Latest results for dark matter search in the DarkSide-50 experiment

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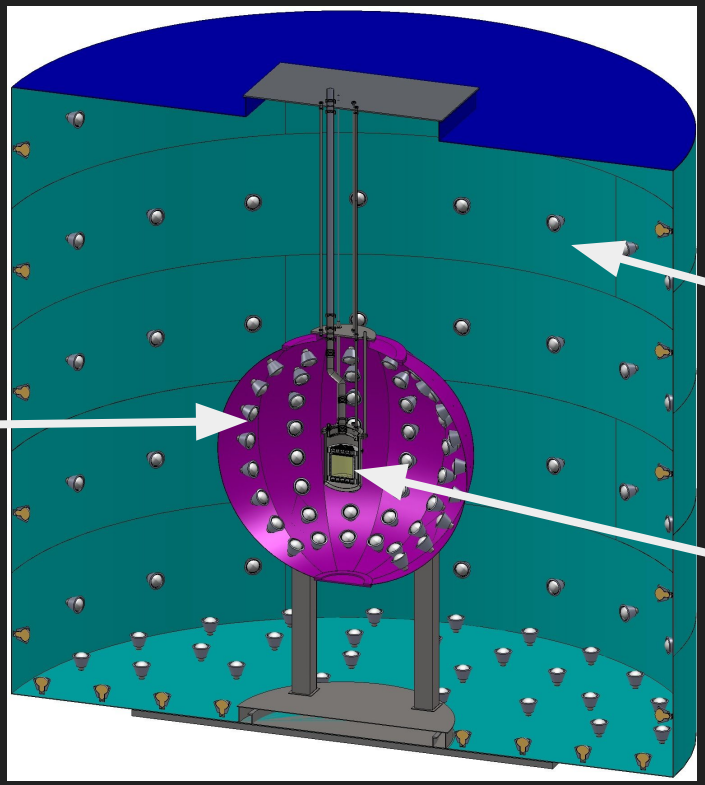
DarkSide-50 project

Dark matter direct detection with two-phase argon TPC.
Design goal: low background.

Located at LNGS, Italy under 3800 mwe overburden

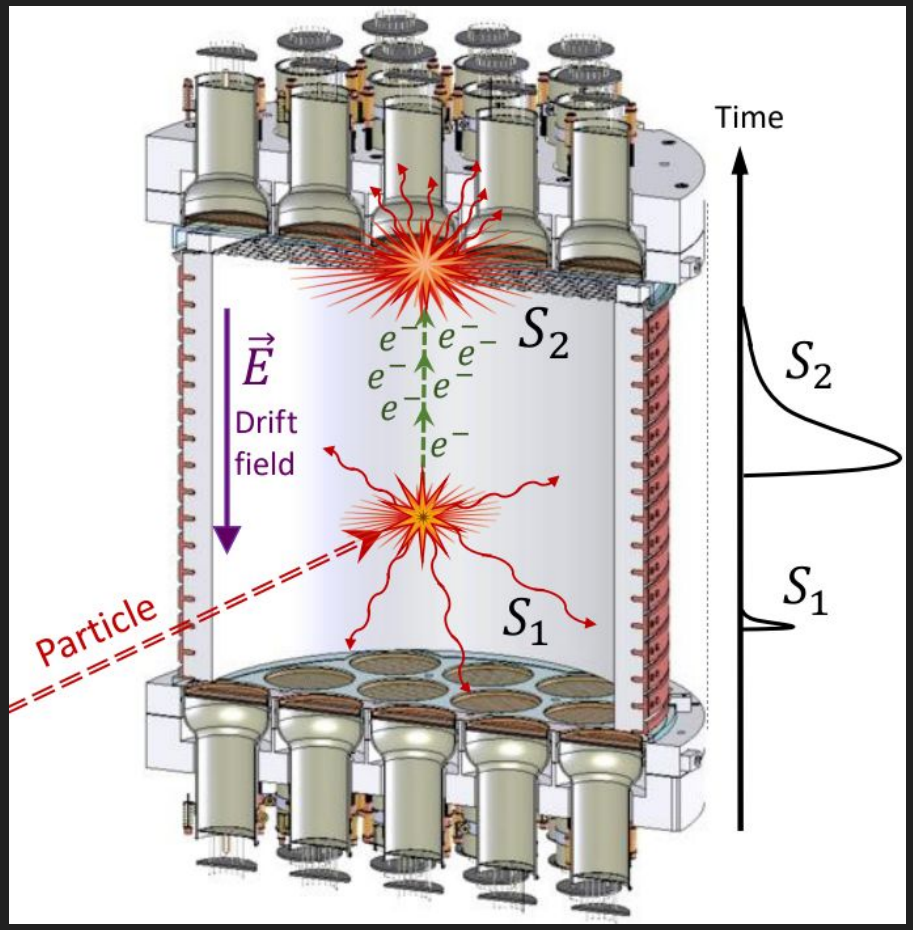
30 tonn of Borated liquid scintillator:
veto neutrons & gammas



1 kt water Cherenkov detector:
veto cosmic muons

50 kg Time Projection Chamber
detect dark matter

Dual-phase Argon TPC: detection principle



TPC is filled with 50kg of liquid Argon

DM particle interacts with Ar, producing recoil.
Recoil energy E_R goes to:

$$E_R = E_{Scintillation} + E_{Ionization} + E_{Thermal}$$

- Scintillation
  - Light detected by PMTs (S1)
- Ionization
  - electrons produce secondary scintillation signal in the Ar gas pocket on the top (S2)

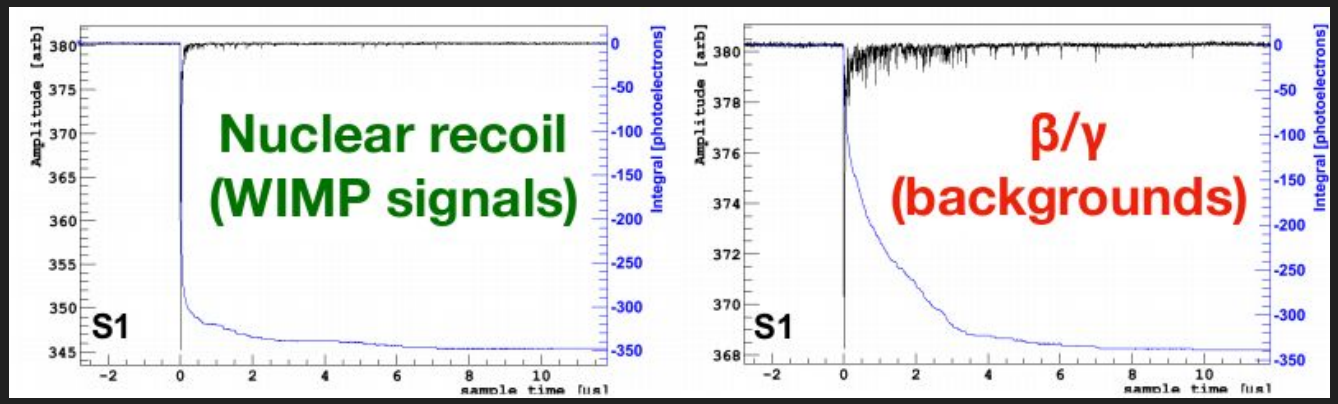
These signals provide:

