Light Dark Matter Search with Liquid Argon

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FEATURES OF NOBLE LIQUID DETECTORS

- **Dense** and **easy to purify** (good scalability, advantage over solid targets)
- High **scintillation** & **ionization** (low energy threshold, not low enough to search < 1 GeV/c^2 DM)
- **Transparent** to own scintillation

For TPC

- High electron **mobility** and **low diffusion**
- Amplification for ionization signal
- **Discrimination** electron/nuclear recoils **(ER/NR)** via **ionization/scintillation ratio**

Liquid **Xenon**

- Denser & Radio pure
- Lower energy threshold
- Higher sensitivity at low mass WIMP

Liquid **Argon**

- lower temperature (Rn purification is easier)
- **Stronger ER discrimination**
- Intrinsic ER BG from ^{39}Ar
- Need wavelength shifter

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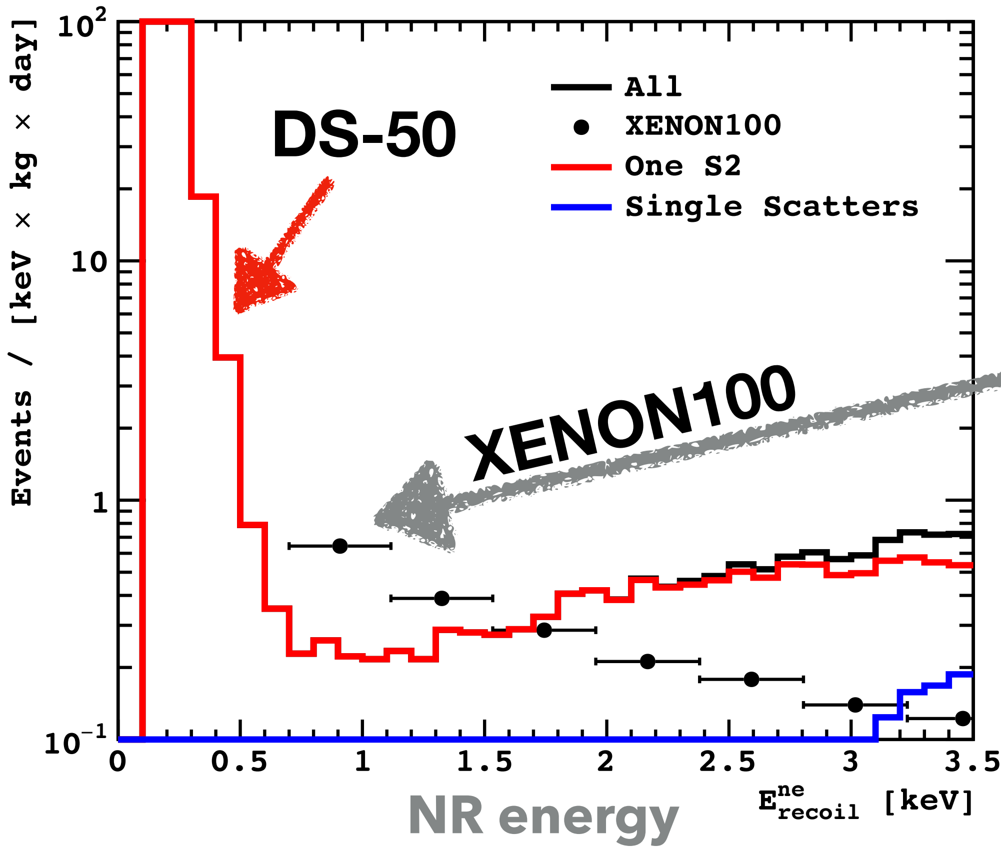
COMPARISON WITH XENON100



Convert with their ionization yield

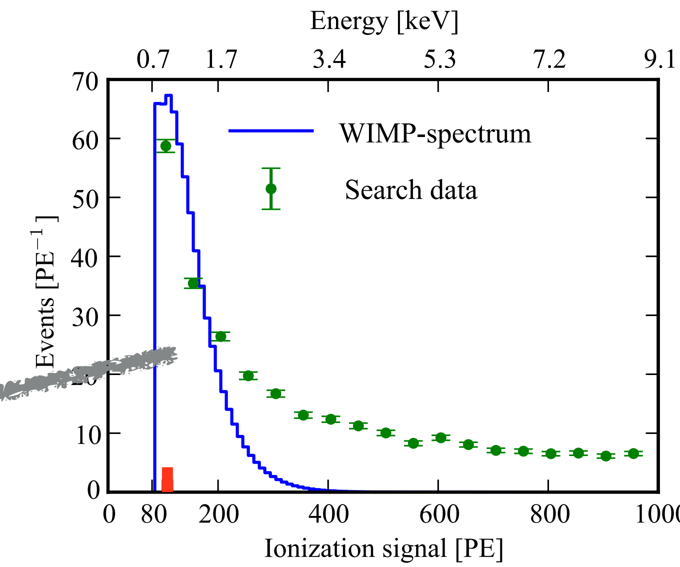


FIG. 4. Energy distribution of the events remaining in the data set after all data selection cuts. As an example, the expected spectrum for a WIMP of 6 GeV/c^2 and a spin-independent WIMP-nucleon scattering cross section of 1.5×10^{-41} cm^2 is also shown. The corresponding nuclear recoil energy scale is indicated on the top axis. The charge yield model assumed

