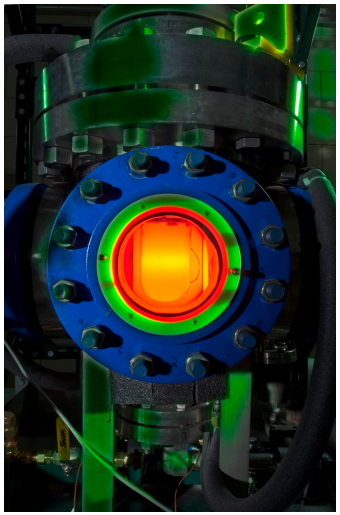
Searching for Dark Matter with a Bubble Chamber
COUPP (Chicagoland Observatory for Underground Particle Physics)

Peter S. Cooper

usually from
Fermi National Accelerator Lab
but not this week

with support gratefully acknowledged from the conference organizers
and my colleagues at the KICP, University of Chicago



COUPP

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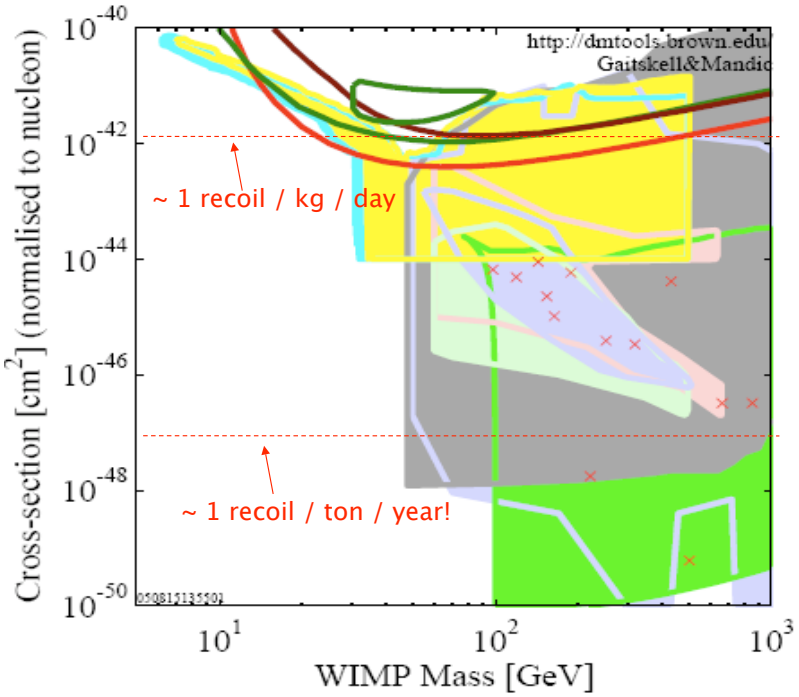
Outline

- Introduction
- Bubble chamber principle of operation
- The Coupp Bubble Chamber
- Calibration and Backgrounds
- Results
- Future Plans
- Conclusions

Wish List for a Tough Problem



Dream Detector:

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

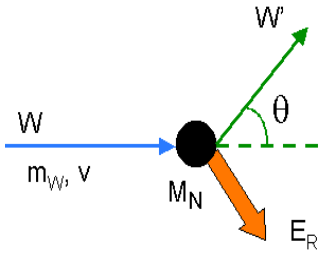
A bubble chamber (bulk superheated liquid detector) potentially fulfills all those wishes…to the level at which backgrounds grow out of control

Nuclear Recoil Induced Bubble Nucleation
Detection with heat, not light

WIMP Nucleon Couplings

- **Coherent Nuclear scattering**
  - **Spin Independent Coupling (Scalar)**

$$\frac{d\sigma_{\chi N}^{SI}}{dq^2} = \frac{1}{\pi v^2}[Zf_p + (A-Z)f_n]^2 F^2(q)$$



- **WIMP and Nucleus both have spin**
  - **Spin Dependent Coupling**
  - **different couplings to protons and neutrons**

$$\frac{d\sigma_{\chi N}^{SD}}{dq^2} = \frac{8G_F^2}{(2J+1)v^2}[a_0^2 S_{00}(q) + a_0 a_1 S_{01}(q) + a_1^2(q) S_{11}(q)] \qquad a_p = \frac{1}{2}(a_0 + a_1),\ \ a_n = \frac{1}{2}(a_0 - a_1)$$

