Bubble Chambers for Dark Matter Detection :

COUPP (Chicagoland Observatory for Underground Particle Physics)

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Fermilab

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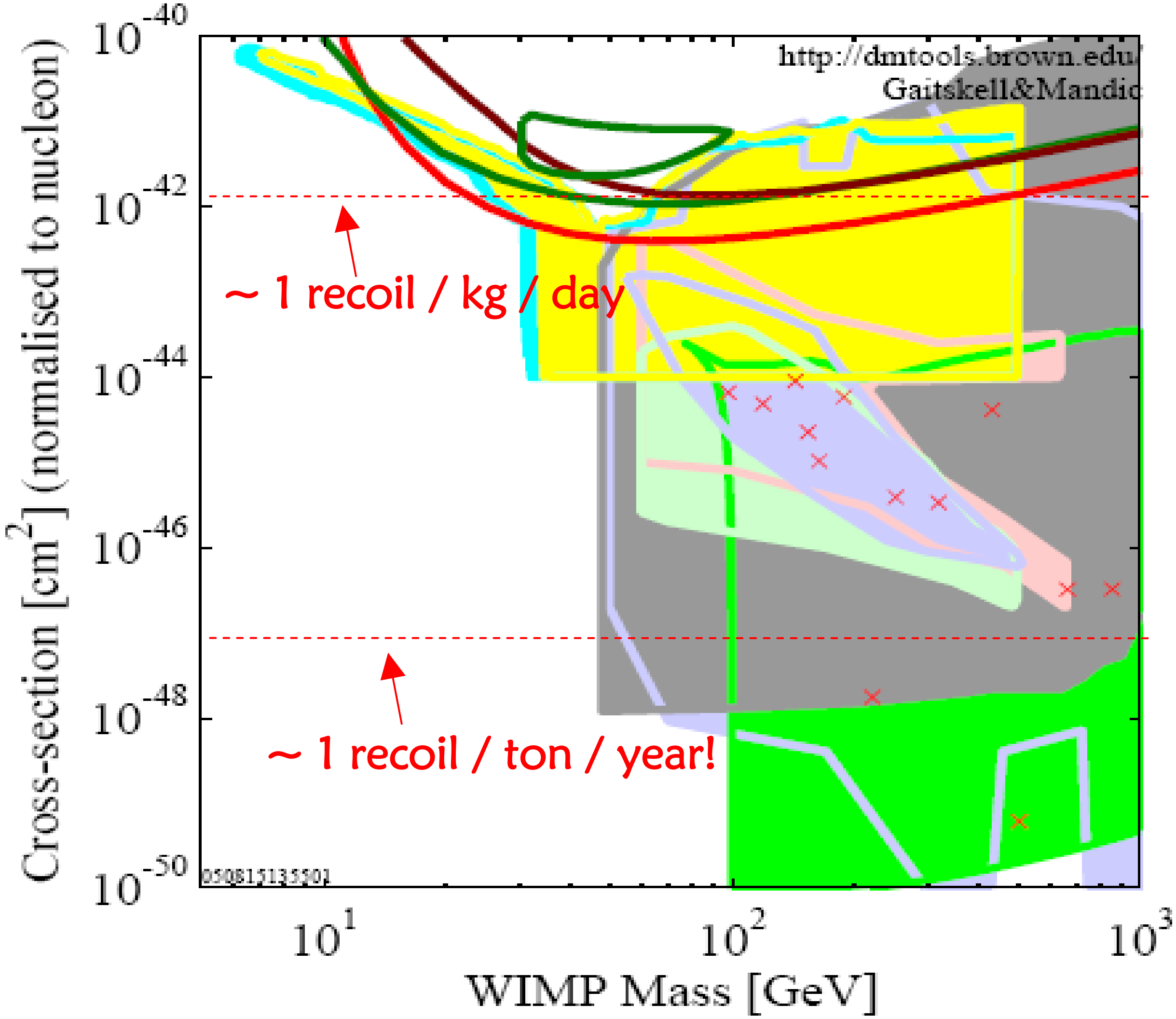
Department of Energy

Wish List for a Tough Problem



Dream Detector:

- Scalable
- Cheap
- Radiopure
- Good background-rejection
- Multiple active nuclei
- Easy to swap targets

A bubble chamber (bulk superheated liquid detector) potentially fulfills all those wishes…if it actually works

Bubble Chambers for Rare Event Searches?

- In recent HEP, bubble chambers with metallic parts were stable for ~ 10 milliseconds…killer dead time
- But the many of the original chambers were glass
- Condensed matter research strongly suggests that both bulk and surface spontaneous nucleation rates can be made low enough

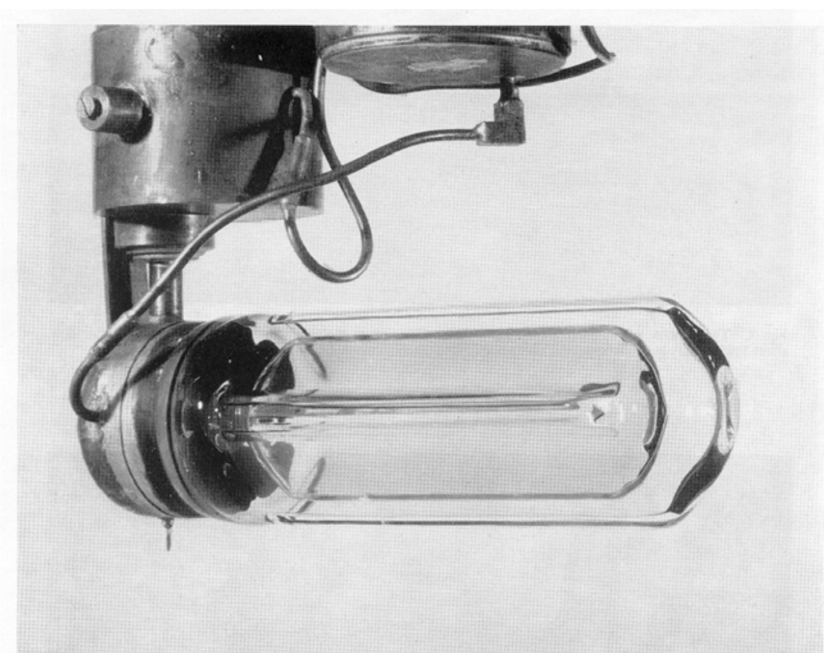


Fig. 2. Assembled bubble chamber and jacket.

Roger Hildebrand at UofC holding the first Hydrogen bubble chamber

Try This At Home?

A single microscopic interaction (nuclear recoil) gives a macroscopic signal (boiling)

➔ The WIMP signal is just as large as the fork signal!

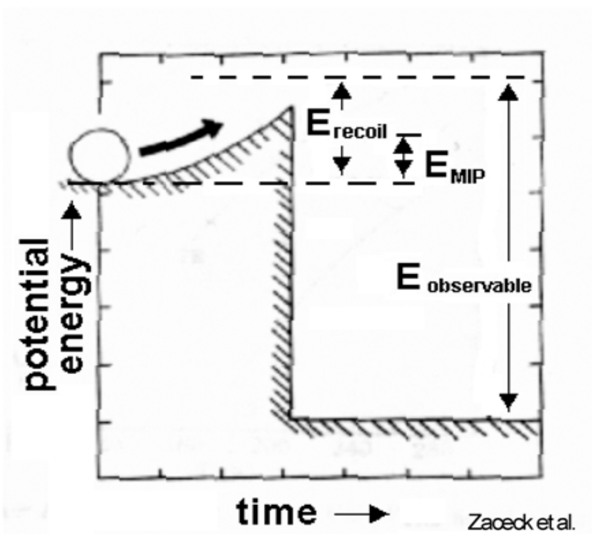
β and γ Insensitivity

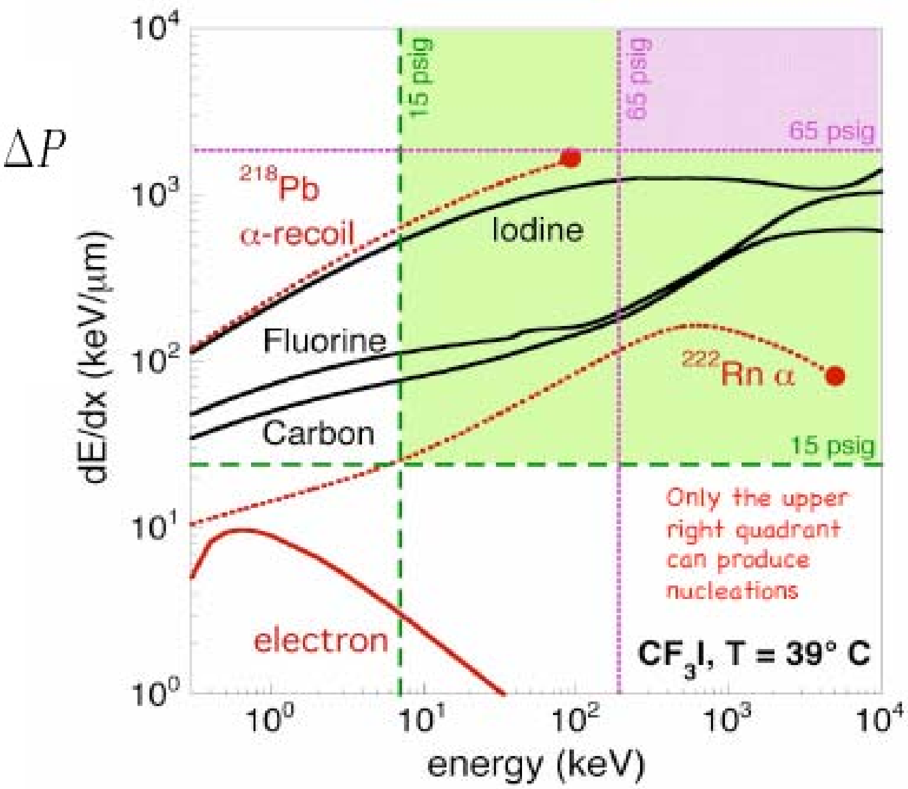
- Most experiments, after heroic cleaning and shielding, still must cut many β, γ events
- Bubble chambers can be operated essentially MIP-blind

