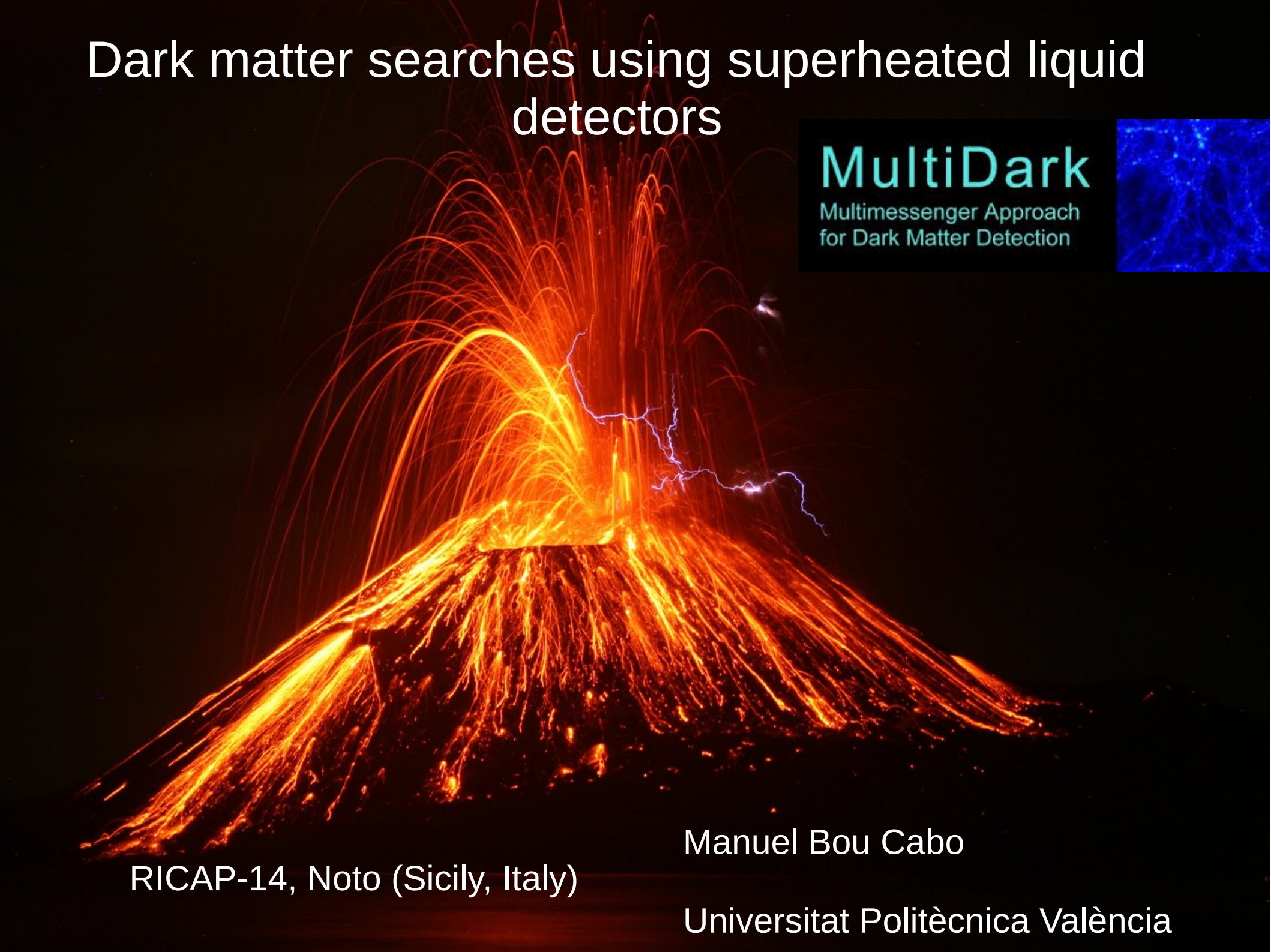
Dark matter searches using superheated liquid detectors

MultiDark
Multimessenger Approach for Dark Matter Detection



RICAP-14, Noto (Sicily, Italy)

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Summary

- PICO: The collaboration
- COUPP / PICO: The Technique
- COUPP / PICO: Detectors.
- COUPP / PICO: The program.
- COUPP-4 Results.
- COUPP-60.
- PICO-2L.
- PICO 250L.
- MOSCAB.
- Conclusions.

PICO

= PICASSO + COUPP

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

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COUPP / PICO: The Technique

- In superheated liquid, bubble is generated when is deposed $E > E_{th}$ in length $L < r_c$ ➡ exist necessary amount of energy to create a macroscopic bubble (Seitz “Hot Spike” Model).

