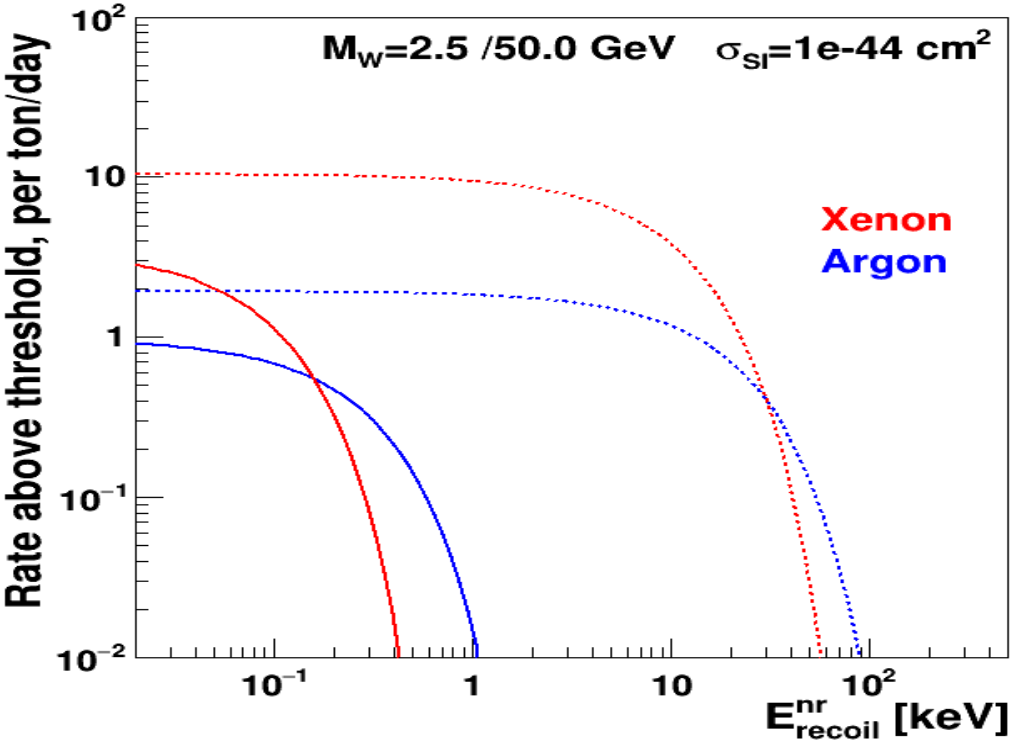
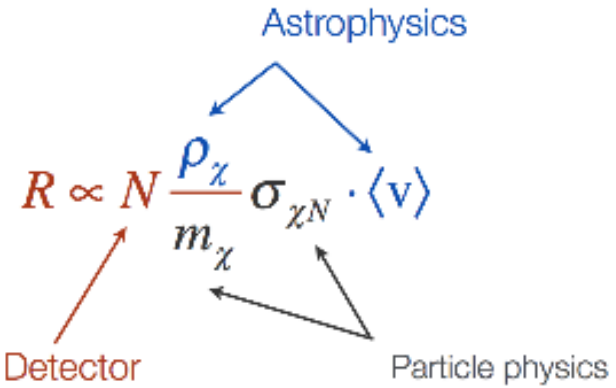
New physics results from Darkside-50

M. Ave (Universidade de São Paulo, Brazil)

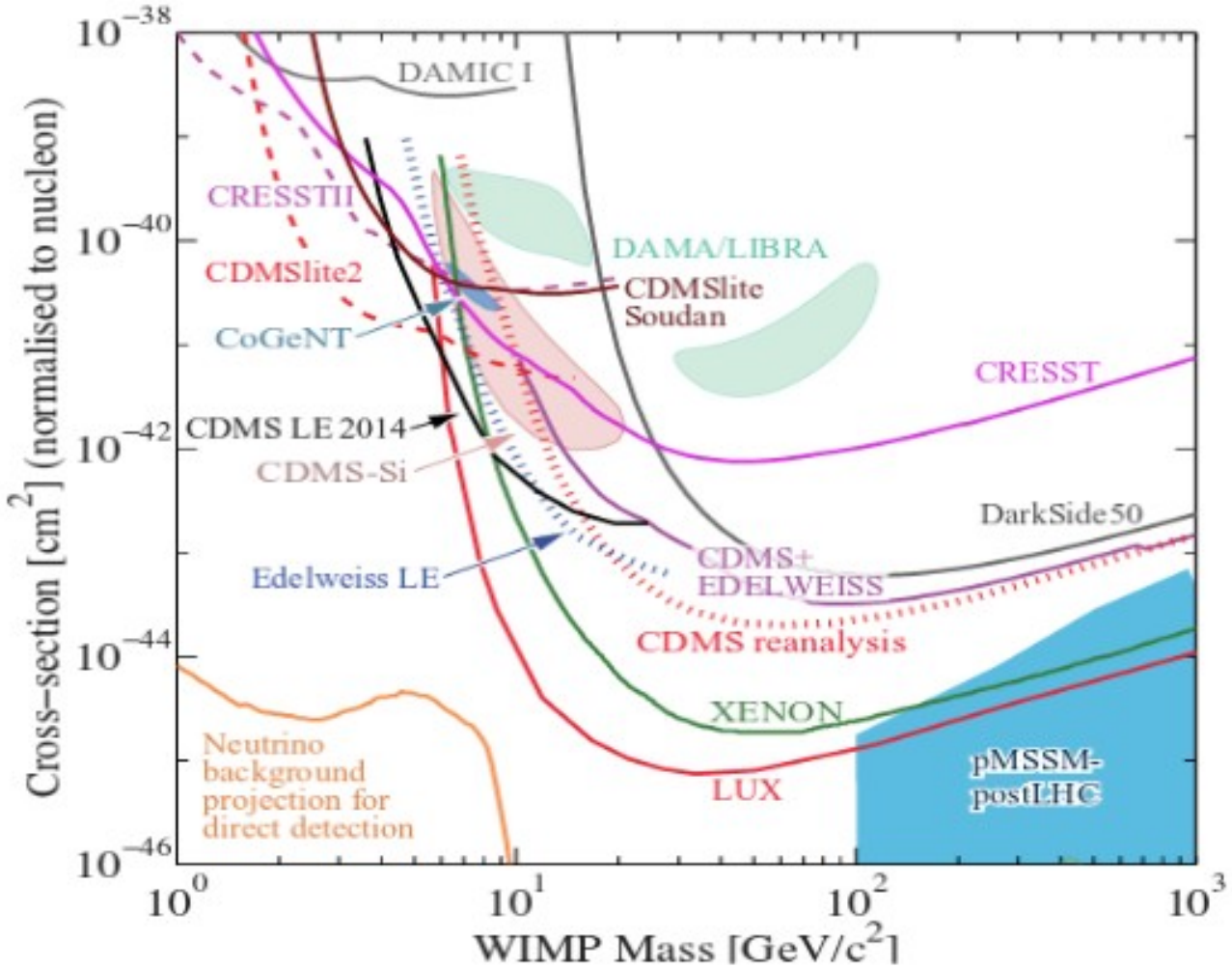
Direct detection: Nuclear Elastic Scattering





Xenon/Argon are complementary.

Direct detection limits



Review plot from Particle Data Book

20 GeV-1 TeV searches : first thought models constrained. The neutrino floor is the target of next generation detectors.
1 GeV-10 GeV searches : weakly constrained (only a small set of dedicated experiments like DAMIC, CDMSLite).

DarkSide Collaboration

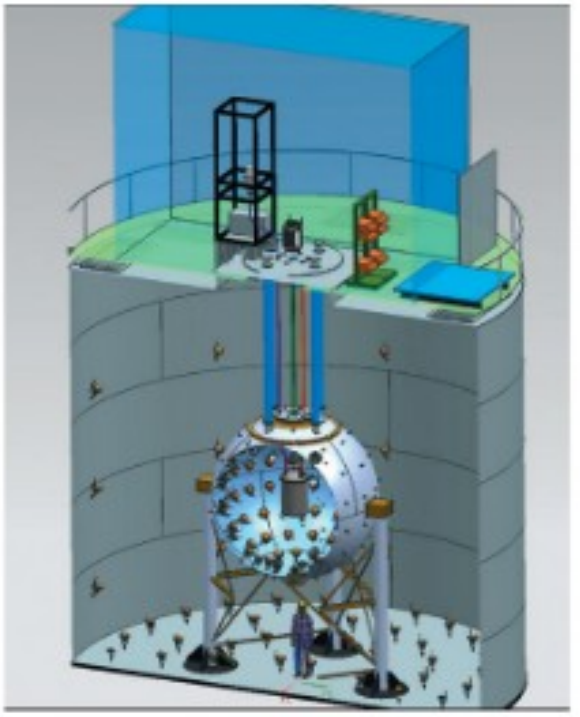
Italy, USA, Russia, Spain, France, China, Brasil, Poland

USP/UNICAMP

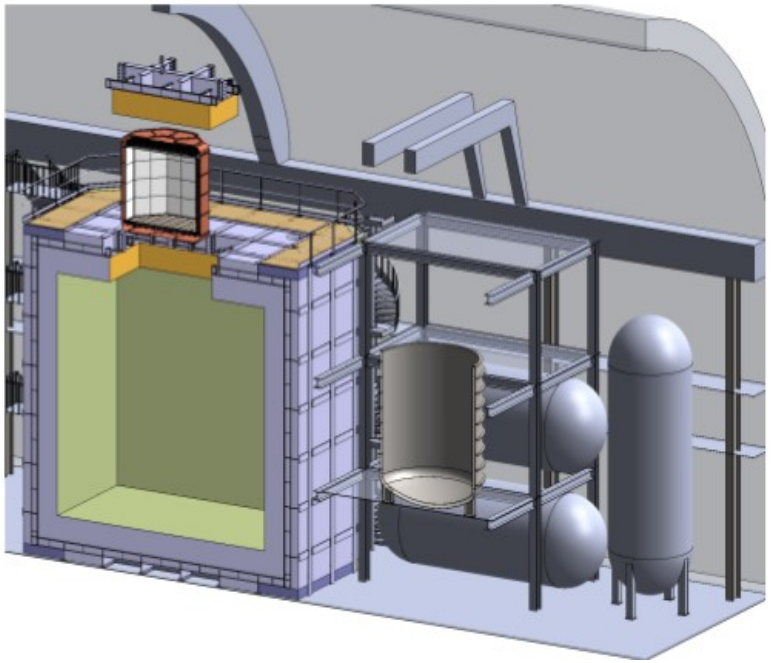
FAPESP (2016/09084-0)

Laboratori Nazionali del Gran Sasso

- DS-50 → 50 kg
- DS-Proto → ~1 ton
- DS-20K → ~20 ton
- Argo → ~200 ton



DS-50



DS-20K

A new collaboration has been formed with groups from DS-50, ArDM and DEAP-3600 to construct DS-Proto, DS-20K and Argo.

