WIMP Searches

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University of Washington

PROGRAM

Workshop Program [PDF]

SEPTEMBER 19, 2013 - THURSDAY

9:00 AM - 9:30 AM *BREAKFAST*

9:15 AM - 9:30 AM *WORKSHOP OPENING*
Rocky Kolb

MORNING SESSION
Chair: Tongyan Lin

Happy to be here again!

9:30 AM - 10:00 AM **Joseph Lykken**, Fermilab
Opening Overview Talk ~ "Prospectus for the Discovery of Dark Matter at the LHC" [PDF, 12.31 MB]

10:00 AM - 10:30 AM **Alvaro Chavarria**, Kavli Institute for Cosmological Physics
DAMIC and low mass WIMP searches [PDF, 34.04 MB]

Outline

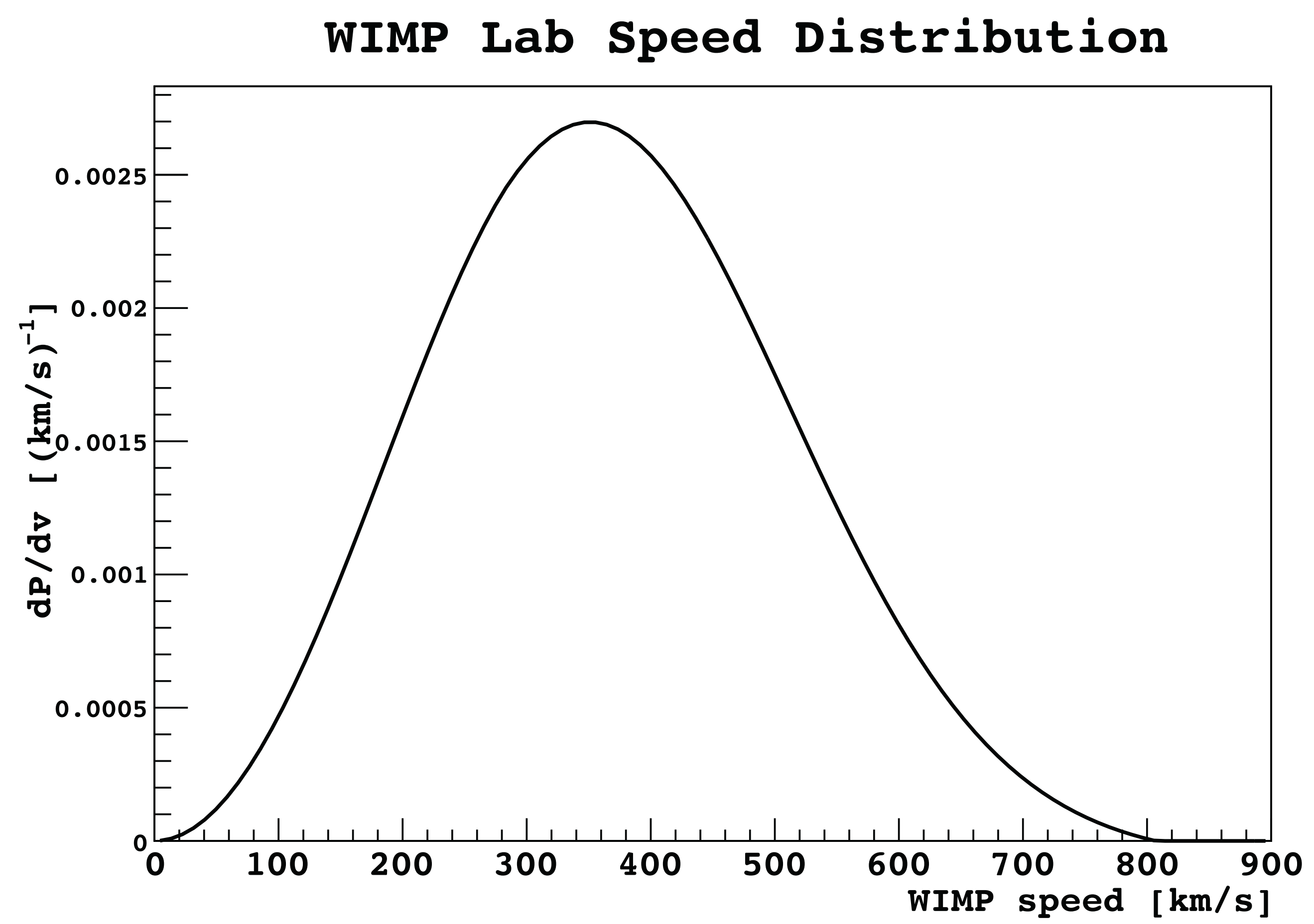
- Direct detection (DD) of “WIMP” dark matter.
- Extending the DD sensitivity to the scattering of lighter WIMPs.
- Technology overview.
- Results from different experiments (focus on leading and recent 2018-19 results).
- Outlook for the coming years.

Galactic dark matter

Local density in ~0.3 GeV c^2 cm^{-3}.

Interaction cross-section is *small*.

Dark matter is *cold*, kinetic energy is ~10^{-6} Mc^2.

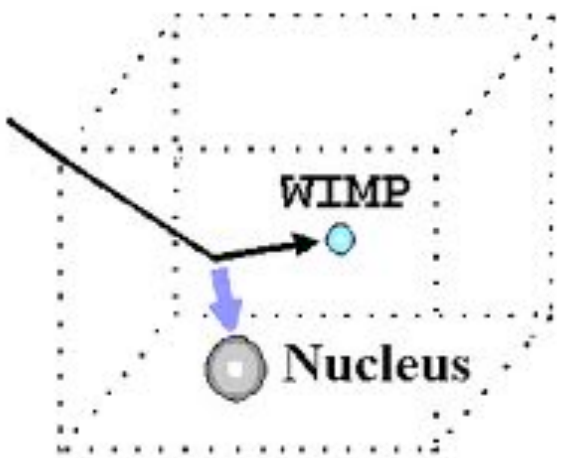


Dark matter particle can deposit at most its kinetic energy (if fermion) or its rest energy (if boson).

Need detector with **low energy threshold**, largest possible exposure and correspondingly low backgrounds.

WIMP-nucleus ES

Traditional mechanism for WIMP searches:

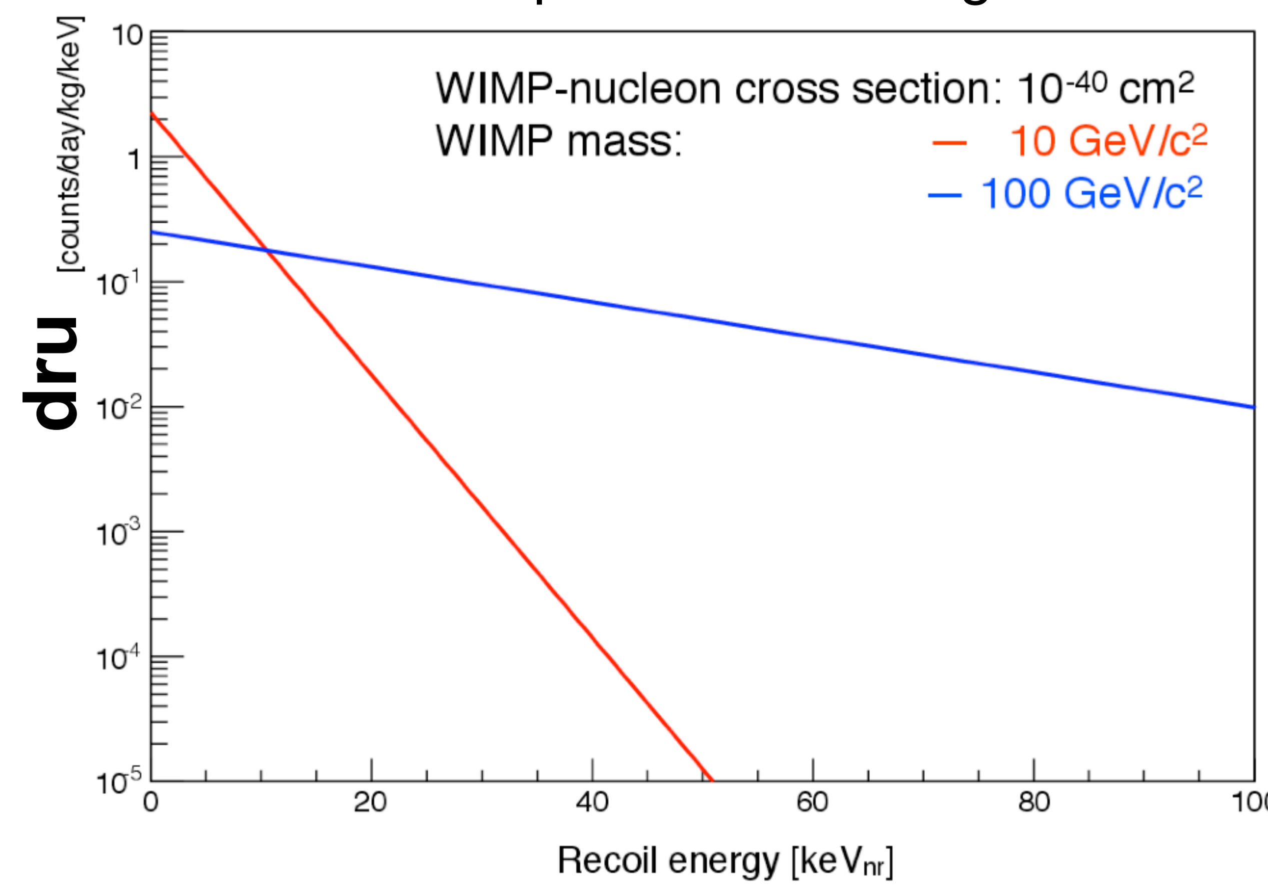


Maximum energy transfer when *M* ~ *A*

For low-mass WIMP:

$$M_T \gg M_\chi \qquad E_T < 4\frac{M_\chi}{M_T}E_\chi$$

Recoil spectrum in Si target



Lower recoil energies for smaller WIMP masses

Coherent enhancement:

$$\sigma_N \propto A^2$$

Lighter WIMPs

Elastic scattering limited:

$$E_T < 4\frac{M_\chi}{M_T}E_\chi$$

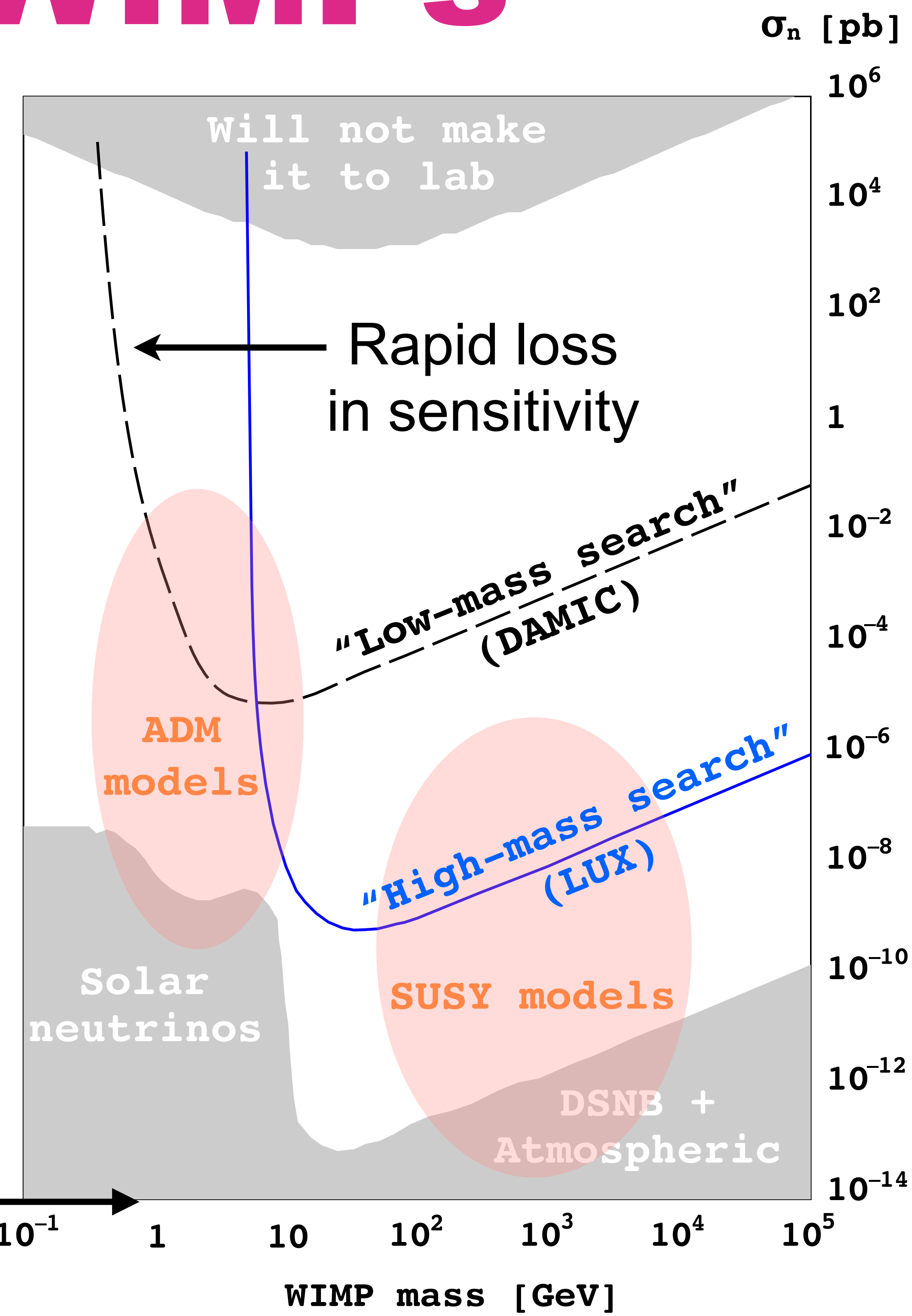
Find process that can extract most (all!) kinetic energy from the DM particle.

- If the energy is deposited by an electron, can probe E_χ down to ionization threshold!

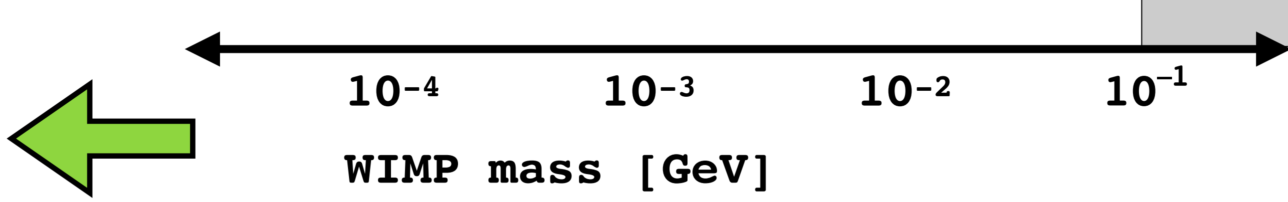
Noble liquids ~ 10 eV

Semiconductors ~ 1 eV!

Can probe scattering of WIMPs as light as MeV/c^2.

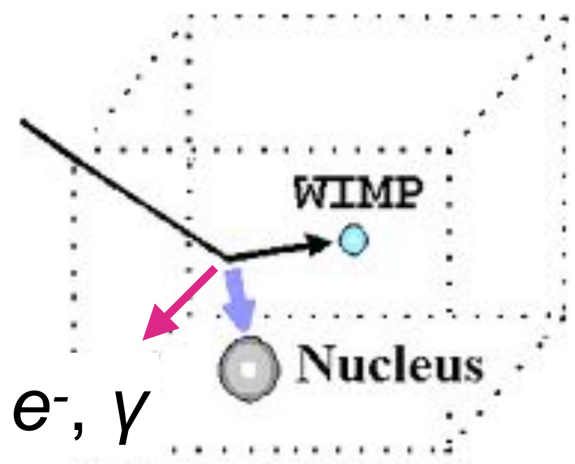


Warm DM



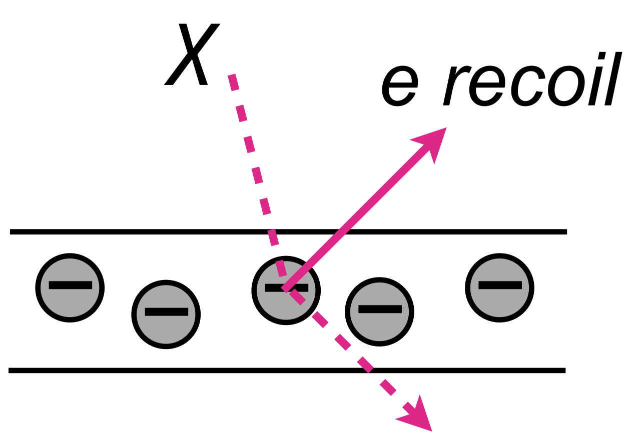
Processes

Three-body final state:



- An additional e^- or γ in the final state.
- *Migdal effect* (atomic e^-) or *Bremsstrahlung* (γ).
- E and p can be conserved even when e^- *or* γ take most of the WIMP kinetic energy.
- Probability of e^- *or* γ emission **<10^{-6}**. Rare.
- Never observed for recoils with keV energies. **Uncalibrated**.

DM-e scattering:

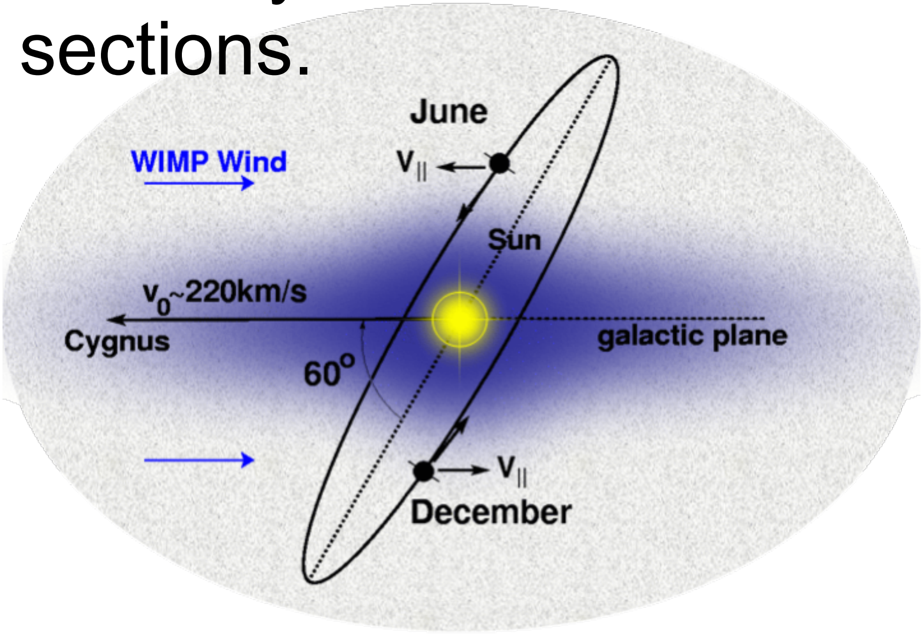


- Electrons are a lighter target.
- Electrons bound with some momentum; there is a region of phase-space where the electron carries most of the WIMP kinetic energy.
- Phase-space 'penalty,' no coherent enhancement and probing DM-e interaction cross-section.

Direct detection

Although there are new ideas motivated by a broader theoretical perspective and enabled by new technologies, the game remains the same

- **Low threshold** (toward the ionization limit and below with heat sensors) to access smaller WIMP masses.
- **Scalable technologies** to increase the number of interactions in the target.
- **Low and controlled backgrounds** to identify the rarest signals and probe the smallest cross sections.
- **(Maybe someday) directionality** to confirm the discovery and WIMP astronomy.



K. Ni PDF 2019

Technologies

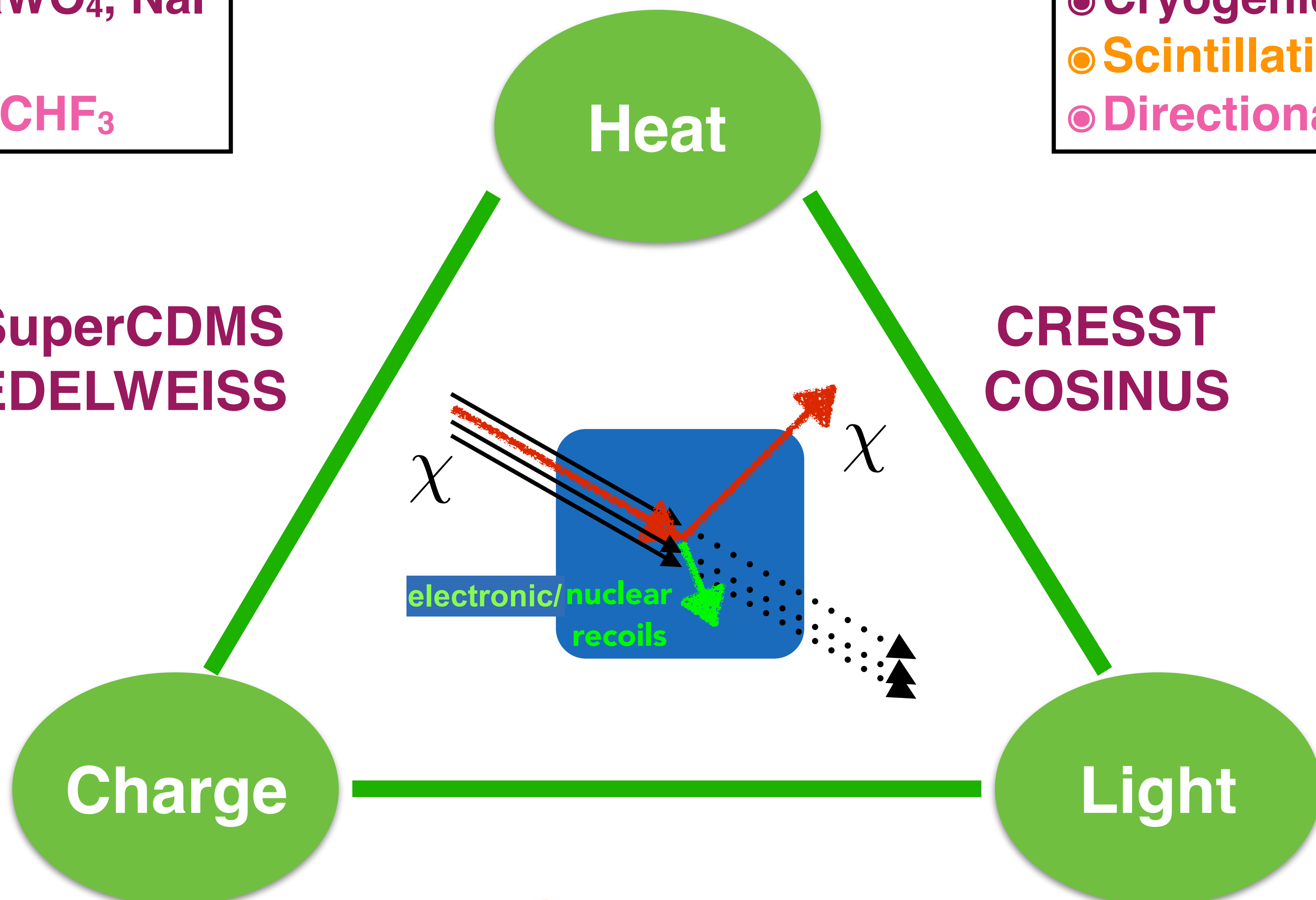
Target Materials
- Xe, Ar, Ne, He
- Ge, Si, He
- C_3F_8, CF_3I
- Ge, Si, $CaWO_4$, NaI
- NaI, CsI
- CS_2, CF_4, CHF_3