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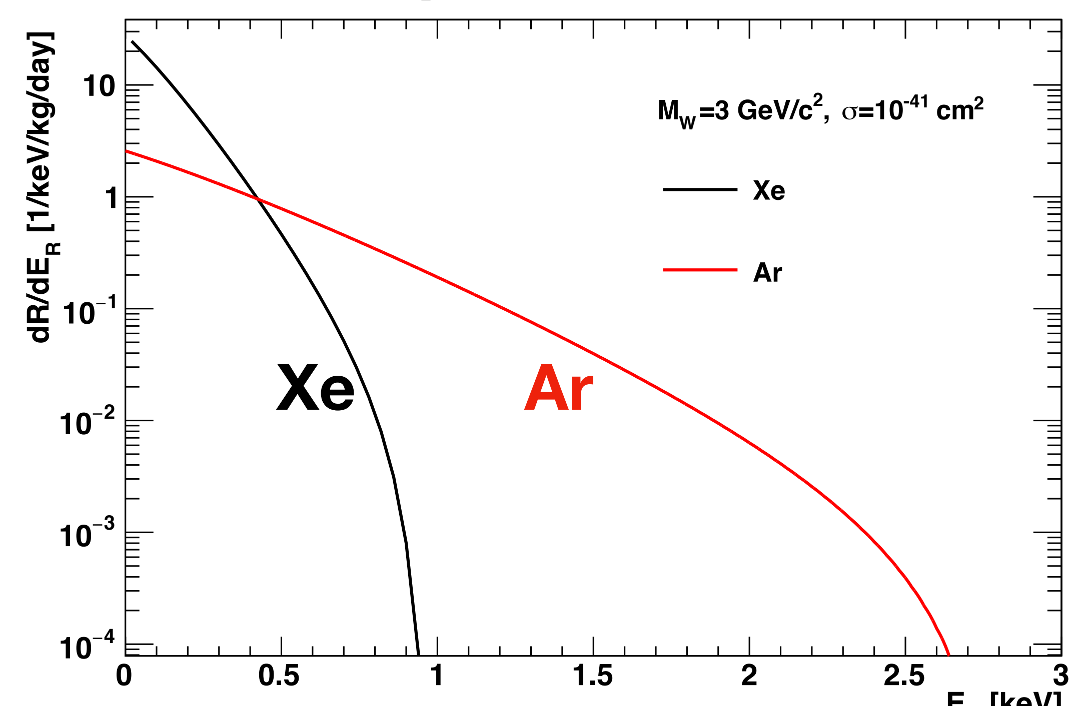
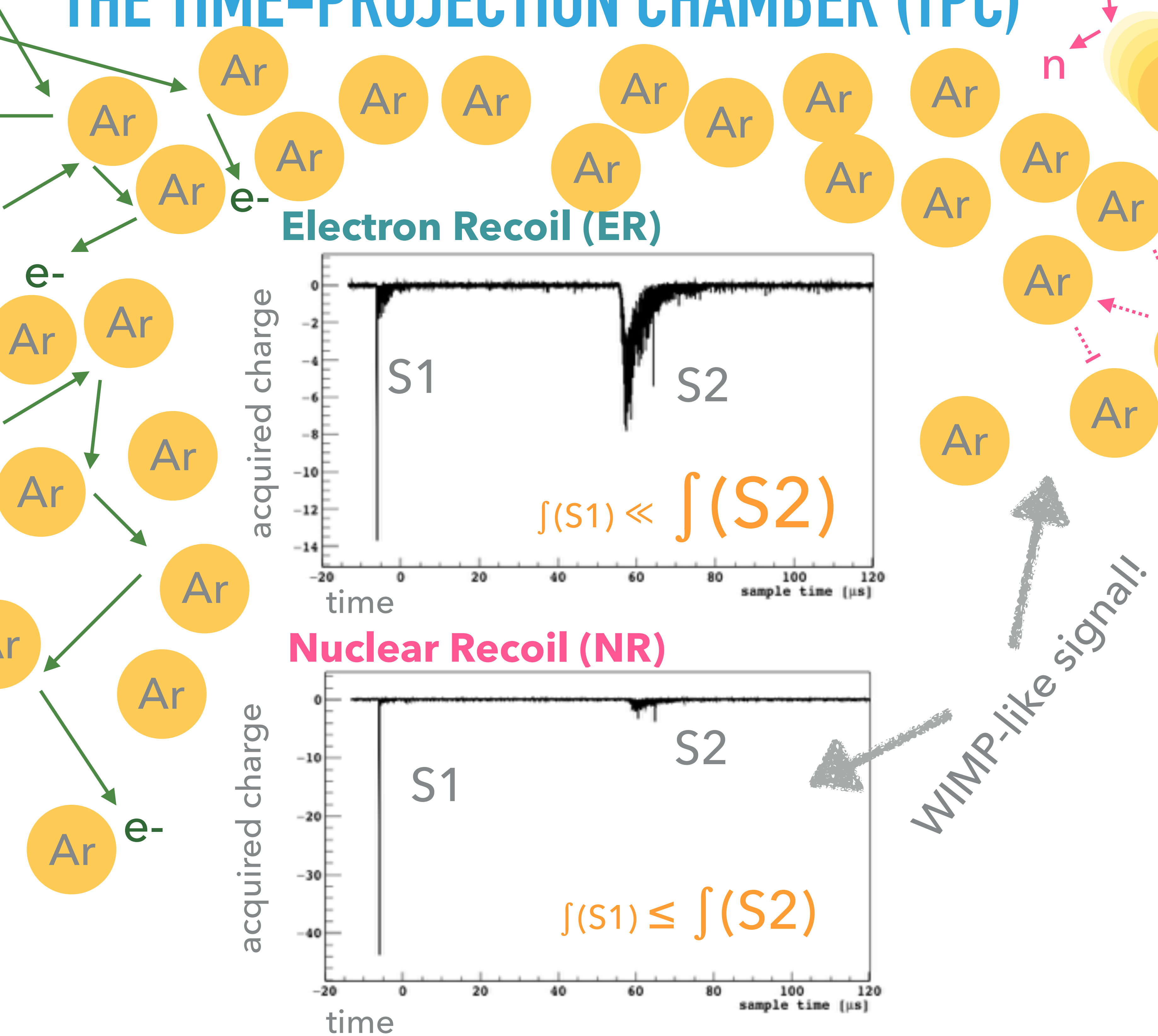
	XENON100	DarkSide-50
BG [evt/keVnr/kg/d]	0.5 in [0.7, 1.7] keVnr	0.2 @ 1.1 keVnr
BG [evt/keVnr/kg/d]	0.07 in [3.4, 9.1] keVnr	0.5 @ 6 keVnr
Analysis threshold	0.7 keVnr	0.6 keVnr