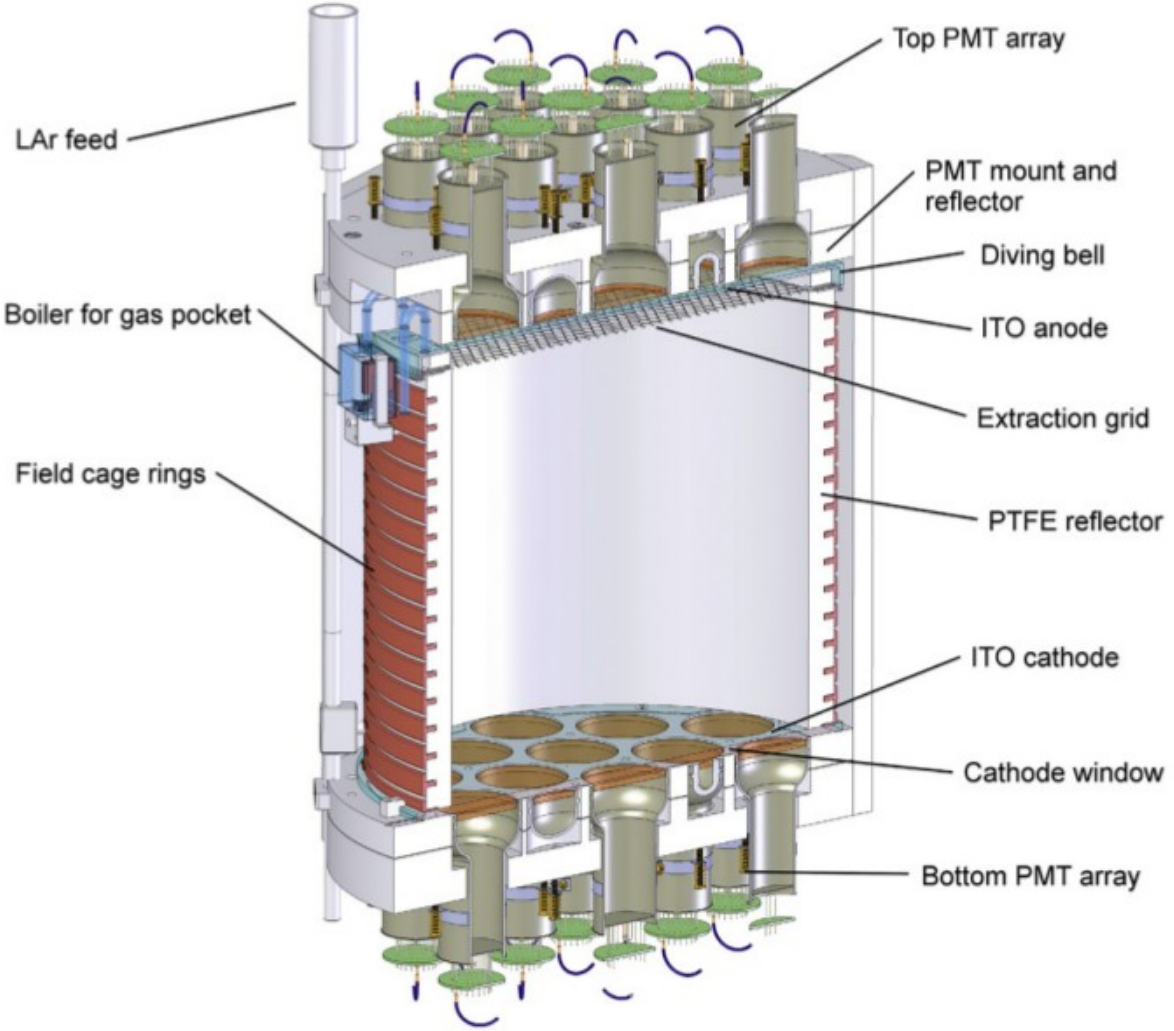
Goals and design

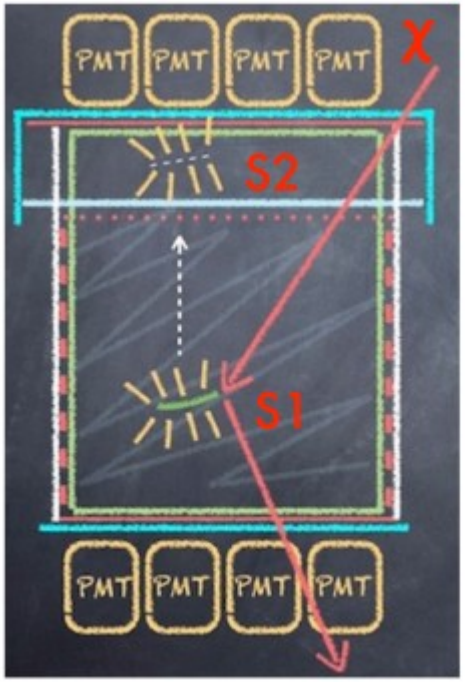
Goal : WIMP search down to the neutrino floor with almost no background

Design:

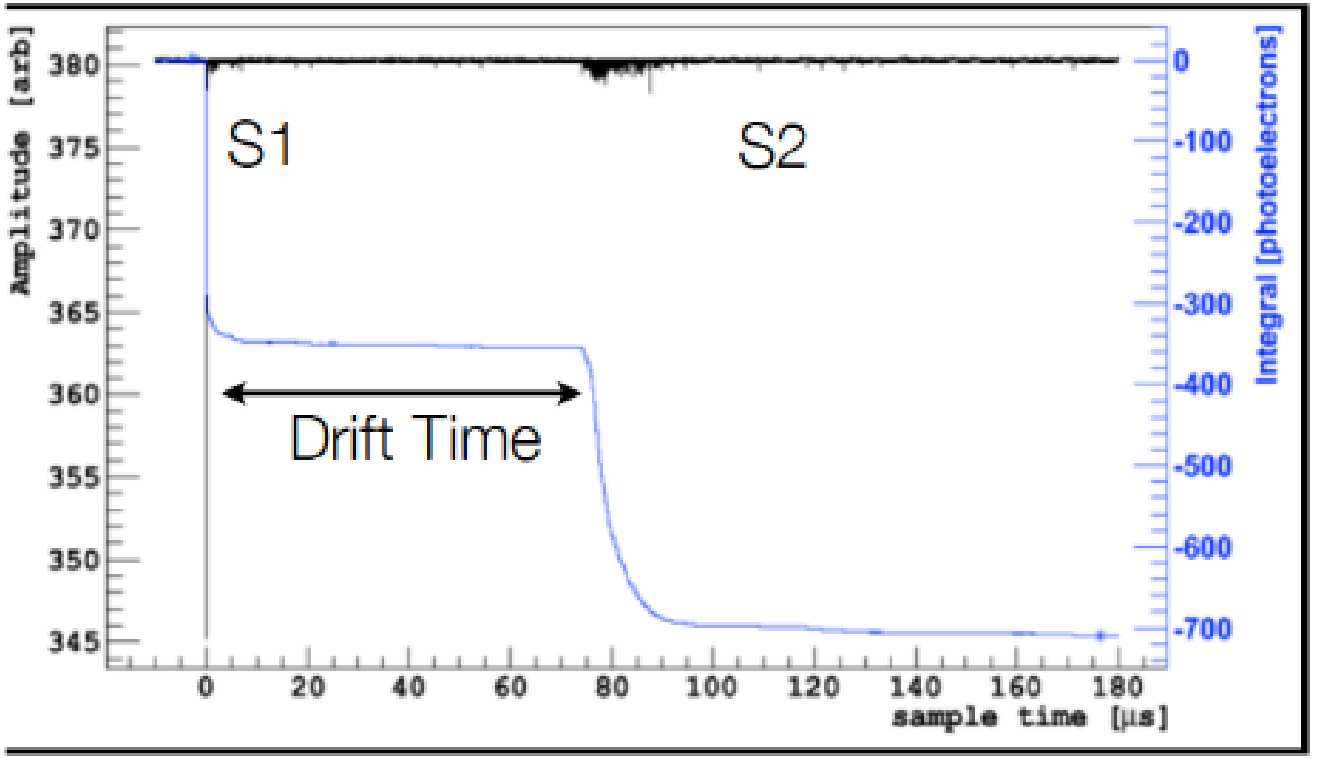
- Double Phase Time Projection Chamber: XYZ fiducialization and Single/Multiple Scatter identification.
- Argon target: discrimination through pulse shape and ionization to scintillation ratio.
- Underground argon naturally depleted in ^{39}Ar (~1400 compared to Atmospheric Argon)
- Outer detectors: shielding and veto neutrons

