Bubble Chambers for Dark Matter Detection

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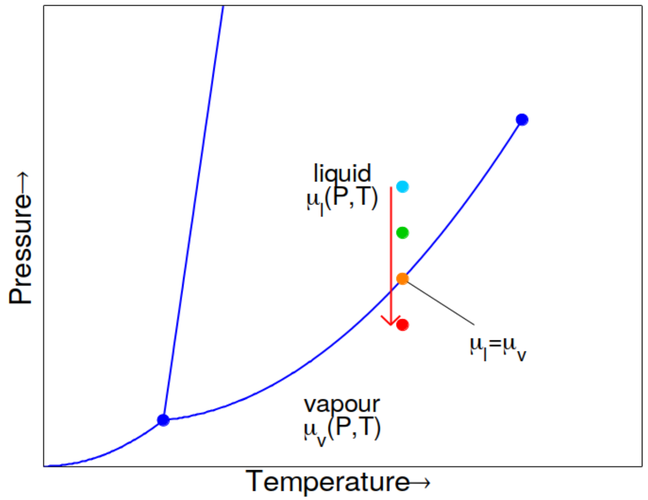
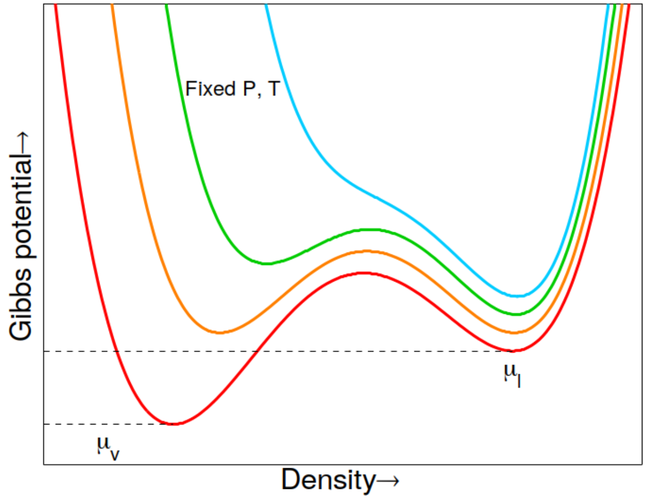
Bubble Chamber Basics





- Small deposit of energy overcomes threshold in Gibbs potential
- This then results in vaporization - production of bubble
- Note that threshold is controllable
  - At most thresholds, gammas not an issue

History in Particle Physics

Table 1
Major bubble chambers used in high-energy physics[a].

	H_2	D_2	Ne/H_2	C_3H_8, Freon, LXe
US chambers (total > 50)				
Berkeley	2″, 4″, 6″, 10″, 15″, 25″, 72″			UM LXe LRL 50 cm, 10″
SLAC	15″, 40″			
BNL	30/31″, 80″, 84″, 7′ (3.9 Mpx)			15 cm, 170 l
Argonne	30″ (4.7 Mpx), 12′ (7 Mpx)		30″, 12′	UM 40″
Fermilab	15′ (2.9 Mpx) UW 30″ [Scotchlite]	15′	15′	Tohoku (Holographic)
European chambers (total > 50)				
German	85 cm (6.3 Mpx)	85 cm	85 cm	
French	80 cm (16 Mpx)			BP3, Gargamelle (4.7 M)
British	150 cm			Oxford He
Russian	Ludmilla		Ludmilla?	1 m, 2 m, SKAT ITEP He, 700 1 LXe
CERN	Mirabelle (3.3 Mpx) 30 cm, 2 m (40 Mpx) BEBC (6.3 Mpx) LEBC (5.2 Mpx triggered)	2 m BEBC	Mirabelle? BEBC	HOBC

BEBC: Big European Bubble Chamber; LEBC: Lexan Bubble Chamber; HOBC: Holographic Bubble Chamber; Gargamelle: Heavy Liquid Bubble Chamber; *Ludmilla*: Russian Heavy Liquid Bubble Chamber; *Mirabelle*: Bubble Chamber built in Saclay/France; Mpx: million pictures, UM: U. Michigan Heavy Liquid and Liquid Xe Bubble Chambers. Data in round brackets () give the number of pictures taken with a chamber, those in straight brackets special features of the chambers.

[a] Adopted from Gert G. Harigel, in "30 Years of Bubble Chamber Physics" (Bologna 2003); Ref. [38].

History of the bubble chamber and related active- and internal-target nuclear tracking detectors, F.D. Becchetti, NIMA 784 (2015) 518-523

Particle	Source of Radiation	Instrument
e^+	Cosmic ray	Cloud chamber
$\mu^\pm$	Cosmic ray	Cloud chamber
$\pi^\pm$	Cosmic ray	Nuclear emulsion
π^0	Accelerator	Counters
$K^\pm$	Cosmic ray	Nuclear emulsion
K^0	Cosmic ray	Cloud chamber
Λ^0	Cosmic ray	Cloud chamber
Σ^+	Cosmic ray	Nuclear emulsion
		Cloud chamber
Σ^-	Accelerator	Cloud chamber
Σ^0	Accelerator	*Bubble chamber*
Ξ^-	Cosmic ray	Cloud chamber
Ξ^0	Accelerator	*Bubble chamber*
Ω^-	Accelerator	*Bubble chamber*
Λ_c^+	Accelerator	*Bubble chamber*
p, n	Accelerator	Counters
B (Σ^+, Ξ^+, Ω^+)	Accelerator	*Bubble chamber*

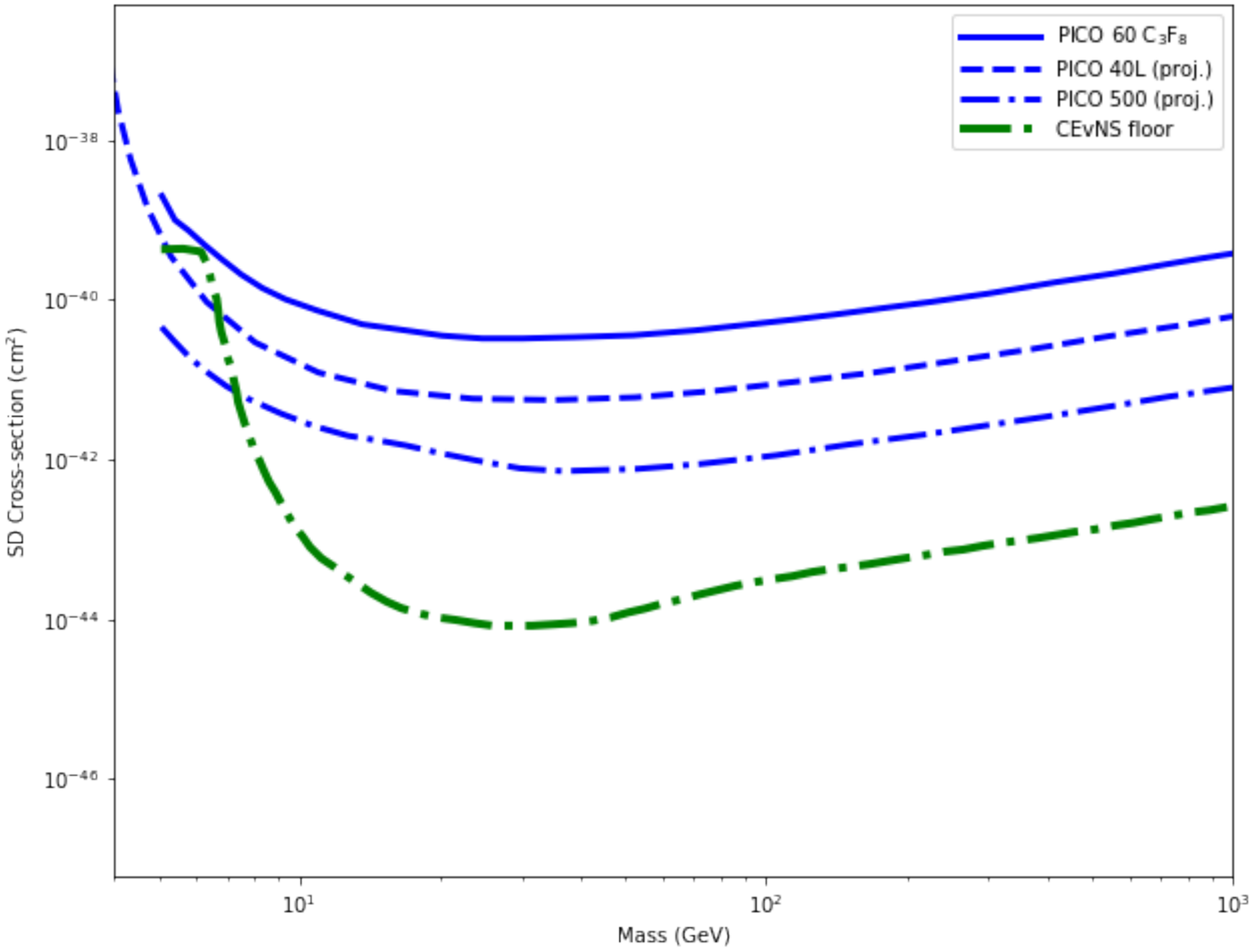
Gert G. Harigel, *Bubble Chambers, Technology and Impact on High Energy Physics*

