

Searching for Dark Matter with PICO-40L

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on behalf of the PICO Collaboration

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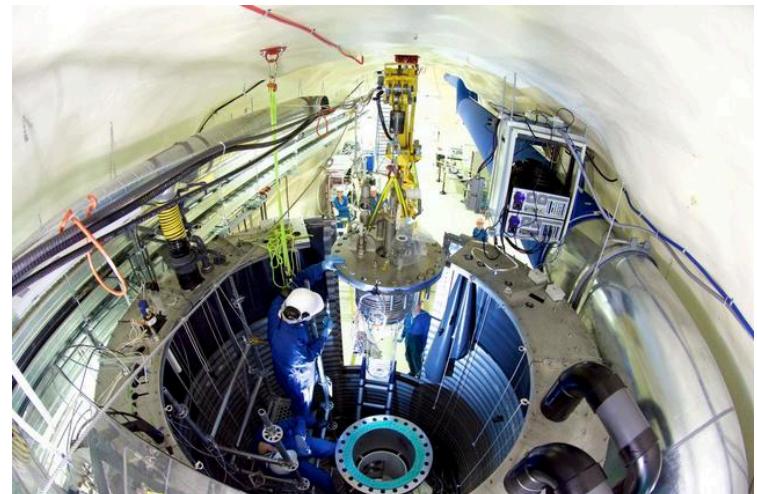
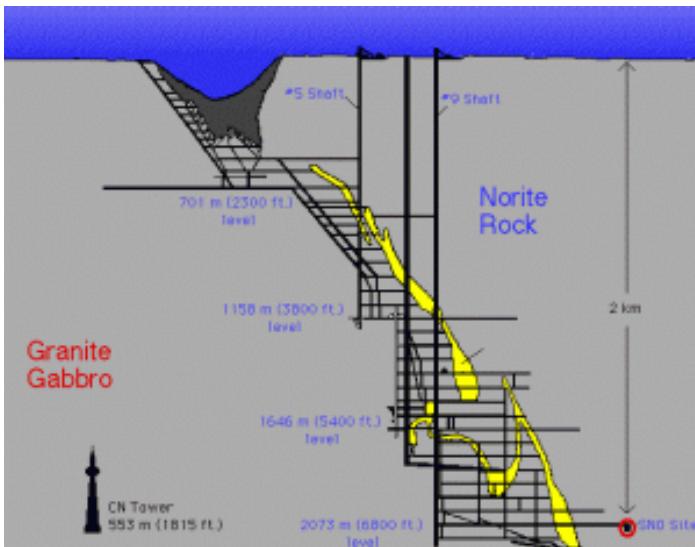
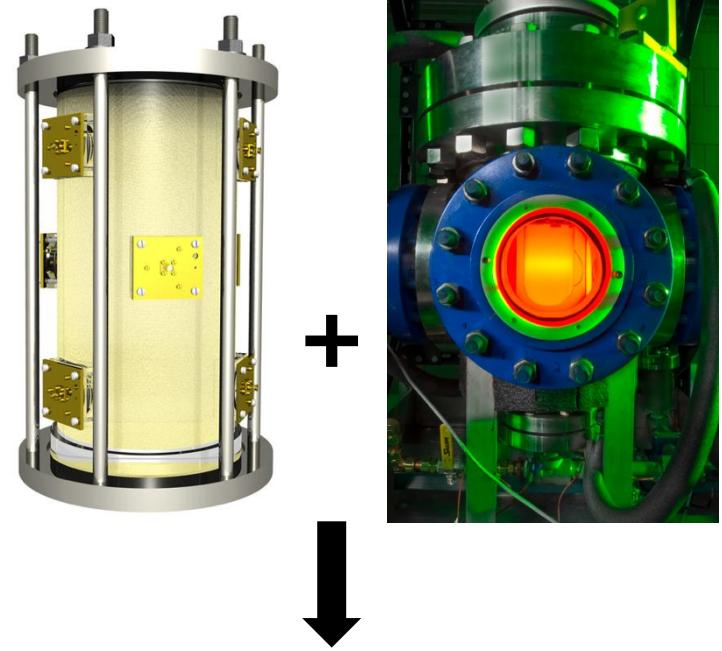


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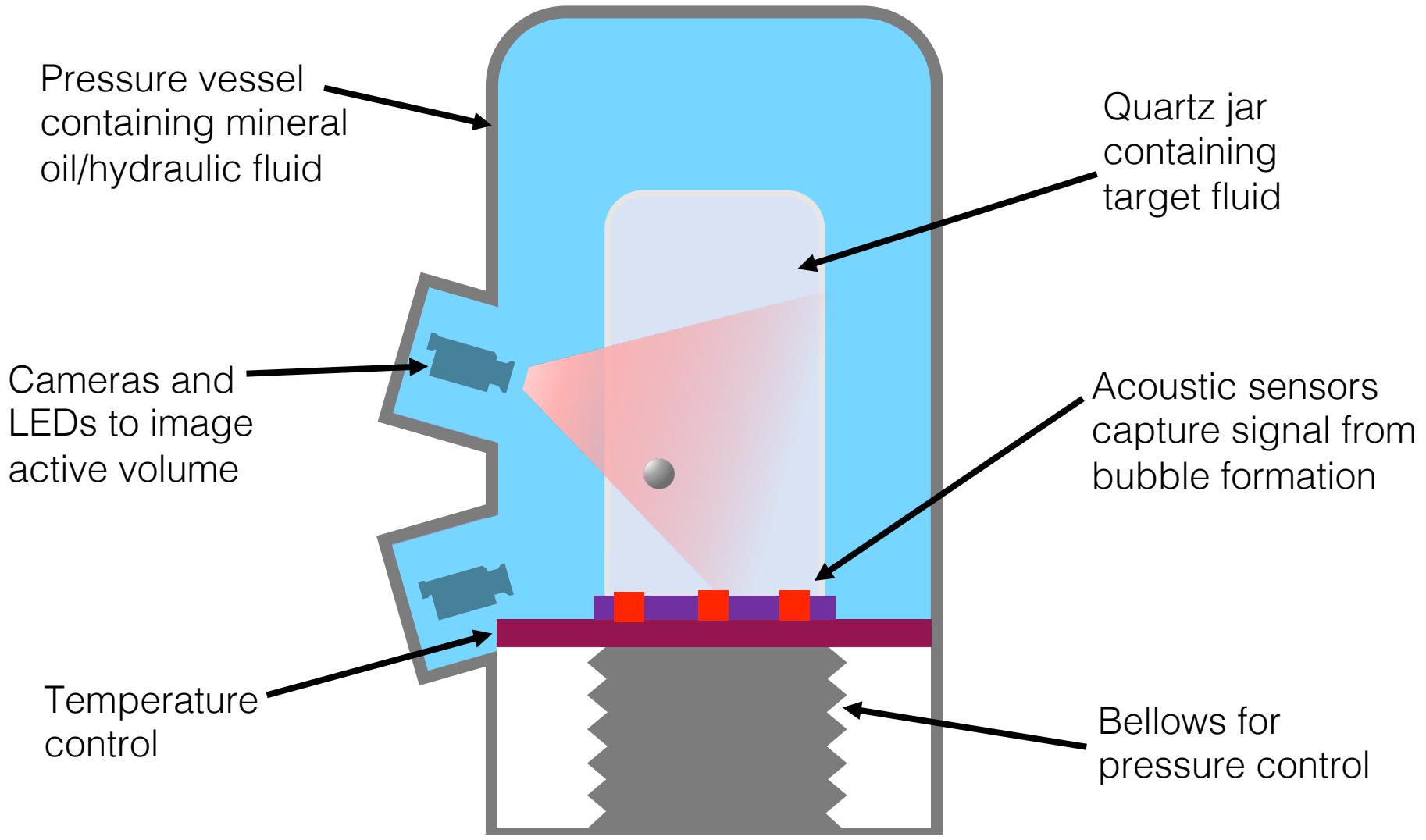
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Overview of PICO

