COUPP: A Bubble Chamber Search for Dark Matter at Fermilab

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Fermilab

15 ft. Bubble Chamber

Why Bubble Chambers for Dark Matter?

1. **Large target masses would be possible.**
    - Multi ton chambers were built in the 50's- 80's.
2. **An exciting menu of available target nuclei.**

***No liquid that has been tested seriously has failed to work as a bubble chamber liquid* (Glaser, 1960).**

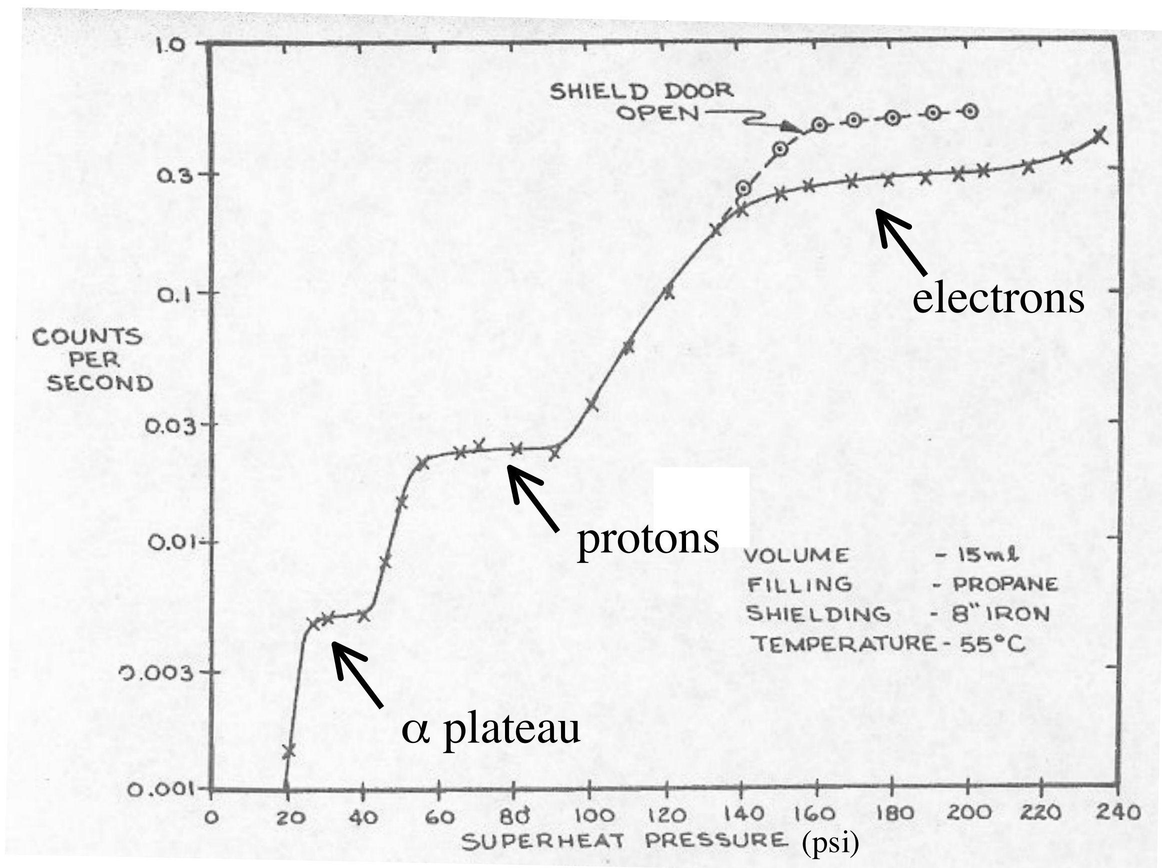
- Most common: Hydrogen, Propane
- But also "Heavy Liquids": Xe, Ne, CF_3Br, CH_3I, and CCl_2F_2.
- Good targets for both spin- dependent and spin-independent scattering.
- Possible to "swap" liquids to check suspicious signals.

3. **Low energy thresholds are easily obtained for nuclear recoils.**
    - $<$ 10 keV easy to achieve according to standard nucleation theory.
4. **<u>Backgrounds due to environmental gamma and beta activity can be suppressed by running at low pressure.</u>**
    - This effect used for superheated droplet detectors (SIMPLE, PICASSO).

dE/dX Discrimination in a Small Propane Chamber

Waters, Petroff, and Koski, IEEE Trans. Nuc. Sci. 16(1) 398-401 (1969)

Plot of event rate vs. “superheat pressure” (= vapor pressure - operating pressure)



COUPP:
Chicagoland **O**bservatory for **U**nderground **P**article **P**hysics

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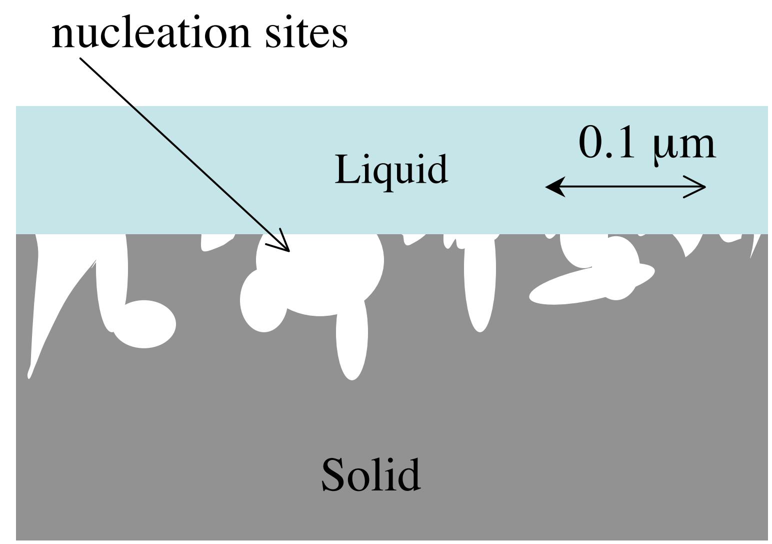
Bubble Nucleation in Cracks

• Trapped gas volumes in surface imperfections are now known to be the primary source of nucleation.

