Searching for dark matter with COUPP

Hugh Lippincott for the COUPP Collaboration

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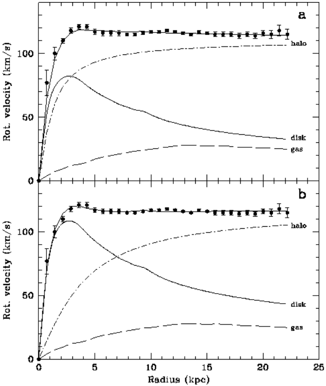
TIPP
Chicago, IL

The COUPP Collaboration

- University of Chicago: Juan Collar (PI, spokesperson), C. Eric Dahl, Drew Fustin, Alan Robinson
- Indiana University South Bend Ed Behnke, Joshua Behnke, Tonya Benjamin, Austin Connor, Cale Harnish, Emily Grace Kuehnemund, Ilan Levine(PI), Timothy Moan, Thomas Nania
- Fermilab: Steve Brice, Dan Broemmelsiek, Peter Cooper, Mike Crisler, Jeter Hall, Martin Hu, Hugh Lippincott, Erik Ramberg, Andrew Sonnenschein, Fermilab Engineers and Technicians
- SNOLAB: Eric Vazquez Jauregui
- Virginia Tech: Shashank Priya

Dark matter



- We think dark matter exists
- We are looking for dark matter particles

How do we find it?

- WIMPs can scatter elastically with nuclei, and the recoil can be detected directly
  - The energy deposited by dark matter in an elastic collision is $\sim$10-100 keV
  - Looking for a handful of events per year

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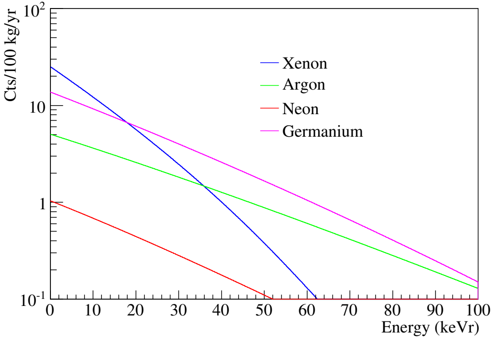
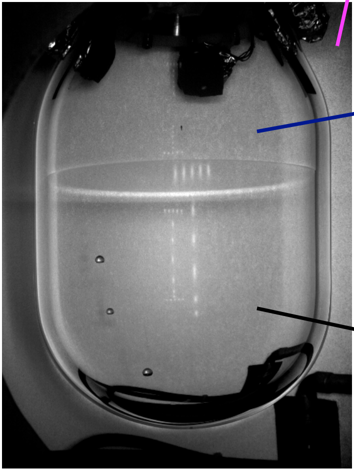
- WIMPs can scatter elastically with nuclei, and the recoil can be detected directly
  - The energy deposited by dark matter in an elastic collision is ∼10-100 keV
  - Looking for a handful of events per year

Integrated rate above threshold, 100 GeV WIMP, $\sigma_0 = 10^{-45}$ cm^2



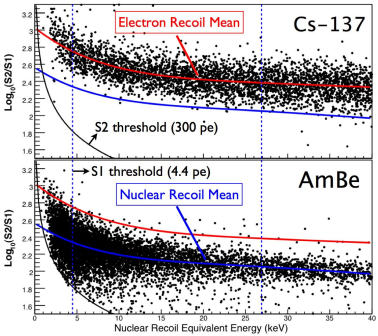
COUPP bubble chambers

- Superheated fluid, CF_3I or other
  - F for spin-dependent
  - I for spin-independent
  - Other - e.g. C_3F_8 for a light WIMP search
- Particle interactions nucleate bubbles
- Cameras see the bubbles
- Recompress the chamber to start over

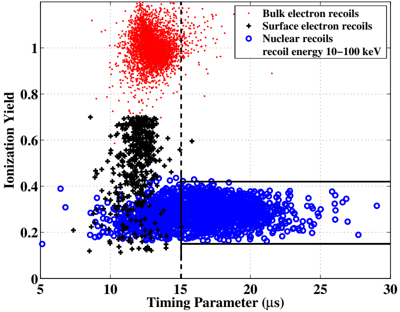


Why bubble chambers?