Why use bubble chambers?

- Lots of other good ways to detect dark matter, what advantages do bubble chambers offer?

1. Explore phase space not easily accessible to other methods
2. Electron recoil backgrounds less of a concern*
3. Easy to adjust focus on the fly
4. Inexpensive

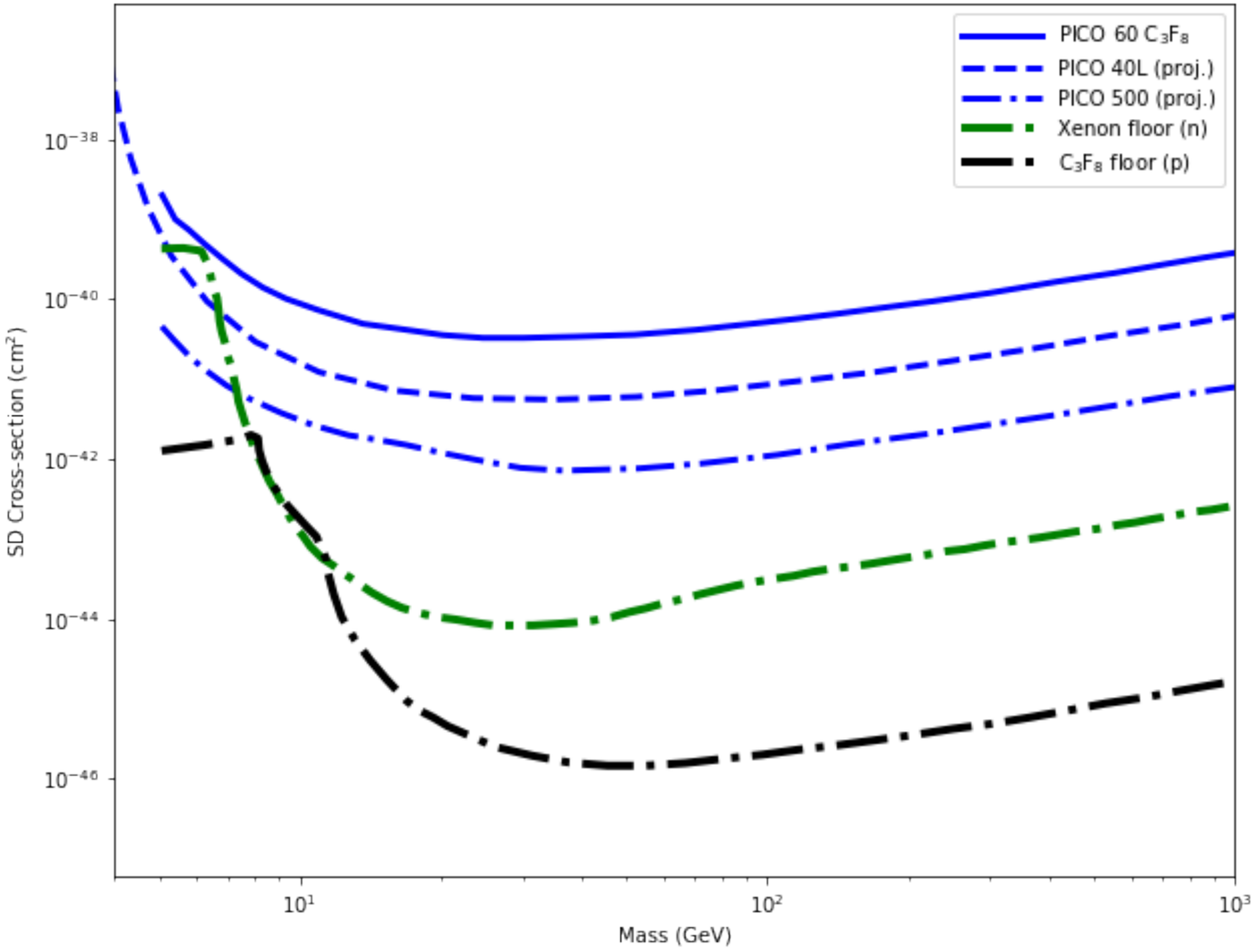
1. Exploring phase spaces



Floor from Battaglieri, et al. arXiv:1707.04591

- PICO conveniently explores the spin-dependent phase space
- Along with other experiments not shown here, pushing down to CEvNS floor

