Dark Matter Searches with COUPP Bubble Chambers

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COUPP. The Collaboration

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U.S. DEPARTMENT OF ENERGY
NSF
THE KAVLI FOUNDATION

Growing Collaboration: PiCo (PICASSO-COUPP) Collaborations have recently been merged towards 250 Liter superheated detector at SNOLAB by 2015.

PICO
Collaboration

Queen's University
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Northwestern University
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E. Behnke, H. Borsodi, C. Harnish, O. Harris, C. Holdeman, I. Levine, E. Mann, J. Wells

Saha Institute of Nuclear Physics, Calcutta
P. Bhattacharjee, M. Das, S. Seth

Fermilab
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N. Dhungana, J. Farine, R. Podviyanuk, U. Wichoski

Czech Technical University in Prague
R. Filgas, S. Pospisil, I. Stekl

University of Alberta
S. Gagnebin, C. Krauss, D. Marlisov, P. Mitra

Virginia Tech
D. Maurya, S. Priya

SNOLAB — Mining for knowledge / Creuser pour trouver... l'excellence
I. Lawson, E. Vázquez Jáuregui

COUPP. The technique

WIMP-Nucleus elastic scattering search
in a sea of background radiation
Detection technique: Bubble Chamber

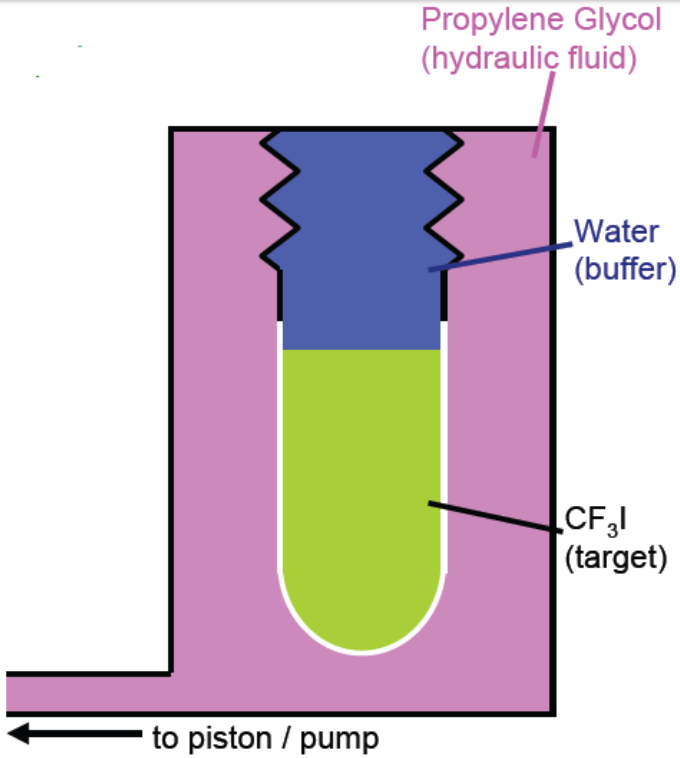
- WIMPs should exist locally!
  - Expected density 0.4 GeV/cm^3
  - rms velocity 230 km/s
- Coherent elastic scattering
  - Recoil energies *O*(10) keV
  - low background, low threshold detectors

Spin dependent

- Superheated CF_3I target

Spin independent

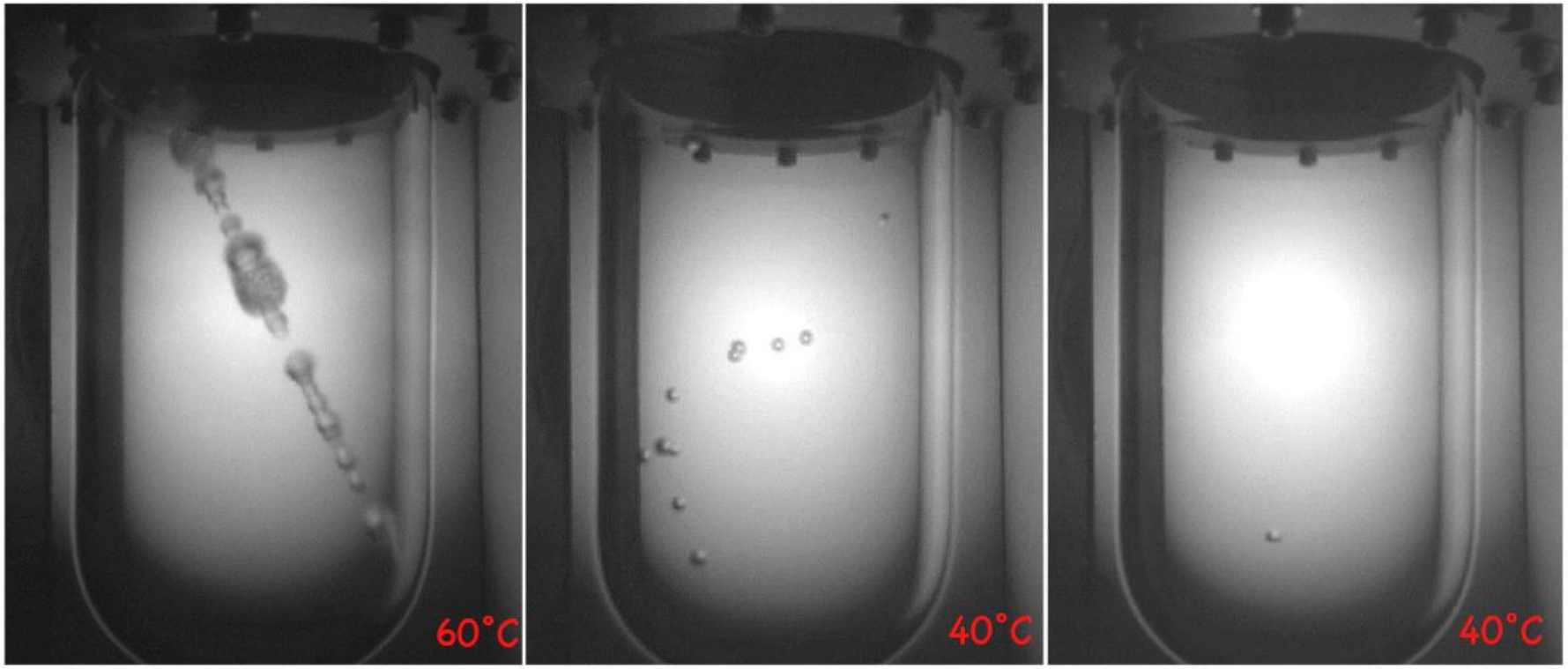
- Particle interactions nucleate bubbles.
- Cameras capture stereoscopic bubble images.
- Pressure and acoustic sensors offer additional information analizing the "acoustic signature" and offering > 99% alpha discrimination.
- Chamber recompresses after each event.
- Pressure and temperature define the operating point (>10^{10} γ/β insensitivity, sensitive to nuclear recoils only)



Introduction to COUPP. The technique

Conventional BC operation
(high superheat, MIP sensitive)

