Astrocent veto PDU test facilities is underway since August 2023.

Detector – Gd-PMMA

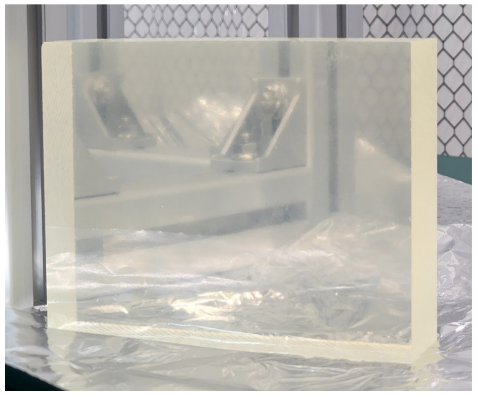
Production of Gd-loaded PMMA from Gadolinium methacrylate

- $Gd(MMA)_3$ is a custom complex compound, derived from Gd_2O_3
- Soluble in acrylic monomer -> Yangzhou University (Y.U., China) developed a procedure to make a stable solution (end product -> 1% Gd in weight)
- Procedure under NDA, tech. transferred to Donchamp company for DS20k production of Gd-PMMA

First full-thickness sample (non radiopure)



$Gd(MMA)_3$ doped acrylic sheet



Challenges

- Production of a 17 cm thick panel -> very long polymerization time, low yield
- Some issues detected in moving to the use of highly radiopure material (vendor from Japan) -> longer polymerization time, detected cluster formation in the intermediate compound
- Company has been working extensively in these last few months to address these issues -> new **radiopure** sample expected for delivery **here** at out October Collab. Meeting

Pure PMMA from DonChamp

Isotope	mBq/kg
137Cs	<0.025
40K	<0.41
232Th_228Ac	<0.14
232Th_228Th	<0.08
235U	<0.07
238U_226Ra	0.05
238U_234mPa	<1.8

Solutions

- Multilayer lamination to reach required thickness
- First full-thickness sample produced and delivered to LNGS in June, from non-radiopure oxide. Cooling test successfully passed; extensive tests ongoing at University of Alberta

Once final samples accepted, pre-production can start:

1 sheet, 4 m x 2 m x 2.5cm, to cut in six pieces and bond to get final thickness panel

Detector – assembly and plastic shielding

Changed assembly strategy → detector now to be fully assembled inside the membrane cryostat.

- Drafting a new storyboard of assembly
- Only Optical Planes will be integrated in NOA-CR2 (optical sensors installed and cabled, veto bricks installed), then they will be shipped underground to Hall C
- In the process of engineering the tools required for piece manipulation, integration
- During last meeting, highlighted issue with increased radioactivity from the cryostat foam -> a new passive shielding layer around the main SS vessel containing the Inner Detector has been introduced (see next slides)

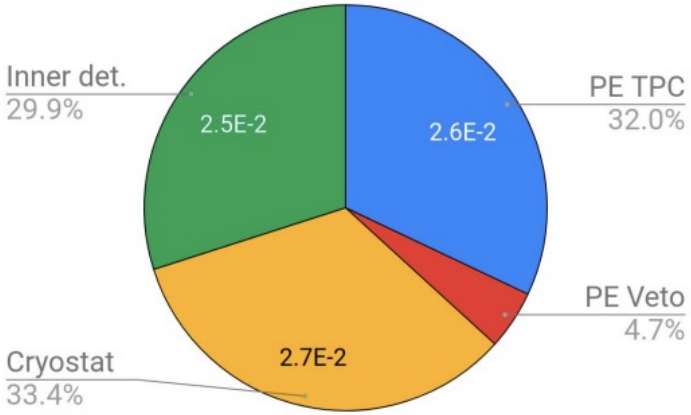
- Effort proceeds in parallel with the design of the cryostat clean room, which must ensure cleanliness and enough space to perform all operations
- New L1 is profiting of this process to review design of the various components and interfaces
  - Realised that Anode Plane will require an additional custom support, to avoid creep during the assembly and pre-filling commissioning phases.
  - Developed new design, to apply to only 1 PDU, to accommodate such support