• Most (all?) construction materials have rough surfaces at scales below 1 μm, but some materials much better than others.

• Historically, problem was overcome for high energy physics experiments by rapid cycling of chamber in sync with a pulsed beam. Bubbling at walls was tolerated because of finite speed of bubble growth.

• A few small "clean chambers" (~10 ml) were built in the 50's and 60's, with sensitive times ~1 minute.



<u>Ways to preserve superheated state:</u>

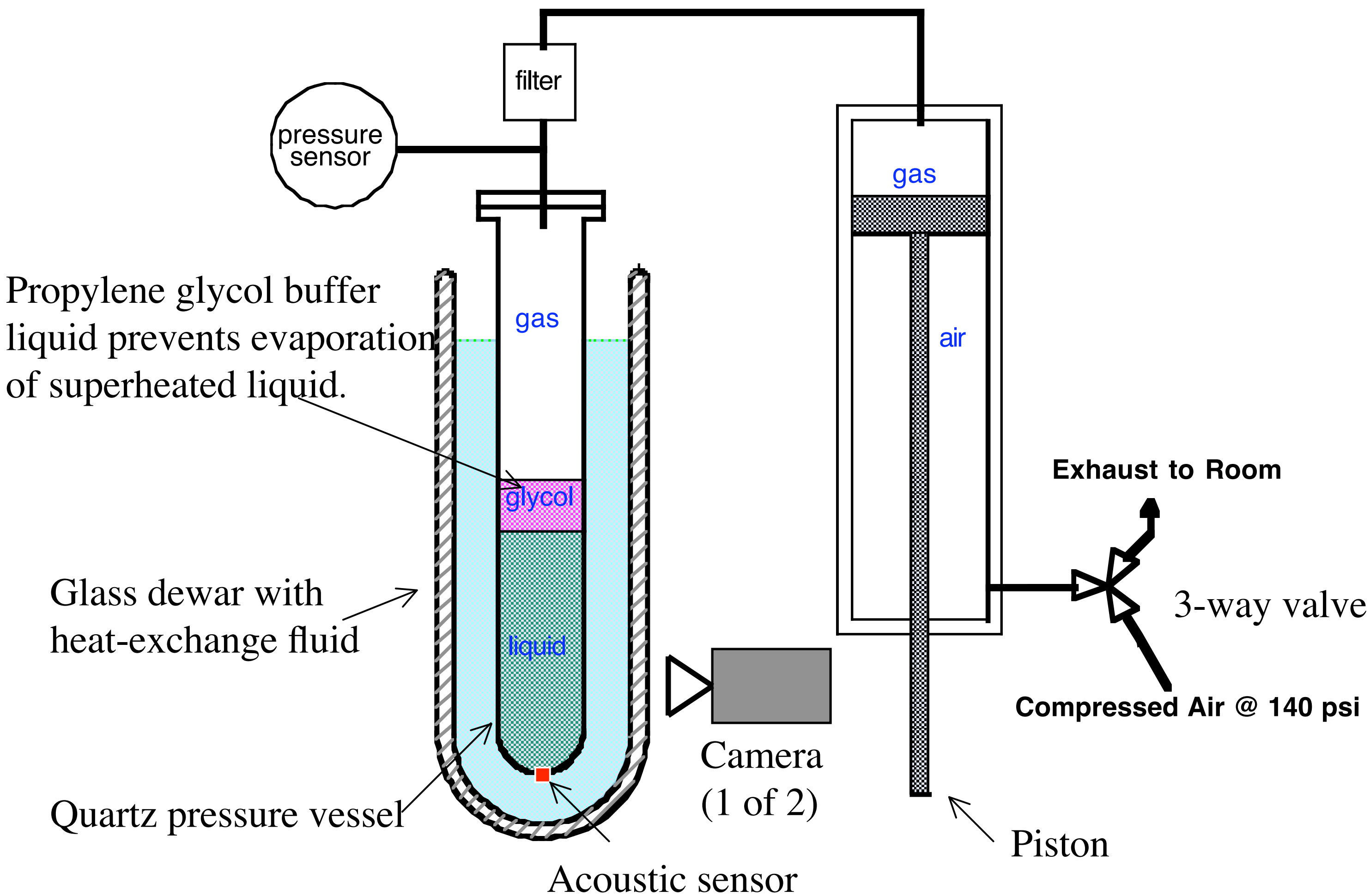
• Elimination of porous surfaces in contact with superheated liquid.

• Precision cleaning to eliminate particulates.

• Vacuum degassing.

