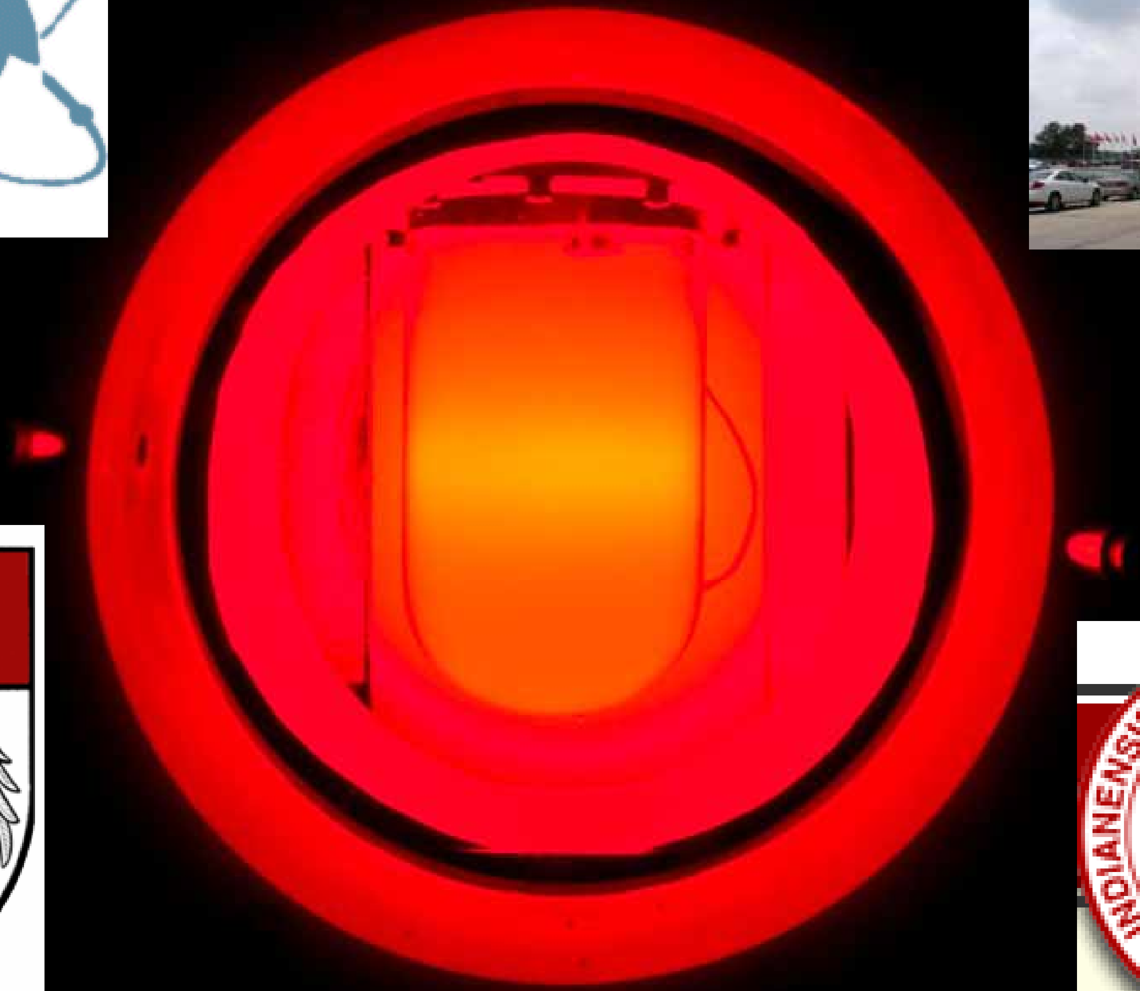
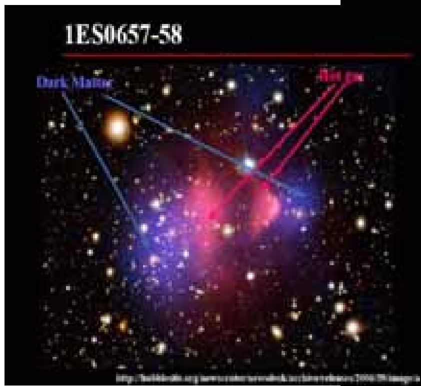
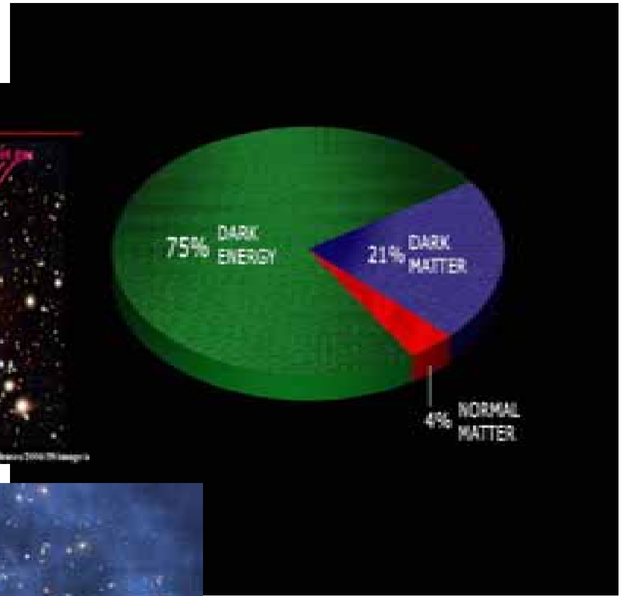
COUPP: Early Results



Direct Detection of Cold Dark Matter: The Challenge Ahead



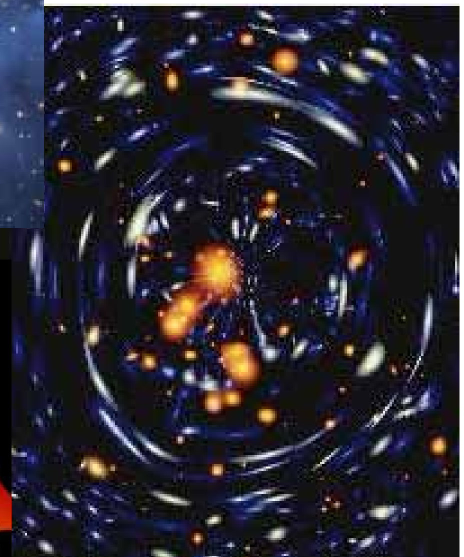


- **Non-baryonic Galactic Dark Matter close to a paradigm (certainly in the minds of many), but yet to be detected.**

- **~20-30% Cold (non-relativistic) DM <u>presently</u> 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)**

