COUPP Iodine Recoil Threshold Experiment T1017

Hugh Lippincott for the COUPP Collaboration

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COUPP Collaboration

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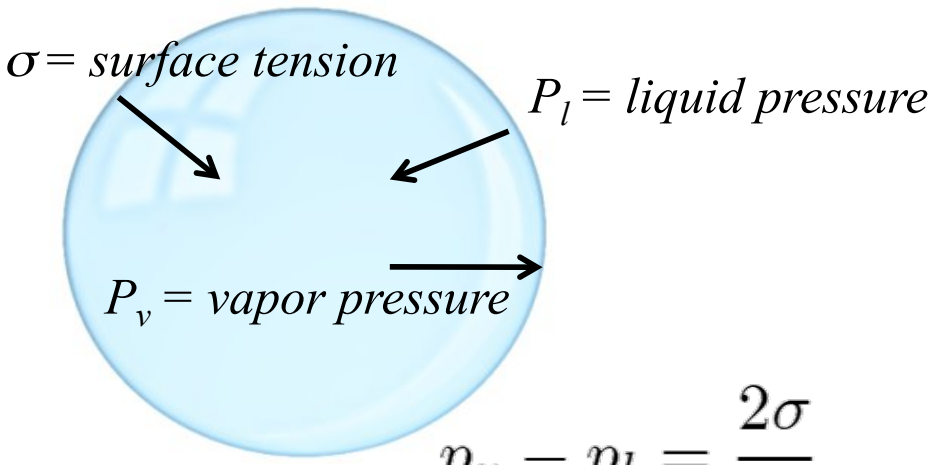
With support from:

Bubble nucleation theory (Seitz, Phys. of Fluids, **1**, 2 (1958))

- Bubbles form from proto-bubbles with radius $r > r_c$
- Requires energy deposition greater than E_{th}
- Recoil path length less than some length scale, R_c, related to critical radius



$$p_v - p_l = \frac{2\sigma}{r_c}$$

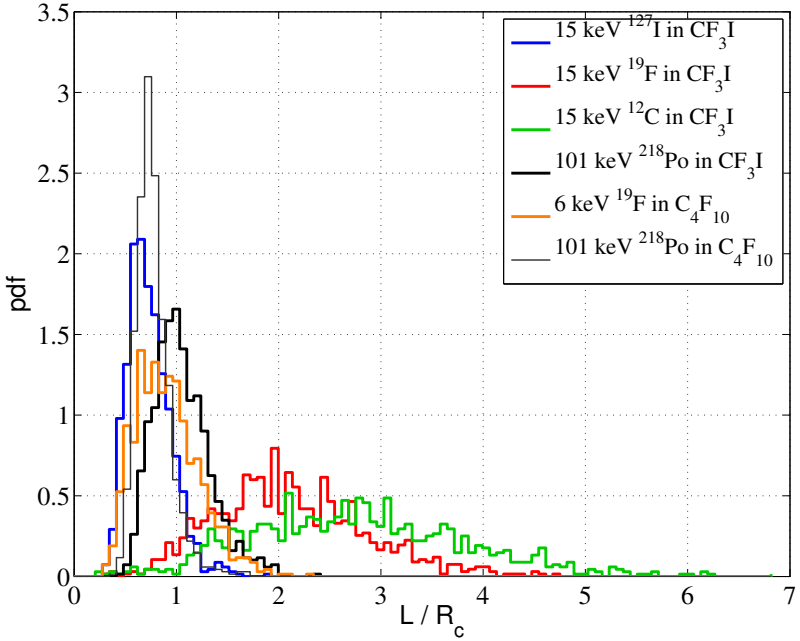
$$E_{th} = \boxed{4\pi r_c^2 \left(\sigma - T\frac{\partial \sigma}{\partial T}\right)} + \frac{4}{3}\pi r_c^3 \rho_v h$$

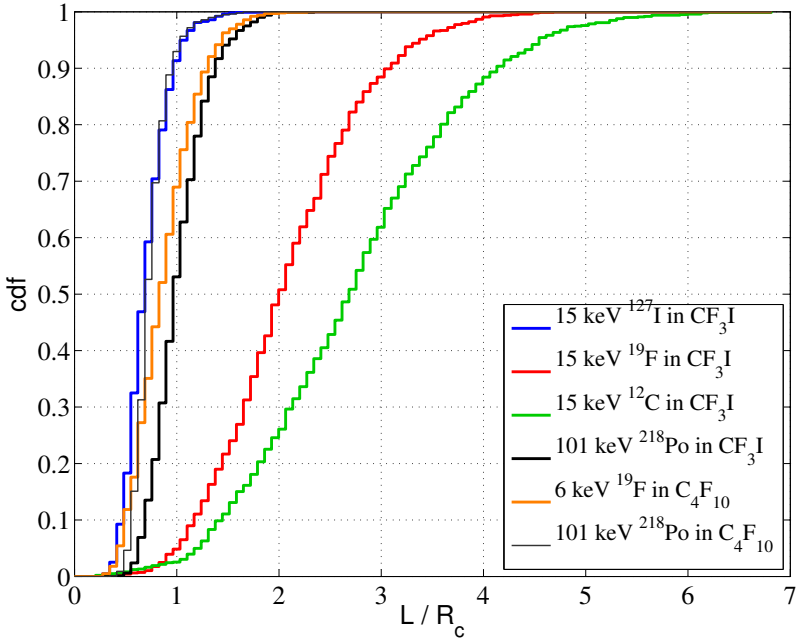
Surface energy

Latent heat

Threshold and efficiency

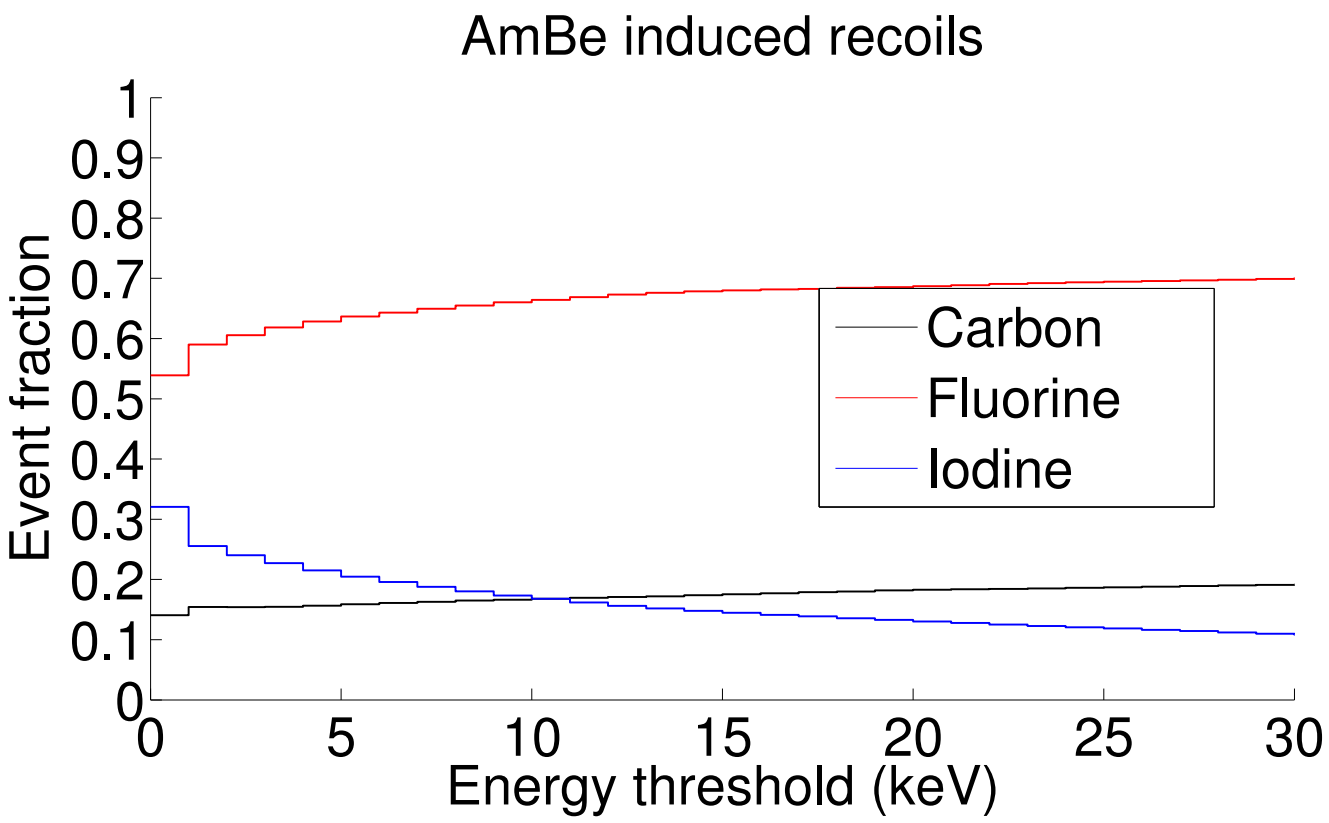
- Calibration remains necessary to validate the Seitz model and measure any threshold softness
- Complicated by the three different types of recoils in CF_3I, with very different track length scales





