Searching for sub-GeV Dark Matter using liquid argon TPCs

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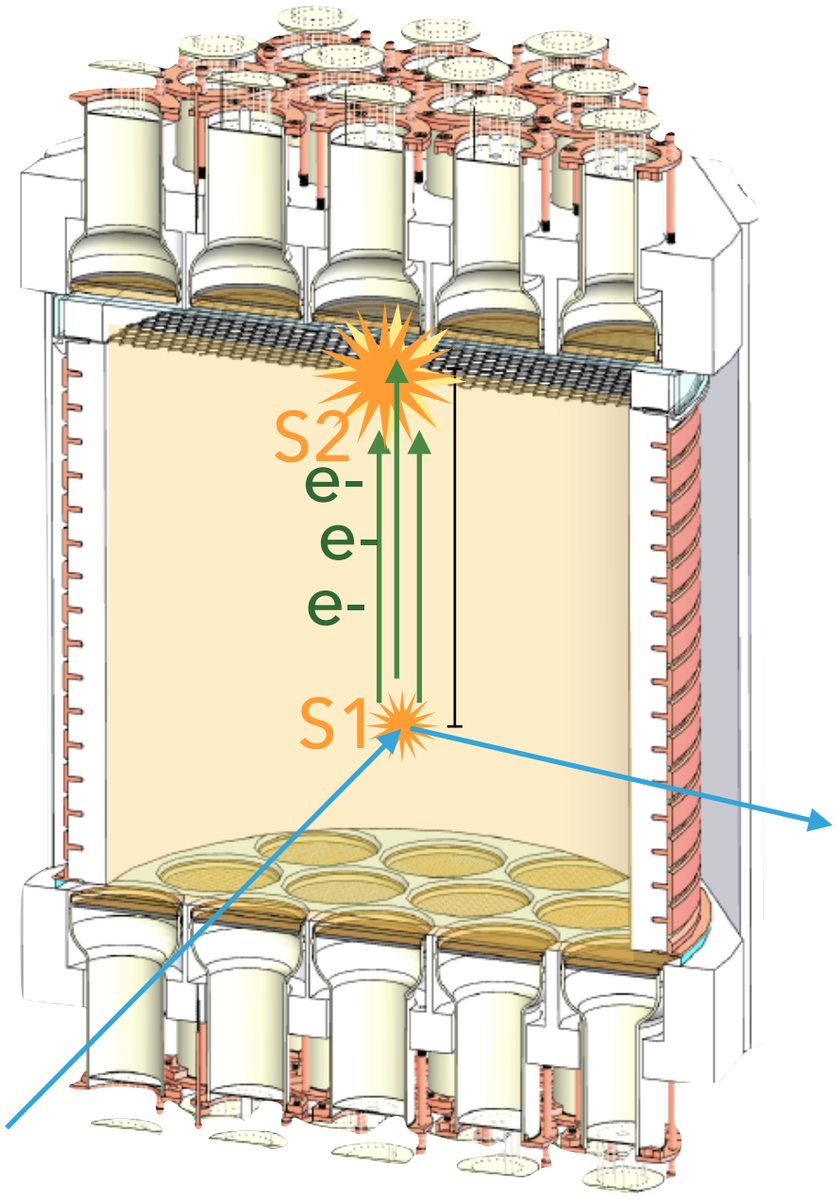
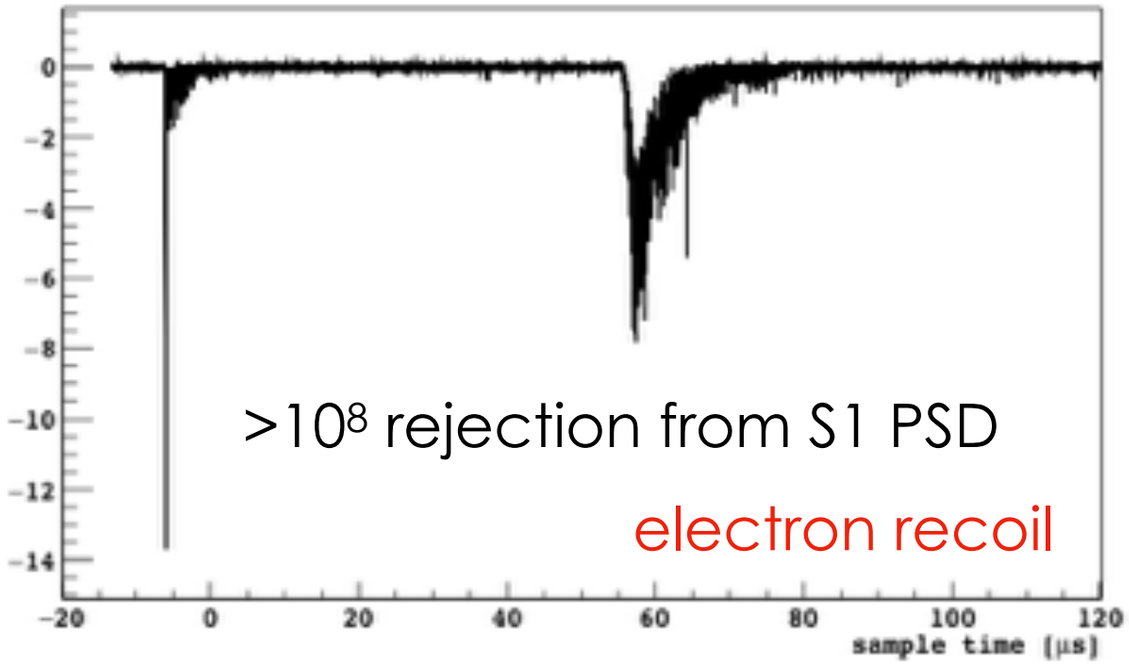
Princeton University

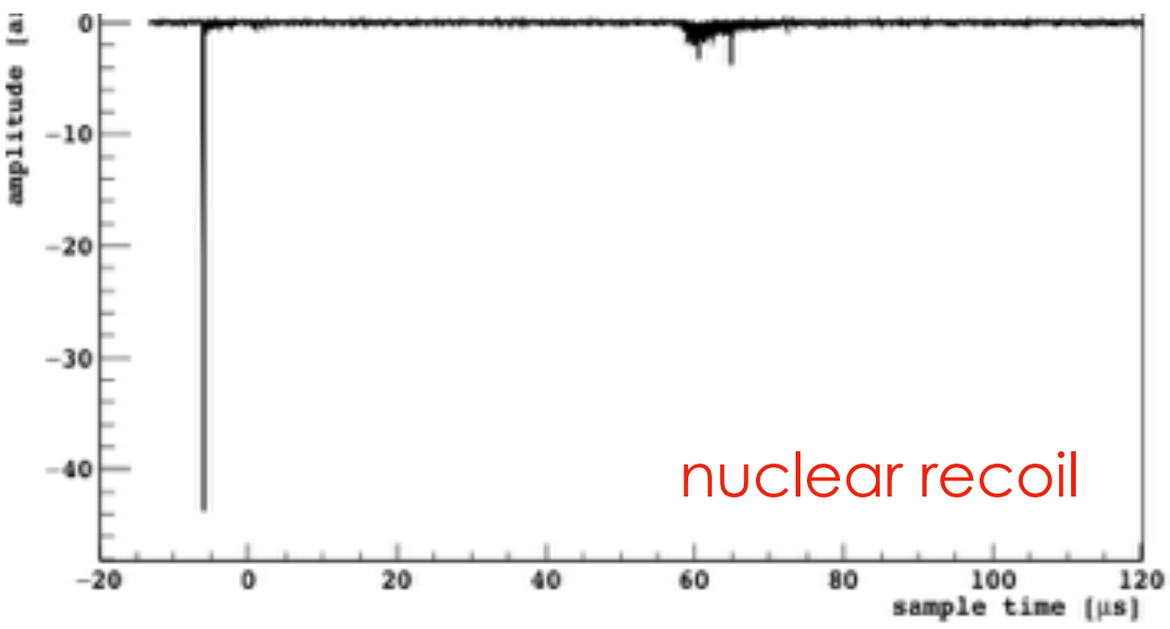
liquid argon TPC concept





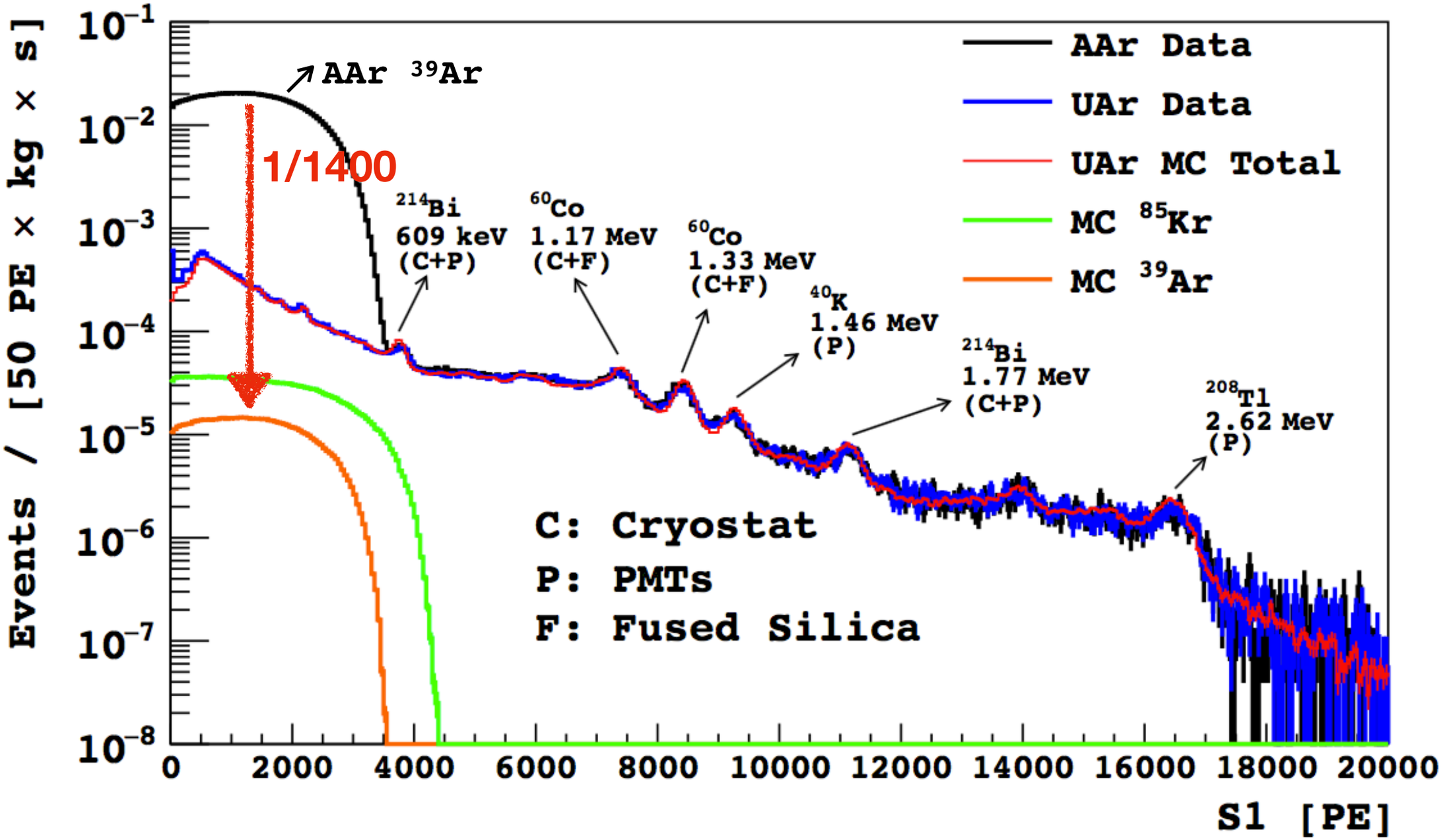
>10^8 rejection from S1 PSD

electron recoil

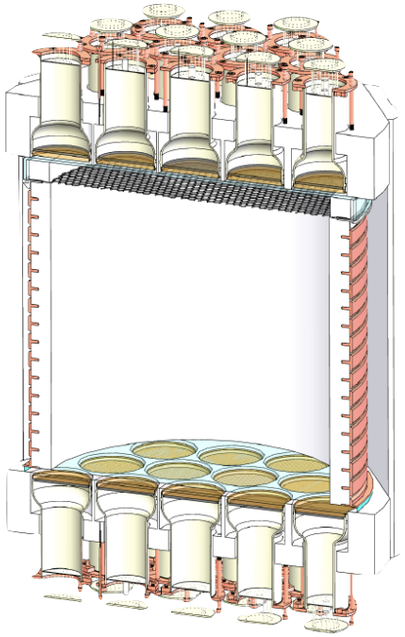


nuclear recoil

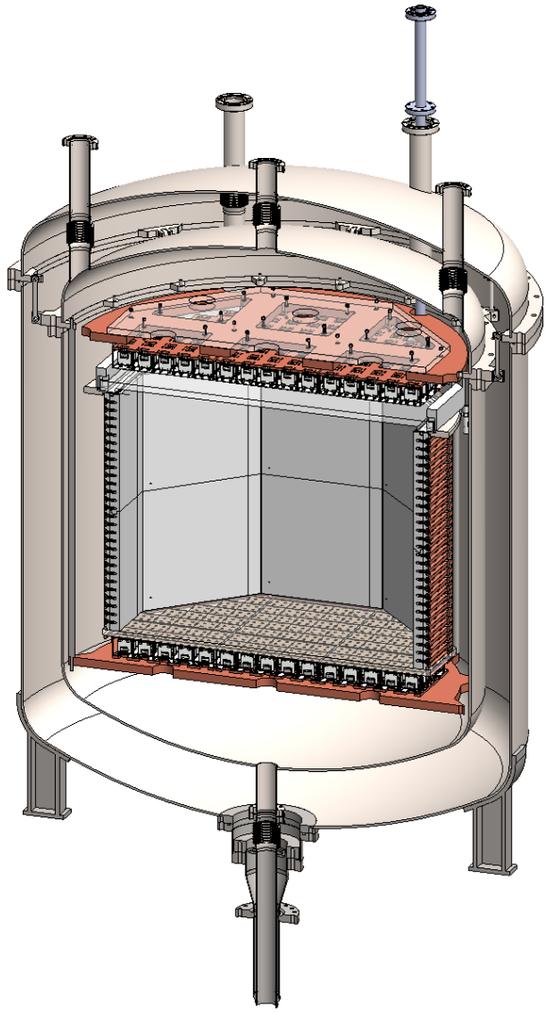
argon has a naturally occurring beta-emitting isotope, ^{39}Ar



