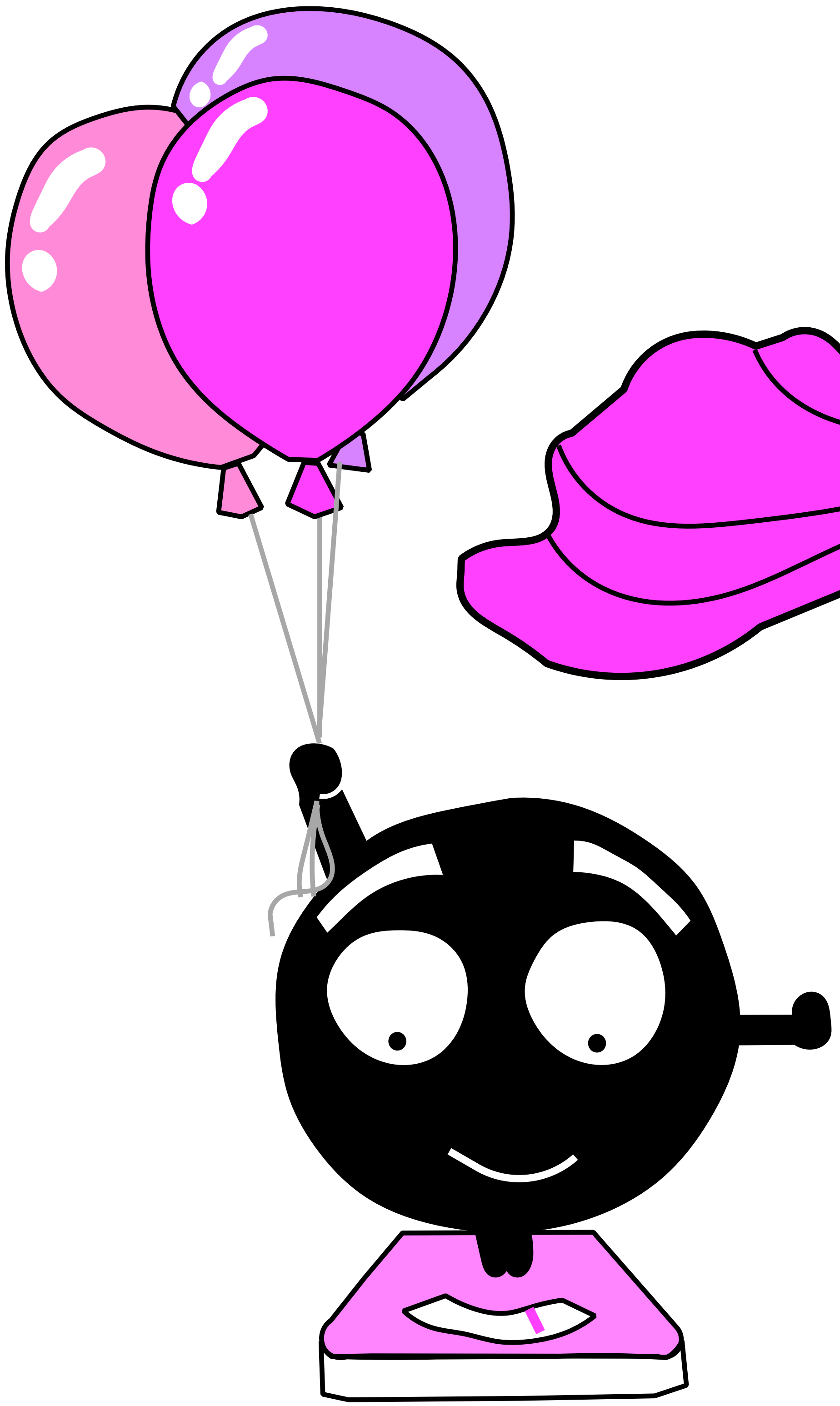
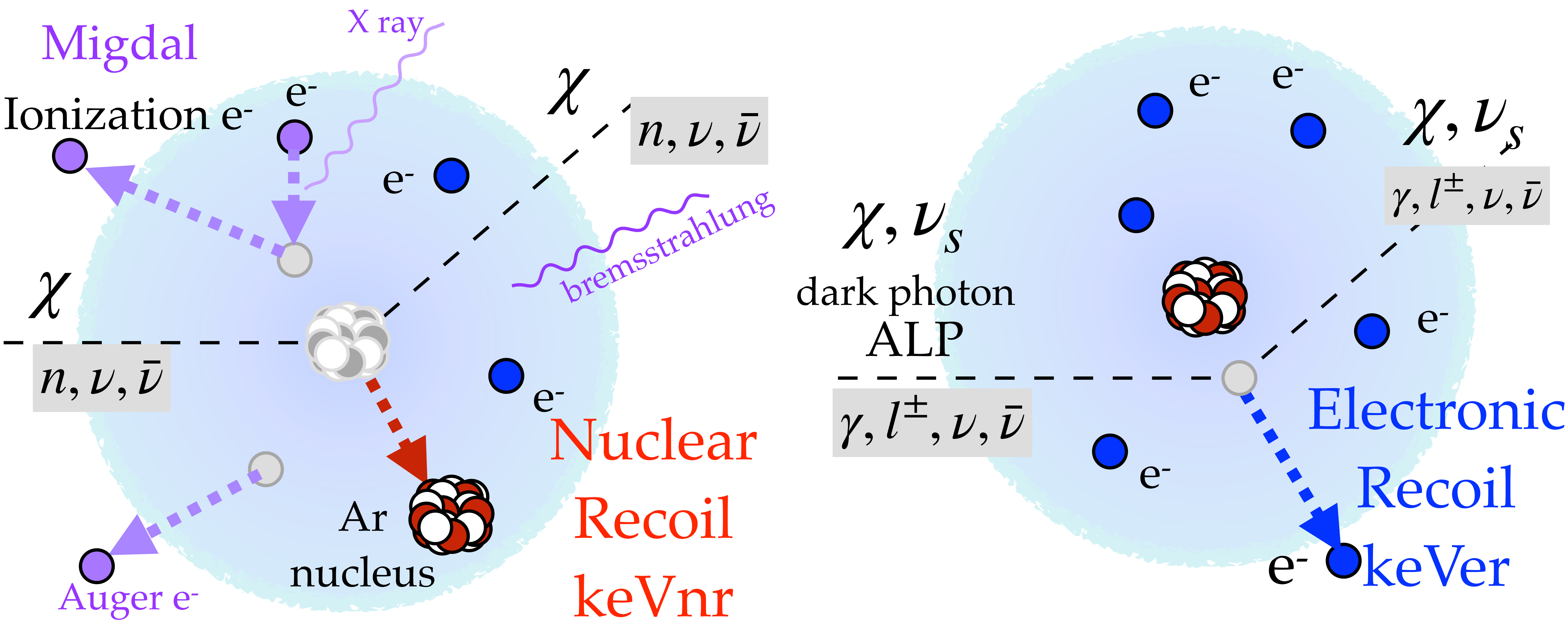
LIGHT DARK MATTER SEARCH RESULTS FROM DARKSIDE-50



Emilija Pantic (UC Davis) on behalf of DarkSide50 collaboration @ TeVPA23

Interactions considered for low mass DM search



Interactions with nucleus

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

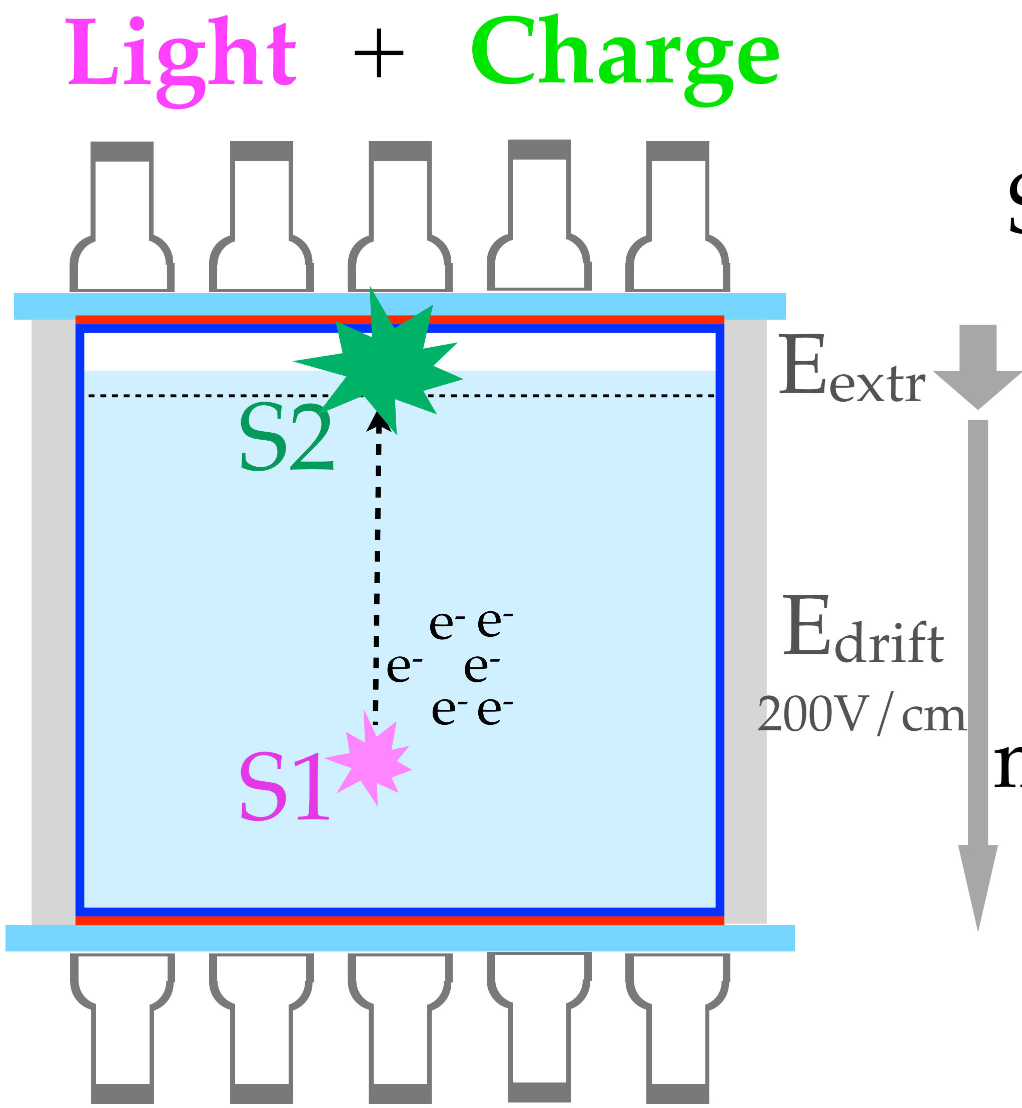
Interaction with nucleus including Migdal effects

DarkSide-50, Phys. Rev. Lett. 130 (2023) 101001, Eur. Phys. J. C 83, 322 (2023)

Interactions with electron final states

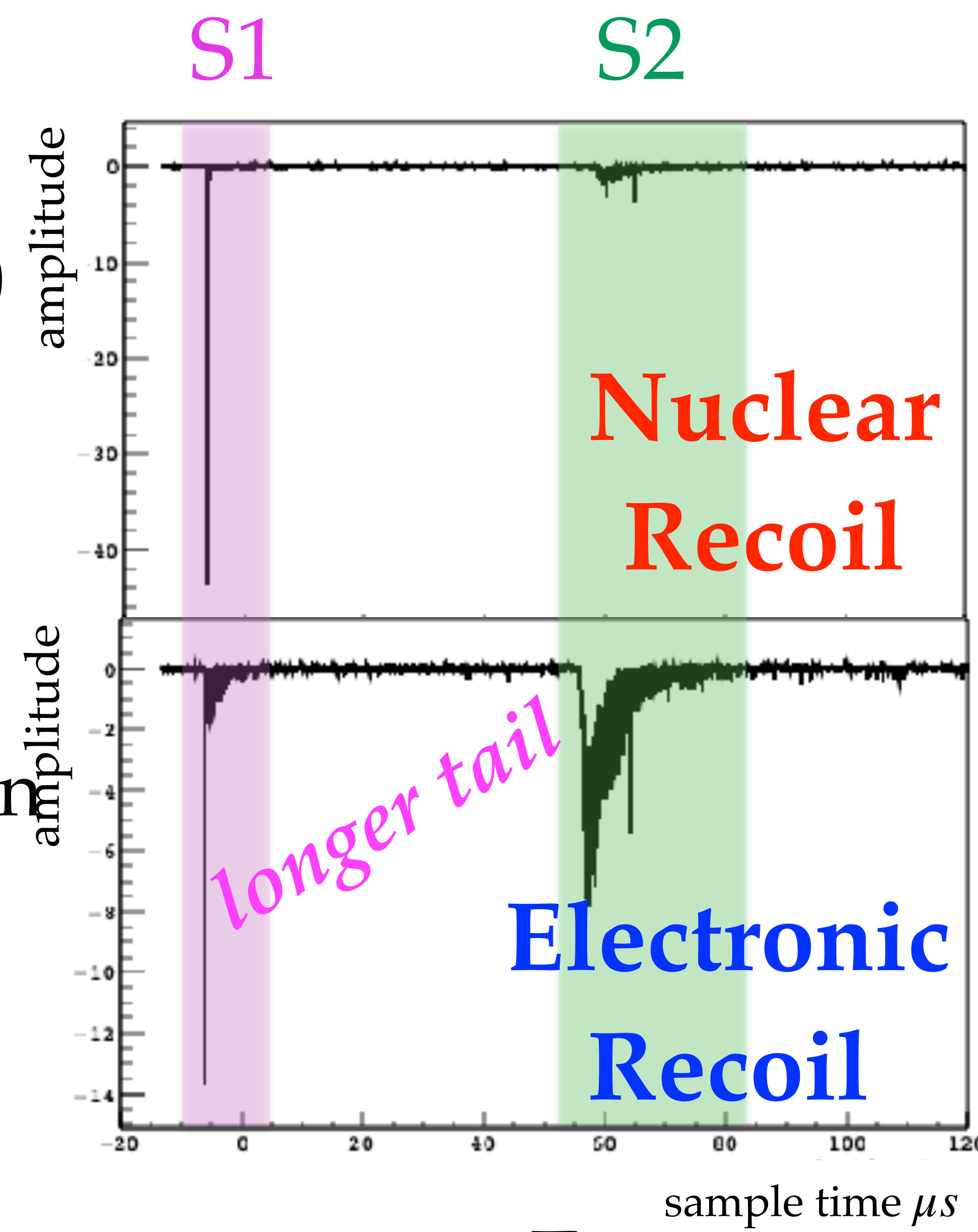
DarkSide-50, Phys. Rev. Lett. 130 (2023) 101001

DarkSide 50 Dual Phase LAr TPC with S1 and S2



S1 yield ~7.0 PE/keVer

S2 multiplication in gas ~23 PE/e



3D positioning/fiducialization

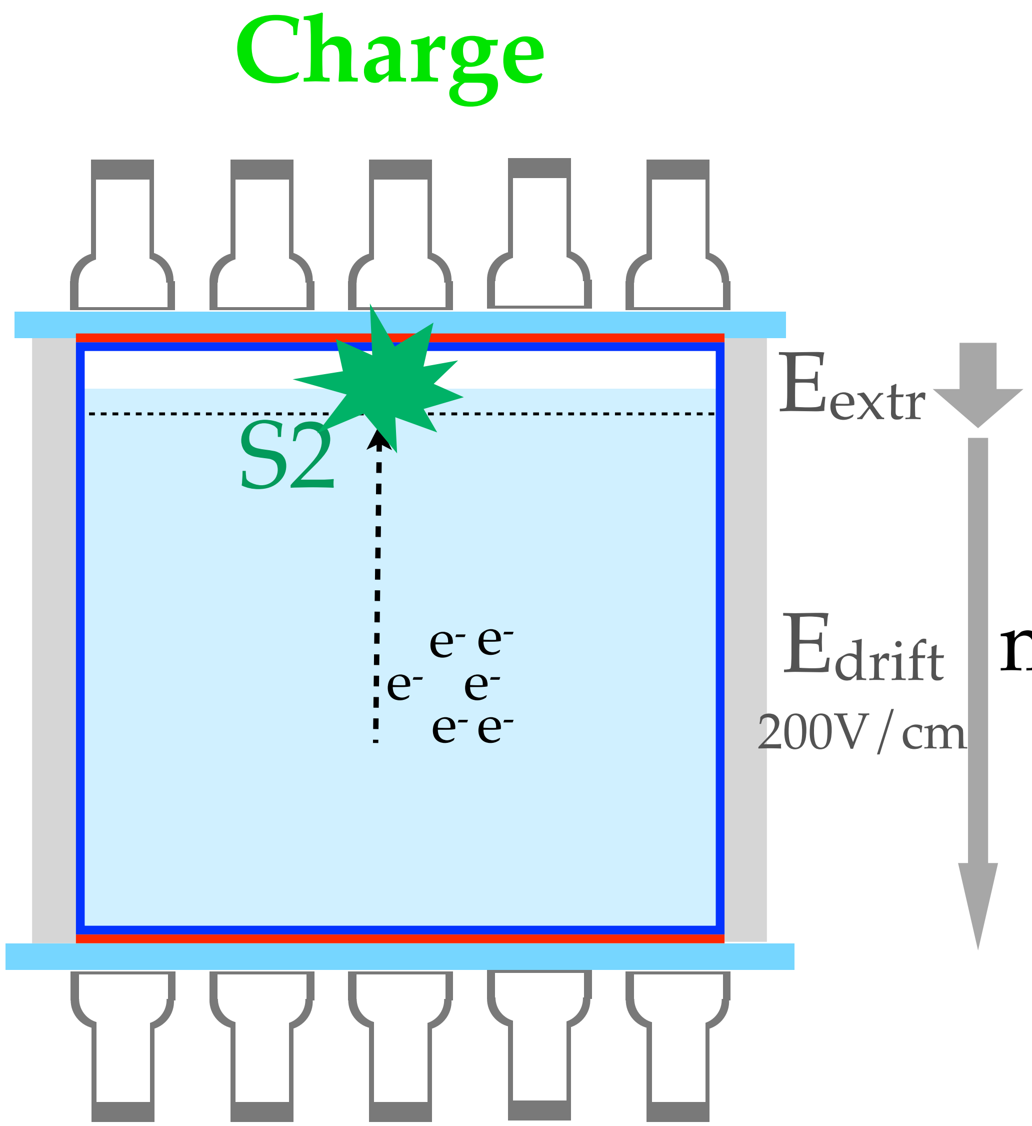
Pulse shape discrimination for NRs vs ERs

