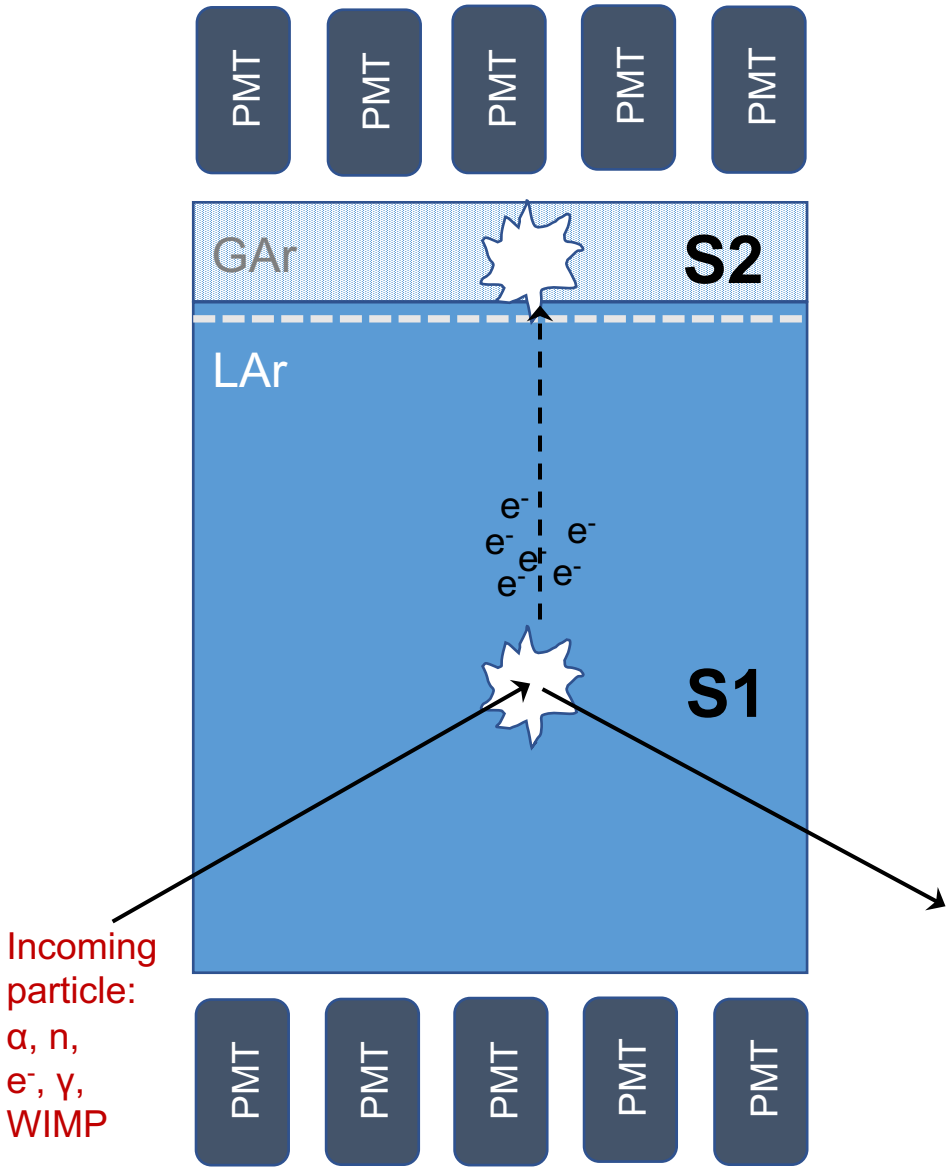
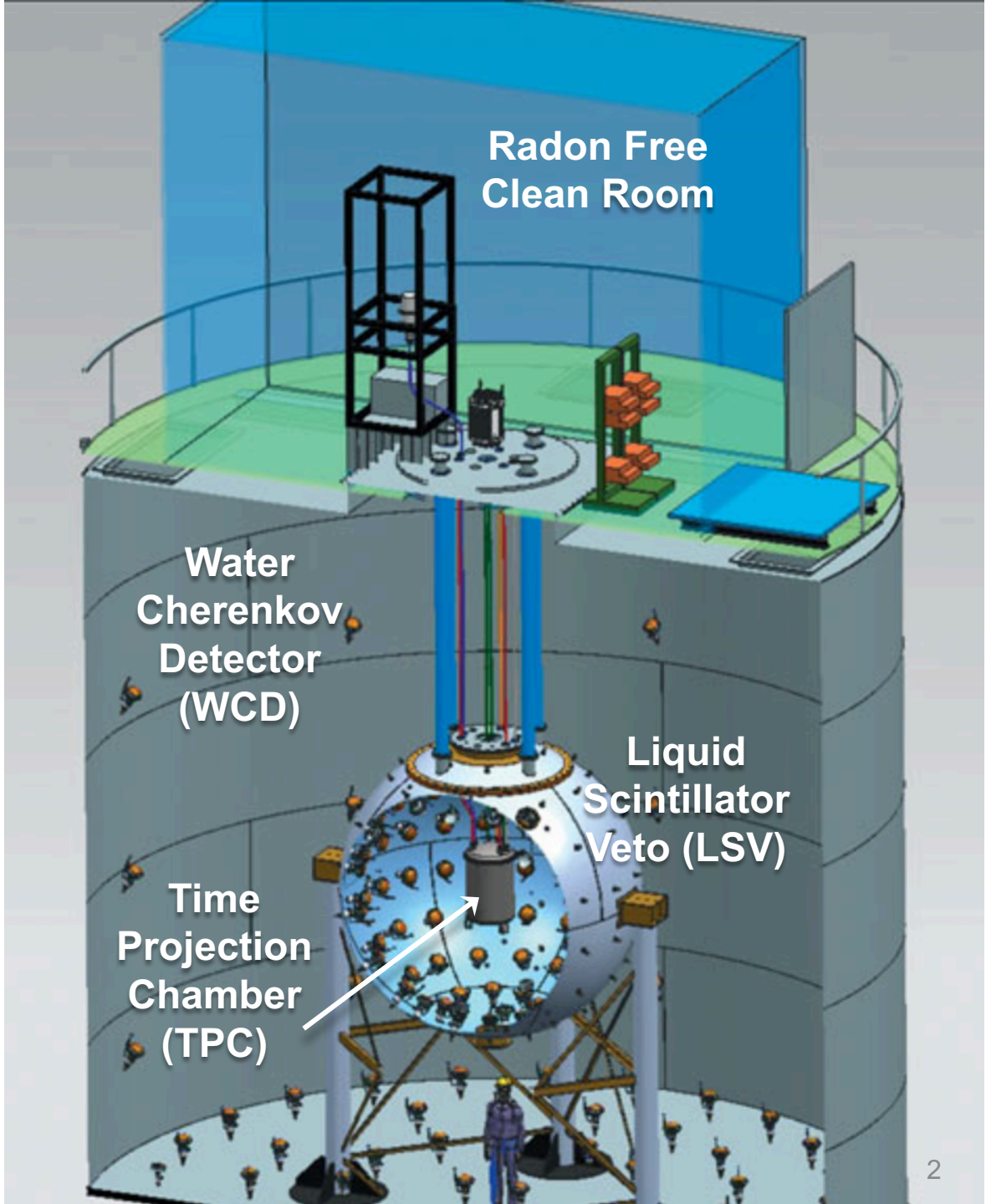
DarkSide in $\mathcal{O}(10)$ Minutes

Alissa Monte
UMass Amherst

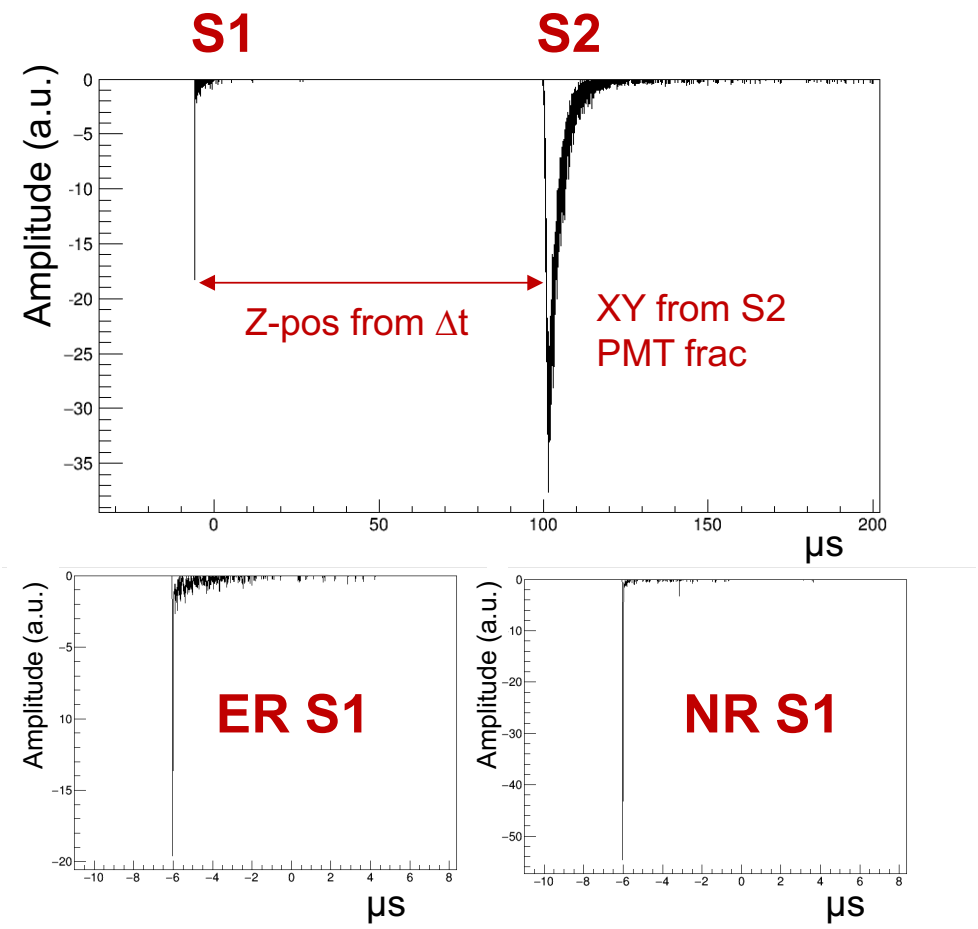
New Perspectives @ Fermilab
June 18th 2018