•… a few other tricks borrowed from chemical engineers

Prototype High-Stability Bubble Chamber



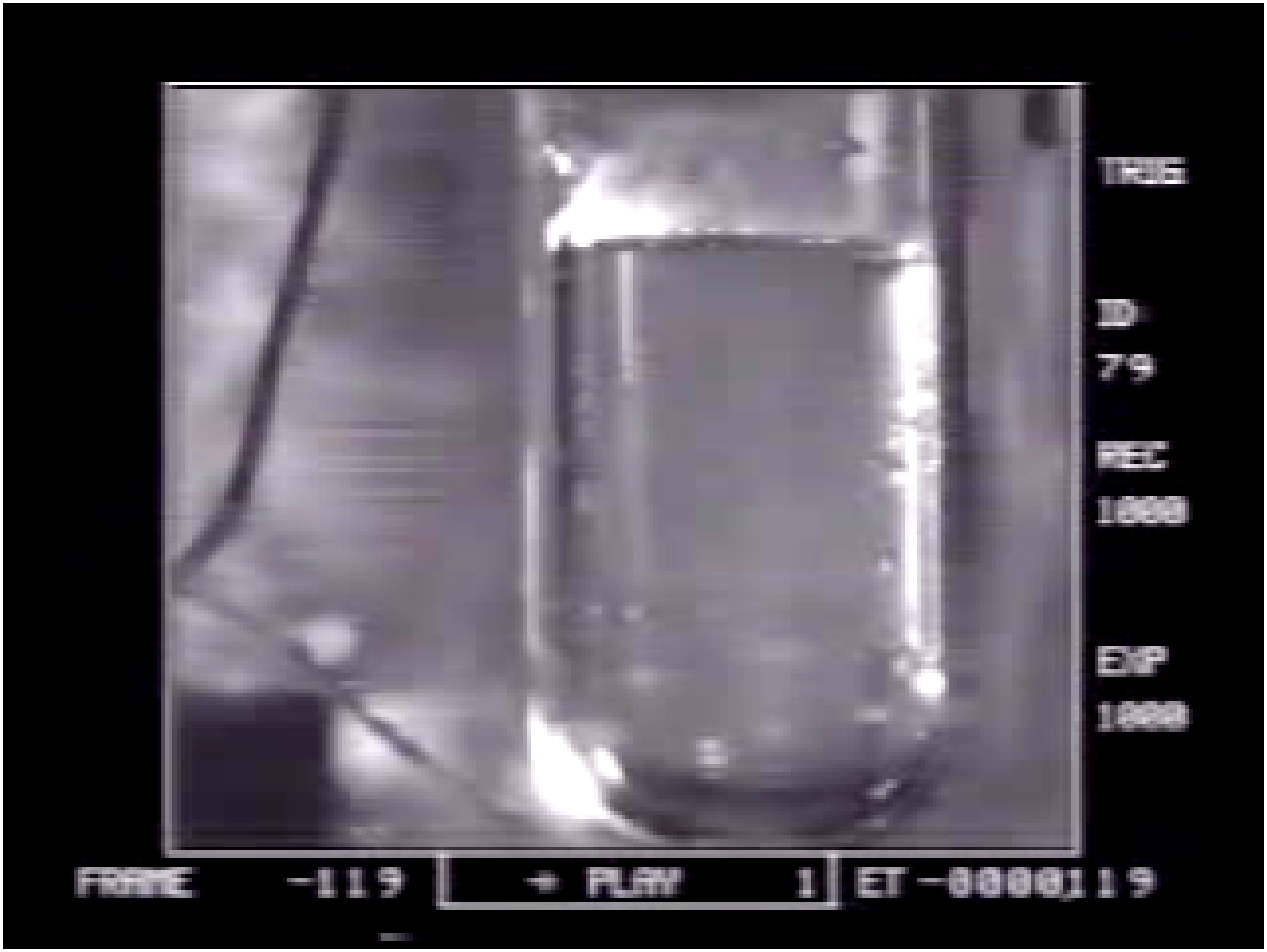
Possible Target Liquids

	Mass Fractions	Density	Boiling Point @ 1 atm	Comments
CF_3Br	8% C (Z=6) 38% F (Z=9) 54% Br (Z=35)	1.5 g/cc	-58 °C	Good for spin-dependent and spin- independent couplings.
CF_3I	6% C 29% F 65% I (Z=53)	2.1 g/cc	-23 °C	Spin-dependent and spin-independent Non- ozone depleting
C_3F_8	19% C 81% F	1.4 g/cc	-37 °C	Spin- dependent only.
Xe	100% Xe (Z=54)	3.0 g/cc	-108 °C	Possible use in hybrid scintillating bubble chamber.