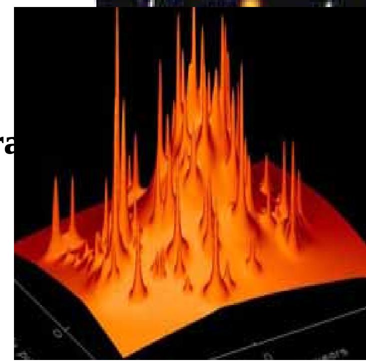
- **Cautious strategy: start by looking first for non-ad hoc particle candidates, i.e., those already invoked by particle theories (e.g., neutralino <-> MSSM, axions <-> strong CP problem)**

- **WIMPs: dominant interaction via low-energy nuclear elastic scattering, expected rates << 1 per kg of target per day in keV region. (local ρ~0.3-0.4 GeV/cm^3, <v>~2-300 km/s, $\sigma < 10^{-42}$ cm^2). <u>Supersymmetric WIMPS can have rates as low as 1 recoil/tonne/yr!</u>**

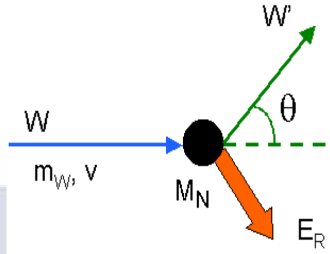


- **The challenge: build cost-effective tonne or multi-tonne detectors sensitive exclusively to WIMP-induced nuclear recoils (down to one a year) and nothing else--not even neutron recoils.**

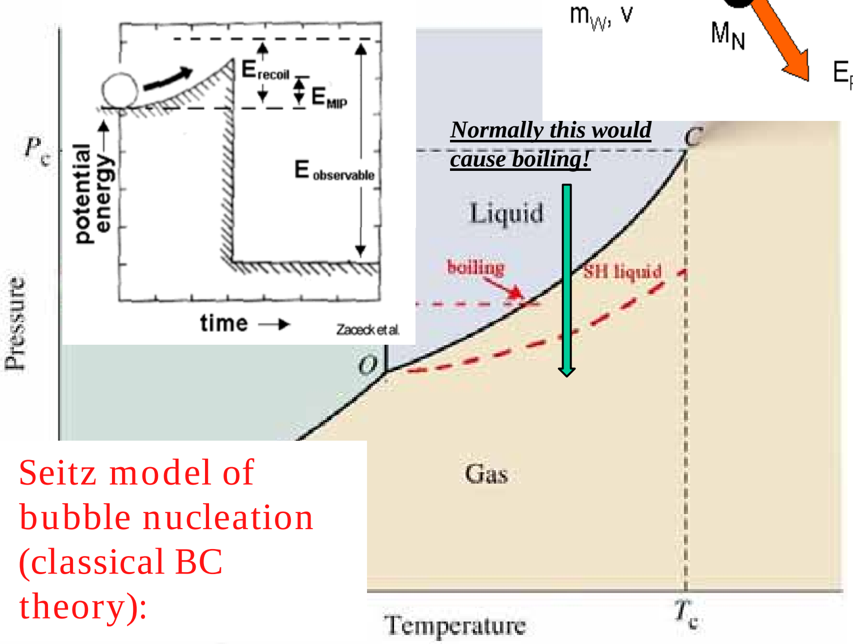
- **The scale of things: a 1 kg Ge detector fires in this room at the ra rate of ~1 kHz, so we certainly have our work cut out for us…**



The 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 (ultrasound), motion sensing (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 separating WIMP- from n-induced recoils and pinpointing WIMP in SUSY parameter space.
- Short mean free path of n's => additional n-rejection mechanism
- Low cost, room temperature operation, safe chemistry (fire-extinguishing industrial refrigerants), moderate pressure (< 150 psig)
- Single concentration: reducing α-emitters in fluids to levels already achieved elsewhere (~10^{-17}) will lead to a complete probing of SUSY models



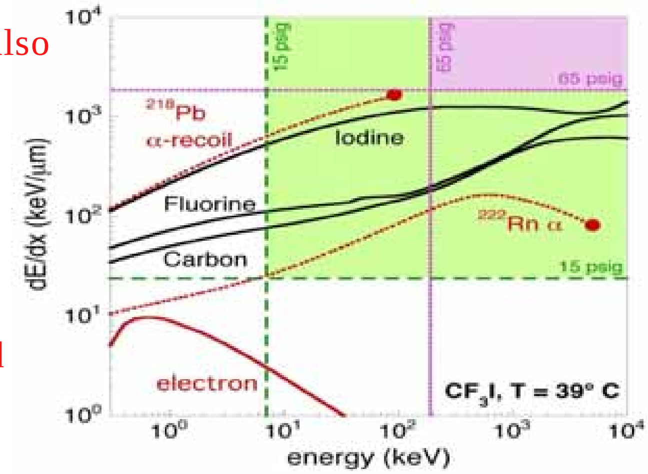
Seitz model of bubble nucleation (classical BC theory):

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

Threshold in deposited energy

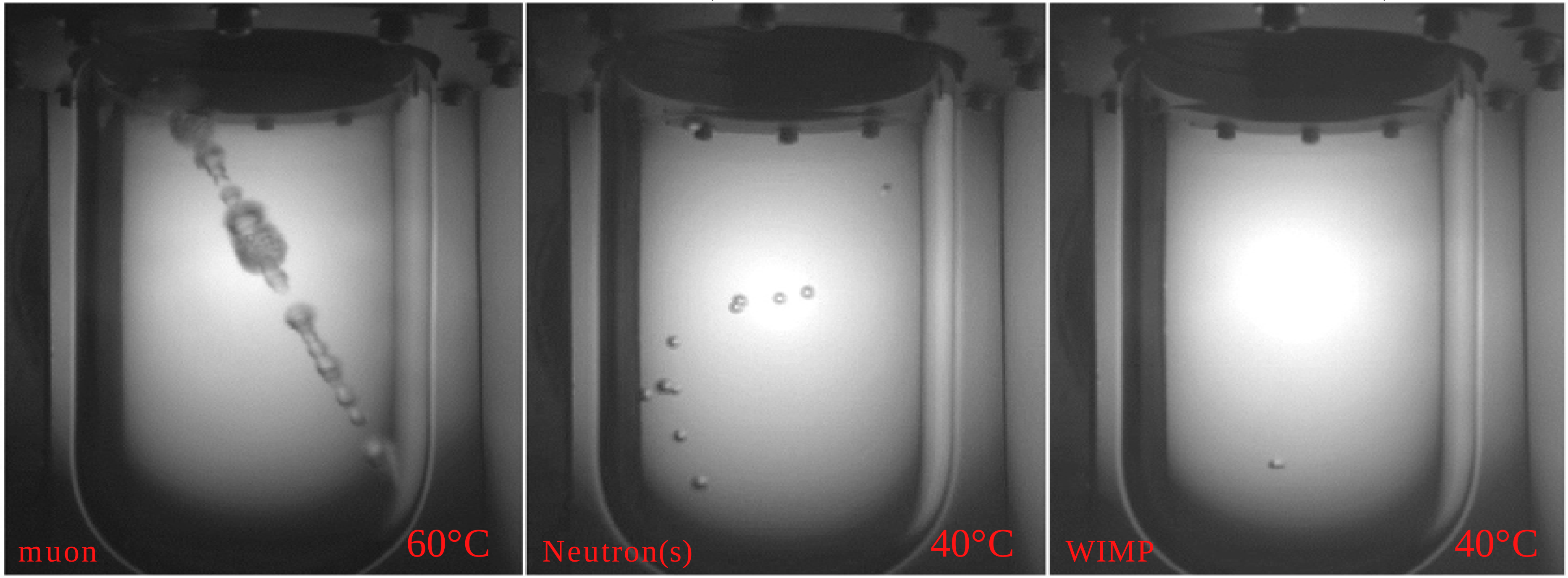
$$\mathrm{d}E/\mathrm{d}x > E_c/(a r_c)$$

