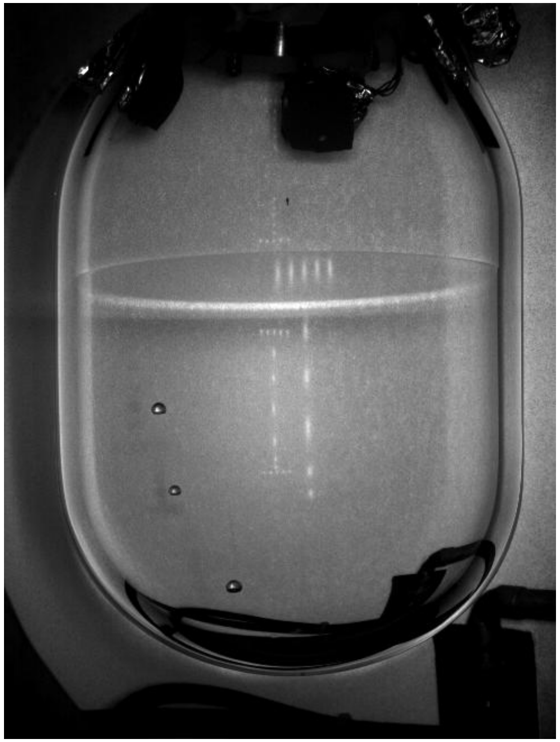
COUPP

Bubble chambers for Dark Matter detection



Russell Neilson, University of Chicago

IPA2013
Madison, WI
May 13th 2013

The Chicagoland Observatory for Underground Particle Physics

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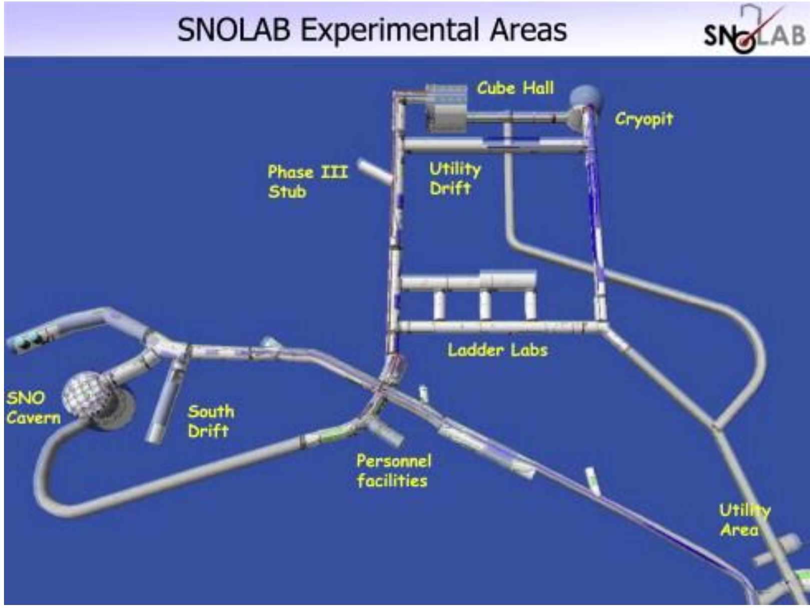


COUPP is currently merging with and collaborating with PICASSO for development of a ton-scale superheated fluid detector.

Particle detection with bubble chambers

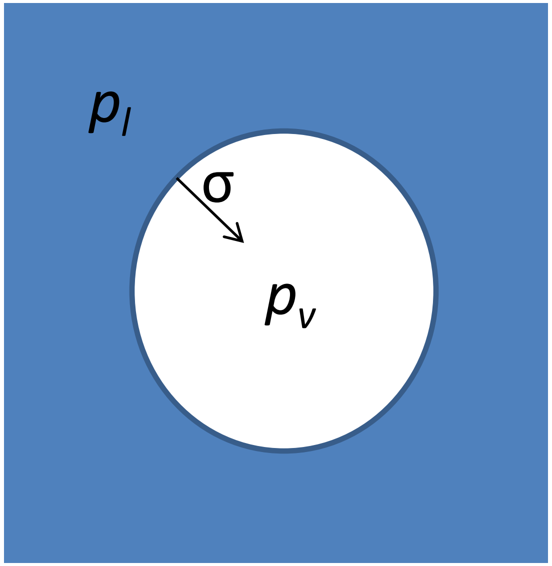
- A bubble chamber is filled a superheated fluid in meta-stable state.
- Energy deposition greater than E_{th} in radius less than r_c from particle interaction will result in expanding bubble *(Seitz "Hot-Spike" Model).*
- A smaller or more diffuse energy deposit will create a bubble that immediately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

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

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

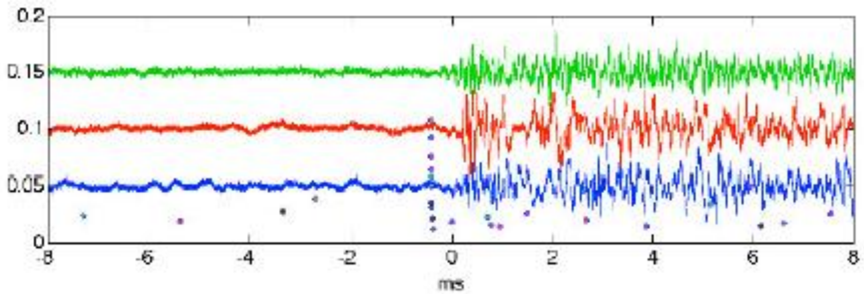
Surface energy

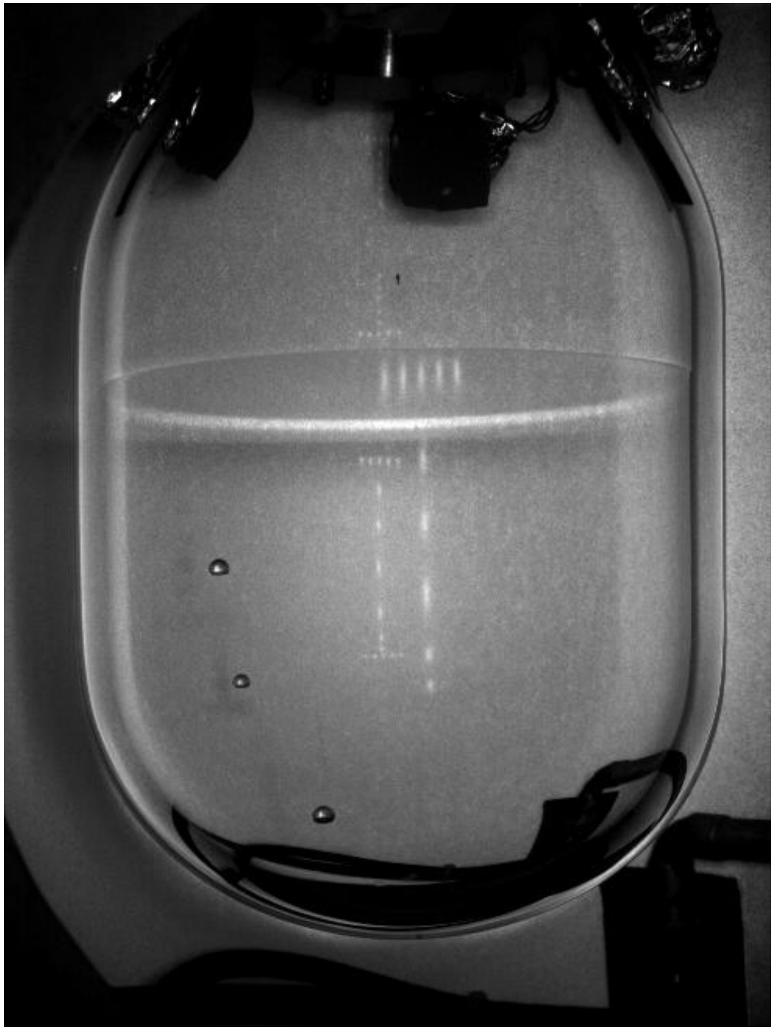
Latent heat



COUPP bubble chambers

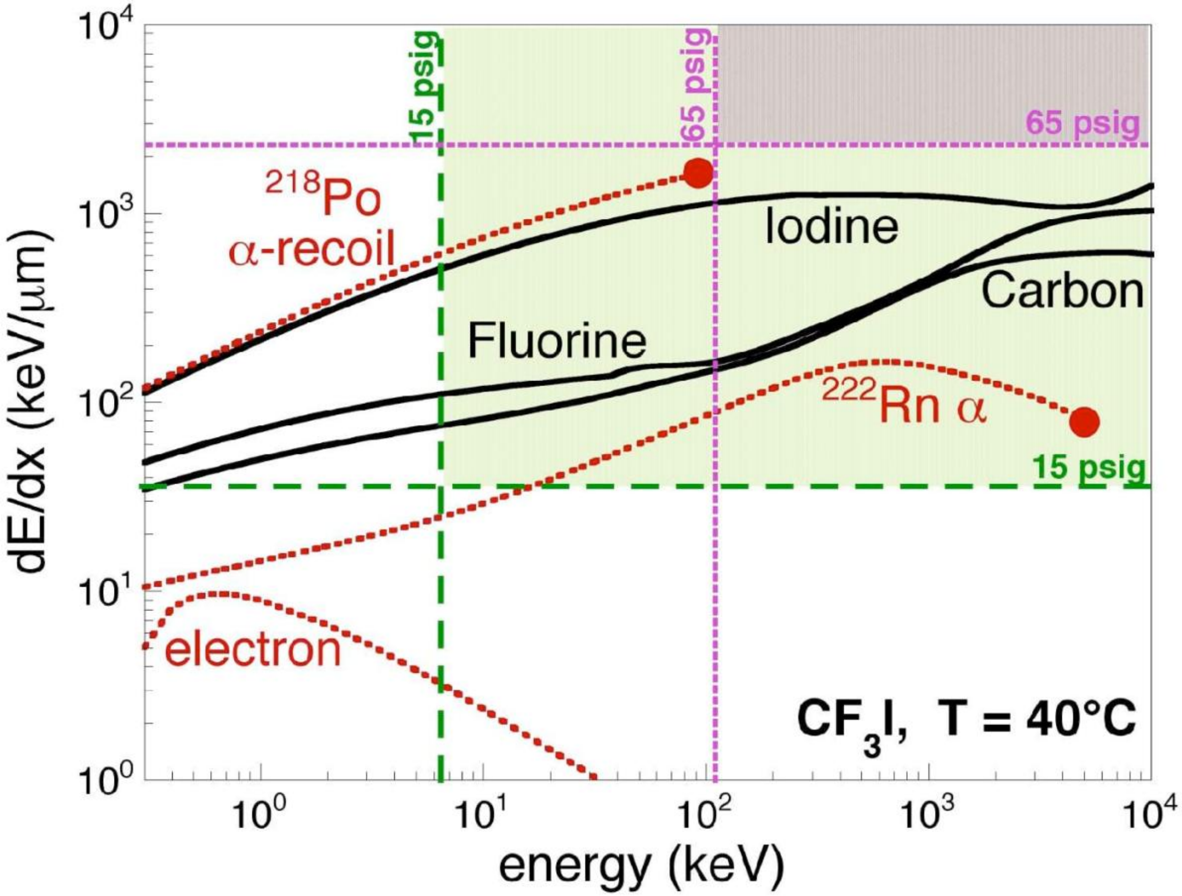
- Detectors sensitive to nuclear recoils from WIMP-nucleon scattering
- Superheated fluid CF_3I
  - F for spin dependent coupling
  - I for spin independent coupling
- Observe bubbles with two cameras and piezo-acoustic sensors.