DarkSide-50

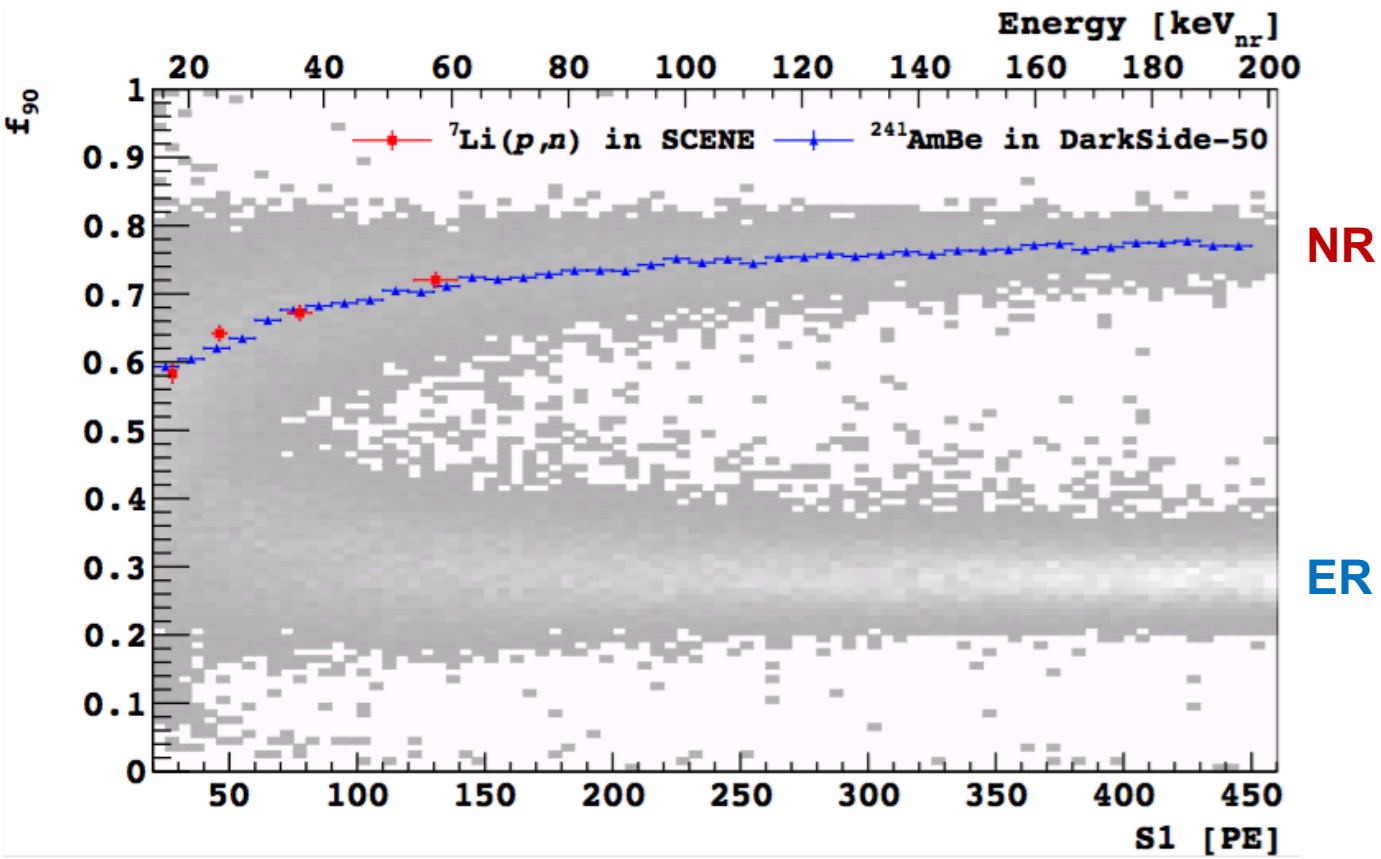

PMT
PMT
PMT
PMT
PMT
GAr
S2
LAr
e-
e-
e-
e-
e-
e-
S1
Incoming particle: α, n, e-, γ, WIMP
PMT
PMT
PMT
PMT
PMT


Radon Free Clean Room
Water Cherenkov Detector (WCD)
Liquid Scintillator Veto (LSV)
Time Projection Chamber (TPC)

DarkSide-50 Signals



^{241}AmBe calibration data



$$f_{90} = \frac{\text{S1 light in first 90ns}}{\text{total S1 light}}$$

discriminates between Electron and Nuclear Recoils (ER/NR)

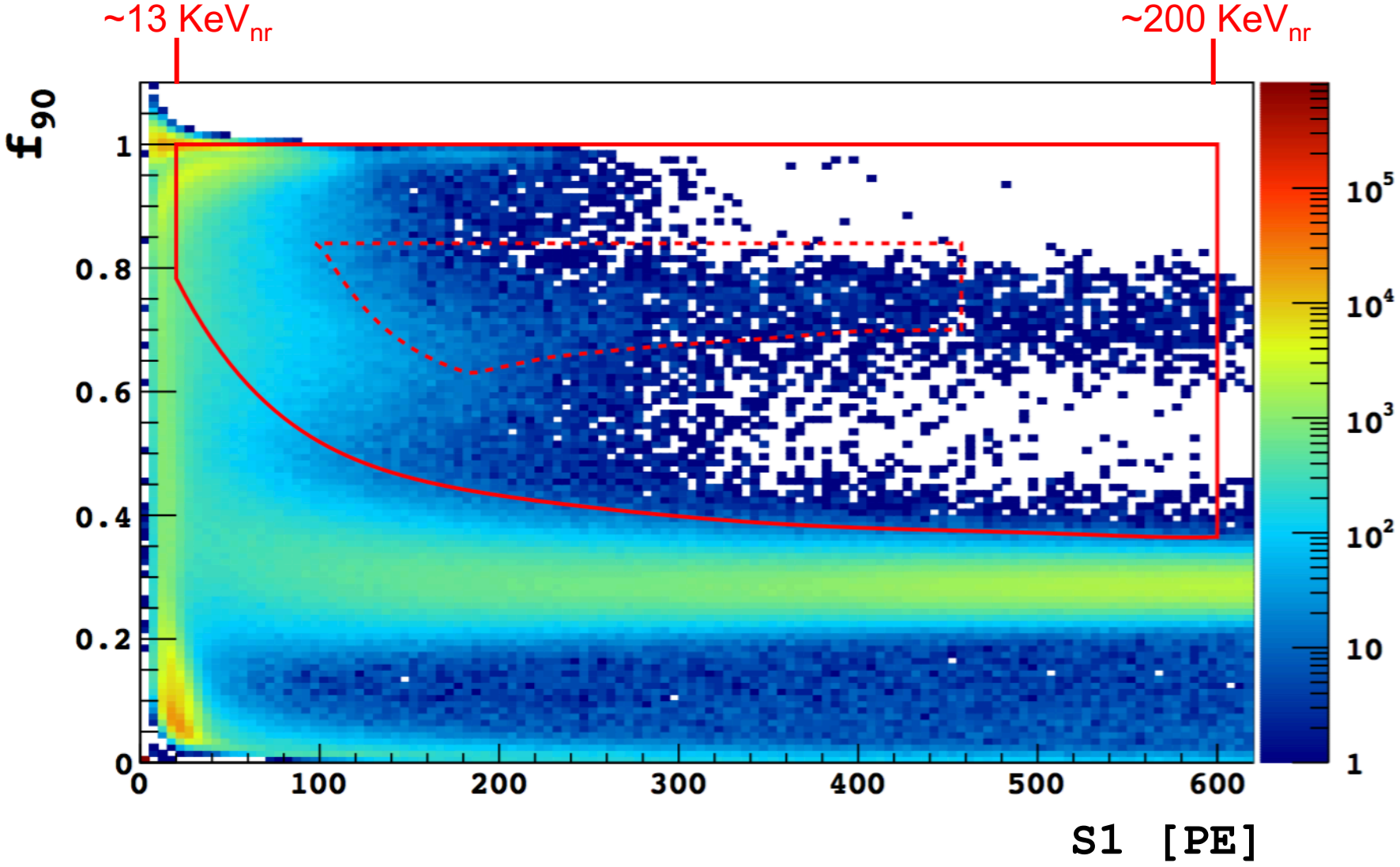
Recent Results

- High-mass analysis [arXiv:1802.07198]
- Low-mass analysis [arXiv:1802.06994, 1802.06998]

High-Mass Analysis

Blind analysis of 532 live-days of WIMP search data

- Blinding box (solid red line) shown with 70 live-days of data from previous publication: *Phys. Rev. D* ***93****, 081101 (2016)*
- Goal: design an analysis with < 0.1 events of background in the to-be-determined search box
- Ultimate WIMP search box given by the dashed red line



NRs: f90 ~ 0.7

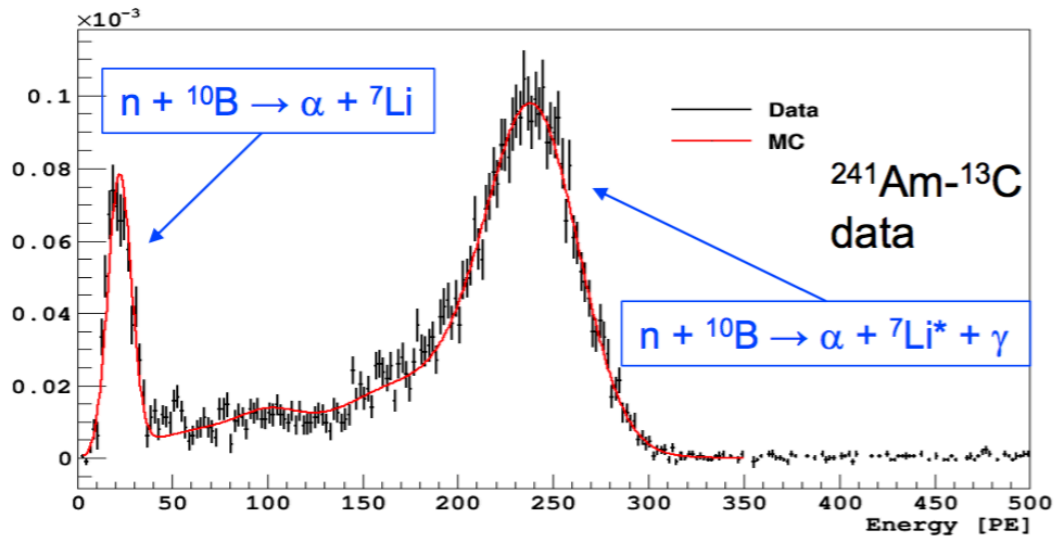
ERs: f90 ~ 0.3

Sources of background

- Neutrons
  - Radiogenic
  - Cosmogenic
- Alpha decays
  - Alphas with S2
  - S1-only + S2-only pileup backgrounds
- Beta and gamma rays
  - ^{39}Ar and ^{85}Kr
  - Cherenkov + scintillation events

Neutron rejection:

- TPC multi-scatter
- Liquid scintillator veto
  - Measured n efficiency for TPC single-NR with AmC: 0.9964 ± 0.0004
- Cosmogenic: water tank
- We can **count** neutrons in data