Classical Thermodynamics says:

$$E_{th} = \underbrace{4\pi r_c^2 \left(\sigma - T\frac{\partial \sigma}{\partial T}\right)}_{\text{Surface energy}} + \underbrace{\frac{4}{3}\pi r_c^3 \rho_v h}_{\text{Latent heat}}$$

- Bubble growth phases
  - Nucleation (negligible contribution to the acoustic emission)
  - Inertia Controlled Growth $\left(R \propto t\right)$.
  - Thermal diffusion controlled growth $\left(R \propto t^{1/2}\right)$

$$\frac{p_B(t) - p_\infty}{\rho_L} = R\frac{d^2R}{dt^2} + \frac{3}{2}\left(\frac{dR}{dt}\right)^2 + \frac{4\nu_L}{R}\frac{dR}{dt} + \frac{2S}{\rho_L R}$$

First approximation to solution of bubble growth Rayleigh – Plesset Eq

Coupp / Pico detectors.

Objective ➡ Detect WIMP- Nucleus nuclear recoil using bubble chamber filled with superheated liquids.

Pressure expansion puts fluid (CF_3I or C_3F_8) in superheated state

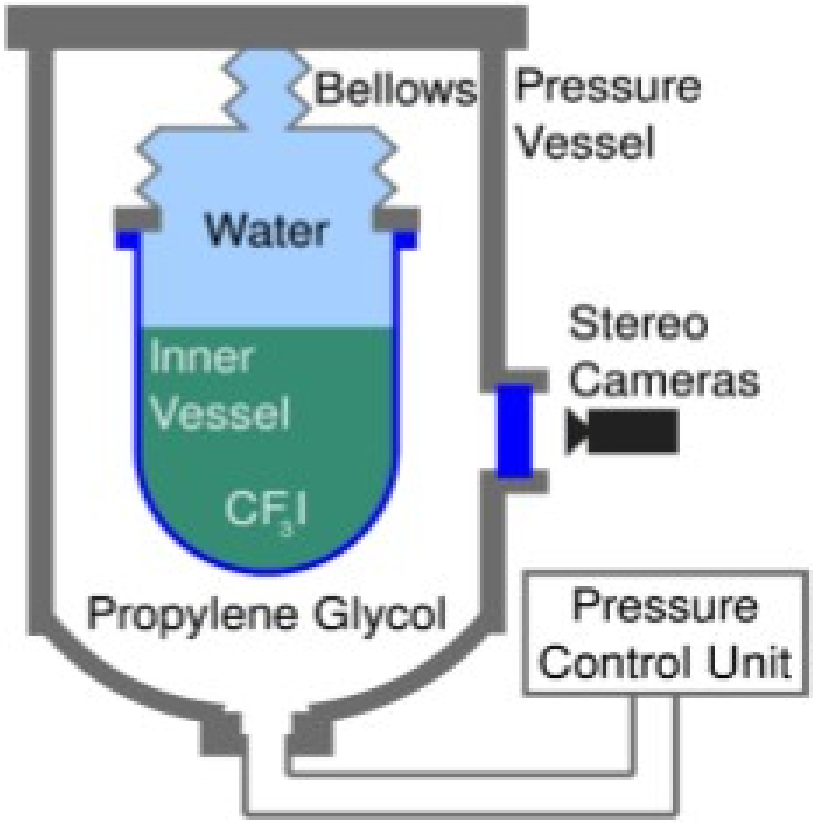
- I for spin-independent
- F for spin-dependent (many fluids possible)

