PICO

explores the spin-dependent dark matter interaction

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Light Dark World 2026
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The University of Montreal and of the world.

Spin-dependent interactions

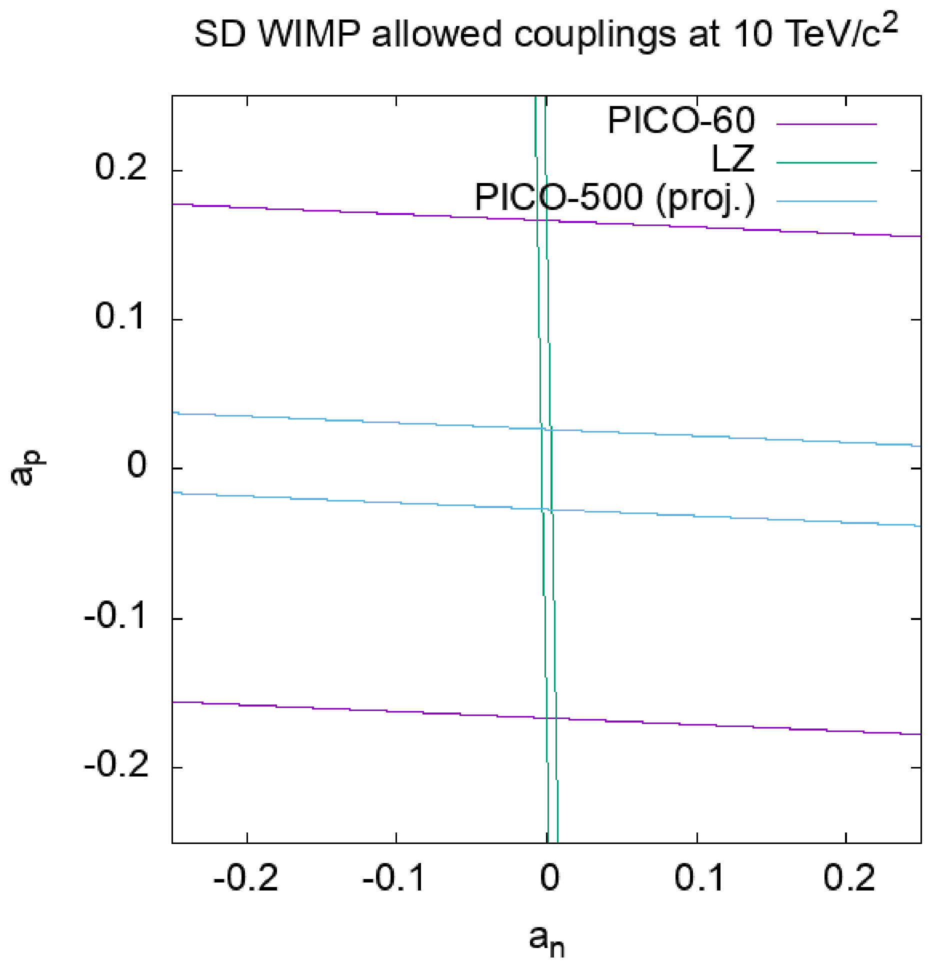
Neutral current-type coupling

Still not completely fine tuned

Spin-dependent tree-level couplings to the Z are still permitted at high-mass

with the caveat that pure spin-dependant $\mathcal{O}_4$ couplings are not Lorentz invariant.

a_n and a_p defined by D.R. Tovey et al. Physics Letters B 488 (2000) 17–26
using nuclear form factors of Hu et al. Phys. Rev. Lett. 128, 072502.



