Lepton Interactions with Nucleons and Nuclei

Marciana Marina, Isola d'Elba, Italy, June 23th - 28th 2019

DarkSide Status and Prospects

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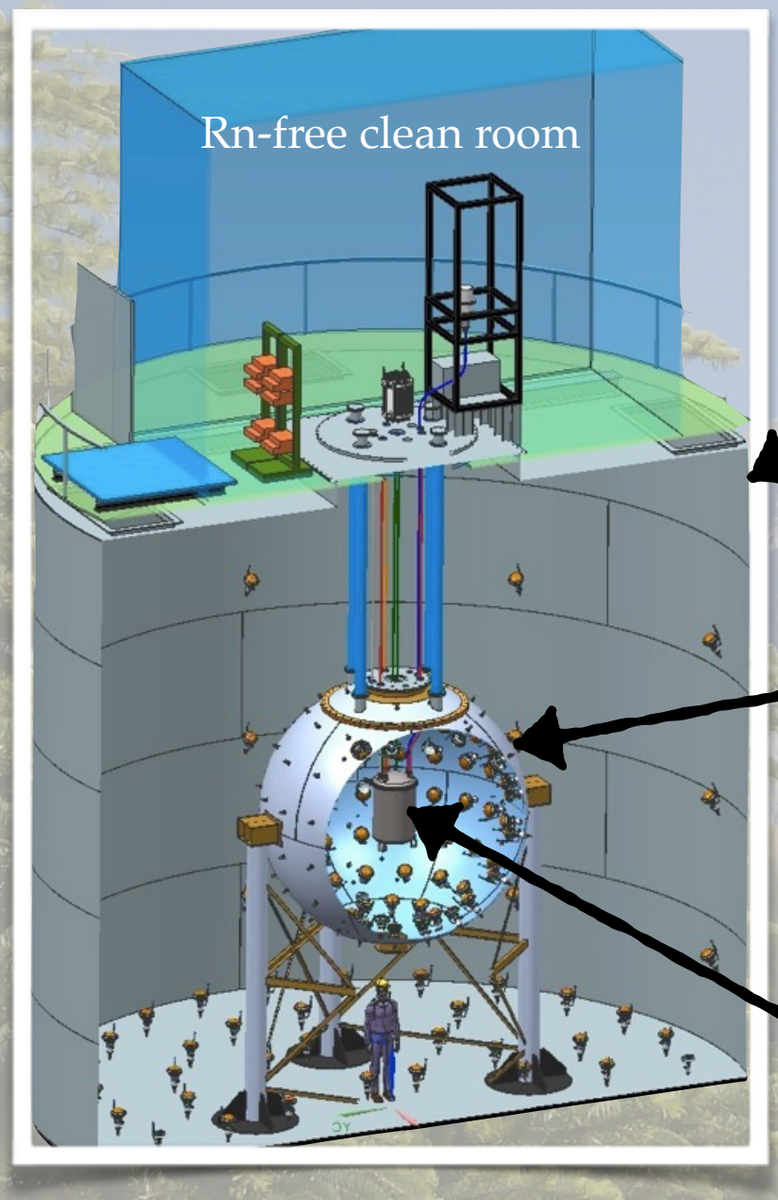
on behalf of the **DarkSide Collaboration**

Outline

- DarkSide-50 detector design;
- Recent results:
  - DarkSide-50 532-day Dark Matter Search with Low-Radioactivity Argon
    Phys. Rev. D 98 (10), 102006 (2018);
  - Low-mass Dark Matter Search with DarkSide-50 Experiment
    Phys. Rev. Lett. 121 (8), 081307 (2018);
  - Constraints on Sub-GeV Dark Matter-Electron Scattering from the DarkSide-50 Experiment
    Phys. Rev. Lett. 121 (11), 111303 (2018);
- Future DarkSide program;
- Conclusions.

DarkSide-50



The Gran Sasso massif provides 3800 m.w.e. passive shielding against cosmic rays

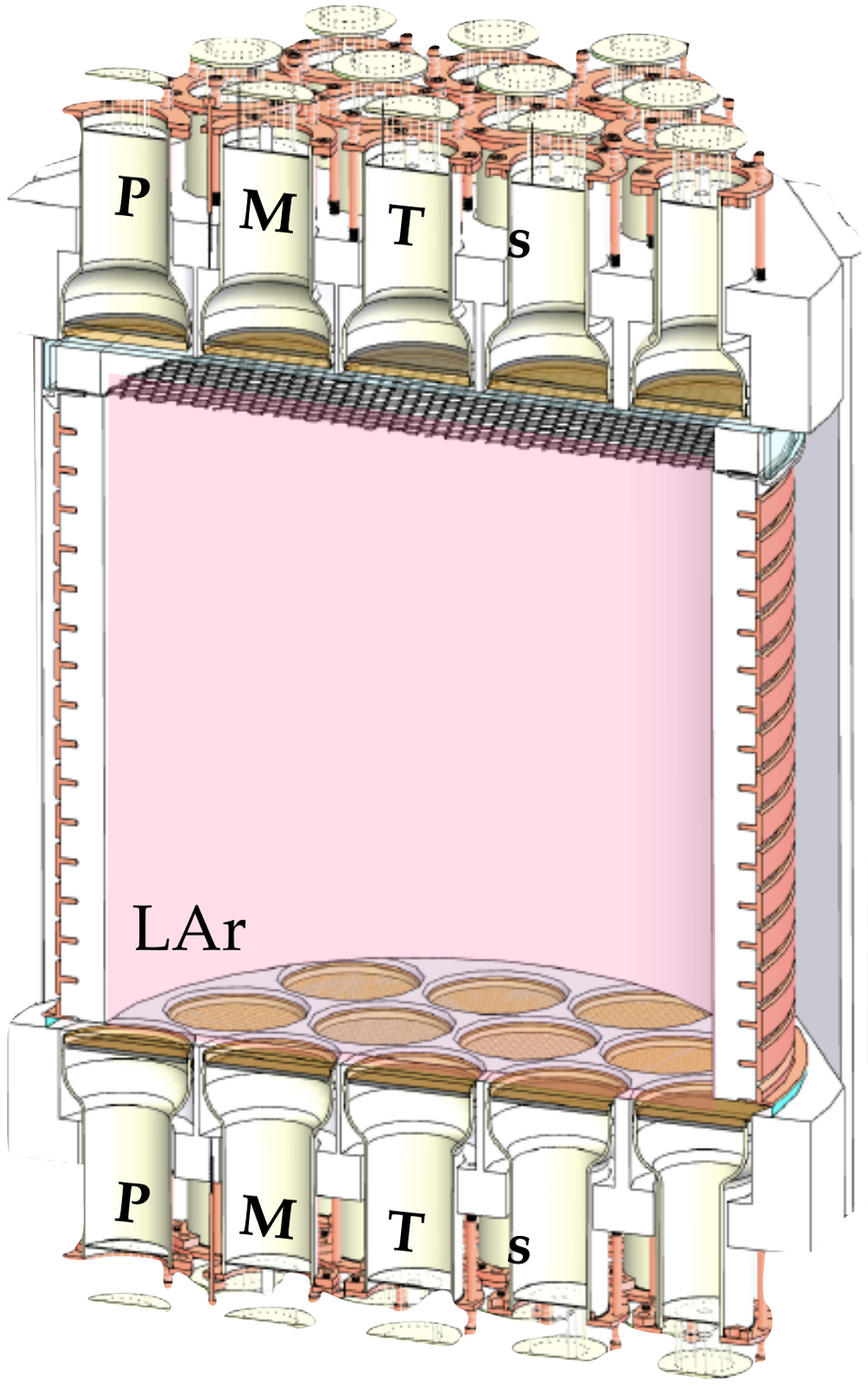
11m-diameter, 10m-tall, 1 kt Water Čerenkov Detector (WCD) instrumented with 80 8”-PMTs provides active shielding against μ’s

4m-diameter 30 t borated Liquid Scintillator Veto (LSV) instrumented with 110 8”-PMTs provides additional active shielding against γ’s, n’s and μ’s

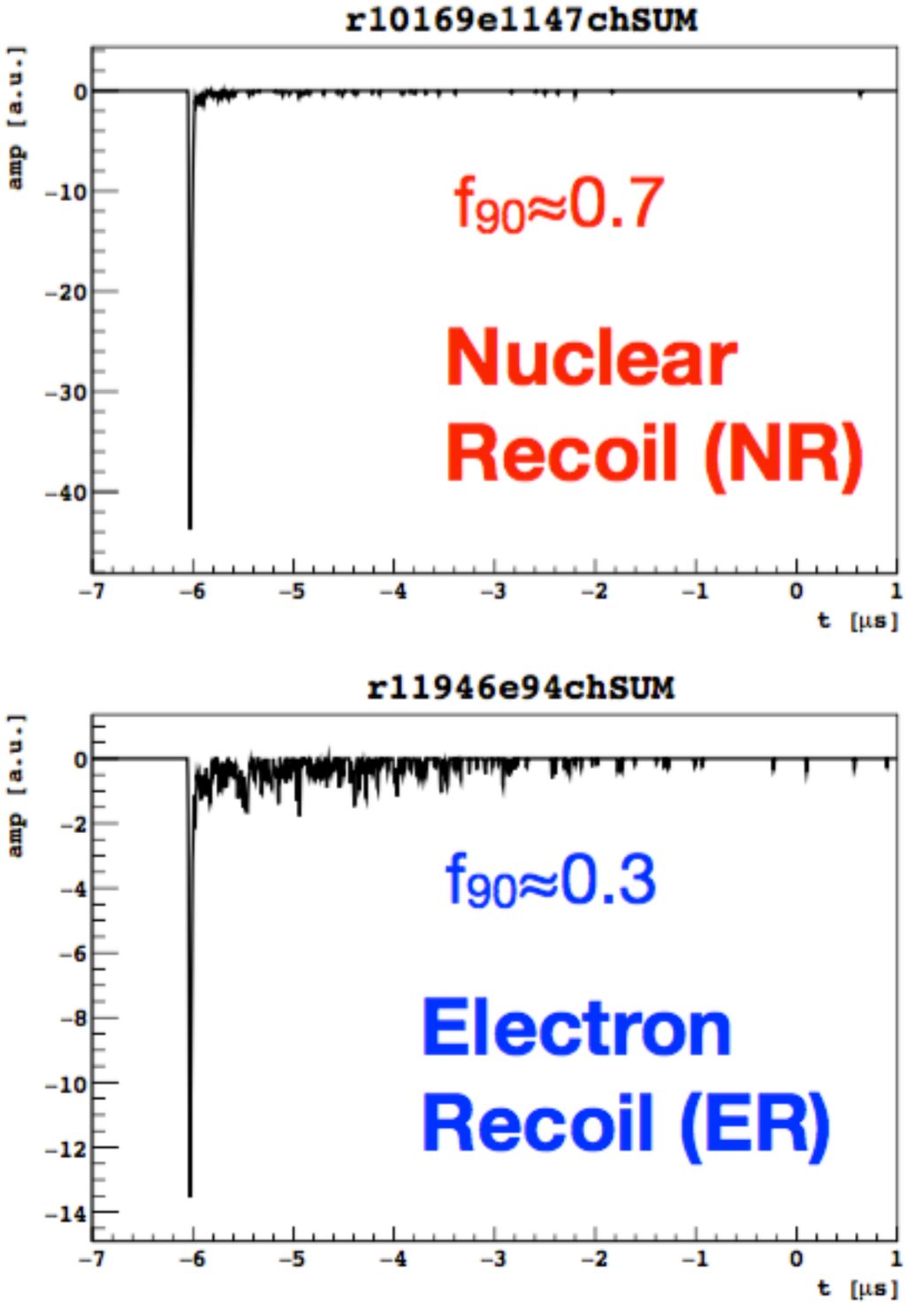
…these all surround the inner detector, the Time Projection Chamber (TPC)

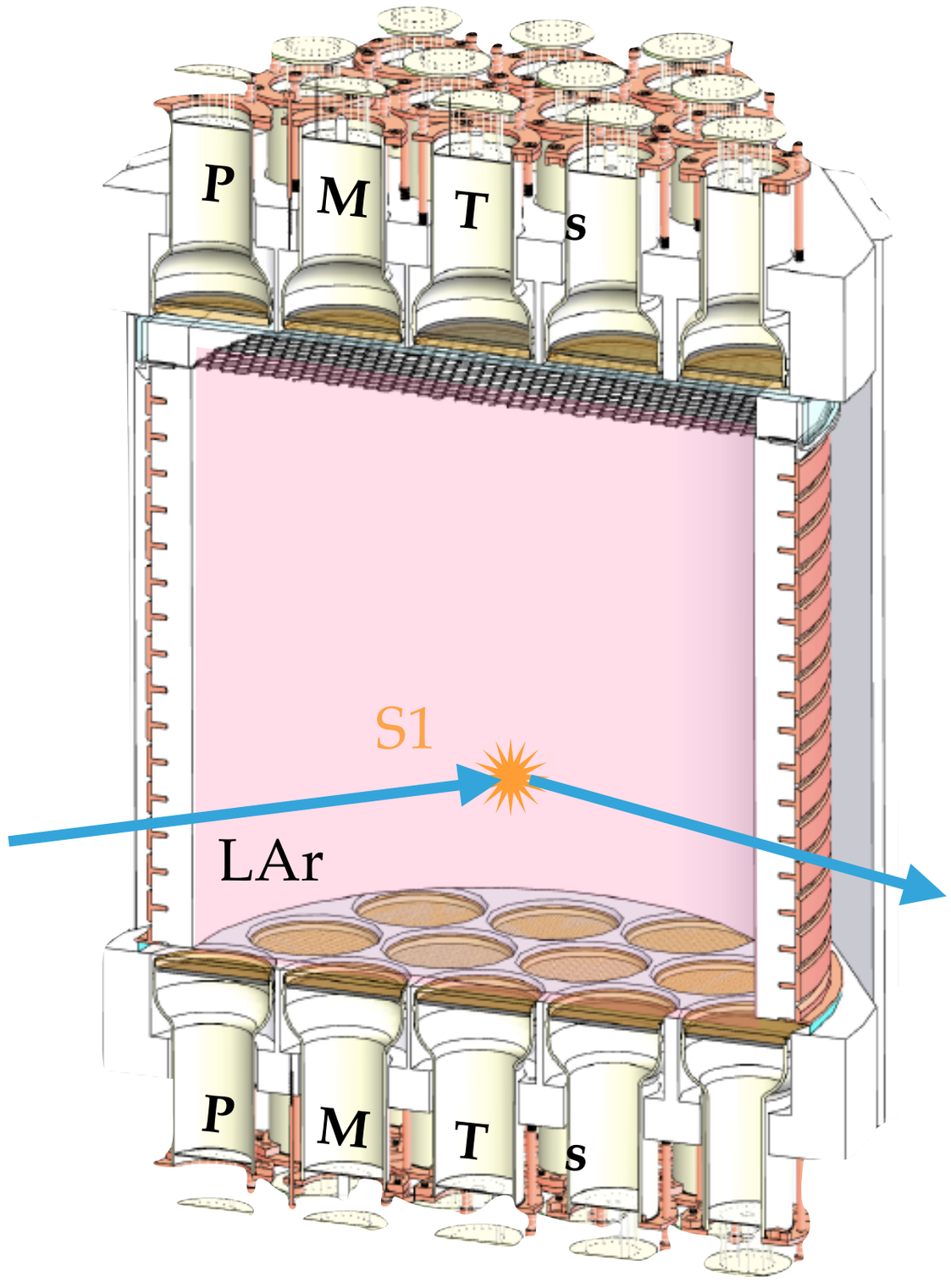
DarkSide-50 Dual-phase TPC

- Cylindrical shape of 35.6 cm radius x 35.6 cm height x 2.54 cm thick with PTFE reflector walls;
- TetraPhenyl Butadiene (TPB) wavelenght shifter on the walls;
- 19 3”-PMTs in the top and 19 on the bottom with cold amplifiers;
- Drift Field: 0.2 kV/cm
- Extraction Field: 2.8 kV/cm