- S1 pulse shape → discrimination for Nuclear/electron recoil
- S1, S2 amplitudes → Recoil energy **E_R**
- S1 & S2 t_{drift} → **z** coordinate
- S2 pattern in the top PMTs → **xy** coordinates

Pulse Shape Discrimination (S1)

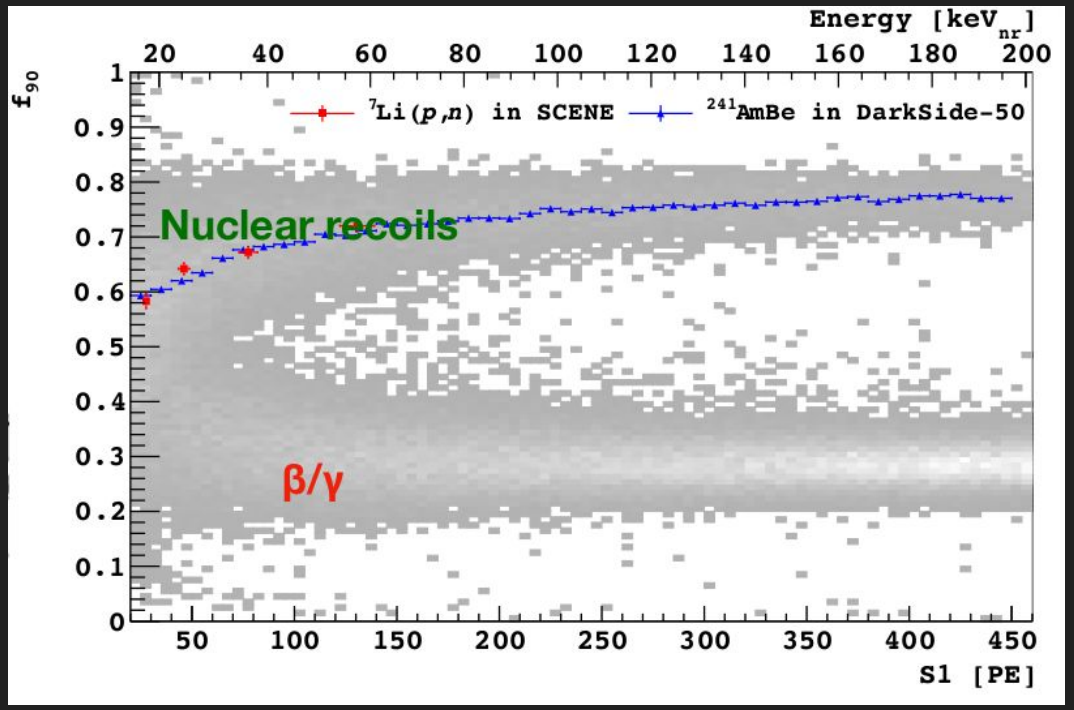
Nuclear and electron recoils produce different fractions of excited states in Argon:

$t_{singlet}$ ~ 7ns
$t_{triplet}$ ~ 1500ns



Discrimination parameter **f90**: fraction of S1 light collected in first 90ns

S1 and f90 define the WIMP search region



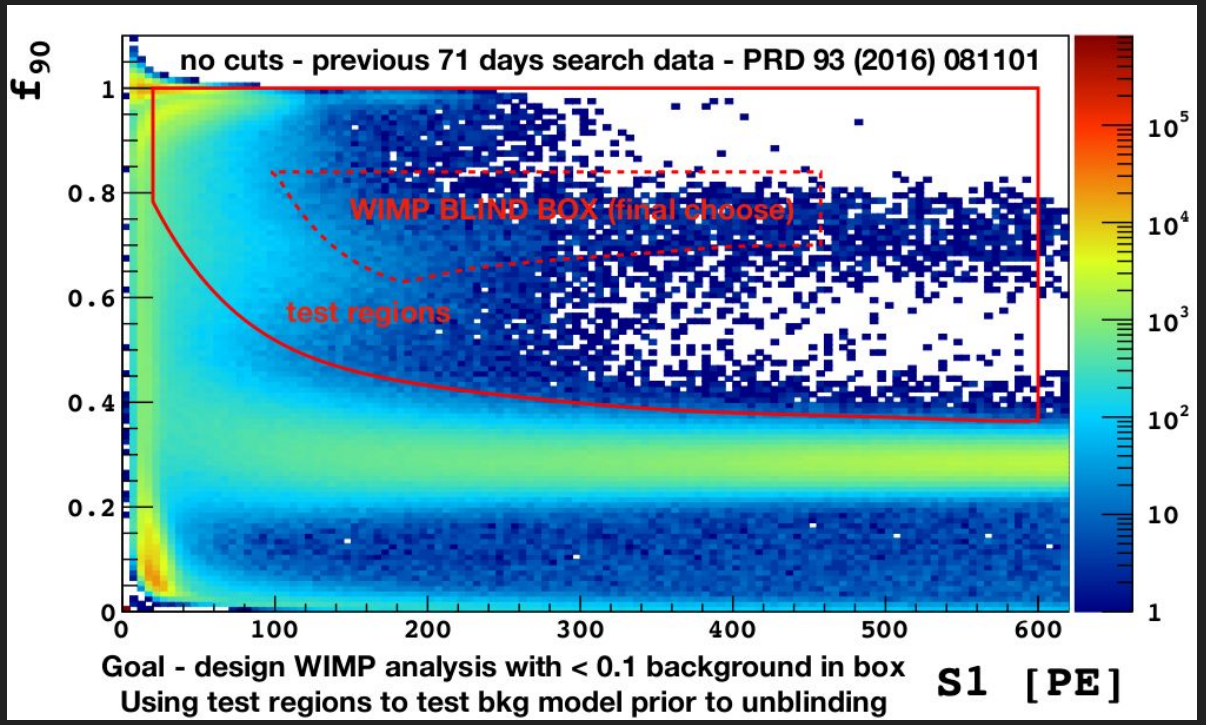
High Mass WIMP (M~100 GeV)