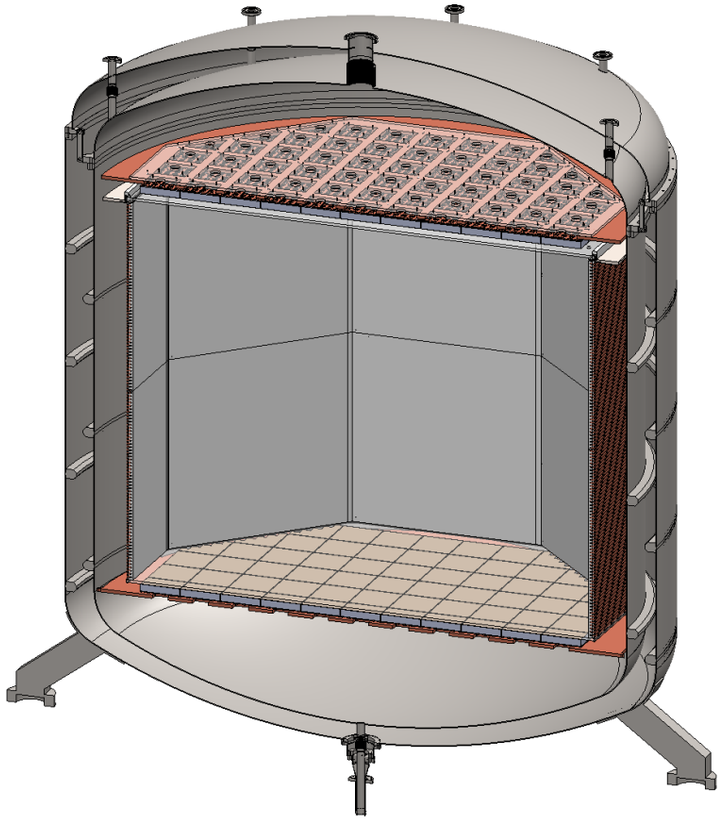
The DarkSide program



DarkSide-50
50 kg



DarkSide-prototype
1 tonne



DarkSide-20k
20 tonne

GADMC
200 tonne

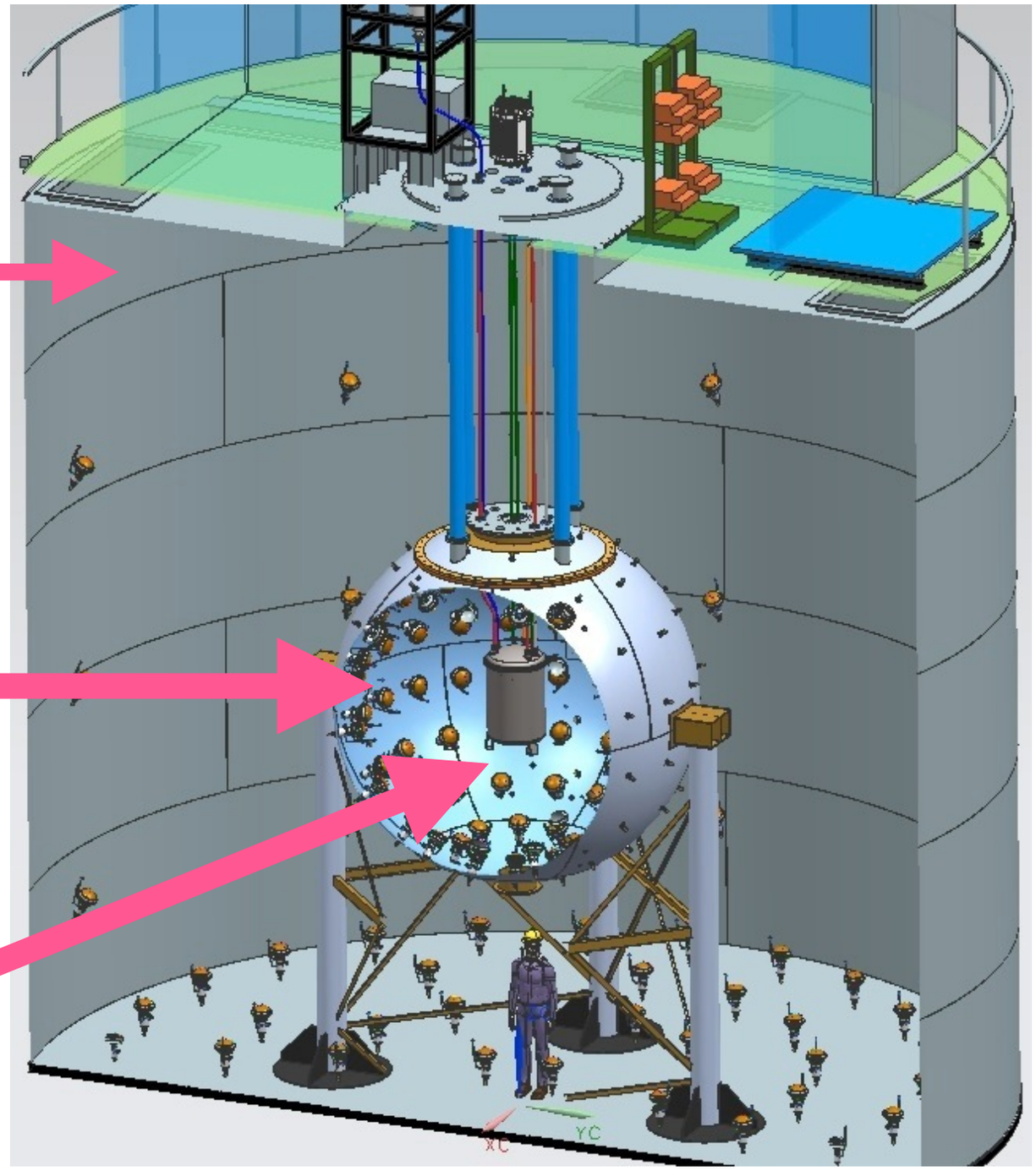
?

The DarkSide-50 detector

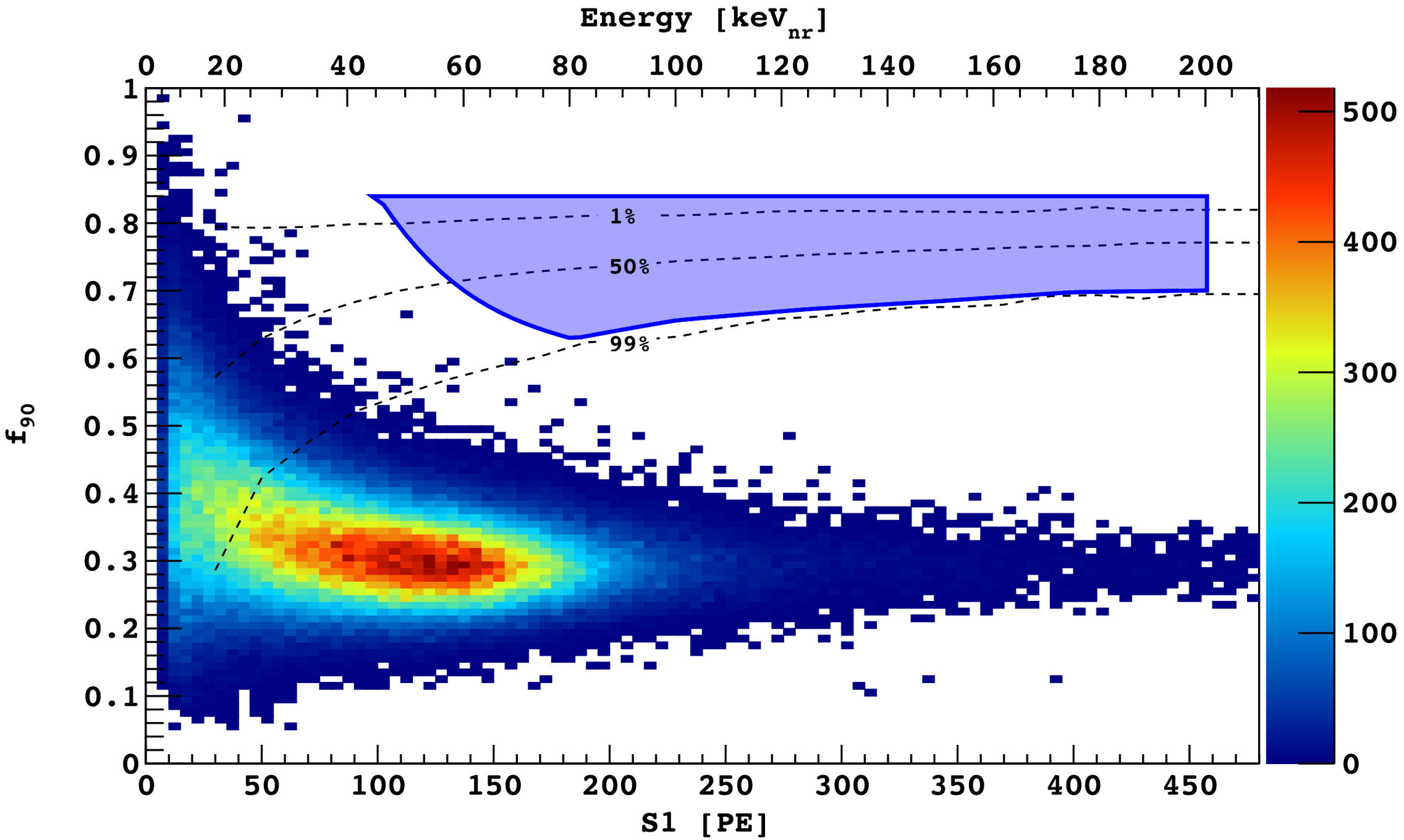
1,000-tonne Water Cherenkov
Cosmic Ray Veto

