PICO Bubble Chamber Array

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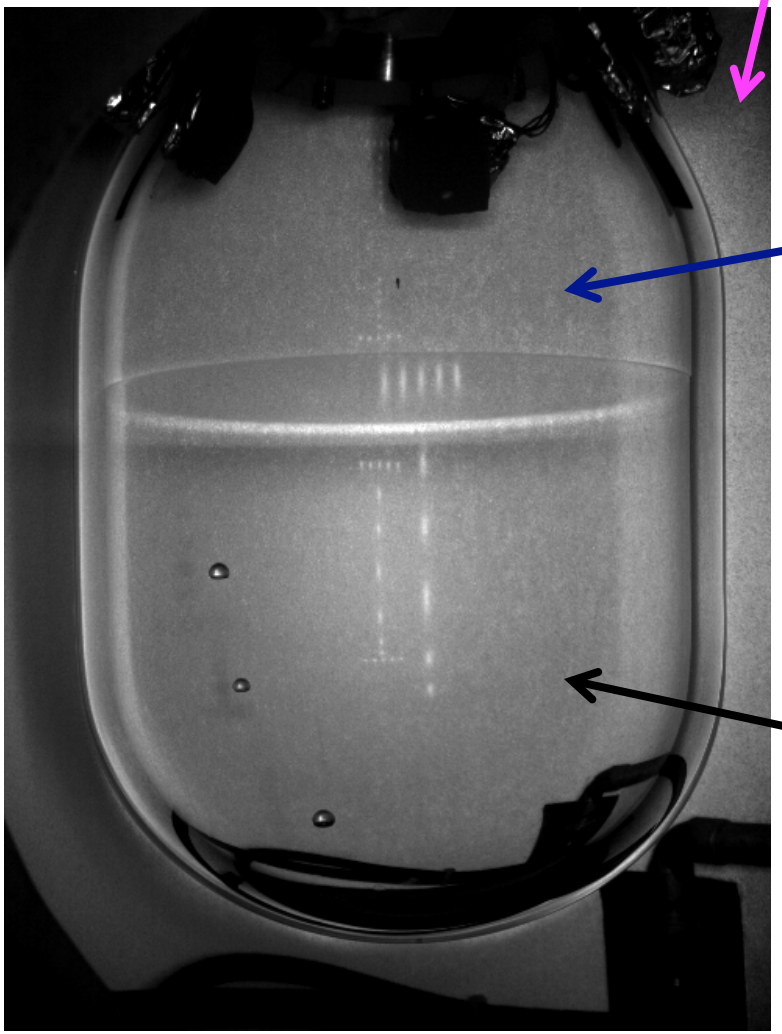
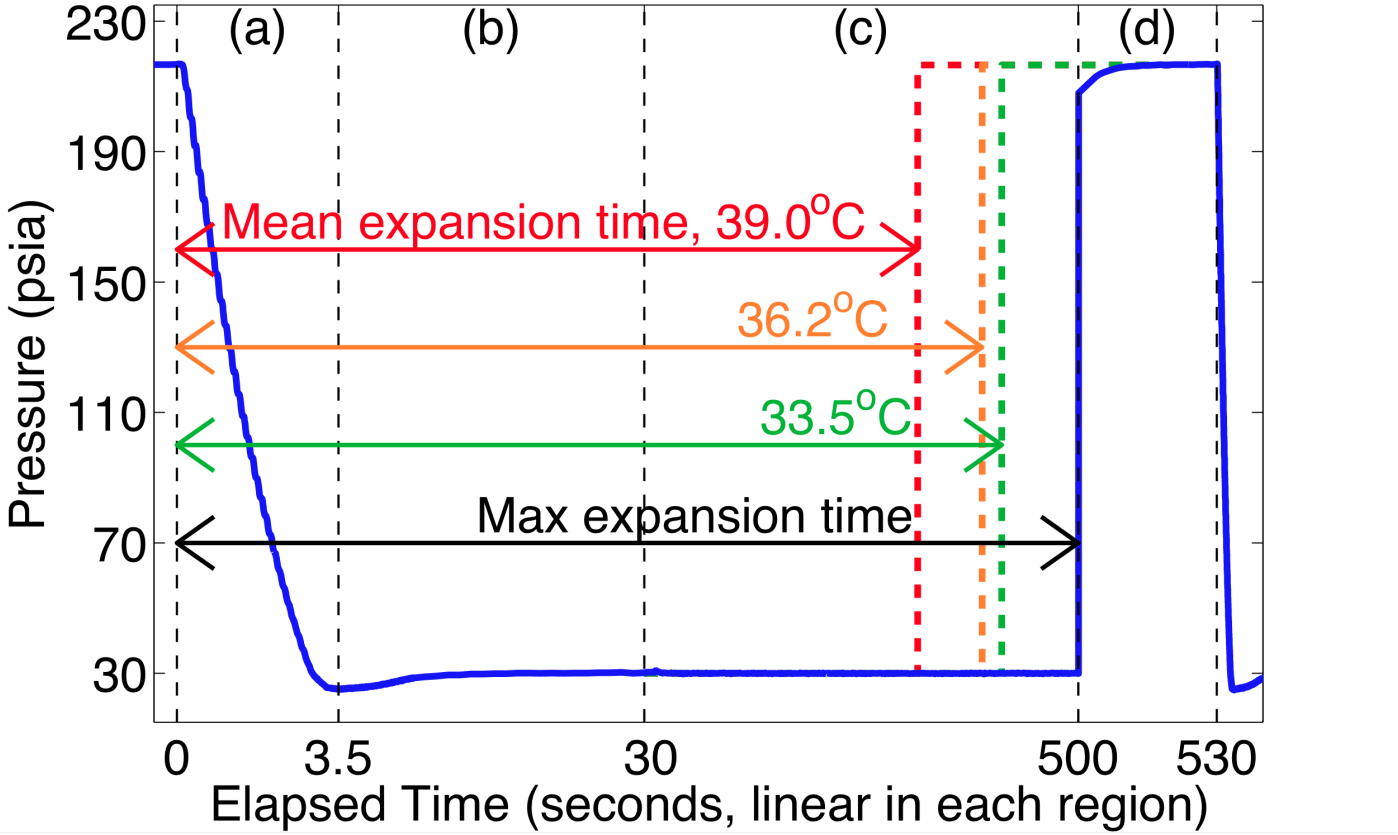
The Dark Matter Bubble Chamber

- Superheated Liquid
  - C_3F_8 , CF3I, CF3Br
  - hydrocarbon
  - Noble liquid
- Only Nuclear Recoils nucleate bubbles
  - Intrinsic γ, β rejection
- Alpha Decays Tagged
  - Acoustic discrimination

