The background of the slide is a grayscale Cosmic Microwave Background (CMB) fluctuation map, showing a complex pattern of dark and light spots representing temperature variations in the early universe.

New Dark Matter Limits from the Chicagoland Observatory for Underground Particle Physics (COUPP)

Jeter Hall

Fermilab Center for Particle Astrophysics

Fermi CPA

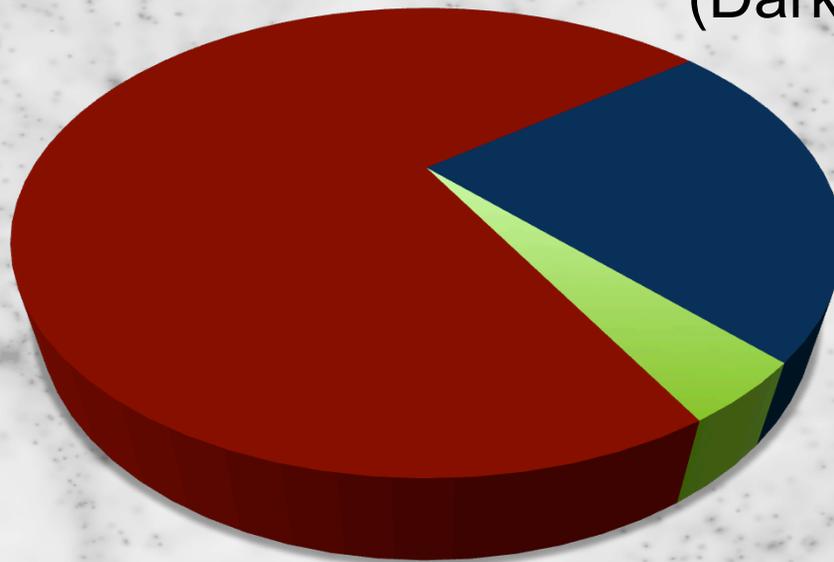


- Fermilab faces a huge budget deficit
- Compare to Illinois' problems
 - \$11B deficit
 - \$50B expenditures
 - 23% budget deficit
- The Fermilab budget deficit is ~**2500%**



The Budget Deficit

Dark Energy
~ 73%



Missing Matter
(Dark, Cold, Non-Baryonic)
~ 23%

Standard Model
~ 4%

Top Quarks $\sim e^{-10^{42}}$

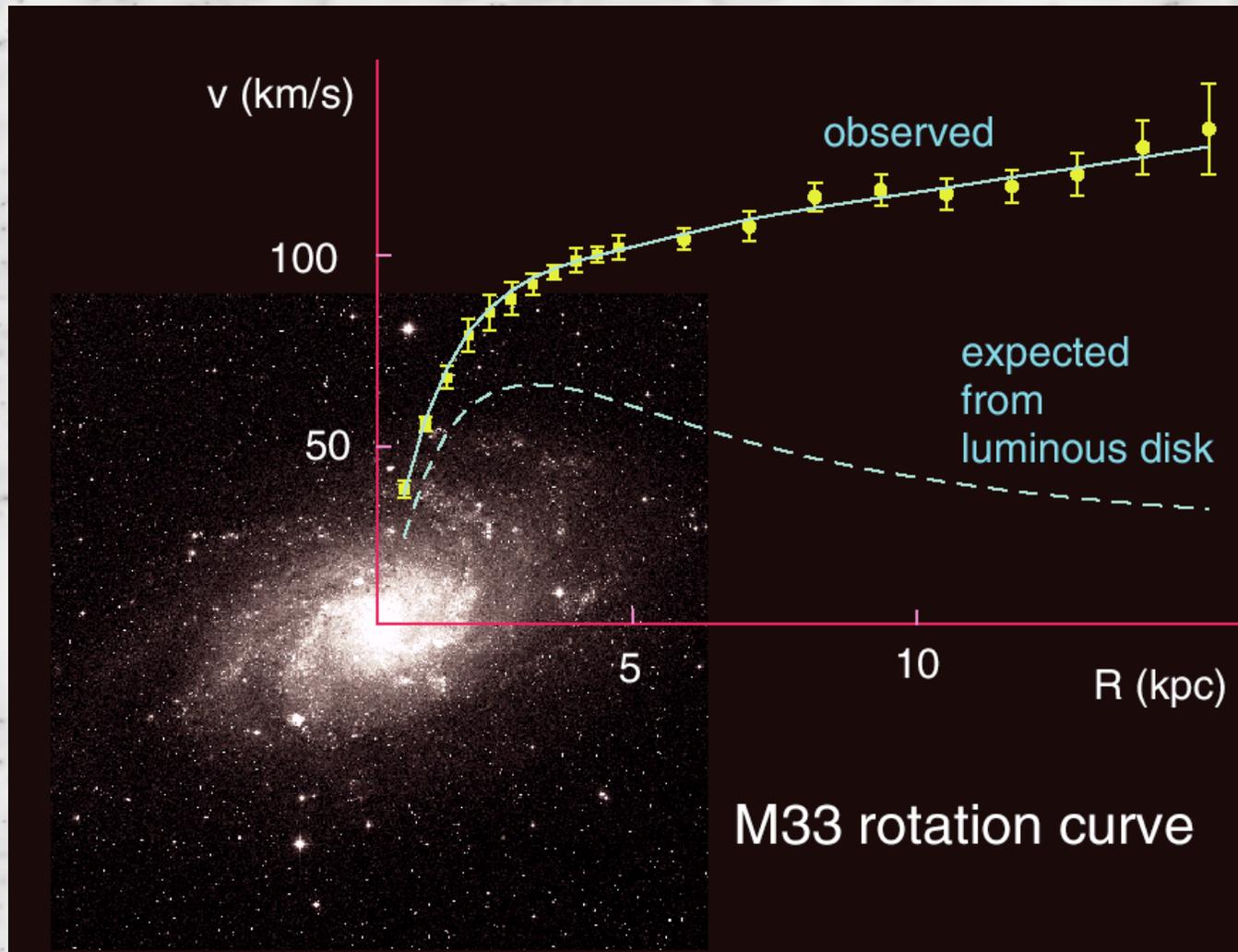
- Not discussing Dark Energy
 - See SDSS/DES/JDEM
- Today we are focusing on the missing dark matter

THE STANDARD MODEL					
	Fermions			Bosons	
Quarks	<i>u</i> up	<i>c</i> charm	<i>t</i> top	γ photon	Force carriers
	<i>d</i> down	<i>s</i> strange	<i>b</i> bottom	Z Z boson	
Leptons	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	W W boson	
	<i>e</i> electron	μ muon	τ tau	<i>g</i> gluon	
			Higgs* boson		

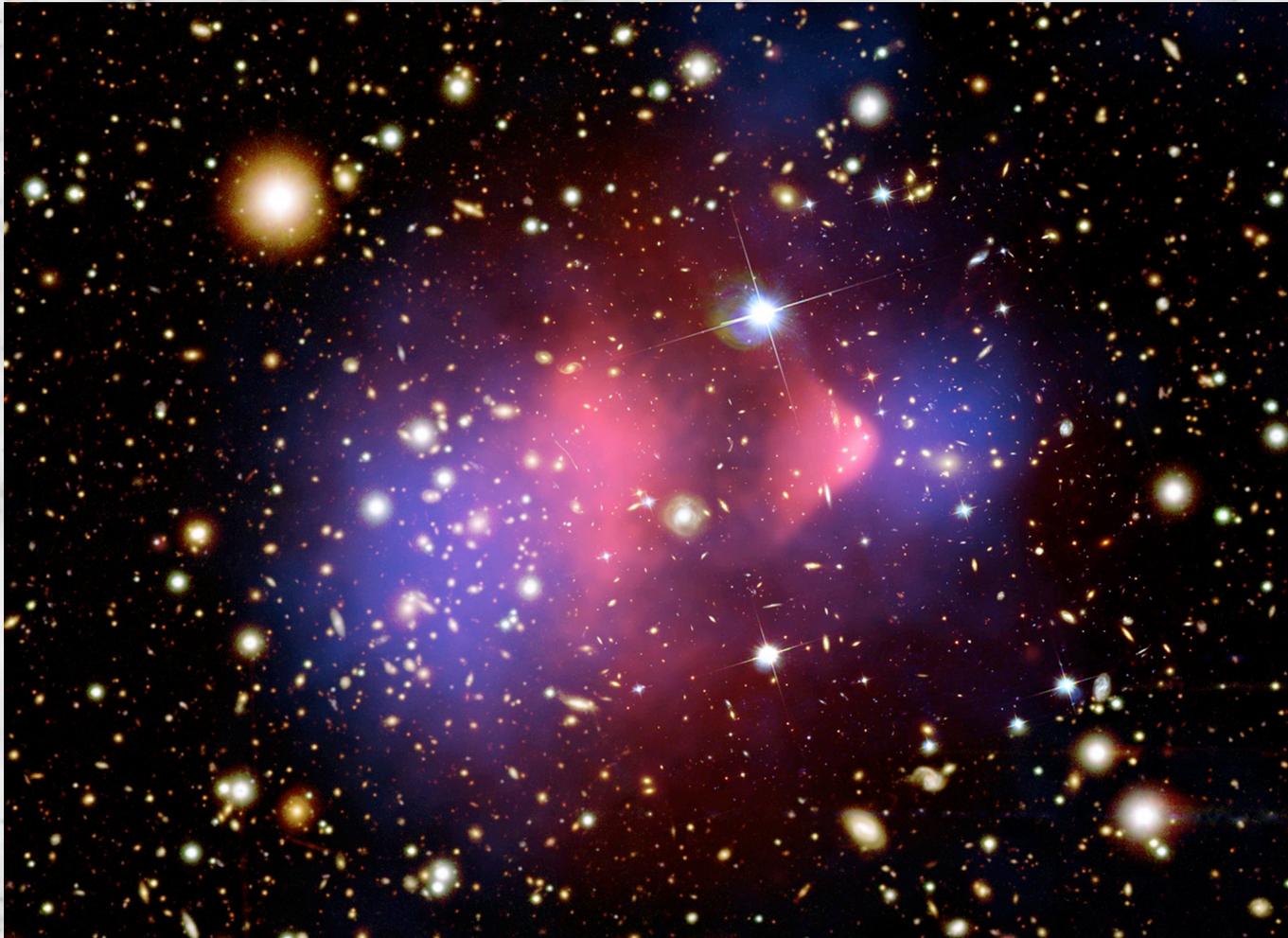
*Yet to be confirmed

Source: AAAS

The Dark Matter Problem

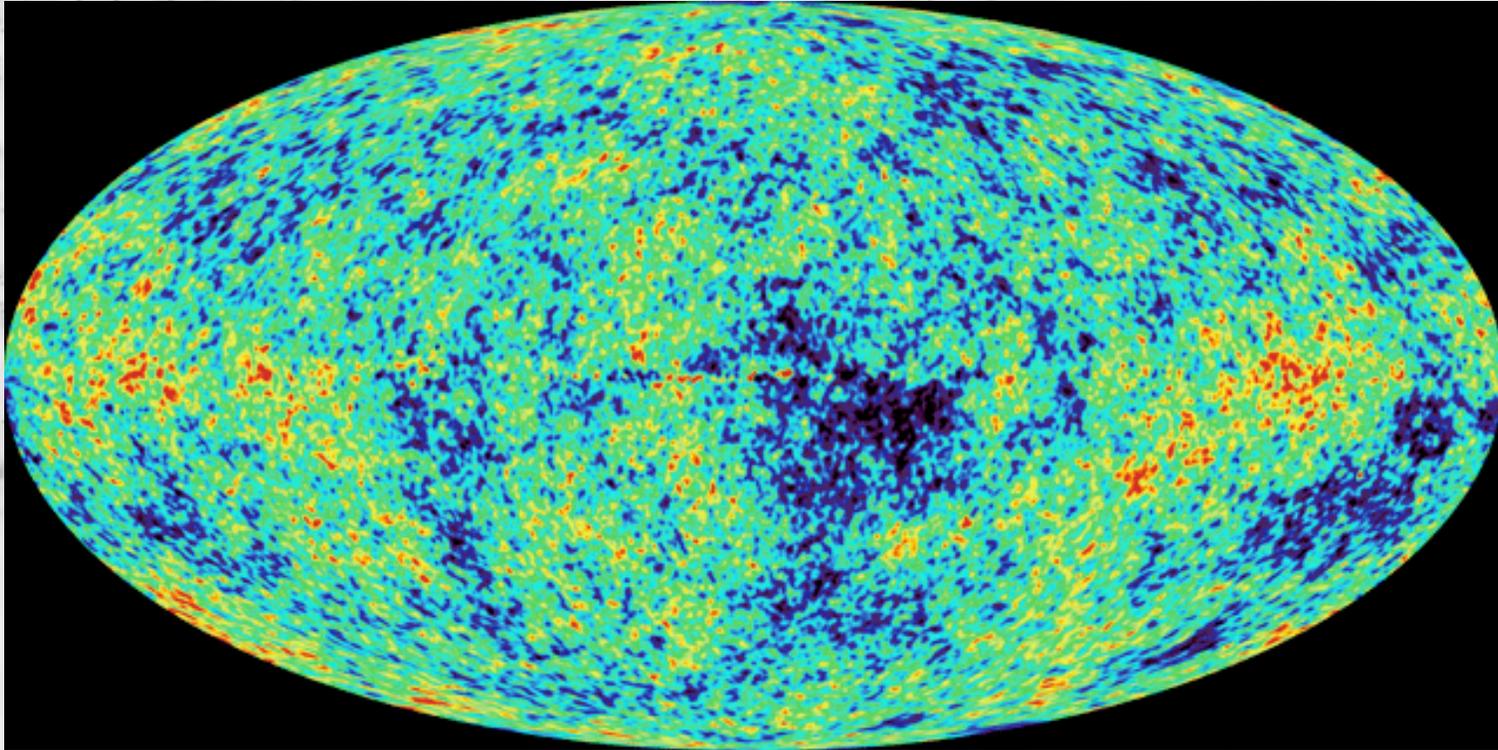


The Dark Matter Problem



High Energy Astrophysics Collider Program

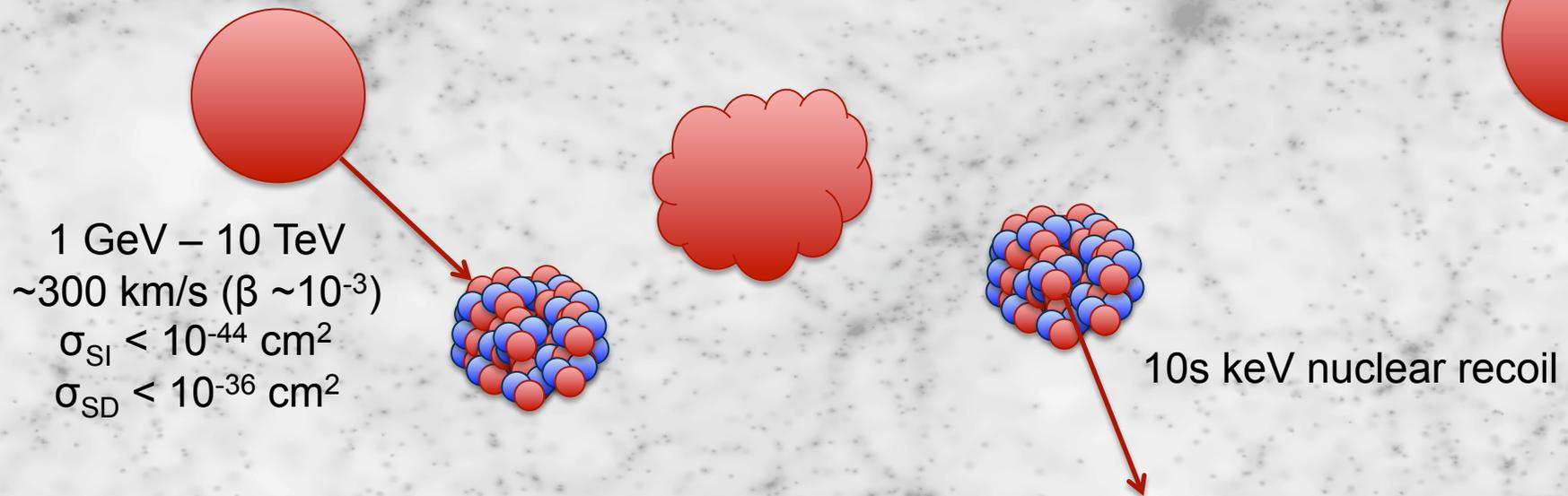
The Dark Matter Problem



- Fluctuations too small for galaxies to have formed via gravitational collapse in the time since decoupling

Direct Detection of Dark Matter

- Searching for WIMP-Nucleus elastic scattering
- In a sea of background radiation
 - Backgrounds, backgrounds, backgrounds...





