Latest Results from the **DarkSide-50** experiment at **LNGS**

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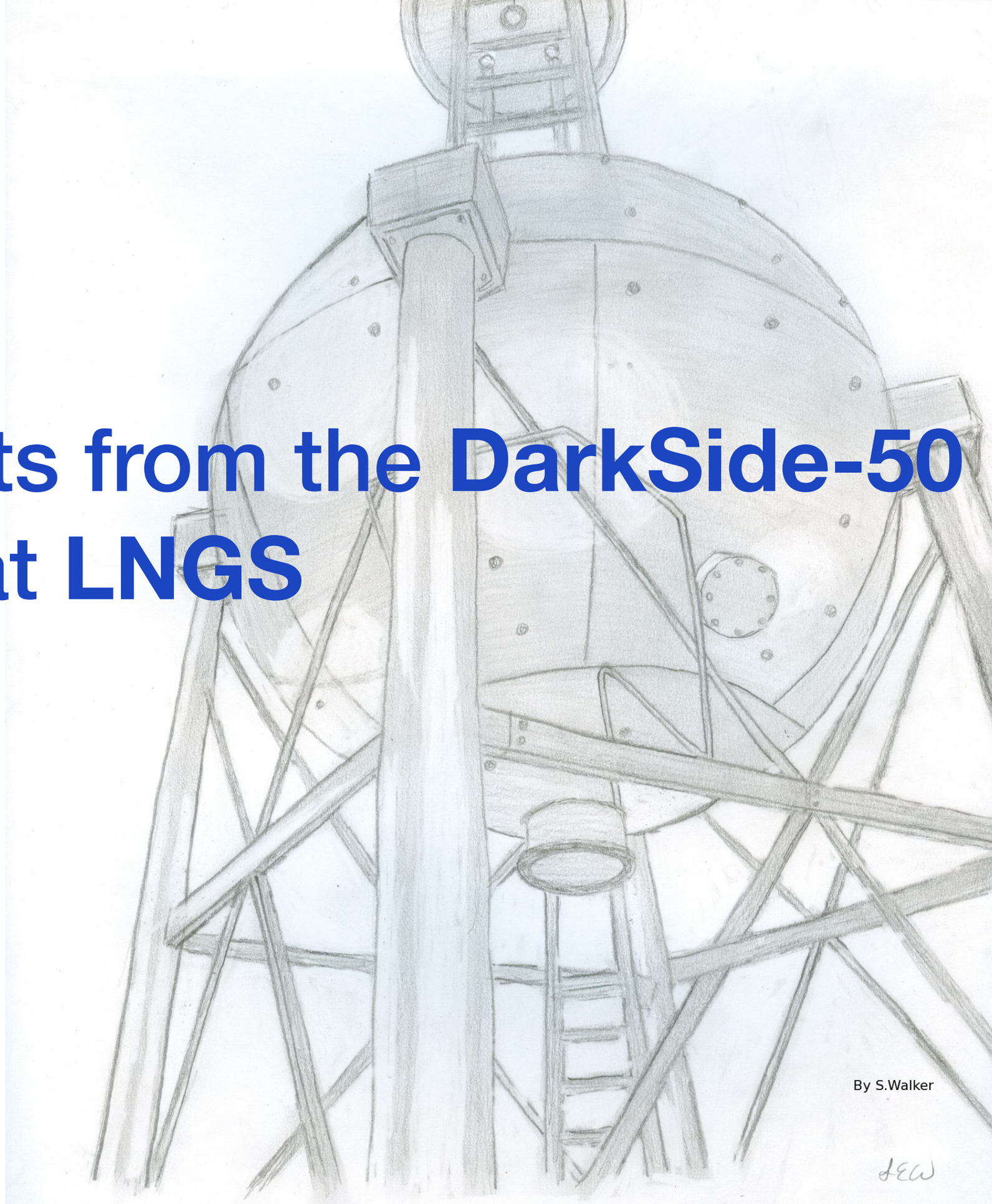
University of Houston

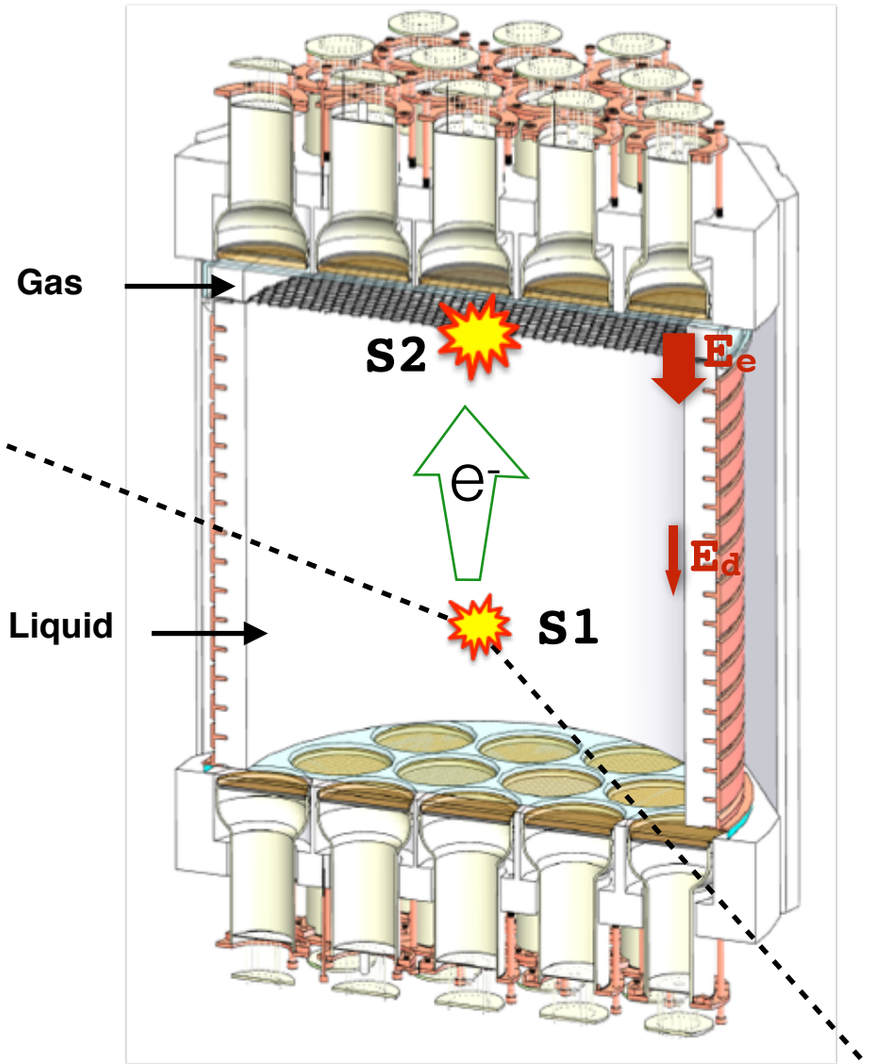
ICHEP 2020

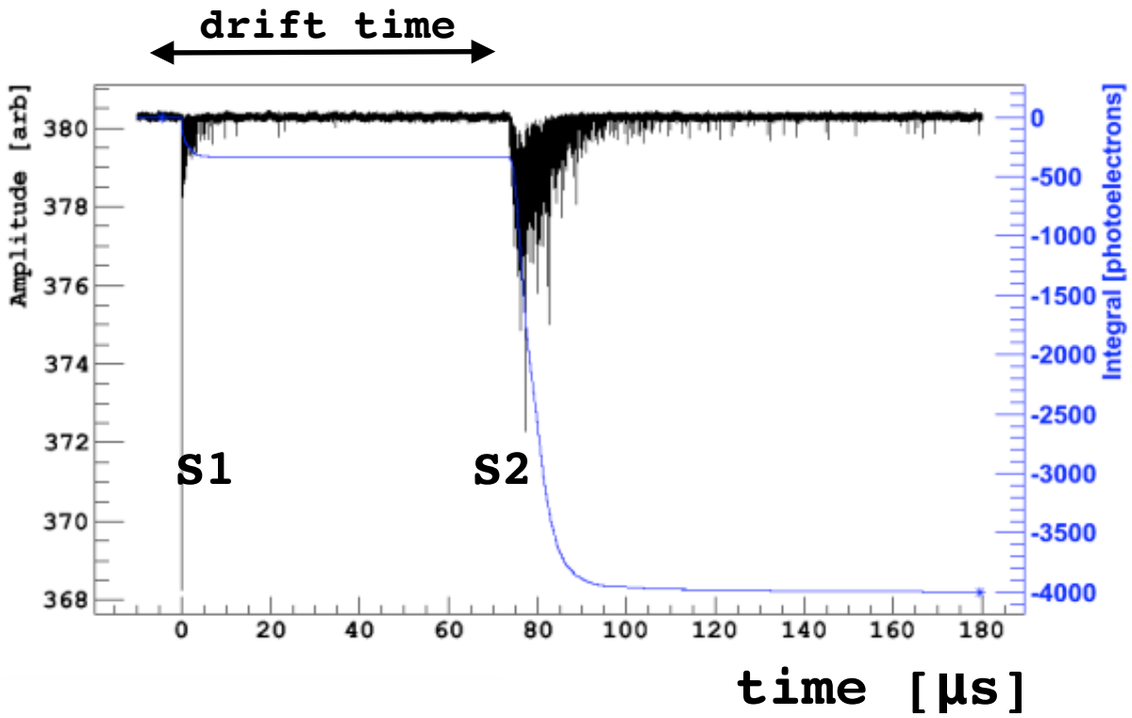
29th July 2020



Dual Phase TPC

When searching for rare **WIMP-induced Nuclear Recoils,** large exposures, low thresholds and background rejection are a challenge





Noble liquid dual-phase TPCs:

- scalability
- 3D vertex reconstruction (surface events, multi-sited events)
- particle identification (background rejection)
- high scintillation/ionisation yields

The DarkSide-50 experiment

A **dual-phase LAr TPC**

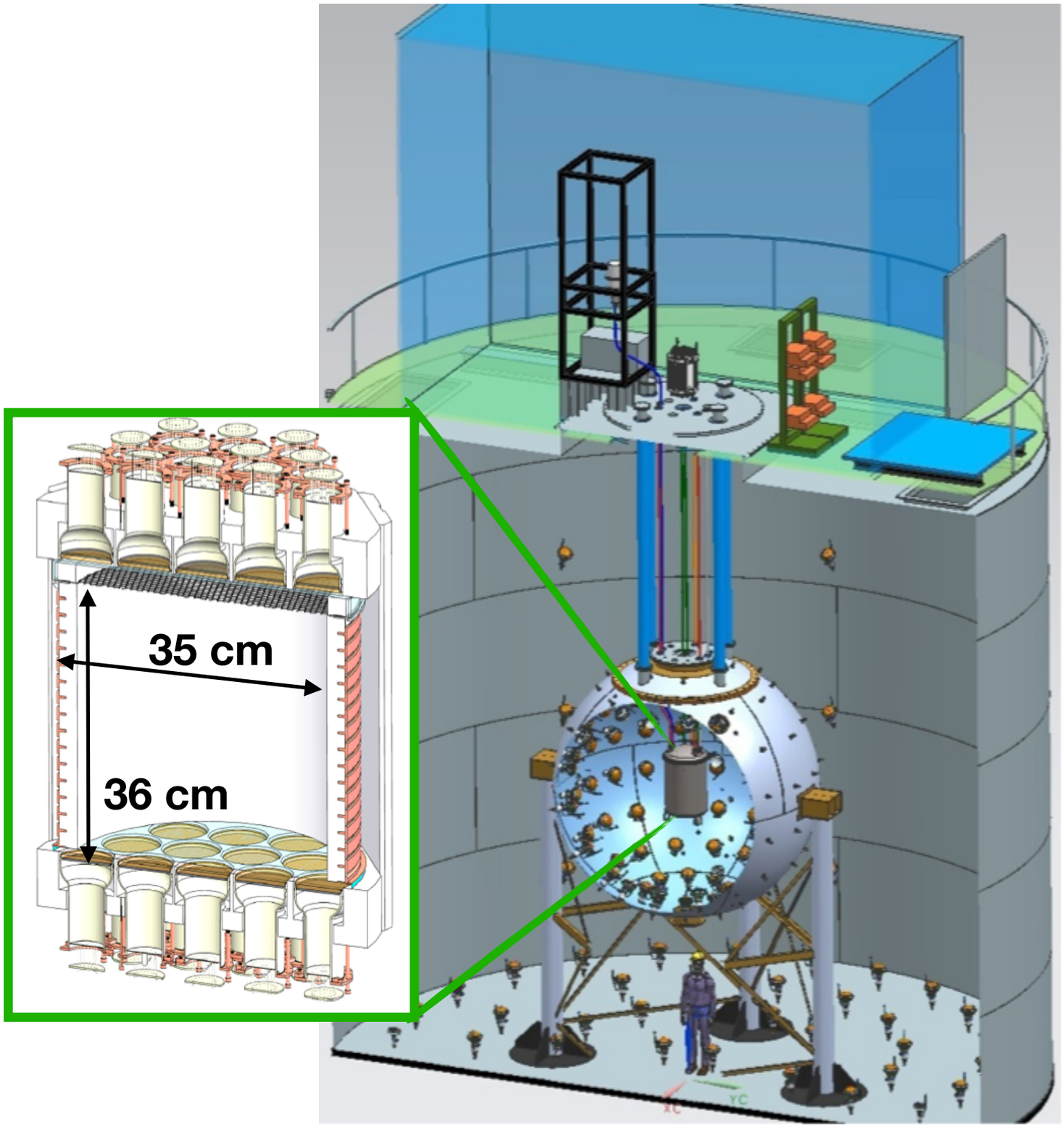
- taking data since 2013 at Gran Sasso
- **50 kg** of **argon** from **underground**
- in a 30 t liquid scintillator veto
- in a 1 kt water Cherenkov detector

S1 and S2 Yields:

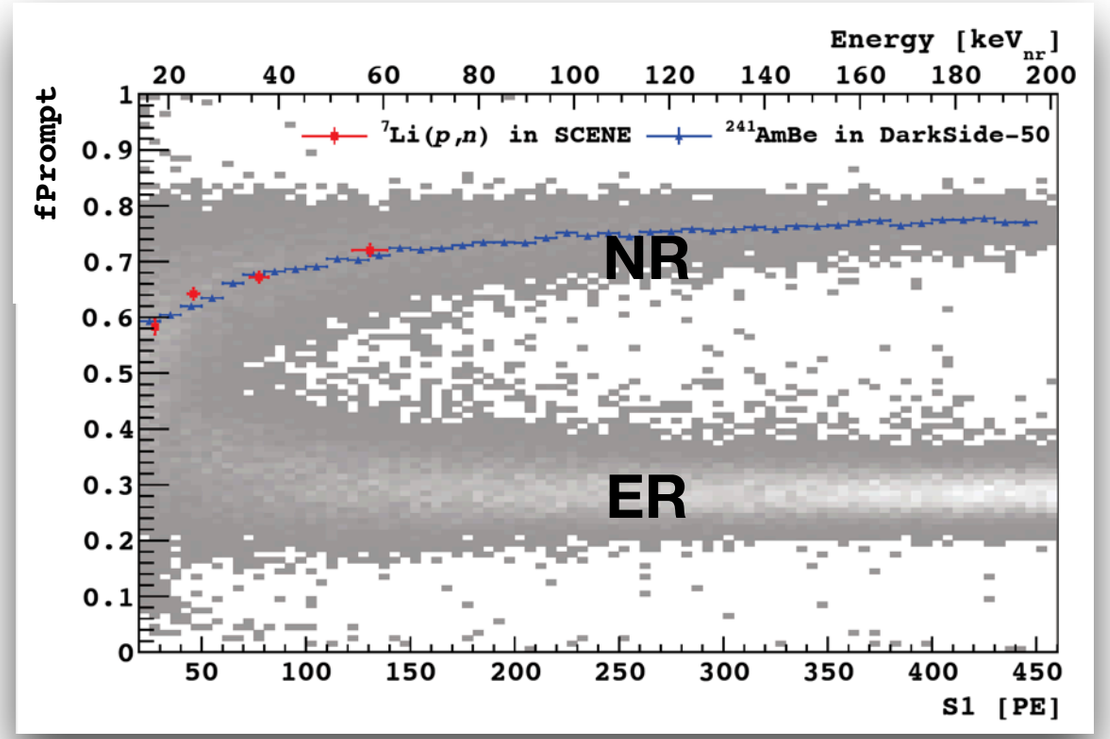
- S1 Yield ~7.9 pe/keV at null field
- S1 Yield **~7.0 pe/keV** at 200 V/cm
- S2 yield **~23 pe / e-**

