Summer 2008 at Fermi National Accelerator Laboratory

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Computing Division, ILC and future programs, DAQ and Controls, Applications and Infrastructure Software

Supervisor: Dr. Peter S. Cooper

Outline

- General overview of COUPP experiment
- My role in the experiment
- Why this year is different from years past
- Work now and in the future
- Q & A

Dark Matter

- Matter particles of unknown composition that do not emit or reflect enough electromagnetic radiation (light) to be detected directly
- Presence may be inferred from gravitational effects on visible matter (stars and galaxies)
- Only 4% of total energy density is visible matter
- Dark Matter is thought to make up 22%
- Dark Energy is thought to make up the remaining 74%

WIMPs

- Weakly Interacting Massive Particles
- One hypothetical form of dark matter (Massive Compact Halo Objects)
- Arguably the best particle candidates for cold dark matter in galaxies like our own
- Interact through the weak nuclear force, gravity, and possibly other weak forces, nuclear recoils
- Have yet to be discovered

Bubble Chamber

- Large target masses are possible
- A glass vessel containing a "heavy" liquid
- Background radiation can cause single and multiple bubbles (neutron recoils), chambers are best located underground, surrounded by shielding
- Fill by vapor condensation prevents vapor entrapment in cavities of container
- When a WIMP hits an Iodine nucleus (in CF_3I molecule), single bubble forms

COUPP

- Chicagoland Observatory for Underground Particle Physics

- The Collaboration:

E. Behnke, J. I. Collar, P. S. Cooper, K. Crum, M. Crisler, M. Hu, I. Levine, D. Nakazawa, H. Nguyen, B. Odom, E. Ramberg, J. Rasmussen, N. Riley, A. Sonnenschein, M. Szydagis, R. Tschirhart

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Spin-Dependent WIMP Limits from a Bubble Chamber

E. Behnke,[1] J. I. Collar,[2]* P. S. Cooper,[3] K. Crum,[2] M. Crisler,[3] M. Hu,[3] I. Levine,[1] D. Nakazawa,[2] H. Nguyen,[3] B. Odom,[2] E. Ramberg,[3] J. Rasmussen,[2] N. Riley,[2] A. Sonnenschein,[3] M. Szydagis,[2] R. Tschirhart[3]

Bubble chambers were the dominant technology used for particle detection in accelerator experiments for several decades, eventually falling into disuse with the advent of other techniques. We report here on a new application for these devices. We operated an ultraclean, room-temperature bubble chamber containing 1.5 kilograms of superheated CF_3I, a target maximally sensitive to spin-dependent and -independent weakly interacting massive particle (WIMP) couplings. An extreme intrinsic insensitivity to the backgrounds that commonly limit direct searches for dark matter was measured in this device under operating conditions leading to the detection of low-energy nuclear recoils like those expected from WIMPs. Improved limits on the spin-dependent WIMP-proton scattering cross section were extracted during our experiments, excluding this type of coupling as a possible explanation for a recent claim of particle dark-matter detection.

With approximately 85% of the total matter of the universe in a form that still eludes direct detection, the need for large-mass background-insensitive detectors that are able to explore the very small couplings expected from weakly interacting massive particles (WIMPs) is urgent. A member of this family of hypothetical particles, the lightest supersymmetric partner, stands out as one of the most likely candidates for composing the dark matter in galaxies (*1*, *2*), but its predicted interaction rate via low-energy elastic scattering off nuclei is much less than one event per kg•day for any target. In some unfavorable (yet entirely plausible) models, this can become a dismayingly small rate of less than one event per ton•year, which is so small that the next generation of massive [O(100)kg] WIMP detectors would necessarily suffer from a penury of statistics from any dark matter signal they might register. Information about WIMP properties (such as the mass of the particle) will be scarce. Thus, we require a variety of detec-

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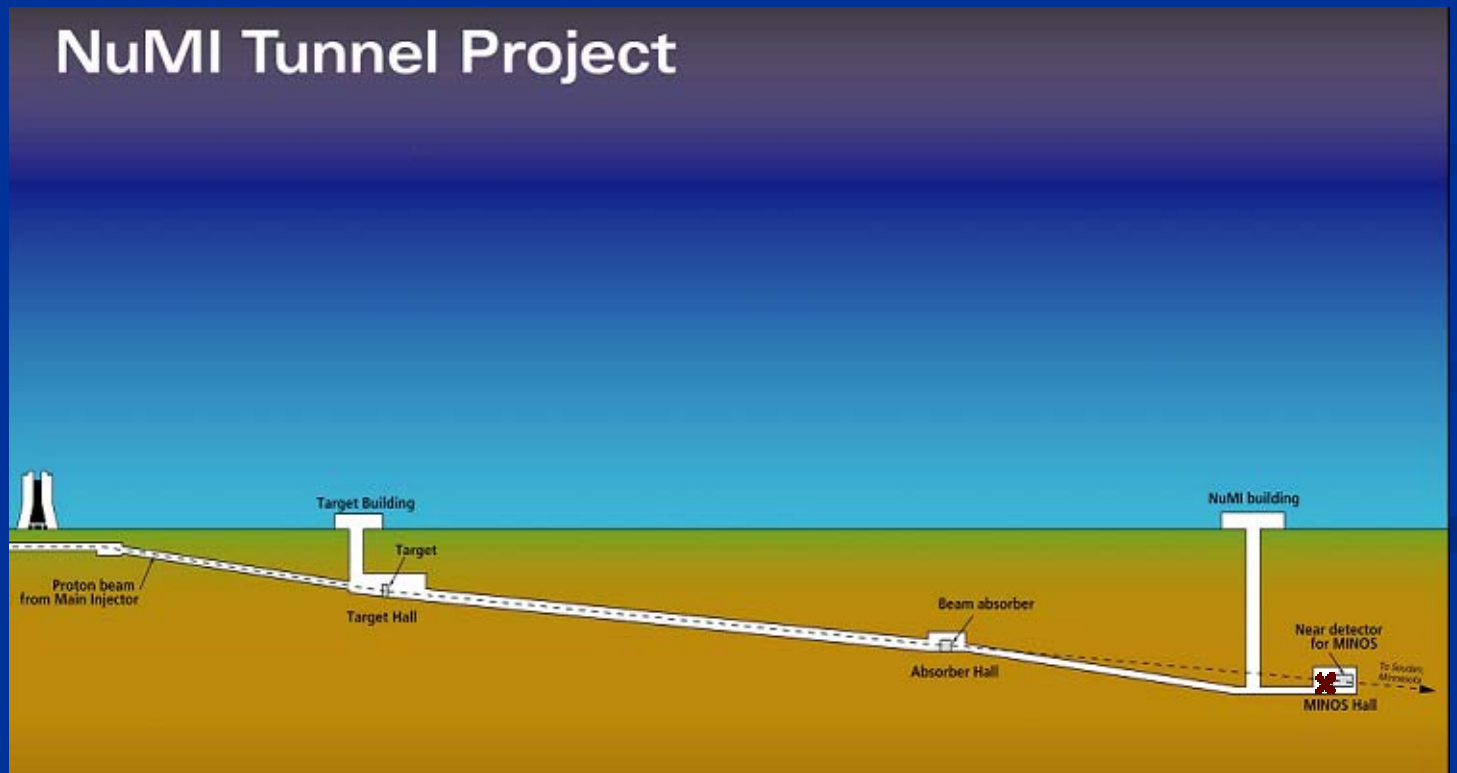
The COUPP experiment