Time Projection Chamber





DS-50 46.4 kg total mass



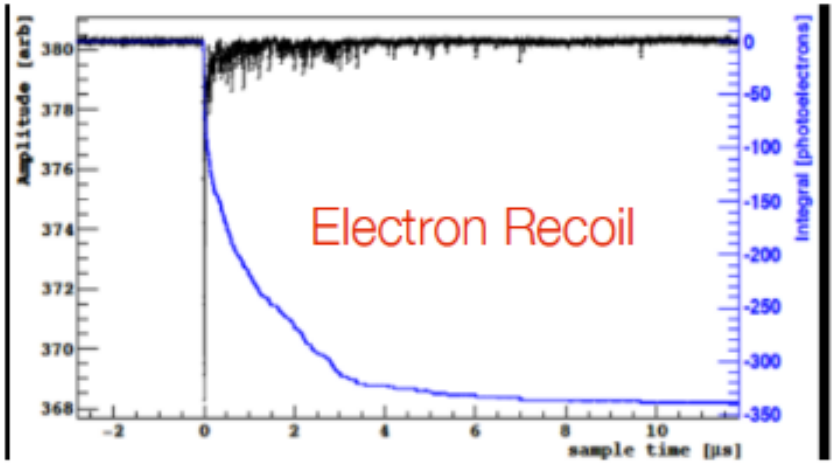
Maximum drift time
375 μs

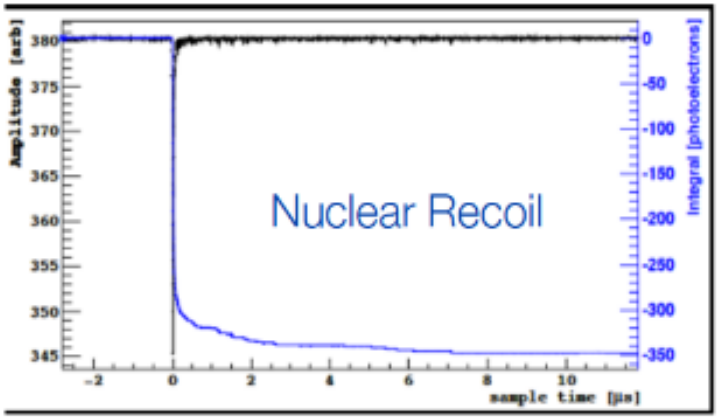
S1 → Scintillation signal (~10 μs pulse with two components)
- Fraction of light within 90 ns : ER/NR discrimination

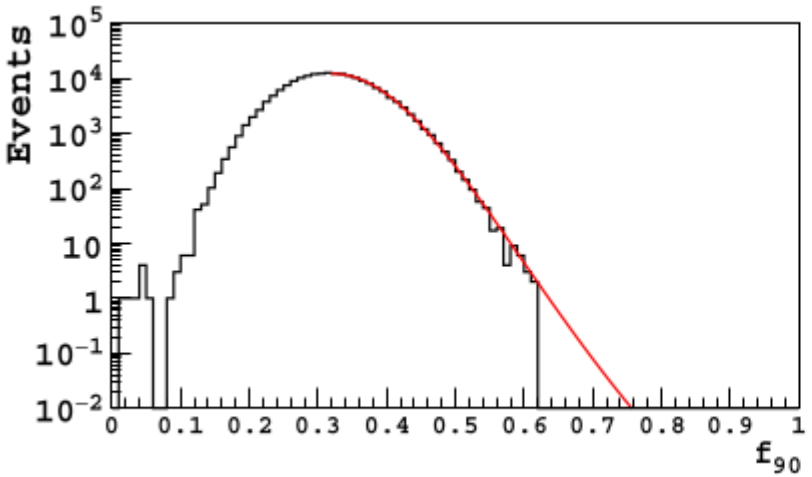
S2 → Ionization signal (~10 μs pulse, shape due to secondary scintillation)
- Drift time: Z position
- Fraction of light in each PMT: XY position
- S2/S1 : ER/NR discrimination

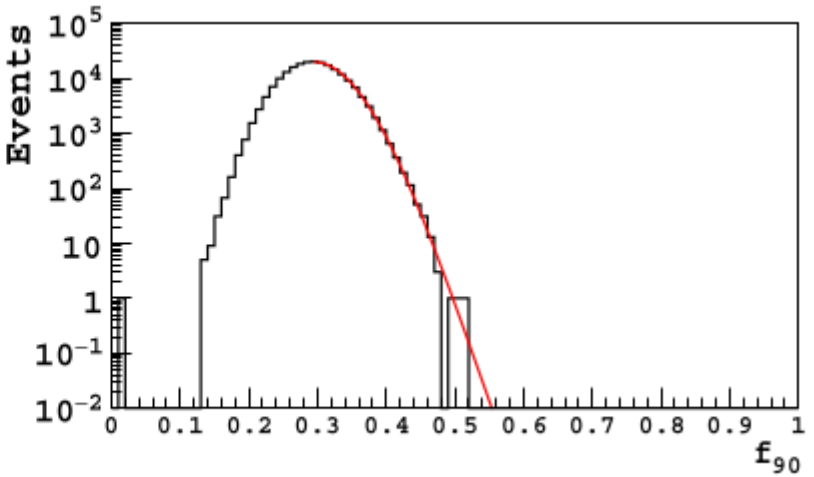
ER → Electron Recoil
NE → Nuclear Recoil

