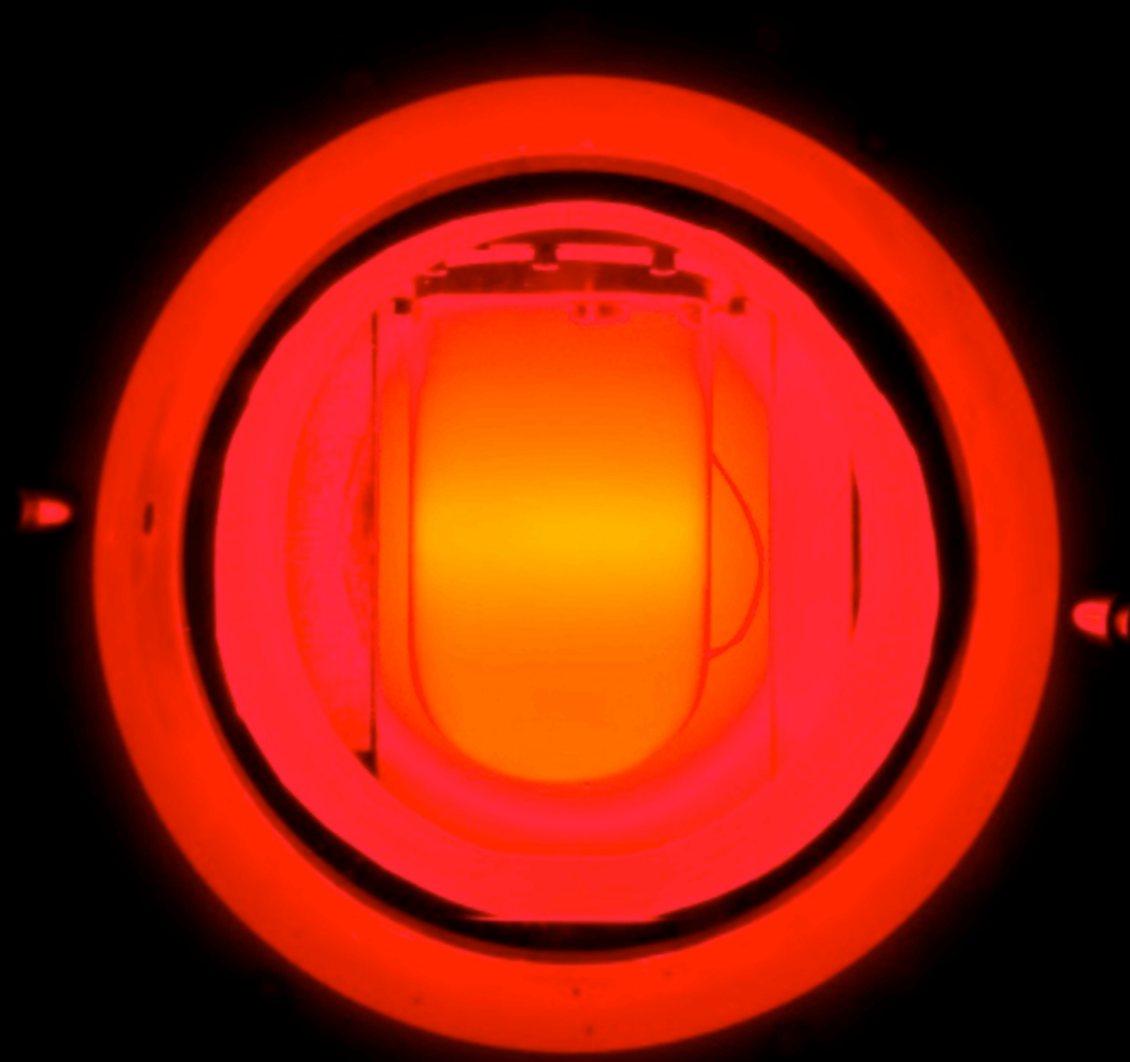
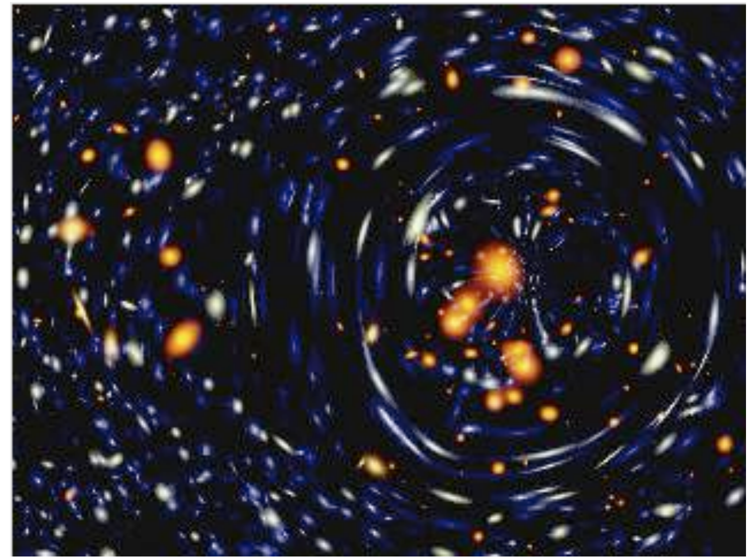
# COUPP: an update



## Direct Detection of CDM: The challenge ahead



- Non-baryonic Galactic Dark Matter close to a paradigm (certainly in the mind of many) but yet to be detected.

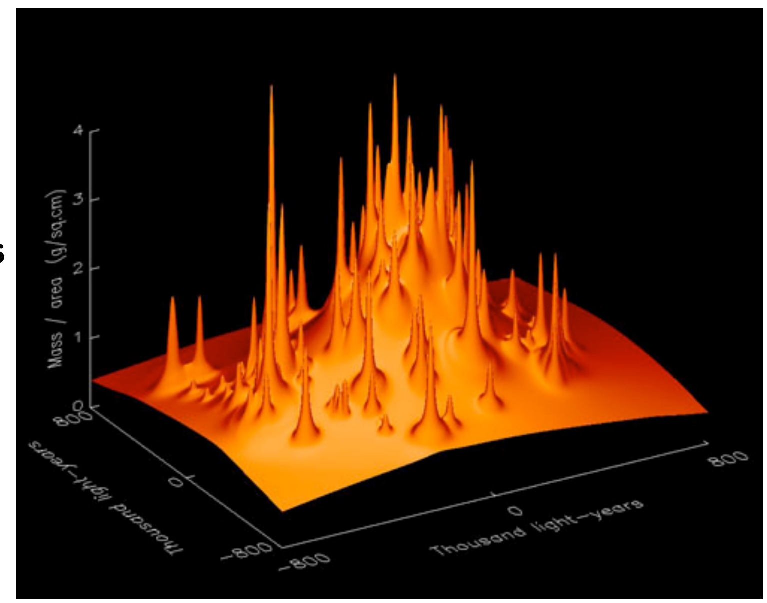
- ~20-30% Cold (non-relativistic) DM presently favored (we don't seem to be able to explain large scale structure of the universe without WIMPs –Weakly Interacting Massive particles–, relics of early stages)

- Cautious strategy: start by looking first for non-ad hoc particle candidates, i.e., those already invoked by particle theories(e.g., neutralino <-> MSSM, axions <-> strong CP problem)

- WIMPs: dominant interaction via low-energy nuclear elastic scattering, expected rates << 1 kg target / day in the keV region. (local $\rho$~0.4 GeV/cm3, <v>~300 km/s, $\sigma < 10^{-42}$ $cm^2$). Supersymmetric WIMPS can have rates as low as 1 recoil/tonne/yr!

- The challenge: build cost-effective tonne or multi-tonne detectors sensitive exclusively to WIMP-induced nuclear recoils (down to 1/year) and nothing else. Not even neutron recoils. Nada. Zilch.

- The scale of things: a 1-kg Ge detector fires in this room at the tune of ~1 kHz (OK to giggle at this point).



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## Particle dark matter? The number of candidates is comparable to the ~30 experiments out to detect it.

- Standard model neutrinos
- Sterile neutrinos
- Axions
- Supersymmetric dark matter (neutralinos, sneutrinos, gravitinos, axinos)
- Light scalar dark matter
- Little Higgs dark matter
- Kaluza-Klein dark matter
- Superheavy dark matter (wimpzillas)
- Q-balls
- CHArged massive particles (CHAMPS)
- Self-interacting dark matter
- D-matter
- Cryptons
- Superweakly interacting dark matter (SWIMPS)
- Brane-world dark matter
- Heavy $4^{th}$ generation neutrinos
- Mirror particles
- Etc., etc.

Patient compilation by C. Hailey (Columbia)

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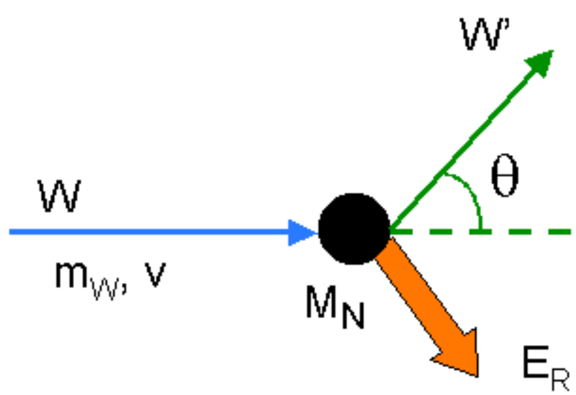
WIMP searches: a quixotic fight against backgrounds

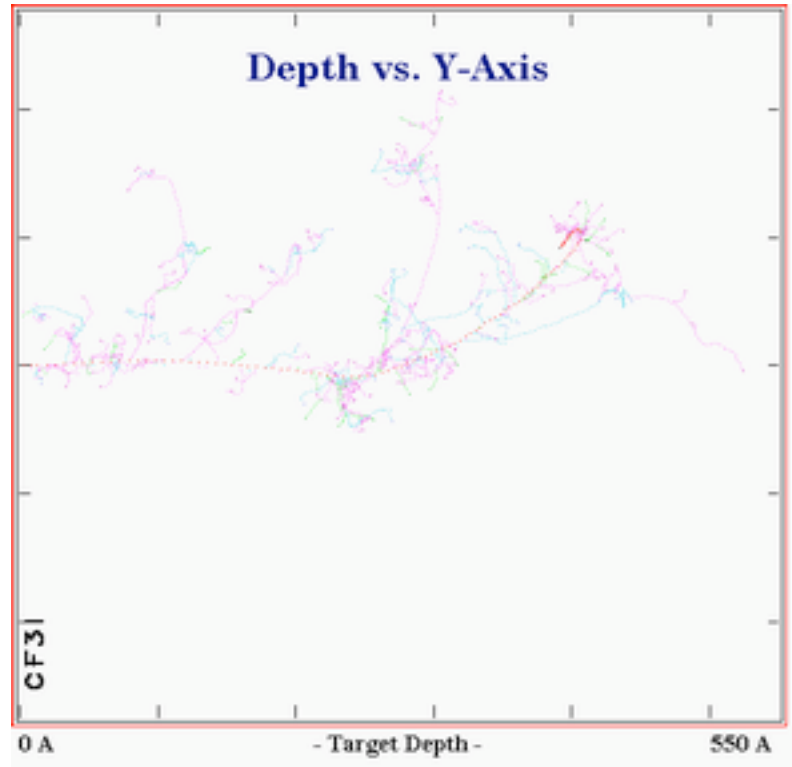
# Do we know anything about these particles?

• Some are expected in particle theories having nothing to do with the dark matter problem.
(e.g., neutralino <-> supersymmetry, axions <-> strong CP problem)

• Supersymmetry attempts to find a common explanation to all known forces in nature. It predicts the existence of new stable particles with the right mass range and stability to make up the galactic dark matter.

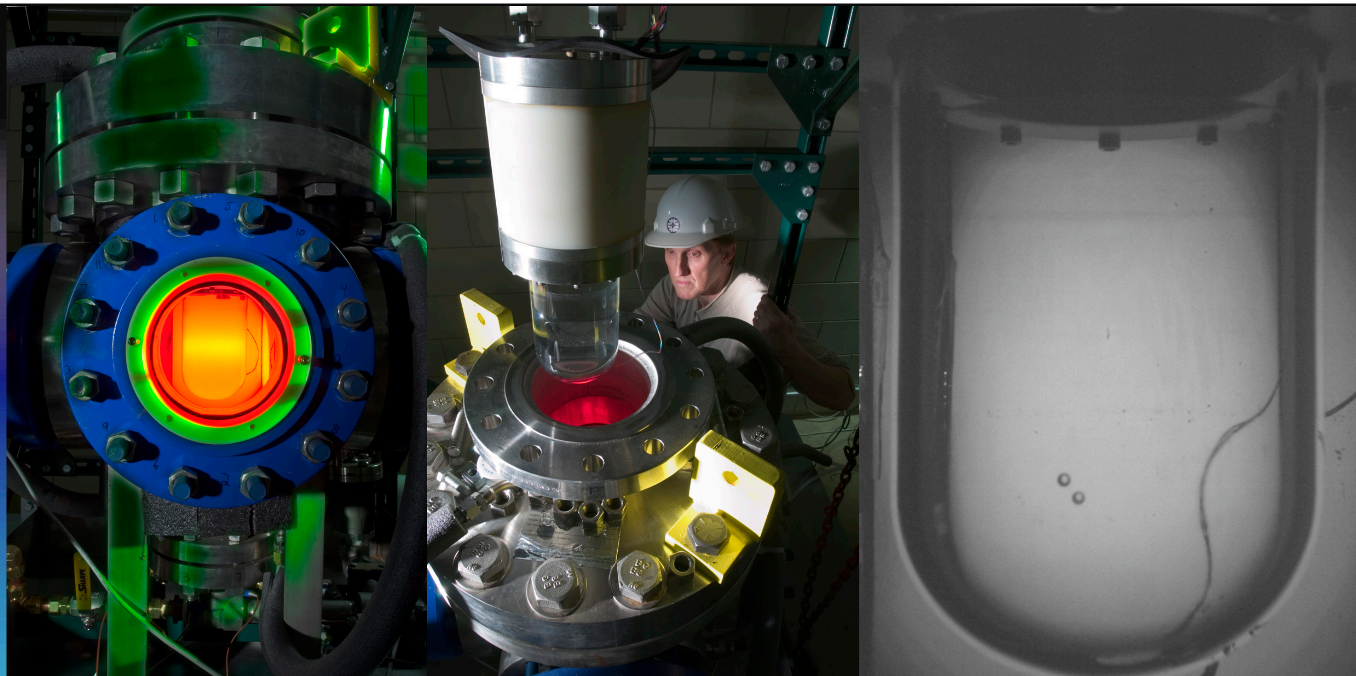
• We expect these to interact (very rarely!) with known matter via "nuclear recoils" = billiard ball collisions. Known particles (e.g. neutrons) can produce the same.



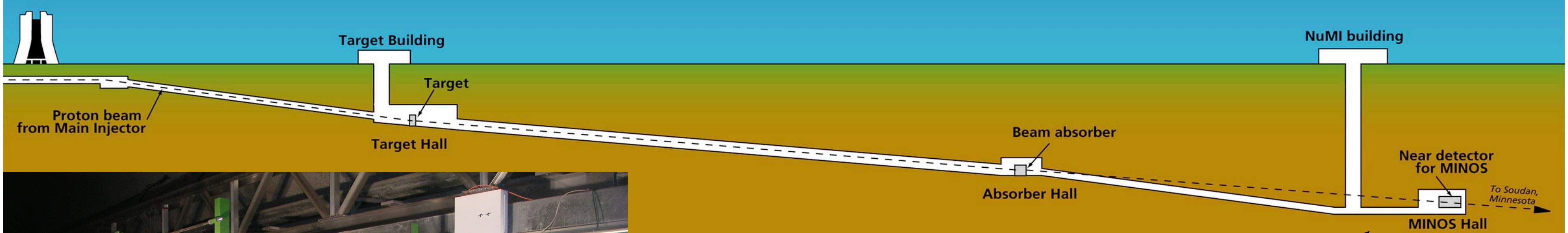

**Things that go bump in the night.**

Few keV iodine recoils injected into CF3I. Movie available from http://cfcp.uchicago.edu/~collar/IonCF3I_1.mov



# COUPP: a direct search for Dark Matter using Bubble Chambers

(Fermilab experiment E961, UC,FNAL,IUSB)




test site
~300 m.w.e.

