DarkSide-20k

Dark Matter Detection in Liquid Argon Dual Phase TPC

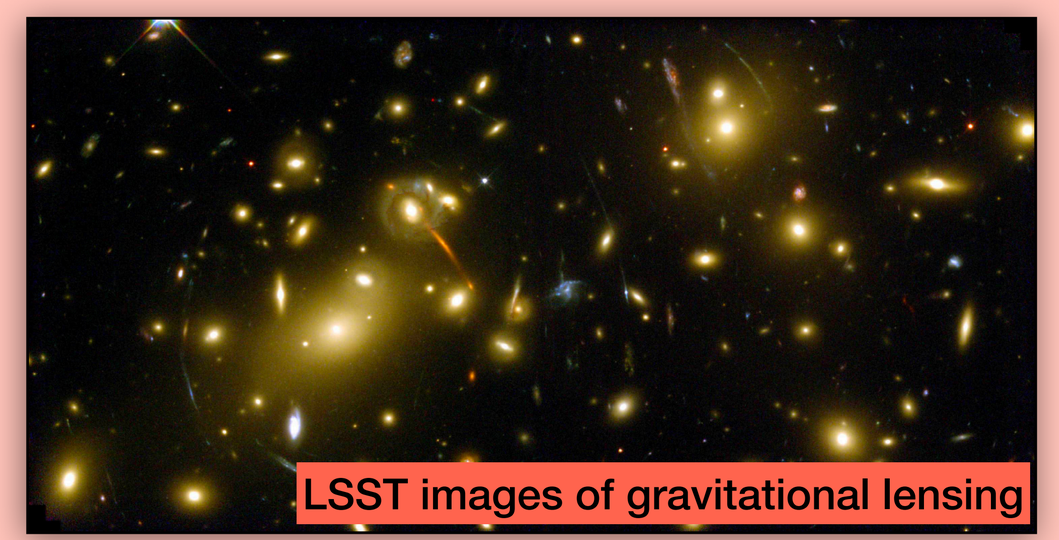
Timothée Hessel, ***on behalf of the DarkSide-20k collaboration***

XeSAT 2023 - Nantes - 07/06/2023

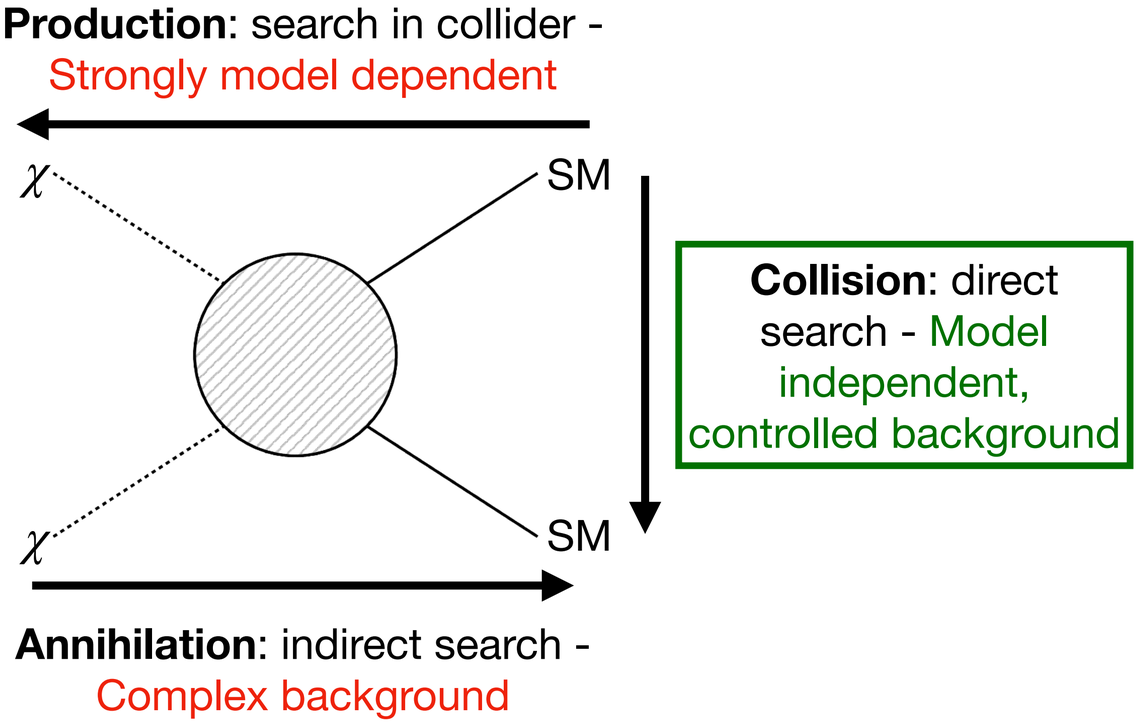
Evidences of dark matter

At different astrophysical scales

- Galaxy rotation curves and gravitational lensing
- Cluster dynamics
- CMB anisotropies

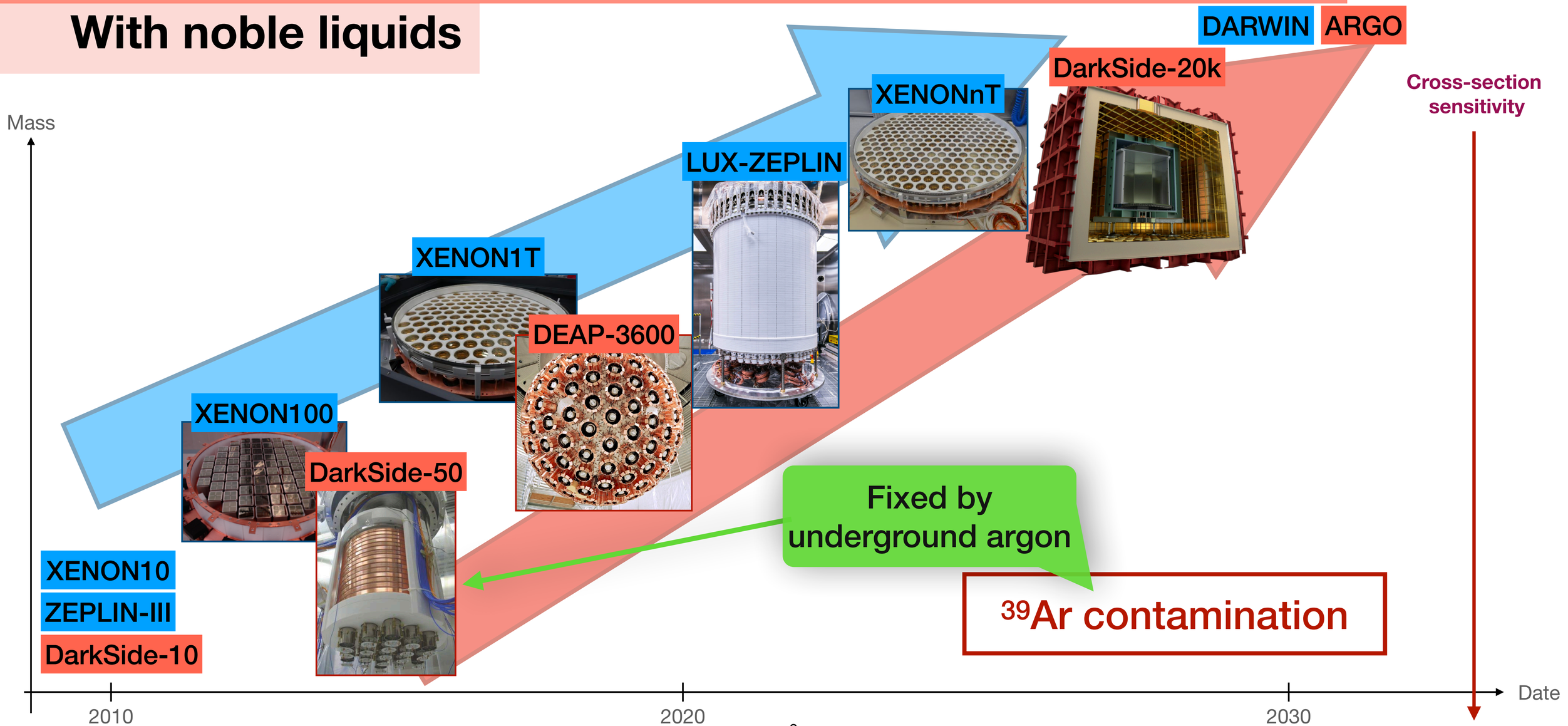


LSST images of gravitational lensing



Direct dark matter search experiments

With noble liquids

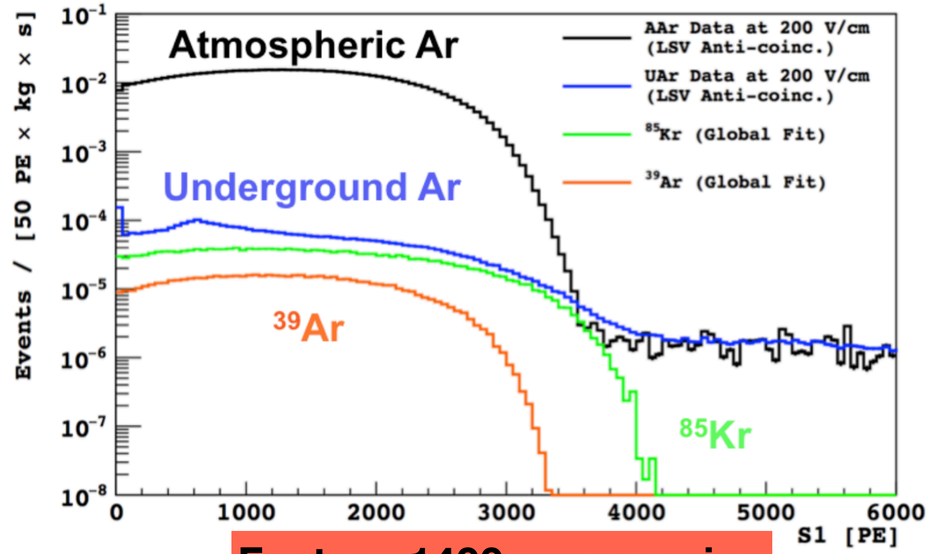


^{39}Ar β-emitter contamination

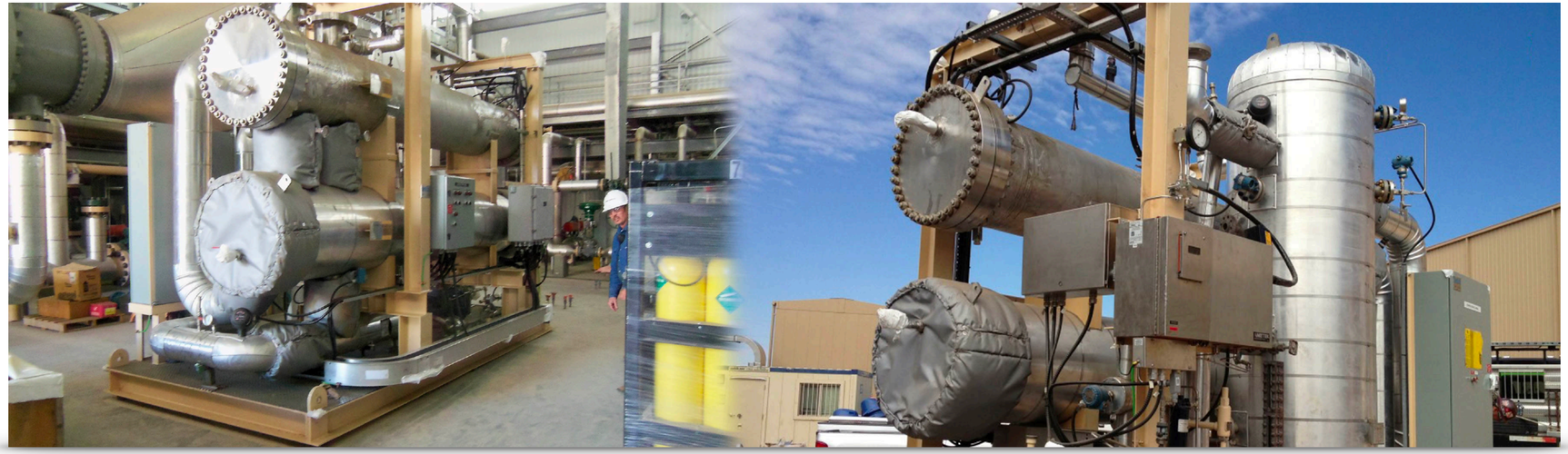
Natural depletion in underground argon

^{39}Ar produced in atmosphere by spallation of cosmic rays.