arXiv: 1802.07198

Blind Analysis strategy

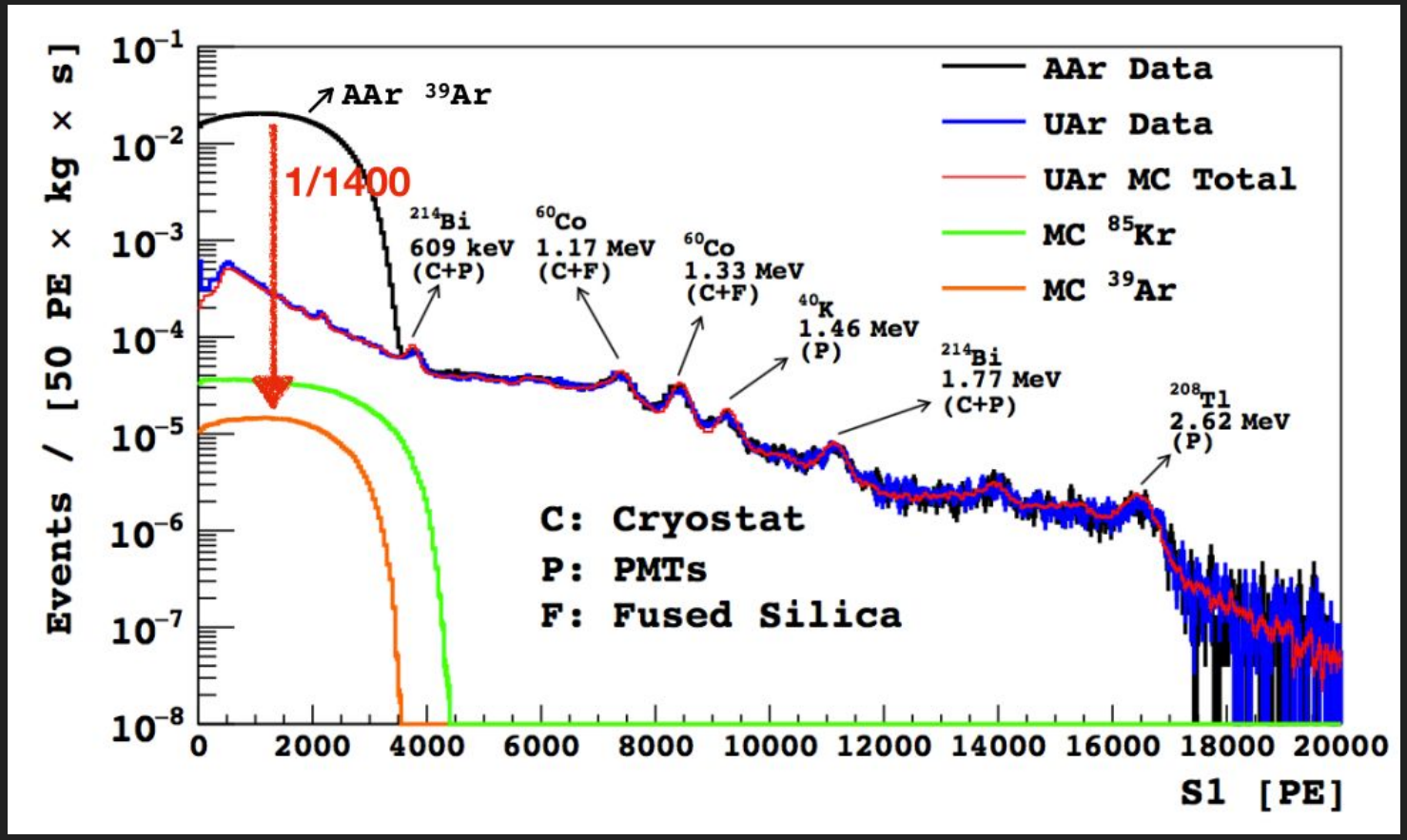
Analysis using **532** days of livetime data

- Define cuts, using BG model and data outside blinded region
- Unblind regions containing specific backgrounds to tune rejection criteria
- Choose final WIMP region (where expected bg <0.1 event)



- Unblind and see what's left there!
- Recalculate region to the WIMP parameters

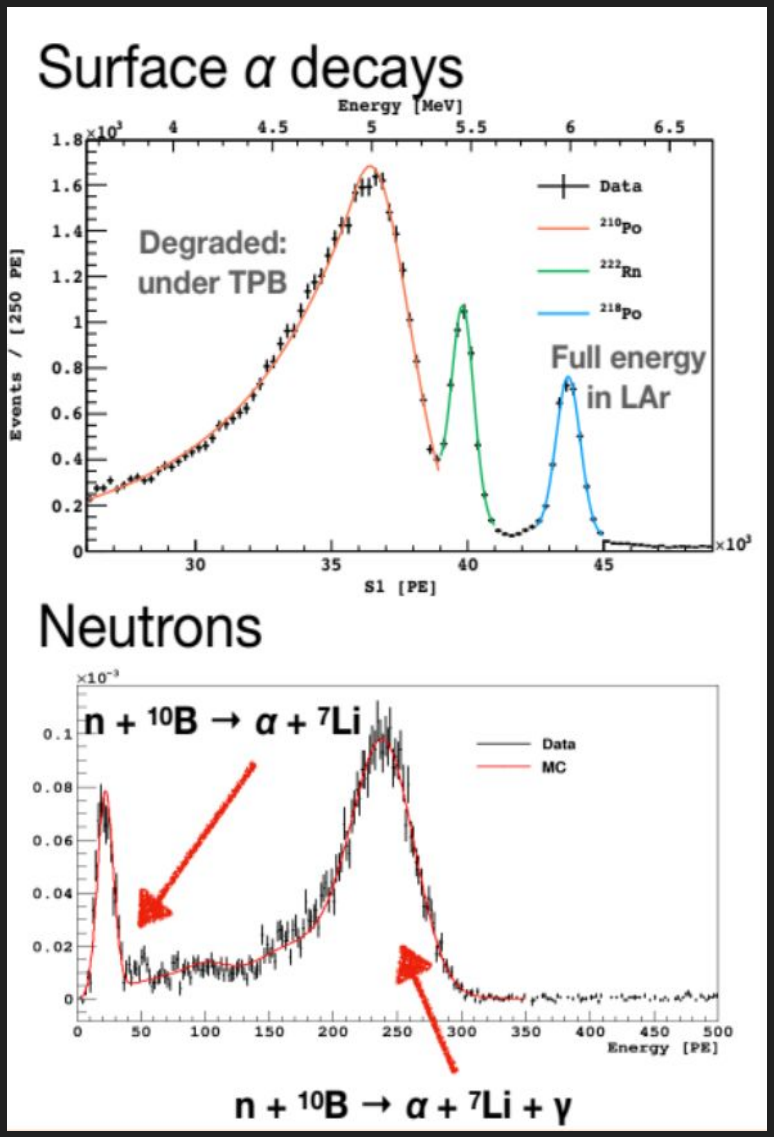
Background sources: intrinsic radioactivity



Atmospheric argon contains cosmogenic ^{39}Ar isotope (beta decay, t~270 years).