Hidden sector models

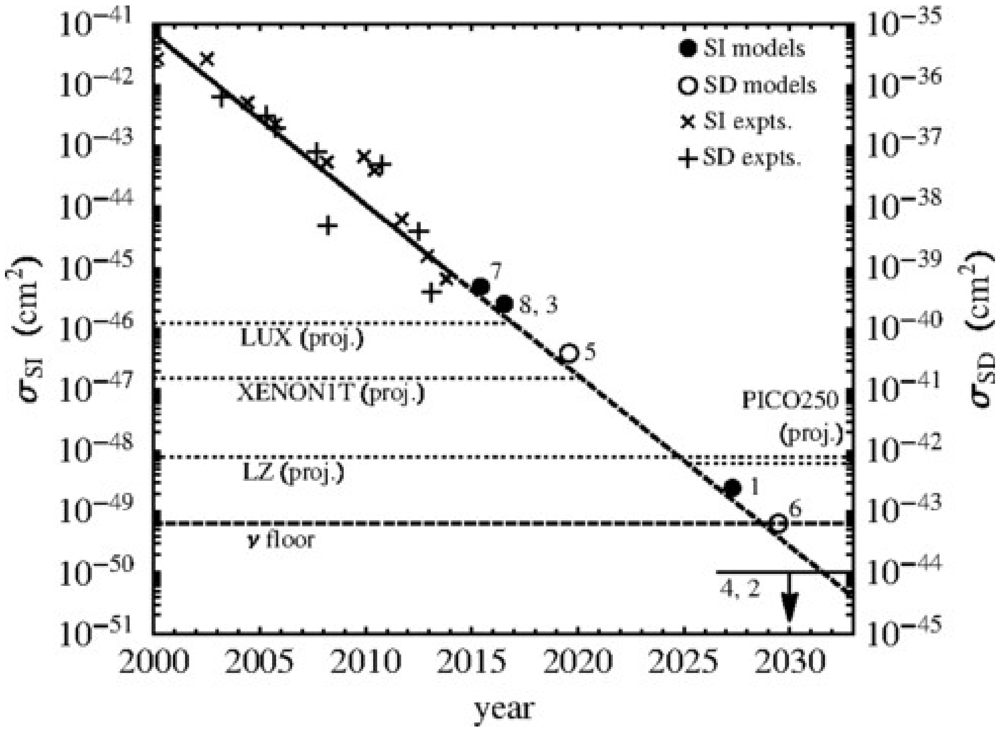
Choose your own adventure

My favourite: Berlin, Hooper, and McDermott, Simplified dark matter models for the Galactic Center gamma-ray excess, Phys. Rev. D **89**, 115022 (2014)

Provides a clear guidepost, but requires xenophobic variants to warant a dedicated SD-experiment

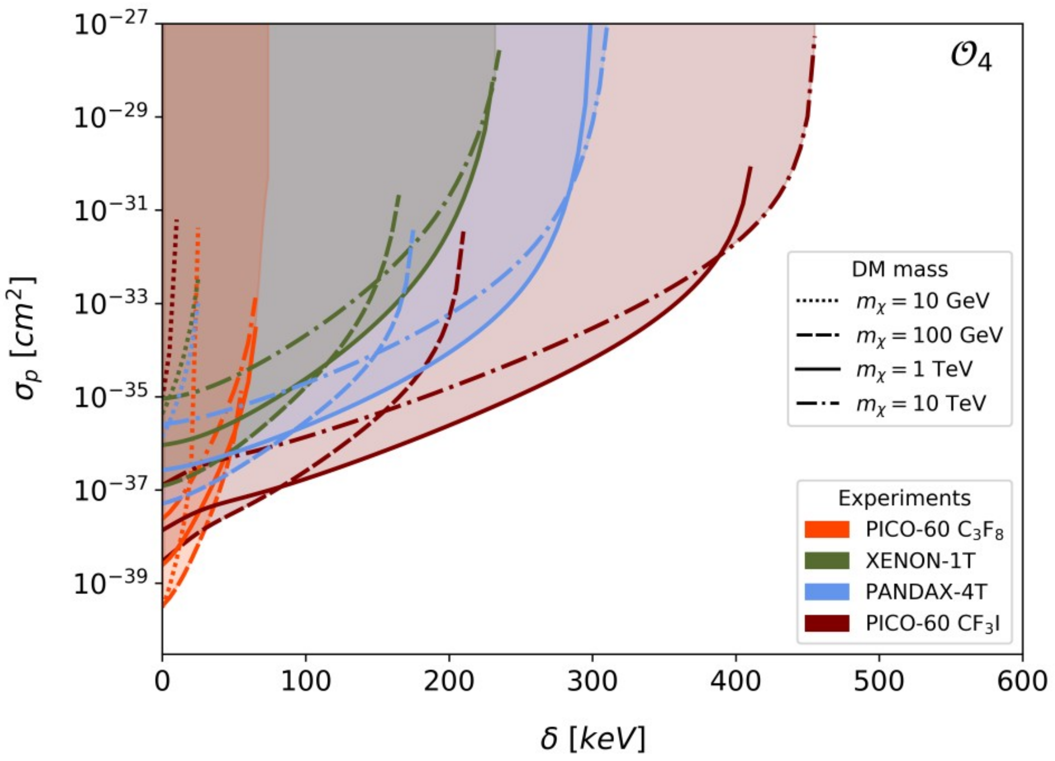
TABLE V. A summary of the simplified models identified in our study as capable of generating the observed gamma-ray excess without violating the constraints from colliders or direct detection experiments. In the last two columns, we indicate whether the model in question will be within the reach of near future direct detection experiments (LUX, XENON1T) or of the LHC. Models with an entry of "never" predict an elastic scattering cross section with nuclei that is below the irreducible background known as the "neutrino floor." The model number given in the first column provides the key for the model points shown in Fig. 9.