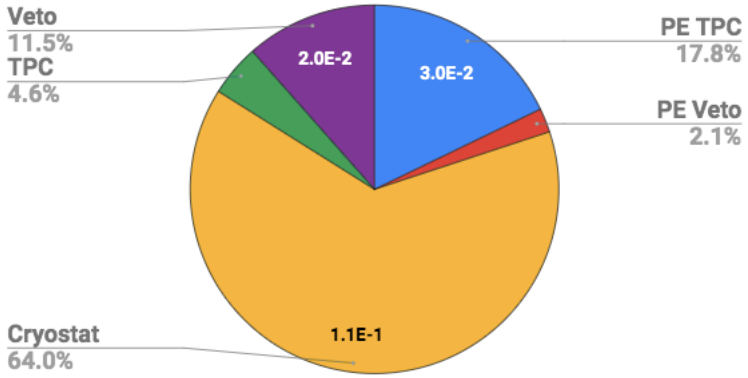
Cryostat foam impact on neutron background

- Two issues with material for insulating polyurethane foam due to changes in industrial processing and vendor :
  - foam expanded with gas containing 70% in mass of fluorine (higher alpha-n cross section)
  - foam radio-assays not as good as those for material procured for SBND cryostat construction (factor 4 more Th contamination), which was used for bkg estimate in TDR

Goal 1E-1 n bkg in 10 yr

Previous estimate 0.08E-1 , new estimate 1.7 E-1 ➔ x2 increase

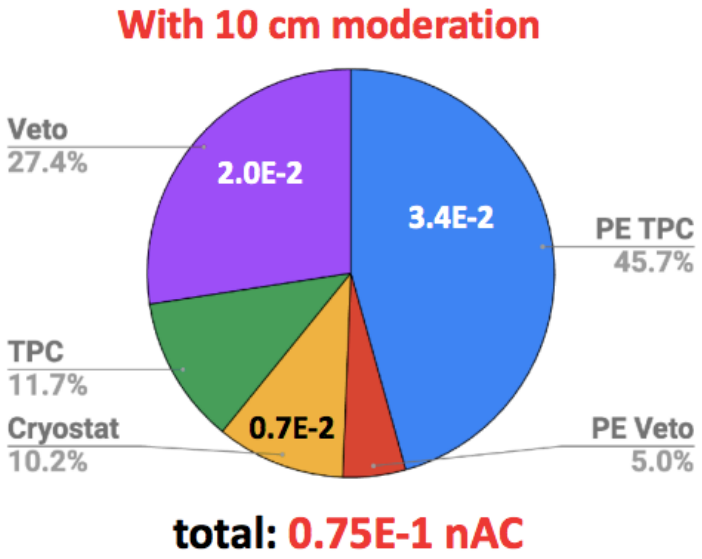


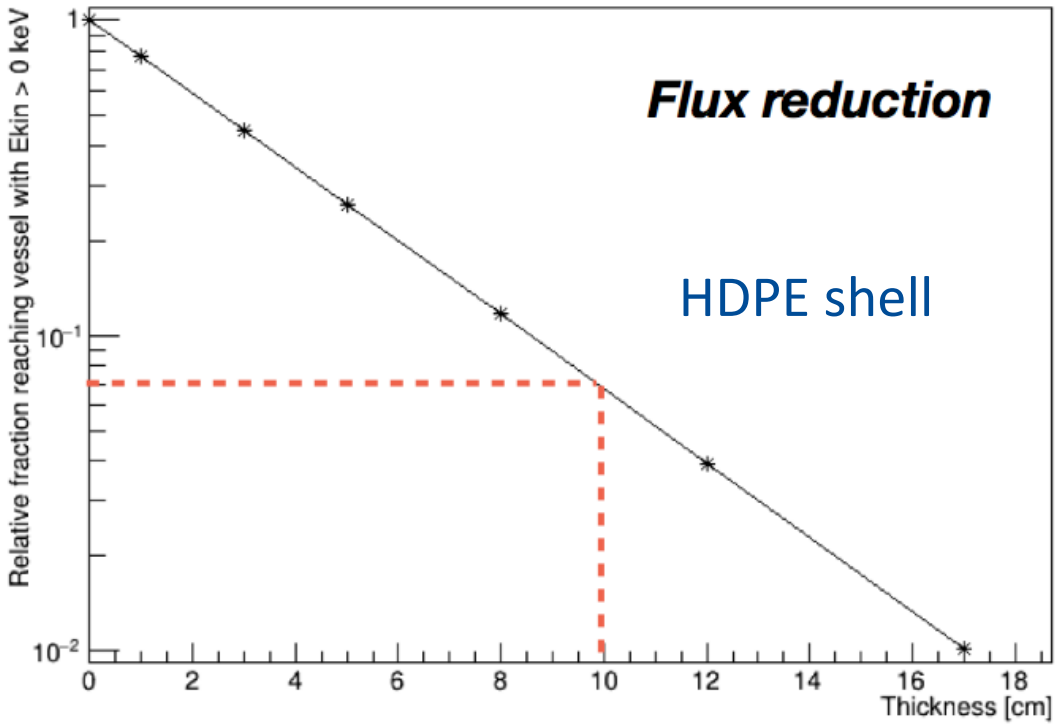


- Not considered here: effect of neutron background from Hall C
- More in back up on this and comparison with irreducible neutrino background