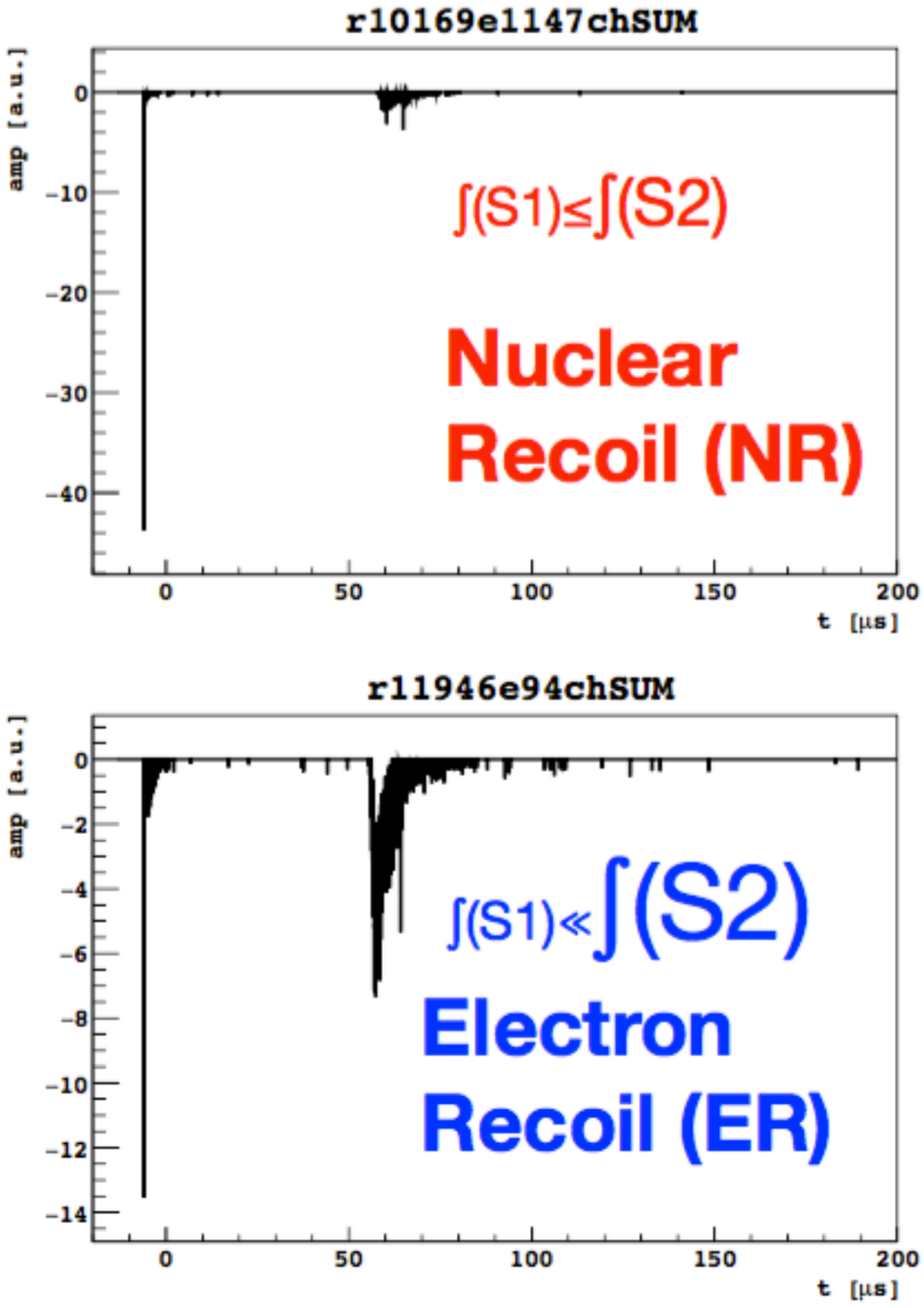


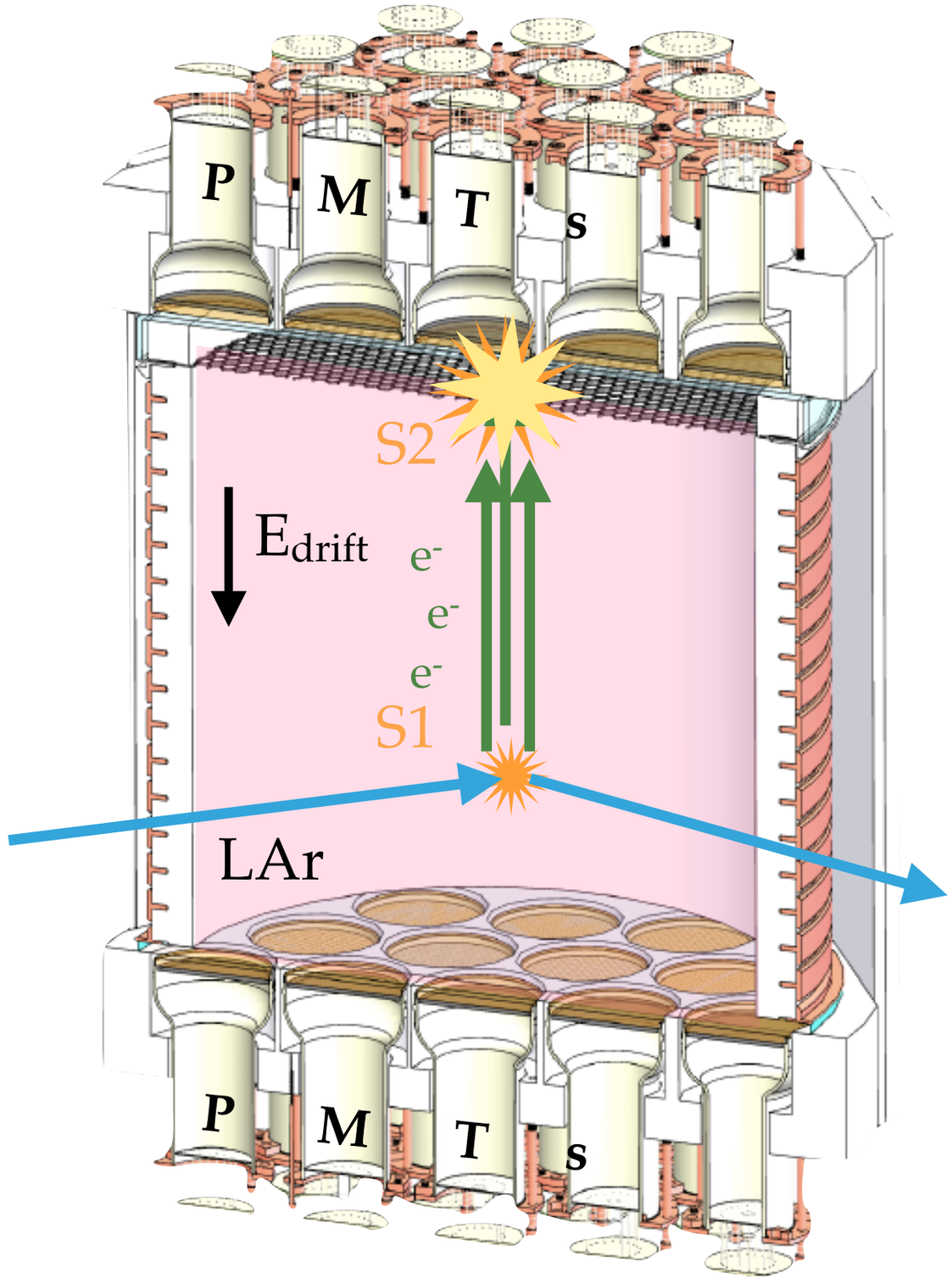
DarkSide-50 Dual-phase TPC





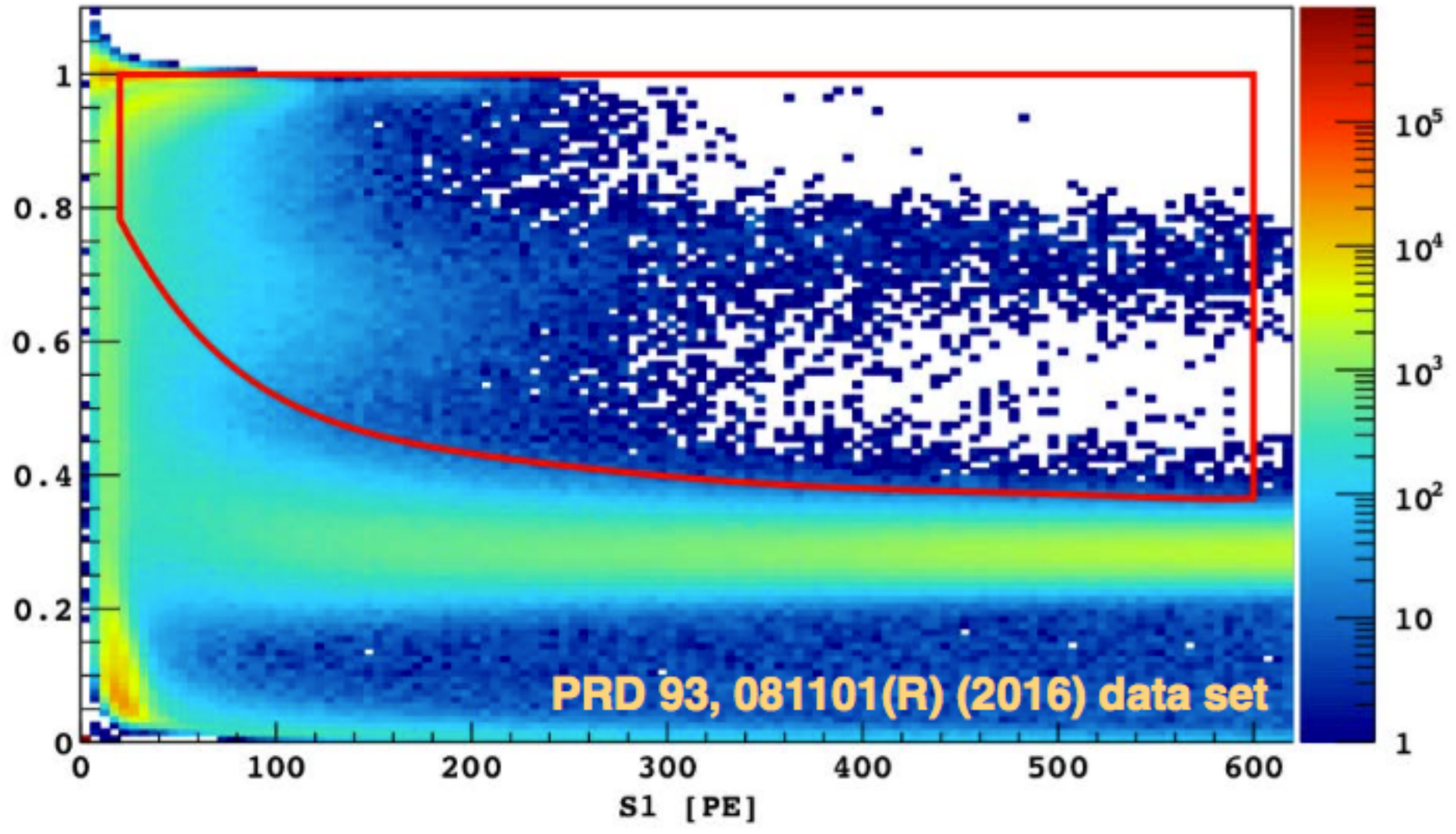
DarkSide-50 Dual-phase TPC





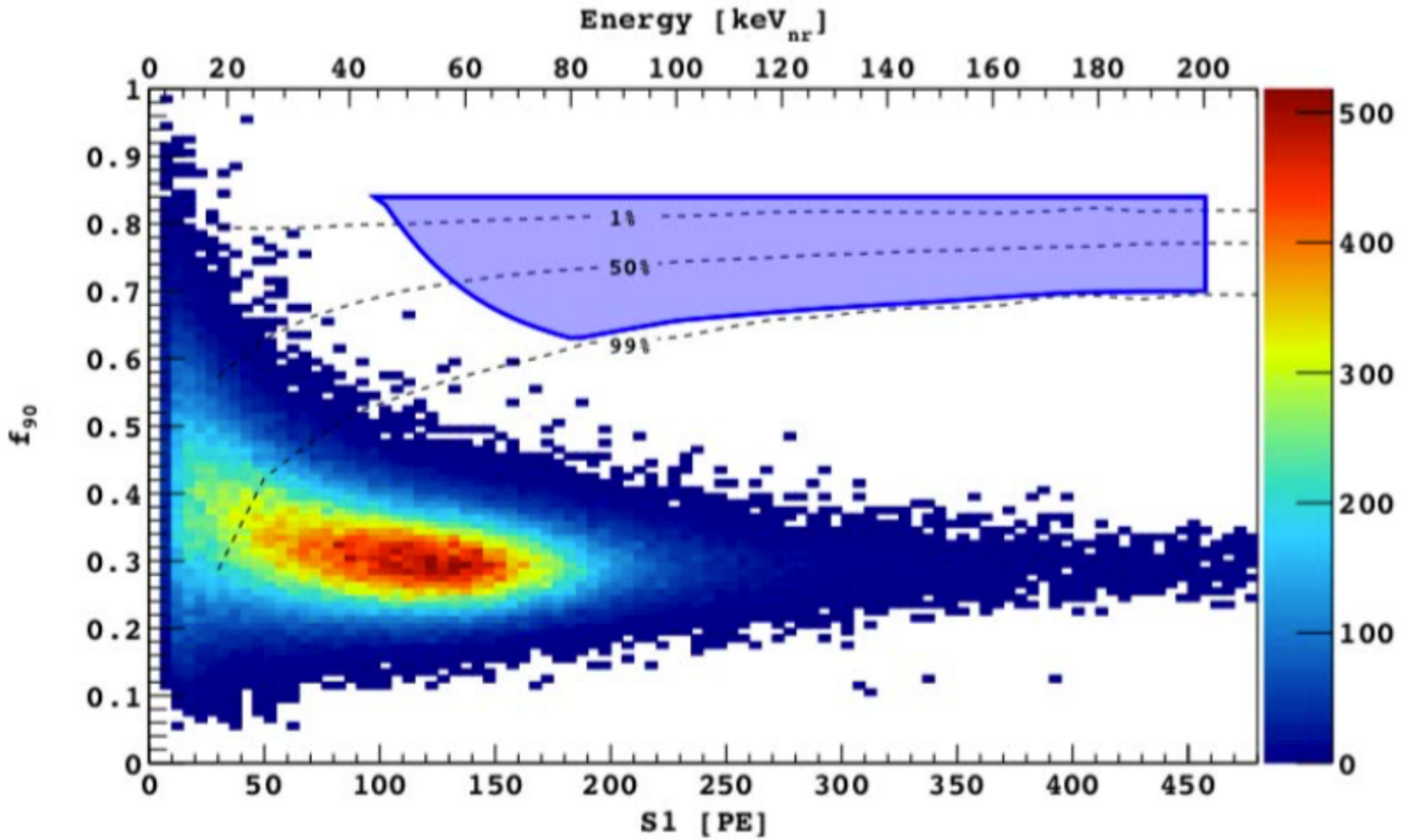
High mass WIMP search: blind analysis

- Blind analysis of about 532 live-days of WIMP search data;
- blinded region defined on 70 live-days of data from Phys. Rev. D 93, 081101 (2016);
- design a background free analysis (< 0.1 background events in the WIMP search box).



