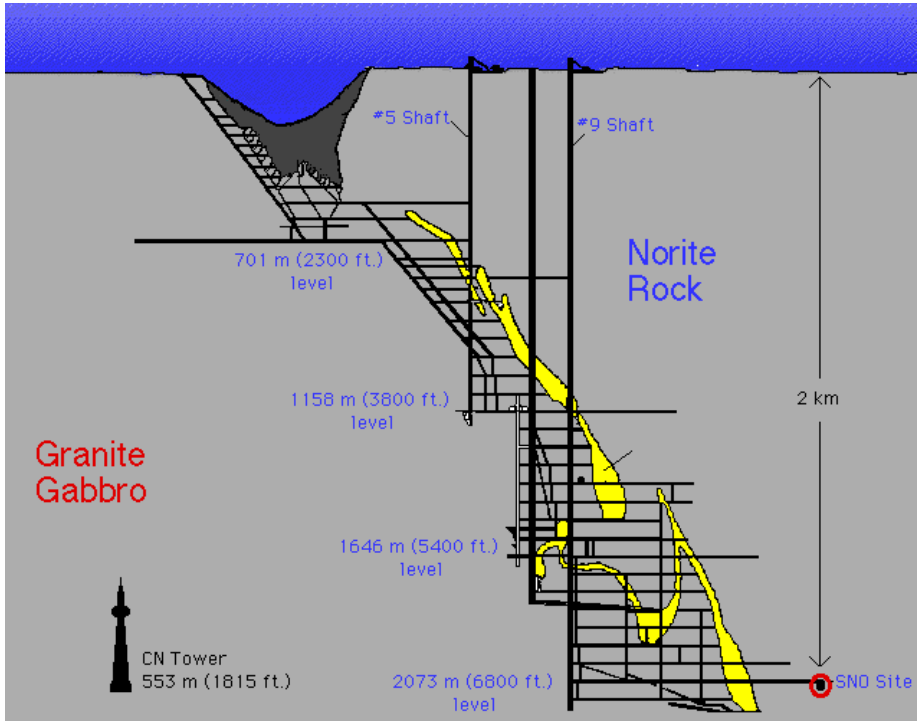
Bubble Chambers for Dark Matter

Alan Robinson
PICO Collaboration

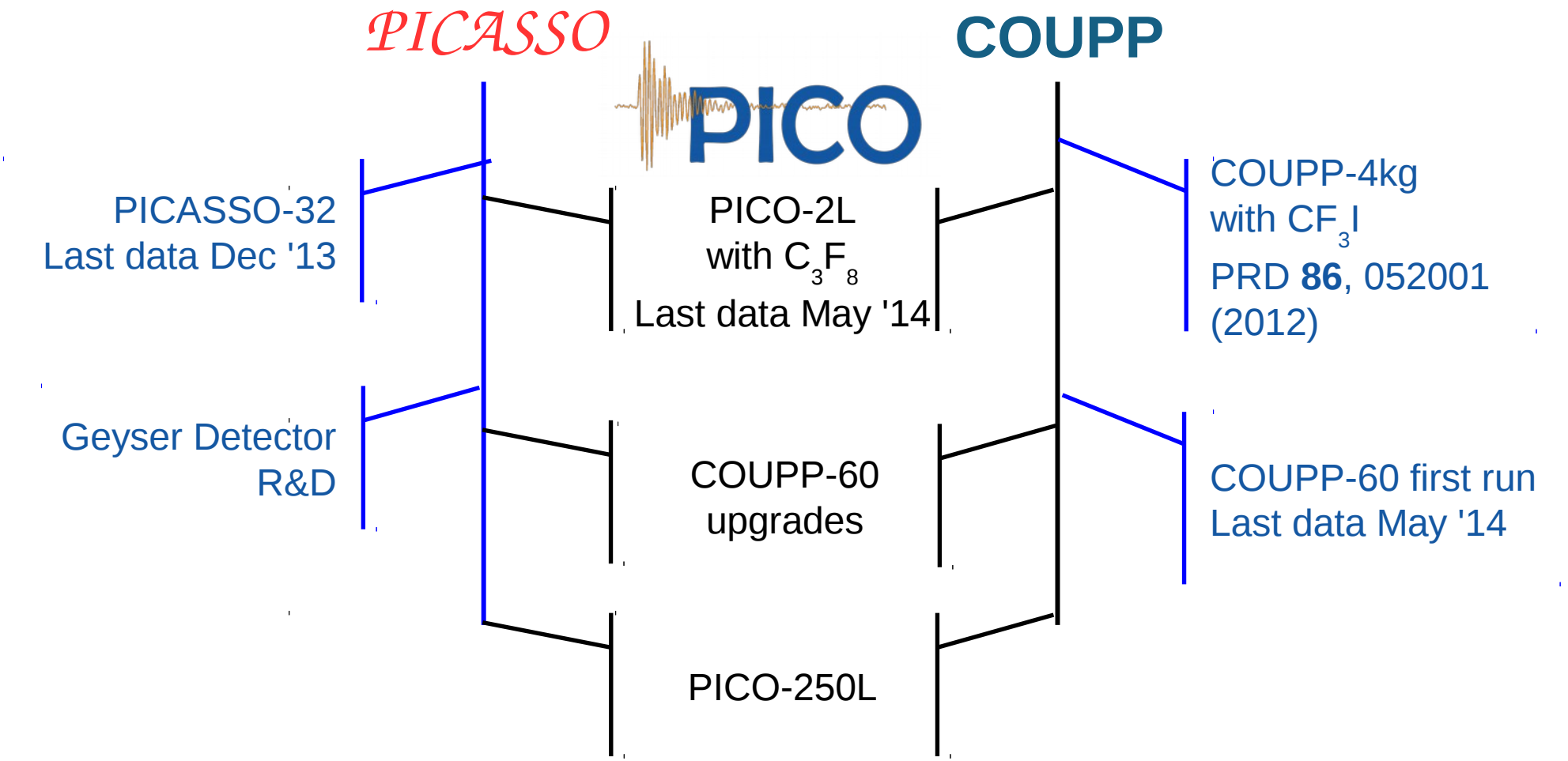
Hamburg, Aug 25, 2014
Particles and Nuclei International Conference

THE UNIVERSITY OF CHICAGO

Searching for dark matter at SNOLAB

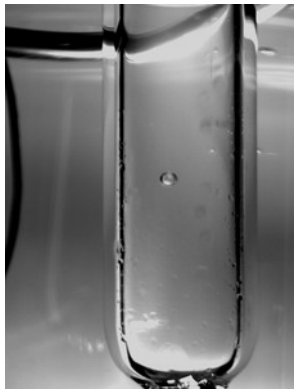


PICASSO & COUPP at SNOLAB



Why Bubble Chambers?