High Speed Bubble Chamber Movie

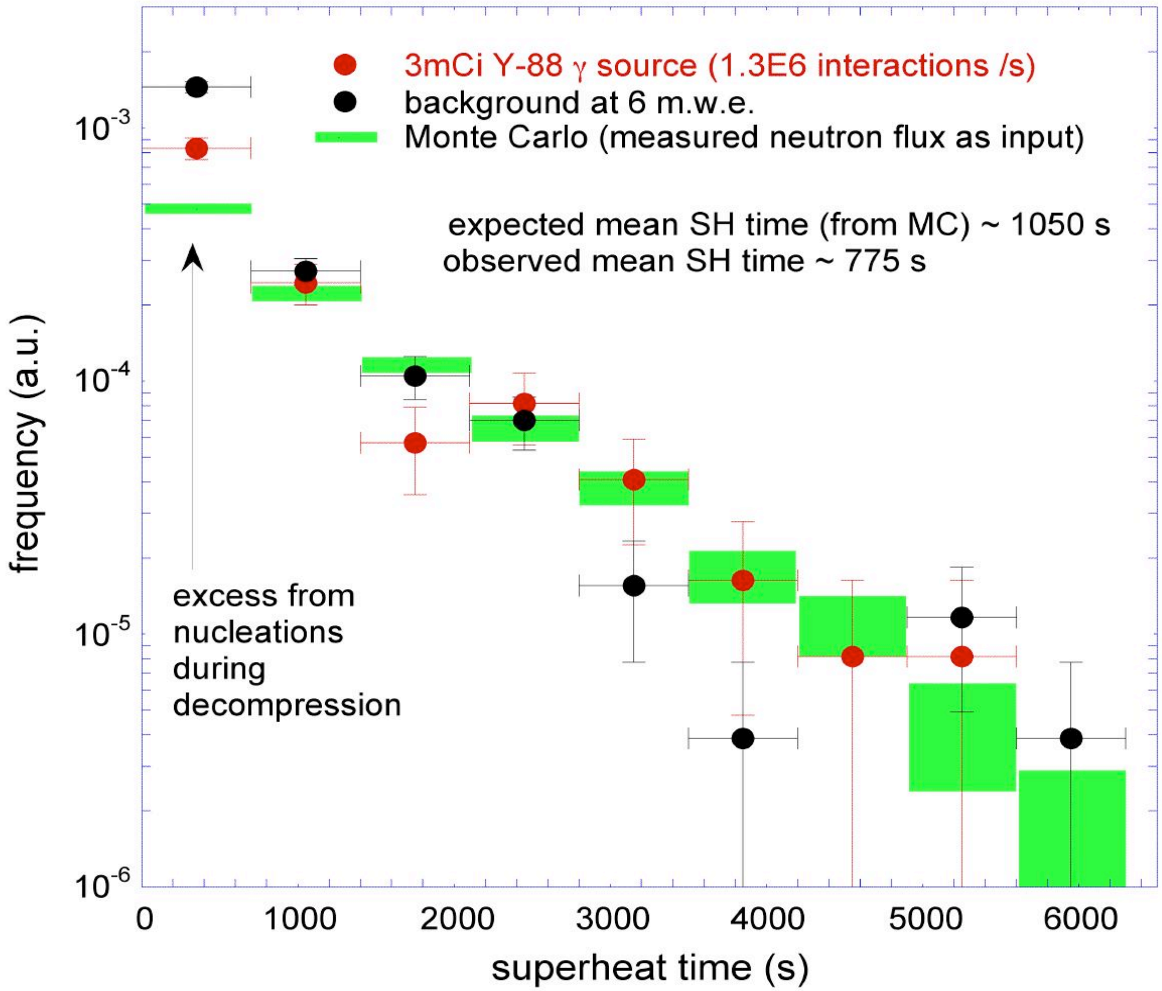
1000 frames/ second

^{241}Am-Be neutron source

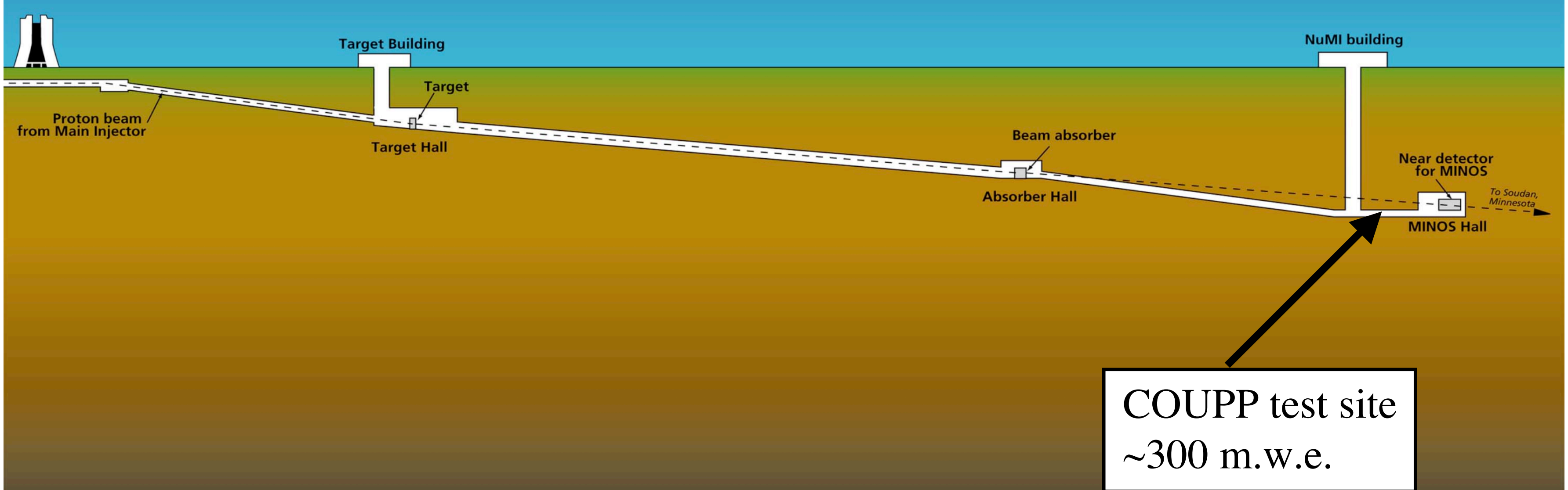


Background Rate

- 1 event/ (15 minutes) for 18 grams of CF_3Br in sub-basement lab (~6 ft. depth).
- Observed rates are consistent with measured ambient neutron flux.