Low degree of superheat, sensitive to nuclear recoils only



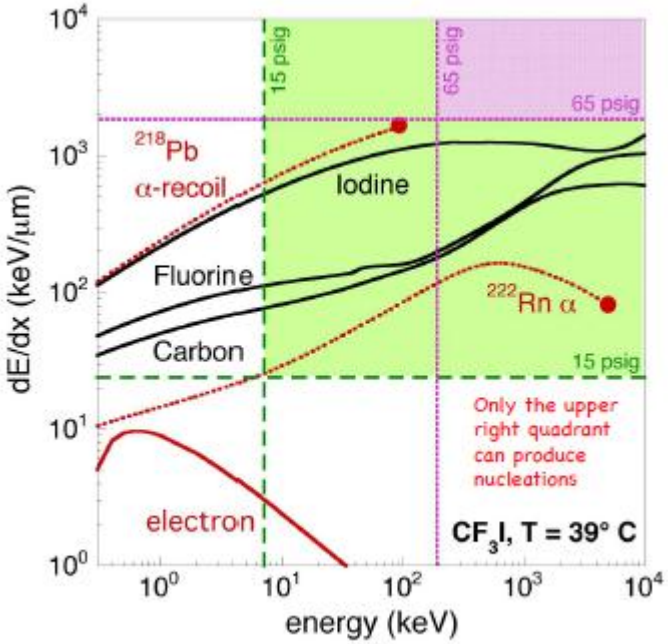
muon

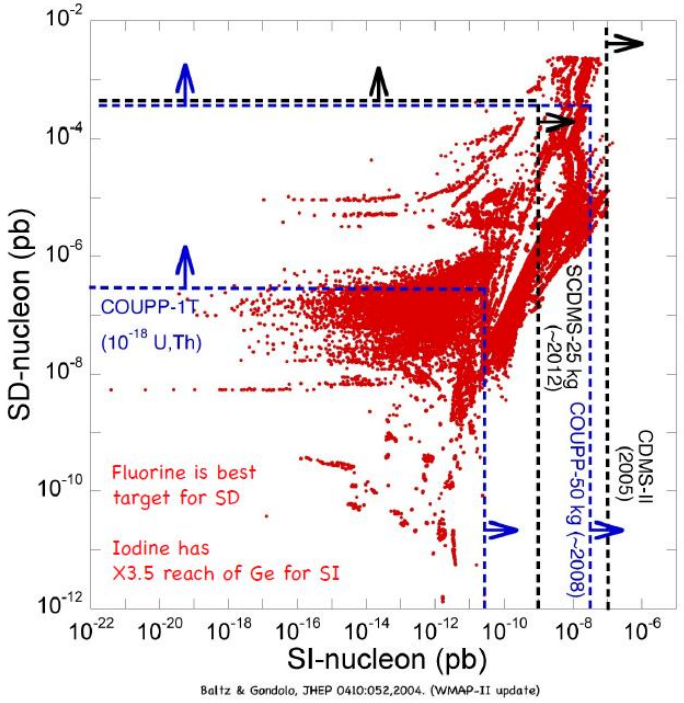
Neutron

WIMP

COUPP. Approach to DM detection

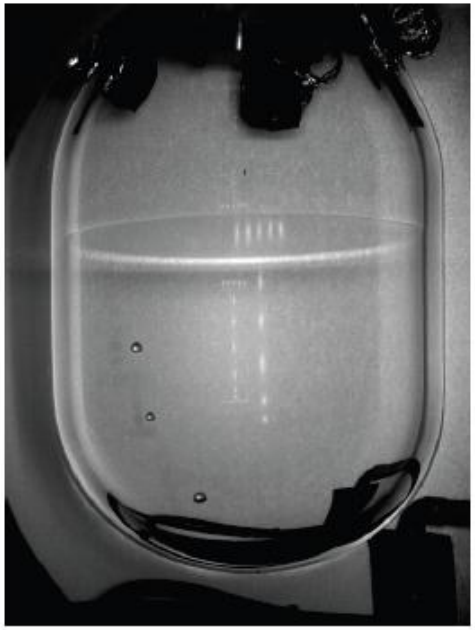
- Detection of single bubbles induced by high-dE/dx nuclear recoils in heavy liquid bubble chambers
- <10^{-10} rejection factor for MIPs. *INTRINSIC* (no data cuts)
- Scalability: large masses easily monitored (built-in "amplification"). Choice of three triggers: pressure, acoustic, motion (video))
- Revisit an old detector technology with improvements leading to extended (unlimited?) stability (*ultra-clean* BC)
- Excellent sensitivity to both SD and SI couplings (CF_3I)
- Target fluid can be replaced (e.g., C_3F_8, C_4F_{10}, CF_3Br). Useful for separation between n- and WIMP-recoils and pinpointing WIMP in SUSY parameter space.
- High spatial granularity = additional n rejection mechanism
- Low cost, room temperature operation, safe chemistry (fire-extinguishing industrial refrigerants), moderate pressures (<200 psig)
- Single concentration: reducing or rejecting α-emitters in fluids to levels already achieved elsewhere (~10^{-17}) will lead to complete probing of SUSY models



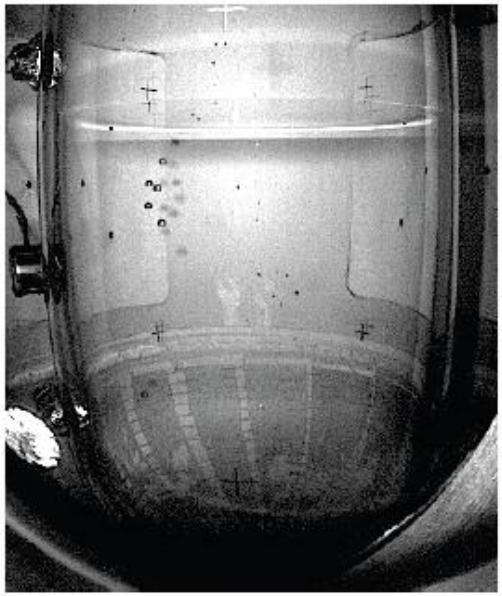


COUPP. The Program

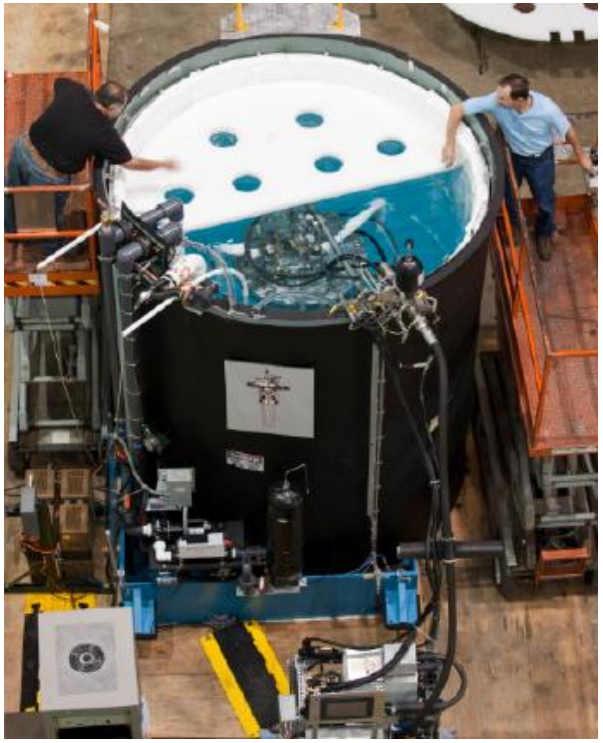
- COUPP-4: a CF3I 2-liter chamber in SNOLAB (2010-2012)
- COUPP-60: a 30-liter CF3I chamber in SNOLAB (2013-2016)
- COUPP-4lite (PiCo-2-Liter): a C3F8 2-liter chamber with low threshold in SNOLAB (2013-2016)
- COUPP-500 (PiCo-250L): 500 kg Superheated detector in SNOLAB (2015 on), now in Design Phase.



