DarkSide-20k sensitivity to light dark matter particles

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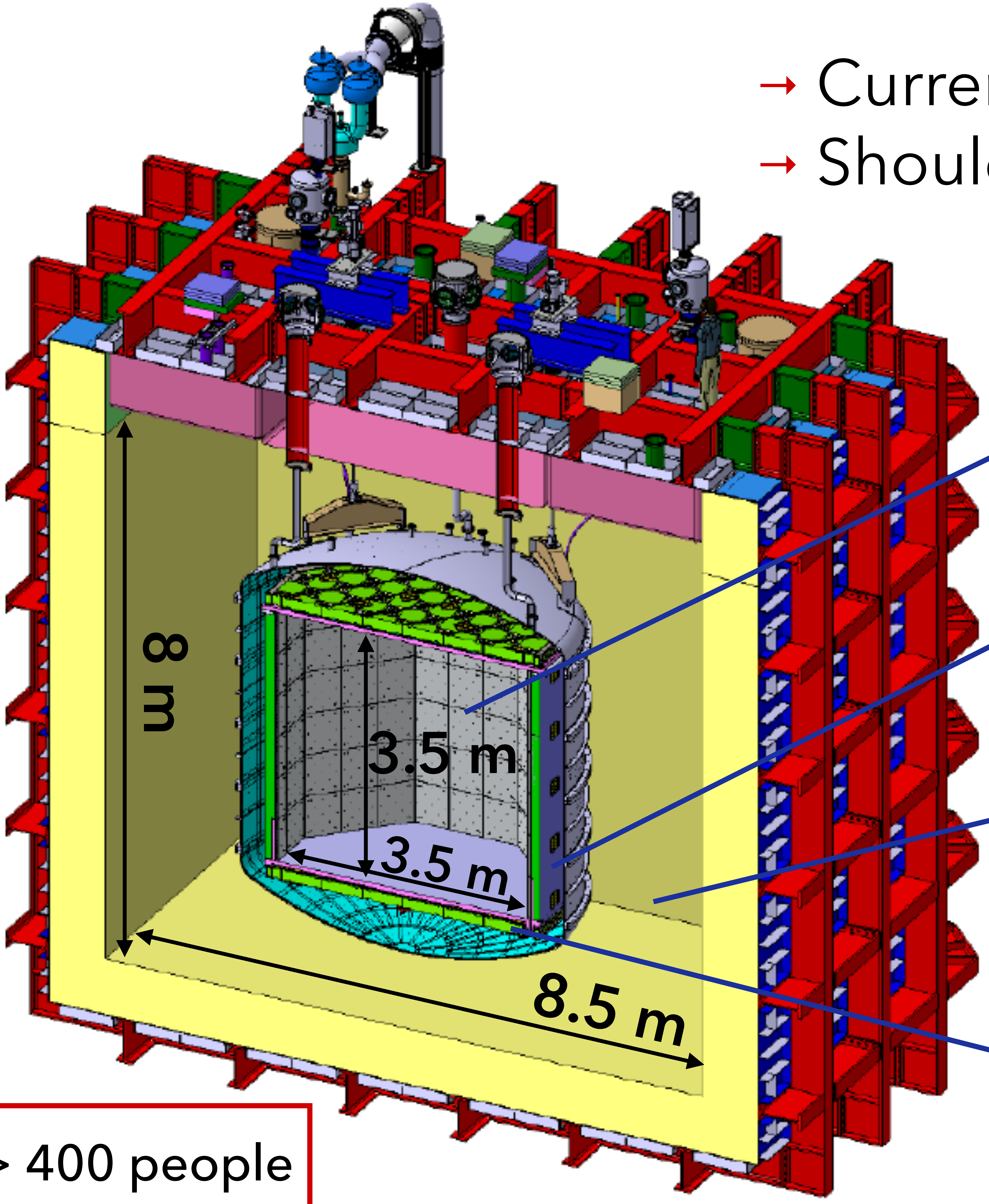
On behalf of the DarkSide-20k collaboration

Light Dark Matter @ Accelerators 2025

The DarkSide-20k experiment 1/2

→ Currently under construction
→ Should start data taking in 2027



TPC: 50 t
Underground **argon**
(UAr)

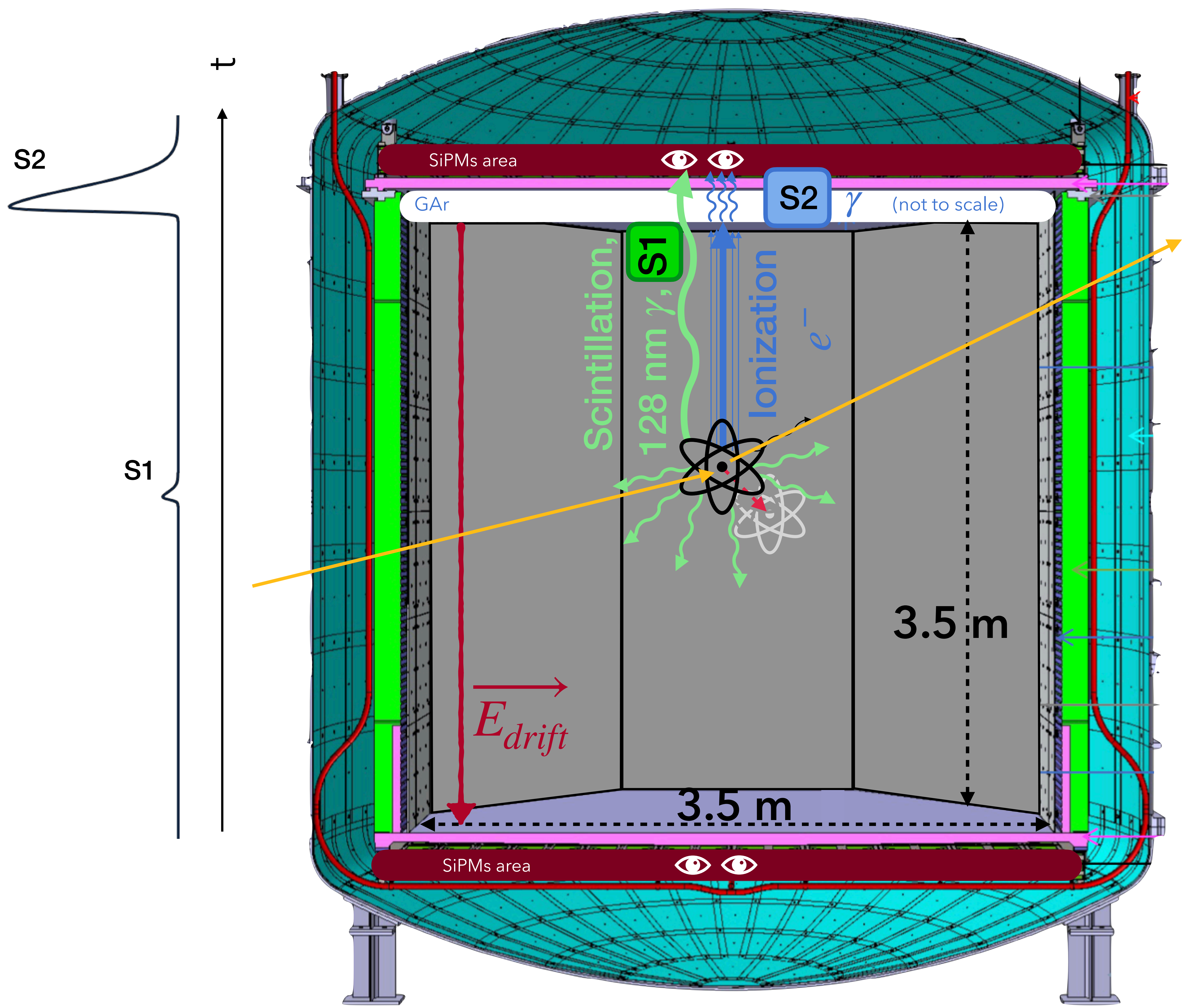
Inner veto
(neutron veto): 32 t
UAr

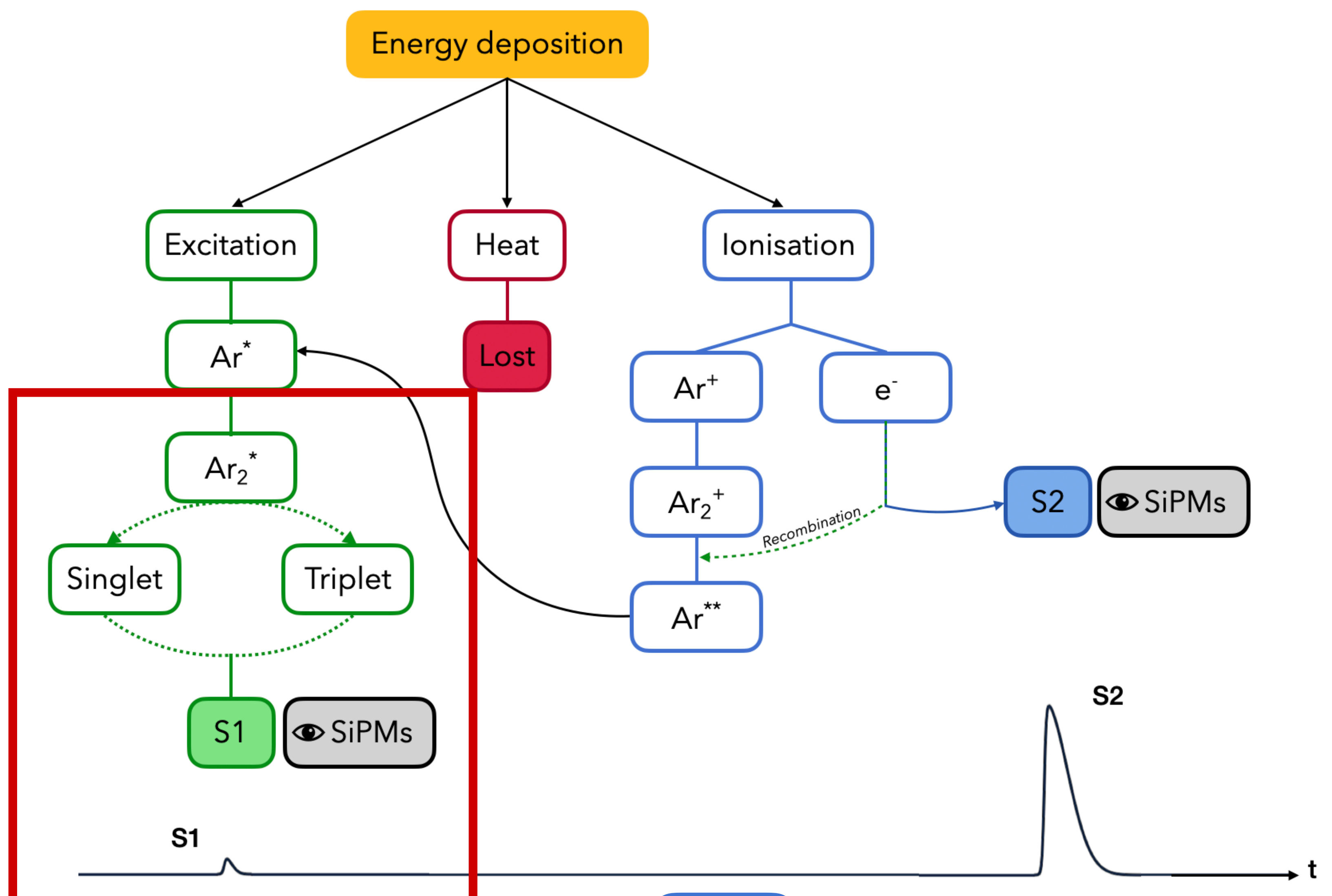
Outer veto
(muon veto): 650 t
Atmospheric argon

TPC photo-electronics
2x10.5 m² SiPMs
arrays
2112 readout channels

> 400 people

The DarkSide-20k experiment 2/2





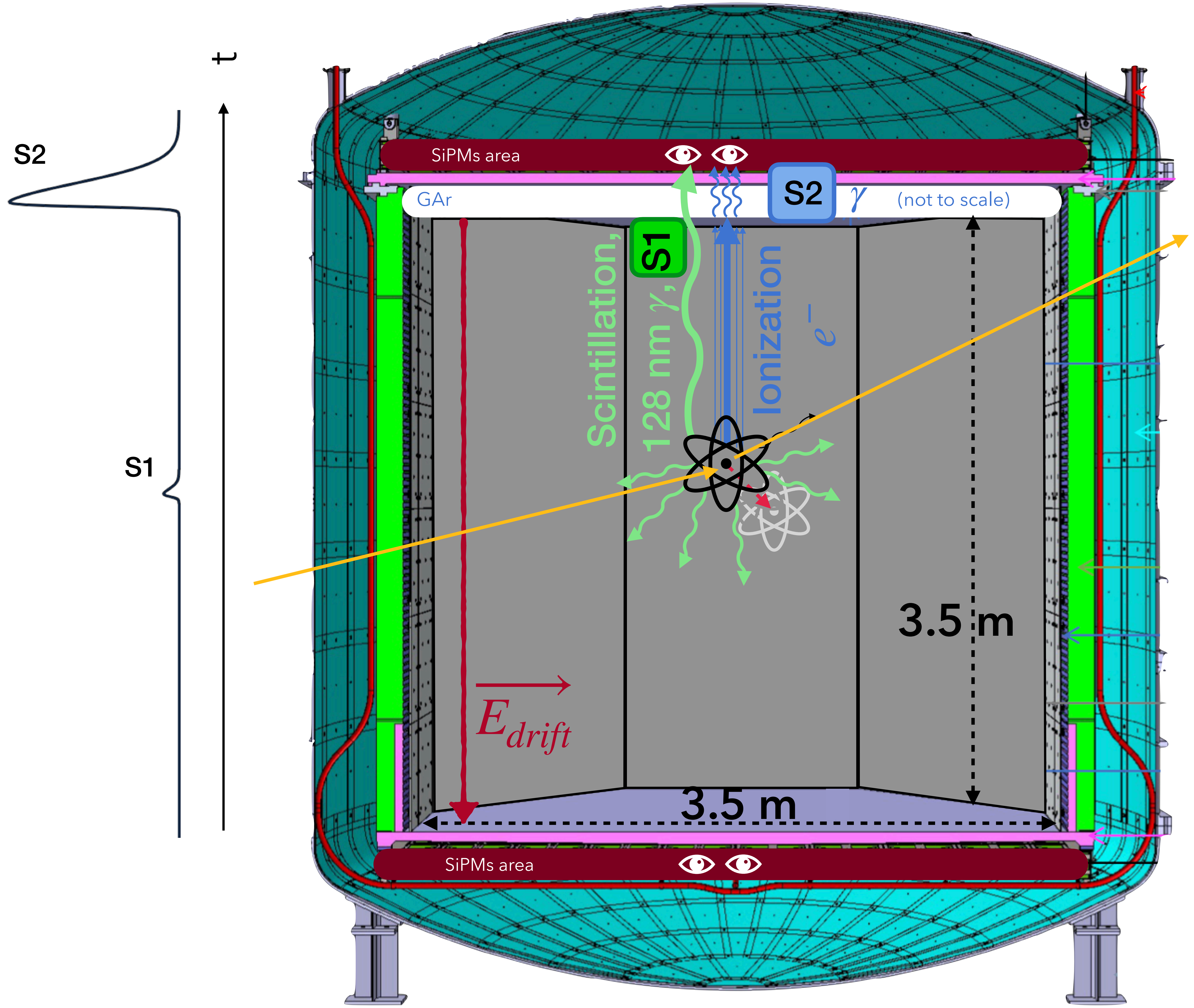
PSD

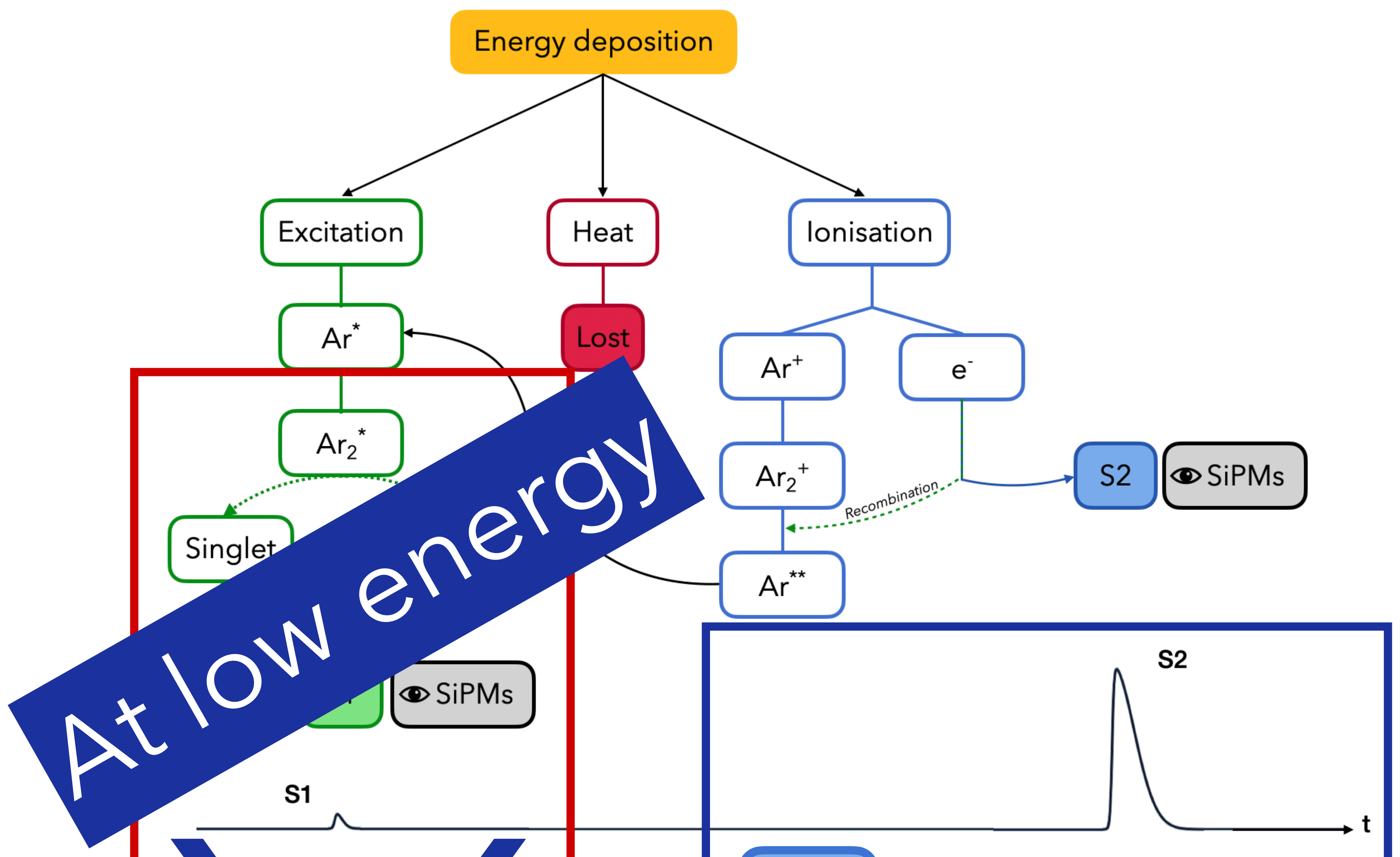
$10^7 - 10^9$ signal-bkg discrimination power