1. Exploring phase spaces



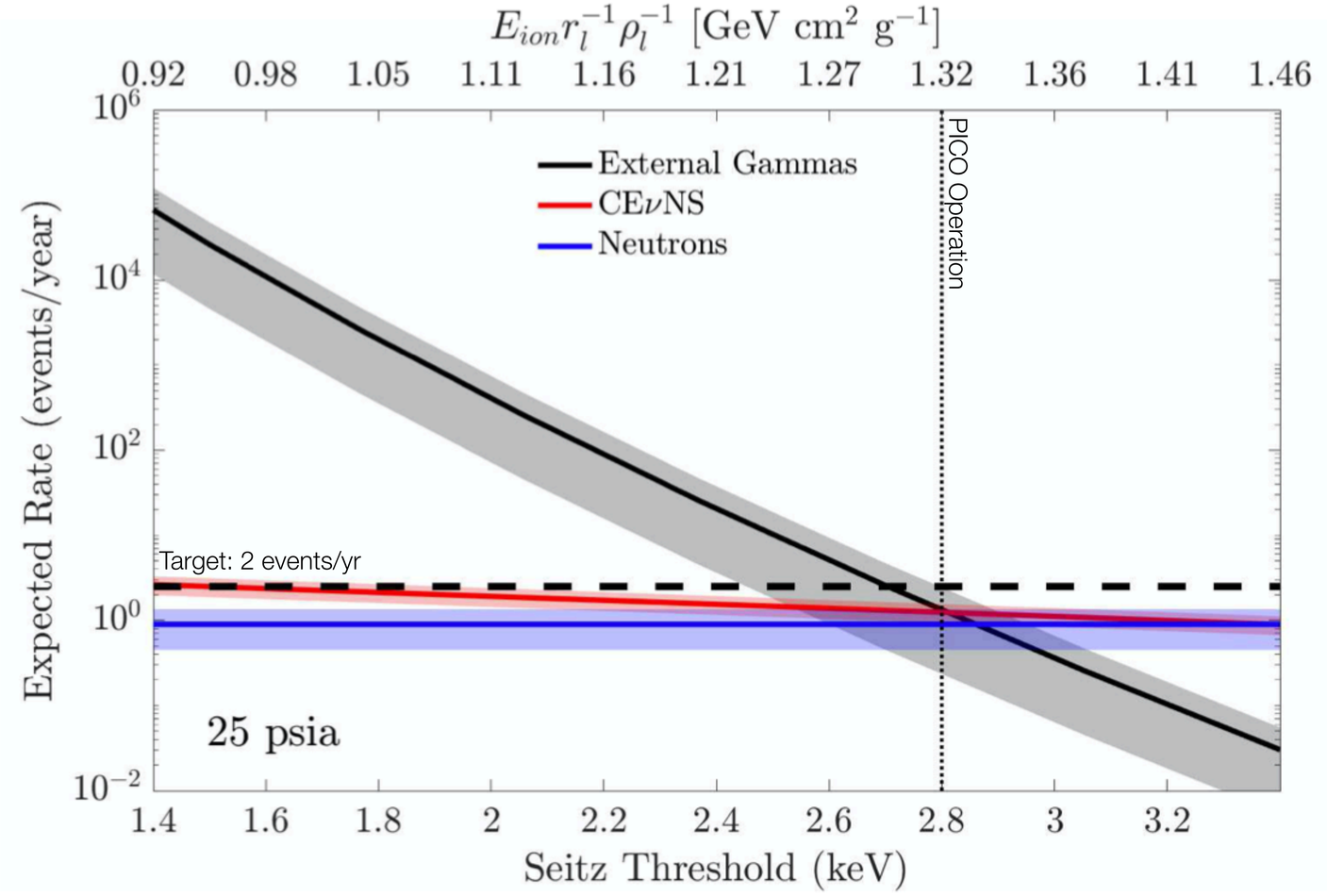
Floor from Battaglieri, et al. arXiv:1707.04591

- The floor varies, with similar limits for “heavy” targets
- Great deal of space accessible to C_3F_8 and not to Xe, Ar, Ge…

2. Electron recoil insensitivity*

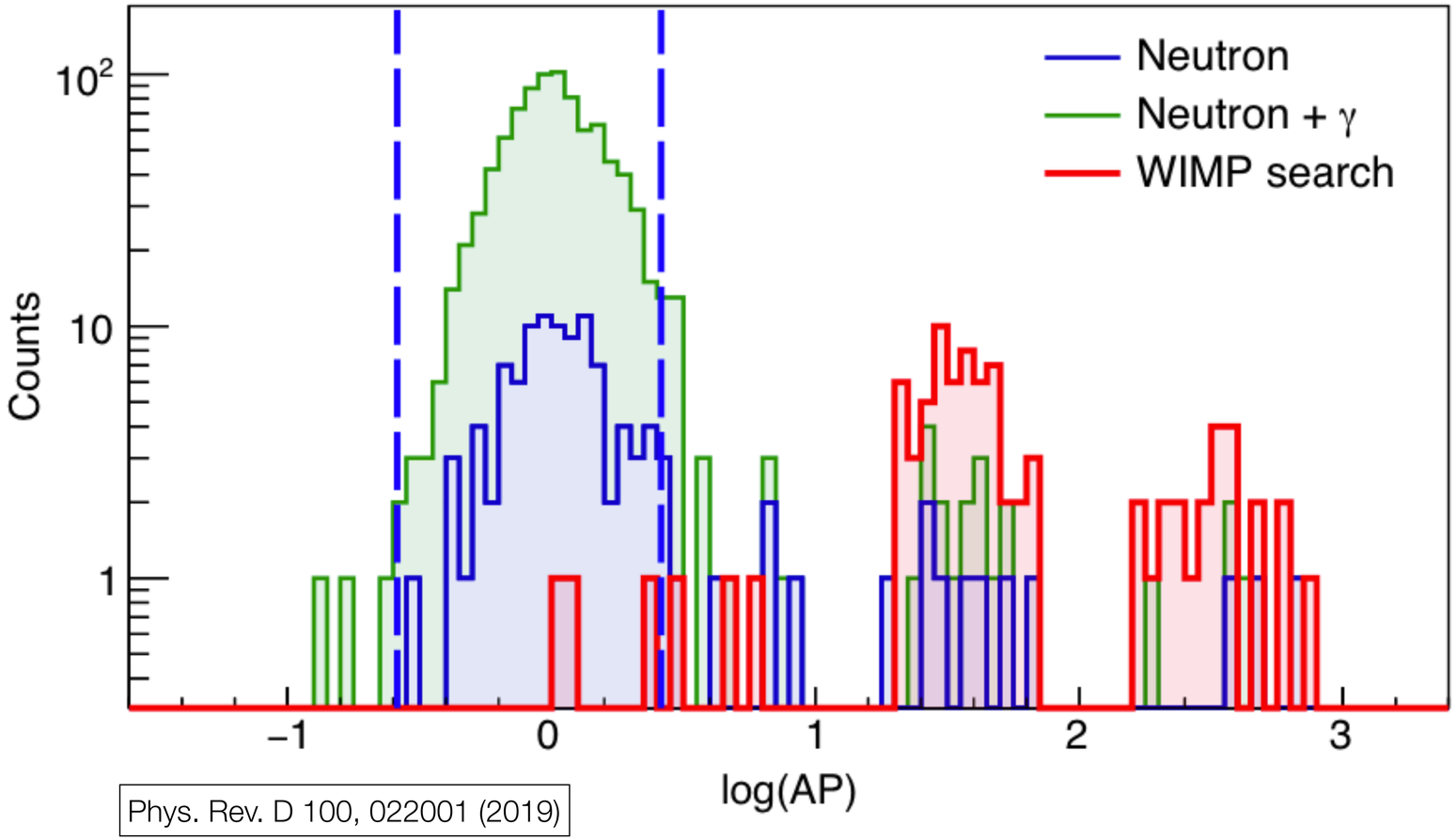
- Threshold of detector set by temperature and pressure of active fluid
- Controllable threshold allows range of sensitivity to electron recoil backgrounds

* at higher thresholds



PICO 40L detector, from Phys. Rev. D 100, 082006 (2019)