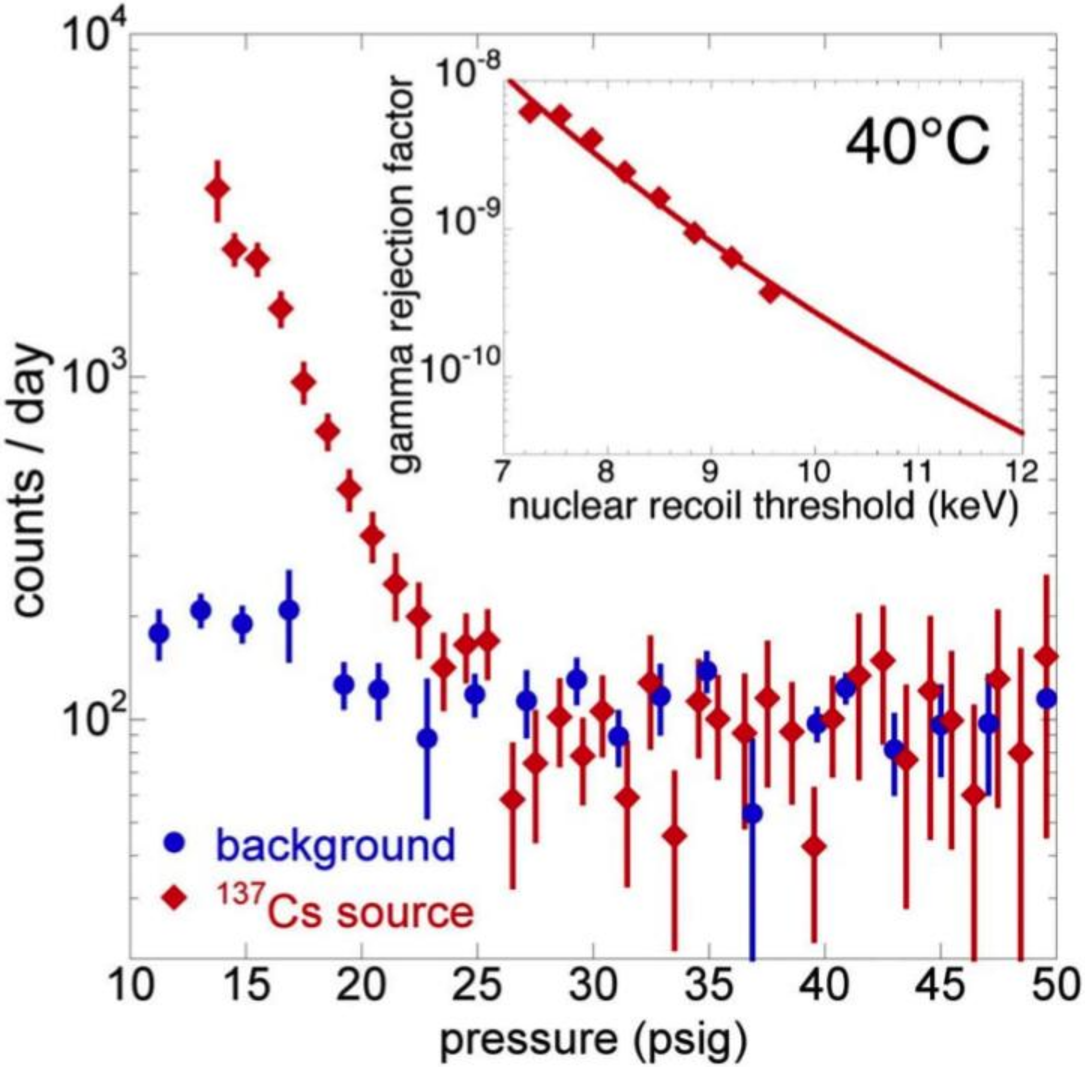


Bubble chambers as nuclear recoil detectors

- 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.



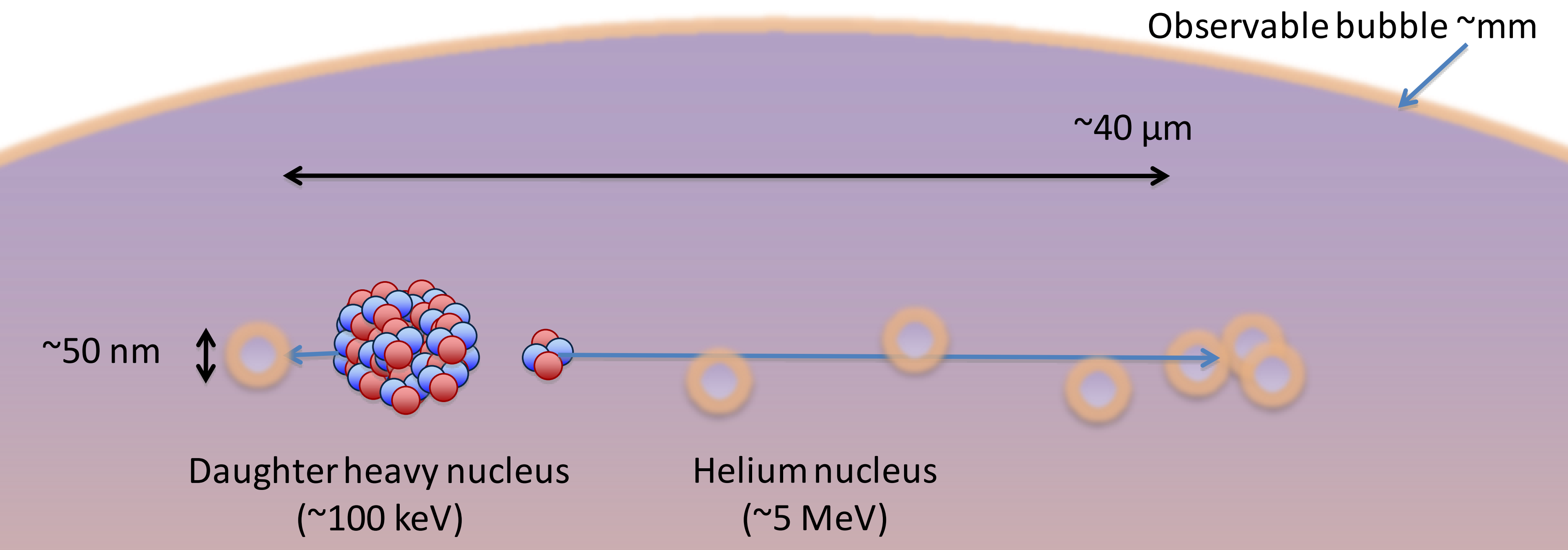
Gamma background rejection



D. Fustin (PhD thesis)
University of Chicago 2012

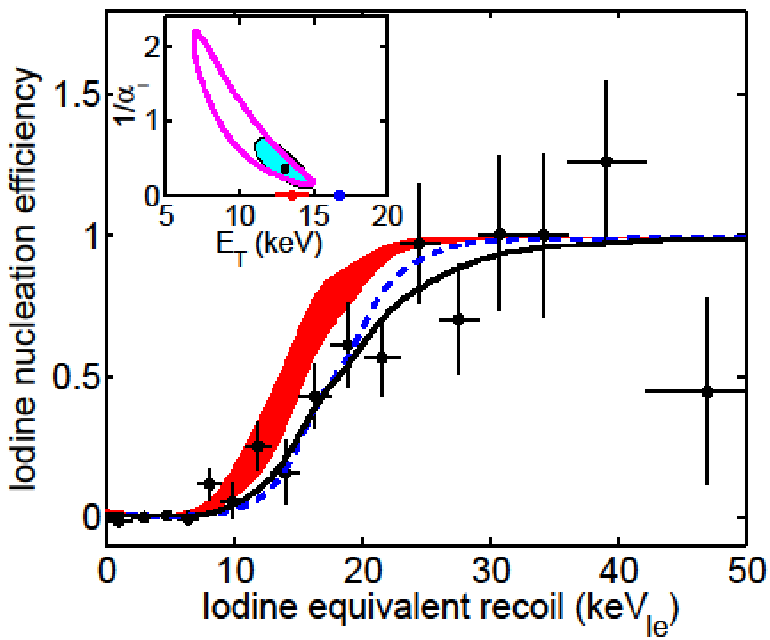
Acoustic discrimination

- 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.