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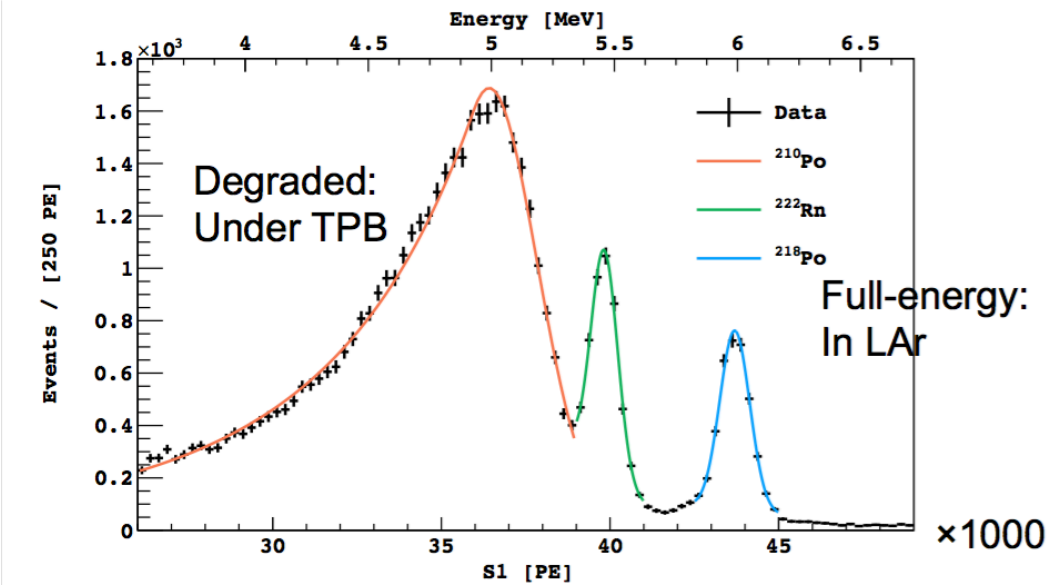
Surface alpha decays:

- WIMP search: S1 < 460 PE
- Self-vetoing in DarkSide-50!
  - Small or no S2
  - Long tail in S1 from TPB scintillation



Pileup backgrounds:

- Rejected by S2 shape, S2/S1, TBA vs tdrift

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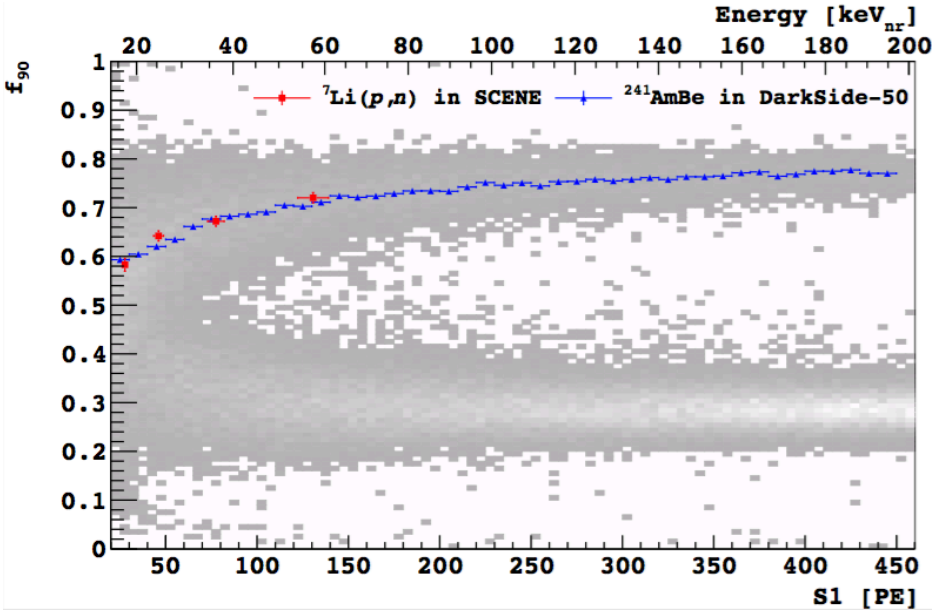
β-decays, γ-rays from bulk radioactivity

- ~1 Bq/kg ^{39}Ar in atmospheric argon (AAr)
- (0.73 ± 0.11) mBq/kg ^{39}Ar and (2.05 ± 0.13) mBq/kg ^{85}Kr in underground argon (UAr)
- PSD via f90 provides 1 in 1.5 × 10^7 discrimination against single-sited ERs



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Cherenkov + scintillation (C+S) events

- Dominant background in this analysis
- C+S: γ-ray multiple Compton-scatters in LAr and a Cherenkov radiator
- Cherenkov f90 ~ 1 + ER f90 ~ 0.3 = NR-like f90 ~ 0.6
- Fused silica Cherenkov rejected by fraction of light in a single PMT
- Teflon Cherenkov more difficult:
  - Restrict f90 signal region
  - Radial fiducialization

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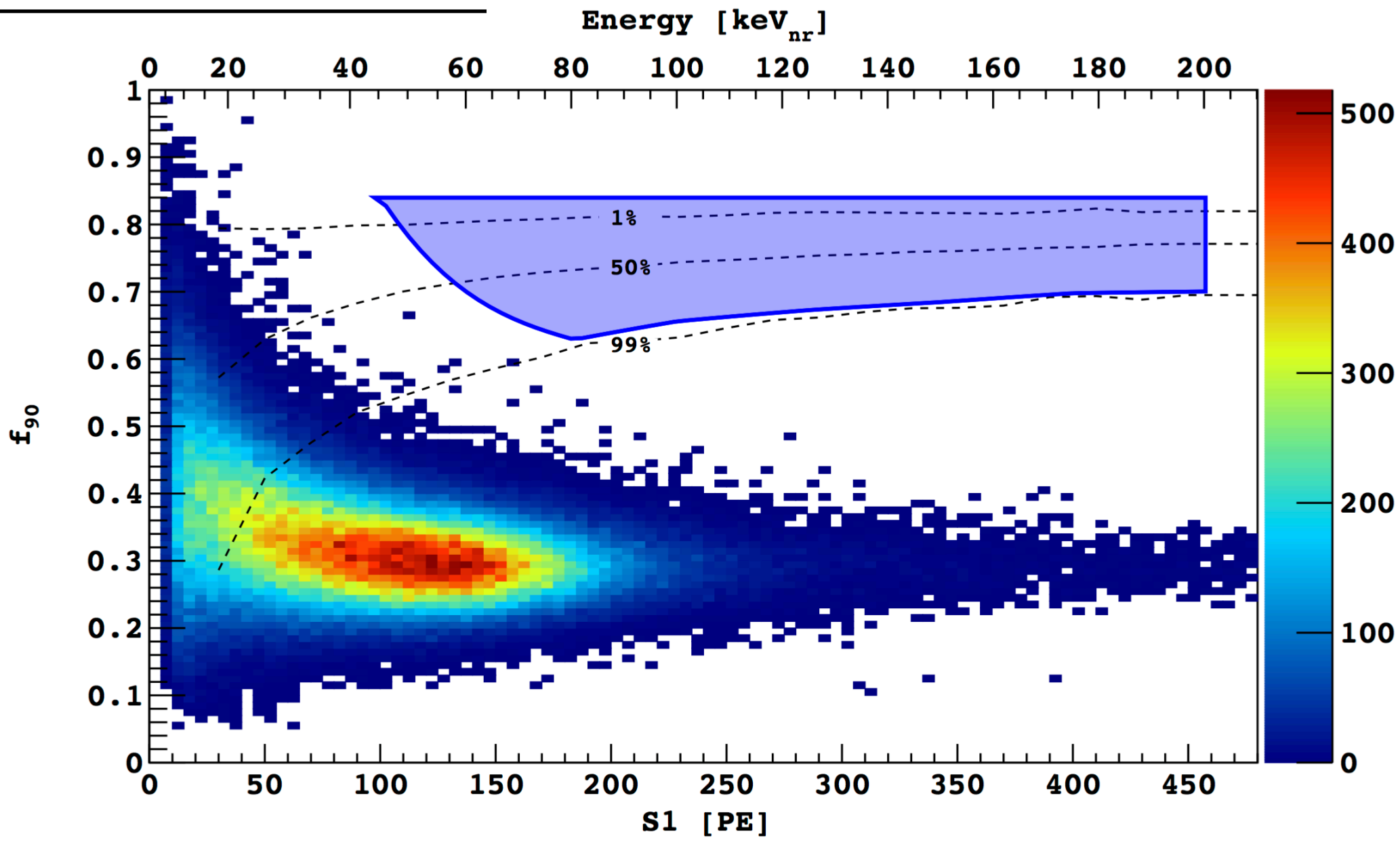
Background	Est. surviving all cuts
Cosmogenic neutrons	< 0.0003
Radiogenic neutrons	< 0.005
Surface alpha decays	0.001
Cherenk + Scint events	0.08*
TOTAL	**0.09 ± 0.04**

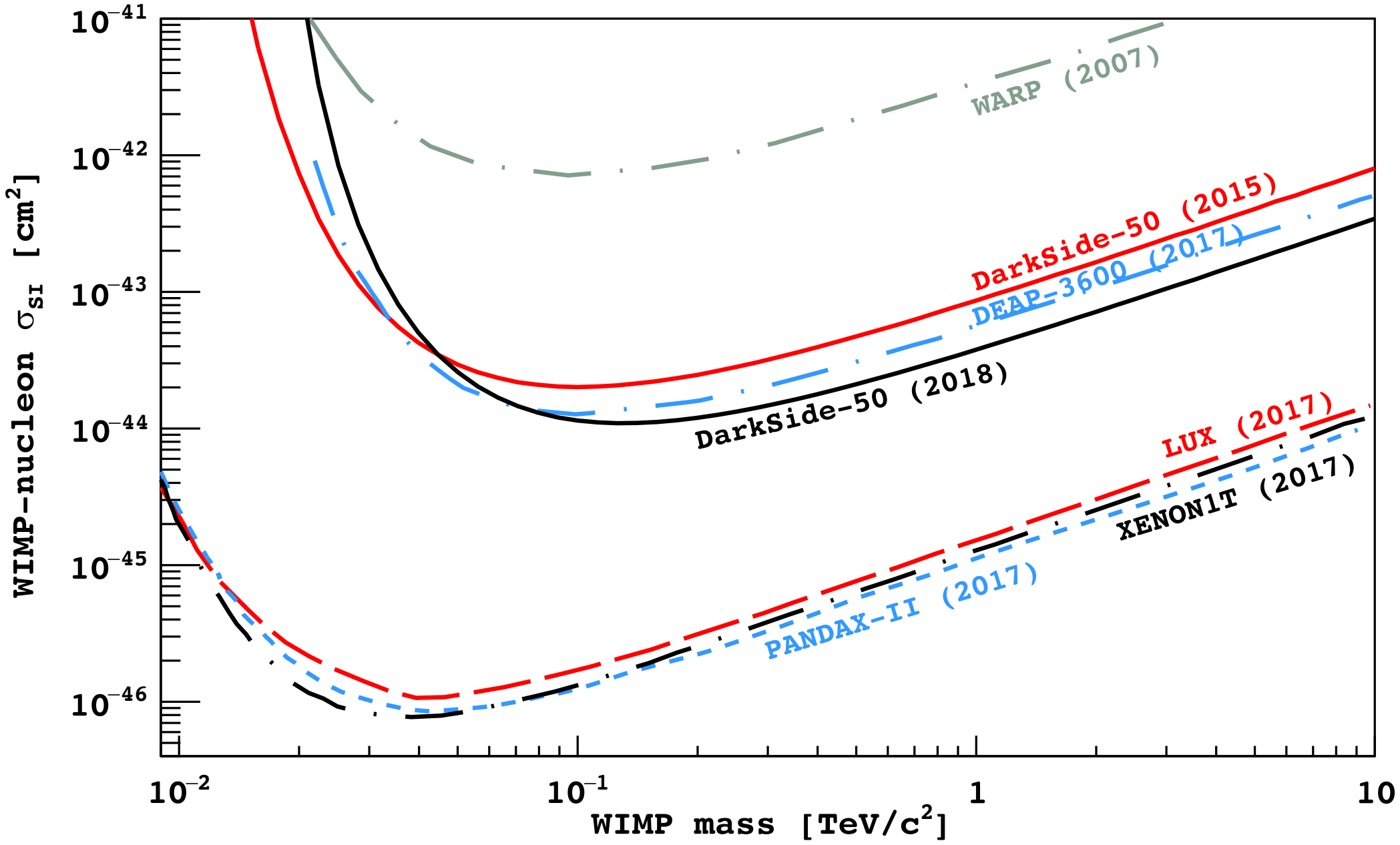
*Cuts designed to allow 0.08 Cherenkov + scintillation events

