COUPP: Searching for Dark Matter with Bubble Chambers

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University of Chicago

LHC, Particle Physics, and the Cosmos
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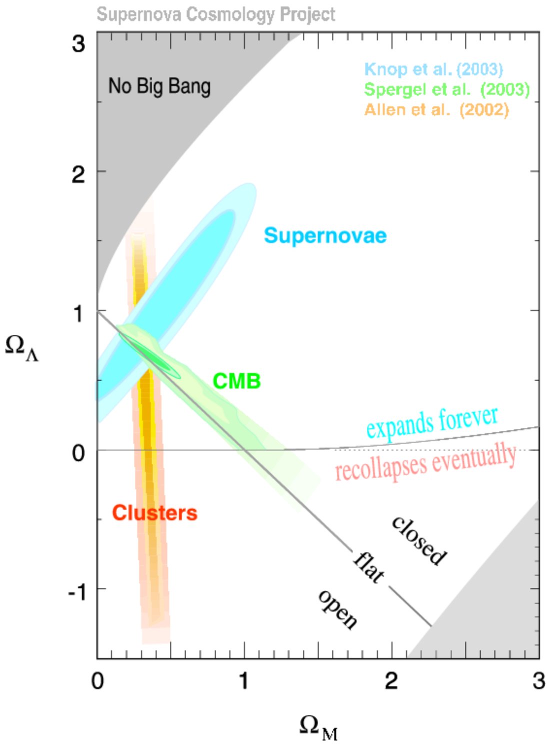
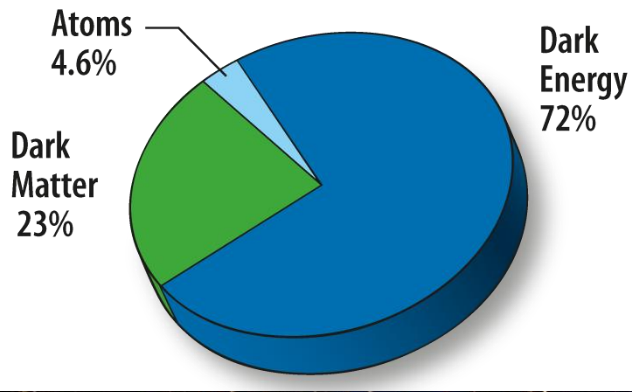
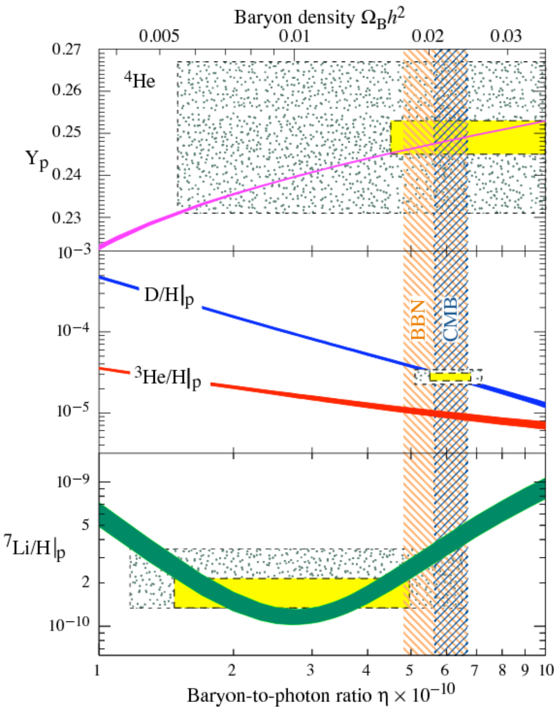
Evidence for dark matter





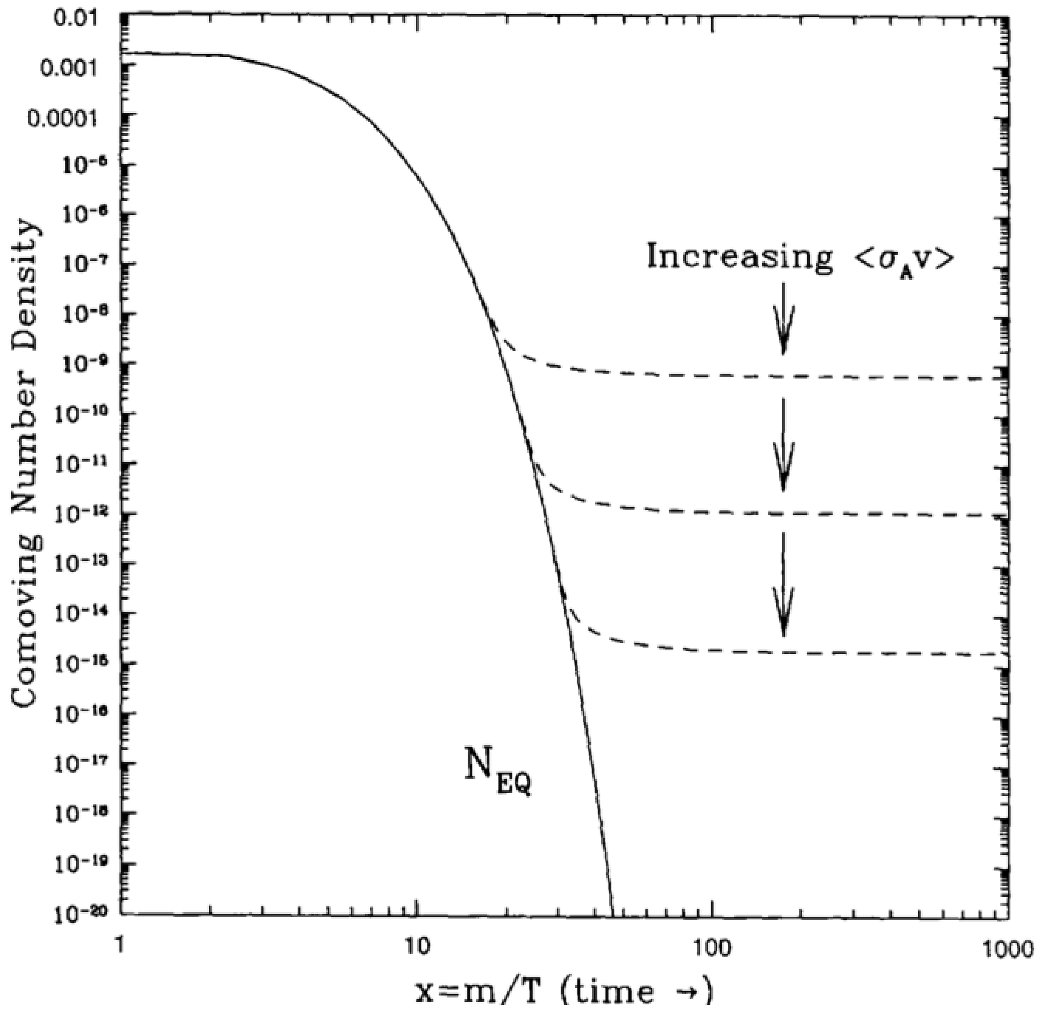


Relics and Miracles

$$\frac{dn_\chi}{dt} = -\langle\sigma_a v\rangle\left[(n_\chi)^2 - (n_\chi^{eq})^2\right] - 3Hn_\chi$$

- Suppose Dark Matter is:
  - Stable Particle (LSP…)
  - Thermal Relic of Big Bang

- Weak-scale interaction gives required density for dark matter



WIMP-nucleon scattering

Spin-independent

Spin-dependent

$$\sigma_0 = \frac{4\mu^2}{\pi}\left[f_p N_p + f_n N_n\right]^2 + \frac{32 G_F^2 \mu^2}{\pi}\frac{J+1}{J}\left[a_p \langle S_p \rangle + a_n \langle S_n \rangle\right]^2$$