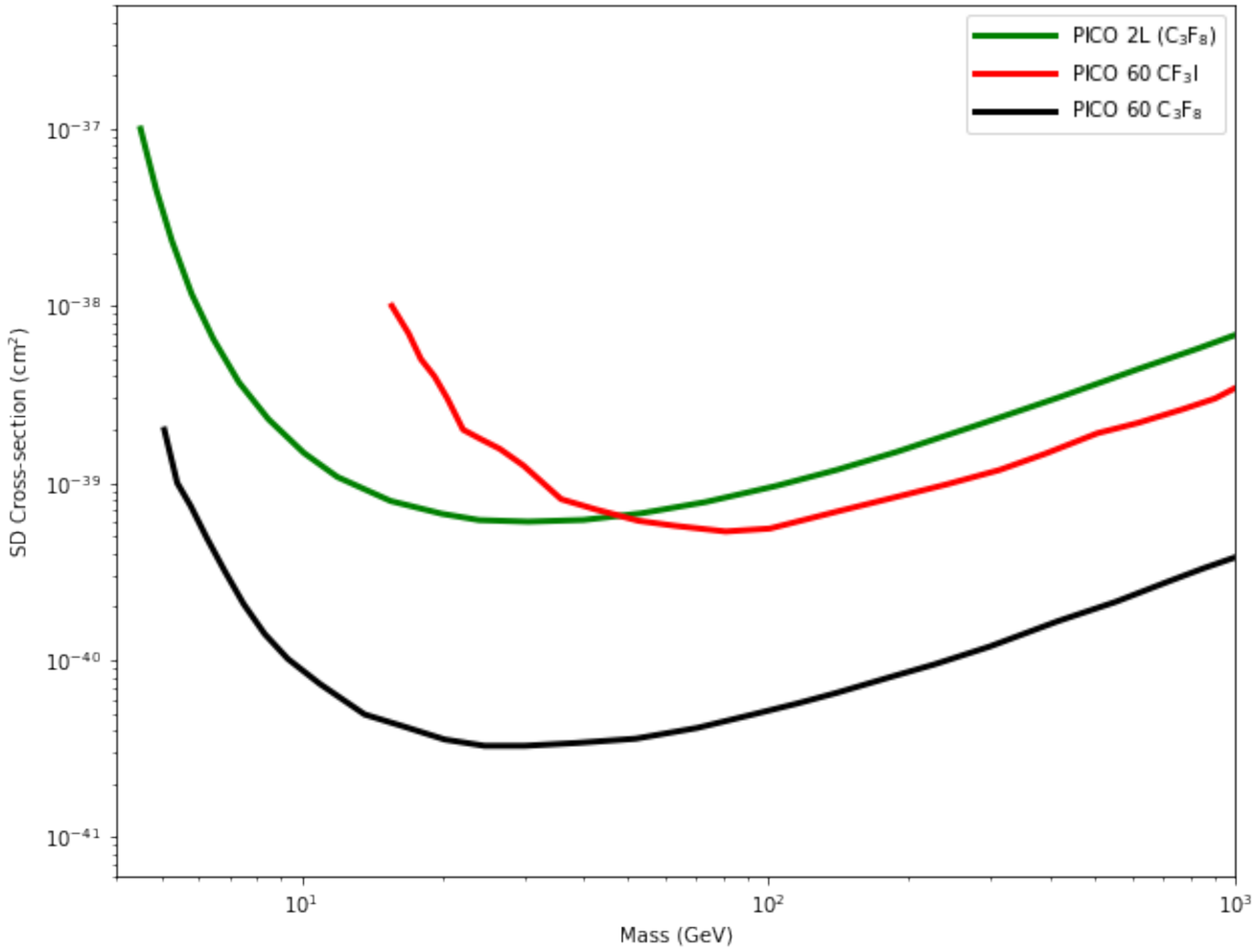
2a. Alpha Backgrounds



Phys. Rev. D 100, 022001 (2019)

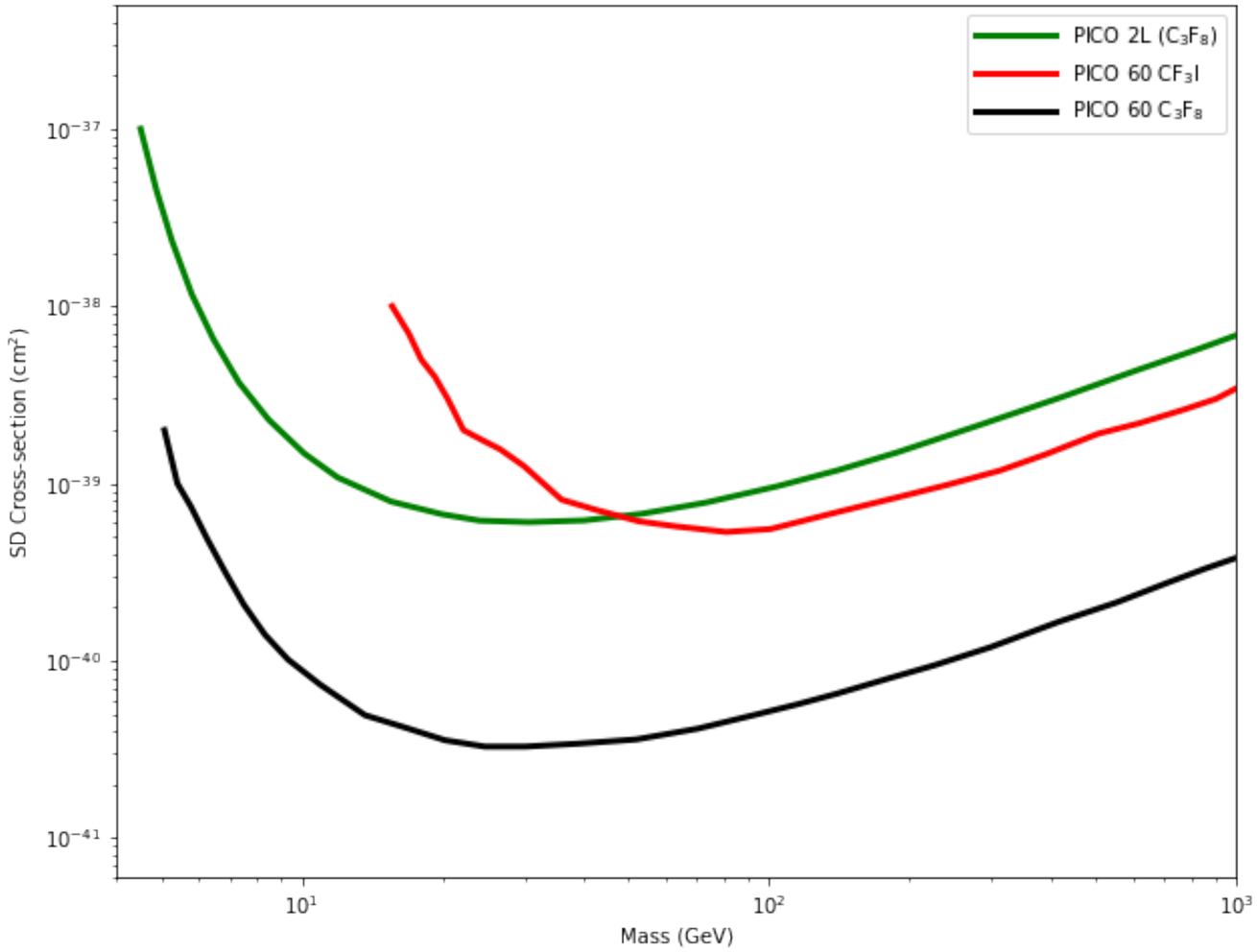
- Alpha backgrounds removed using the acoustics
- AP (Acoustic Parameter) shown to be a reliable discriminator

3. Ease of adjustments



- Target fluid can be changed to focus on different areas of phase space
  - Already demonstrated when PICO 60 switched from CF_3I to C_3F_8, trading SI sensitivity for increased SD range
- Future detectors can use hydrogenated fluids to target lower masses or noble elements to increase the reach