- Merger of **PICASSO** and **COUPP** collaborations in 2012
- Direct detection of dark matter using bubble chambers
- Located at SNOLAB 2 km underground in Creighton Mine near Sudbury, Canada

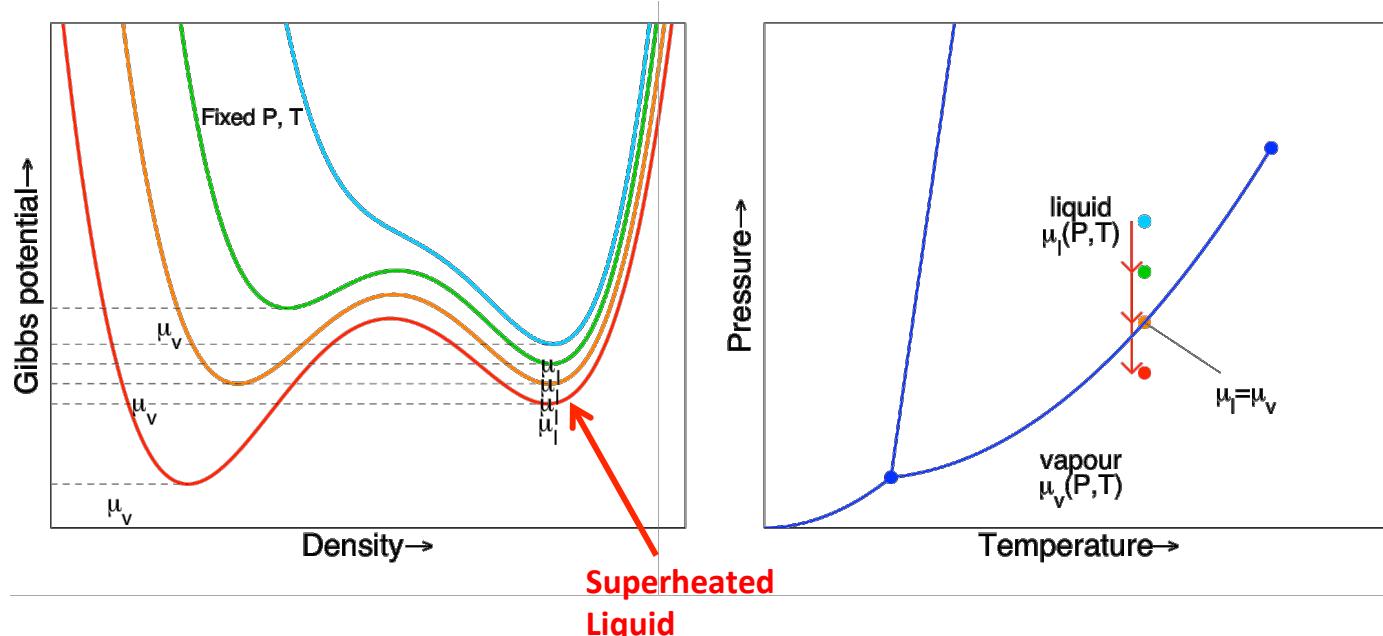


Components of a PICO Detector



Why Bubble Chambers?

- Principle of operation
 - Expand under constant temperature to reach metastable superheated state
 - Energy deposition from nuclear recoils causes a phase transition



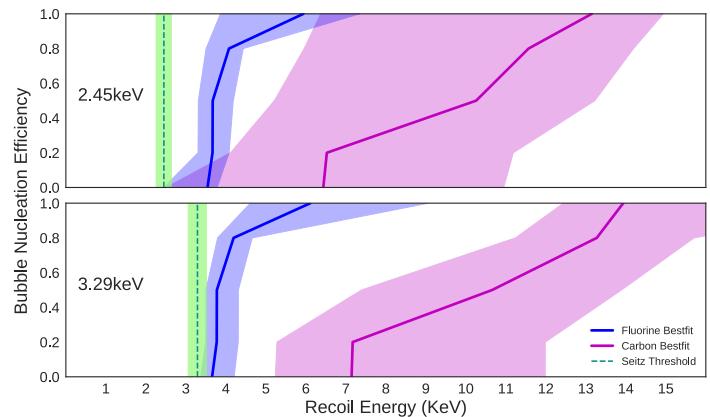
- Some requirements for dark matter direct detection:
 1. **Target** sensitive to WIMP interactions
 2. Low **background** rates
 3. Capability for particle **discrimination**

Target

- Fluorocarbon targets for sensitivity to spin-dependent interactions on ^{19}F due to unpaired proton