The COUPP Collaboration



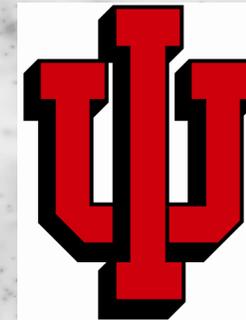
Kavli Institute
for Cosmological Physics
AT THE UNIVERSITY OF CHICAGO

University of Chicago

J. Collar, C.E. Dahl, D. Fustin, M. Szydagis

Indiana University South Bend

E. Behnke, J. Behnke, J.H. Hinnefeld, I. Levine, A. Palenchar, T. Shepard, B. Sweeney

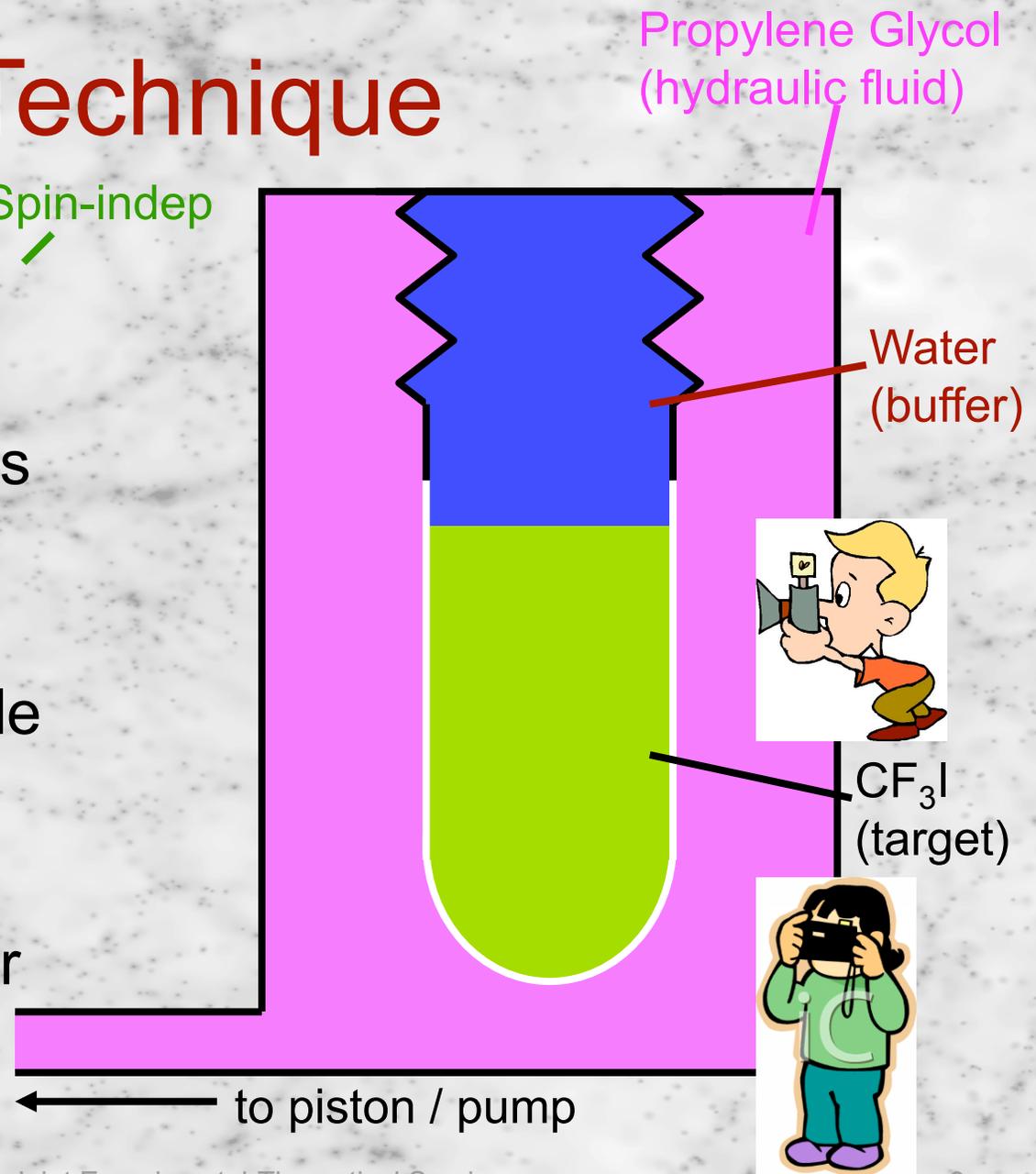


Fermi National Accelerator Laboratory

**S.J. Brice, D. Broemmelsiek, P. Cooper, M. Crisler,
J. Hall, M. Hu, E. Ramberg, A. Sonnenschein**

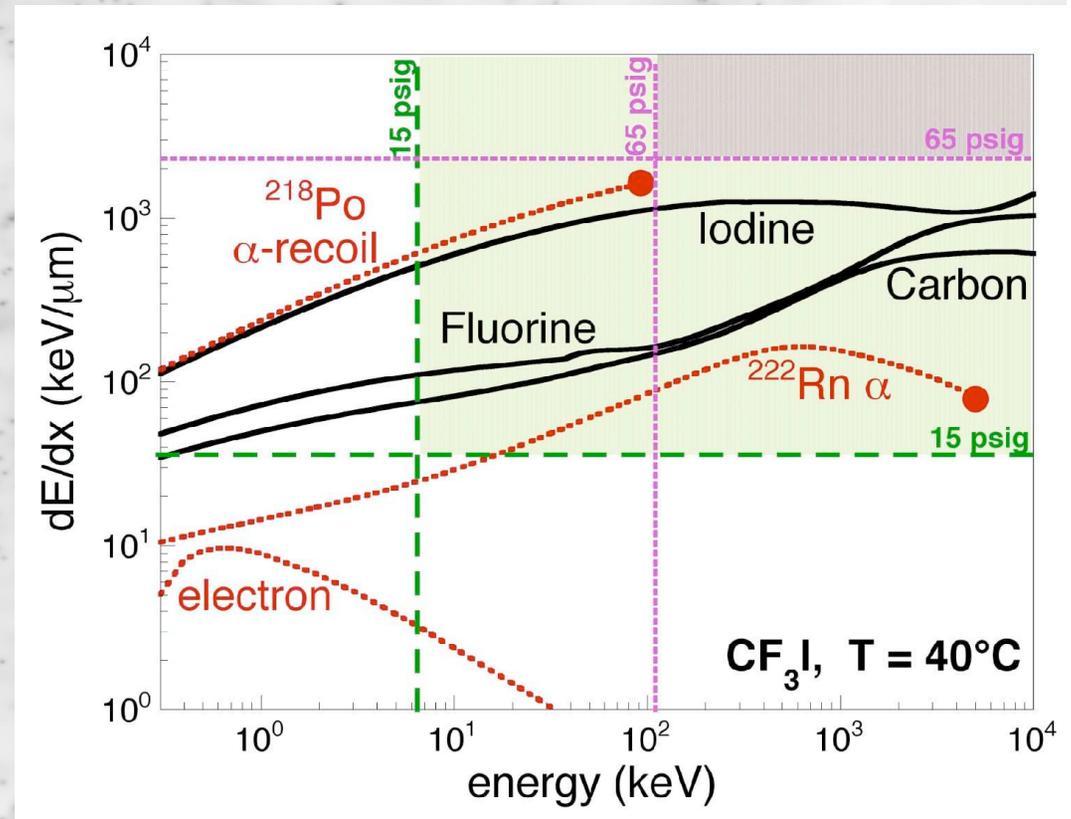
Technique

- Superheated CF_3I target
Spin-dep
- Particle interactions nucleate bubbles
Spin-indep
- Cameras capture stereoscopic bubble images
- Chamber recompresses after each event



Backgrounds, Backgrounds...

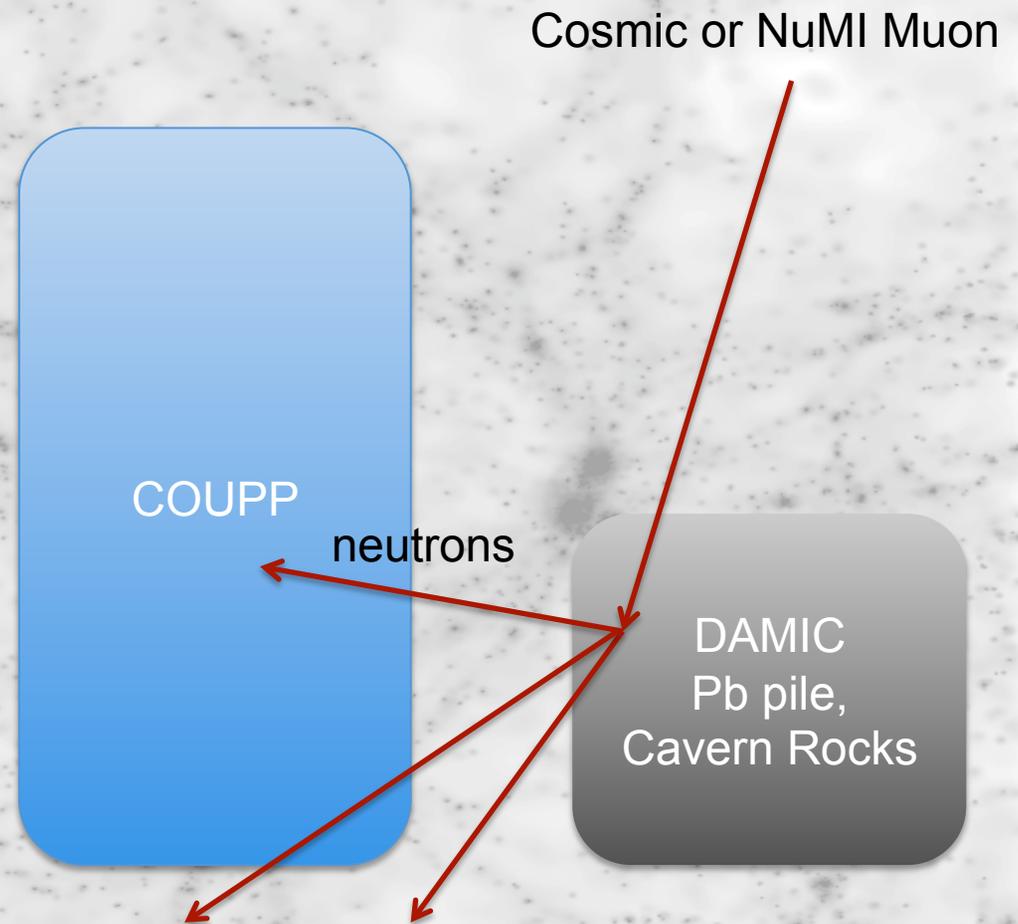
- Only proto-bubbles with $r > r_{\text{crit}}$ grow to be macroscopic
- Minimum Energy
- Minimum dE/dx



No sensitivity to γ 's or β 's!
 α 's do make bubbles

Backgrounds, Backgrounds...

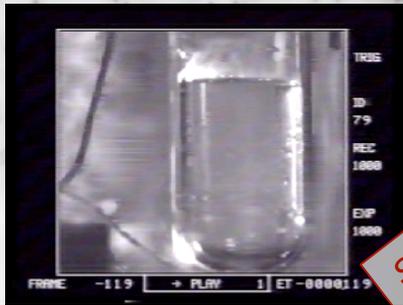
- Alpha decays
“alphas”
- Neutron-nucleus
elastic scattering
“neutrons”
 - natural or sAmBe
radioactivity*
 - cosmic radiation*
 - NuMI beam*



*Useful calibration source when tagged

COUPP Bubble Chamber Program

- Take long runs with smaller chambers to understand backgrounds, operations, and for research and development while developing and commissioning an order of magnitude larger chamber



Test tube
(U Chicago)



Science 319:933-936 (2008)

COUPP 2kg



This Seminar

COUPP 4kg



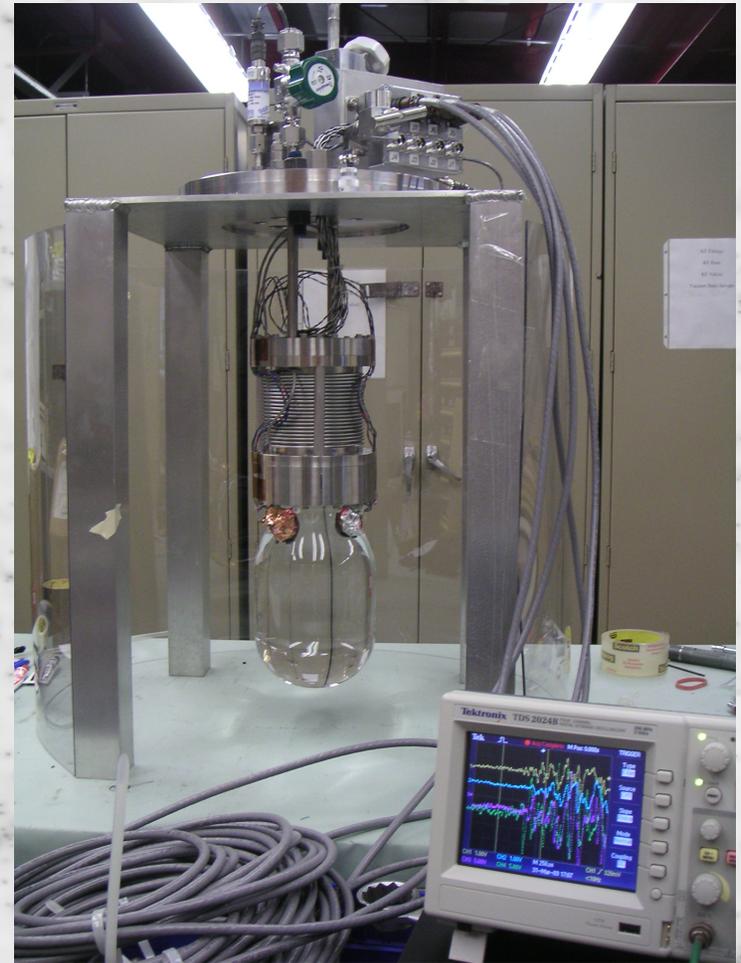
Stay Tuned

Ton Scale?