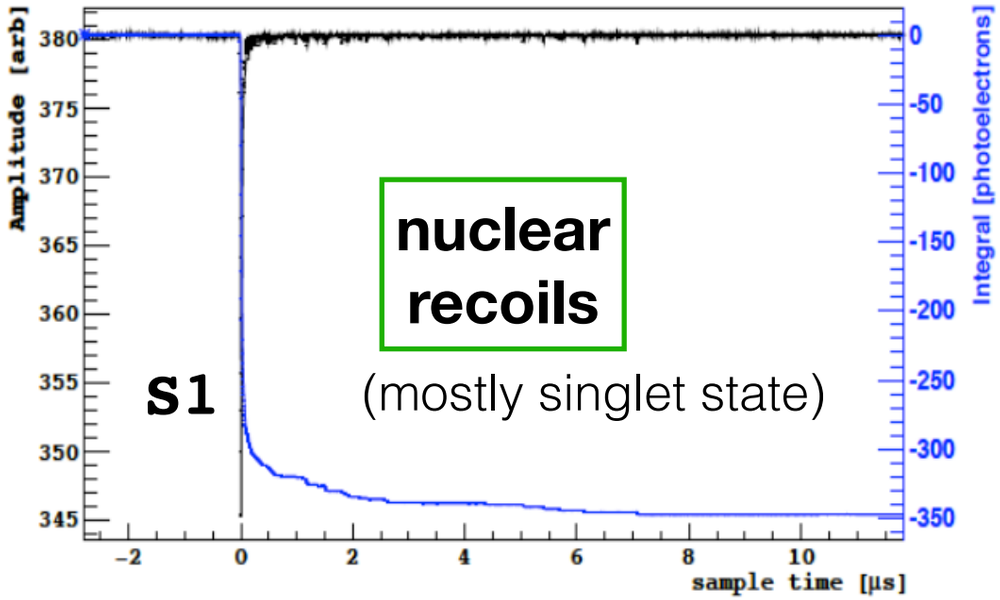
Electron lifetime > 5 ms

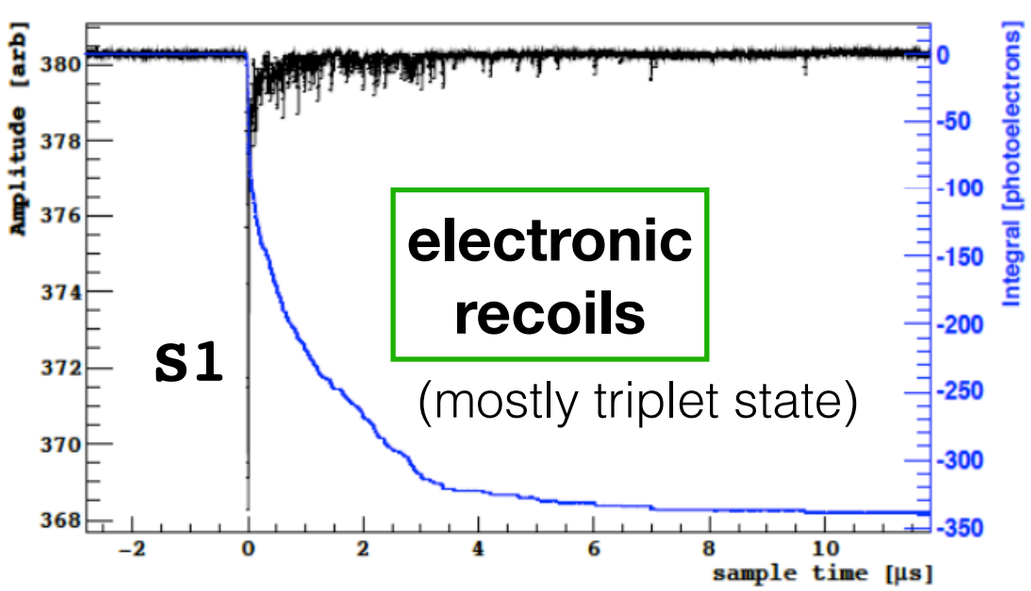
Maximum drift time: 376 μs



Bg Mitigation 1: Pulse Shape Discrimination in LAr







Rejection of Electronic Recoil background:

Ionization/Scintillation: **~ 10^3**

Pulse Shape Discrimination: **~ 10^9**

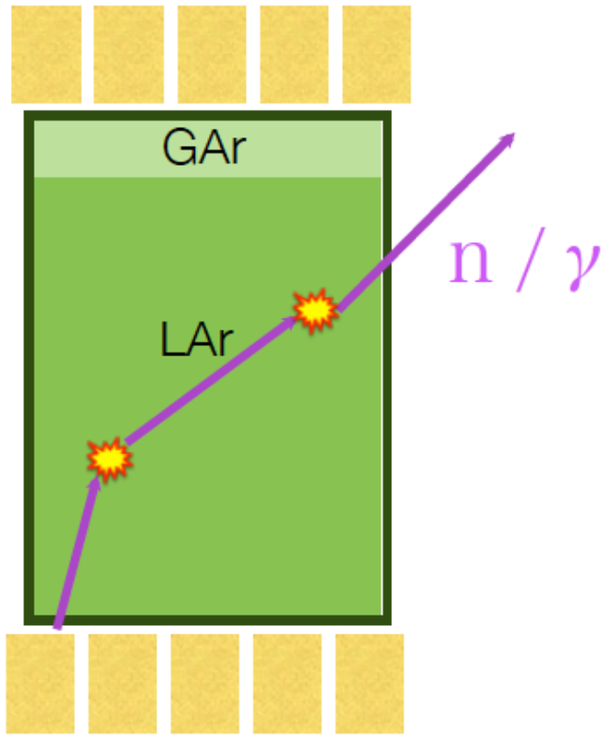
XENON-1t: PRL 121, 111302 (2018)

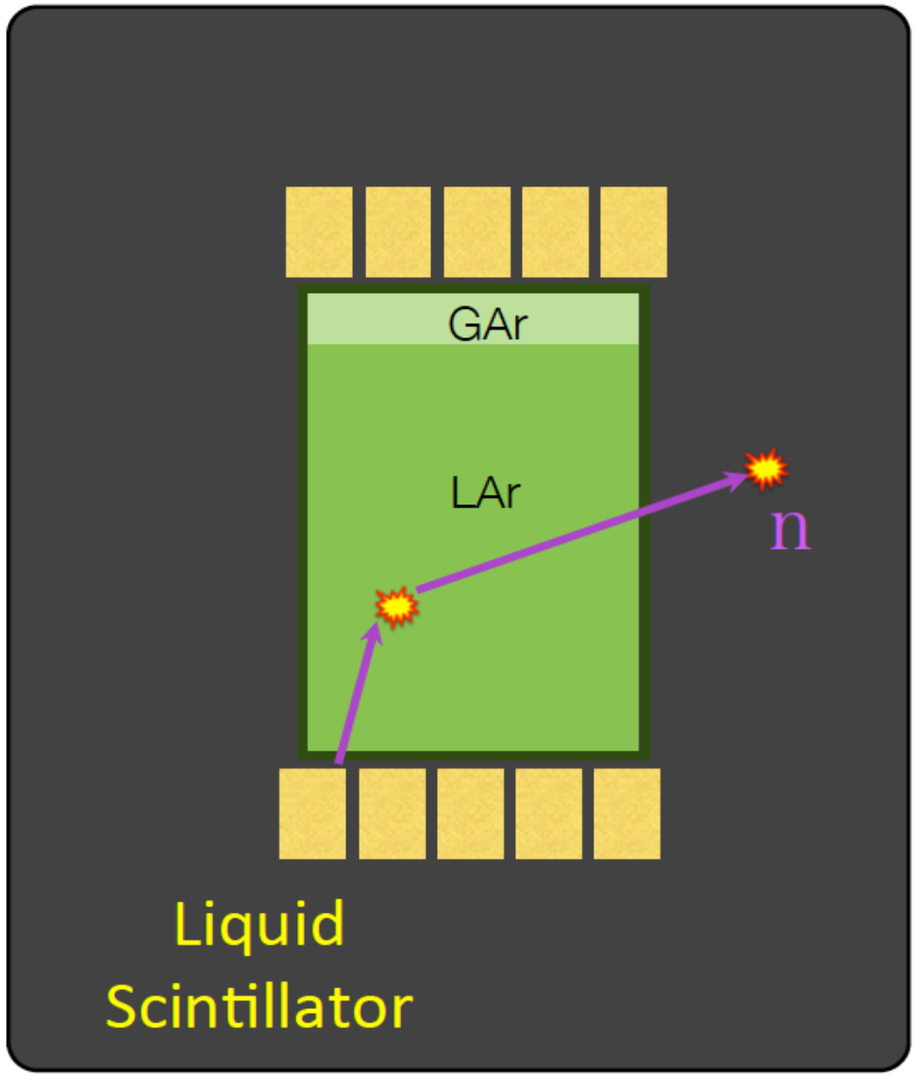
DEAP-3600: Phys. Rev. D 100, 022004

Ar_2^* —> $^1\Sigma_+$: 7 ns
—> $^3\Sigma_+$: 1500 ns

Bg Mitigation 2: Active Rejection

Multiple S2 signal





DarkSide-50 Liquid Scintillator Veto: 30 tons of PC loaded with TMB.
The n capture produces a localised alpha (heavily quenched) and a gamma (BR>90%)

$$^{10}\mathrm{B} + n \rightarrow \begin{cases} ^{7}\mathrm{Li}\ (1015\ \mathrm{keV}) + \alpha\ (1775\ \mathrm{keV}) & (6.4\%) \\ ^{7}\mathrm{Li}^{*} + \alpha\ (1471\ \mathrm{keV}), ^{7}\mathrm{Li}^{*} \rightarrow ^{7}\mathrm{Li}\ (839\ \mathrm{keV}) + \gamma\ (478\ \mathrm{keV}) & (93.6\%) \end{cases}$$

Bg Mitigation 3: Underground Argon

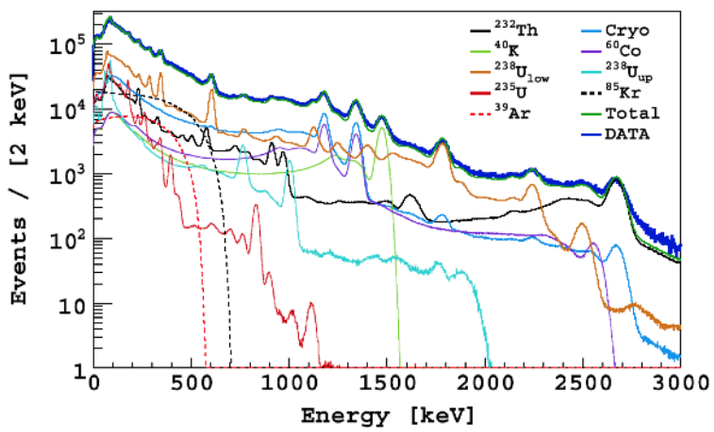
^{39}Ar is produced by cosmic rays in the atmosphere. **β-decay** with **Q = 565 keV**; $\tau_{1/2}$ = 269 yr

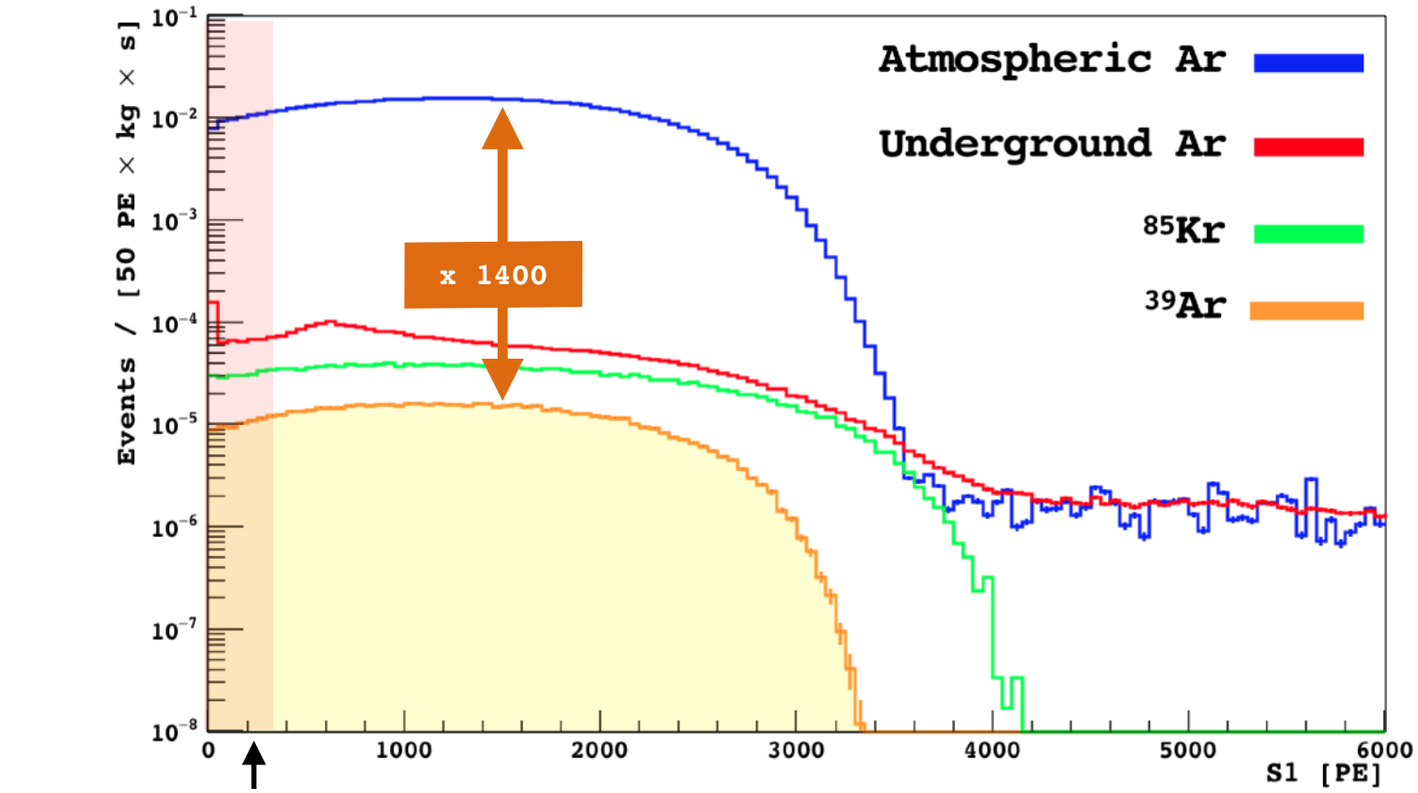
- **^{39}Ar activity in atmospheric argon** (~ 1 Bq/kg): limiting dual-phase target mass

==> extract argon from underground (CO_2 well in Colorado) !