S2/S1 discrimination of ERs

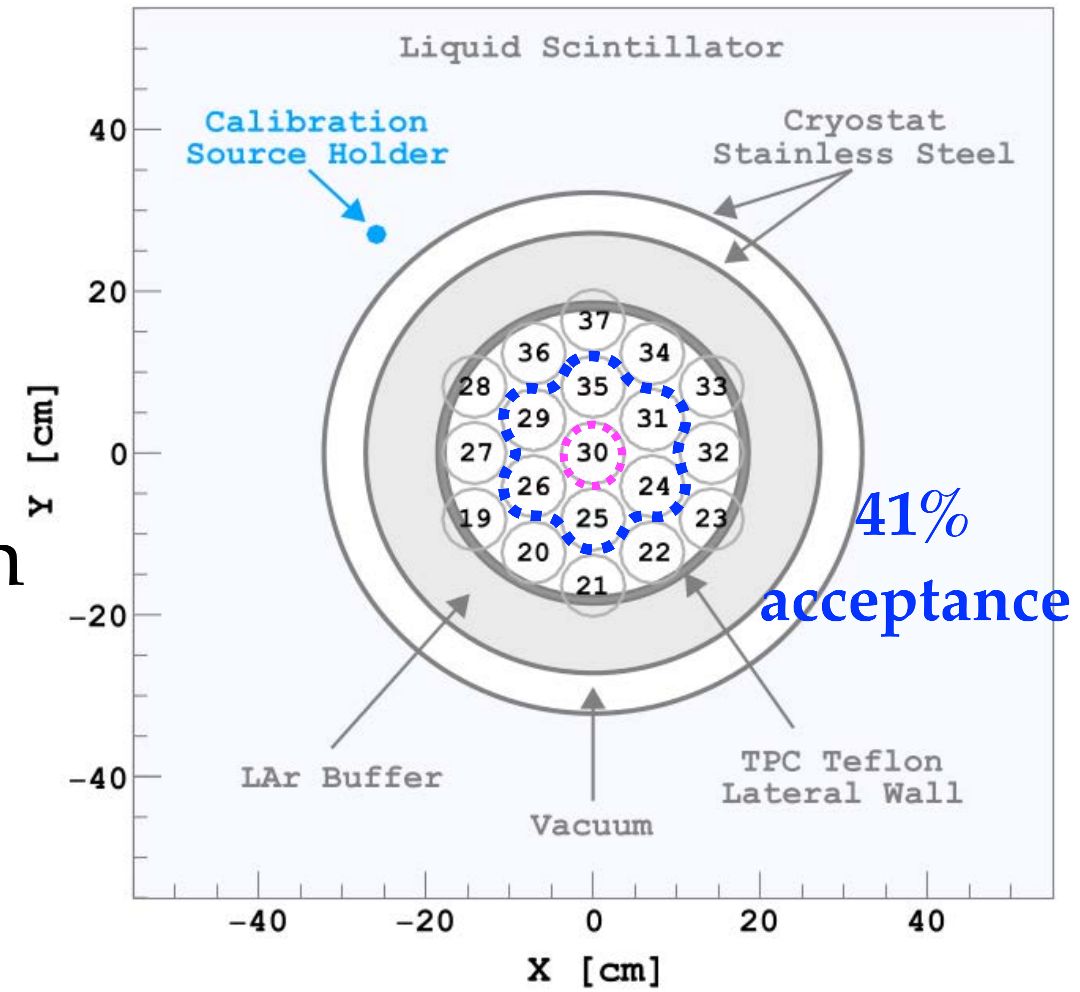
Energy threshold ~6 keVnr

ER rejection up to factor 10^9 - DEAP-3600 in [16,33] keVee EPJC 81,823(2021)

DarkSide 50 Dual Phase LAr TPC with S2 only



S2 multiplication in gas
~23 PE/e



XY positioning/fiducialization

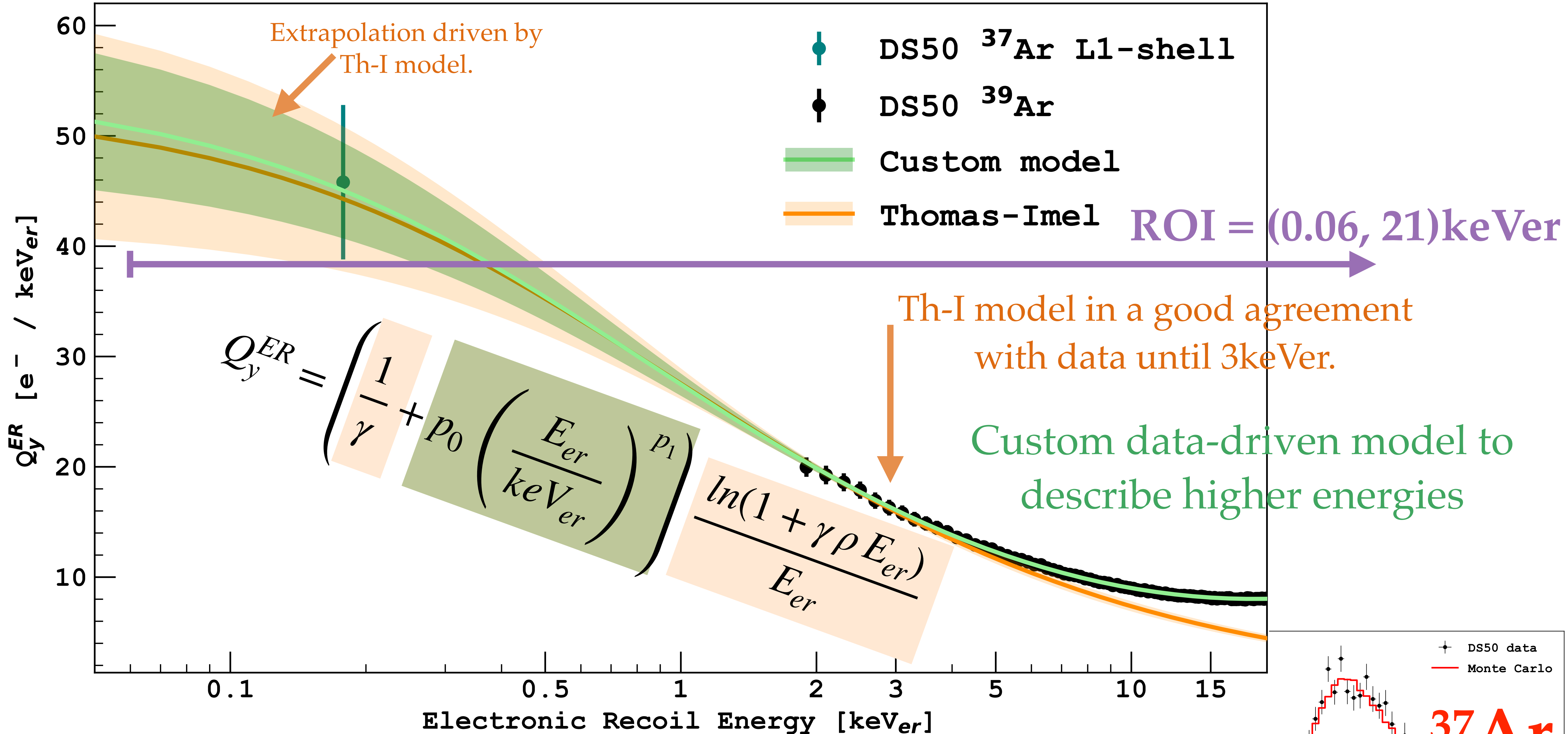
~~Pulse shape discrimination for NRs vs ERs~~

~~S2/S1 discrimination of ERs~~

Energy threshold ~0.6 keVnr

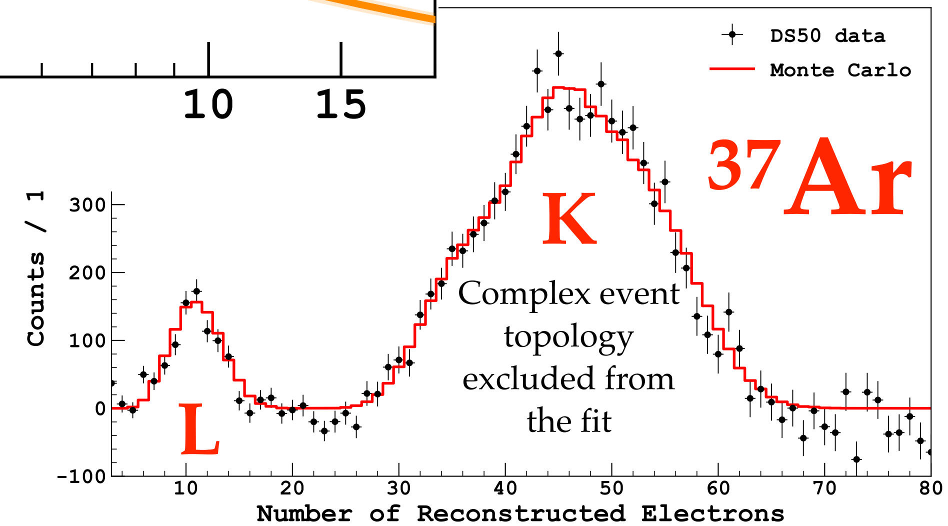
Ionization response to electronic recoils

in terms of primary ionization electrons



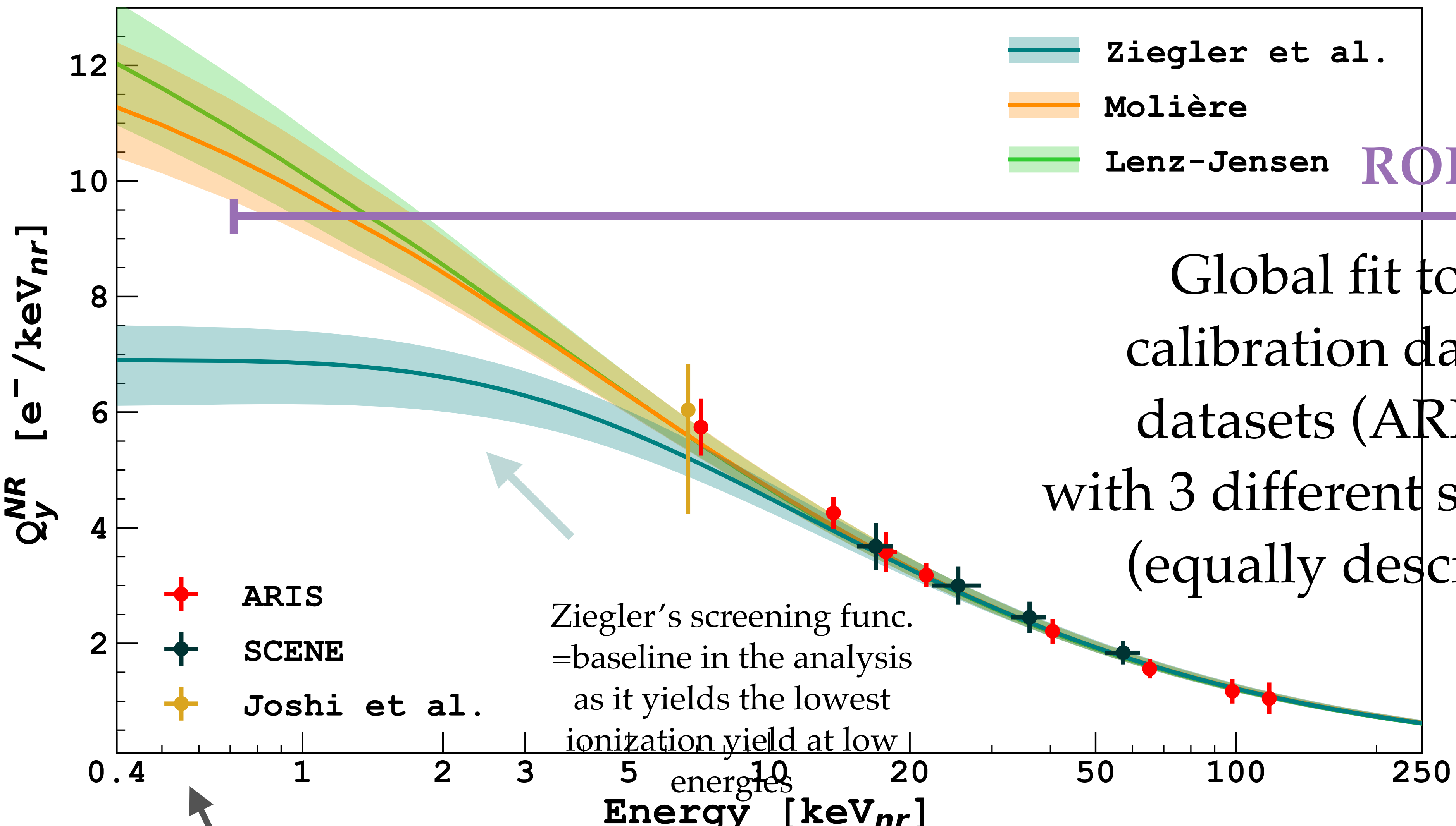
Calibration data:

1. ^{39}Ar beta decay in the AAr 2013-2014 campaign
2. ^{37}Ar L-shell ~ 170 eV



Ionization response to nuclear recoils

in terms of primary ionization electrons

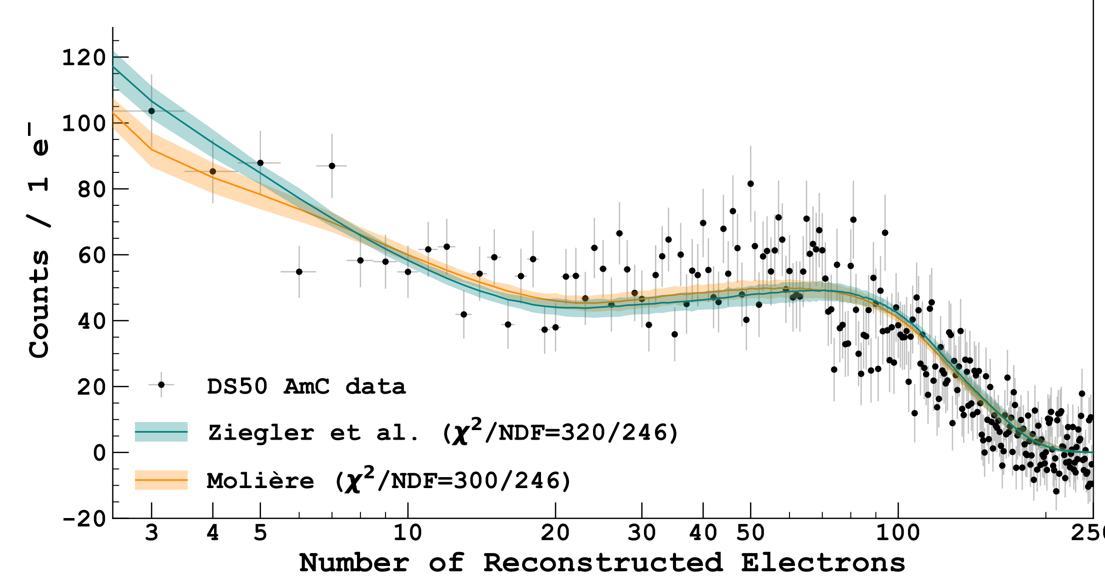


ROI = (0.64, 288)keVnr

Global fit to AmBe, AmC calibration data and external datasets (ARIS and SCENE) with 3 different screening functions (equally describing the data)

Ziegler's screening func. =baseline in the analysis as it yields the lowest ionization yield at low energies

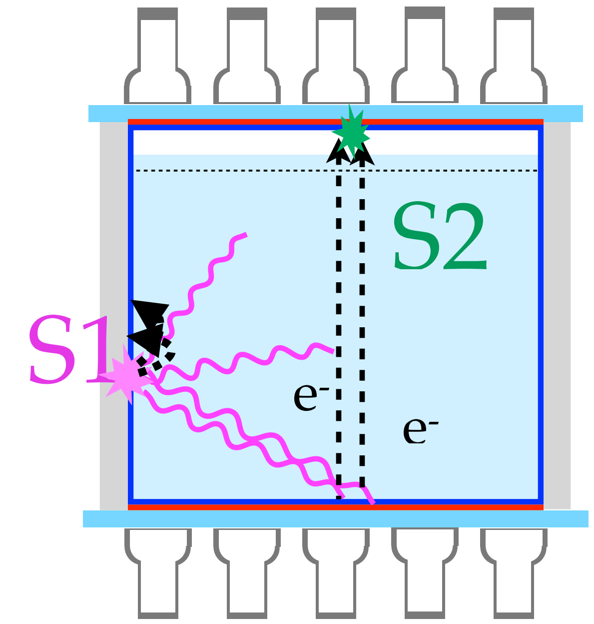
Models constrained at low energy by AmC data with minimum value of ~0.435 keVnr=3e-