COUPP 60kg

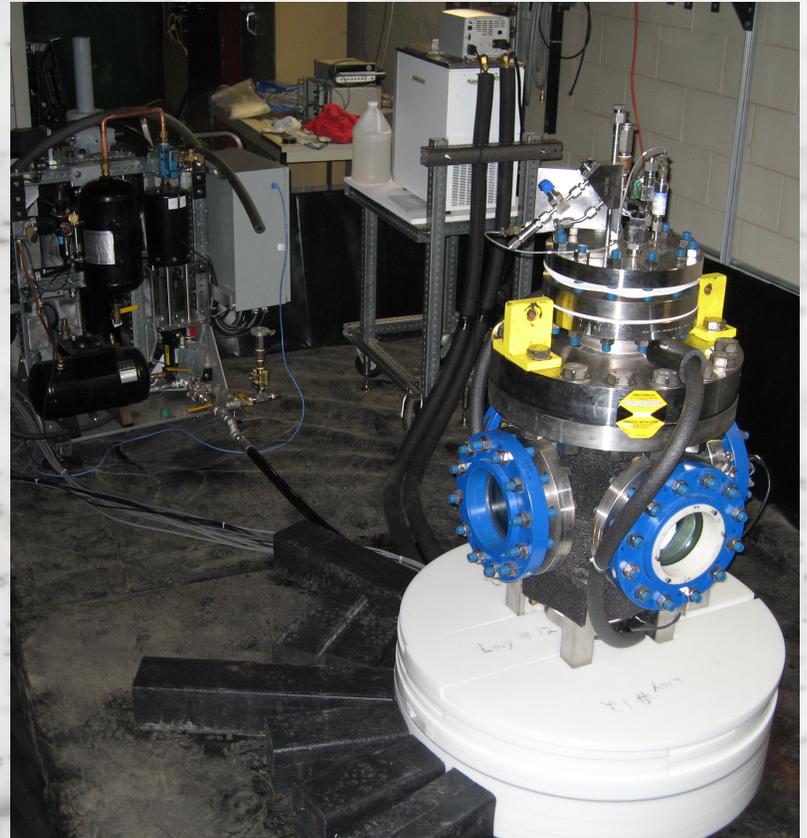
T945-A2

- 2L synthetic silica bubble chamber
- Filled with 4 kg CF_3I
- In the MINOS near hall
- Surrounded by a liquid scintillator cosmic ray veto



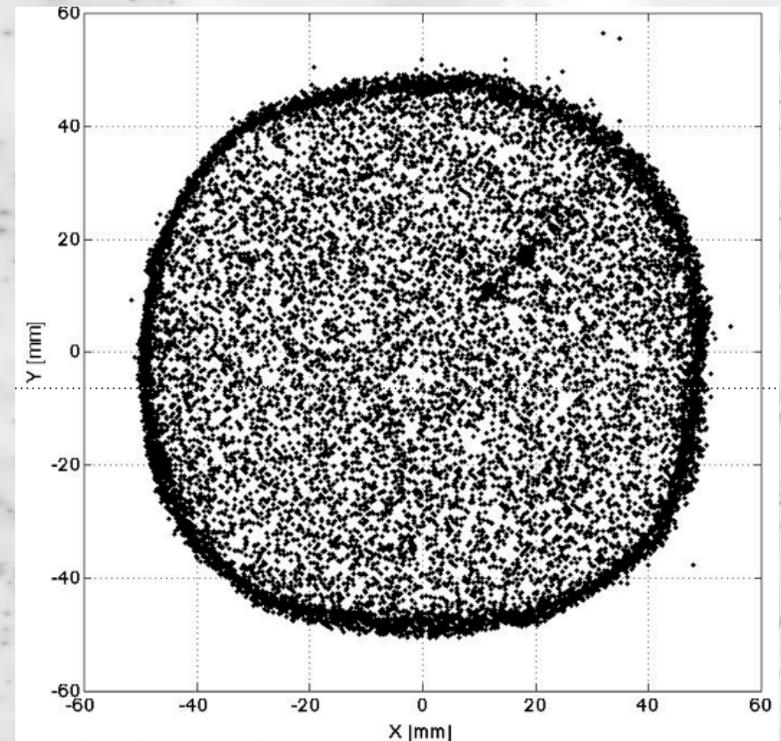
T945-A2 Goals

- Wall rate reduction
- Alpha rate reduction
- New cosmic veto
- Mission creep
 - Acoustic discrimination
 - Dark matter limits



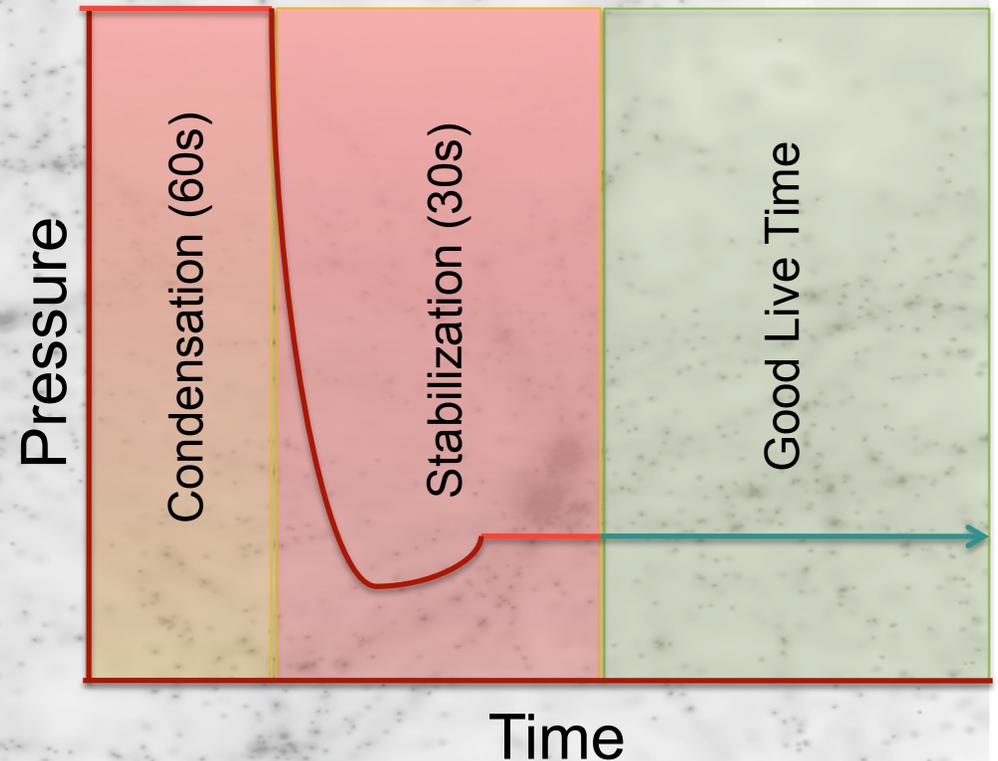
Wall Rate Reduction

- Previous bubble chambers demonstrated a rate of $\sim 1 / \text{day} / \text{cm}^2$ emanating from the quartz bell jar
- This represents a fundamental dead time issue for larger chambers



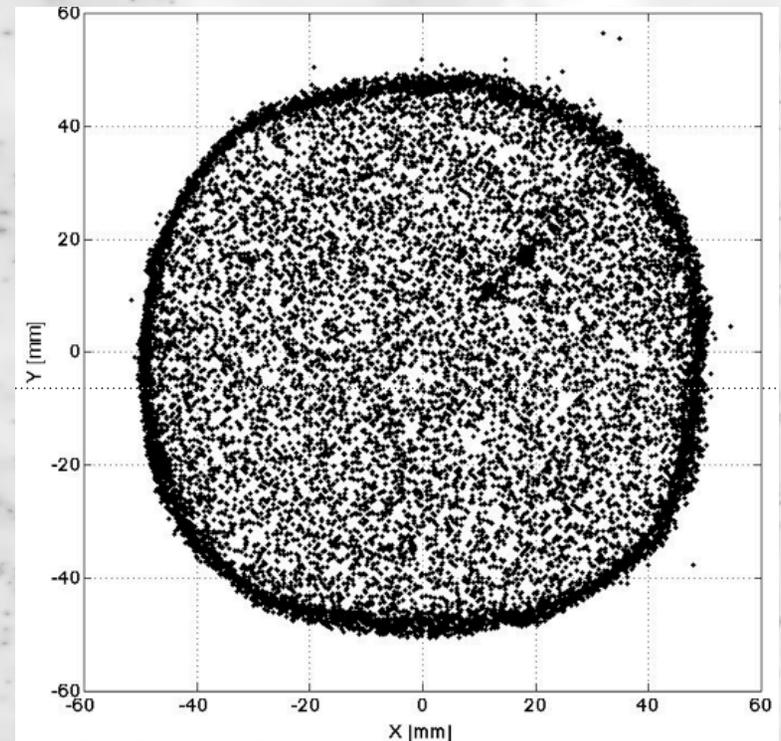
Dark Matter Bubble Chamber Cycle

- Each good expansion cycle includes 90 sec of deadtime
- For ~30 sec of the deadtime, bubbles can form
- 1000 cycles/day = 13% livetime



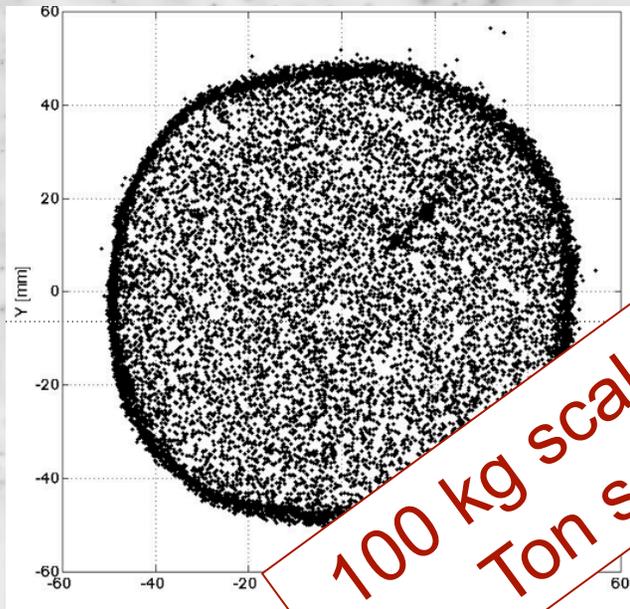
Wall Rate Reduction

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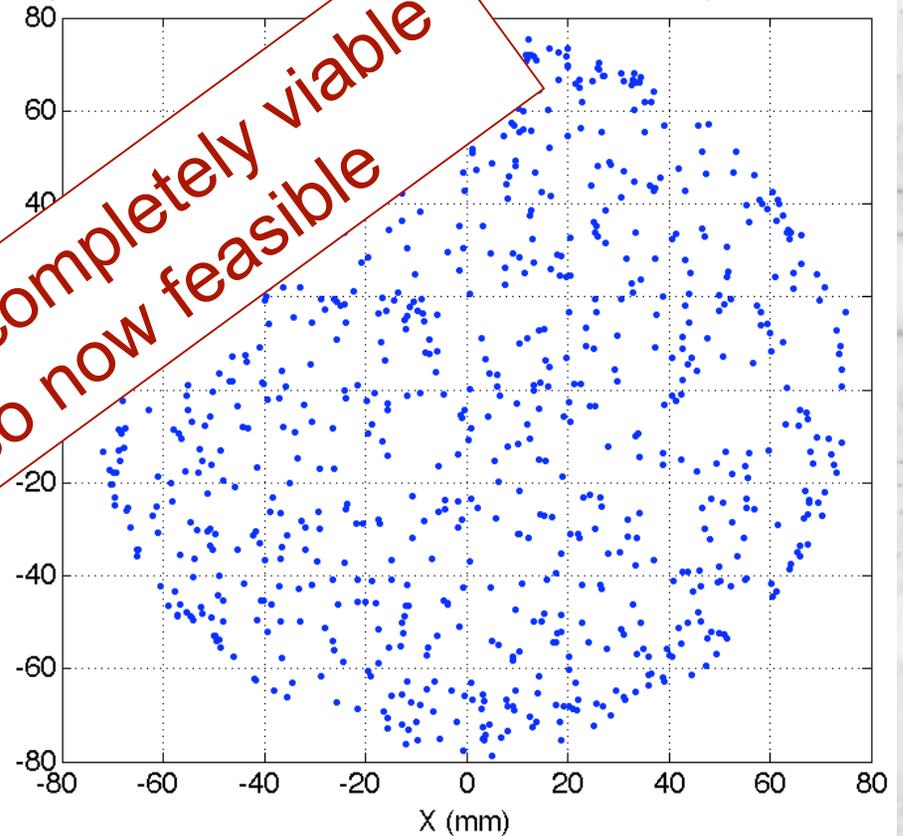
Wall Rate Reduction

Natural Quartz: $0.8/\text{day}/\text{cm}^2$



~40 live-
(2007-0...)

Synthetic Silicon $\leq 1e-2/\text{day}/\text{cm}^2$

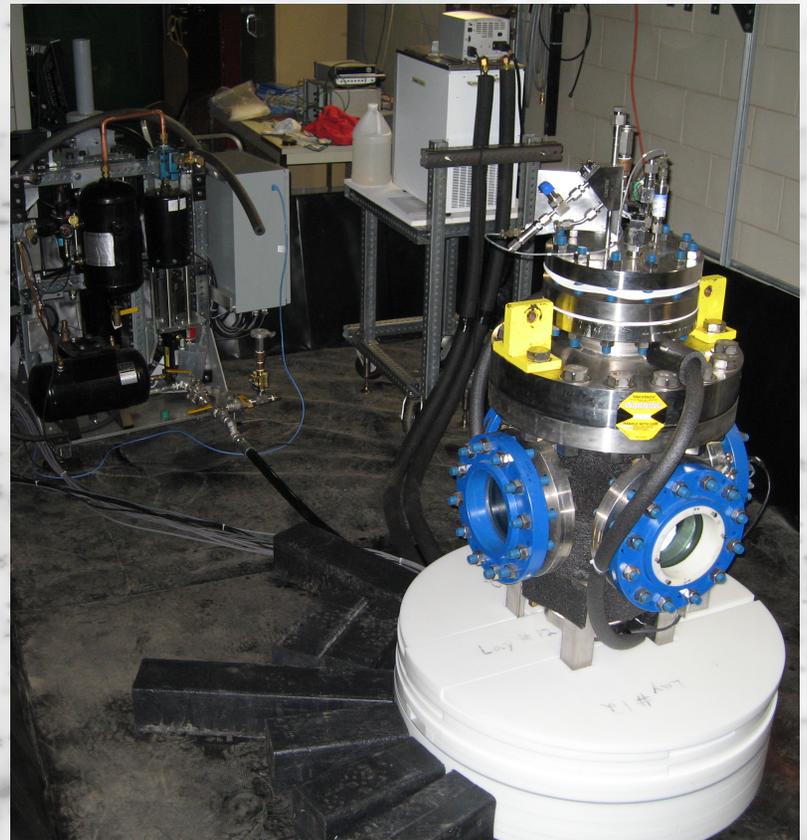


64 live-days (2009)

100 kg scale now completely viable
Ton scale also now feasible

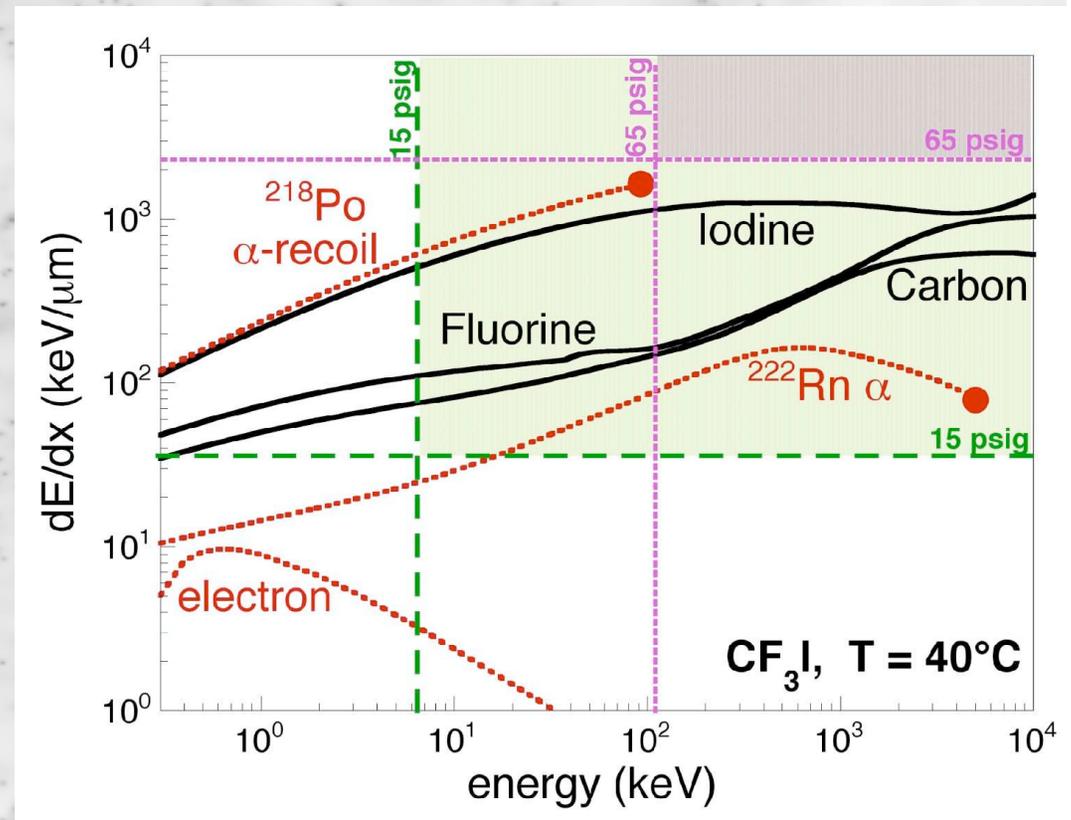
T945-A2 Goals

- Wall rate reduction 
 - $>100X$ reduction
 - Next (60 kg) bubble chamber fine
 - Visions of a ton scale dark matter bubble chamber
- Alpha rate reduction
- New cosmic veto
- Mission creep
 - Acoustic discrimination
 - Dark matter limits