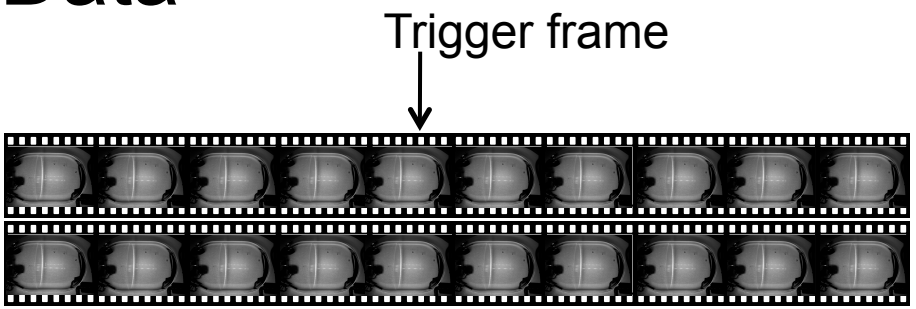


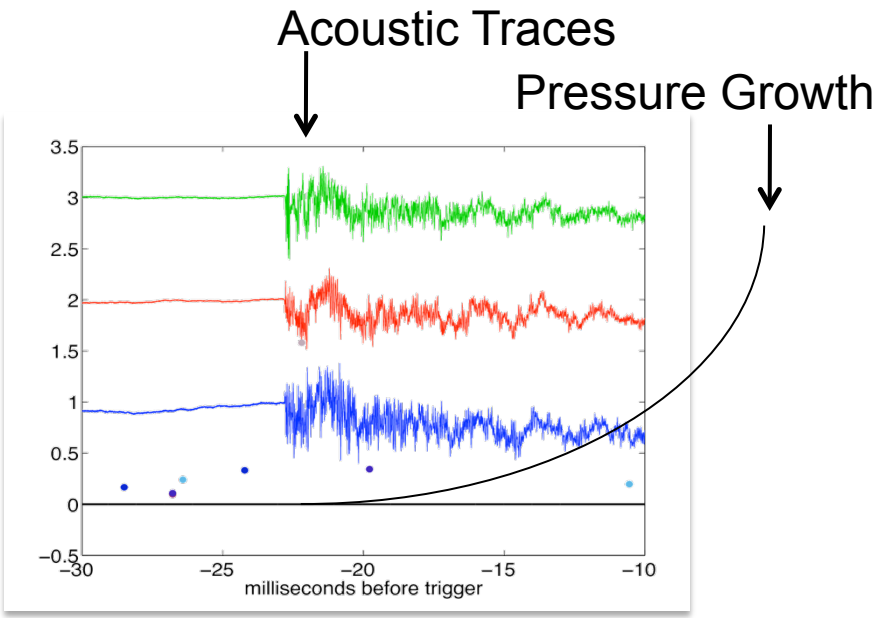
Bubble Chamber Operation Cycle



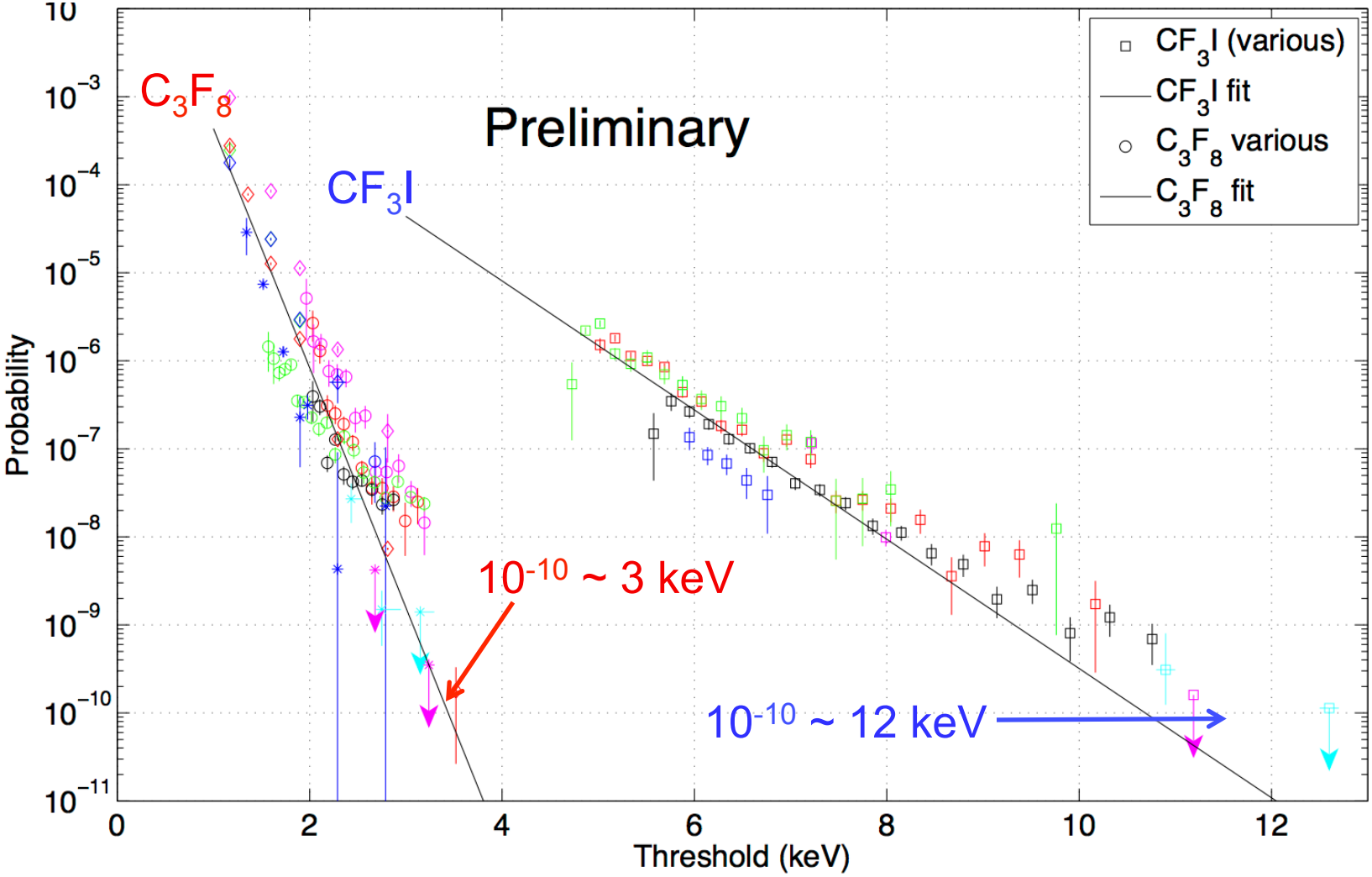
The Data

- 10 frames of Stereo Camera Images
- Synchronized measurements of P, T, and control parameters
- 2.5 Mhz waveform digitizer for acoustics and fast pressure transducer.





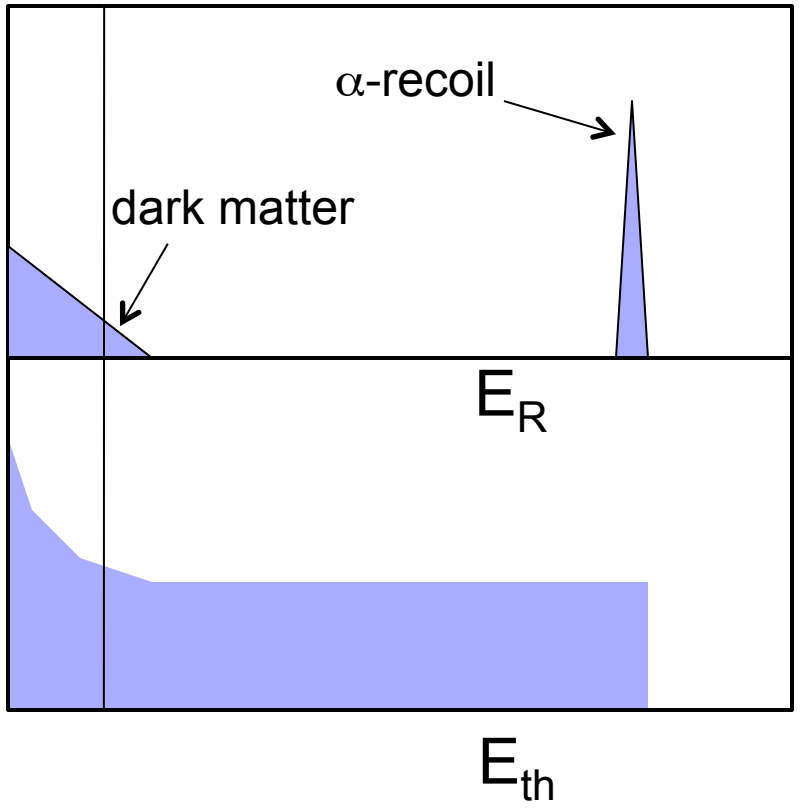
Gamma Rejection Measurements



The Bubble Chamber is a Threshold Device

We do not measure E_R…

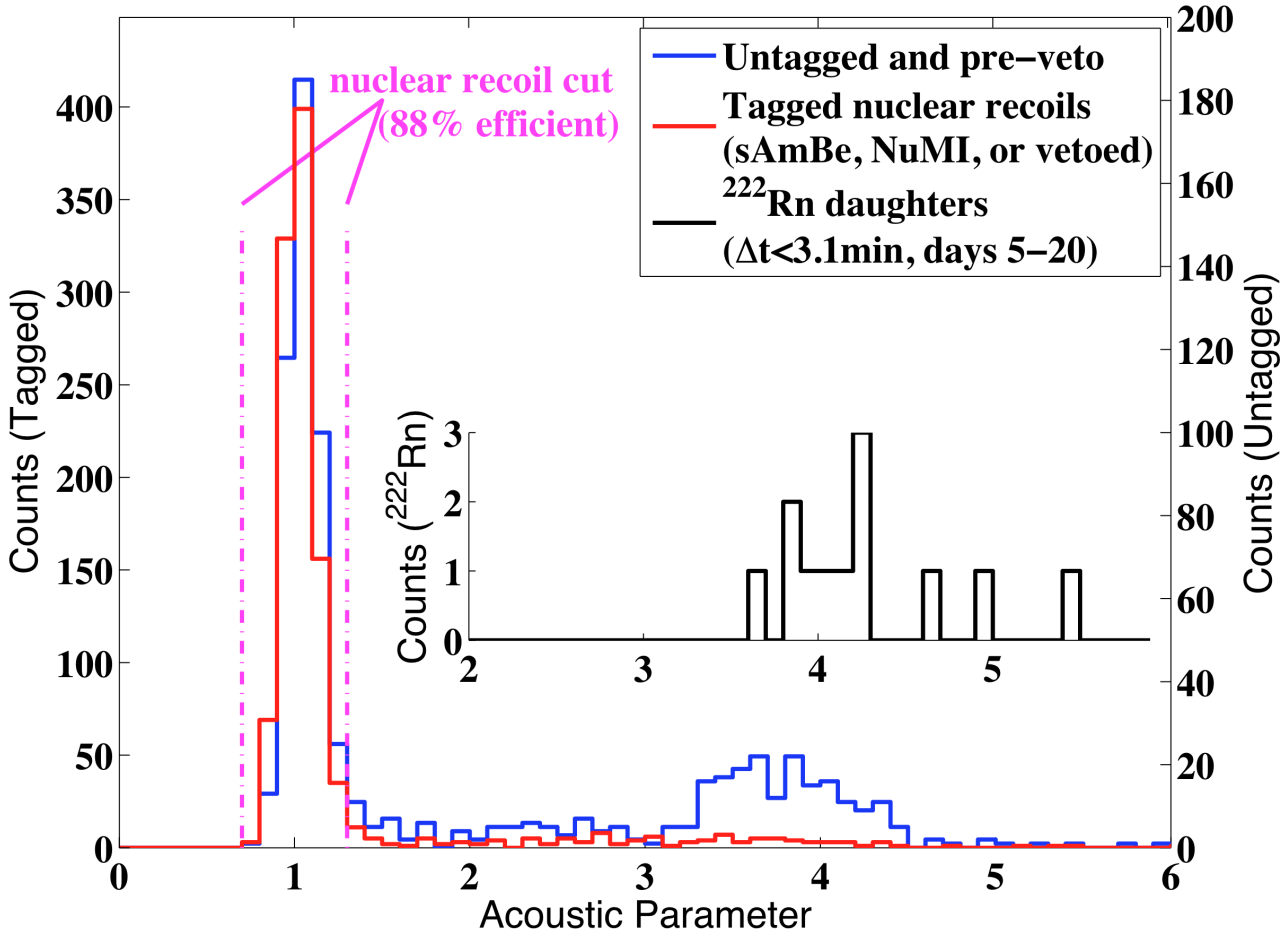
…we measure $\int_{E_{th}}^{\infty} \frac{dN}{dE_R} dE_R$