- **Underground argon** is naturally depleted.
- Extraction wells for large production.
- Urania facility in Colorado for extraction and purification (99.99% purity).



Factor ~1400 suppression

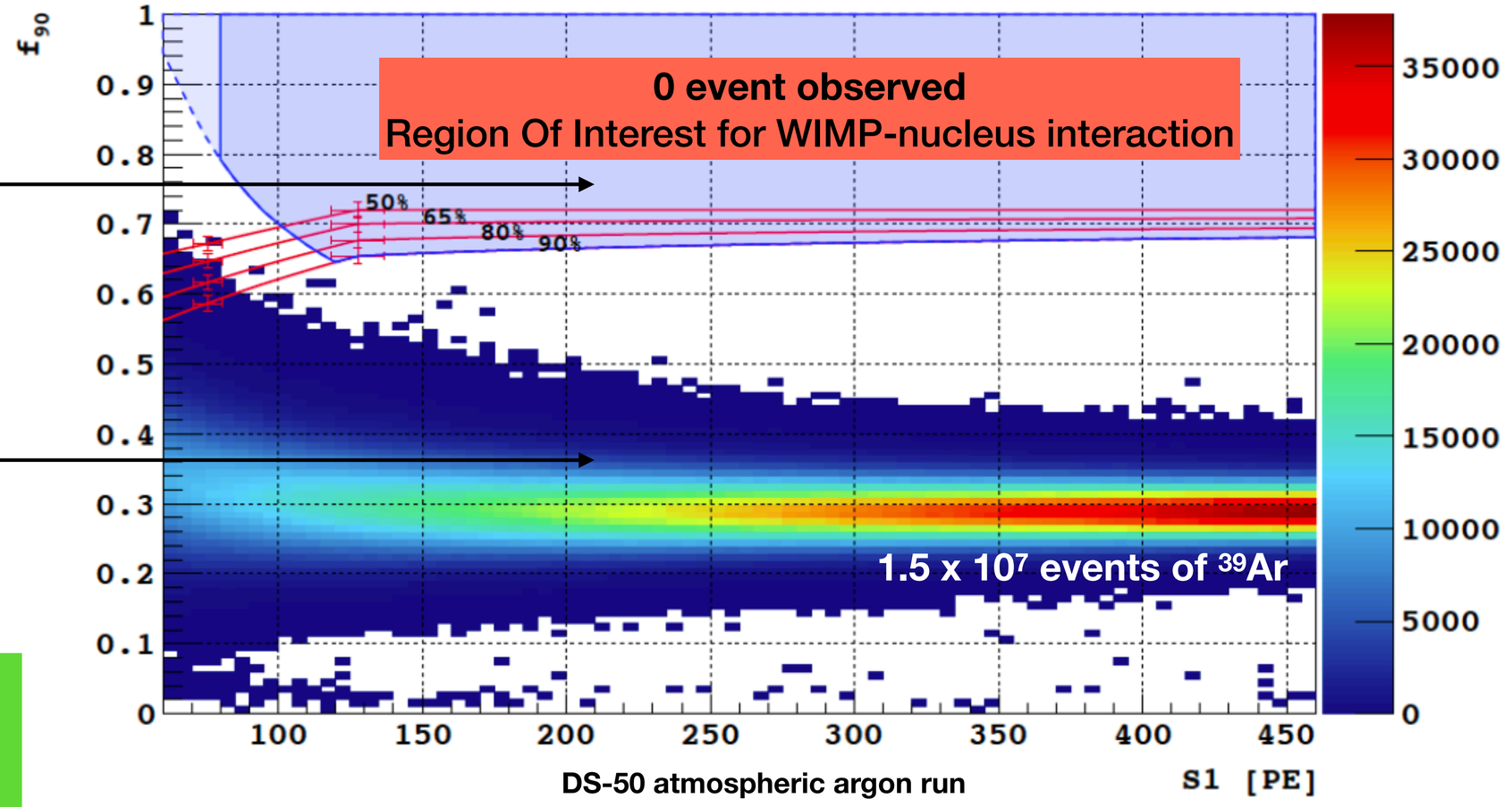


Why liquid argon?

Pulse shape discrimination

Nuclear recoil band:
mostly triplet states (**1600 ns**)

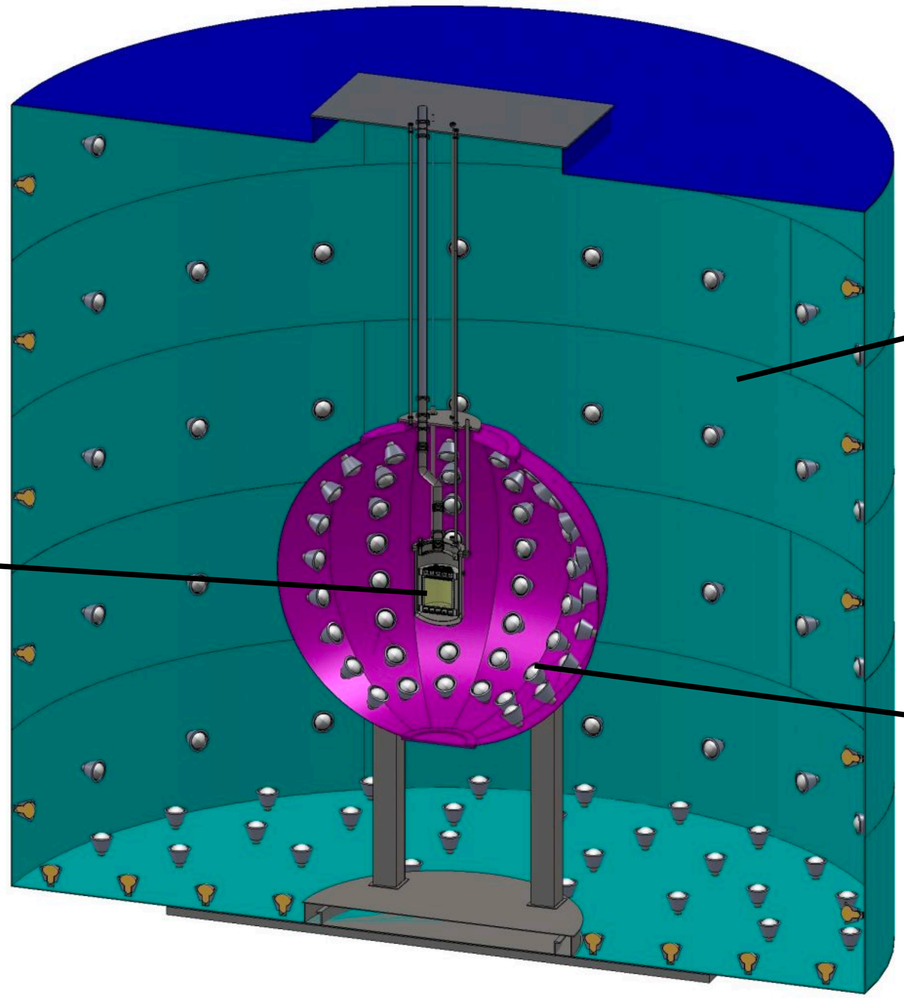
Electron recoil band:
mostly singlet states (**6 ns**)



Allowing for large scale nearly instrumental background free experiments

DarkSide-50

A first successful milestone



Dual Phase Time Projection Chamber

- 46.6 kg of UAr
- 1 cm thick gas pocket
- 2x19 Photo-Multiplier Tubes

Water Cerenkov veto

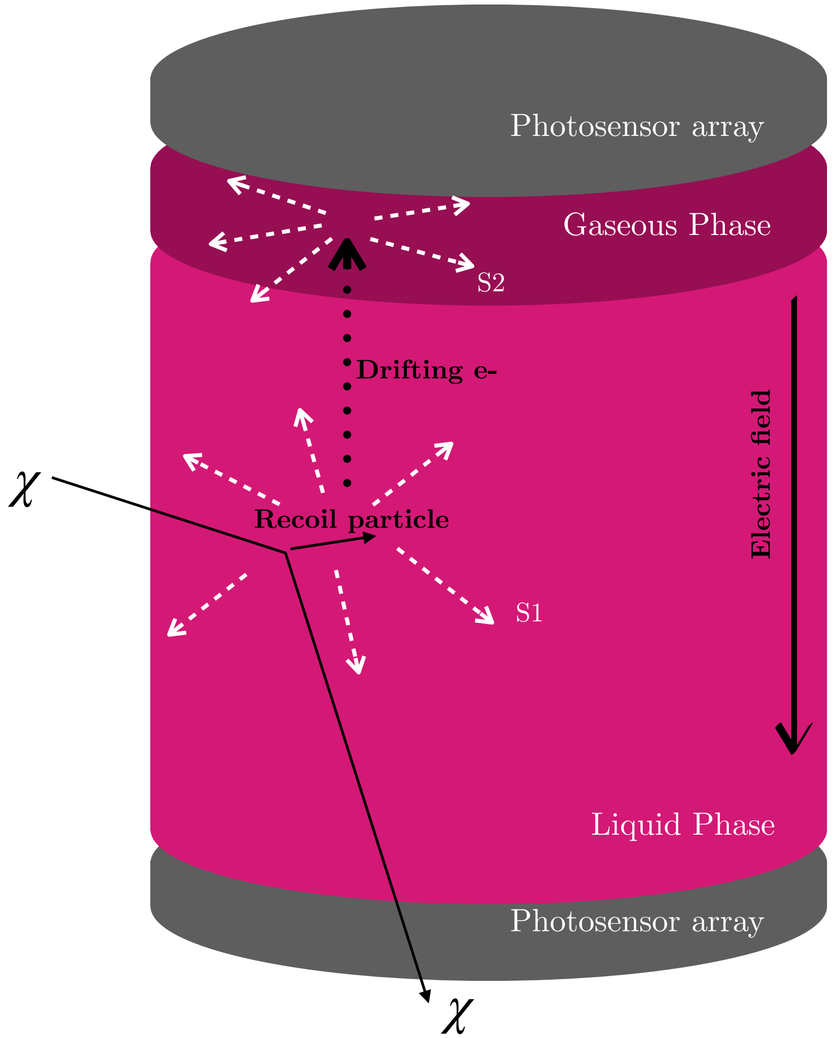
- Neutron shielding and μ detection
- 1000 tonnes of purified water

Liquid scintillator veto

- Neutron and γ tagging
- 30-tonnes of boron-loaded scintillator

Dual Phase Time Projection Chamber

Working principle

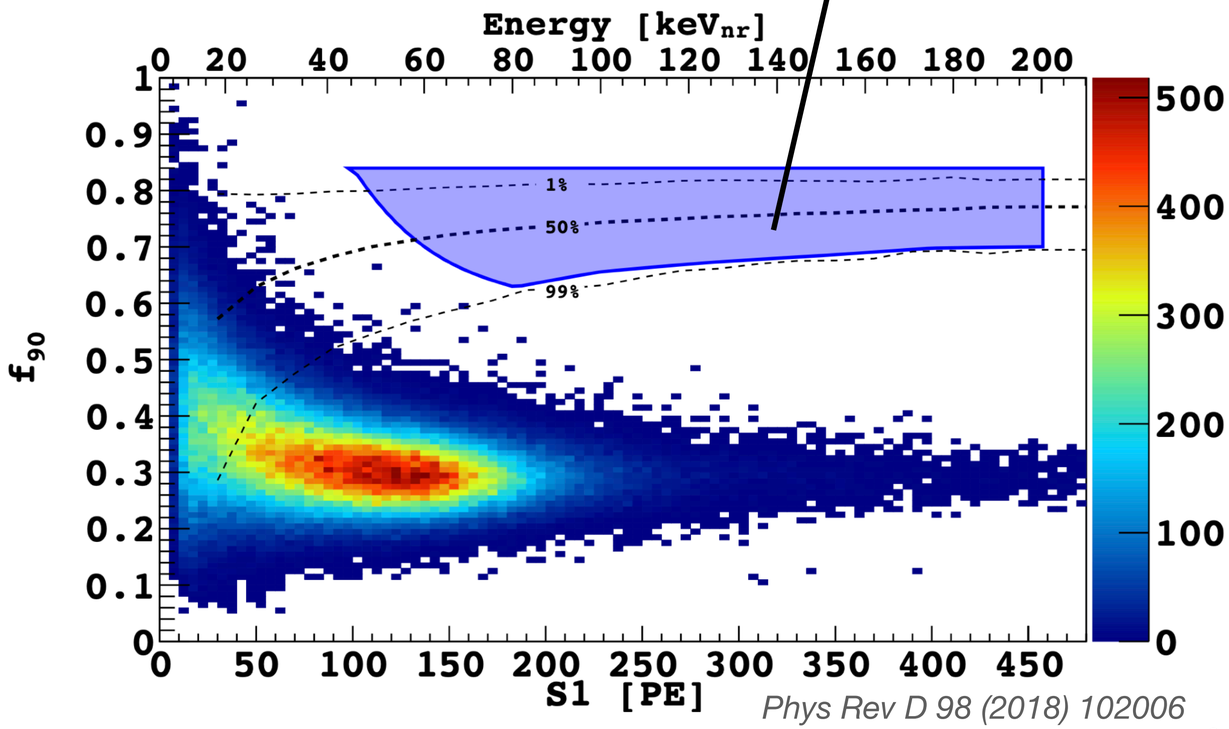


- Interacting particle induces **ER** or **NR**
- The recoil produces **scintillation** (S1) and ionization
- Ionization electrons are drifted and produce **electro-luminescence in the gas pocket** (S2)
- S1 and S2 lights are seen by **photosensor arrays** on top and bottom