Alpha Rate Reduction

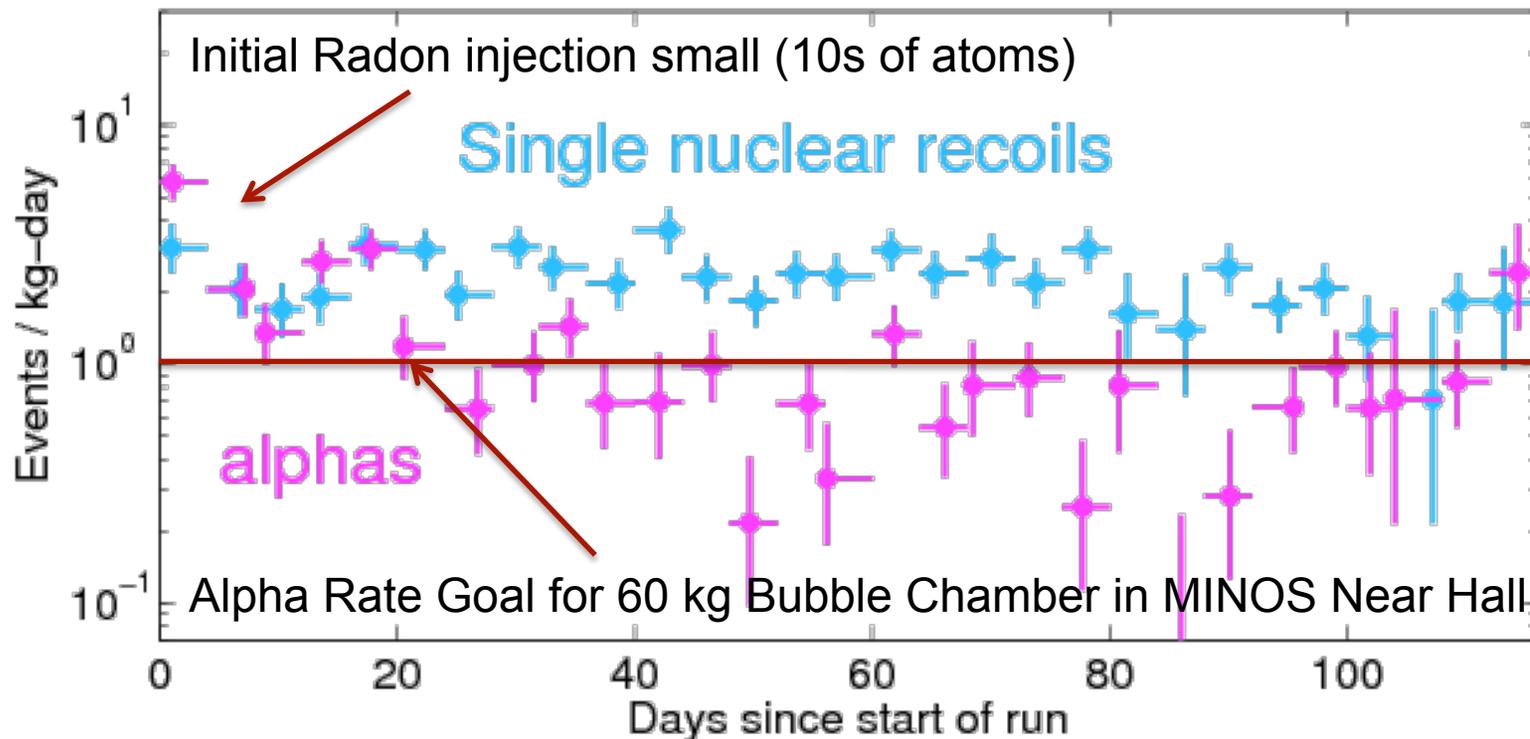
- Only proto-bubbles with $r > r_{\text{crit}}$ grow to be macroscopic
- Minimum Energy
- Minimum dE/dx



α 's do make bubbles

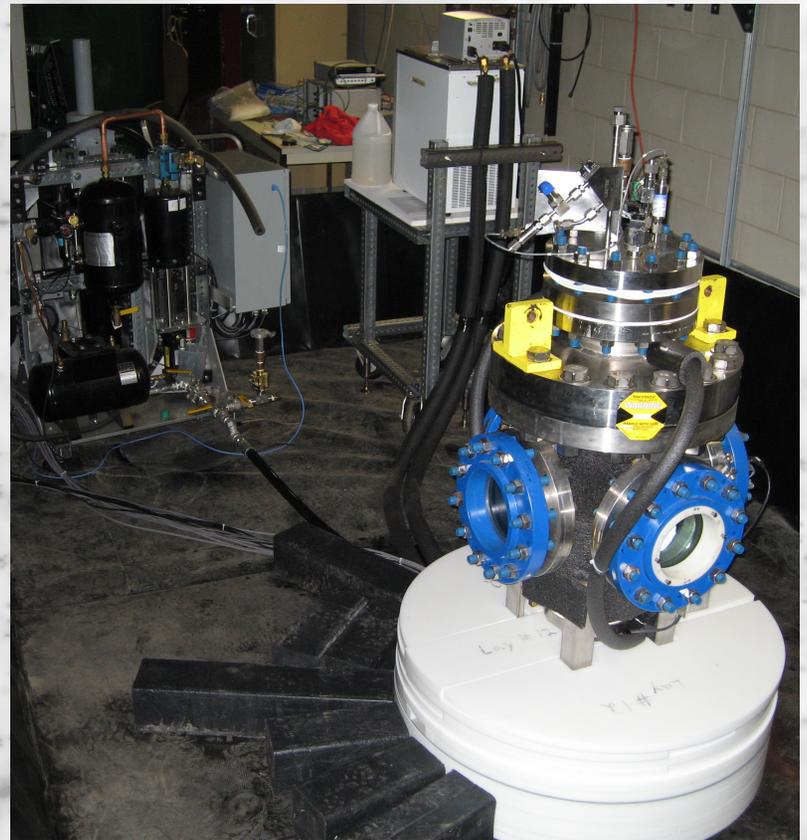
4 kg Alpha Rate Reduction

- Initial Radon injection $\sim 10X$ lower due to improved fluid transfer
- Met the collaboration goals for the next bubble chamber run (60 kg vessel in MINOS near hall)



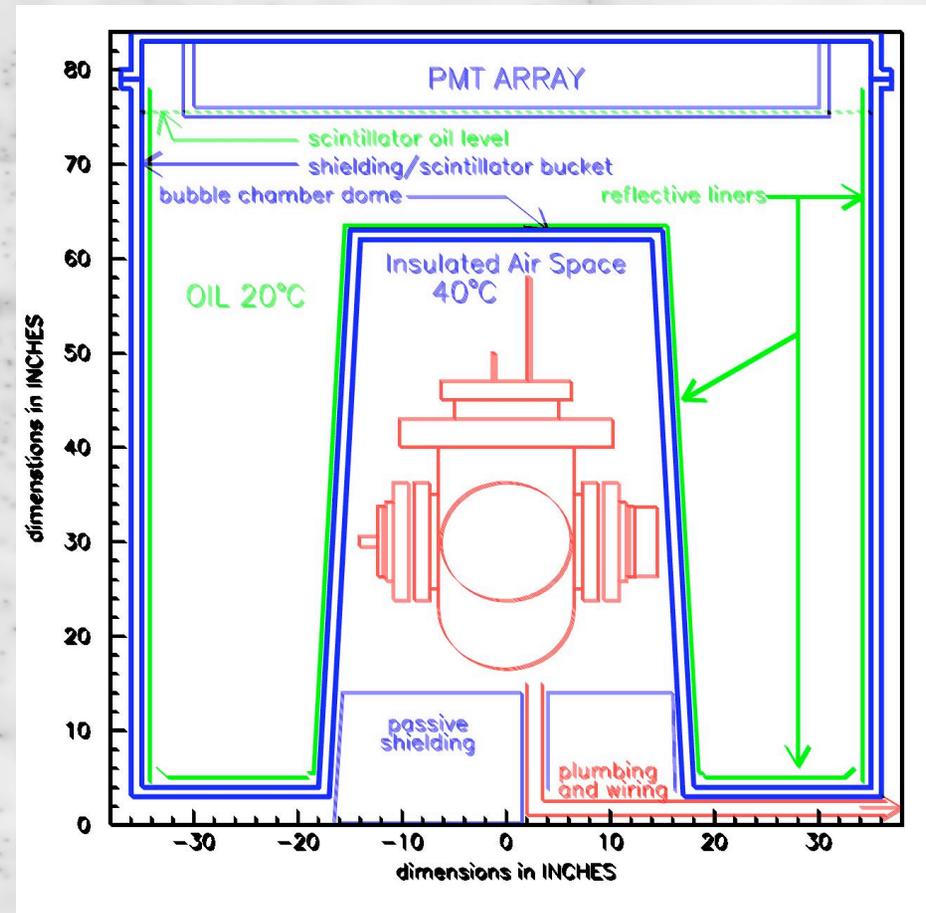
T945-A2 Goals

- Wall rate reduction ★
- Alpha rate reduction ★
 - 10X injection reduction
 - Met rate goals for the next (60 kg) bubble chamber
- New cosmic veto
- Mission creep
 - Alpha discrimination
 - Dark matter limits



Muon Veto

- Liquid scintillator bundt cake
 - Recycled oil (thanks to NuTeV)
 - Minimum of 10 inches above and surrounding the chamber
- Polyethylene shielding below and in cracks



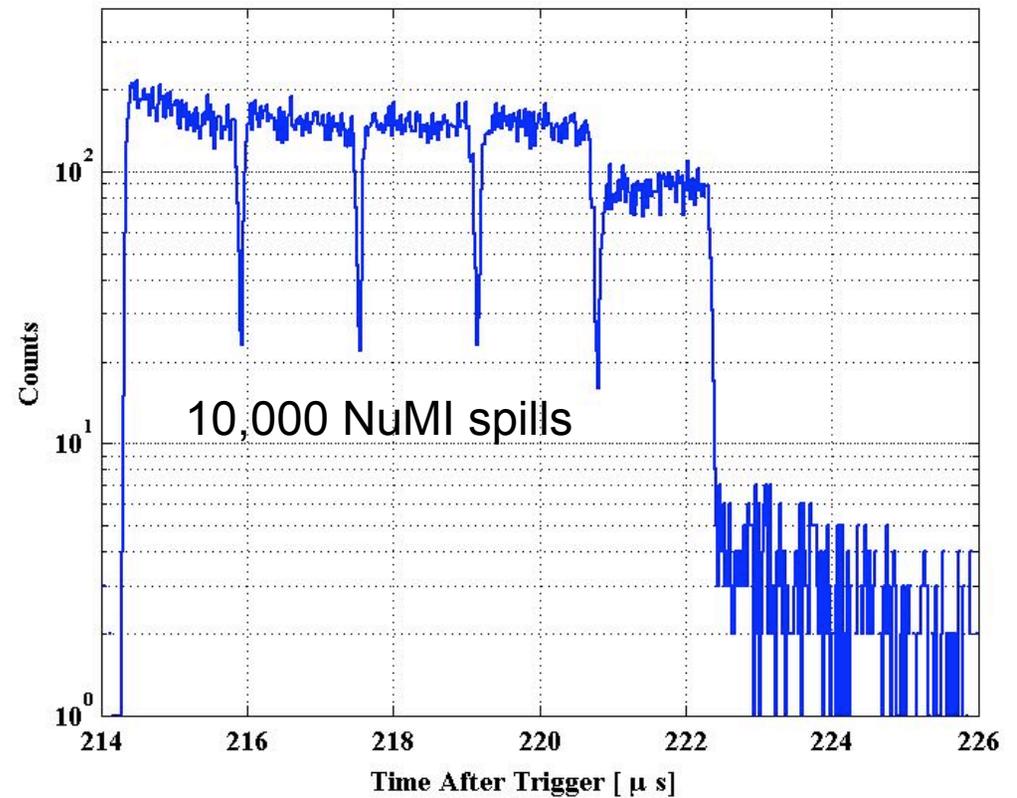
Muon Veto

- 19 PMTs
 - 5" RCA-4525
- New intelligent bases
 - Low HV power (CW) capacitive chain
 - 625 MHz TDC
 - 40 MSPS fADC
 - Up to 24 PMTs in 4 daisy chains
 - Thanks to S. Hansen and PPD EE