30-tonne Liquid Scintillator
Neutron and γ Veto

inner TPC



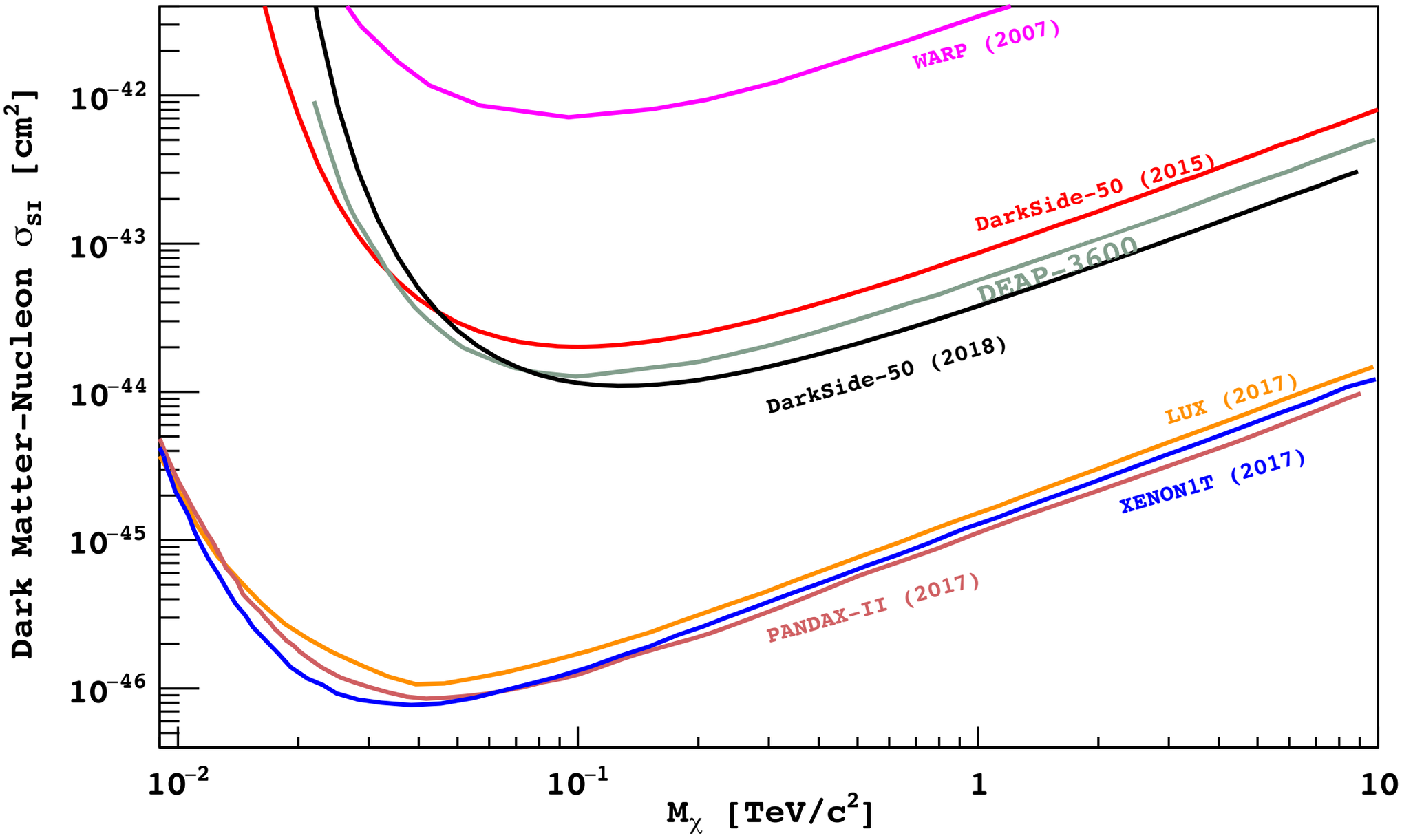
DarkSide-50 was designed for 100 GeV WIMPs



background-free 532 day exposure - blind analysis

arXiv: 1802.07198

DarkSide-50 532 day 90% C.L. exclusion

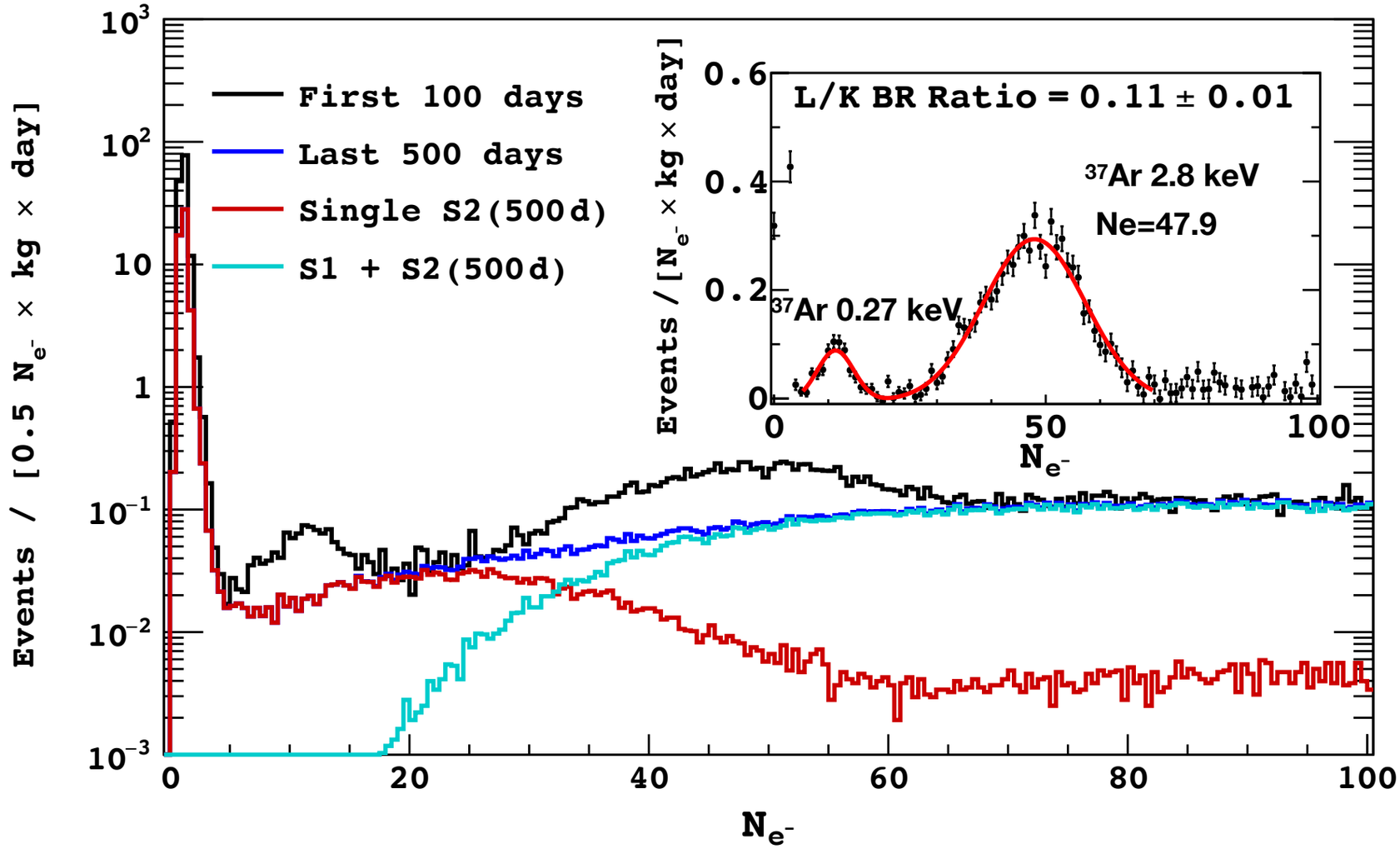


arXiv: 1802.07198

can we reduce the energy threshold?

S1 scintillation signal threshold at 2 keVee = 10 keVnr

S2 ionization signal threshold at <0.1 keVee = 0.4 keVnr



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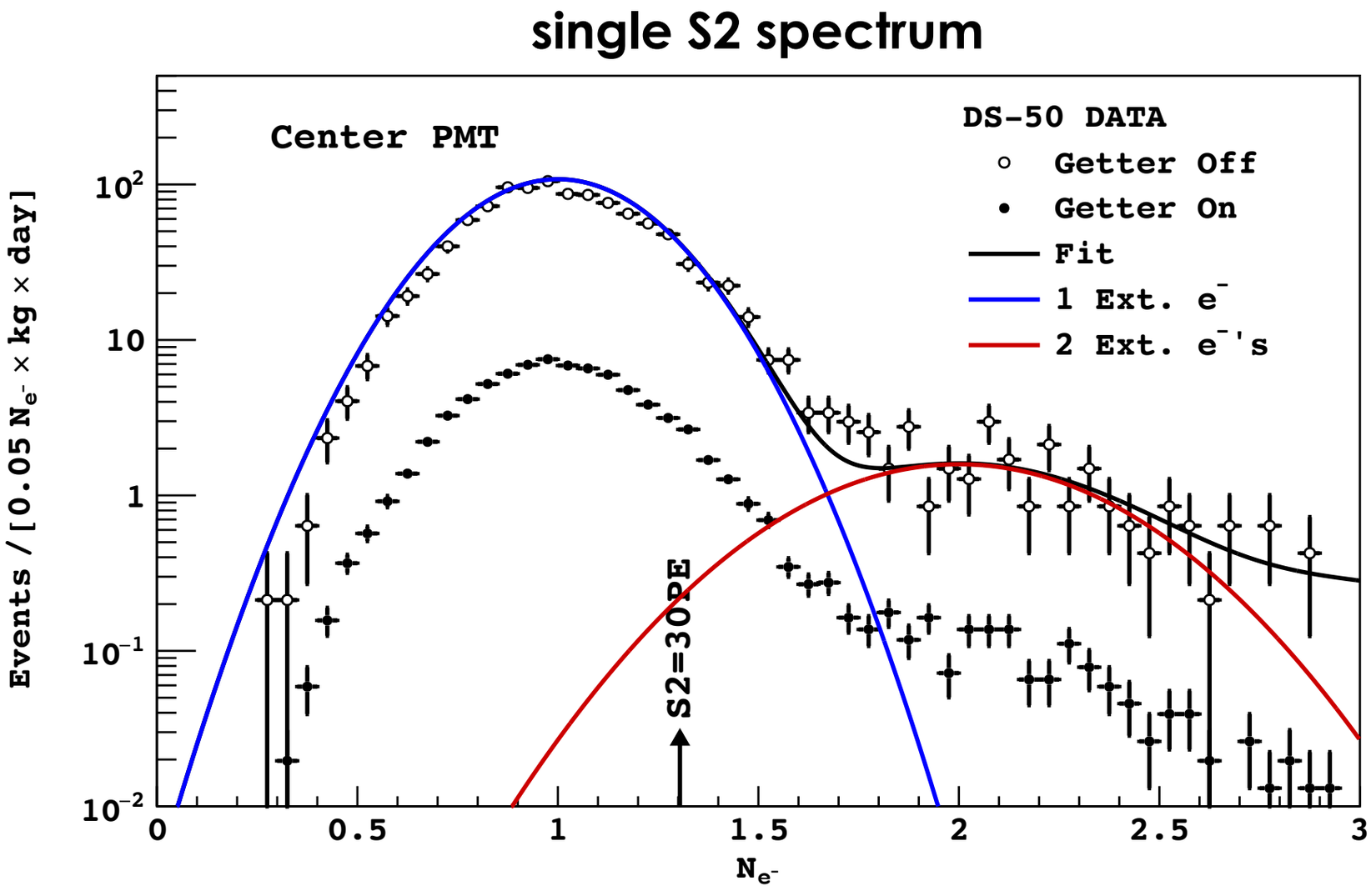


can we reduce the energy threshold?

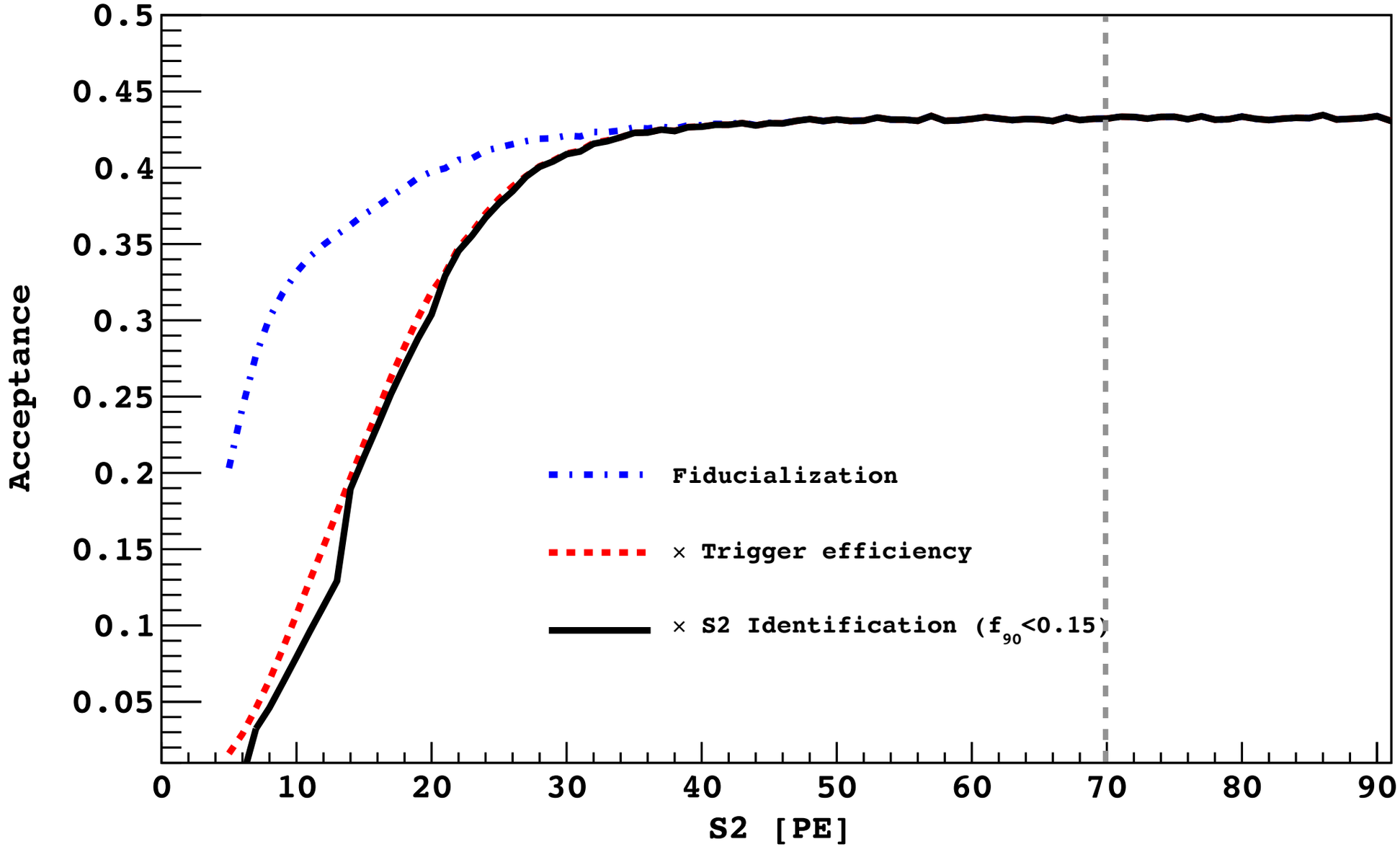
S1 scintillation signal threshold at 2 keVee = 10 keVnr