- **^{39}Ar activity in underground argon** (0.73 ± 0.10 mBq/kg)
- Possibly smaller: identification of a ^{85}Kr contamination

DarkSide-50 running with UAr (since 2015) after first AAr run





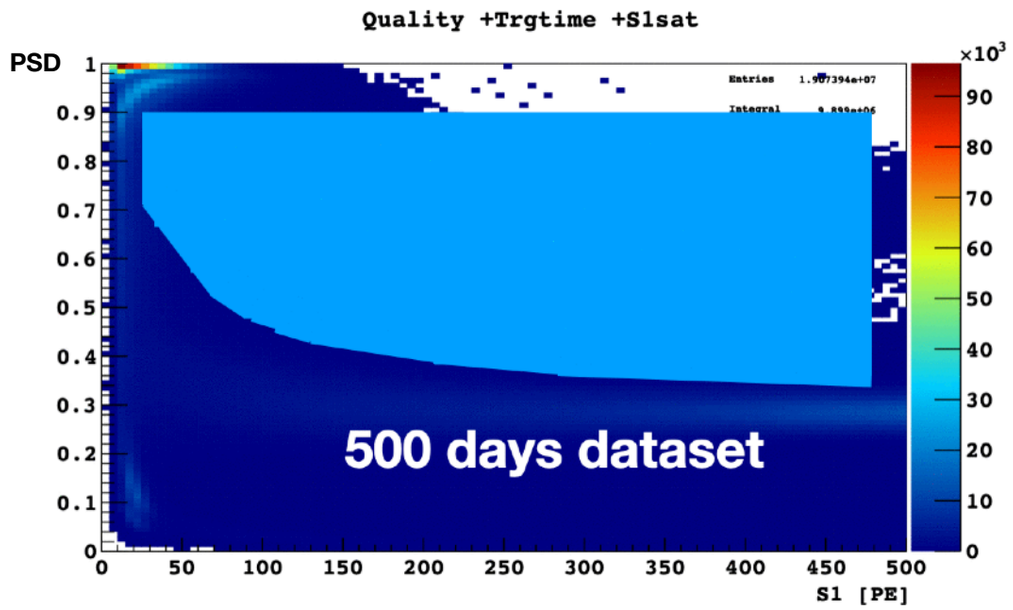
Phys. Rev. D 93, 081101 (2016)

High-mass WIMP result

Blind analysis published in 2018

- Use first 70 days of UAr dataset to tune cuts
- Minimise backgrounds while maximising acceptance to NR

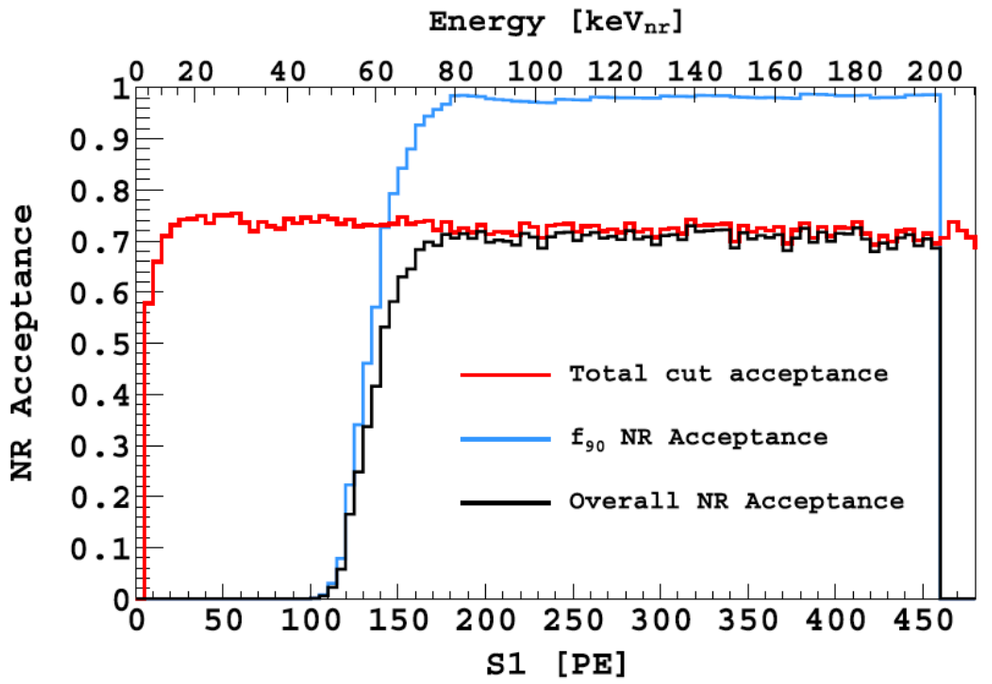
- **Background-free** exposure of +500 days!



Expected backgrounds in ROI, before opening box

surface alphas	0.001
cosmogenic neutrons	<0.00035
radiogenic neutrons	<0.005
electron recoil	0.08
	0.09±0.04

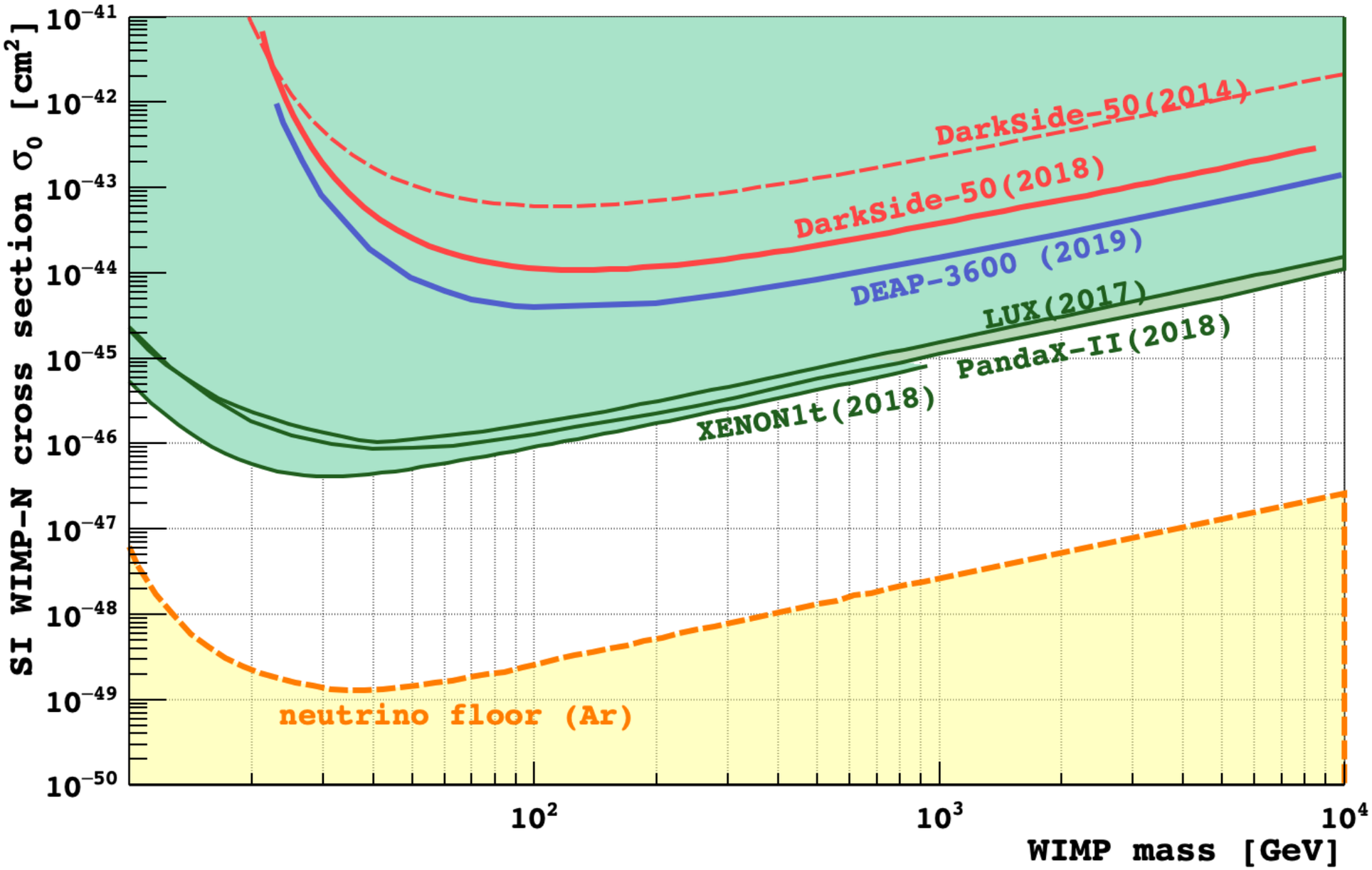
NR acceptance after all cuts. Threshold driven by PSD:



Phys. Rev. D 98, 102006 (2018)

High-mass WIMP result

90% CL upper limits on spin-independent WIMP-nucleon coupling



DS-50: Phys. Rev. D 98, 102006 (2018)

DEAP-3600: Phys. Rev. D 100, 022004 and S. Viel talk here

DS-20k: L. Rignanese talk here

PandaX-II: Phys Lett B 792, 193 (2018)

XENON-1t: PRL 121, 111302 (2018)

Low-energy signals

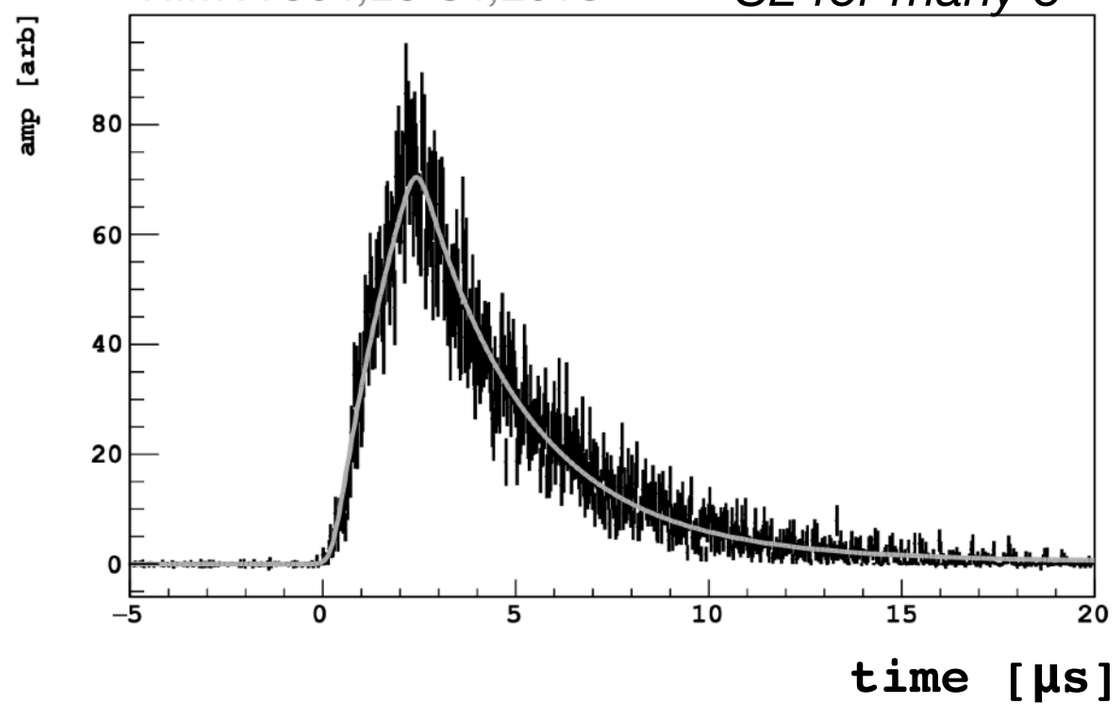
Below 3 keV_{ee}: **ionization-only analysis.**

- No scintillation (S1):
  - Fiducialization lost (vertical)
  - **No discrimination available**
- Multiplication in gas phase (**23±1 PE/e^-**)
  - **100% trigger** efficiency at 1.3 e^- (W_{ion} = **23.5 eV**)

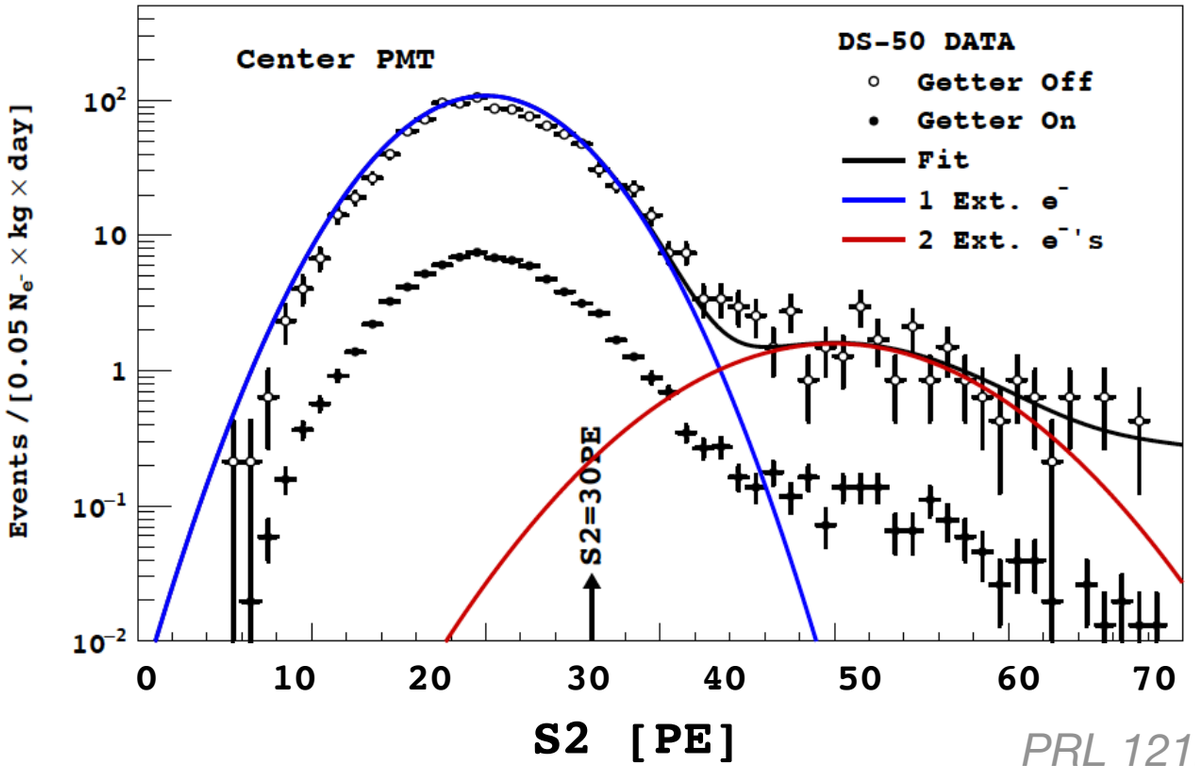
(Trigger condition: 2 PMTs firing in 100 ns)

