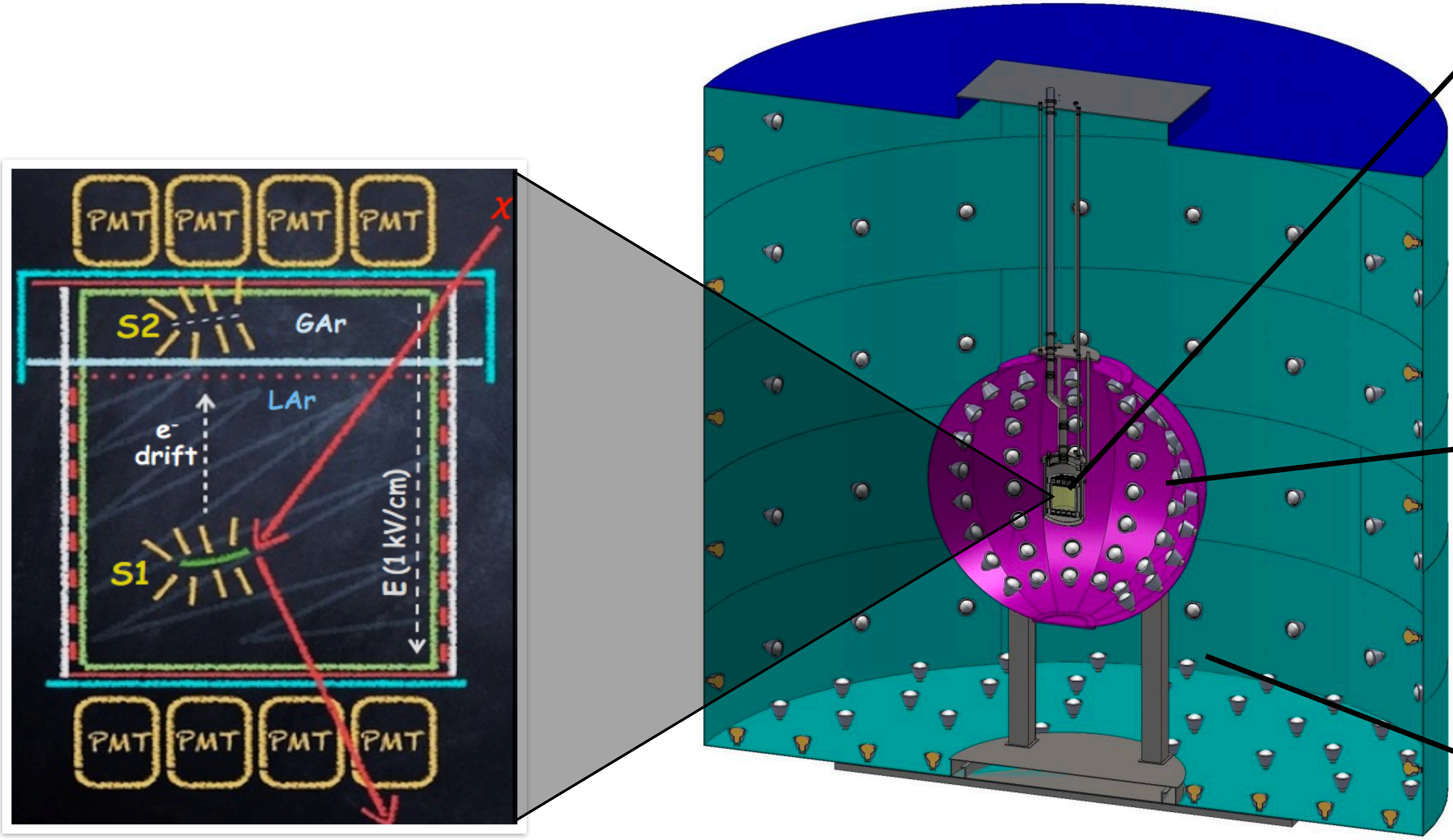
DarkSide-50

Light dark matter search

Timothée Hessel, *on behalf of the DarkSide-20k collaboration*

DarkSide-50

Efficient **electronic recoil (ER) background rejection** thanks to LAr scintillation **Pulse Shape Discrimination** through the “f90” observable (fraction of light detected in the first 90 ns).



The Dual-Phase TPC:

- 50 kg active mass of UAr
- 19 top + 19 bottom R11065 HQE 3” PMTs
- 36cm height, 36 cm diameter
- Low field of 0.2 kV/cm drift

Liquid Scintillator Veto against neutrons:

- 4 m diameter sphere
- Boron-loaded: 1:1 PC and TMB
- 110 8” PMTs
- LY ~ 500 pe/MeV

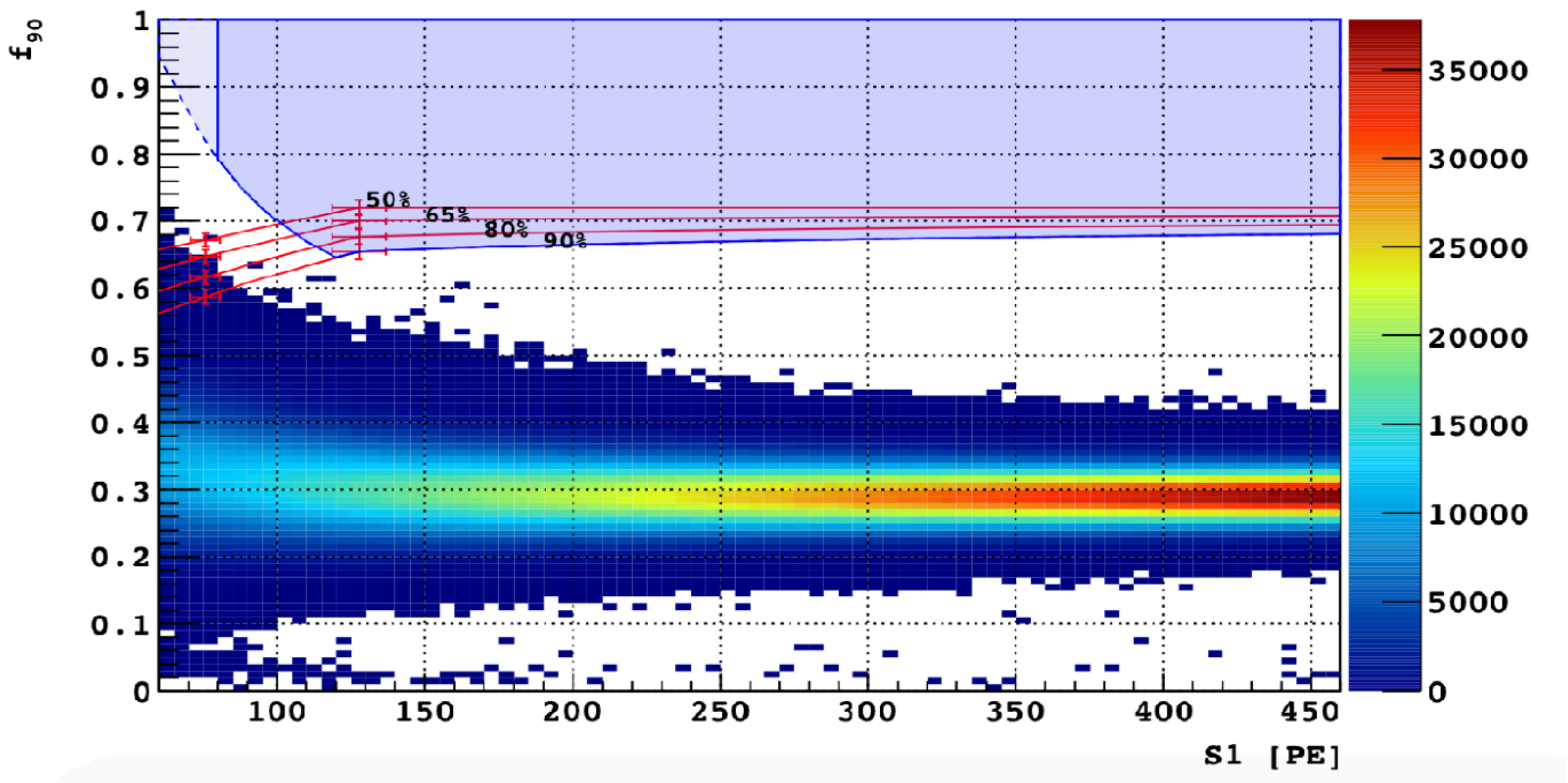
Cherenkov Water Detector:

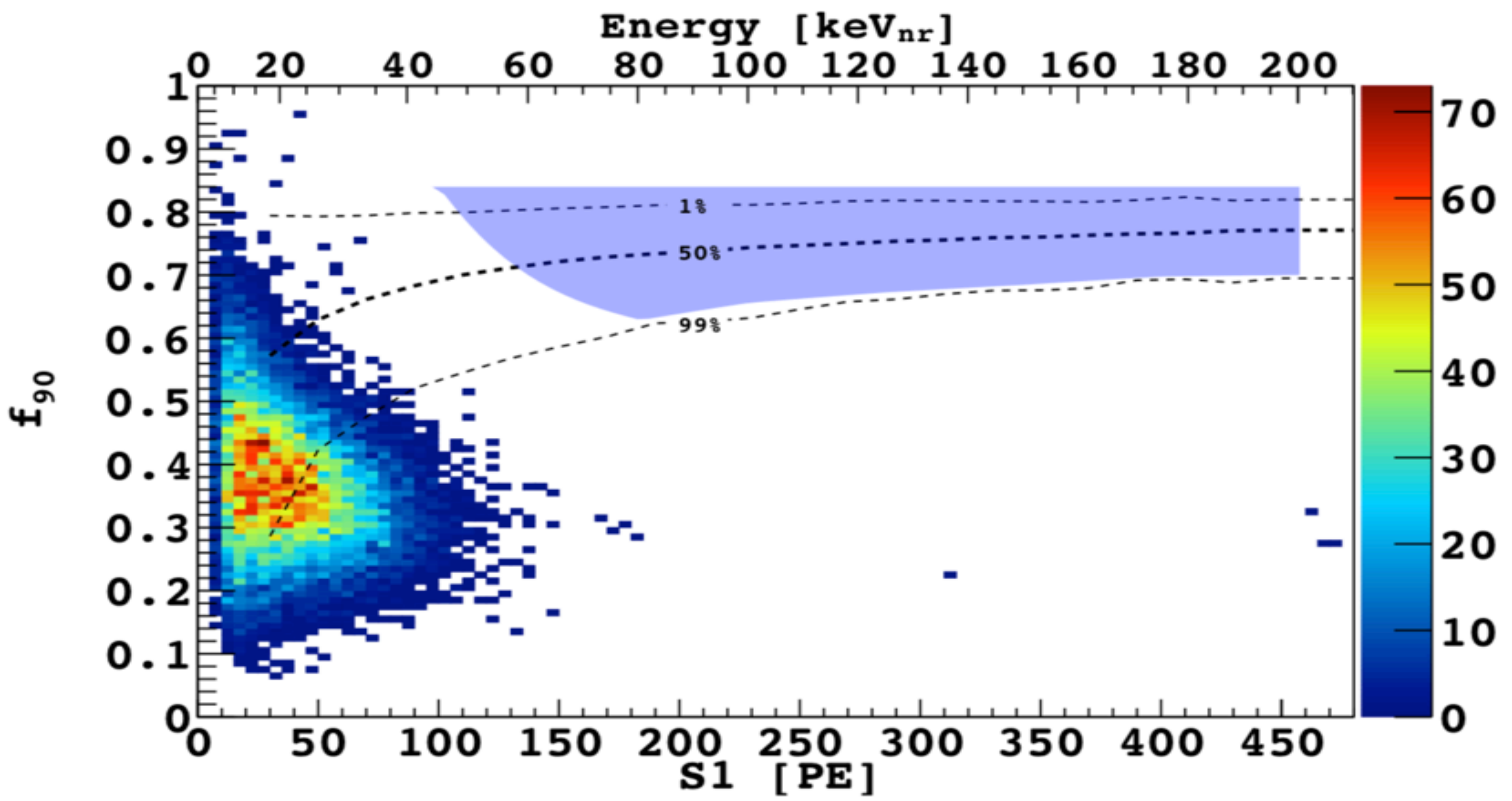
- 11 m diameter x 10 m
- 80 PMTs

The DS-50 WIMP search

Pulse Shape Discrimination

« High mass » WIMP search





Ionization Only

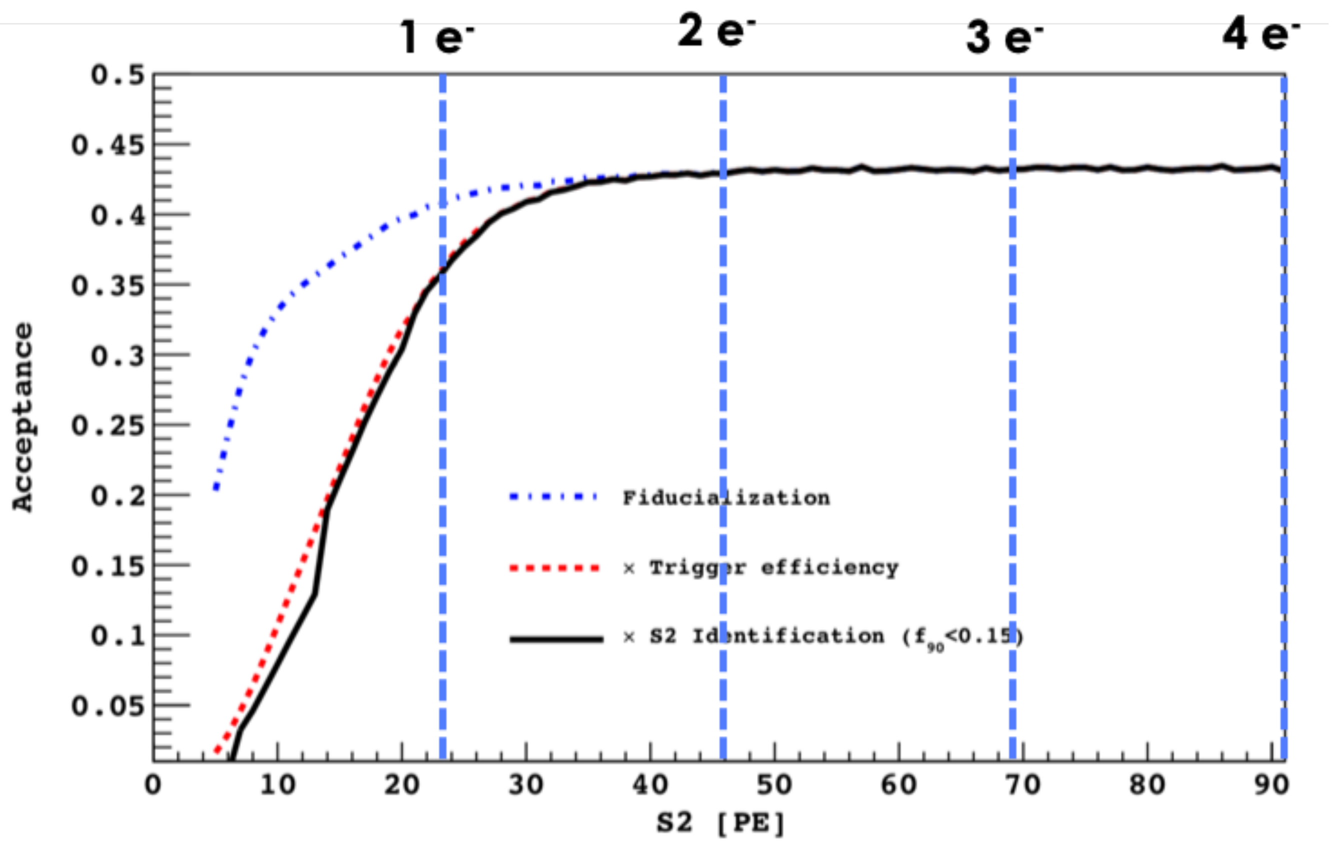
« Low mass » WIMP search

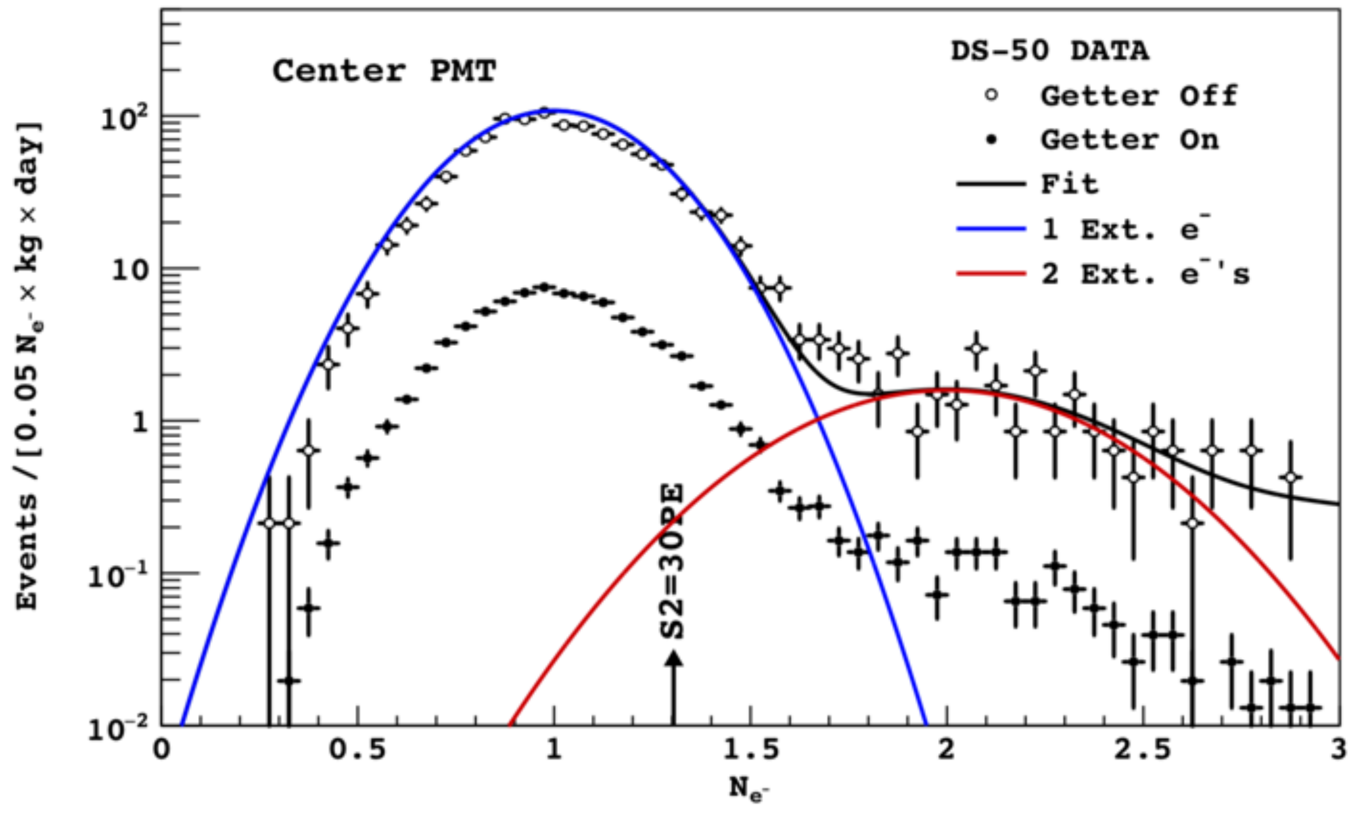
Scintillation (S1):