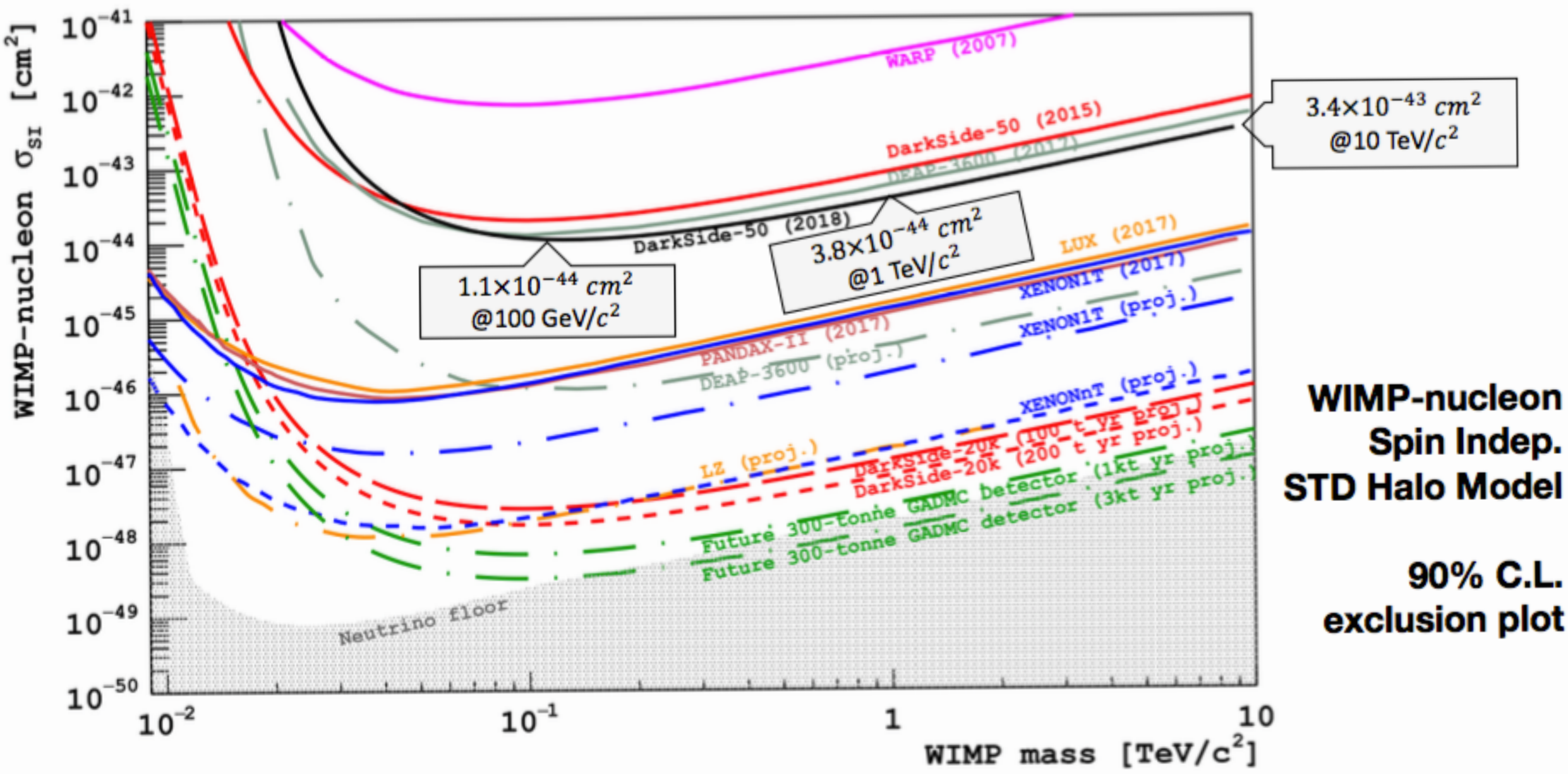
Physical Review D 98 (10), 102006 (2018)

Blind analysis: unblinded data



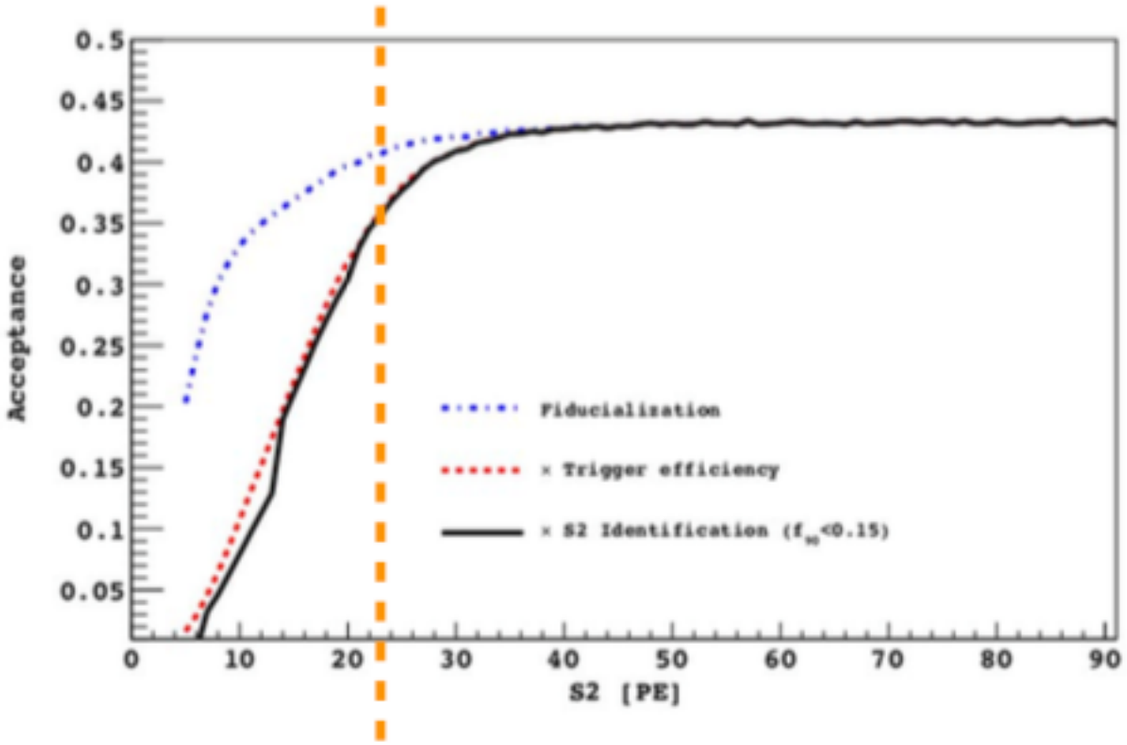
Physical Review D 98 (10), 102006 (2018)

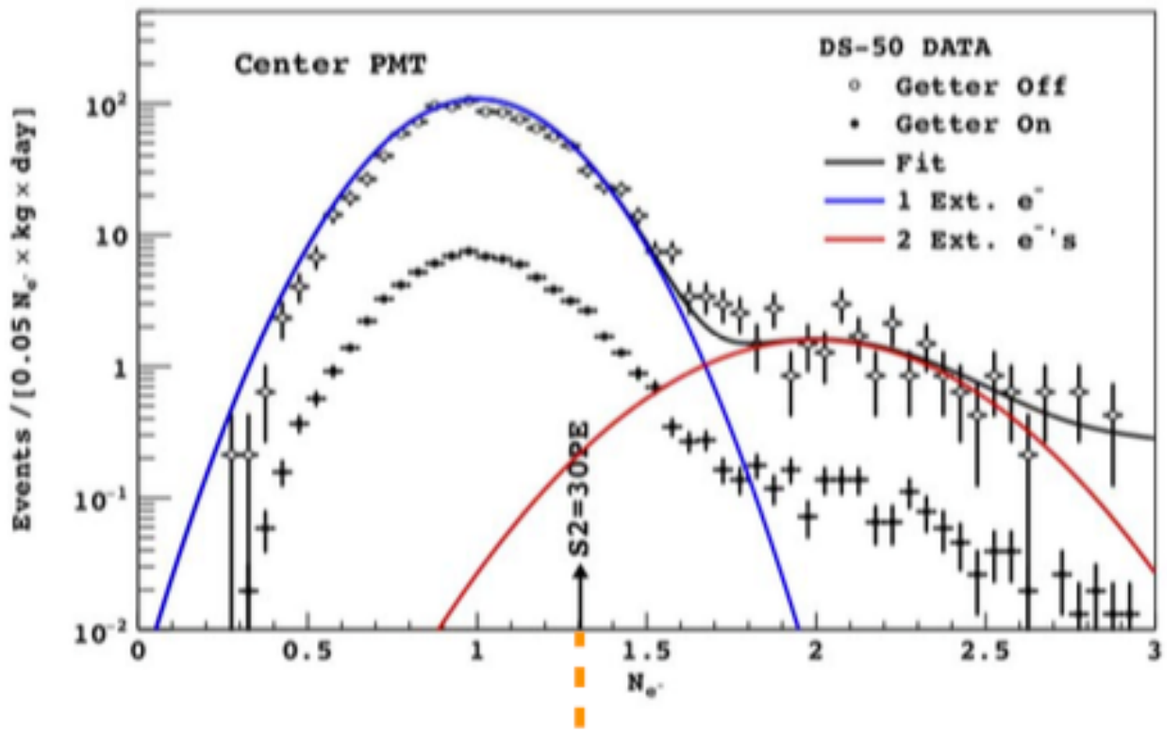
High mass WIMP search: results



Physical Review D 98 (10), 102006 (2018)

Low mass WIMP search: S2-only analysis



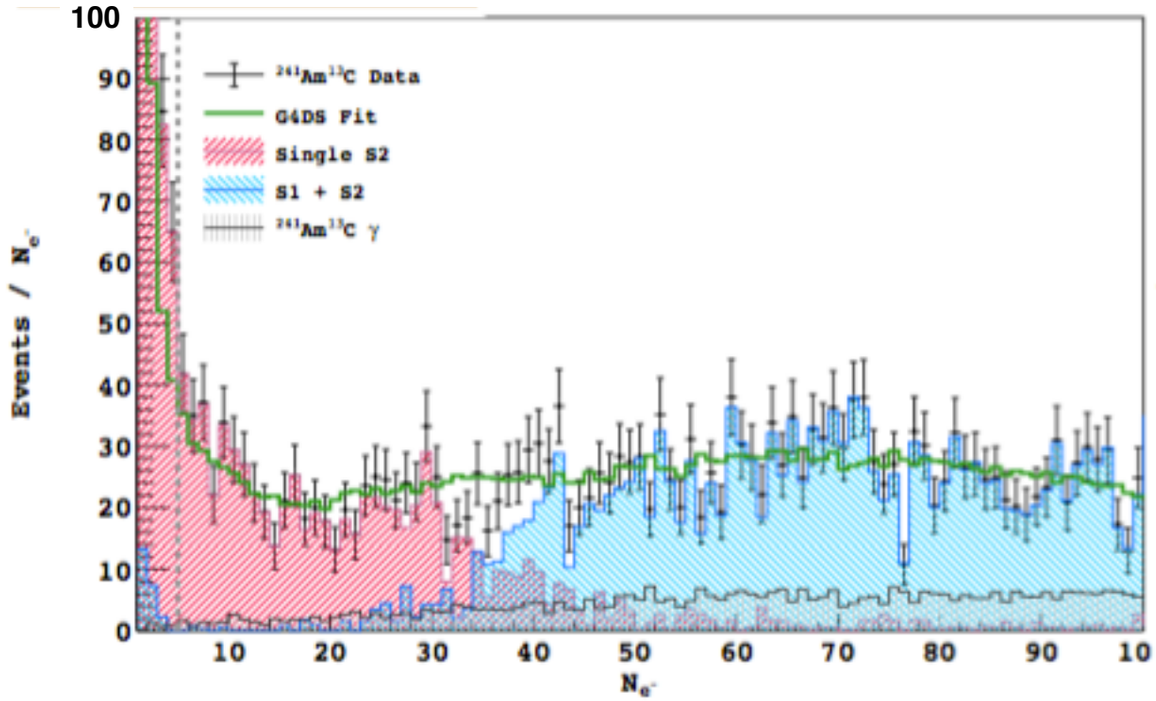


single electron (23±1)PE **30 PE**

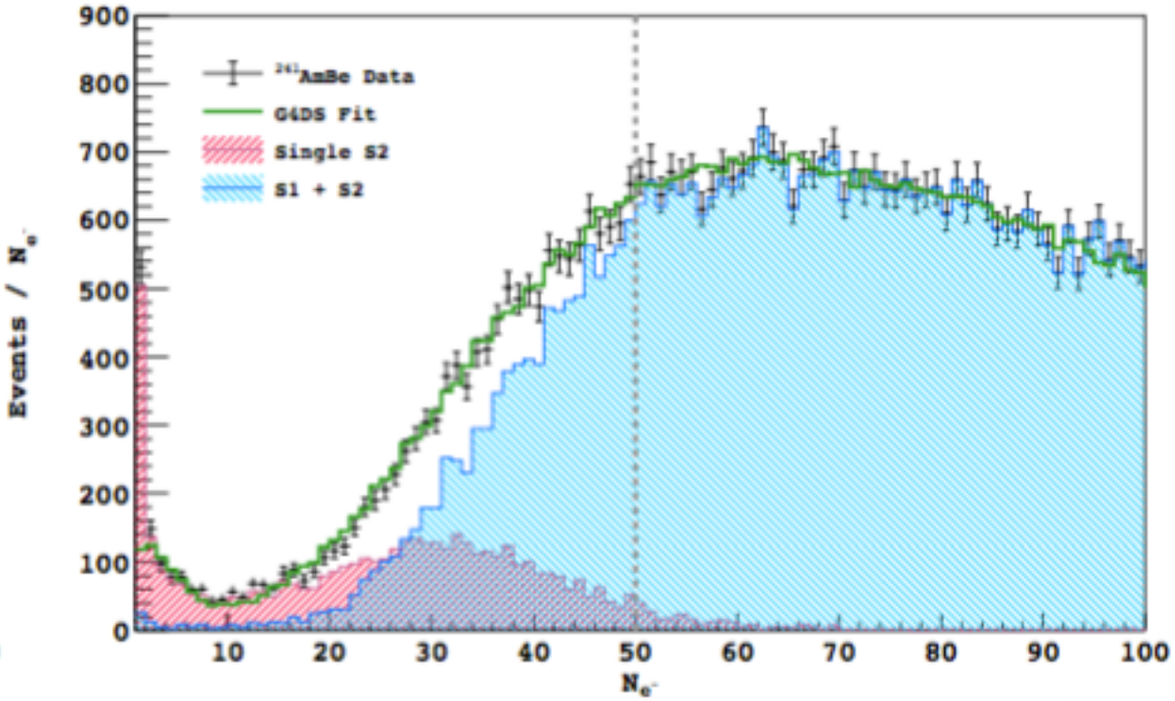
- Use S2 signal only:
  - give up S1 signal, PSD, vertical position and S2/S1;
  - lower detection threshold to single electron;
  - sensitivity to lower mass dark matter (~1.8 GeV/c^2);
- Trigger efficiency and pulse finding efficiency are 100% for S2 > 30 PE.

Phys. Rev. Lett. 121, 081307 (2018)

S2-only analysis: NR (*in-situ*) energy calibration



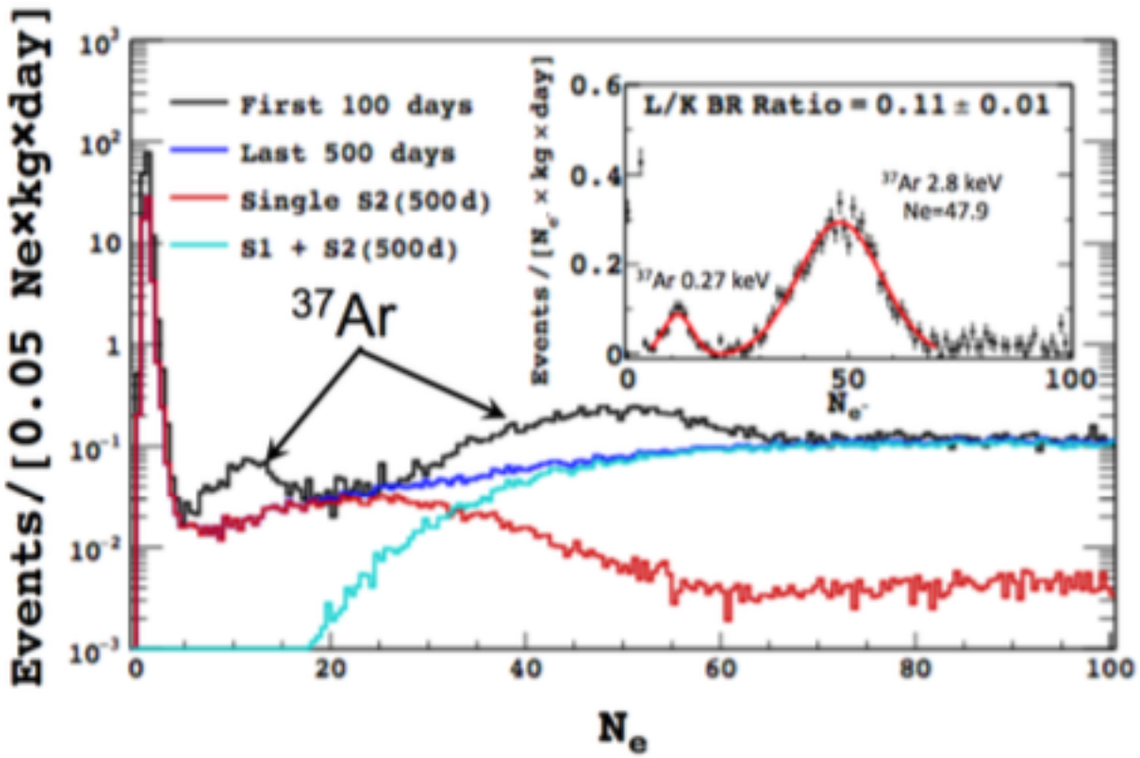
- *In-situ* calibration with ^{241}Am^{13}C source;
- low rate source with little γ activity;
- find NR scale by fitting simulated spectrum to data and background distribution;
- allow measure down to 4 Ne^- threshold.