S2 ionization signal (delayed)

S1 scintillation signal (prompt)

The DarkSide-20k experiment 2/2





~~PSD~~
~~10^{7} — 10^{9} signal/bkg discrimination power~~

S1 scintillation signal

$\lesssim$ 1keV$_{ee}$
$\lesssim$ 5keV$_{nr}$
From DS-50

S2 ionization signal (delayed)

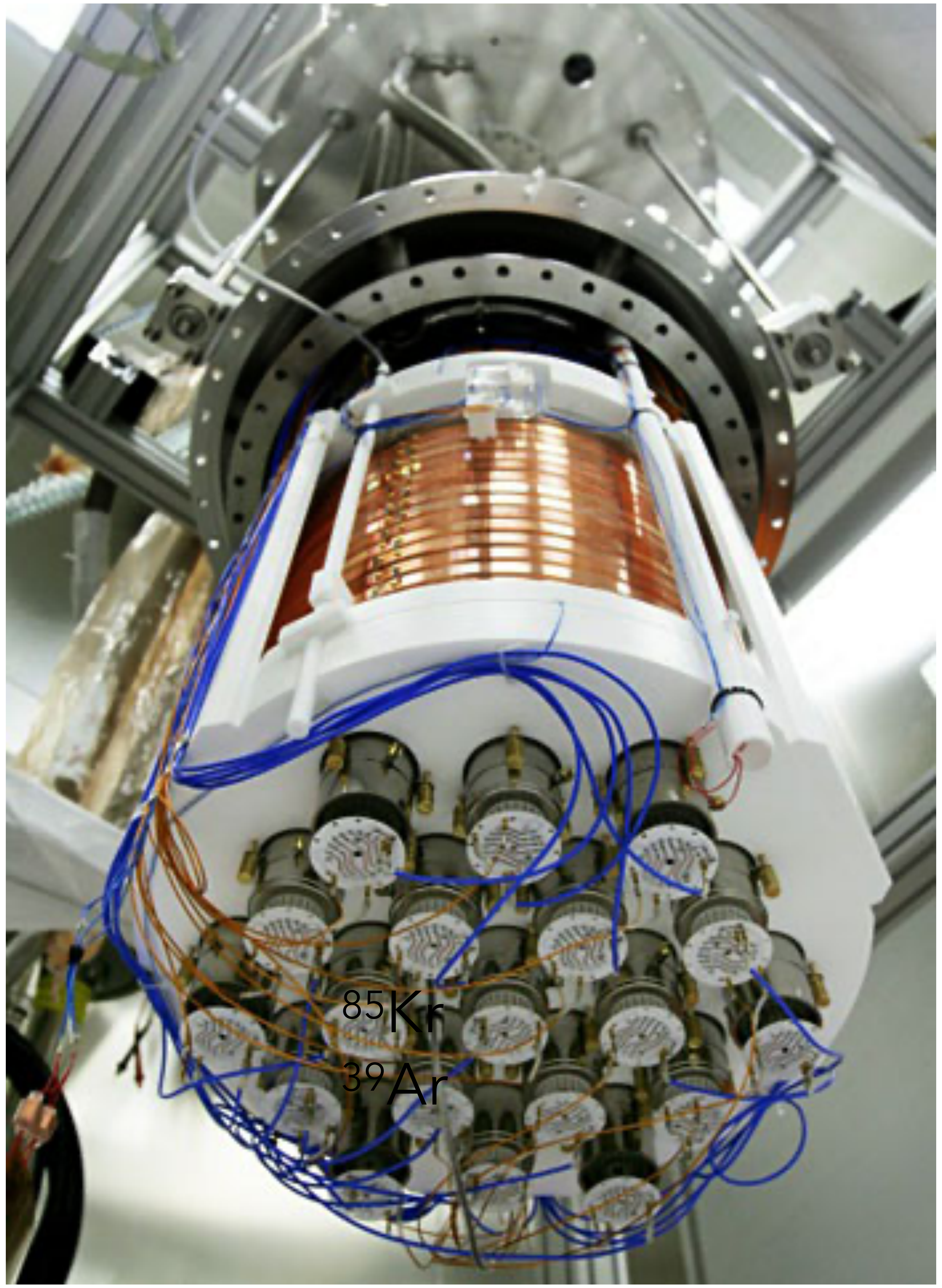
Only information

☑ Sub-keV threshold to extract S2

☒ (ER) bkg-dominated analysis

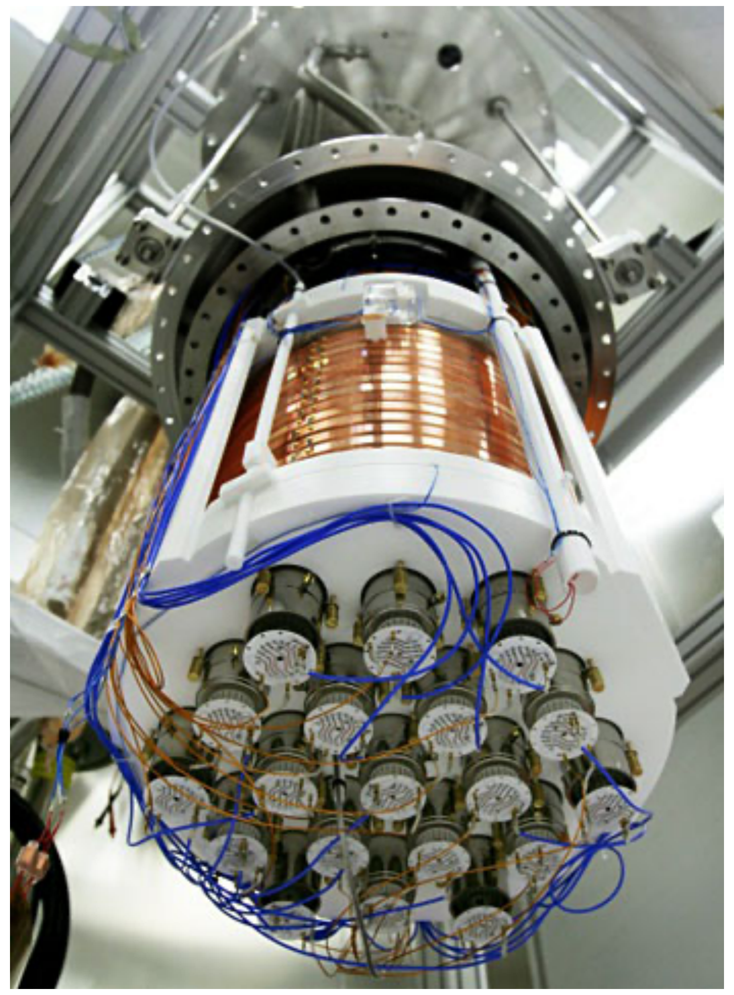
DarkSide-50 recent results

DarkSide-50

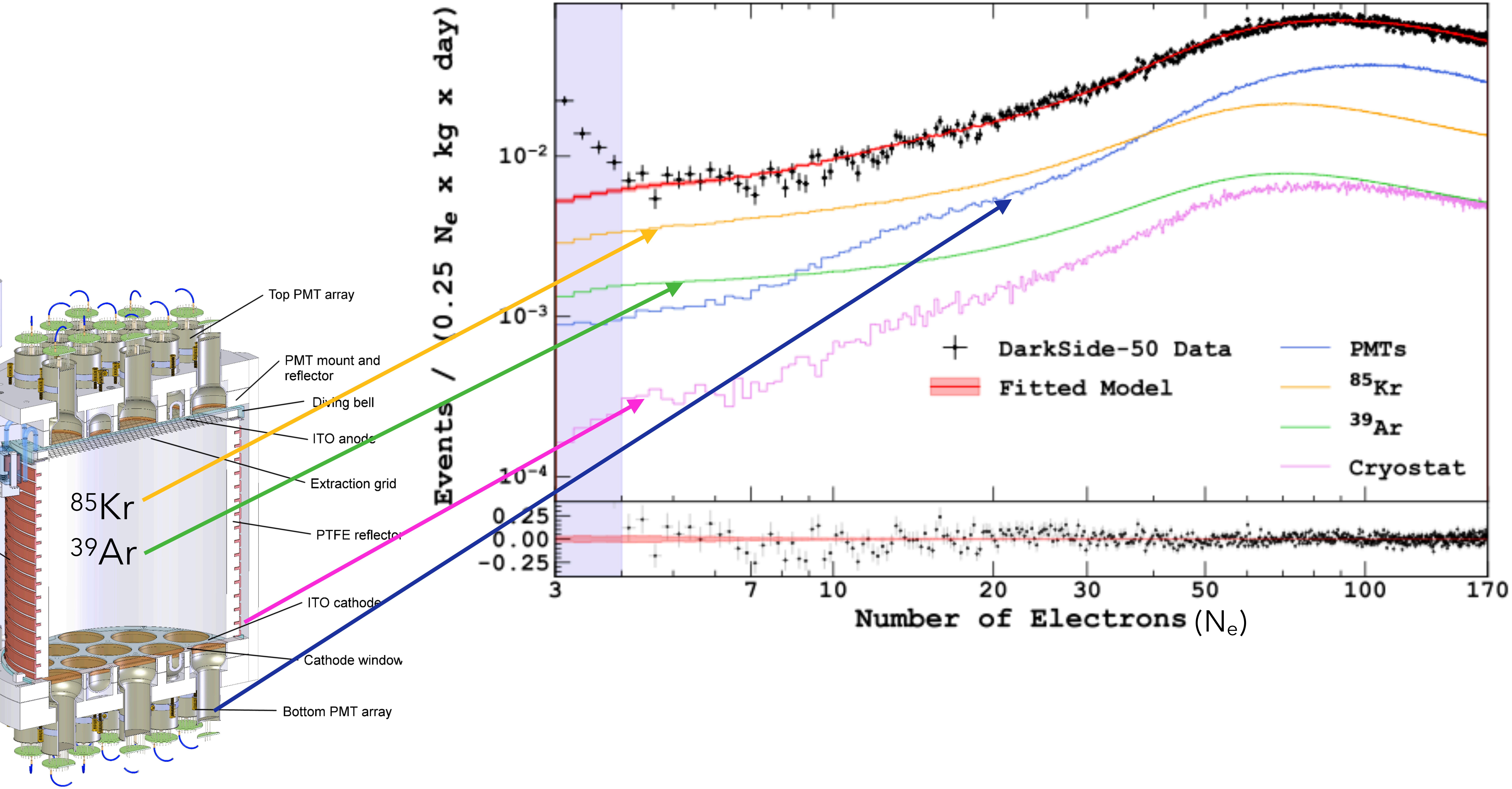


DarkSide-50 recent results

DarkSide-50

