Light dark matter search with DarkSide-50

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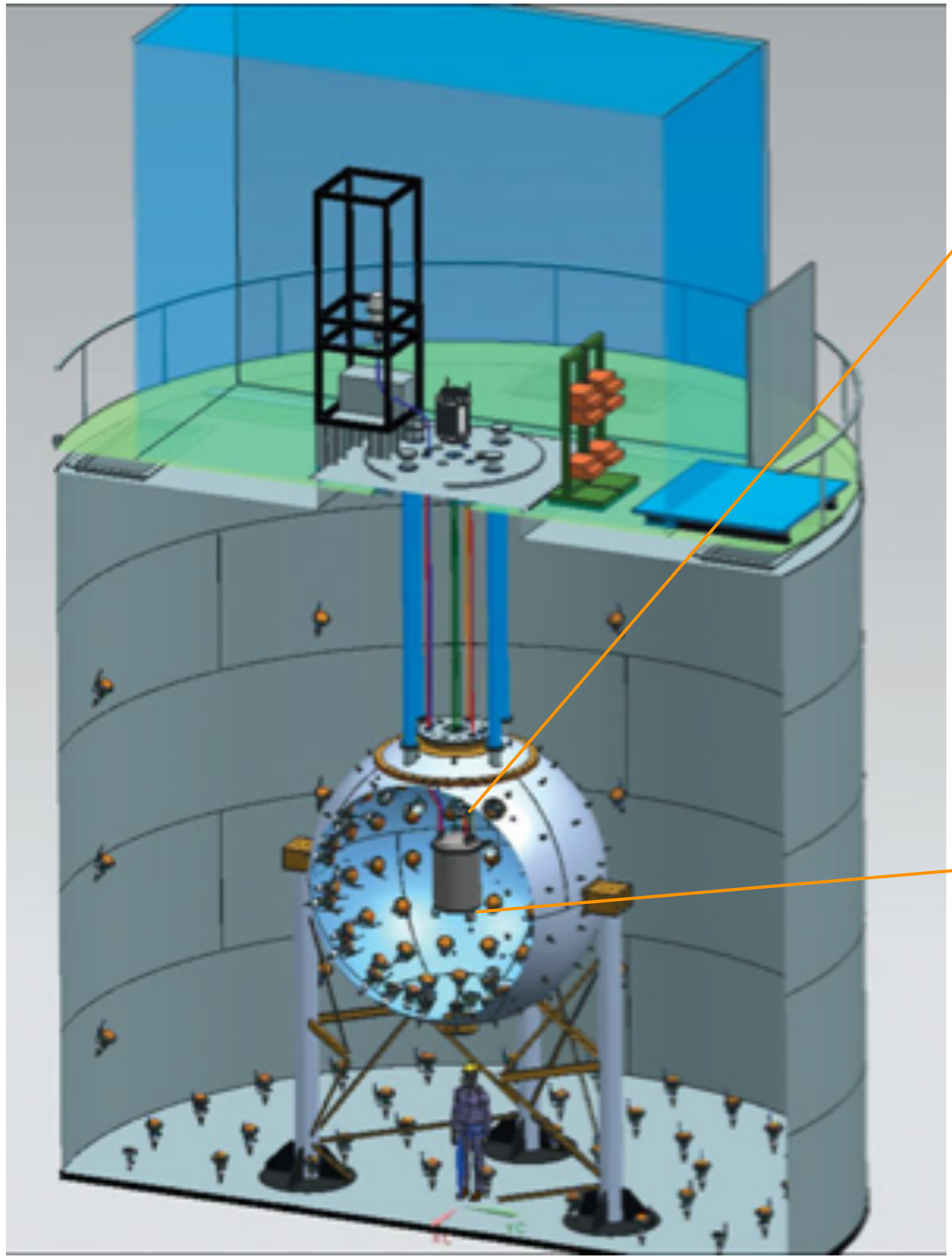
on behalf of the DarkSide-50 Collaboration

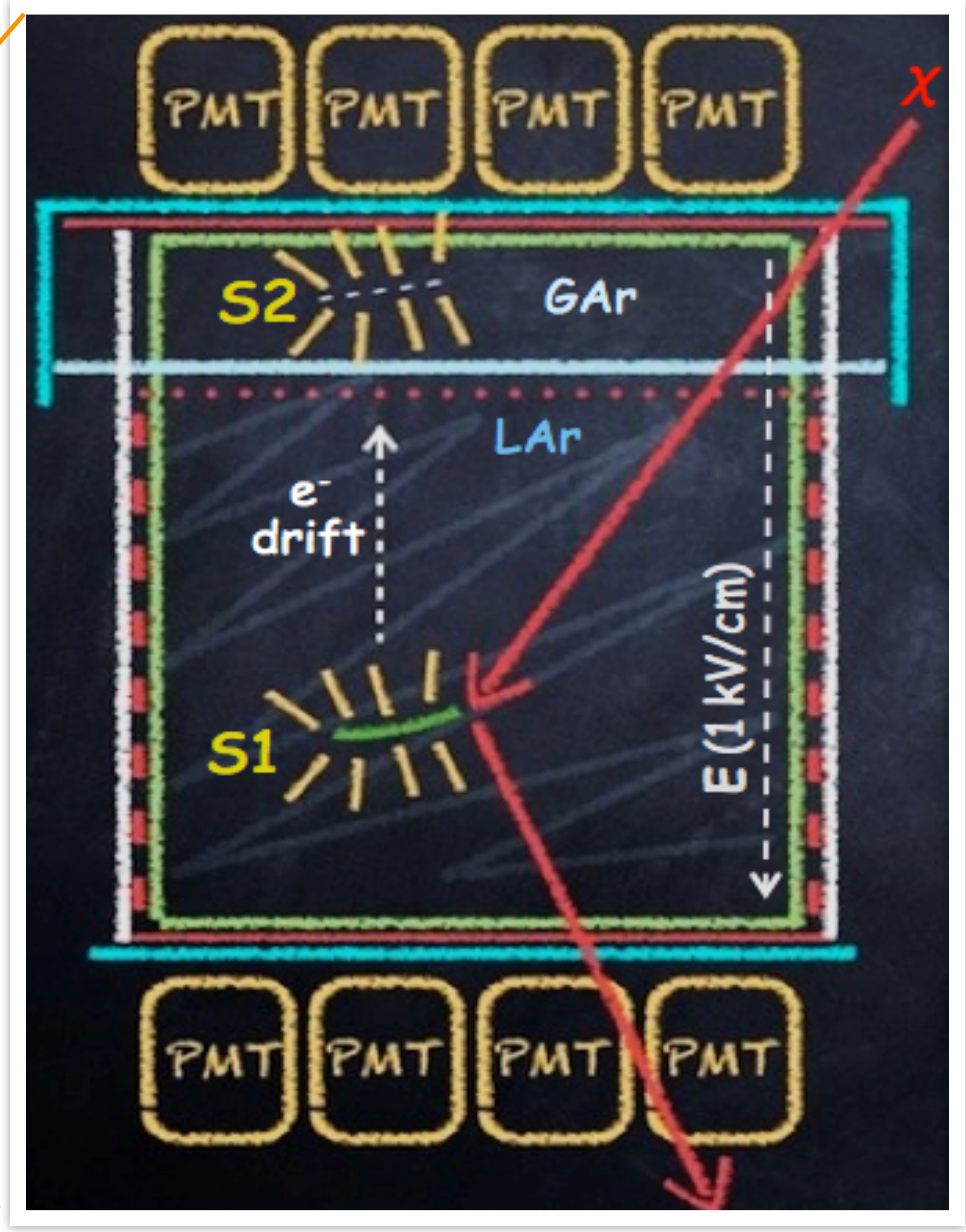
Rencontres de Moriond - Electroweak Interactions & Unified Theories - March 2023

The Dual-Phase TPC
- 50 kg active mass of UAr
- 19 top + 19 bottom R11065 HQE 3" PMTs
- 36 cm 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 diam. x 10 m
- 80 PMTs



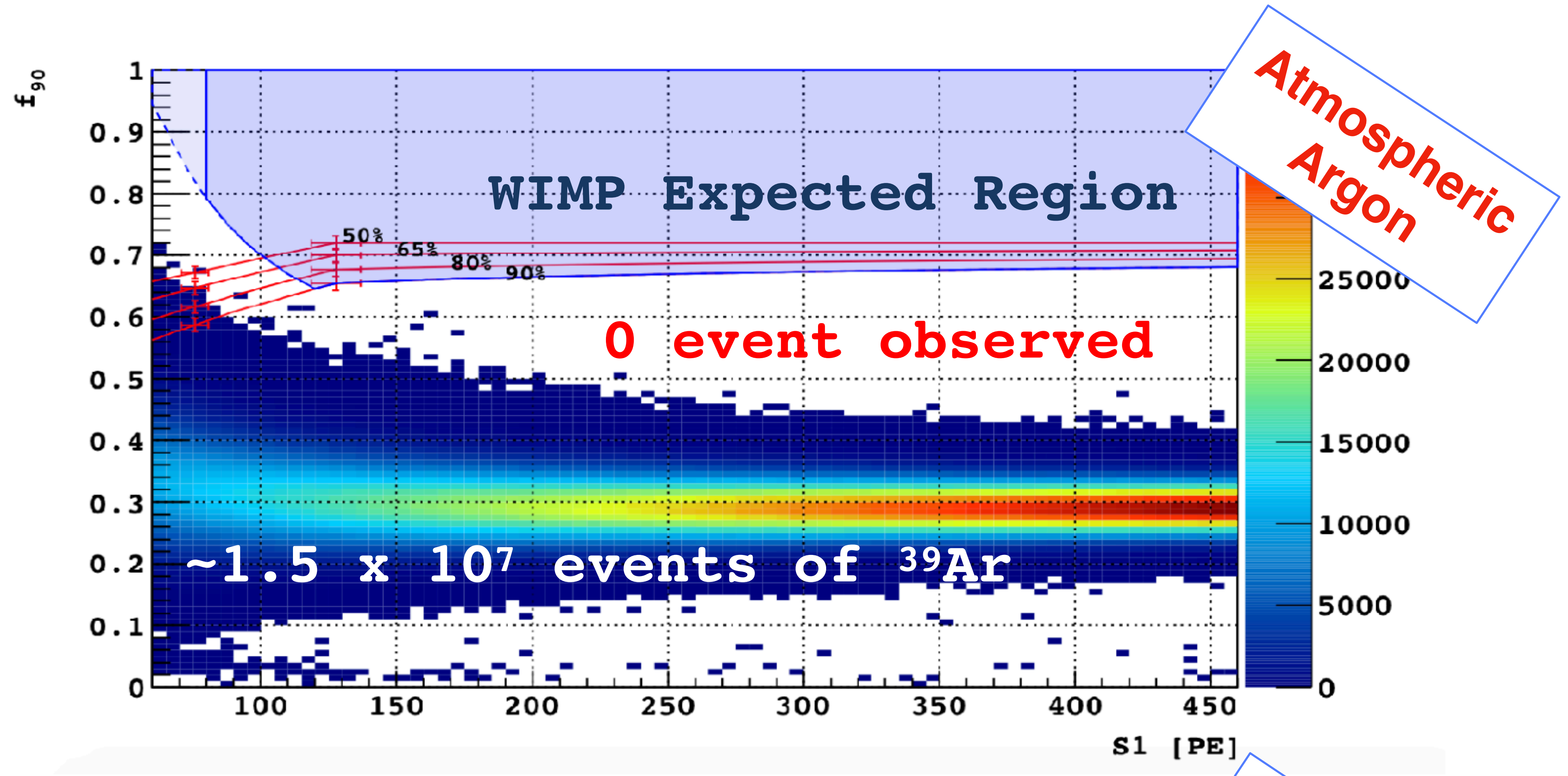


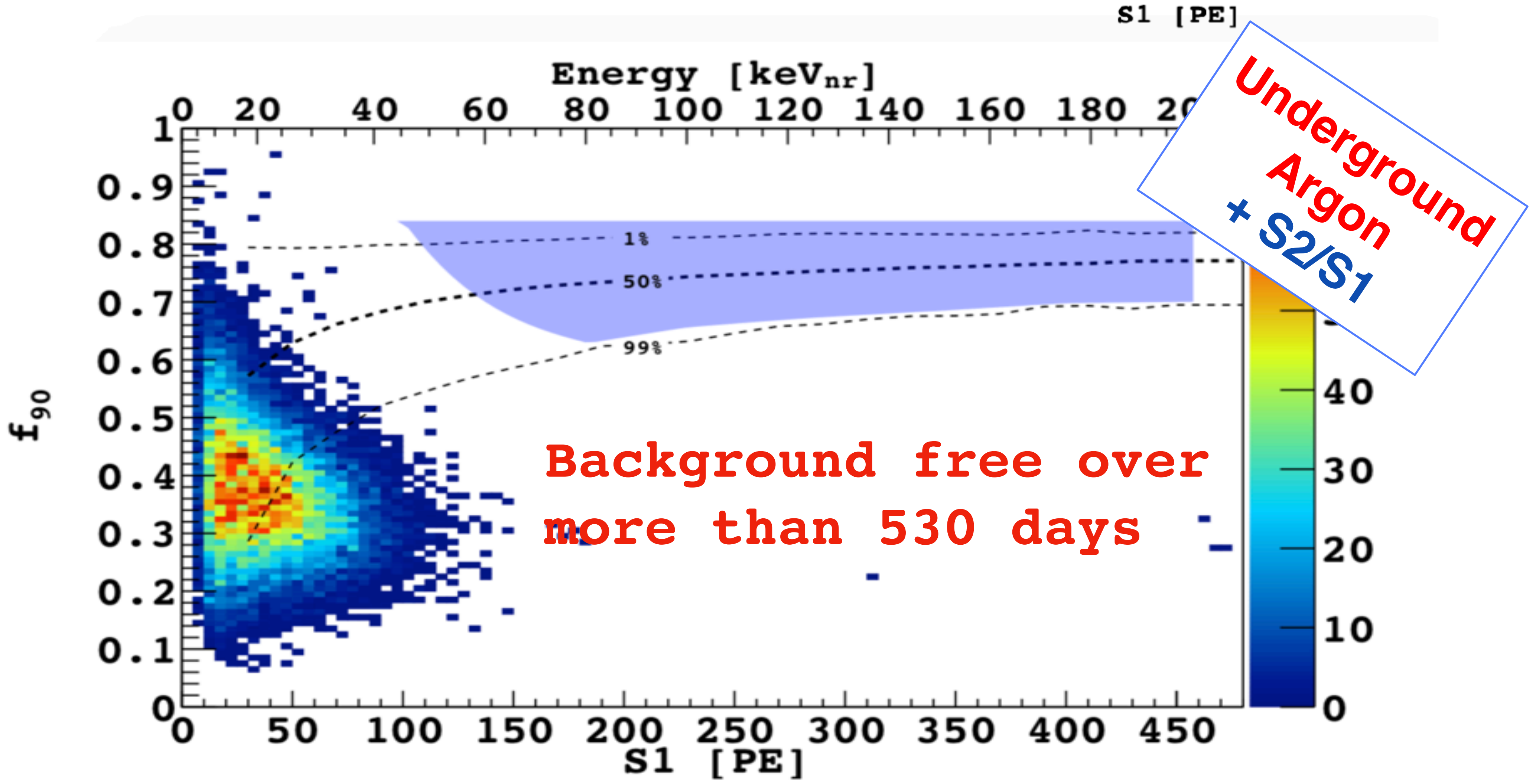
Efficient electronic recoil (ER) background rejection thanks to LAr scintillation **Pulse Shape Discrimination** trough the "f90" observable (fraction of light detected in the first 90 ns)