- Detection efficiency (g1) ~ 16%

Ionization (S2):

- Efficiency to extract 1 e- in the gas pocket ~100%
- Amplification factor (g2) ~ 23 pe/e-



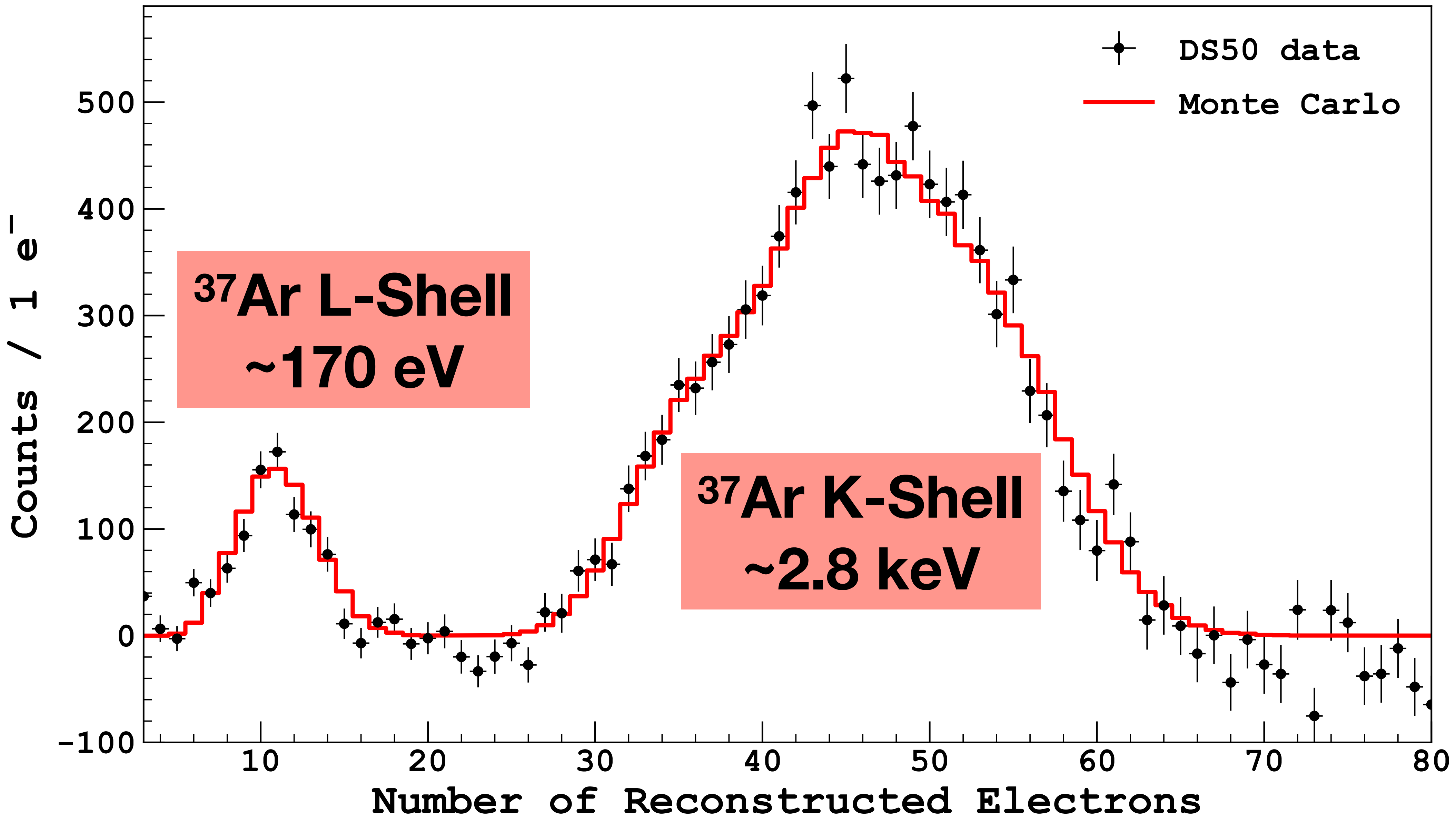


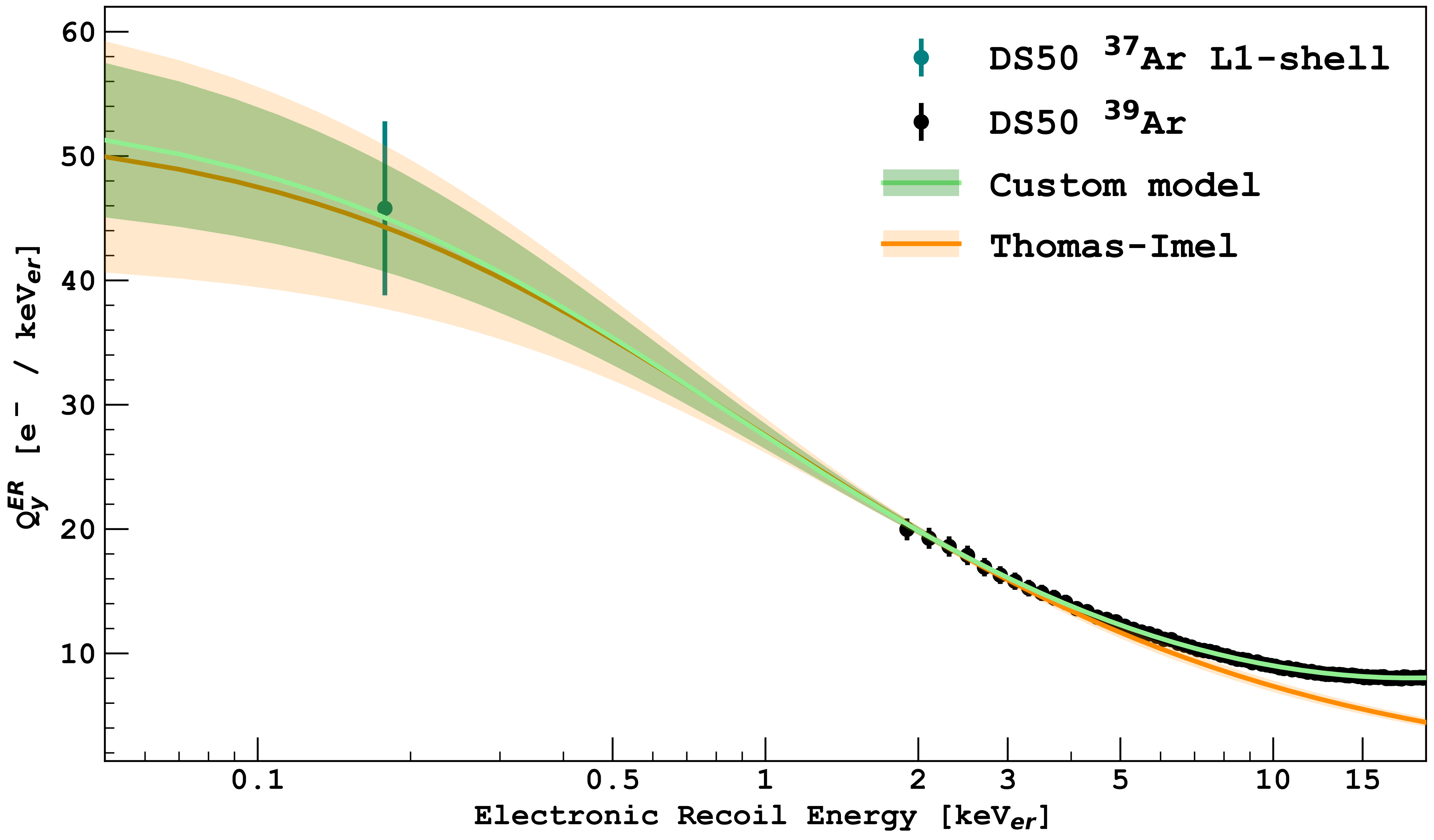
Ionization response to electron recoil

Thomas-Imel model

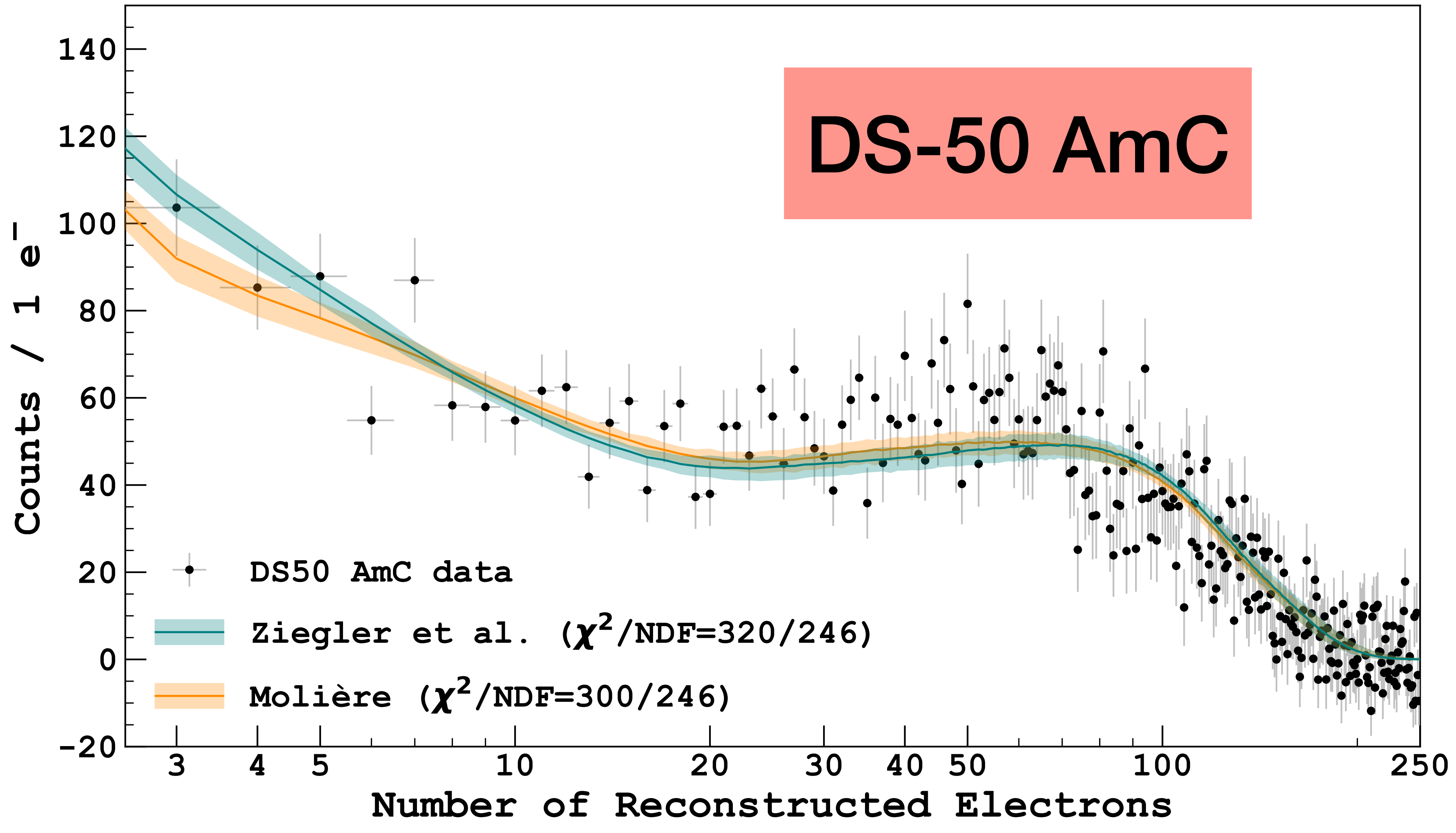
$$Q_y^{ER} = \left(\frac{1}{\gamma} + p_0 \, (E_{er}/\mathrm{keV}_{er})^{p_1} \right) \frac{\ln(1+\gamma\,\rho\,E_{er})}{E_{er}}$$