Solution: use underground argon, where ^{39}Ar is mostly depleted!

Background sources: alpha decays and neutrons



Small fraction at low energies

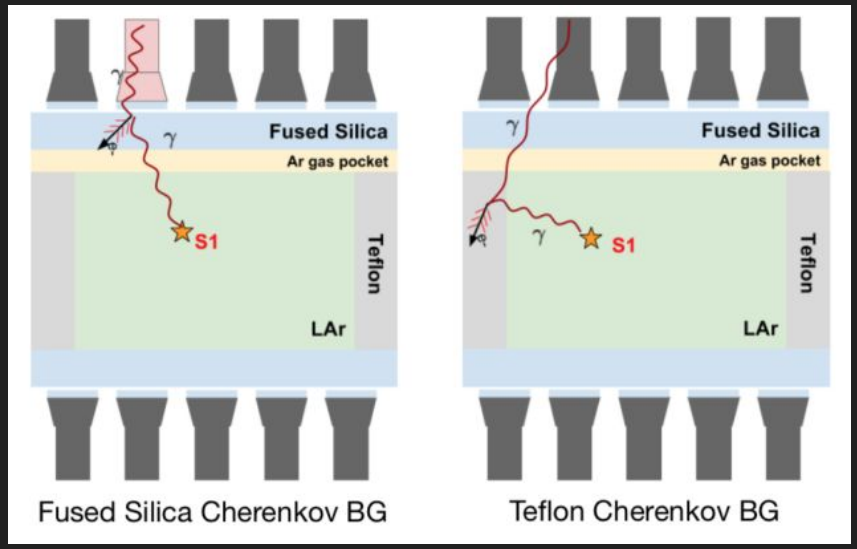
- Self-vetoing in DS-50!
- Small or no S2
- Long S2 tail from TPB fluorescence

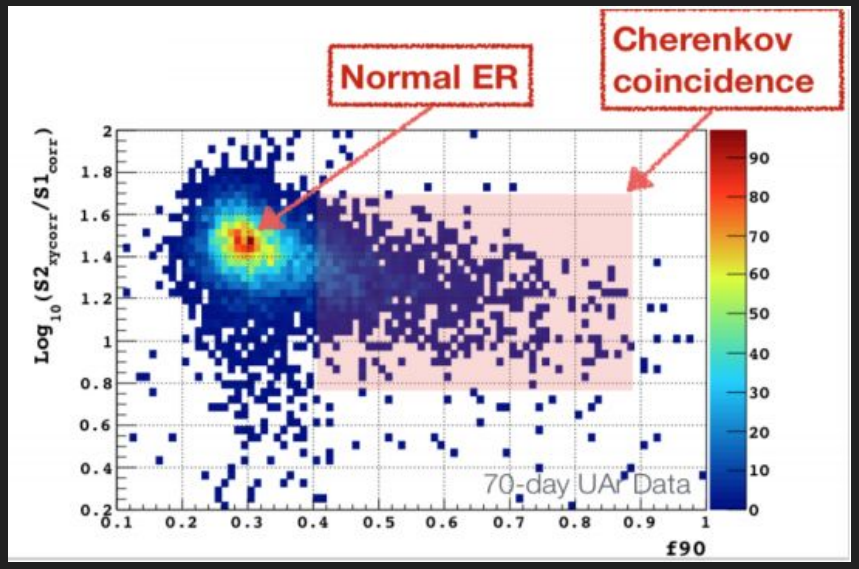
- TPC: multi-scatter
- LS Veto, calibrated with AmBe & AmC neutron sources
- Cosmogenics: Water Cherenkov Veto

Background sources: ER+Cherenkov

Electron recoil+Cherenkov can mimic the S1 with high f90

This is important background source, tricking our Pulse Shape Discrimination



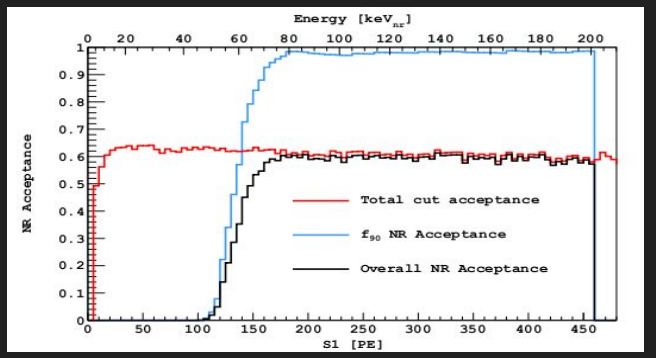


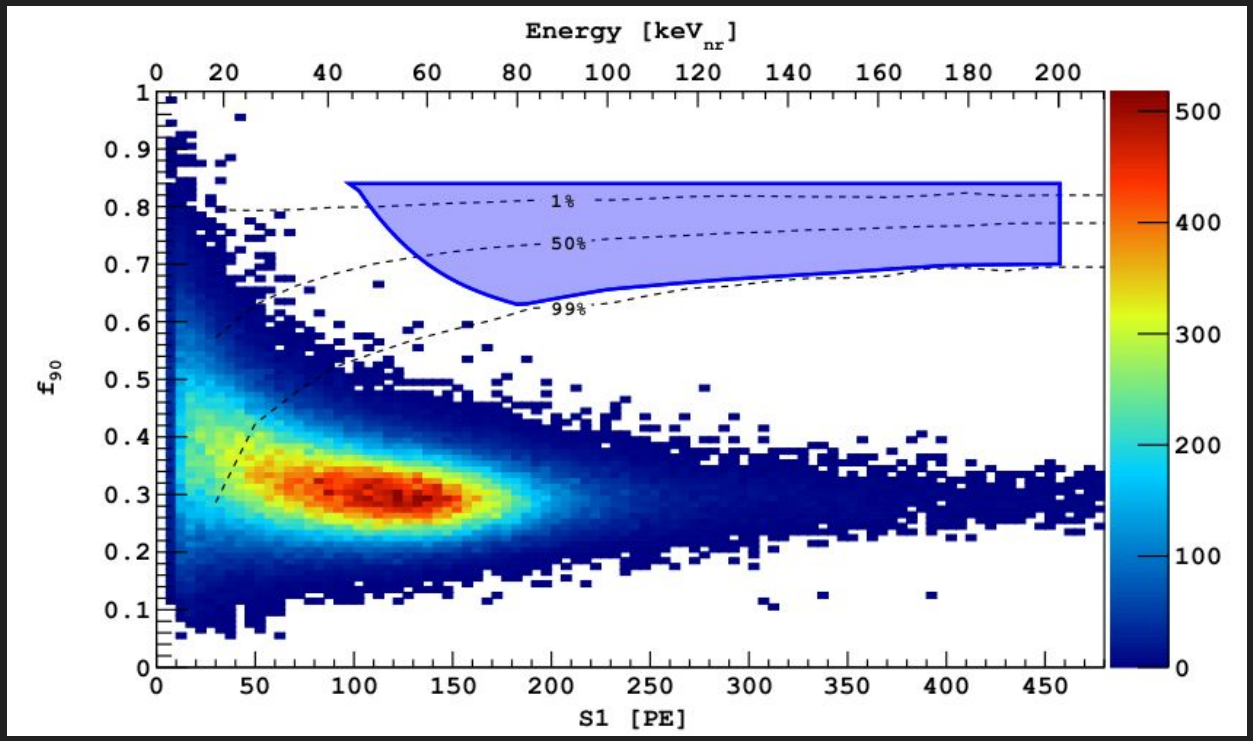
Rejection:

- S1 signal localized in one PMT
- S1/S2 ratio cut
- Change signal region to mitigate this BG

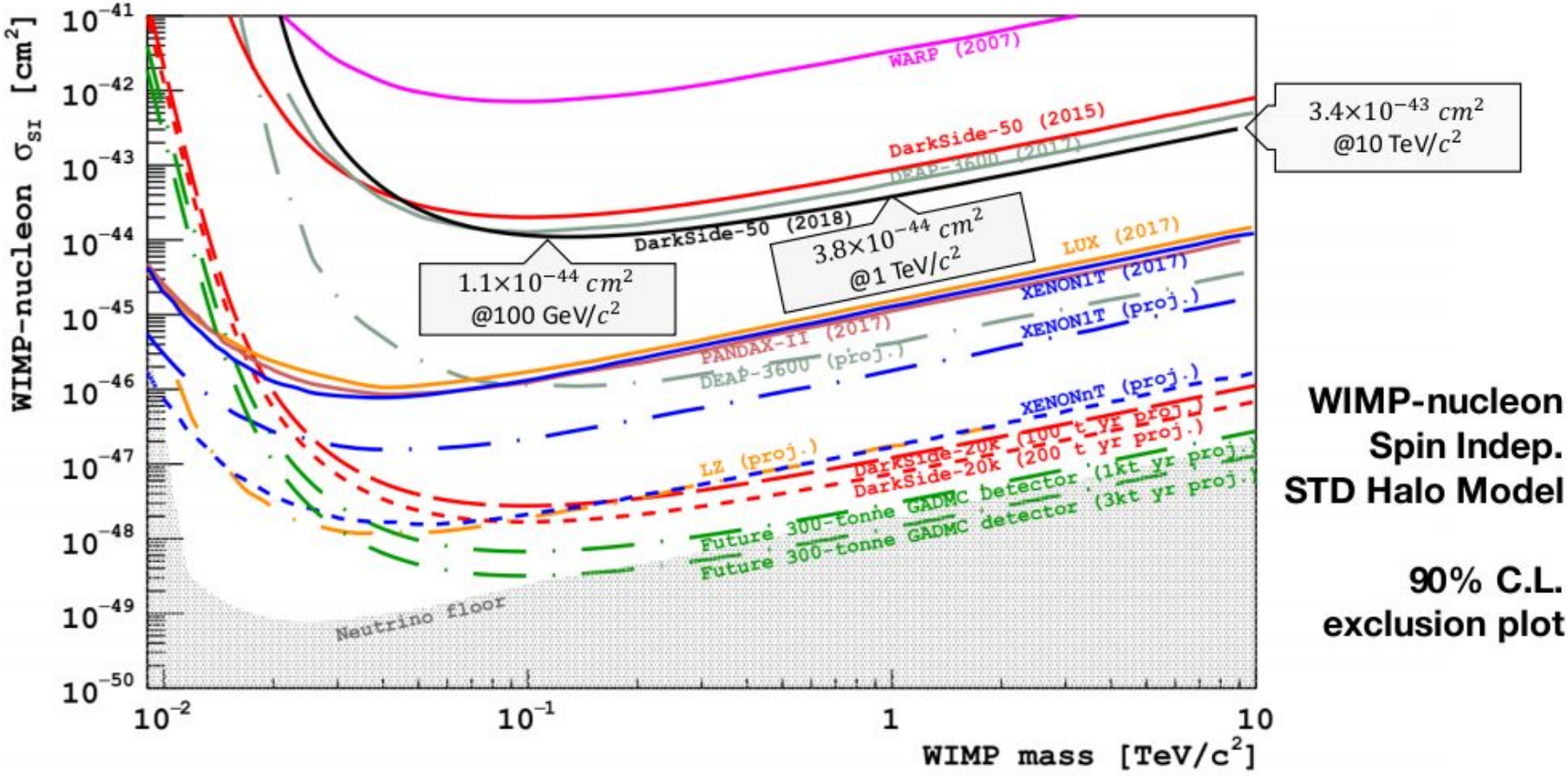
Box opening

Background	Events surviving all cuts
Surface Type 1	0.0006 ± 0.0001
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





High Mass WIMP analysis result



Low Mass WIMP search (M<20 GeV)

arXiv: 1802.06994

Can we see the lighter WIMPs?

$$E_R = \frac{q^2}{2m_N} \leq \frac{2\mu_{\chi N}^2 v^2}{m_N}$$

$m_N^{Ar} \sim 37$ GeV

For $m_\chi = 10$ GeV $\quad E_R \sim 1.4$ KeV

Using scintillation signal S1:

- light yield ~2 PE/keVnr (measured during calibration campaigns)

S1 threshold at 2 keVee = 10 keVnr

We'll not see the S1 signal from such events.