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

After all analysis cuts are applied



arXiv:1802.07198



Low-Mass Analysis

Ionization-only analyses

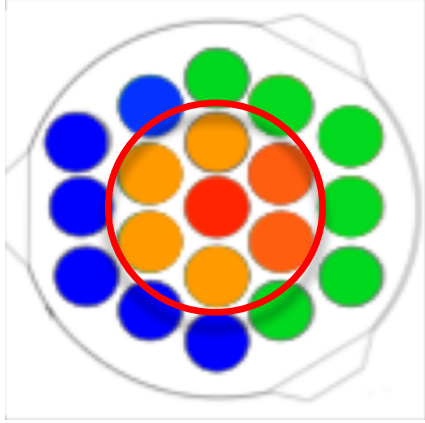
- WIMP-nucleon interactions → nuclear recoil [arXiv:1802.06994]
- WIMP-electron interactions → electron recoil [arXiv:1802.06998]

- Scintillation signal (S1) threshold at ~2 keV_{ee} / 6 keV_{nr}, little sensitivity to low-mass WIMPs

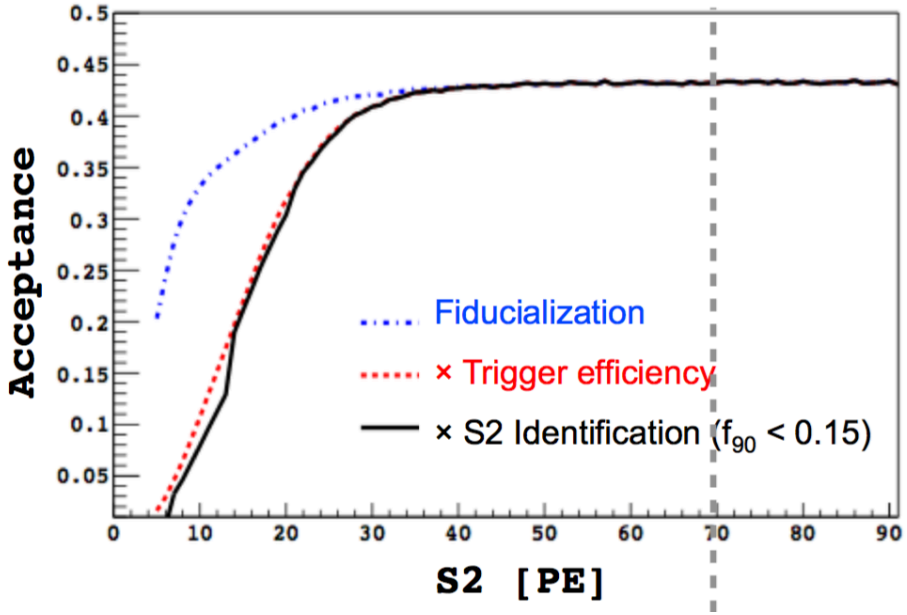
- Gain on ionization signal (S2) allows us to easily detect single ionization electrons, threshold < 0.1 keV_{ee} / 0.4 keV_{nr}, sensitive to low-mass WIMPs!

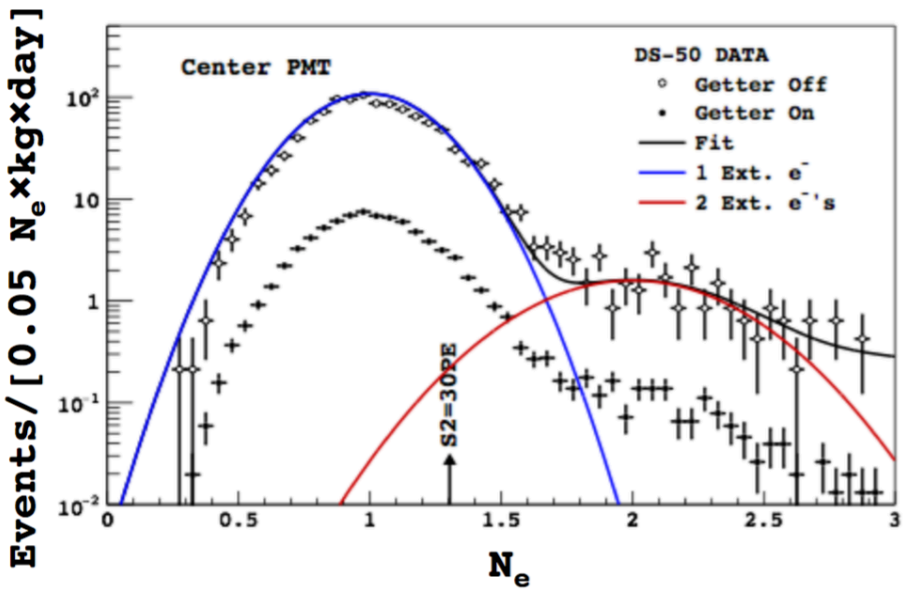
Use S2 signal only; gain in threshold but give up PSD, vertical position, vetoes, S2/S1…

Ionization-only analysis efficiencies



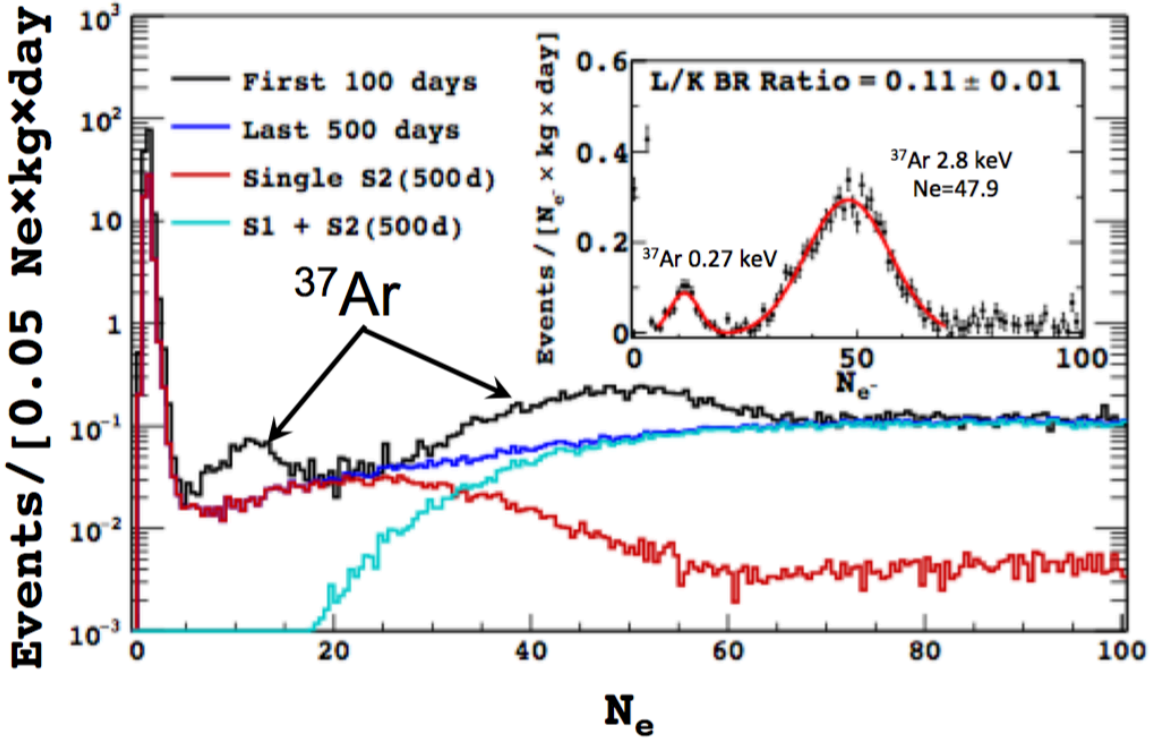
- One ionization electron (N_e = 1) under the central PMT produces S2 = (23 ± 1) PE
- Trigger efficiency and pulse finding efficiency are 100% for S2 > 30 PE
- Fiducialization: select events with majority of light in inner PMTs

