Dark Matter Search Results from the COUPP 4kg Bubble Chamber at SNOLAB

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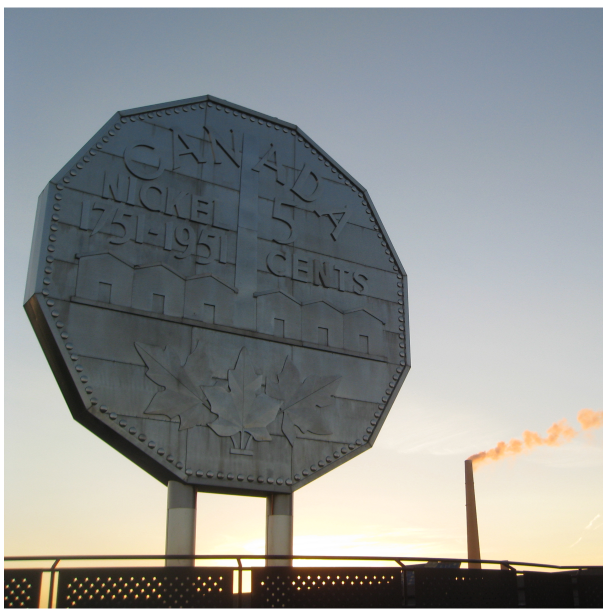

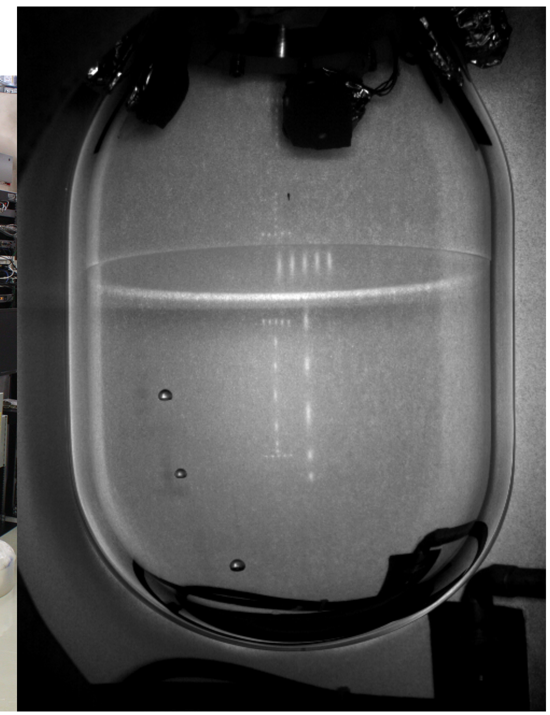

COUPP Collaboration

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KICP Kavli Institute for Cosmological Physics at the University of Chicago

SNOLAB Mining for knowledge / Creuser pour trouver... l'excellence

Northwestern University

Fermilab

Indiana University South Bend

Virginia Tech

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U.S. Department of Energy

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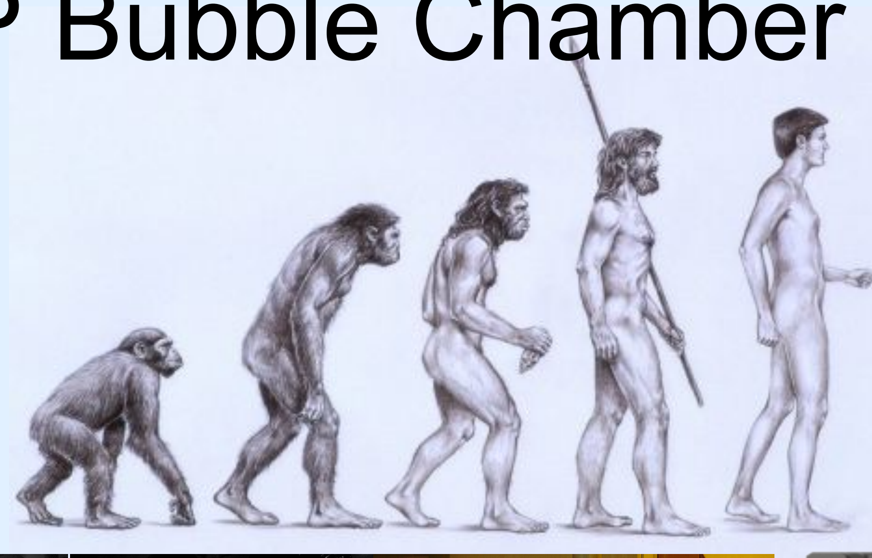
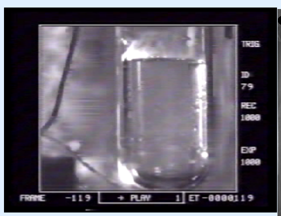
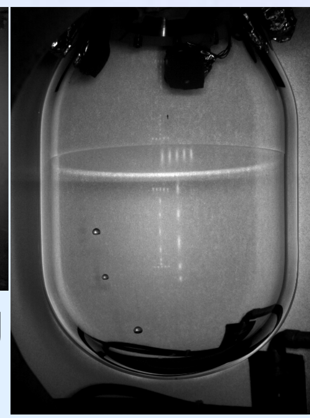
COUPP Bubble Chamber Program





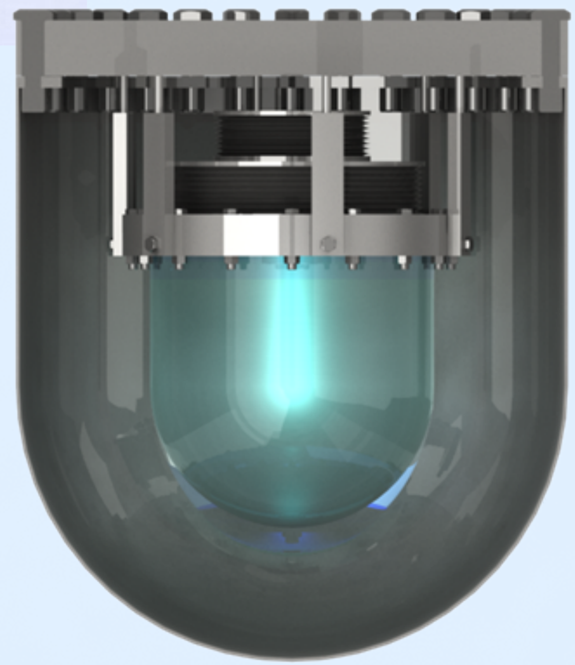
Test tube

COUPP 2kg



COUPP 4kg

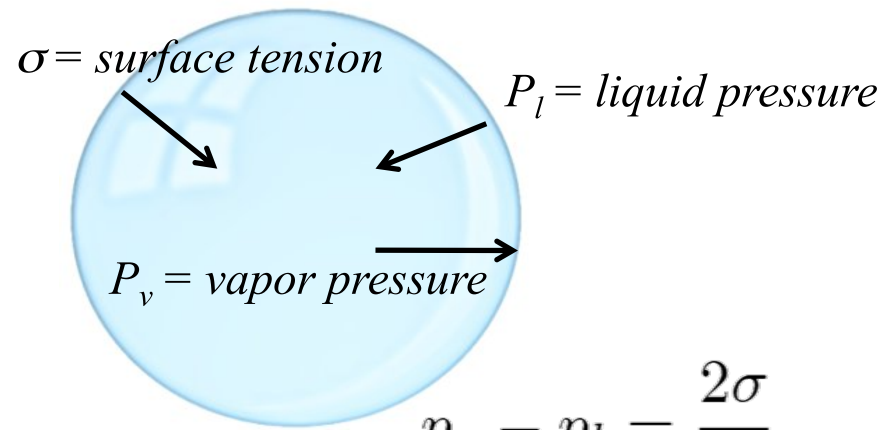
COUPP 60kg



COUPP 500kg

The Physics of Bubble Nucleation

- Energy from particle interactions produces “proto-bubbles”
- Macroscopic bubbles arise from proto-bubbles with radius $r > r_c$
- The energy threshold E_{th} is the energy required to produce a critical radius bubble
- Bubble nucleation requires $E_R > E_{th}$ *and* recoil path length < R_c