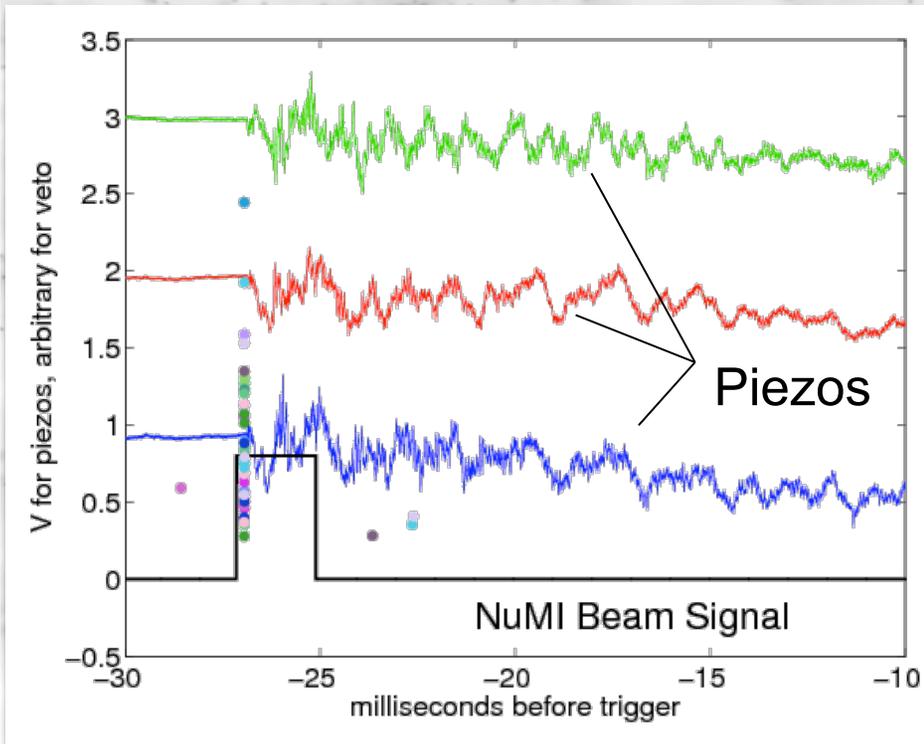
Muon Veto

- 15 Hz Cosmic Muon rate
- ~2-3 muons per NuMI spill
- 100 ns timing

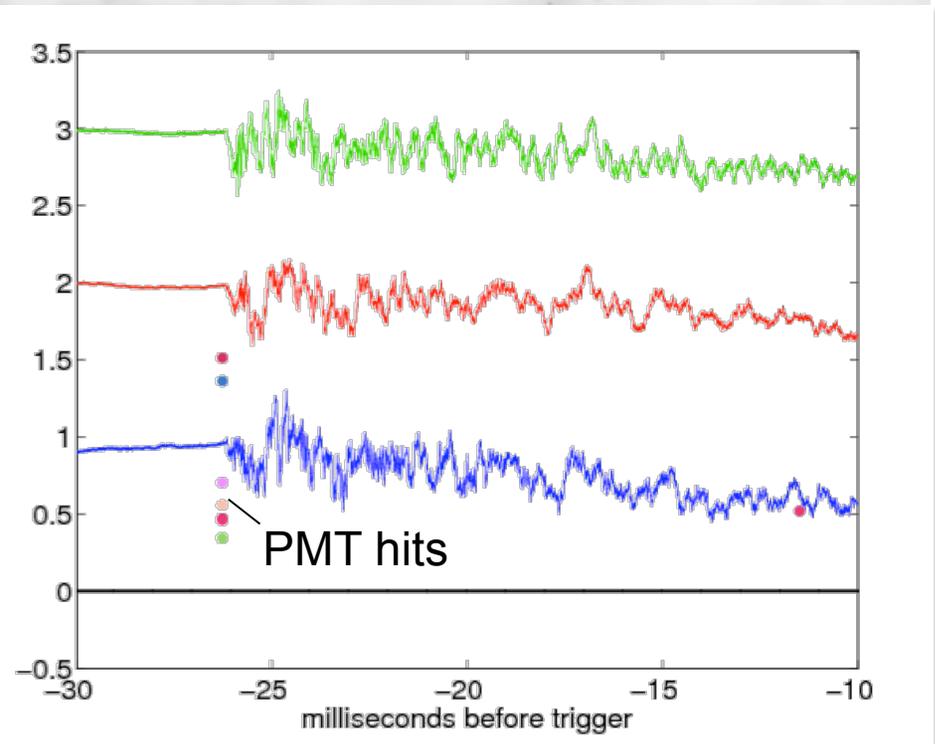


Muon Veto

NuMI Event



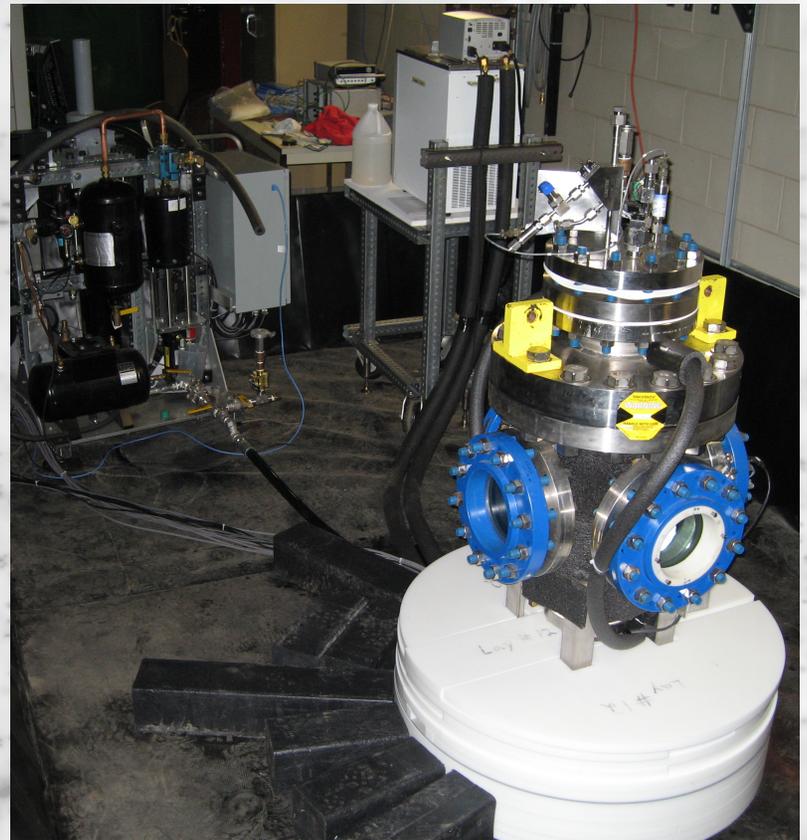
Cosmic Event



- 100 ns coincidence between PMTs
- 500 μ s coincidence with piezos (15 Hz cosmic rate)
- Thank you to Accelerator Division for the excellent calibration source and especially for the NuMI spill signal

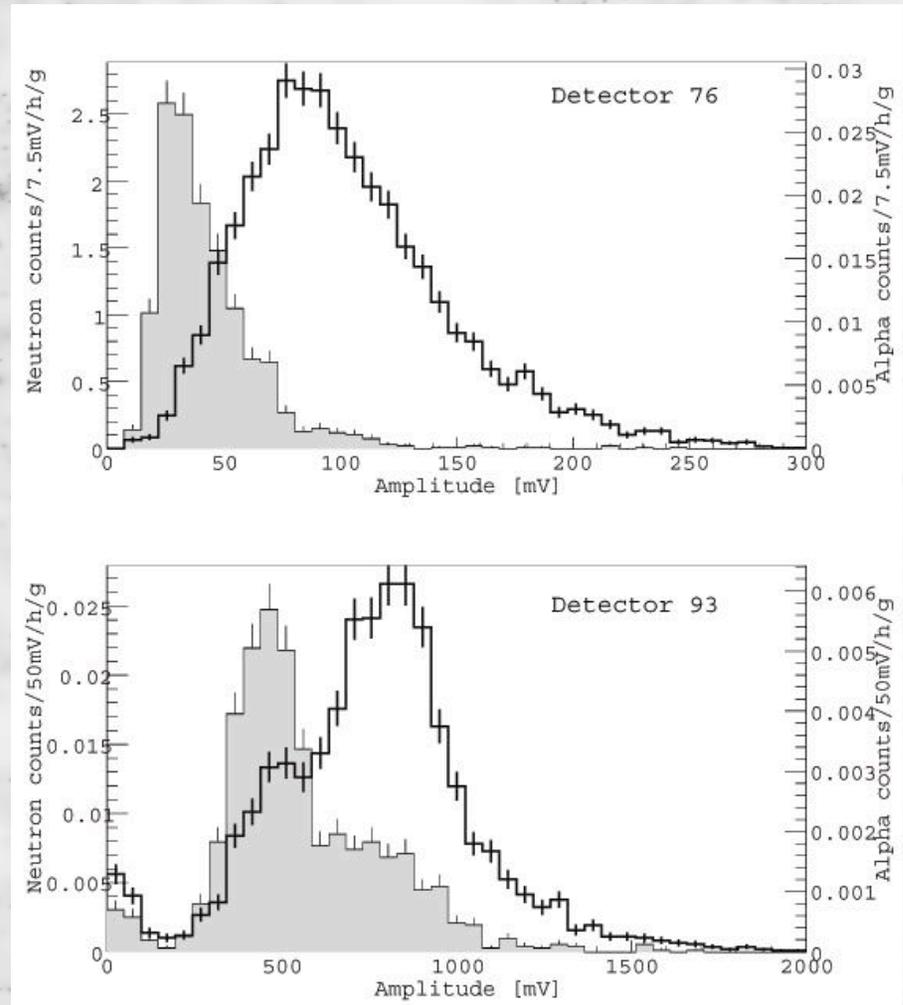
T945-A2 Goals

- Wall rate reduction
- Alpha rate reduction
- New Cosmic Veto
 - 15 Hz Cosmic Muon Rate
 - 100 ns timing with 1-30 PMTs
 - High efficiency, low
deadtime
- Mission Creep
 - Alpha Discrimination
 - Dark Matter Limits



Acoustic Discrimination

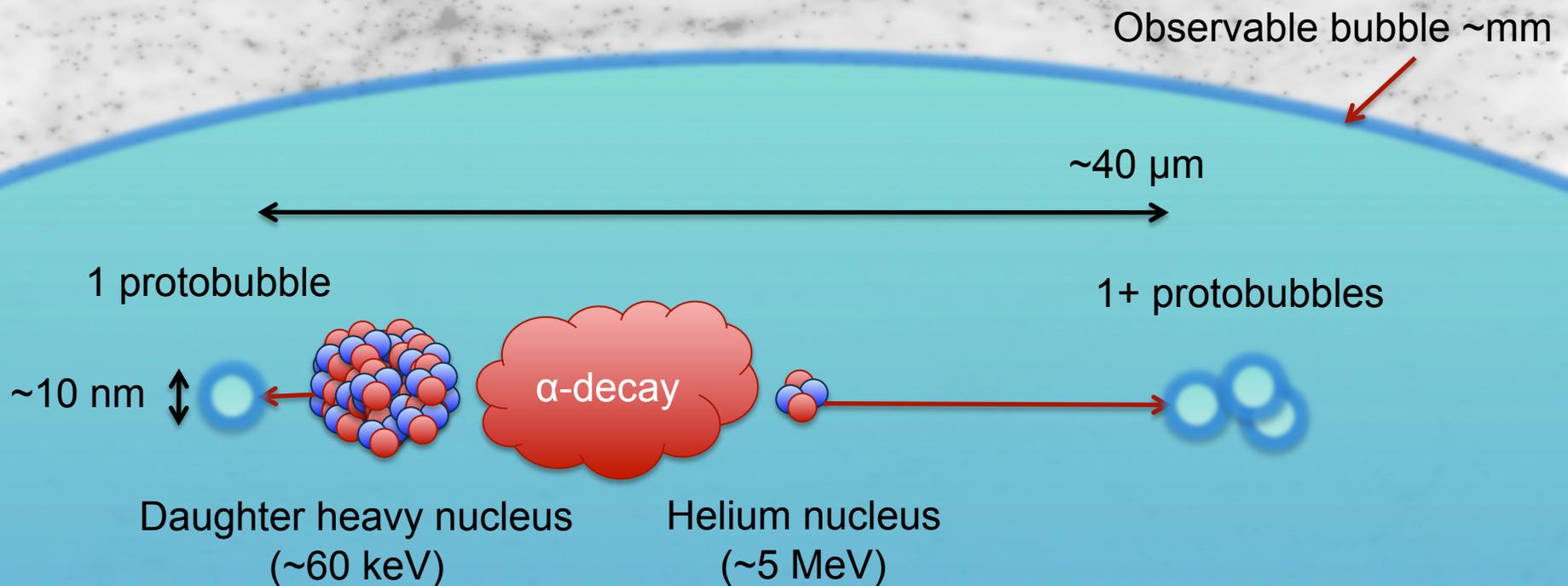
- PICASSO (a search for dark matter with superheated droplets) reports alpha decays are louder than nuclear recoils



New Journal of Physics arXiv:0807.1536

Acoustic Discrimination

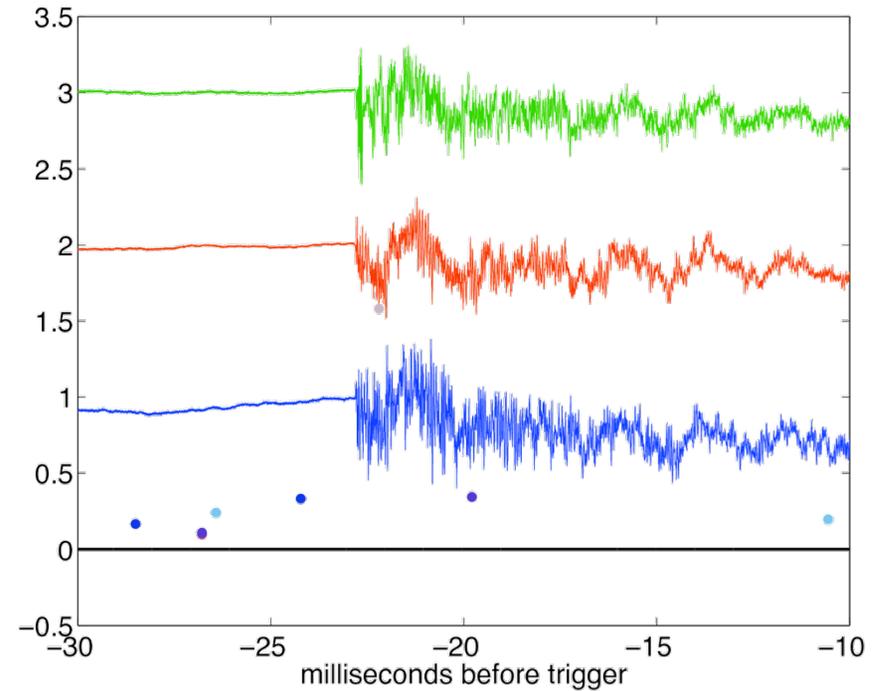
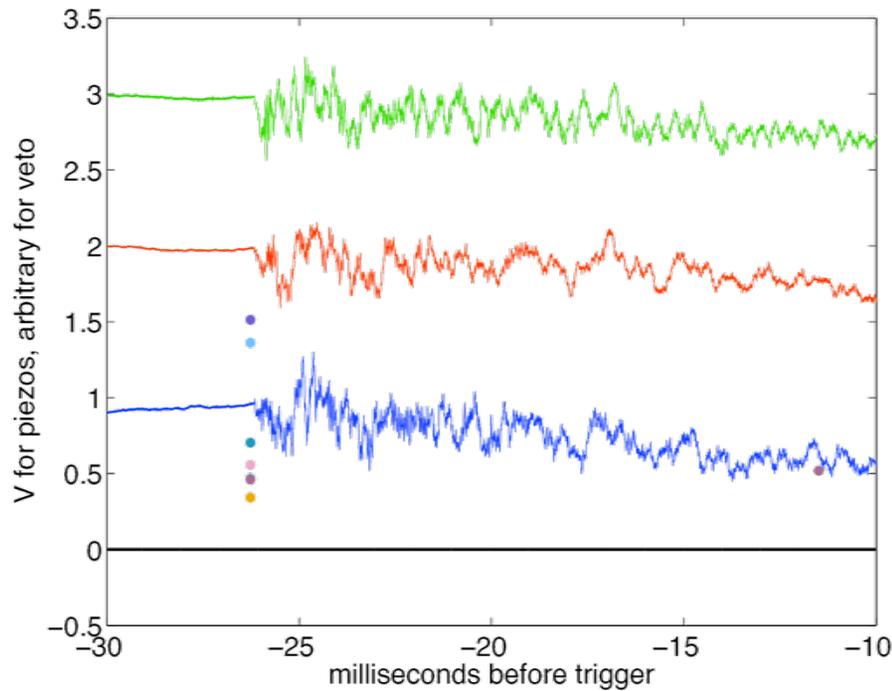
- High frequency acoustic information probes smaller scales
- Alpha decays produce more than one protobubble, so they should produce more sound at high frequencies



Time Domain

Neutron 

Alpha 

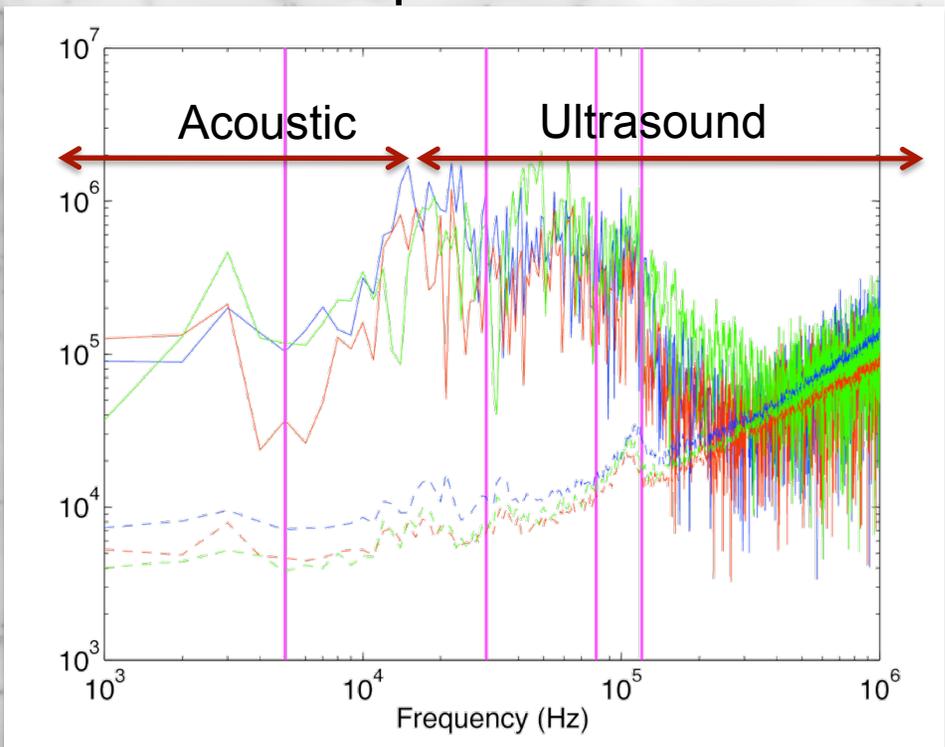
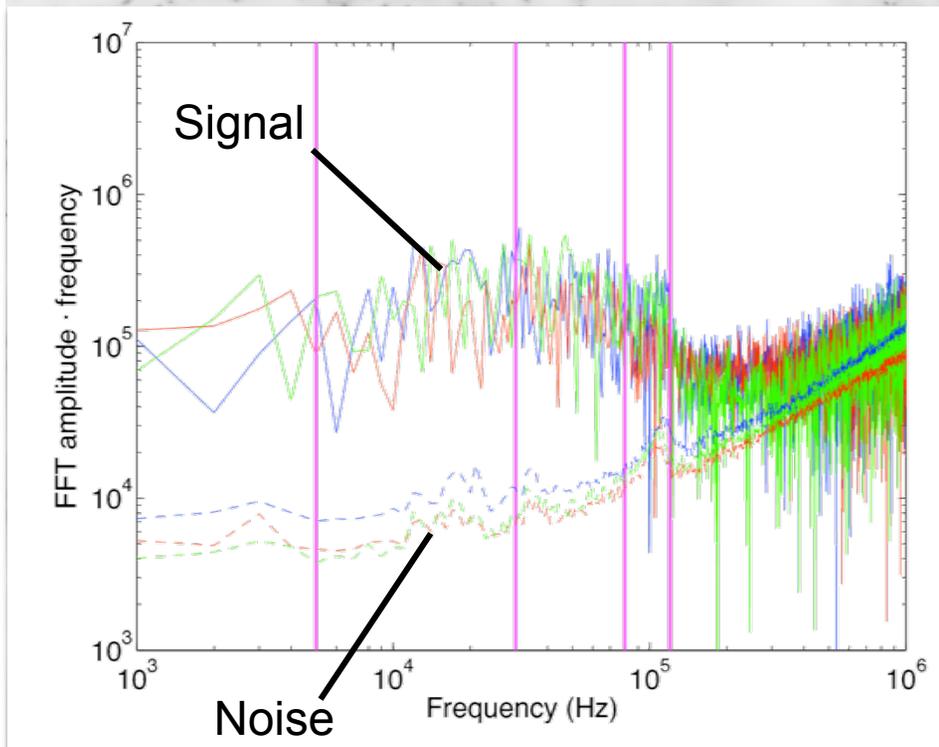


