Neutron tagging with gadolinium loaded PMMA

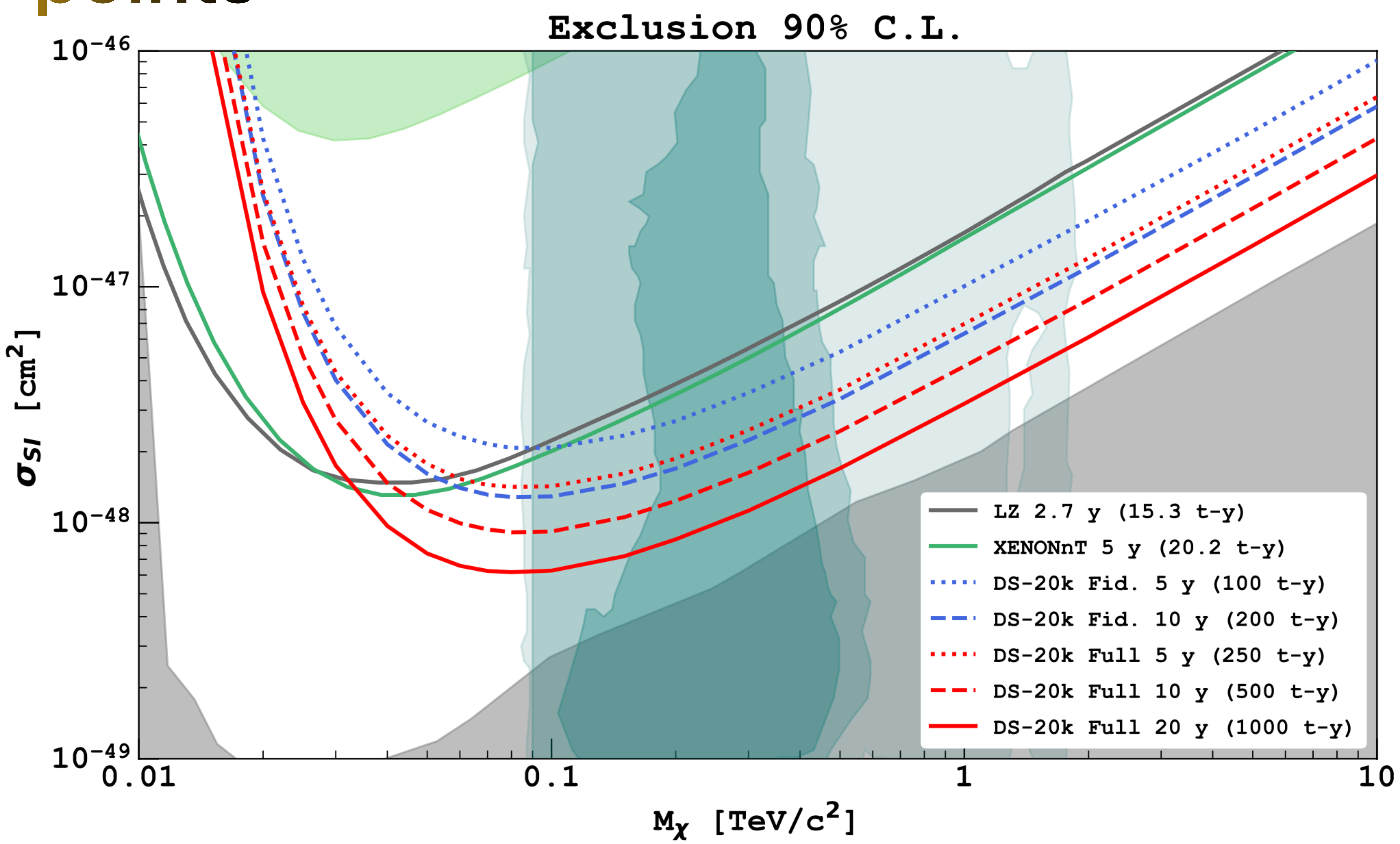
DARKSIDE

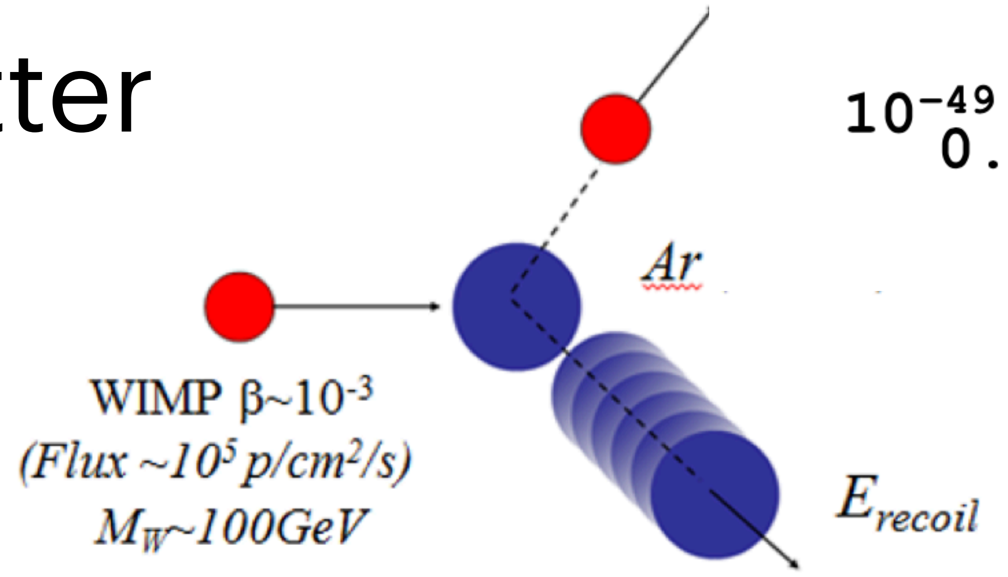
A. Caminata (INFN-Genova), on behalf of the DarkSide collaboration

