COUPP, the "Chicagoland Observatory for Underground Particle Physics"
Recent Progress

University of Chicago

Juan Collar (PI, spokesperson), Keith Crum, Smriti Mishra, Brian Odom, Nathan Riley, Matthew Szydagis

Indiana University South Bend

Ed Behnke, Ilan Levine (PI), Nate Vander Werf

Fermilab

Peter Cooper, Mike Crisler, Martin Hu, Erik Ramberg, Andrew Sonnenschein, Bob Tschirhart

Additional materials:

General approach, deactivation of surface nucleation sites: astro-ph/0503398

DMSAG presentation (denser version of these transparencies): http://www.ps.uci.edu/~sobel/Public_DMSAG/index.html

COUPP approach to WIMP detection:

- Detection of single bubbles induced by high-dE/dx nuclear recoils in heavy liquid bubble chambers

- $>10^{10}$ rejection factor for MIPs. *INTRINSIC* (no data cuts)

- Scalability: large masses easily monitored (built-in "amplification"). Choice of three triggers: pressure, acoustic, motion (video))

- Revisit an old detector technology with improvements leading to extended (unlimited?) stability (*ultra-clean* BC)

- Excellent sensitivity to both SD and SI couplings (CF_3I)

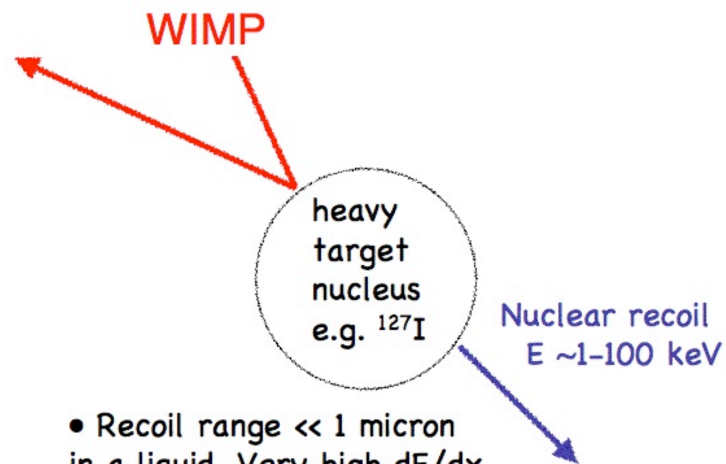
- Target fluid can be replaced (e.g., C_3F_8, C_4F_{10}, CF_3Br). Useful for separation between n- and WIMP-recoils and pinpointing WIMP in SUSY parameter space.

- High spatial granularity = additional n rejection mechanism

- Low cost (<350 USD/kg target mass *all inclusive*), room temperature operation, safe chemistry (fire-extinguishing industrial refrigerants), moderate pressures (<200 psig)

- Single concentration: reducing α-emitters in fluids to levels already achieved elsewhere ($\sim 10^{-17}$) will lead to complete probing of SUSY models

Dark matter particle from galactic halo
velocity ~300 km/s
mass 10-10000 GeV (SUSY?)



- Recoil range << 1 micron in a liquid. Very high dE/dx

Signal is single bubble corresponding to point-like WIMP recoil (not tracks as in conventional BC)

<- neutron-induced event (multiple scattering)

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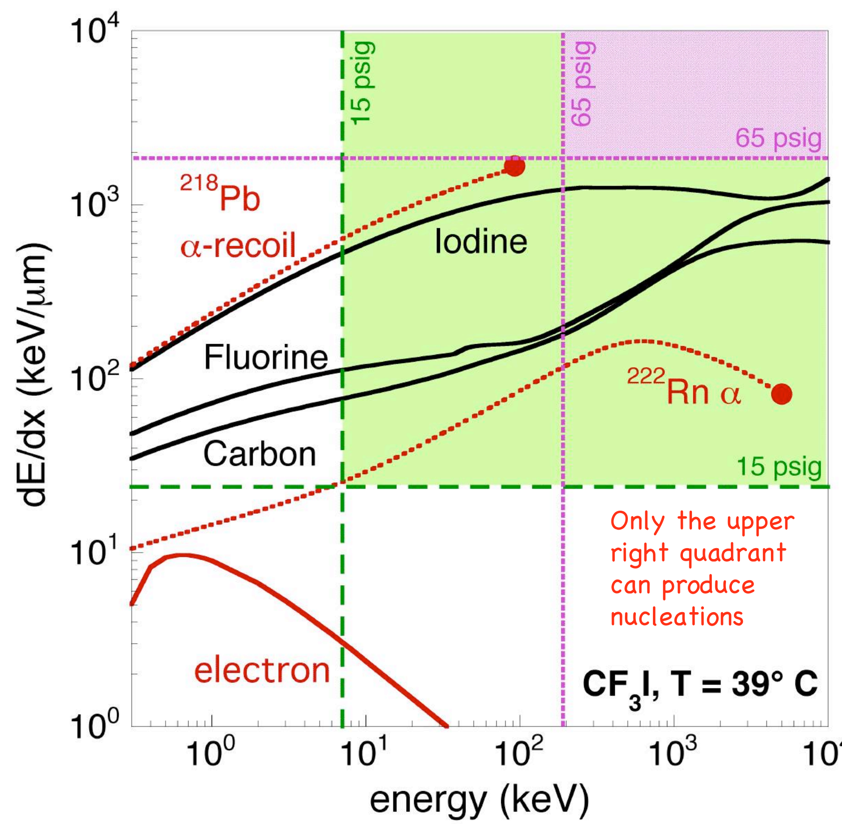
Seitz model of bubble nucleation (classical BC theory):

Threshold in deposited energy

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

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

Threshold also in stopping power, allows for efficient INTRINSIC MIP background rejection



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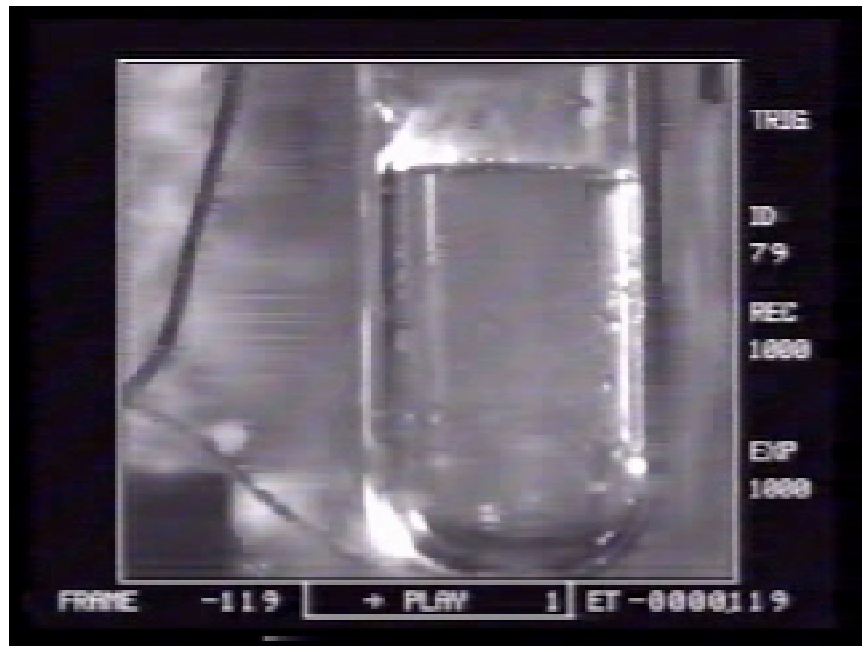
neutron-induced nucleation in 20 c.c. CF_3Br (0.1 s real-time span)
Movie available from http://cfcp.uchicago.edu/~collar/bubble.mov



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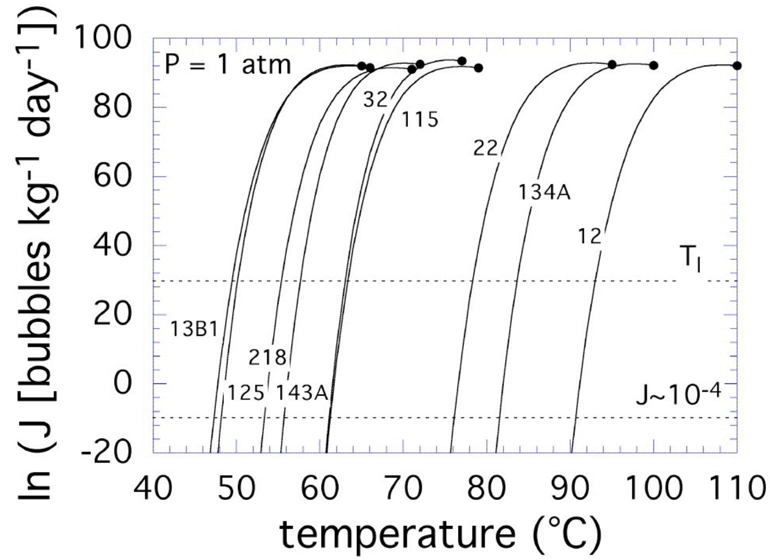
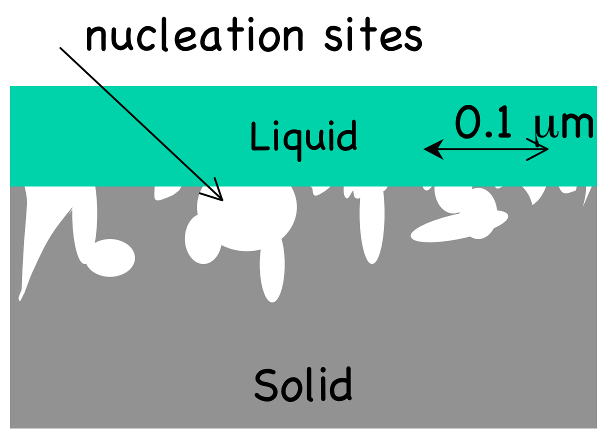
Spontaneous bulk nucleation rate
Log_n(-2.5E5) /kg day!! (T_c= 122°C, run at ~40°C)



Surface nucleations are produced by gas-filled voids: learned how to control them (cleaning, outgassing, buffer liquid, etc.: astro-ph/0503398)