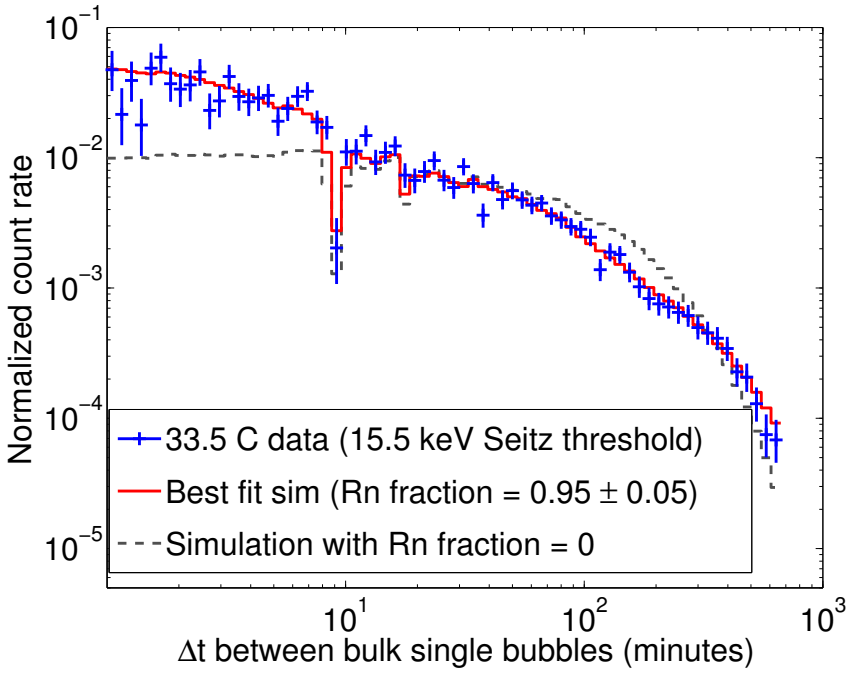
Threshold and efficiency of iodine

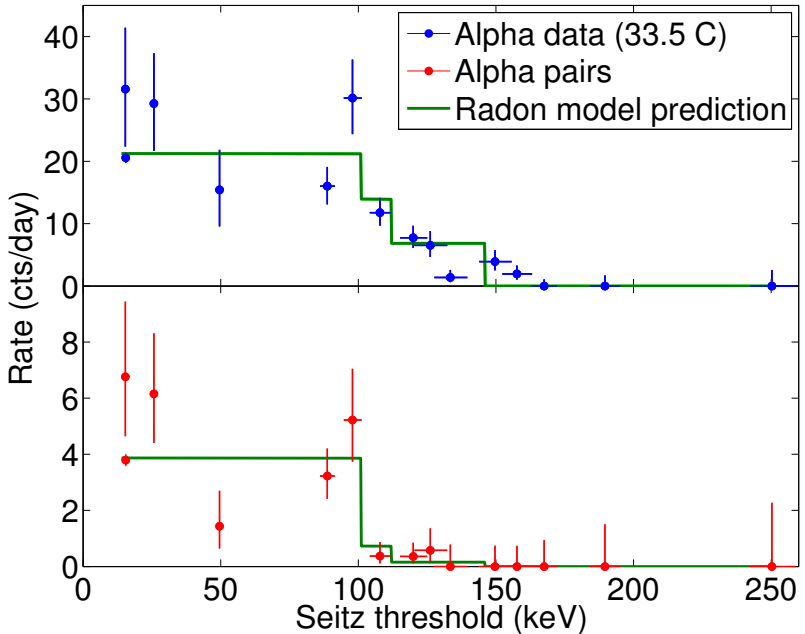
- Iodine provides main sensitivity to spin-independent interactions
- Use AmBe and ^{252}Cf neutron sources for calibrations
  - However, iodine recoils comprise only $\sim$ 15% of these events, with very few directly at threshold



Threshold and efficiency iodine

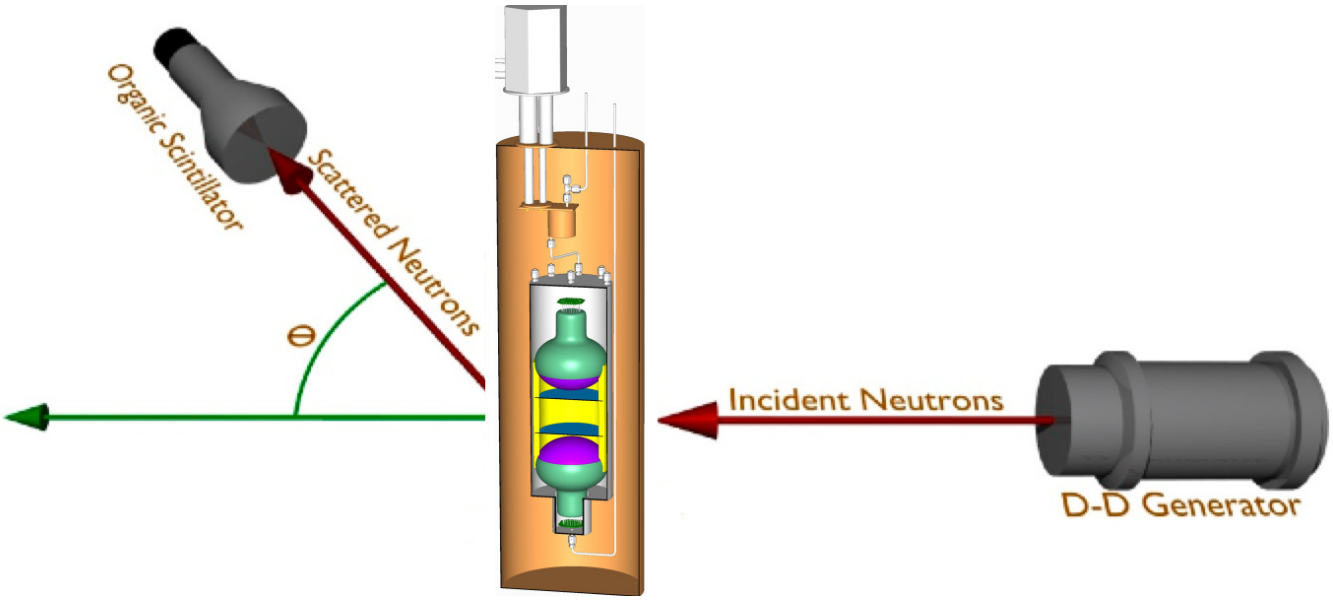
- Use radon daughters as proxy for iodine
- Consistent with 100% nucleation efficiency near threshold
- Needs explicit confirmation





Nuclear recoil calibrations

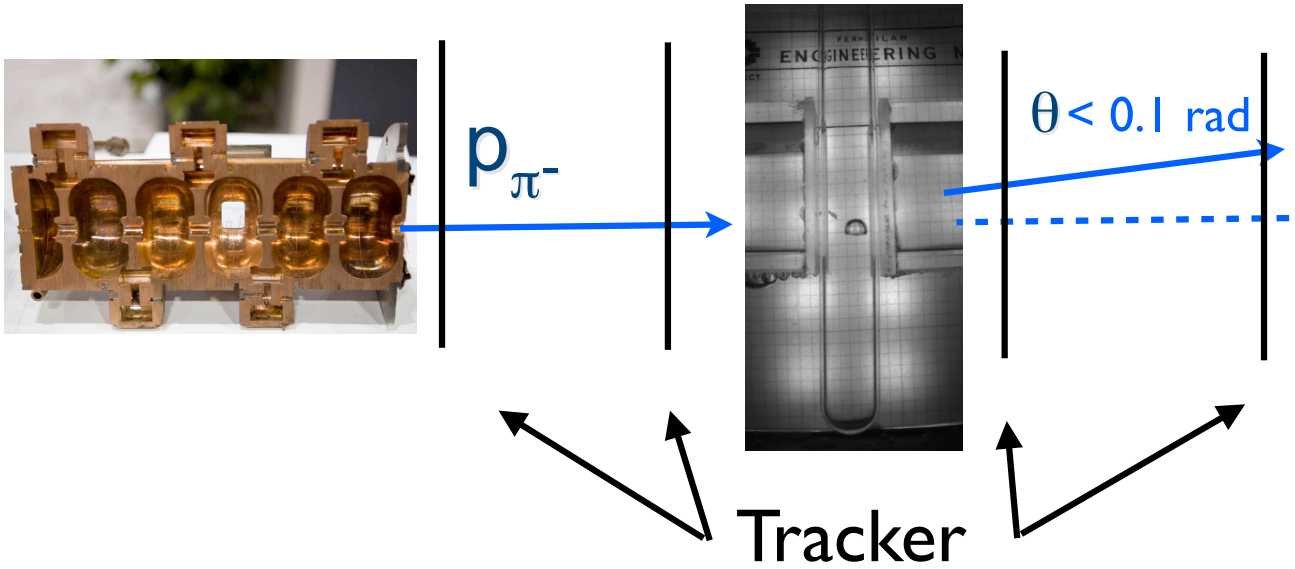
- Common problem in dark matter experiments
  - One method uses elastic scattering of monoenergetic neutrons (e.g. L_{eff} in noble liquids or calibrations of superheated droplet detectors by Picasso)



