DarkSide-50 Results and future Liquid Argon Dark Matter Program

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on the behalf of the DarkSide collaboration

DarkSide-50

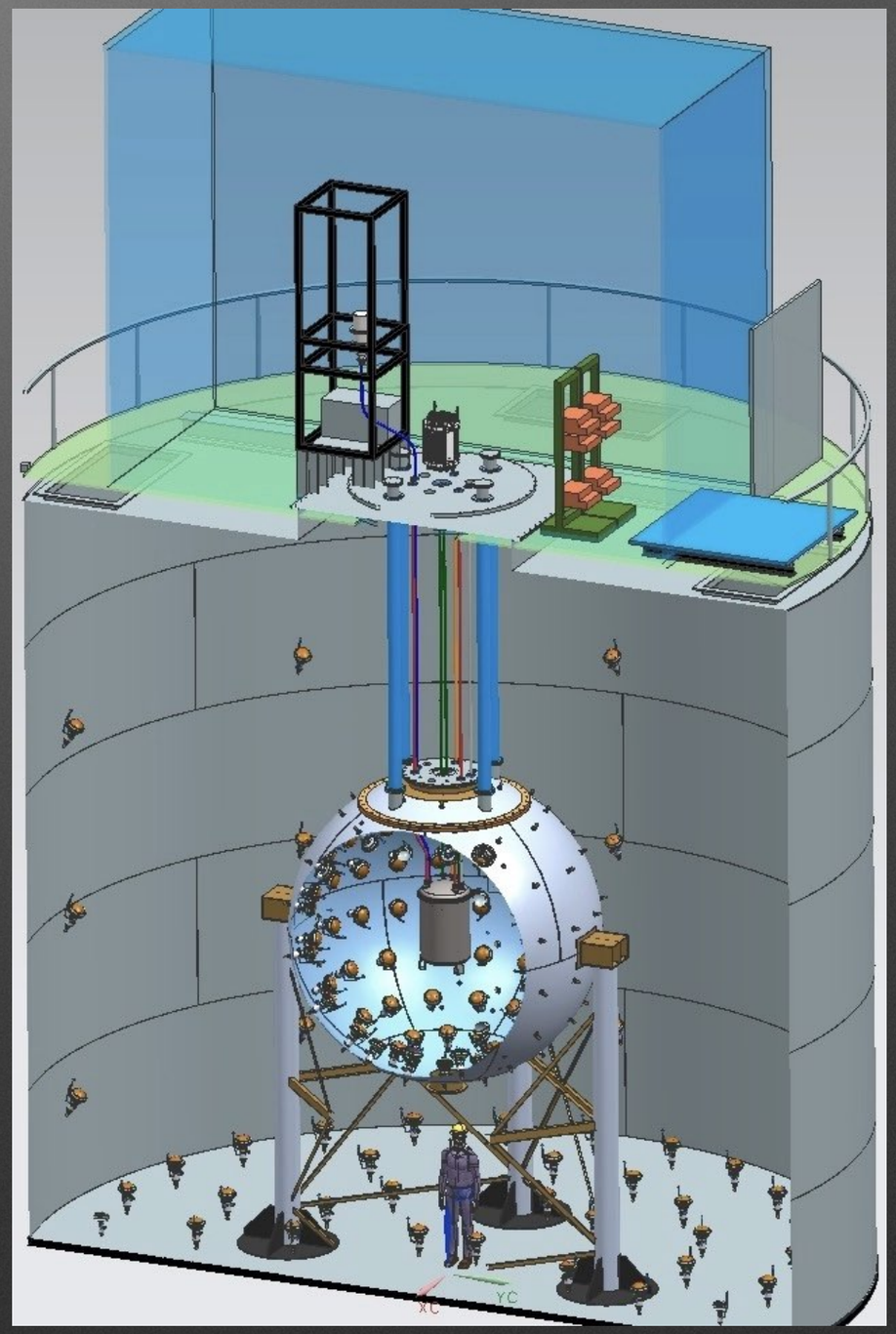
A. Caminata, INFN Genoa

DarkSide-50 @ LNGS - detector overview

- Water Cherenkov detector (1kton of ultra pure water, 10m tall, 11m diameter): passive shield against external radiation and active μ veto [80 8”-PMTs]

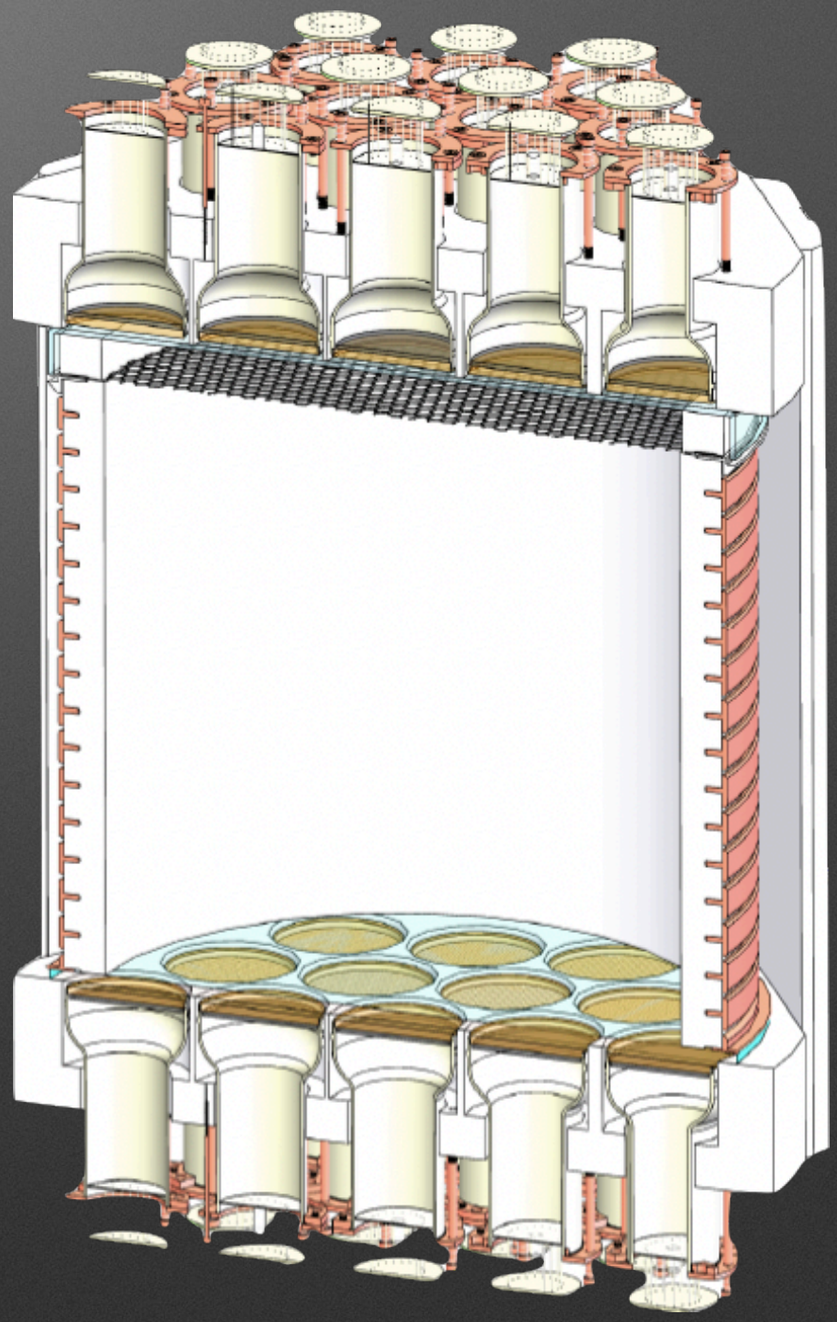
- Liquid scintillator detector (30 tons of PC+PPO+TMB, 4m diameter): active γs and neutron detector [110 8”-PMTs]

- LAr TPC detector (~ 50 kg of LAr in the fiducial volume)



DarkSide-50 @ LNGS - detector overview

- 35.6 cm radius, 35.6 cm height, 2.54 cm thickness. PTFE reflector walls coated with TPB
- 19 3” PMTs in the top and in the bottom with cold amplifiers
- Drift field: 0.2 kV/cm
- Extraction field: 2.8 kV/cm



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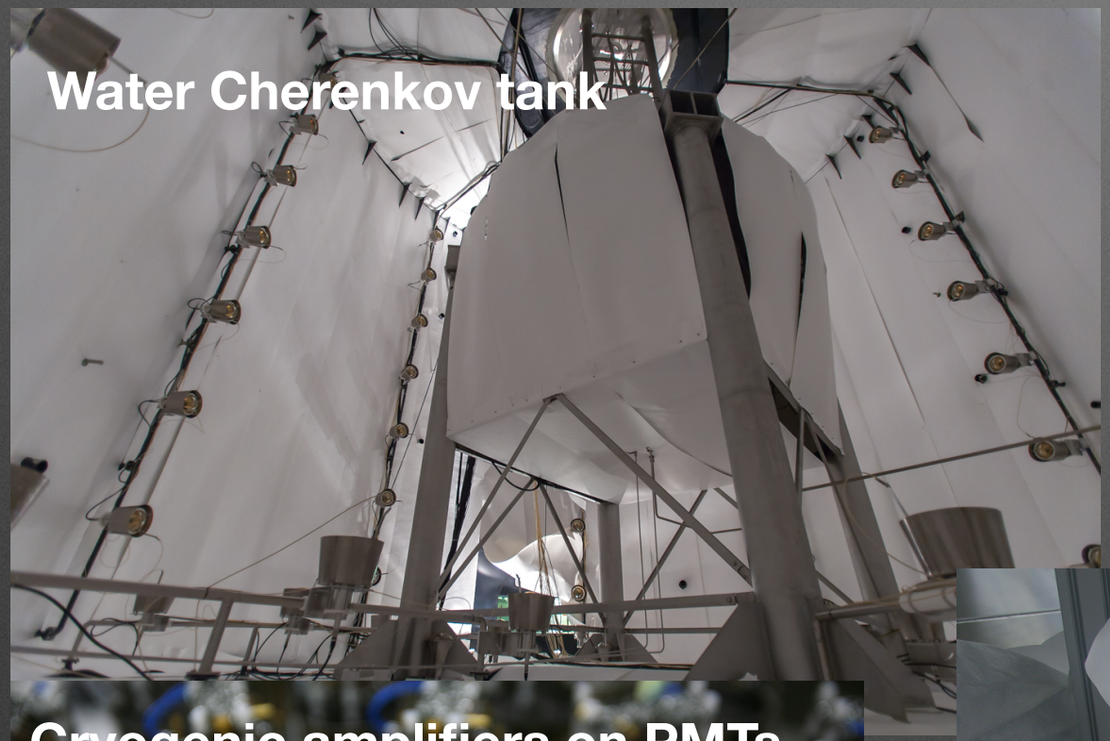
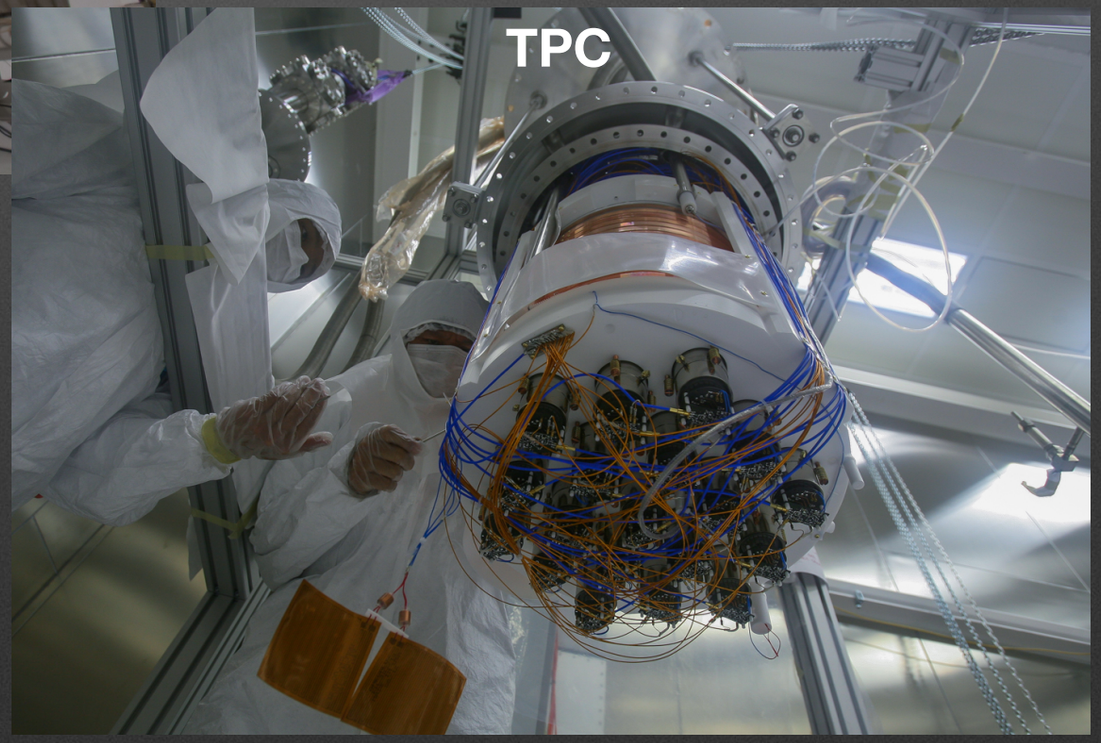
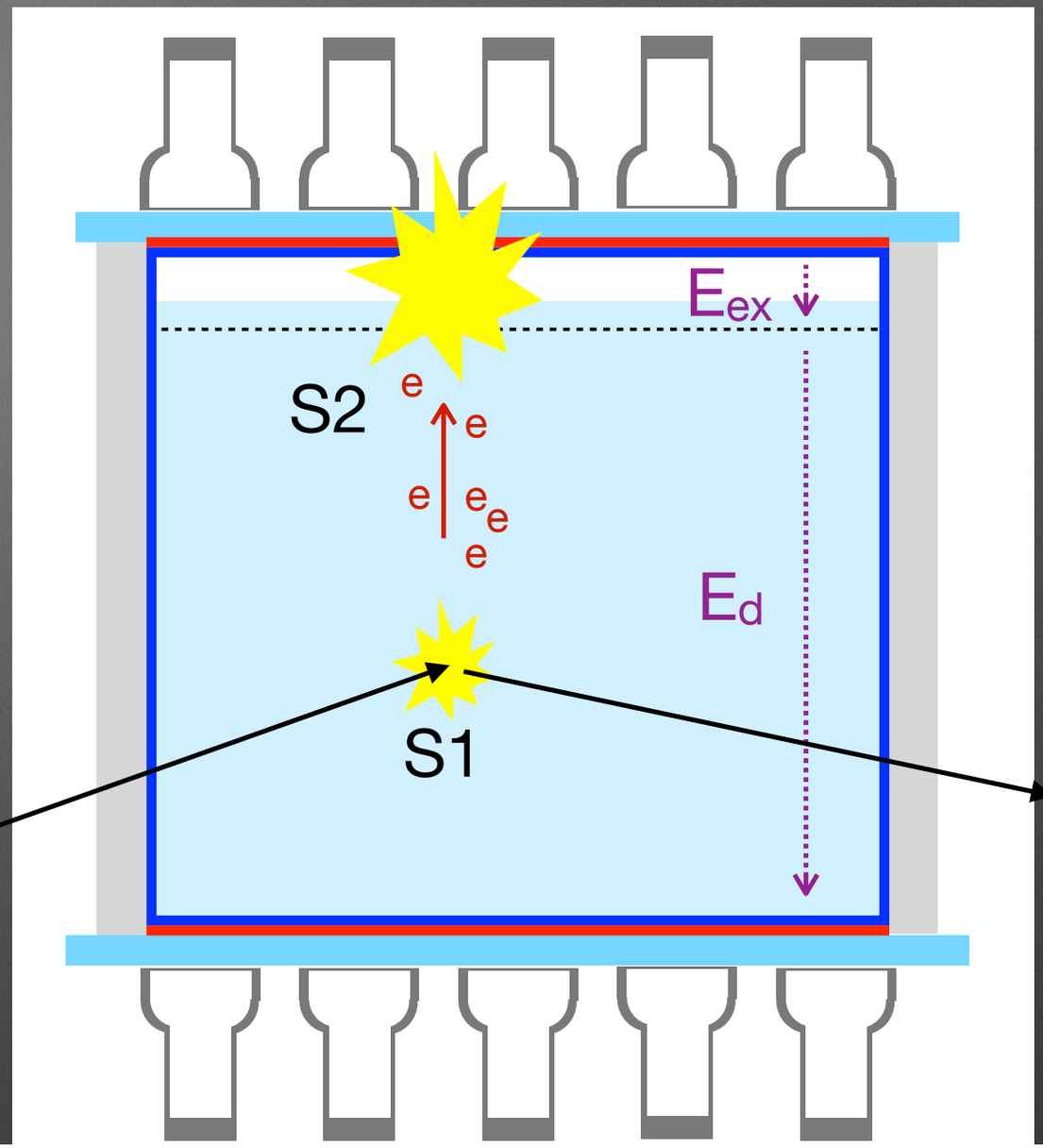
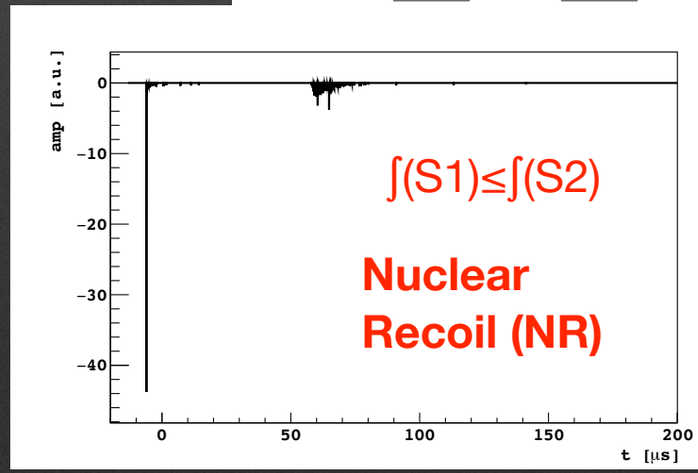