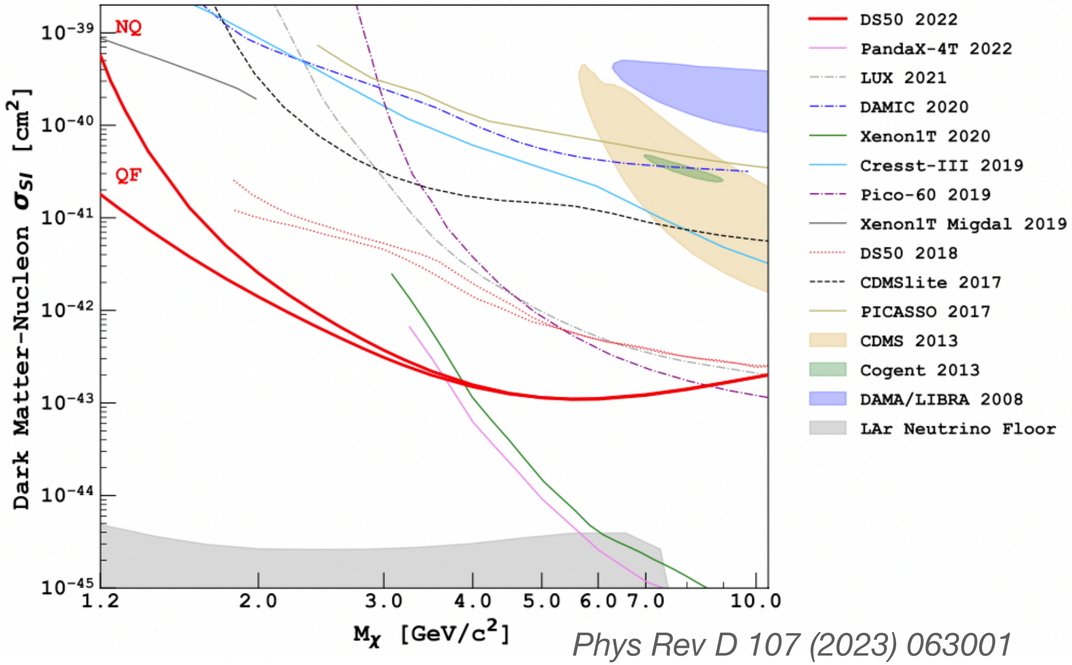
Results after 532 days exposure

High mass and low mass analysis

Empty ROI after all selection cuts
Exclusion limit down to ~10^{-44} cm^2 at high mass (100 GeV/c^2)



Phys Rev D 98 (2018) 102006



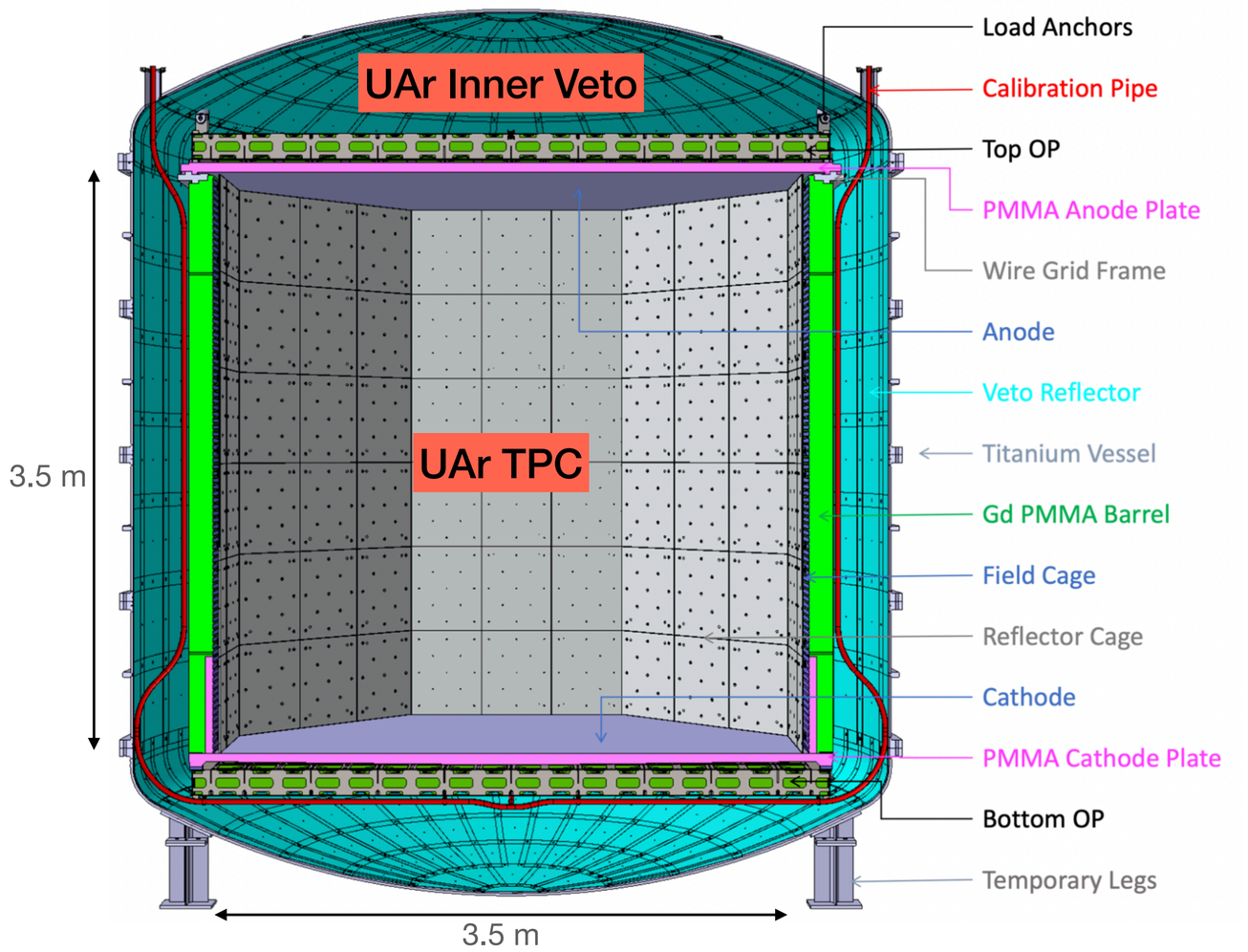
Phys Rev D 107 (2023) 063001

Low mass analysis using ionization channel only:

- Nearly 100% efficiency in single electron S2 detection.
- Threshold down to: **4 e^- ⇔ 90 PE ⇔ 0.6 keV_{nr}.**
- Considering Migdal effect and WIMP-Electron scattering.

Moving on to DarkSide-20k

Down to the neutrino floor

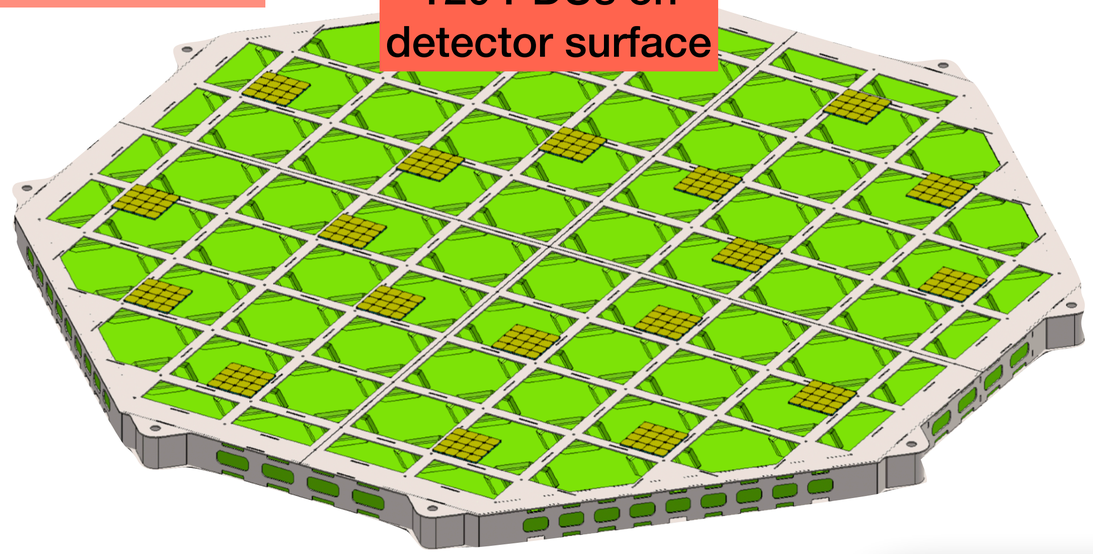


- **Larger volume:** 1 day of DS-20k has the same exposure as DS-50 full data taking.
- **TPC:** 50 tons of UAr, 20 tons fiducial.
- **Inner veto:** 32 tons of UAr.
- **SiPMs** instead of PMTs: better radio-purity.

DS-20k photo-detection

In TPC and inner veto

Inner veto
120 PDUs on detector surface



Tile
24 SiPMs

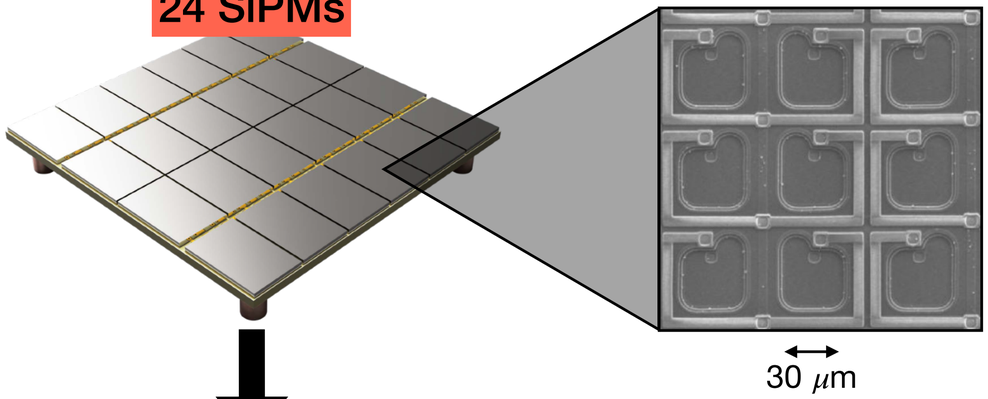
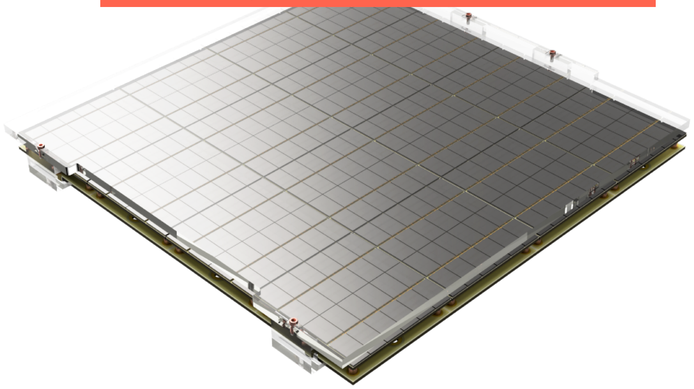
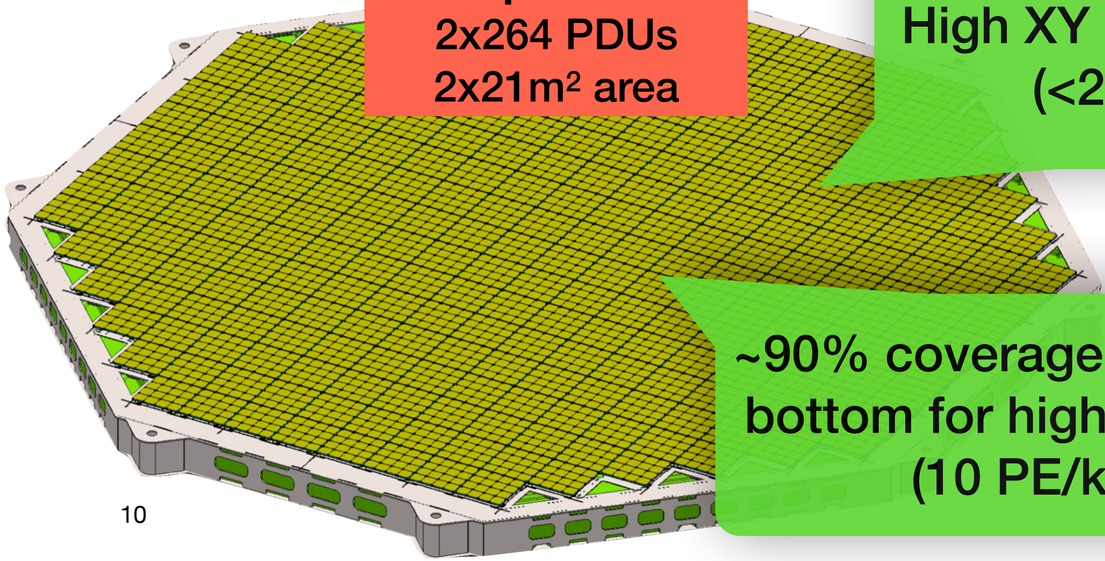