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

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

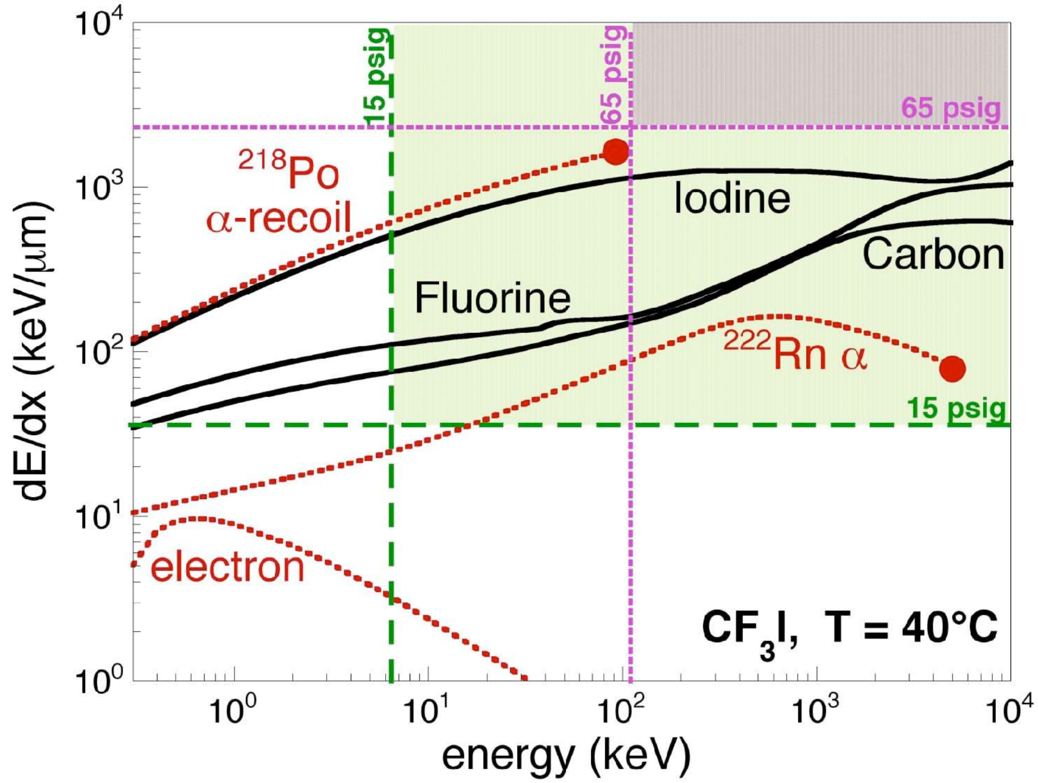
Surface energy

Latent heat

Seitz “Hot Spike” Model
Phys. Fluids 1, 2 (1958)

The Physics of Bubble Nucleation

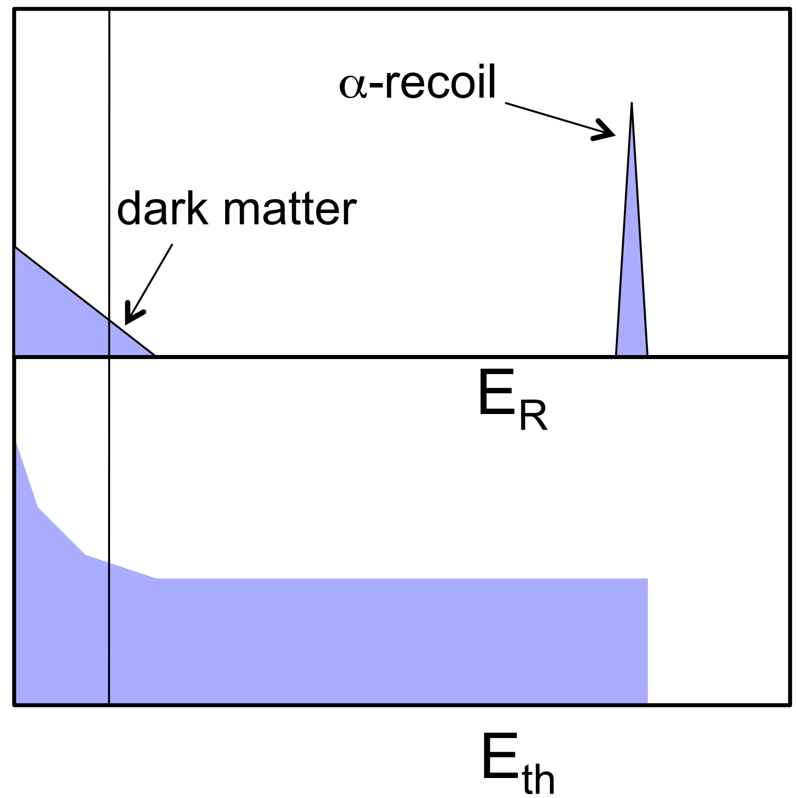
- Tune Temperature T and Pressure P for set nuclear recoil threshold.
- No sensitivity to electron recoils



The Bubble Chamber is a Threshold Device

We do not measure E_R…

…we measure $\int_{E_{th}}^{\infty} \frac{dN}{dE_R} dE_R$

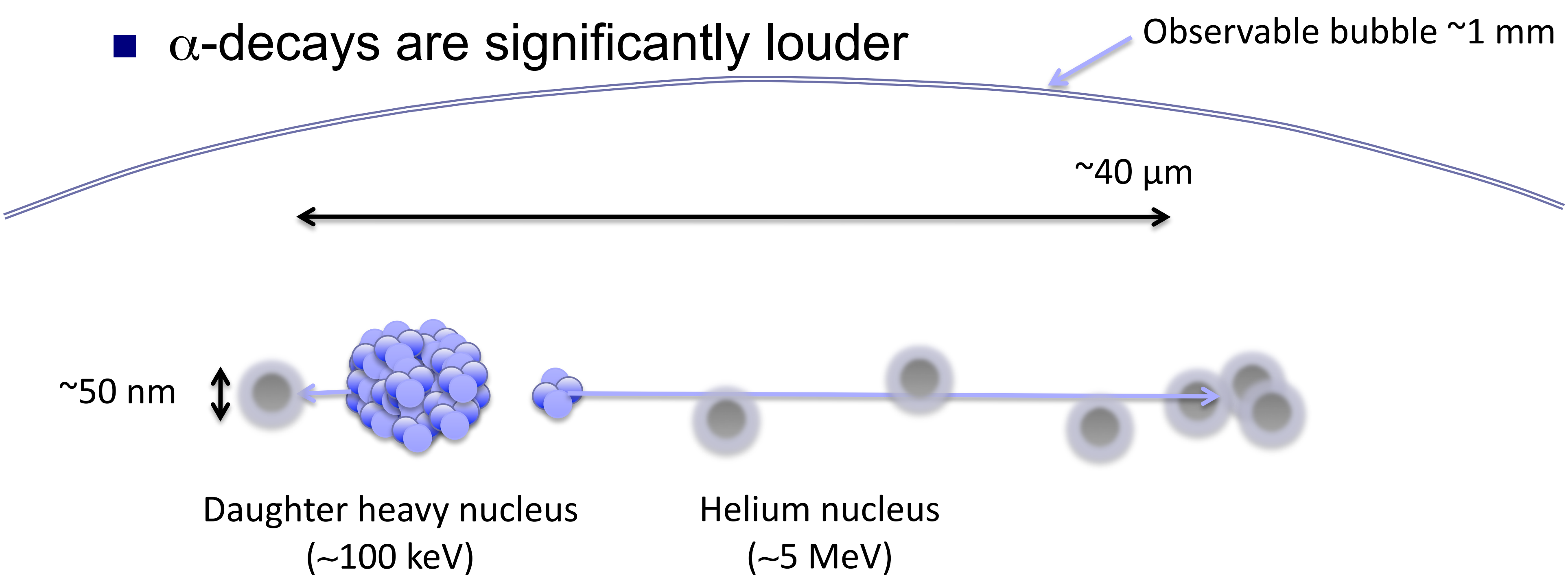


…so bubbles initiated by recoiling α-decay daughters are counted along with dark matter candidate events.

The Physics of Bubble Growth

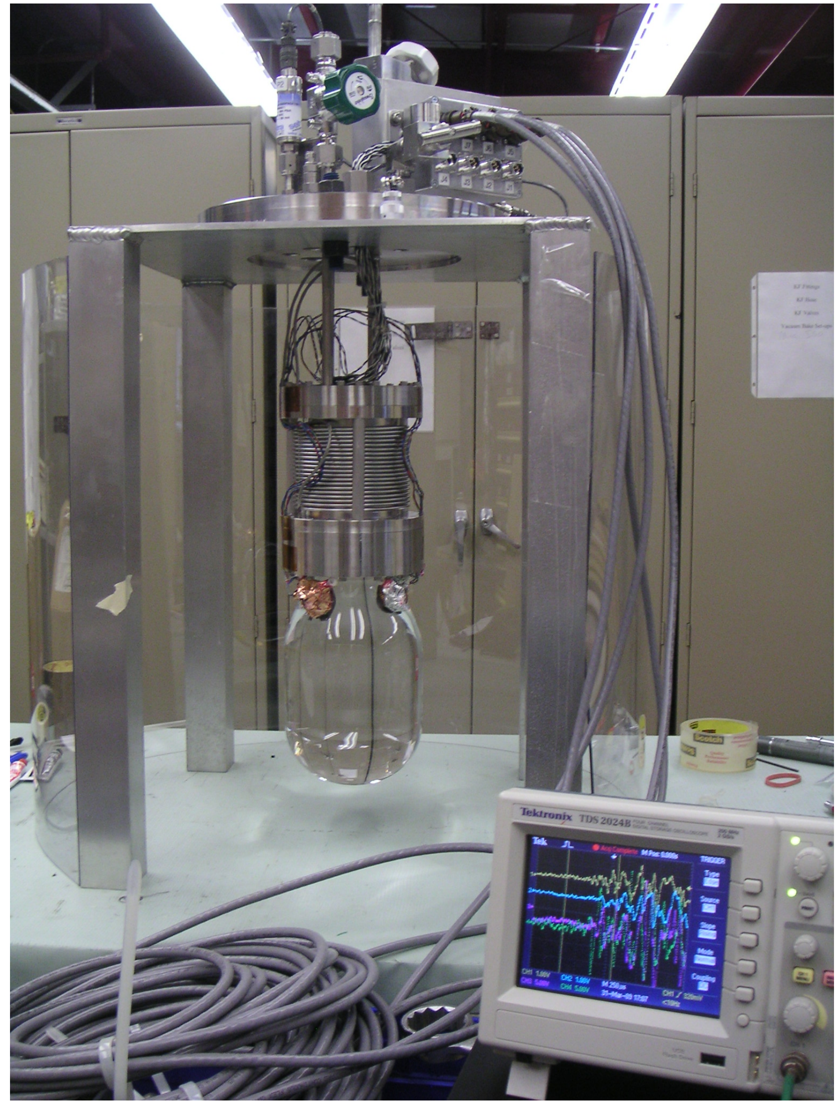
PICASSO (Aubin et al., arXiv:0807.1536)