INFN
Istituto Nazionale di Fisica Nucleare

DarkSide-20k
Key points

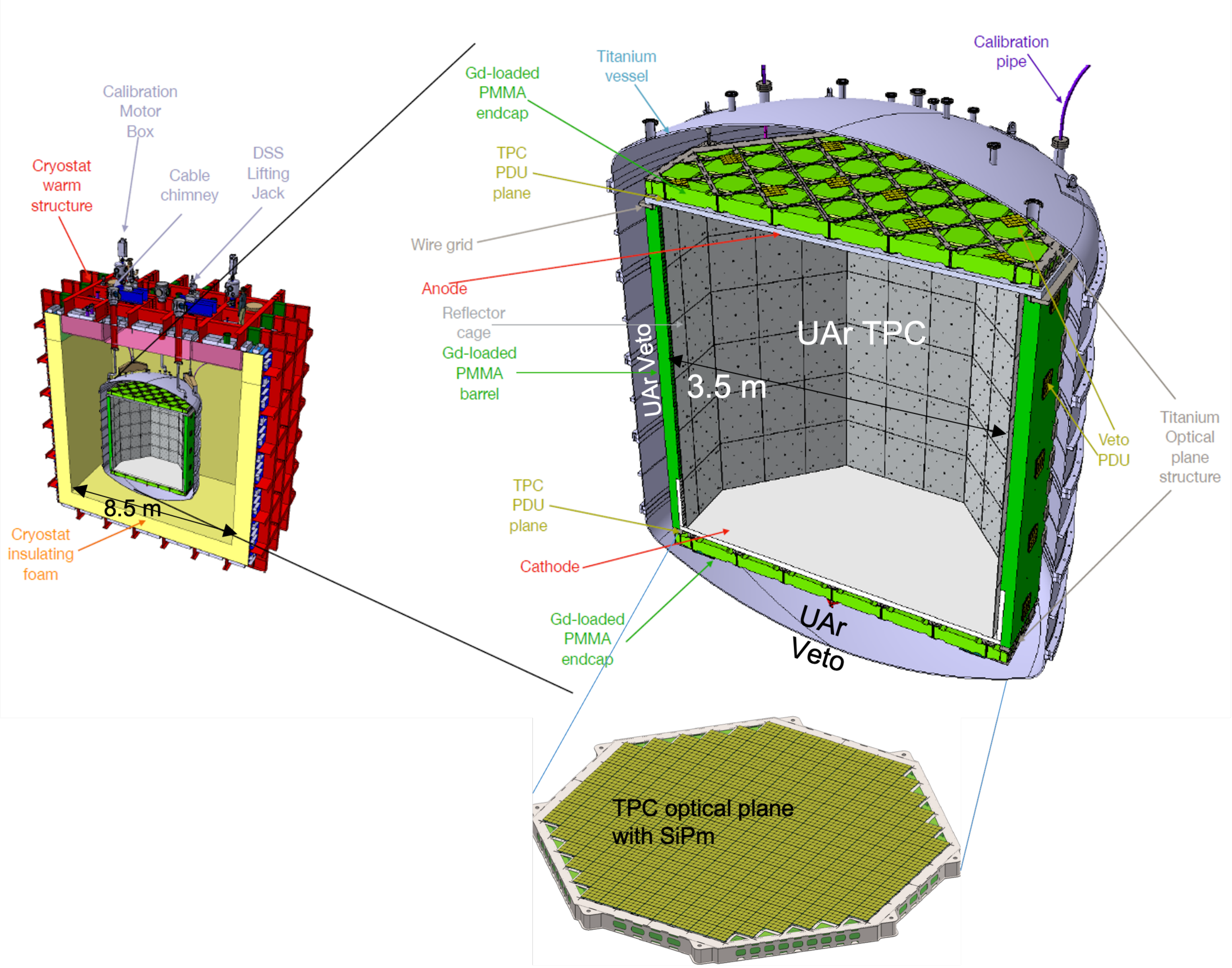
- Large exposure
- Low energy threshold < 10 keV
- Low background rate < 0.1 ev in RoI (30-200 keVnr) with 200 t-y exposure
- Topology-based background discrimination: multi-scatter vs single scatter
- Pulse-shape based bkg discrimination (PSD) > 10^8





DarkSide-20k
Key points

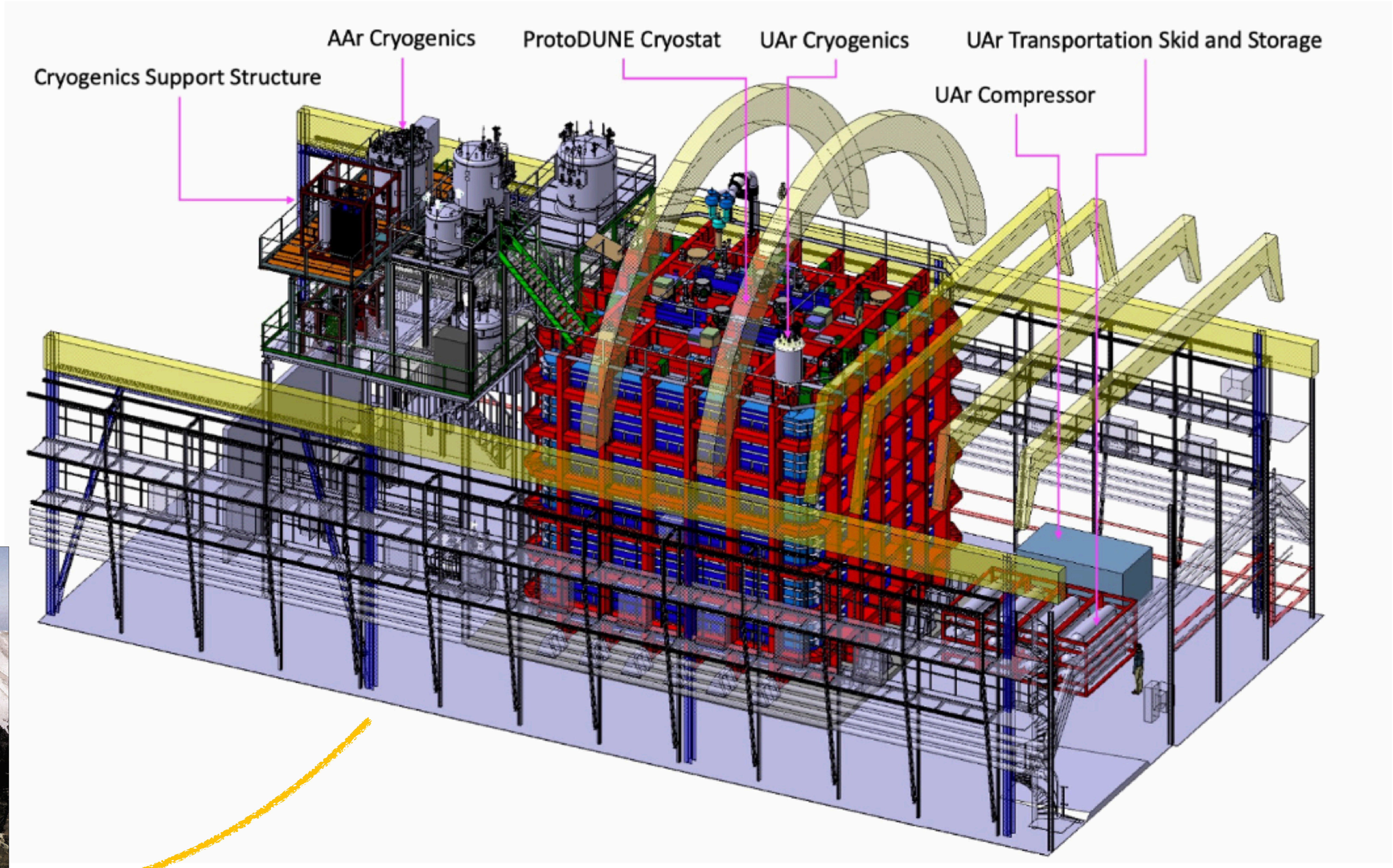
- The detector is based on an ultrapure liquid low radioactivity Argon (UAr) double-phase Time Projection Chamber (TPC): 50 t (20 t FV) of UAr
- TPC surrounded by a single phase LAr neutron veto detector
- Wavelength shifters: TPB in the TPC, PEN in the veto
- 21 m^2 of cryogenic SiPMs
- Integration of TPC and veto in a single object
- 99 t total UAr in a vessel