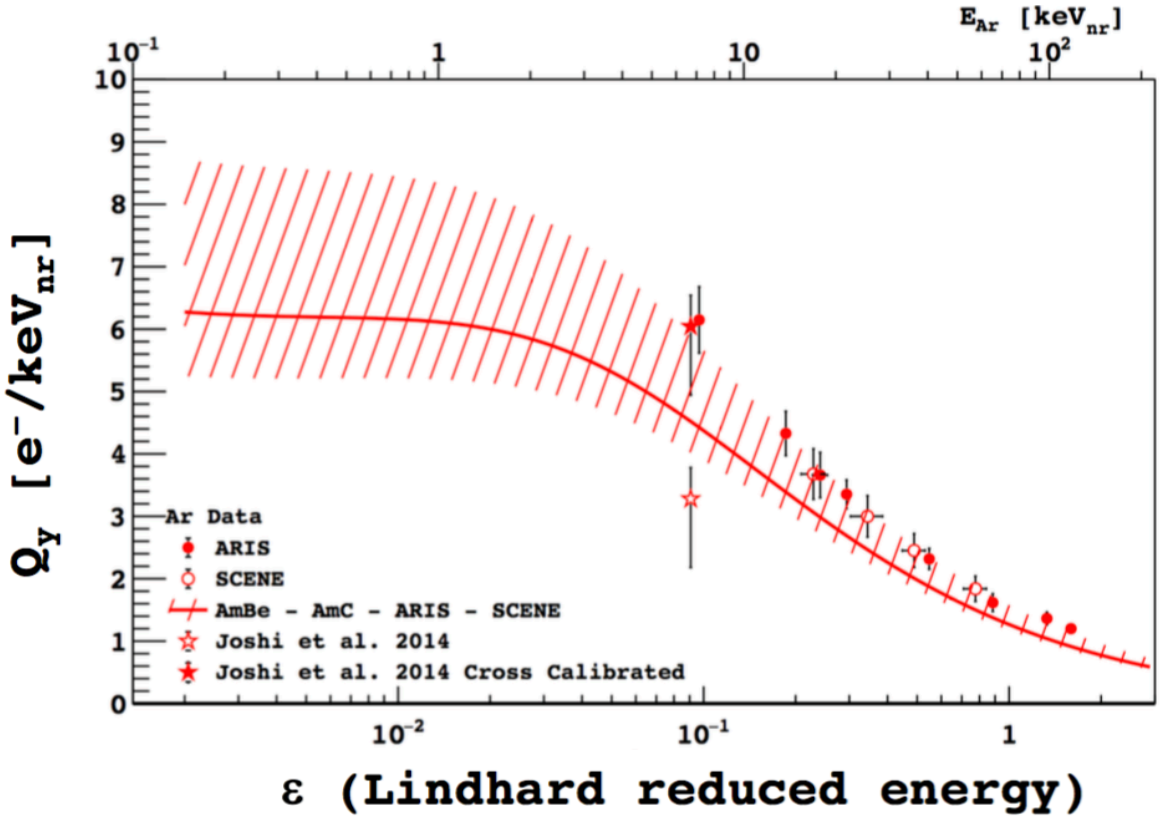




N_e = 4 analysis threshold

Energy calibration for ER/NR

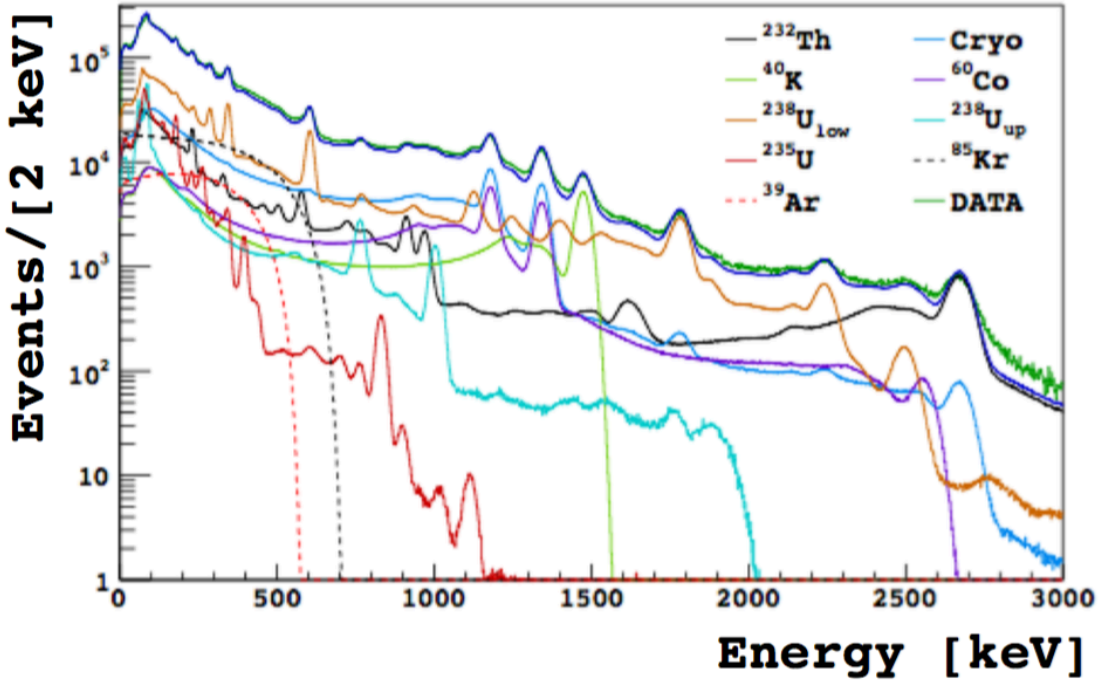


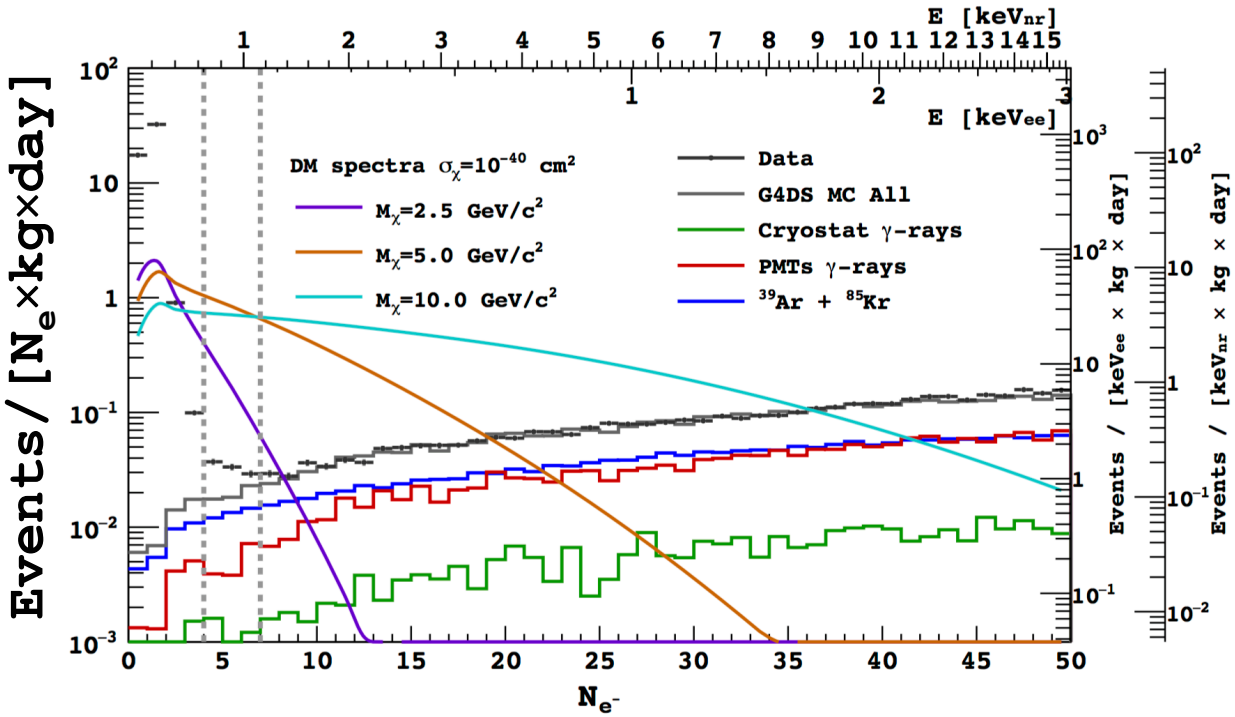


- Excellent low-energy ER calibration point from ^{37}Ar
- From cosmogenic activation ($t_{1/2}$ = 37 days)

- NR ionization yield extracted from MC fits to DS-50 AmBe/AmC data
- Uncertainty informed by many inputs

Background estimates and WIMP Search



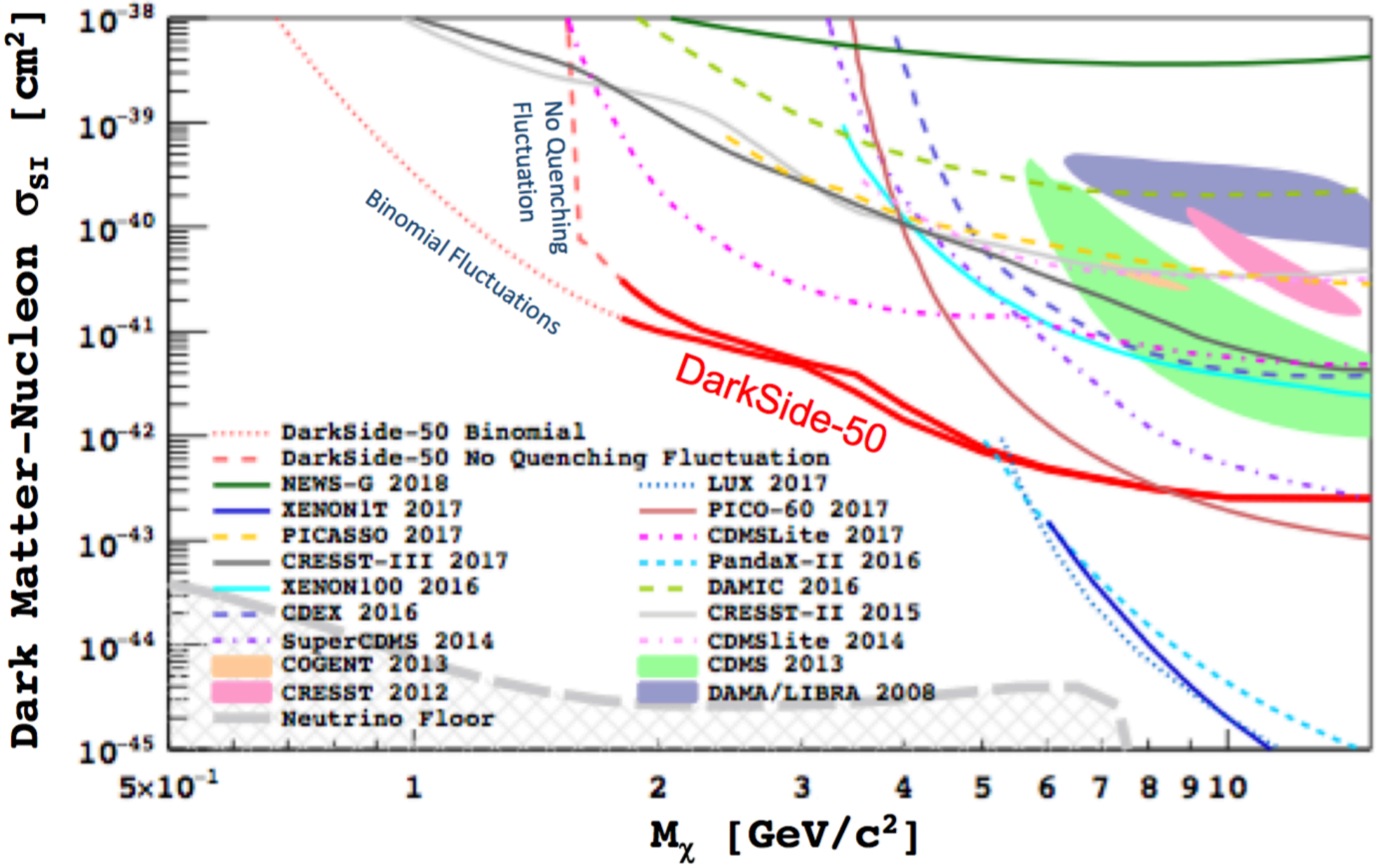


- Detector activities from the same analysis used for the high-mass WIMP search
- Extrapolated to low energies

- DM spectra plotted w/o quenching fluctuations
- Analysis threshold at $N_e > 4$
- Excess below $N_e \sim 4$ due to trapped electrons

Ionization-only search is made possible by low-radioactivity UAr purified at FNAL

90% CL upper limits on WIMP-nucleon cross section



Summary

- **Background free** blind analysis of high-mass WIMP search data [arXiv:1802.07198]
    - Exclusion limit for WIMP-nucleon cross section > 1.1 x 10^{-44} @ 100 GeV/c^2
    - Leading limit from an argon experiment