# 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, room temperature operation, safe chemistry (fire-extinguishing industrial refrigerants), moderate pressures (<200 psig)

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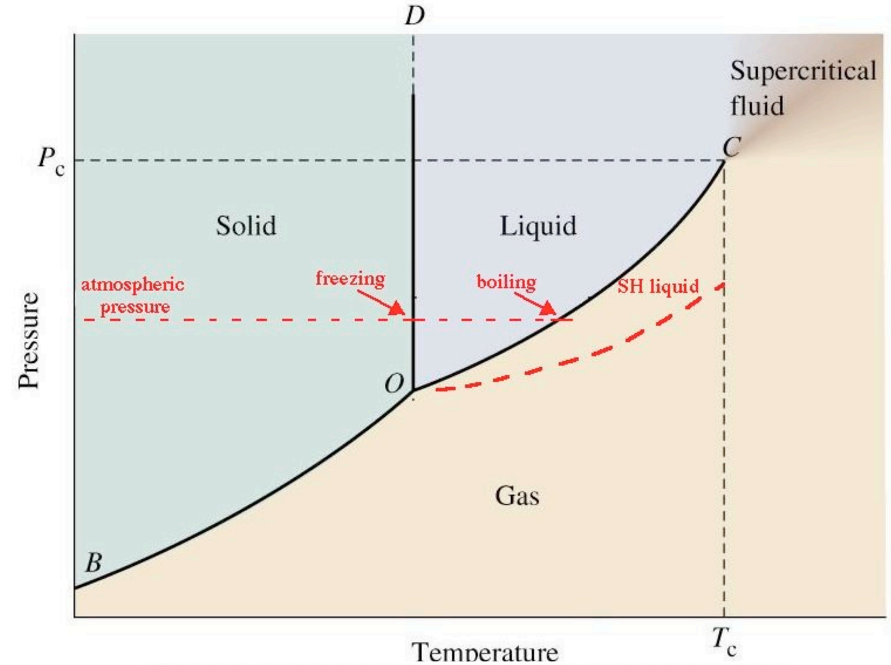
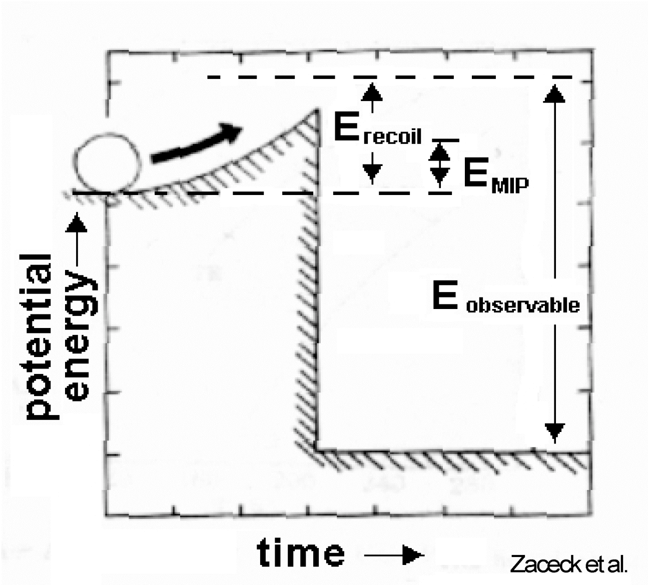
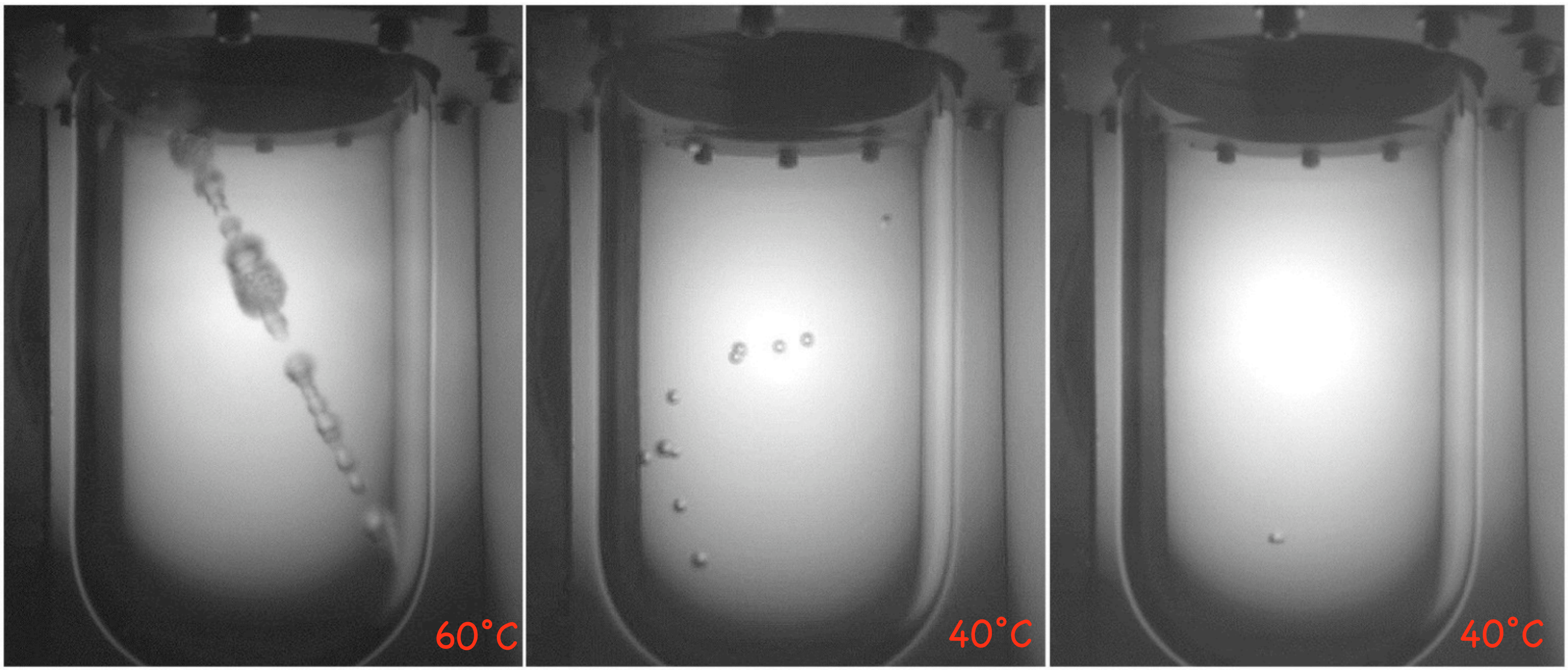


# Not your daddy's bubble chamber:

Conventional BC operation
(high superheat, MIP sensitive)

Low degree of superheat, sensitive to nuclear recoils only




muon | Neutron | WIMP

**ultra-clean BC: Bolte *et al.*, NIM A577 (2007) 569**

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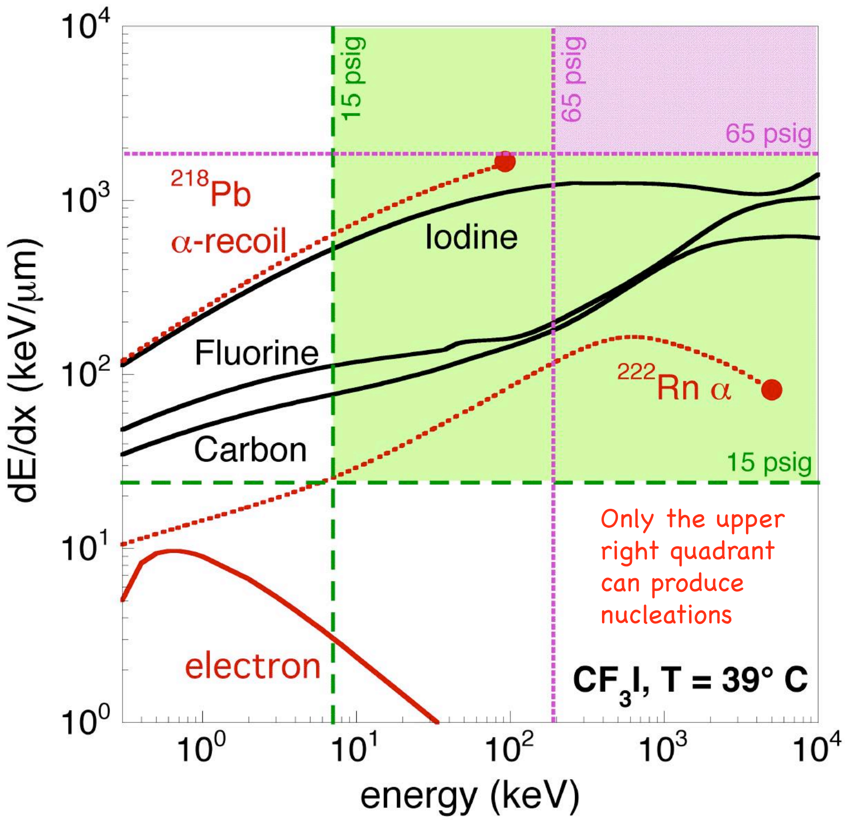
Seitz model of bubble nucleation (classical BC theory):

Threshold in deposited energy

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

$$dE/dx > E_c/(a r_c)$$

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



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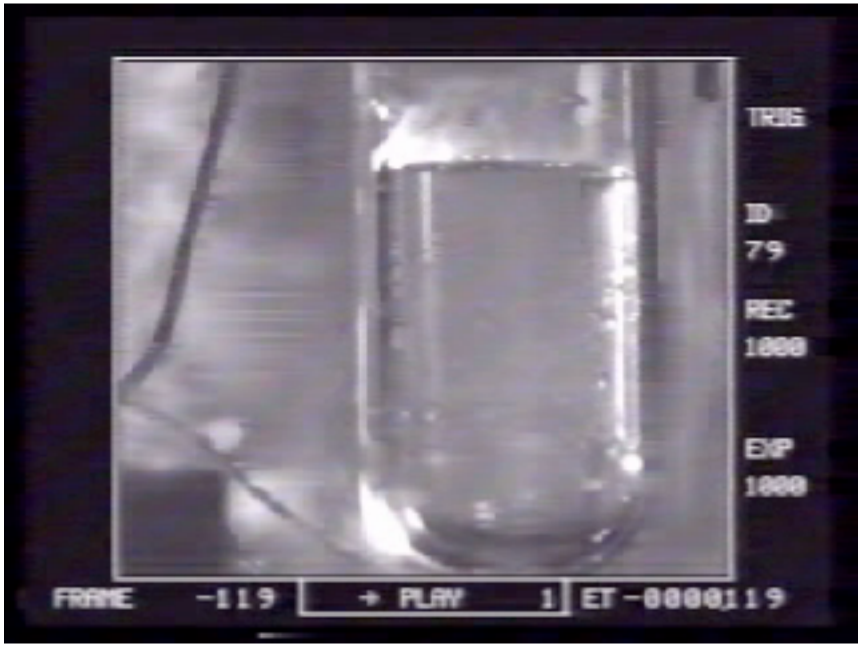
neutron-induced nucleation in 20 c.c. $CF_3Br$ (0.1 s real-time span)
Movie available from http://cfcp.uchicago.edu/~collar/bubble.mov



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As seen in Mythbusters ("Deadly Microwaves")

Movie available from
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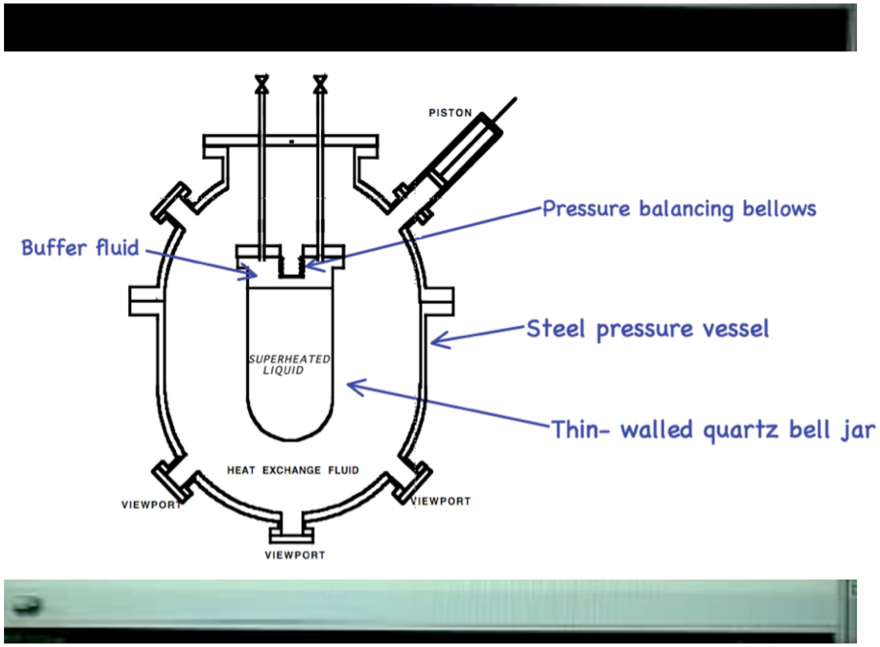


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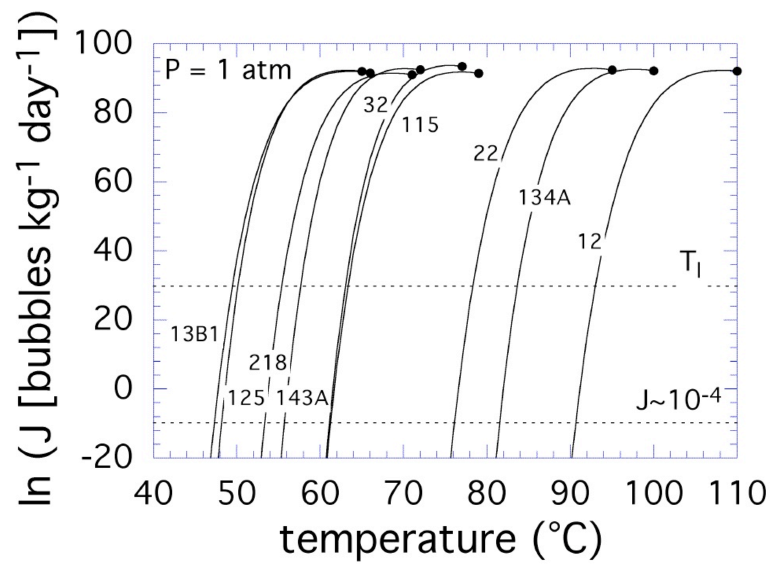
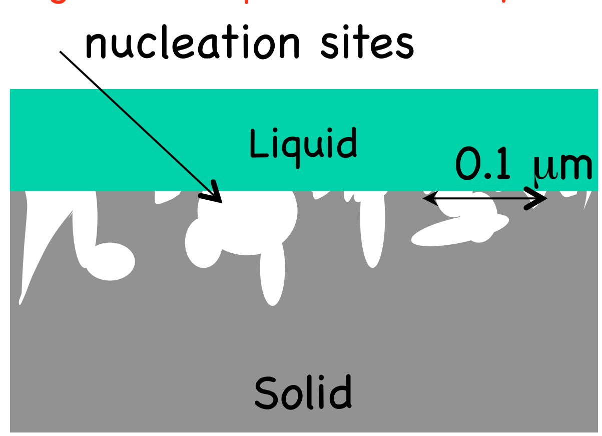
Spontaneous bulk nucleation rate
$Log_n$(-2.5E5) /kg day!! ($T_c$= 122°C, run at ~40°C)




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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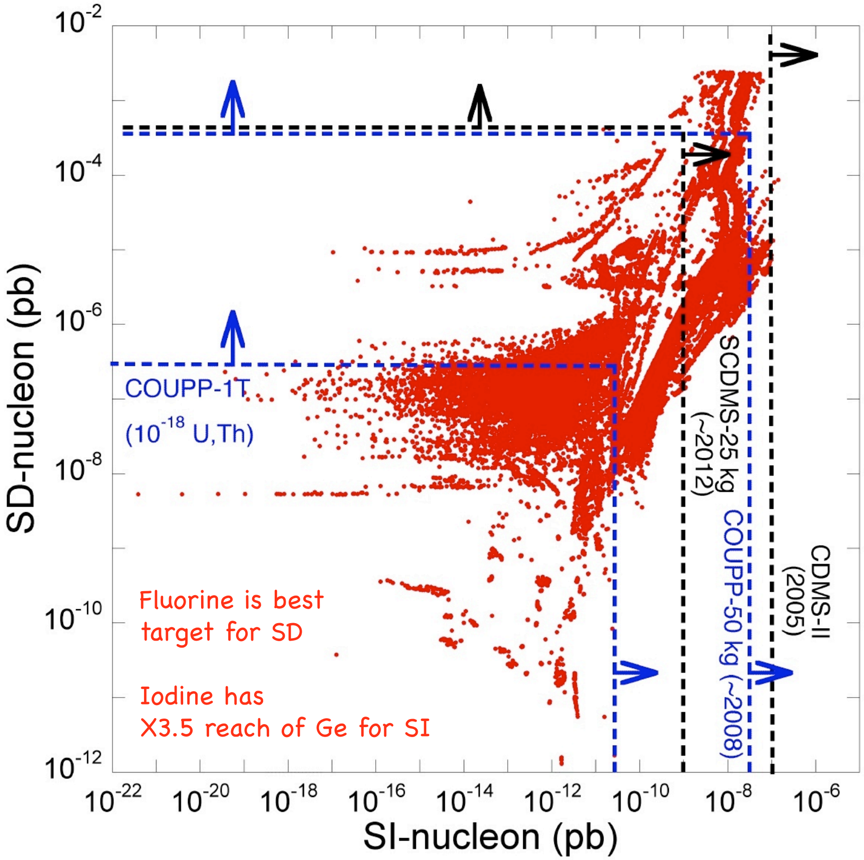
An old precept: attack on both fronts