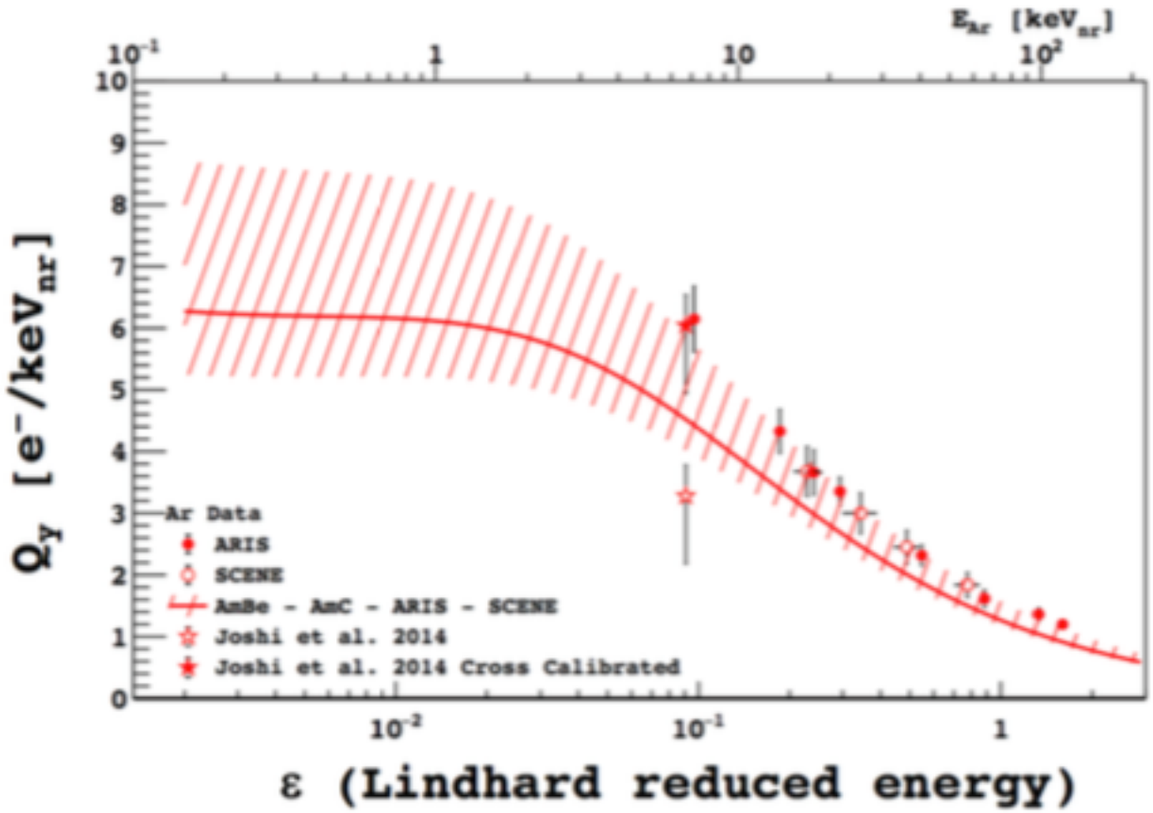


- *In-situ* calibration with ^{241}AmBe source;
- high rate source: neutrons produced with associated γs;
- find NR scale by fitting simulated spectrum to data with 4.4 MeV γ in LSV detector;
- deep at low Ne due to LSV data available only for S1 triggers. Joint fit with AmC data for Ne^- >50.

Phys. Rev. Lett. 121, 081307 (2018)

S2-only analysis: ER/NR energy calibration



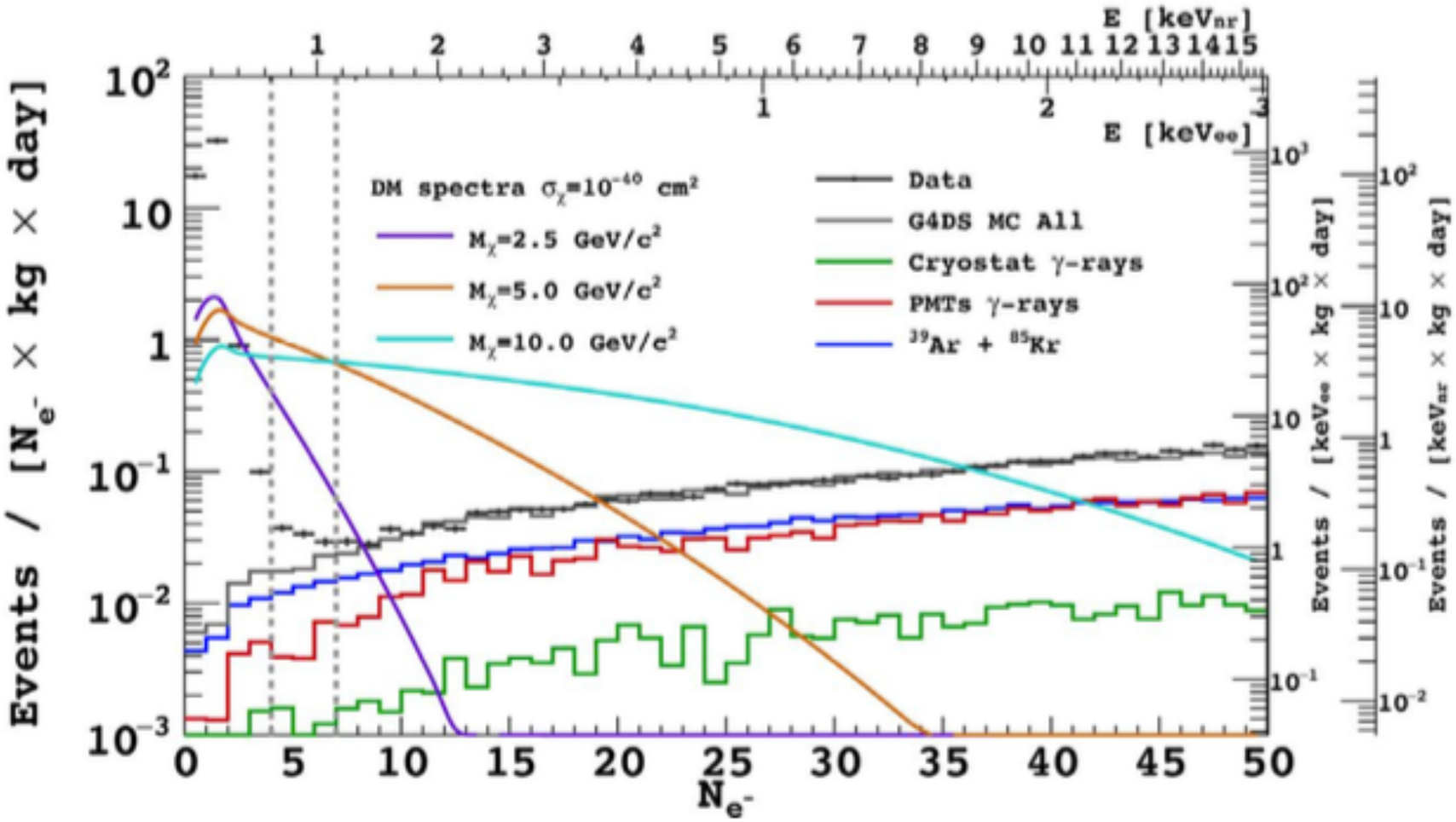


- Excellent low-energy ER calibration point from ^{37}Ar:
  - from cosmogenic activation ($t_{1/2}$ ~ 35 days);
  - 0.27 keV L-shell and 2.82 keV K-shell following e^- capture in ^{37}Ar.

- Ionization yield from NR energy:
  - measured with DS-50 neutron calibrations and neutron beam experiments like SCENE and ARIS;
  - no knowledge of ionization yield at low energy recoil neither of the shape of charge distribution (probably with ReD, see next).

Phys. Rev. Lett. 121, 081307 (2018)

S2-only analysis: Ne spectrum

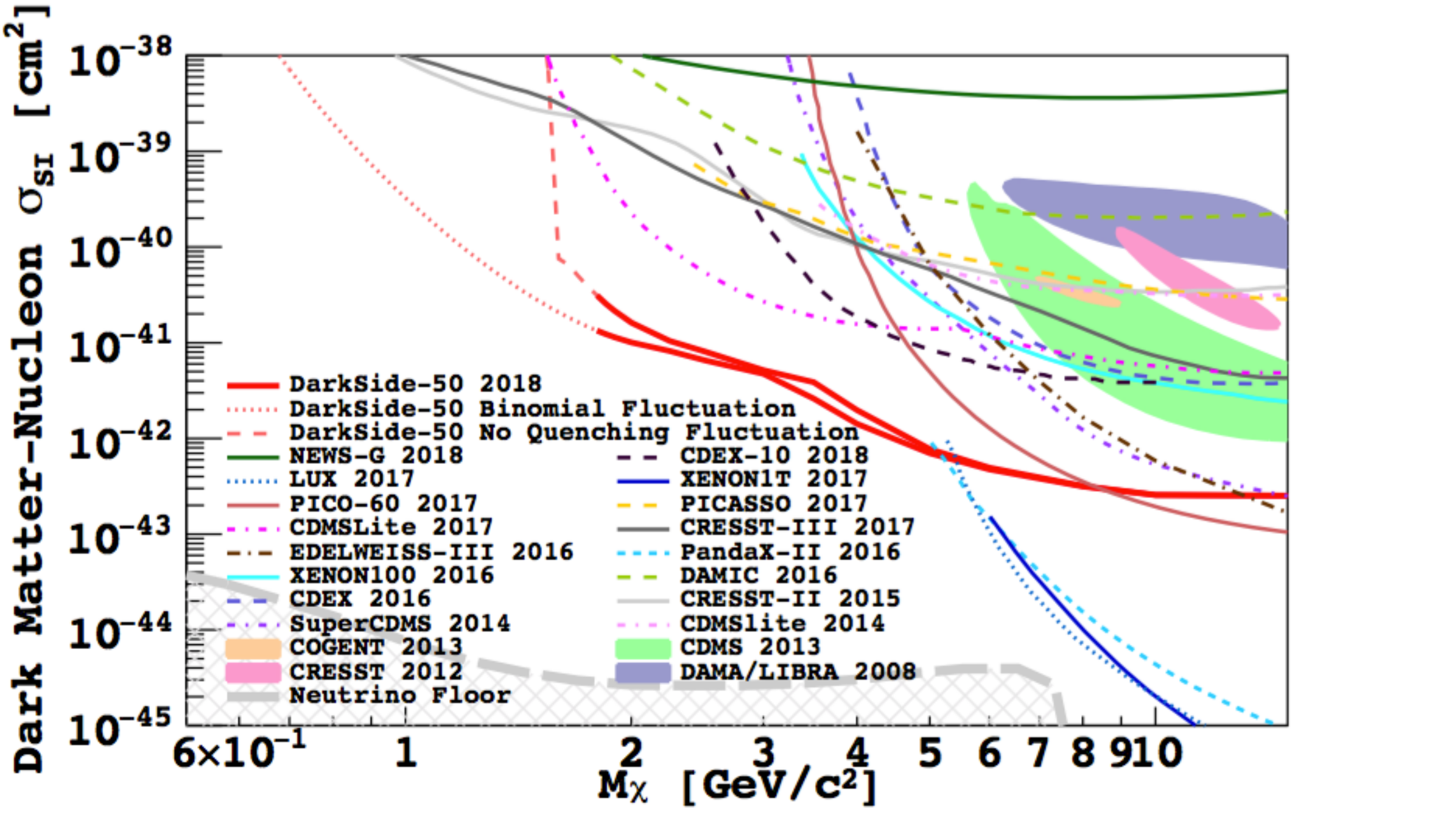


- Analysis threshold at $Ne^- > 4$;
- excess below $Ne^- \sim 4$ due to trapped electrons;
- expected signal assumes standard DM halo;
- uncertainties in signal dominated by fluctuations in ionization yield.

Phys. Rev. Lett. 121, 081307 (2018)

S2-only analysis: results

90 % CL upper limits on WIMP-nucleon cross section



Phys. Rev. Lett. 121, 081307 (2018)

Sub-GeV dark matter search

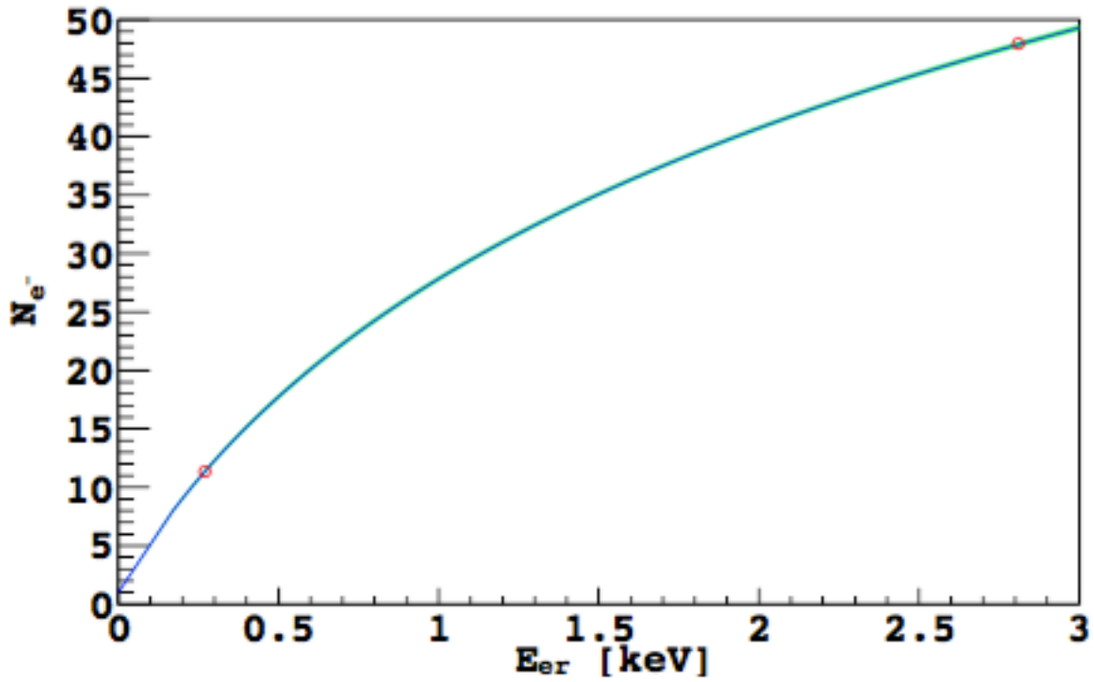
- WIMP-electron interaction parametrized by form factor $F_{DM} = F_{DM}(q)$ which, depending on the mass of the mediator ($m_{A'}$) has different asymptotic momentum (q) dependence:

$$F_{\mathrm{DM}}(q) = \frac{{m_{A'}}^2 + \alpha^2 {m_e}^2}{{m_{A'}}^2 + q^2} \simeq \begin{cases} 1, & m_{A'} \gg \alpha m_e \\ \frac{\alpha^2 {m_e}^2}{q^2}, & m_{A'} \ll \alpha m_e \,, \end{cases}$$