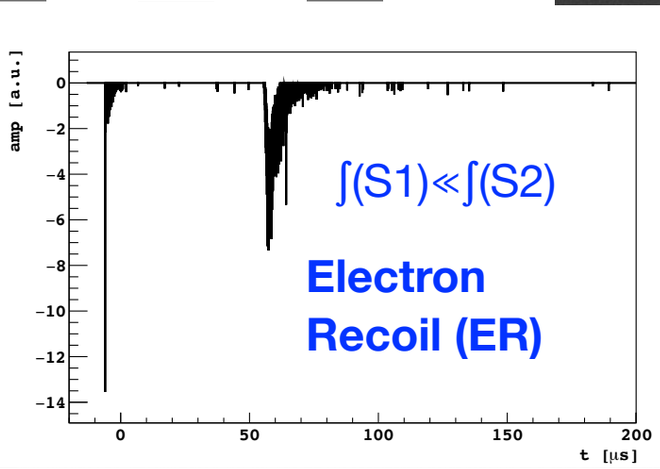


Dual phase TPC

- PSD (f90) → See Pollman's talk
- Electroluminescence signal (S2):
  - Additional γ/n discrimination (S2/S1)
  - Radial fiducialization: S2 signal distribution among PMTs compared with maps generated using MC events → 3D reconstruction of the event





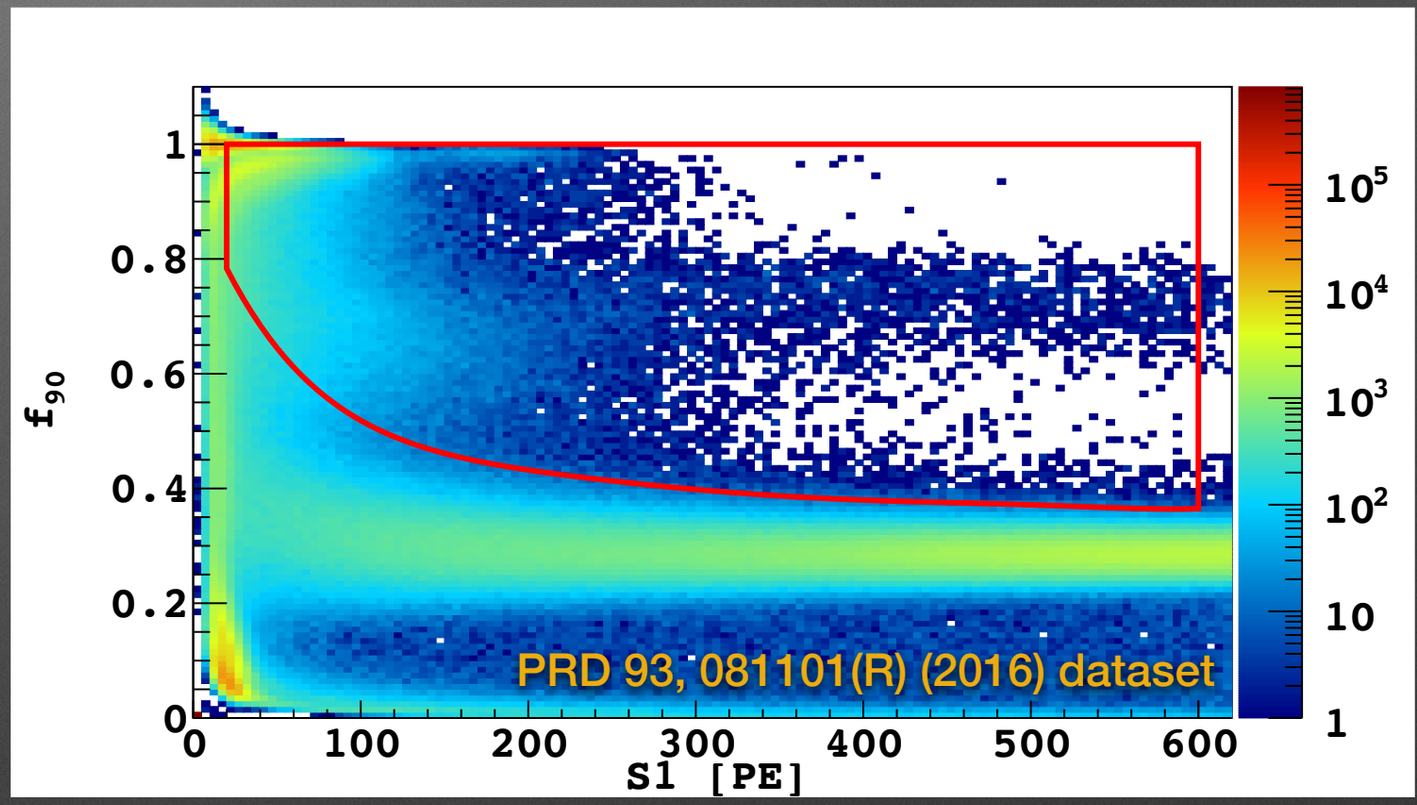


DarkSide-50 recent results

- High mass WIMP search (S1+S2)
  Physical Review D 98 (10), 102006 (2018)
- Low mass WIMP searches:
  - S2-only
    Physical Review Letters 121 (8), 081307 (2018)
  - Sub-GeV
    Physical Review Letters 121 (11), 111303 (2018)

High mass WIMP search

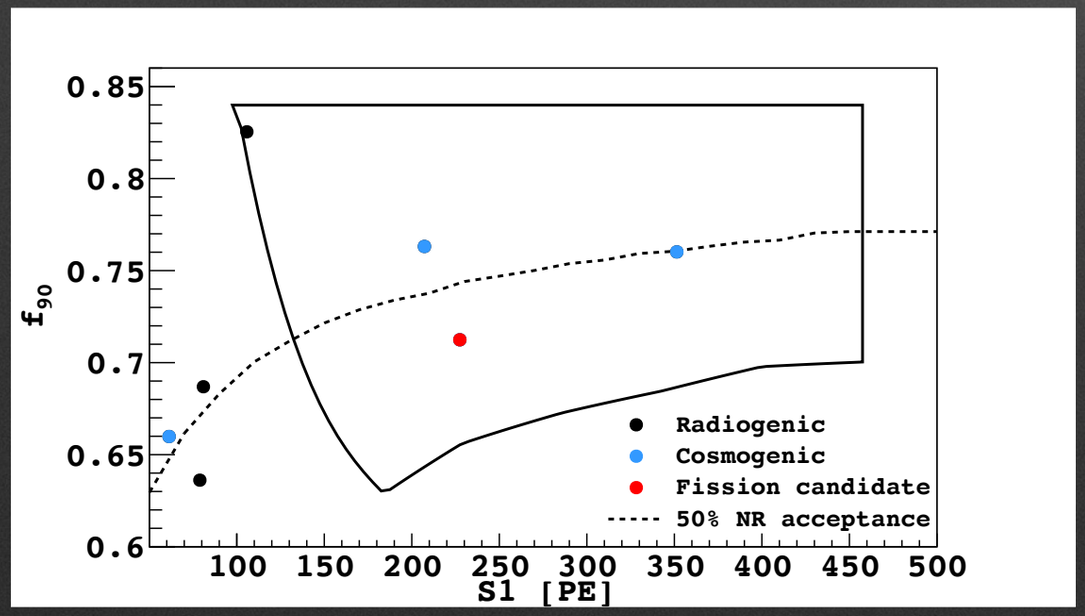
- Blind analysis: 532-days (16 660 kg d) exposure
- Target: low-radioactivity argon extracted from underground sources PRD 98, 102006 (2018)
- Blinding box (**red solid line**) drawn using early 71-days (2616 kg d) results PRD 93, 081101(R) (2016)
- Analysis goal: <0.1 background events in the to-be-designed search box
- Backgrounds:
  - ERs: β, ɣ, and Cherenkov+scintillation
  - NRs: neutrons, surface α

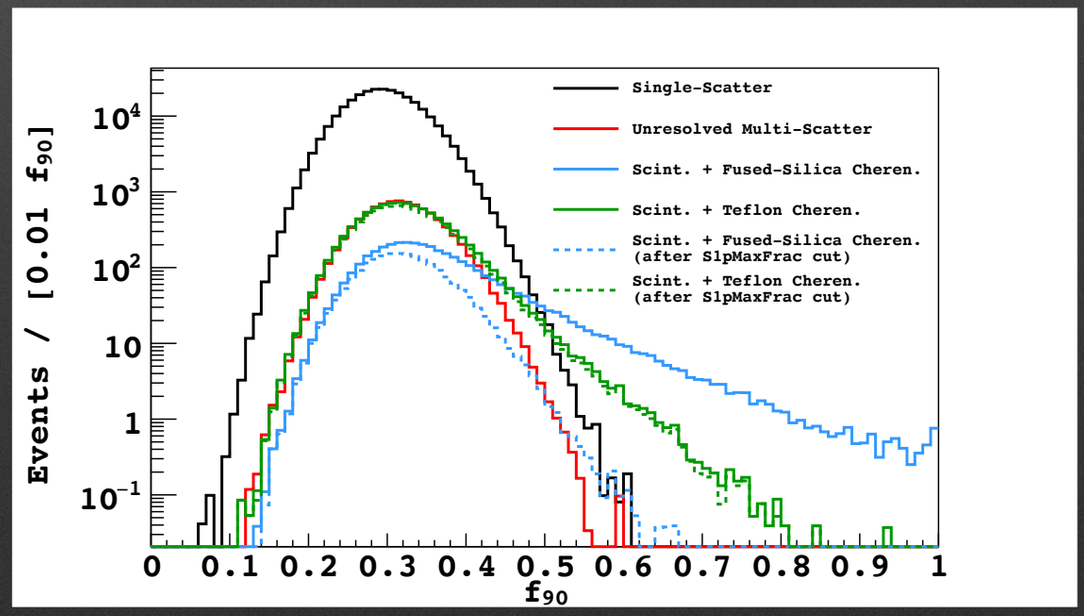


Example of background

- Neutrons: cosmogenic or (α,n) reactions
- PMTs are the main source
- Rejection strategy:
  - Multiple scatter in TPC
  - Coincidence with LSV: measured efficiency with AmC 99.64±0.04% (fraction of event surviving veto cuts)
  - Coincidence with WCD

- <u>Cherenkov + scintillation</u>: γ multiple scatters in LAr and PTFE or fused-silica. Cherenkov (f_{90}≈1) moves regular scintillation into NR band.
- Rejection strategy:
  - light distribution in top PMTs
  - radial fiducialization





Let's open the box

BACKGROUND	EVENTS SURVIVING ALL THE CUTS
Cosmogenic neutrons	$< 3 \times 10^{-4}$
Radiogenic neutrons	$< 5 \times 10^{-3}$
Surface α	$< 1 \times 10^{-3}$
Cherenkov + scintillation	0.08
Total	**0.09±0.04**

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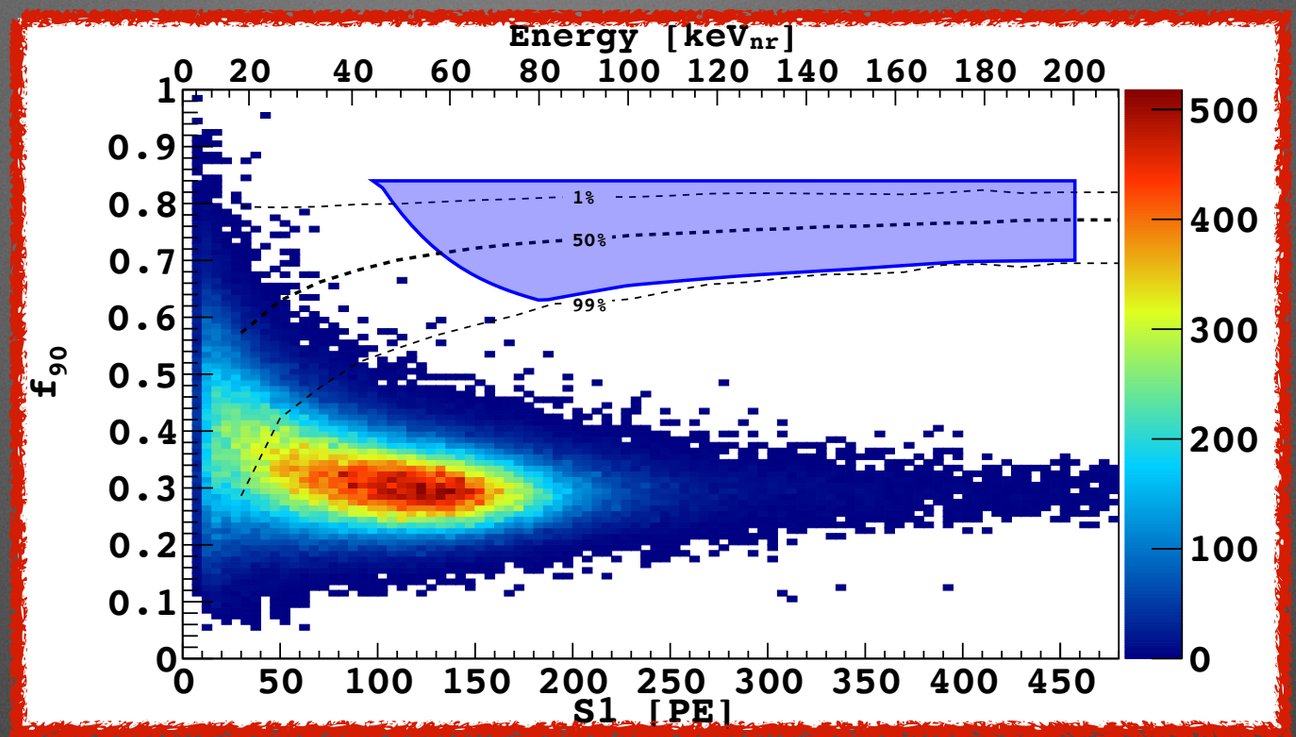
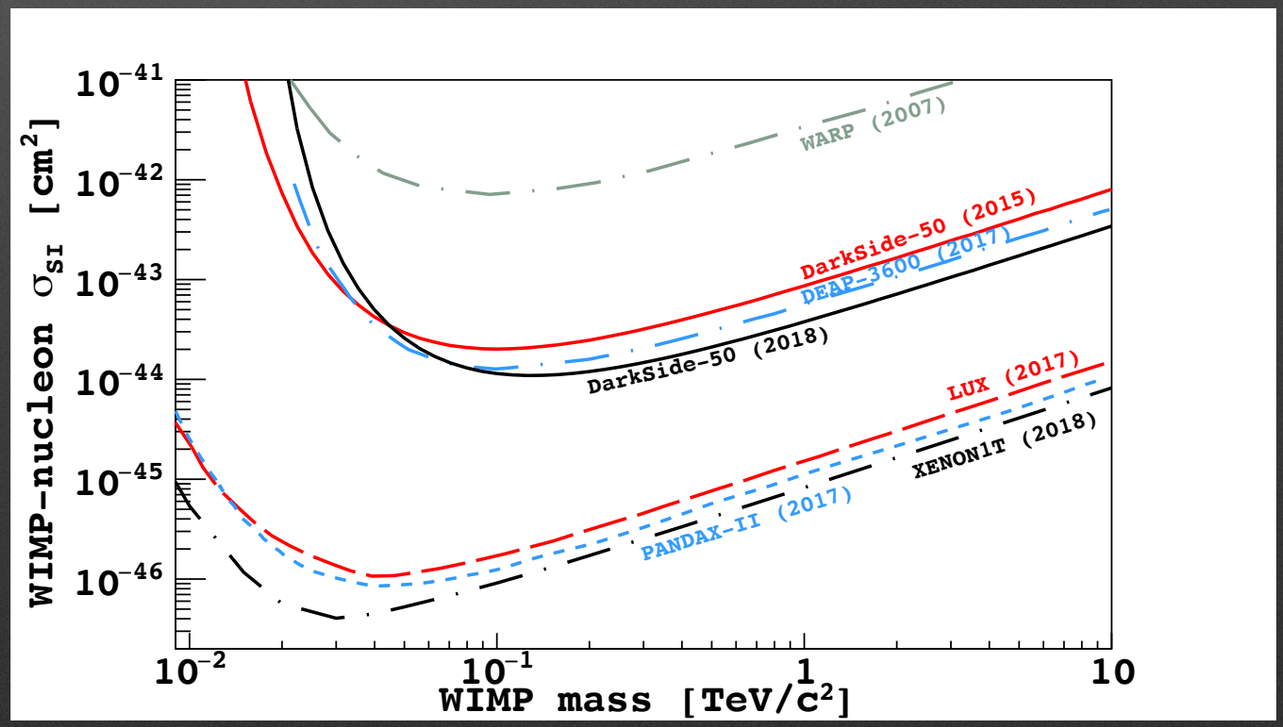
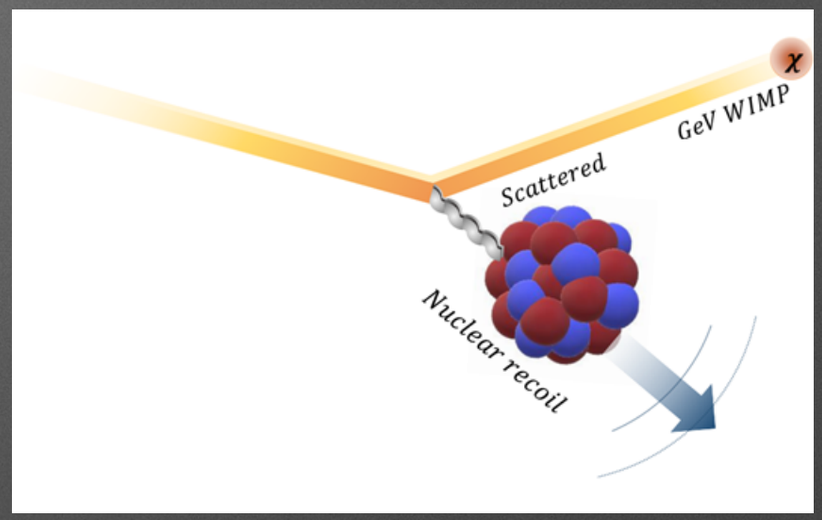




