The **DarkSide-20k Experiment**

DARKSIDE

ON BEHALF OF THE DARKSIDE-20K COLLABORATION

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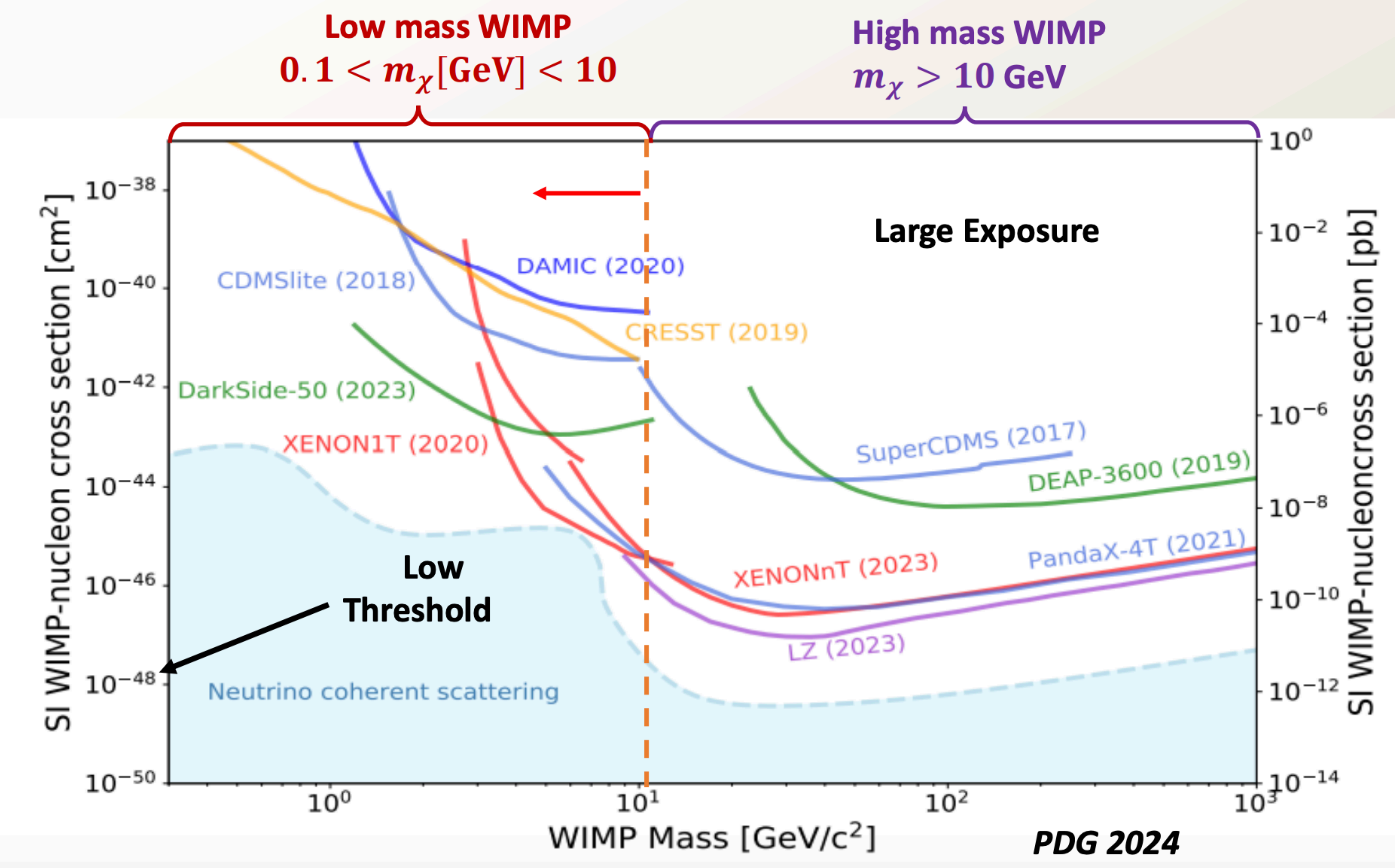
LNGS IN ASSERGI, ITALY

PATRAS WORKSHOP, 17/09/2024

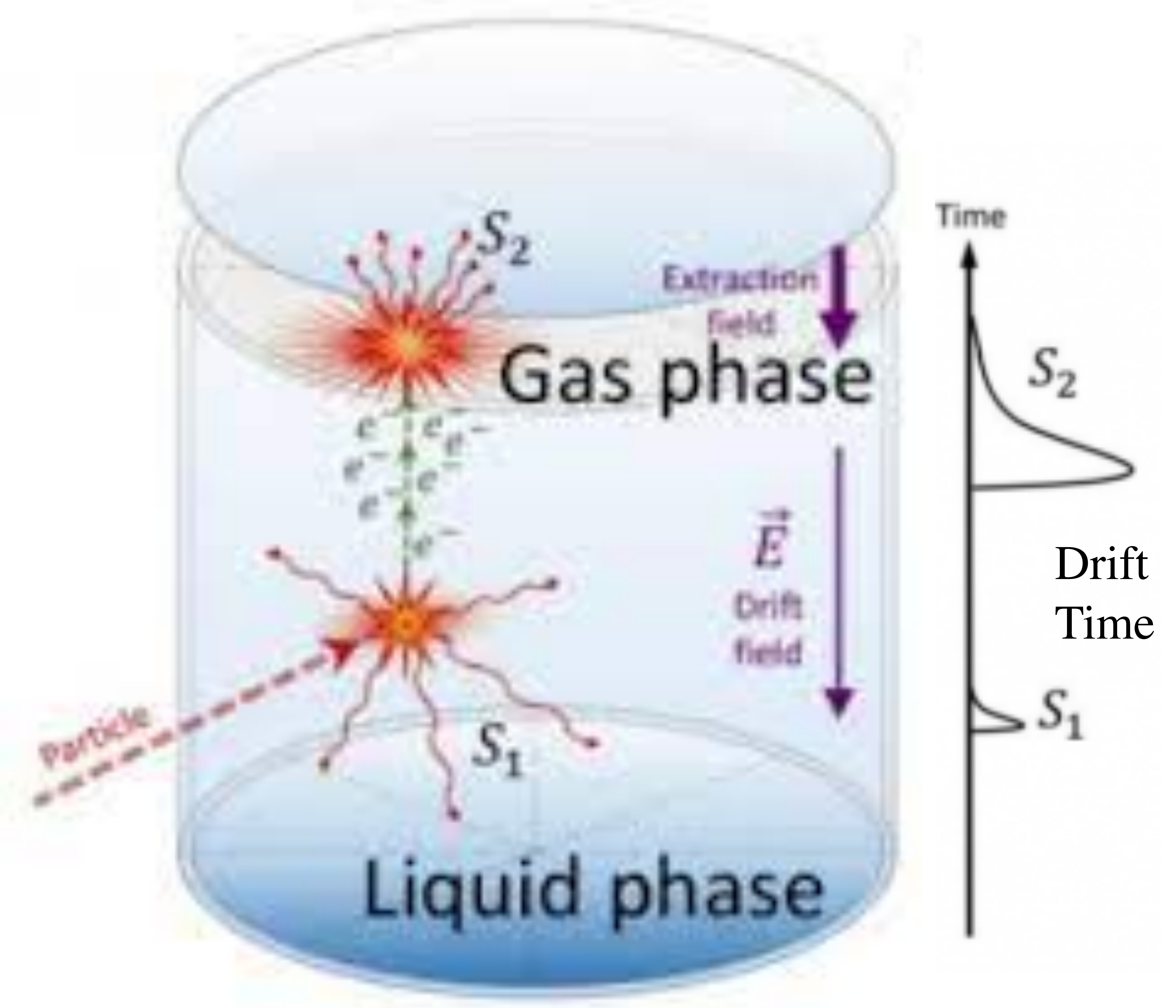
WIMParticles as candidates for DM

- Weak scale interaction lead to correct density in the universe
- Mass scale: MeV - 100 TeV
- Motivated by many theories

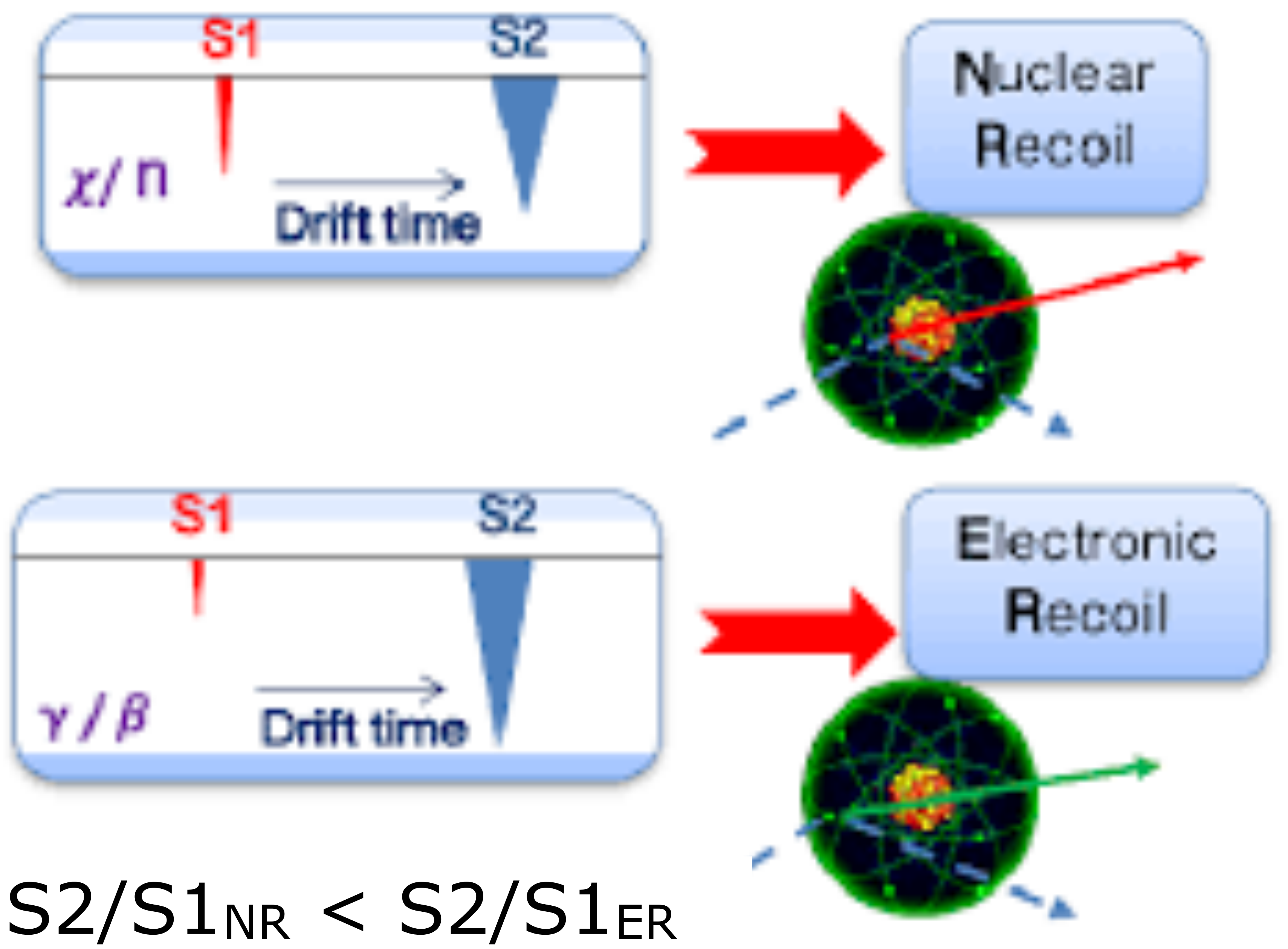


Noble gases TPC

Dual phase Time projector Chamber (TPC)



- Signal: S1 (primary scintillation) + S2 (charge signal)
- S2 light pattern gives x-y position
- Drift time give z position
- S1-S2 relative size give particle information



DarkSide Target material: liquid Ar from underground (UAr)

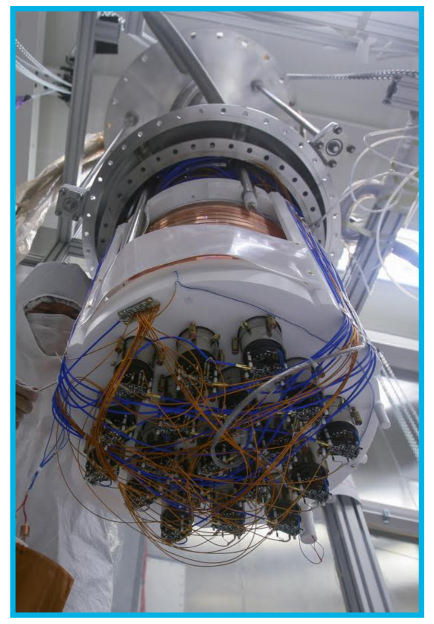
$S2/S1_{NR} < S2/S1_{ER}$

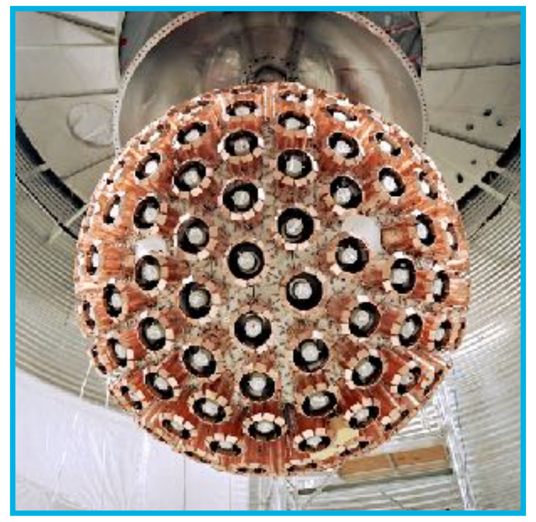
Global Argon Dark Matter Collaboration

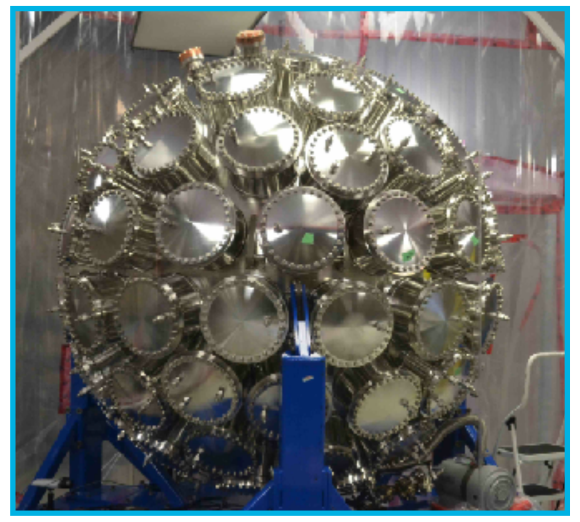
500 people, about 100 Institutions,

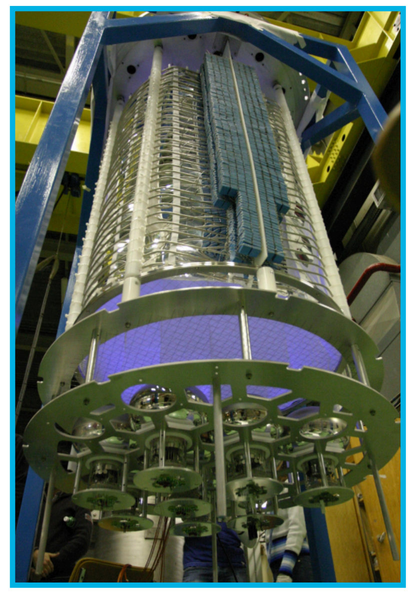
4 argon experiments: DarkSide-50 at LNGS; DEAP 3600 at Snolab; ArDM at Canfranc; Mini Clean at Snolab

Joined expertise about low background liquid Argon based detectors


DarkSide-50


DEAP-3600


MiniCLEAN


ArDM

Multi step program towards <u>WIMP dark matter</u> detection:

- **Present goal: DarkSide 20k, LNGS, ~50 t of UndergroudnLAr (20 t FV) in the double phase TPC** (Eur.Phys.J.Plus 133 (2018)131)

  Construction started
  Operation at 2027, Nominal run time: 10 years
  Search for dark matter candidates with masses from the keV (through ER arXiv: 2407.05813(2024)) to Planck scale (DEAP arXiv:2108.09405 (2022)).