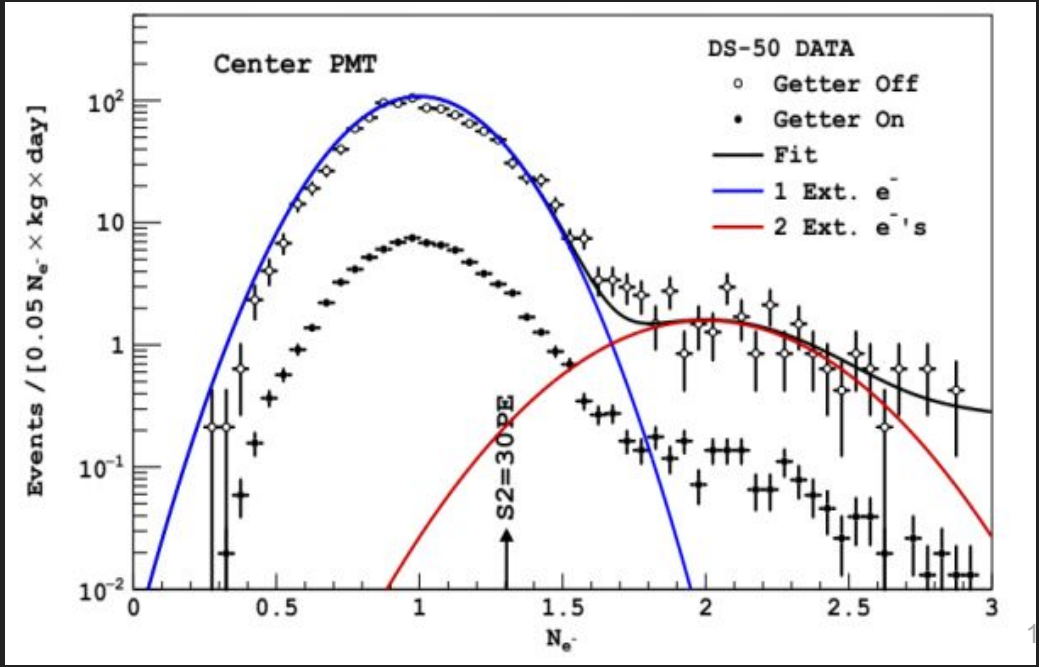
Can we use S2? Yes, but we need to define energy scale.

DS50 is sensitive to single ionization electrons!

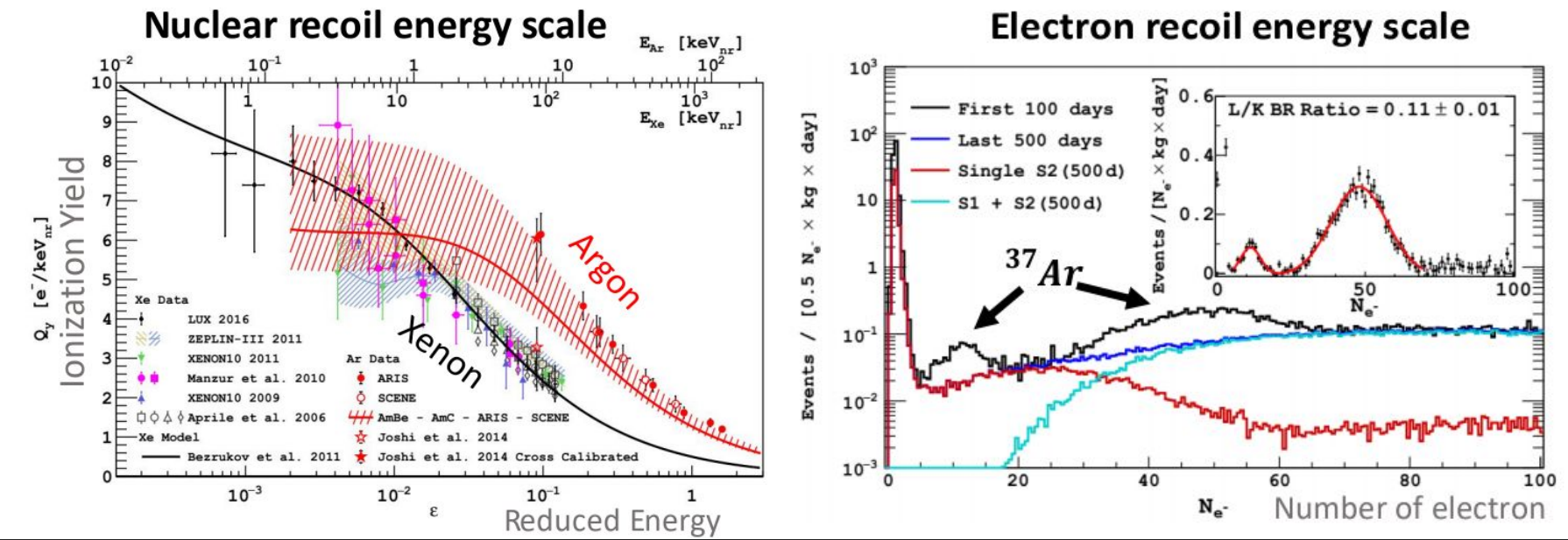
S2 charge yield = 23 PE/e

But we lose values for selection:

- PSD
- z reconstruction
- S1/S2



Energy scale for S2



S2:

- charge yield ~6 e-/keVnr
- electrolum. yield ~23 PE/e-

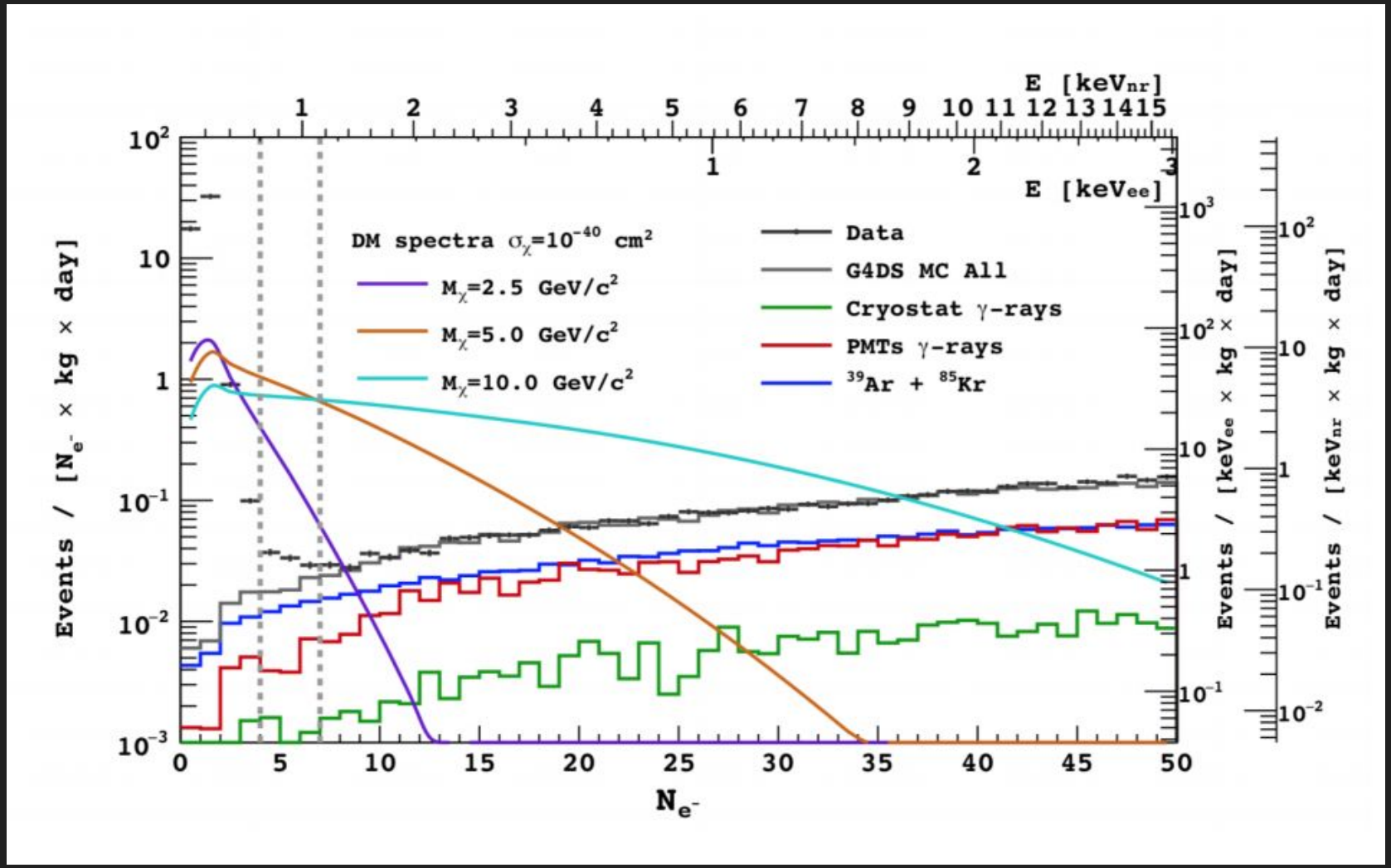
S2 ionization signal threshold at
<0.1 keVee = 0.4 keVnr