- A lot of effort goes into discriminating electronic recoils produced by electrons and gamma rays from nuclear recoils produced by neutrons and WIMPs



- Xenon S1/S2 discrimination



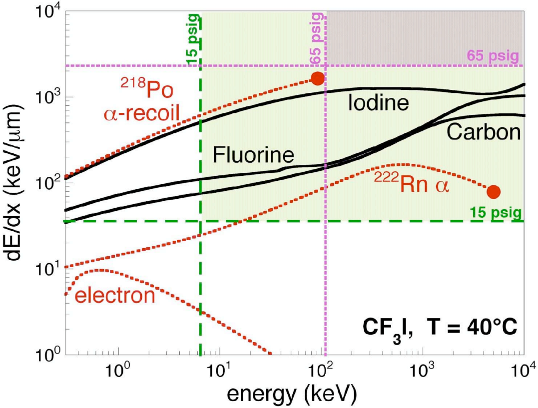
- Charge and timing parameters in CDMS

Why bubble chambers?

- A lot of effort goes into discriminating electronic recoils produced by electrons and gamma rays from nuclear recoils produced by neutrons and WIMPs
- Bubble nucleation depends on both total energy deposited and the density of energy deposition
  - Two thresholds for nucleation: E and dE/dx
- By choosing superheat parameters (temperature and pressure), bubble chambers are blind to electronic recoils

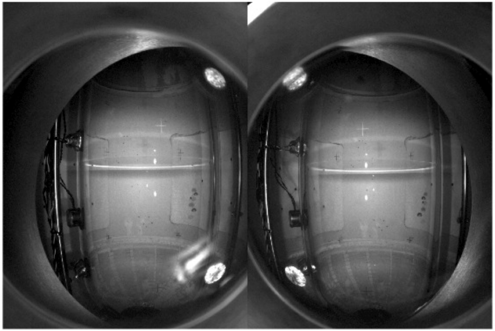
Why bubble chambers?

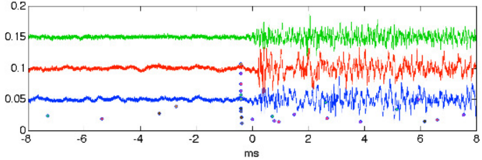
- A lot of effort goes into discriminating electronic recoils produced by electrons and gamma rays from nuclear recoils produced by neutrons and WIMPs



Why bubble chambers?

- Easy to identify multiple scatter events $\rightarrow$ Neutron backgrounds
- Relatively easy DAQ and analysis chain
  - Two cameras
  - Piezo acoustic sensors
  - Slow control
- No PMTs, no high voltage



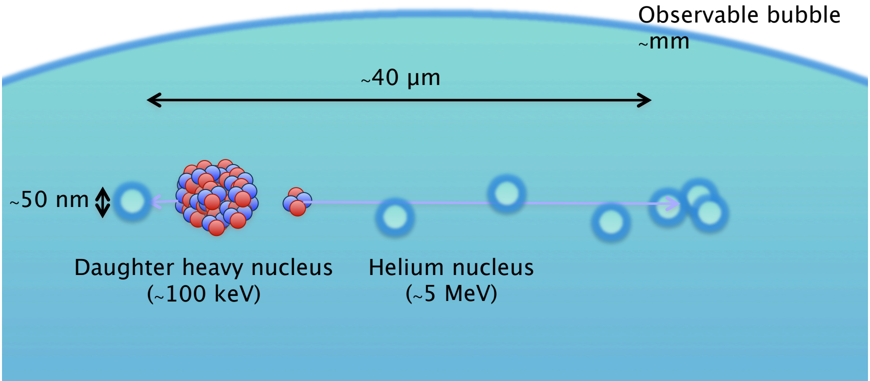


Are there any drawbacks?