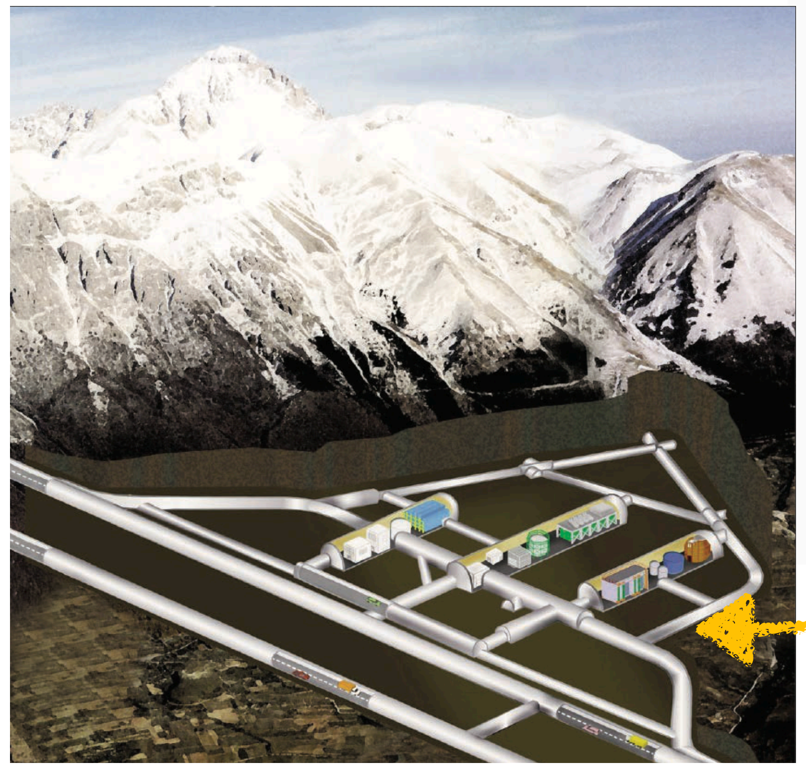


DarkSide-20k

Key points

- Vessel contained in a 650 t of standard liquid Argon within a membrane cryostat (similar to Proto-Dune)
- Detector in Hall C, underground at LNGS (Italy)





DarkSide-20k
Background mitigation

Source	Strategy & Tools
β/ γ	UAr, PSD, material selection, …
Radon progeny	Surface cleaning, Rn suppressed air, …
Radiogenic neutron, mostly (α, n)	Neutron veto, fiducialization, material selection, …
Cosmogenic neutron	Muon veto, …
Neutrino induced NRs	Irreducible (~3.2 ev in 200 t-y)

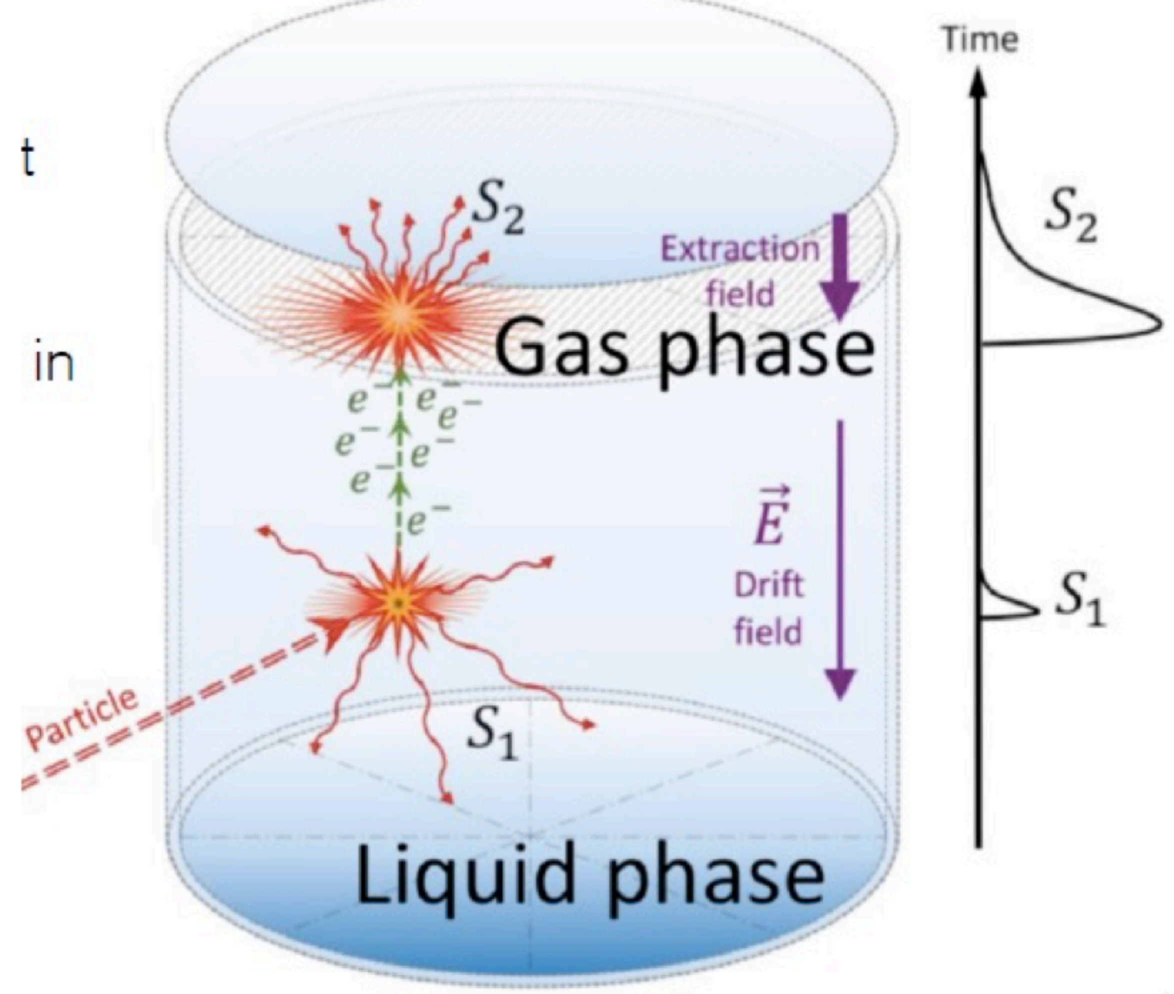
DARKSIDE

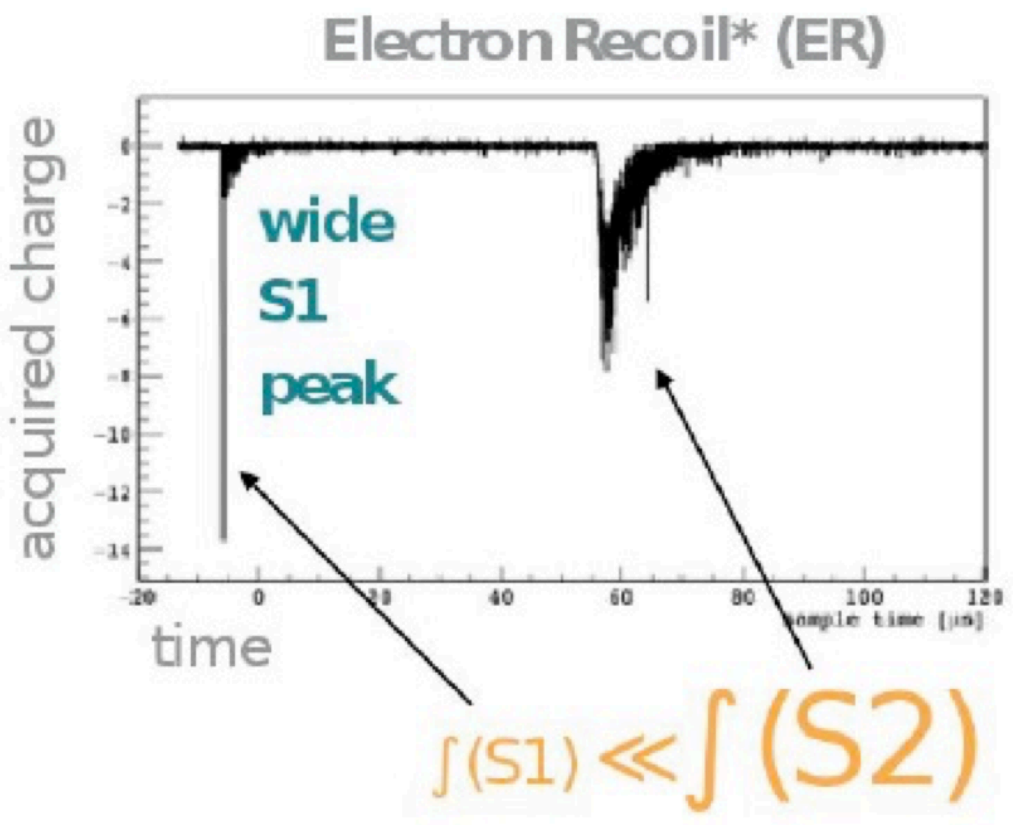
INFN
Istituto Nazionale di Fisica Nucleare