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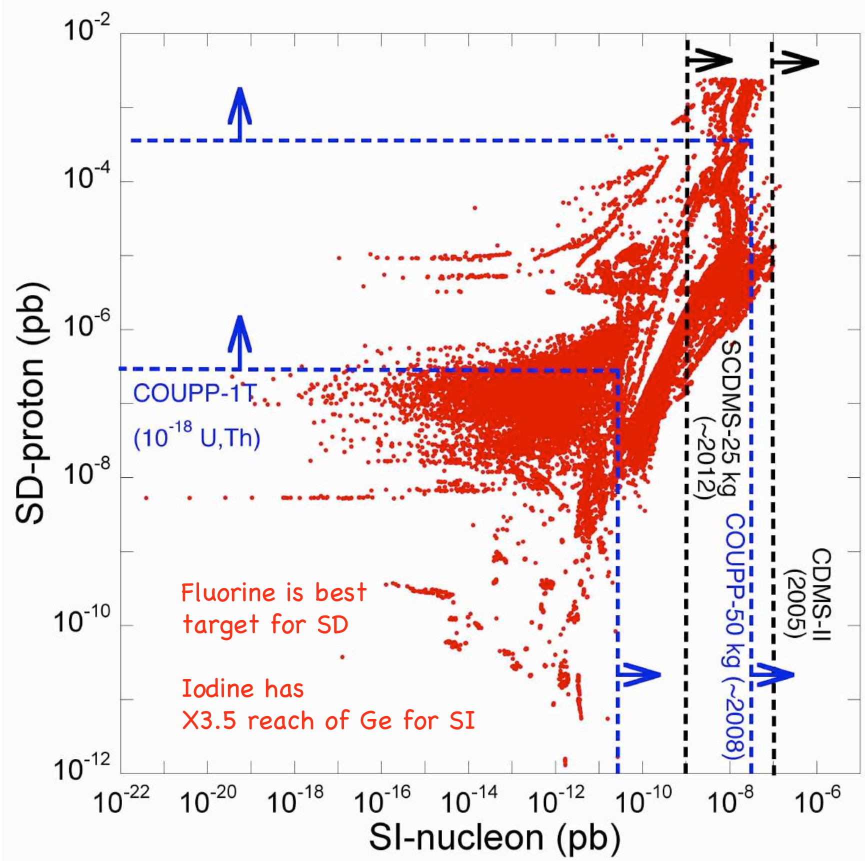
An old precept: attack on both fronts



Baltz & Gondolo, JHEP 0410:052,2004. (WMAP-II update)

SD SUSY space harder to get to, but more robust predictions (astro-ph/0001511, 0509269, and refs. therein)

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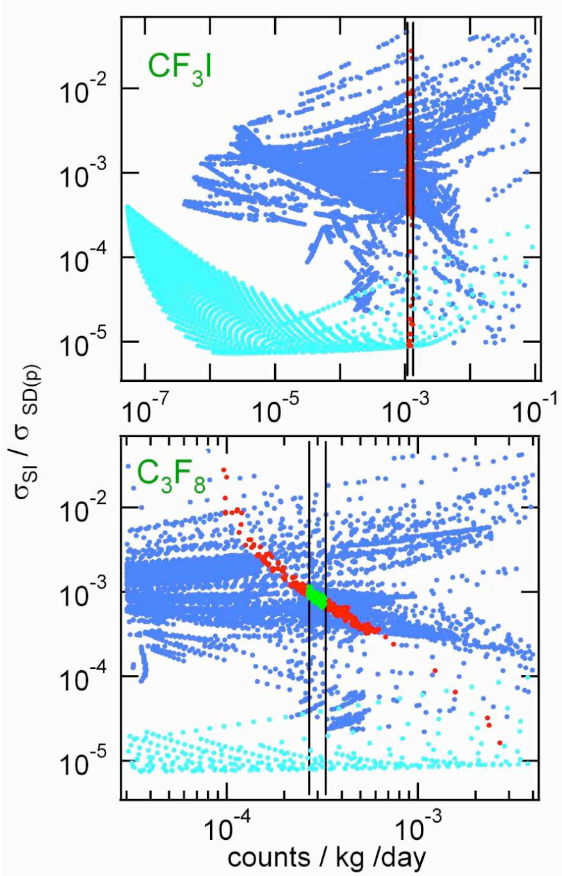
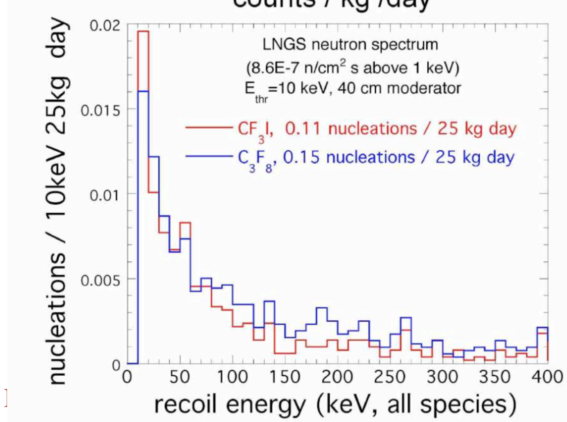


Bertone, Cerdeno, Collar and Odom (in preparation)

Rate measured in CF_3I and C_3F_8 (vertical bands) tightly constrains responsible SUSY parameter space and type of WIMP (LSP vs LKKP)



Neutrons on the other hand produce essentially the same rates in both (σ_n for F and I are very similar)

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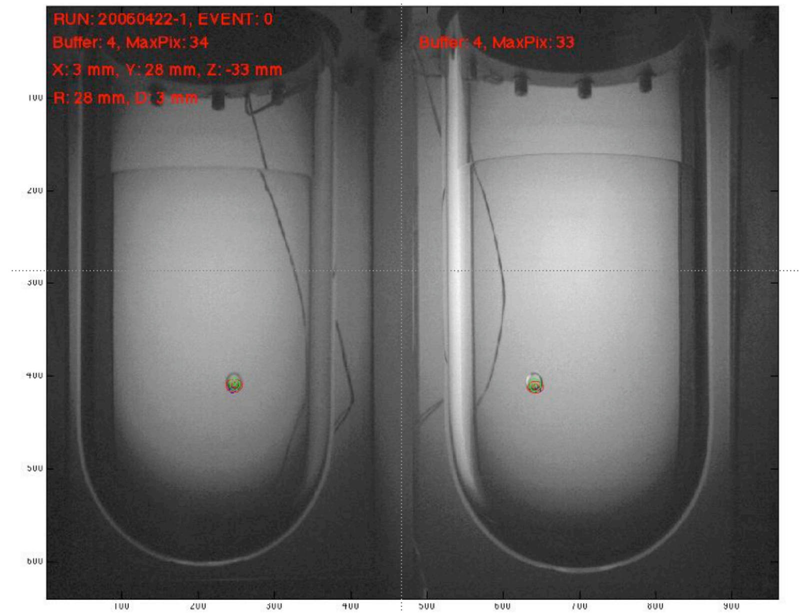
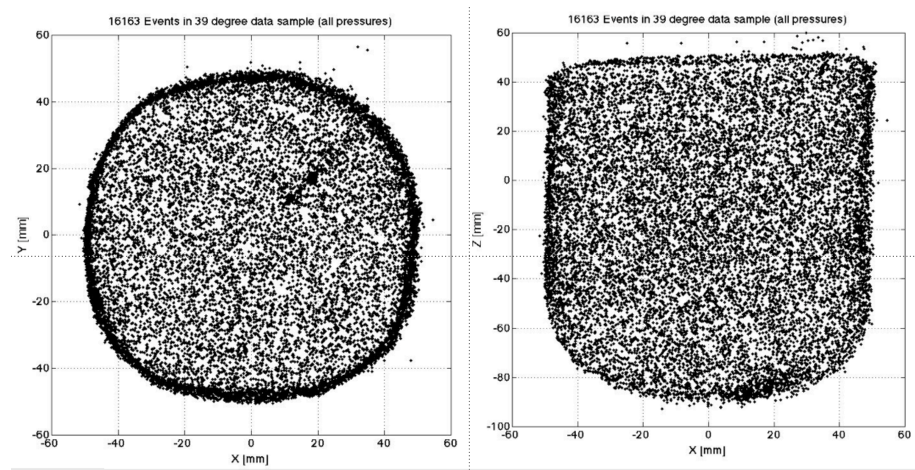
Stereo view of a typical event in 2 kg chamber





Spatial distribution of bubbles (~1 mm resol.)

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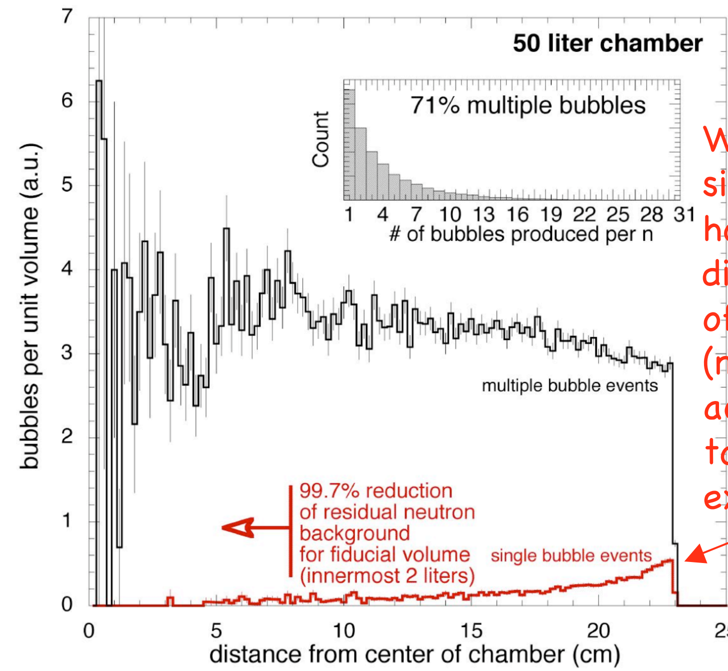
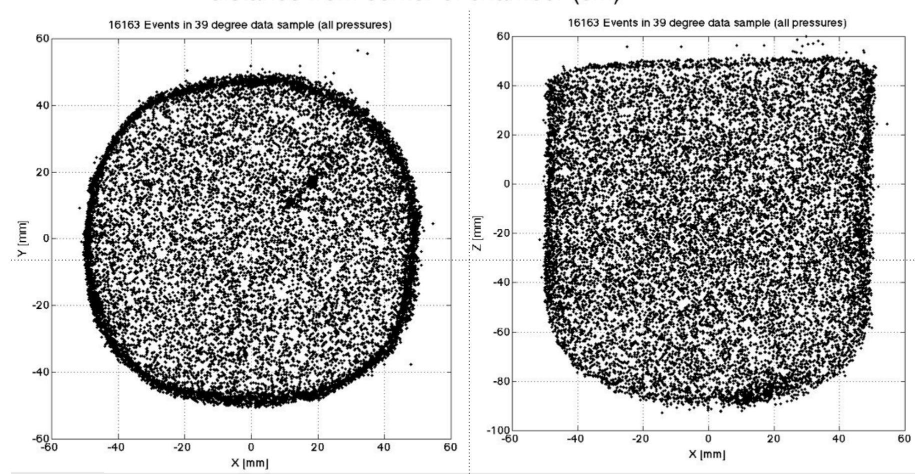
Larger chambers will be "self-shielding"