Nuclear recoil efficiency (iodine)

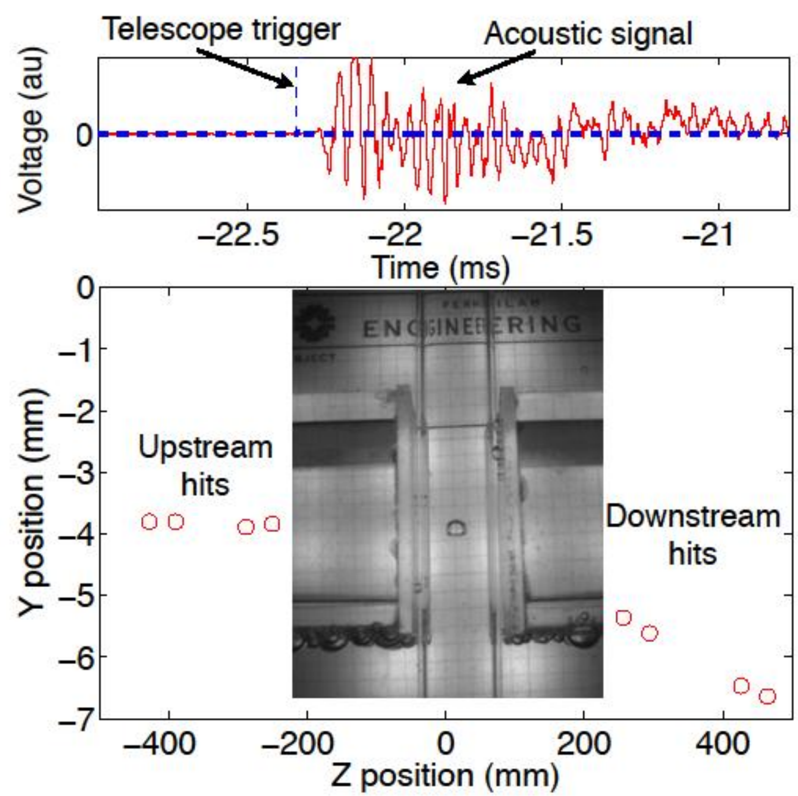
• Pion-scattering calibration of iodine threshold in CF_3I.



arXiv:1304.6001

• 12GeV pion beam with silicon pixel telescope to measure scattering angle.

• Example event: 6mrad scatter, 20keV Iodine recoil.

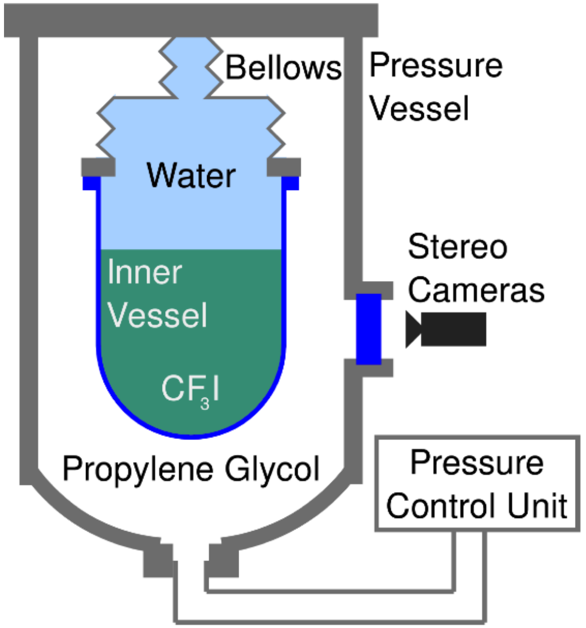


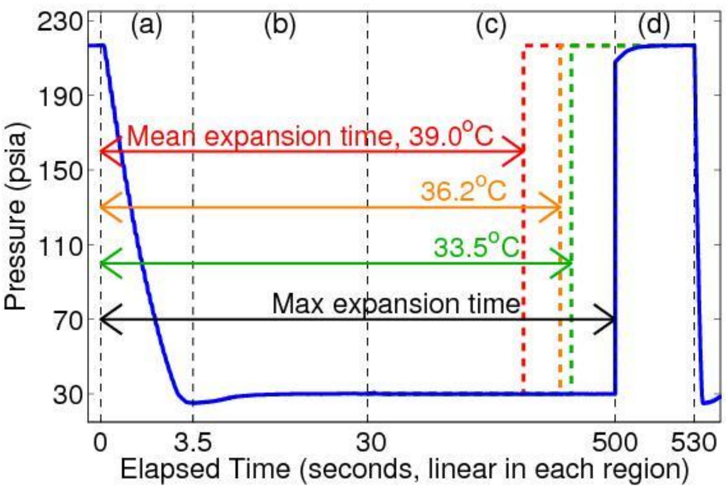
Bubble chamber operation

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

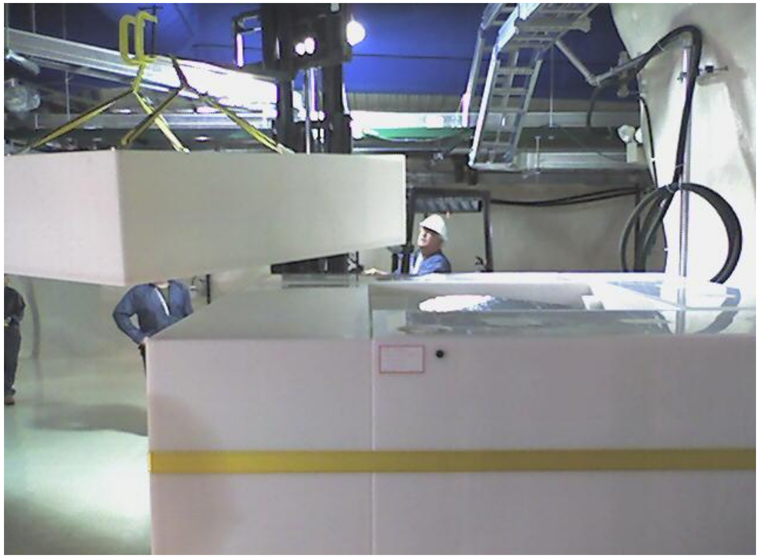
- Cameras see the bubble
  - Trigger
  - Stereoscopic position information