The DS-50 WIMP Search

Pulse Shape Discrimination

"high-mass" WIMP search

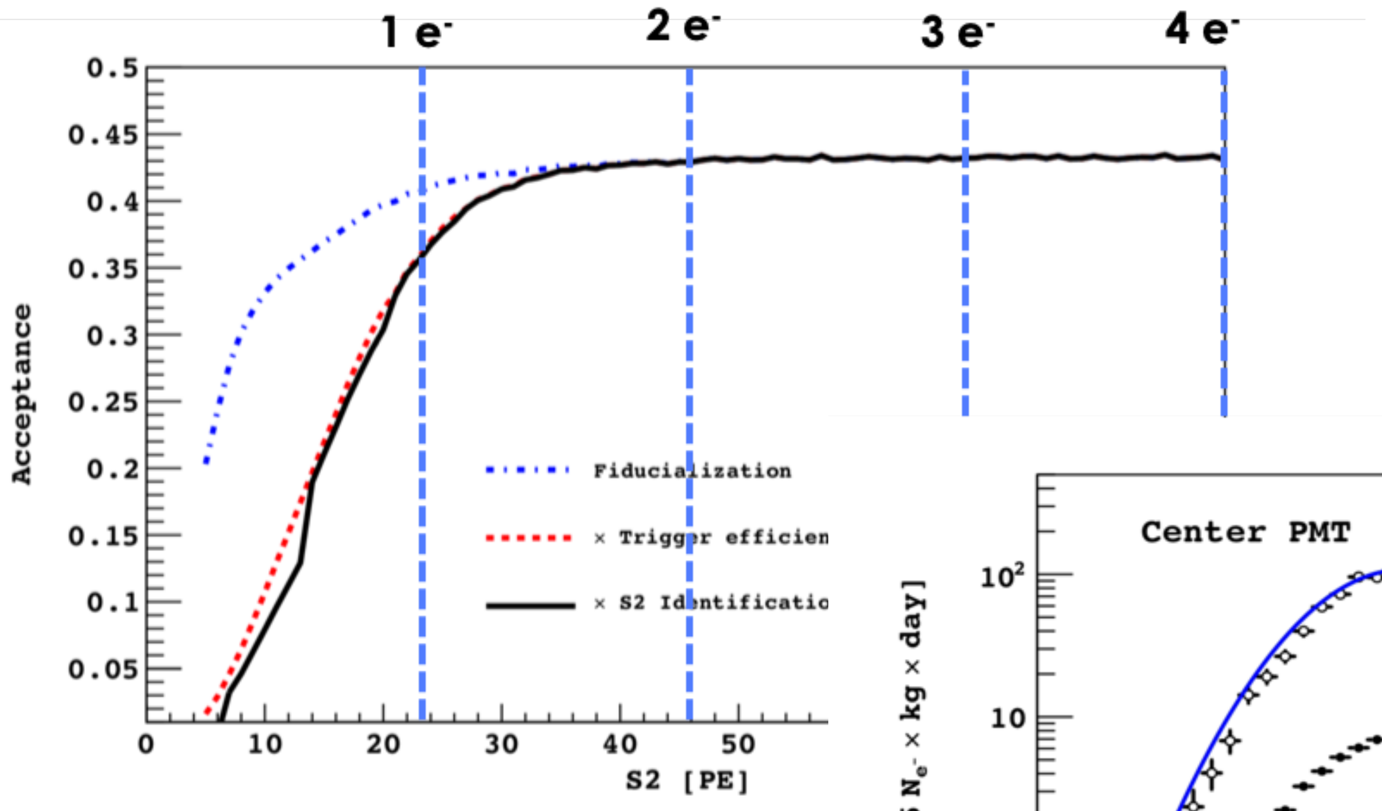


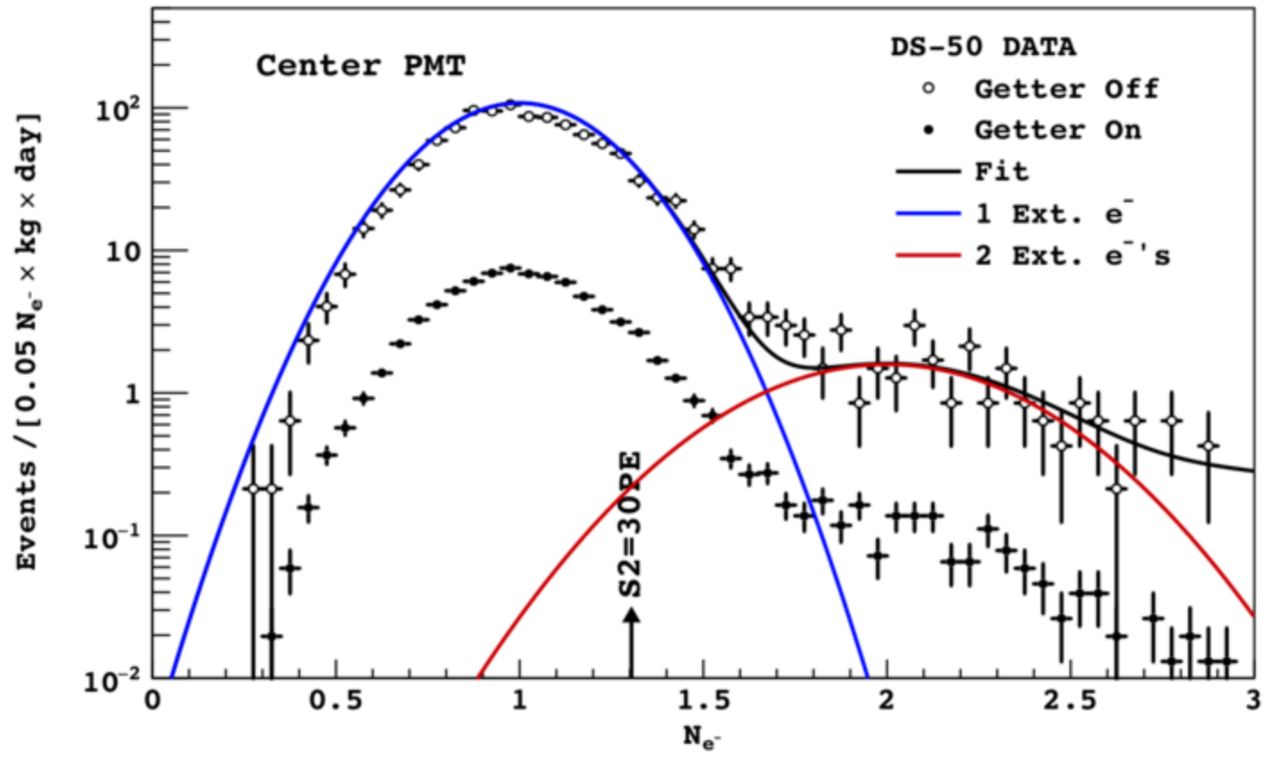


Ionization Only

"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-

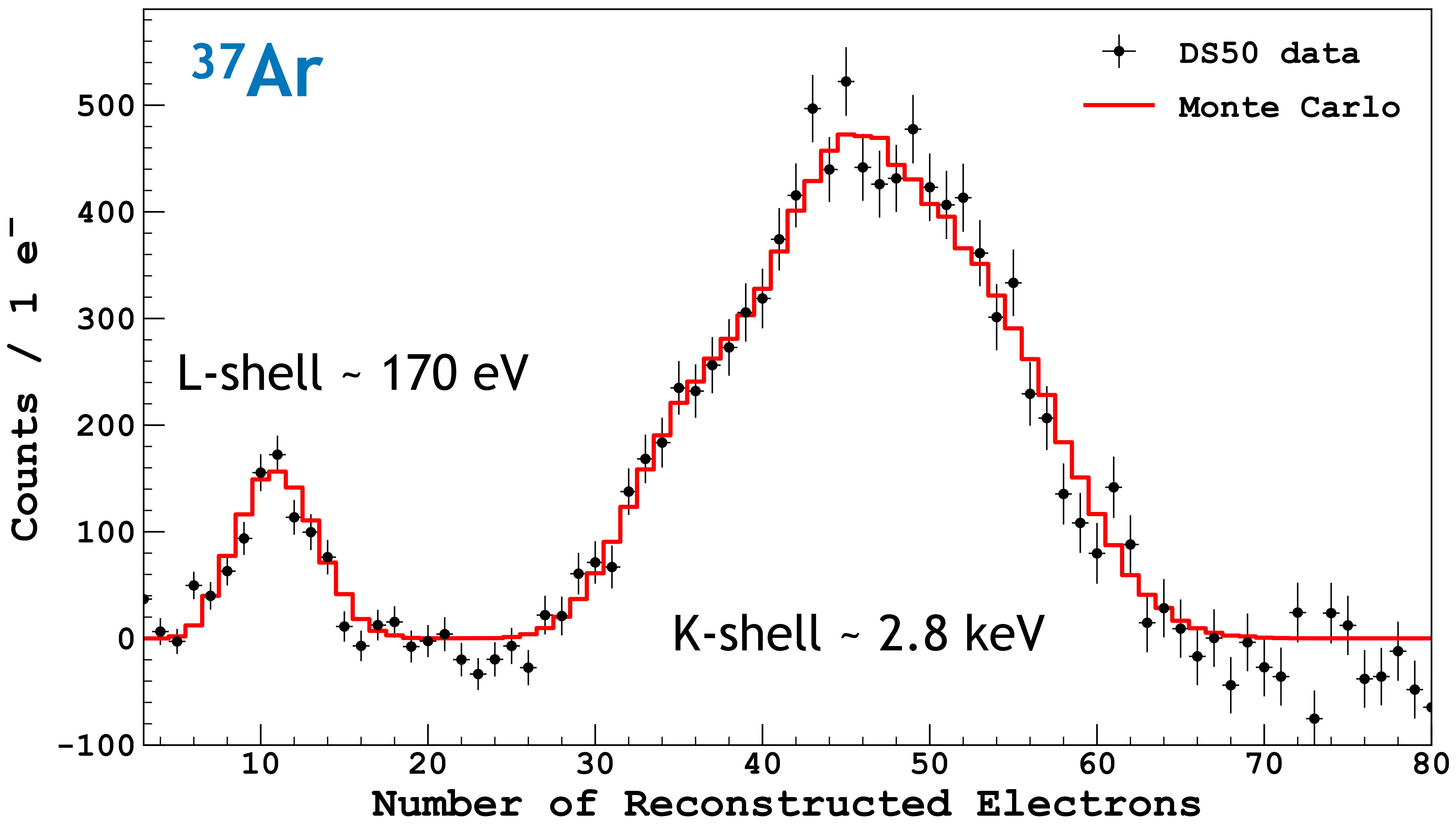


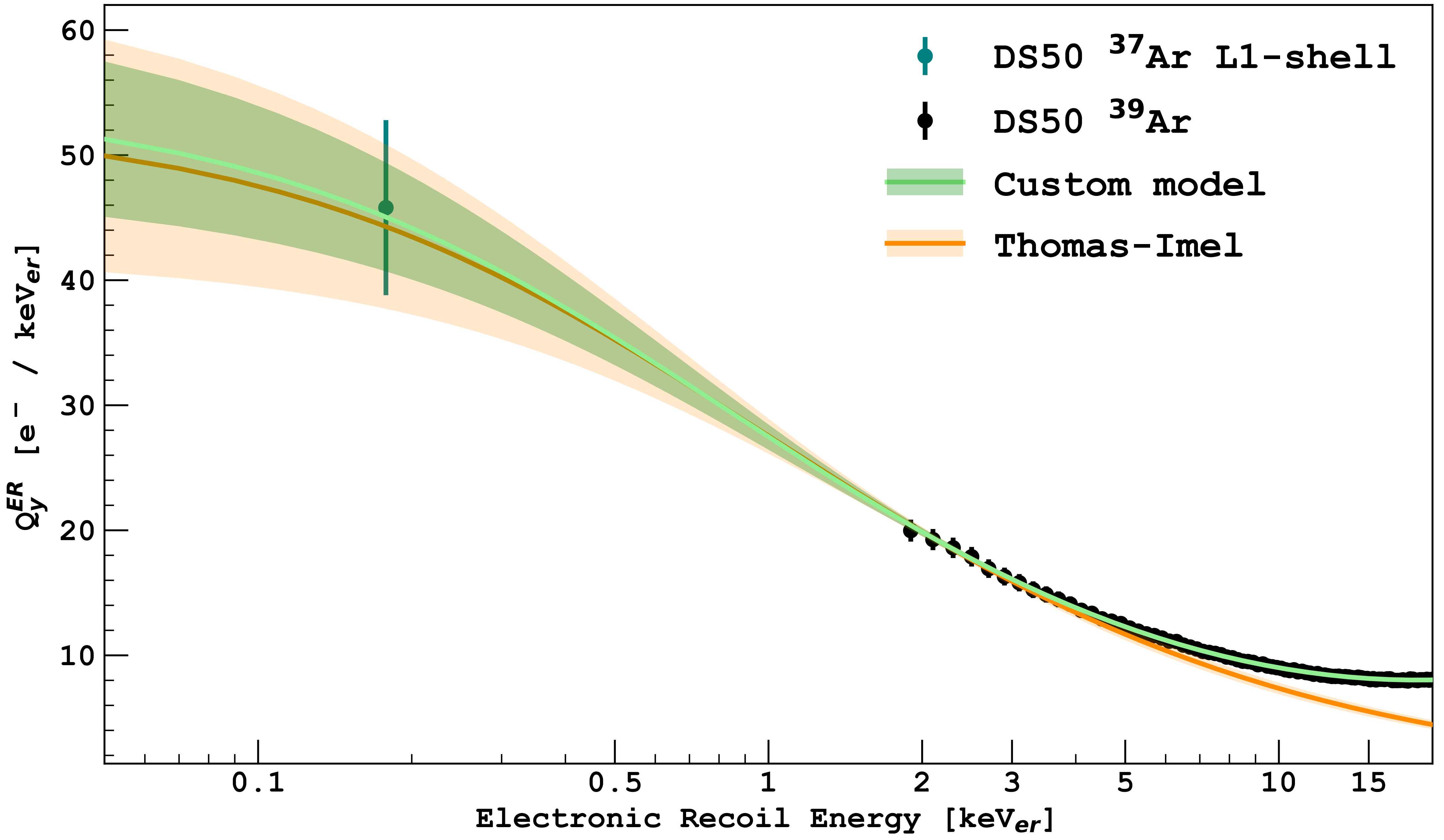


Ionization Response to Electronic Recoils

Thomas-Imel + extended custom model

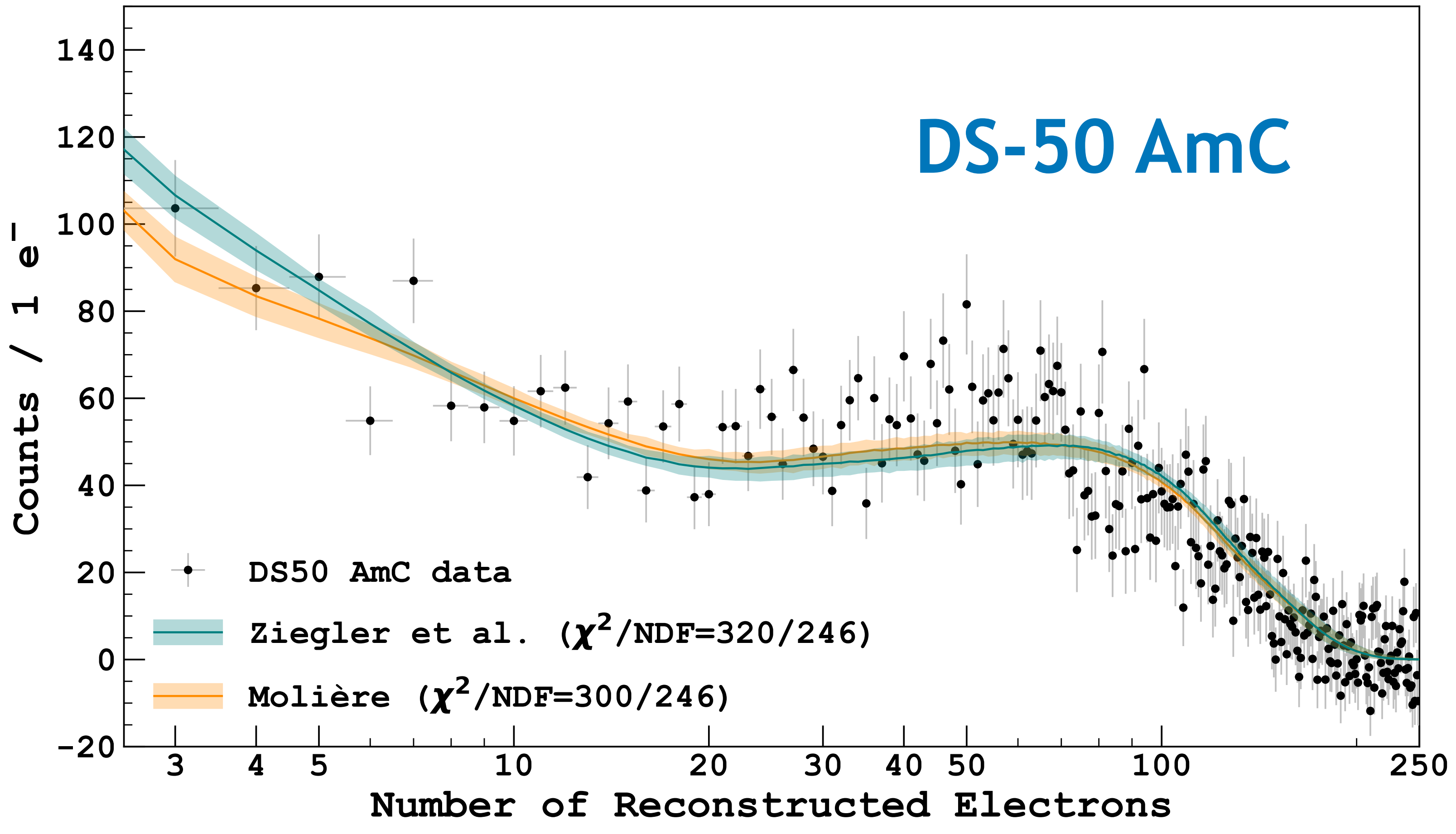
$$Q_y^{ER} = \left(\frac{1}{\gamma} + p_0 \left(E_{er}/\mathrm{keV}_{er}\right)^{p_1}\right) \frac{\ln(1+\gamma\,\rho\,E_{er})}{E_{er}}$$