- On going, continuously improving experiment
- Started taking data December of 2005
- Working cooperatively with experiment members at University of Chicago and Indiana University South Bend
- Located 300 feet underground, close to NEAR detector



2 kg Bubble Chamber

Installation of 2 kg Bubble Chamber:

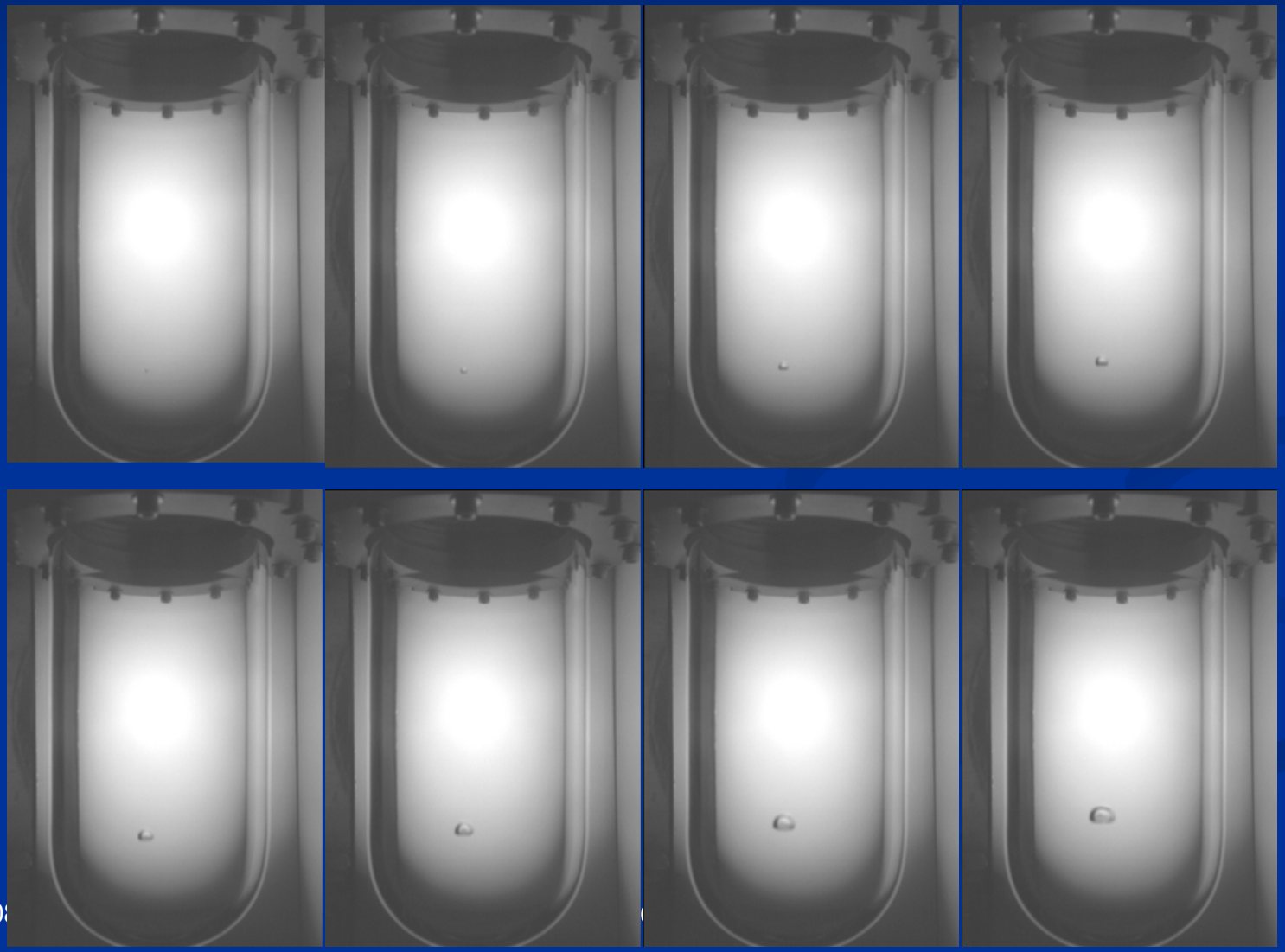
- CF_3I
- Quartz jar
- Outer pressure vessel
- High-speed cameras
- Compression control
- Lighting
- DAQ