- **Future goal: ARGO, SNOLAB: 400 t (300 t FV) - conceptual studies**

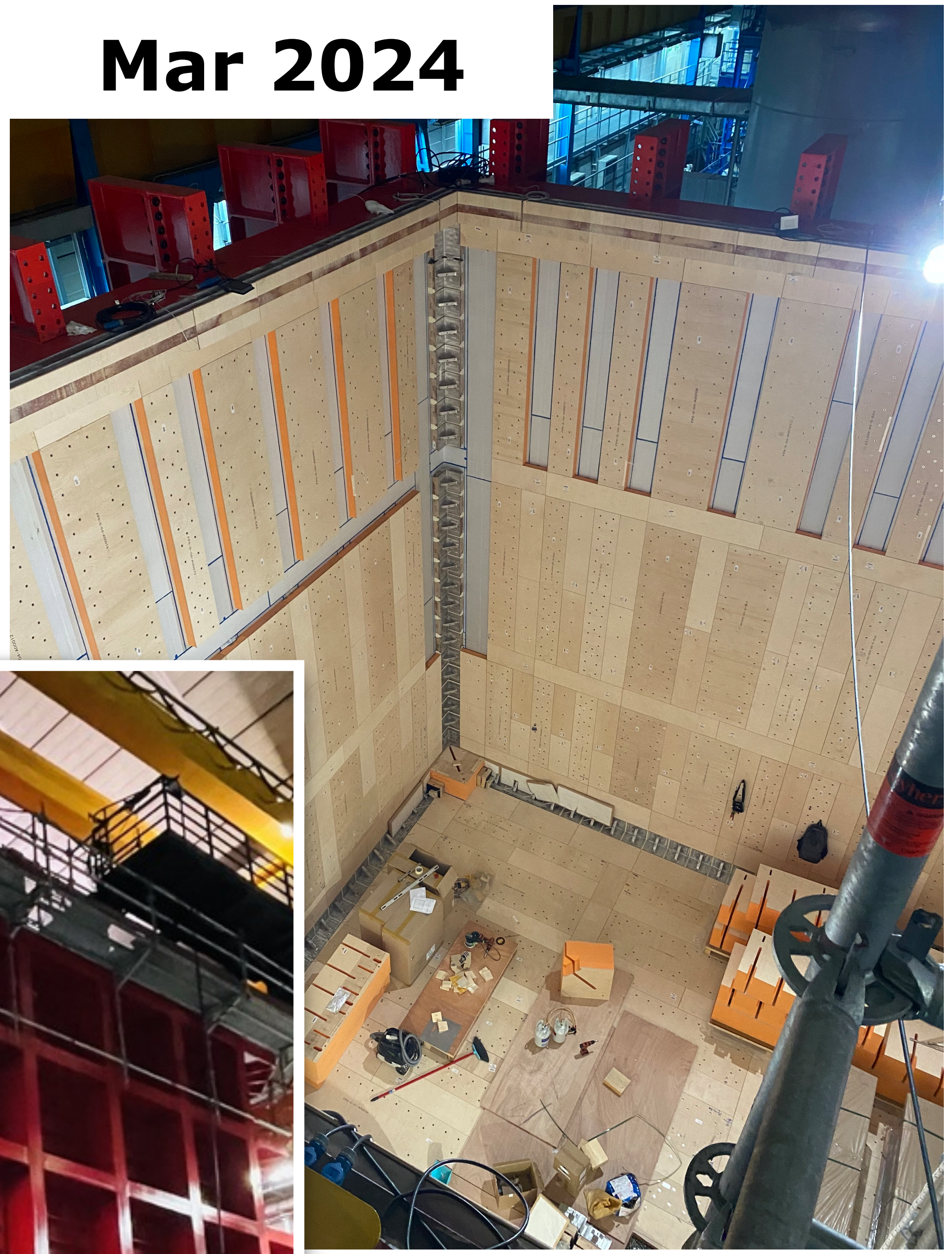
DarkSide-20k

DarkSide-20k installation has started
Data taking will start in 2027

DarkSide is located in HALL C at LNGS, Italy at 3400 m of water equivalent

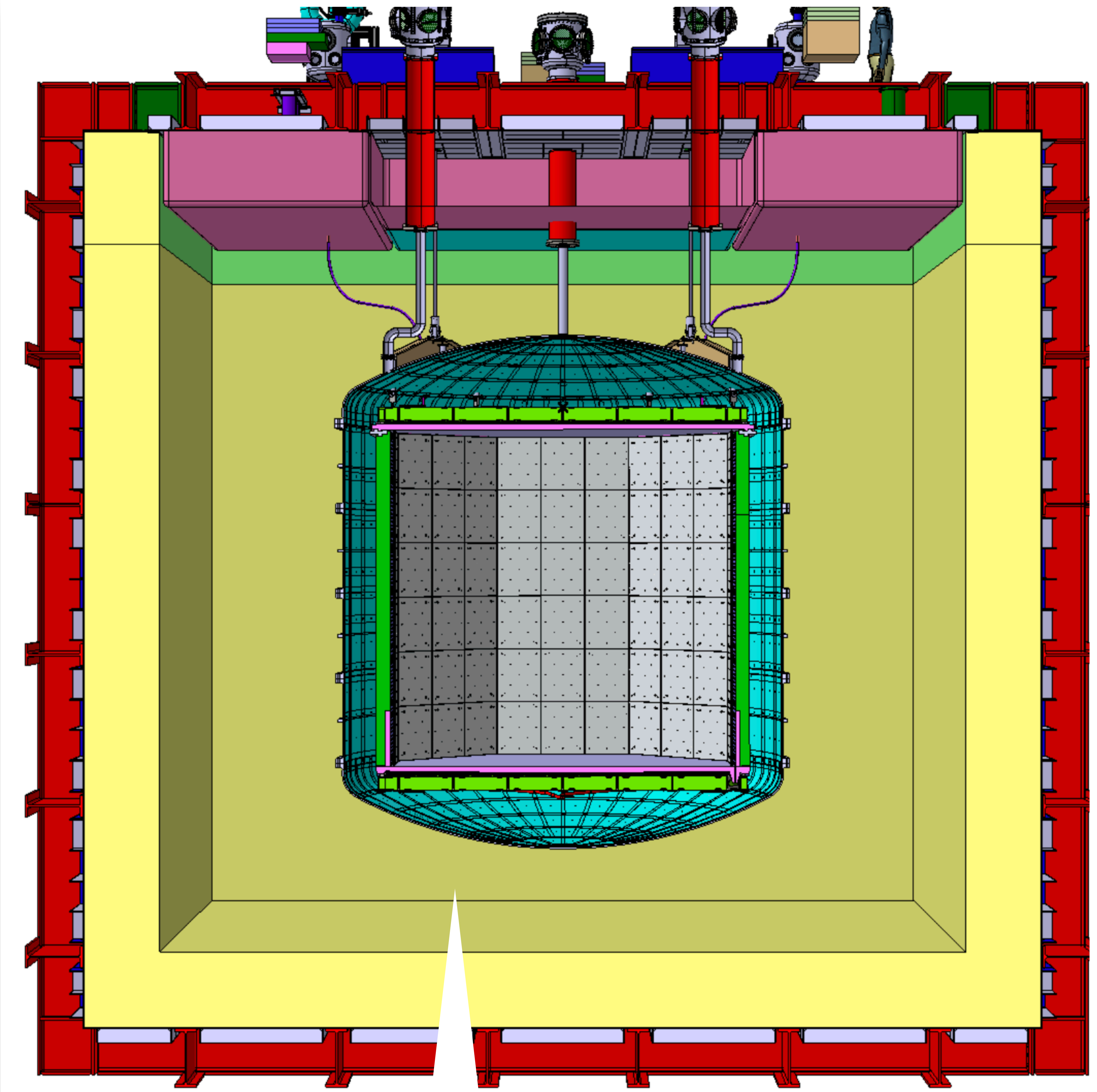
June 2023

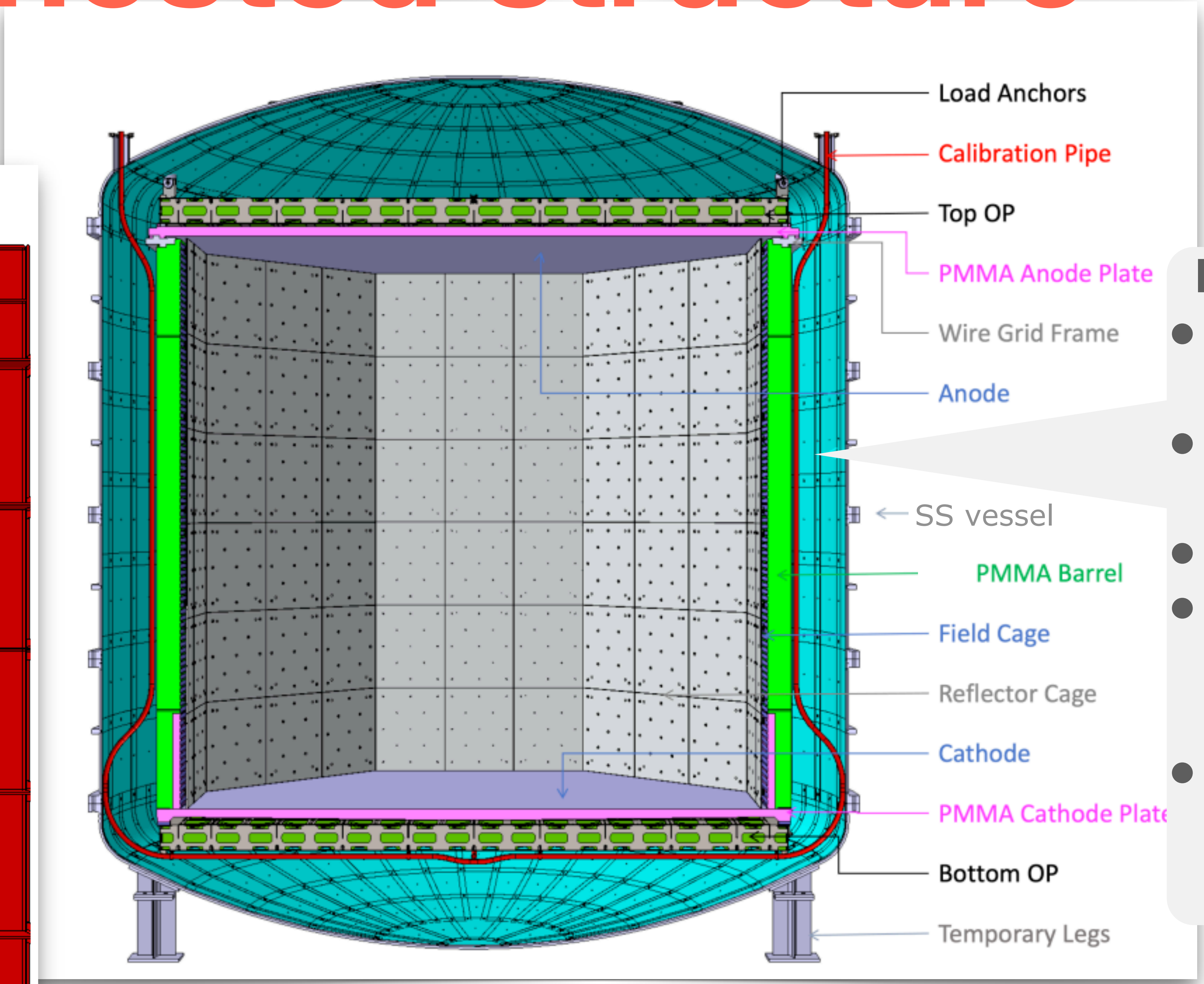
Mar 2024



June 2024

DarkSide-20k - nested structure



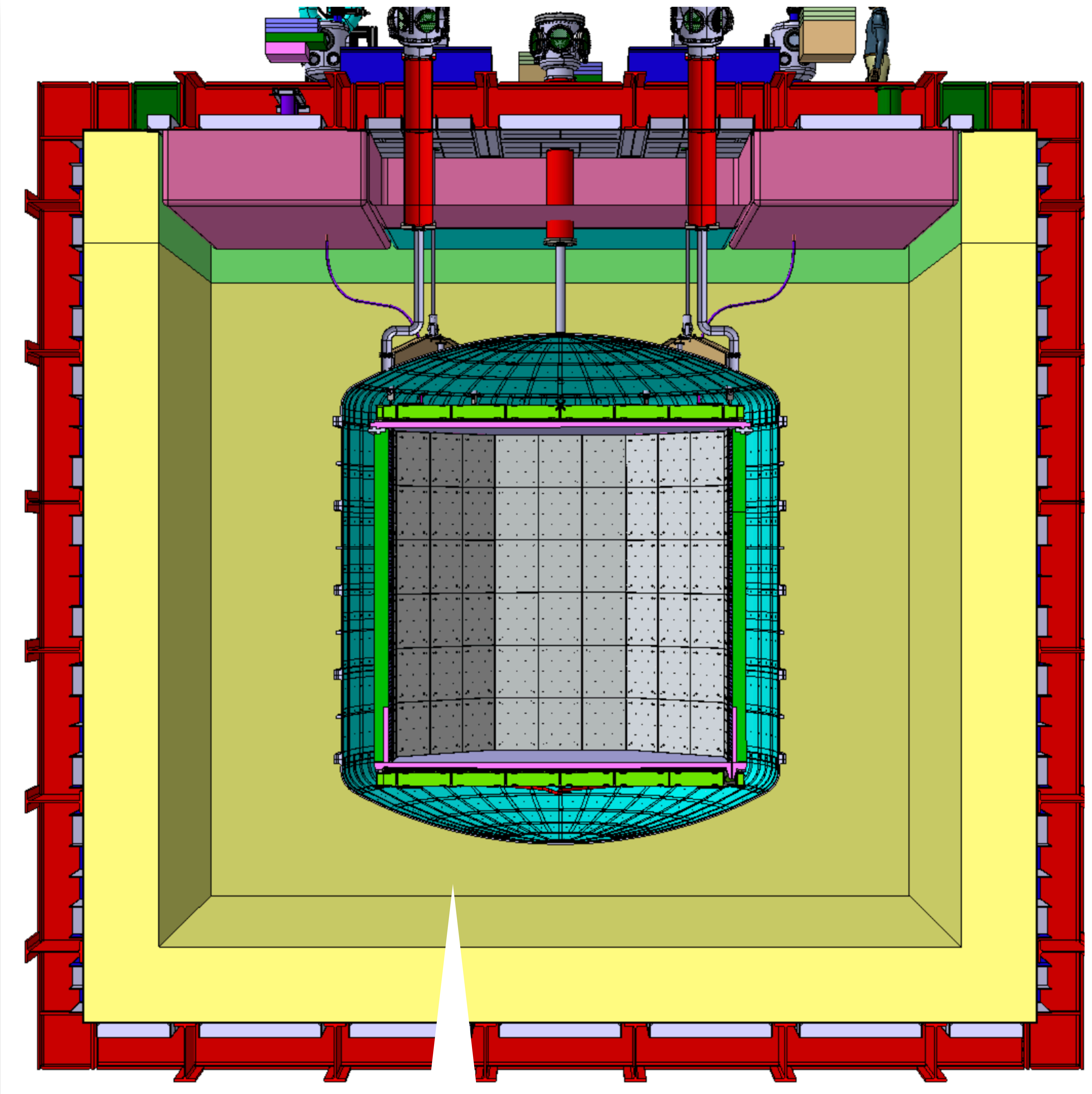


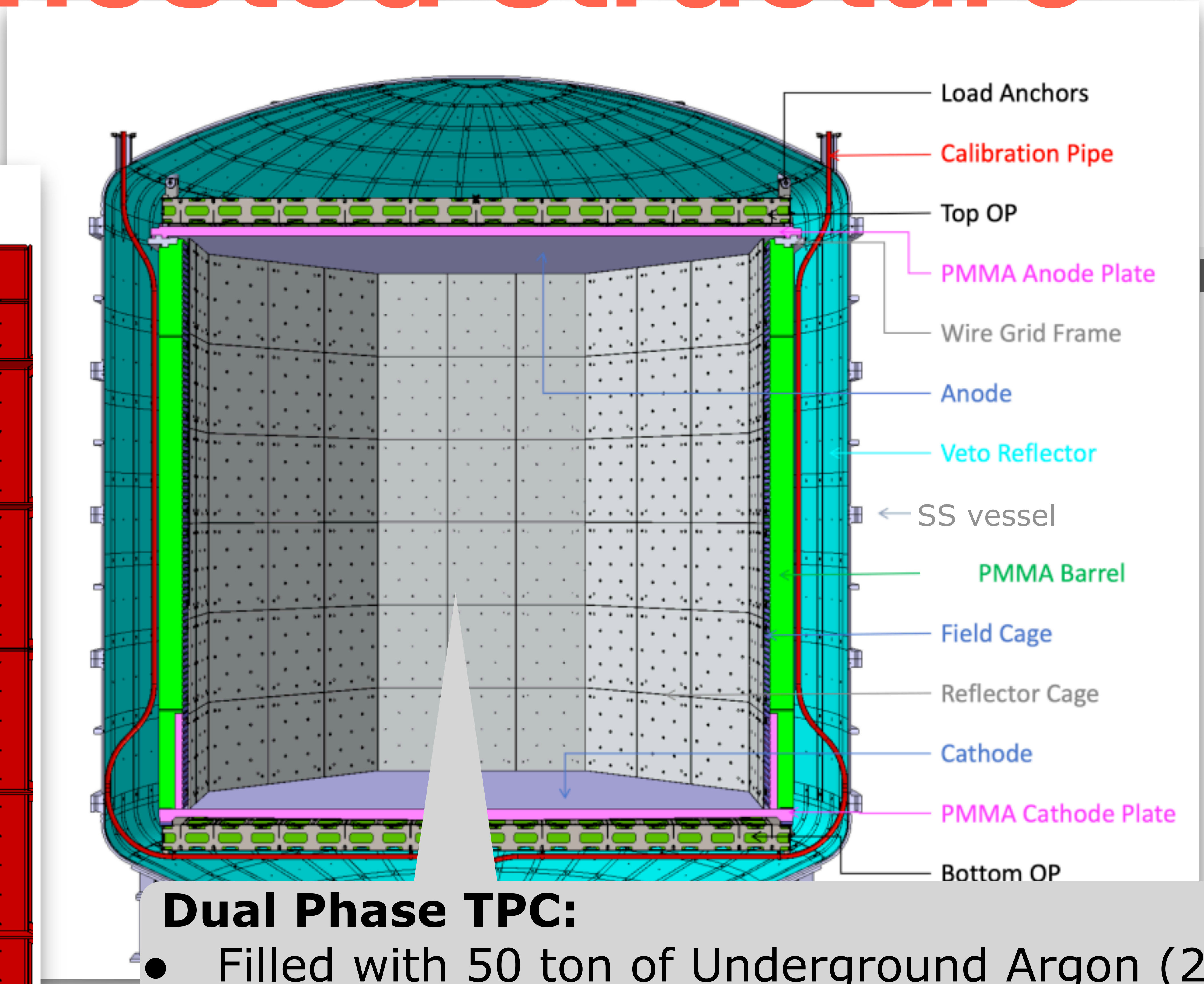
Neutron veto:

- Enclosed in a SSteel vessel
- 35 t of Underground Ar
- (Gd) PMMA barrel
- Equipped with SiPM array for 5 m^2 coverage
- Light yield: 2 pe/keV

Outer veto (cosmics) filled with 600 tonnes of atmospheric argon

DarkSide-20k - nested structure





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Dual Phase TPC:

- Filled with 50 ton of Underground Argon (20 t FV)
- Clevios™ (conductive polymer)coated field shaping rings, anode and cathode
- Steel wire grid
- Equipped with **two optical planes** -> large array of SiPM for 21 m^2 coverage
- Light yield:
  - S1 (scintillation signal): 10 pe/keV
  - S2 (charge signal): 20 pe/e-