S2 ionization signal threshold at <0.1 keVee = 0.4 keVnr

- PMTs have negligible dark rate at 88 K
- center PMT sees ~23 photoelectrons per electron
  - high trigger efficiency
  - single electron sensitivity
- lose PSD, Z-reconstruction, and S2/S1

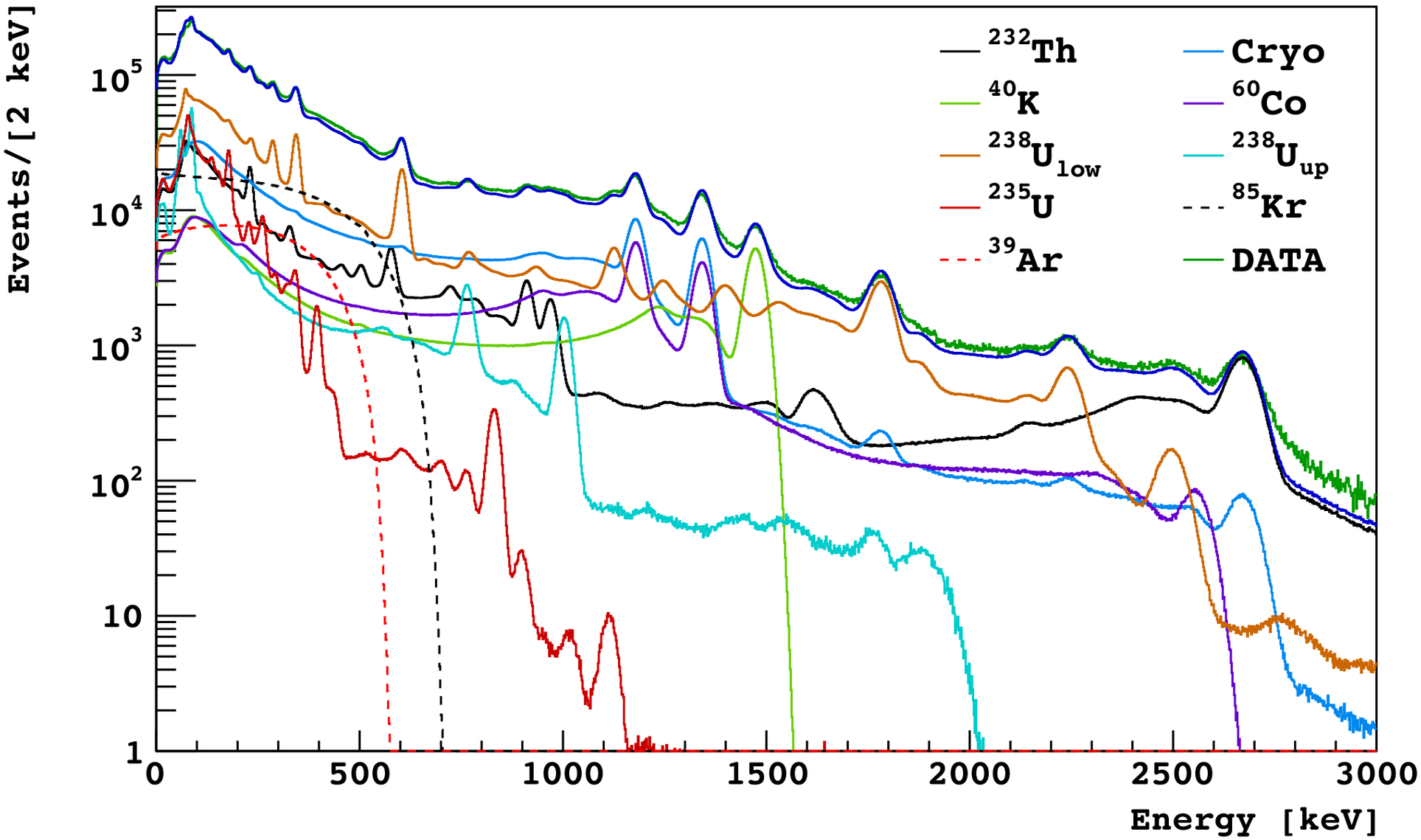
trigger efficiency

estimated using data and MC

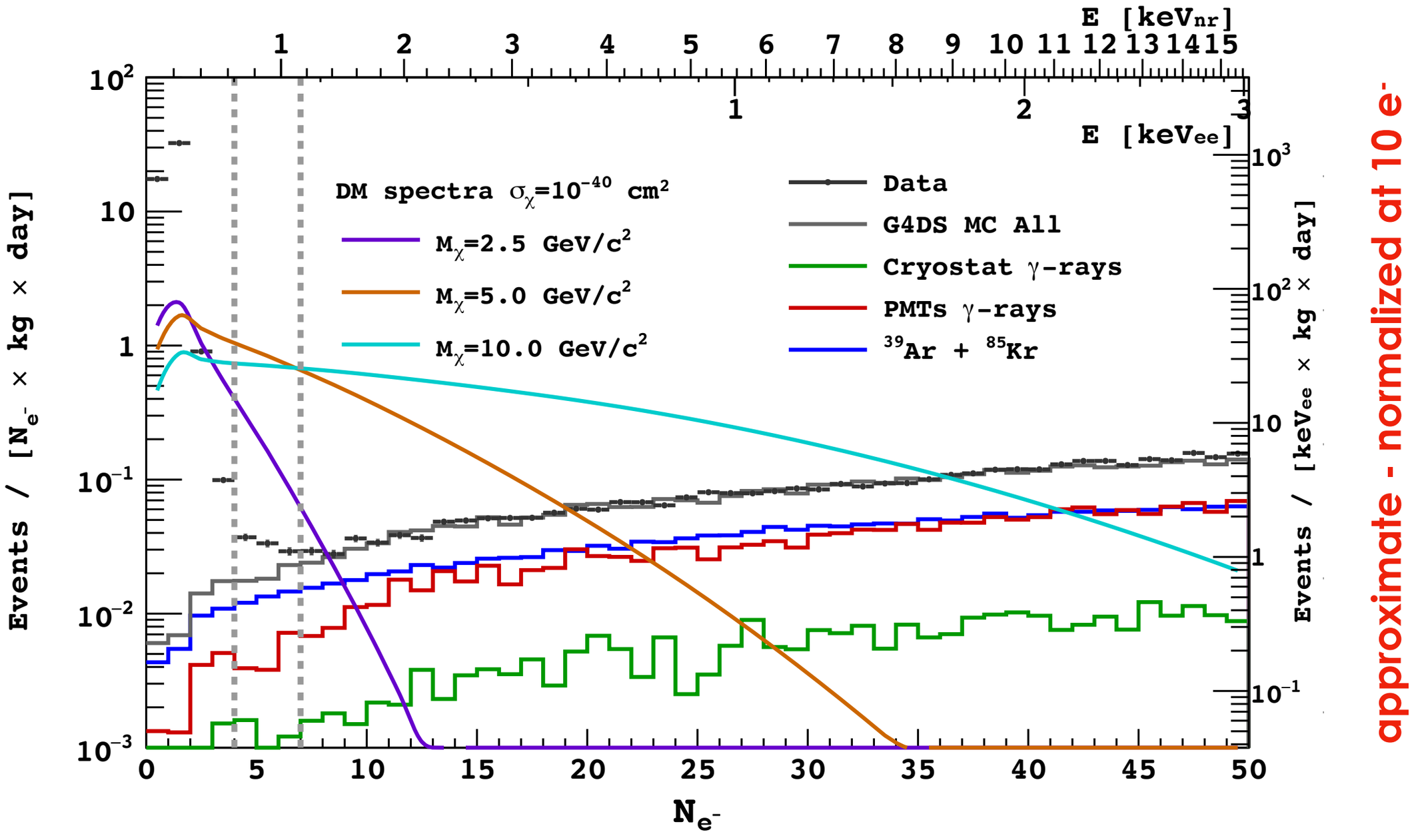


background estimation

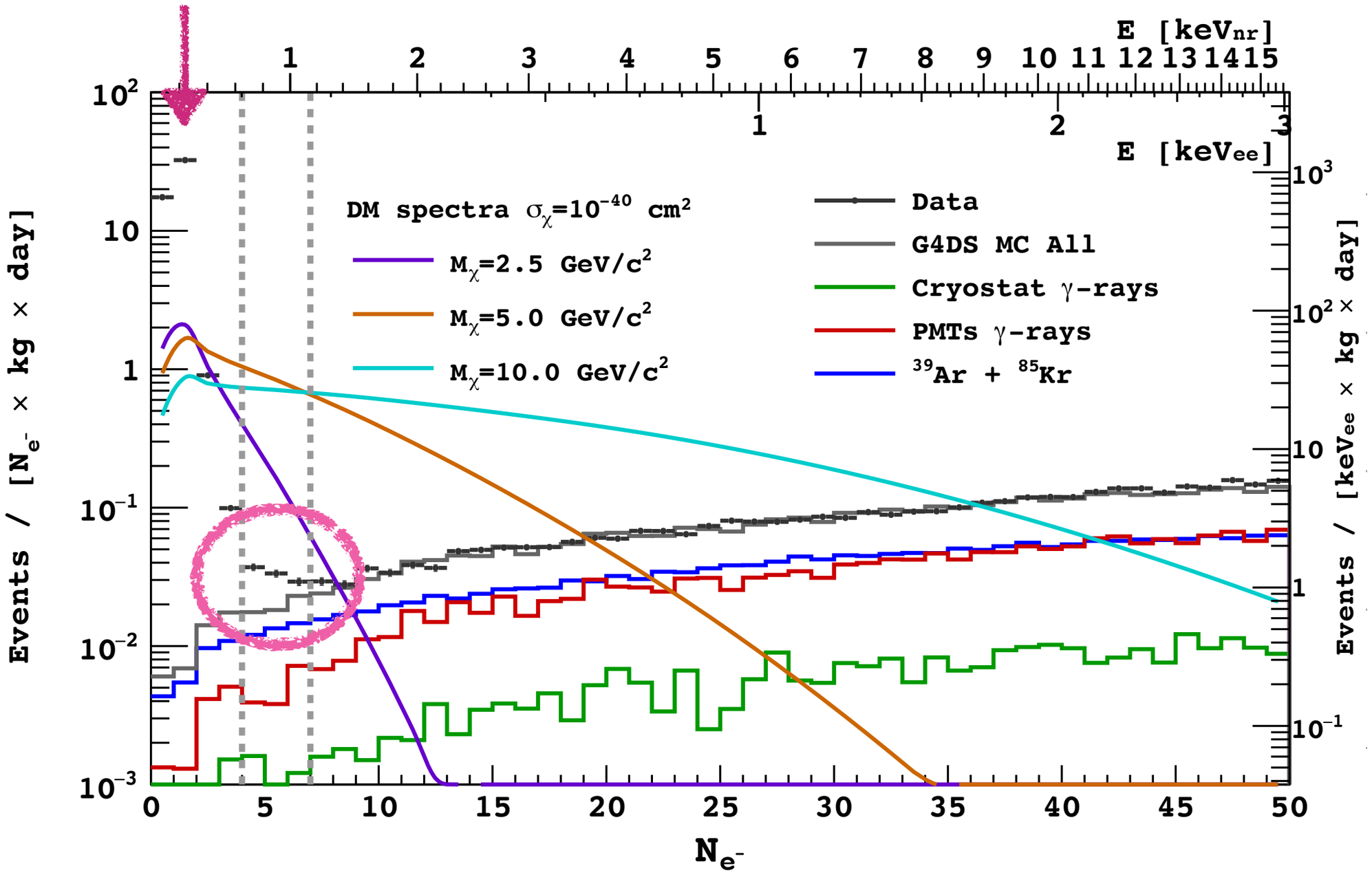
fit of background data (with some constraints based on radio-assay results)



