UCR PHYSICS & ASTRONOMY

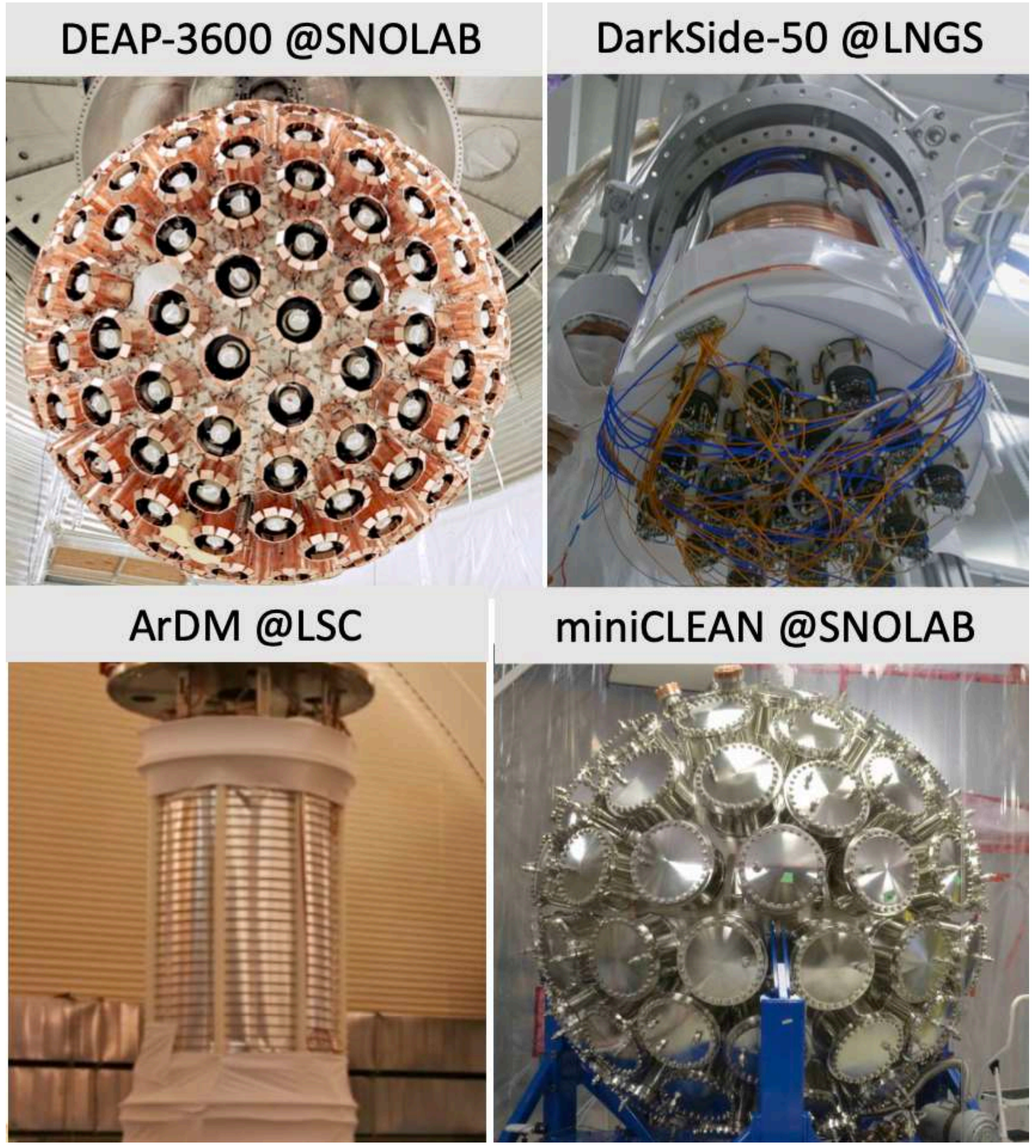
DBD23

The DarkSide-20k search for dark matter interactions with argon

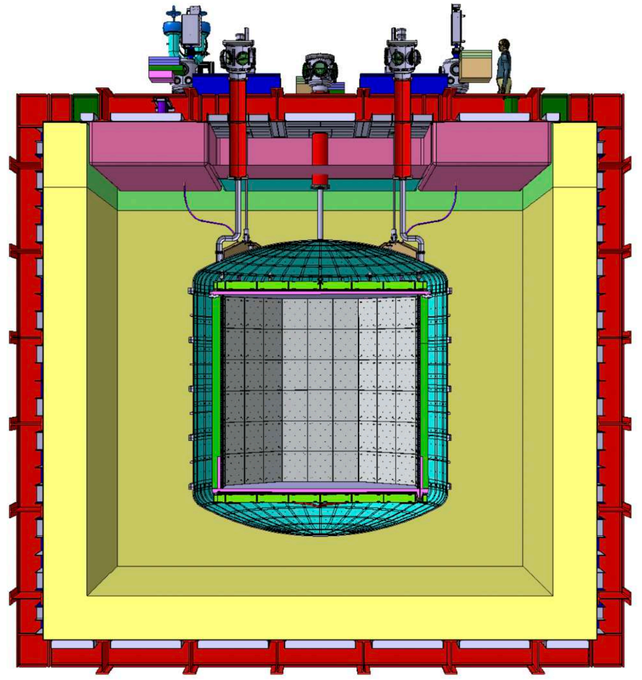
Michela Lai

On behalf of DARKSIDE

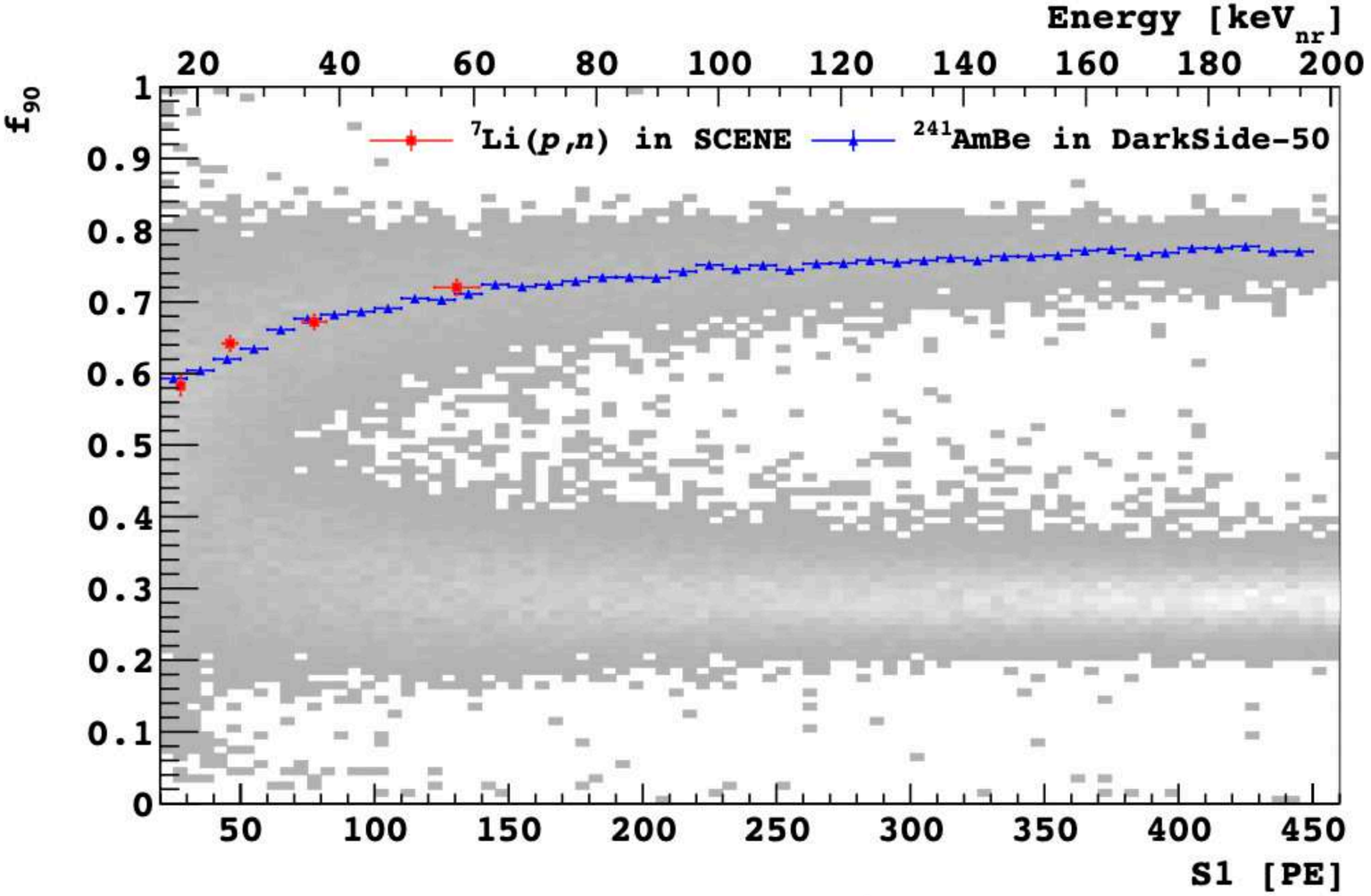
Global Argon Dark Matter Collaboration



- **DarkSide-20k @ LNGS (49.7 tonnes active), foreseen by late 2026**
- Established in 2017
- Counting > 500 members > 100 institutions in 14 countries
- Future detectors:
  - ✦ARGO (3000 tonne-year exposure, foreseen in 2030s)
  - ✦DarkSide Low-Mass (1 tonne-year exposure)



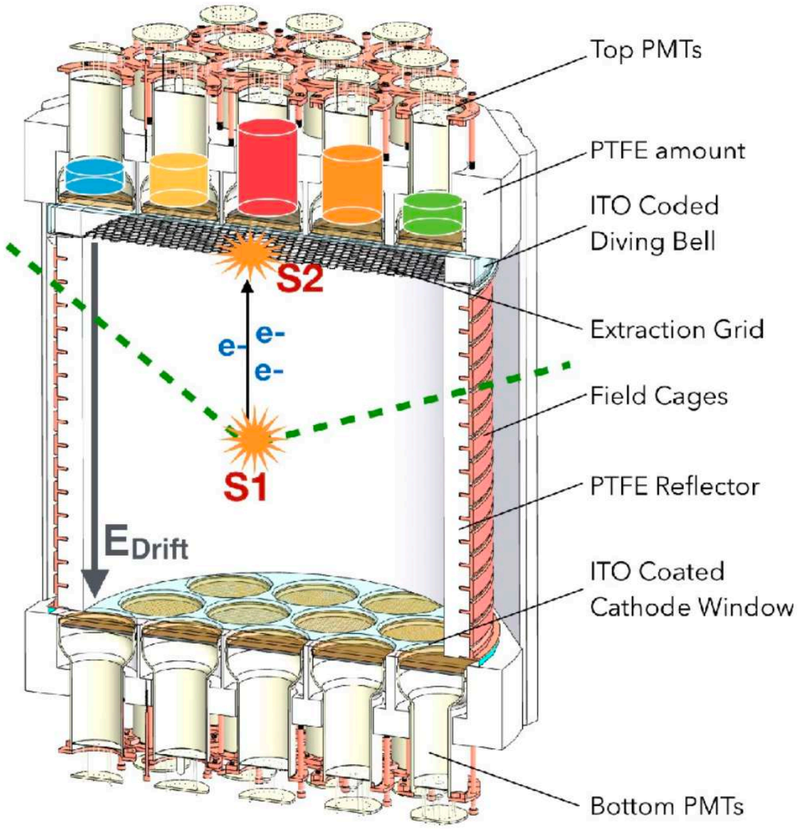
Pulse shape discrimination



Phys. Rev. D 93, 081101 (2016)

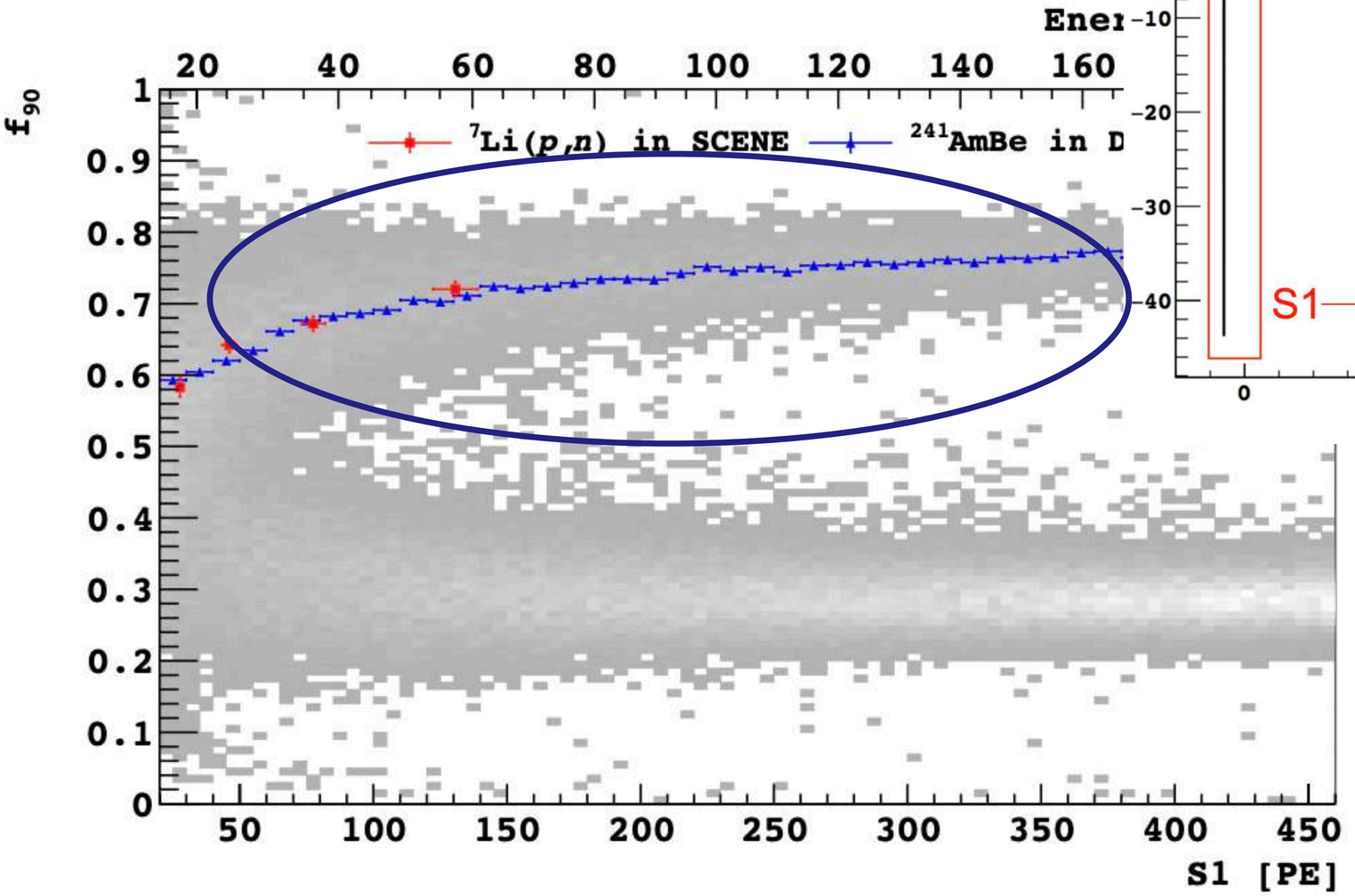
$$f_{90} = \frac{\int_{-5\mu s}^{2\mu s} S_1 dt}{\int_{0}^{90ns} S_1 dt}$$

- Argon: $\tau_s \approx 6$ ns, $\tau_t \approx 1600$ ns →PSD

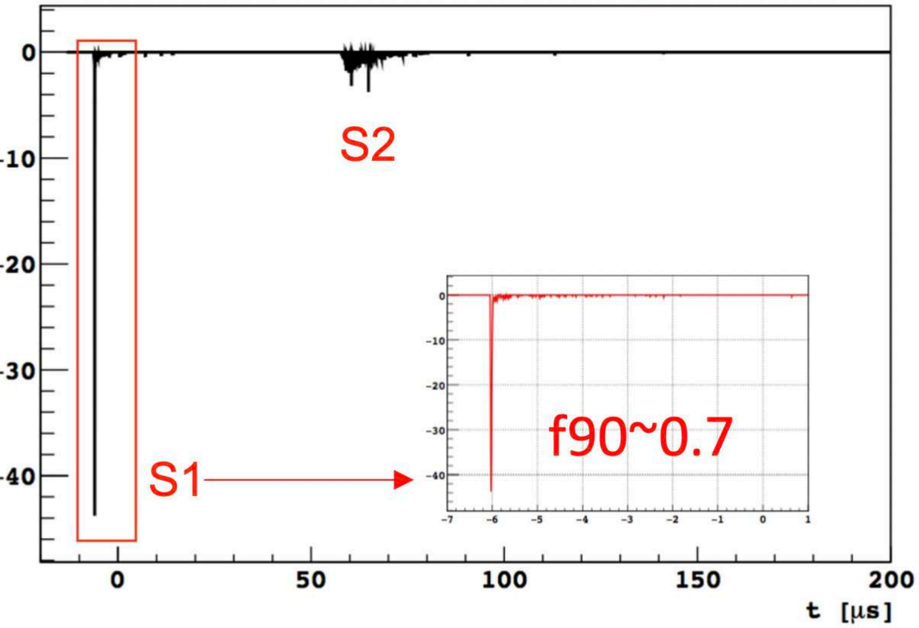


Drawing of DarkSide-50

Pulse shape discrimination



Nuclear Recoil (NR)



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Pulse shape discrimination

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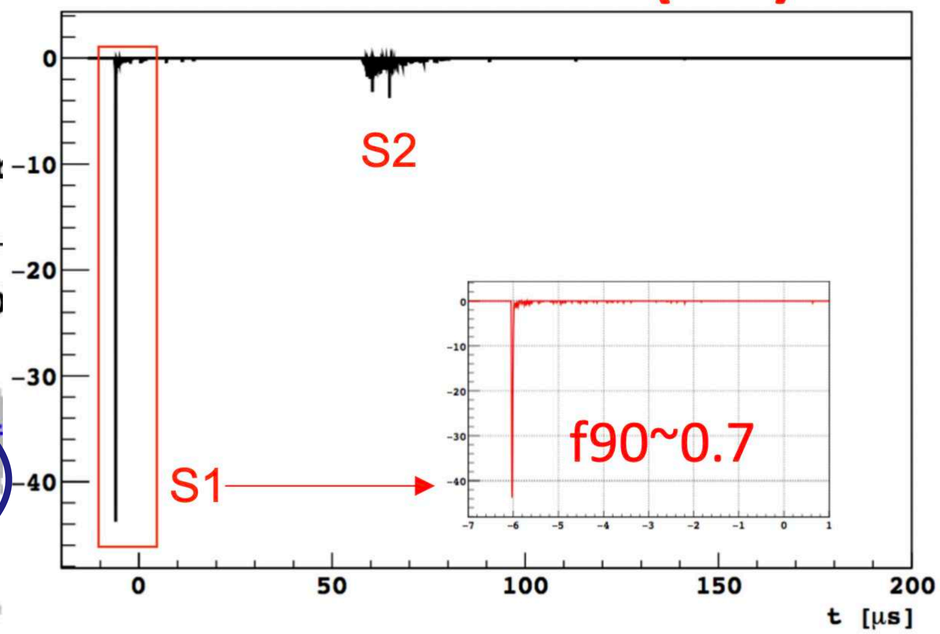
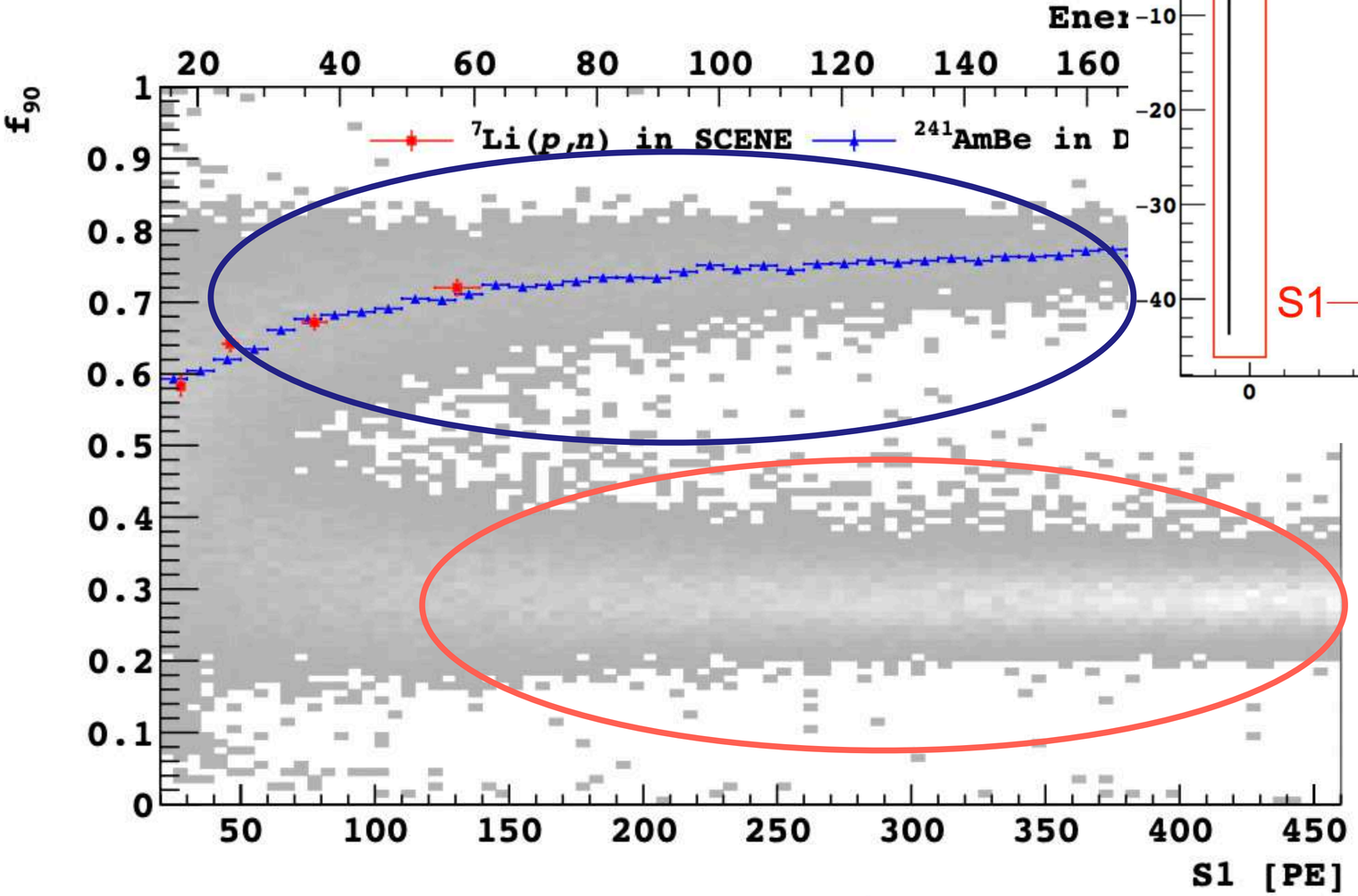
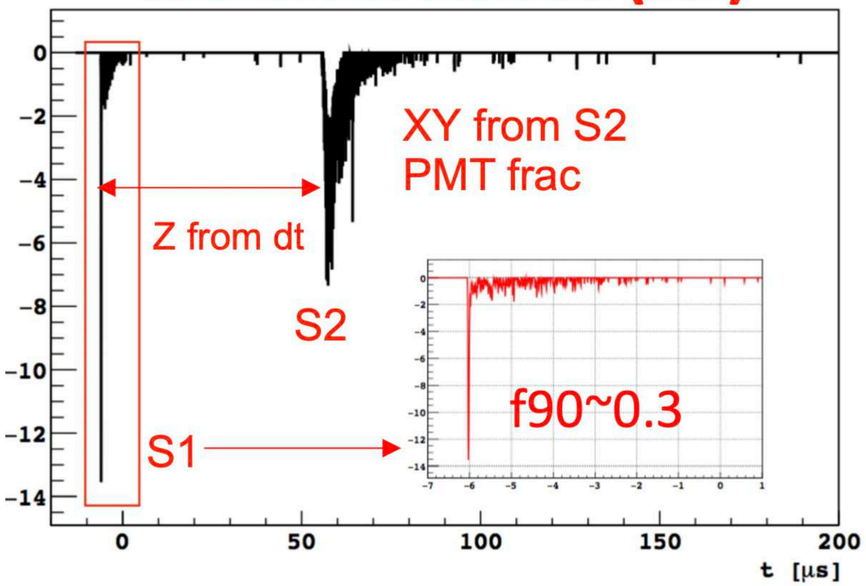




Electron Recoil (ER)



Phys. Rev. D 93, 081101 (2016)