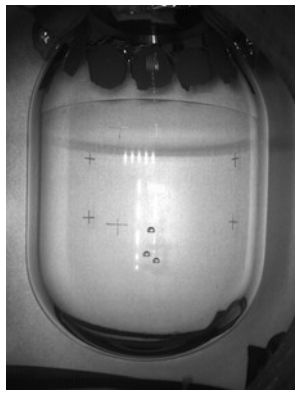
They're Scalable



2005
First COUPP prototype

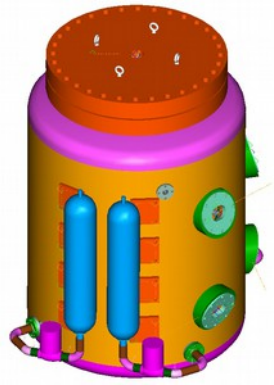
2007
1-L bubble chamber

2009
COUPP-4kg at FNAL
Acoustic Discrimination



2010
COUPP-4kg at SNOLAB
COUPP-60 at FNAL

2013
COUPP-60 at SNOLAB
PICO-2L

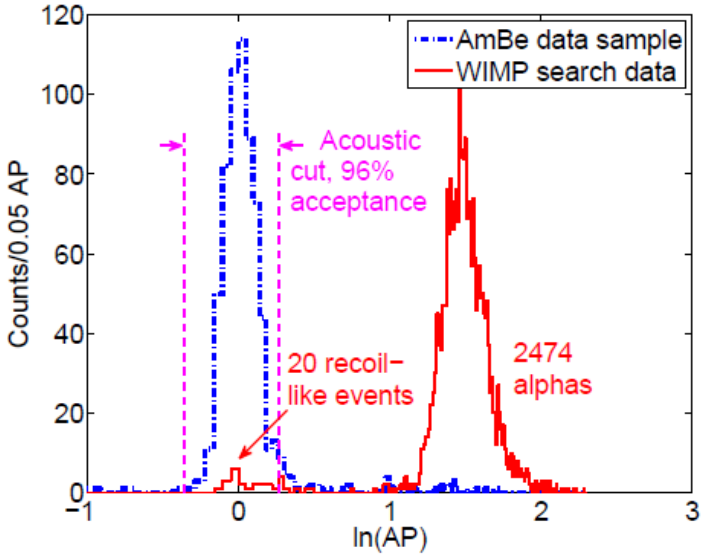


2016
PICO-250 ?

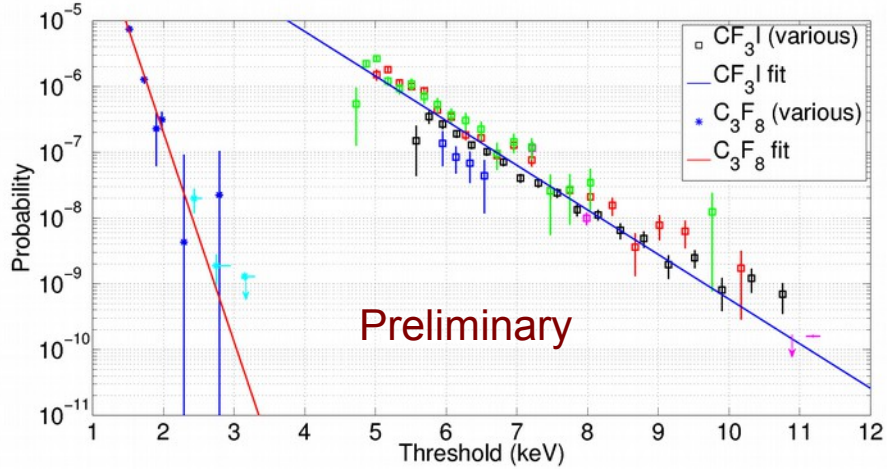
Why Bubble Chambers?

Impressive Background Rejection

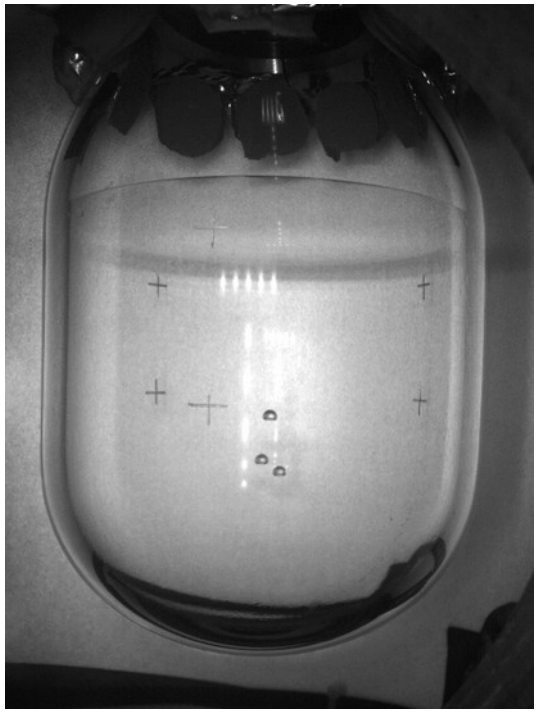
Acoustic Alpha Discrimination



Gamma Interaction Insensitivity



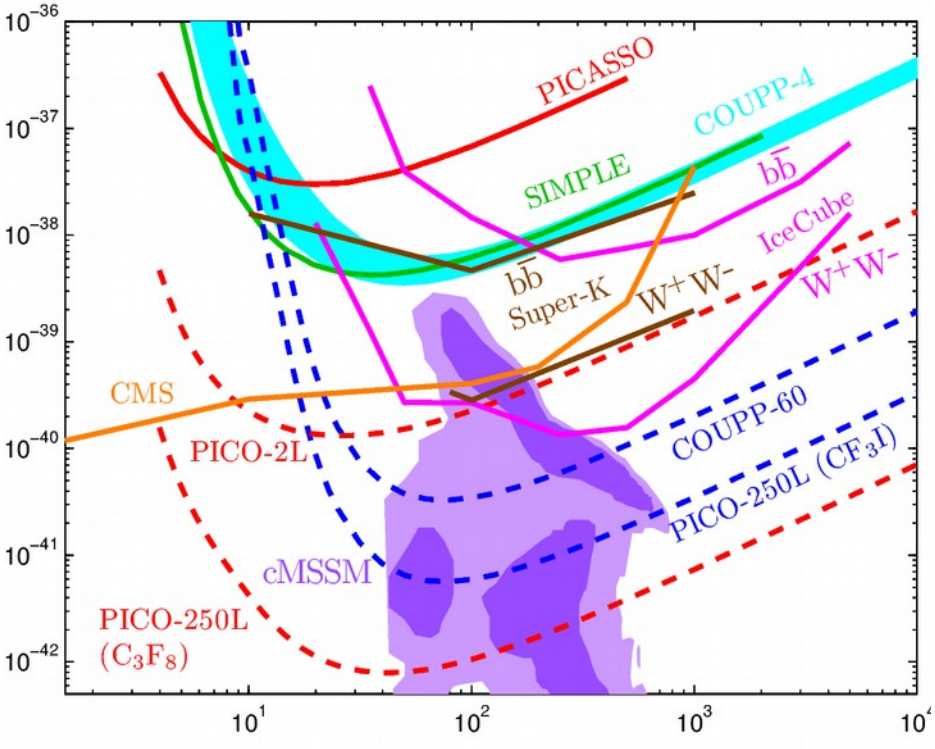
Multiple Neutron Scattering

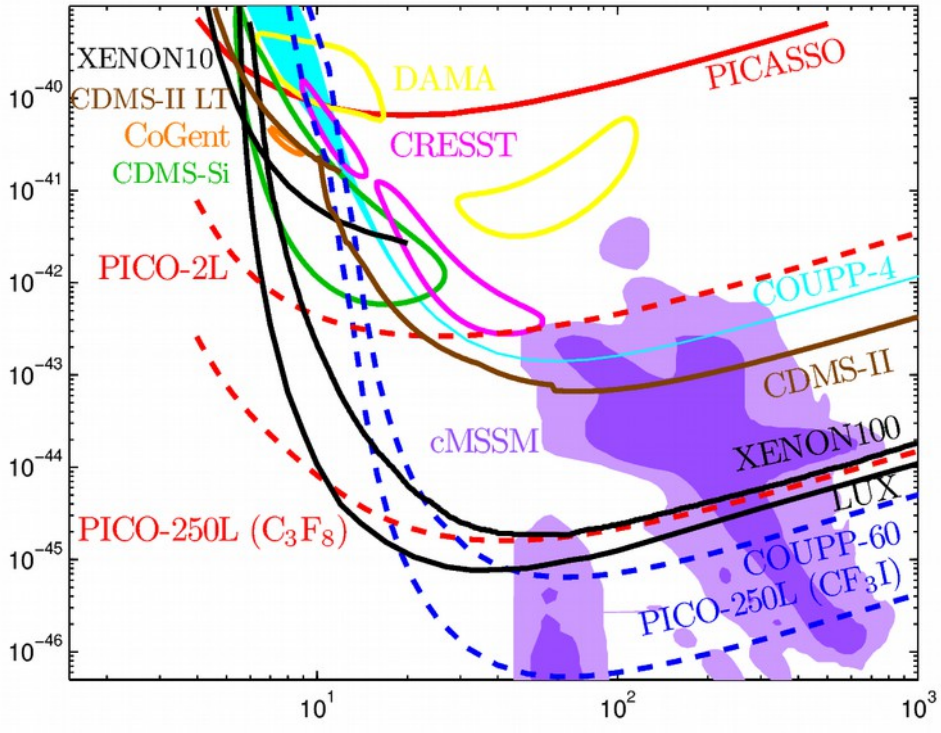


Why Bubble Chambers?

Spin-dependent & Low mass

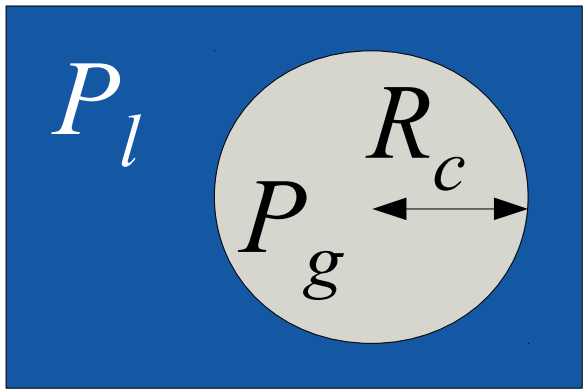
Ability to change target fluid



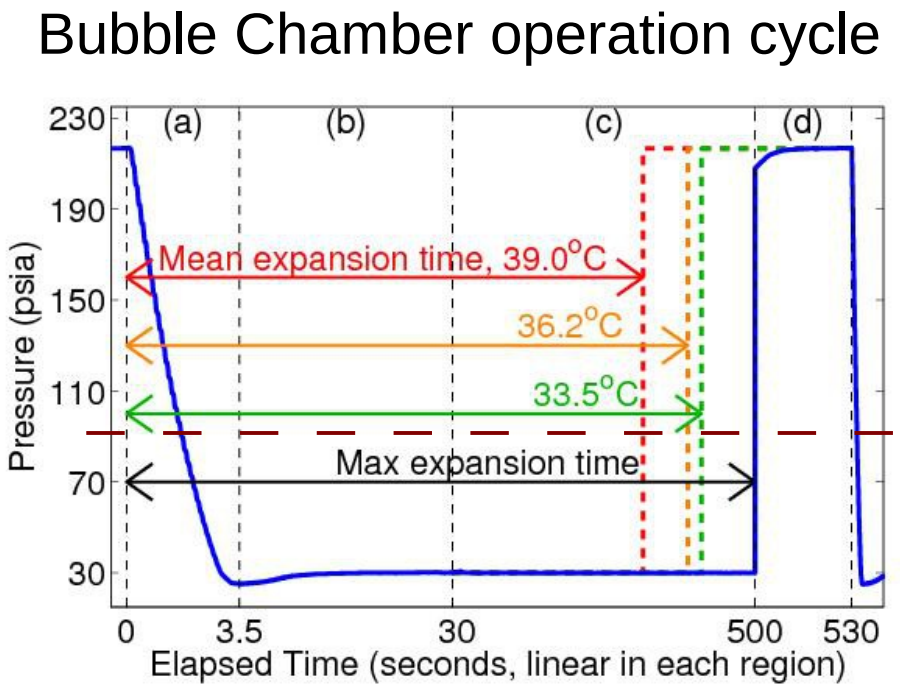


How it works

Radiation induced boiling of superheated fluid.