…so bubbles initiated by recoiling α-decay daughters are counted along with dark matter candidate events.

Acoustic Parameter

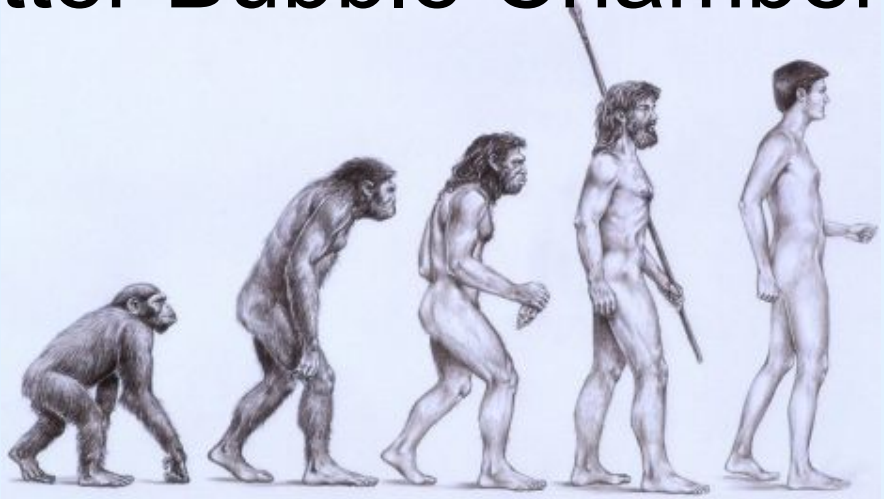
- (Amp • ω)^2
  (Normalized and position-corrected for each freq-bin)
- Measure of acoustic energy deposited in chamber
- Alphas are louder than neutrons

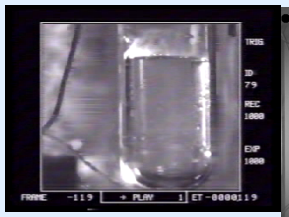


Dark Matter Bubble Chambers

- Insensitive* to γ and β backgrounds
- Threshold device, integral distribution
- Event-by-event tagging of α-recoils
- Only background should be neutrons

Dark Matter Bubble Chamber Evolution

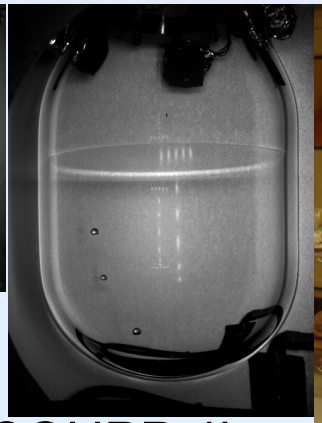




Test tube

COUPP 2kg

PICO 0.01



COUPP 4kg

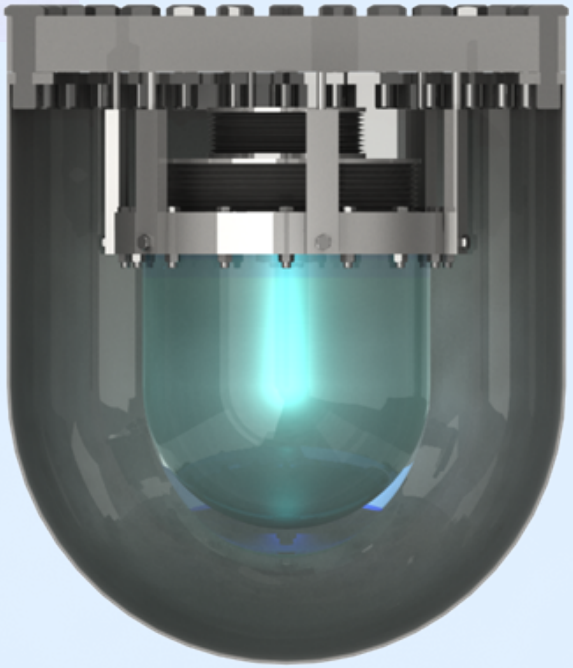
PICO 0.1

COUPP 60kg

PICO 1liter

PICO 2liter

PICO' 2liter



PICO 250 liter

PICO

SNOLAB
Mining for knowledge
Creuser pour trouver... l'excellence

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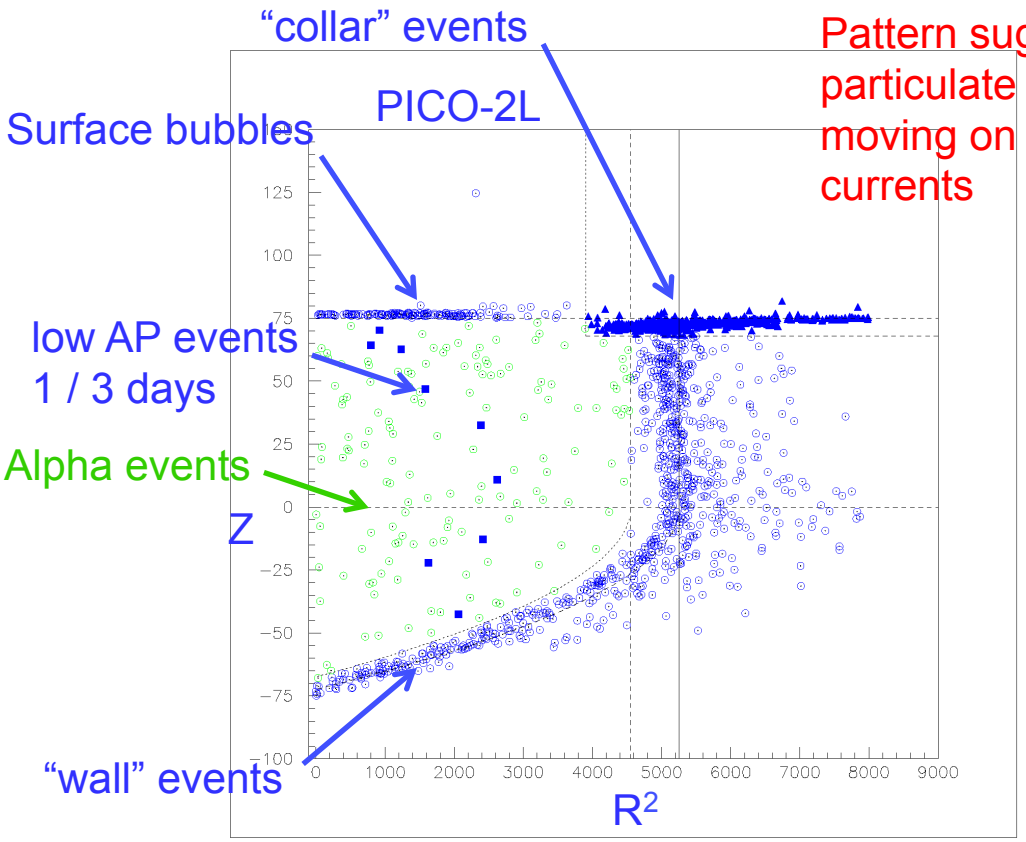
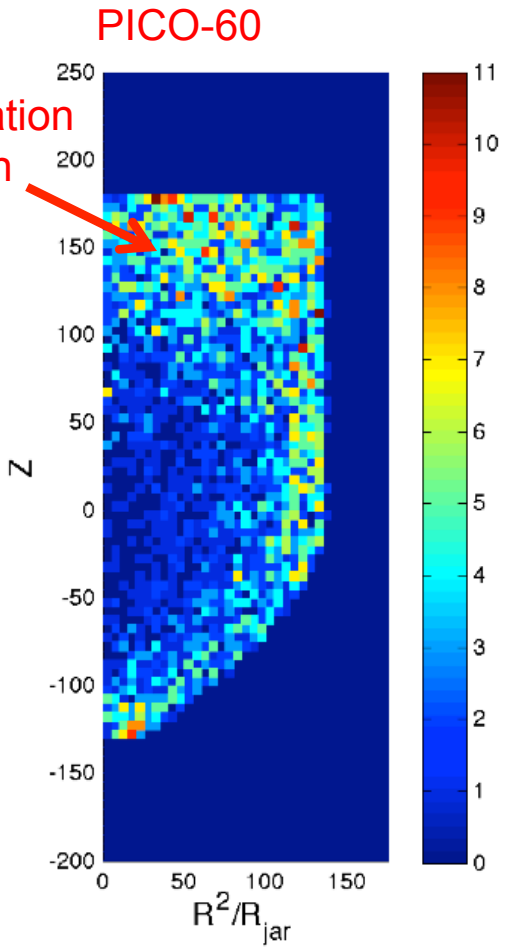
Anomalous Low-AP Backgrounds