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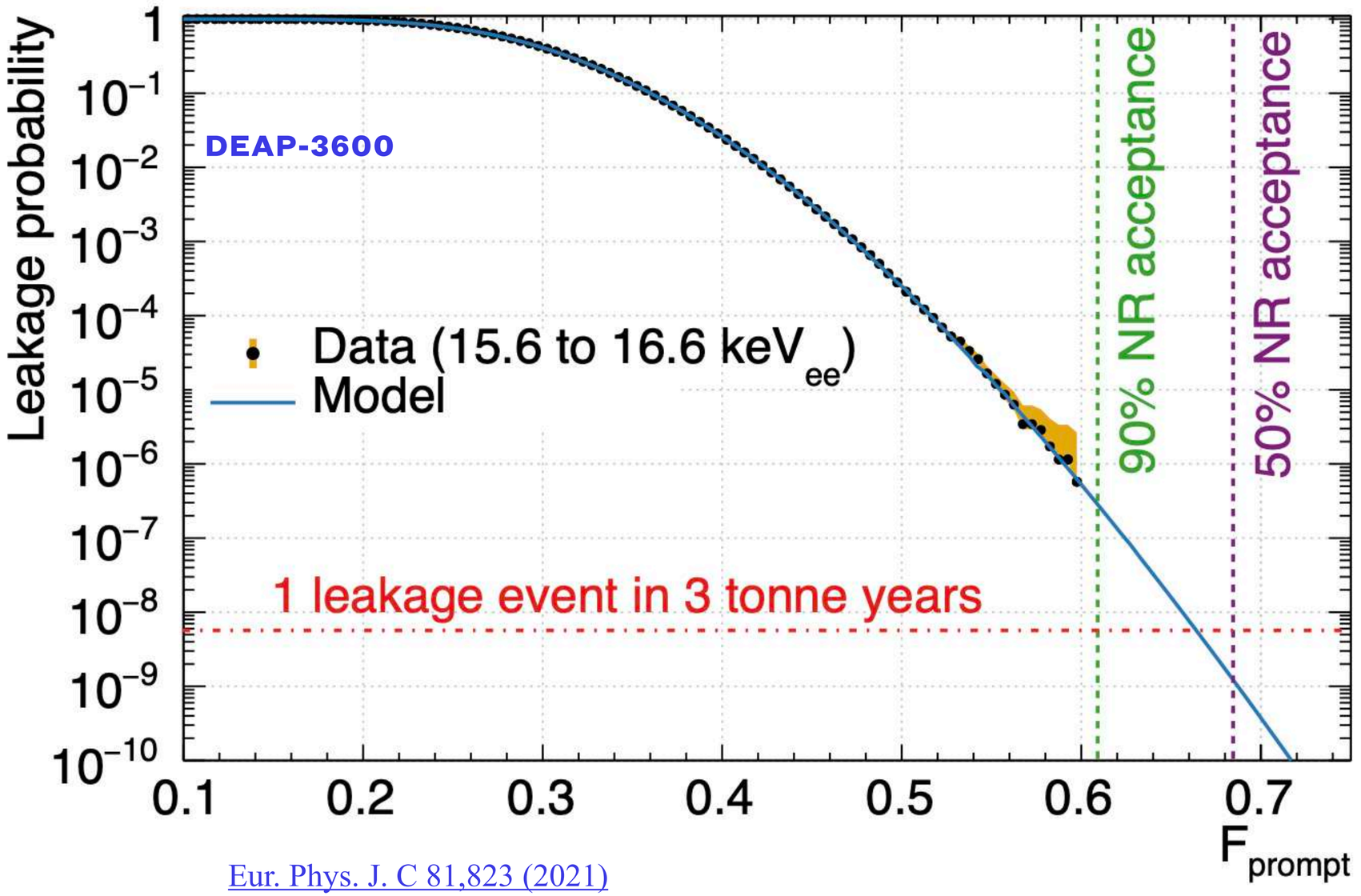
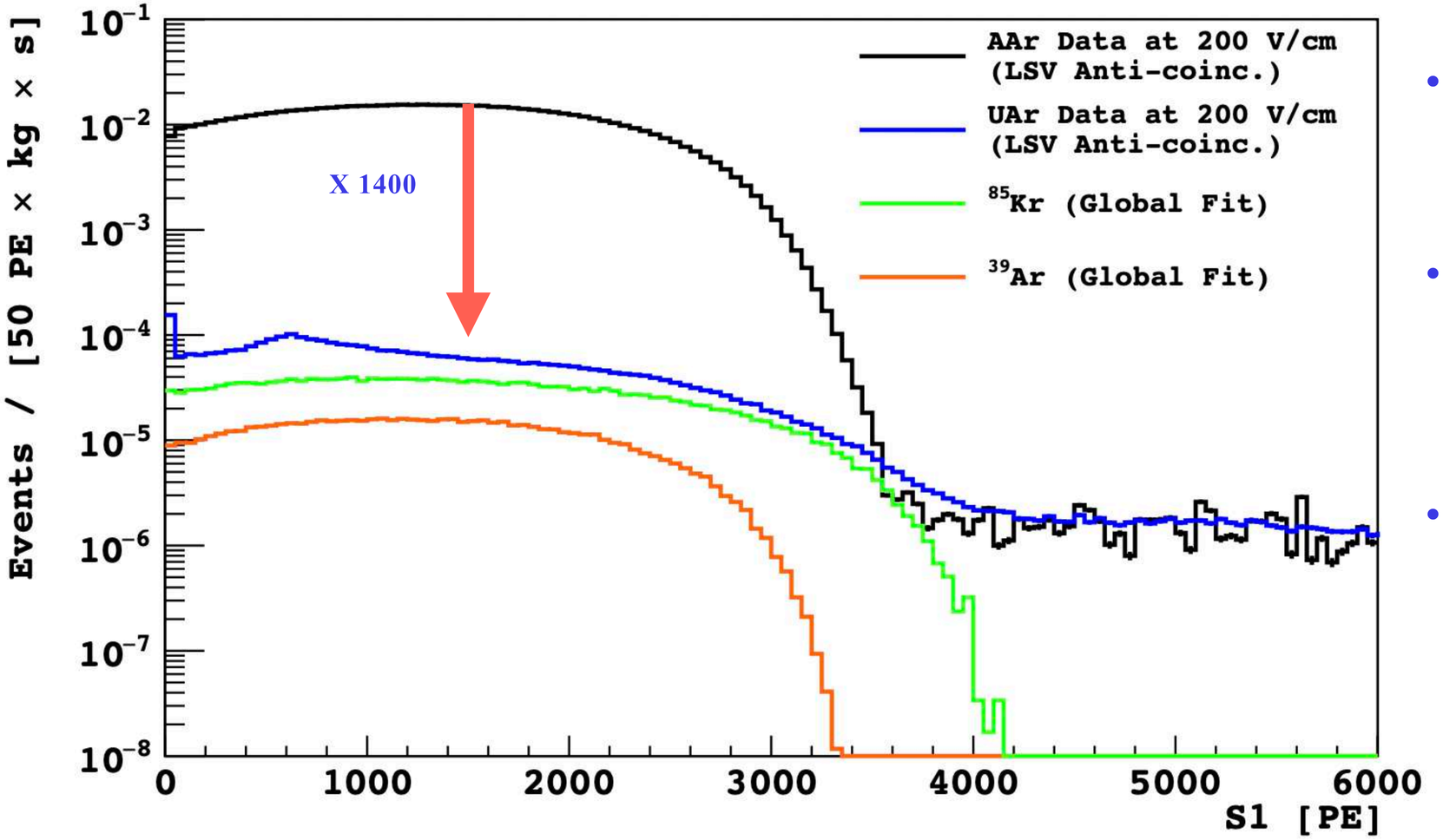
Pulse shape discrimination



Eur. Phys. J. C 81,823 (2021)

- World-leading PSD was demonstrated in DEAP-3600, using Atmospheric Argon
- ER background rejection efficiency as high as 10^8 in DarkSide-50, using a double phase TPC

Underground Argon

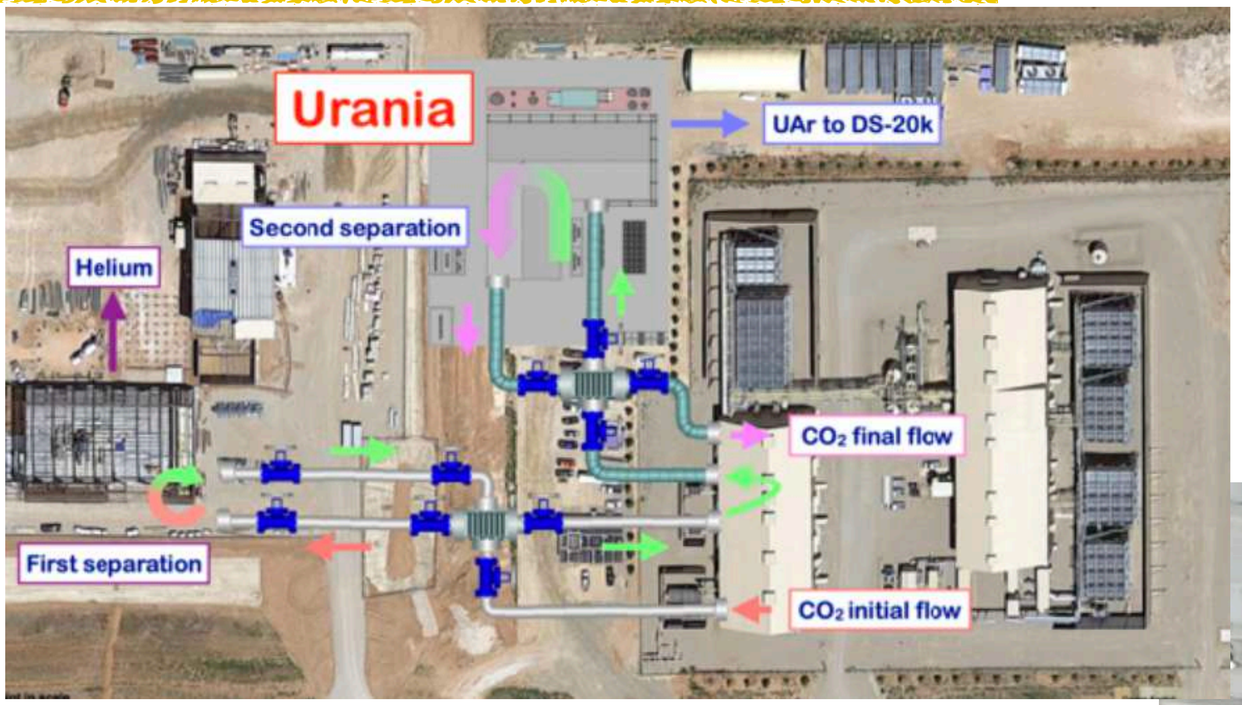


Phys.Lett.B 743 (2015) 456-466

- Atmospheric Argon has 1 Bq/kg of activity due to ^{39}Ar βdecays (Q = 565 keV, $t_{1/2}$ = 269 years)
- Underground Argon extracted from a CO_2 mine in Colorado (400 ppm Argon in CO_2) strongly reduced ERs in DarkSide-50
- Overwhelming pile-up within 3.5 m drift length in DarkSide-20k if filled with AAr

Underground Argon

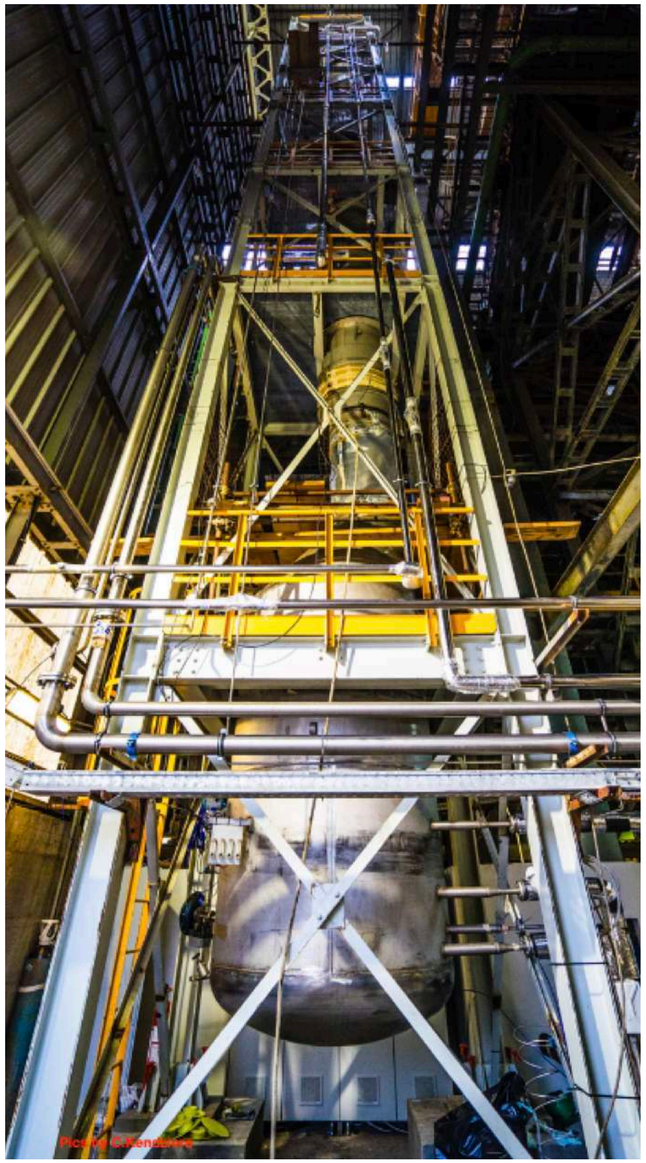
Argon Extraction: Urania

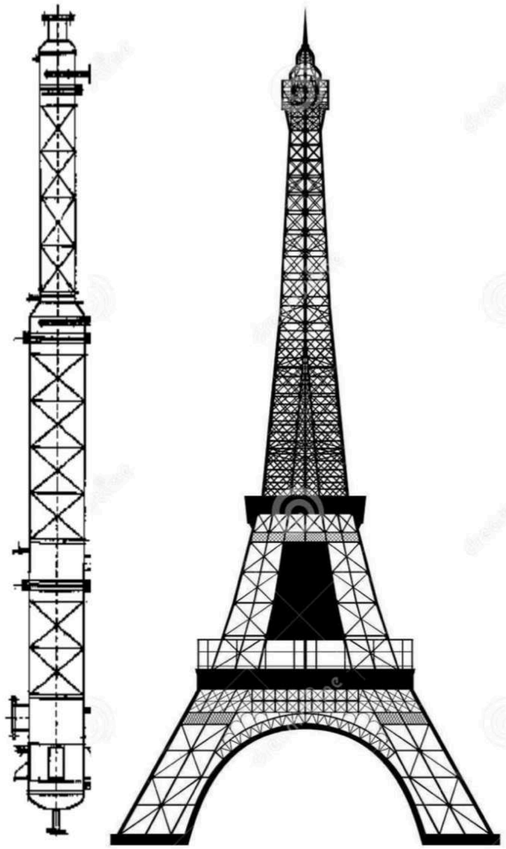


- Low activity UAr found in 2009 at Southwest Colorado CO_2 wells and purified at FNAL for DarkSide-50, with a rate 140 g/day
- Urania will be built next to the previous site by Polaris S.p.A.

- Expected extraction rate 250 kg/day
- Additional experiments interested in UAr from Urania: Argo, COHERENT, LEGEND

Argon purification: Aria

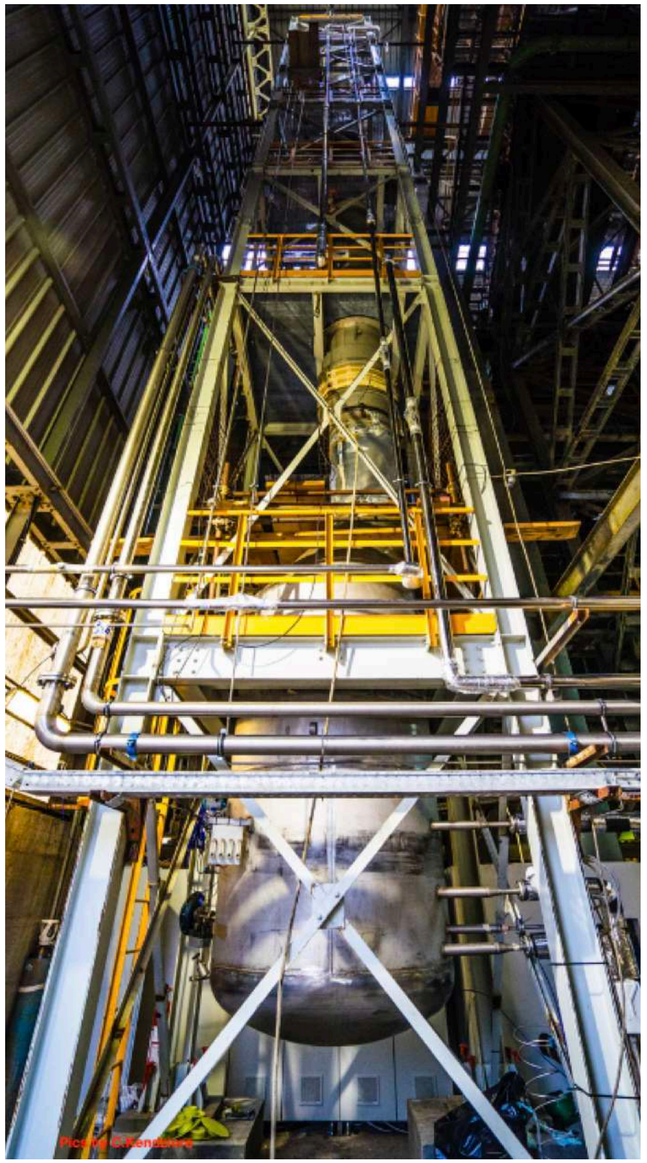


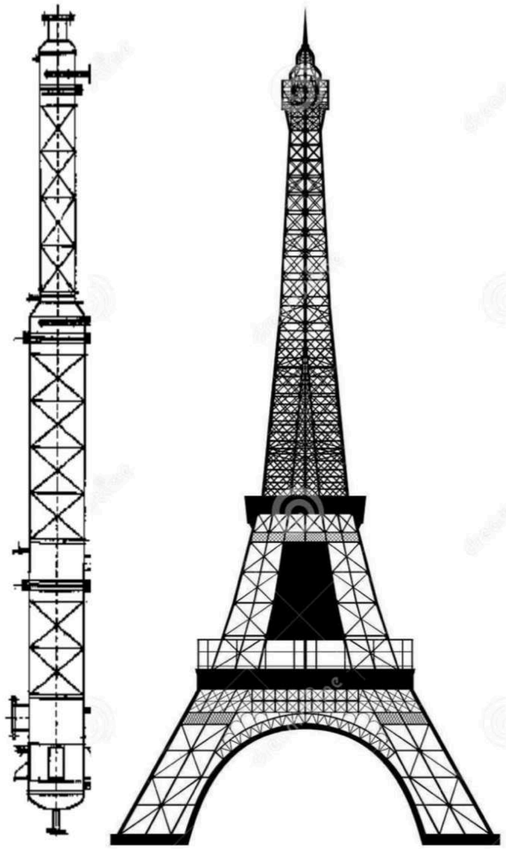


- Expected purity from URANIA: 99.999 %
- At least two more orders of magnitude needed for DarkSide-20k
- Aria: argon cryogenic distillation plant
  - Seruci-1: 350 m tall distillation column

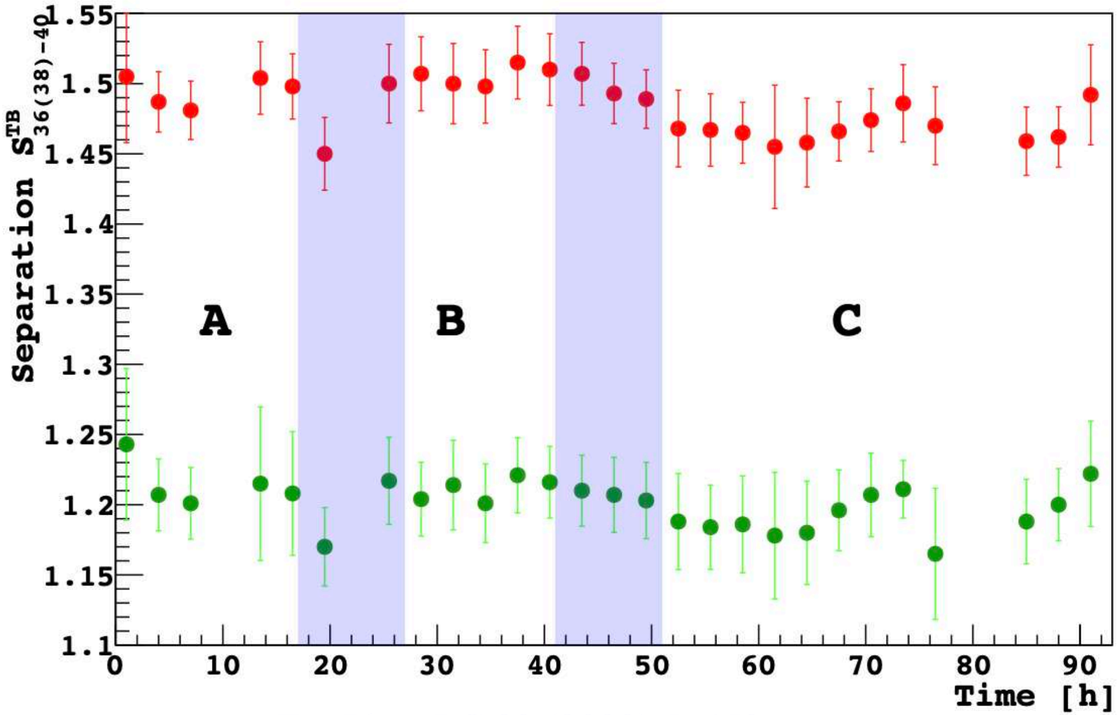
Eur.Phys.J.C 81 (2021) 4, 359

Argon purification: Aria





- Expected purity from URANIA: 99.999 %
- At least two more orders of magnitude needed for DarkSide-20k
- Aria: argon cryogenic distillation plant
  - Seruci-1: 350 m tall distillation column
  - Seruci-0: 26 m tall already demonstrated ^{36}Ar - ^{40}Ar separation performances in a few days run

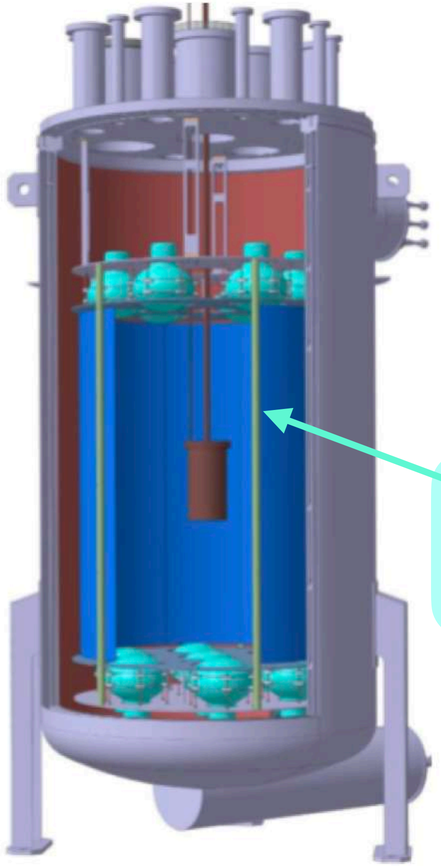


Eur.Phys.J.C 81 (2021) 4, 359

Eur.Phys.J.C 83 (2023) 5, 453

Argon essay: DArT

- DArT: small low-background detector located at Laboratorio Subterràneo de Canfranc (LSC, Spain), 1400 m.w.e undergound



ArDM, a LAr TPC (850 kg AAr)

