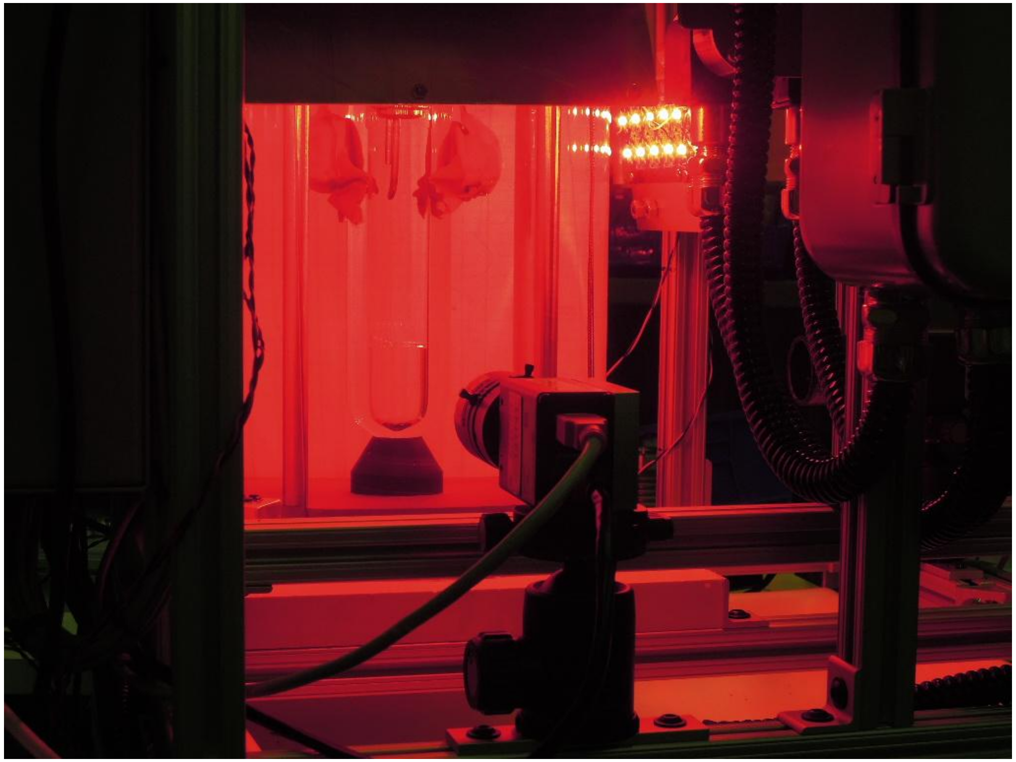
COUPP

Bubble chambers for Dark Matter detection

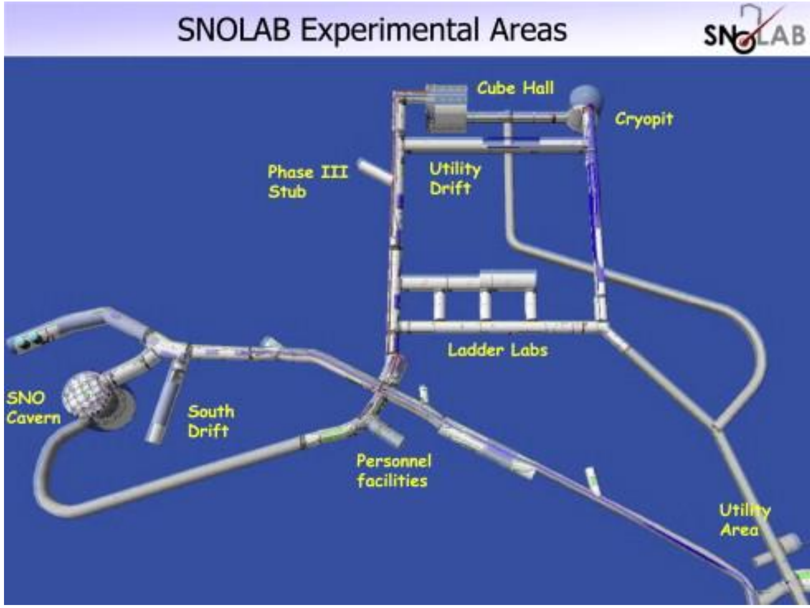


Russell Neilson, University of Chicago

Aspen Winter Conferences
Closing in on Dark Matter
Jan 28th - Feb 3rd 2013

The Chicagoland Observatory for Underground Particle Physics

University of Chicago: J. Collar, R. Neilson, A. Robinson
Indiana University South Bend: E. Behnke, T. Benjamin, E. Grace, C. Harnish, I. Levine, T. Nania
Fermilab: S. Brice, D. Broemmelsiek, P. Cooper, M. Crisler, J. Hall, W.H. Lippincott, E. Ramberg, A. Sonnenschein
PNNL: D. Asner, J. Ely, J. Hall, E. Hoppe, T. Hossbach, D. Jordan, M. Kos, H. Miley
Northwestern University: C.E. Dahl
SNOLAB: E. Vazquez Jauregui
U. Politecnica de Valencia: M. Ardid, M. Bou-Cabo
Virginia Tech: D. Maurya, S. Priya



Two new institutions in the last few months and we are also in the process of merging with the PICASSO collaboration.

Particle detection with bubble chambers

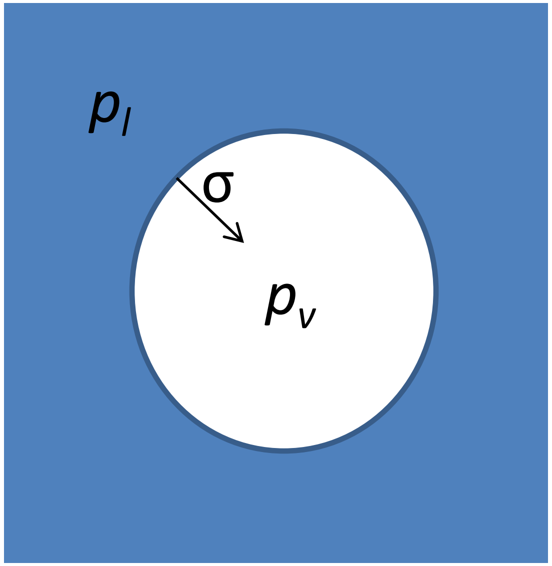
- A bubble chamber is filled a superheated fluid in meta-stable state.
- Energy deposition greater than E_{th} in radius less than r_c from particle interaction will result in expanding bubble *(Seitz "Hot-Spike" Model).*
- A smaller or more diffuse energy deposit will create a bubble that immediately collapses.
- Classical Thermodynamics says-

$$p_v - p_l = \frac{2\sigma}{r_c}$$

$$E_{th} = 4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right) + \frac{4}{3}\pi r_c^3 \rho_v h$$