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

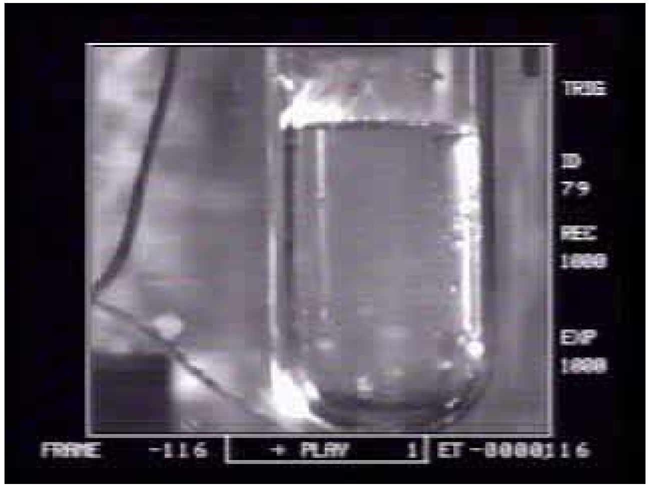


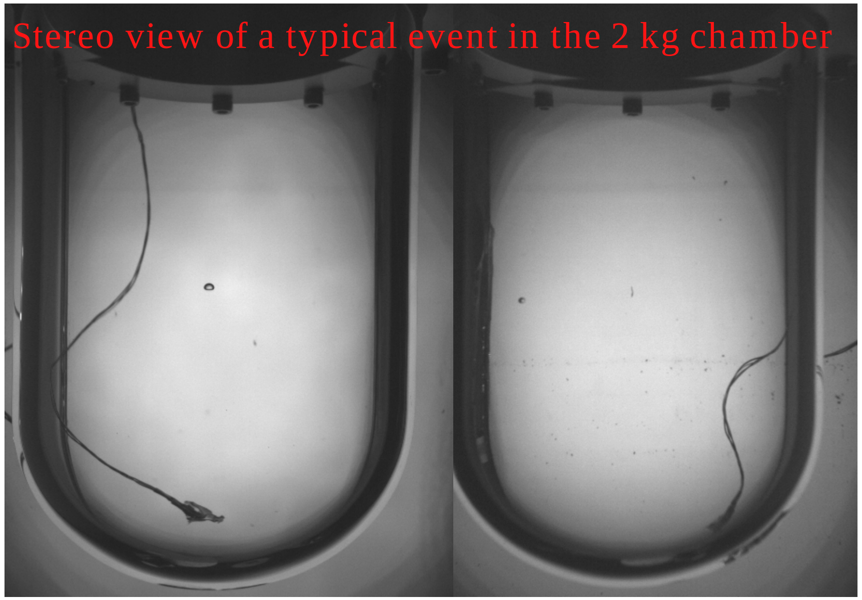
Conventional BC operation
(high superheat, MIP sensitive)

Low degree of superheat, sensitive to nuclear recoils only



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




Stereo view of a typical event in the 2 kg chamber

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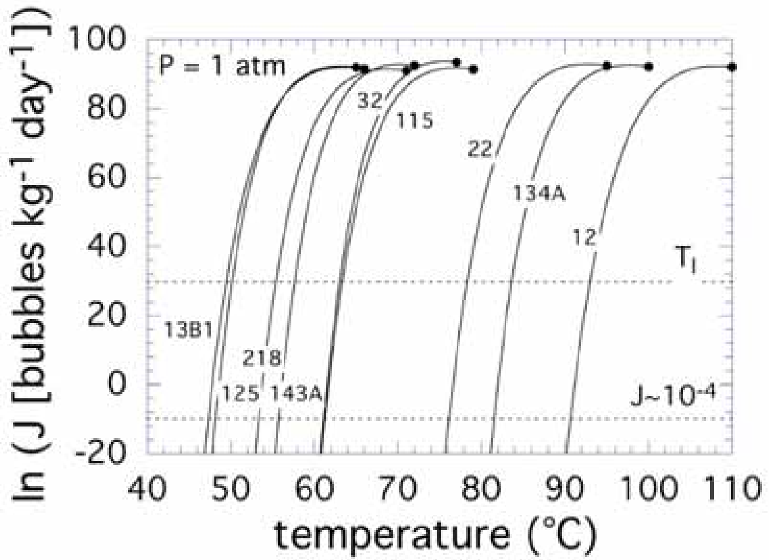
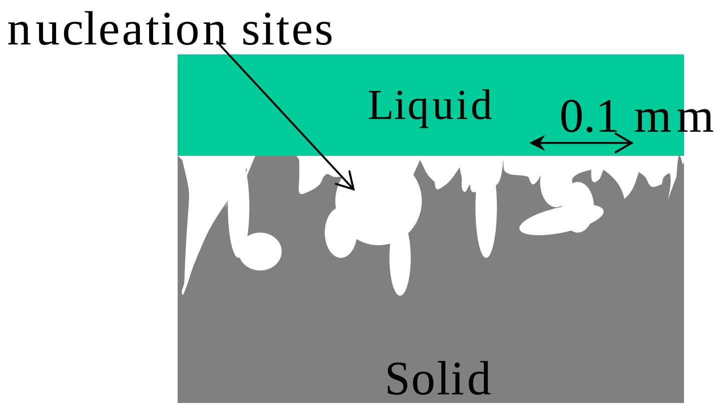
Spontaneous bulk nucleation rate = log(-2.5e5) / (kg*day)!! (T_c= 122°C, run at ~30-40°C)



