Search for low-mass WIMPs with the DarkSide-50 experiment

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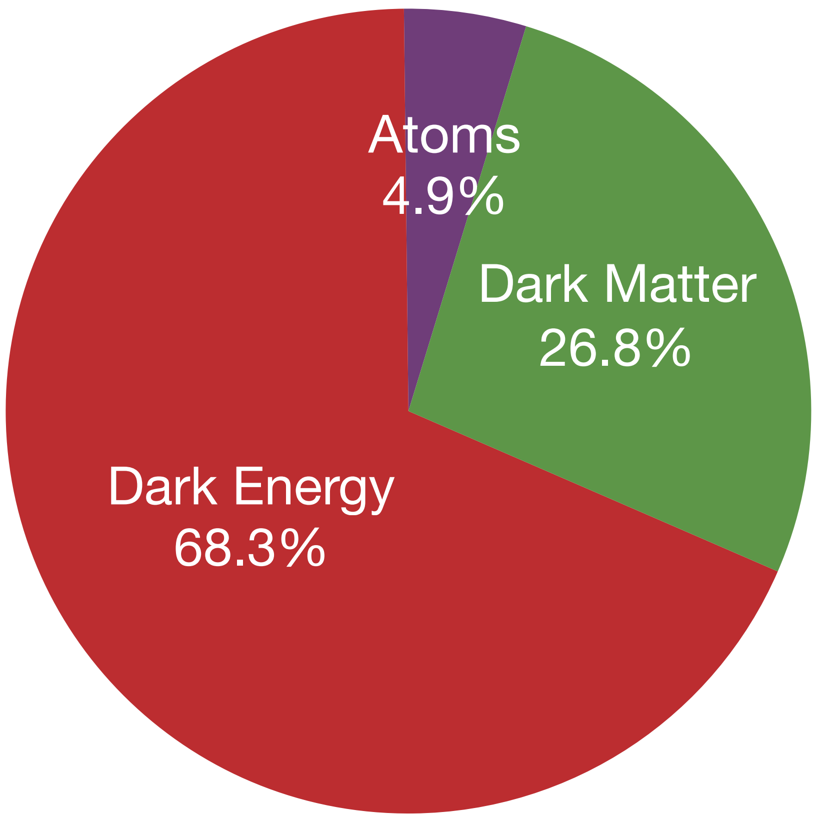
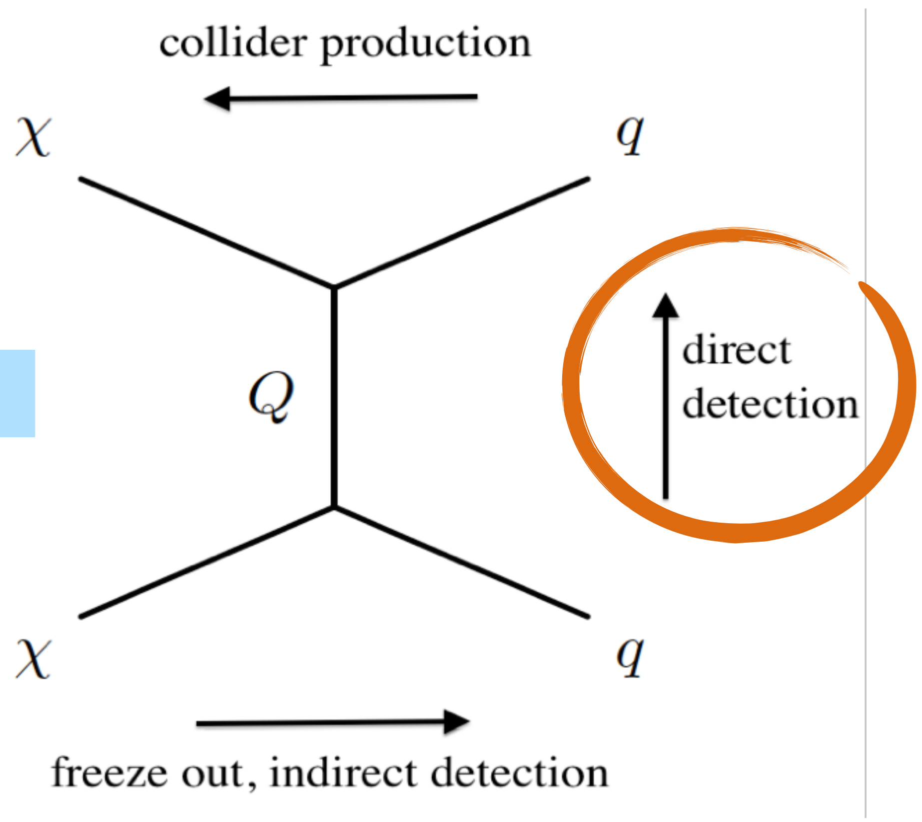
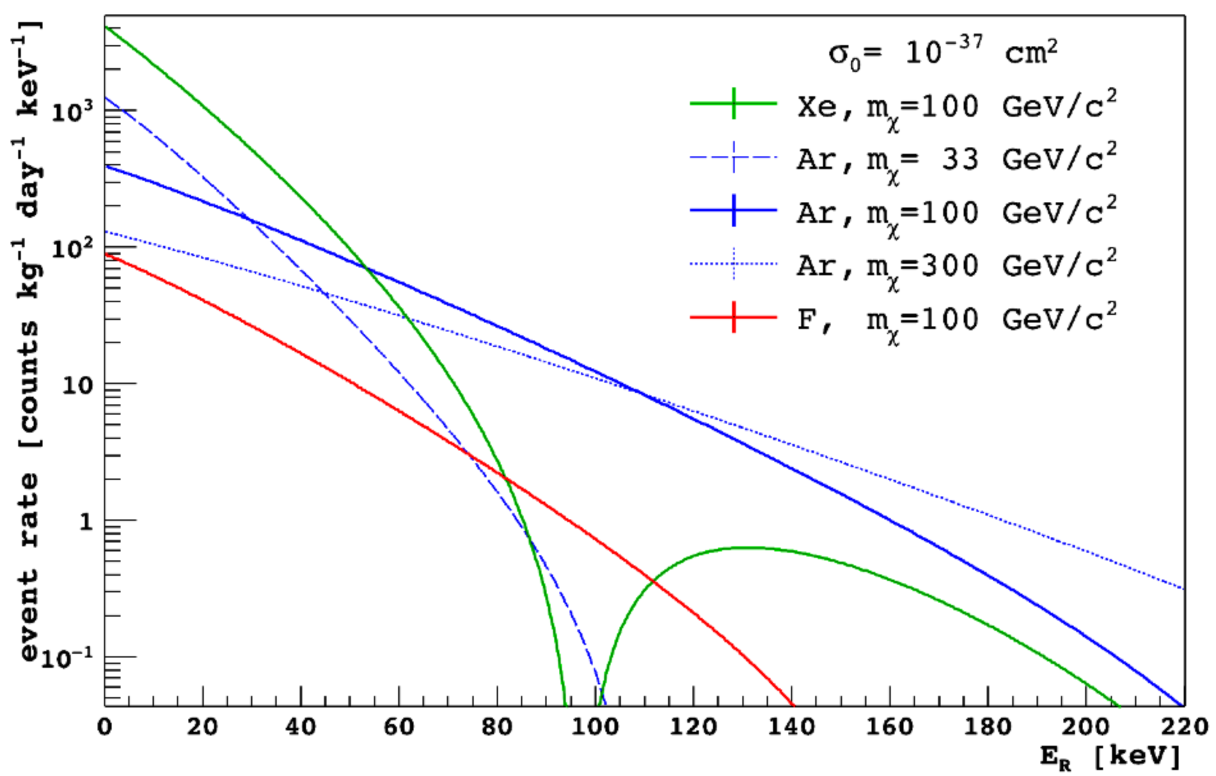
By S.Walker

