The DarkSide Experiment: Results and Near Future Prospects

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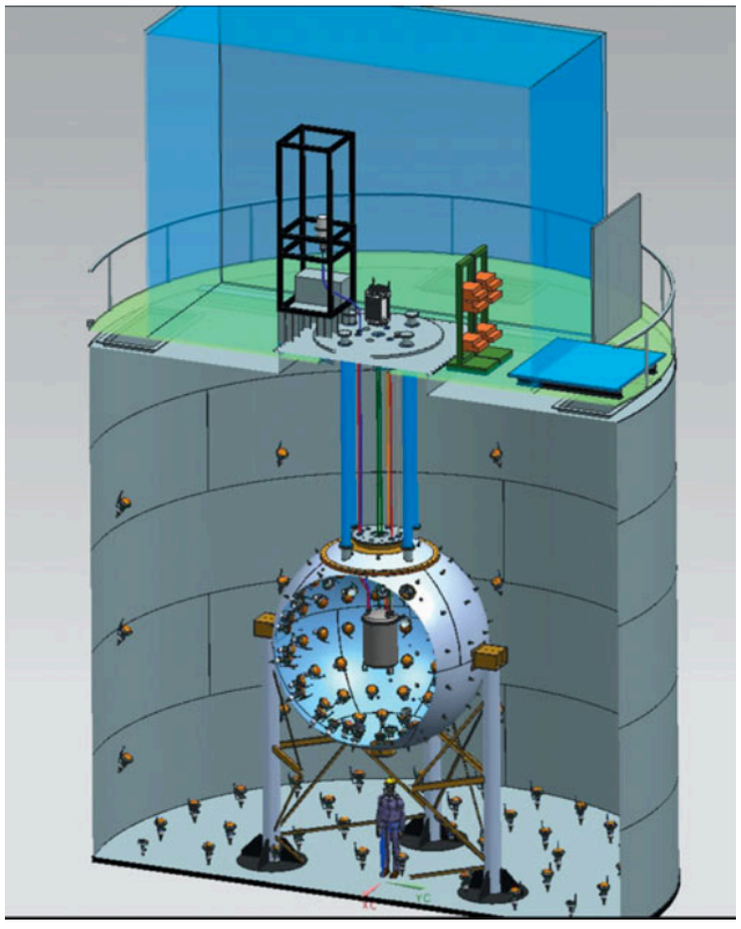
Dark Matter and Weak Interactions Conference
IIP - Natal - Sept 2019

Outline

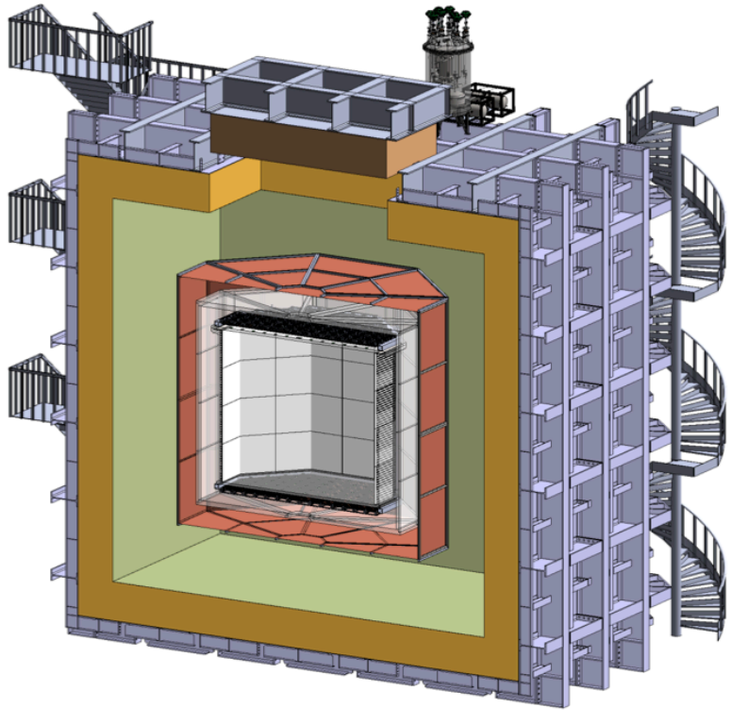
1. DarkSide Liquid Argon Program
2. DS50k Dual Phase TPC
3. Recent Results (DS50k)
   - WIMP search
   - Low Mass Search
   - SubGeV Search
4. DS20K and Beyond

DarkSide LAr Program

DS-50



532 days DATA



DS-20K
(50 tonnes)
2023

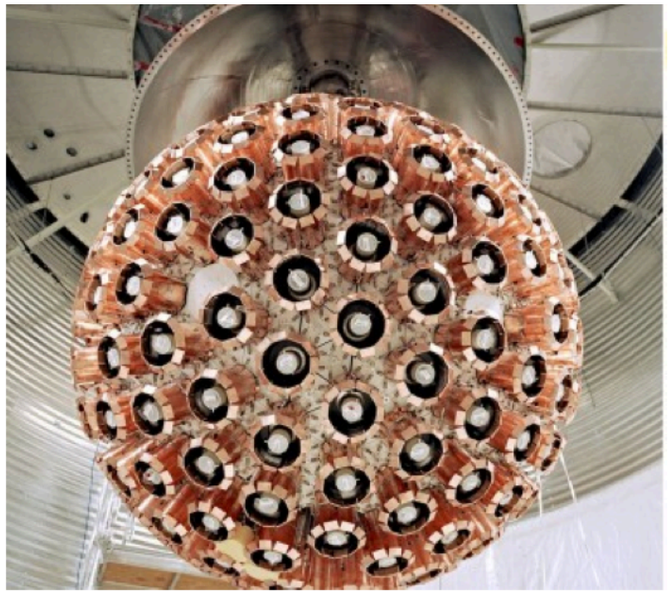
DS Proto
(1 tonne)
2021

Global Argon Dark Matter Collaboration
GADMC

DarkSide
+

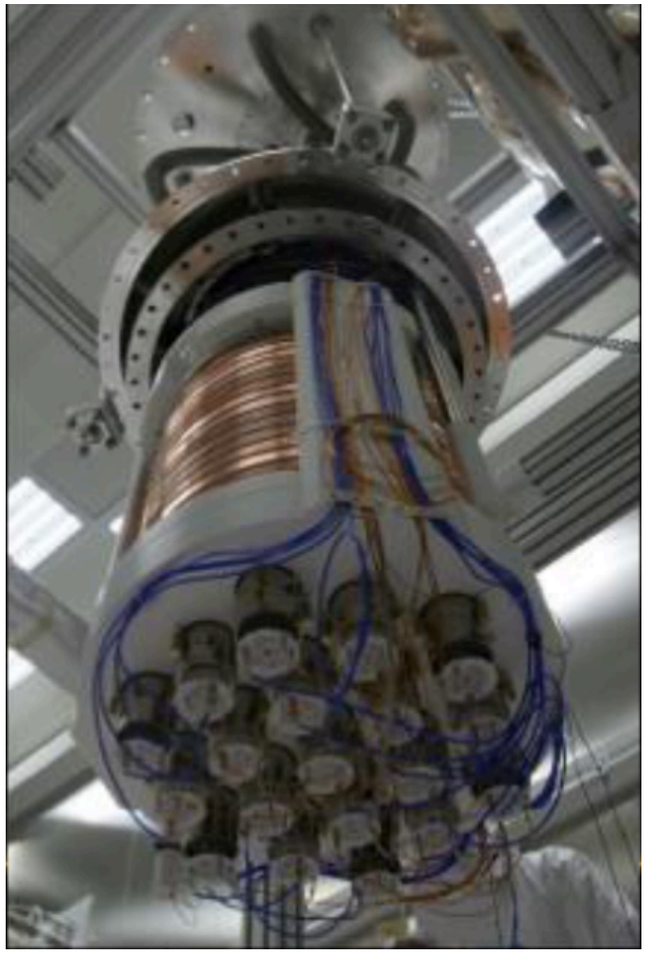
ArDM
(1tonne)

+ DEAP3600 (running)
single phase - 3.6 tons

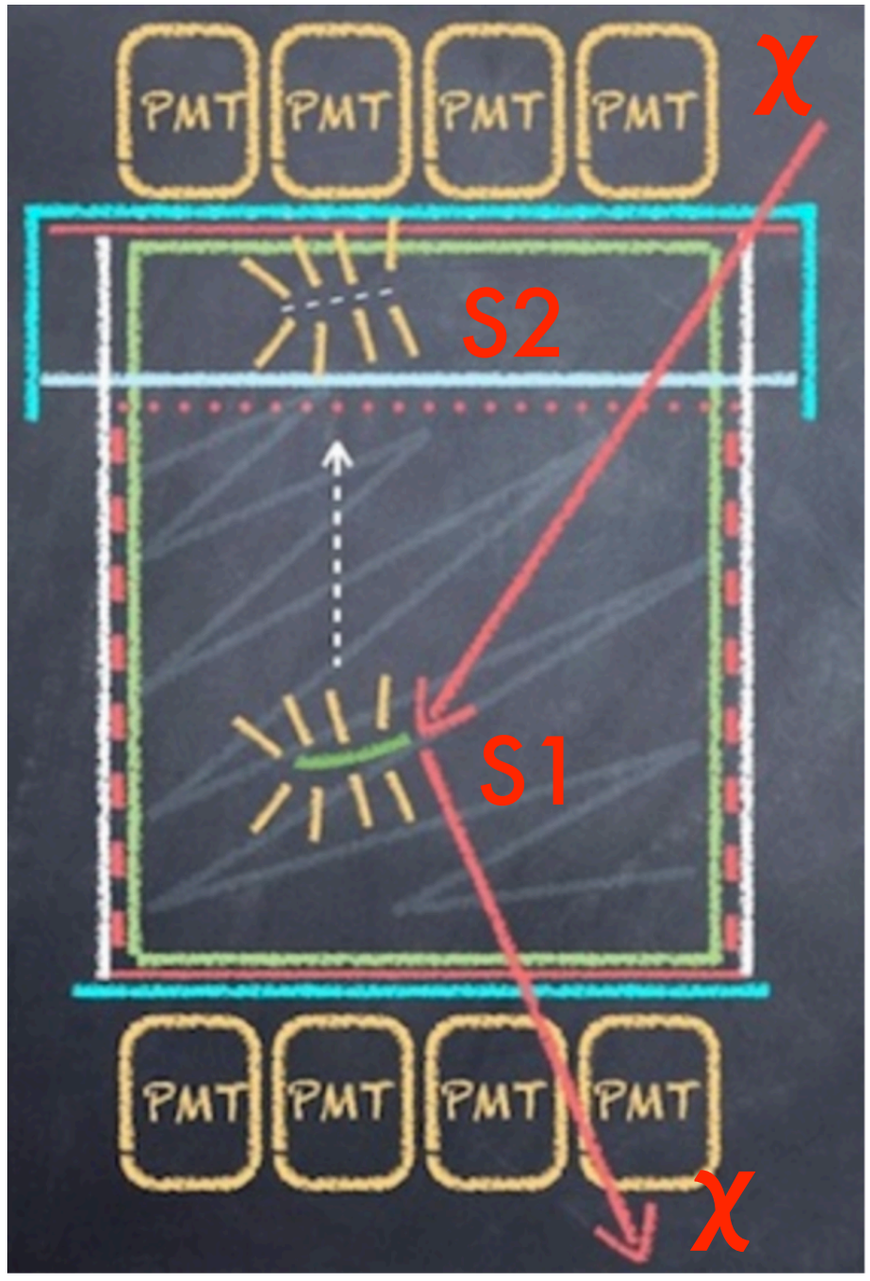


ARGO
300-400 (tonnes)

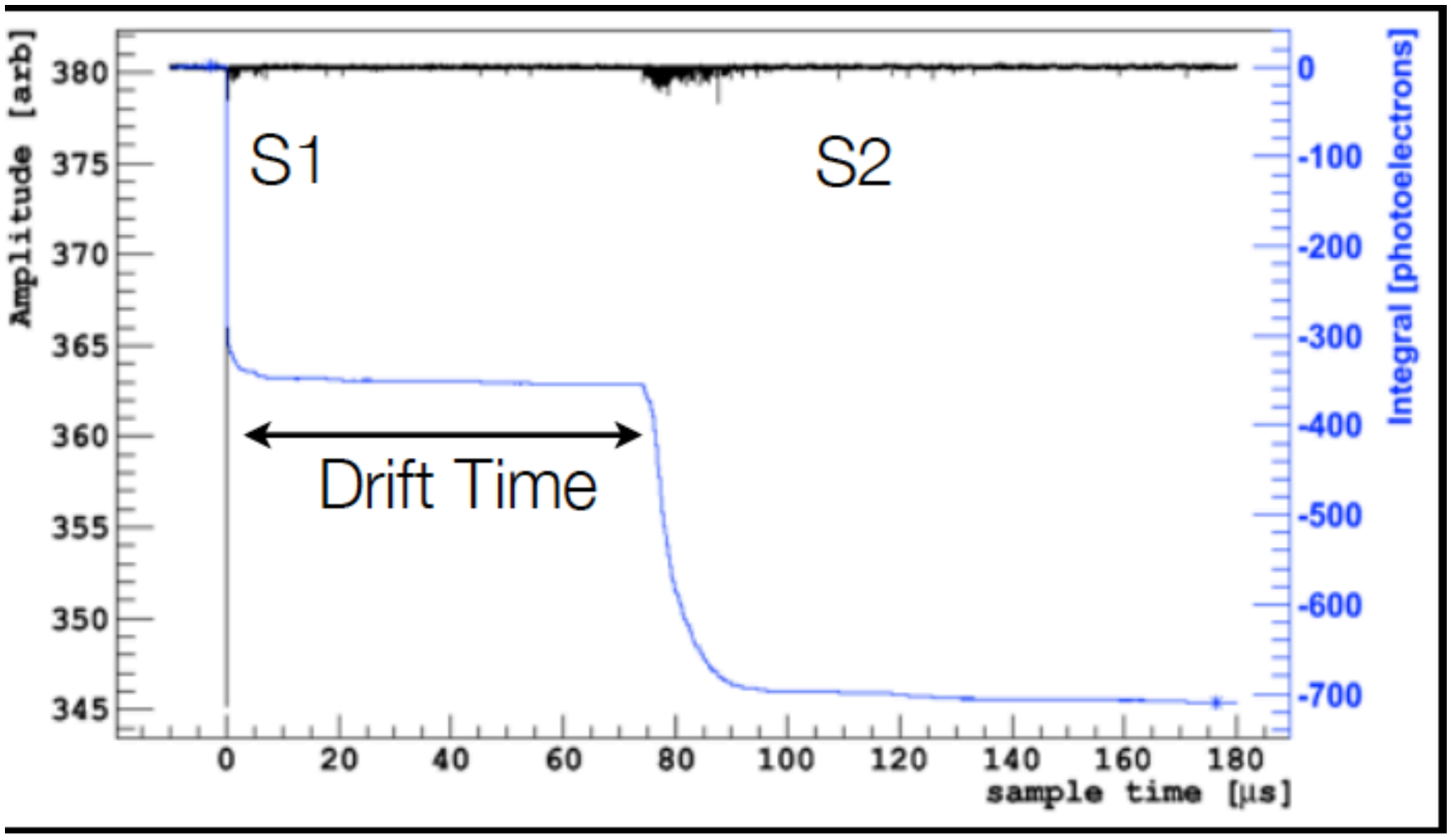
Liquid Argon Dual Phase Time Projection Chamber (TPC)