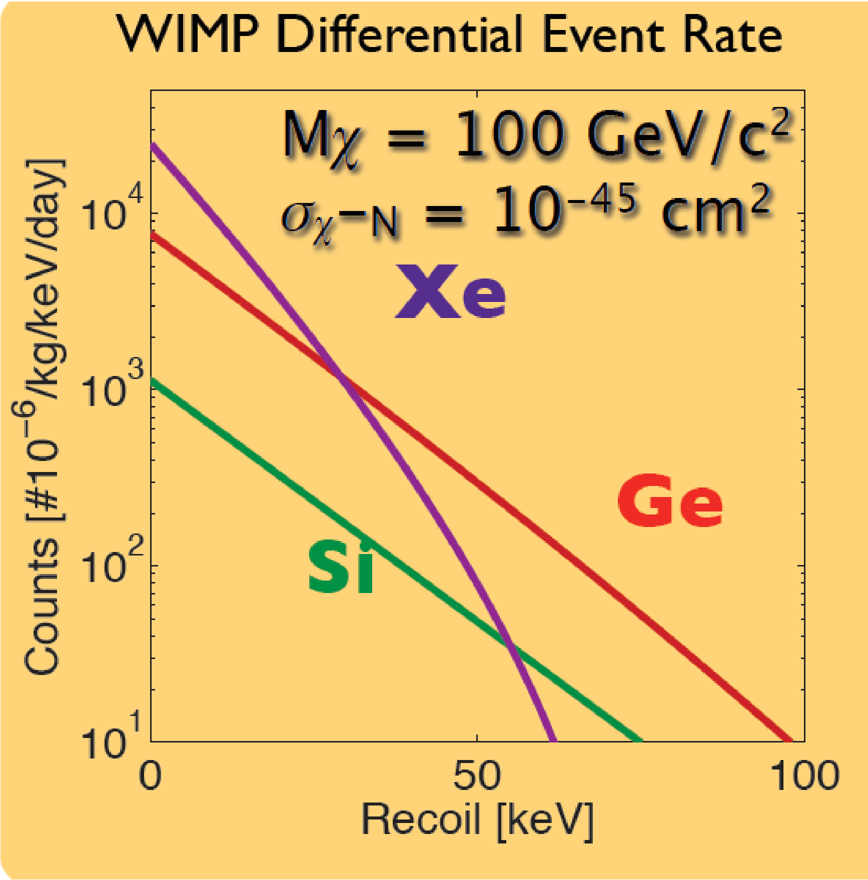
Nucleus	Z	Odd Nucleon	J	$\langle S_p \rangle$	$\langle S_n \rangle$	C_A^p/C_p	C_A^n/C_n
^{19}F	9	p	1/2	0.477	-0.004	9.10×10^{-1}	6.40×10^{-5}
^{23}Na	11	p	3/2	0.248	0.020	1.37×10^{-1}	8.89×10^{-4}
^{27}Al	13	p	5/2	-0.343	0.030	2.20×10^{-1}	1.68×10^{-3}
^{29}Si	14	n	1/2	-0.002	0.130	1.60×10^{-5}	6.76×10^{-2}
^{35}Cl	17	p	3/2	-0.083	0.004	1.53×10^{-2}	3.56×10^{-5}
^{39}K	19	p	3/2	-0.180	0.050	7.20×10^{-2}	5.56×10^{-3}
^{73}Ge	32	n	9/2	0.030	0.378	1.47×10^{-3}	2.33×10^{-1}
^{93}Nb	41	p	9/2	0.460	0.080	3.45×10^{-1}	1.04×10^{-2}
^{125}Te	52	n	1/2	0.001	0.287	4.00×10^{-6}	3.29×10^{-1}
^{127}I	53	p	5/2	0.309	0.075	1.78×10^{-1}	1.05×10^{-2}
^{129}Xe	54	n	1/2	0.028	0.359	3.14×10^{-3}	5.16×10^{-1}
^{131}Xe	54	n	3/2	-0.009	-0.227	1.80×10^{-4}	1.15×10^{-1}

Detector requirements

- Sensitivity to O(10 keV) nuclear recoils.

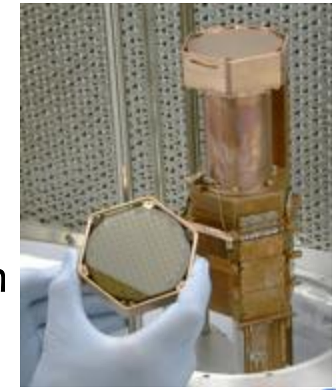
- Scalability to ton-scale.

- Discrimination against backgrounds.
    - gammas
    - betas
    - alphas
    - neutrons

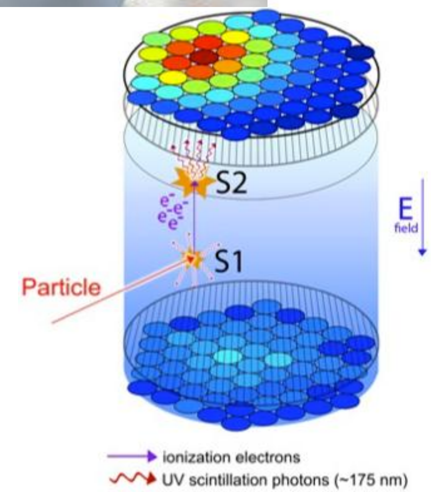


Detector Styles

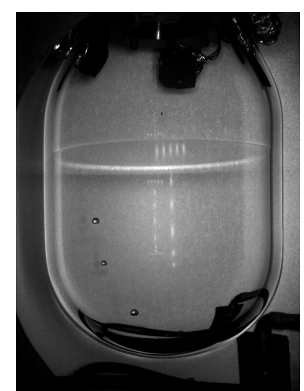
- Cryogenic
  - CDMS, EDELWEISS — Ge, phonon + chanrge
  - CRESST — $CaWO_4$, phonon + scintillation



- Liquid Noble
  - XENON, LUX, ZEPLIN — Xe, TPC (charge + scintillation)
  - XMASS — Xe, scintillation
  - Darkside — Ar, TPC (charge + scintillation)
  - DEAP/CLEAN — Ar, scintillation



- Superheated Fluid
  - COUPP — CF_3I, bubble chamber
  - PICASSO, SIMPLE — C_4F_{10}, superheated droplets



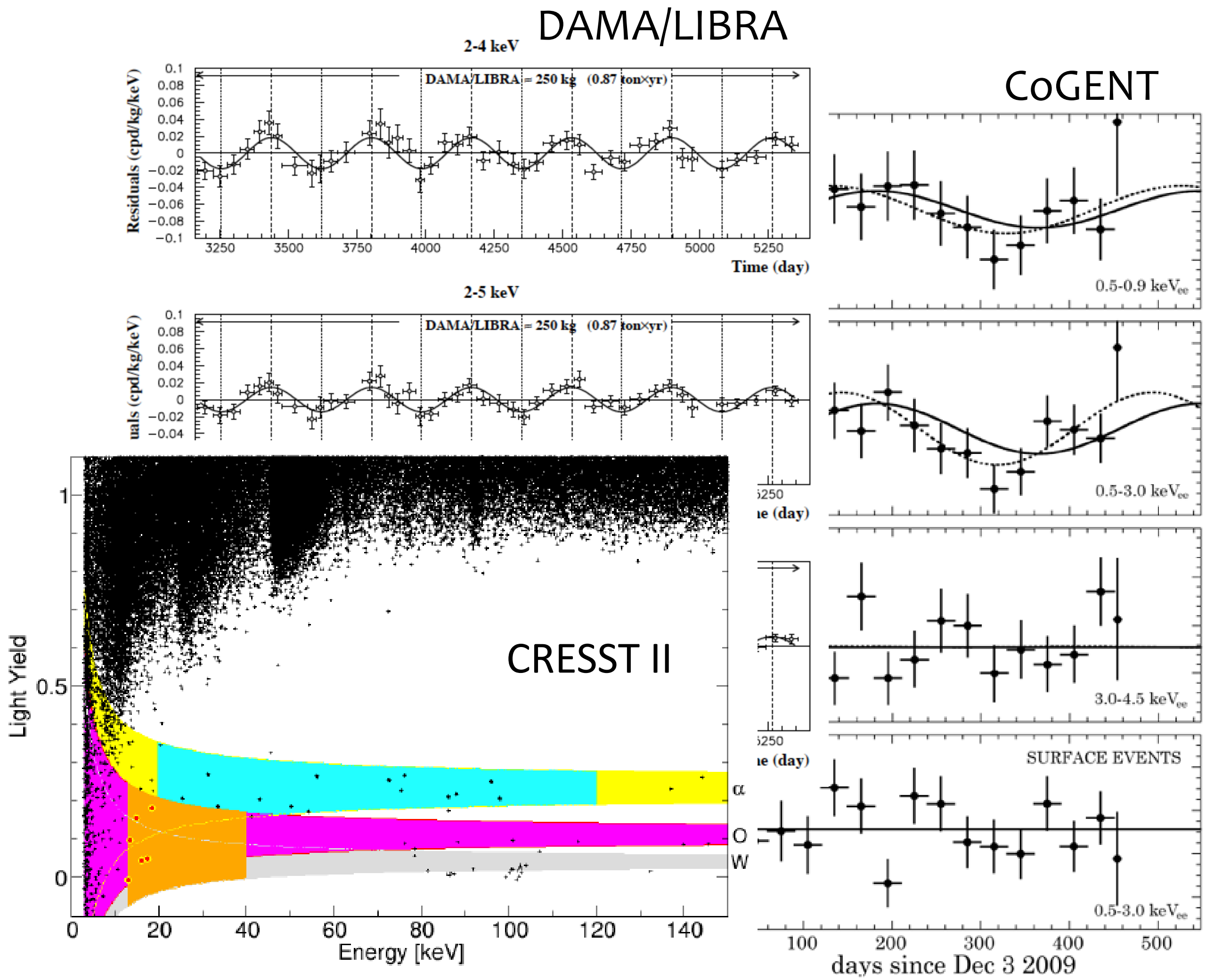
Low mass WIMPS (~10GeV)

- 2008: DAMA/LIBRA reports an annual modulation in event rate consistent with dark matter (8.9σ)