NIM A 904,23-34,2018

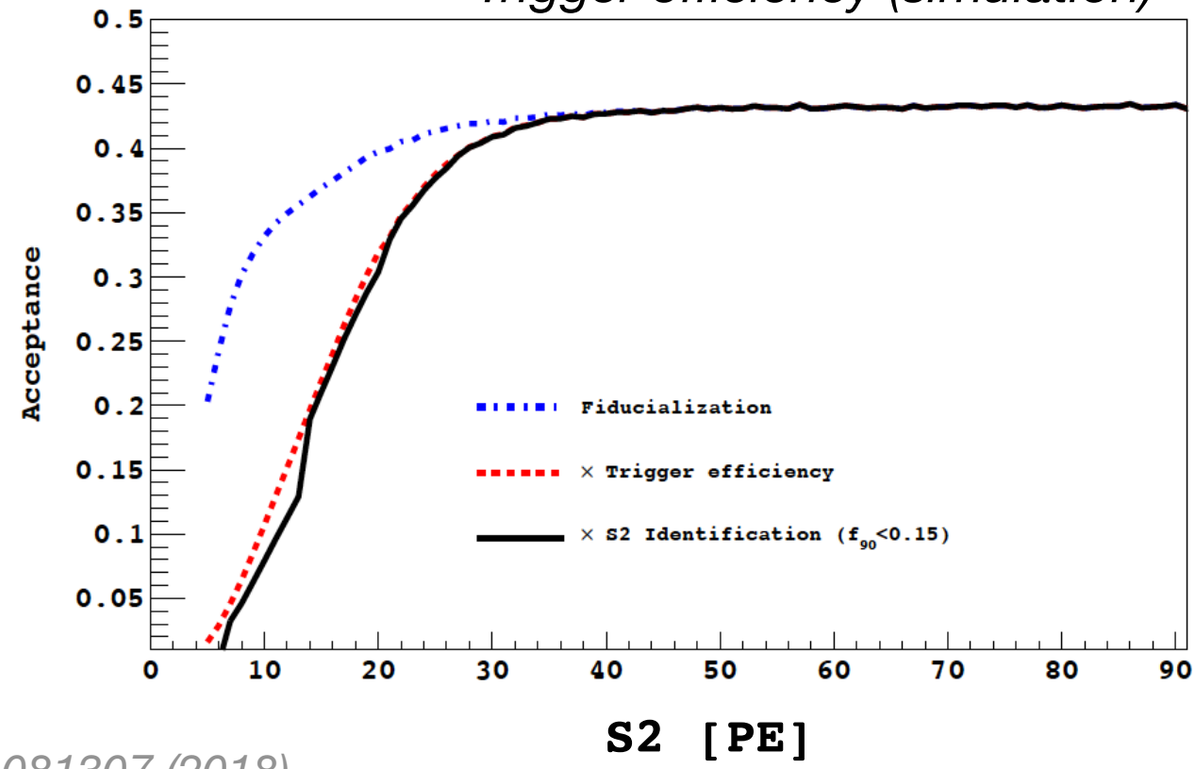
S2 for many e^-



Spectrum of single electrons



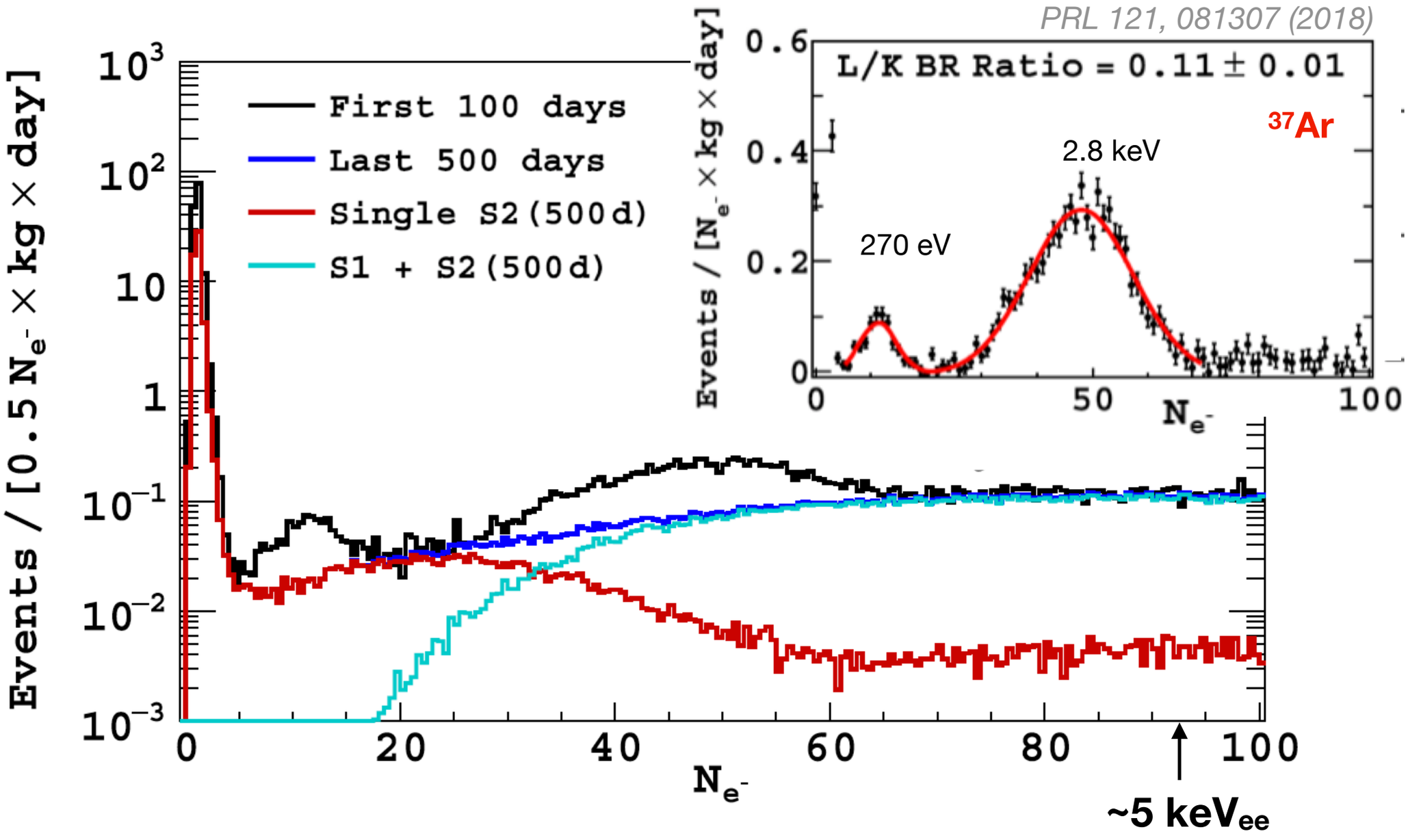
Trigger efficiency (simulation)



PRL 121, 081307 (2018)

Calibration of ER at low-energy

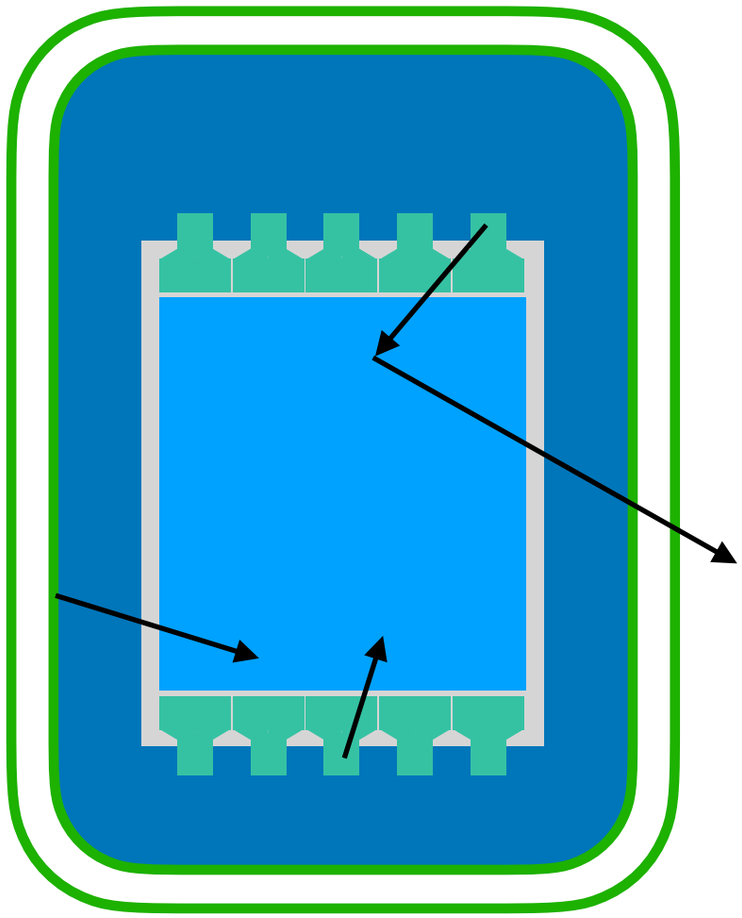
- Calibration of **electronic recoil energy scale** down to **270 eV** thanks t ^{37}Ar ($\tau_{1/2}$ ~ 35 days)
- Activated during **transport**

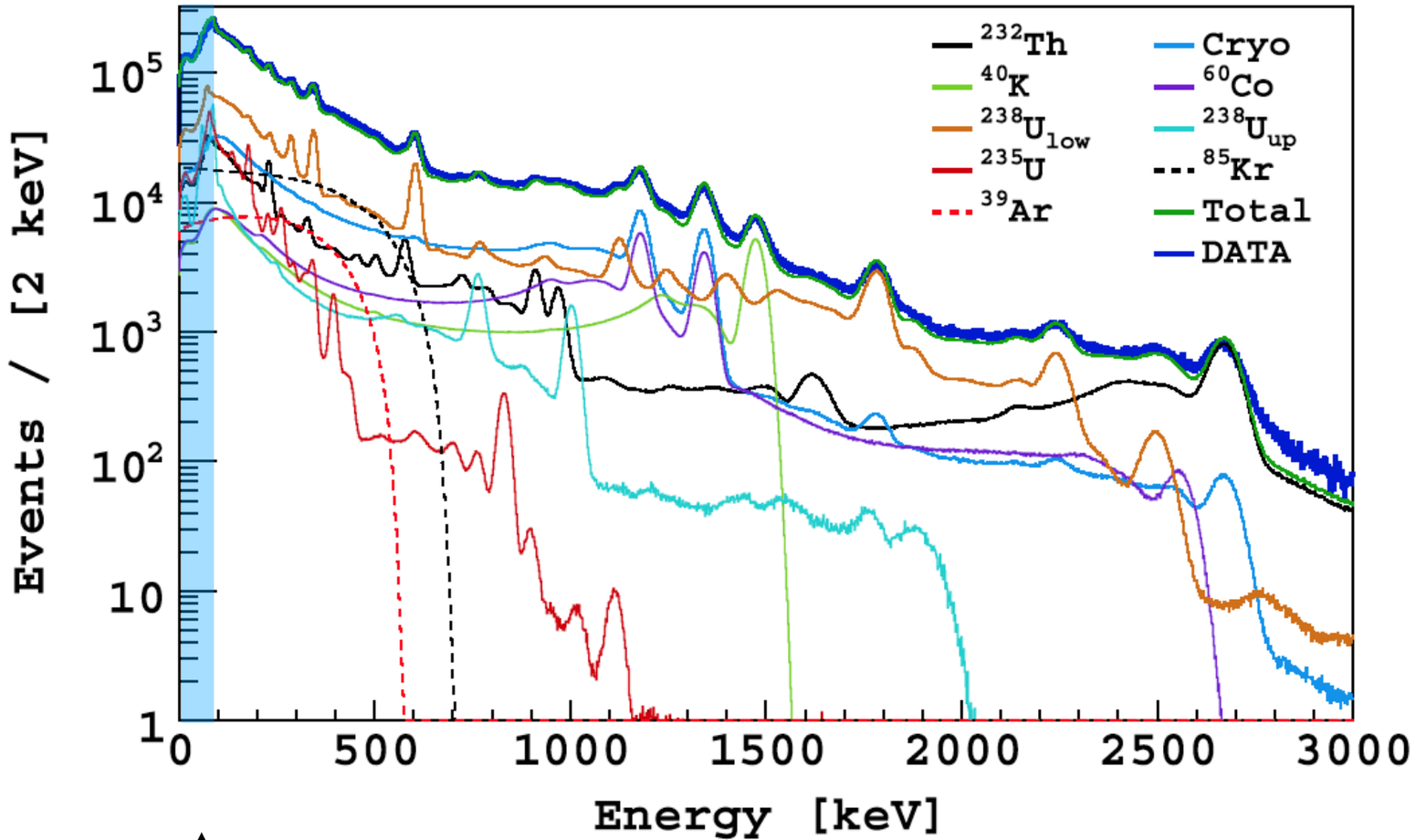


Background model

Background model for DarkSide-50

- Full simulation of **each radioactive component** (^{238}U, ^{232}Th, ^{40}K, ^{60}Co) from detector materials and intrinsic to the target (^{39}Ar and ^{85}Kr).
- **Multivariate fit** based on S1 single scatter, S1 multiple scatter, and drift time
- Covers a wide energy range





WIMP search region (< 50 keV$_{ee}$)

Calibration of NR at low-energy

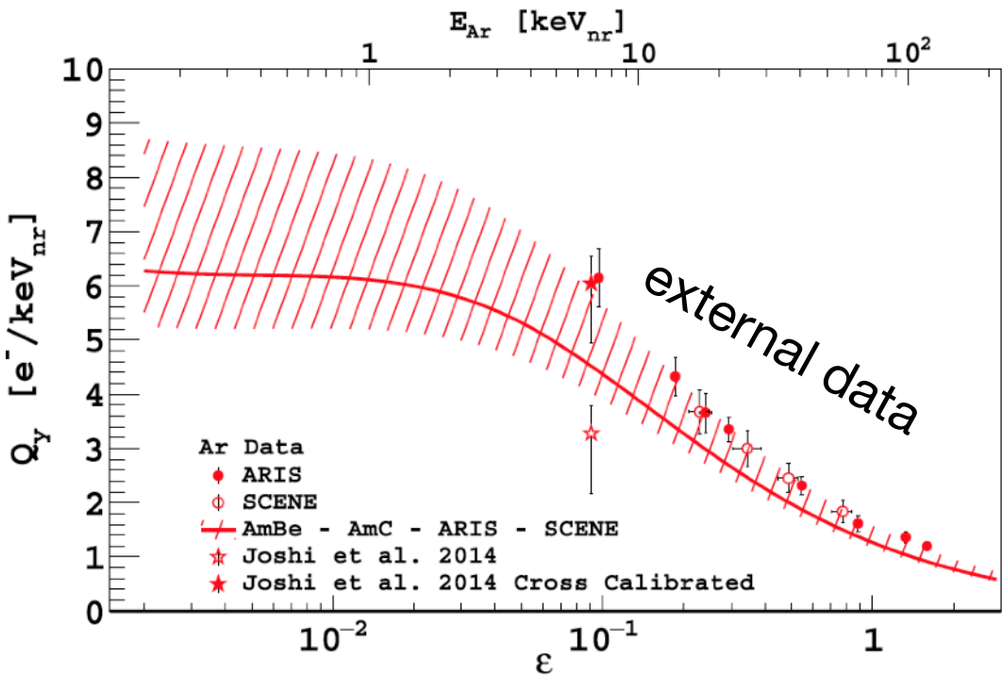
Nuclear recoil energy scale below ~1 keV_{NR}