					Near future reach?	
Model number	DM	Mediator	Interactions	Elastic Scattering	Direct	LHC
1	Dirac fermion	spin-0	$\bar\chi\gamma^5\chi$, $\bar f f$	$\sigma_{SI} \sim (q/2m_\chi)^2$ (scalar)	no	maybe
1	Majorana fermion	spin-0	$\bar\chi\gamma^5\chi$, $\bar f f$	$\sigma_{SI} \sim (q/2m_\chi)^2$ (scalar)	no	maybe
2	Dirac fermion	spin-0	$\bar\chi\gamma^5\chi$, $\bar f\gamma^5 f$	$\sigma_{SD} \sim (q^2/4m_n m_\chi)^2$	never	maybe
2	Majorana fermion	spin-0	$\bar\chi\gamma^5\chi$, $\bar f\gamma^5 f$	$\sigma_{SD} \sim (q^2/4m_n m_\chi)^2$	never	maybe
3	Dirac fermion	spin-1	$\bar\chi\gamma^\mu\chi$, $\bar b\gamma_\mu b$	$\sigma_{SI} \sim$ loop (vector)	yes	maybe
4	Dirac fermion	spin-1	$\bar\chi\gamma^\mu\chi$, $\bar f\gamma_\mu\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$ or $\sigma_{SD} \sim (q/2m_\chi)^2$	never	maybe
5	Dirac fermion	spin-1	$\bar\chi\gamma^\mu\gamma^5\chi$, $\bar f\gamma_\mu\gamma^5 f$	$\sigma_{SD} \sim 1$	yes	maybe
5	Majorana fermion	spin-1	$\bar\chi\gamma^\mu\gamma^5\chi$, $\bar f\gamma_\mu\gamma^5 f$	$\sigma_{SD} \sim 1$	yes	maybe
6	Complex scalar	spin-0	$\phi^\dagger\phi$, $\bar f\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	no	maybe
6	Real scalar	spin-0	ϕ^2, $\bar f\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	no	maybe
6	Complex vector	spin-0	$B^\dagger_\mu B^\mu$, $\bar f\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	no	maybe
6	Real vector	spin-0	$B_\mu B^\mu$, $\bar f\gamma^5 f$	$\sigma_{SD} \sim (q/2m_n)^2$	no	maybe
7	Dirac fermion	spin-0 (t ch.)	$\bar\chi(1\pm\gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	yes	yes
7	Dirac fermion	spin-1 (t ch.)	$\bar\chi\gamma^\mu(1\pm\gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	yes	yes
8	Complex vector	spin-1/2 (t ch.)	$X^\dagger_\mu\gamma^\mu(1\pm\gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	yes	yes
8	Real vector	spin-1/2 (t ch.)	$X_\mu\gamma^\mu(1\pm\gamma^5)b$	$\sigma_{SI} \sim$ loop (vector)	yes	yes