- First observed in COUPP-4kg CF_3I (2010)
  - events correlated in time, not dark matter
- Re-confirmed in COUPP-4kg CF_3I (2012)
- High statistics in COUPP-60 CF_3I (2013)
- Still present in PICO-2L C_3F_8 (2013)

Low AP backgrounds in PICO



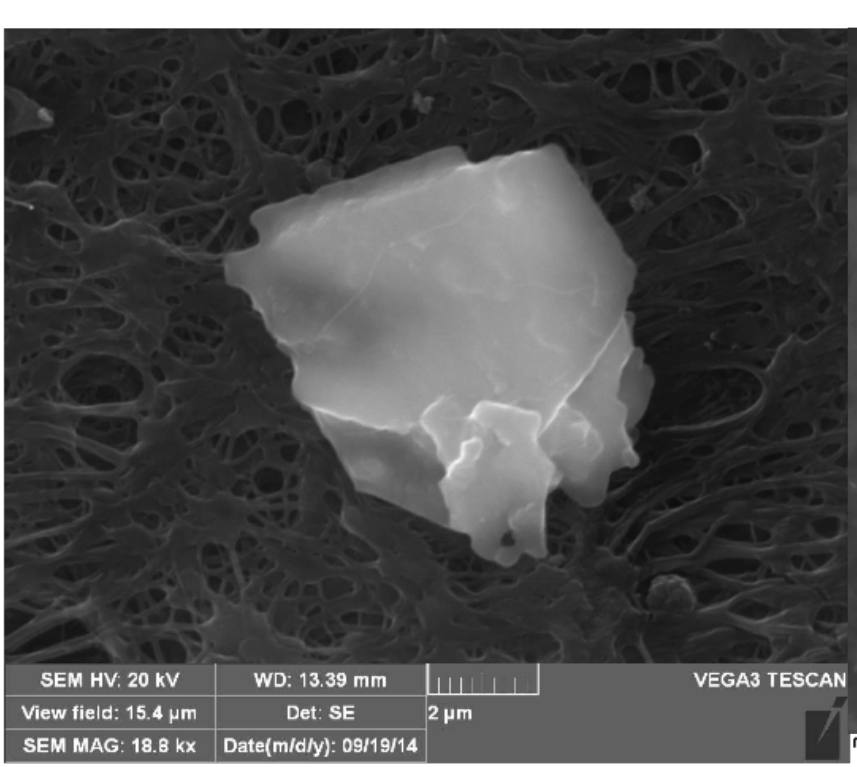
Pattern suggests particulate contamination moving on convection currents

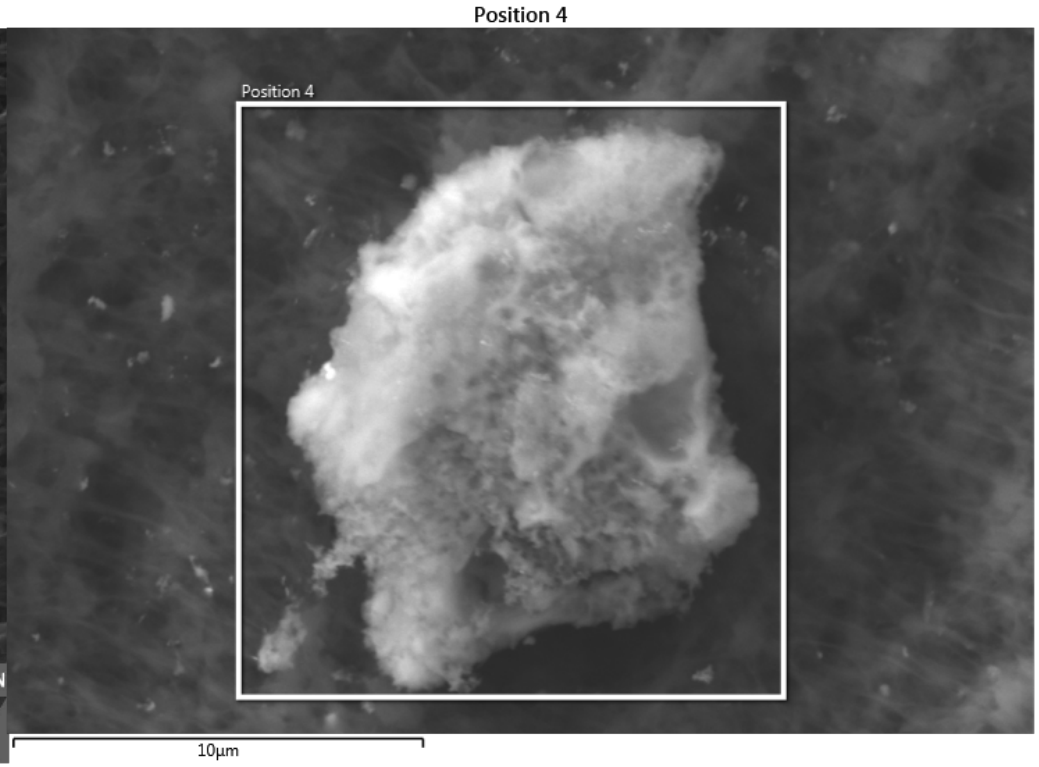


Low-AP Backgrounds Four Step Program

- Assay
  - analyze the contamination in the chambers
- Reproduce
  - add contamination to test chambers
  - reproduce the low-AP events
- Mitigate
  - Control the particulates in the existing chambers
- Eliminate
  - Revised Bubble Chamber Design

Assay result: Particulate contamination





Quartz

Steel

Particulate contamination = construction material

Assay Results

- Particulate Inventory Reflects Construction Materials
  - Steel and metal oxides
  - Silica
  - *Water*
- 10x more steel that silica
  - But silica is typically 100-1000x more radioactive
- Sufficient Radioactivity (Th) to explain rate
- Water is a wild card

Reproduction of backgrounds

- Ongoing work at Queen's University, Northwestern University
  - Add silica and metallic particulates to test C_3F_8 bubble chambers
  - Success in reproducing surface, collar rates
  - Gamma sensitivity from Auger cascades