Techniques
- Noble liquids
- Low-threshold
- Bubble chambers
- Cryogenic bolometers
- Scintillating crystals
- Directional detectors

SIMPLE
PICASSO
COUPP
PICO

SuperCDMS
EDELWEISS

CRESST
COSINUS



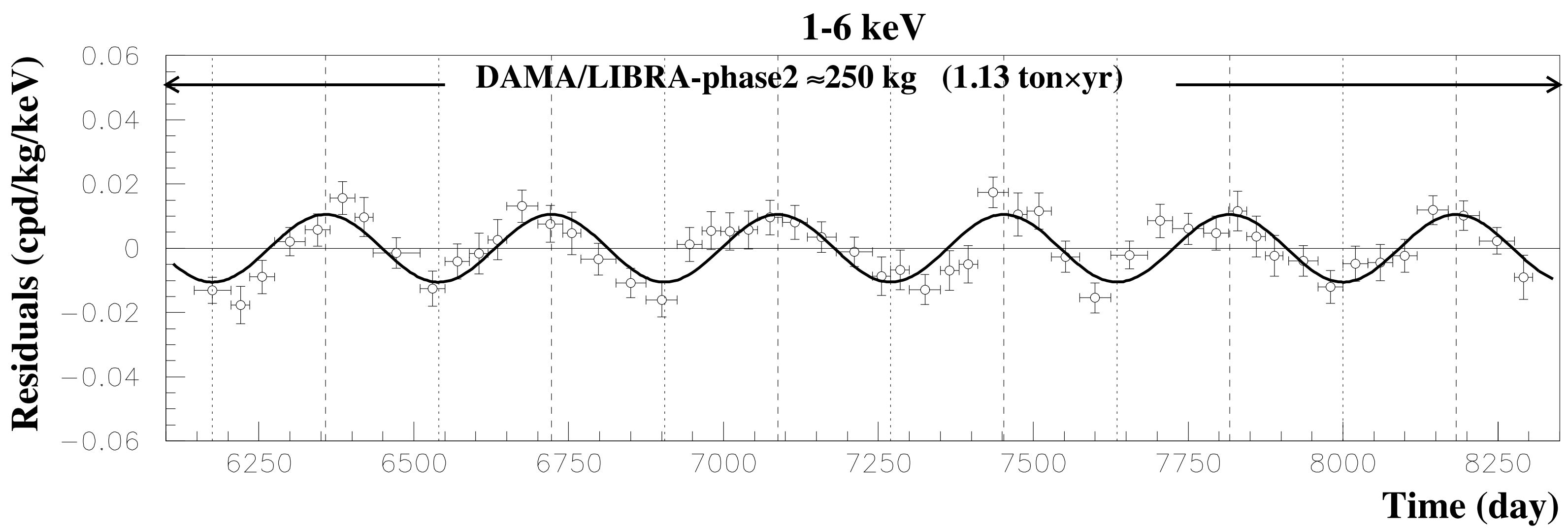
CoGeNT
CDEX
DAMIC
SENSEI
NEWS-G
DRIFT
MIMAC
DMTPC
NEWAGE

LUX/LZ
PandaX
XENON

ArDM
DarkSide

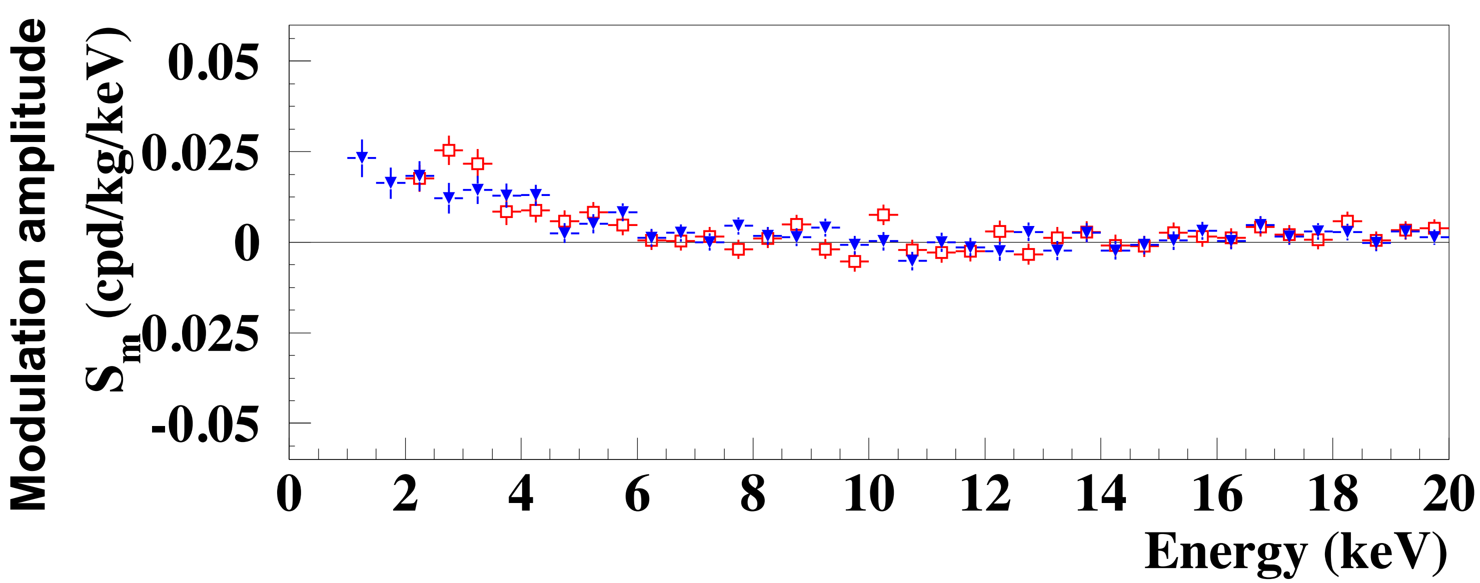
DAMA
DM-Ice
COSINE
SABRE
ANAIS
DEAP
XMASS

DAMA/LIBRA



Annual modulation (9.5 σ) of **total** low-energy signal rate in array of NaI scintillating crystals.

“Smoking gun” evidence for dark matter



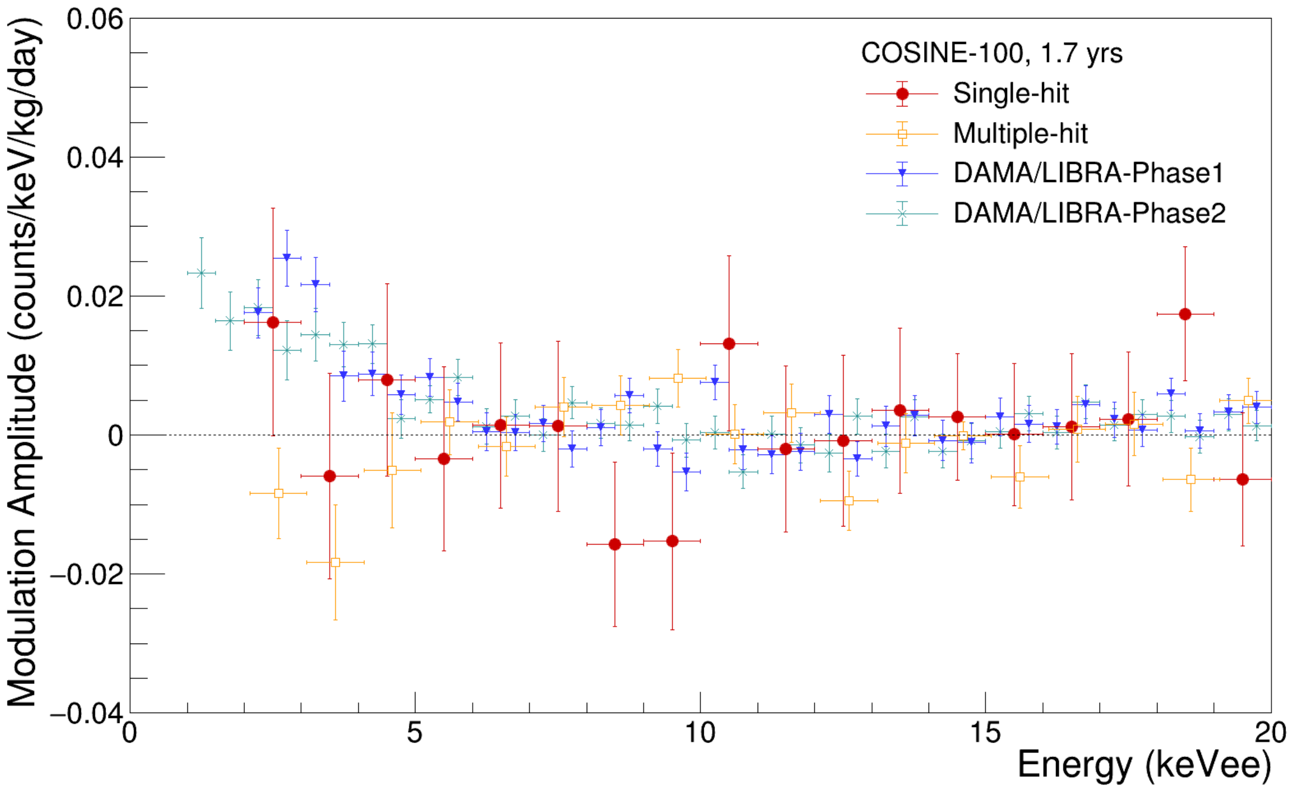
<u>Phase 2 results</u> 2011-2017 confirmed and extended modulation to 1 keV

Note: Modulation amplitude is larger than total recoil rates in iodine and electron targets.