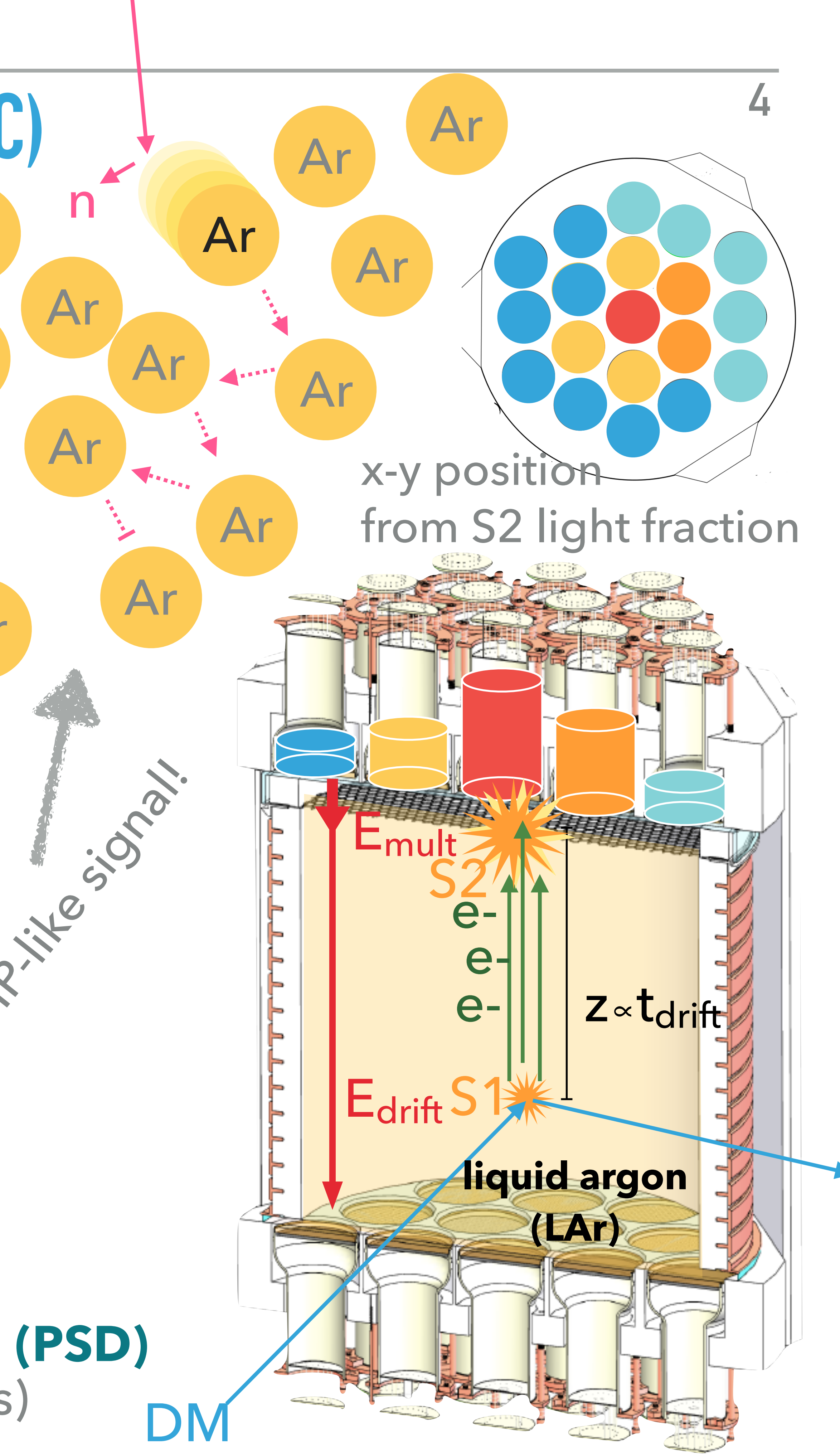
- DS-50 has lower BG at the lowest Ne bins.
- Ar sees more events with given WIMP mass and cross section.

WIMP spectra in Xe and Ar



THE TIME-PROJECTION CHAMBER (TPC)





S2/S1 ratio and **Pulse Shape Discrimination (PSD)**

WIMPs will generate nuclear recoils (NRs)

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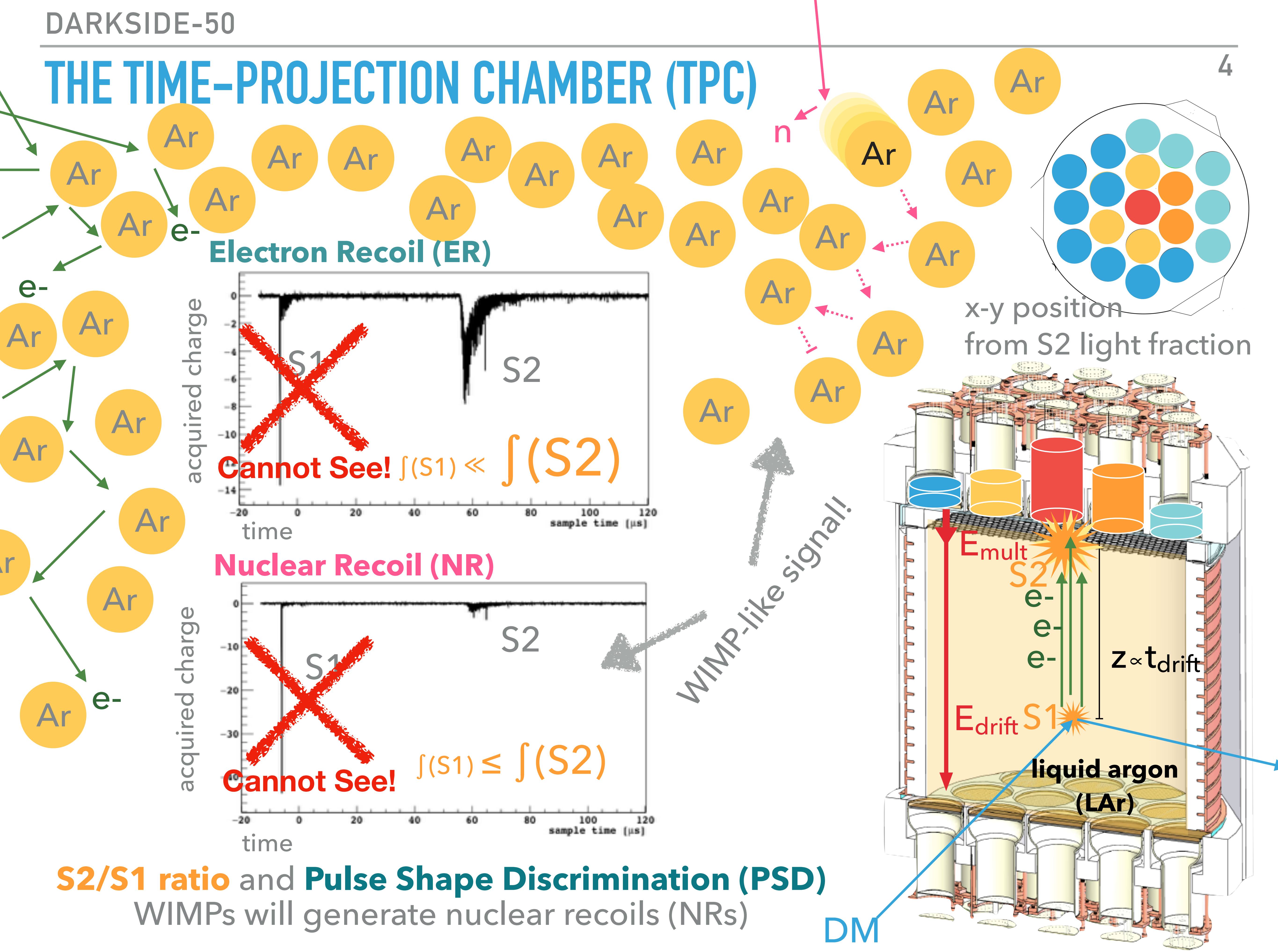