$$P_g - P_l = \frac{2\sigma}{R_c}$$

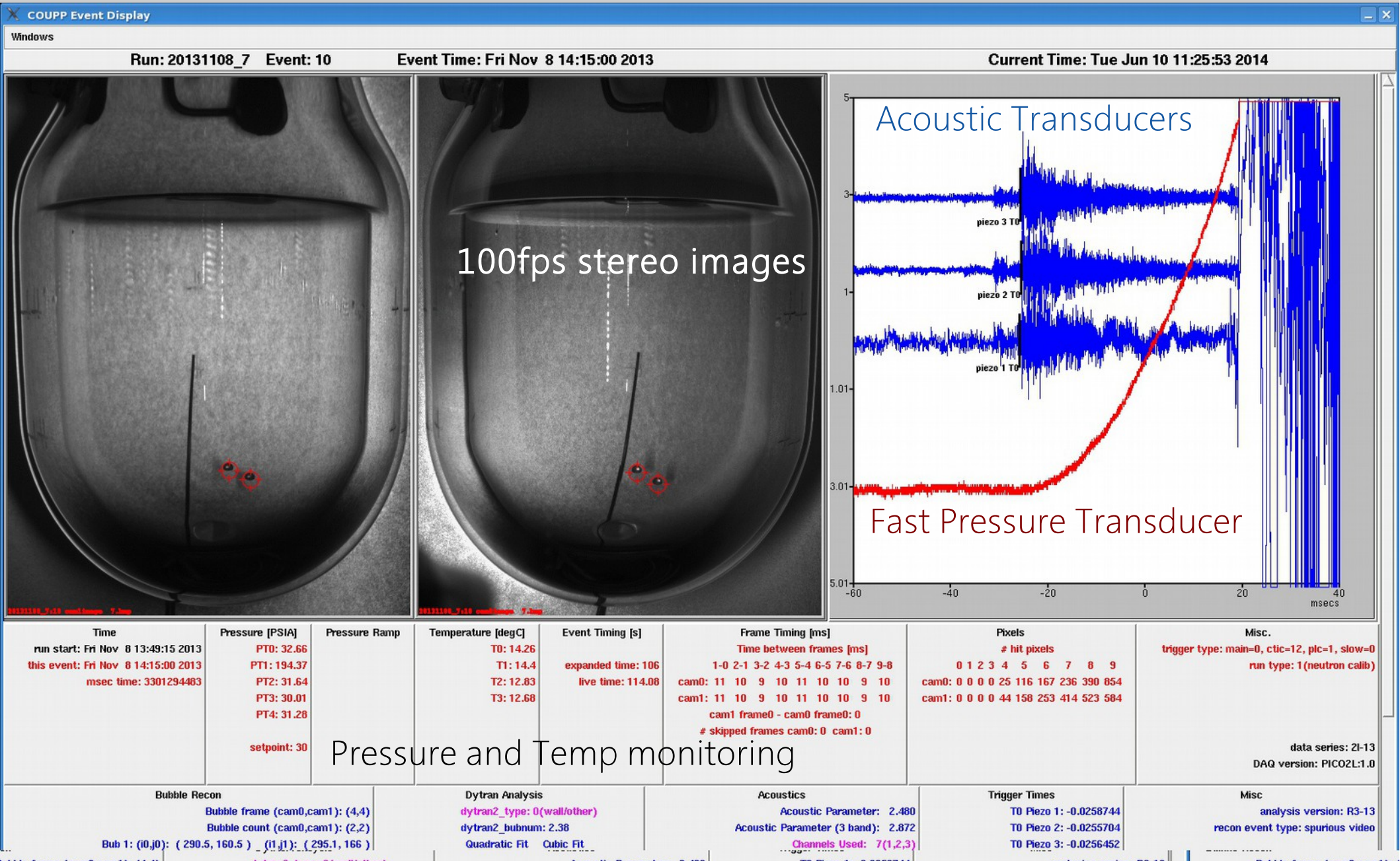


Boiling Point
(33.5° C, 90 psia)

Latent Heat Surface Formation

$$Q = \frac{4\pi}{3} r_c^3 \rho_b (h_b - h_l) + 4\pi r_c^2 \left(\sigma - T \frac{d\sigma}{dT} \right)$$