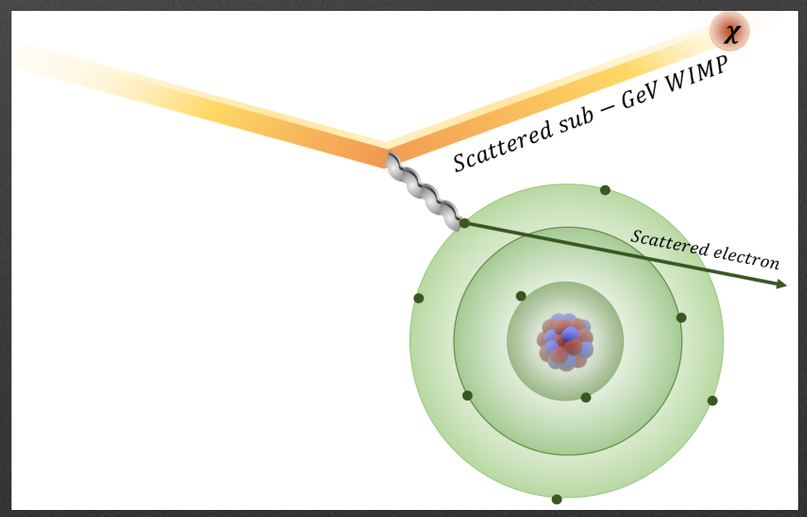
Low mass WIMP searches

- Trigger on S1 → 13 keV_{nr} threshold → limited sensitivity for WIMPs with mass <10 GeV/c^2

- Trigger on S2 → Analysis threshold >0.6 keV_{nr}

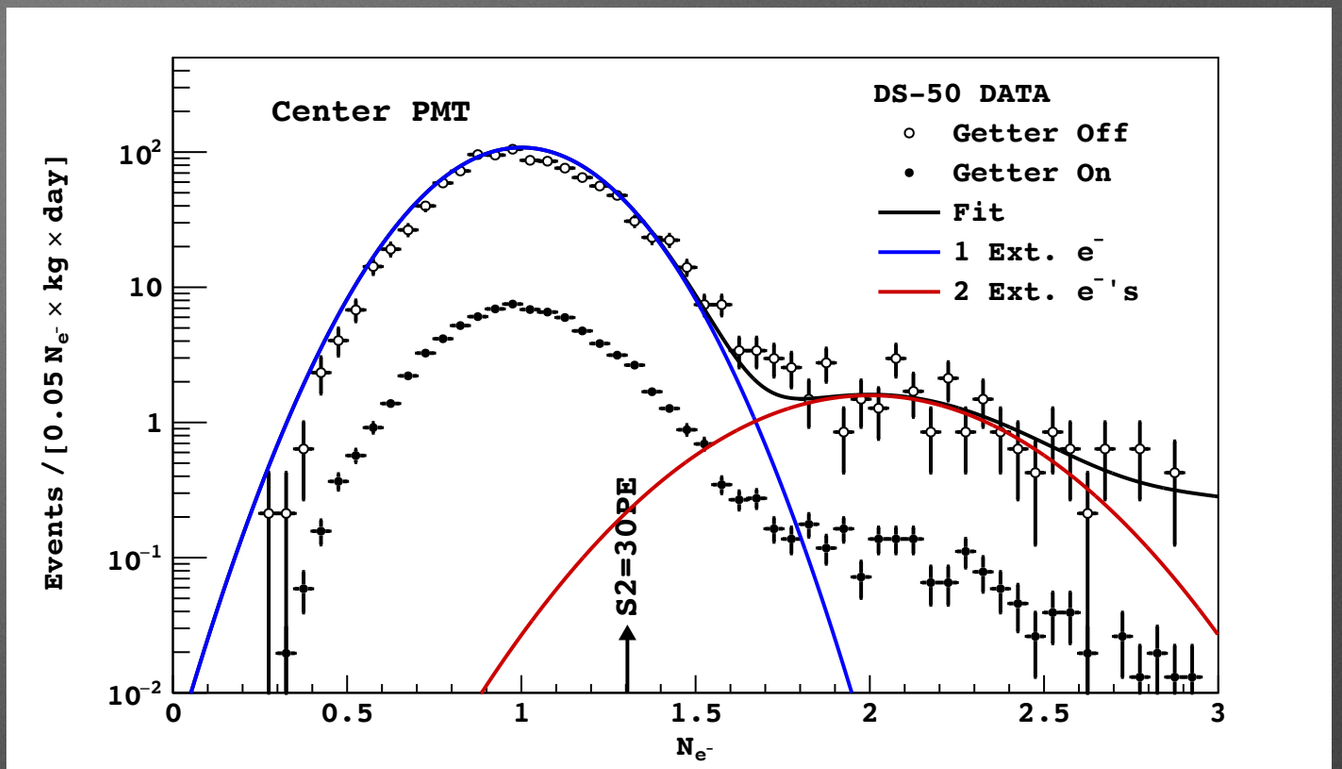


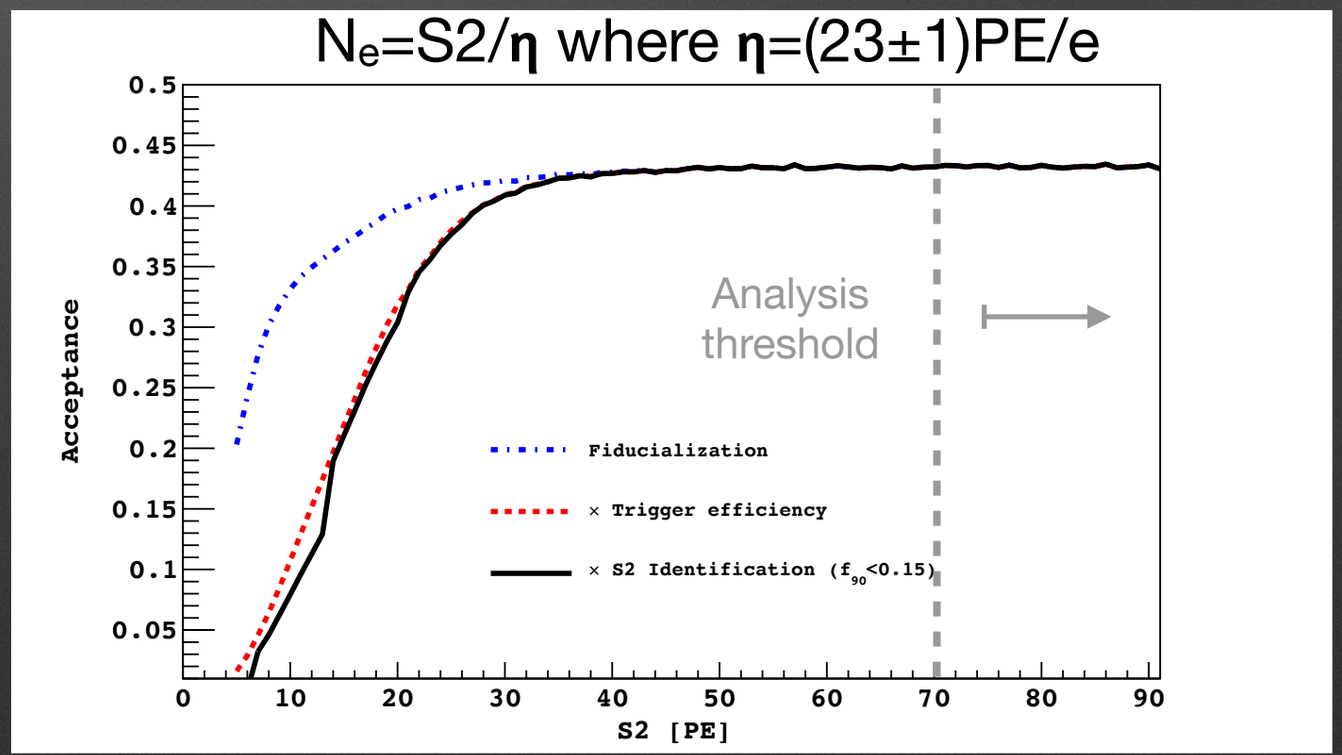
- With S2-only events the existence of low mass WIMPs interacting both with **nuclei** or even with **electrons** (with background) is investigated



S2-only analysis

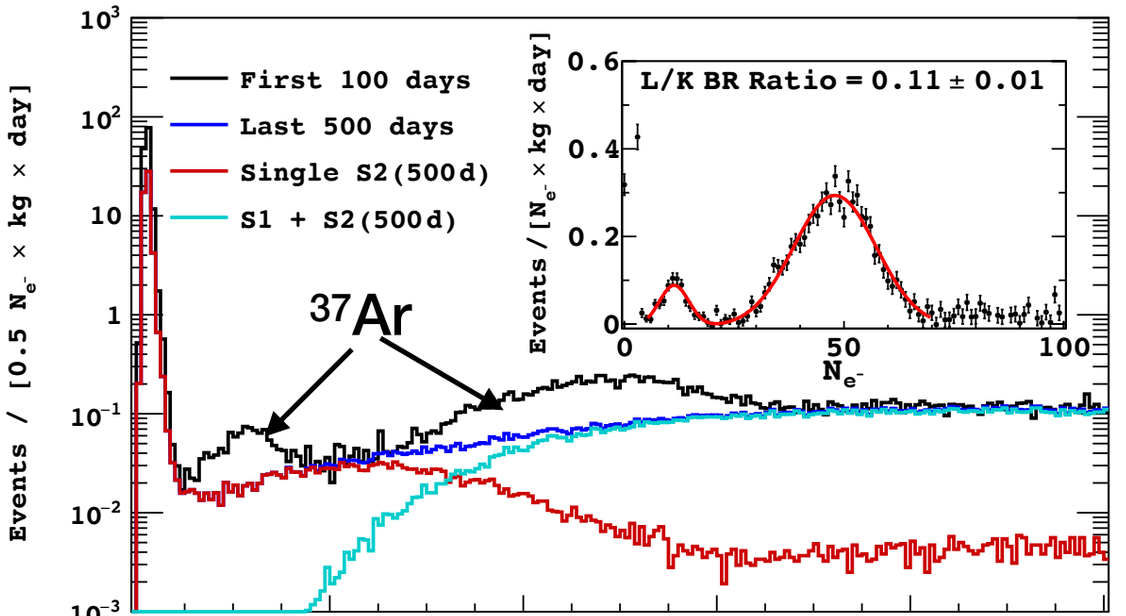
- S2-only signal:
  - Sensitive to single extracted electron
  - No PSD
- Acceptance: estimated by data+MC
- Fiducialization: no xy available, but use volume under inner 7 PMTs

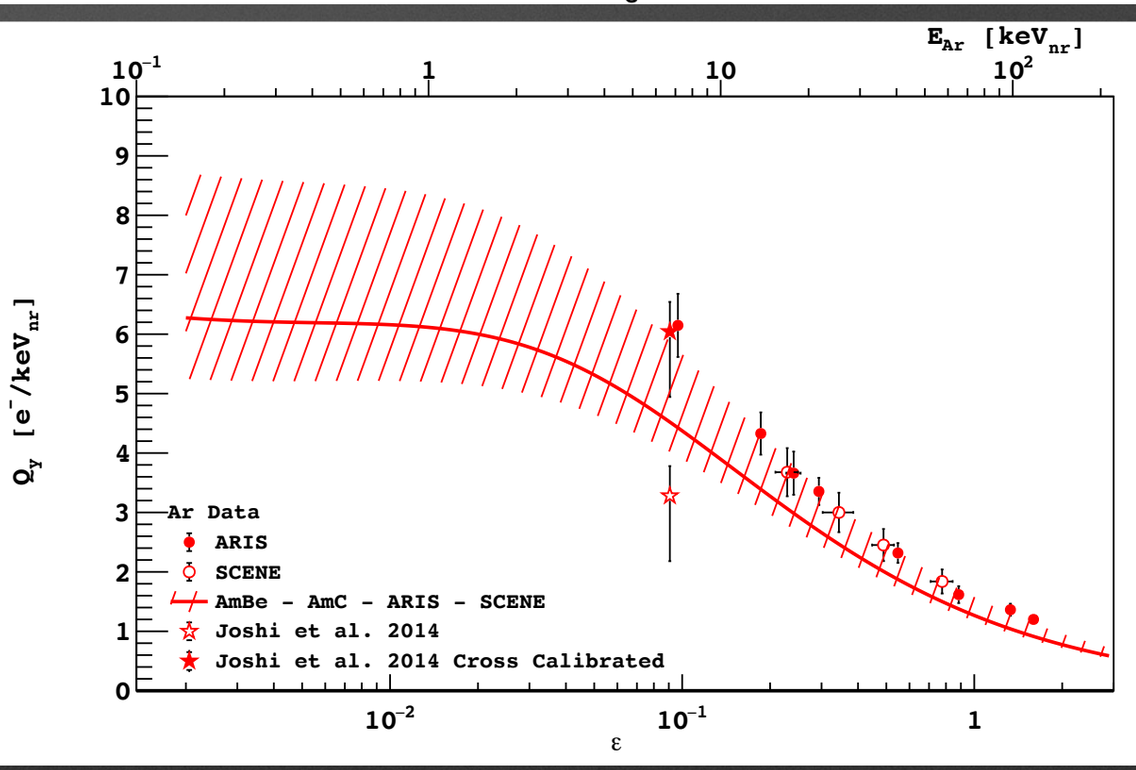




Energy scale - S2 only

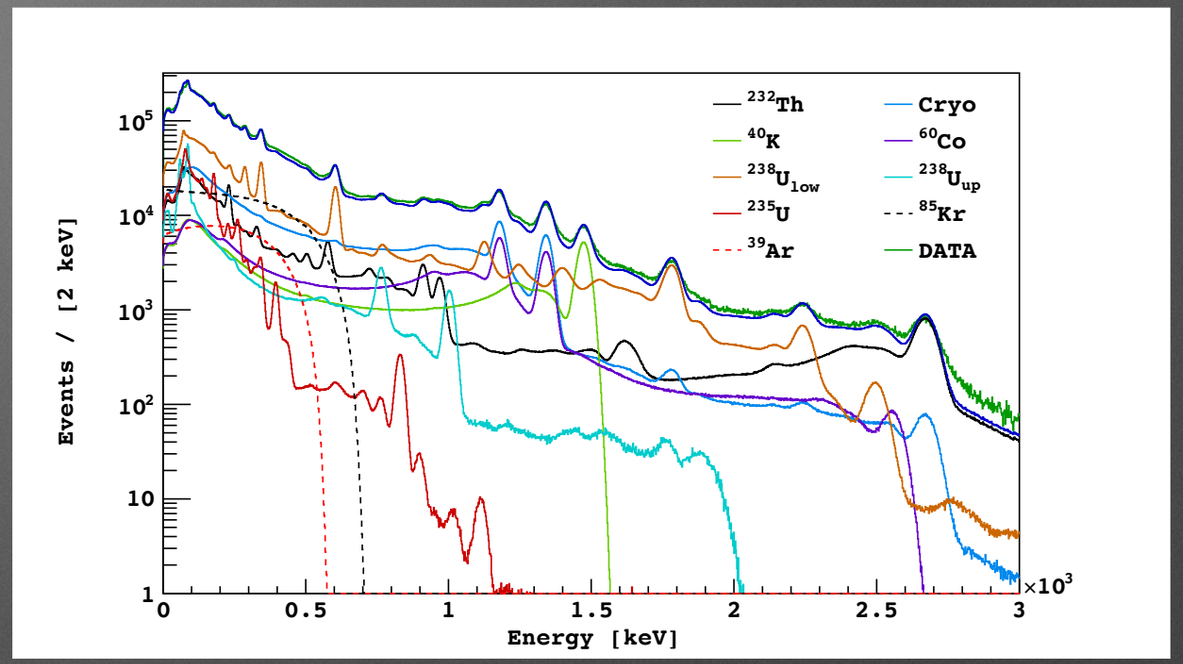
- ER energy scale obtained with ^{37}Ar
  - Provides 2 X-rays: 0.27 keV and 2.82 keV
  - $t_{1/2}$ =35 d → no remain in the last 500 d data set
- NR energy scale obtained with AmBe and AmC
  - Bezrukov model fitted on calibration data
  - Difference with other measured points taken as systematic
  - Conservative assumption - measured points are higher than fit:
    less ionization → less e- → less sensitivity