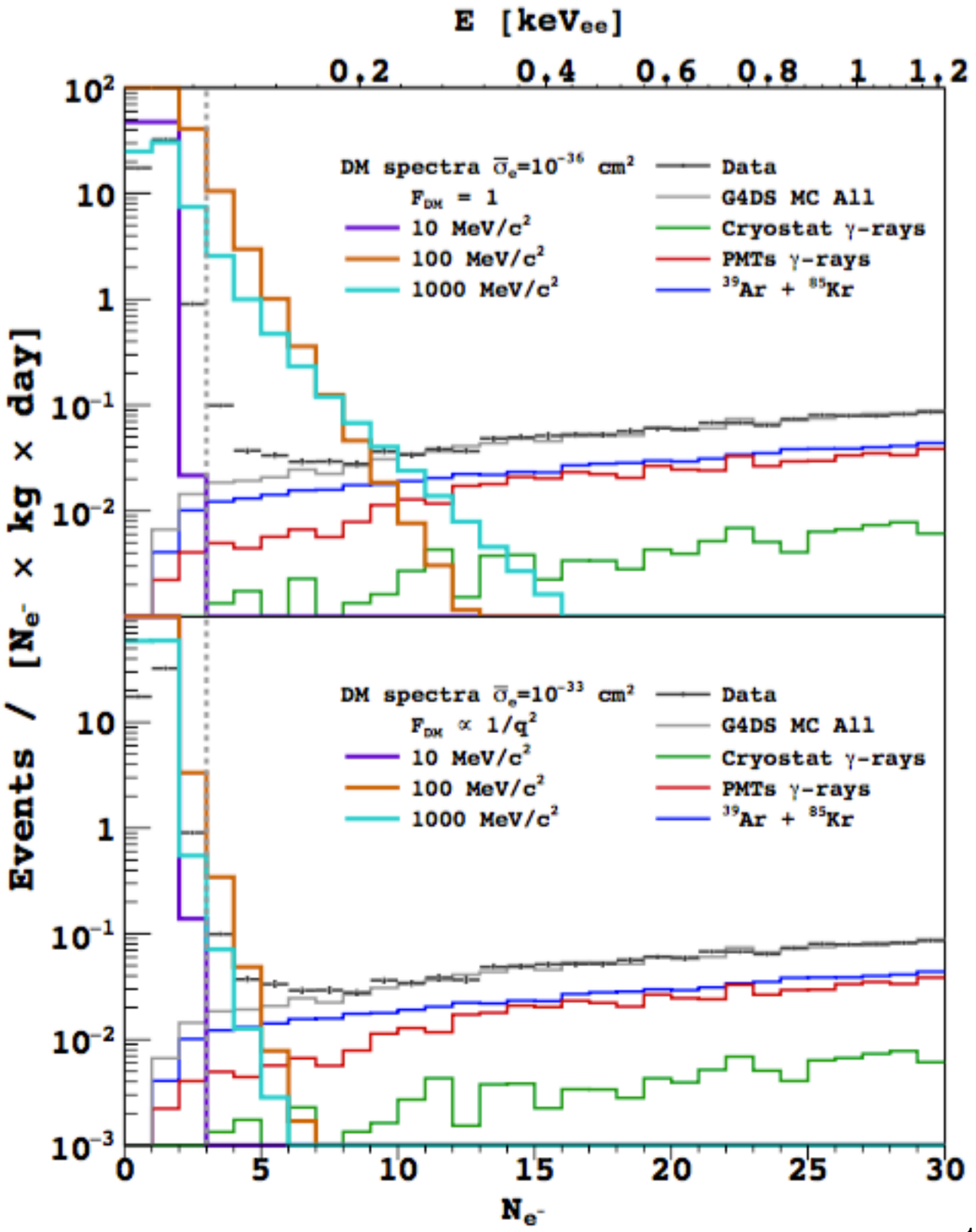
- ^{37}Ar X-rays are used to convert electron recoil spectra to ionization spectra:

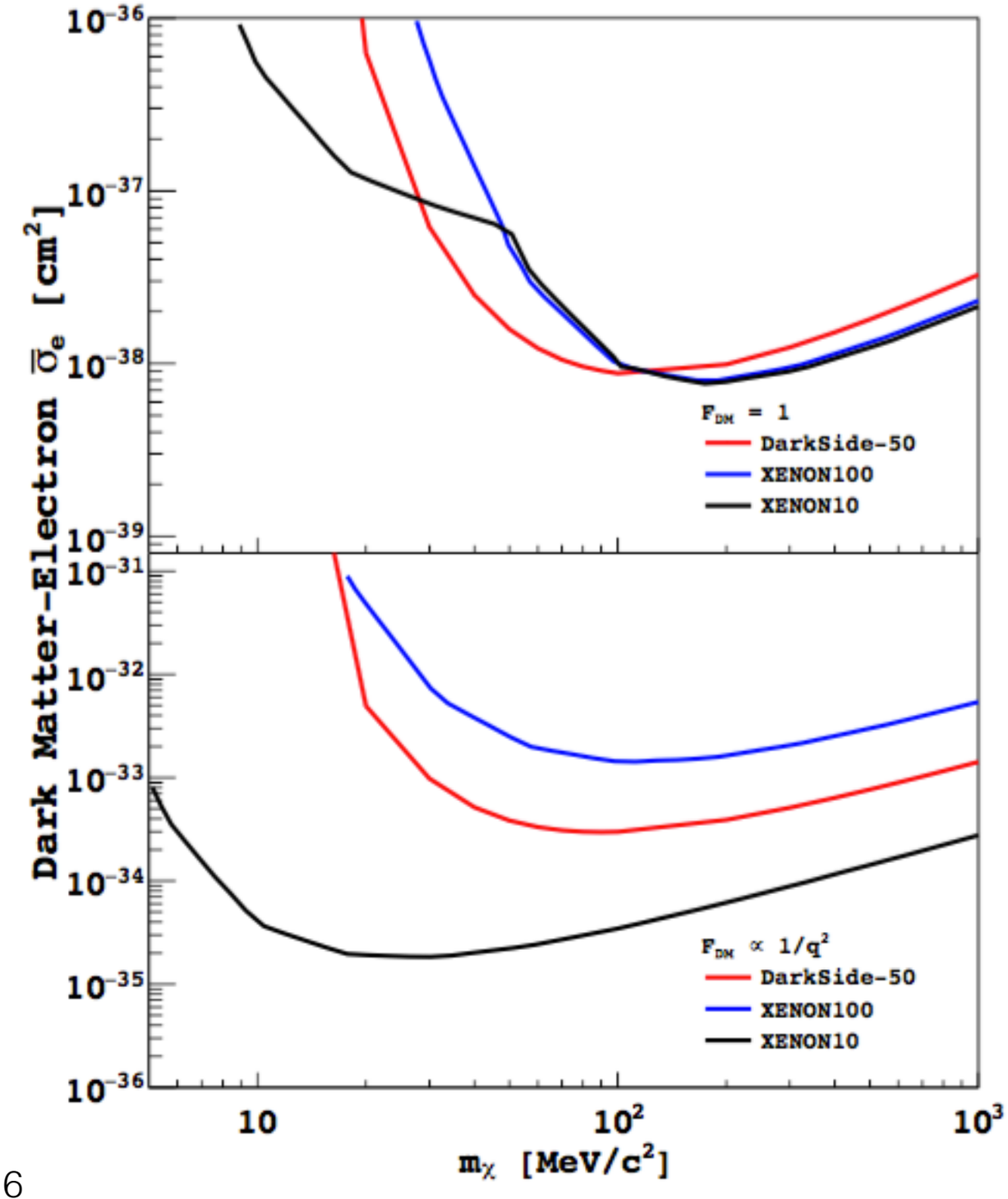
- L-shell: 0.27 keV

- K-shell: 2.82 keV



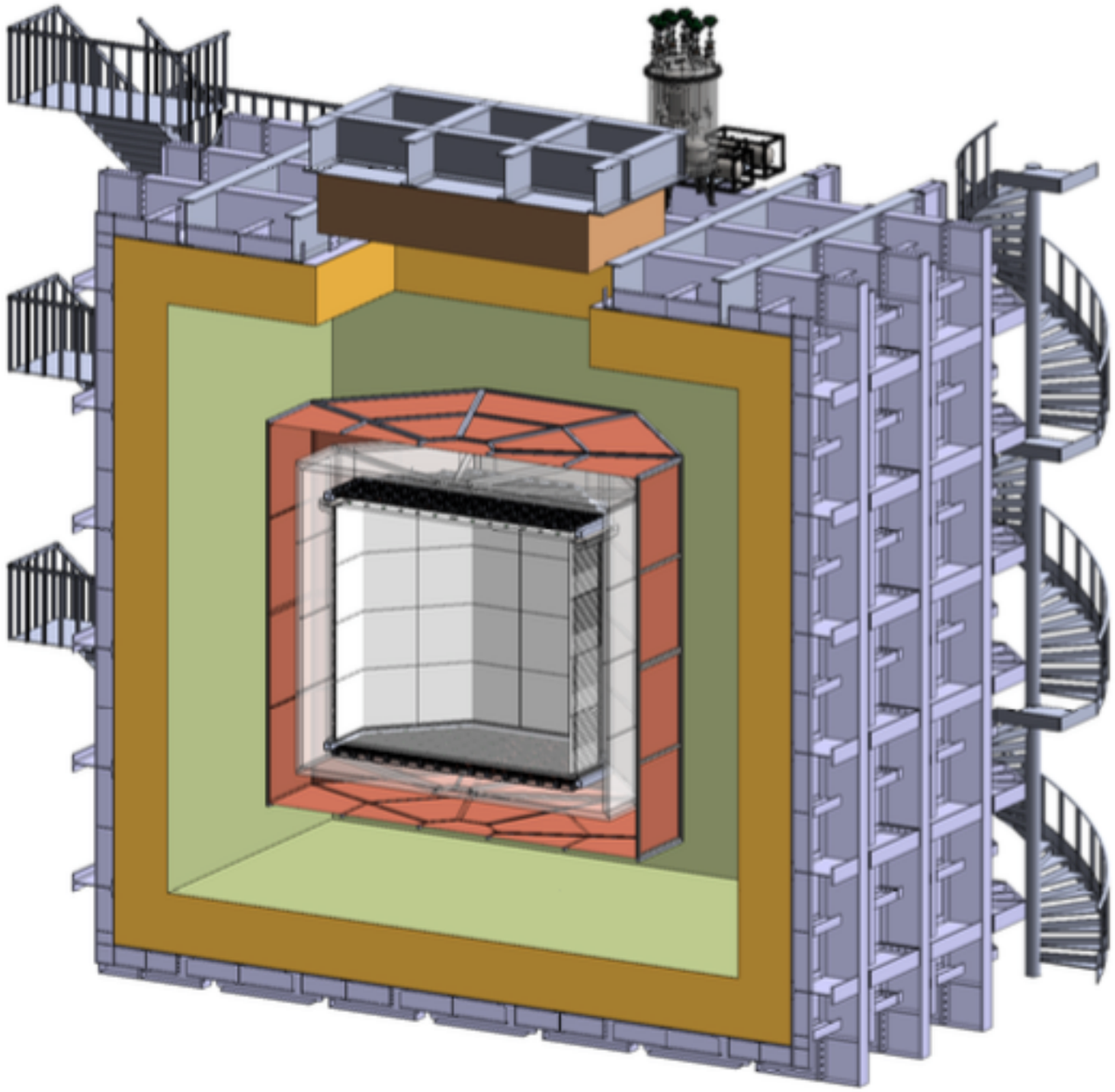
Sub-GeV dark matter search





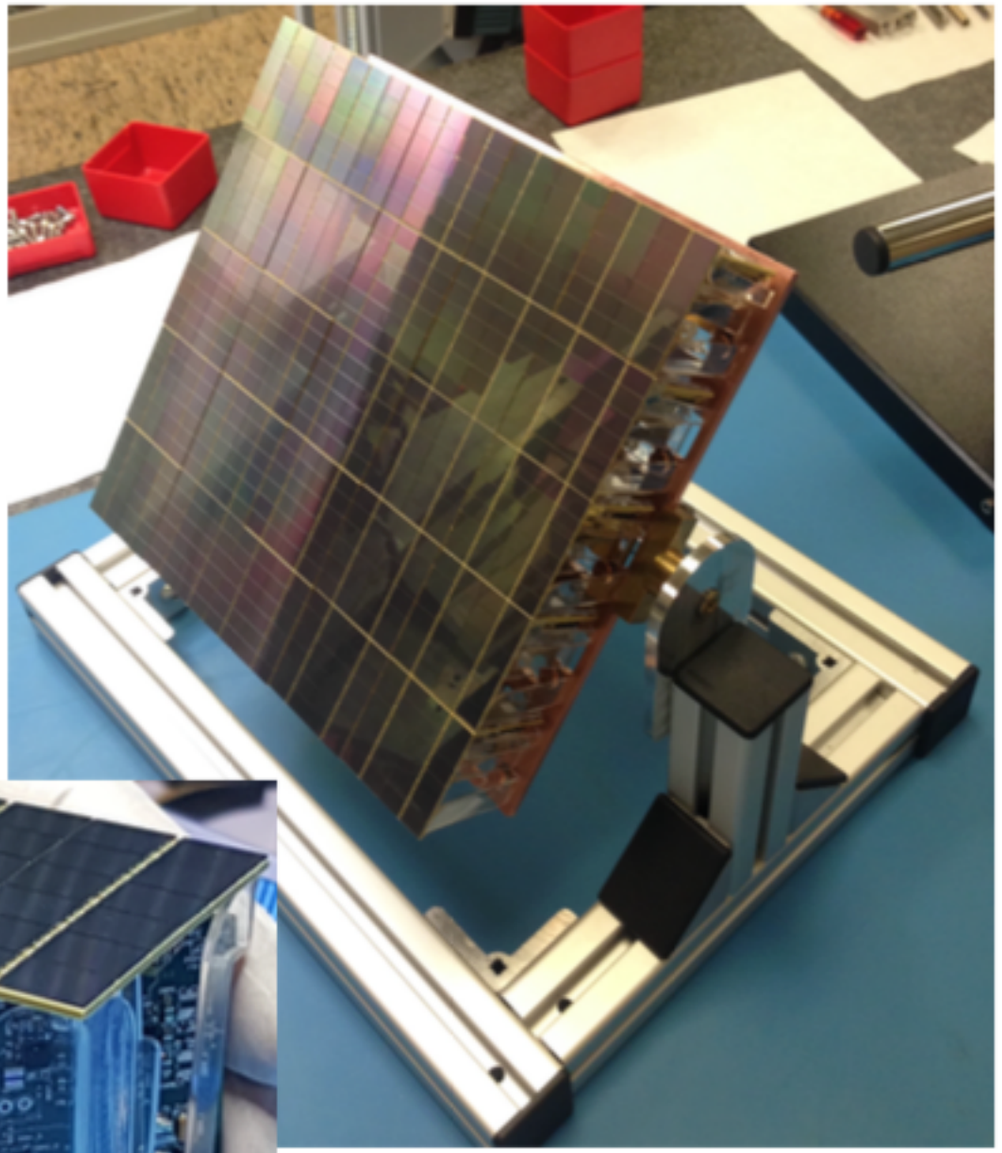
The future of DarkSide: DS-20k

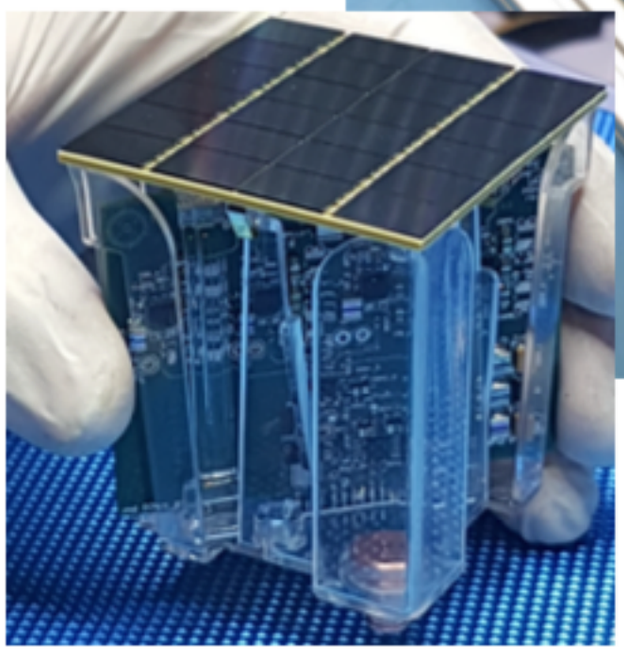
- 50 tonnes UAr acrylic dual-phase TPC in a ProtoDUNE-like cryostat filled with ~700 tonnes of AAr;
- 30 tonnes fiducial volume;
- 30 m^2 of SiPM scintillation detecting surface (8280 channels for TPC and ~3000 channels for Veto);
- TPC thin acrylic vessel to be surrounded by an active plastic scintillator layer (Gd-doped acrylic panels) as neutron veto;
- detector concept minimize internal neutron background sources and allow easier scaling for bigger target mass.