$$E_{recoil} \approx \frac{2 m_N m_r E}{(m_N + m_r)^2} (1 - \cos\theta)$$

Alternate approach

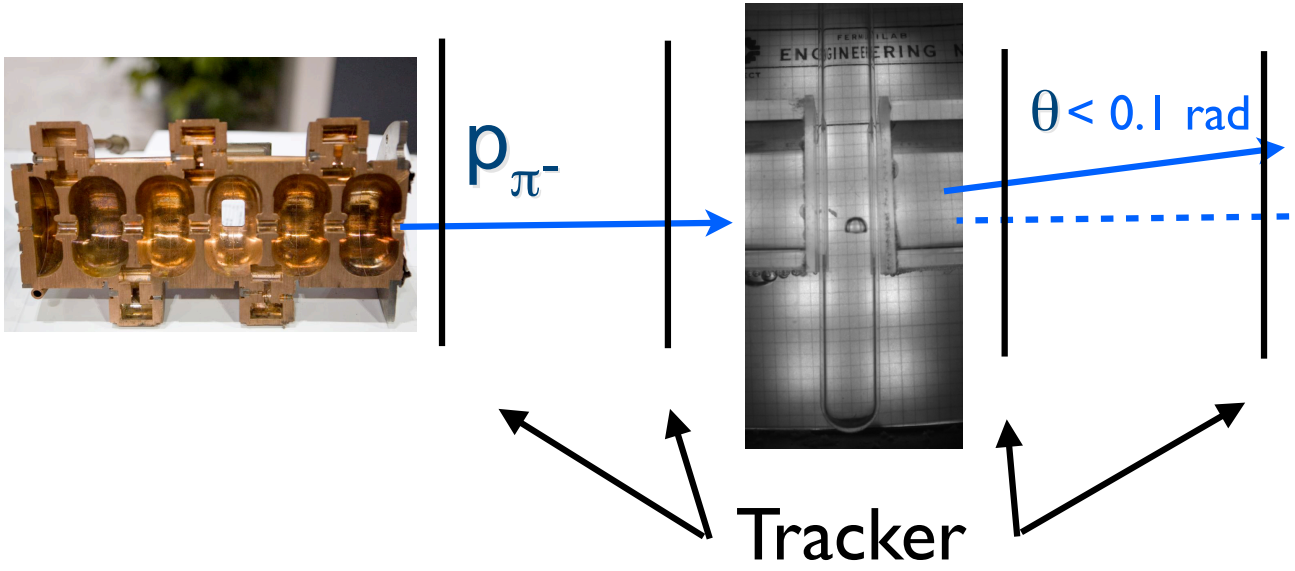
- Superheated fluids are unique among dark matter detectors- they are insensitive to MIPs
  - Allows for elastic scattering of high momentum charged particles - can be tracked with very high precision



$$T = E_{recoil} = \frac{(p\theta)^2}{2m_r}$$

Pion elastic scattering

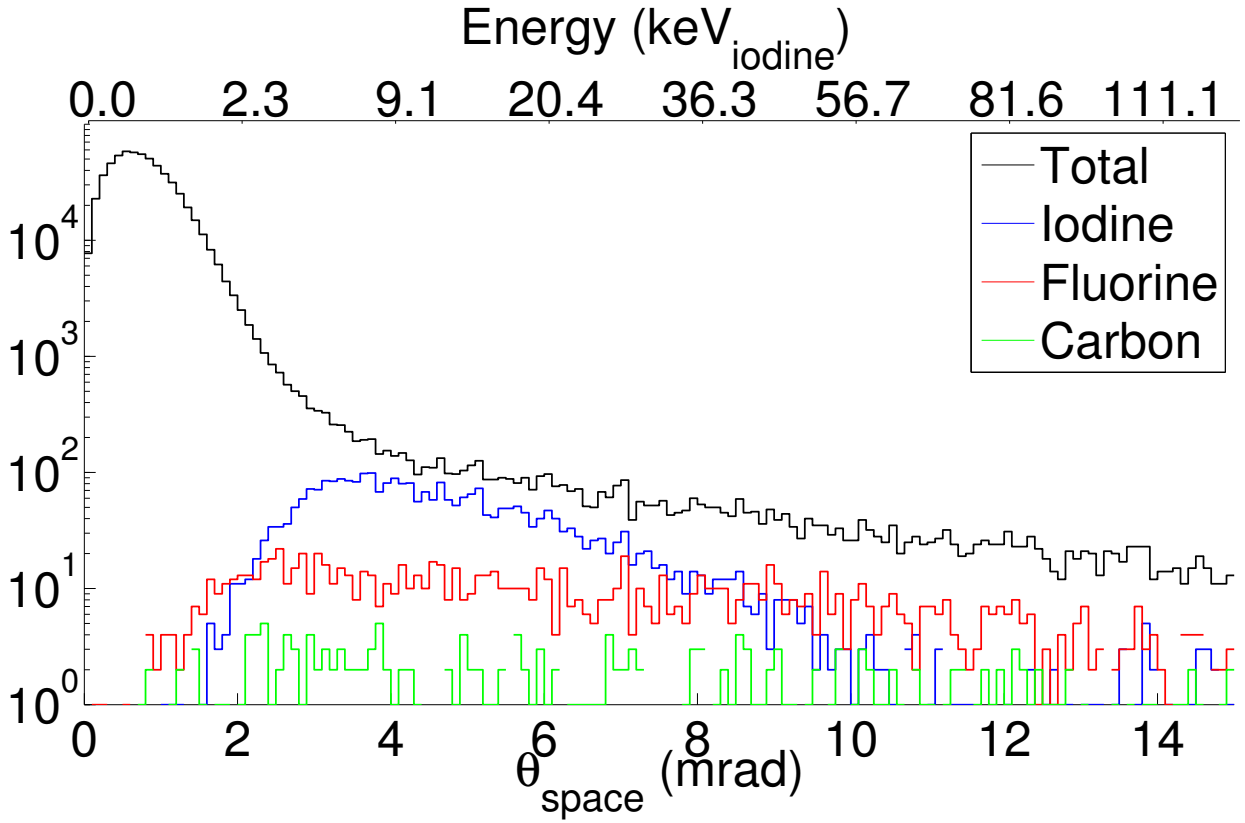
- For 12 GeV π, 15 mrad $\rightarrow$ 125 keV iodine recoils
  - Can measure 0-125 keV recoils at the same time - impossible with tagged neutron scattering (particularly with bubble chambers)
- Tracking gives us event by event energy information which bubble chambers normally cannot provide



$$T = E_{recoil} = \frac{(p\theta)^2}{2m_r}$$

How does this address iodine recoils

- Neutron calibrations give us integral spectra dominated by carbon and fluorine
- With pion beam, we can measure energy event by event and explicitly at threshold
- Moreover, iodine is dominant at low recoil energies because C and F are diluted by the mass ratio ($E_r \propto 1/m_r$)



What do we need

- A tunable beam - Fermilab Test Beam Facility (http://www-ppd.fnal.gov/FTBF/)