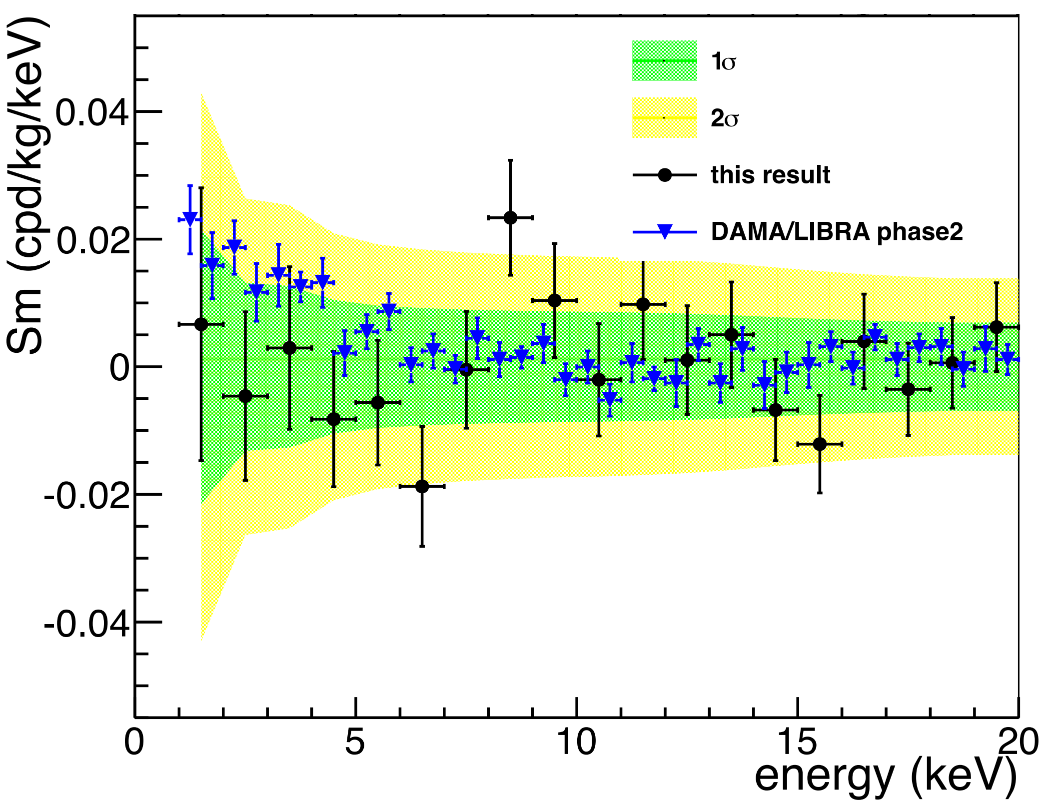
No proposed DM explanation is consistent with DAMA and other experiments:

Direct tests of DAMA

COSINE-100



ANAIS-112

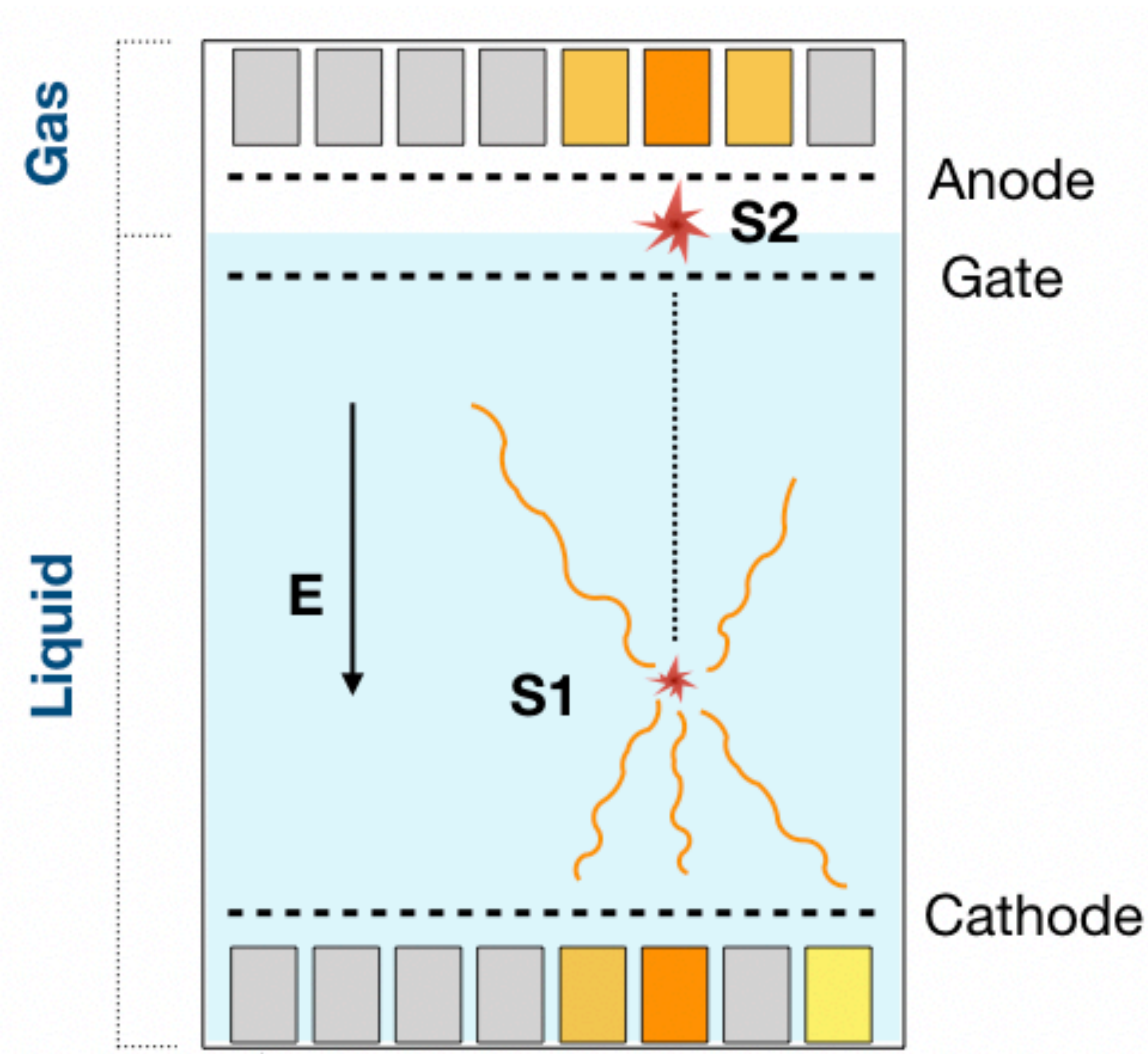


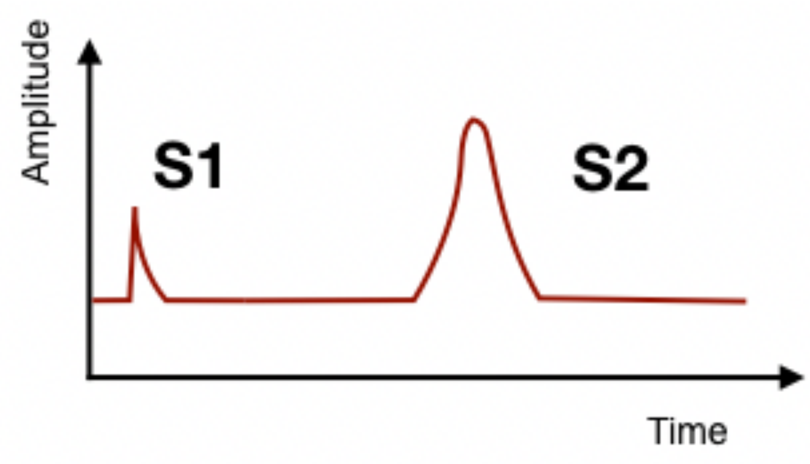
100-kg NaI arrays in Korea and Spain released first annual modulation results in **2019**: Observed modulation amplitudes **consistent** with both DAMA and no modulation.

Wait 3-5 years for 3-*σ* sensitivity to test DAMA!

Noble liquids

Two-phase time-projection chamber (TPC)

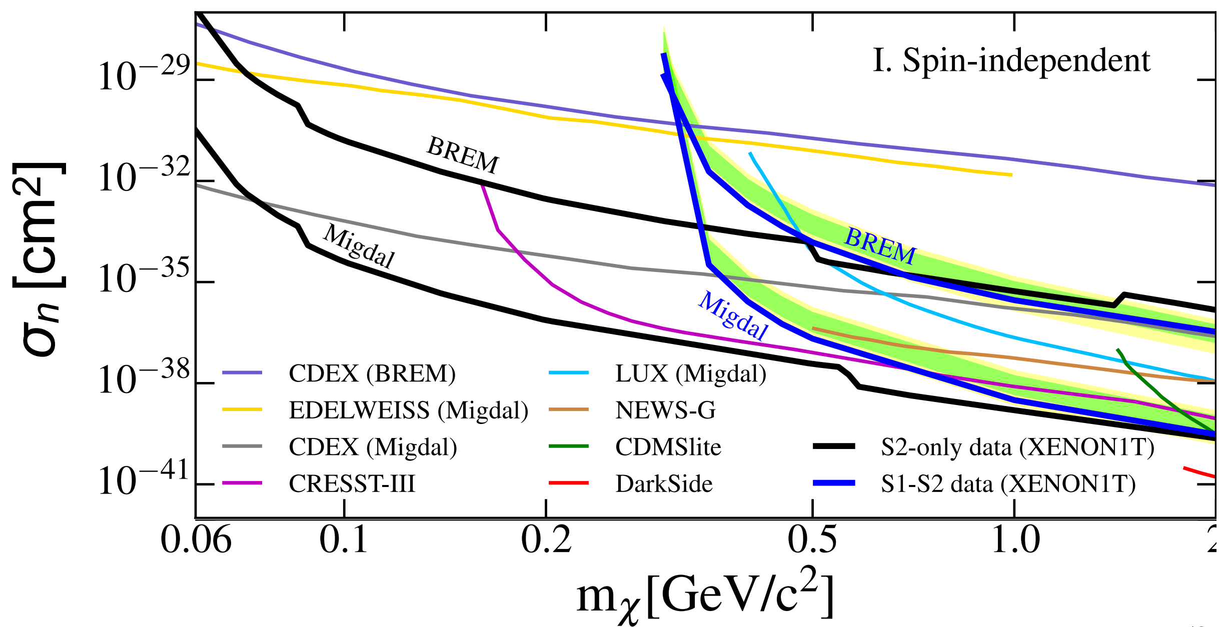




- Xenon or argon.
- 3D position reconstruction: fiducialization.
- Discrimination between electronic and nuclear recoils.
- Large target mass (tonne scale).
- Easy to purify.
- Sensitivity to single-photon (S1) and **single**-electron (S2) signals.

Noble liquids

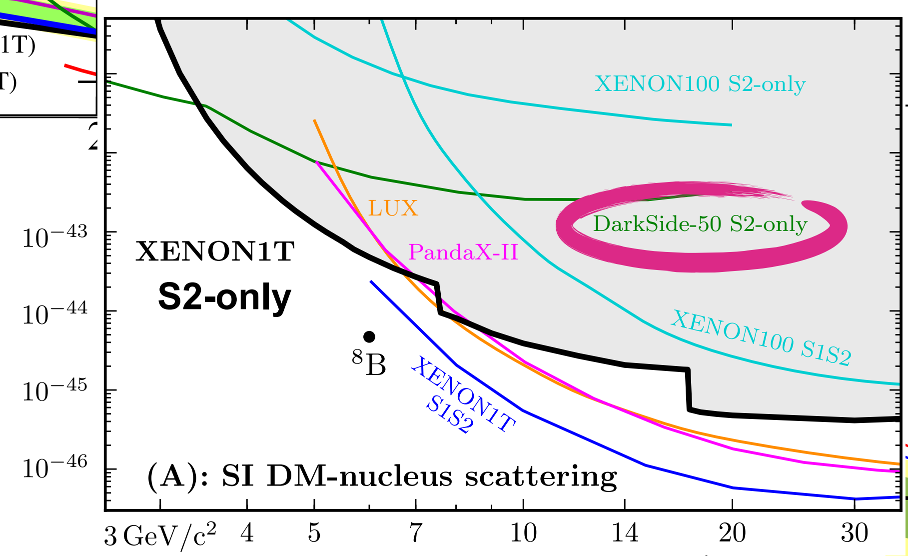
XENON1T Migdal + Brems.