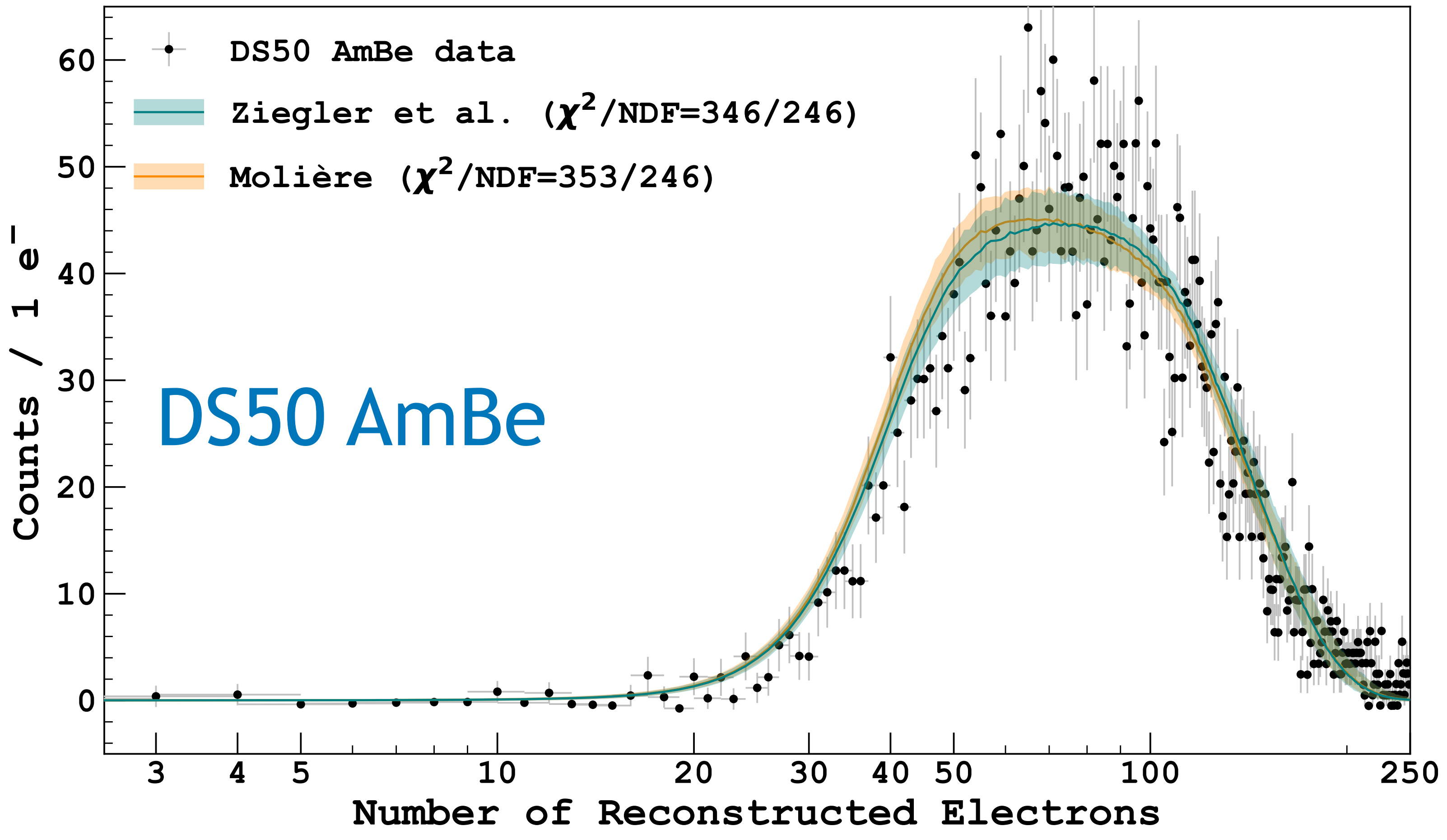


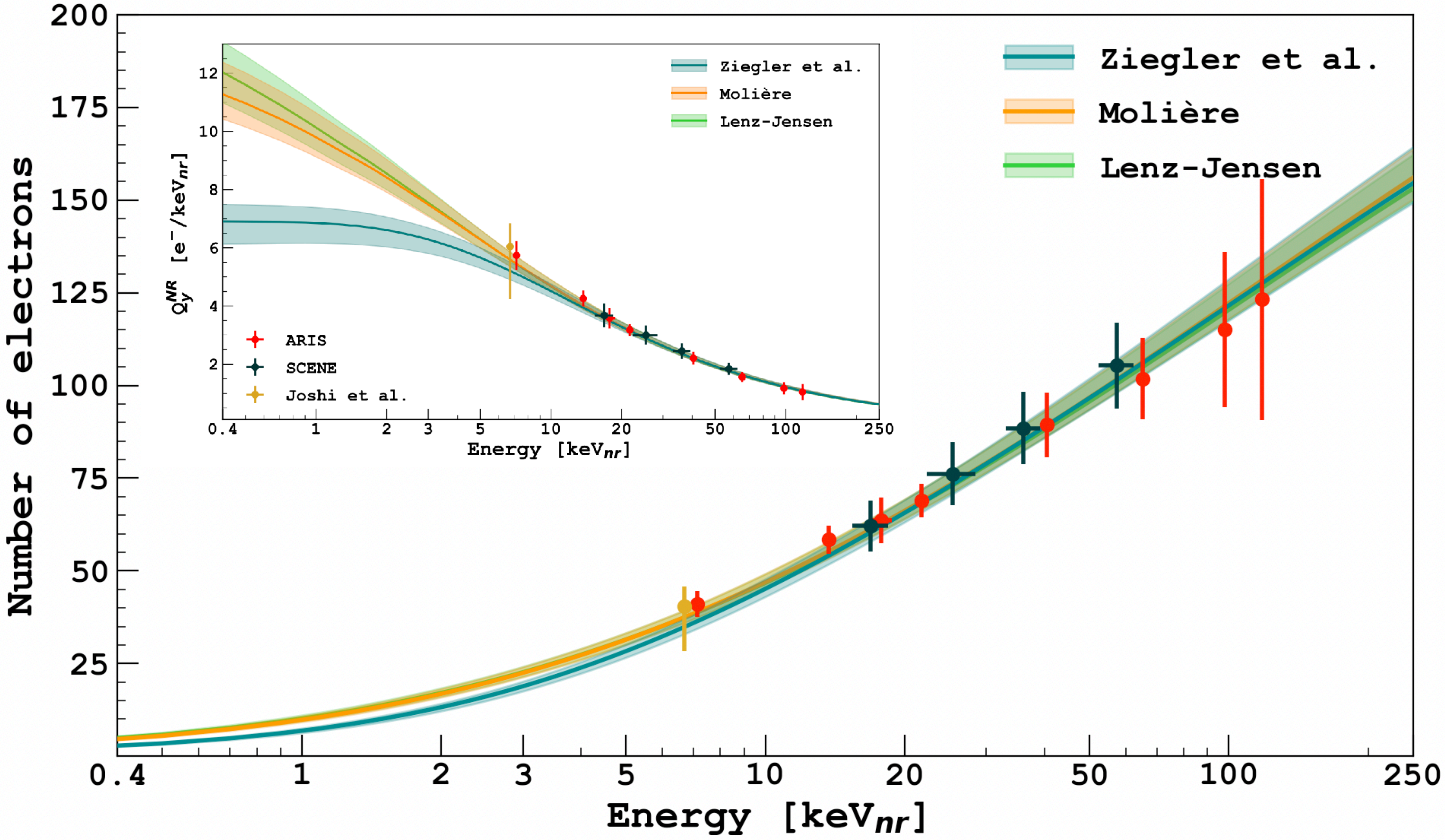


Ionization Response to Nuclear Recoils

Global fit to **DS-50 calibration data** with neutrons sources + **external datasets** (ARIS and SCENE)







Ziegler's screening function is the baseline for this analysis

First results on light dark matter candidates with LAr in 2018

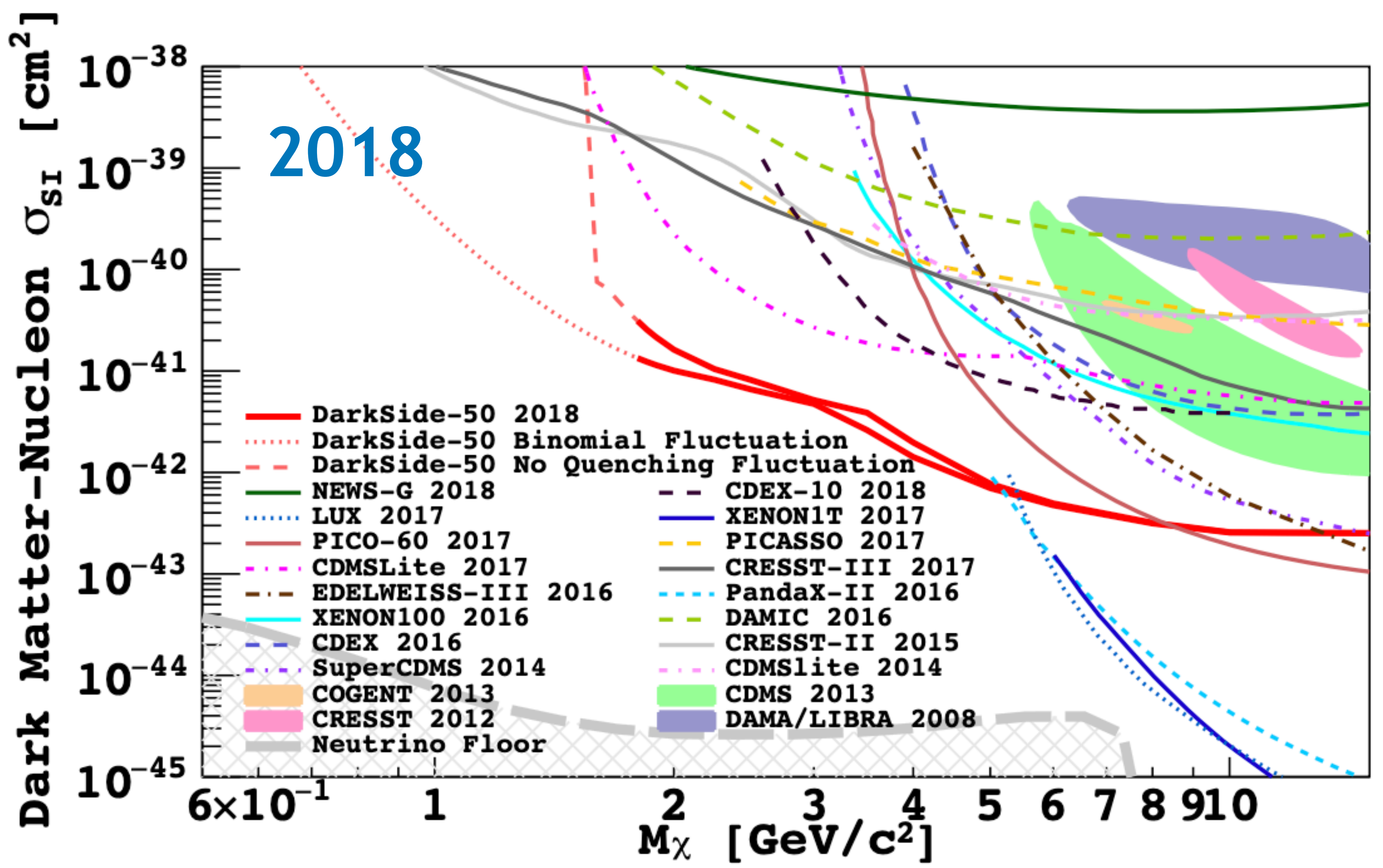
- DarkSide-50, Phys. Rev. Lett. 121 (2018) 081307
- DarkSide-50, Phys. Rev. Lett. 121 (2018) 111303

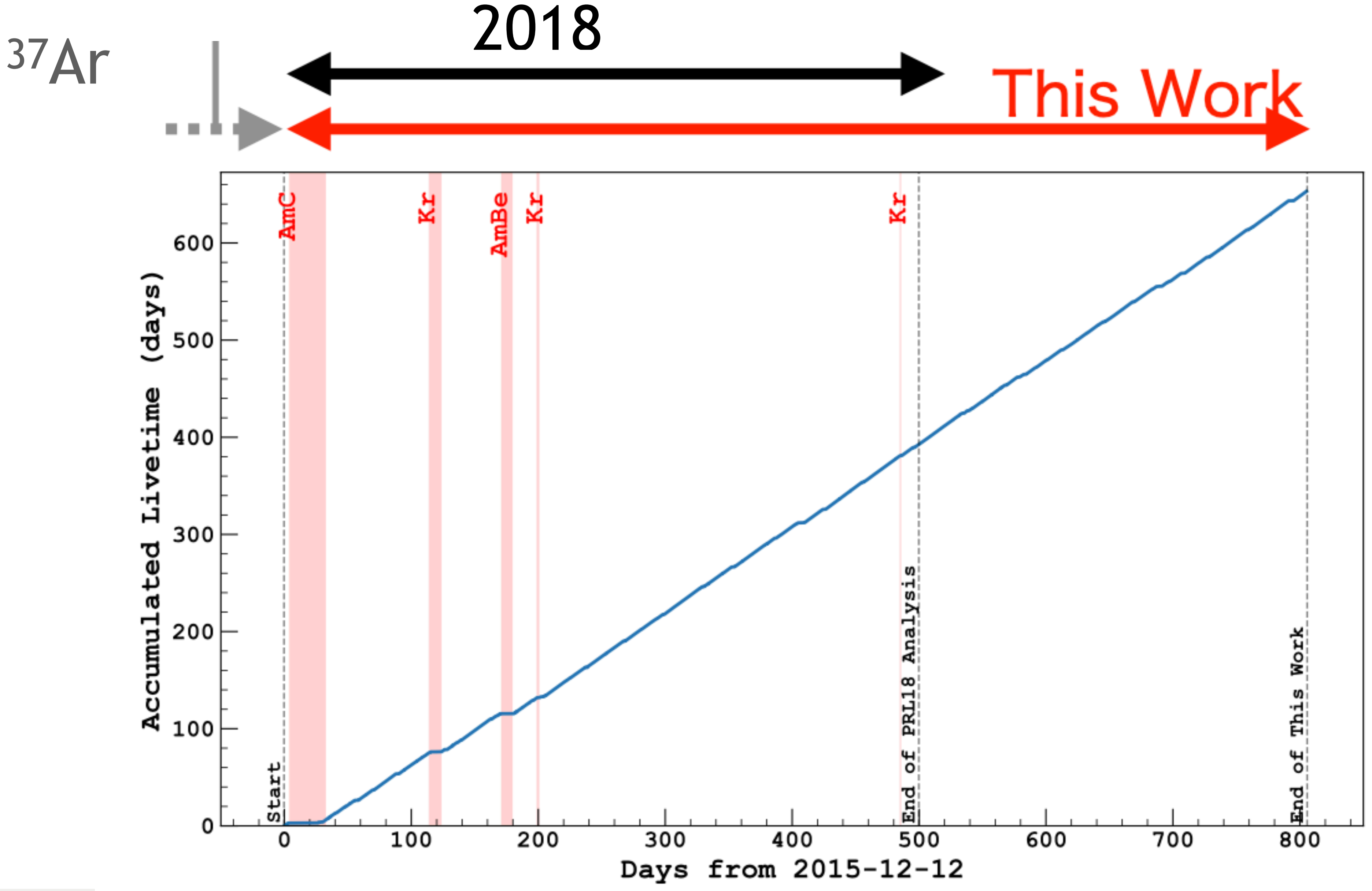
New exposure

- 650 live-days / 12 ton-day
- x 1.8 exposure used in 2018

Data Selection

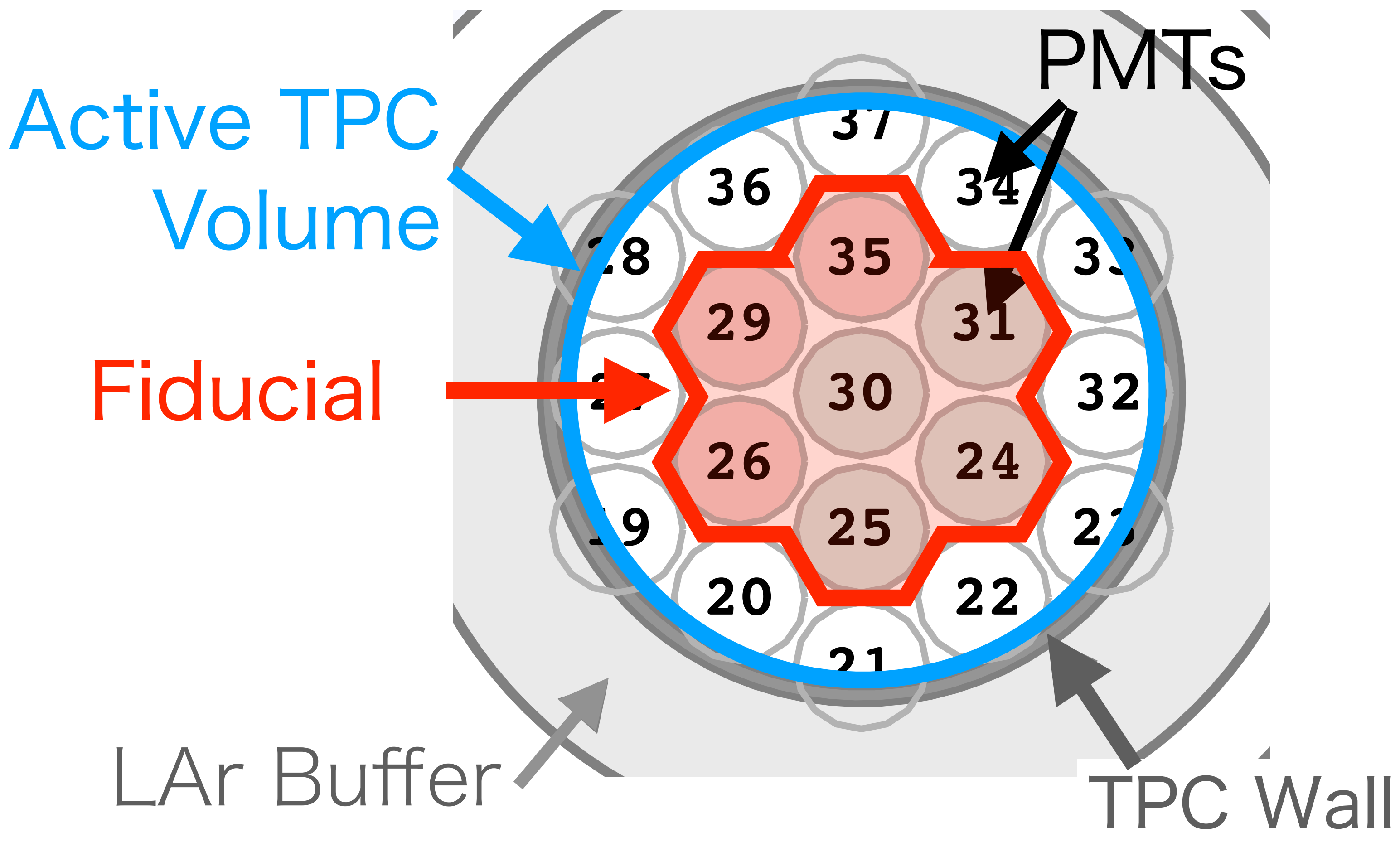
- Quality cuts
  - Pulse-shape: remove anomalous pulses due to the pile-up of multiple S2's or S1+S2
  - Acceptance: 95% at 4 Ne and 99% at >15 Ne
- Selection cuts
  - Fiducialization against external bg
  - S2/S1 against S2's from alphas on the walls
  - Time veto agains spurious (or "single") electrons