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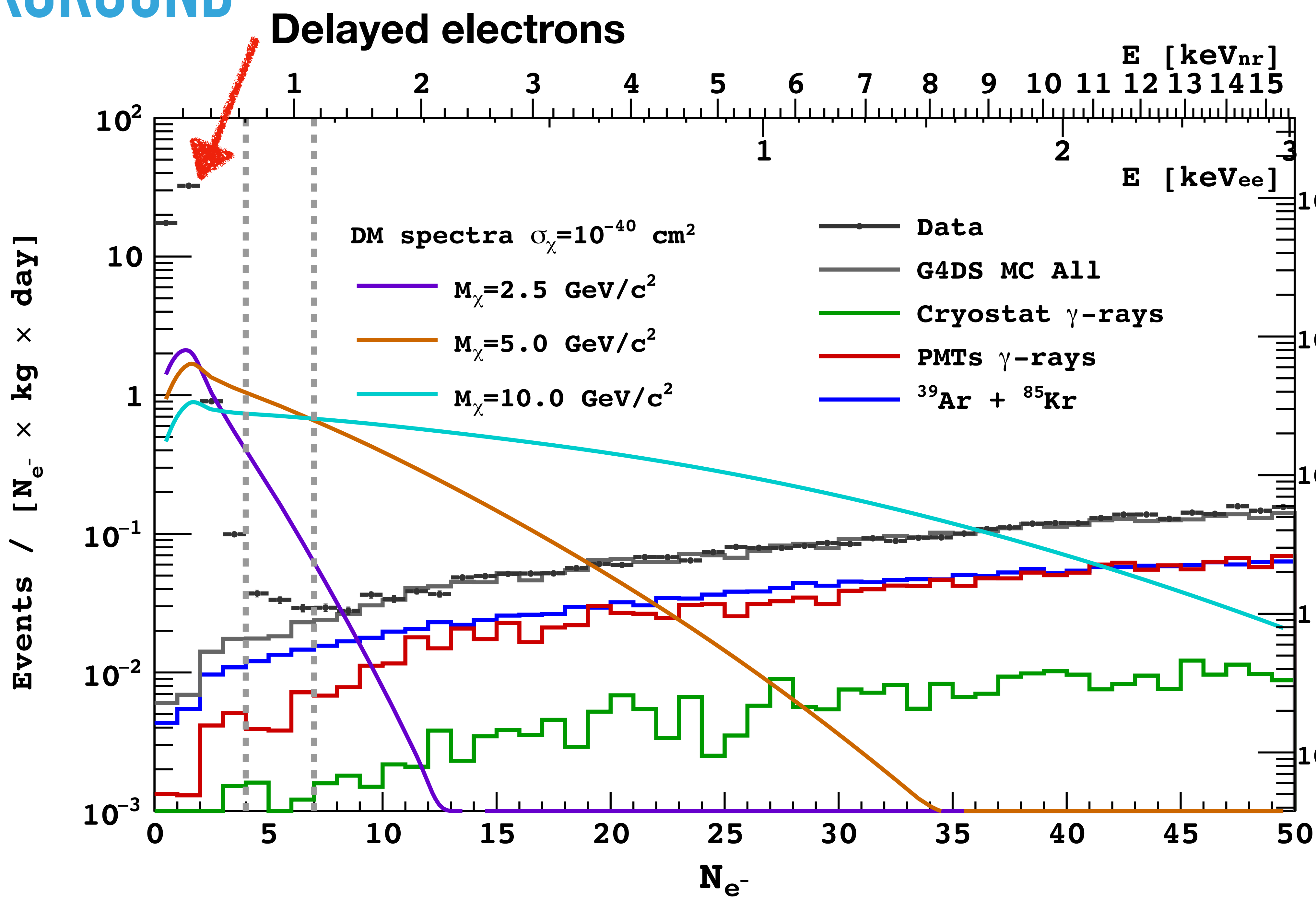
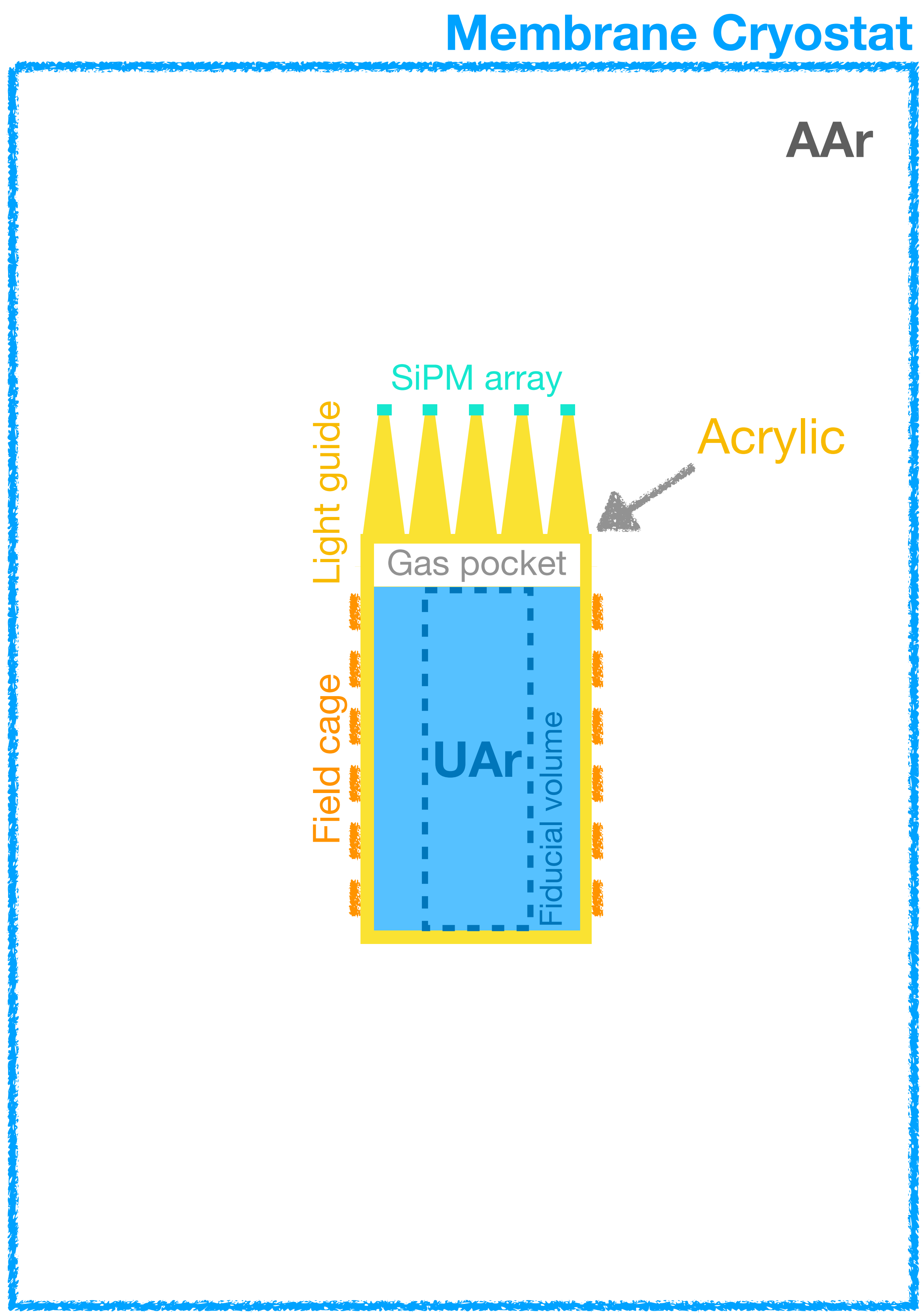
BACKGROUND