JINST 15 (2020) 02, C02044

Argon essay: DArT

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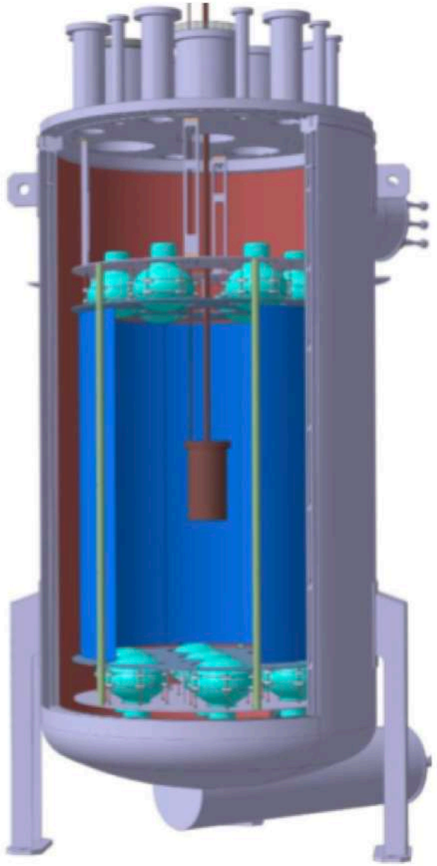
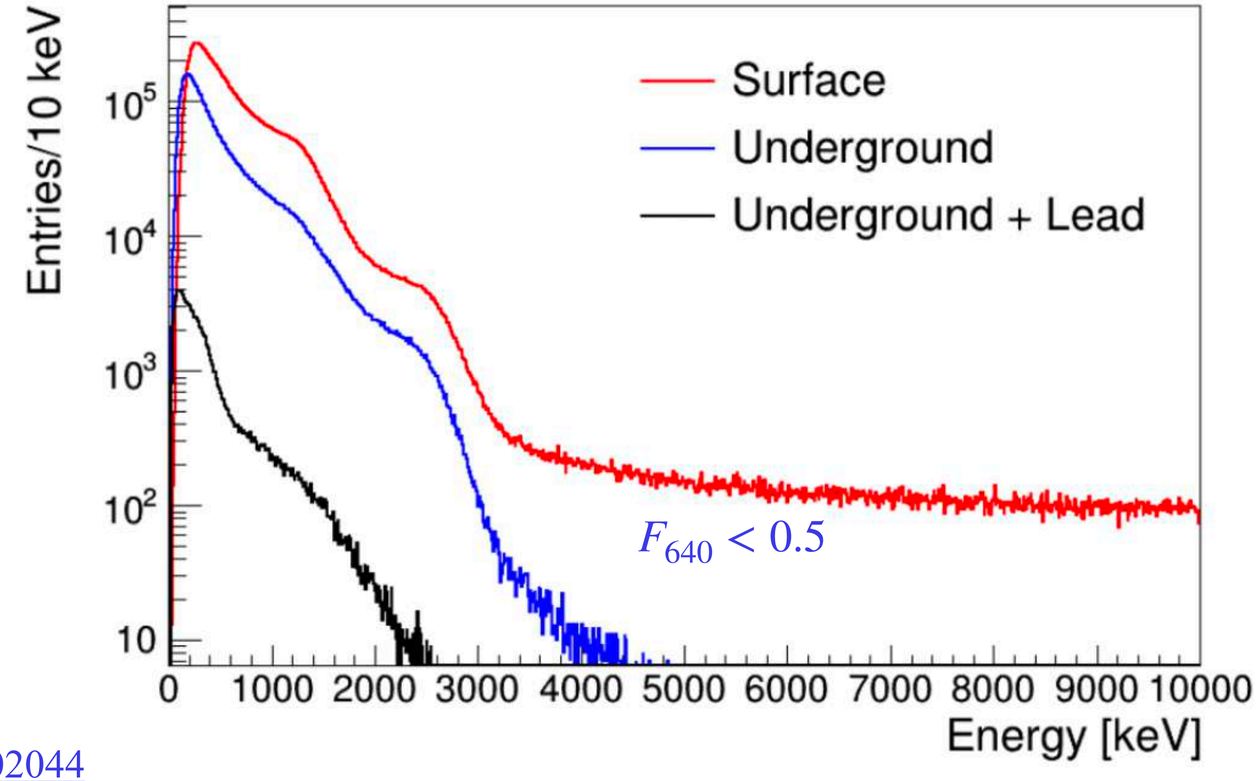
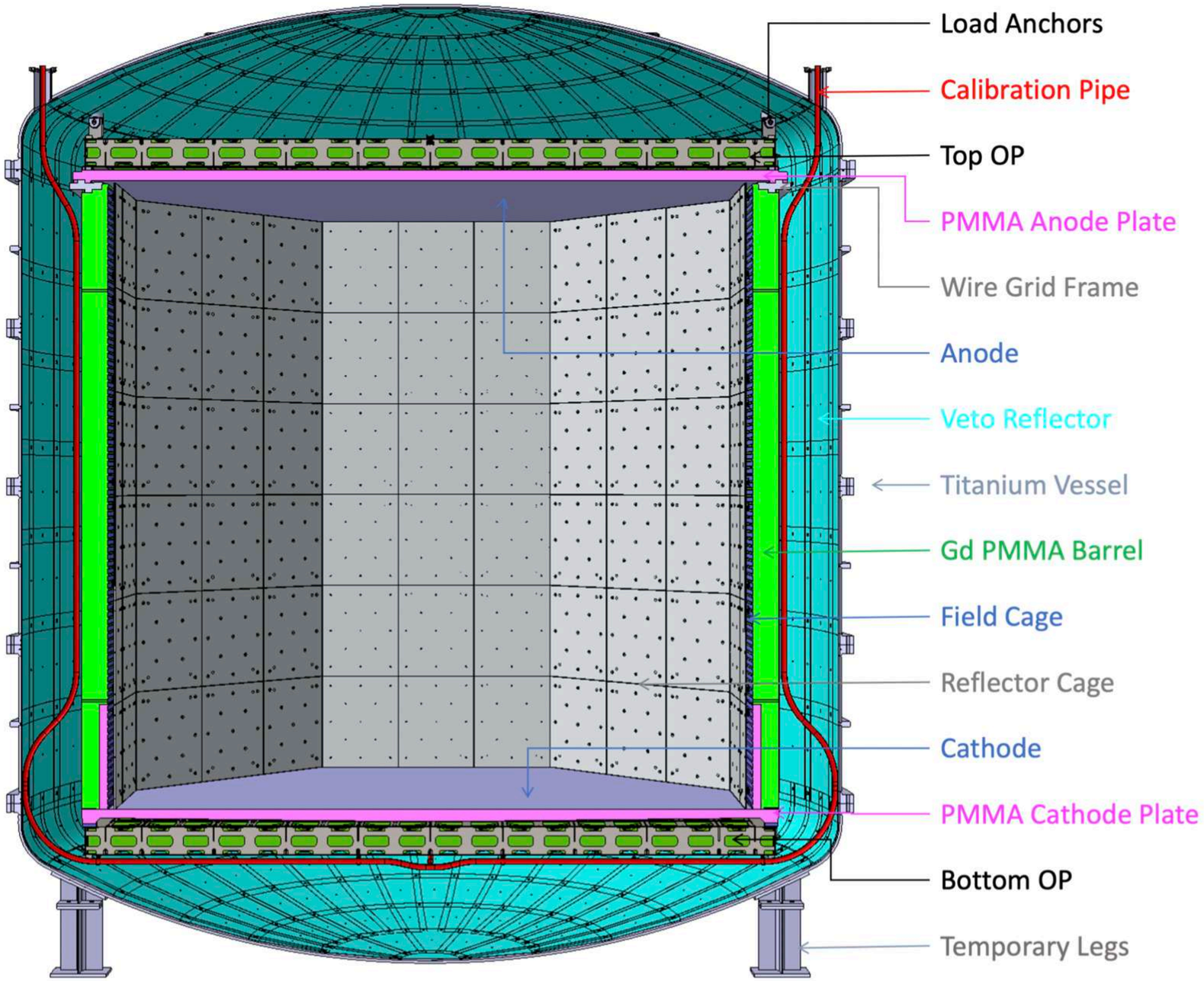


JINST 15 (2020) 02, C02044

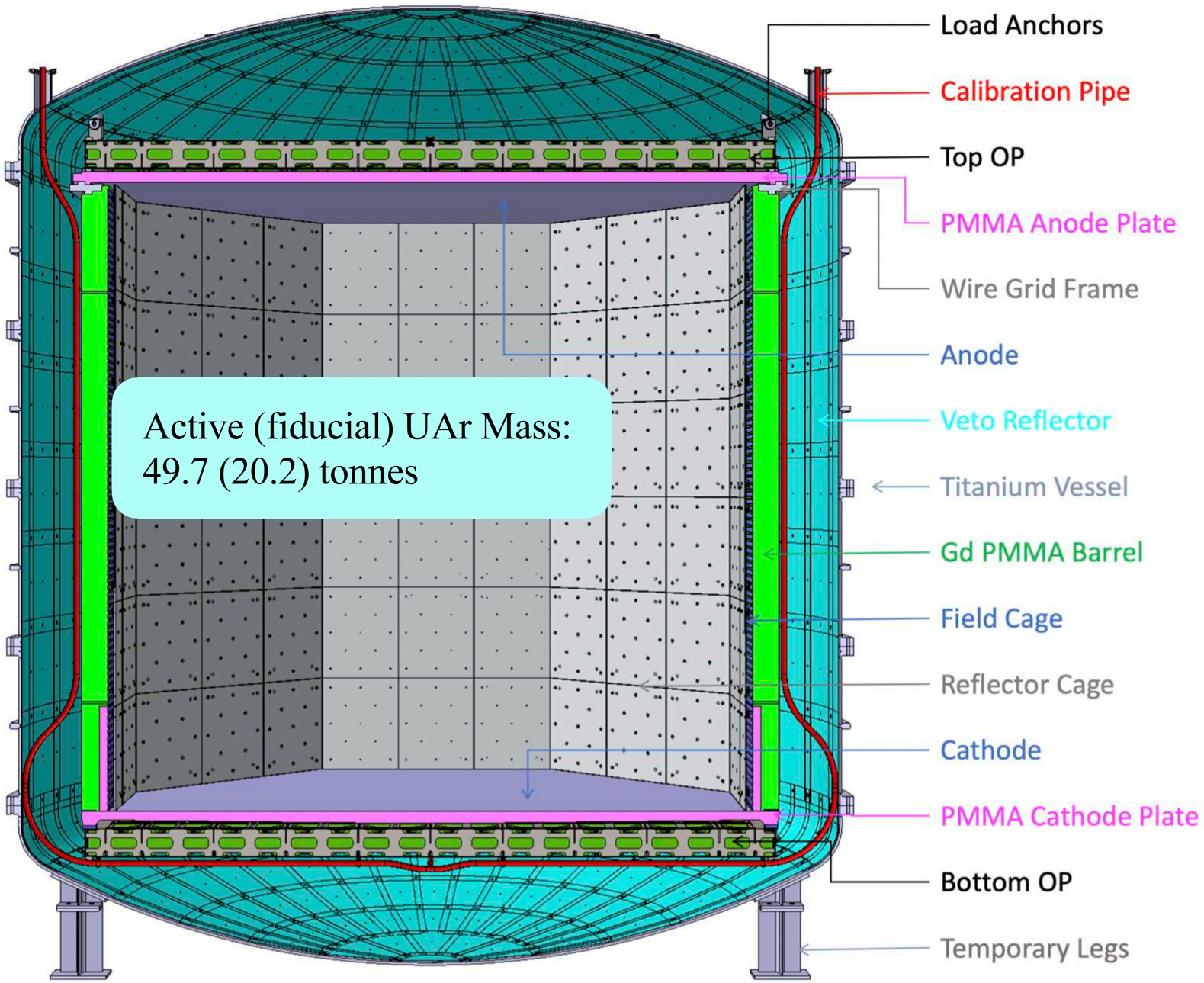


J. Phys.: Conf. Ser. 2156 012043

Inner Detector

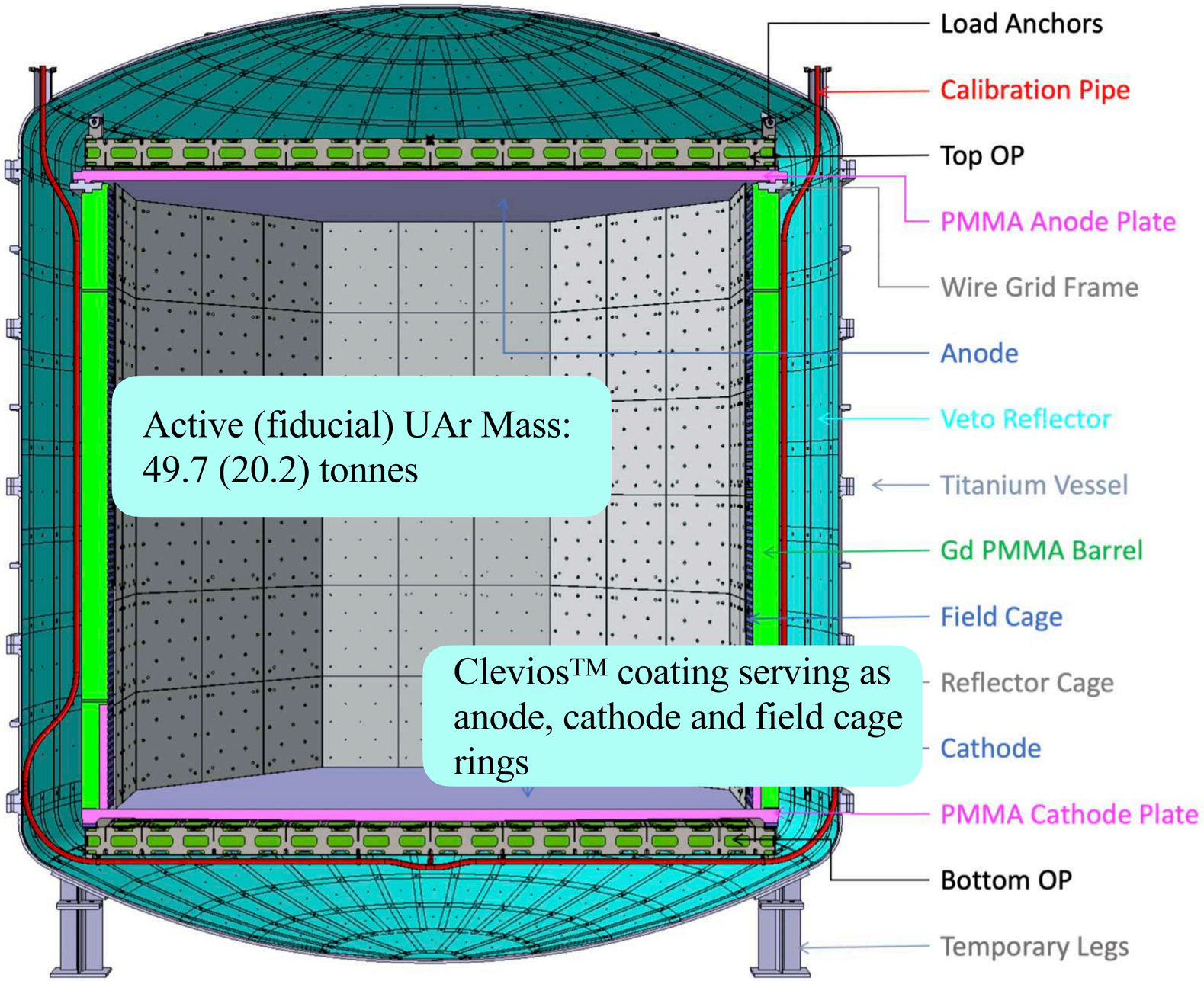


TPC



Active (fiducial) UAr Mass:
49.7 (20.2) tonnes

TPC



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Clevios™ coating serving as anode, cathode and field cage rings

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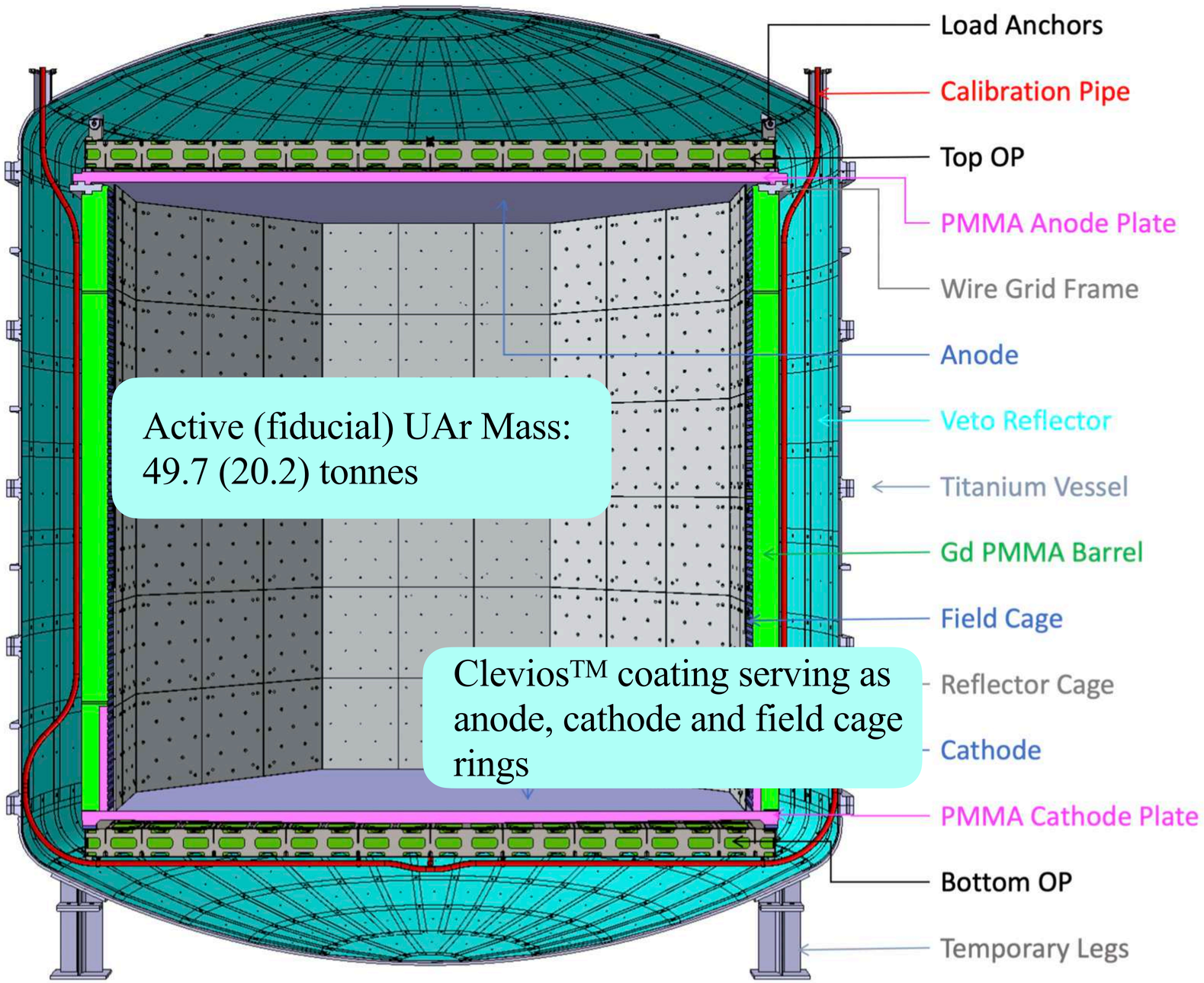

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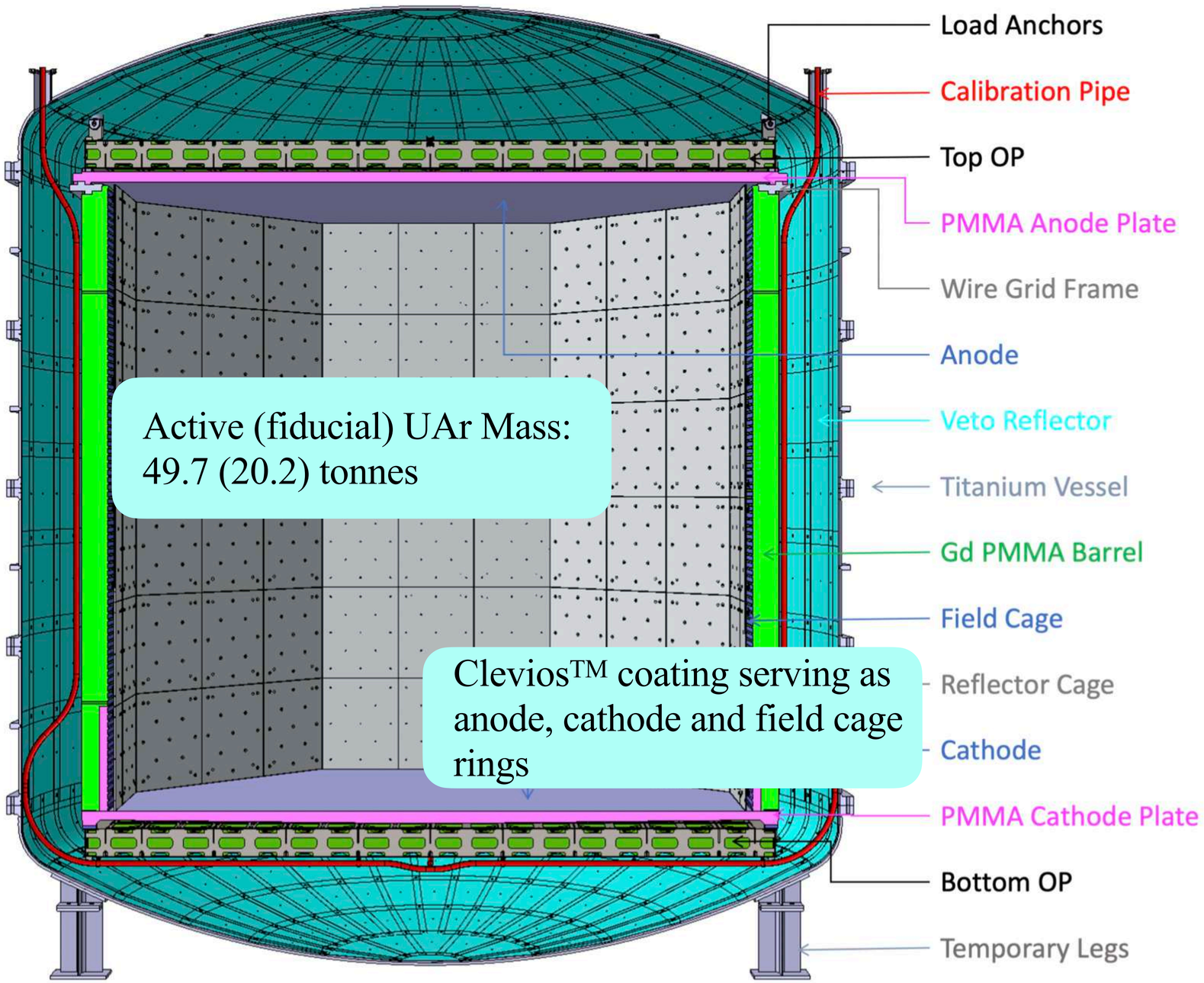
ESR + TPB

TPC



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49.7 (20.2) tonnes

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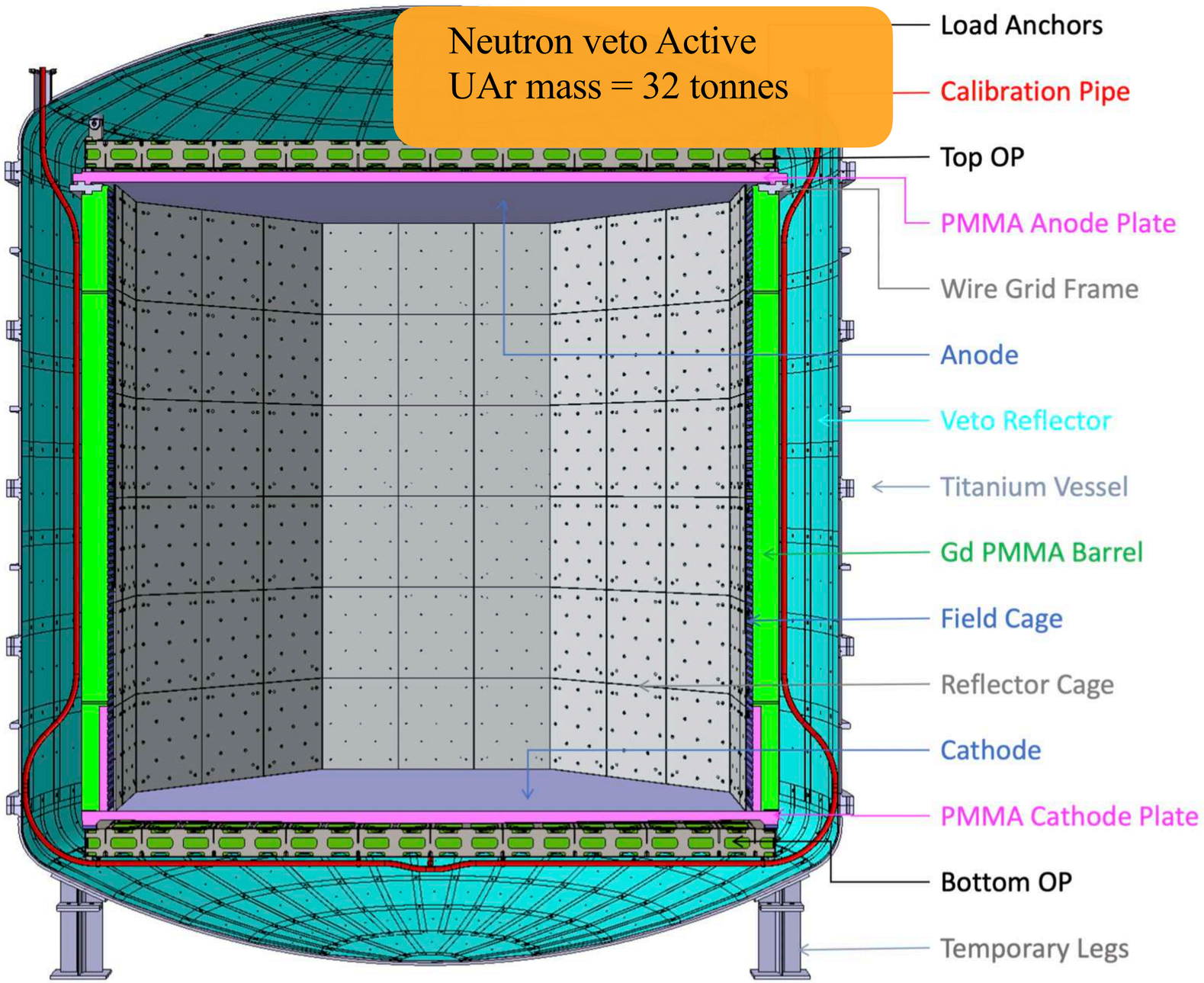
- LY at null field: 10 PE/keV$_{ee}$
- S2 yield > 20 PE/e-