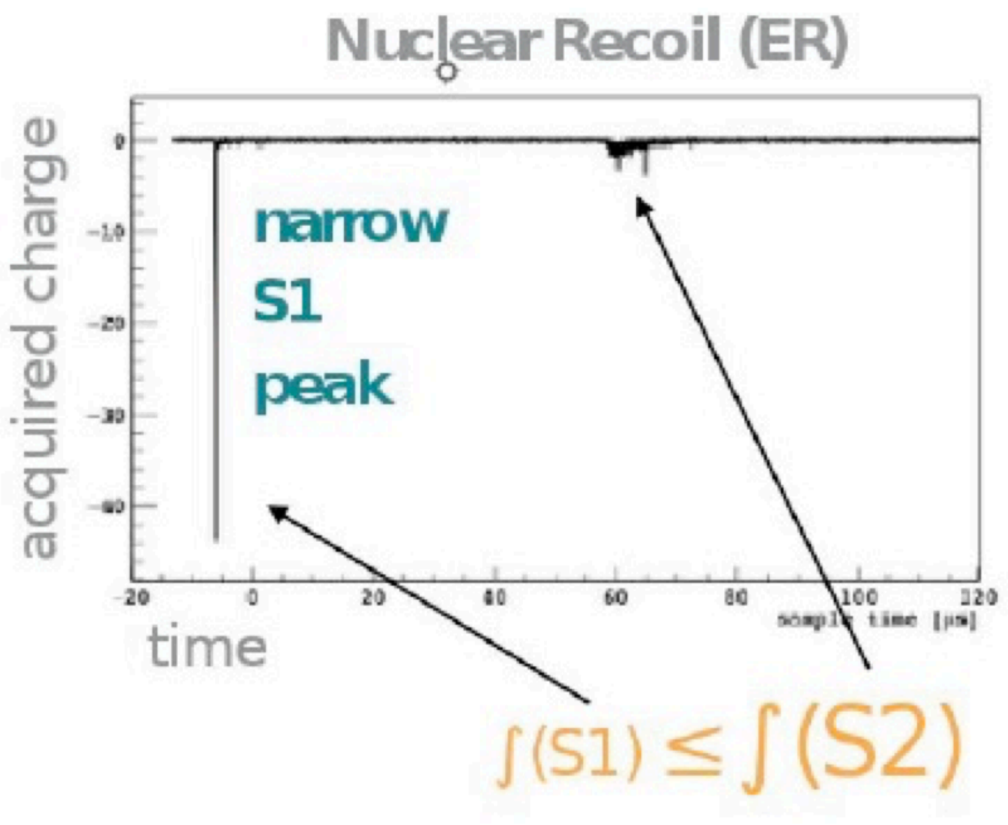
DarkSide-20k

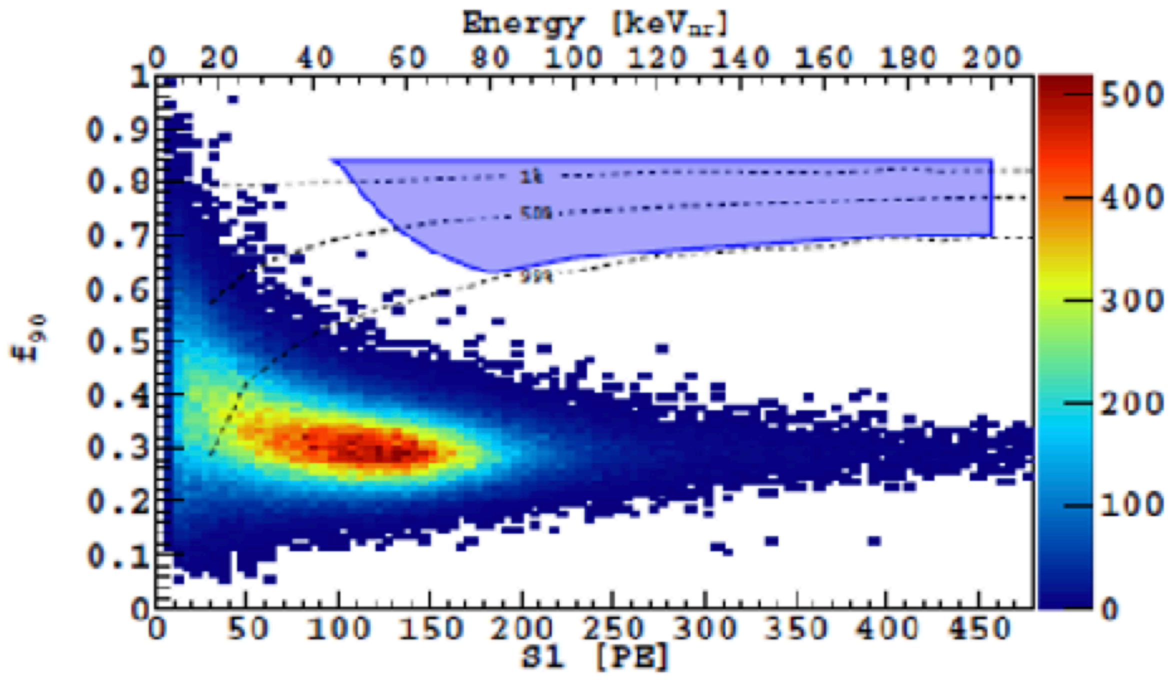
LAr and TPC technology

- Scintillation (S1):
  formation of excited Ar2* and decay short singlet state 6.7 ns long triplet state 1600 ns
- Electroluminescence (S2):
  drift of e- in electric field extraction in gas