Surface energy

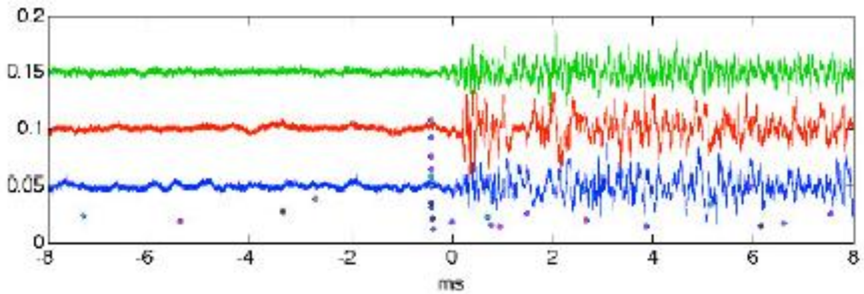
Latent heat

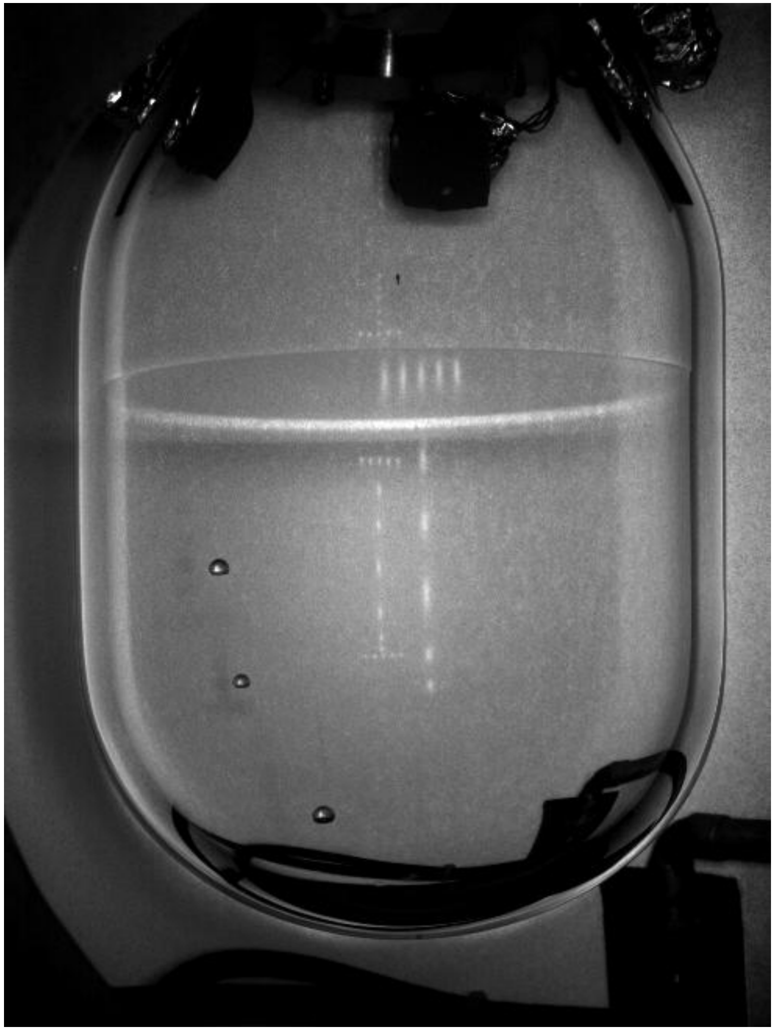


COUPP bubble chambers

- Superheated fluid CF_3I
  - F for spin dependent
  - I for spin independent

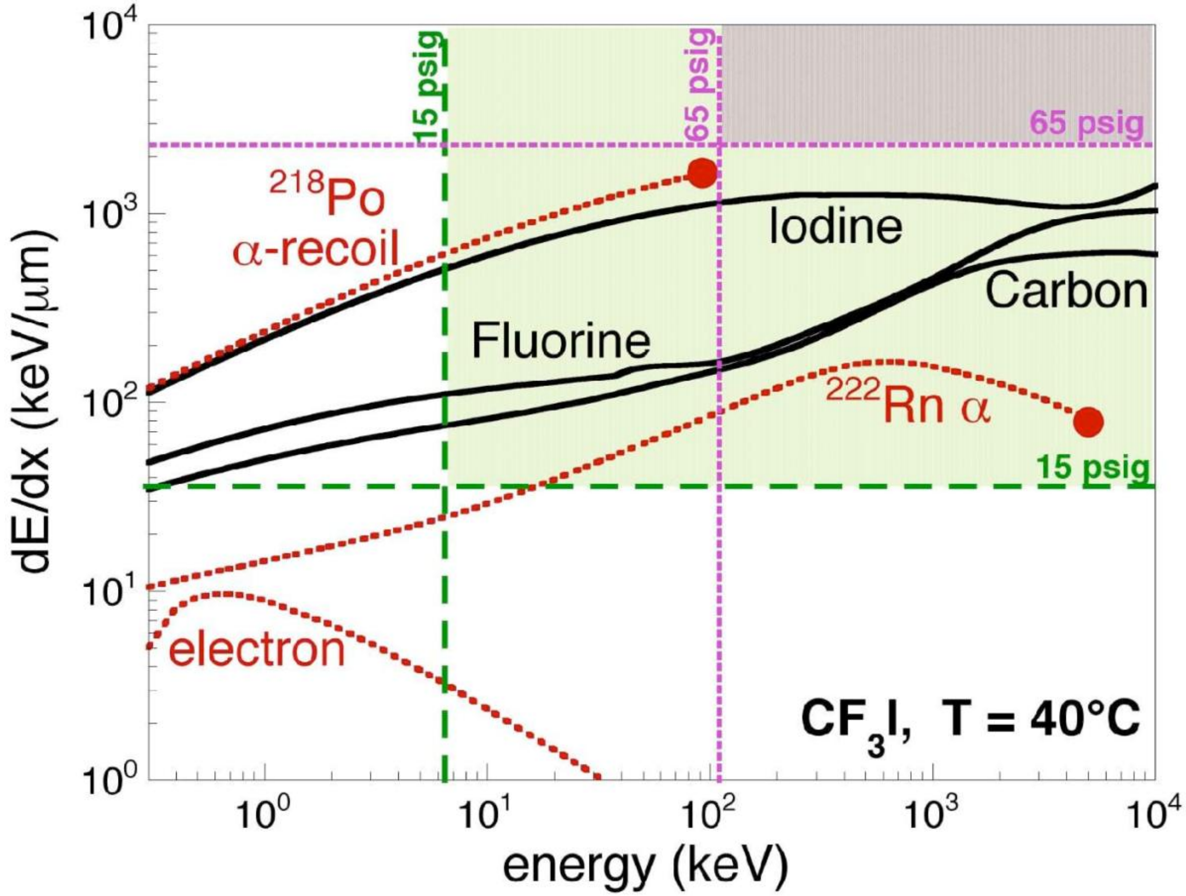
- Observe bubbles with two cameras and piezo-acoustic sensors.



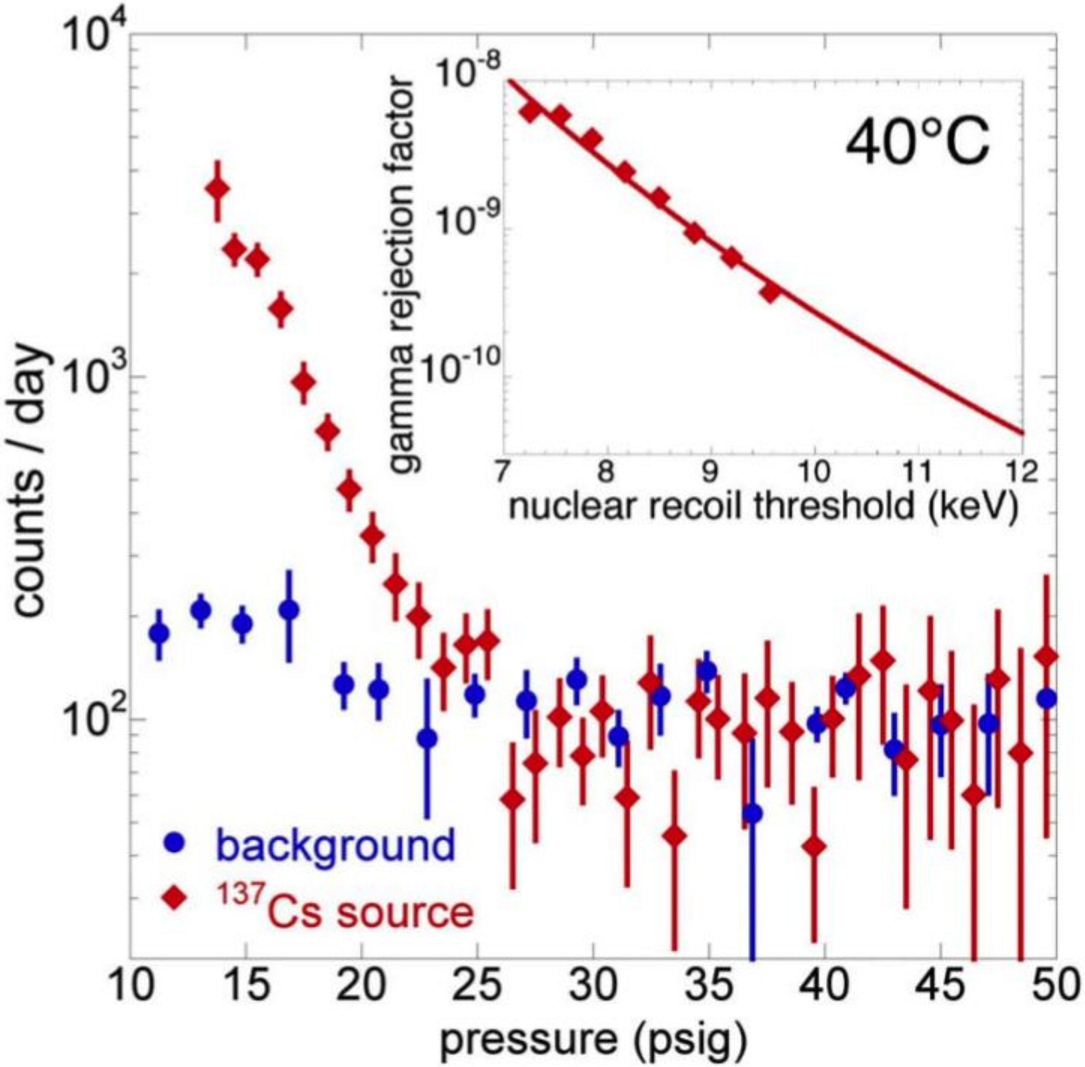


Bubble chambers as nuclear recoil detectors

- Thermodynamic parameters are chosen for sensitivity to nuclear recoils but not electron recoils.
- Better than 10^{-10} rejection of electron recoils (betas, gammas).
- Alphas are (were) a concern because bubble chambers are threshold detectors.