New Dataset: 653.1 live-days of UAr data

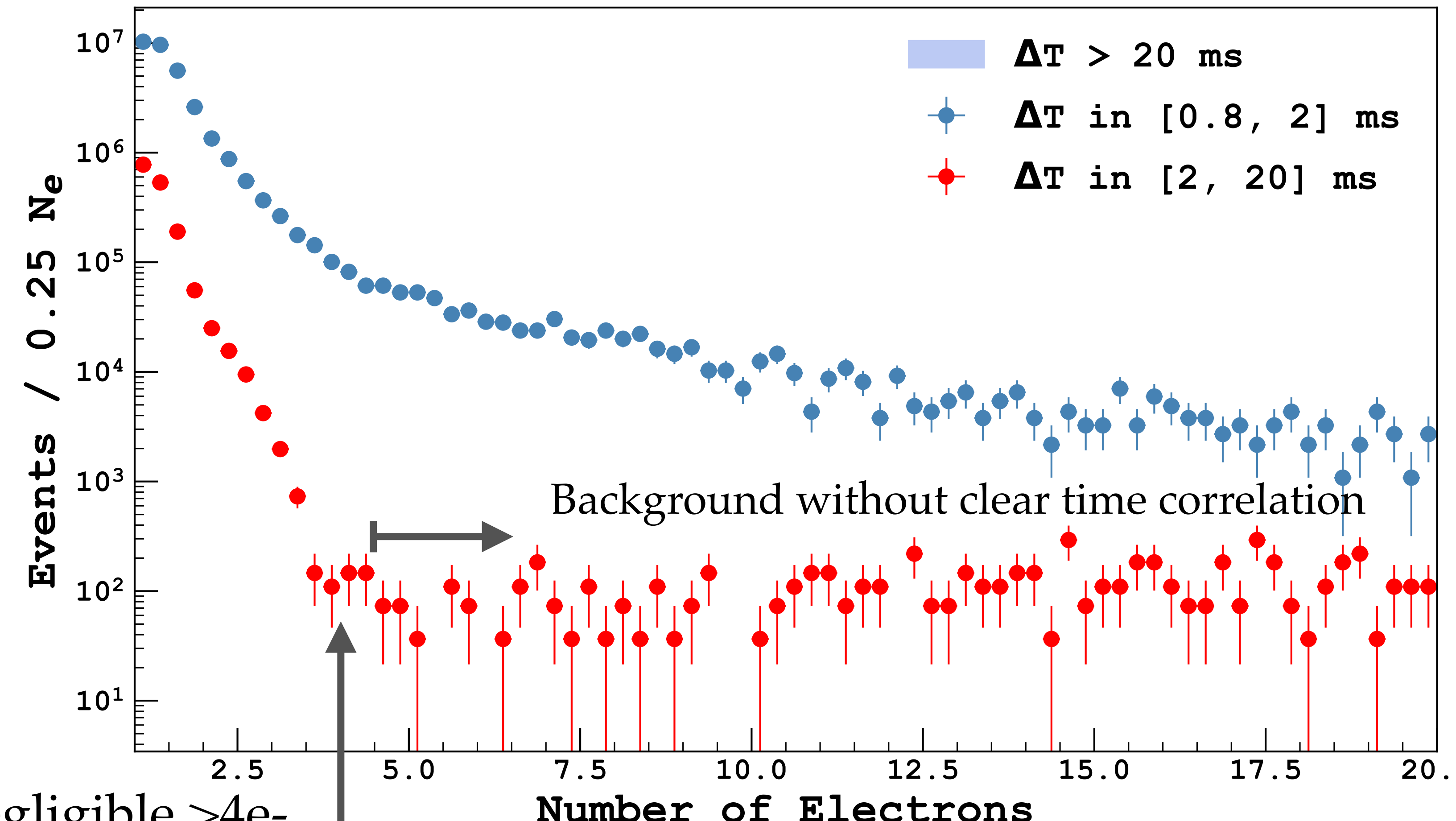
Quality cuts against pile-up:
-Pulse-shape via peak time and FWHM to remove overlapping S1 and S2.
-Anomalous pulse start time to remove S2 only event from the tail of larger pulse.
-Pulse length and peak time to remove multiple S2's.

Using S2 only and, S1 and S2 events



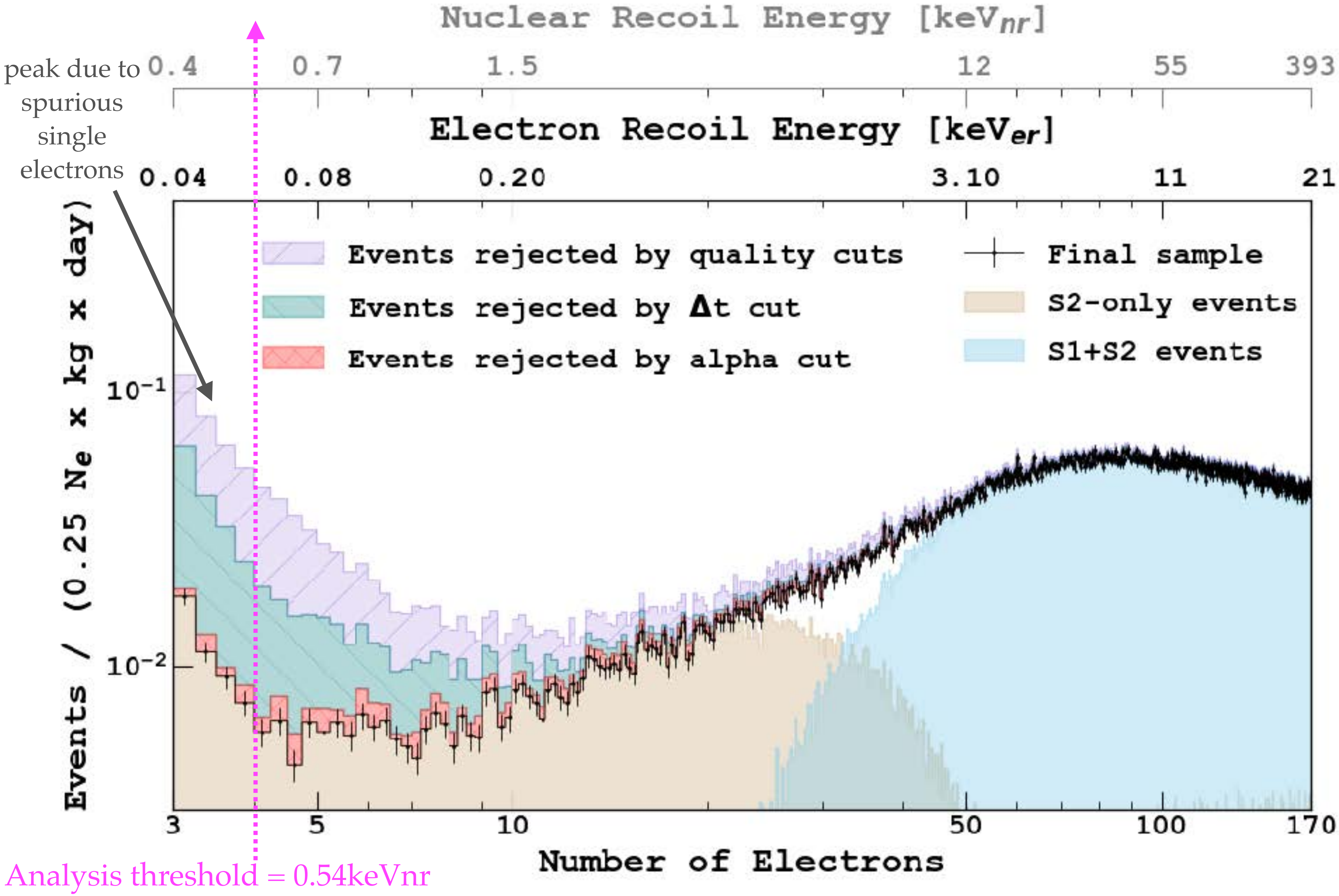
Quality cuts against alpha-induced S2 only pulses:
- S2/S1 ratio tuned on calibration data

Quality cuts against spurious electrons:
- Reject correlated events (if within 20 ms from the previous one)

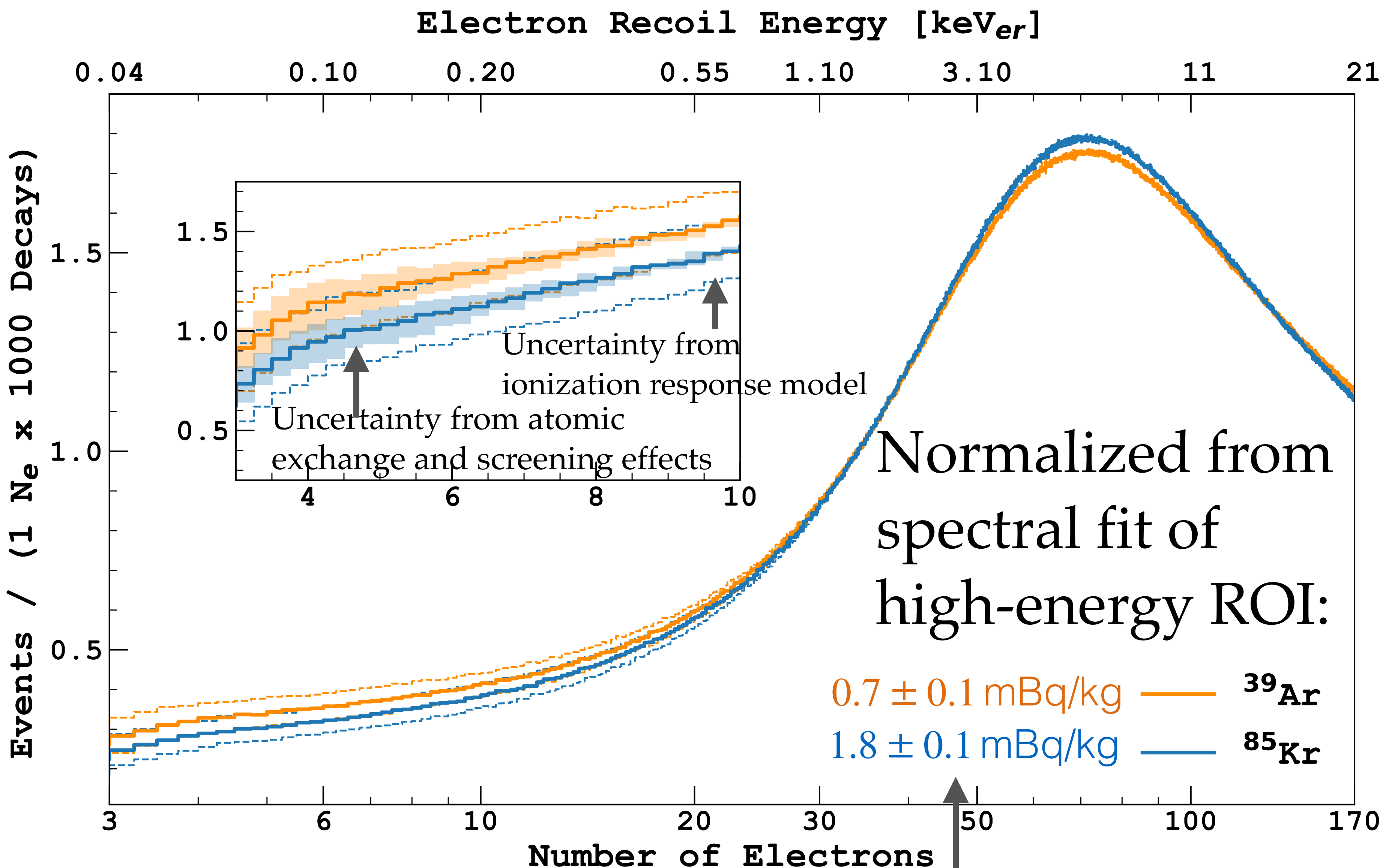


Contribution negligible >4e-

DarkSide-50 653.1 live days low mass DM search dataset

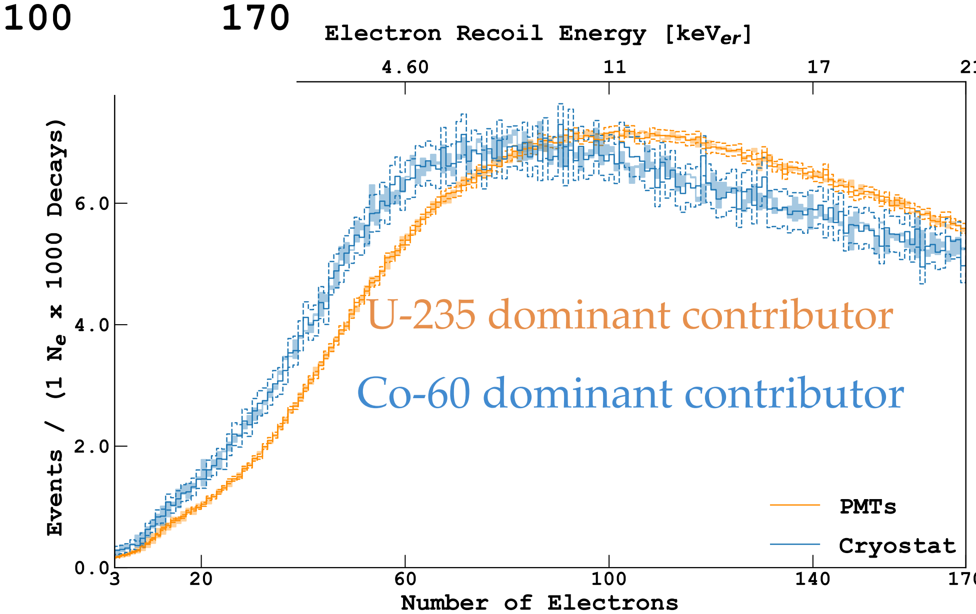


Background model: ^{39}Ar, ^{85}Kr and γs



New background model (using materials screening campaign) including internal and external ER background sources.

Additional estimate for ^{85}Kr from fast coincidence through metastable state and decay time search

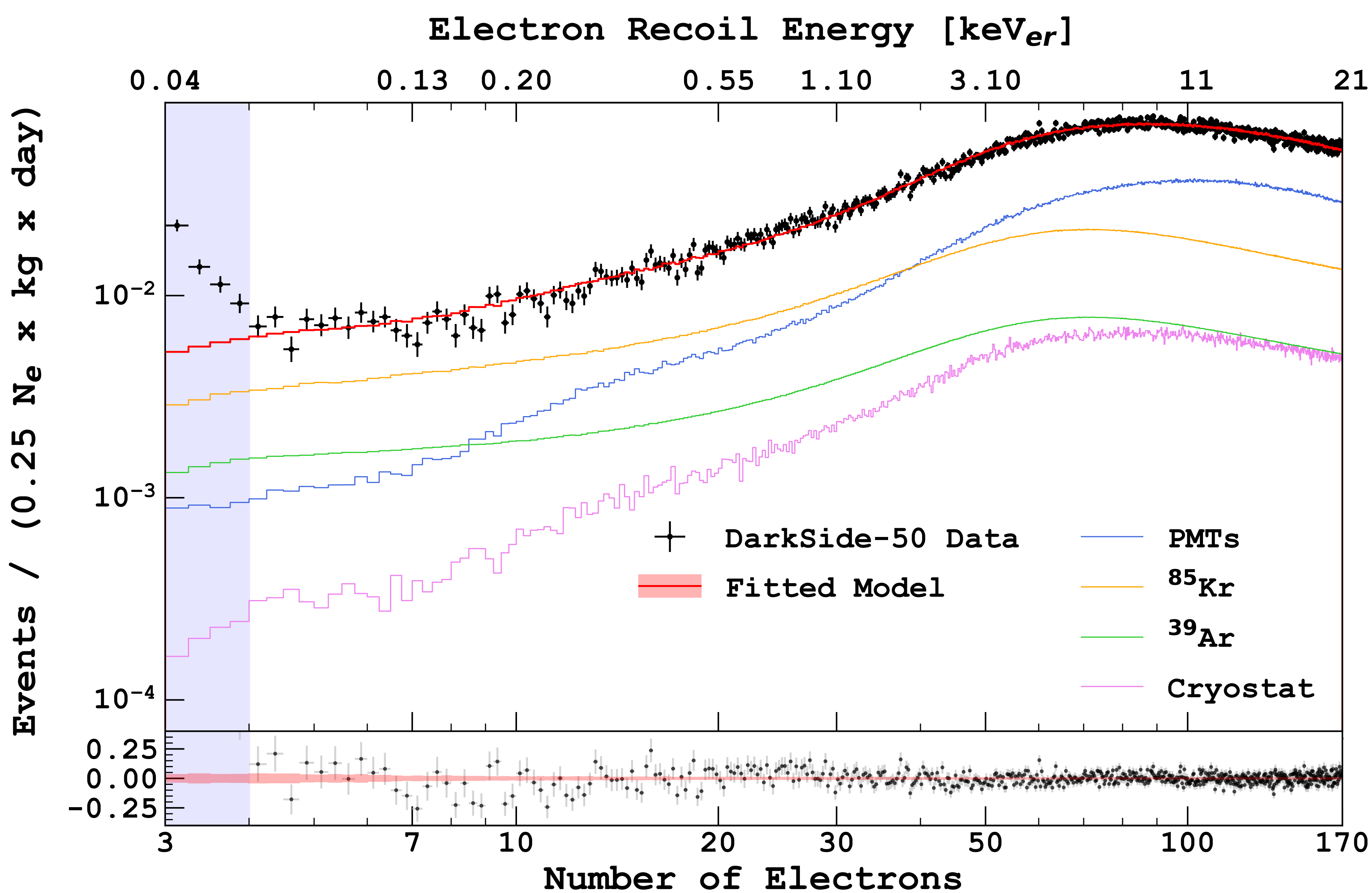


Assumption is that internal sources are uniformly distributed in fiducial volume

Background only fit: frequentist approach binned likelihood

$\mathscr{L} =$ [Poisson distribution in each bin] $\times$ [Gaussian penalties for nuisance parameters: Amplitude (5) and shape (5)] $\times$ [Statistical uncertainties of the simulated sample in each bin]

The fit from 4 Ne is compatible with data.