ESR + TPB

Neutron Veto

Neutron veto Active
UAr mass = 32 tonnes



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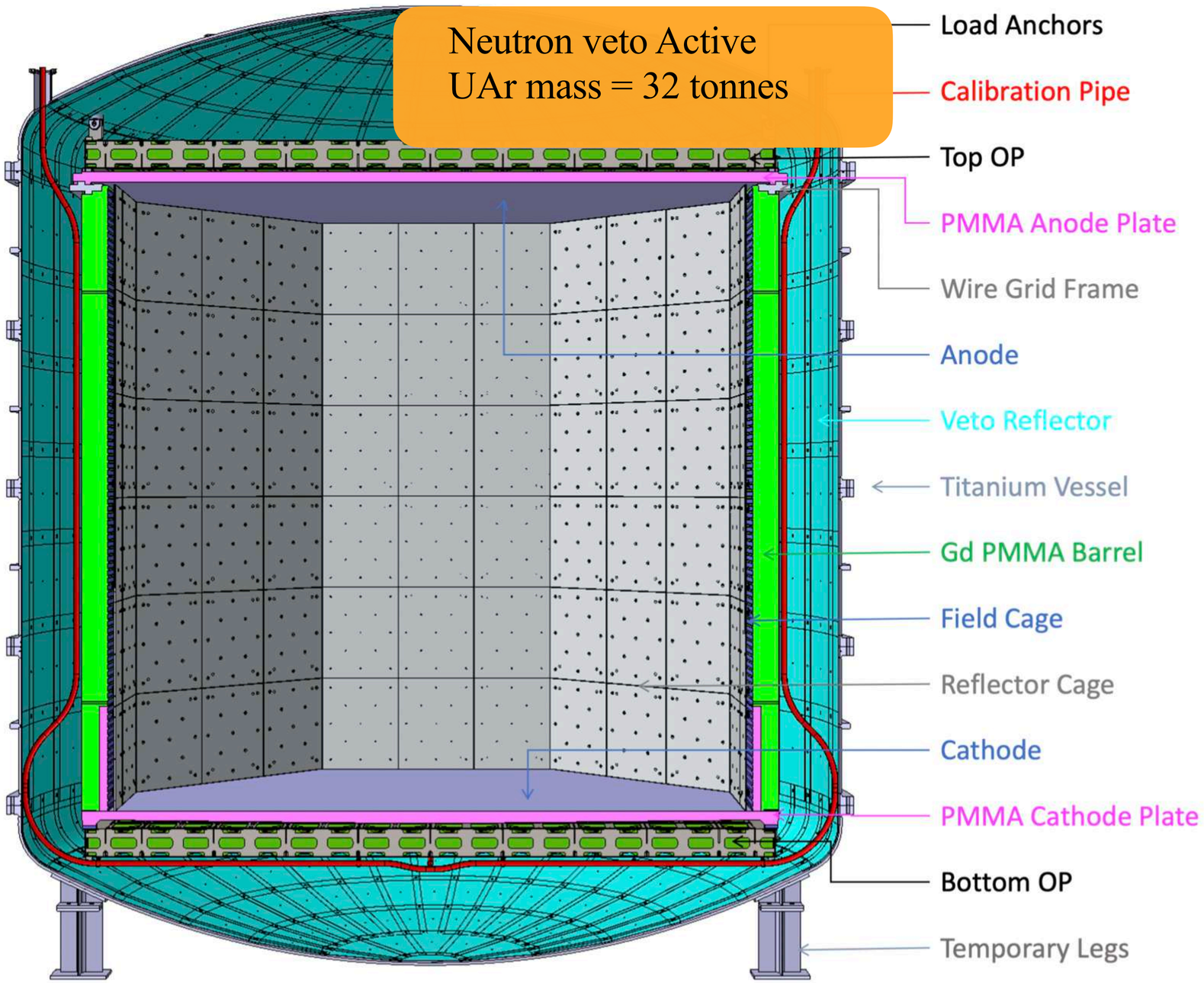

ESR + PEN

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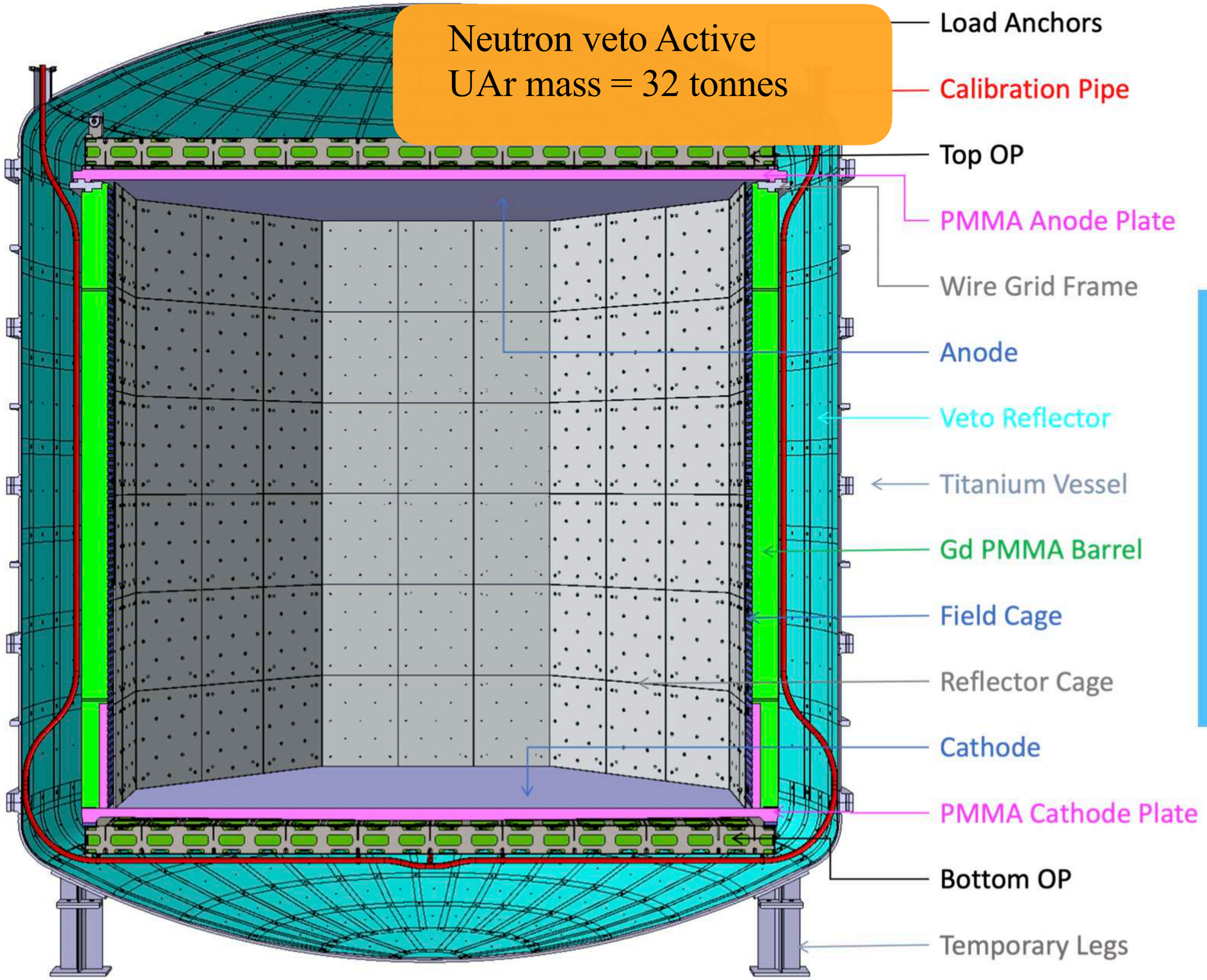
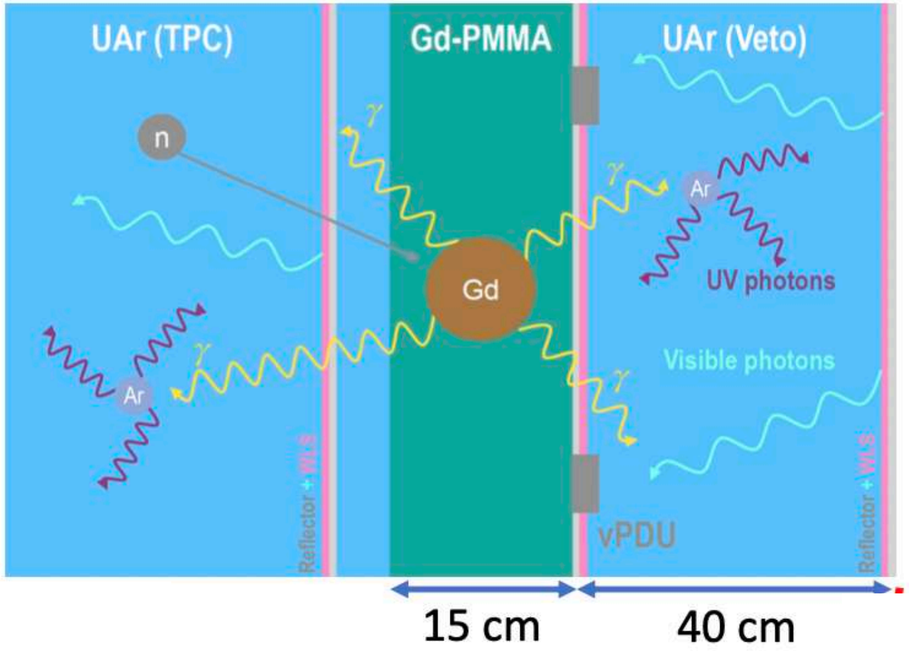
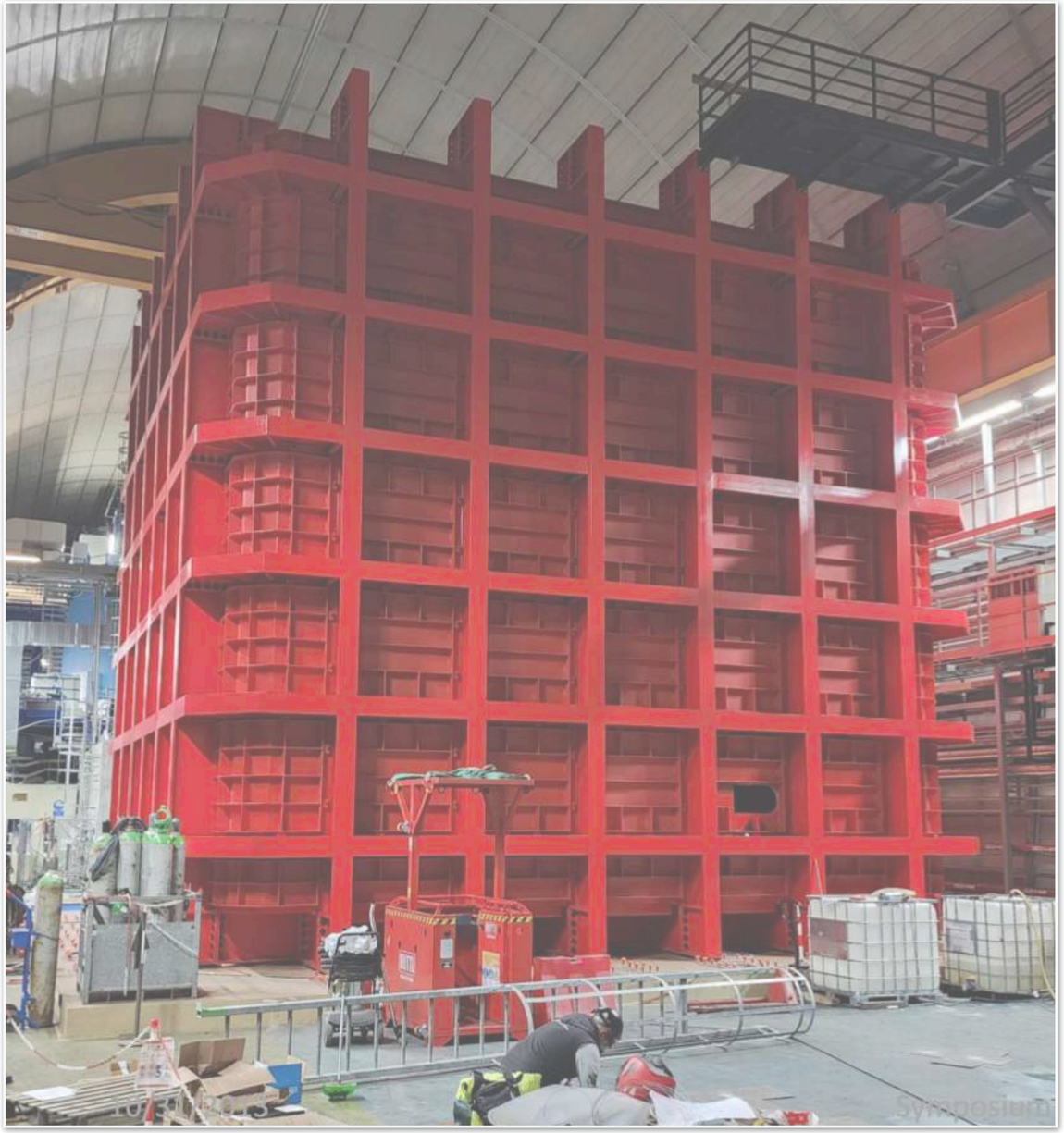
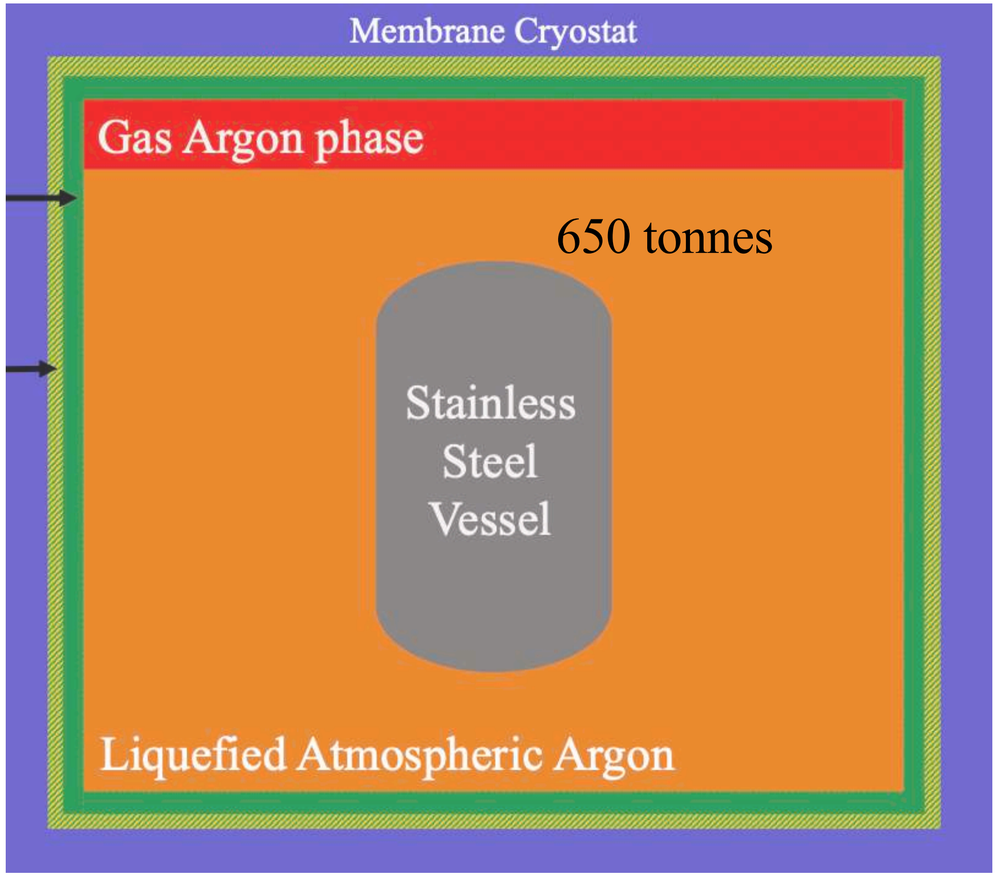


ESR + PEN

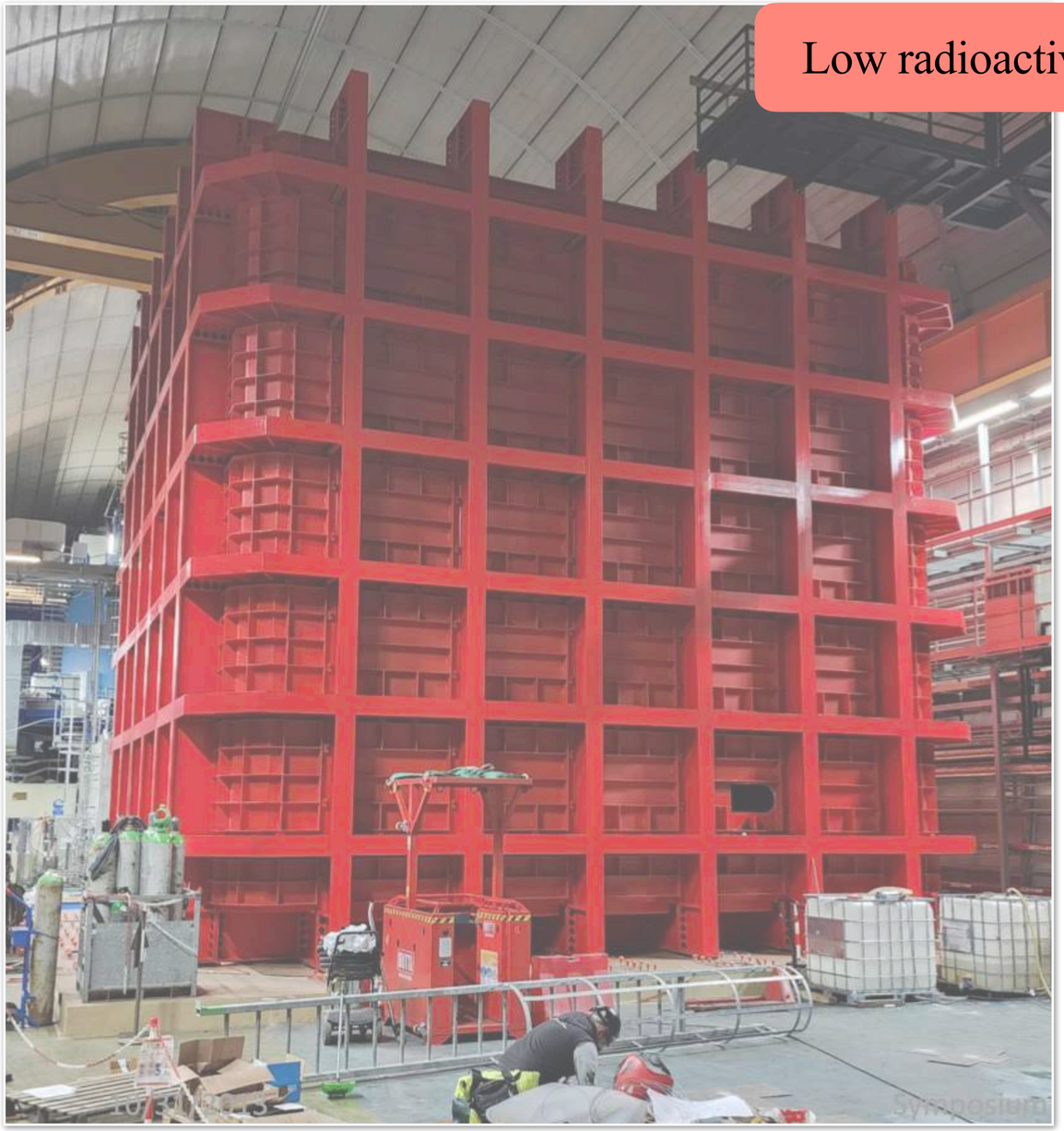


Outer veto

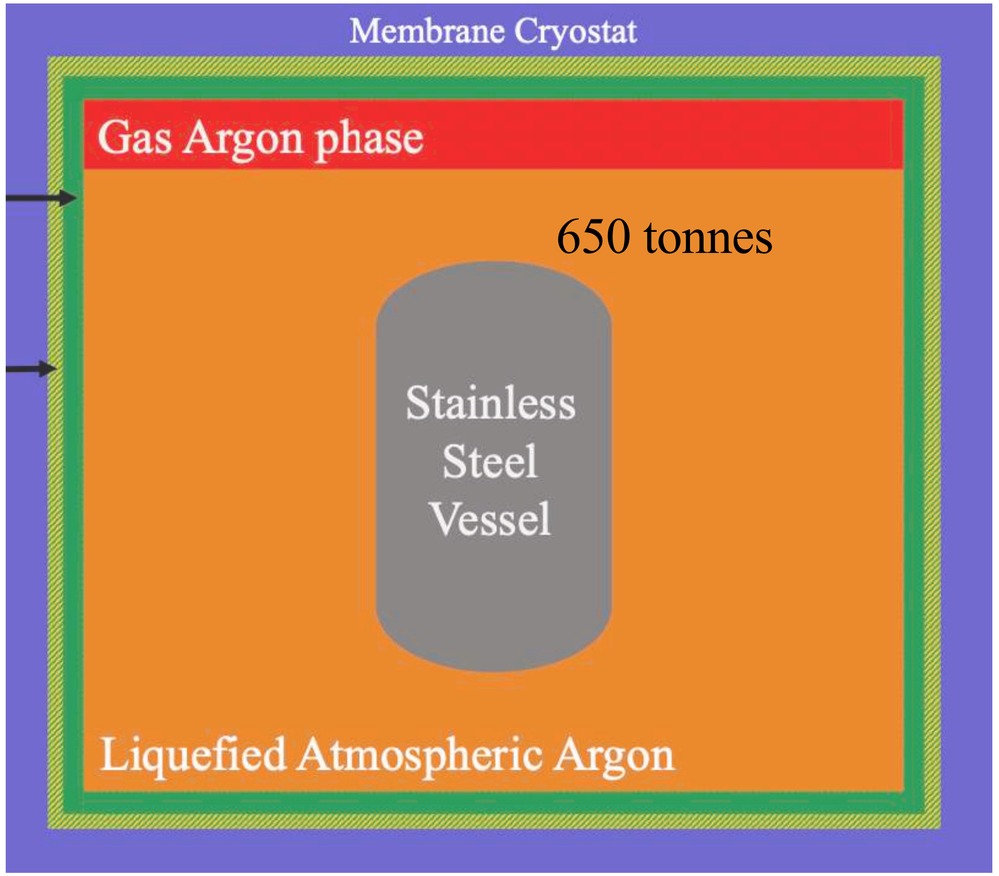



Membrane Cryostat
Gas Argon phase
650 tonnes
Stainless
Steel
Vessel
Liquefied Atmospheric Argon