What do we need

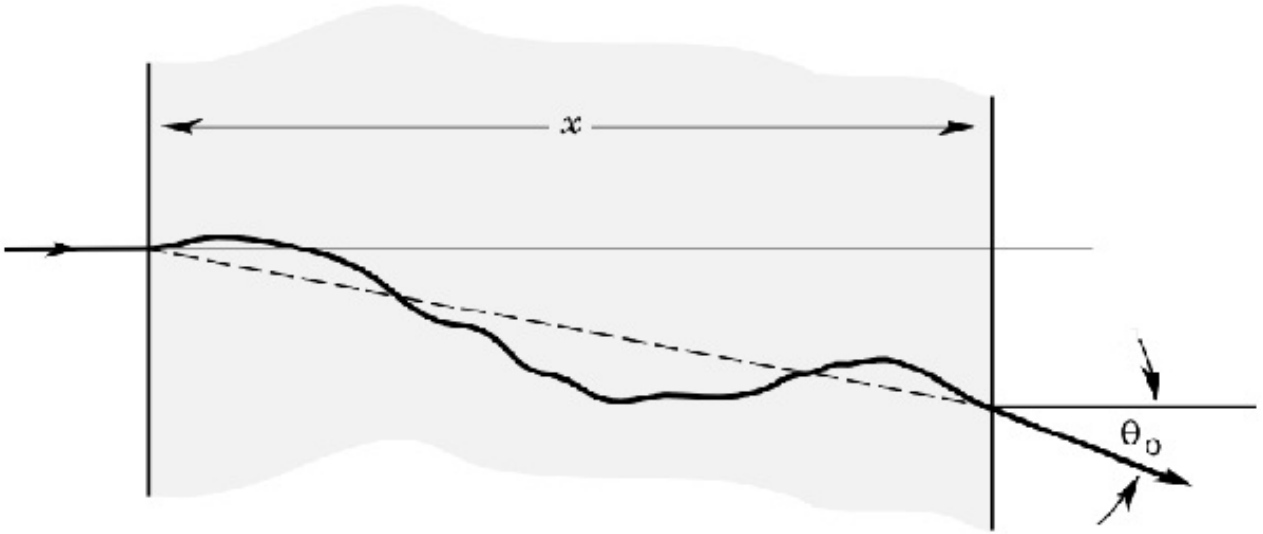
- Resolution - only significant instrumental uncertainty is on scattering angle θ

$$\frac{\sigma_{E_r}}{E_r} = \frac{2\sigma_\theta}{\theta}$$

- For 12 GeV π, $E_r = 15$ keV $\rightarrow \theta = 5$ mrad. We'd like $\sigma_\theta \approx 0.5$ mrad
- Scattering angle uncertainty determined by Multiple Coulomb Scattering (MCS) in combination with angular resolution of tracker

Multiple Coulomb Scattering

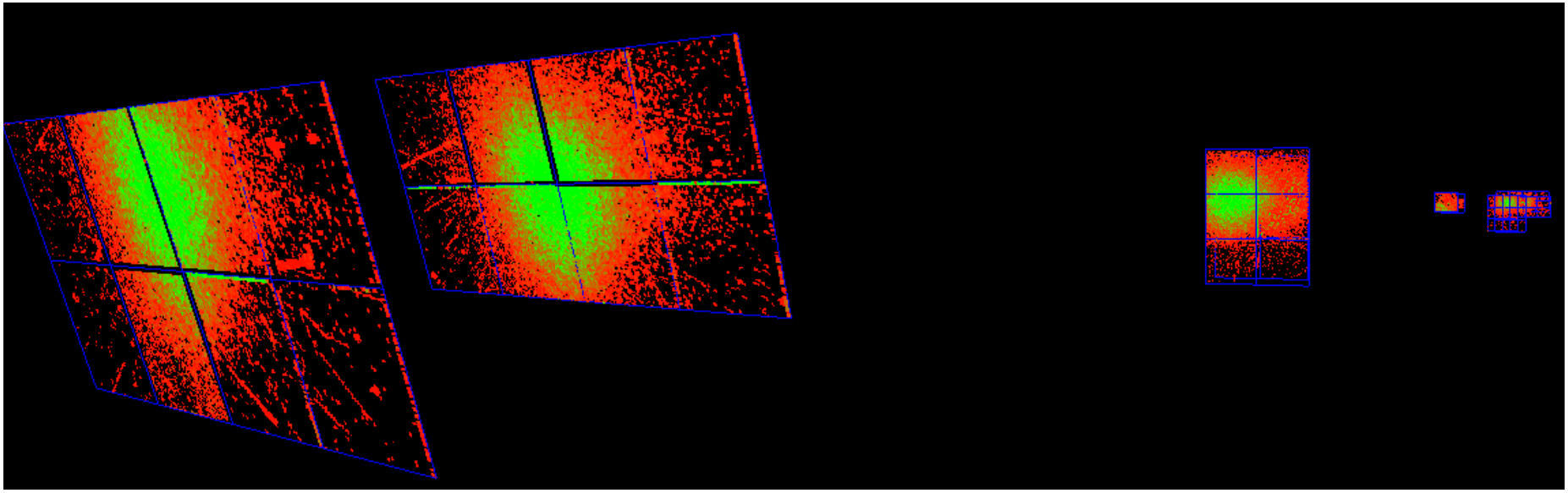
- Multiple Coulomb Scattering affects all charged particles traversing a medium



- Approximated by a Gaussian with width $\theta_{MCS} \approx \frac{13.6}{p}\sqrt{\frac{x}{R}}$ where x is path length and R is radiation length of the medium
- $R_{CF_3I} = 5.8$ cm, so for 12 GeV π, 1 cm of CF_3I, $\theta_{MCS} = 0.5$ mrad

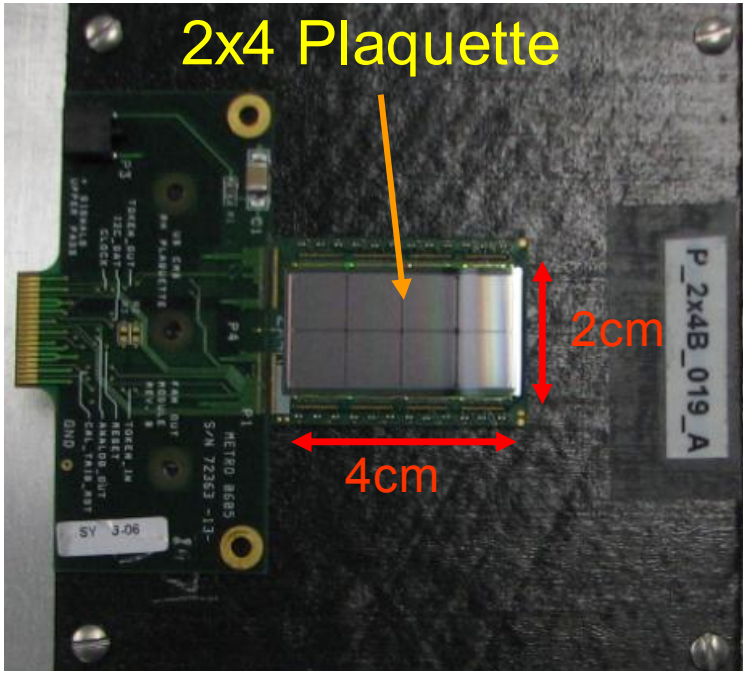
Spatial resolution

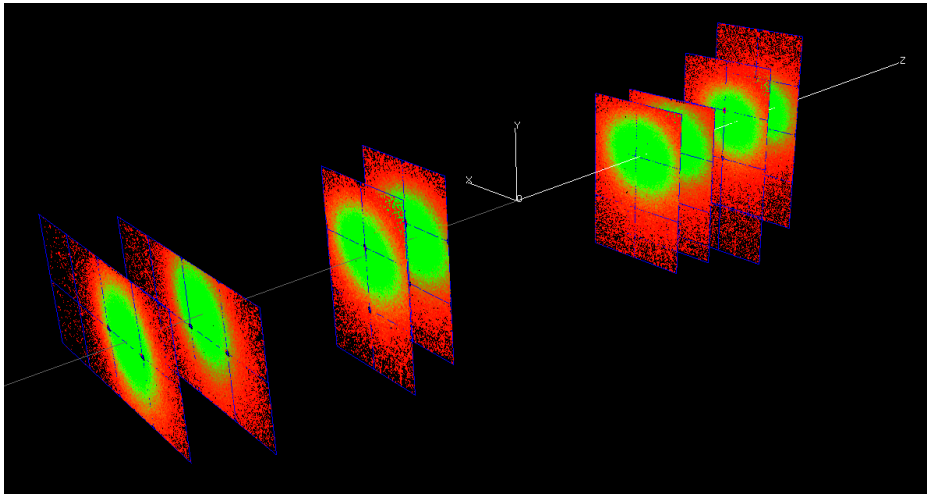
- Ideally below MCS - For a 50 cm long tracker, measuring an angle with uncertainty of 0.5 mrad requires $\sim$250 micron resolution
- Fermilab/CMS has a lot of experience with silicon pixel technology
- FTBF offers the use of a silicon pixel detector telescope (about 90 cm long) with $\sim$10-100 micron resolution (courtesy of Computing Division Detector Instrumentation Group and CMS)