Photo-Detection Unit
16 tiles, 4 readout channels



TPC Optical Plane
2x264 PDUs
2x21m^2 area



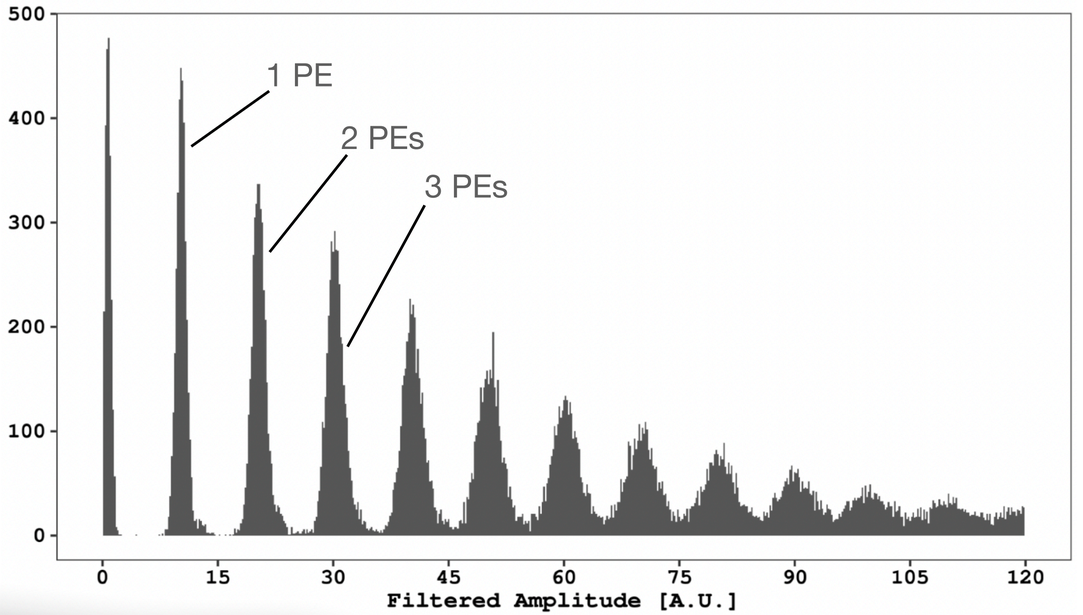
High XY resolution (<2 cm)

~90% coverage of top and bottom for high light yield (10 PE/keV)

SiPM characterisation

Crucial proof of concept

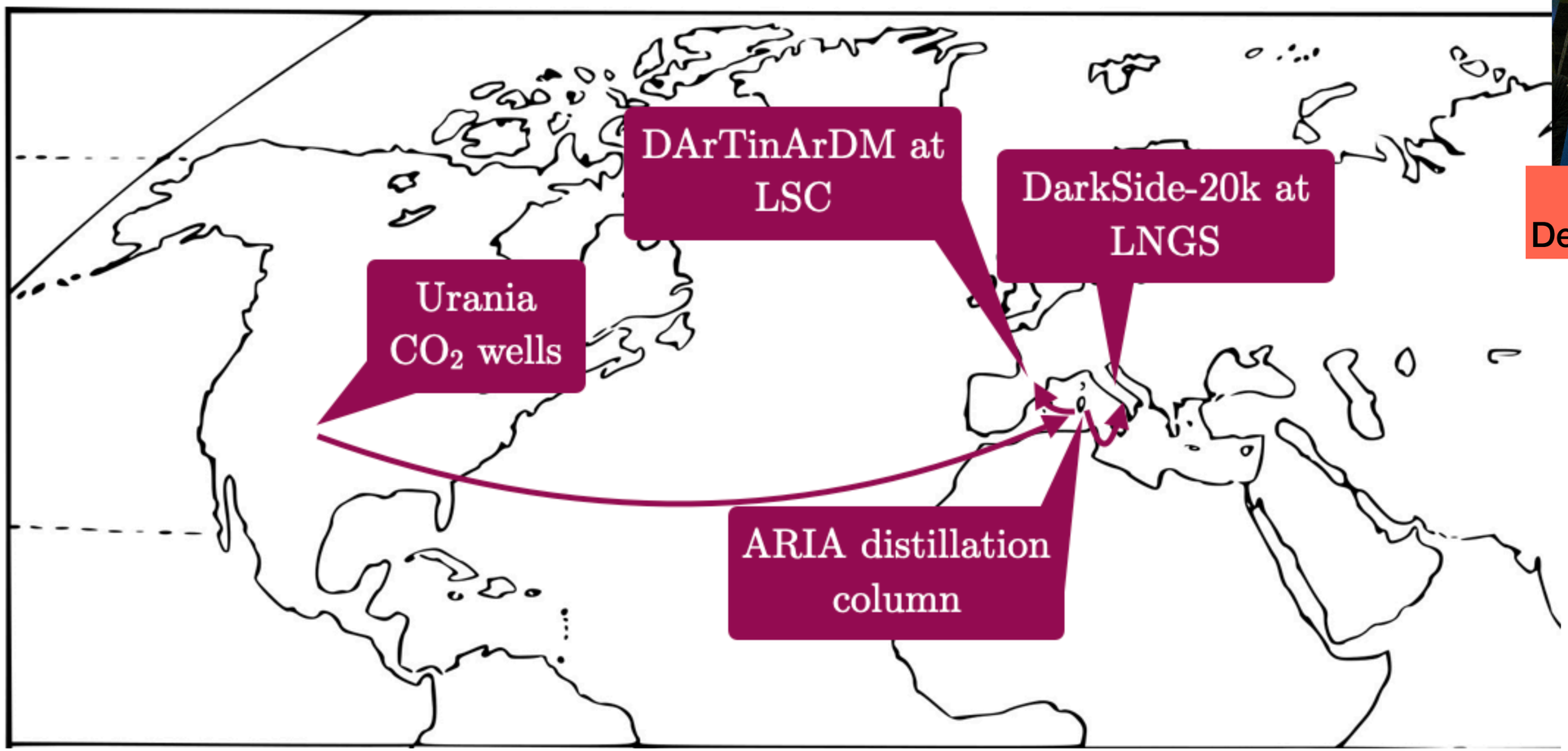
Parameter	Requirement	Achieved
Photo-detection efficiency at 420 nm	> 40%	**> 42%**
Dark Count Rate (87 K)	250 Hz/tile	**~20 Hz/tile**
Afterpulses, cross talk	< 50% + 50%	**< 10% + 35%**
SiPM gain	> 1e6	**> 1e6**
SNR after filtering	> 8	**>10**
Time resolution	~10 ns	**~15 ns**

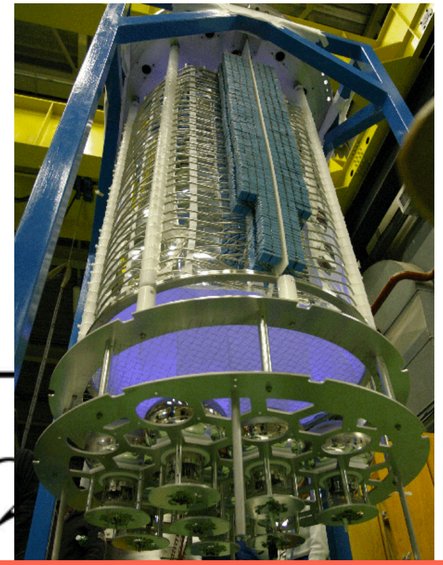


Requirements fulfilled!