Outer veto



Low radioactivity membrane cryostat



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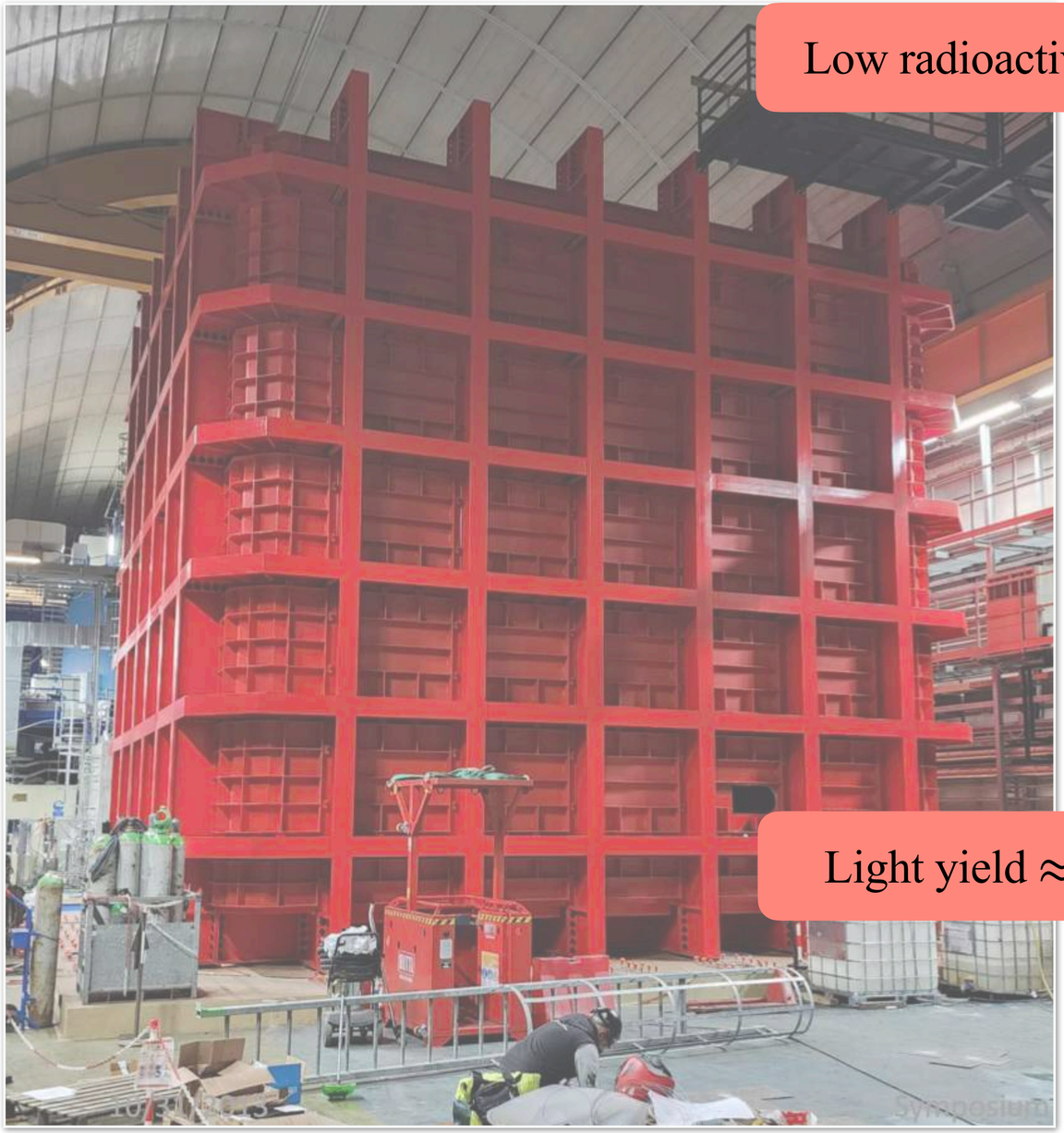
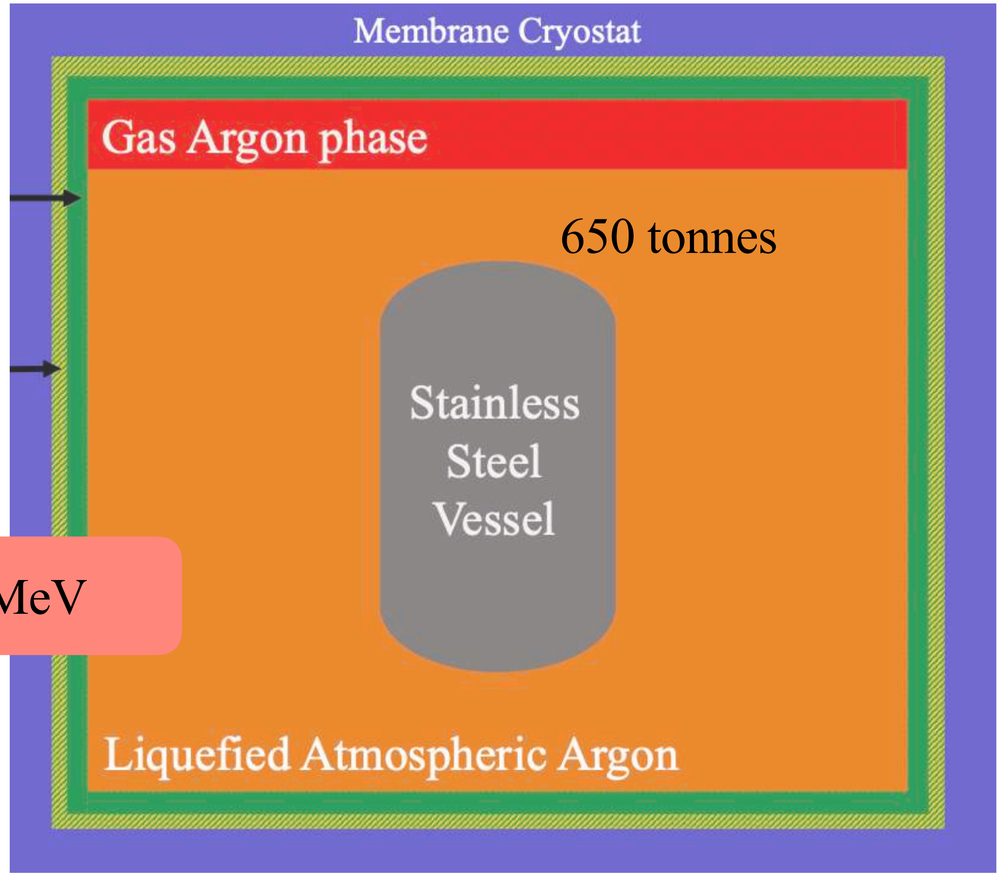


Low radioactivity membrane cryostat

Light yield ≈10 PE/MeV



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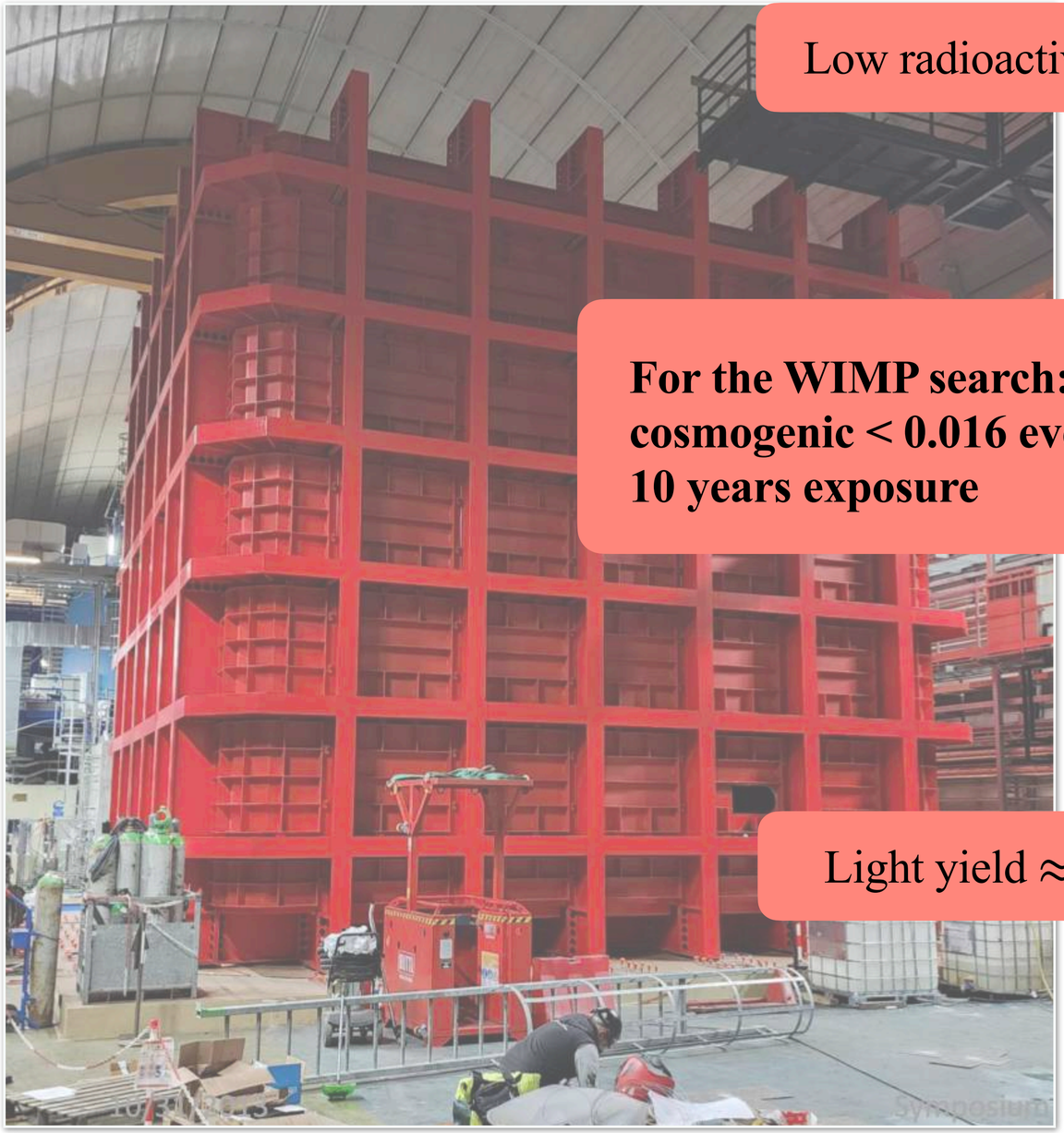

Low radioactivity membrane cryostat

For the WIMP search: cosmogenic < 0.016 events in 10 years exposure

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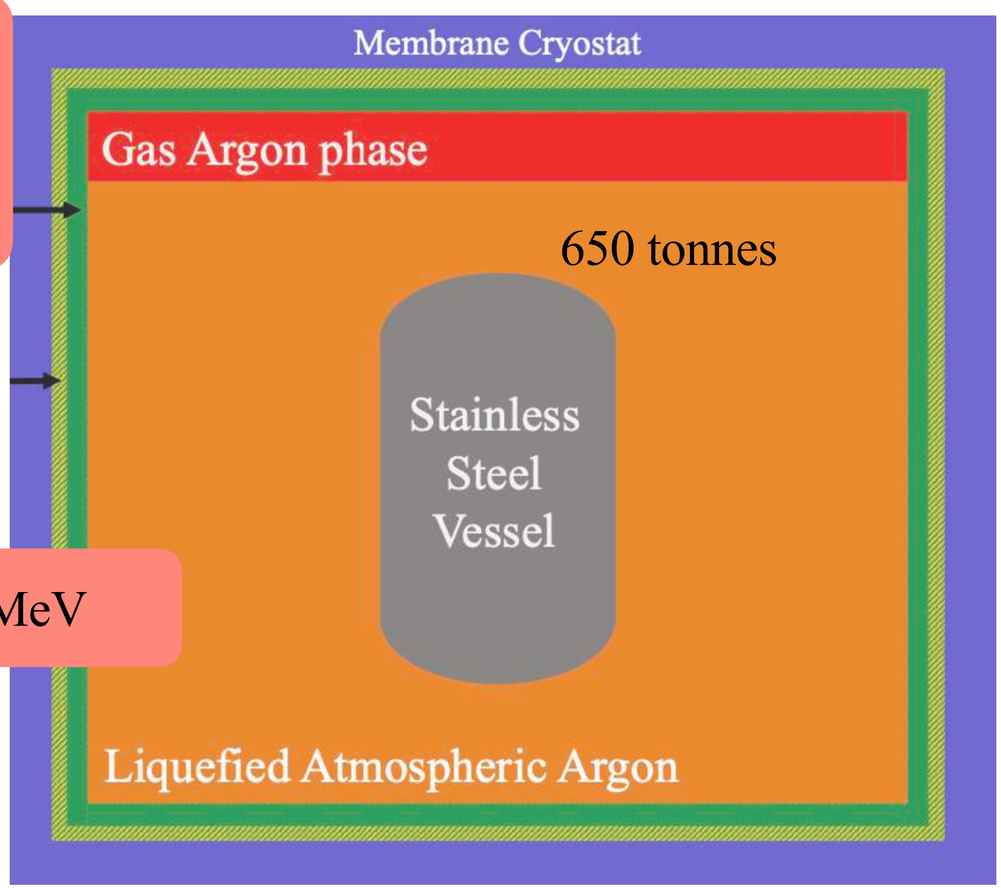

Photodetection

- Silicon Photomultipliers (SiPMs) guarantees the best energy resolution compared to photomultipliers tubes

Requirement for DarkSide-20k

Parameter	7 V of OV	9 V of OV
Internal Cross Talk probability at 77 K	< 33 %	< 50 %
Dark noise rate at 77 K	< 0.01 Hz/mm^2	< 0.1 Hz/mm^2
Afterpulse probability at 77 K [within 5μs]	-	< 10 %
PDE at 420 nm at 77 K	-	>40 %
Breakdown Voltage at 77 K (SPE charge)	26.8 ± 0.2 V	
Breakdown Voltage at 77 K (SPE amplitude)	27.5 ± 0.2 V	
Single Cell Capacitance (from SPE charge)	62.5 ± 2.5 fF	

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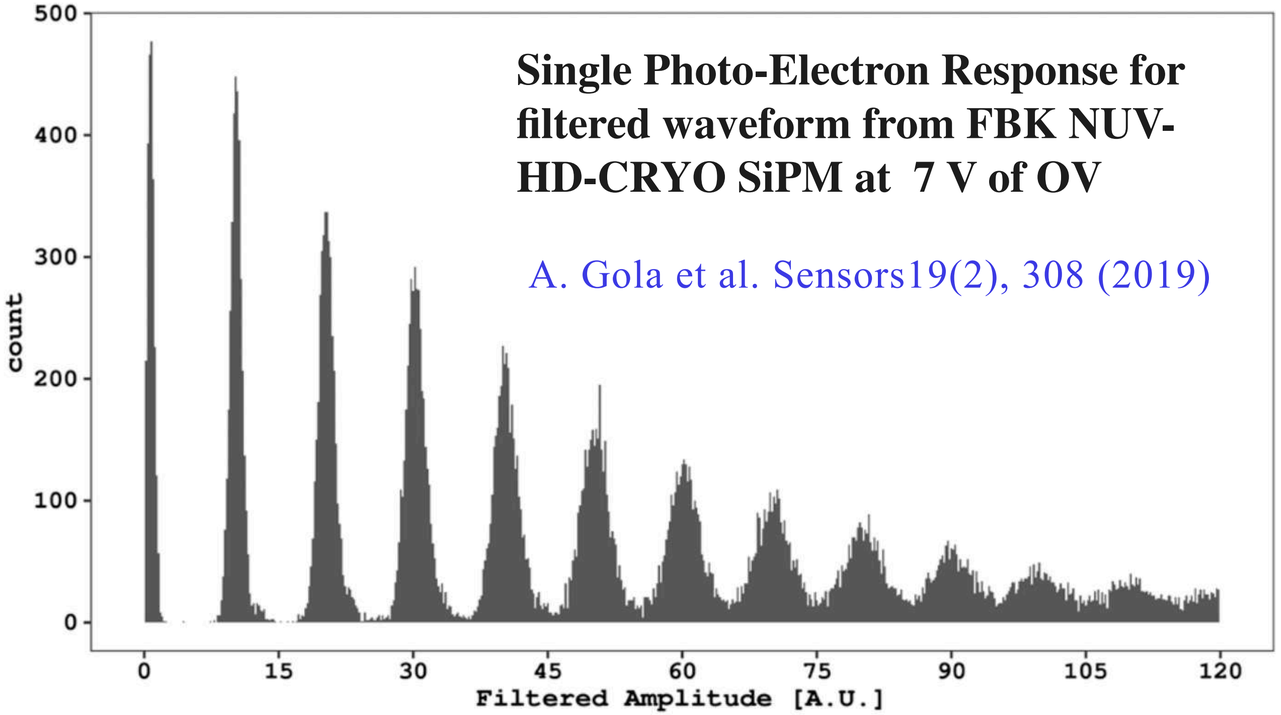
Photodetection

- Silicon Photomultipliers (SiPMs) guarantees the best energy resolution compared to photomultipliers tubes
- NUV-HD Cryo SiPMs developed with Fondazione Bruno Kessler meet all DarkSide-20k requirements



Single Photo-Electron Response for filtered waveform from FBK NUV-HD-CRYO SiPM at 7 V of OV

A. Gola et al. Sensors19(2), 308 (2019)

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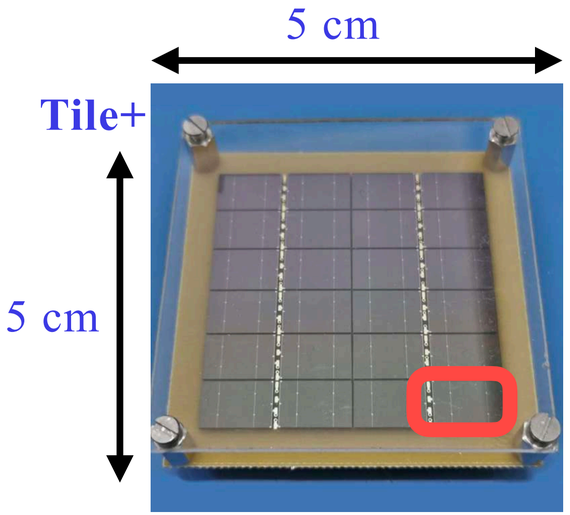
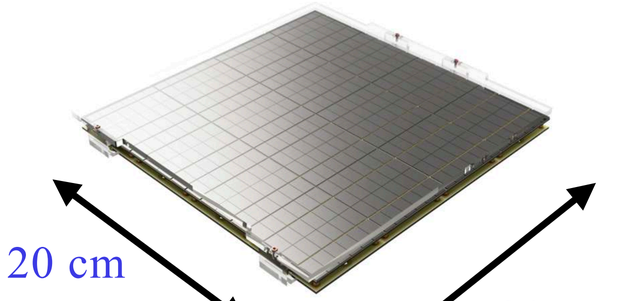
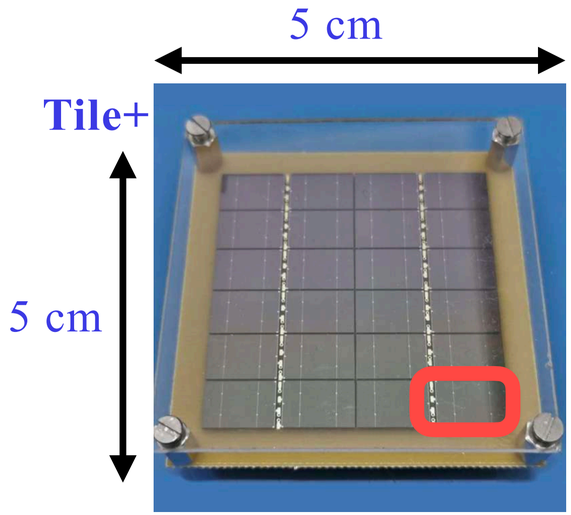


24 SiPMs = 1 Tile

Photodetection

14 Tiles = 1 PDU





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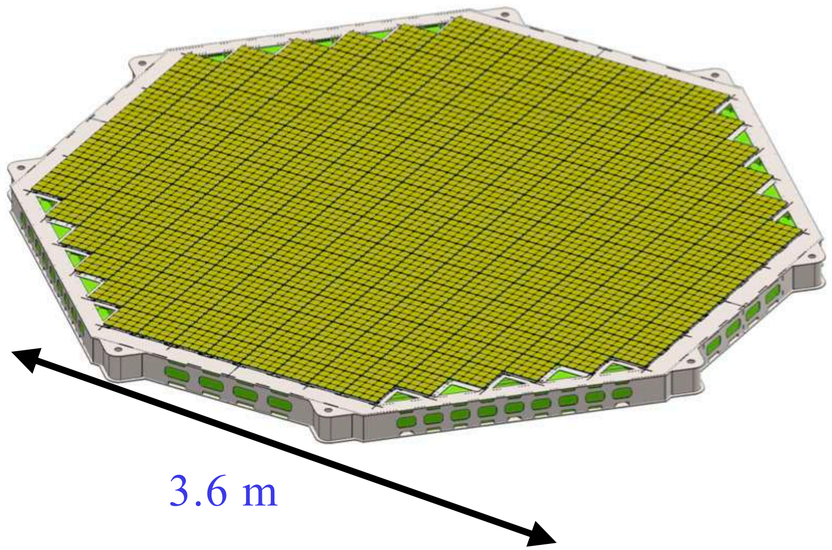

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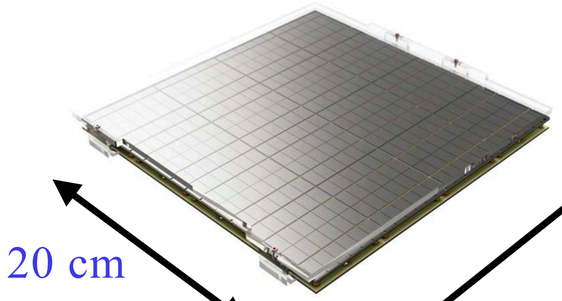
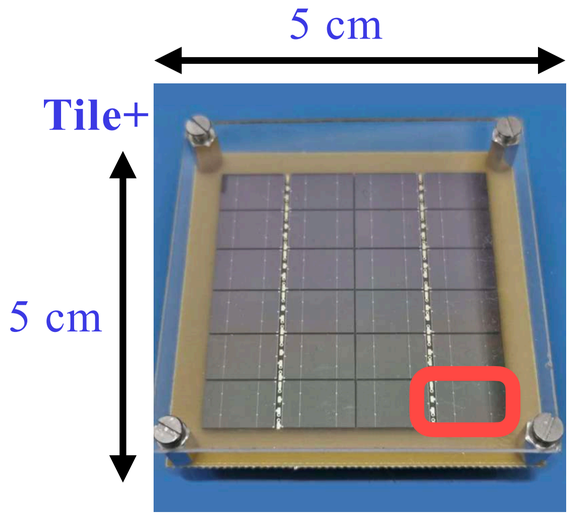


TPC: 525 vPDU

IV: 20 vPDU

OV: 32 vPDU



24 SiPMs = 1 Tile

DAQ

Parameter	Value
Total number of readout channels in TPC detector	2112
Total number of readout channels for inner Veto detector	480
Total number of readout channels for outer Veto detector	128
Minimum number of digitizer boards for TPC readout	36
Minimum number of digitizer boards for inner and outer Veto readout	12

DAQ

2 Waveform digitizers

2 Waveform digitizers

2 x 250 MB/s

Parameter	Value
Total number of readout channels in TPC detector	2112
Total number of readout channels for inner Veto detector	480
Total number of readout channels for outer Veto detector	128
Minimum number of digitizer boards for TPC readout	36
Minimum number of digitizer boards for inner and outer Veto readout	12

DAQ

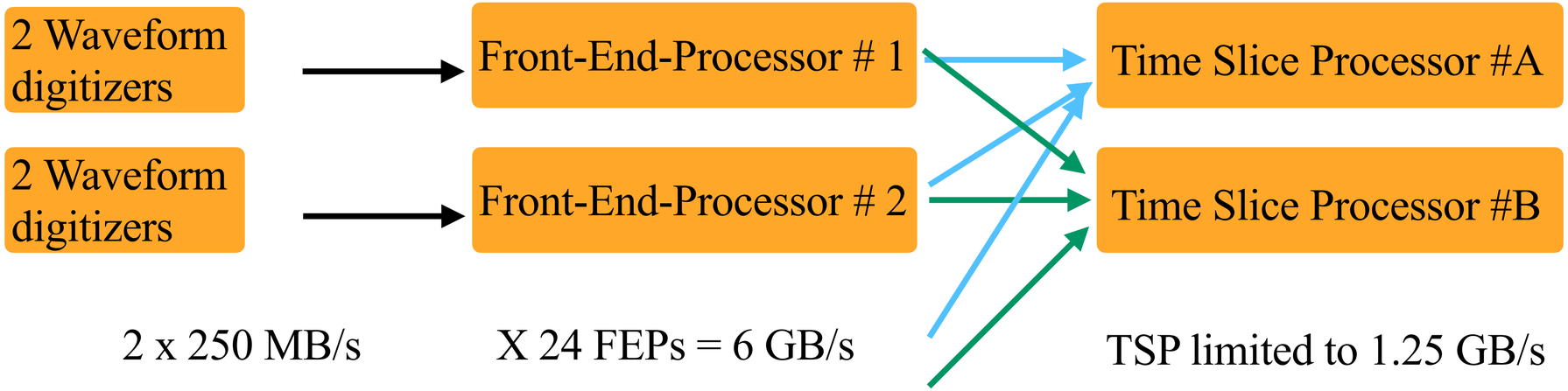
2 Waveform digitizers → Front-End-Processor # 1

2 Waveform digitizers → Front-End-Processor # 2

2 x 250 MB/s X 24 FEPs = 6 GB/s

Parameter	Value
Total number of readout channels in TPC detector	2112
Total number of readout channels for inner Veto detector	480
Total number of readout channels for outer Veto detector	128
Minimum number of digitizer boards for TPC readout	36
Minimum number of digitizer boards for inner and outer Veto readout	12

DAQ



Parameter	Value
Total number of readout channels in TPC detector	2112
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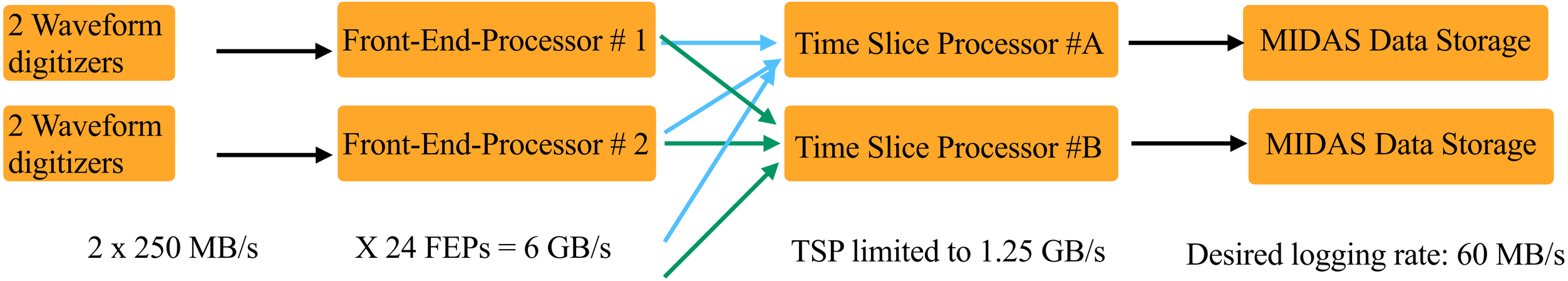
Minimum number of digitizer boards for inner and outer Veto readout	12