- Sound emission from a bubble peaks at r_{bubble} ~ 10 um
- Clear acoustic signature for a *single* nuclear recoil
- α-decay results in separate nucleation sites ~ 40 μm
- α-decays are significantly louder



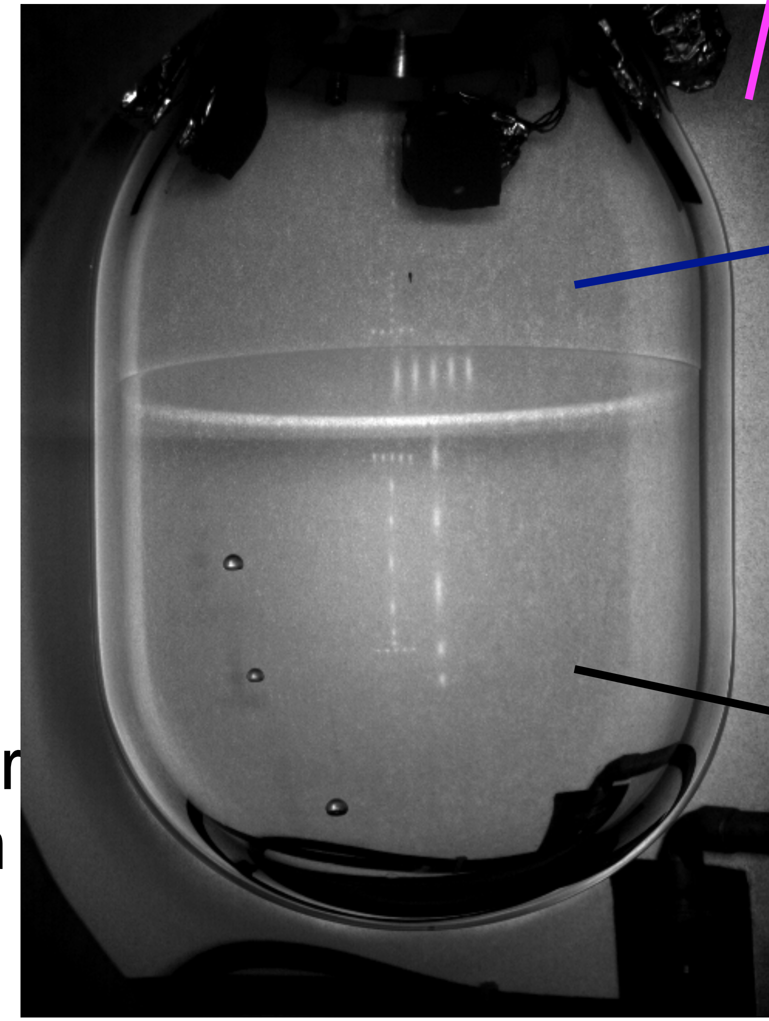
The Bubble Chamber

- 150 mm diameter fused silica jar
- Closed by a flexible stainless steel pressure balancing bellows
- Instrumented with
  - Temperature, Pressure Transducers
  - Fast Transient Pressure Transducer
  - Piezo Electric Acoustic Transducers
- Immersed in hydraulic fluid within a stainless steel pressure vessel
- Hydraulic pressure controls the superheated fluid pressure
- Viewed by machine vision cameras

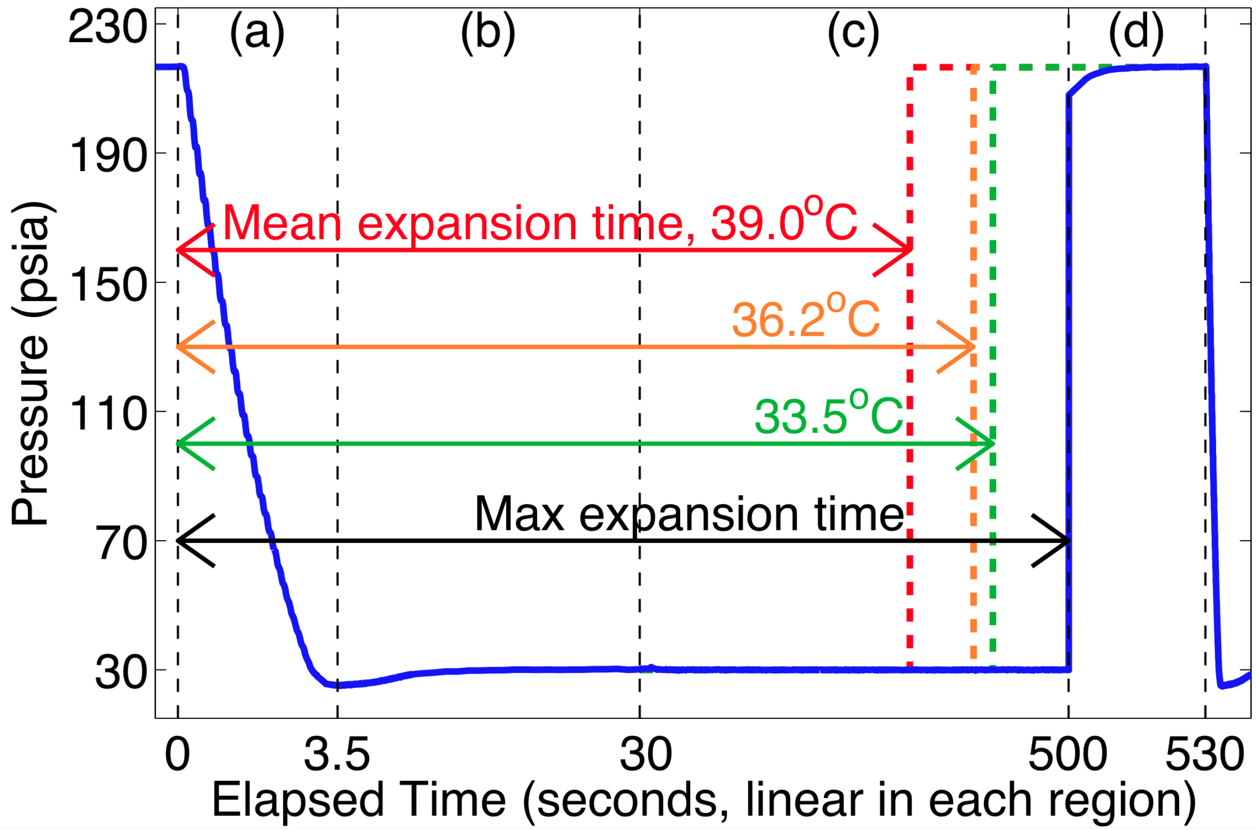


The Bubble Chamber

- Superheated CF_3I target
  Spin-indep
  Spin-dep
- Particle interactions nucleate bubbles
- Cameras capture bubbles
- Data Logged, Chamber compressed after each event