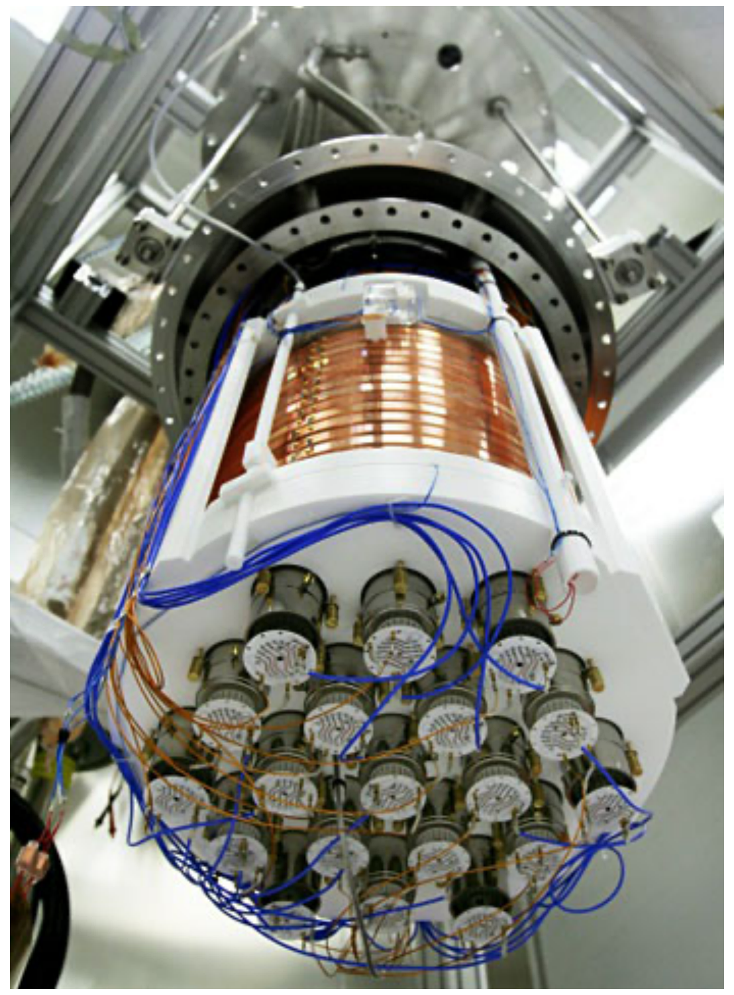


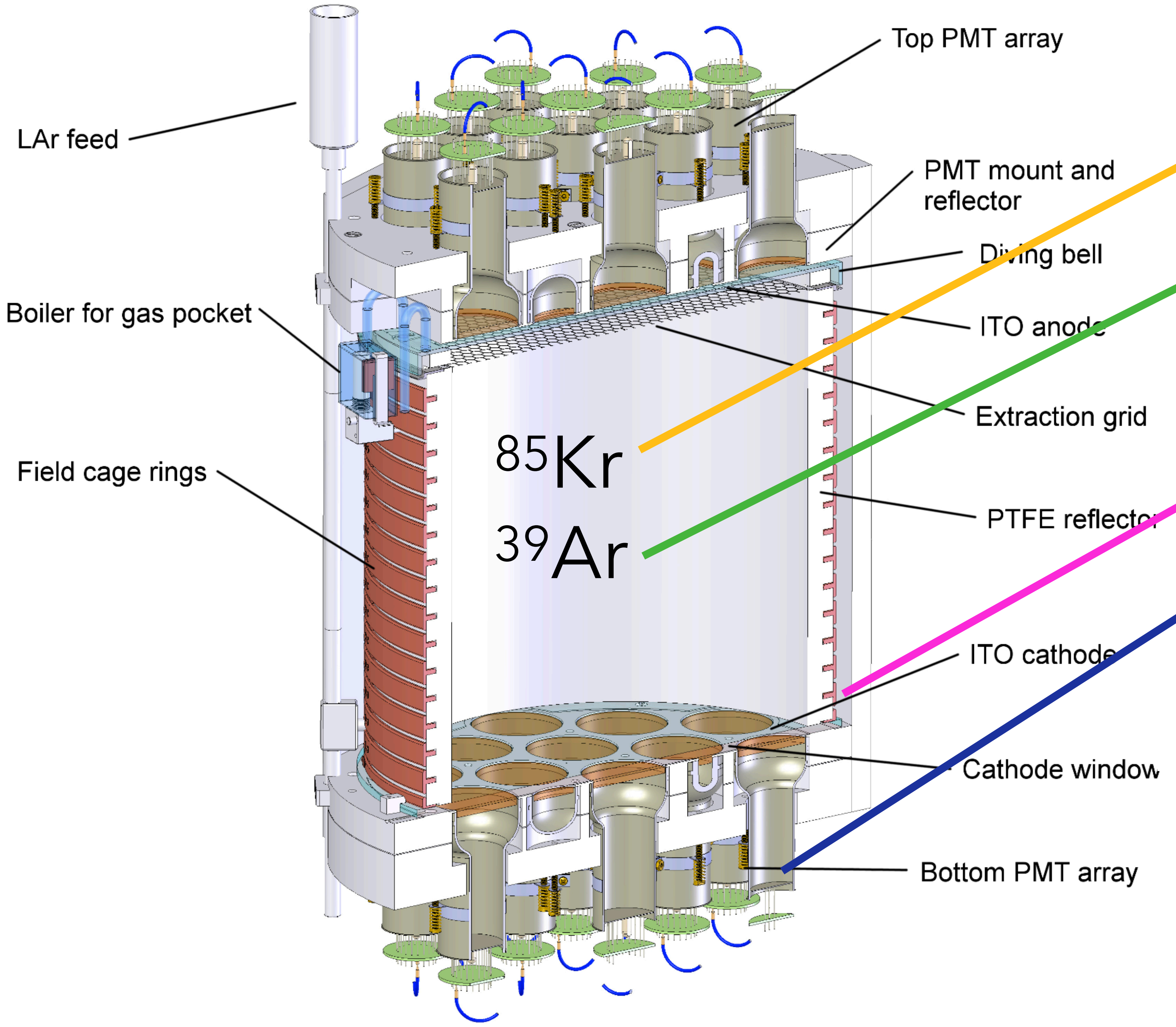
Phys.Rev.D 107 (2023), 063001



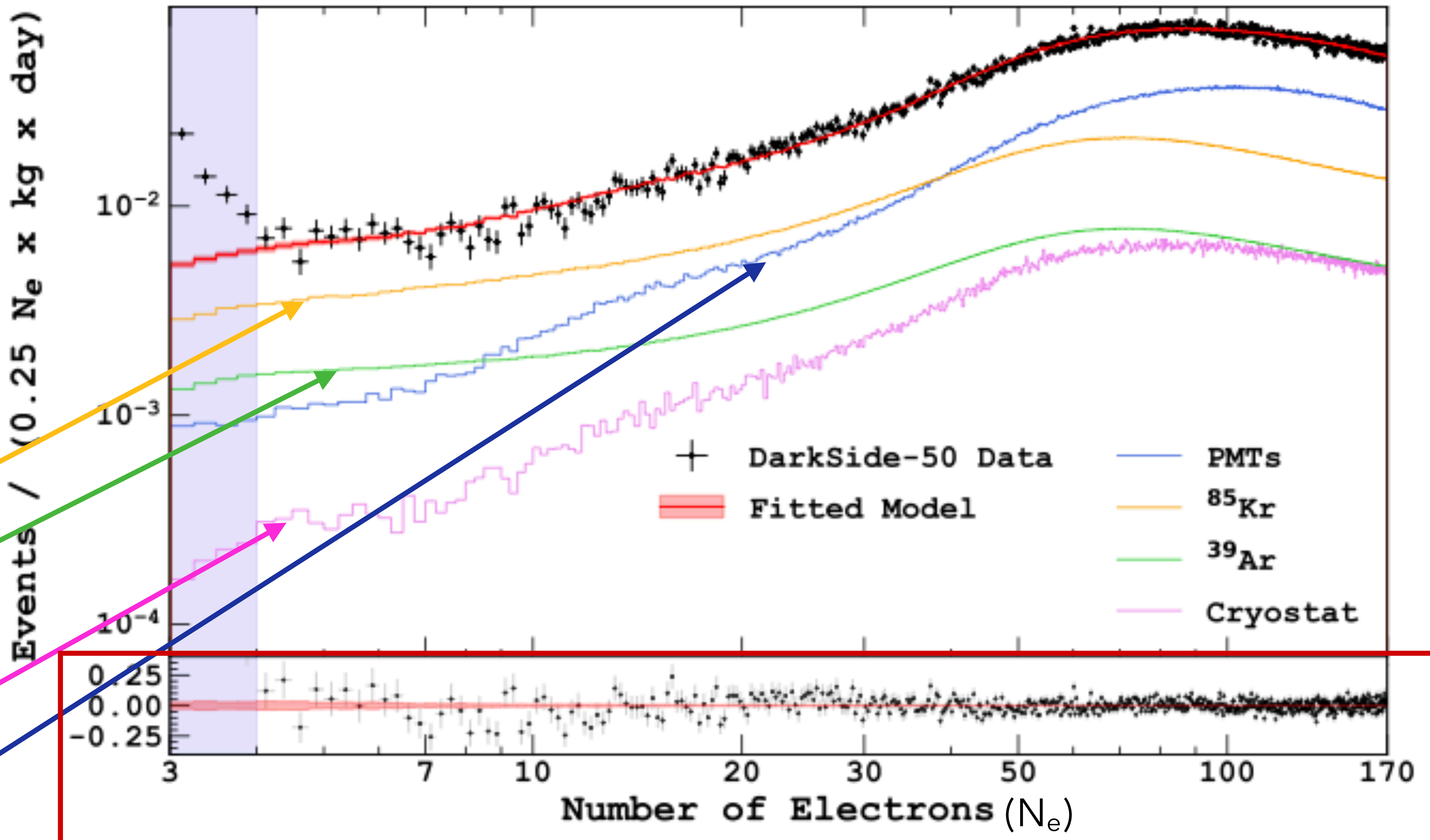
DarkSide-50 recent results

DarkSide-50





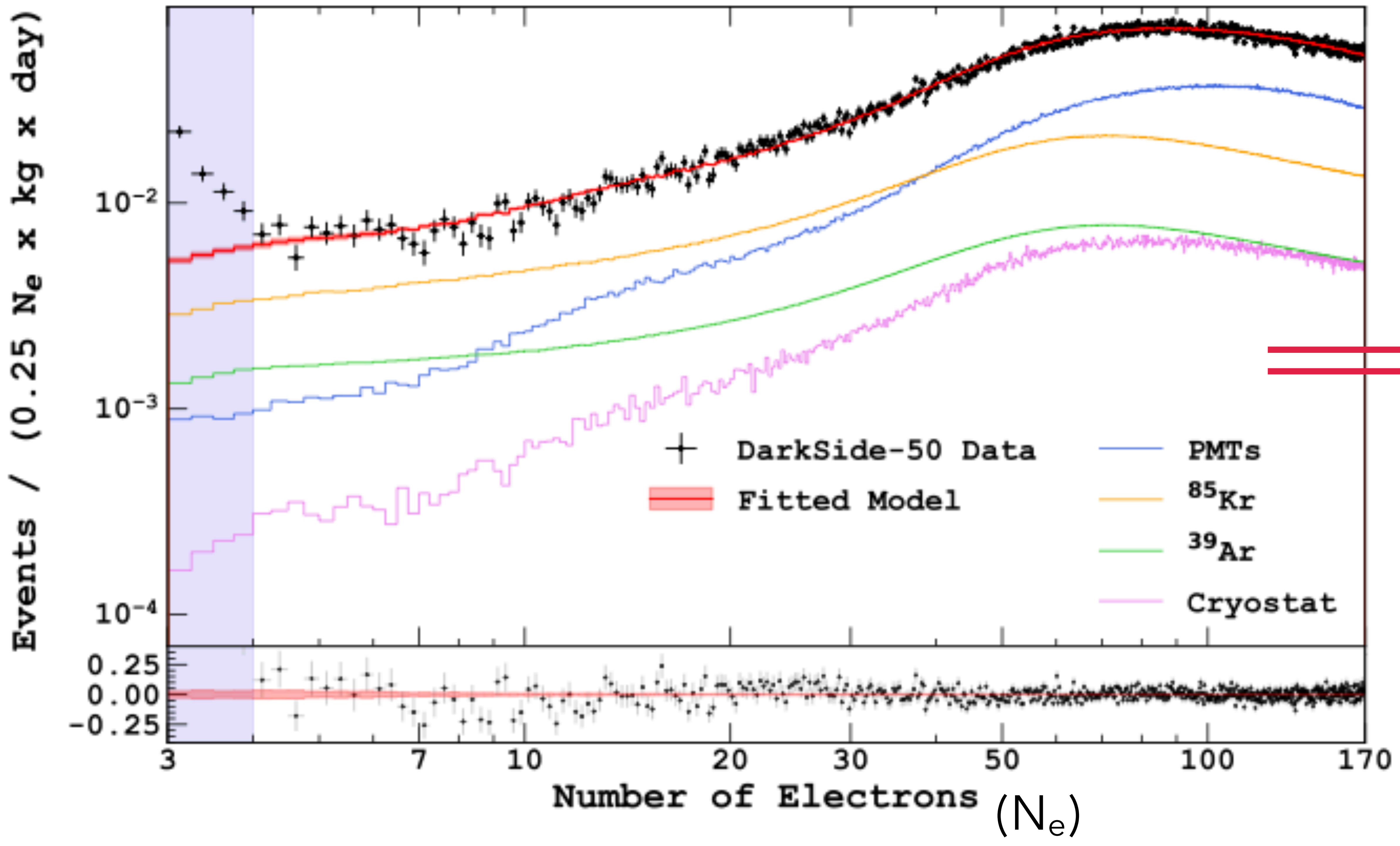
Phys.Rev.D 107 (2023), 063001



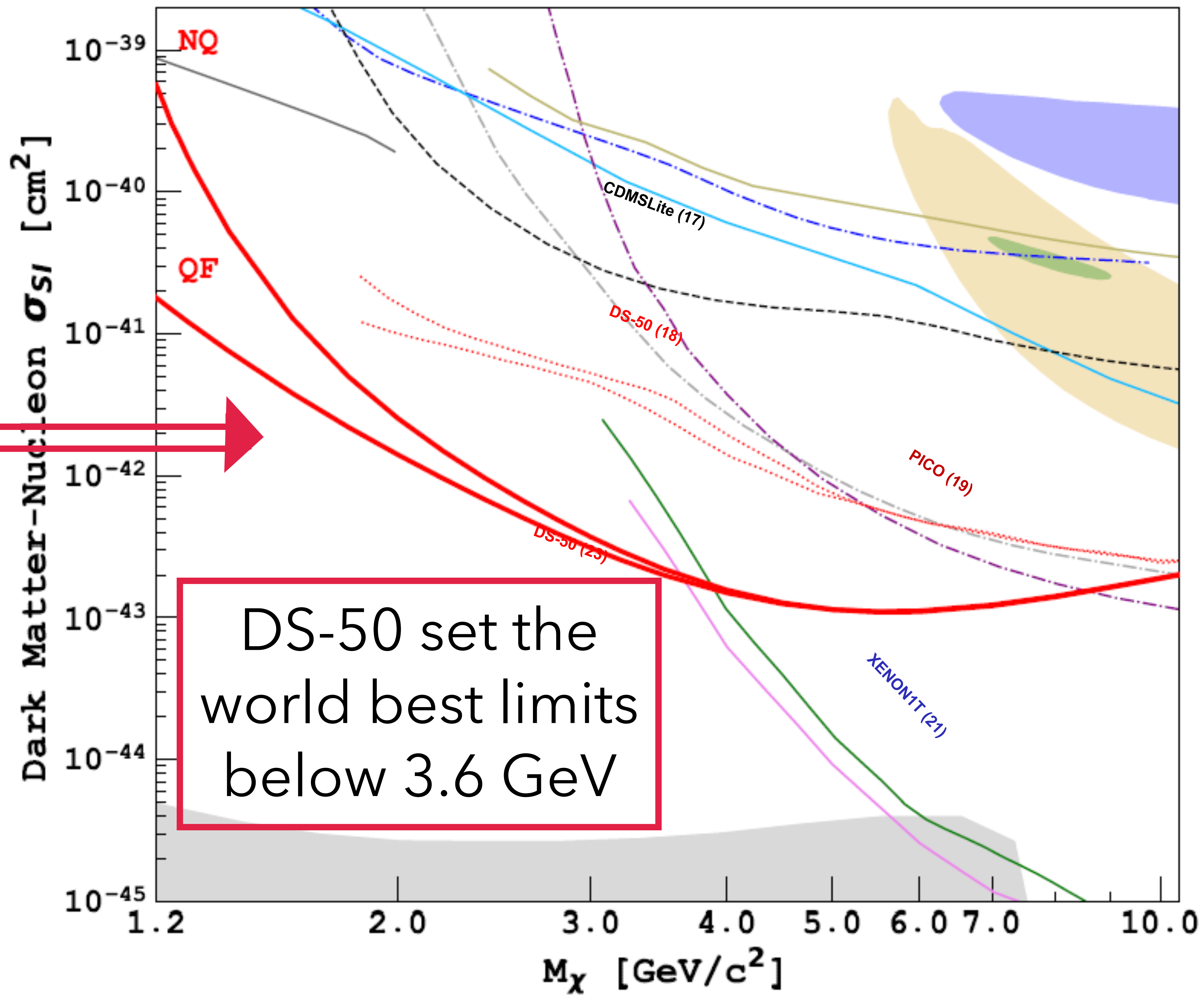
Excellent bkg modelling above 4 N_e

DarkSide-50 low mass analyses

Phys.Rev.D 107 (2023), 063001



Phys.Rev.D 107 (2023), 063001



DS-50 set the world best limits below 3.6 GeV

+ Migdal:

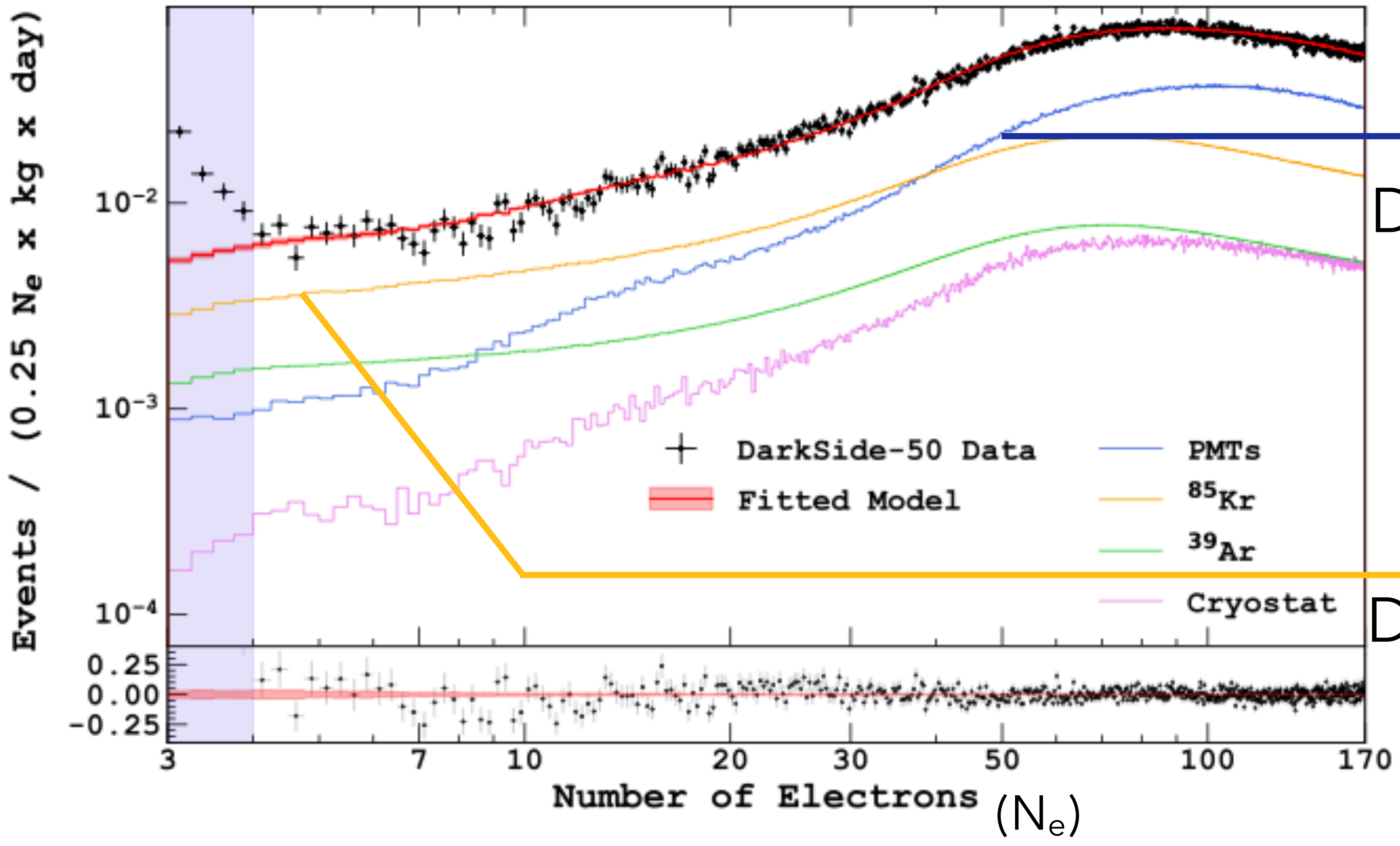
Phys.Rev.Lett. 130 (2023), 101001

+ Other light DM:

Phys.Rev.Lett. 130 (2023), 101002

From DarkSide-50 to DarkSide-20k

Phys.Rev.D 107 (2023), 063001



PMTs

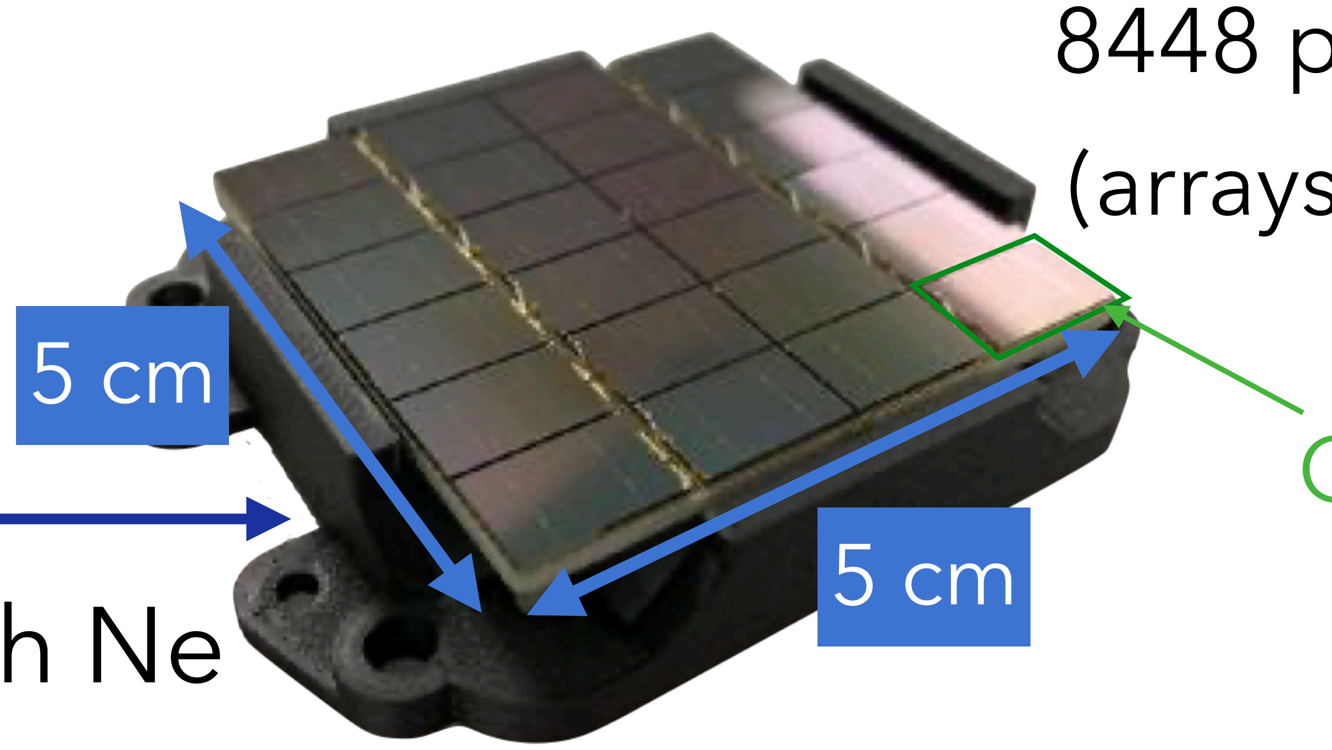
Dominant at high Ne

^{85}Kr

Dominant at low Ne

DarkSide-20k

8448 photosensors (arrays of 24 SiPMs)



Use SiPMs

Reduced radio-activity wrt PMTs

URANIA UAr

Extraction facility

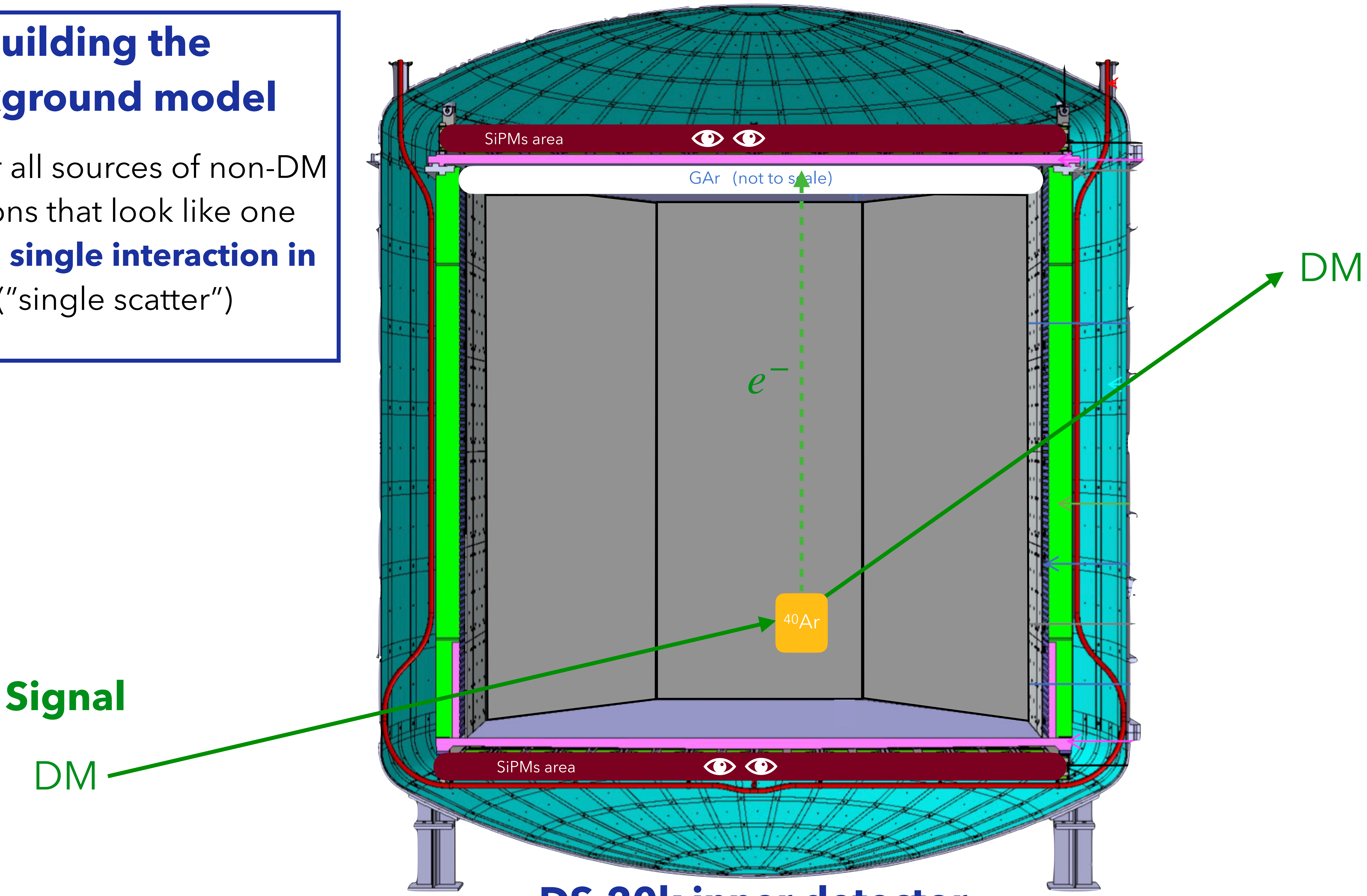
→**reduced contamination**

Less ER background → benefitting to the low mass analysis

Background sources in DarkSide-20k

Building the background model

- Consider all sources of non-DM interactions that look like one
- **DM-like: single interaction in the TPC** ("single scatter")



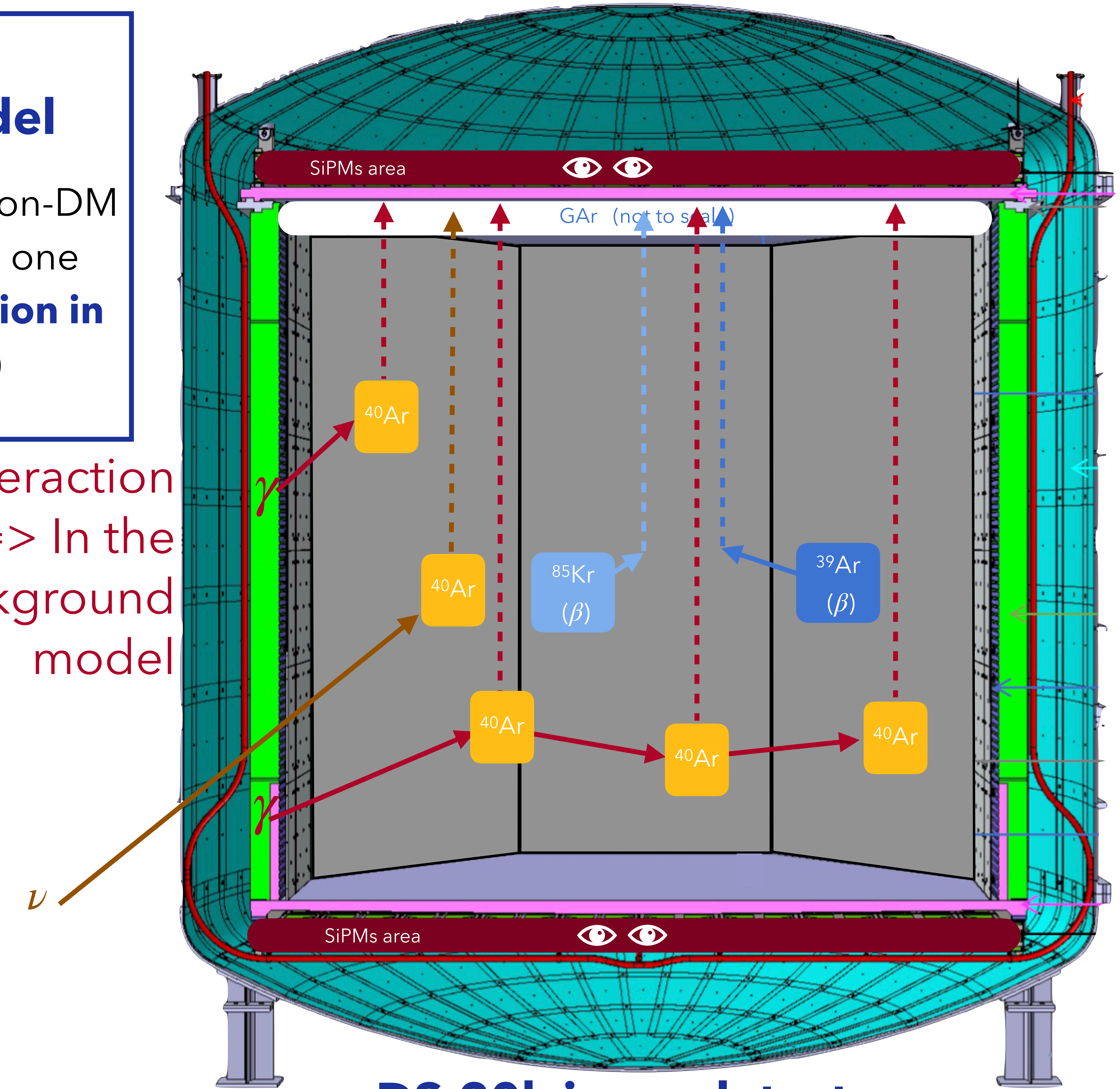
DS-20k inner detector

Background sources in DarkSide-20k

Building the background model

- Consider all sources of non-DM interactions that look like one
- **DM-like: single interaction in the TPC** ("single scatter")

Single interaction => In the background model



Several interactions ("multiple scatter") => rejected

DS-20k inner detector

DarkSide-20k low mass analysis

Pile up

- Expect 80 Hz from β, X and γ backgrounds
- **Select isolated S2**, with other S2 occurring at times greater than one maximum drift time (3.7 ms)

51% of effective livetime

Fiducialization

- **Radial**: 30 cm fiducialization from the walls
- Drift direction: no fiducialization

69% of signal acceptance

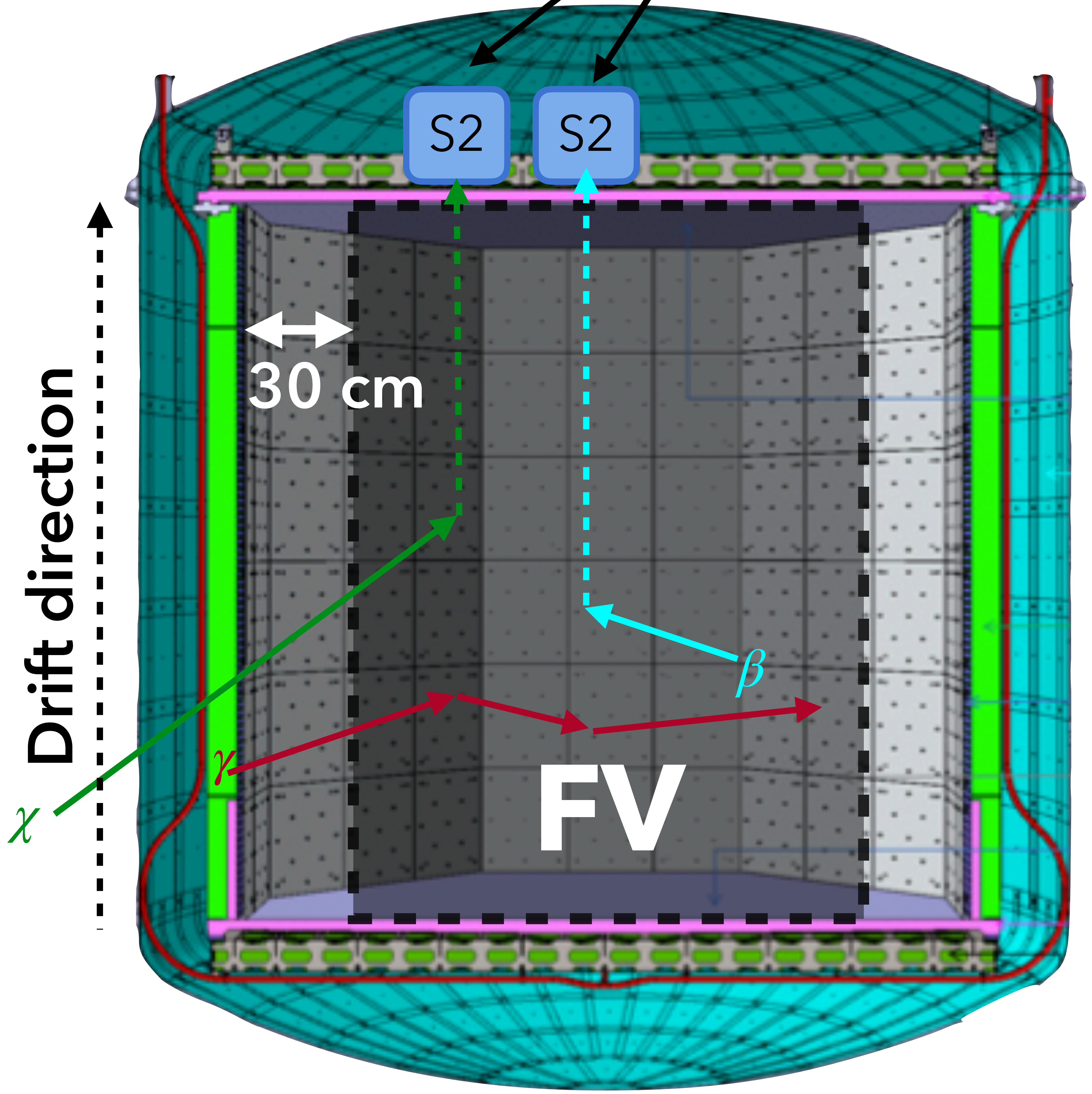
TPC:
49.7 t UAr

x 0.51

x 0.69

Exposure = **17.4 ton.year**
for 1 year of data taking

May arrive close in time and look like a multiple scatter



DS-20k inner detector

DarkSide-20k low mass background model

- Uniformly distributed in the fiducial volume
- Include recent calculations of β-decay energy spectra

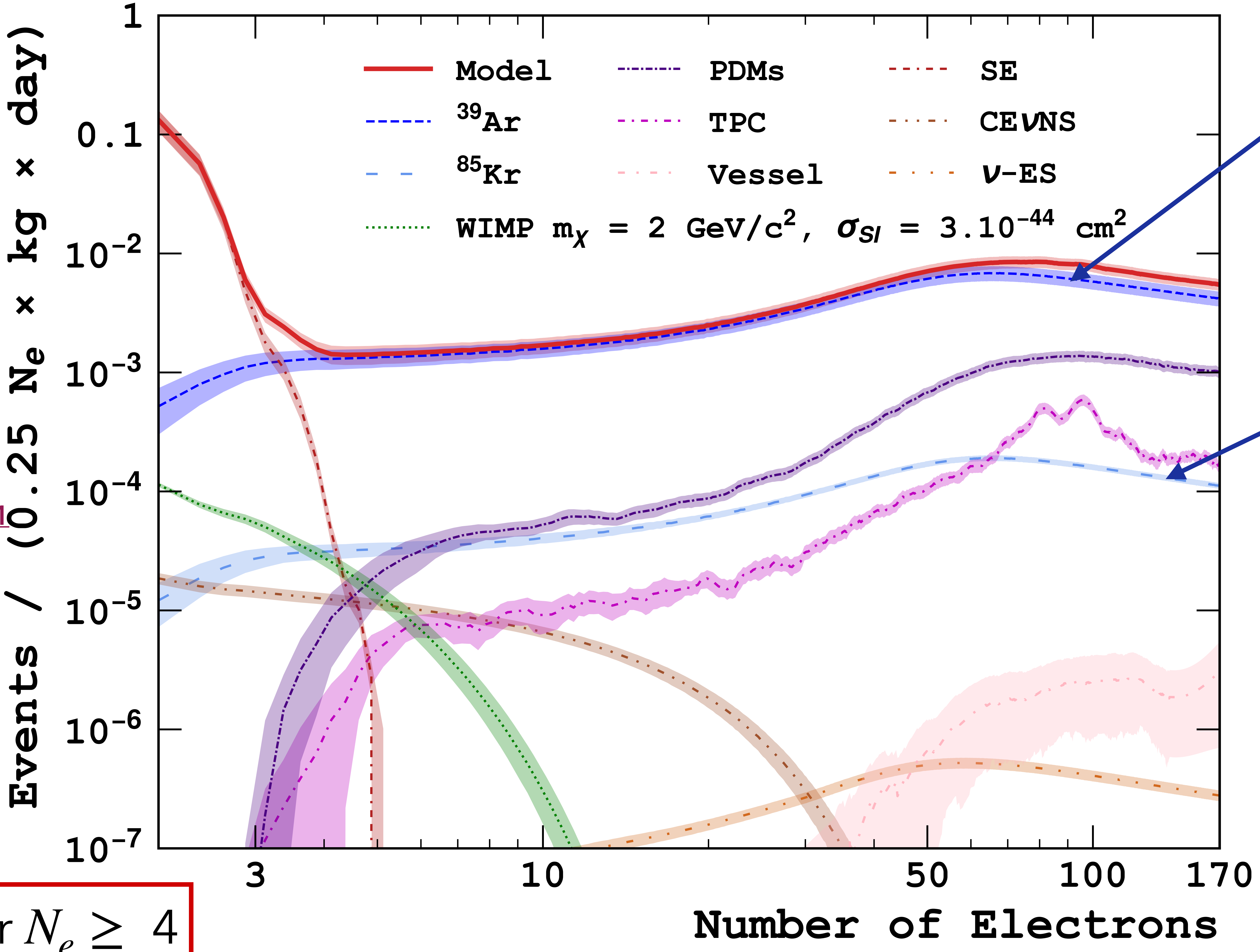
Phys.Rev.A 90 (2014) 012501

Phys.Rev.C 102 (2020) 065501

- Include shape systematics (atomic exchanges, screening effect, Q-value)