DAQ



Parameter	Value
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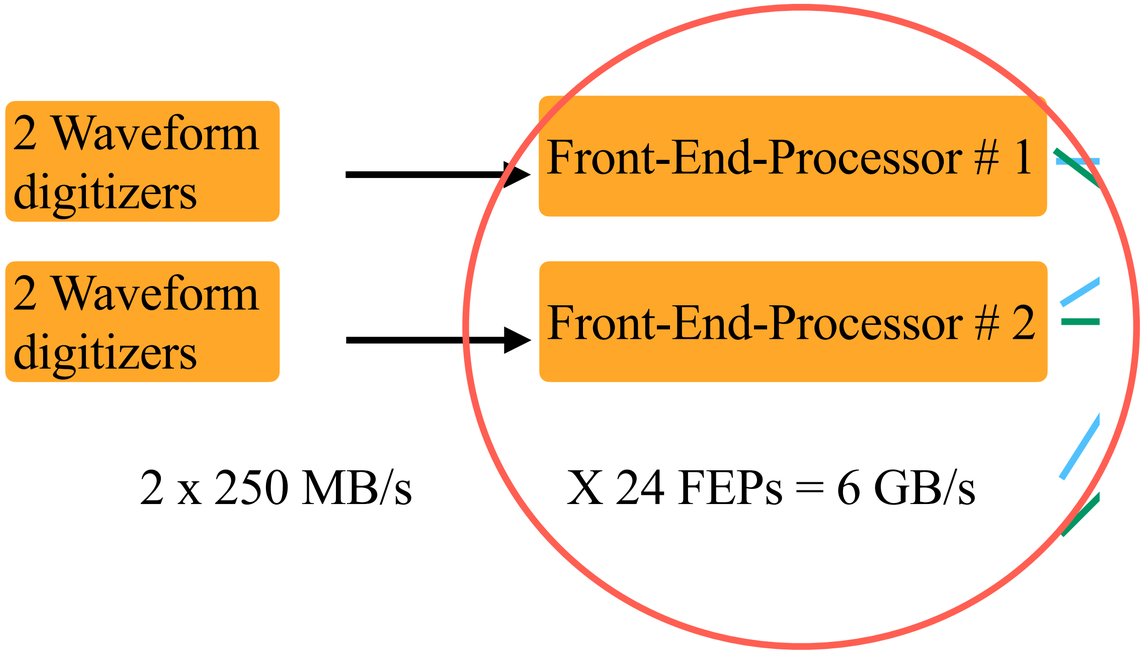
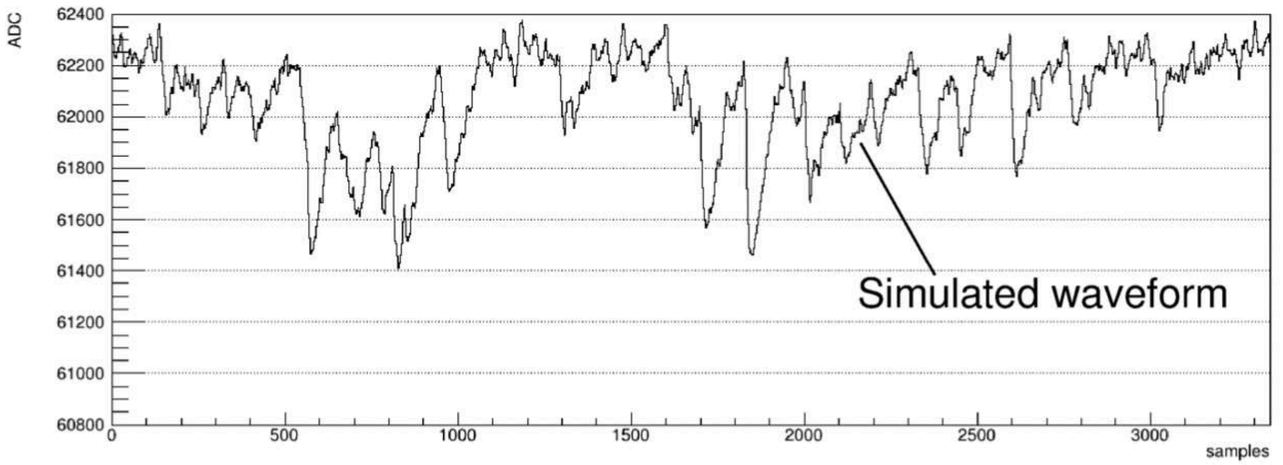
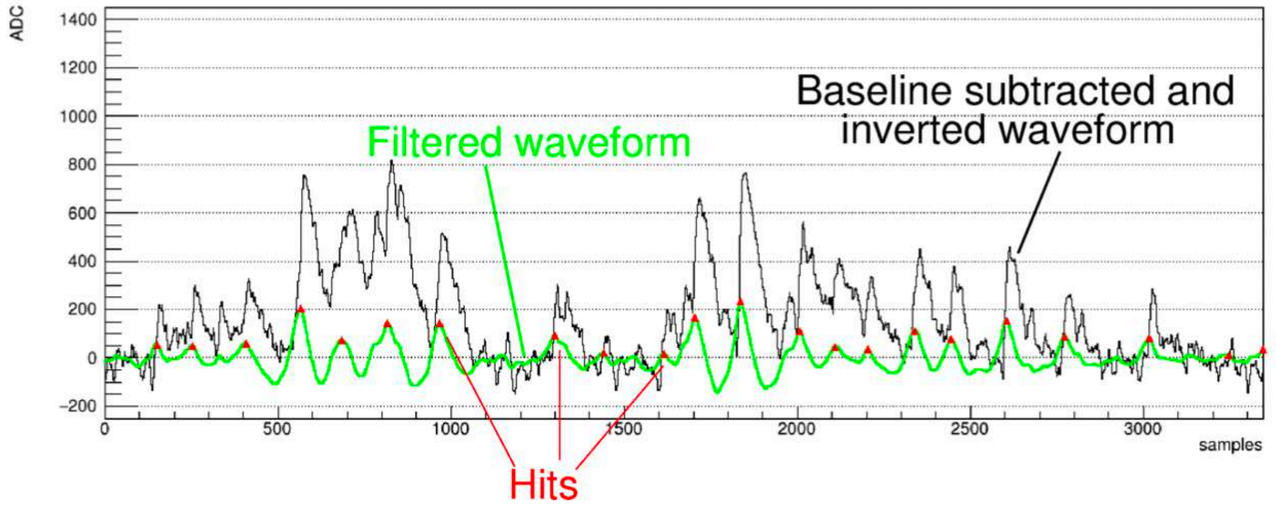
DAQ

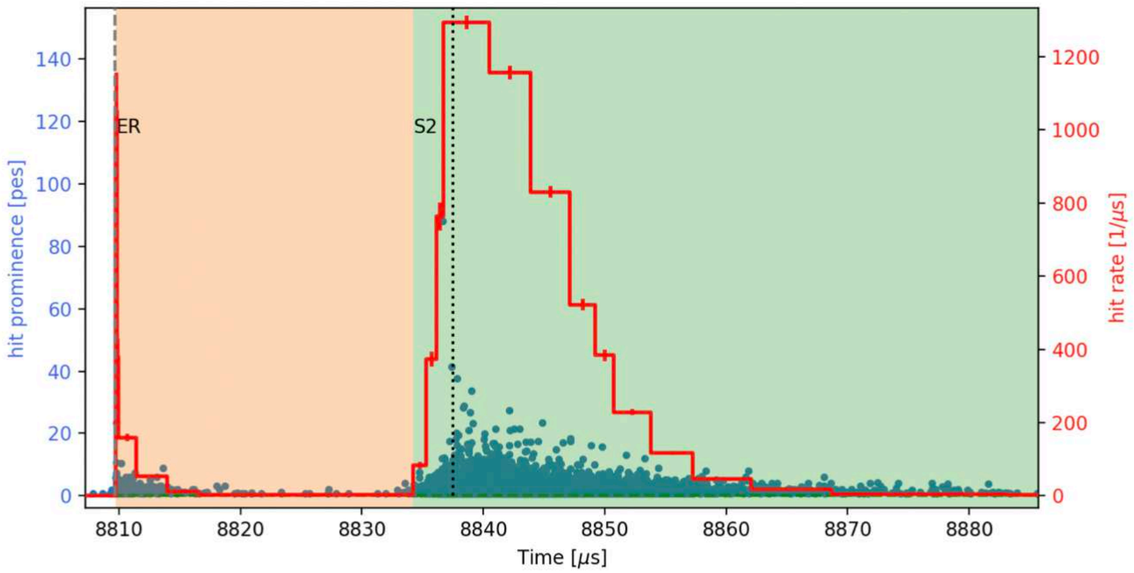






Parameter	
Total number of readout channels in TPC	
Total number of readout channels for inn	
Total number of readout channels for out	
Minimum number of digitizer boards for	
Minimum number of digitizer boards for inner and outer Veto readout	12

DAQ



Example detector analysis: clustering and *pulse shape discrimination* (Credit: T. Hessel, APC)

Parameter	Value
Total number of readout channels in TPC detector	2112
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Total number of readout channels for outer Veto detector	128
Minimum number of digitizer boards for TPC readout	36
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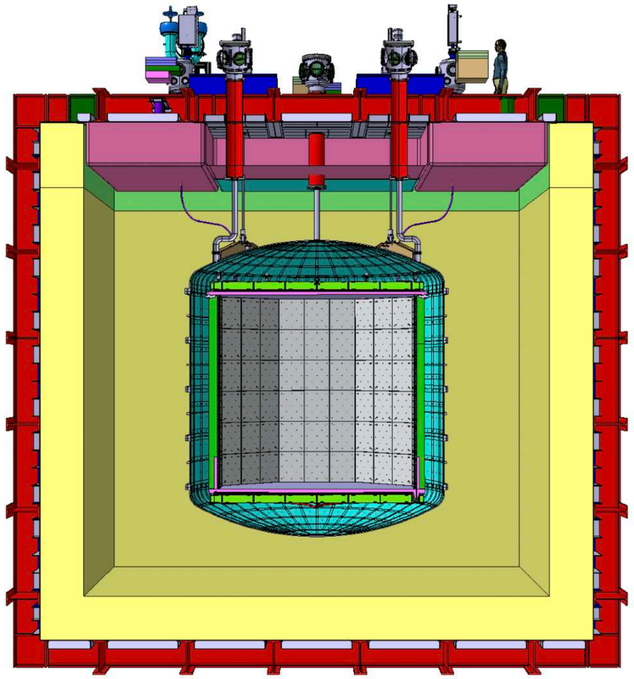
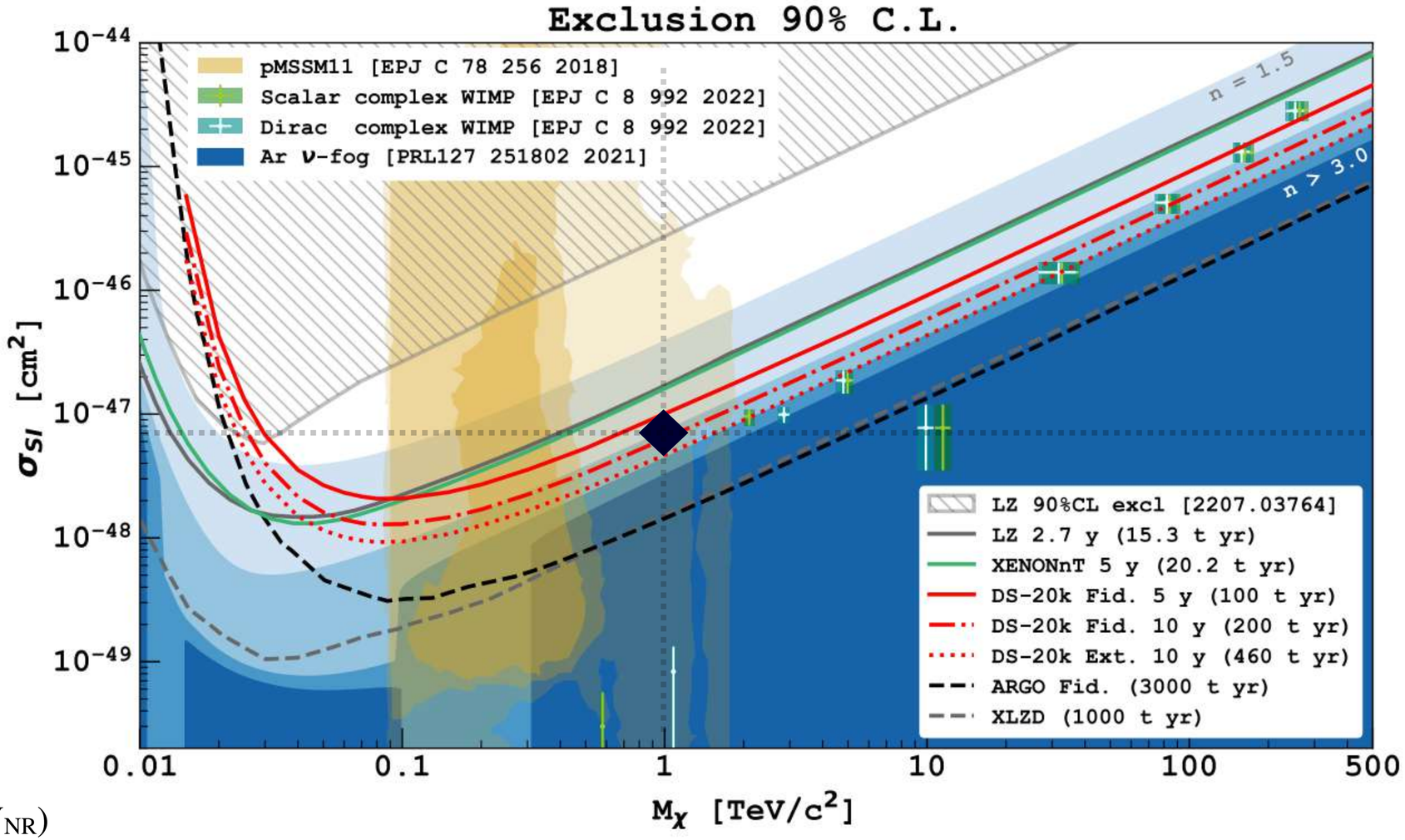
Double Phase TPC





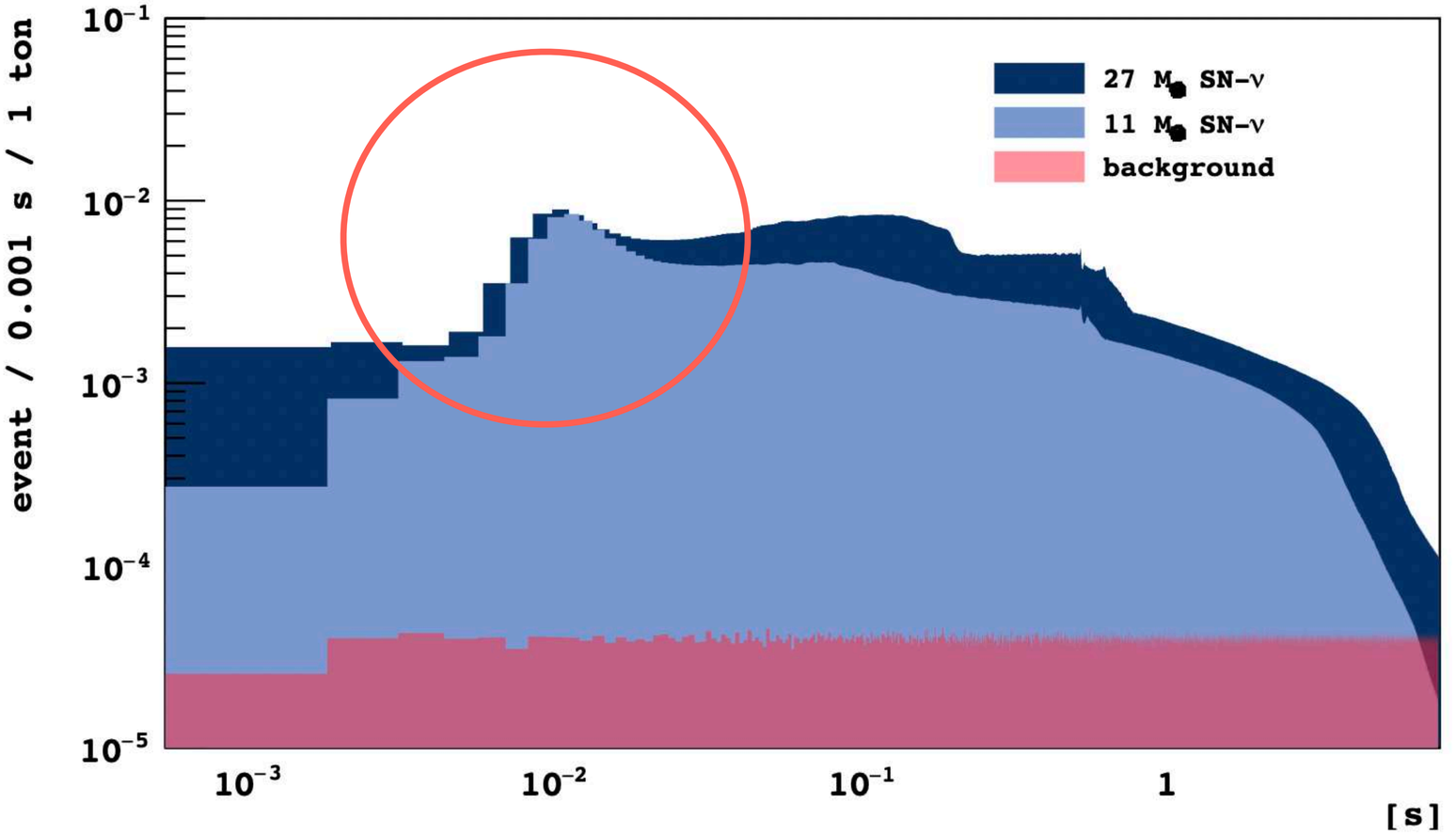
- With 20 tonnes x 10 years:
  - Instrumental background:
    < 0.1 neutrons in RoI (30~200 keV$_{NR}$)
  - 90% C.L. exclusion:
    6.3 x 10^{-48} cm^2 at 1 TeV/c^2

Multi-messenger

- **Demonstrated outstanding sensitivity to neutrinos from an eventual Core Collapse Supernova**

Multi-messenger

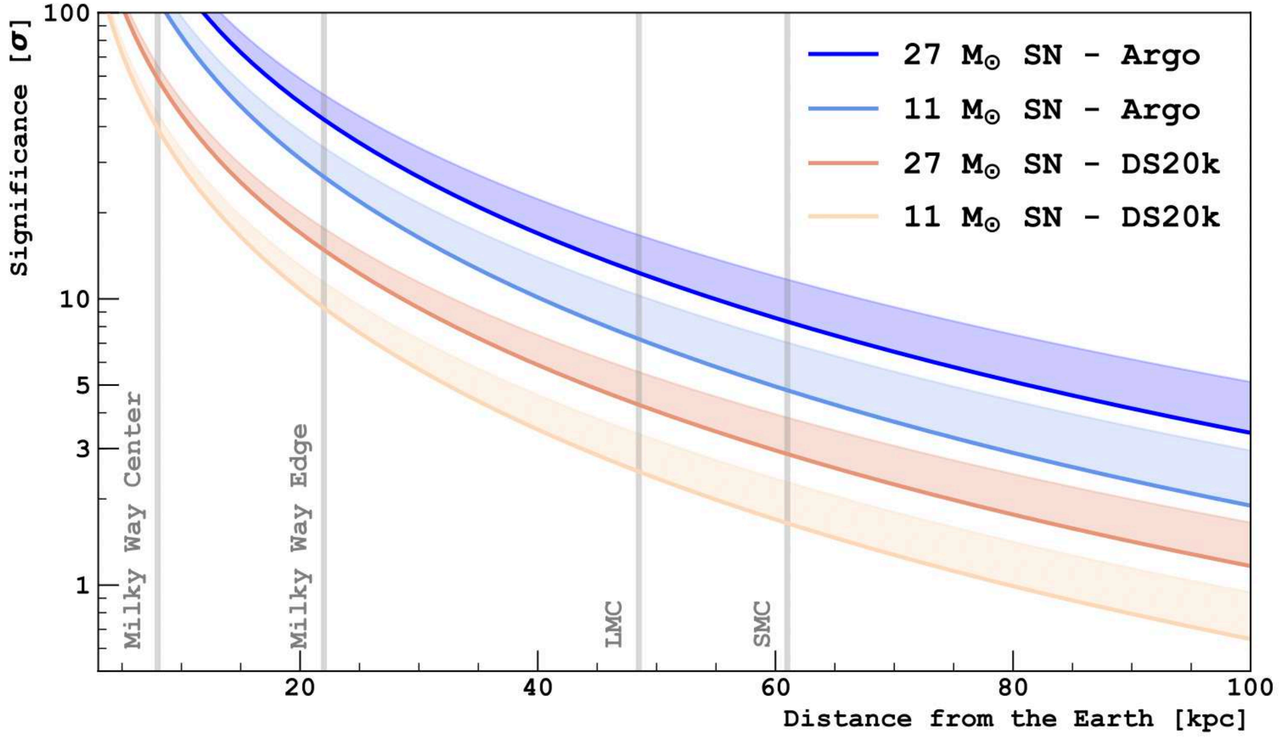
- **Demonstrated outstanding sensitivity to neutrinos from an eventual Core Collapse Supernova**



Journal of Astroparticle Physics 03(2021)043

Multi-messenger

- No PSD available, extremely low background in the SN time-lapse
- Unique sensitivity among noble liquid detectors to Core-Collapse supernovae
- Sensitive to all neutrino flavors

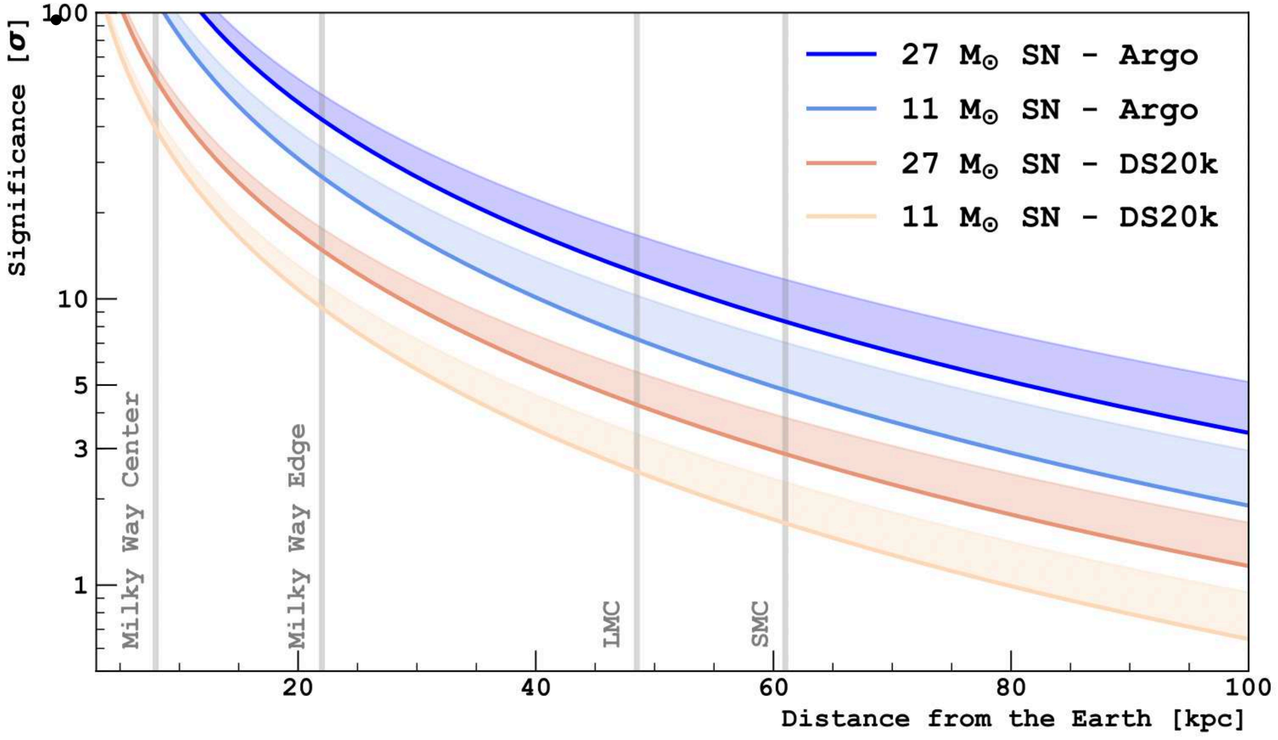


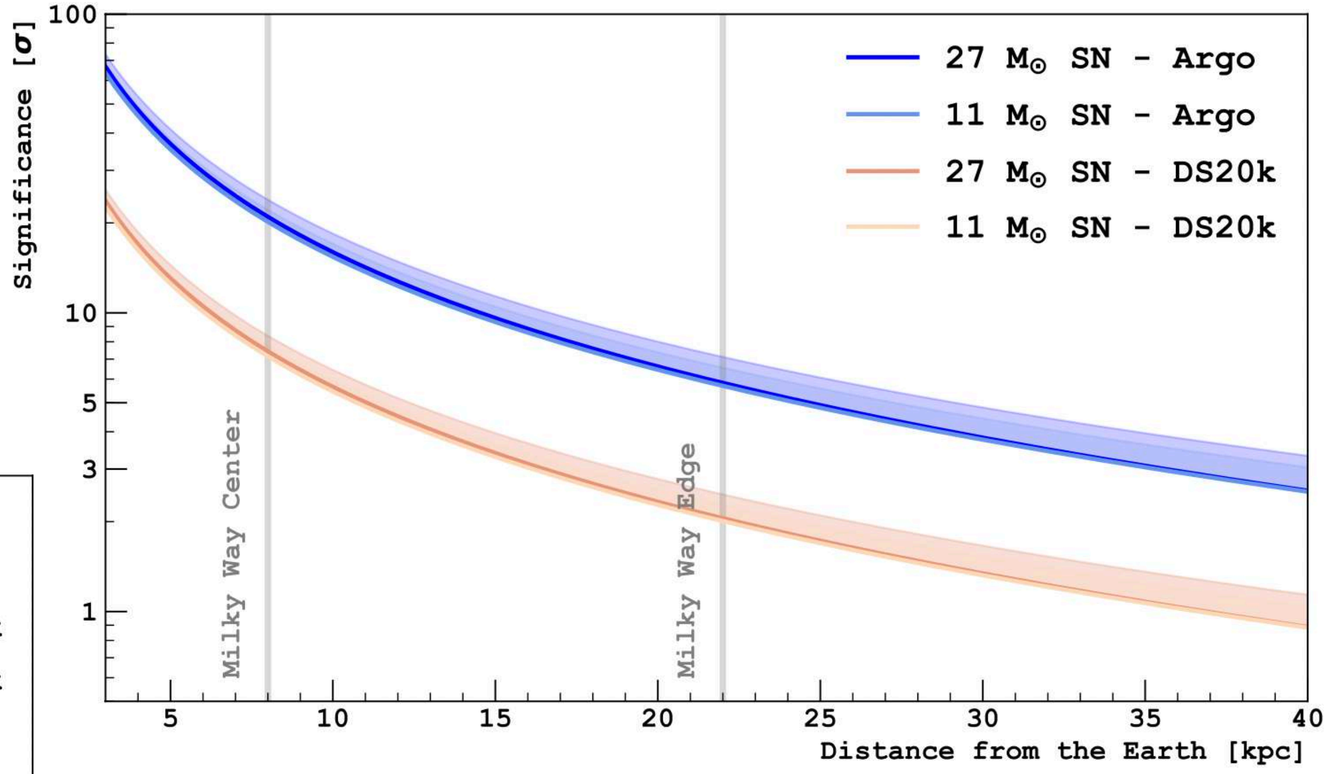
	DarkSide-20k	Argo
11-$M_\odot$ SN-νs	181.4	1396.6
27-$M_\odot$ SN-νs	336.5	2591.6
^{39}Ar	4.3	33.8
external background	1.8	8.8
single-electrons	0.7	5.1