3. Ease of adjustments



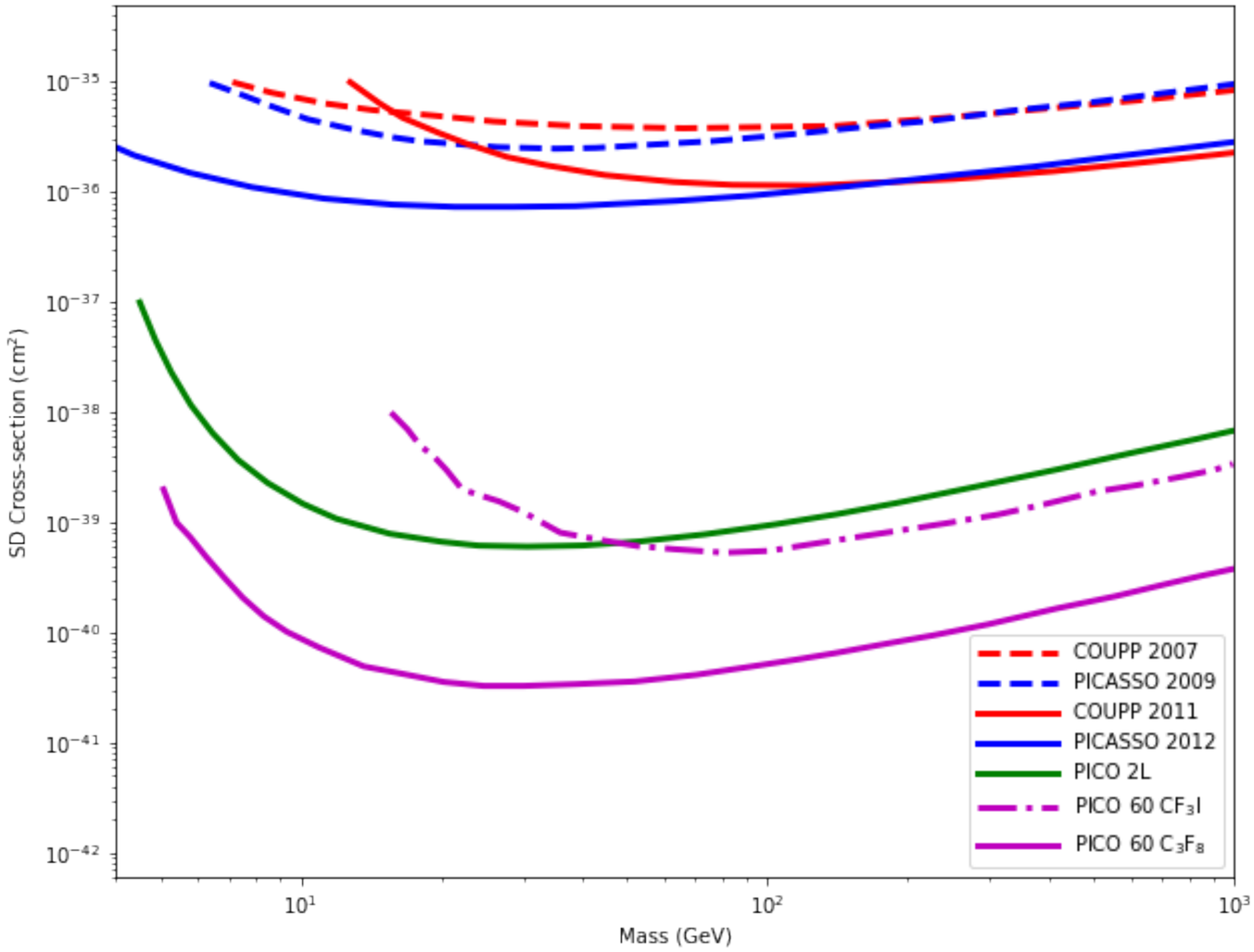
- Complementarity also a significant advantage
- Any signal seen with another technology can be verified using a target tailored to specific parameters

4. Inexpensiveness

- PICO 500 (active mass roughly 500 kg) completely funded and on the order of single $M (CAD)
- Alternatives being investigated for the quartz jars, the most expensive elements

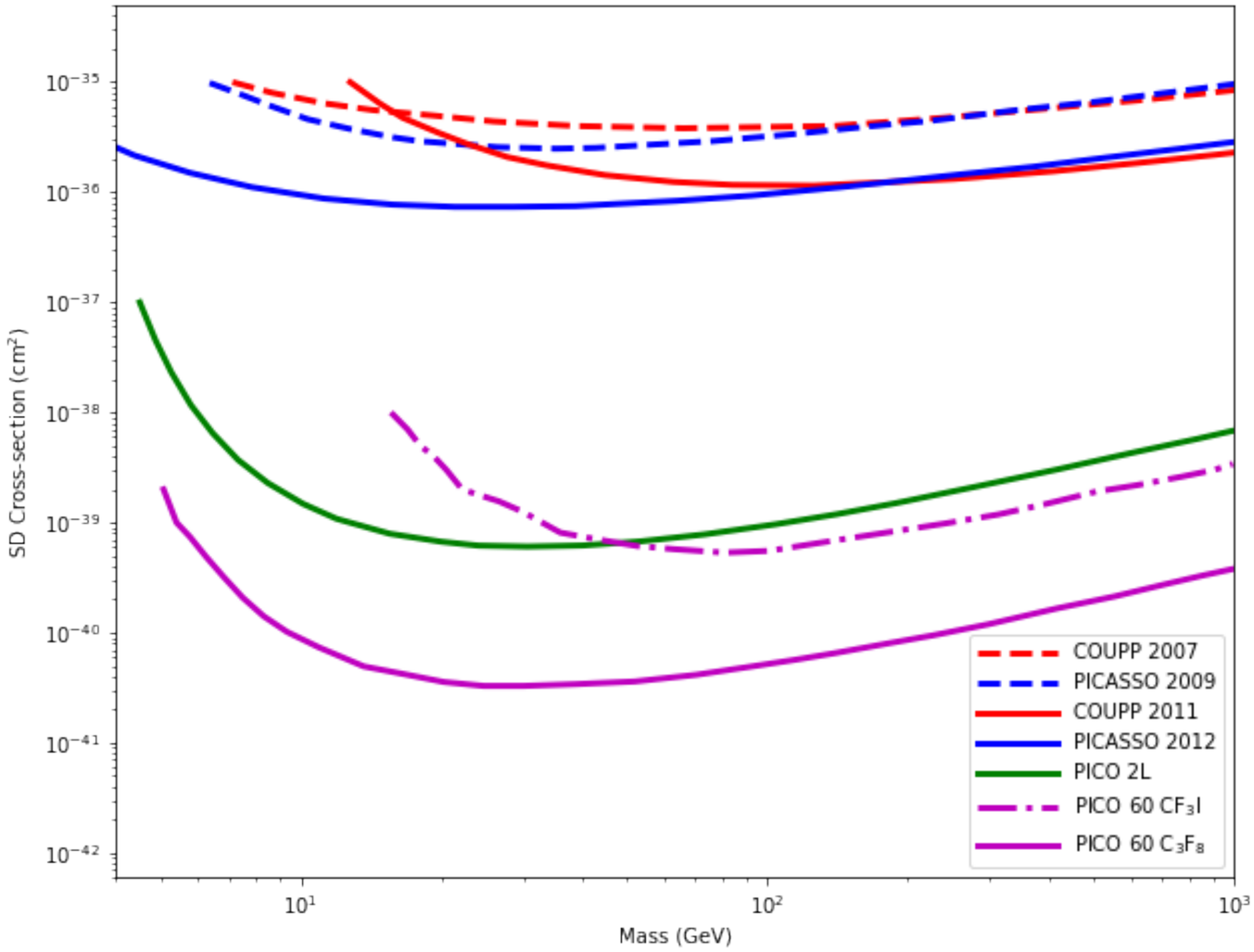
PICO History

- Not the only project, but superheated limits primarily from PICO
- **PI**CASSO and **CO**UPP merged in 2012 to form PICO
  - Take the best parts of both experiments
- Results from several joint efforts