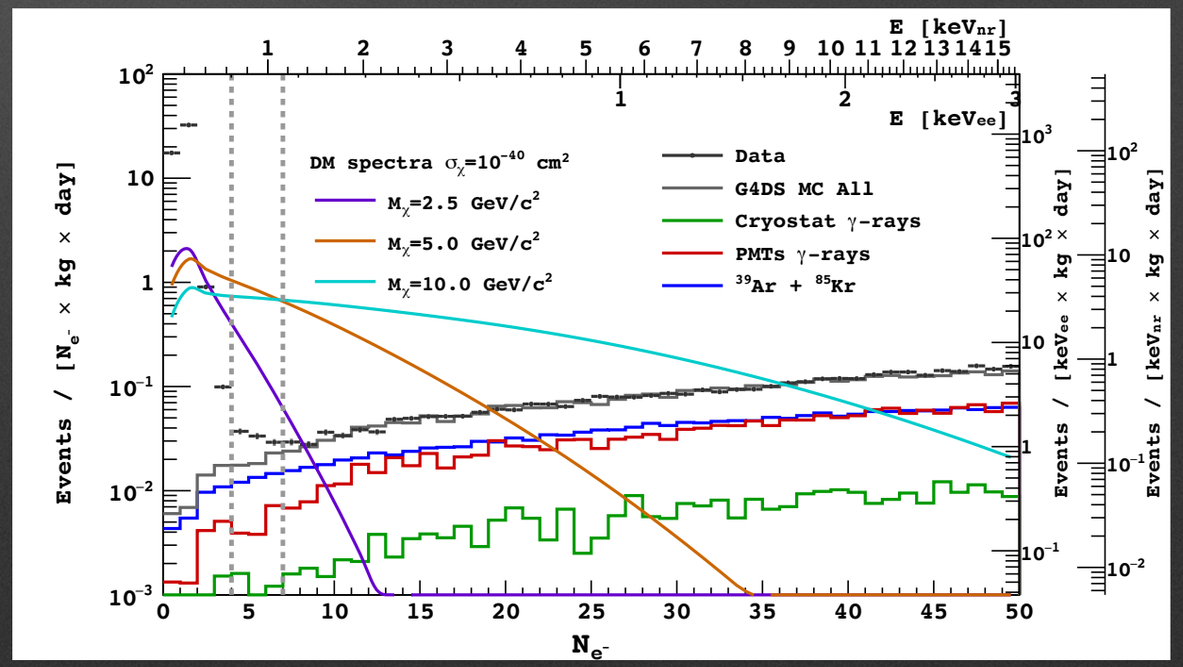




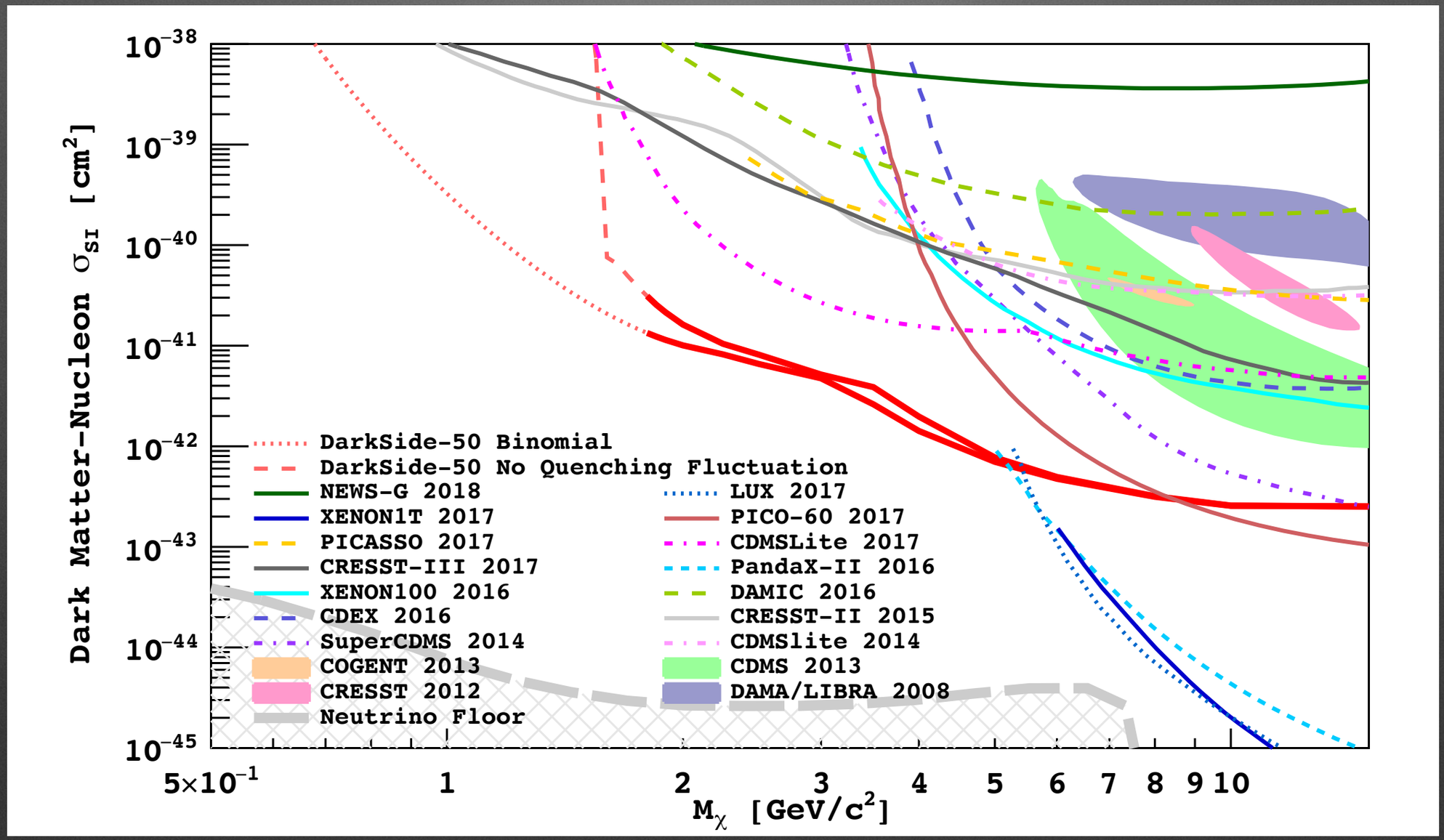
Signal and background

- Background constrained from high energy part of the spectrum
- Impurity related single electron bkg limiting analysis sensitivity
- WIMP recoil spectra modeled with ionization, energy quenching, and detector response.
- Binned profile likelihood analysis, average ionization yield dominates uncertainties! Due to lack of knowledge two assumptions about fluctuation at low recoil energy: no fluctuation and binomial





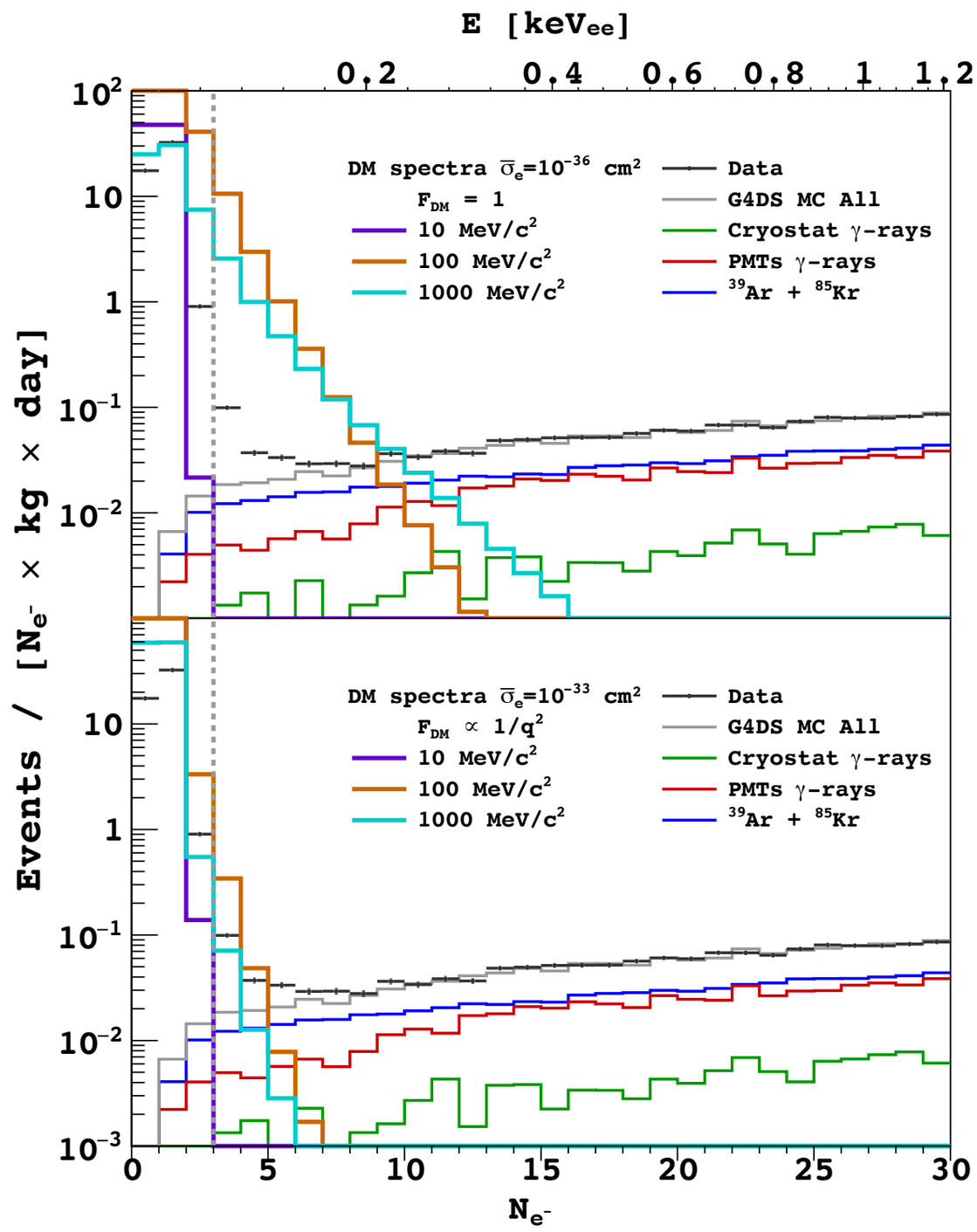
90% C.L. exclusion limit

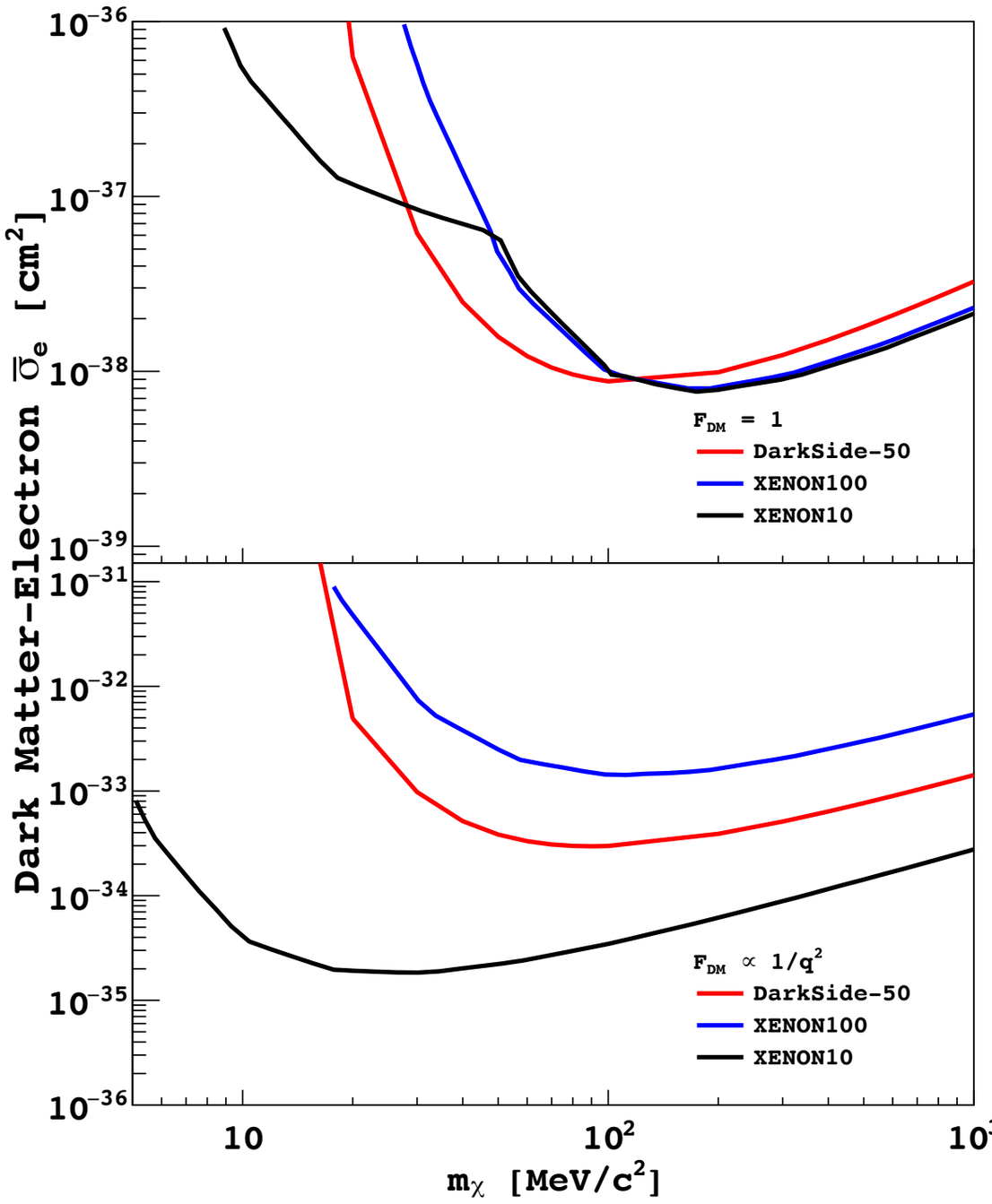


Sub-GeV DM searches

- WIMP-electron interaction parametrized by form factor $F_{DM} = F_{DM}(q)$ which, depending on the mass of the mediator ($m_{A'}$) has different asymptotic momentum (q) dependence:
  - $F_{DM} \approx 1$ (heavy mediator: $m_{A'} >> \alpha\, m_e$)
  - $F_{DM} \approx 1/q^2$ (light mediator: $m_{A'} << \alpha\, m_e$)
- ^{37}Ar X-rays are used to convert electron recoil spectra to ionization spectra
  - Physical Review Letters 121 (11), 111303 (2018)