PSD discrimination: the strength of the Argon target





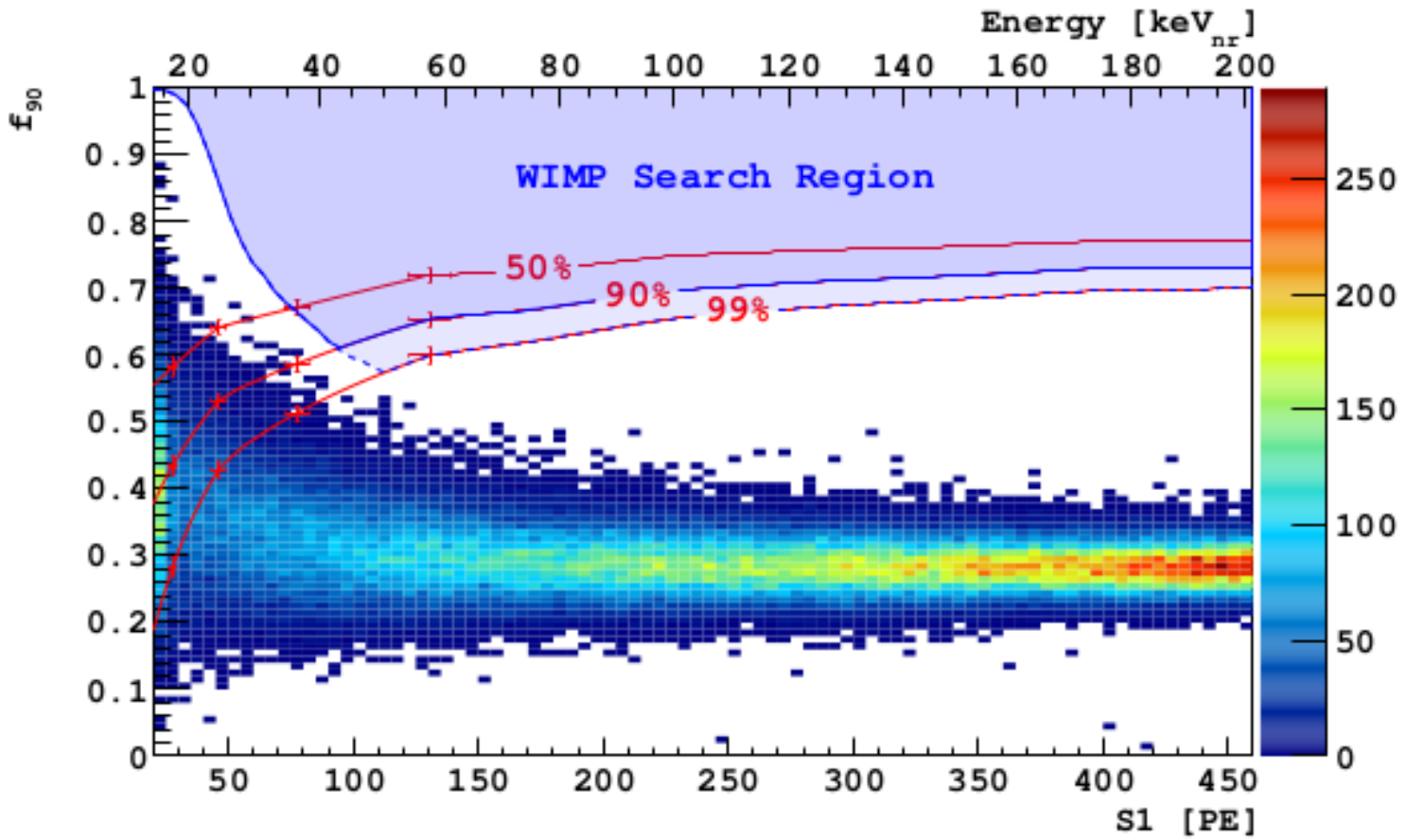




Atmospheric Argon Data.
f90 ER calibration

S1= 80-85 PE

S1= 180-185 PE



70 day Underground Argon run

Decreasing rejection power due to photo-statistics

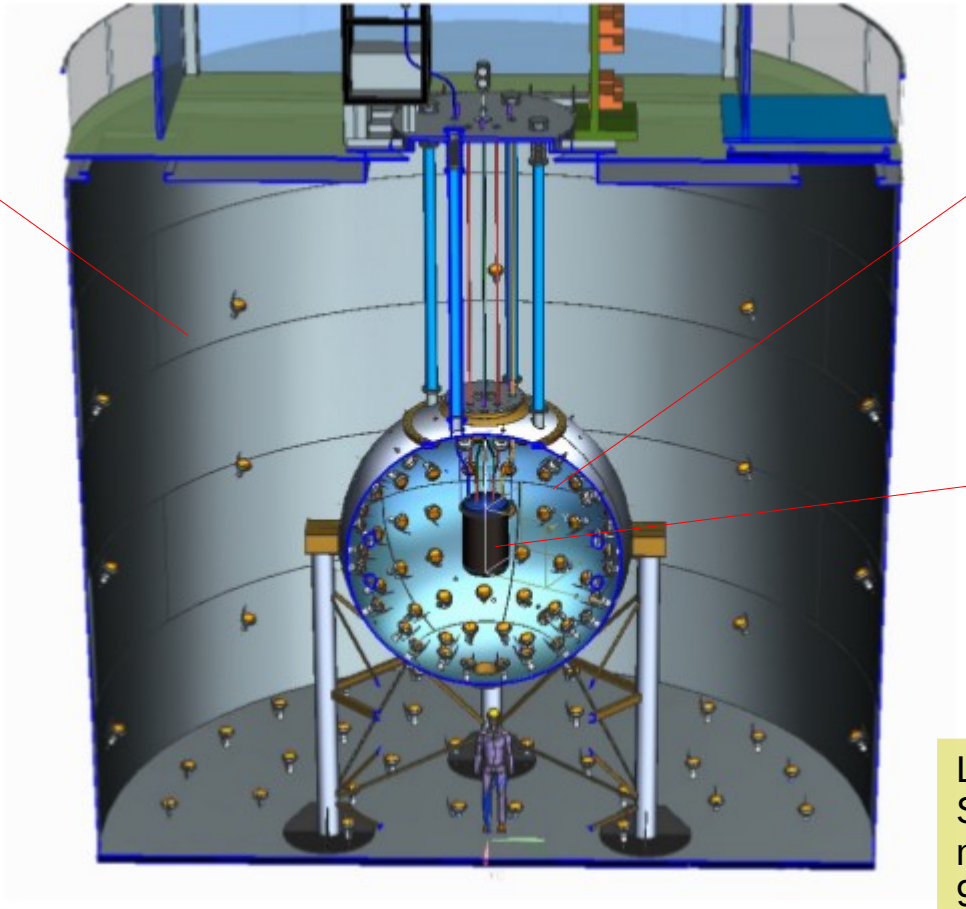
WIMP search region:

- Intersection of desired ER leakage line (~1 event in 70 days in this example) with neutron recoil acceptance line.
- Effective threshold: ~30 keV^{ne}

The f90 ER leakage into the NR band is of the order of 1 in 10^7

The outer detectors

Water Cherenkov Detector
(WCD)
80 PMTs (8”)
1000 tonnes



Liquid Scintillator Veto
(LSV)
110 PMTs (8”)
30 tonnes , 3 m diameter

TPC+Cryostat

Shielding and anticoincidence,
Radiogenic and Cosmogenic neutrons,
Gammas and Cosmic Rays.

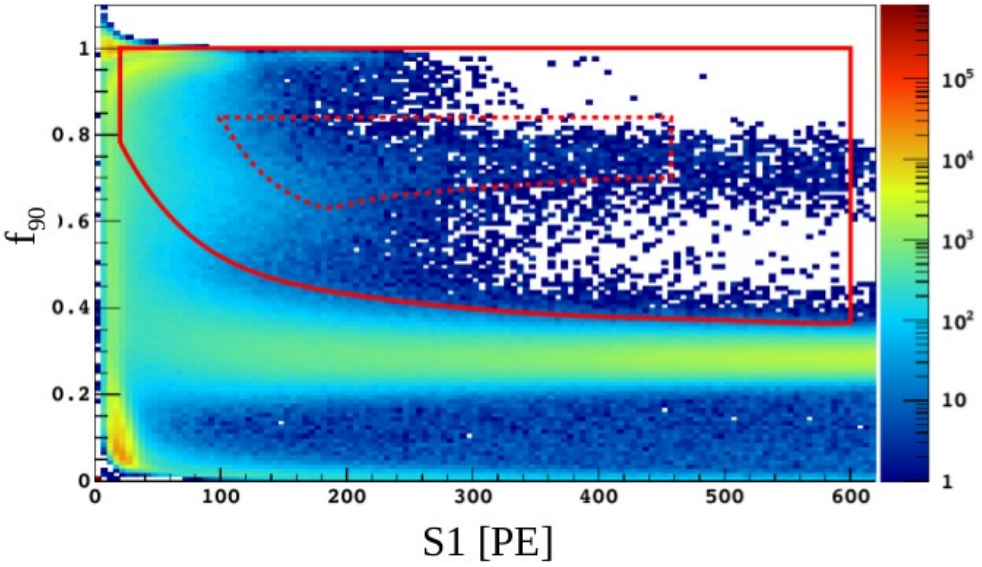
LSV uses Boron Loaded Scintillator (PC+TMB+PPO), neutron rejection efficiency 99.64%.

^{14}C purification was required to detect α from neutron capture (short range particle)

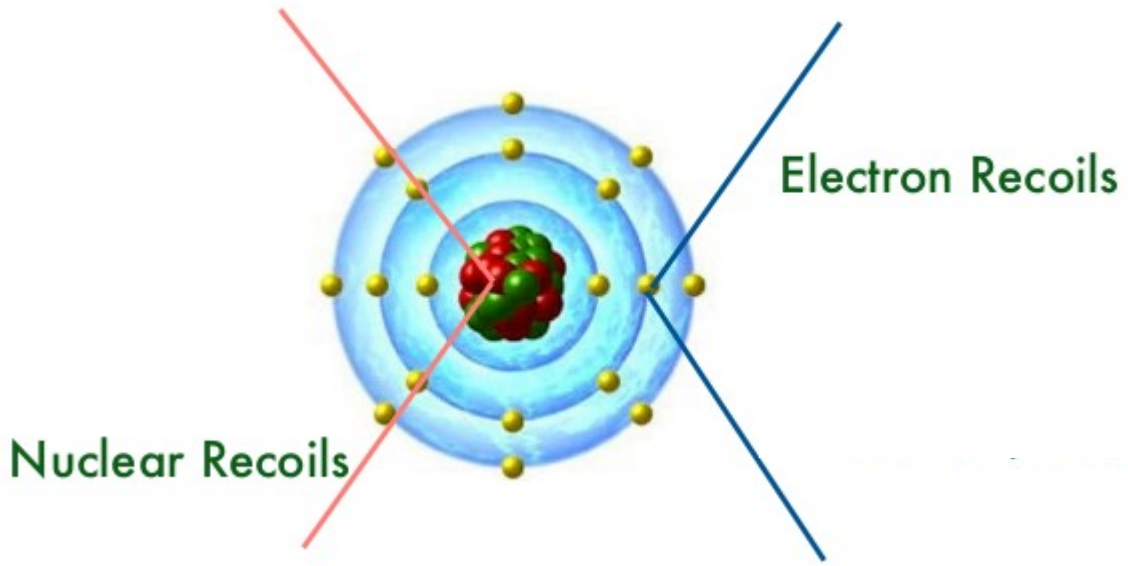
DS-50 long run: 532.4 days

Blind analysis

- blind enlarged box containing WIMP search region in the a F90 vs S1 parameter space (at event reconstruction level)
- **model BG events:** calibration data and MC tuning
- Refine cuts based on leakage BG events (≤ 0.1 events total)
- Test **BG models** on outer strip of blind box
- Unblind WIMP region

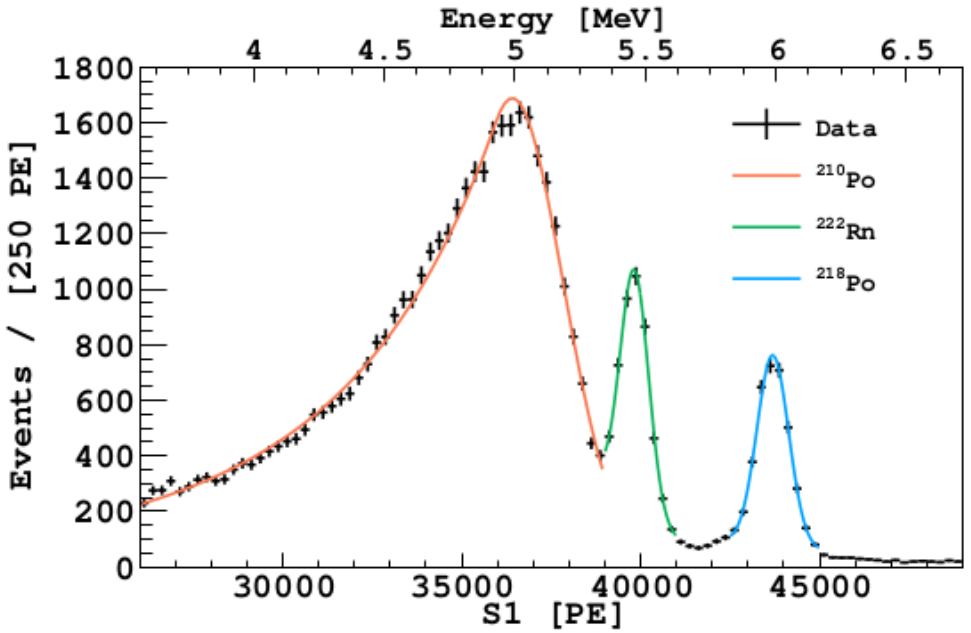


Backgrounds



Background	Events surviving all cuts
Surface Type 1	<0.0007
Surface Type 2	0.00092 ± 0.00004
Radiogenic neutrons	<0.005
Cosmogenic neutrons	<0.00035
Electron recoil	0.08 ± 0.04
Total	0.09 ± 0.04