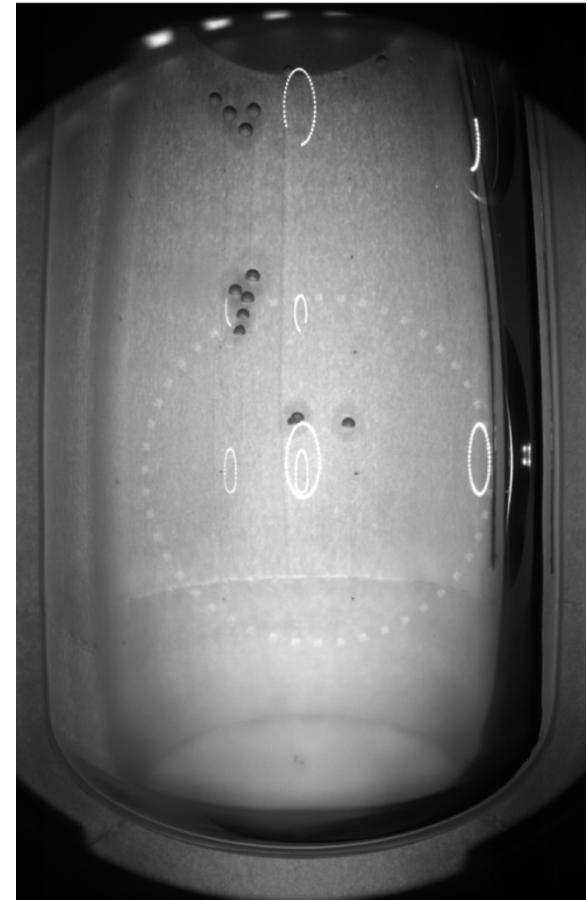
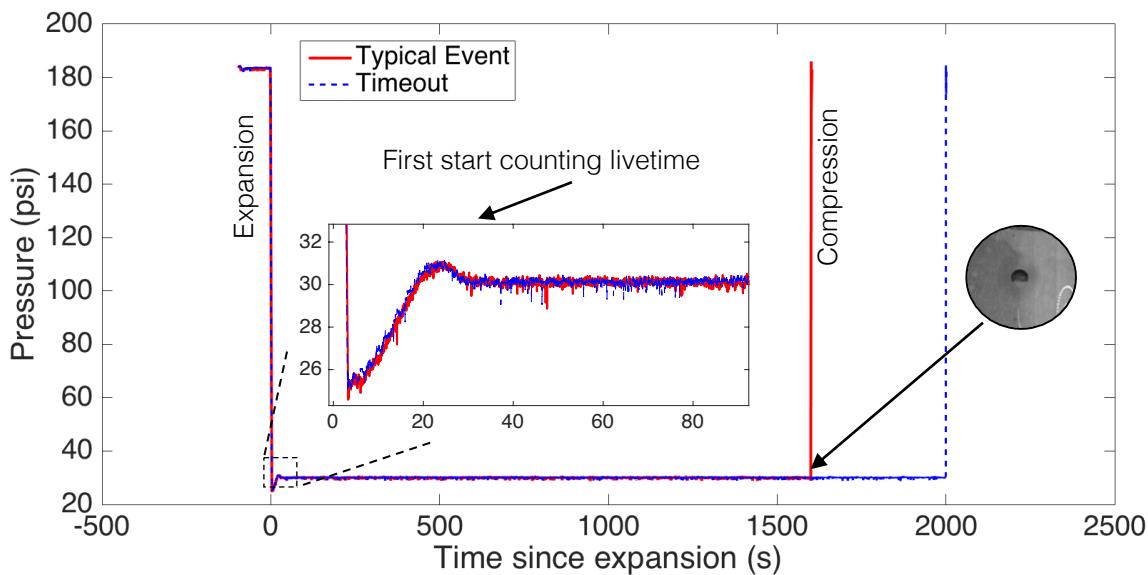
Nucleus	A	Z	Isotopic Fraction	J	$\langle S_p \rangle$	$\langle S_n \rangle$
Xe	131	54	0.2129	3/2	-0.009	-0.227
Xe	129	54	0.264	1/2	0.028	0.359
I	127	53	1.0	5/2	0.309	0.075
Ge	73	32	0.0776	9/2	0.030	0.378
F	19	9	1.0	1/2	0.477	-0.004

- Variety of targets can be used
 - CF_3I for better SI sensitivity (scales with A^2)
 - C_3F_8 for better SD sensitivity and electron recoil rejection
- Variable energy threshold
 - Determined by setting temperature and pressure
 - Sensitive down to a few keV
 - Nucleation efficiency determined using calibration data



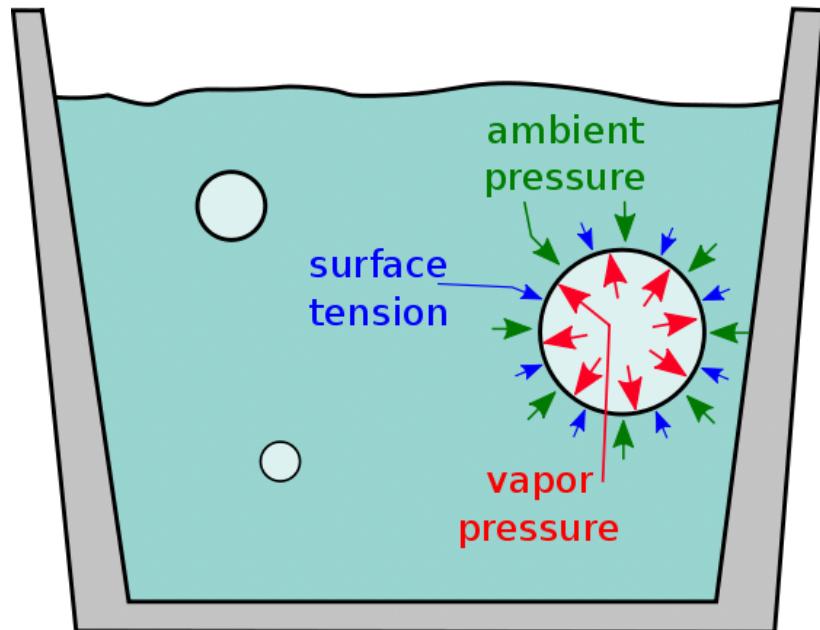
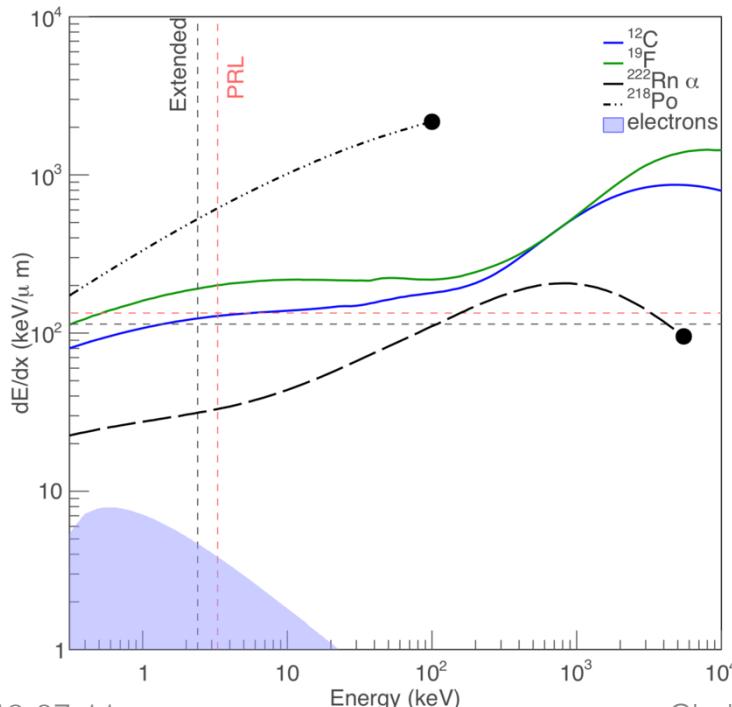
Detector Operation

- Event cycle
 - Set temperature then expand to desired pressure for a particular threshold
 - Event trigger from bubble visible in cameras or after timeout
 - Record pressure, temperature, acoustic signal, images, etc.
 - Recompress and then expand for next cycle
 - Live fraction of >80%