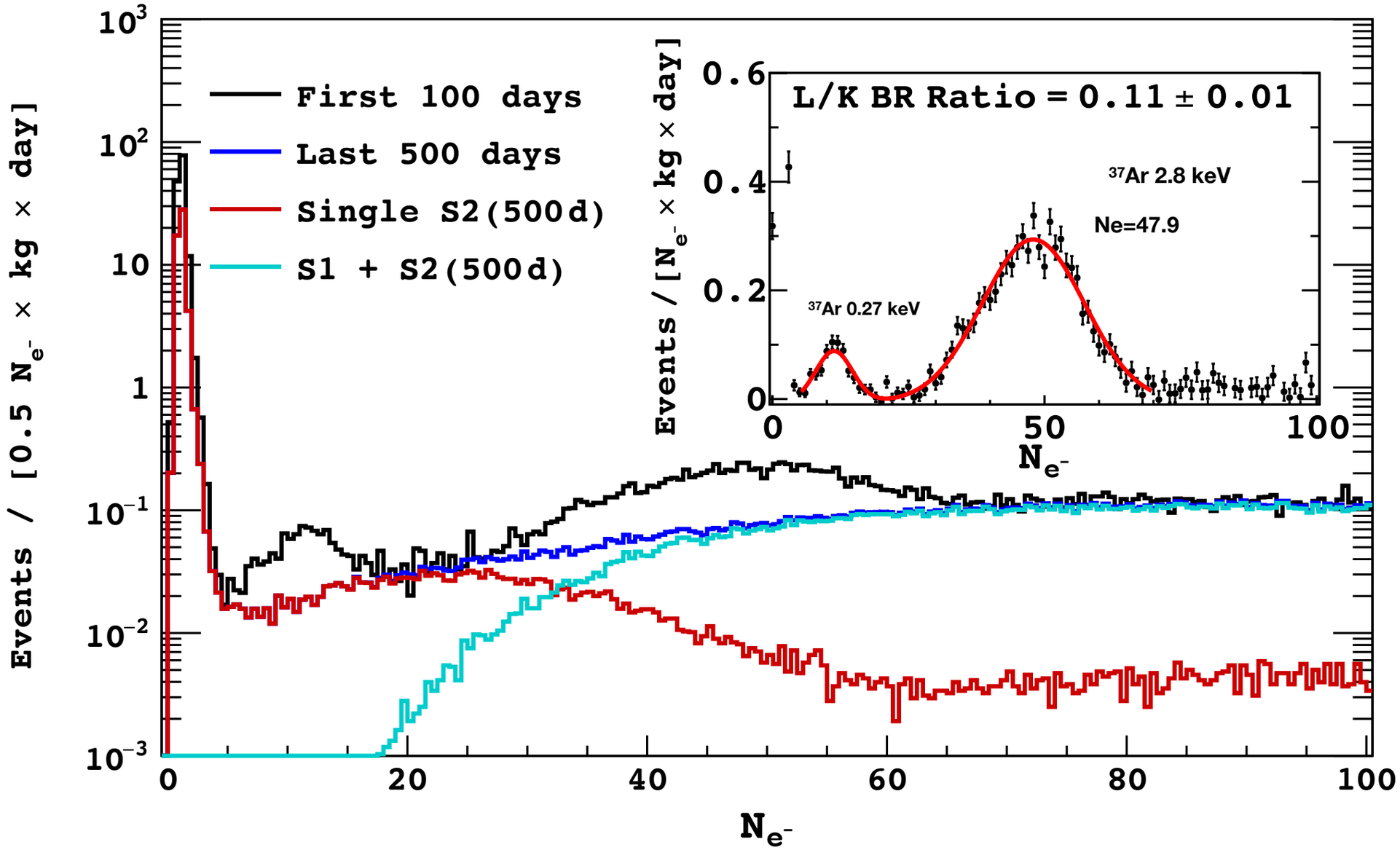
background estimation



background estimation



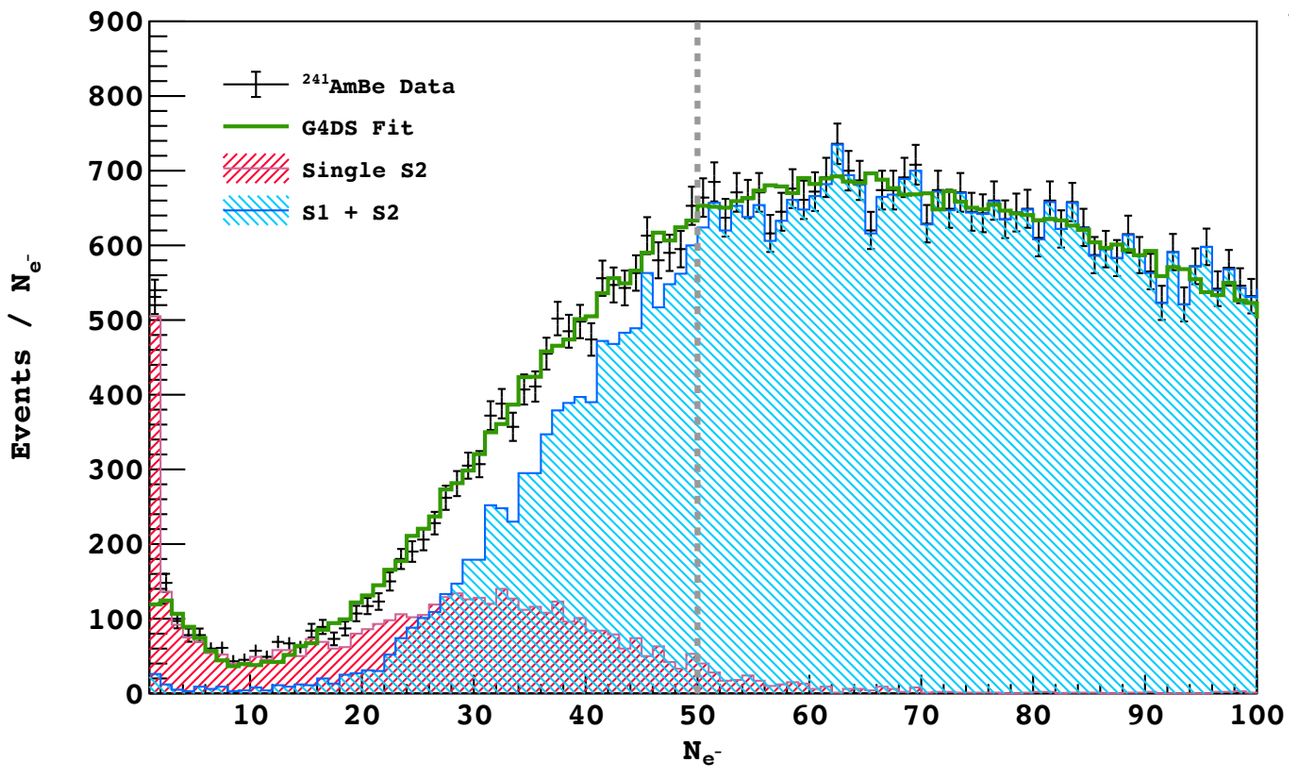
determining electron recoil energy scale



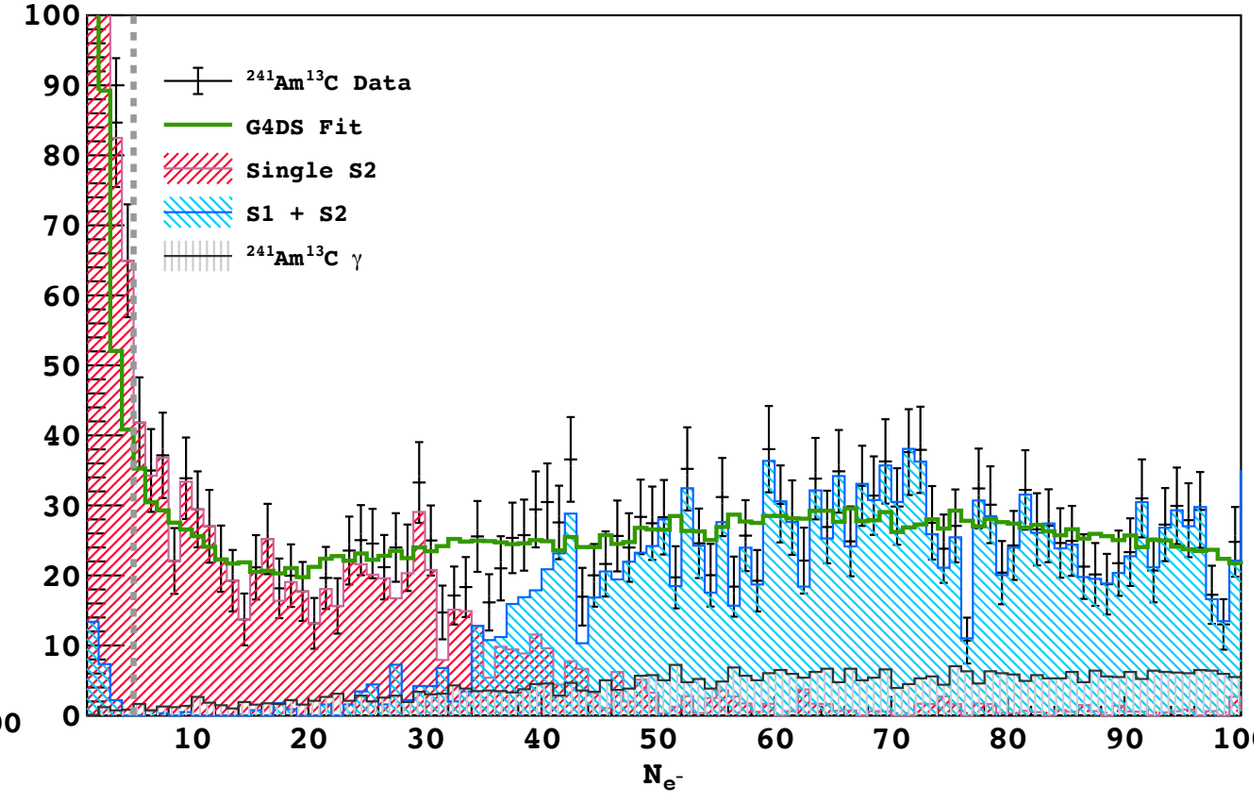
determining nuclear recoil energy scale

We don't have a direct calibration at these energies. Instead, we fit MC + Bezrukov ionization model to neutron calibration source data