Plastic shielding

- Solution under study: a shell of hydrogenated material around SS vessel
- Effective also on neutrons from Hall-C rocks (not negligible)
- 10 cm thickness to cut neutron flux by a factor 14, and recover TDR sensitivity
- Radio-purity requirements under study but does not represent a show-stopper





- Optimization and engineering ongoing
- First draft design completed, aiming at maximum coverage
- To be submitted to simulation group for review and, hopefully, optimization (first draft design ~ 13 t material)
- Should act as support for the vPDU of the outer veto. AAr circulation through the shield also to be checked

Thank you

Back Up

Mock-up

Installation in the North side of Hall C, aimed at:

- Optimization of UAr cryogenics
- Test runs of UAr cryogenics, cooling technique
- Aiming to host a mock-up of DS20k TPC, to certify design choices (mechanics, HV, coatings)

Upcoming activities

- Leak checks of all the system : September (this week)
- Installation of new components through the Summer, pressure test needed to obtain green light for operations

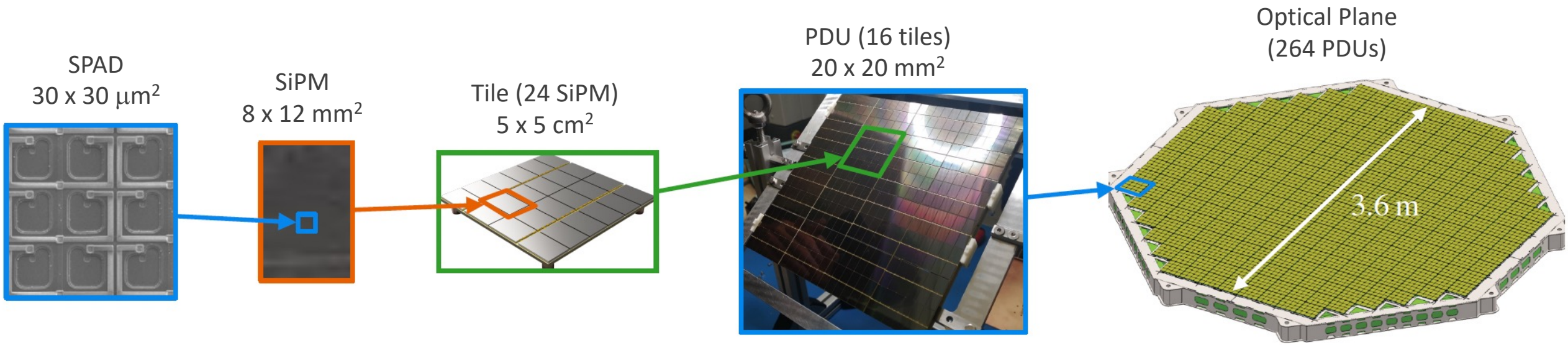
Medium-term Test Schedule

- 2 UAr cryogenics test runs planned in 2023
  - First run started last week (4-8 weeks); second, shorter planned before Christmas
- 2024: run with mock-up TPC planned, to be confirmed against delays in acrylic procurement (space in Hall C is available until April-May 2024, at present).
  - It is an important integration test: a plan B for assembly is being drafted, even if it could be in a site different that Hall C

Towards PhotoDetectors production

PhotoDetectors for DS20k based on Silicon Phomultipliers (SiPMs) technology

- Developed with Fondazione Bruno Kessler (FBK)
- Grouped together to obtain large-area detection units
- Low-radioactivity, low-noise (@ cryo temp) devices
- Photon detection efficiency (PDE) > 40% at 77K
- Dark count rate (DCR) < 0.01 Hz/mm^2 at 77K (7 Volts overVoltage)
- Signal-to-Noise ratio (SNR) > 8 (TPC PDU)



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

Nuova Officina Assergi (NOA)

INFN Facility managed by LNGS – clean room class ISO 6

Two main rooms:

- **CR3**: 3.0 m x 350 m^2 -> photodetector production area, equipped with highly sophisticated packaging machines for the assembly of photosensors in a dust-controlled environment
- **CR2**: 5.8 m x 68 m^2 -> large volume detector assembly
- To be equipped with dedicated Rn-abatement system (currently, Rn level in CR3: 6-10 Bq/m^3)

Fully commissioned in early 2023

- Currently populated with machines needed by DarkSide for SiPM packaging, test and integration

- 2023, so far: start-up of activities, characterization of silicon wafers procured for the in-house production of the PhotoDetector Units (PDU).