Direct detection of dark matter



A favored candidate for DM:
Weakly Interactive
Massive Particles



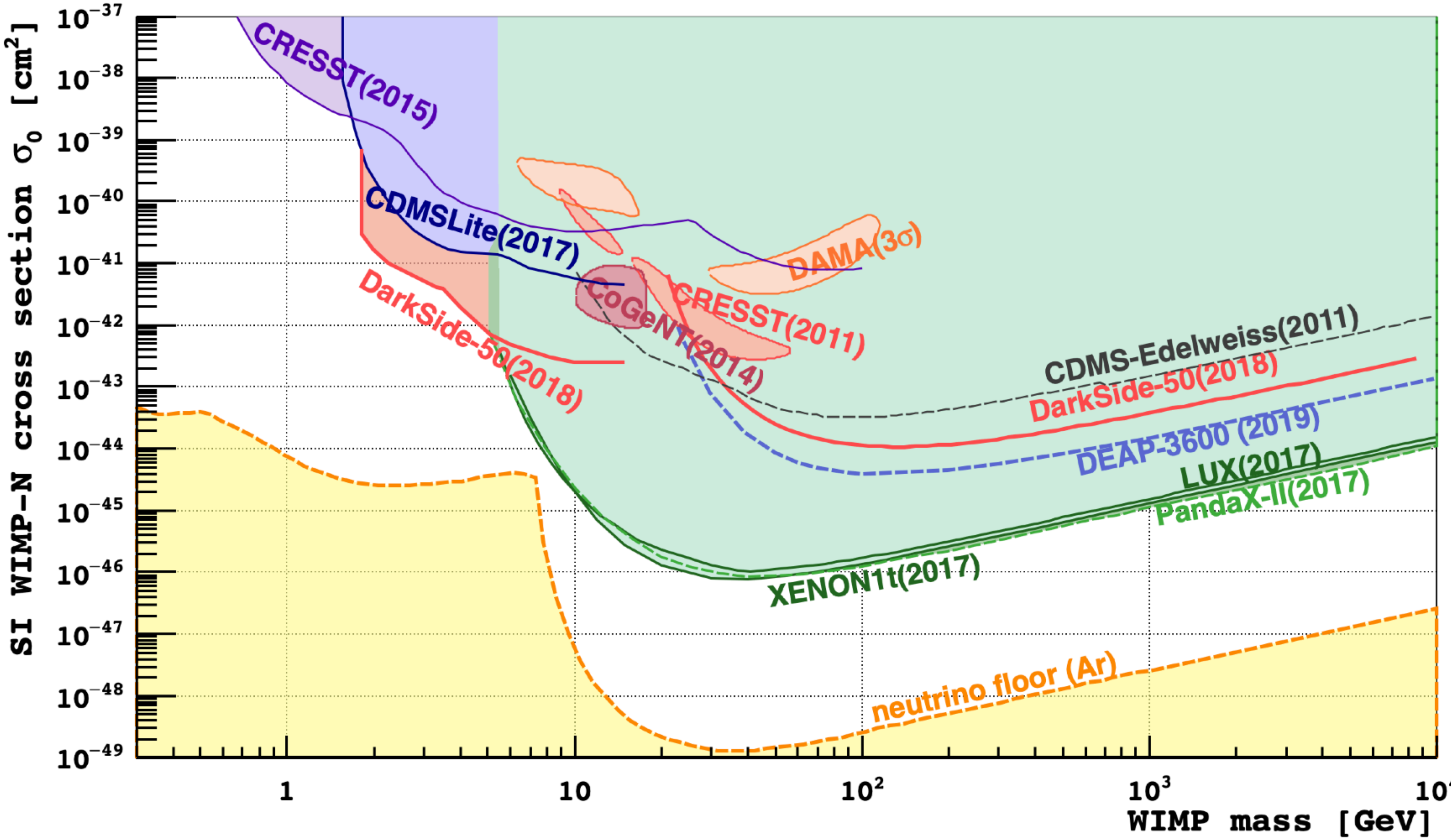


At $\sigma_0 = 10^{-47}$ cm^2 expected ~1 ev t^{-1} yr^{-1}

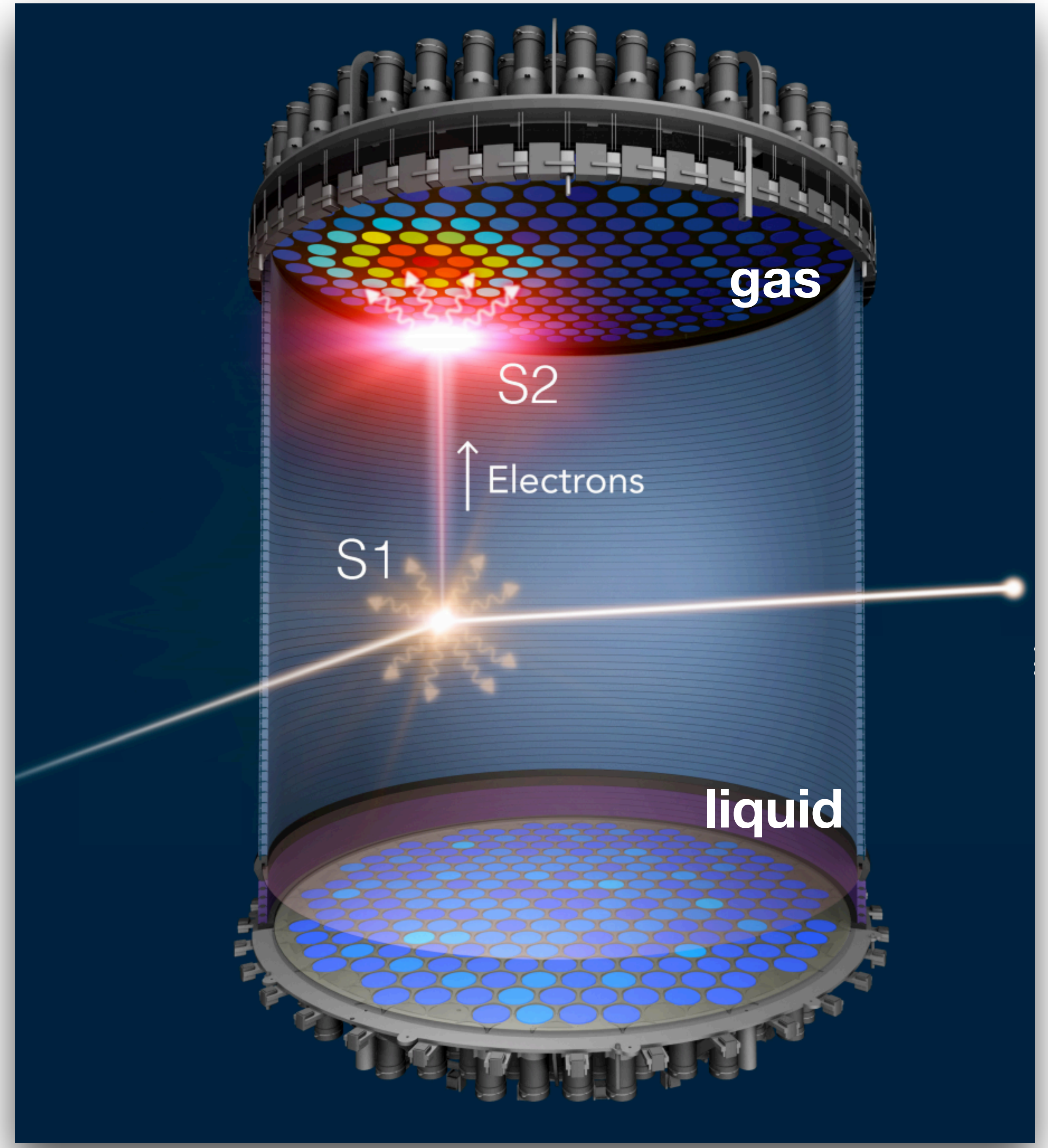
Need for background suppression and/or rejection

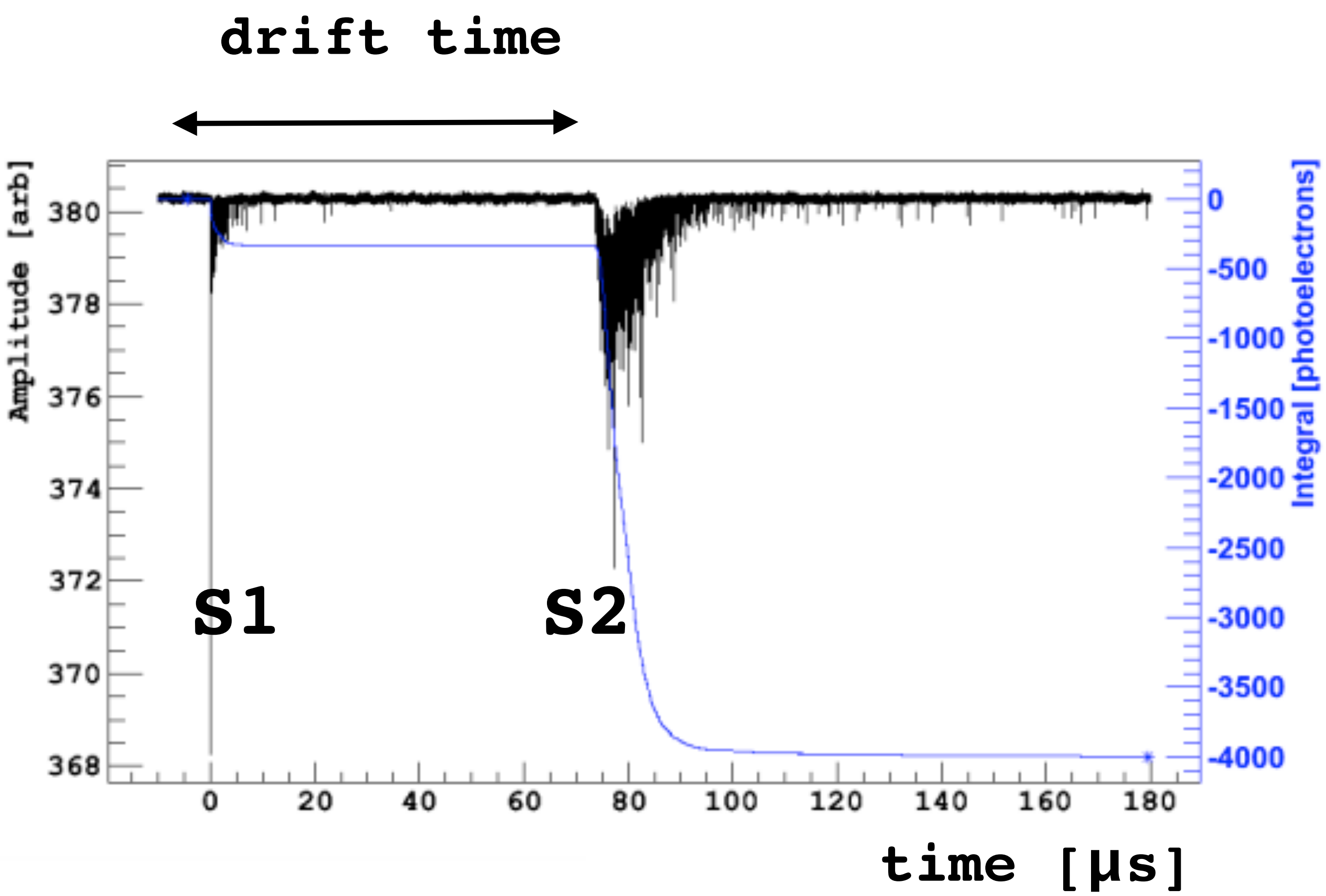
Noble liquids are suitable targets:

- ☑ dense, stable, easy to purify, inexpensive
- ☑ large ionization/scintillation yields **(W~10 eV)**
- ☑ background discrimination



Dual-phase Time Projection Chamber





Performance:

Resolution in Z: ~ mm

Resolution in XY: ~ cm

Good energy resolution using S1 + S2

Rejection of Electronic Recoil background:

Ionization/Scintillation: $< 2 \times 10^{-3}$

PSD in liquid argon: 4×10^{-9}

DEAP: arXiv:1902.04048

The DarkSide-50 detector

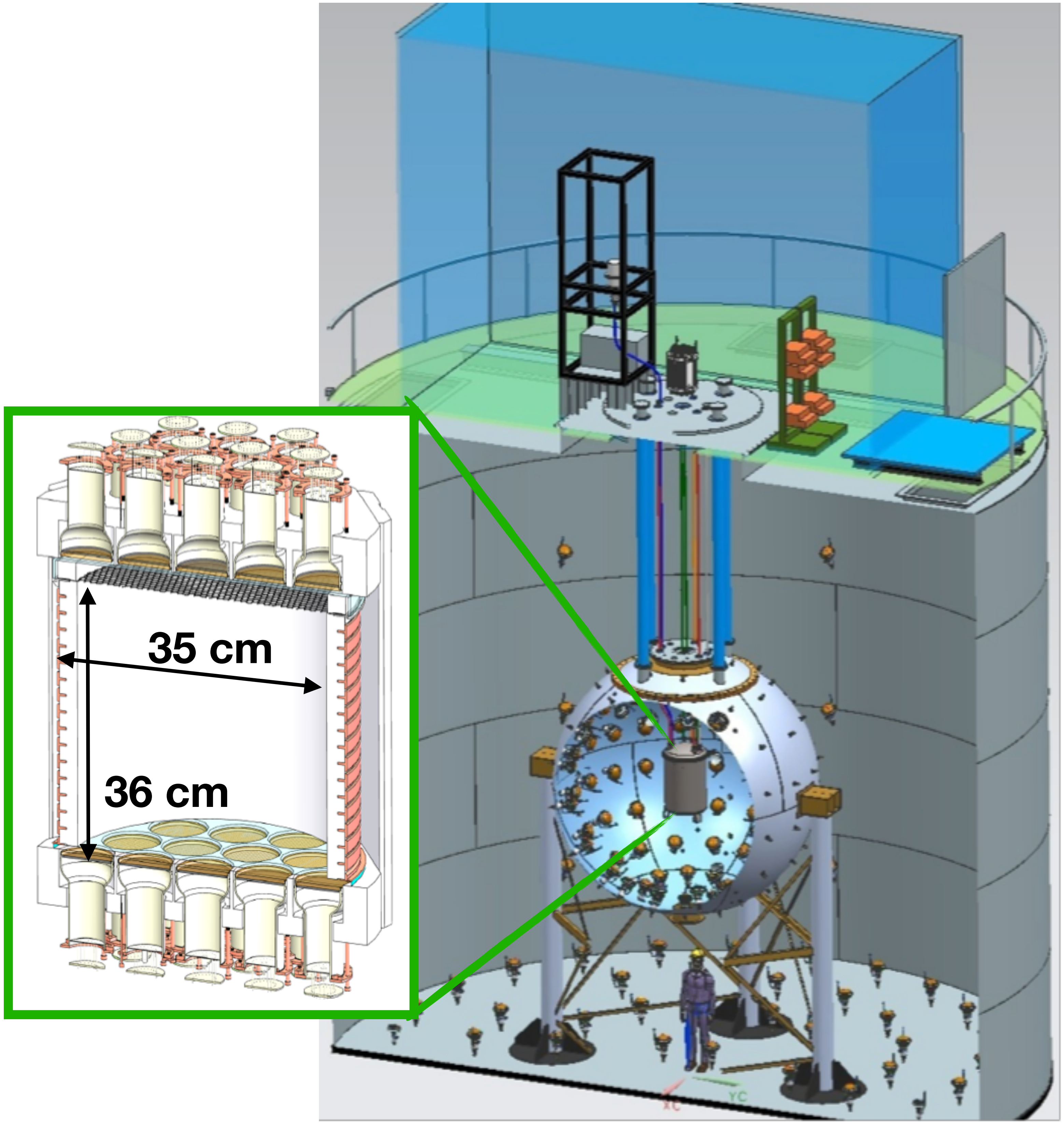
A **dual-phase LAr TPC**
- taking data since 2013 at Gran Sasso
- **50 kg** of **argon** from **underground**
- in a 30 t liquid scintillator veto
- in a 1 kt water Cherenkov detector

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

Position reconstruction:
- Resolution in Z **~1 mm**
- Resolution in XY **<1 cm**