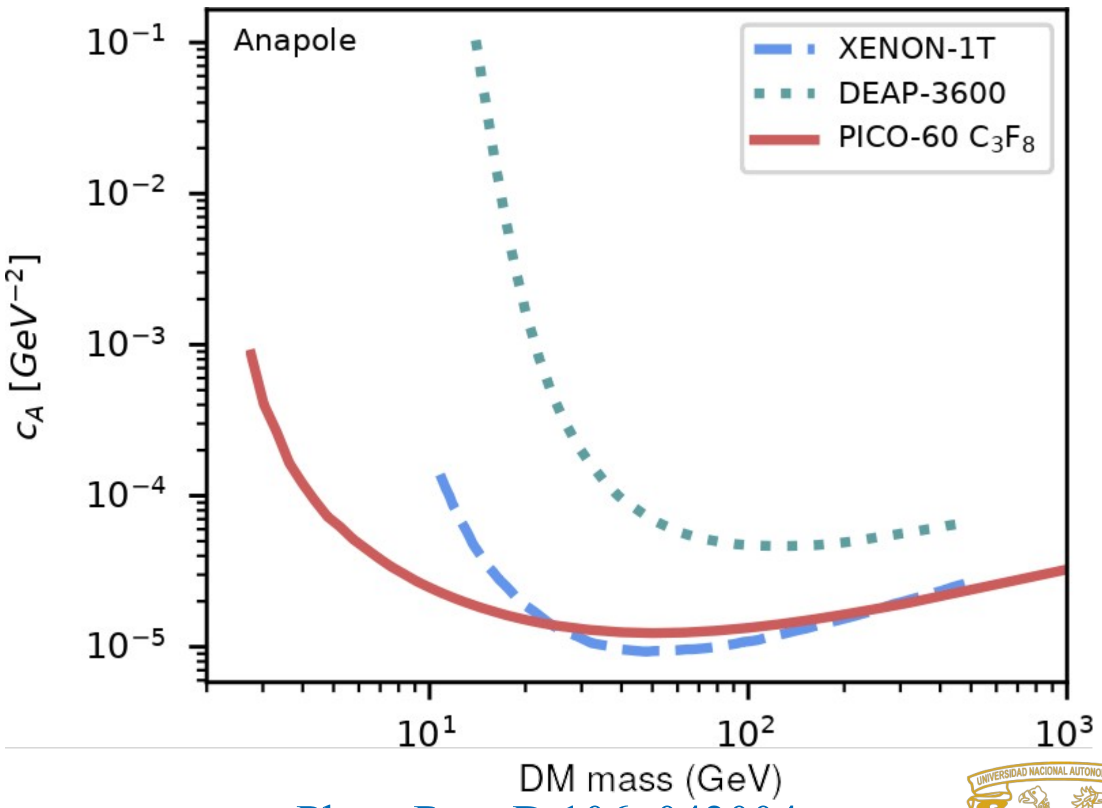


Other nuclear couplings

Fluorine and iodine can have enhanced sensitivity: i.e. inelastic or anapole-coupled DM