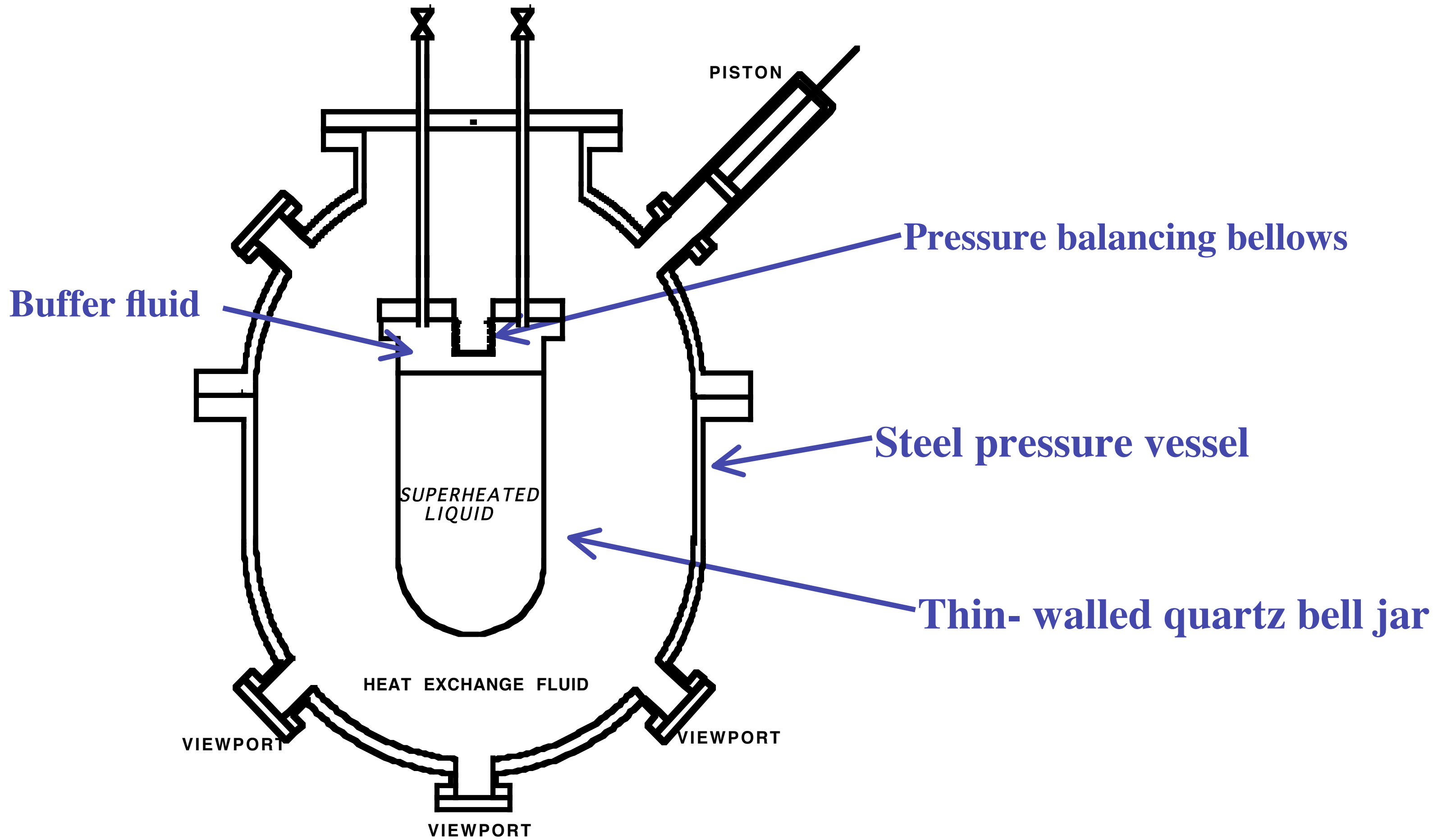
NuMI Tunnel Project
at Fermilab



Design Concept for Large Chambers

• Central design issue is how to avoid metal contact with superheated liquid.

• Fabrication of large quartz or glass pressure vessels is not practical, but industrial capability exists for thin-walled vessels up to ~ 1 m^3 in volume.