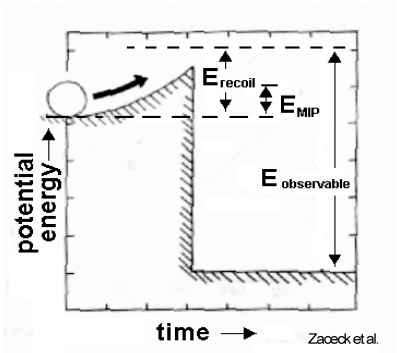
Bubble Chamber Theory of Operation

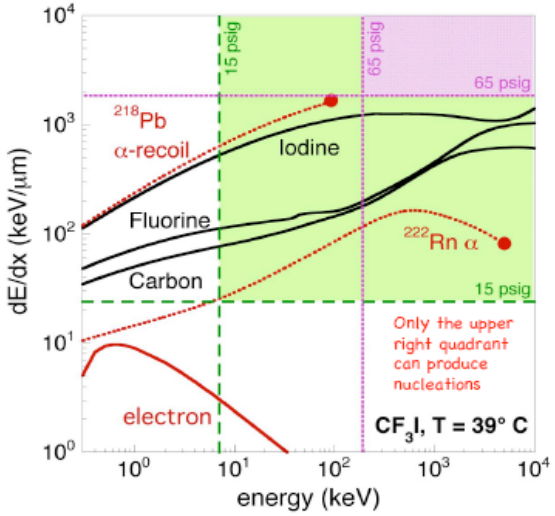
Seitz (hot spike) model

- A small volume of liquid (~100nm, ~10^6 atoms) boils.
- Bubbles too small to overcome surface tension collapse.
- Once big enough they grow without bound (∞ gain).
- Key is enough energy deposited in a small enough volume.

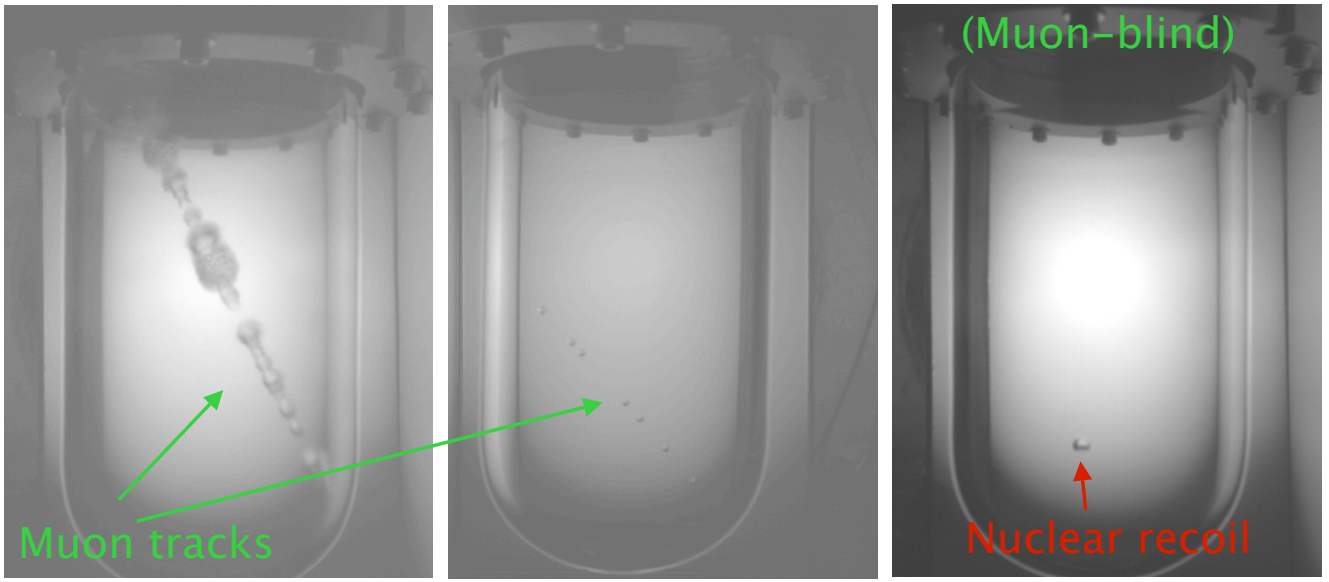
$$E > E_c = 4\pi r_c^2\left(\gamma - T\frac{\partial\gamma}{\partial T}\right) + \frac{4}{3}\pi r_c^3\rho_v\frac{h_{fg}}{M} + \frac{4}{3}\pi r_c^3 P \ , \ \ r_c = 2\gamma/\Delta P$$