DarkSide-20k: SiPMs

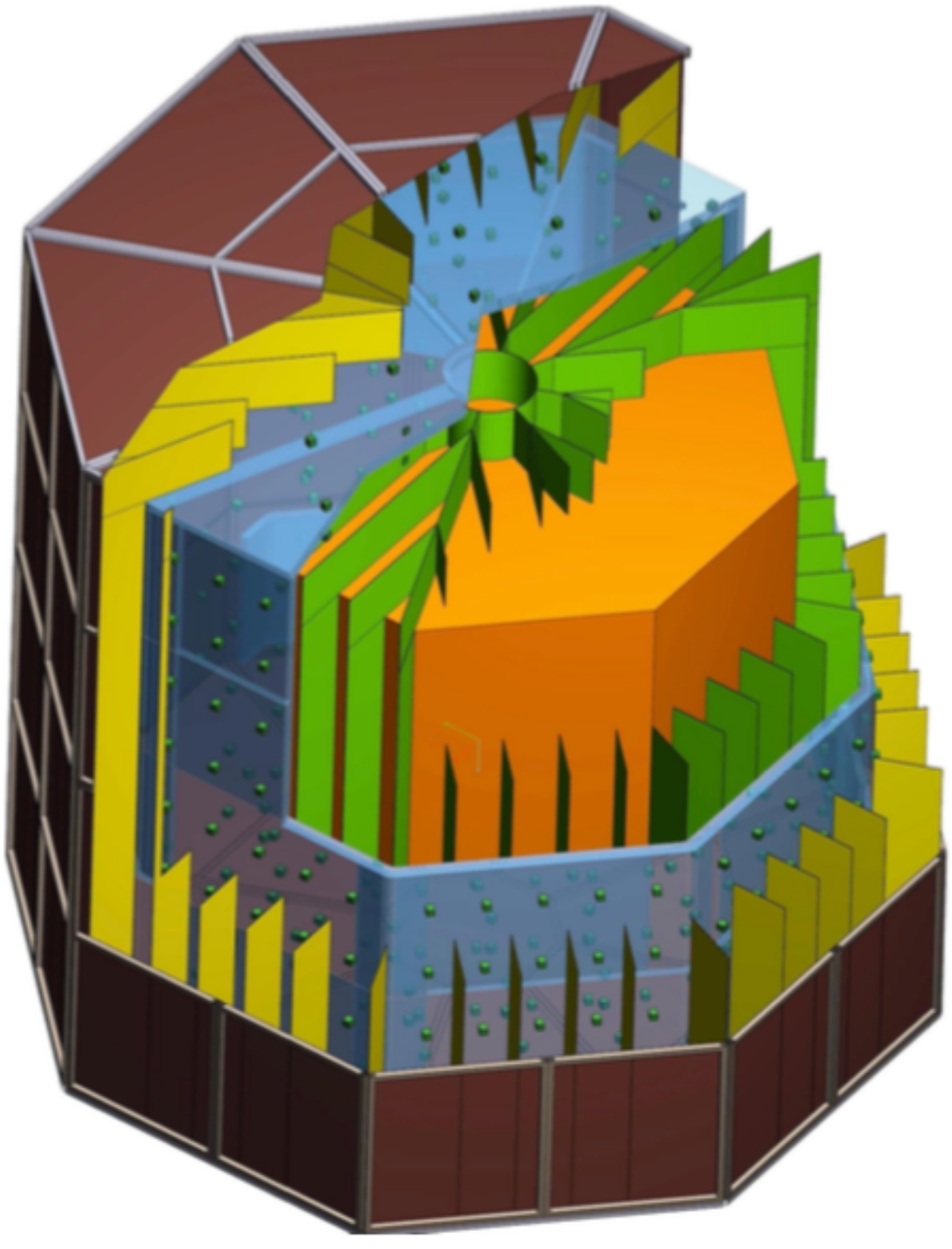
- Designed for LAr by combined effort between DarkSide and Fondazione Bruno Kessler (FBK);
- compact and high coverage;
- high SNR (> 8);
- high PDE (~50%);
- massive production by LFoundry and packaging of PDMs in NOA, L'Aquila;
- full production chain largely funded by Regione Abruzzo, Italy.





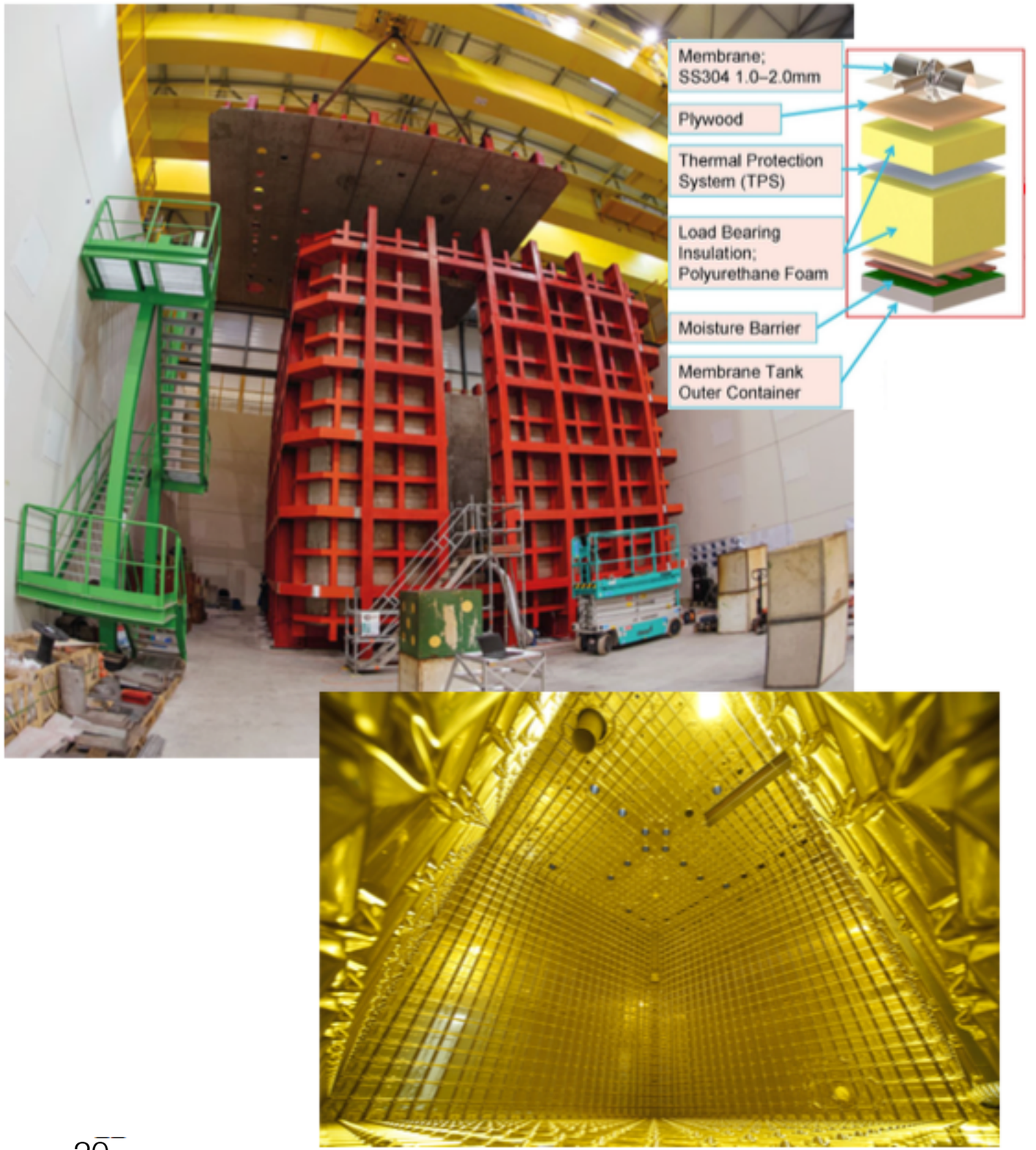
DarkSide-20k: the neutron veto

- 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 to detect gamma cascade due to neutron capture on Gd;
- Faraday cage to optically and electrically isolate both veto and TPC;
- vertical segmentation to reduce pile-up rate of ^{39}Ar (1Bq/kg in AAr) event from AAr and ESR foil as reflector to maximize light collection;
- all internal surface of each sector coated with TPB as wavelength shifter.



DarkSide-20k: the cryostat

- Developed at CERN for ProtoDUNE neutrino experiment;
- membrane and passive thermal insulation;
- maturated technique adopted from the Liquified Natural Gas carriers and vessels;
- access and support of TPC and Veto from top roof;
- penetrations on top roof determined by the requirements of all sub-systems.

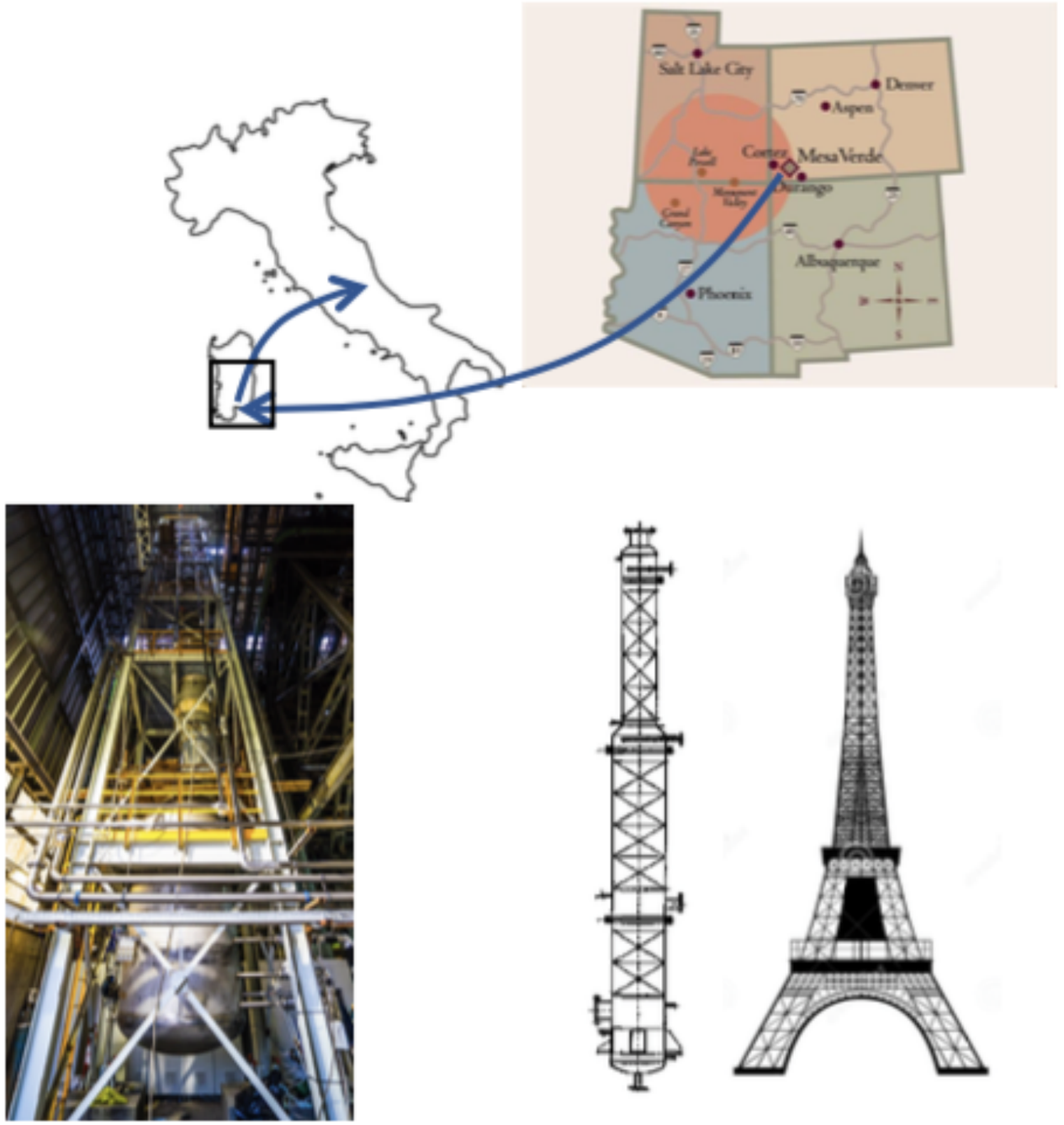


DarkSide-20k: the UAr

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

- **Aria:** UAr shipped to Sardinia, Italy, for chemical purification via a 350 m tall cryogenic distillation column in the former Seruci Mine:

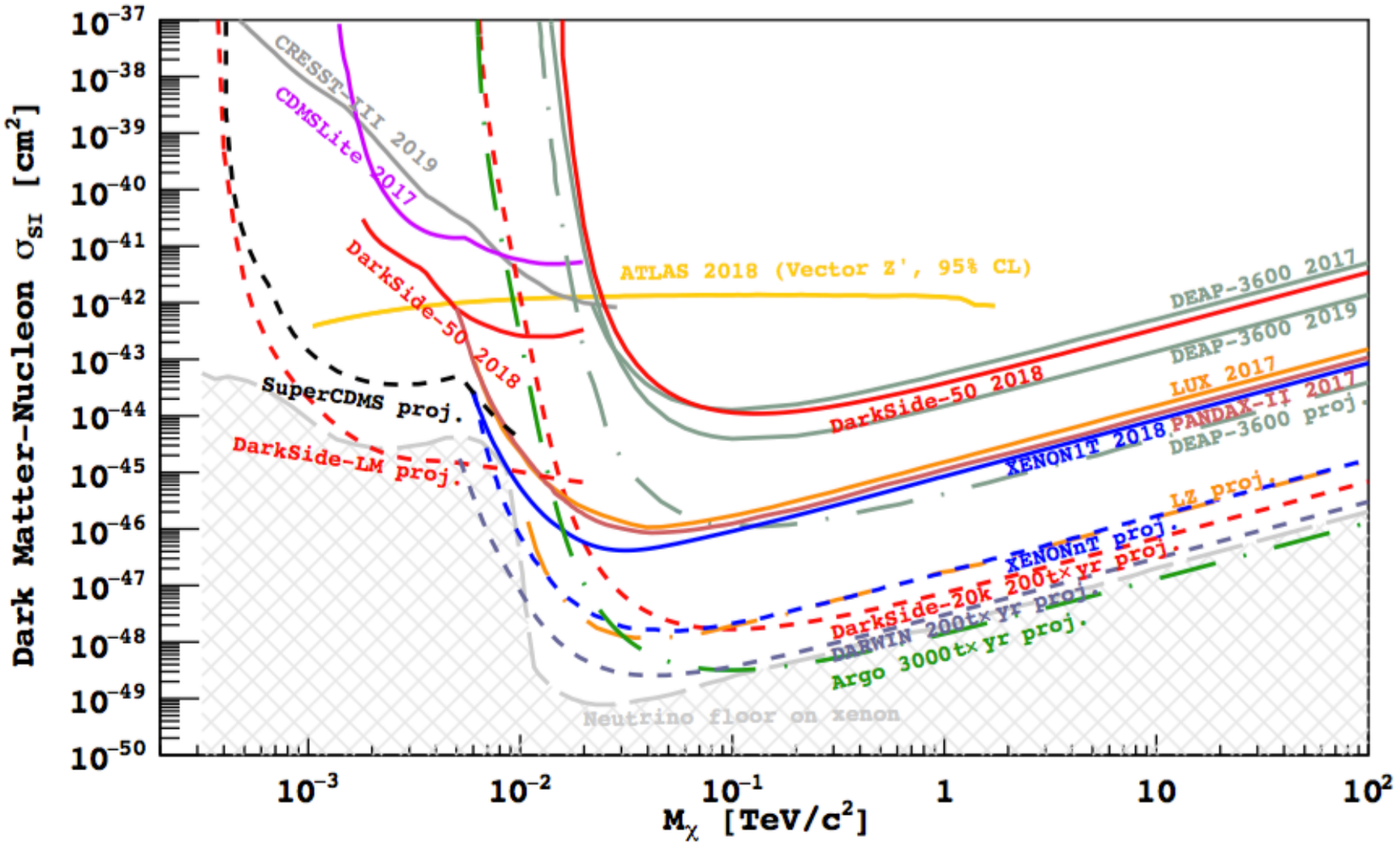
  - process ~1 tonnes/day with 1000 reduction of all chemical impurities and isotopically separate ^{39}Ar from ^{40}Ar.