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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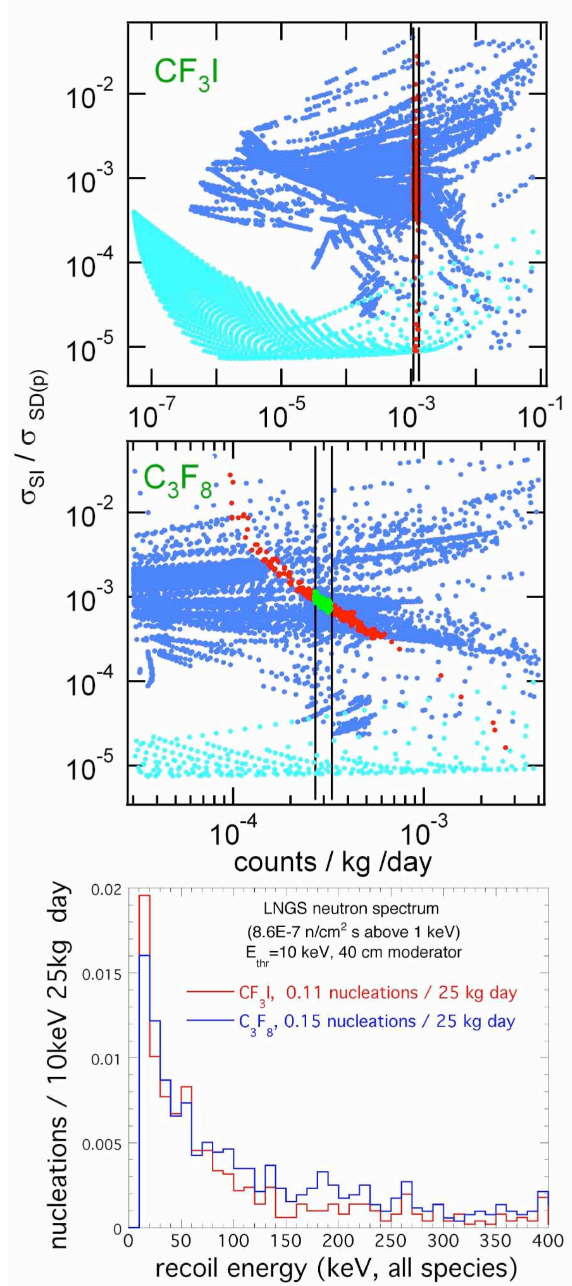


Bertone, Cerdeno, Collar and Odom (PRL 99(2007)151301)

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 ($\sigma_n$ for F and I are very similar)

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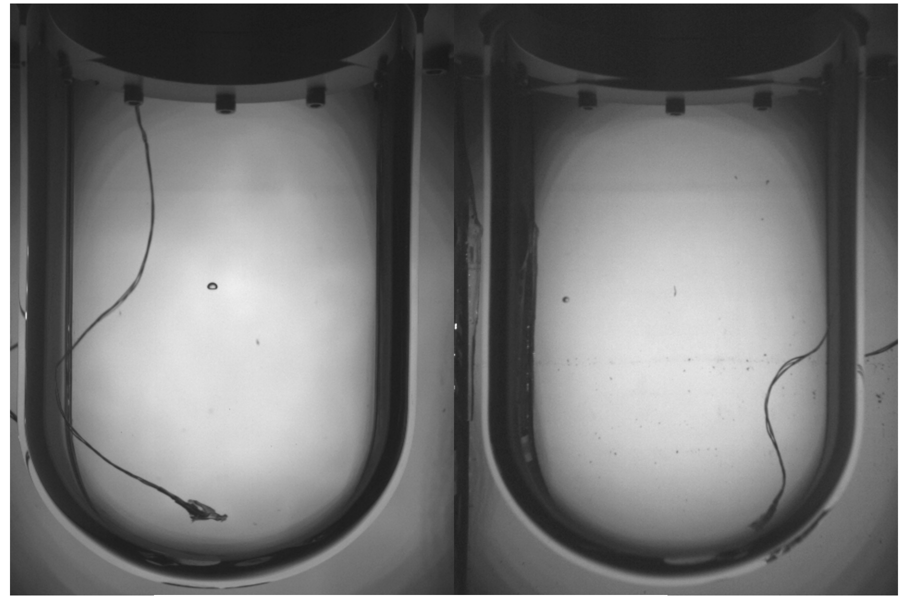
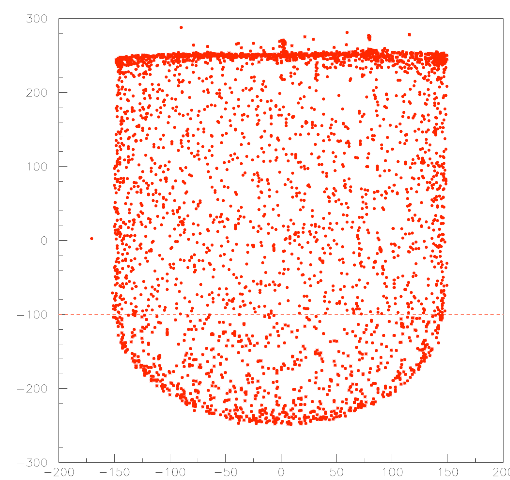
Stereo view of a typical event in 2 kg chamber






Spatial distribution of bubbles (~1 mm resol.)

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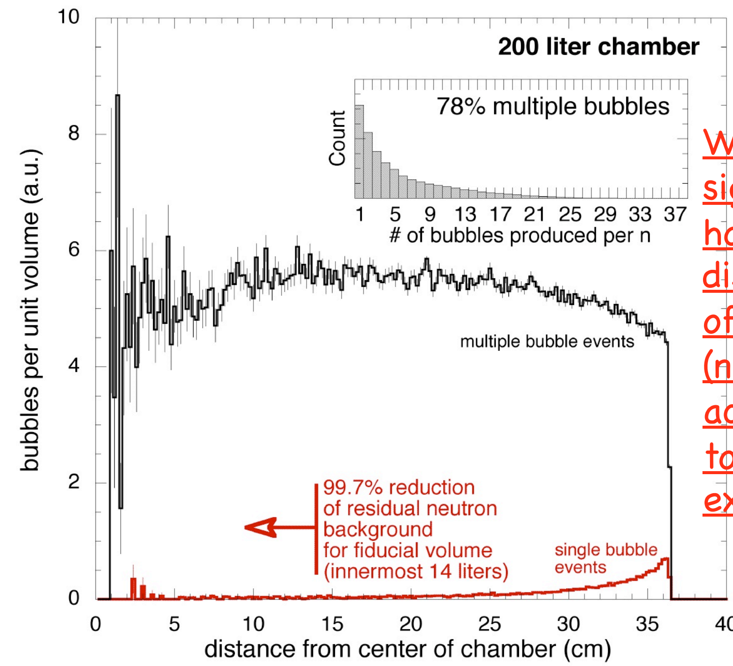
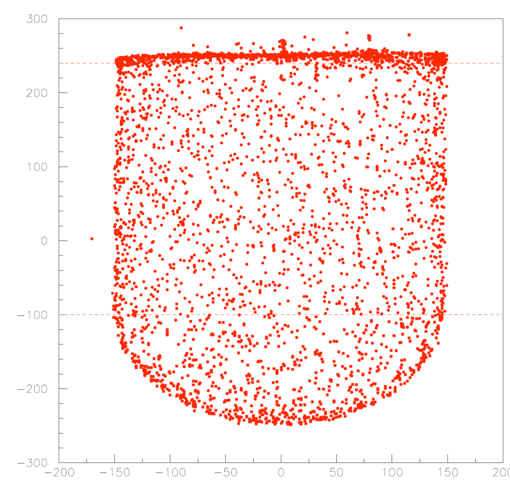
Larger chambers will be "self-shielding"




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



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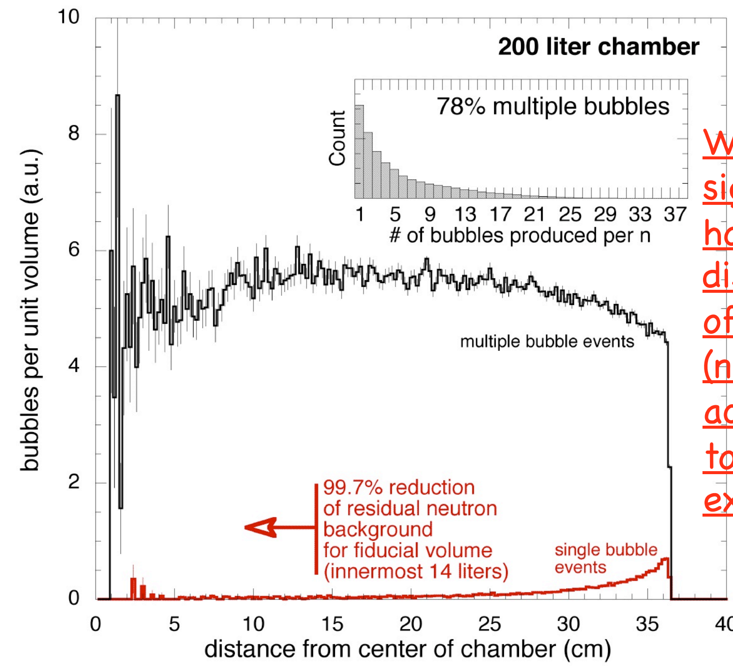


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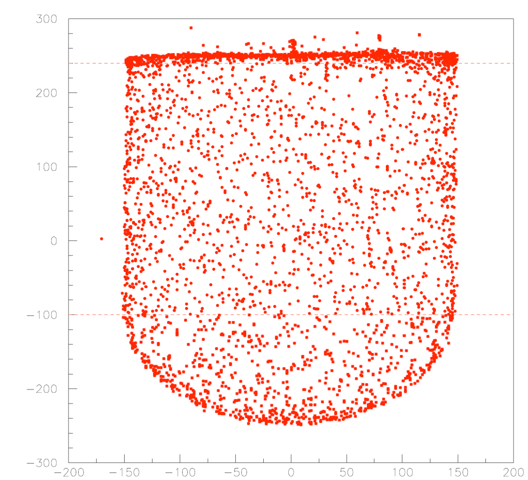

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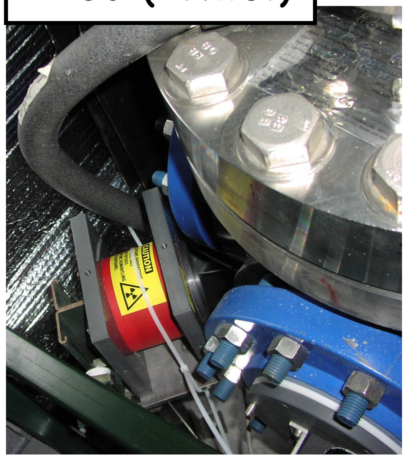
$^{137}Cs$ (13mCi)



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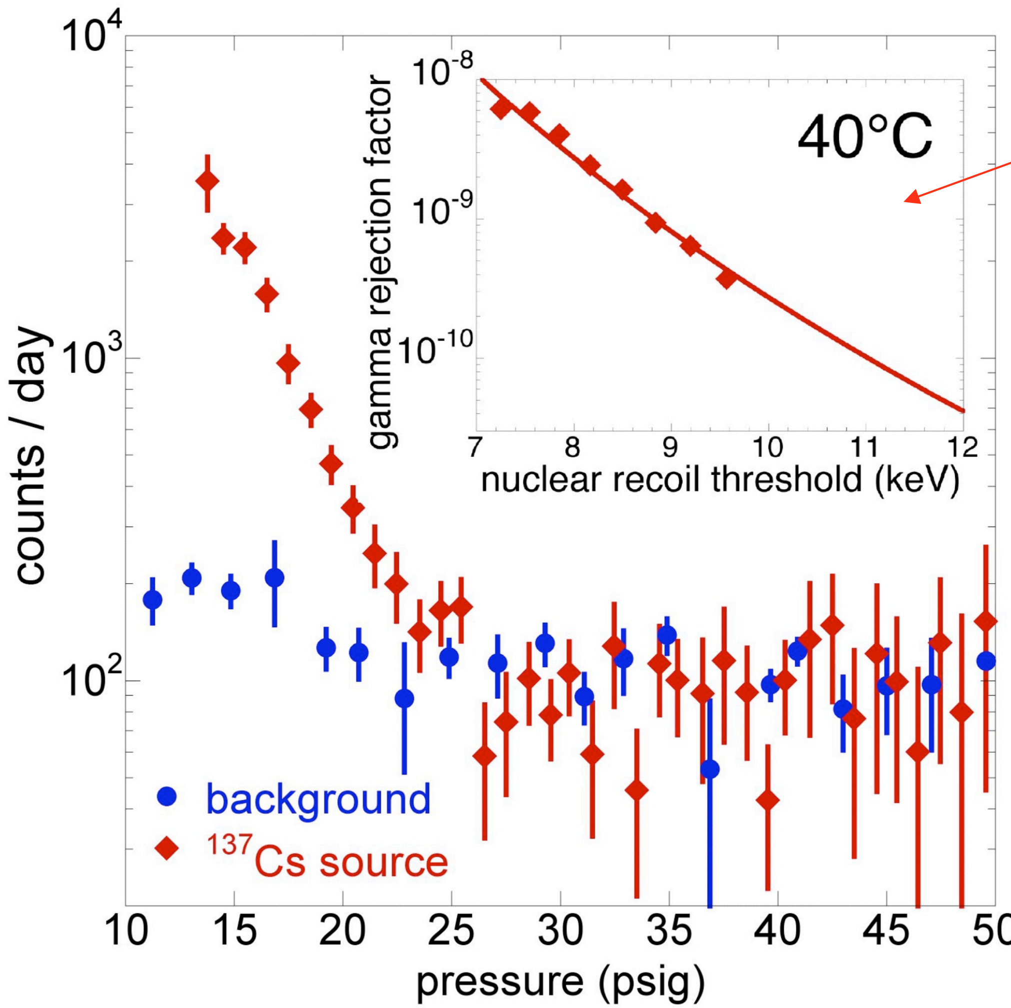


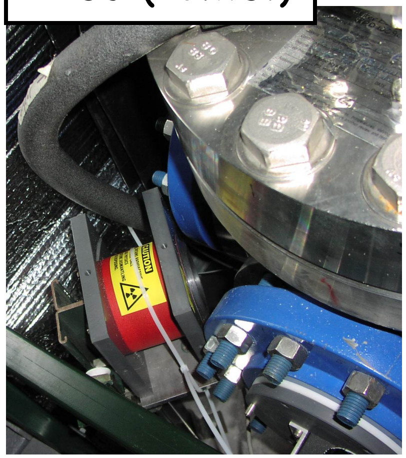

Best MIP rejection factor measured anywhere ($<10^{-10}$ INTRINSIC, no data cuts)