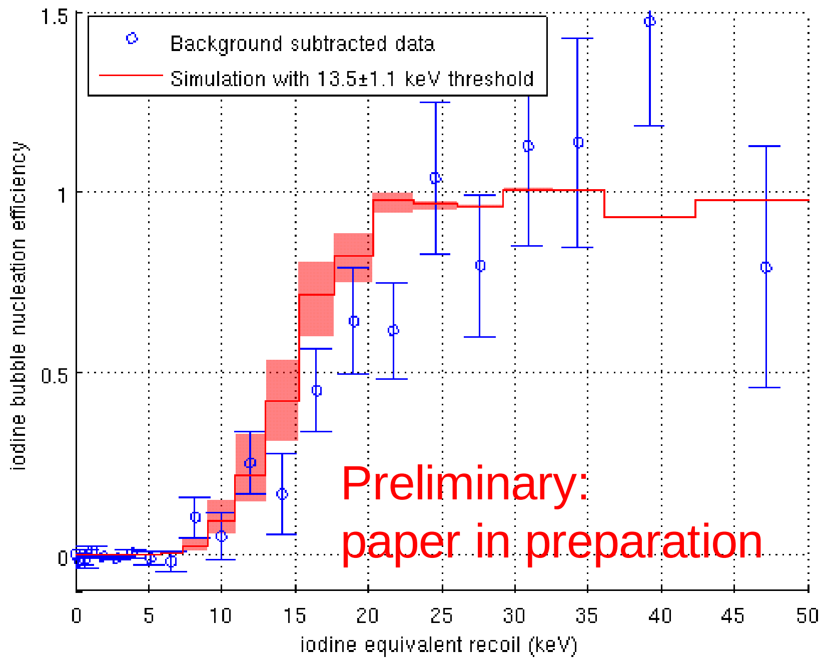
Gamma background rejection



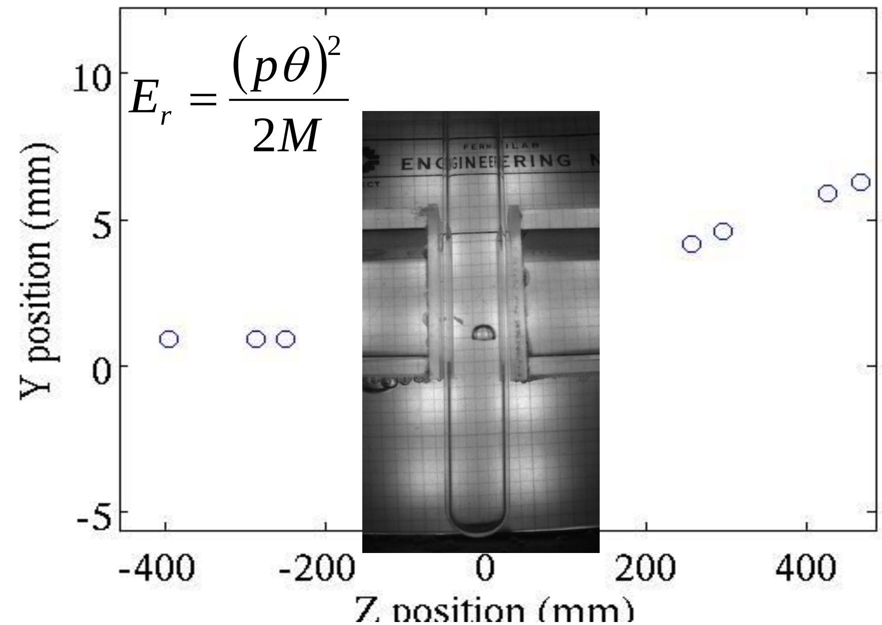
D. Fustin (PhD thesis)
University of Chicago 2012

Nuclear recoil efficiency (iodine)

- Pion-scattering calibration of iodine threshold in CF_3I.

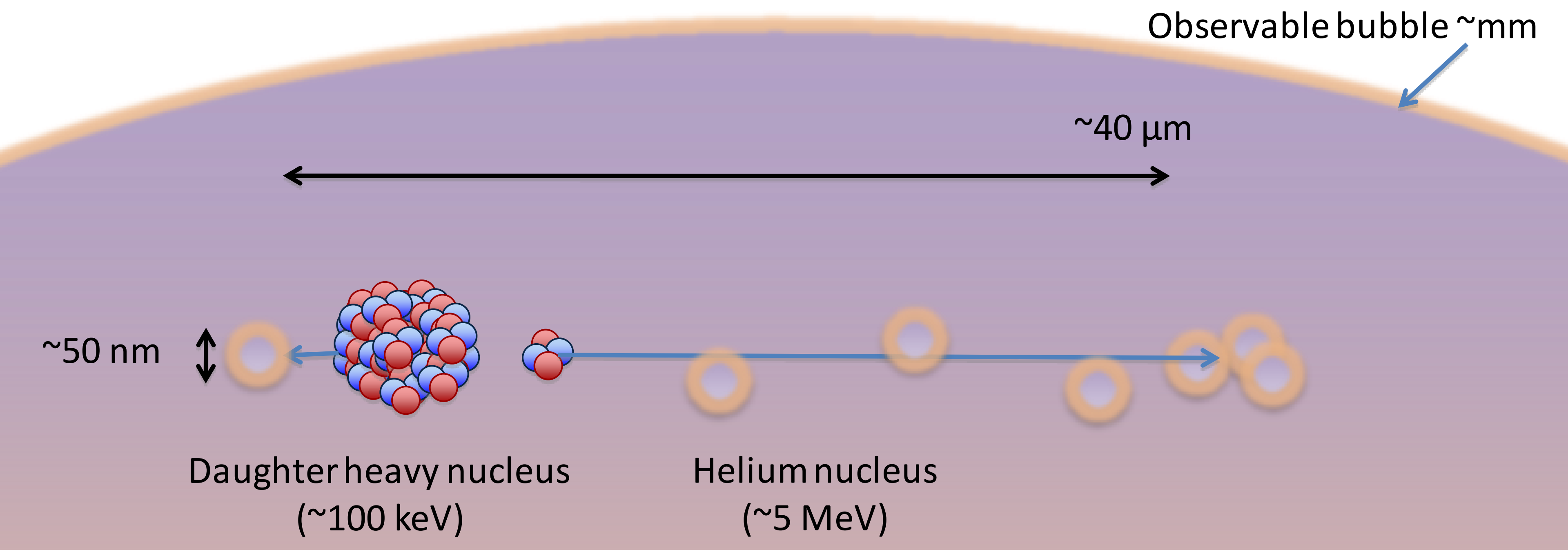


- 12GeV pion beam with silicon pixel telescope to measure scattering angle.
- Example event: 10mrad scatter, 56keV Iodine recoil.



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.