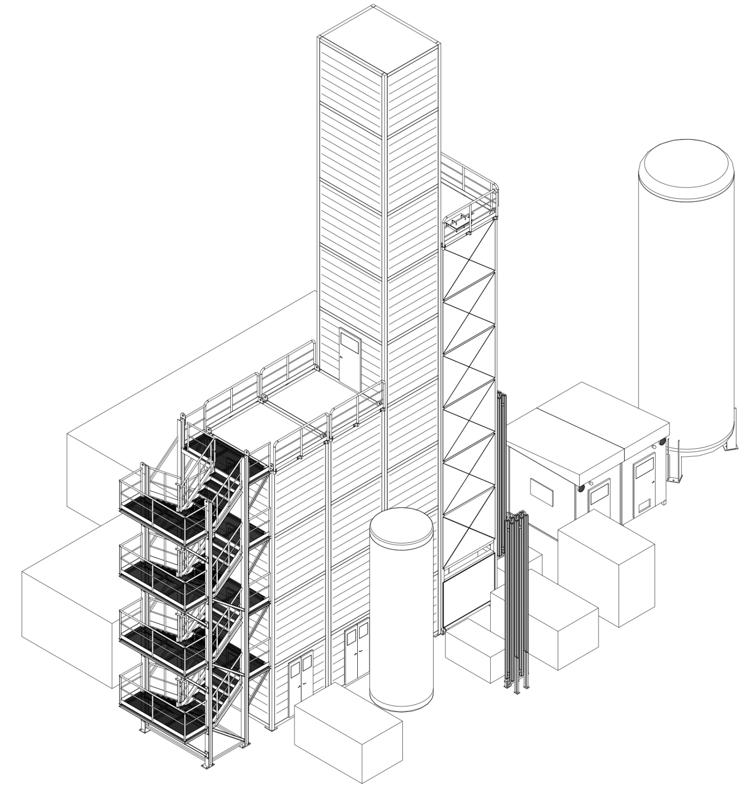
- The events in Ne<4 are delayed electrons related to impurities.
- The origin of the excess at low Ne events (4<Ne<10) is unknown and under investigation.

CRITERIA FOR FUTURE LAr TPC

- Low activity of ^{39}Ar
- Low impurity
  - good electron lifetime
  - low rate of the single electron events
- Ultra-pure photo-sensor
- Pure (or no) cryostat



FURTHER DEPLETION OF Ar

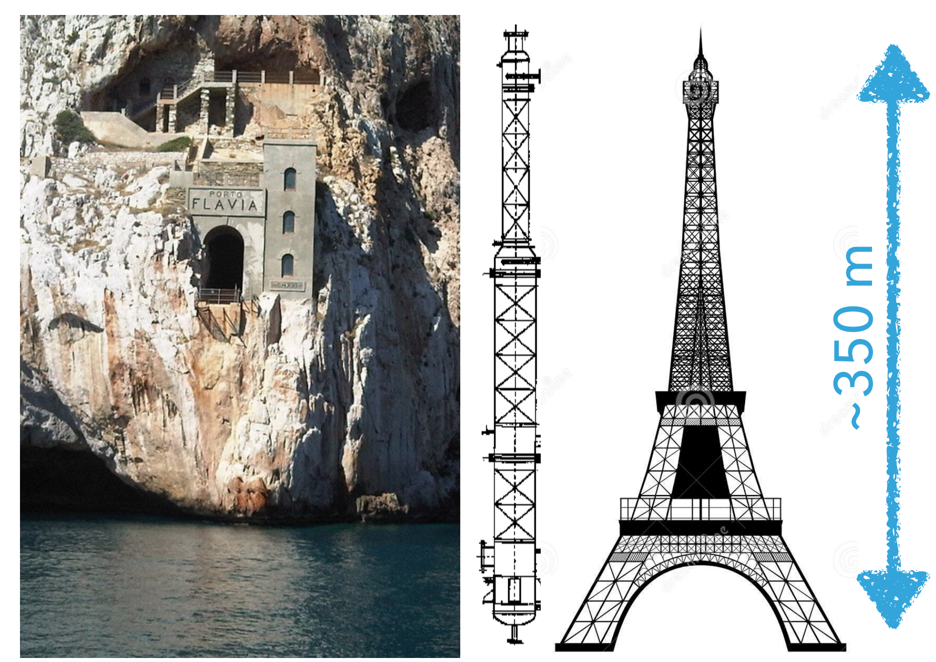


Urania (Underground Argon):