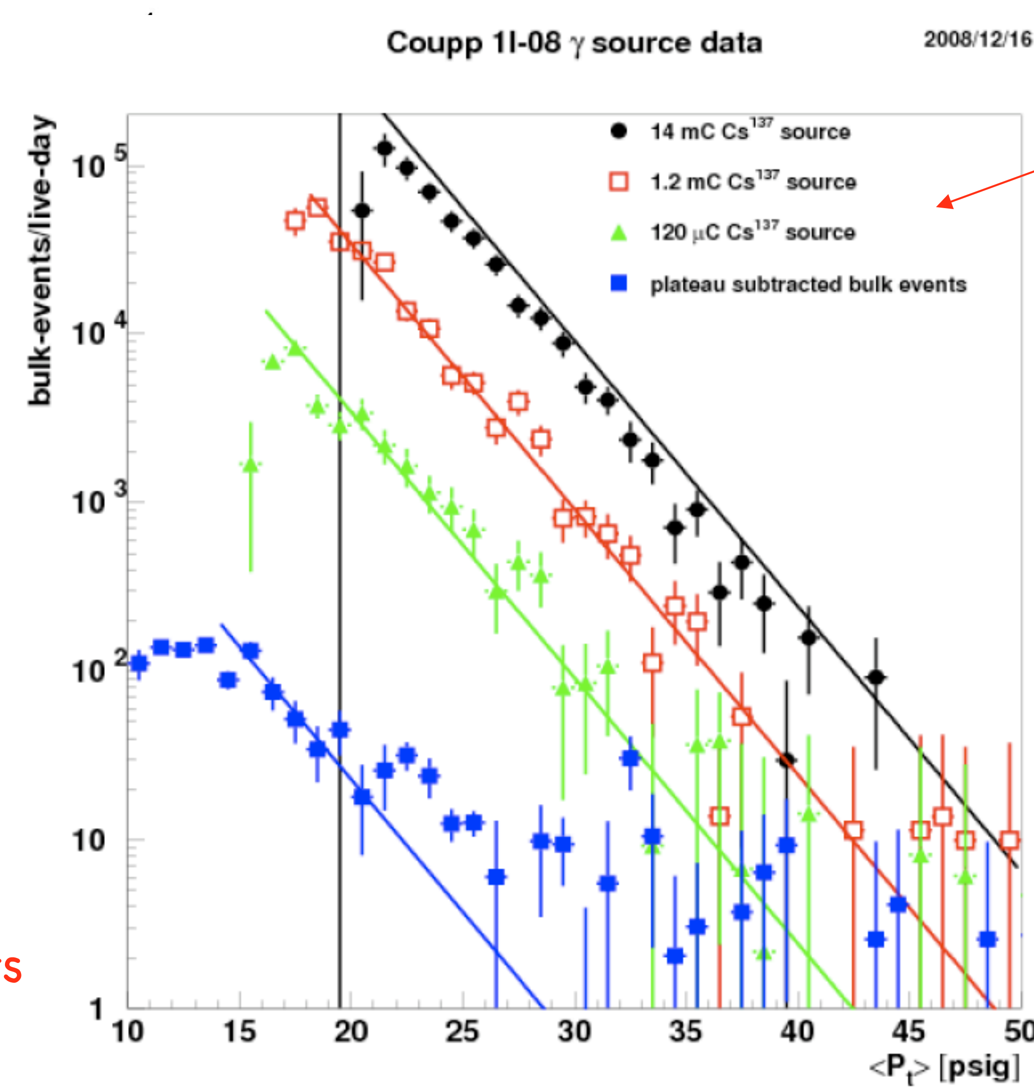
Other experiments as a reference:
XENON ~$10^{-2}$-$10^{-3}$
CDMS $10^{-4}$–$10^{-5}$
WARP ~$10^{-7}$-$10^{-8}$

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

# 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 ~$10^{-2}$-$10^{-3}$
CDMS $10^{-4}$–$10^{-5}$
WARP ~$10^{-7}$-$10^{-8}$

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

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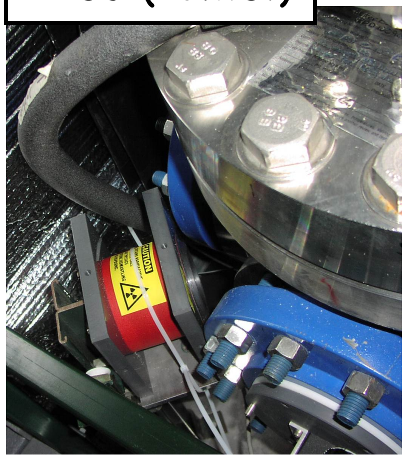

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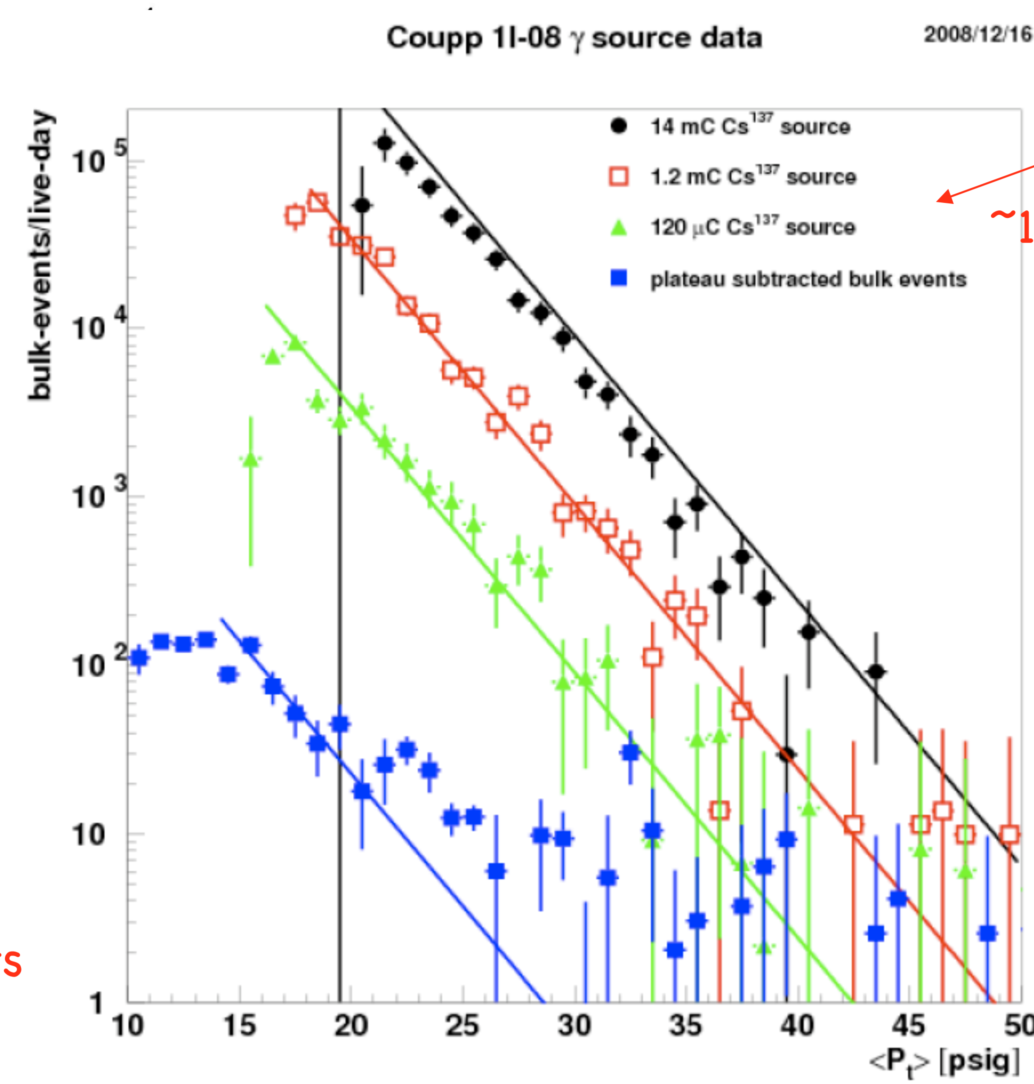


Best MIP rejection factor measured anywhere (<10$^{-10}$ INTRINSIC, no data cuts)

~10$^{-13}$!

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Switchable Am/Be (5 n/s)

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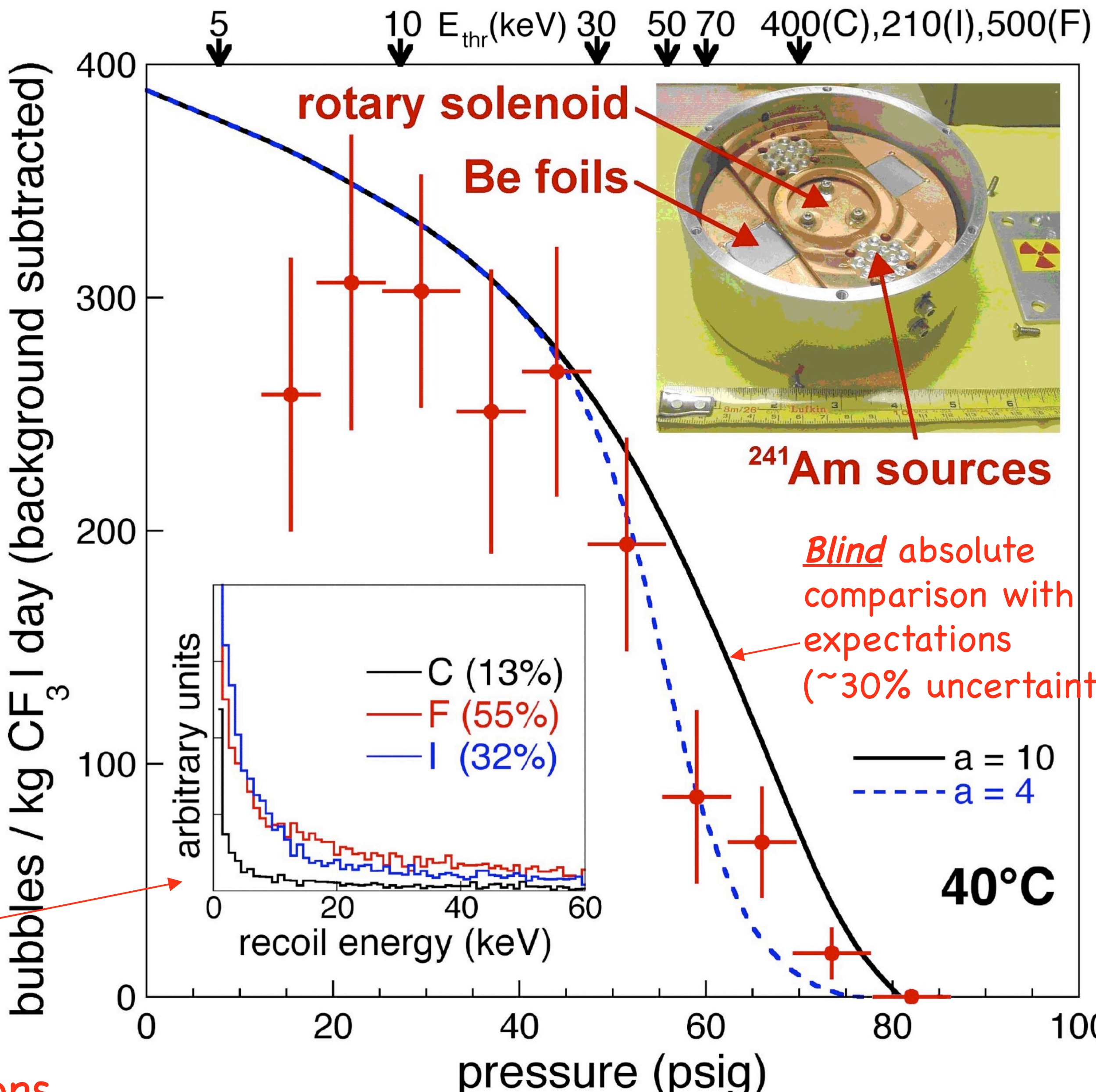
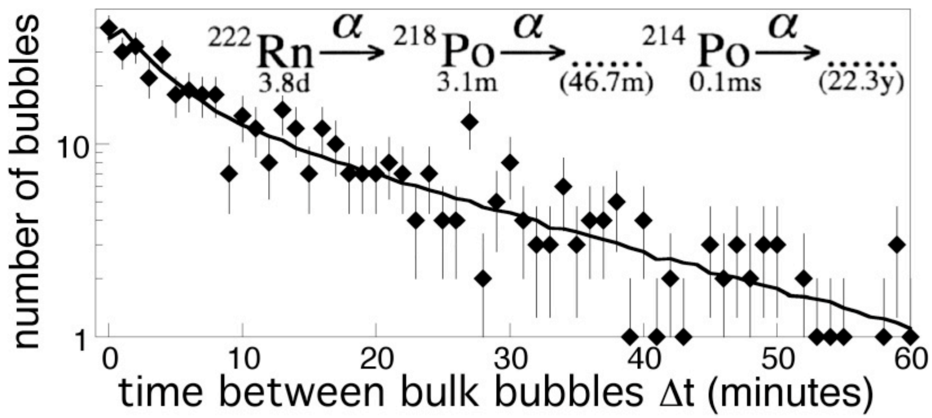
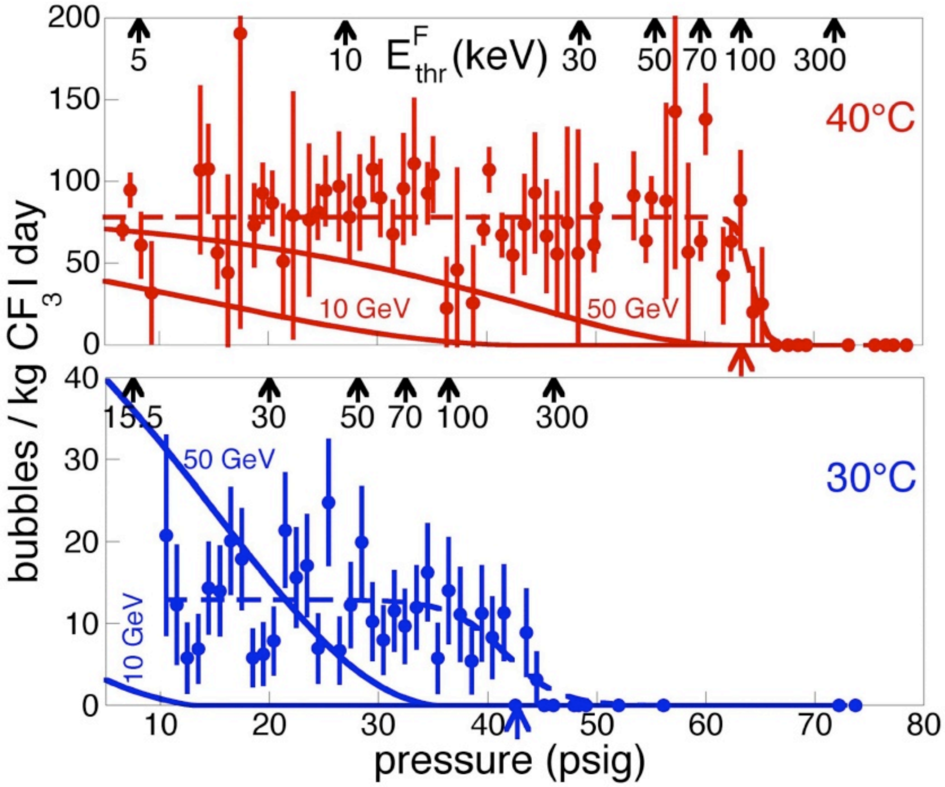



*Blind* absolute comparison with expectations (~30% uncertainty in those)

Low-energy WIMP-like recoil energy signal used in these calibrations

# A look at the 1st period data: Rn and only Rn



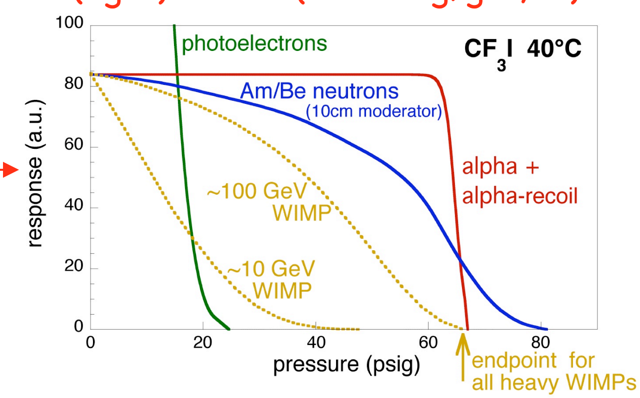

## Surface events

- Surface (alpha) rate consistent with measured 50 ppb U and 30 ppb Th in standard quartz
- 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 during vessel manufacture and use of synthetic silica (few ppt)

## 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. Max. likelihood analysis Favors 100% Rn and 100% efficiency to it.
- Addressed by use of metallic gaskets, lanthanated tips for flange welding, custom-made bellows (electron beam welded) and SNO (light) water (~1E-15 g/g U,Th).