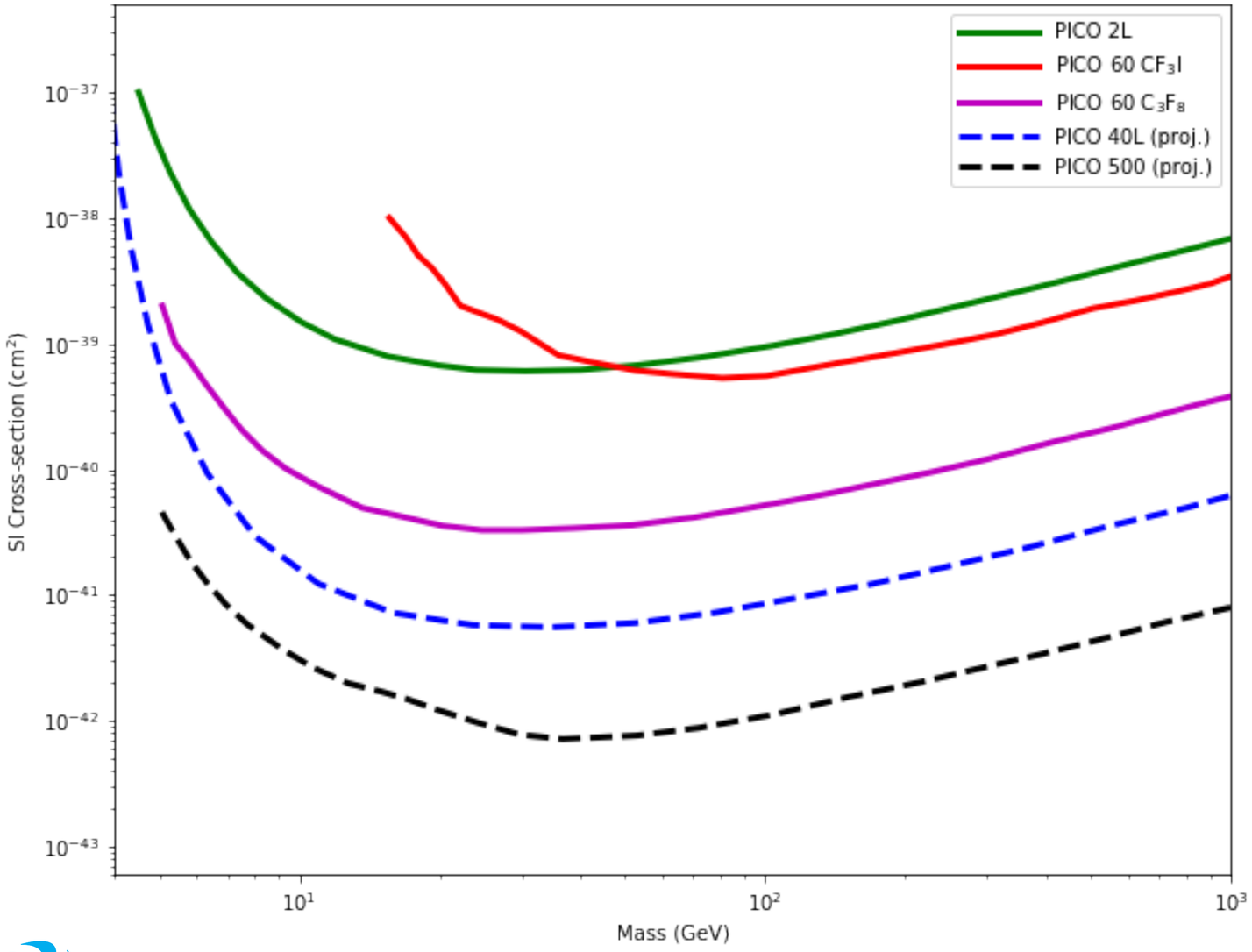


PICO History

- Several “bumps in the road”
- A particularly vexing background was found at a bad time (in terms of finances)
- This issue has been fixed, however it led to the latest generation being supported by Canada



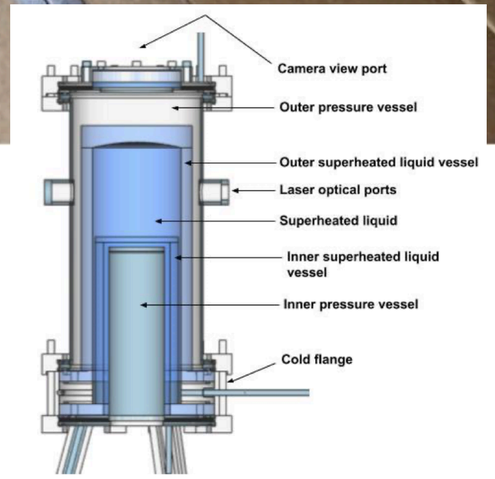
PICO Short Term Future



- PICO 40L currently taking commissioning data
- PICO 500 funded by CFI
  - Significant US intellectual involvement
- Installation at SNOLAB planned for 2021, data taking in 2022