COUPP-4

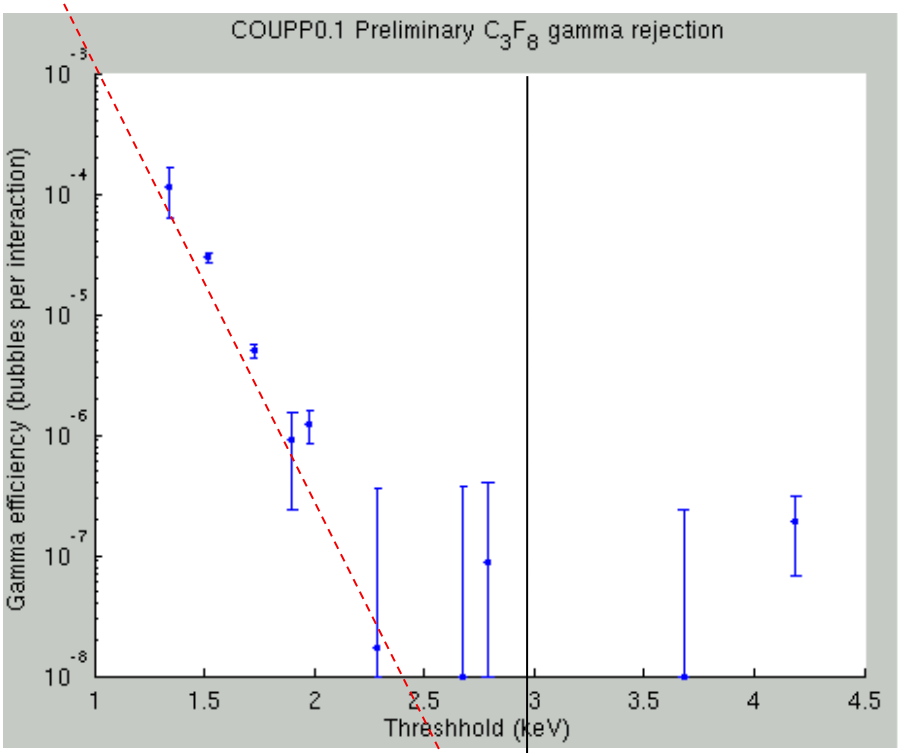


COUPP-60



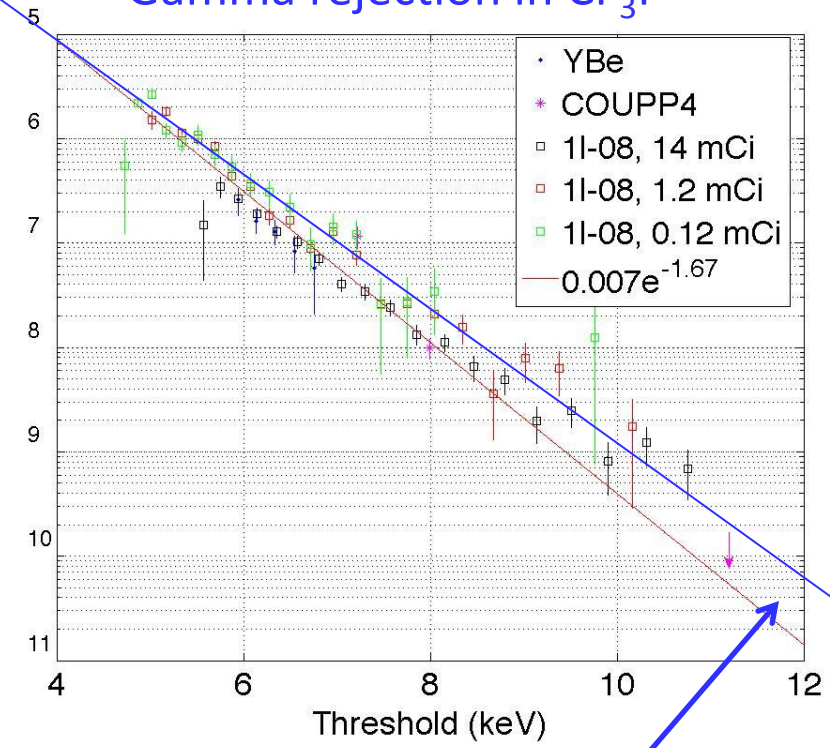
Tests and Calibrations

Gamma rejection in C_3F_8



10^{-10} ~ 3 keV

Gamma rejection in CF_3I

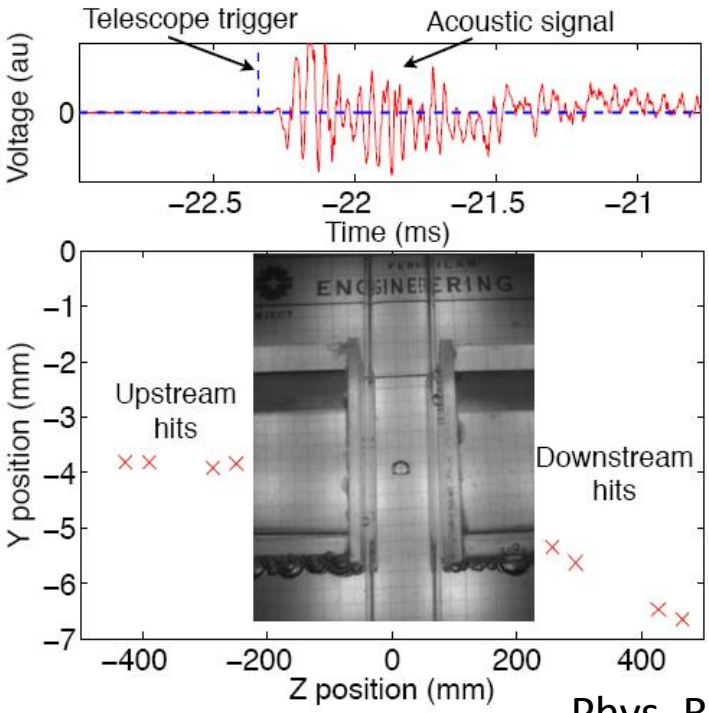


10^{-10} ~ 12 keV

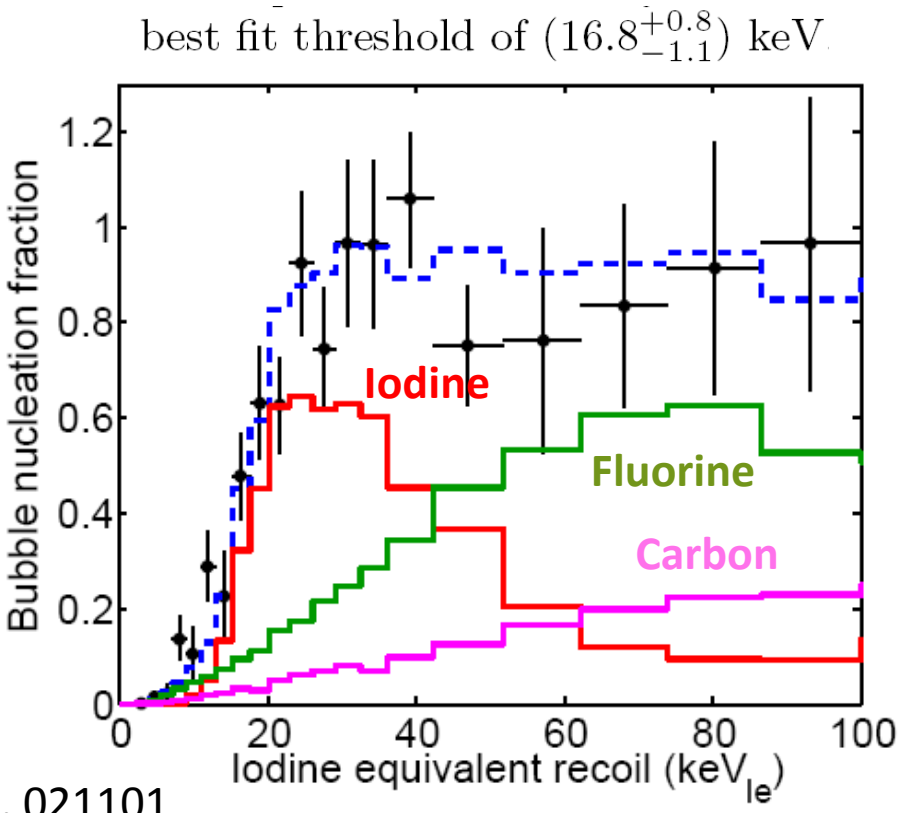
Tests and Calibrations

CIRTE: Nuclear recoil efficiency (Iodine)

- 12 GeV pion beam with silicon pixel telescope to measure scatt. angle.
- Example event: 6 mrad scatter



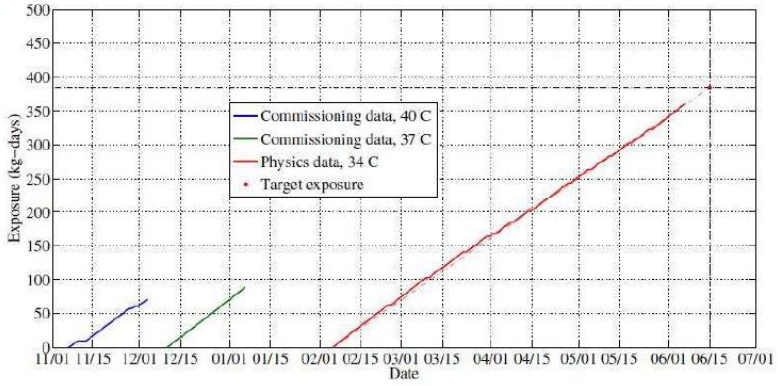
- Pion-scattering calibration of iodine threshold in CF3I.