Light readout: Large SiPM array

SiPM

~ 1 cm^2
94.900 SPADs
- Single Photon Avalanche Diodes

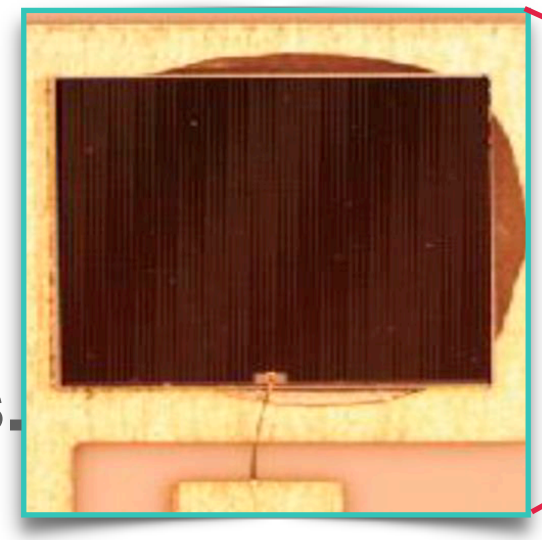
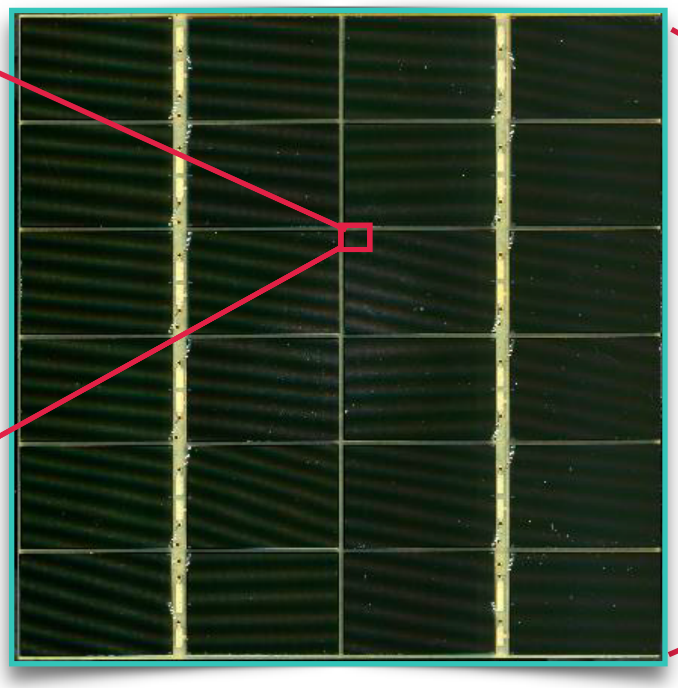
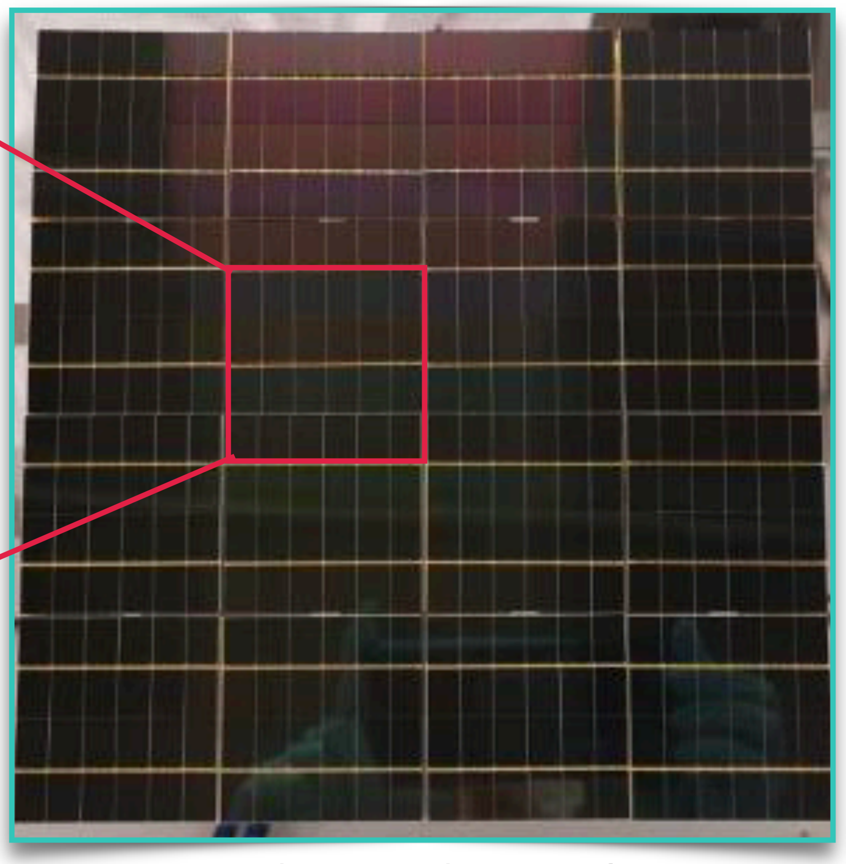


Photo Detector Module (PDM)



5 x 5 cm^2
24 SiPMs,
Front-end electronics

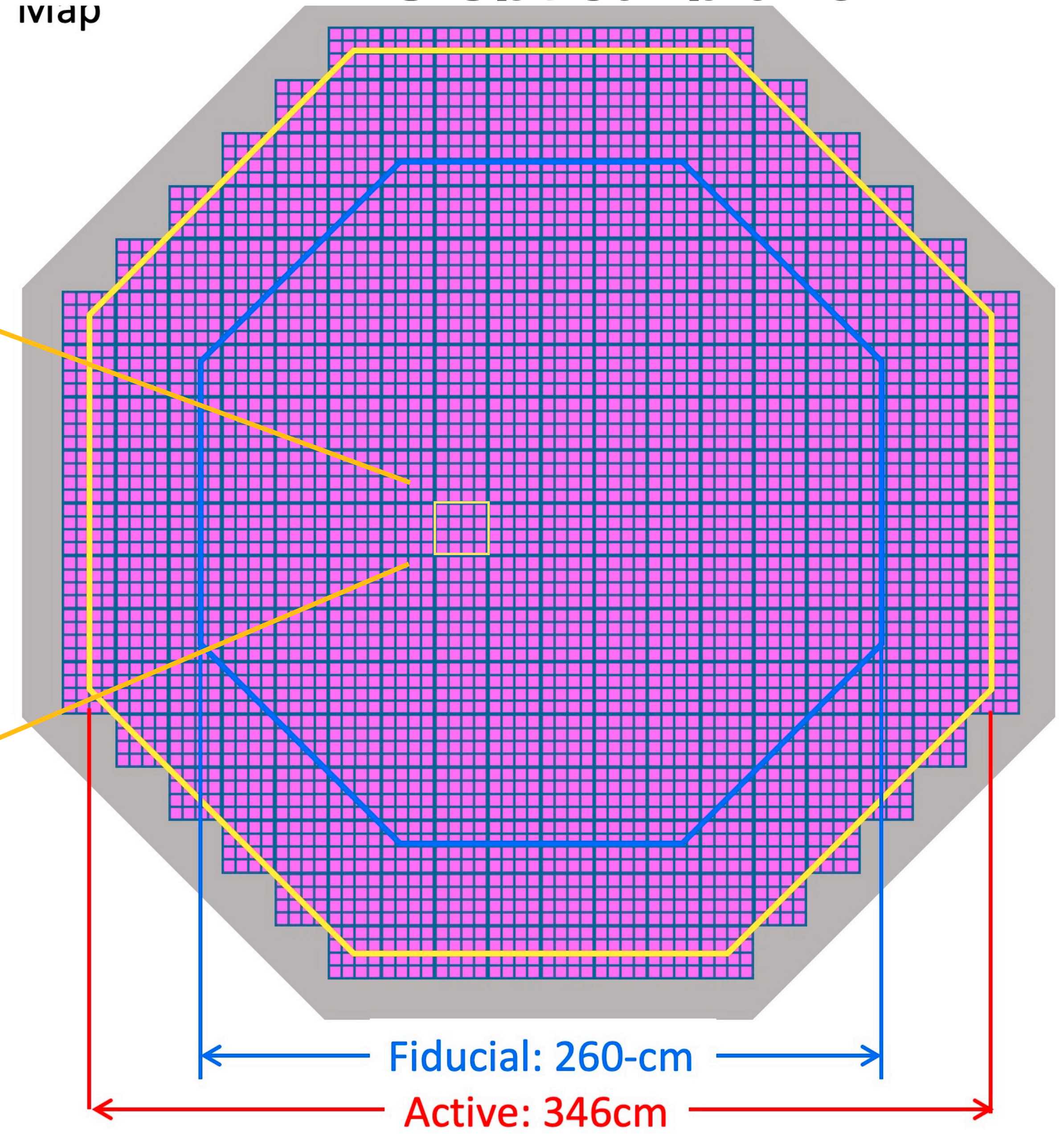
Photo Detector unit (PDU)



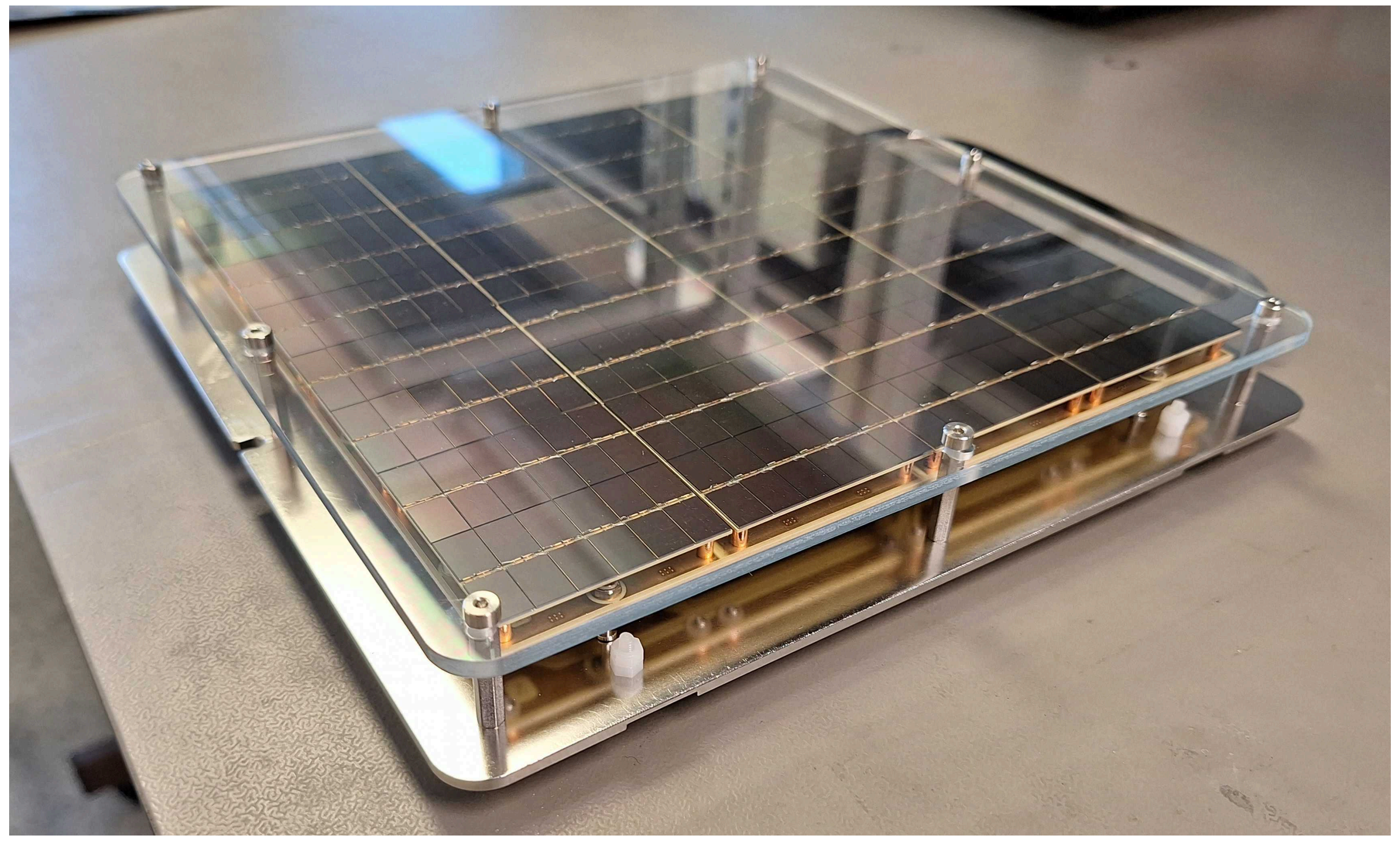
20 x 20 cm^2
PDU of 16 PDMs

~21 m^2
528 PDUs

TPC optical plane



- 16 tiles are assembled together in a **PDU**: **20 x 20 cm^2**
- 1 large PCB to individually enable/disable and bias each single tile and to sum the signals from a quadrant
- 4 tiles are summed together, i.e. 4 tiles correspond to 1 DAQ channel
- **4 outputs: 1/4 DAQ channels -> 1/4 cables-> lower radioactivity**



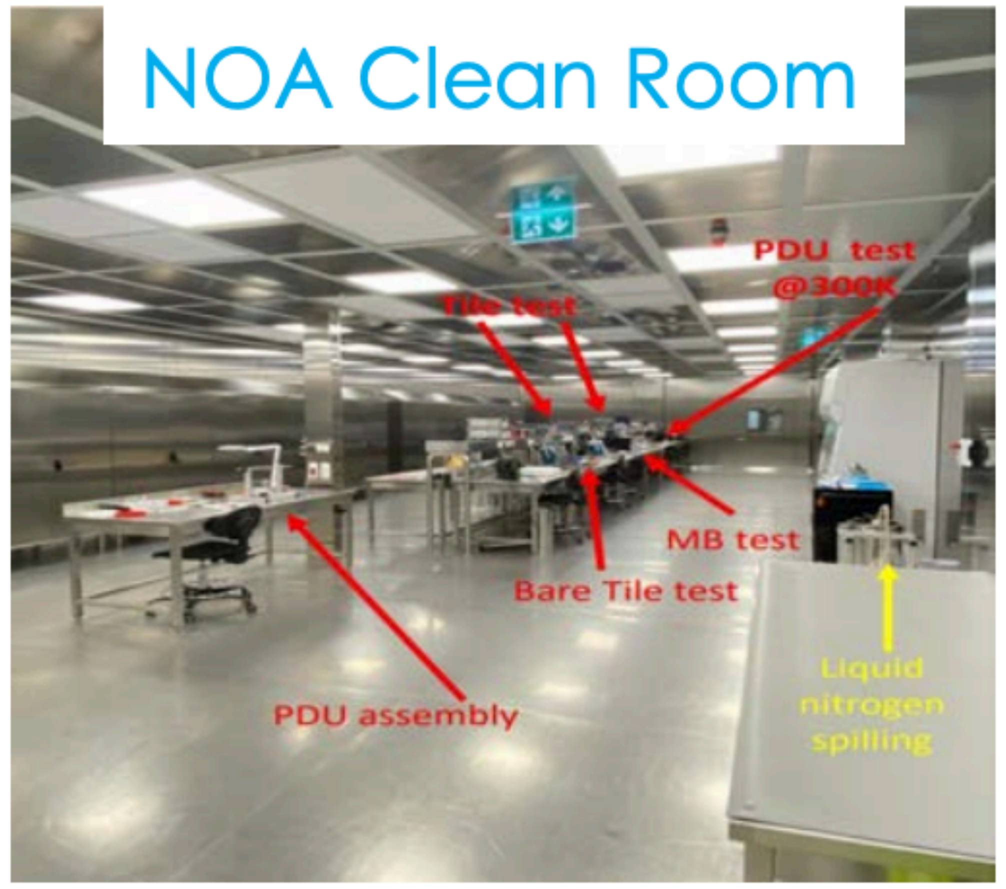
518 PDUs in the TPC

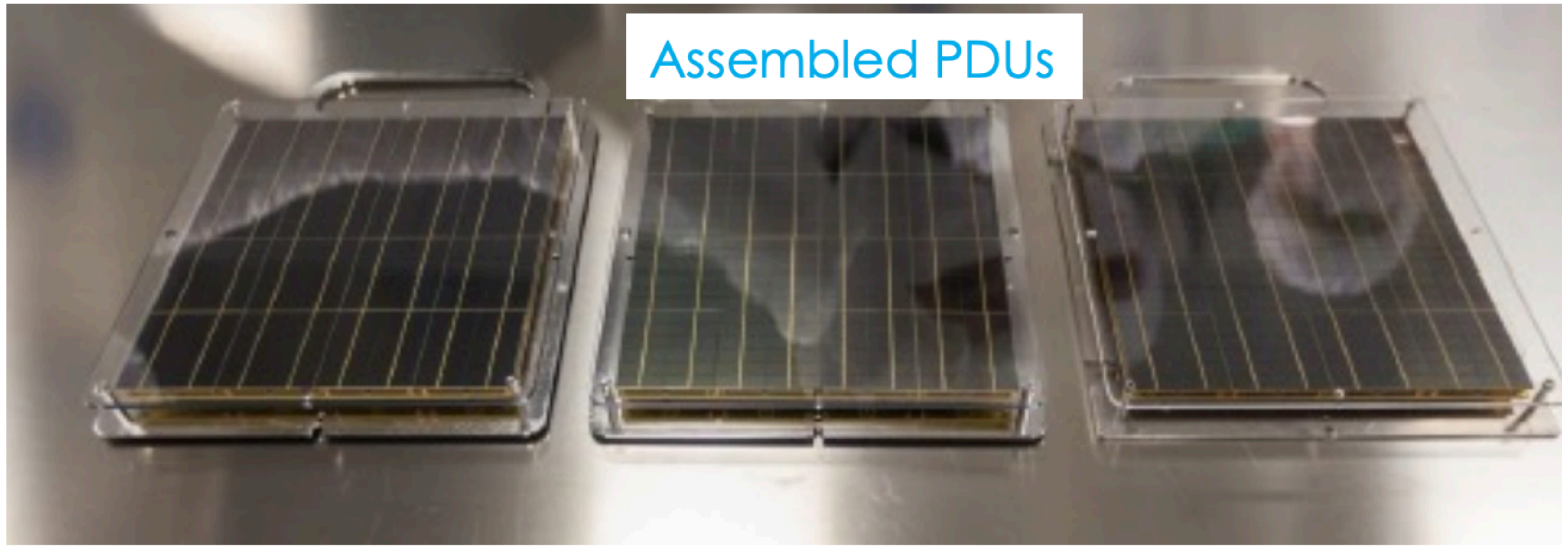
120 PDUs in the neutron veto

30 PDUs in the outer veto

DarkSide-20k PDU Production and Test

- PDU Production: TPC PDUs at NOA – vPDUs at Birmingham, STFC interconnect, Manchester and Liverpool