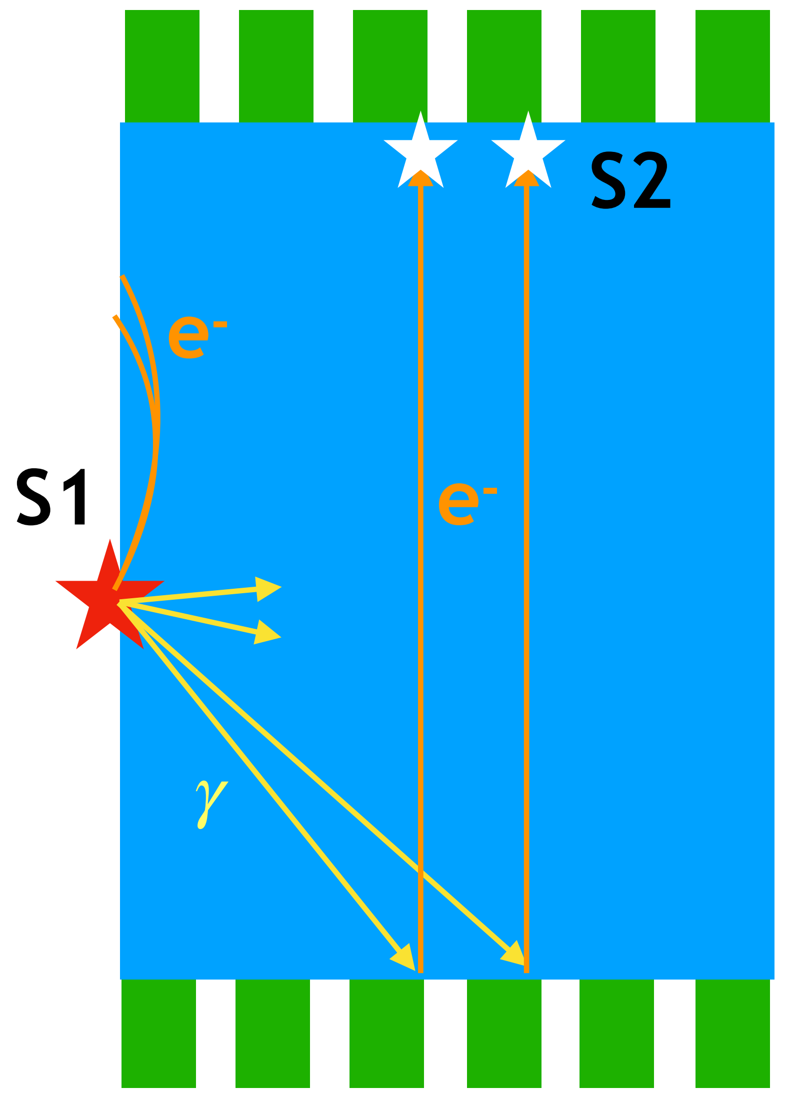
Data Selection

Fiducialization



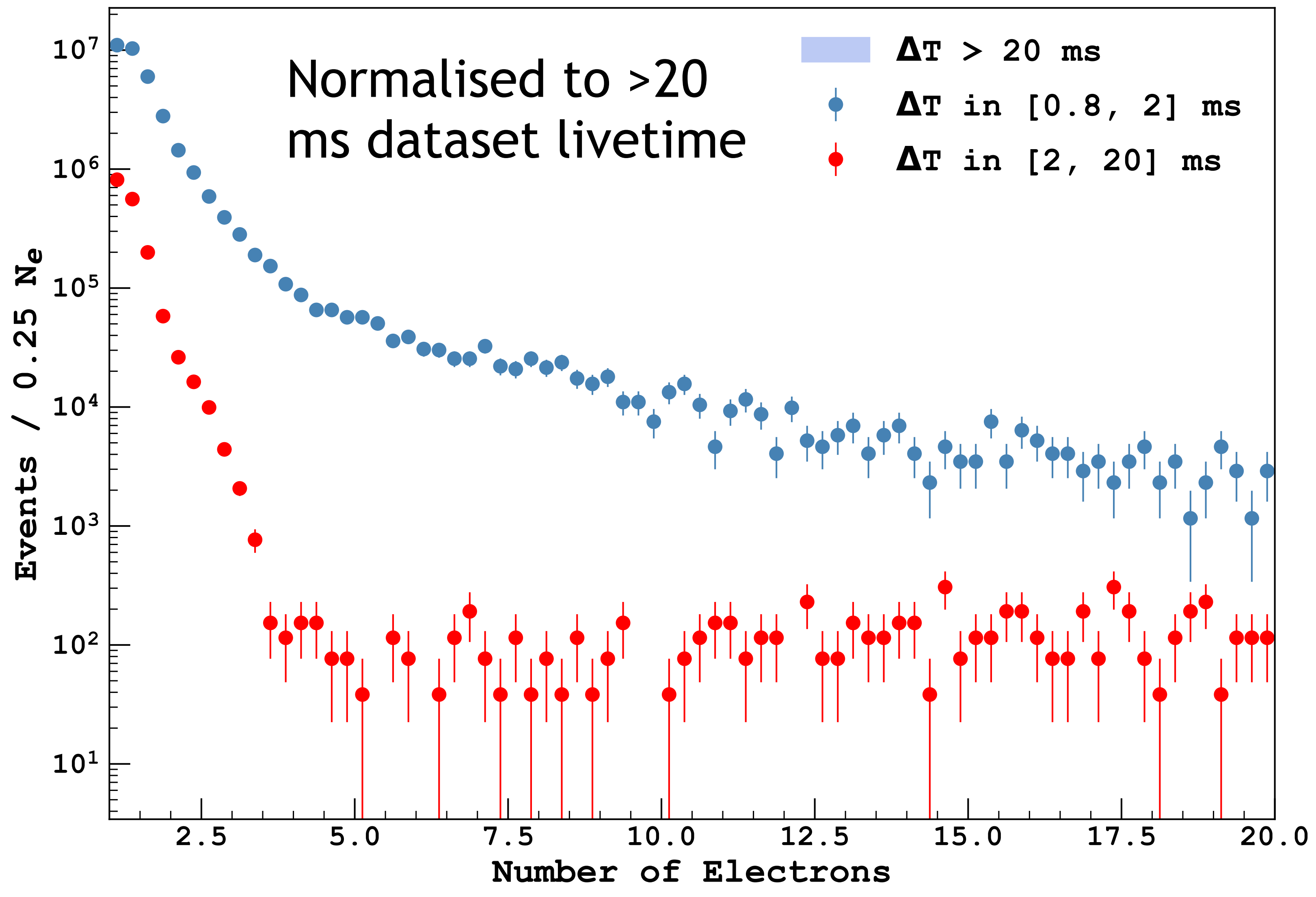
- Select events with max fraction of pes in one of the 7 central top PMTs
- Acceptance ~ 41%

Alpha-induced S2 pulses



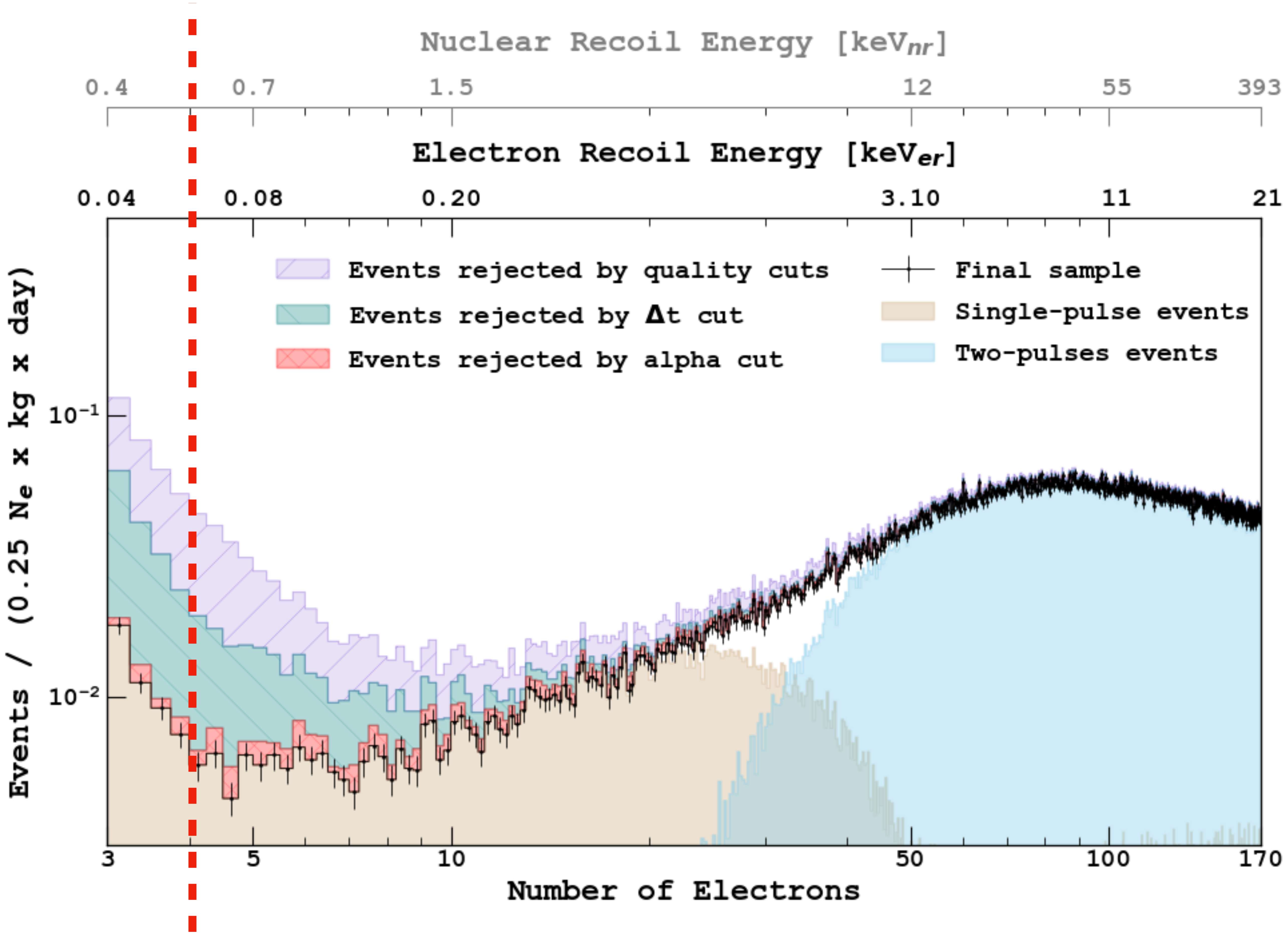
- Reject events with "anomalous" S2/S1
- Cut tuned on calibration data
- Acceptance ~ 99%

Spurious Electrons

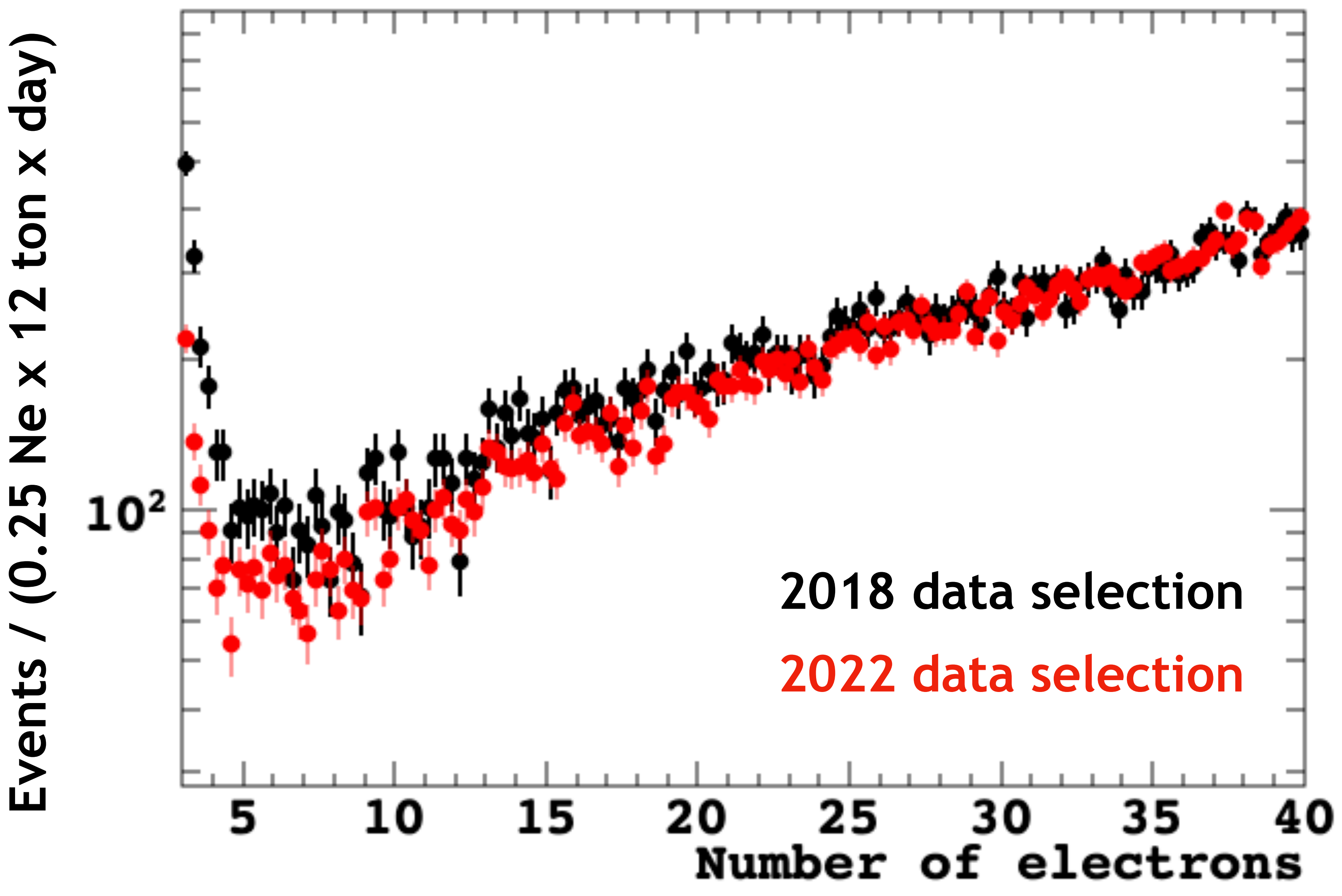


- Reject correlated events (if within 20 ms from the previous one)
- Acceptance ~ 97%

Data Selection



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



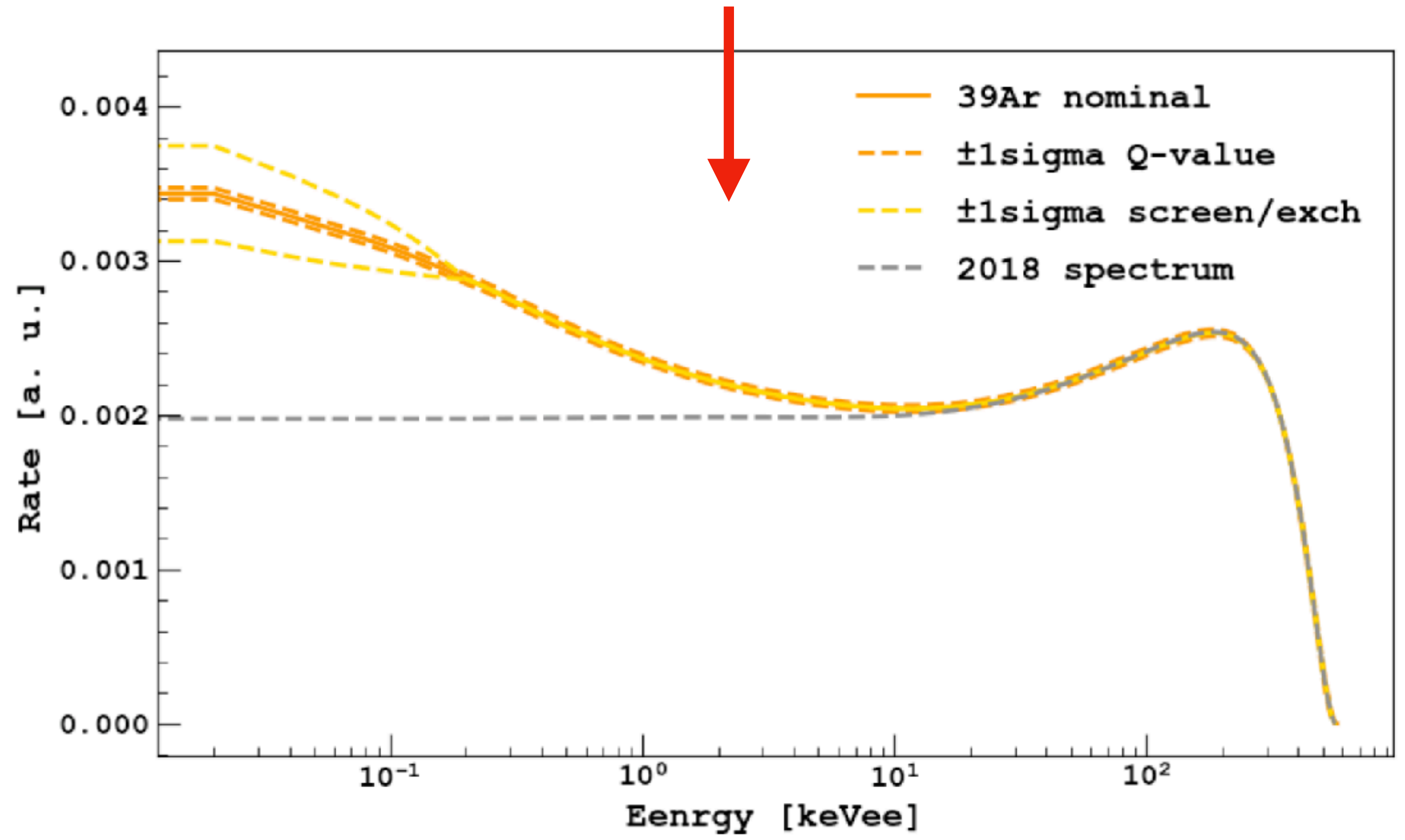
Background Model: Internal ^{39}Ar and ^{85}Kr