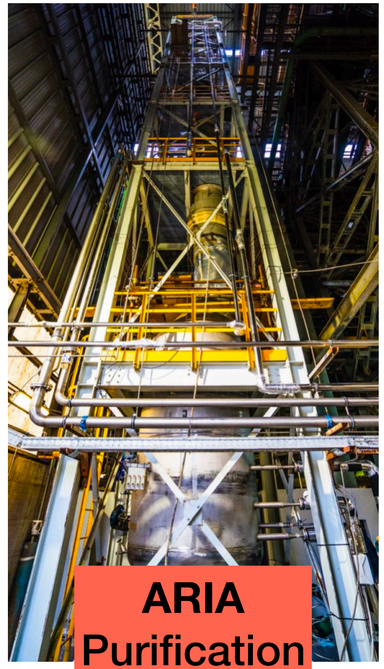
Argon 39 depletion

From the extraction to Gran Sasso





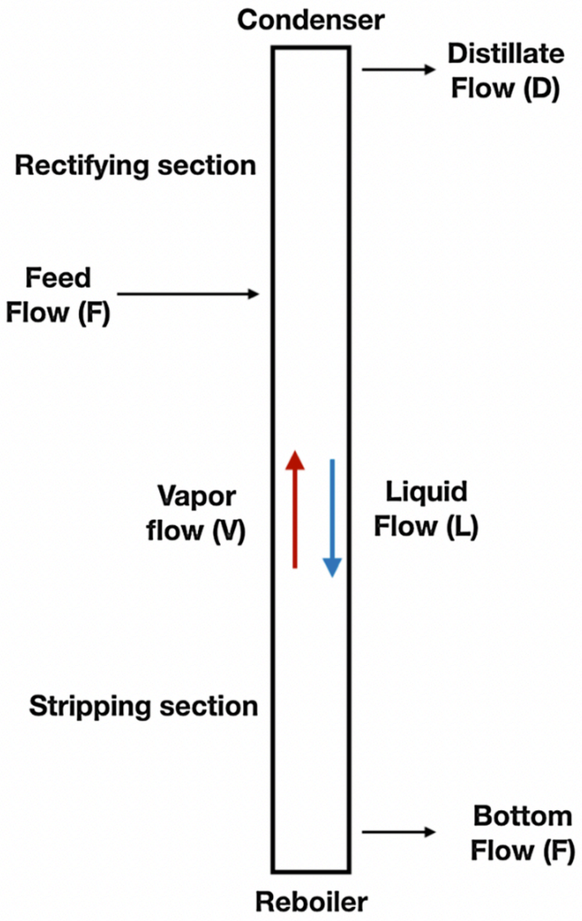
DArTinArDM
Depletion measurement



ARIA
Purification

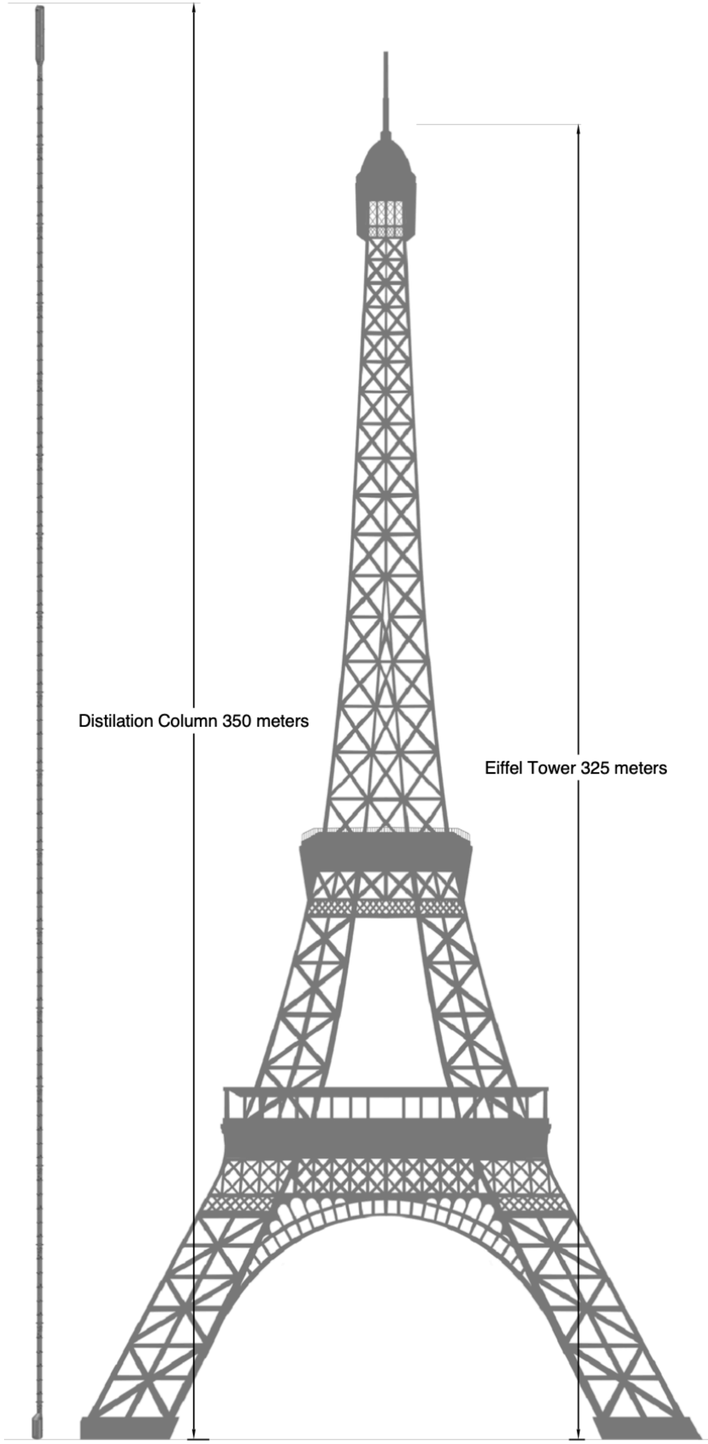
ARIA distillation column

For purification and ^{39}Ar-^{40}Ar separation



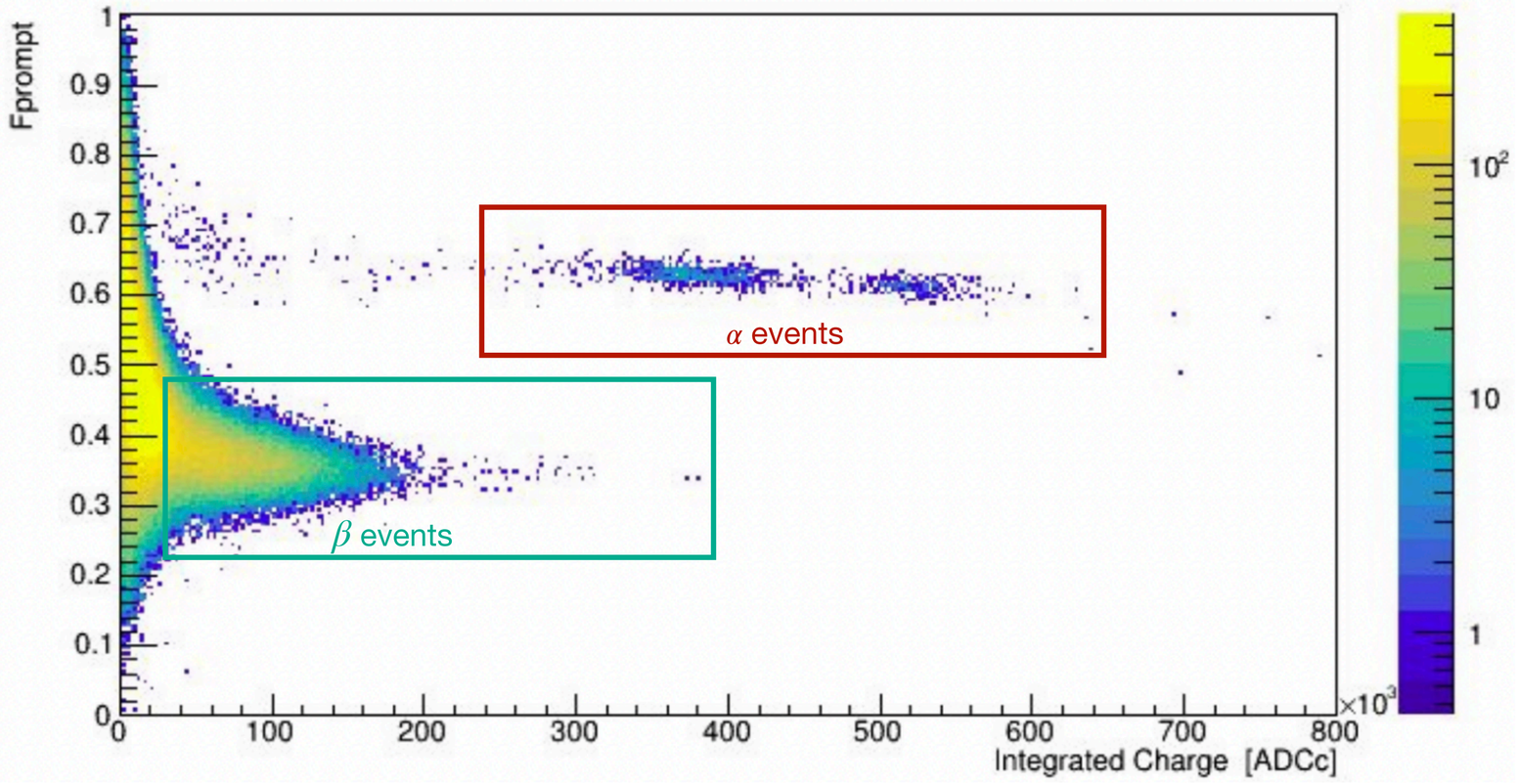
The highest distillation column in the world, currently under assembly:

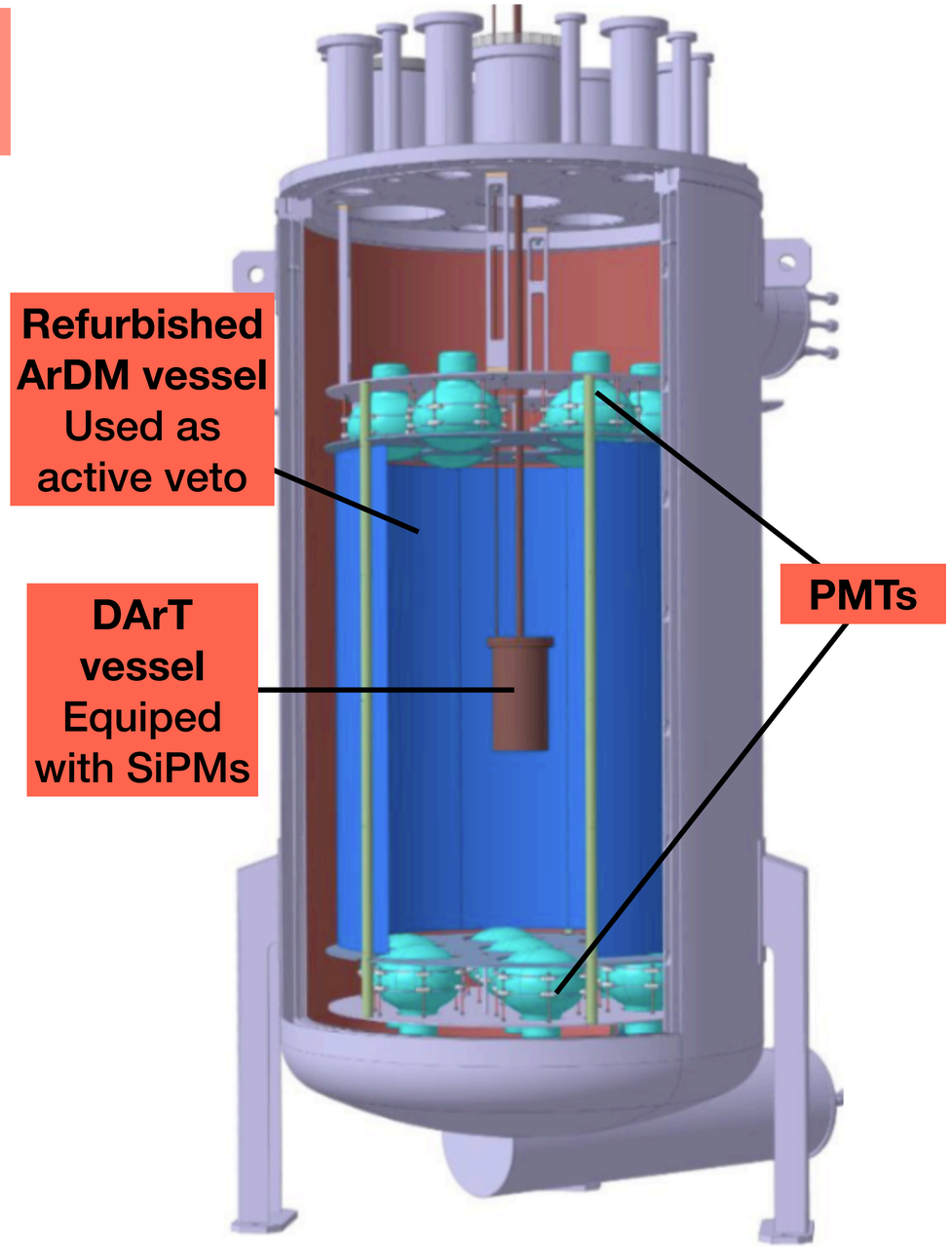
- Chemical purification rate: **1t/day**
- Argon purity to **ppt (10^{-12})**
- Relative volatility of ^{39}Ar with respect to ^{40}Ar: 1.0015
- Isotope purification rate: O(10) kg/day (not needed to reach DS20k sensitivity)



DArT (Depleted Argon Test)