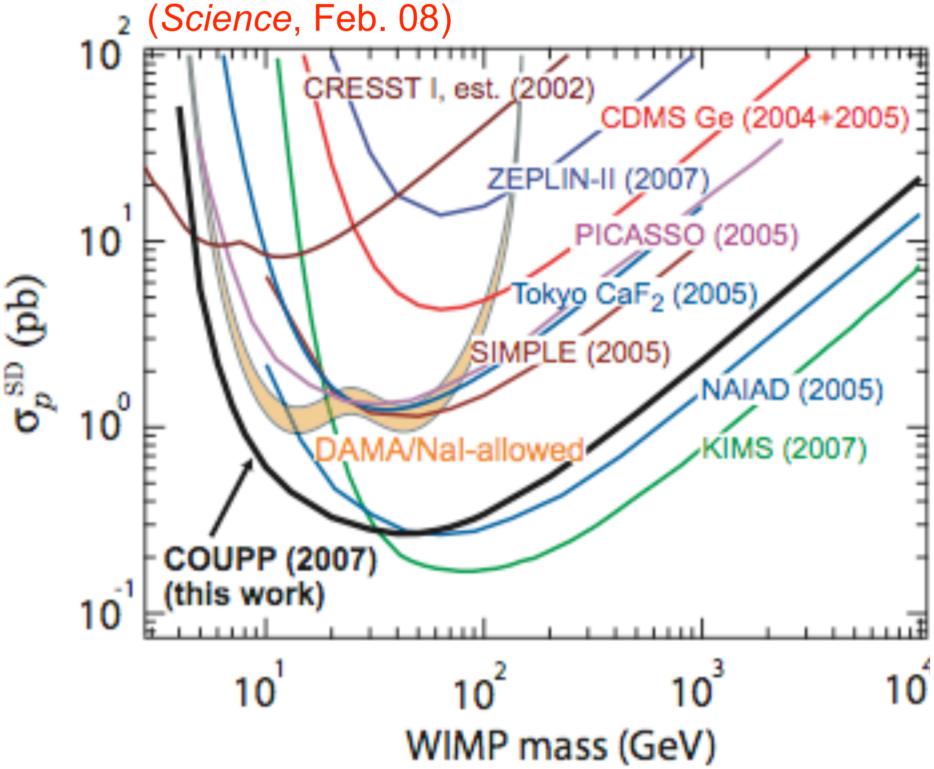
when life gives you lemons... →

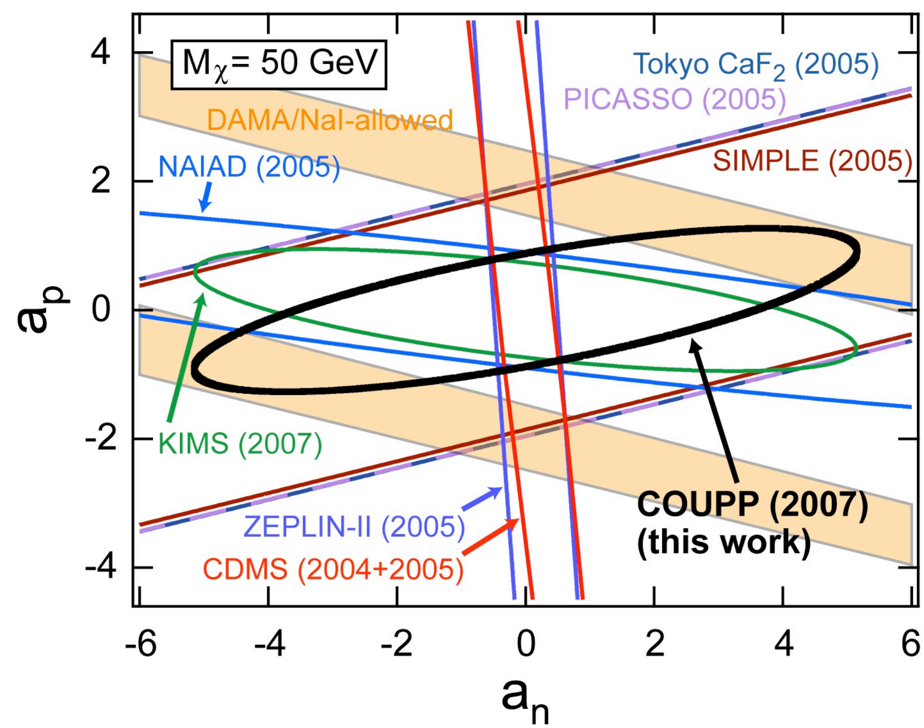


# First COUPP results

The bubble chamber is back

**Improved SD WIMP sensitivity with 2kg chamber**
(*Science*, Feb. 08)




New limits exclude the low-mass region favored by a SD interpretation of the DAMA/NaI signal

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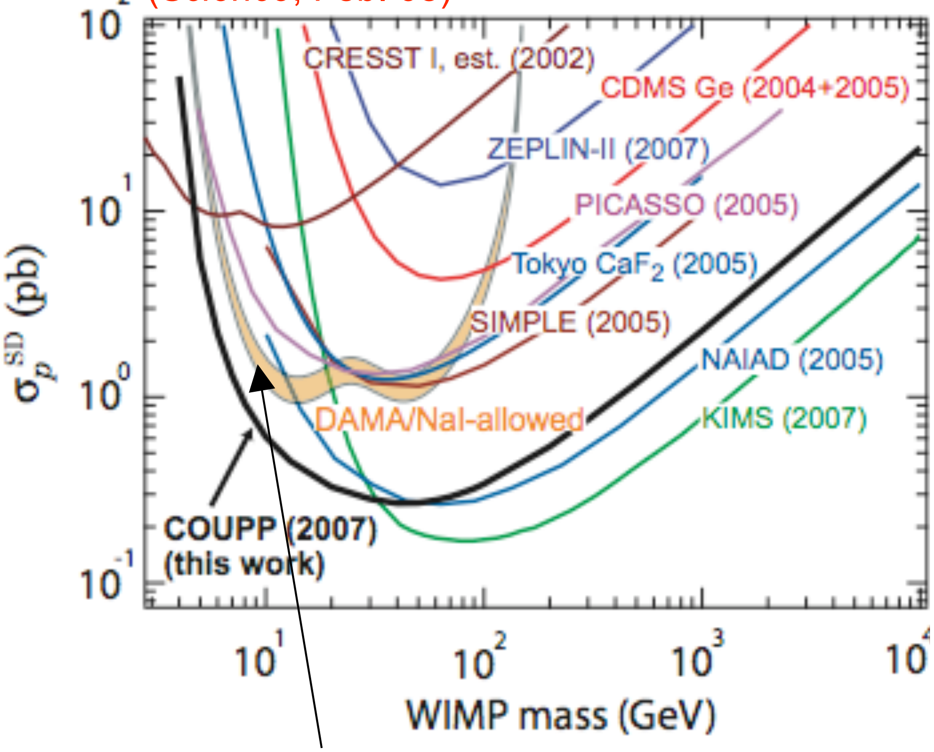
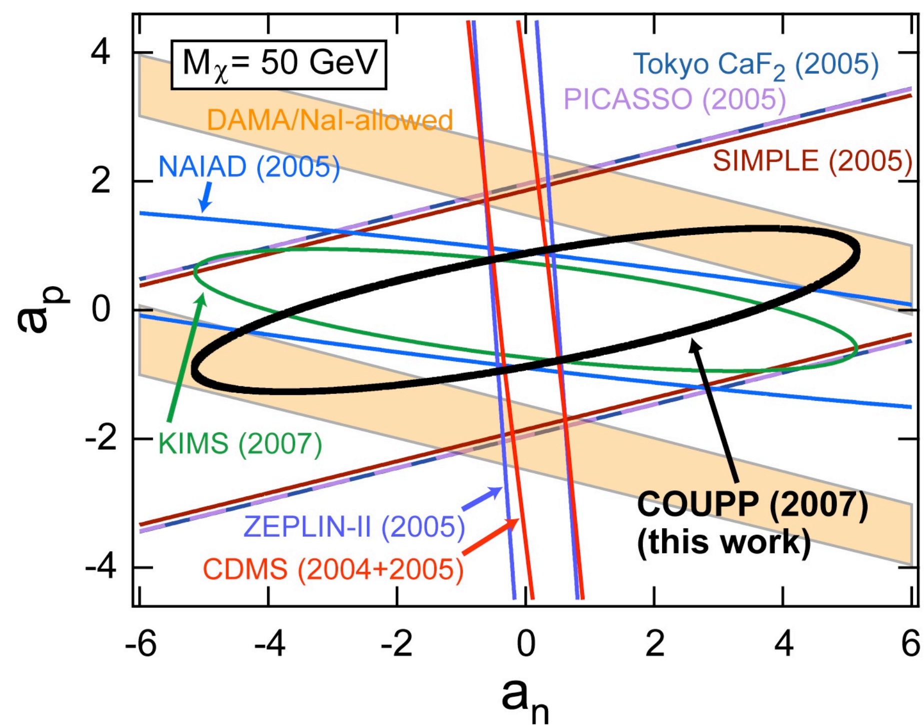
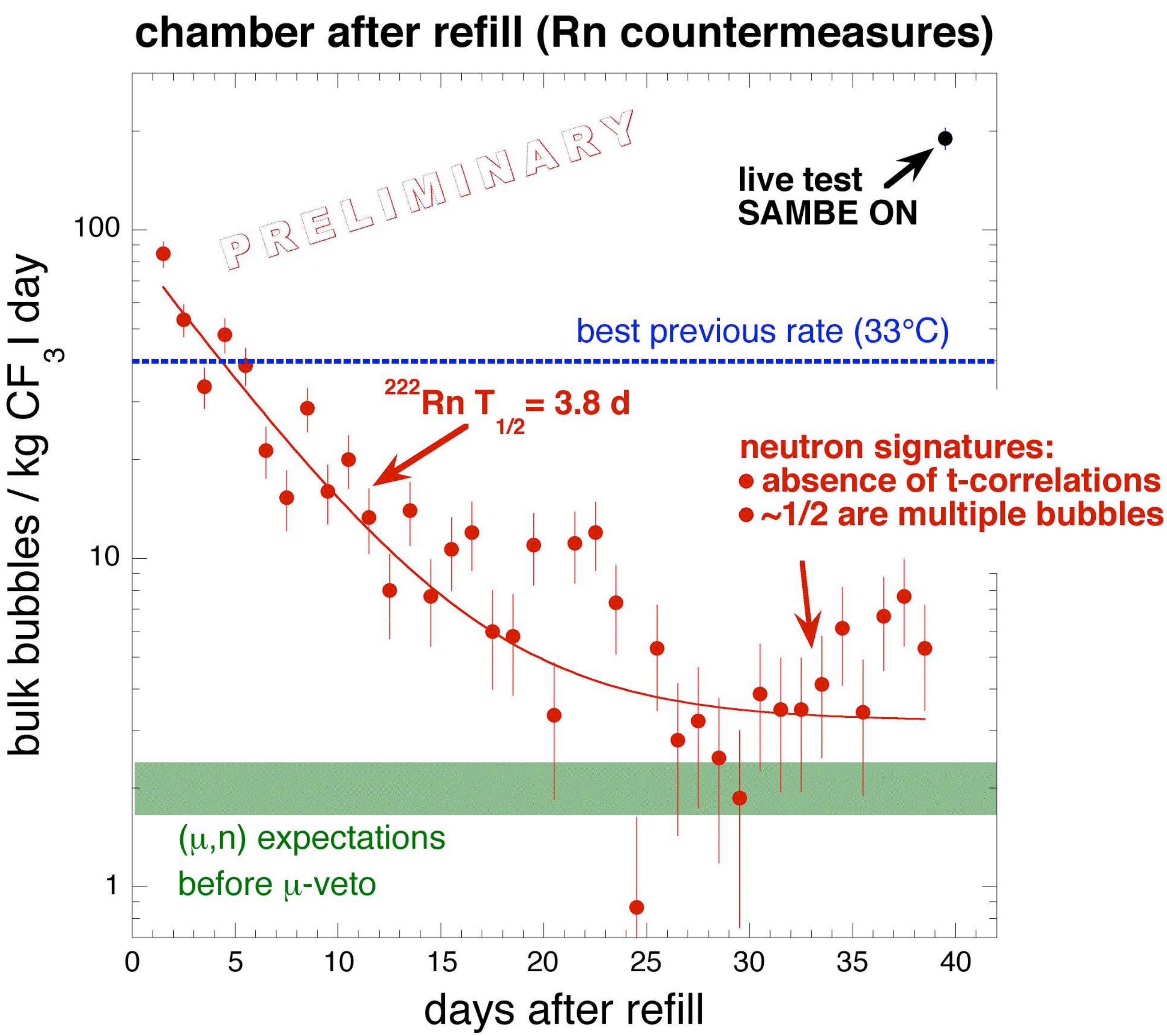



New limits exclude the low-mass region favored by a SD interpretation of the DAMA/NaI signal

# A peek at the future (which is here)



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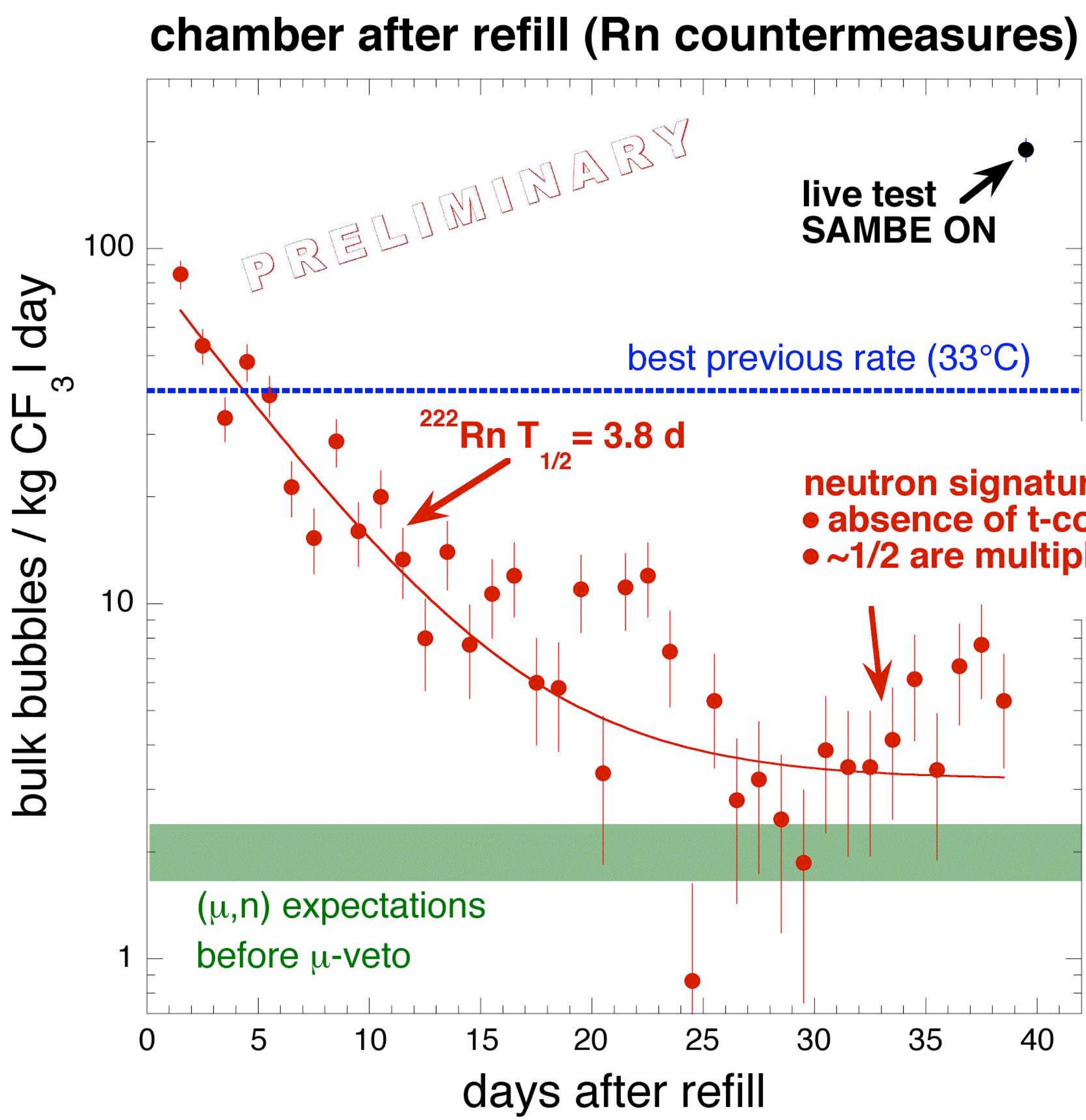
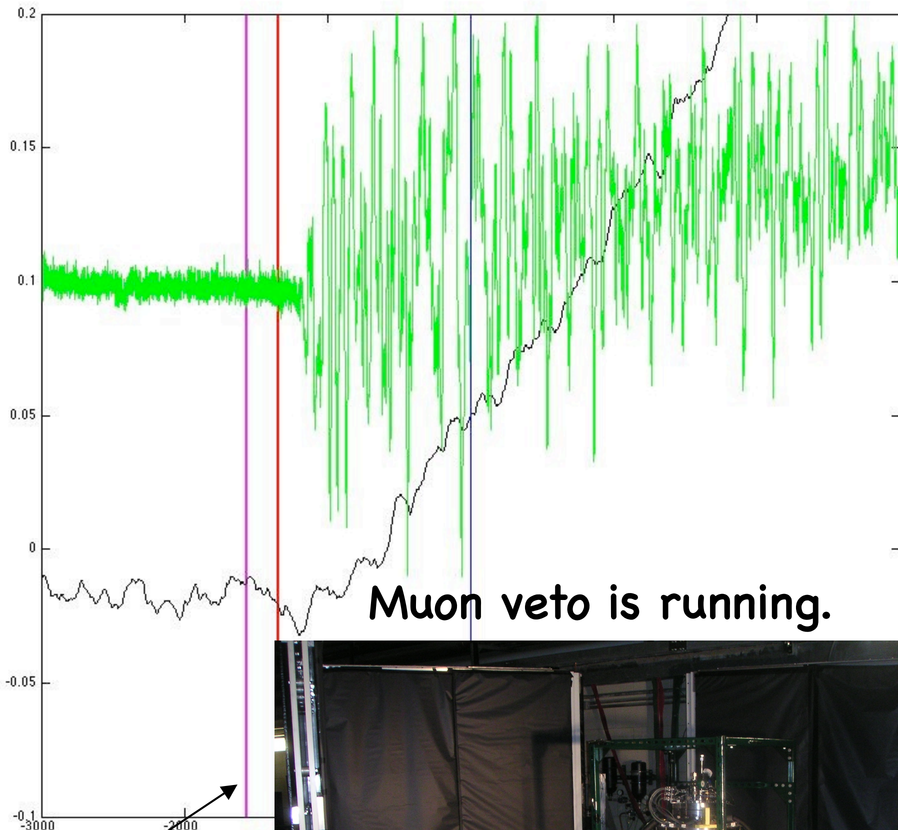
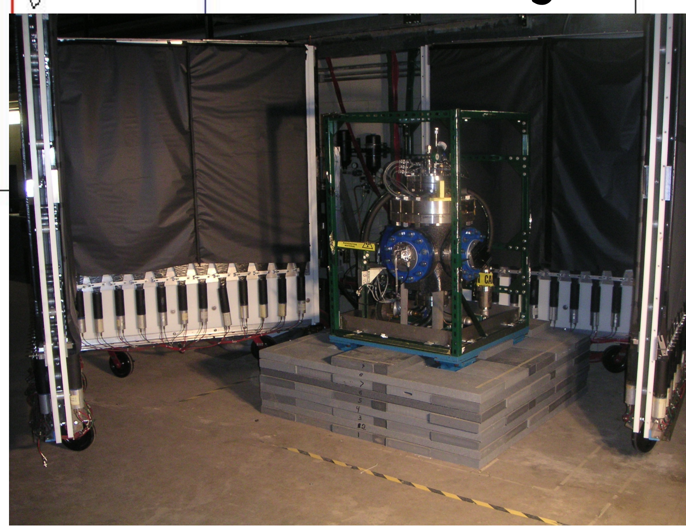