NR: quenched due to nuclear collisions

Effective model (quenching, recombination probability: *Astrop. Phys. 35, 119–127, 2011*) **fit to neutron sources data**

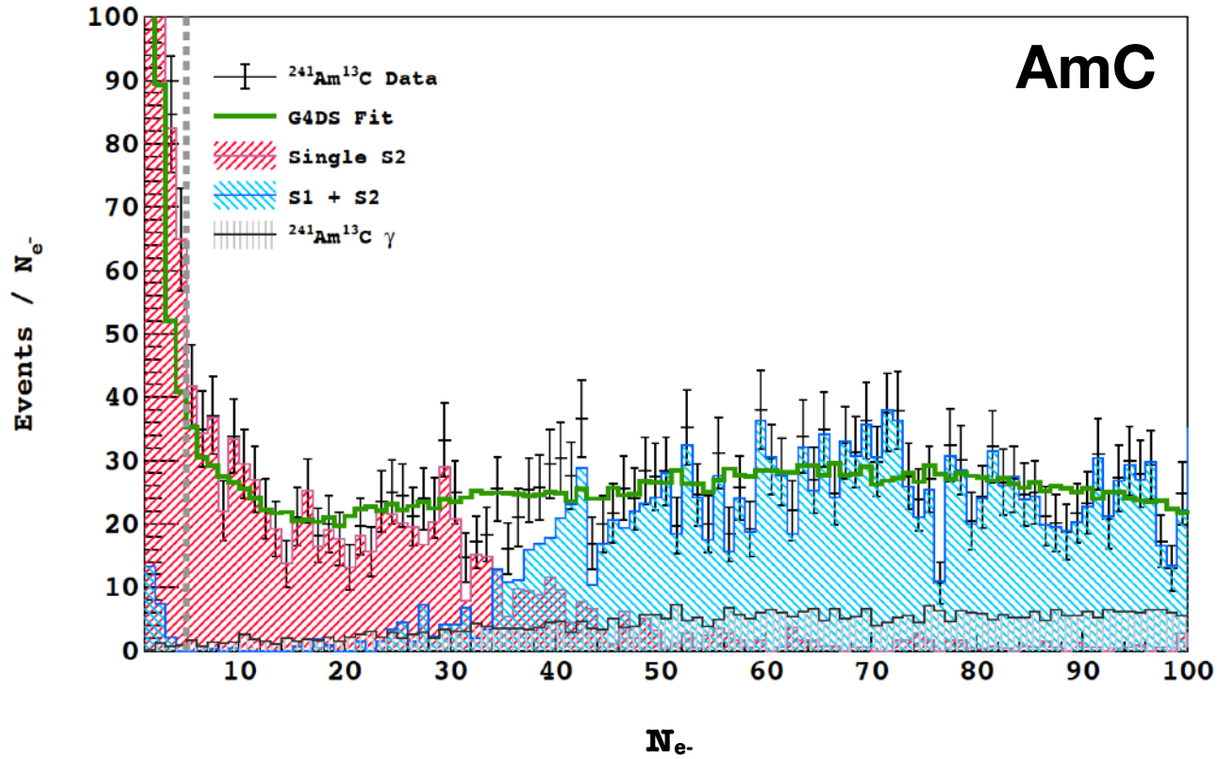
Validation through extrapolation at higher energy: **agree** with **external** calibrations

Calibrated ionization yield

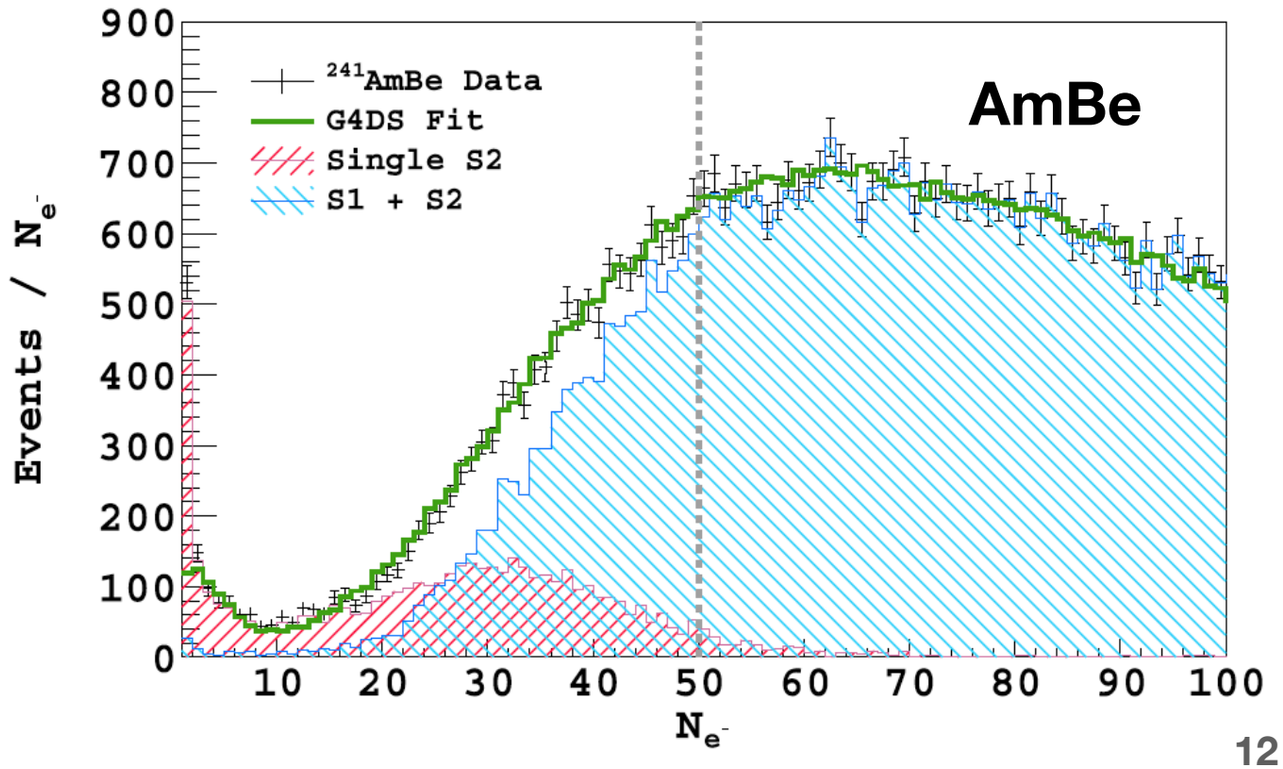


PRL 121, 081307 (2018)

Calibration of nuclear recoils with AmC source

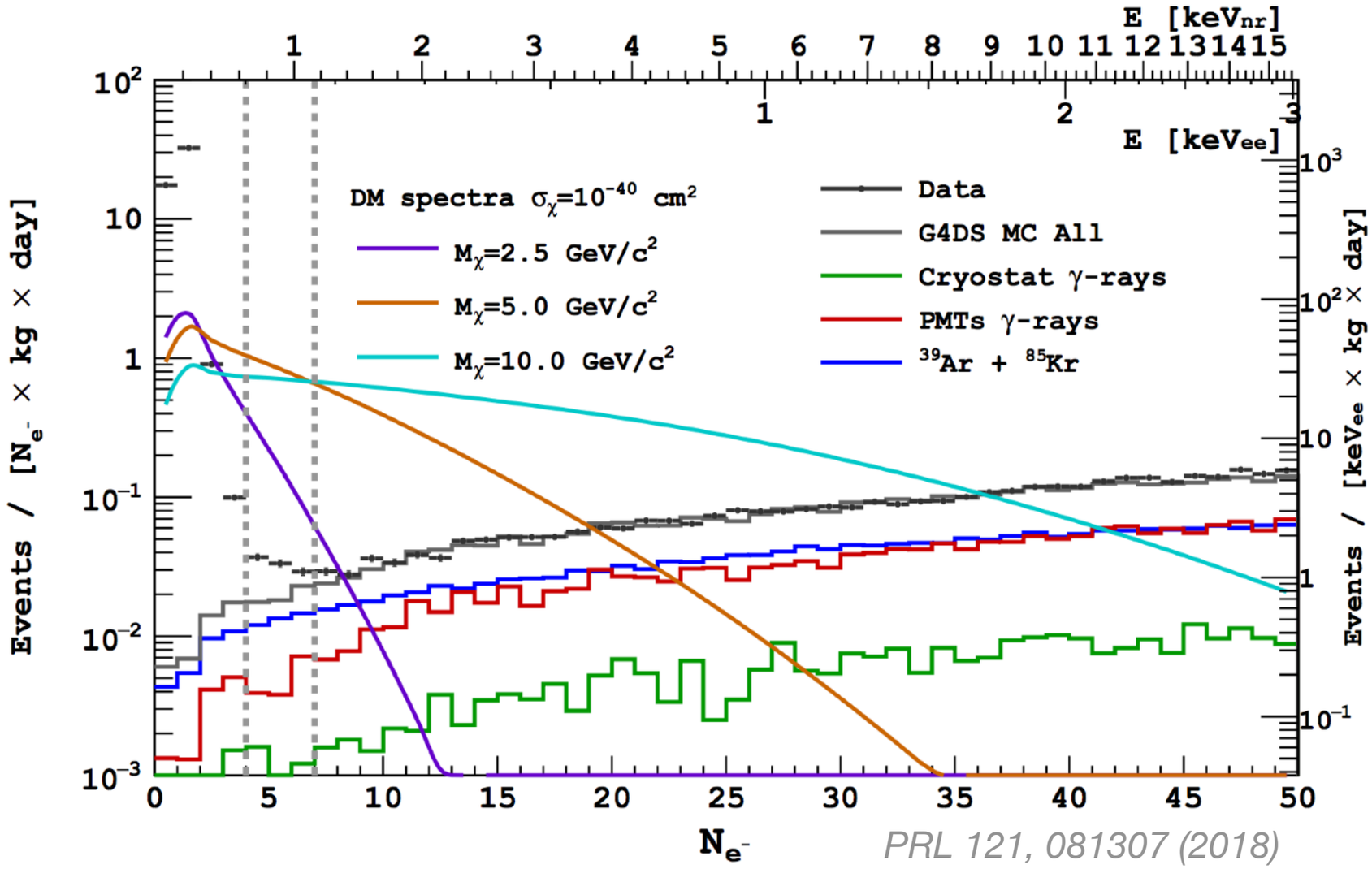


Calibration of nuclear recoils with AmBe source



Low-mass WIMPs

- **Calibration of ER energy scale: predict backgrounds** using result at **high energy** (internal and external β's and γ's). Peak at very low N_{e^-} un-modeled but understood
- **Calibration of NR energy scale: predict signal** for any light WIMP mass
- Profile Likelihood analysis; analysis threshold set at 4 electrons
- Good agreement above 7 electrons

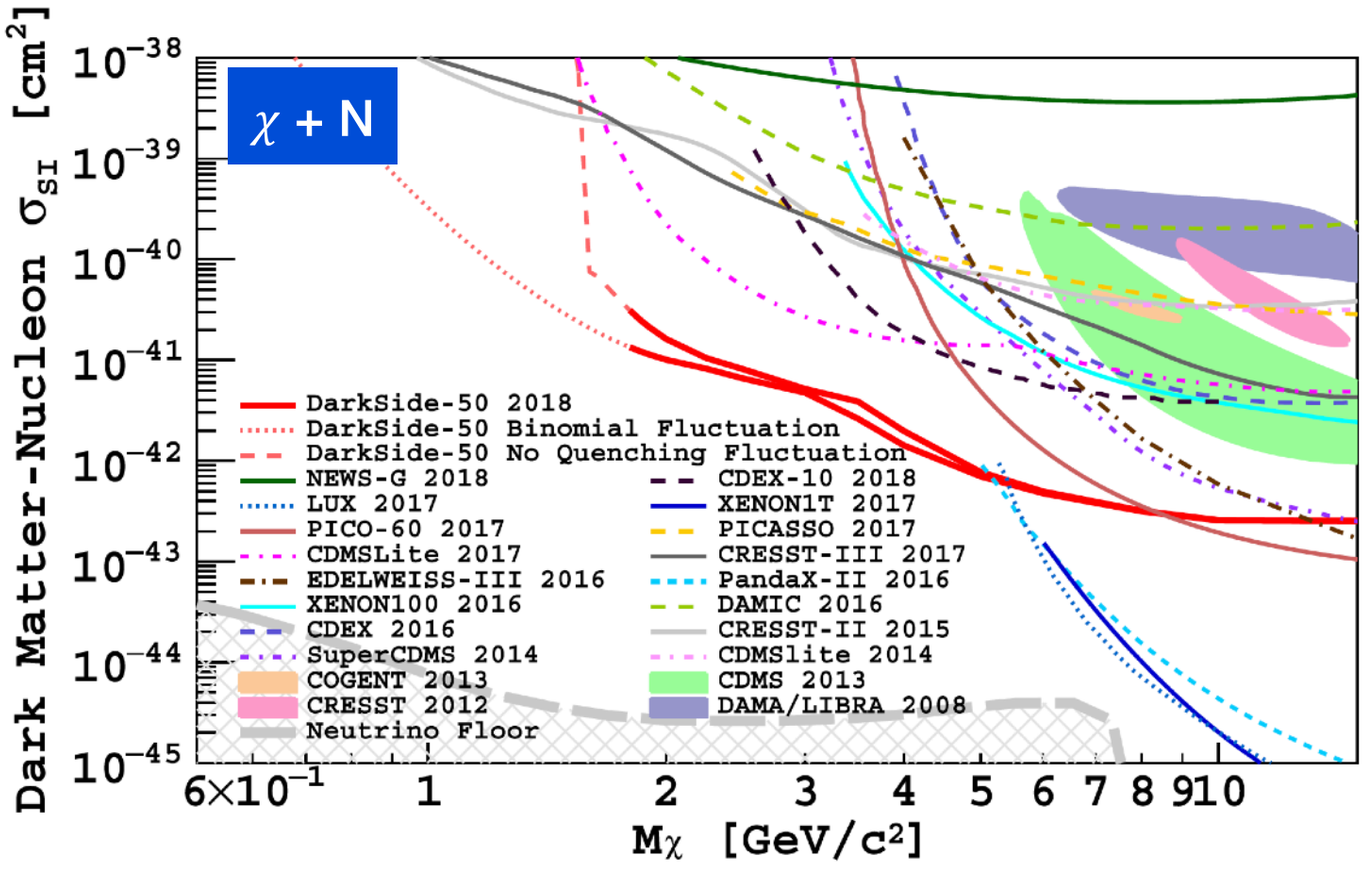


PRL 121, 081307 (2018)