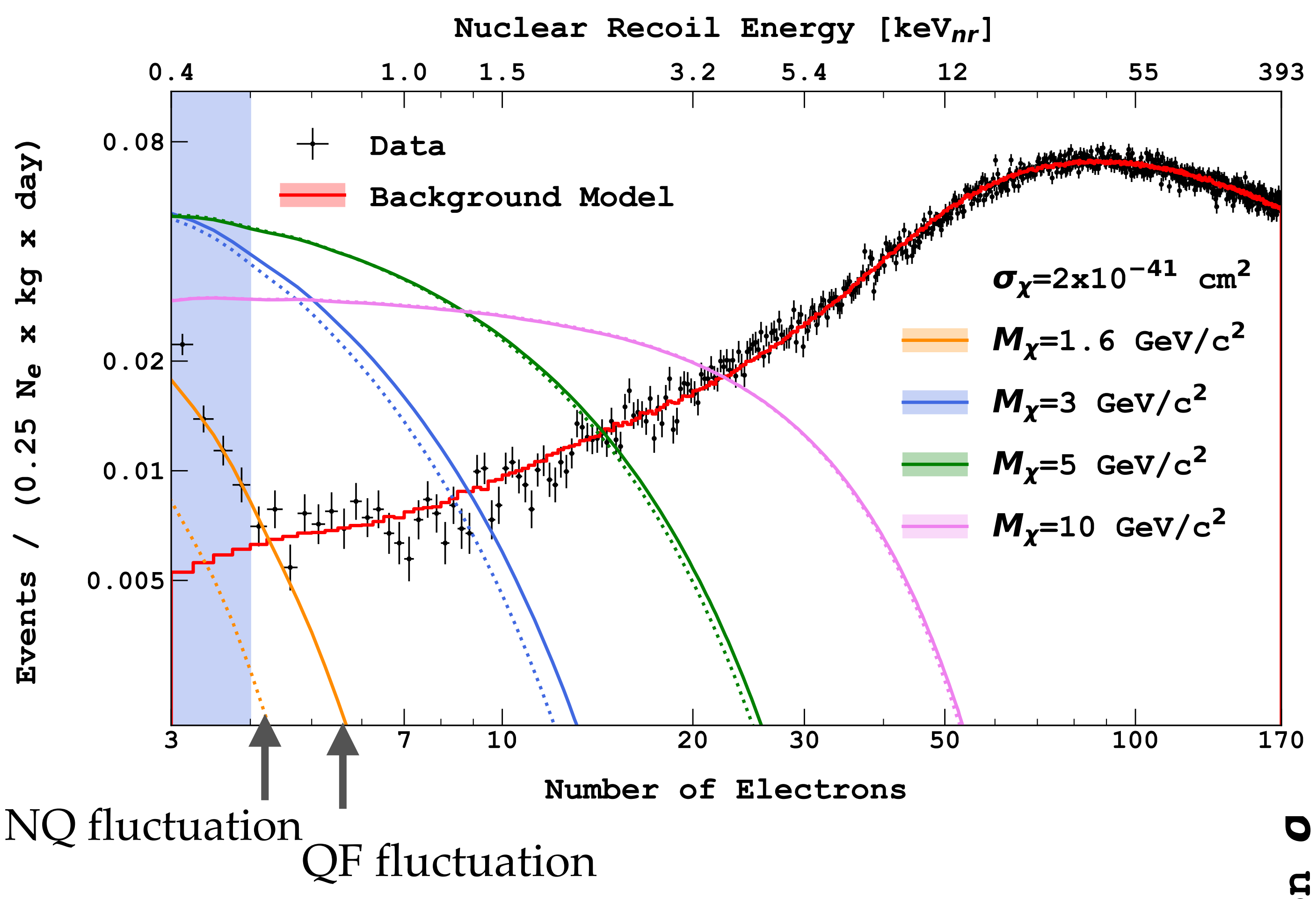


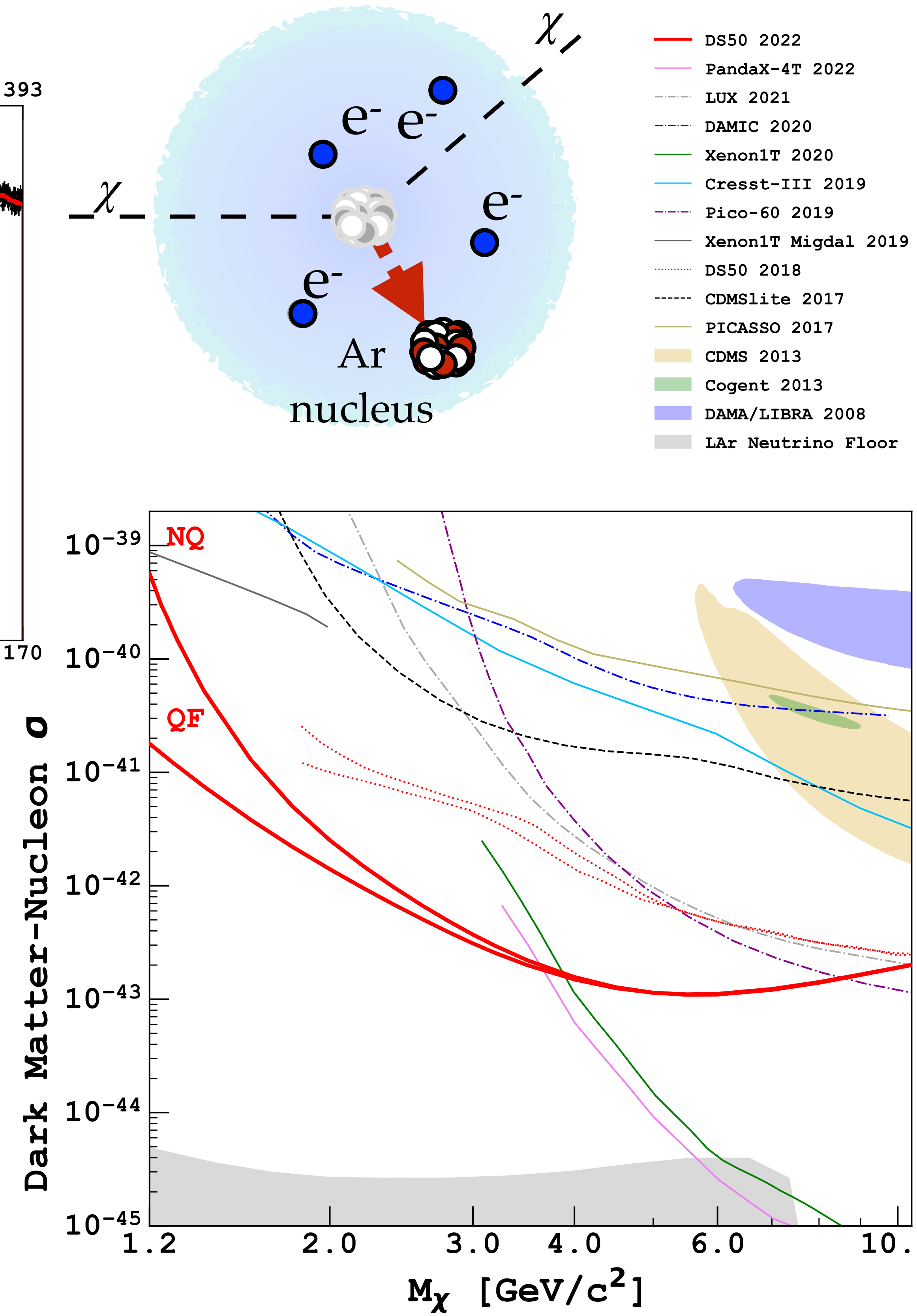
Tritium contamination tested and found compatible with zero ($< 1 \mu Bq/kg$).

	Q_y^{ER}	S_{Ar}	S_{Kr}	Q_{Ar}	Q_{Kr}	A_{Ar}	A_{Kr}	A_{PMT}	A_{Cryo}	A_{FV}
A_{FV}	0.01	0.00	0.00	0.01	0.01	-0.13	-0.32	-0.66	-0.04	1.00
A_{Cryo}	-0.08	0.01	0.06	0.00	0.01	-0.04	-0.15	-0.35	1.00	-0.04
A_{PMT}	-0.16	0.01	0.06	-0.00	0.01	0.04	0.05	1.00	-0.35	-0.66
A_{Kr}	0.07	-0.03	-0.03	0.05	-0.05	-0.77	1.00	0.05	-0.15	-0.32
A_{Ar}	0.10	0.02	-0.04	0.03	0.11	1.00	-0.77	0.04	-0.04	-0.13
Q_{Kr}	-0.01	0.02	-0.01	-0.01	1.00	0.11	-0.05	0.01	0.01	0.01
Q_{Ar}	-0.00	0.00	-0.00	1.00	-0.01	0.03	0.05	-0.00	0.00	0.01
S_{Kr}	0.15	-0.19	1.00	-0.00	-0.01	-0.04	-0.03	0.06	0.06	0.00
S_{Ar}	0.05	1.00	-0.19	0.00	0.02	0.02	-0.03	0.01	0.01	0.00
Q_y^{ER}	1.00	0.05	0.15	-0.00	-0.01	0.10	0.07	-0.16	-0.08	0.01

similarity in spectra between various components causes anti correlation

WIMP-nucleon interaction: frequentist approach



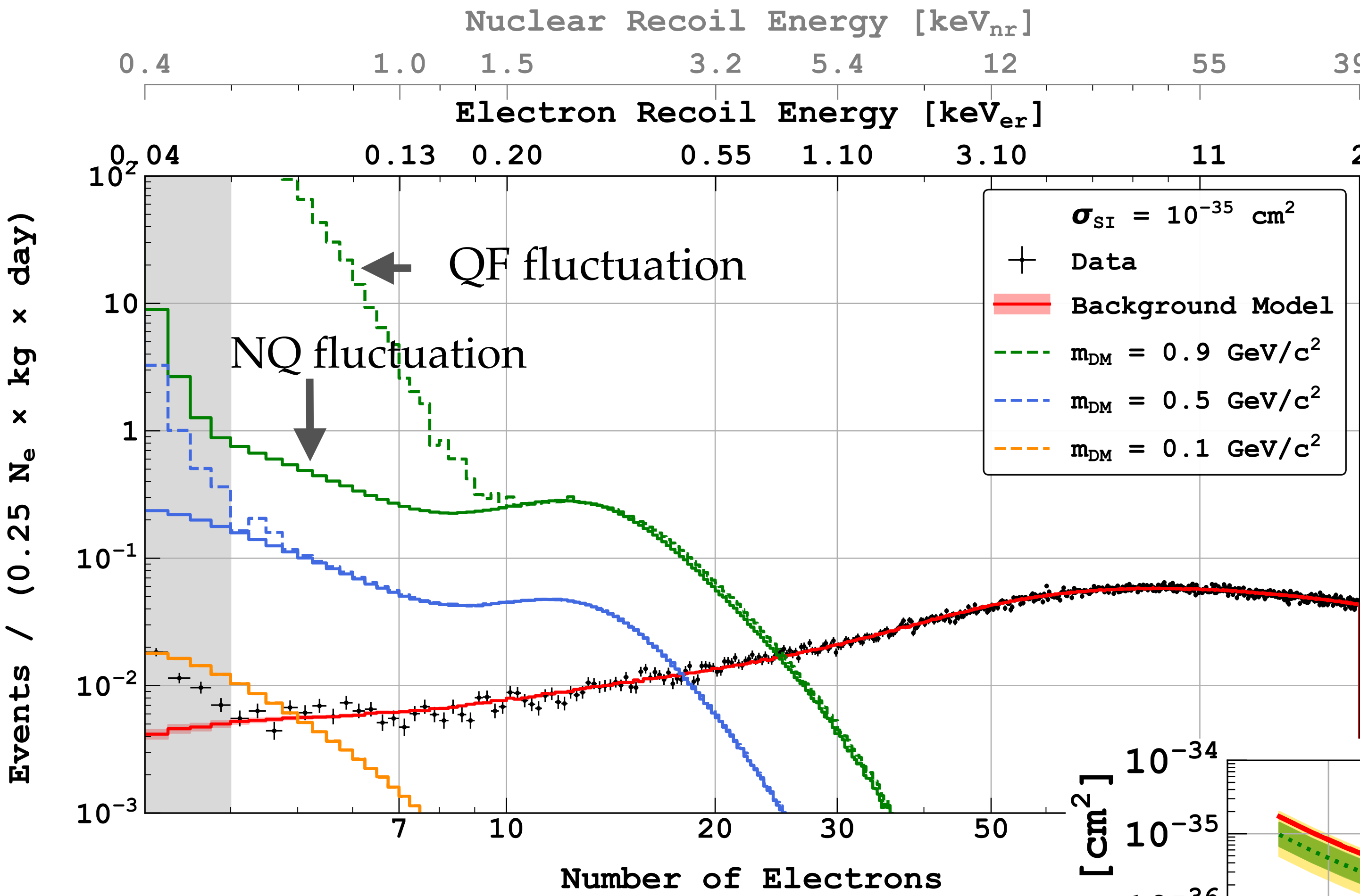


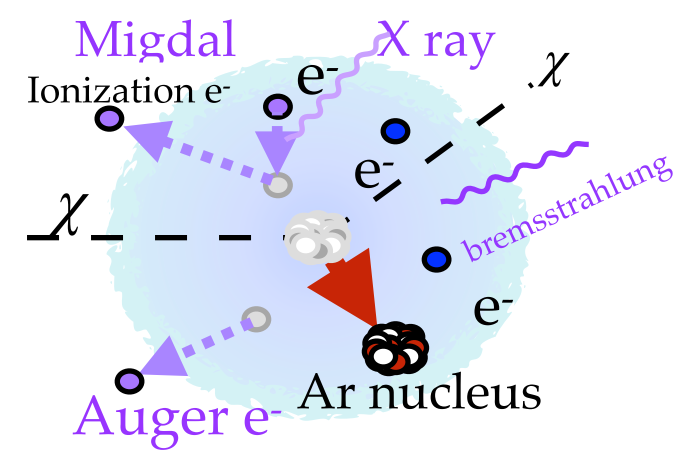
Interaction: Elastic scatter off LAr nucleus

Signal amplitude mostly affected by uncertainty on the NR ionization response and fiducial volume.