(46.4 +- 0.7) Kg
Fiducial volume:
(36.9 +- 0.6) Kg



Dual Phase TPC



S1: prompt scintillation signal

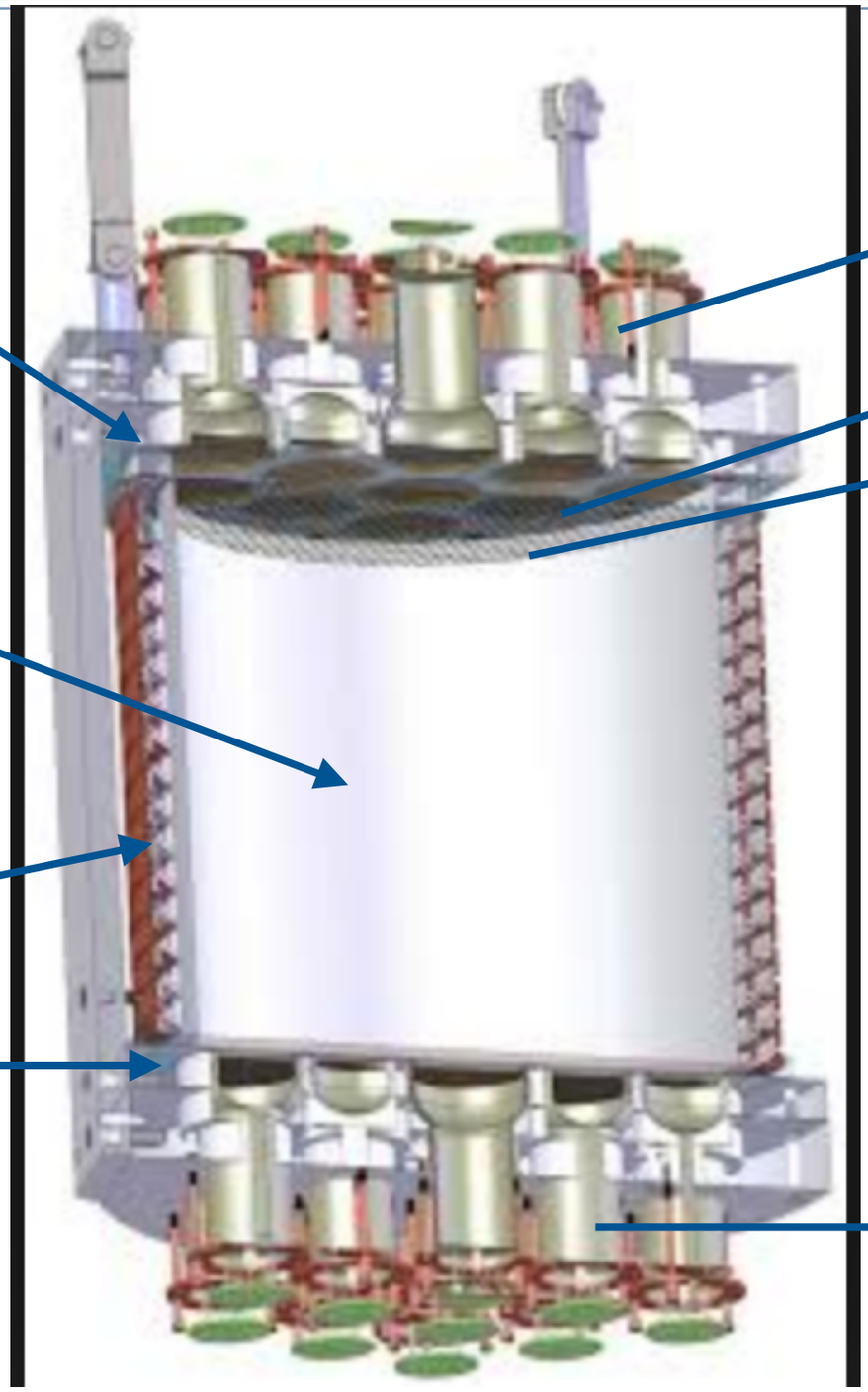
Pulse Shape Discrimination (elec vs nucl recoil)

S2: secondary scintillation (ionization)

light fraction in each PMT: XY reconstruction

Time difference: Z position + background rejection

Time Projection Chamber (TPC)



anode

Liquid Ar

36 cm diameter

36 cm high

~ 31 Kg fiducial

Field Rings

cathode

19 PMTs (3″)

Gaseous Ar

Extraction Grid

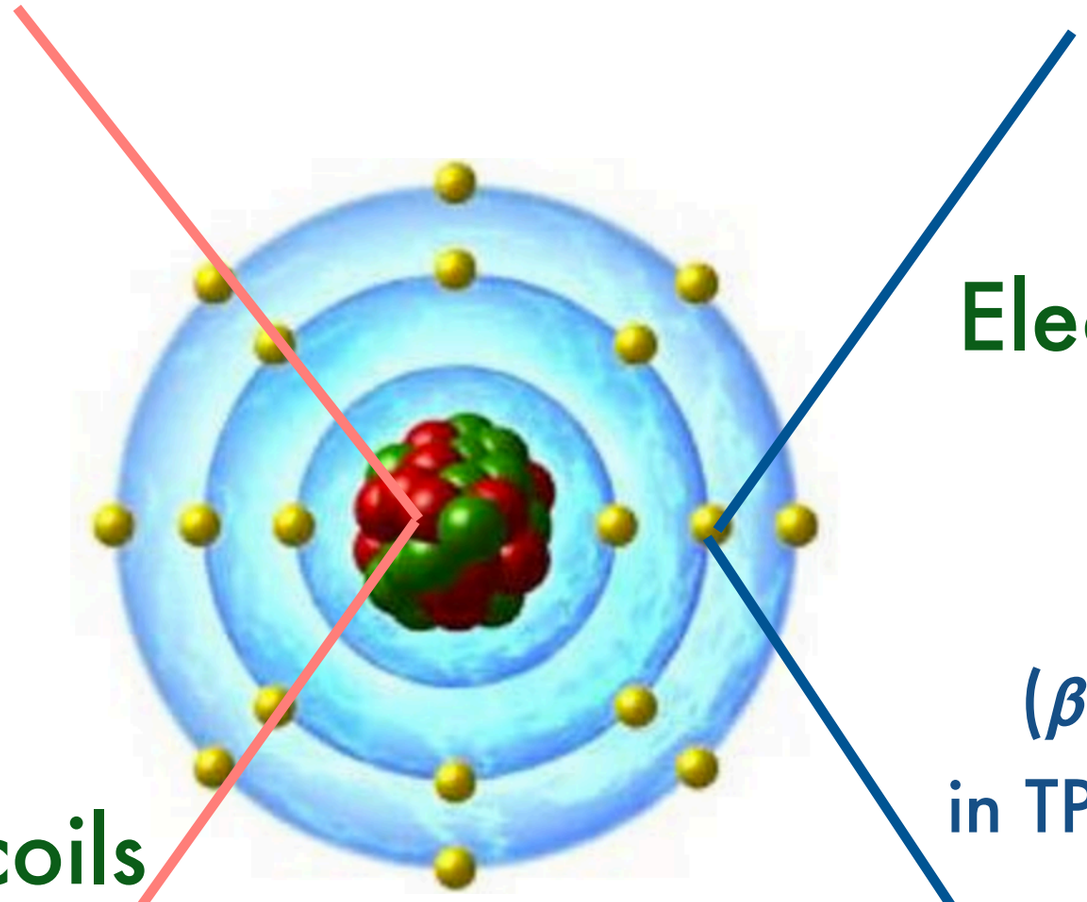
200 V/cm Drift Field

2.8 kV/cm Extraction Field

19 PMTs (3″)

DS50 Dual Phase TPC

Backgrounds

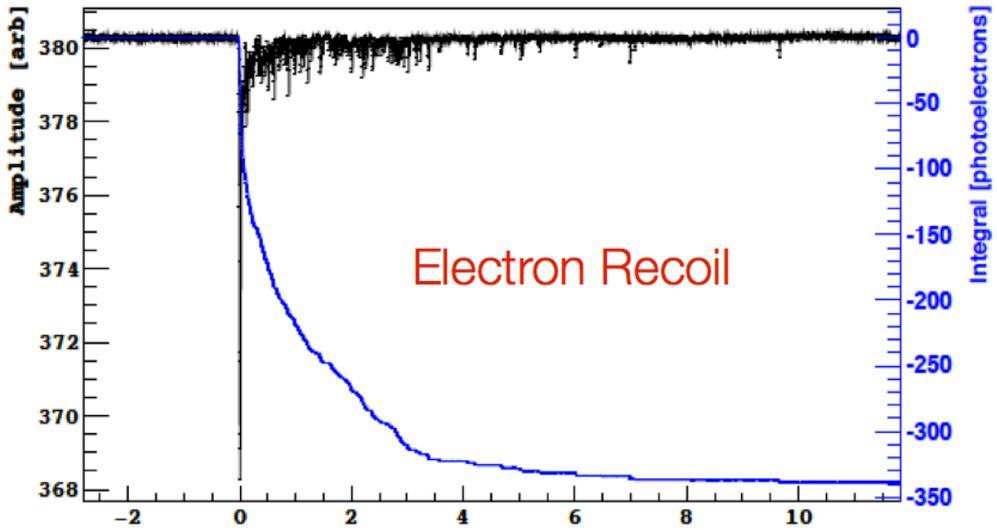


Electron Recoils
electrons
gammas
(β and γ decays
in TPC and Cryostat)

Nuclear Recoils
neutrons
(radiogenic, alphas)

same recoil as
Wimps

Pulse Shape Discrimination in LAr



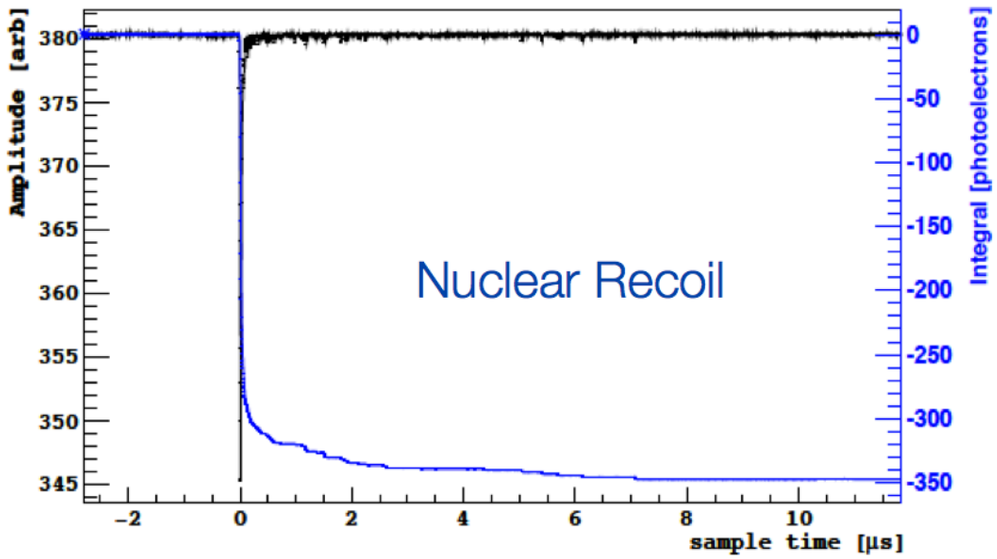
τ singlet ~ 7 ns

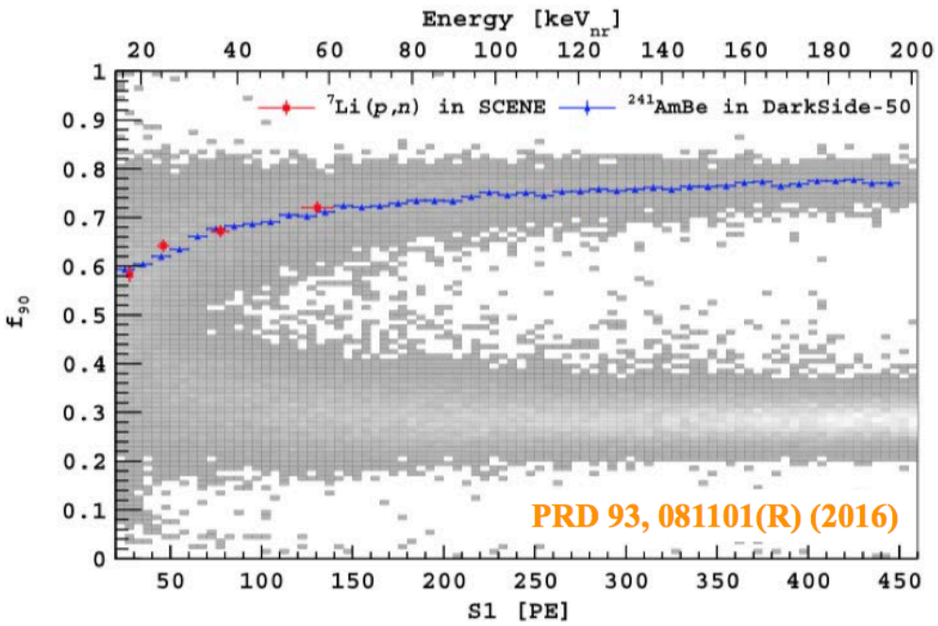
τ triplet ~ 1500 ns

PSD parameter, F90

Fraction of total light detected in the first 90 ns of the pulse

(Fraction of singlet state excited dimers)