S1:

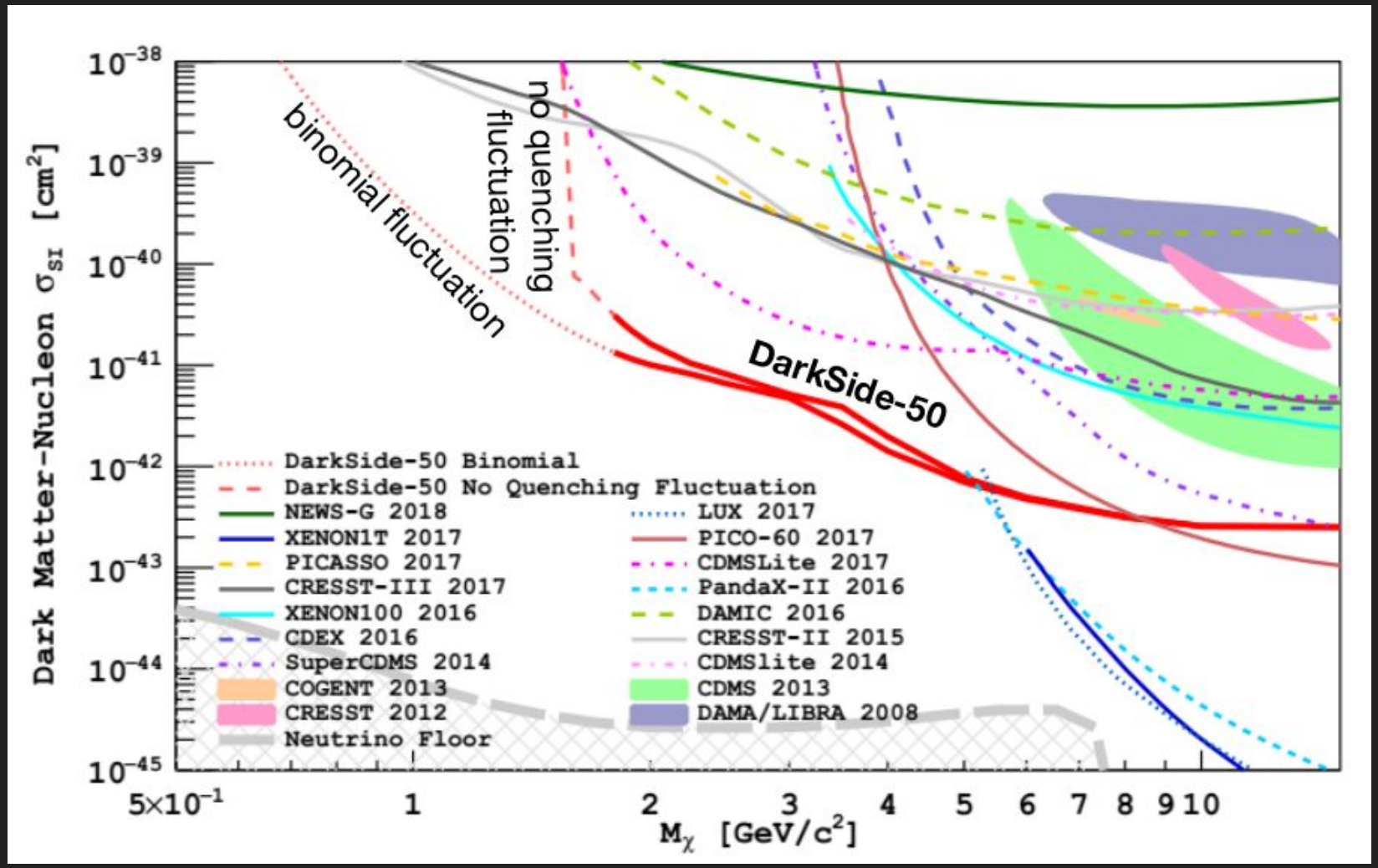
- light yield ~2 PE/keVnr

S1 scintillation signal threshold at
2 keVee = 10 keVnr

Background sources



Low mass WIMP search: Results



Light Dark Matter search (sub-GeV particles)