- Bubble chambers are threshold detectors - no energy resolution
  - Harder to distinguish backgrounds based on spectral information
    - Alpha backgrounds were big concern
  - Understanding energy threshold - calibrations are complicated and important
- Bubble chambers are slow - $\sim$ 30 s of deadtime for every event
  - Must keep overall rate low

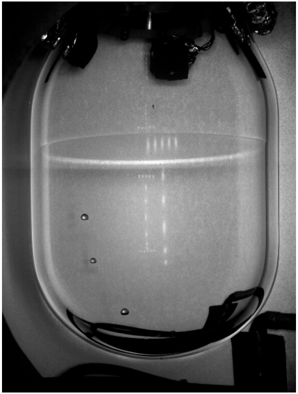
About those alphas...

- 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 in tens of nanometers
- In COUPP bubble chambers, alphas are several times louder

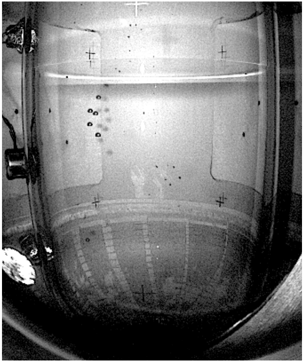


The COUPP program

- COUPP-4: A 2-liter chamber - shallow site in 2009, at SNOLAB since September, 2010
- COUPP-60: A 30-liter chamber commissioning at Fermilab, goal is to move to SNOLAB within a year

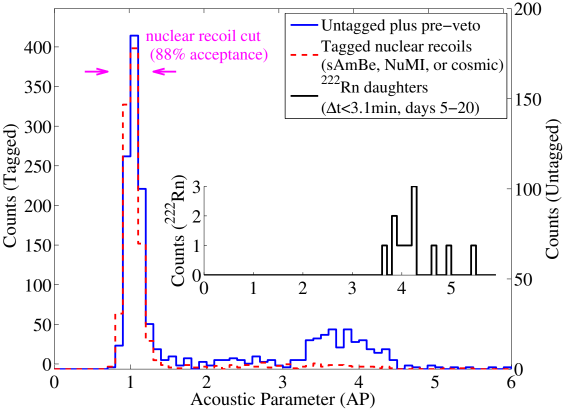


COUPP-4



COUPP-60

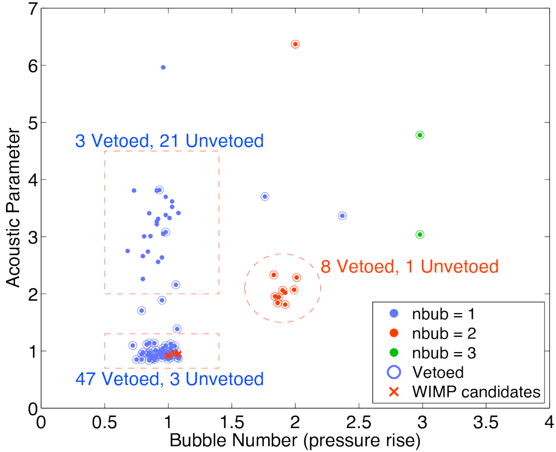
COUPP-4 at Minos in 2009



- AP - "Acoustic Parameter"
  - Measure of acoustic energy deposited in event

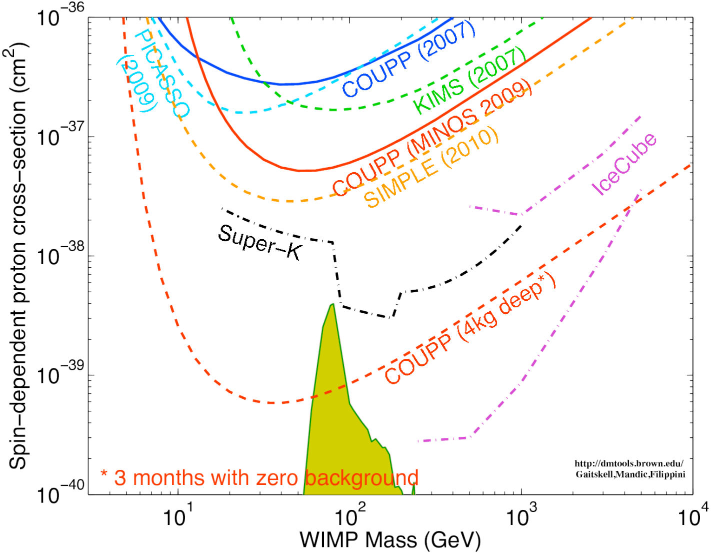
- First demonstration of acoustic discrimination in COUPP bubble chamber