Nuclear recoils

Electron recoils

Powerful only for LAr

Detector Shielding

Clean Room

Water Cherenkov Detector (WCD)

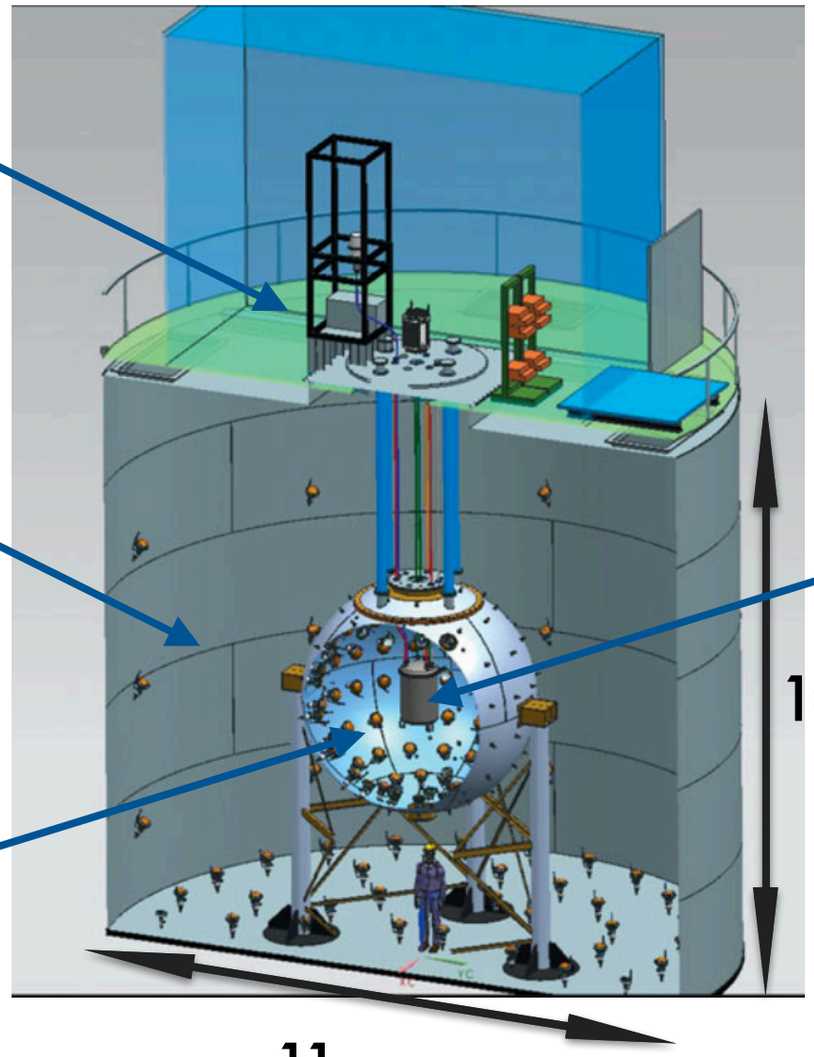
80 PMTs (8″)

1000 Tons

Liquid Scintillator Veto (LSV)

110 PMTs (8″)

30 diameter - 30 Tons



TPC

153 Kg

38 PMTs (3″)

200 V/cm Drift Field

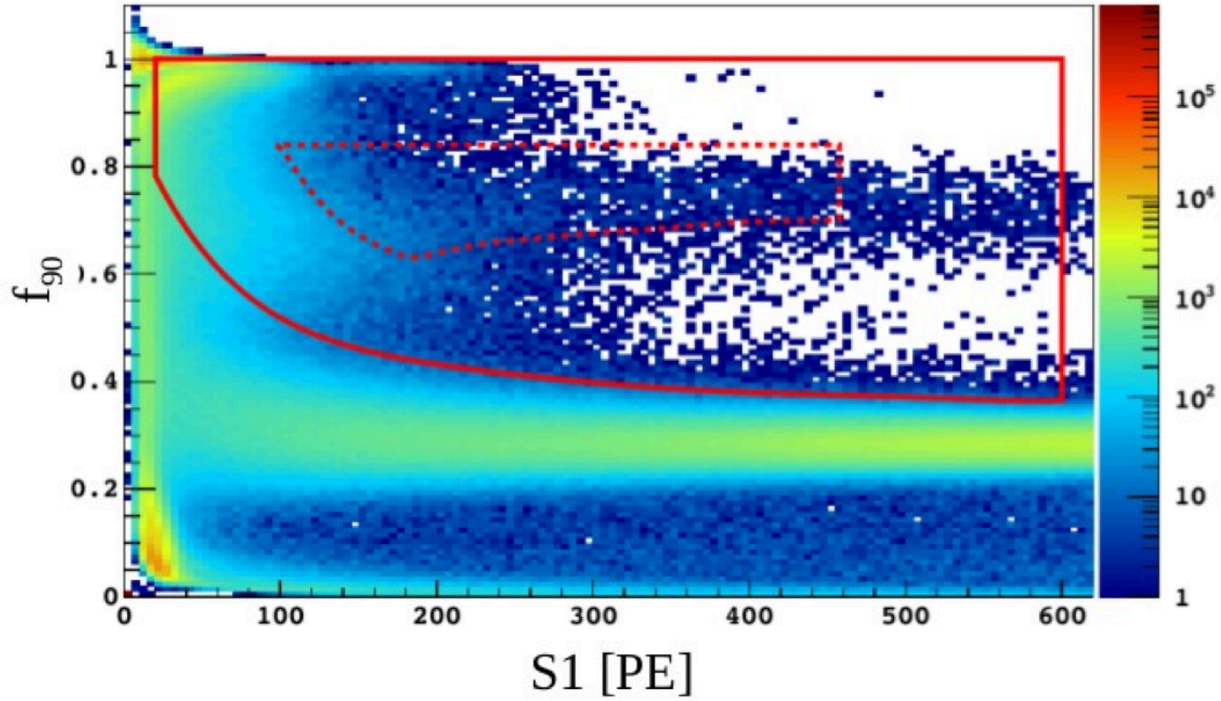
2.8 kV/cm Extraction Field

Shielding and anti-coincidence
radiogenic and cosmogenic neutrons
γ and CRμ

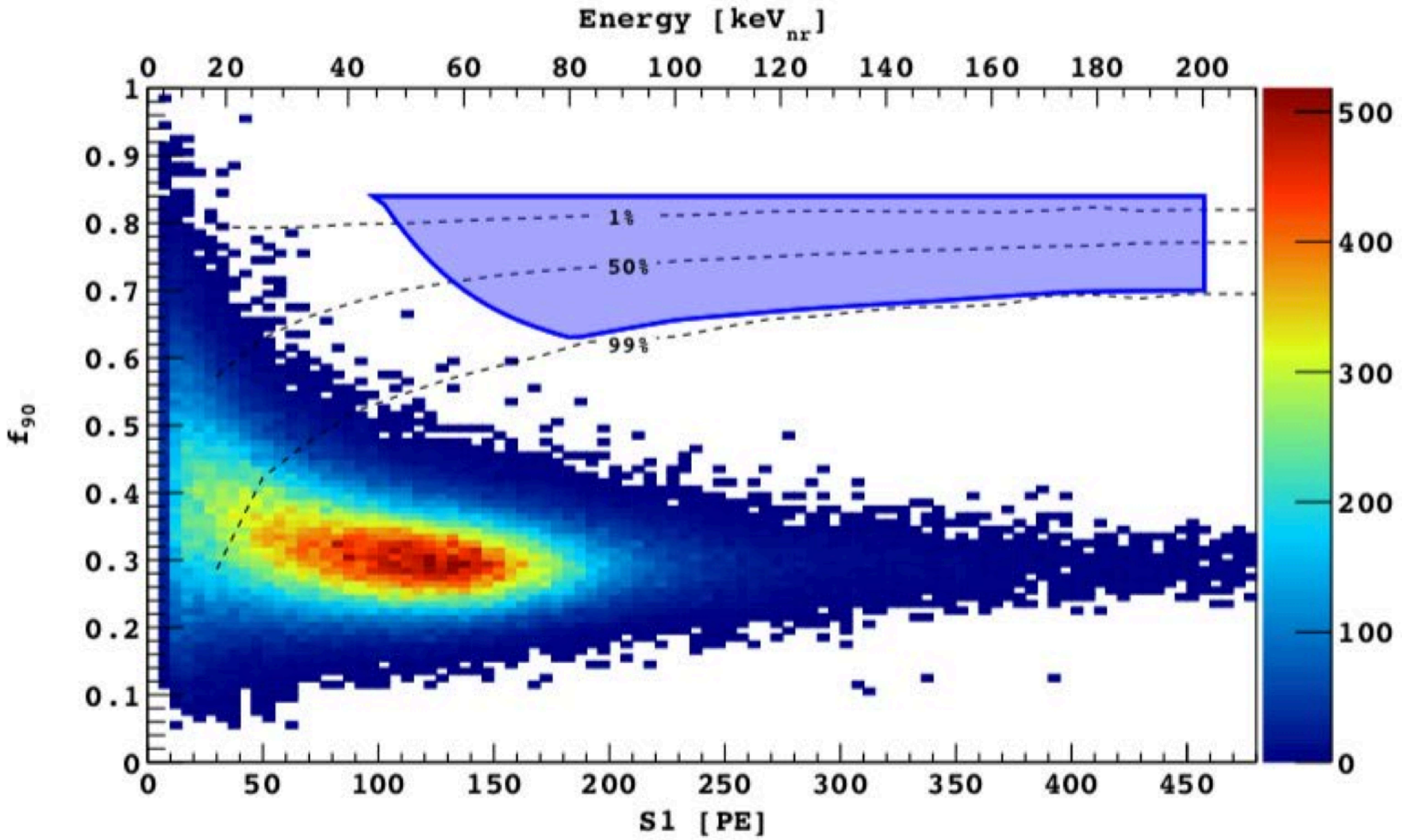
DS50k 532.4 days

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



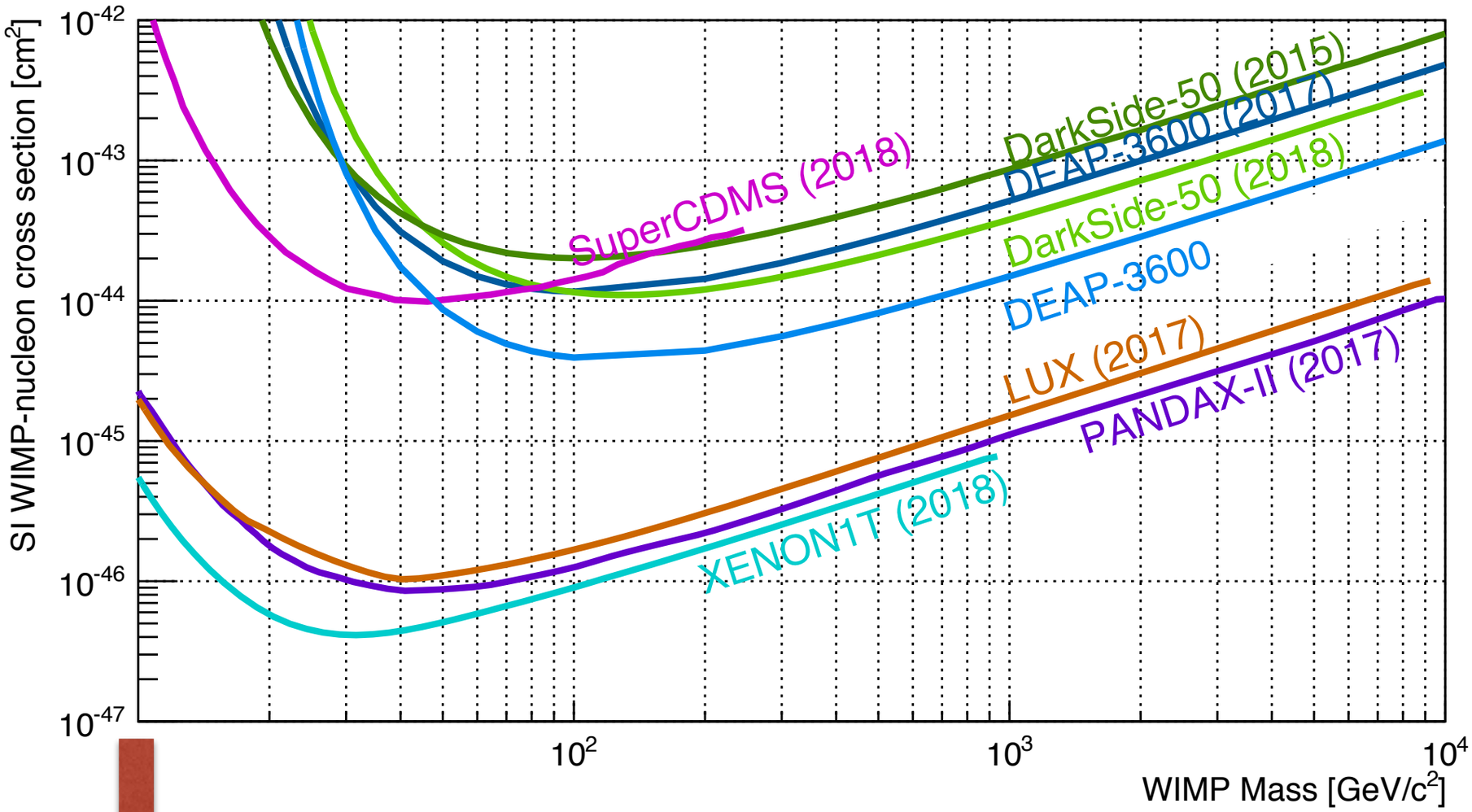
DarkSide WIMP Search



arXiv:1802.07198

DS50K Coll - PRD 98 (2018)