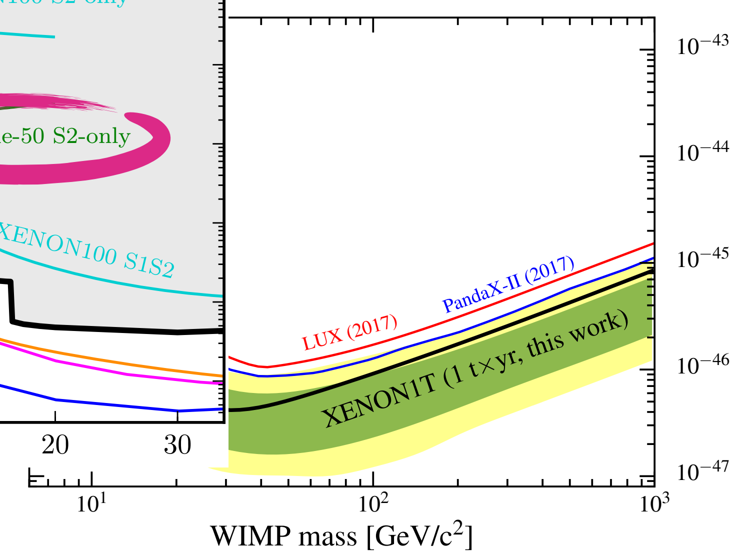
XENON1T has the best limit on SI cross sections for WIMP masses >60 MeV/c^2

For these low masses, <10^{-6} of WIMP interactions in the target produce a signal

XENON1T S2-only

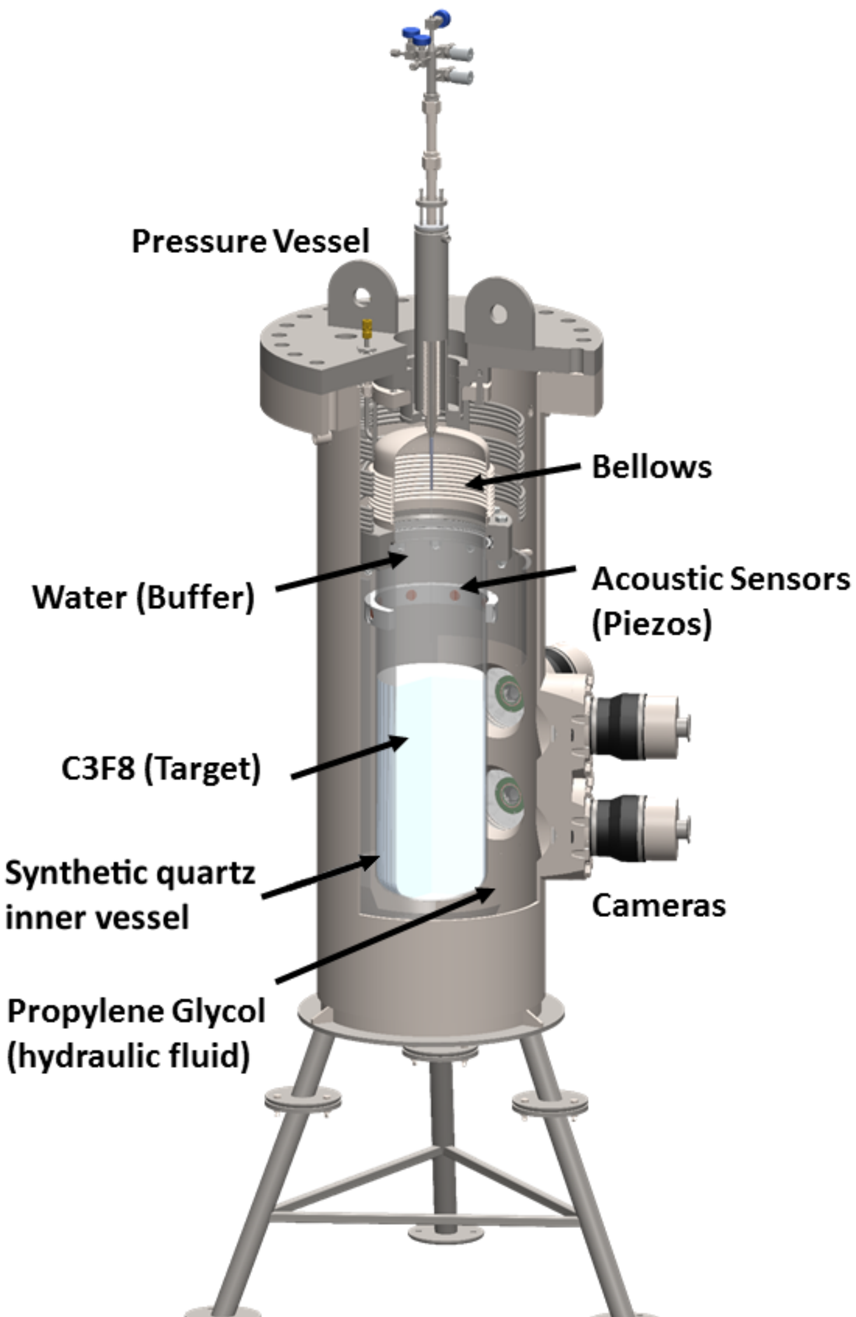


S1+S2

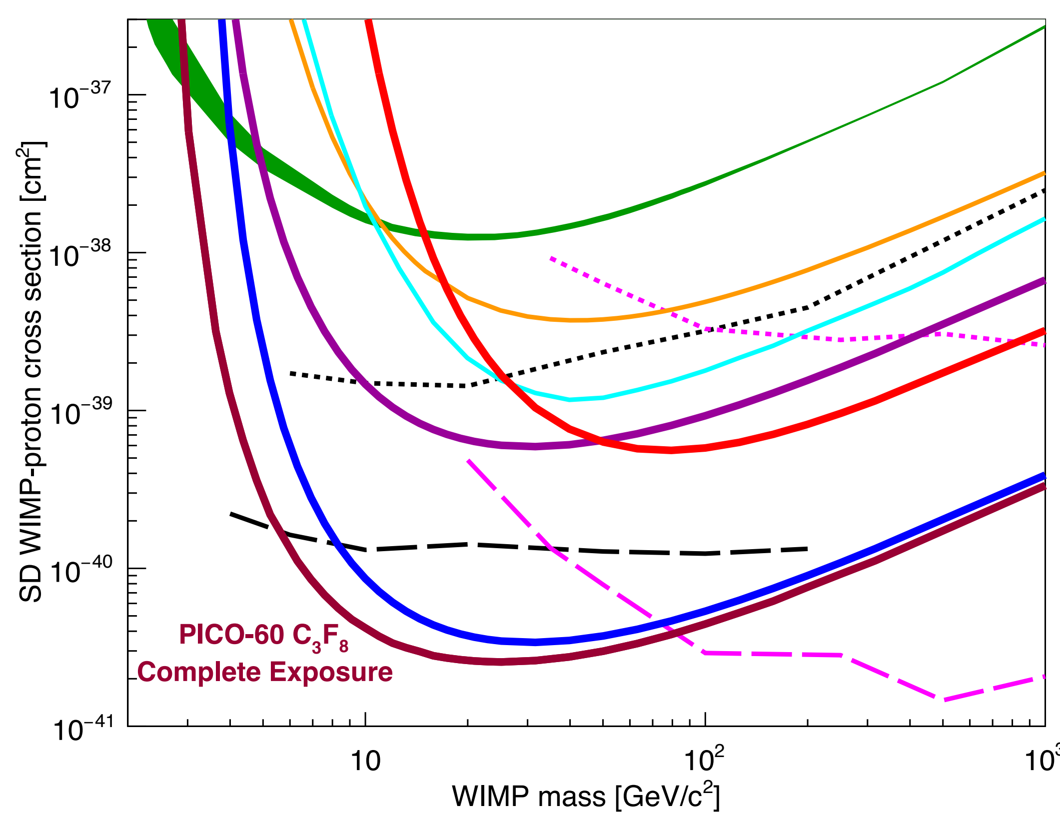


At lower masses limits become less robust. For what WIMP mass range can XENON really discover the WIMP?

PICO



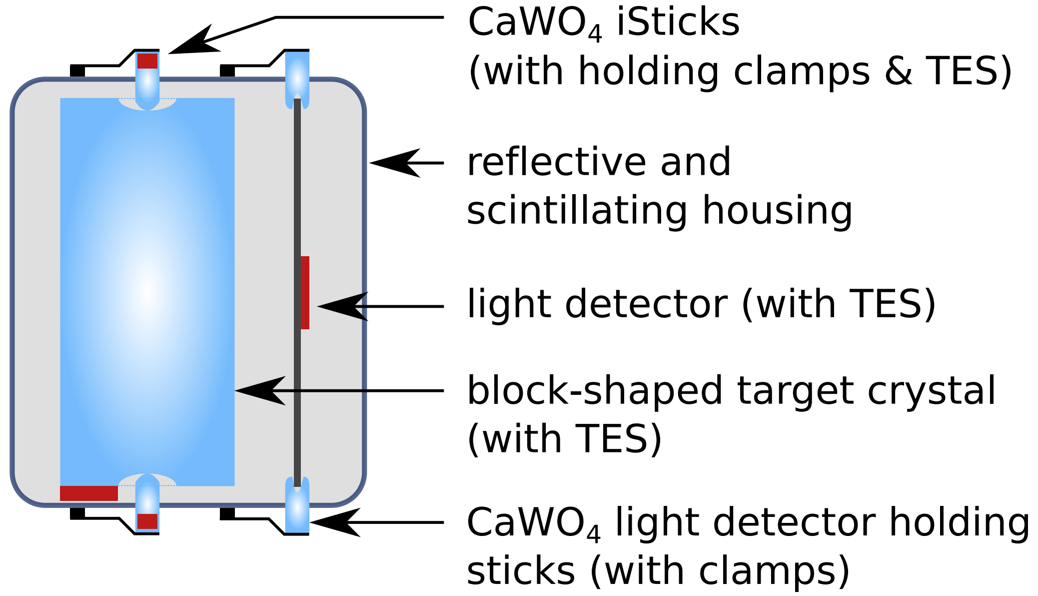
- Bubble chamber 52 kg of C_3F_8.
- No energy measurement; threshold detector.
- Insensitive to electronic recoils.
- Acoustic rejection of αs.
- No unexpected backgrounds in latest run.
- New upside-down chamber design PICO-40L under installation at SNOLAB.



<u>Best limits</u> for SD interaction with protons!