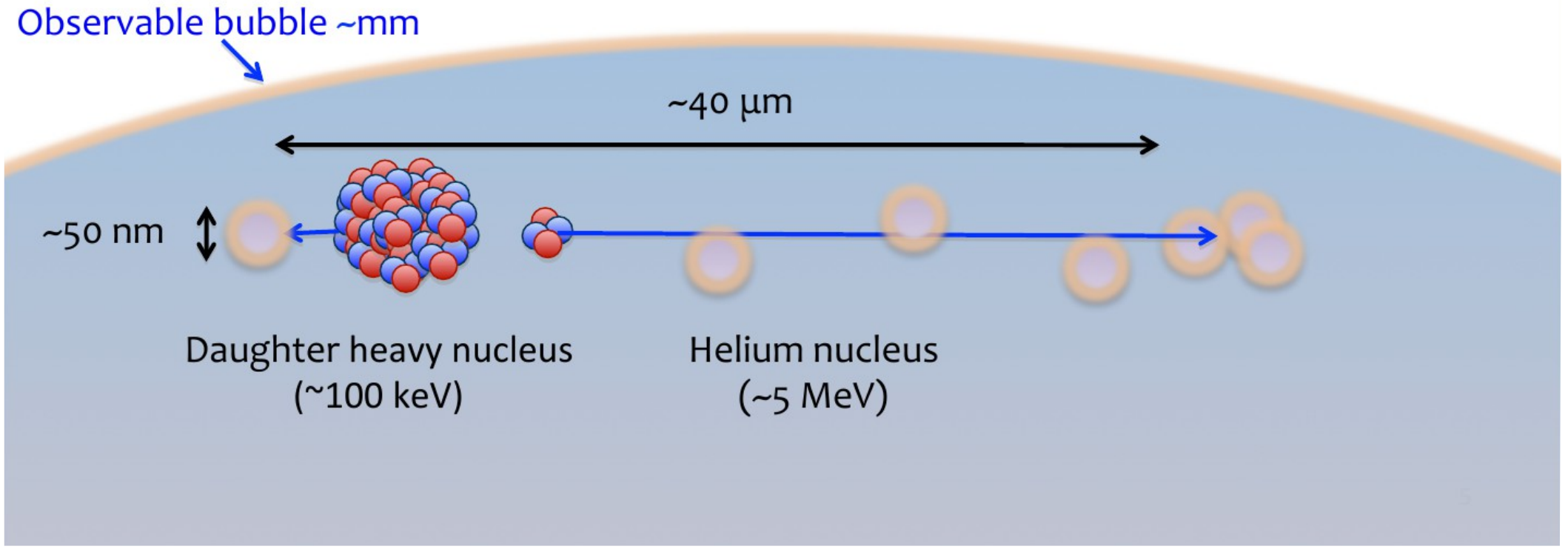
How it works


COUPP Event Display
Windows
Run: 20131108_7 Event: 10
Event Time: Fri Nov 8 14:15:00 2013
Current Time: Tue Jun 10 11:25:53 2014
100fps stereo images
Acoustic Transducers
piezo 3 T0
piezo 2 T0
piezo 1 T0
Fast Pressure Transducer
msecs
Time
run start: Fri Nov 8 13:49:15 2013
this event: Fri Nov 8 14:15:00 2013
msec time: 3301294483
Pressure [PSIA]
PT0: 32.66
PT1: 194.37
PT2: 31.64
PT3: 30.01
PT4: 31.28
setpoint: 30
Pressure Ramp
Temperature [degC]
T0: 14.26
T1: 14.4
T2: 12.83
T3: 12.68
Event Timing [s]
expanded time: 106
live time: 114.08
Frame Timing [ms]
Time between frames [ms]
1-0 2-1 3-2 4-3 5-4 6-5 7-6 8-7 9-8
cam0: 11 10 9 10 11 10 10 9 10
cam1: 11 10 9 10 11 10 10 9 10
cam1 frame0 - cam0 frame0: 0
skipped frames cam0: 0 cam1: 0
Pixels
hit pixels
0 1 2 3 4 5 6 7 8 9
cam0: 0 0 0 0 25 116 167 236 390 854
cam1: 0 0 0 0 44 158 253 414 523 584
Misc.
trigger type: main=0, ctic=12, plc=1, slow=0
run type: 1(neutron calib)
data series: 2l-13
DAQ version: PICO2L:1.0
Pressure and Temp monitoring
Bubble Recon
Bubble frame (cam0,cam1): (4,4)
Bubble count (cam0,cam1): (2,2)
Bub 1: (i0,j0): (290.5, 160.5) _ (i1,j1): (295.1, 166)
Dytran Analysis
dytran2_type: 0(wall/other)
dytran2_bubnum: 2.38
Quadratic Fit Cubic Fit
Acoustics
Acoustic Parameter: 2.480
Acoustic Parameter (3 band): 2.872
Channels Used: 7(1,2,3)
Trigger Times
T0 Piezo 1: -0.0258744
T0 Piezo 2: -0.0255704
T0 Piezo 3: -0.0256452
Misc
analysis version: R3-13
recon event type: spurious video

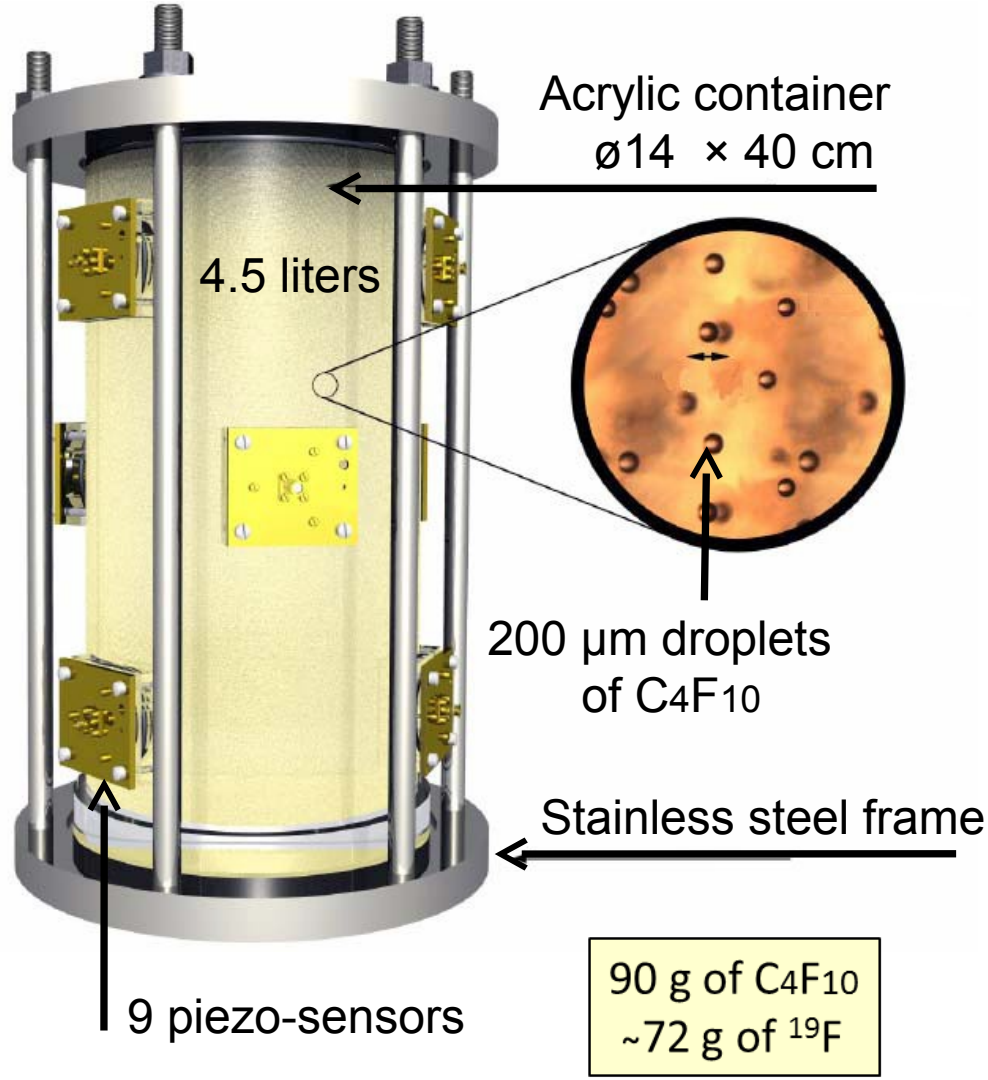
How it works

Alphas are ~4 times louder than nuclear recoil bubbles.

>99.4% discrimination against alpha events demonstrated.



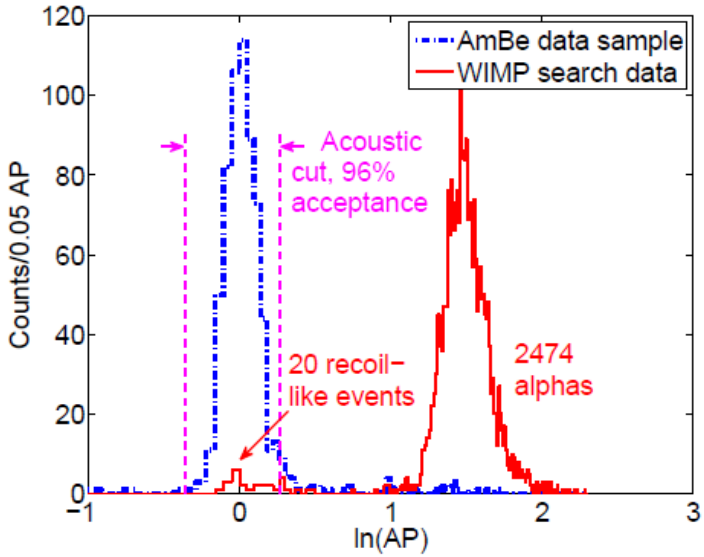
PICO PICASSO



- Superheated Droplet Detector
  - Each droplet individually triggered
- Background Limited by alpha activity in gel matrix.

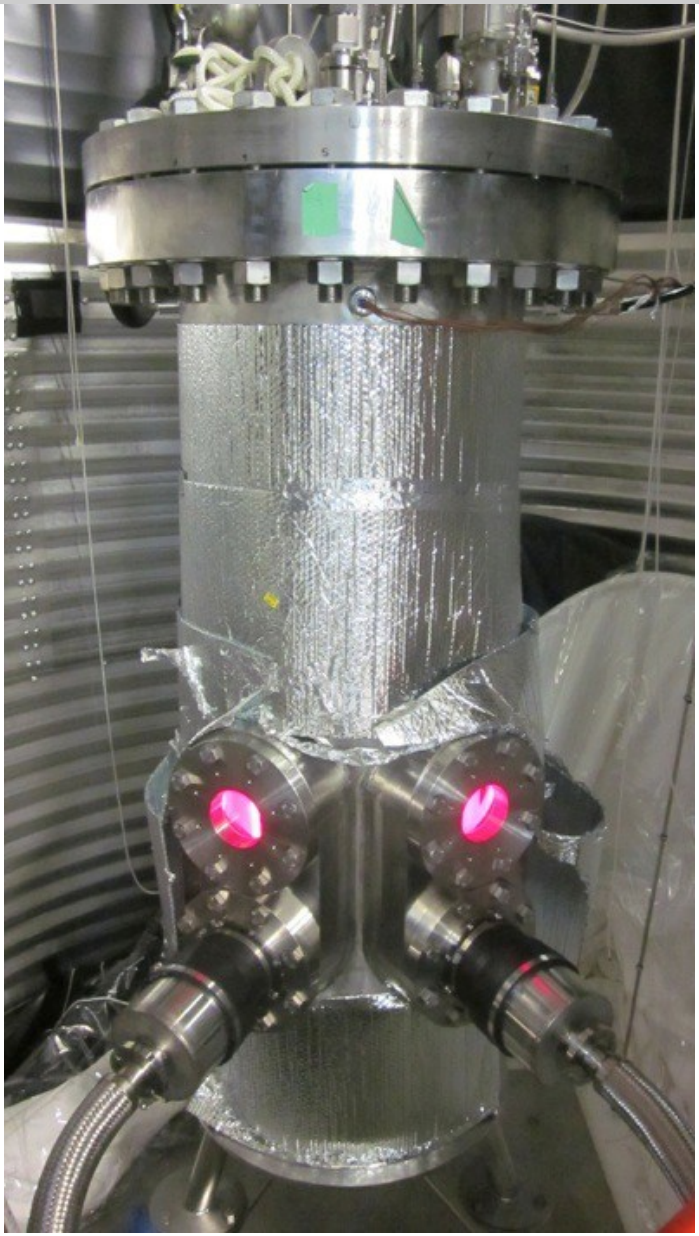
COUPP-4kg at SNOLAB

- First run deep underground.
- Demonstrated 99.4% alpha discrimination



- Backgrounds
  - (α,n) neutrons from components
  - Time-clustered events.