Seitz (hot spike) model:

$$E > E_c = 4\pi r_c^2 \left(\gamma - T\frac{\partial\gamma}{\partial T}\right) + \frac{4}{3}\pi r_c^3 \rho_v \frac{h_{fg}}{M} + \frac{4}{3}\pi r_c^3 P \ , \quad r_c = 2\gamma/\Delta P$$

$$\mathrm{d}E/\mathrm{d}x > E_c/(a r_c)$$





Freedom to Choose Target

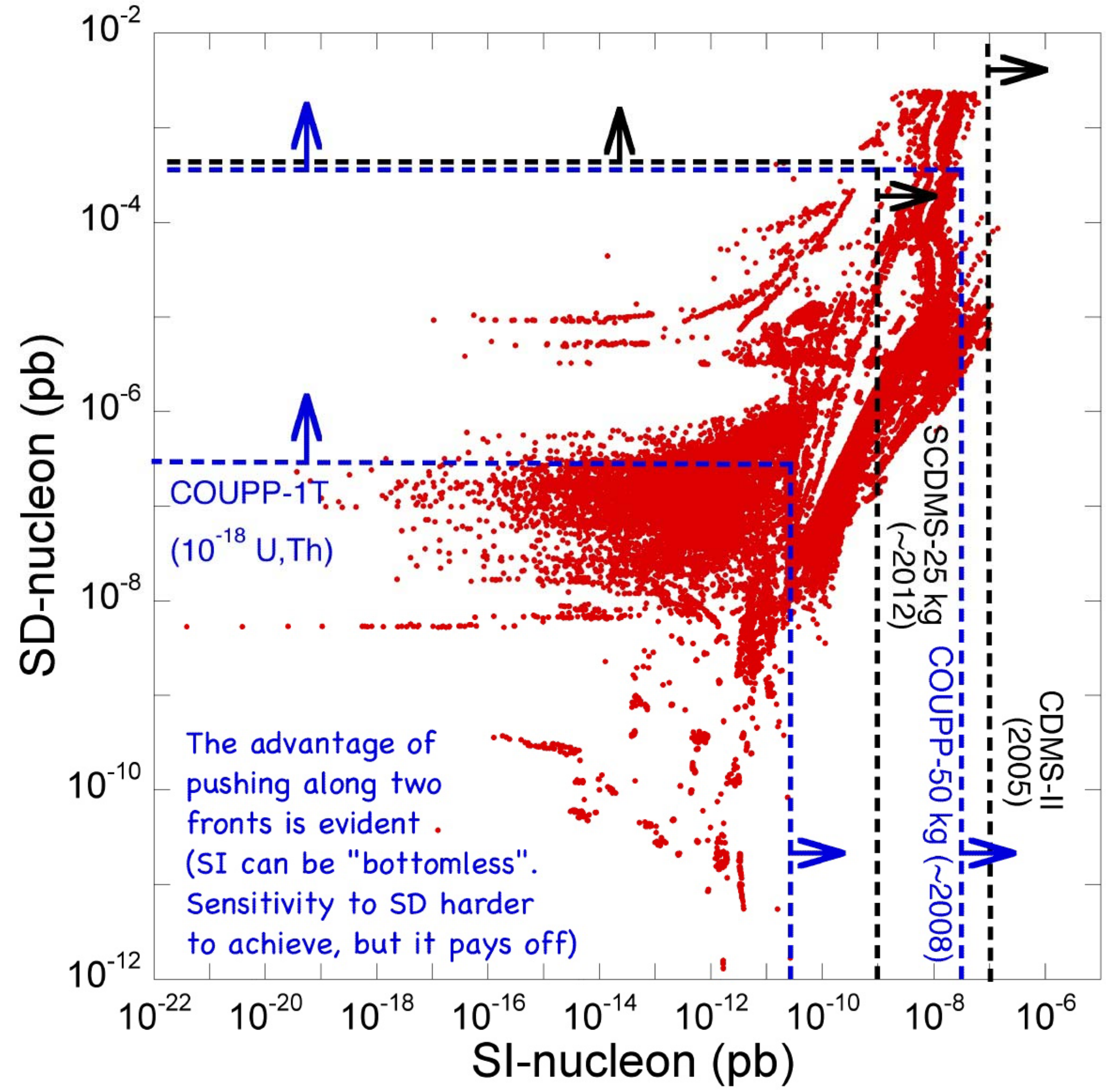
In general SUSY, channel of first detection is unknown:

- Spin-dependent: use fluorine
- Spin-independent: use something heavy

We use CF_3I, for excellent sensitivity in both channels.

Other advantages of CF_3I :

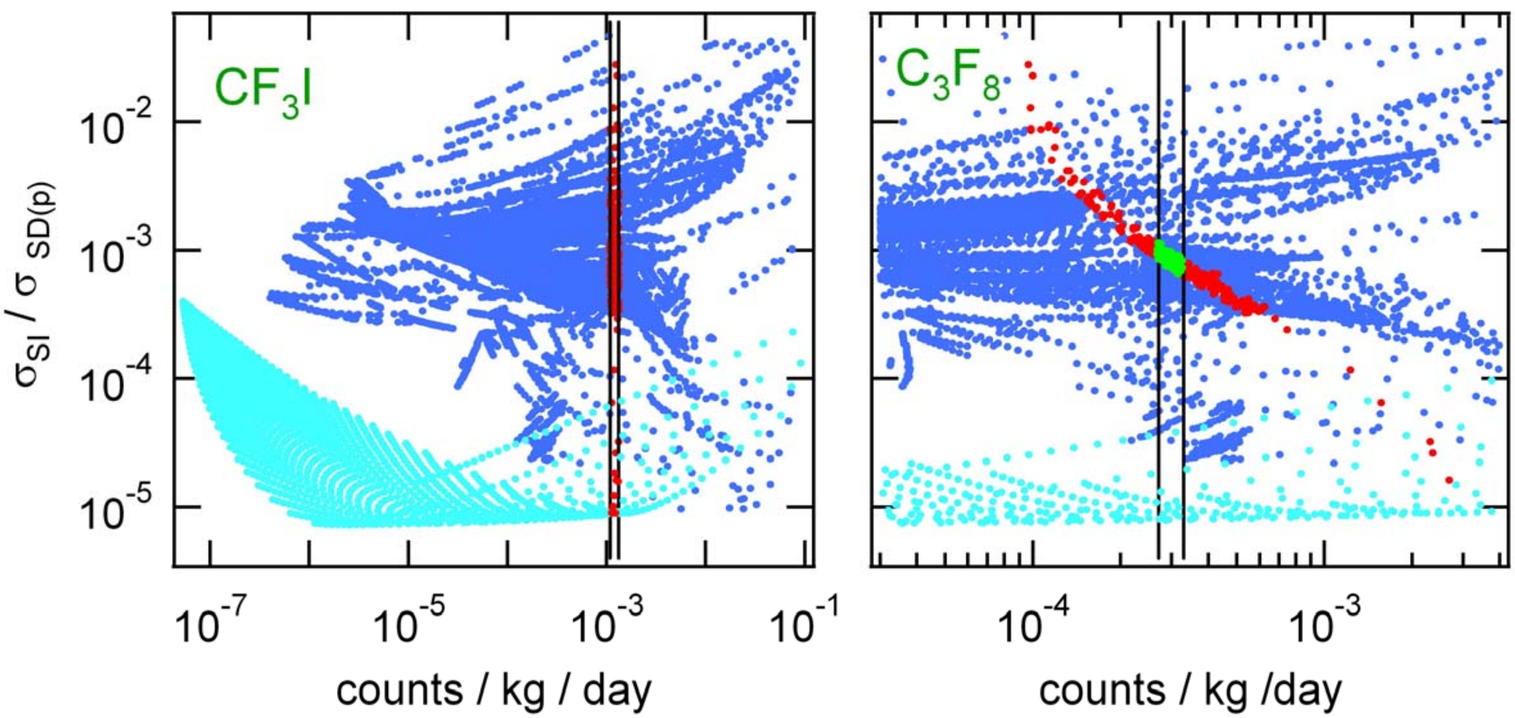
- Inexpensive (40 USD / kg)
- Near room temperature operation (~ 40 C)
- Safe (non-toxic, fire extinguisher)



Baltz & Gondolo, JHEP 0410:052,2004.