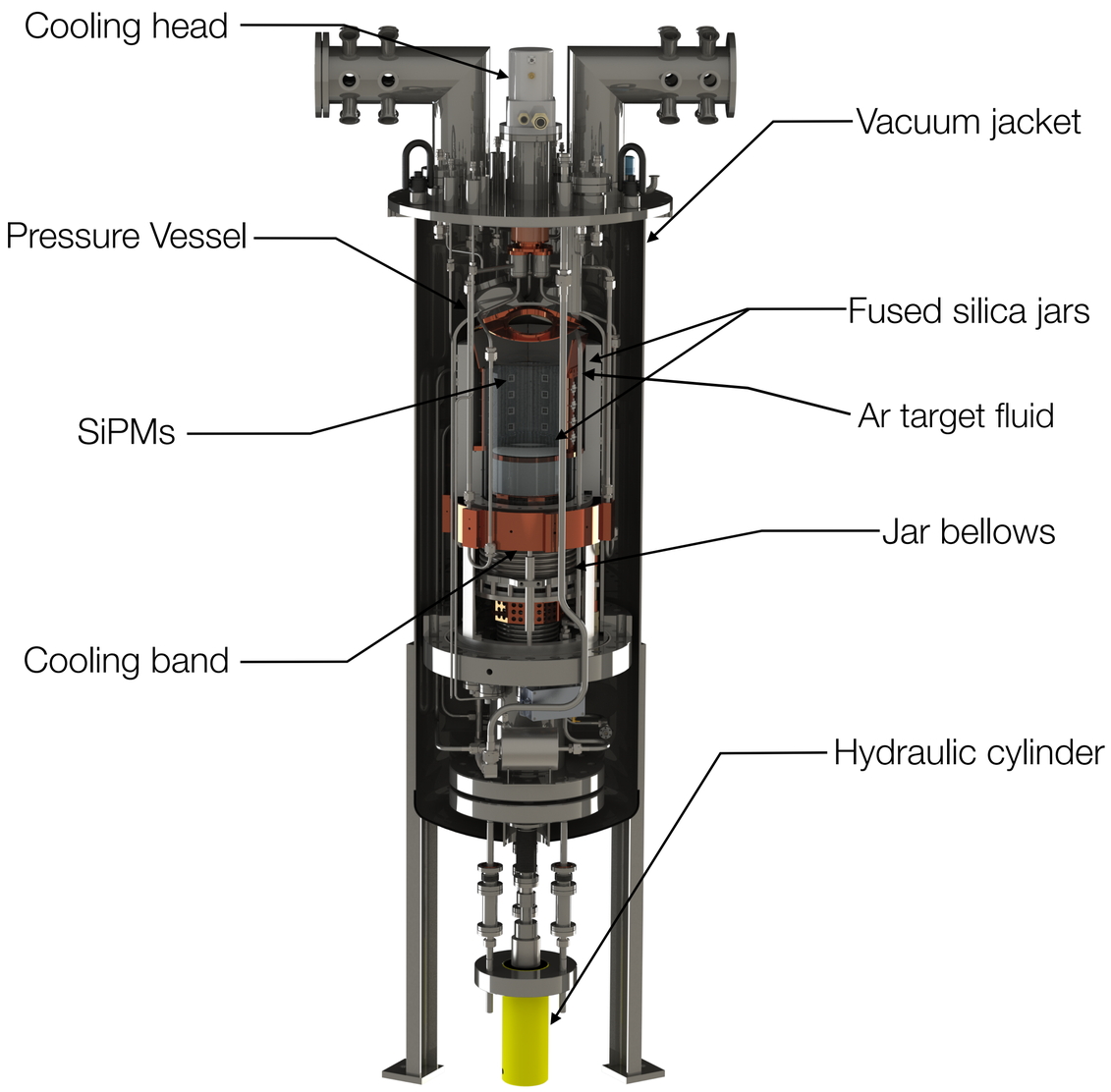
Longer term future

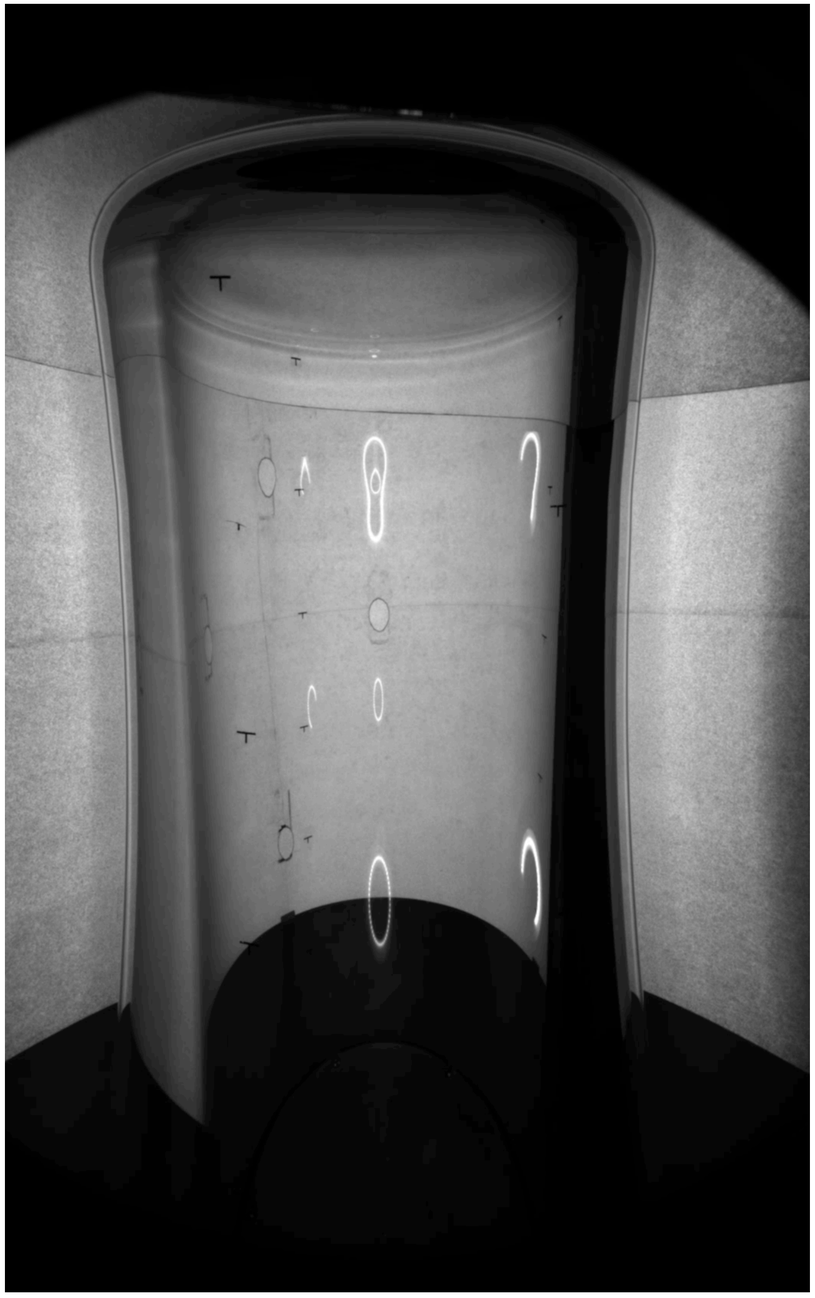
- Tonne-scale detector will require a new solution for the jars
- Testing currently ongoing with acrylic containers, initial results look promising



Longer term future

- Alternate target fluids also being tested
- One candidate ($C_2H_2F_4$) under investigation
- Use of noble elements also appealing and being tested