Alpha background abatement:
Mainly fiducialization and energy range

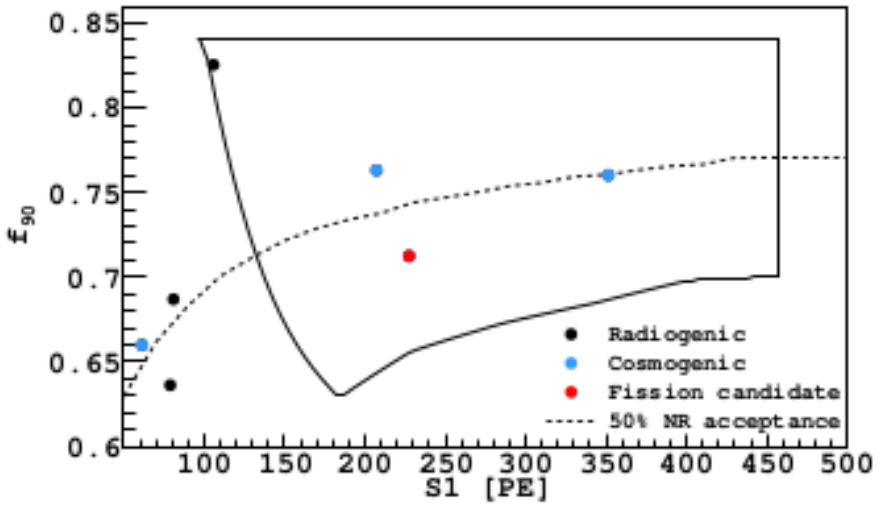


~2.5 mBq/m^2 ^{210}Po surface activity
~2.1 µBq/kg ^{222}Rn bulk activity

Surface alphas whose energy is not fully contained in the TPC are the most dangerous. But a loose **fiducial cut** is very effective against them.

The ***wall effect*** and ***TPB scintillation*** are also signatures of surface background

Neutron background abatement:
LSV cuts : 99.64% rejection efficiency



Monitoring neutron rate:
LSV Prompt Tag + f90(S1)

Given LSV efficiencies measured with AmBe/AmC sources.

Delayed LSV signal (neutron captures): 99.58%

σ=3837 barn on ^{10}B (20% natural abundance)

$$^{10}\mathrm{B} + n \rightarrow \begin{cases} ^{7}\mathrm{Li}\,(1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) & (6.4\%) \\ ^{7}\mathrm{Li}^{*} + \alpha\ (1471\ \mathrm{keV}),\ ^{7}\mathrm{Li}^{*} \rightarrow ^{7}\mathrm{Li}\,(839\ \mathrm{keV}) + \gamma\ (478\ \mathrm{keV}) & (93.6\%) \end{cases}$$

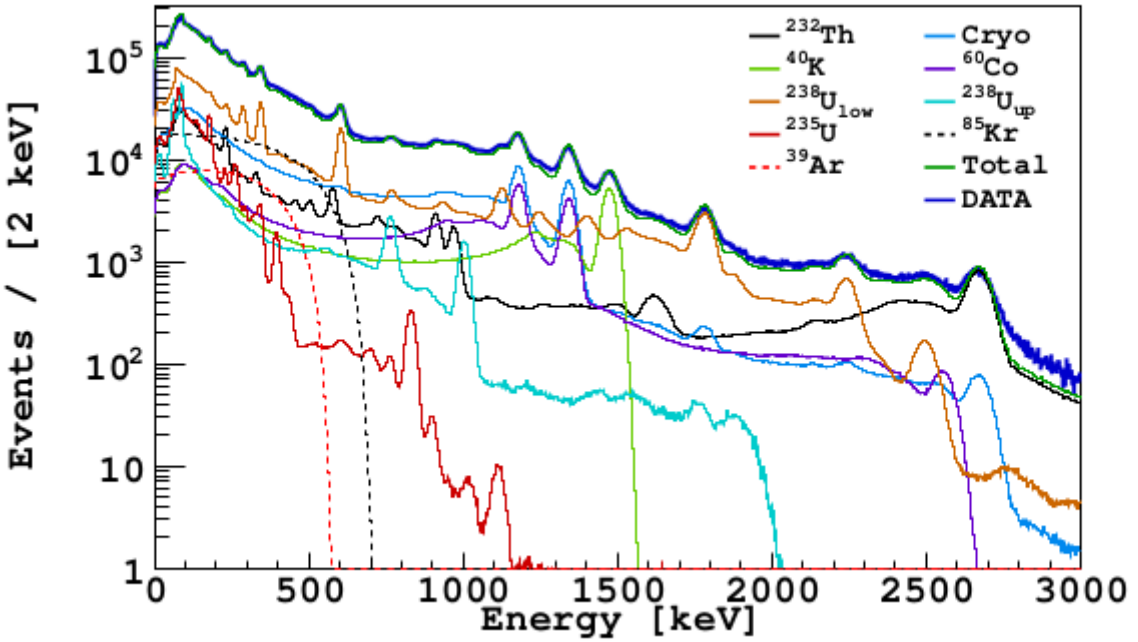
$$^{1}\mathrm{H} + n \rightarrow ^{2}\mathrm{H} + \gamma\ (2223\ \mathrm{keV}) \qquad I_\gamma/I_\gamma(\mathrm{max}) = 100\% \qquad \sigma = 0.33\mathrm{b}$$

$$^{12}\mathrm{C} + n \rightarrow \begin{cases} ^{13}\mathrm{C} + \gamma\ (3090\ \mathrm{keV}) & I_\gamma/I_\gamma(\mathrm{max}) = 100\% \\ ^{13}\mathrm{C} + \gamma\ (4945\ \mathrm{keV}) & I_\gamma/I_\gamma(\mathrm{max}) = 67\% \qquad \sigma = 0.0034\mathrm{b} \\ ^{13}\mathrm{C} + \gamma\ (1860\ \mathrm{keV}) & I_\gamma/I_\gamma(\mathrm{max}) = 57\% \end{cases}$$

Prompt LSV signal (neutron thermalization): 99.27%

- *Phase-I* Nov. 2013 – June 2014: 50% mass fraction of PC, 50% TMB, 2.5 g/L PPO
- *Phase-II* Feb. 2015 – present: 95% mass fraction of PC, 5% TMB, 1.4 g/L PPO

Beta and gamma background



Source	PMTs [Bq] fitted	PMTs [Bq] assayed	Cryostat [Bq] assayed
^{232}Th	0.277±0.005	0.23±0.04	0.19±0.04
^{40}K	2.74±0.06	3.0±0.4	$0.16^{+0.02}_{-0.05}$
^{60}Co	0.15±0.02	0.17±0.02	1.4±0.1
^{238}U^{low}	0.84±0.03	0.69±0.05	$0.378^{+0.04}_{-0.1}$
^{238}U^{up}	4.2±0.6	5.3±1.1	$1.3^{+0.2}_{-0.6}$
^{235}U	0.19±0.02	0.27±0.4	$0.045^{+0.007}_{-0.02}$
Liquid Argon Activity [mBq/kg]			
^{85}Kr	1.9 ± 0.1	^{39}Ar	0.7±0.1

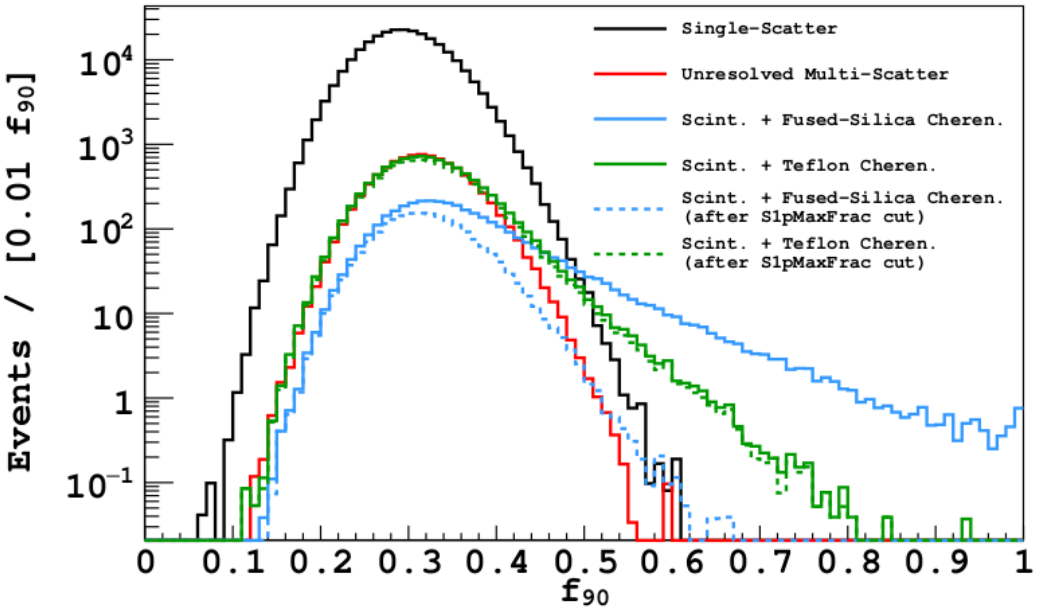
Prediction and refinement of the assayed activities.