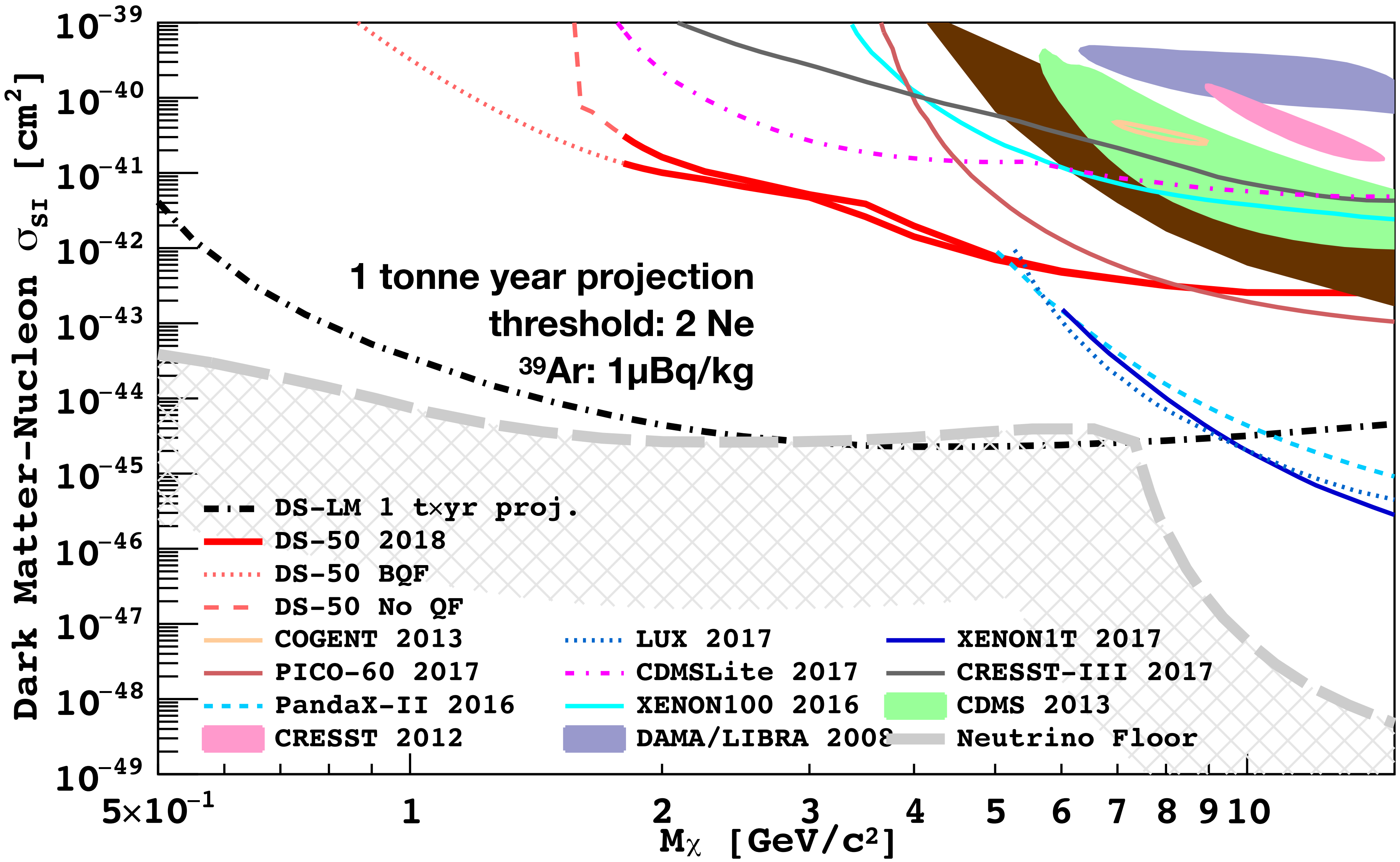
- Expansion of the argon extraction plant in Cortez, CO, to reach capacity of **100 kg/day** of Underground Argon

Aria (UAr Purification):

- Very tall column in the Seruci mine in Sardinia, Italy, for high-volume chemical and isotopic purification of Underground Argon. A factor 10 reduction of ^{39}Ar per pass is expected.



SENSITIVITY

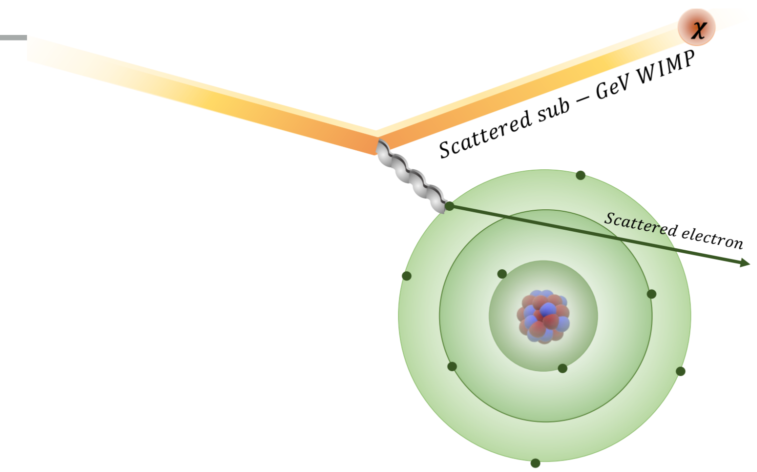


- Exposure: 1 tonne year
- ^{39}Ar: 1μBq/kg (currently ~1mBq/kg in DS-50) with ^{39}Ar depletion in Aria plant
- SiPM: 50 times lower contribution than currently achieved in DS-20k (cleaner and reduced electronics)
- Acrylic: 5 mm thickness with the activities achieved by JUNO collaboration.
- No cryostat
- Analysis threshold: 2 Ne (~0.4 keVnr)
- No systematic uncertainties are included