WIMP signature: homogeneous distribution of singles (n-induced accumulate towards the exterior)



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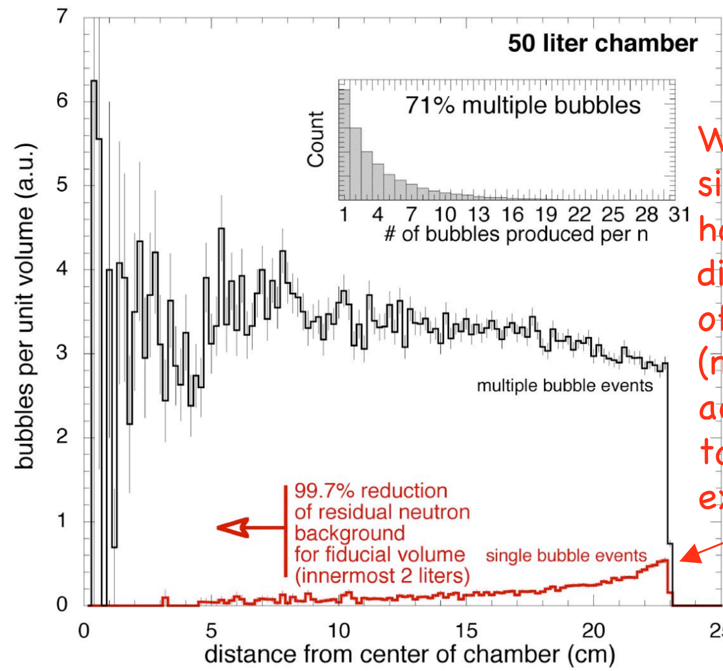

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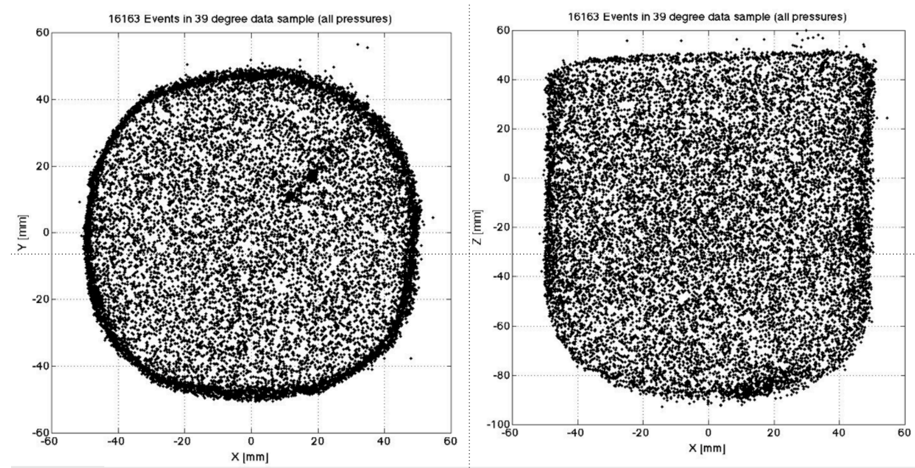

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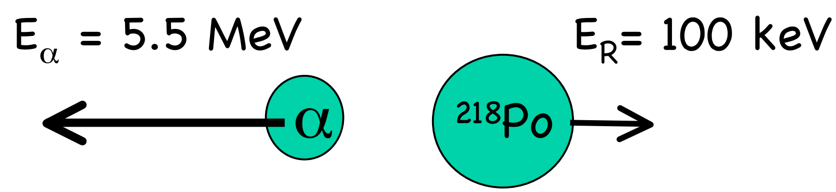
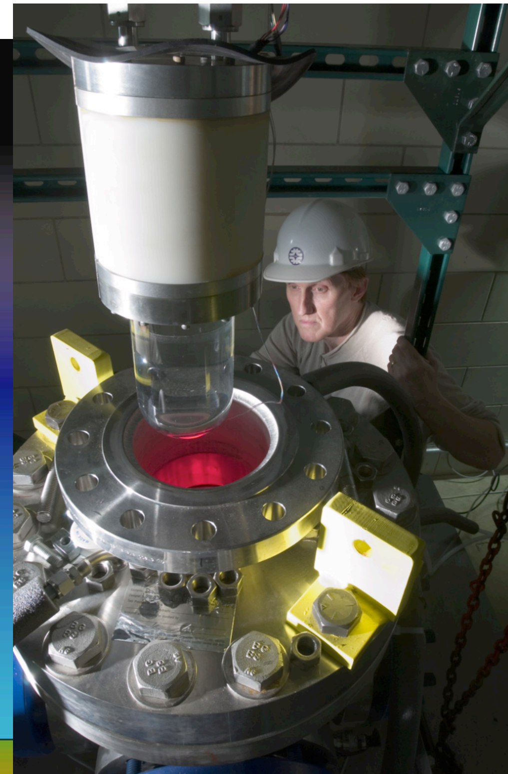
Example, consider $^{222}Rn \to ^{218}Po$:

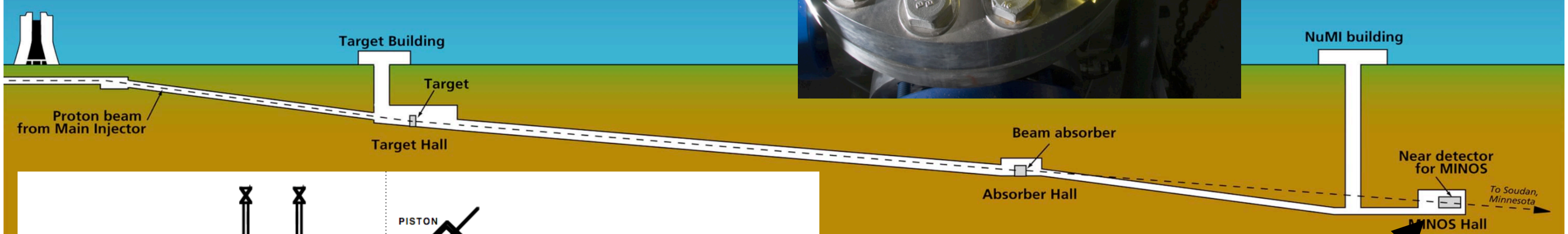


- The recoiling nucleus creates a bubble in a BC sensitive to lower energy WIMP (~10 keV) recoils
- ^{238}U and ^{232}Th decay series include many α emitters, including Radon (^{222}Rn) and its daughters.

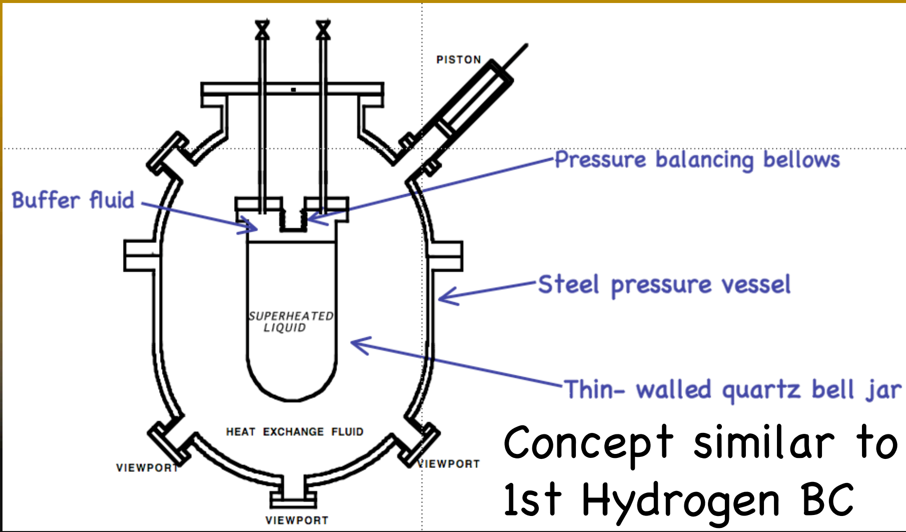
COUPP @ NuMI Tunnel Project (Fermilab Test Beam Proposal T945)



2kg (1l) CF_3I chamber built at UC installed May '05



test site ~300 m.w.e.