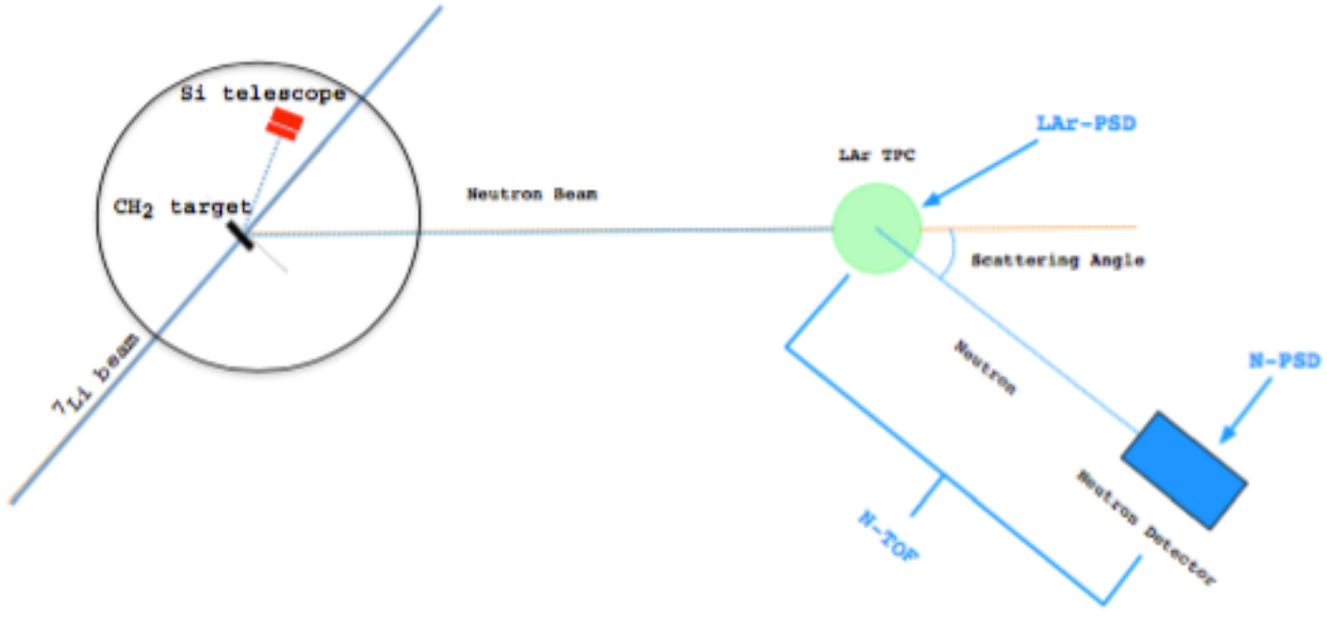
The Global Argon Dark Matter Collaboration

ArDM
DarkSide
DEAP
MiniCLEAN

A Single Global Program for Direct Dark Matter Searches
Currently taking data: ArDM, DarkSide-50, **DEAP-3600**
Next step: DarkSide-20k at LNGS (2021-)
Last Step: **300 tonnes detector**, location t.b.d **(2027-)**

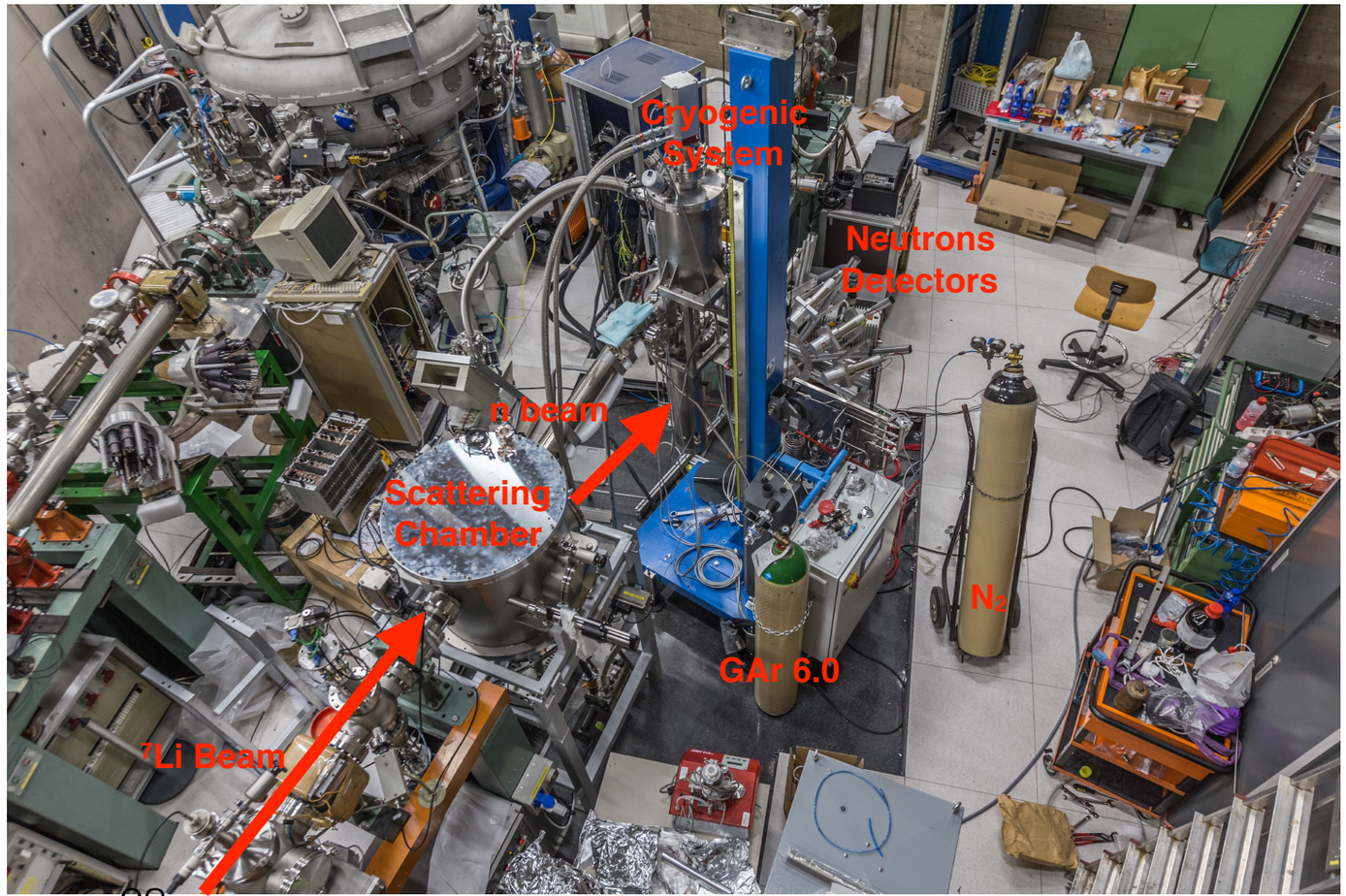


DarkSide R&D: the ReD experiment



- **Main goal:** irradiate a small LAr TPC with neutrons and produce **recoil parallel or orthogonal wrt the E field** in order to probe the **directionality of NR** in liquid argon;
- **How:** neutron beam is produced at **INFN - Laboratori Nazionali del Sud (LNS)** in Catania by the **15 MV Tandem** via the **p(^{7}Li,n)** reaction;
- **Bonus: direct measurement of low energy nuclear recoil** with the same TPC by tuning appropriately the beam and the geometry setups.

- ReD saw **beam in June and July 2018**:
  - for 6 nA of ^{7}Li and 0.2 mg/cm^2 target of CH_2: **~10^5 n/s (expected)**;
  - TPC-beam: 22°, TPC-LSci: 37°;
  - **TPC rate: ~Hz**;
  - **TPC+LSci: a few 100's of ev/day/nA expected**);
- **next runs this summer**.



Summary and Conclusions

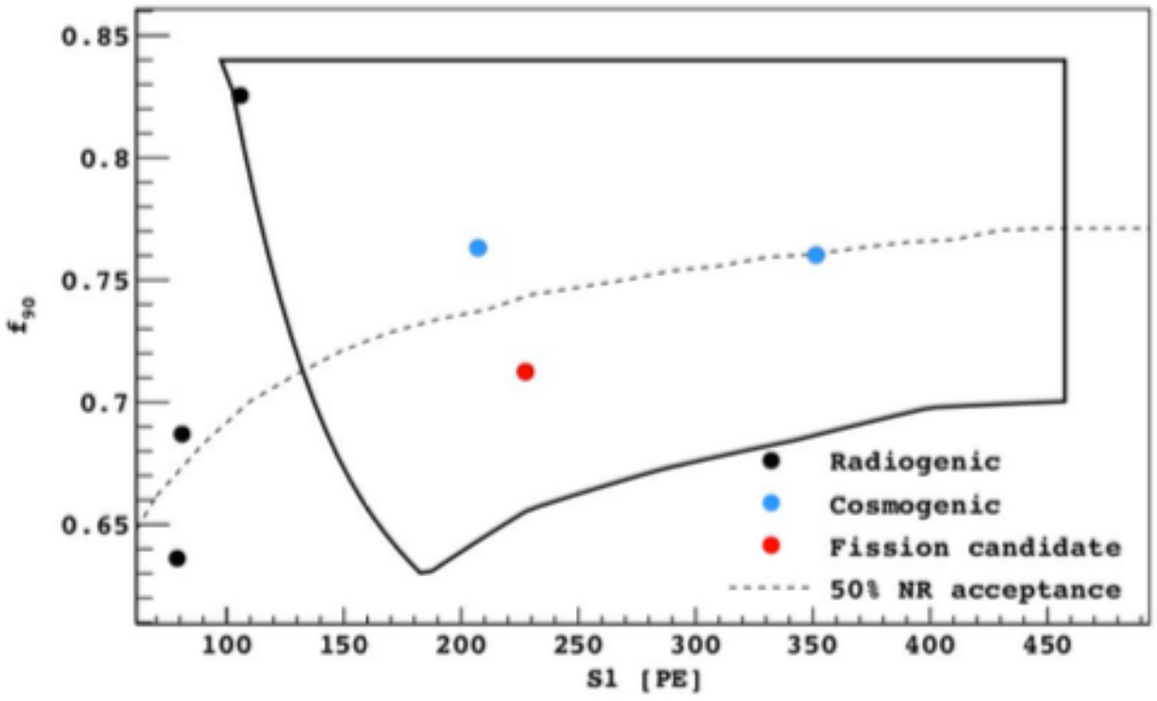
- DarkSide-50 at LNGS: LAr TPC technology proven competitive for a wide range of WIMP masses:
  - Physical Review D 98 (10), 1022006 (2018): background free analysis of high-mass WIMP search data;
    - best exclusion limit from a LAr experiment for WIMP-nucleon cross section > 1.1 x 10^{-44} cm^2 @ 100 GeV/c^2;
  - best sensitivity limit from a LAr experiment in the field of low mass WIMP search in the range of 1.8-6 GeV/c^2: Physical Review Letters 121 (8), 081307 (2018) and Physical Review Letters 121 (11), 111303 (2018);
- Ambitious dark matter search program with the ***Global Argon Dark Matter Collaboration*** (DarkSide-Proto, DarkSide-20k, …).


ENJOY THE DARK SIDE!

Backup

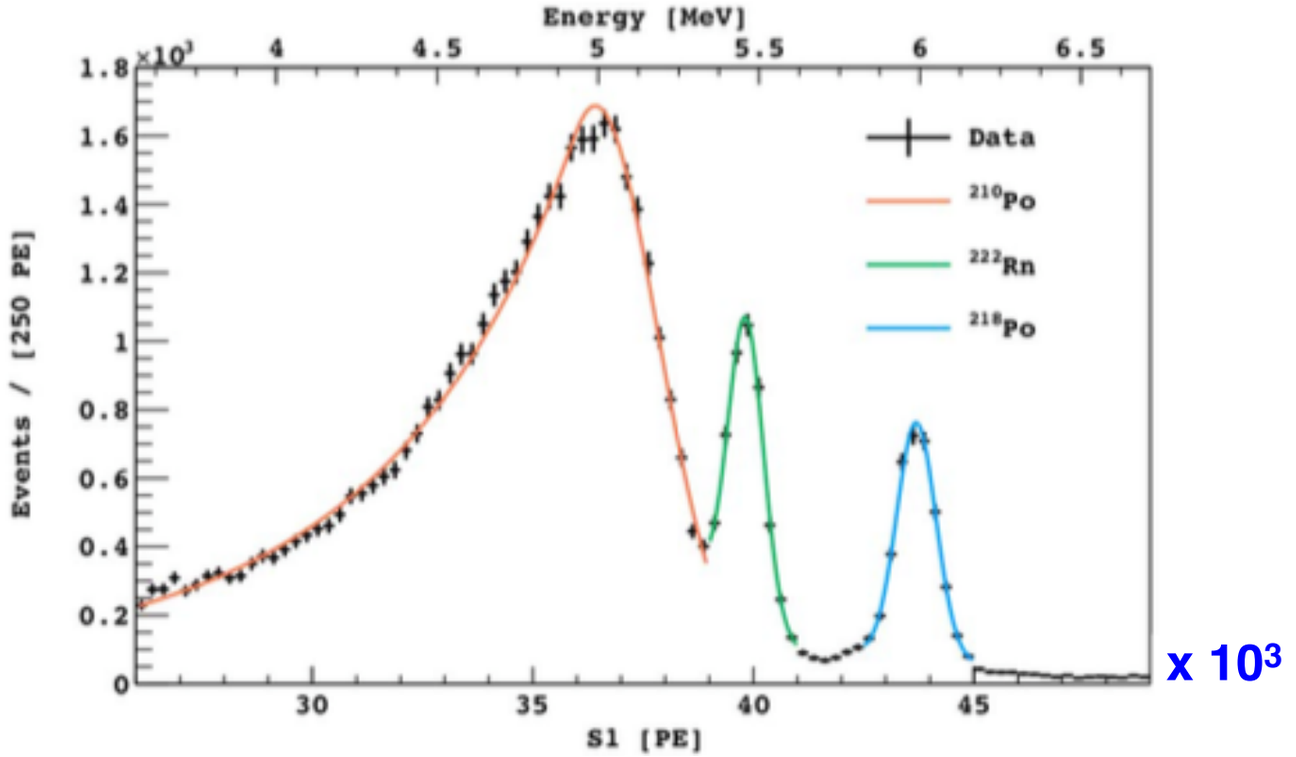
Blind analysis: background

Neutron background



- Radiogenic and cosmogenic;
- Rejection:
  - TPC multi scatter;
  - Liquid Scintillator Veto (LSV);
  - Water tank (cosmogenic).