Sub-GeV DM searches





DarkSide-20k

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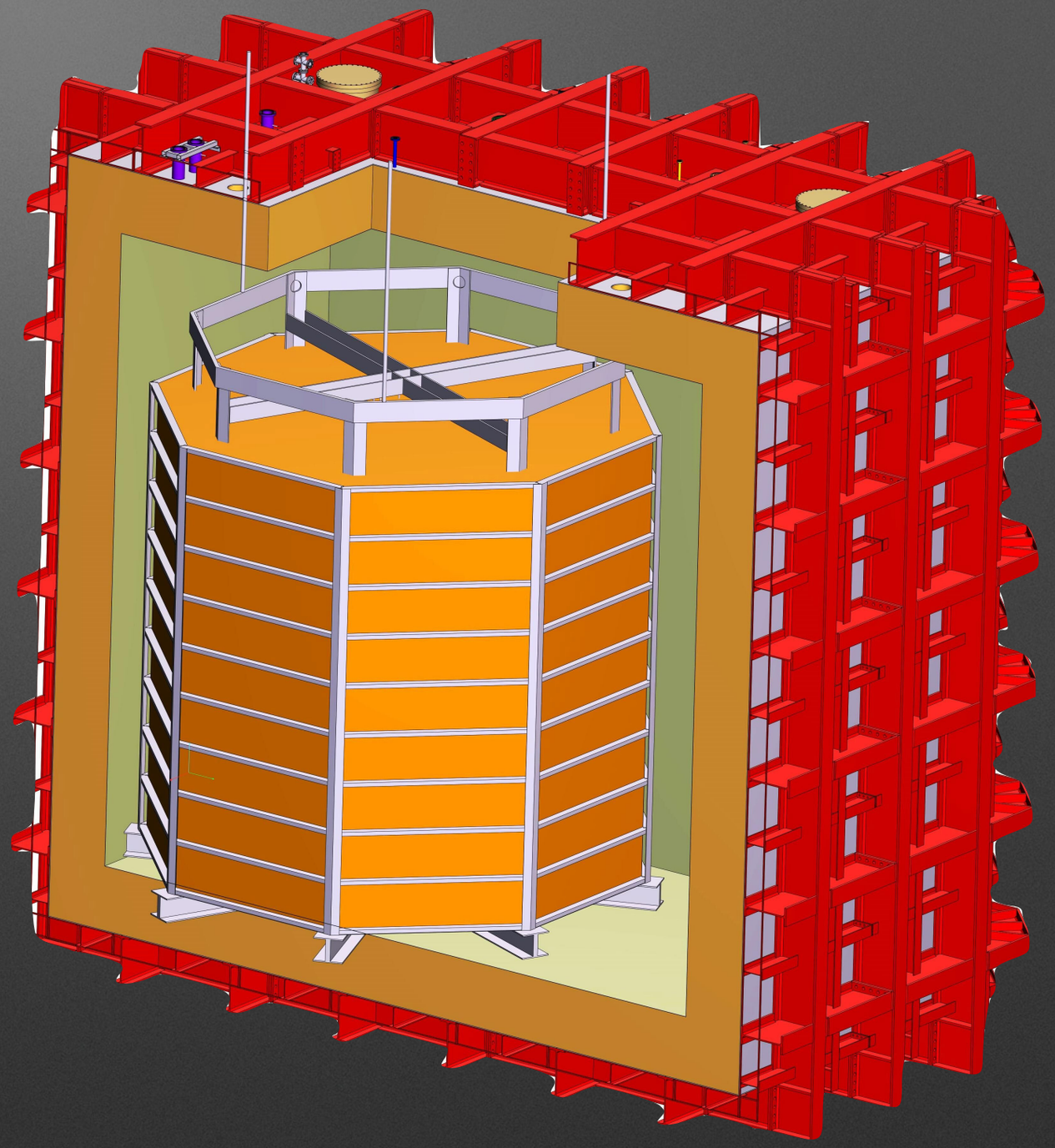
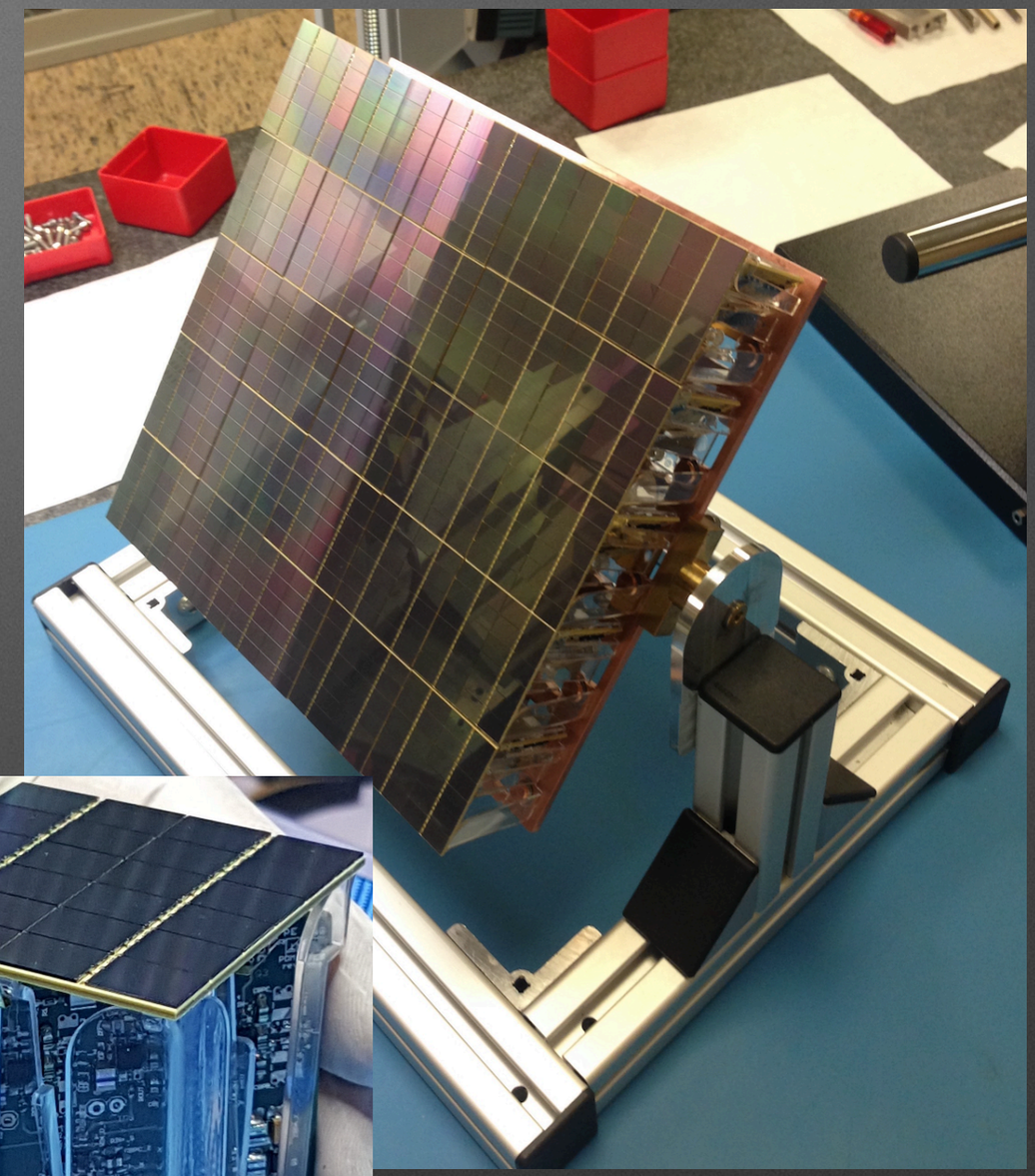
DarkSide-20k @ LNGS

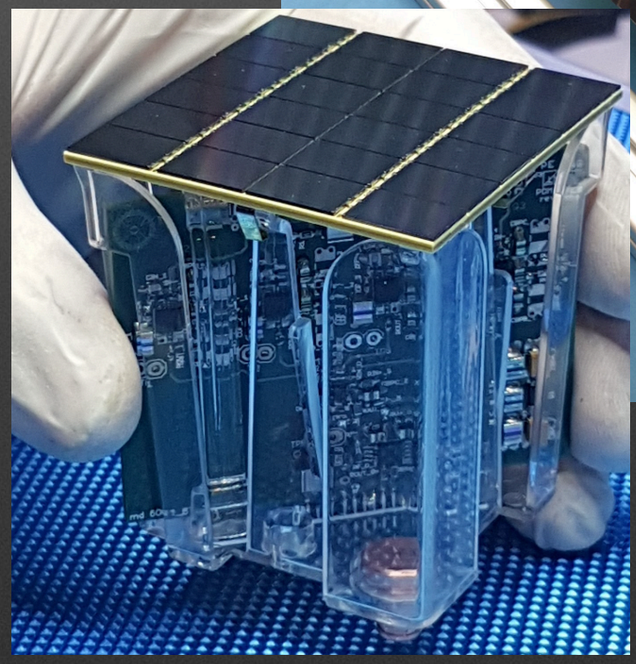
- Sealed acrylic TPC containing 50 tonnes of UAr (20 tonnes fiducial) in a ProtoDUNE-like cryostat filled with ~700 tonnes of AAr
- 30 m² SiPMs as photosensors (8280 channels for TPC and ~3000 channels for Veto)
- Gd-doped acrylic panels as neutron veto
- Detector concept minimises internal neutron background sources and allows easy scaling to bigger detector



Light detection in DS-20k

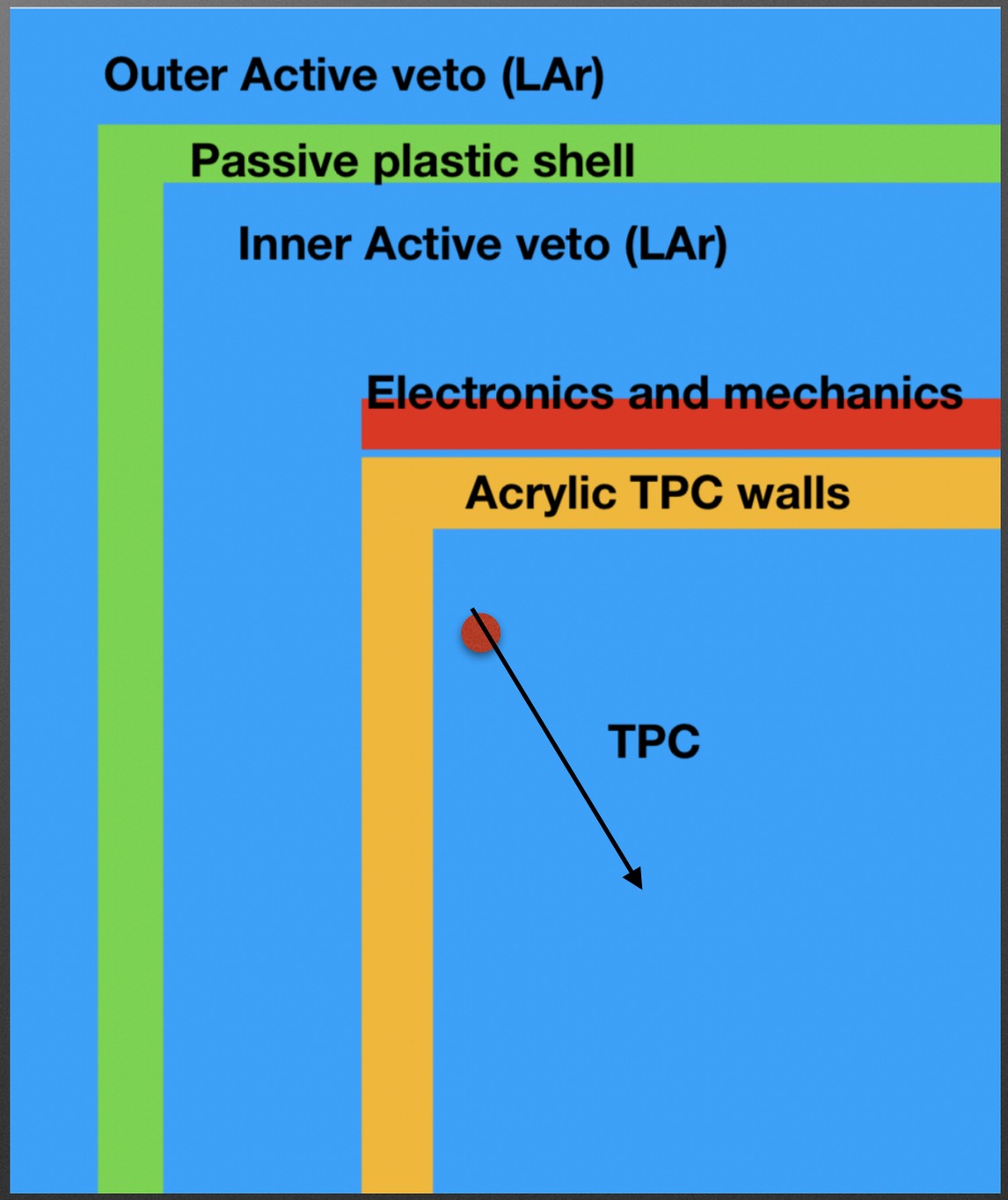
- SiPM will replace PMTs at LAr temperature
- Combined effort between DarkSide and Fondazione Bruno Kessler (FBK)
- High S/N (~8) and PDE (~50%)
- Massive production by LFoundry and packaging in NOA (L'Aquila)
- Full production chain founded by Regione Abruzzo, Italy





Neutron Veto

- LAr Veto substitutes LSV
- Veto and TPC can stay in the same cryostat: less material nearby the TPC
- Gd-loaded PMMA shell between argon buffers:
  - PMMA moderates neutrons
  - γ's from neutron capture on Gd interact in the argon buffers and scintillation light is detected



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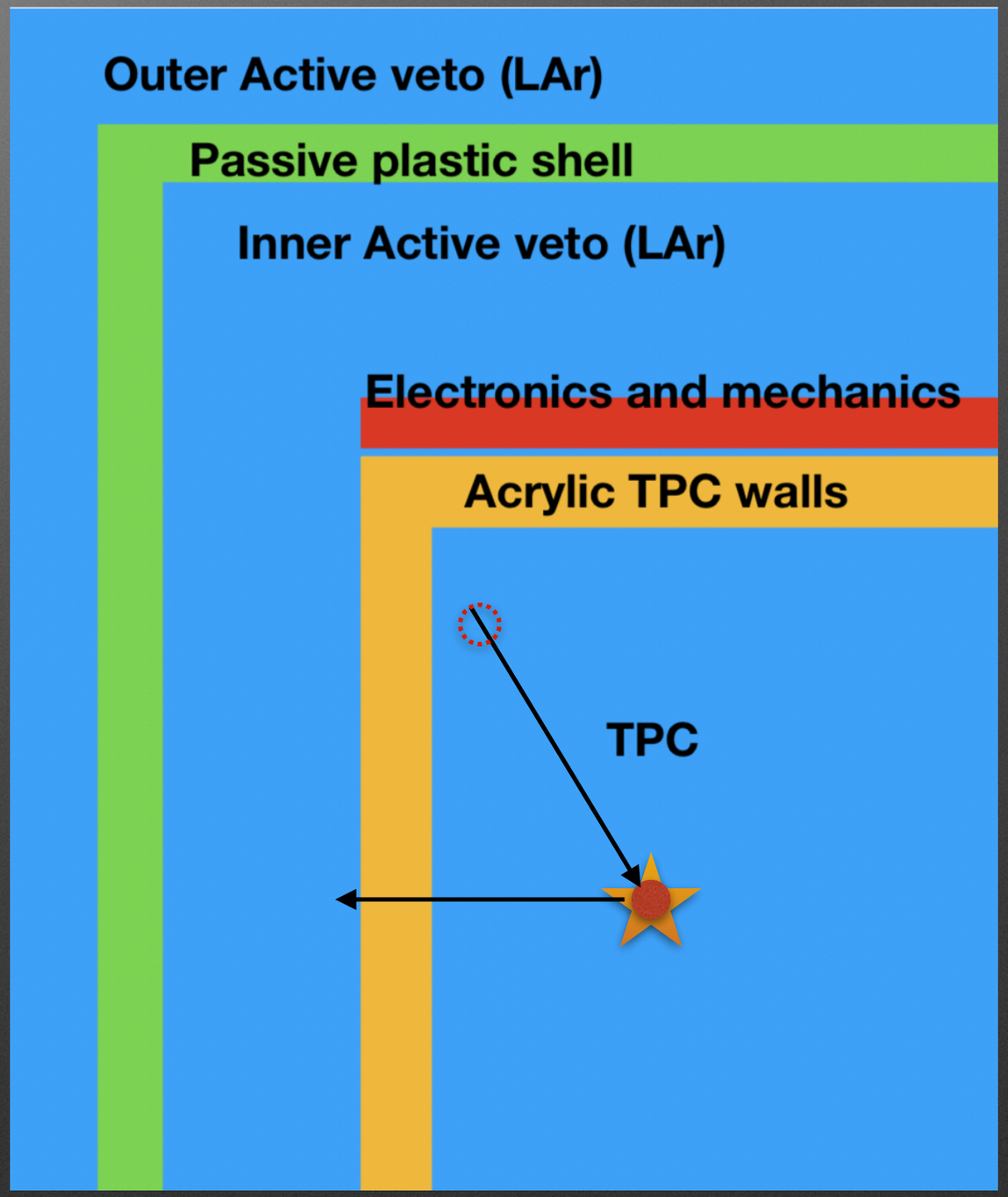

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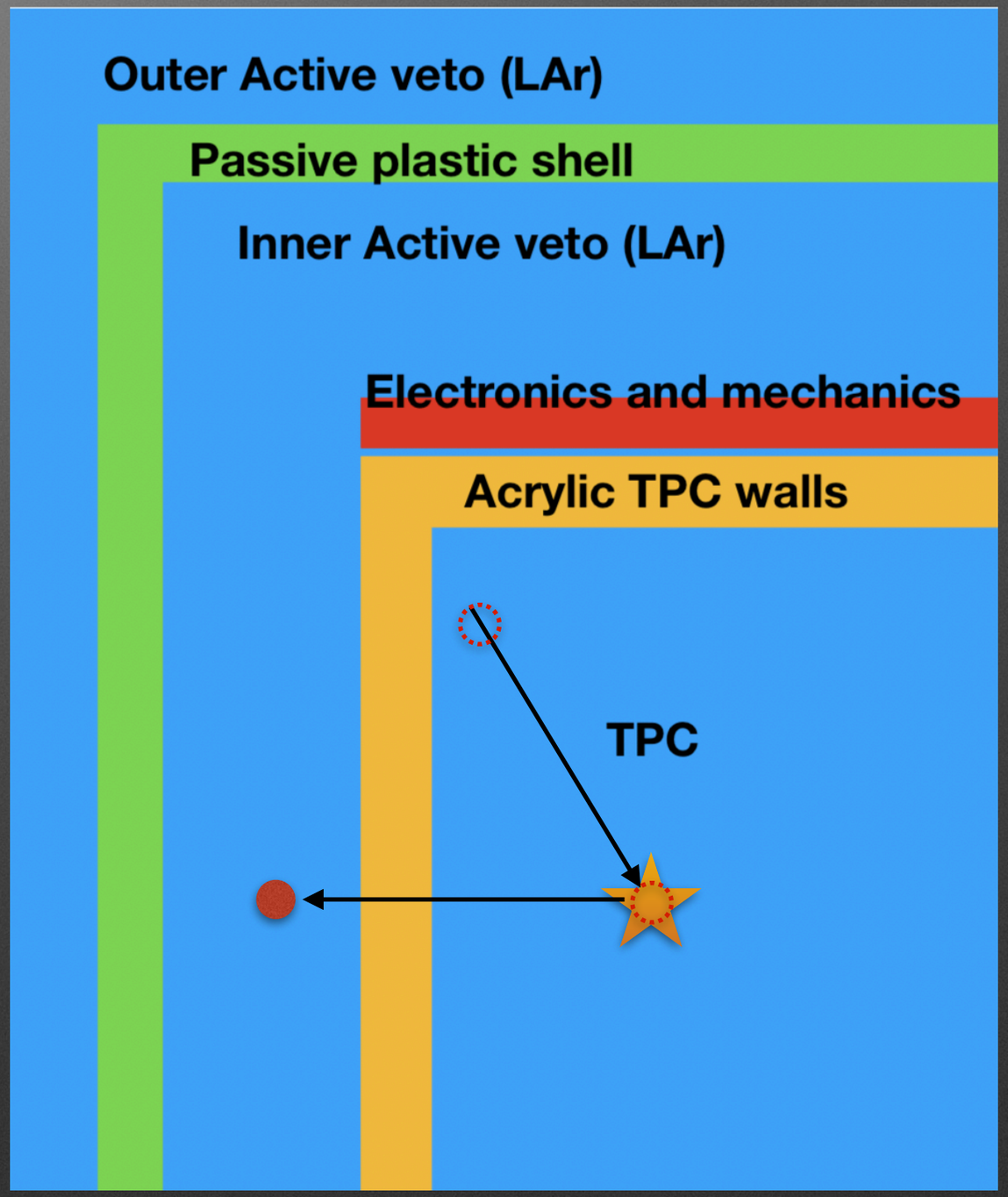