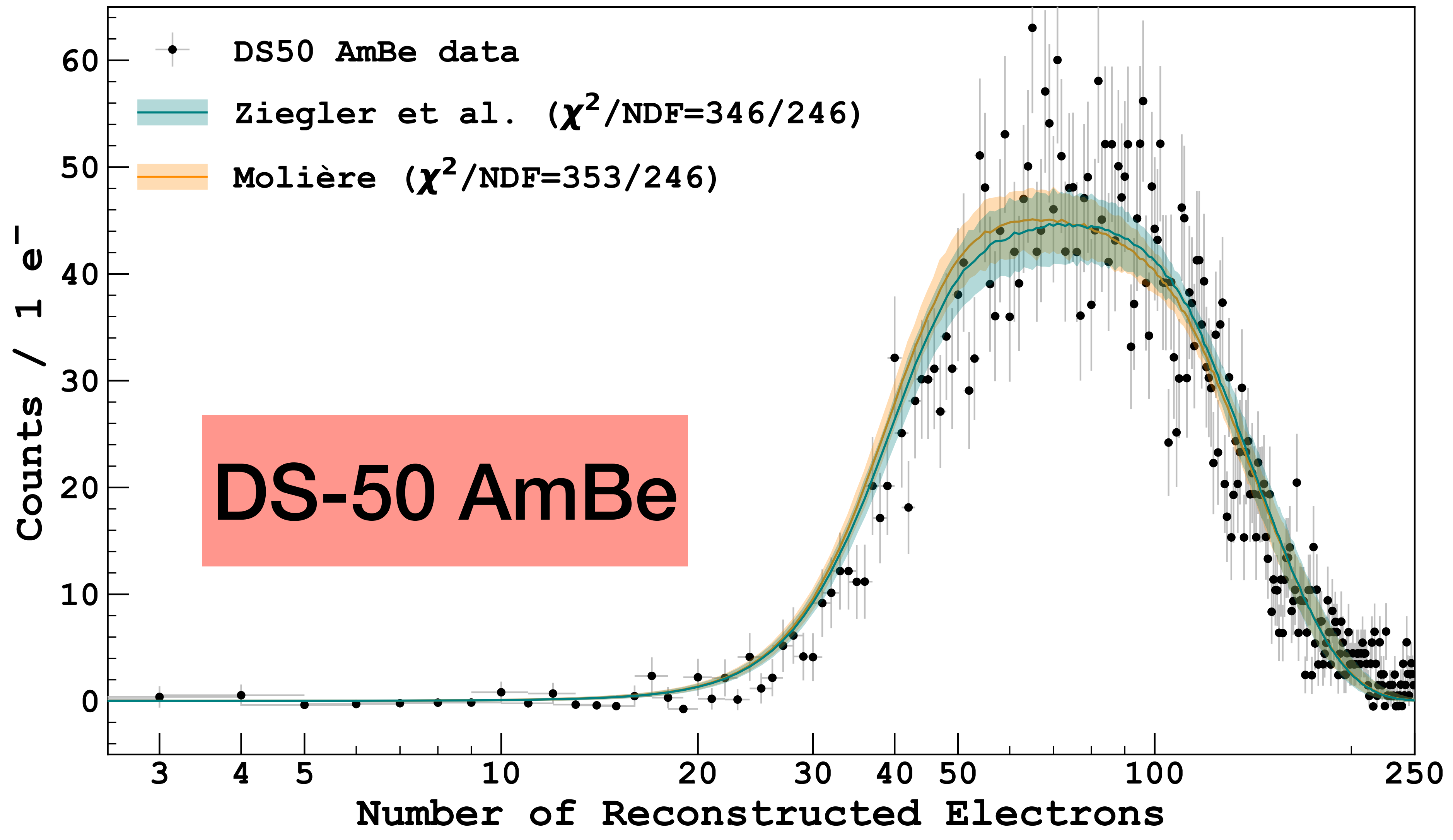
Extended custom model





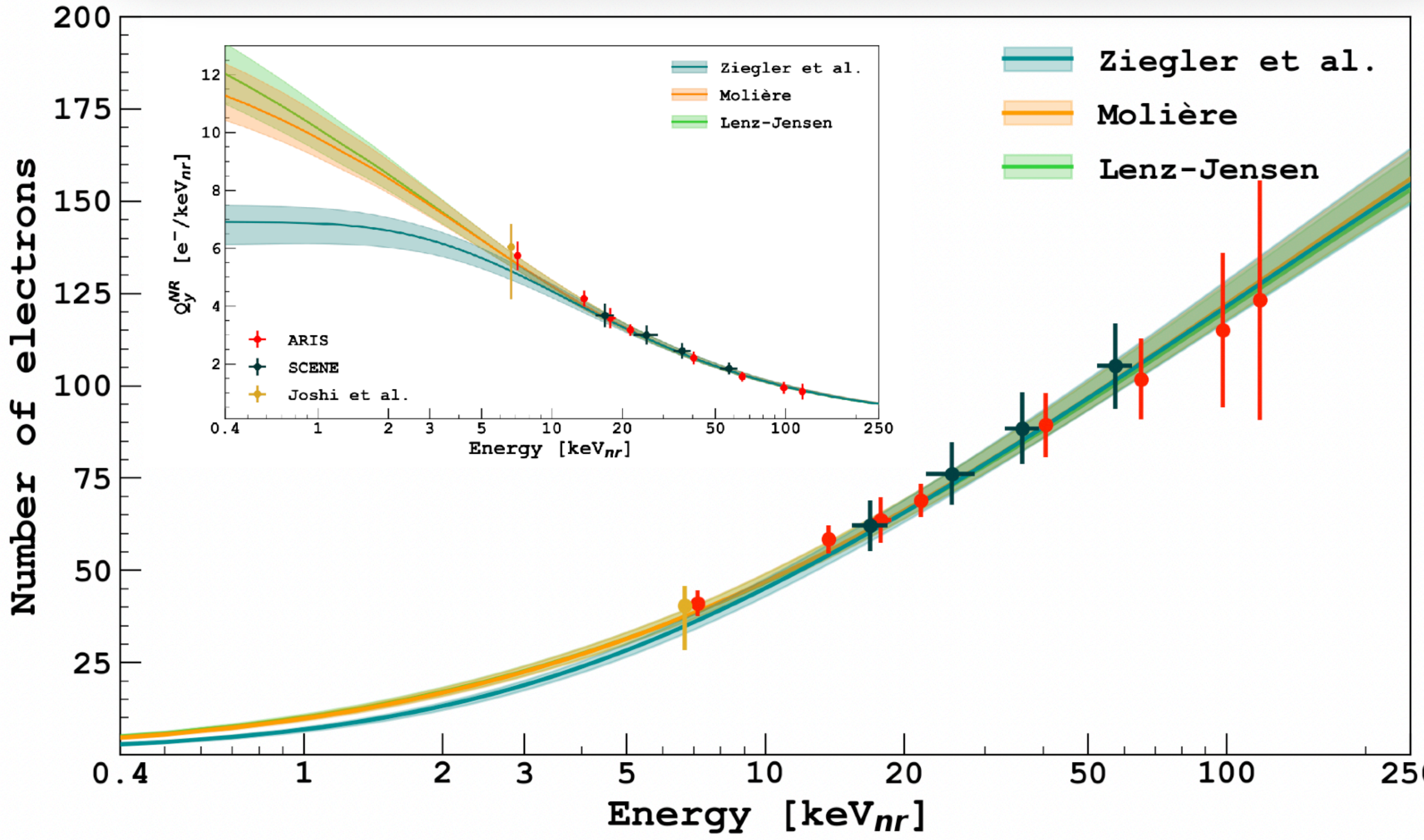
Ionization response to nuclear recoil





Global fit to:

- DS-50 calibration data with neutron sources
- External data set (ARIS and SCENE)
- Using Ziegler function as a baseline



Dataset and data selection

New exposure:

- 650 live-days / 12 ton-day
- x1.8 exposure used in 2018

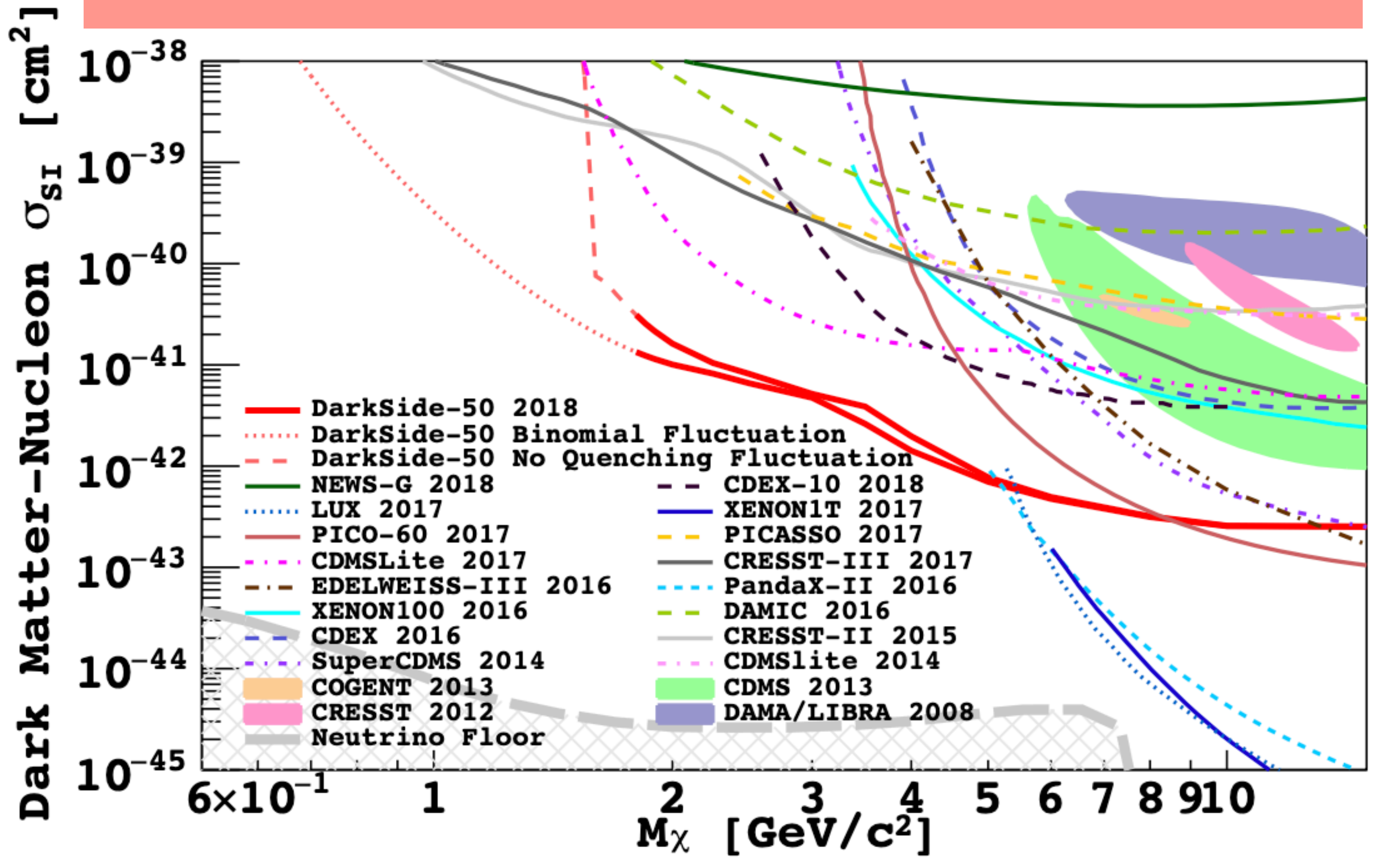
Quality cuts:

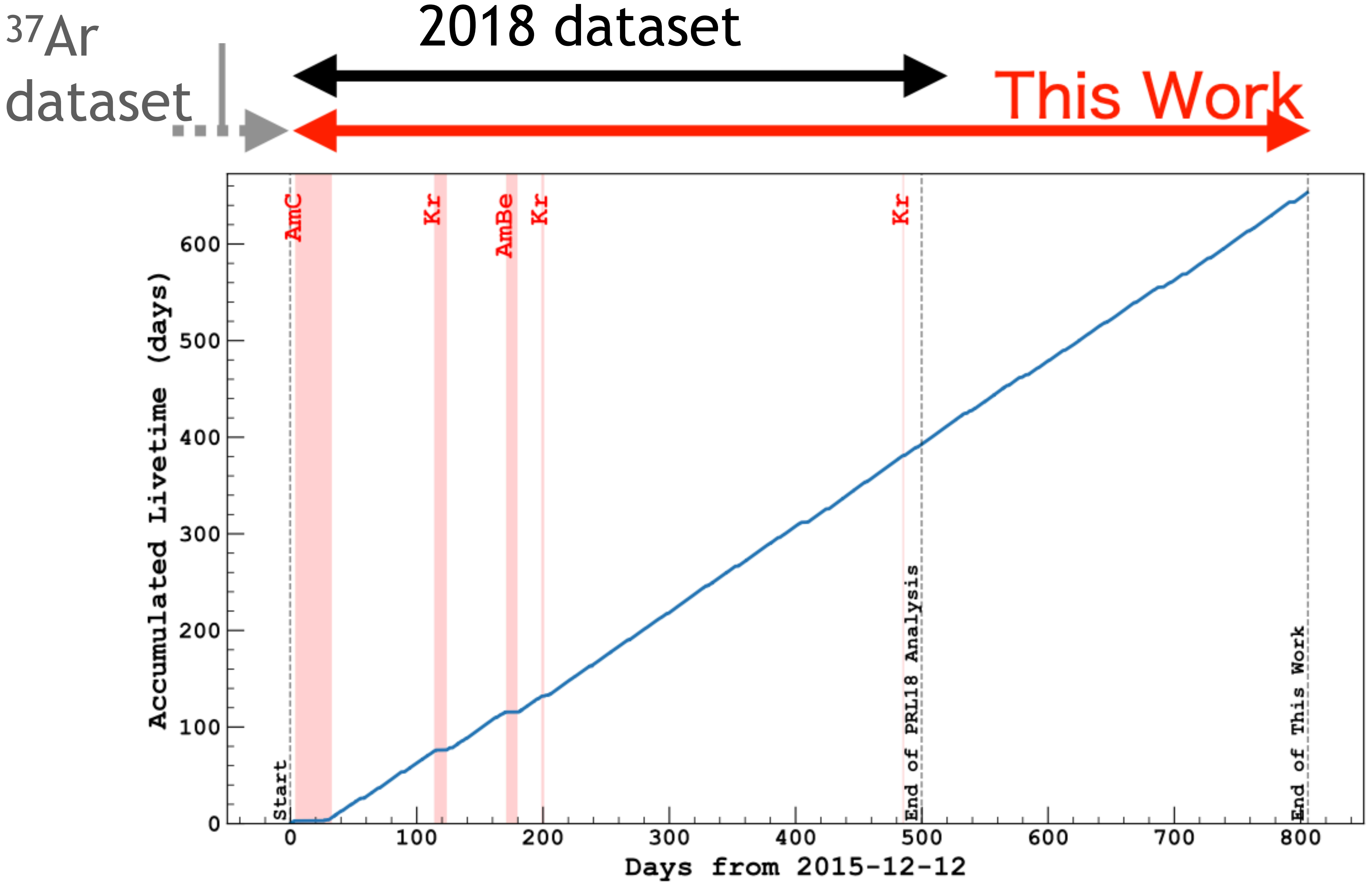
- Pulse-shape: remove anomalous pulses due to the pile-up of multiple S2’s or S1+S2
- Acceptance: 95% at 4 Ne and 99% at >15 Ne

Selection cuts:

- Fiducialization against external backgrounds
- S2/S1 against S2’s from alphas on the walls
- Time veto agains spurious (or “single”) electrons