COUPP-4 at Minos in 2009



- 3 ”WIMP” candidates
- Unvetoed 2 bubble event
- At least 74% alpha discrimination

COUPP-4 at Minos in 2009 (PRL, **106**:021303, 2011)



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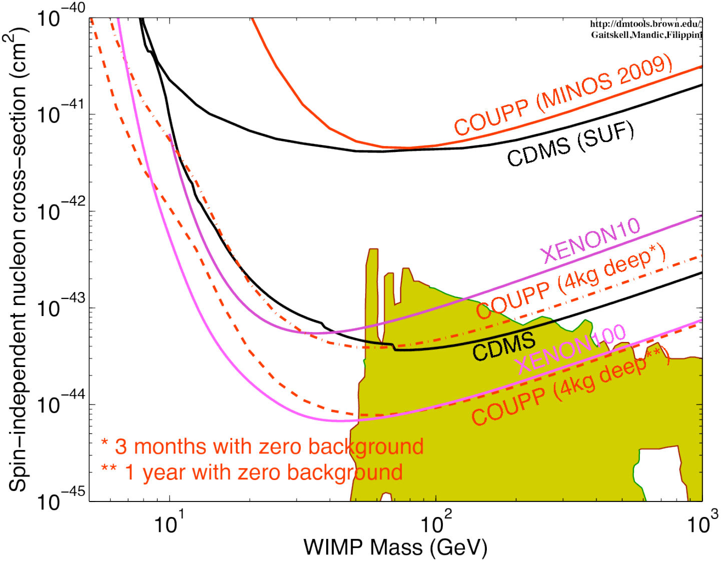

COUPP-4 at SNOLAB

- To SNOLAB at 6800 ft below

COUPP-4 at SNOLAB

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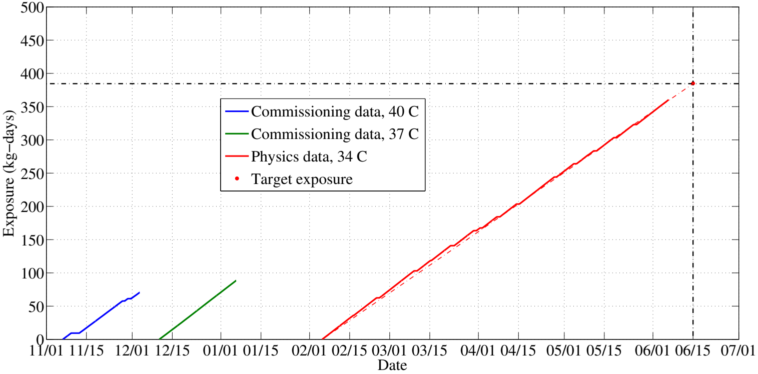
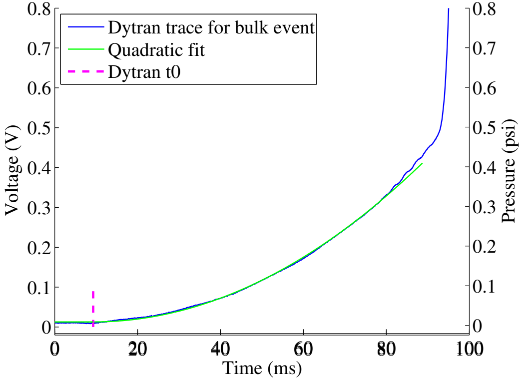
COUPP-4 at SNOLAB