Phys. Rev. D 88, 021101

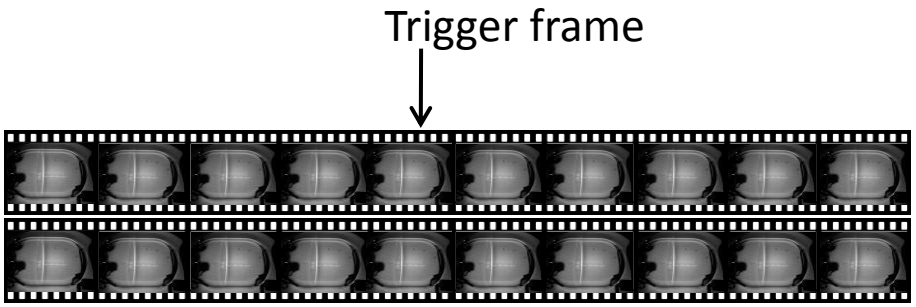
COUPP 4 kg Bubble Chamber

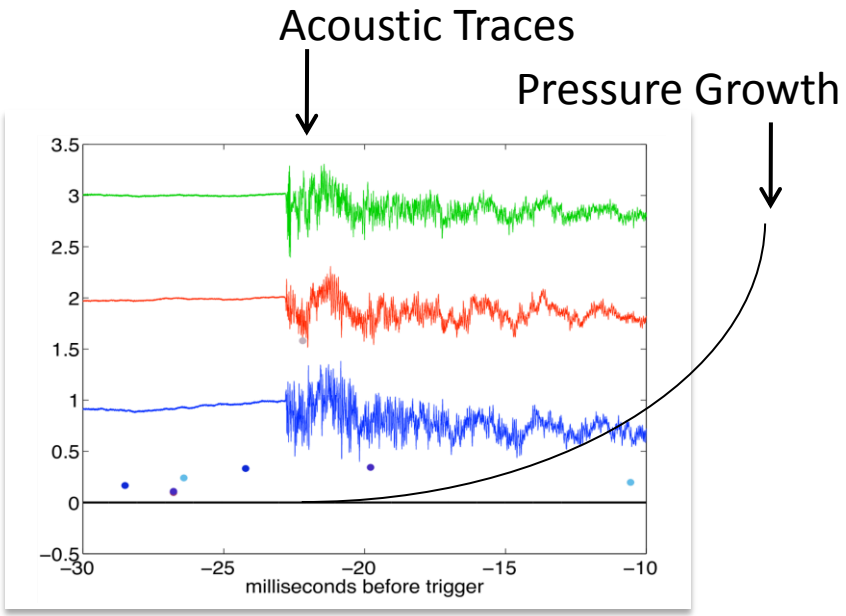
- Installation in summer 2010
- First Physics run begins Nov. 3, 2010
  (second Physics run in 2012)
- Run settings (P=30.5 psia):
  - 17.4 days at 8 keV (39^oC)
  - 21.9 days at 10 keV (36^oC)
  - 97.3 days at 15 keV (33.5^oC)
- 4.048 kg of CF_3I
- Calibrations:
  - Neutron calibration runs: AmBe and ^{252}Cf
  - Continuous source of ^{222}Rn



COUPP 4 kg Bubble Chamber: Data

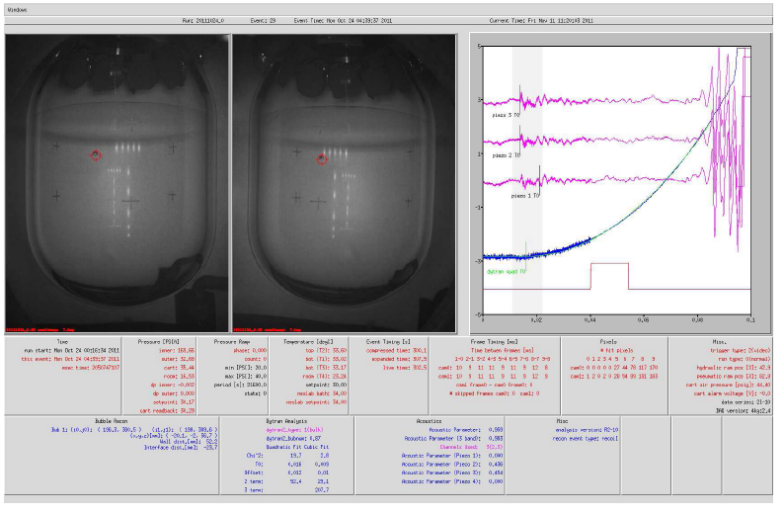
- 10 frames of Stereo Camera Images
- Synchronized measurements of P, T, and control parameters
- 2.5 Mhz waveform digitizer for acoustics and fast pressure transducer.





COUPP 4 kg Bubble Chamber: Data Analysis

- Examination of images: algorithm searching for clusters among pixels that changed between consecutive frames
- Examination of pressure rise: fit to the rate of pressure rise by a quadratic time dependence for bubbles in the bulk
- Examination of the acoustic signal



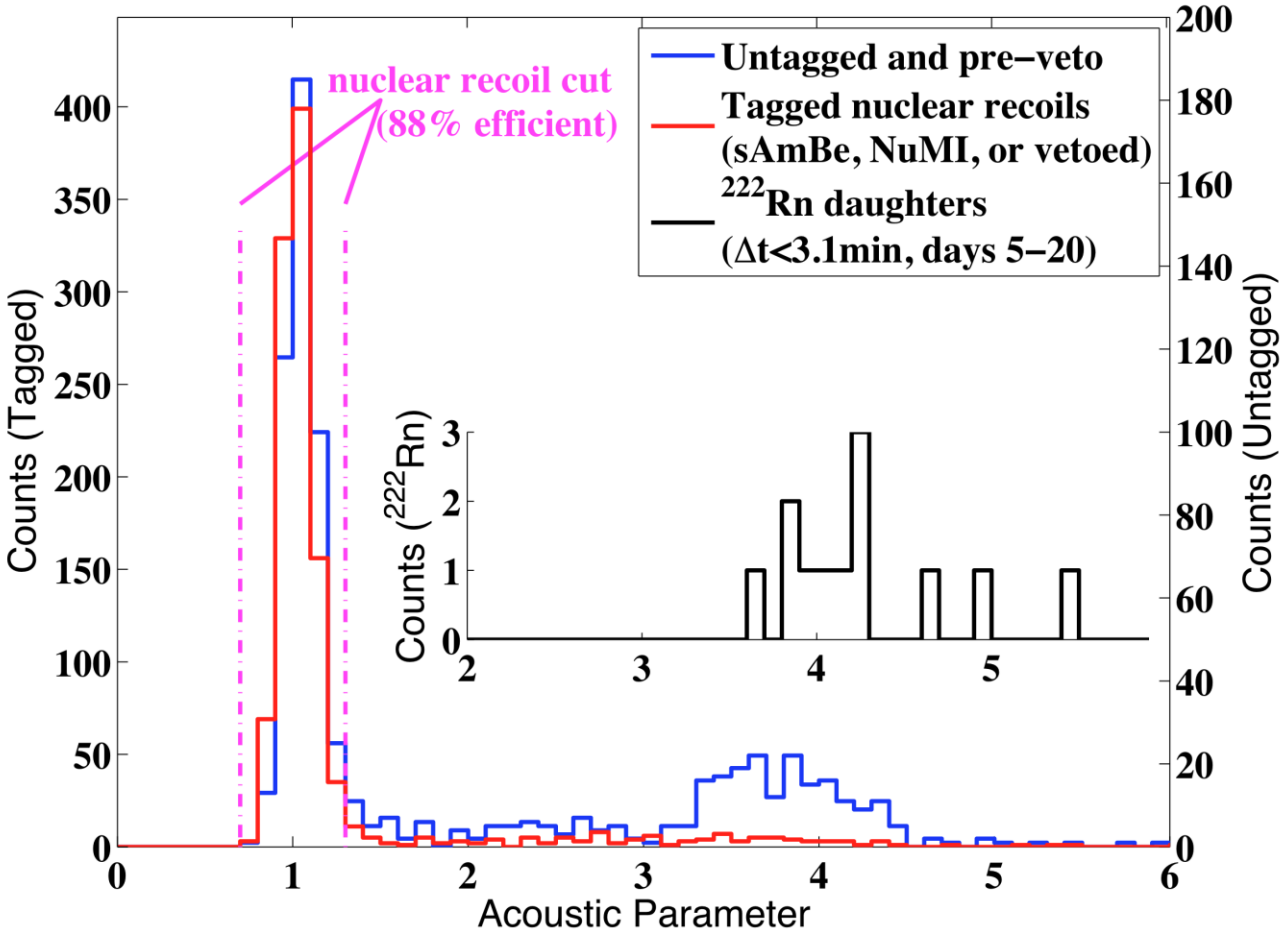
hand-scanned to resolve disagreement

overall efficiency for all data quality and fiducial volume cuts is $82.5 \pm 1.9\%$