1- Liter Detector at Fermilab

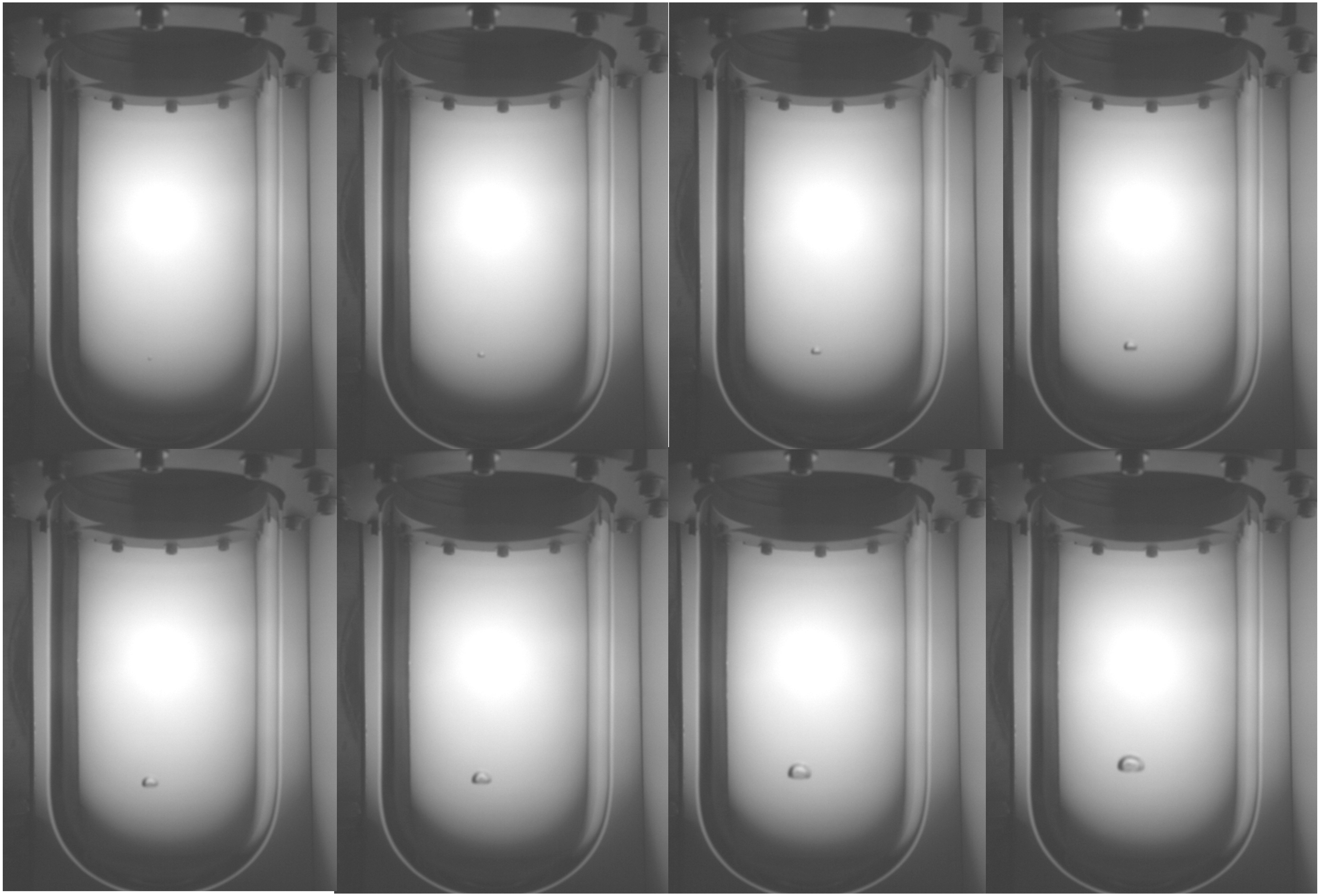
CF_3I target liquid

1400g iodine

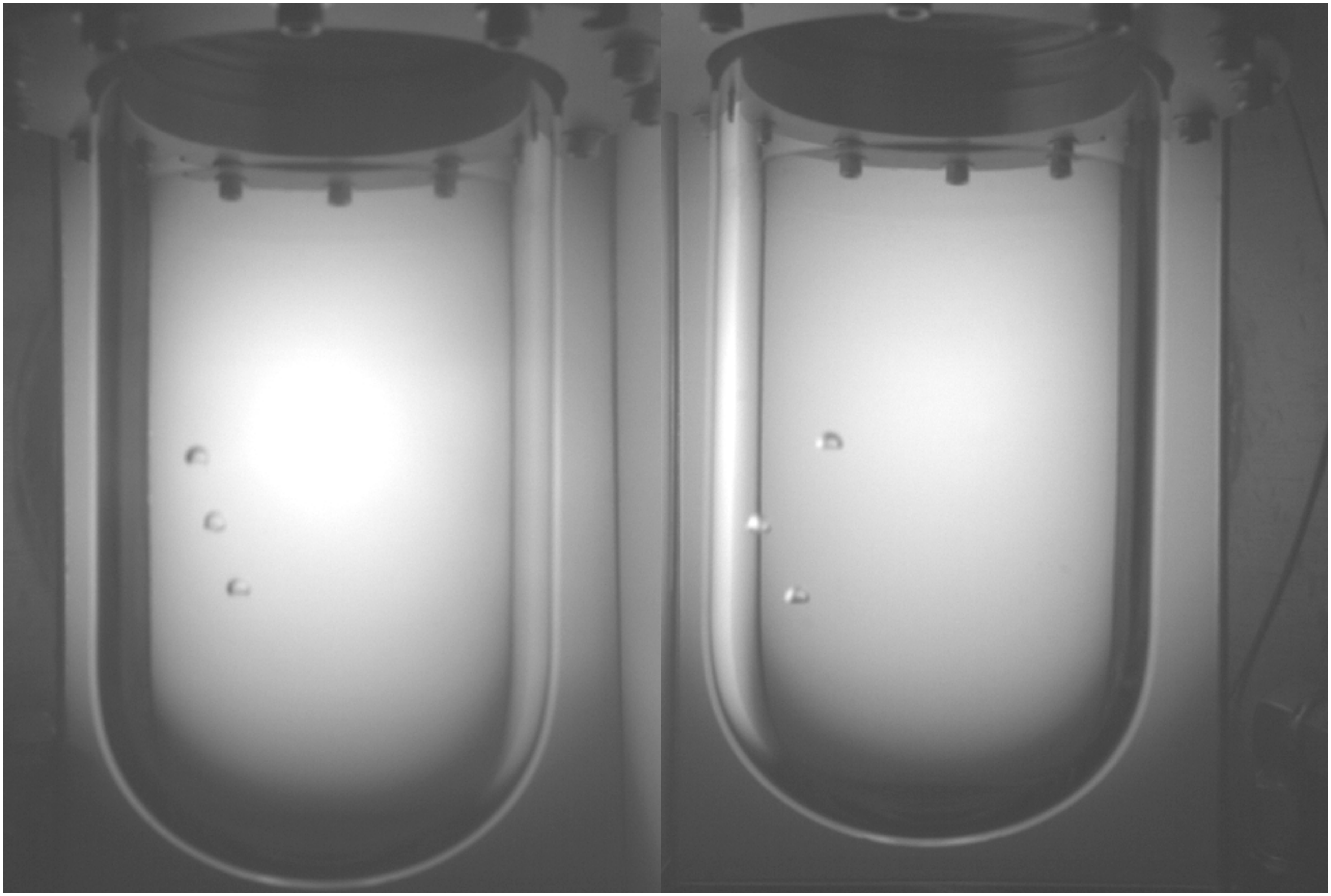
600g fluorine

100g carbon

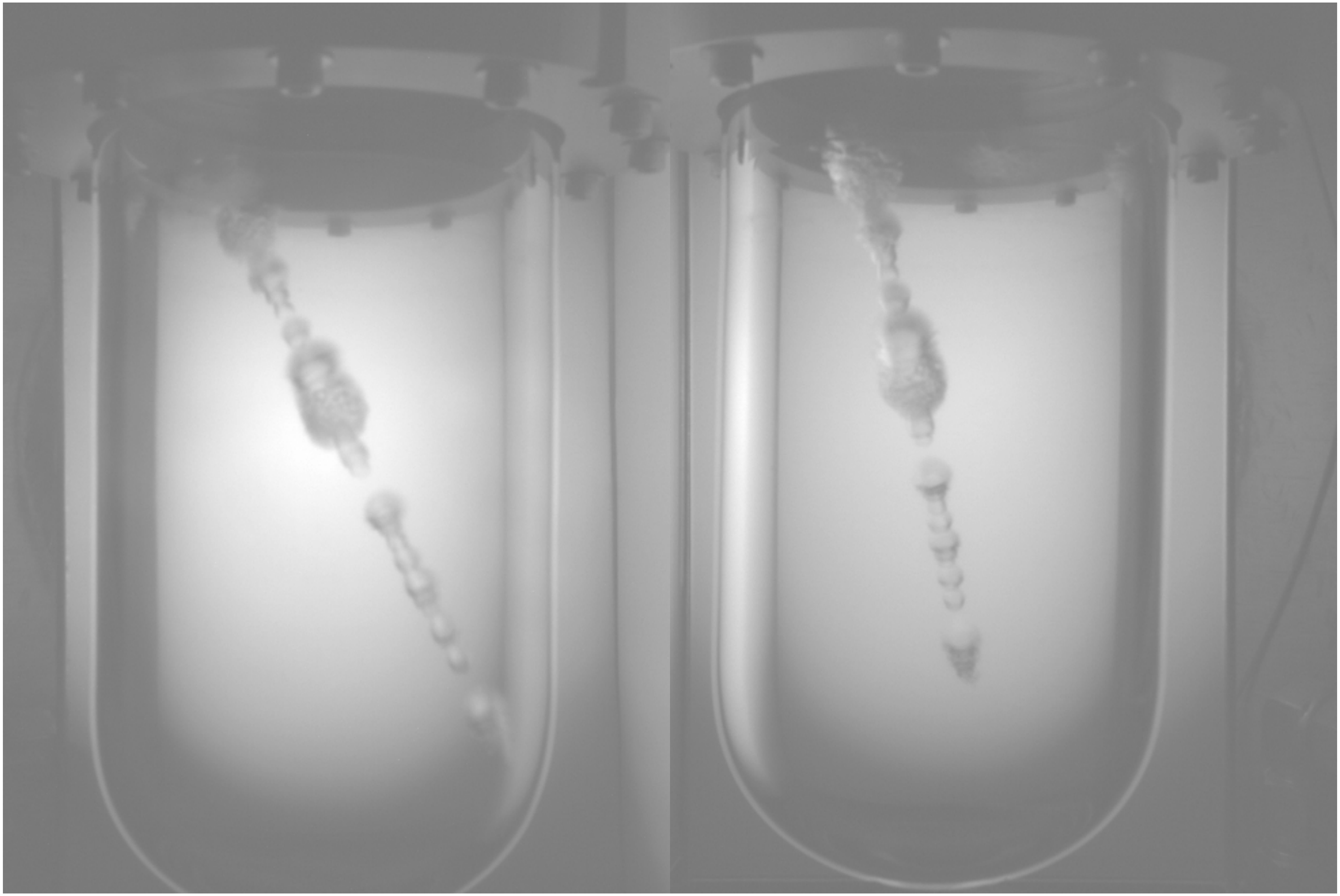
160 msec of Video Buffer (20 msec/frame)