$$dE/dx > E_c/(ar_c)$$



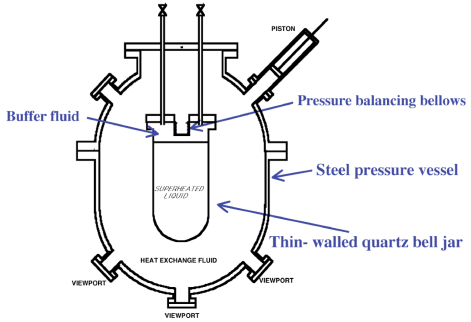


Leaving "Normal" BC mode far behind

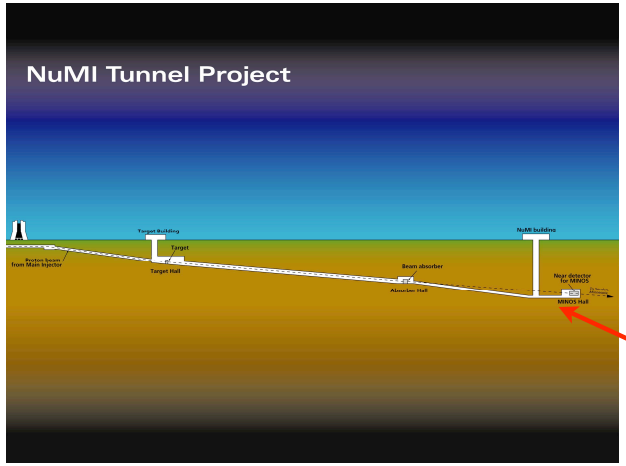


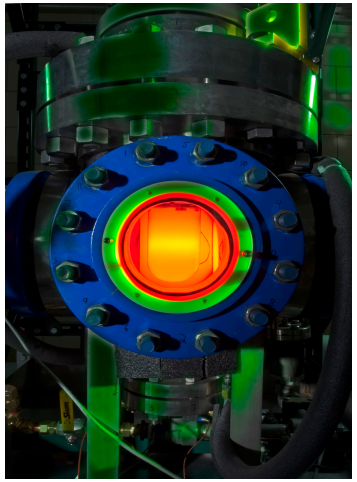
- Muon tracks are visible only at high superheats
- We operate at low superheat; β, γ, MIP blind
- 1 nuclear recoil = 1 bubble
- neutrons scatter more than once – multiple bubble events

2 kg Prototype Chamber @ Fermilab



Bulk CF_3I touches only the quartz





Yes – we see neutrino induced events

DAQ and Reconstruction

Data taking

Event cycle

- Rest 30 seconds to allow previous bubble to condense.
- Expand chamber to a given sensitivity (scan pressure at fixed T)
- Photograph at 20 Hz with 2 cameras
- Trigger on either a pressure spike or a 6 pixel image difference
- Record 10 pictures in each view + operating parameters
- Repeat scanning pressure from min to max every 6 hours
- Integral detector - measure rate above an adjustable threshold

Typical trigger rates are ~200/day, live-time ~85%

Data sets with sources in/out, different temperatures, etc.