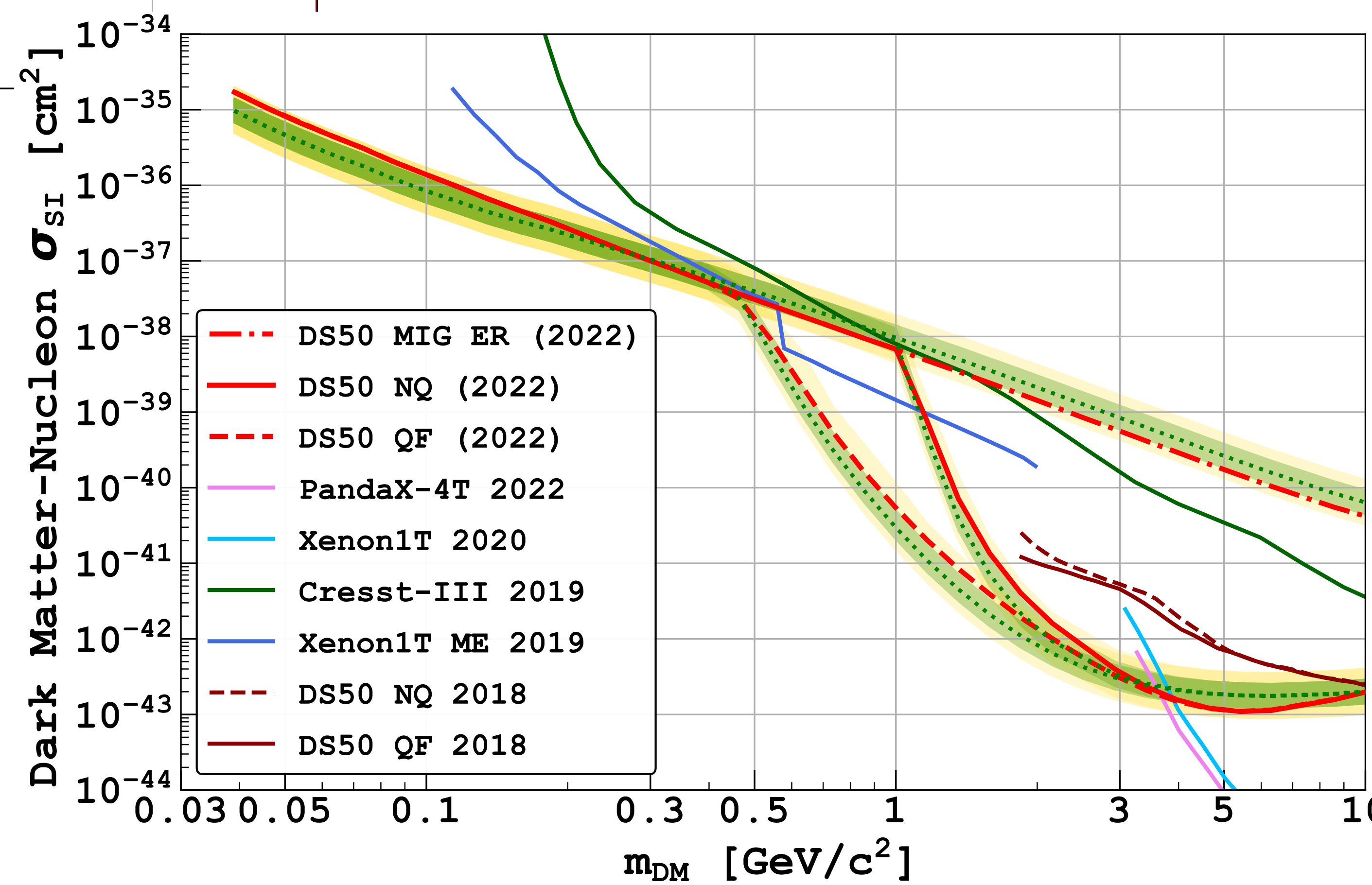
X10 more stringent limit @ 3GeV/c2

Migdal effect: frequentist approach





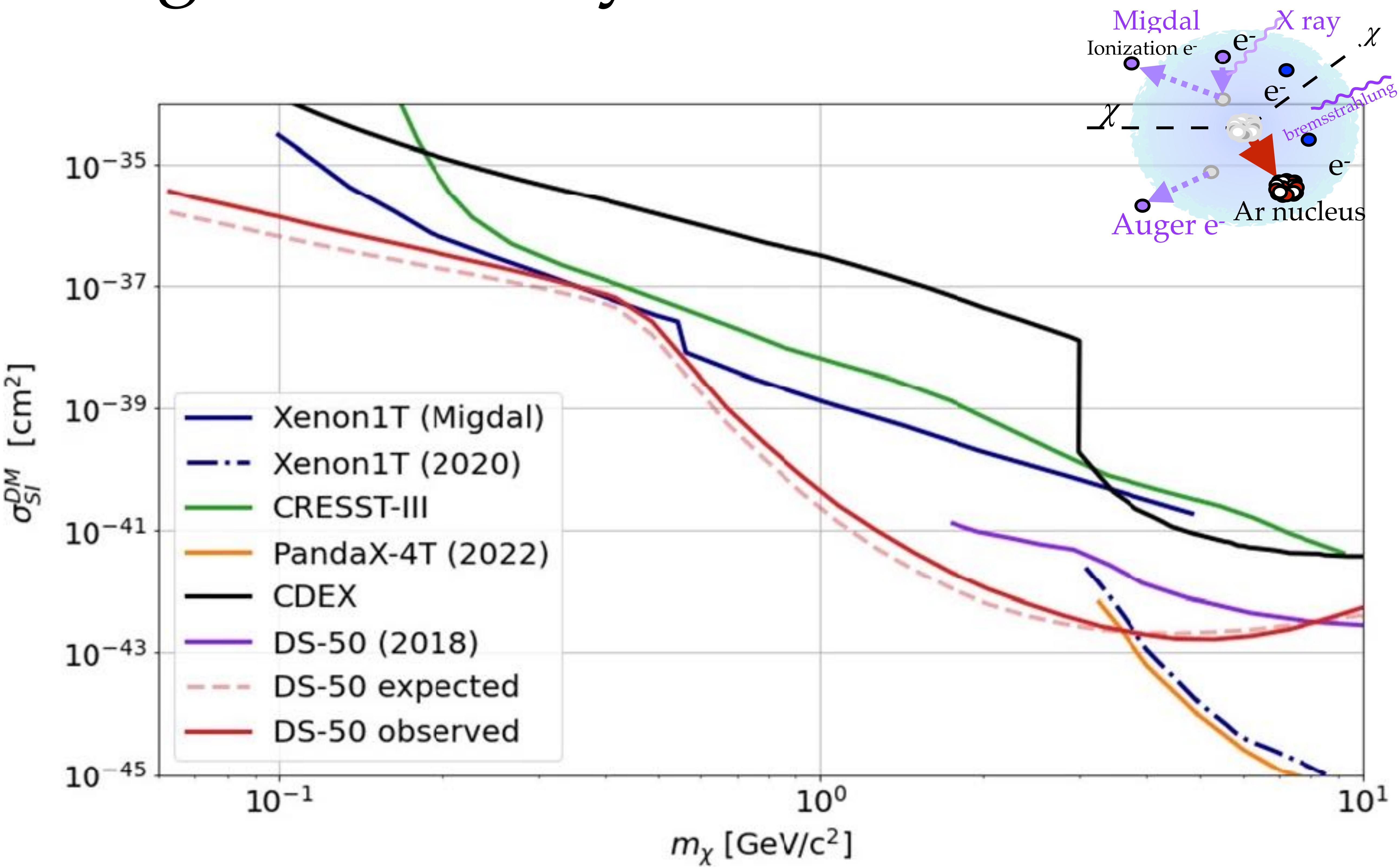
MIG = NR and ER as two independent energy deposits, ionisation clouds assumed not to interact with each other. ER assumed as a single energy deposit (ER + Auger/Xray).



The ER channel, as opposed to NR one, is not quenched -> enhance sensitivity to low-mass DM candidates.

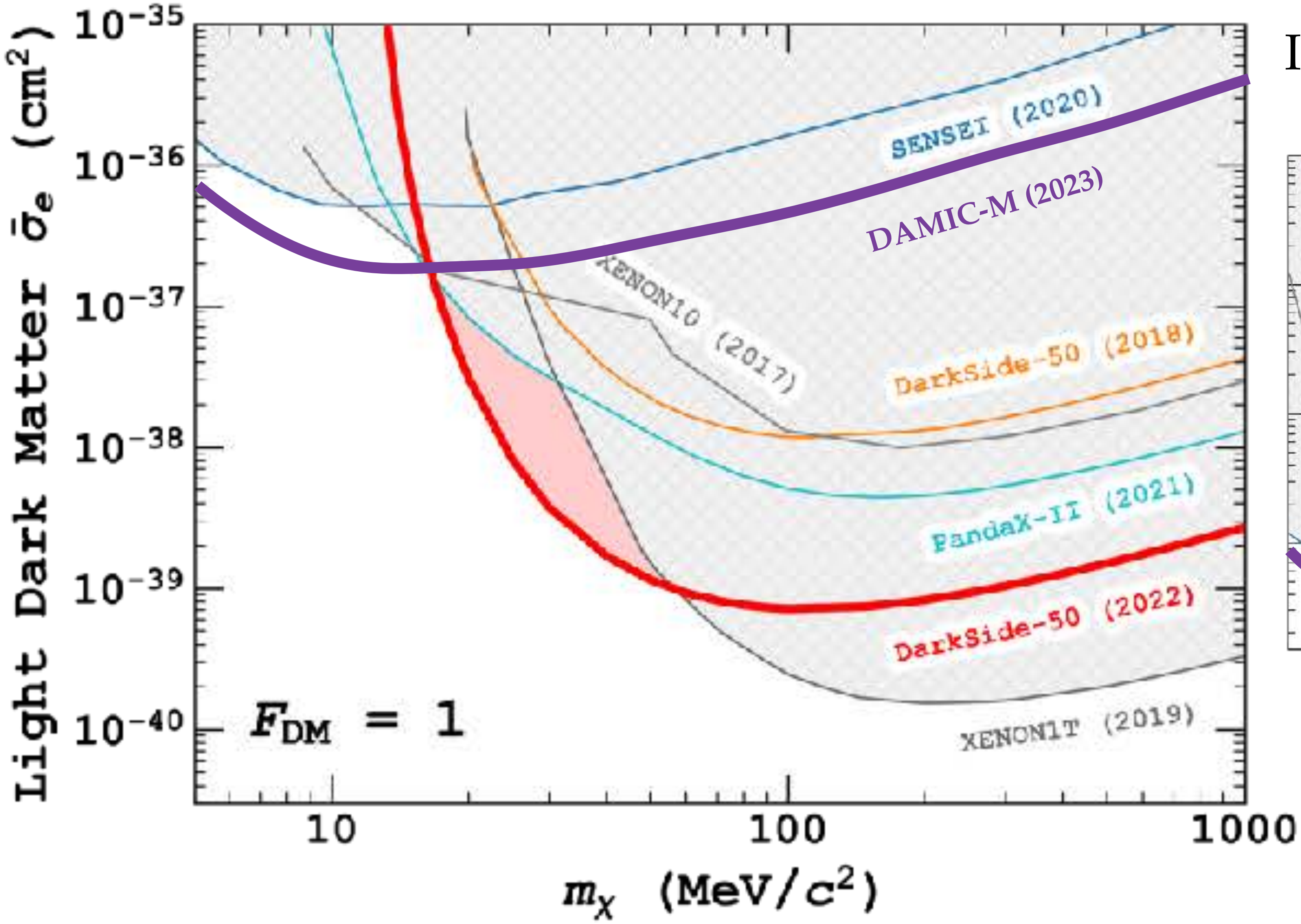
Sharp transition between NR and ER dominated.

Midgal effect: bayesian network

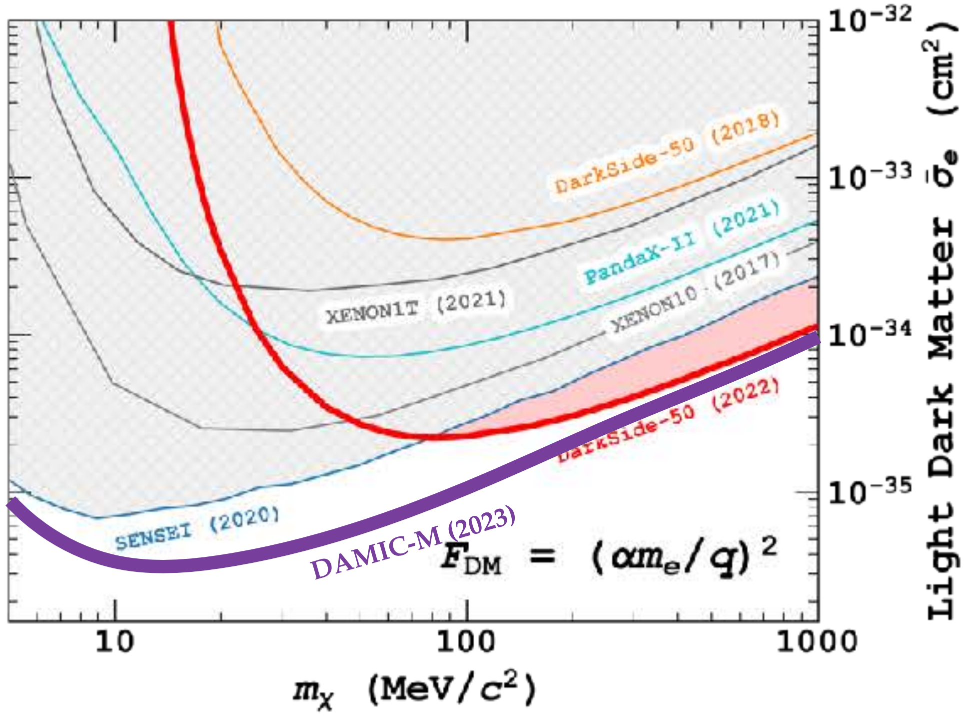


Results are confirmed.

WIMP-e⁻ interactions: frequentist approach



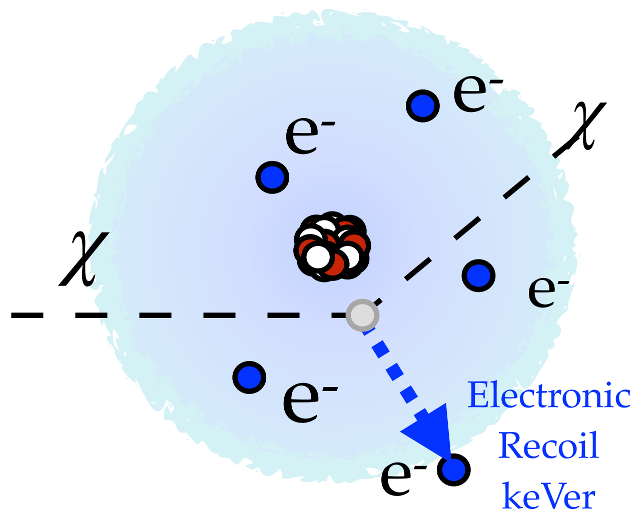
Interactions with electron final states



Light dark matter: Sub-GeV fermion or scalar boson particle may couple to electrons

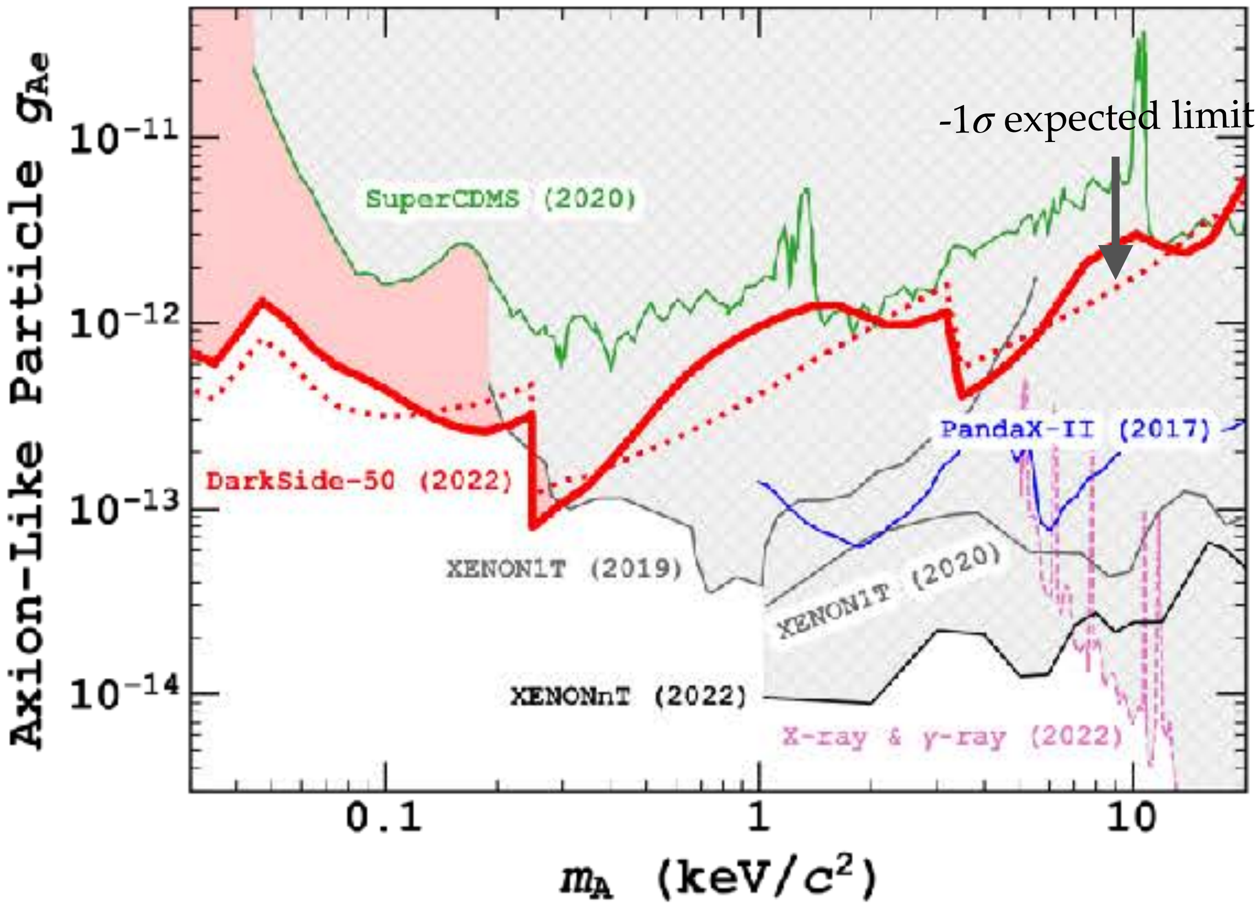
Heavy and light vector mediators considered