- 2010/11: CoGeNT reports an excess of low-energy events, and an annual modulation, only ~2σ significance

- 2012: CRESST-II reports a 4.2σ excess of low-energy events

- All claims controversial and excluded by other experiments (eg XENON10, XENON100, CDMS II)



The Chicagoland Observatory for Underground Particle Physics

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Indiana University South Bend: E. Behnke, J. Behnke, T. Benjamin, A. Connor, C. Harnish, E. Grace Kuehnemund, I. Levine, T. Moan, T. Nania

Fermilab: S. Brice, D. Broemmelsiek, P. Cooper, M. Crisler, J. Hall, W.H. Lippincott, E. Ramberg, A. Sonnenschein

Northwestern: C.E. Dahl

SNOLAB: E. Vazquez Jauregui

Virginia Tech: D. Maurya, S. Priya

U. Politecnica de Valencia: M. Ardid, M. Bou-Cabo

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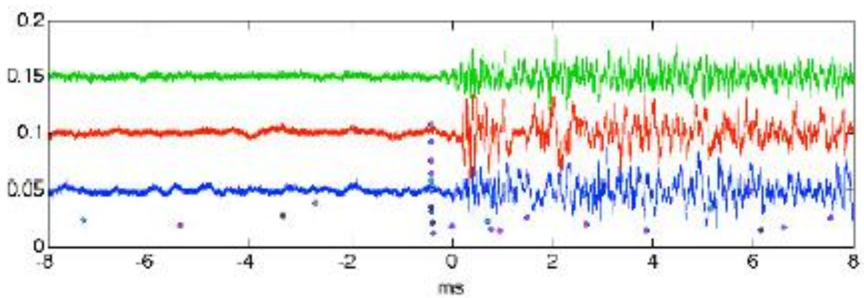
Fermilab

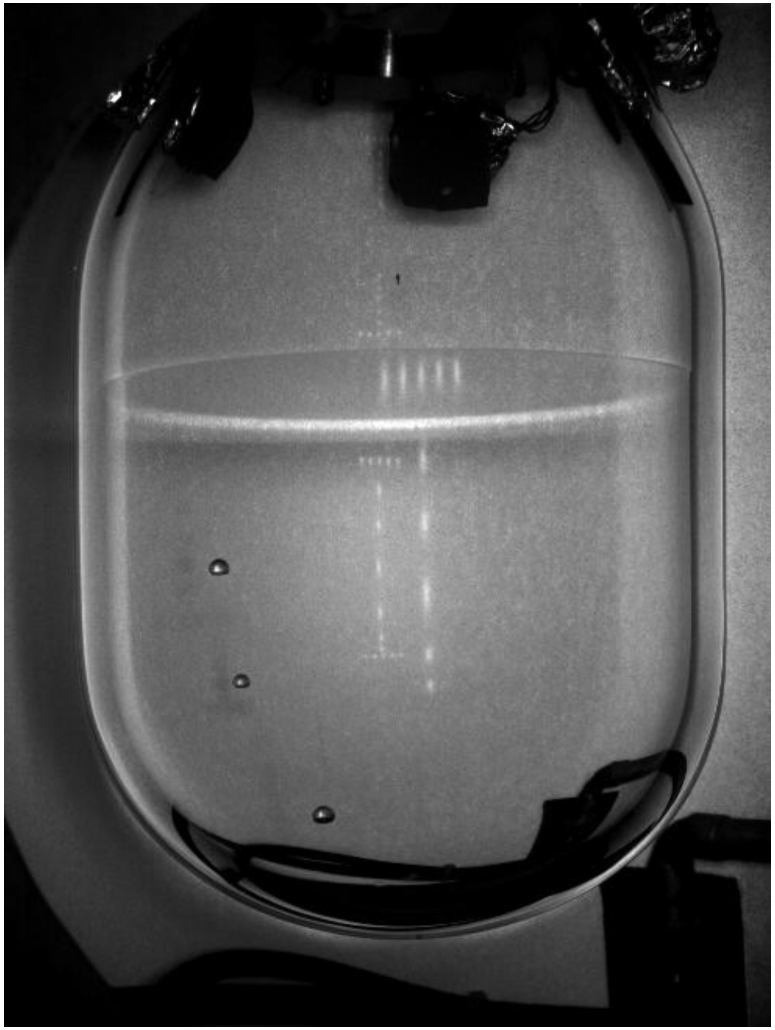
SNOLAB MINING FOR KNOWLEDGE CREUSER POUR TROUVER... L'EXCELLENCE

COUPP bubble chambers

- Superheated fluid CF_3I
  - F for spin dependent
  - I for spin independent
  - Other fluids, eg C_3F_8 offer complementary sensitivity.

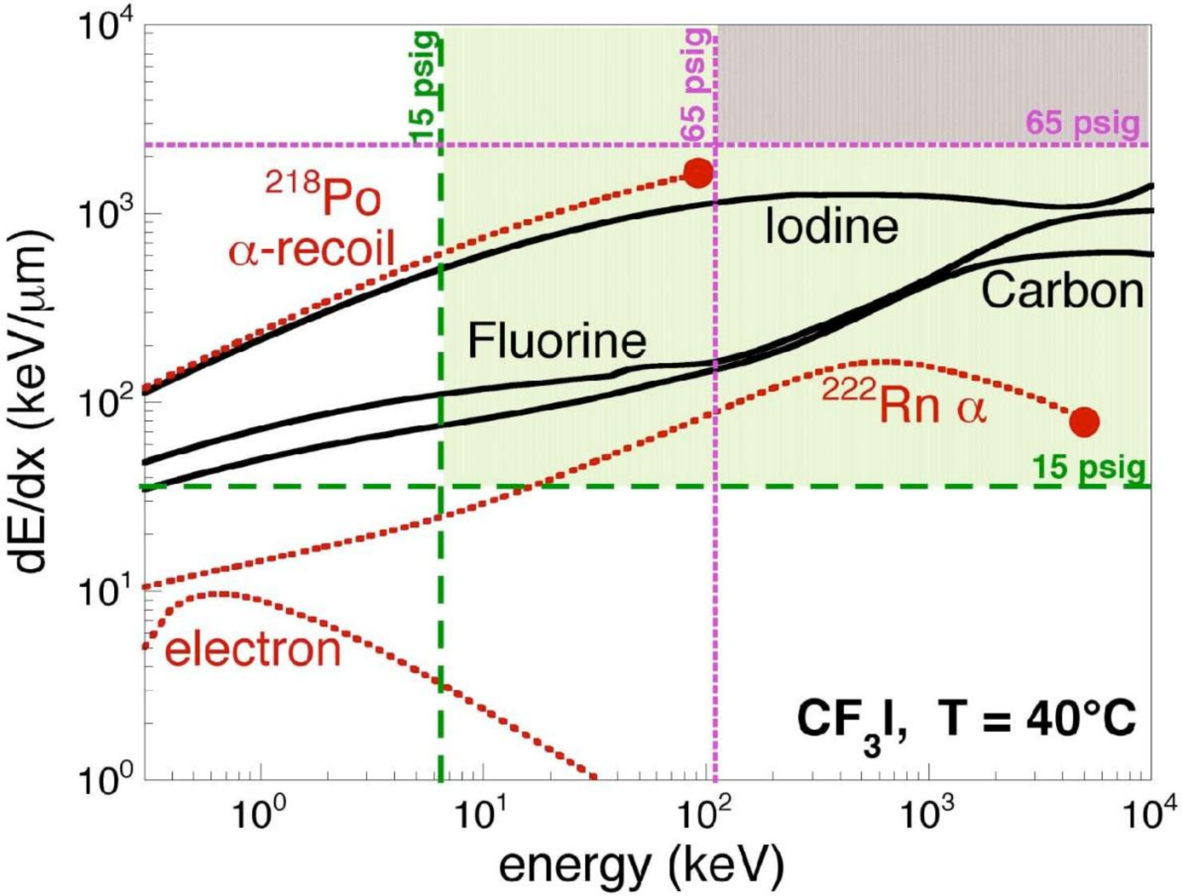
- Observe bubbles with two cameras and piezo-acoustic sensors.