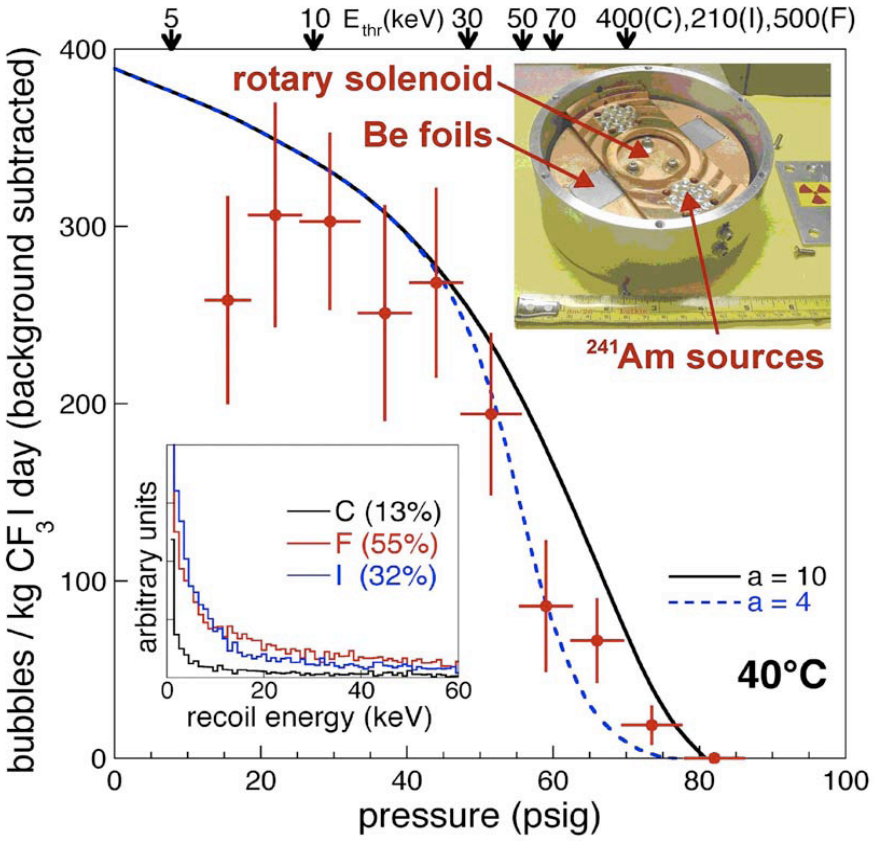
Reconstruction

Program

- Each bubble found and recorded with operating parameters
- Characterized as Bulk, Wall, Surface or Other
- Now done in realtime as the triggers come in

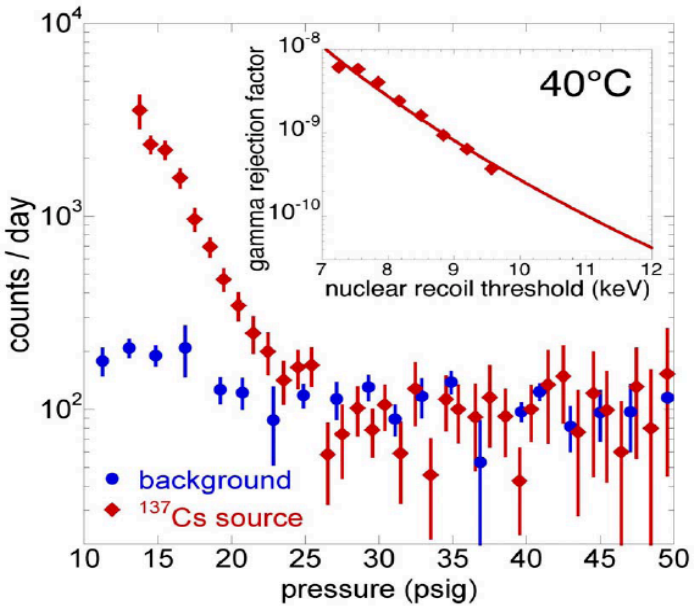
Fiducial volume 70% ==> 90% of 1.5 Kg of CF_3I

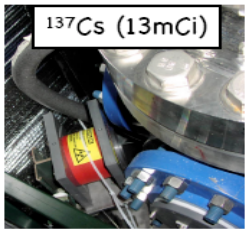
Neutron calibration, in situ



- Switchable Am/Be source yields ~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
- Multiple bubble events quantify neutron background.