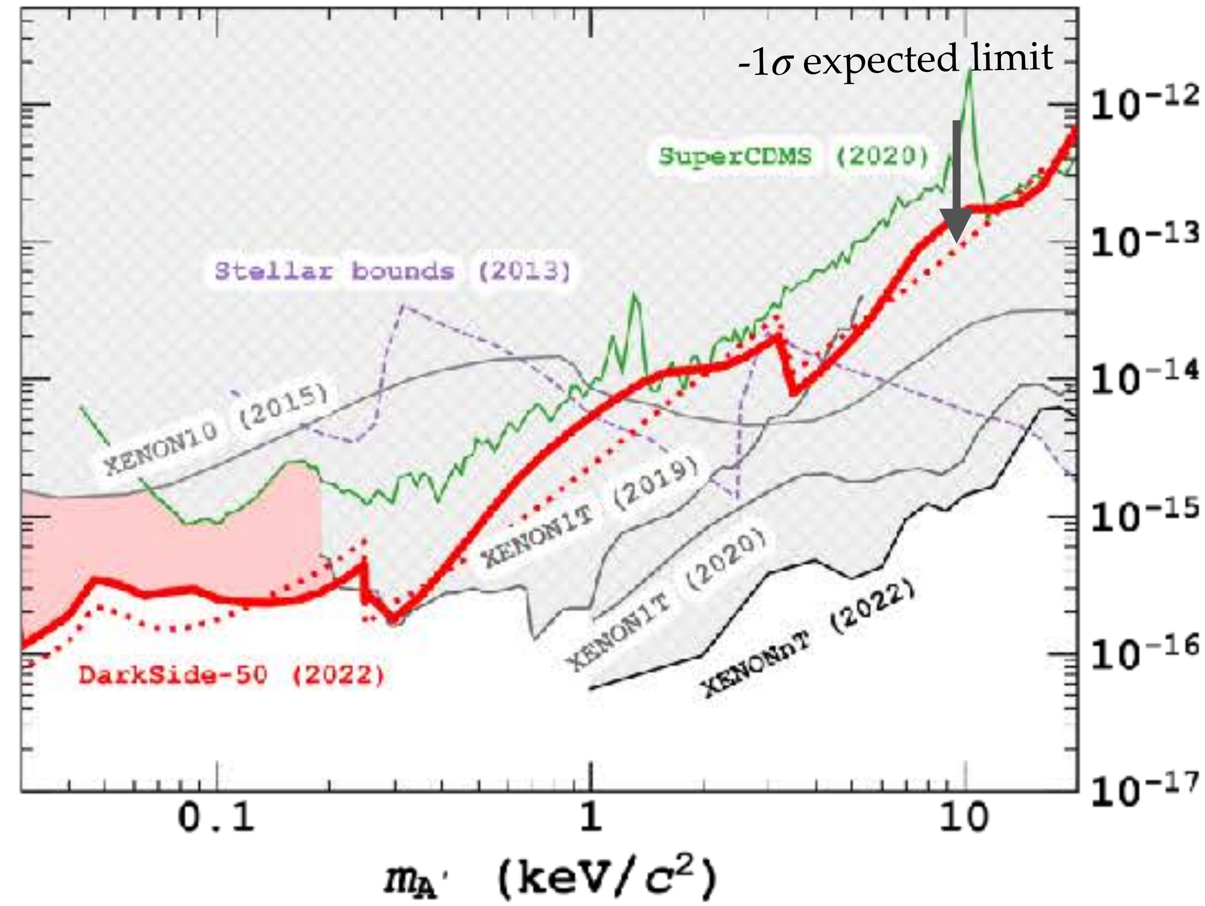
Interaction: Elastic scatter off bound electrons



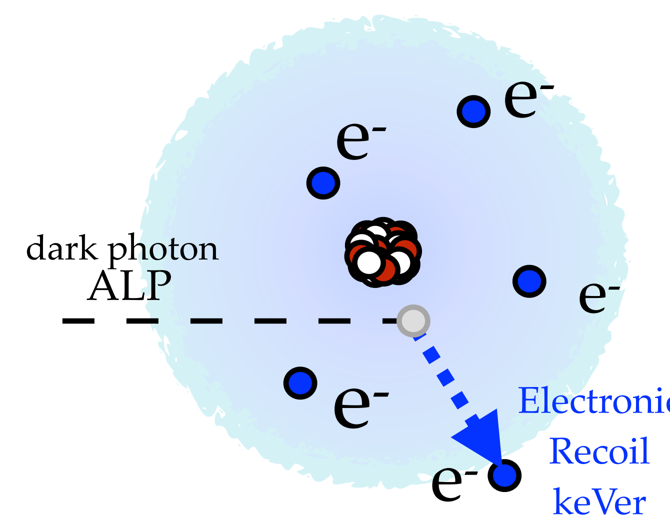
ALP and Dark Photon interactions: frequentist approach

Interactions with electron final states





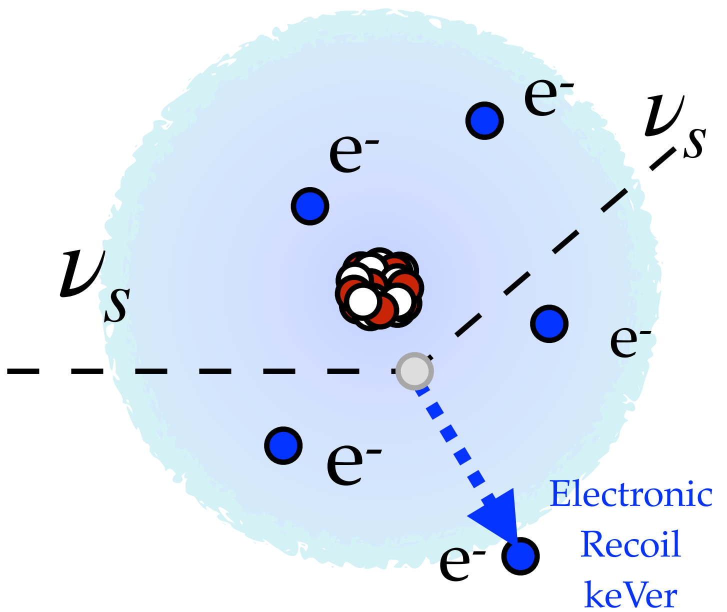
Galactic axion-like particle (ALP) Pseudo-scalar particle
Connection between mass and symmetry breaking scale is relaxed (hence axion-like).
Interaction: Absorption by bound electrons resulting in a monoenergetic signal



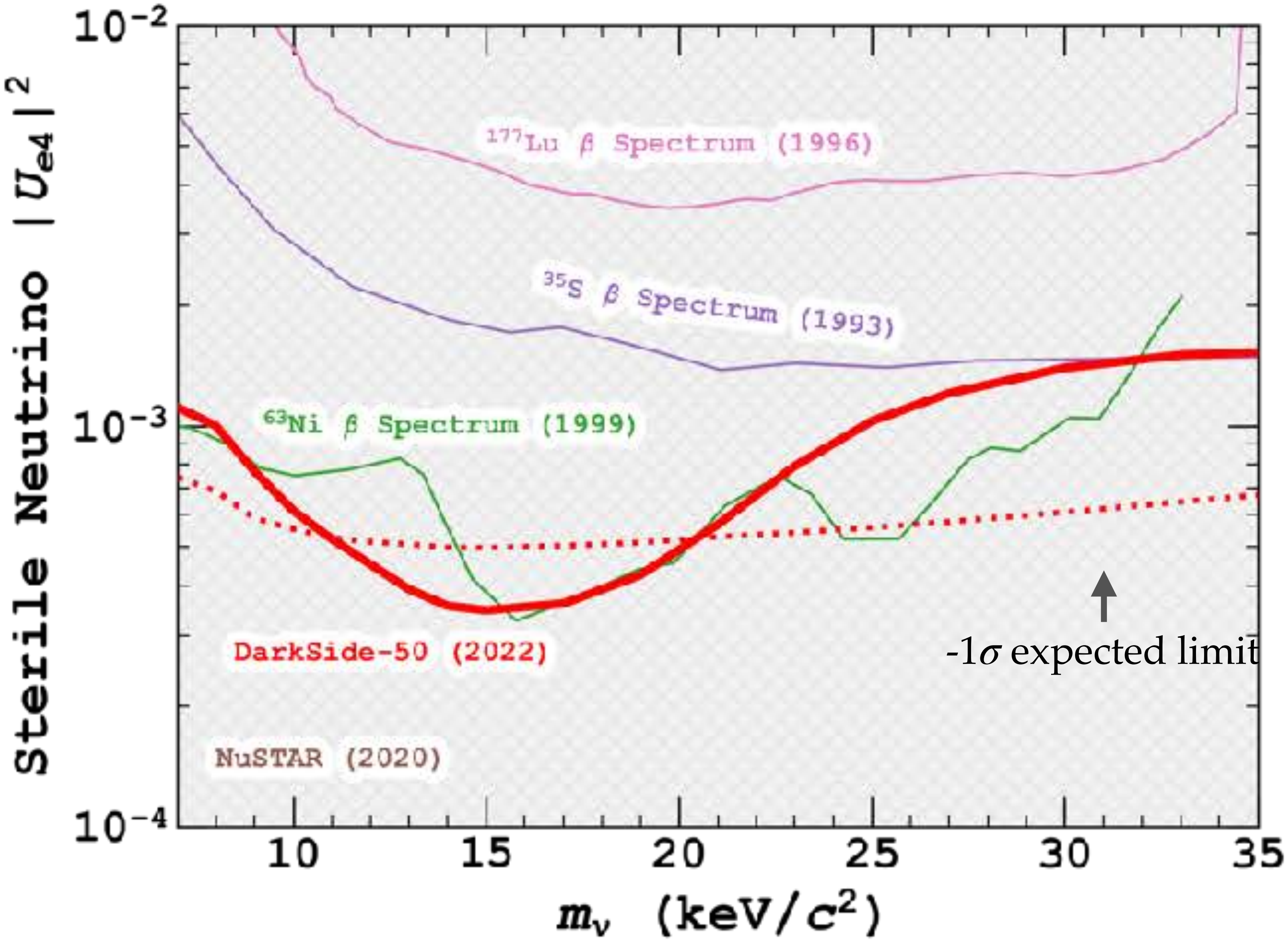
Dark photon Vector-boson particle
Mediate a new dark force in models with a new local U(1) symmetry
Interaction: Absorption by bound electrons resulting in a monoenergetic signal

Sterile neutrinos interactions: frequentist approach

A sterile neutrino with a mass between 7 keV and 36 keV can be a viable DM candidate
Can mix with active neutrinos
Interaction: Inelastic scatters off bound electrons



Interactions with electron final states



Indirect detection limits by the NuSTAR already exclude this full parameter space but DS50 curve improves limits based on the precision measurement of various beta spectra.

Conclusions

1. Extended constraints on WIMP-nucleon SI scattering in (1.2-3.6) GeV/c²

2. Extended range for constraints on WIMP-nucleon SI scattering with Migdal effect down to ~ 40MeV/c²

3. Excluded new parameter space for light Dark Matter with heavy vector mediator, galactic ALPS and Dark Photon candidates.

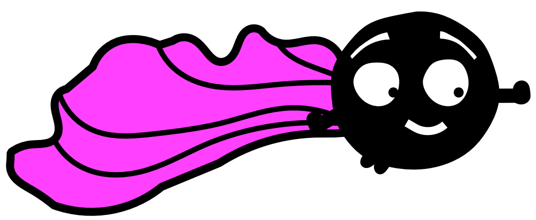
4. First DM direct-detection constraints on for keV sterile neutrinos.

Not covered in this talk but see also

5. New results on annual modulation with DarkSide50 (arXiv:2307.07249)

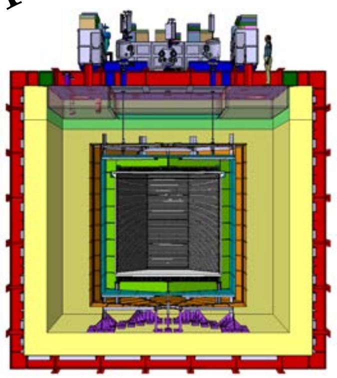
6. Sensitivity projection for DarkSide LowMass detector optimized for light dark matter searches through the ionization channel (Phys. Rev. D 107, 112006, 2023)

7. Detecting SN neutrino bursts via CEvNS with DarkSide-20k (see talk at SNvD 2023@LNGS)



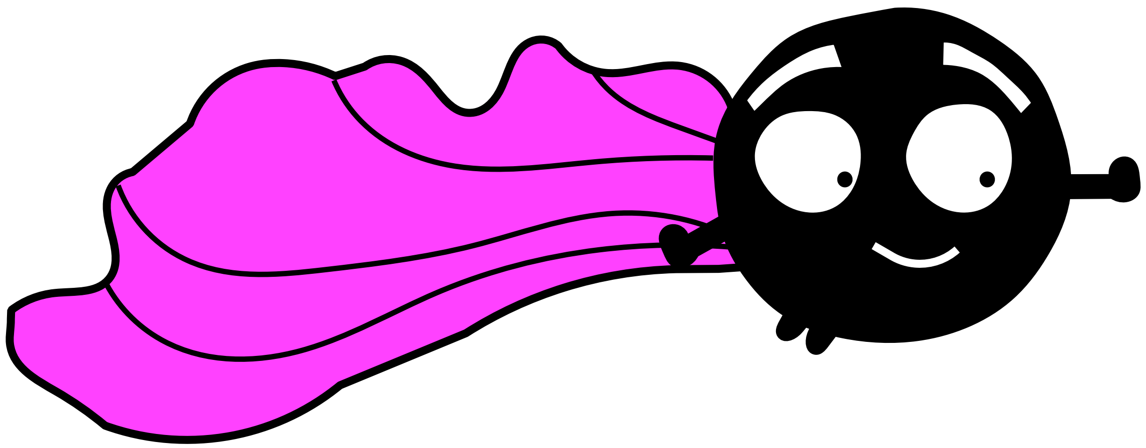
Future work:
Sensitivity projections for DarkSide-20k.

See the talk about DarkSide20k

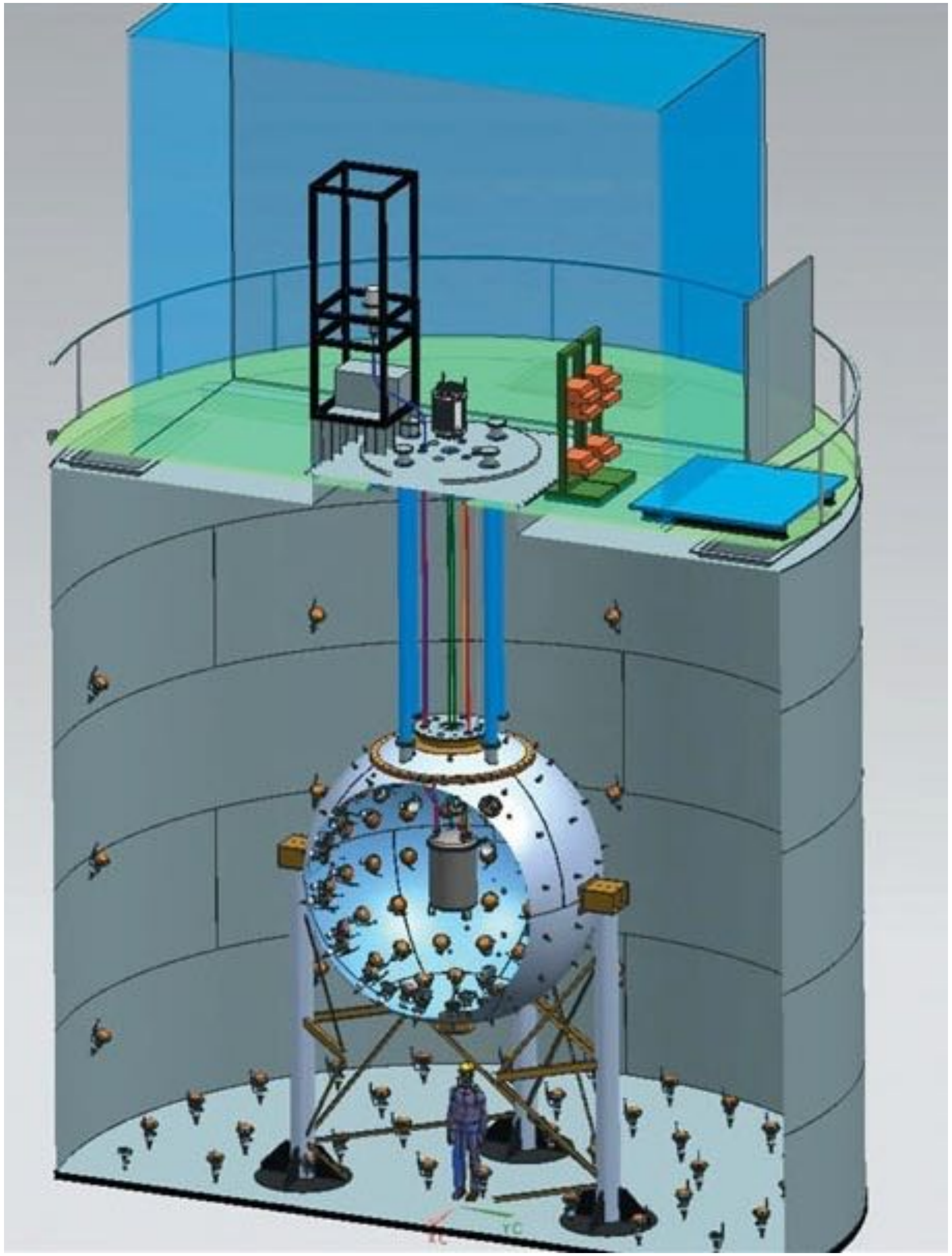


This material is based upon work supported by the NSF () as well as other grants.