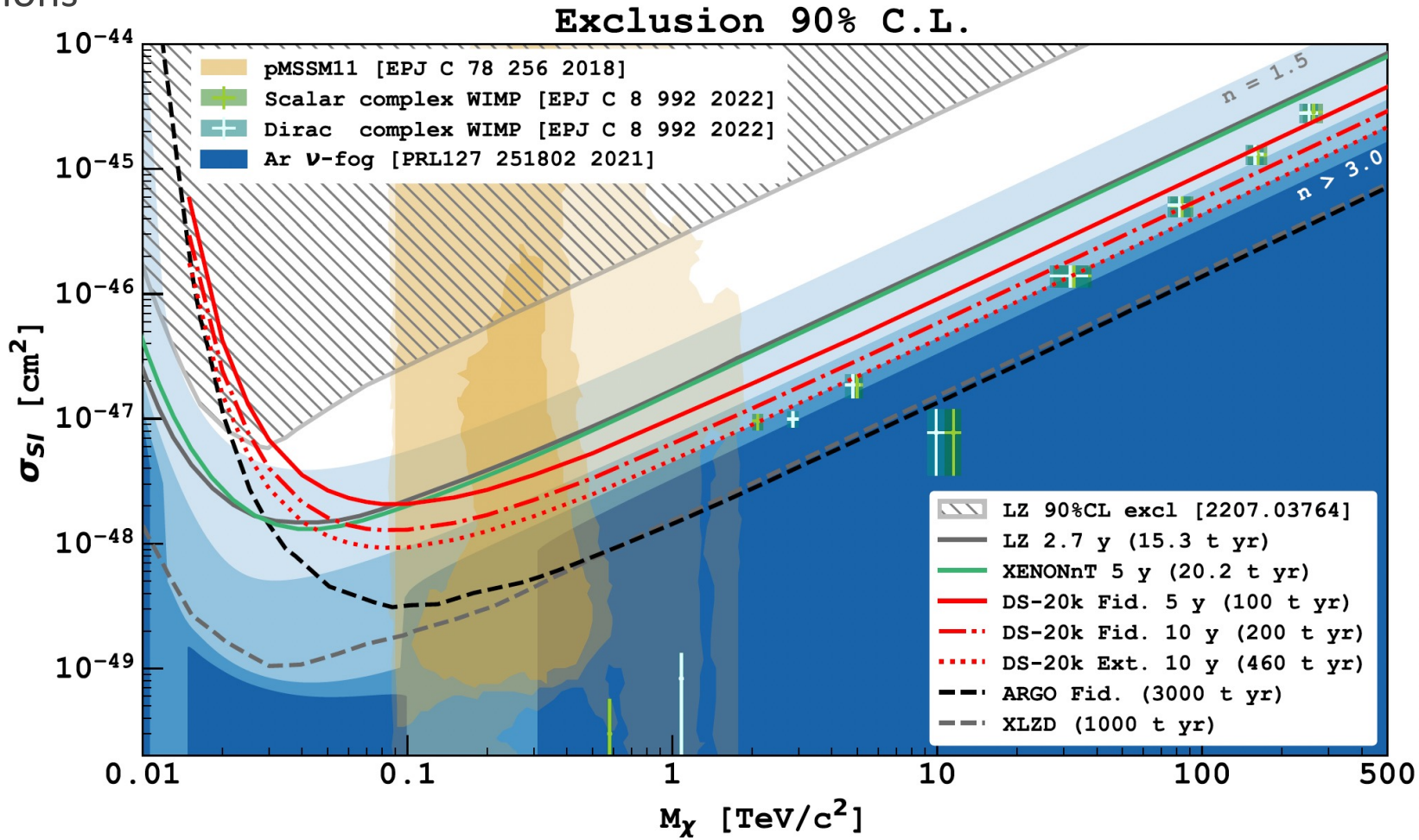
Sensitivity: DS20k & beyond

Sensitivity to Spin-Independent interactions

Nominal exposure (200 t-y) :