Phys.Rev.D 108 (2023) 6, 062003



Phys. Rev. D 106, 042004
analyses by E. Vasquez's group

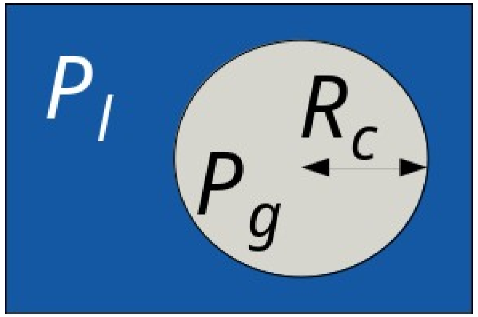
Other nuclear couplings

Your thoughts

PICO at SNOLAB

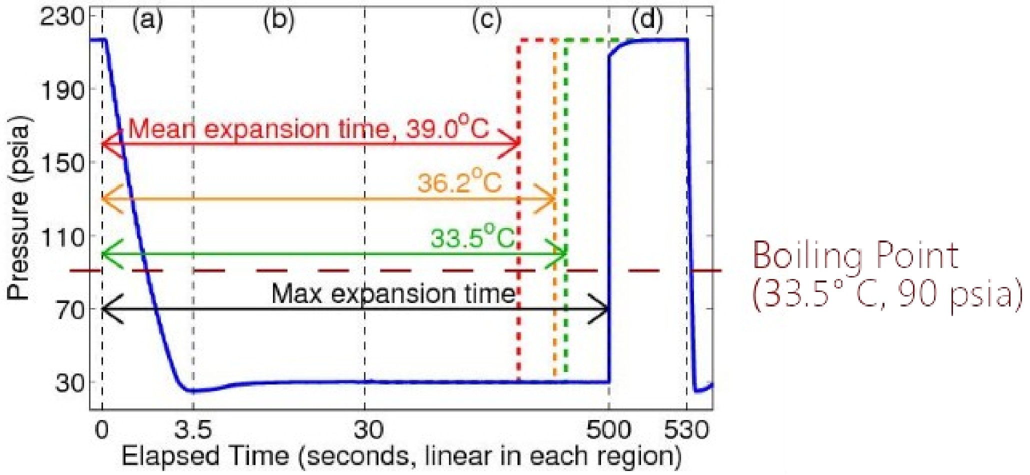
How it works

Radiation induced boiling of a superheated liquid