Measurement of ^{39}Ar depletion factor

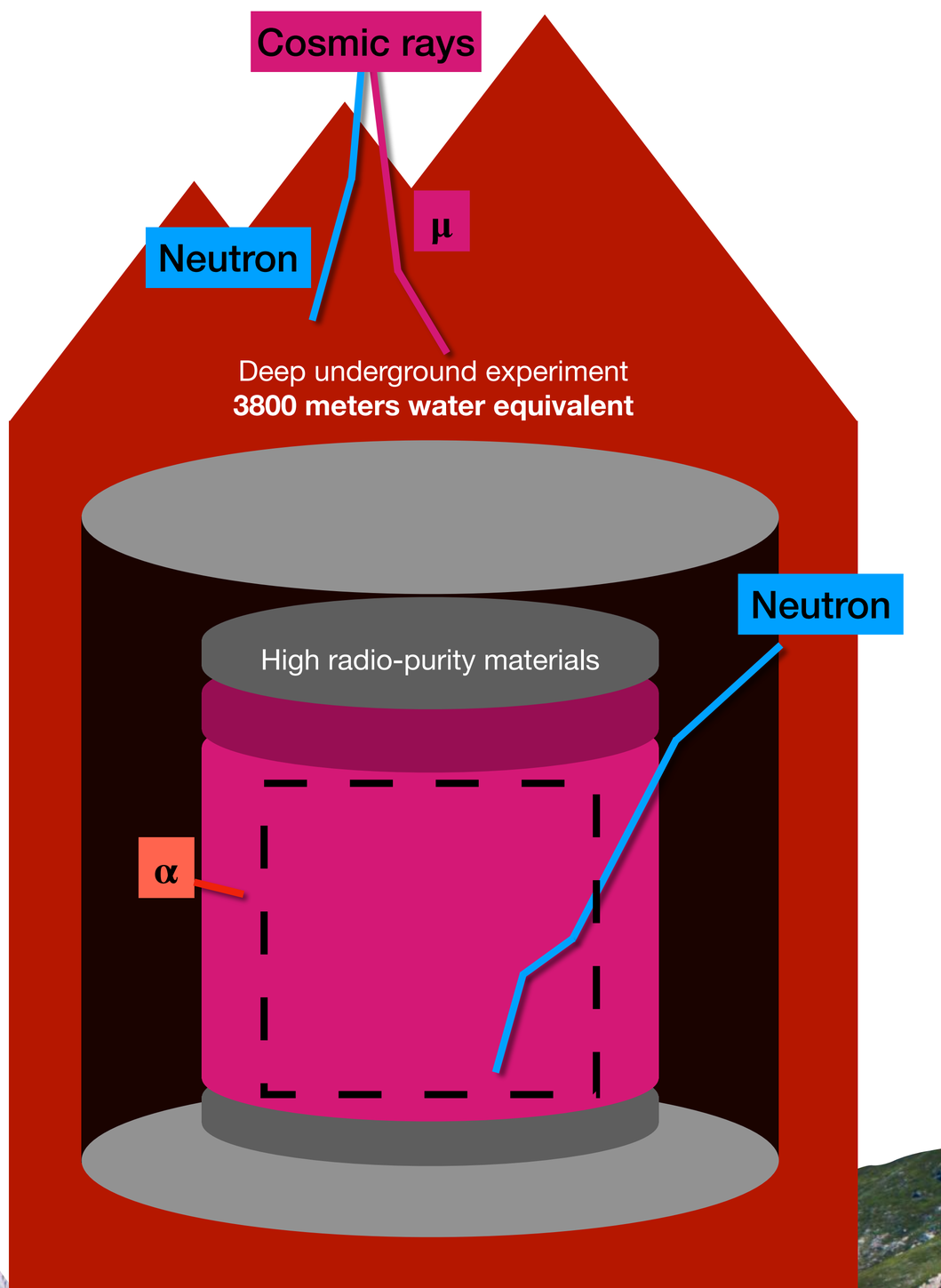




Background

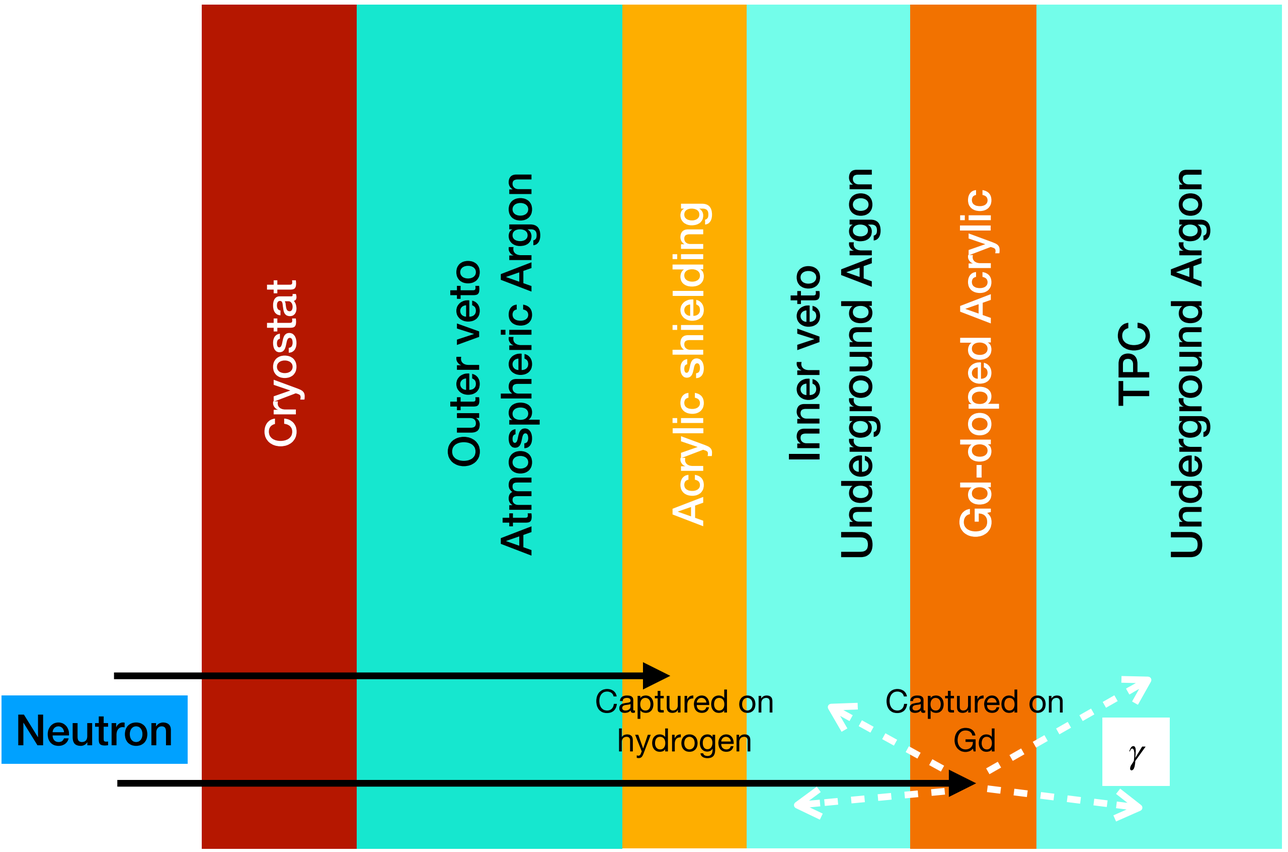
Mitigation and rejection

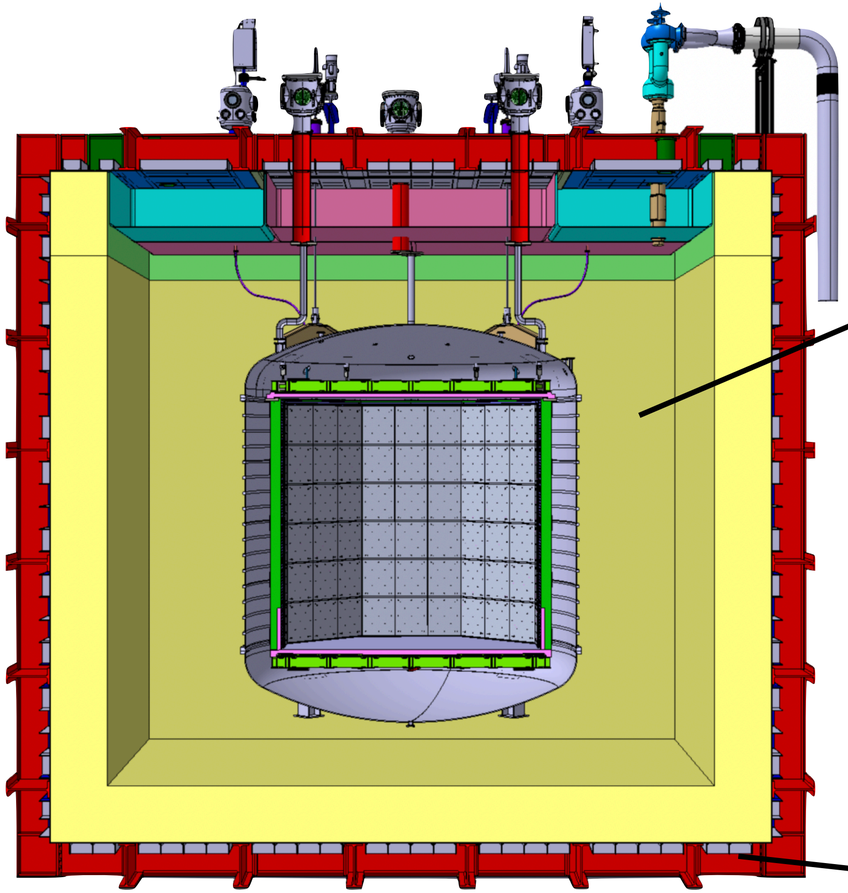
- LNGS **underground** laboratory at Gran Sasso.
- Anti-coincidence with **vetoes**.
- Rejecting **multiple scattering** events.
- **Fiducialisation** to reject materials radioactivity.