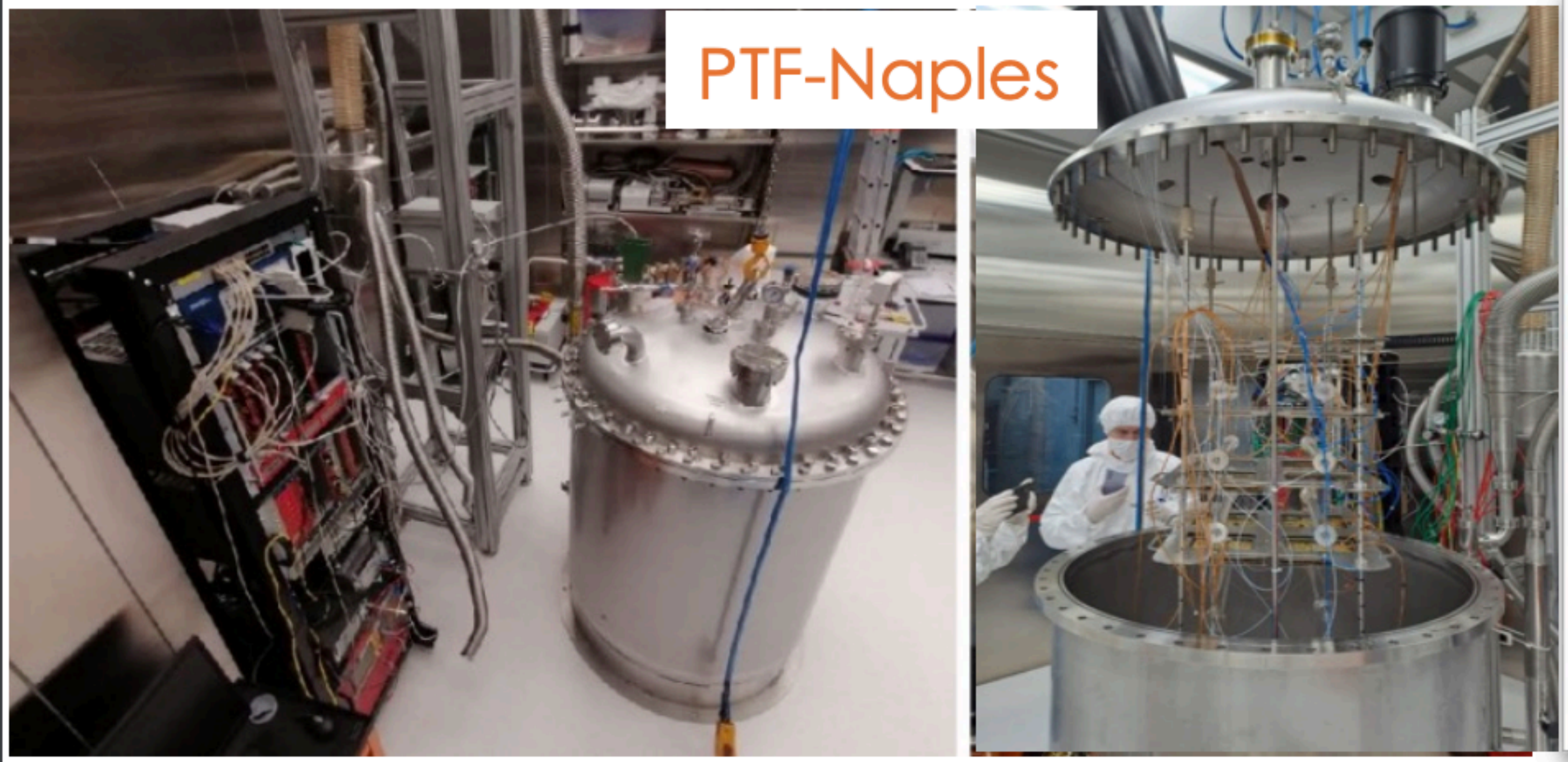


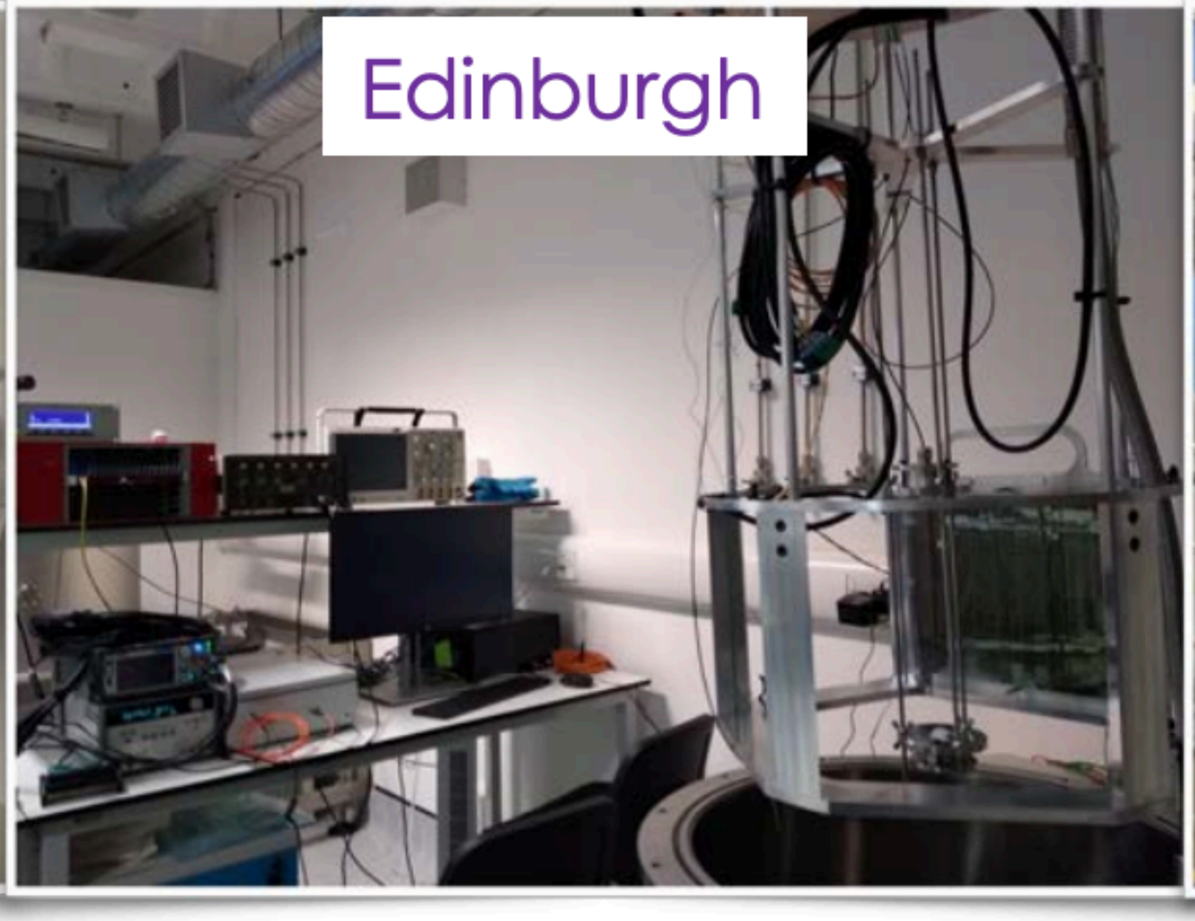


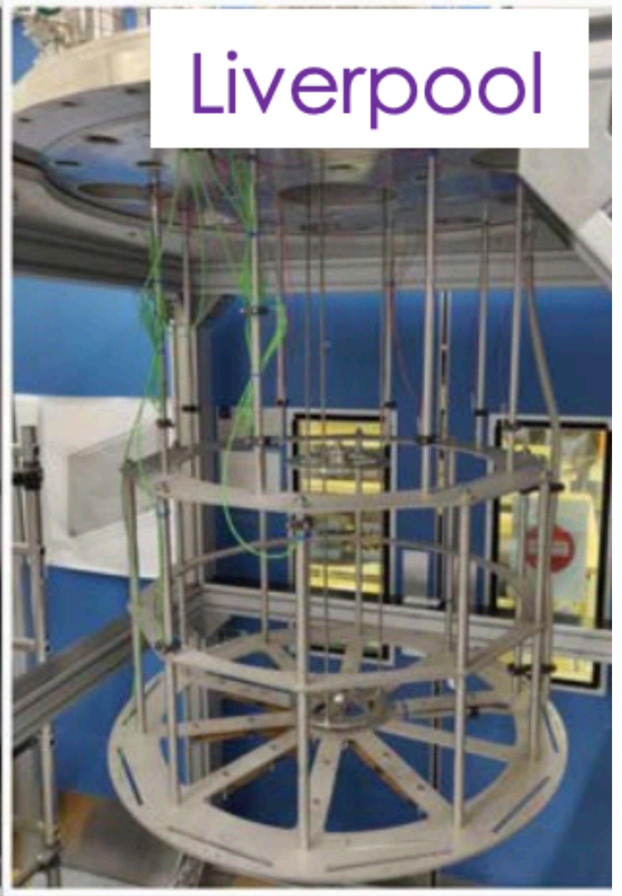
SiPM production at LFoundry, Italy

PDU packaging and assembly in Nuova Officina Assergi (NOA) in a ISO6 clean room at LNGS

- PDU and vPDU Testing







Assembly PDUs will be tested in a cryogenic test facility in Naples – vPDUs will be tested in facilities at AstroCeNT, Edinburgh and Liverpool

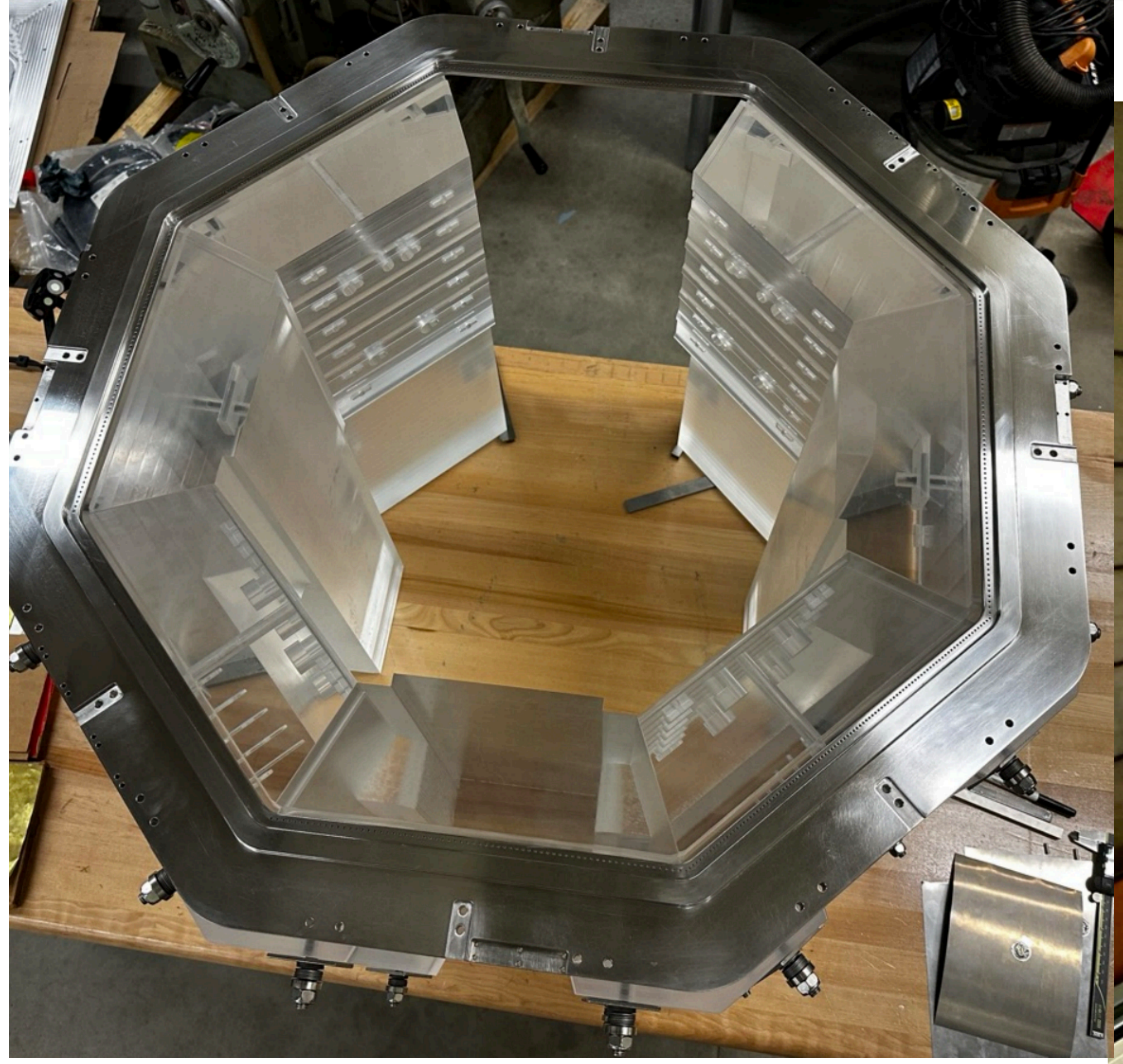
(From N.Canci LIDINE2024)

Mock-up test

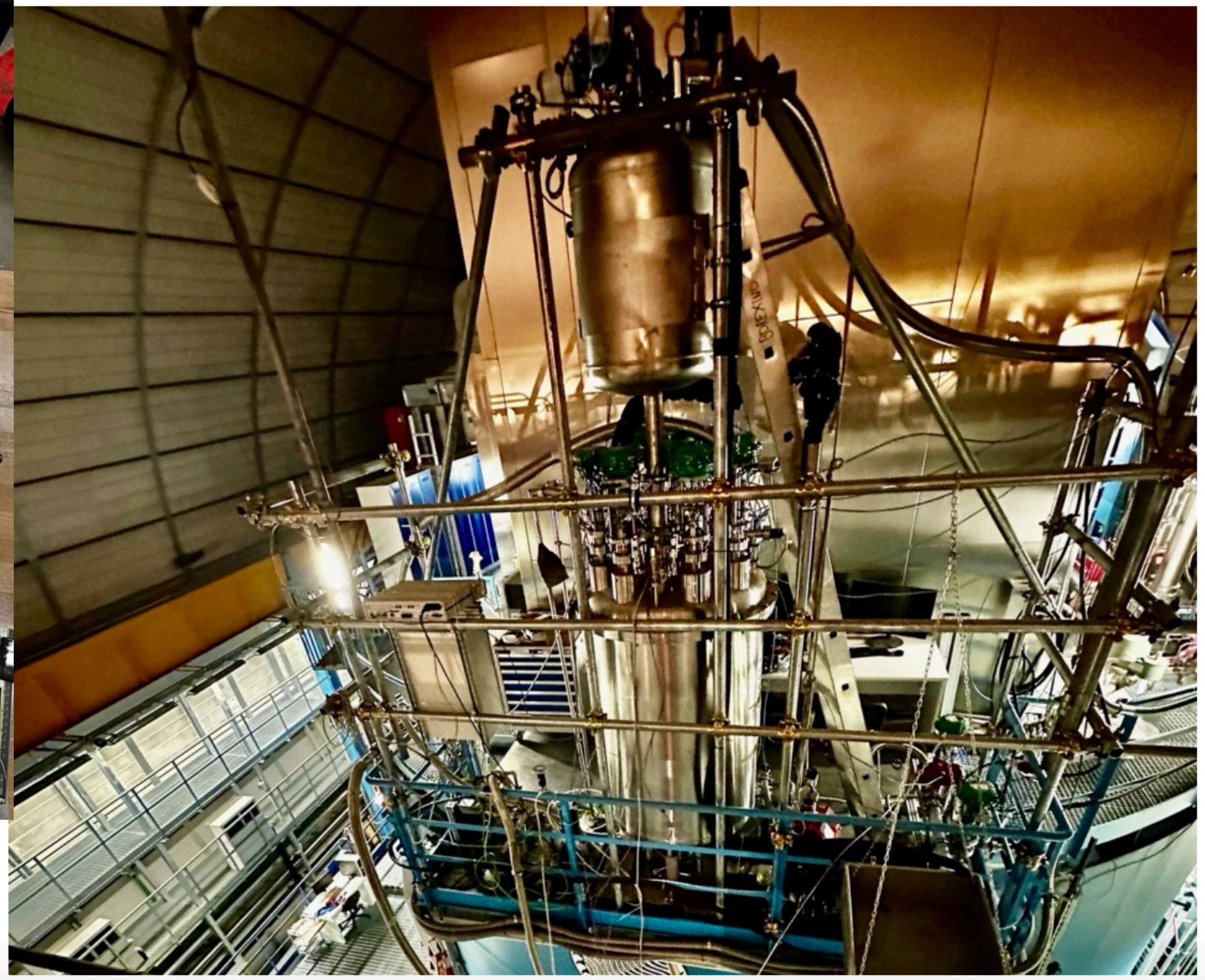
~1 ton LAr TPC currently at LNGS

<u>Validation of the technical choices:</u>

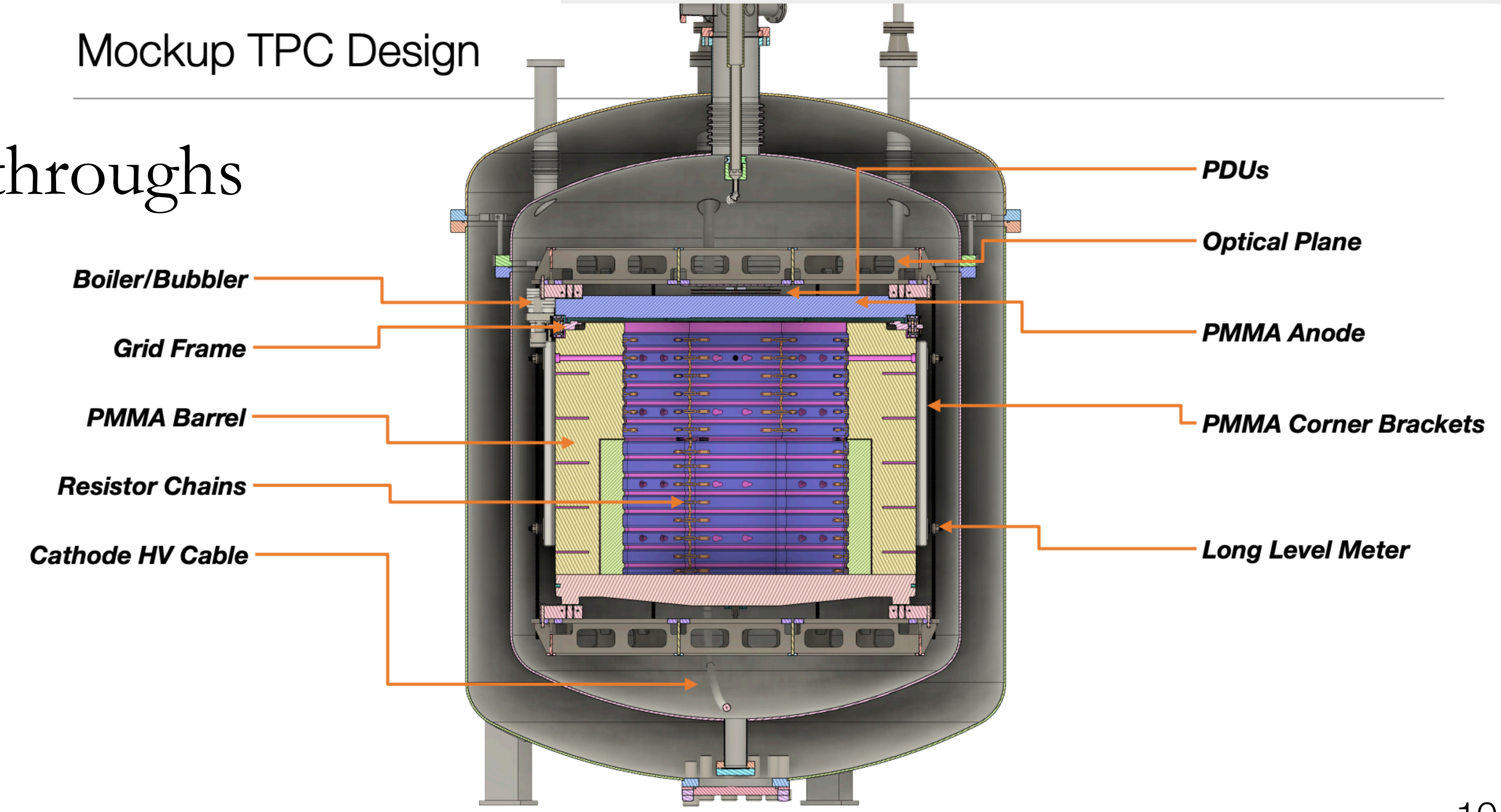
- Mechanics, Robustness of the PMMA, Clevios and TPB coating on PMMA
- Electric field values and high voltage feedthroughs
- Resistor chains elements
- Grids and wires
- **Cryogenics**