# Physics Reach at Fermilab Site

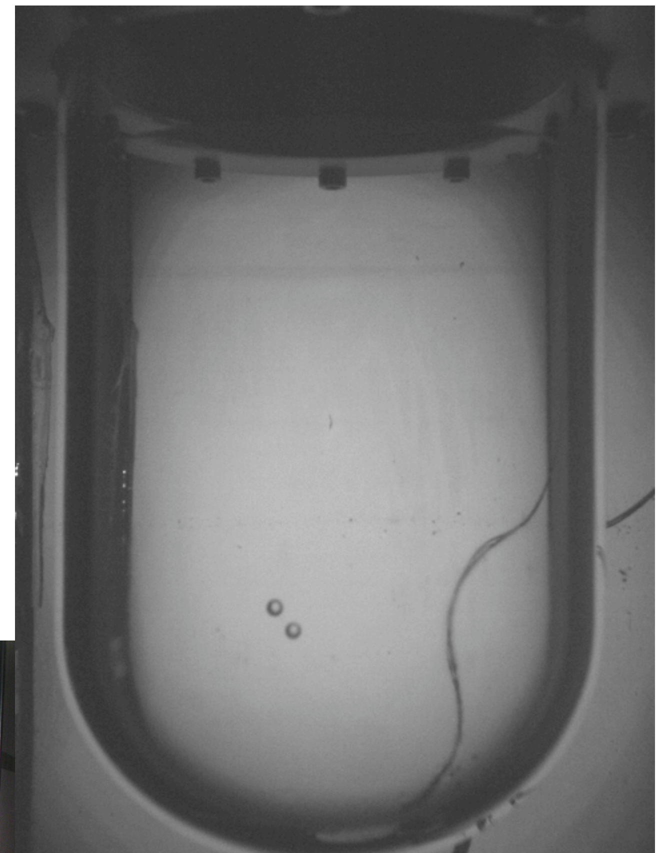
Background goal for E-961: <<1 event per kg per day




Muon veto is running.



(NuMi signal comes 220 μs before actual spill)



Last refill (with Rn countermeasures in place) already producing very interesting results.

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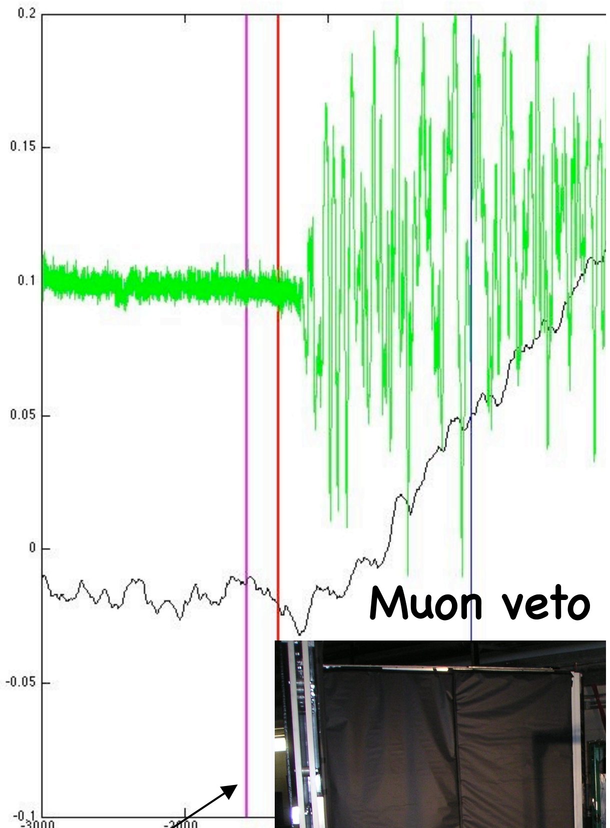


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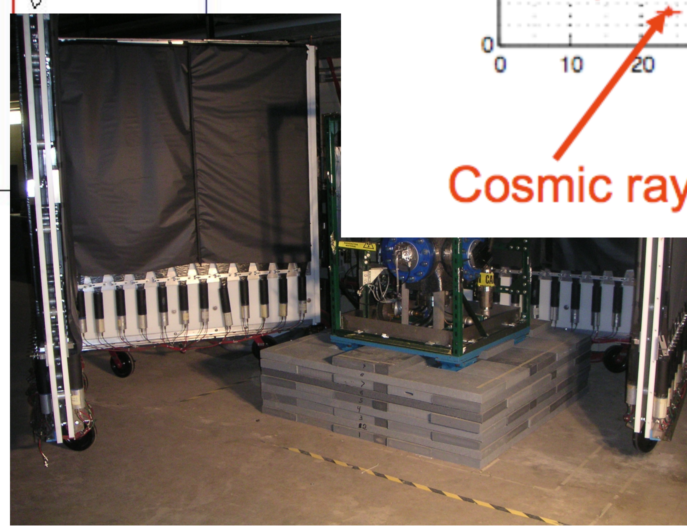
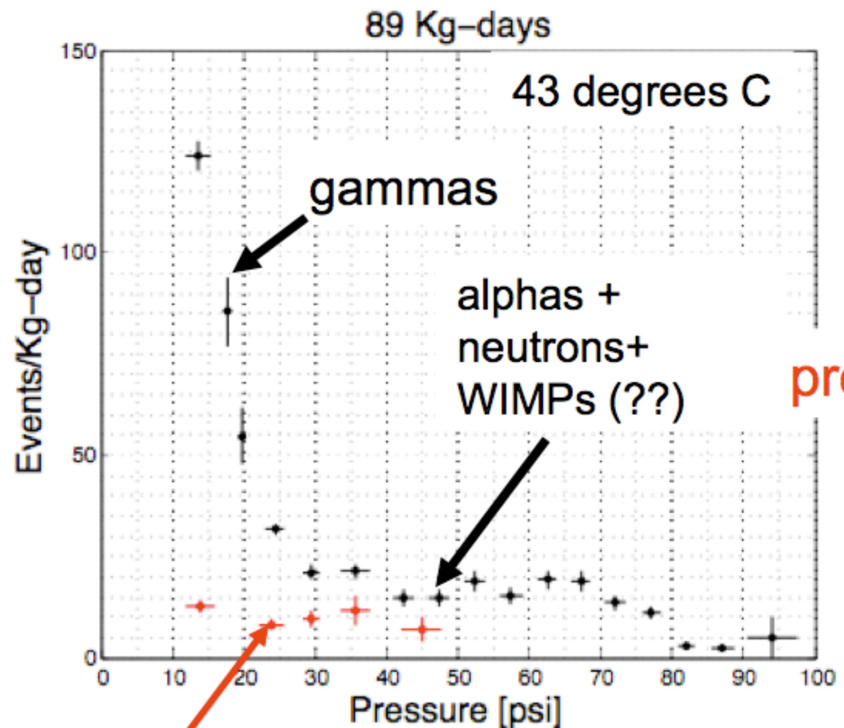
Muon veto





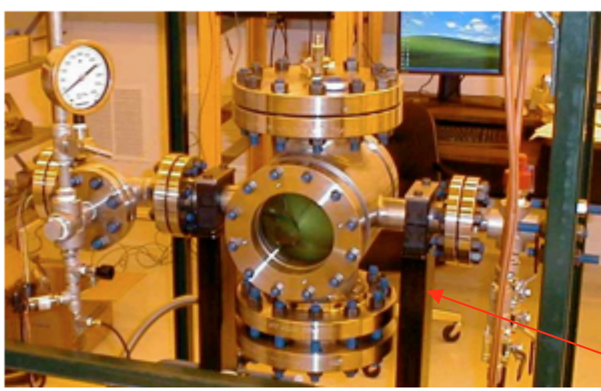

preliminary

Cosmic ray coincident

Last refill (with Rn countermeasures in place) already producing very interesting results.

# α-neutron discrimination with acoustics

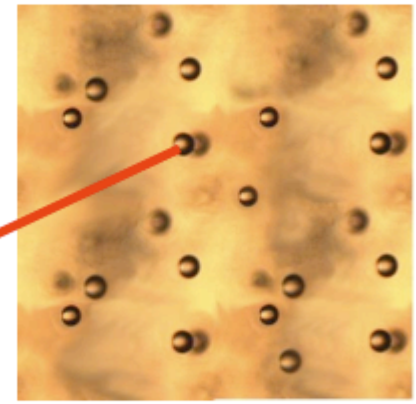
- The Picasso collaboration uses superheated droplets in gel for dark matter search.
- Have recently observed discrimination power in the acoustic signal between alpha interactions and neutron interactions
- Conceivably could give bubble chambers extremely powerful background rejection ability.
- We will have many such sensors on the chamber.

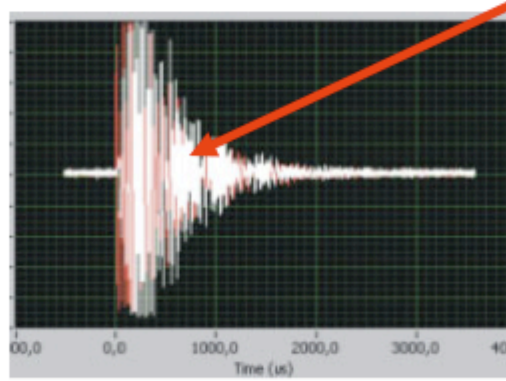


dedicated chamber

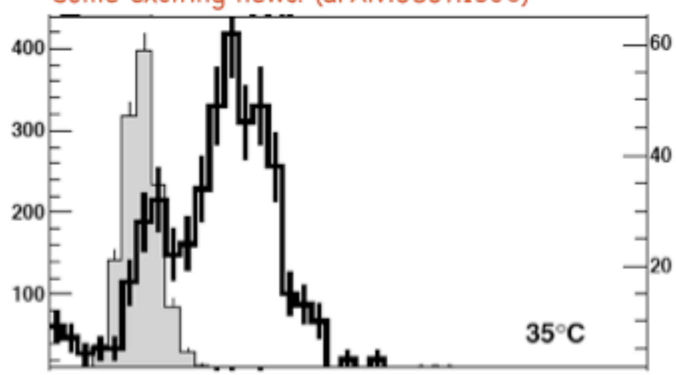
150µm droplets of C4F10

dispersed in polymerised gel

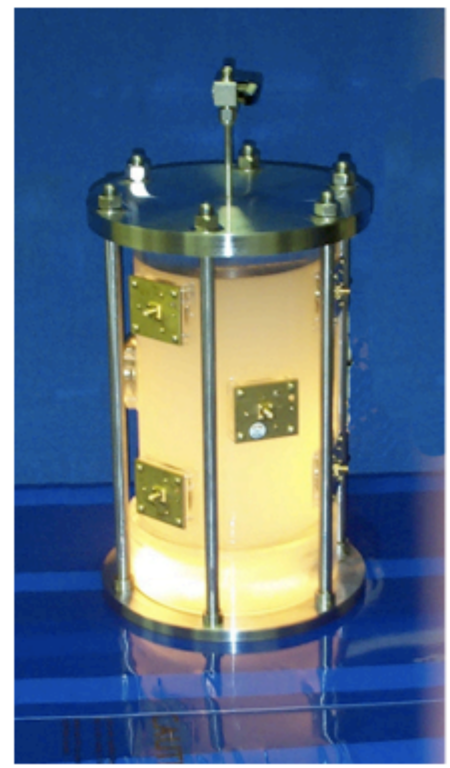




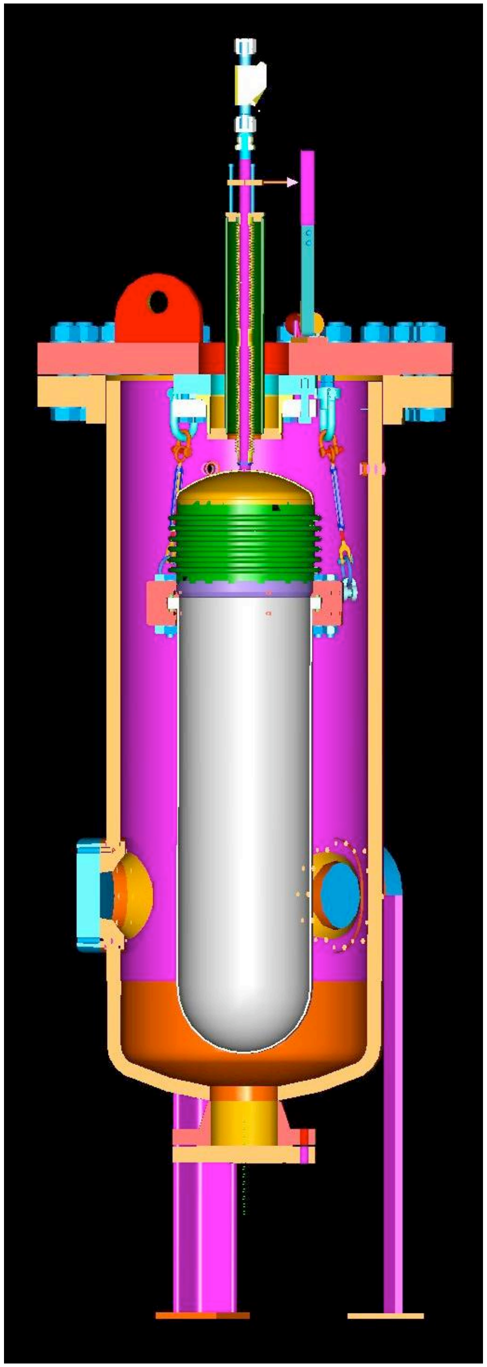

Some exciting news! (arXiv:0807.1536)