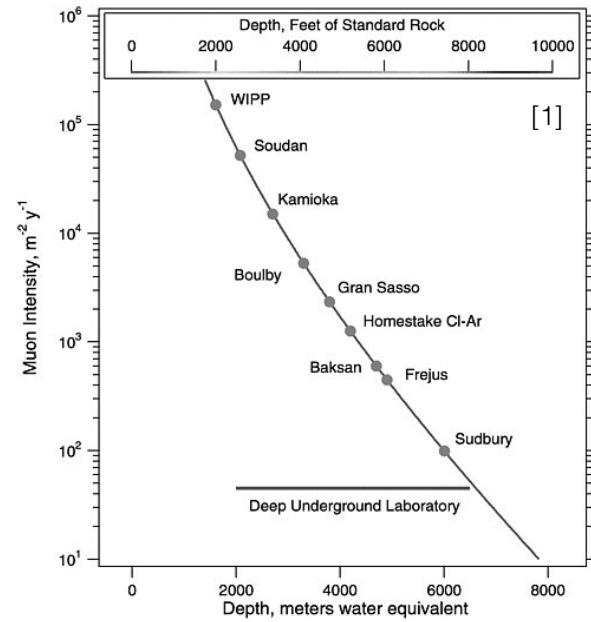
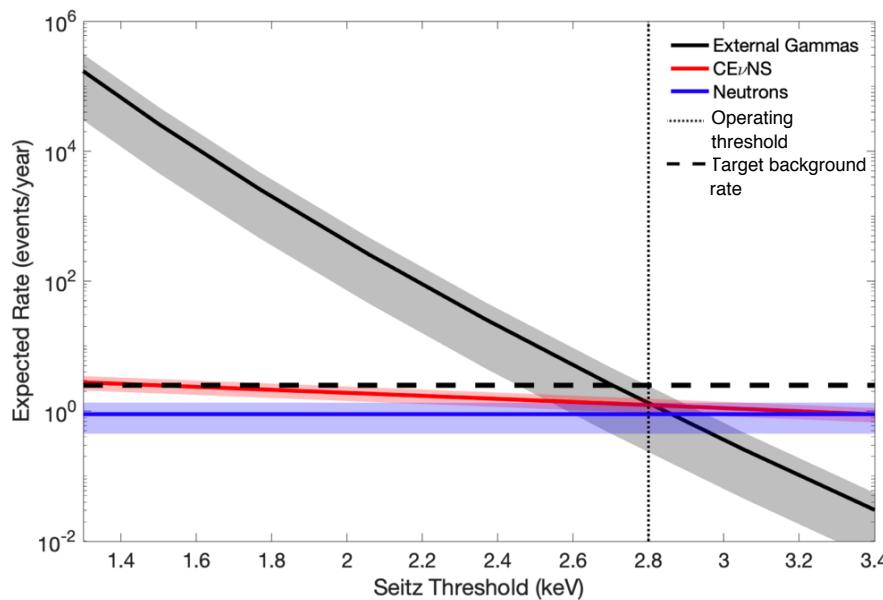
Backgrounds

- Bubble nucleation mechanism differs between background particles
- In general, two conditions for bubble nucleation:
 - Energy deposited must exceed threshold
 - Energy must be deposited within a critical radius
- Seitz “heat-spike” model used to determine threshold for nuclear recoils



Nuclear Recoils

- Radiogenic neutrons from detector components and surrounding rock
 - Veto multiple bubble events
- Coherent elastic neutrino-nucleus scattering (CEvNS)
 - Dominant background at proposed operating threshold
- Cosmogenic muons
 - Highly suppressed at depth of SNOLAB ($\sim 0.29 \mu/\text{m}^2/\text{day}$)



Electron Recoils from β and γ

- Probability of nucleation from electron recoils in C_3F_8 given by exponential function of pressure and temperature

$$\mathcal{P} = Ae^{-Bf(P,t)}$$

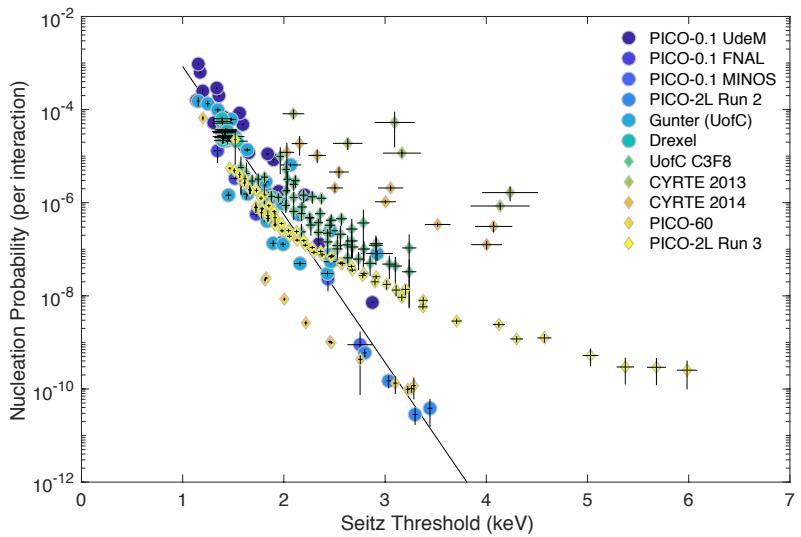
- Seitz model
 - Probability **per photon interaction** with $f(P,t) = Q_{Seitz}$

- New model [arXiv:1905.12522]
 - Probability **per energy deposited** with $f(P,t) = \frac{E_{ion}}{r_l \rho_l}$

$$Q_{Seitz} \approx 4\pi r_c^2 \left(\underbrace{\sigma - T \frac{\partial \sigma}{\partial T}}_{\text{surface energy}} \right) + \underbrace{\frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l)}_{\text{bulk energy}} - \underbrace{\frac{4\pi}{3} r_c^3 (P_b - P_l)}_{\text{reversible work}}$$
$$E_{ion} \approx 4\pi r_c^2 \left(\sigma - T \frac{\partial \sigma}{\partial T} \right) + \underbrace{\frac{4\pi}{3} r_c^3 P_l}_{\text{work done by liquid reservoir}}$$