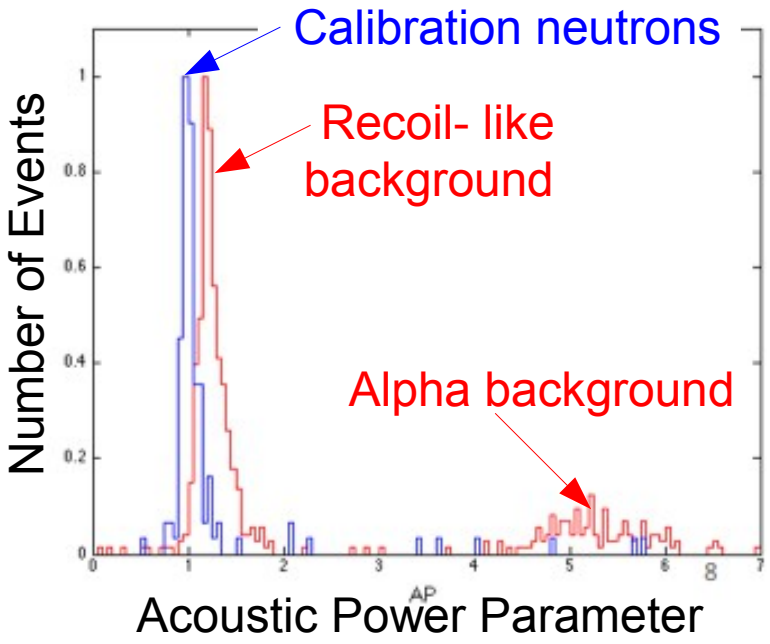
PICO COUPP-60

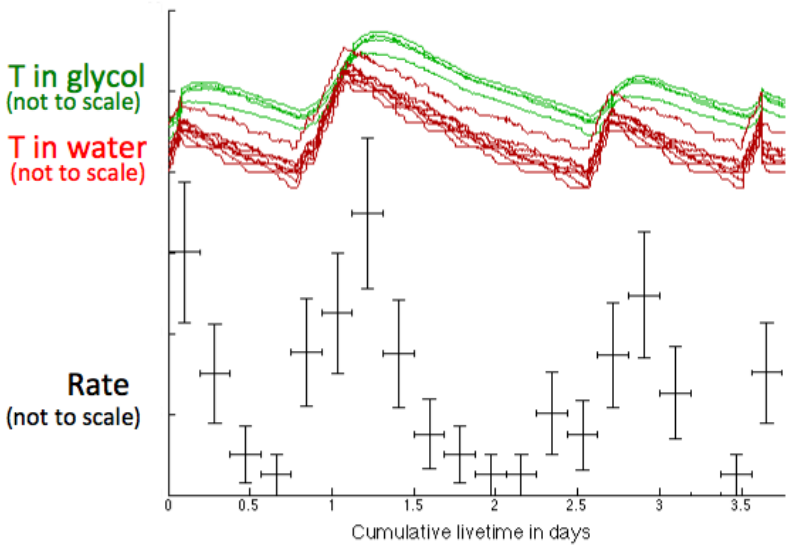


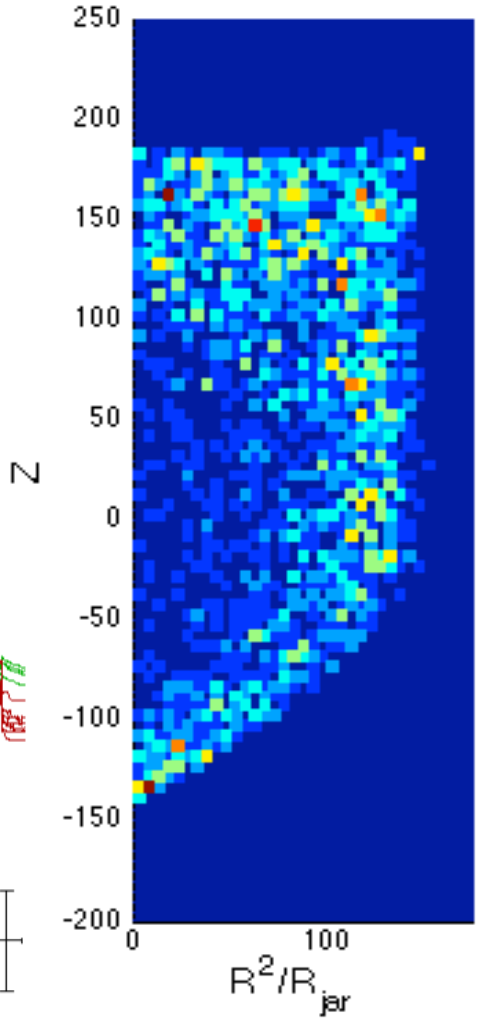
- Operational success:
  - 10x more massive
    - (35 kg of CF_3I)
  - > 80% live fraction
  - No multiple bubble events from neutrons
  - Acoustic discrimination confirmed in large chamber
  - > 3000 kg-days DM search data collected.

PICO COUPP-60

- Time-clustered background:
  - Correlated with temperature ramp
  - Spacially clustered around outside of active volume.
  - Anomalous acoustic power