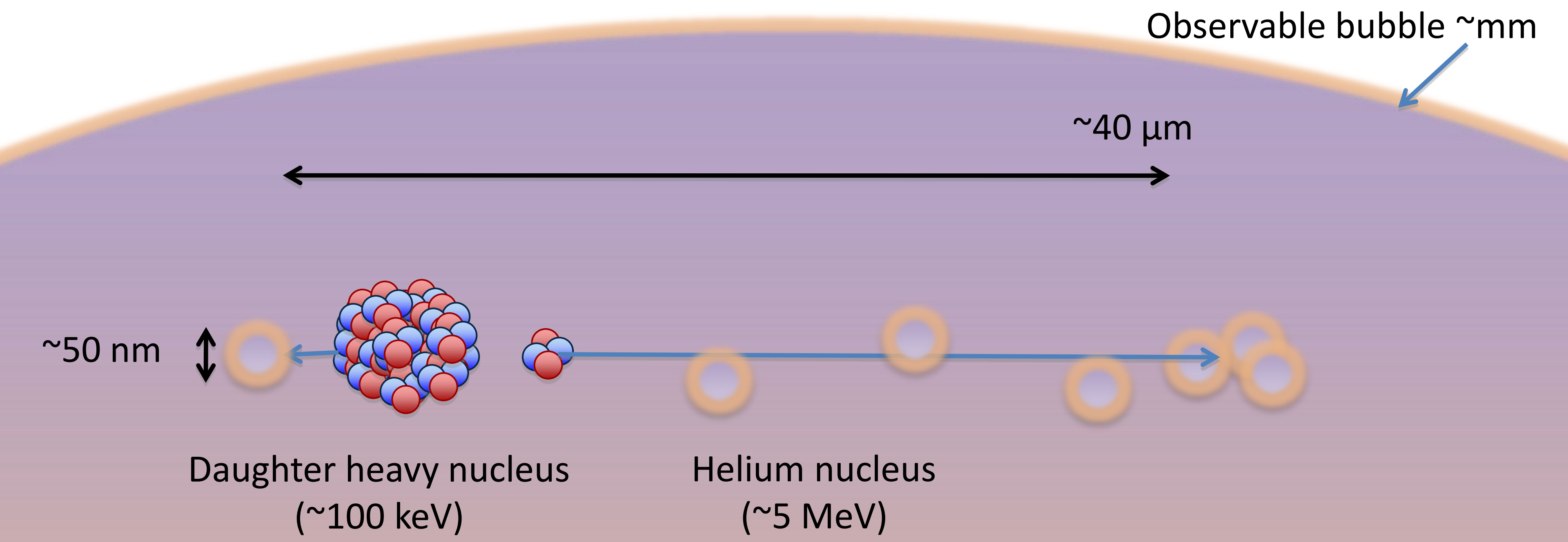
Why bubble chambers?

- Only proto-bubbles with $r > r_{crit}$ grow to be macroscopic
- Better than 10^{-10} rejection of electron recoils (betas, gammas).
- Alphas are (were) a concern because bubble chambers are threshold detectors.



Acoustic discrimination

- Discovery of acoustic discrimination against alphas (Aubin et al., New J. Phys.10:103017, 2008)
  - Alphas deposit their energy over tens of microns.
  - Nuclear recoils deposit theirs over tens of nanometers.
- In COUPP bubble chambers alphas are several times louder.

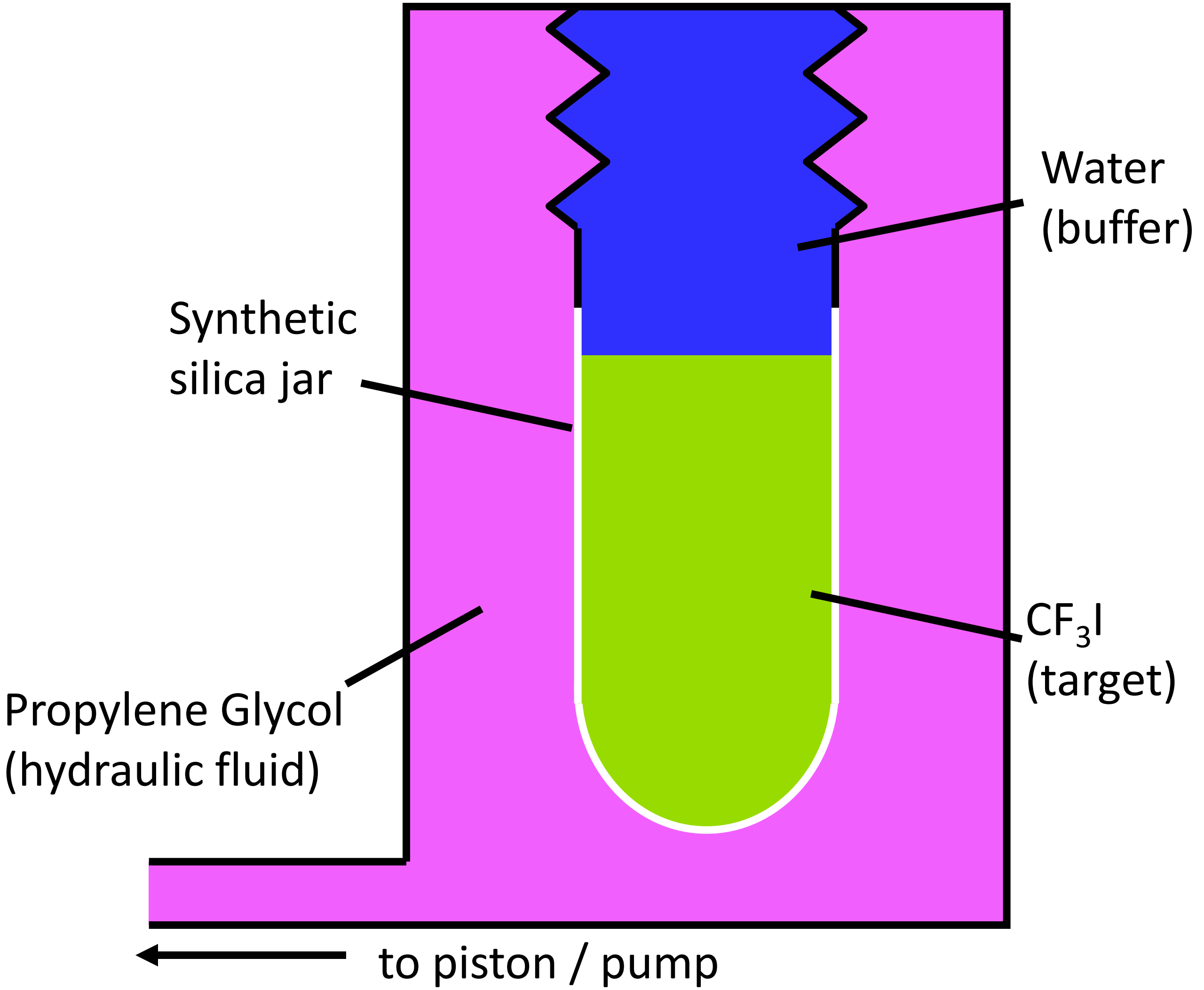


Bubble chamber operation

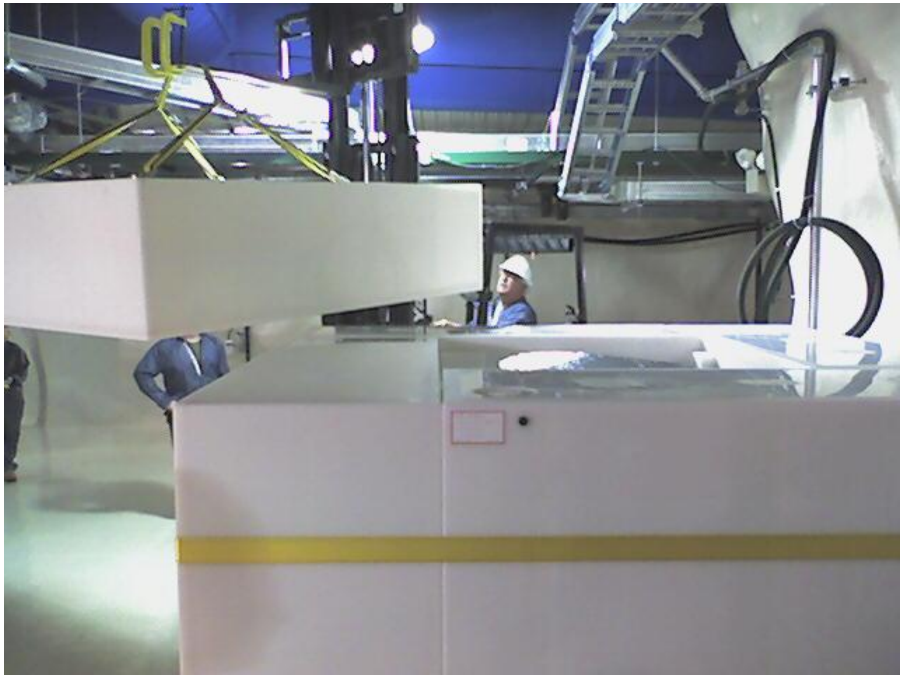
- Expand the chamber to the superheated state (10sec).

- Cameras see the bubble
  - Trigger
  - Stereoscopic position information

- Recompress the chamber (100msec) and wait 30sec after every bubble.