Concept similar to 1st Hydrogen BC

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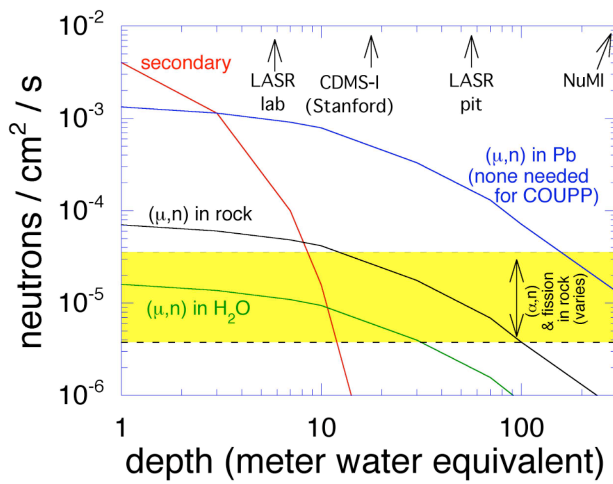
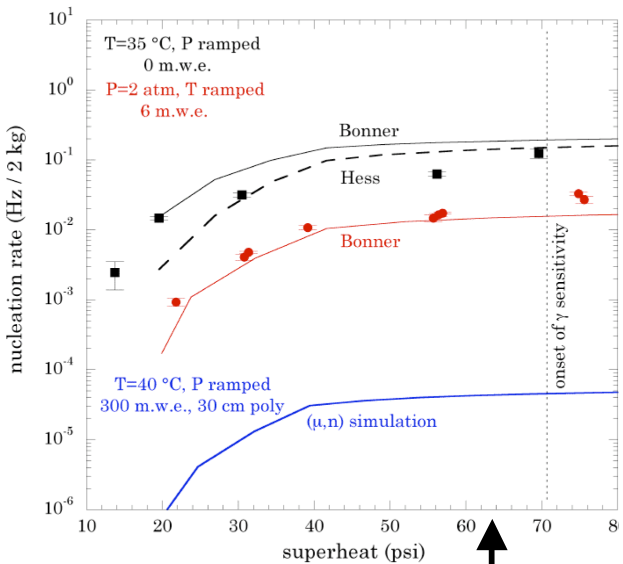
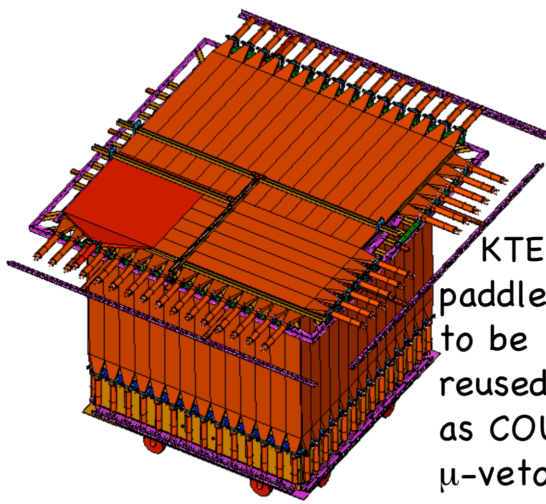


n flux already dominated by rock radioactivity in a site this deep. Muon veto and 30 cm of polyethylene allow to reach ~0.03 c/kg day (= CDMS-II sensitivity)

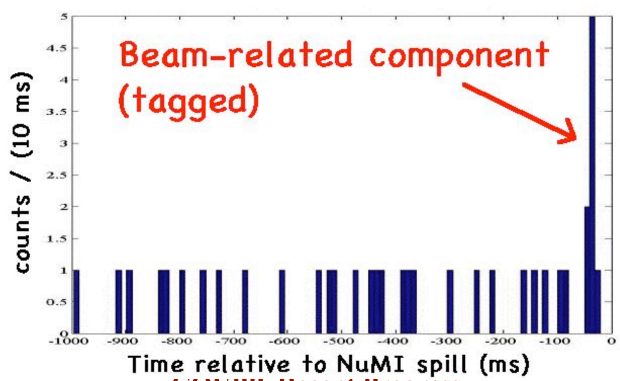
NuMI neutron flux ~ 3E-5 n / cm² s

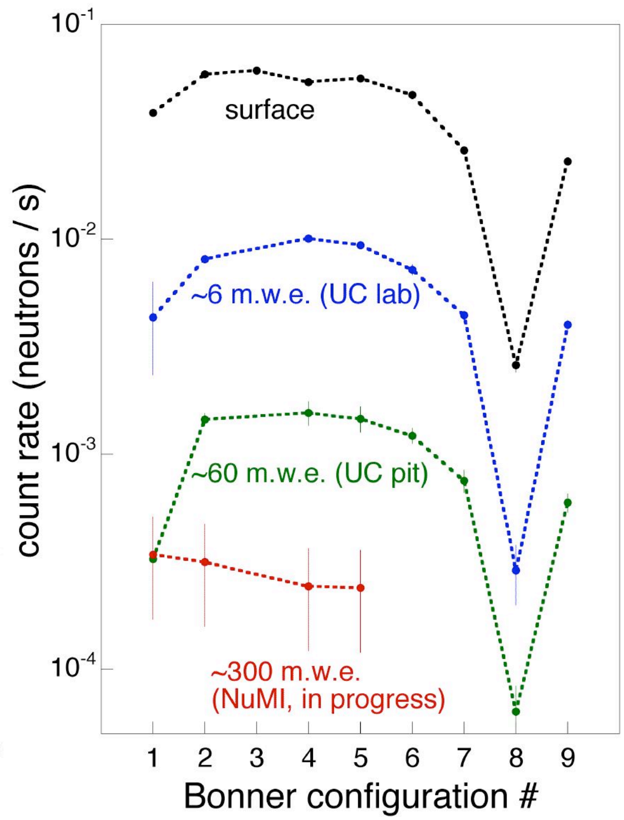


Nucleation rate at surface and shallow UC site (6 m.w.e.) in good agreement with environmental n's (a first "calibration") >100 improvement expected at NuMi



KTEV paddles to be reused as COUPP μ-veto





Continuous Operation: December '05 to Oct '06

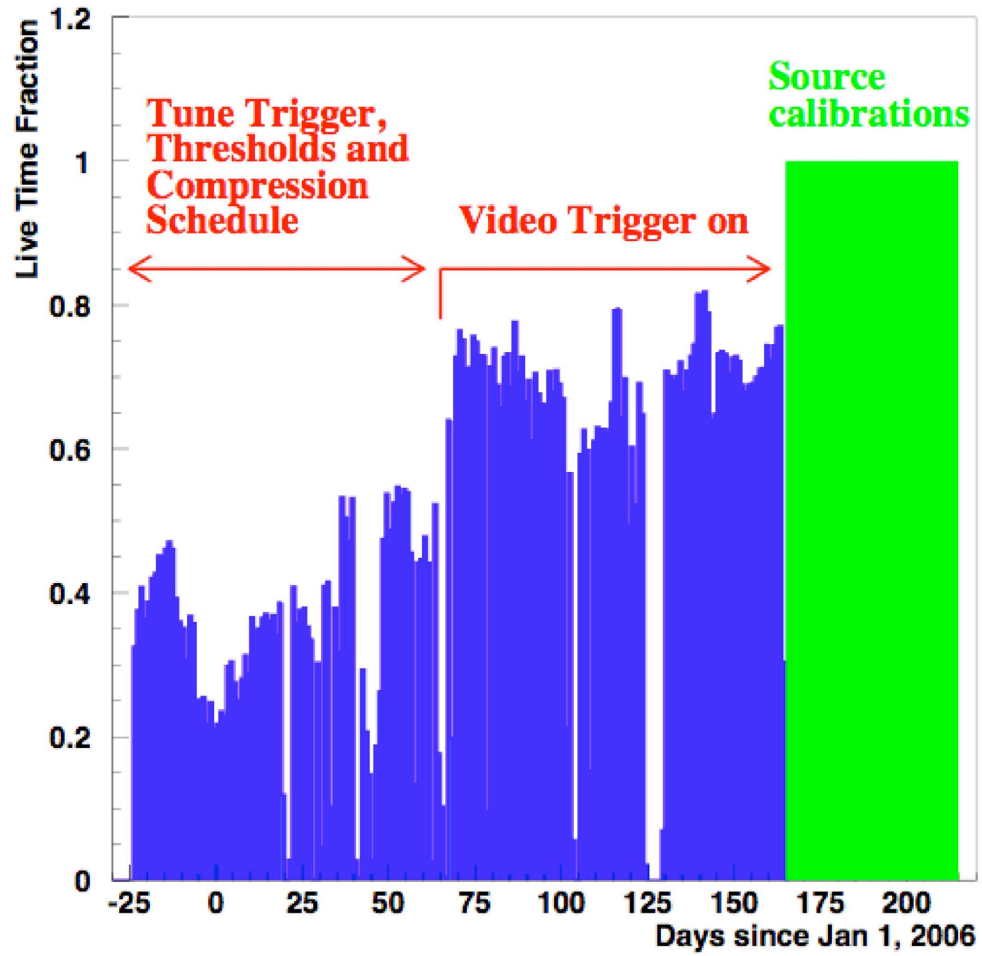
307 days in run
115k expansions
140 seconds mean
superheated time

170 live days
= 55% of calendar time

~70% live time after stabilization

50.8k bubbles counted

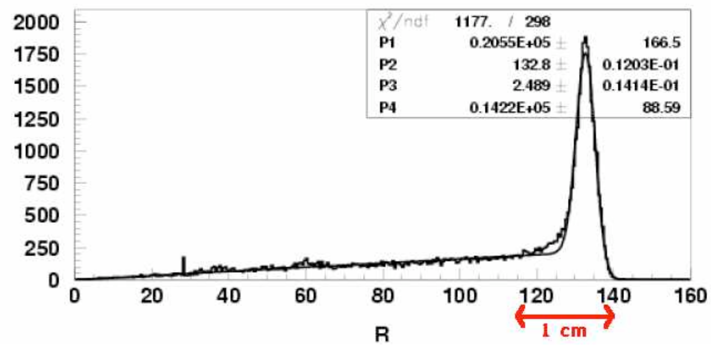
324 GB in Enstore

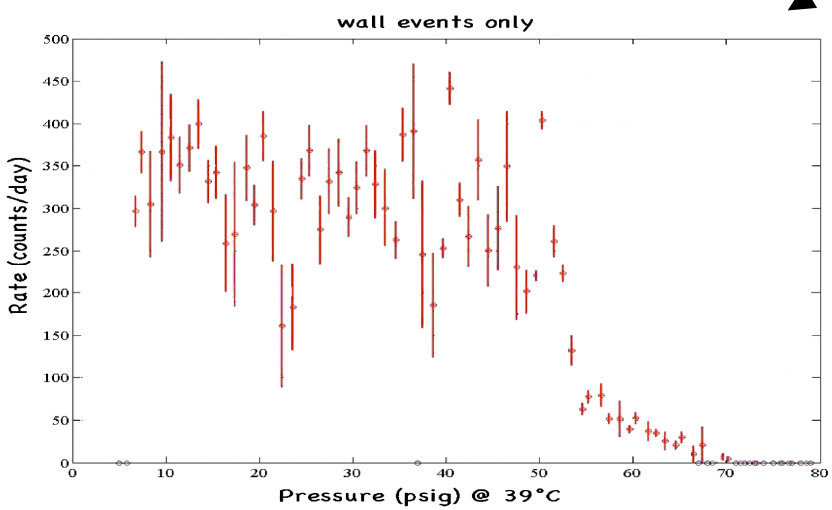


Goals of TBP T945:

- Demonstrate reliable operation.
- Study backgrounds (they were expected!)
- Calibrate with sources: γ, n.