CF_3I target liquid

- 1400g iodine
- 600g fluorine
- 100g carbon

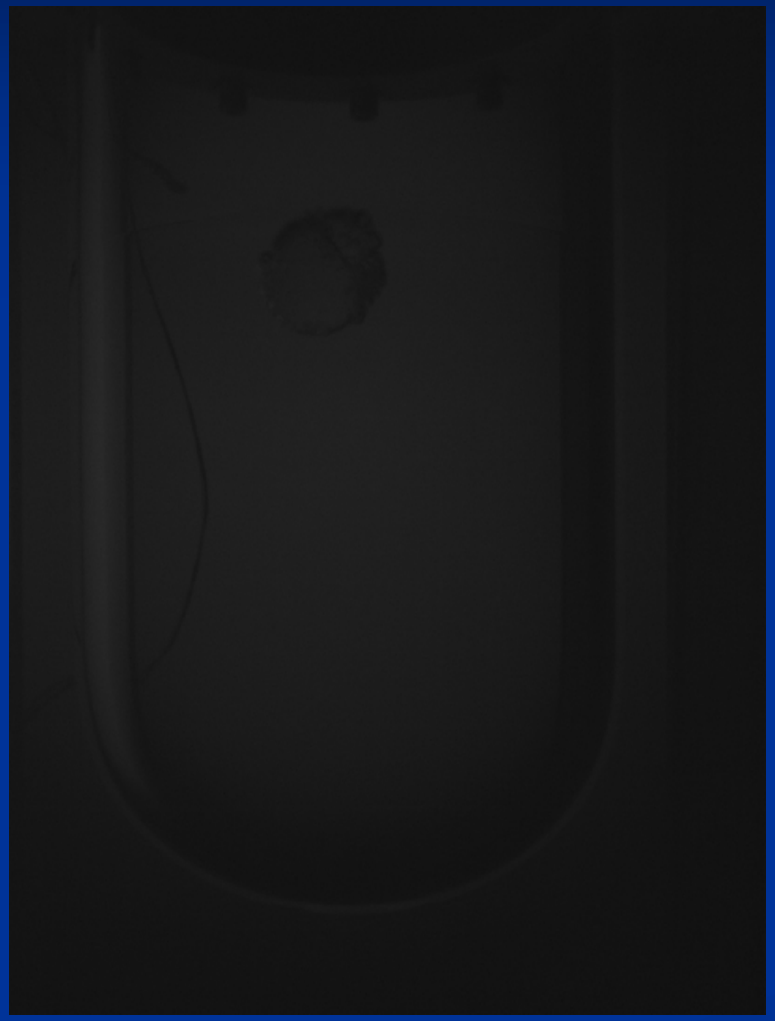
Bubble Formation

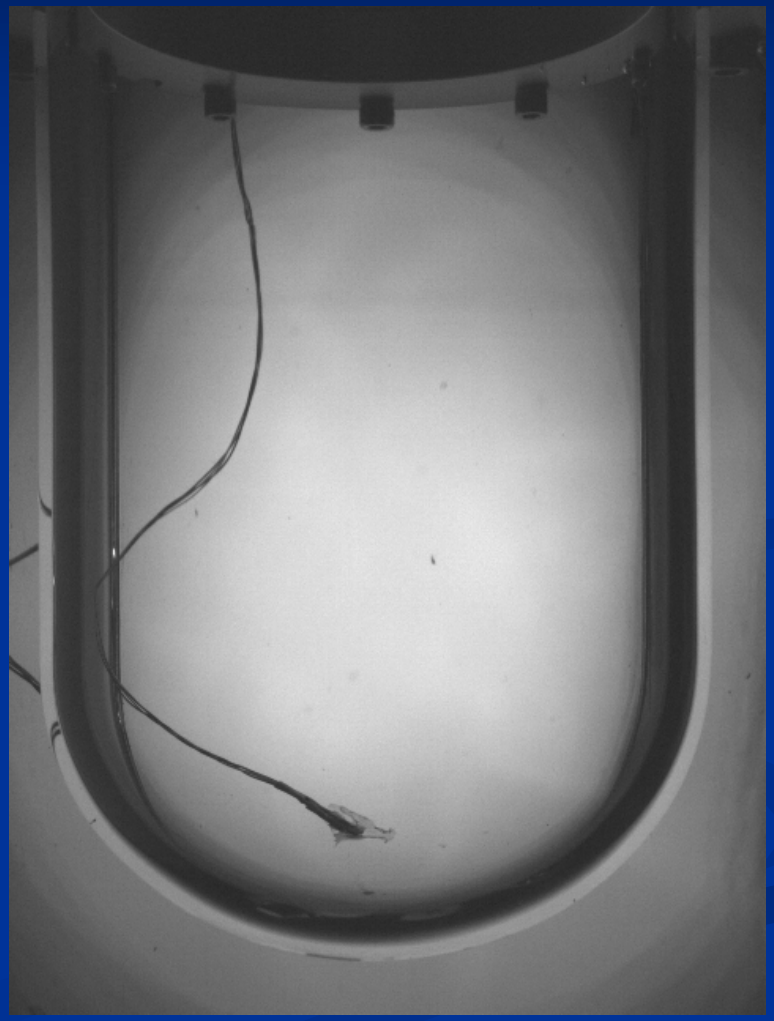
160 milliseconds (20 msec/frame)