Electron Recoils from β and γ

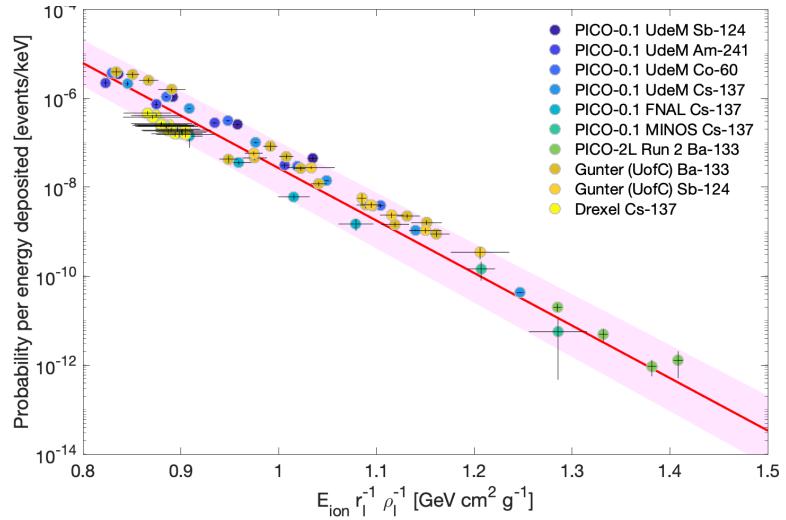
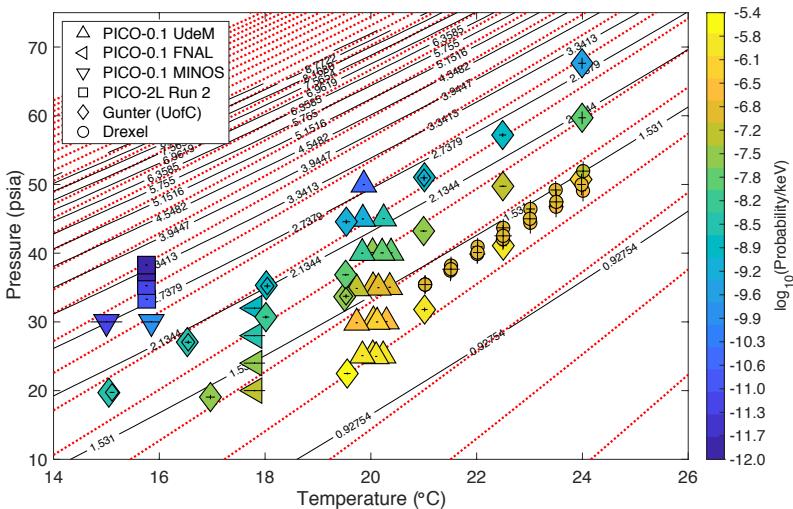
- New model (right) provides much better fit to existing data than Seitz model (left)*
- **Seitz threshold** decreases faster with decreasing pressure than **stopping power** using ionization threshold
- Lower pressure maximizes ER rejection for a given Q_{Seitz}



* Iodine-contaminated data (diamonds) require an additional nucleation mechanism to be fully described (see arXiv:1905.12522)

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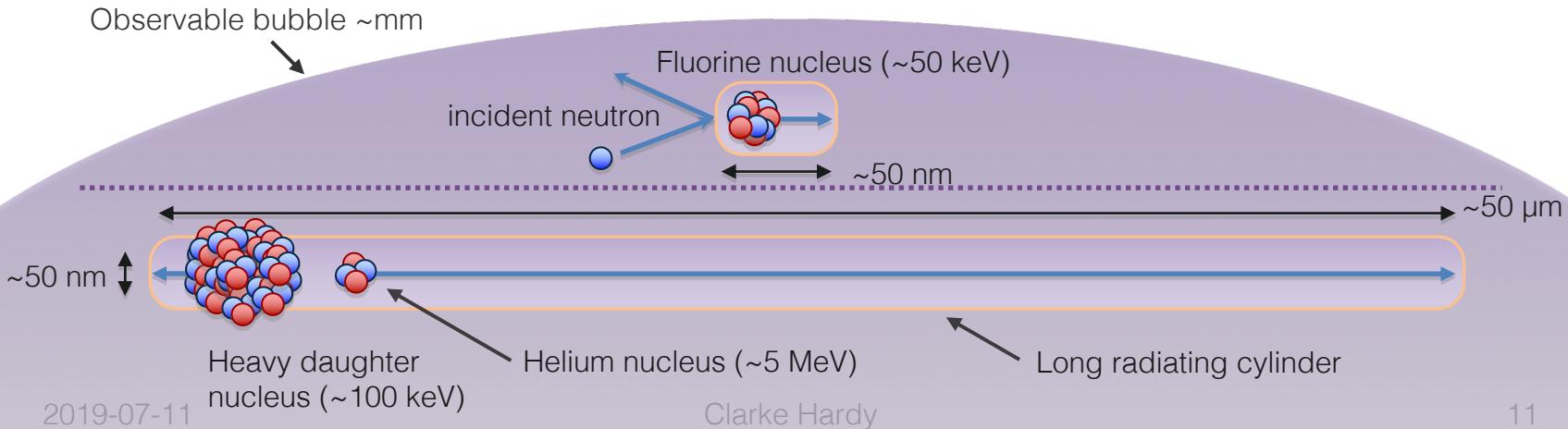
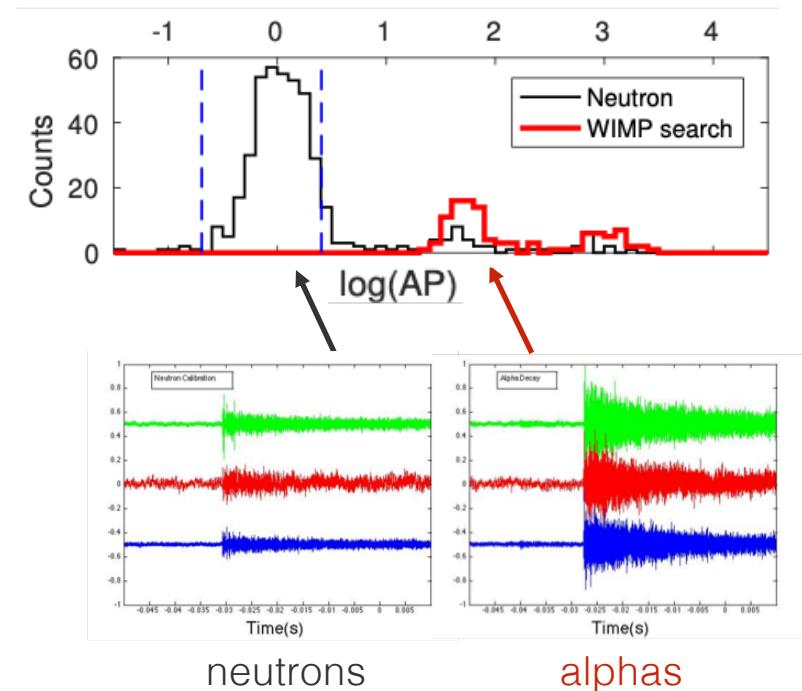
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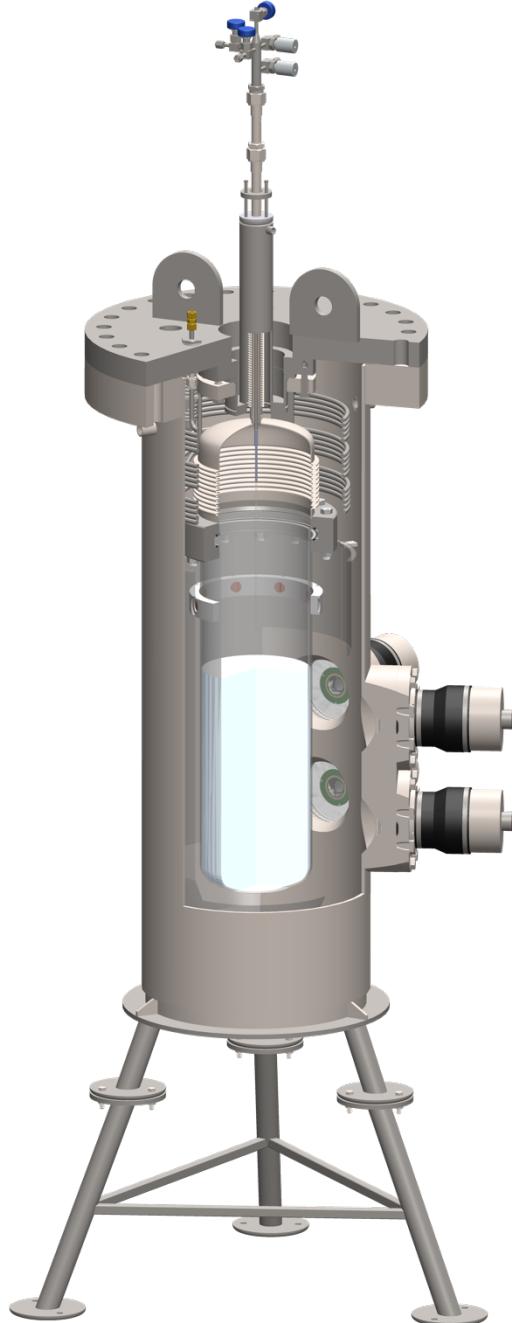
Alpha Discrimination