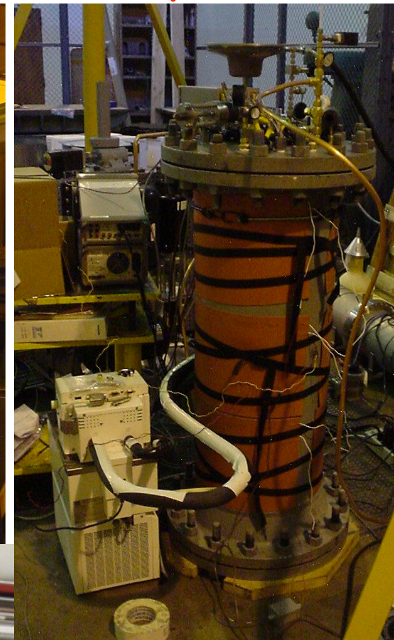



Acoustic alpha/neutron discrimination in SDDs (we believe the effect should be much larger in bulk superheated liquids)



# Next step: 100 kg target mass, deeper site





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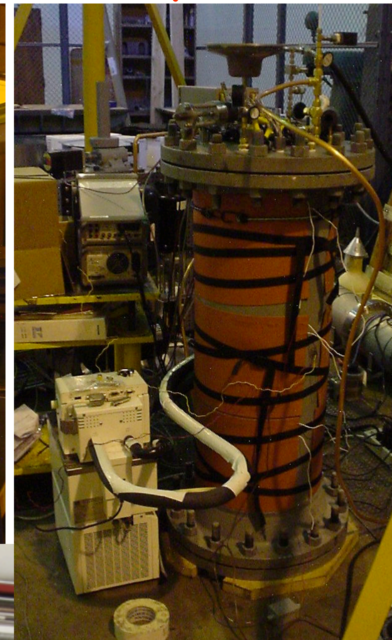

Encouraged by FNAL directorate to start thinking "1 ton"

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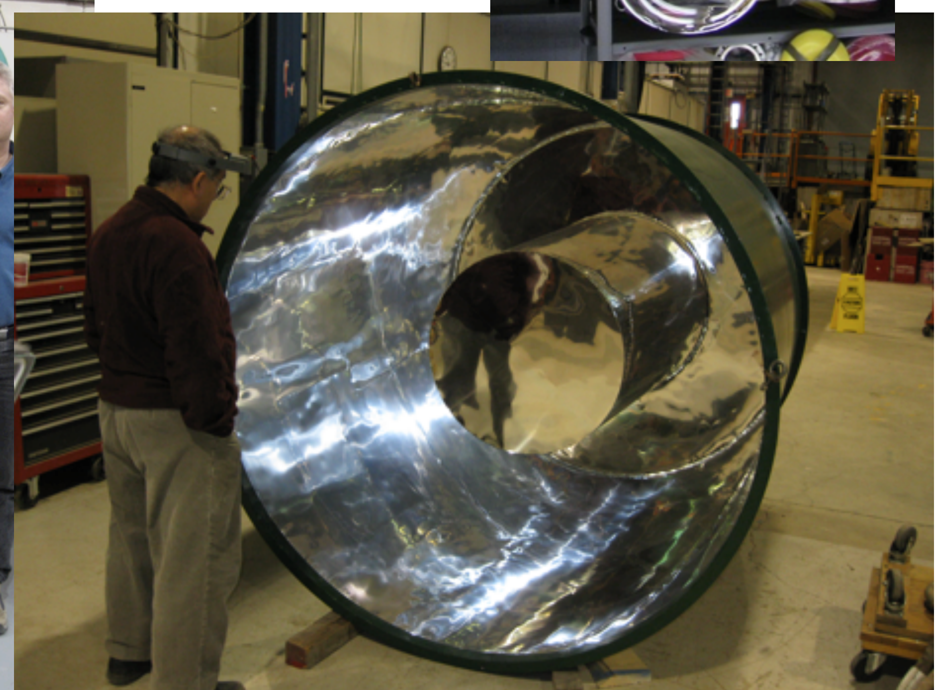

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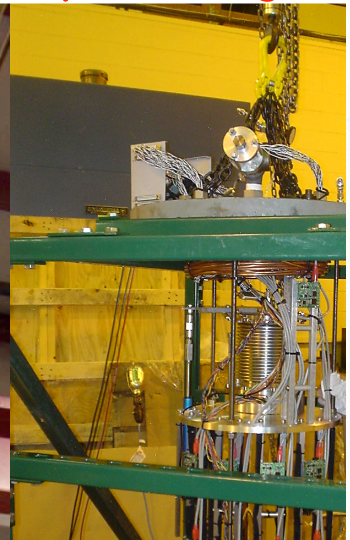


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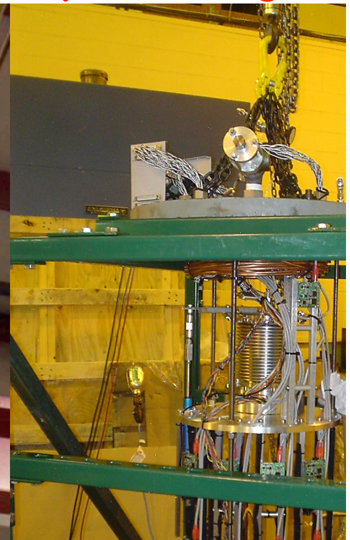

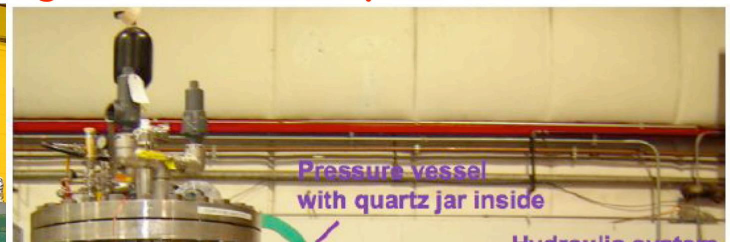


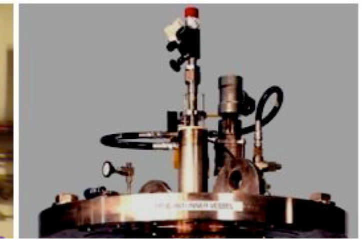

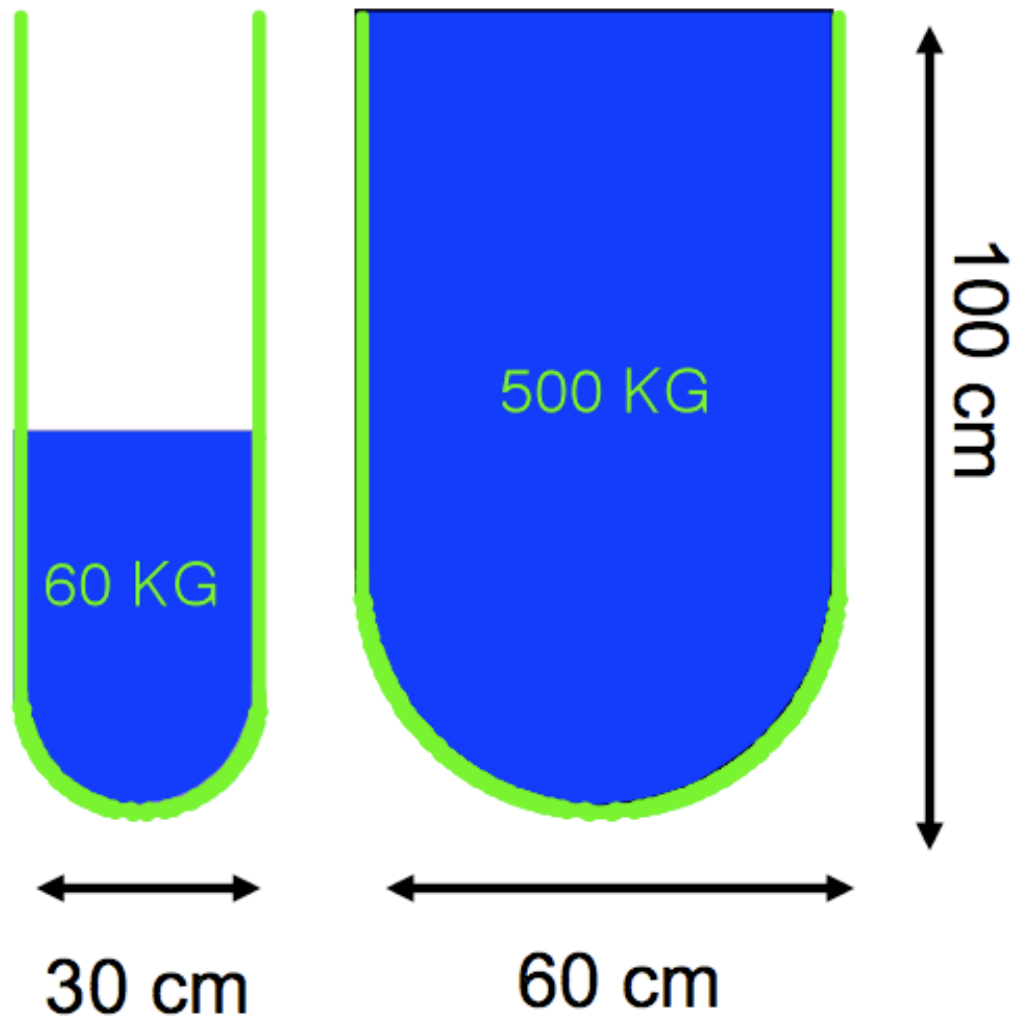


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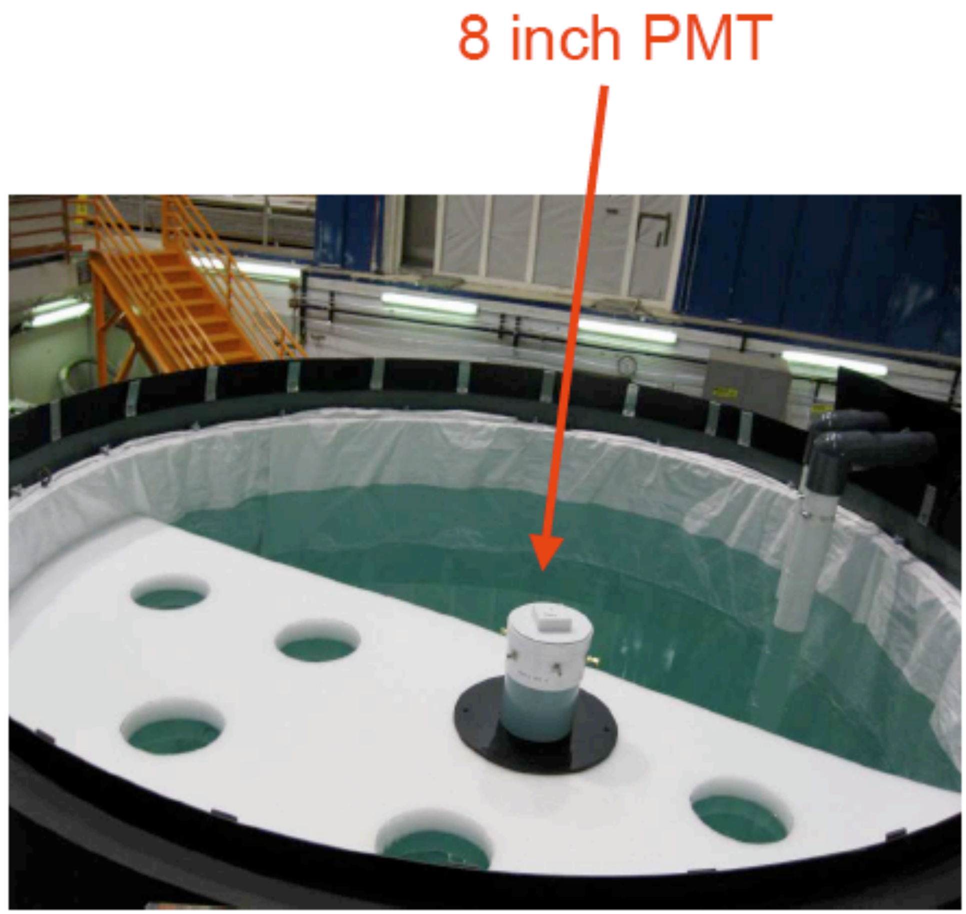
60-Kg System Ready for Testing

# 60-Kg System Ready for Testing

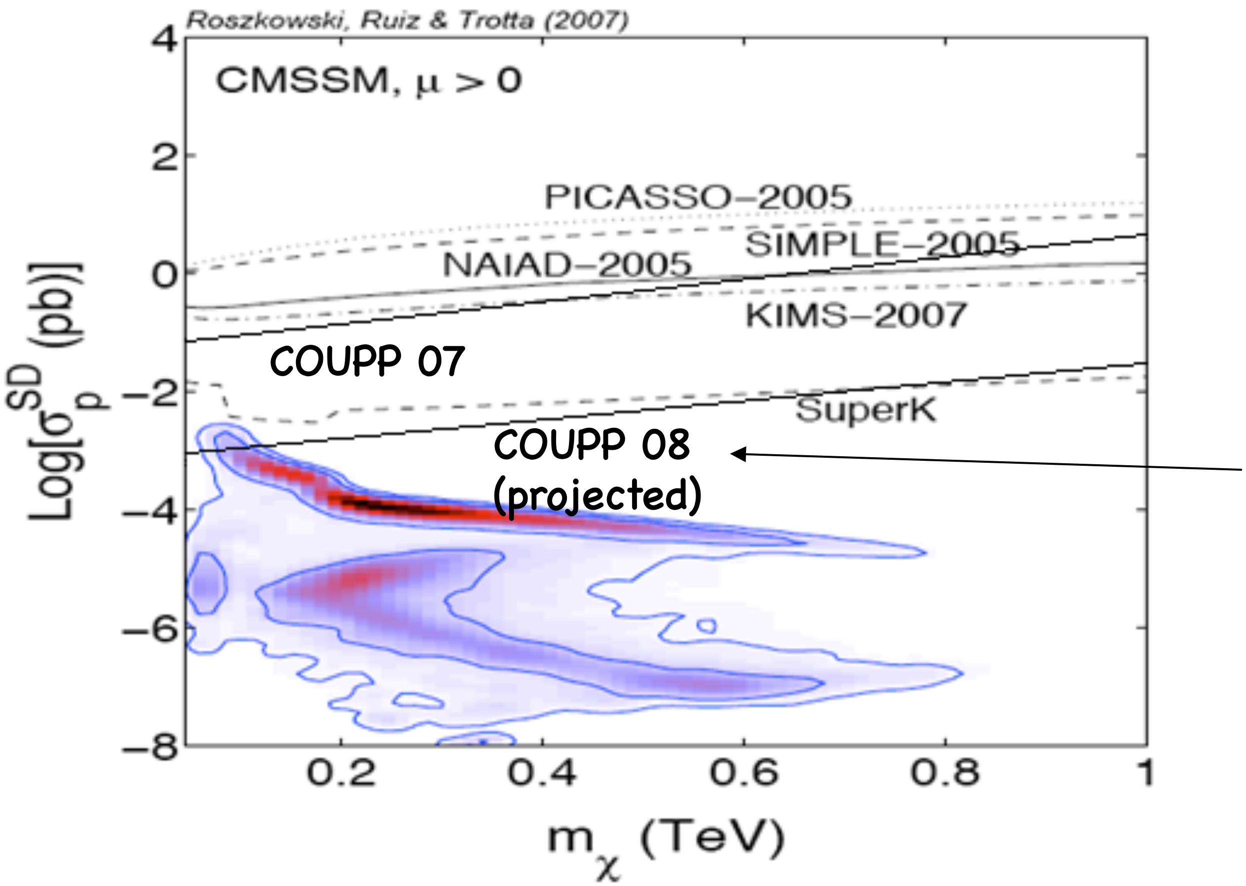
# Water Shield Testing- March, 2009

• Water tank will provide temperature control, neutron shielding and cosmic ray tags via Cerenkov light.



# Physics Reach at Fermilab Site

Background goal for E-961: <<1 event per kg per day




2008 goals: exploring SD favored region for the first time,

competitive SI limits.