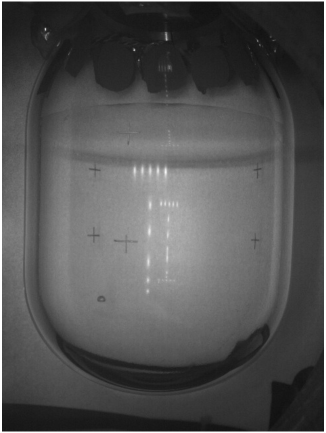
- 17.4 live-days at 7 keV threshold
- 21.9 live-days at 10 keV threshold
- Physics run at 15 keV threshold since February 2, ending June 15



Improvements: the "dytran"

- A fast pressure transducer measures the pressure rise during bubble expansion
- The shape gives position information





- A bulk event is quadratic

Improvements: the ”dytran”

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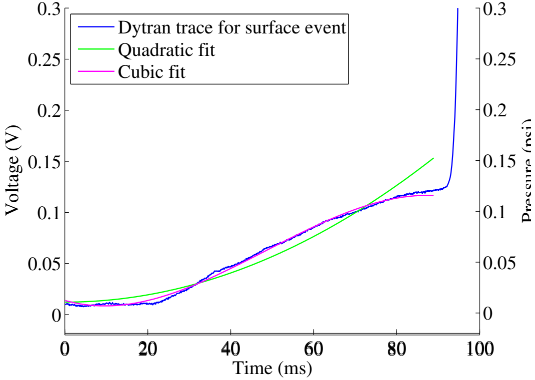

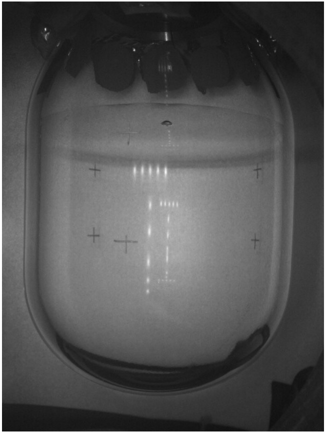

- A surface event turns over

Improvements: the ”dytran”

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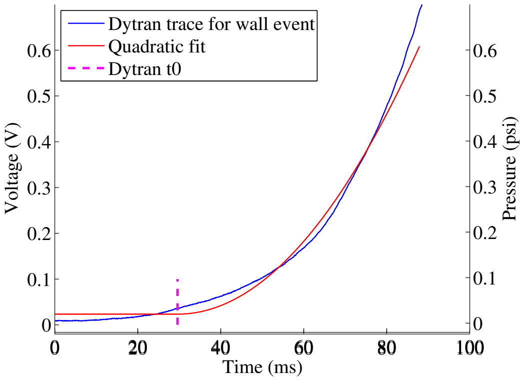
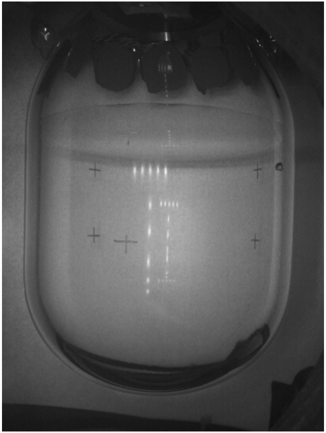
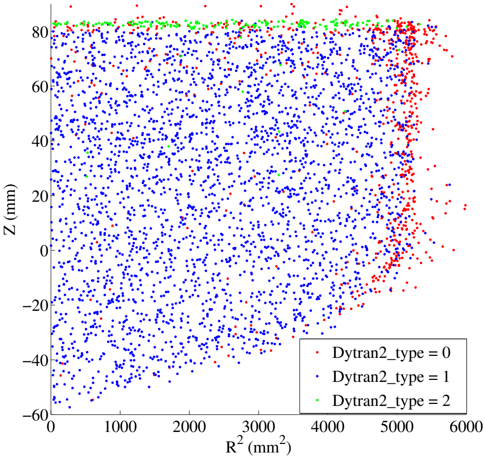