Luxeon III Pack

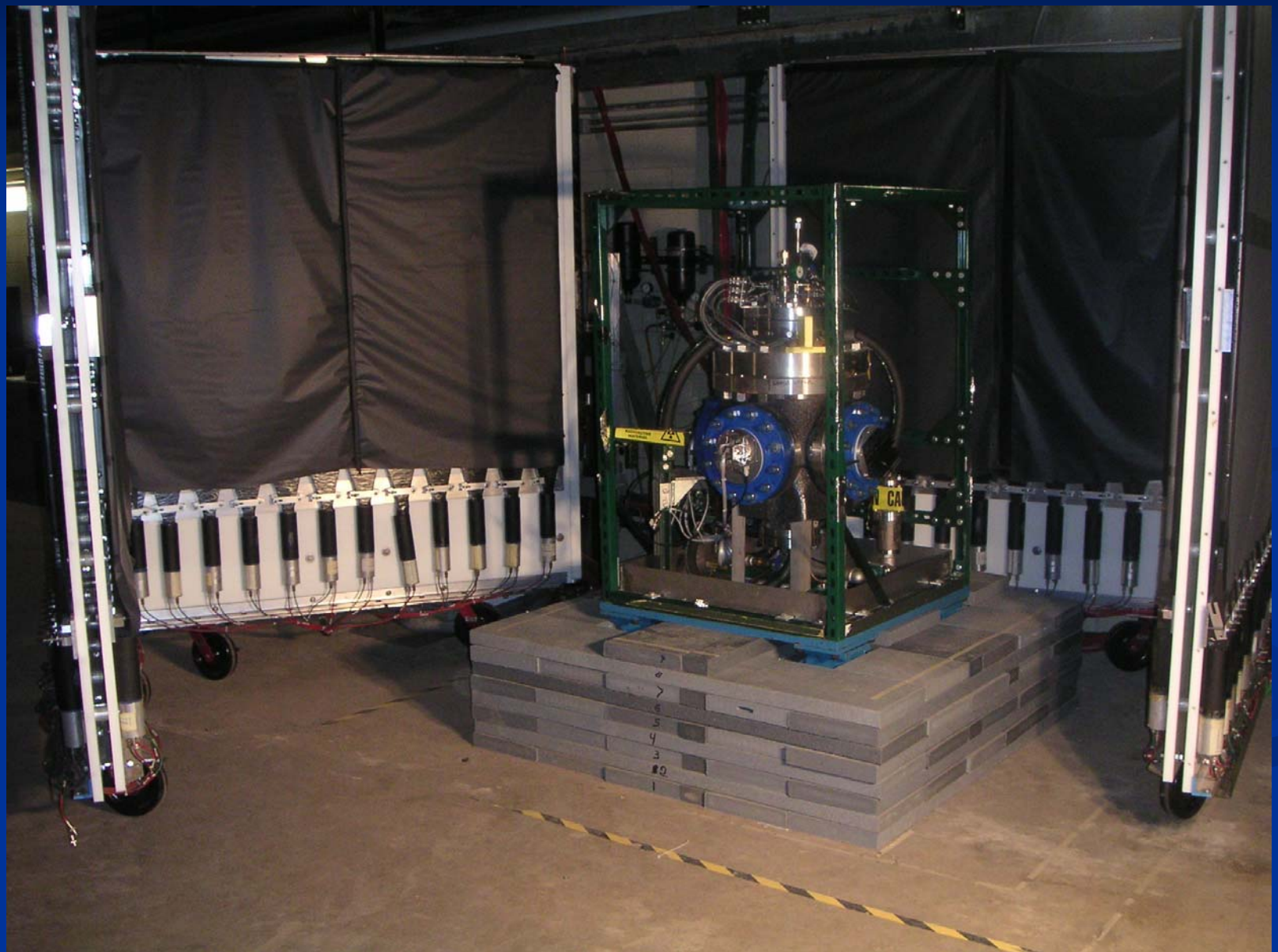
Picture Comparison: what the cameras see