Low-mass WIMPs

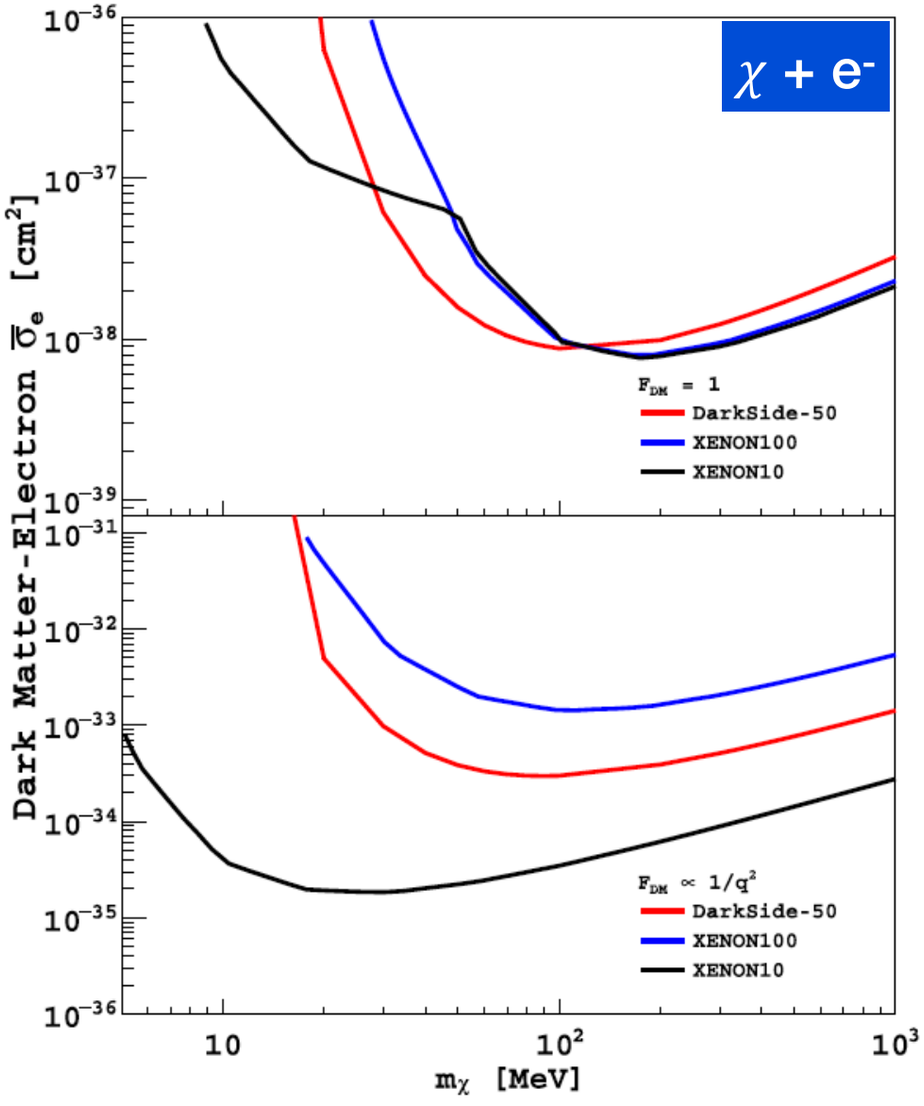
- **World leading exclusion** on WIMP-N cross section **between 2 and 6 GeV/c²**
- **Two curves** reflect uncertainty on the **statistics** of nuclear recoil **quenching**

- **Interpretation** of results on WIMP-electron coupling



PRL 121, 081307 (2018)

XENON-1t provides better exclusion in some region of param space

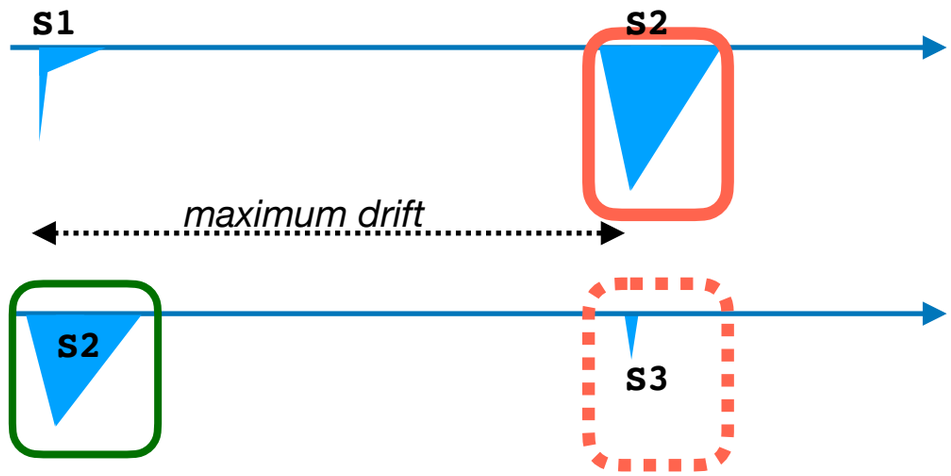


PRL 121, 111303 (2018)

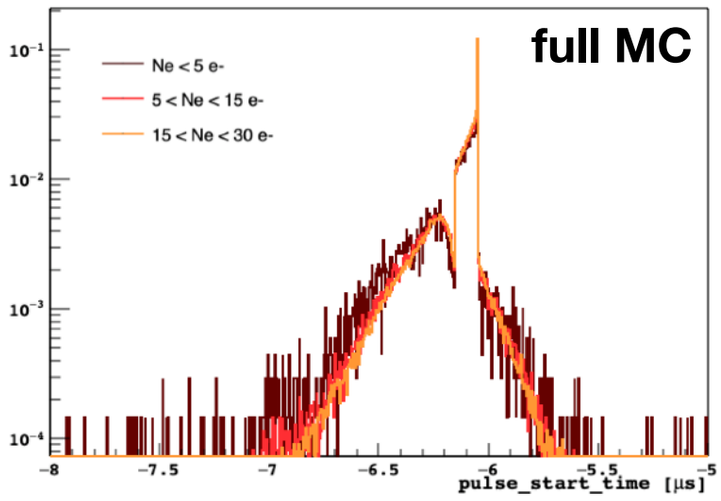
Improvements - data selection and bg model

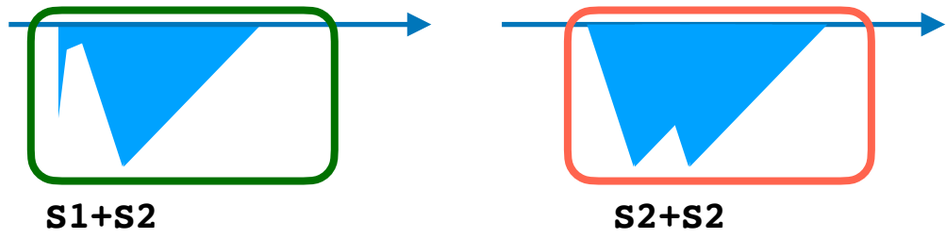
Increased **statistics**: +1.5x the 2018 dataset.

Improved **data selection**:
- recover acceptance for certain classes of events
- improve rejection un-modelled/pathological ones

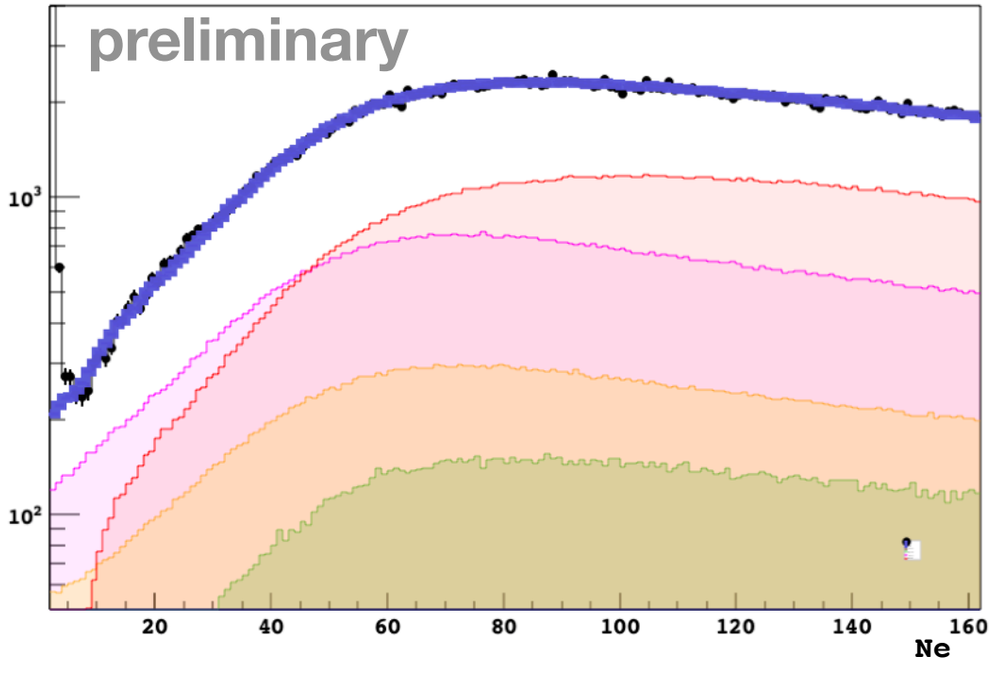


pulse finder mis-reconstruct S2 pulse start times





Improved **background model**:
- extended above 50 Ne (constrain bg above signal)
- more accurate pdfs, improved constraints on internals, new calibration



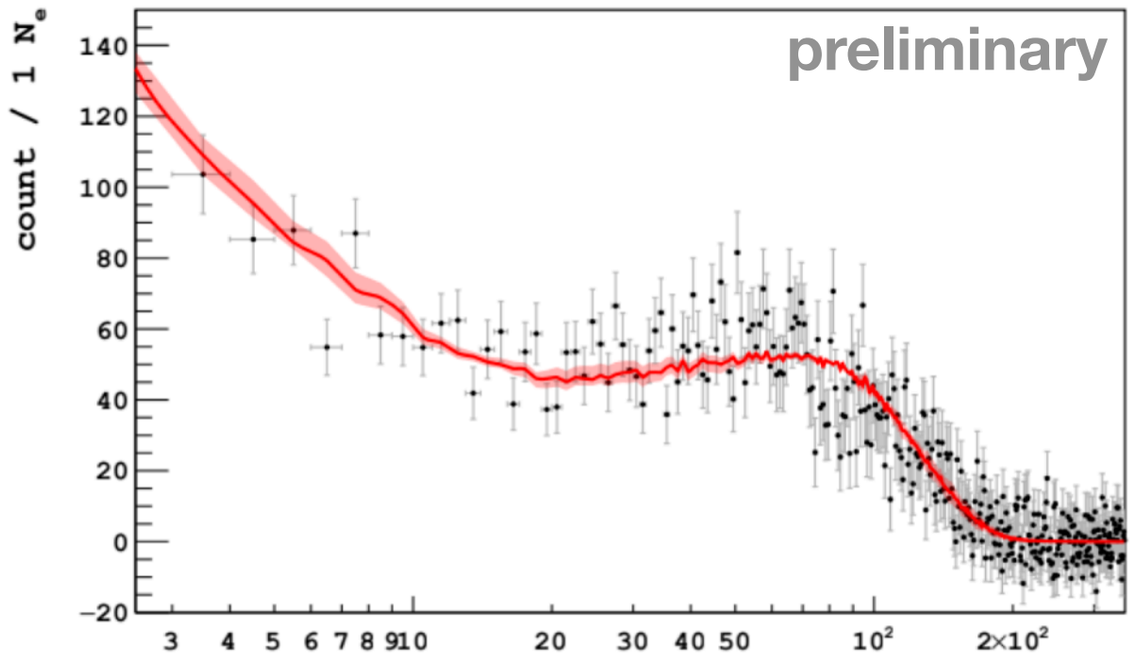
Improvements - calibration

Improved **calibrations**: both for NR (signal) and ER (background) responses.

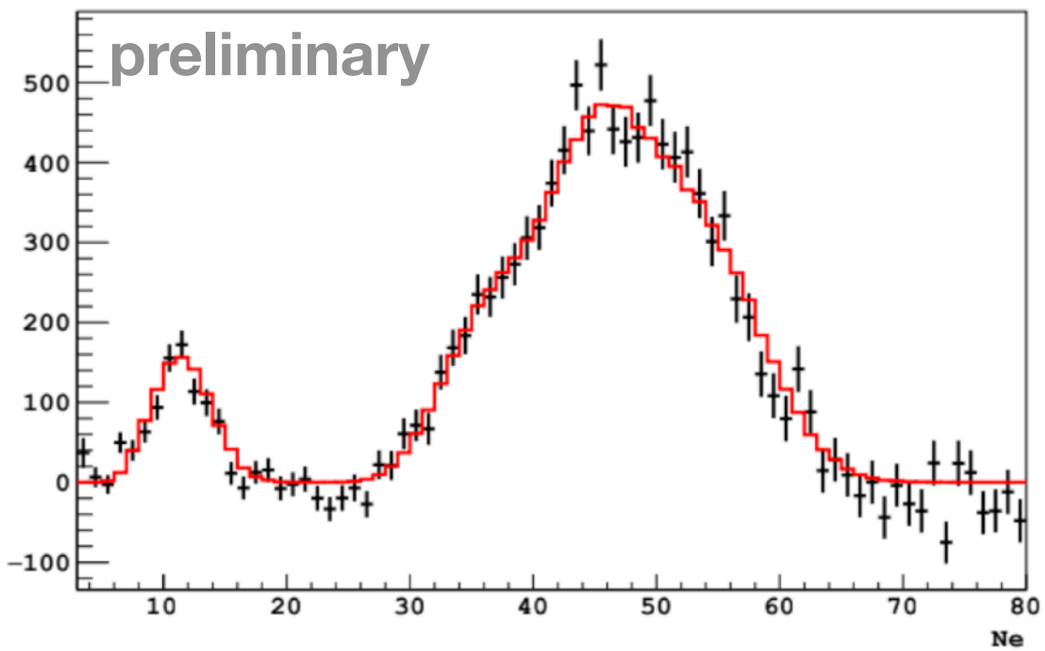
Disentangle detector effects (radial dependency, g2 multiplication, geometry) from signal fluctuations and energy scale