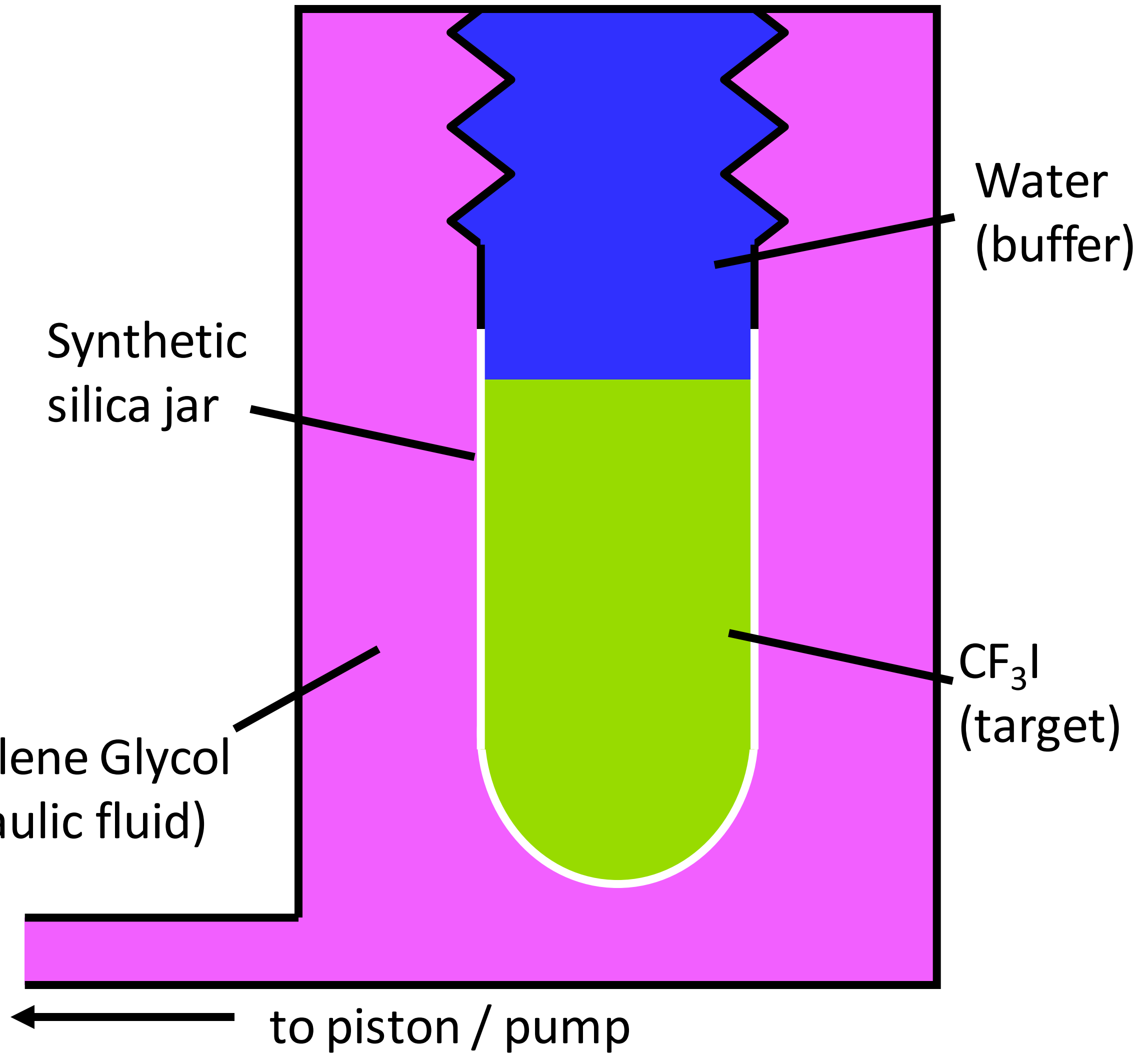


Bubble chamber operation

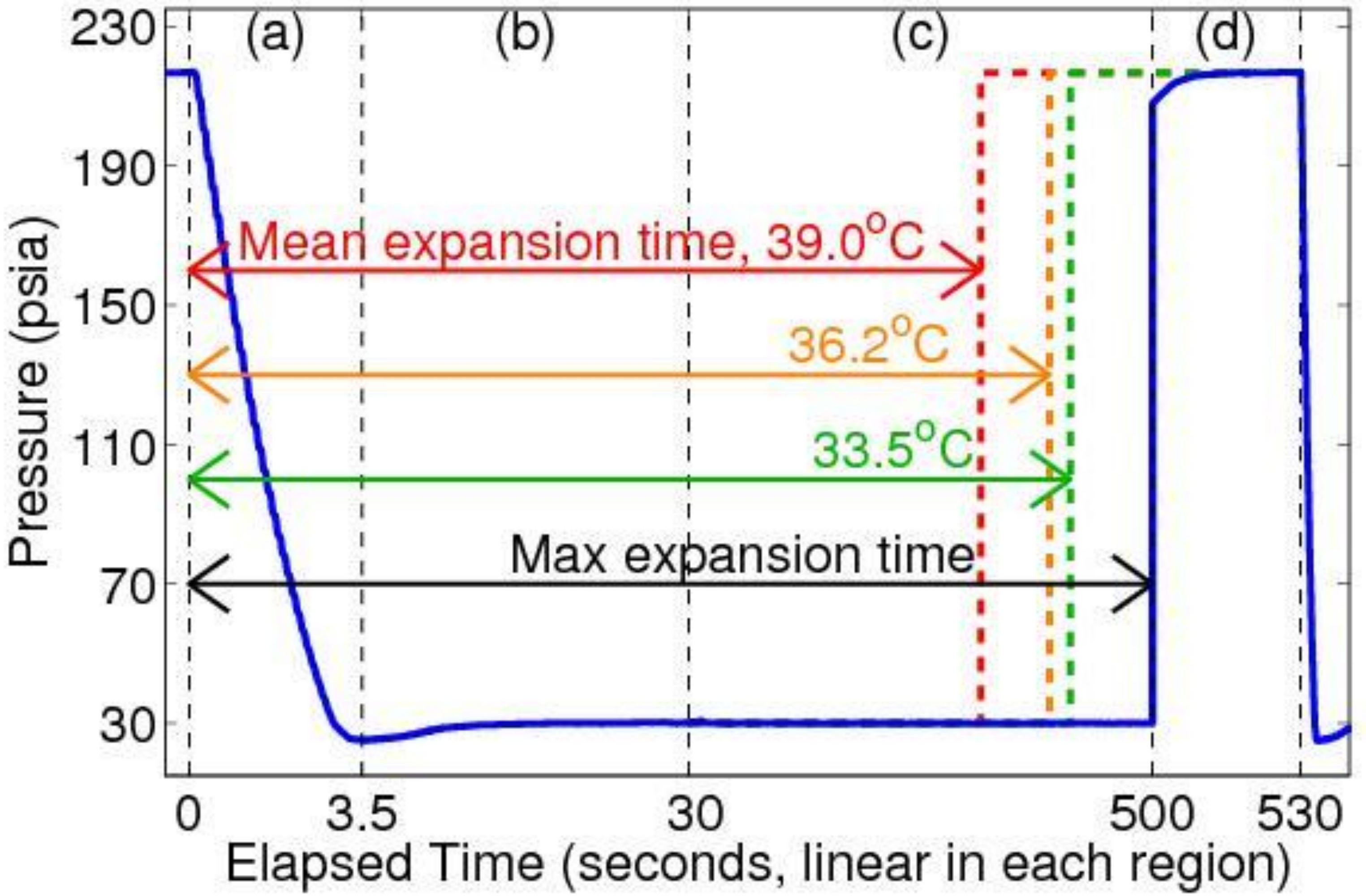
- Expand the chamber to the superheated state (10sec).

- Cameras see the bubble
    - Trigger
    - Stereoscopic position information

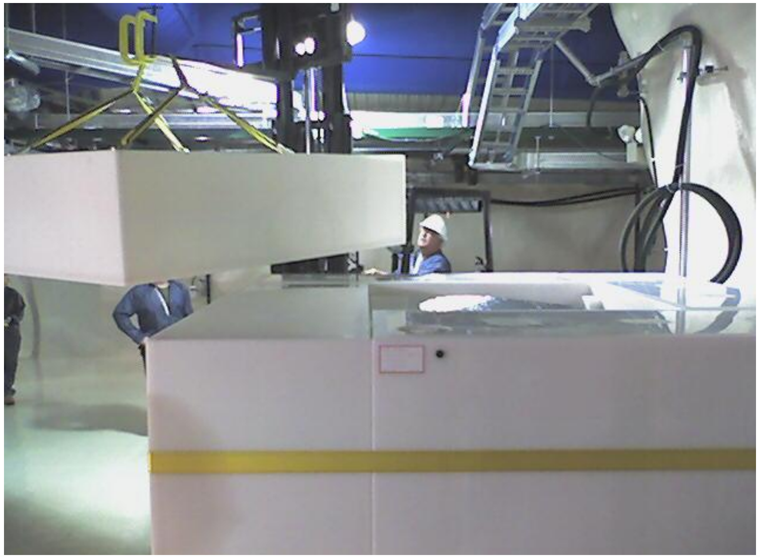
- Recompress the chamber (100msec) and wait 30sec after every bubble.