Beam profile on the FTBF pixel telescope display

FTBF Pixel Telescope

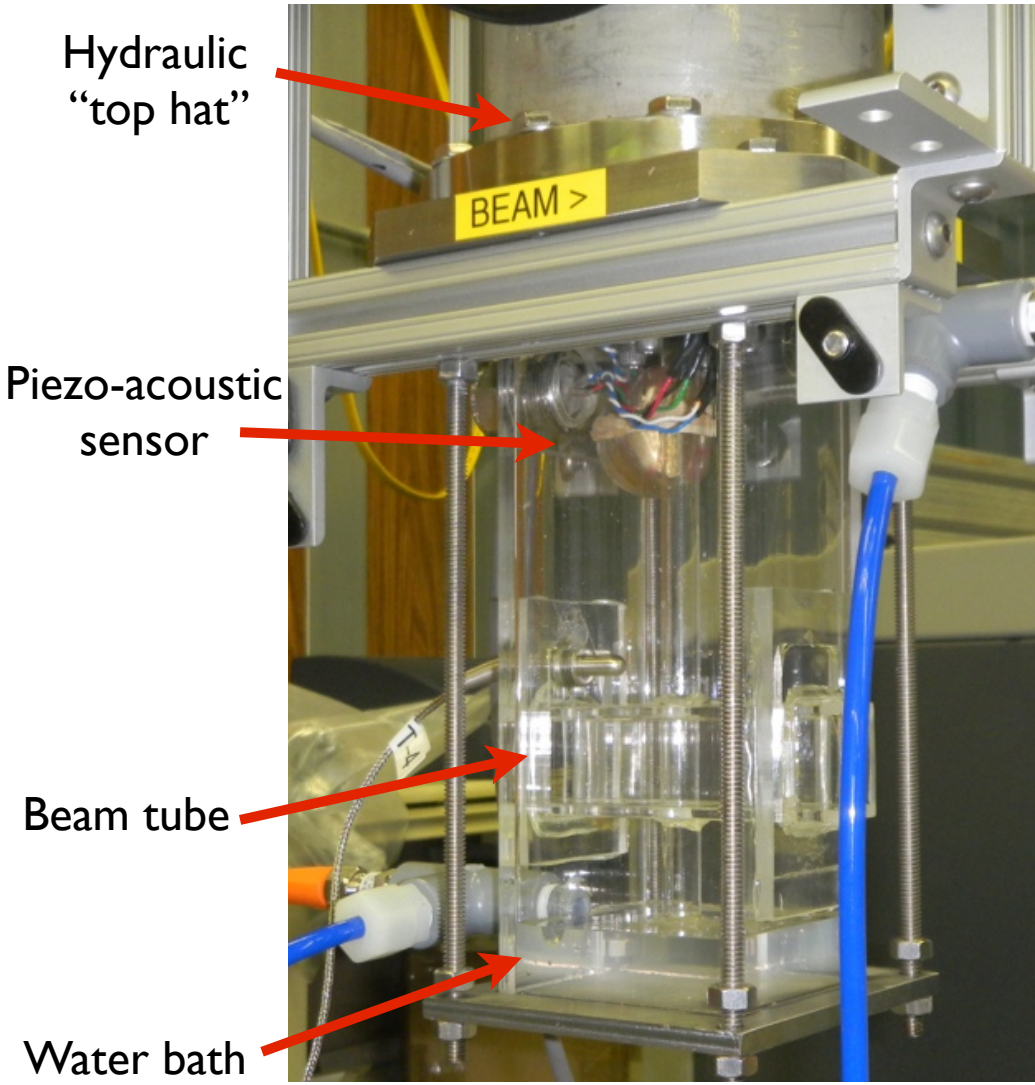




- Pixel pitch is 100 μm x 150 μm
- Chips of pixels are combined into either 20 mm x 30 mm or 20 mm x 40 mm plaquettes
- Plaquettes are movable and rotateable (up to about 90 cm maximal separation along the beam axis)
- For this experiment, plaquette overlap is about 15 mm x 15 mm