Current SI WIMP limits



10 GeV/c^2

DS50K Coll - PRD 98 (2018)

Low Mass Motivation

Asymmetric Dark Matter

$$\frac{\rho_{\mathbf{DM}}}{\rho_{\mathbf{Baryons}}} \sim 5$$

- No connection in standard WIMP scenario

  -- ρ_{DM} **is set by freeze out temperature**

- However a connection arises when

$$\frac{\rho_\chi}{\rho_{\overline{\chi}}} \neq 1$$

$$(1 \leq \mathbf{m}_\chi \leq 10)\ \mathbf{GeV/c^2}$$

Zurek
Phys. Reports 537, 2016

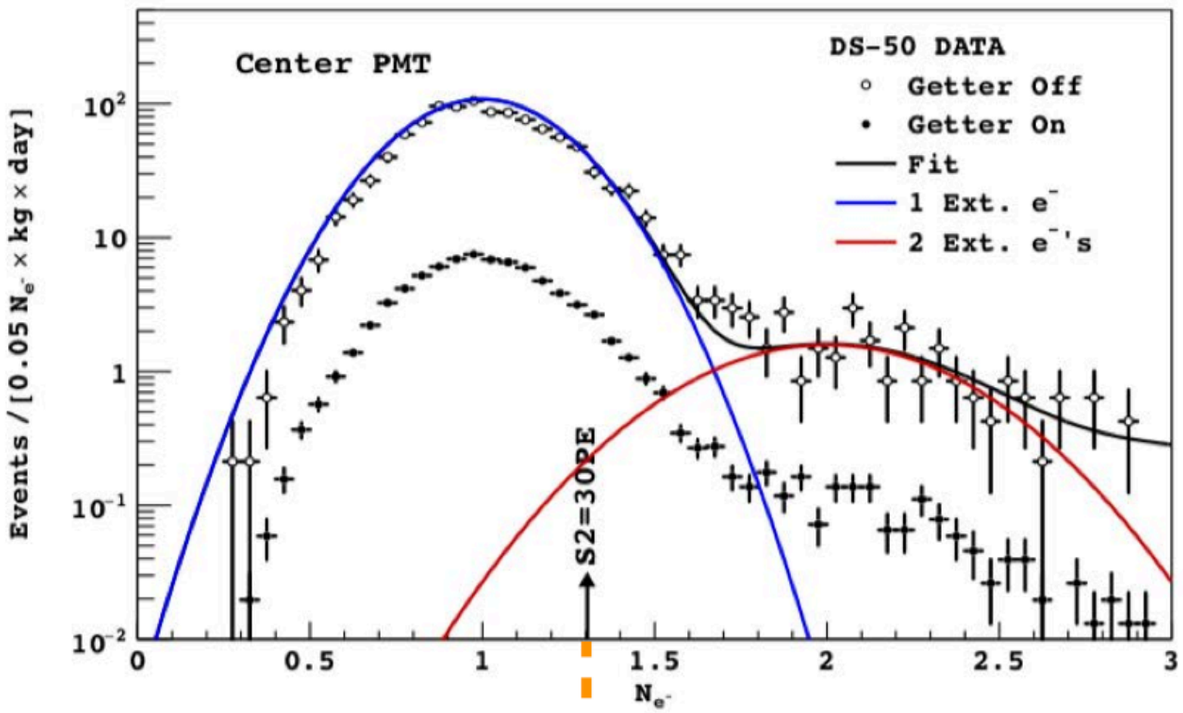
Low Mass Analysis

$$(1 \leq m_\chi \leq 10)\ \mathrm{GeV}/c^2$$

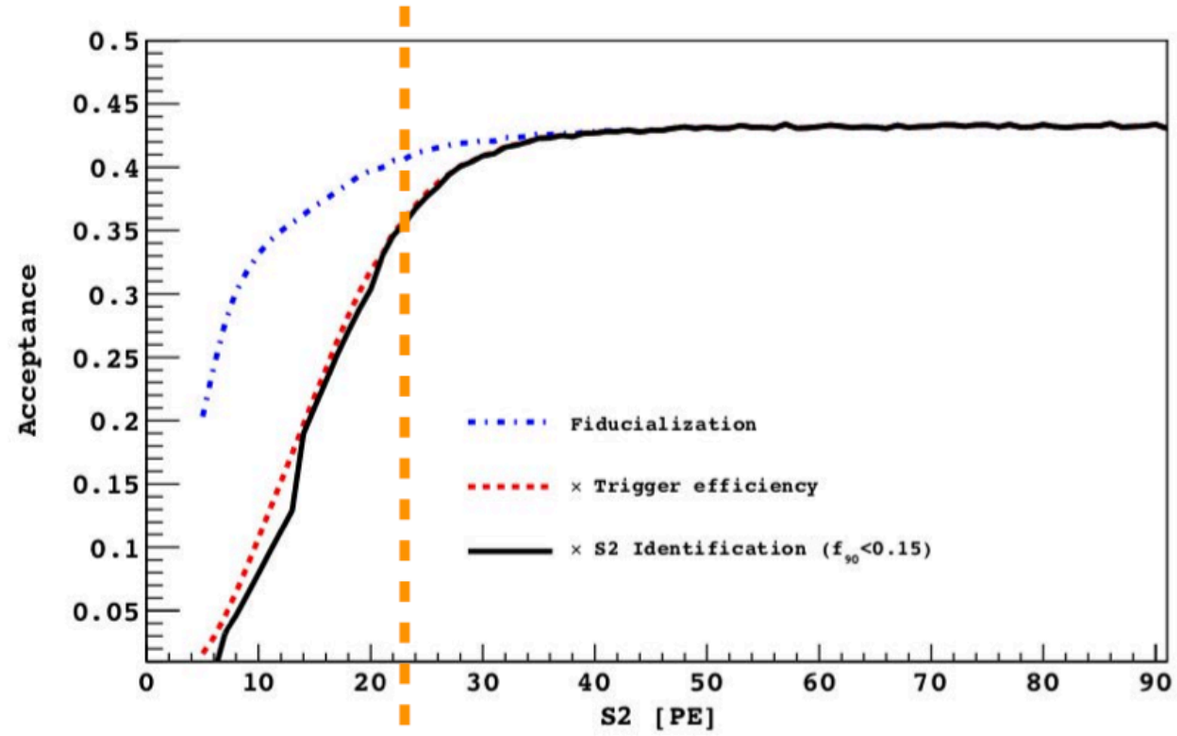
S2 only analysis

- Scintillation light (S1) is too low => not detectable
  - Give up Pulse Shape Discrimination

S2 Single Electron Yield



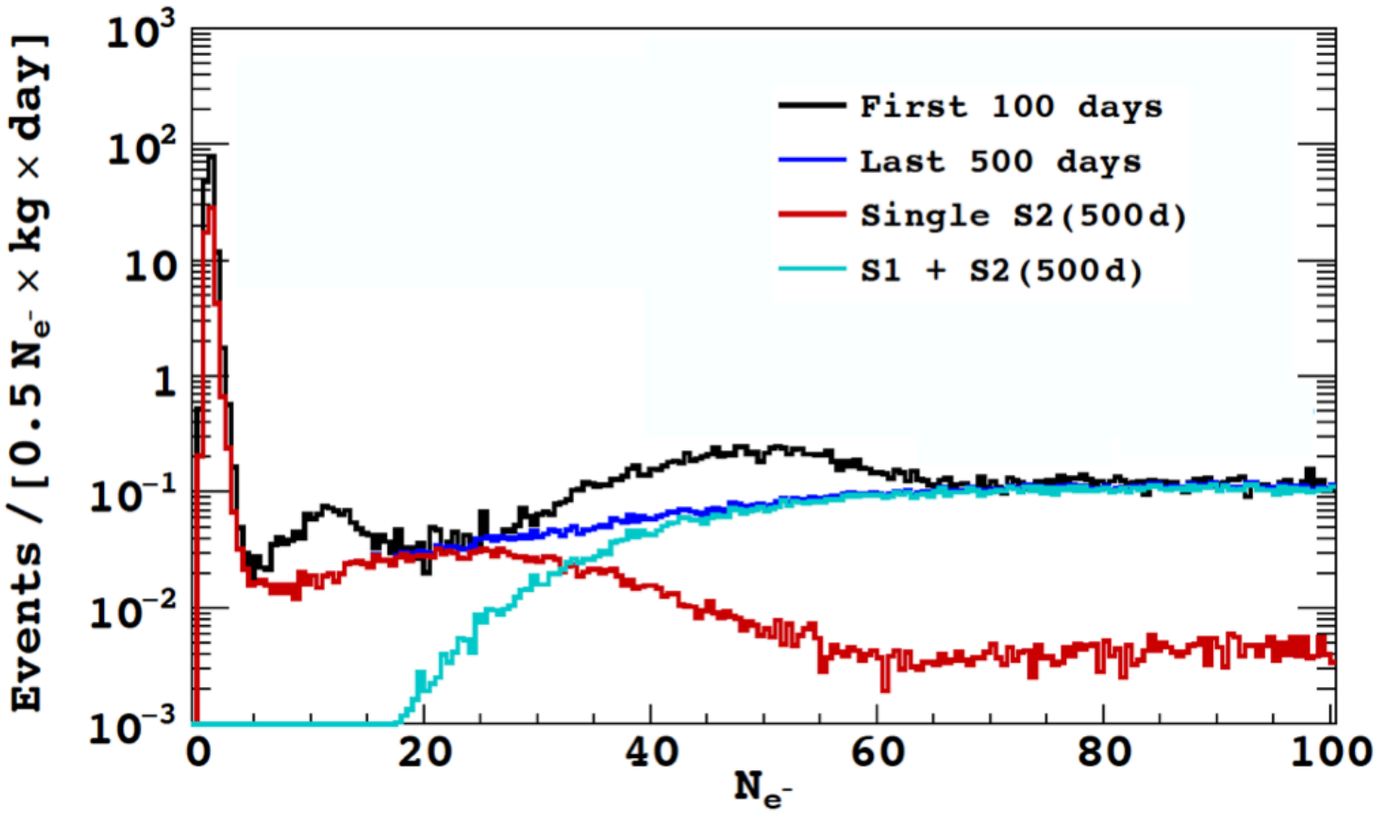
30 p.e.