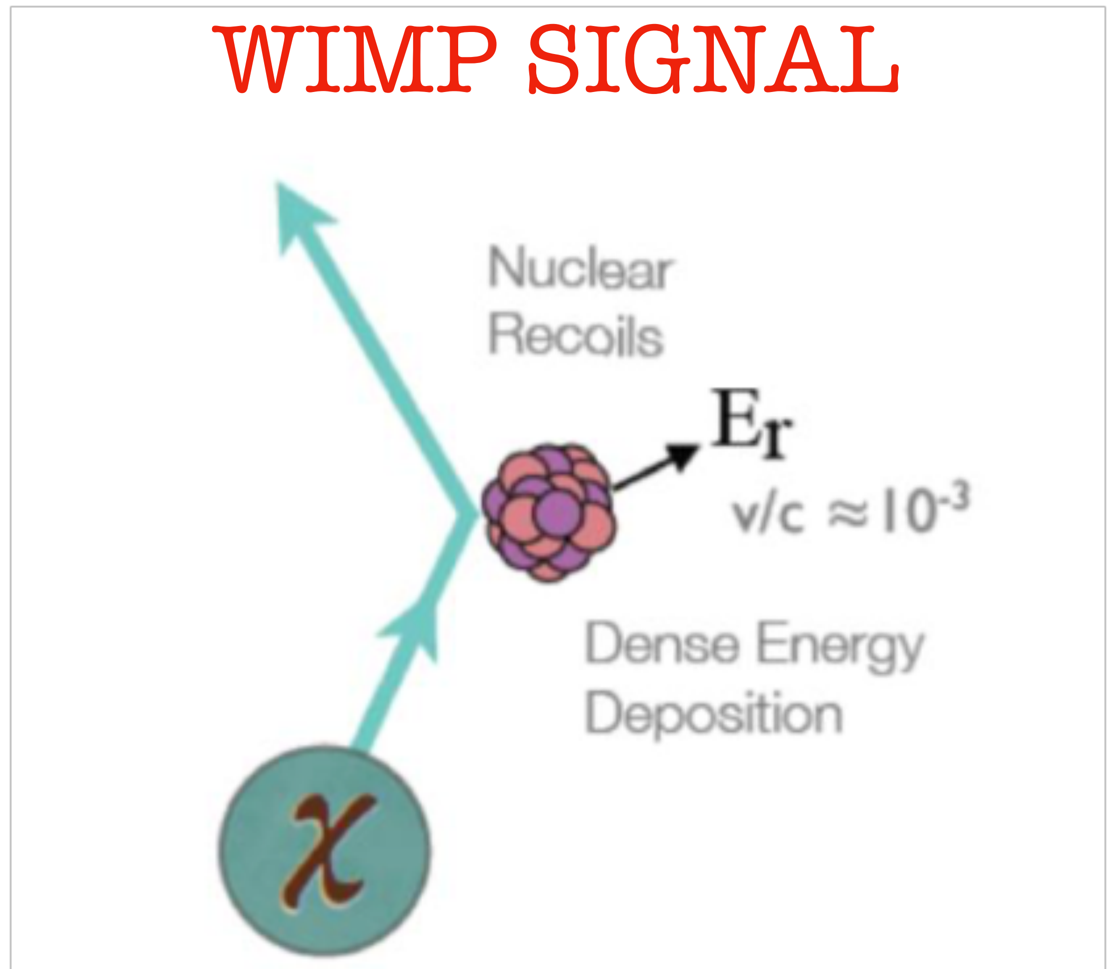
LN Phase Separator on top of Condenser Box



Mockup TPC Design



WIMP Signal & Backgrounds



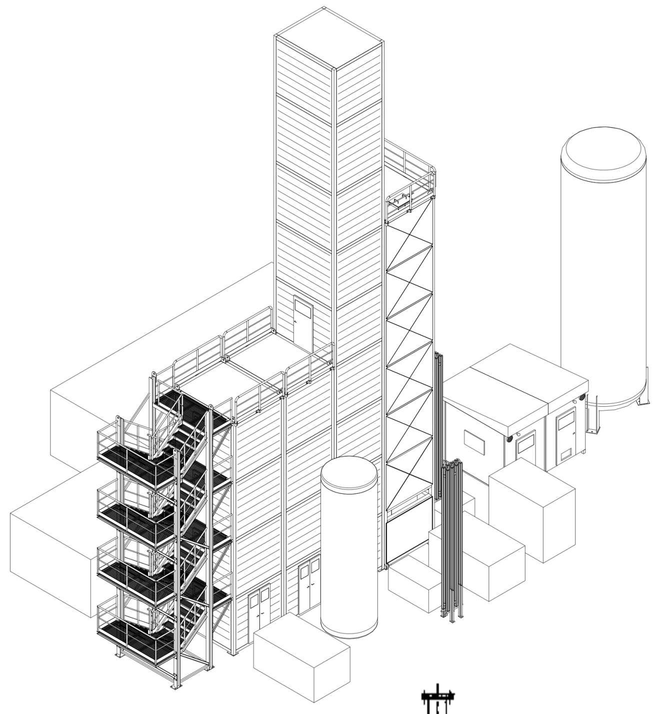
- Single nuclear recoil
- Energy recoil between 1 and 100 keV

Radiopurity requirements for 10 year operation:

- **neutrons after cuts < 0.1**
- **< 0.05 from β and γ**

Background source	Mitigation strategy
^{39}Ar β decay	Use Underground Argon + pulse shape discrimination
γ from rock and γ,e from material	Pulse shape discrimination Selection material
Radiogenic neutron **(α,n) reaction in detector material**	Material screening & selection, MC study Definition of Fiducial volume in the TPC Veto to reject neutron signal
Surface contamination due Rn progeny	Surface cleaning Reduce the number of surfaces Installation of Rn abated system
Muon induced background	Cosmogenic veto
Neutrino coherent scatter	Irreducible

Underground argon

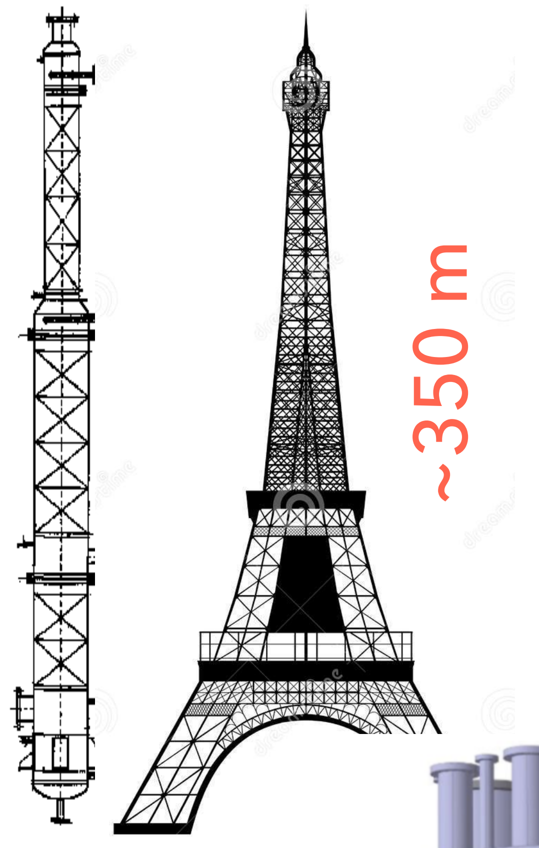


Urania US (Extraction from underground sources):

- Use of the argon extraction plant in Cortez, Colorado, to reach capacity of acquiring 330 kg/day of argon.
- **UAr depleted in ^{39}Ar isotope**, but poor chemical purity.

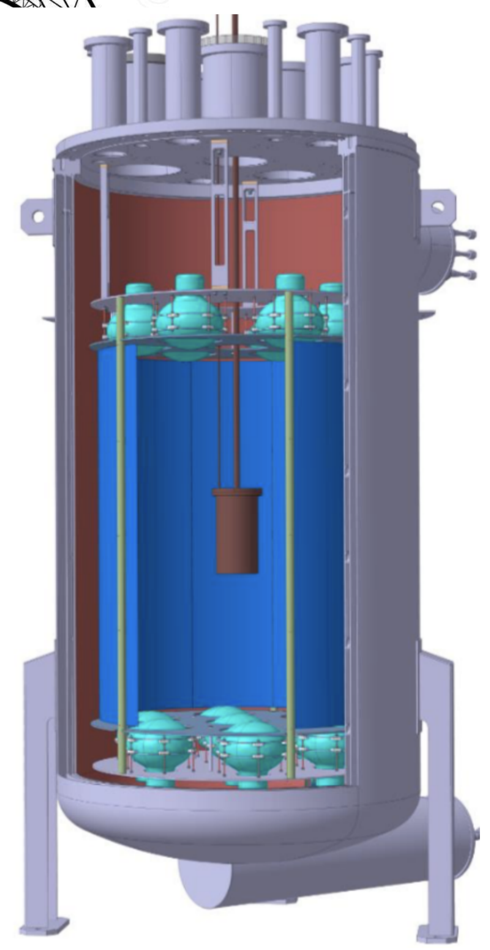
Ar-39 depletion factor in UAr: around 1400

- **TPC= 50 tons -> 36 Hz of Ar-39**
- **Veto = 35 tons -> 26 Hz of Ar-39**



Aria Italy (Separation):

- 350 m tall column in the Seruci mine in Sardinia, Italy, for high-volume **chemical** and isotopic separation of Underground Argon. *Eur.Phys.J.C* 81 (2021) 4, 359

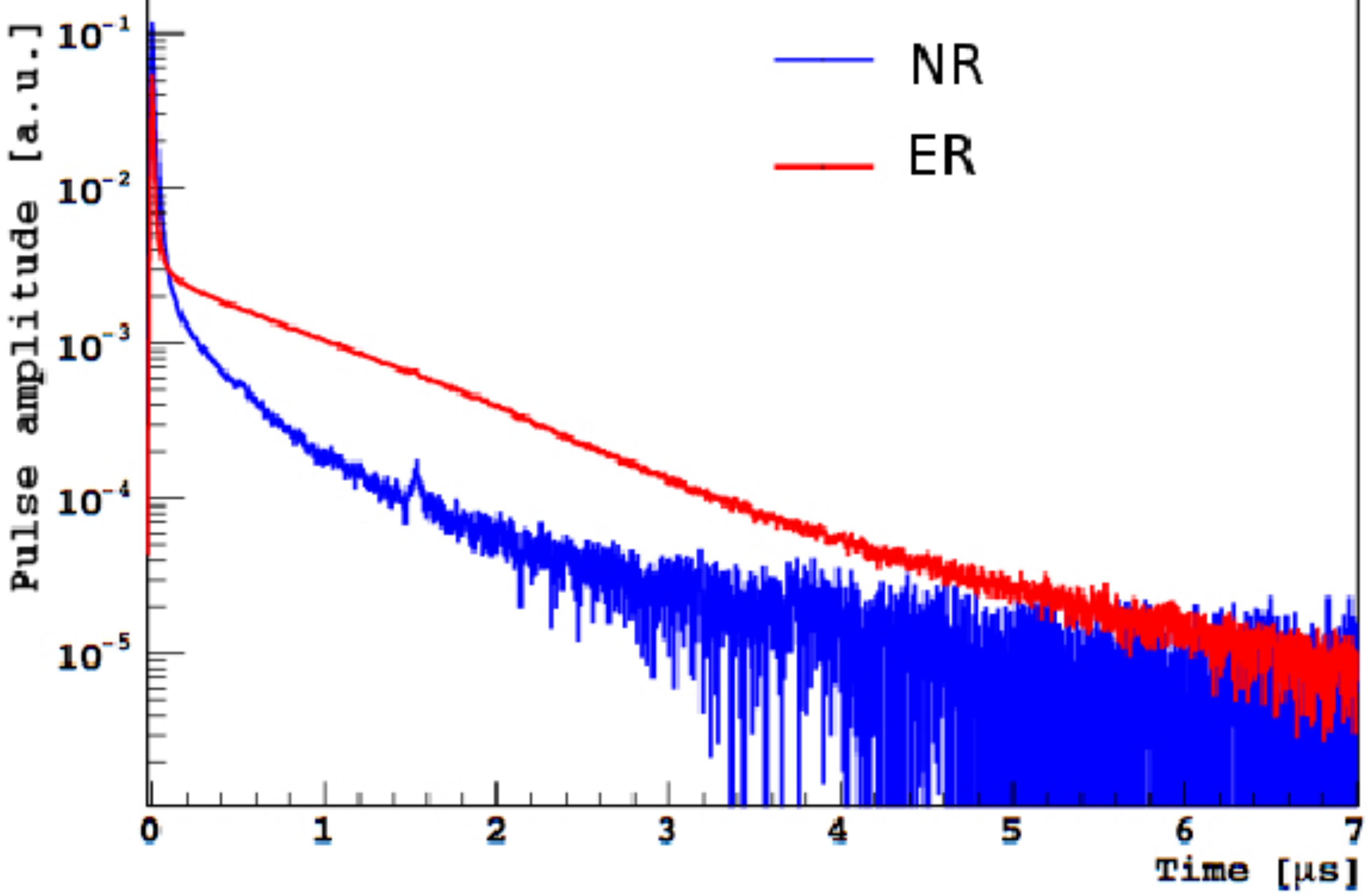


DArT in ArDM Canfranc, Spain (Quality control)

- A "1.4-litre" single-phase low-background detector to measure the ^{39}Ar depletion factor of different underground argon batches (URANIA+ARIA). Ar-39 depletion factor sensitivity: 6 x 10^4 90% C.L in 1 week of counting time. More details of DArT: JINST 15 P02024 (2020)
- In 2024 successful run with UAr from DS-50.

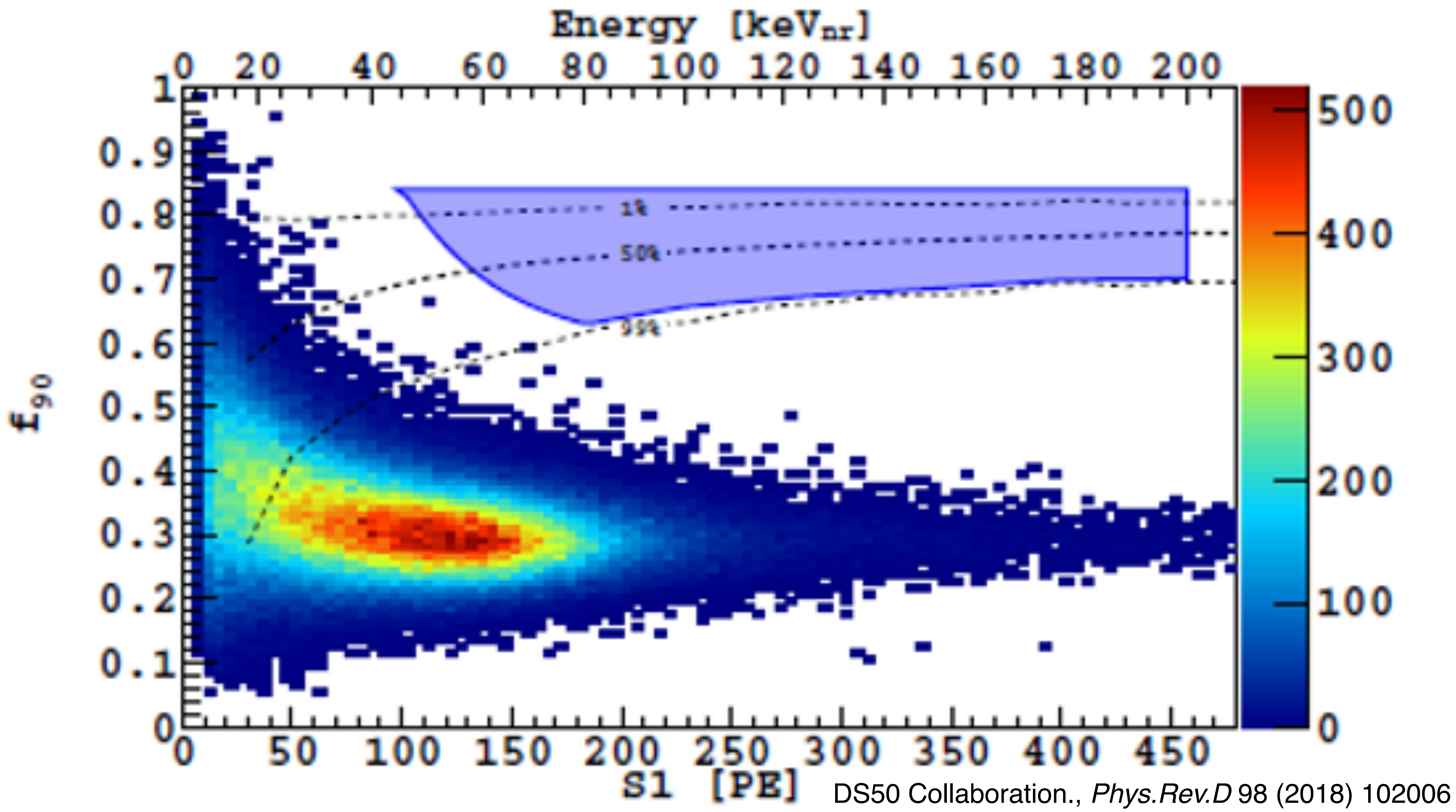
ELECTRON recoil - PSD method

S1(scintillation signal) pulse shape in LAr
- fast (singlet) and slow (triplet) component



- **Expected:**
- **TPC= 50 tons -> 36 Hz of Ar-39**
- **Veto = 35 tons -> 26 Hz of Ar-39**