Non-response to MIPs, β's, & γ's

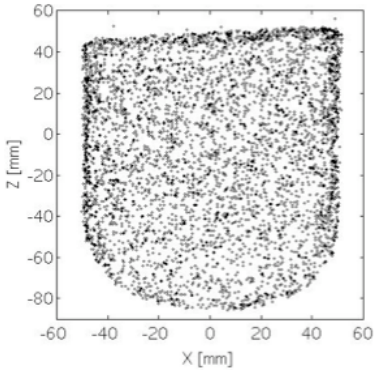


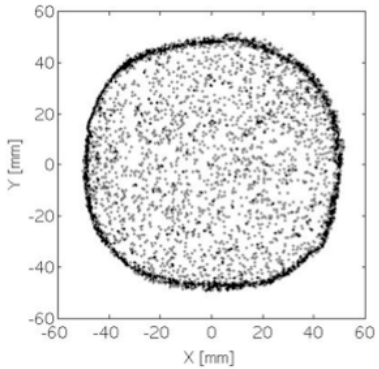


XENON ~10^{-2}
CDMS 10^{-4}-10^{-5}
WARP ~10^{-7}-10^{-8}

- Intrinsic γ rejection > 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 is O (100/kg-day)

Wall Background: α Emitters



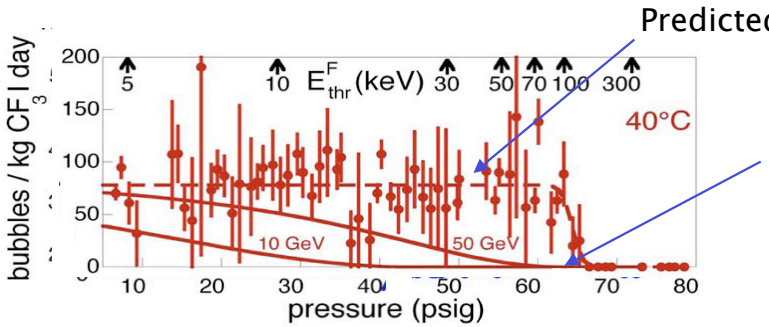


- Wall rate (0.8 /cm^2/day) OK for small vessels (200 /day for 2 kg chamber)
- These make dead time not background
- γ-counting of our Ge-214 natural fused quartz found U (Th) at typical level of 50 (30) ppb —consistent with 100% of wall-event rate
- Commercial α-counting gives consistent rate
- Next-generation 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
- Demonstration underway at UC now!

Bulk Background: Radon & Progeny

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

- Flat rate with sharp onset at predicted value
- Analysis of time correlation between events supports hypothesis
- 100% Rn, 100% efficiency

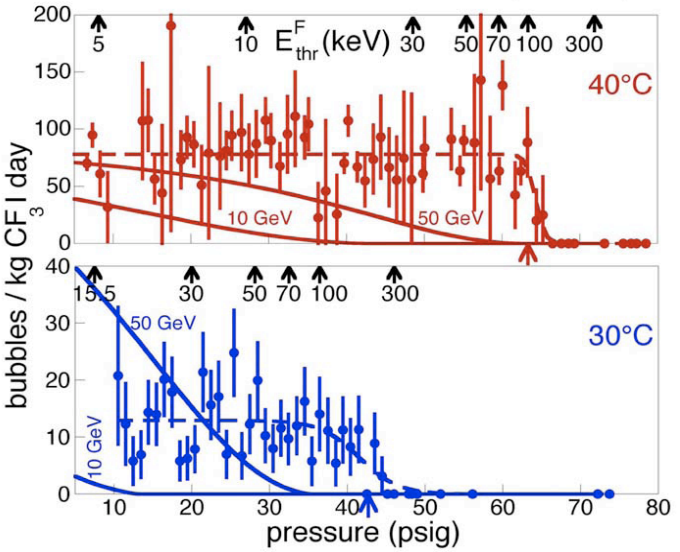


Next chambers:

1. Non-thoriated welds
2. Metal seals against Rn
   DONE - Rn gone!

Any WIMPs in the Data?