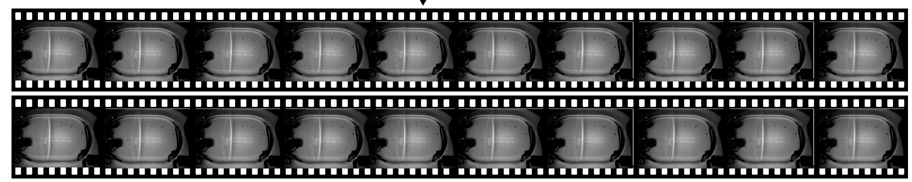


Bubble Chamber Operation Cycle



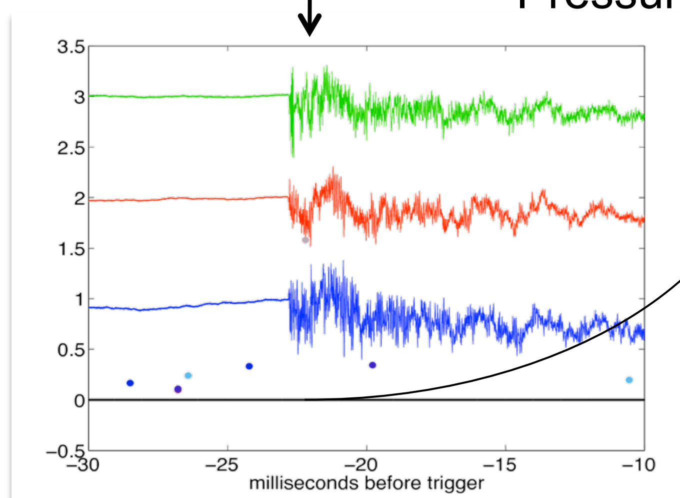
The Data

- 10 frames of Stereo Camera Images



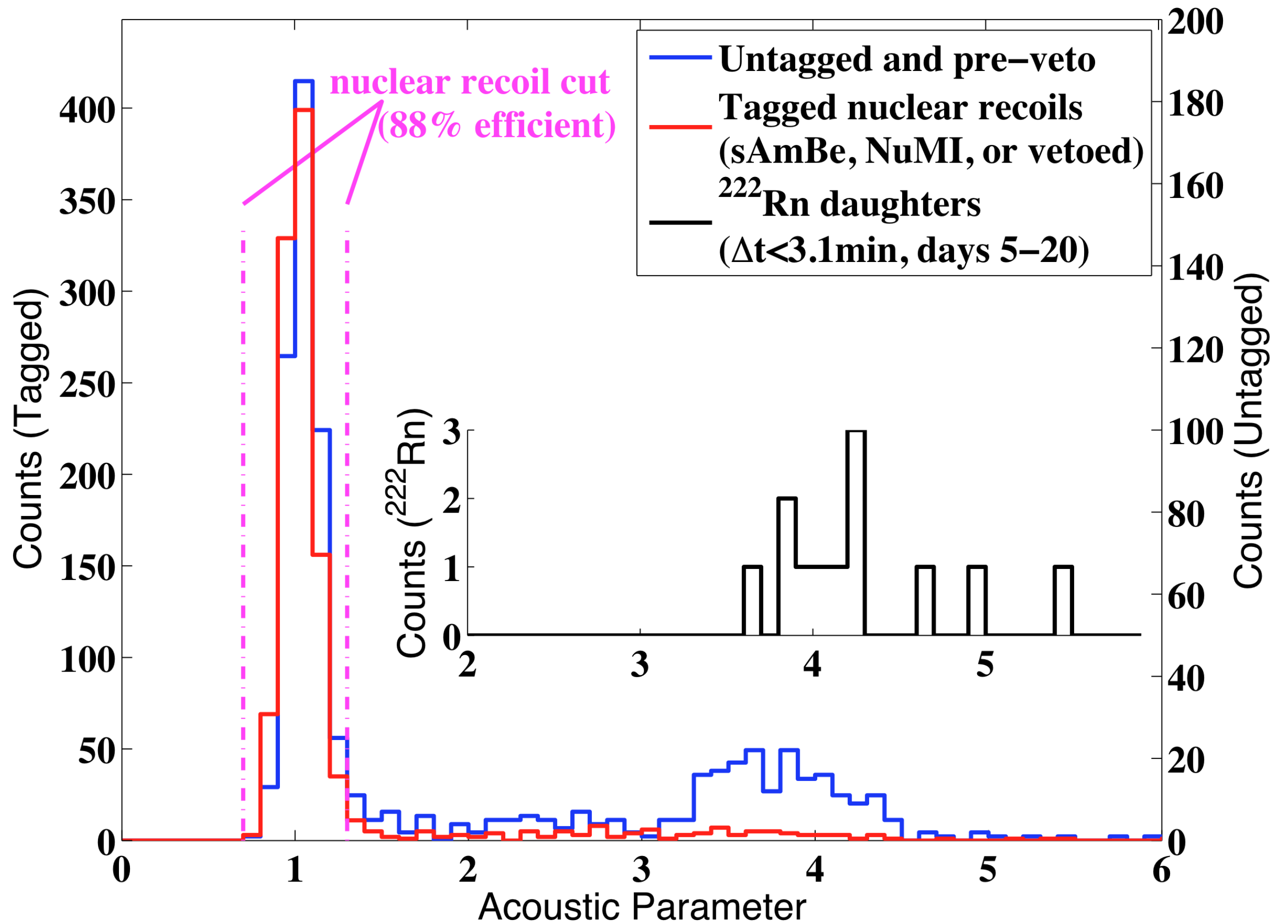
- Synchronized measurements of P, T, and control parameters

- 2.5 Mhz waveform digitizer for acoustics and fast pressure transducer.



Acoustic Parameter

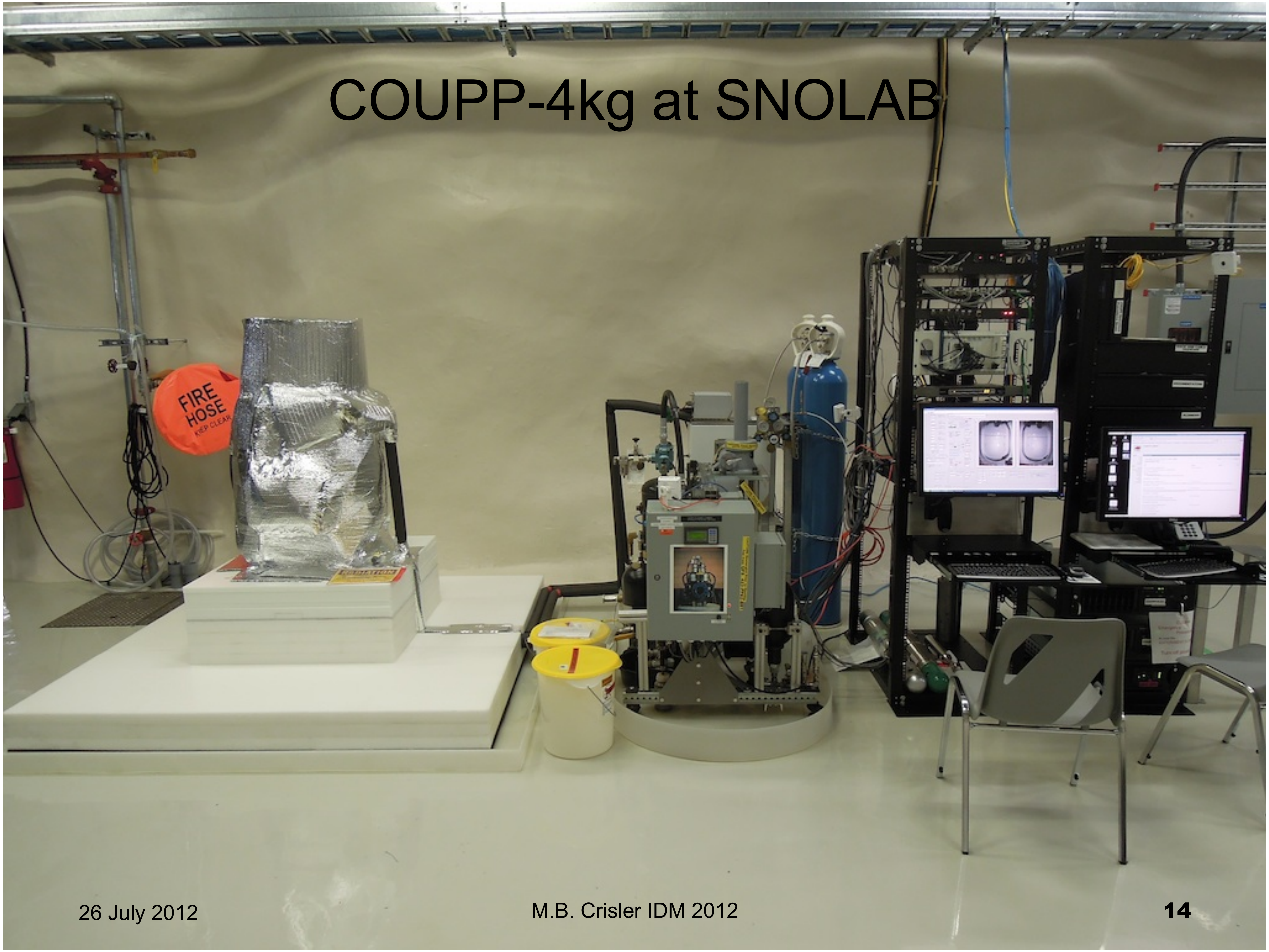
- $(Amp \bullet \omega)^2$ (Normalized and position-corrected for each freq-bin)
- Measure of acoustic energy deposited in chamber
- Alphas are louder than neutrons