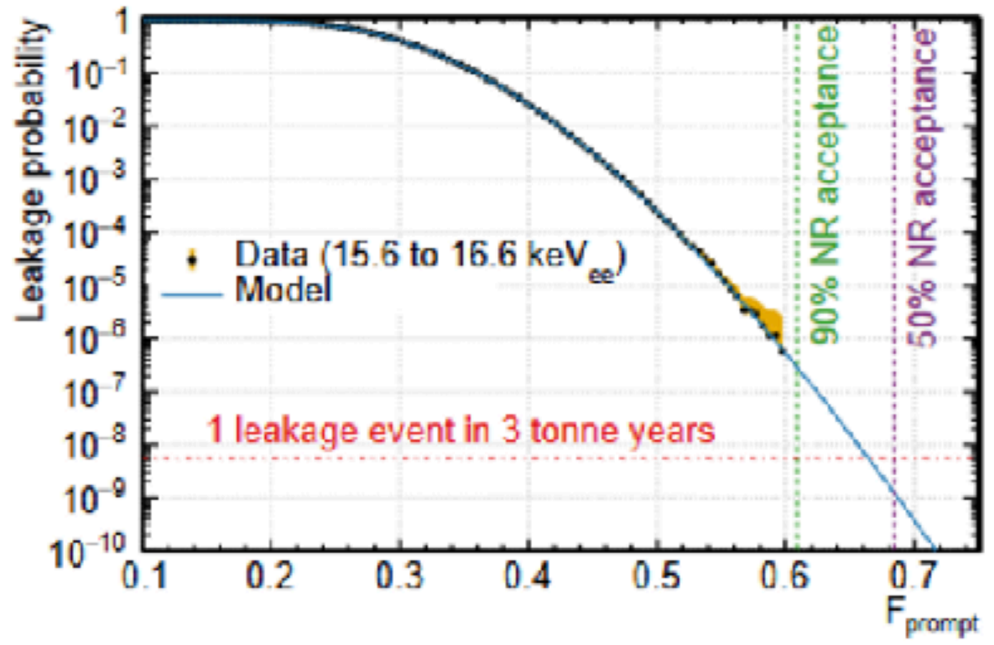








DS50 Coll, Phys Rev D 98 (2018) 102006



DEAP Coll, Euro Phys J C 81 (2021)

DarkSide-20k
Background mitigation

Background

Electron recoil ← PSD → Nuclear recoil

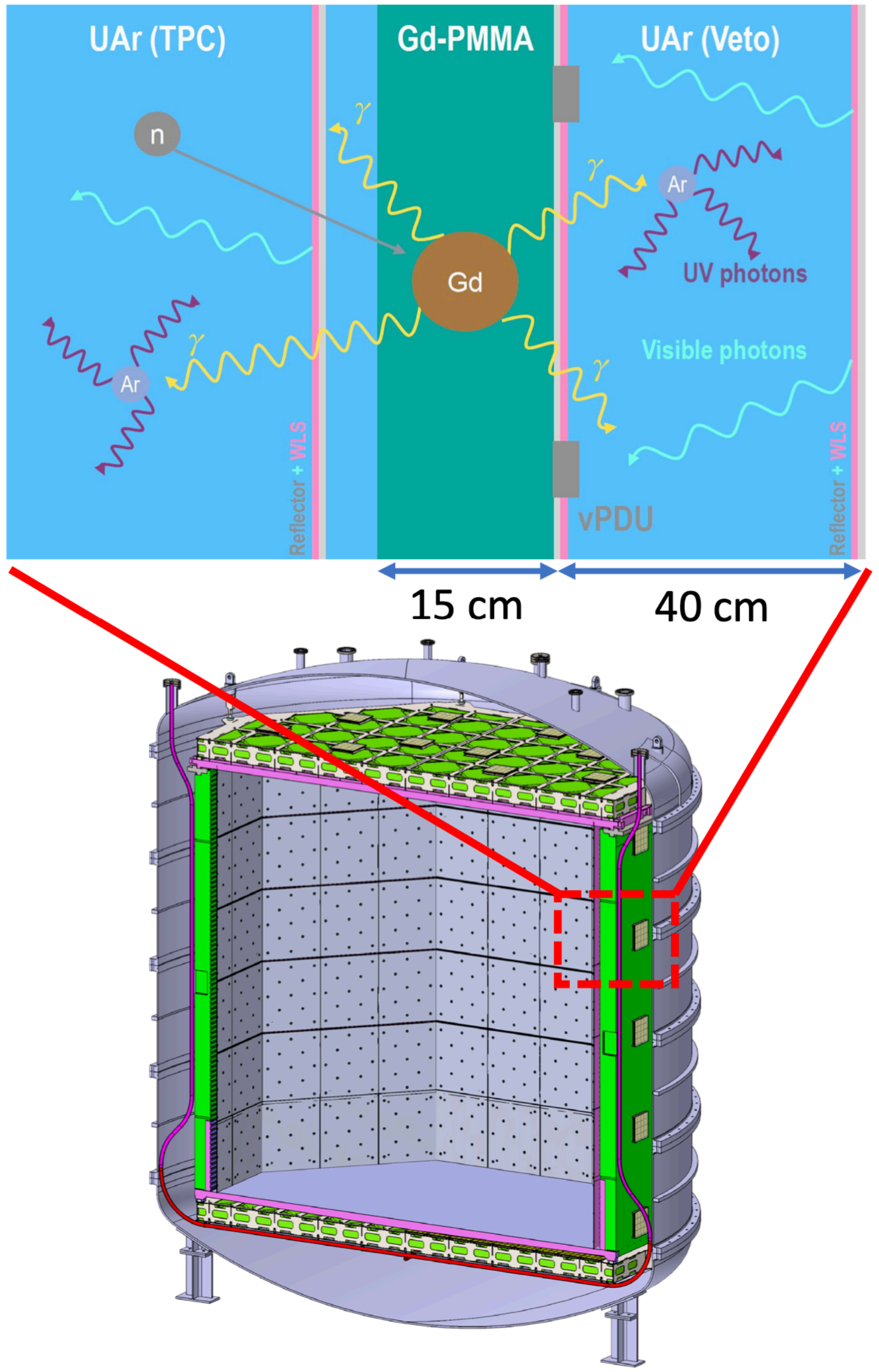
How to overcome?

How to overcome?

- Low ^{39}Ar content
- Use of dual-phase TPC
- PSD
- Strict materials selection

- Active Veto detector
- Strict materials selection

Extraction of underground Ar
(UAr, ^{39}Ar content equal to ~1/1400
with respect to atmospheric Ar)