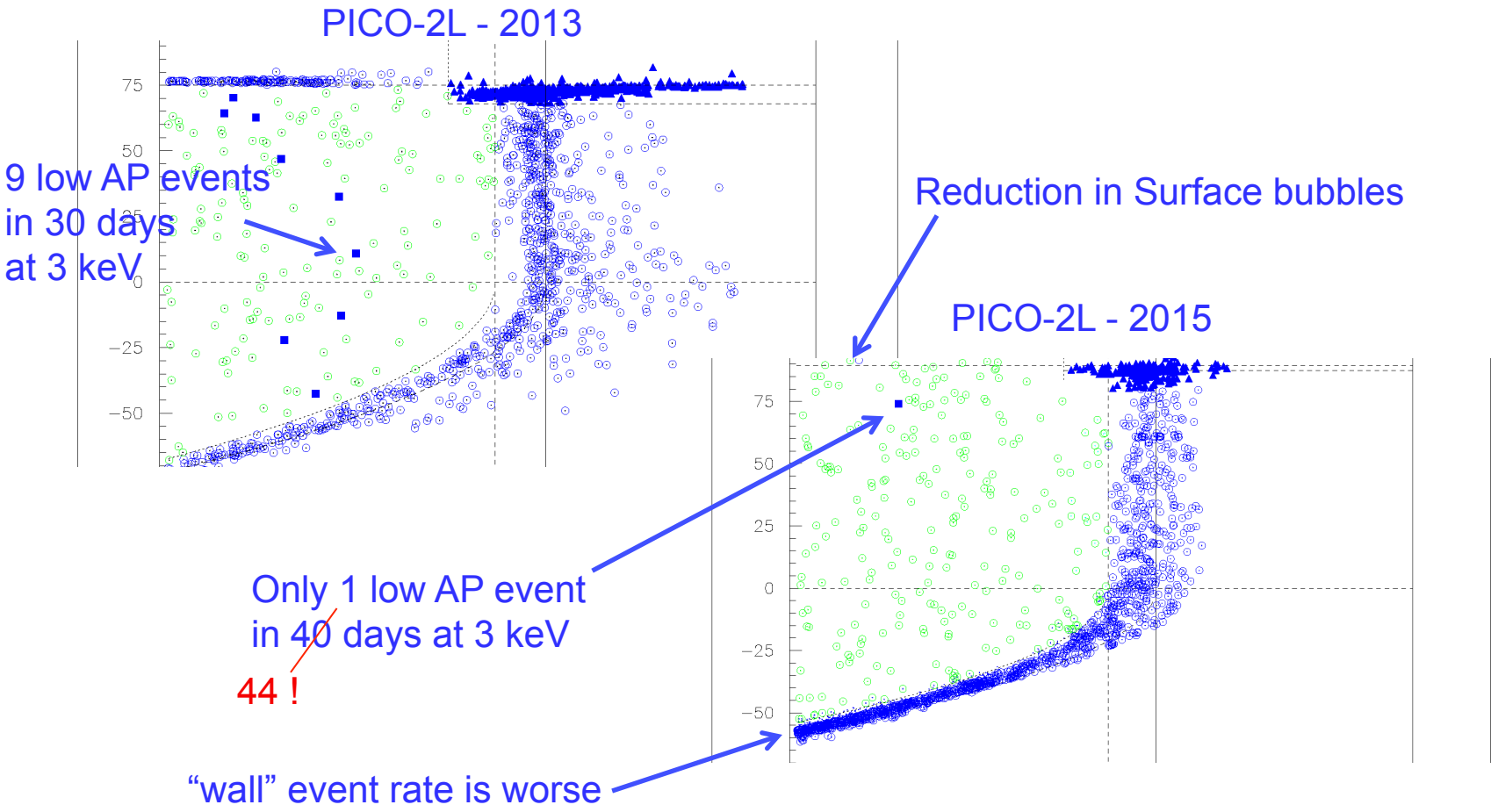
Mitigation options

- Fused silica flanges, Lower stress seals
  - reduce silica activity, reduce particulate emission
- Plastic coating or lining for bellows
  - Suppress corrosion, metallic particulate
- Alternate buffer fluids (LAB)
  - Lower density, reduced surface tension
- Active Recirculation and Filtering

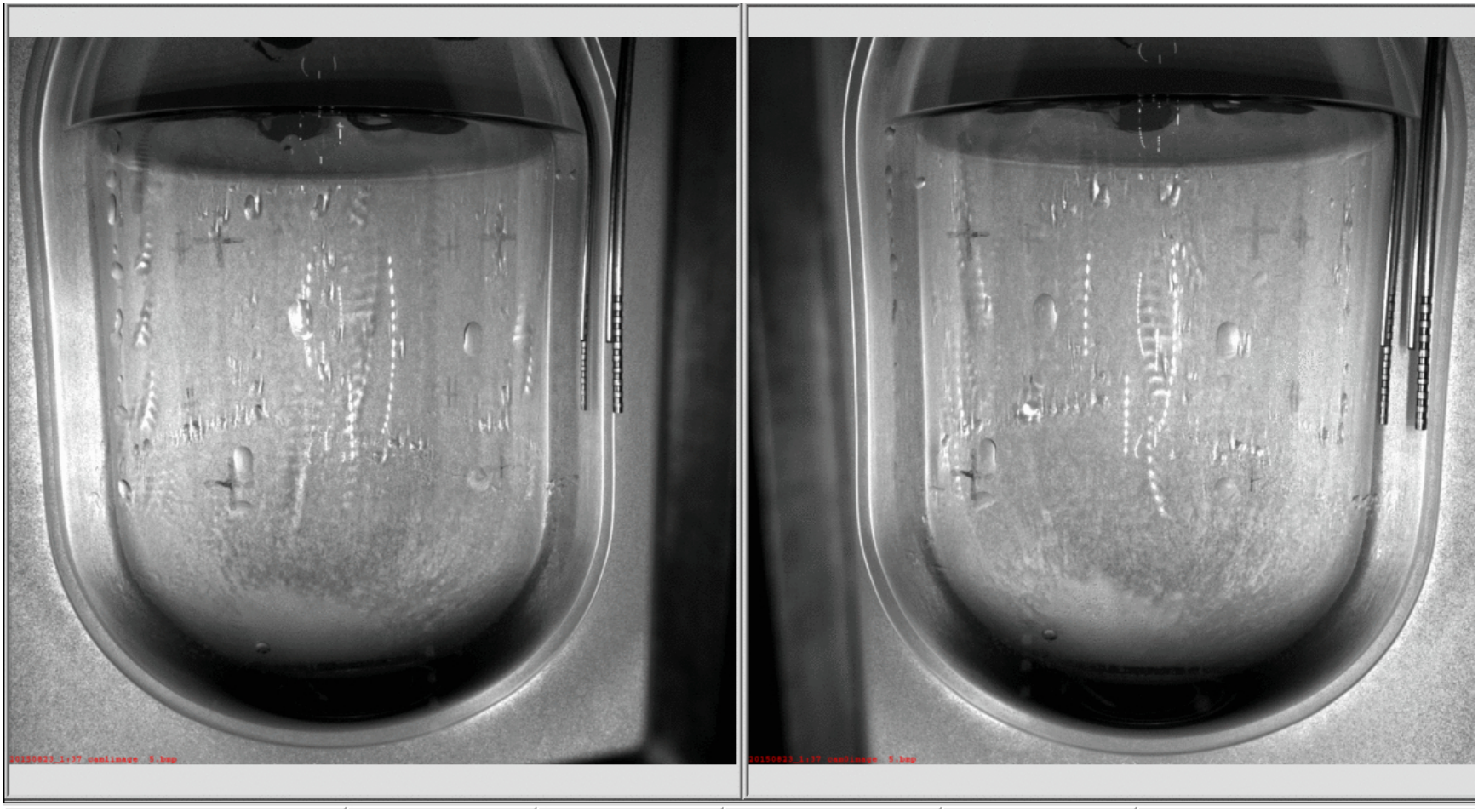
Mitigation first try:

- New PICO-2L Run
  - New fused silica flange only
  - Eliminate exposure to scroll vacuum pump
  - Careful assessment of initial cleanliness
    - To compare to post-run assay
- Bellows, water buffer unchanged
- First of possible 3 planned runs
  - Plastic Bellows Liner
  - Water Replaced by LAB

PICO-2L Results: First Look



PICO-2L 2015 typical event



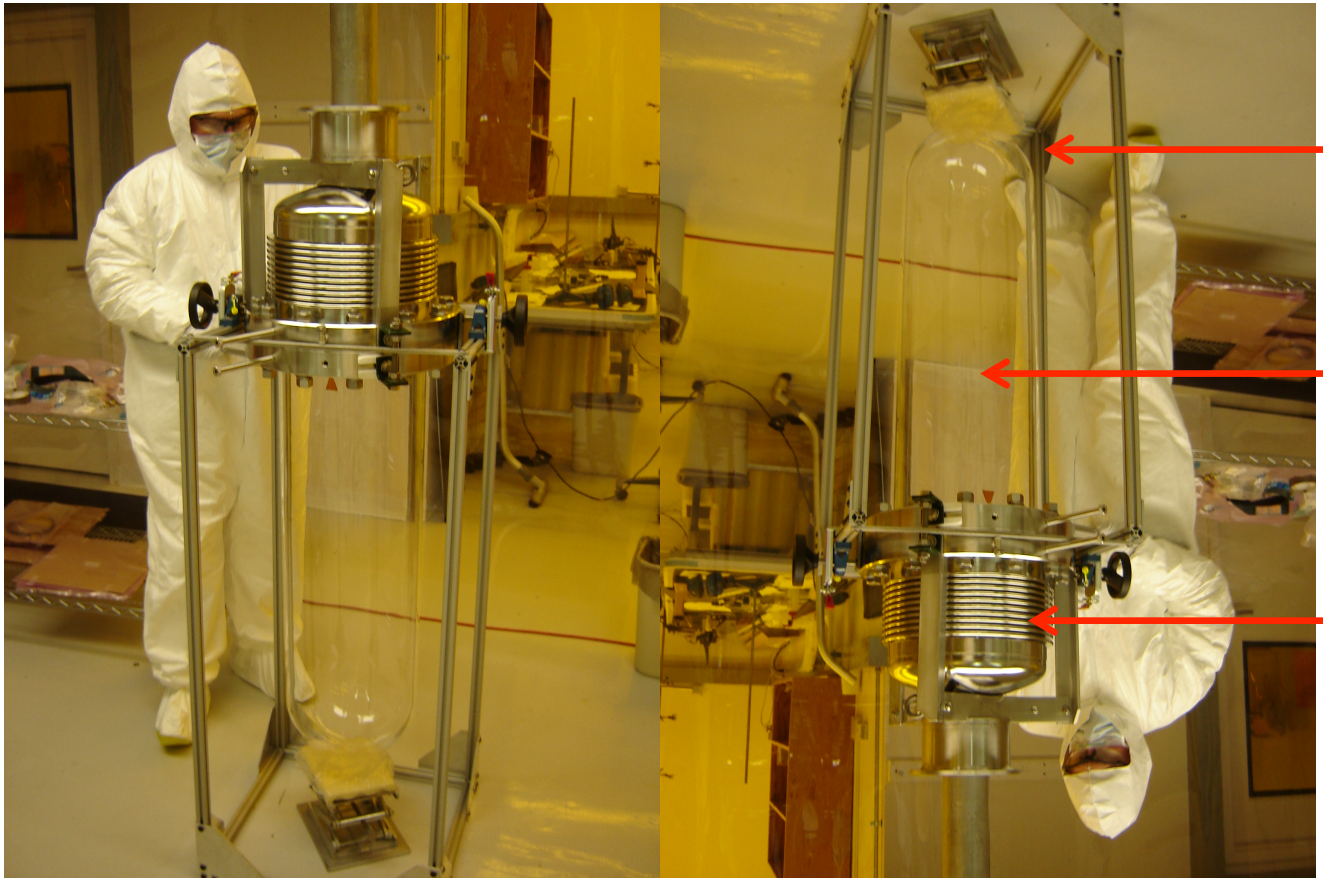
Interpretation of PICO-2L Results

- Radioactive quartz dust likely leading source of low-AP backgrounds
- Water is a bad actor in the chamber
  - Possibly a source of low-AP events as well…
- Steel particulate appears to be less effective at producing background
  - But avoid sprinkling it onto the target fluid from above…