$$P_g - P_l = \frac{2\sigma}{R_c}$$

Bubble Chamber operation cycle

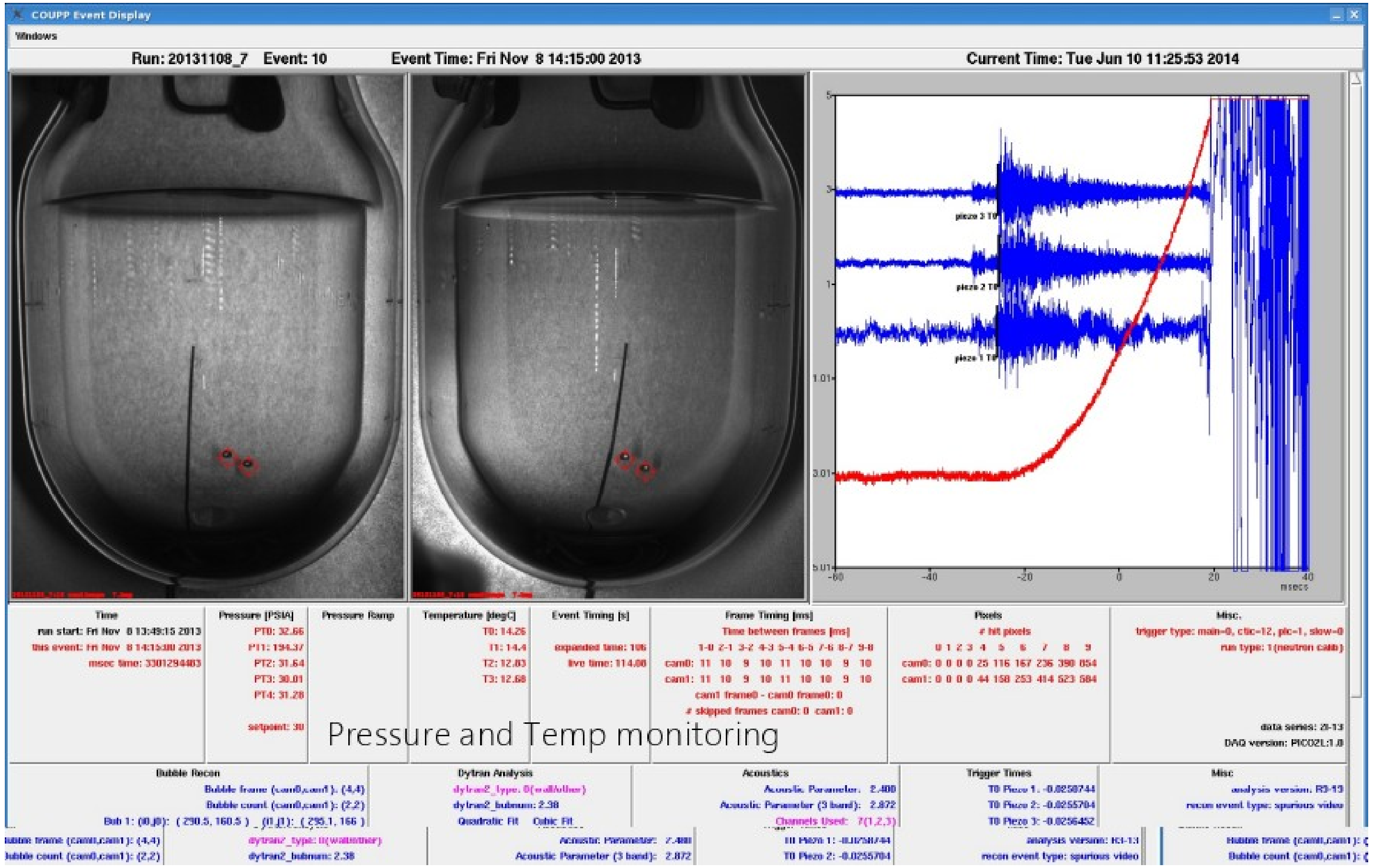


Latent Heat Surface Formation

$$Q = \frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l) + 4\pi r_c^2 \left(\sigma - T \frac{d\sigma}{dT} \right)$$