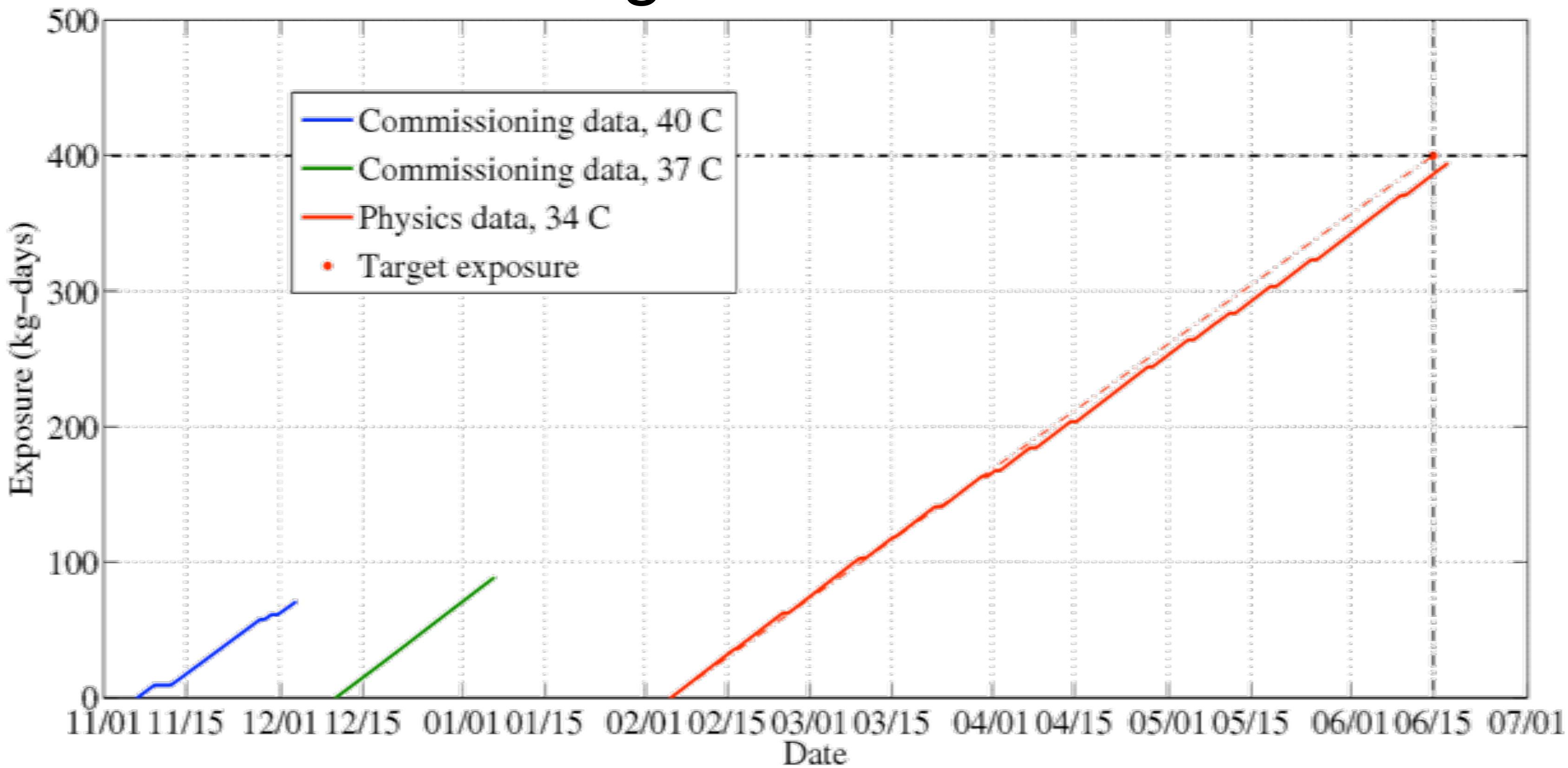
Dark Matter Bubble Chambers

- Insensitive to γ and β backgrounds
- Threshold device, integral distribution
- Event-by-event tagging of α-recoils
- Only background should be neutrons

COUPP-4kg at SNOLAB



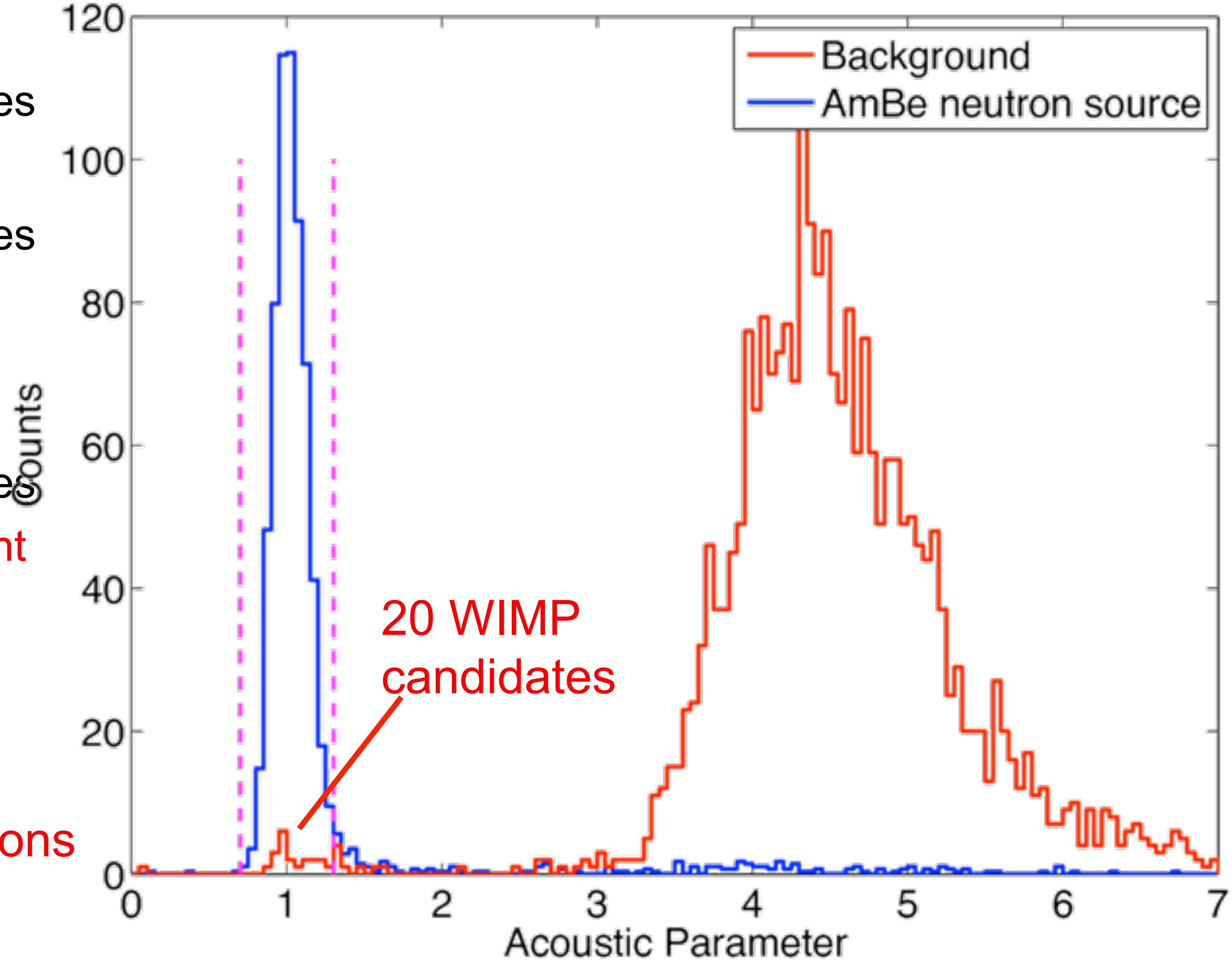
COUPP-4kg SNOLAB Data Sets



- 17.4, 21.9, 97.3 live-days at 8, 10, 15 keV thresholds
- 4.048 kg target, 79% cut-efficiency for nuclear recoils
  - 90% quality cuts, 92% fiducial cut, 96% acoustic cut

COUPP 4kg @ SNOLAB

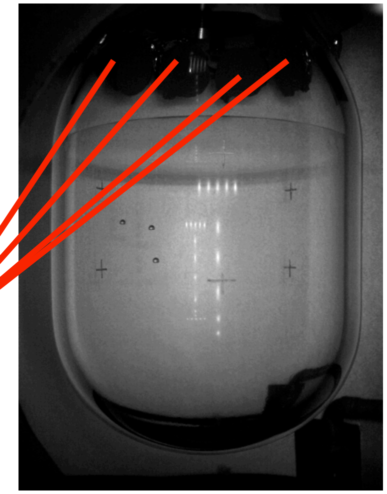
- At 8 keV: **
  - 6 WIMP candidates
- At 10 keV: *
  - 6 WIMP candidates
  - 2 three-bubble events
- 15 keV data set:
  - 8 WIMP candidates
  - 1 two-bubble event
- α rejection >98.9%
- α rejection > 99.3% 15 keV data
- 2,3 bubbles = neutrons

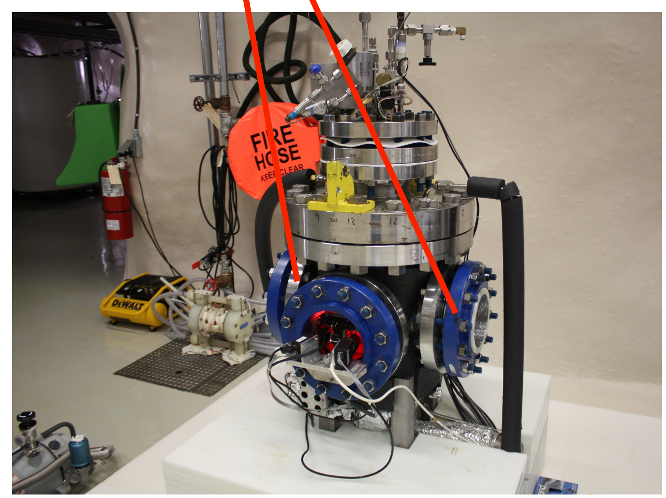


Neutron Sources Internal to the Apparatus

- Piezoelectric elements
  - ceramic PZT(Lead zirconate titanate)
- 4.0 ppm ^{238}U - 1.9 ppm ^{232}Th
  plus lots of modern lead with ^{210}Pb
- Both fission and (α,n) on light elements
- Accounts for *~2 background singles*