Particle interactions nucleate bubbles

Cameras see bubbles, trigger

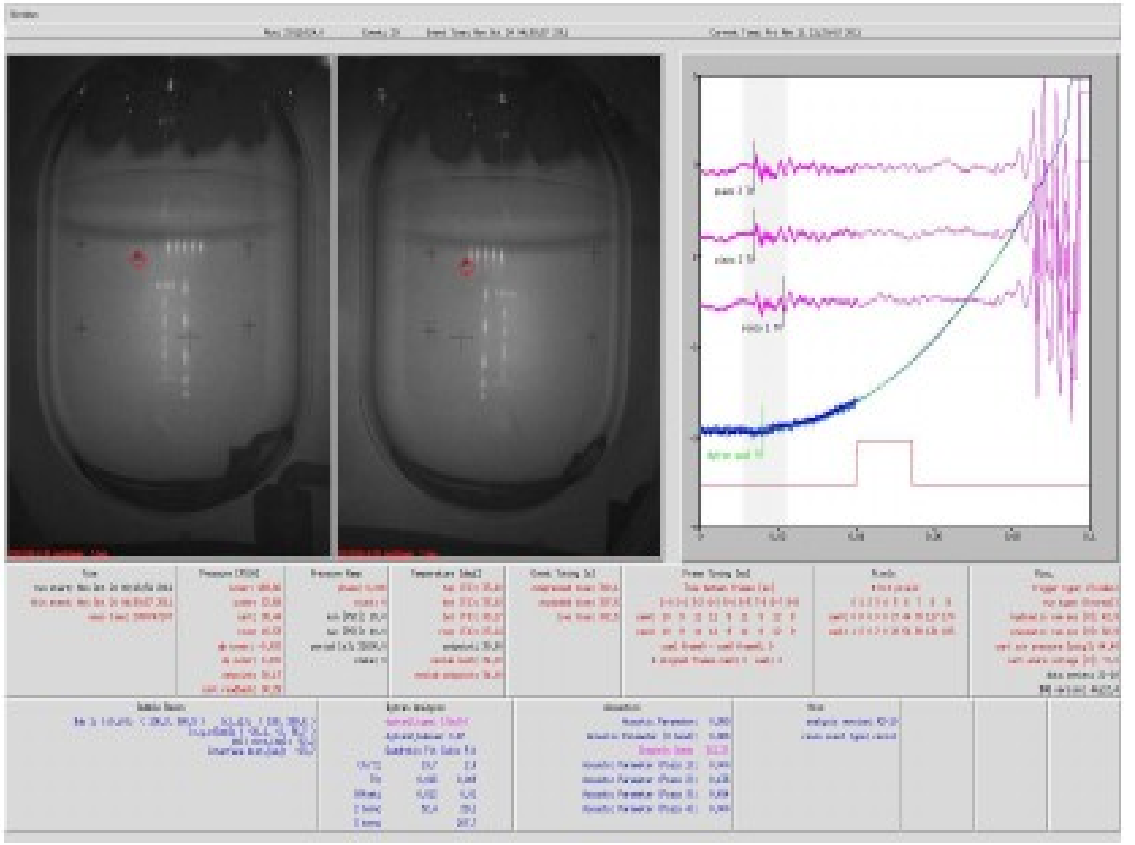
- Stereo reconstruction of bubble position, multiplicity
- Pressure rise gives redundant fiducial, multiplicity information
- Acoustics used to identify alphas

Recompress to reset chamber



Coupp / Pico detectors.

Basic analysis chain involves:



- Examination of images:

  algorithm searching for clusters among pixels that changed between consecutive frames (trigger based on comparison of consecutive images).

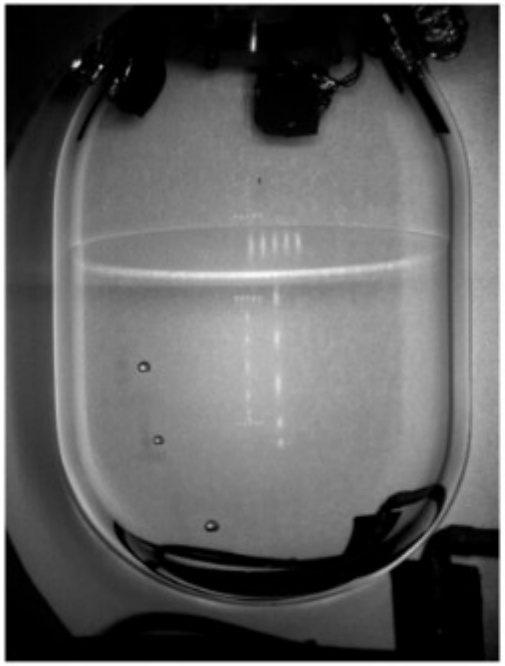
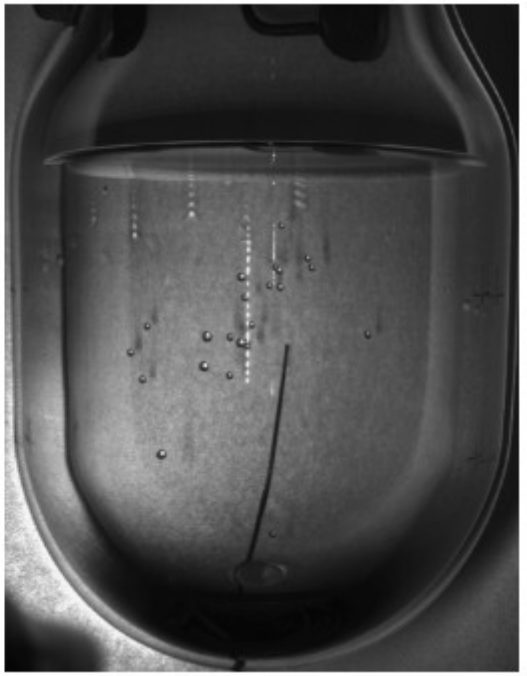
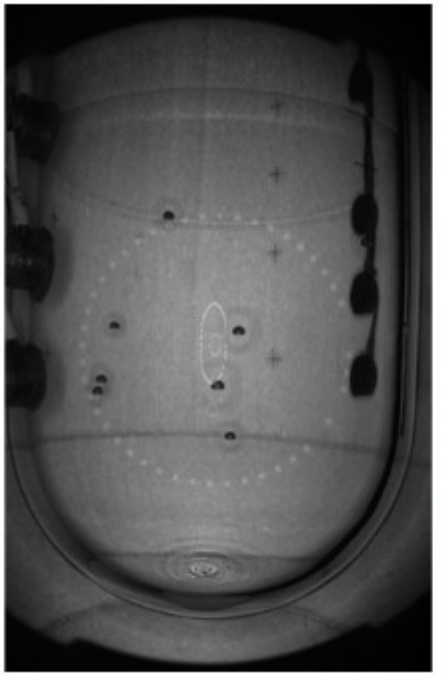
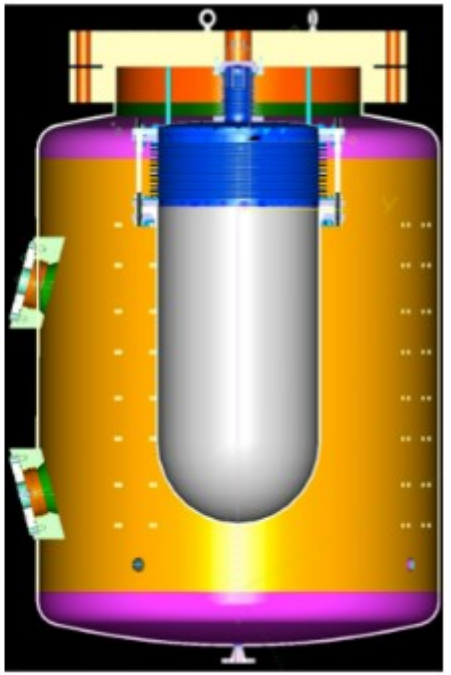
- Examination of pressure rise:

  fit to the rate of pressure rise by a quadratic time dependence for bubbles in the bulk.

- Examination of acoustic signal received by piezo-electric transducers.

COUPP / PICO: The program

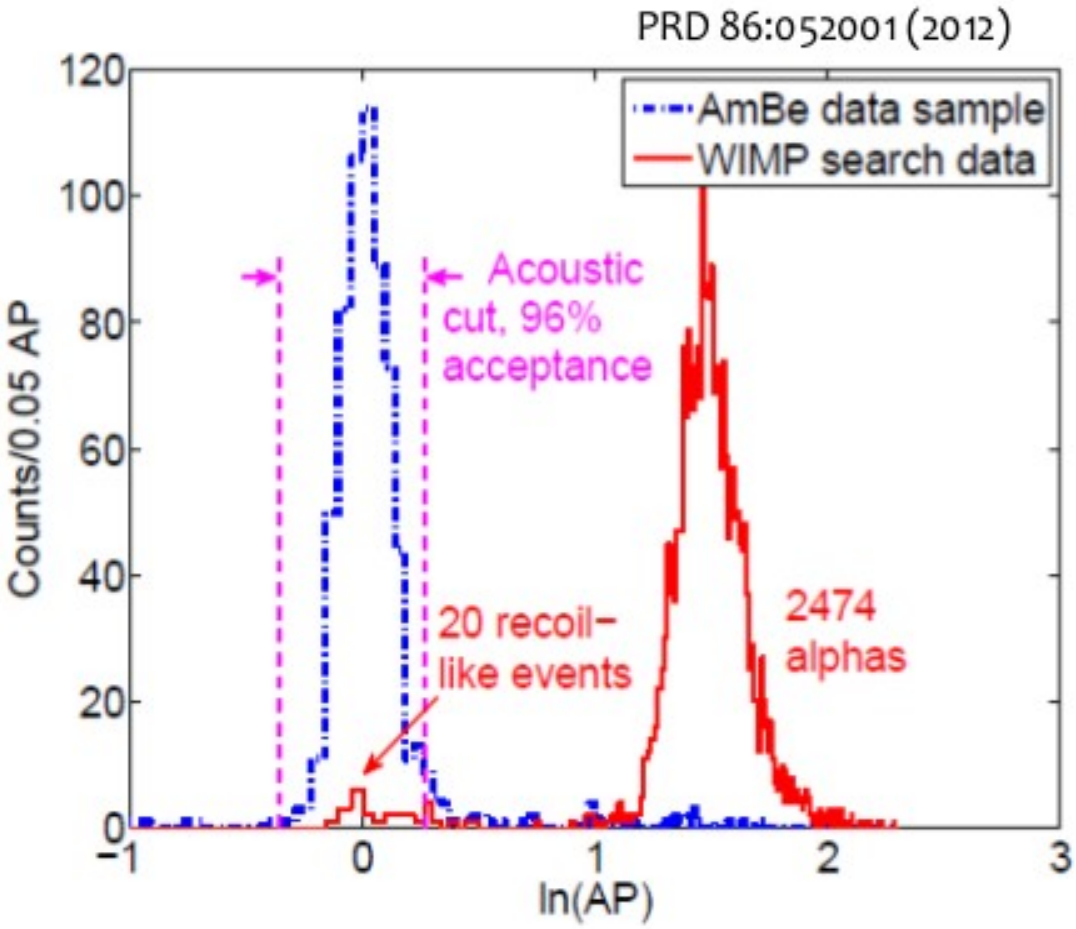
- COUPP-4: A 2-liter CF3I chamber run at SNOLAB in 2010, 2012
- COUPP-60: Up to 40 liter CF3I chamber currently running at SNOLAB
- PICO-2L: A 2-liter C3F8 chamber currently running at SNOLAB
- PICO-250L: Ton-scale G2 experiment, construction 2015-2016, data 2017