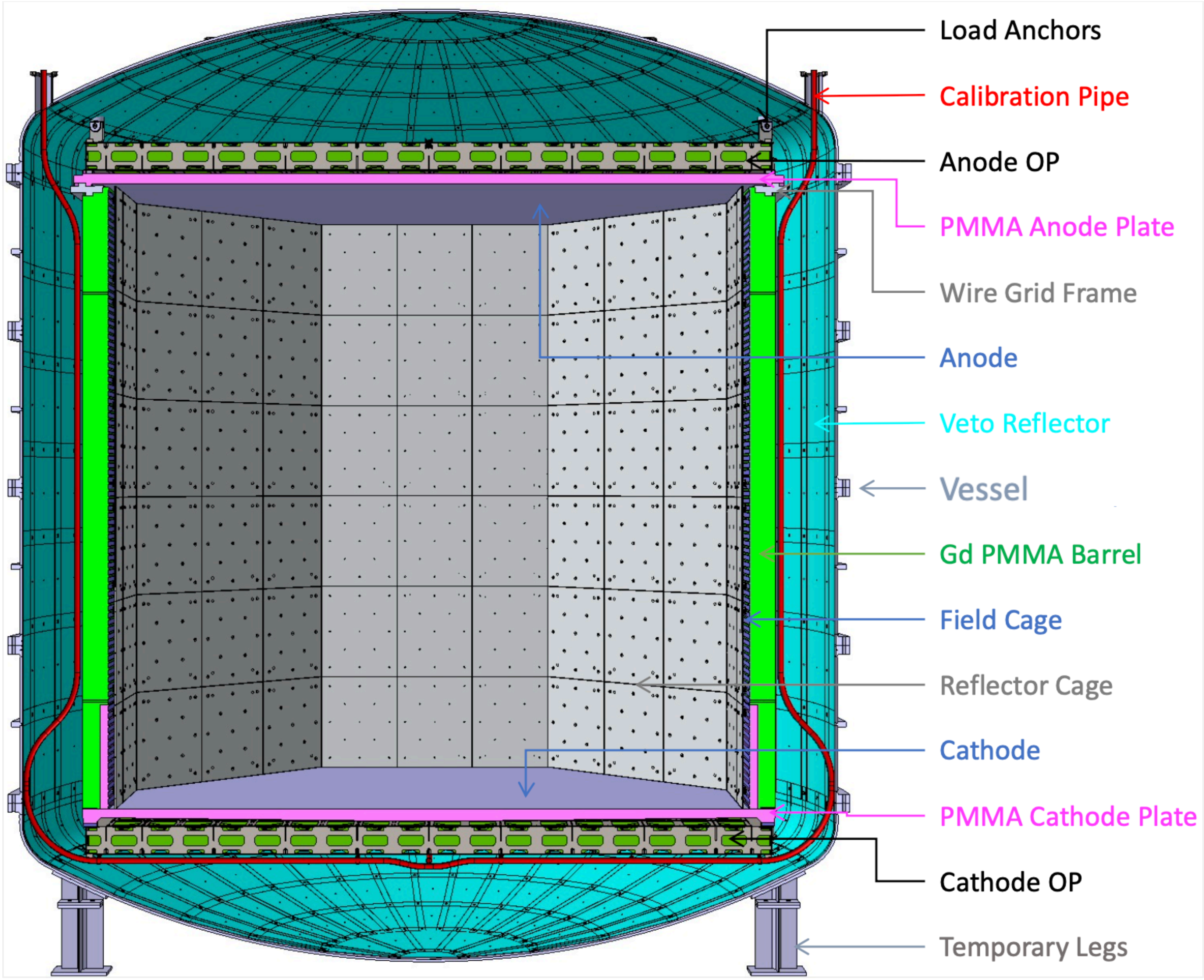


DARKSIDE

INFN
Istituto Nazionale di Fisica Nucleare

DarkSide-20k
Neutron tagging with veto

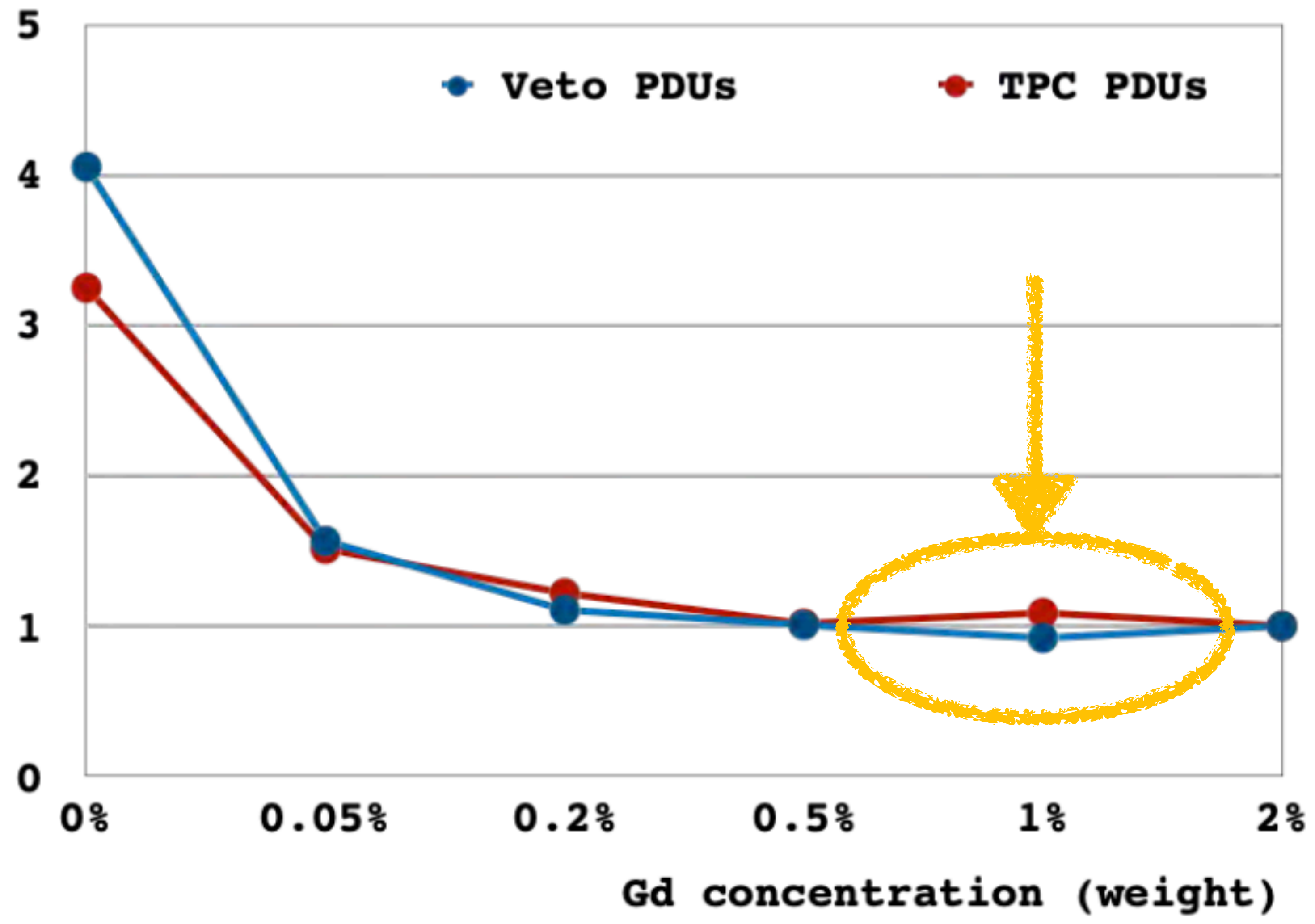
- Gd-PMMA is the chosen material for the neutron veto: 11.2 t needed
- The plastic has to survive at LAr temperature
- Gd-PMMA is highly efficient at moderating and then capturing neutrons
- The TPC barrel and the endcaps will be made of Gd-PMMA (4π coverage)
- The capture results in the emission of several γs, with energy up to 7.9 MeV.