neutron sources

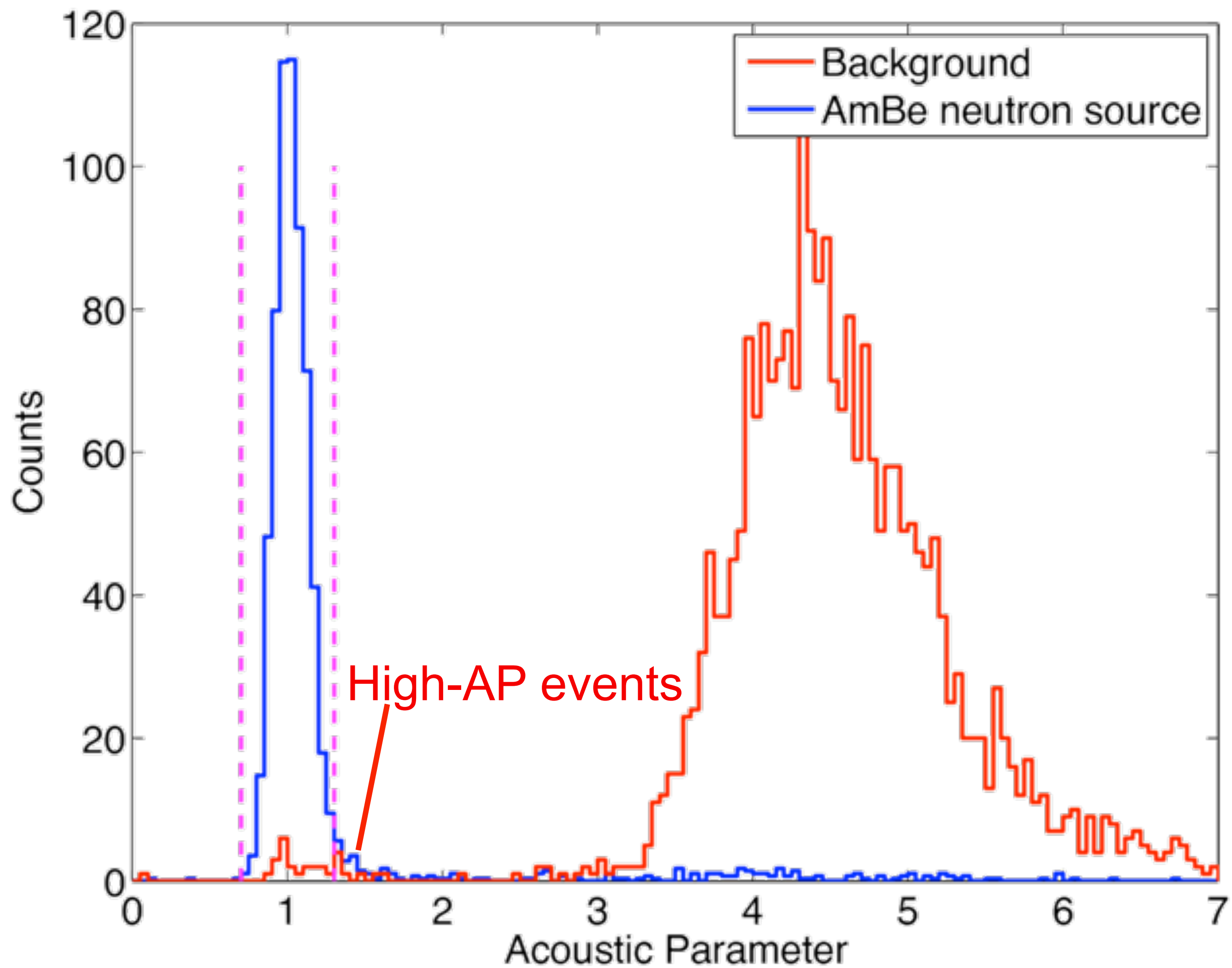




- Camera Viewports
  - Proprietary formulation, probably soda-lime glass
- 0.5 ppm ^{238}U - 0.8 ppm ^{232}Th
- (α,n) on light elements
- Accounts for *~5 background singles*

A New Background?

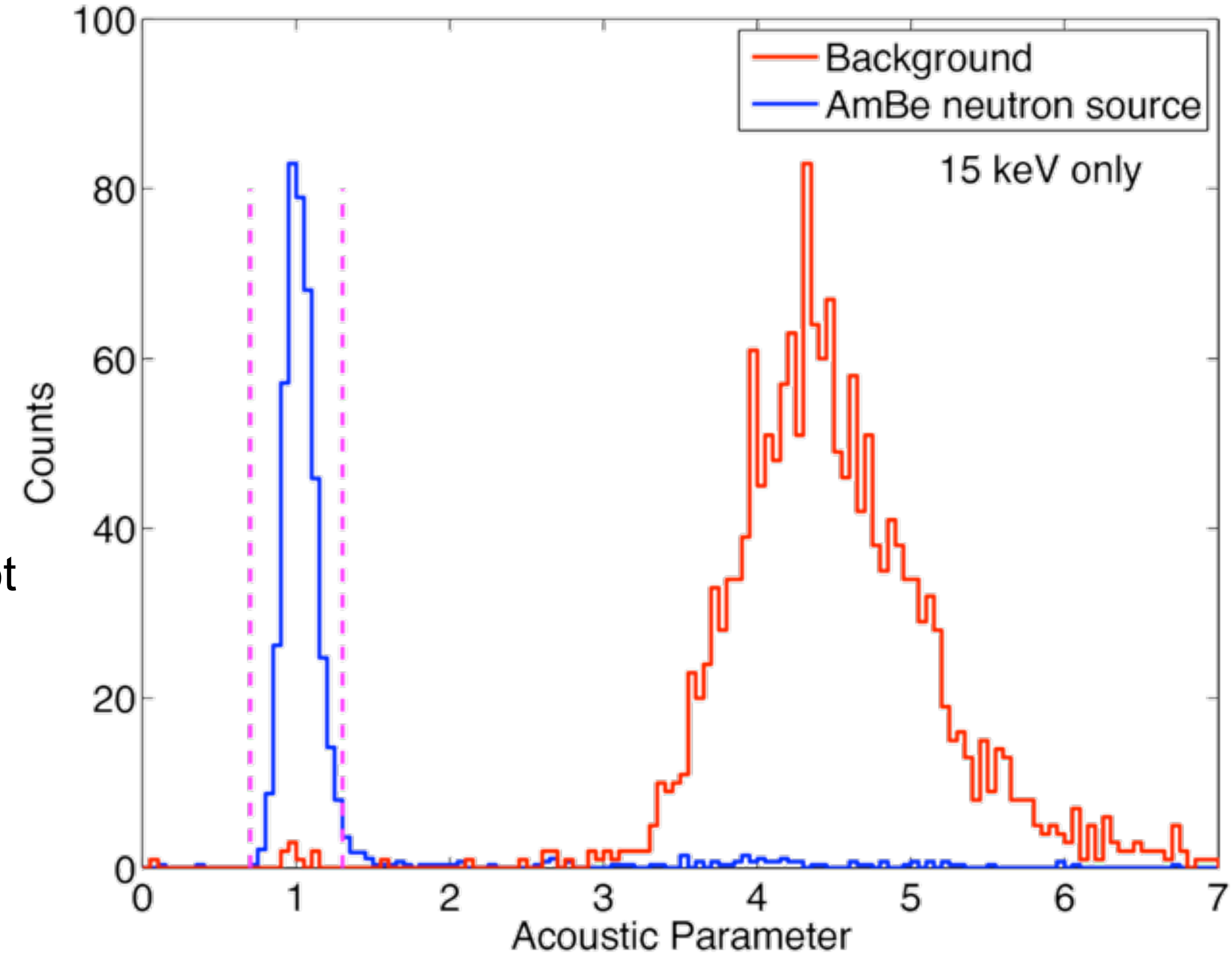
- High AP
  - 4 evts at 8 keV
  - 2 evts at 10 keV
- Clustered in time at 8 keV
  - 3 High-AP evts in 3 hours
  - 4 evts (1 High-AP) in 9 hours
- <10 minutes after normal events
  - At 8 keV: 4/6 “WIMP”s and all High-AP evts
  - At 10 keV: 3/6 “WIMP”s and 1/2 High-AP evts



A New Background?

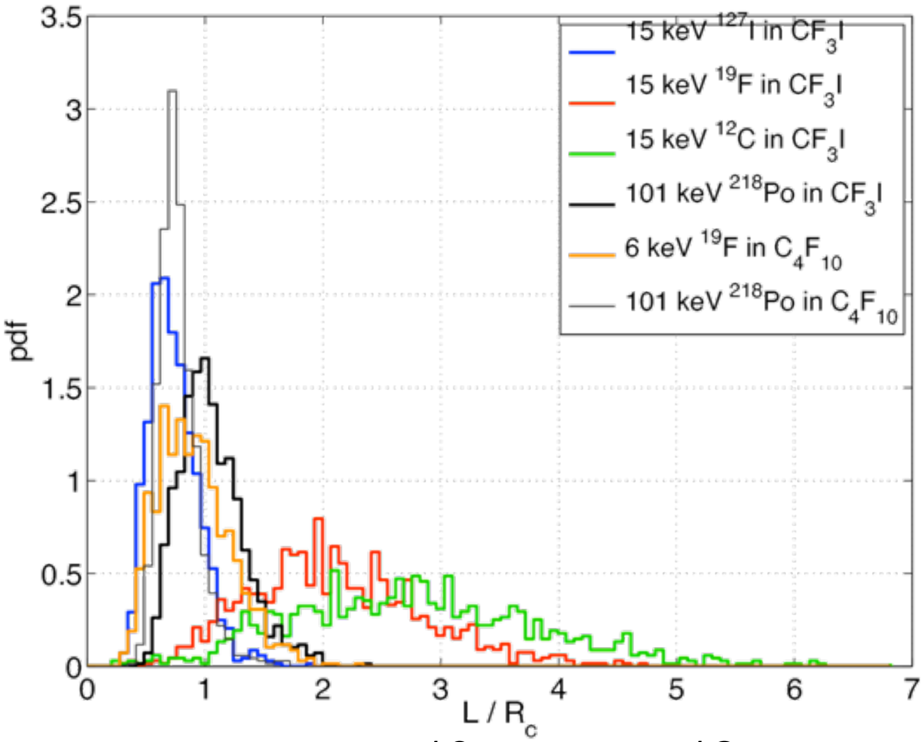
- No anomalous background at 15 keV
- Still investigating source of this background
- Almost certainly not WIMPS!