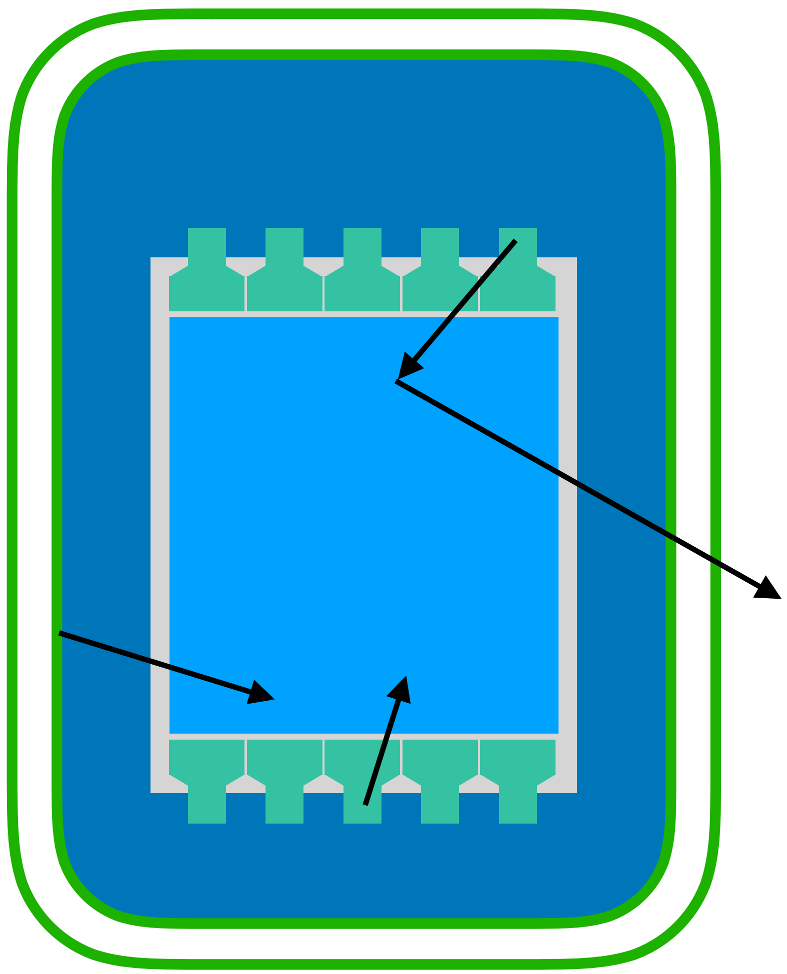
Neutron Veto Efficiency: 99.6%

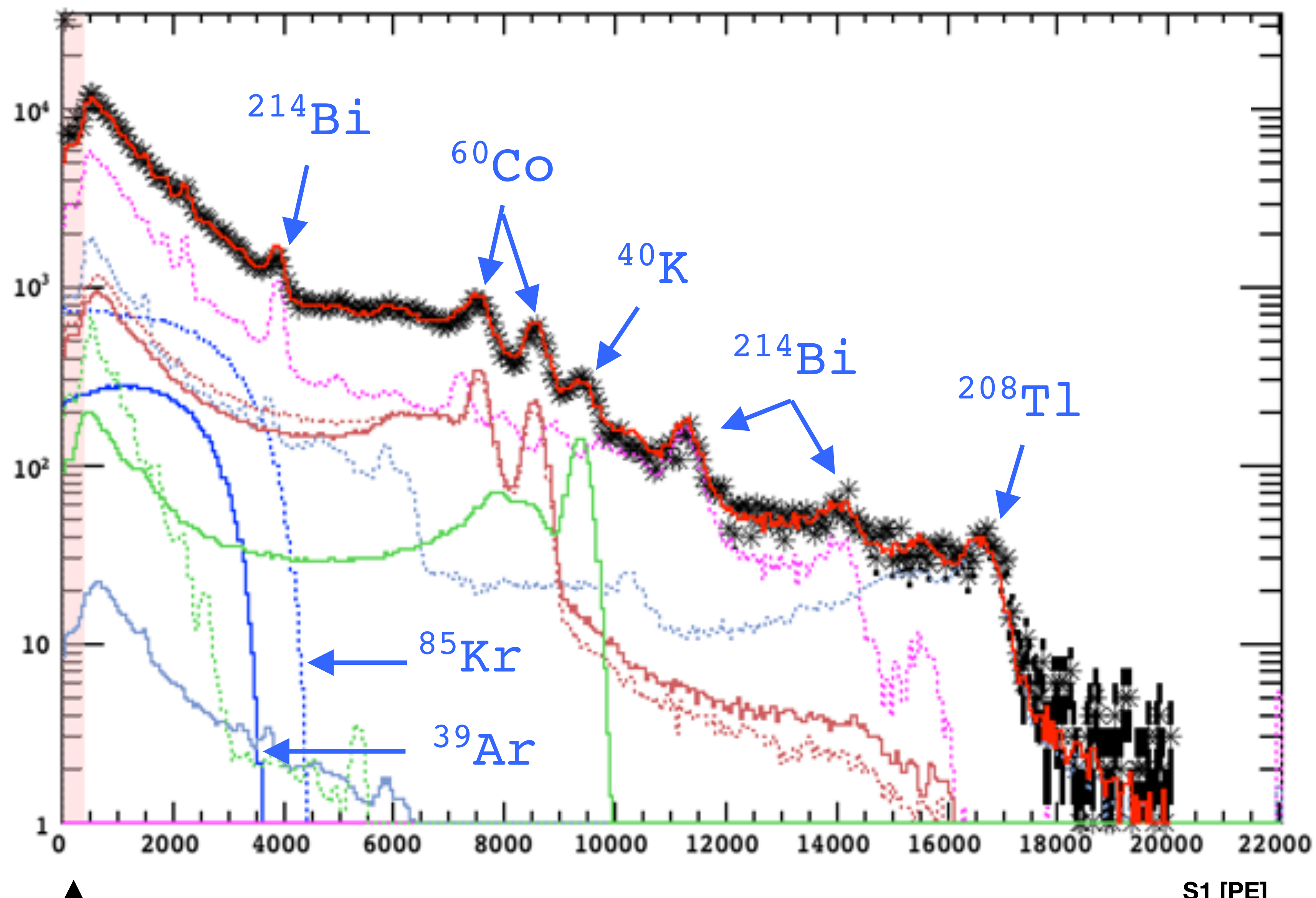


Background model for DarkSide-50

- 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

PhysRevD.93.081101





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

Low-energy signals

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

- No scintillation (S1):

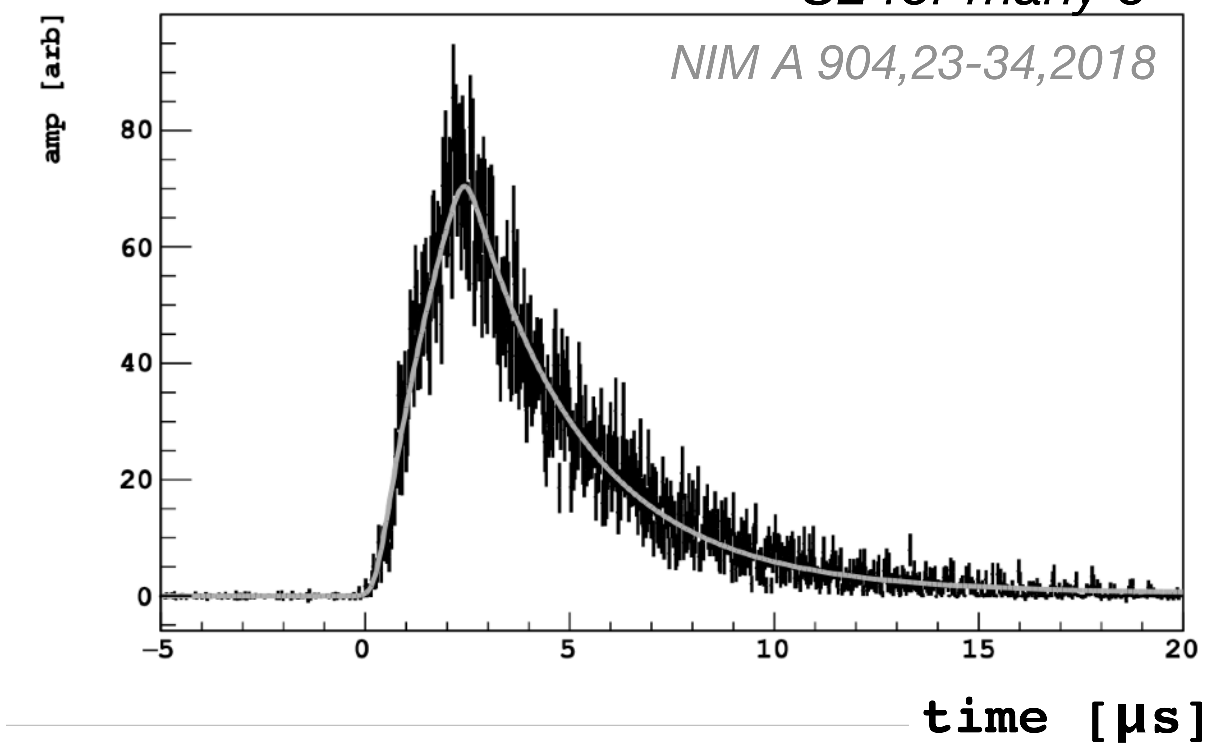
- Fiducialization lost (vertical)
- **No discrimination available**

- Multiplication in gas phase (**23 PE/e^-**)

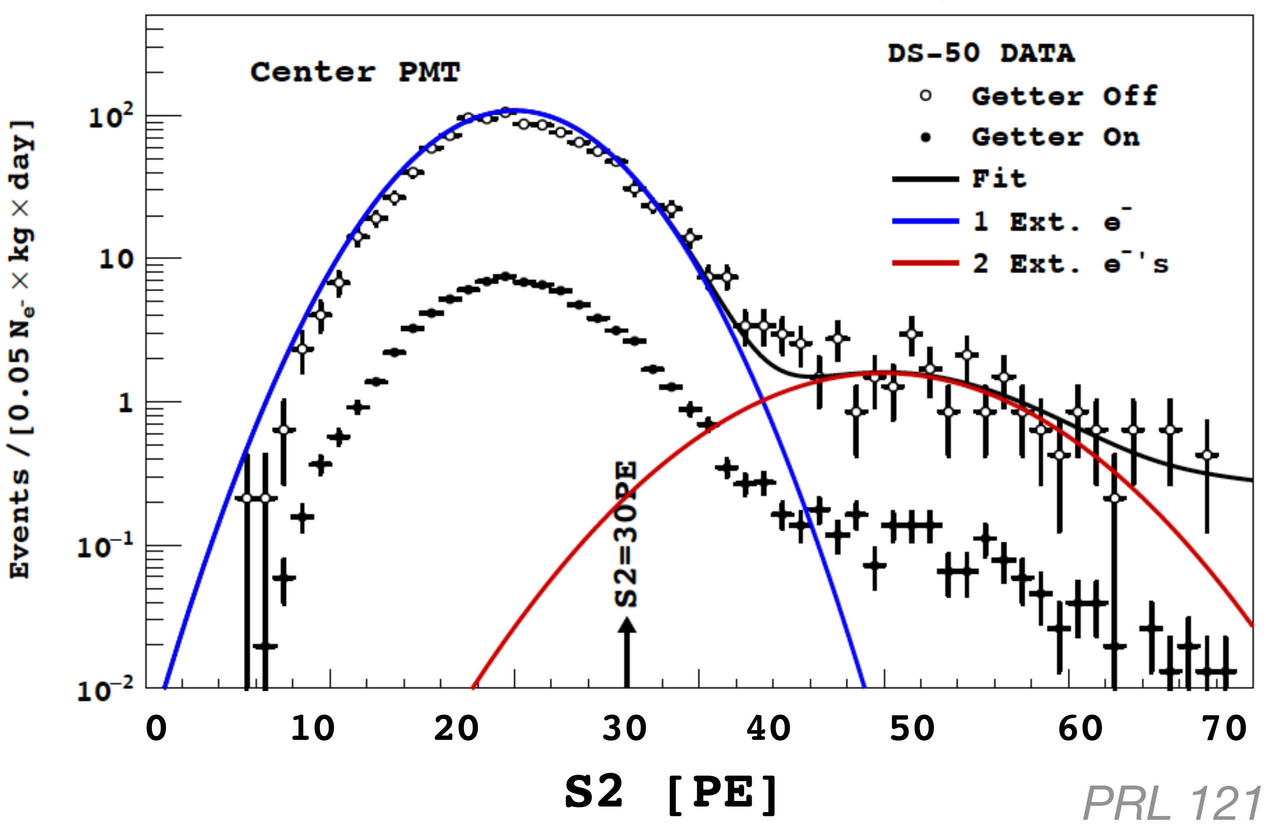
- **100% trigger** efficiency at 1.3 e^- (~30 eV)

(Trigger condition: 2 PMTs firing in 100 ns)

S2 for many e^-

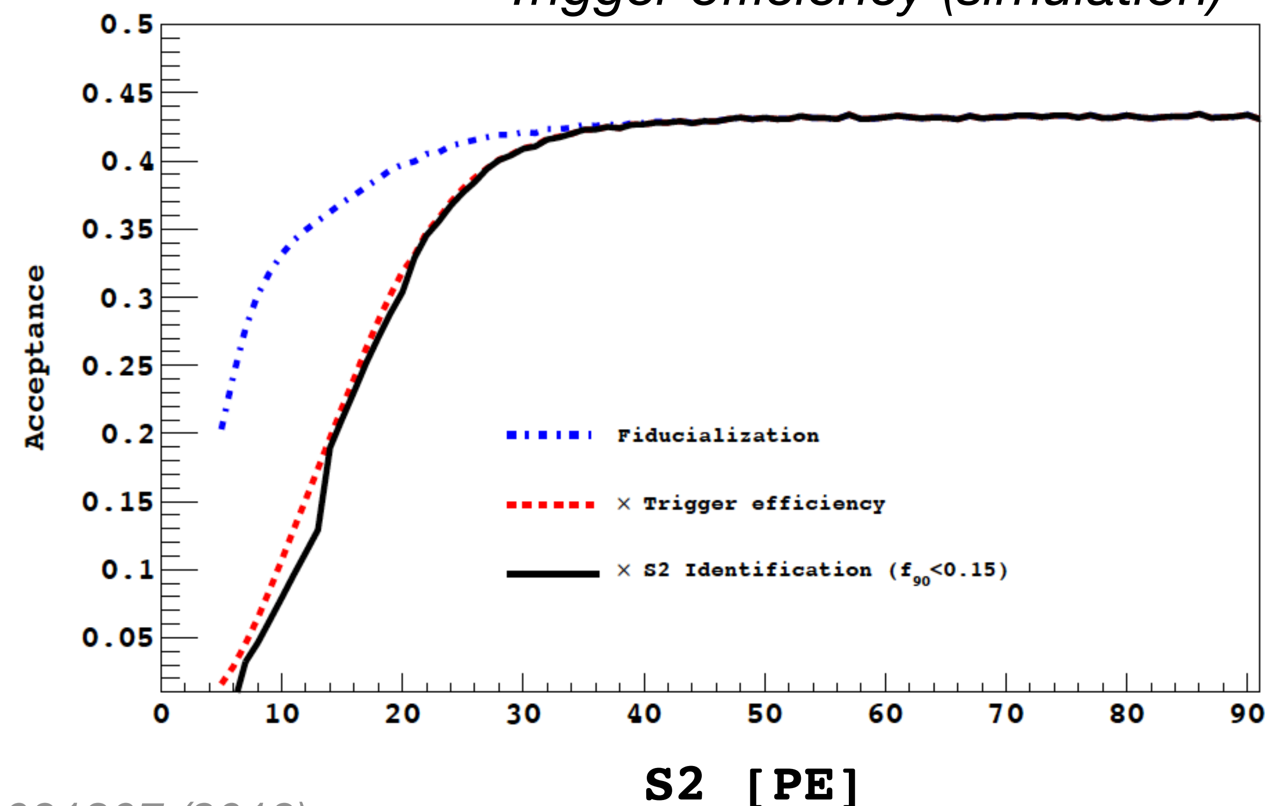


Spectrum of single electrons



PRL 121, 081307 (2018)

Trigger efficiency (simulation)



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**?