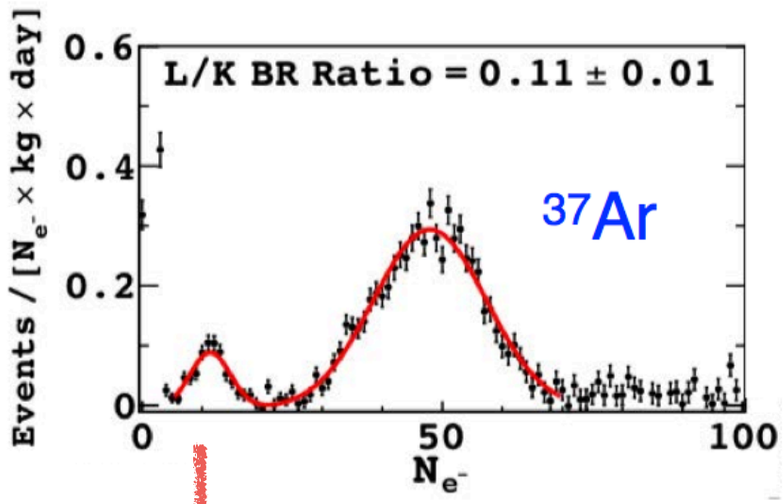


single electron

- Signal down to single electron
- approximately 23 PE/e^- at detector axis

S2 Only Analysis - Ar^{37}

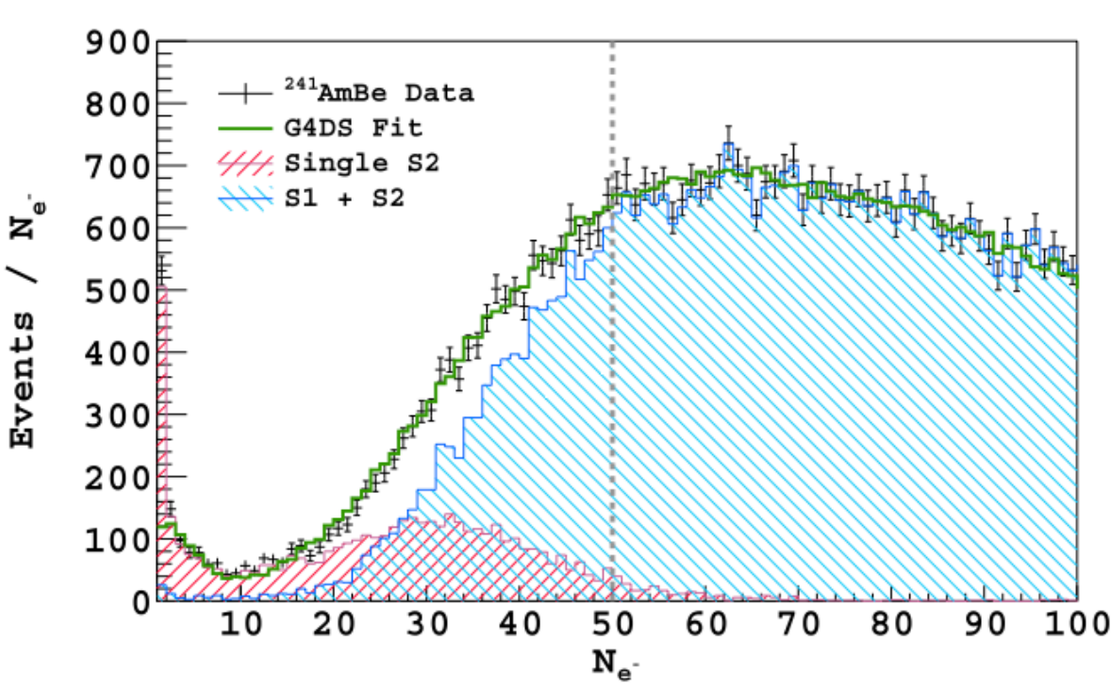




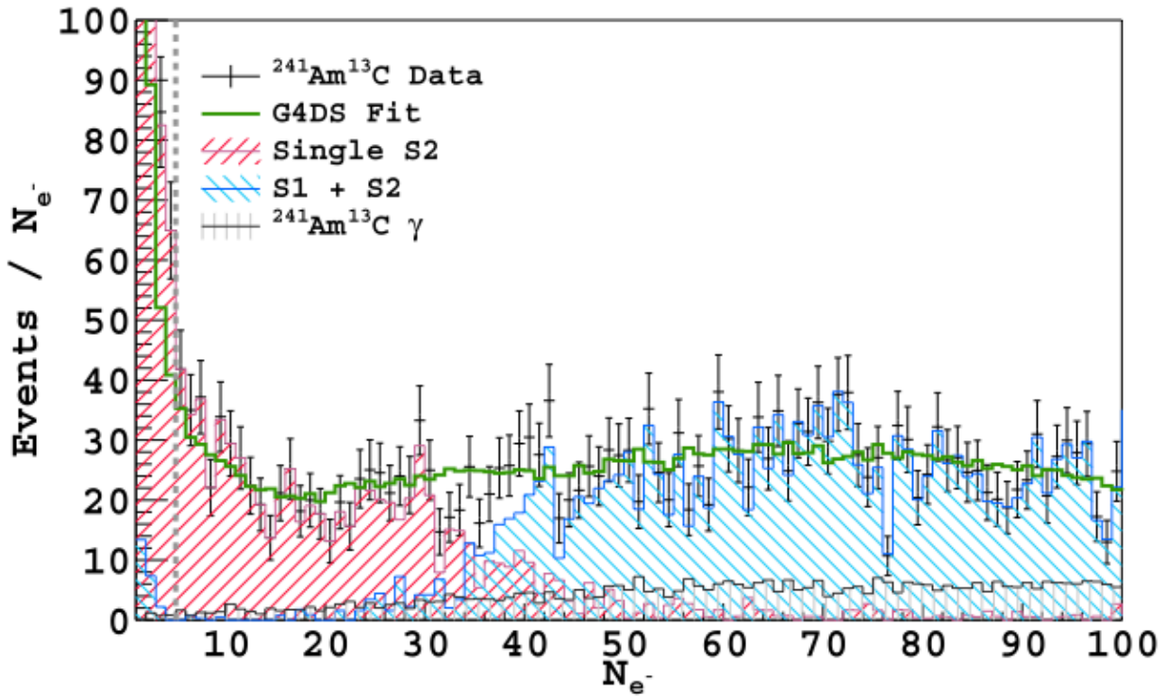
0.27 **2.82 keV**

direct N_e calibration for low energy electrons

Ionization Yield (Q_y) from Nuclear Recoils



4.4 MeV γ signal in veto required

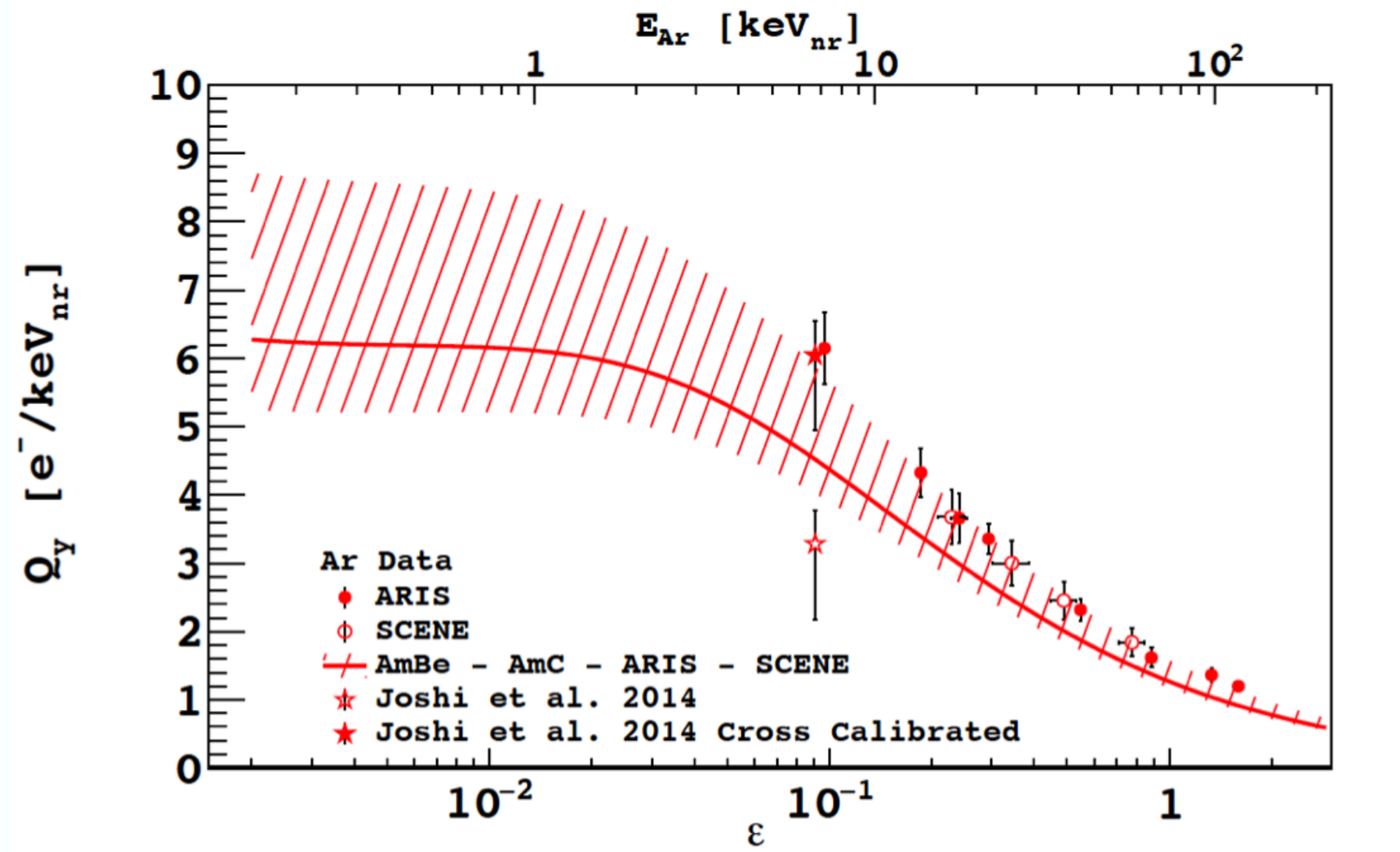


only 4 farthest PMTs

G4DS uses Bezrukov model

(Bezrukov et al., Astropart.Phys. 35 (2011)

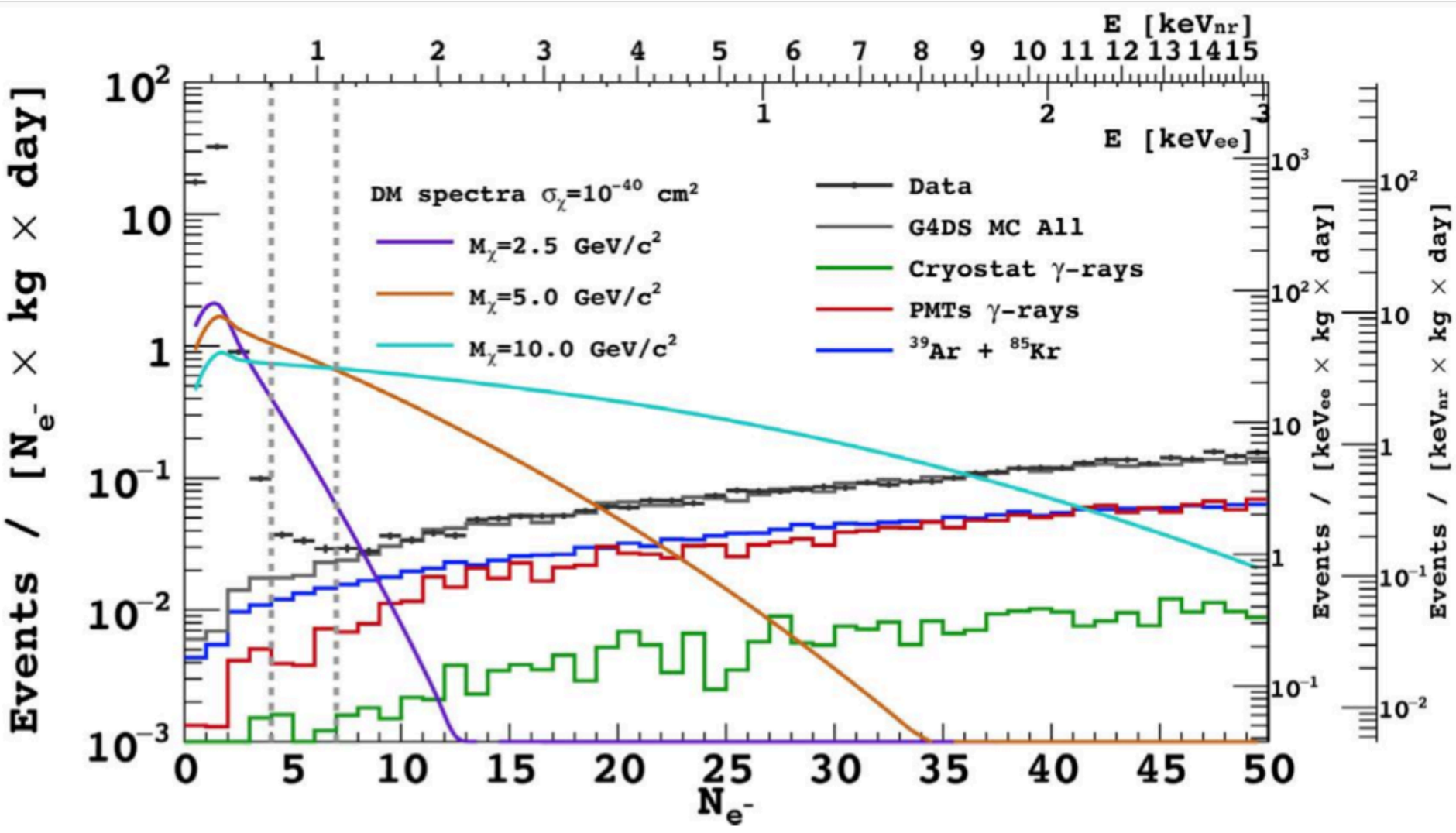
Ionization Yield (Q_y) from Nuclear Recoils



Q_y from AmBe + AmC + Bezrukov model

Agree within bounds with other data => systematics

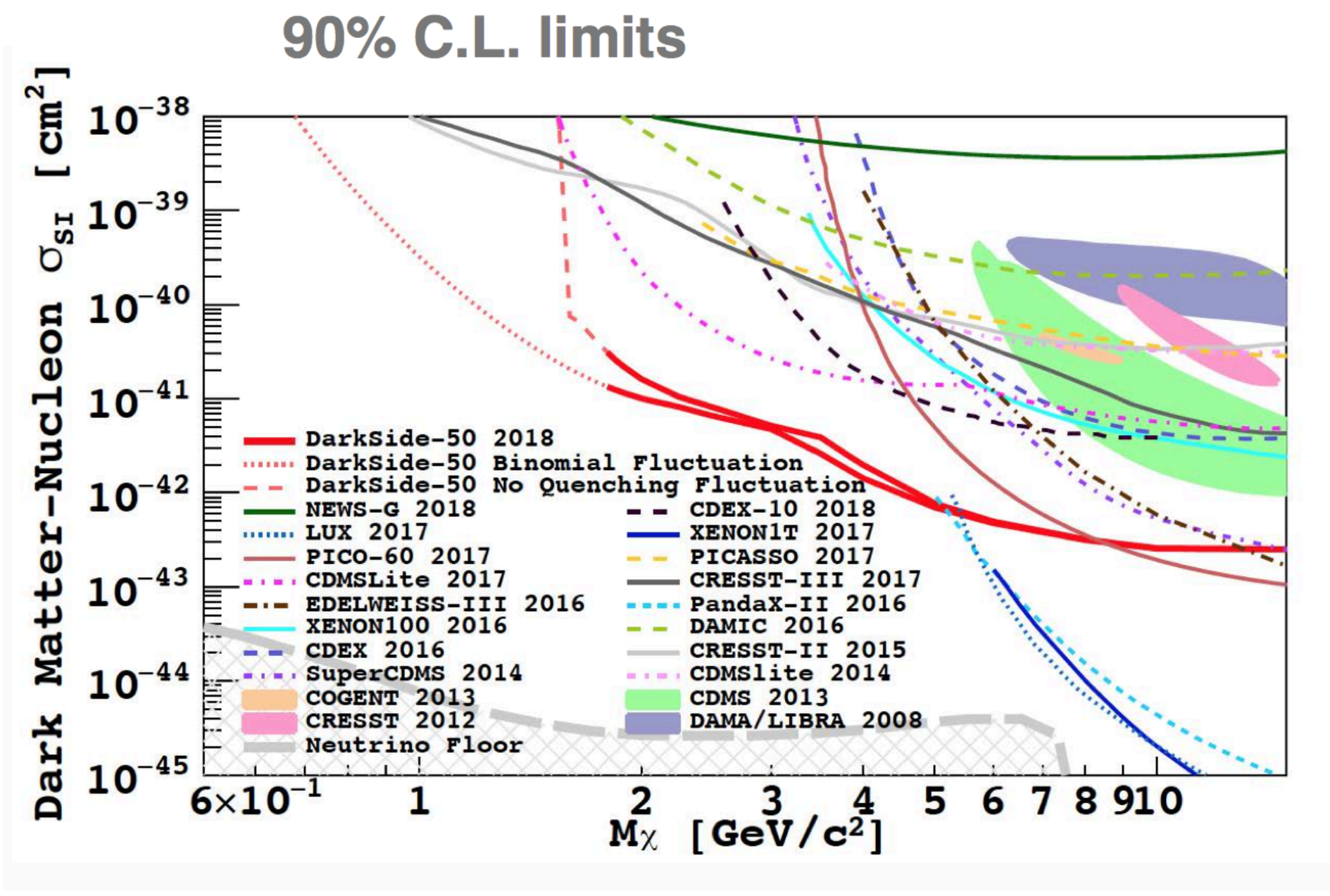
Low Mass Wimps: Signal vs Backgrd



Expected signal assumes standard DM halo

Uncertainties in signal dominated by Q_y fluctuations

Low Mass Wimps: Limits



DS50K Coll - PRL 121 (2018)