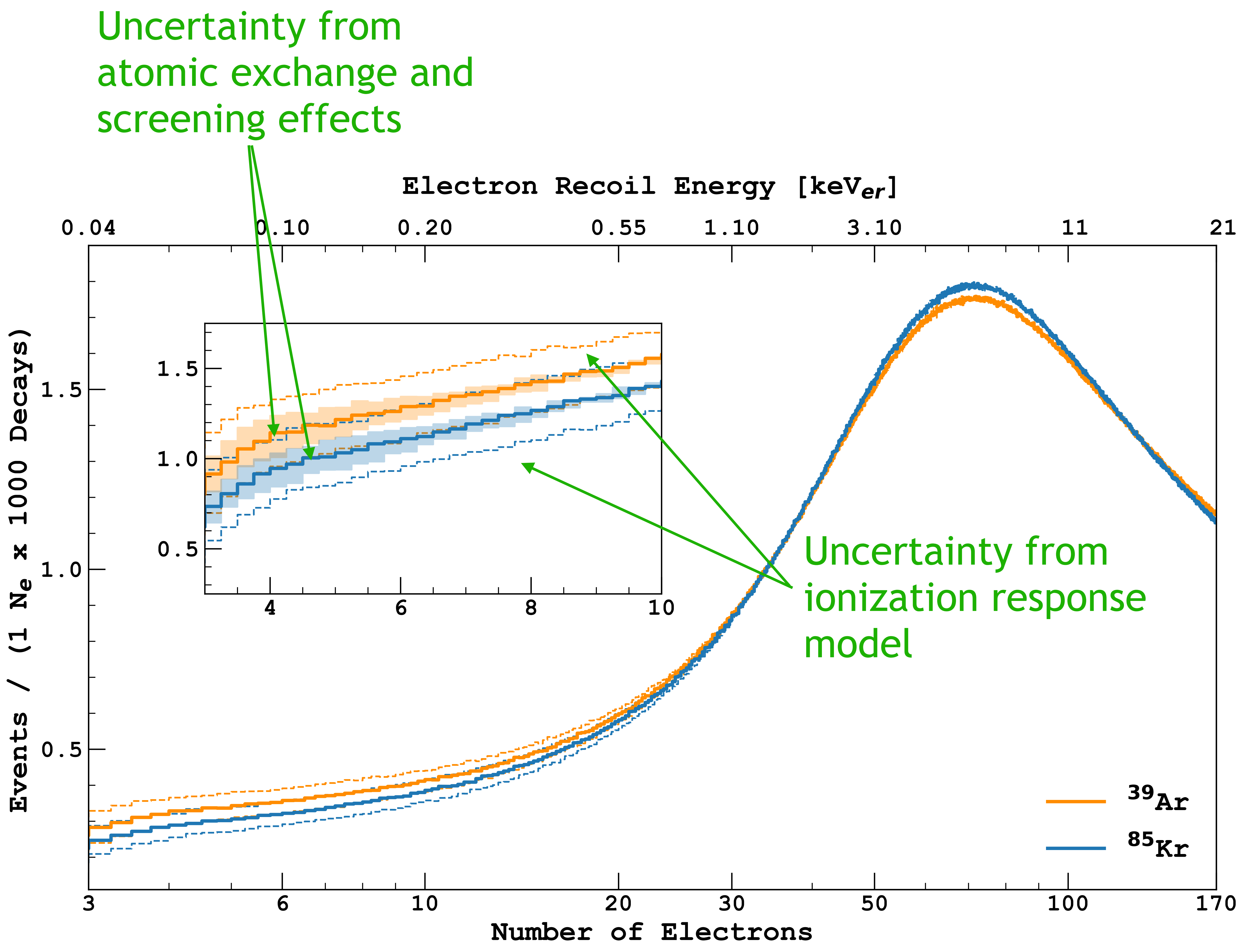
- Both ^{39}Ar and ^{85}Kr **uniformly distributed** in the LAr bulk

- ^{39}Ar activity: **0.7 ± 0.1 mBq/kg**
  - from high energy spectral fit

- ^{85}Kr activity: **1.8 ± 0.1 mBq/kg**
  - from high energy spectral fit
  - from fast coincidence through metastable state
  - from decay time fit

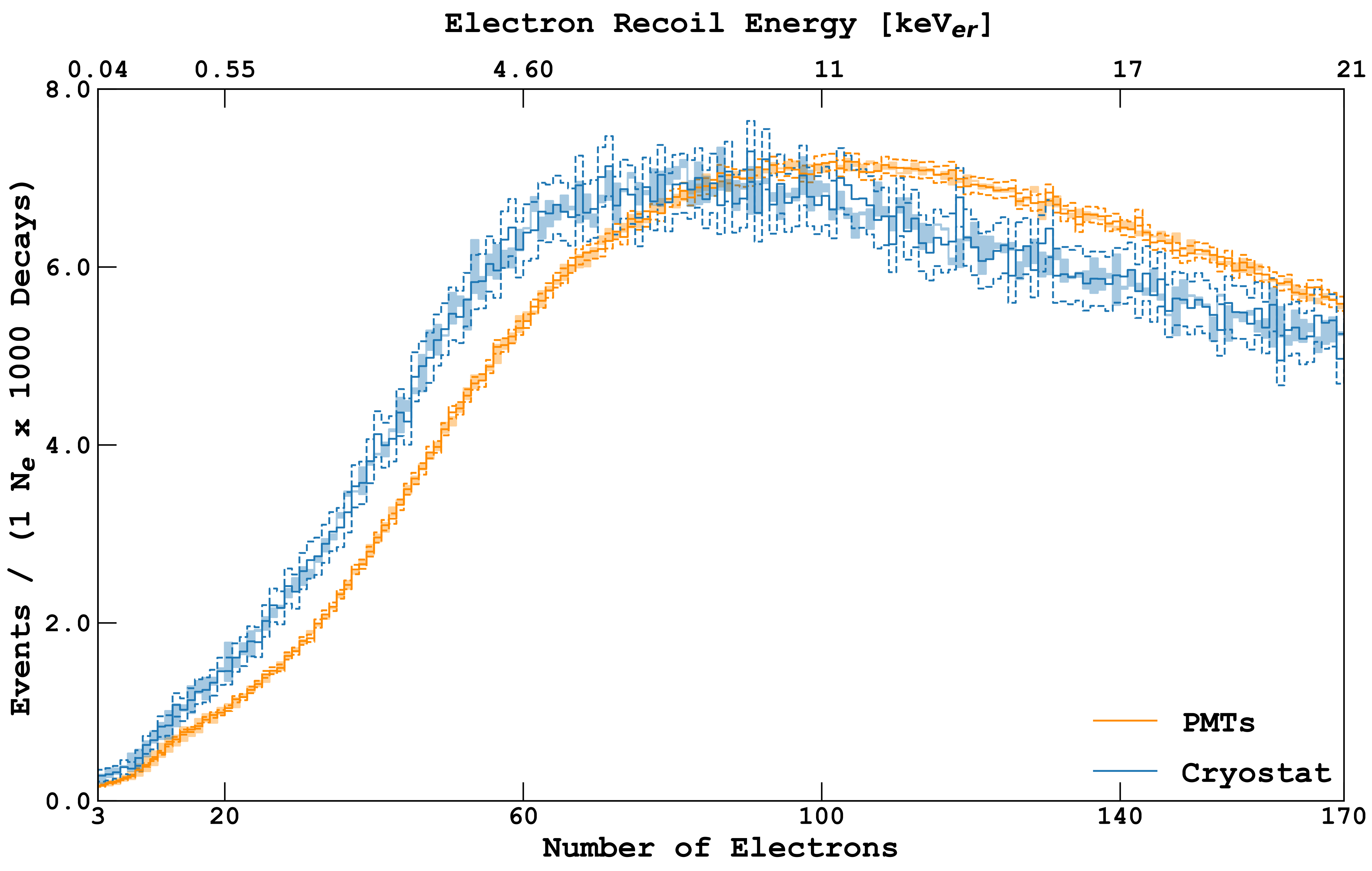
- Both unique first-forbidden beta decays: **additional atomic exchange and screening effects**

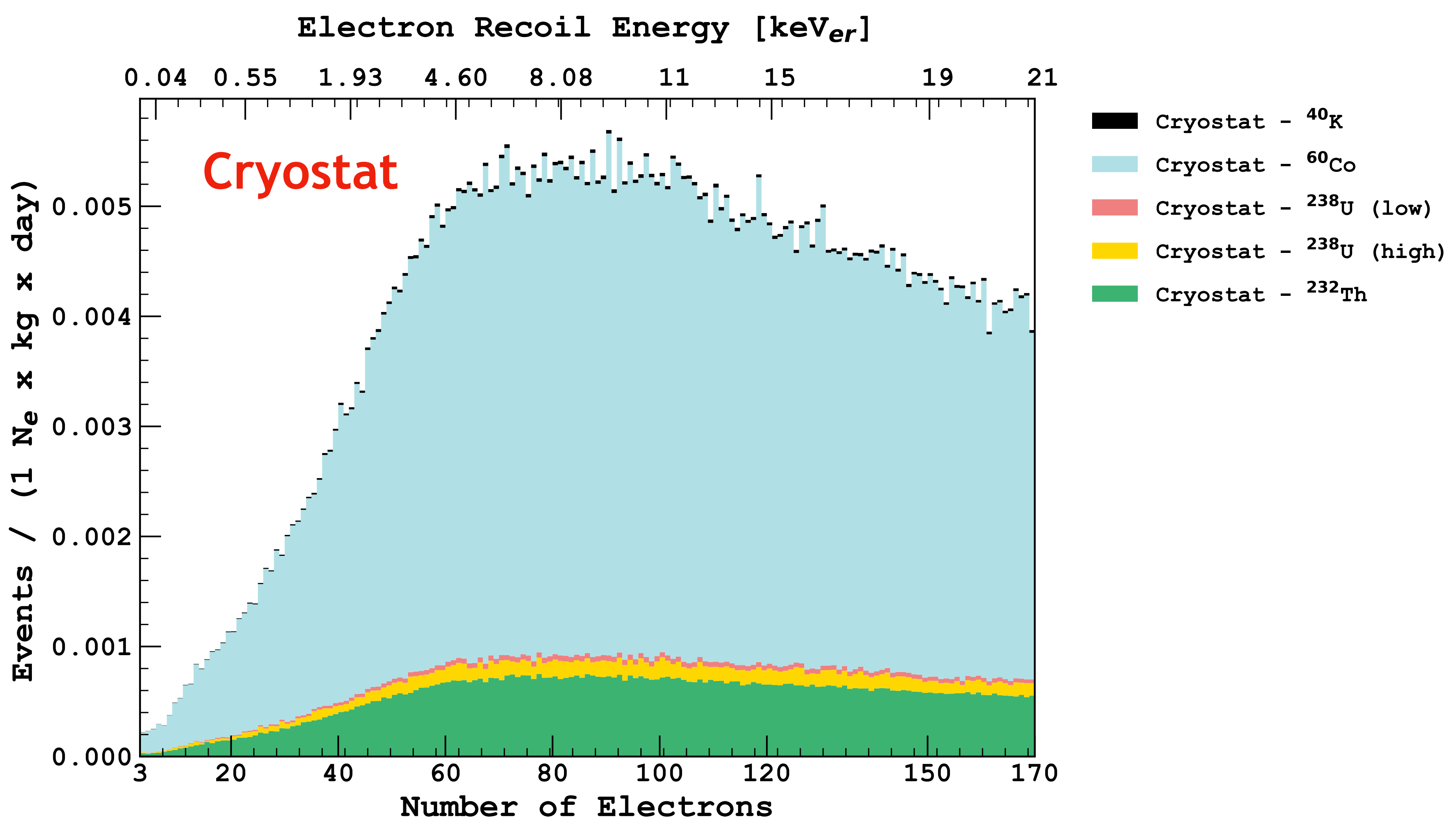


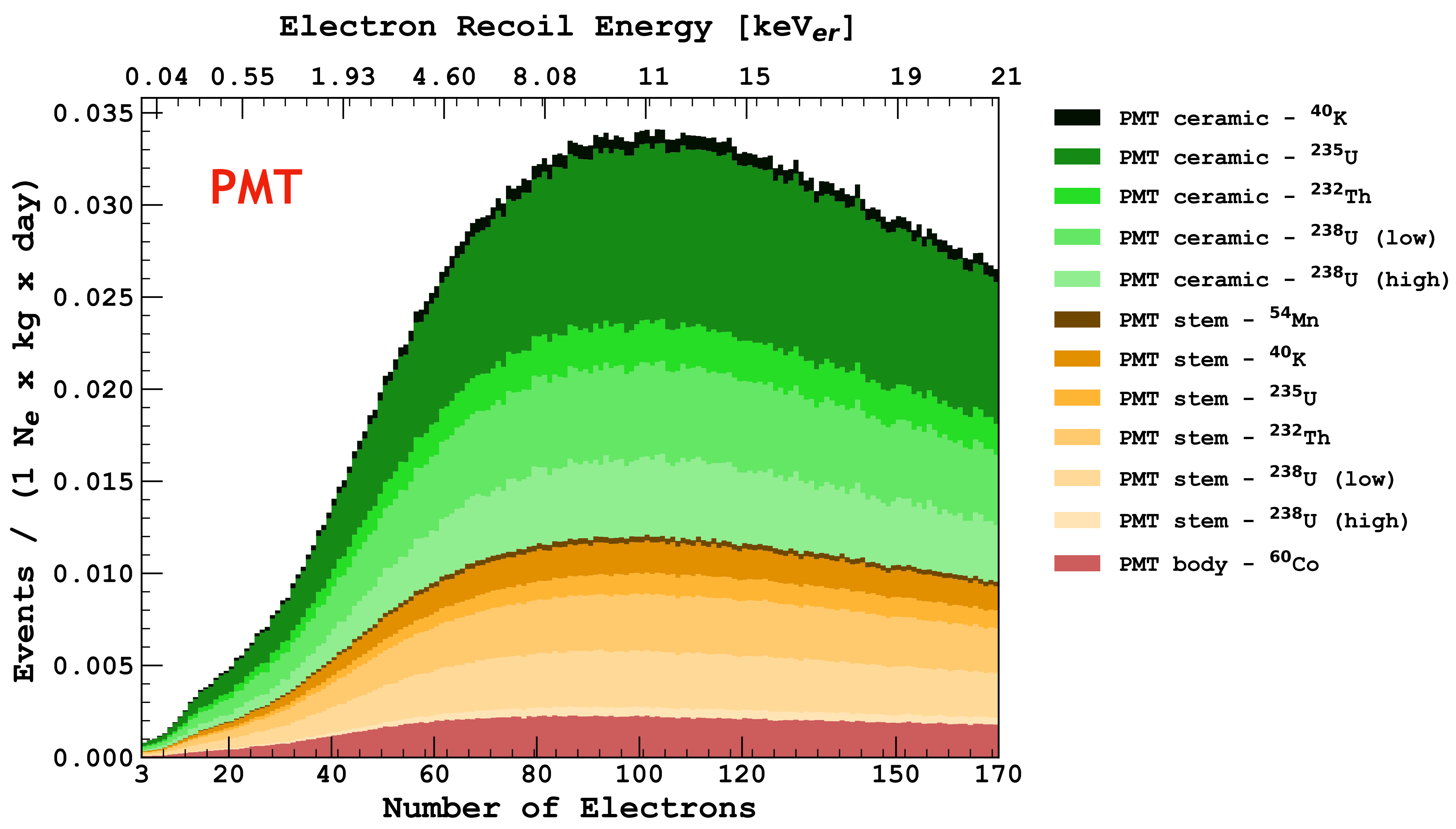


Background Model: External Gammas

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







Profile Likelihood and Systematics

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

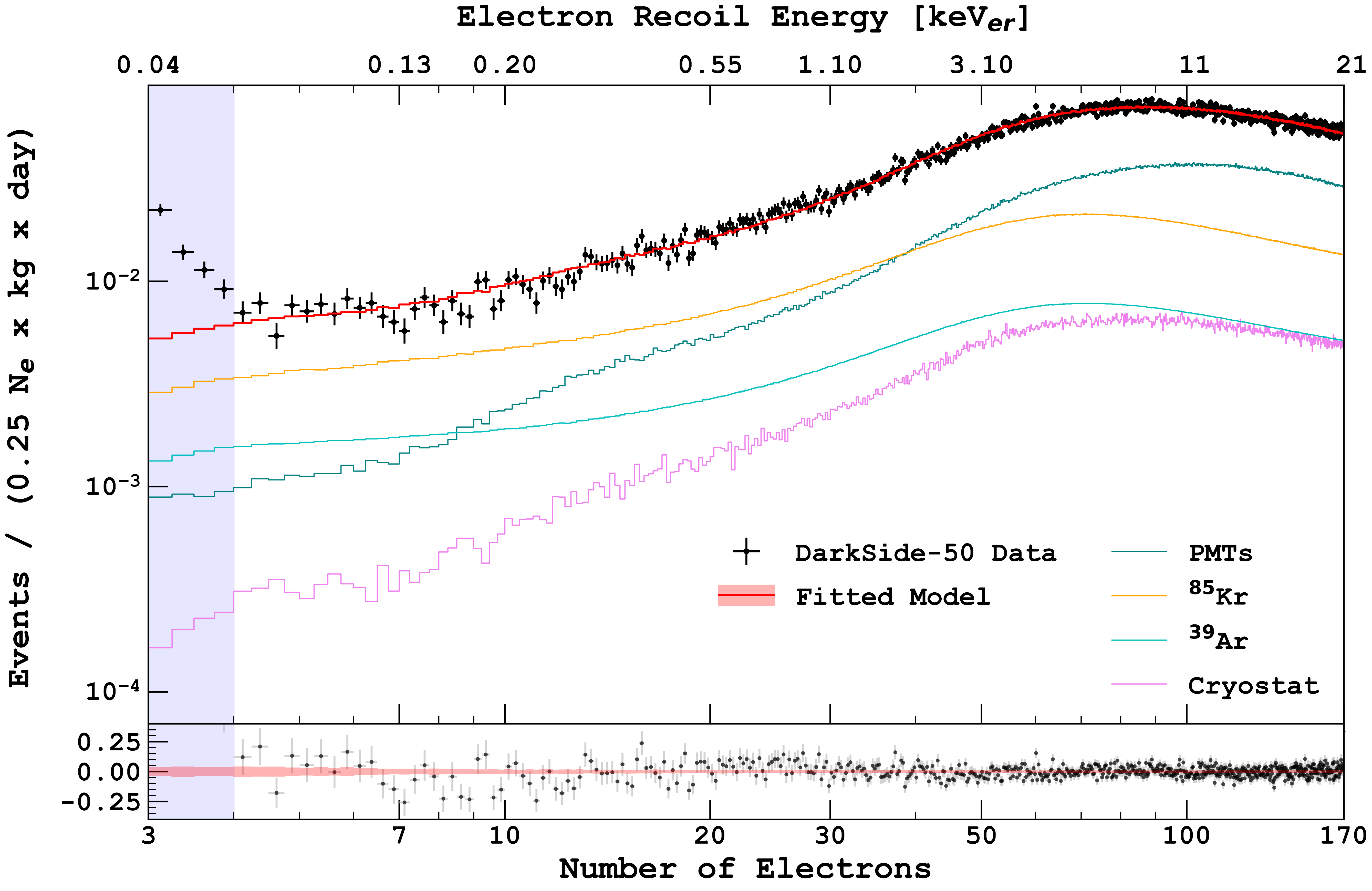
Poisson probability of observing n_i events in the i^{th}-bin with respect to the expected ones, $m_i(\mu_s,\Theta)$, with μ_s the signal strength