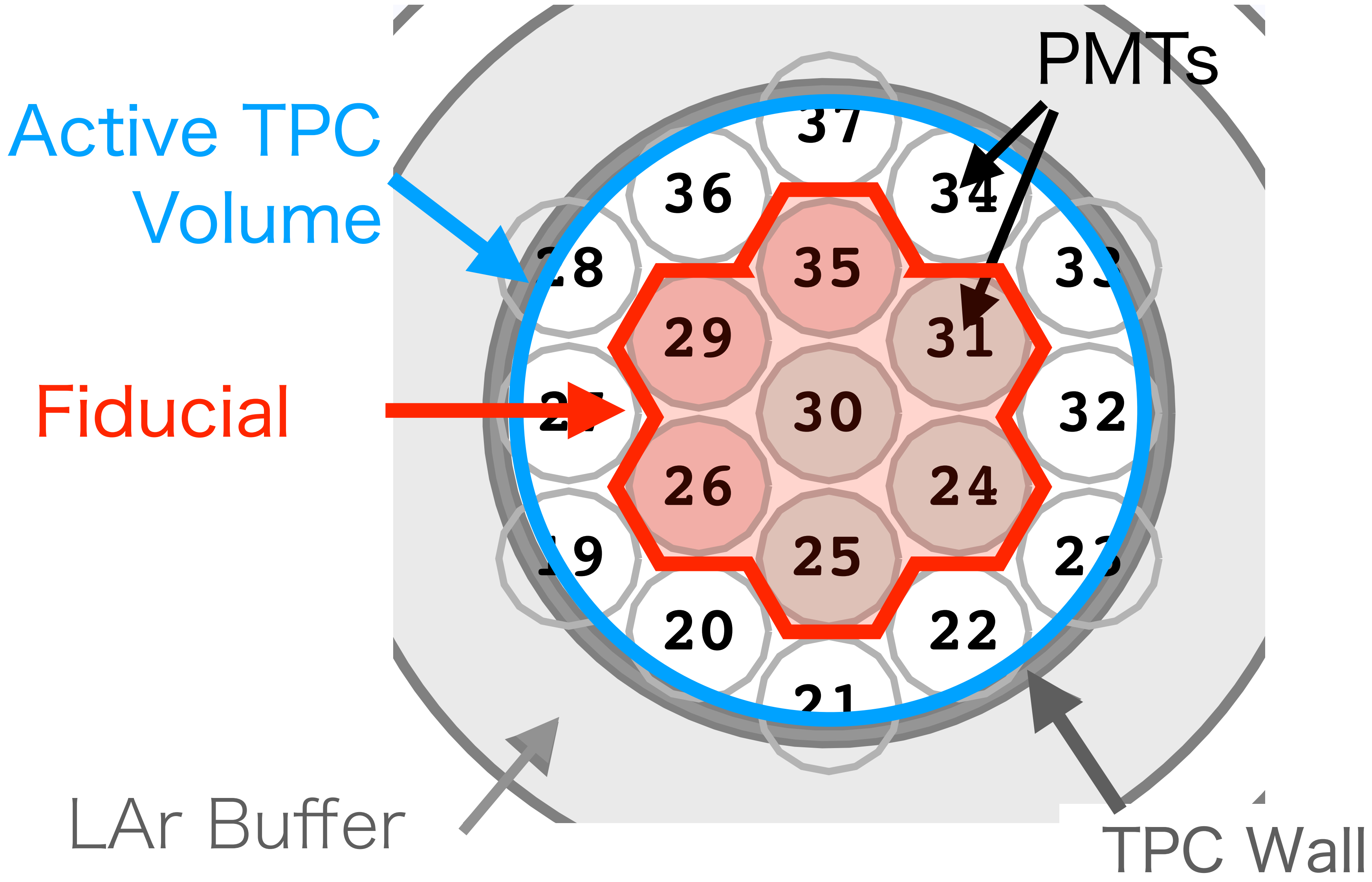
Light dark matter results of 2018





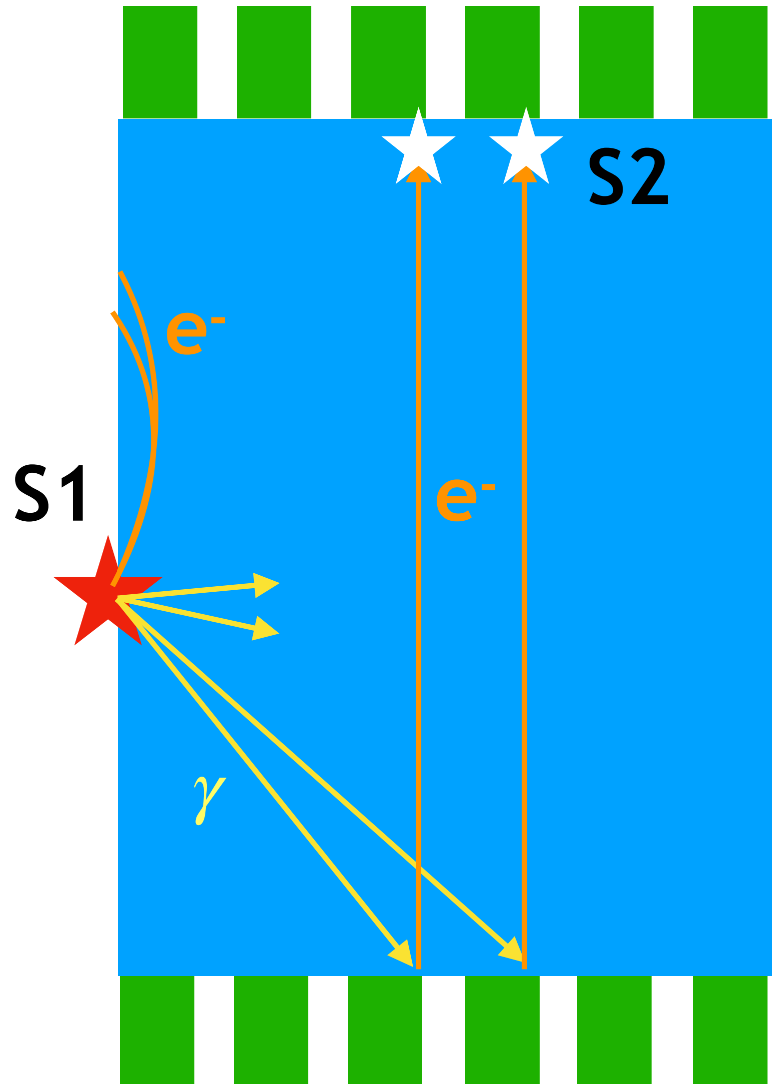
Data selection

Fiducialization



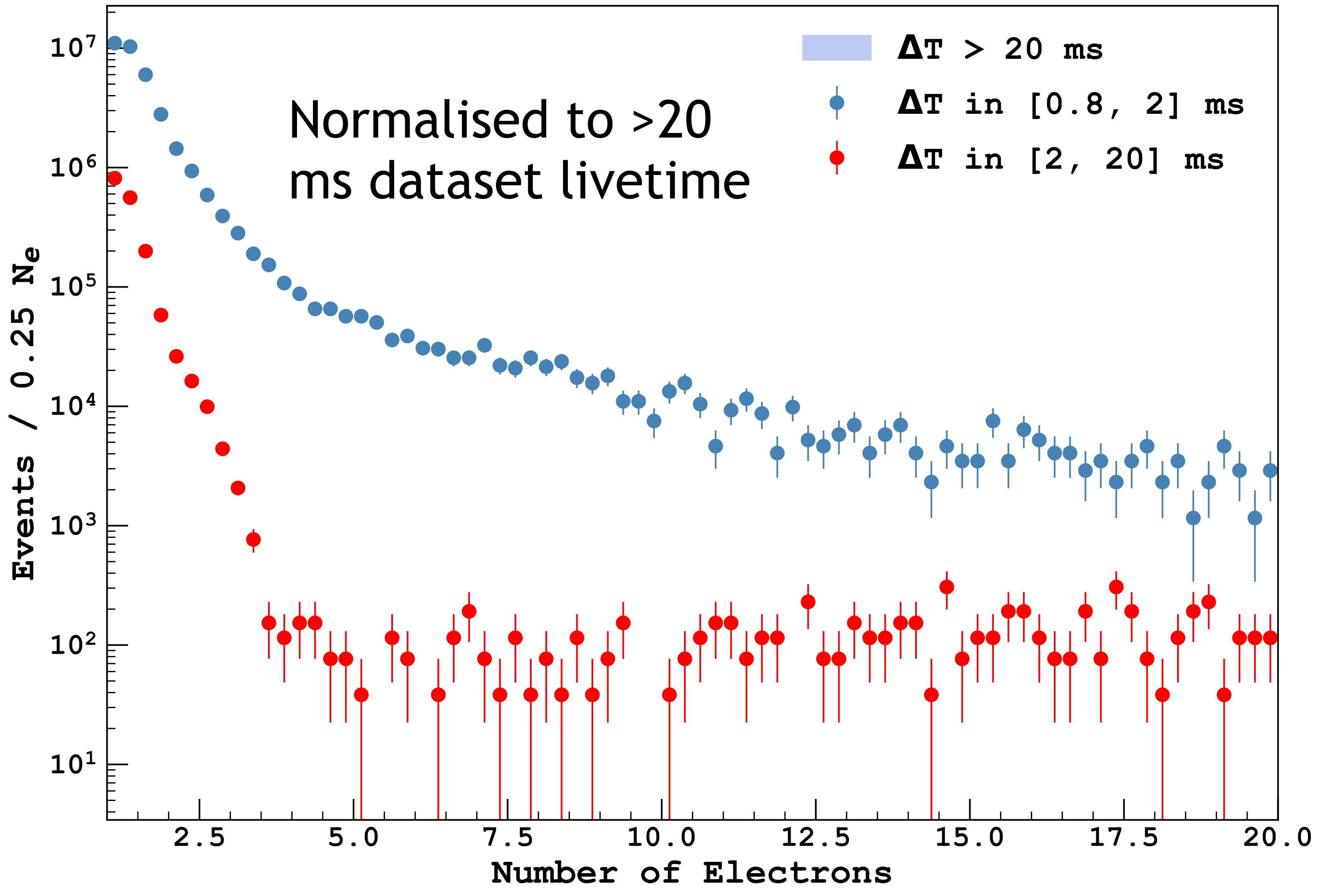
- Select events with max fraction of pes in one of the 7 central top PMTs
- Acceptance ~ 41%

Alpha-induced S2 pulses



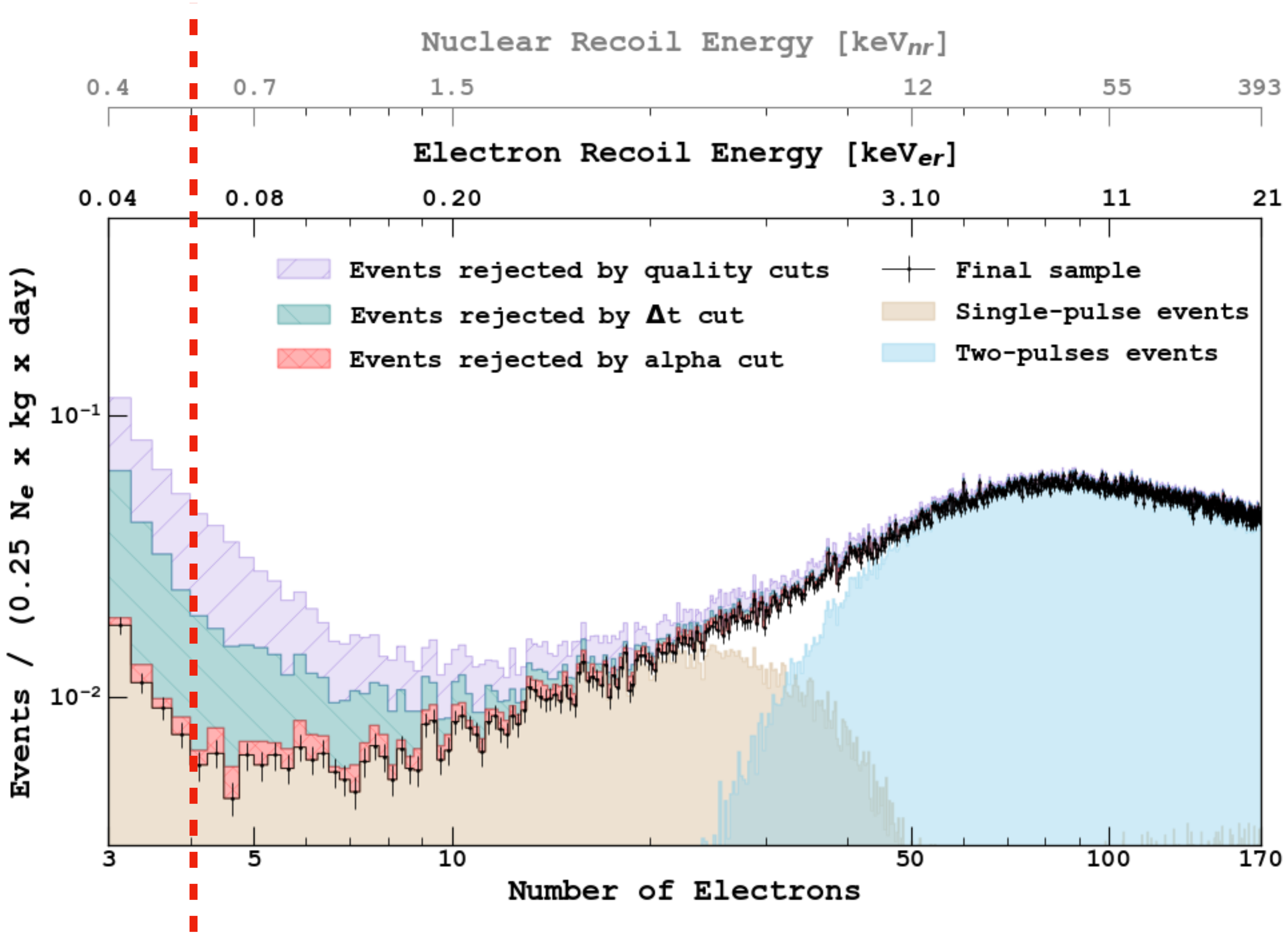
- Reject events with "anomalous" S2/S1
- Cut tuned on calibration data
- Acceptance ~ 99%

Spurious electrons



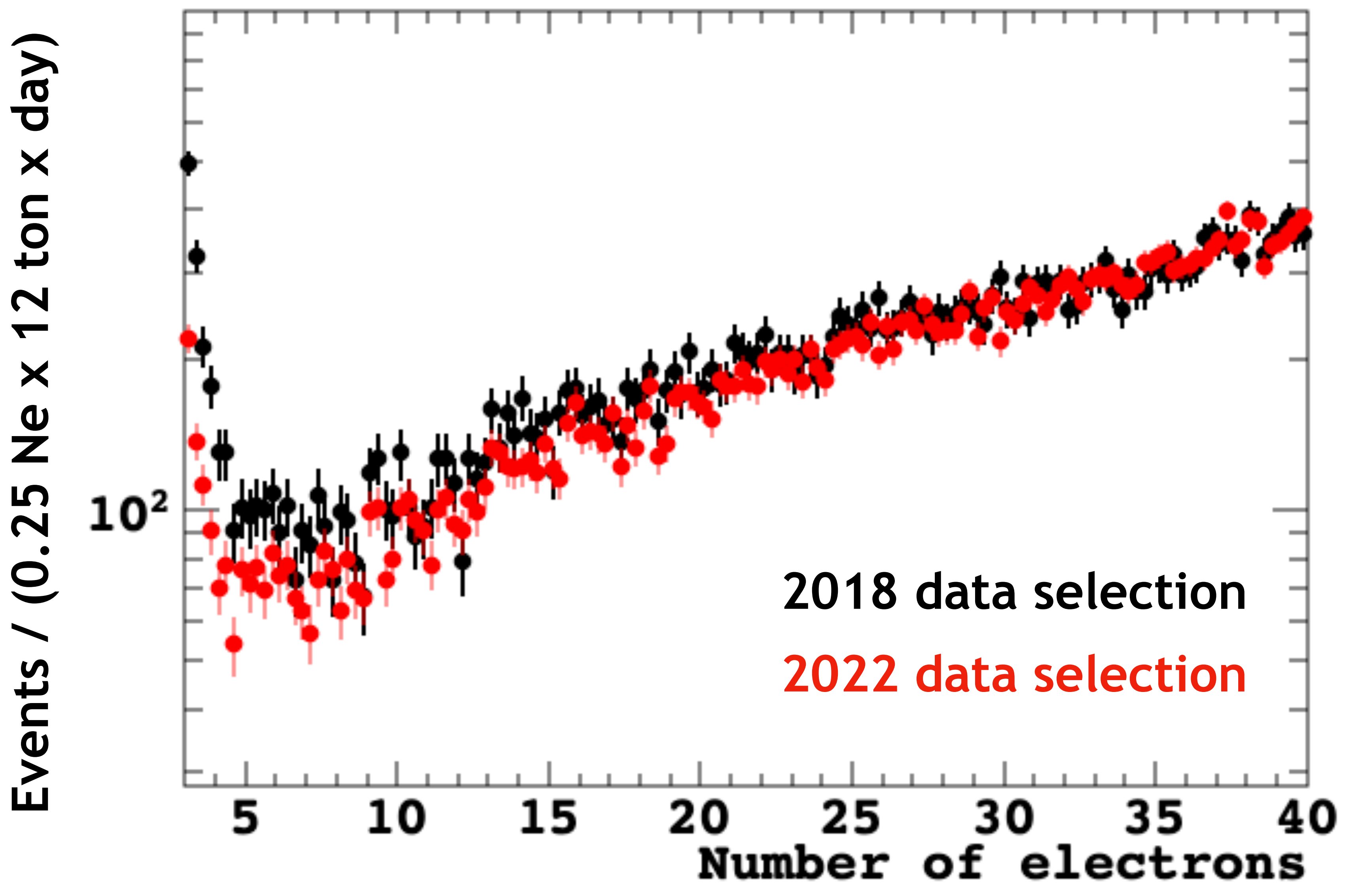
- Reject correlated events (if within 20 ms from the previous one)
- Acceptance ~ 97%

Threshold and overall acceptance



Analysis threshold

- Overall acceptance almost flat: 38.2% at 4 e- and 40.2% at ≥15 e-
- Low-Ne region more depleted than in 2018



Internal 39Ar and 85Kr

Both 39Ar and 85Kr **uniformly distributed** in the LAr bulk.

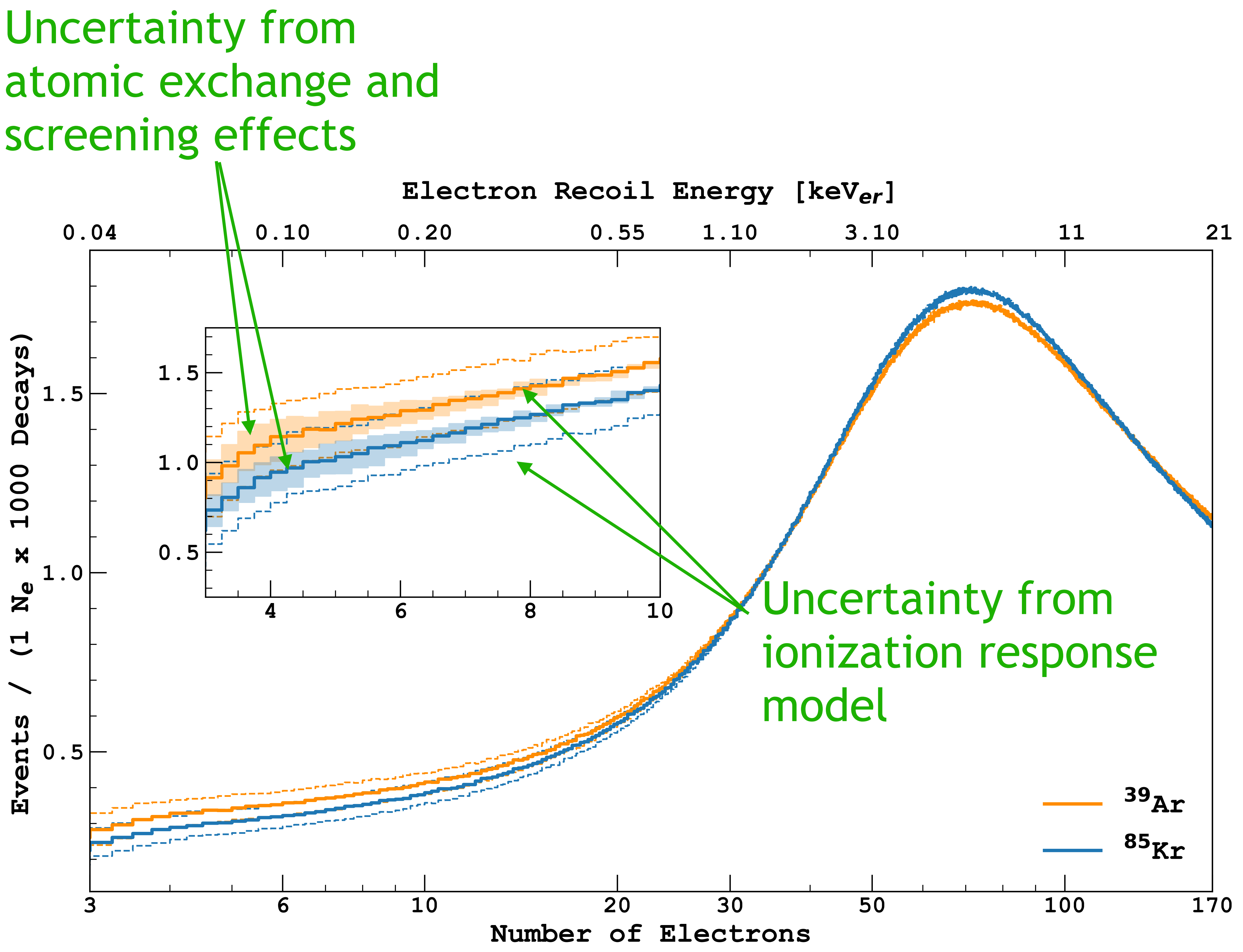
39Ar activity: 0.7 ± 0.1 mBq/kg

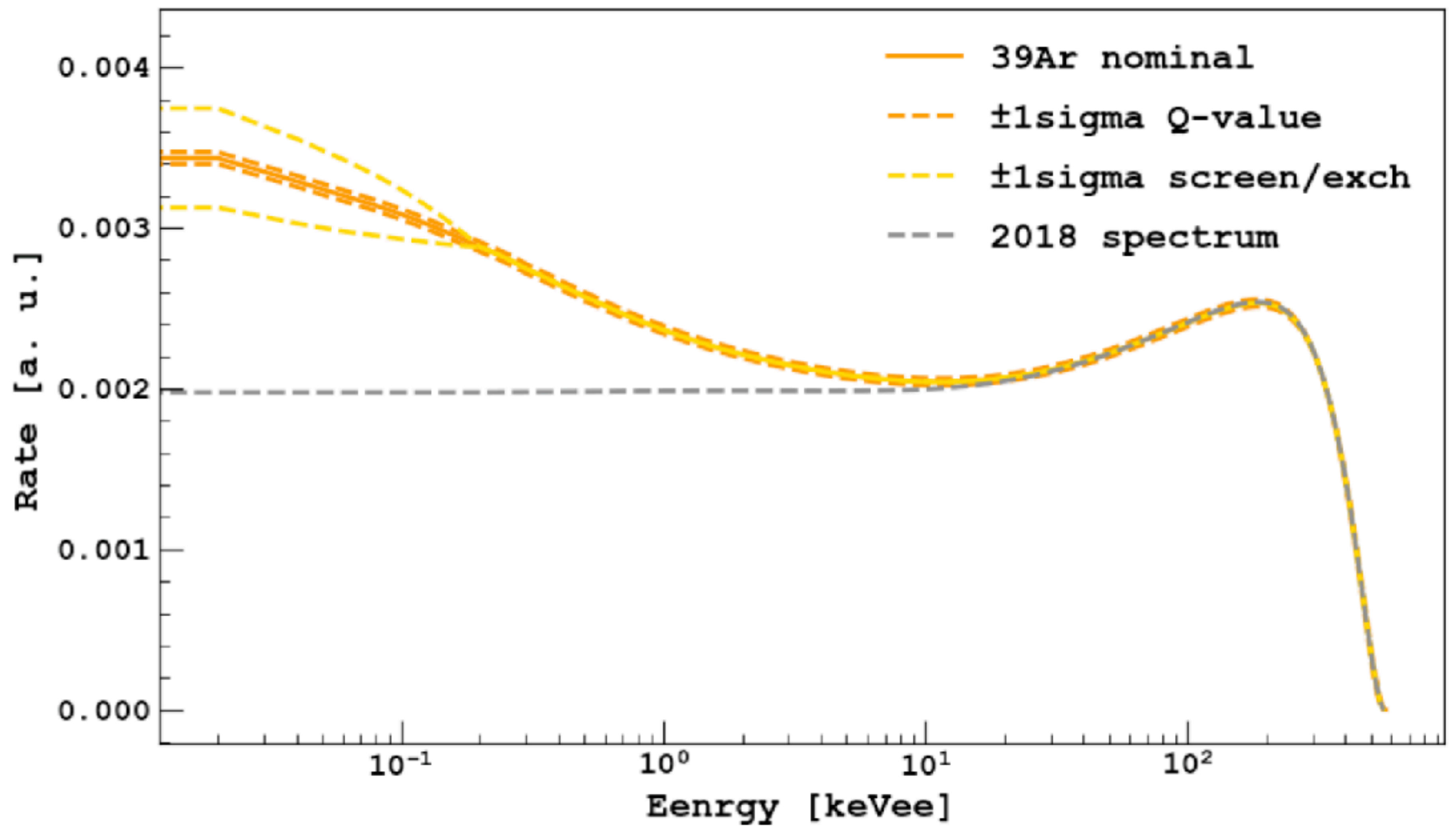
- from high energy spectral fit.