Mitigation Future

- PICO-2L background too low to study
- Process continues with PICO-60
  - Coat or line the bellows with plastic
  - Replace water with LAB
  - Active recirculation/filtering
  - Possibly leading to background free 40-liter device

The long term solution is to return to a "right side up" bubble chamber design



The original right side up chamber

- Waters, Petroff, Koski 1969
- COUPP turned this design upside-down and added the water buffer to build a larger scale device
- We need a better way to scale up from this design concept

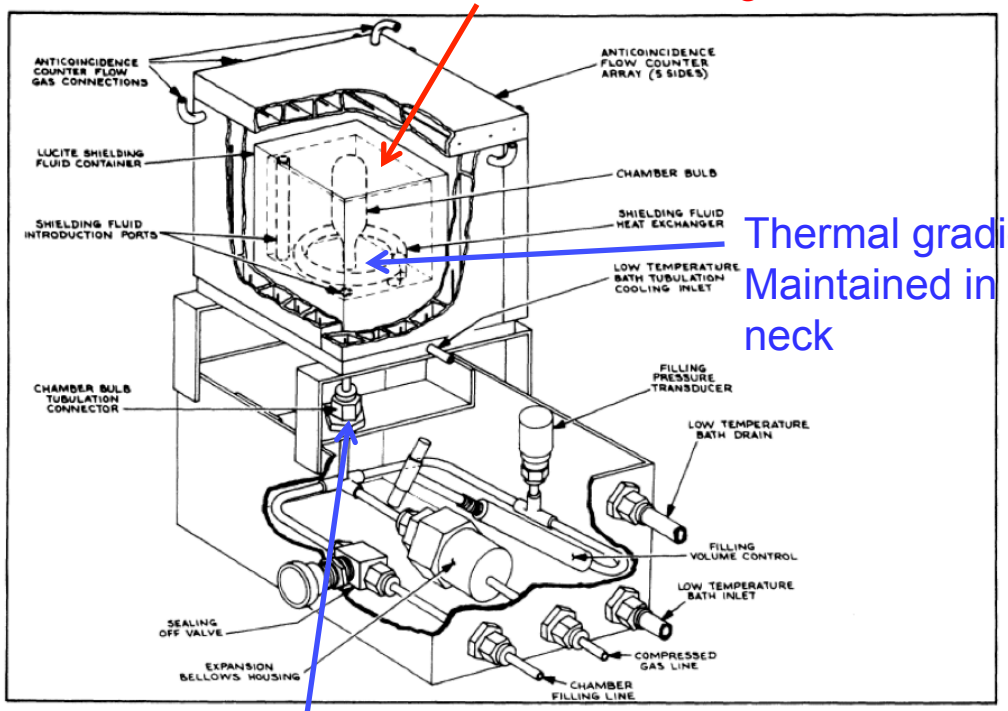


Fig. 1. Automatic Bubble Chamber with Anticoincidence Counter Array.

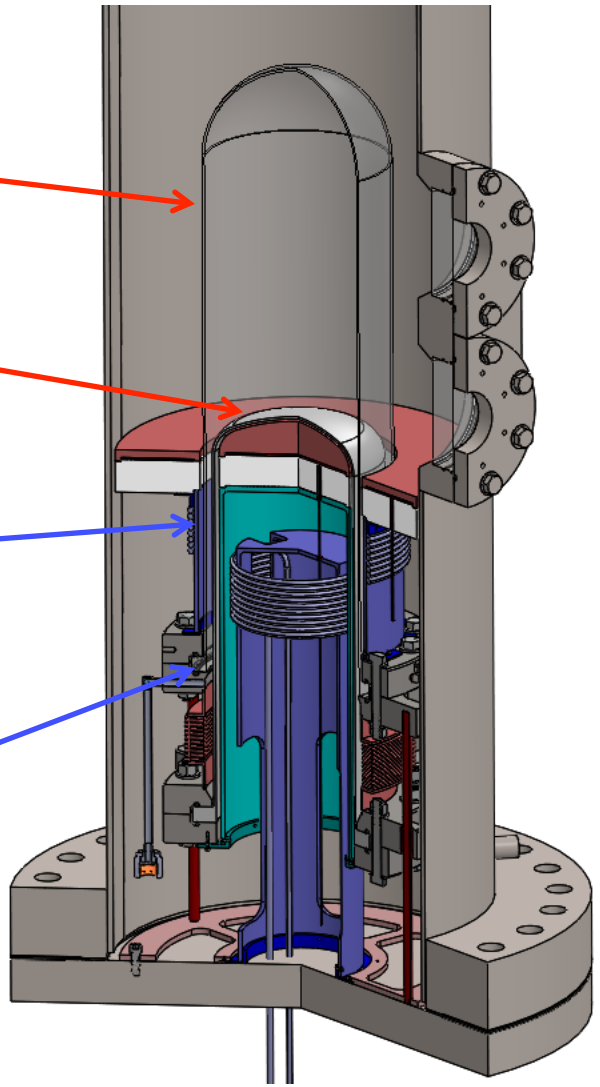
PICO-60 RSU

Warm active region

Water “piston” replaced by second fused silica (moving) vessel

Thermal gradient Maintained in thin annulus

Cold plumbing region



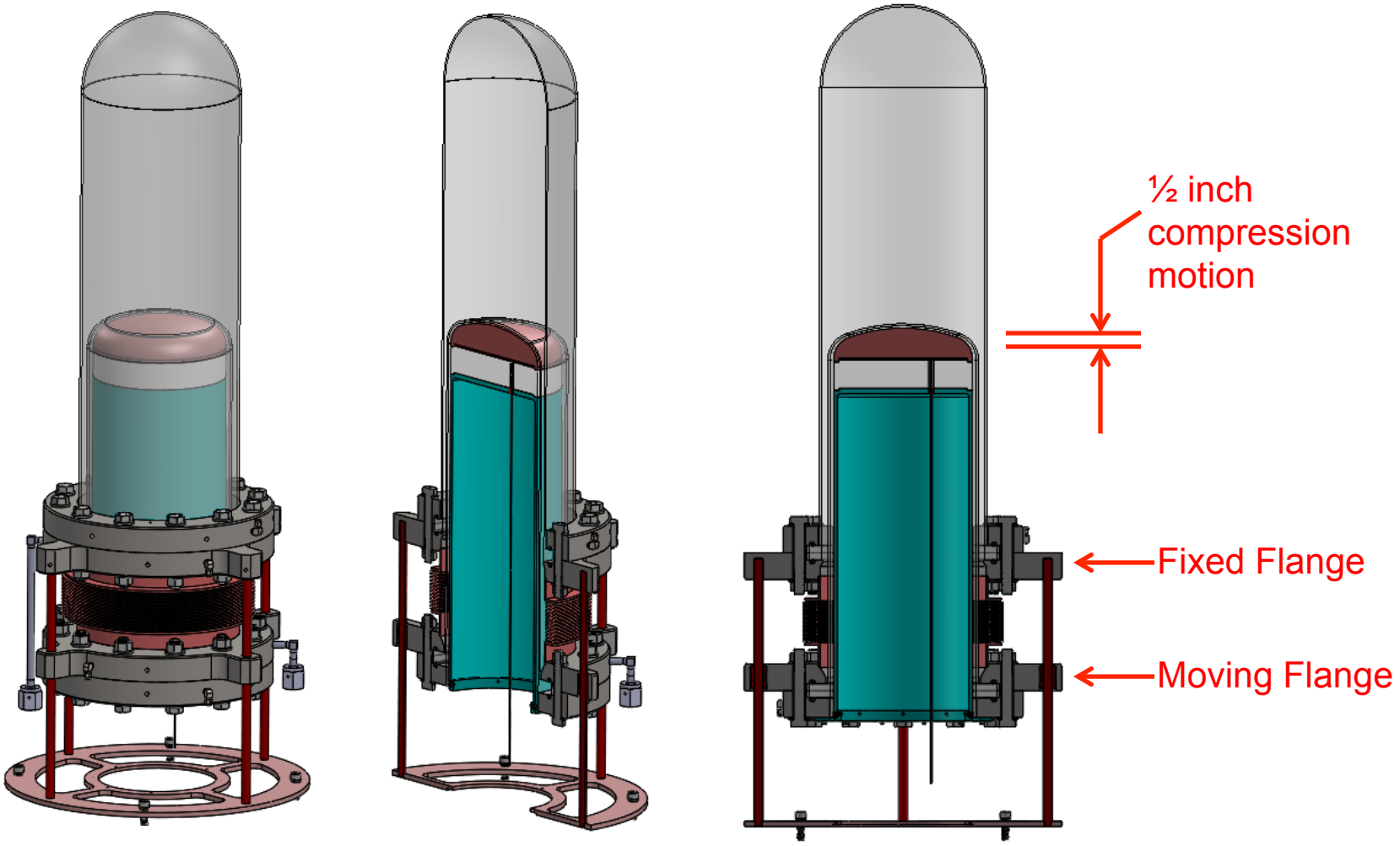
Right Side Up design virtues:

- Superheated/normal transition is maintained by a thermal gradient with no buffer fluid
  - No buffer fluid means no constraint on target fluid
  - Works with any refrigerant, hydrocarbon, even xenon.
- Thermal gradient is naturally stable
- All metals at the bottom
  - Cold zone, no boiling to liberate particulate
  - No convection to move particulate up
- Geometry naturally lends itself to a recirculation loop
- Design allows for low stress edge-welded bellows

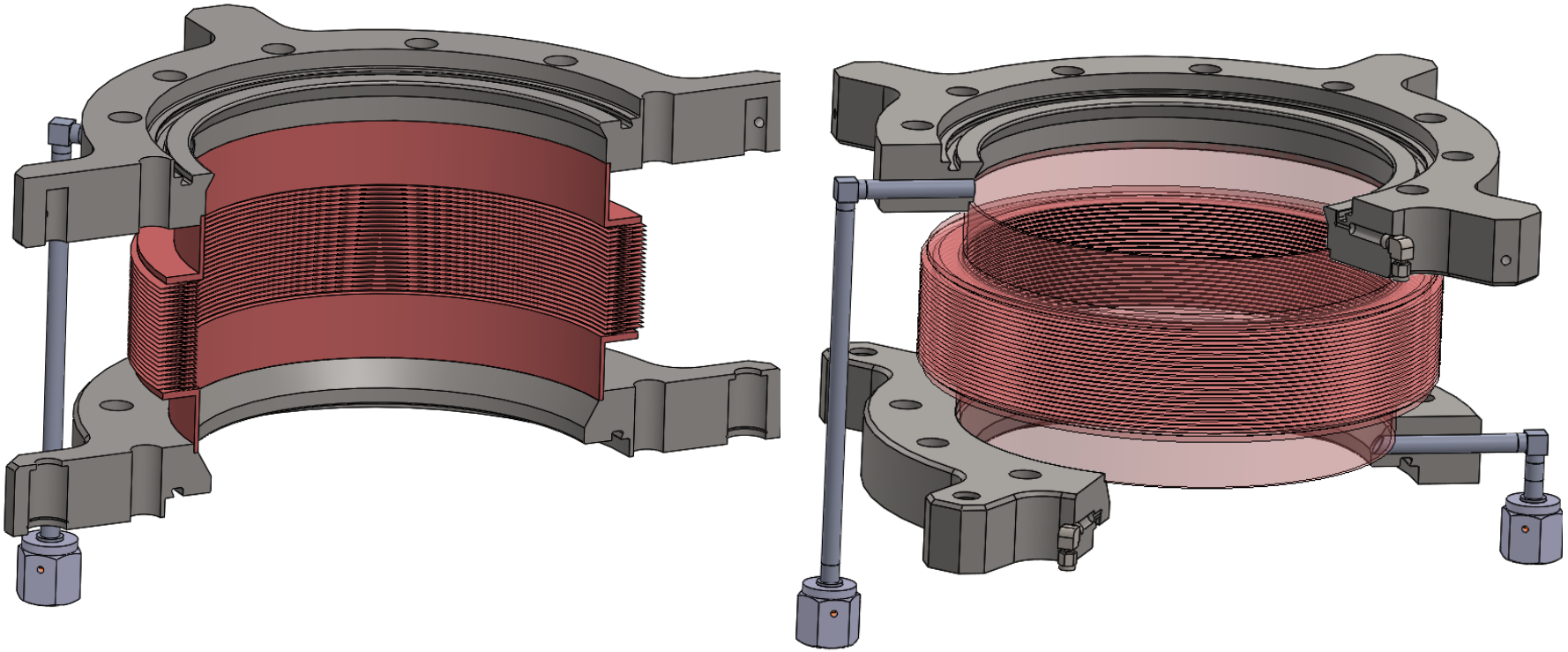
Conservative Design Approach

- PICO-60 parts
  - Inner vessel
  - Bellows and clamping flanges
  - Seals and vent port designs
  - PICO-60 pressure vessel