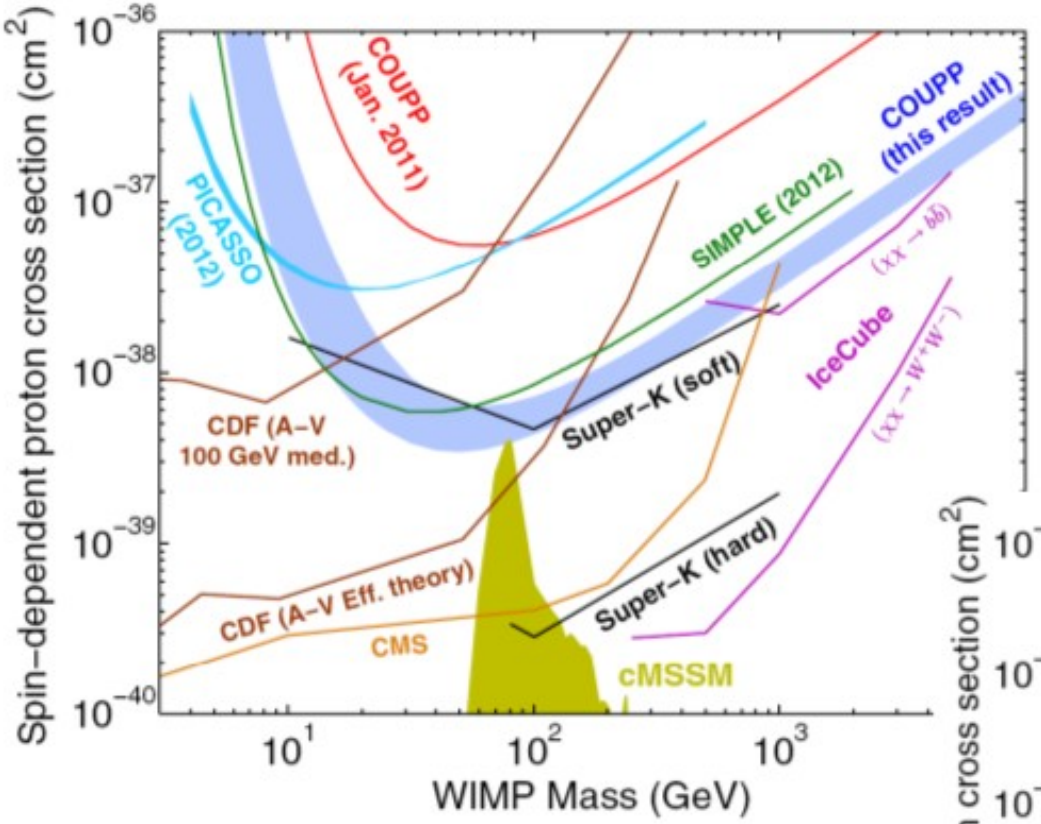
COUPP-4 Results

- Clear acoustic discrimination of alphas (>99.3% rejection, limited by statistics and backgrounds)
- 20 recoil-like events
  - 6 at 8 keV (71 kg-days)
    6 at 11 keV (89 kg-days)
    8 at 16 keV (394 kg-days)
  - 3 multiple bubble events imply some contribution from neutrons (U, Th in the piezo-acoustic sensors and the viewports)