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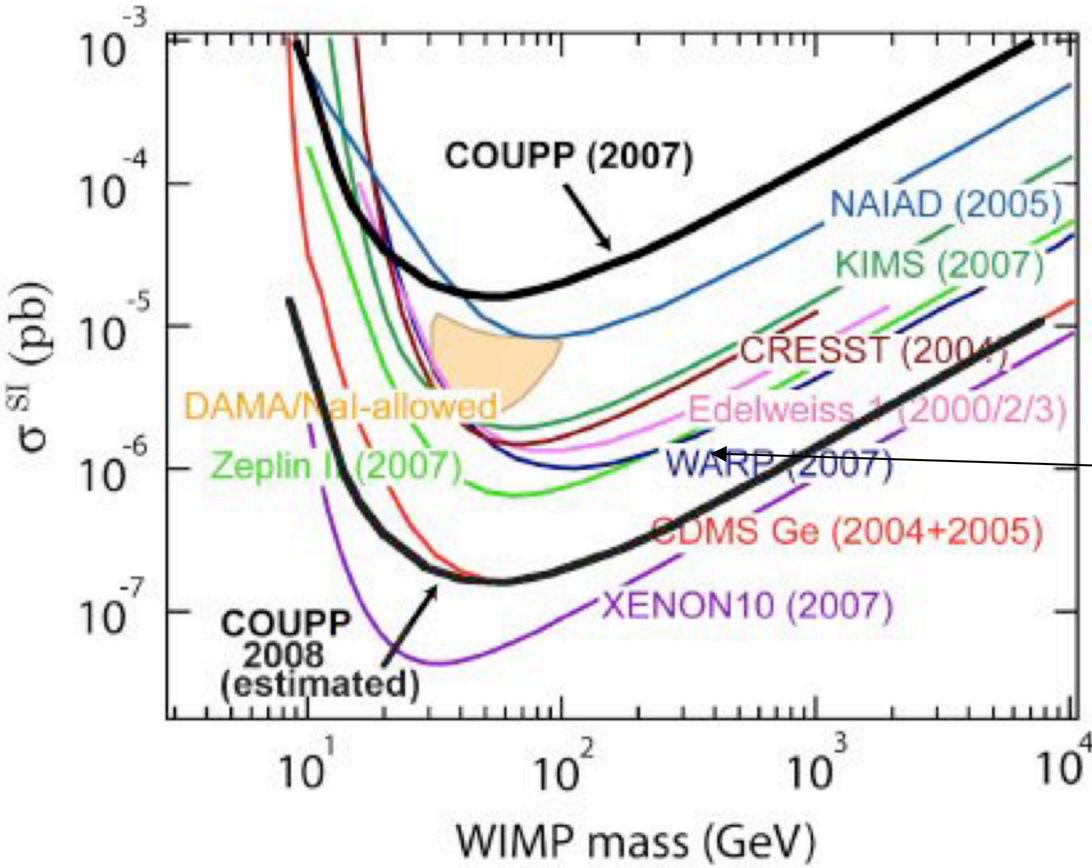


2008 goals: exploring SD favored region for the first time,
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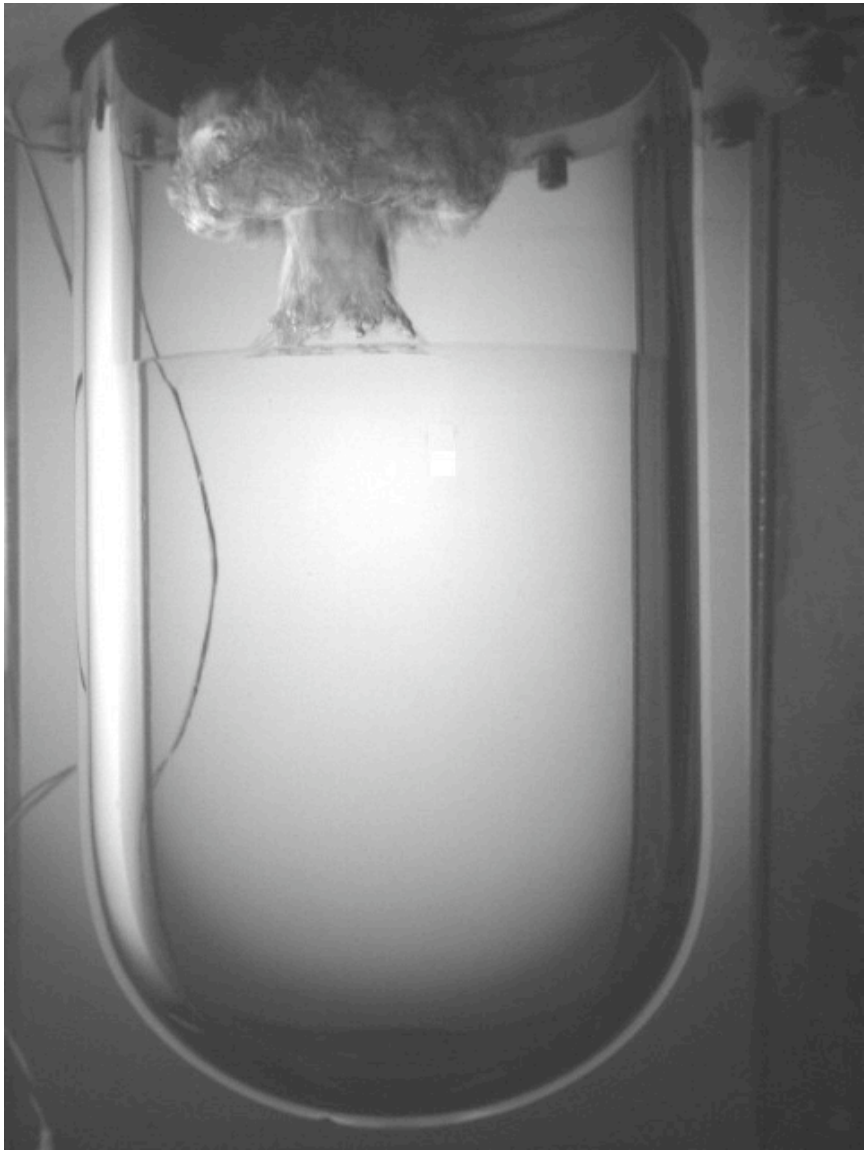
# Physics Reach at Fermilab Site

Background goal for E-961: <<1 event per kg per day

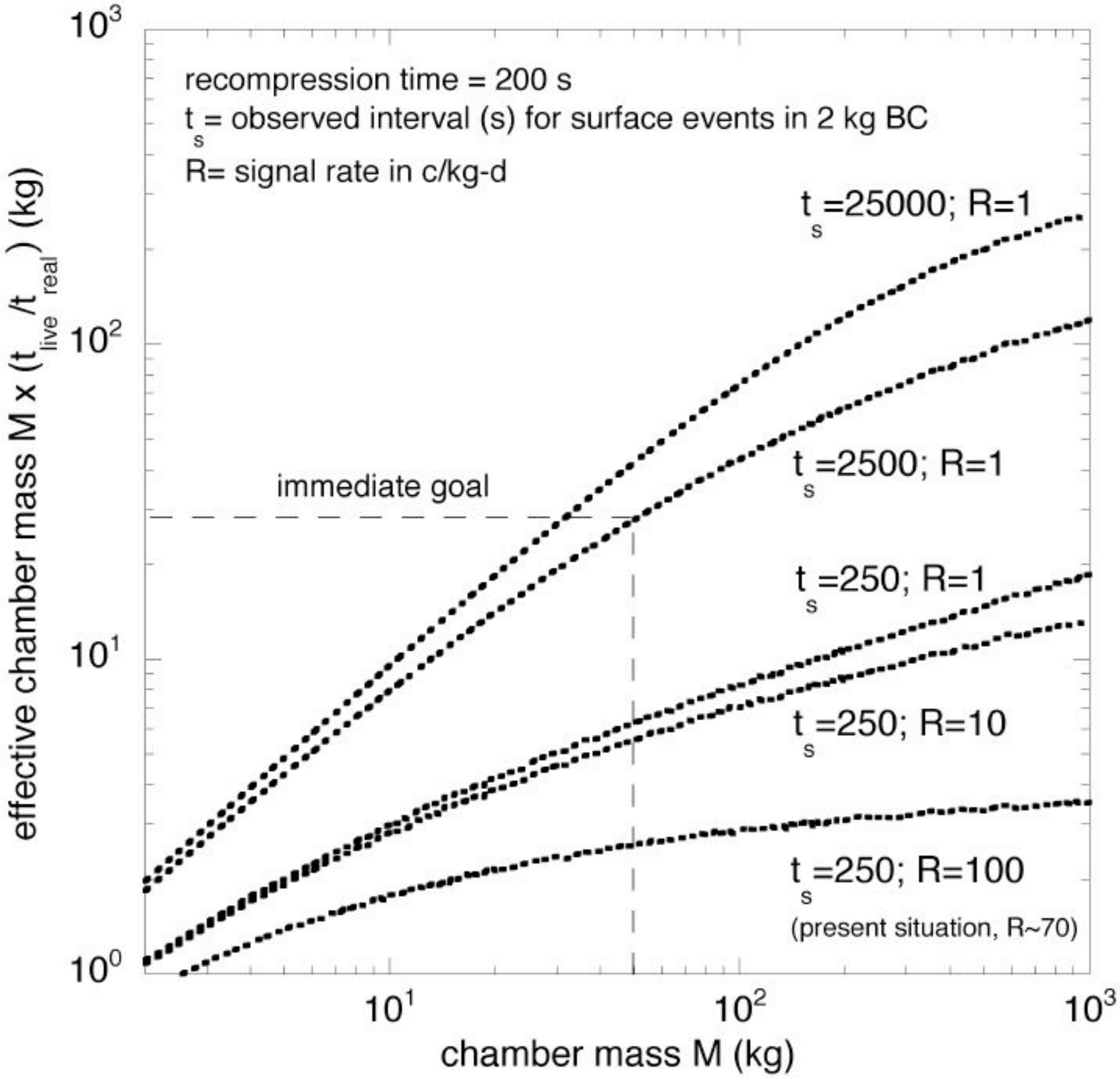
...coming up...


First COUPP results...

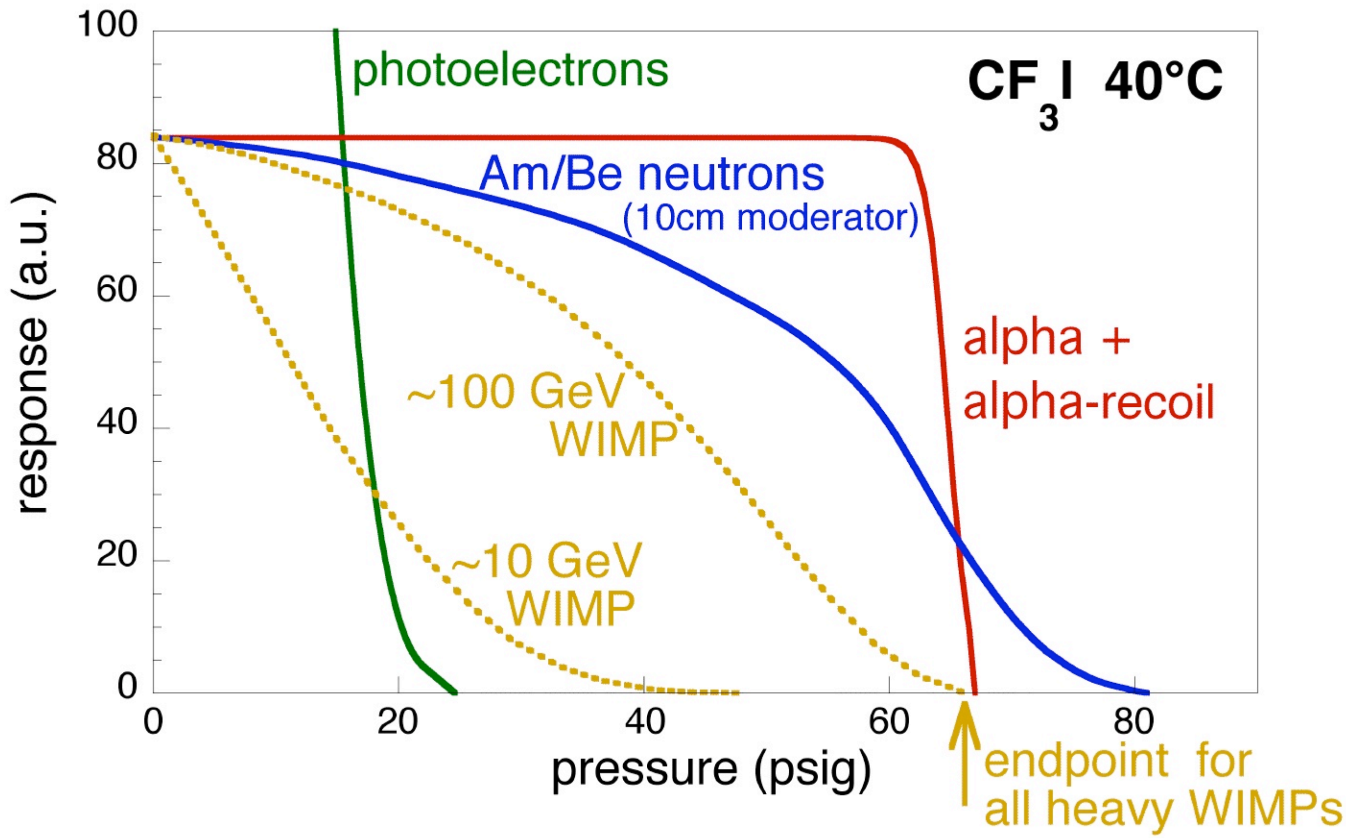


Questions?

# Reserve transparencies


recompression time = 200 s
t_s = observed interval (s) for surface events in 2 kg BC
R= signal rate in c/kg-d
t_s =25000; R=1
t_s =2500; R=1
t_s =250; R=1
t_s =250; R=10
t_s =250; R=100
(present situation, R~70)
immediate goal
effective chamber mass M x (t_live /t_real) (kg)
chamber mass M (kg)
10^0
10^1
10^2
10^3

# Templates for the future:



# Continuous Operation: December '05 to Oct '06

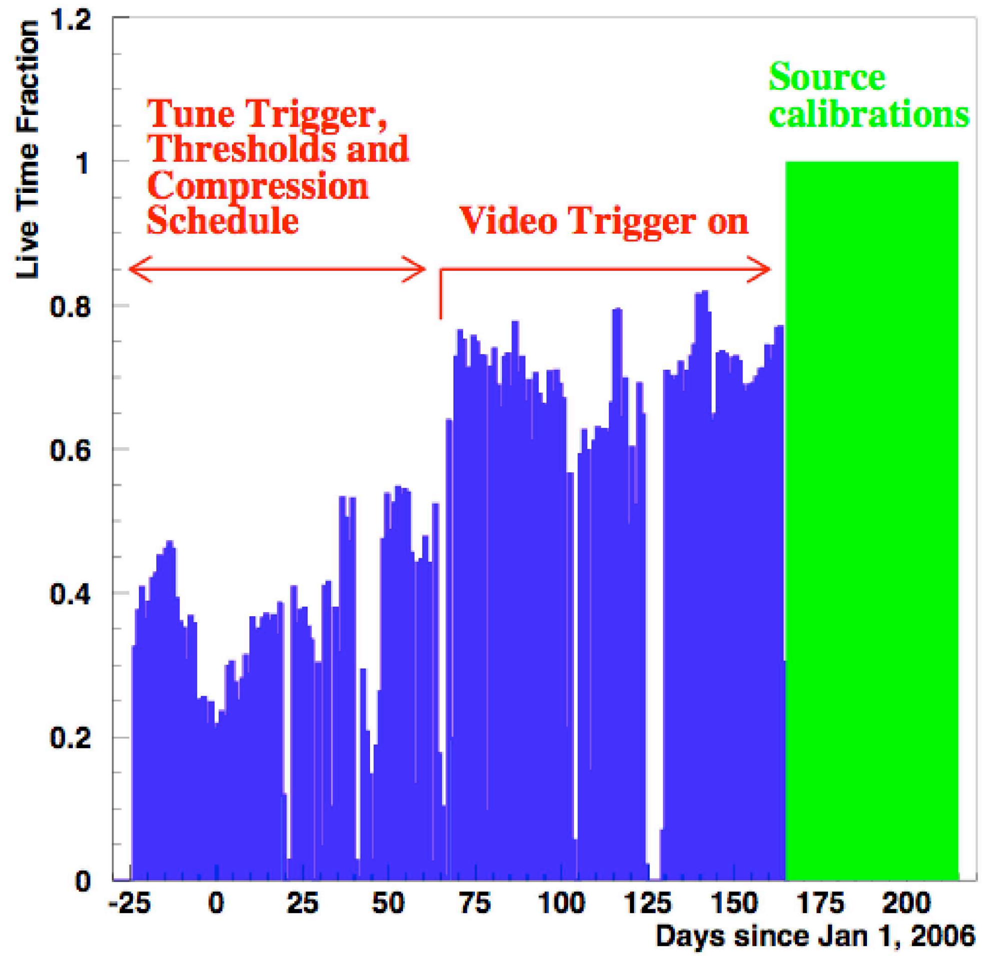
307 days in run
115k expansions
140 seconds mean
superheated time

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: $\gamma$, n.