- A wall event blows up

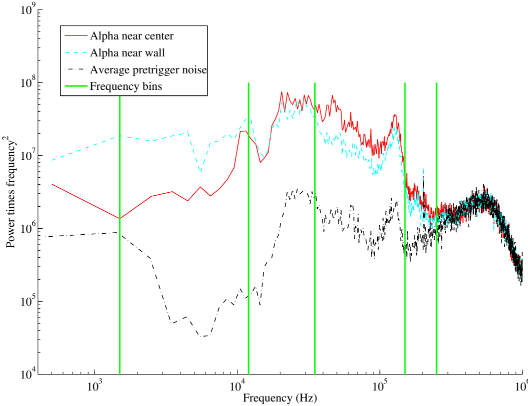
Improvements: the ”dytran”

- A fast pressure transducer measures the pressure rise during bubble expansion
- The shape gives position information



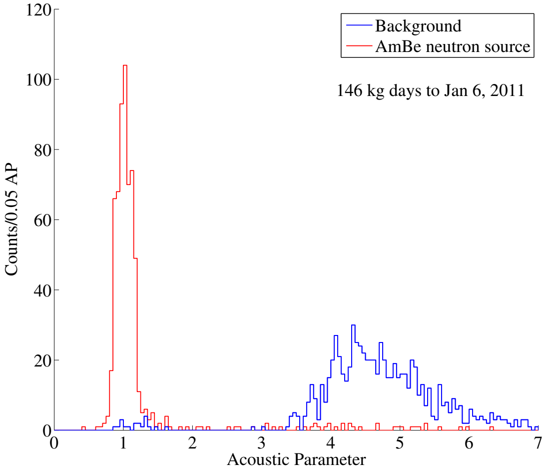
Improvements: AP

- Larger calibration data set
- Improved handle on frequency vs. position dependence
  - Events near the center $\rightarrow$ more power at high frequencies
  - Events near the walls $\rightarrow$ more power at low frequencies



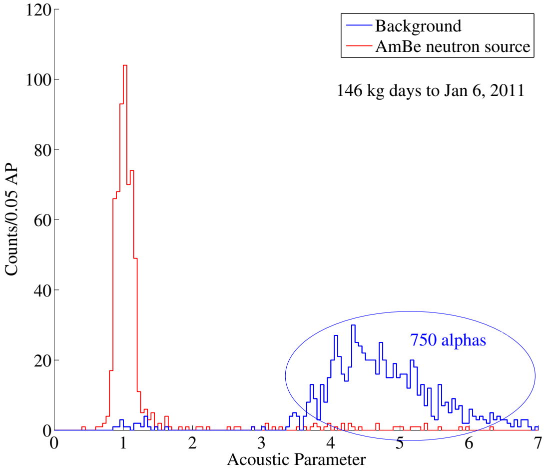
Status through Jan 6, 2011

- Better separation
- More robust to bubble position



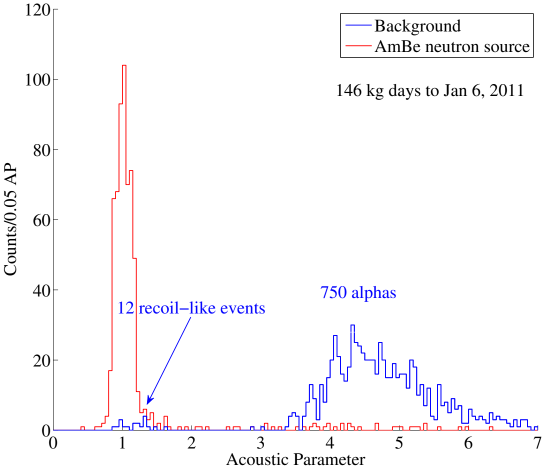
Status through Jan 6, 2011

- 750 alphas - 5.1/kg/day
  - $>$ 80% from ^{222}Rn and daughters
- $>$ 98% alpha rejection