85Kr activity: 1.8 ± 0.1 mBq/kg

- from high energy spectral fit.
- from fast coincidence through metastable state.
- from decay time fit.

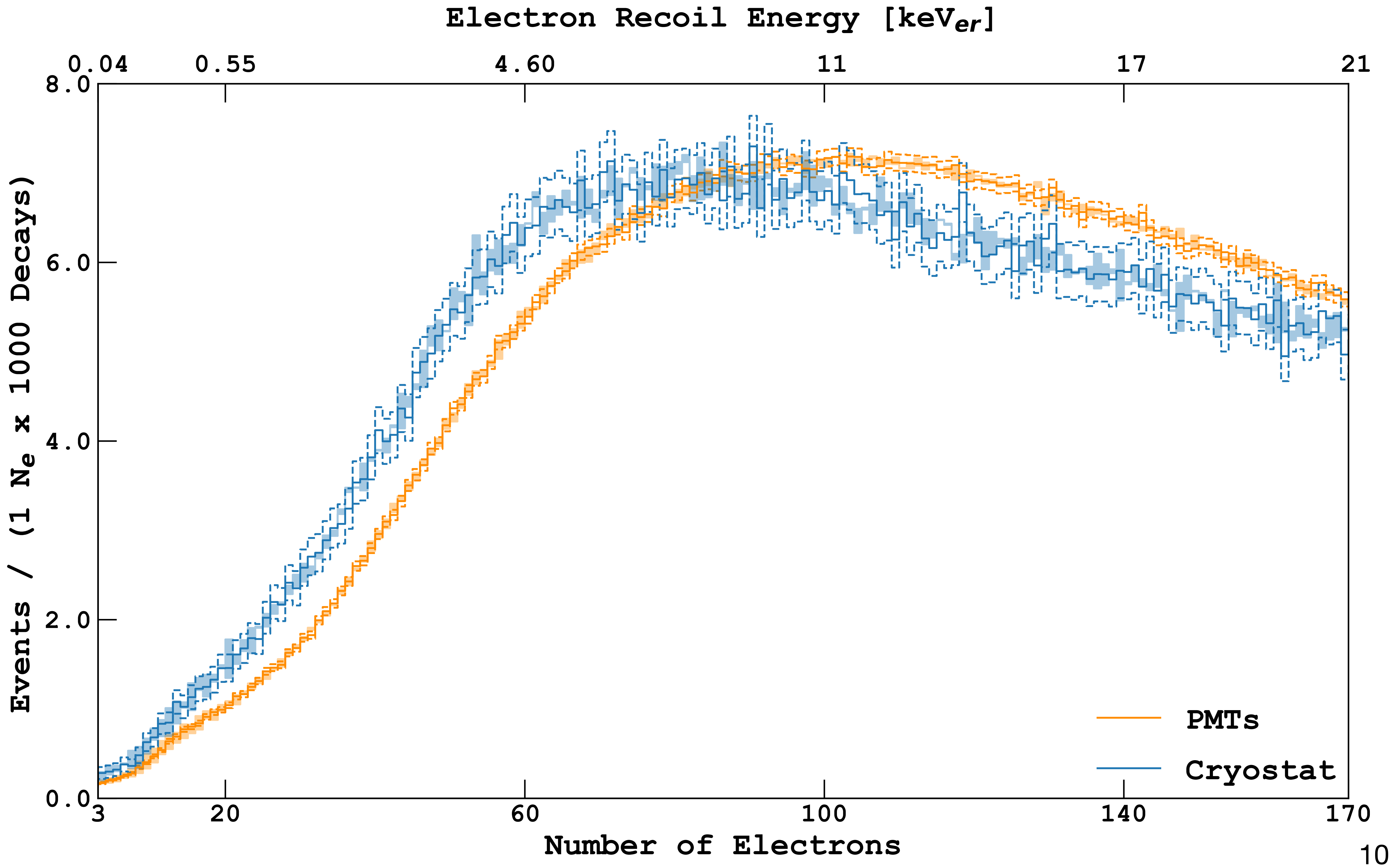
Both unique first-forbidden beta decays: **additional atomic exchange and screening effects.**

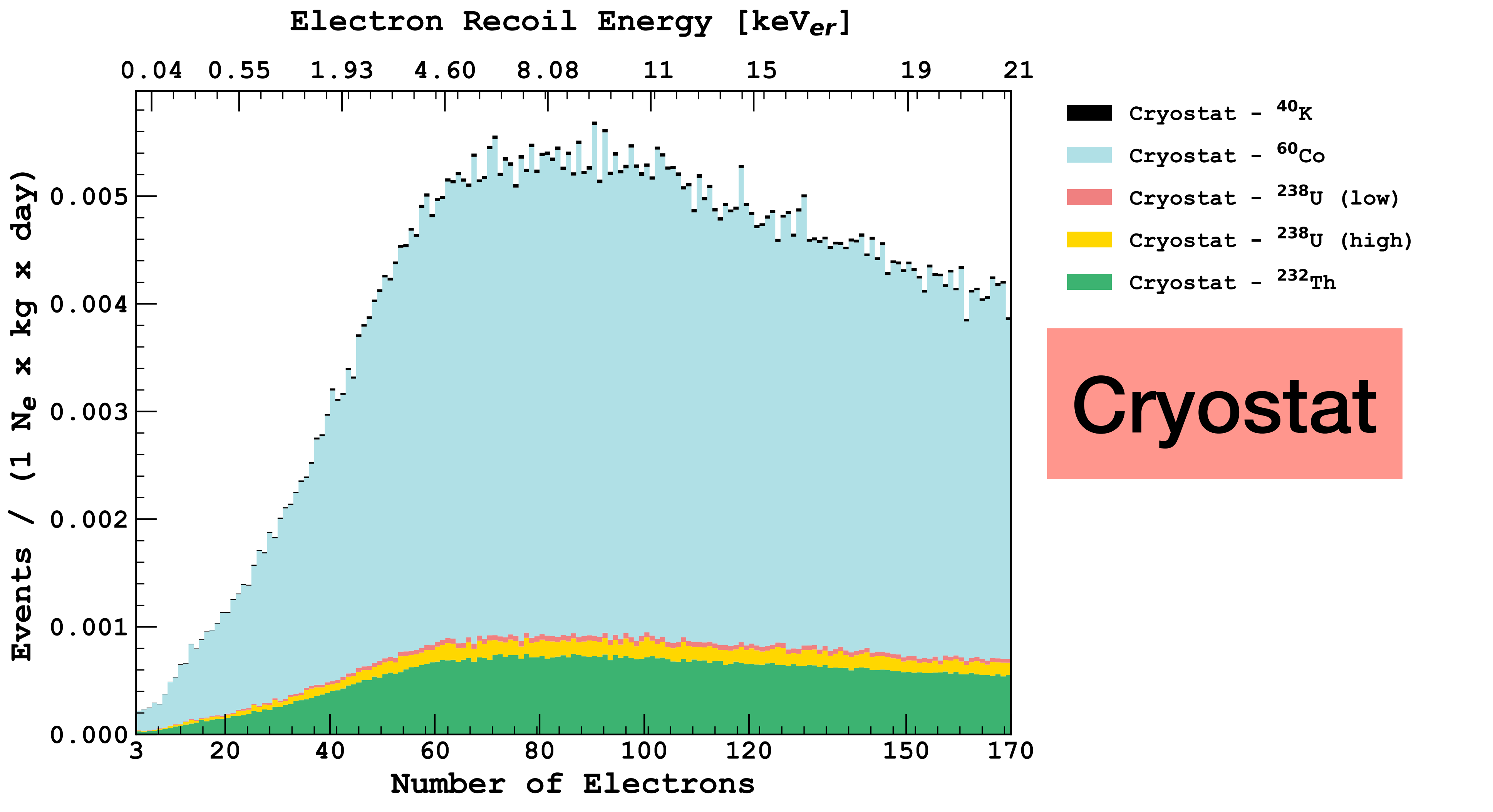




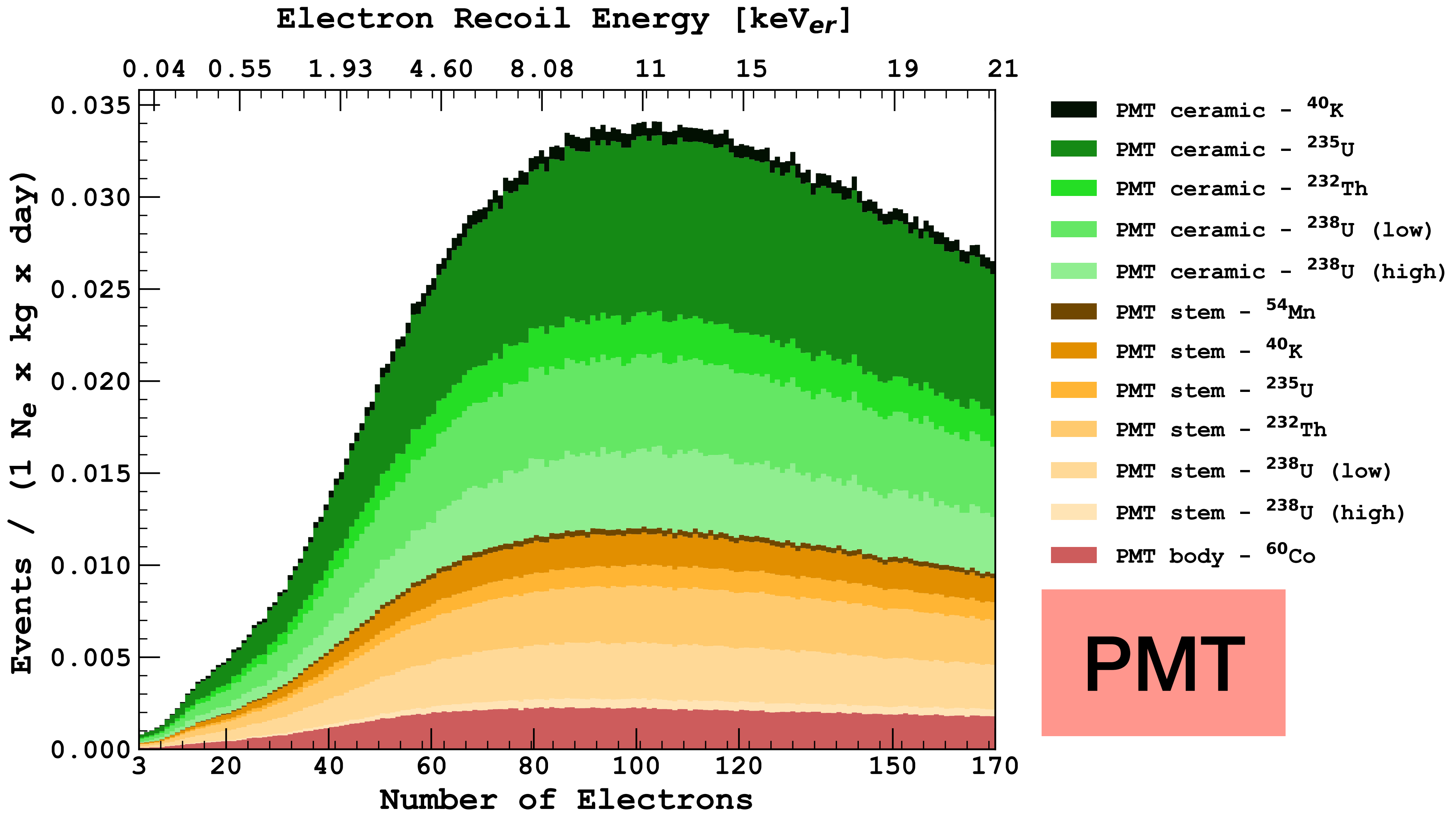
External gammas

- New background model from material screening campaign.
- In 2018 it was extrapolated from the fit of the high energy spectrum.





Cryostat



PMT

Profile likelihood and systematics

$$\mathcal{L} = \prod_{i \,\epsilon\, \text{bins}} \mathcal{P}\left(n_i | m_i(\mu_s, \Theta)\right) \times \prod_{\theta_i \,\epsilon\, \Theta} \mathcal{G}(\theta_i^0 | \theta_i, \Delta\theta_i) \times \prod_{i \,\epsilon\, \text{bins}} \mathcal{G}\left(m_i^0 | m_i(\Theta), \delta m_i(\Theta)\right)$$

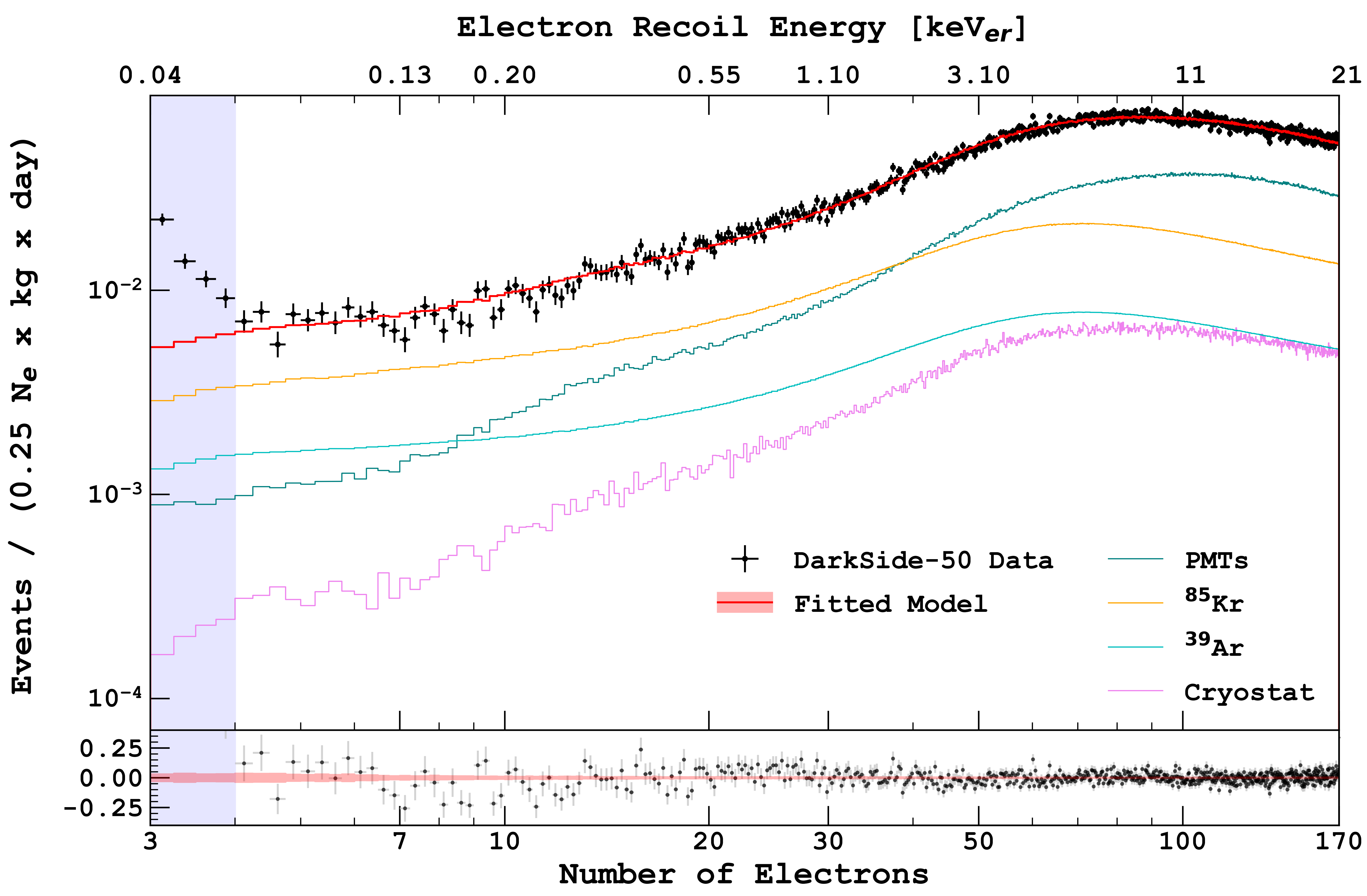
Poisson probability of observing n_i events in the i^{th}-bin with respect to the expected ones, $m_i(\mu_s,\Theta)$, with μ_s the signal strength.