Cryogenic bolometers

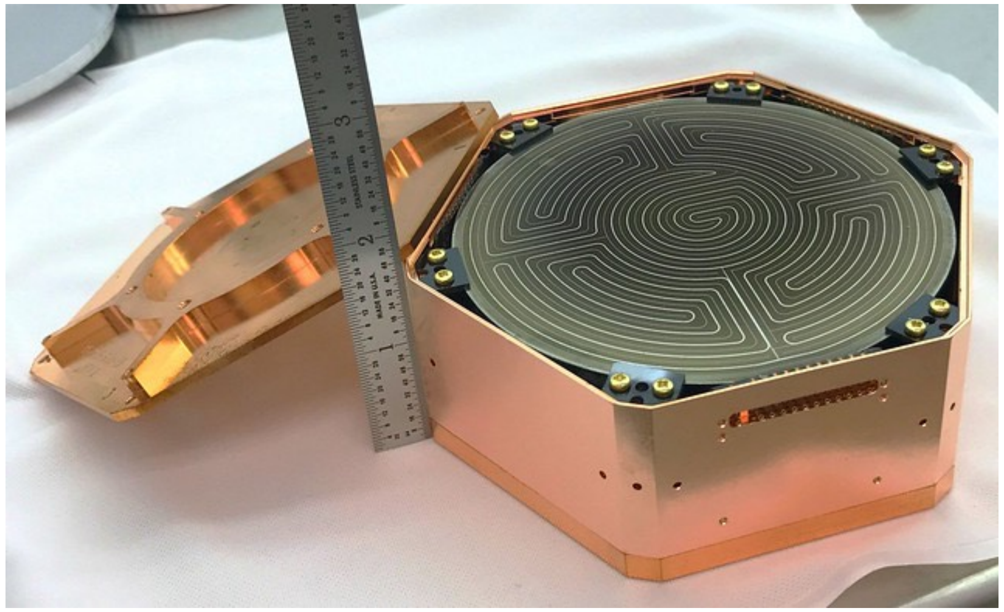
CRESST-III



- ~25 g $CaWO_4$ crystals.
- Phonon + scintillation readout.
- ~30 eV phonon threshold.
- First results with a single crystal in 2019.

EDELWEISS

SuperCDMS at SNOLAB

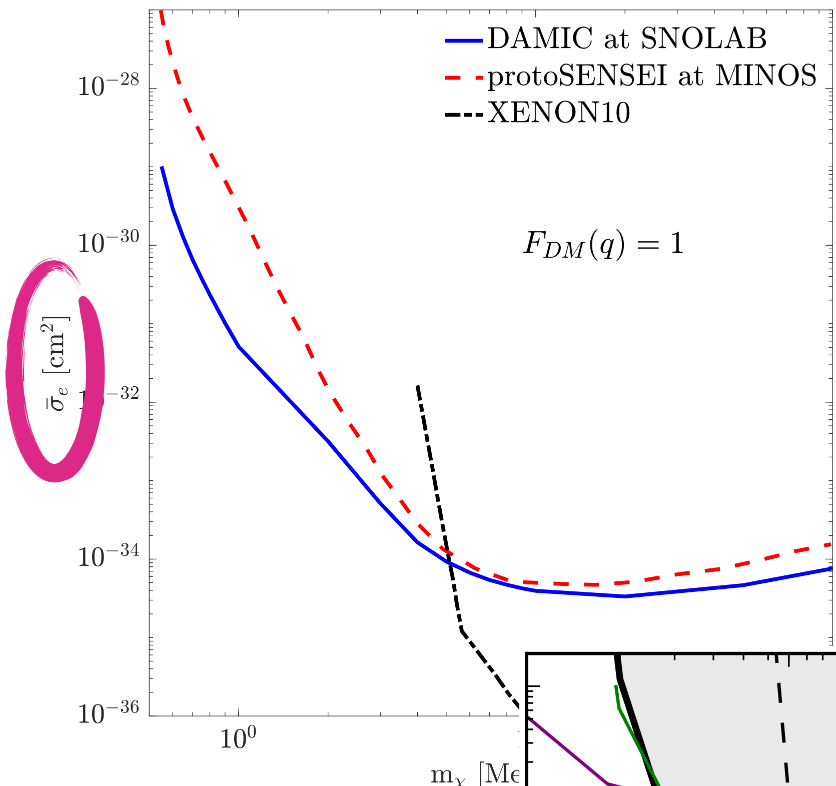


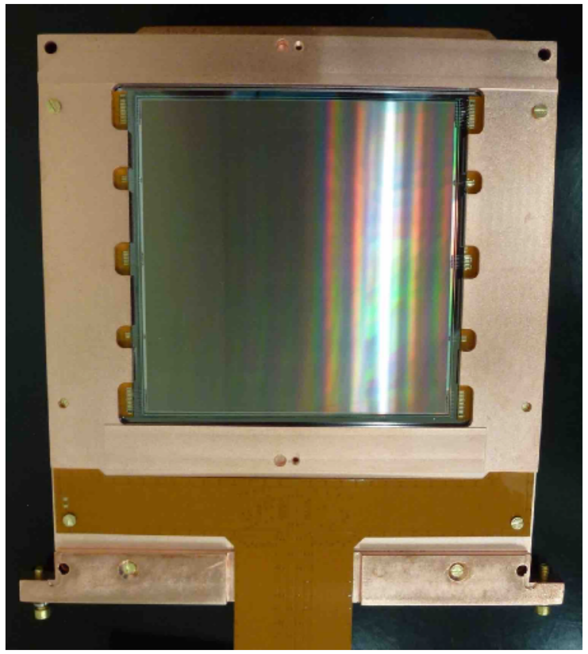
- Demonstrated HV operation as ionization sensor.
- 1.4 kg (0.6 kg) Ge (Si) detectors.
- Previous results with <100 eV_{ee} threshold.
- 24-detector tower under installation at SNOLAB.

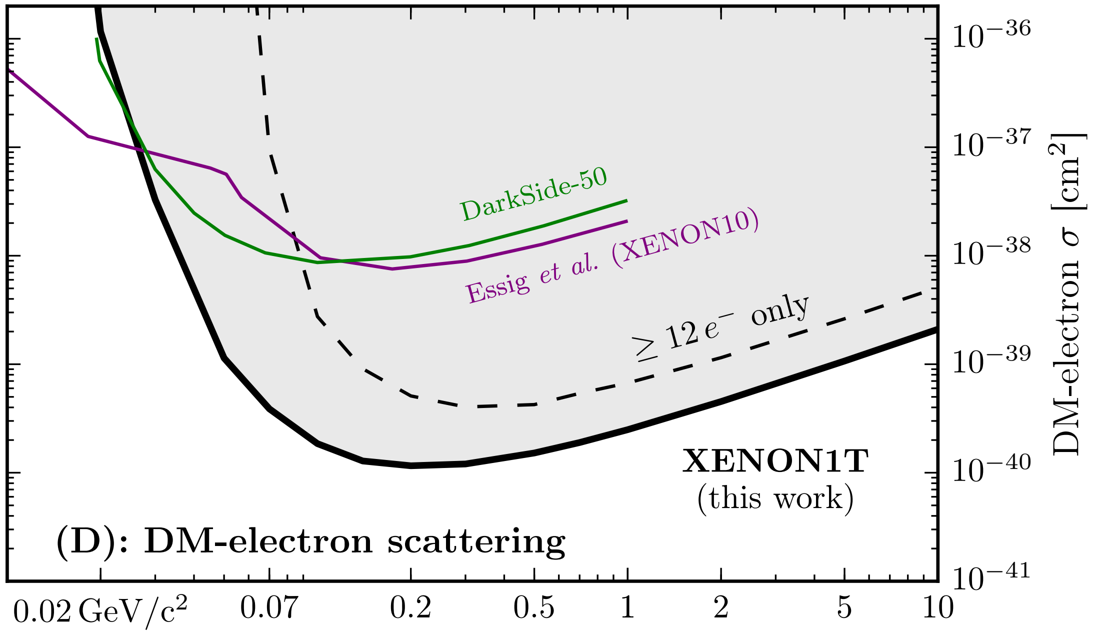
Ionization sensors

DAMIC

- Pixelated charge readout.
- 7-CCD 40-g detector operating at SNOLAB.
- Low-threshold analysis sensitive to single charges in silicon.
- ~1 eV band gap in silicon.







Scattering of 0.5-5 MeV/c^2 particles *fundamentally* out of reach for xenon TPC

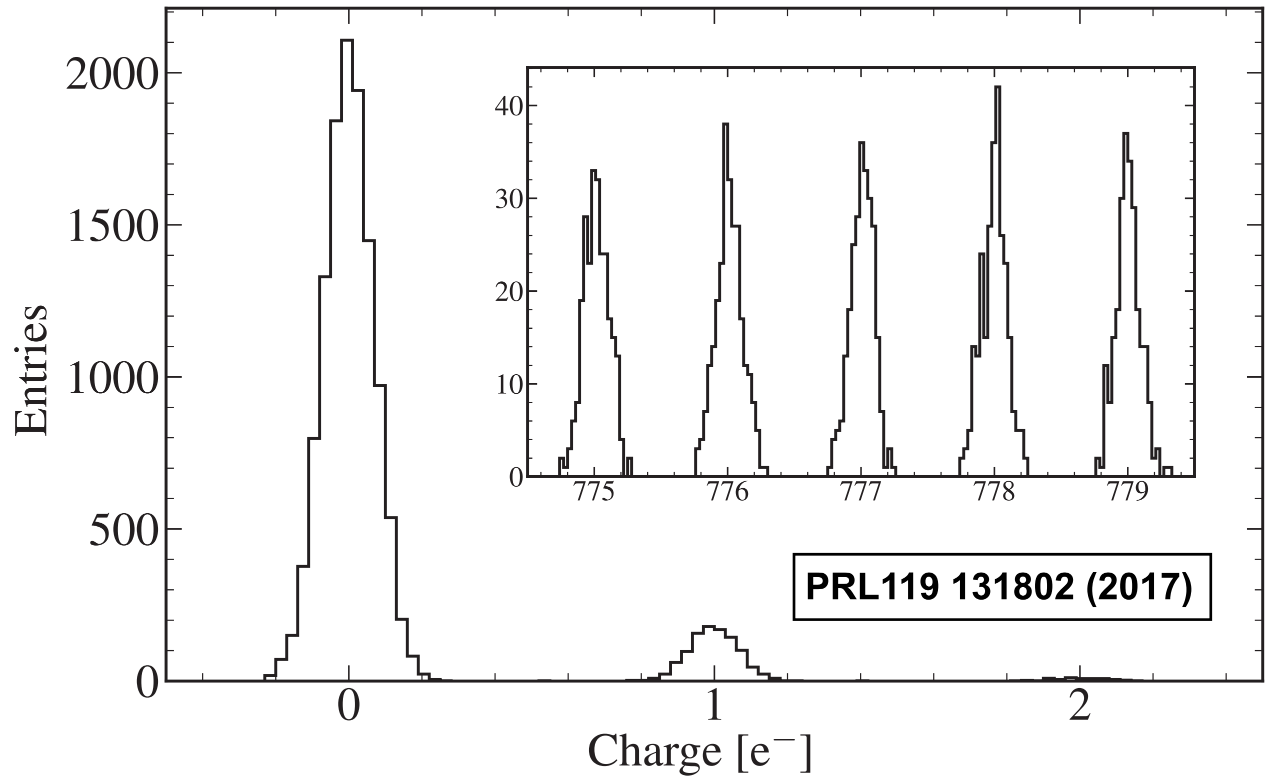
'WIMP' kinetic energy below ionization threshold