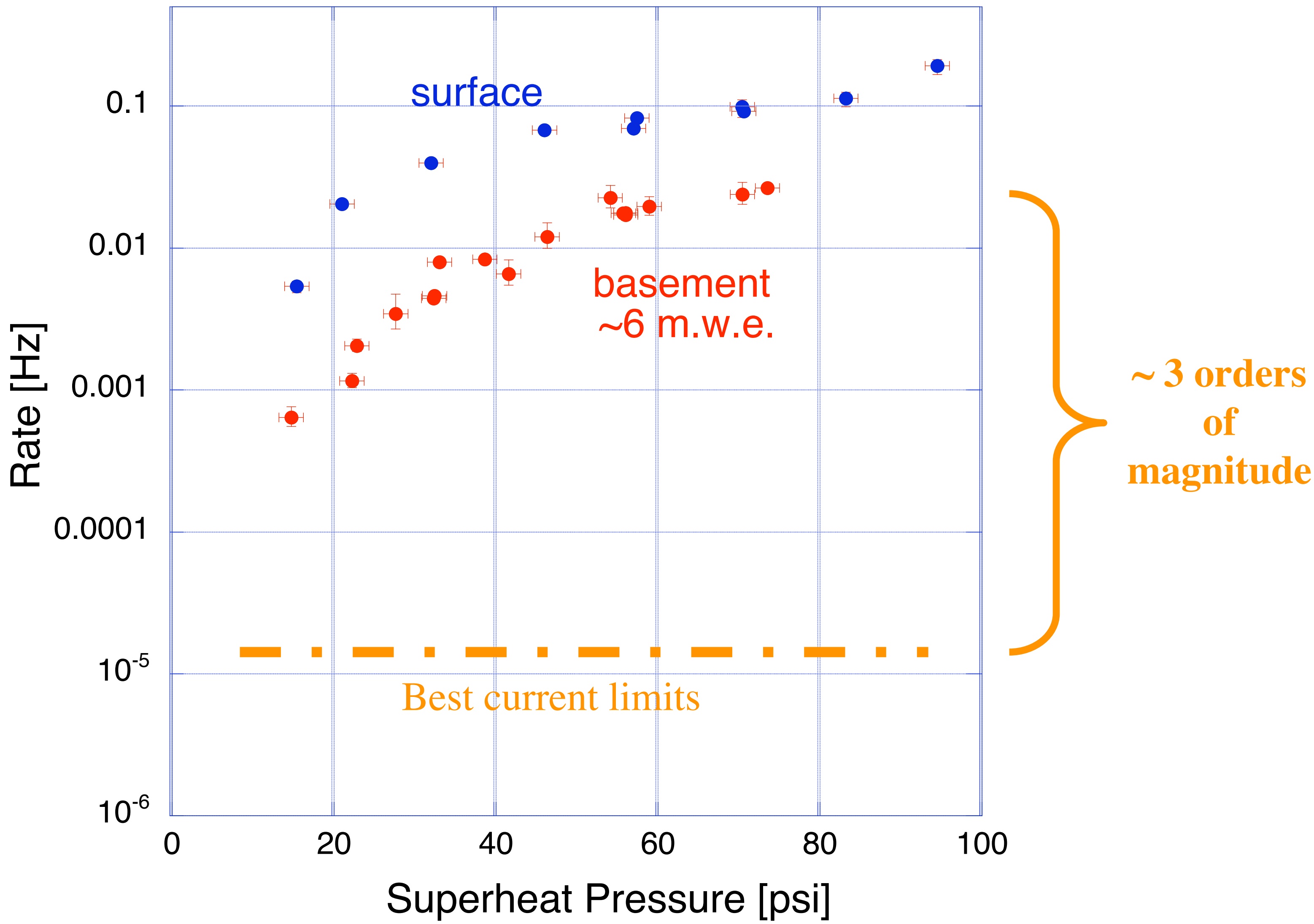
Triple Neutron Scatter



Muon Track @ 160 psi Superheat Pressure



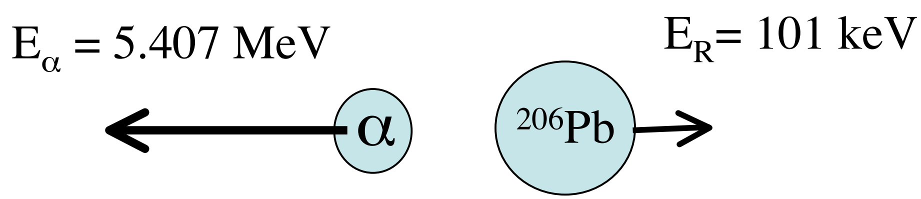
How low in rate do we have to go to be sensitive to WIMPs?