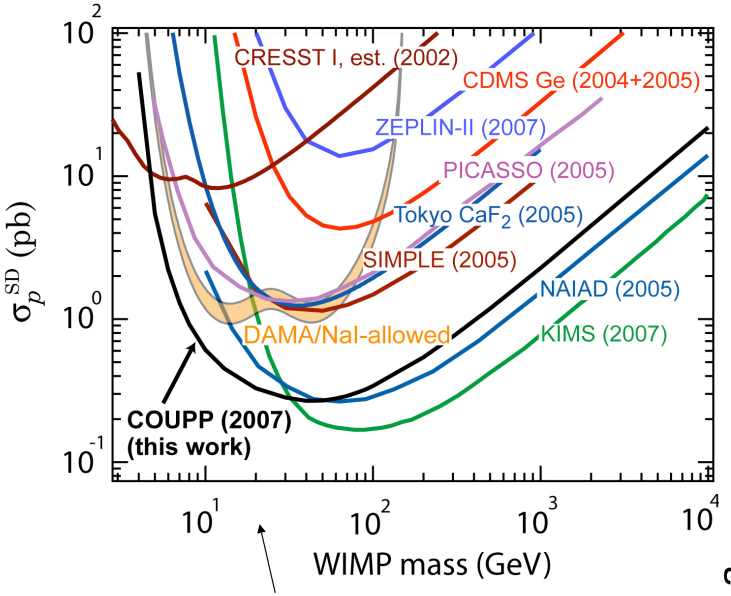
Q: How much WIMP signal could be hiding beneath the radon & progeny?



(Note: these are integral energy spectra)

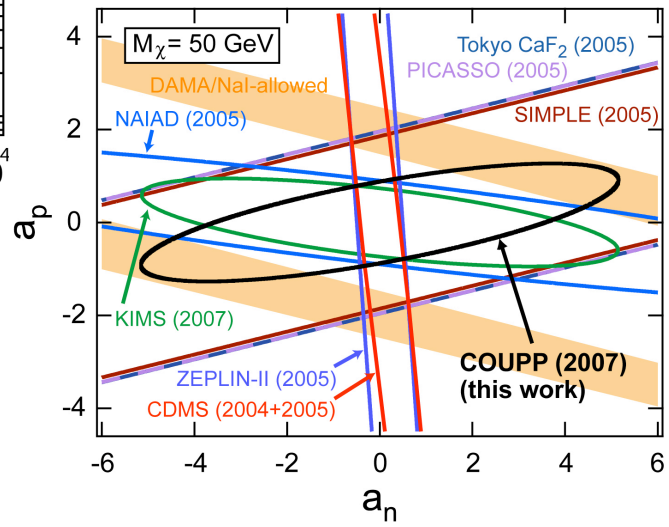
- Total exposure of 250 kg-days (Dec '05 – Nov '06), with live-time fraction reaching 80%
- Dashed curves: best fit for null hypothesis (only Rn & progeny)
- Solid lines: expected WIMP response for $\sigma^{SD(p)}$=3 pb
- Null hypothesis is favored
- Combined limits obtained by taking weighted mean of cross-sections from best fit WIMP-response, from three data sets

COUPP (2007) Exclusion Limits

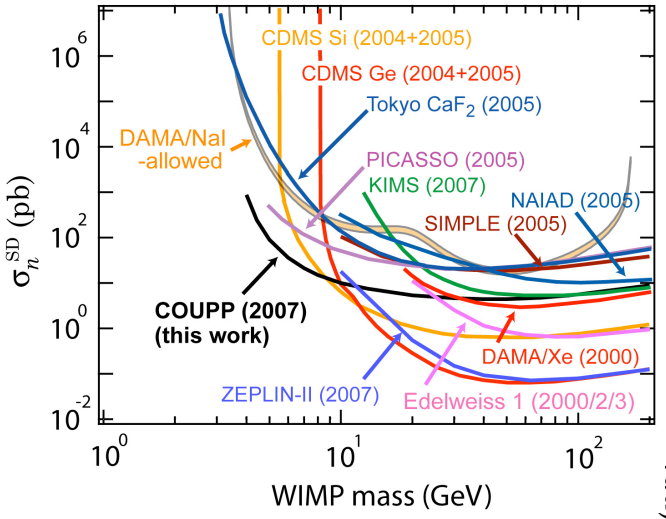


Limits are placed in the low-mass region favored by an SD interpretation of the DAMA/NaI signal