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

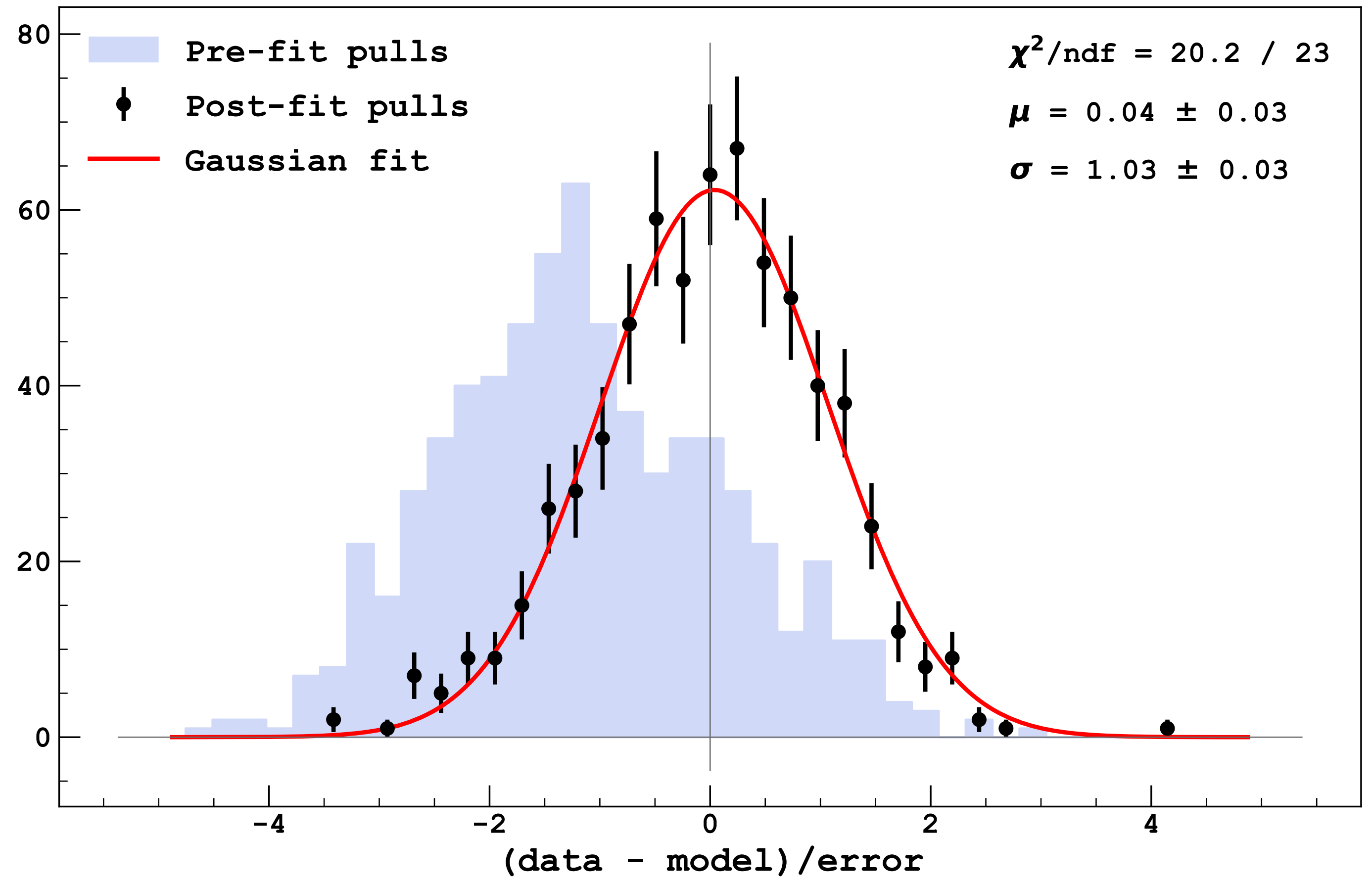
Statistical uncertainties of the **simulated** sample

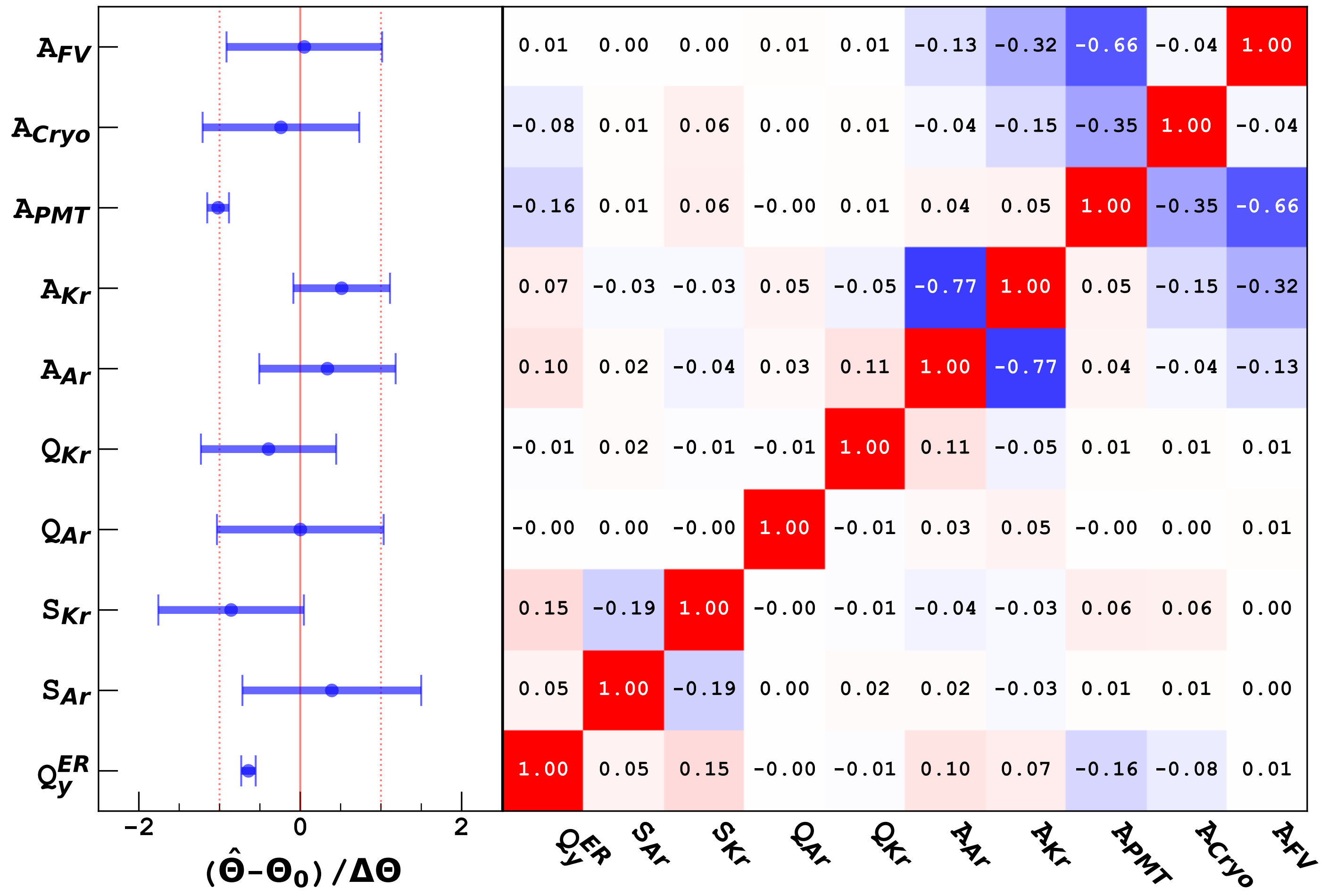
	Name	Source	Affected components
Amplitude	A_{FV}	uncertainty on the fiducial volume	WIMP, ^{39}Ar, ^{85}Kr, PMTs, Cryostat
	A_{Ar}	14.0% uncertainty on ^{39}Ar activity	^{39}Ar
	A_{Kr}	4.7% uncertainty on ^{85}Kr activity	^{85}Kr
	A_{pmt}	11.5% uncertainty on activity from PMTs	PMT
	A_{cryo}	6.6% uncertainty 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



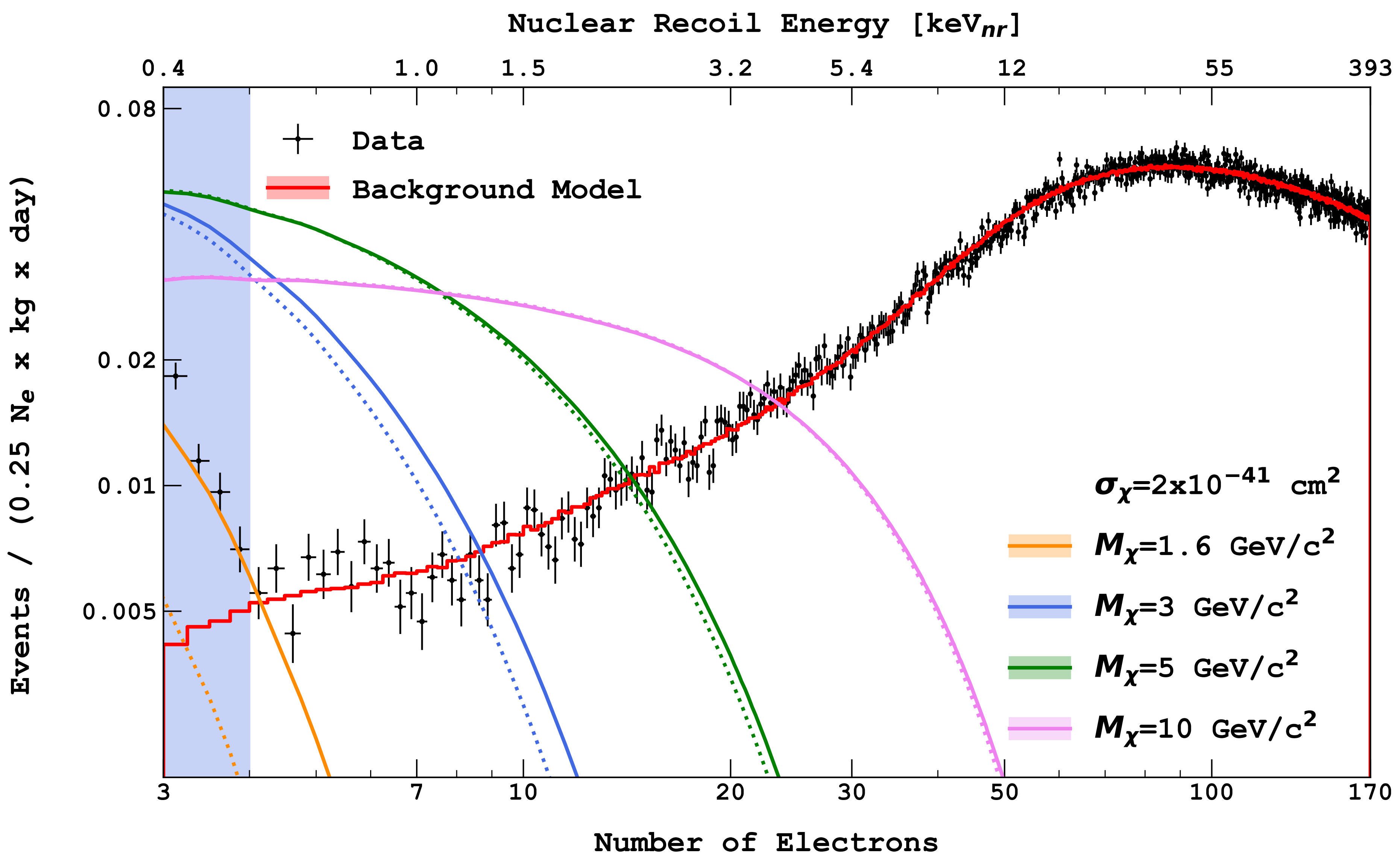
Tritium activity <1 μBq/kg (90% CL)