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



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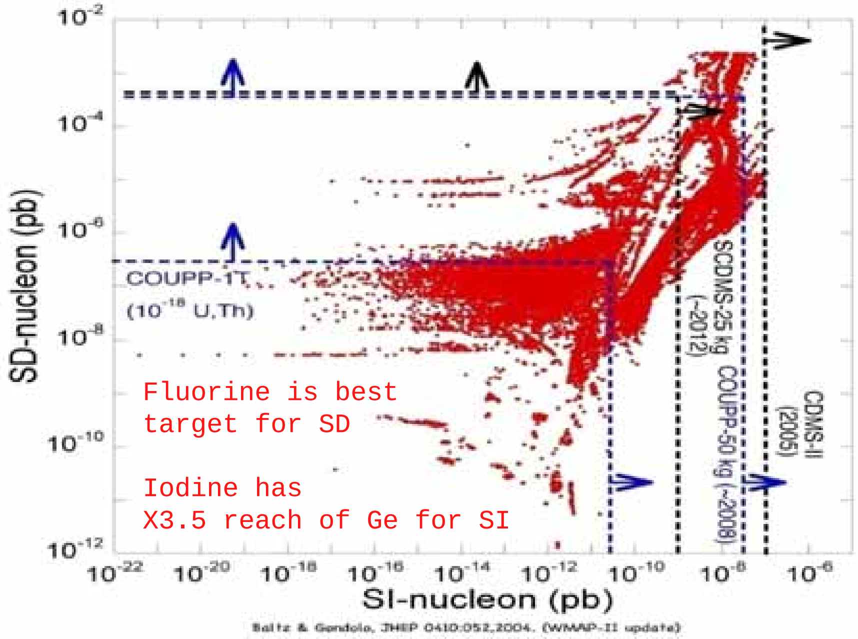
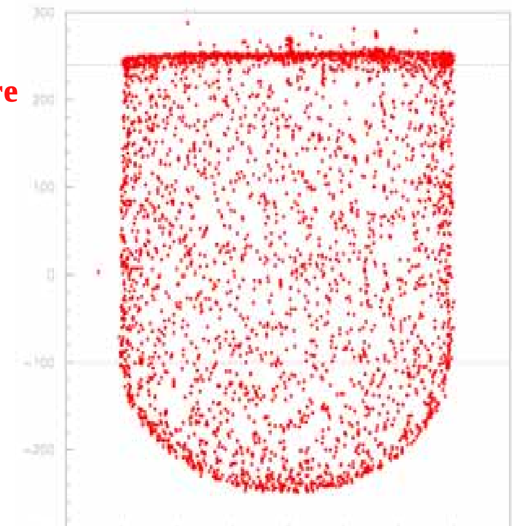
An old precept: an attack on both fronts



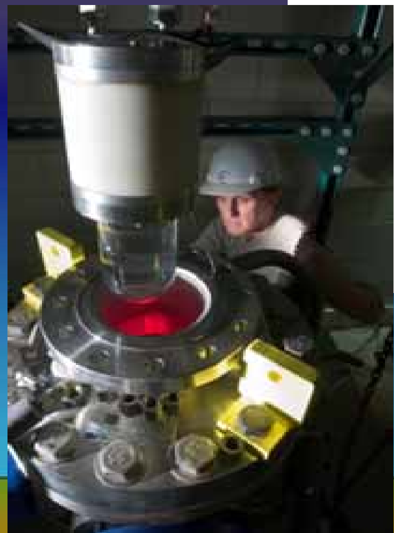
SD SUSY space harder to get to, but more robust predictions there (astro-ph/0001511, 0509269, and refs. therein)

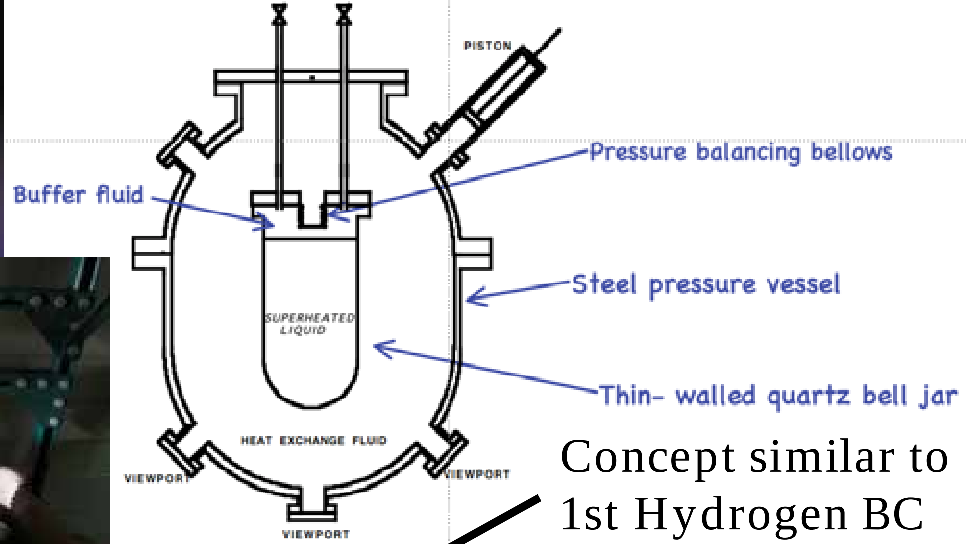


Spatial distribution of bubbles (~1 mm resol.)

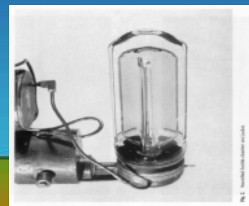
COUPP @ NuMI Tunnel Project (Fermilab Test Beam Proposal T945, now experiment E961)

2 kg (1 L) CF_3I engineering prototype chamber built at Uchicago, installed May '05

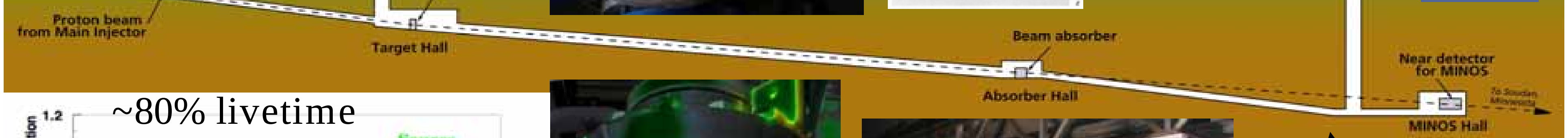




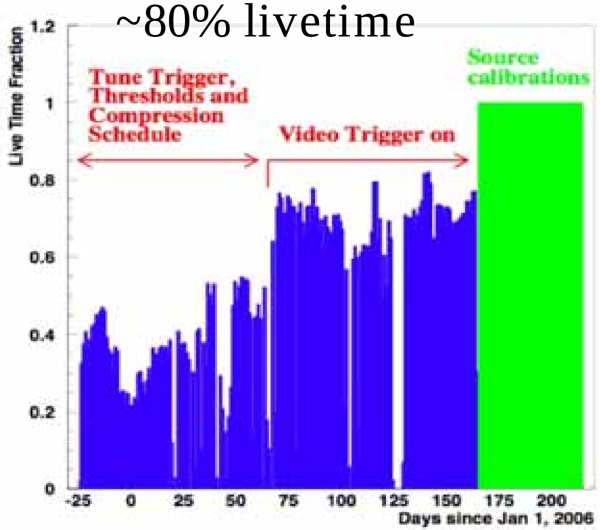
Concept similar to 1st Hydrogen BC



evolution! .....