==> **reduction** of the overall **systematic** uncertainties

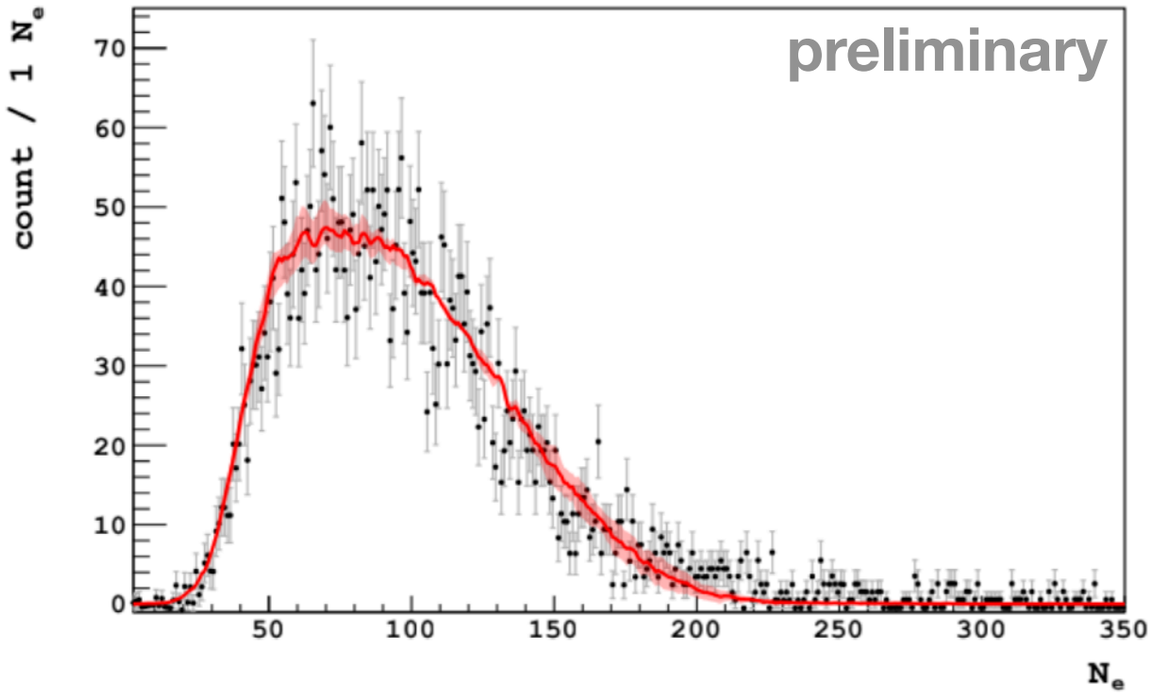
NR calibration with AmC



ER calibration with 37Ar



NR calibration with AmBe

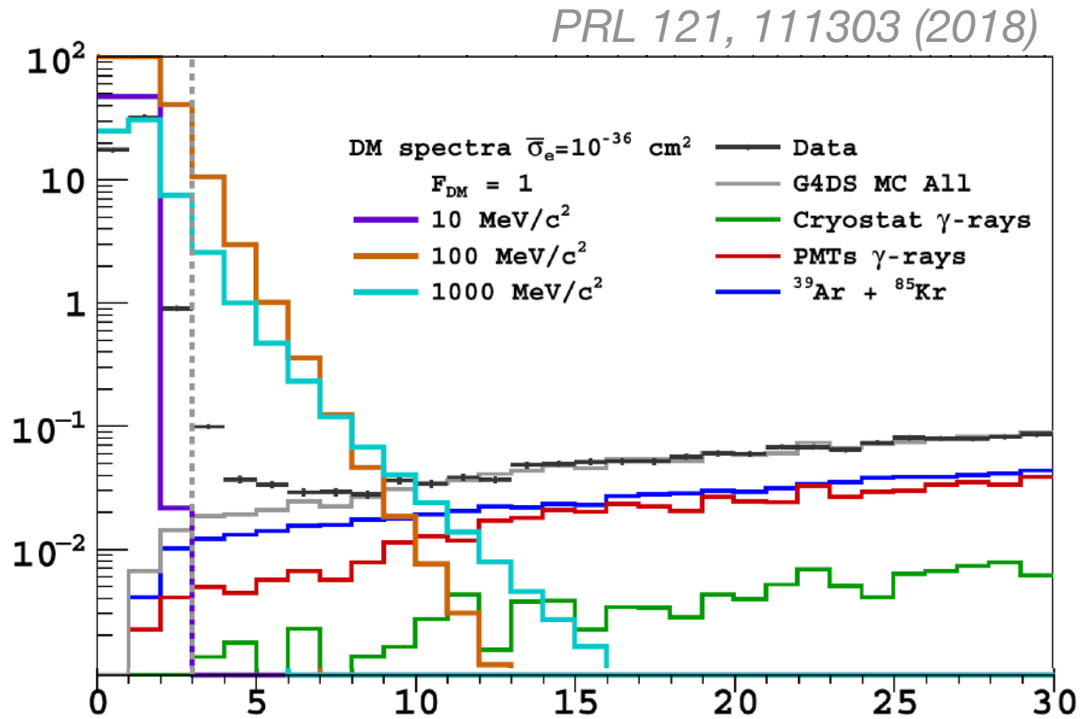


Low-energy analyses

Expect significant improvements in the exclusion limits for light-WIMP-n searches. Currently being finalised

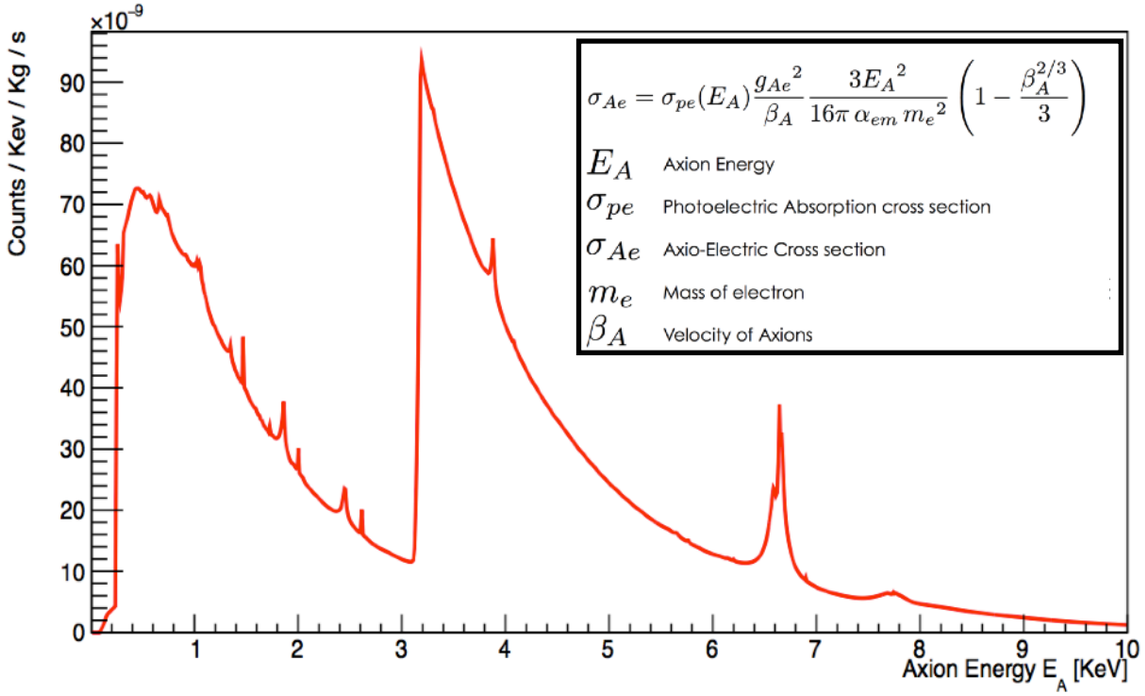
Same data to constraint other interactions with electron final states

- WIMP-electron coupling ==>



PRL 121, 111303 (2018)

- Axions (solar, galactic)



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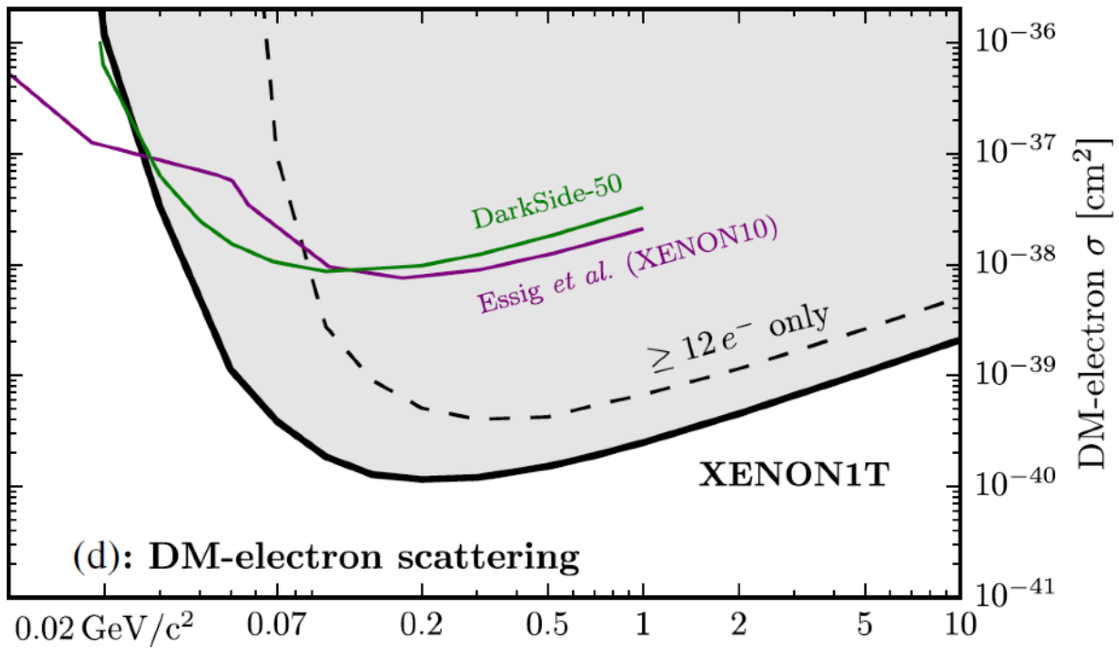


PRL 123, 251801 (2019)

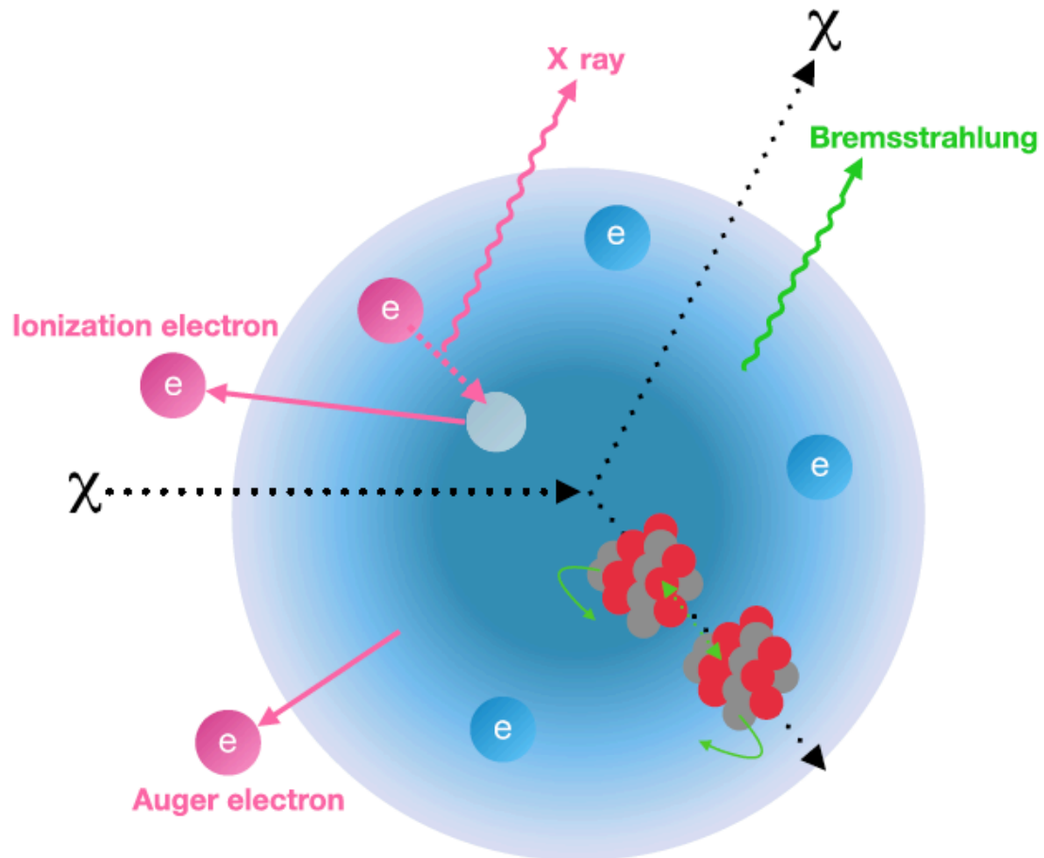
Low WIMP mass with Migdal Effect

Struck atom may **release electron(s)**

Predicted probability is << 10^{-3} and a function of ***q***, thus:

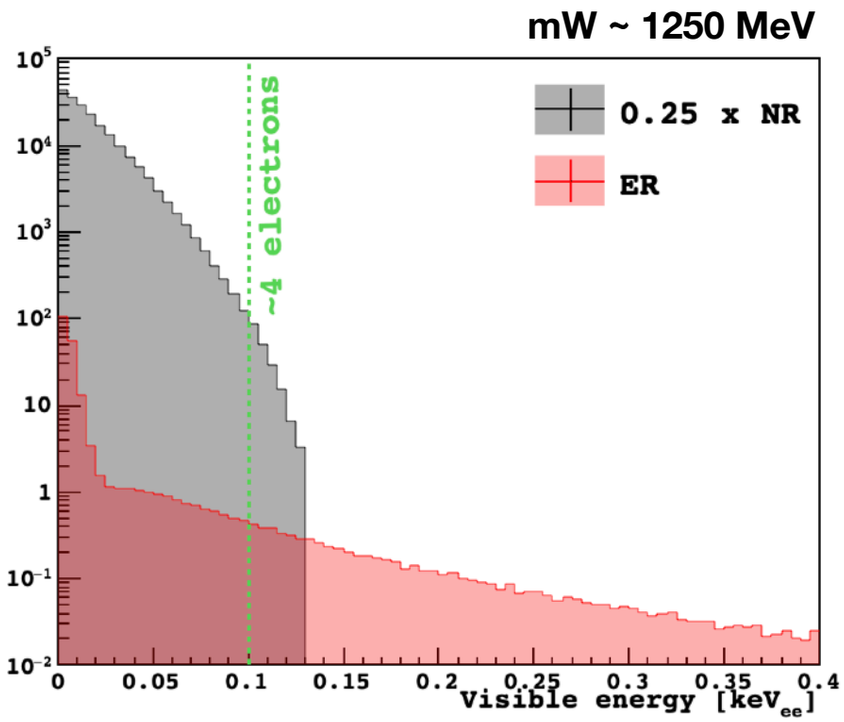
- only small correction for high-mass WIMPs
- decreases for light DM particles

However, the ER channel, as opposed to NR one, is **not quenched** and may **enhance** sensitivity to low-mass candidates



picture from PRL123, 241803 (2019)