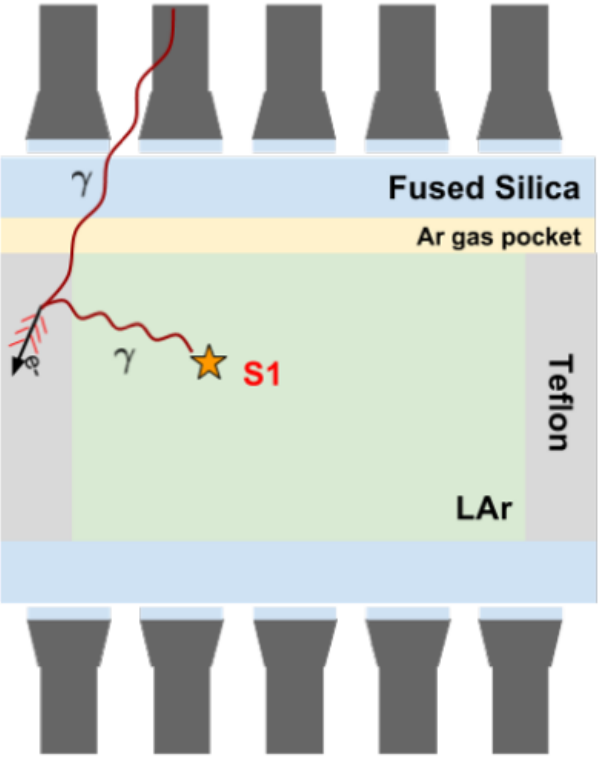
^{39}Ar Atmospheric 1 Bq/kg
Underground 0.7 mBq/kg

PMT gamma background dominates the budget.

Given the ER leakage into NR band, this background should not be a problem, **BUT**

Cherenkov mixed events spoils it

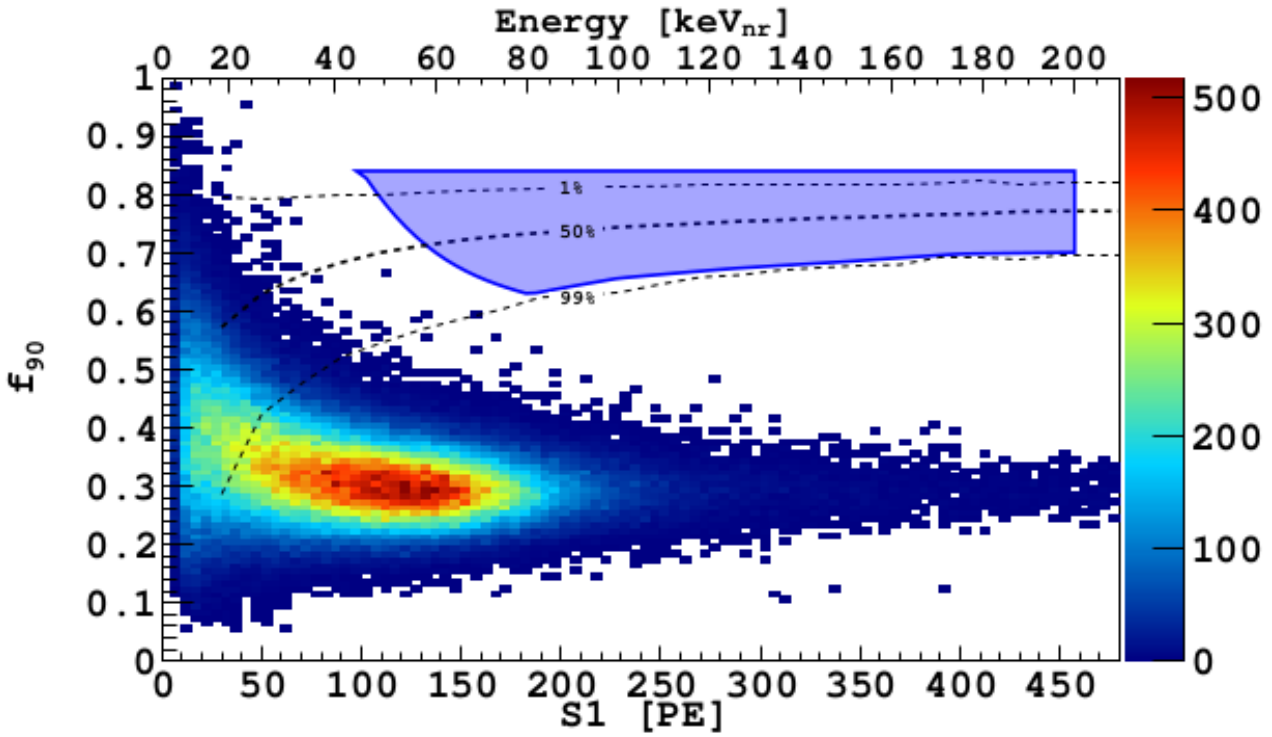




Fused silica Cherenkov effectively removed thanks to unusual high light fraction in a single PMT
Teflon Cherenkov is the dominant background

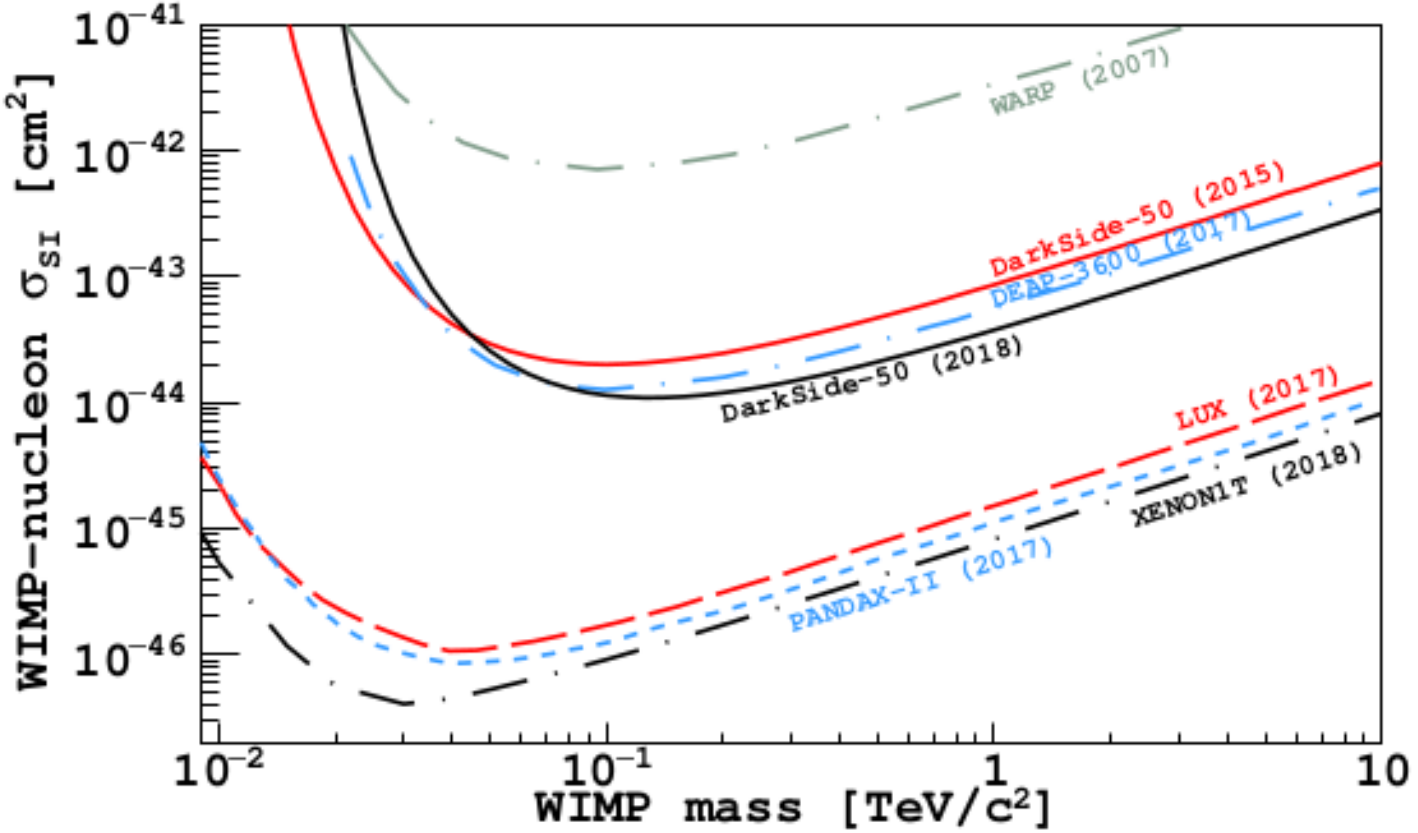
To reach <0.1 background of Teflon Cherenkov it was required:

- New S1(f90) WIMP search region.
- XYZ fiducialization.