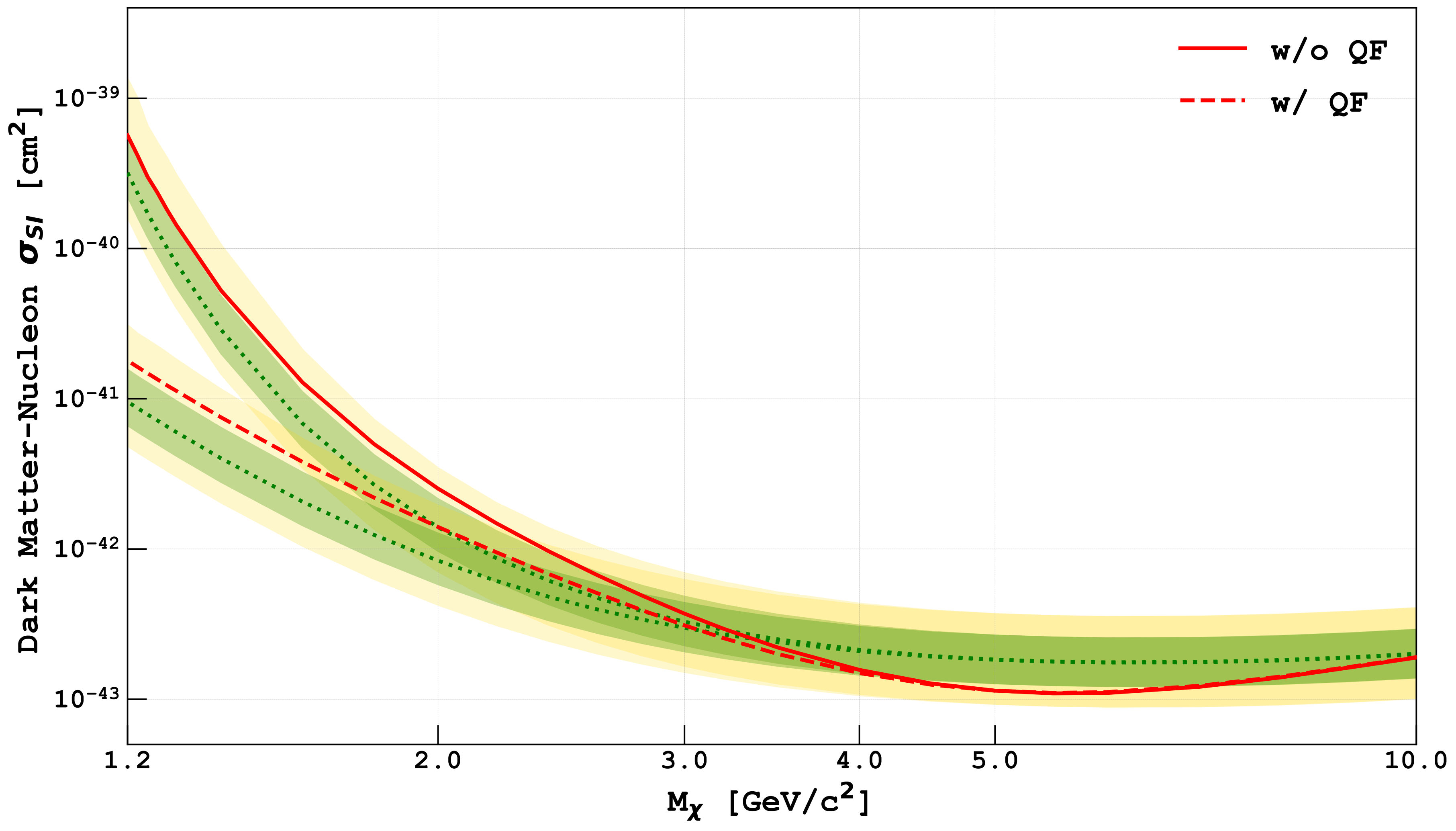


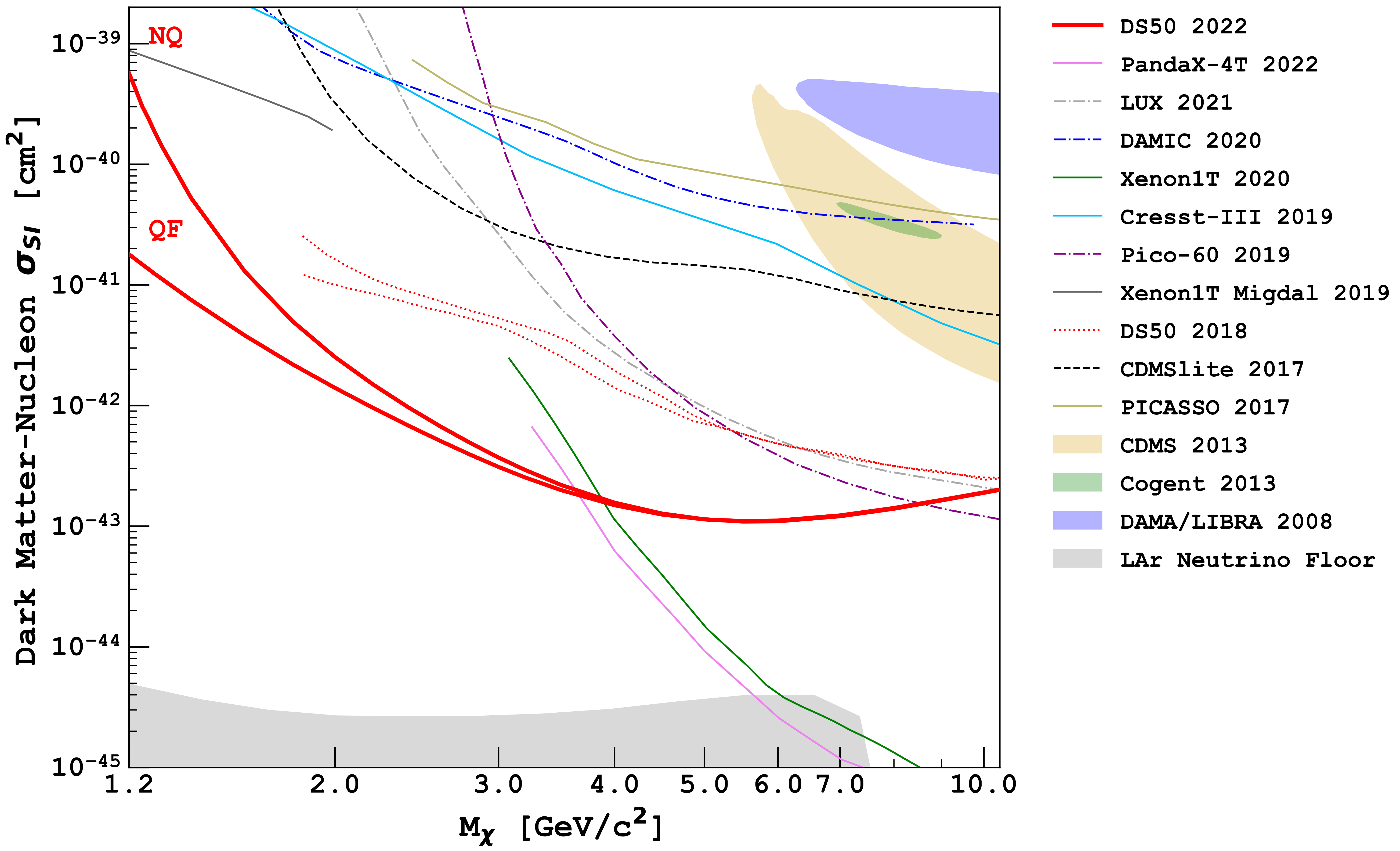


WIMP-Nucleon Interactions

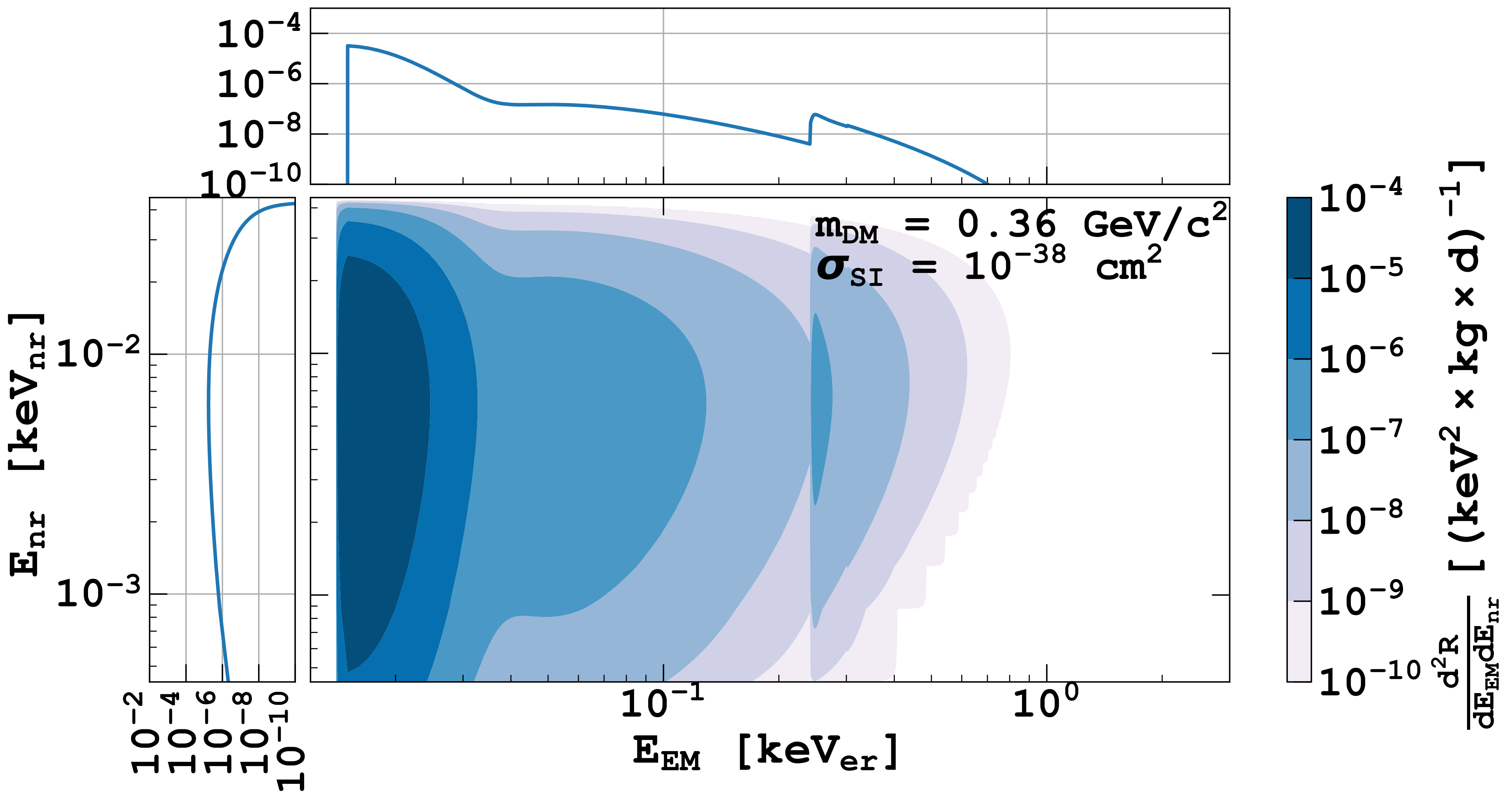
[DarkSide-50, Phys. Rev. D 107 (2023) 063001]