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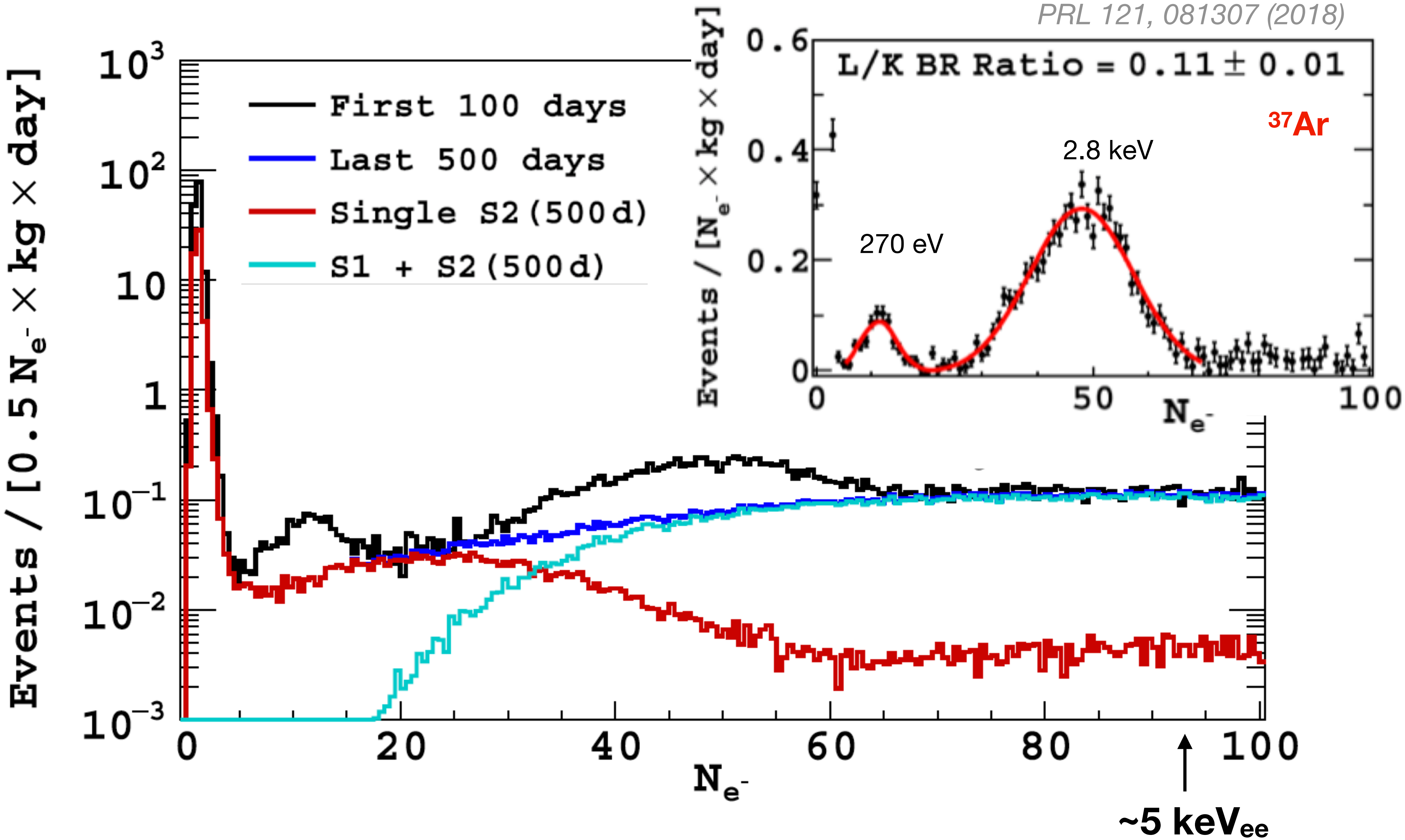


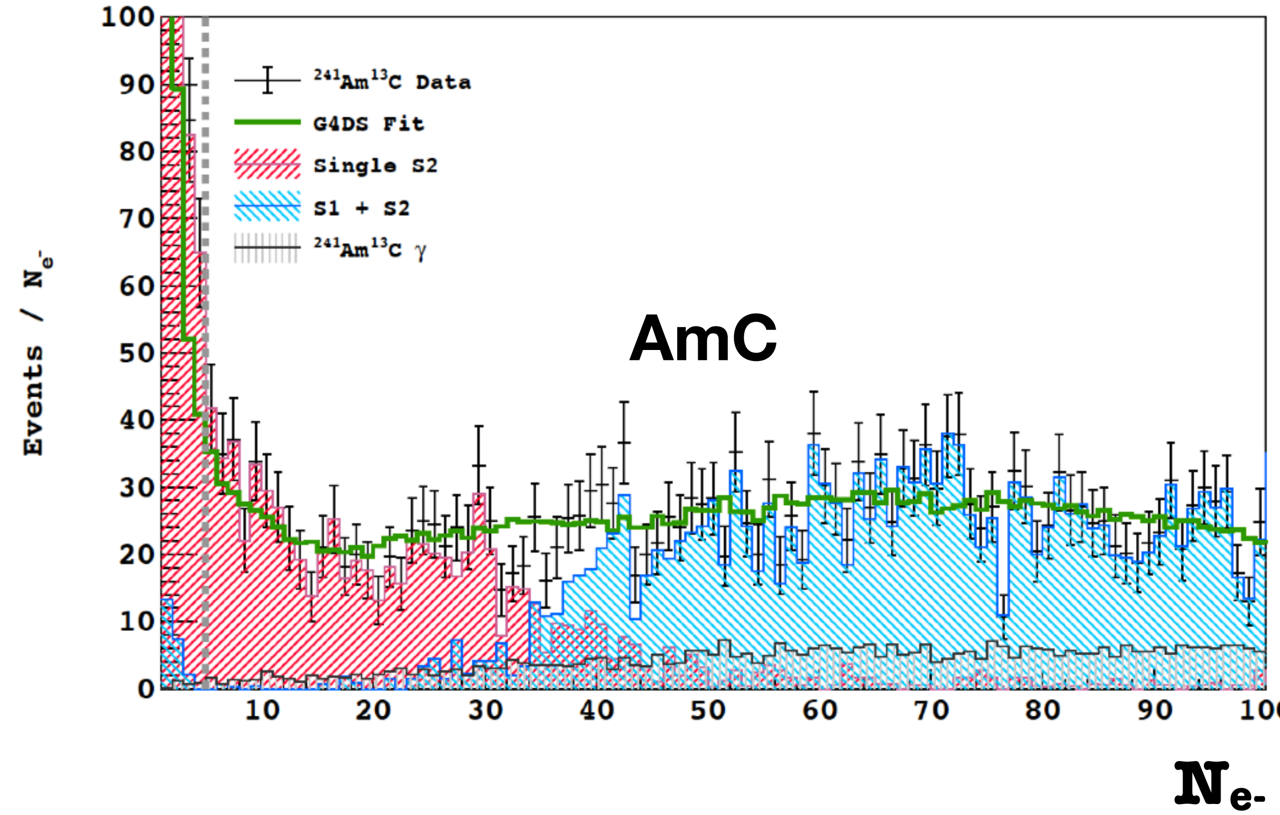
Nuclear recoil energy scale down ~1 keV_{NR}

Quenched due to nuclear collisions

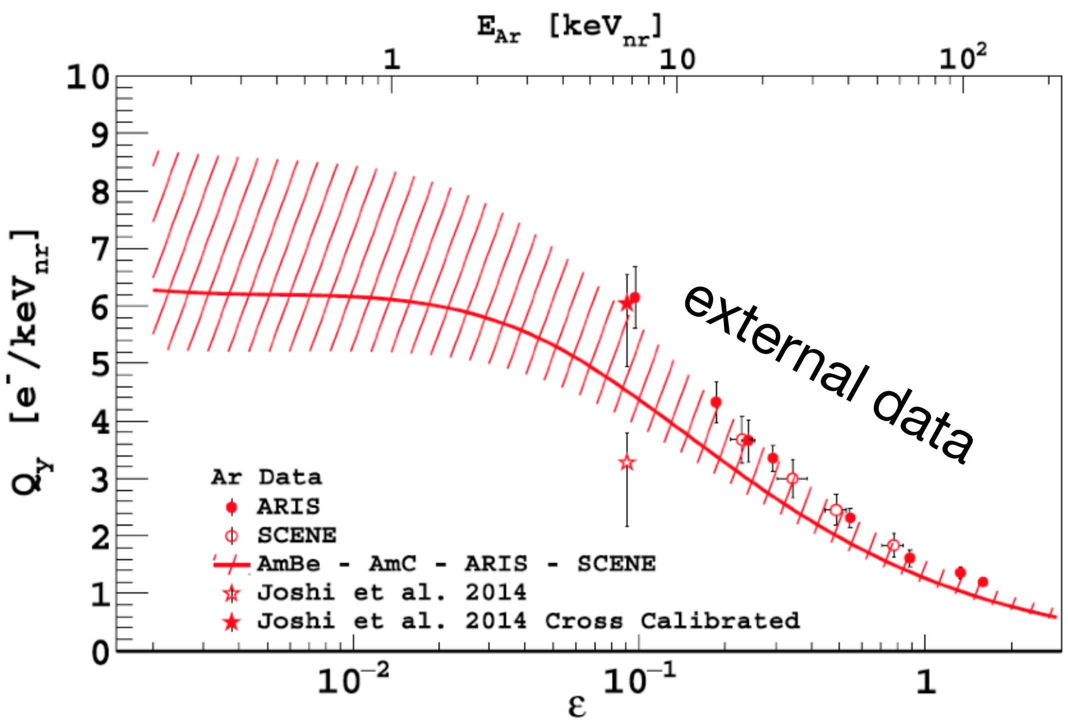
Effective model (quenching, recombination probability: Astrop. Phys. 35, 119–127, 2011) **fit to neutron sources data**

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

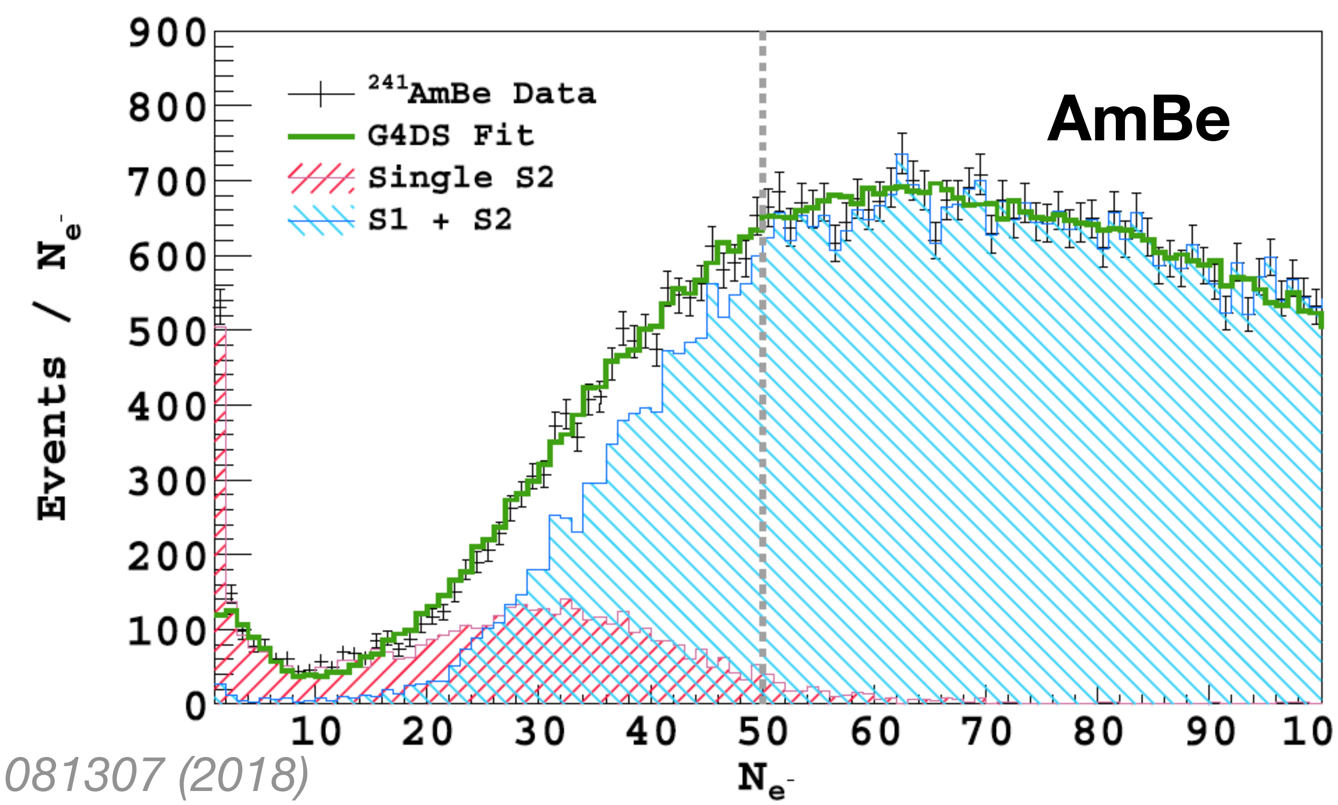
Calibration of nuclear recoils with AmC source