How it works

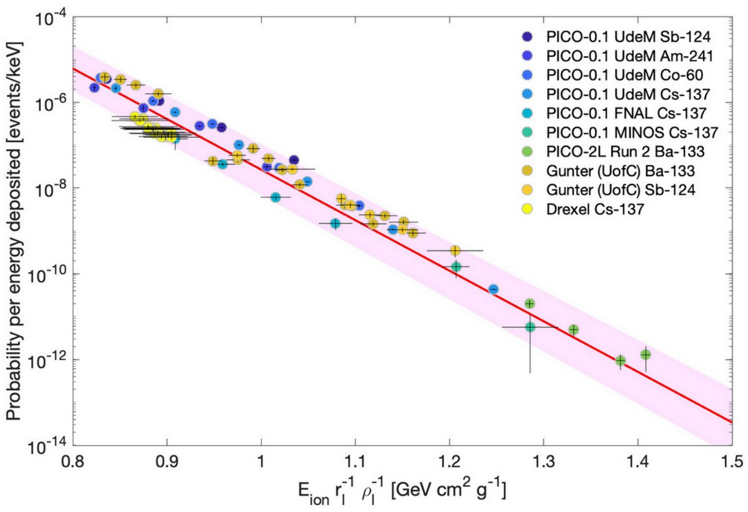
See and hear the bubbles



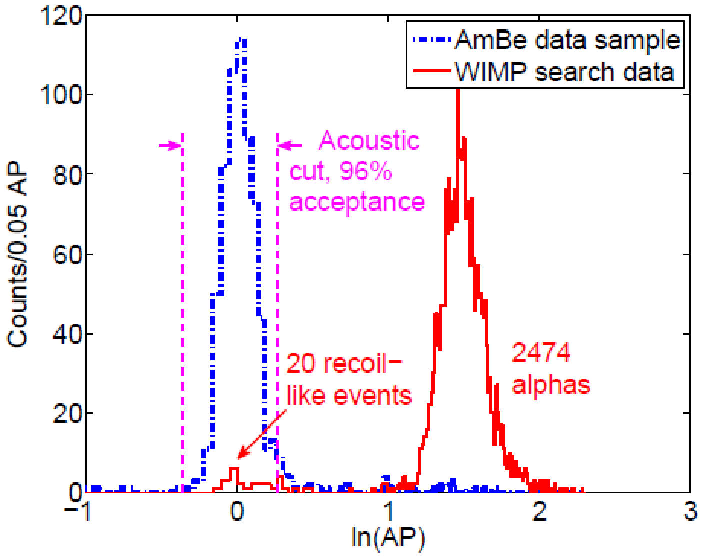
How it works

Impressive background rejection

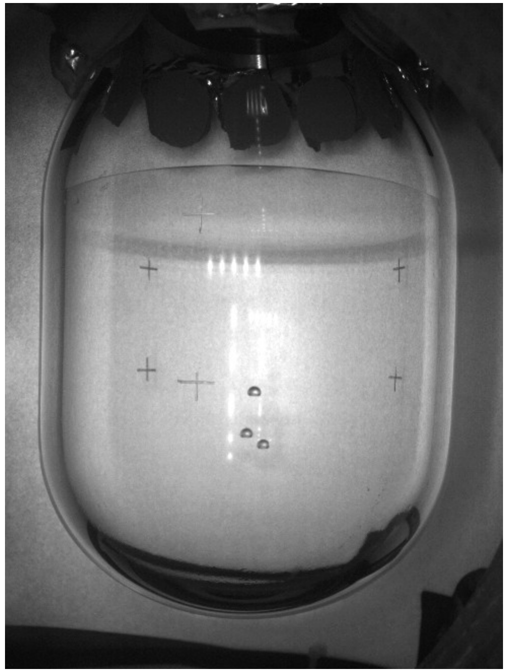
Electron recoil blind



Alpha discrimination



Multiple neutron scattering coverage



How we got here

2005
First COUPP prototype

2010
COUPP-4kg at SNOLAB
COUPP-60 at FNAL

2013-14
COUPP-60 at SNOLAB
PICO-2L

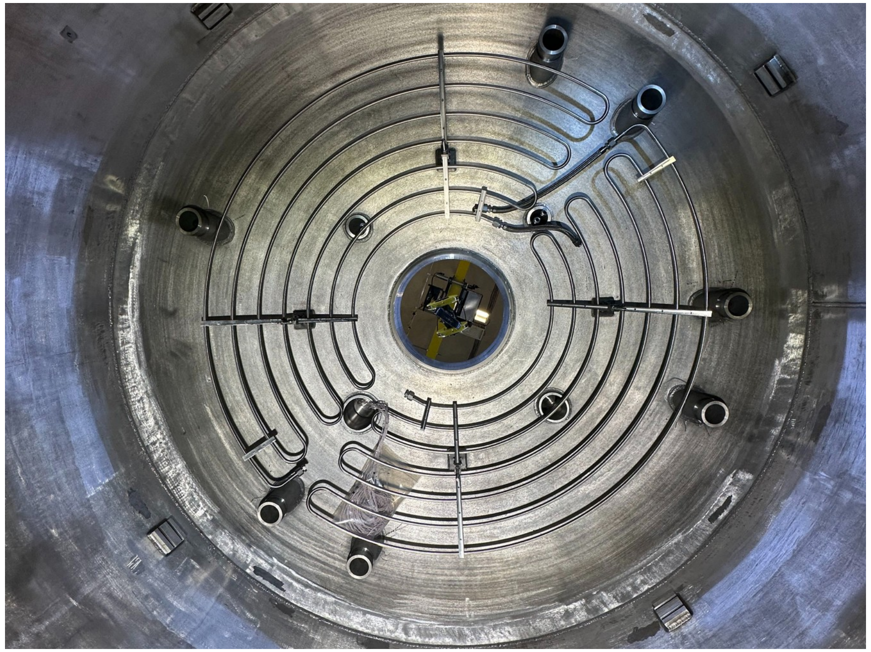
2016-17
PICO-2L run 2
PICO-60 C_3F_8

2022/23
PICO-40L RSU

2027
PICO-500

	2005	2010	2013-14	2016-17	2022/23	2027
α-decay	X	solved	-	-	-	-
Neutrons	-	X	■	■	■	■
Particulates	-	unidentified	X	■	solved	-
γ/β	solved	-	-	-	■	■
ν/μ	-	-	-	-	-	■