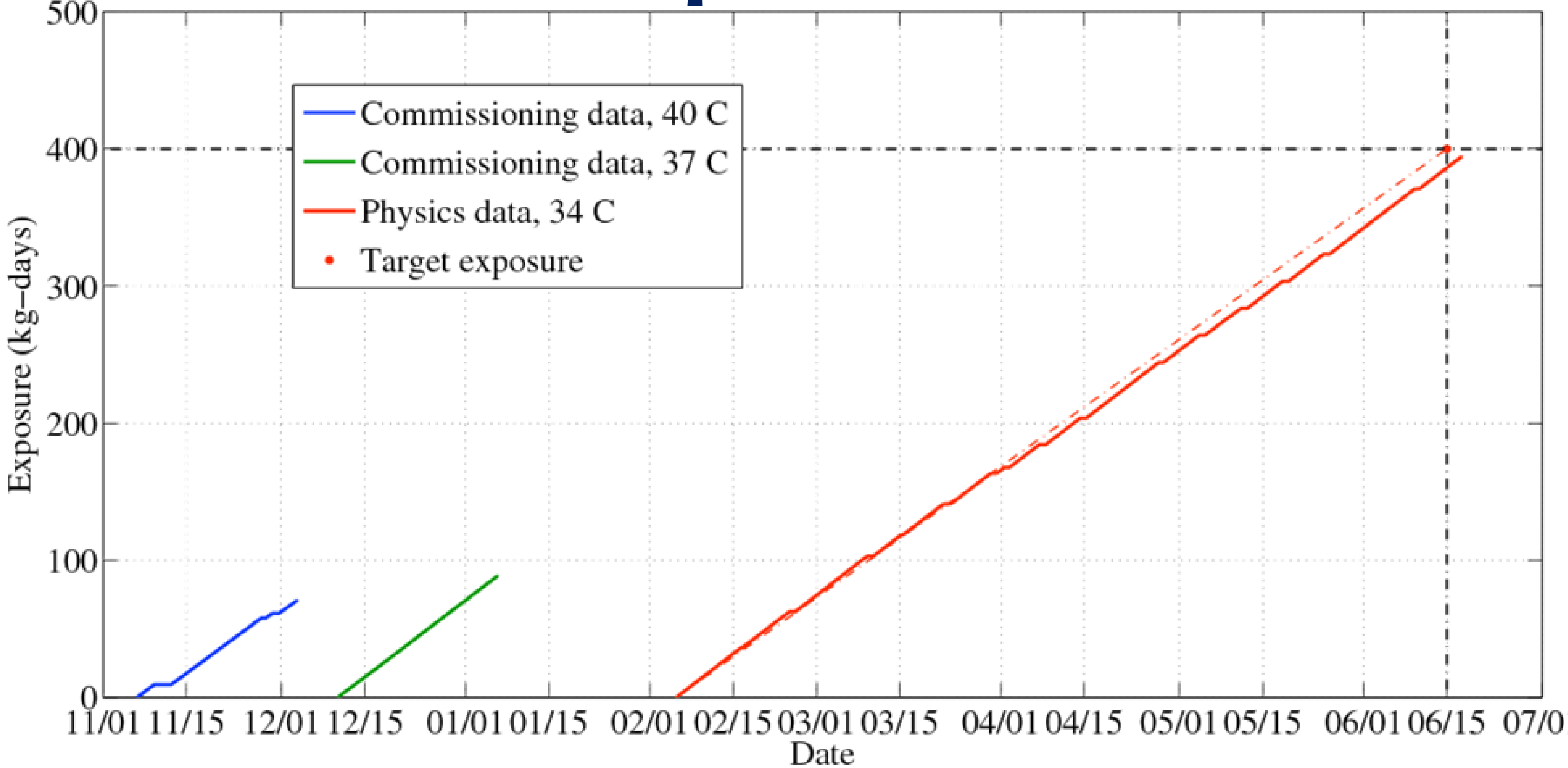
COUPP-4 at SNOLAB



SNOLAB: 2.1km underground near Sudbury, Ontario

COUPP-4 ran 2010-2011

Exposure

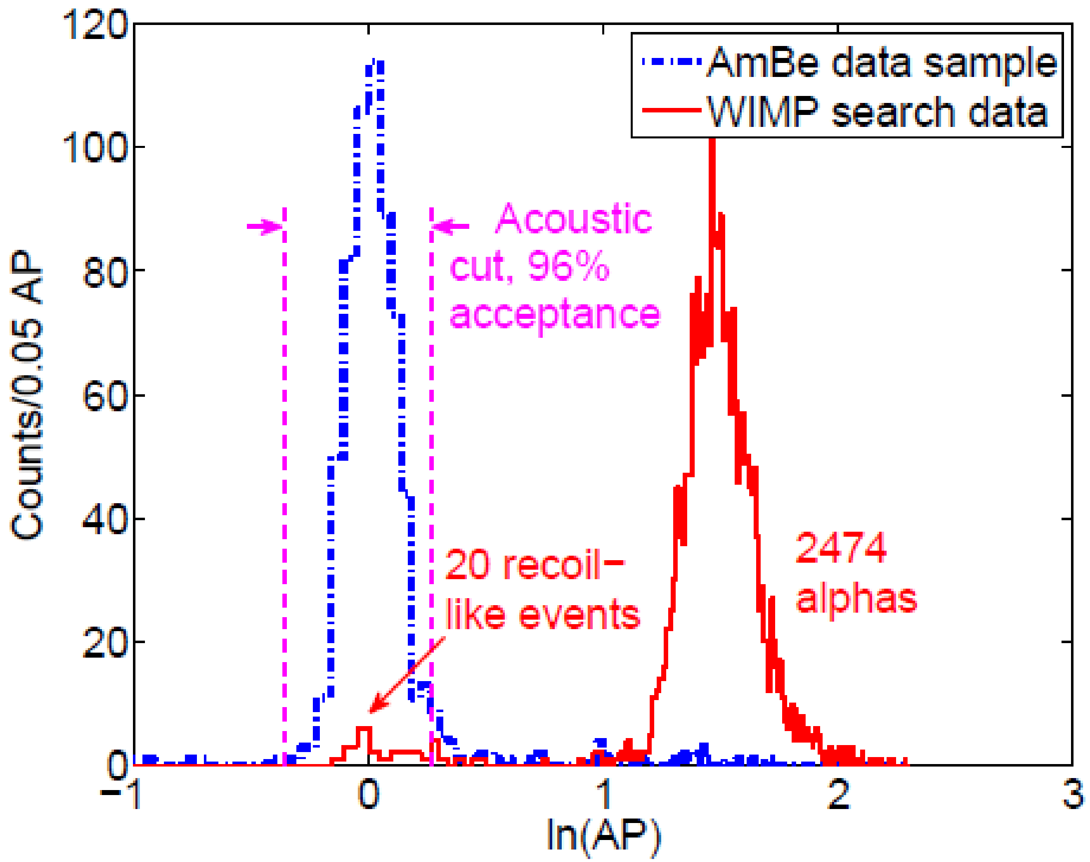


- 17.4, 21.9, 97.3 live-days at 8, 11, 16 keV thresholds
- 4.048 kg target, 79% cut-efficiency for nuclear recoils