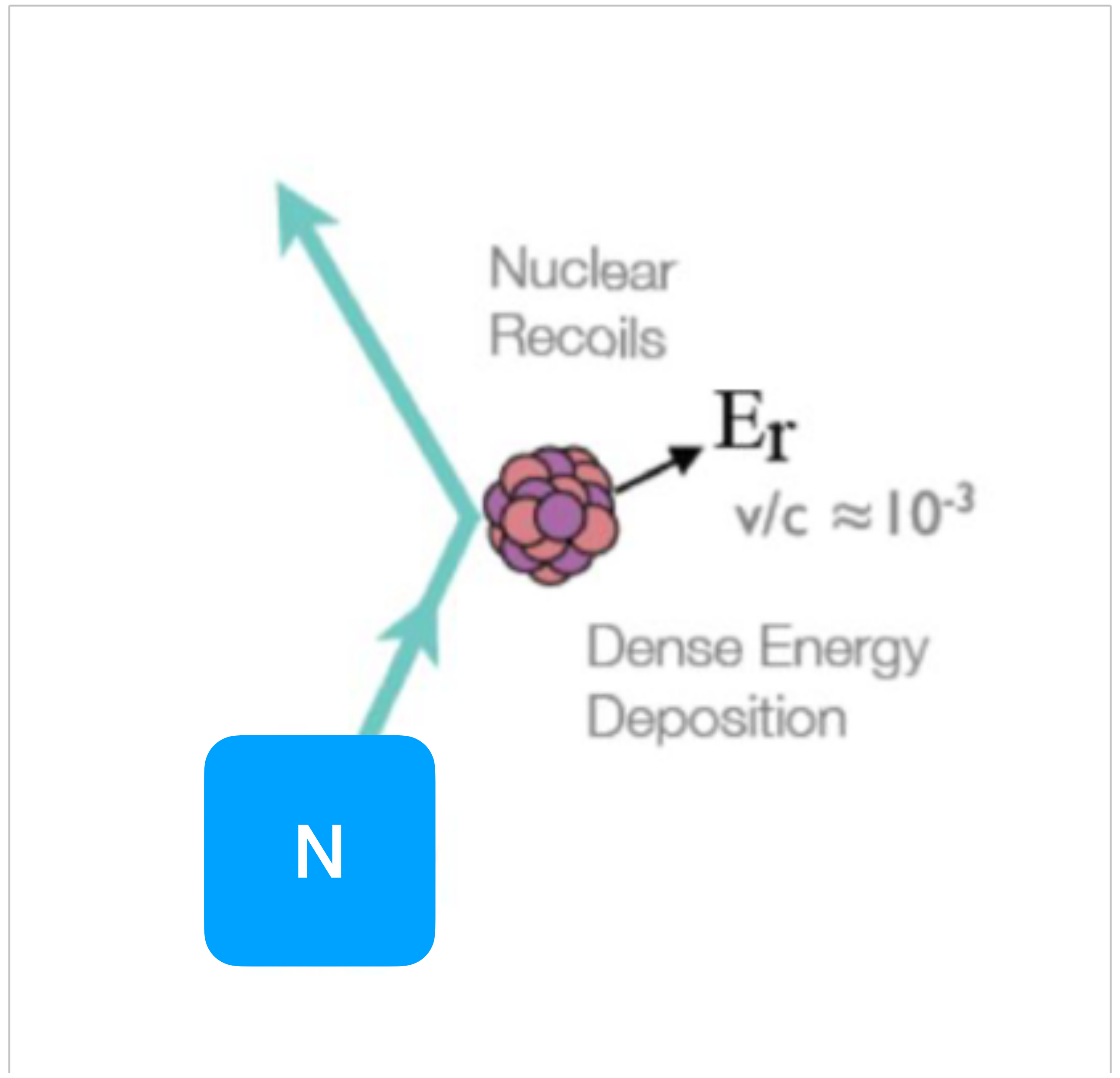
Mitigated with pulse shape discrimination:
- residual background is < 0.01 events / 200 tonne x year
- dead time negligible



DS50 Collaboration., *Phys.Rev.D* 98 (2018) 102006

$$PSD(f90) = \frac{PROMPT\ LIGHT}{PROMPT + LATE\ LIGHT}$$

the discrimination parameter f90 defined as a ratio of detected light in the first 90 ns (optimised for DS-50), compared to the total signal



NUCLEAR recoil

Neutron background is the most dangerous: undistinguishable recoil from potential WIMP

Complete control needed!
over every component that goes into the detector

Main Neutron sources:

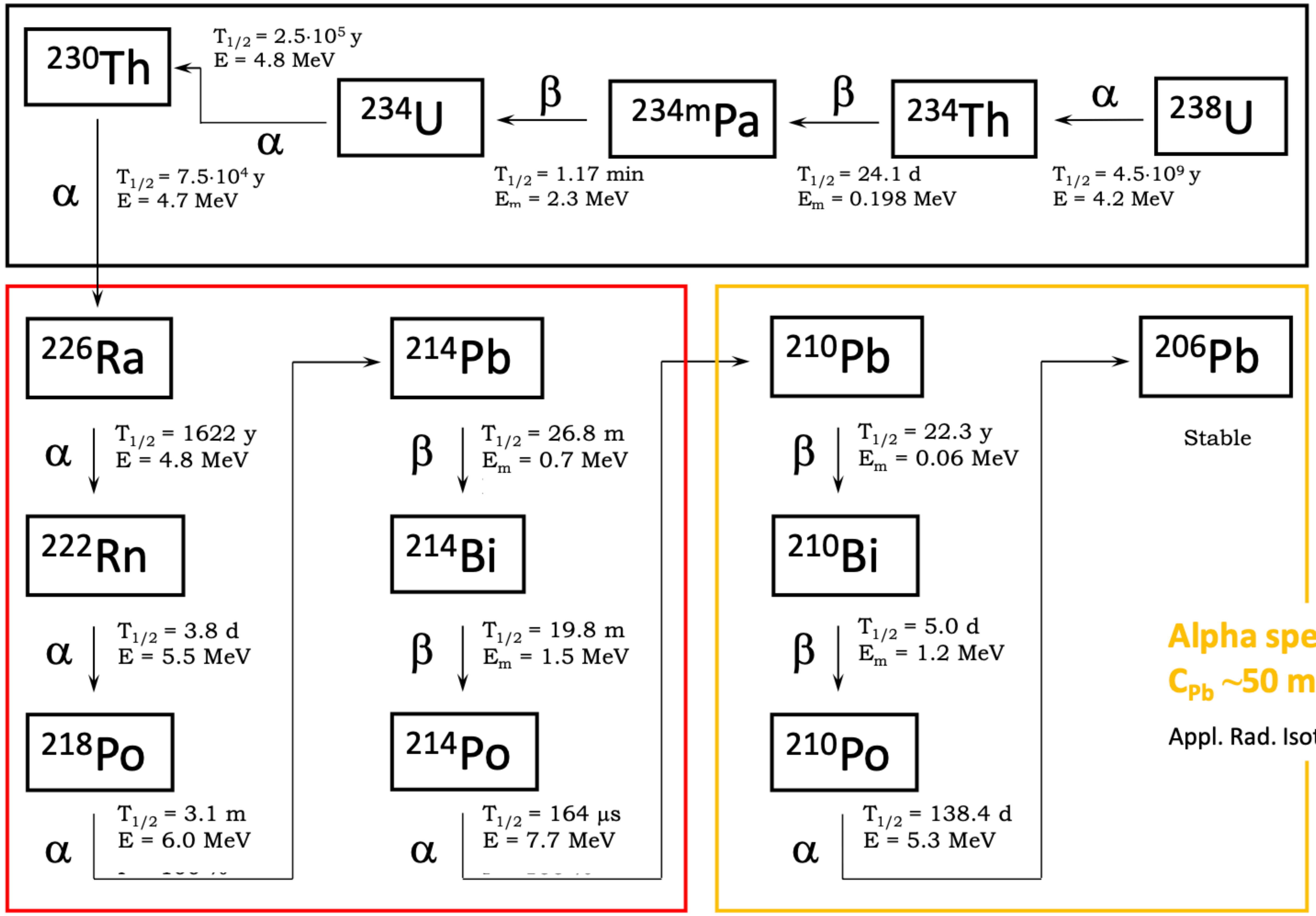
- ^{238}U and ^{232}Th contaminations of the detector material
  - (α,n) reaction in the detector material
- cosmic ray induced neutron production

Material screening campaign

- **Big effort engaging laboratories around the world:**
- CIEMAT,
- SNO,
- Jagiellonian University,
- Canfranc,
- Boulby,
- LNGS,

NUCLEAR recoil

1. Each uranium (^{238}U, ^{226}Ra, ^{210}Pb; ^{235}U) and thorium chain is measured **separately using different methods, this allows to take into account potential secular disequilibrium.**



ICP-MS:
$C_{U/Th}$ < 0.1 μBq/kg
NIM A 775 (2015) 93

HPGe:
C_{Ra} ~10 μBq/kg
Appl. Rad. Isot. 53 (2000) 191
Astrop. Phys. 18 (2002) 1

Alpha spectrometry
C_{Pb} ~50 mBq/kg
Appl. Rad. Isot. 126 (2017) 165

Potential disequilibrium in ^{238}U

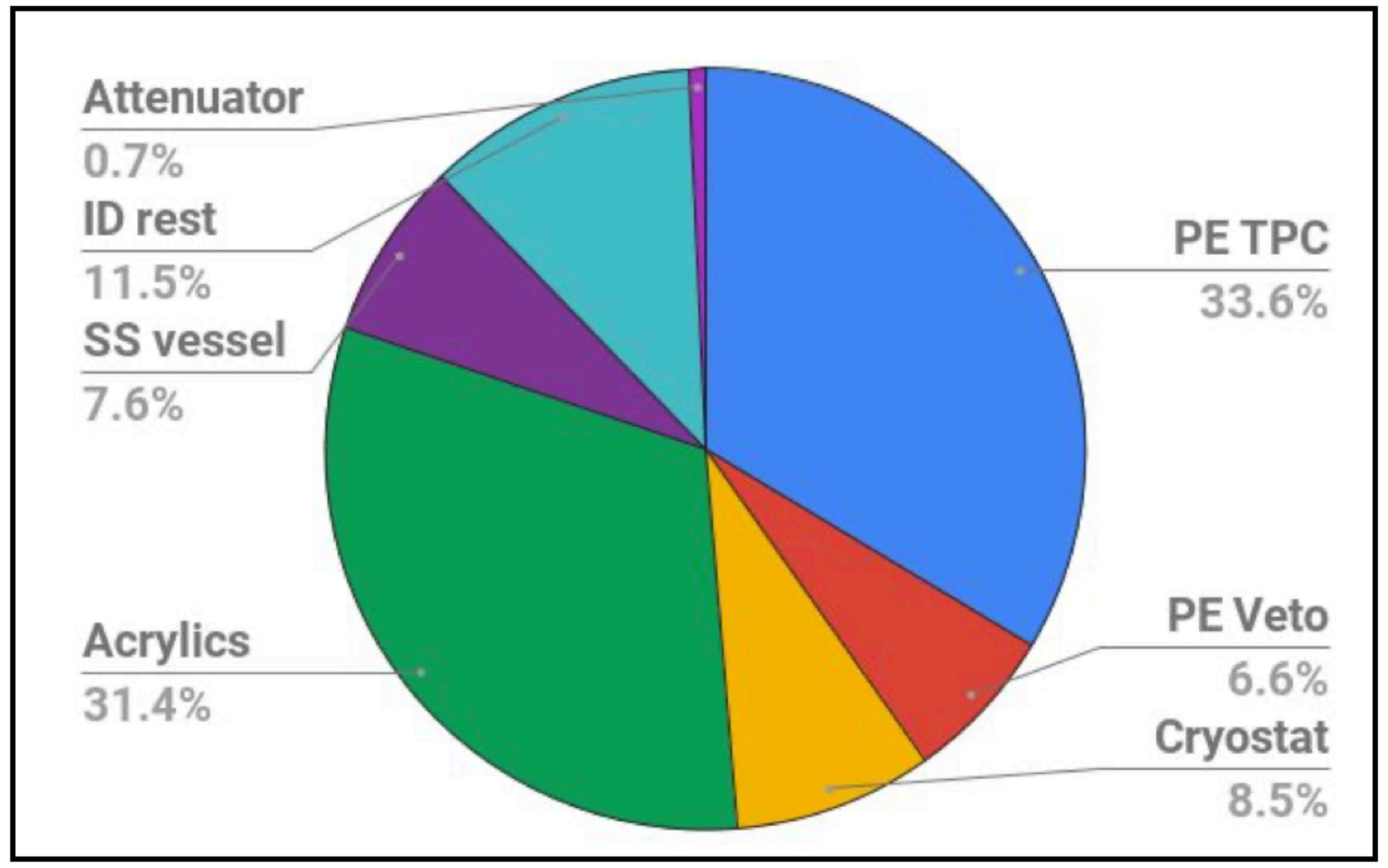
Sample	^{238}U (ICP-MS)	^{226}Ra (HPGe)	^{210}Pb
Arlon 55NT (DarkSide Collaboration)	(1.95 ± 0.05) mBq/kg	(53 ± 5) mBq/kg	(128 ± 26) mBq/kg

NUCLEAR recoil

2. MC simulation

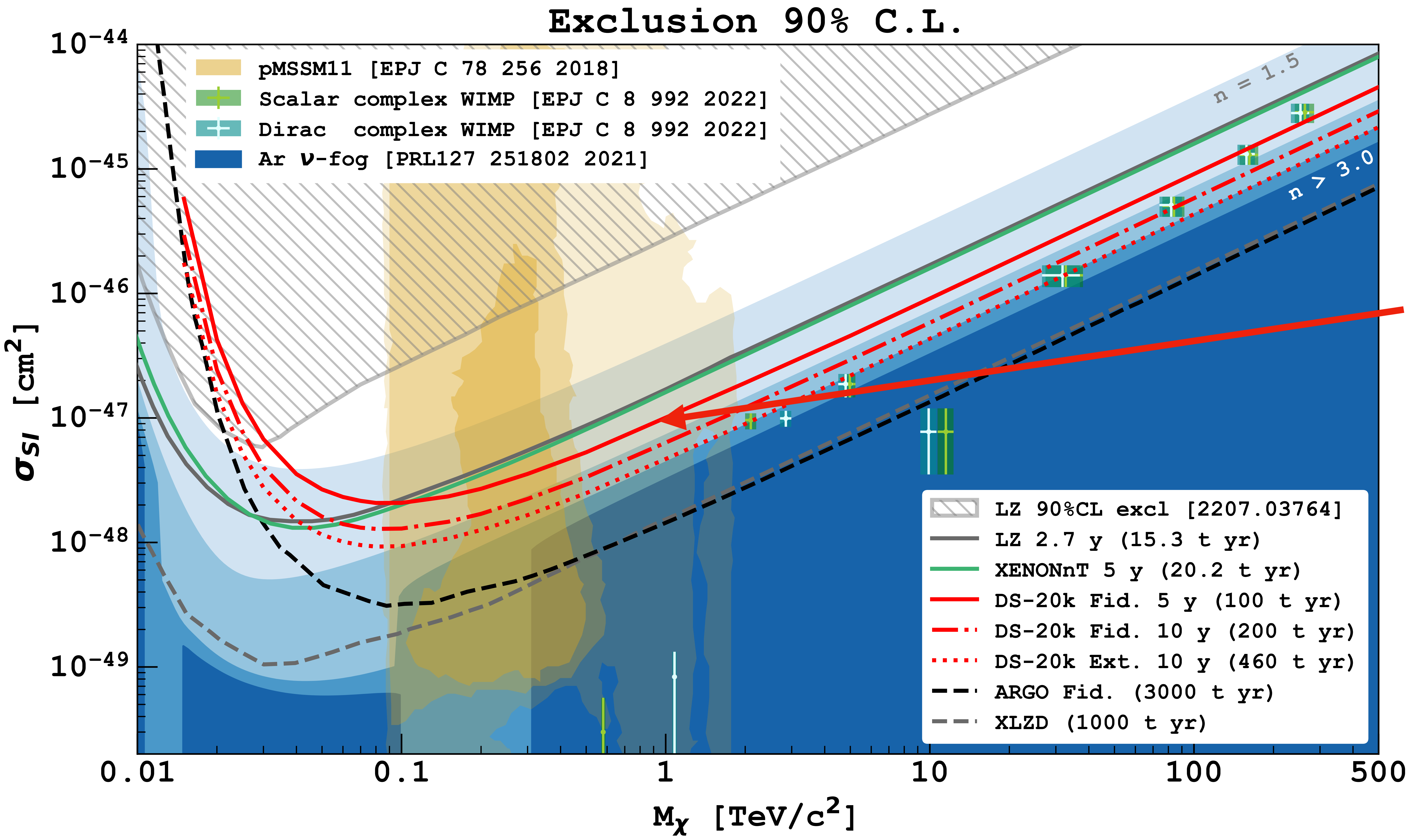
- Detector design choices and precise knowledge of the alpha flux allows to **simulate the (α, n) reactions** in DS-20k.

- Geant4 based SaG4n package: http://win.ciemat.es/SaG4n/
- Simulations including the chemical composition of the materials uncertainties and different interaction models/tables (Thalys, JENDL/Tendle)
  arXiv:2405.07952v2((α, n)neutron yield calculations)



- **Estimation of neutron background events** expected during DS-20k operation is within a set goal limit of 0.1 n/(200 t yr) in the fiducial volume for the current design of the detector.

High mass WIMP Sensitivity



Sensitivity to high mass WIMP-nucleon scatter cross section of
7.4×10^{-48} cm^2
for a 1 TeV/c^2 WIMP
for a total exposure
of 200 tons x years.

Both signals (S1 scintillation and S2 ionisation) used.