Background Due to Nuclear Recoils from Alpha Decay

- Alpha decay produces monoenergetic, low energy nuclear recoils.

For example, consider ^{210}Po->^{206}Pb:



- The recoiling nucleus will nucleate a bubble in any chamber that is sensitive to the lower energy (~10 keV) recoils expected from WIMP scattering.
- The ^{238}U and ^{232}Th decay series include many alpha emitters, including radon (^{222}Rn) and its daughters.
- Radon is highly soluble in bubble chamber liquids.

Backgrounds for a Large Bubble Chamber Experiment

	Assumptions	Total Event Rate
neutrons	Deep site with shielding	<0.01/ton-day
Gammas & betas	"Rejection factor" better than 10^{-9}	<0.1/ton-day
Alphas	Best Borexino CTF level dominated by radon decay	~1/ton-day?

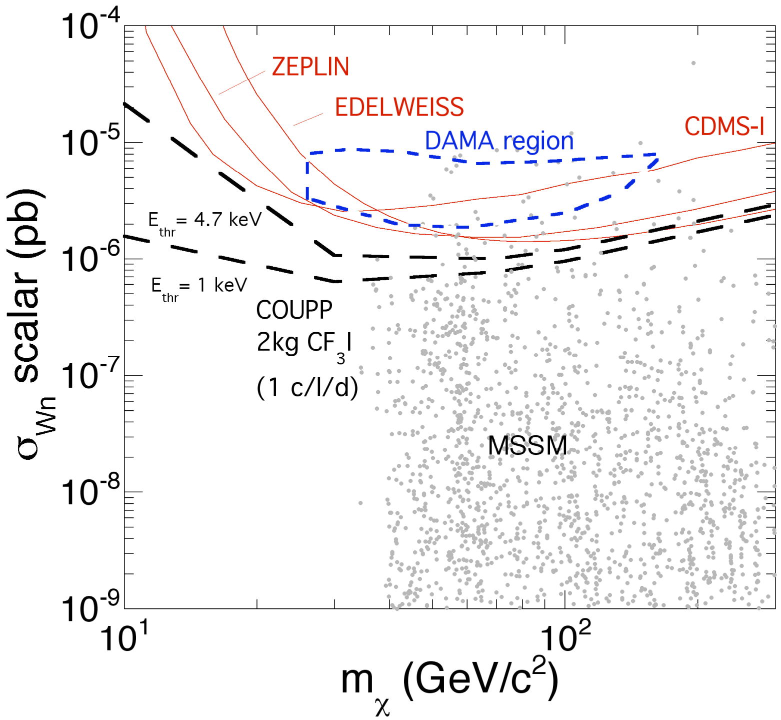
• Fluid handling techniques to be adapted from Borexino solar neutrino observatory.

• Background likely to be dominated by radon and its daughters.

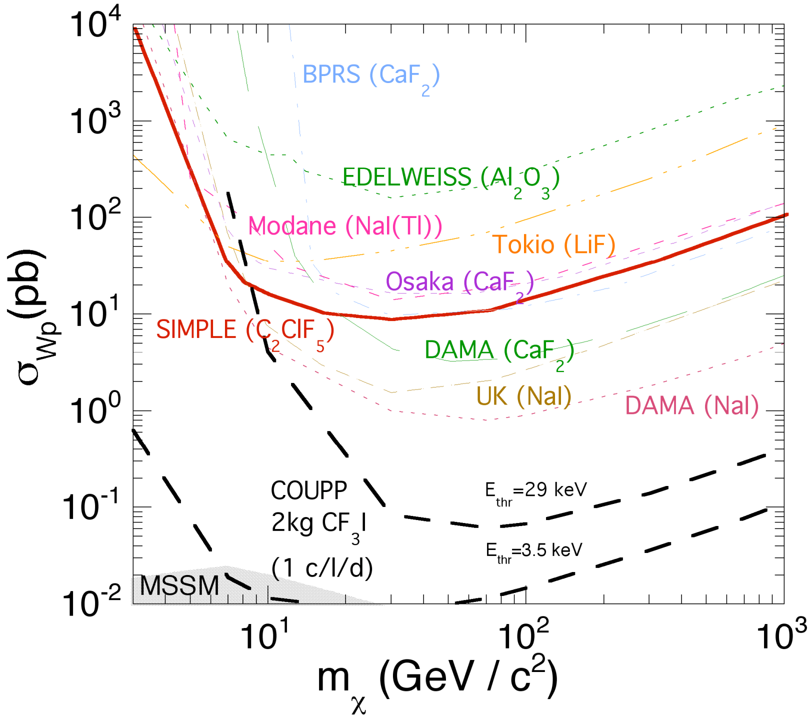
• These levels are ~3 orders of magnitude lower than seen in current generation dark matter experiments.

Potential Sensitivity Of 1-Liter Chamber at Fermilab Site

Spin-independent



Spin-dependent



Conclusions

Bubble chambers might be the best instruments for detecting WIMPs, because:

- **They can be built big at moderate cost.**
- **Virtually zero response to beta and gamma radiation.**
- **Low thresholds for nuclear recoils.**
- **Neutron backgrounds measured by counting multiple bubbles**
- **Wide selection of interesting target nuclei.**

} **Already demonstrated**

- **Alpha backgrounds in chamber liquids can be made small.**

} **To test at Fermilab site**

Tours of COUPP

Requirements: No shorts or sandals.
Meeting place: In front of registration booth.

4:00 PM	May be 1 or 2 openings left
5:00 PM	Open