Outer veto and neutron shielding

With Gd-doped acrylic





AAr Outer Veto
For μ tagging

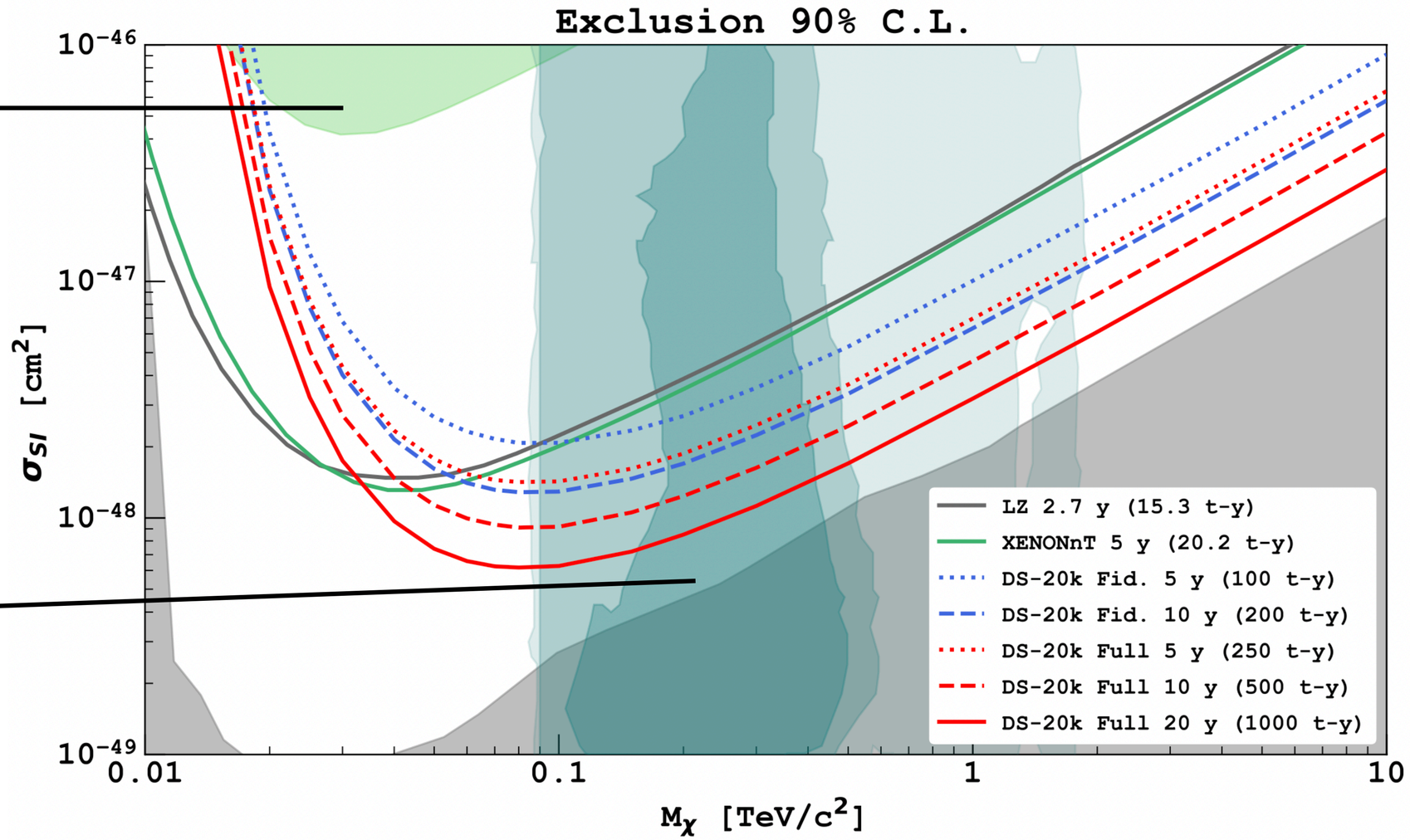
Refurbished
ProtoDUNE
Cryostat

DS-20k expected limits

High discovery potential for the next direct search generation

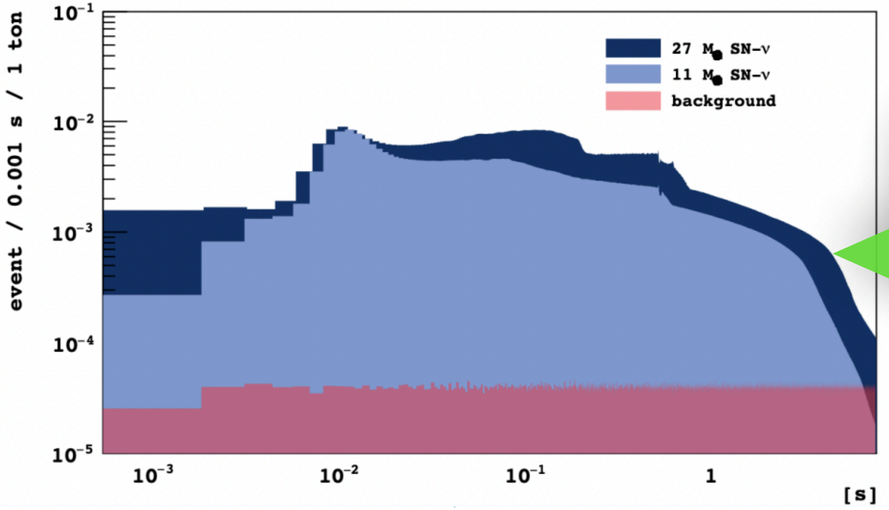
XENON1T excluded region

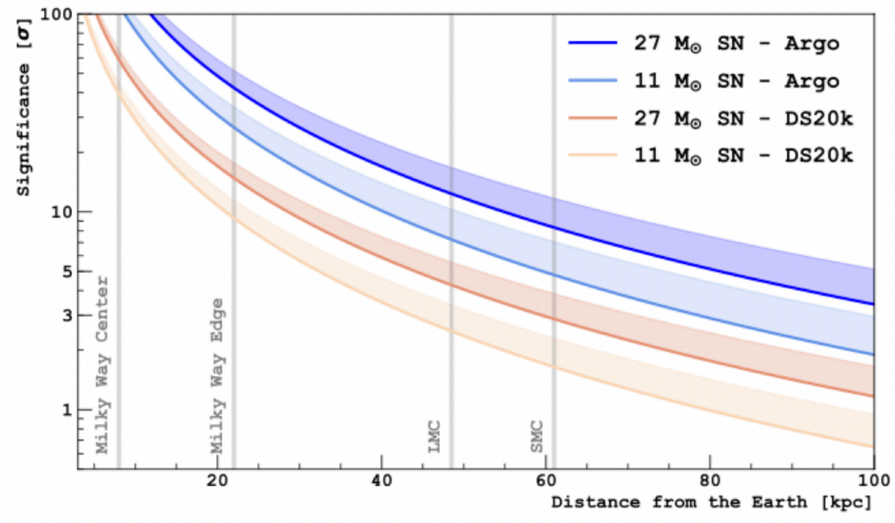
Favored region from pMSSM11 given astrophysical constraints and LHC data



Supernova detection in DS-20k

Neutrinos interacting via CEνNS





JCAP 03 (2021) 043

27 $M_\odot$ at 10 kpc:
350 events expected in ~10 s

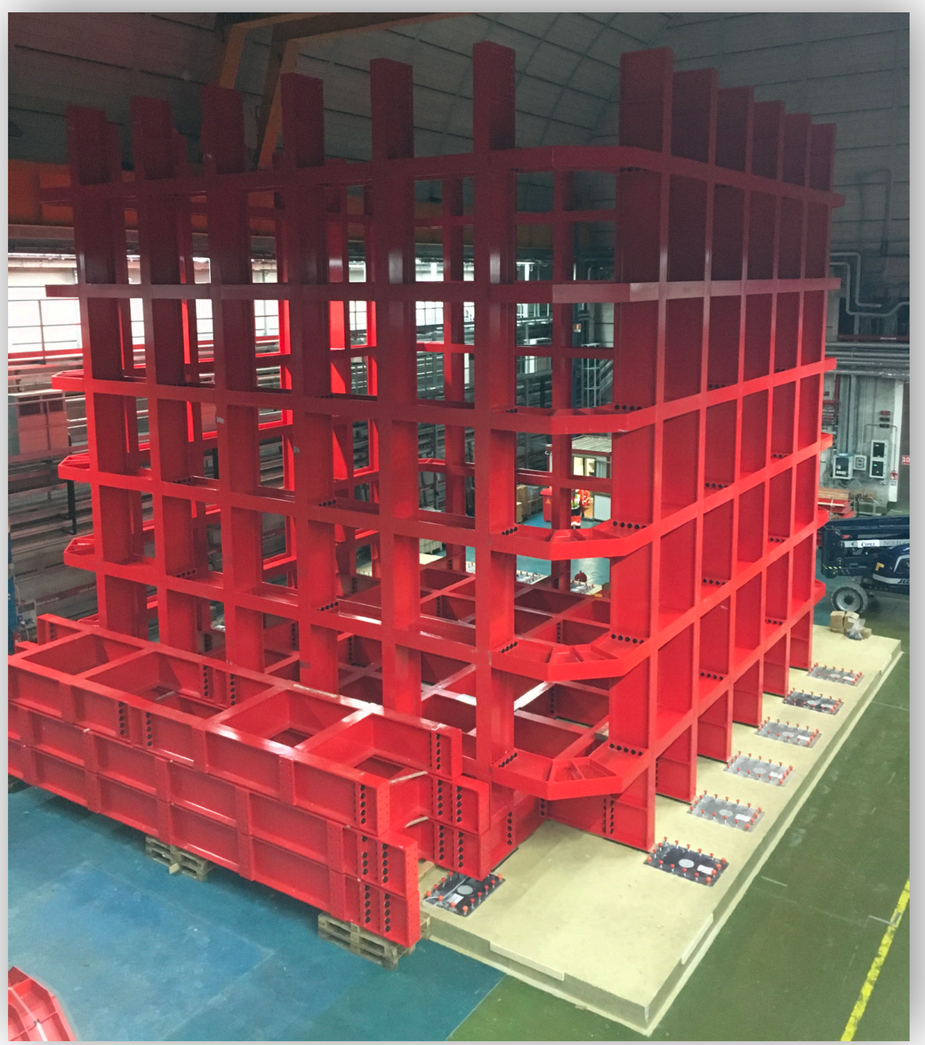
During a core collapse supernova, 99% of the energy is emitted through neutrinos (~10^{53} erg):

- **CEνNS signature**: low energy (S2 only) nuclear recoil.
- DS-20k **alarm system** for supernova observation?

Conclusion

Unprecedented physics reach

- **Construction started** (infrastructures and photo-electronics).
- Data taking starting in 2026.
- 5σ discovery down to **3×10^{-48} cm^2** at 0.1 TeV/c^2 after 10 years.