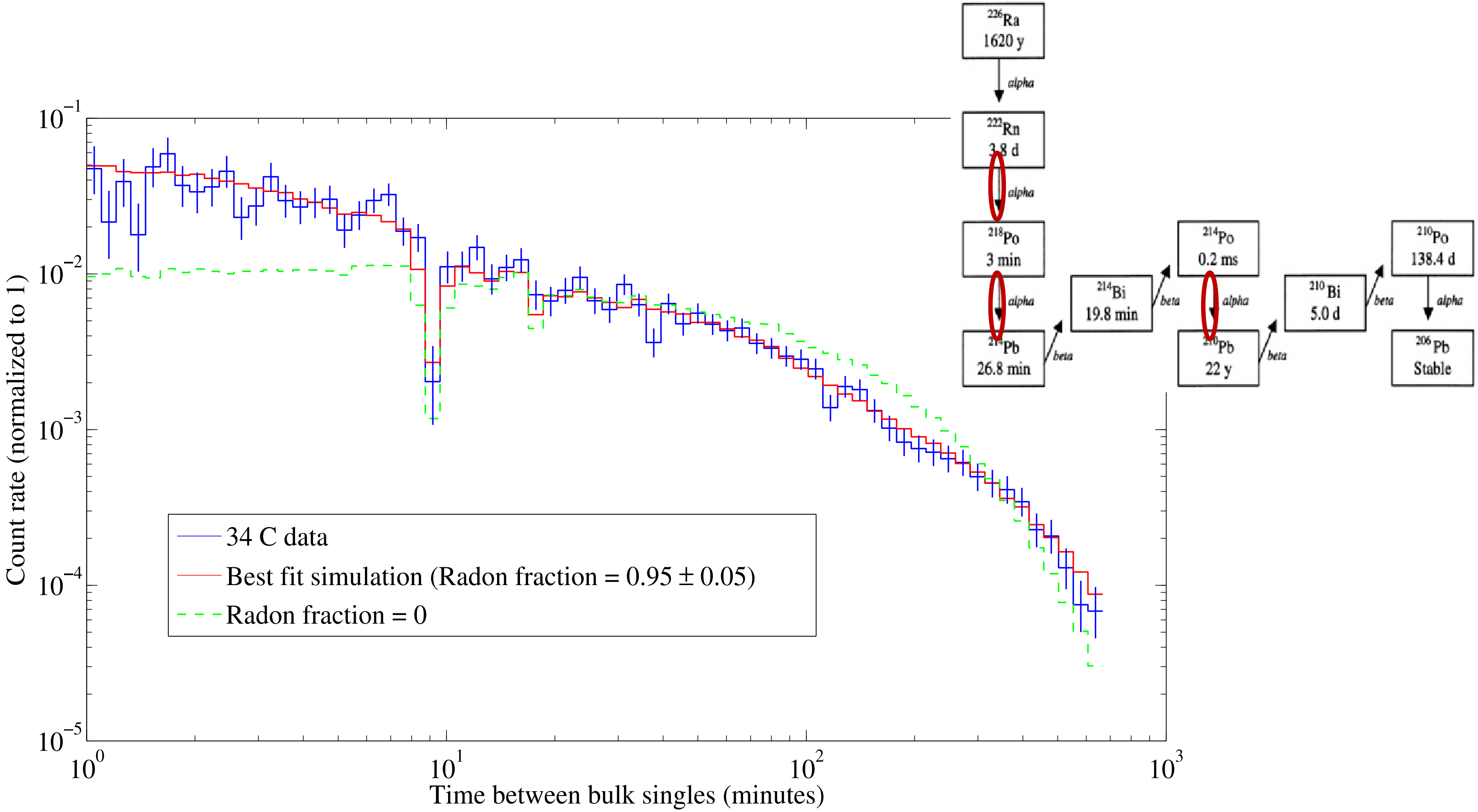
Alpha rejection

- Better than 98.9% rejection against alphas with all data sets.

- Better than 99.3% rejection at 16keV threshold.



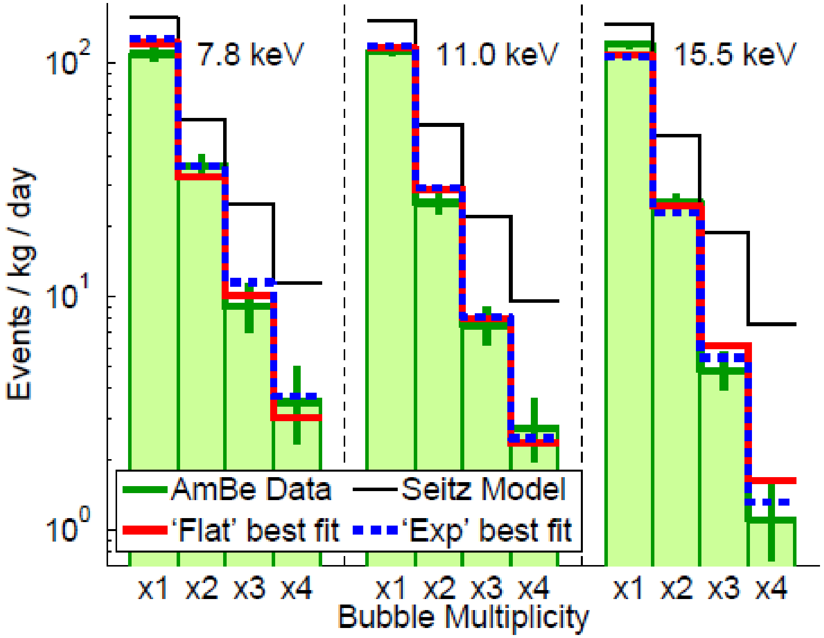
Alpha timing (radon)

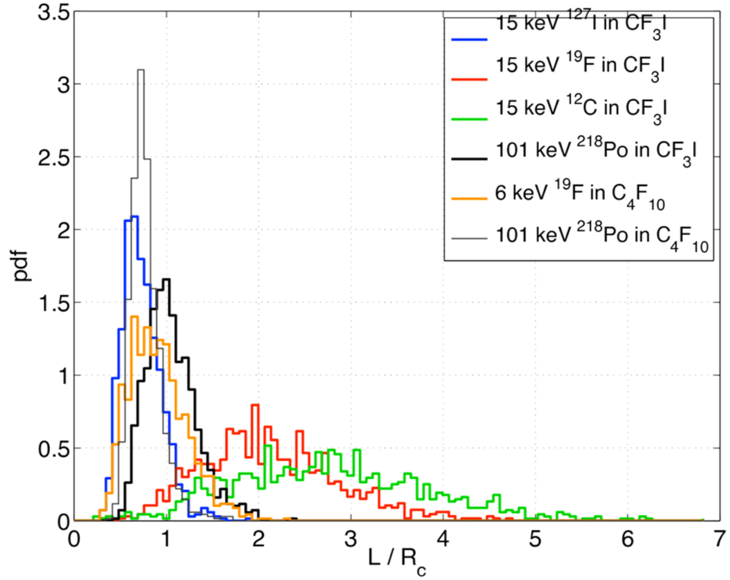


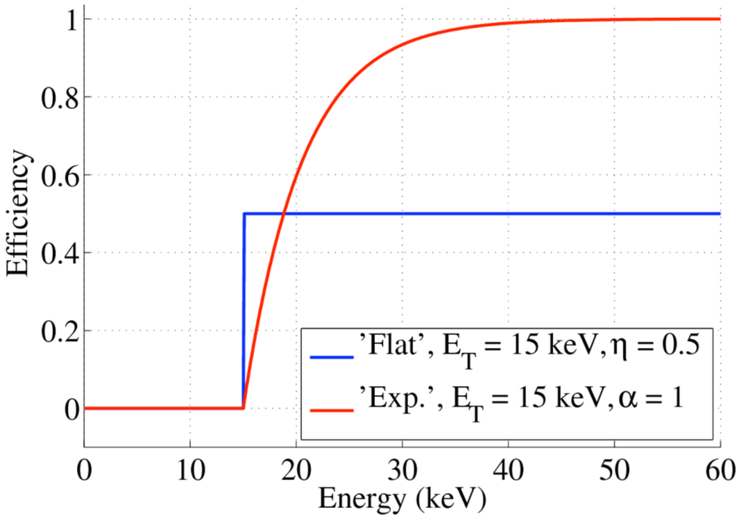
Neutron calibrations

•Threshold is determined using Seitz 'Hot Spike'Model, Phys. Fluids 1, 2 (1958).

•Checked with neutron sources (AmBe, ^{252}Cf) employed regularly during the run.