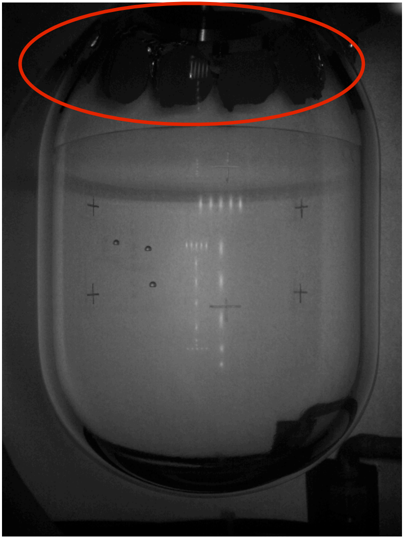
Status through Jan 6, 2011

- Single bubble background of $\sim$0.08 events/kg/day
- 2 three-bubble events in this dataset confirms neutron background



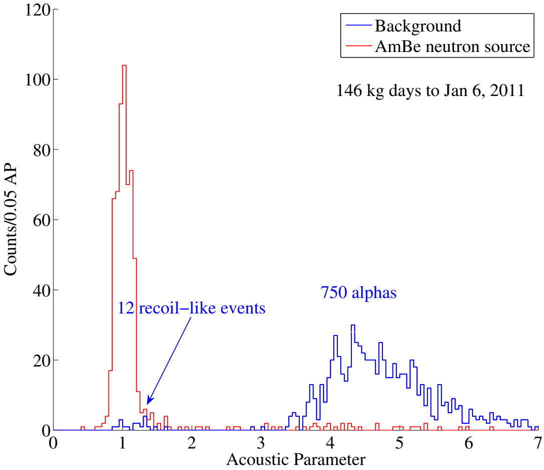
Status through Jan 6, 2011

- Piezo-acoustic sensors made of lead zirconate titanate
  - Both fission and (α,n) neutrons
- High pressure viewport also contributor



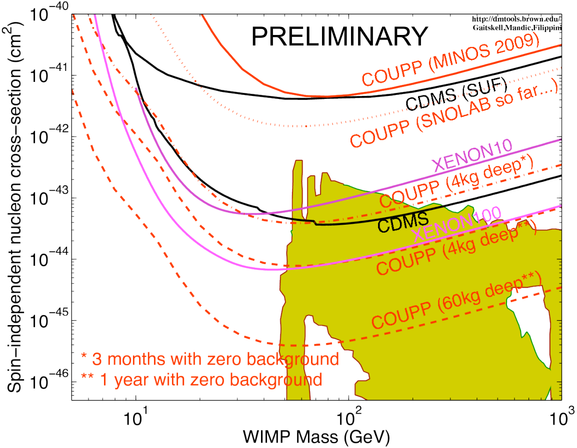
Status through Jan 6, 2011

- Evidence for 2nd source?
  - Clusters of 3 and 5 events in 3 and 9 hours respectively
  - Weighted to high end of AP distribution



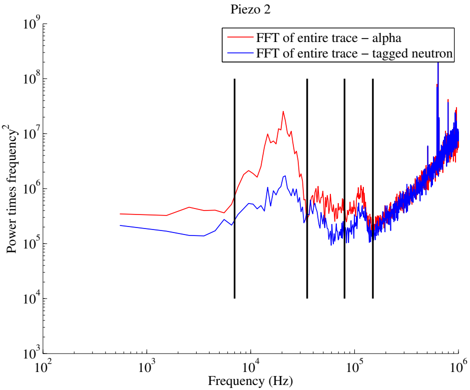
COUPP-4 at SNOLAB

- Current run ends in less than a week (June 15)
- First direct detection experiment limited by internal neutrons
  - A known neutron background that can be removed