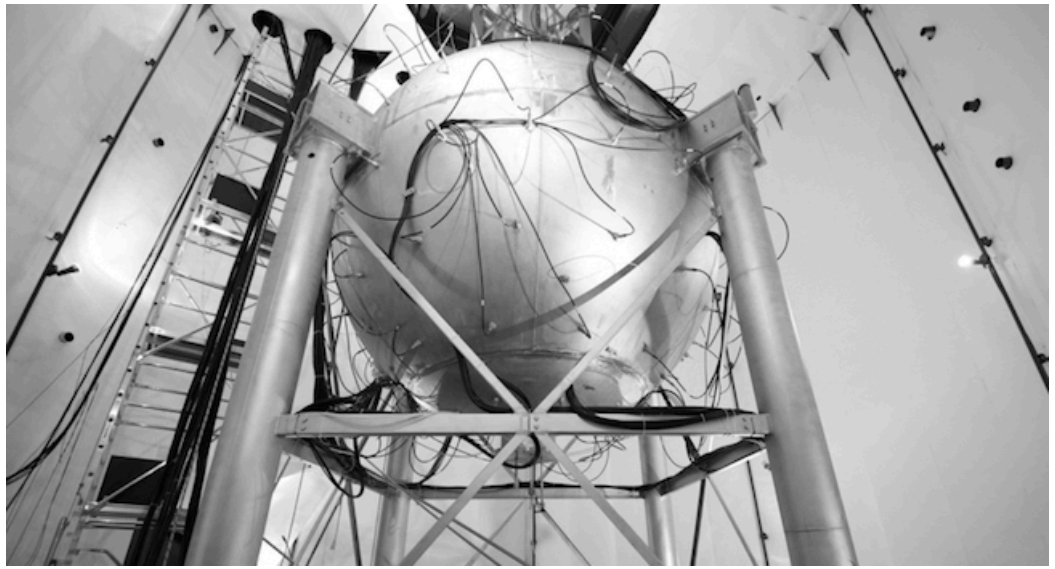
- **Low threshold using ionization signal**
    - Made possible by low background from UAr (FNAL critical in producing)
    - WIMP-nucleon interactions [arXiv:1802.06994]
    - WIMP-electron interactions [arXiv:1802.06998]
    - Leading limit in the field for WIMP-nucleon interactions in the 1.8-6 GeV/c^2 mass range

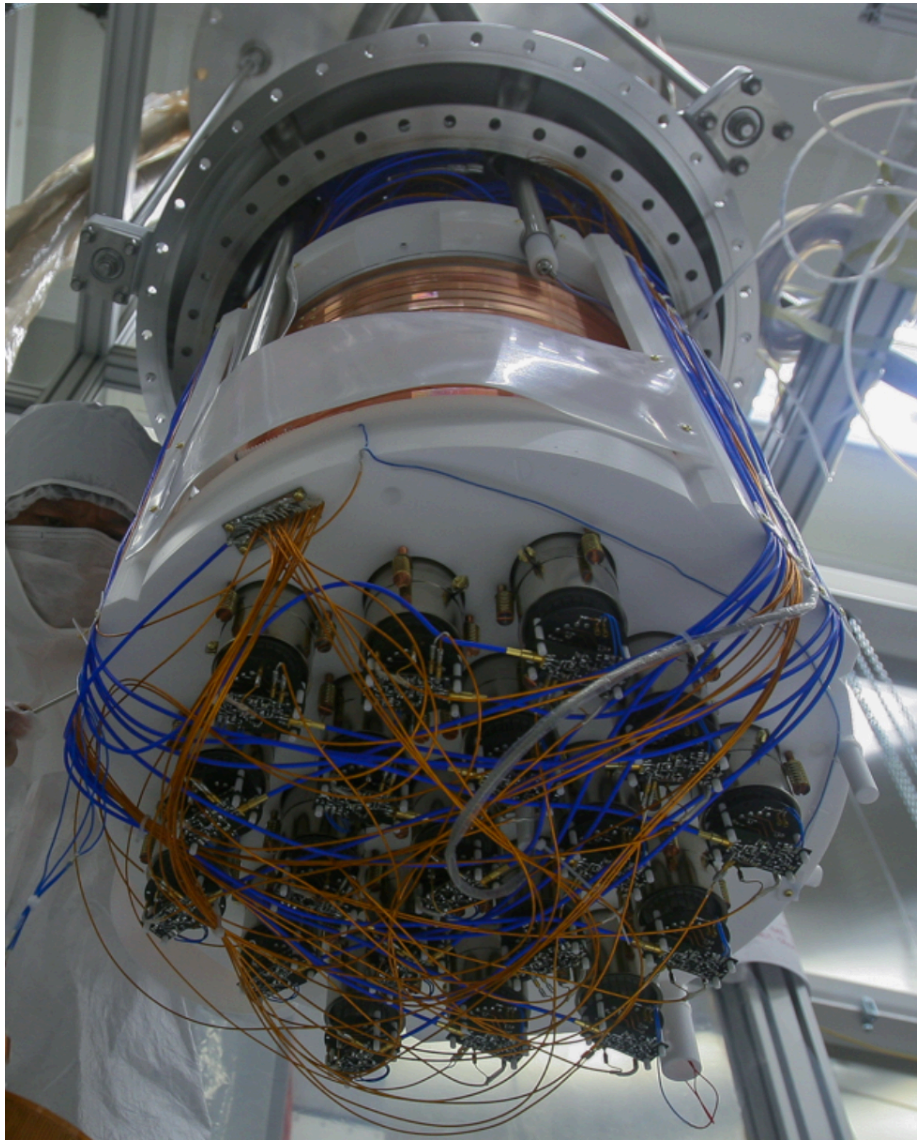
- DarkSide-50 has shown the potential of the liquid argon technology