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





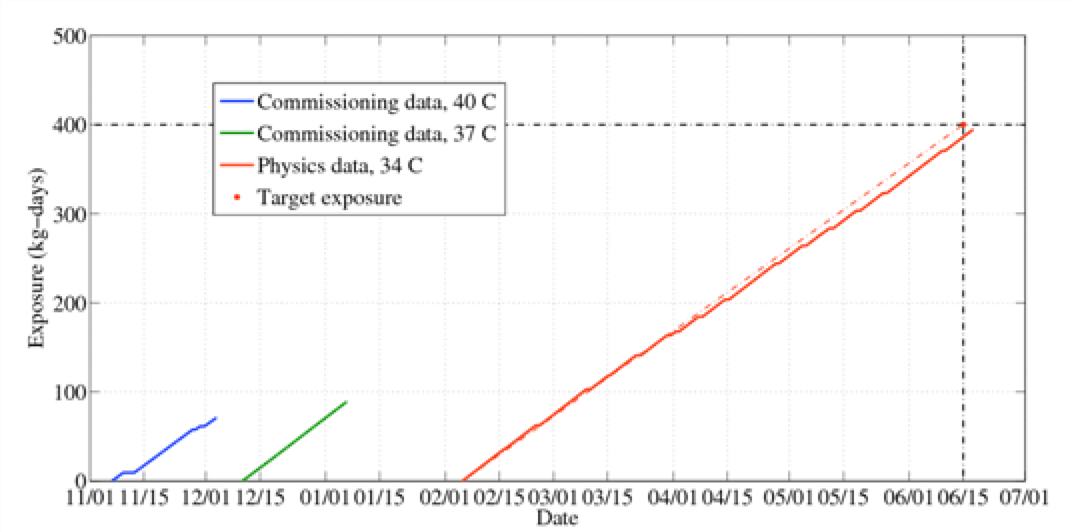
COUPP-4



•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

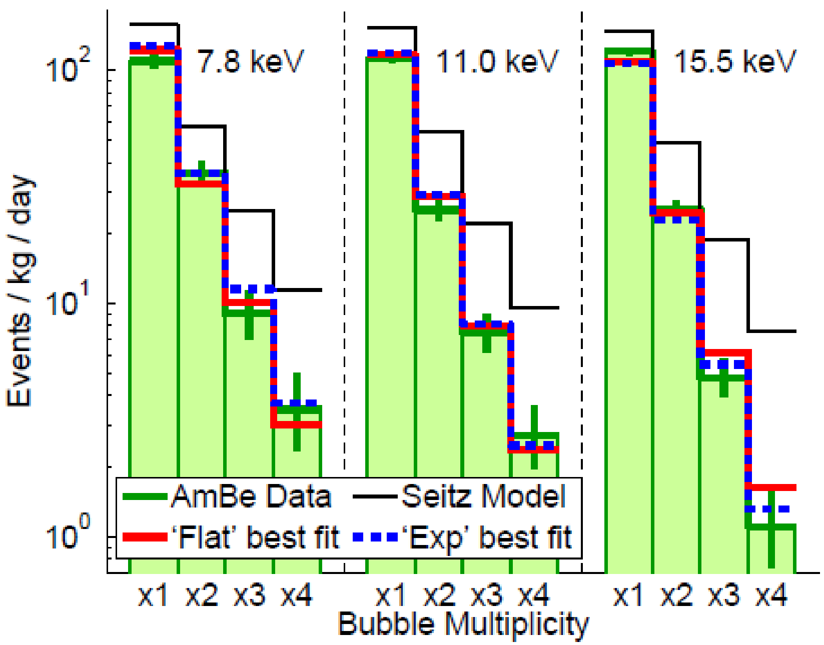


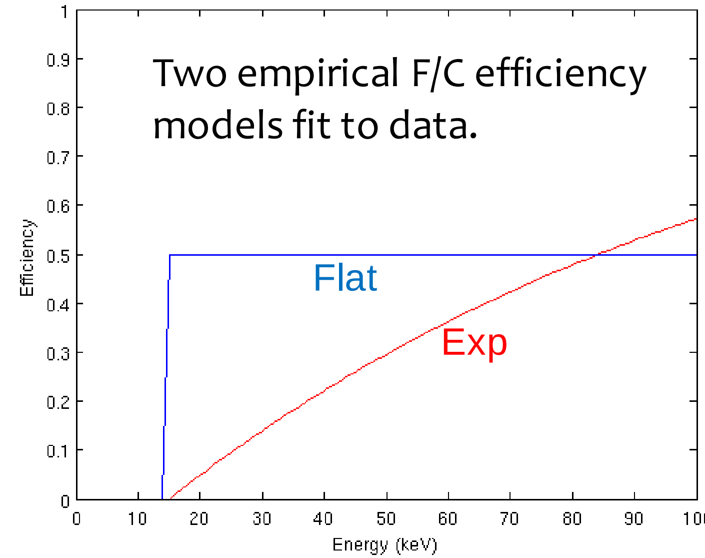
Neutron calibrations

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

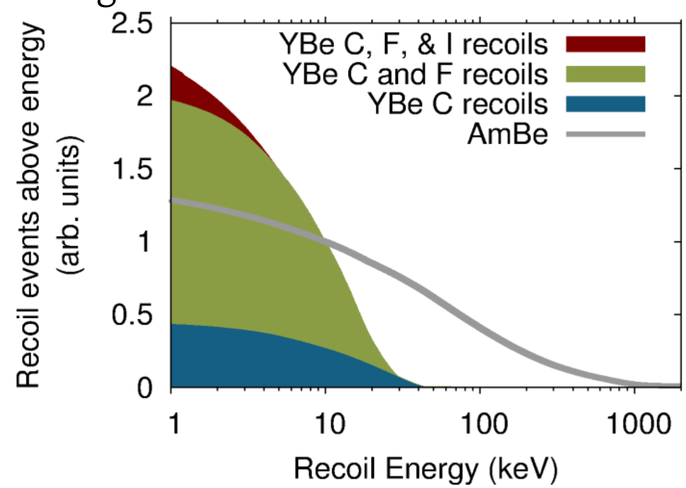
•Checked with neutron sources (AmBe, ^{252}Cf) employed regularly during the run.

•Evidence for a soft threshold in fluorine/carbon.





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



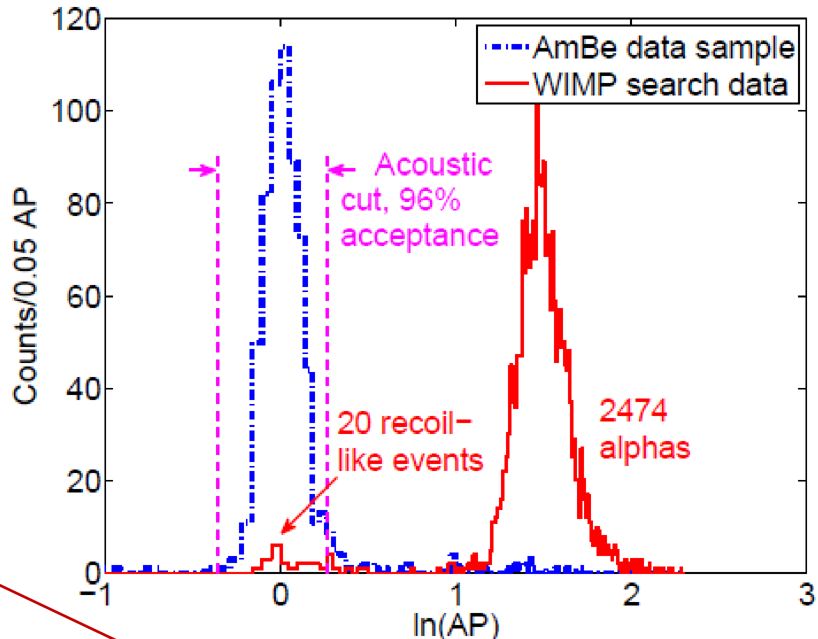
COUPP-4 results

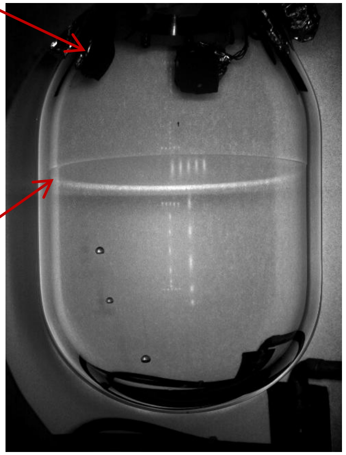
- 20 WIMP candidates
  - 6 at 8keV
  - 6 at 11keV
  - 8 at 16keV

- 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





COUPP-4 2nd dark matter run

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

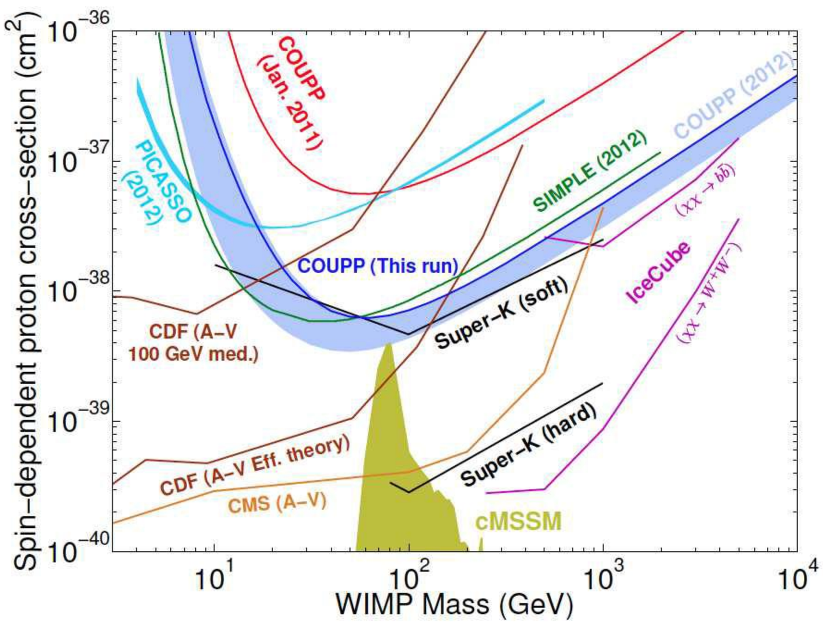
• Piezo-acoustic sensors and viewport windows replaced with certified low-background parts.

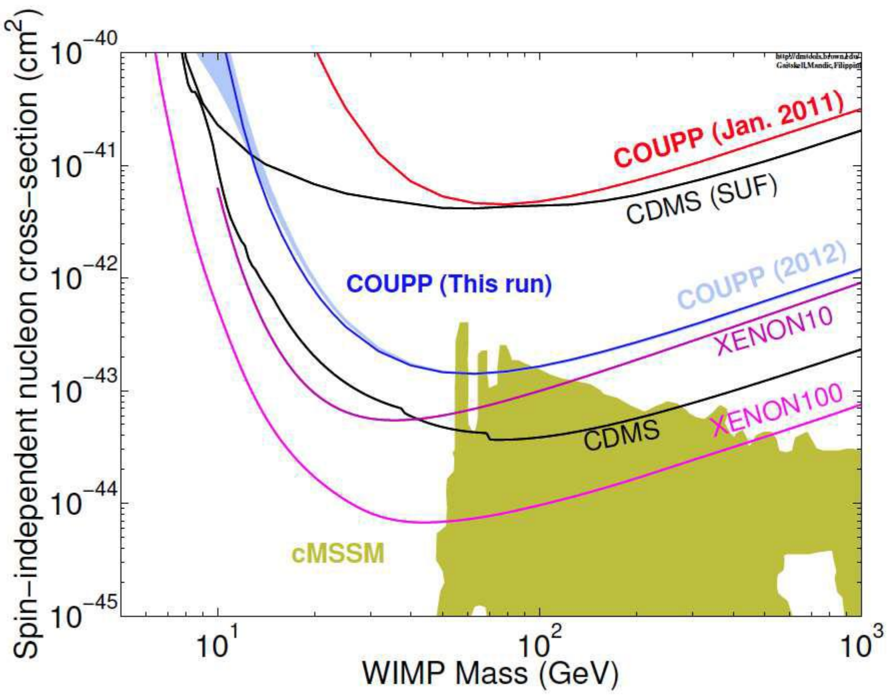
• 8 singles events observed.

• 1 double, 1 triple → **neutrons.**

• Dark matter sensitivity similar to 1st run.