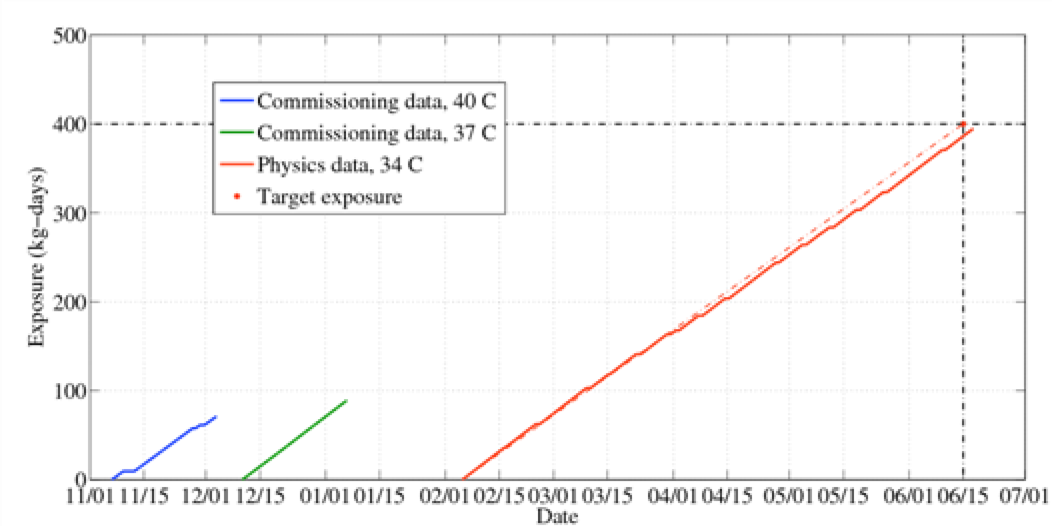


Pressure cycling



COUPP-4



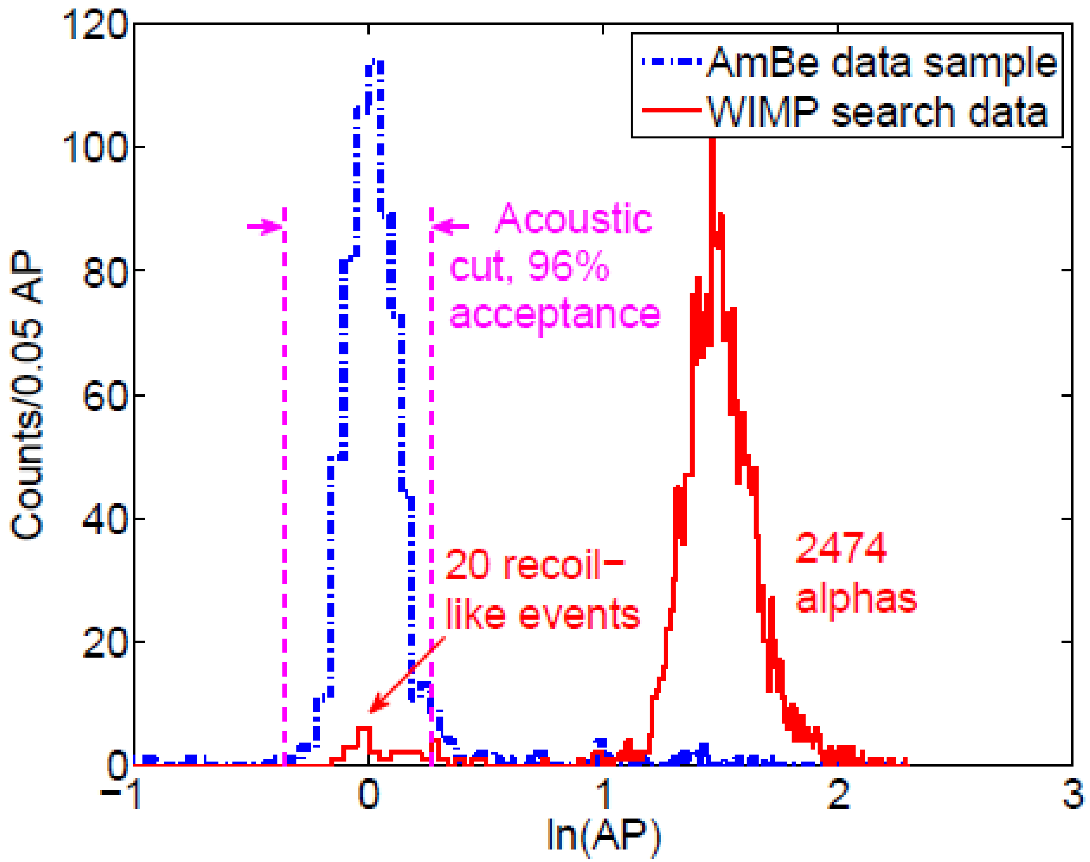


- First dark matter run 2010-2011 at SNOLAB.
- 17.4, 21.9, 97.3 live-days at 8, 11, 16 keV thresholds
- 4.048 kg target, 79% cut-efficiency for nuclear recoils

Alpha rejection

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

- Better than 99.3% rejection at 16keV threshold.

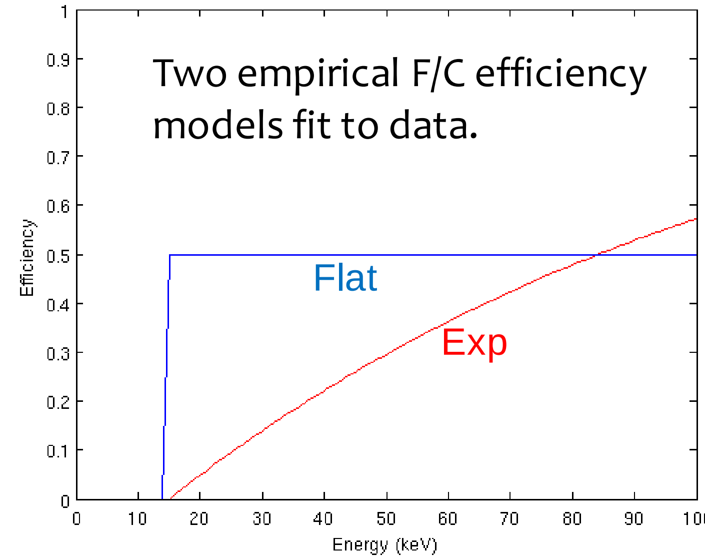


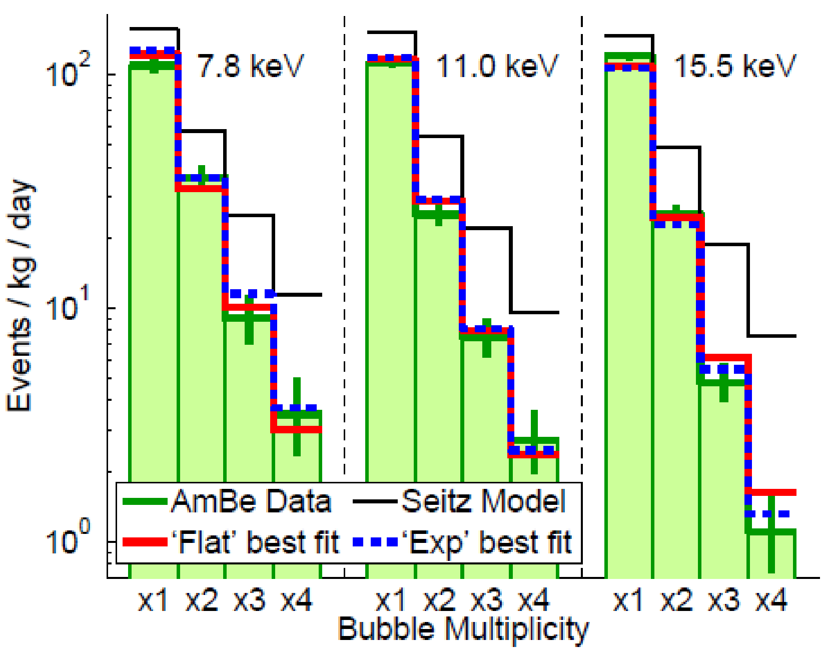
Neutron calibrations

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

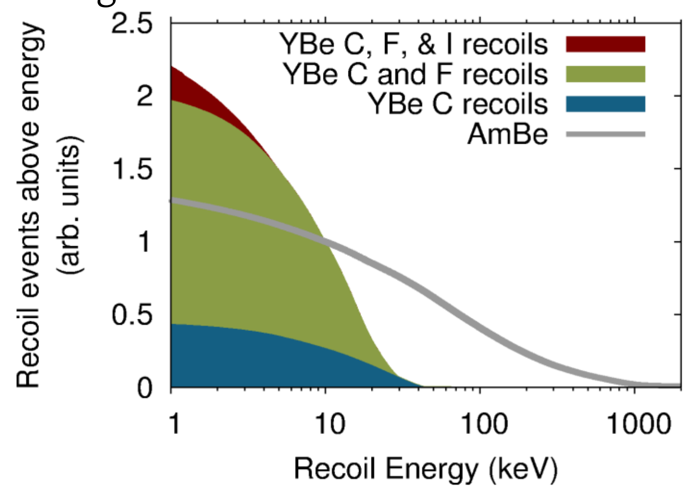
•Checked with neutron sources (AmBe, ^{252}Cf) employed regularly during the run.

•Evidence for a soft threshold in fluorine/carbon.