<u>The future is bright for DarkSide-20k!</u>

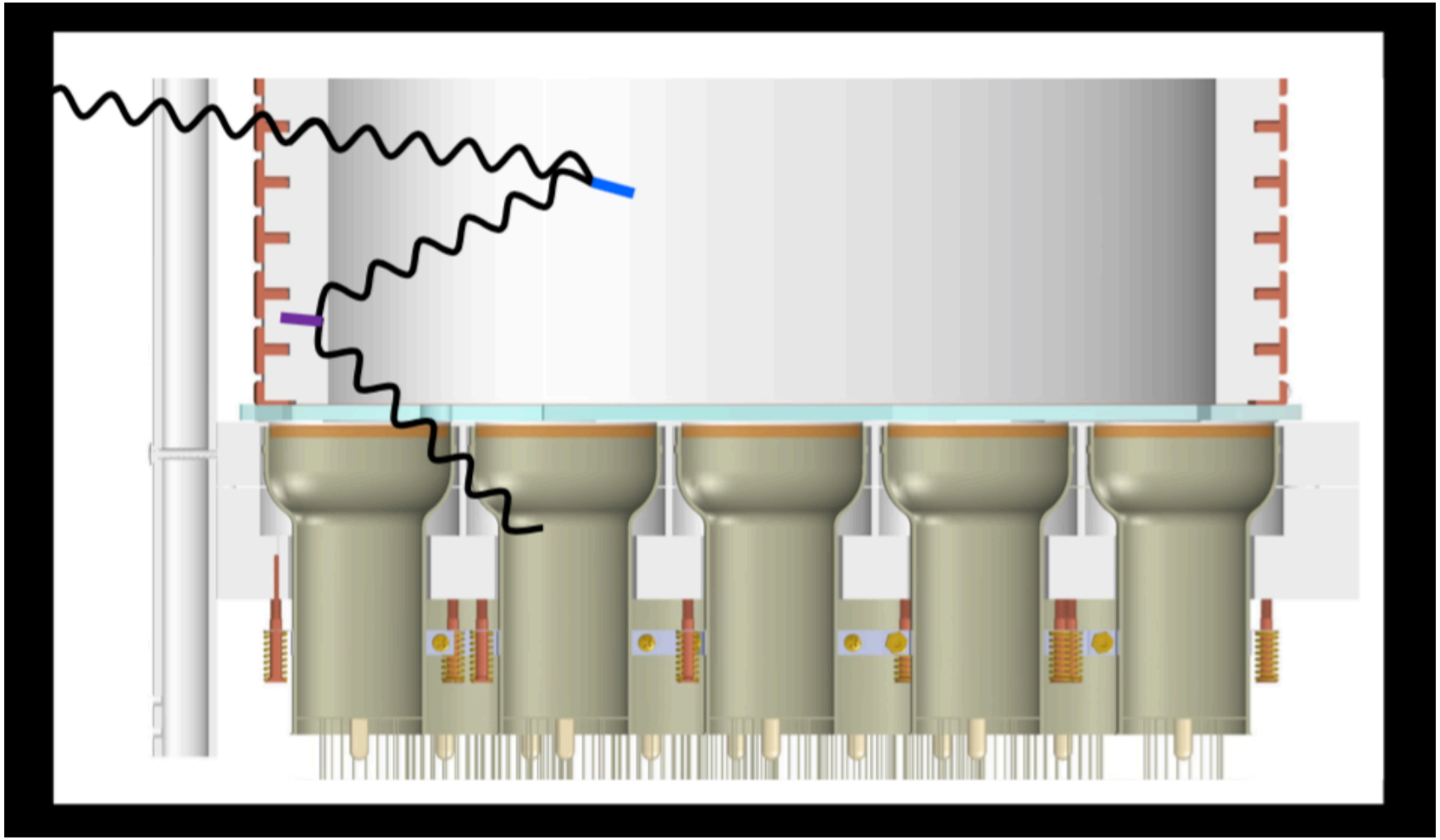
Backups

DarkSide-50





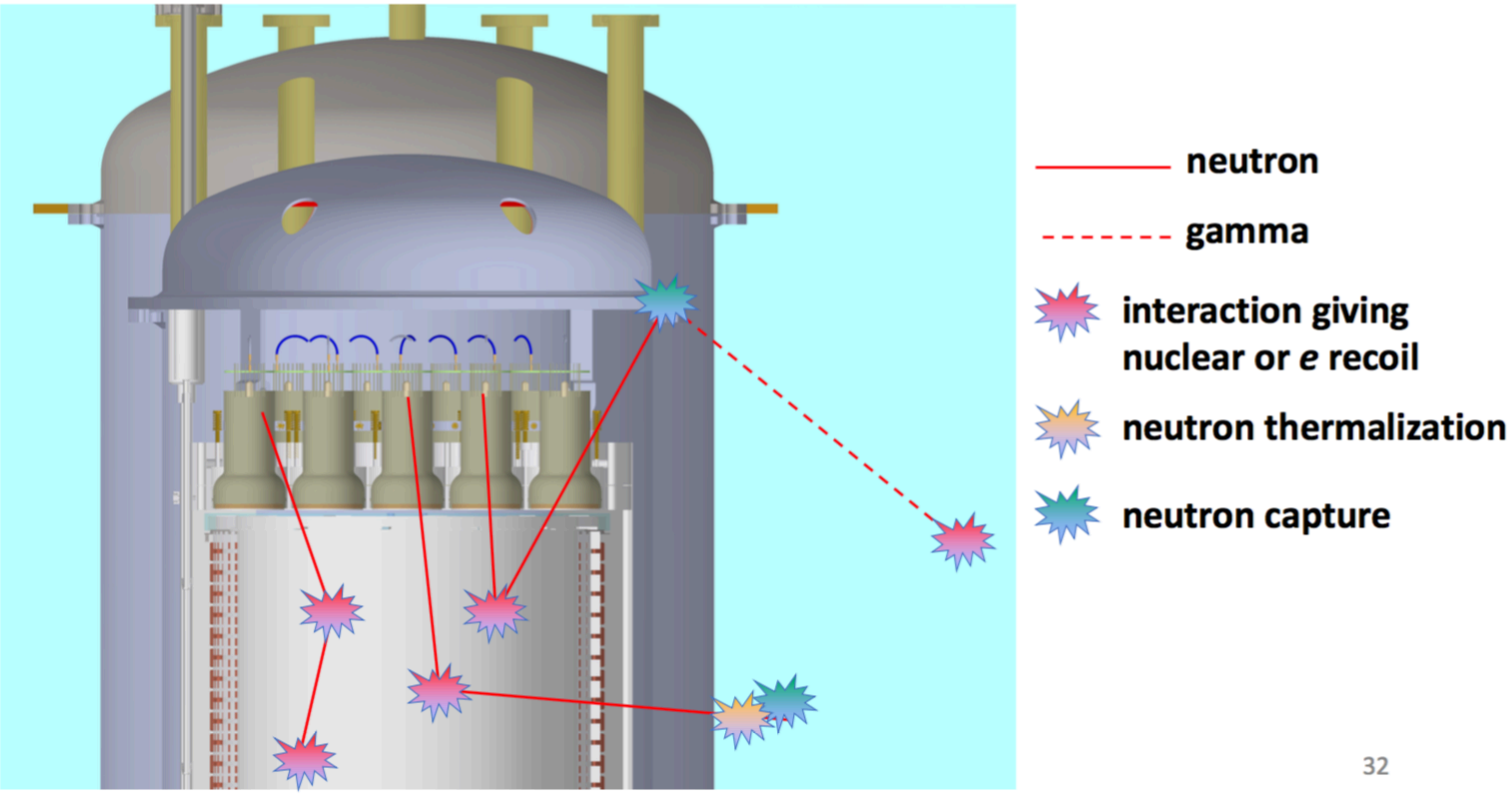
Cherenkov + Scintillation



Neutron Rejection

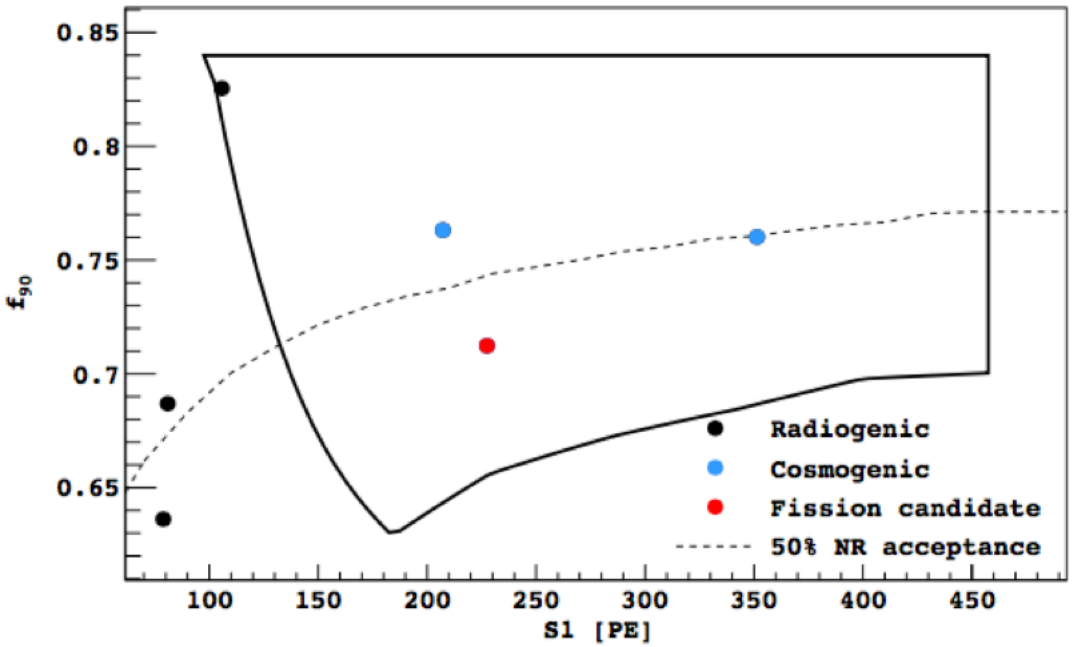
Borated-liquid-scintillator neutron veto

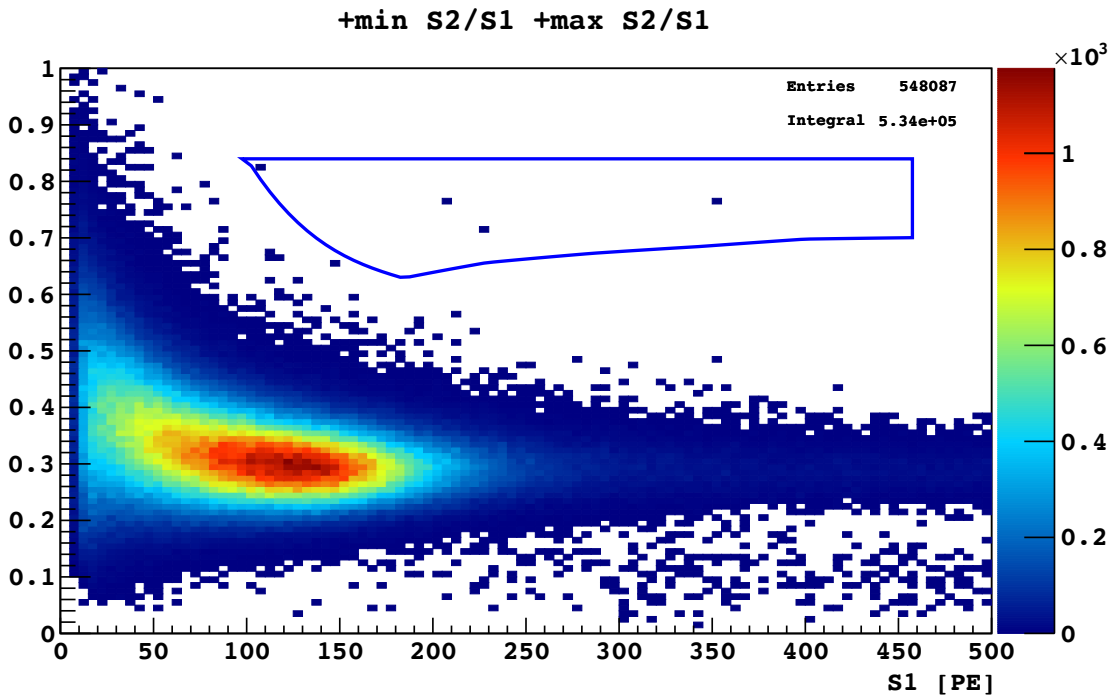
- (α,n) from PMT U and Th are the dominant neutron source.
- Separately detect both thermalization and capture signals from neutron.
- Rejection **measured** with AmC neutrons giving WIMP-like TPC signature.
- Rejection for radiogenic neutrons **~500**.
- Also effective for cosmogenic neutrons.