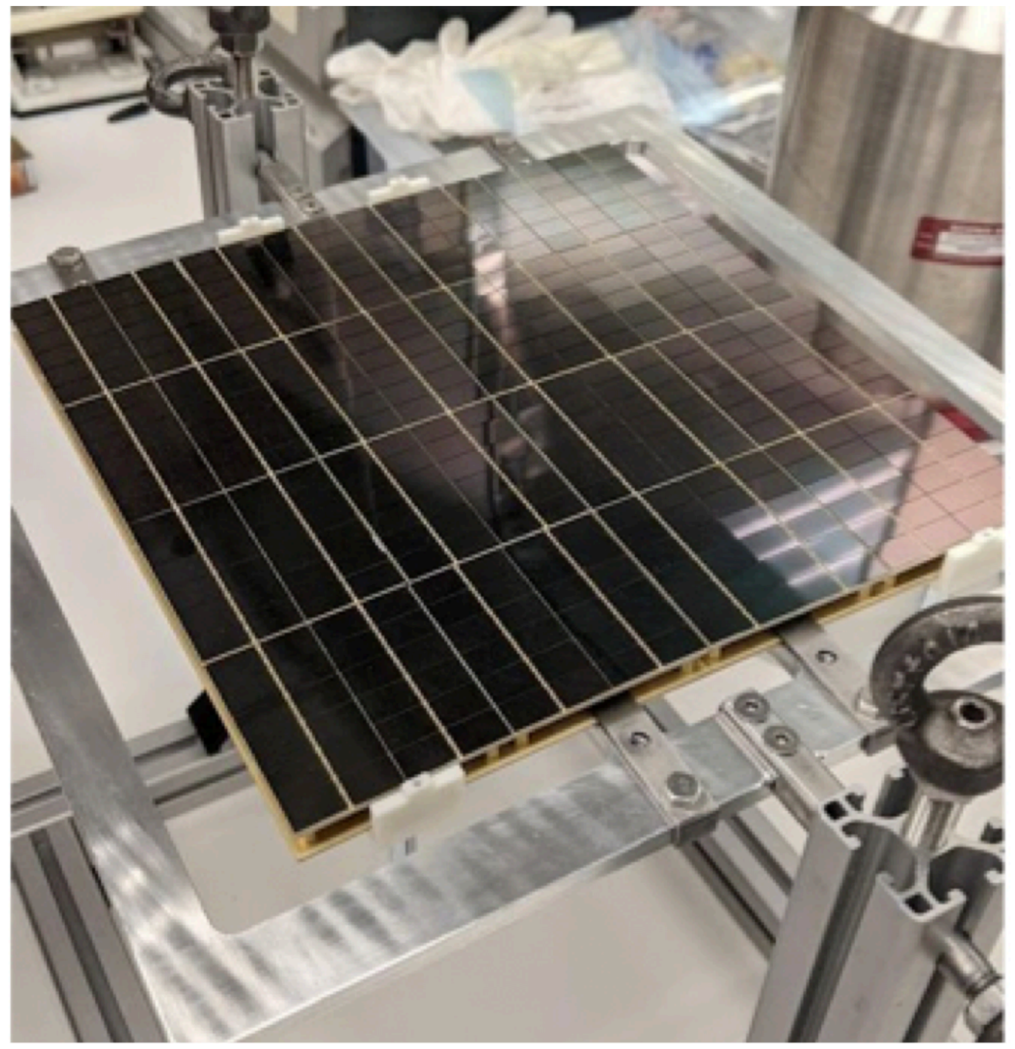
DarkSide-20k

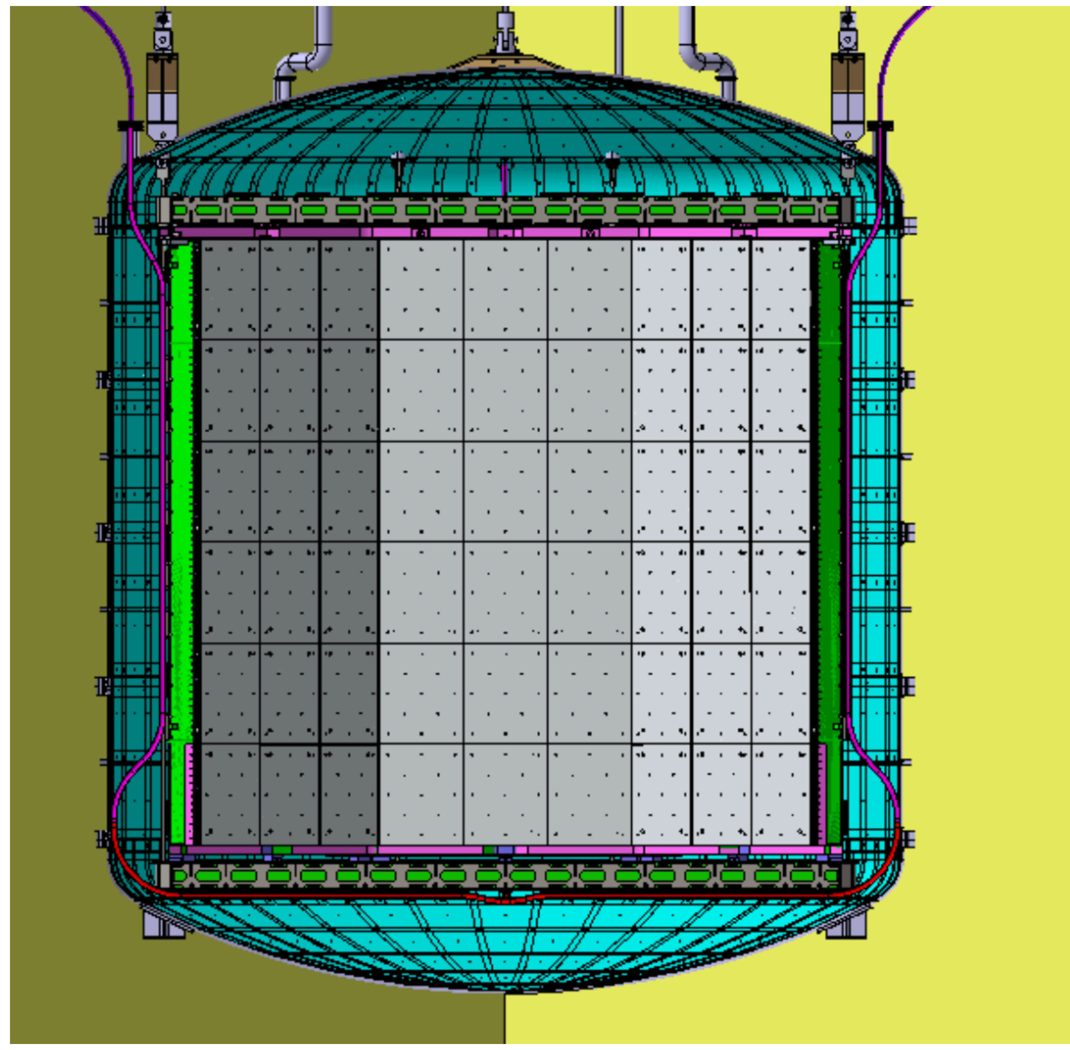
Neutron tagging with veto

- Gd concentration is chosen to have neutron capture on Gd dominates w.r.t. capture on H
- Neutron tagging = maximising the probability of neutron capture and detection of de-excitation γs
- Final thickness of the Gd-loaded parts will be 15 cm at room temperature
- Passive volumes reduced as much as possible



Reduced-thickness light sensor





Gd-loaded acrylic

Development of the hybrid material

The collaboration performed R&Ds in Italy, Russia and China.