Much better for triggering based off difference in pixels

The 2 kg Chamber

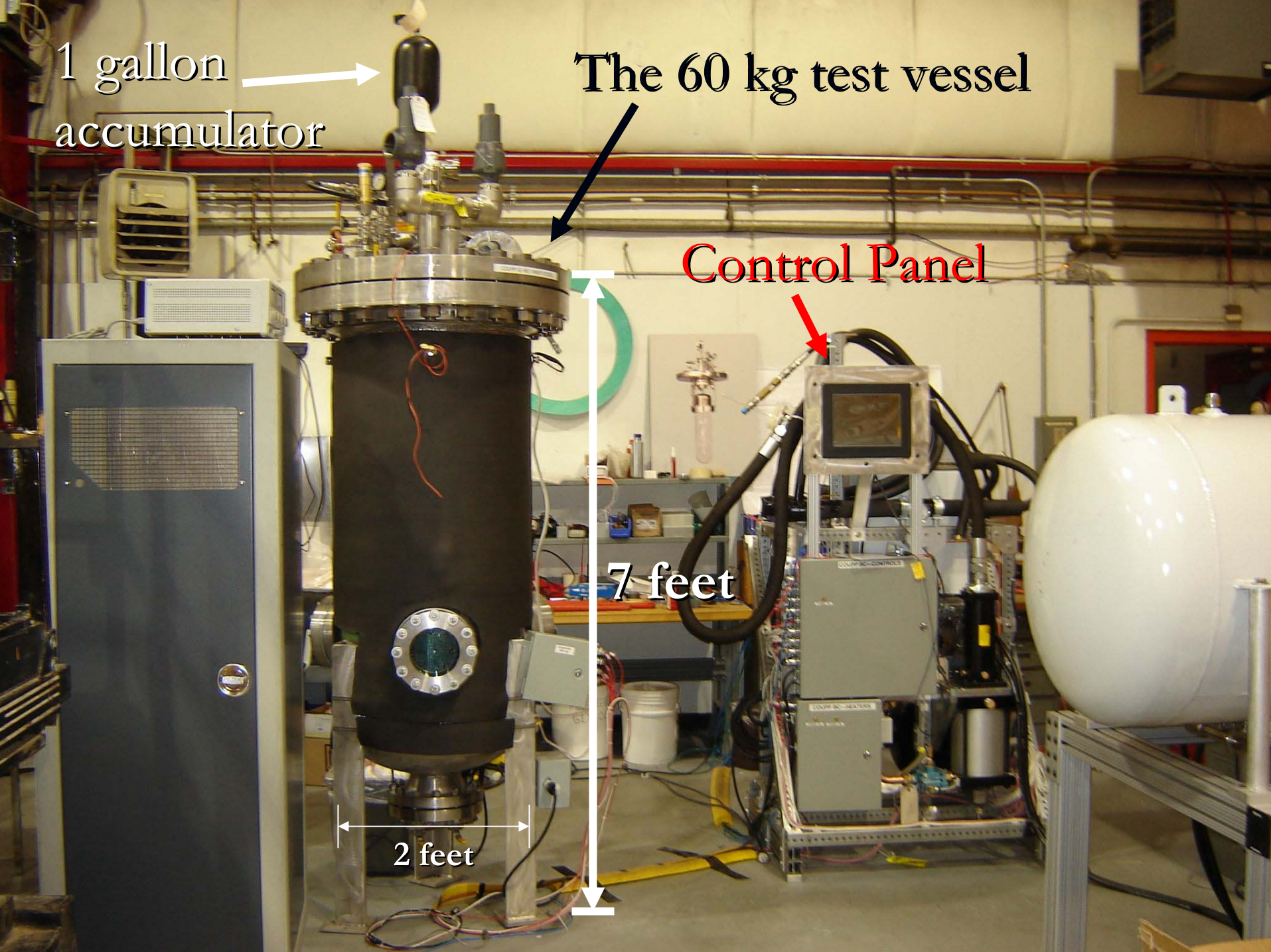


The 2 kg Chamber

Where the 60 kg chamber started

The Future is here

- 60 kg test vessel is assembled
- Quartz jar is complete and in place
- Thermal insulation covers the entire outer vessel
- Pressure sensors and control panel are running
- Compression triggers have been tested
- Pressure spikes have been dealt with by strategic placement of an accumulator


1 gallon accumulator
The 60 kg test vessel
Control Panel
7 feet
2 feet

1 gallon accumulator

Inner 30 Liter Chamber

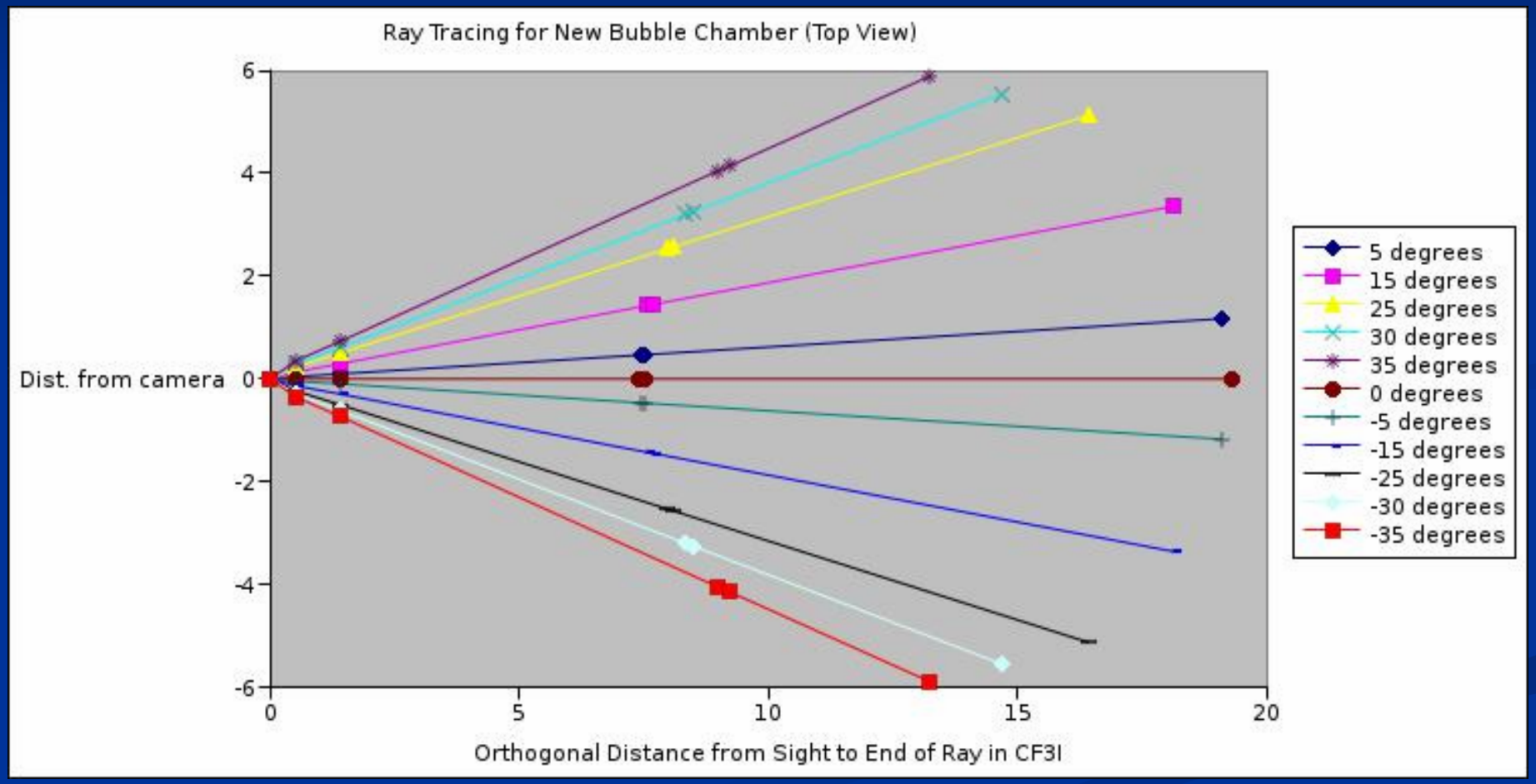
My Role: 60 kg

- Ensure success of optics design with new cameras and lighting setup and accumulator position
- Work with other engineers and technicians to develop a lighting and accumulator setup that works, with no future consequences (epoxy problems)
- Often difficult to understand problems that occur
- Test, then test again (can't work just once)