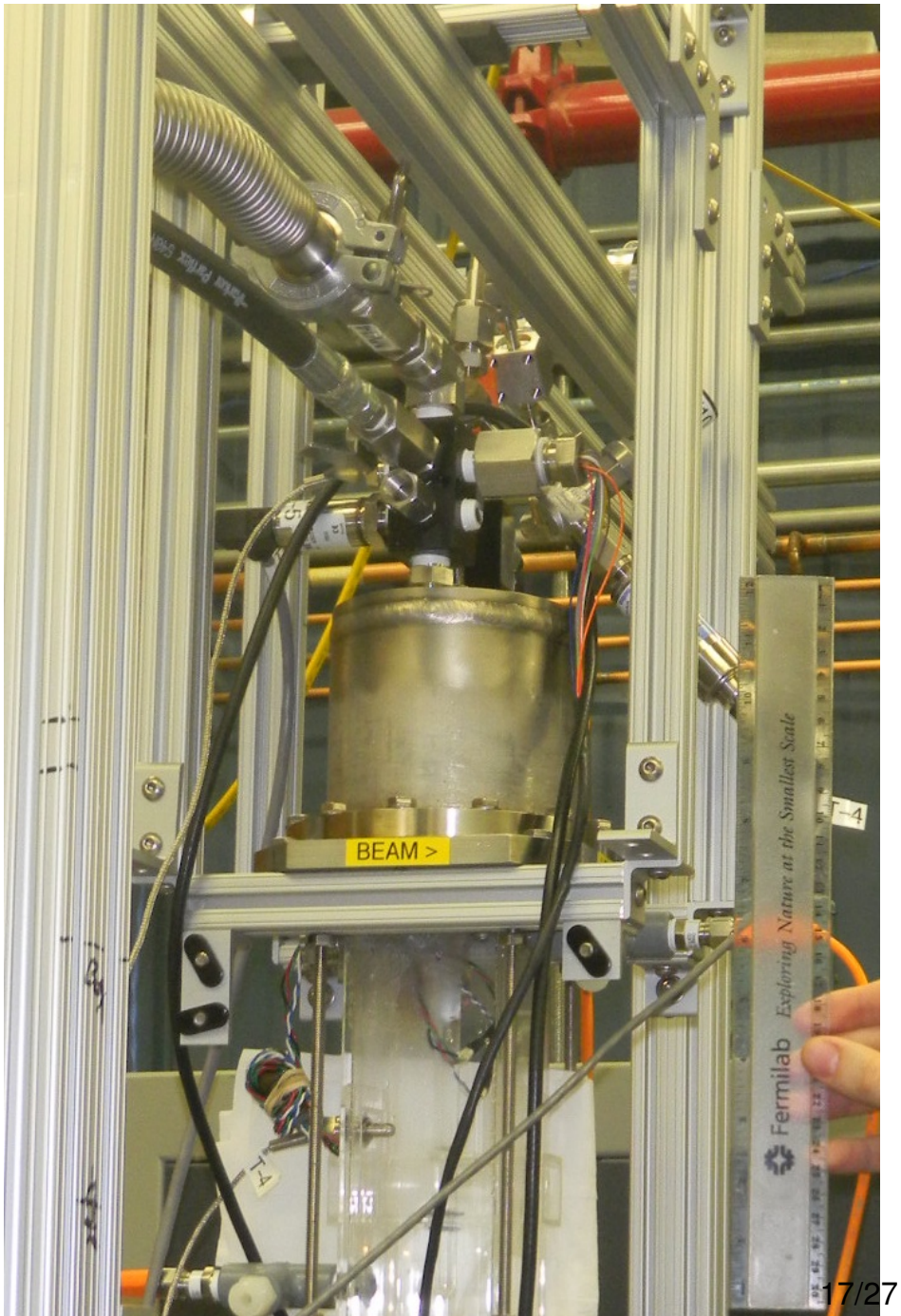
A test tube bubble chamber

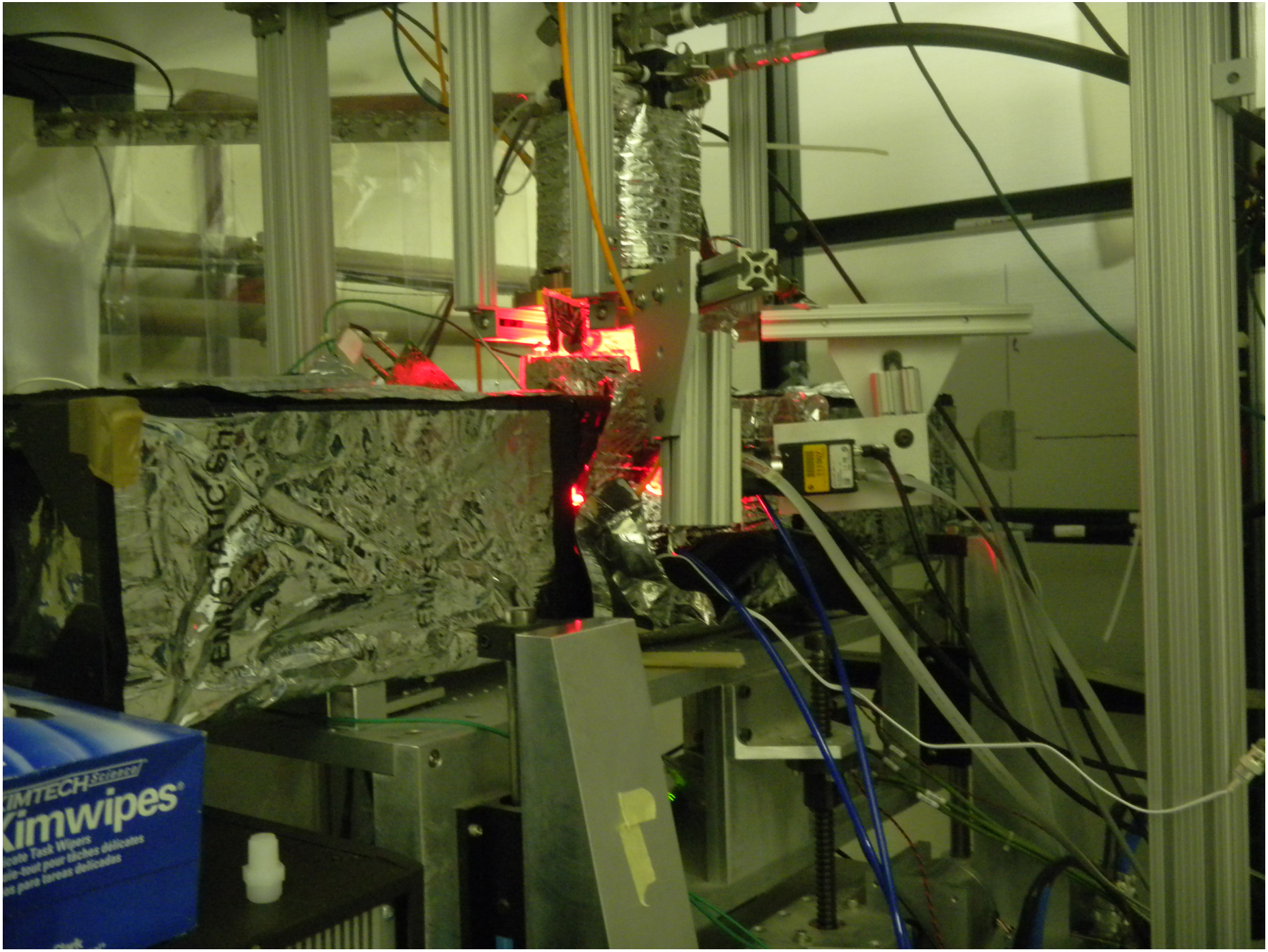
- Small path length to minimize MCS ($\sim$ 5 ml CF_3I in 1 cm test tube)
- Hydraulics for pressure control
- Water bath for temperature control
- Beam tube penetrations in bath
- Acoustic sensor for timing
  - To align bubbles with tracks in the pixel telescope
- Small overall package to fit inside the telescope



A test tube bubble chamber

- First bubbles observed Jan. 28, 2012
- Short beam run from Feb. 7-9
  - Tested timing and physical integration of system
  - Led to improved design of water bath
- Run from March 14-28 at 15 keV Seitz threshold, before year-long accelerator shut down