COUPP 4 kg Bubble Chamber: Data Analysis

Acoustic Parameter and alpha discrimination

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



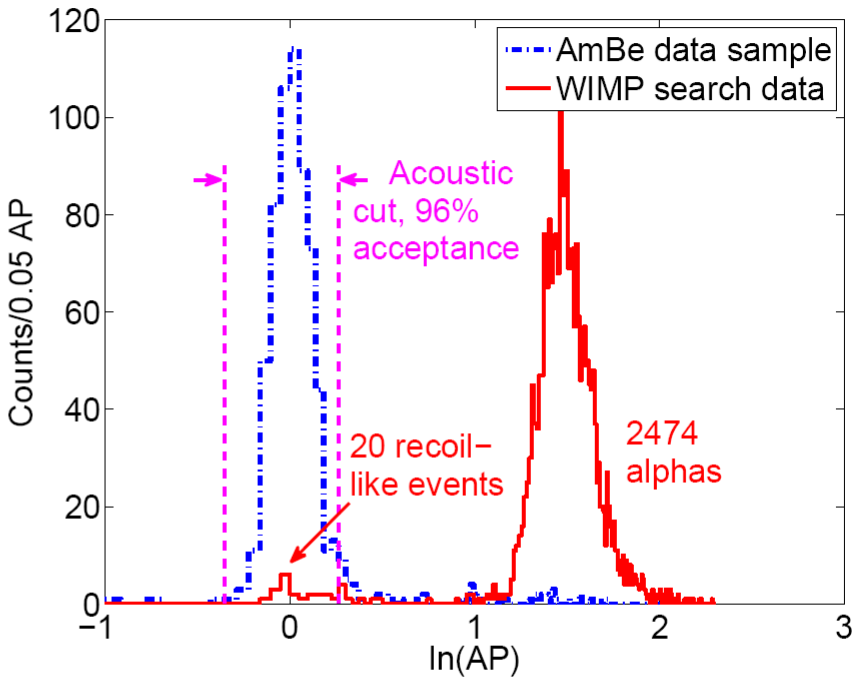
COUPP 4 kg Bubble Chamber: Data Analysis

456 kg-days, 2474 alphas
1733 alphas (15 keV data)

5.3 alpha decays/ kg-day
95% from radon

$> 98.9\%$ α rejection
$> 99.3\%$ (15 keV data)

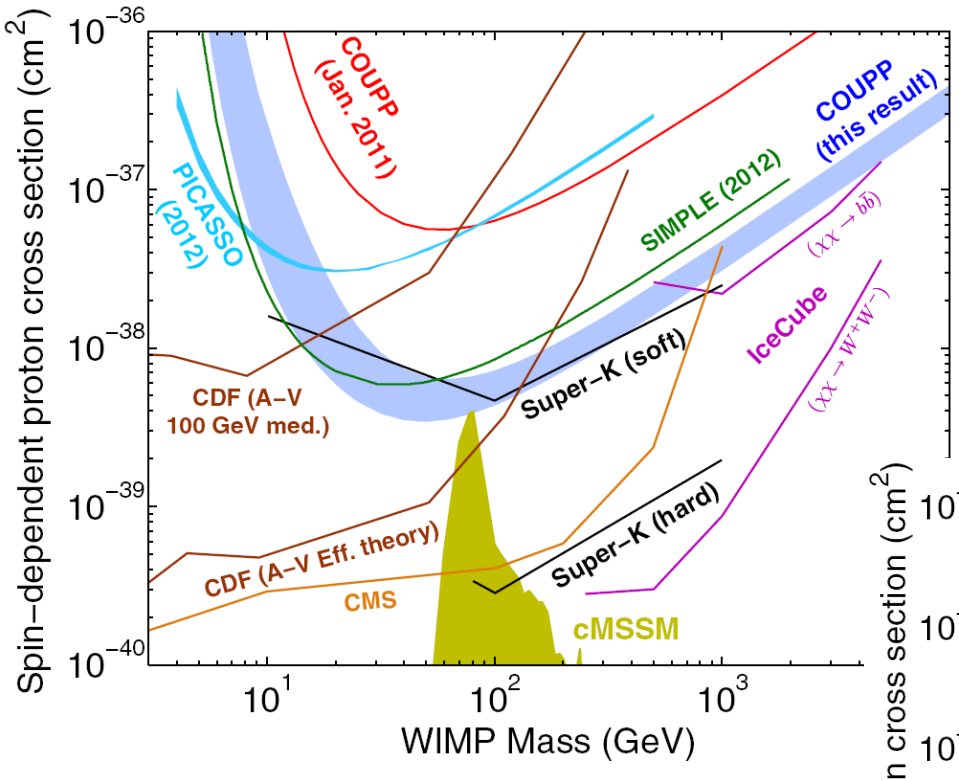
- 6 events at 8 keV
- 6 events at 10 keV (2 triples)
- 8 events at 15 keV (1 double)



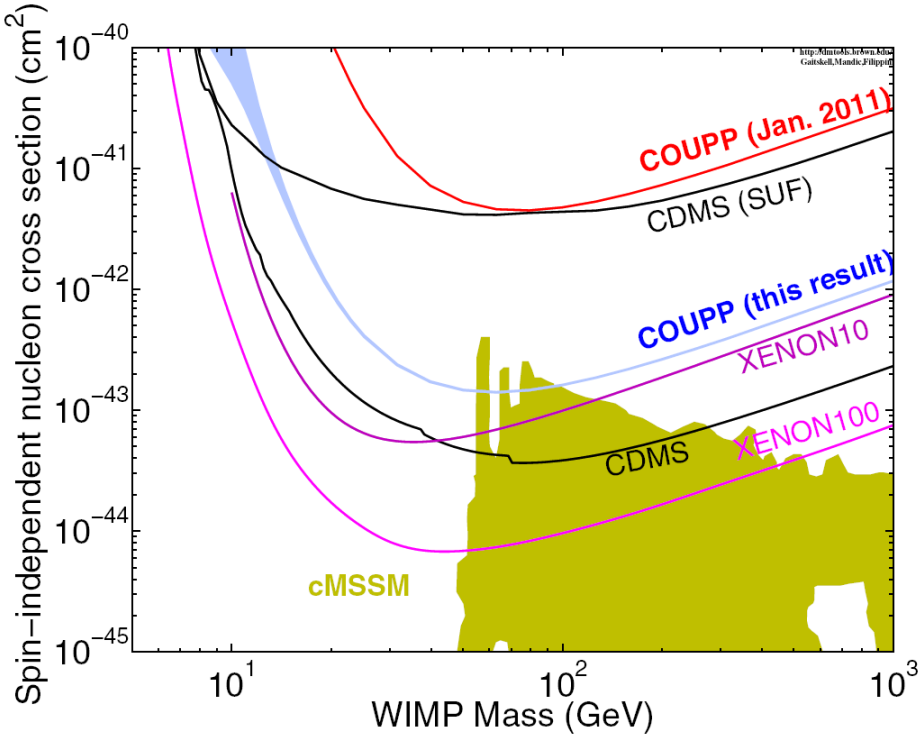
20 WIMP candidates

(Neutrons from rock: < 1/year)