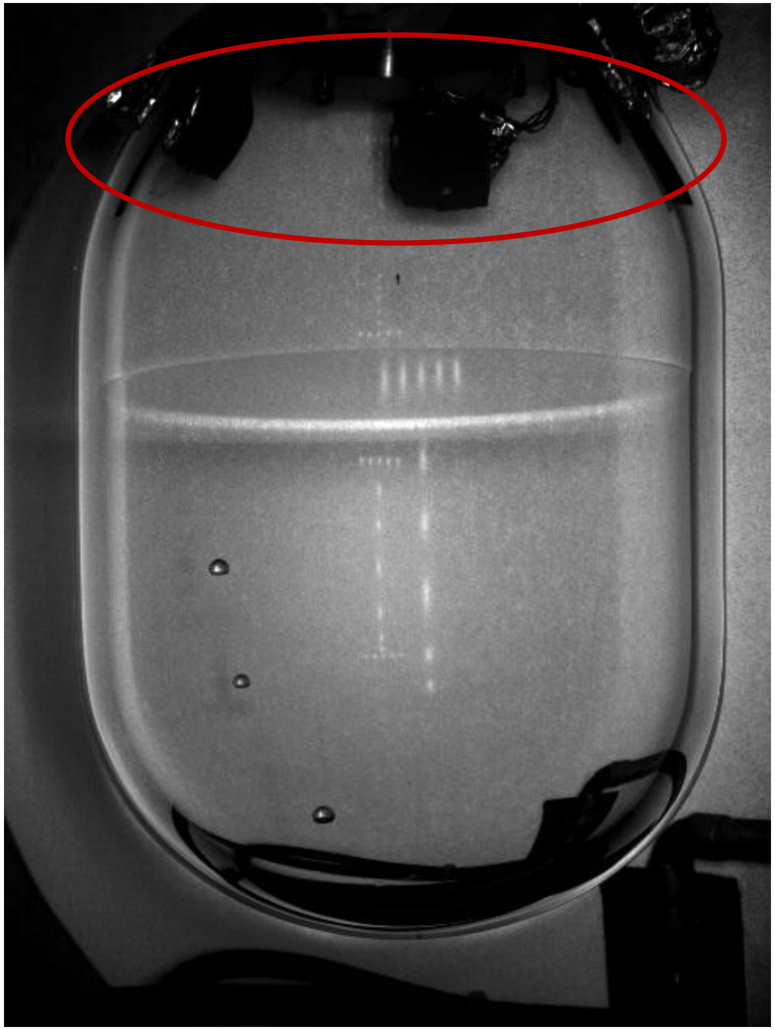
COUPP-4 results

- 20 WIMP candidates
  - 8 at 8keV
  - 6 at 11keV
  - 8 at 16keV

- 3 multiple bubble events → **neutrons**

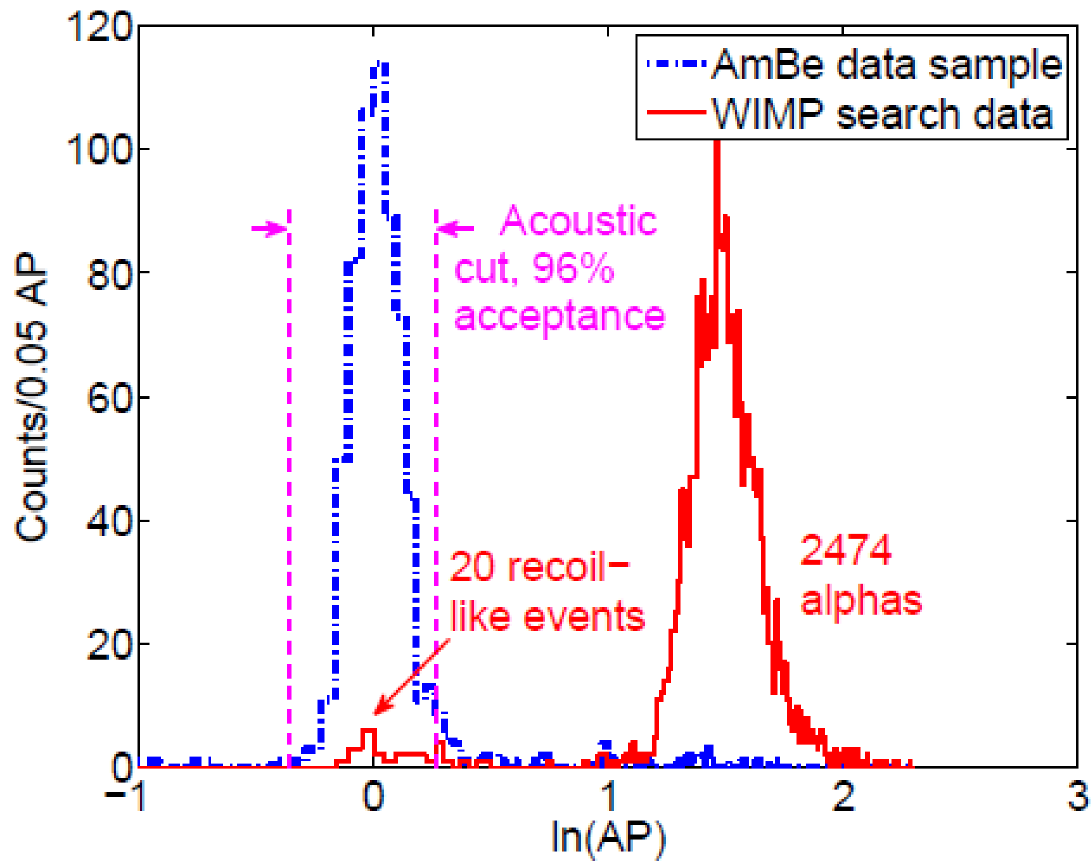
- 5 expected neutron events from U, Th (α,n) in piezo-acoustic sensors and viewport windows.

- Events at low threshold in particular are inconsistent with WIMPs
  - events show clustering in time (e.g. 3 in 3 hours, 4 in 9 hours)
  - events are not consistent with neutron AP distribution
  - events are correlated with activity at the water/CF_3I boundary



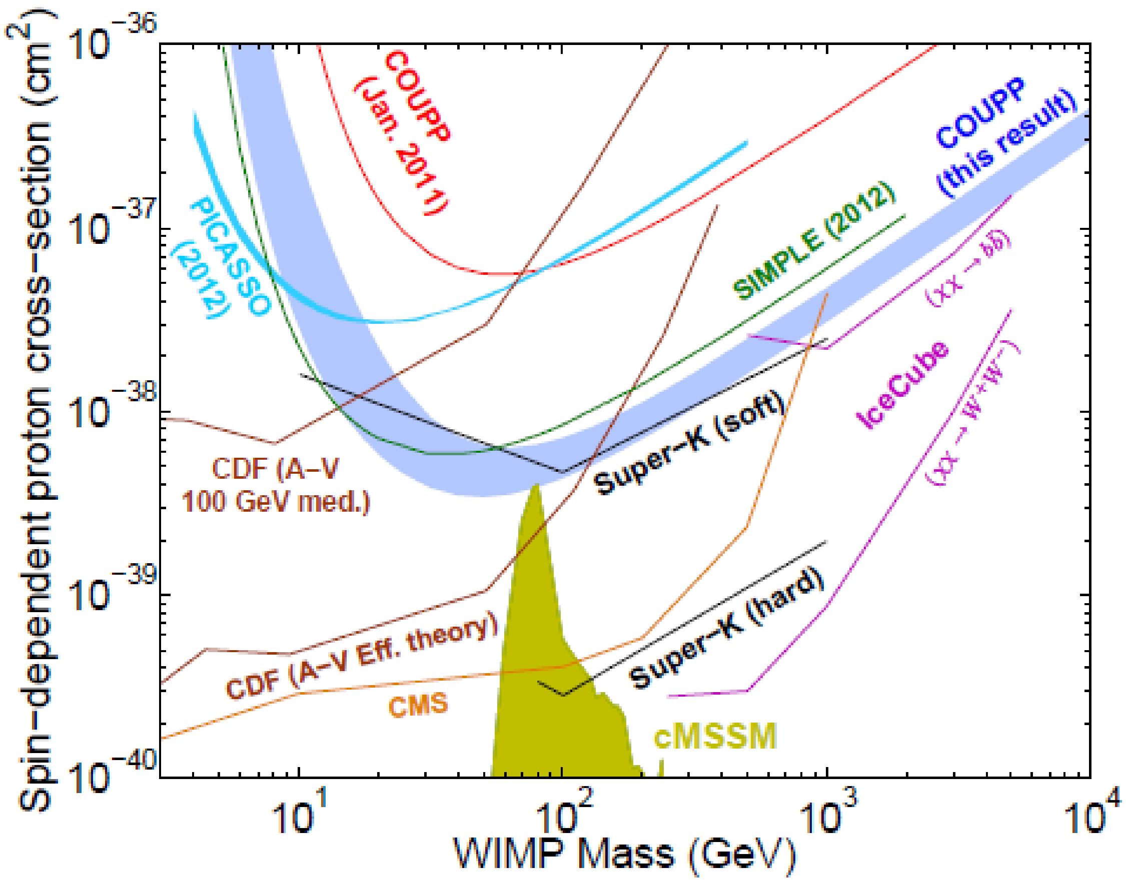
COUPP-4 results

Combined data from all three thresholds.

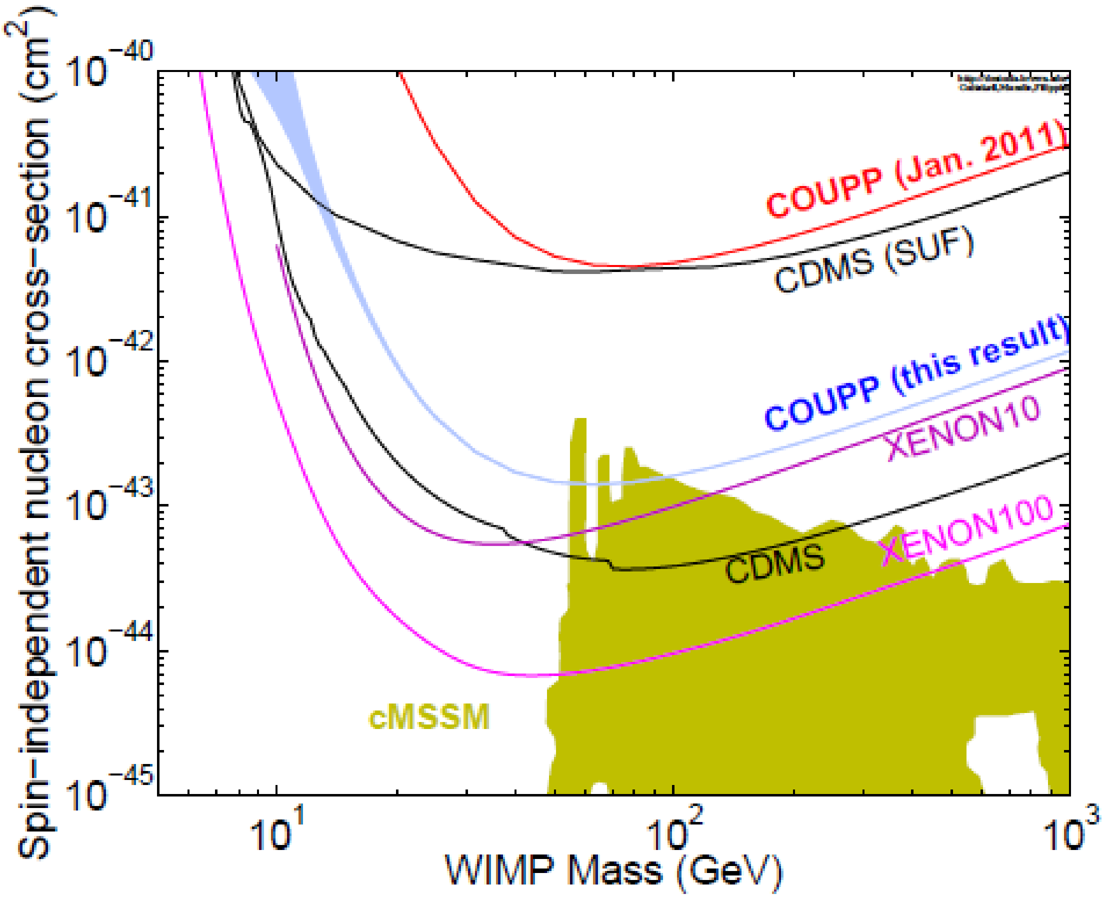


Spin-dependent limits

•Given uncertainties on background predictions, we do no background subtraction, arxiv:1204.3094