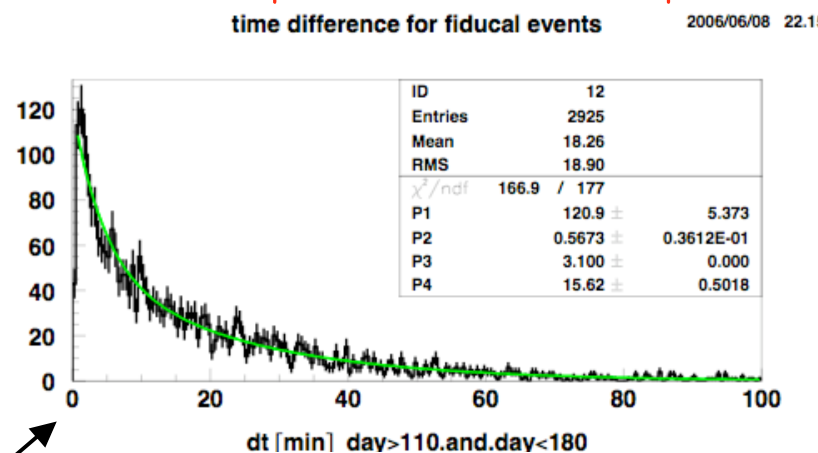
Two (expected) backgrounds found and addressed during T945





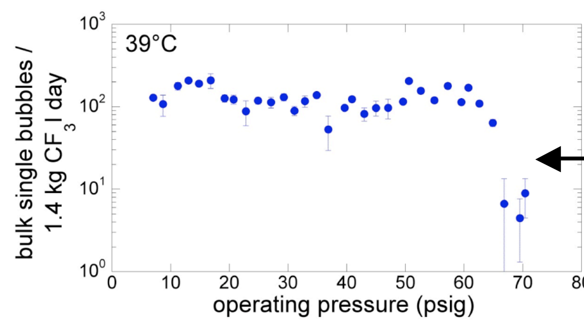
1) Excess surface nucleations from Rn daughter implantation

- Rate consistent with ~200 days of quartz exposure to air
- Tell-tale pressure sensitivity onset (α's)
- Can be rejected, but must be reduced by > 10 to allow >60% live-time in ~50kg chambers
- Addressed via modified etch at vessel manufacturer (up to x200 reduction expected)



2) Radon Decays Presently Dominate Bulk Events

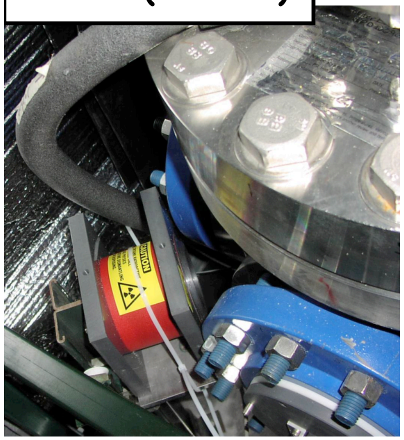
- Rn sources present: viton o-ring, thoriated weld lines.
- Time correlations of bulk events are consistent with 3.1 minute half-life of Po-218 (this provides rejection)
- Addressed by use of metallic gaskets, lanthanated tips for flange welding and custom-made bellows (electron beam welded)



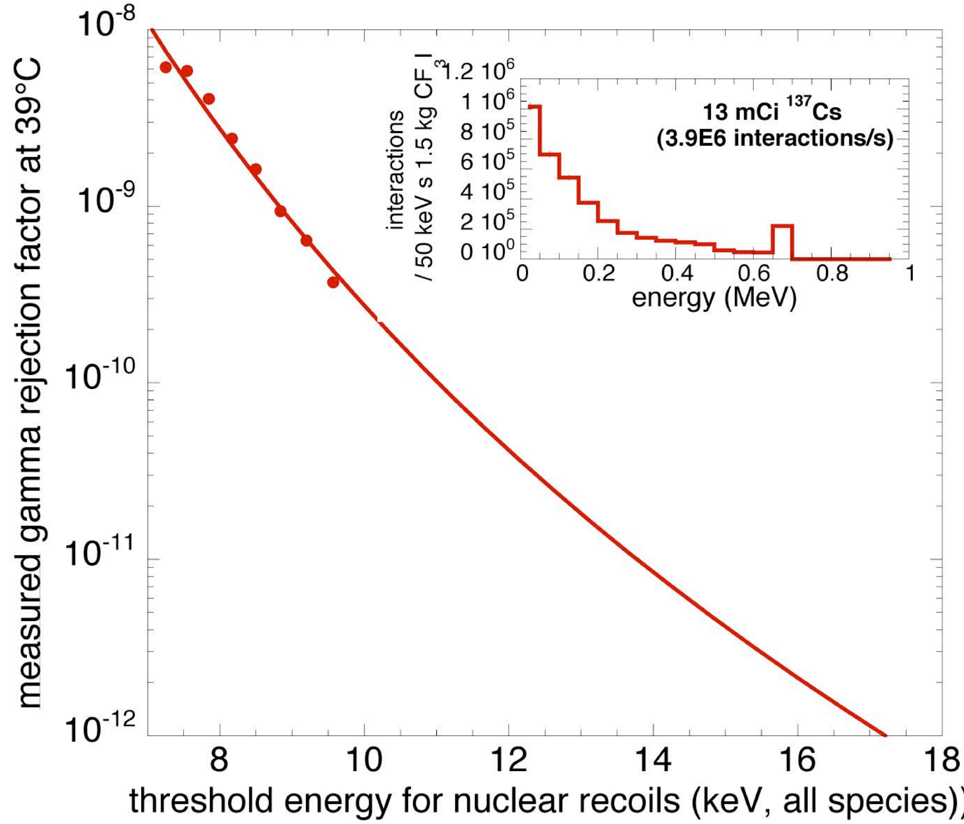
Second signature: P-onset as predicted, flat rate below.

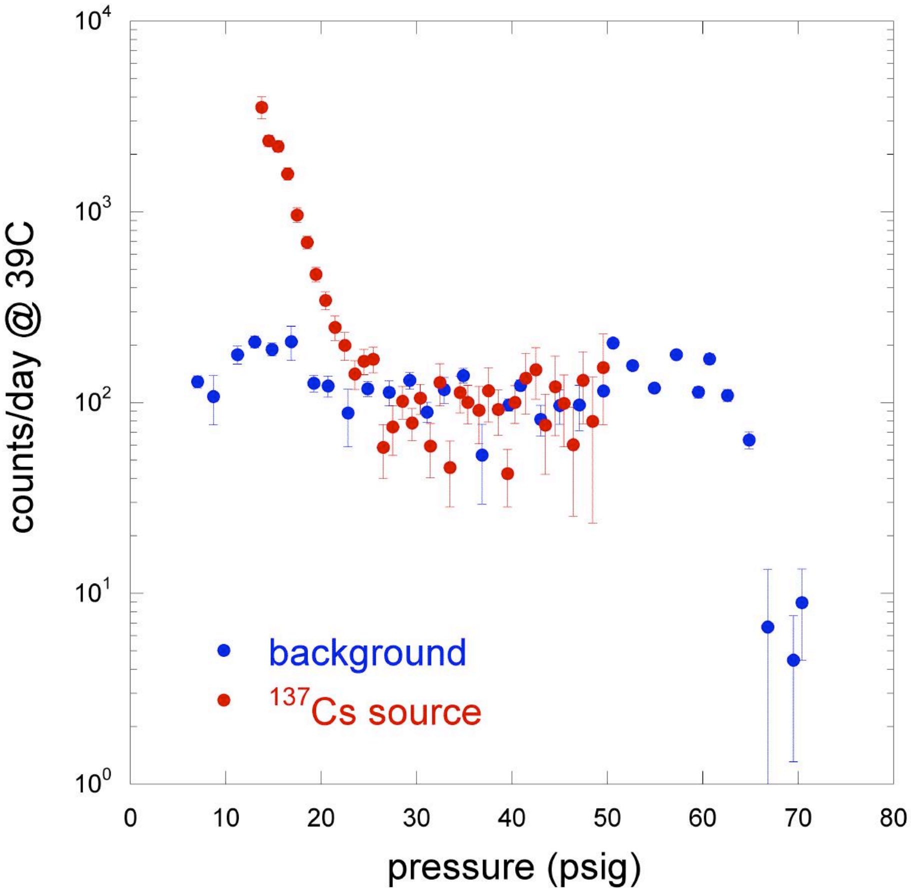
Gamma and neutron calibrations *in situ:*

^{137}Cs (13mCi)



Best MIP rejection factor measured anywhere ($<10^{-10}$ INTRINSIC, no data cuts)



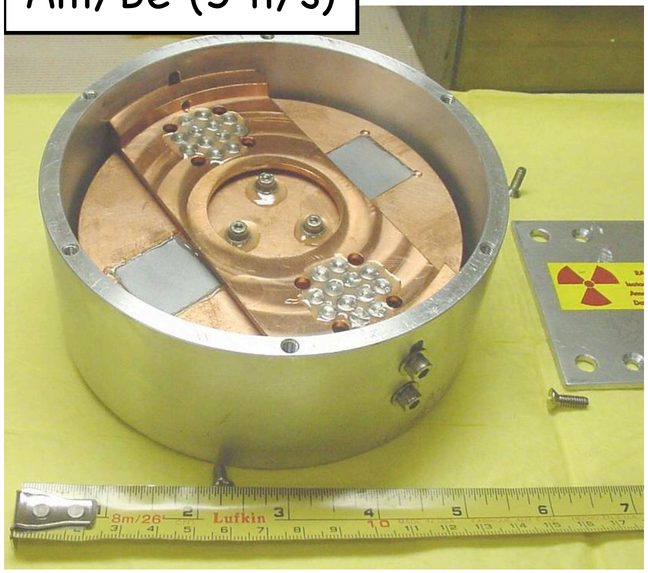


Other experiments as a reference:
XENON ~10^{-2}
CDMS 10^{-4}-10^{-5}
WARP ~10^{-7}-10^{-8}