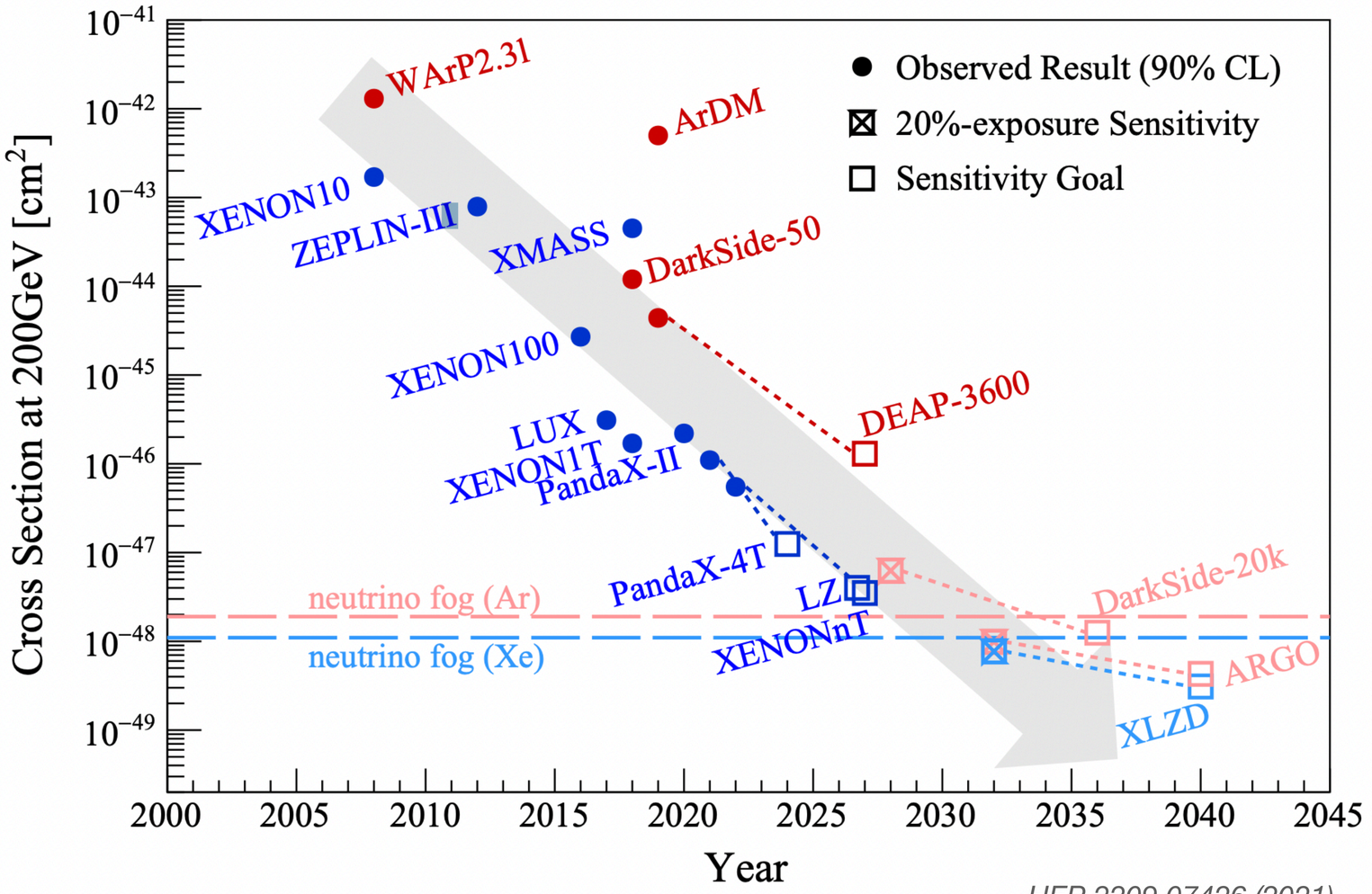


Thank you for your attention

Backup slides

WIMP-nucleon sensitivity

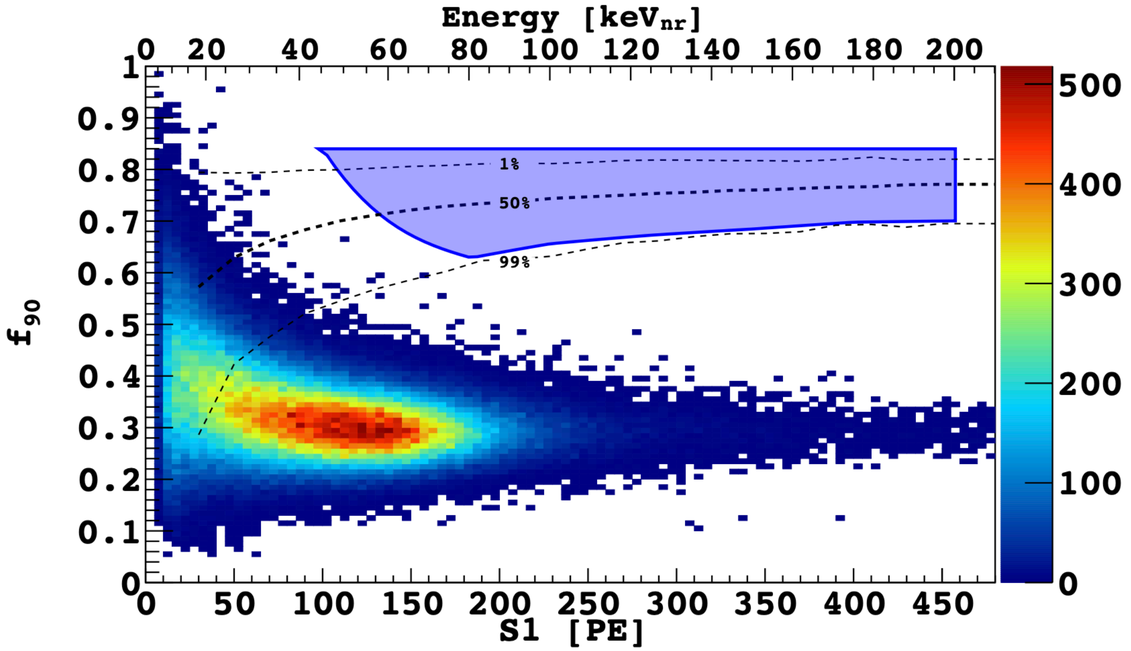
With noble liquids experiments

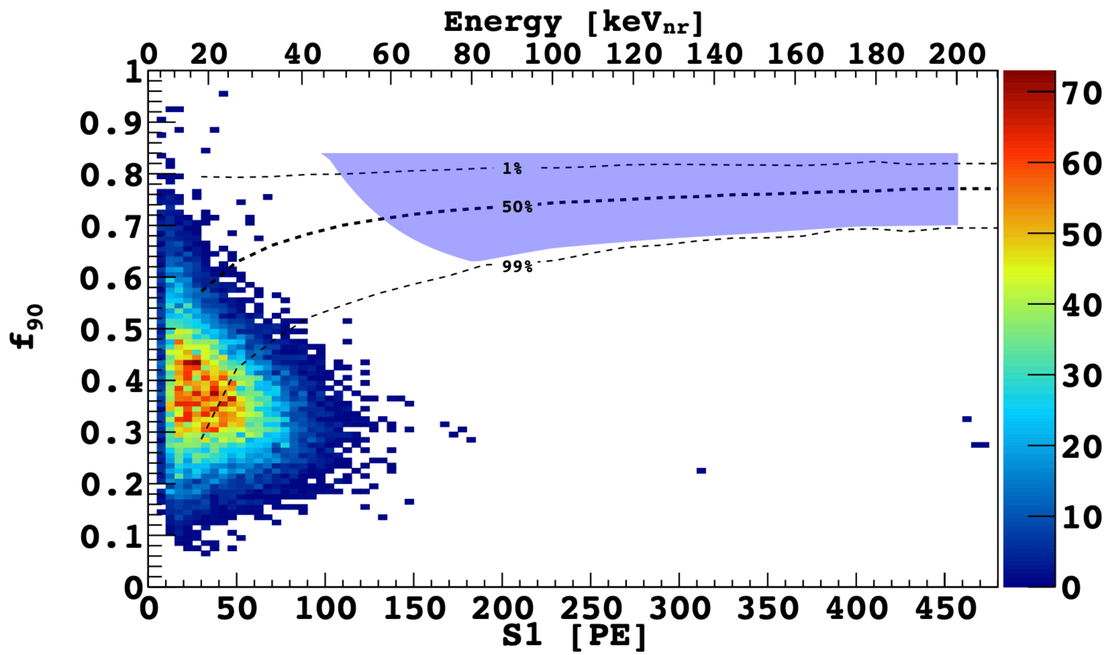


HEP 2209.07426 (2021)

High mass search in DS-50

Before and after analysis cuts

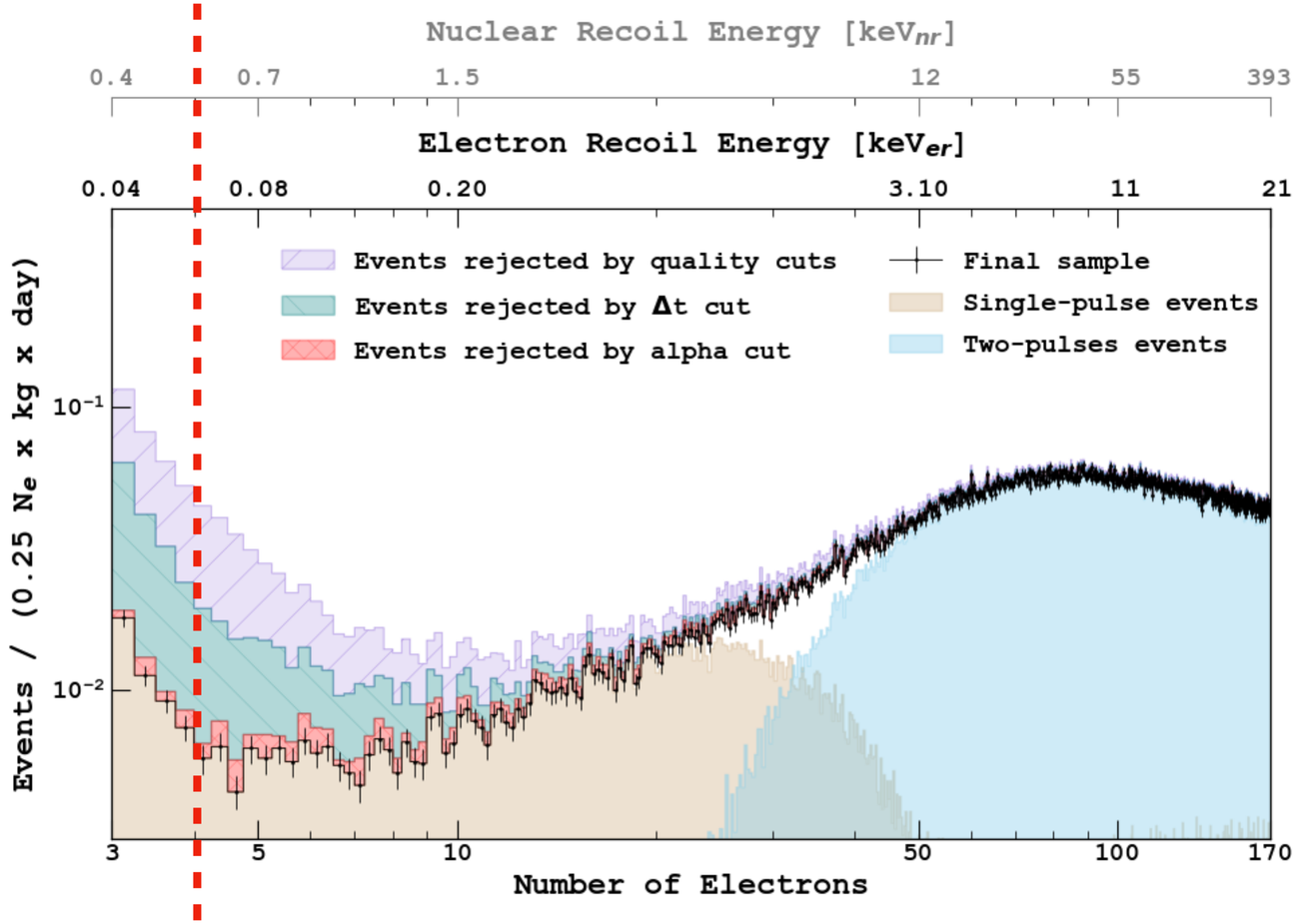




Phys Rev D 98 (2018) 102006

Low mass search in DS-50

Before and after analysis cuts



Analysis threshold

Improved light dark matter limits from 2018 analysis thanks to:

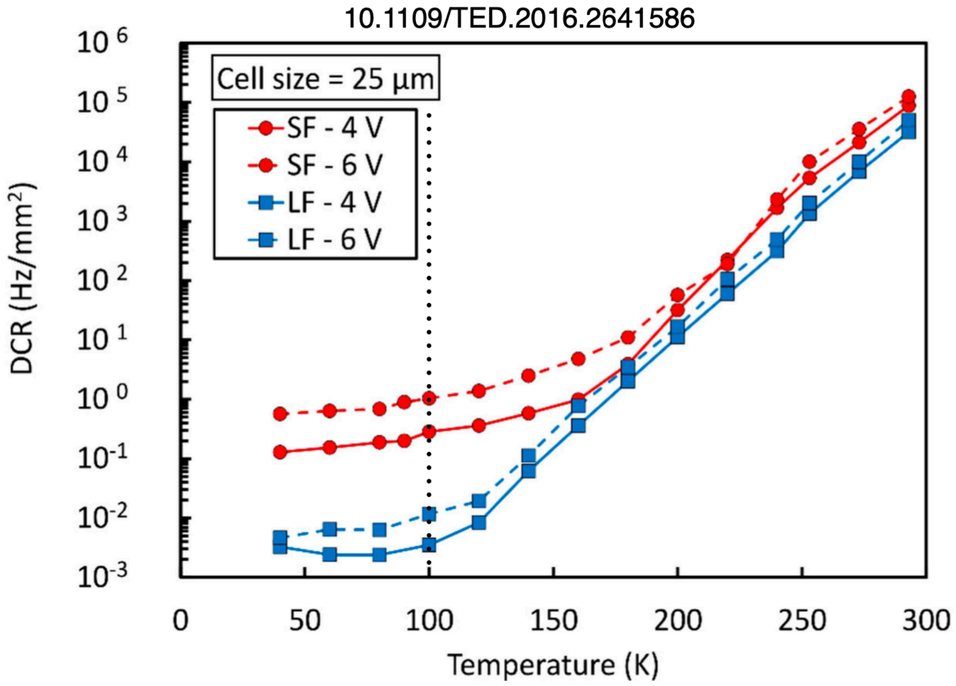
- **Calibration** of ionization response to ERs and NRs down to <1 keV
- Extended **exposure**
- Better **data selection**

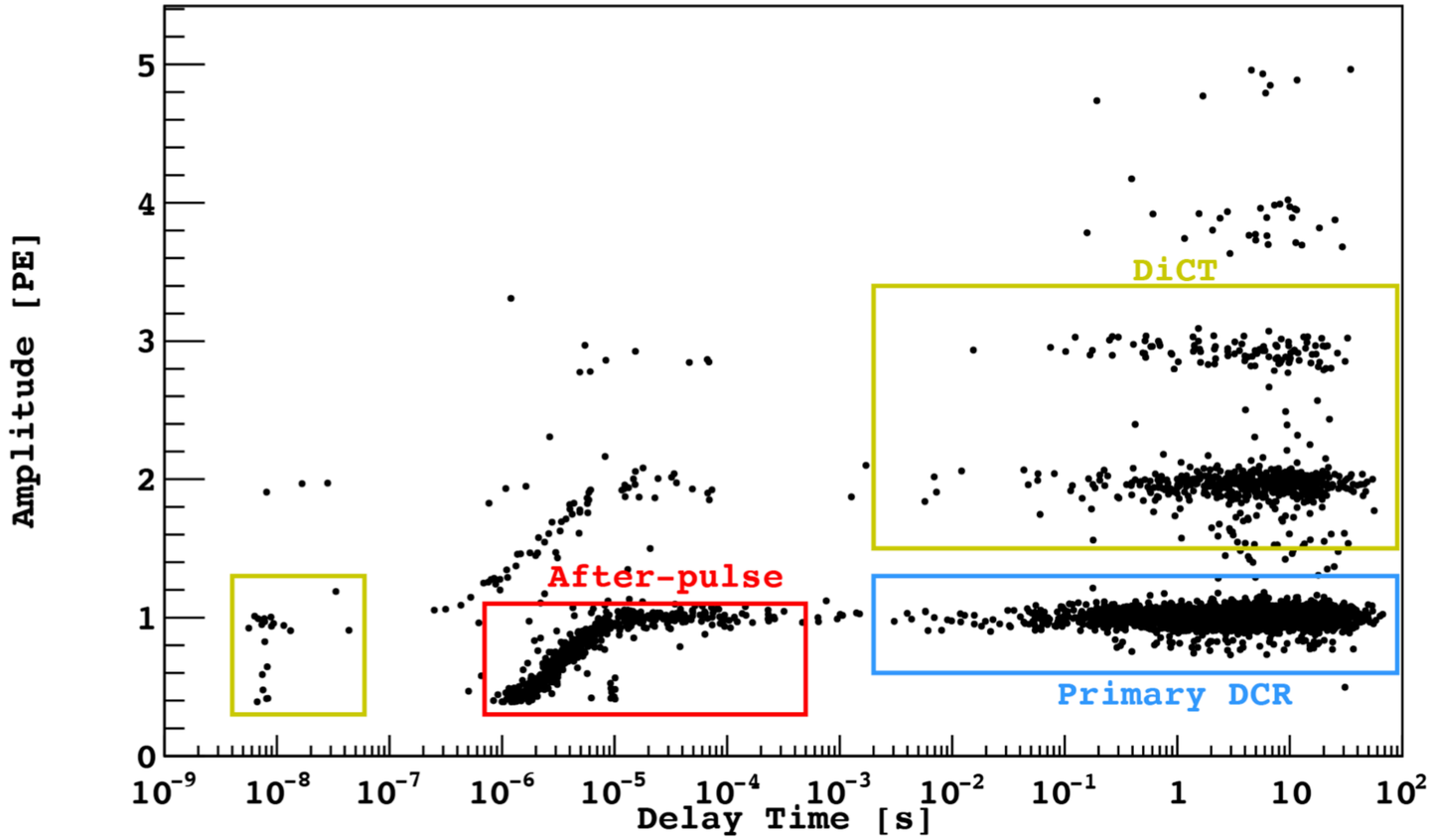
Best SI WIMP-nucleon limits down to 1.2 GeV/c^2 (40 MeV/c^2) WIMP mass without (with) Migdal effect.

Improved limits on **WIMP-electron** interactions, galactic ALPs, dark photons, and sterile neutrinos.

SiPM characterisation

Noise measurements





Hit finder algorithm

Matched filtering

- Convolute waveform with a **reversed template** of the single photo-electron response.
- Subtract **moving average.**
- Apply **time-over-threshold.**