Recently expanded by Baltz (WMAP-II range $0.103 < \Omega h^2 < 0.112$
lambda.gsfc.nasa.gov/product/map/current/parameters.cfm.)
Courtesy of P. Gondolo

Freedom to Swap Target



Dark blue: LSP (SUGRA)
Light blue: LKP

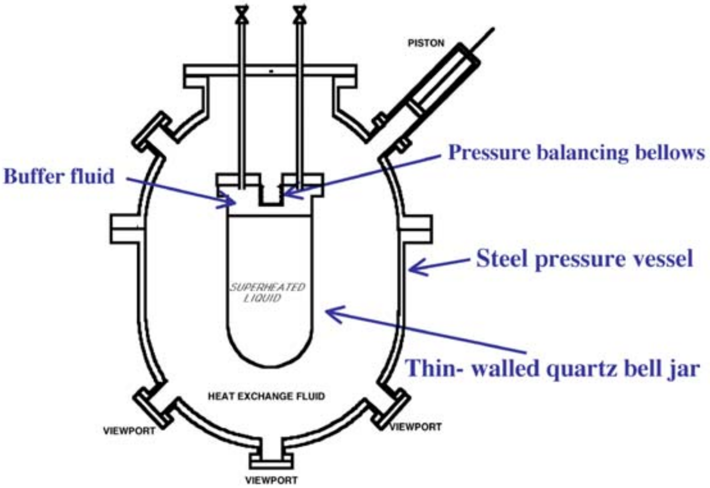
(Bertone, Cerdeno, Collar, and Odom, to appear in PRL, arXiv:0705.2502)

Swapping Target Liquids:

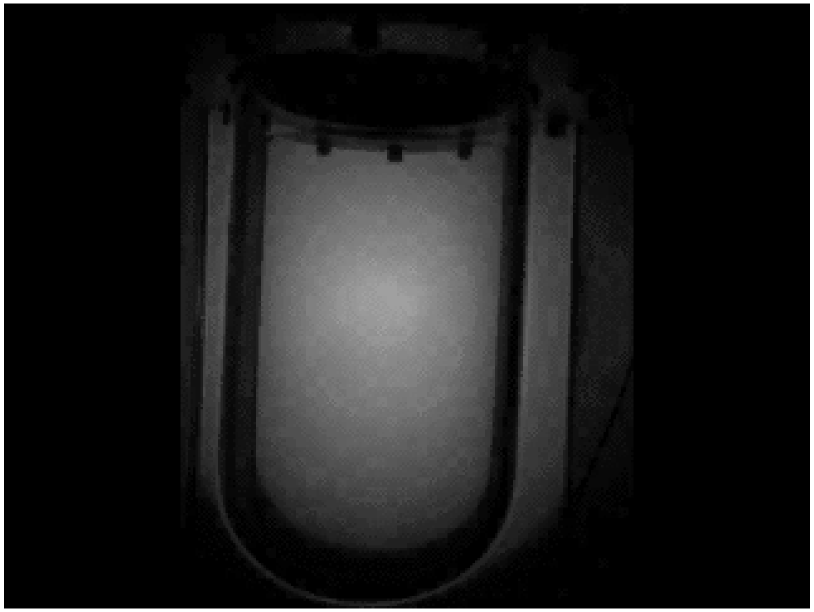
- Upon discovery, makes ~ orthogonal cuts in parameter space
- Alternatively, use different targets for neutron rejection.

(Response of CF3I and C3F8 to neutrons is very similar, but, for example, SI WIMP response is very different)