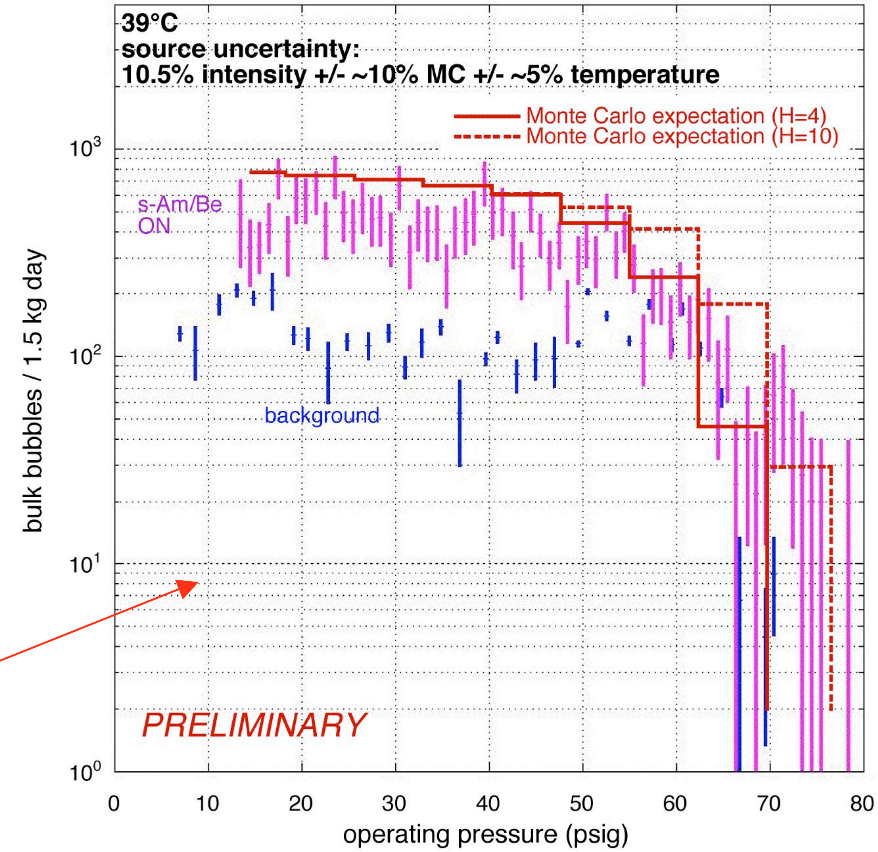
^{14}C betas not an Issue for COUPP (typical O(100)/kg-day)
<u>No need for high-Z shield nor attention to chamber material selection</u>

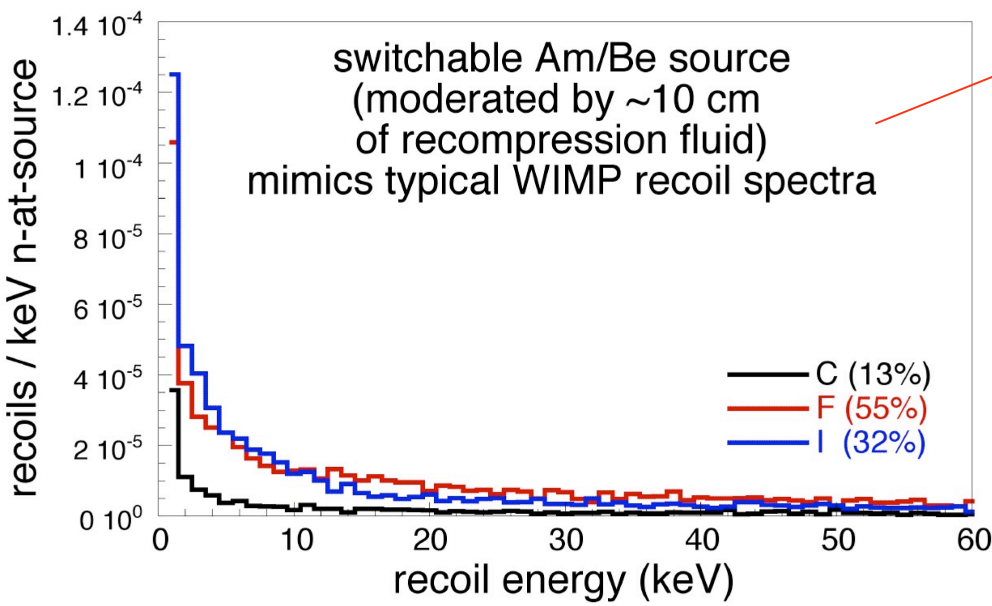
Gamma and neutron calibrations *in situ:*

Switchable Am/Be (5 n/s)



O(0.2) n/day when OFF. Second generation design produces none.





S-Am/Be can be used for ~daily calibration of chamber response (important when searching for DM modulations)

Physics Reach at Fermilab Site

Goal for E-961: reduce background to <<1 event per kg per day

Summary of improvements for next refill:

- Etched quartz vessel (surface nucleations)
- metallic gaskets, lanthanated welds (Rn)
- e-beam welded bellows (Rn)
- TAMApure or SNO H_2O (< 10^{-15} U and Th)
- CF_3I U,Th measured to ~10^{-14} sensitivity (ongoing AMS@ANL), use of nitric acid scrubbing column and multiple distillation if finite value found
- Better commercial chemical purity of CF_3I, electropolished storage vessels
- Attention to U,Th in dust (class <100 conditions, limited exposure, improved cleaning)

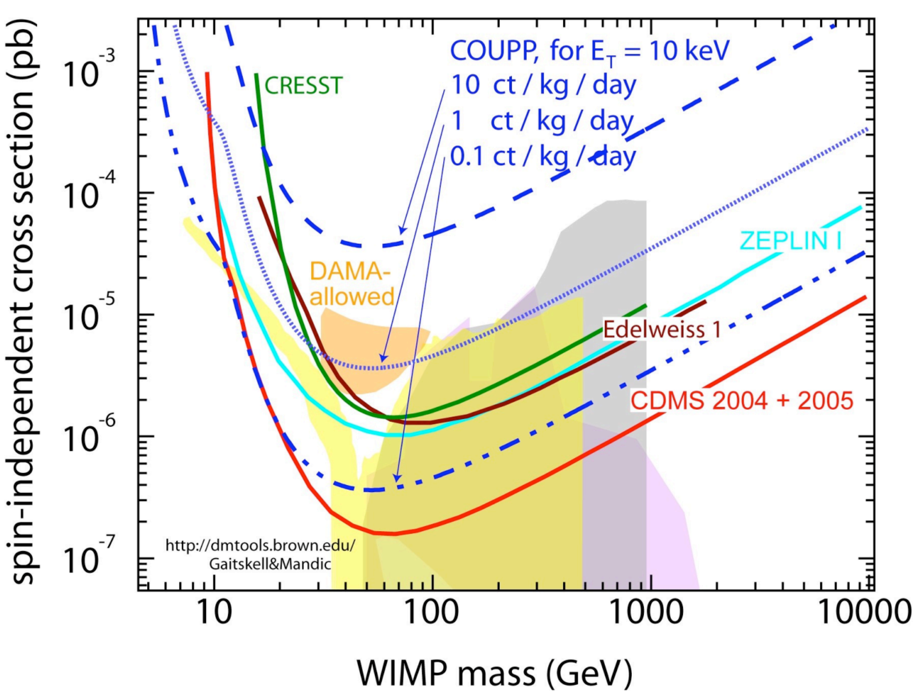
U,Th in CF_3I and buffer liquid	10^{-14}-10^{-15} within reach (commercial H_2O + AMS radioassay). But beyond?	✗
Rn penetration	Sealed container.	✔
Rn emanation	Expected < 5μBq/m^2 from SS and SiO_2. Metallic gaskets, lanthanated tips, clean valves. Also time correlations.	✔
Rn adsorption (ulterior ^{210}Pb release)	Cleaning (etching, ultrasound, EDTA)	?
Rn daughter implantation	Spatial resolution tags these but limits live-time in large chambers. Should be down to < 40 α's / m^2 day now (sufficient)	? ✔
Dust control	~0.1 events / day / m^2 inner surface per hour of class 200 air exposure after the last cleaning (10 ppm U,Th in dust assumed)	✔

A two-step process: we can get to ~10^{-14}-10^{-15} U,Th relatively easy, REAL challenge is to get beyond (KAMLAND is <10^{-17} U,Th)

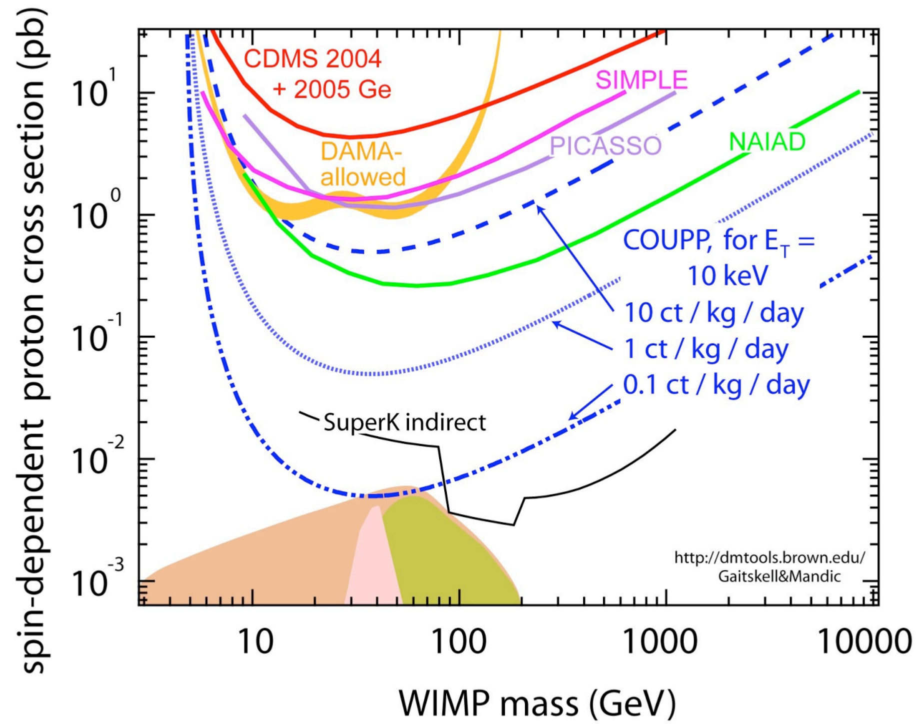
Physics Reach at Fermilab Site

Goal for E-961: reduce background to <<1 event per kg per day

Spin-independent



Spin-dependent



Three projections are offered: ~10c/kg-d can be extracted from present data. ~1c/kg-d expected from simulated (μ,n). ~0.1c/kg-d is for 90% efficient μ veto.