Calibrated ionization yield

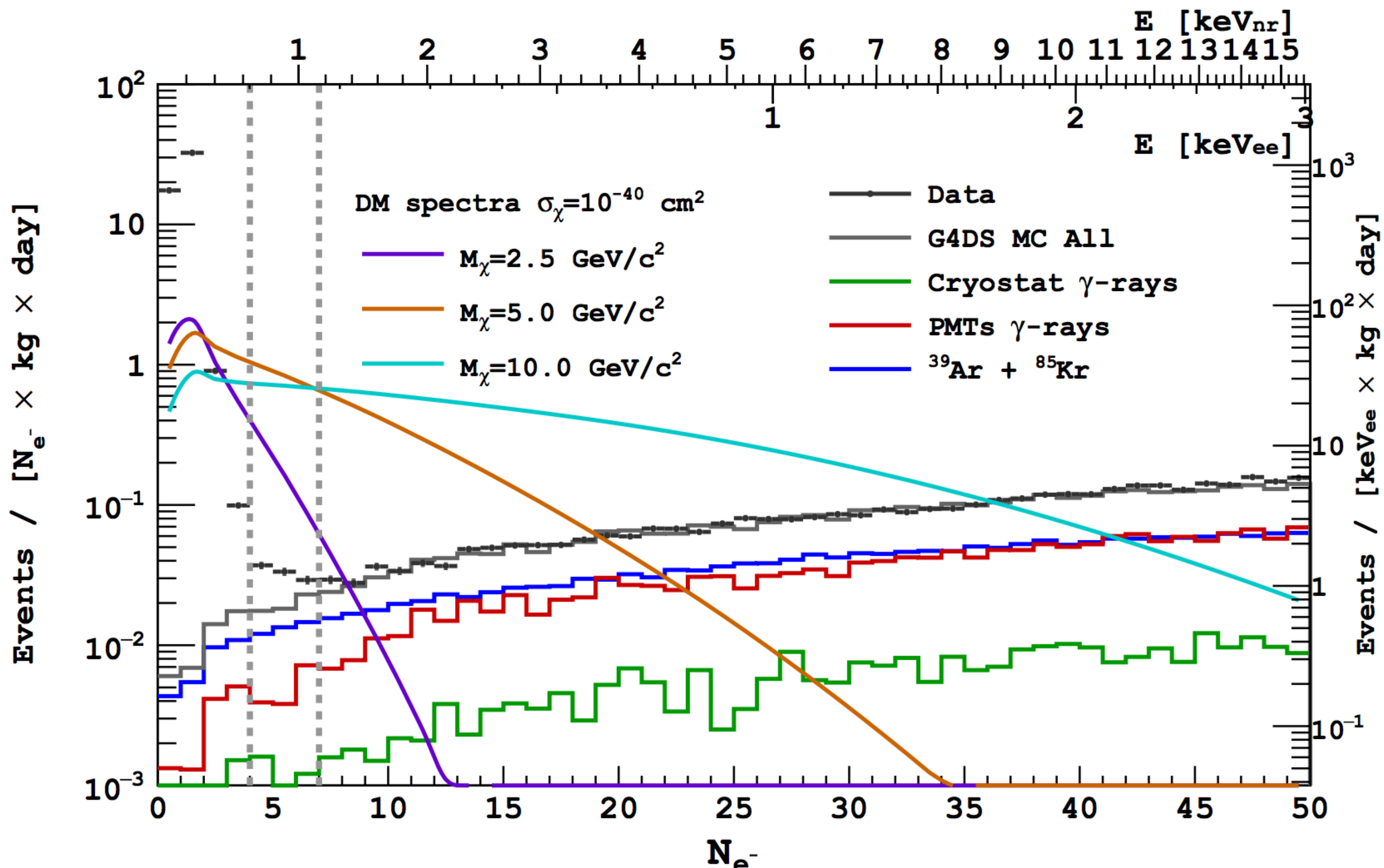


Calibration of nuclear recoils with AmBe source



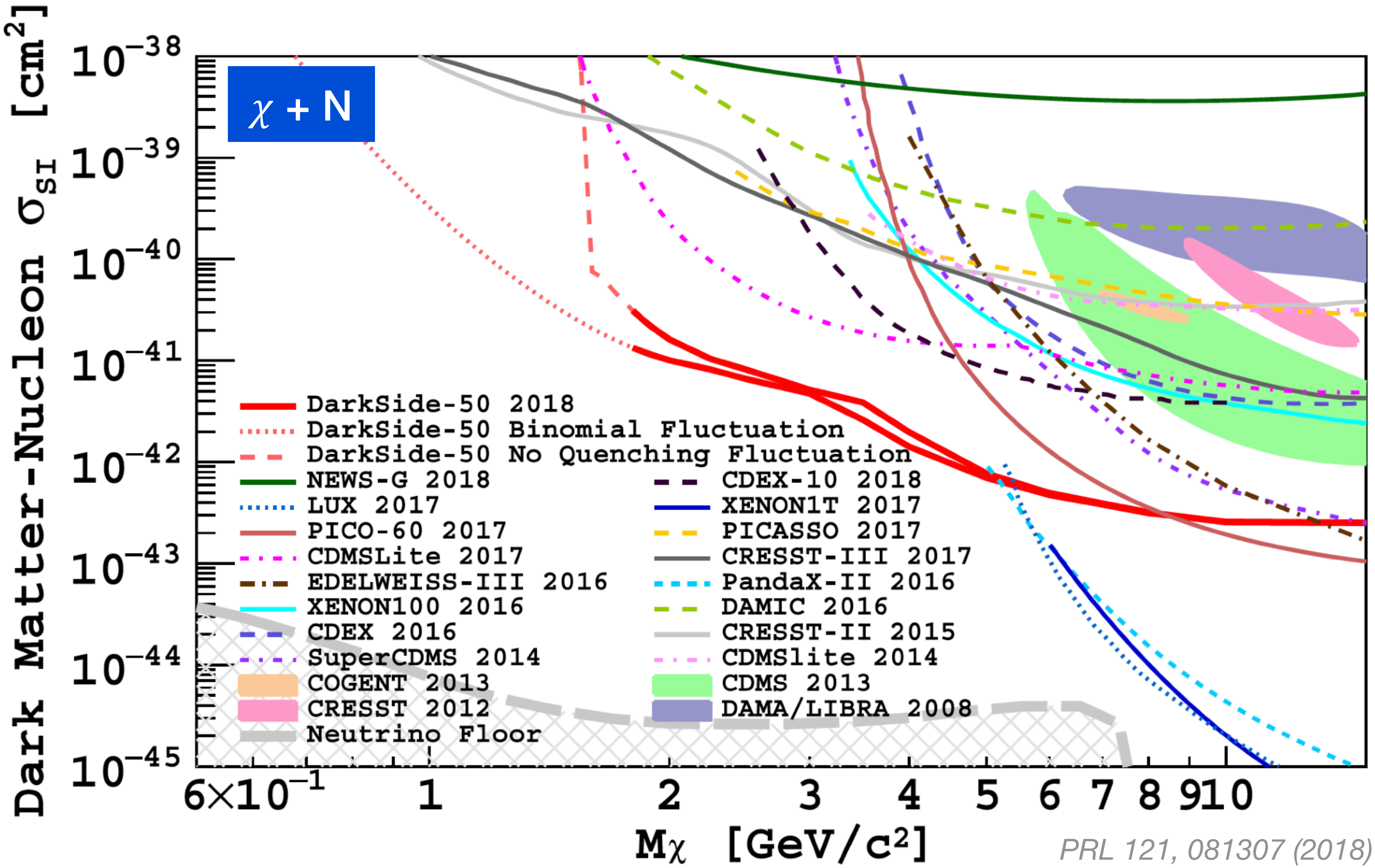
PRL 121, 081307 (2018)

- **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 cale: 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)

- **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**



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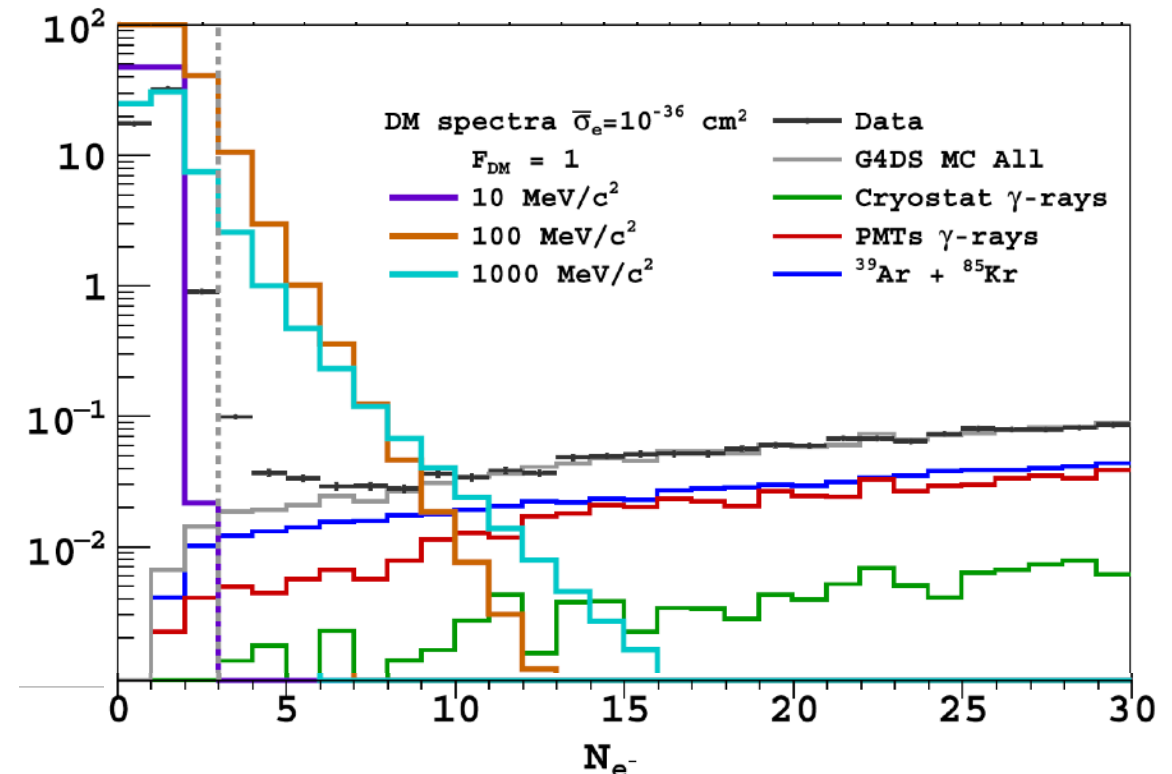
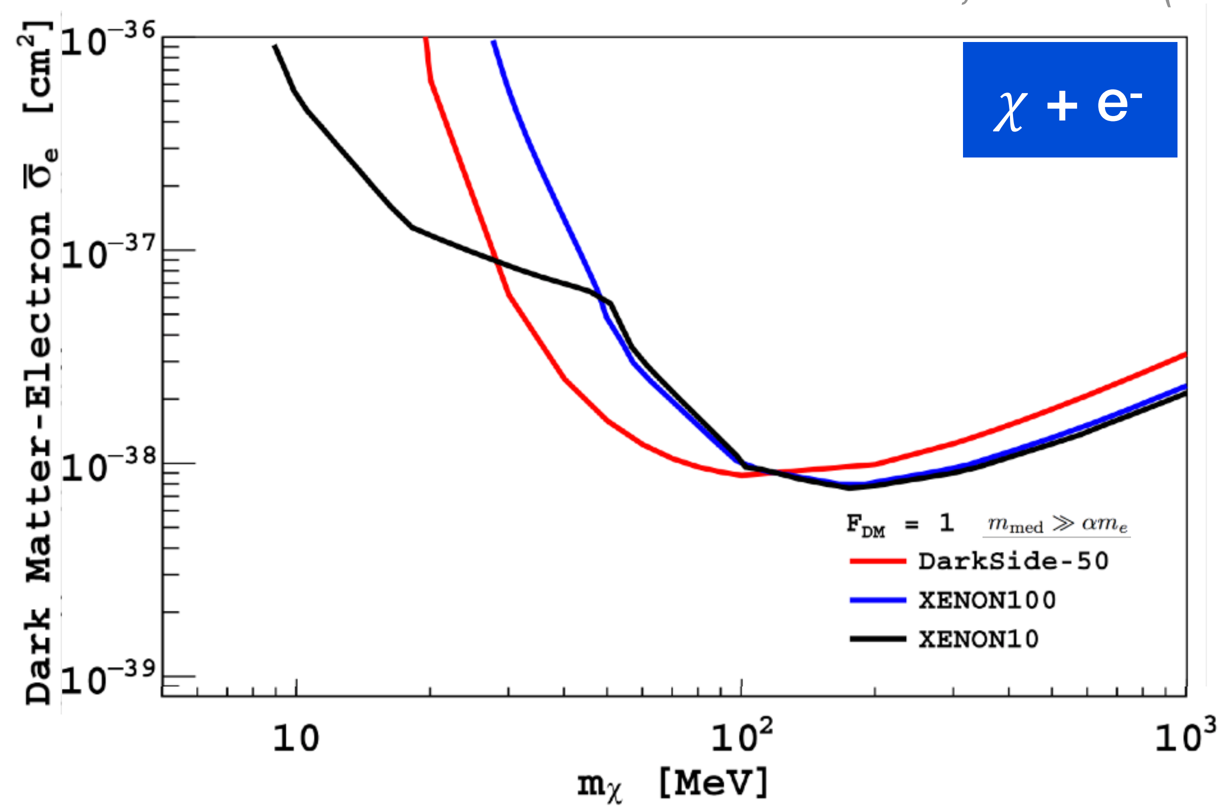
Same data to constraint other interactions