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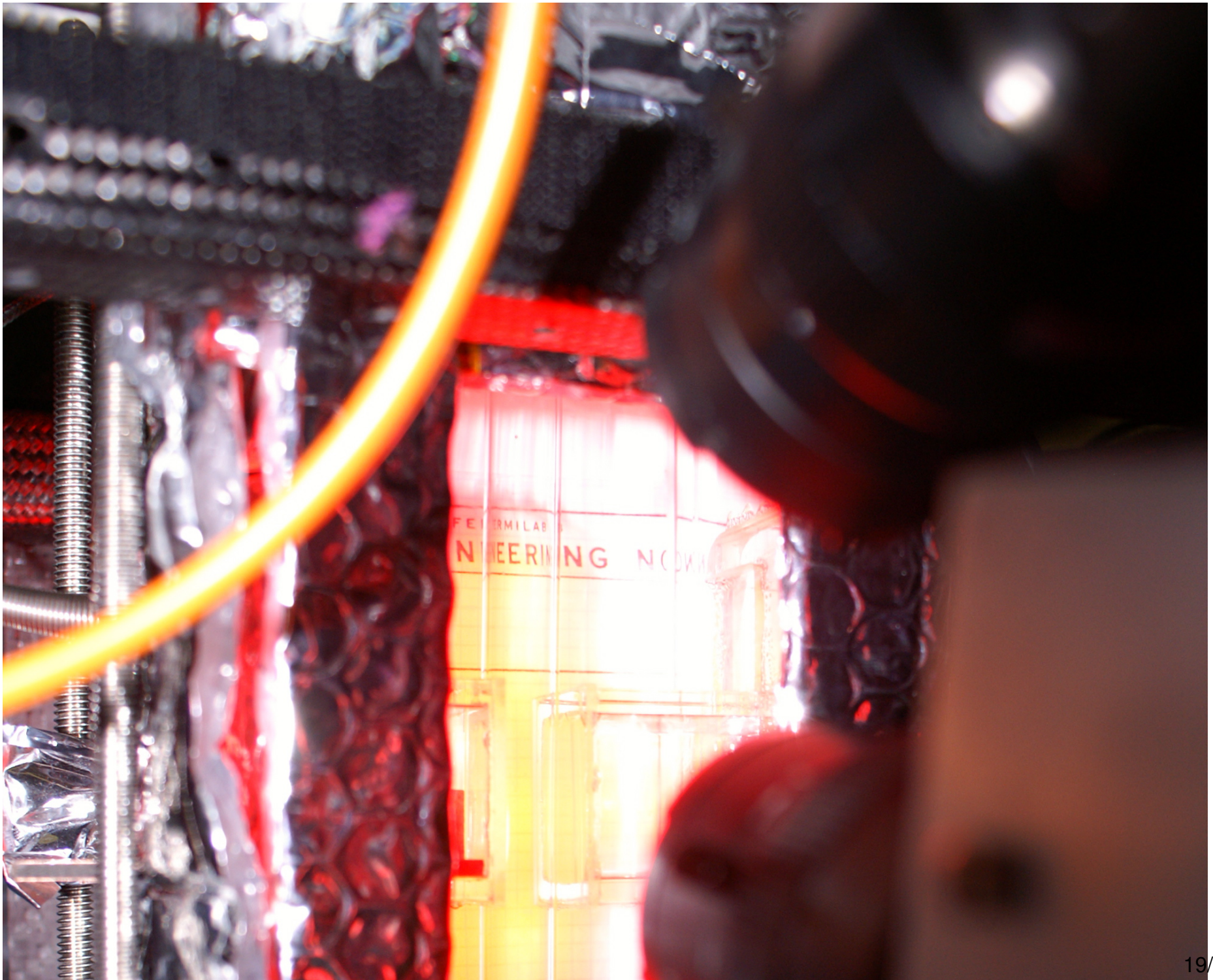
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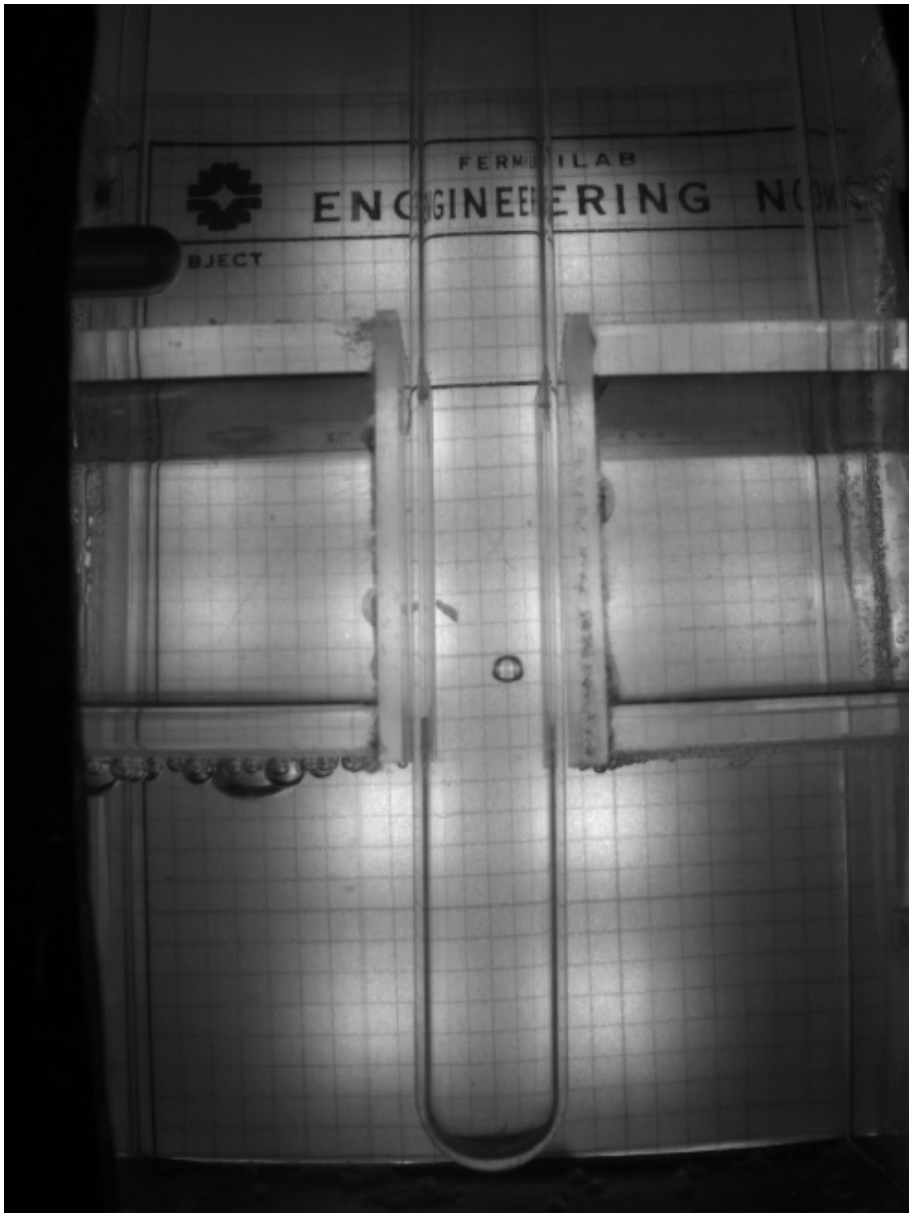
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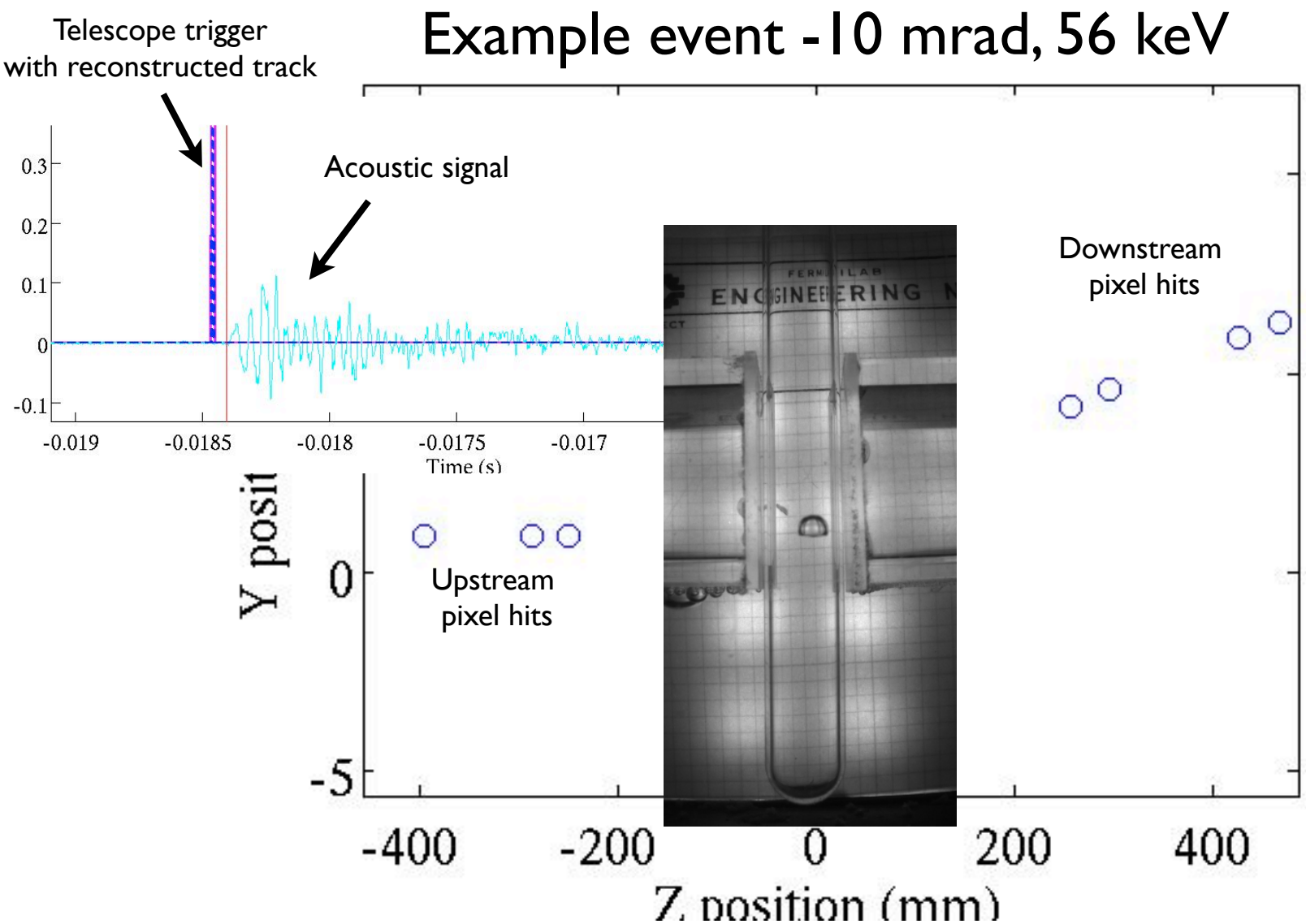
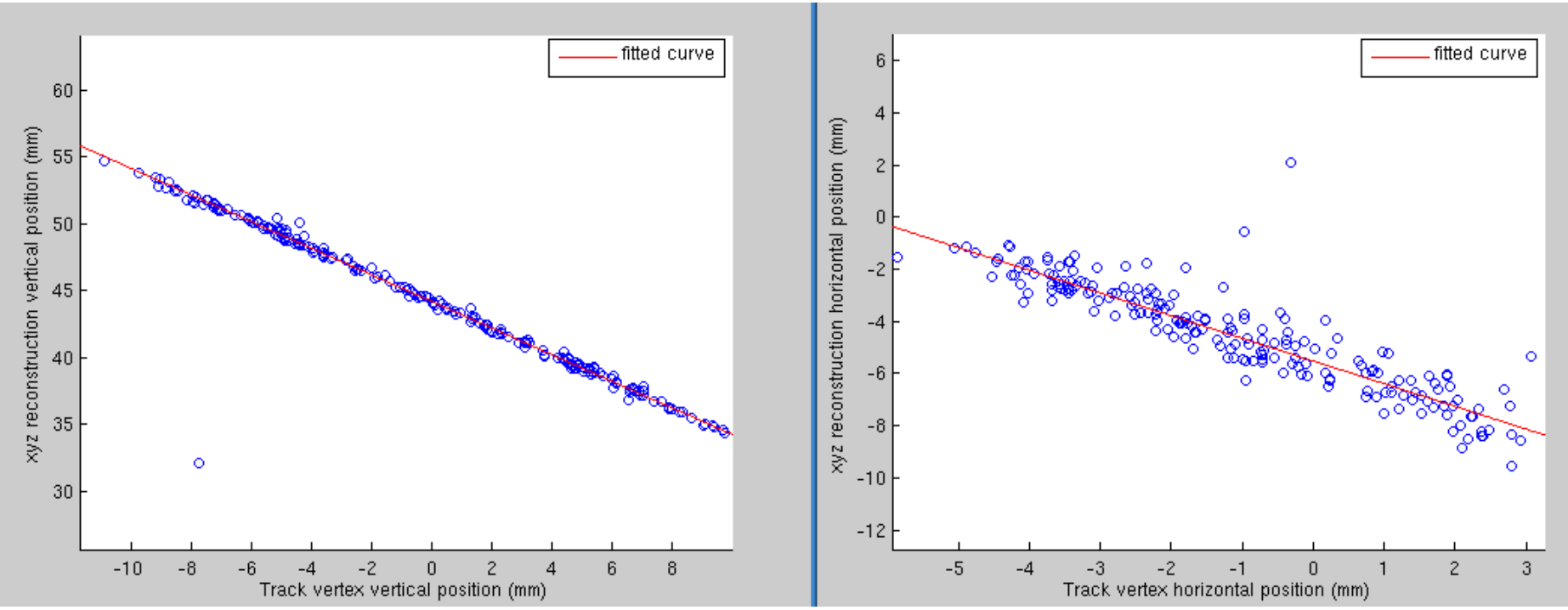
An example good scattering event