Backup



DarkSide-50 (2013-2019) @LNGS



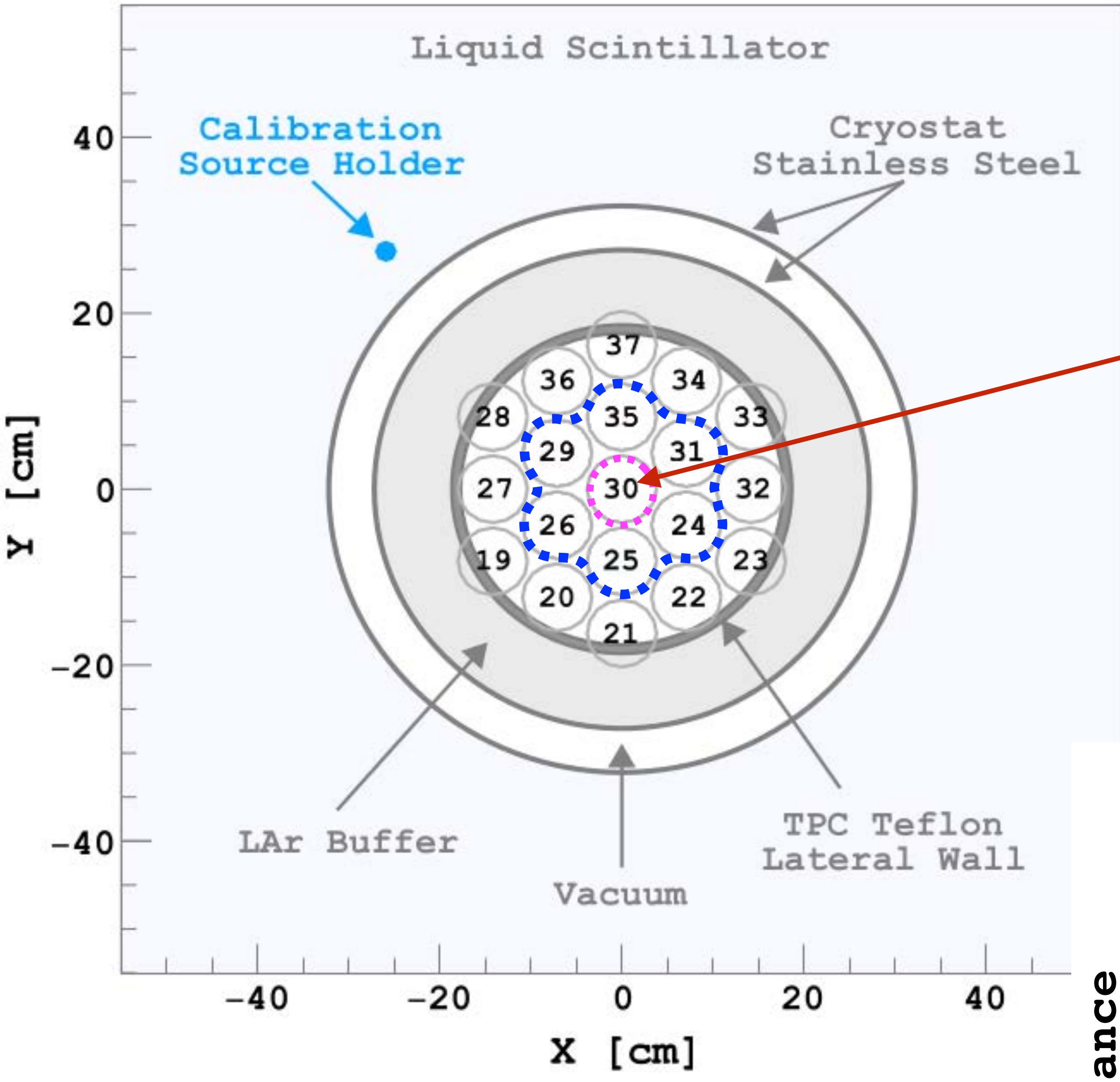
Water Cherenkov Detector
1 kt water, 5.5 m radius 80 PMTs

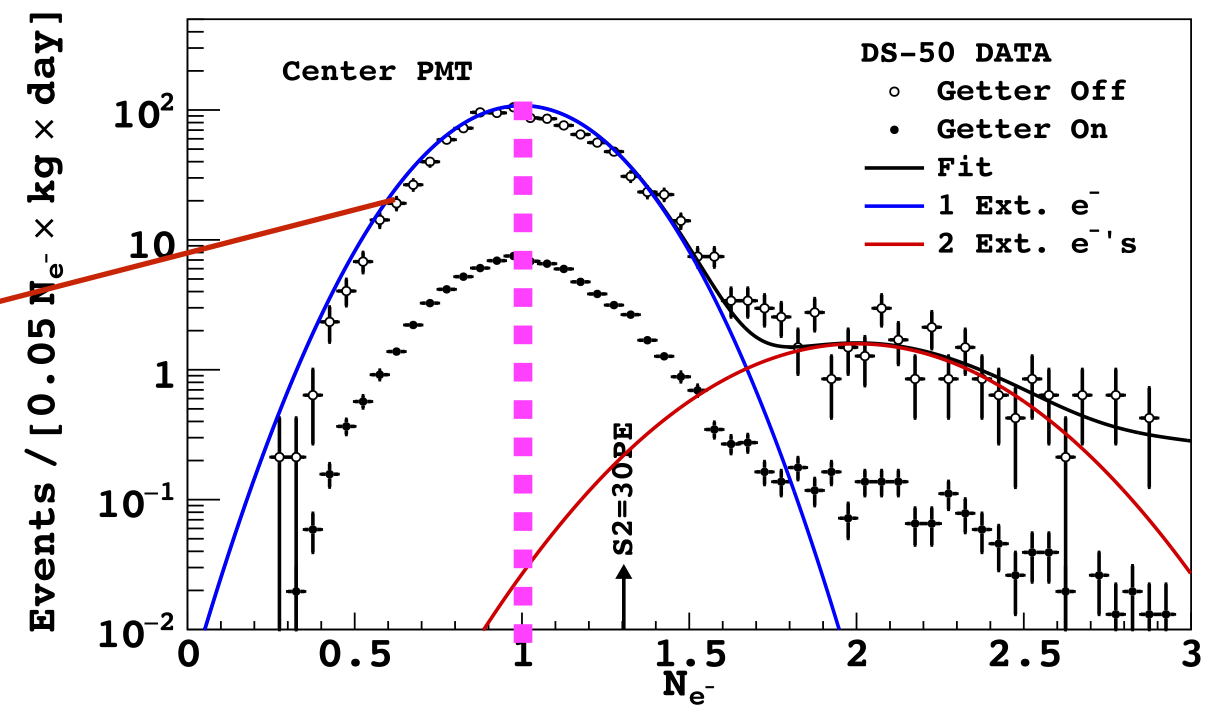
Liquid Scintillator Veto
30 tons, 2 m radius
Boron loaded scintillator
110 PMTs (LY = 0.5 pe/keV)

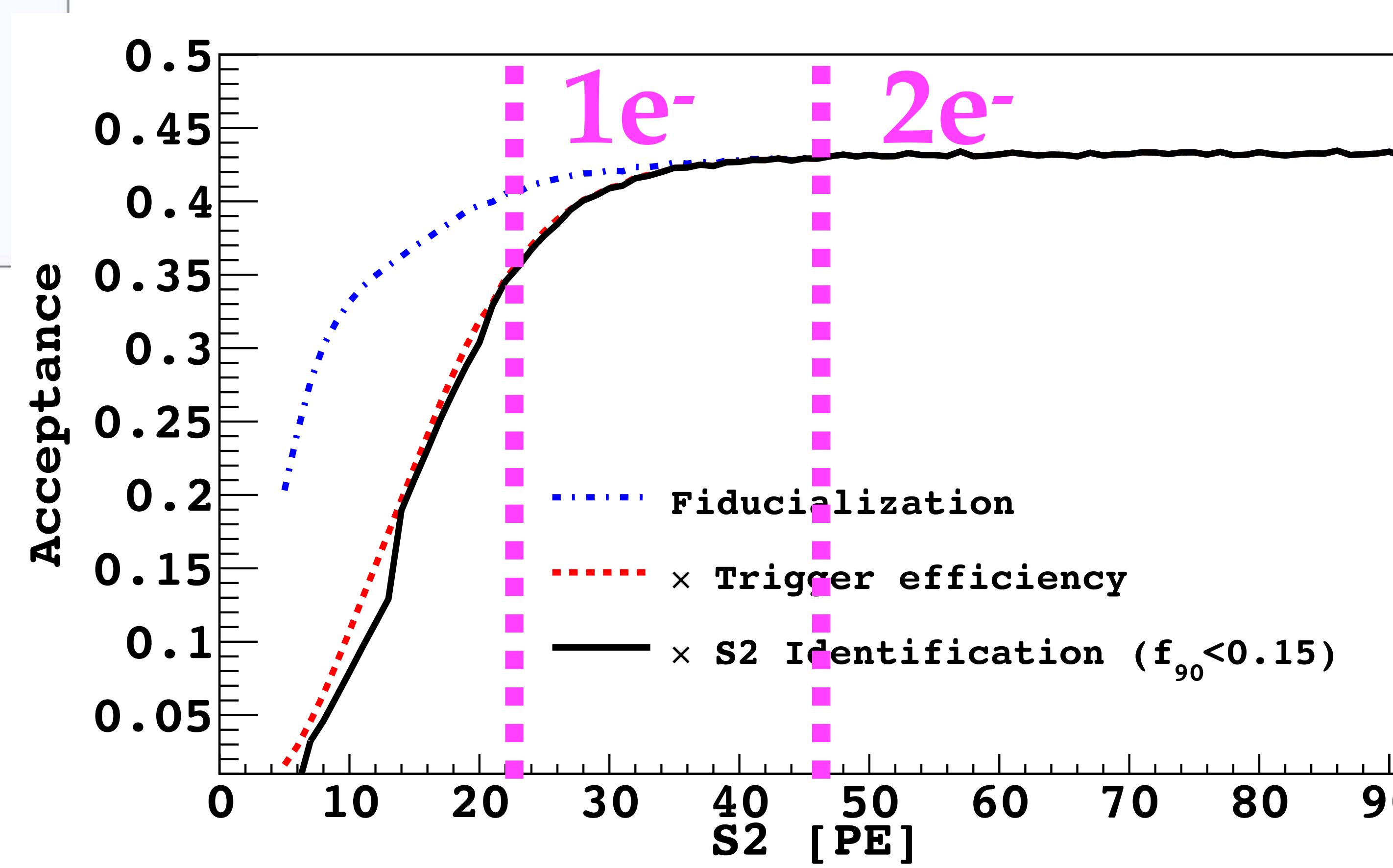
Low radioactivity LAr TPC
50 kg, 0.36 m
19 + 19 3'' PMTs
Reflectors and TPB coating

Detector response from previous analysis (2018)

applicable to this analysis



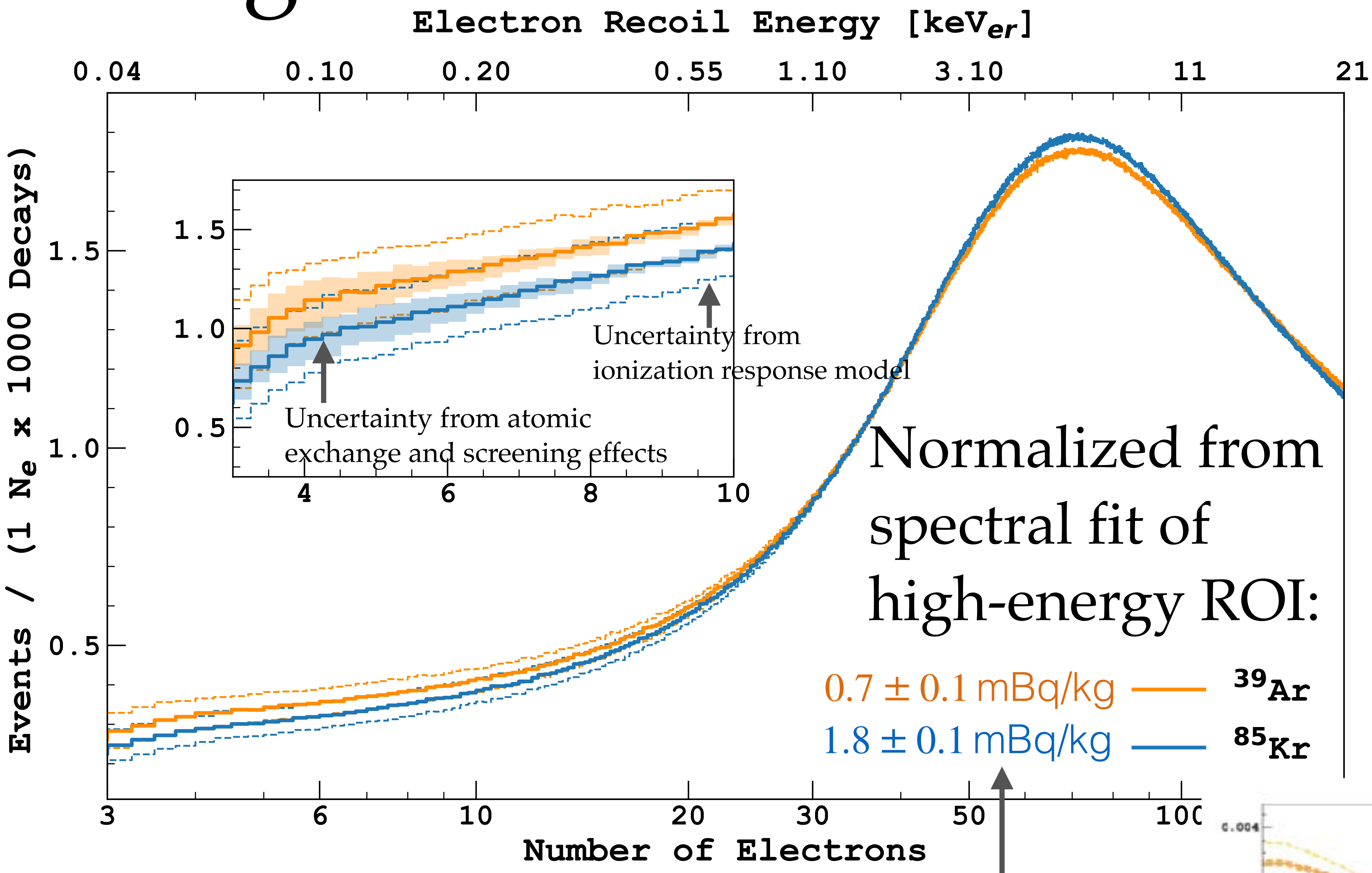




Radial fiducialization 7 center PMTs ->41% acceptance

Trigger efficiency is 100% in the ROI (4-170e-)

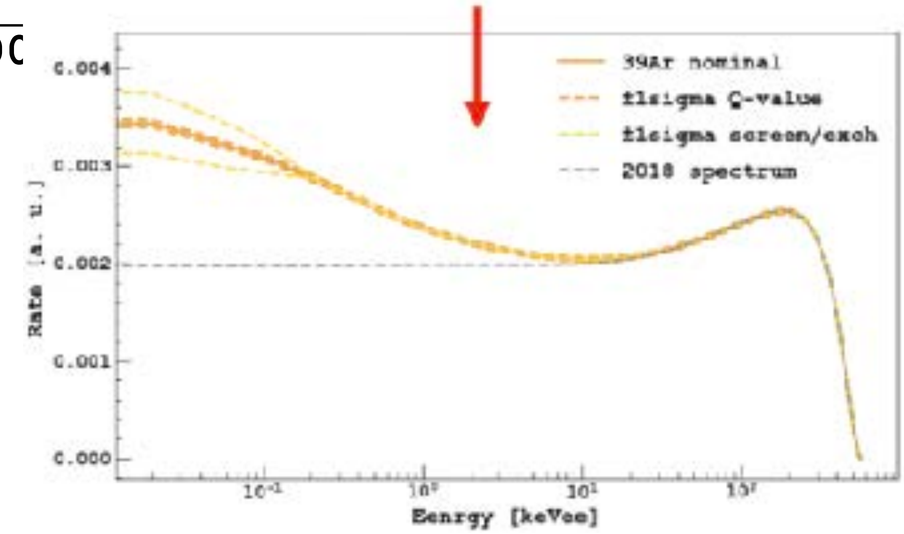
Background model: ^{39}Ar and ^{85}Kr



Normalized from spectral fit of high-energy ROI:

New background model (using materials screening campaign) including internal and external ER background sources.

^{39}Ar with exchange and screening corrections

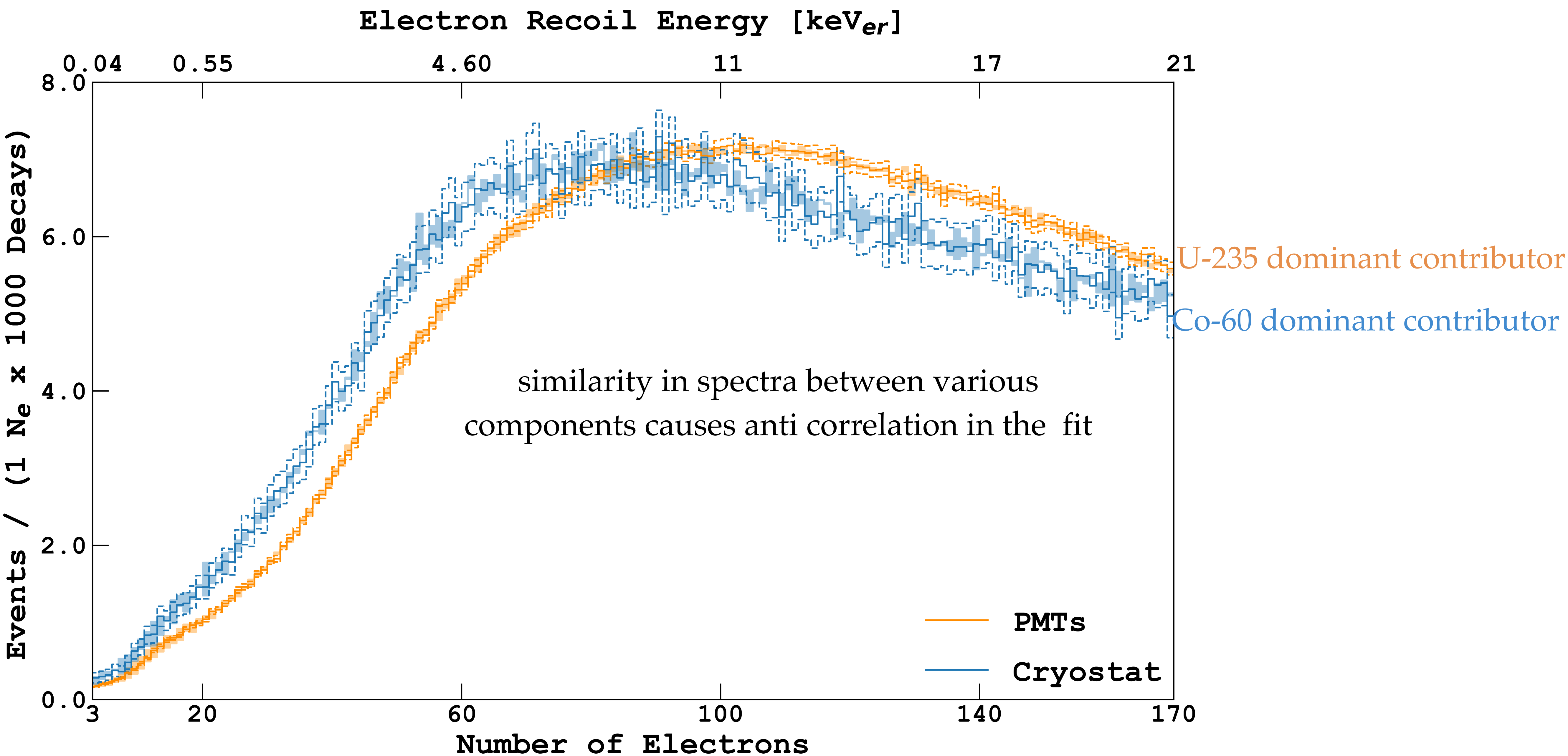


Both ^{39}Ar and ^{85}Kr are unique first-forbidden beta decays.