2 kg Prototype Chamber

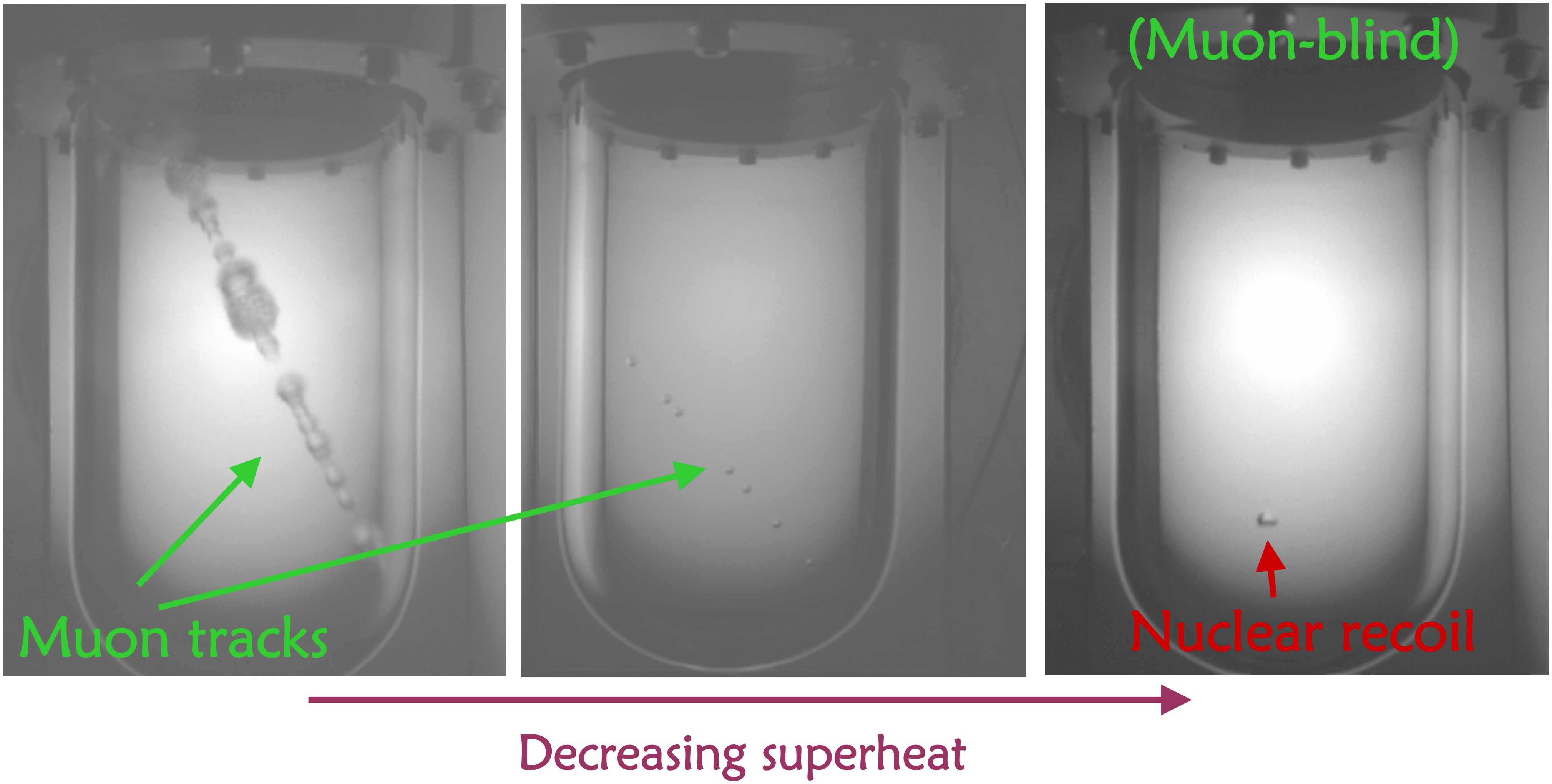


Bulk CF3I touches only the quartz



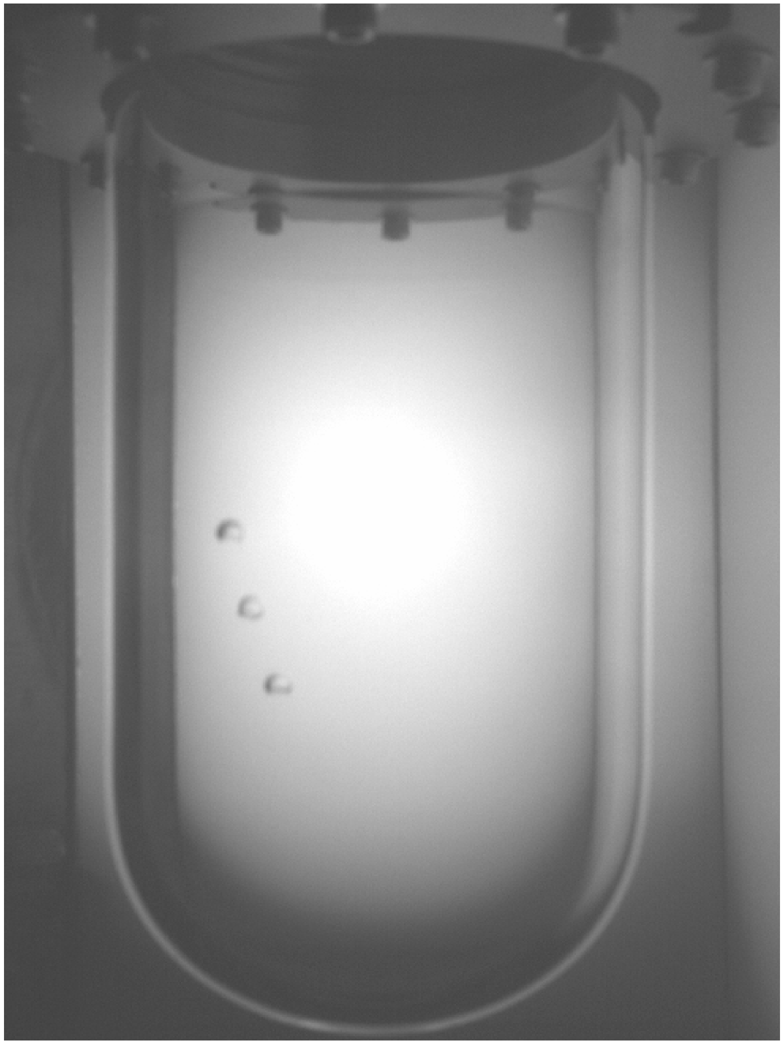
Movie posted at http://kicp.uchicago.edu/~odom/presentations/bubble3.avi

Leaving "Normal" BC Mode Far Behind



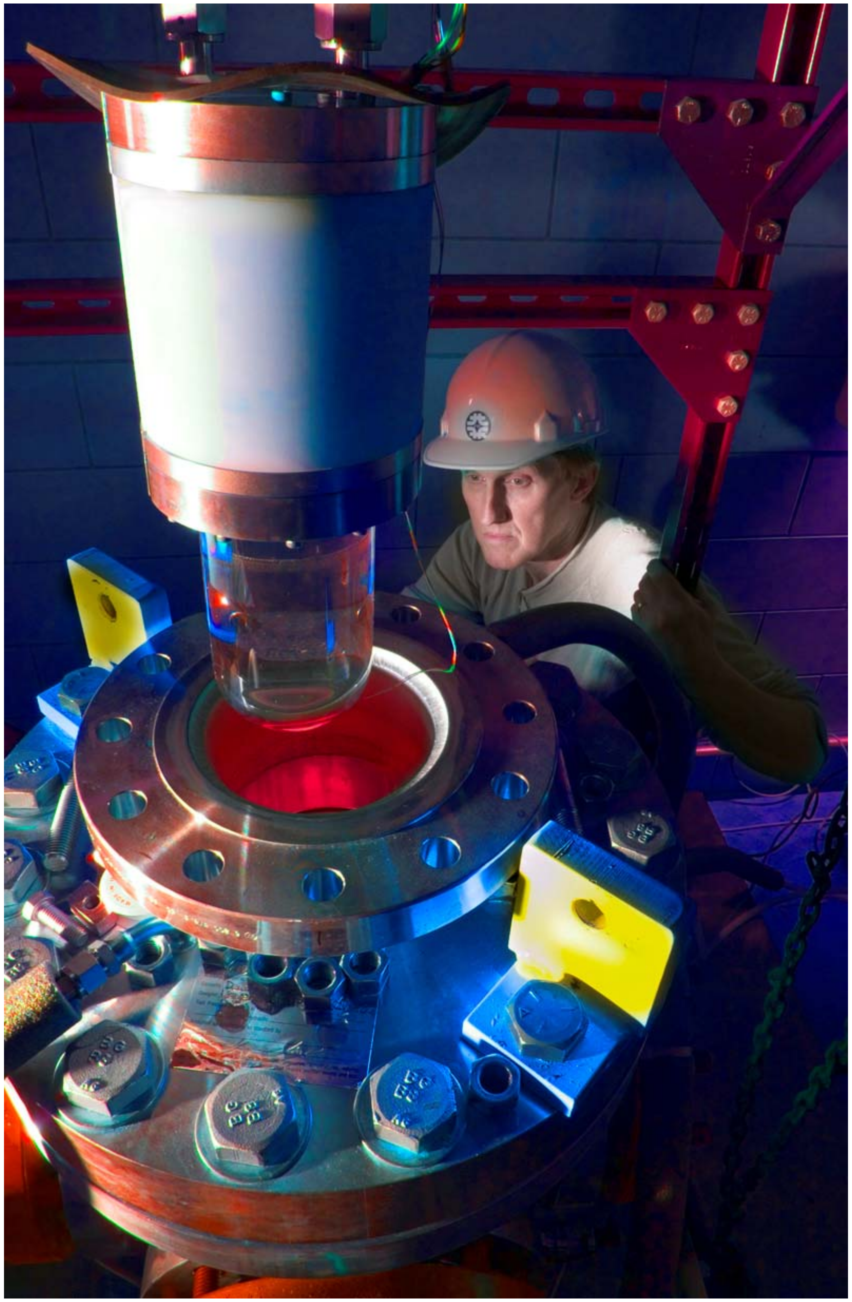
- Muon tracks are visible only at high superheats
- We operate at low superheat, MIP blind
- 1 nuclear recoil = 1 bubble

Stereo View for Bubble Position

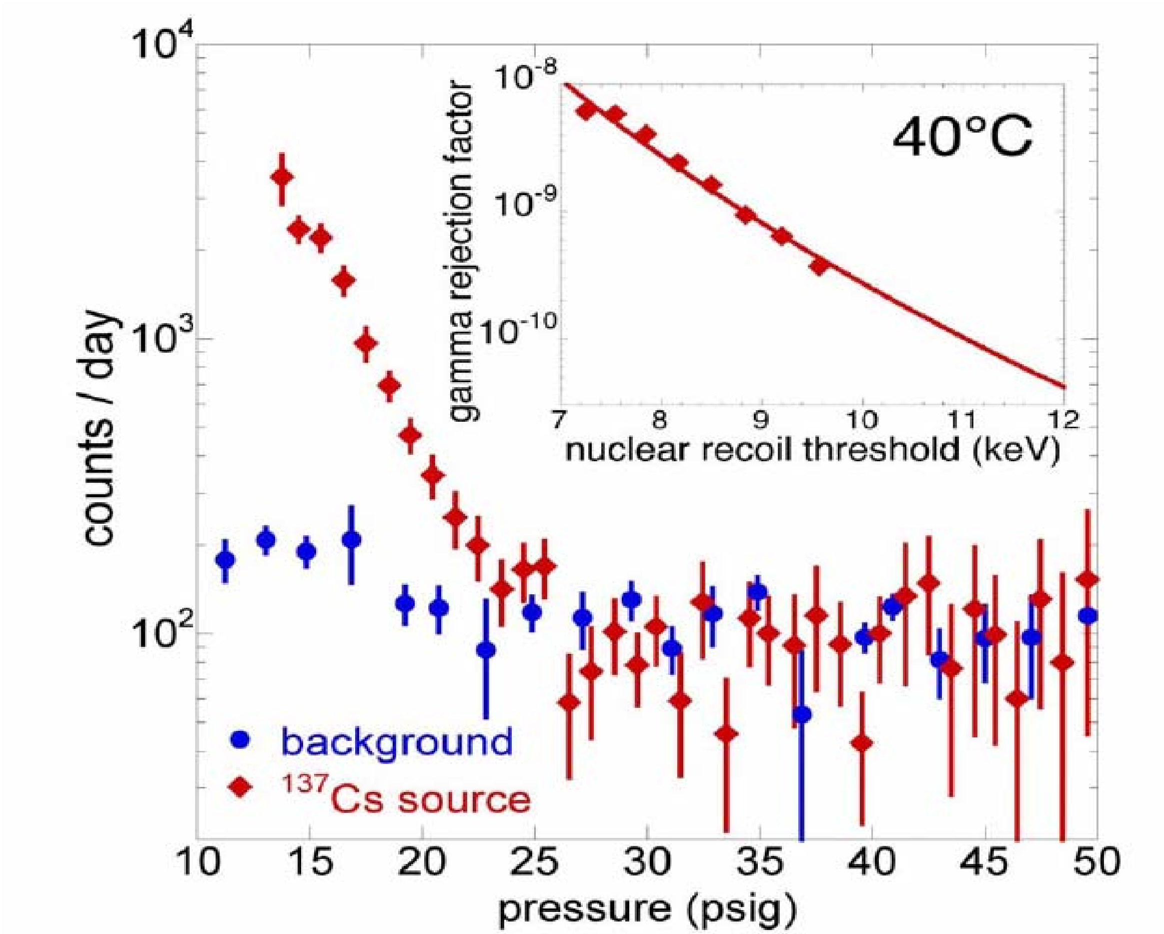


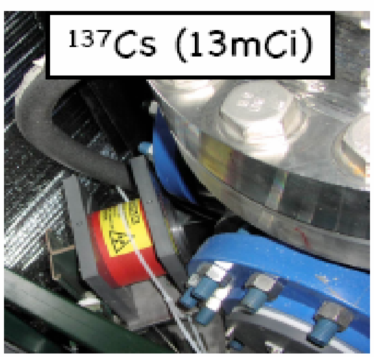
Position reconstruction is important for background rejection, of both wall events and neutron events (multiple scattering)