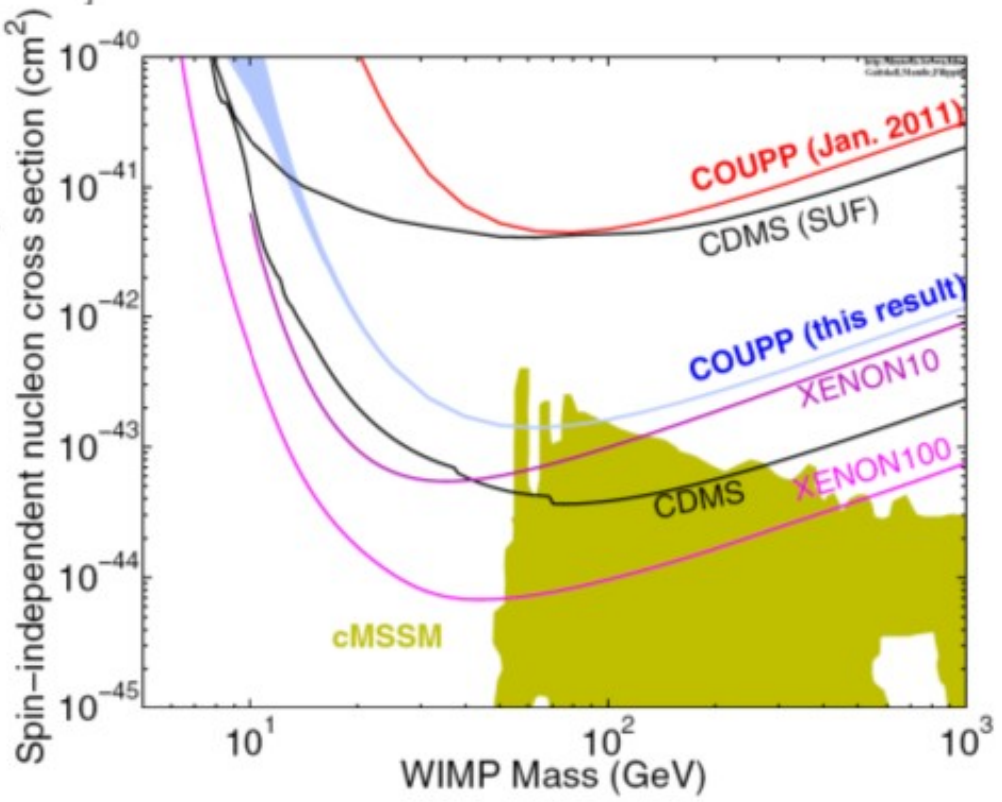
4-kg CF_3I target operated in SNOLAB in 2010, 2012



COUPP-4 Results



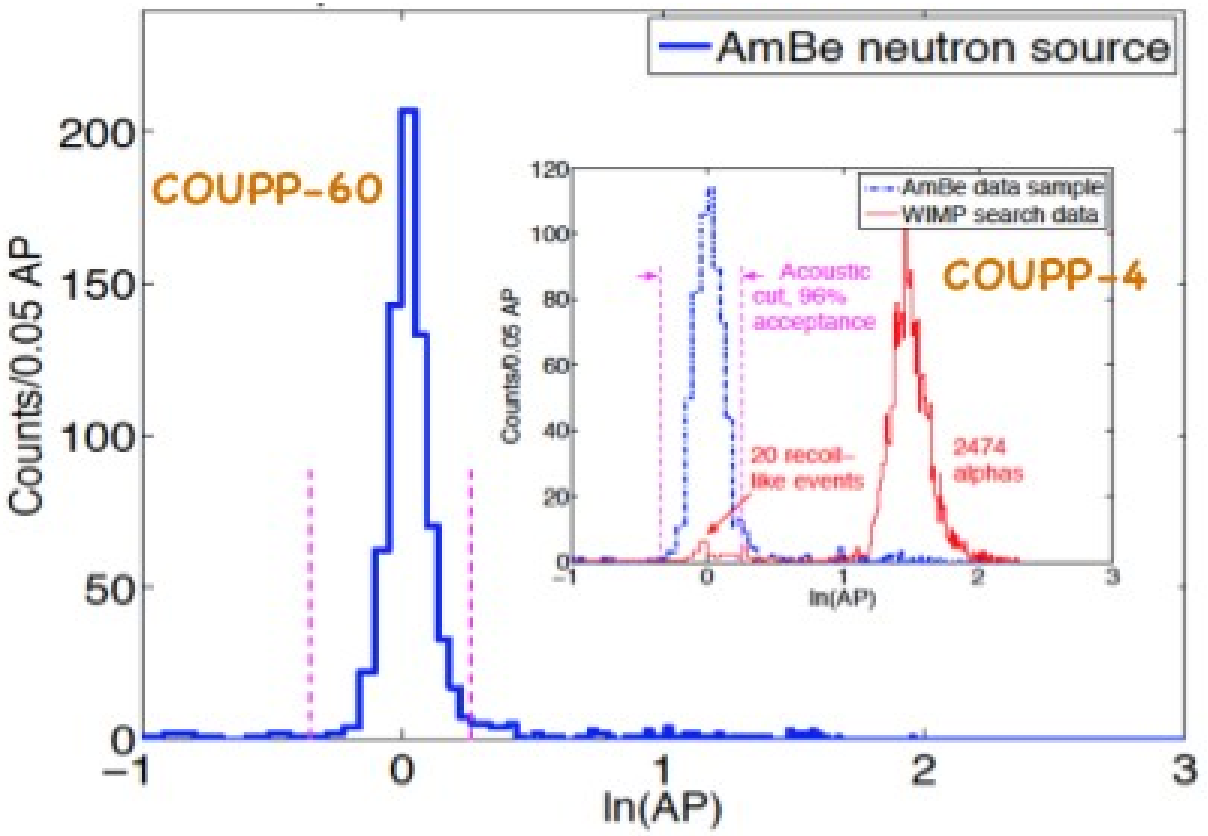
Given uncertainties on background predictions, no background subtraction is applied,
Phys. Rev. D 86, 052001 (2012)