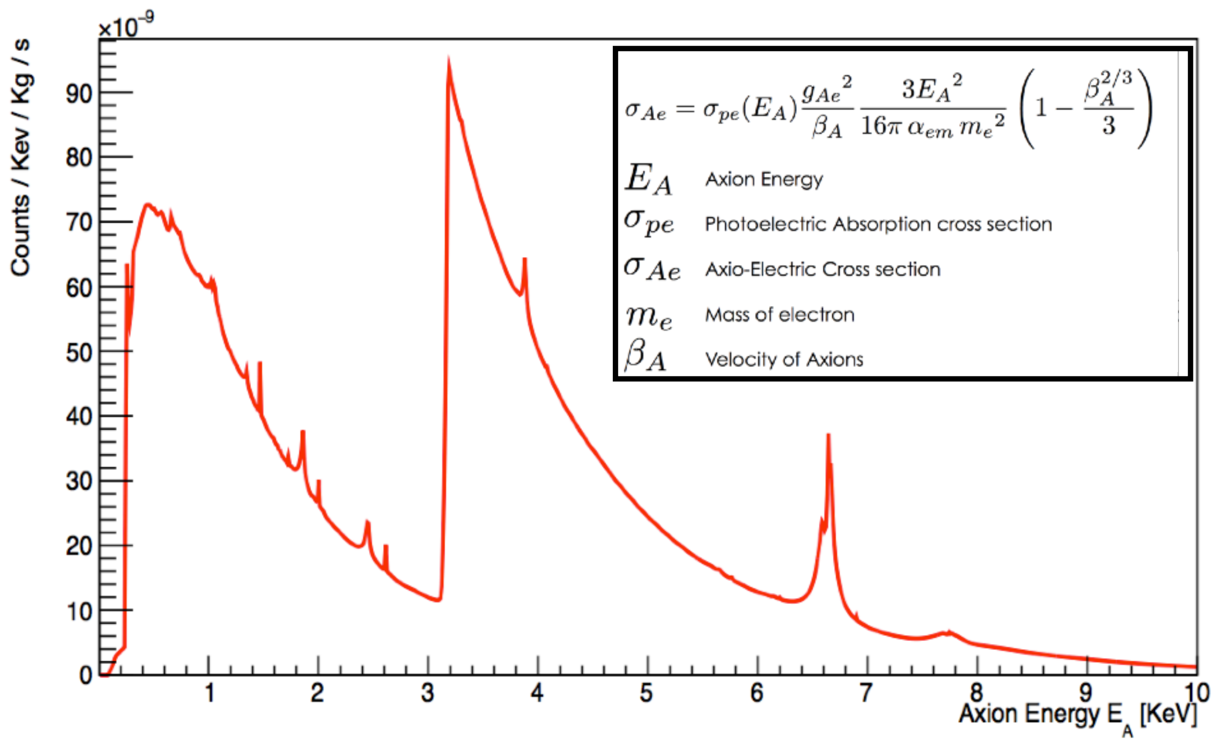
- WIMP-electron coupling ==>



PRL 121, 111303 (2018)



- Axions (work in progress)



- ...

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

The **main goal** of the experiment is to search for "**classical WIMP**" dark matter (**$m_\chi \gtrsim$ 10 GeV/c^2**), not discussed here.

Thanks to:

- **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

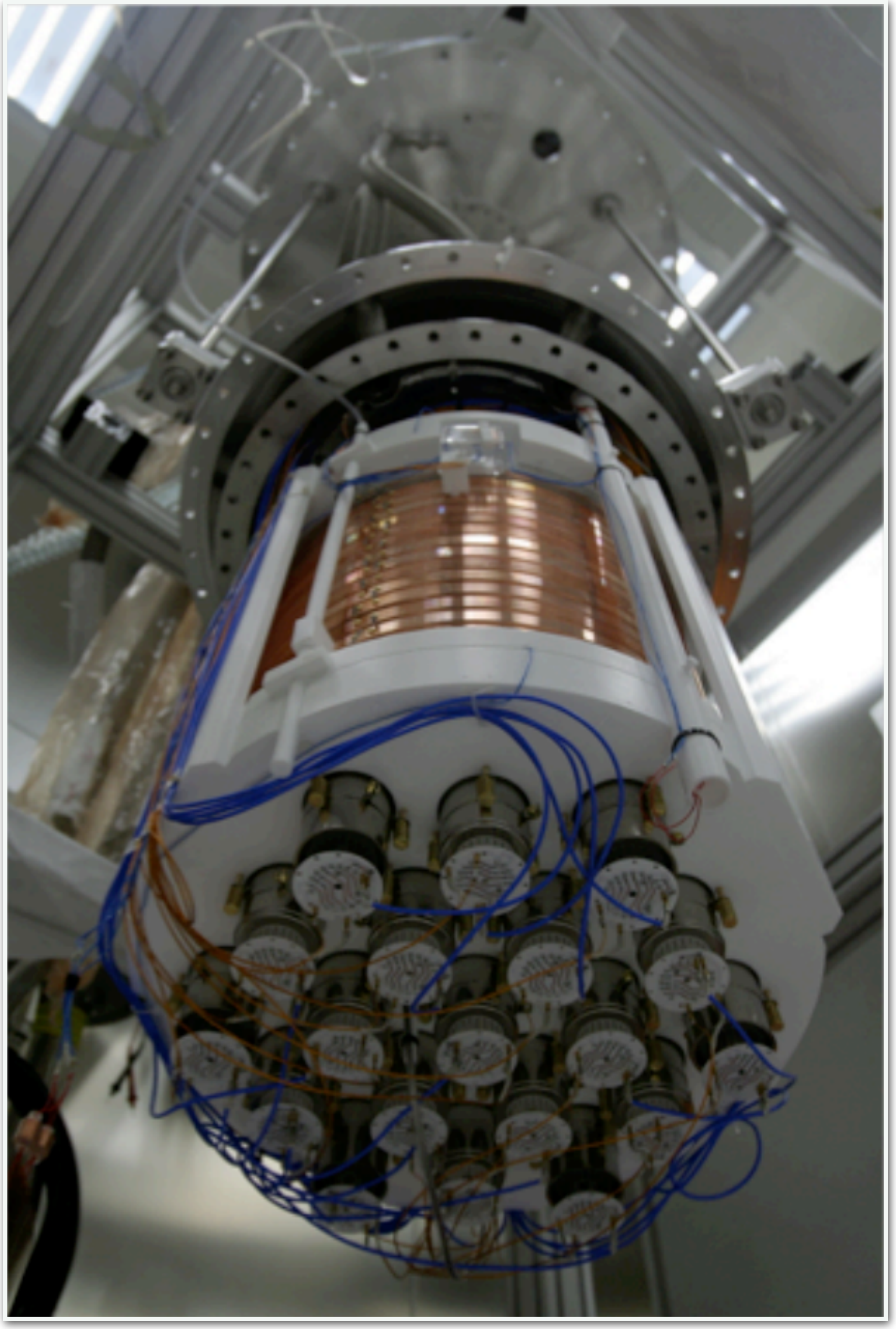
DarkSide-50 improved exclusion (~10^{-41} cm2) **for WIMPs with mass in [2, 6] GeV/c^2 range**

The **same data** can be used to constrained other WIMP interactions (WIMP-e-…)

A **new detector** is required to significantly improve the current limits at low-mass.

Extra Slides

DarkSide-50 installation



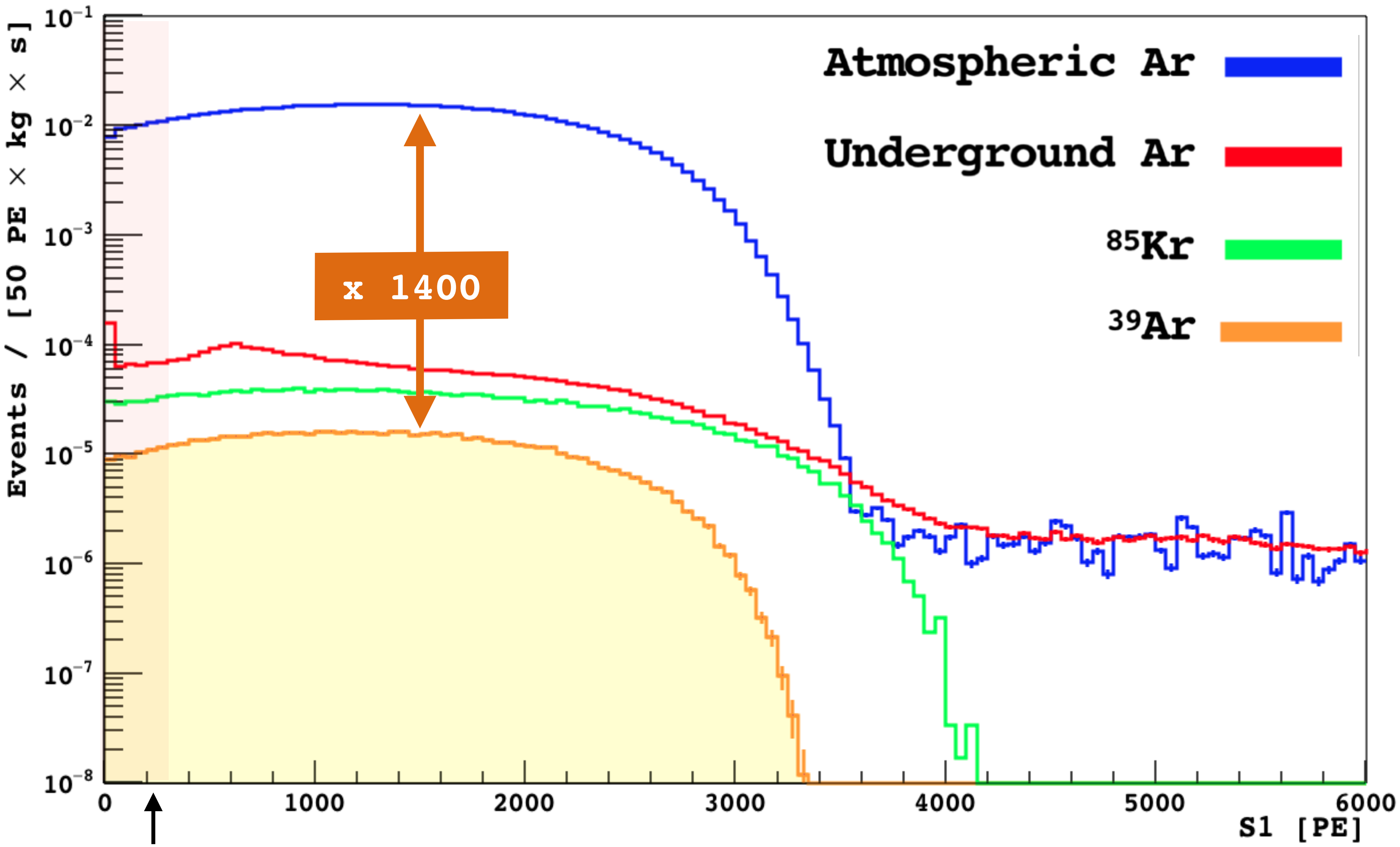
^{39}**Ar** is produced by cosmic rays in the atmosphere. **β-decay** with **Q = 565 keV**; $\tau_{1/2}$ = 269 yr

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

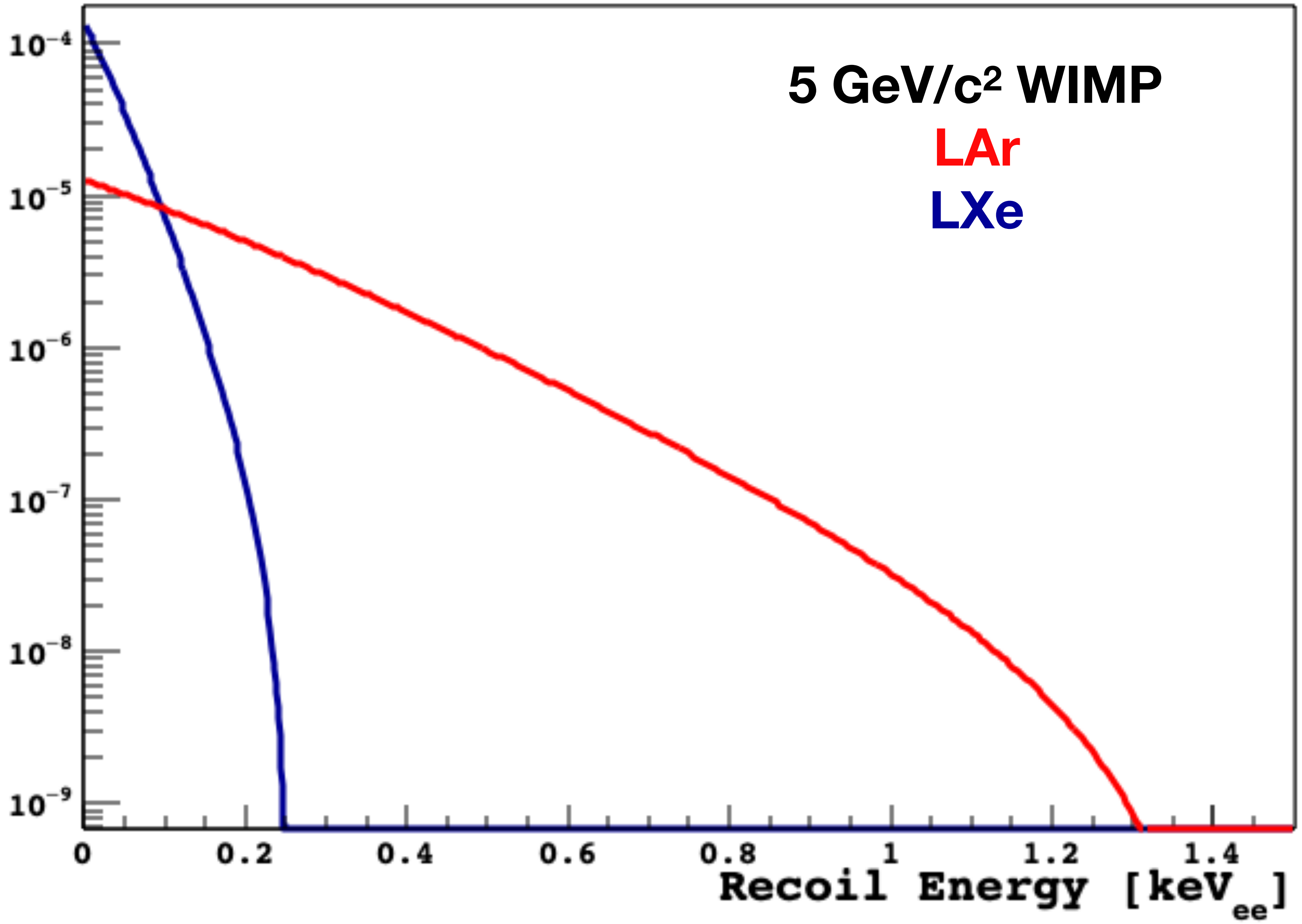
==> extract argon from underground (CO_2 well in Colorado) !