^{39}Ar dominant for $N_e \geq 4$

LAr intrinsic backgrounds (β decays)



^{39}Ar

Same activity as DS-50 (same UAr mine)

A(^{39}Ar) = 0.73 mBq/kg

^{85}Kr

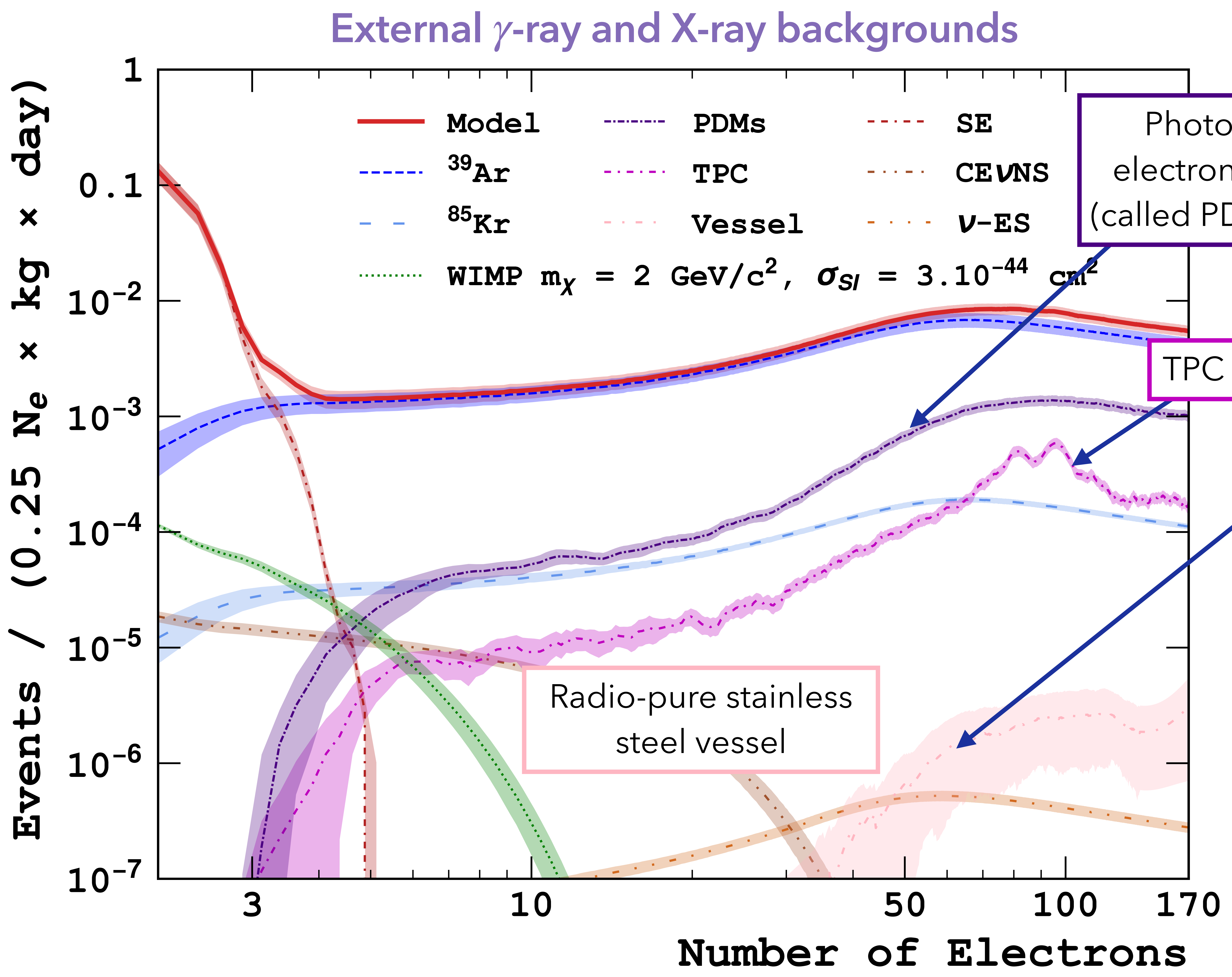
Urania (Colorado, USA): dedicated facility for extraction

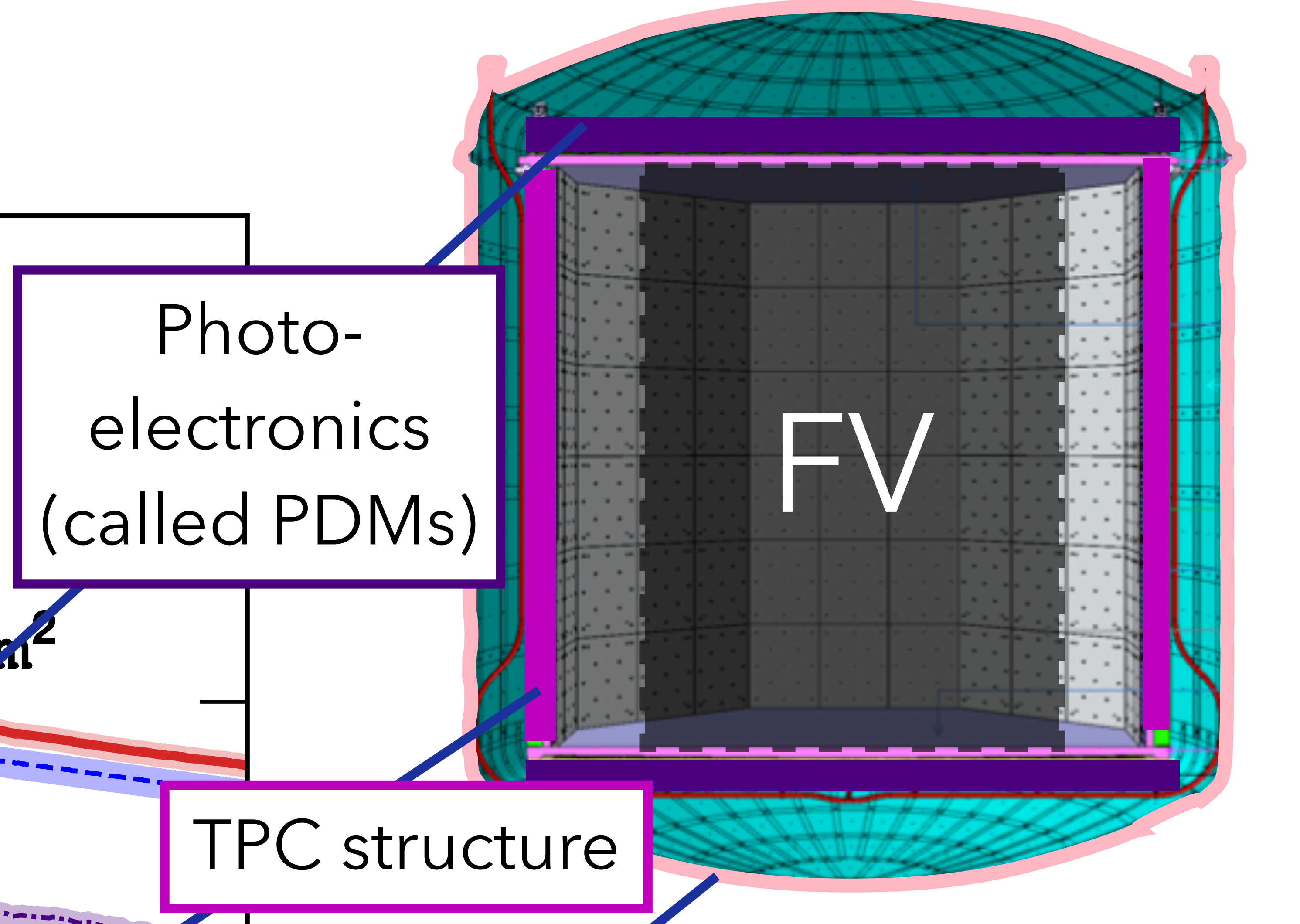
Reduced ^{85}Kr activity wrt DS-50

A(^{85}Kr) = 1.9 10^{-2} mBq/kg

DarkSide-20k low mass background model

- Simulated with a GEANT-4 based simulation tool
- ≈ 2.5x reduced bkg contamination per surface area wrt DS-50





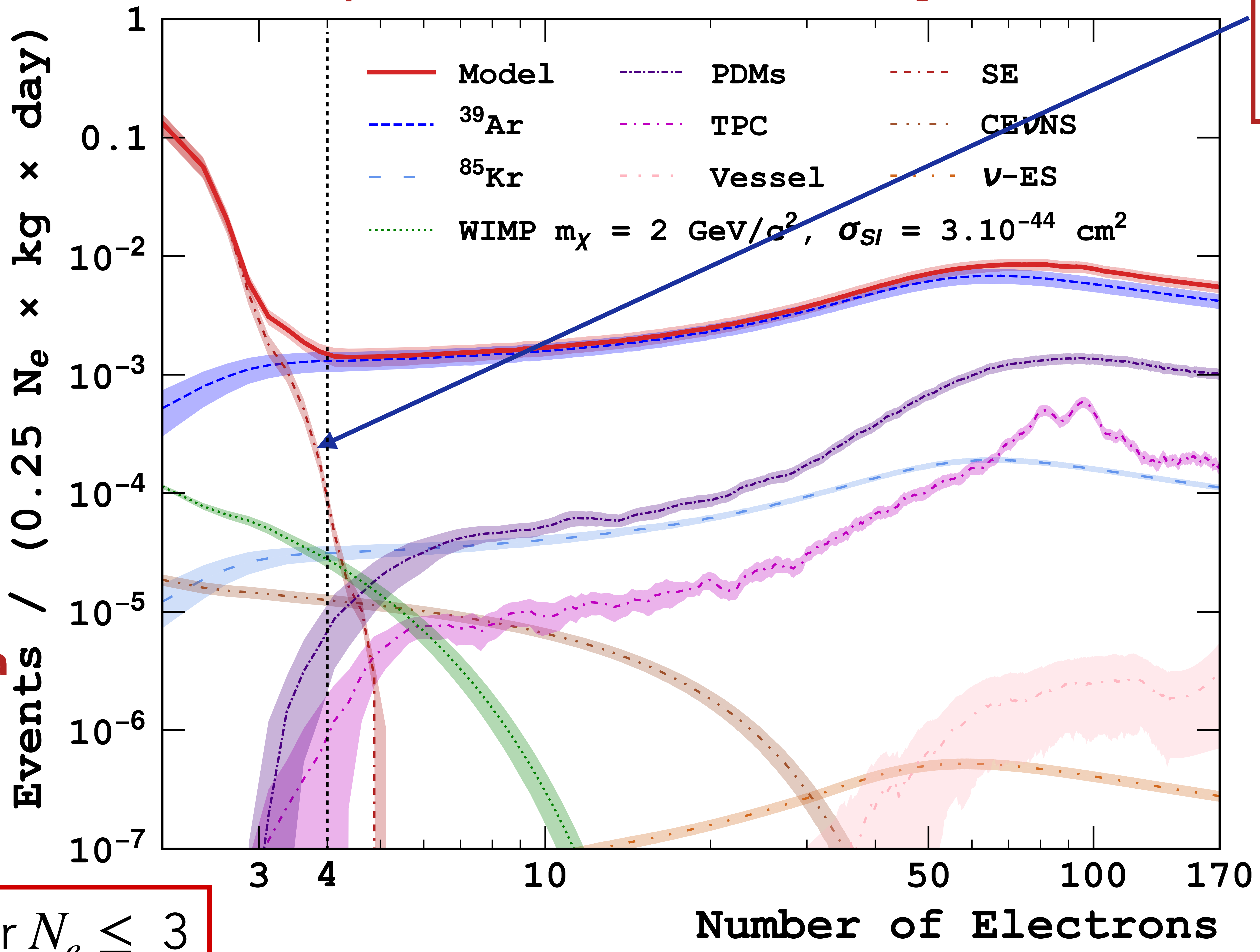
Radio-contamination estimated from **material assays**

Radio-contaminant	Activity (Bq)		
	TPC	PDMs	SS vessel
^{238}U up	16.1	38.8	21
^{238}U mid	11.5	18.4	8.8
^{238}U low	16.4	449	62
^{232}Th	4.2	17.8	33
^{235}U	0.7	1.8	1.0
^{137}Cs	2.5	2.9	5.0
^{60}Co	2.0	5.1	13
^{40}K	102	269	49

DarkSide-20k low mass background model

- Low energy component observed in DS-50
- Origin might be trapped electrons by impurities and released later
- For DS20k: **Extrapolation from DS-50 data**

Spurious electron (SE) background



SE 18x lower than ^{39}Ar at $N_e = 4$

SE dominant for $N_e \leq 3$

2 fit scenarii:

- **Conservative** (almost indep. of SE modelling): Fit from $N_e = 4$ (DS-50 strategy)
- **Ultimate**: Fit from $N_e = 2$ assuming good control of rate and spectral shape of SE in DS-20k

DarkSide-20k low mass background model

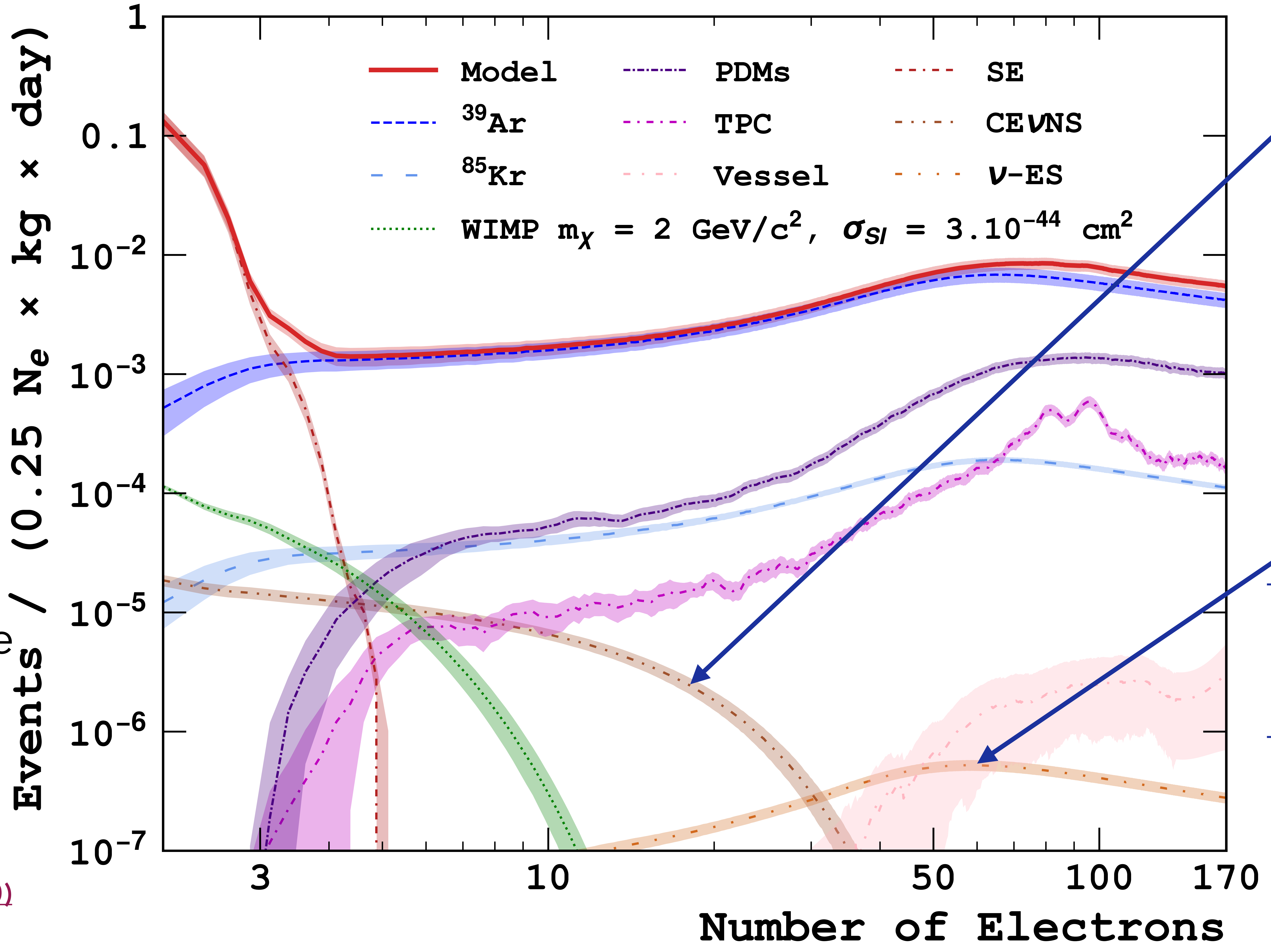
- Mostly from solar neutrinos (^{7}Be, ^{15}O, pep, ^{8}B, hep)
- Include radiative corrections in CEνNS