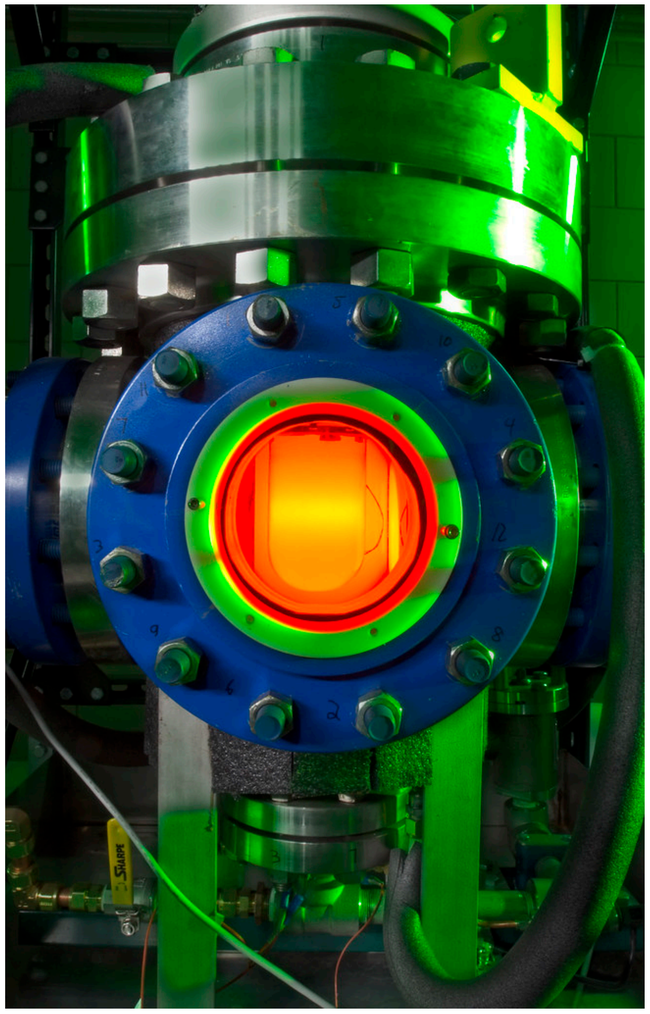




Conclusion

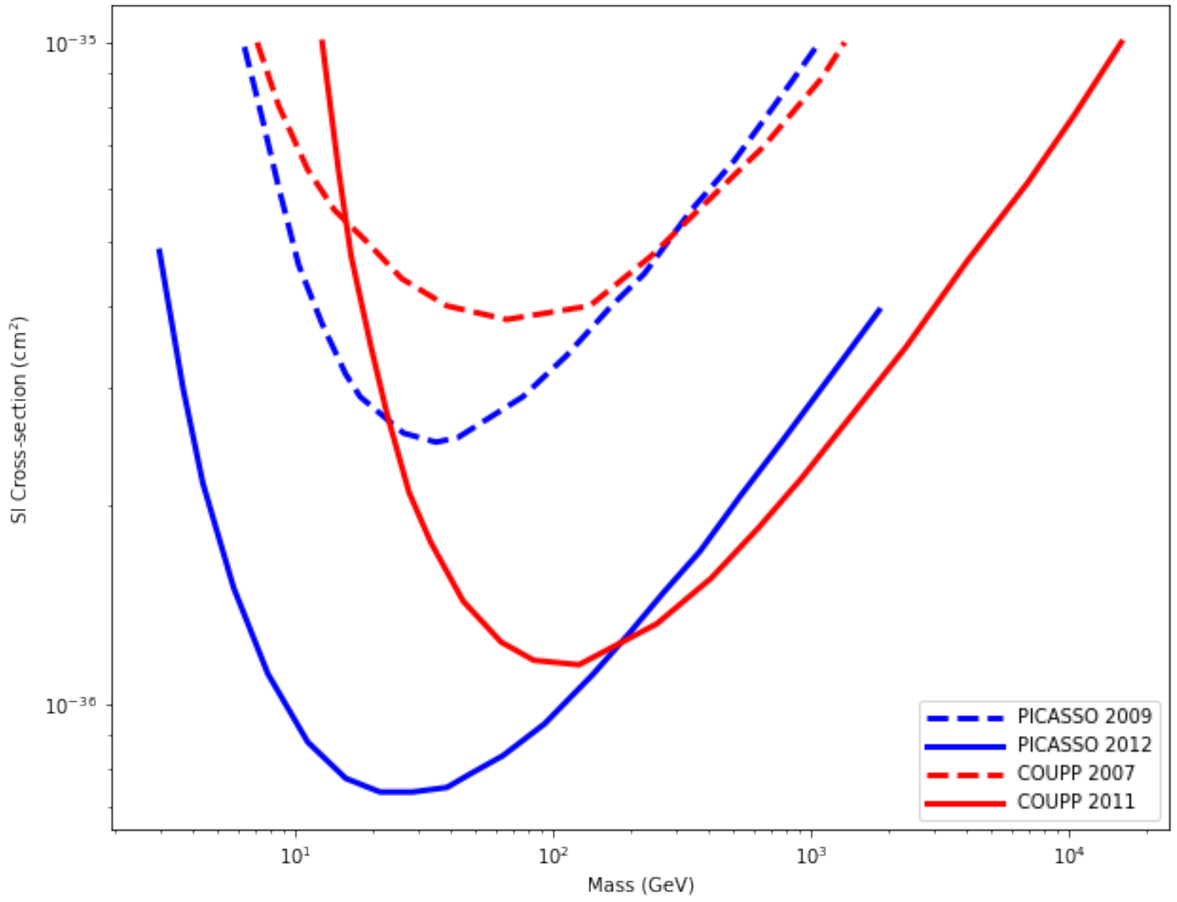
- Bubble chambers are alive and well as dark matter detectors, and are an important addition to the landscape
- They have been producing world-leading results for a decade
- Solid pathway to continuing this track into the future

Dark Matter Detectors



- Several experiments, notably COUPP and PICASSO
- COUPP primarily American, PICASSO mostly Canadian
- Advanced understanding for several years using slightly different implementations

Dark Matter Detectors



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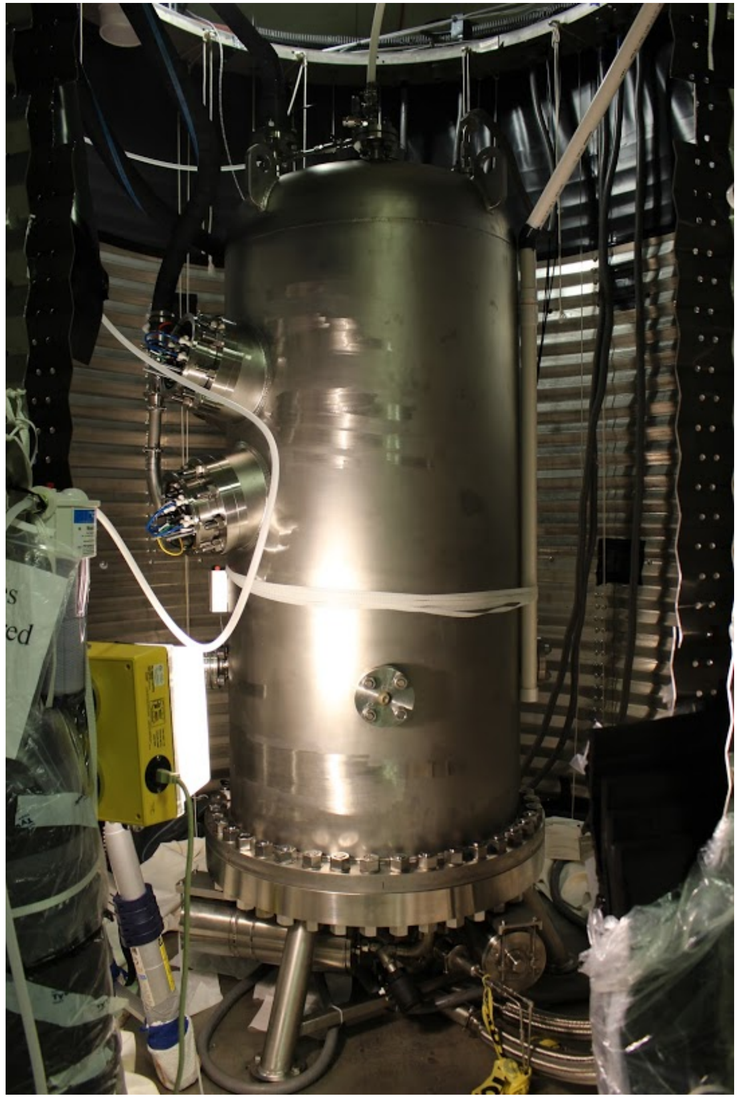
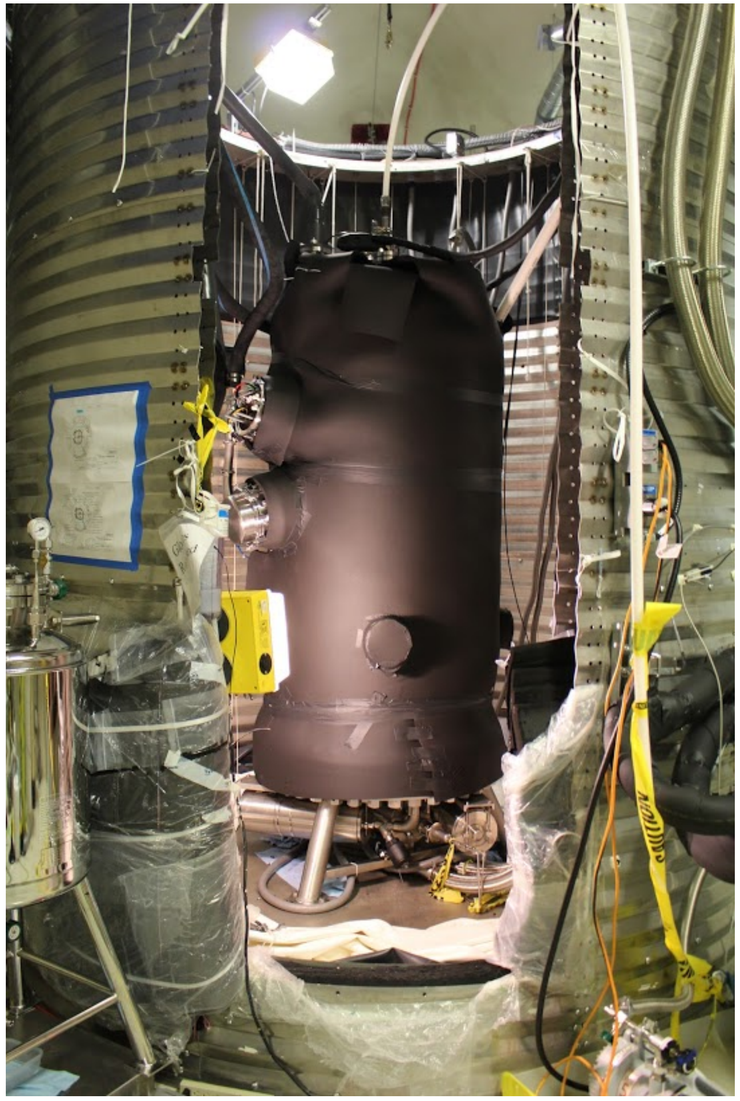
PICO 40L Current Status

August 2019



November 2019



December 2019