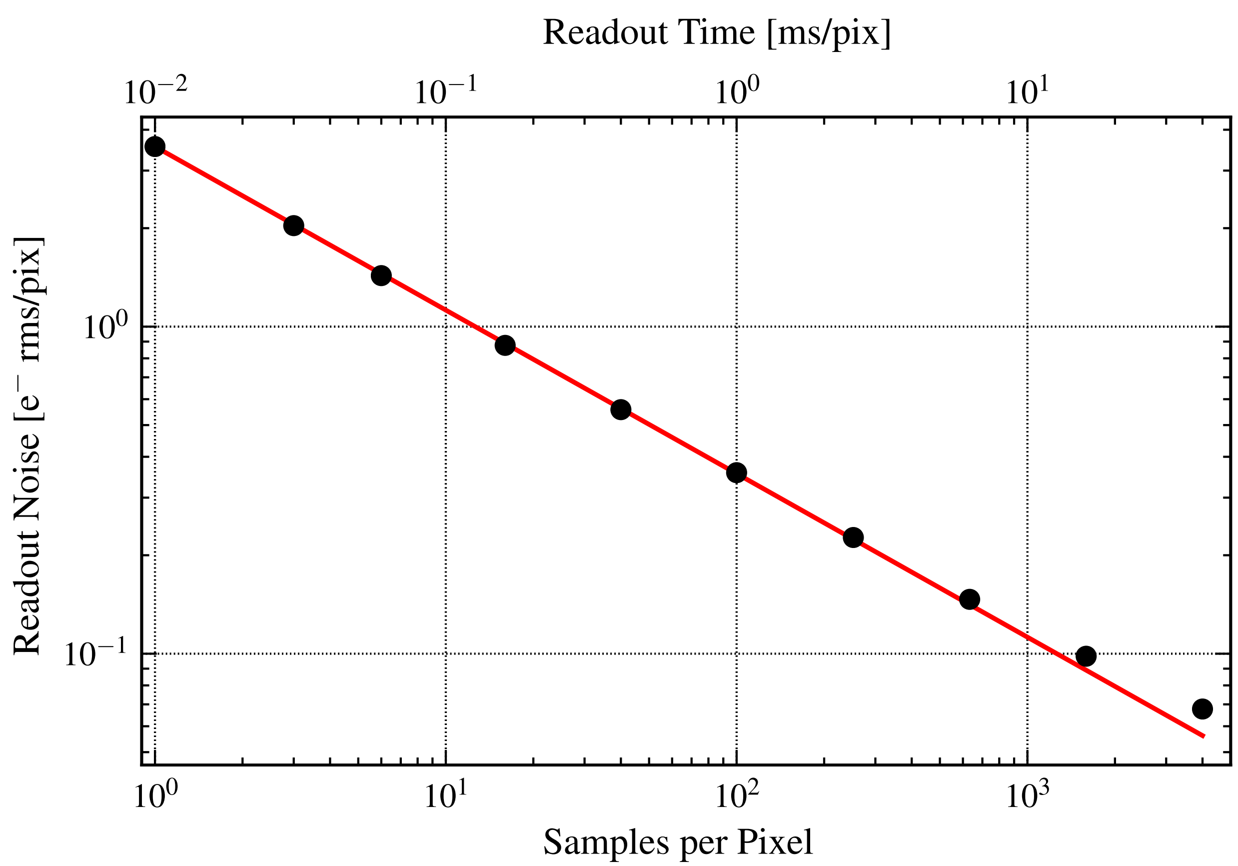
Skipper CCD

SENSEI at Fermilab: Skipper CCDs (**LBNL design**) successfully tested with sub e⁻ noise. X-ray spectroscopy demonstrated.

Technology will allow 2 e⁻ (few eV) threshold.

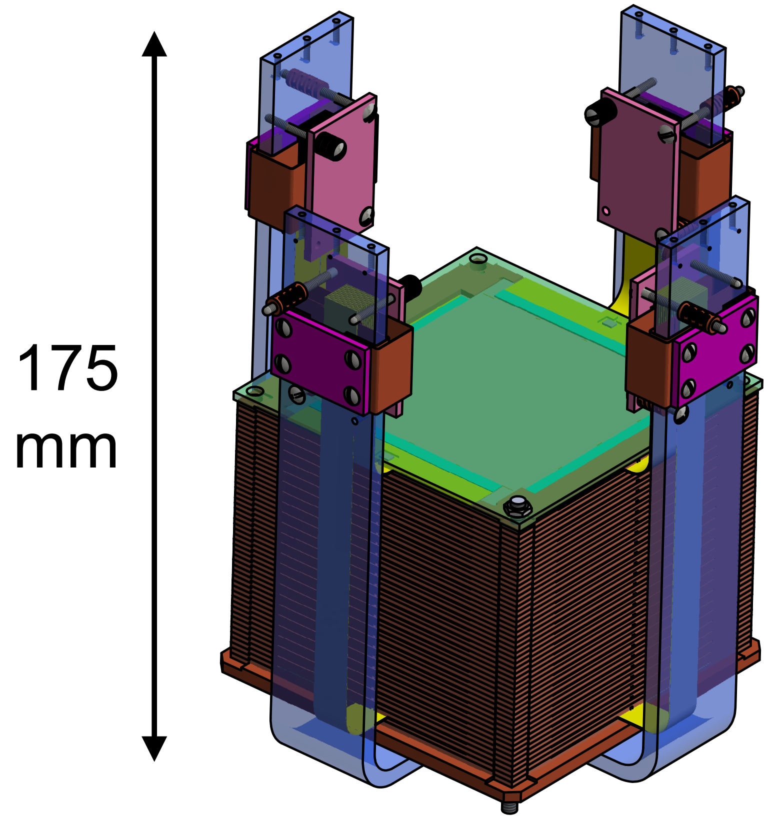
Observed ~$1/\sqrt{N}$





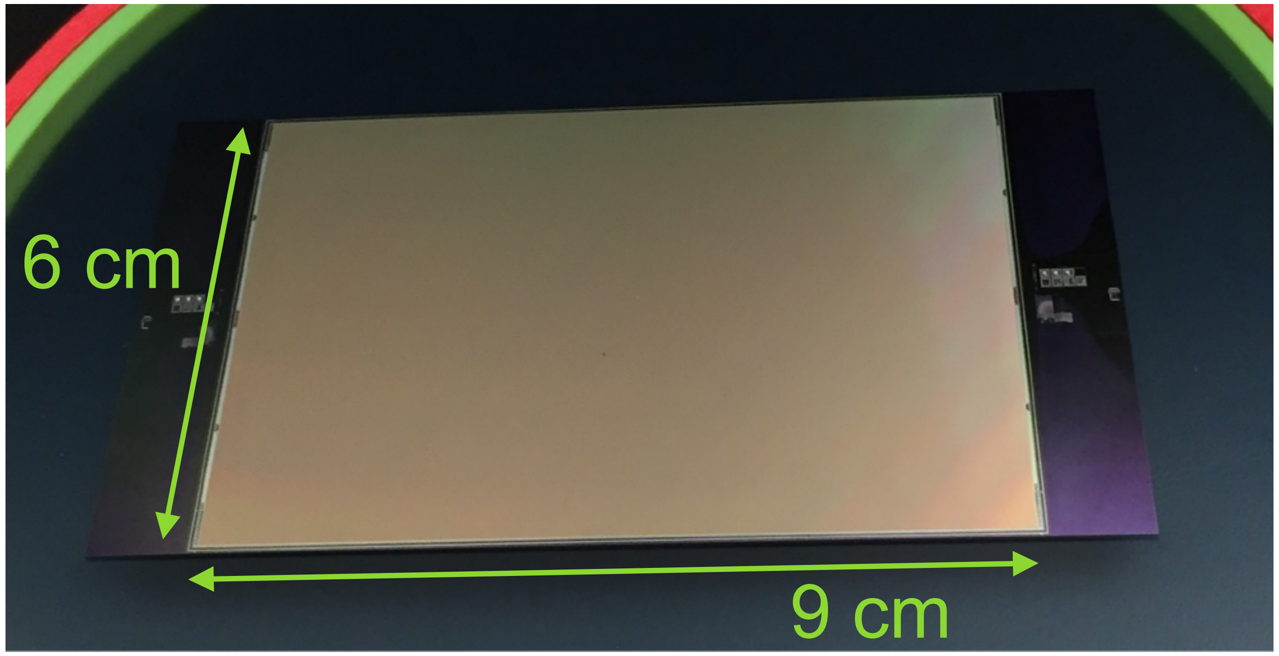
DAMIC-M will adopt LBNL skipper design tested by SENSEI

DAMIC-M



- **50 CCDs** (0.7 kg target mass) at LSM (France).
- Most massive CCDs ever built (**6k x 6k x 0.675 mm, mass 14 g**).
- Skipper readout for **~eV threshold.**
- **Background reduction to a fraction of dru** (improved design, materials, procedures).

24 Mpix CCD at UW: 10 g!



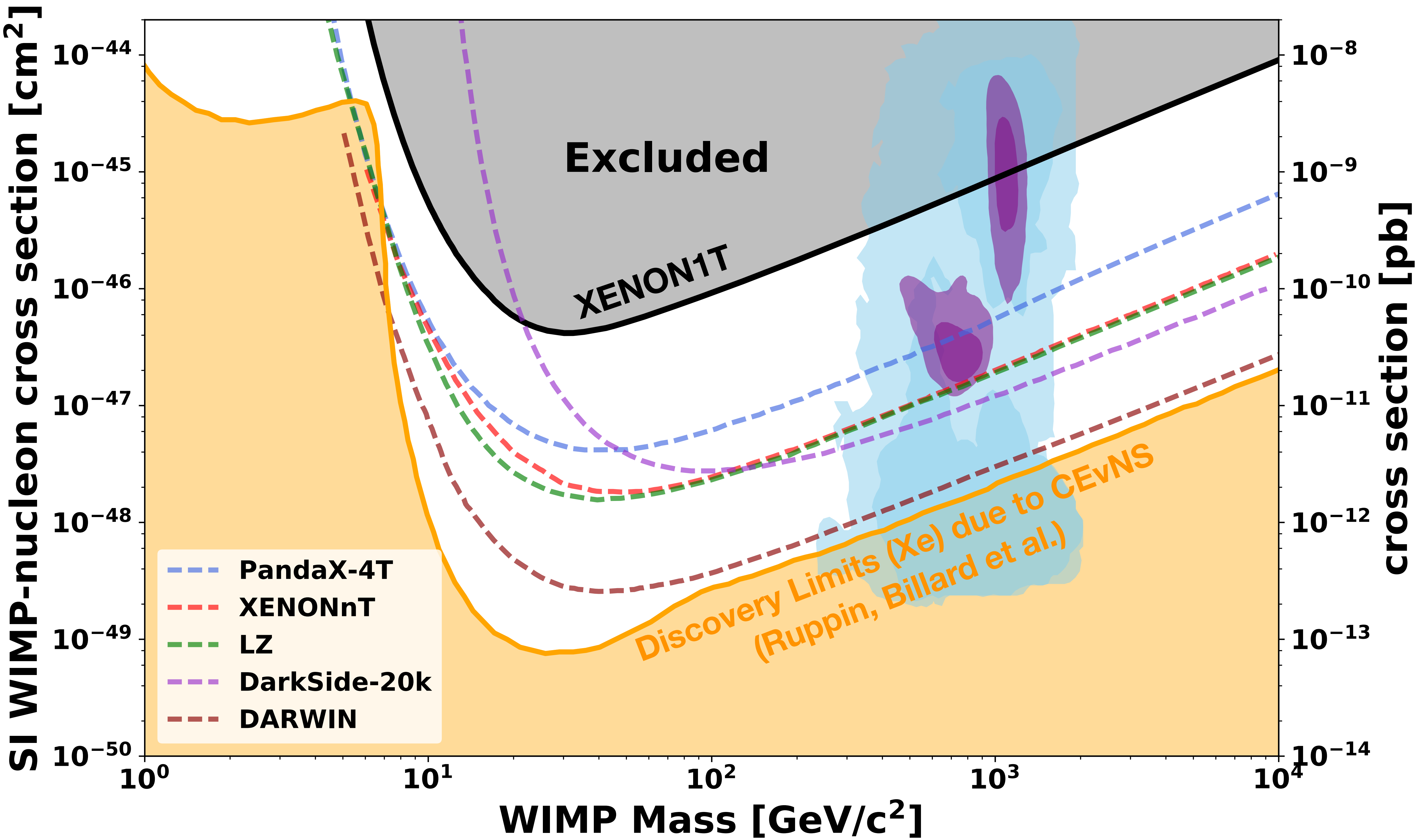
Institutions:

The University of **Chicago**, University of **Washington**, Pacific Northwest National Laboratory (**PNNL**), **SNOLAB**, Laboratoire de Physique Nucléaire et de Hautes Energies (**LPNHE**), Laboratoire de l'Accélérateur Linéaire (**LAL**), the Laboratoire Souterrain de Modane/Grenoble (**LSM**), University of **Zurich**, **Niels Bohr Institute**, University of **Southern Denmark**, University of **Santander**, Centro Atómico **Bariloche**

Outlook

(consider the following plots sketches)

Prospect for heavy WIMP Searches



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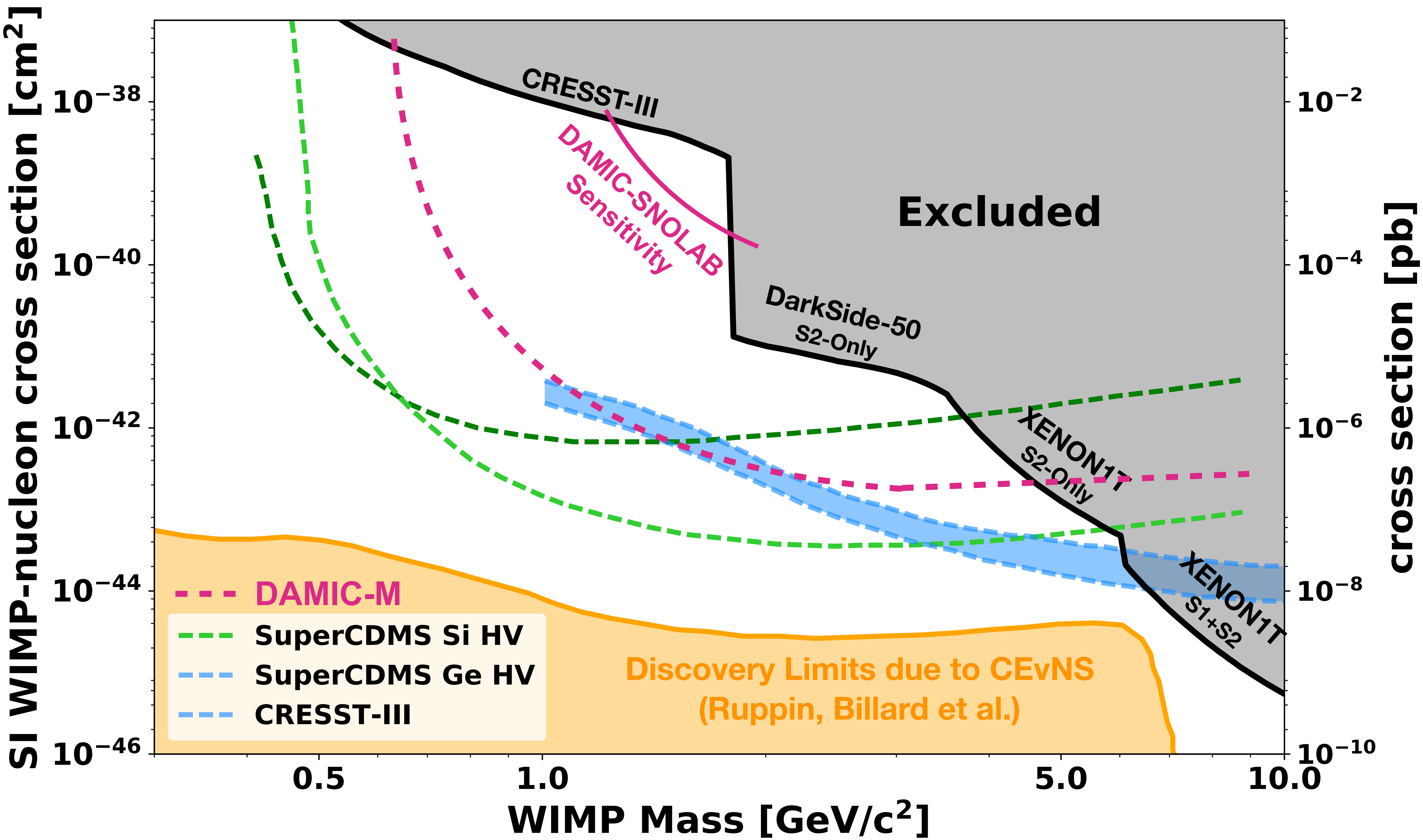
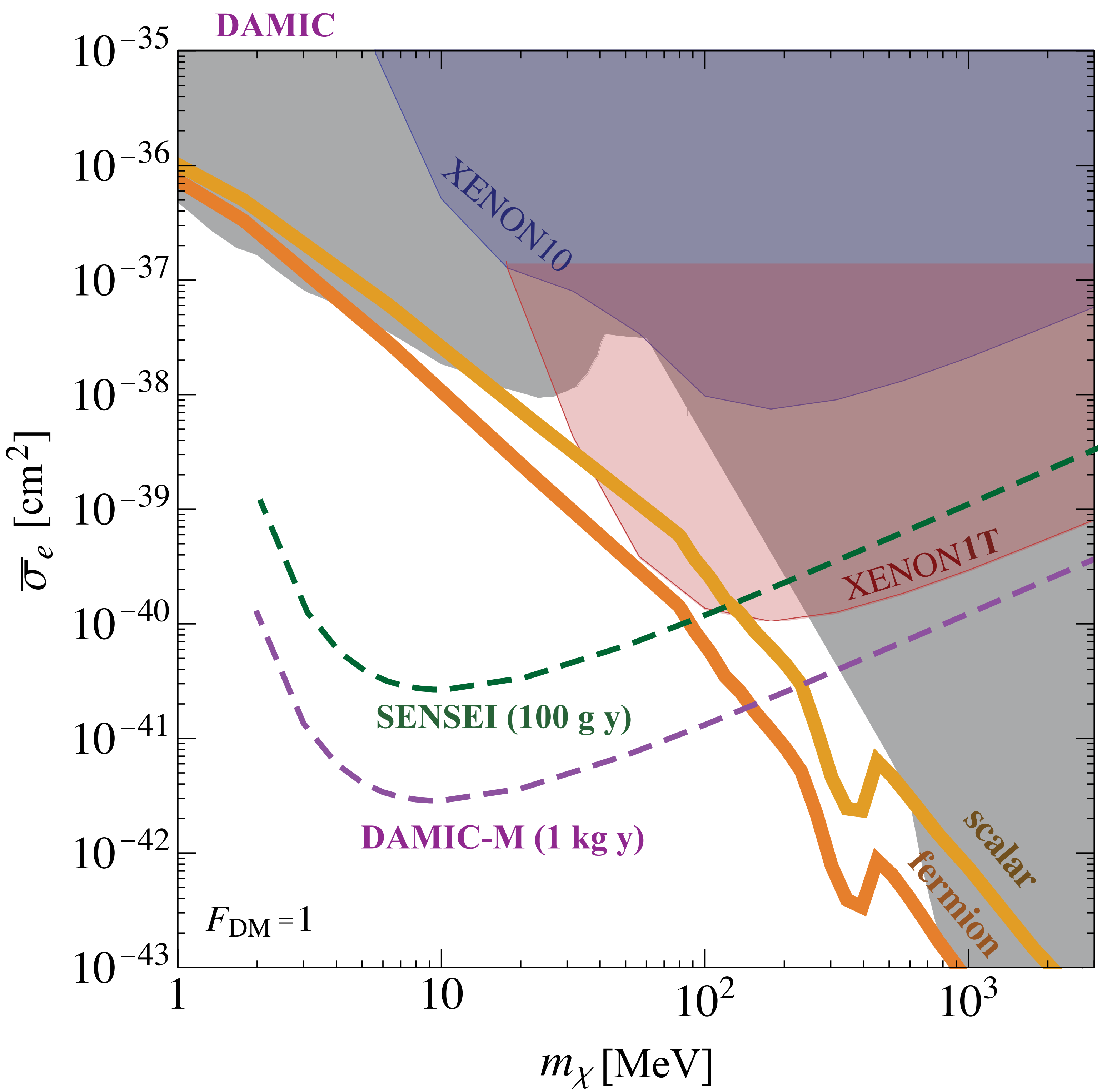
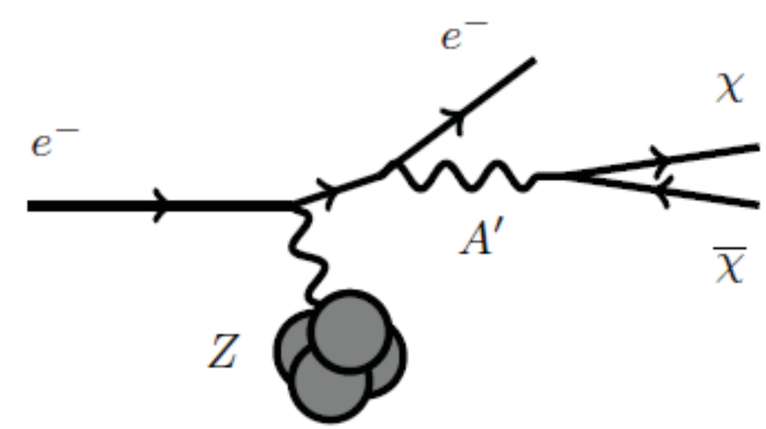
Prospects for low-mass WIMP searches



Prospects for DM-e scattering searches



Complementary to searches at **accelerators** for electron's missing momentum (**LDMX**) or χ interacting directly (**BDX**):



E.g., $M_A > 2M_X$

Conclusions

- Direct detection field still very vibrant!
- Continued push toward lower masses: now we have ‘WIMP’ scattering lifts down to ~0.5 MeV/c^2.
- New approaches with noble liquid TPC make XENON rule.
- But also development of new technologies where noble liquids are fundamentally limited.
- Keep in mind experimental uncertainties! The difference between placing an exclusion limit over background and a discovery.
- International program to increase sensitivity by orders of magnitude in the 0.5 MeV/c^2 to TeV-scale in the next five years.
- **Note**: I only reviewed DM scattering by contact interactions! There are many other interaction mechanisms.