JHEP 05, 271

- Include accurate parametrization of the nucleus structure

Phys.Rev.D 102 (2020) 015030

Neutrino backgrounds



CEνNS

Mainly from solar ^{8}B ν (E_{dep} < 10 keV$_{nr}$)

ν-ES

→ Mainly from pp (+ ^{7}Be) ν (E_{dep} < 20 keV$_{er}$)

→ Dominates over CEνNS at $N_e \gtrsim 30$

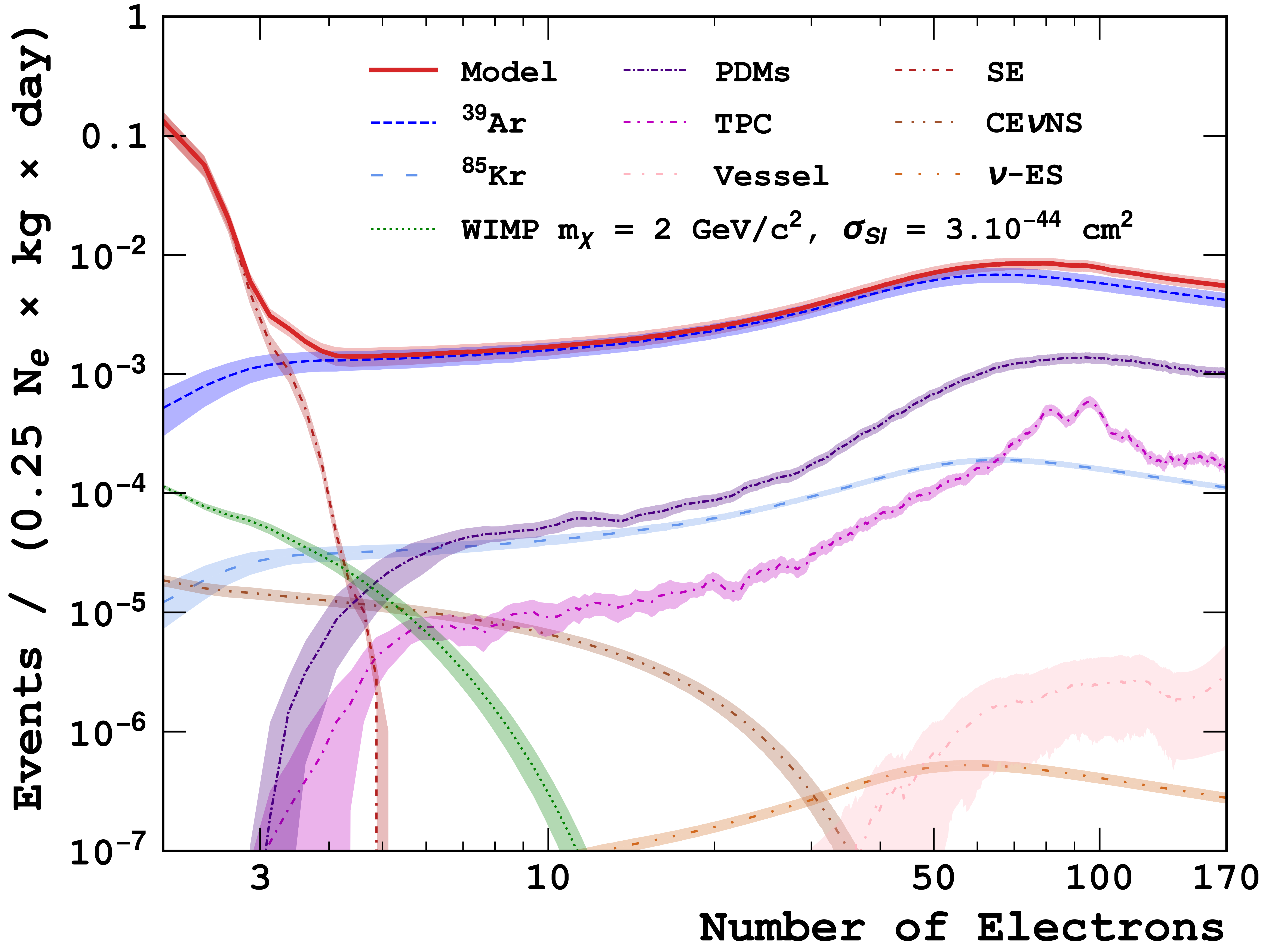
Signal models

- Assuming **Standard Halo Model**

  Eur. Phys. J. C 81 (2021), p. 907

- Localised at low N_e

WIMP



Systematic uncertainties

	Source uncertainty	Affected components
Amplitude	5% on the exposure	All
	15% on ^{39}Ar activity	^{39}Ar
	15% on ^{85}Kr activity	^{85}Kr
	20% on SE normalization	SE
	10% on activity from PDMs	PDMs
	10% on activity from the vessel	Vessel
	10% on activity from the TPC	TPC
	10% on neutrinos normalization	Neutrinos
Shape	atomic exchange and screening	^{39}Ar
	atomic exchange and screening	^{85}Kr
	1% on the ^{39}Ar-decay Q-value	^{39}Ar
	0.4% on the ^{85}Kr-decay Q-value	^{85}Kr
	SE modelling	SE
	ER ionization response	All backgrounds but CEνNS, SE
	NR ionization response	WIMP, CEνNS

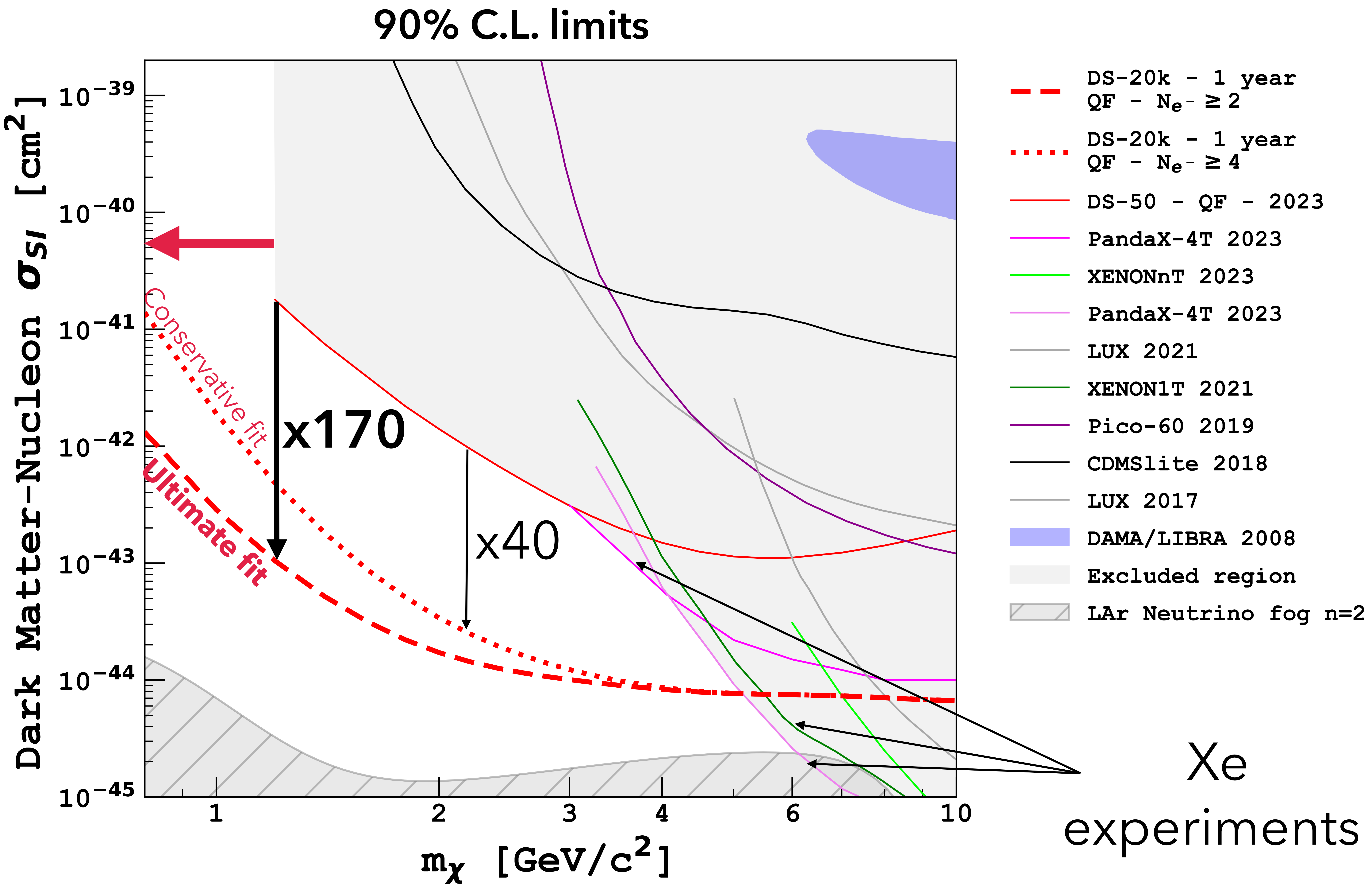
Main bkg components and **ER ionization yield → Dominant systematic uncertainties & constrained by the fit**

DarkSide-20k sensitivity to low mass WIMPs

Assuming 1 live-year of data taking

- **More than one order of magnitude** of uncharted theory parameter space will be probed
- Stable against detector model assumptions

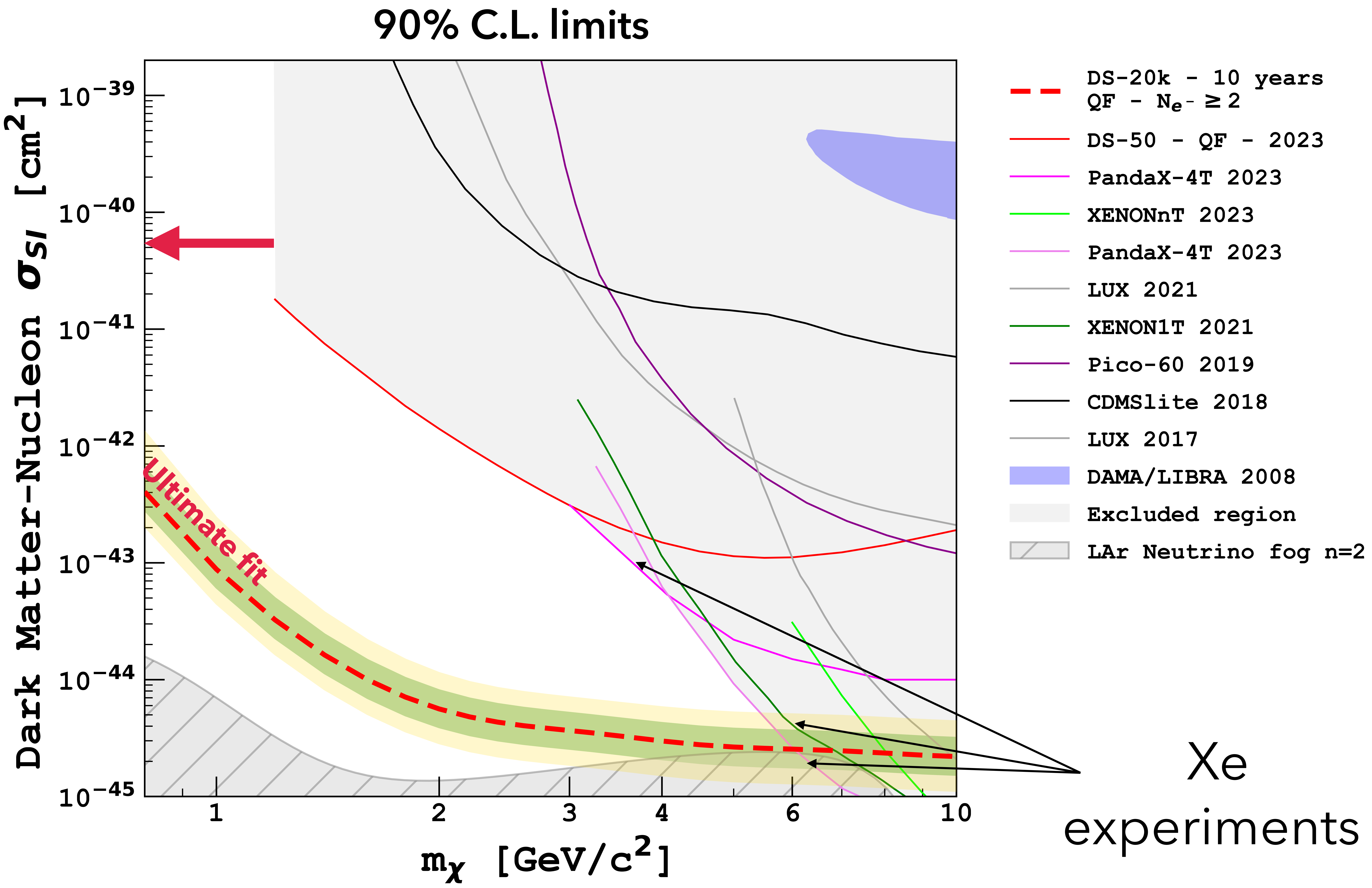
DarkSide-20k will lead the low mass WIMP search below $m_\chi \approx 5$ GeV/c^2 after only one year of data collection



DarkSide-20k sensitivity to low mass WIMPs

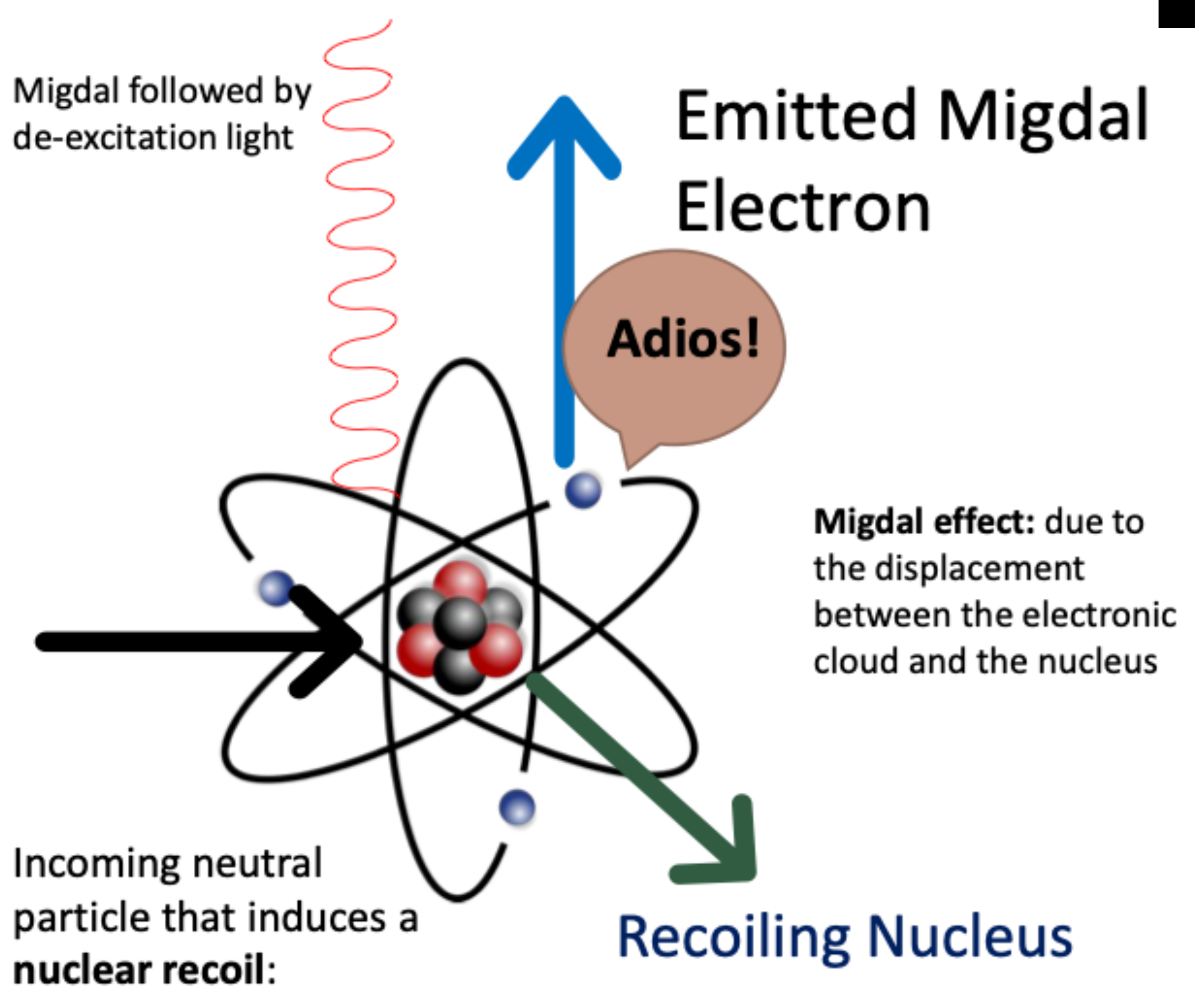
Assuming 10 live-years of data taking

➡ **Scales with $\sqrt{\text{exposure}}$**



DarkSide-20k will reach the neutrino fog around $m_\chi \approx 5$ GeV/c^2 after 10 years of data collection