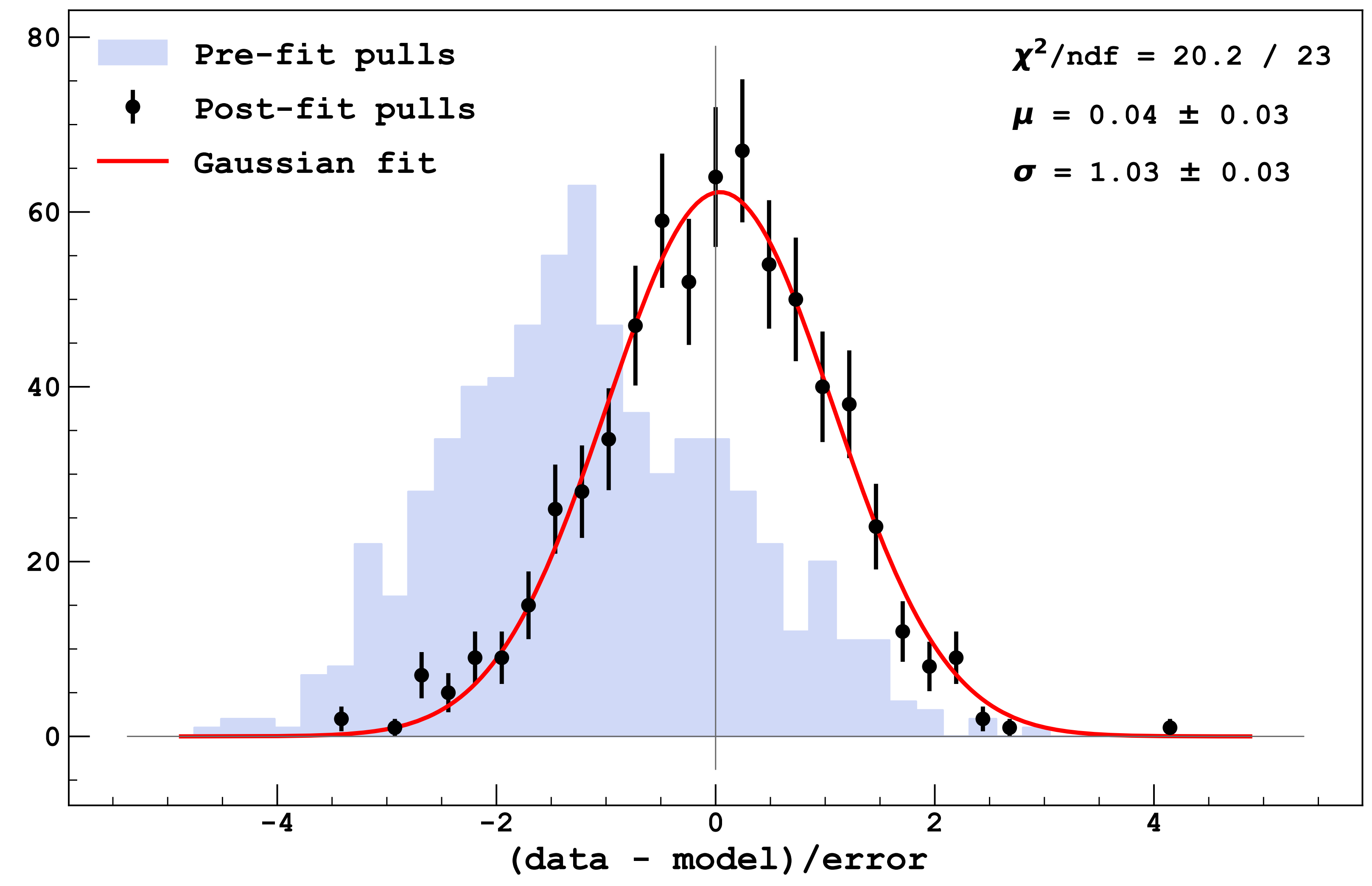
Gaussian penalties to account for the nuisance parameters (θ_0 and $\Delta\theta$ are the nominal central values and uncertainties)

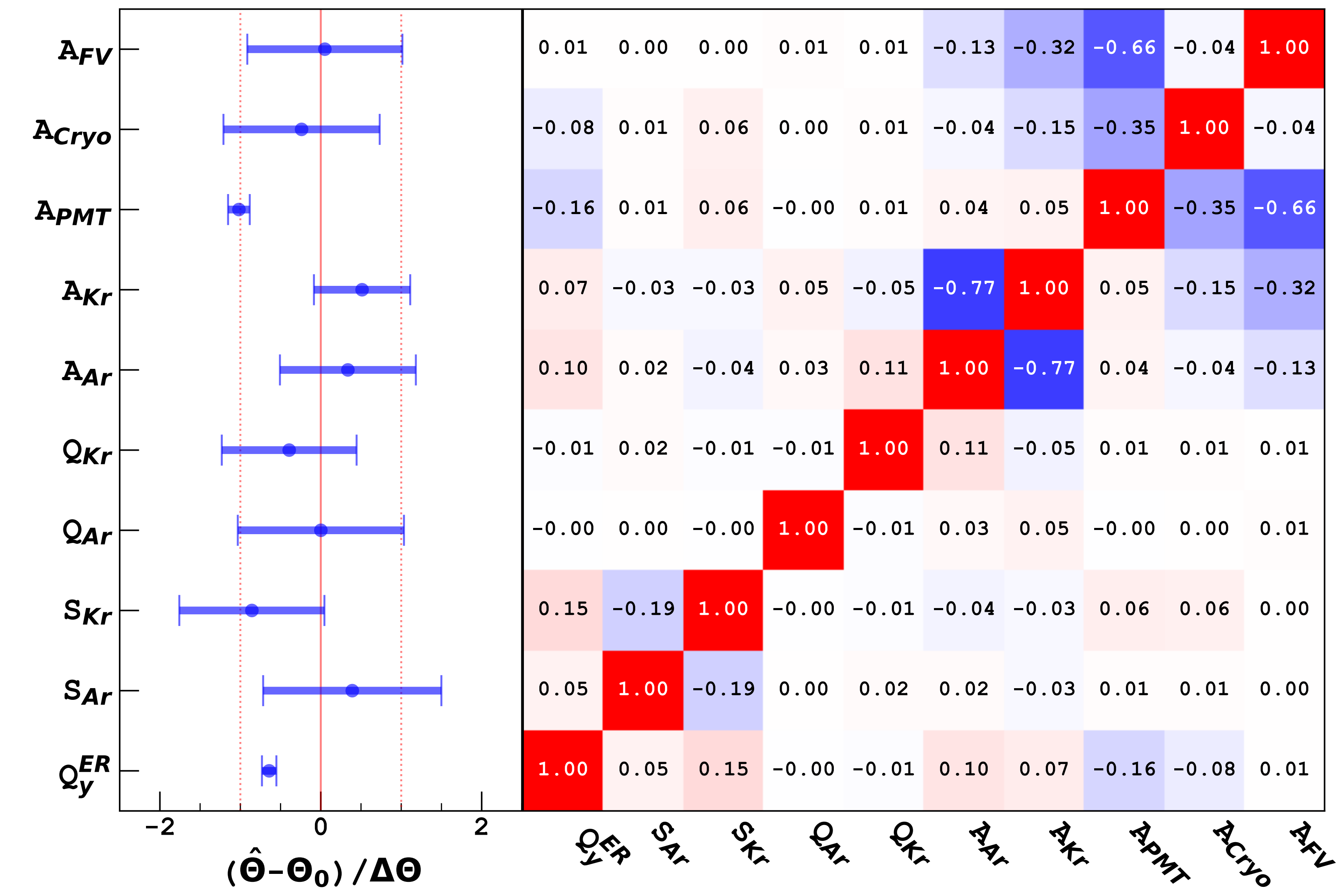
Statistical uncertainties of the simulated sample

	Name	Source	Affected components
Amplitude	A_{FV}	uncertainty on the fiducial volume	WIMP, ^{39}Ar, ^{85}Kr, PMTs, Cryostat
	A_{Ar}	14.0% uncertainty on ^{39}Ar activity	^{39}Ar
	A_{Kr}	4.7% uncertainty on ^{85}Kr activity	^{85}Kr
	A_{pmt}	11.5% uncertainty on activity from PMTs	PMT
	A_{cryo}	6.6% uncertainty on activity from the cryostat	Cryostat
Shape	Q_{Kr}	0.4% uncertainty on the ^{85}Kr-decay Q-value	^{85}Kr
	Q_{Ar}	1% uncertainty on the ^{39}Ar-decay Q-value	^{39}Ar
	S_{kr}	spectral shape uncertainty on atomic exchange and screening effects	^{85}Kr
	S_{Ar}	spectral shape uncertainty on atomic exchange and screening effects	^{39}Ar
	Q_y^{er}	spectral shape systematics from ER ionization response uncertainty	^{39}Ar, ^{85}Kr, PMTs, Cryostat
	Q_y^{nr}	spectral shape systematics from NR ionization response uncertainty	WIMP

Background-only fit

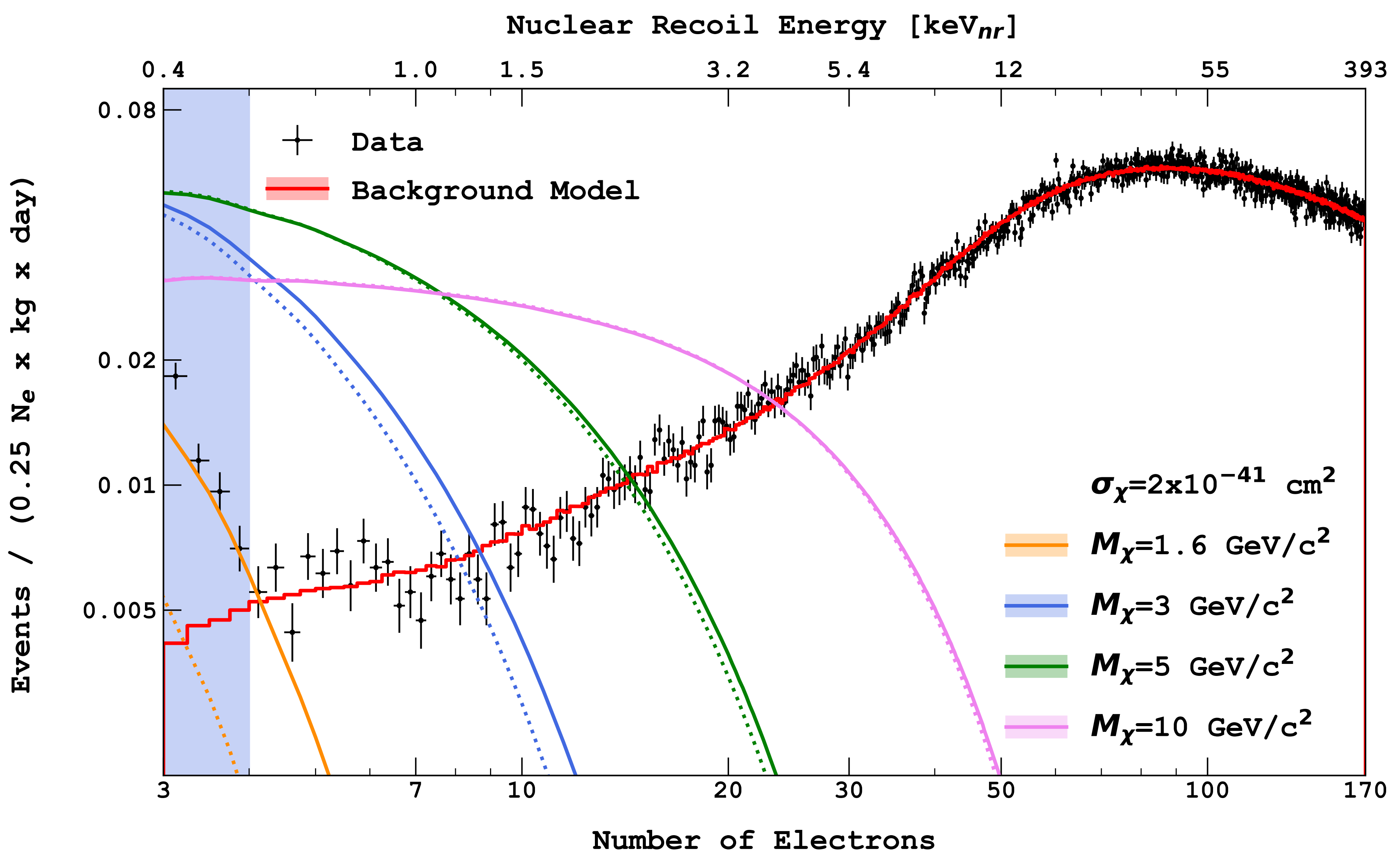


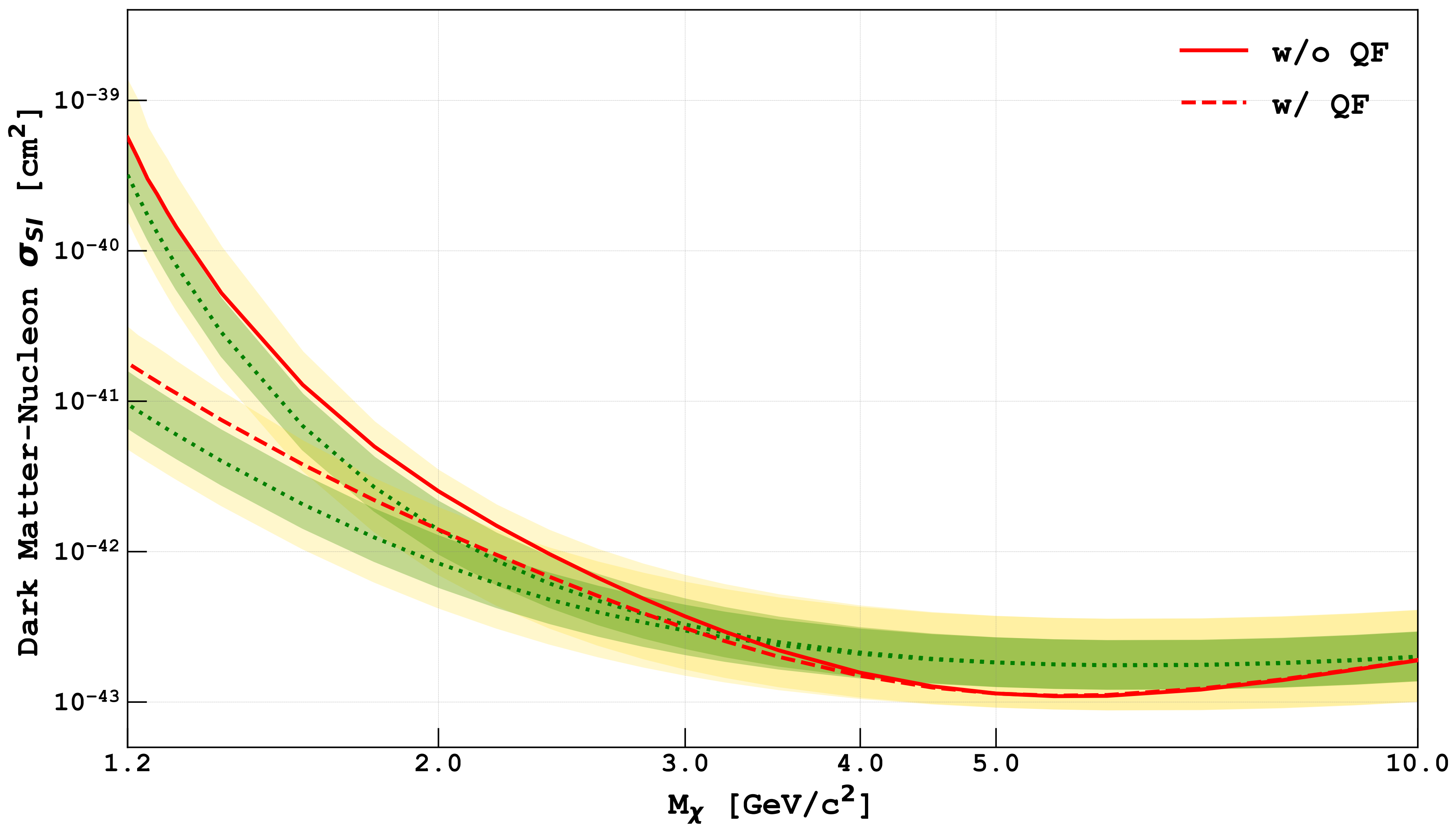


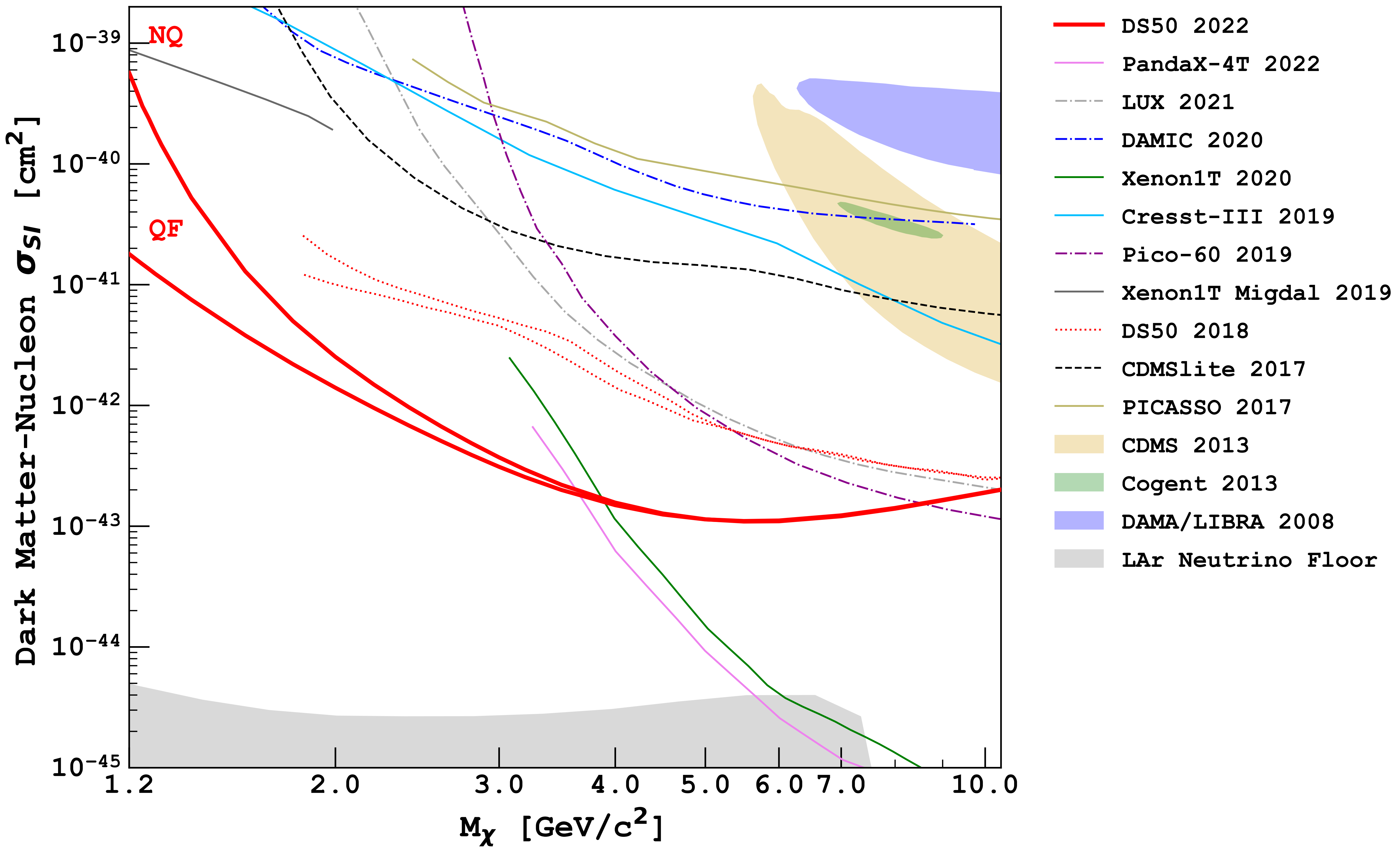


Tritium activity < 1 μBq/kg (90% CL)