SubGeV Search

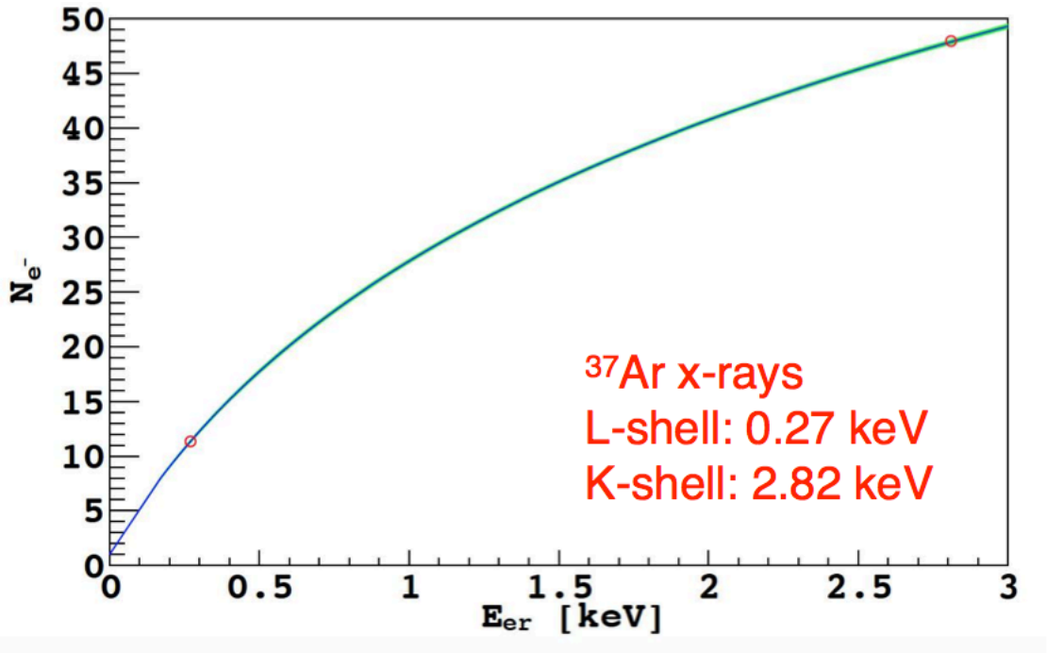
DARK SECTOR

- Hidden sector with not only one DM particle, but multiple particles and forces
- Portals connecting with Standard Model particles

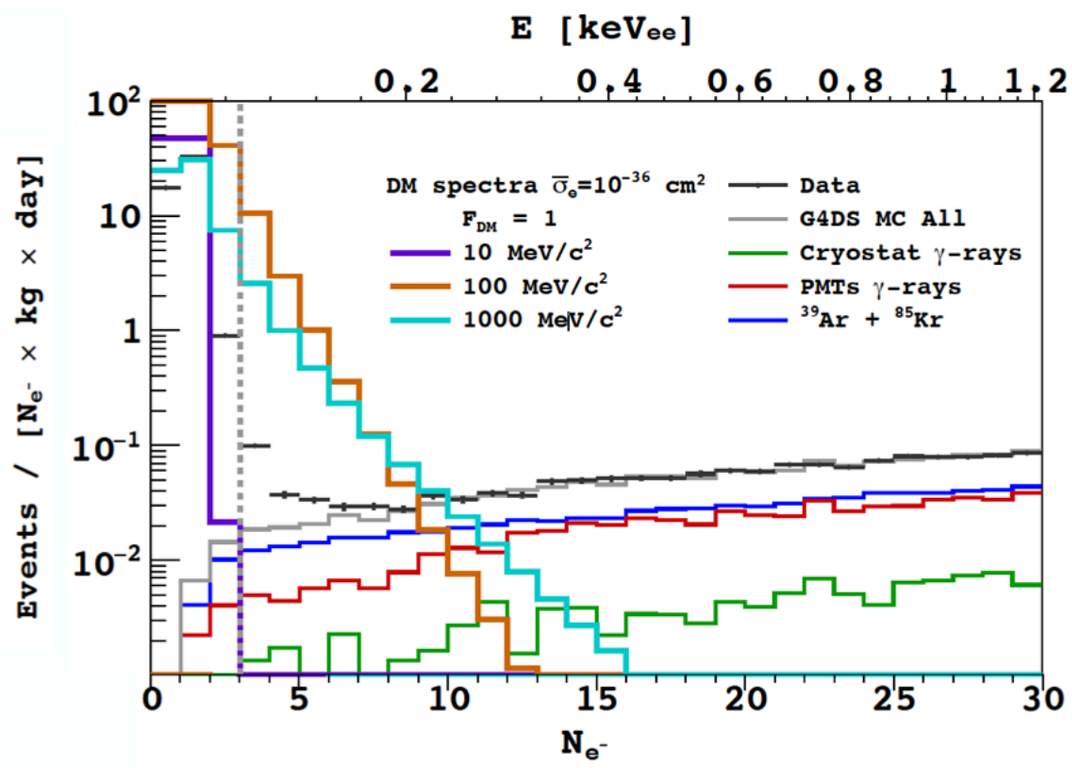
Also an S2 only analysis

DM - electron scattering

SubGeV Analysis

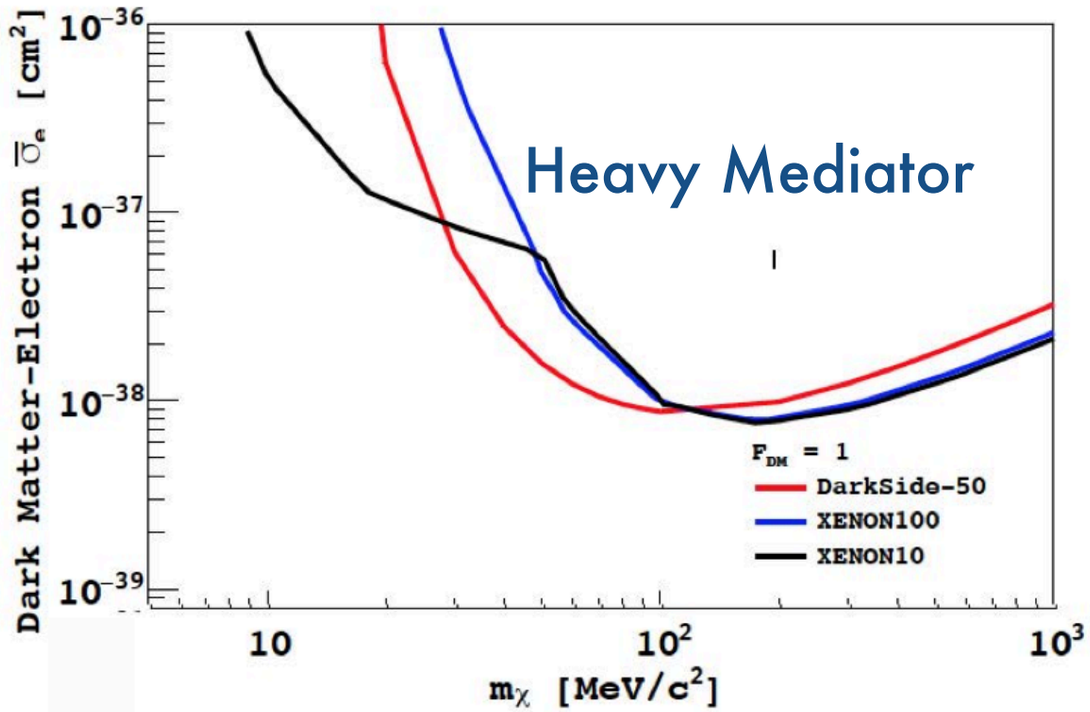


- DM-electron interaction parametrized by a DM form factor with two limiting values (heavy and light mediator)



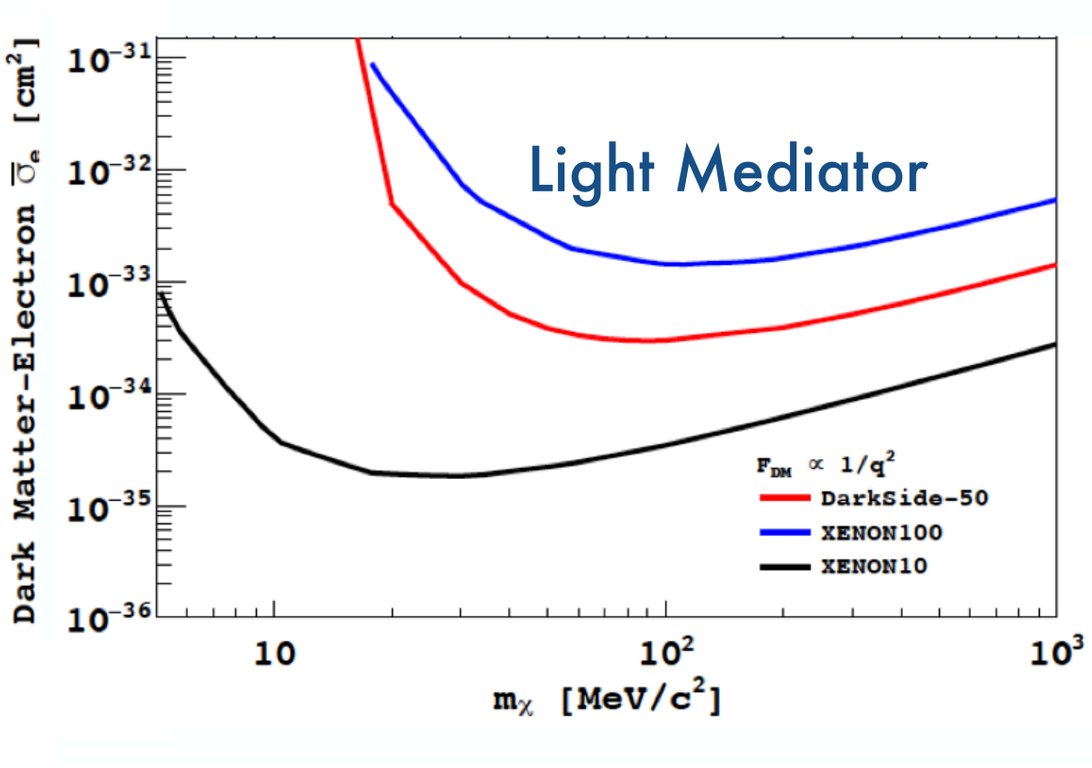
$$|F_{\rm DM}(q)|^2 = \begin{cases} 1, & m_{\rm med} \gg \alpha m_e \\ (\alpha m_e/q)^4, & m_{\rm med} \ll \alpha m_e \,, \end{cases}$$