~80% livetime



test site @ ~300 m.w.e.

^{137}Cs (13

Neutron and Gamma Calibrations *in situ*:

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

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

Switchable Am / Be (5 n / s)

^{14}C betas not an issue for COUPP (typical O(100) / kg-day)

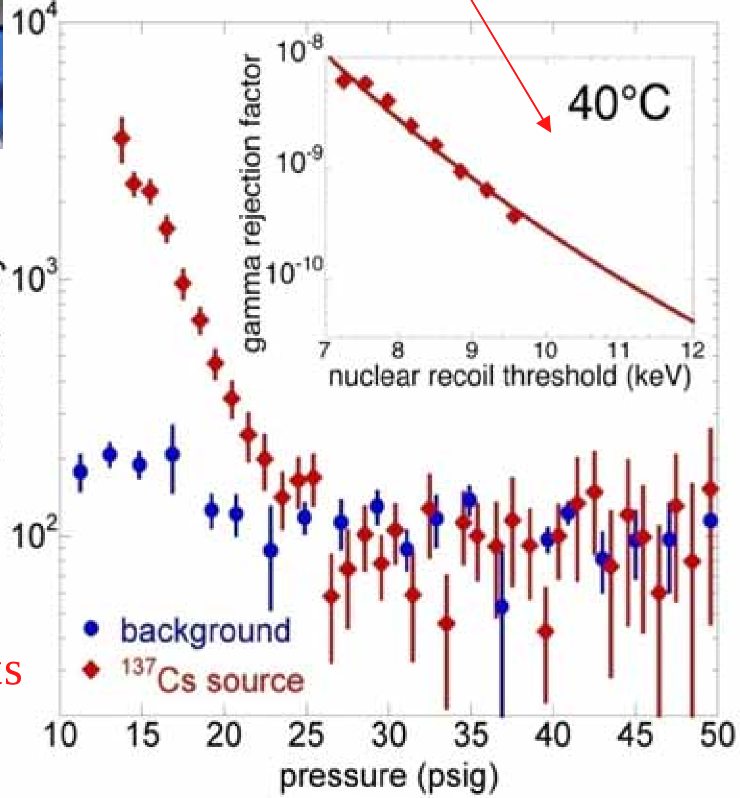
<u>No need for high-Z shielding, or attention to chamber material selection</u>

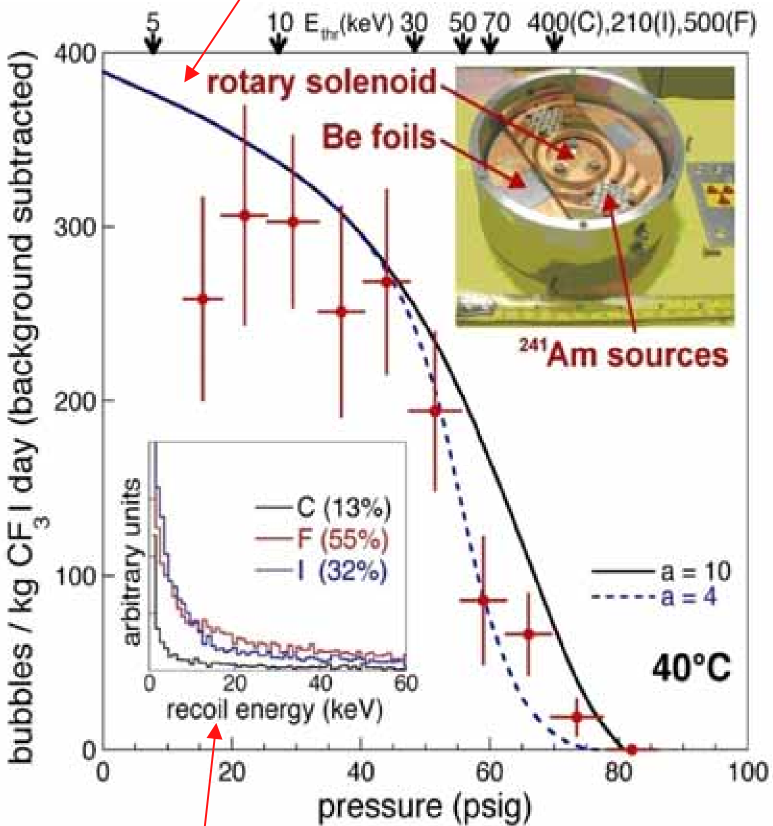
Other experiments as references:

XENON ~ 10^{-2}

CDMS 10^{-4} - 10^{-5}

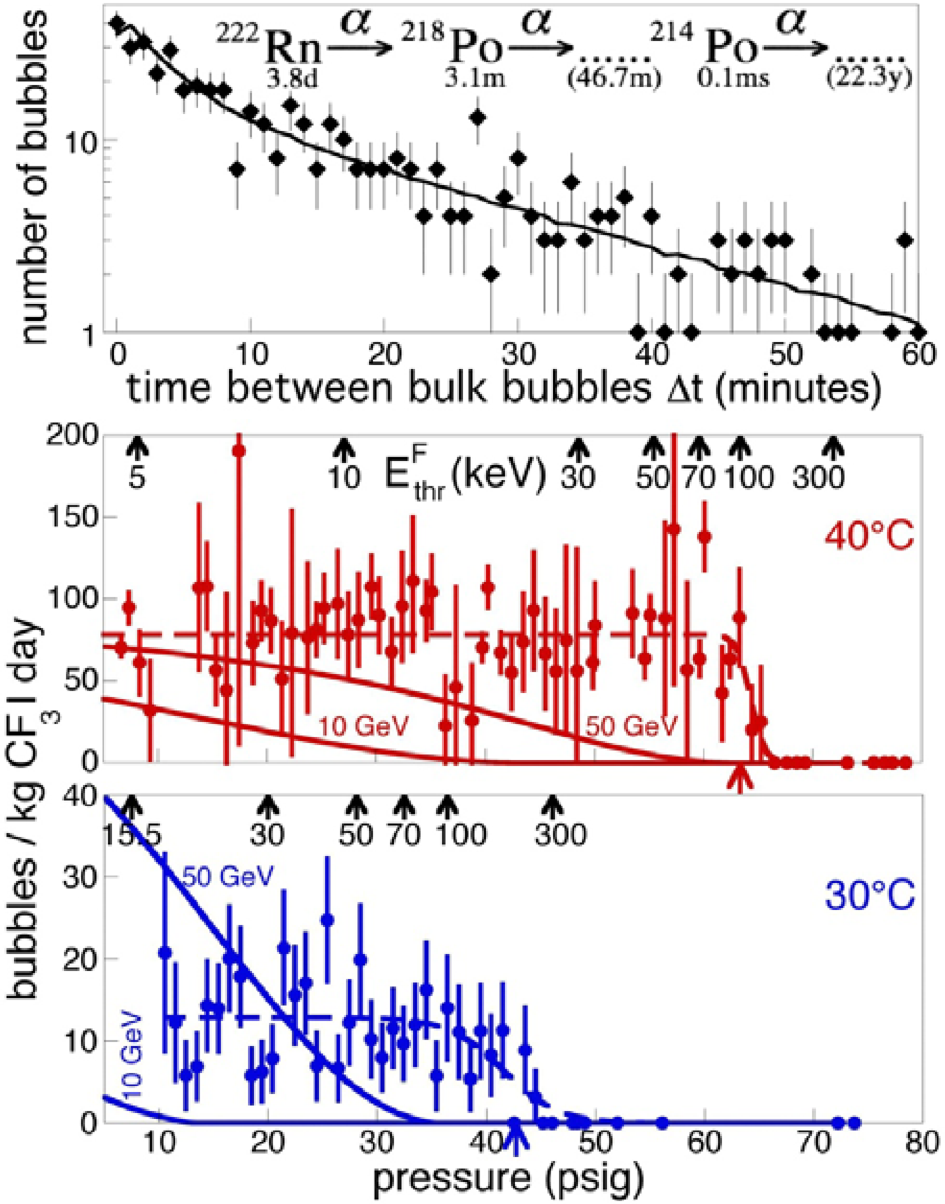
WARP ~ 10^{-7} - 10^{-8}





WIMP-like recoil energy signal

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



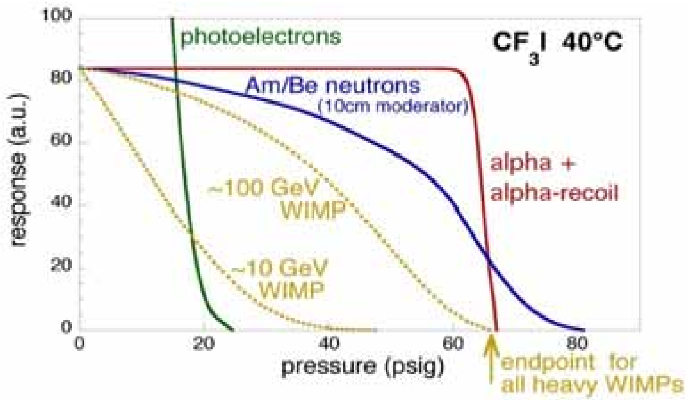
Surface events

- 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 for > 60% live-time in ~50 kg 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 favored 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).