My Role: Lighting

- Testing to find best possible setup
- Developing a safe method of securing LED's, pressurized in glycol
- Researching/testing various designs
- Ideas:
  - Epoxy, screws, etc.
  - Backlighting with panels of LED's in glycol

My Role: Ray Tracing



Why this year is different

- More freedom, more responsibility
- Not just one large project, many projects at once
- Feels less like an internship, more like a real engineering job
- Variability in each new task, each day is different
- Learning the business of engineering, being taught through mistakes and experience more than ever

Work Today

- New challenges every day, never boring
- Lots of pressure…calculations
- Attending weekly engineering and COUPP meetings
- Luxeon III setup fully operational
- Developing ideas for final lighting setup for 60 kg
- Ordering parts, completing three unique pressure setups with similar problems
- Calculating/Correcting high pressure drops in Lab B compressor cooling water system
- Always looking for ways of improving/maintaining existing setups
- Proud of any lasting impressions and accomplishments

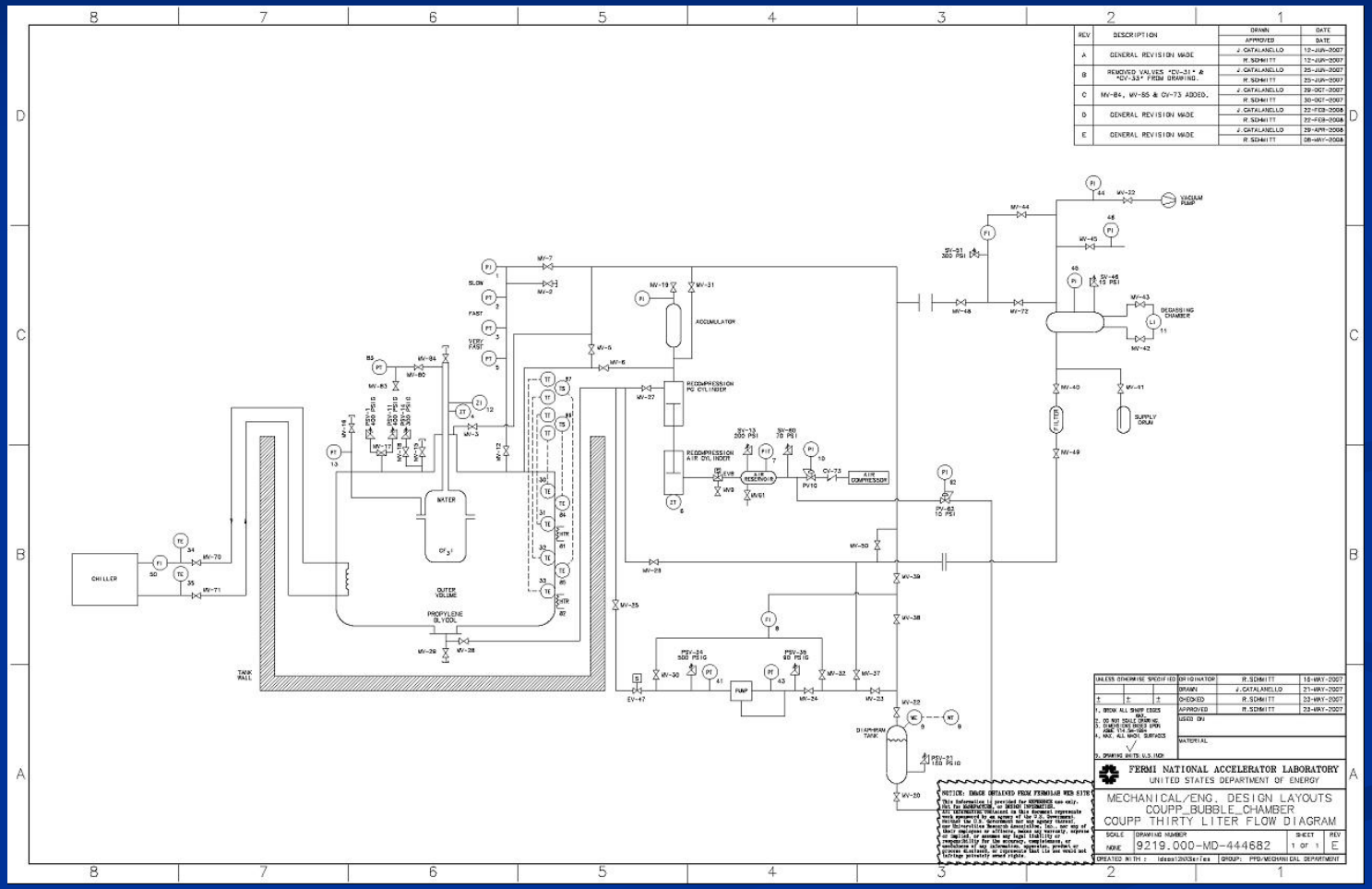
Many tasks done, more to go

- Thermodynamic analysis for Cryo System Process w/Nitrogen [1st Next Screen]
- Creating a log of valves and instrumentation for the Princeton Fridle Teit Facility
- Covering 60kg chamber with thermal insulation
- Setting up particle counters in clean room to check class of clean room
- Updated engineering drawing for Cryo System Process w/Nitrogen [2nd Next Screen]
- Modifying every run plan situation for the 60 kg chamber
- Making various quick calculations of pressures/forces
- Creating a graph display to show trends of Lab 3 liquid levels from log book
- Creating visual instructions and marking storage bags for packaging quartz jar in Japan
- Designing/Ordering/Modifying/Installing three unique accumulator setups for pressure systems
- Analyzing the Lab B compressor water cooling system and correcting high pressure drop situation
- Designing final LED setup for physics-ready 60 kg chamber
- Many tasks that, unfortunately, are impossible to show in PowerPoint due to the large scale involved or the nature of the tasks