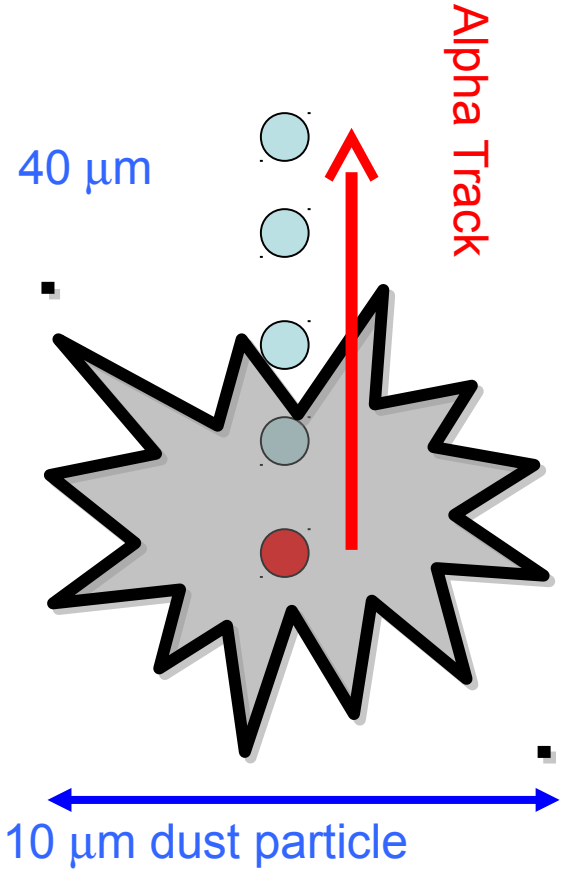






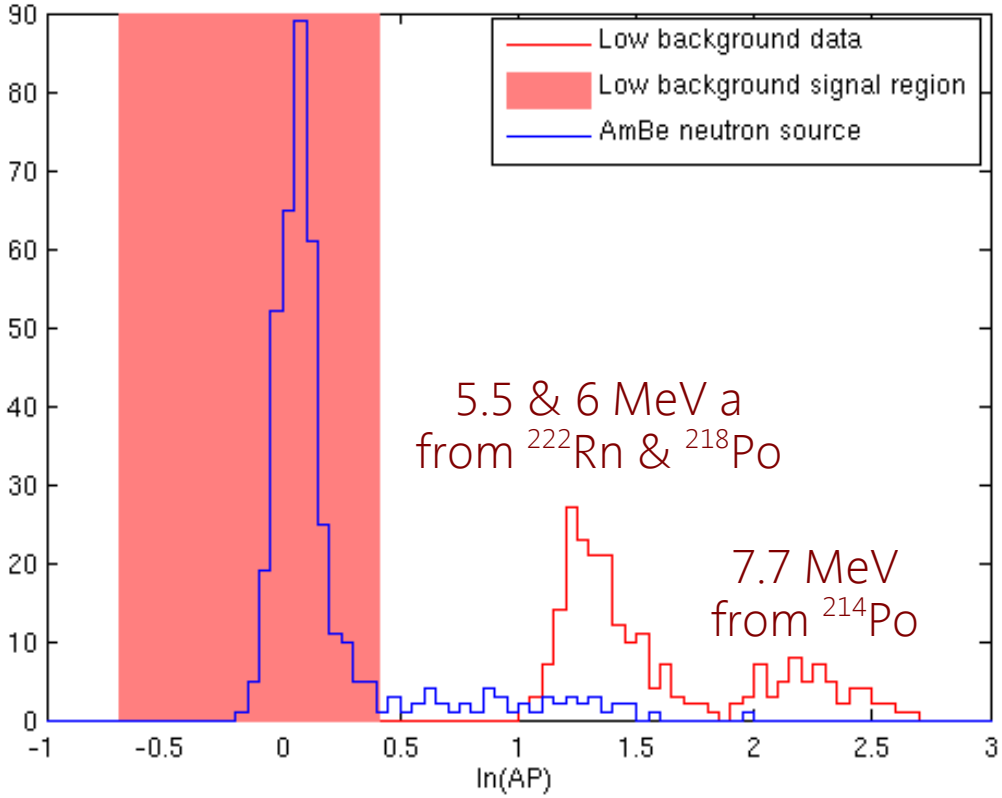
COUPP-60 upgrade

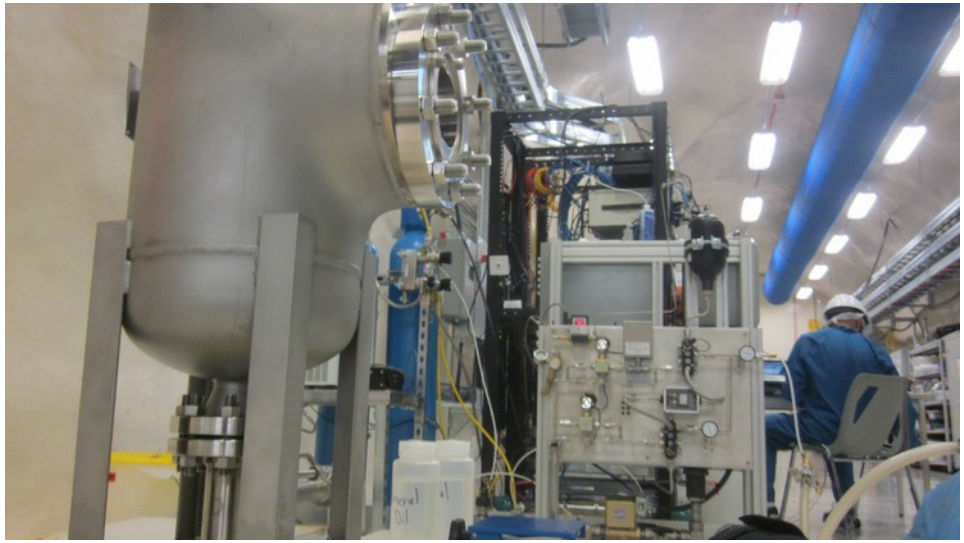
- Suspect background from dust.
- Next steps:
  - Assay target fluid for particulates.
  - Installation of in-situ fluid filtration system.
  - Elimination of sources of particulate



PICO-2L

- C_3F_8 filled:
  - Lower threshold
  - Spin-dependent sensitivity
  - Chemically inert

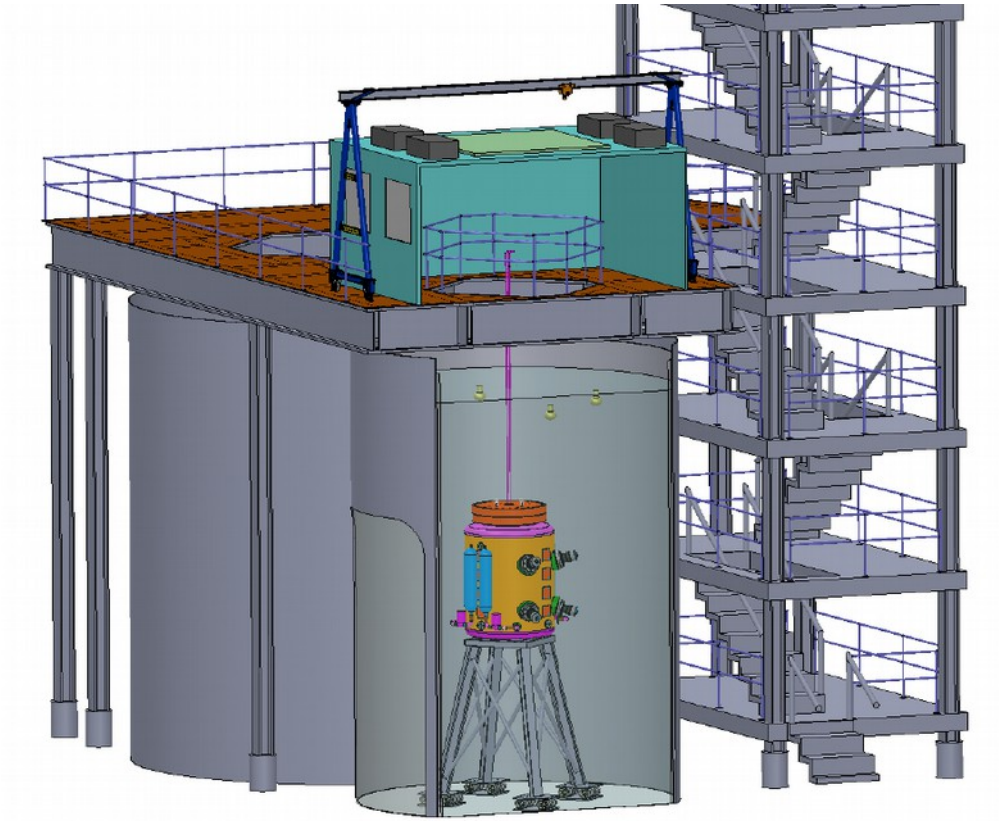


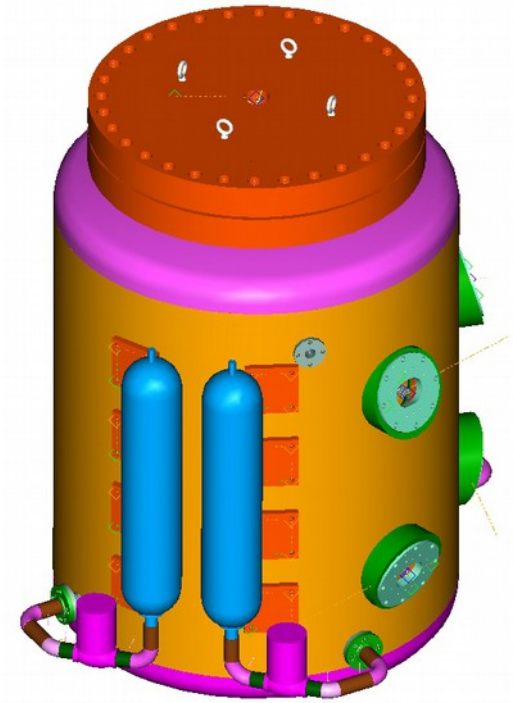


- >300 kg-days exposure.
- Run completed in May.
- Acoustic calorimetry.