A cut in S2/S1 ratio was also applied

Cross section limits

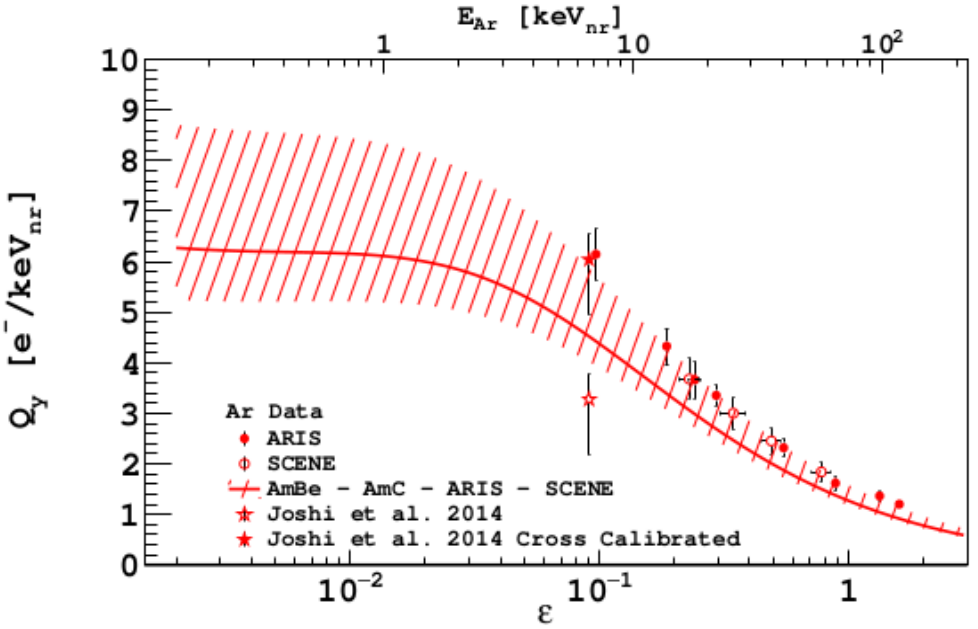


The reflector design in the next generation experiments has been redefined to inhibit Cherenkov production.

Technology validated. Now increase the target mass.

*"DarkSide50 **532 day** Dark Matter Search with Low Radioactivity Argon"*
ArXiv:1802.07198

DS-50 results for 2-10 GeV WIMPs



Ionization yield

- Argon/Xenon are sensitive to 1-10 GeV WIMPs if nuclear recoil detection threshold is <=1 keV^{ne}
- No ER/NR discrimination (Limits based on spectral shape)
- Sensitivity depends on overall background level.

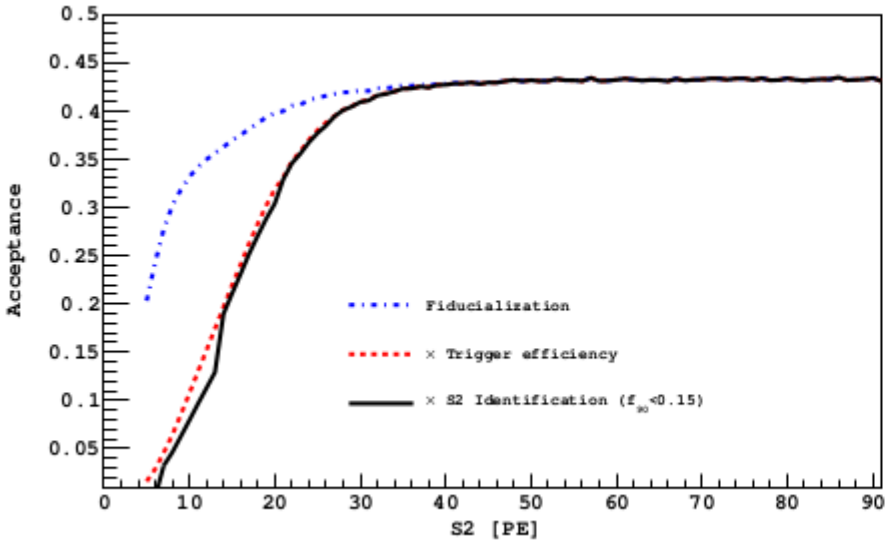
Scintillation signal threshold too high. Ionization signal needs to be used.

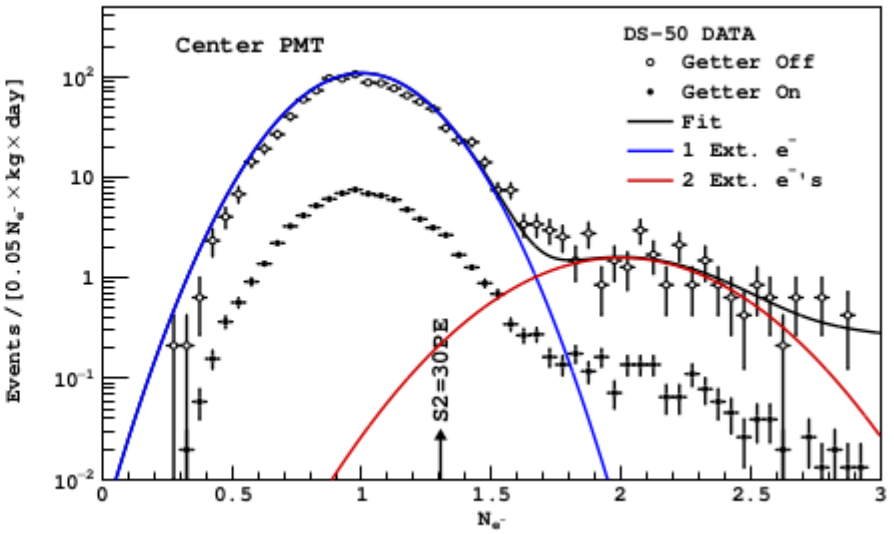
For Argon, 1 keV^{ne} → 5-9 electrons

arXiv: 1802.06994

Accepted for publication in PRL

1 electron → 23 PE (at the center of the TPC)



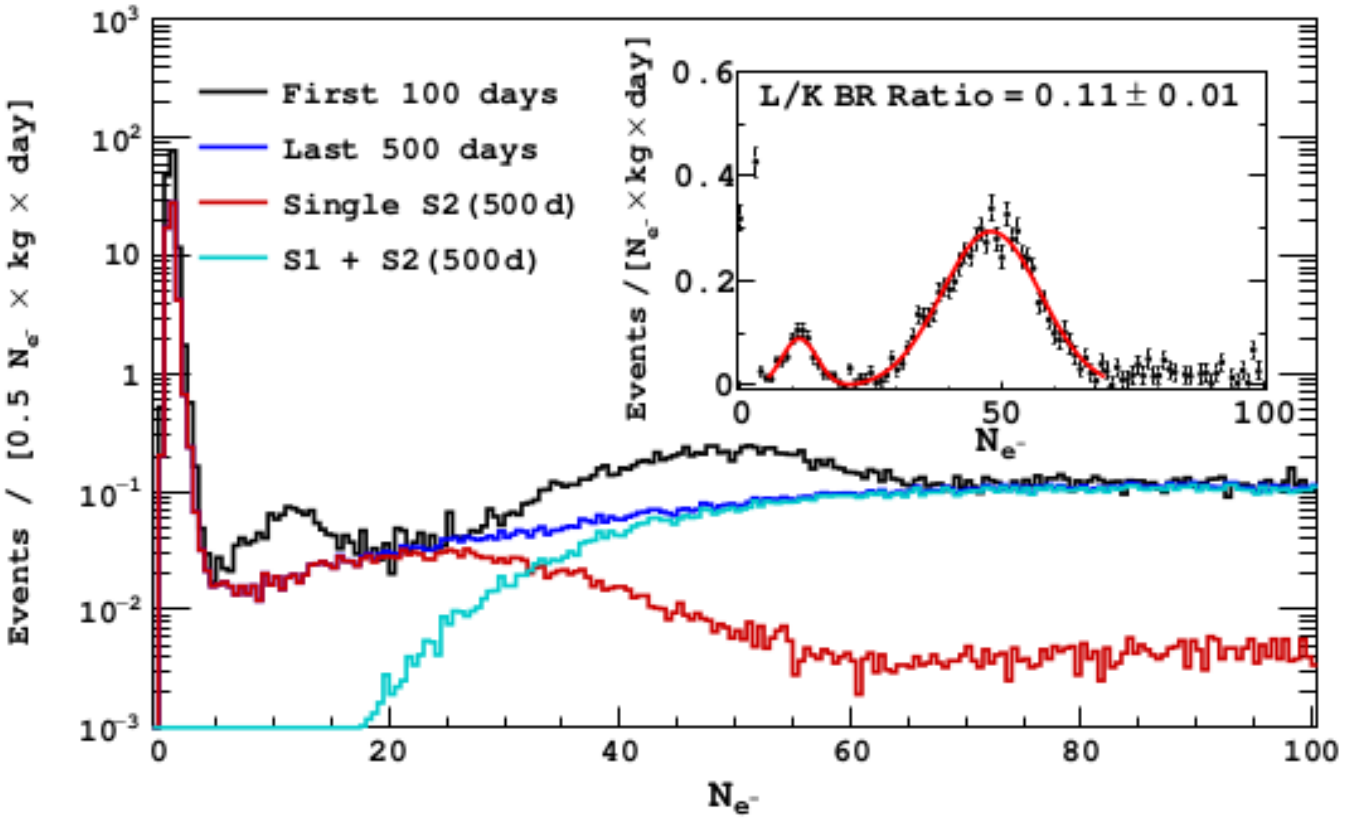


DS-50 is fully efficient for N_e >2

Only events in TPC core are used (less background,a better single electron resolution)