2nd Physics run in 2012 with similar results

COUPP-60Kg

- Good news.
- >4,500 kg-days collected (ongoing) at SNOLAB, with 80-95% live-time at ~11 keVnr threshold.
- No multiple events (~1 neutron/yr expected).



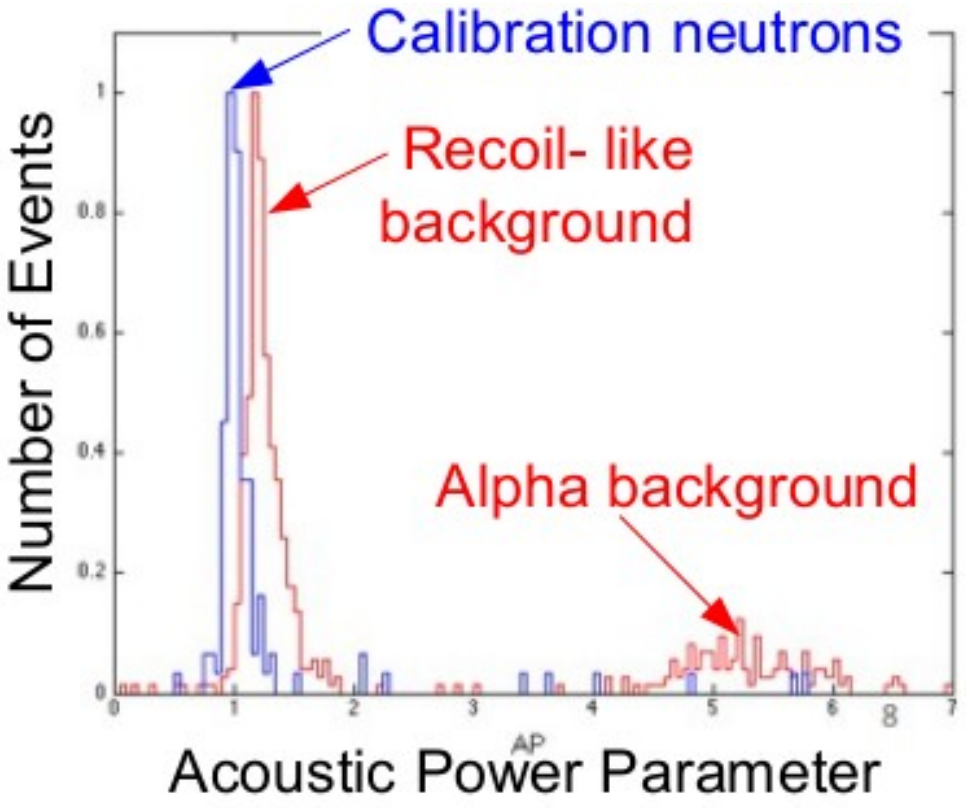
All systems working very well.

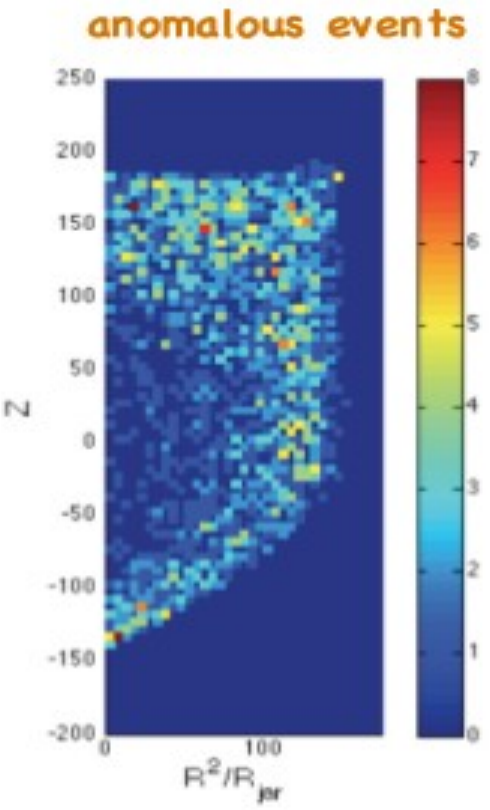
No darkening of CF3I.