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

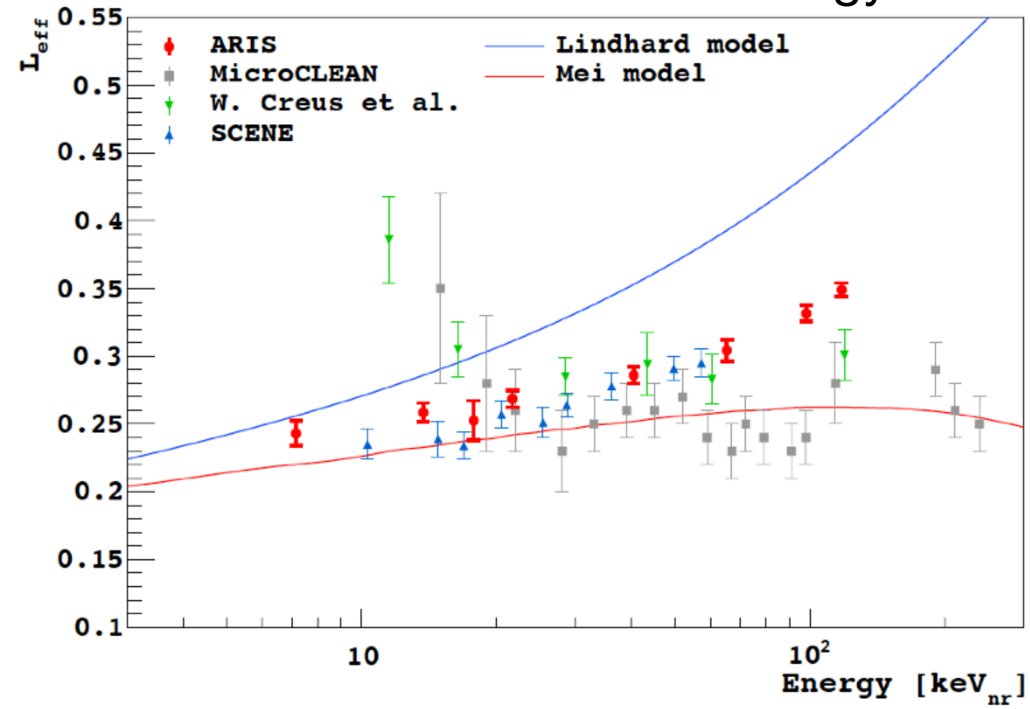
DarkSide-50 running with UAr (since 2015) after first AAr run

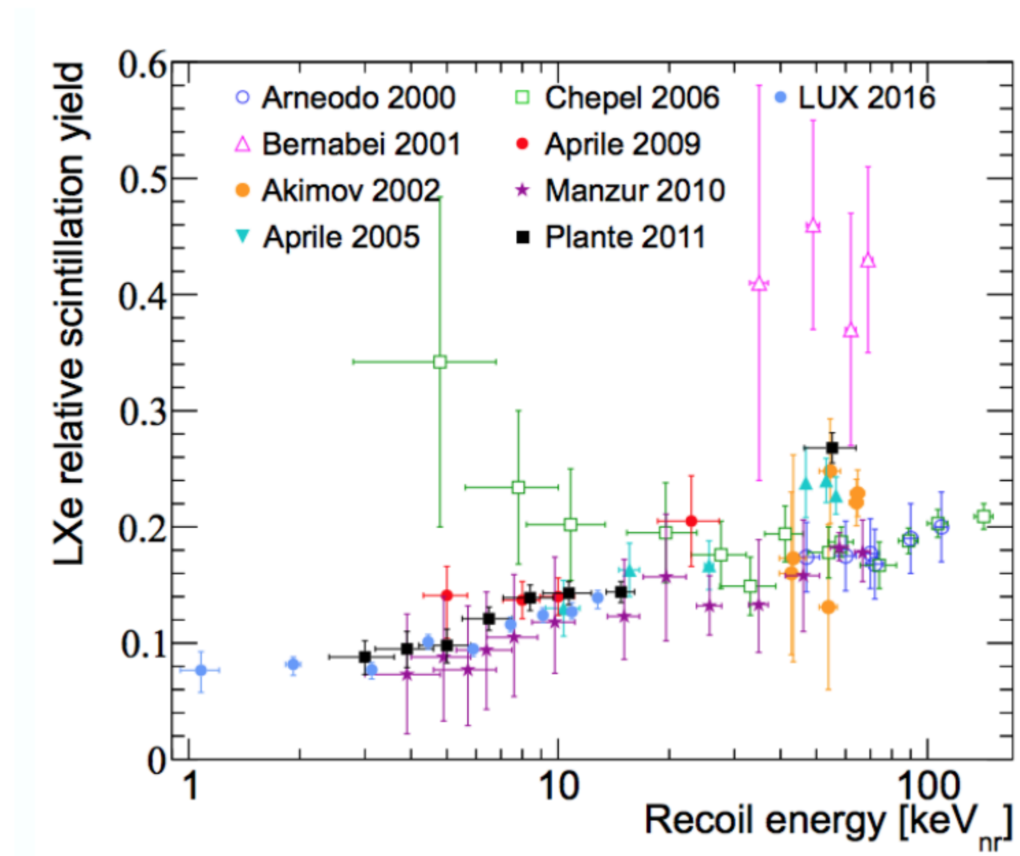


dark matter search region (< 50 keV_{ee})



Precision L_{eff} at low energy





Missing: Eq -> electrons
WAr ~ 20 eV, WXe ~ 10 eV

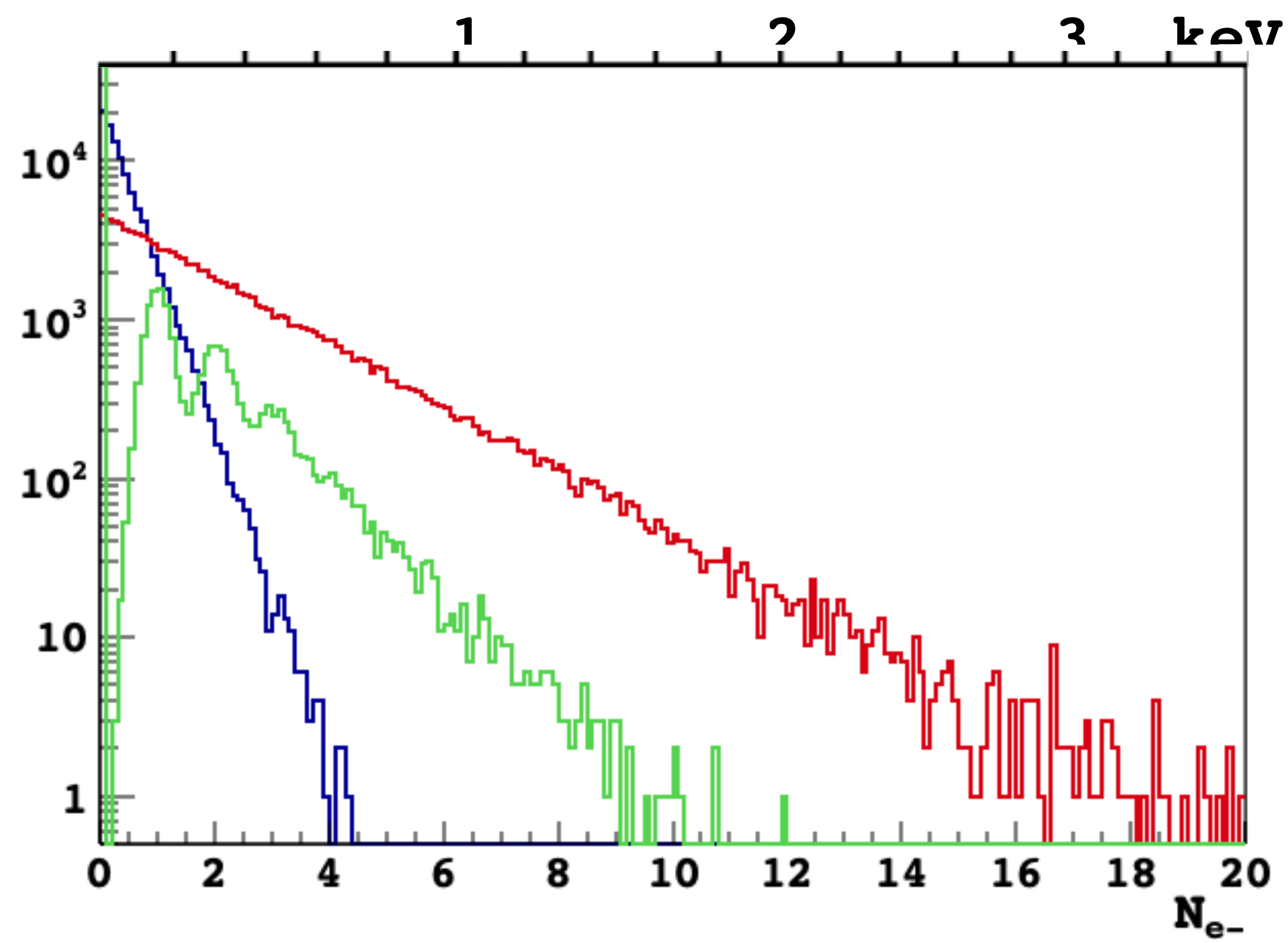
Bezrukov Model

signal produced by a 1 GeV/c^2 WIMP

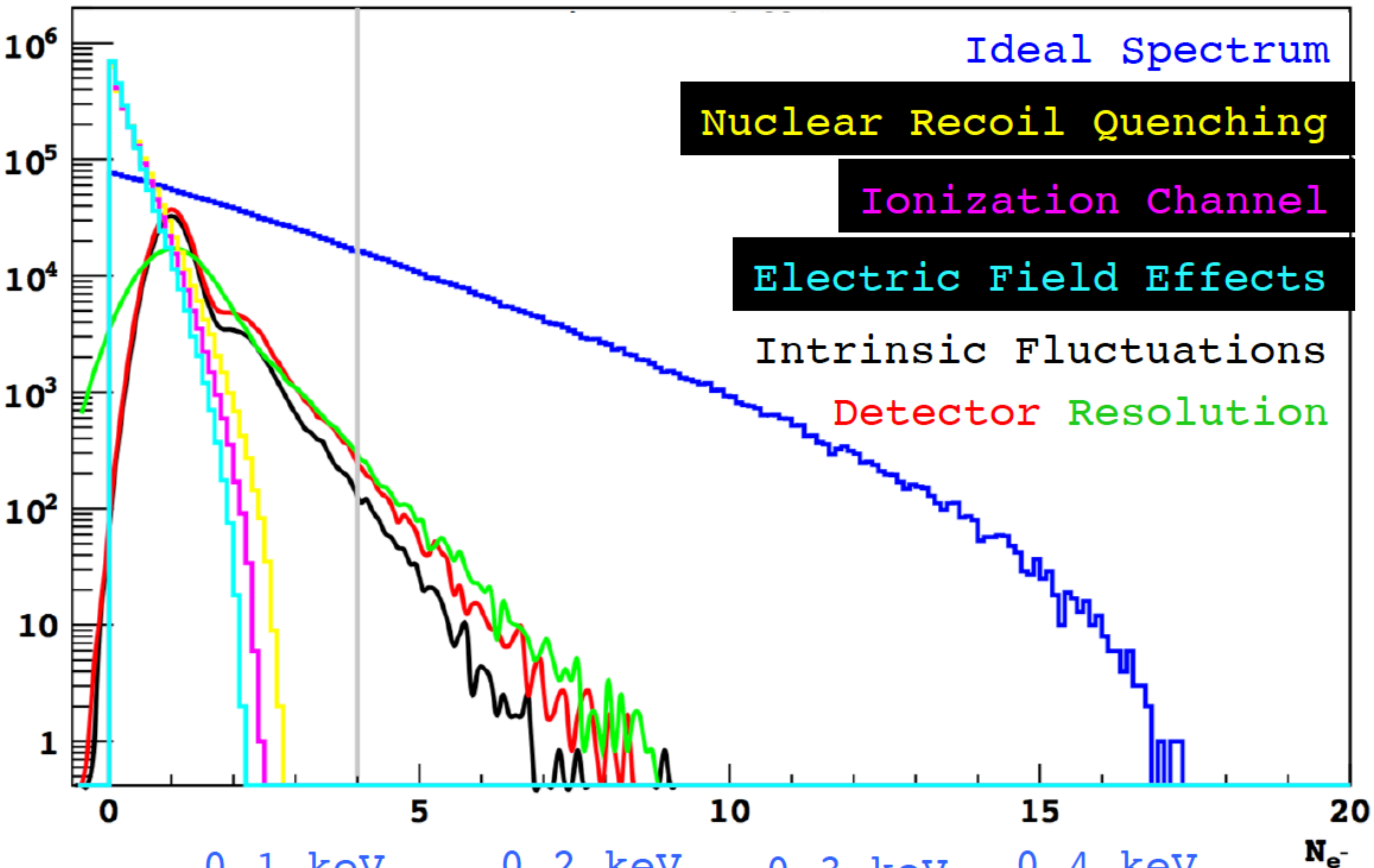
no quenching (Ne = E/W$_i$)