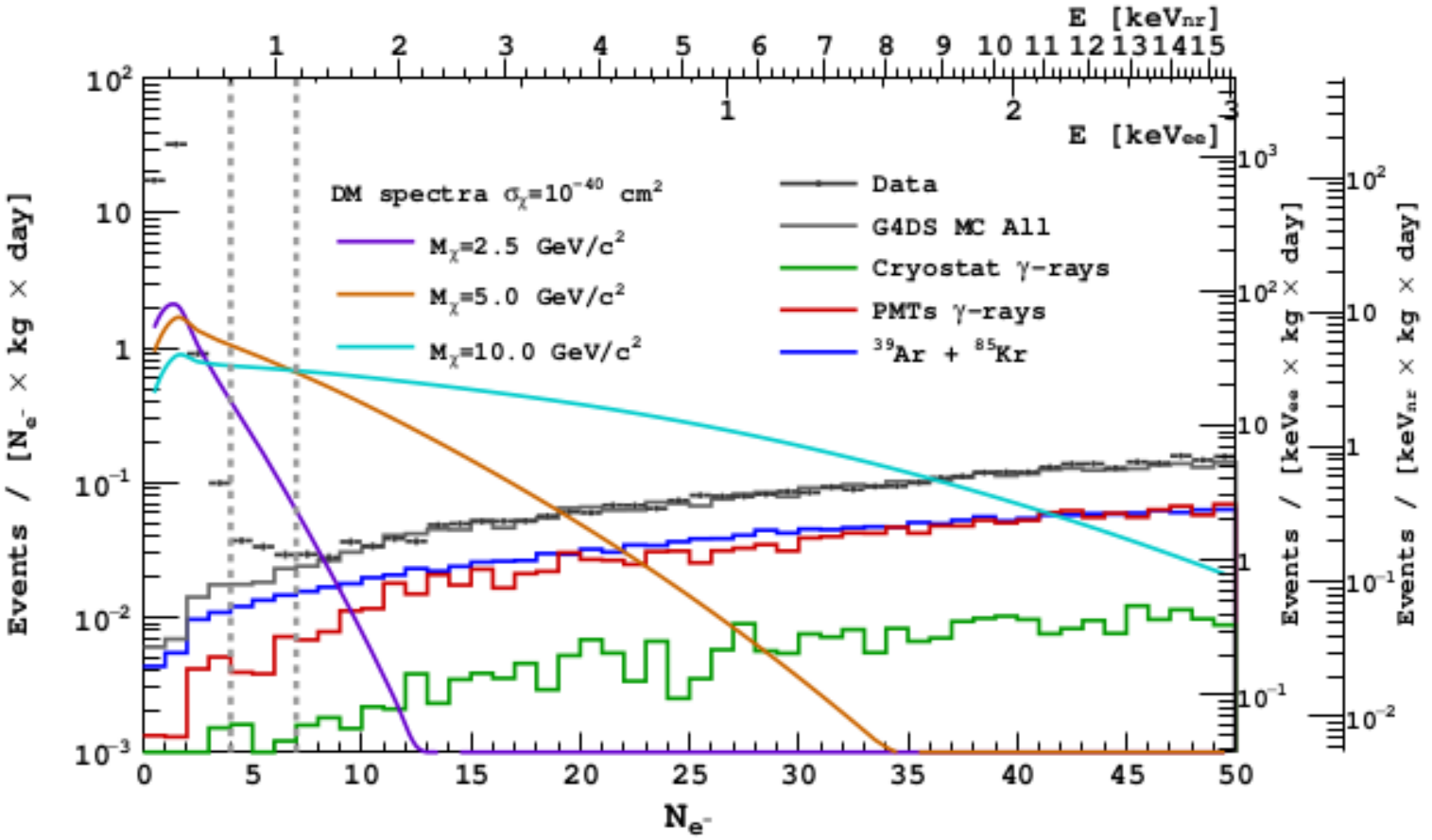
For N_e <3 background is mostly due to impurities.

The N_e spectrum

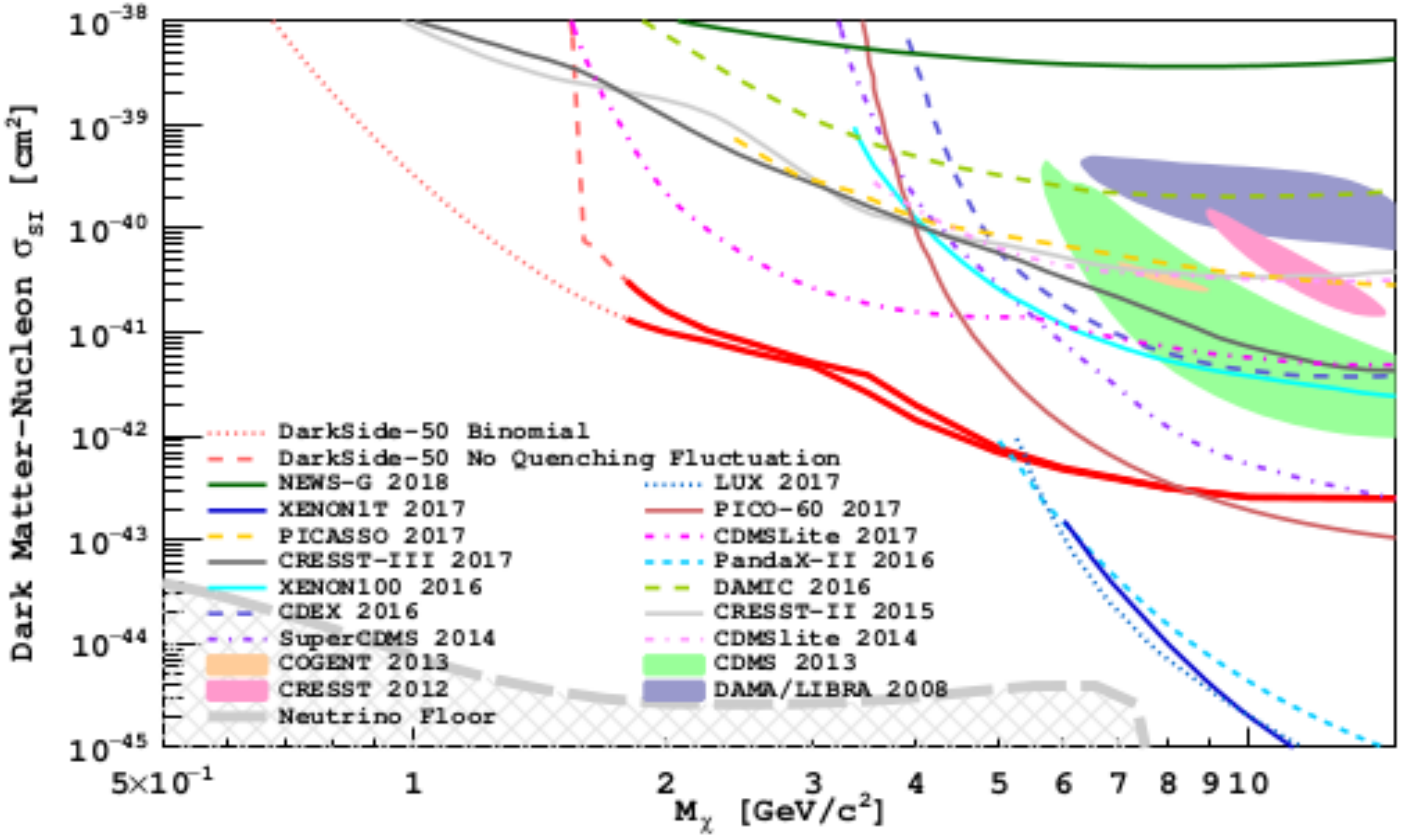


The first 100 days of the UAr run have ^{37}Ar, very useful to calibrate the ER ionization yield at energies as low as 270 eV.

The expected N_e spectrum for WIMPs



The corresponding cross section limits



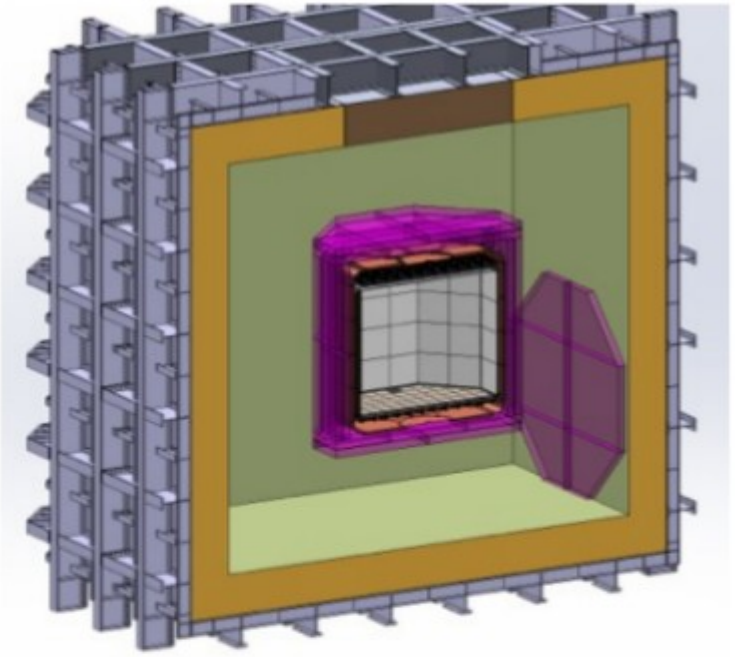
DS-50 has excellent sensitivity in the 2-10 GeV mass range.

Not possible without **Underground Argon** (1400 lower ^{39}Ar content than Atmospheric)

Very good prospects for DS-Proto and DS-20K.

DS-20K

- New collaboration: DS-50, ArDM and DEAP-3600.
- Radio pure SiPMs
- Underground Argon procurement and purification (ARIA+URANIA)
- Data taking from 2022.
- Cherenkov BG abatement: 3M foil instead of PTFE.
- Neutron BG abatement: Cyogenic Veto system
- ~50 ton UAr
- <0.1 evt/100 ton yr
- Scalability for 300 ton.



Expected sensitivity