AmBe source

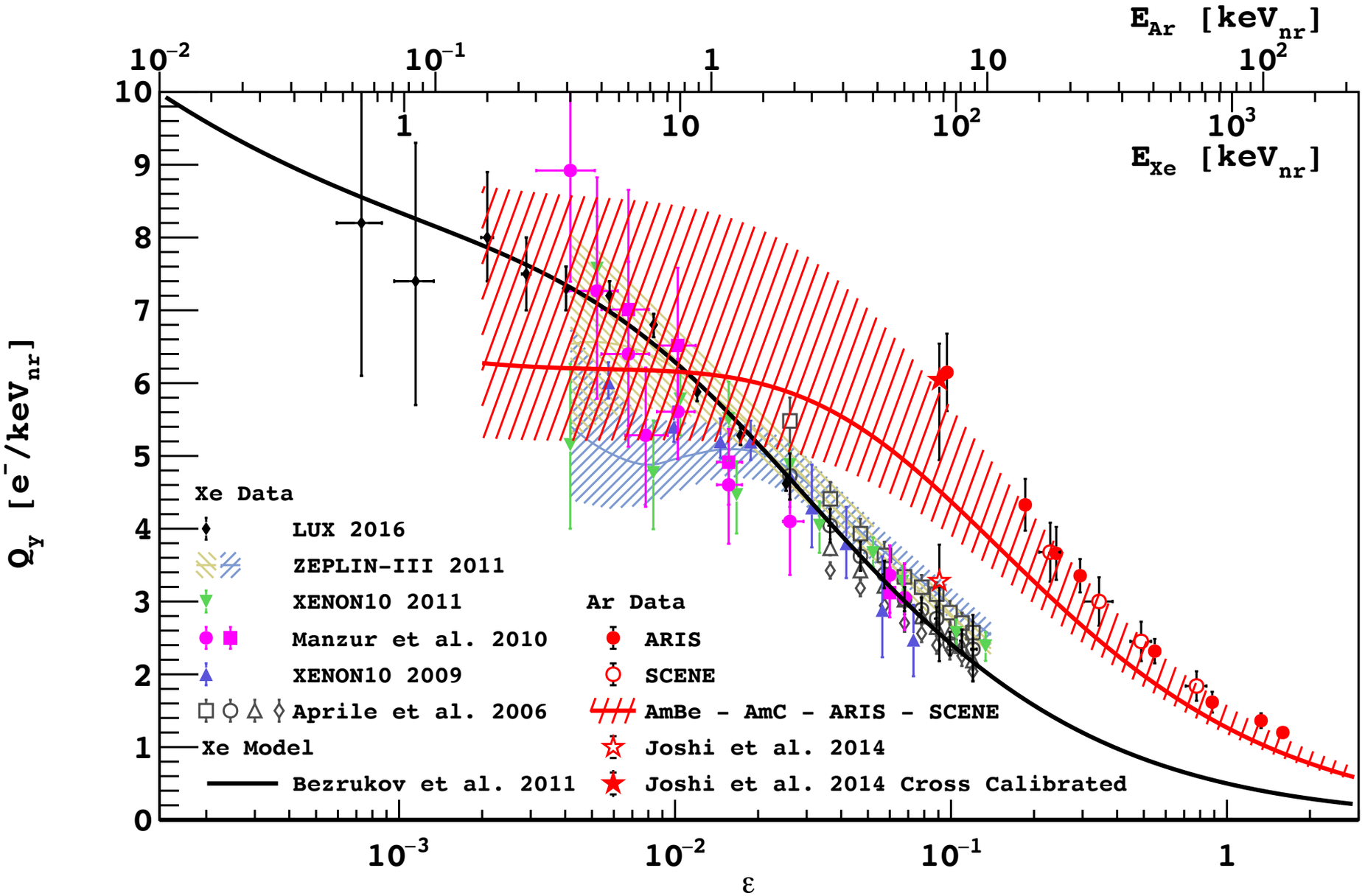


AmC source

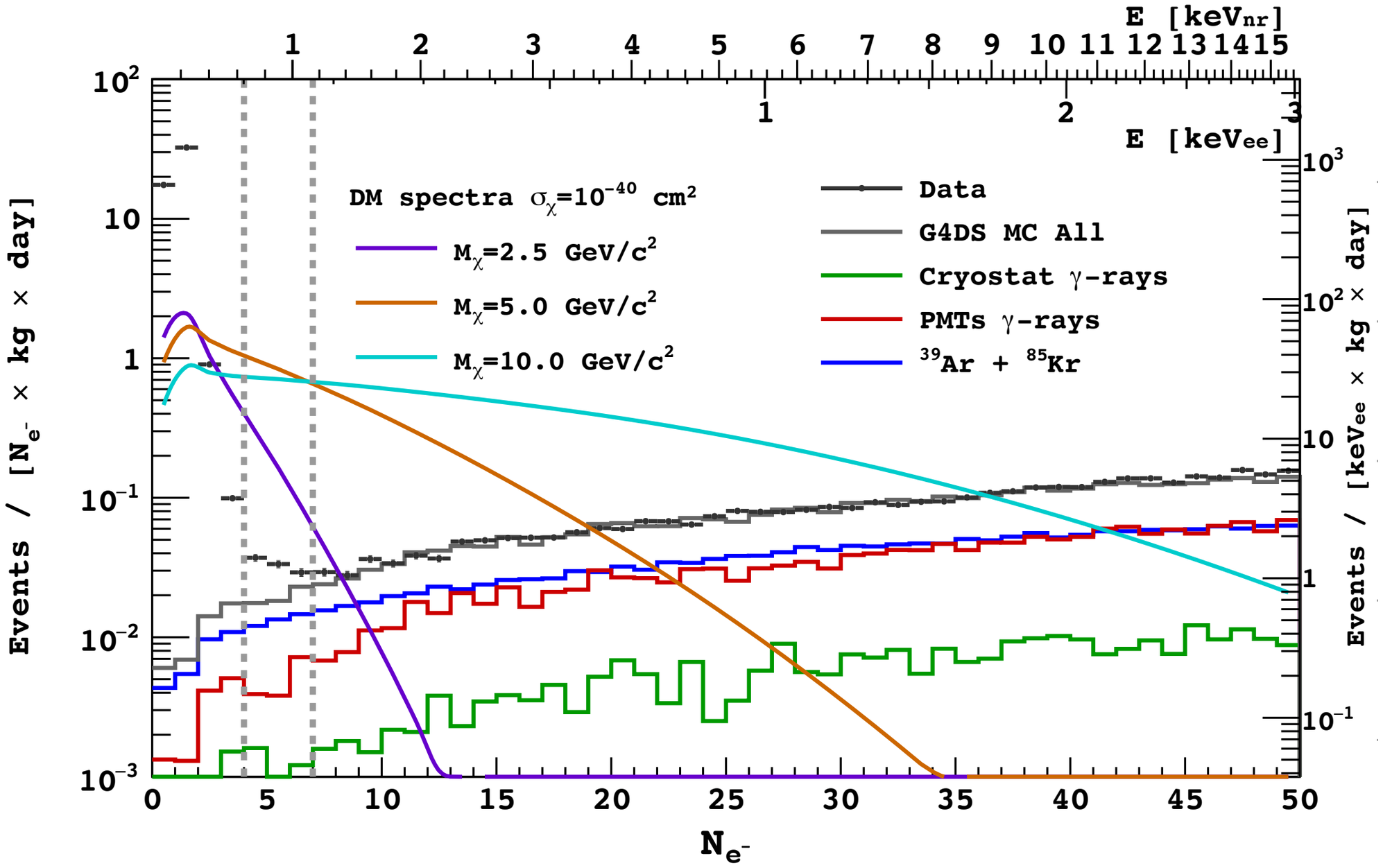


F. Bezrukov, F. Kahlhoefer, and M. Lindner, Astropart. Phys. 35, 119 (2011)

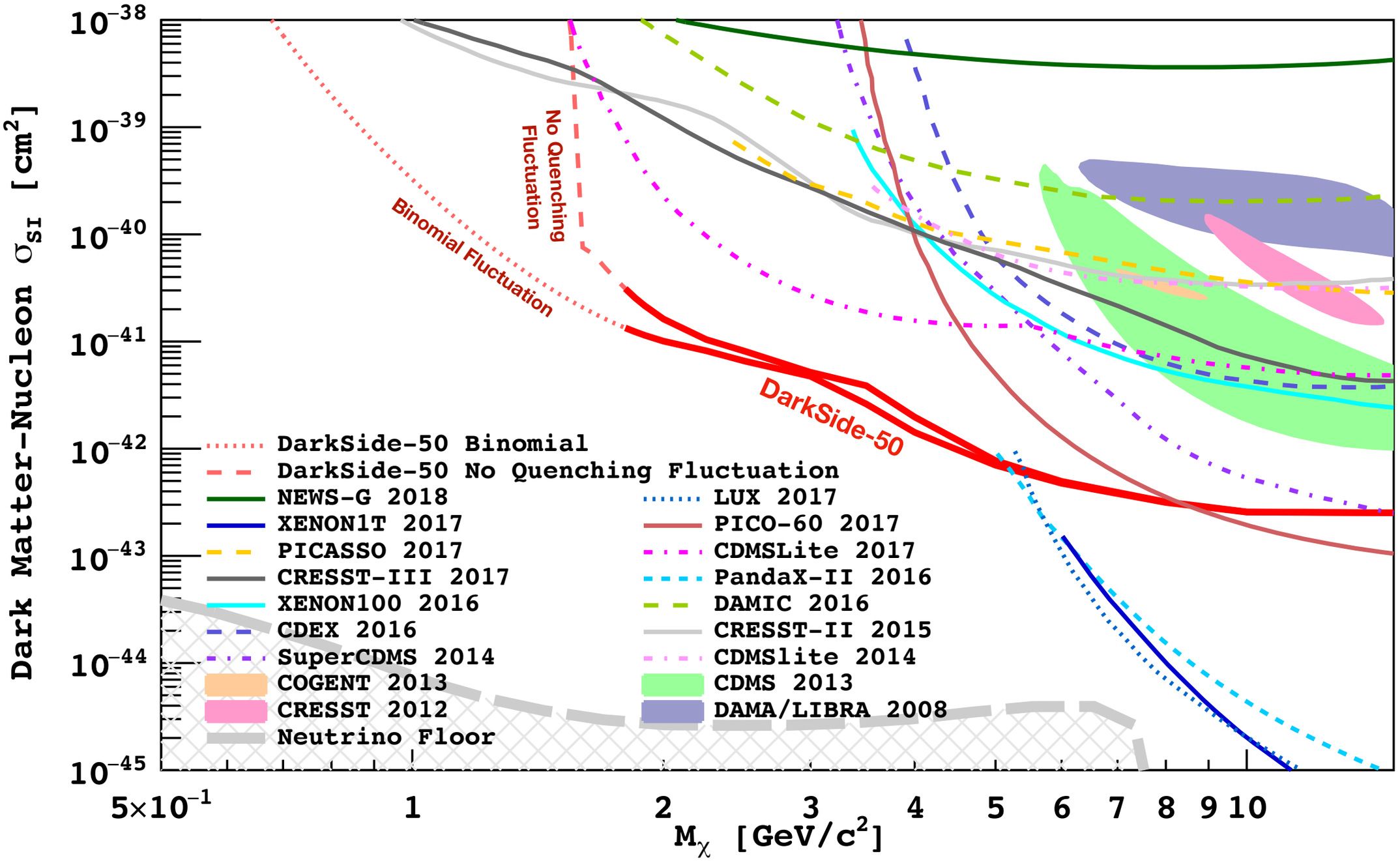
determining nuclear recoil energy scale



example WIMP NR spectra



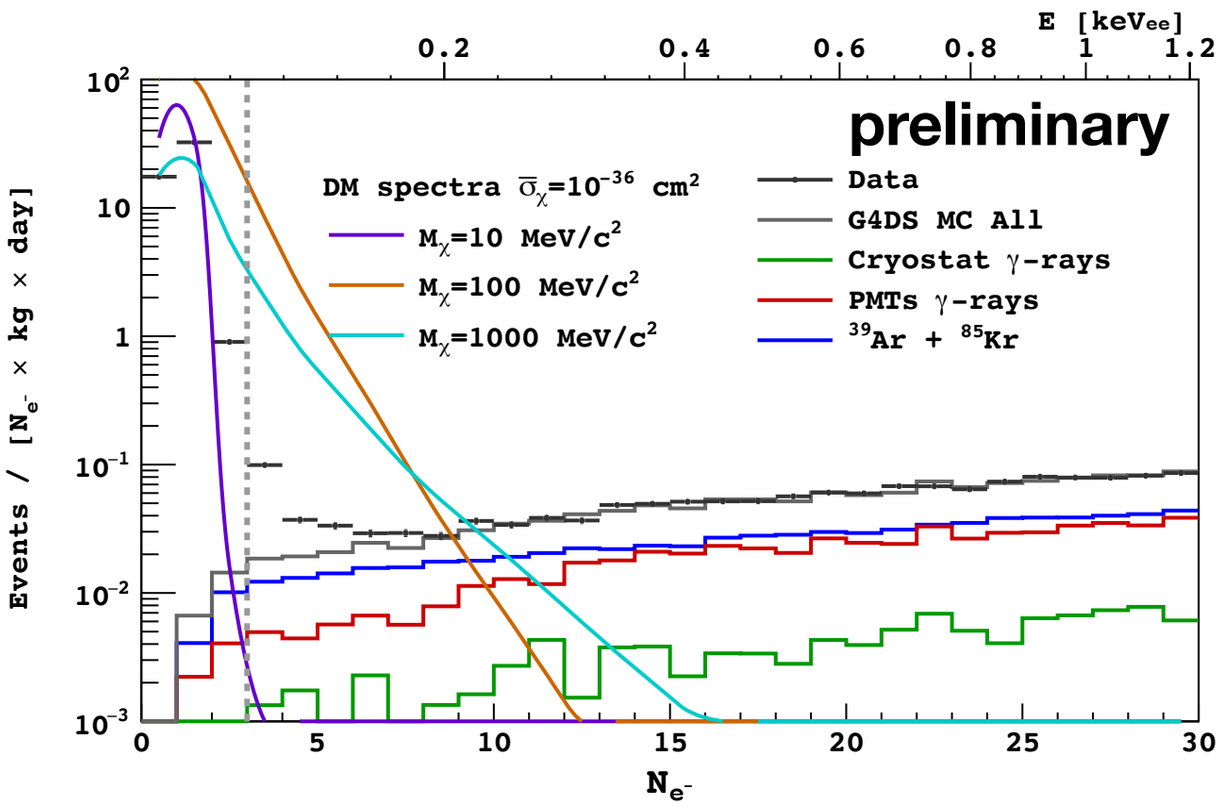
90% C.L. WIMP exclusion curves



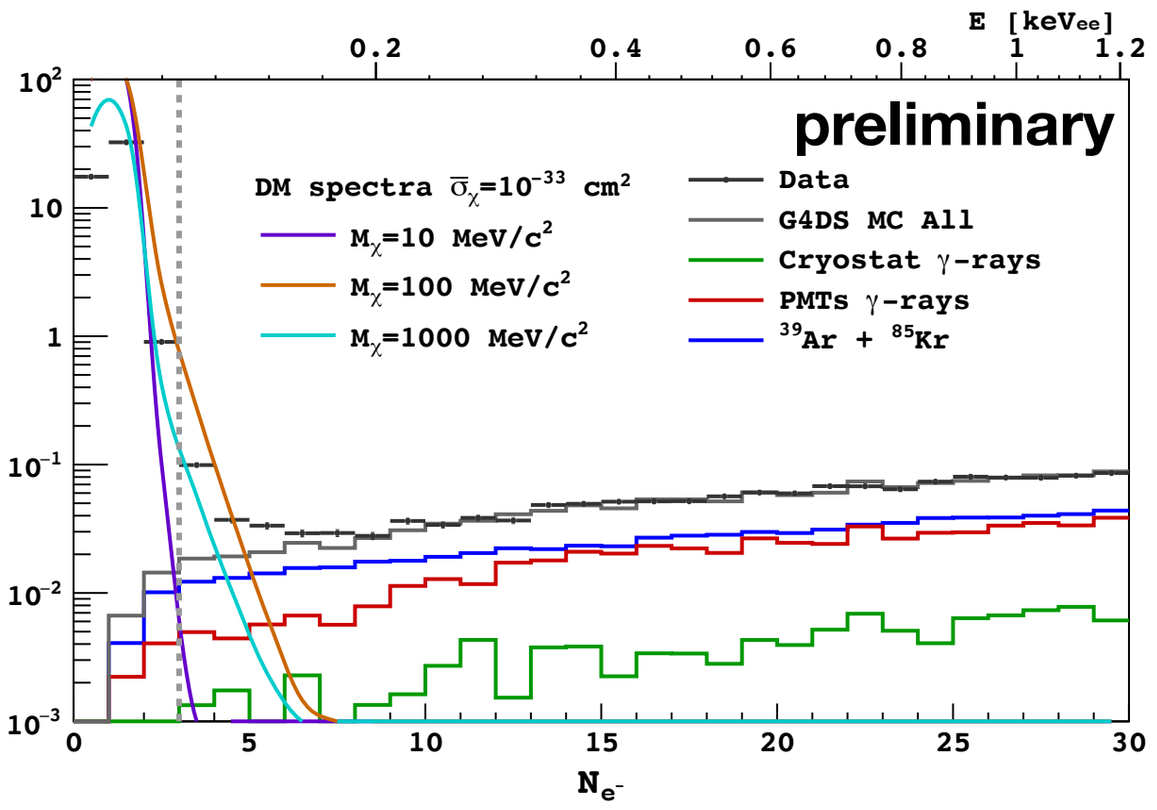
arXiv: 1802.06994

example DM-electron scattering spectra