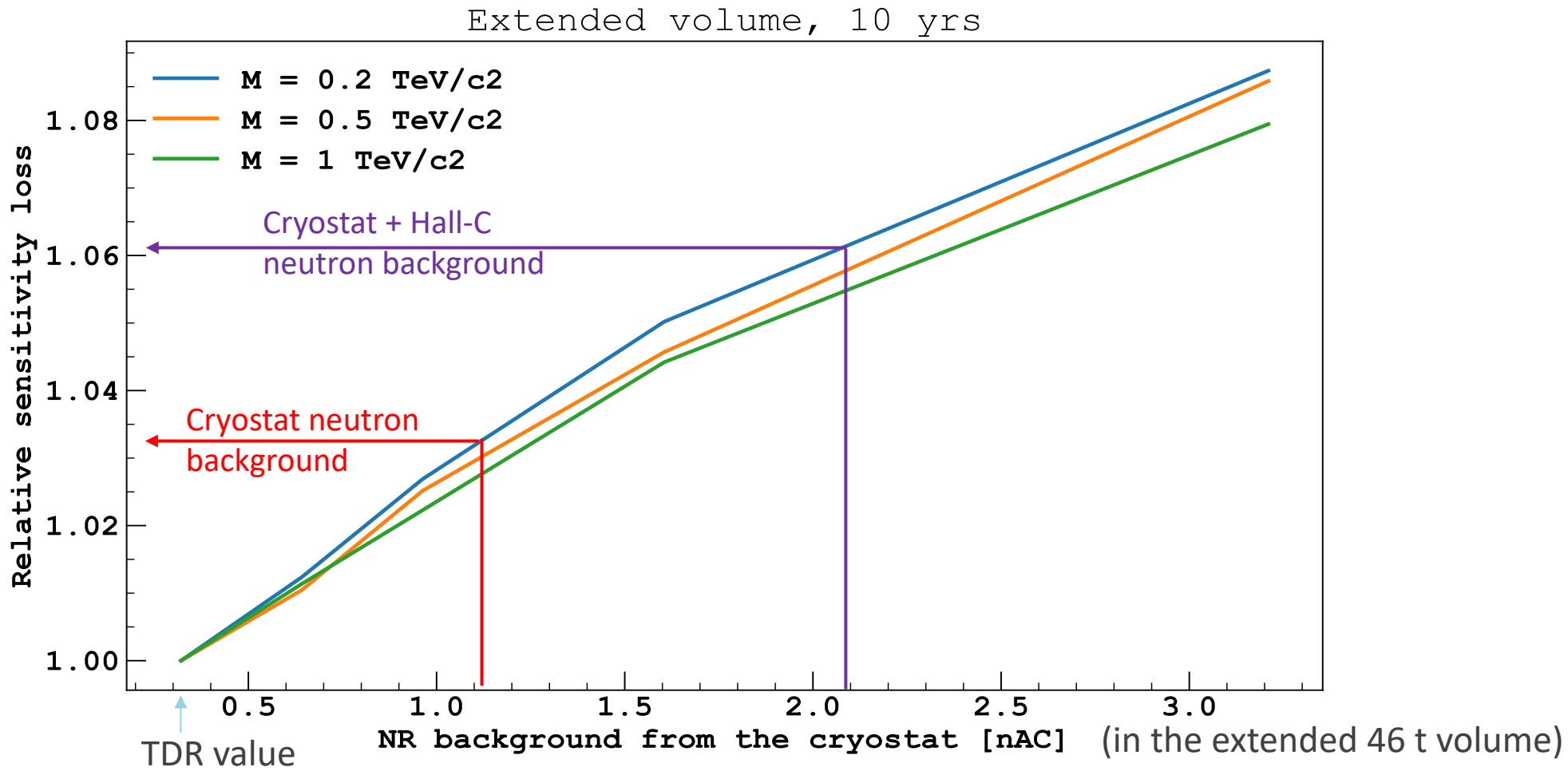
- 90% C.L. exclusion:
  - 6.3 x 10^{-48} cm^2 @1 TeV/c^2 ;
- 5 σ discovery:
  - 2.1 x 10^{-47} cm^2 @1 TeV/c^2 ;
- 3.2 CEvNS events expected.