Operation at 300 m.w.e., Fermilab



Demonstration of MIP-Blindness

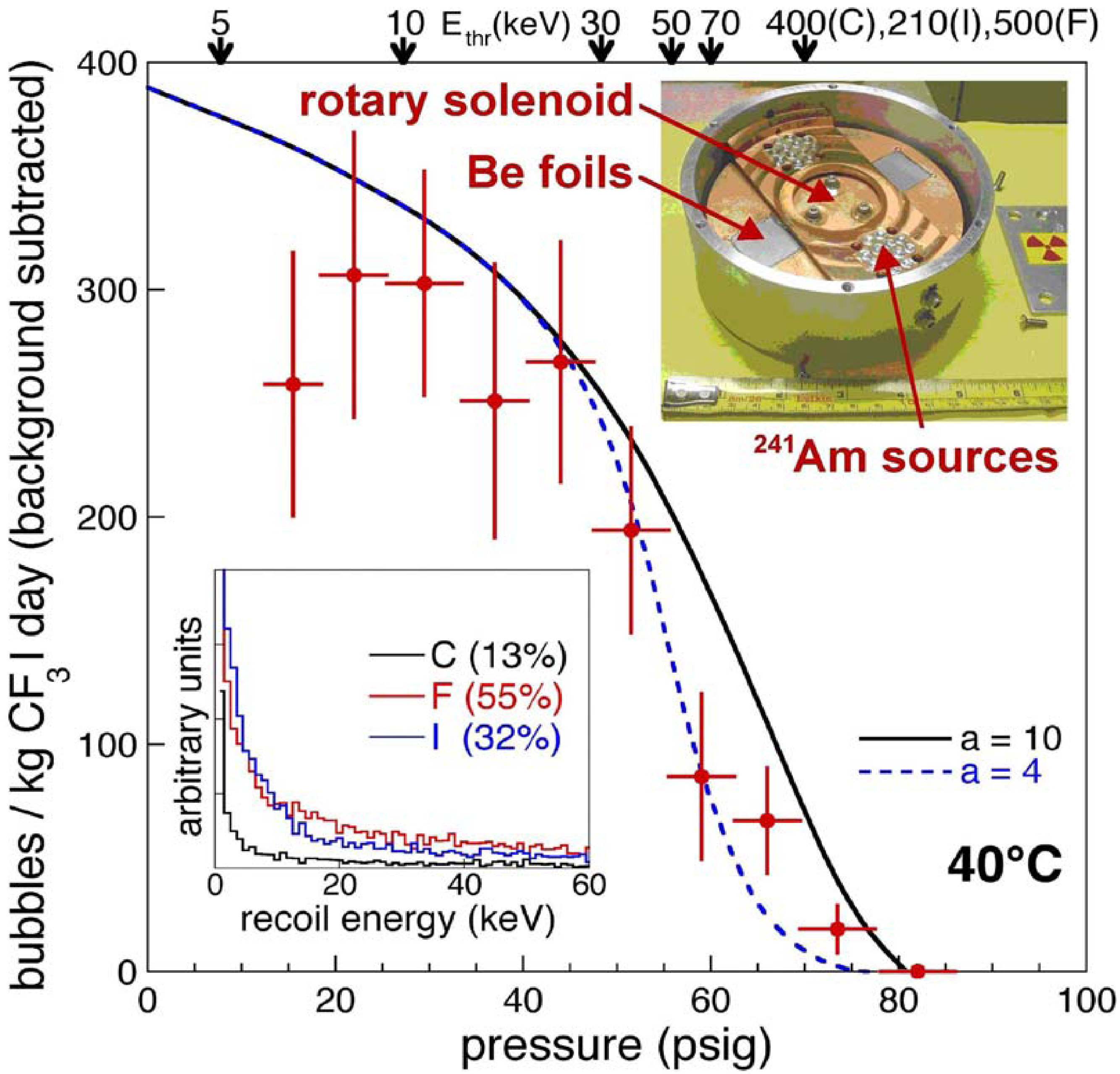




XENON ~10^{-2}
CDMS 10^{-4}-10^{-5}
WARP ~10^{-7}-10^{-8}

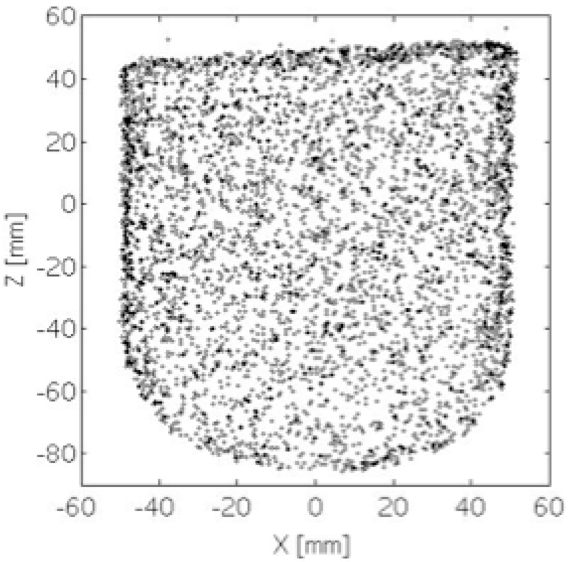
- *Intrinsic* γ rejection better than 10^{-10} at 10 keV threshold (best measured MIP-rejection)
- No cuts required!
- No need for β, γ shielding or attention to β, γ radiopurity. E.g. ^{14}C are *O* (100 / kg-day)

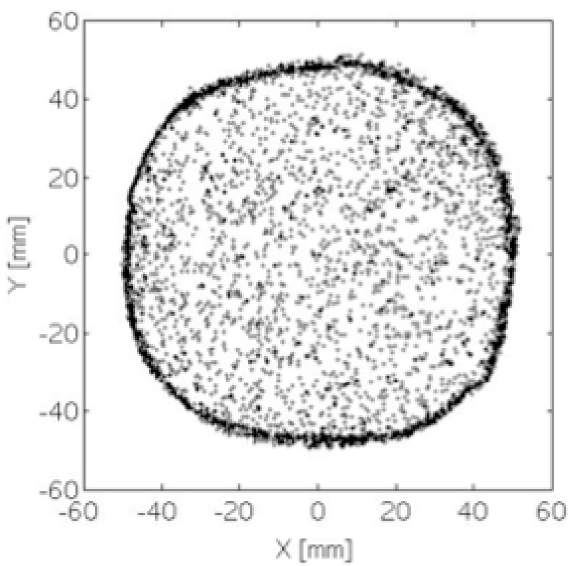
Neutron calibration, *in situ*



- Switchable Am/Be source yields 5 +/- 0.5 n /s when on and *O* (0.2 n/day) when off
- Left: blind absolute comparison, consistent with 100% efficiency
- Moderated spectrum produces recoils approximating WIMP spectrum

Current Wall Background: α-Emitters





- Wall rate (0.9 /cm²/day) OK for small vessels (200 /day for 2 kg chamber)

- γ-counting of our Ge-214 natural fused quartz found U (Th) at typical level of 50 (30) ppb — consistent with 100% of wall-event rate

- Commercial α-counting gives consistent rate

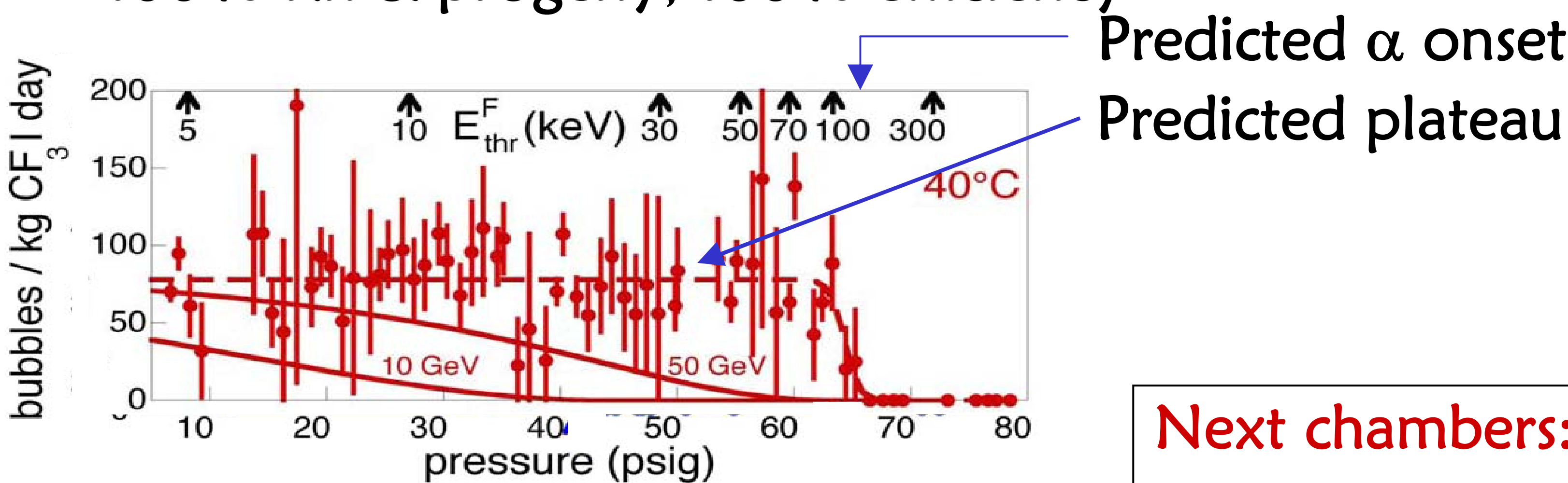
- Next-generation vessels made from synthetic fused silica, with expected U, Th level < 10 ppt