$F_{DM} = 1$



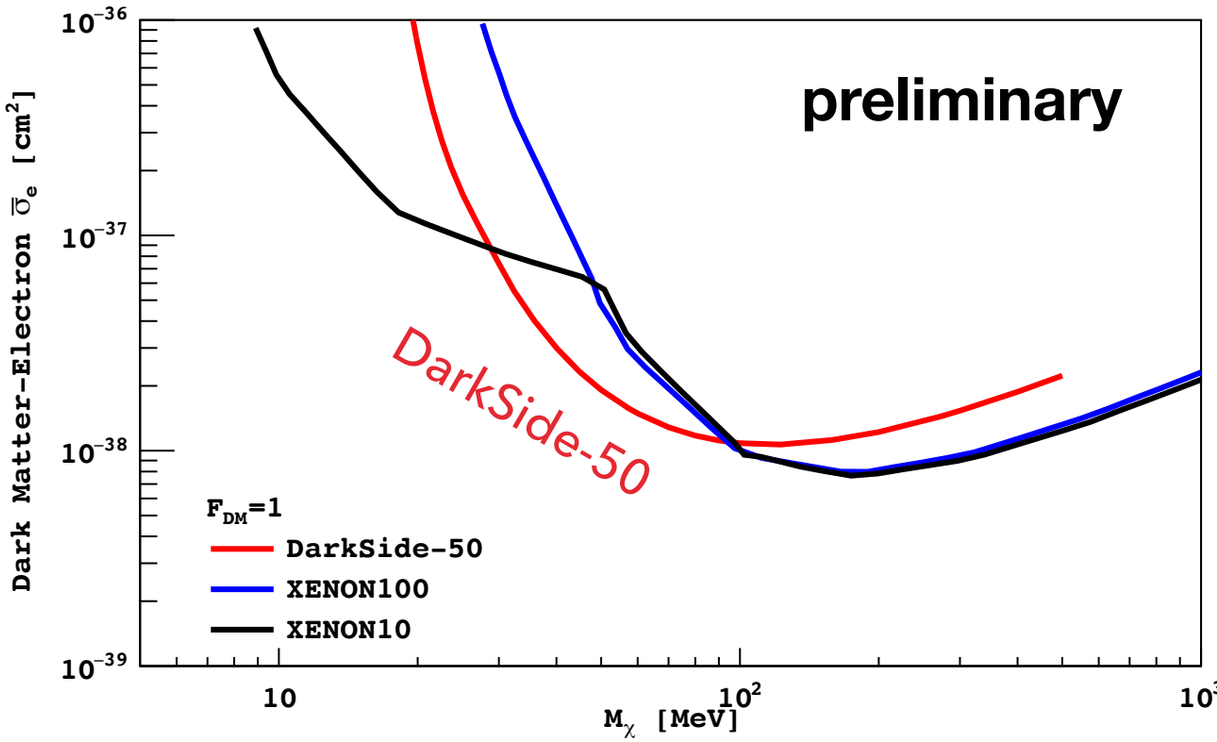
$F_{DM} \propto 1/q^2$



arXiv: 1802.06994

90% C.L. exclusion for DM-electron scattering

$F_{DM} = 1$



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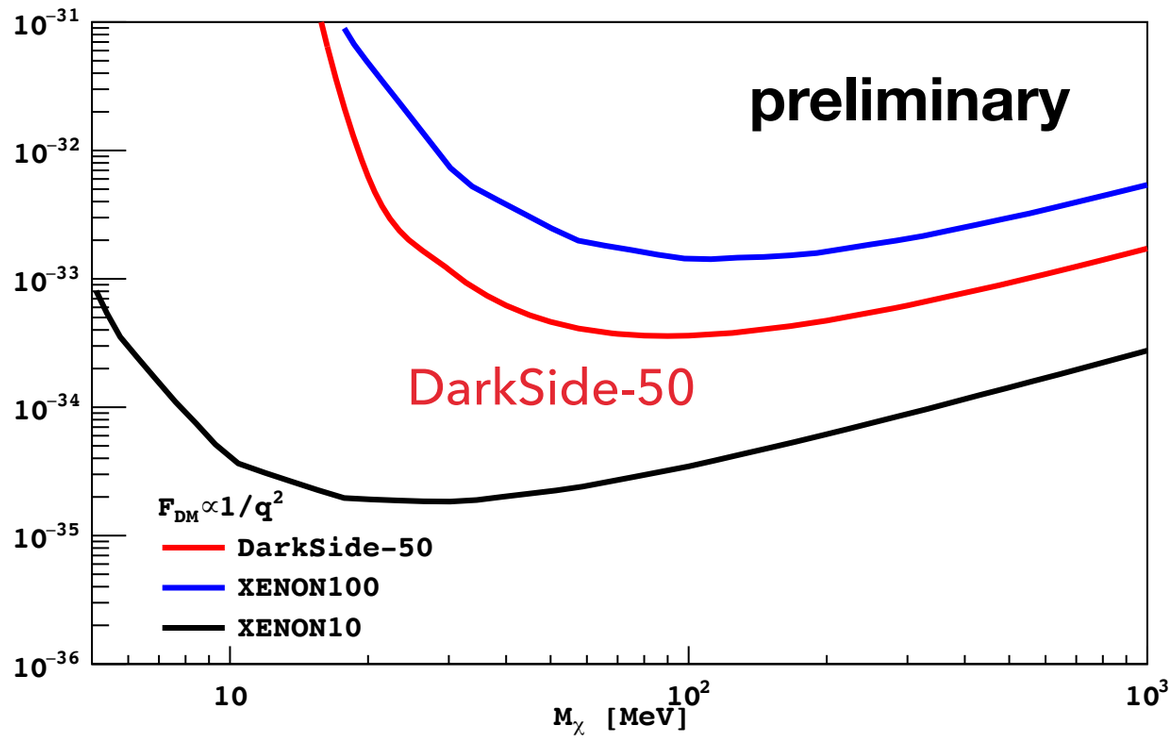
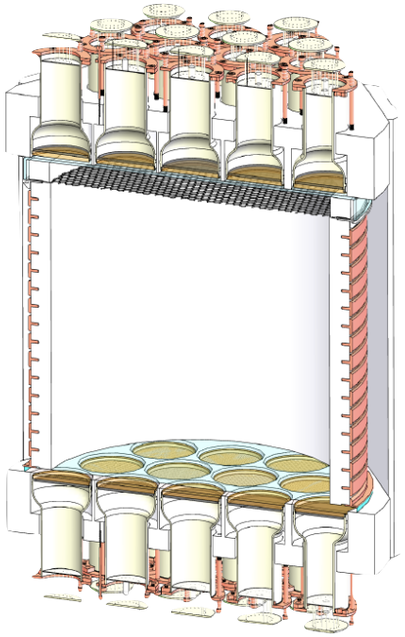
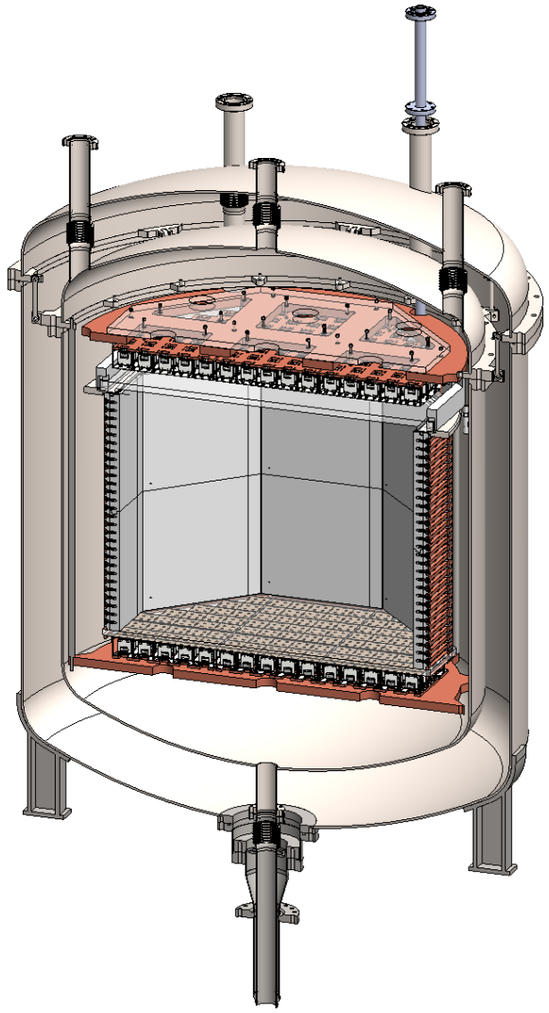


arXiv: 1802.06998

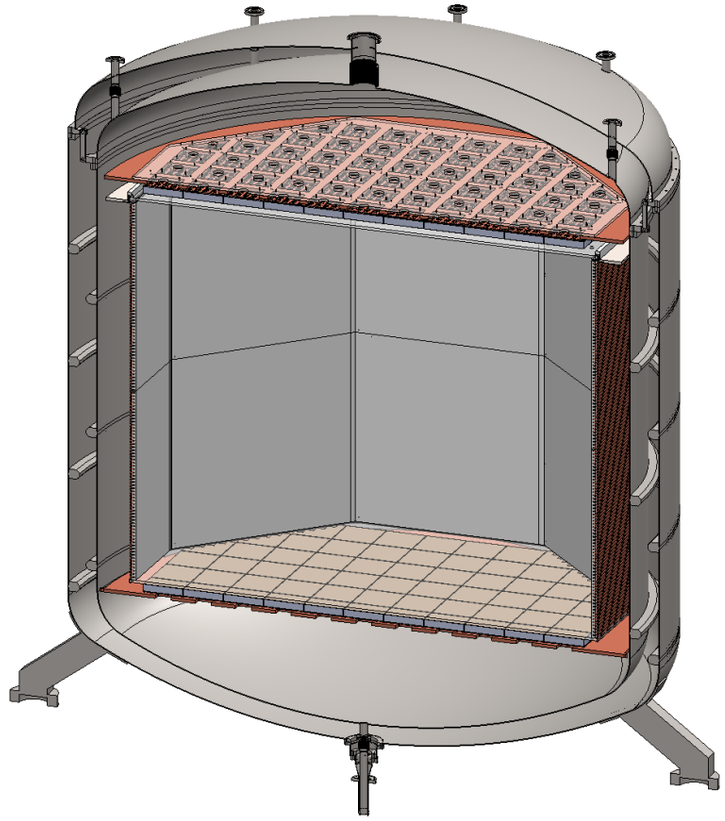
can we make improvements going forward?