The COUPP 2 kg prototype detector, even with no measures against radon, sets competetive SD(p) limits

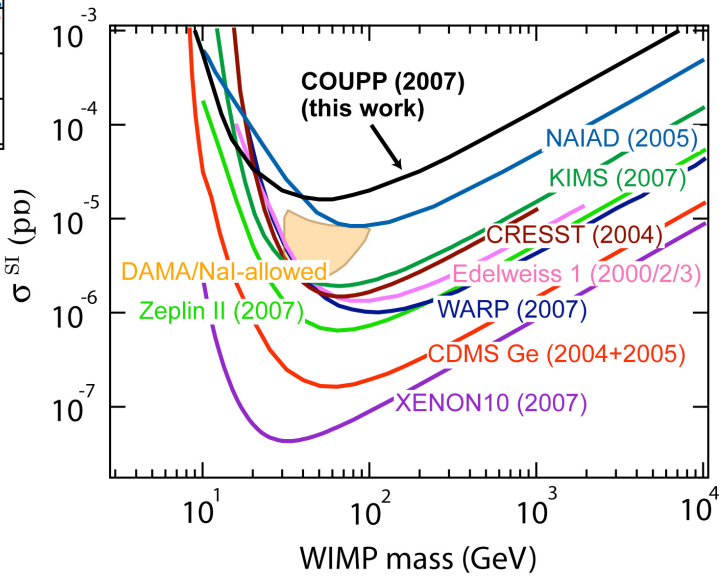


COUPP (2007) Exclusion Limits



SD(n) and SI limits are not 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 extremely promising…



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60 kg Fermilab chamber under construction

For initial installation in NUMI tunnel at Fermilab.

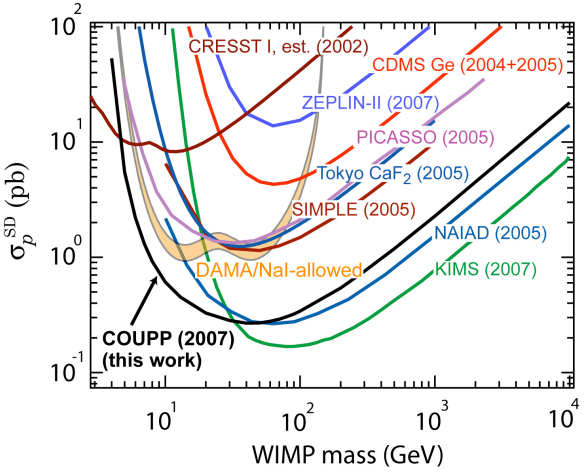
We'll "go deep" if and when backgrounds allow. First I'd like to measure them.

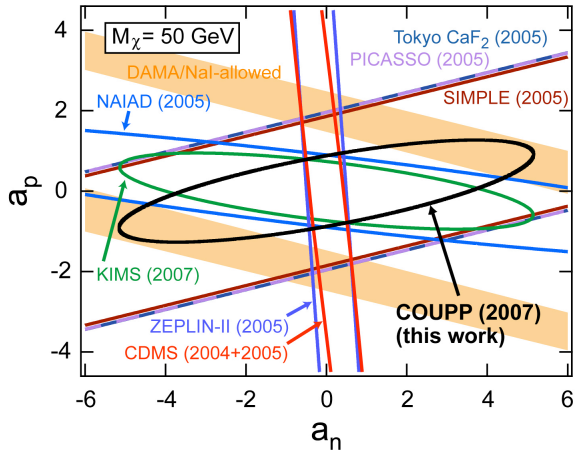
20Kg chamber also being commissioned at UC for initial installation in TARP tunnel in Cicero.

Conclusions

A Bubble Chamber as a WIMP Search detector

- Scalable: liquid target with simple instrumentation
- Low cost (<$100/Kg + plumbing)
- Outstanding γ-rejection
- Single concentration: reducing alpha-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 soon





Questions?

"*I was like a boy playing on the sea-shore, and diverting myself now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me.*"
Isaac Newton

Extras

160 msec Movie (20 msec/frame)