- New vessels also undergo extra quartz etch before final annealing and are then sealed, to guard against embedded Rn progeny

Current Bulk Background: Radon & Progeny

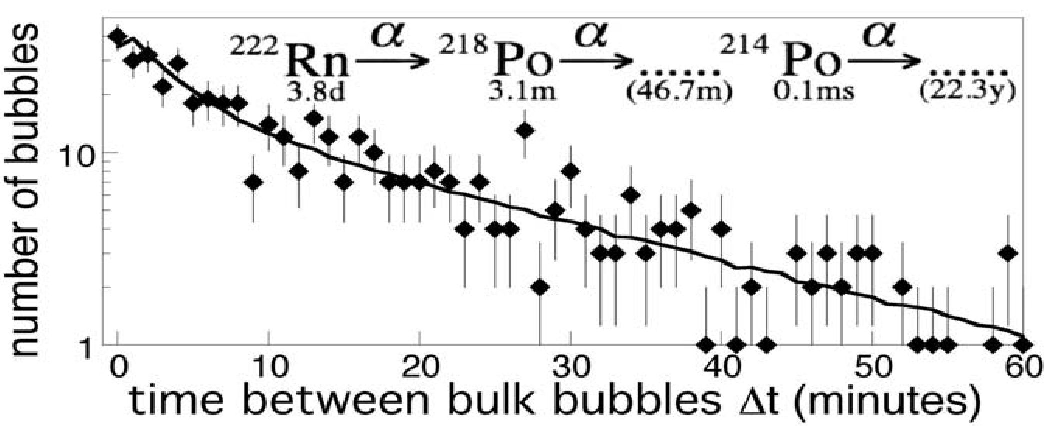
Bulk background is consistent with 100% Rn and progeny α's

1. Flat rate with sharp onset at predicted value
2. Analysis of time correlation between events supports 100% Rn & progeny, 100% efficiency



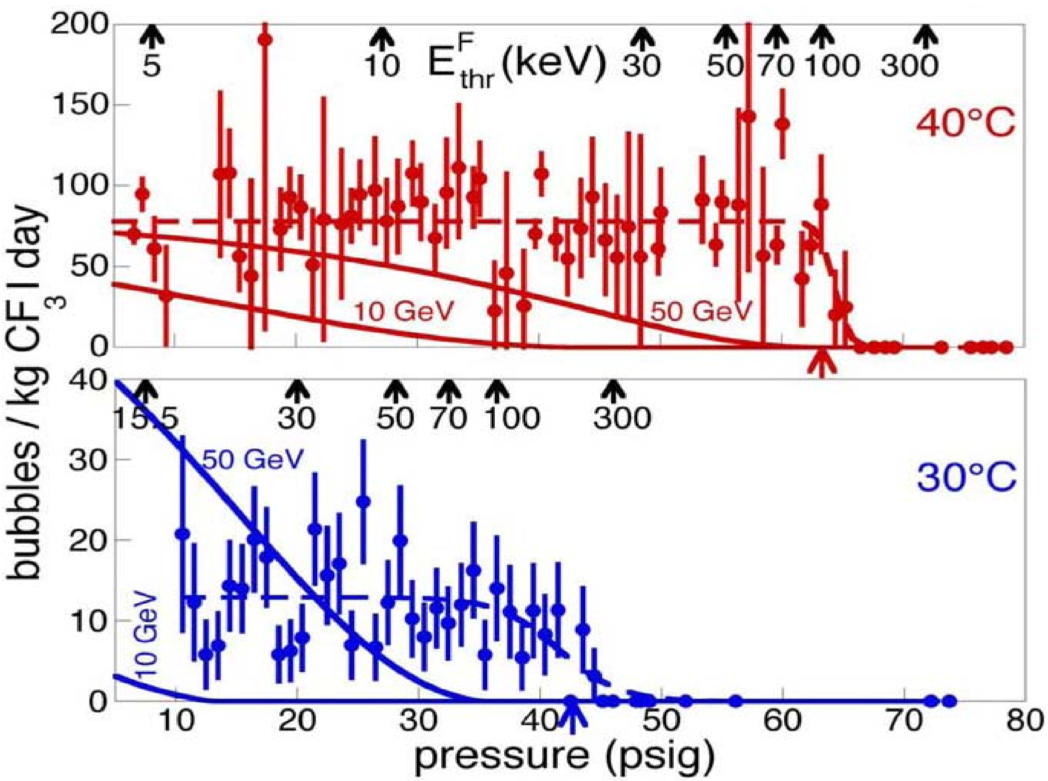
Next chambers:

1. Non-thoriated welds
2. Metal seals against Rn



Any WIMPs in the Data?

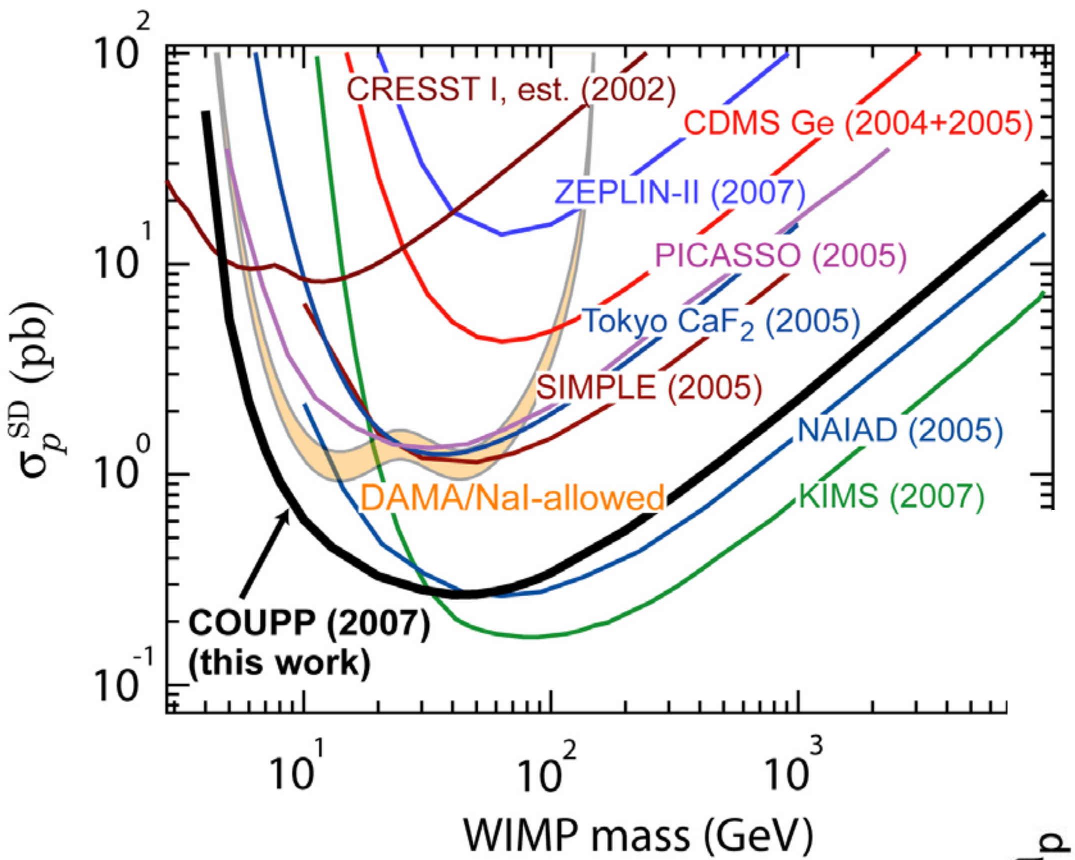
Q: How much WIMP signal could be hiding beneath the radon & progeny?