Journal of Astroparticle Physics 03(2021)043

Multi-messenger

- No PSD available, extremely low background in the SN time-lapse
- Unique sensitivity among noble liquid detectors to Core-Collapse supernovae
- Sensitive to all neutrino flavors
- Sensitivity up to the Milky Way Center also to the neutronization burst only
- Contribution to the Supernova Early Warning System





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Journal of Astroparticle Physics 03(2021)043

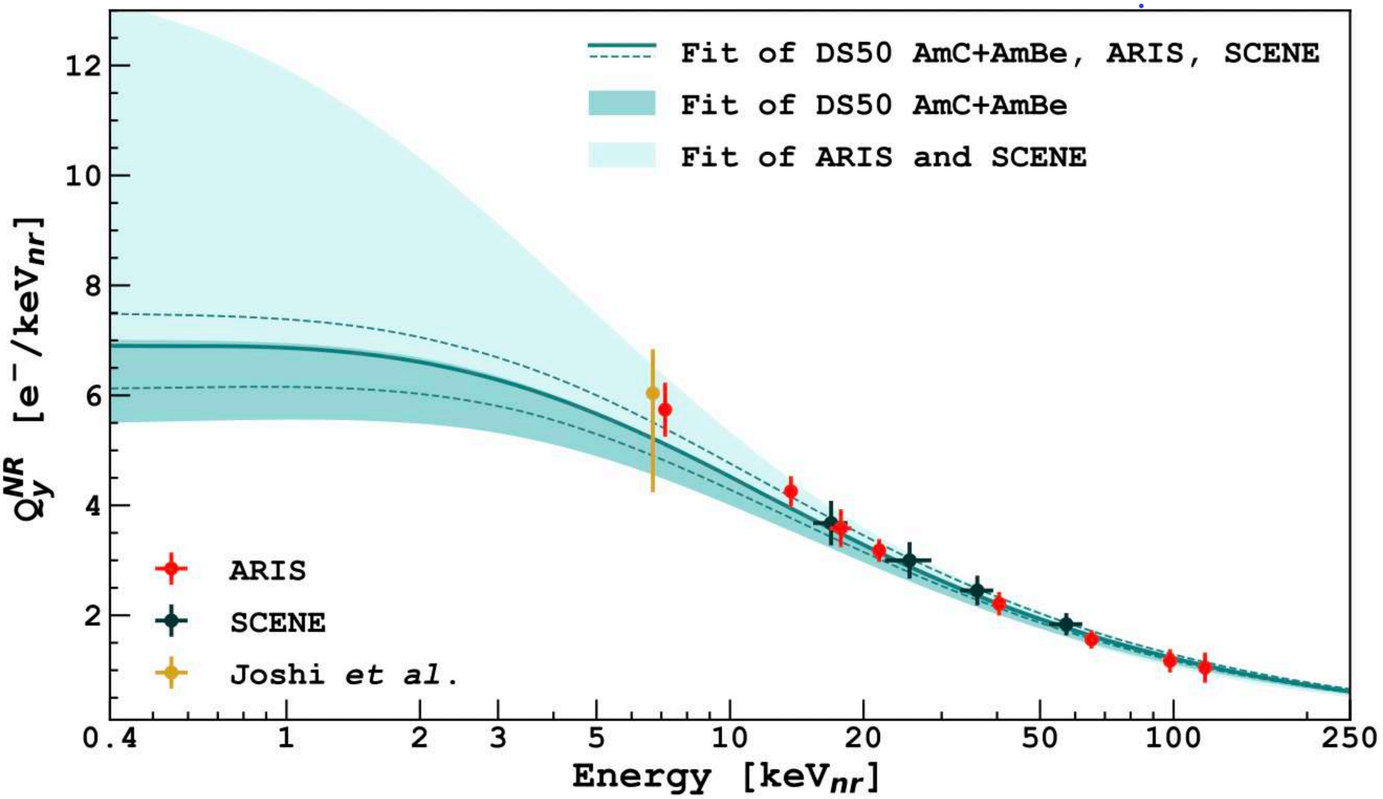
Low mass searches

Additional research program:

sensitivity to low mass candidates with S2-only

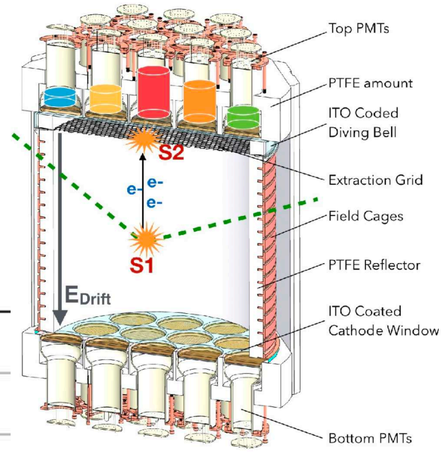
No PSD available

Background from spurious electrons at < 4 e-

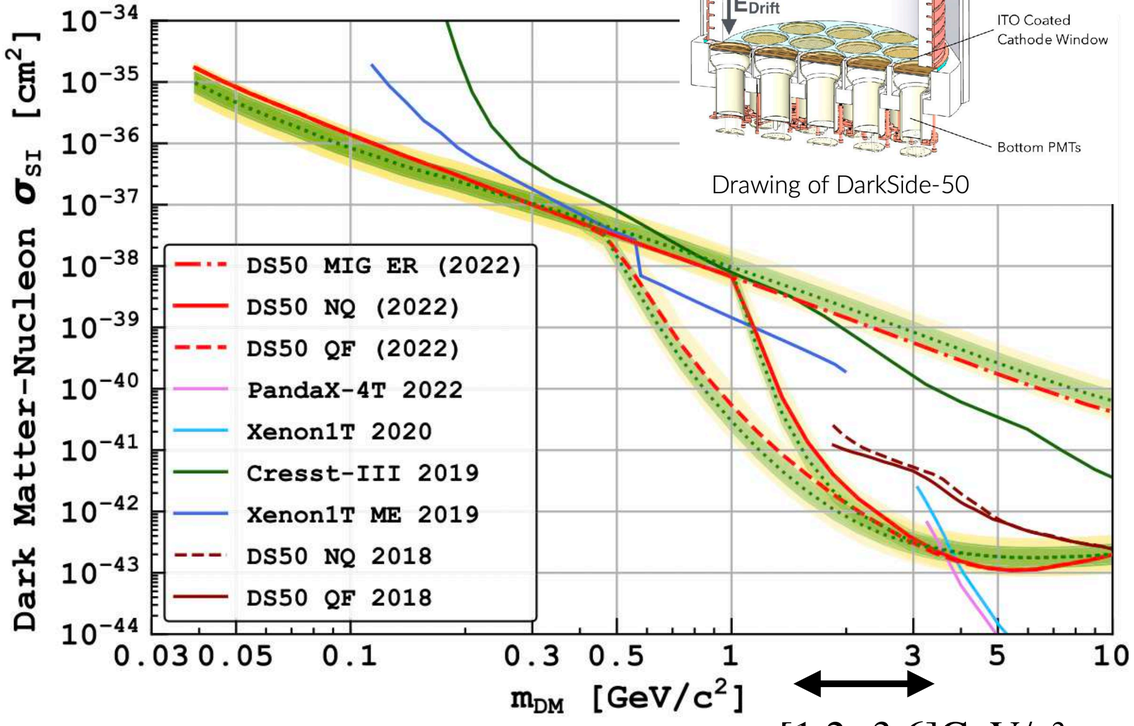


[Physical Review D 104, 082005 (2021)]

0.4 keV (S2-only) 6 keV (S1+S2)



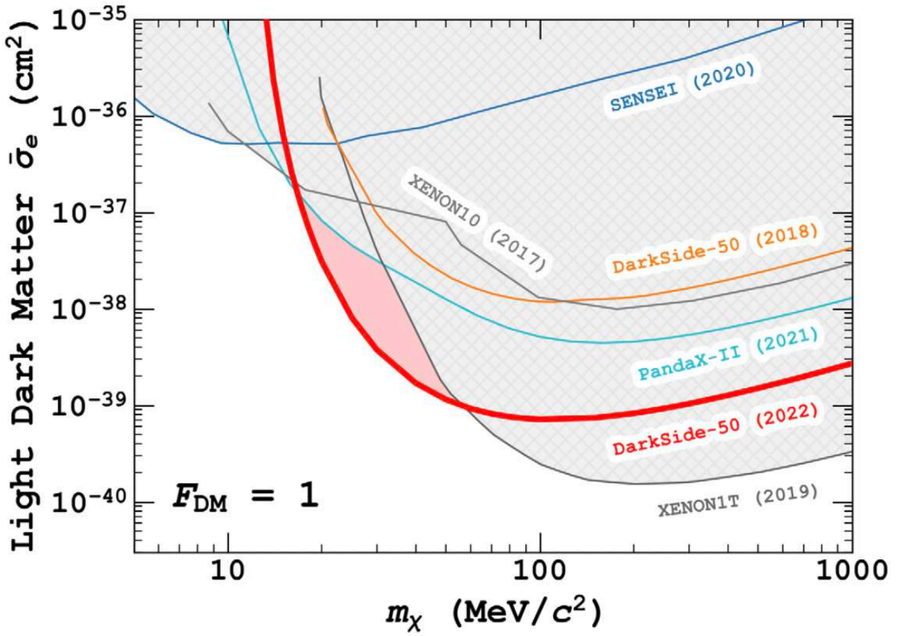
Drawing of DarkSide-50

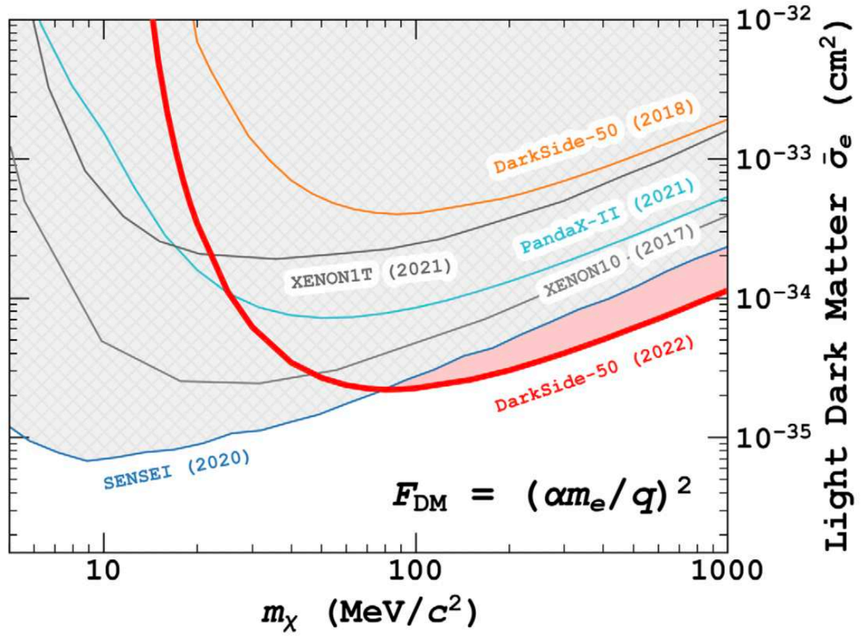


[1.2 -3.6]GeV/c^2

[Physical Review Letters 130, 101001 (2023)]

Low mass searches

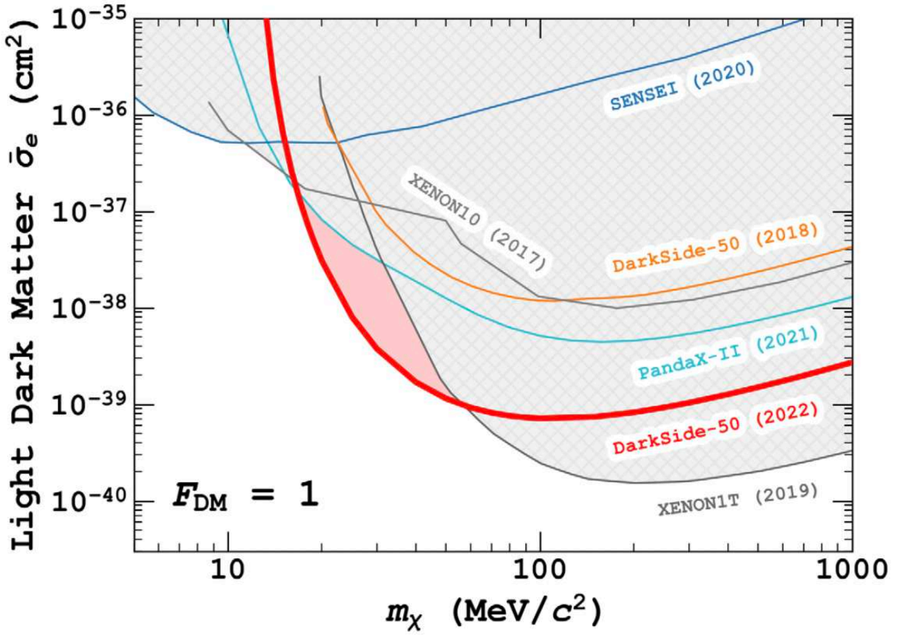


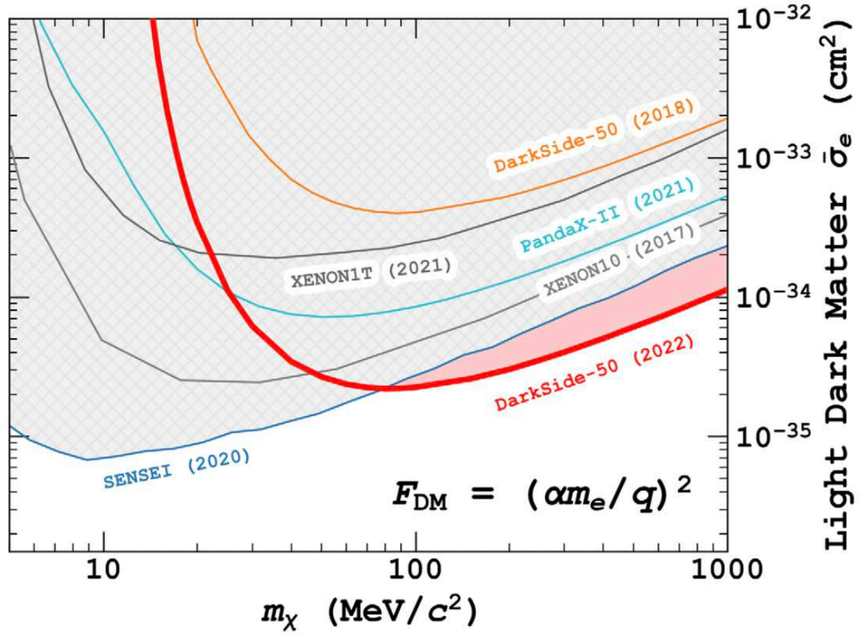


Anelastic scattering of fermion or bosons on Argon through light mediators

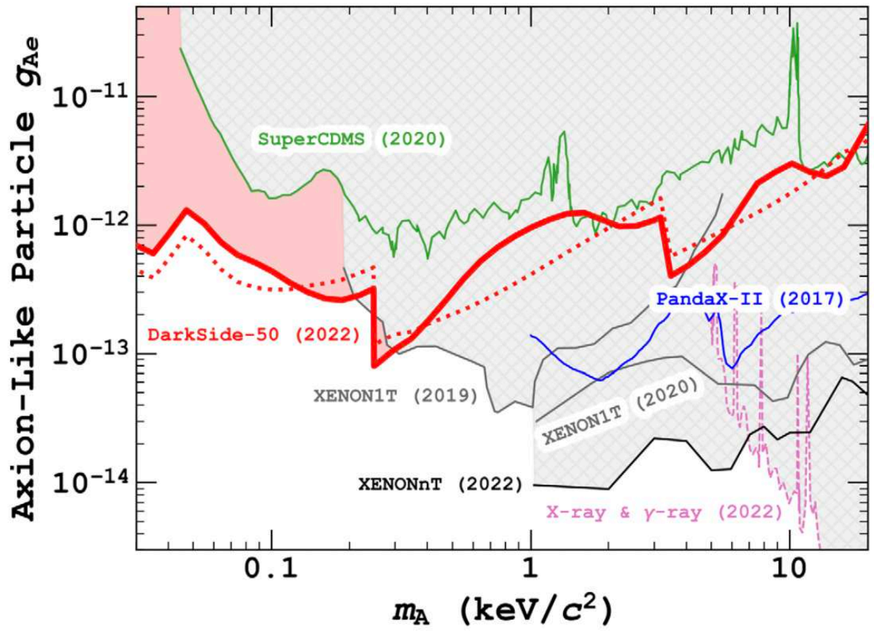
Physical Review Letters 130, 101002 (2023)

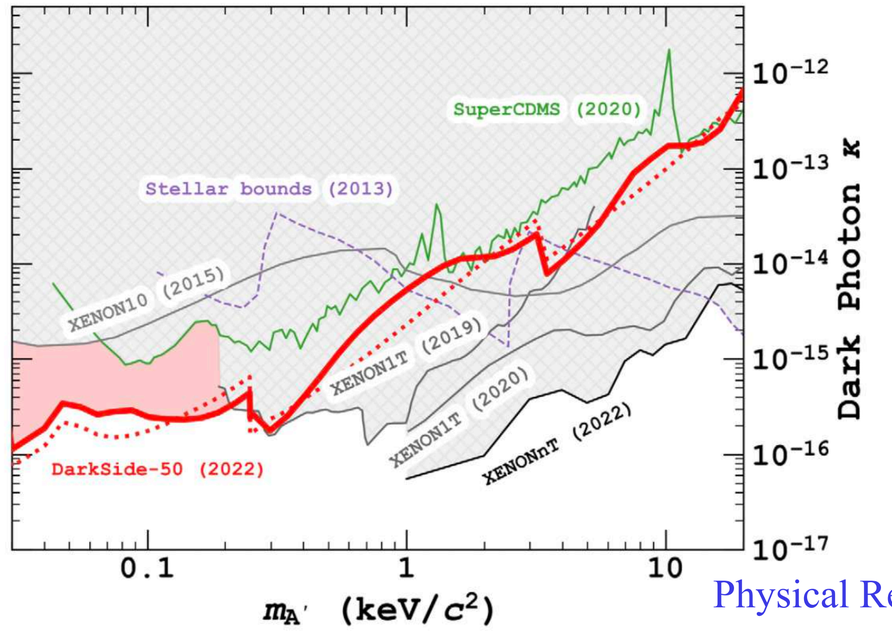
Low mass searches





Anelastic scattering of fermion or bosons on Argon through light mediators

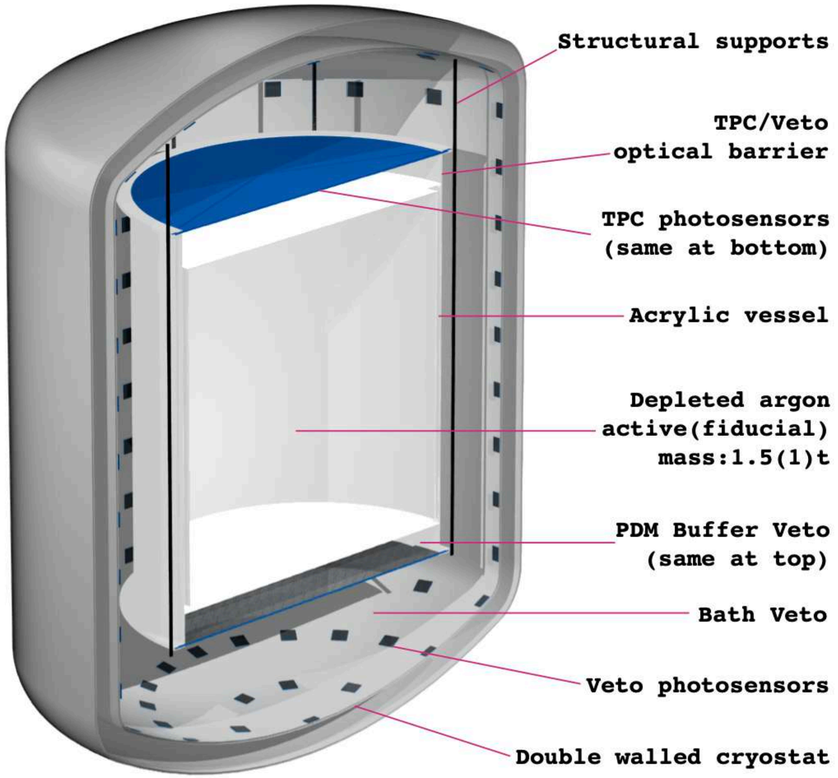




Absorption of ALPS by argon shell electrons

Physical Review Letters 130, 101002 (2023)