- Promising results have been obtained with Gd_2O_3, $Gd(acac)_3$, and $Gd(MAA)_3$.
- All of these compounds are satisfactory from the chemical and radiopurity points of view (the (α, n) process is a dangerous source of background)

Two approaches reached industrial production readiness:

- Gadolinium oxide nanograins (Gd_2O_3) mechanical dispersion in MMA
- $Gd(MAA)_3$ dispersion in the liquid monomer (MMA)

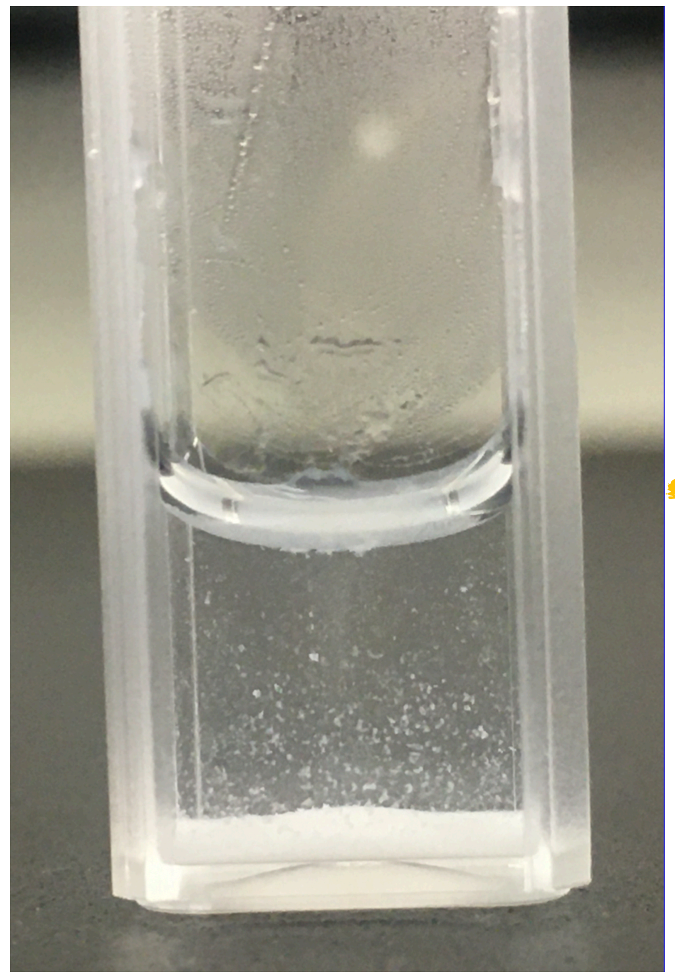
DARKSIDE

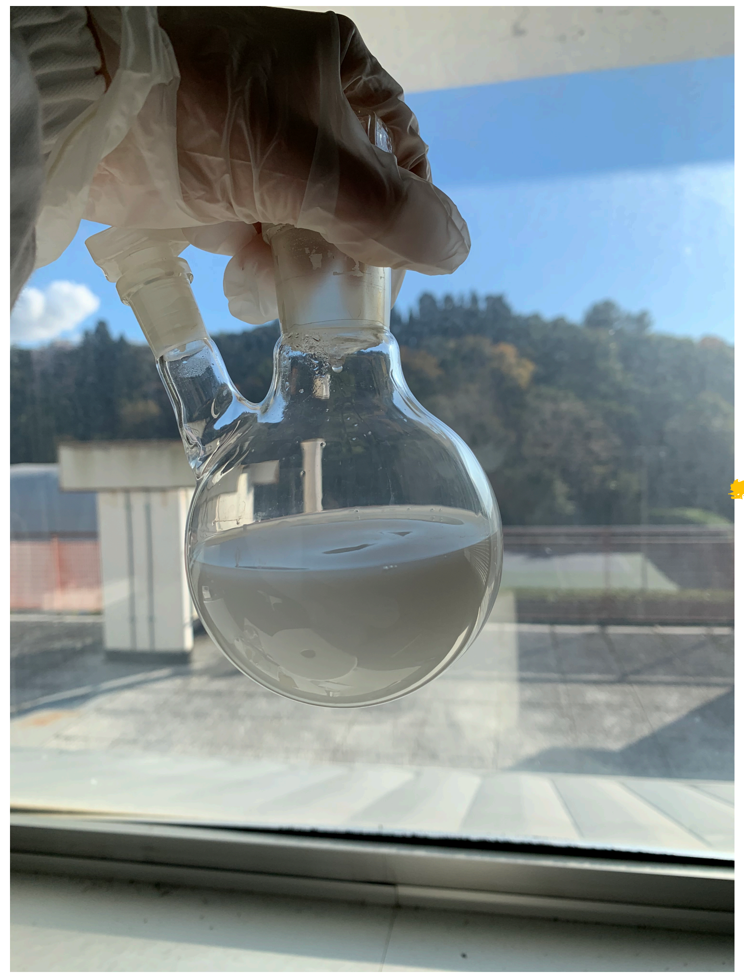
INFN
Istituto Nazionale di Fisica Nucleare

Gd_2O_3 in nano grains
R&D, purification & screening

- Gd_2O_3 is a stable and known compound commercially available
- Found vendor with radio pure oxide [3 batch assayed with HPGe @ LSC]
- Gd oxide is not soluble in the acrylic monomer -> mechanical dispersion of coated nanograins with surfactant to avoid sedimentation
- Surfactant showed non negligible ^{40}K contamination ($3.19\ 10^4$ mBq/kg)
- Developed a surfactant purification procedure using an ionic exchange resin (reduction factor ~50) which makes surfactant presence negligible
- Obtained up to 21 cm thick lab scale sample with Gd_2O_3 concentration up to 2%

Gd2O3 Sample #	^{238}U [mBq/kg]	^{232}Th [mBq/kg]	^{40}K [mBq/kg]
1	13.6 ± 3.0	< 27	< 37
2	6.6 ± 1.8	< 19	< 23
3	2.68 ± 0.47	2.31 ± 0.68	< 13





Gd_2O_3 in nano grains

Industrial scaling

- Procedure transferred to an Italian company
- 250 kg of Gd-PMMA plastic produced: 12 cm thick sheets
- Gd uniformity of industrial samples is very good (95%), measured by calcination
- Material's properties extensively investigated

DARKSIDE

INFN
Istituto Nazionale di Fisica Nucleare

Gadolinium methacrylate

Receipt and radiopurity

- $Gd(MAA)_3$ is a customised complex compound, derived from Gd_2O_3
- The compound is soluble in acrylic monomer -> Yangzhou University (Y.U.) developed a procedure to make a stable solution up to 10% Gd wt
- Procedure under NDA, technology transferred from Y.U. to DonChamp company for the DarkSide Gd-PMMA production
- DonChamp: previous experience in low background environments -> JUNO acrylic PMMA production
- Company made 5 cm thick samples and finalised the receipt for 17 cm thick panels (15 cm after machining)
- Radiopurity:
  - PMMA from DonChamp satisfies DarkSide requirements
  - $Gd(MAA)_3$ radiopurity depends on selecting pure Gd_2O_3

Pure PMMA measured at LGNS

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

$Gd(MAA)_3$ doped acrylic sheet (5 cm thick)

Gadolinium methacrylate

Logistics

- Production of $Gd(MAA)_3$ from pure Gd_2O_3 at YU
- Transport of radiopure MMA from the company to the university labs.
- Dissolve $Gd(MAA)_3$ into MMA $10\%_w$
- Transport Gd-doped MMA back to the company infrastructure in controlled environment
- Dilute with pure MMA to get $1\%_w$
- Polymerisation
- Machining
- Onsite cleaning

Reaction kettles at YU for the $Gd(MAA)_3$ production

5-axis CNC capable of machining the TPC barrel

R&Ds conclusions

- DarkSide-20k design foresees an integrated design of TPC and neutron veto
- Hydrogen-rich TPC walls act as neutron moderator, gadolinium presence in the material enhance detection capability
- This design has led to the development of hybrid plastic materials loaded with gadolinium
- The background requirements of the experiment apply stringent limits on the material radiopurity
- Different strategies have been investigated
- Two techniques have been scaled to industrial level production, one has been selected for the usage in DarkSide-20k

Thank you for your attention!

For further informations: caminata@ge.infn.it

More about DarkSide@ IDM 2022

- Search for low mass WIMP dark matter with DarkSide-50
  M. Kimura - 19 July 2022 17:30 EI7
- The DarkSide-20k TPC and underground argon cryogenic system
  T. Thorpe - 19 July 2022 14:40 EI9