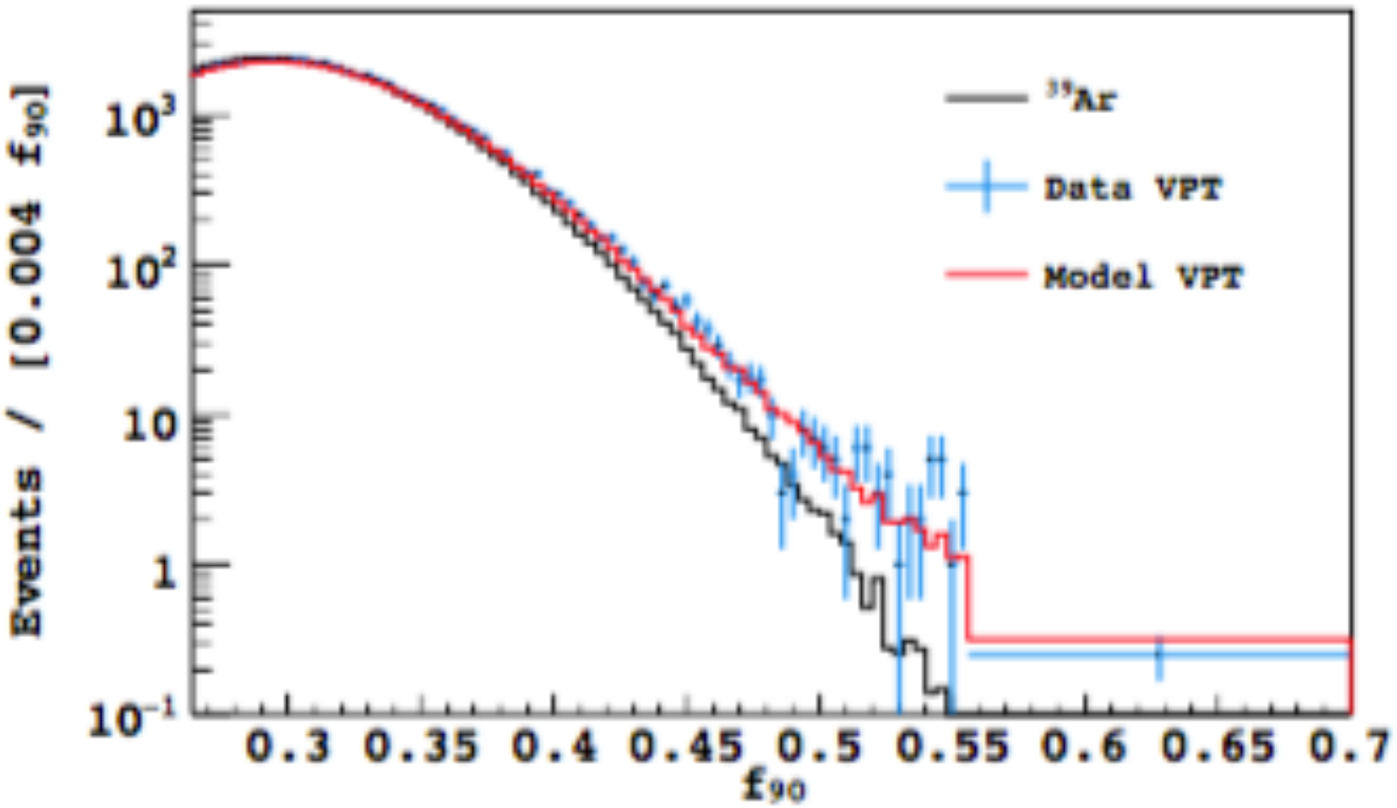
Alpha background



- $0.5 < f_{90} < 0.9$;
- Radon daughters: primarily ^{210}Pb-supported ^{210}Po decays:
  - α's degraded in energy (surface events);
  - TPB fluorescence (simultaneous α scintillation).

arXiv:1802.07198v2 (submitted to Phys. Rev. D)

Blind analysis: ER background

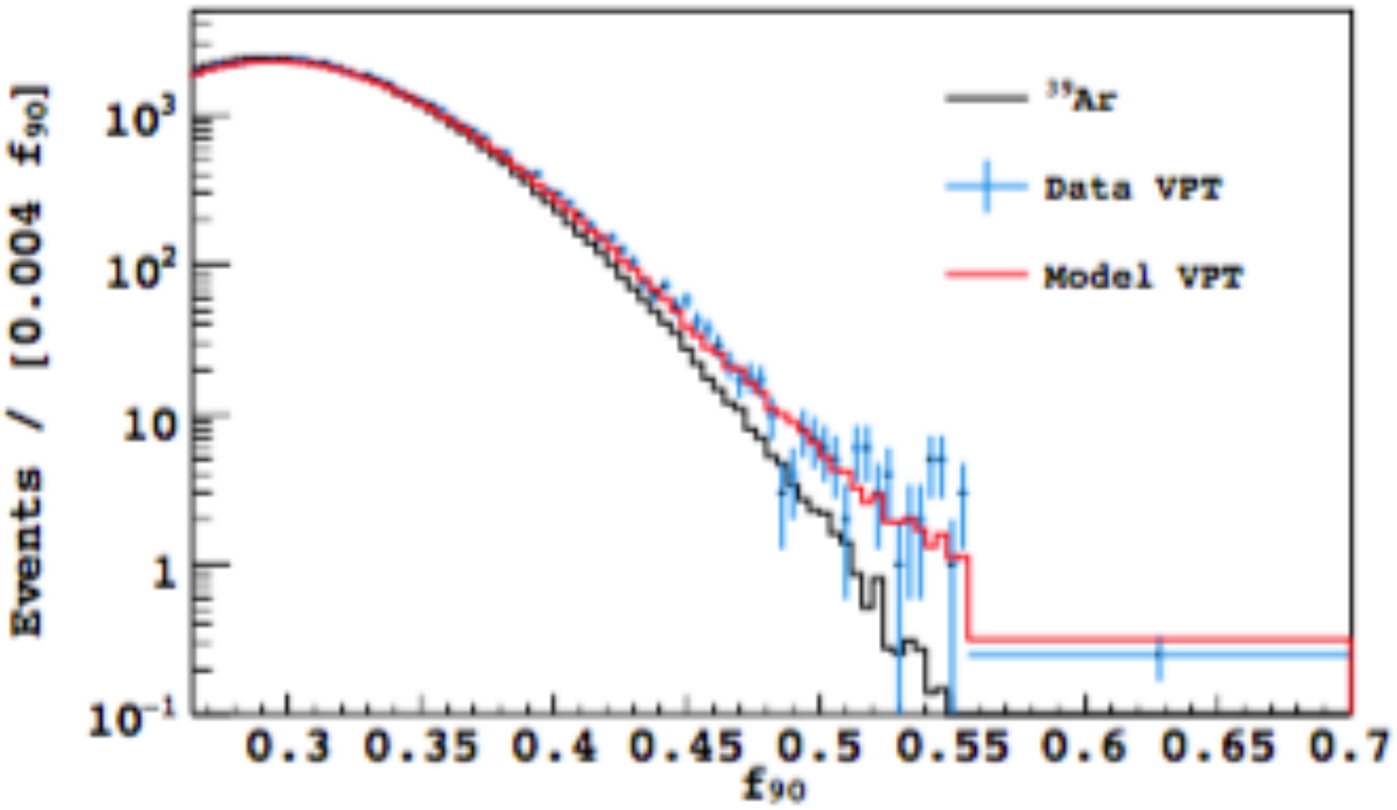


- Make a model using ^{39}Ar data and Čerenkov light in PTFE and Fused Silica windows (100 < S1 < 180 PE);

- check rate and shape with a background sample from ^{22}Na source.

arXiv:1802.07198v2 (submitted to Phys. Rev. D)

Blind analysis: ER background



- Make a model using ^{39}Ar data and Čerenkov light in PTFE and Fused Silica windows (100 < S1 < 180 PE);
- check rate and shape with a background sample from ^{22}Na source.

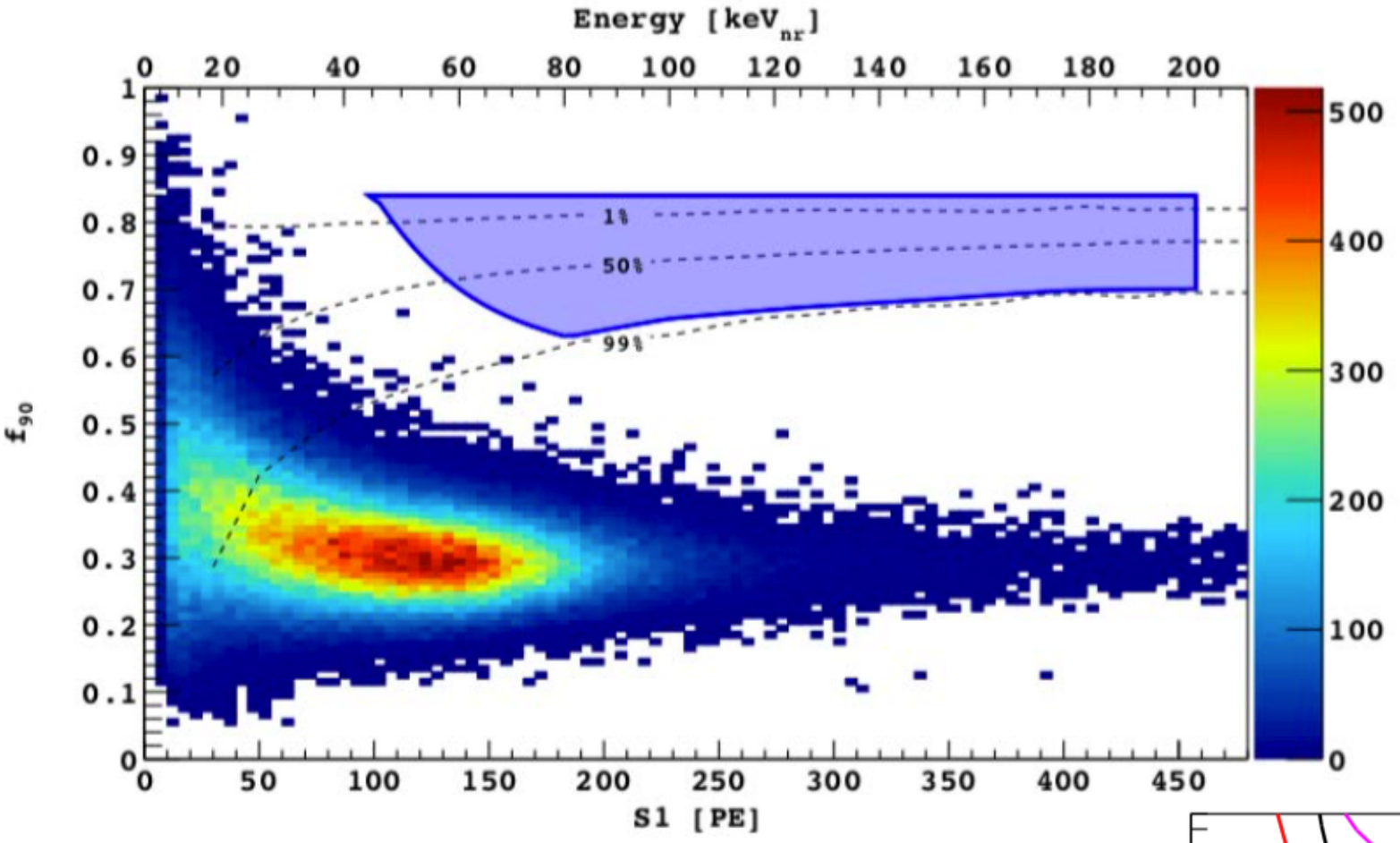
Background	Est. surviving all cuts
Cosmogenic neutrons	< 0.0003
Radiogenic neutrons	< 0.005
Surface alpha decays	0.001
Cherenk + Scint events	0.08*
TOTAL	**0.09 ± 0.04**

*Cuts designed to allow 0.08 Cherenkov + scintillation events

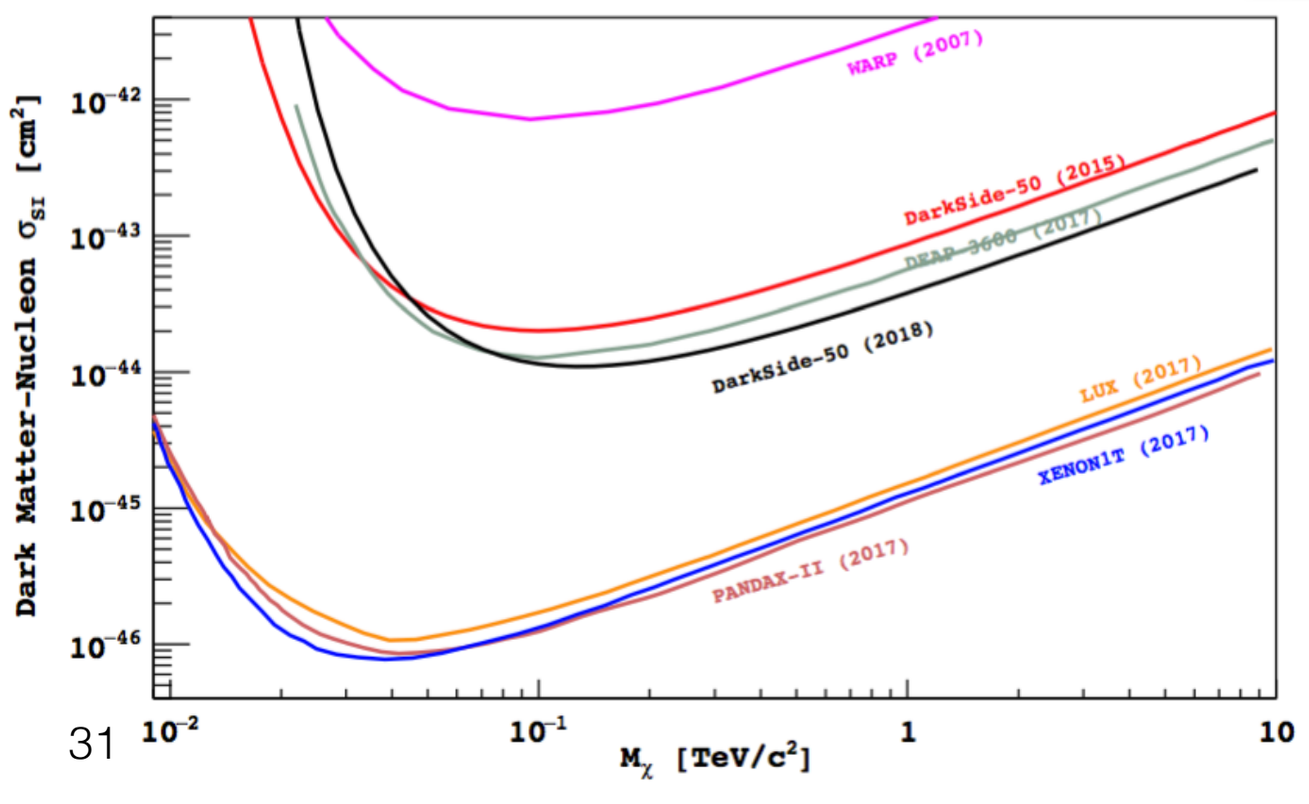
Goal of < 0.1 total background achieved, open the box!

arXiv:1802.07198v2 (submitted to Phys. Rev. D)

High mass WIMP search: results



Best exclusion limit from a LAr experiment for WIMP-nucleon cross section > 1.14 x 10^{-44} cm^2 (3.78 x 10^{-44} cm^2, 3.43 x 10^{-43} cm^2) @ 100 GeV/c^2 (1 TeV/c^2, 10 TeV/c^2).



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