Note: these are integrated energy spectra

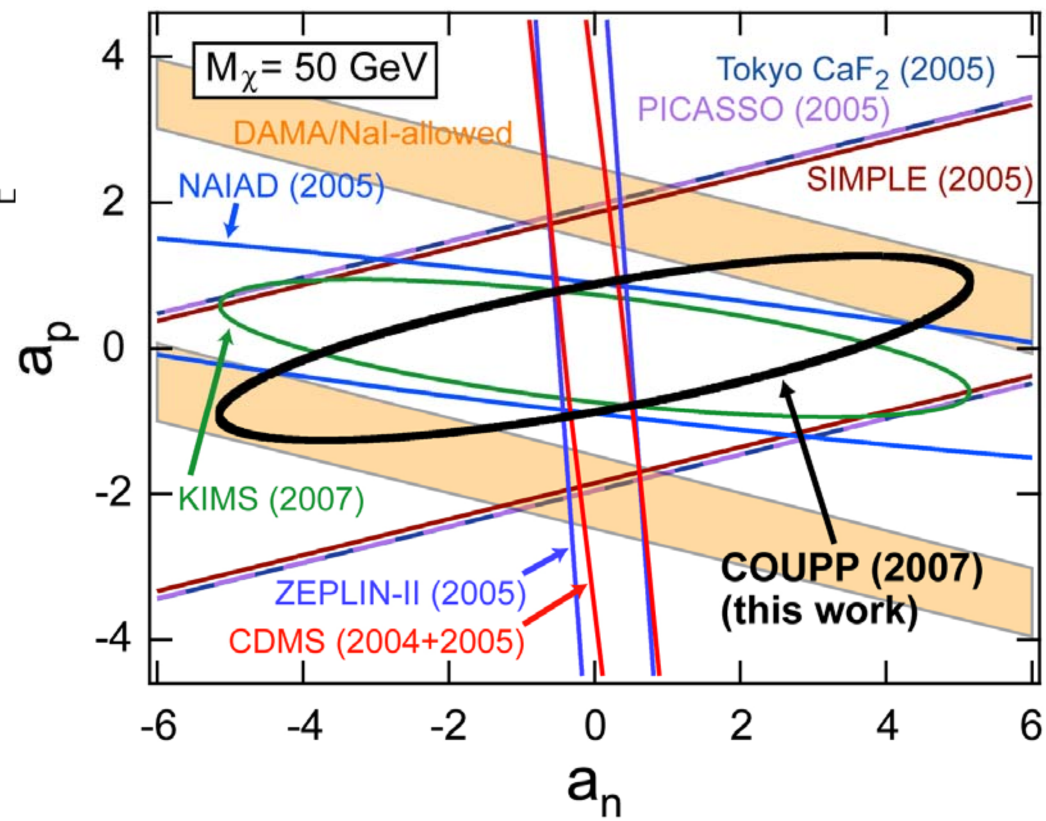
- Total exposure of 250 kg-days (Dec '05 – Nov '06), with live-time fraction reaching 80%. 51 kg-livedays used for WIMP analysis.
- Dashed curves: null hypothesis function (NHF)--only Rn & progeny
- Solid lines: expected WIMP response function (WRF) for $\sigma^{SD(p)}=3$ pb
- Perform 2-parameter fit a*NHF + b*WRF (constrain b≥0). b=0 is generally favored. (Error matrix analysis, checked against MINUIT, is used to obtain 90% C.L.)
- Cross-section limits obtained from weighted mean of WRF parameter "b", from 3 data sets

COUPP (2007) Exclusion Limits



The COUPP 2 kg prototype detector, even with minimal measures against radon, sets competitive SD(p) limits

Worth noting: new limits are placed in the low-mass region favored by a SD interpretation of the DAMA/NaI signal



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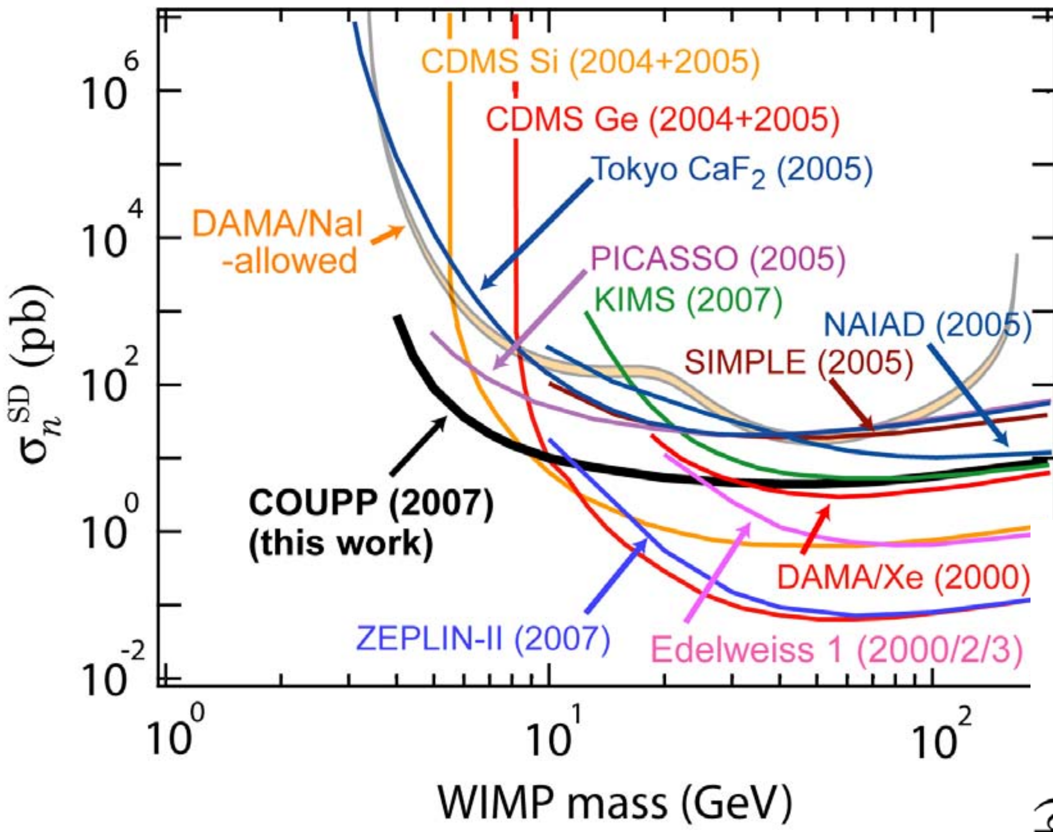
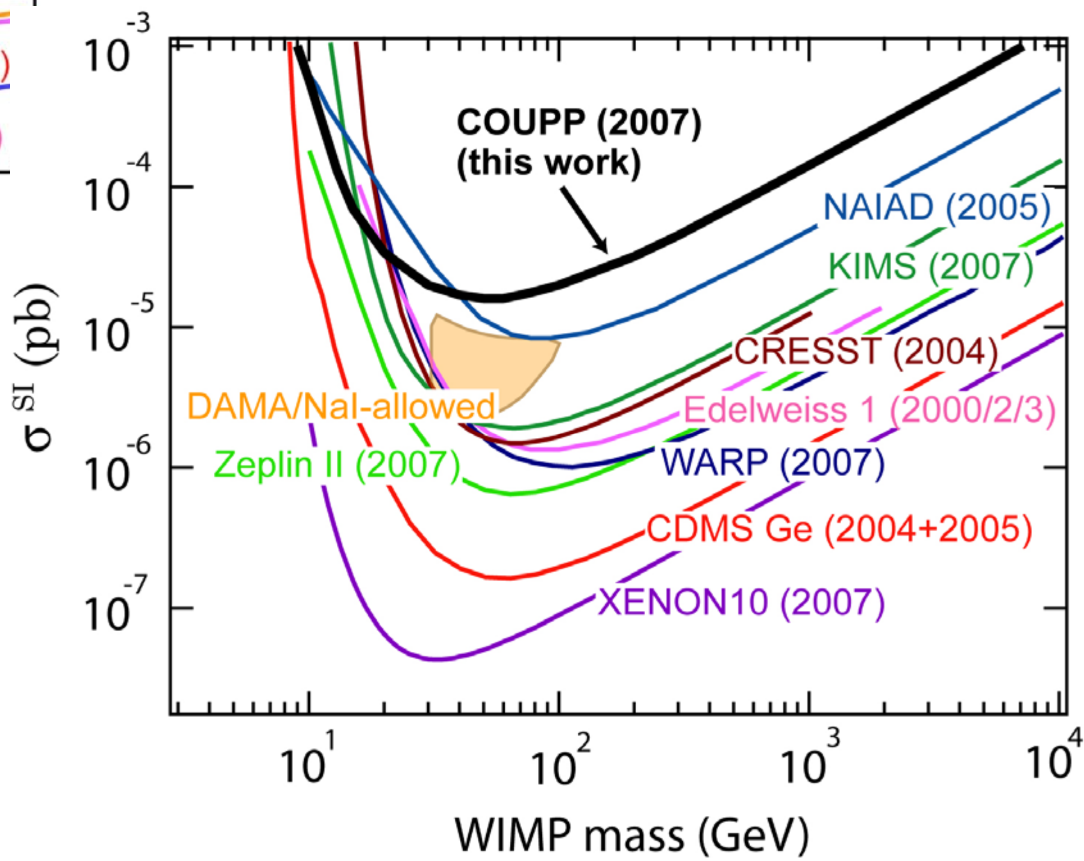