Track to bubble correlation



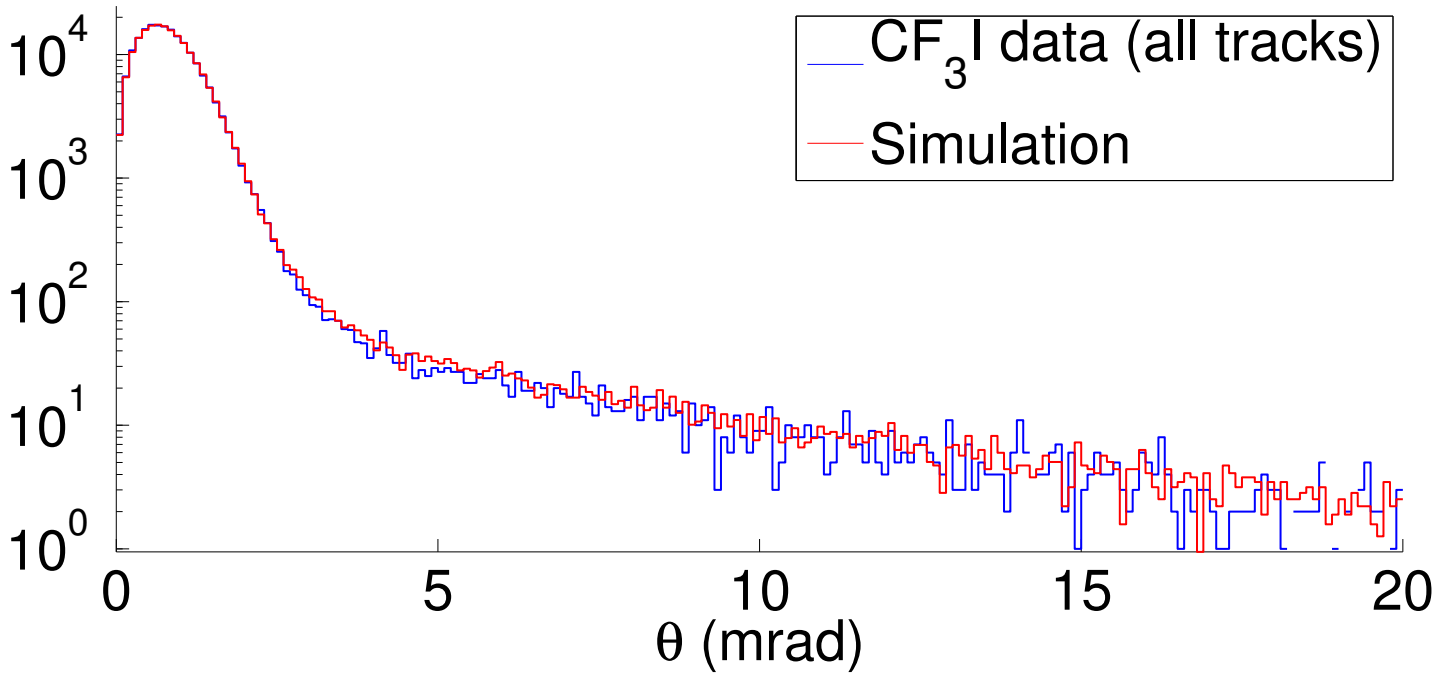
- Reconstruction and track matching looks very good
  - Strong correlation between bubble position from the cameras and telescope vertex position

March 14-28 run

- Data collection rate is fairly low - final data will only have several hundred good scattering events
- 1 beam spill/minute means at most 1 event/minute
- Significant losses to beam down time, commissioning, alignment etc. - collected over 9000 spills with good run conditions
- 80% of bubbles correlated with spill (efficiency losses to backgrounds, water bubbles)
- Large fraction of events contain multiple bubbles (inelastic scattering, poor beam bunching)
- 1/3 of single bubbles scatter out of the telescope (i.e. no downstream track)
- Another half of bubble induced particles miss the telescope entirely

Analysis ongoing

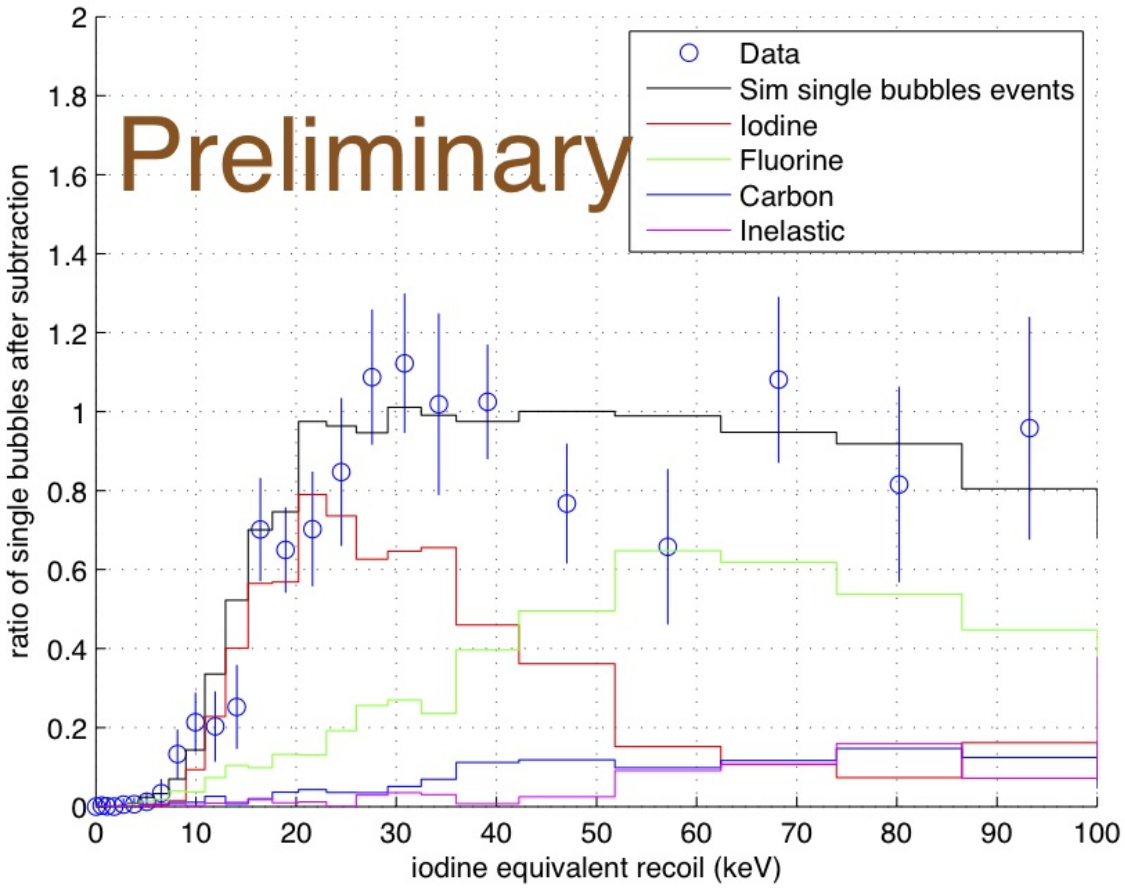
- Use passive target data from a test run in December and target full and target empty data to validate MC models
- For example, comparing the scattering angle distribution for the CF_3I target



Analysis ongoing

- Use MC to isolate iodine component of data
- Final fit to a ratio of bubble-correlated tracks to all tracks in a given scattering angle
  - Minimize track reconstruction and acceptance systematics
  - In this ratio, correct for multiple bubble tracks and scatters in the water bath and quartz tube using data-validated Monte Carlo

Preliminary results for 15 keV Seitz threshold



- Premature to perform an actual fit
- Plot compares the data to our published exponential efficiency model applied to MC, with no other parameter tuning

Conclusion

- Successfully operated a test tube bubble chamber in the existing pixel telescope at the FTBF
- Two week run in March collected several hundred good, single bubble events
- Analysis ongoing, and preliminary results for iodine recoils are encouraging