COUPP 4 kg Bubble Chamber: WIMP Search Results

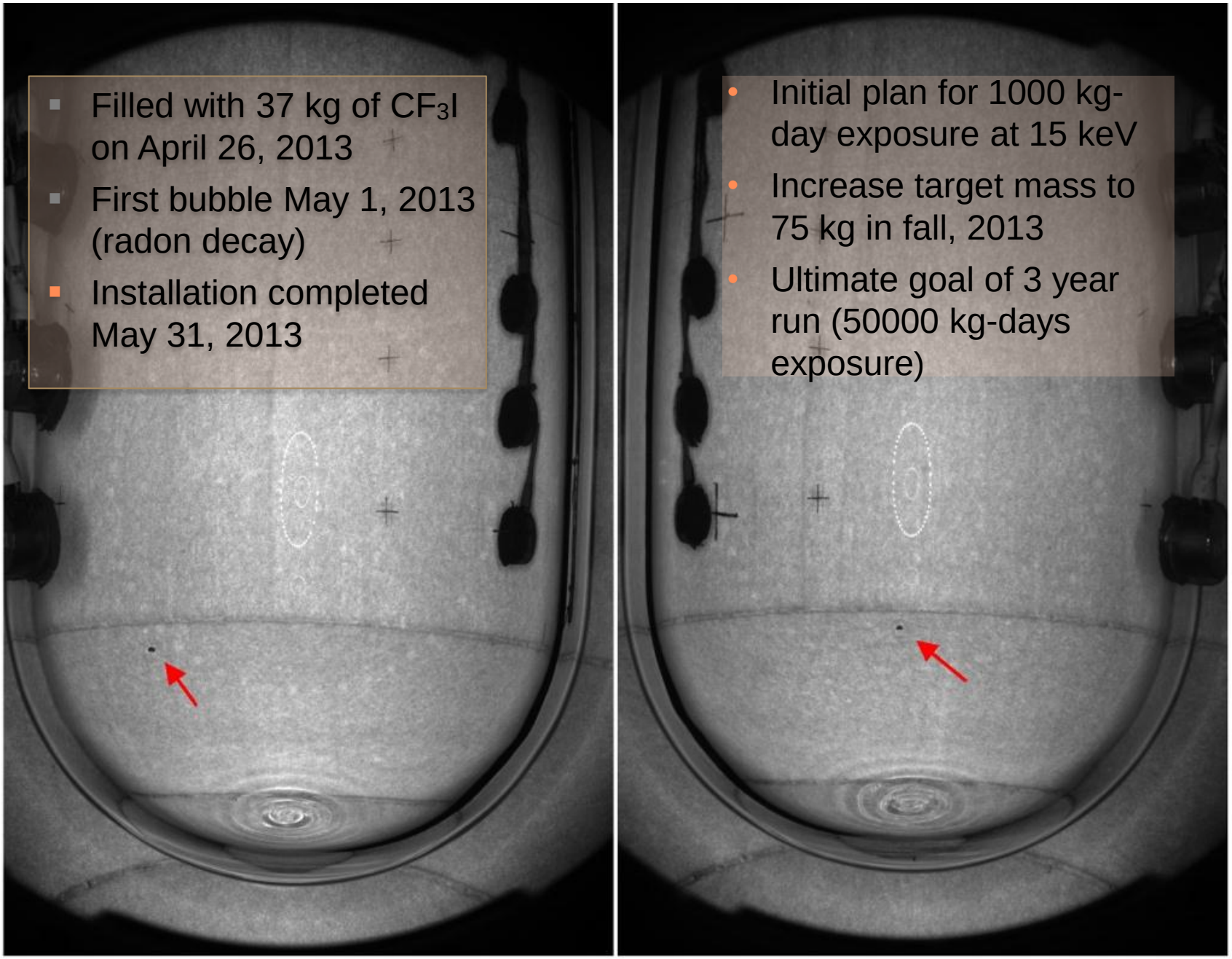


Given uncertainties on background predictions, no background subtraction is applied,
Phys. Rev. D 86, 052001 (2012)



2nd Physics run in 2012 with similar results

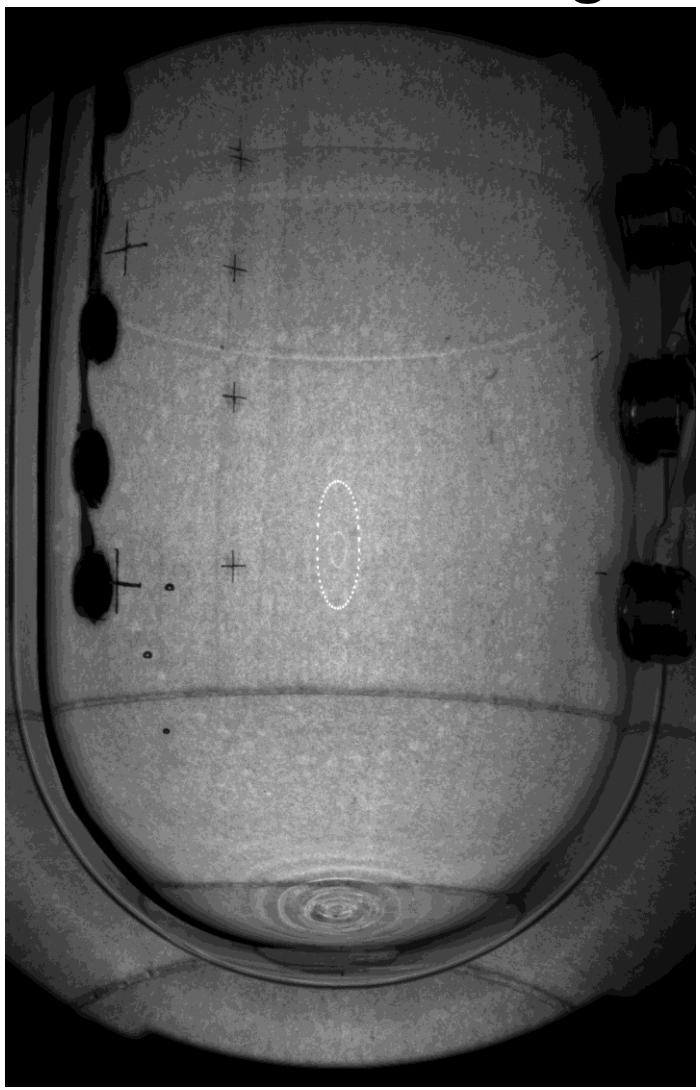
COUPP-60: running in SNOLAB



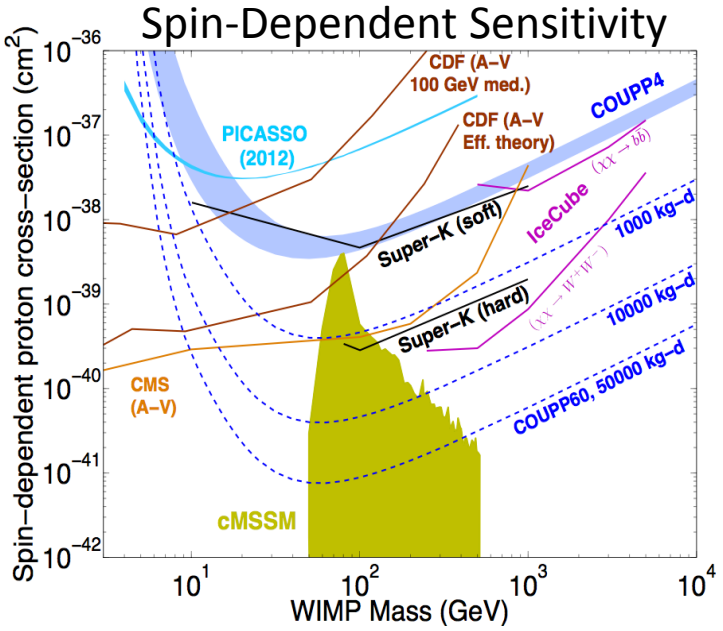
- Filled with 37 kg of CF_3I on April 26, 2013
- First bubble May 1, 2013 (radon decay)
- Installation completed May 31, 2013

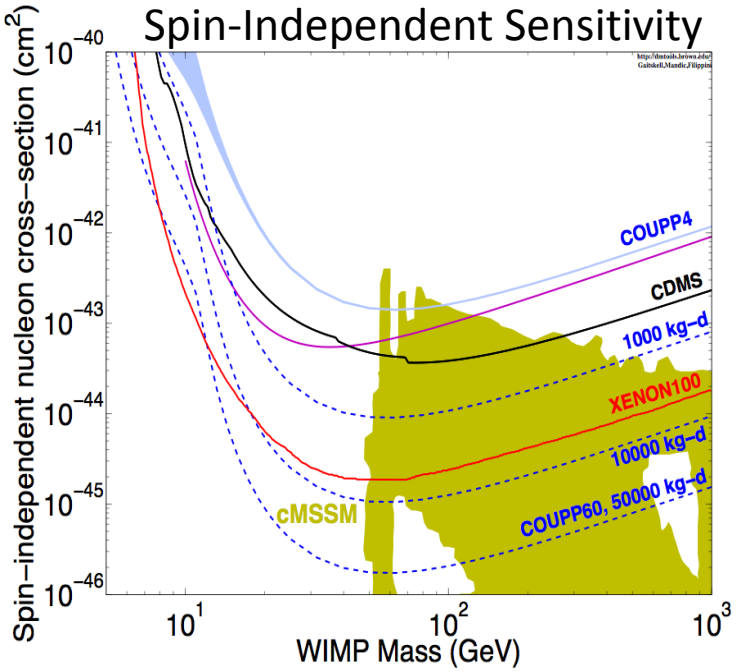
- Initial plan for 1000 kg-day exposure at 15 keV
- Increase target mass to 75 kg in fall, 2013
- Ultimate goal of 3 year run (50000 kg-days exposure)

COUPP-60: running in SNOLAB



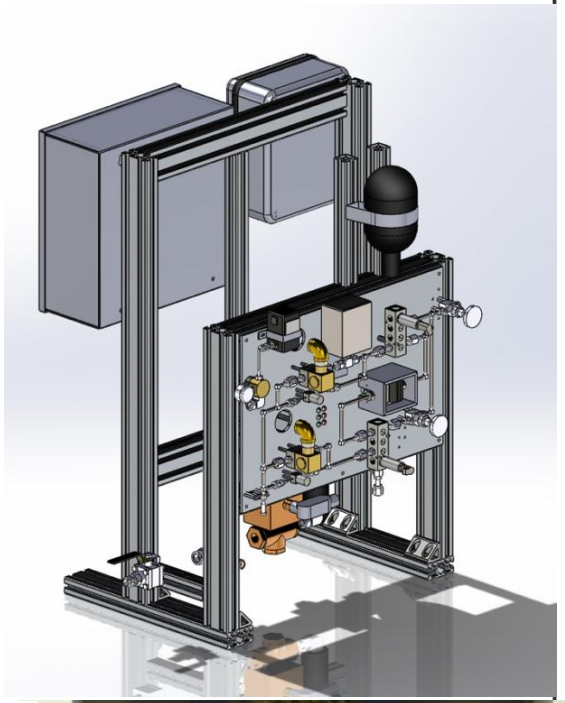
Triple bubble event in COUPP-60 with Am/Be neutron calibration source. May 2013.