DarkSide-20k low mass background model

- Uniformly distributed in the fiducial volume
- Include recent calculations of β-decay energy spectra

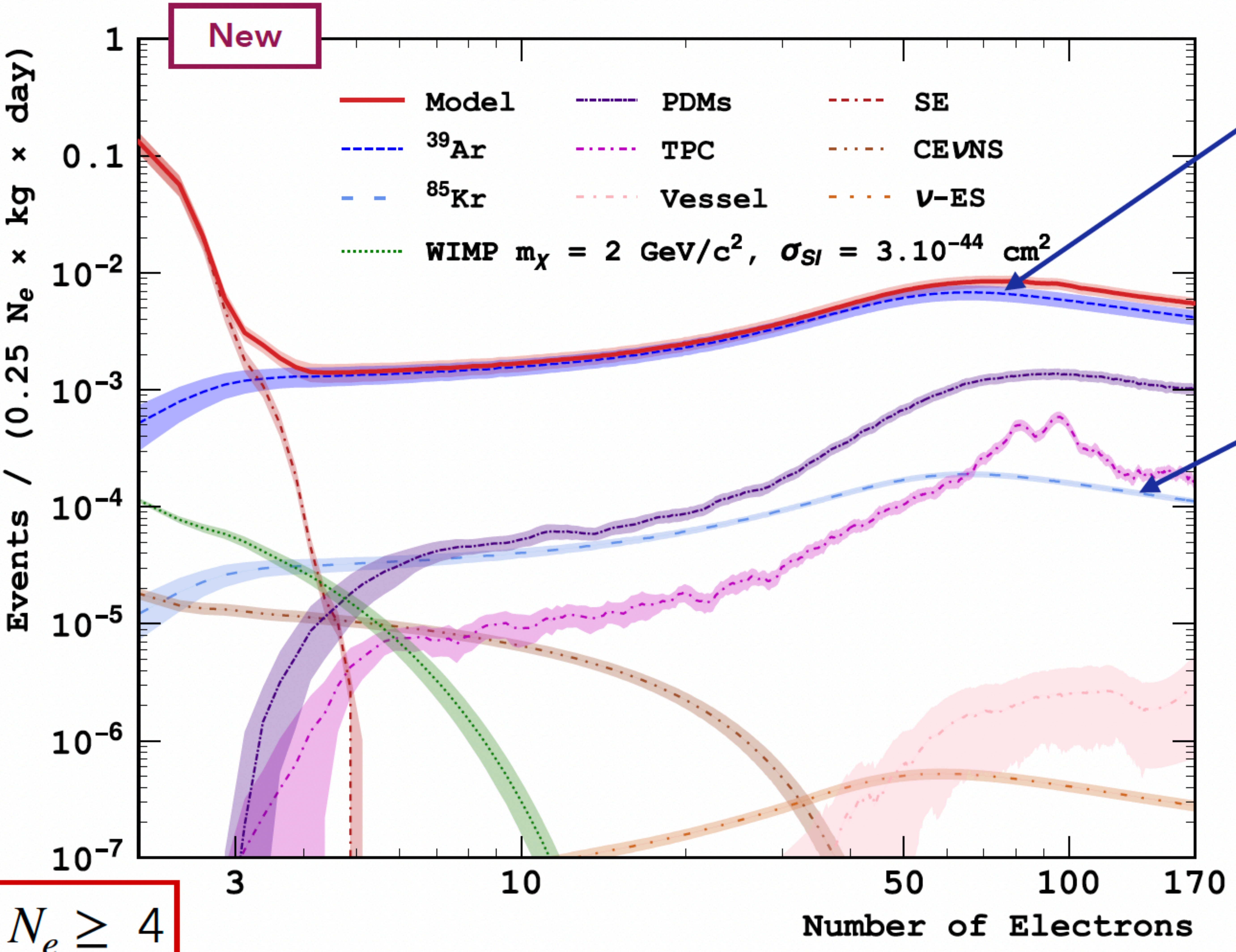
Phys.Rev.A 90 (2014) 012501

Phys.Rev.C 102 (2020) 065501

- Include shape systematics (atomic exchanges, screening effect, Q-value)

^{39}Ar dominant for $N_e \geq 4$

LAr intrinsic backgrounds (β decays)



^{39}Ar

Same activity as DS-50 (same UAr mine)

A(^{39}Ar) = 0.73 mBq/kg

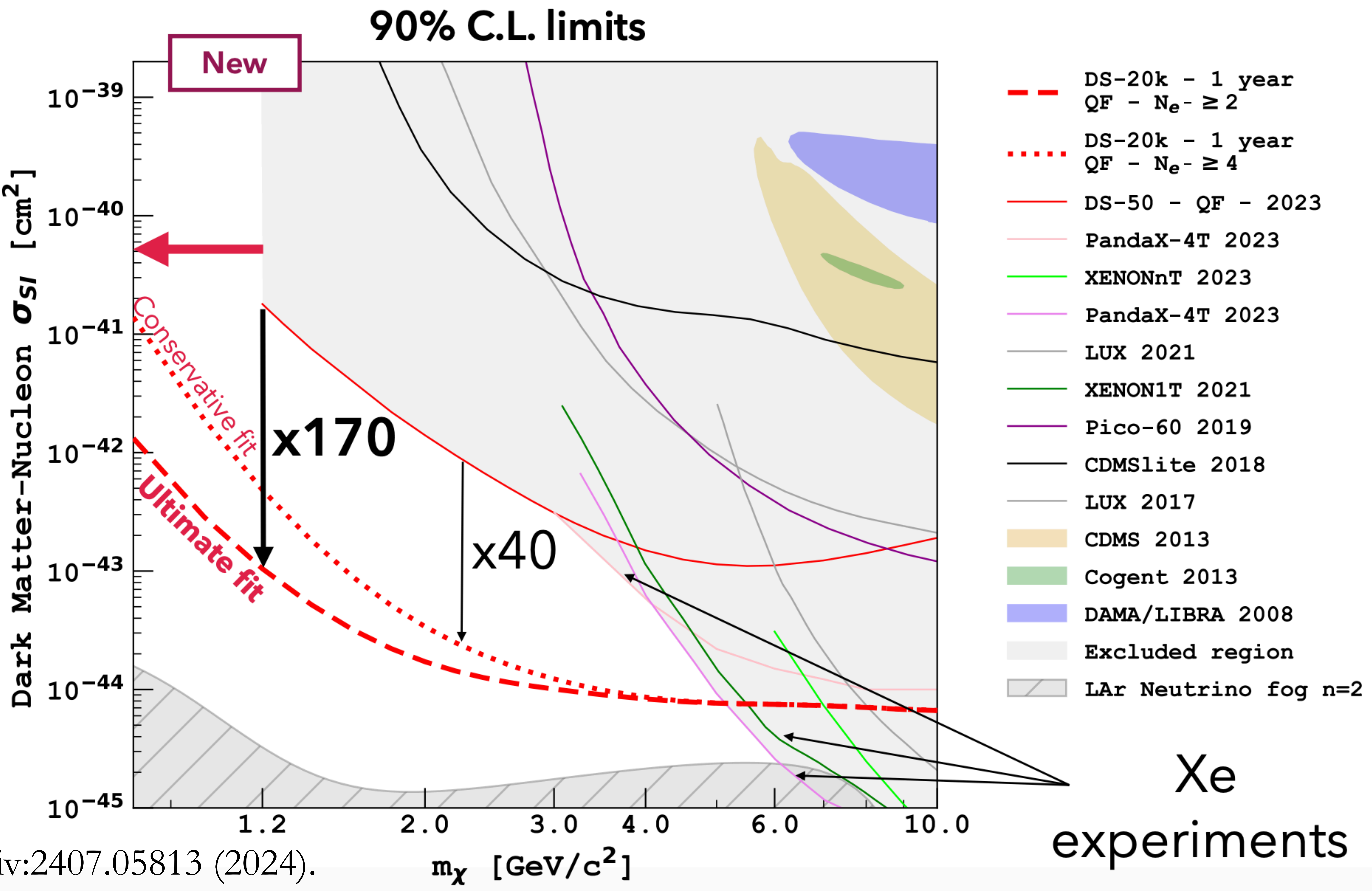
^{85}Kr

Urania (Colorado, USA): dedicated facility for extraction

Reduced ^{85}Kr activity wrt DS-50

A(^{85}Kr) = 1.9 10^{-2} mBq/kg

Low mass WIMP Sensitivity
1 year of data taking



arXiv:2407.05813 (2024).
[sent to Nature Communications]

Using S2 (ionisation signal) only.

Detailed background study, information from DarkSide-50 data.

Prediction for many light DM candidates.

First assessment of DarkSide-20k sensitivity to low mass dark matter particles

Further strengthens the physics reach of DarkSide-20k with a leading role below 5 GeV/c²

Scales with sqrt(exposure)

CONCLUSIONS

- **DarkSide-20k is pushing the state-of-the-art in several directions**: SiPM technology, underground argon extraction & purification, background assay campaign

- **DarkSide-20k is in position to lead the search for WIMPs**, with complimentary reach above the LHC center of mass energy

- **Achieving the <0.1 instrumental backgrounds** to the dark matter search is realistic
  And allowing to expand the reach beyond heavy WIMPs!

- **Darkside-20k construction has started**

- **Data taking will start in 2027**

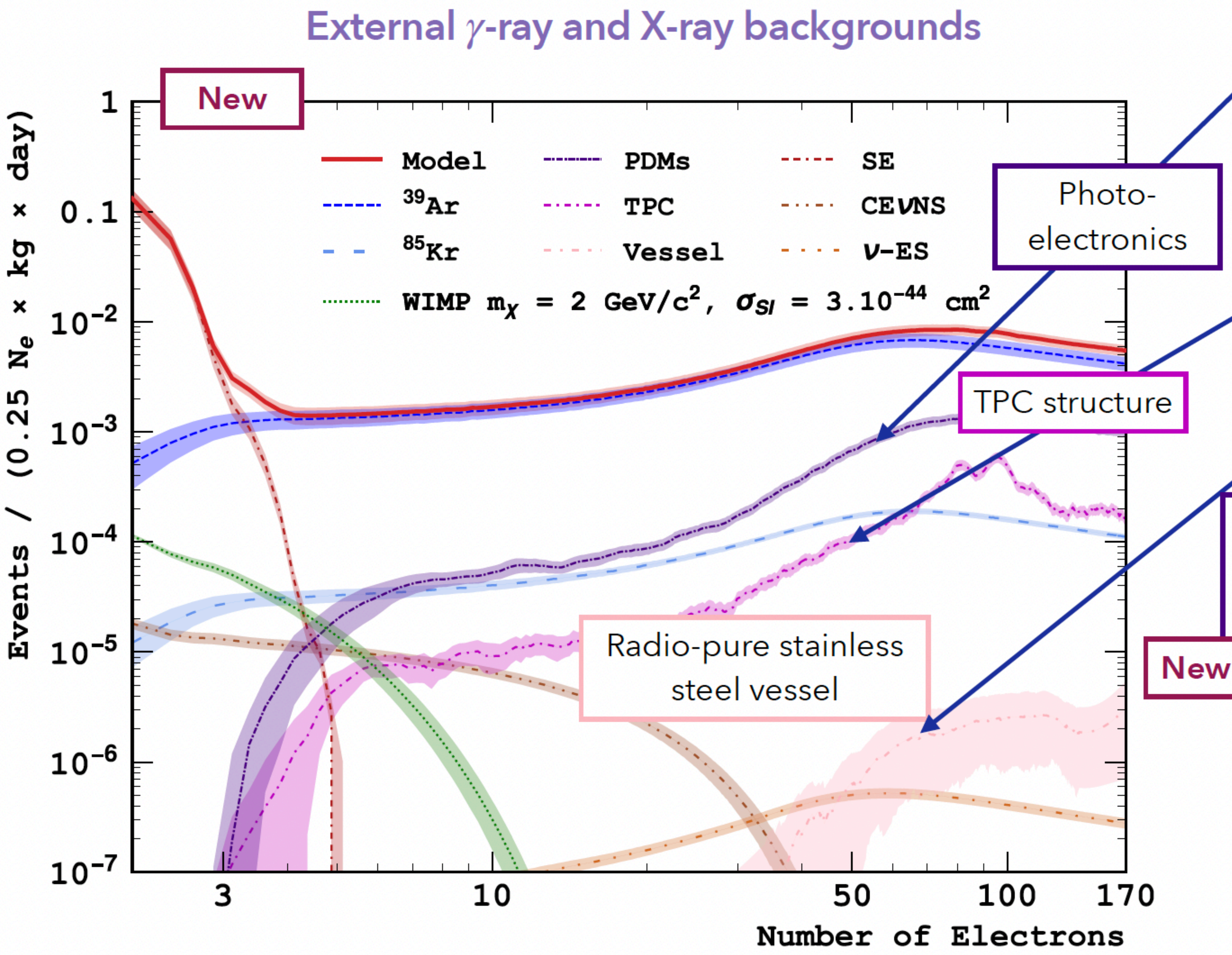

Gran Sasso
3800 m w. e.
Deep underground location at LNGS, Italy.
Italy
National Institute
for Nuclear Physics...
Rome
Slovenia
Croatia
Bosnia and
Herzegovina
San Marino
Monaco
Milan
Turin
Genoa
Bologna
Florence
Venice
Verona
Padua
Trieste
Zagreb
Zadar
Split
Sarajevo
Corse
Sardegna
Cagliari
Tyrrhenian Sea
Adriatic Sea
Naples
Pompeii
Bari
Taranto
Matera
Lecce
Reggio
Cannes
Como
Pisa
Podgorica
Подгорица

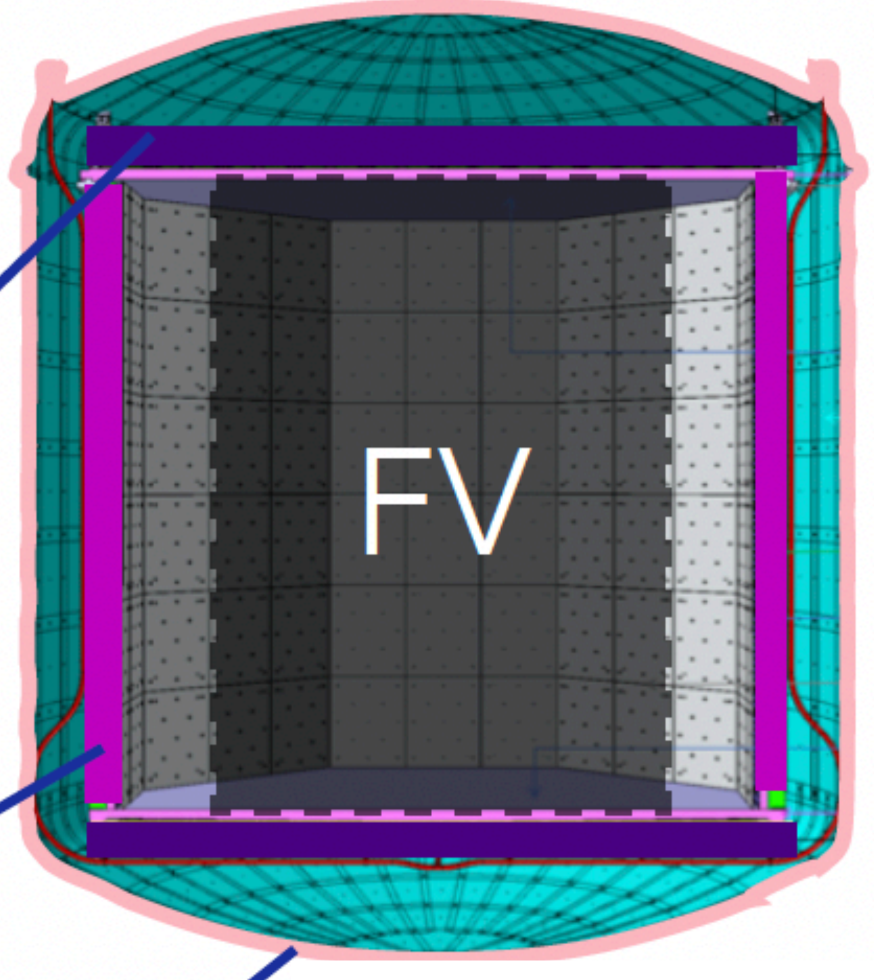
BACKUP

DarkSide-20k low mass background model

6

- Simulated with a GEANT-4 based simulation tool
- ≈ 2.5x reduced bkg contamination per surface area wrt DS-50





Radio-contamination estimated from **material assays**

New

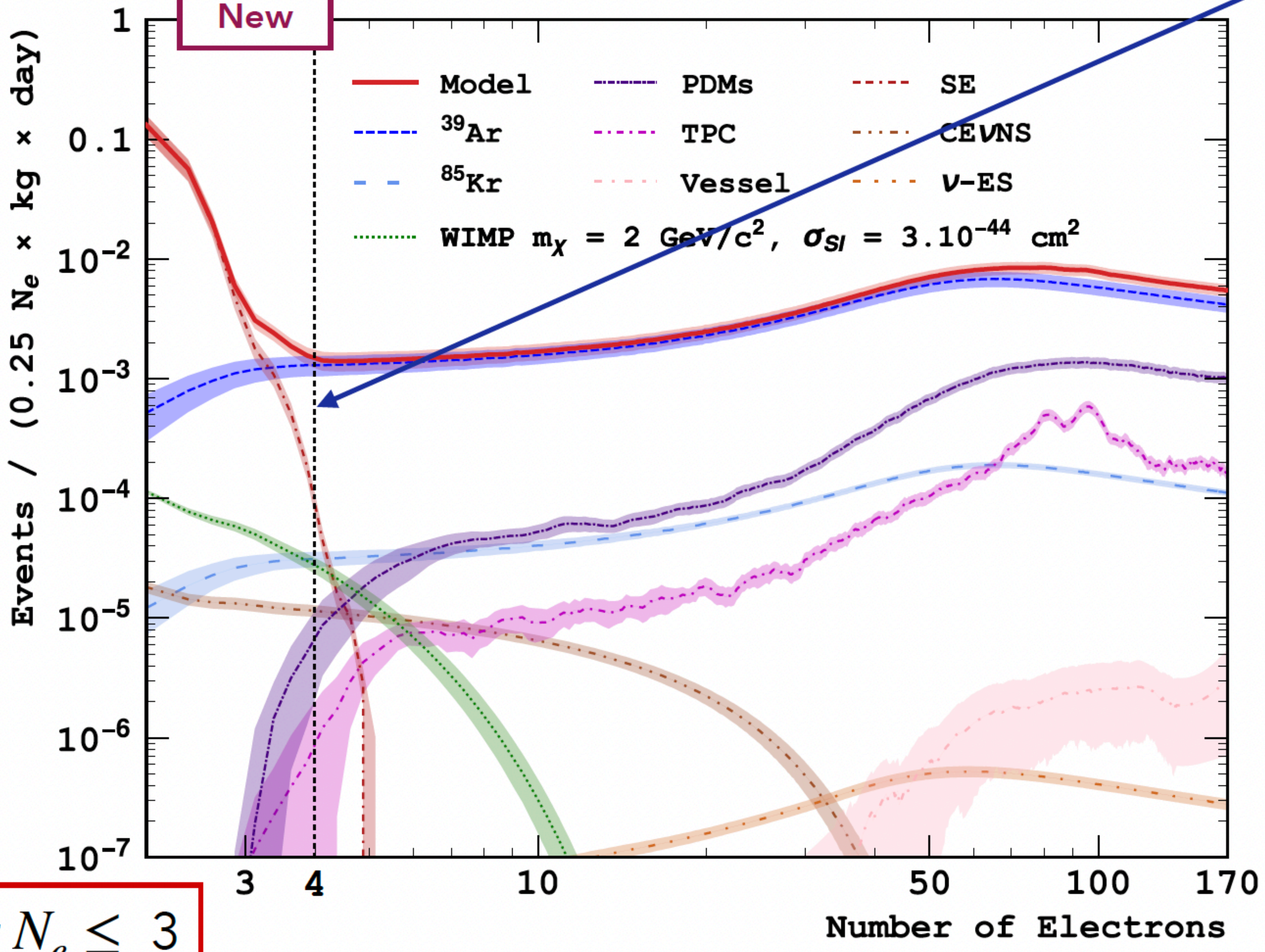
Radio-contaminant	Activity (Bq)		
	TPC	PDMs	SS vessel
^{238}U up	16.1	38.8	21
^{238}U mid	11.5	18.4	8.8
^{238}U low	16.4	449	62
^{232}Th	4.2	17.8	33
^{235}U	0.7	1.8	1.0
^{137}Cs	2.5	2.9	5.0
^{60}Co	2.0	5.1	13
^{40}K	102	269	49