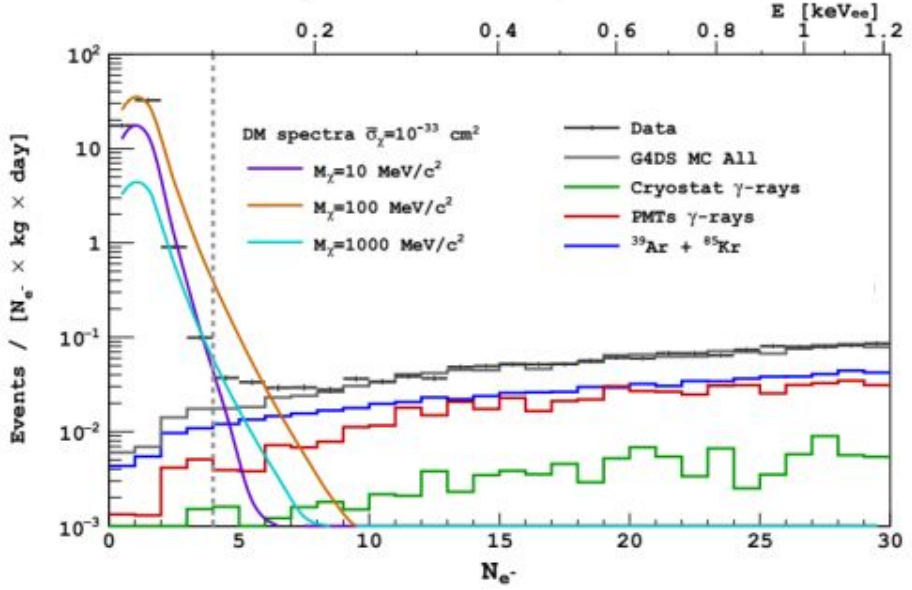
arXiv: 1802.06998

Light dark matter search

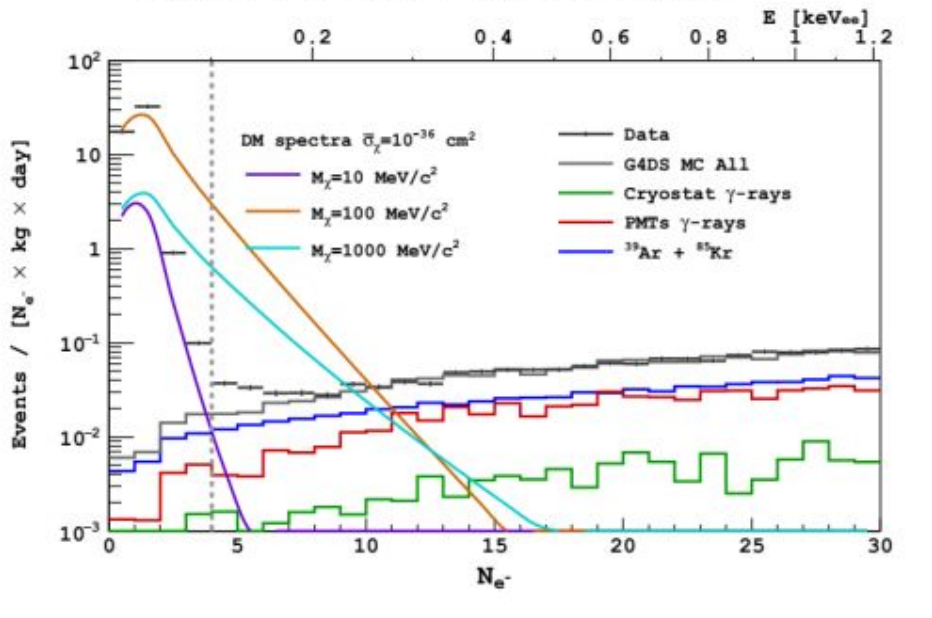
This analysis is the same as previous one, but we consider electron S2 signals.

Model: sub-GeV DM particles, interacting with electrons via some vector mediator. DM formfactor (F_{DM}) depends on the mediator mass. We consider two cases:

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

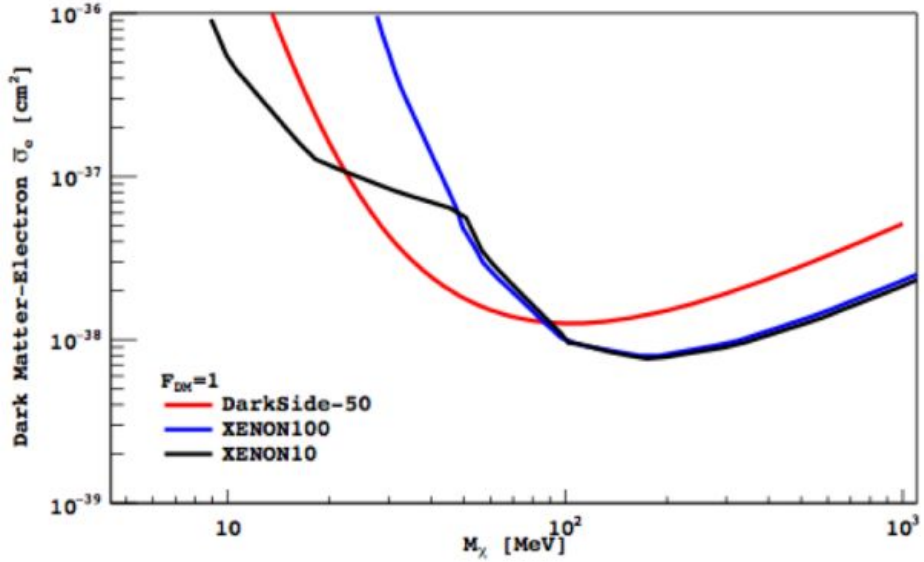


$F_{DM}(q^2) \propto 1/q^2$: "light mediator"



Results for light dark matter search: constraints

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



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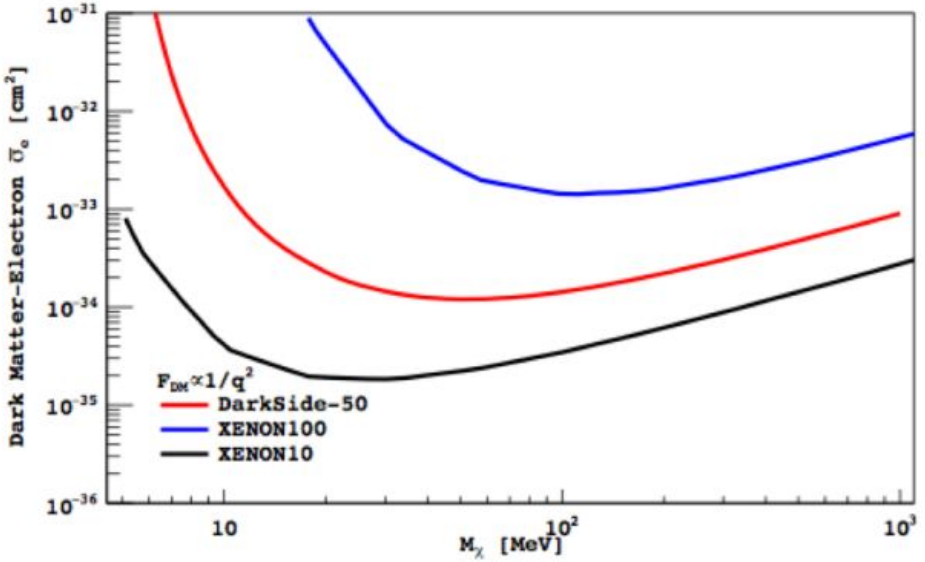

Conclusions

- DS-50 has reached low thresholds (<keVnr) and low background rate
- DS-50 is sensitive to
  - high mass (~100 GeV) WIMPs - 0 background
  - low mass (<20 GeV) WIMPs - best limits!
  - sub-GeV DM electron - improved limits

Bright future for DarkSide:

DS-20k - next generation experiment with **20t** of LAr.
Currently in preparation (expected start at 2021)