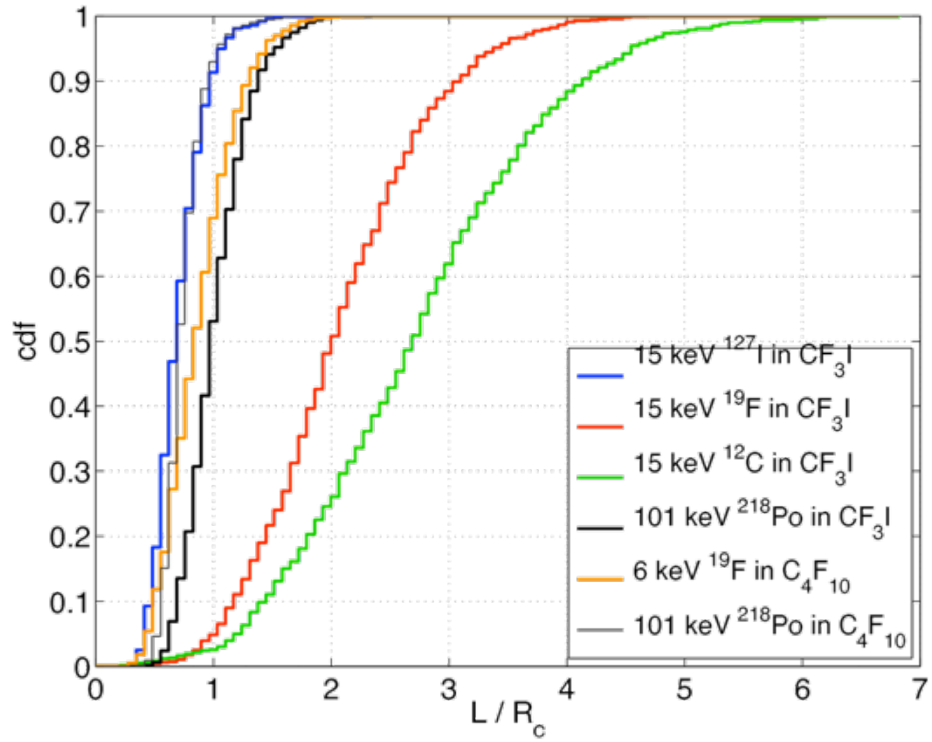
  (But counted as WIMP candidates in limit calculation)



Threshold and Efficiency: SRIM simulation

- Which recoils cause problems…



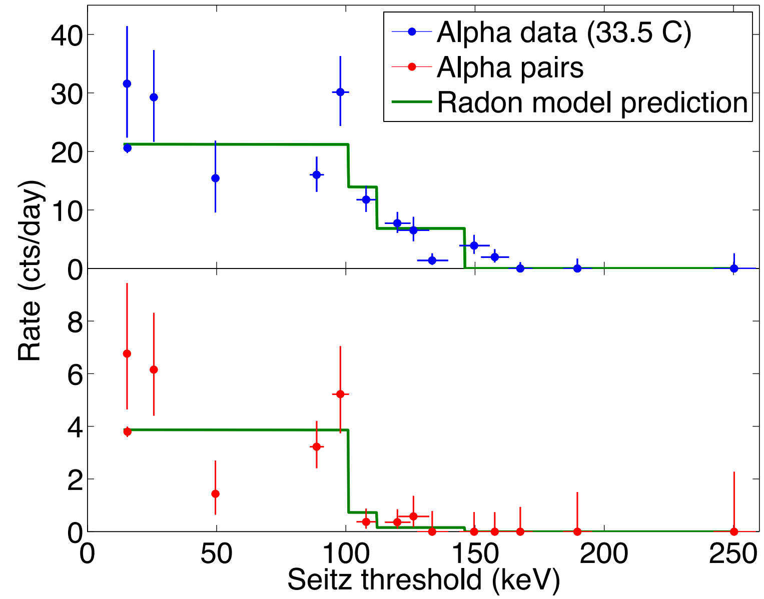


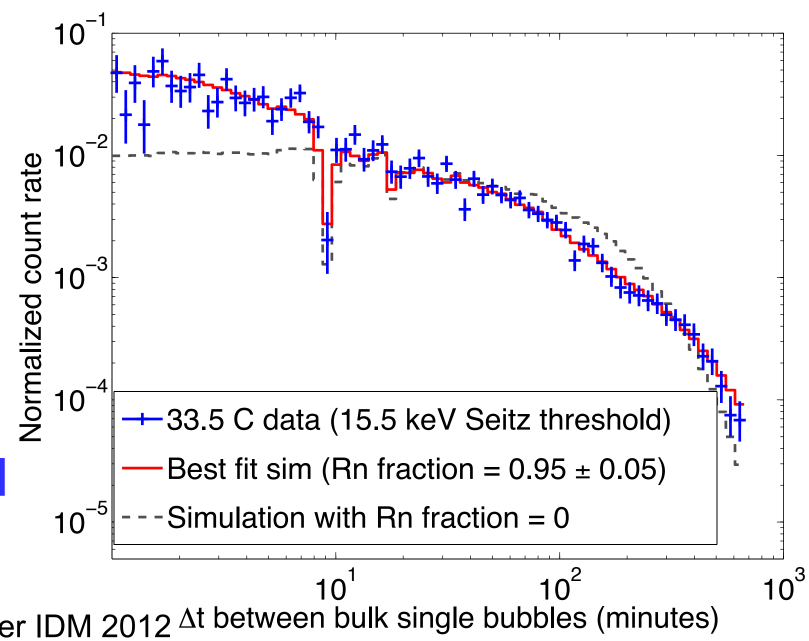
- 15 keV ^{19}F and ^{12}C in CF_3I have tracks significantly longer than critical radius

Infer Iodine recoil effciency from 222Rn chain:

- ΔT Analysis shows:
  - 95+-5% radon
  - 100% nucleation efficiency
  - A event population consists of
    - ^{222}Rn   101 keV
    - ^{218}Po   112 keV
    - ^{214}Po   146 keV

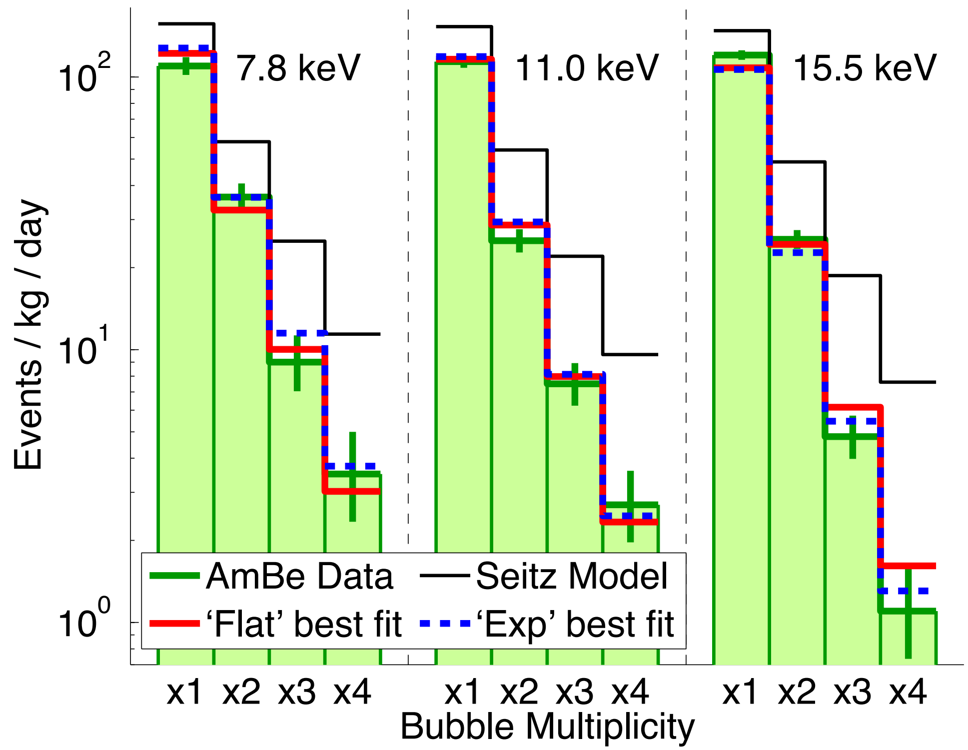
- Threshold Scan shows:
  - Correct Seitz Model Thresholds
  - ^{222}Rn nucleation efficiency is >75% (90% CL) at 100 keV
- *Iodine Recoils should be similar*
- NEEDS EXPLICIT CONFIRMATION