32

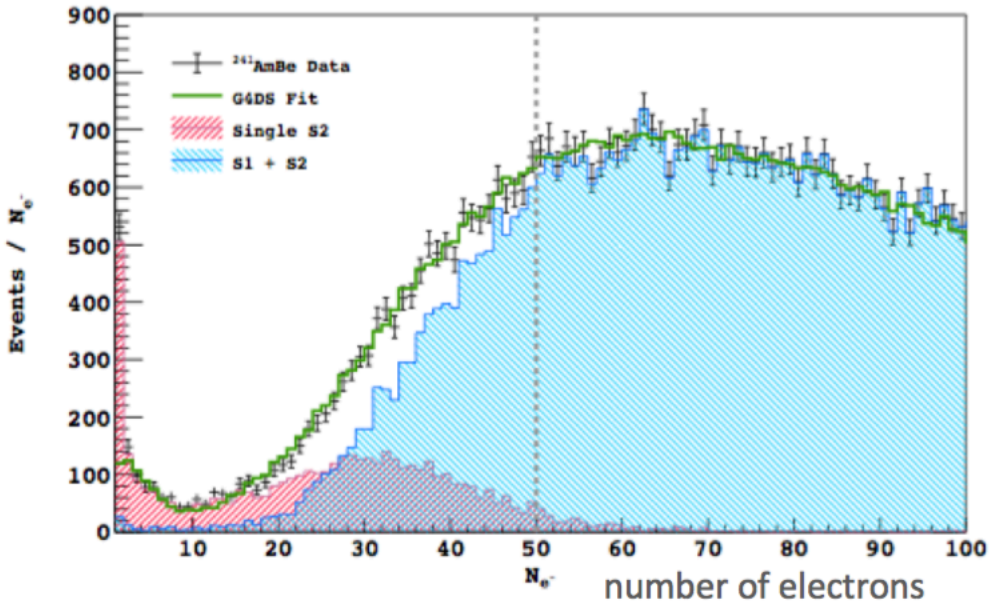
Tagged neutrons



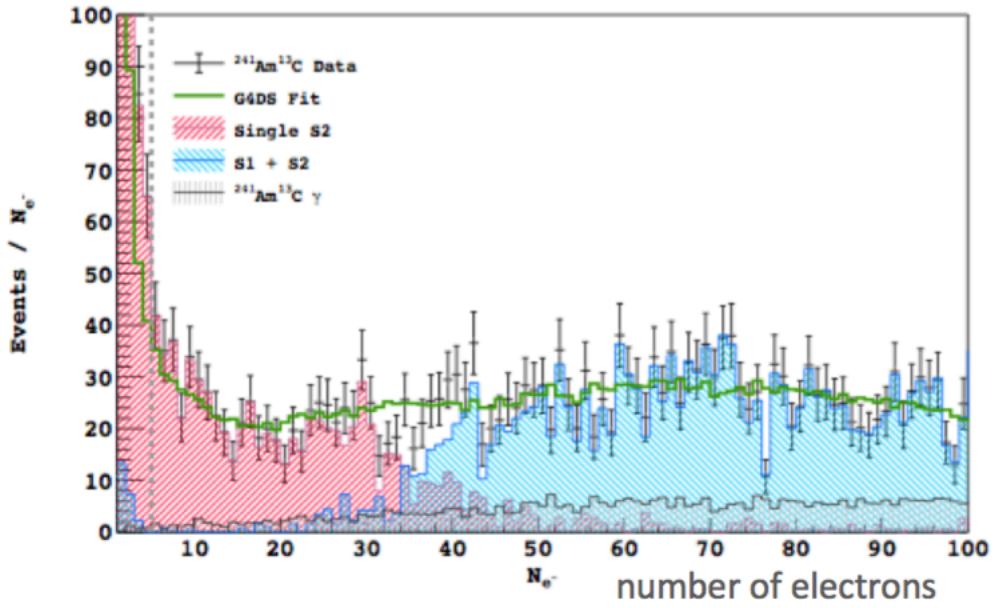


MC ionization/recombination model fit to AmC/AmBe

AmBe neutron source



AmC neutron source

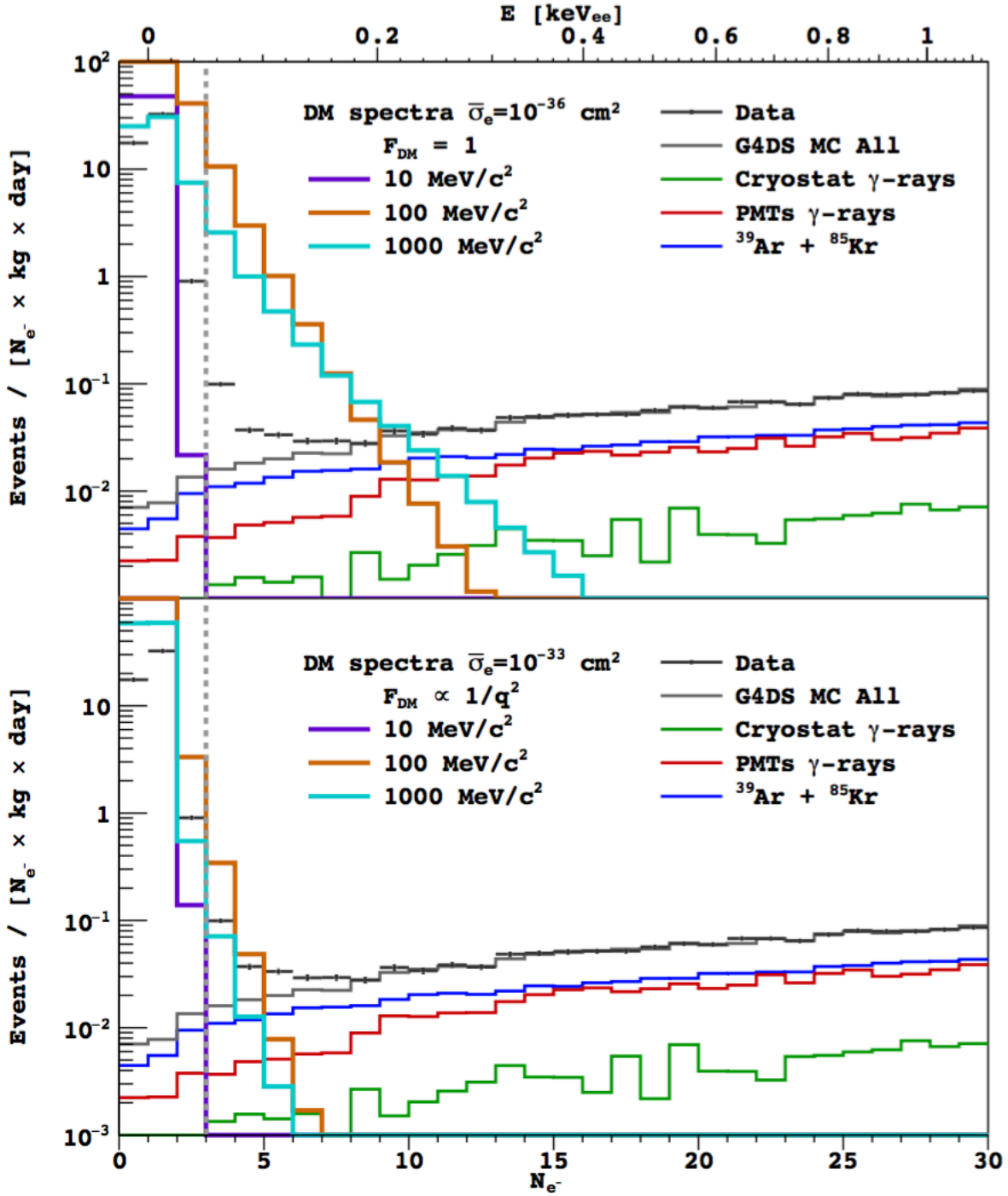


WIMP-electron scattering

$F_{DM}(q^2) = 1$: "heavy mediator"

Analysis is unchanged, only energy scale changes.

$F_{DM}(q^2) \propto 1/q^2$: "light mediator"



90% CL upper limits on WIMP-electron cross section

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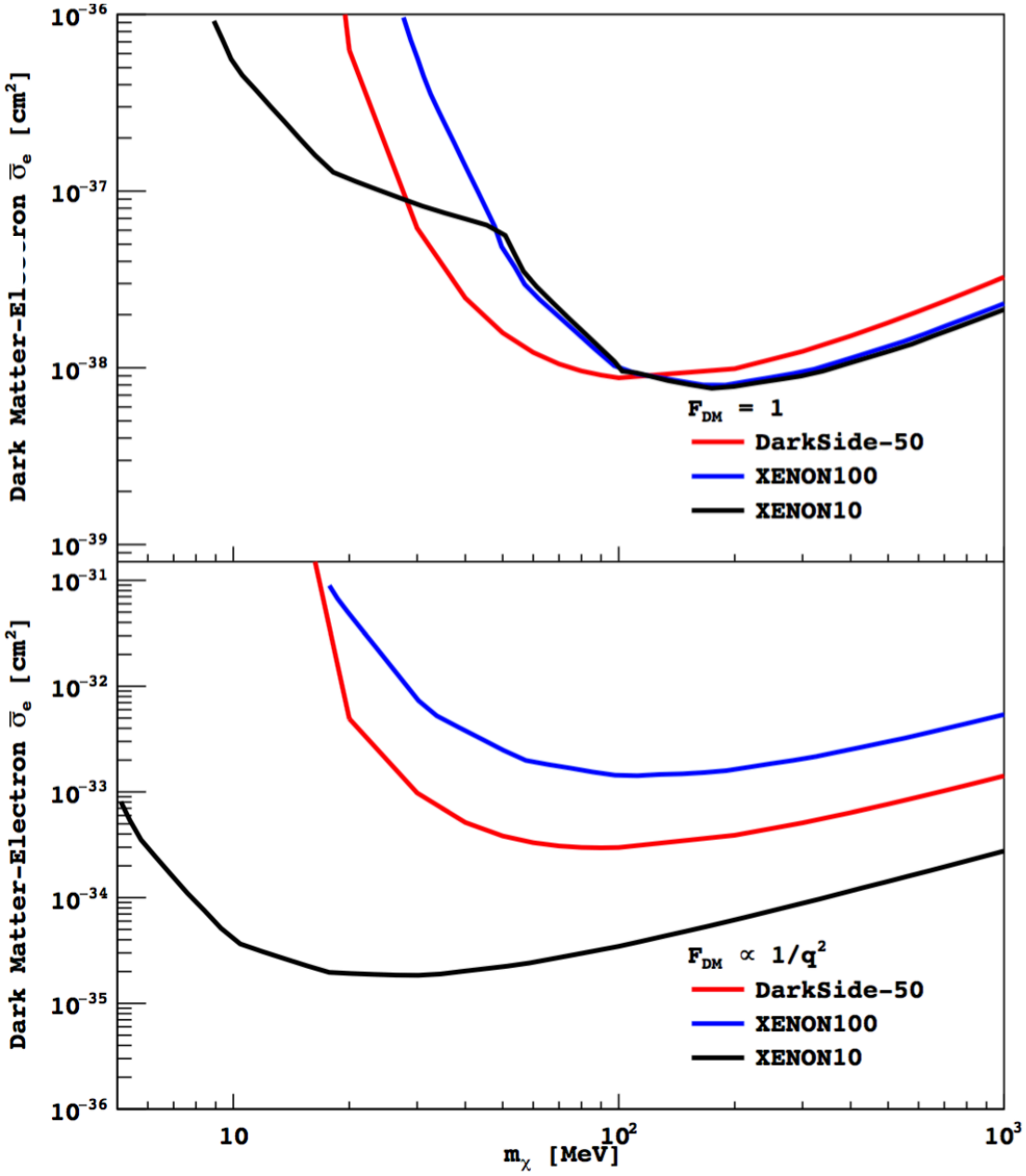
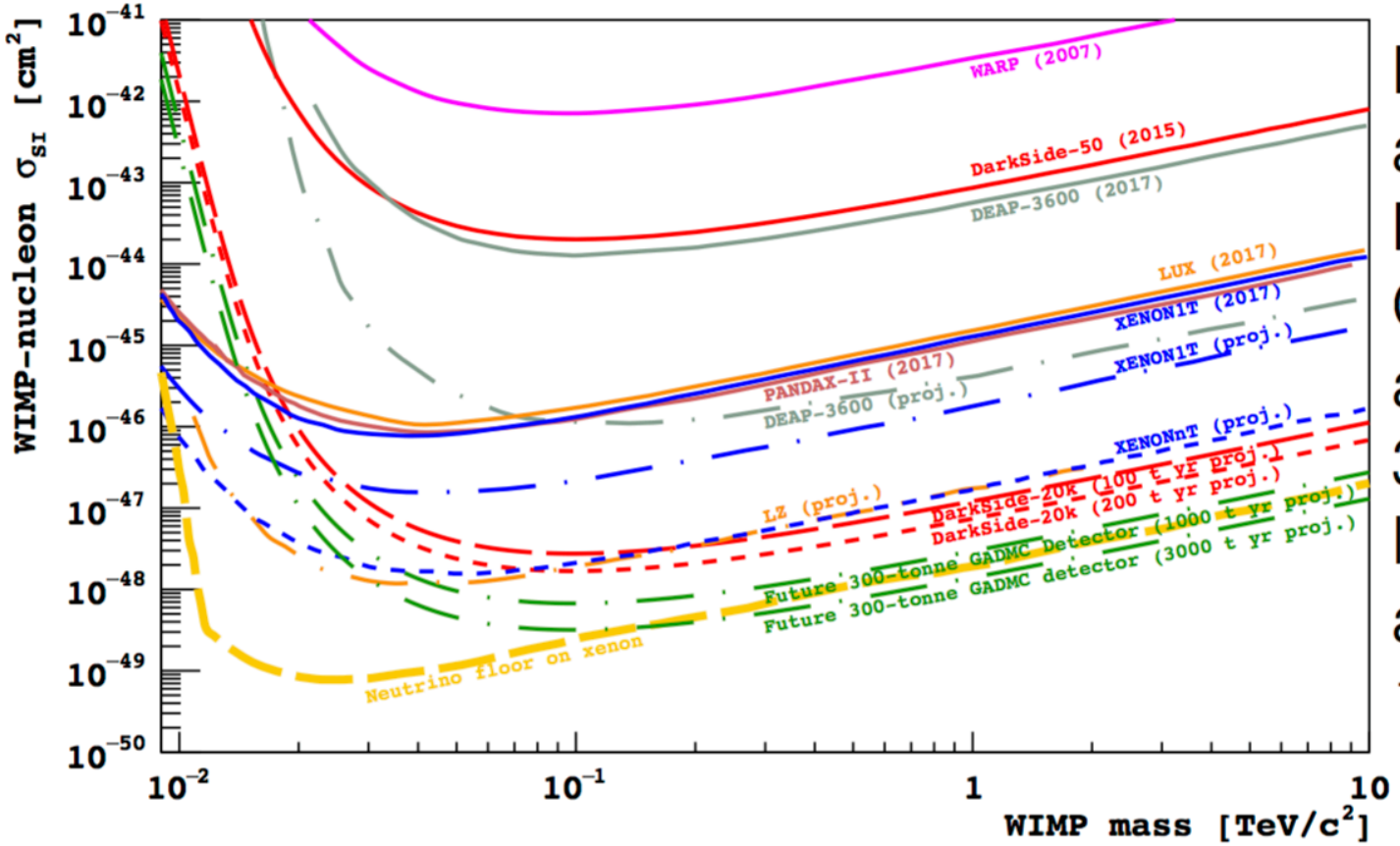


The Global Argon Dark Matter Collaboration

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-20k approved by INFN and LNGS in April 2017 and by NSF in Oct 2017
Officially supported by LNGS, LSC, and SNOLab
30 tonnes (20 tonnes fiducial) of low-radioactivity underground argon
14 m^2 of SiPM coverage