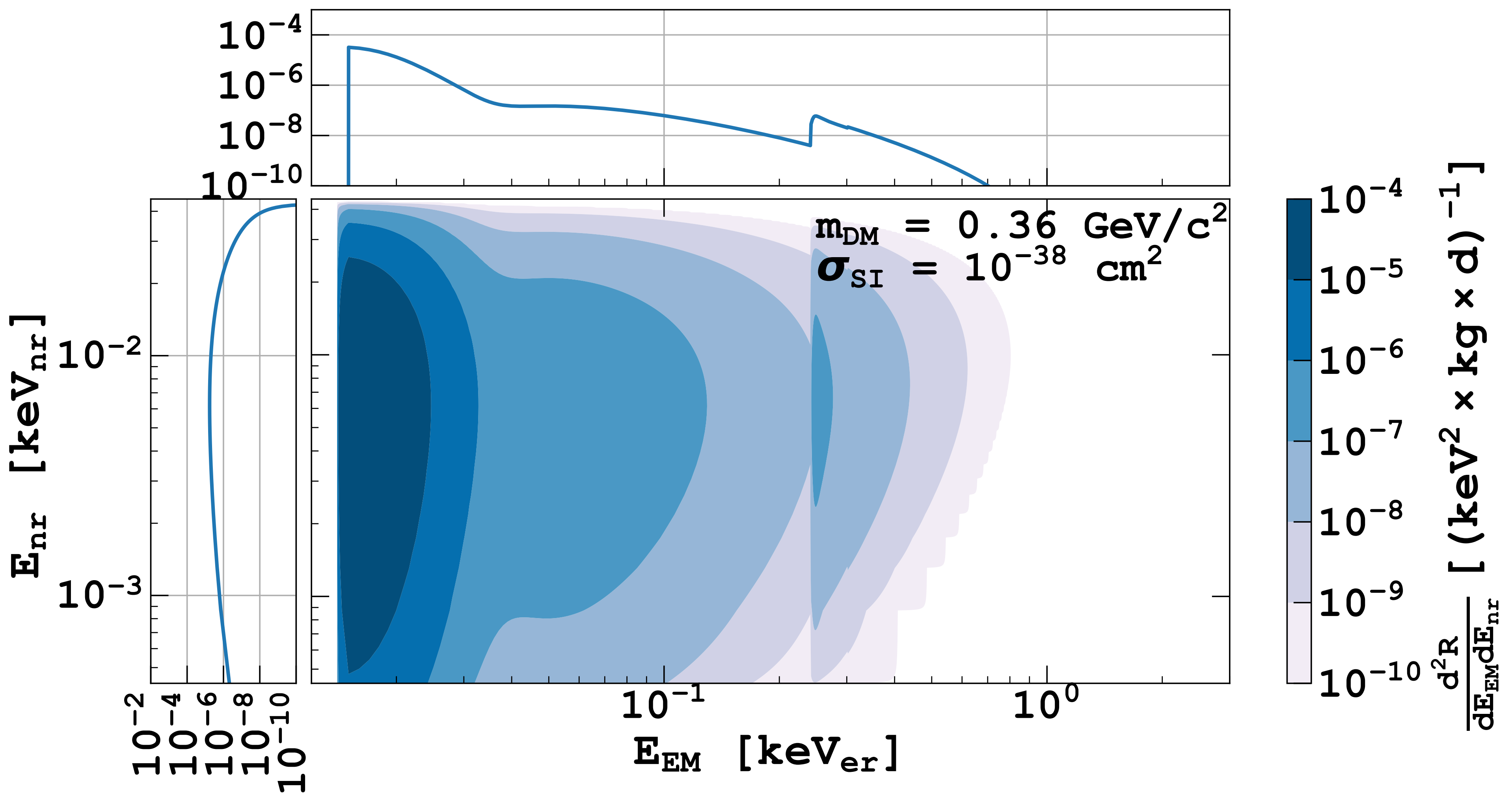
WIMP-nucleon interaction

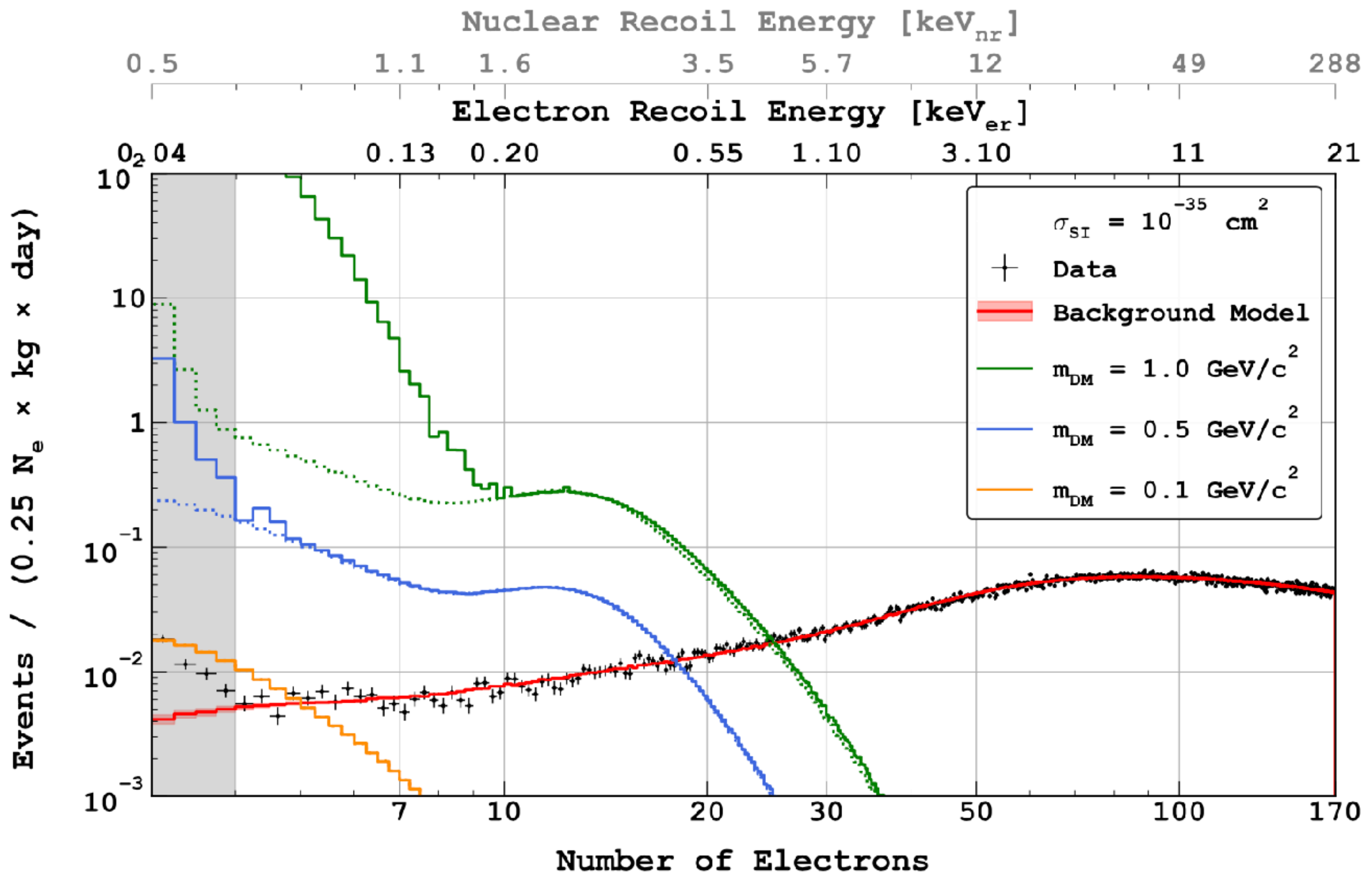


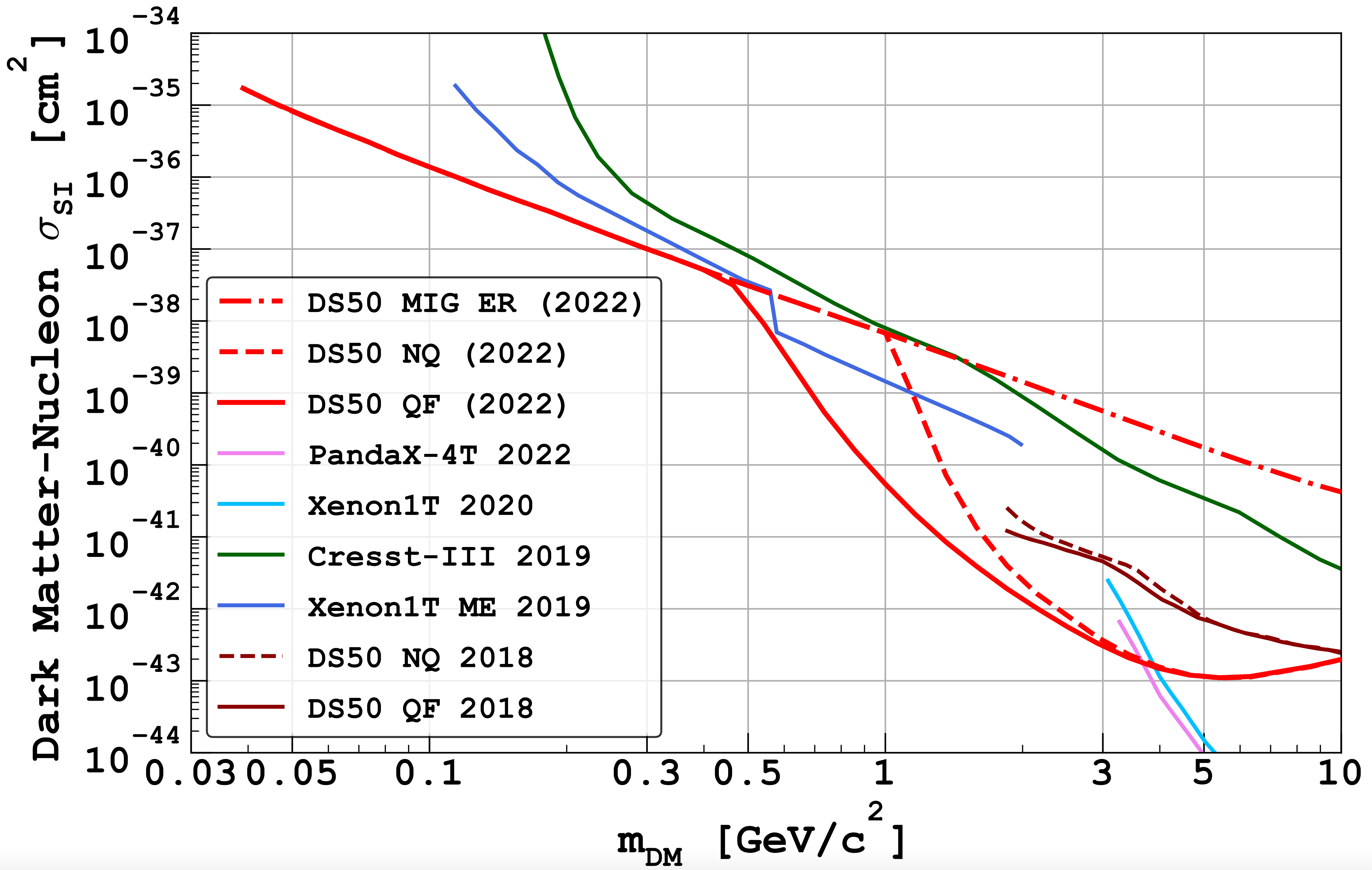




The Migdal Effect



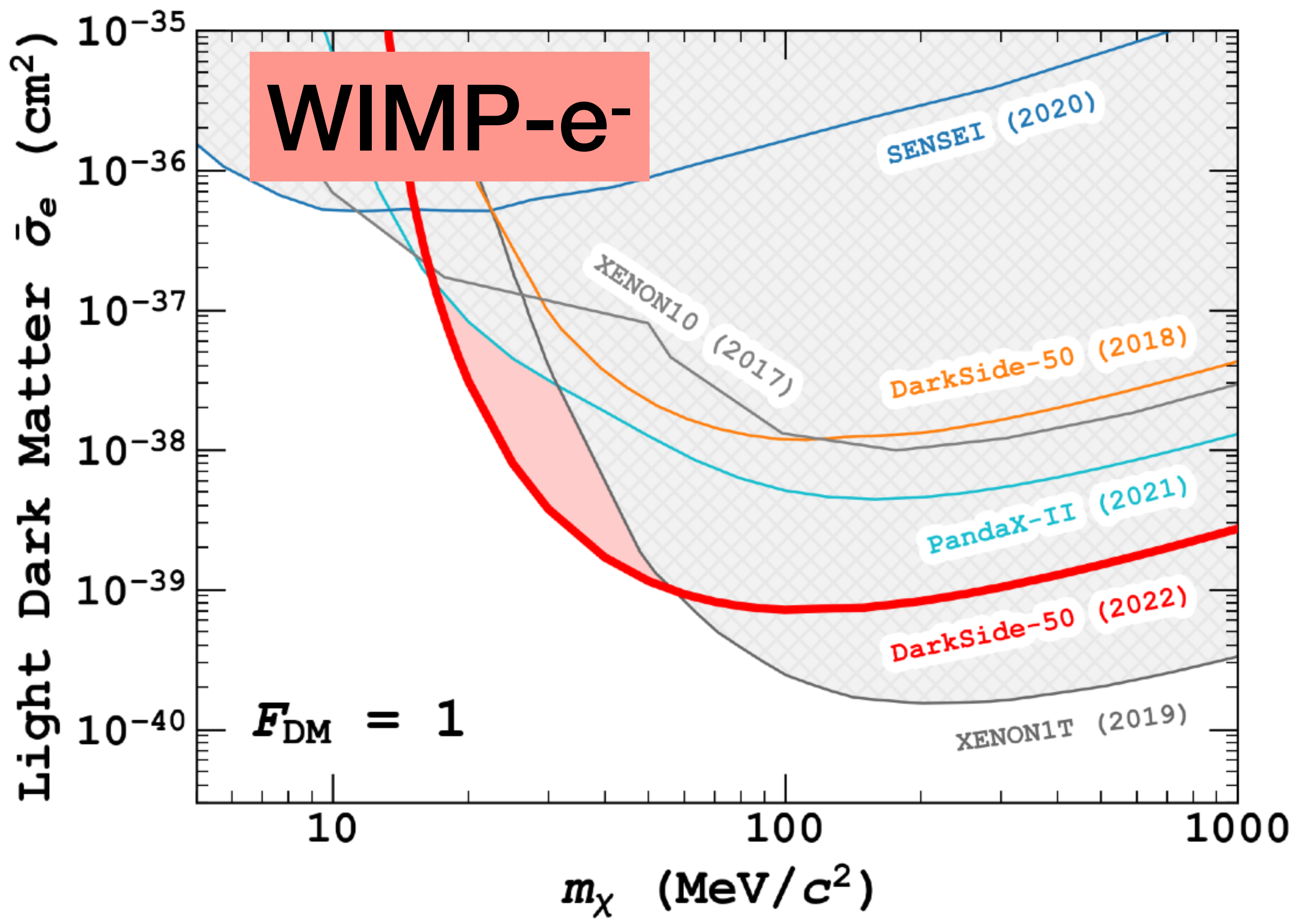


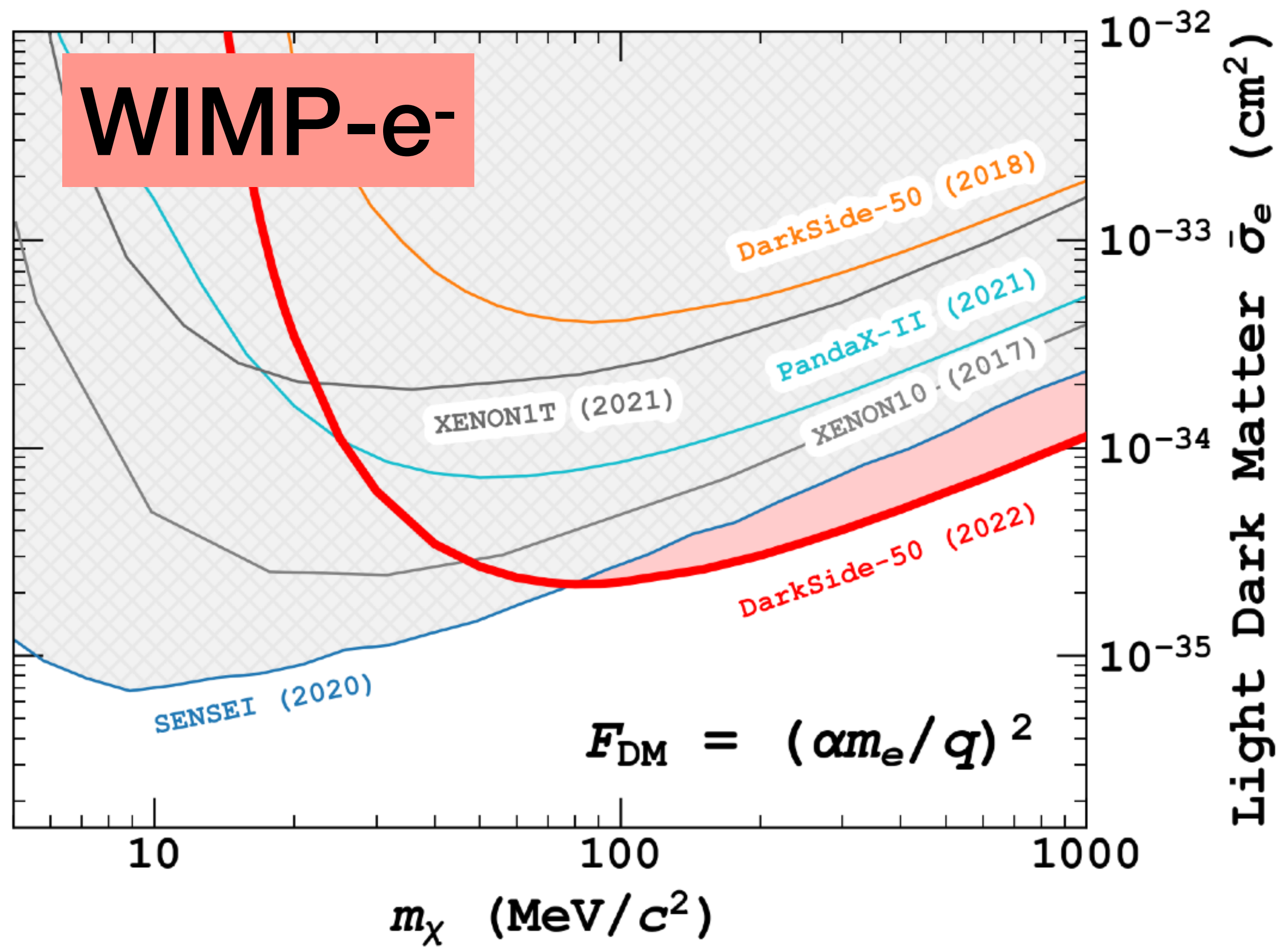


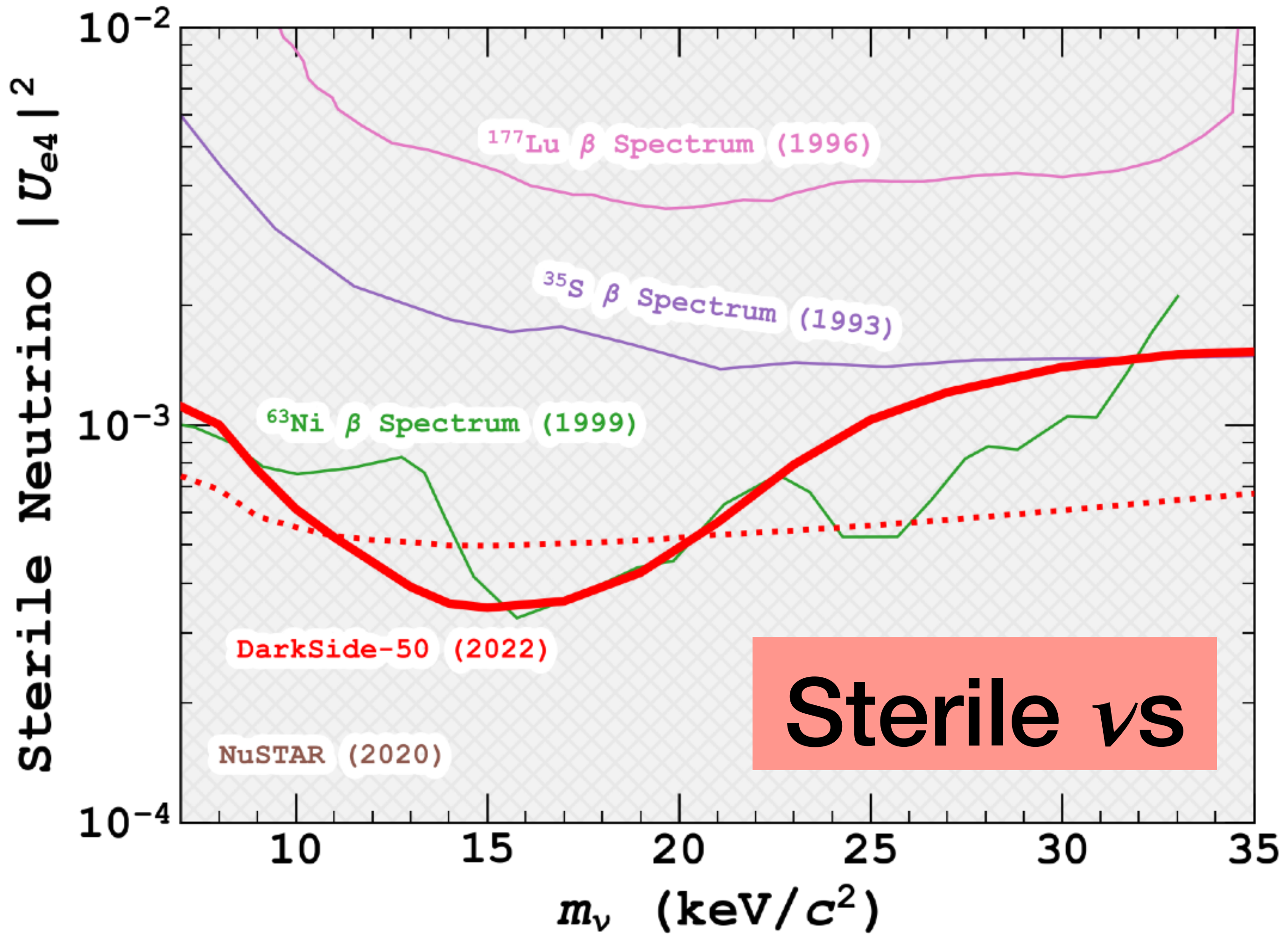
Results confirmed by using Bayesian Networks (arXiv:2302.01830):

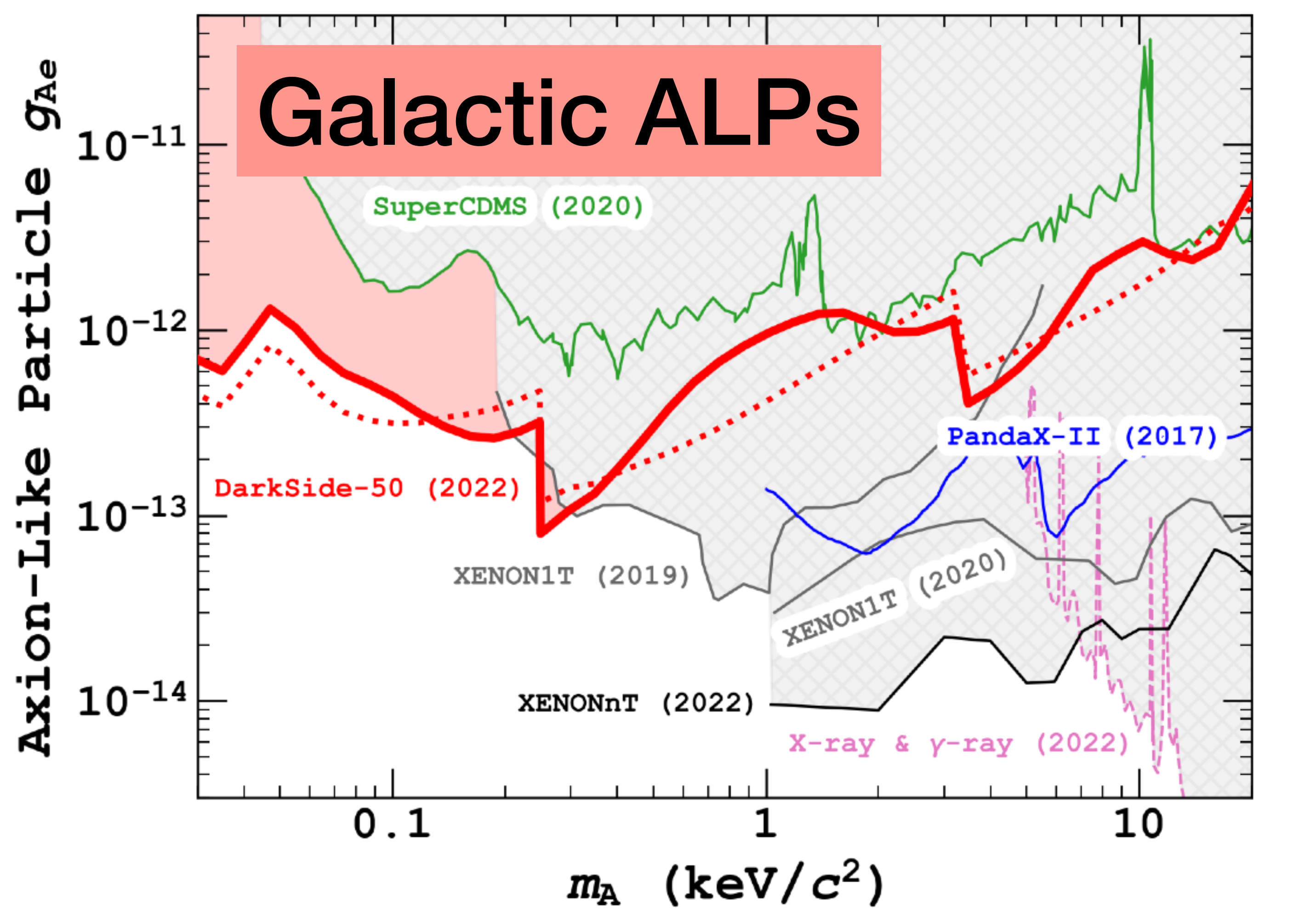
- Detector response model included in the likelihood function.
- Markov Chain Monte Carlo for posterior probability.

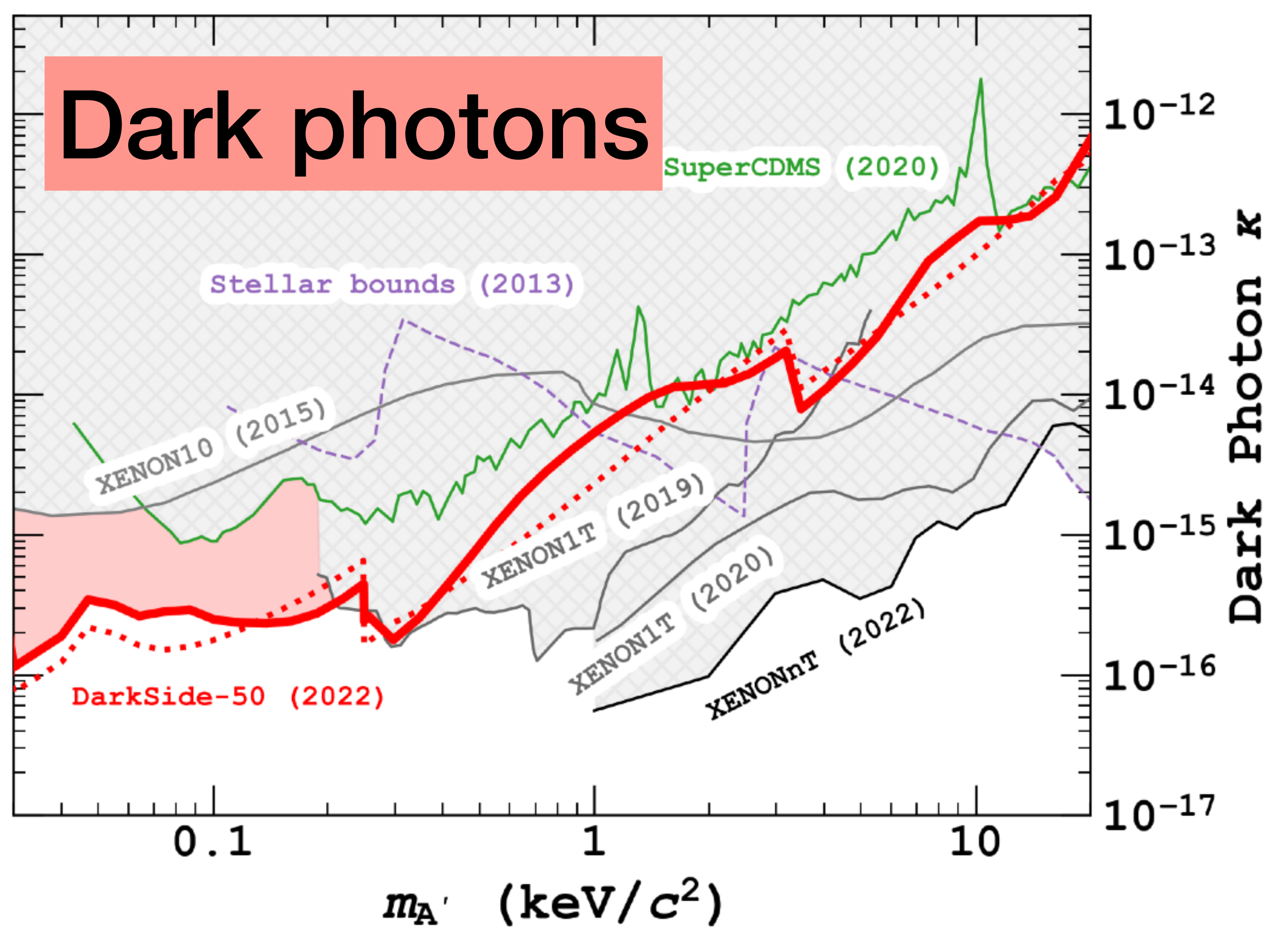
Leptophilic dark-matter