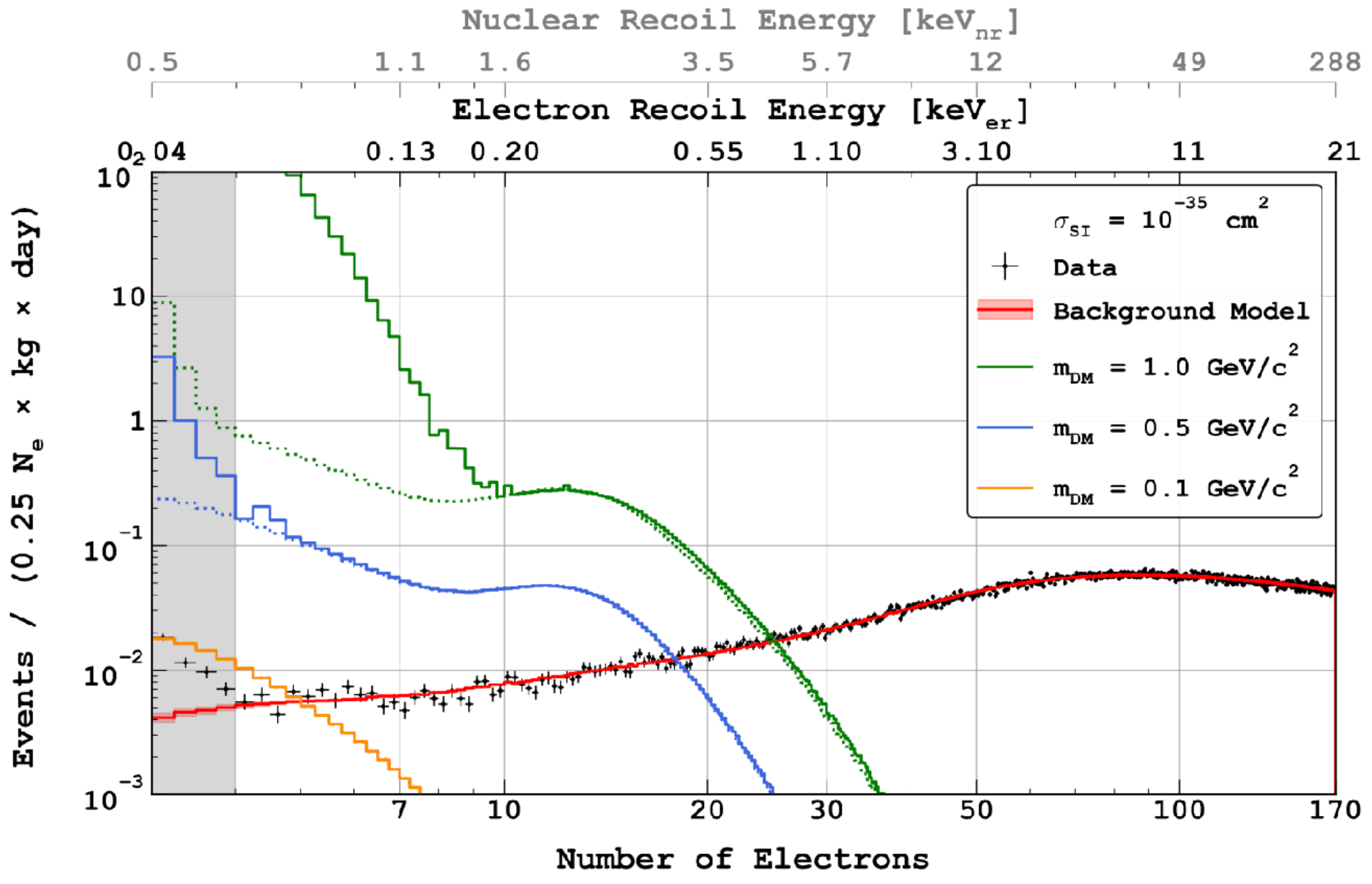


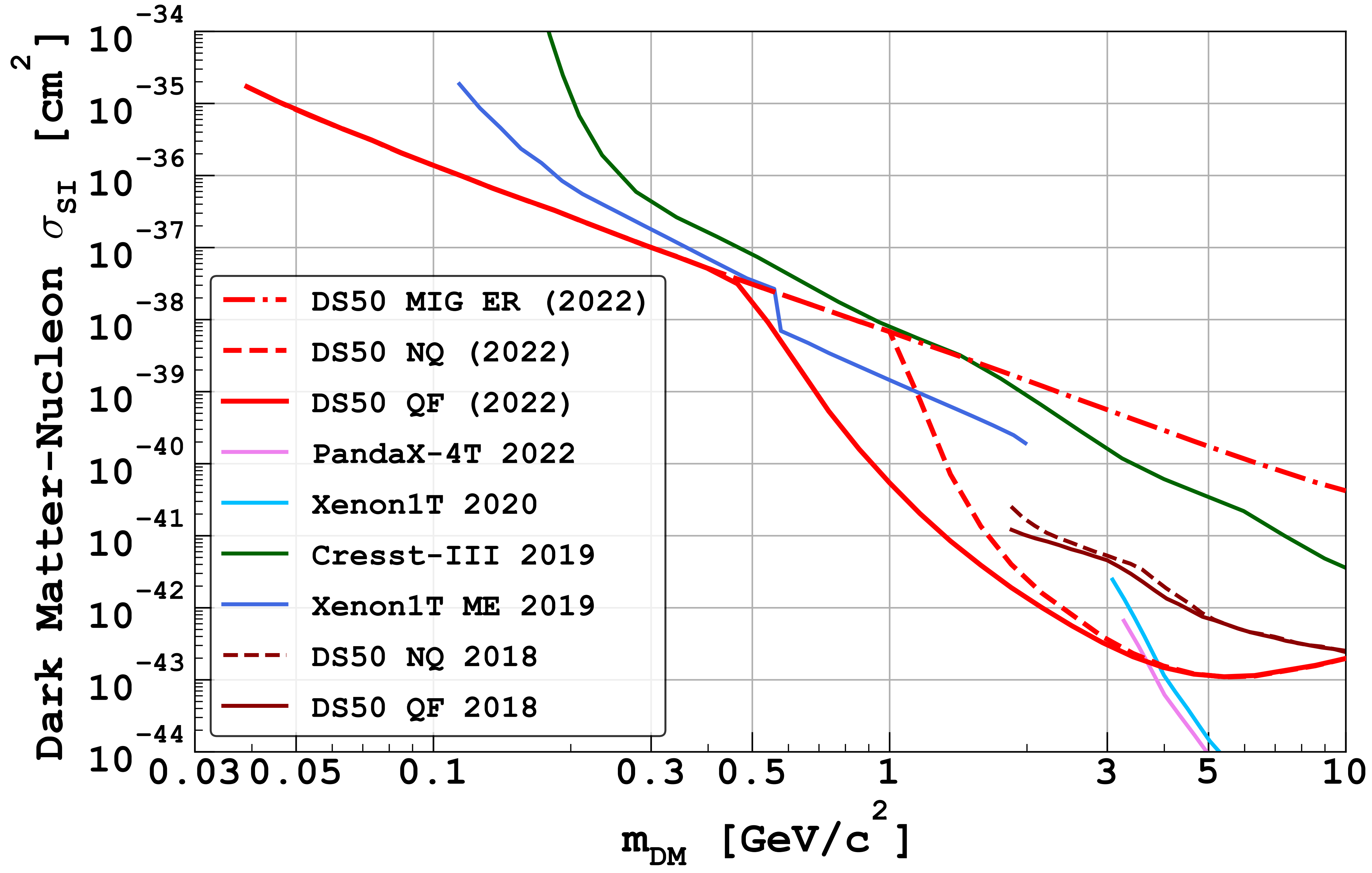




The Migdal Effect





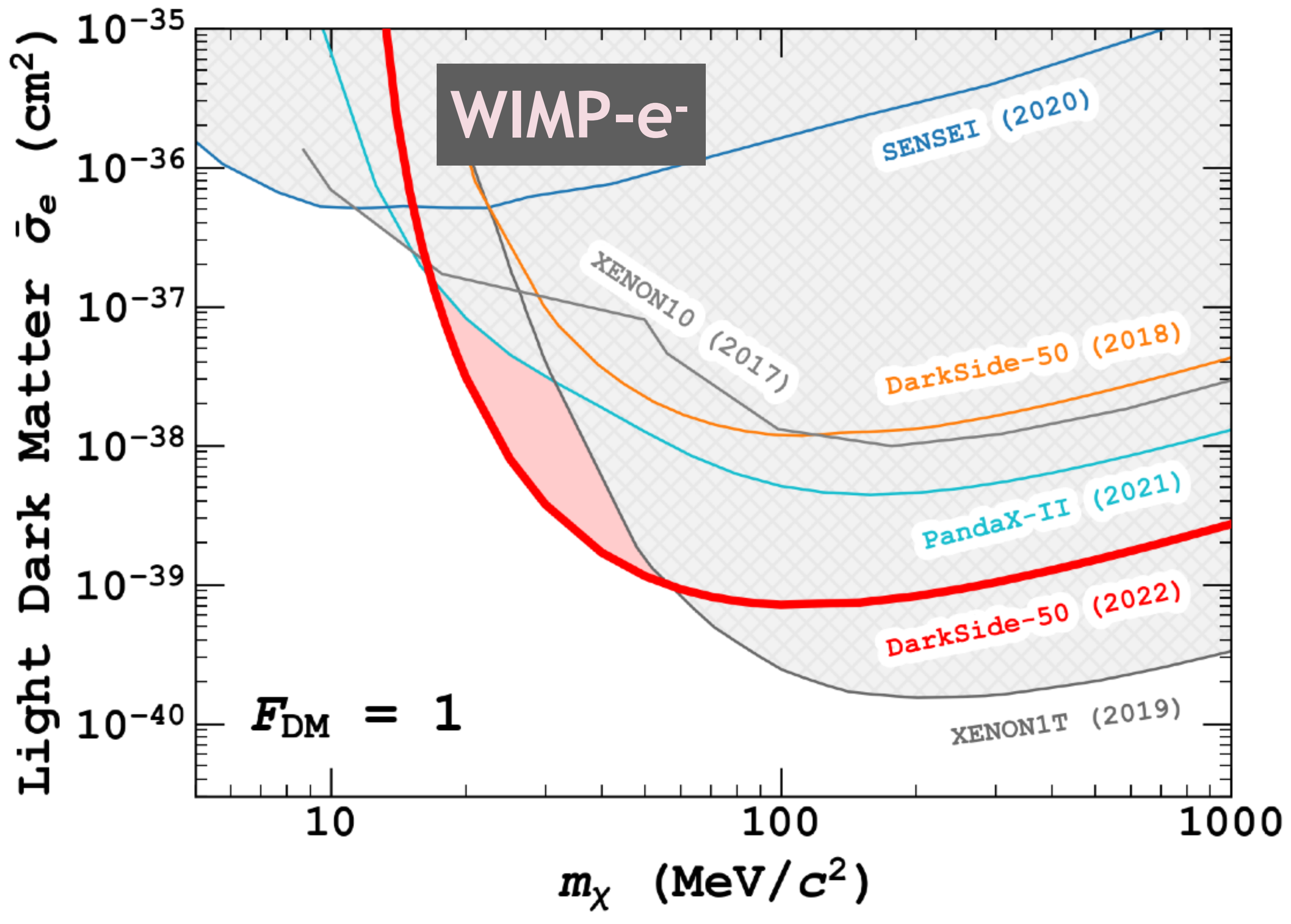


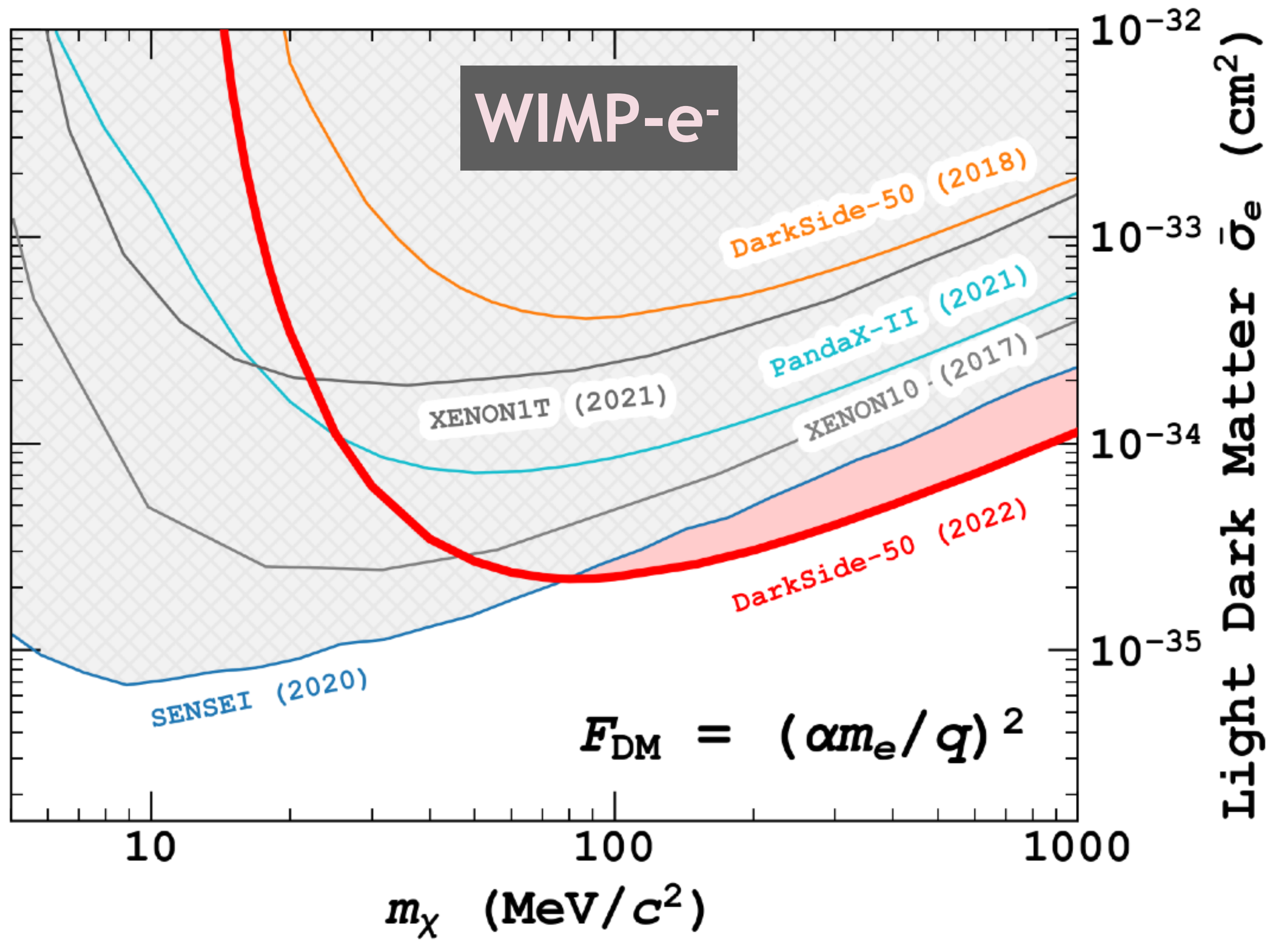
Results confirmed by using **Bayesian Networks** (arXiv:2302.01830)

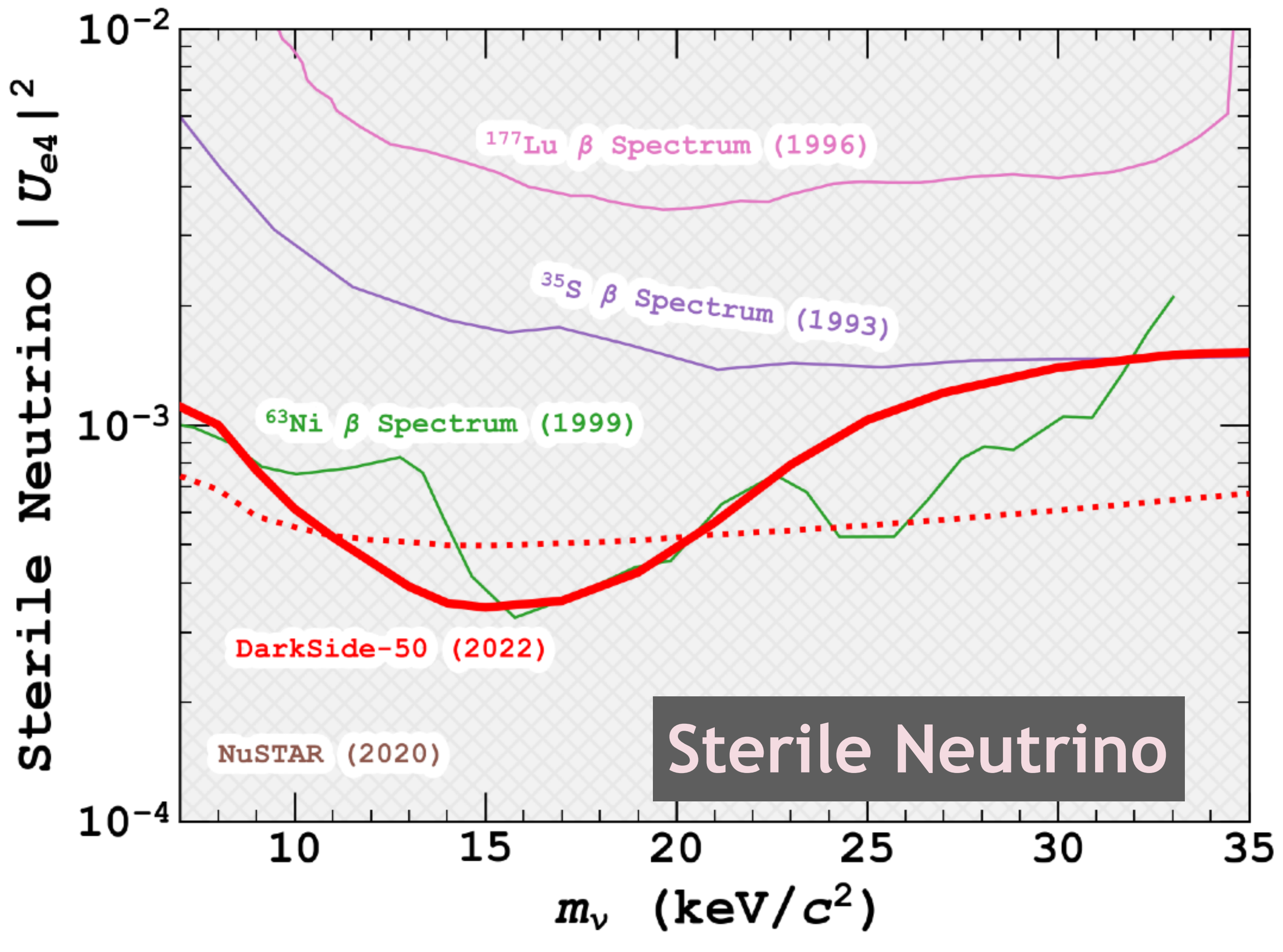
- detector response model included in the likelihood function
- Markov Chain Monte Carlo for posterior probability

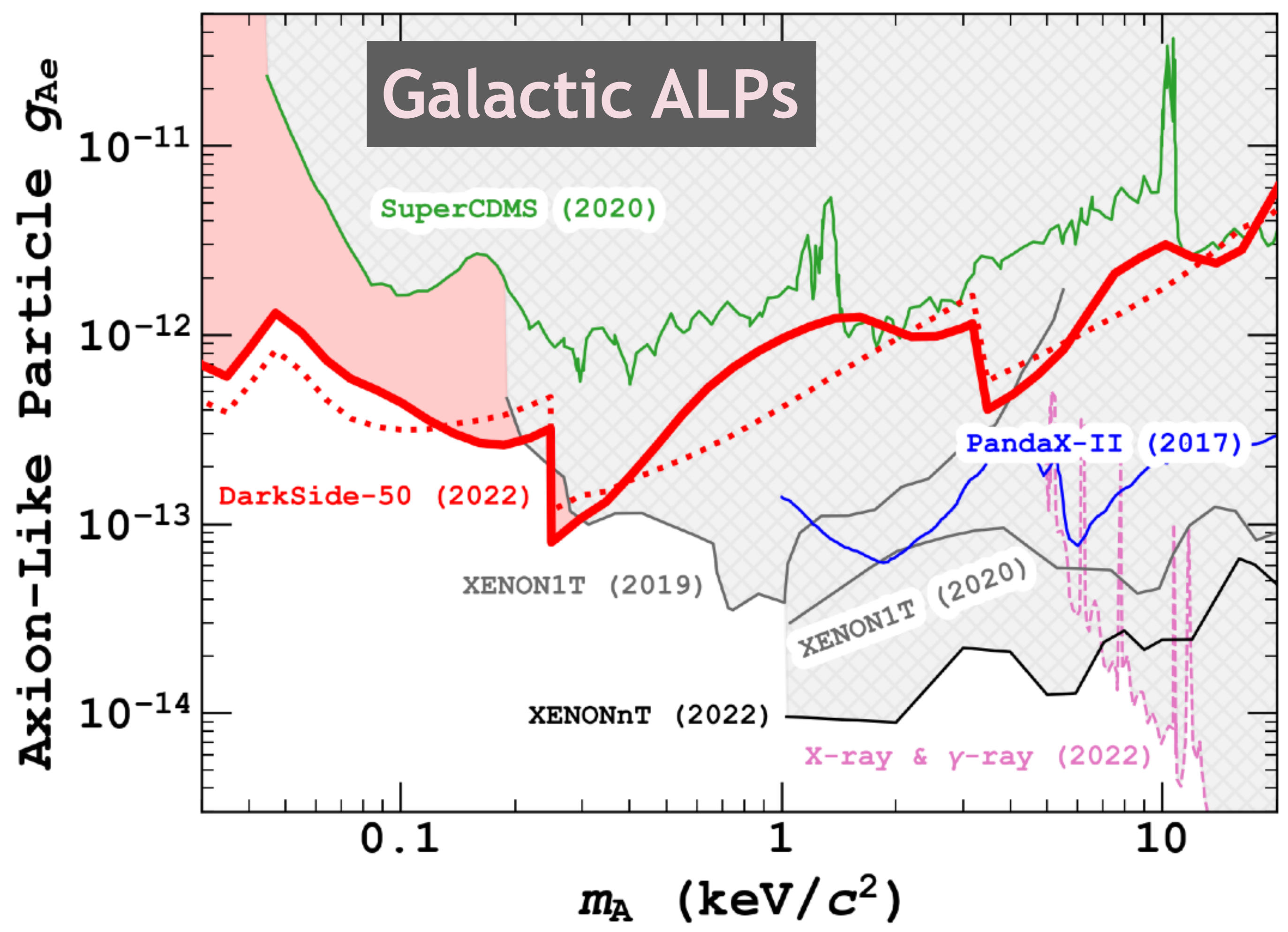
Leptophilic Dark Matter

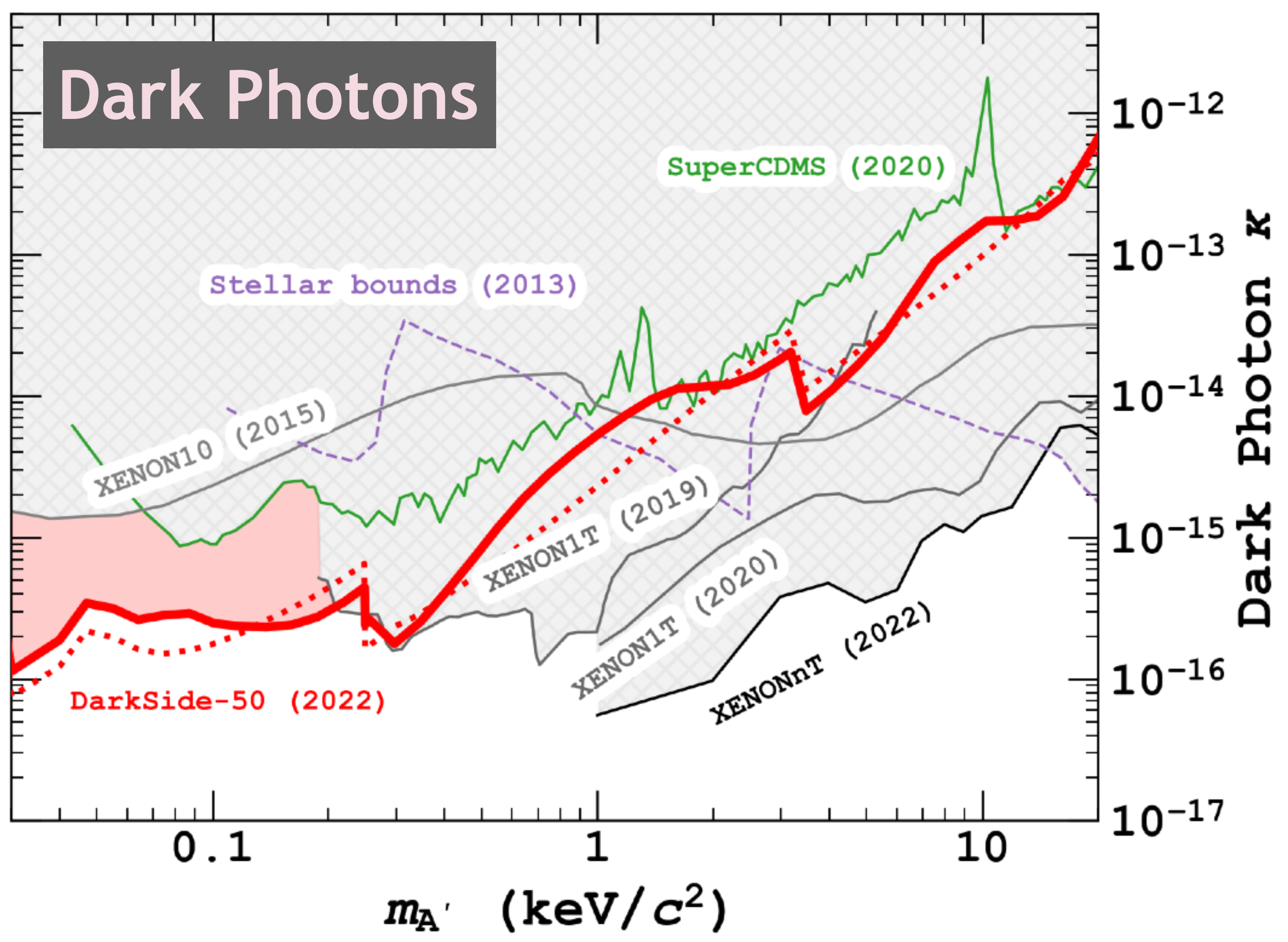
DarkSide-50, Phys. Rev. Lett. 130 (2023) 101002











Conclusions

The DarkSide-50 low-mass search

- 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/c²** (**40 MeV/c²**) WIMP mass without (with) **Migdal effect**
- Improved limits on **WIMP-electron** interactions, galactic **ALPs**, **dark photons**, and **sterile neutrinos**
- More results on **annual modulations** and **non-standard operators** in progress

Follow up of the DarkSide-50 search

- Sensitivity projection for a **1 ton-year exposure** dual-phase LAr TPC optimized for light dark matter searches through the ionization channel (arXiv:2209.01177)

- Sensitivity projections for **DarkSide-20k** in progress (see Marie Van Uffelen's talk for more details on DarkSide-20k)