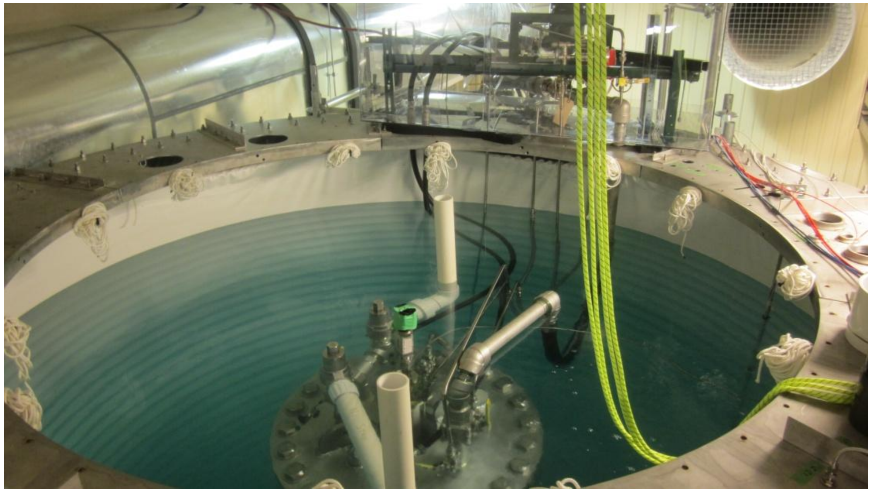
COUPP-4 WIMP limits

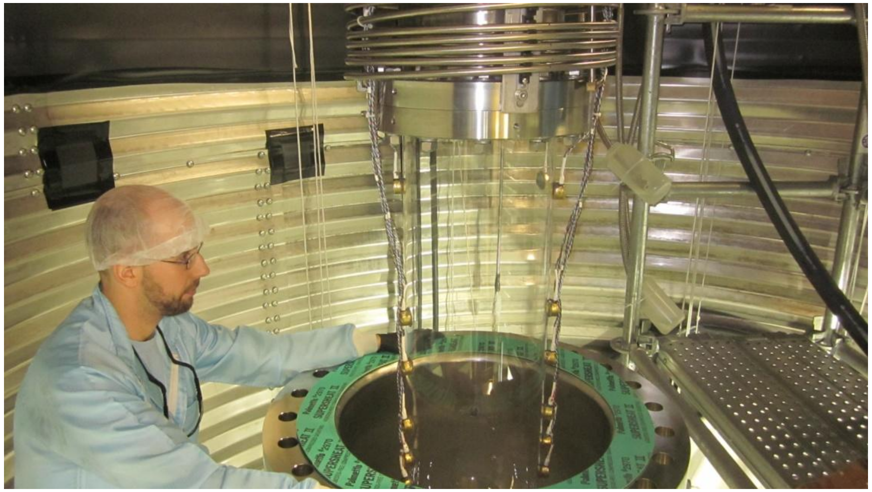




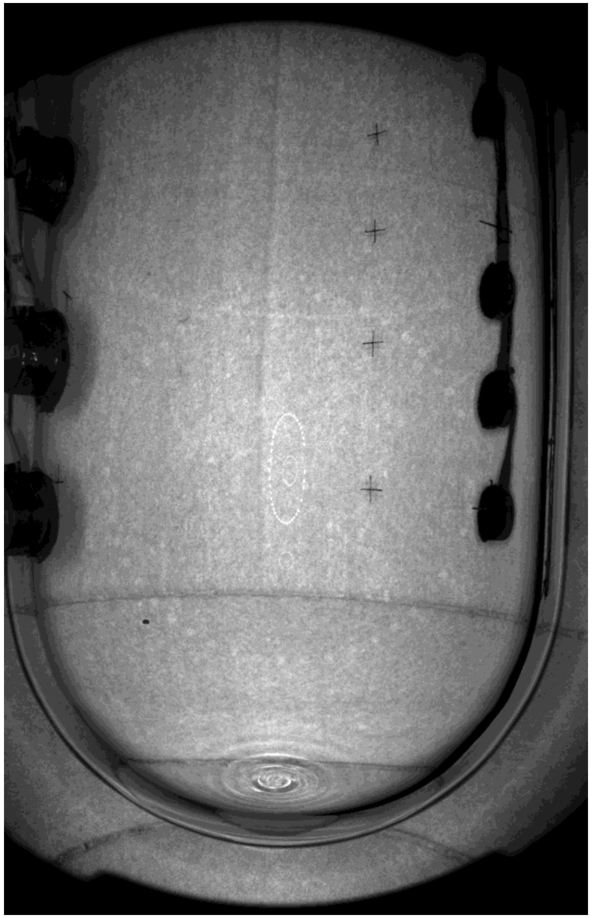
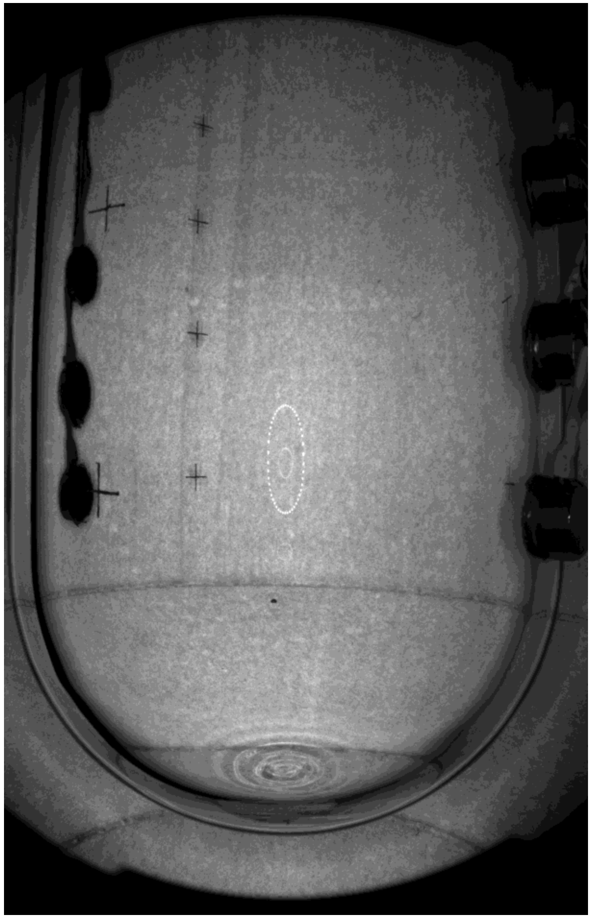
COUPP-60

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





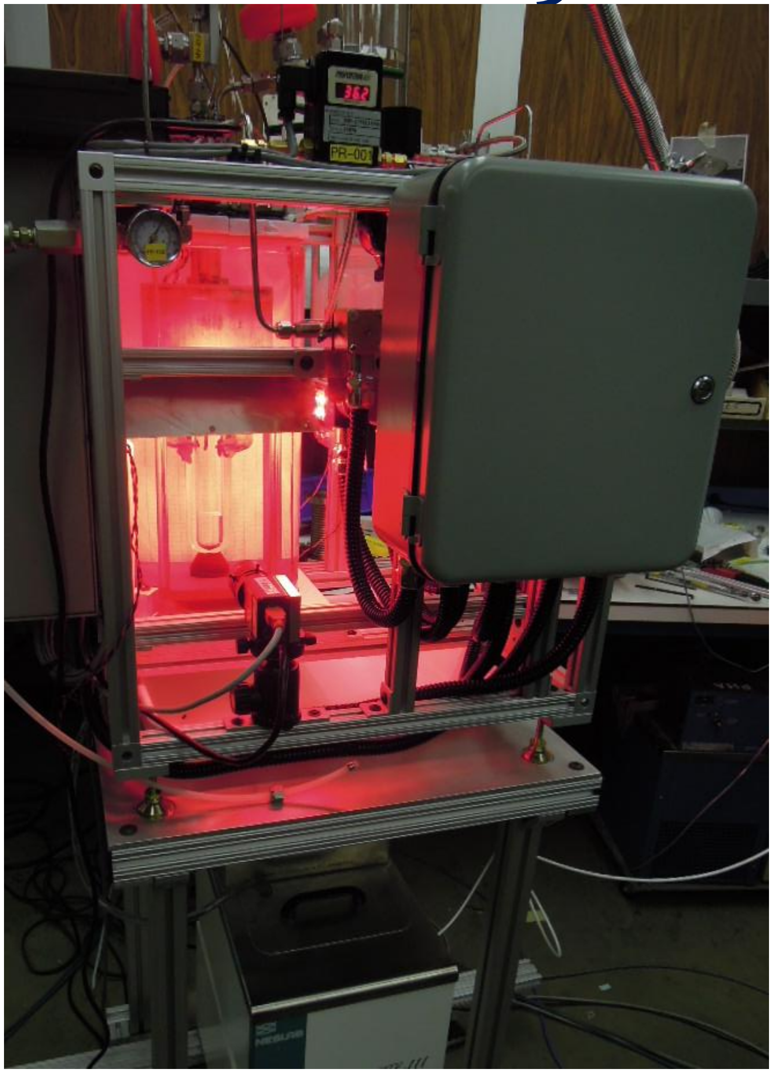
First bubble

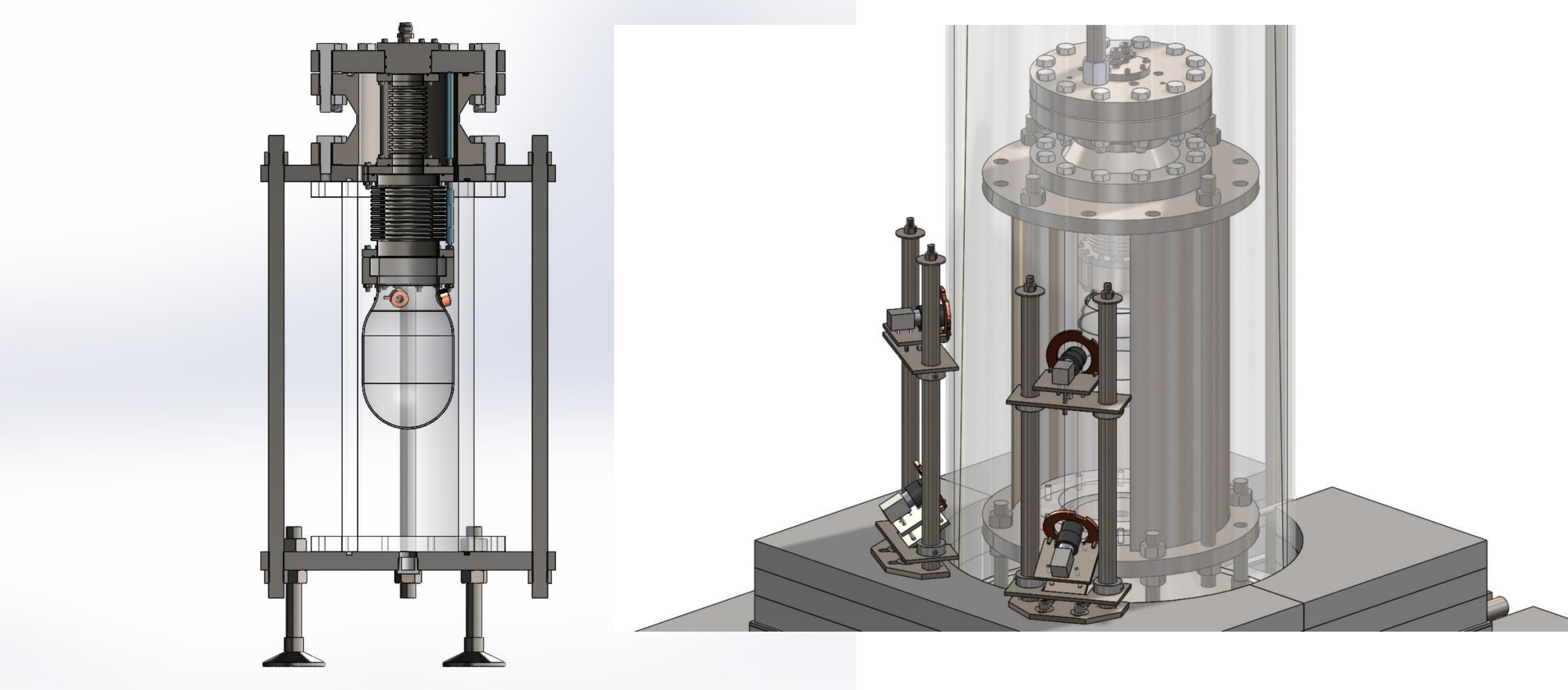
- First underground bubble seen on May 1st 2013.
- Shielding water tank filled last week.
- Currently heating tank to operating temperature (~34C).