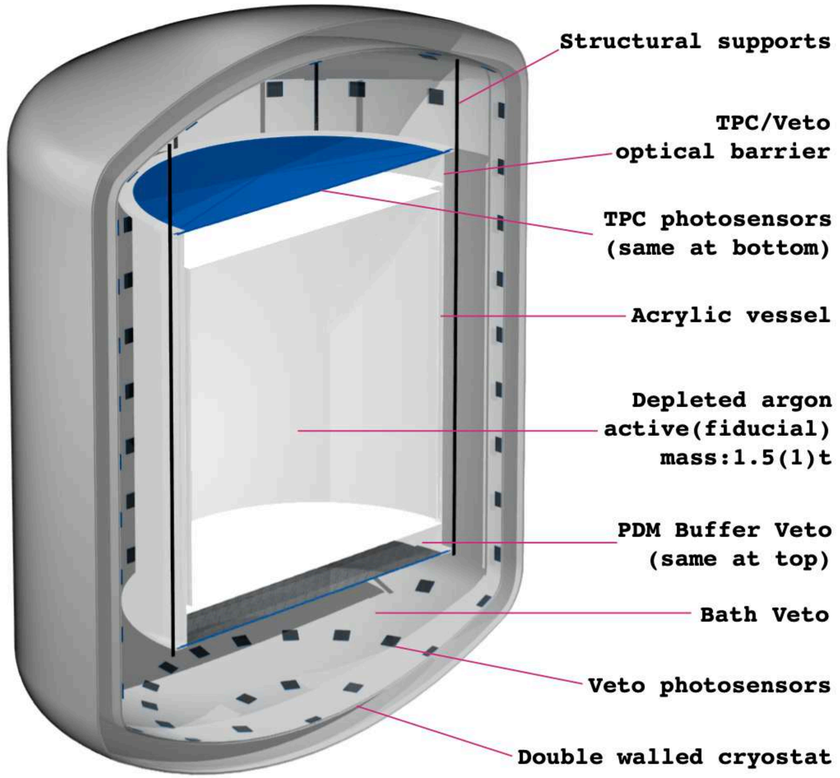
Low mass



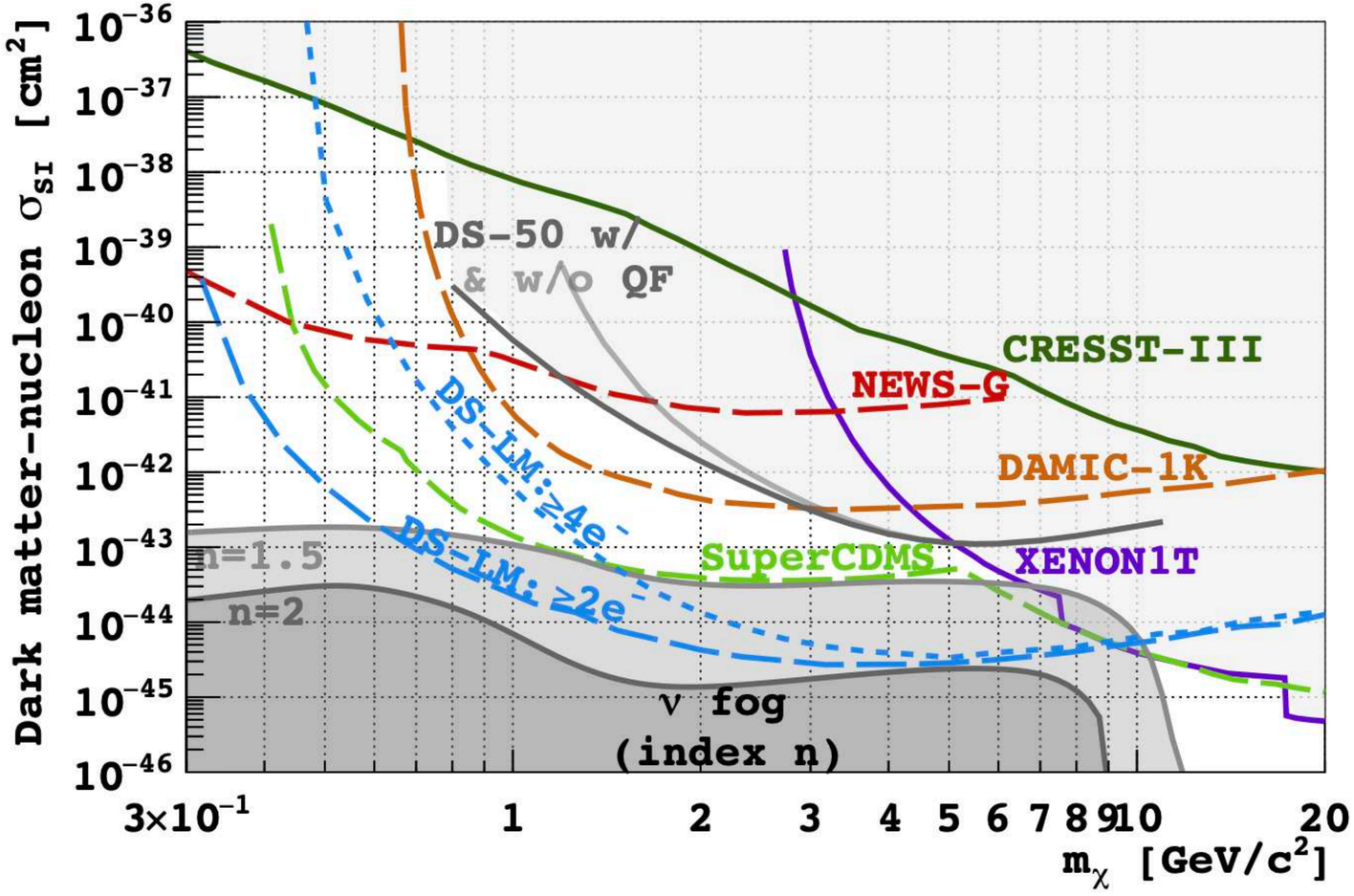
- Optimized for the S2-only analysis

Phys. Rev. D 107, 112006 (2023)

Low mass

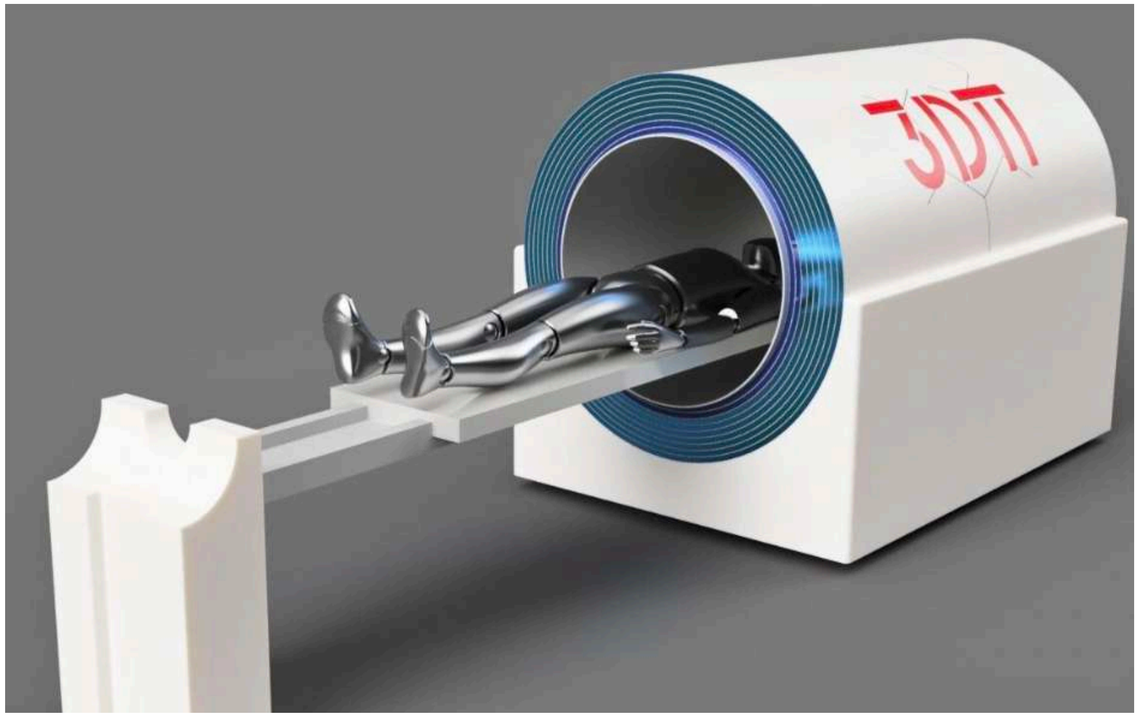


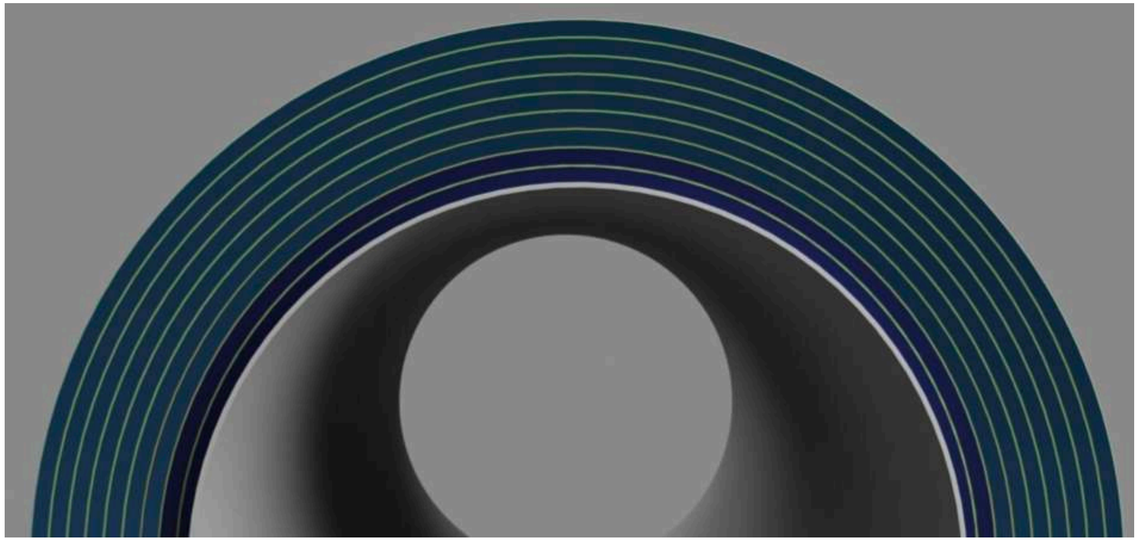
- Optimized for the S2-only analysis
- Sensitive to the neutrino fog with 1 tonne year exposure

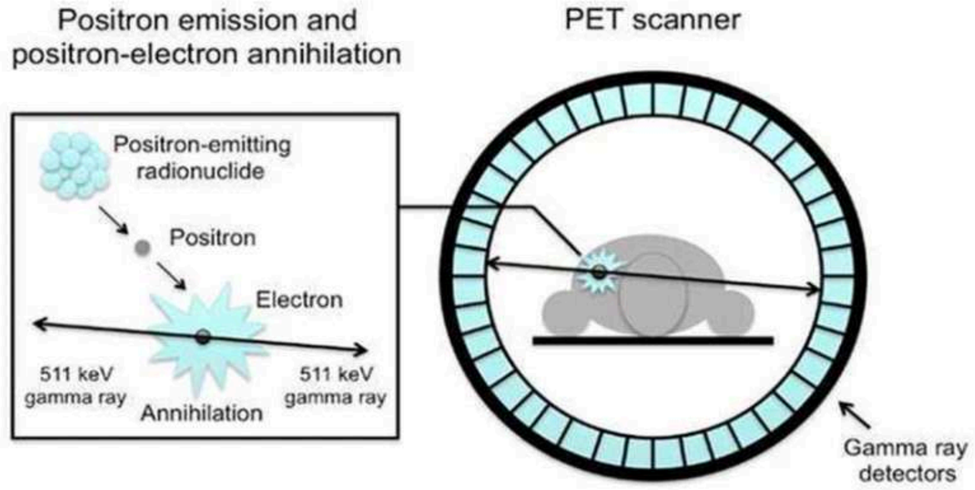


Phys. Rev. D 107, 112006 (2023)

3DPi







- Time-of-Flight PET scanner Total body design
- Ongoing R&D using DarkSide-20k technology on medical physics
- Xenon-doped argon as scintillator medium observed by VUV-sensitive SIPMs
- Low dose or ultra-fast scanning time!

NSS/MIC 2021 and RTSD2021 Proceeding

PoS EPS-HEP2021 (2022) 778

Take home

- DarkSide-20k is the first experiment from GADMC, now in the construction phase at LNGS
- Material essay, geometry and R&Ds pursued to make it an instrumental background free experiment
- DarkSide-50 has achieved instrumental background free high mass WIMP results, and world-leading low mass WIMP results
- These results will at minimum scale with DarkSide-20k target mass
- Contribution to SNEWS

UCR PHYSICS & ASTRONOMY

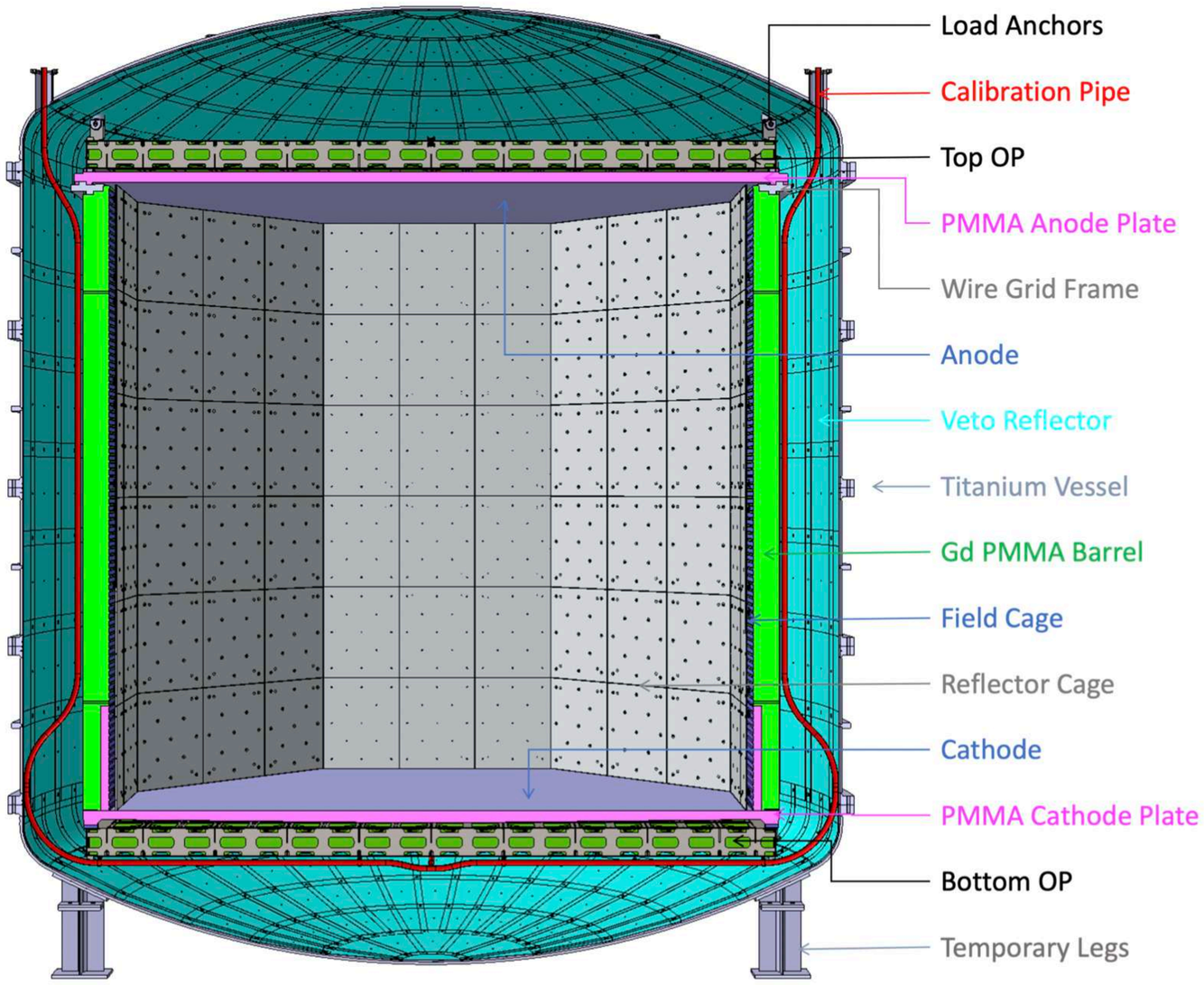
DBD23

Back-up

Michela Lai

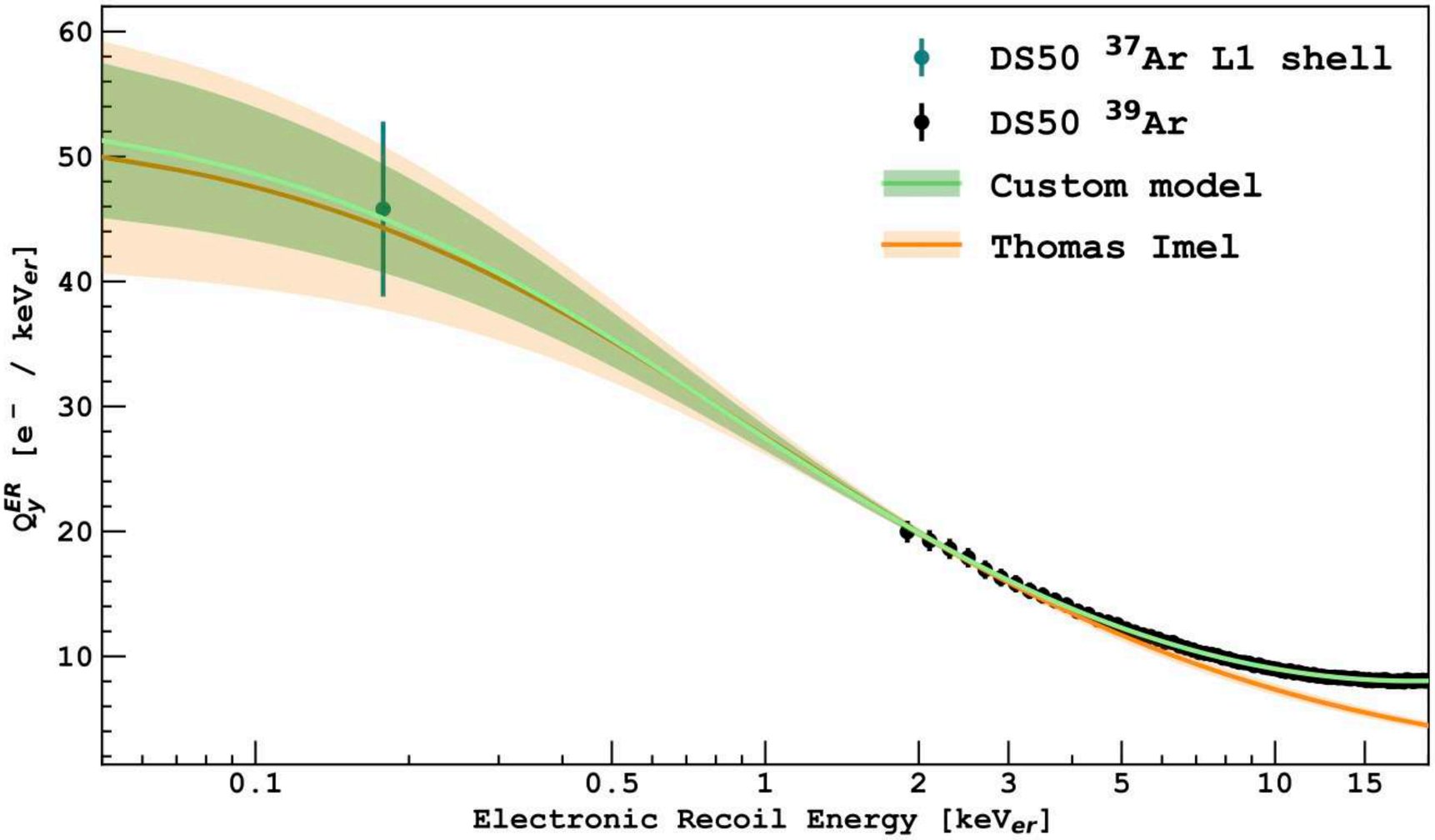
On behalf of DARKSIDE

Inner detector

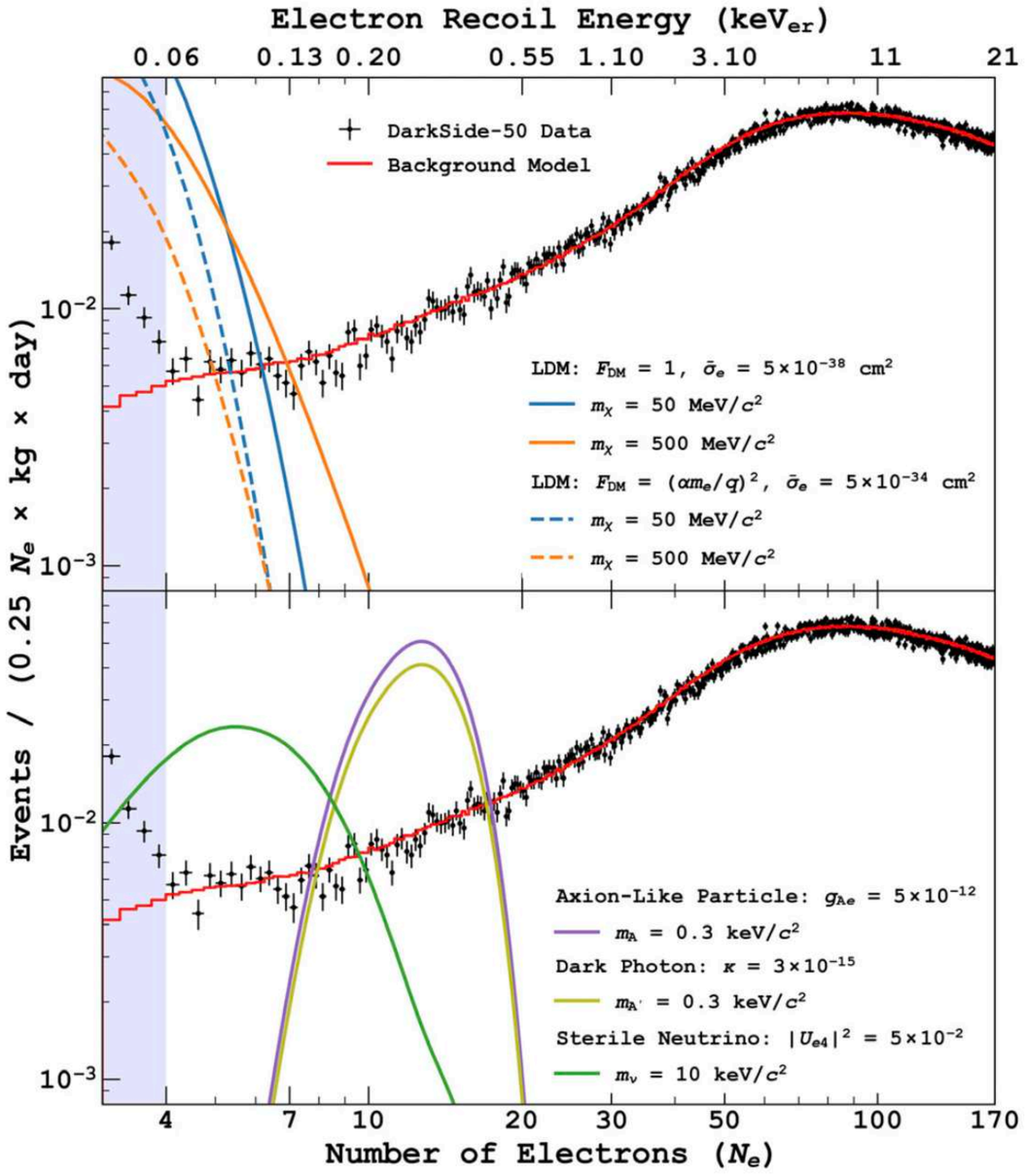


- Octagonal shape dual phase TPC
- Active UAr Mass: 49.7 tonnes
- Fiducial UAr Mass: 20.2 tonnes
- Structure built in pure and Gd-doped acrylic
- ESR serving as reflector and TPB as wavelength shifter
- Drift field: 200 V/cm
- Extraction field $\geq$ 2.8 kV/cm
- Clevios™ coating serving as anode, cathode and field cage rings
- Stainless steel wire for the electron extraction grid
- Gas pocket thickness: (7.0 $\pm$ 0.5) mm
- LY at null field: 10 PE/keV$_{ee}$
- S2 yield > 20 PE/e-

ER Ionization yield

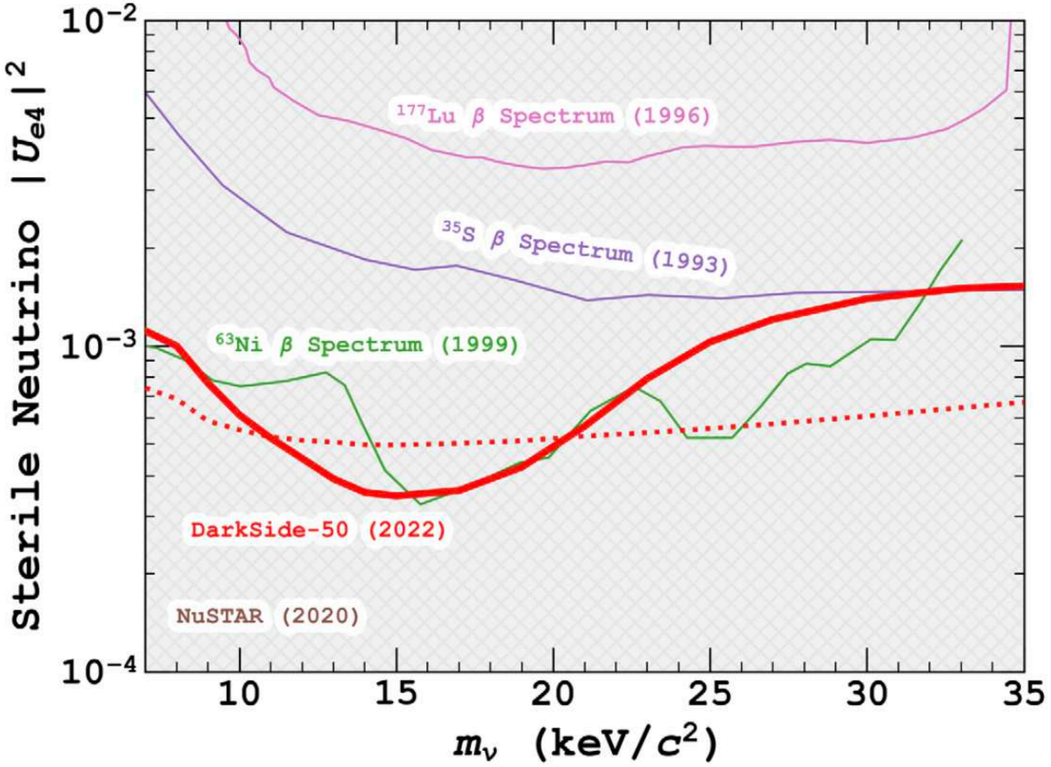


Low mass searches



First search for sterile neutrinos in a noble liquid filled dark matter detector

$$\nu_s + e^- \rightarrow \nu_e + e^- \qquad \bar{\nu}_s + e^- \rightarrow \bar{\nu}_e + e^-$$



Physical Review Letter 130, 101002 (2023)