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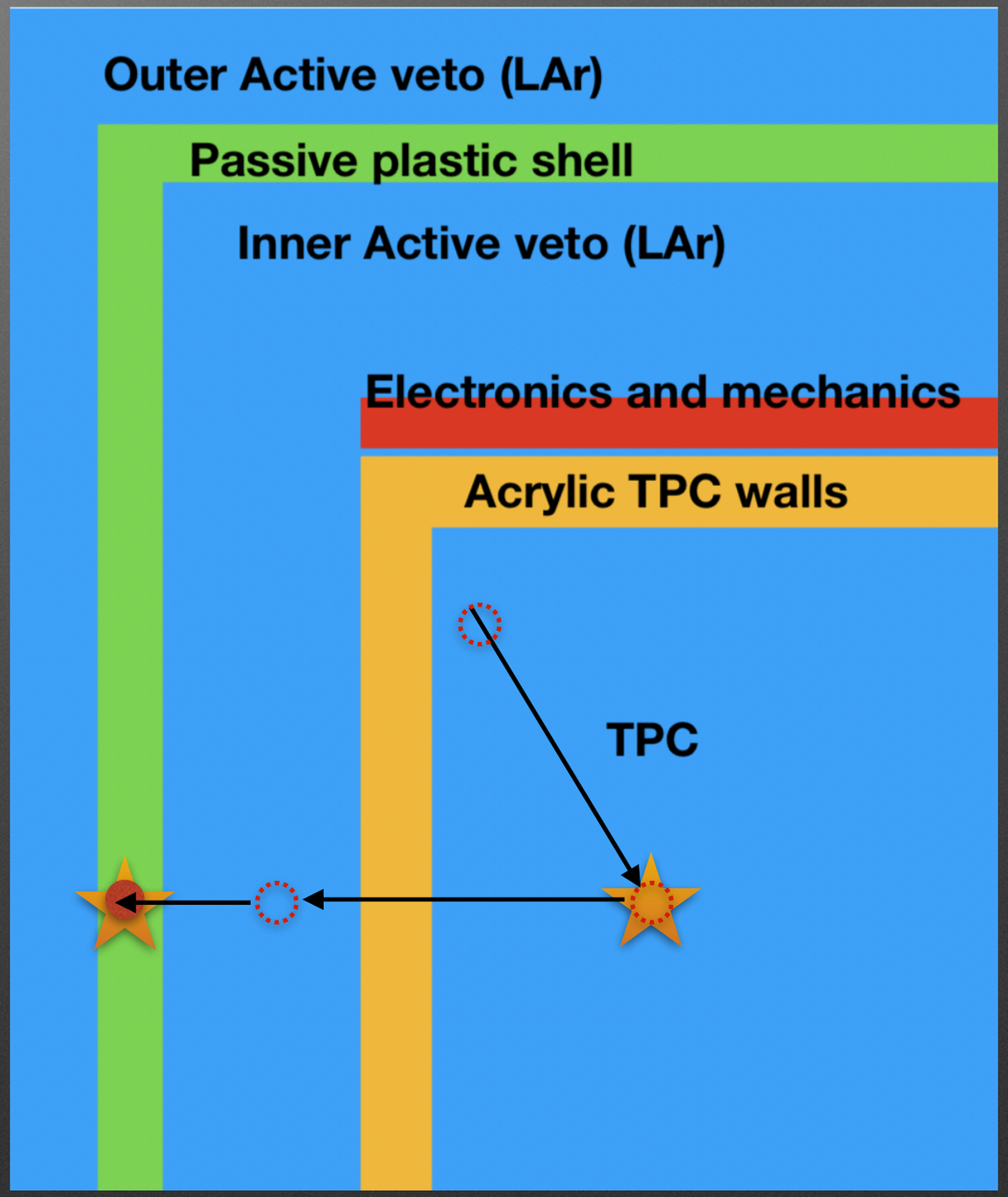

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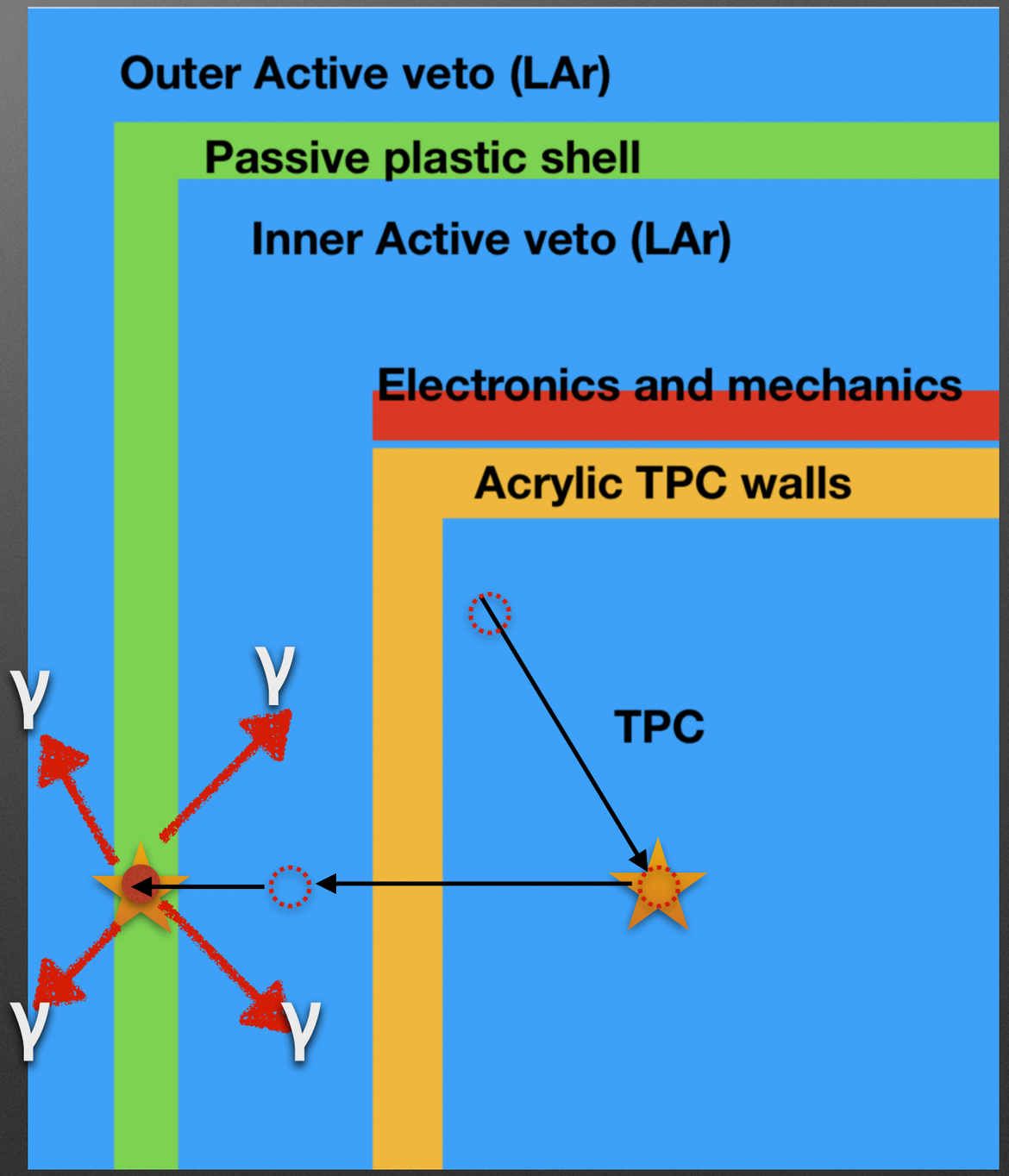
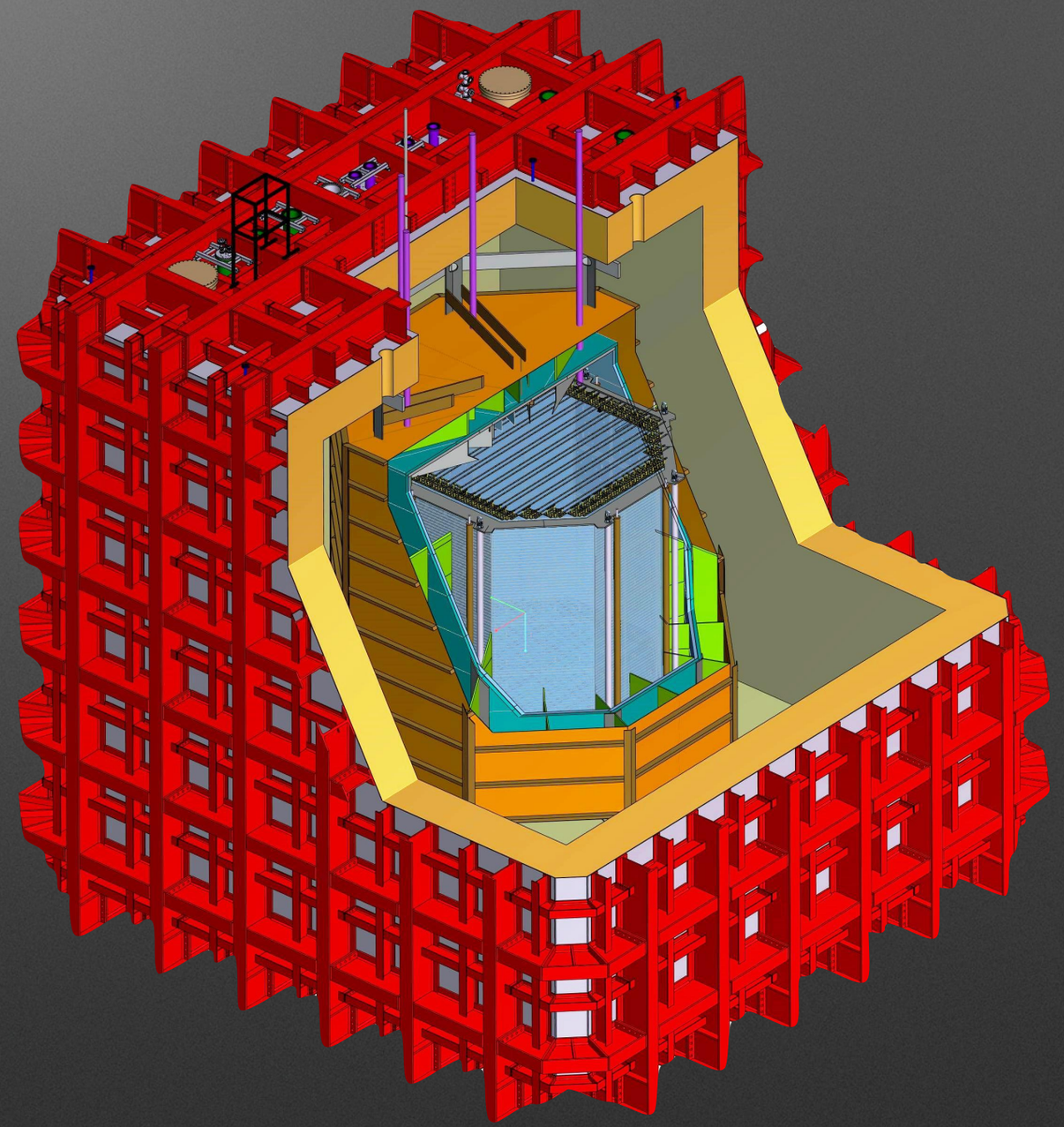


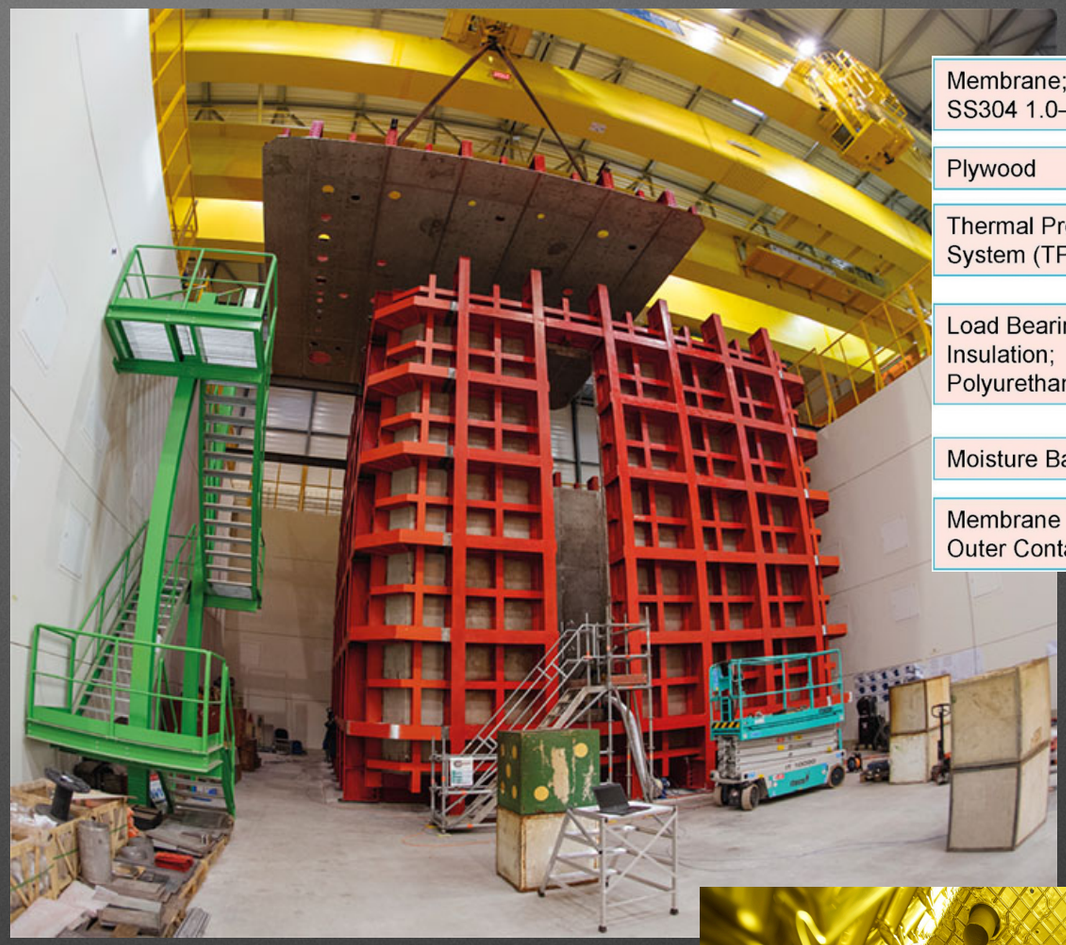
Neutron Veto

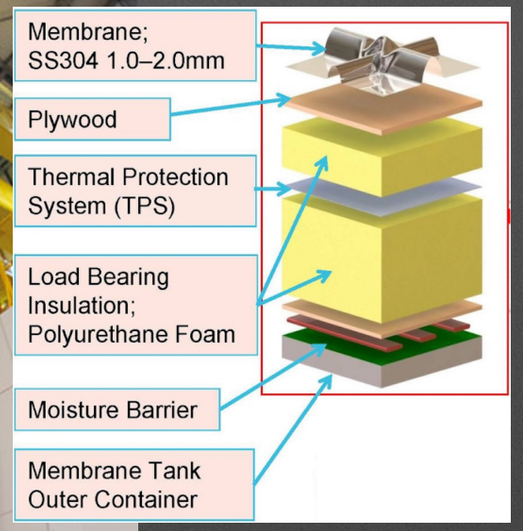
- 4π coverage
- 10 cm thick passive Gd-loaded acrylic shell to moderate and capture neutrons
- 40 cm thick inner and outer active liquid AAr volumes
- External Faraday cage to optically and electrically isolate both veto and TPC

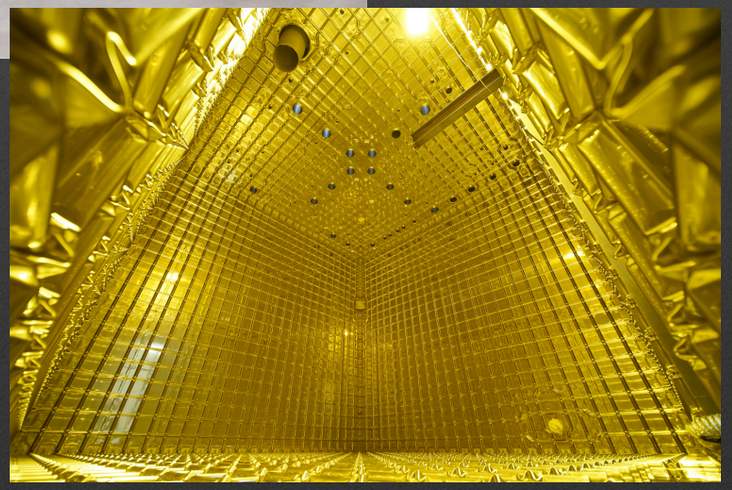


The DarkSide cryostat

- Membrane + passive thermal insulation
- Technology extensively used at CERN for ProtoDUNE experiment
- Access and support of TPC and Veto from the top roof