DarkSide-50
50 kg



DarkSide-prototype
1 tonne



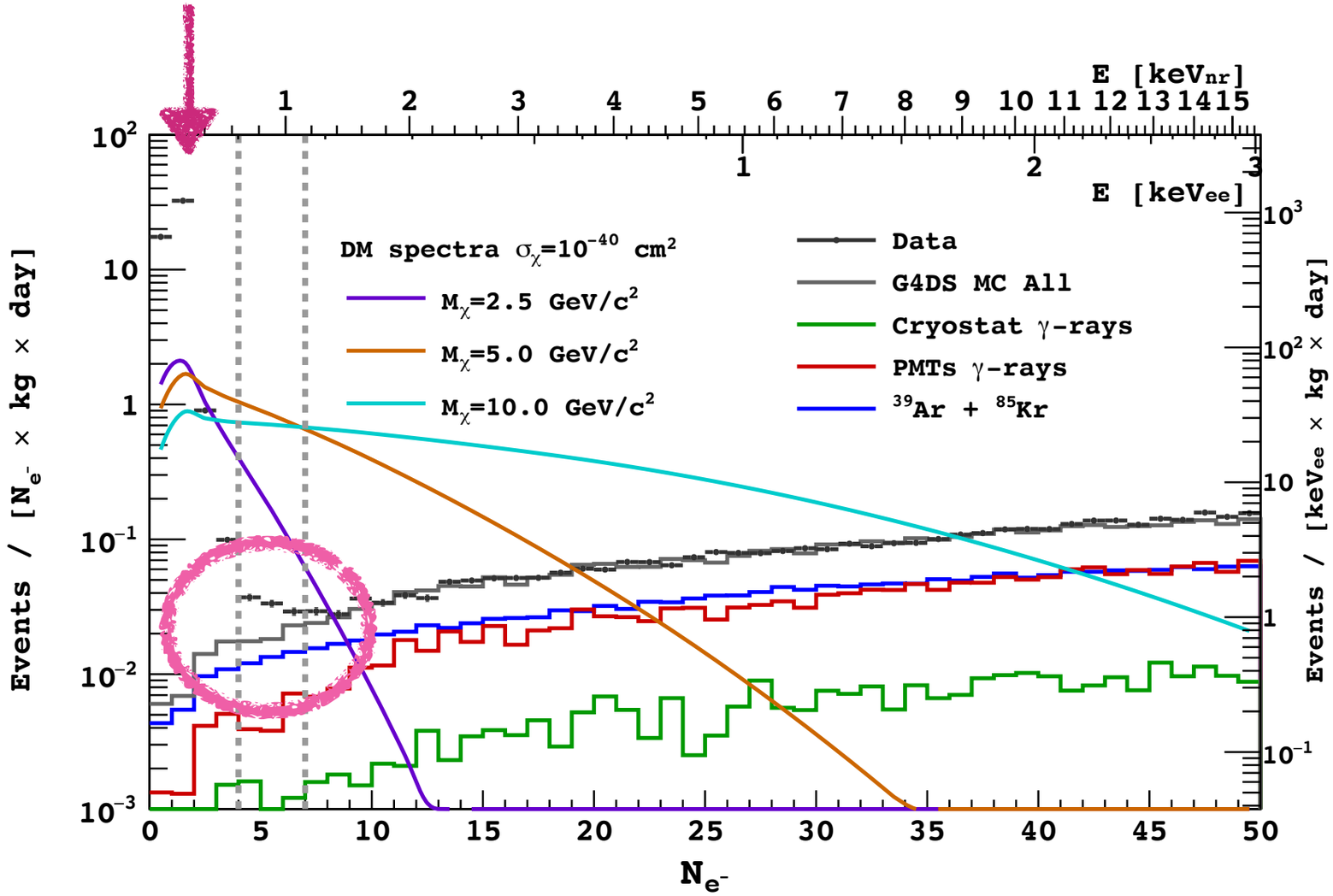
DarkSide-20k
20 tonne

GADMC
200 tonne

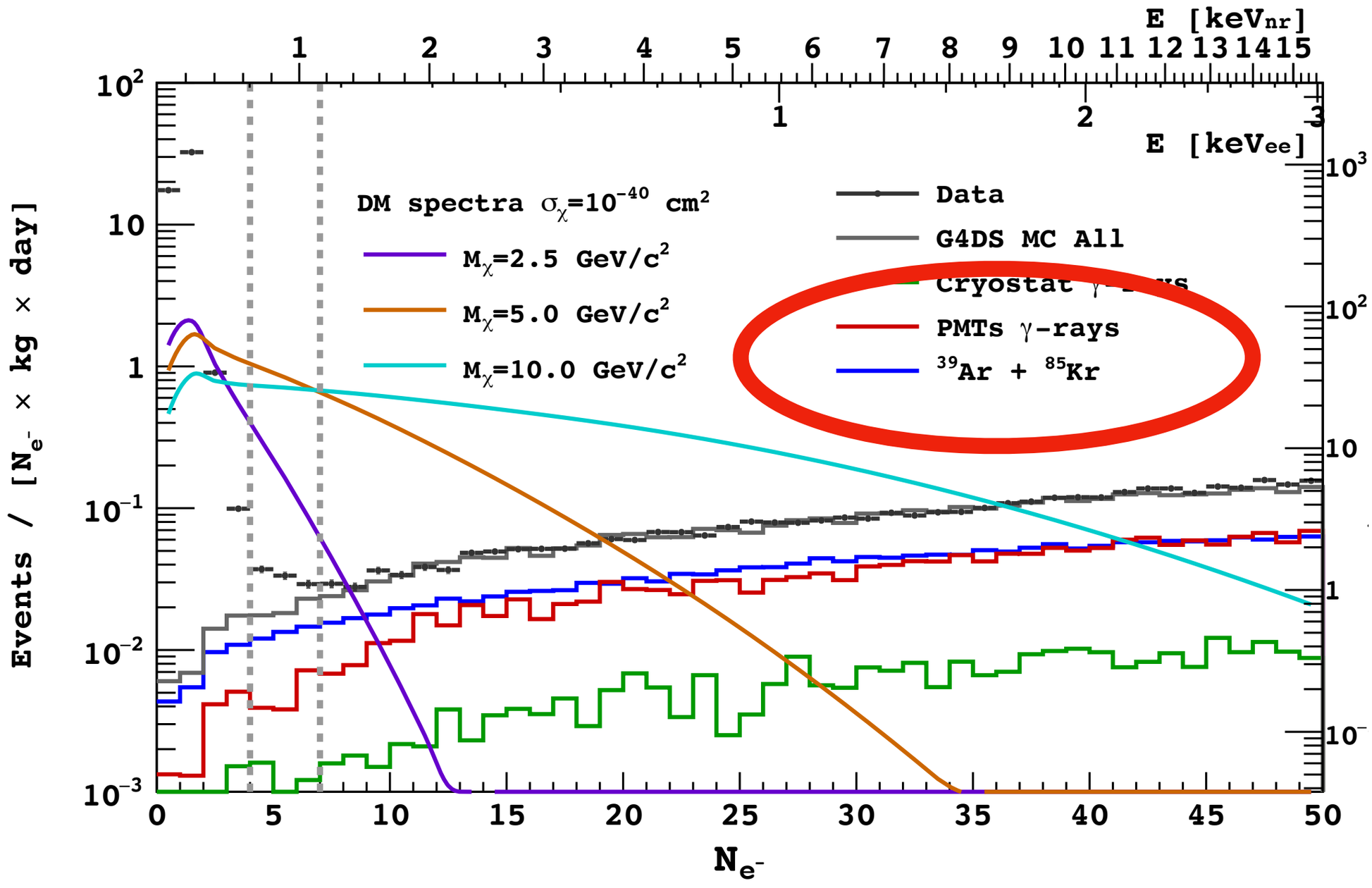
?

improvements with DS-50

- time correlated cuts
- S2 pattern cuts
- use veto
- increase extraction field and lower threshold
- measure ionization yield from nuclear recoils at these energies with calibration experiment

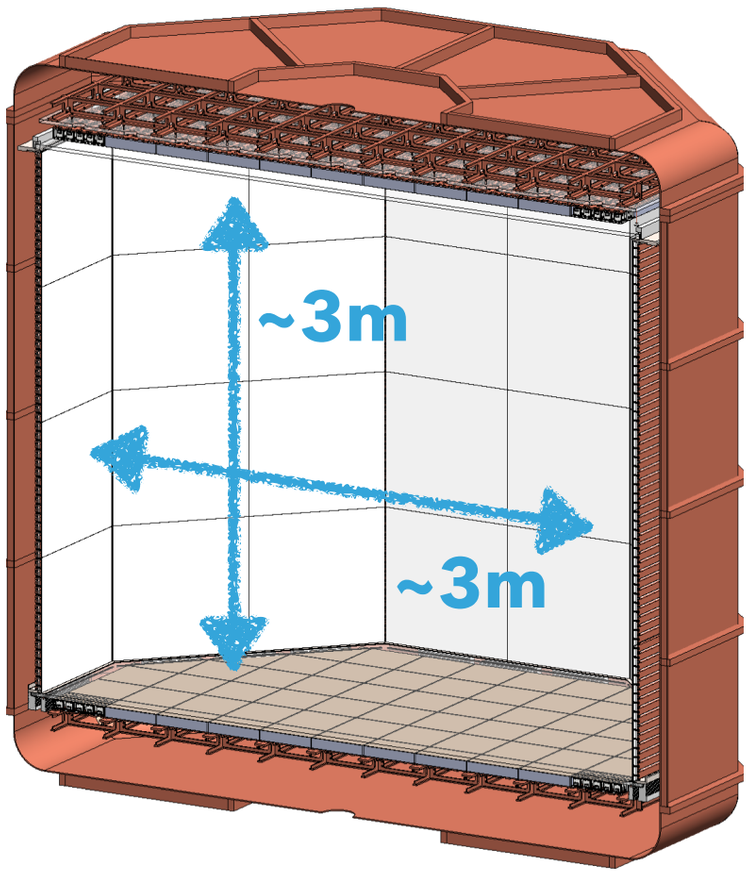


background reduction in future detectors

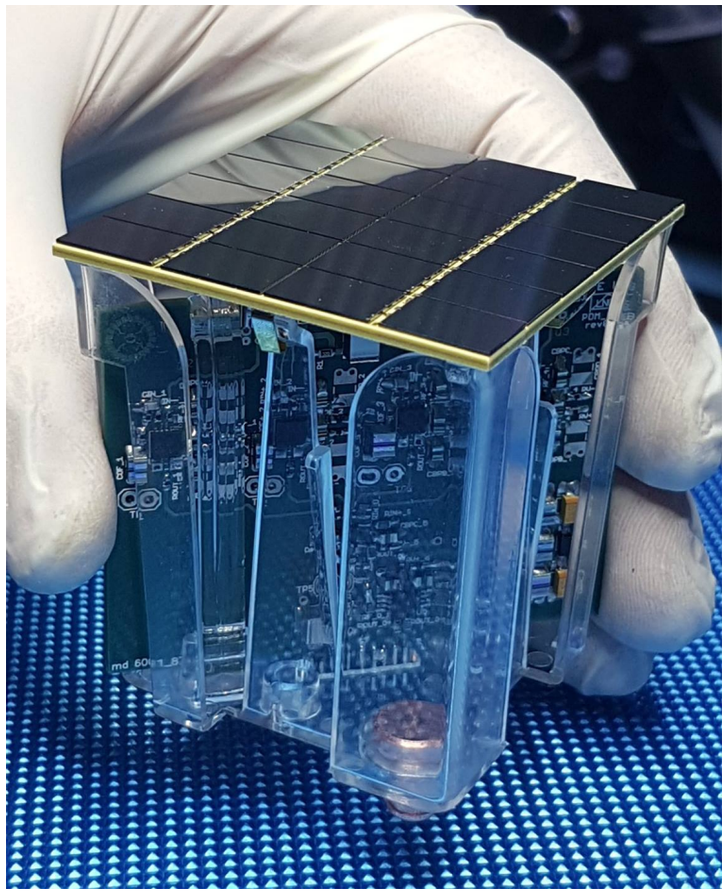


background reduction in future detectors

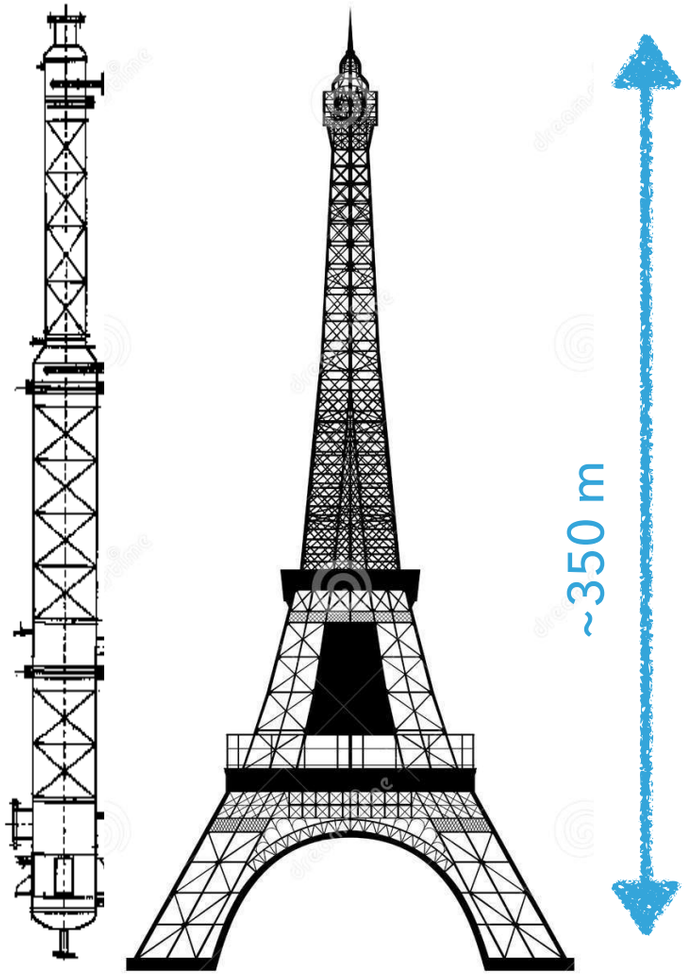
fiducialize



use cleaner materials*



purify UAr**



*no PSD means we now have to worry about additional background sources

**or at least eliminate air leaks

summary

- LAr TPCs can/have achieved sub-keVnr energy thresholds and competitively low background rates
- DS-50 is sensitive to 1-10 GeV WIMPs and sub-GeV DM-electron scattering
- There are potential incremental improvements possible with DarkSide-50
- And greater sensitivity with follow-on detectors