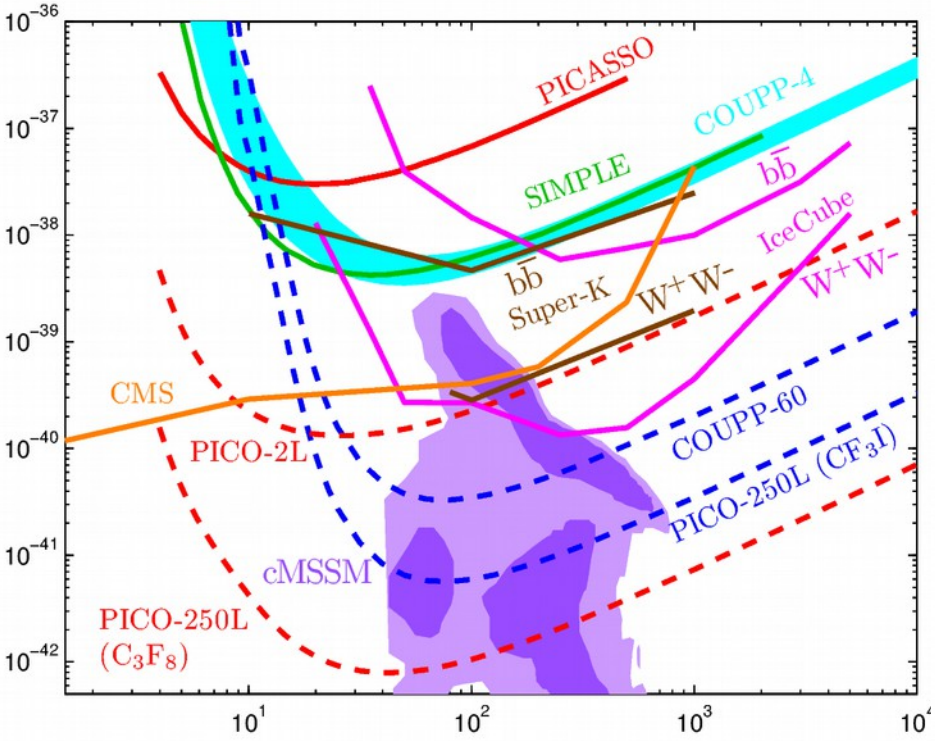
PICO-250L Proposal

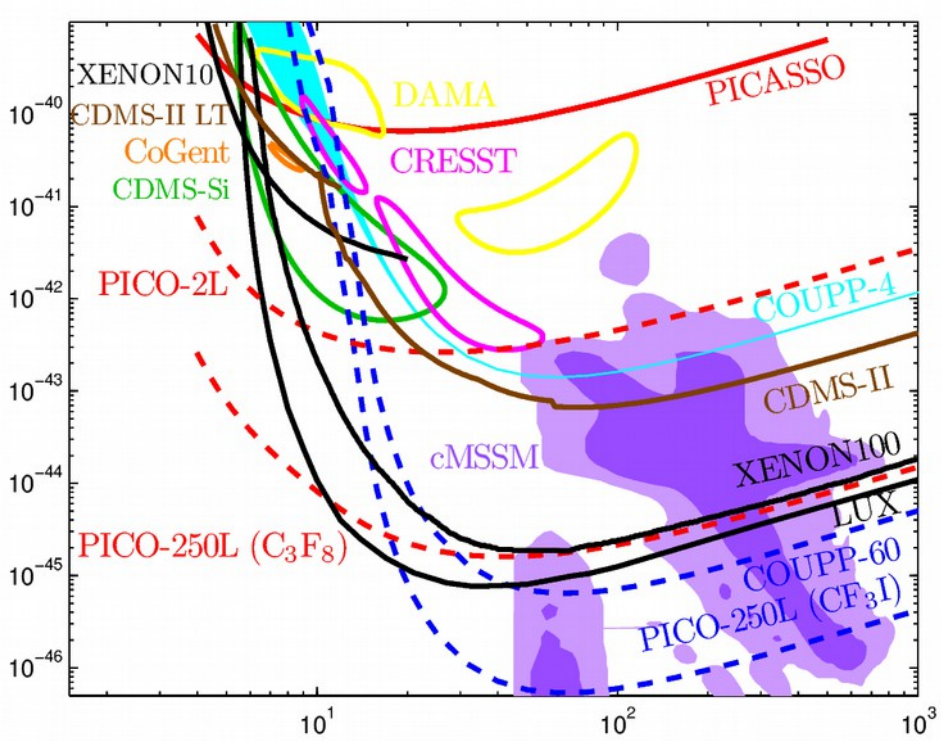
- 250L of C_3F_8 or CF_3I target fluid
- Engineering of components underway





Sensitivity Projections





PICO

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

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Fermilab

S.J. Brice, D. Broemmelsiek, P.S. Cooper, M. Crisler, W.H. Lippincott, M.K. Ruschman, A. Sonnenschein

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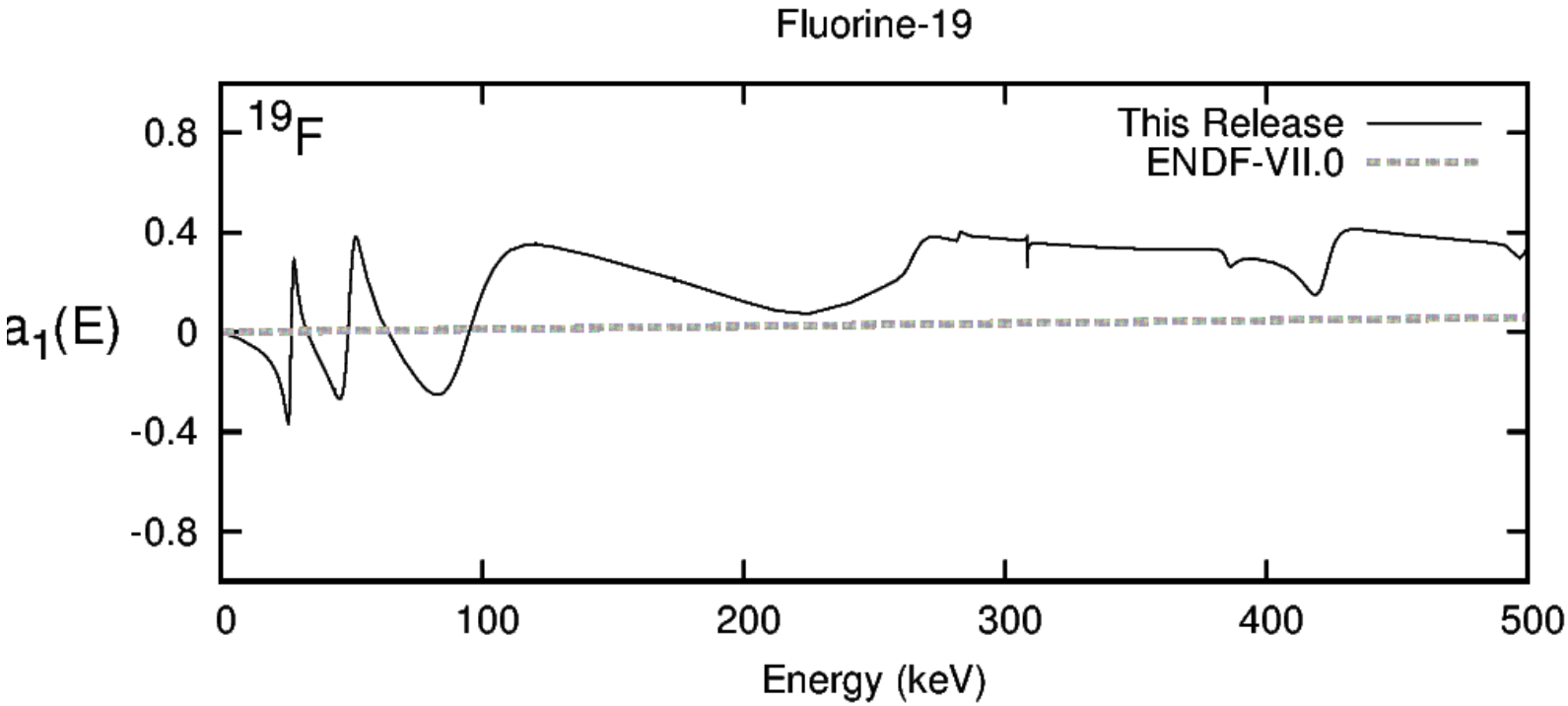
Virginia Tech

D. Maurya, S. Priya

Extra slides

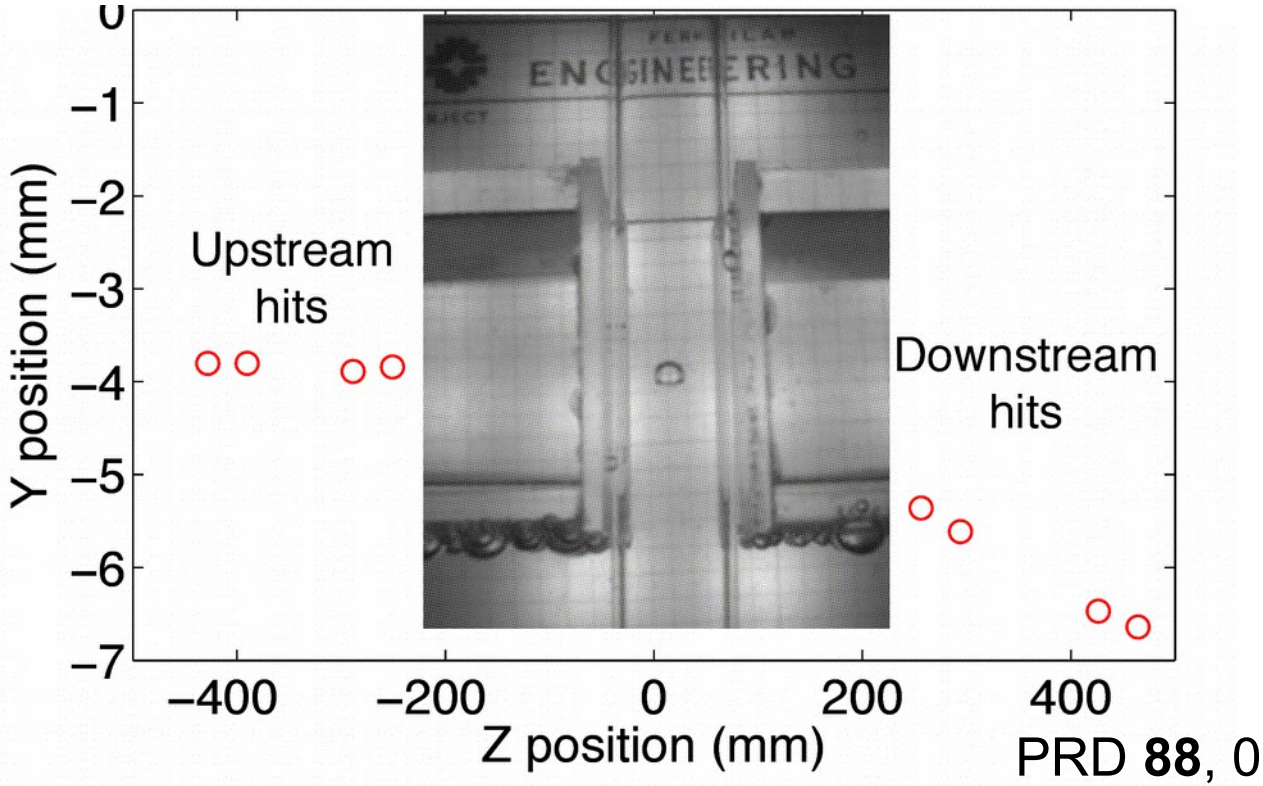
Neutron scattering

- New libraries for MCNP and Geant4 created with R-matrix calculated angular scattering distributions in the Resolved Resonance Region
  - PRC **89**, 032801 (2014)