SubGeV Limits



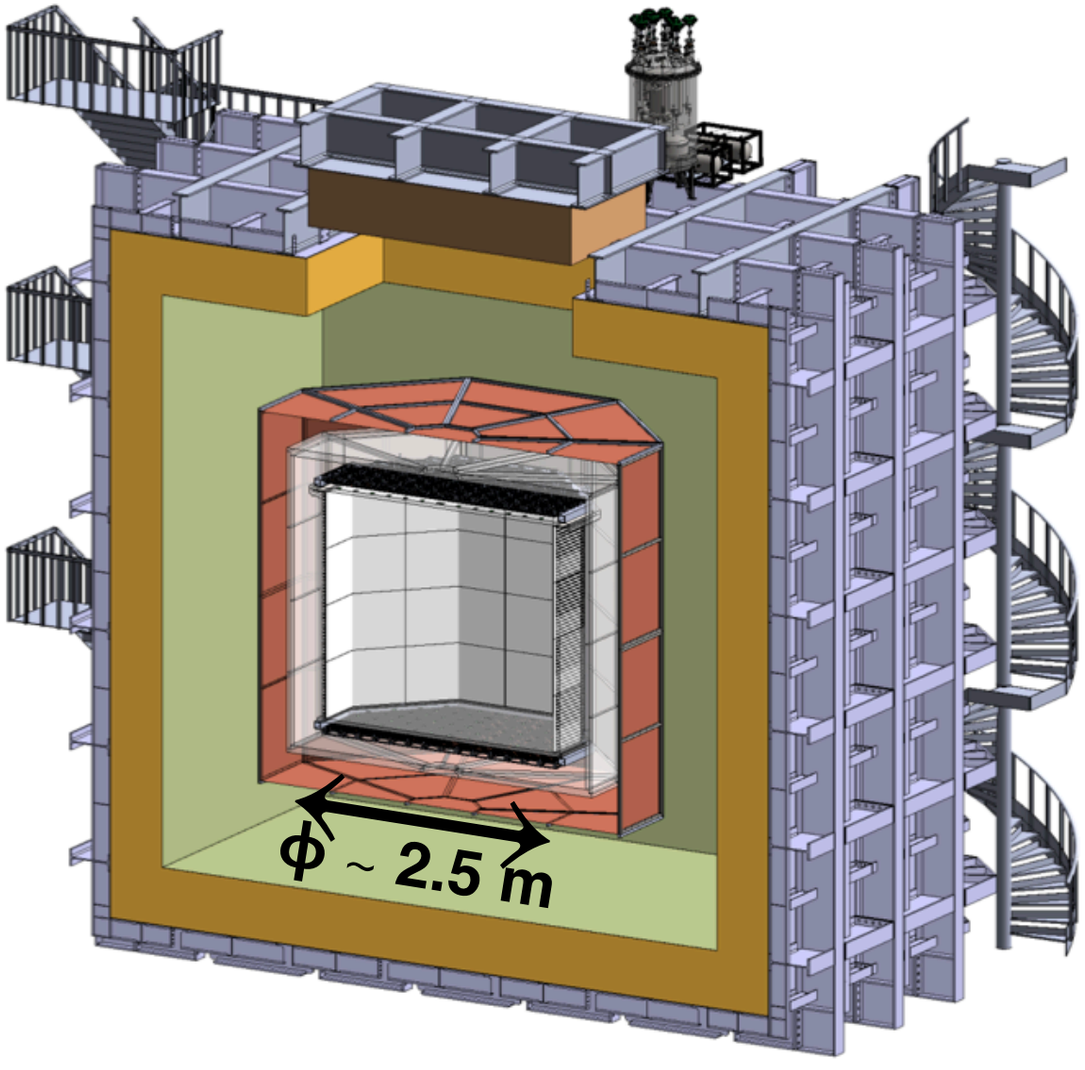
DS50K has best result
25 -100 MeV region

DS50K Coll - PRL 121 (2018)



Xe analysis
Essig, Volansky and Yu,
PRD 96 (2017)

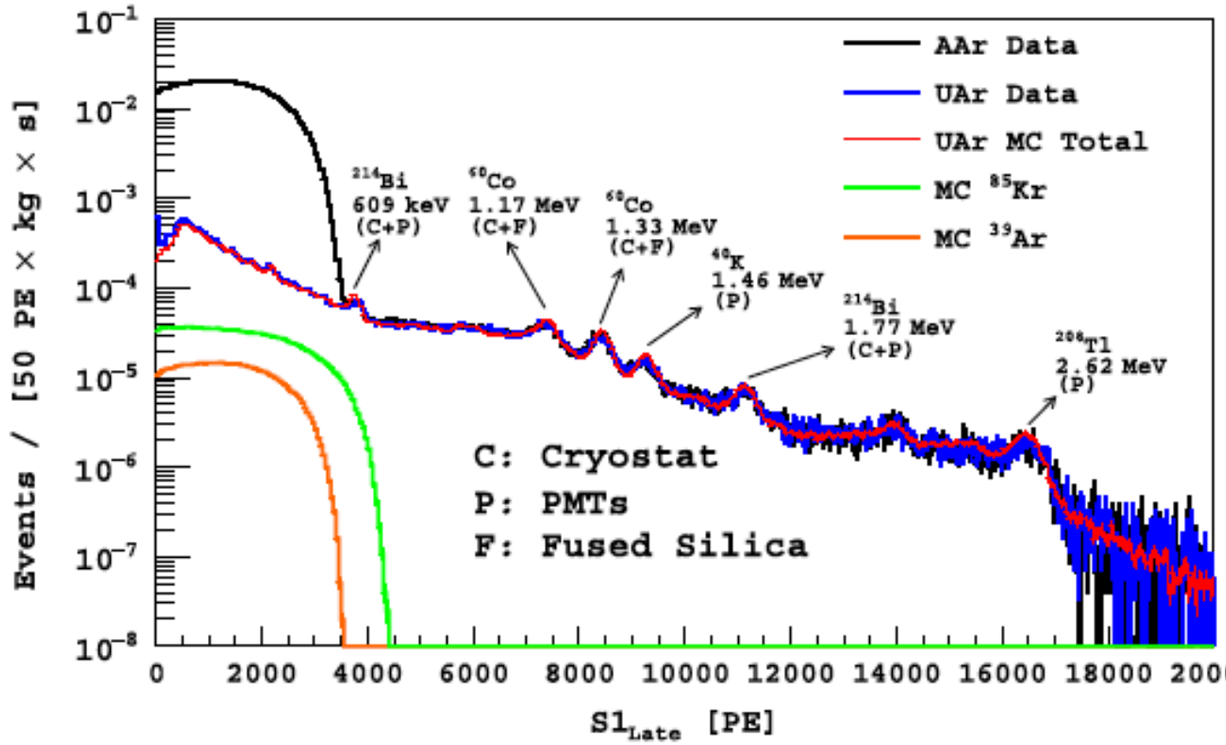
Beyond DS50: DS20k



Laboratori Nazionali del Gran Sasso

- 50 ton UAr Dual Phase TPC in sealed vessel (30 ton fiducial)
- 20 m^2 SiPM
- AAr Veto (ProtoDUNE membrane cryostat)
- Background free(<0.1/100ton year)
- Data from 2023

Underground Argon

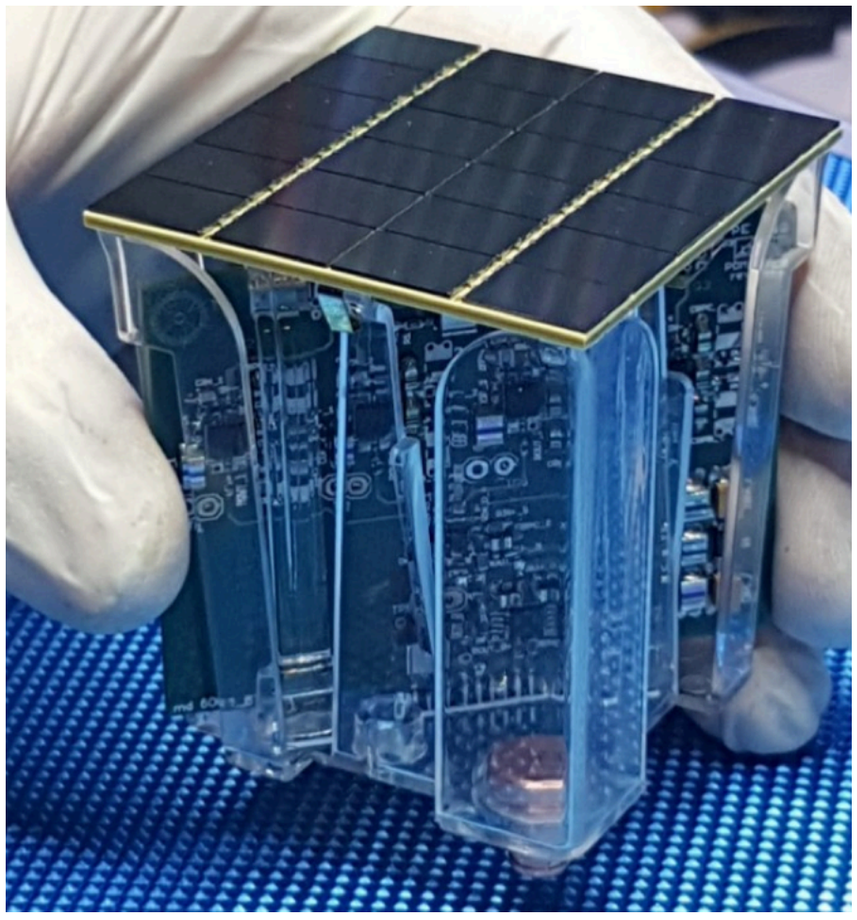


URANIA
UAr extraction @ Colorado
~250 kg/day of low-39Ar argon
(99.9% pure)

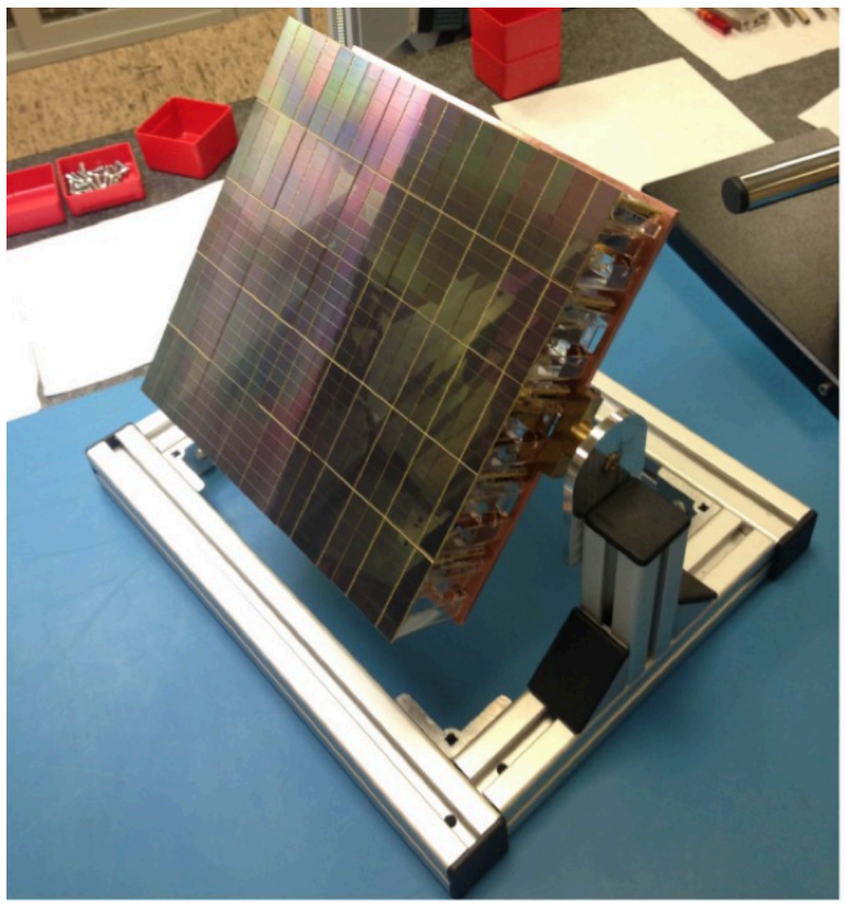
ARIA
distillation plant @ Serucci
Sardinia (350 m long)
further purification of UAr

PMT ➡ SiPM

PDM (5 x 5 cm)