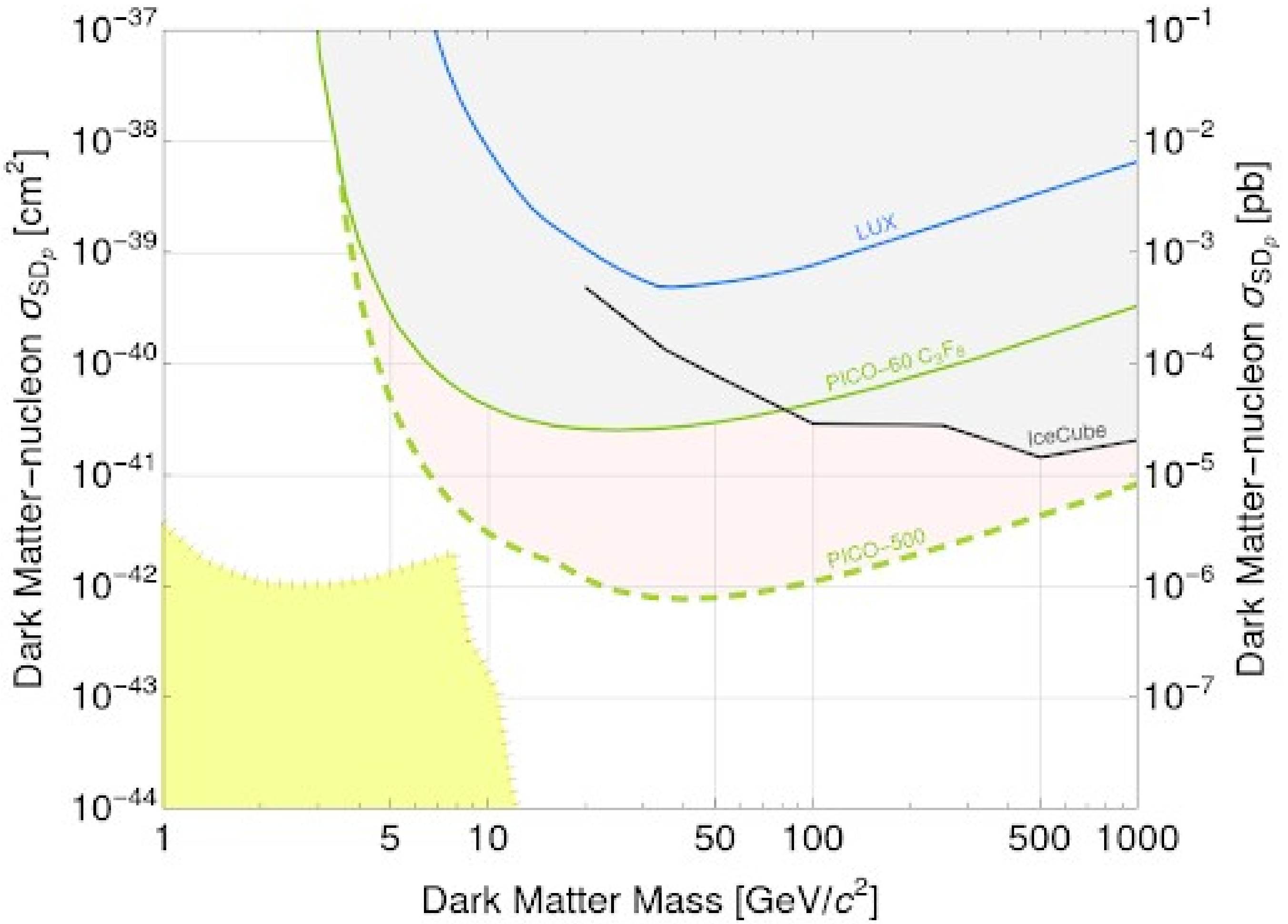
PICO-500 under construction



PICO-500 projected sensitivity

Assumes:
- 6 months at 2.5 keV Seitz threshold seeing one neutrino event
- then 2.5 live-years at 10 keV Seitz threshold seeing up to one background event.

PICO-40L to provide a new limit on radon-rejection at both thresholds.



The future

Hydrogen targets

R-134a - $C_2H_2F_4$

Bubble nucleation efficiency under study.

- Observation of hydrogen-recoil induced bubbles, but not at a controlled threshold.

- If bubble nucleation is demonstrated below 4 keVnr, this can cheaply improve low-mass sensitivity of PICO.

New 15-foot bubble chamber?

This would no longer be PICO

Bubble chamber scaling is limited by deadtime (1-2 minutes) following alpha decays on the vessel walls, even if a larger synthetic silica vessel could be produced.

With a radiopure and non-nucleating film on the inner vessel wall, an up to 50 tons, approximately 15-foot diameter, design may be possible.

This requires a strong science case to develop.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Guillaume Giroux
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Mackenzie Dean
ashley mathewson
Shane Meister
Armin
PICO 2025 August
Collaboration Meeting