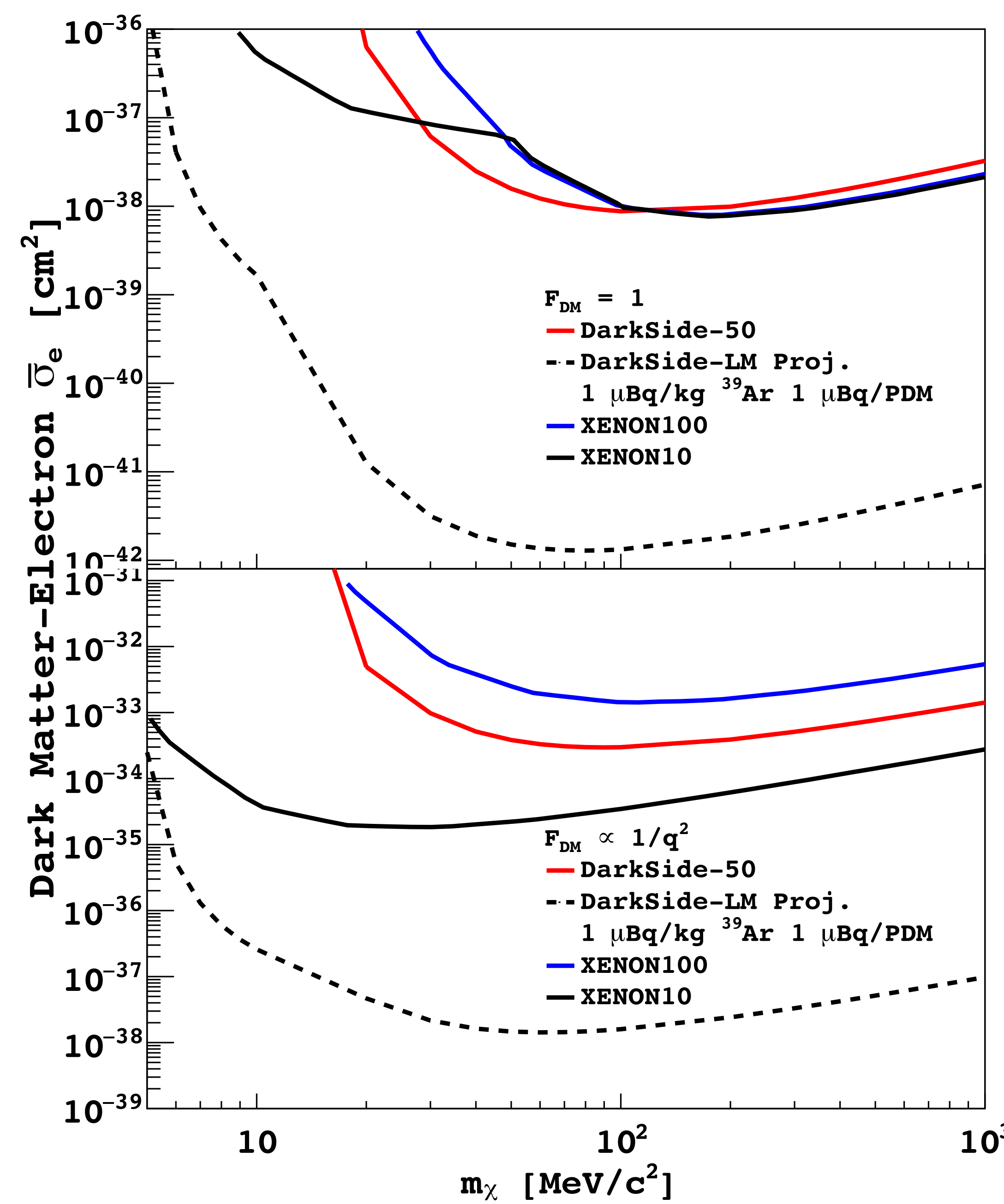
ASSUMPTIONS

- No BGs except the internal ^{39}Ar BG, external gamma BGs from the detector components, and coherent neutrino BGs (the neutrino electron scattering is an order smaller and ignored).
- Low Ne events will be suppressed via deep fiduciallization, pulse shape, and reduced activity in the active volume.

SUB-GEV DARK MATTER SEARCH

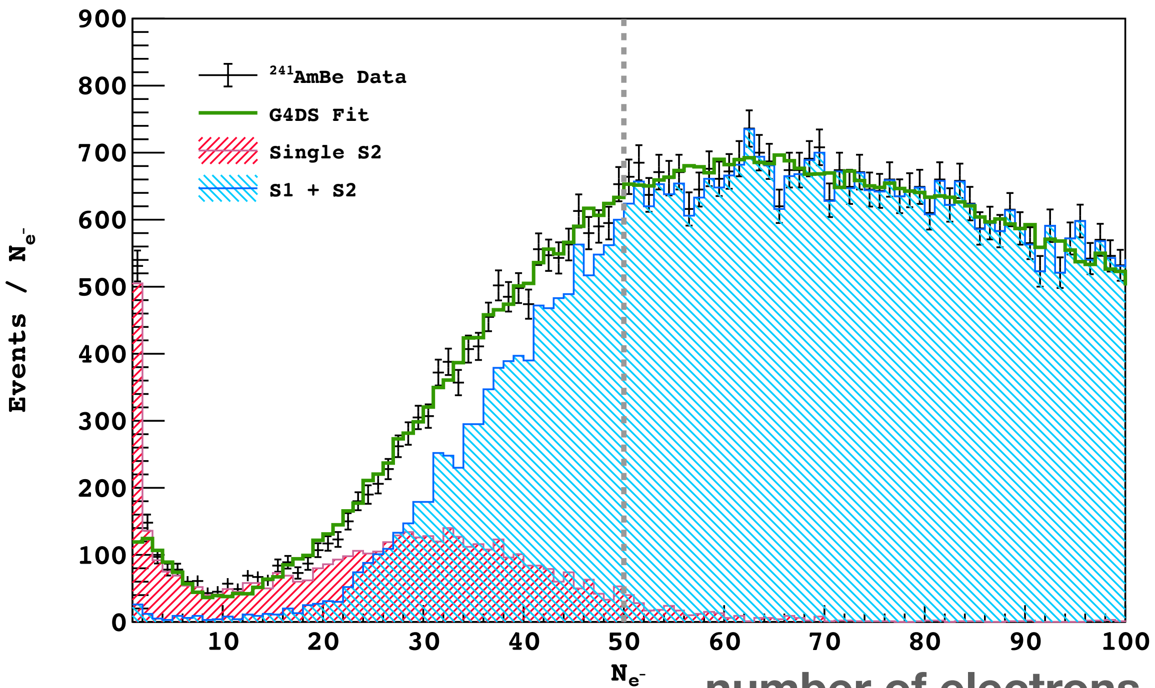


- Ultra-light DM ($m_\chi \ll 1$ GeV) scatter off electrons
- DM signals are also ER.
- The same measured spectrum as the WIMP search can be used.
- Two extreme cases of Dark Matter form-factor are considered
  - $F_{DM}=1$ heavy mediator
  - $F_{DM} \propto 1/q^2$ light mediator
- The dashed lines are with assumptions of 1 uBq/kg for ^{39}Ar, 1 uBq/PDM, Cu cryostat, 80,000 kg day, and 2e- threshold