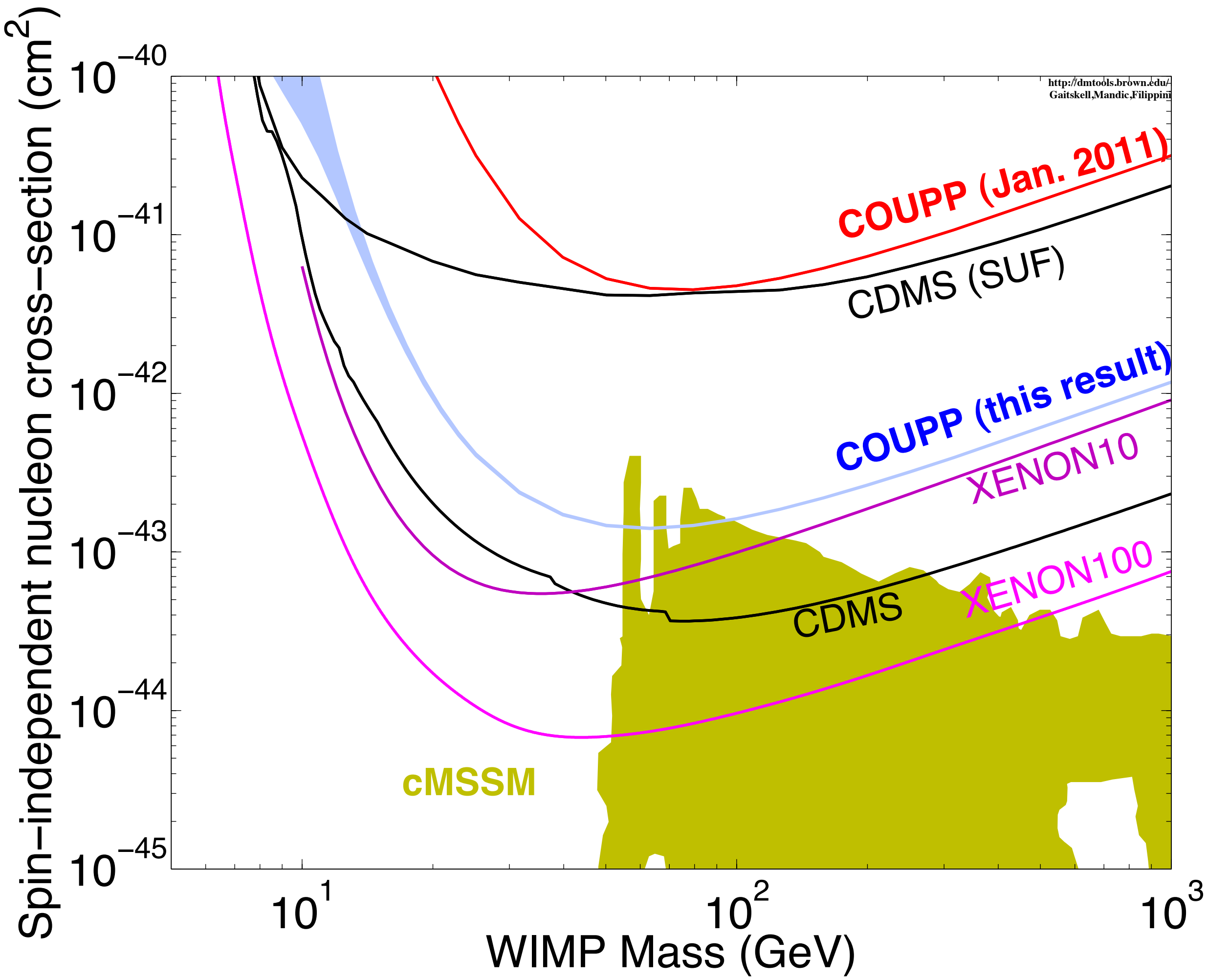


Neutron Calibration Results

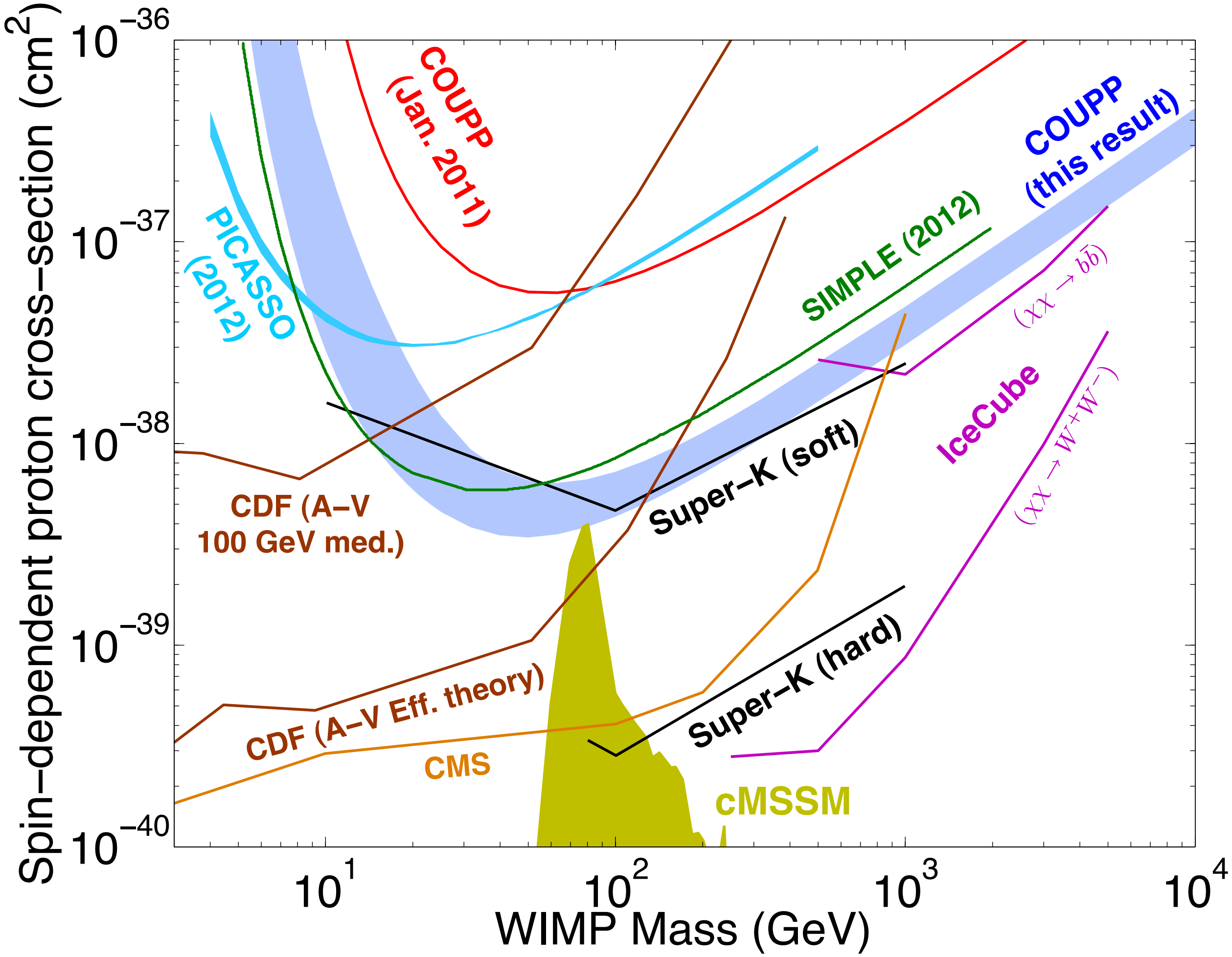
- Treat ^{127}I recoils according to the Seitz Model
- Assume functional form for ^{19}F and ^{12}C recoils
  - "flat model" = step function at Seitz threshold, finite efficiency $\eta_{C,F}$
  - "PICASSO MODEL"
  - $P(E_R,E_T) = 1-\exp(-\alpha_{C,F}(E_R-E_T)/E_T)$
- Both Models Fit:
  - $\eta_{C,F} = 0.49$, $\alpha_{C,F} = 0.15$
- …but predict very different behavior near threshold.
- NEW CALIBRATION TECHNIQUE NEEDED



Spin-Independent Limits



Spin-Dependent Limits



Summary

- Spin-Independent
  - We're on the map. But our Iodine threshold understanding is indirect.
  - New result coming on Iodine threshold. See Hugh Lippincott's talk on tagged iodine recoils via pion elastic scattering.
- Spin-Dependent
  - Good results, in spite of poor ^{19}F nucleation
  - Better understanding coming… See Alan Robinson's talk in this session on our NEW Y-Be calibration technique.

Future

- COUPP-4.1 New SNOLAB Running
  - Low background piezos, low background viewport
  - Improved CF3I purity, Improved Cleaning
  - New results later this year
- COUPP-60 installation in progress at SNOLAB.
  - See Andrew Sonnenschein's talk in this session
- COUPP-500 engineering design in progress
  - See Eric Vazquez-Jauregui's talk this session