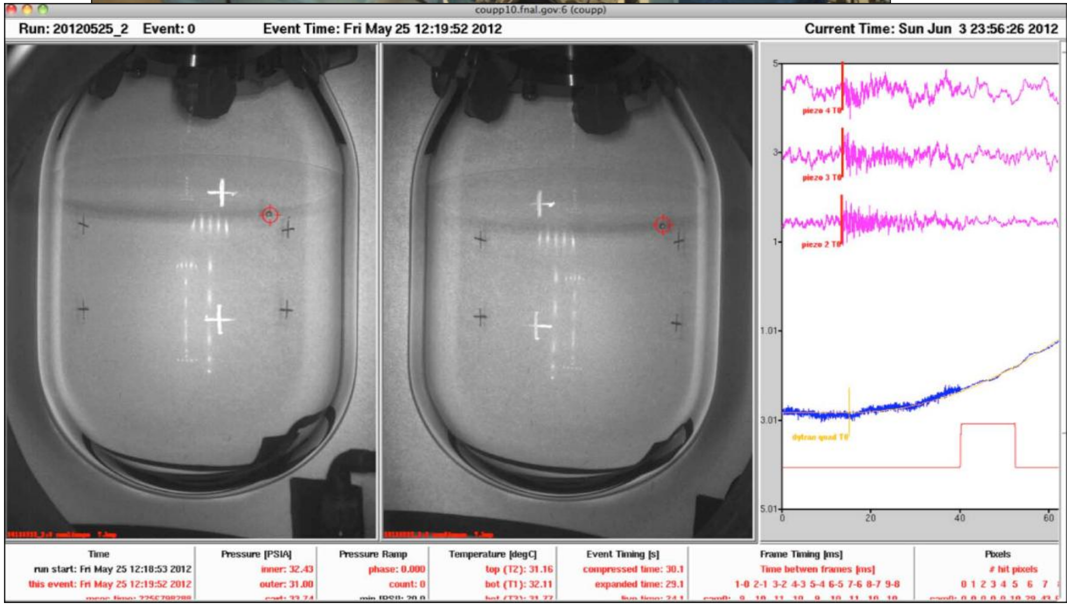


Spin-independent limits



COUPP-4 new run

- COUPP-4 re-installed at SNOLAB in May 2012.
- Piezo-acoustic sensors and viewport windows replaced with certified low-background parts.
- Higher purity CF_3I.
- Results in a few months.

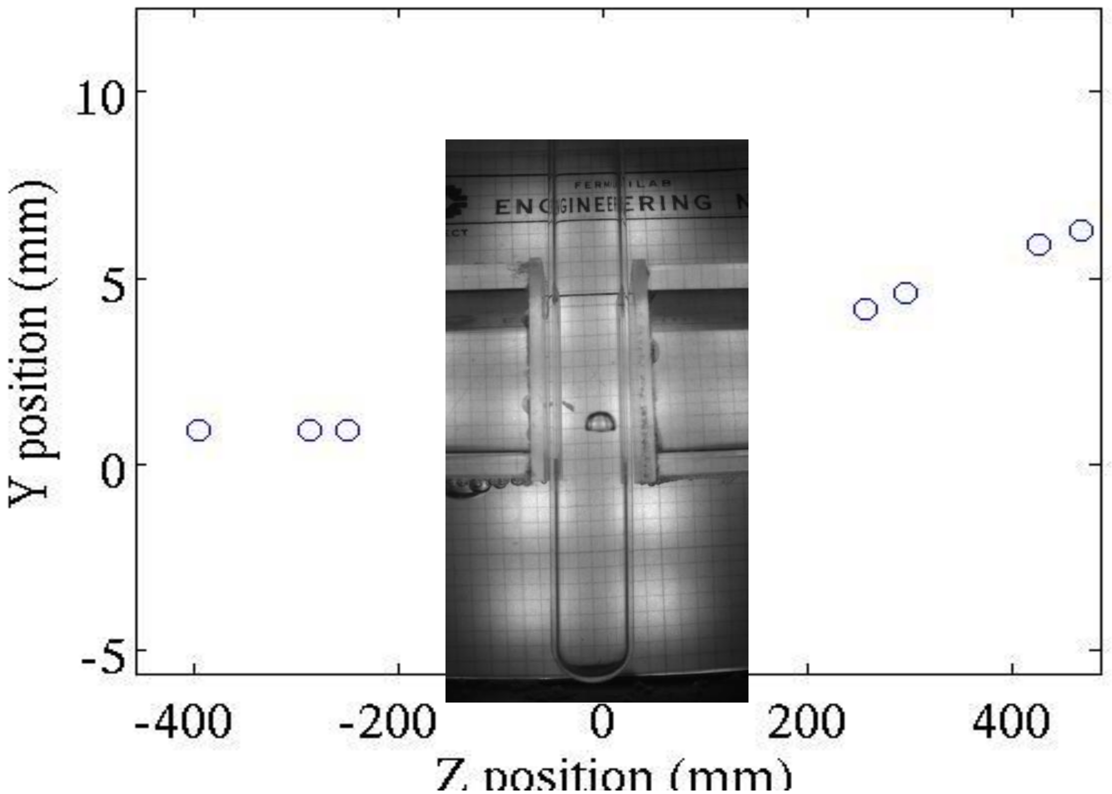


Threshold/efficiency calibrations

• Pion-scattering experiment at Fermilab test beam to measure threshold and efficiency on iodine directly.

• Low, mono-energetic YBe neutron source to attack carbon and fluorine.

• Neutron beam measurements at Notre Dame.



• 12GeV pion beam with silicon pixel telescope to measure scattering angle.
• Example event: 10mrad scatter, 56keV Iodine recoil.

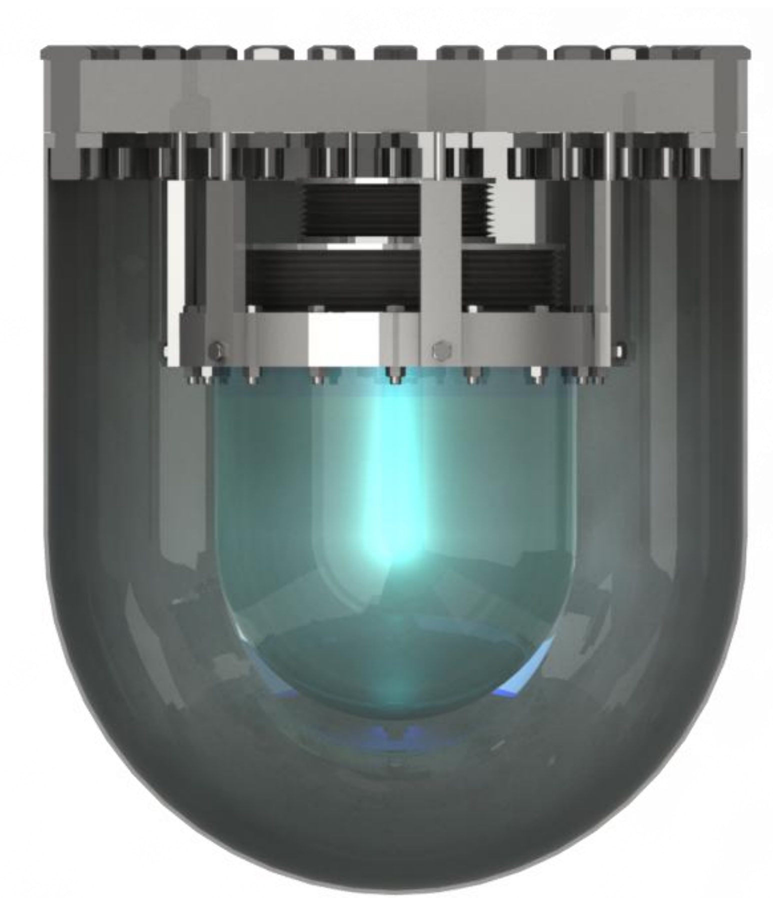
COUPP 60

•COUPP-60 ran at shallow site in 2010-2011.

•Being installed at SNOLAB.

•Data taking begins in a few months.

COUPP 500



- COUPP-500 engineering and background studies under way.
- Construction 2014-2015.
- Data taking in ~2016.

Sensitivity projections