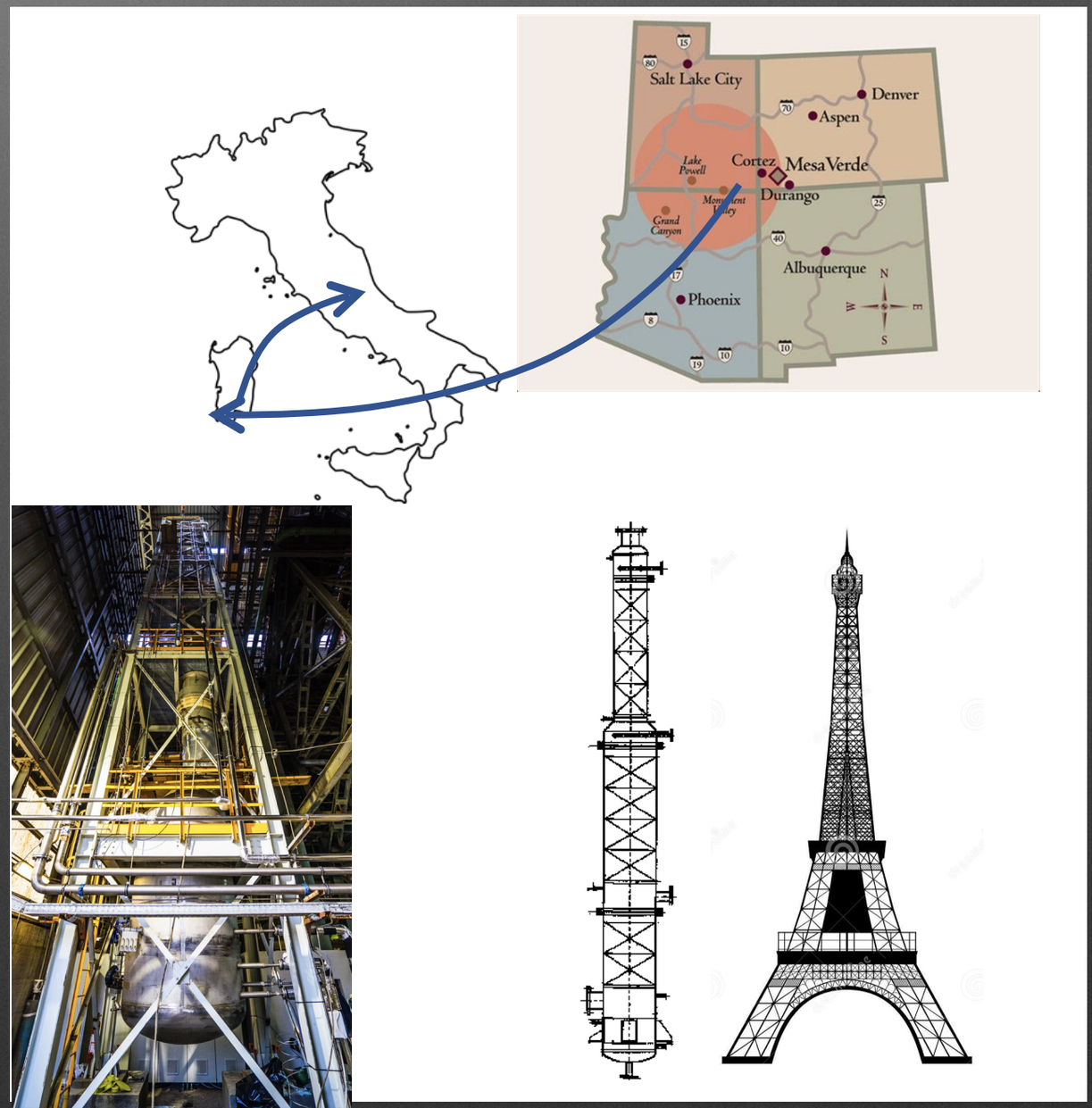


Procurement of low radioactivity argon

- **Urania:** procurement of at least 60 tonnes of UAr from Colorado, USA (same as DS50) withe extraction rate of 250 kg/day, with 99.9% purity

- **Aria:** UAr transported to Sardinia, Italy for final chemical purification via a 350 m tall cryogenic distillation column in Seruci, Sardinia, Italy

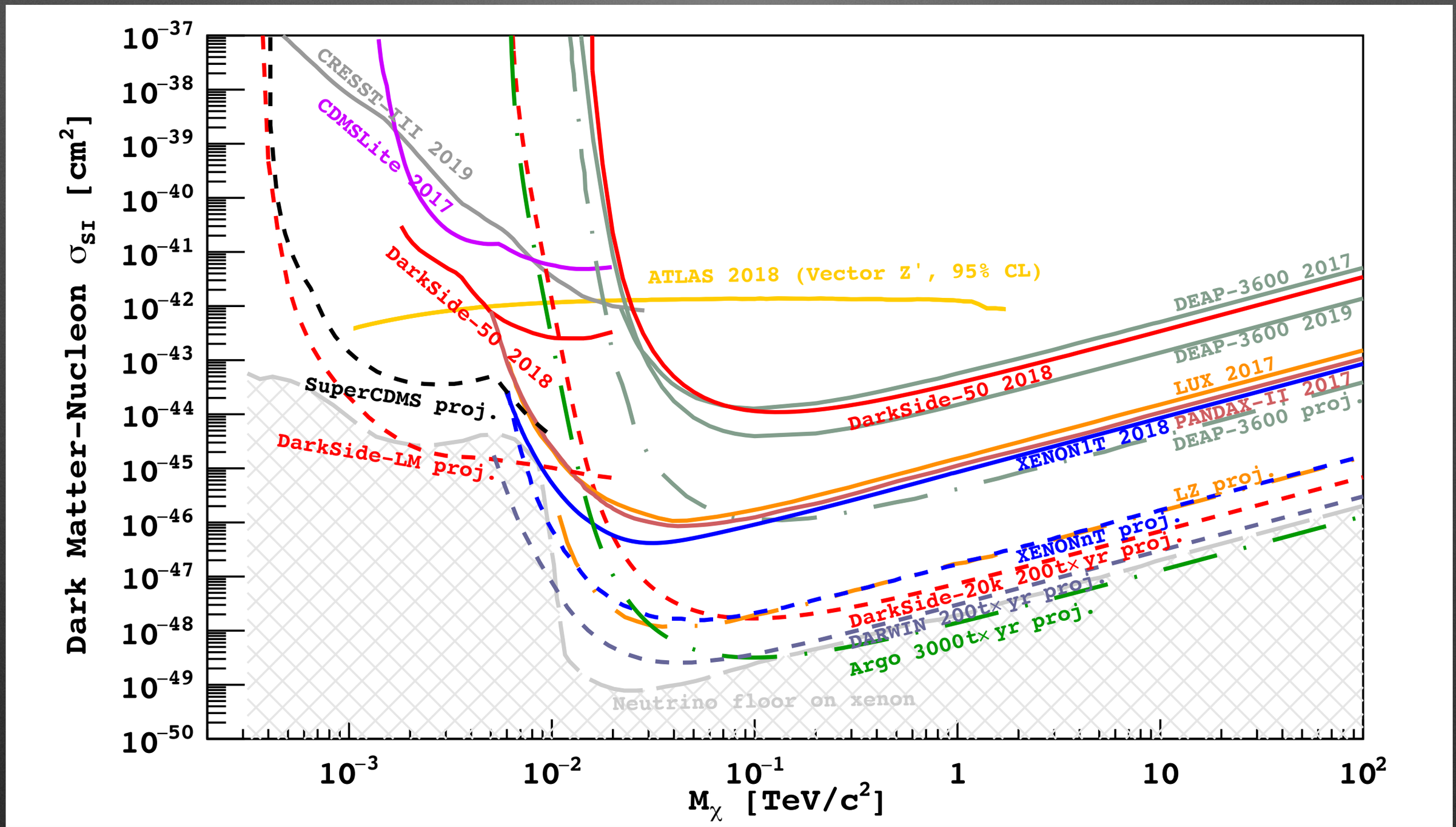
  - Process ~1 tonne/day with 1000 reduction of all chemical impurities and isotopically separate ^{39}Ar from ^{40}Ar



Seruci-0 - prototype

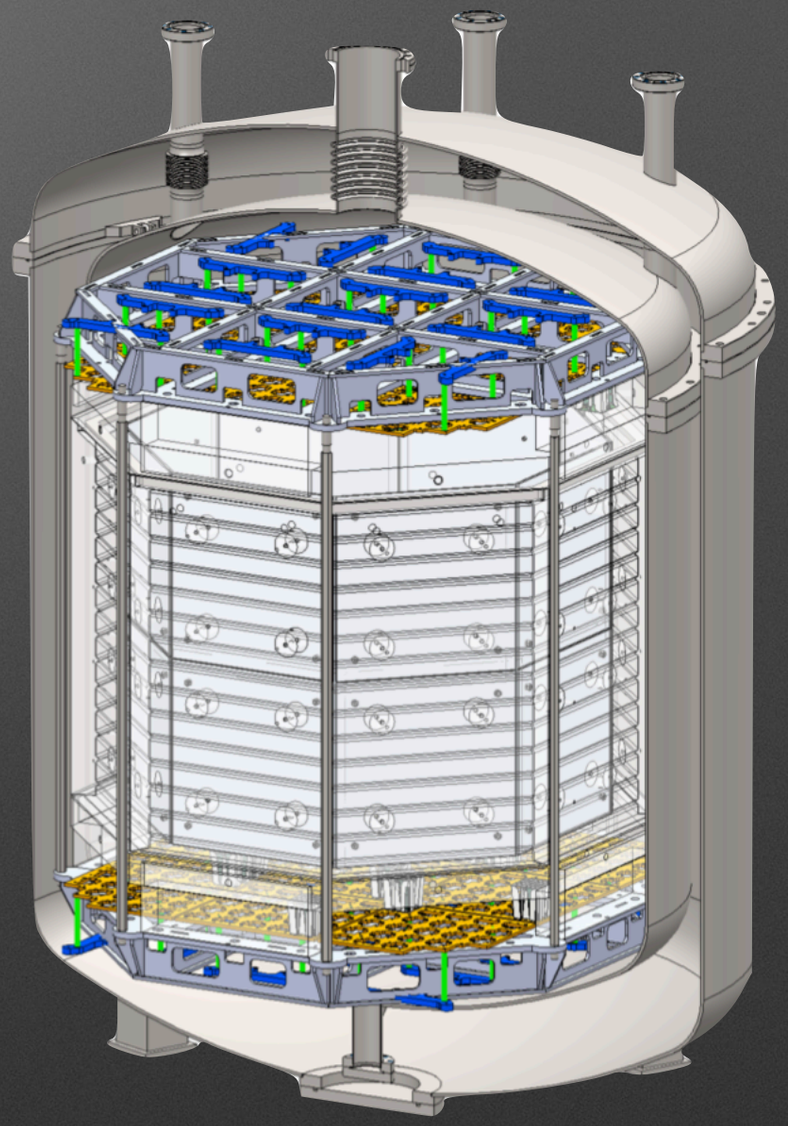
Seruci-I and II

Projected sensitivity



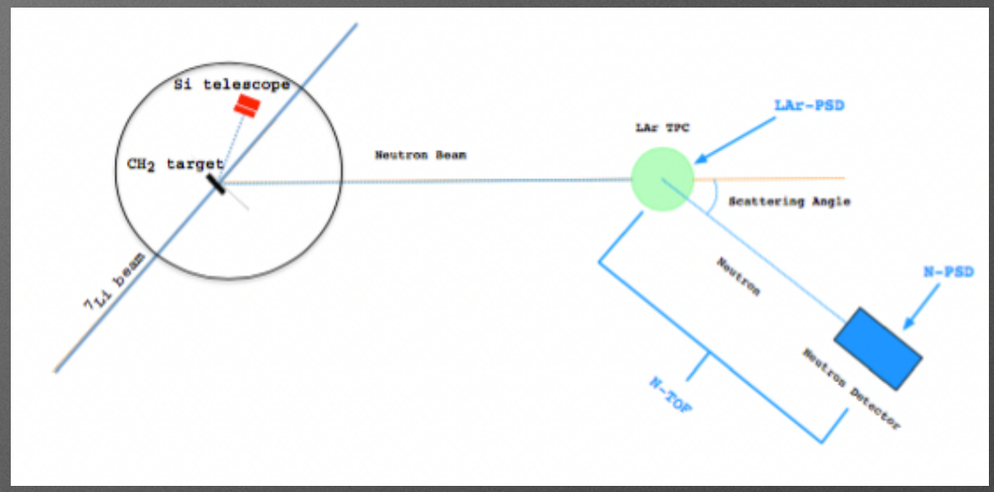
DarkSide-LowMass

- Look for low mass WIMP using a DS-20k-like detector
- Starting point for the study: DS-20k prototype at LNGS with active or passive system
- 800 kg (360 kg fiducial) depleted Ar
- Possibility to further reduce radioactivity from SiPM
- Need to characterise low energy nuclear recoils

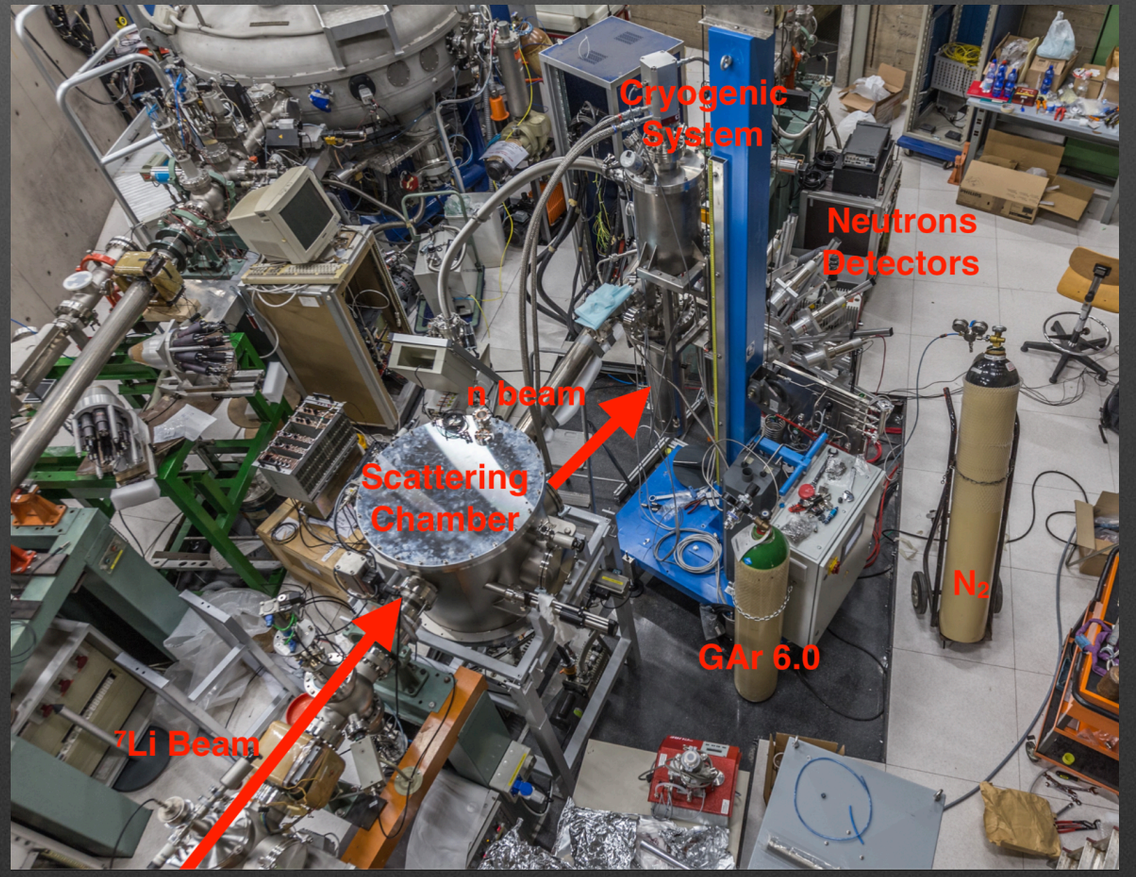


RED

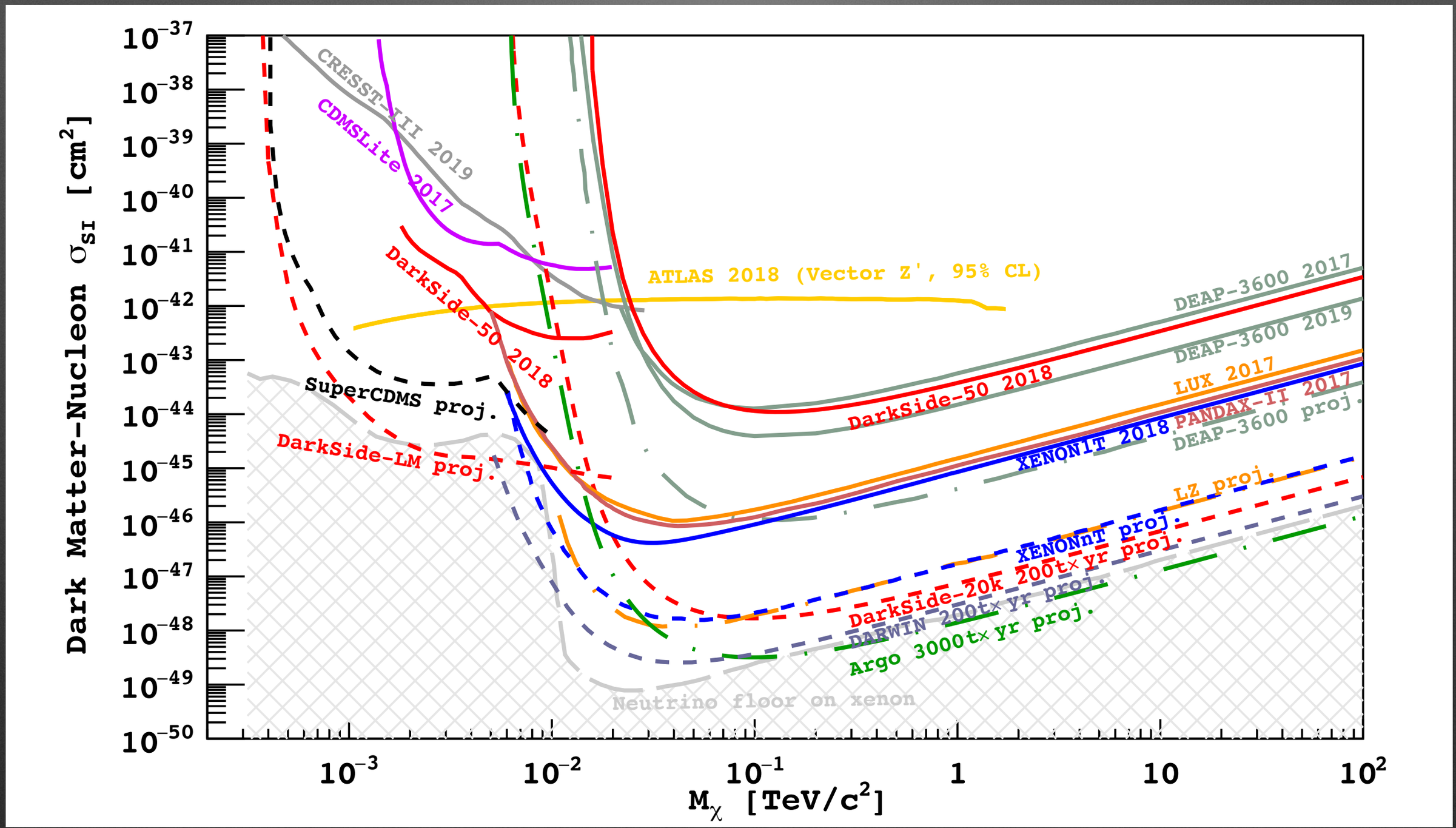
- Irradiate small LAr TPC with neutrons [p(^{7}Li,n) reacition] and study the response for recoil parallel or orthogonal to the electric field