Add quenching w\out fluctuations (Ne = q x E/ W = Q$_y$ x E)

Add quenching w\ fluctuations (Ne = Poisson (Binomial (E/W, q)))



Ionization Signal in a Liquid Argon Target at 1 GeV WIMP Mass



0.1 keV 0.2 keV 0.3 keV 0.4 keV

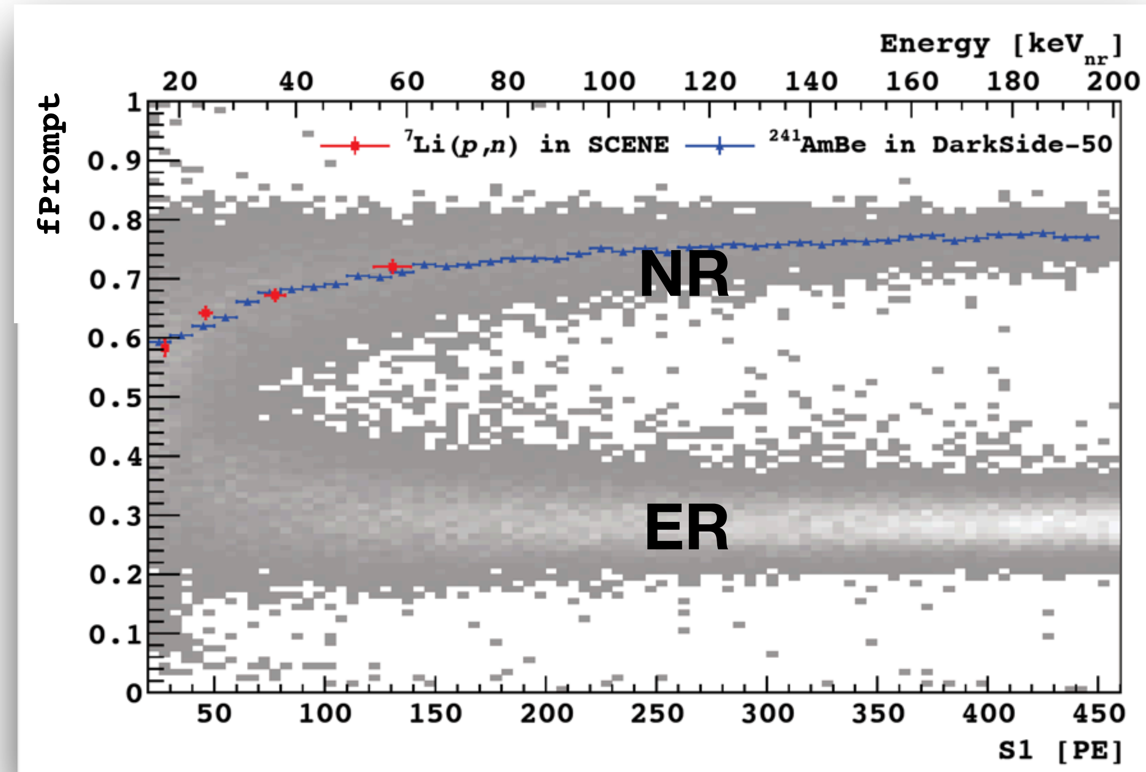
Visible Energy

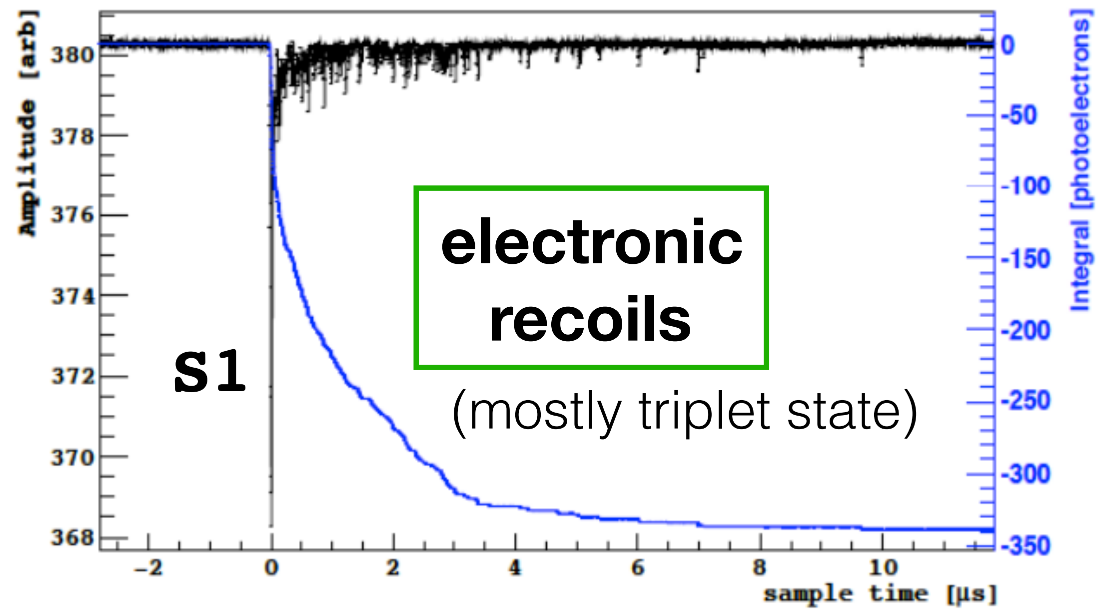
0.6 keV 1.0 keV 1.7 keV 2.5 keV

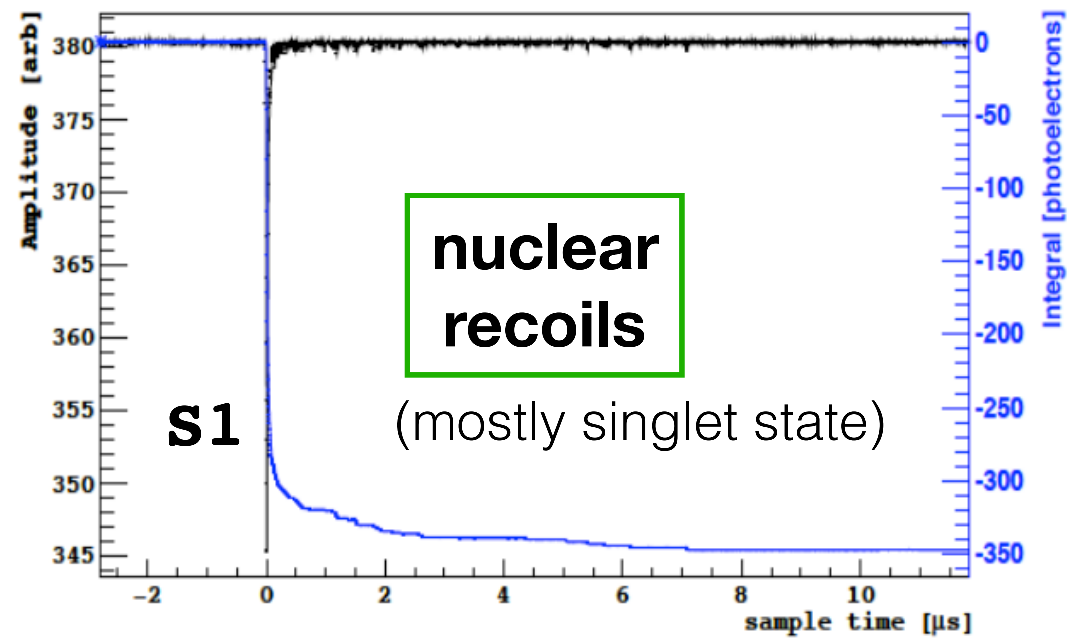
Nuclear Recoil Energy

Next Frontier:

- Ionization scale down to sub-keV
- Fluctuation models
- Recombination probability

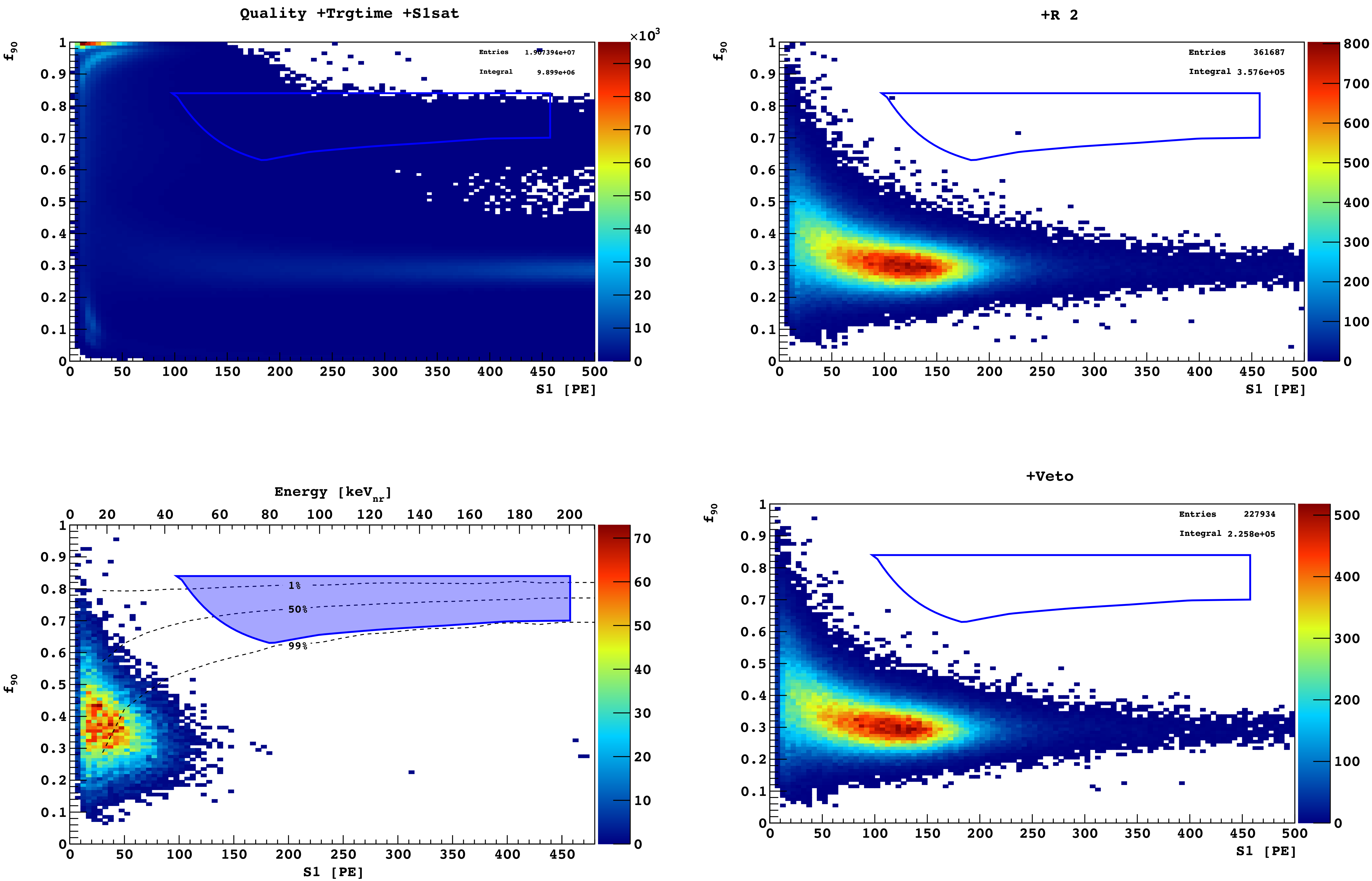






Scintillation in Liquid Argon:

☑ **ER Rejection** based on **Pulse Shape Discrimination: 10^9**


Quality +Trgtime +S1sat
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Integral 9.899e+06
×10³
+R 2
Entries 361687
Integral 3.576e+05
Energy [keV$_{nr}$]
1%
50%
99%
+Veto
Entries 227934
Integral 2.258e+05
f_{90}
S1 [PE]