- Alphas deposit energy over much longer range than nuclear recoils
 - Emitted acoustic power scales with surface area of initial energy deposition region where target liquid is vaporized [arXiv:1906.04172]
 - Construct parameter “AP” from integrated acoustic power over a frequency band
- Acoustic signals blinded for WIMP-search run to set unbiased cut
- Machine learning techniques developed as an alternative to simple AP cut
(C. Amole *et al.*, PRL 118, 251301 (2017)) [arXiv:1811.11308]



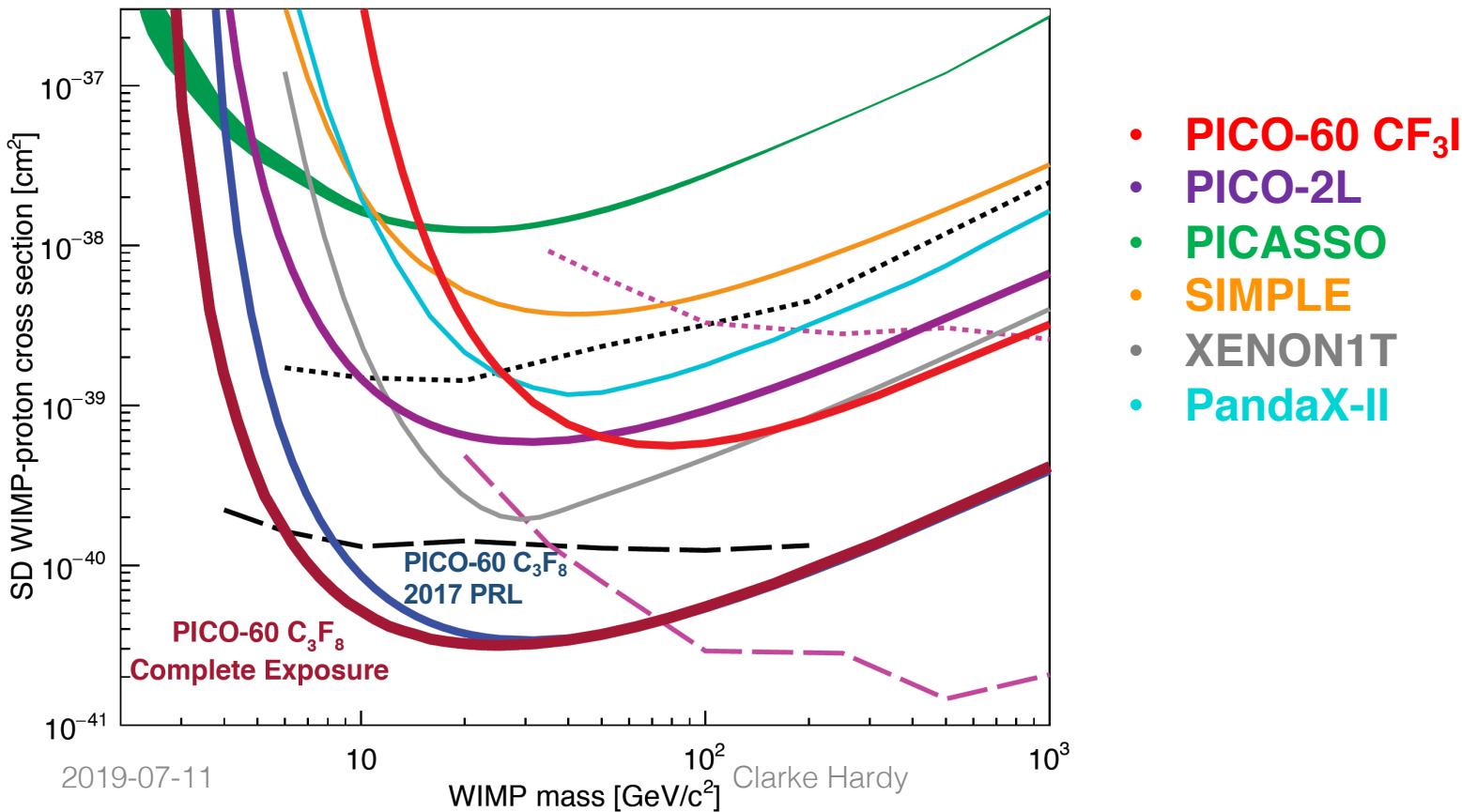
PICO-60 Detector

- In operation from 2013-2017
- First run with CF_3I for 3415 kg-days
- Added two cameras and increased frame rate
- Next run with C_3F_8 for 1167 kg-day at 3.3 keV, then 1404 kg-day at 2.45 keV
- Water interface separates active region from stainless steel bellows
- Background events observed around chamber walls and at water interface
- Particulates from bellows falling into active volume causing background events



PICO-60 Results

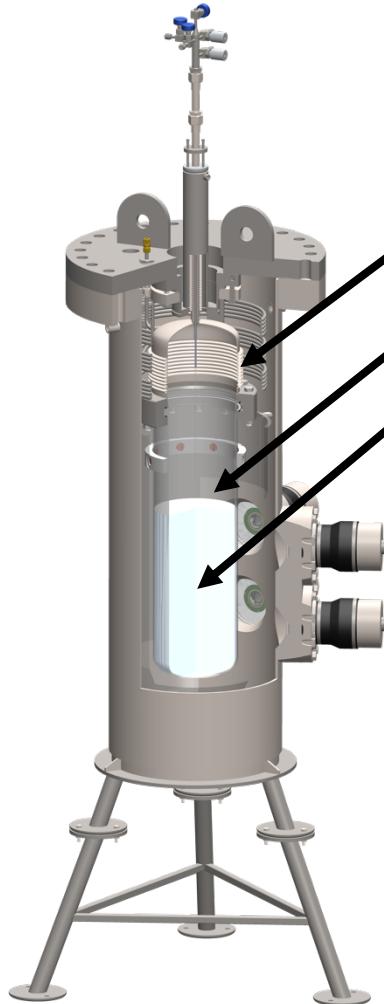
- World-leading limits on spin-dependent WIMP-proton cross section from first C_3F_8 run (C. Amole *et al.*, PRL 118, 251301 (2017))
- Improved low-mass limits by including data from second C_3F_8 run at lower threshold (C. Amole *et al.*, Phys. Rev. D 100, 022001 (2019))