Y/Be low energy neutron source now being used for calibrations



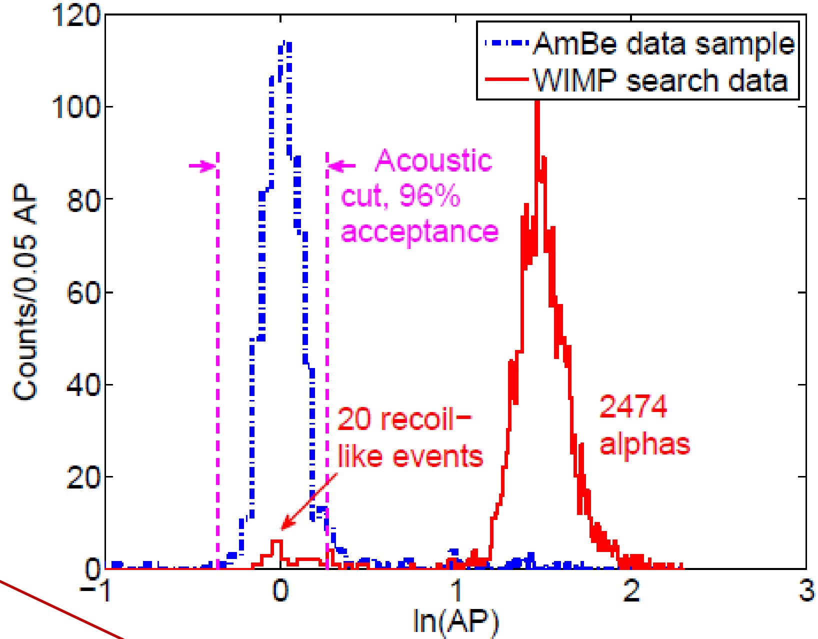
COUPP-4 WIMP results

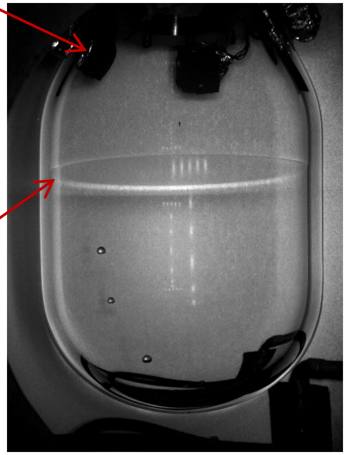
- 20 WIMP candidates
  - 6 at 8keV
  - 6 at 11keV
  - 8 at 16keV

- 3 multiple bubble events → **neutrons**

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

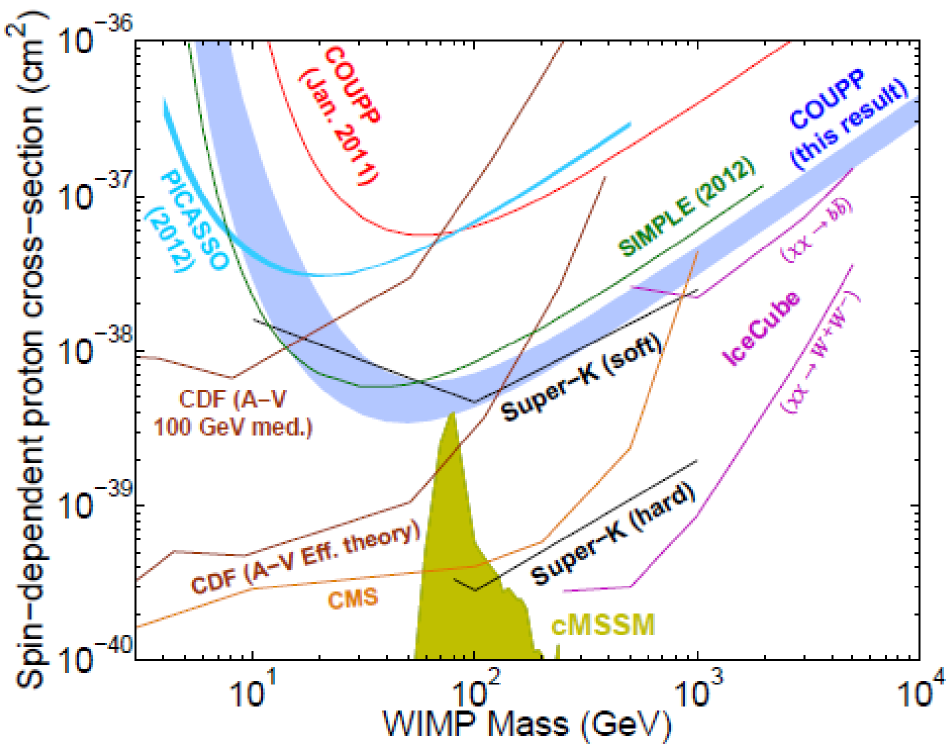
- Many of the events at low threshold are inconsistent with WIMPs
  - events show clustering in time (e.g. 3 in 3 hours, 4 in 9 hours)
  - events are not consistent with neutron AP distribution
  - events are correlated with activity at the water/CF3I boundary

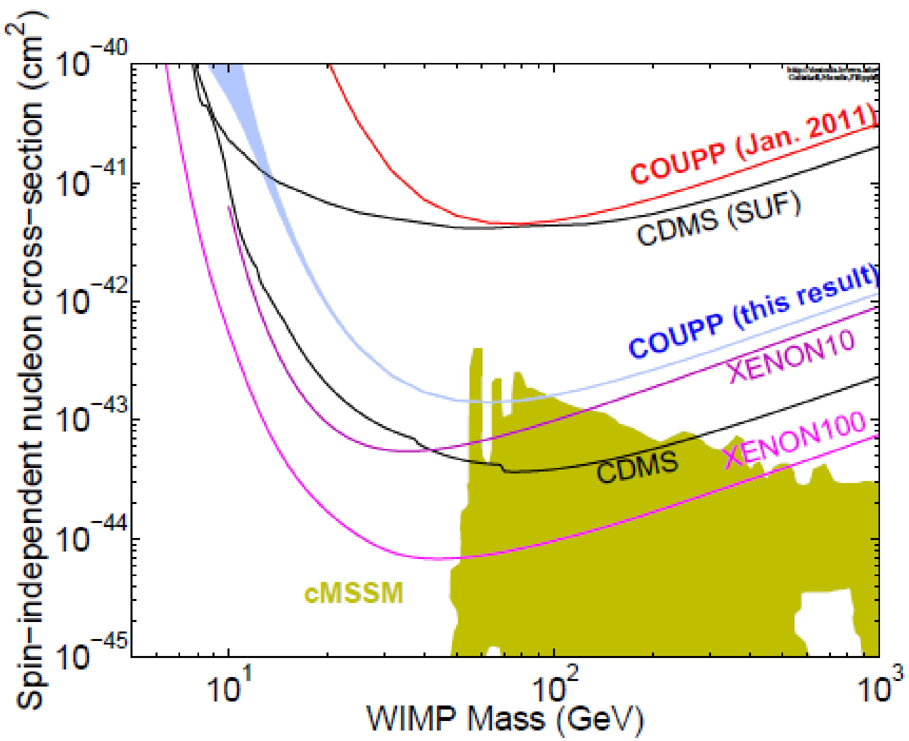




WIMP limits

- Given uncertainties on background predictions, we do no background subtraction, (Behnke et al., Phys. Rev. D 86 (052001) 2012).
- Even with a clear neutron background world class SD limits in a 4 kg detector.





COUPP-4 2nd dark matter run

• COUPP-4 2nd run at SNOLAB May-Dec 2012.

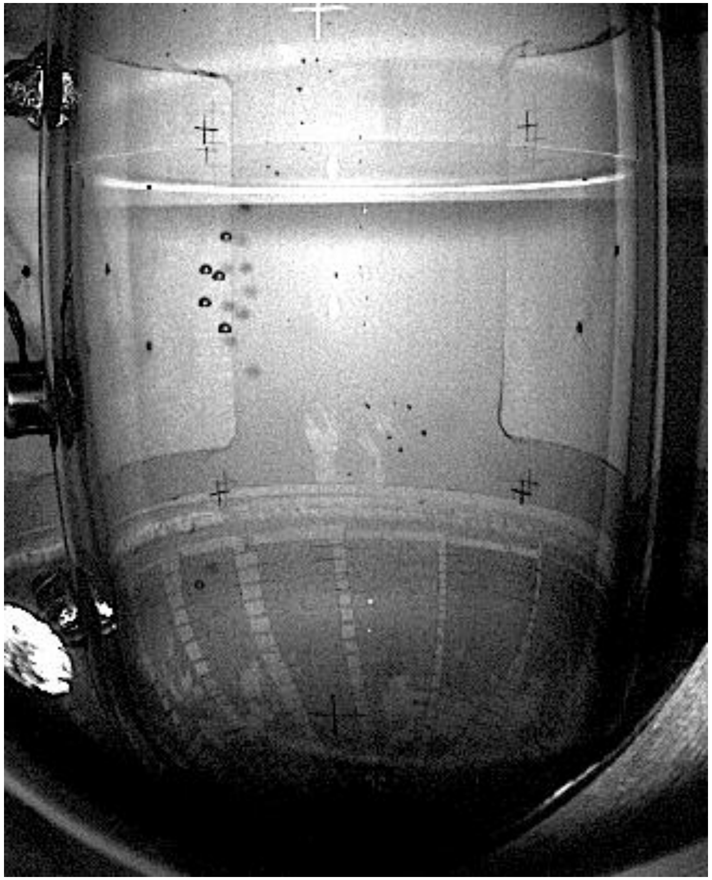
• Piezo-acoustic sensors and viewport windows replaced with certified low-background parts.

• Higher purity CF_3I.