New COUPP-4 target fluid (C_3F_8)

- Test chamber operated at Fermilab Jan – Feb 2013 with 1.5-4 keV threshold.
- Two times the ^{19}F density as CF_3I.
- Expected better fluorine nucleation efficiency than CF_3I based on PICASSO calibrations with C_4F_{10}. Much improved low-mass and SD sensitivity.
- Measured gamma rejection $<10^{-8}$ at 3keV threshold.
- C_3F_8 can run in the same bubble chambers as CF_3I.



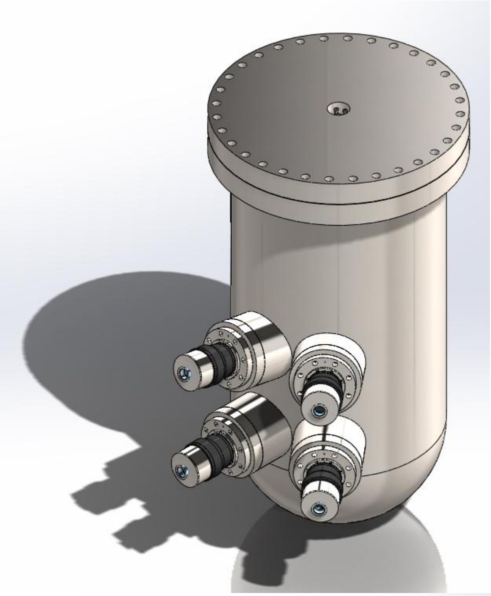
2-Liter C_3F_8 chamber

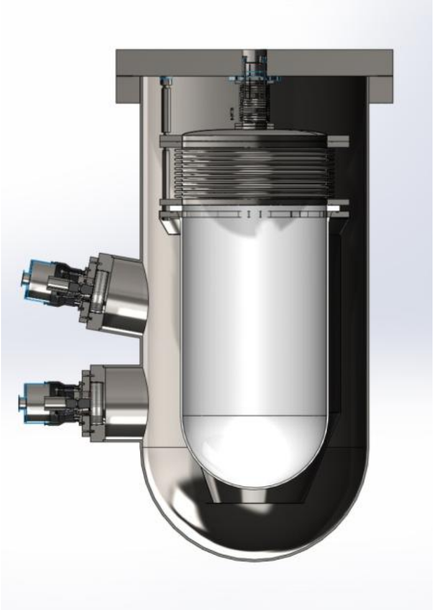


- Replaces COUPP-4 inner vessel and pressure vessel at SNOLAB.
- Joint COUPP/PICASSO project.
- Data Summer 2013

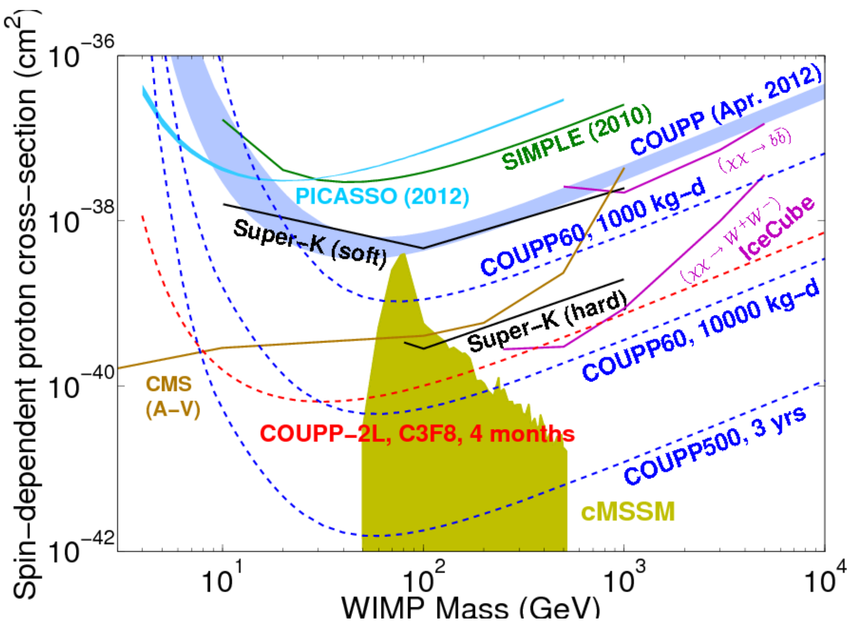
COUPP-500

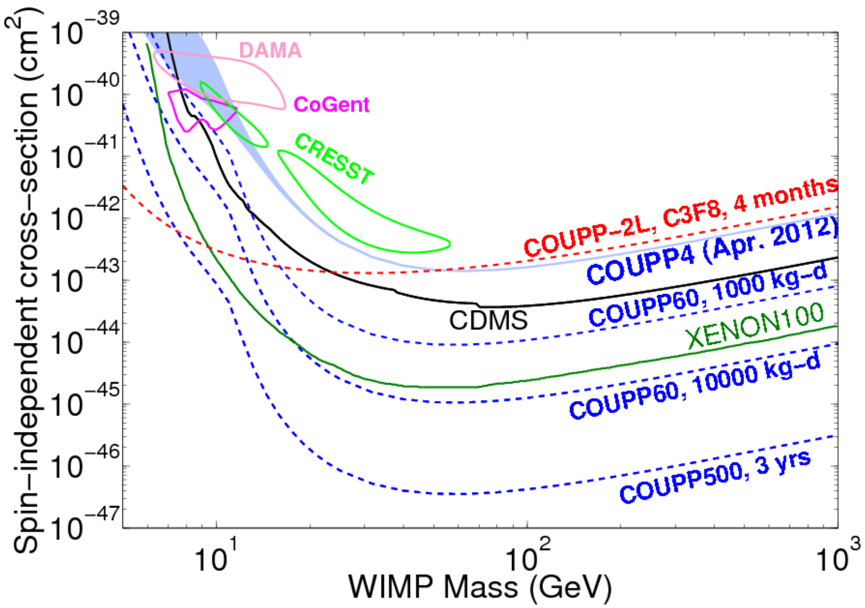
- Ton-scale detector with few times 10^{-47} cm^2 SI sensitivity.
- Engineering and background studies under way.
- Construction 2014-2015.





Sensitivity projections





CF_3I limits for 10keV threshold .

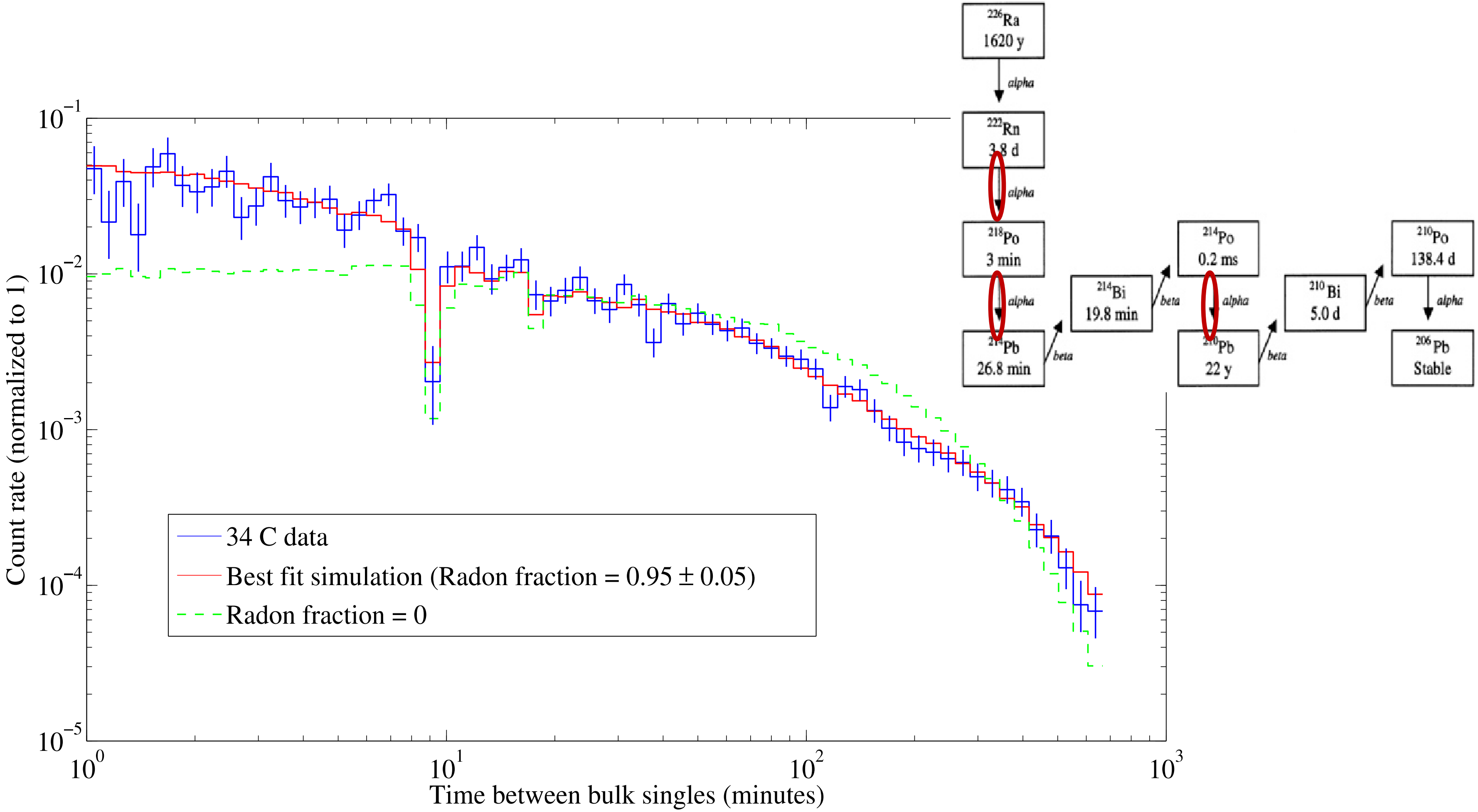
C_3F_8 limits for 4keV threshold.