See Y. Kahn talk on Tuesday



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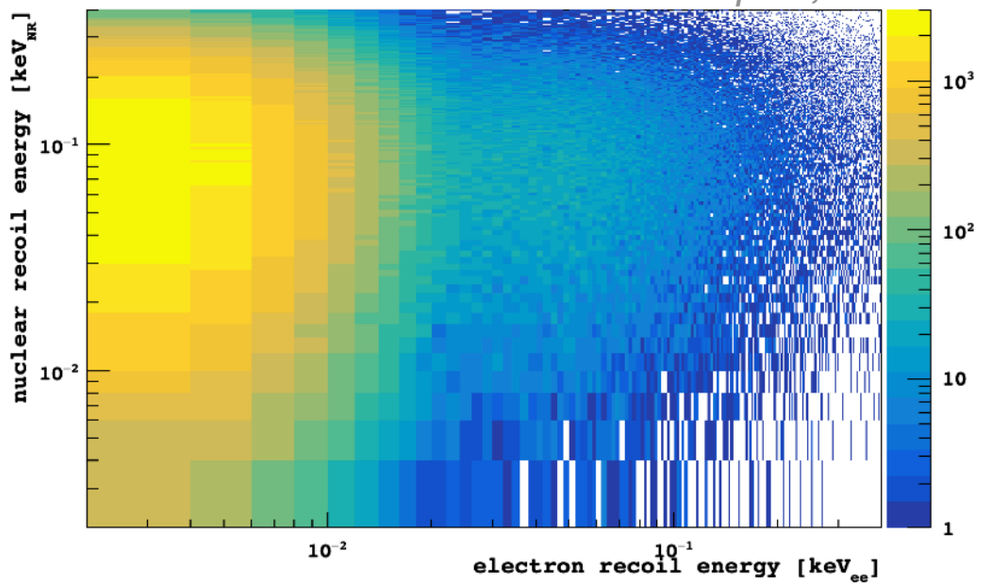
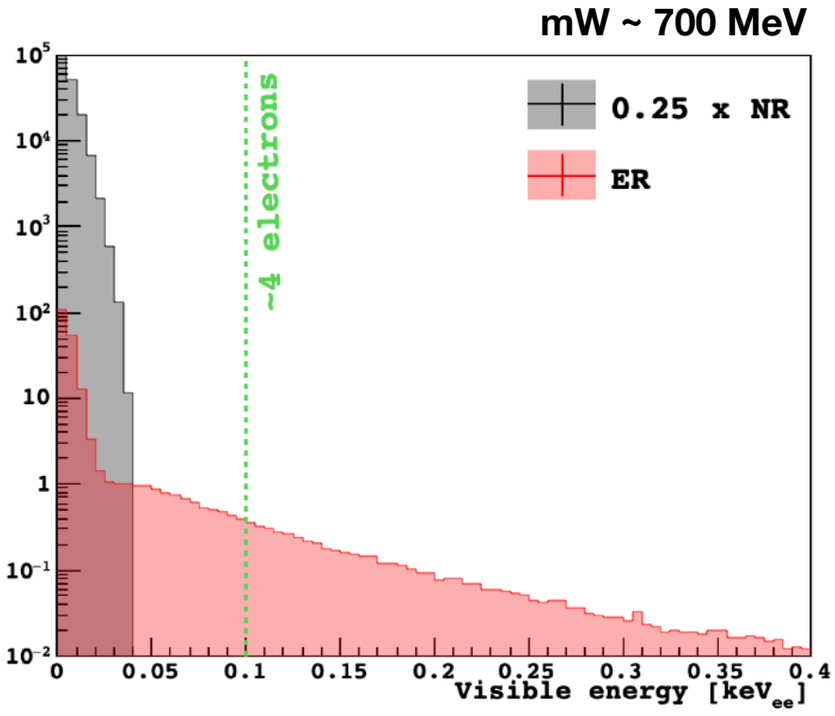
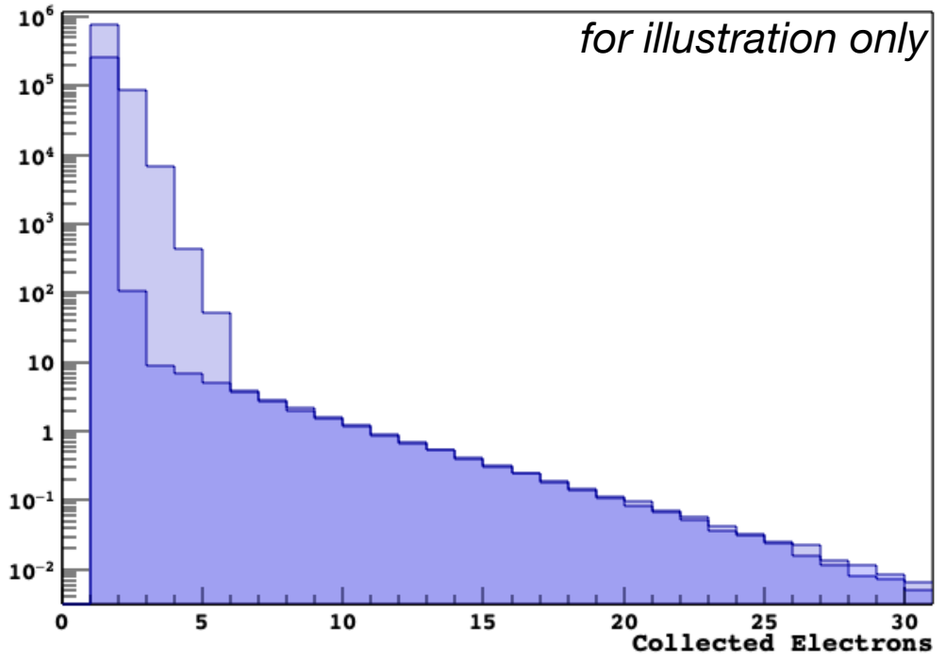
credits to M. D. Campos, KCL



- **conserve** NR and ER **correlation**
- treat **NR and ER** as **independent**





EFT operators

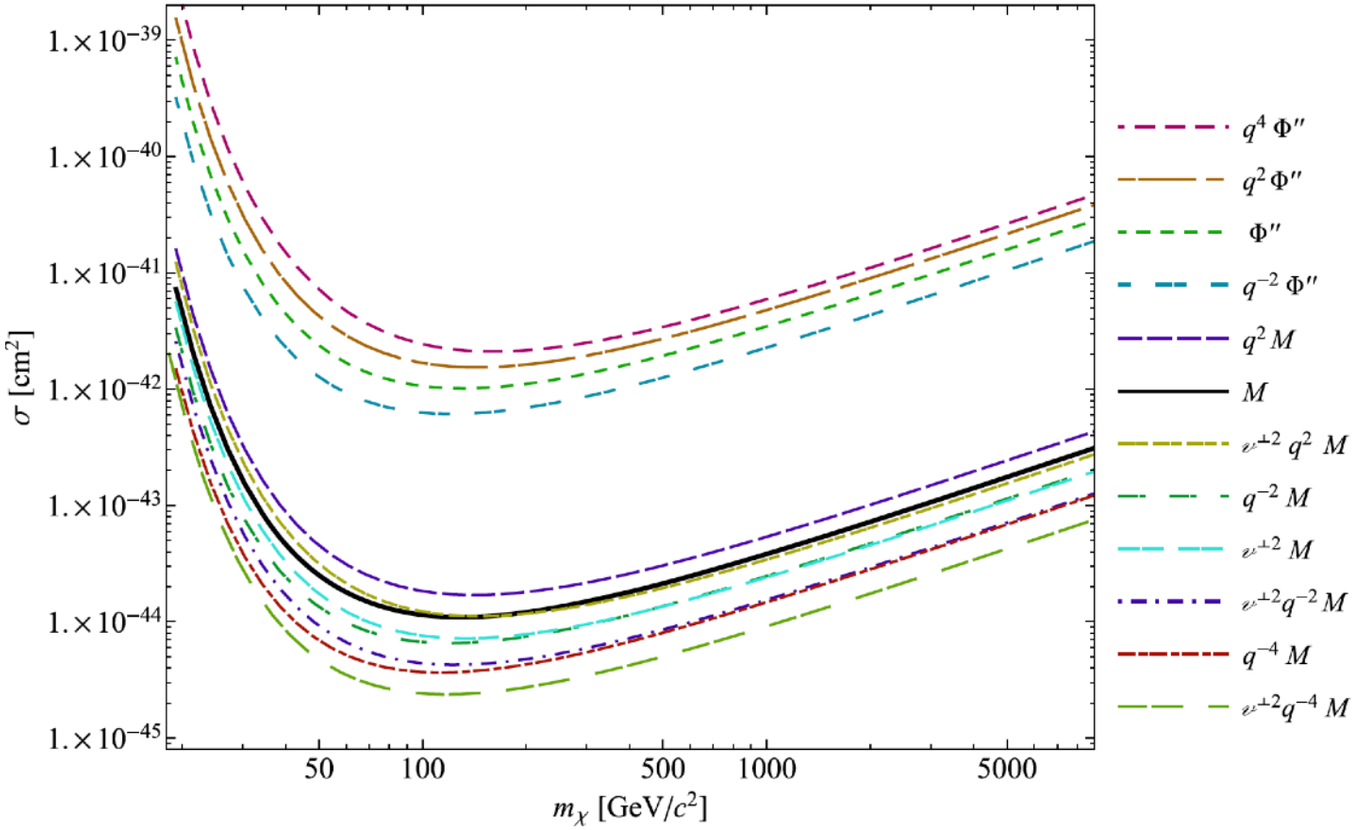
The DS-50 **high-mass WIMP** null result can be interpreted in the framework of **EFTs**.

Among 15 operators, 7 do not depend on nuclear spin. The EFT expansion includes 16 terms, which differ according to the power of q and $v^{\perp}$ or different *nuclear response functions (1, M, Φ)*

The standard SI interaction corresponds to one of these terms (M). In a similar approach, one can test **12 possible dependencies** as if their weight is the only ≠ 0.

Important variations! The complementarity of experiments using different targets could be crucial for probing the full parameter space.

$$\mathcal{O}_1 = 1_\chi 1_N$$
$$\mathcal{O}_3 = i\vec{S}_N \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^{\perp}\right)$$
$$\mathcal{O}_5 = i\vec{S}_\chi \cdot \left(\frac{\vec{q}}{m_N} \times \vec{v}^{\perp}\right)$$
$$\mathcal{O}_8 = \vec{S}_\chi \cdot \vec{v}^{\perp}$$
$$\mathcal{O}_{11} = i\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}$$
$$\mathcal{O}_{12} = \vec{S}_\chi \cdot (\vec{S}_N \times \vec{v}^{\perp})$$
$$\mathcal{O}_{15} = -\left(\vec{S}_\chi \cdot \frac{\vec{q}}{m_N}\right)\left[\vec{S}_N \times (\vec{v}^{\perp}) \cdot \frac{\vec{q}}{m_N}\right]$$



Phys. Rev. D 101, 062002 (2020)

Conclusions

DarkSide-50 is a dual-phase liquid argon Time Projection Chamber (**50 kg active mass**), operated since 2013 at *Laboratori National del Gran Sasso* (IT).

The experiment performed searches for **high-mass WIMP** dark matter ($\mathbf{m_\chi \gtrsim 10\ GeV/c^2}$). Blind analysis of 2018 reported null result and **background-free** exposure

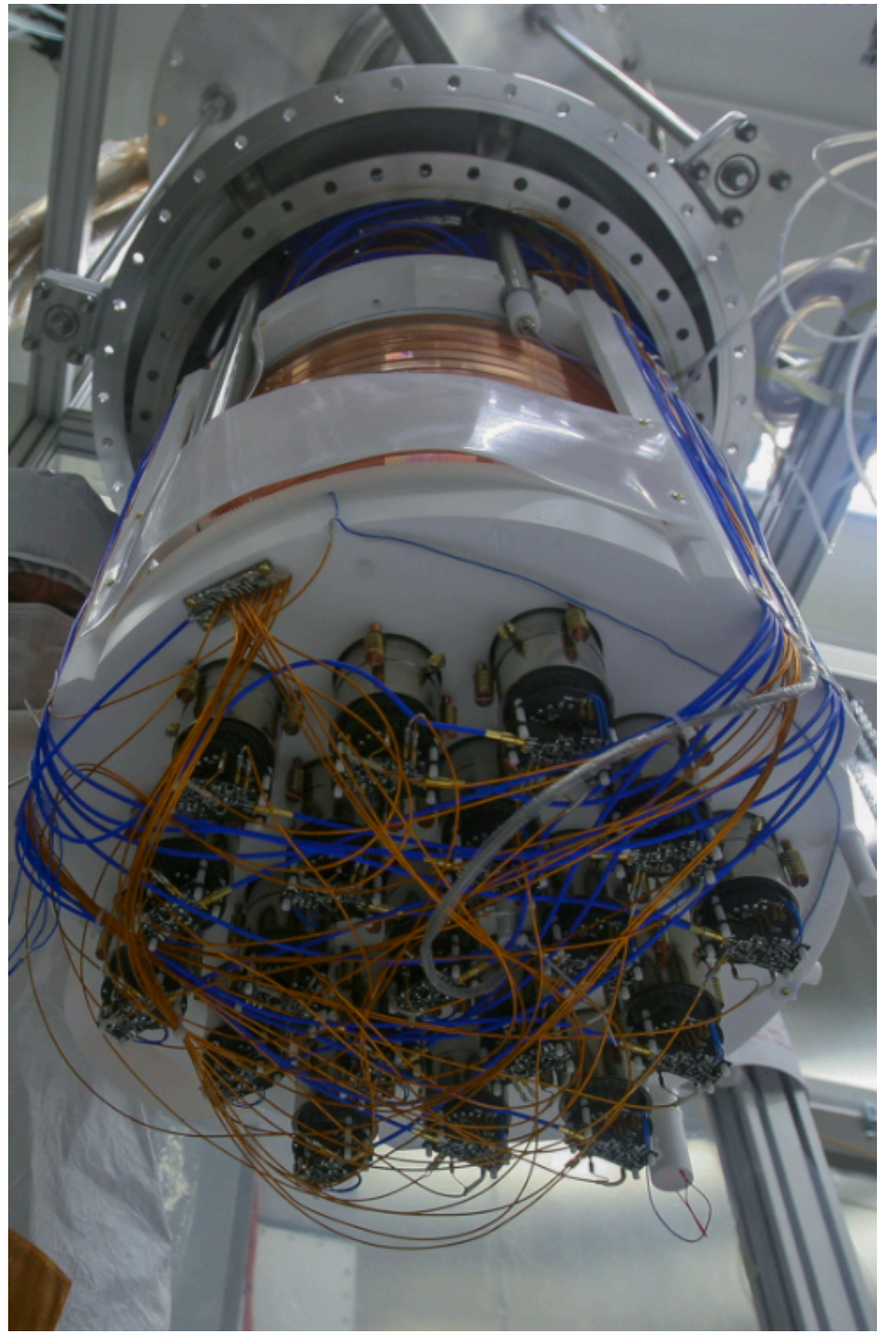
This results has been recently interpreted in the framework of **EFT operators.**

The **world-leading low-mass WIMP** results of 2018, based on:

- **low energy threshold** (~20 eV required to produce e-/ion pair)
- **calibrations** at low energy with internal ^{37}Ar and neutrons
- **background model** extrapolated at low energy

are being updated thanks to improvements in the detector calibration and data selection. **Stay tuned**!

The **same data** can be used to constrained other WIMP interactions (WIMP-e-, axions, WIMP-nucleon with Migdal…)



zoom channel for further discussion at **this link** (opening at 19h45 CEST)

Extra Slides