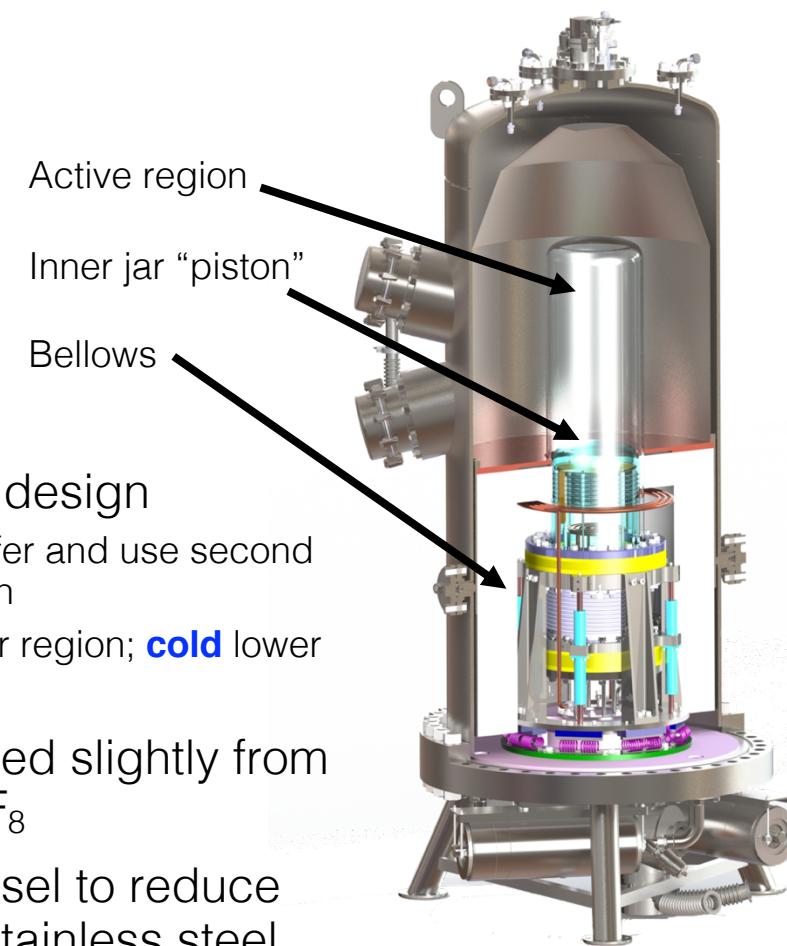
PICO-60



PICO-40L

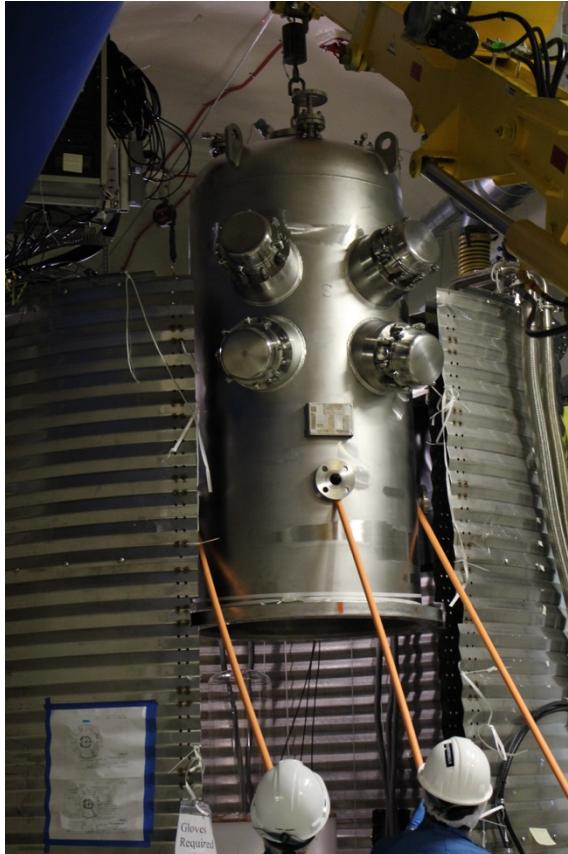


- New “right-side-up” design
 - Eliminate water buffer and use second quartz jar as a piston
 - **Superheated** upper region; **cold** lower region
- Active mass increased slightly from 52 kg to 58.5 kg C_3F_8
- Larger pressure vessel to reduce backgrounds from stainless steel
- Proof-of-concept for future ton-scale detector



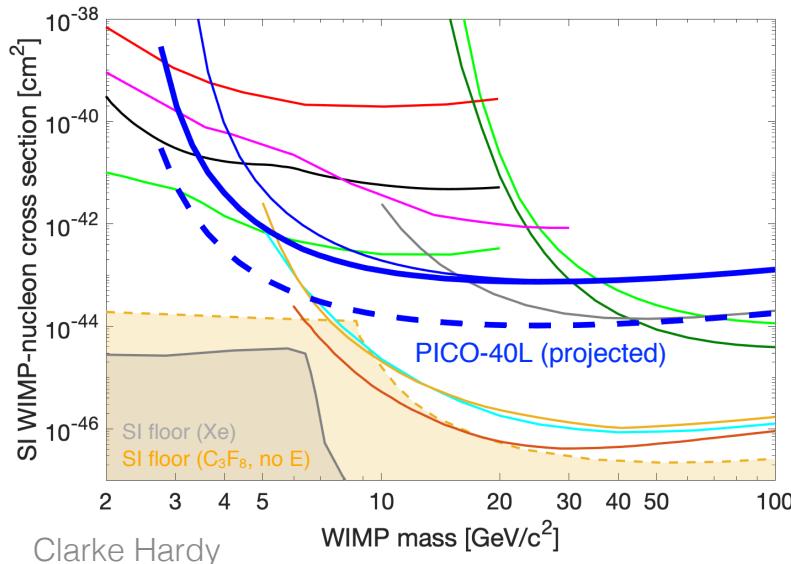
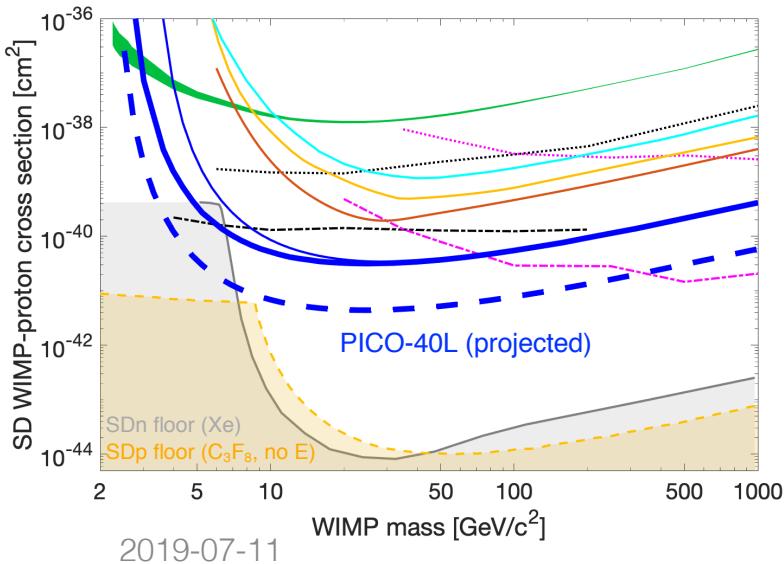
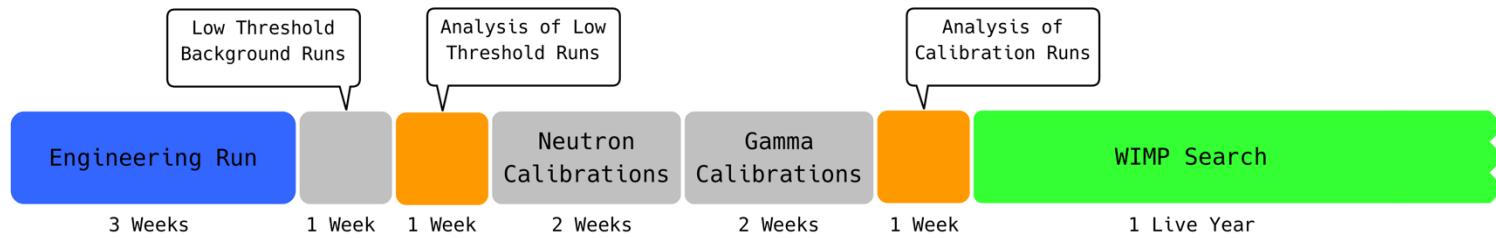
PICO-40L Installation Progress