- High signal to noise for bubble “ping”
- Two populations were apparent in the first few days

Frequency Domain

Neutron

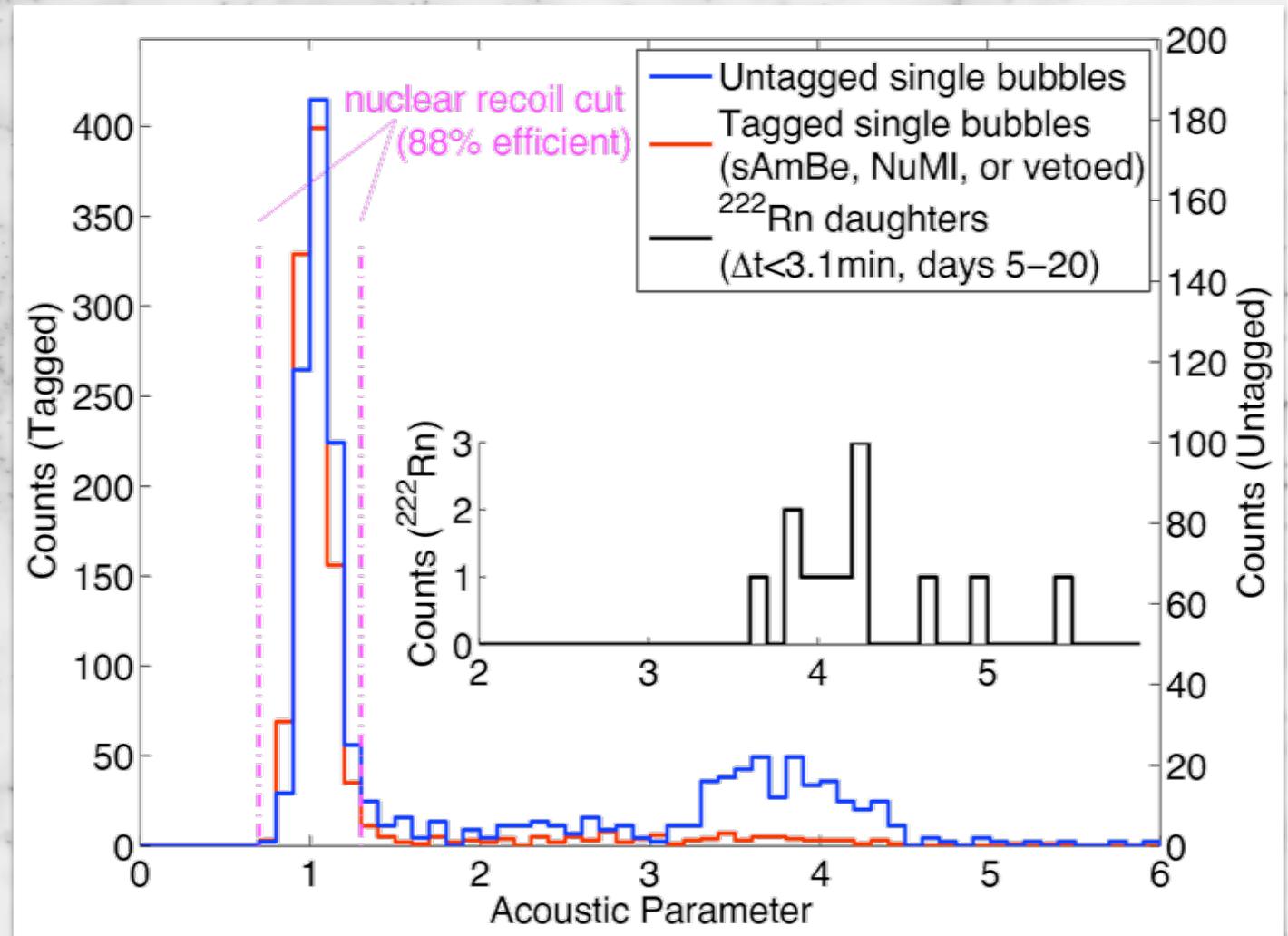
Alpha



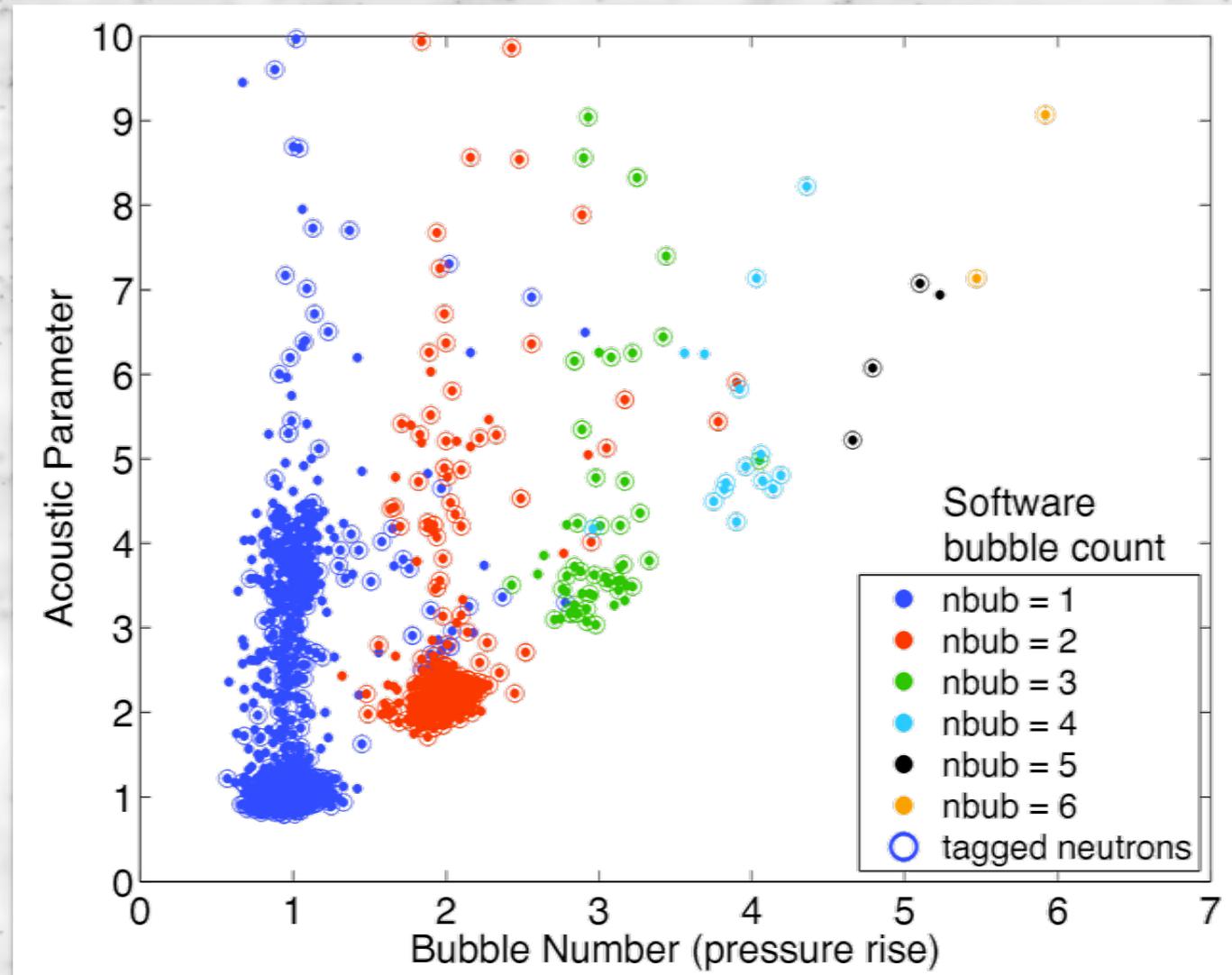
- Analysis separates power in a few observed resonances
- Acoustic power is calibrated w.r.t. bubble position

Acoustic Parameter

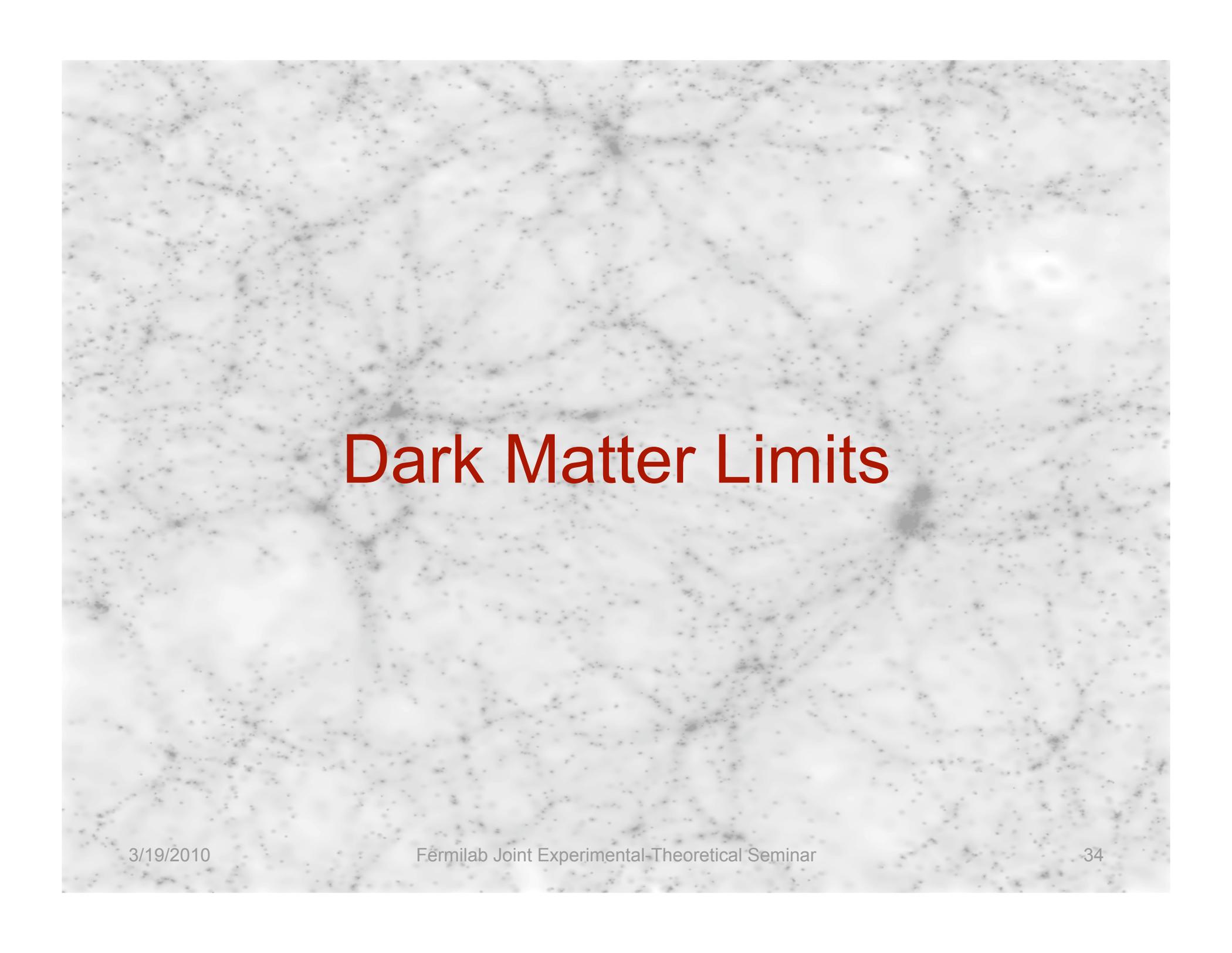
- $(\text{Amp} \cdot \omega)^2$
(Normalized and position-corrected for each freq-bin)
- Measure of acoustic energy deposited in chamber
- Alphas are louder than neutrons
- ~200 well separated alpha events



Counting Bubbles



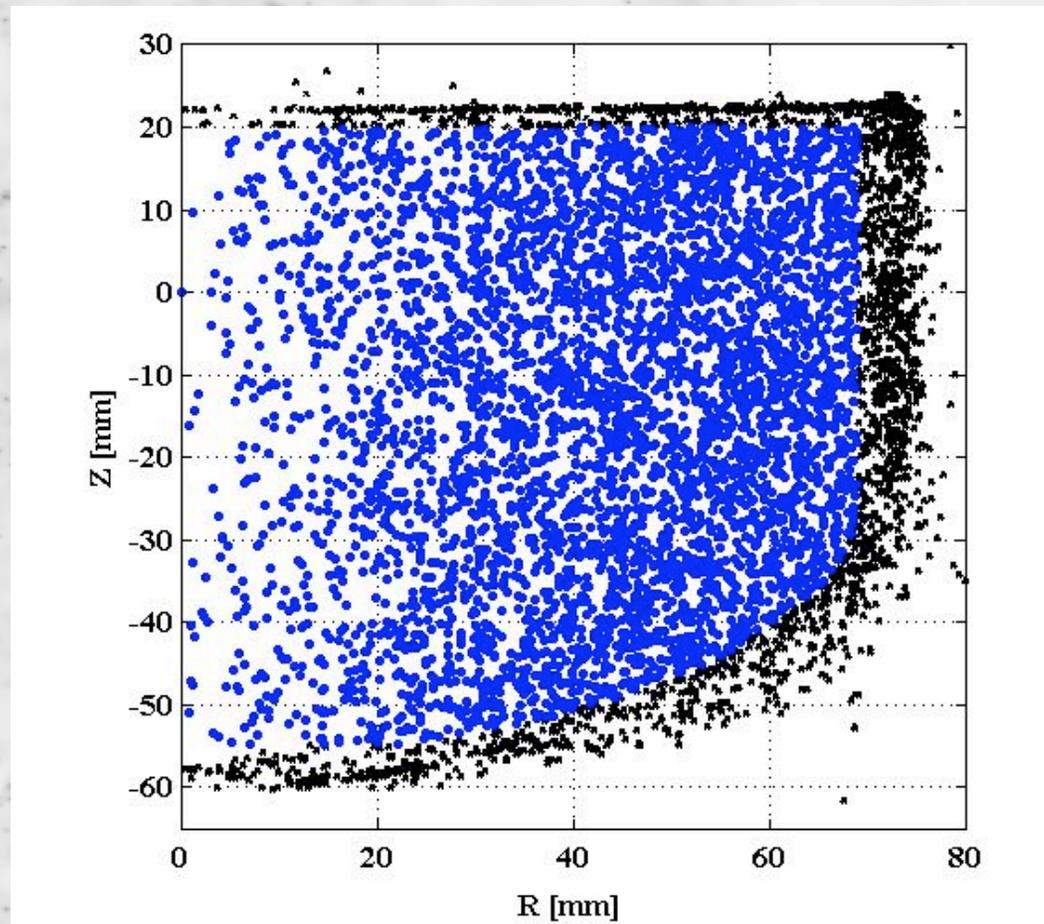
- 3 Methods of counting bubbles
 - Camera Images
 - Pressure Rise
 - Acoustic Parameter
- Acoustic Parameter (AP) scales with # of bubbles
- No tails at low AP
- 291 kg-days, mostly before veto installation

A grayscale map of the Cosmic Microwave Background (CMB) showing temperature fluctuations. The map displays a complex, interconnected network of dark and light regions, representing the distribution of matter and energy in the early universe. The fluctuations are most prominent along the edges of large-scale structures, forming a web-like pattern.