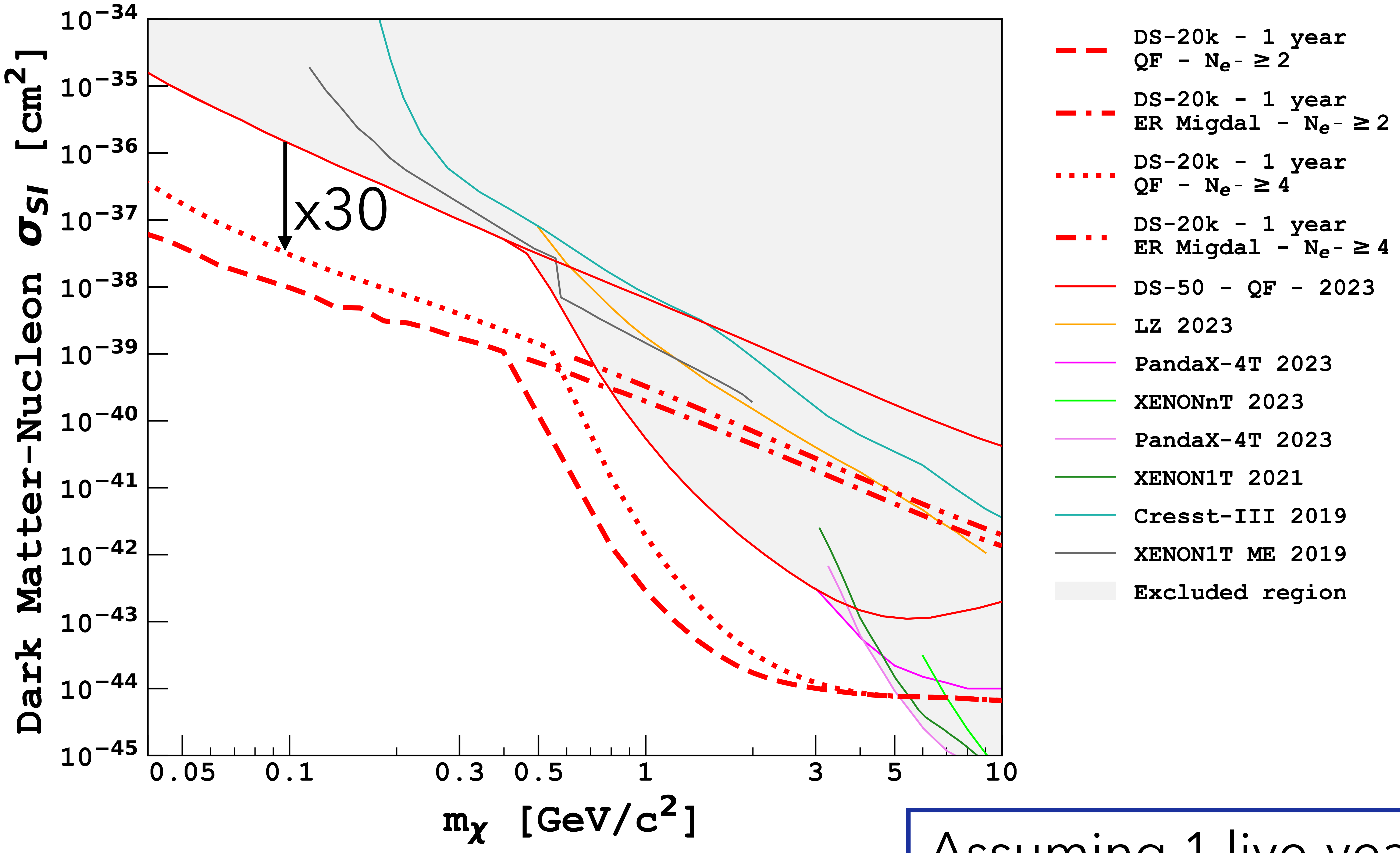
Including Migdal effect



- Migdal effect = possible atomic effect
- Electron released in NR
  - Lower the detection threshold

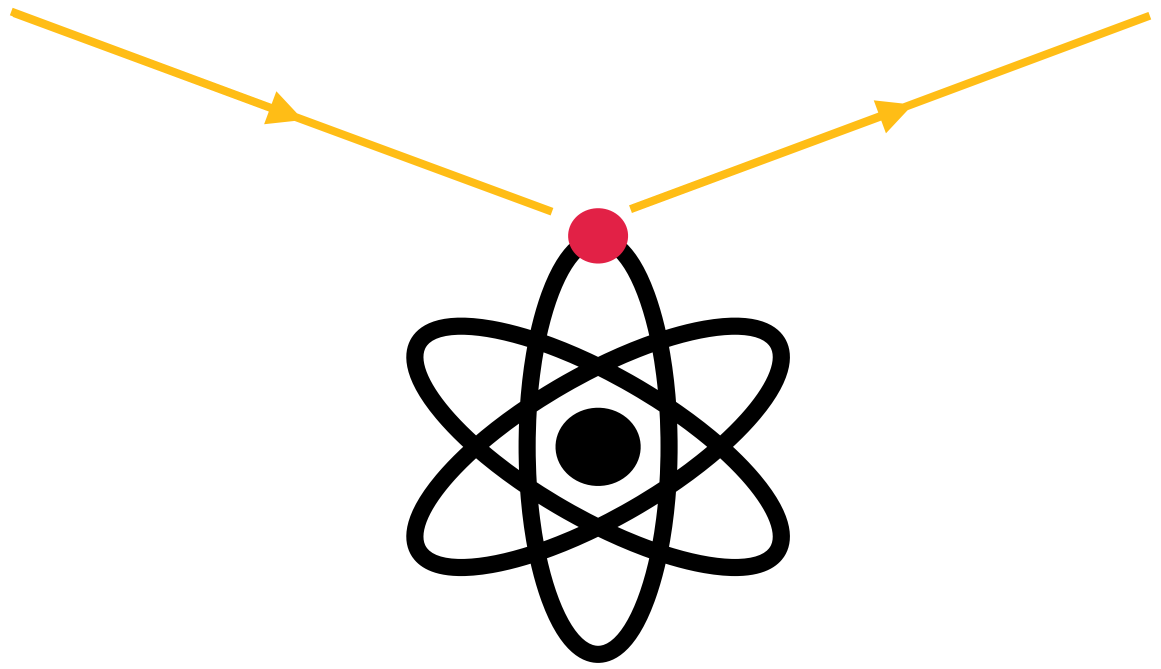
➡ **With Migdal effect:** best limits from 40 MeV/c² to 5 GeV/c²

➡ Expect **> 1 order of magnitude improvement** wrt to current experiments in **1y** only



Assuming 1 live-year of data taking

Light dark matter (LDM)

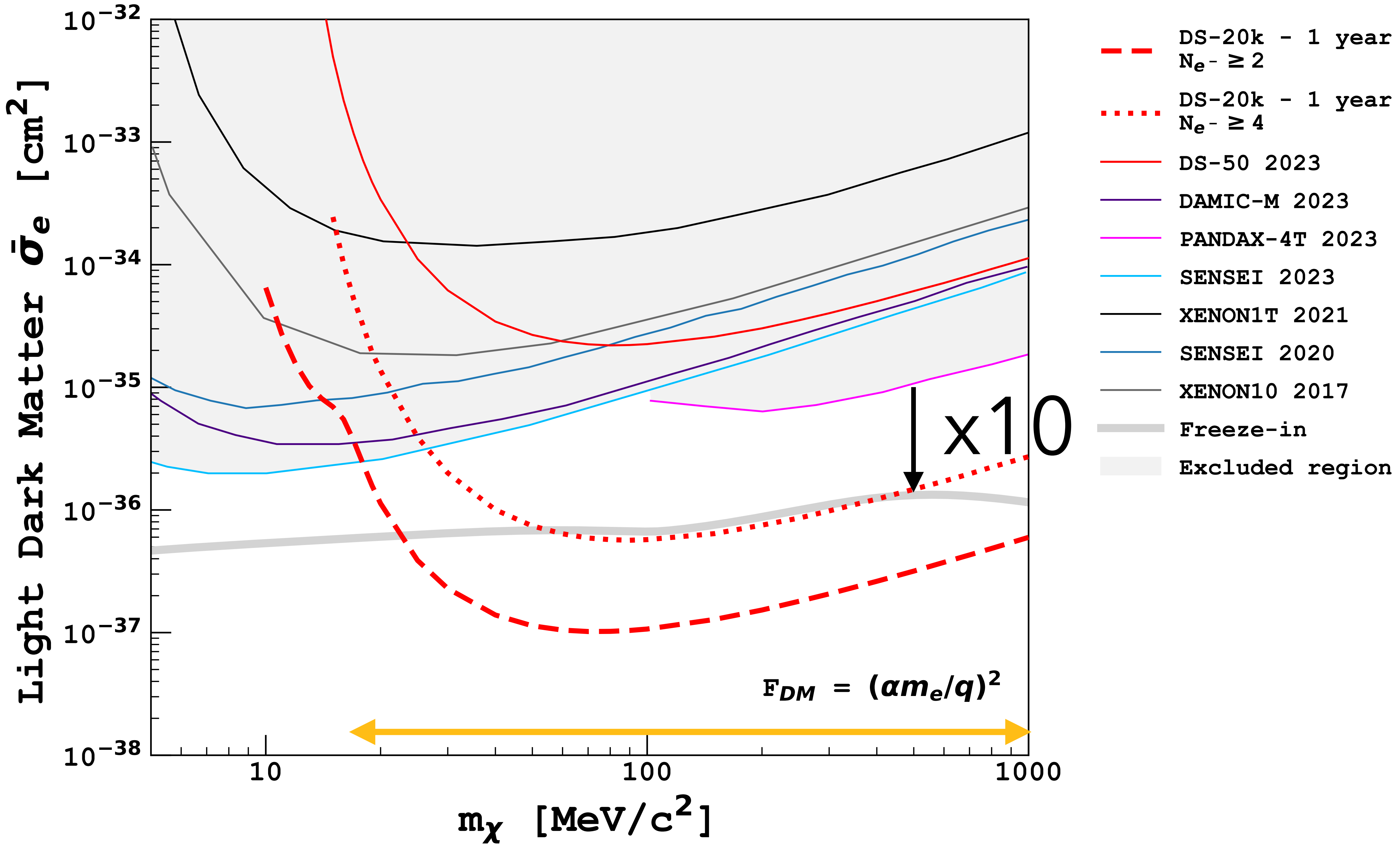


- Elastic scatter of Light Dark Matter (LDM) off bound electrons
- LDM = Sub GeV fermion or scalar boson
- Mediator can be light (→ F~1/q²) or heavy (→ F~1)

Expect **> 1 order of magnitude improvement** wrt to current experiments in **1y** only

Assuming 1 live-year of data taking

90% C.L. limits



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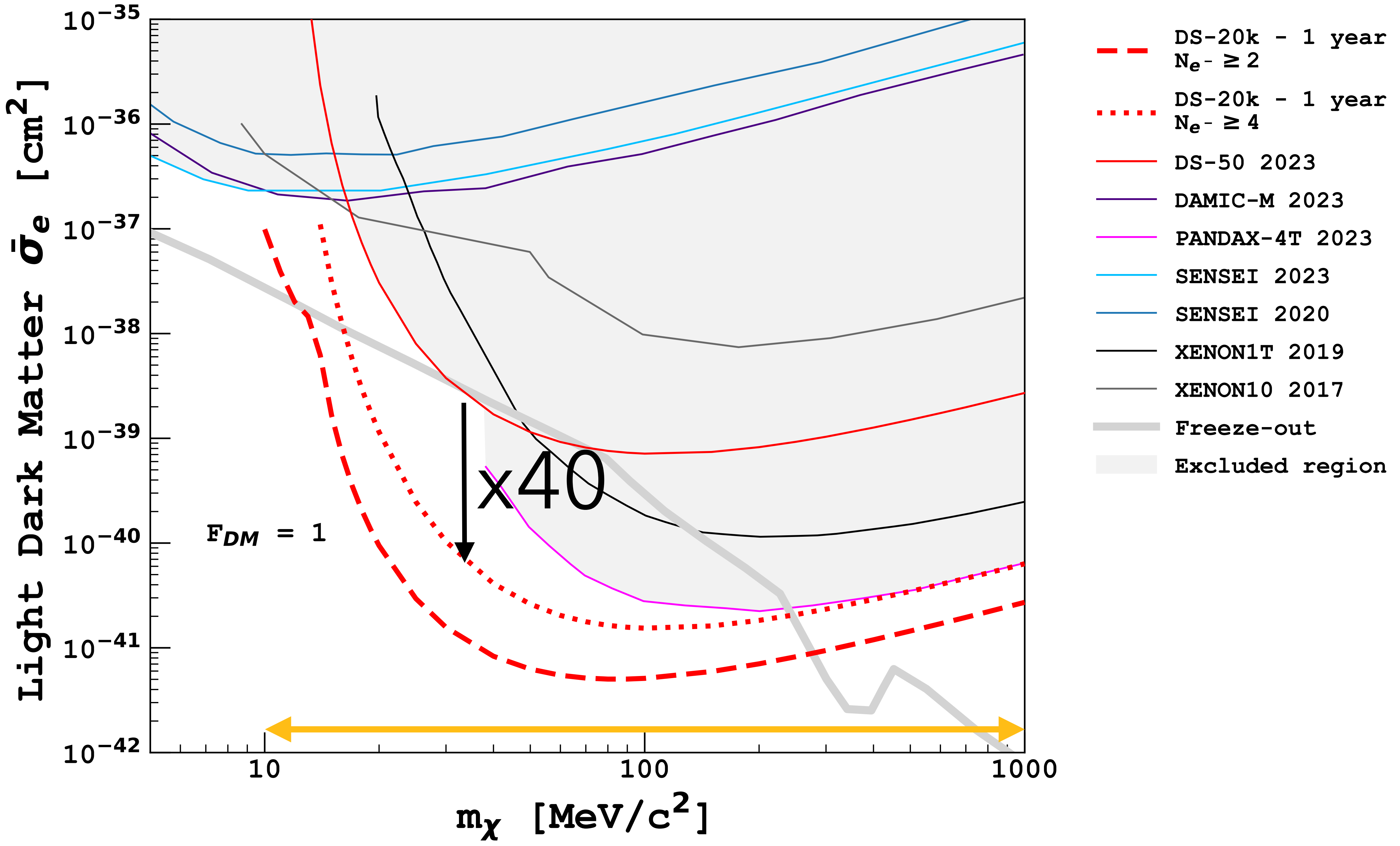
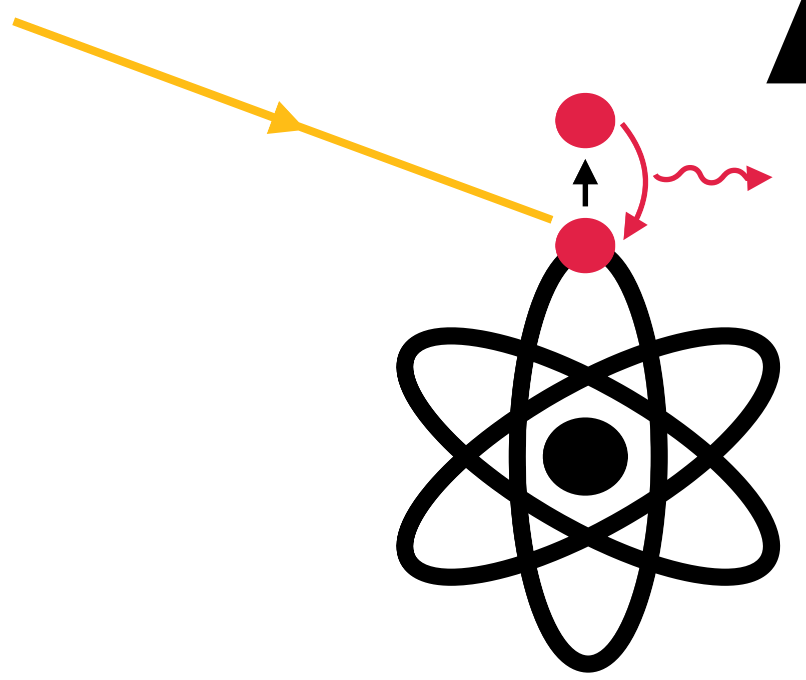


ALP and dark photon (DP)