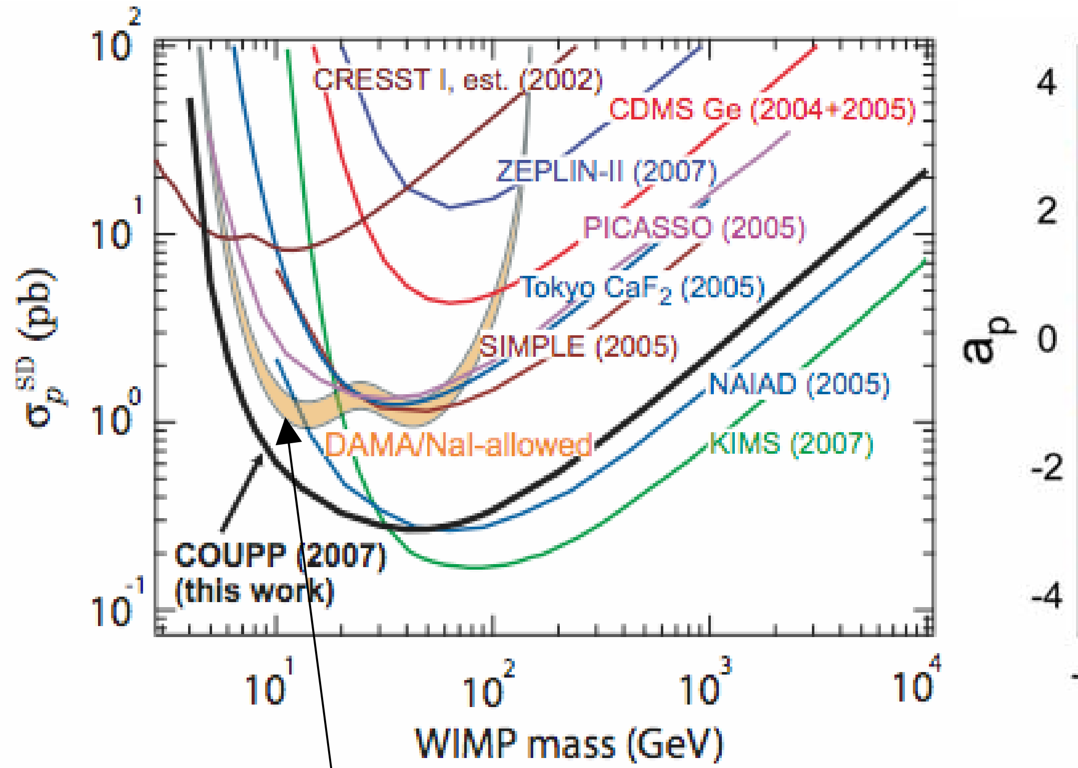
when life gives you lemons… ⟶

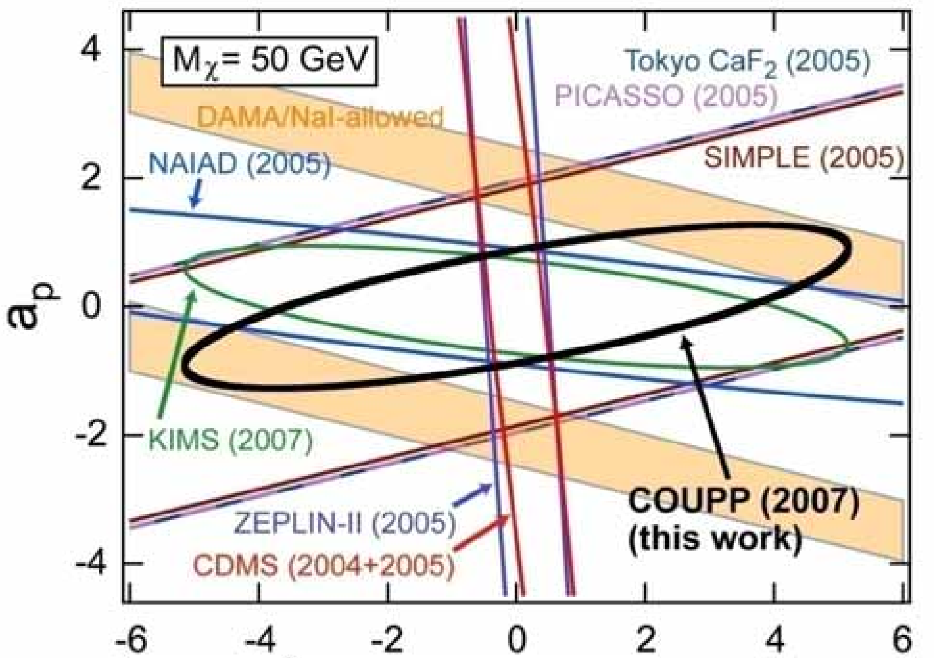


First COUPP Results

The bubble chamber is back

Science, 15 February





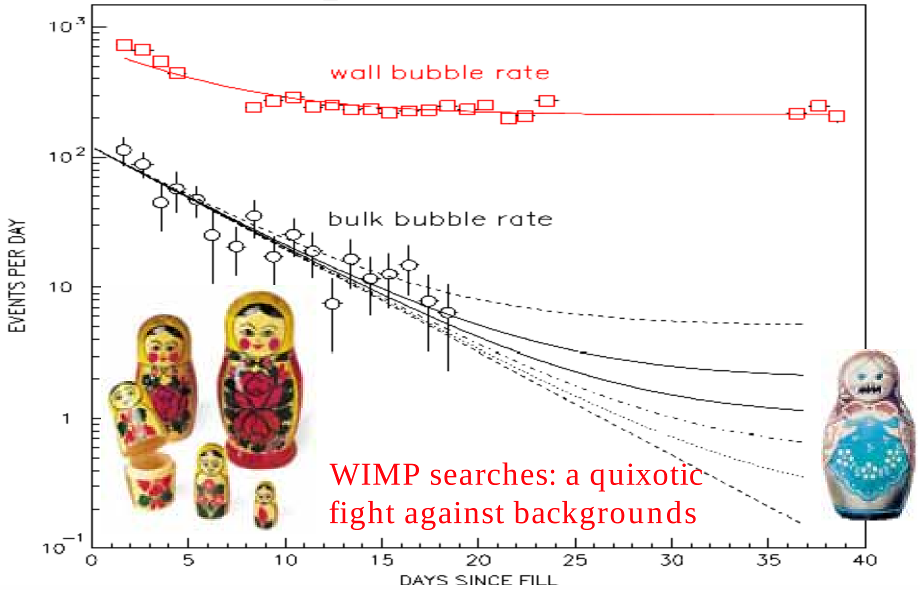
New limits exclude the low-mass region favored by a SD interpretation of the DAMA NaI signal

(last bastion for a conventional explanation)

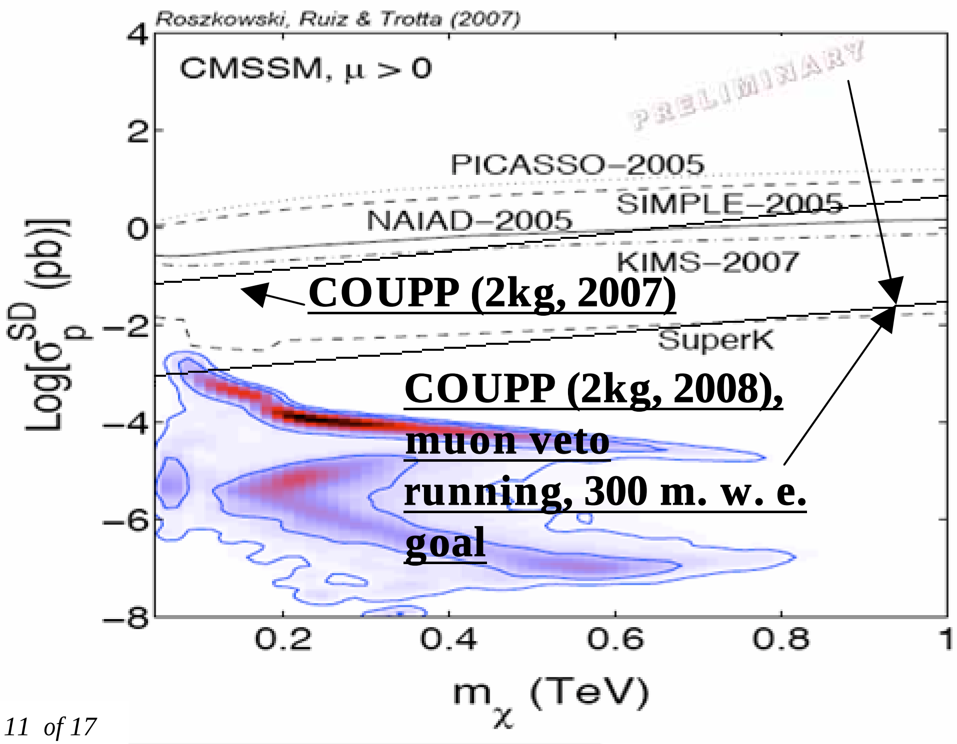
…coming up…

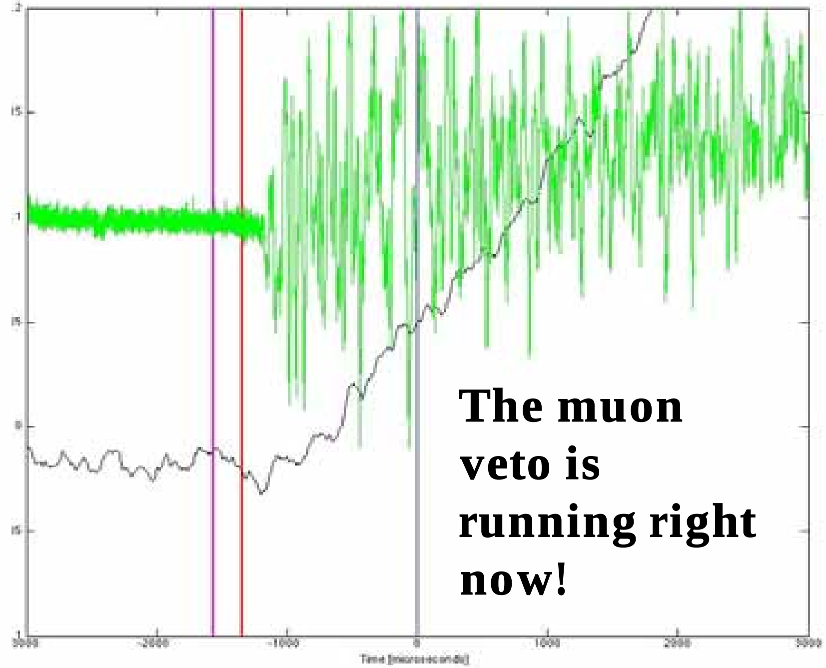
First COUPP results…

A peek at the future (which is here already)



- **New run of 1-liter chamber, started on July 30, 2007, with Rn countermeasures in place, already producing <u>very</u> interesting data.**
- **Some radon introduced during filling--now has decayed to equilibrium**
- **2008 goals: exploring SD favored region for the first time, matching best SI limits.**





Numerous ongoing activities

THE UNIVERSITY OF CHICAGO Fermilab
a small but very ACTIVE collaboration!