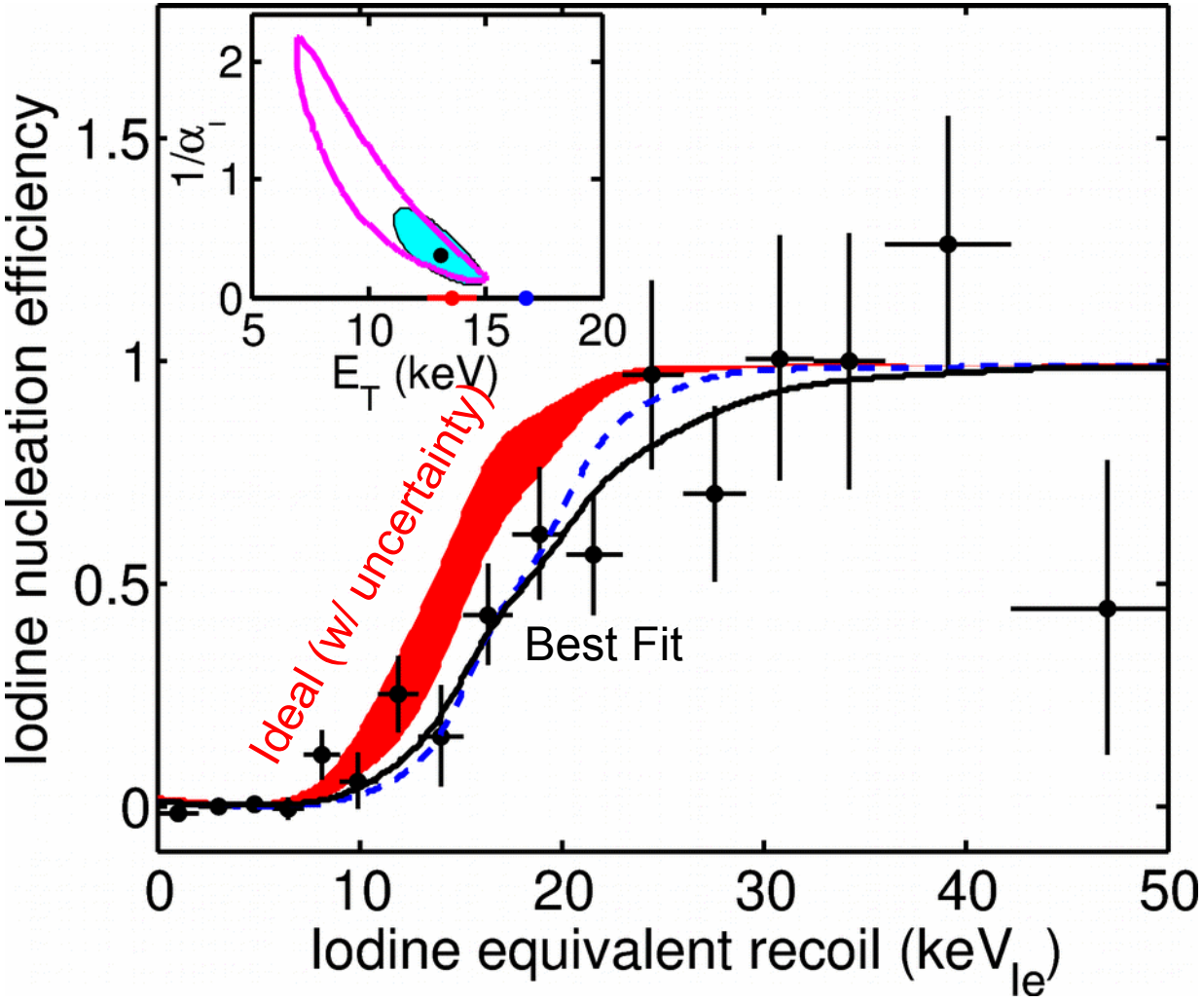
Efficiency calibrations

- Measure elastic scatters of a 12 GeV π^- beam
  - Event-by-event recoil energy measurement.
  - Preferentially scatters on iodine.



PRD **88**, 021101

Efficiency calibrations



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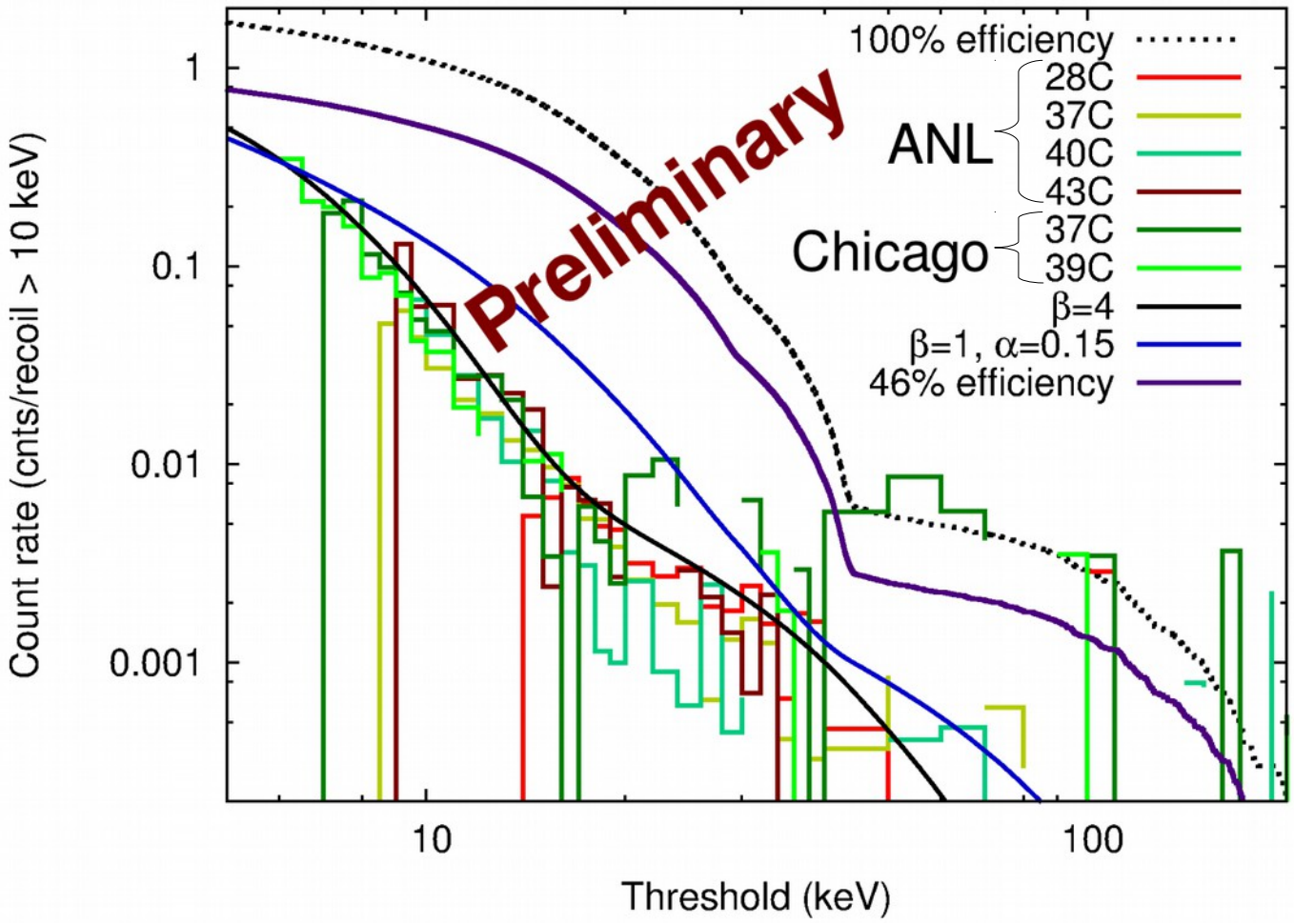
CF_3I C/F Efficiency

Normalized background subtracted count rate for Y/Be neutrons on CF_3I bubble chambers



C_3F_8 Efficiency

Expectation and Fit from Y/Be neutrons on C_3F_8