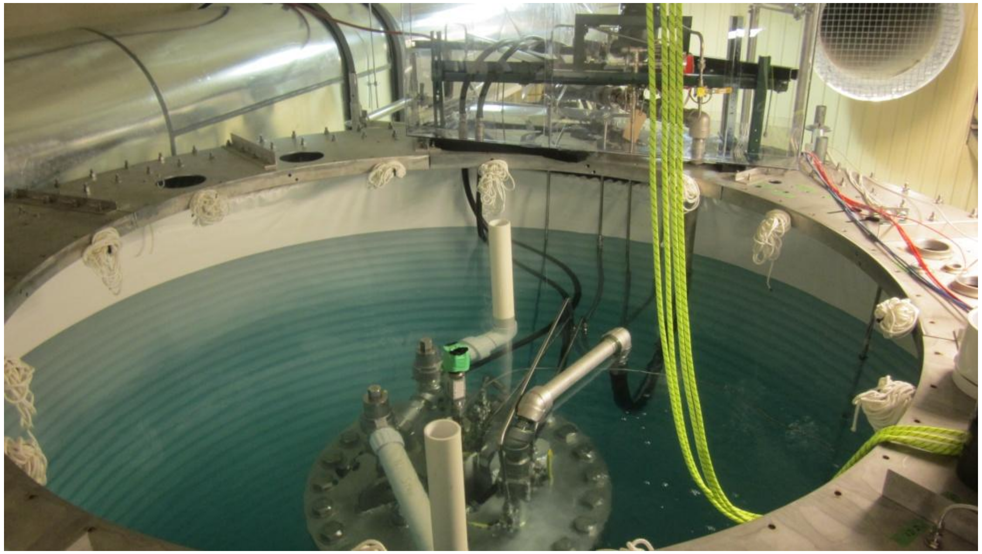
• Analysis underway.

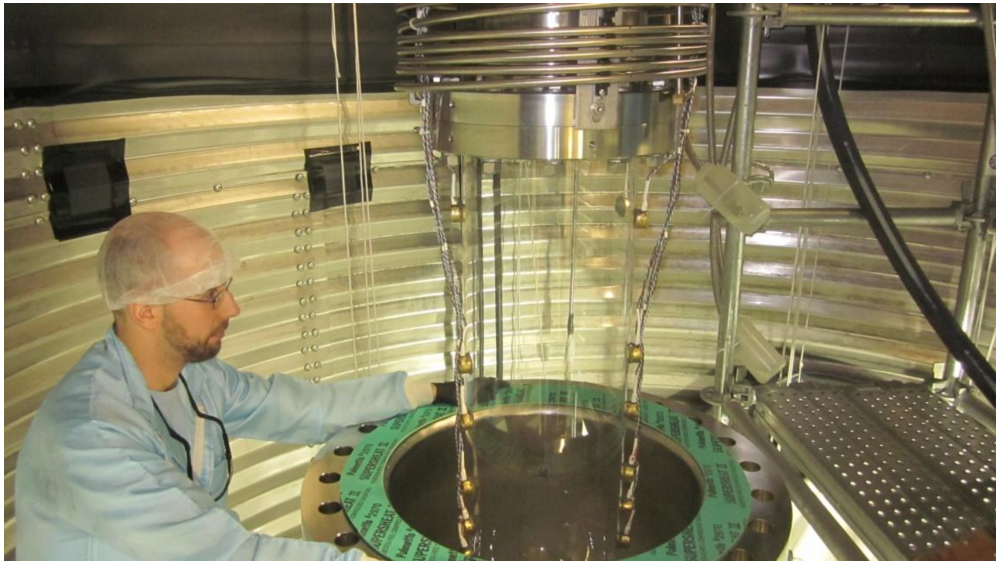
COUPP-60

- 60 kg CF_3I detector installed at SNOLAB with 10^{-45} cm^2 SI projected sensitivity.



COUPP-60 at SNOLAB





Inner vessel installation

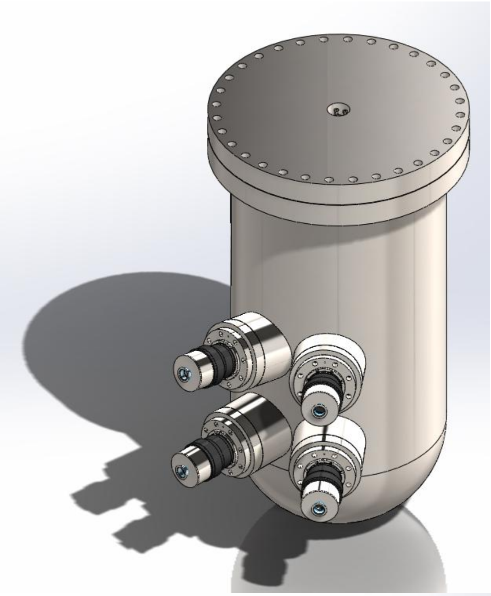
- Inner vessel installed Jan 24, 2013.
- Currently filling with water.
- CF_3I fill at the end of February and first expansions in March.

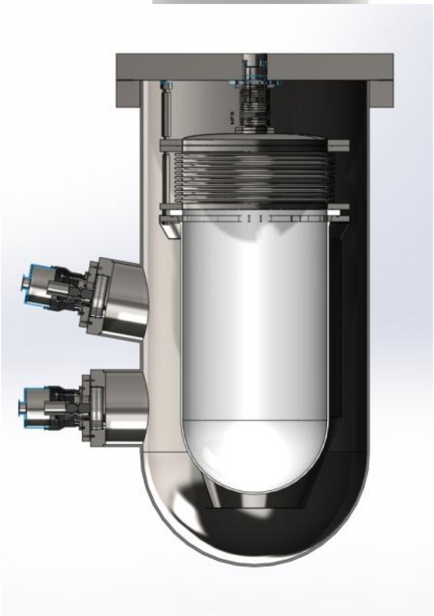
COUPP-500

• Ton-scale detector with few times 10^{-47} cm^2 SI sensitivity.

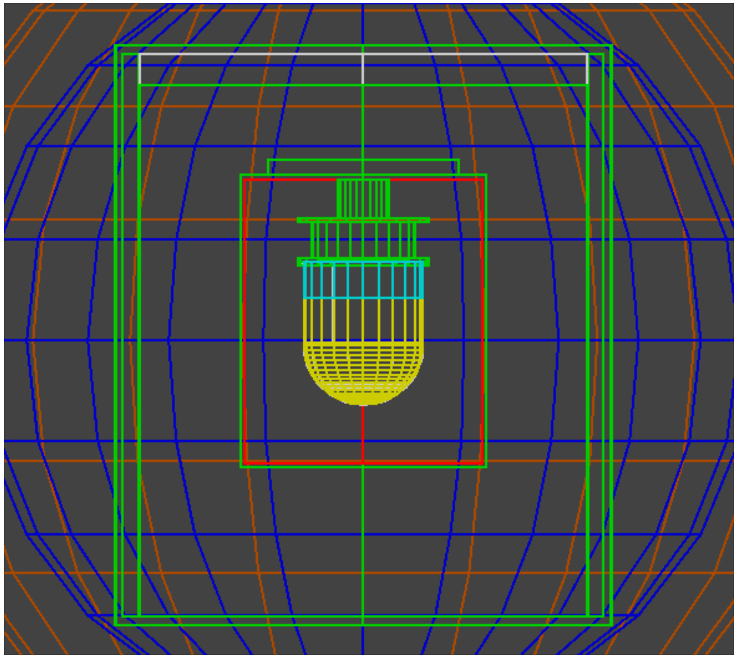
• Engineering and background studies under way.

• Construction 2014-2015.