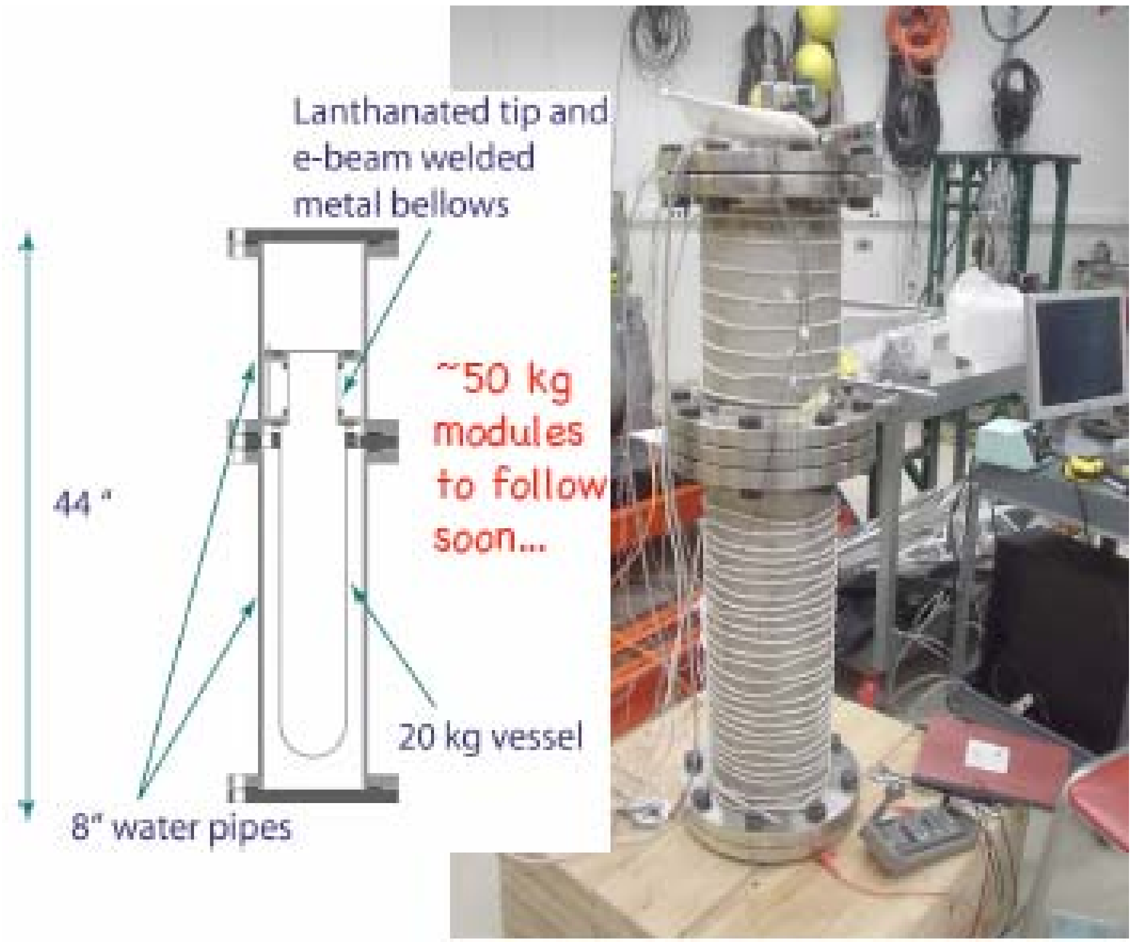
SD(n) and SI limits are not *yet* as interesting

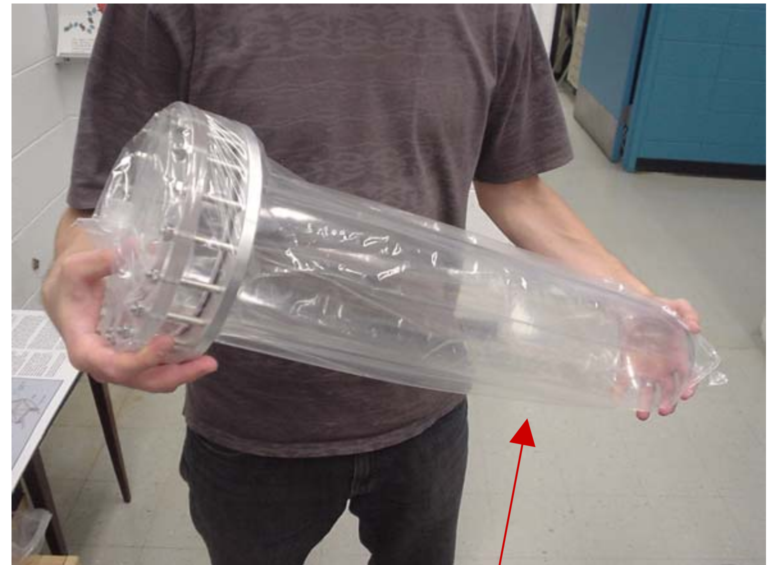
…but data already coming in from the new fill (2 kg chamber, with better seals against Rn and no thoriated weld lines) look very promising…



Under construction: 20 kg Windowless Chamber

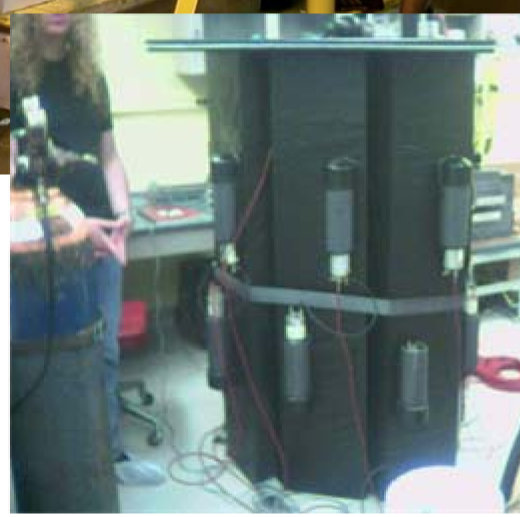
Pressure vessel is off-the-shelf water pipe. Readout is from internal cameras and encapsulated piezos.





20 kg synthetic fused silica vessel, sealed against exposure to Rn

Under construction:
20 kg Windowless Chamber



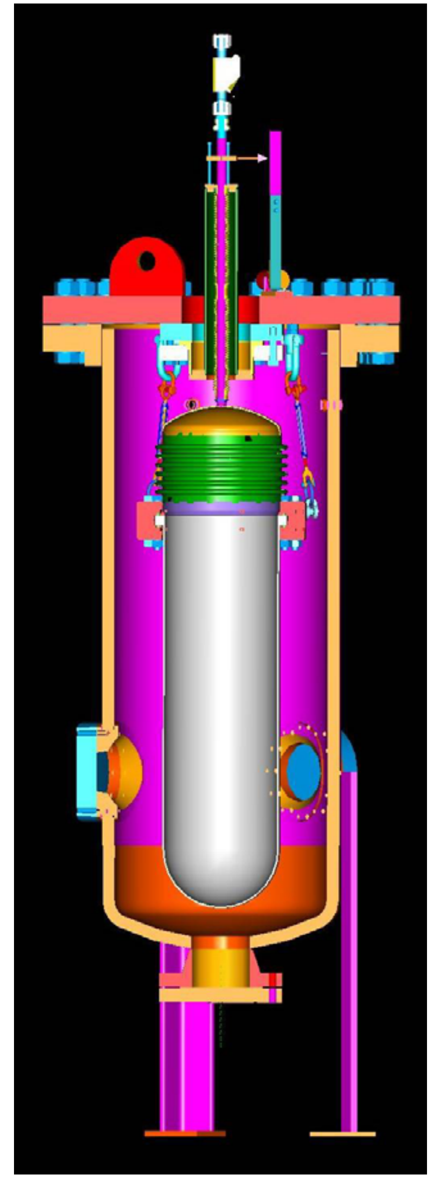
4π water shielding and muon veto

Shielding installation at TARP tunnel (300 mwe) near UofC

Under construction: 60 kg Chamber

For installation in NUMI tunnel, Fermilab.

30 cm x 1 meter inner vessel



Conclusions

- Scalable: liquid target with simple instrumentation
- Low cost (<1000 USD/kg)
- Outstanding γ-rejection
- Single concentration: reducing α-emitters to ~10^{-17} (achieved elsewhere) probes most SUSY models
- 2 kg prototype already contributes to SD(p) limits, with lower background run underway
- Larger masses coming (20 and 60 kg modules under construction)