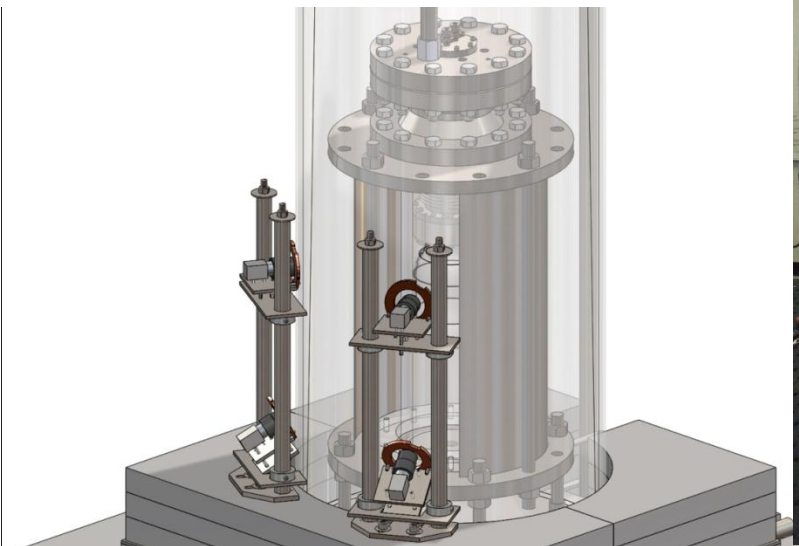


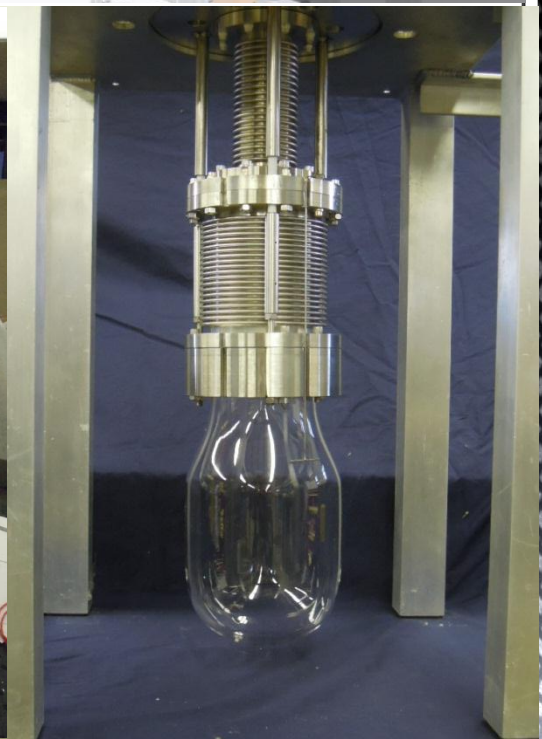


COUPP-4lite (or PiCo-2Liter)

- C_3F_8 chamber in existing COUPP-4 infrastructure at SNOLAB
- 3 keV threshold
- Excellent low-mass WIMP and SD coupling sensitivity
- CDMS-Si result gives 1 event/day in COUPP-4lite
- First joint effort with PICASSO
- It is being deployed, soon commissioned and starting physics runs.



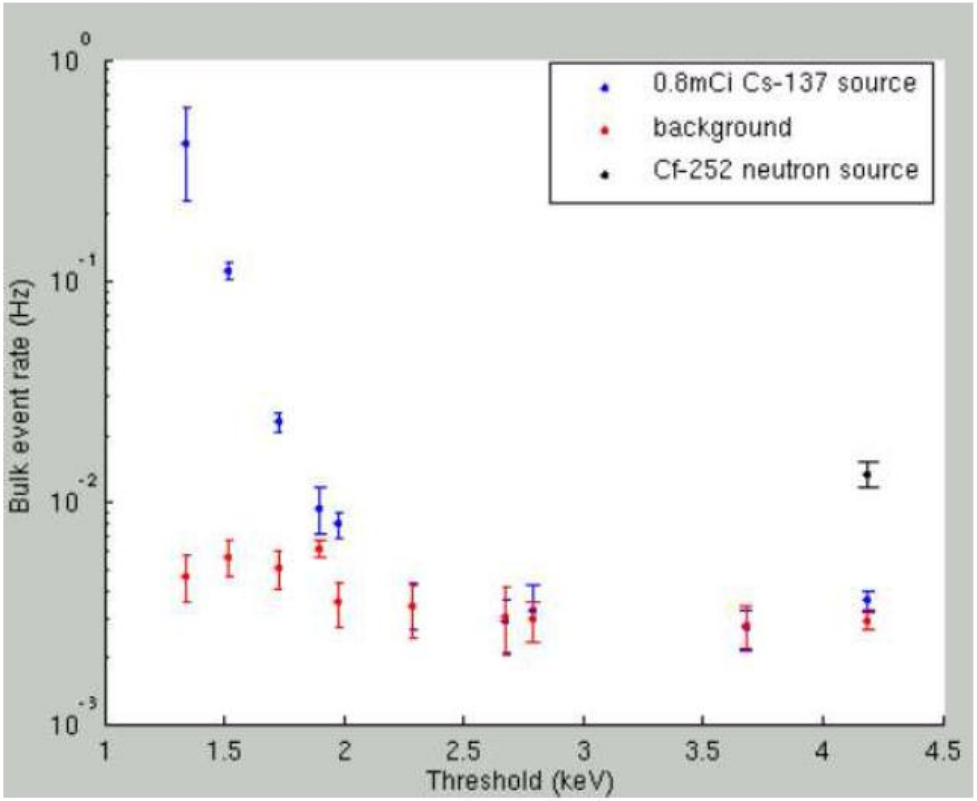


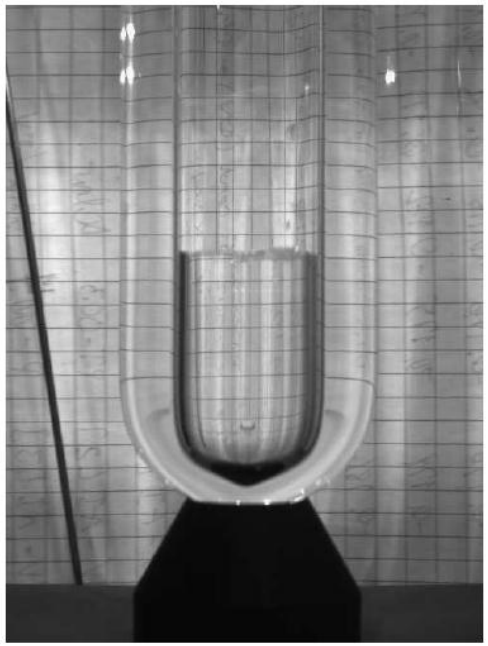


COUPP-4lite (or PiCo-2Liter)

C_3F_8 as target material

- Very low threshold achievable: 3 keV
- Excellent for low-mass WIMP studies
- Excellent for Spin Dependent coupling sensitivity