Expect ≈**5x improvement** wrt to current experiments in **1y** only

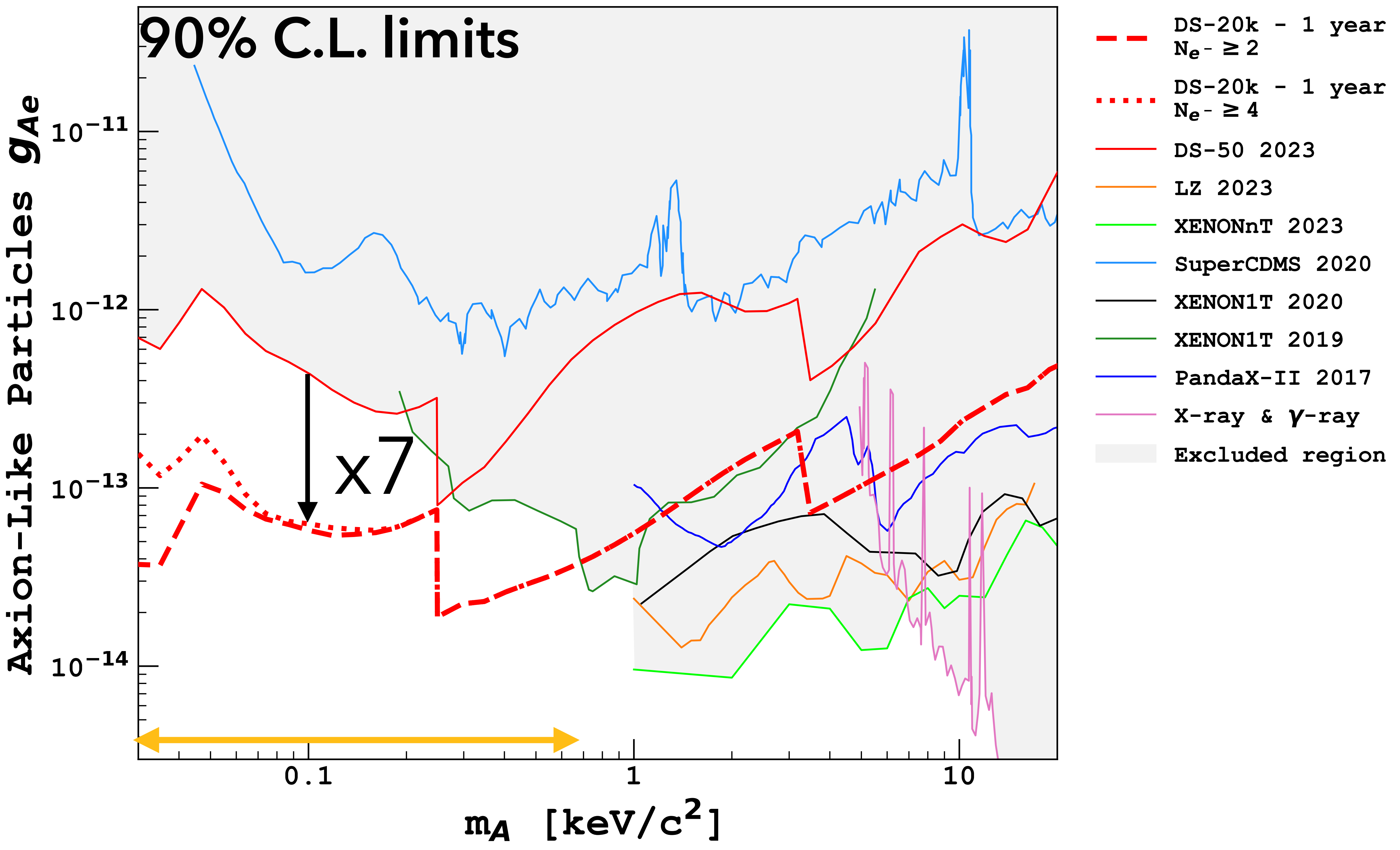


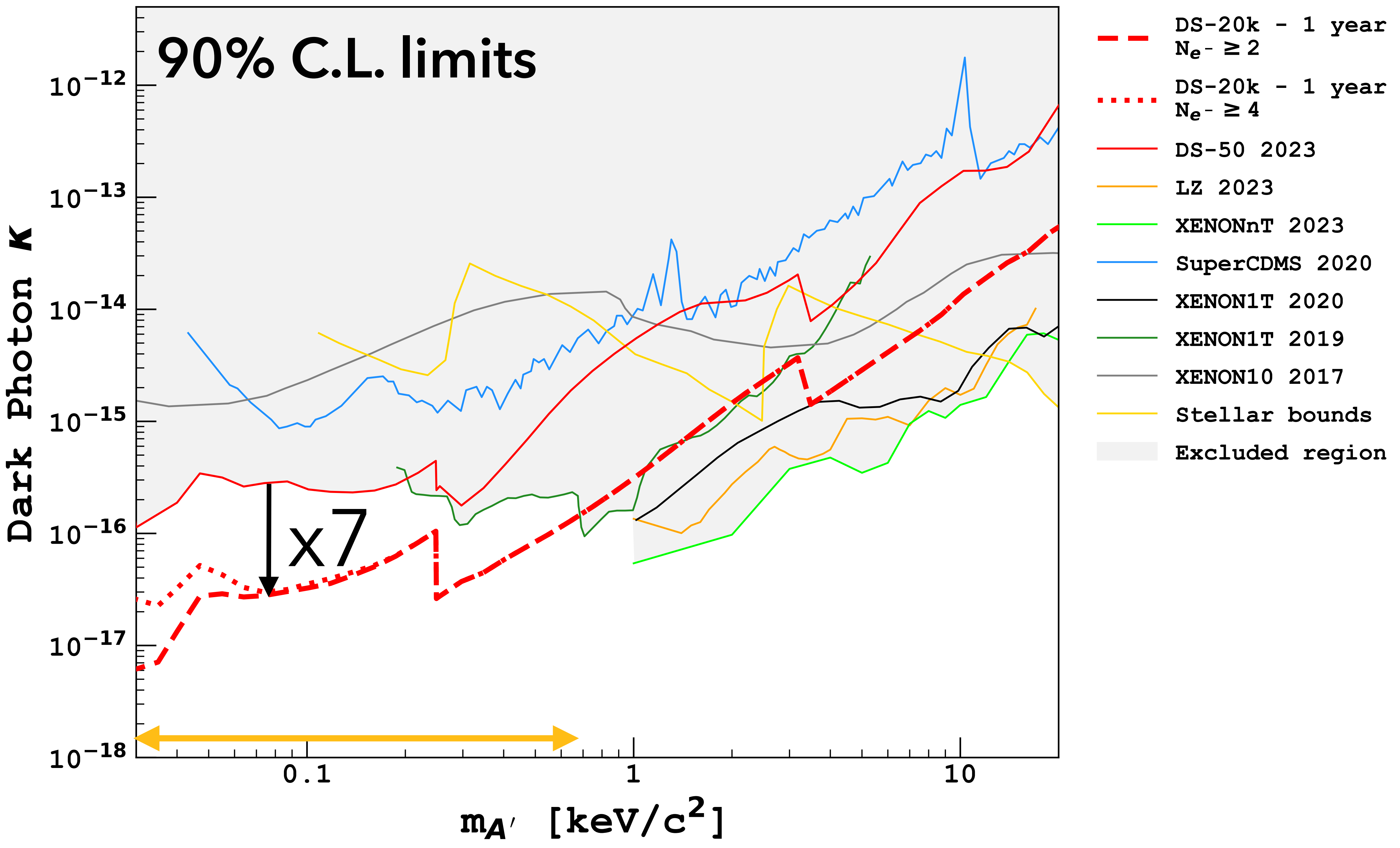
Absorption of ALP/DP by bound electrons → mono-energetic signal

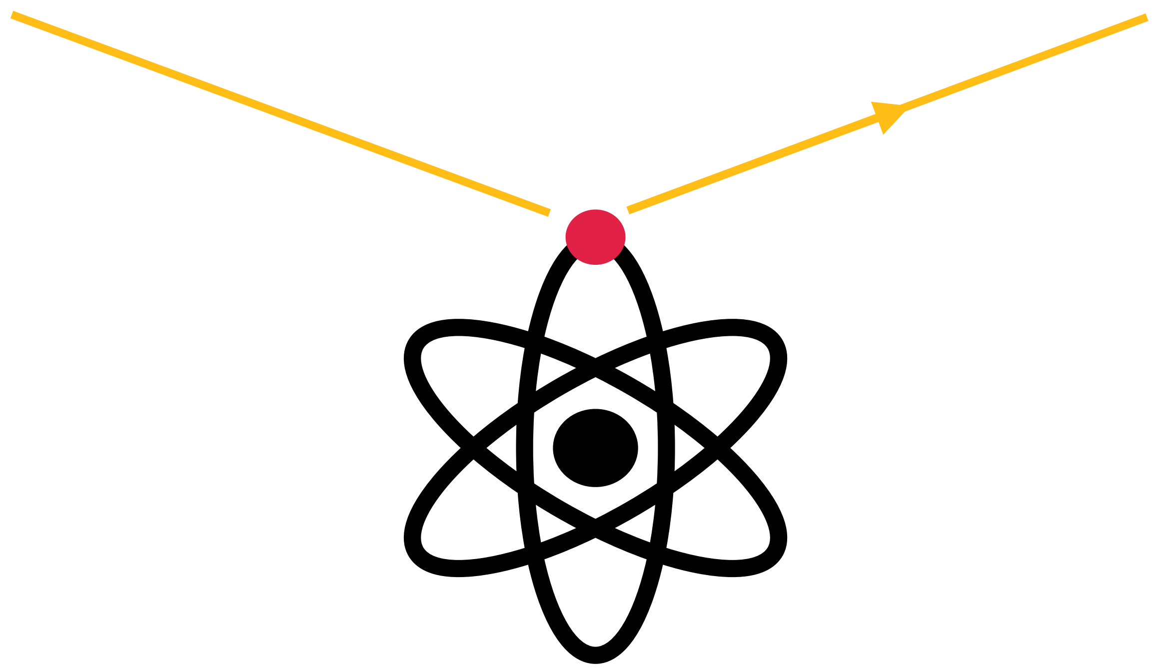
- ALP = pseudo scalar particle
- Coupling ALP - electrons → g_{Ae}

- DP = vector boson particle
- Kinetic mixing between DP and SM photons → strength κ

Assuming 1 live-year of data taking



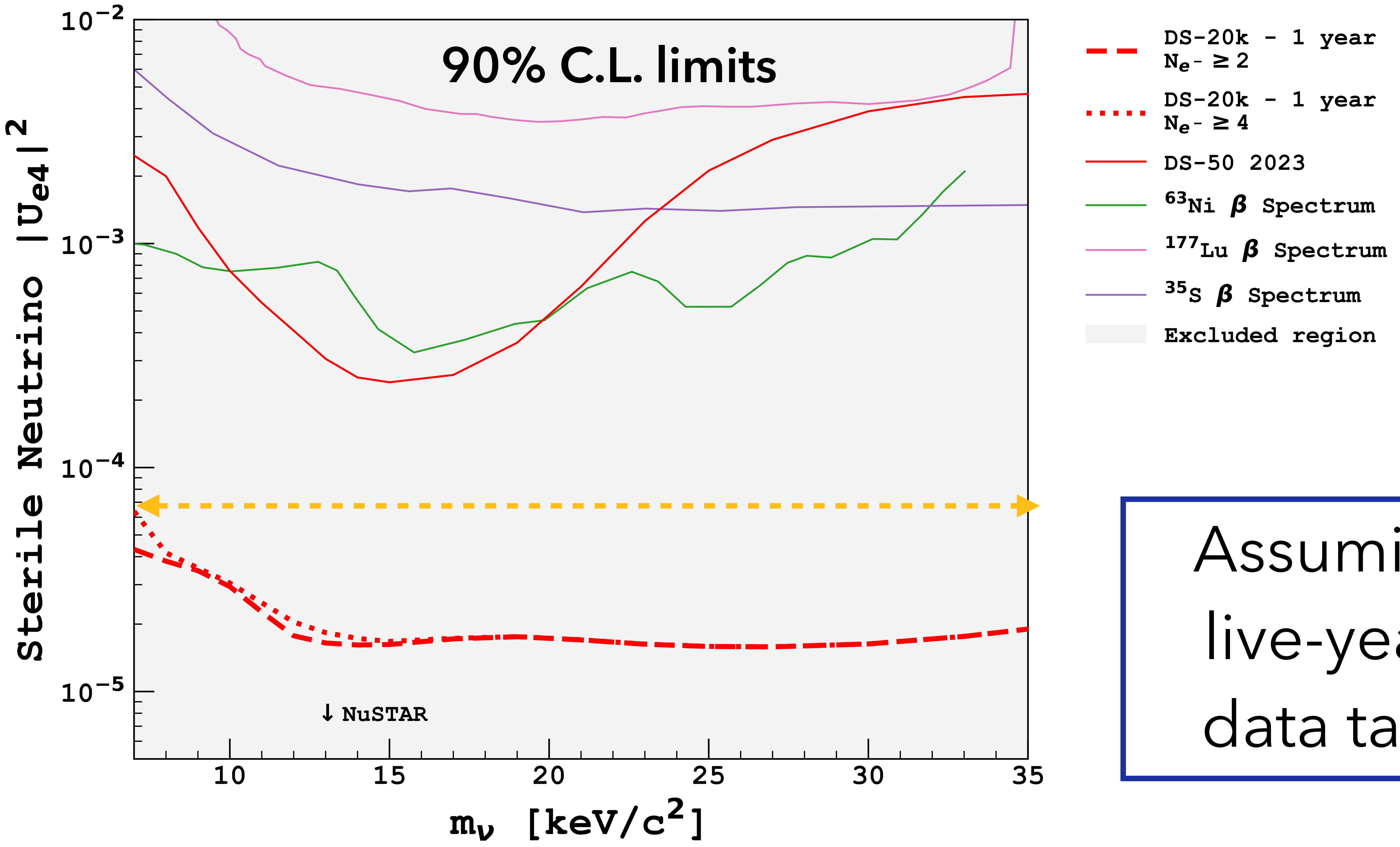




Sterile neutrino ν_s

- Inelastic scatter of sterile ν_s off bound electrons
- Possible mixing with active neutrinos → PMNS-like matrix element $|U_{e4}|^2$

Best direct limits (1 live-year) but phase space already rejected by NuSTAR indirect measurements

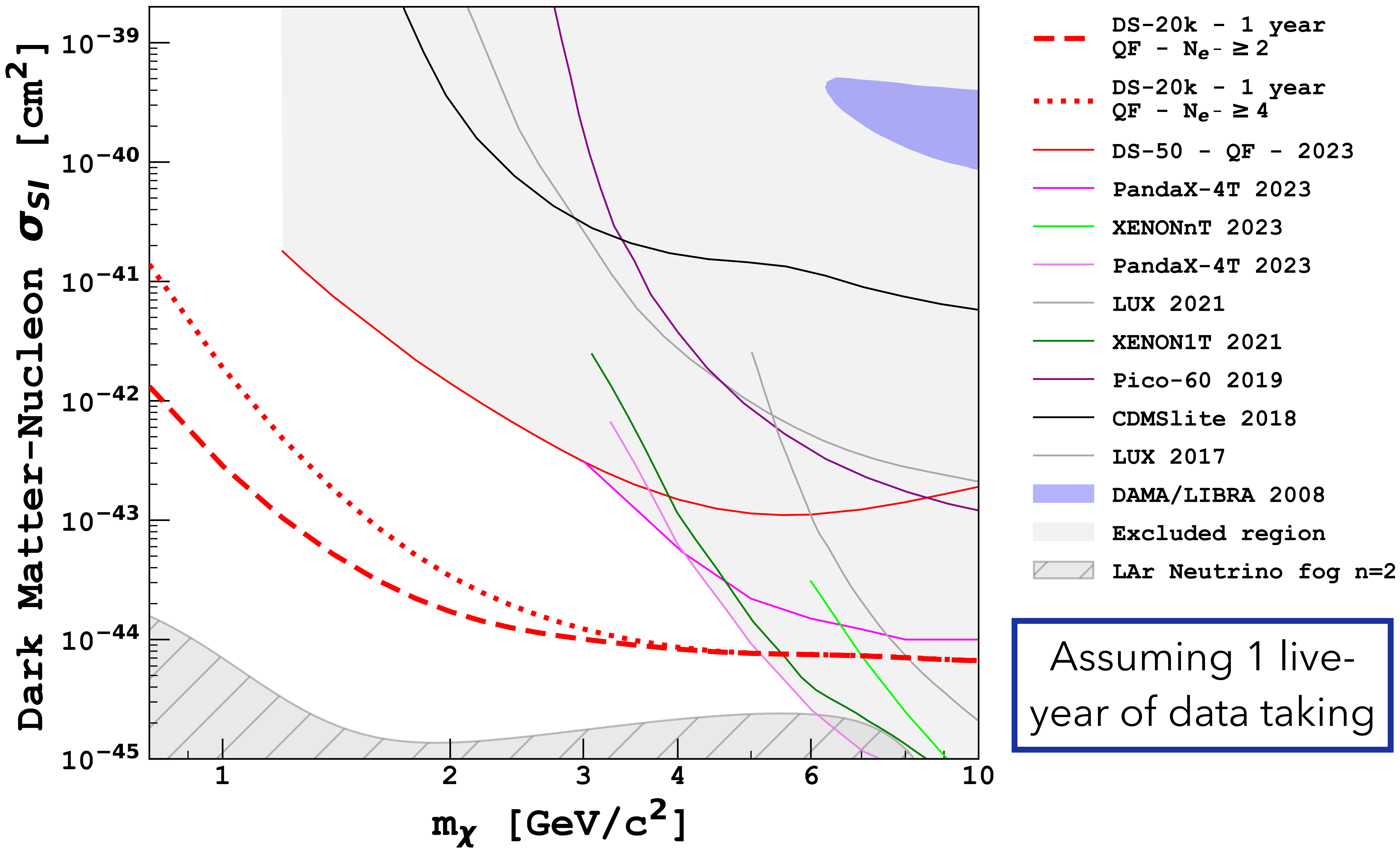


Assuming 1 live-year of data taking

Conclusions

- First assessment of **DarkSide-20k sensitivity to low mass dark matter particles**
- Further strengthens the physics reach of DarkSide-20k with a leading role below 5 GeV/c²
- Expect to probe > 1 order to magnitude of un-charted theory parameter space **within 1 live-year only** for a **variety of dark matter particles**
- For WIMPs:
  - Probe $\sigma_{SI} < 10^{-42}$ cm² above m_χ = 800 MeV/c²
  - Reach the neutrino fog at 5 GeV/c² after 10 years

90% C.L. limits



Assuming 1 live-year of data taking

Paper published in Nature Communications Physics
[Commun Phys 7, 422 (2024)]

Thank you!

Back up