Conclusion

Improved light dark matter limits from 2018 analysis thanks to:

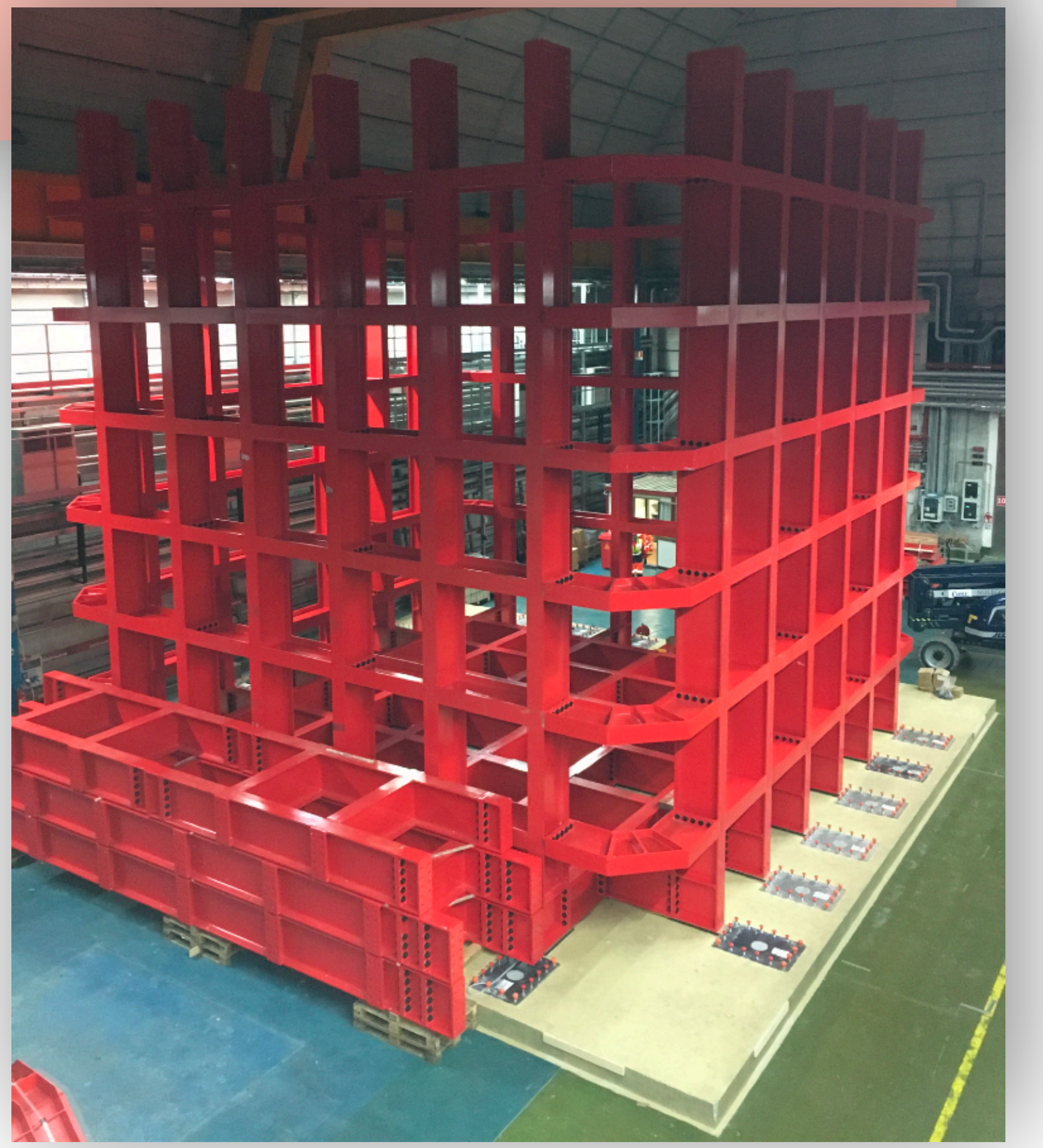
- **Calibration** of ionization response to ERs and NRs down to <1 keV
- Extended **exposure**
- Better **data selection**

Best SI WIMP-nucleon limits down to 1.2 GeV/c^2 (40 MeV/c^2) WIMP mass without (with) Migdal effect.

Improved limits on **WIMP-electron** interactions, galactic ALPs, dark photons, and sterile neutrinos.

Incoming results:

- Annual modulation
- Non-standard operators
- **Low-mass sensitivity projection in DarkSide-20k**



Thank you for your attention