Dark Matter Limits

Fiducial Mass

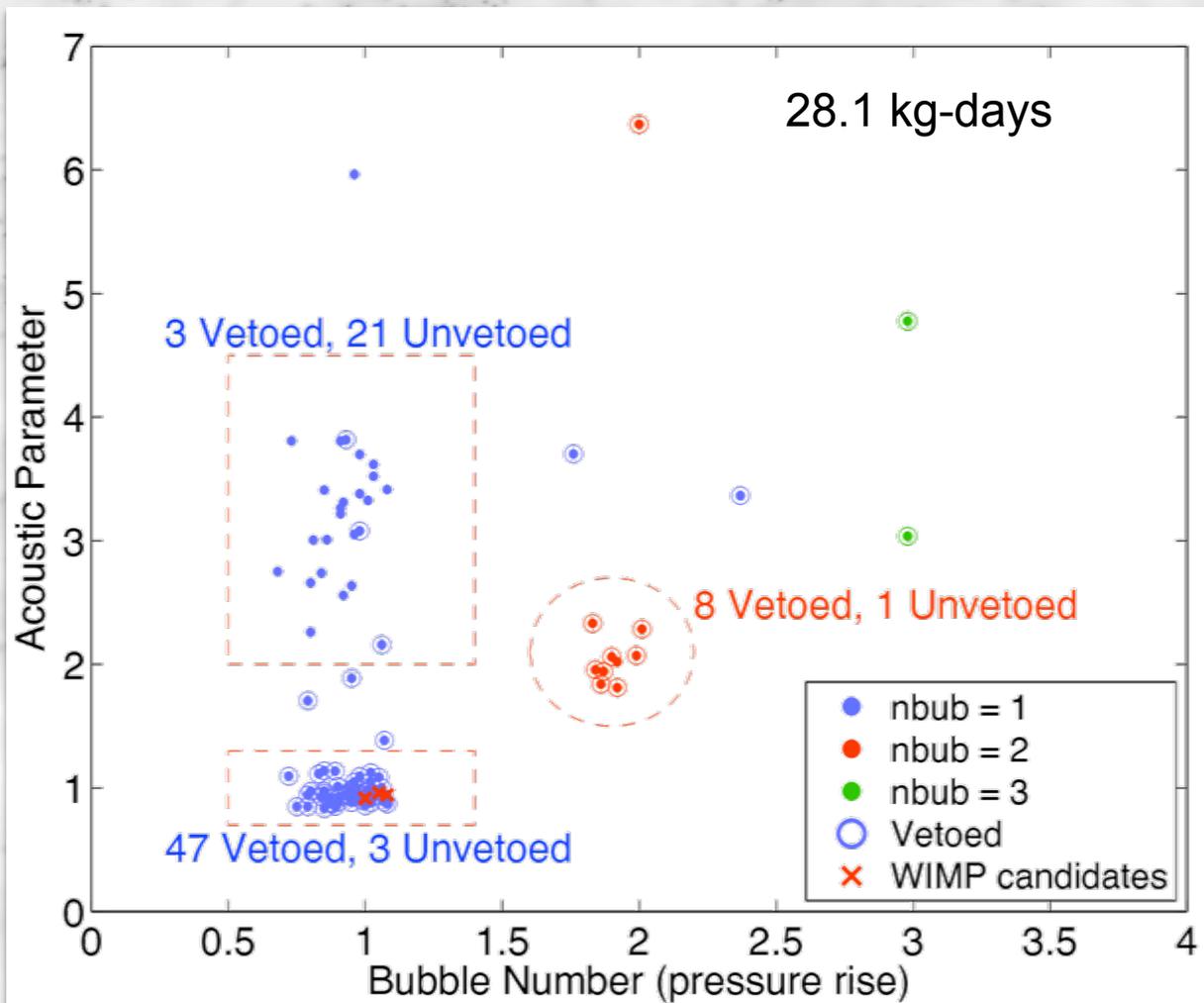
- Acoustic discrimination worsens near glass jar
- 3 calibration datasets consistent, fiducial mass is 75% of the active volume
- 3.5 kg CF_3I total
- 2.6 kg CF_3I fiducial
 - 0.76 kg ^{19}F (SD)
 - 1.6 kg ^{127}I (SI)



Other Cuts

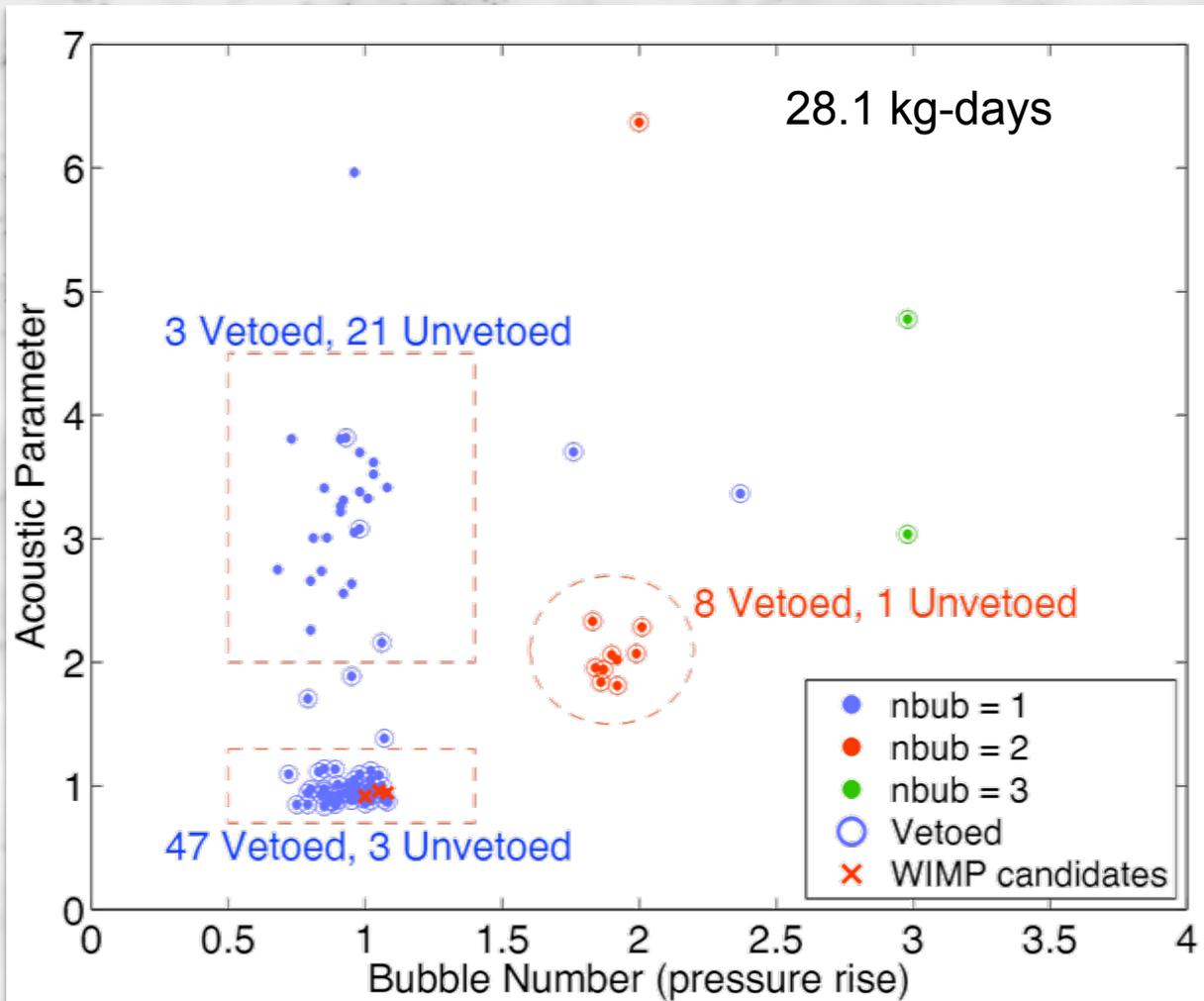
Cut	Efficiency
Dark Matter Exposure	23 days × 3.5 kg CF ₃ I
Data Quality	52%
• Acoustic Noise Cut	58%
• Veto Data Integrity Cut	94%
• T0 Data Reconstruction Cut	91%
• Other Quality Cuts	98%
Veto Anti-Coincidence	98%
NuMI Anti-Coincidence	96%
Acoustic Nuclear Recoil Cut	88%
Fiducial Volume	75%
Total	35%
	18.2 kg day I 8.2 kg day F 1.7 kg day C

Candidate Events



- 3 Events Pass All Cuts
 - Alphas?
 - Neutrons?
 - WIMPs?
- Note 1 double scatter leaks through veto
- Most likely limited by cosmic radiation

Candidate Events

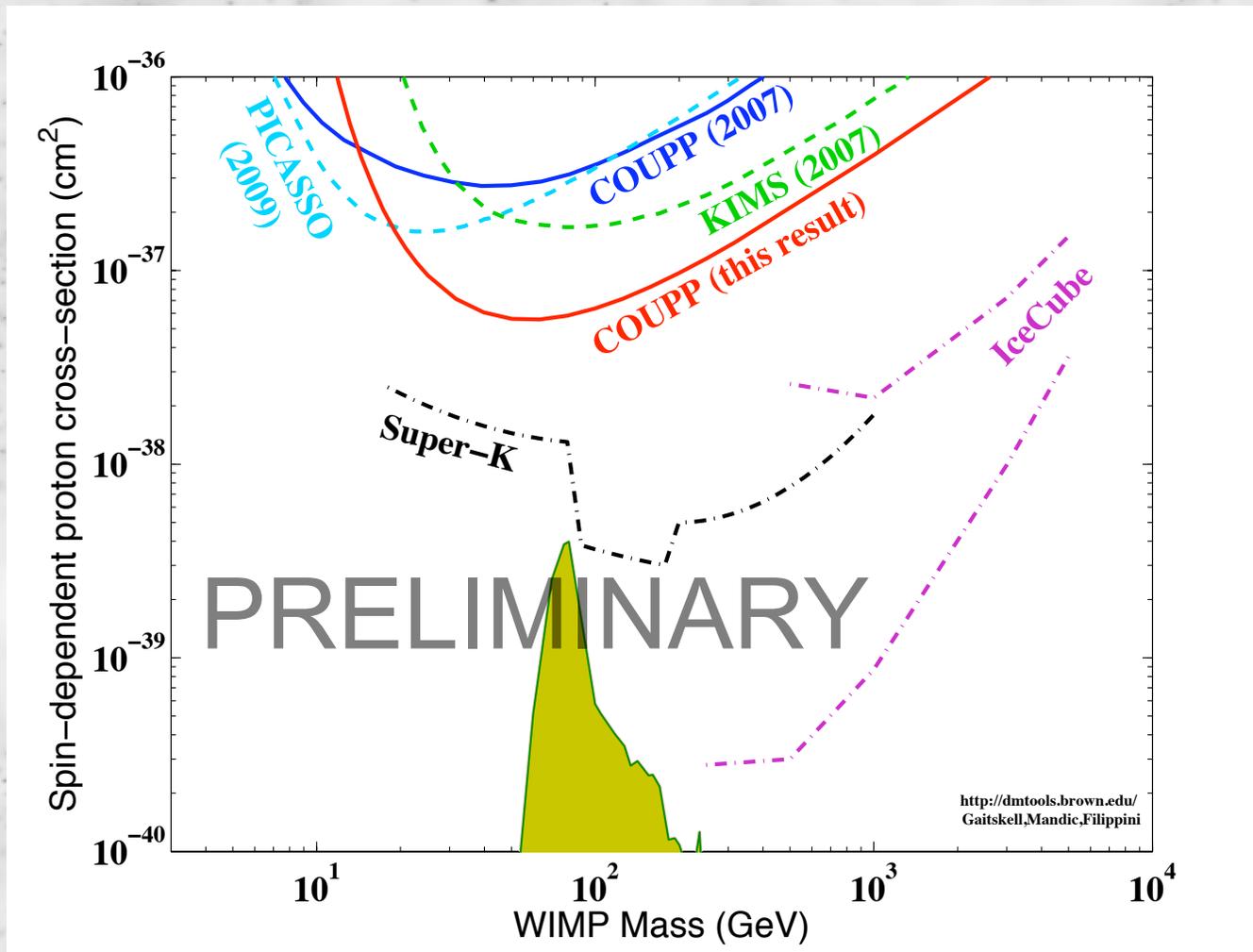


- Taking the 3 unvetoed events as alphas
- Alpha rejection >80% at 90% confidence level
- Consistent with >99% alpha rejection

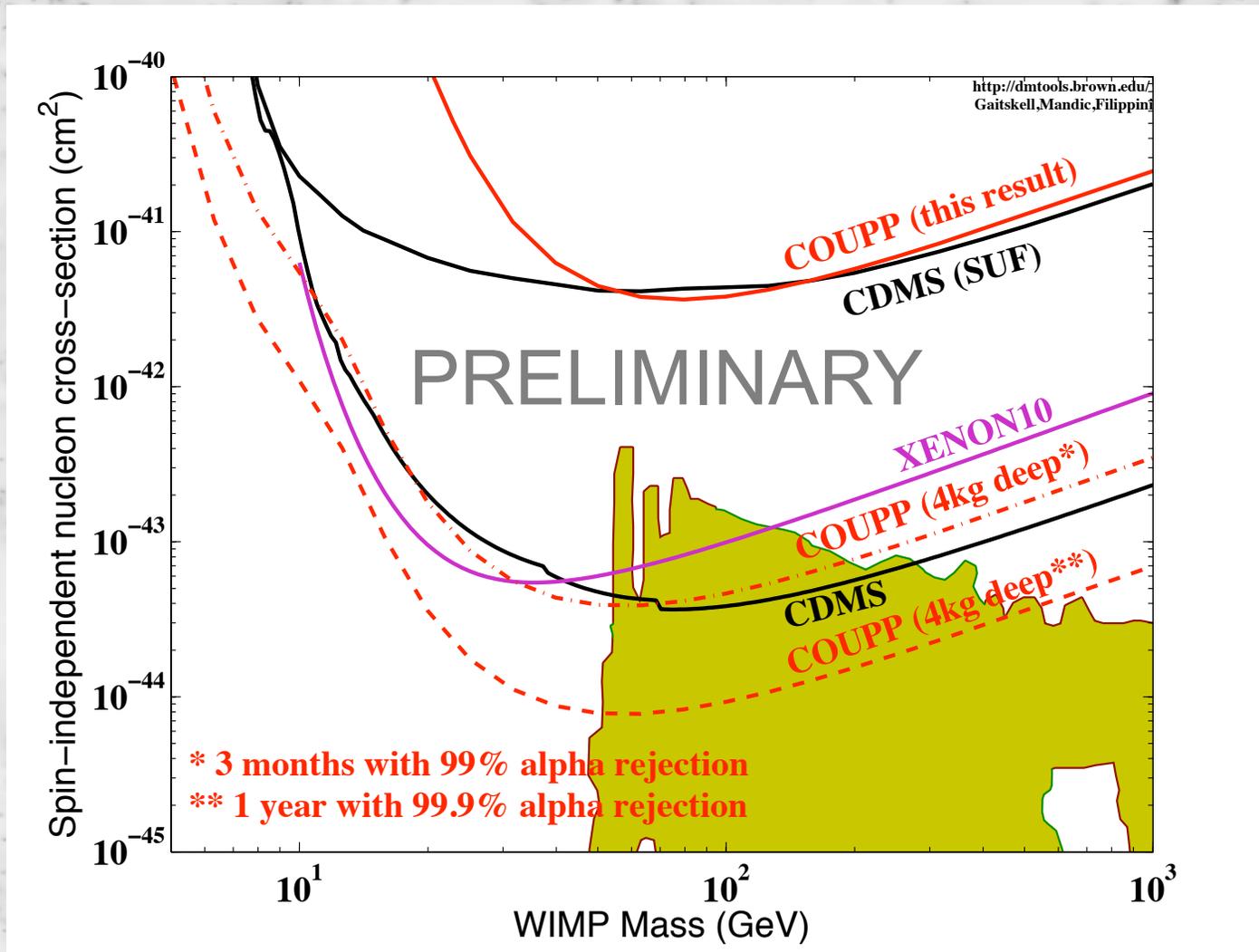
Threshold and Efficiency

- Pressure = 27 PSIA, Temp = 30°C
- Bubble nucleation threshold of 20 keV
- Bubble nucleation efficiency of ~40%
- Nucleation efficiency is ≈100% at higher operating temperatures
- Thresholds of 5-10 keV have been achieved at higher temperature with high gamma rejection
- Also expect acoustic alpha discrimination to improve with temperature (as seen by PICASSO)