Conclusions

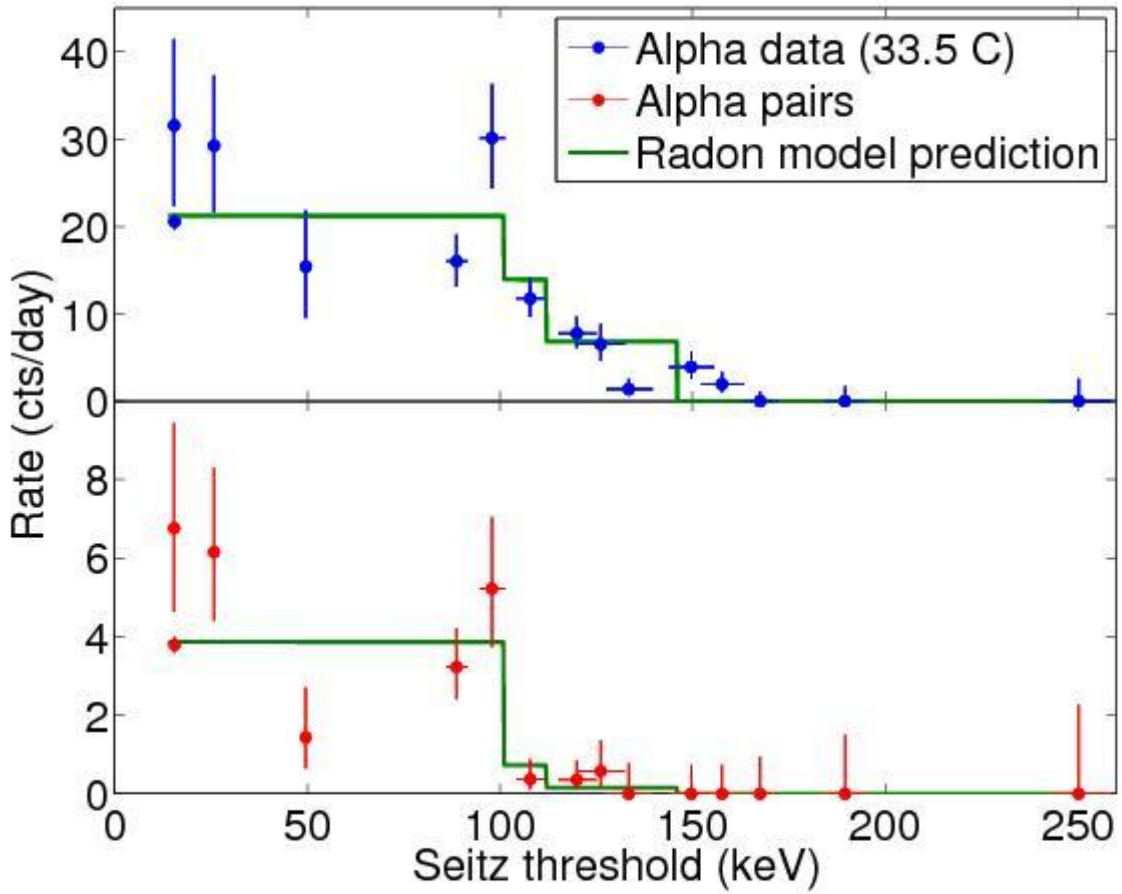
- COUPP-4 has demonstrated superb gamma rejection and that alpha backgrounds can be acoustically rejected. Neutron backgrounds are dominant.
- Results are world leading in SD direct detection and there is a path to competitive SI sensitivity.
- COUPP-60 is installed at SNOLAB and is taking commissioning data. Physics data within days.
- COUPP-500 design is funded and well underway for construction in 2014-2015. The collaboration is growing rapidly for the move to ton-scale.
- COUPP-4 is being rebuilt as a C_3F_8 chamber as a joint COUPP/PICASSO effort with excellent sensitivity to light WIMPS, demonstrating the versatility of the technology to multiple targets.

Backup

Alpha timing (radon)



Alpha threshold

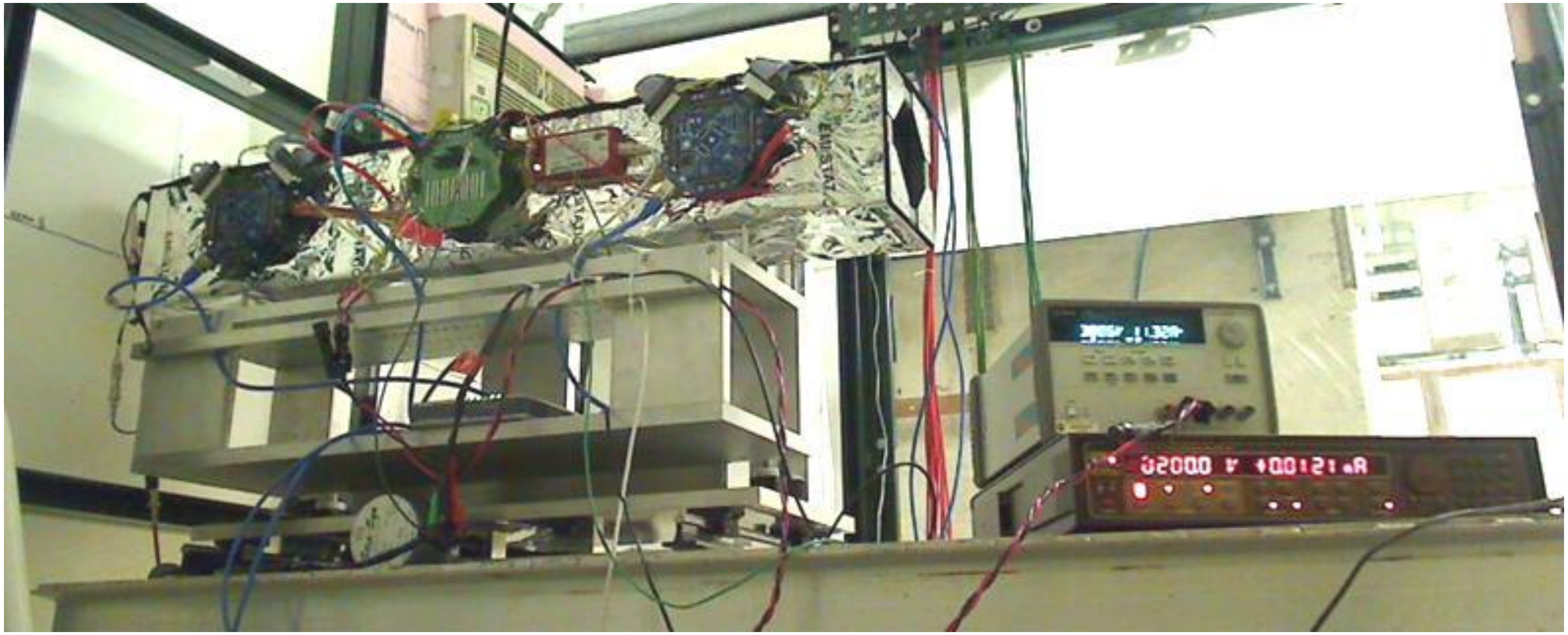


All alphas

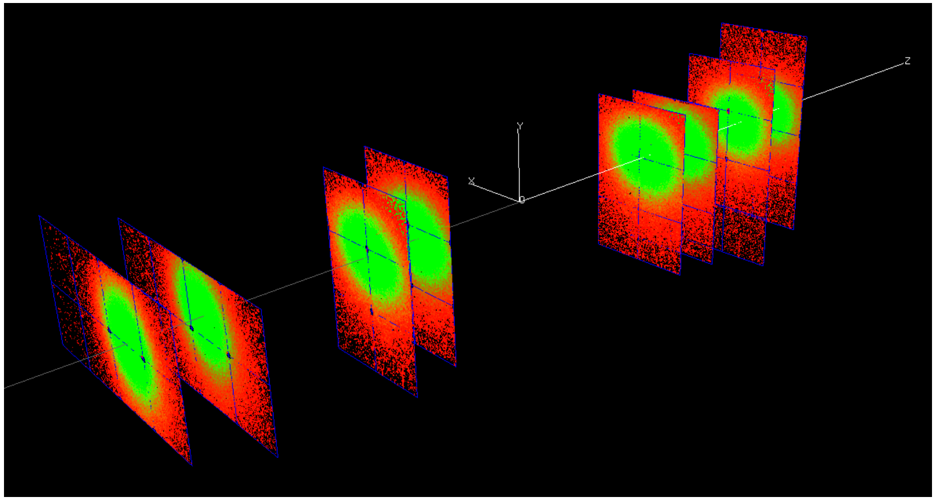
Alphas in <10 min coincidences.