20 kg windowless chamber neutron shield

4π water shielding

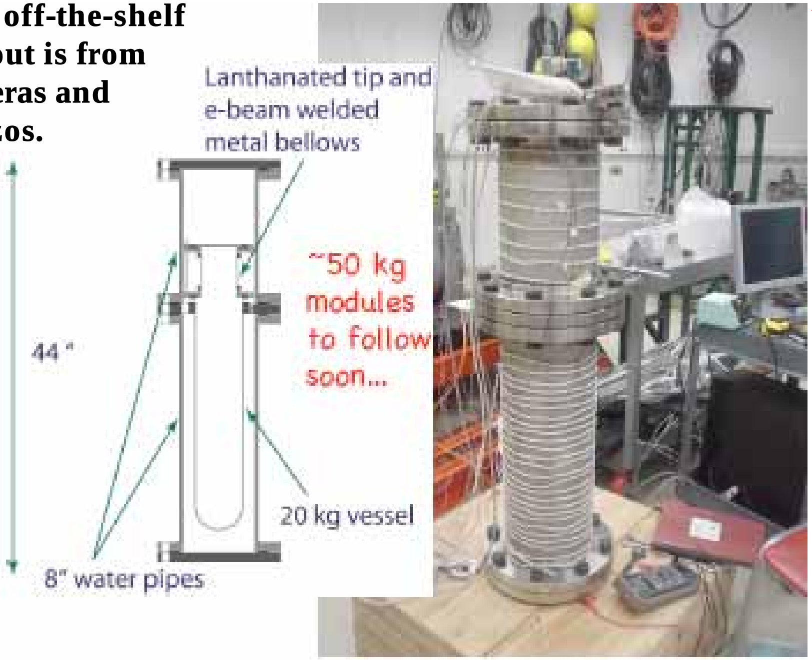
modular recompression and pressure control unit

“skinny” chamber for inelastic n scattering exp.

20 kg (10 L) chamber muon veto

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

Windowless (naked CCD board camera in dielectric fluid inside)



1 L chamber for pion beam calibration

Infrastructure in place

Spray-wash system for
RF cavities (@FNAL)

Clean room gowning area (@FNAL)

Ultrasound baths

Clean room (@ U of C)

Most importantly:

←

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

(muon veto visible)

Under construction at FNAL: 60 (80?) kg Chamber

(A big THANKS for FNAL's technical support, from all of us on COUPP)

Completed muon veto in NUMI tunnel, for use with 2 kg and 60 kg

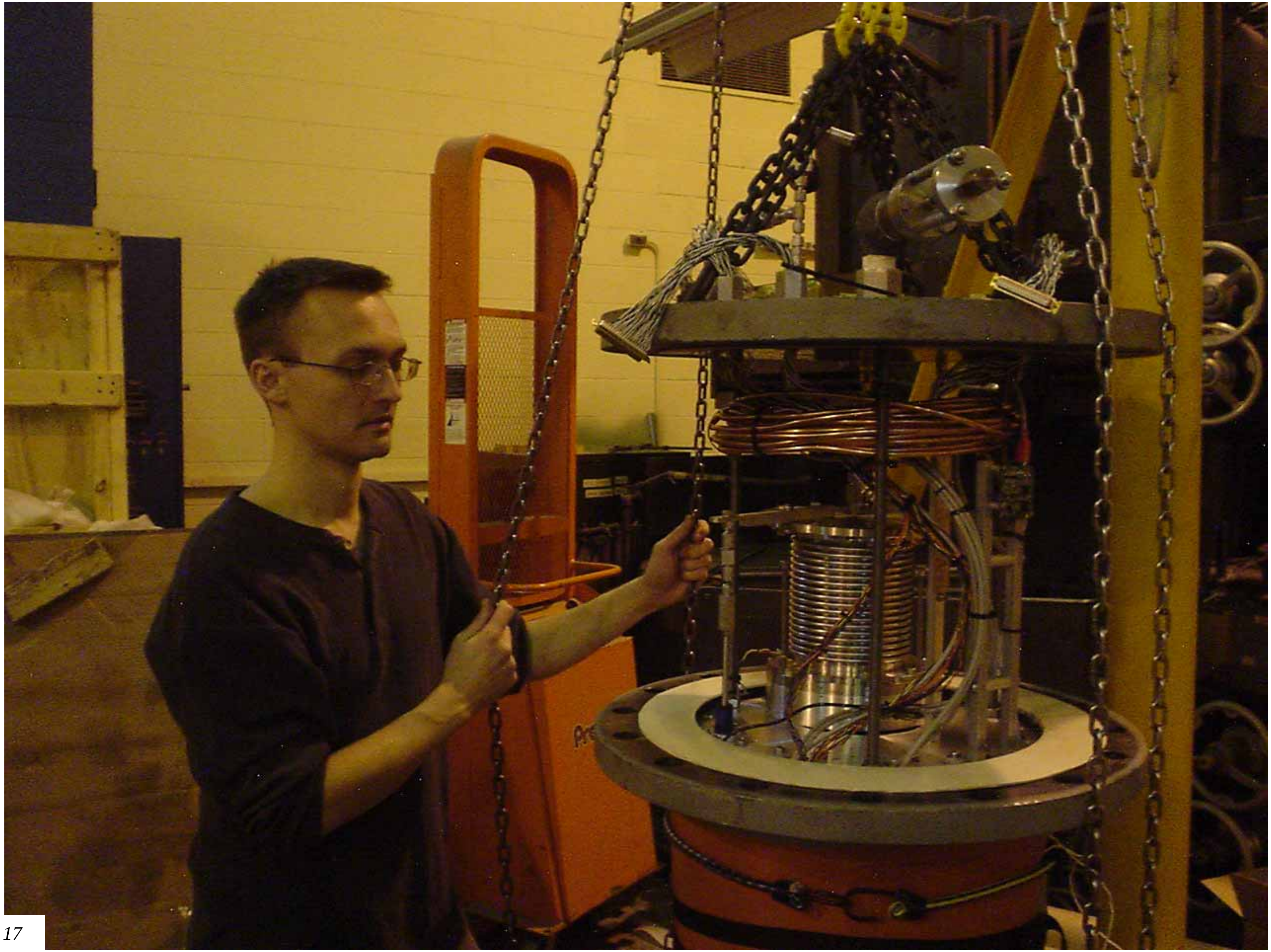
Commissioning in NUMI tunnel for later deployment even deeper underground

GOAL (2009): ~1-200 kg deep underground (equiv. of 600 kg Ge) in SI sensitivity

Encouraged by FNAL directorate to start thinking "1 ton"

2 weeks ago, windowless prototype installation

2 weeks ago, windowless prototype installation



Any Questions?