- Commissioning expected to be completed this month
- Physics data collection to begin in October 2019



Current PICO-40L Run Plan

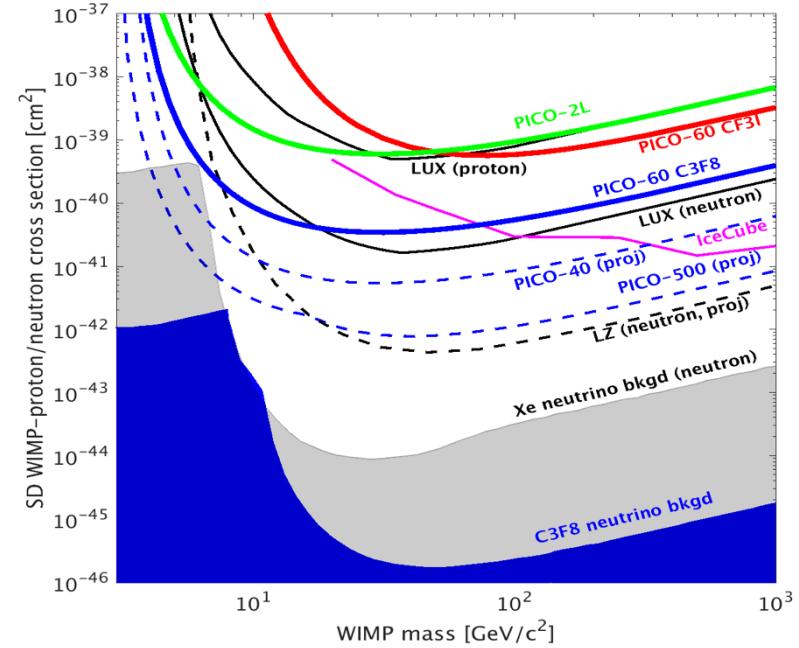
- Calibrations using ^{252}Cf and ^{60}Co prior to first physics run
- WIMP search at Seitz threshold of 2.8 keV
- Operate at 18 psia instead of 30 psia as in PICO-60 in accordance with new ER nucleation model



PICO-60
PICASSO
LUX
XENON1T
PandaX-II
DarkSide-50
DEAP-3600
CDMSlite
SuperCDMS
CRESST-III
DAMIC-100

Next Steps: PICO-500

- ~260 L C_3F_8 with same “right-side-up” design as PICO-40L
- Currently in design/procurement phase
- Installation in SNOLAB cube hall to begin in 2020
- Sensitive to supernova neutrinos (T. Kozynets *et al.*, Astroparticle Phys. 105 (2019) 25-30)



Conclusions

- PICO-60 set world-leading limits on SDp cross section
- PICO-40L uses a new design to reduce background sensitivity from PICO-60 and provide proof-of-concept for PICO-500
- Commissioning in SNOLAB nearly complete
- First physics data expected in fall 2019

PICO

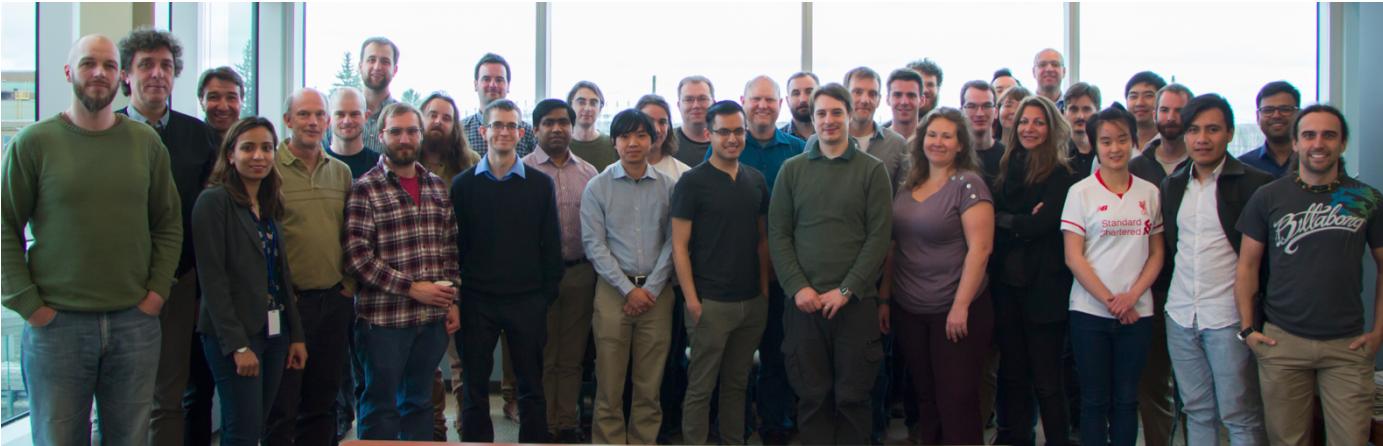


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References

- [1] "4. Science Potential of a Deep Underground Laboratory." National Research Council. 2003. *Neutrinos and Beyond: New Windows on Nature*. Washington, DC: The National Academies Press. doi: 10.17226/10583
- [2] arXiv:1905.12522
- [3] arXiv:1906.04172
- [4] C. Amole *et al.*, PRL 118, 251301 (2017)
- [5] arXiv:1811.11308
- [6] C. Amole *et al.*, Phys. Rev. D 100, 022001 (2019)
- [7] T. Kozynets *et al.*, Astroparticle Phys. 105 (2019) 25-30