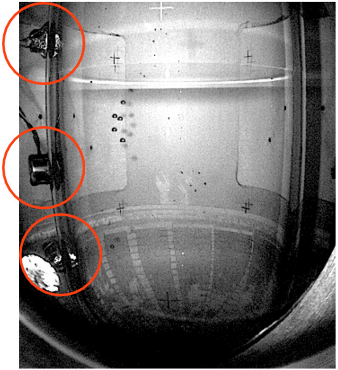
COUPP-60 Update

- Commissioning at shallow site last summer and fall
- Achieved background goals
  - 2.2 alphas/kg/day, identified by acoustic signature



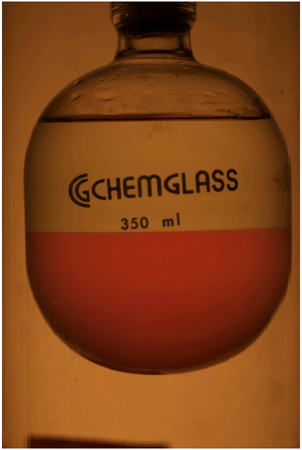
COUPP-60 Update

- Commissioning at shallow site last summer and fall
- Achieved background goals
  - 2.2 alphas/kg/day, identified by acoustic signature
- $\sim$1 recoil-like event/kg/day - piezos are closer to the fluid



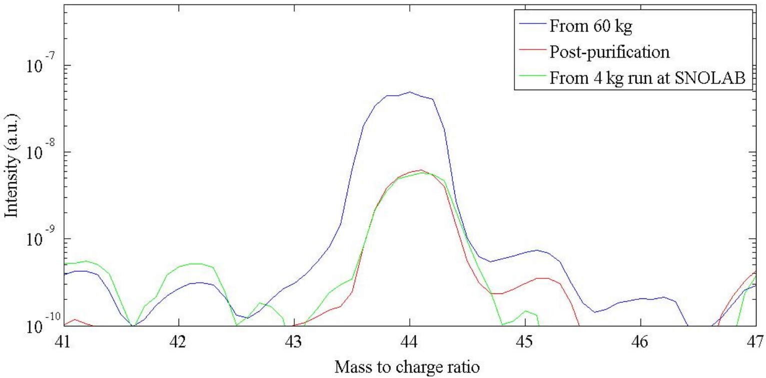
COUPP-60 Update - Chemistry issues

- Fluid turned red due to the release of iodine
  - Photodissociation
  - Impurities
- Recreated on test stand
- Solutions to be tested on new commissioning run this month
  - Sodium sulfite in water to draw out iodine
  - Infrared illumination to limit photodissociation



COUPP-60 Update - Chemistry issues

- Surface boiling
  - Carbon dioxide discovered in post-run fluid analysis
  - New purification step using molecular sieve and SAES getter produces levels comparable to current, stable COUPP-4 run at SNOLAB



COUPP-60 Plans

- Second commissioning run beginning this month
  - Demonstrate stability of optics
  - Absence of surface boiling?
    - If not, still work to do on understanding chemistry
- Begin move to SNOLAB
  - Study of safety requirements
  - Replace high radioactivity components
  - Pack up and move

Other considerations

- Calibrations - we need a better understanding of our threshold and efficiency
- Comparing rate of single and multiple bubble events from a calibrated neutron source with MC simulation
  - Agreement with theory at high temperatures (44 C)
  - $\sim$ 50% efficiency between 30 and 40 C
  - Can fit data with wide range of efficiency curves
  - What other calibrations can we do?

Other considerations

- Calibrations - we need a better understanding of our threshold and efficiency

- Test chamber at Argonne for neutron source studies
- Pion scattering at test beam at Fermilab
- Gamma-n reaction using High Intensity Gamma Source at North Carolina

Conclusions

- COUPP-4 producing strong results
  - Approaching the world leaders in spin independent sensitivity
  - Clear way forward on current limiting backgrounds
  - Potential to address light WIMP controversy with low threshold running
- COUPP-60 slowly getting to SNOLAB
  - Testing solutions for limiting problems
  - Moving to SNOLAB as soon as possible
- Calibration efforts ongoing

Conclusions