Aimed instrumental background:
< 0.1 neutrons in Region of Interest
(E ~ 30 –200 keV$_{nr}$)



Future: next-gen experiment by the Global Argon Dark Matter Collaboration after DS20k is the ARGO project in SNOLAB (300 t fiducial)

Sensitivity impact (46 t extended volume)

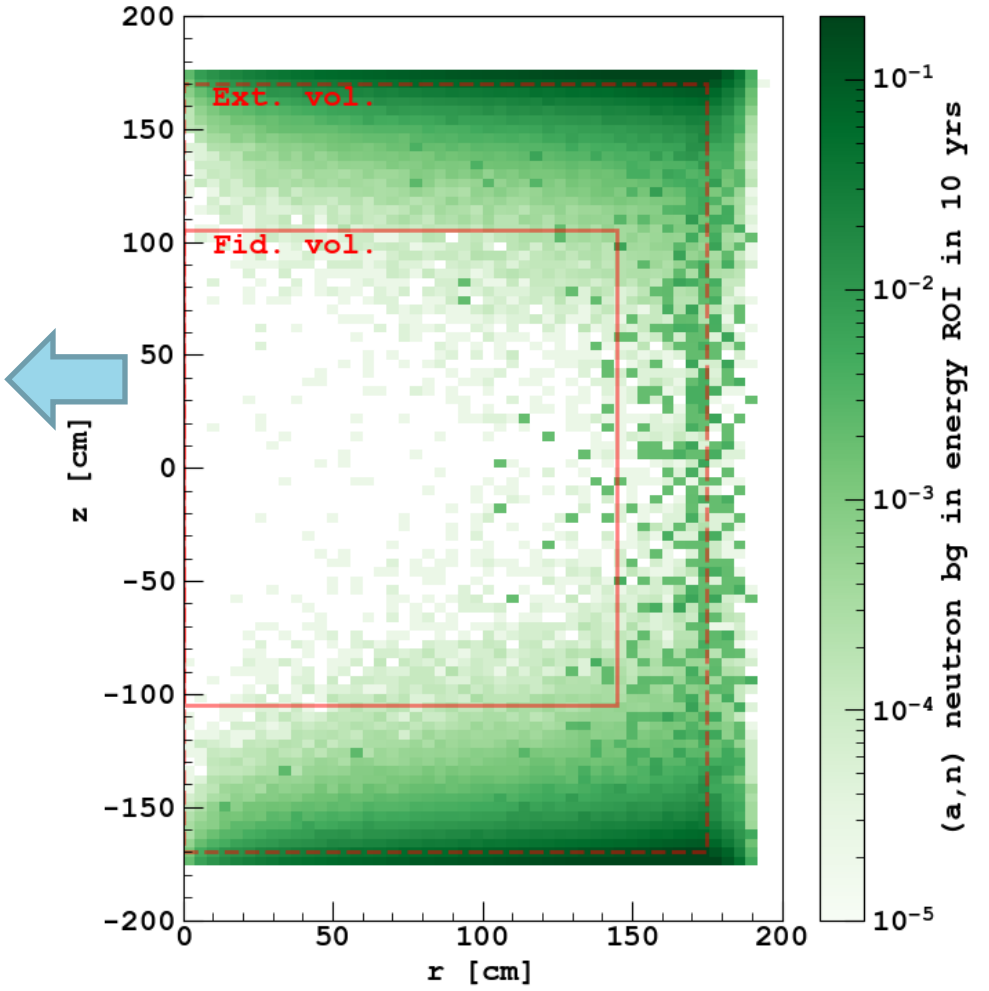


Neutron spatial distribution in TPC

Comparison with irreducible neutrino background

Background events (10 live yrs) 20 t fiducial volume	
nu-atm CEνNS	3.2
Neutrons	~ 0.1
ER	<0.1

Cryostat neutrons (thick dots) and PDU neutrons overlayed



Background events (10 live yrs) 46 t extended volume	
nu-atm CEνNS	7.2
Neutrons	12
ER	<0.1

Different flavours of Argon

Underground Argon (UAr)

- Depleted of ^{39}Ar (~1400 depletion factor) produced in interaction with Cosmic Rays – main target
- Extracted in **Colorado** with **Urania** Plant
  – industrial site, 250 kg/d; purity 99.99%
- Further refined in **Aria** plant (**Sardinia**)
  – 350 m cryogenic distillation column; Purity 99.999%
- Characterized @ **Canfranc (LSC)** with DArT detector
  – Measurement of ^{39}Ar depletion factor
- Gas recirculation equipped with purification, Radon trap and custom liquefaction system

Atmospheric Argon (AAr)

- Commercial 6.0 Argon (99.9999% pure)
- Recirculated and purified continuously, industrial plant derived from ProtoDUNE one
- Target for Outer Muon Veto
- Doubles as cryogenic bath for UAr volume