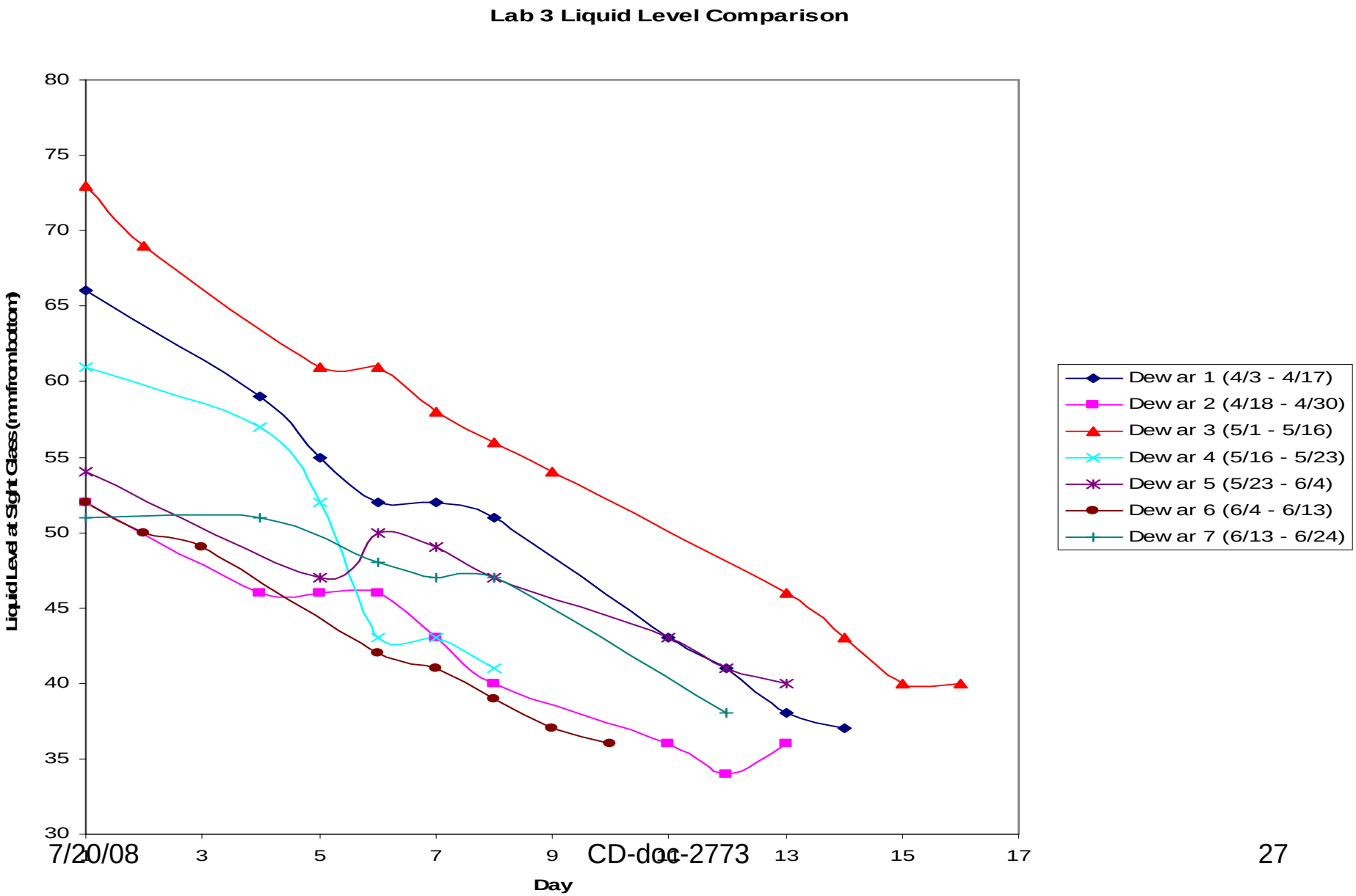
Thermodynamic Analysis Details

Position	Temperature (K)	Pressure (psig)	Enthalpy (J/g)	Liquid Enthalpy (J/g)	Vapor Enthalpy (J/g)	Quality (g/g)	mass flow rate (g/s)
100	92.5	50	-90.1	-90.1	86.0	0	3.392
101	90.5	40	-90.1	-94.5	85.2	0.025	0.082
102	77.7	1	-90.1	-121.3	77.4	0.157	0.082
103	77.7	1	77.4	-121.3	77.4	1	0.082
104	90.5	40	-90.1	-94.5	85.2	0.025	3.310
105	90.5	40	-59.9	-94.5	85.2	0.193	3.310
106	90.5	40	-59.9	-94.5	85.2	0.193	1.105
107	77.7	1	-59.9	-121.3	77.4	0.309	1.105
108	77.7	1	77.4	-121.3	77.4	1	1.105
109	N/A	N/A	N/A	N/A	N/A	N/A	N/A
110	90.5	40	-74.5	-94.5	85.2	0	3.310
111	90.5	40	-59.9	-94.5	85.2	0.193	1.105
112	77.7	1	-59.9	-121.3	77.4	0.309	1.105
113	77.7	1	77.4	-121.3	77.4	1	1.105
114	N/A	N/A	N/A	N/A	N/A	N/A	N/A
115	N/A	N/A	N/A	N/A	N/A	N/A	N/A
116	N/A	N/A	N/A	N/A	N/A	N/A	N/A
117	N/A	N/A	N/A	N/A	N/A	N/A	N/A
118	N/A	N/A	N/A	N/A	N/A	N/A	N/A
119	N/A	N/A	N/A	N/A	N/A	N/A	N/A
120	90.5	40	-59.9	-94.5	85.2	0.193	1.100
121	89.3	35	-59.9	-97.0	84.7	0.204	0.011
122	77.7	1	-59.9	-121.3	77.4	0.309	0.011
123	77.7	1	77.4	-121.3	77.4	1	0.011
124	N/A	N/A	N/A	N/A	N/A	N/A	N/A
125	88.1	30	-99.5	-99.5	84.1	0	1.089
126	88.1	30	84.1	-99.5	84.1	1	0.545
127	88.1	30	84.1	-99.5	84.1	1	0.545