Silicon pixel telescope

8 pixel planes.



4cm x 2cm pixel plane.

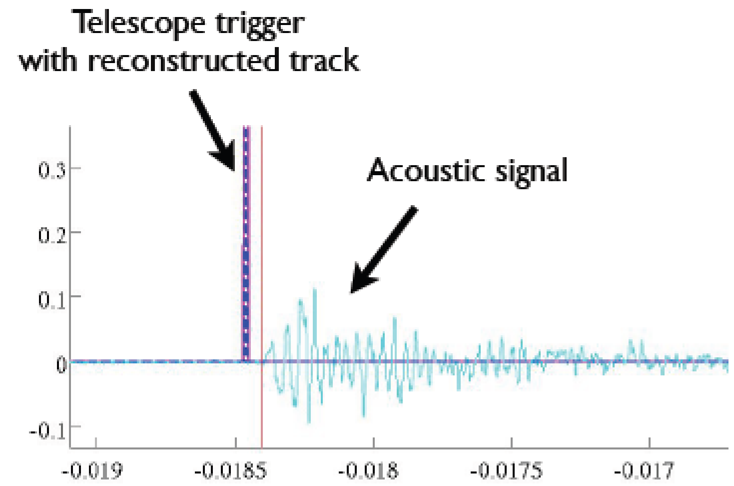


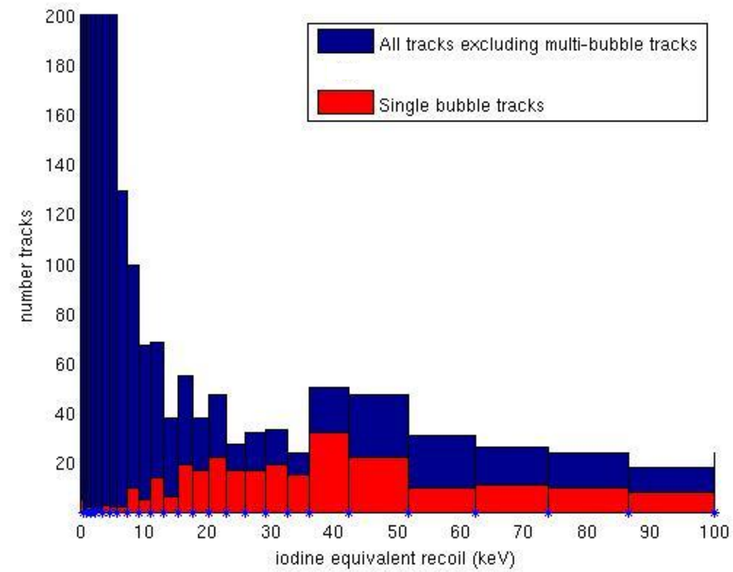
Pion scattering analysis

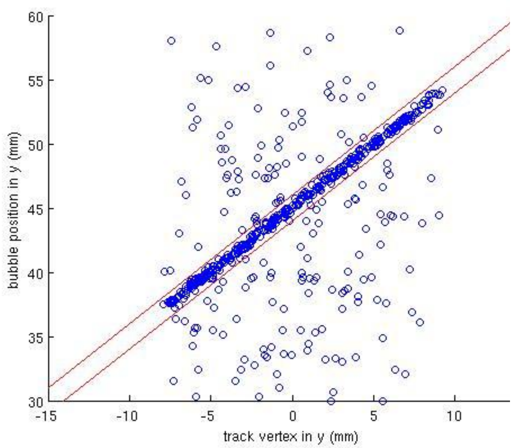
•Bubble timing is determined from the acoustic signal and bubbles are correlated in time and position with pion tracks.

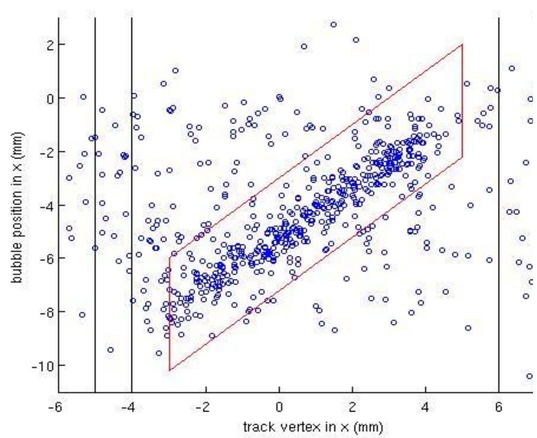
• Multiple bubble events from inelastic interactions are removed from the data set.

• Data taken with CF_3I and with an empty test tube to isolate scattering from CF_3I only.



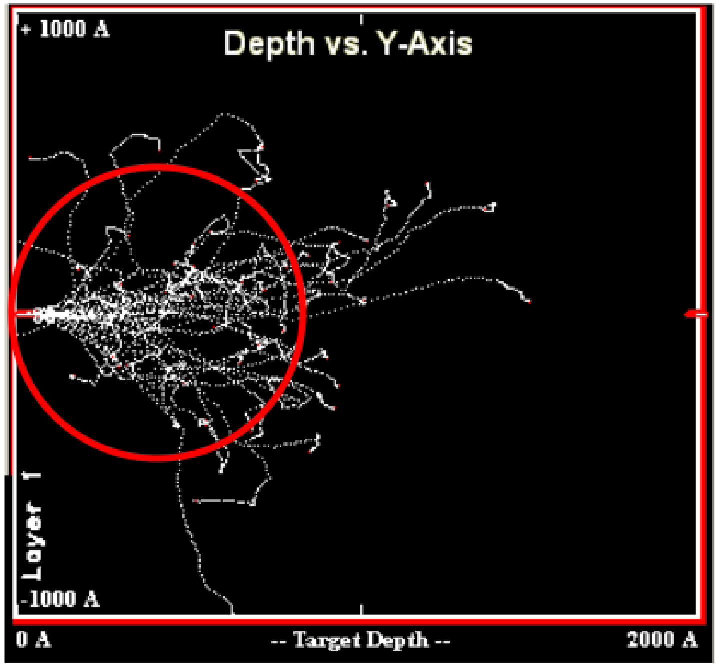


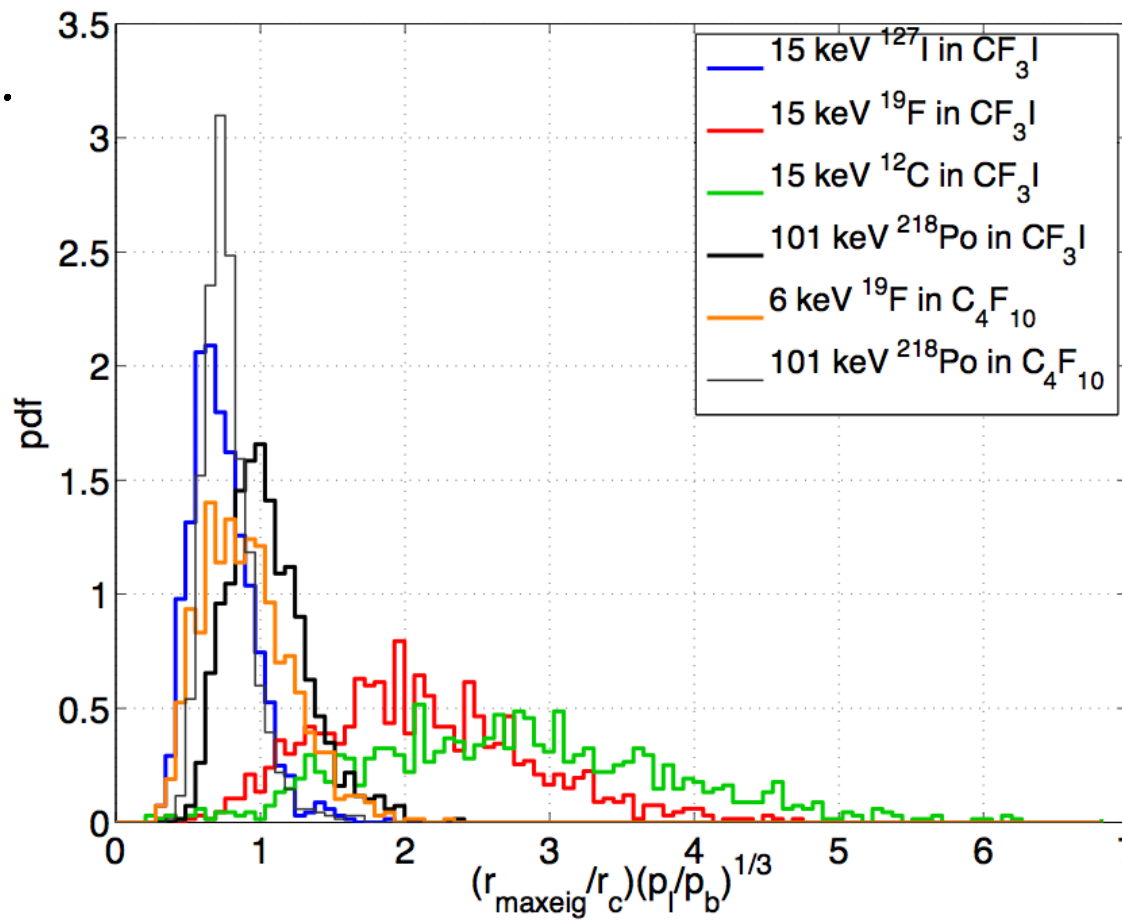




Understanding low efficiency from fluorine recoils

SRIM simulation of 15keV F recoils.





Preliminary ^{88}YBe results

New empirical efficiency curve

$$P = 1 - \exp\left(-\alpha\left(\frac{E_r - E_{th}}{E_{th}}\right)^{\beta}\right)$$