Background simulations

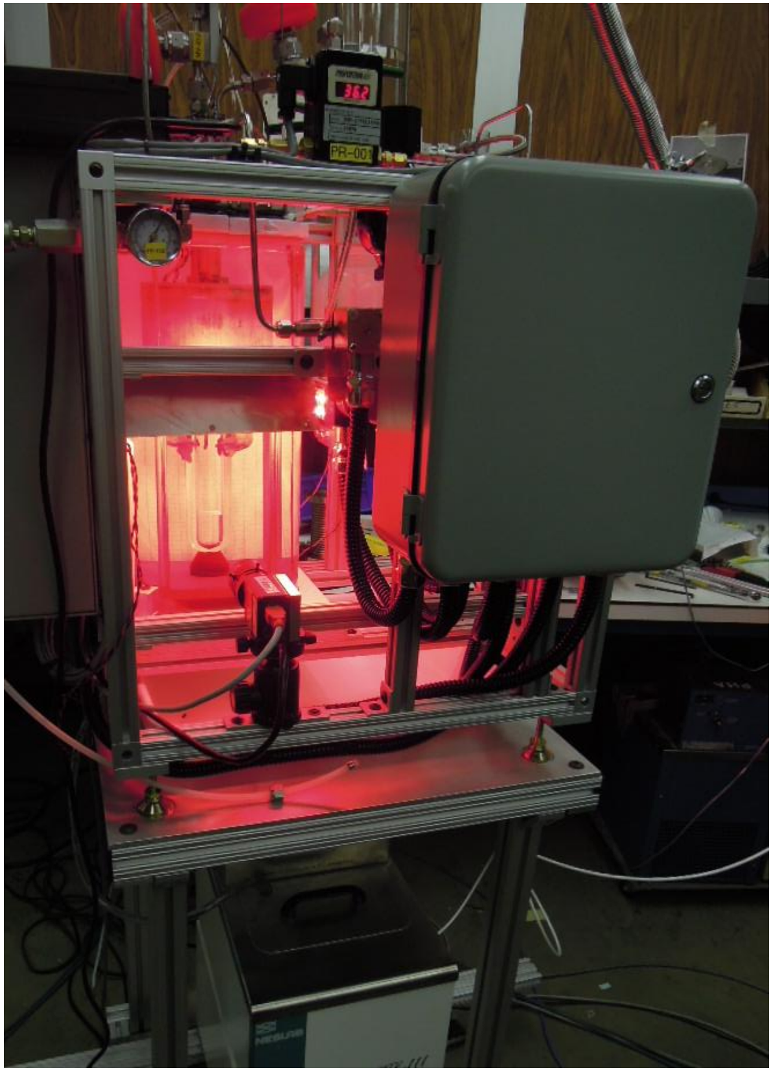


Neutron source	Rate	Single evts/yr	Multiple evts/yr
Rock	4000 ± 1000 n/m^2/d	$O(10^{-11})$	$O(10^{-11})$
Muon induced from rock	5.4×10^{-11} n/cm^2/s	0.0904 ± 0.0131	0.2544 ± 0.0219
Muon induced from shield or detector	$67.11 \pm 1.85\ \mu$/d	0.493 ± 0.014	1.050 ± 0.030
U and Th in detector materials		0.0504 ± 0.0030	0.1242 ± 0.0068
↳ steel only	1ppb ^{238}U and ^{232}Th	0.0360 ± 0.0026	0.0922 ± 0.0062
↳ quartz only	10^{-2}ppb ^{238}U and ^{232}Th	0.0131 ± 0.0012	0.0290 ± 0.0026
Radon deposition onto and diffusion into outer surface of quartz jar	Dep. Rate= 10^{-3}/m/y 100 Bq^{222}Rn/m^3 in air t=3 months A=2.21m^2 S=10, d_e=1.0 mm	0.0198 ± 0.0015	0.0415 ± 0.0030
Radon in water tank	S=0.25, 100 Bq/m^3 Rn inner 18500L	$(1.83 \pm 0.28) \times 10^{-3}$	$(5.17 \pm 0.60) \times 10^{-3}$
Radon in heat exchange pipes	S=0.25 100 Bq/m^3 Rn, 10L	0.0230 ± 0.0021	0.0572 ± 0.0052
Radon emanation from quartz and steel	A=34.81m^2 100 μBq/m^2 Rn	$(1.39 \pm 0.13) \times 10^{-3}$	$(2.93 \pm 0.26) \times 10^{-3}$
Mine dust on top surfaces	0.01 g/m^2, 2.21 m^2 1.11 ppm ^{238}U 5.56 ppm ^{232}Th	0.0127 ± 0.0011	0.0286 ± 0.0026
^{127}I(γ,n)^{126}I	4.0 γ/cm^2/yr > 9MeV	< 0.0069	
other photonuclear		$< 1.3 \times 10^{-4}$	
Piezoelectric acoustic transducers, 50g	10 ppb ^{238}U 10 ppb ^{232}Th	0.0577 ± 0.0031	0.142 ± 0.008
↳ side only, 25g	0.1 ppb ^{235}U	0.0036 ± 0.0002	0.0072 ± 0.0004
↳ bottom only, 25g	10 Bq/kg ^{210}Pb	0.0541 ± 0.0031	0.134 ± 0.008
CF_3I U and Th (α,n)	0.0159 ppt ^{238}U 0.0488 ppt ^{232}Th 0.0025 ppt ^{235}U 25 μBq/kg ^{222}Rn 25 μBq/kg ^{210}Pb	1.078 ± 0.061	4.37 ± 0.25
Other radon induced backgrounds	6mo. deposition on steel 92.6μBq/m^3 in IV	$(8.0 \pm 0.5) \times 10^{-6}$	$(2.00 \pm 0.12) \times 10^{-5}$
Total		1.84 ± 0.06	6.08 ± 0.25
Total unvetoable		0.264 ± 0.014	0.663 ± 0.025

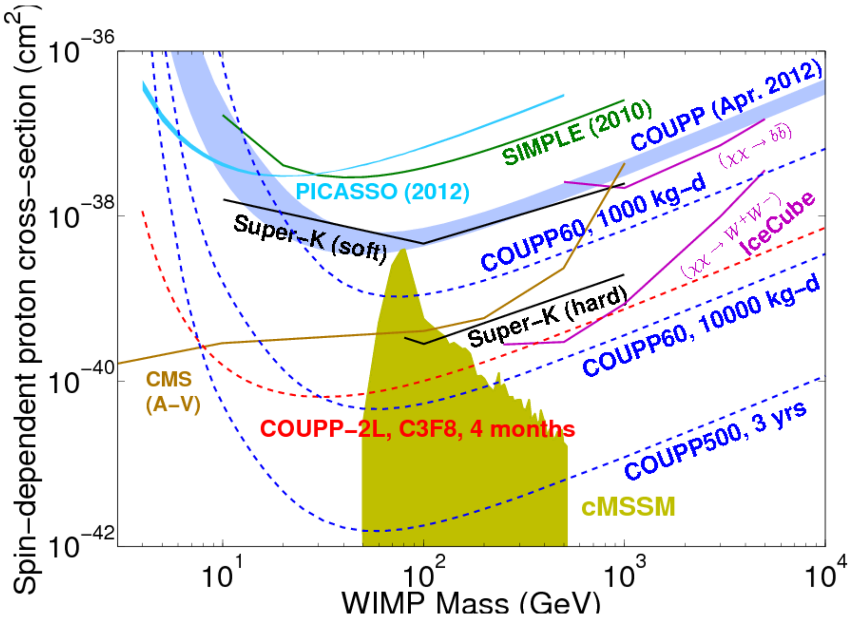
- GEANT4 model.
- 10^5 – 10^6 years simulated.

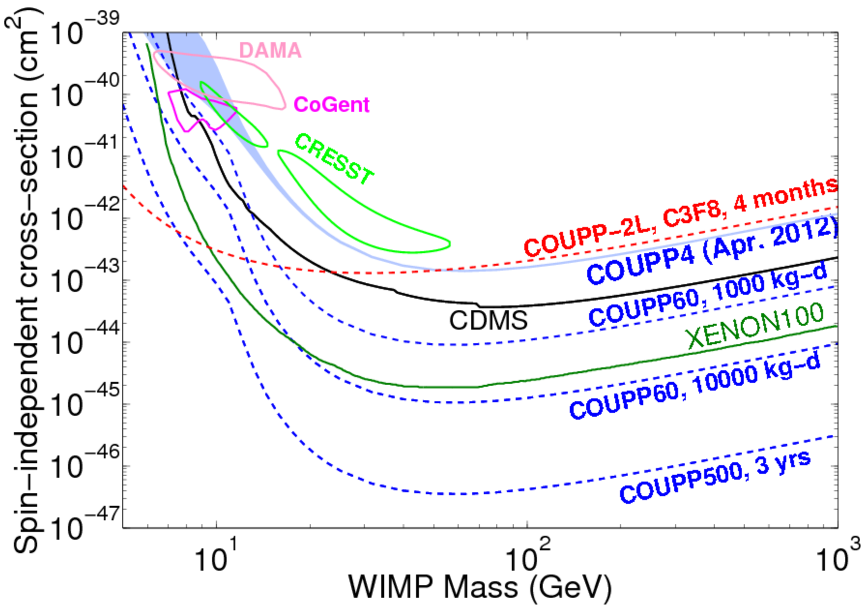
C_3F_8 test chamber

- Running since Jan 2013 at Fermilab with <5keV threshold and >1 min mean superheat time.
- Two times the ^{19}F density as CF_3I.
- Potentially better fluorine nucleation efficiency and gamma rejection than CF_3I. Would improve low-mass and SD sensitivity.
- C_3F_8 can run in the same bubble chambers as CF_3I with no modifications.
- Also a test of new hydraulic system paradigm and DAQ for COUPP-500.



Sensitivity projections





CF_3I limits for 10keV threshold.

C_3F_8 sensitivity limits assume we achieve 4keV threshold.

Conclusions

- COUPP-4 has demonstrated superb gamma rejection and that alpha backgrounds can be acoustically rejected. Neutron backgrounds are already dominant.
- Results are world leading in SD direct detection and there is a clear path to competitive SI sensitivity.
- A novel pion scattering calibration confirms threshold of CF_3I for iodine recoils. Efficiency calibrations of fluorine recoils with Y/Be low energy neutron sources are ongoing.
- COUPP-60 is installed at SNOLAB and will be running within weeks.
- COUPP-500 design is funded and well underway for construction in 2014-2015. The collaboration is growing rapidly for the move to ton-scale.
- An operating C_3F_8 test chamber demonstrates the versatility of the technology to switch targets for complementary searches.