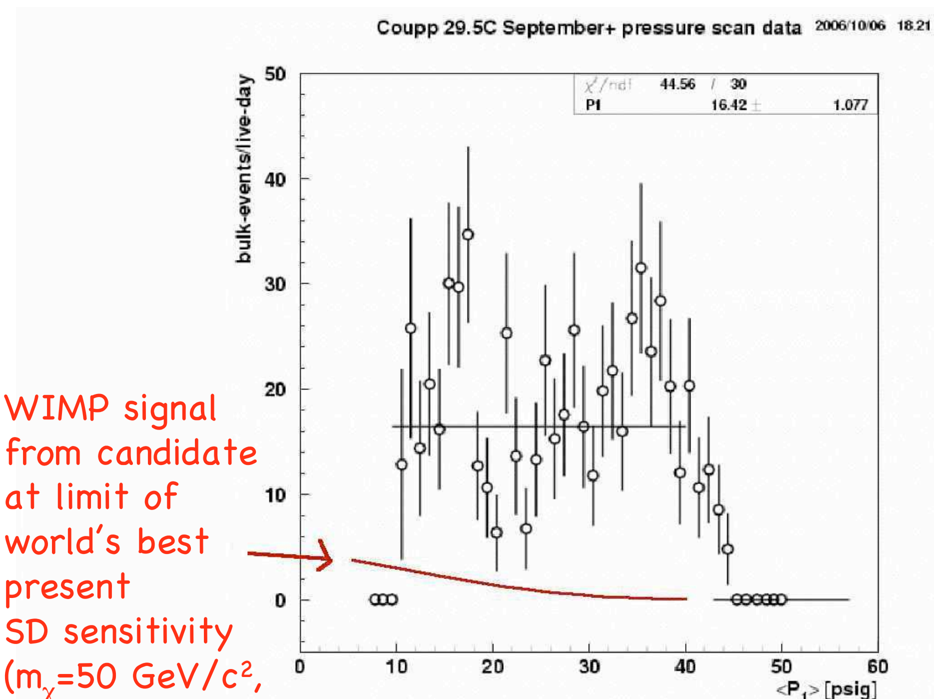
A further reduction to ~0.03 c/kg-d is possible (simulated gallery n's percolate through 30 cm polyethylene shield at that level).

By then better than 10^{-15} U,Th needed (World best is KAMLAND @ ~10^{-18}).

Physics Reach at Fermilab Site

Goal for E-961: reduce background to <<1 event per kg per day

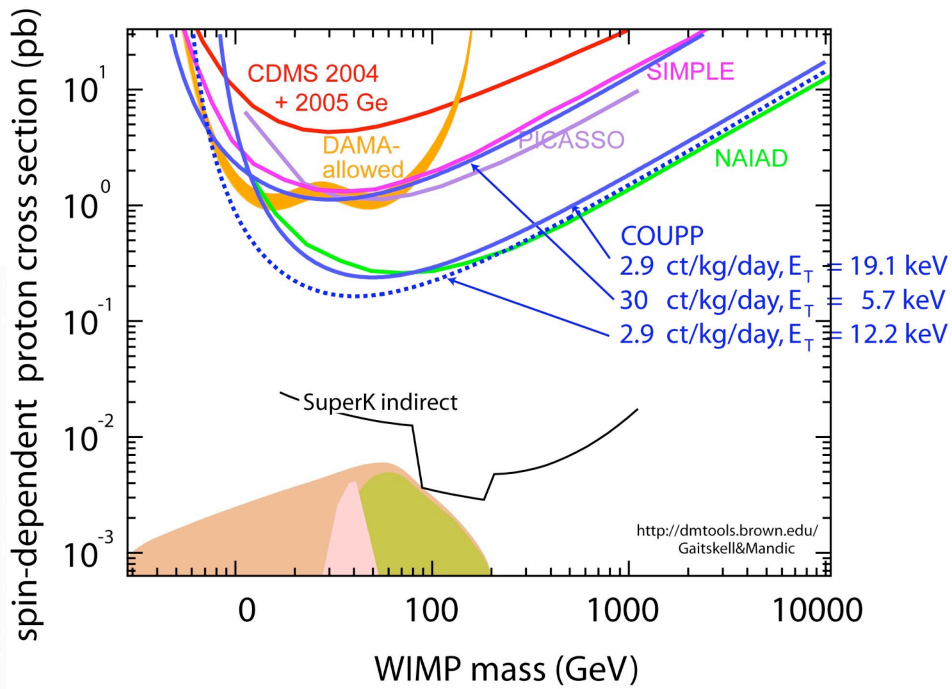
Where exactly are we
in sensitivity as of today?
(next refill should improve it dramatically)



WIMP signal from candidate at limit of world's best present SD sensitivity (m_χ=50 GeV/c^2, σ_{Wp}= 0.3 pb)

Telltale signature:
Response to α's is flat,
not the case for WIMPs
(or neutrons)

Spin-dependent



Not a limit yet
(trying to include systematics, increase statistics, reduce threshold)

However, even before any Rn mitigation best SD limits are within reach
(the effect of optimal targets and MIP insensitivity)

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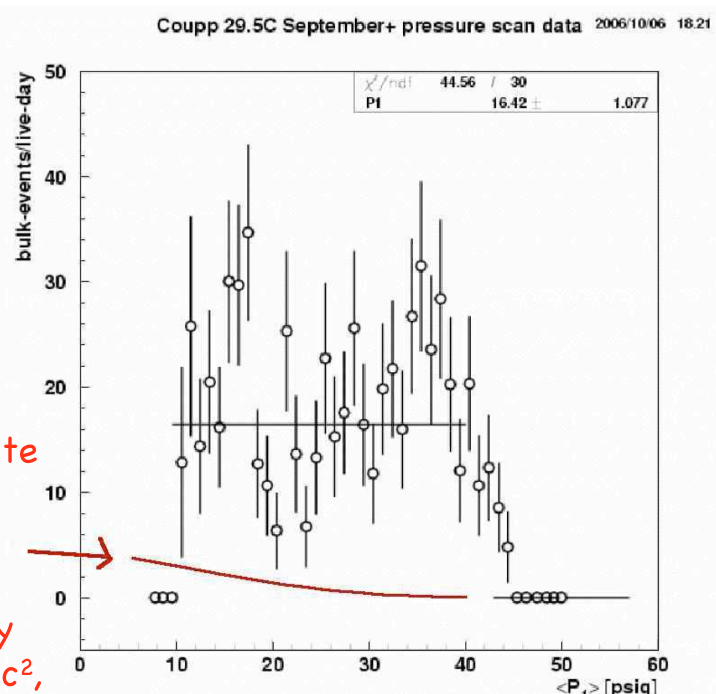

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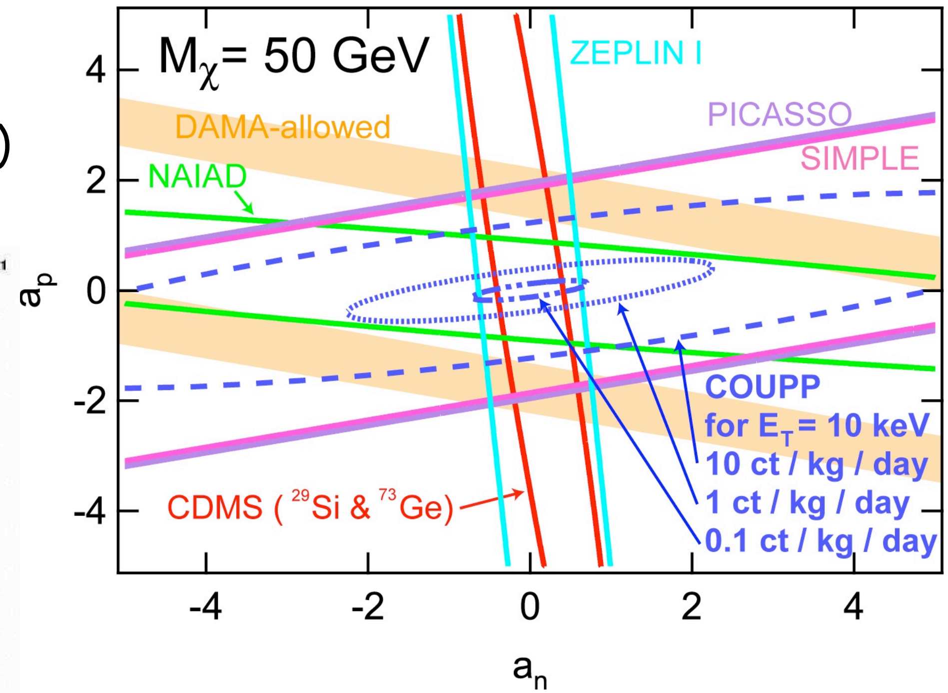