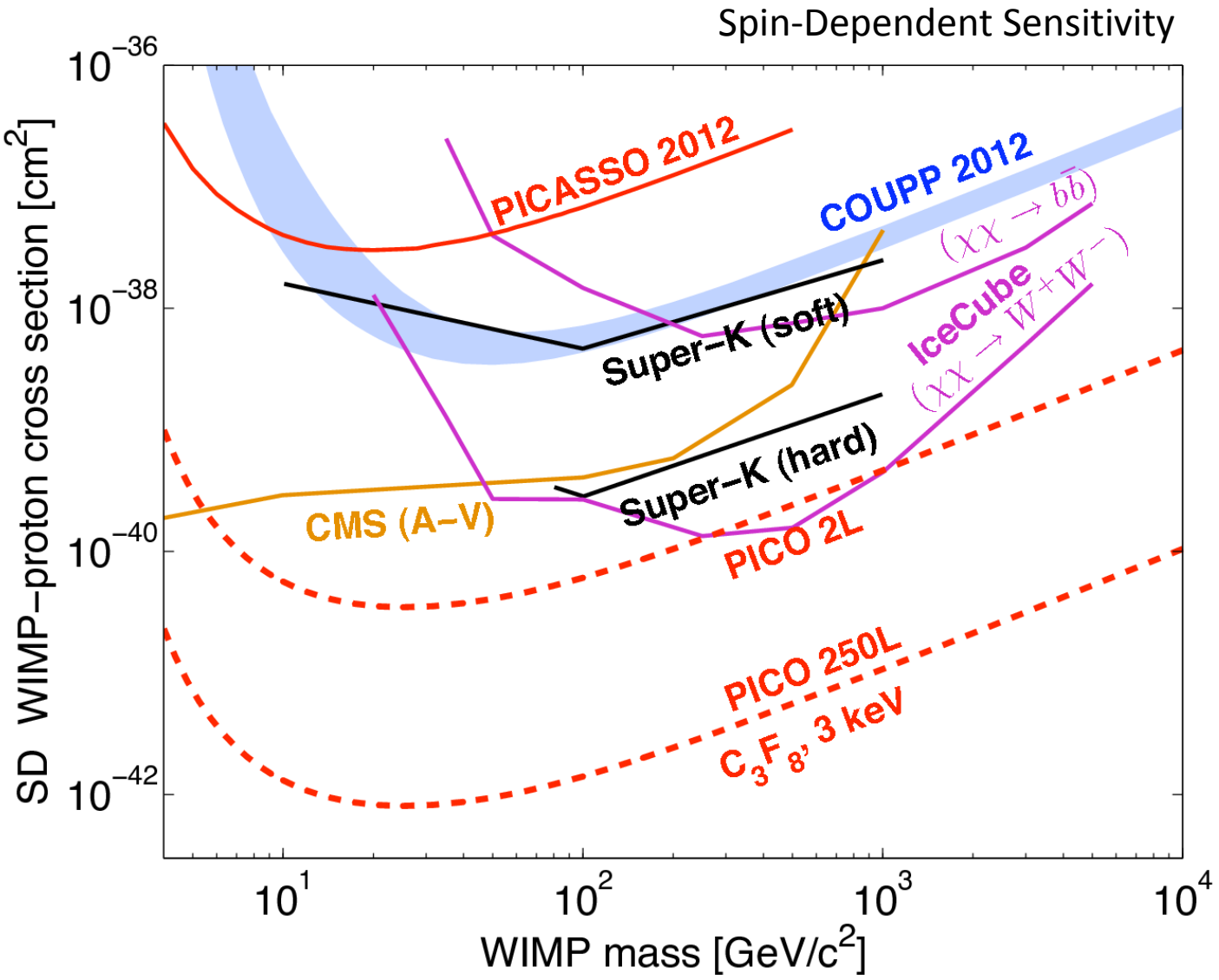
First bubble in the 0.1L test using C3F8 as target material

COUPP-500 (or PiCo)-250L

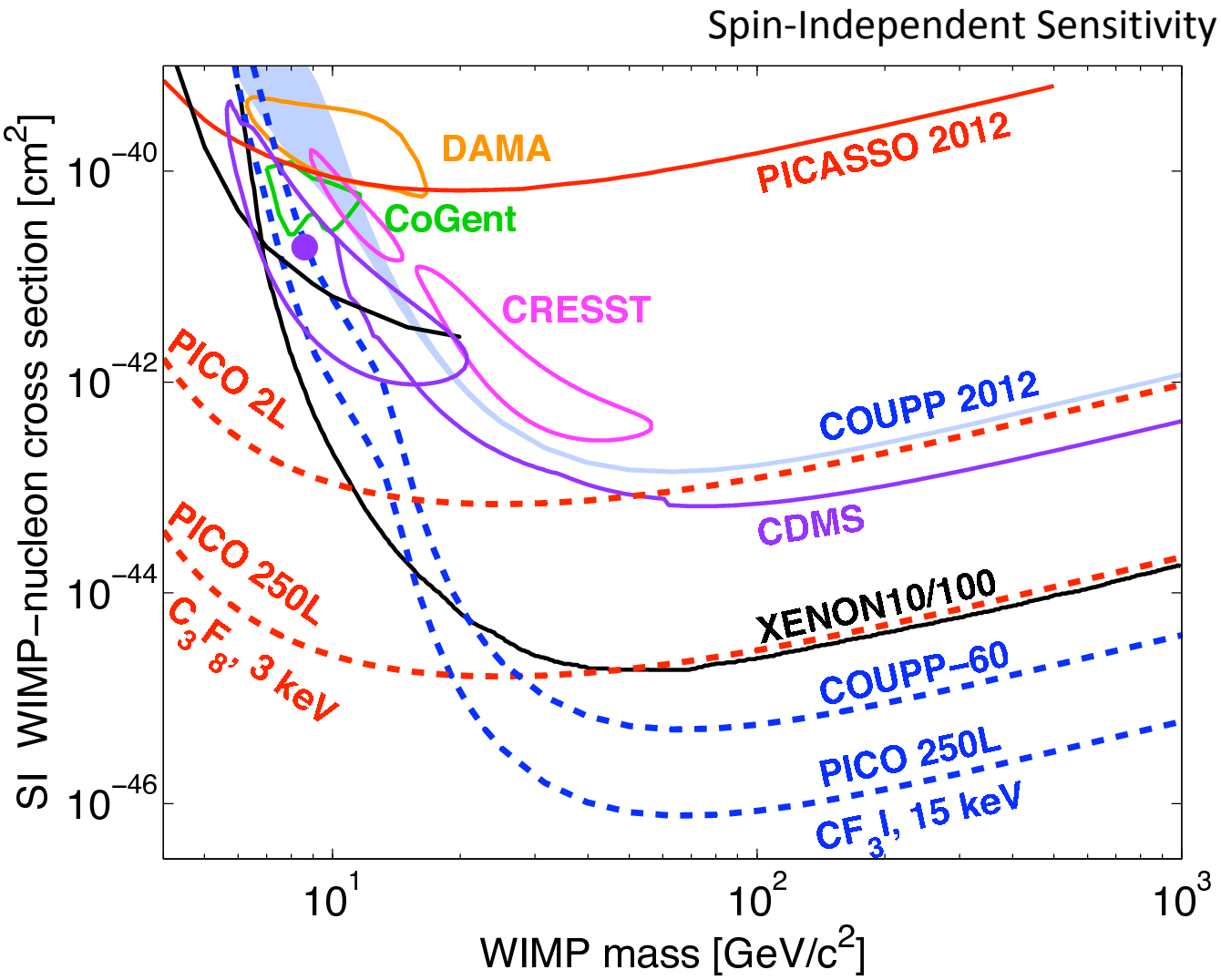
250 liter bubble chamber design effort

- Well developed Conceptual Design. Straightforward scale-up from COUPP-4 and COUPP-60
  - ✓ > 10^{10} γ/β insensitivity
  - ✓ > 99.3% acoustic α discrimination
  - ✓ Multi-target capability
    - SD- and SI-coupling
    - High- and low-mass WIMPs
  - ✓ Easily scalable,
  - ✓ Inexpensive to replicate

Expected Sensitivities



Expected Sensitivities



Summary and Conclusions

- *Physics run at SNOLAB completed for COUPP-4*
  - *Results published in 2012*
  - *Spin-dependent competitive limit achieved*
  - *Excellent acoustic alpha rejection: > 99%*
- *Growing Collaboration (PiCo): merged with PICASSO*
- *COUPP family of detectors making huge improvements*
  - *COUPP-60 at SNOLAB: physics run going on (with 37kg), 75 kg in the fall*
  - *Calibrations, calibrations and calibrations: CIRTE, 88Y/Be, gamma, neutron, ...*
  - *PiCo-2Liter: will be running soon with C3F8 as target.*
  - *PiCo-250Liter is coming fast*