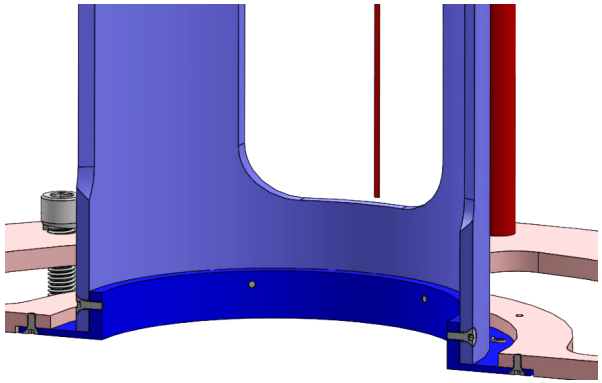
Inner Vessel Assembly

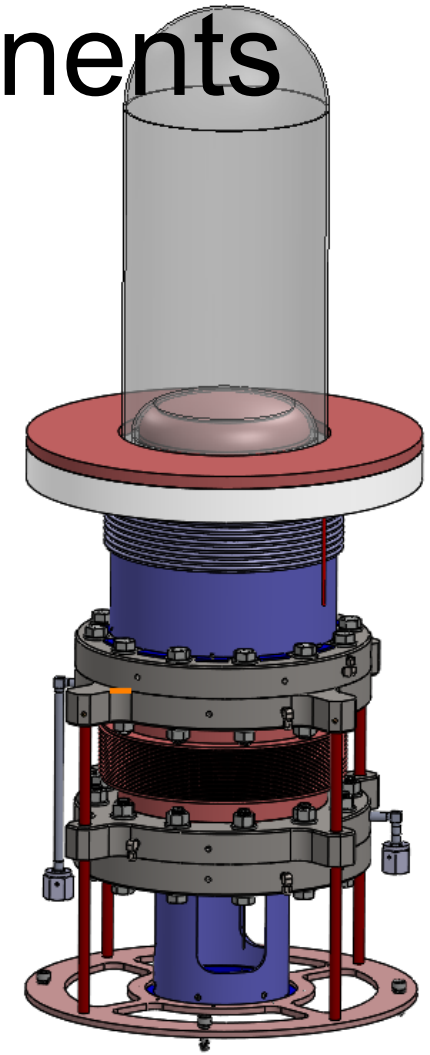


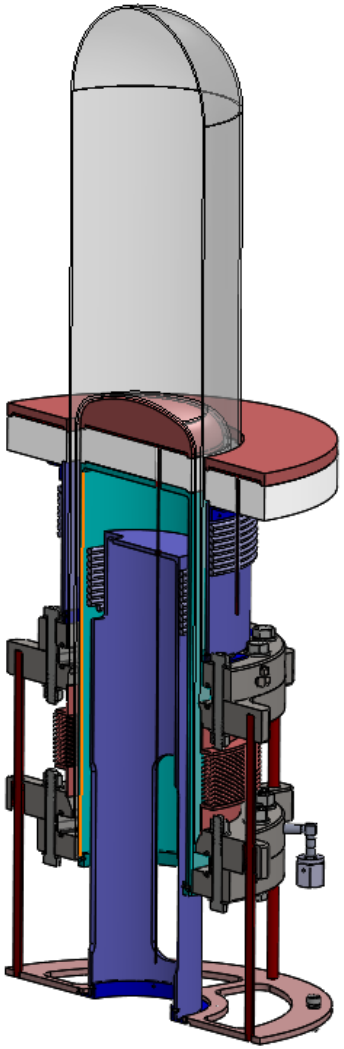
Bellows Detail



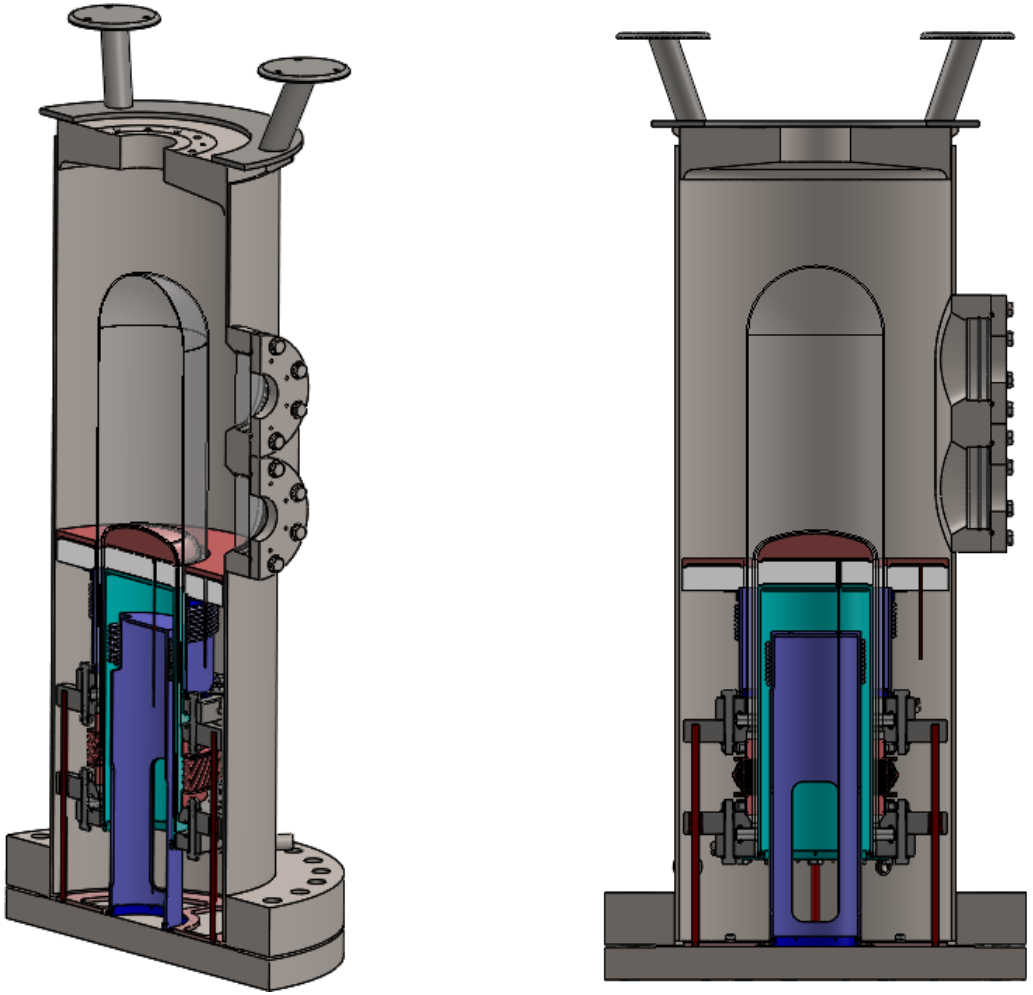
Cooling components







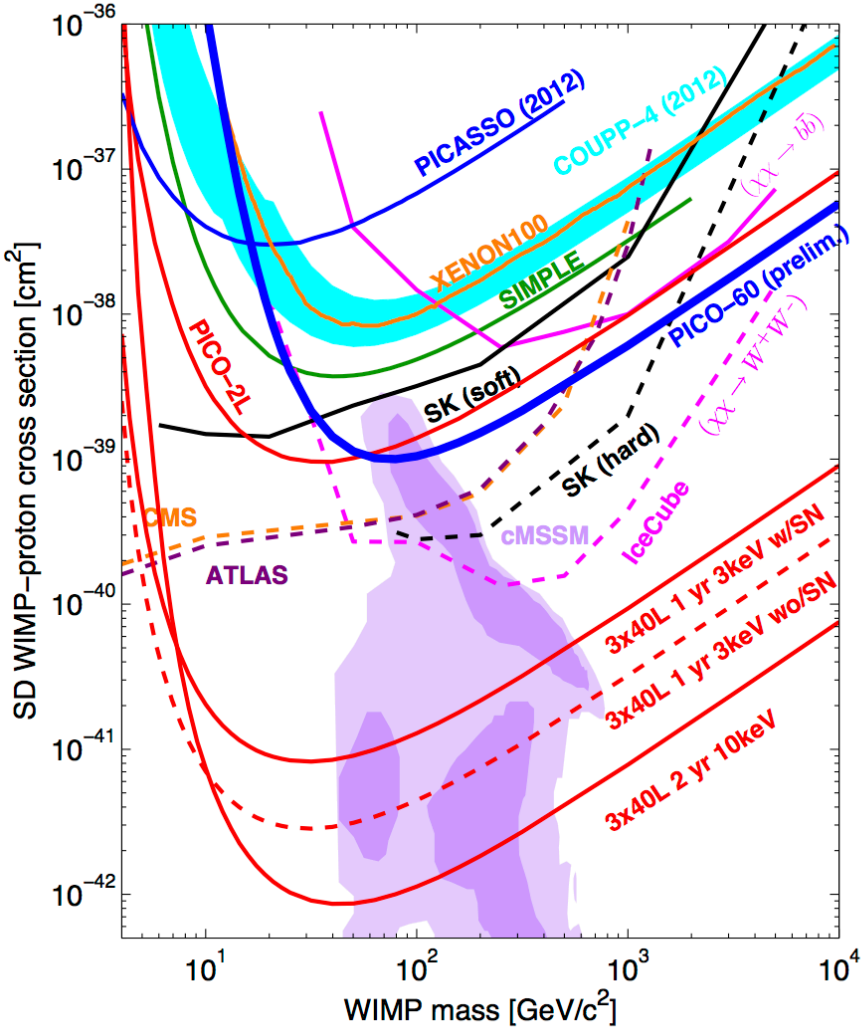
PICO-60 RSU assembled

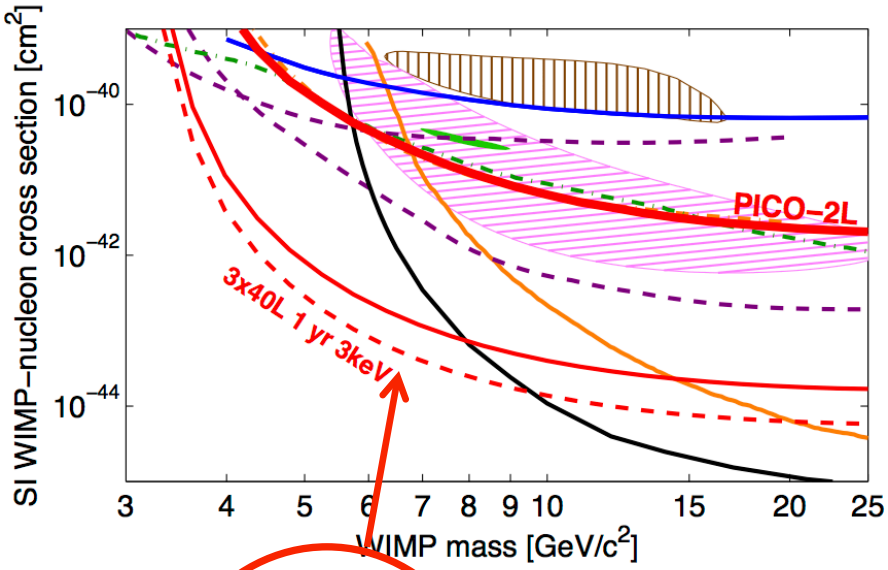


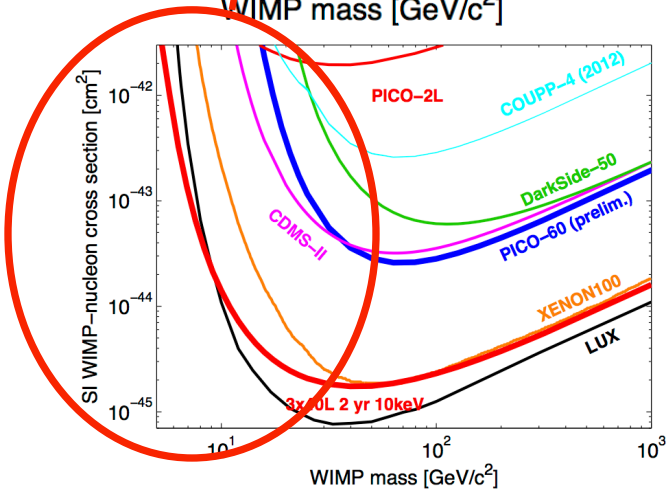
Incremental Commissioning

- Initially require small footprint at SNOLAB
  - Initial operation demonstration without shield
  - Expected to be operational late 2016
- Options
  - Could be a drop in replacement for PICO-60
  - Could be a second PICO-60 installation
    - Would require a second 3 meter water tank
  - Could be the first chamber in a 3 chamber array
    - Upgrade to ~ 5 meter tank

Dark matter reach (120 liters C_3F_8)







Longer Term (but not that long)

- Scale up to PICO-250 (or larger) device
  - Array of three ~250-500 liter bubble chambers
  - 750-1500 liters in one large water tank

- Broad spectrum of target choices