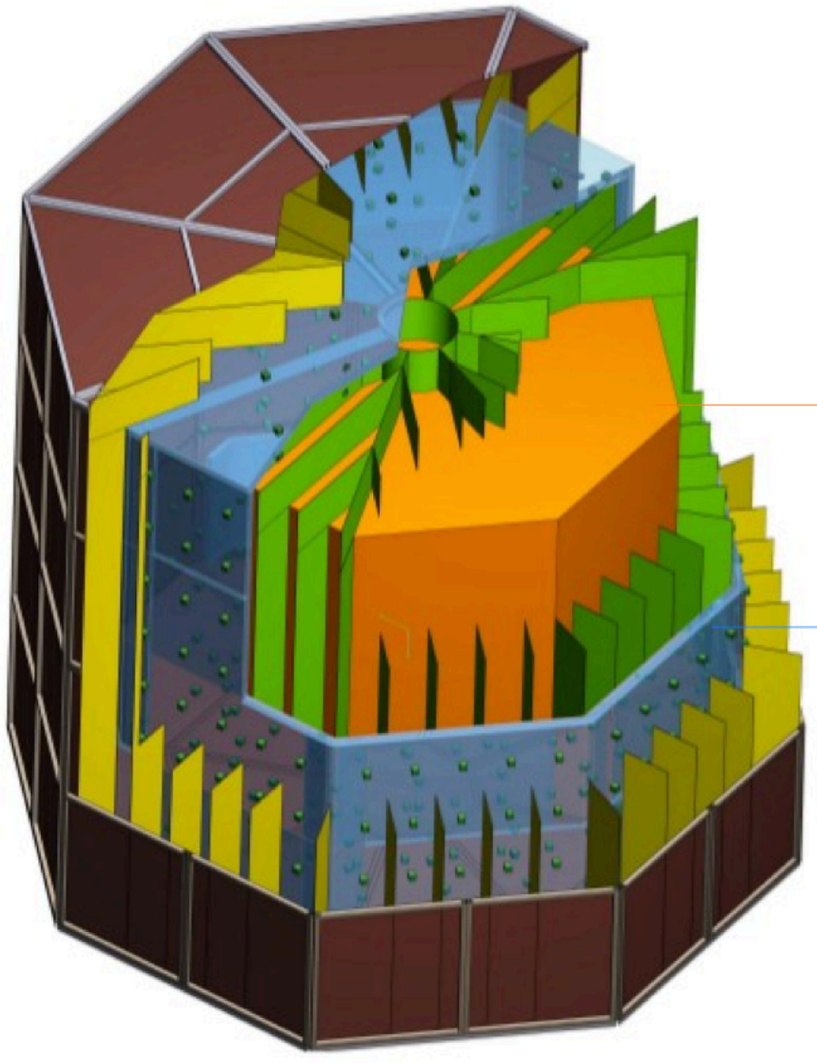


Motherboard (25 x 25 cm)
25 PDMs



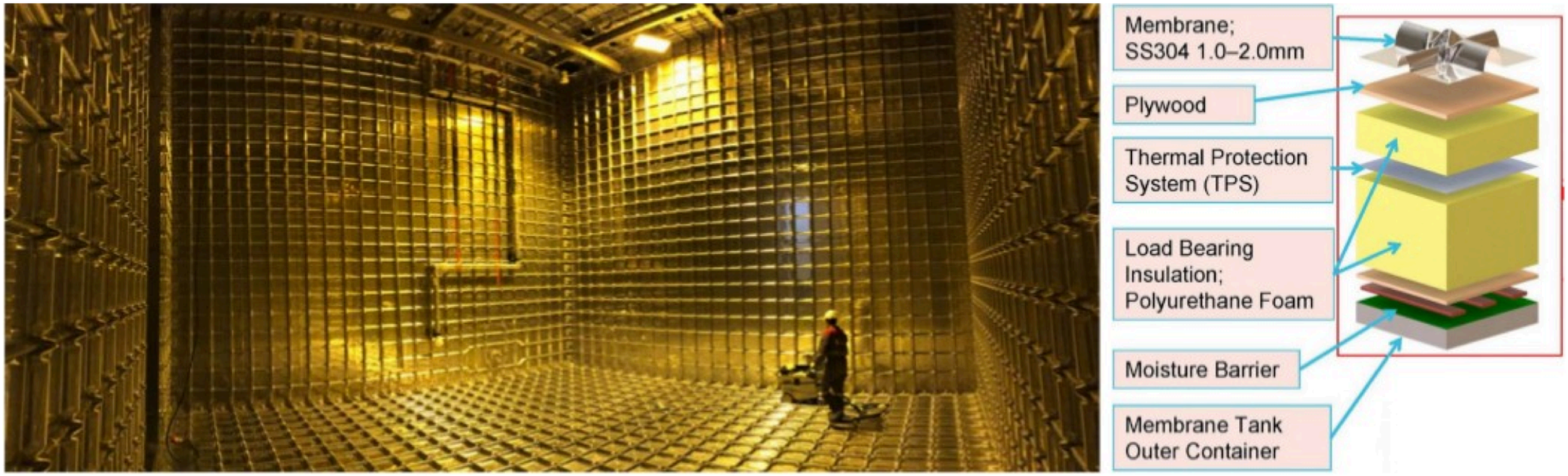
High Photon Detection
Efficiency (>45% at 420 nm)
Easily Integrated into tiles

Neutron Abatement



Material radio purity
Fiducialization: 50 to 20 tonne
Outer Neutron Veto

Cryostat

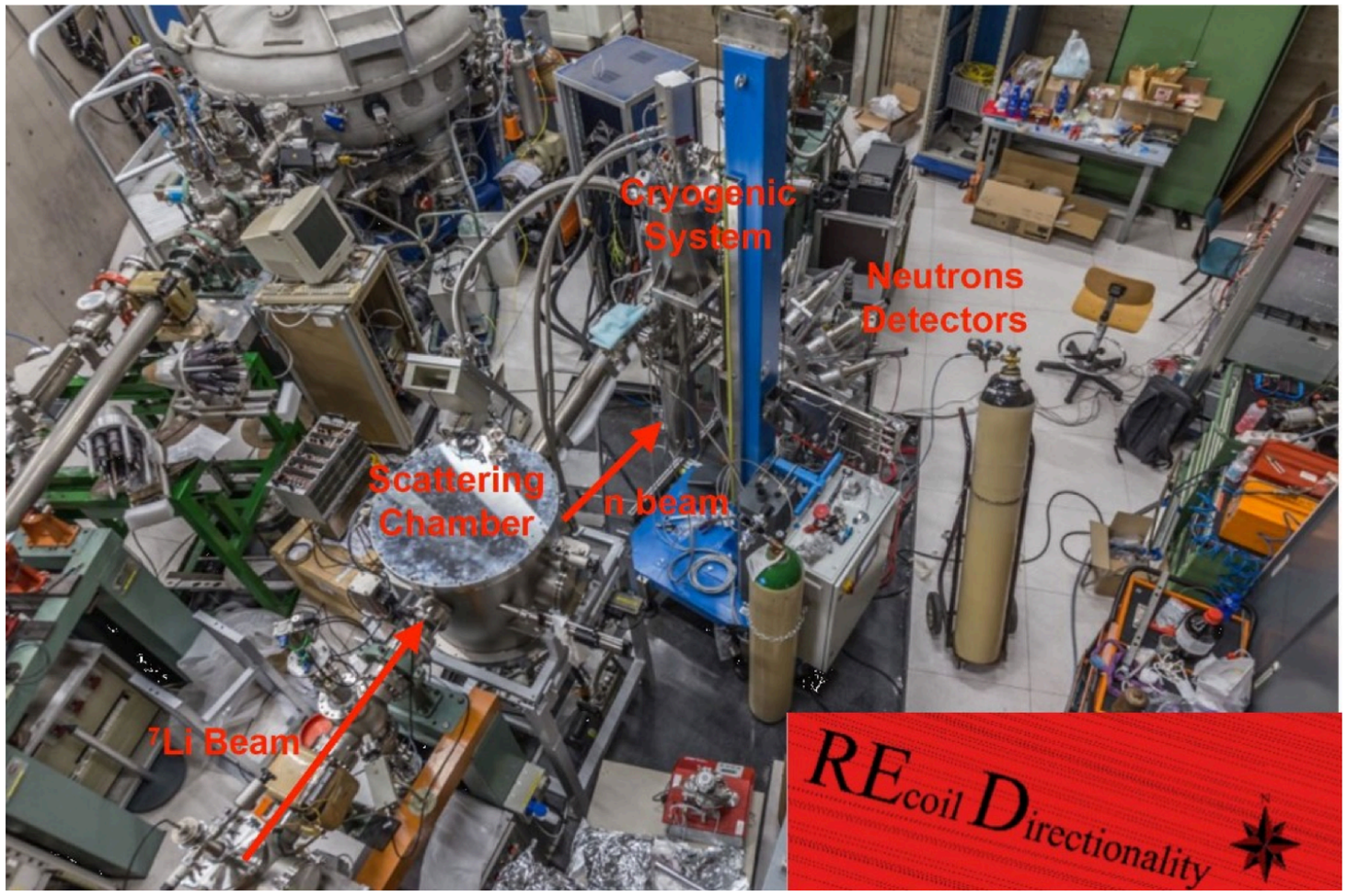


ProtoDune cryo (8x8 m2)
DarkSide + CERN neutrino platform partnership

Radioactivity from cryo faraway from UAr
SiPM out of UAr region

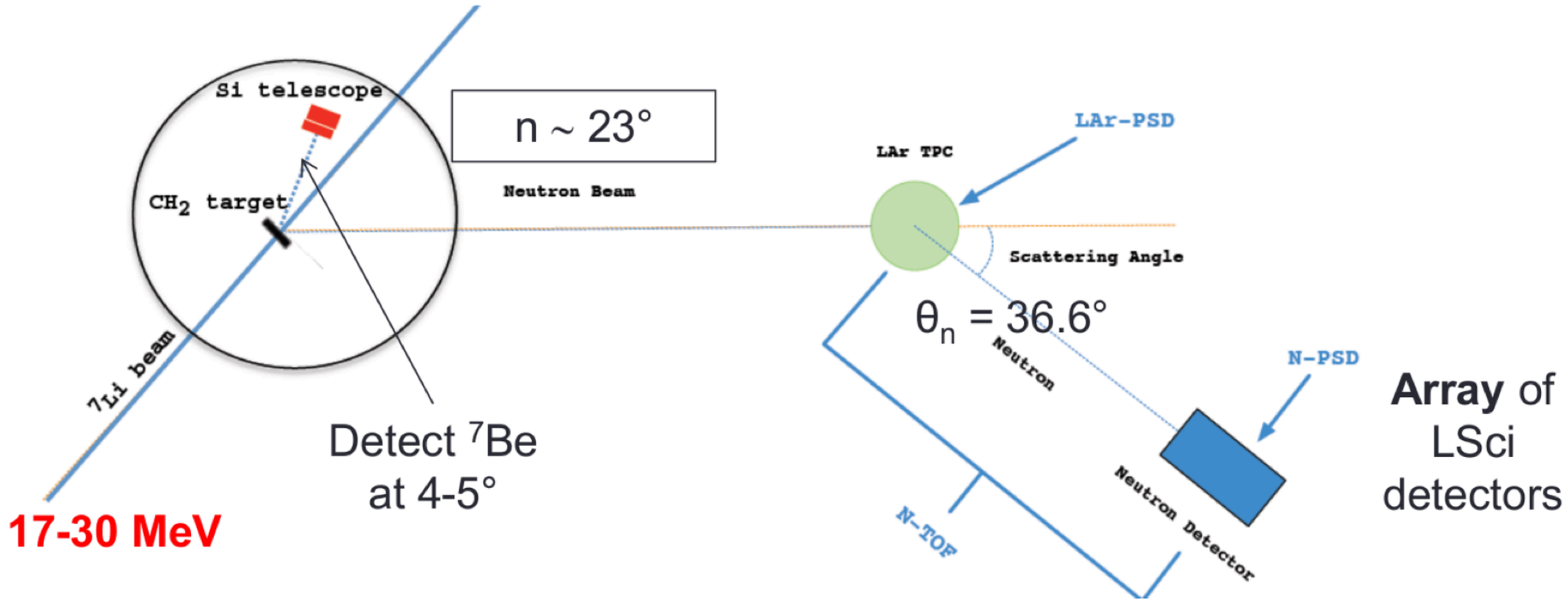
Recoil Energy Measurement

Recoil energy Directionality (Red)



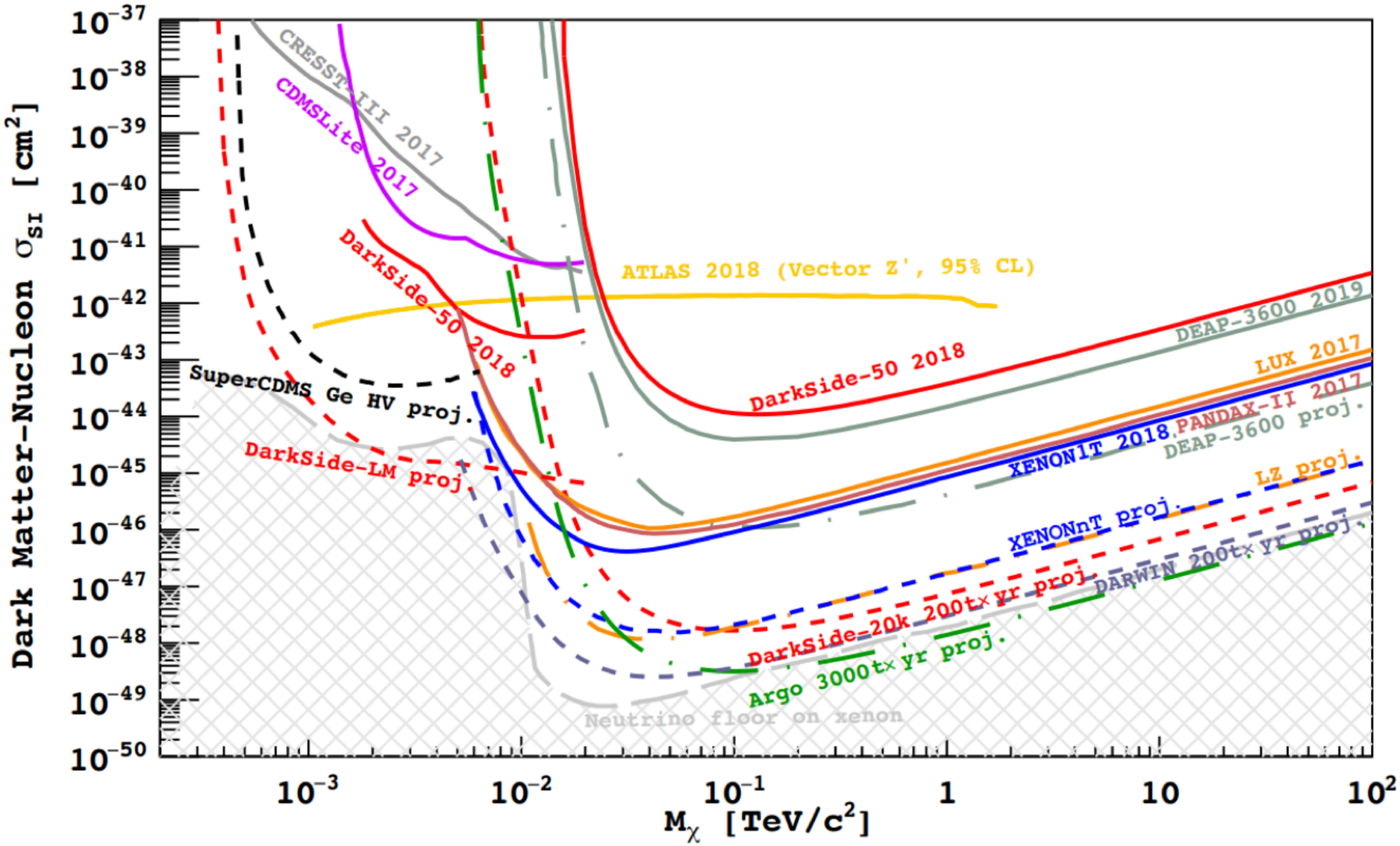
Running @ LNS (Catania - Italy)

ReD



- $^{7}Li(p,n)^{7}Be$ tagging ^{7}Be with Silicon detector
- Neutron scatters elastically off ^{40}Ar at TPC
- Tagged by Liquid Scintillator detector with PSD capabilities
    - Array of LSci so recoils parallel/perpendicular to the electric field are tagged

Conclusions



LAr dark matter search program will soon reach the neutrino floor in a background free mode.