DarkSide-20k low mass background model

- Observed in DS-50
- Origin might be trapped electrons by impurities and released later
- For DS20k: **Extrapolation from DS-50 data**

Spurious electron (SE) background

New



SE 18x lower than ^{39}Ar at $N_e = 4$

SE dominant for $N_e \leq 3$

2 fit scenarii:

- **Conservative** (almost indep. of SE modelling): Fit from $N_e = 4$ (DS-50 strategy)
- **Ultimate**: Fit from $N_e = 2$ assuming good control of rate and spectral shape of SE in DS-20k

DarkSide-20k low mass background model

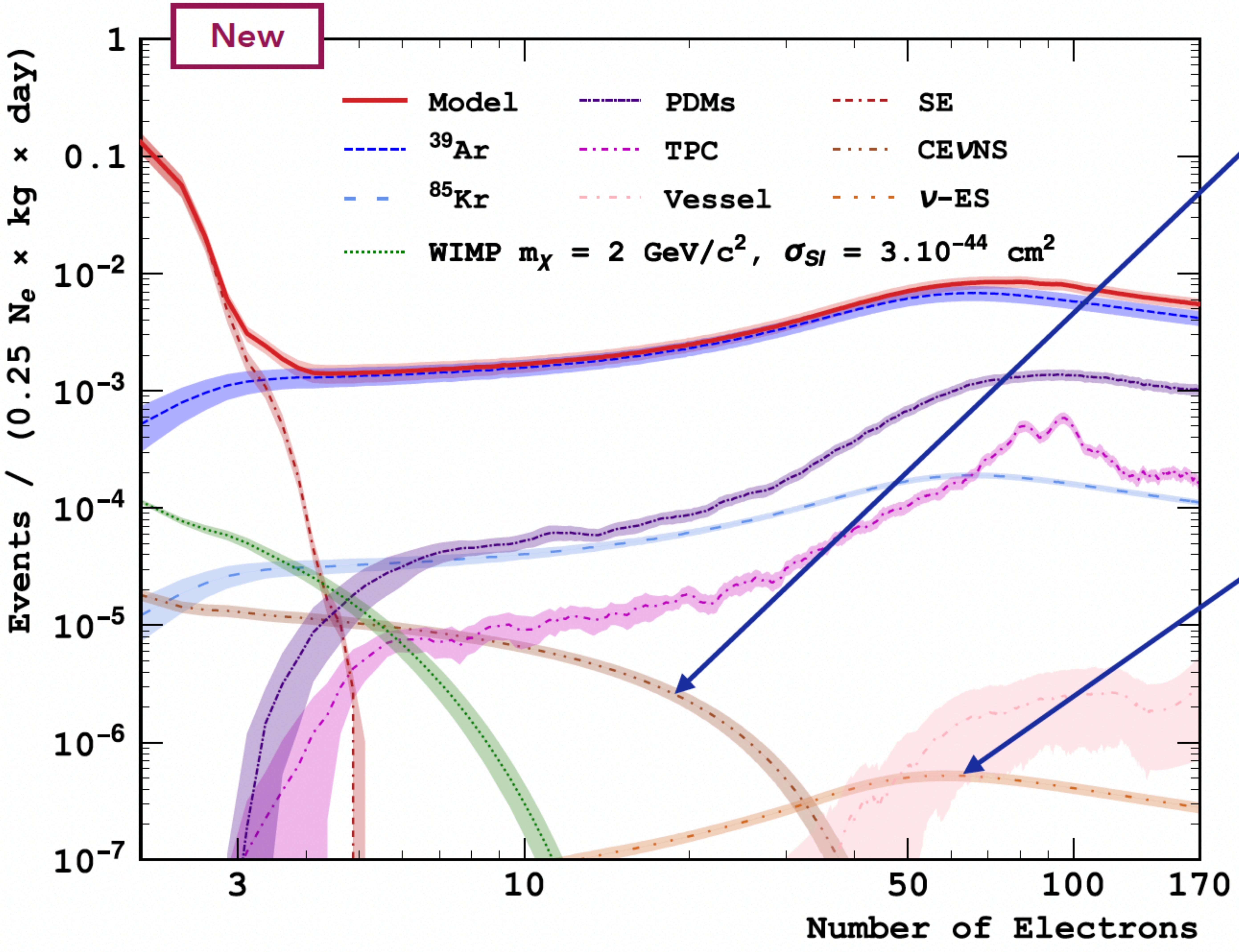
- Mostly from solar neutrinos (^{7}Be, ^{15}O, pep, ^{8}B, hep)
- Include radiative corrections in CEνNS

JHEP 05, 271

- Include accurate parametrization of the nucleus structure

Phys.Rev.D 102 (2020) 015030

Neutrino backgrounds



CEνNS

Mainly from solar ^{8}B ν (E_{dep} < 10 keV$_{nr}$)

ν-ES

→ Mainly from pp (+ ^{7}Be) ν (E_{dep} < 20 keV$_{er}$)

→ Dominates over CEνNS at $N_e \gtrsim 30$

Signal models

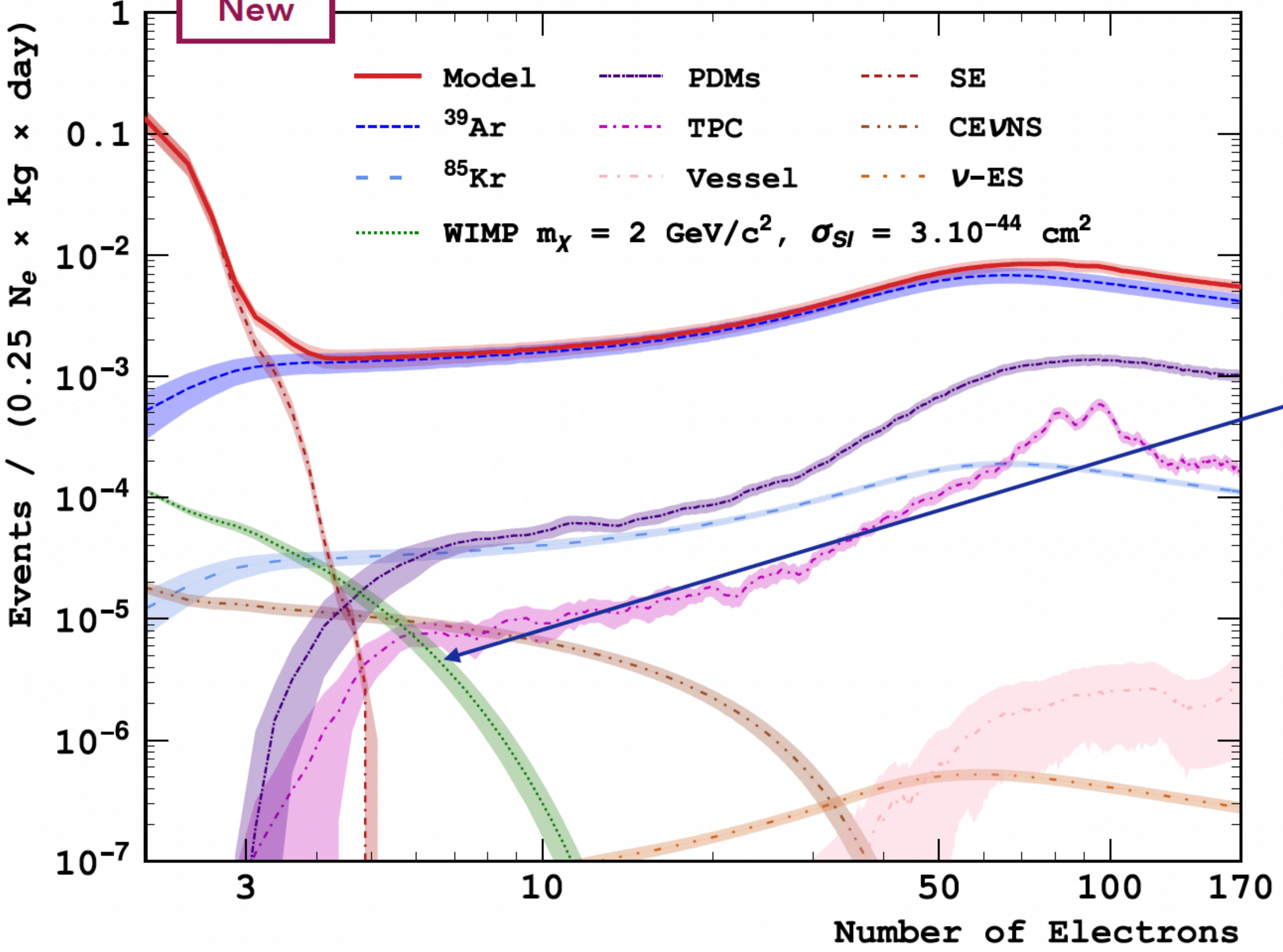
- Assuming Standard Halo Model and recommended conventions

  Eur. Phys. J. C 81 (2021), p. 907

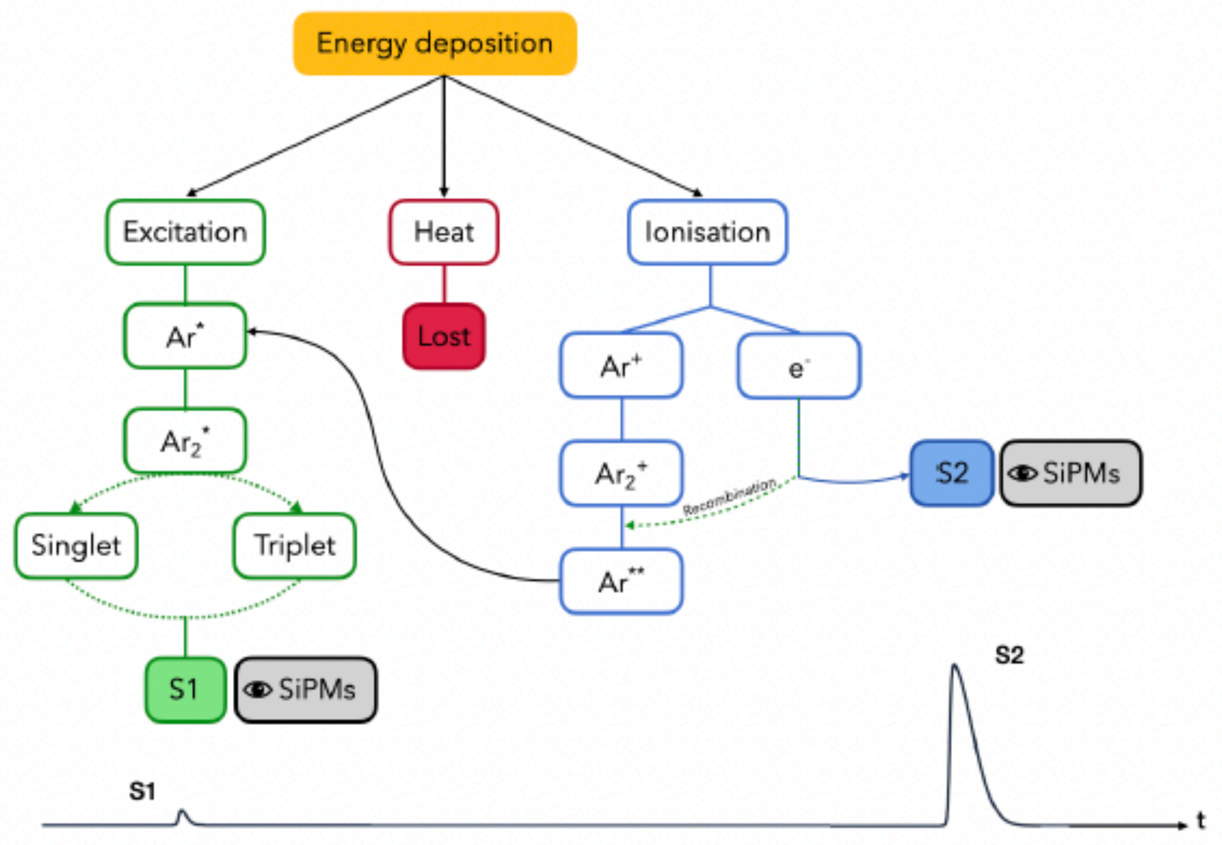
- Localised at low N_e

WIMP (pure NR part)

New



Two ^{40}Ar response models for NR



QF

Assuming **binomial fluctuations** in the fraction of quanta doing quenching

NQ

Assuming no fluctuations

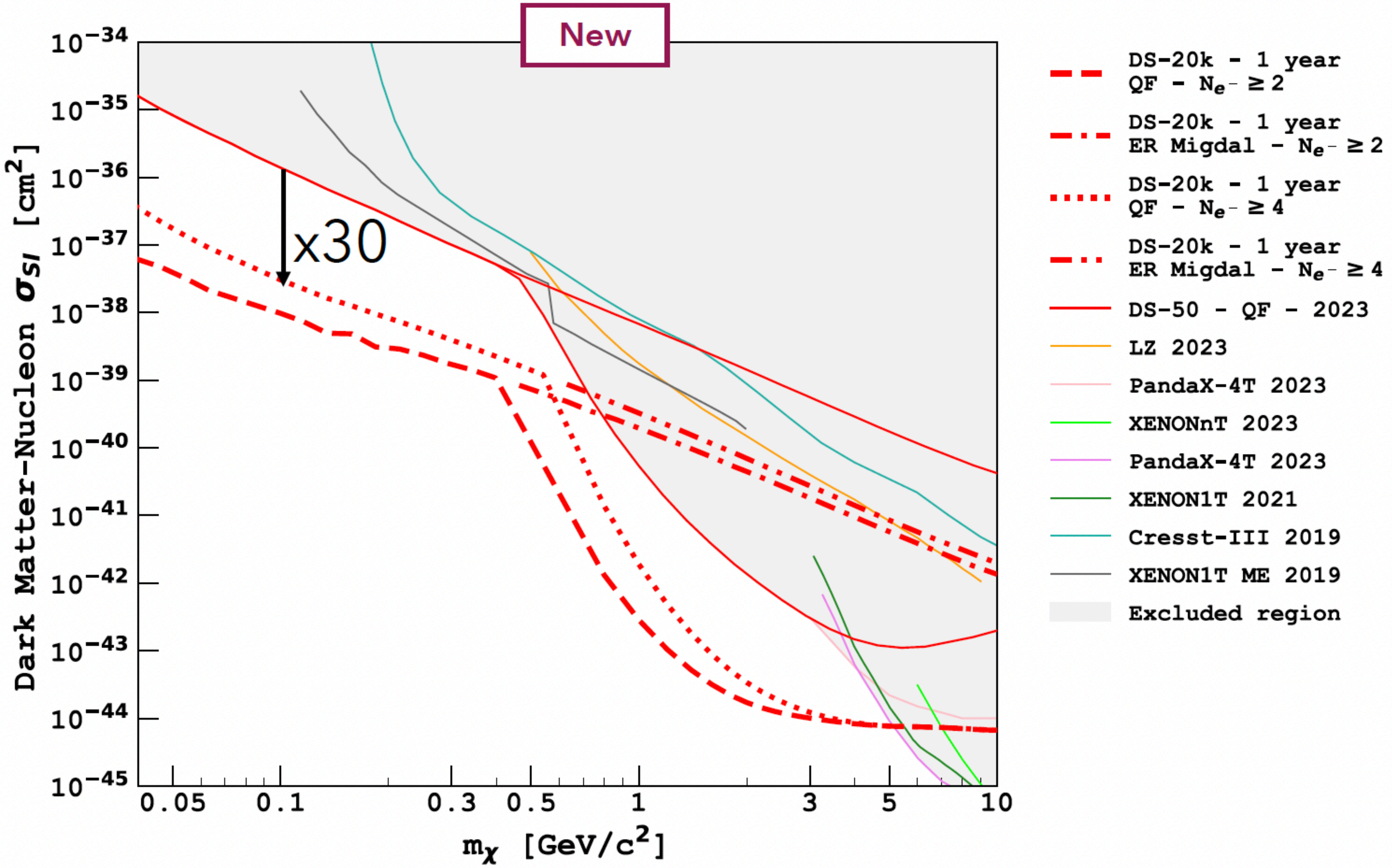
Including Migdal effect

Assuming 1 year of data taking

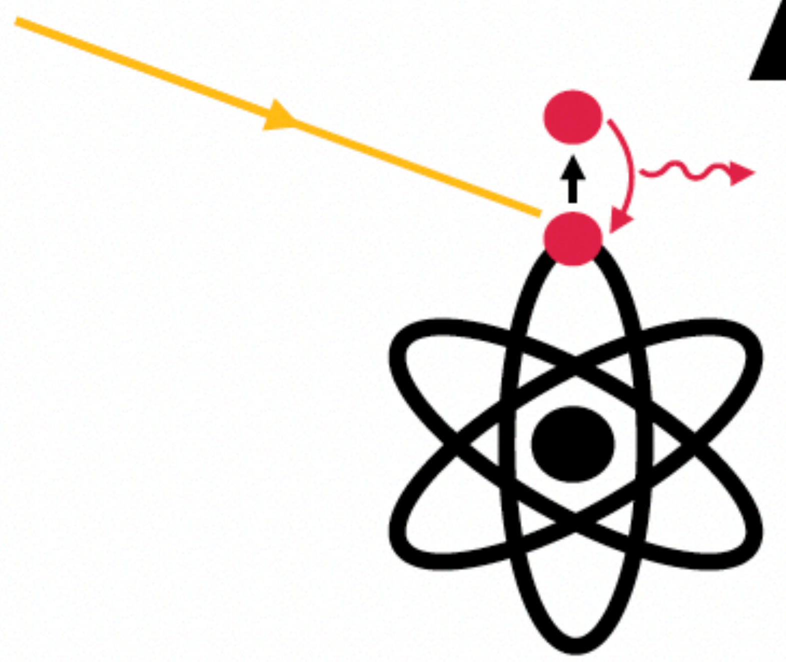
- Migdal effect = possible atomic effect
- Electron released in NR
  - Lower the detection threshold

➡ **With Migdal effect:** best limits from 40 MeV/c² to 5 GeV/c²

➡ Expect **> 1 order of magnitude improvement** wrt to current experiments in **1y** only



ALP and dark photon (DP)



Absorption of ALP/DP by bound electrons → mono-energetic signal

Expect ≈**5x improvement** wrt to current experiments in **1y** only

- ALP = pseudo scalar particle
- Coupling ALP - electrons → g_{Ae}

- DP = vector boson particle
- Kinetic mixing between DP and SM photons → strength κ

Assuming 1 year of data taking