New Dark Matter Limits

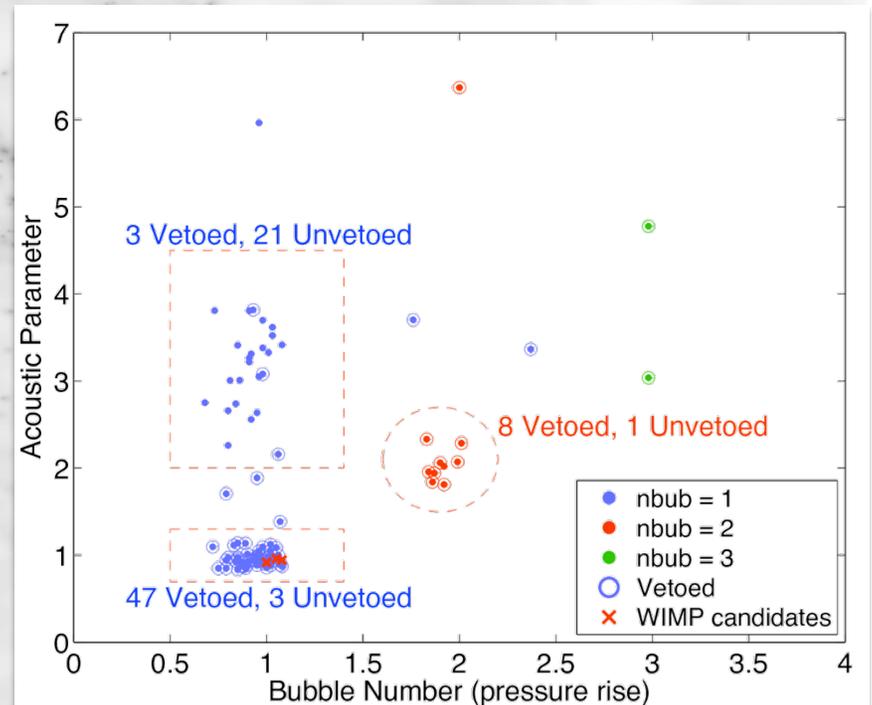


New Dark Matter Limits



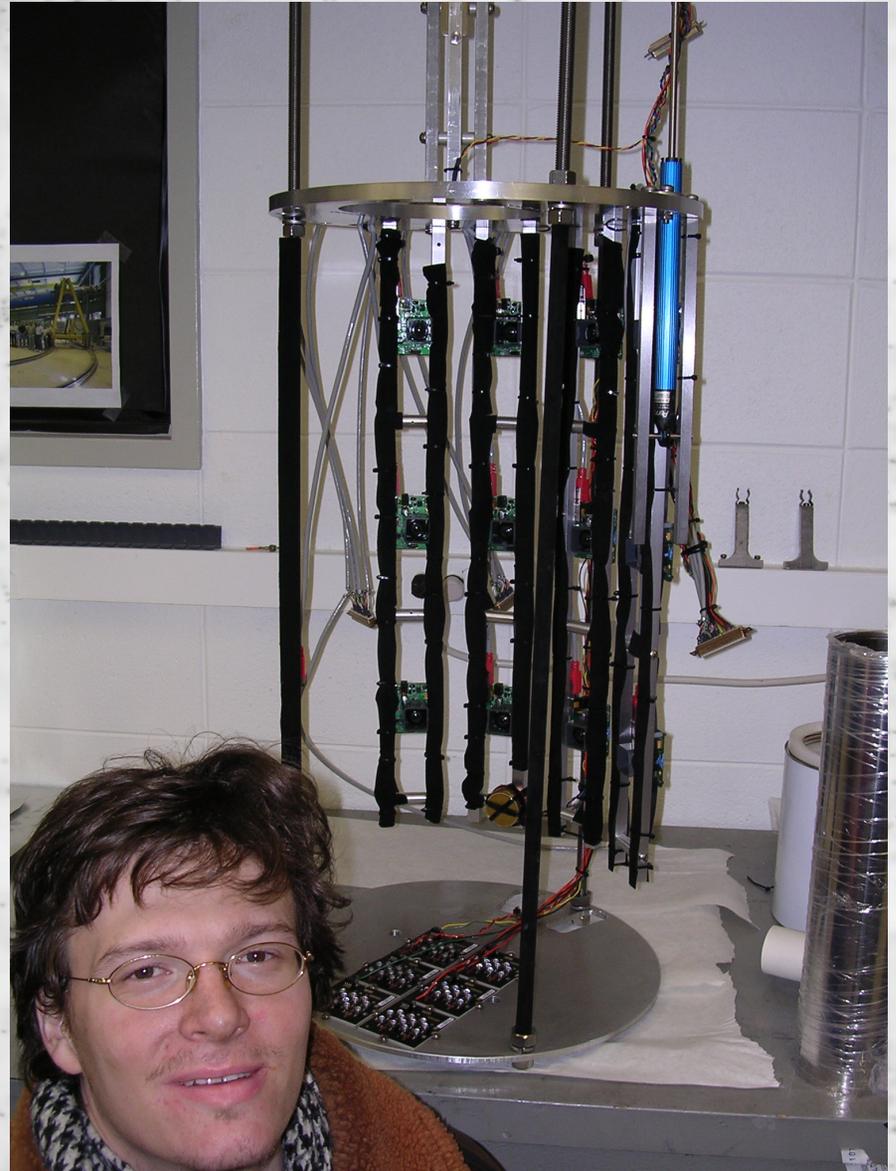
T945-A2 Goals

- Wall rate reduction
- Alpha rate reduction
- New Cosmic Veto
- Mission Creep
 - Alpha Discrimination
 - >80% at 90% CL
 - Probably >99%
 - WIMP Dark Matter Limits
 - Worlds best SD limit
 - Sensitivity limited by cosmic radiation in MINOS near hall



Coming Soon:

- 20kg chamber (TARP)
 - Now taking physics data
 - Acoustic discrimination looks promising



The End

COUPP 4 kg chamber is decommissioned, drained, and moved to Lab F

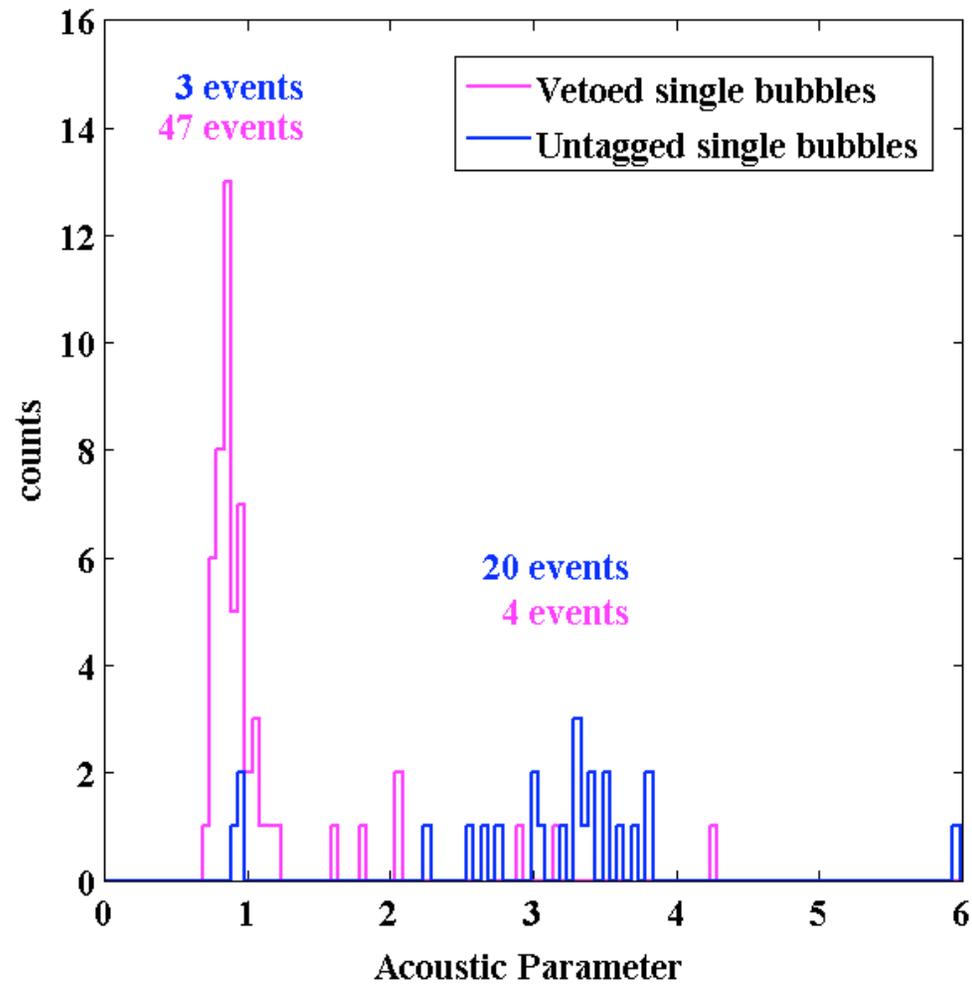
To make room for the COUPP 60 kg bubble chamber in the MINOS near hall (installation next week)

And to prepare for deployment in a deeper site



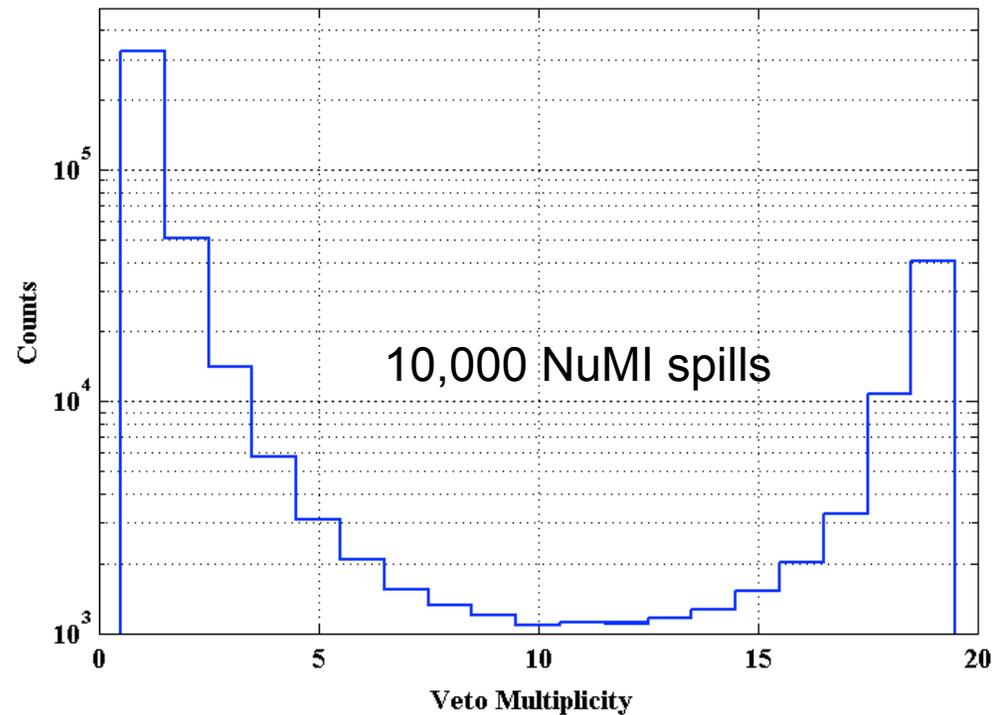
Backup Slides

AP Vetoable Data



Muon Veto Efficiency

- Efficiency measurement ongoing
- 2-3 18-19 PMT multiplicity events seen per NuMI spill



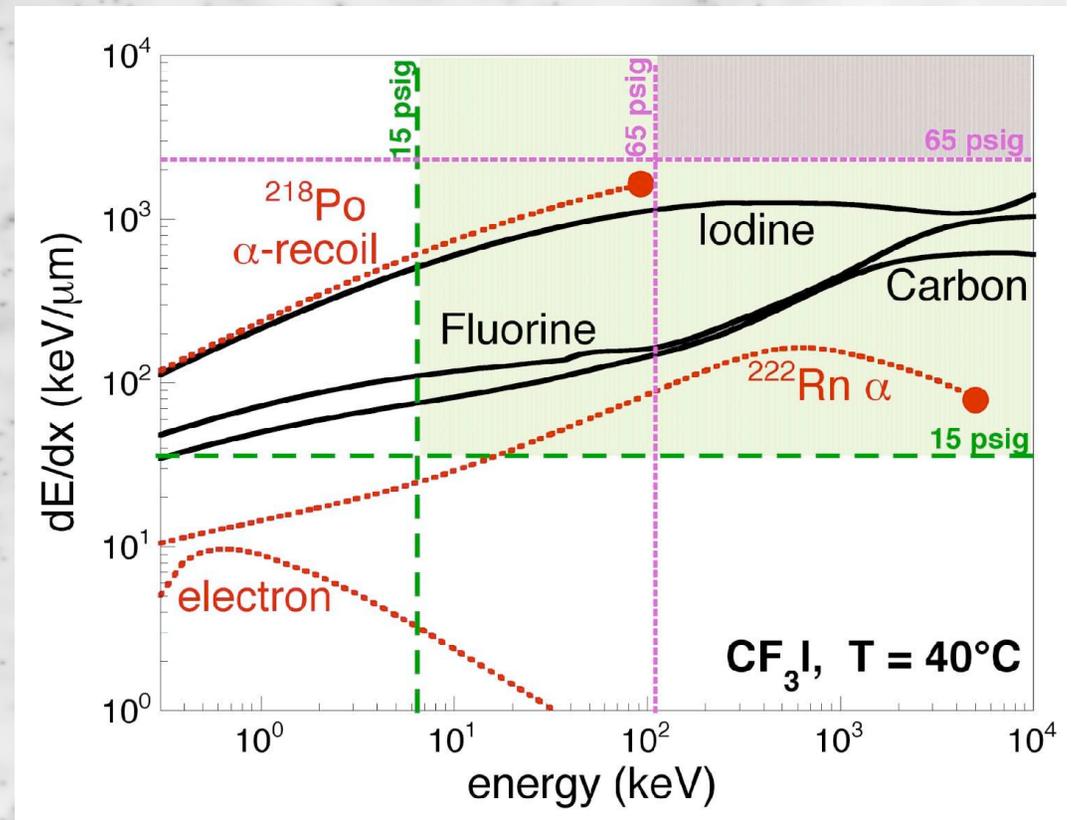
Coming Soon:

- 60kg chamber
 - Engineering runs with prototype last fall
 - Better fluid handling to further reduce the bulk alpha rate
 - High-purity assembly with updated ultrasound transducers completed
 - Installation in MINOS near hall next week
 - SNOLAB soon...



Backgrounds, Backgrounds...

- Only proto-bubbles with $r > r_{\text{crit}}$ grow to be macroscopic
- Minimum Energy
- Minimum dE/dx



No sensitivity to γ 's or β 's!
 α 's do make bubbles

Nucleation Efficiency Fit