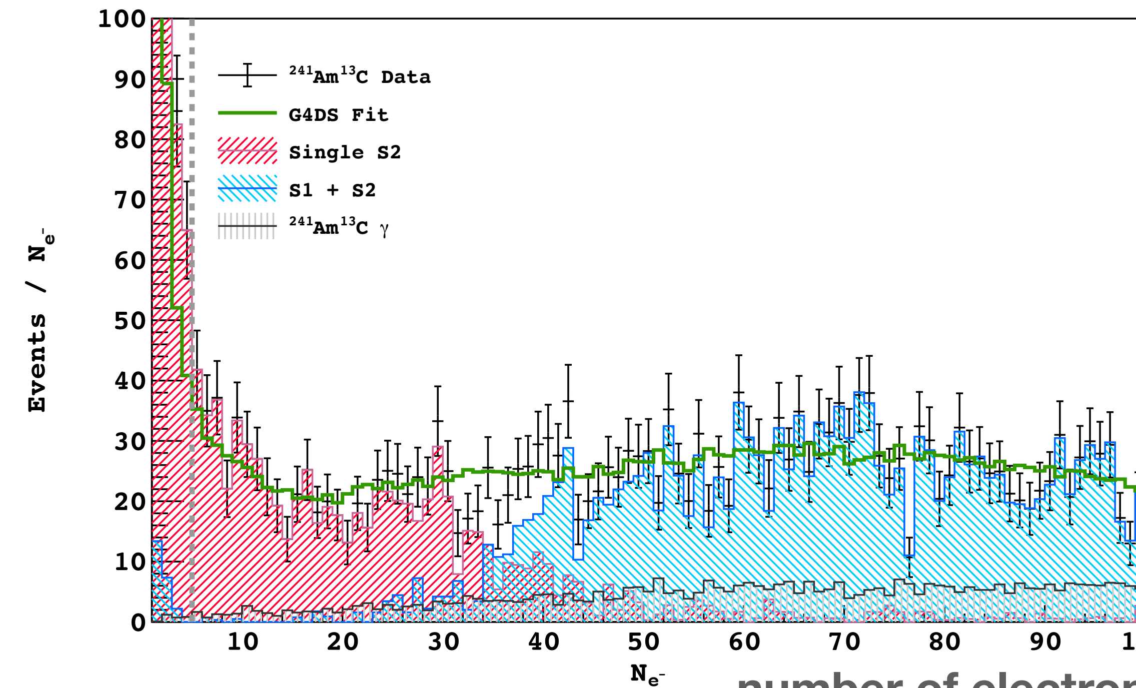
NR IONIZATION YIELDS

AmBe neutron source



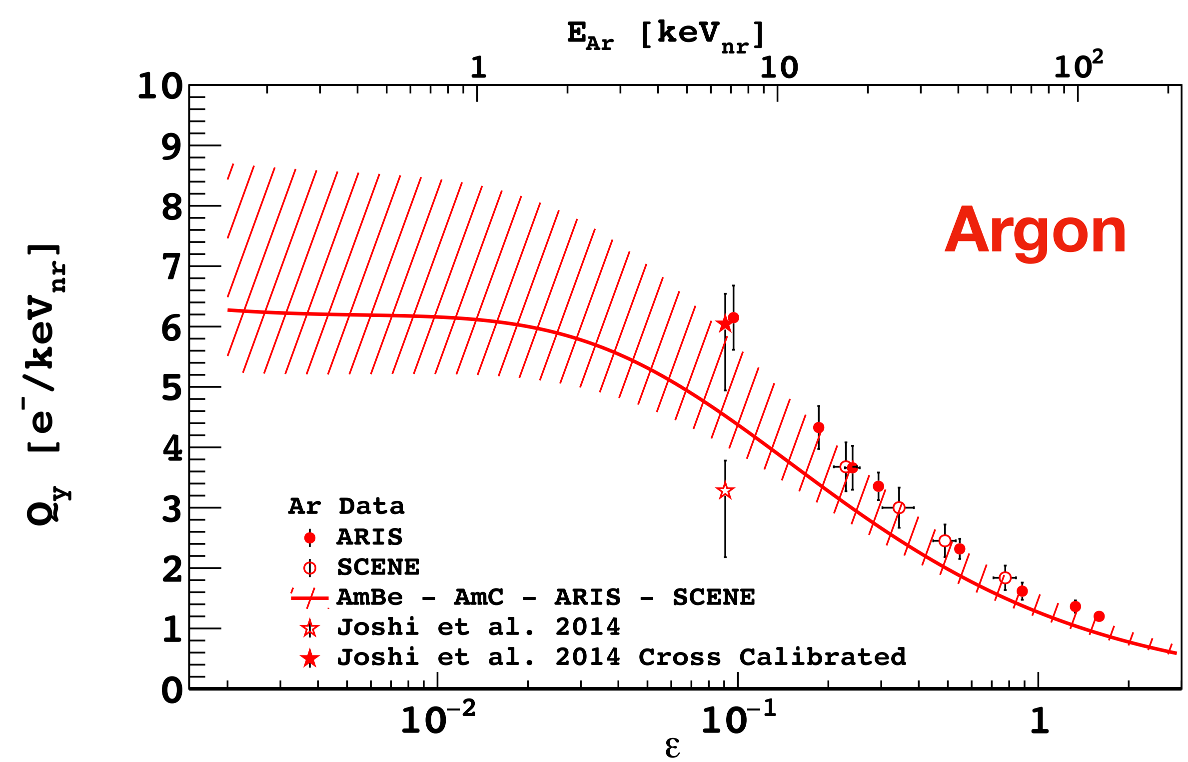
number of electrons

AmC neutron source



number of electrons

- MC + Ionization model [1] fit to NR data from AmBe and AmC.
- Need calibration points at low recoil energies



Reduced Energy

[1] F. Bezrukov, F. Kahlhoefer, and M. Lindner, Astropart. Phys. 35, 119 (2011).