Additional estimate for ^{85}Kr from fast coincidence through metastable state and decay time search

Assumption is that internal sources are uniformly distributed in fiducial volume

Background model: External Gammas



Normalization from material screening, including measurement errors
Account for detailed location in the detector (eg breakdown contribution of different PMT parts) and source decay times (eg ^{60}Co)

Location and source		Activity [Bq]	Single-scatter events in the RoI: Event rate [Hz]	Single-scatter events in the RoI: Total rate [Hz]
LAr	^{39}Ar	0.034 ± 0.005	$(6.5 \pm 0.9) \times 10^{-4}$	$(6.5 \pm 0.9) \times 10^{-4}$
LAr	^{85}Kr	0.084 ± 0.004	$(1.7 \pm 0.1) \times 10^{-3}$	$(1.7 \pm 0.1) \times 10^{-3}$
PMT Stems	^{232}Th	0.16 ± 0.03	$(3.2 \pm 0.6) \times 10^{-4}$	$(3.5 \pm 0.4) \times 10^{-3}$
PMT Stems	^{238}U up	1.06 ± 0.22	$(4.9 \pm 1.0) \times 10^{-5}$	
PMT Stems	^{238}U low	0.34 ± 0.03	$(3.2 \pm 0.3) \times 10^{-4}$	
PMT Stems	^{235}U	0.05 ± 0.01	$(1.2 \pm 0.2) \times 10^{-4}$	
PMT Stems	^{40}K	2.39 ± 0.32	$(1.8 \pm 0.2) \times 10^{-4}$	
PMT Stems	^{54}Mn	0.05 ± 0.02	$(3.5 \pm 1.4) \times 10^{-5}$	
PMT Ceramic	^{232}Th	0.07 ± 0.01	$(2.4 \pm 0.3) \times 10^{-4}$	
PMT Ceramic	^{238}U up	4.22 ± 0.88	$(4.2 \pm 0.9) \times 10^{-4}$	
PMT Ceramic	^{238}U low	0.34 ± 0.03	$(5.3 \pm 0.5) \times 10^{-4}$	
PMT Ceramic	^{235}U	0.21 ± 0.03	$(9.8 \pm 1.4) \times 10^{-4}$	
PMT Ceramic	^{40}K	0.61 ± 0.08	$(8.1 \pm 1.1) \times 10^{-5}$	
PMT Body	^{60}Co	0.17 ± 0.02	$(2.4 \pm 0.3) \times 10^{-4}$	
Cryostat	^{232}Th	0.19 ± 0.04	$(7.9 \pm 1.7) \times 10^{-5}$	$(5.9 \pm 0.4) \times 10^{-4}$
Cryostat	^{238}U up	1.30 ± 0.2	$(1.5 \pm 0.2) \times 10^{-5}$	
Cryostat	^{238}U low	$0.38^{+0.04}_{-0.19}$	$(5.3^{+0.6}_{-2.6}) \times 10^{-6}$	
Cryostat	^{235}U	$0.045^{+0.01}_{-0.02}$	$(1.5^{+0.3}_{-0.7}) \times 10^{-5}$	
Cryostat	^{60}Co	1.38 ± 0.1	$(4.7 \pm 0.3) \times 10^{-4}$	
Cryostat	^{40}K	$0.16^{+0.02}_{-0.05}$	$(3.4^{+0.4}_{-1.1}) \times 10^{-6}$	

Background-only fit:bayesian network

Posterior $= \mathscr{L} \times$ Flat prior for signal $\times$ Prior calibration results

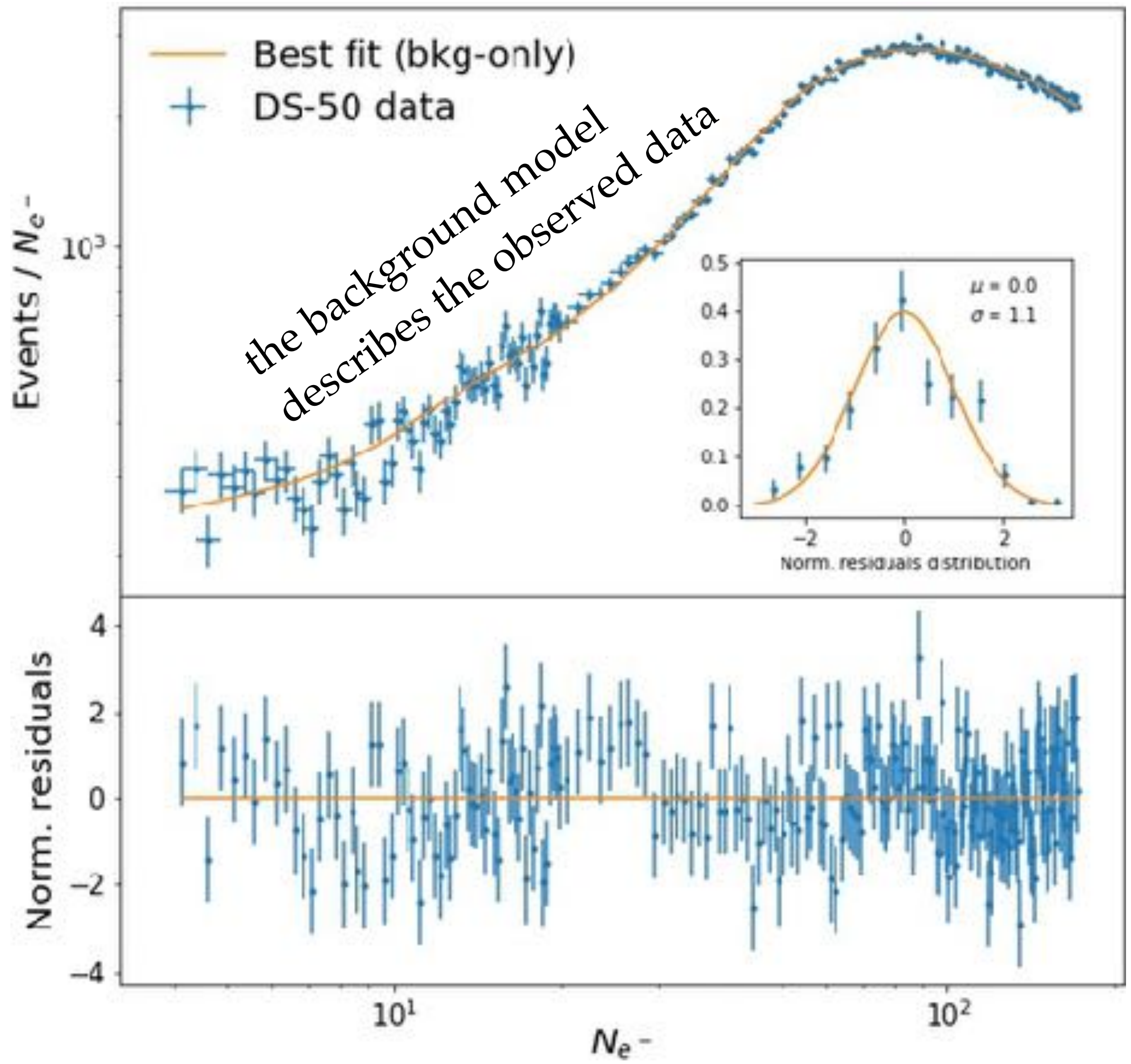
Equivalent to the frequentist gaussian constraints

Markov Chain Monte Carlo

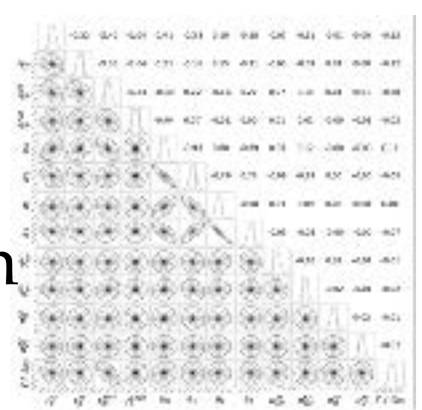
Bin-by-bin Poisson likelihood detector response model included in the likelihood function via semi-analytical functions

Treats the systematic uncertainties in a straightforward way.

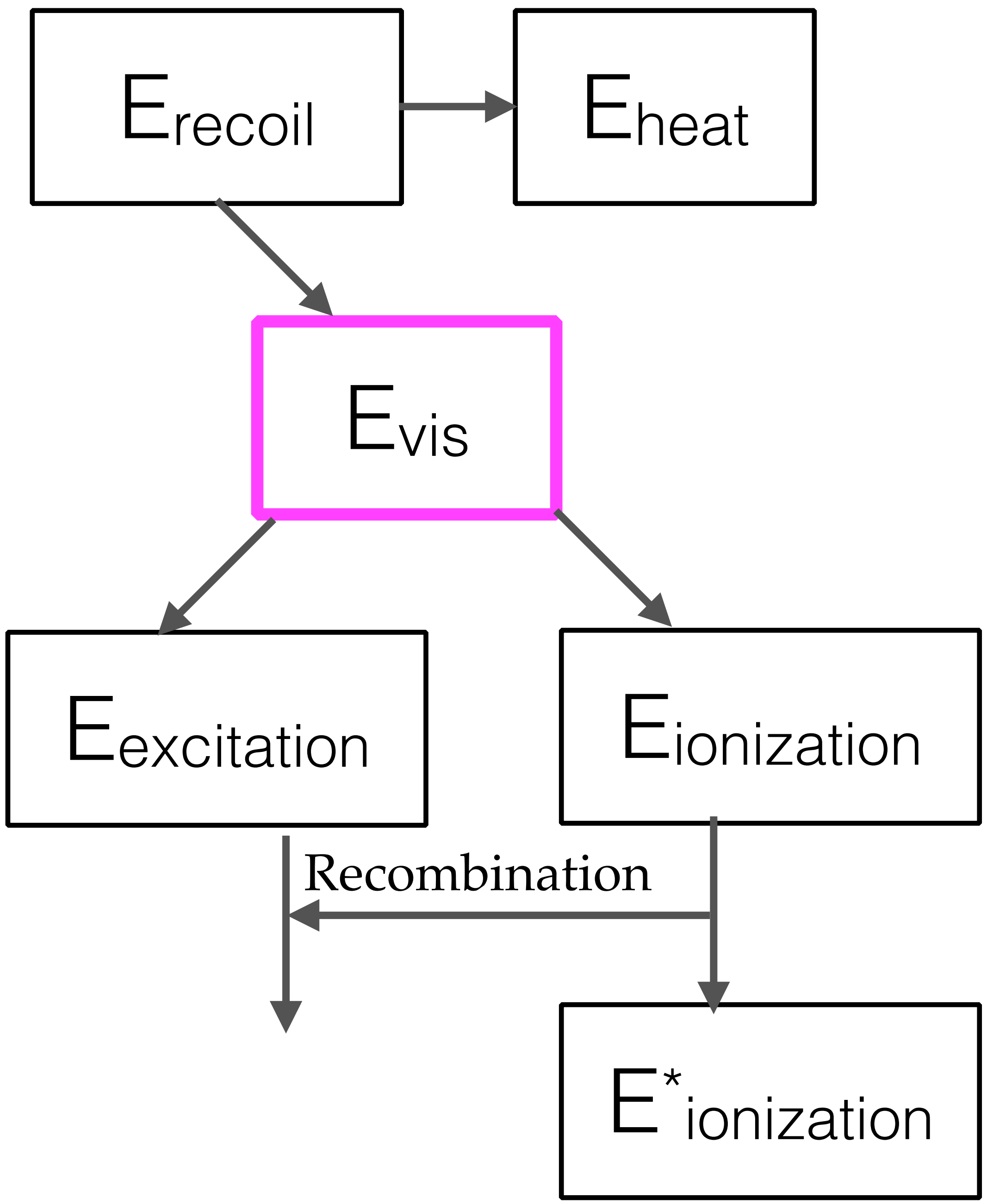
Fluctuations treated as binomial.



Posterior pdf on the fit parameters, no significant deviation from the prior distribution



NR Quenching fluctuation: frequentist approach

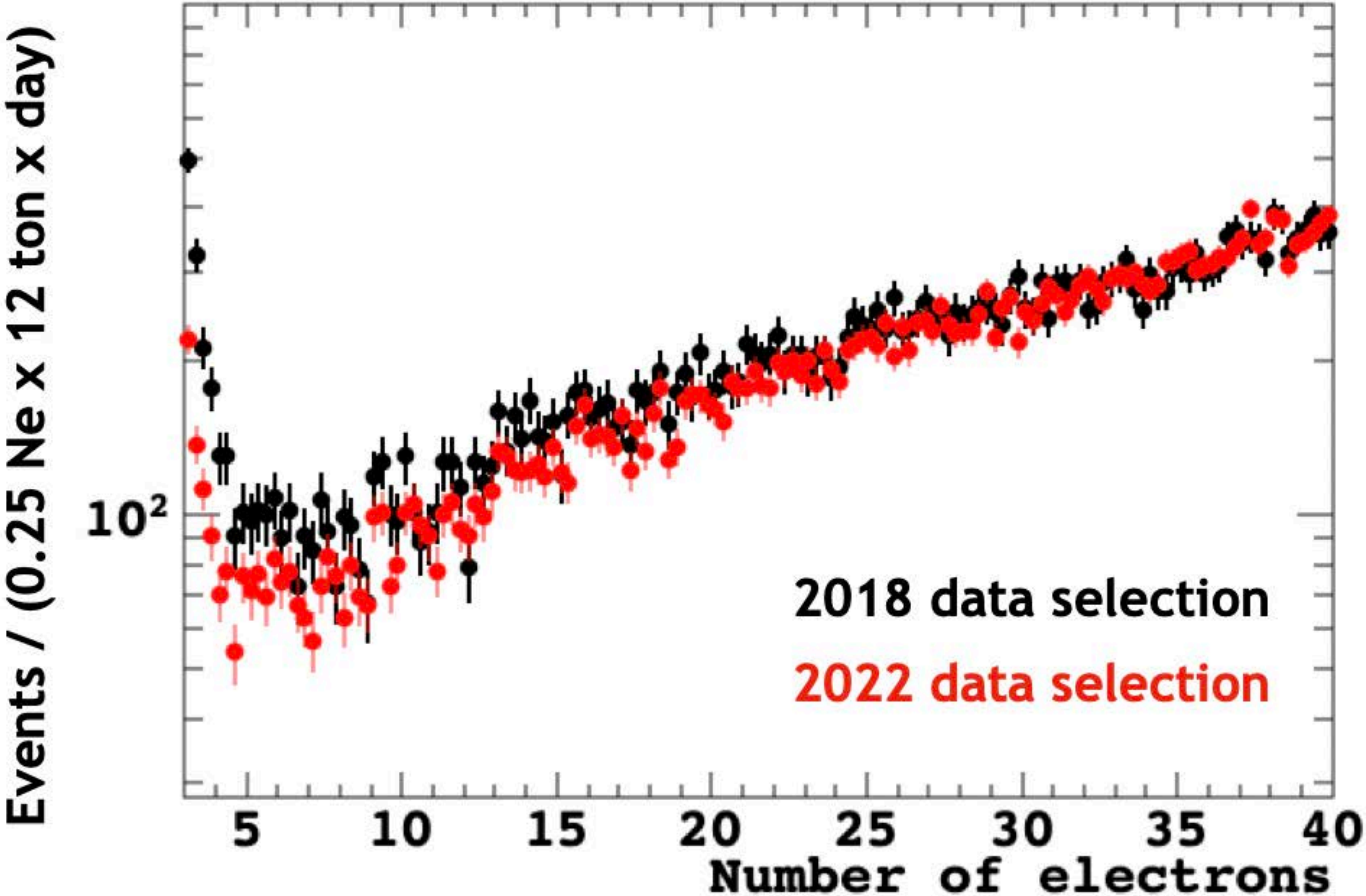


NQ model: Suppression of quenching fluctuations. Visible energy is fixed to its average (measured) value. Not physical but provides conservative approach.

QF model: Visible energy fluctuates with a binomial distribution due to quenching.

Analysis of DS50 NR calibration data does not distinguish between two models

Note: quenching fluctuations are added to fluctuations resulting from the partitioning between excitons and ionization electrons and from ion-electron recombinations.



Events / (0.25 Ne x 12 ton x day)
10^2
5
10
15
20
25
30
35
40
Number of electrons
2018 data selection
2022 data selection