- Primary goal: investigate hint of directionality proposed by SCENE
- RED is the first prototype using ds-20k technologies
- Direct measurement of low energy nuclear recoil properly tuning the beam energy and the geometry setup
- Next run this summer



DarkSide-LowMass



Conclusions

- DarkSide-50 results proved LAr technology is competitive both for high- (background free) and low-mass (best sensitivity for 1.8-5.5 GeV) WIMP searches

- Ambitious dark matter search program with DarkSide-20k which is developing essential technologies on several fronts

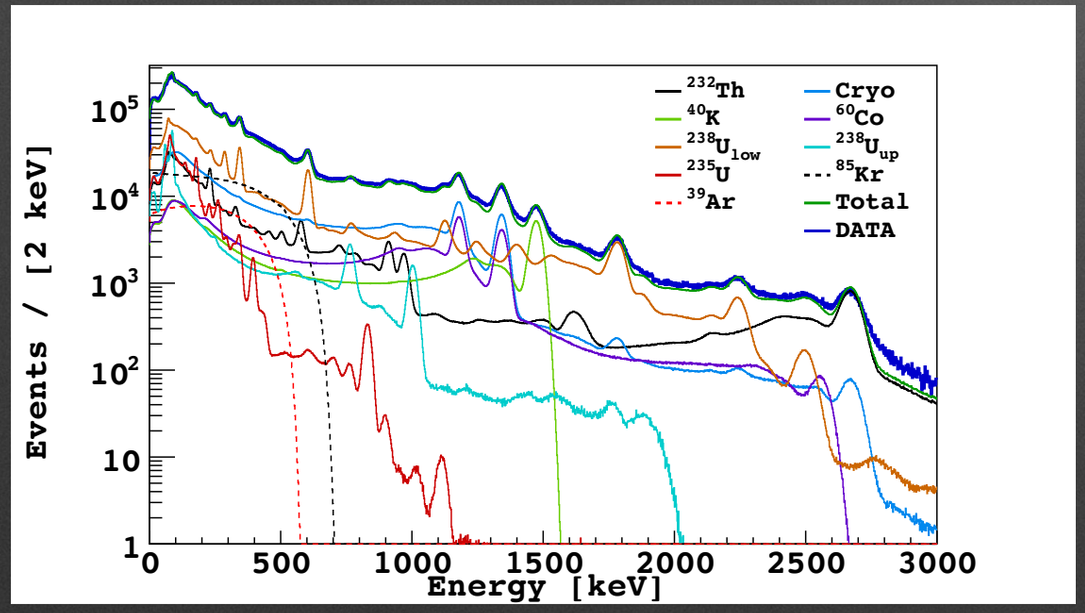
- LAr technology is very promising to lead the path towards the neutrino floor in both high- and low-mass WIMP regions

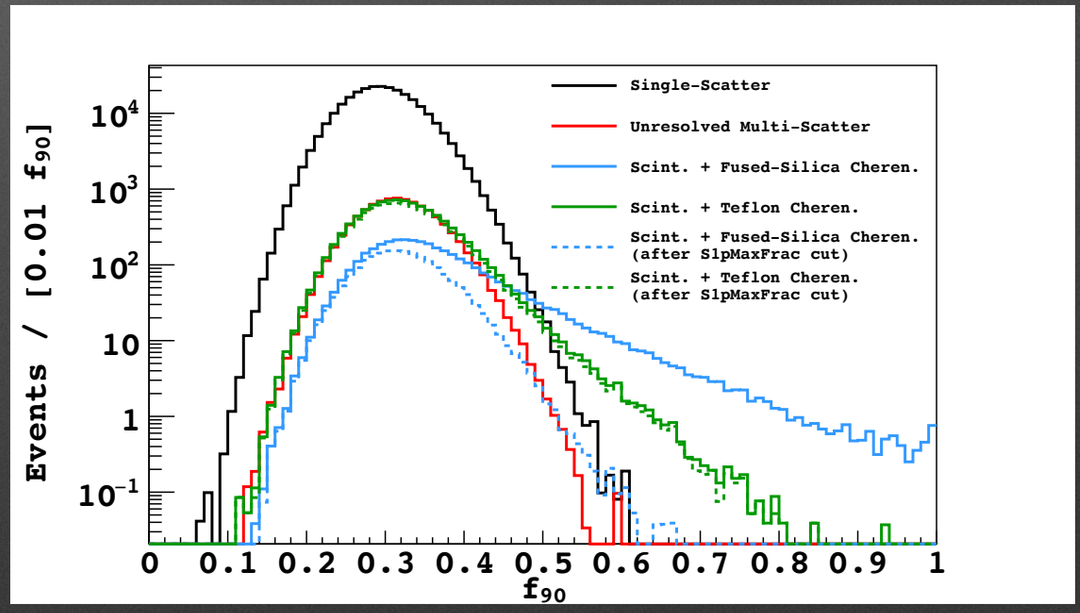
Backup

Background ERs

- β and γ: predominant contribution from construction material. UAr has (0.73 ± 0.11) mBq/kg of ^{39}Ar, and (2.05 ± 0.13) mBq/kg of ^{85}Kr.
- Rejection strategy:
  - PSD rejection power in ROI is down to 6×10^{-8} for single-site ERs
  - WCD + LSV

- Cherenkov + scintillation: γ multiple scatters in LAr and PTFE or fused-silica. Cherenkov ($f_{90} \approx 1$) moves regular scintillation into NR band.
- Rejection strategy:
  - light distribution in top PMTs
  - radial fiducialization

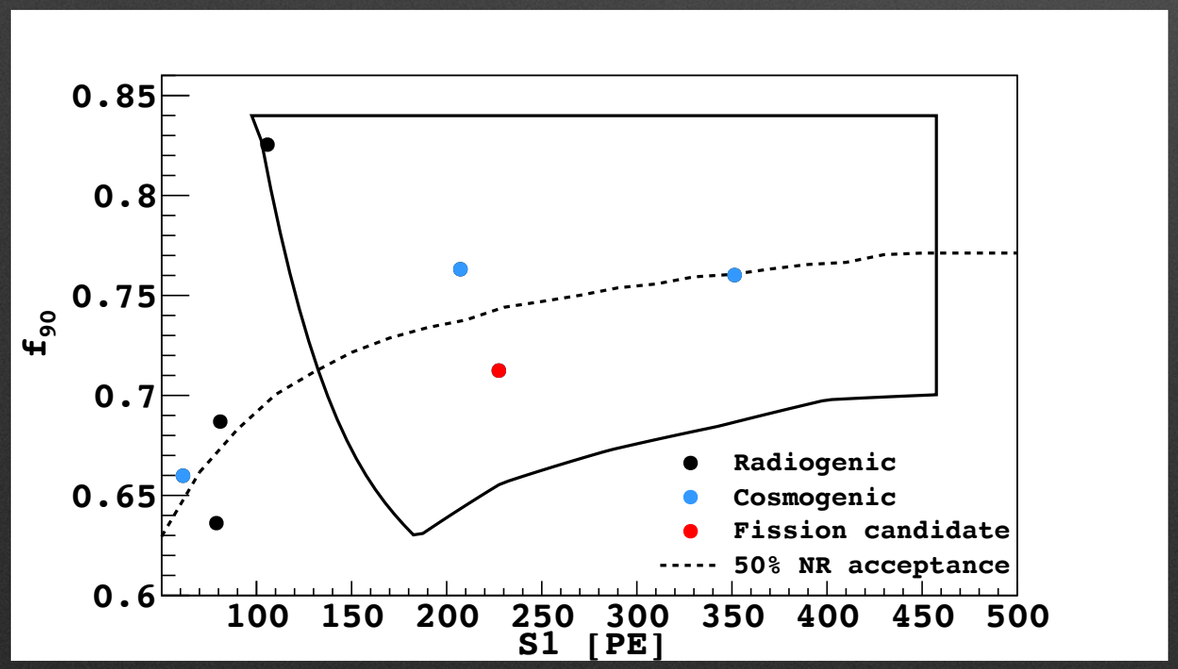


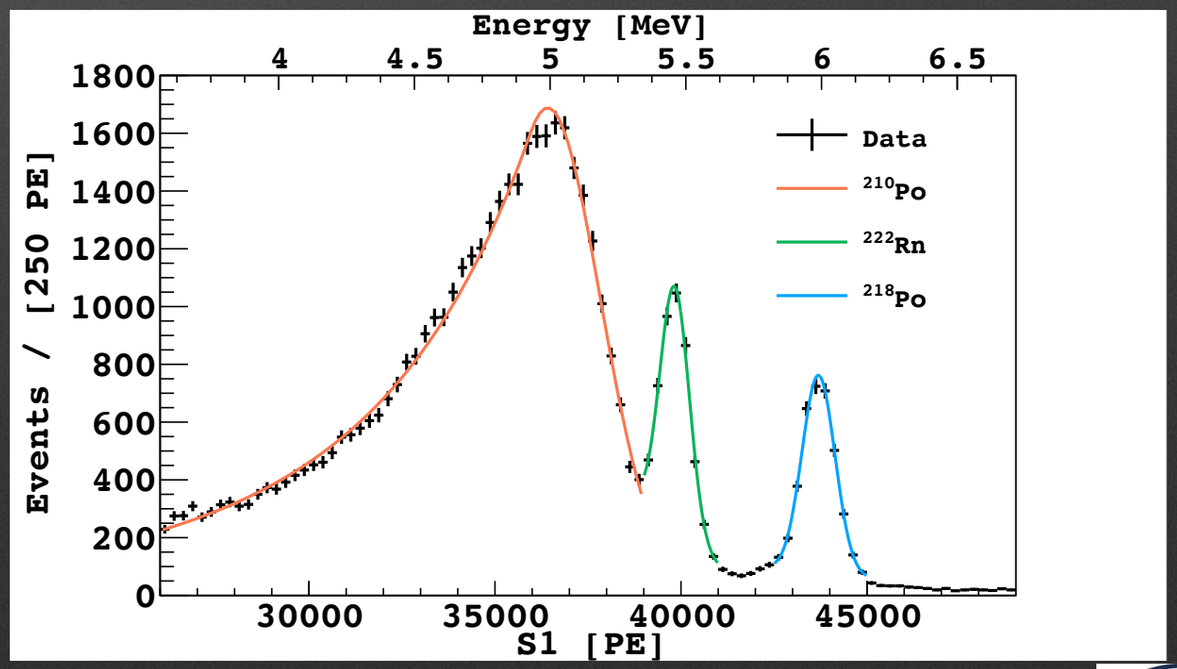


Intensive background modelling done with a data/MonteCarlo hybrid approach - JINST 12, P10015 (2017)

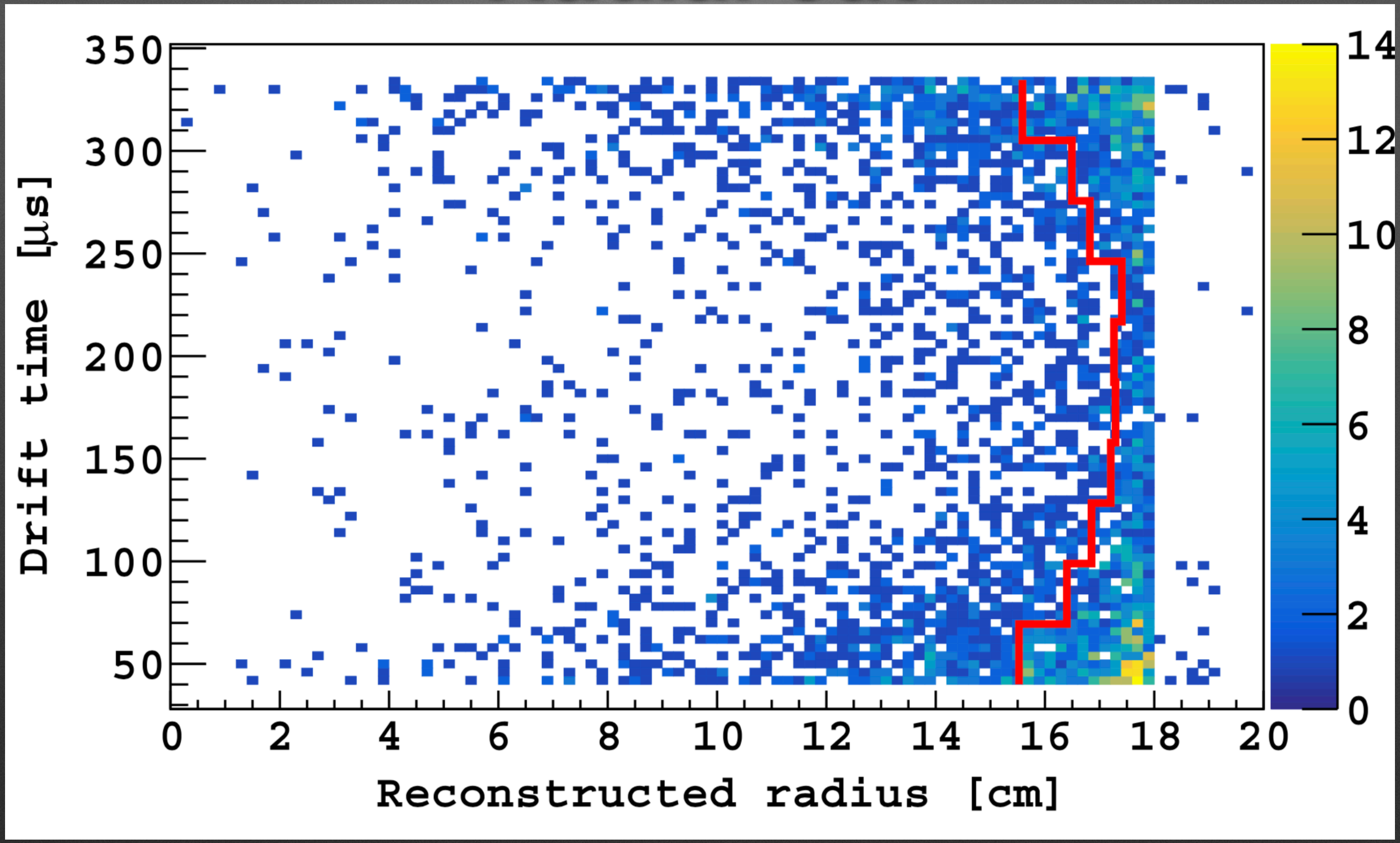
Background NRs

- Neutrons: cosmogenic or (α,n) reactions
- PMTs are the main source
- Rejection strategy:
  - Multiple scatter in TPC
  - Coincidence with LSV: measured efficiency with AmC 99.64±0.04% (fraction of event surviving veto cuts)
  - Coincidence with WCD
- α: stringent material selection constraints α emitters to Rn daughters on surfaces or in LAr (recirculation)
- Degraded in energy **α** can follow in NR band.
- Rejection strategy:
  - Very small or absent S2
  - S2 has long scintillation tail due to TPB scintillation





Radial cut


Drift time [μs]
350
300
250
200
150
100
50
0
2
4
6
8
10
12
14
16
18
20
Reconstructed radius [cm]
14
12
10
8
6
4
2
0