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(trying to include systematics,
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However, even before any Rn mitigation
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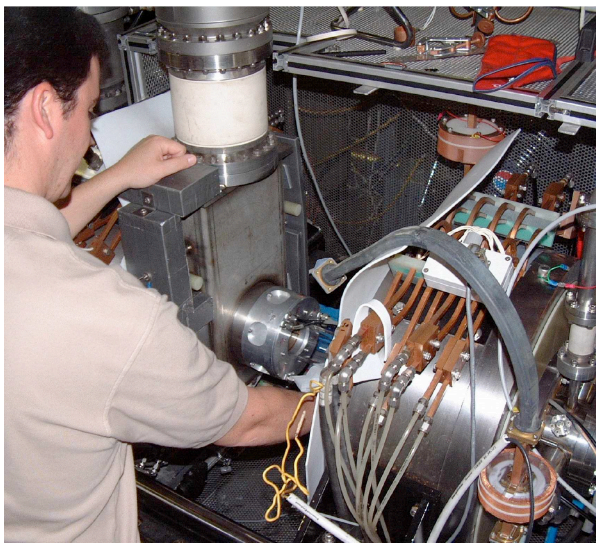
Numerous ongoing activities

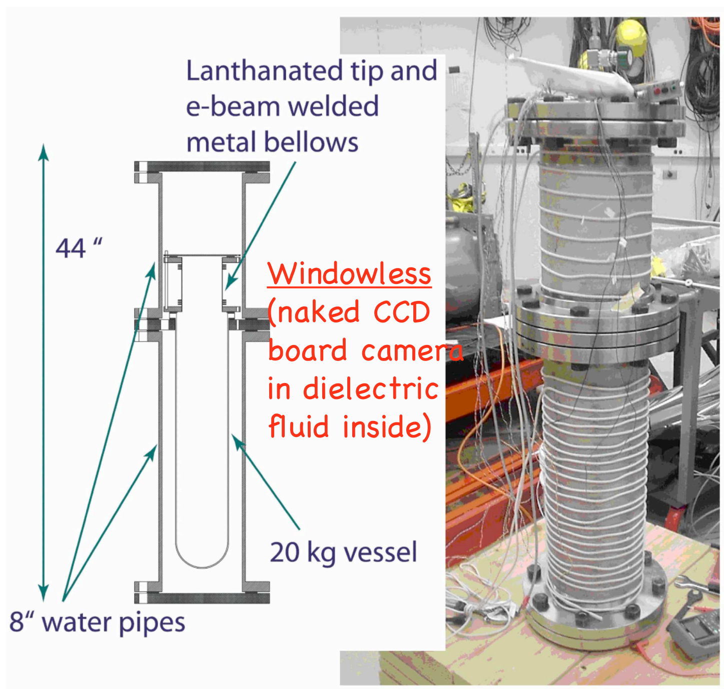
Modular recompression and P-control unit

- Determination of free parameters (efficiency, softness of threshold and "Harper" factor) using dedicated small chambers.
- Separation of response to Iodine and Fluorine recoils (two methods, inelastic neutron scattering and pion beam test)
- Measurement of U,Th in CF_3I down to <10^{-14} using AMS @ ANL, w/ and w/o purification stage (scrubbing column).
- Design and construction of 20 and 60 kg modules. Monolithic "blind" bubble chambers (encapsulated cameras inside). Applications to neutron detection (DOE/NNSA funded).
- Others: recompression and P-stabilization units for upcoming chambers, ultralow-background high-sensitivity fast neutron monitor (to be housed within shield), development of CF_3I SDDs (for alpha calibrations)

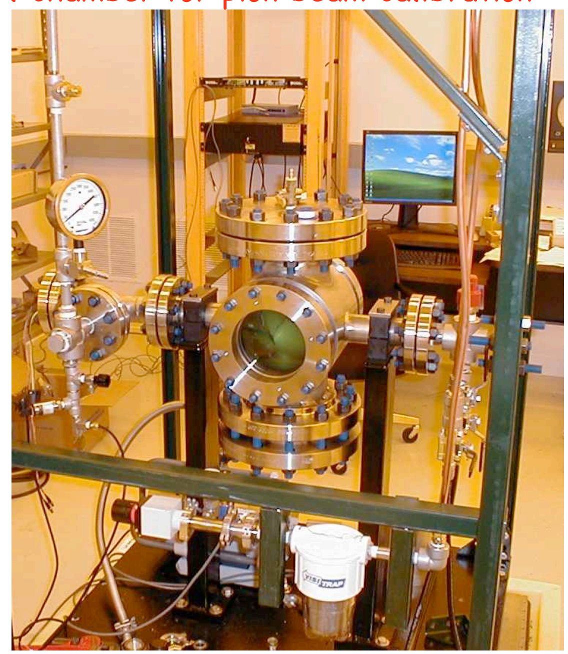
"skinny" chamber for inelastic n scattering exp.

AMS of CF_3I @ ANL (10^{-14} g/g U,Th sensitivity)





1 l chamber for pion beam calibration



Infrastructure is in place

Spray-wash system for
RF cavities (FNAL)

Clean room gowning area (FNAL)

Ultrasound baths

Most important:

←

~300 m.w.e.
location "on site"
and in
nobody's way…

(muon veto under
construction
visible)

Clean room (UC)

Short term plans (next 3 years)

- Replace inner vessel of 1-liter chamber with measures against Radon and other improvements.
- Commission muon veto system to extend sensitivity at NuMi site.

  Goals: Understand backgrounds.

  World's best sensitivity for spin-dependent scattering.

  Potentially competitive with CDMS-II for spin-independent.

  Attract the partnership and expertise needed for the longer term by demonstrating viability.

- Improve understanding of bubble nucleation threshold and efficiency through test beam experiments and neutron experiments. Study response of C_3F_8 and C_4F_{10}.
- Obtain modest additional funding aiming at the construction of a target mass O(250)kg. Multiple modules envisioned at this stage (facilitates upgrades as backgrounds become evident).

  Present funding: CAREER (NSF), KICP (NSF+Kavli), NSF (IUSB), DOE/NNSA, DOE (Wilson fellowship)

  Short term targeted funding envisioned: ~1MUSD (NSF, 4yr), ~250K/yr (DOE).

- Finish design and construction of chambers in the 20-60 kg regime.
- Commission chambers at Fermilab NuMi site. Goals: Further understanding of weaker backgrounds.
- Deploy chambers at a deep underground location (Soudan? DUSEL? SNOlab?)

Longer term plans

- Successful runs deep underground with ~50 kg modules may lead to the design of larger devices. Needless to say, the ability to reach state-of-the-art alpha-emitter radiopurity must also be in place before this.

To wind it up

- COUPP is at a turning point. Safe, reliable long-term operation of a considerable target mass (2 kg) has already been illustrated during T-945.

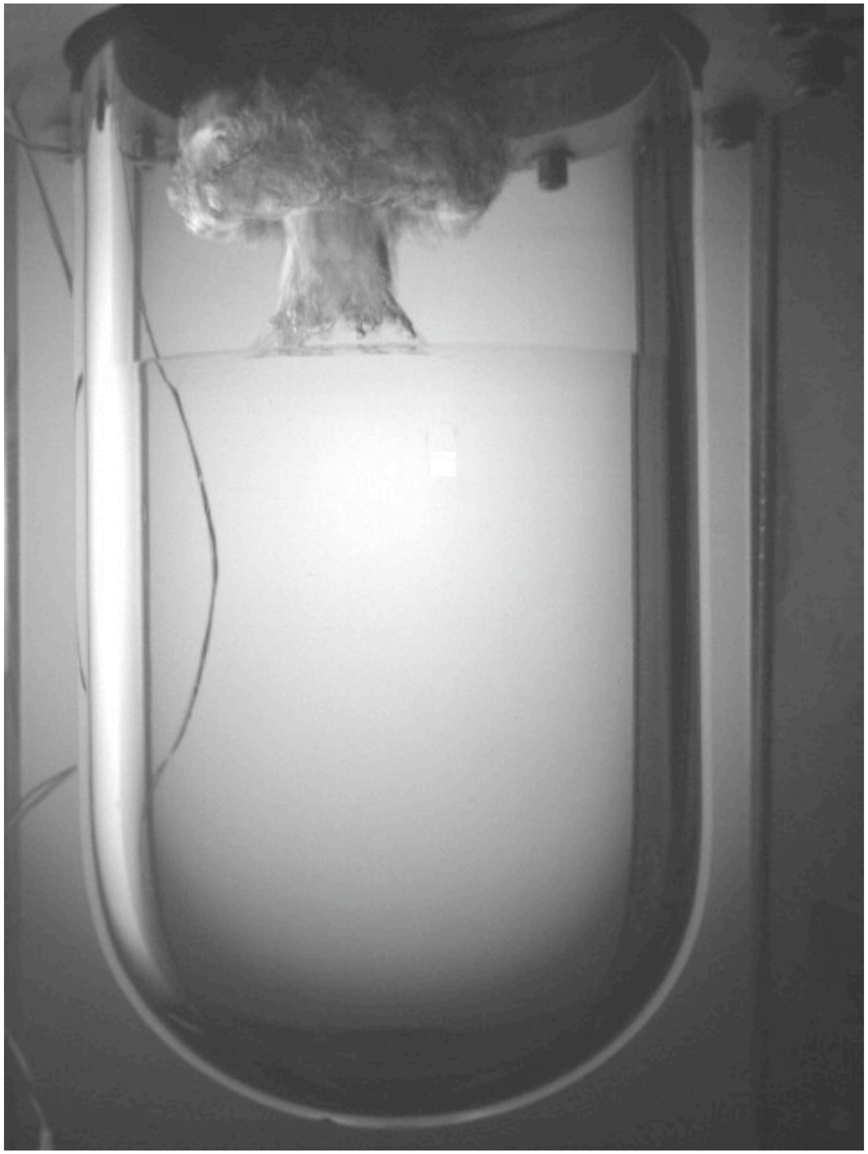
- COUPP is unparalleled in the speed at which it can be scaled-up. Similarly, in potential sensitivity vs. cost. For COUPP to reach its full promise, we will work in parallel on chamber development and alpha-emitter mitigation.

Fact:
The COUPP target mass presently under construction (80 kg) has the SI-equivalent potential reach of ~150 kg of Ge

(superCDMS circa 2014)

(but backgrounds?)

- COUPP's concentration is not just on developing yet another method to increase sensitivity to DM particles, but also on demonstrating that the signals come from WIMPs and not some background. No DM detector is perfect in this sense, calling for a variety of techniques. COUPP has much to offer on this front.



Questions?