Engineering Drawing Layout and Run-Plan Schematic for 60 kg



Lab 3 Liquid Nitrogen Levels



Visual Instructions for Packaging Quartz Jar

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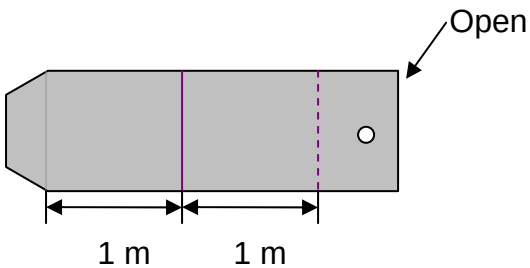

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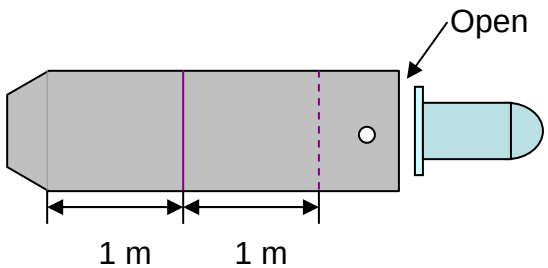

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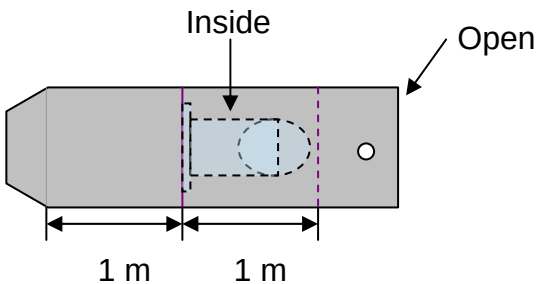

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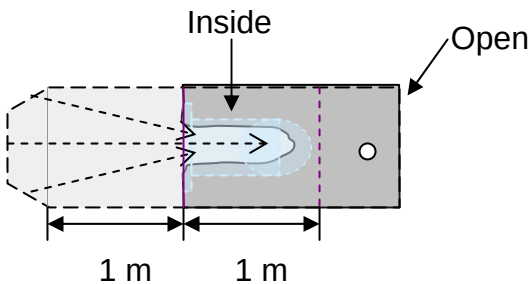

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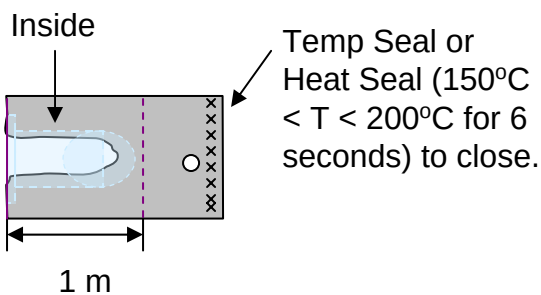

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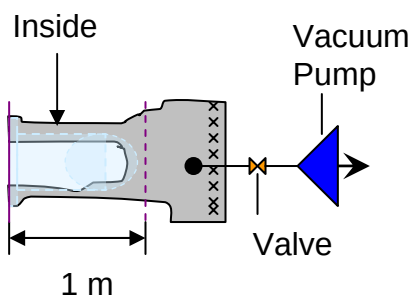

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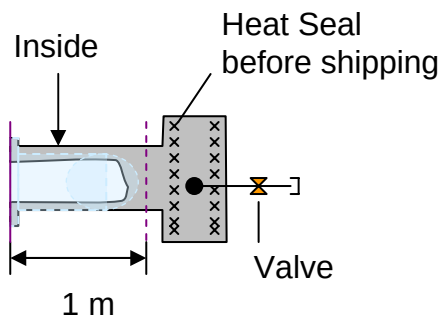

Goals for the Future

- Overall goal for COUPP: Discover WIMPs, or set a limit on their existence
- Fill test 60 kg chamber, perform pressure tests
- Get a 60 kg chamber physics ready
- Finalize lighting setup for 60 kg chamber
- Designing/Ordering/Modifying/Installing three unique accumulator setups for pressure systems
- Analyzing the Lab B compressor water cooling system and correcting high pressure drop situation

Acknowledgments

- Dr. Peter S. Cooper for welcoming me back for my fourth summer at Fermilab
- Rich Schmitt and Russell Rucinski for guidance and supervision throughout this summer
- Dr. Martin Hu and Dr. David Ritchie for continued guidance
- The IMPRINT program for a dream job in the top field of mechanical engineering
- Ms. Shelley Krivich for constant help and support
- The COUPP team
- God, family, and friends for continuous support

References

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- http://www-coupp.fnal.gov/
- www.sciencemag.org (Subs. req'd; Search for COUPP.)

Question & Answer

- Any Questions?