Excellent acoustic α discrimination in a large vessel.

COUPP-60Kg.

- Population of clearly anomalous recoil-like events present.
- Suspicious about these may be chemically-reactive nature.
- Fortunately, these events seem to be rejectable using acoustic discrimination.
- Refining the method. Collected data should be usable.





PICO-2L

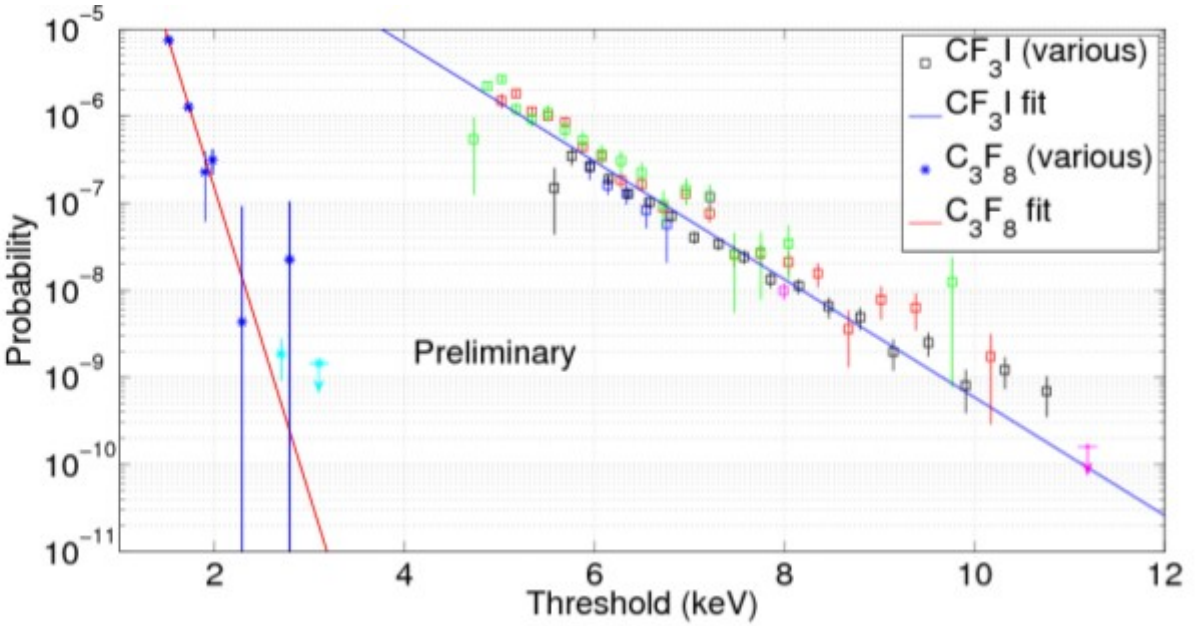
- Pico 2L is the first detector built by the new collaboration merged by COUPP, PICASSO collaborations.
- Pico 2L detector, replace the previous COUPP4 detector, and use a different target material [C3F8].
- Twice the F density
- Lower threshold
- Improved efficiency
- More stable chemistry
- Lower background hardware
- Prototyping for PICO-250L

Simplified pressure vessel – ¼ the mass of steel as COUPP-4.

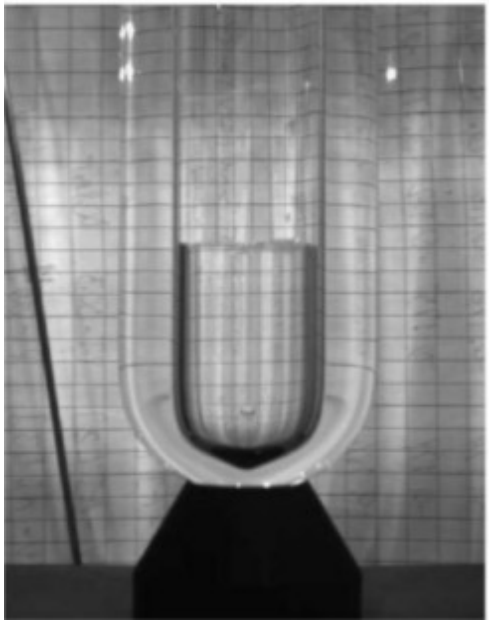
Silica Jar is a replica of COUPP4 vessel

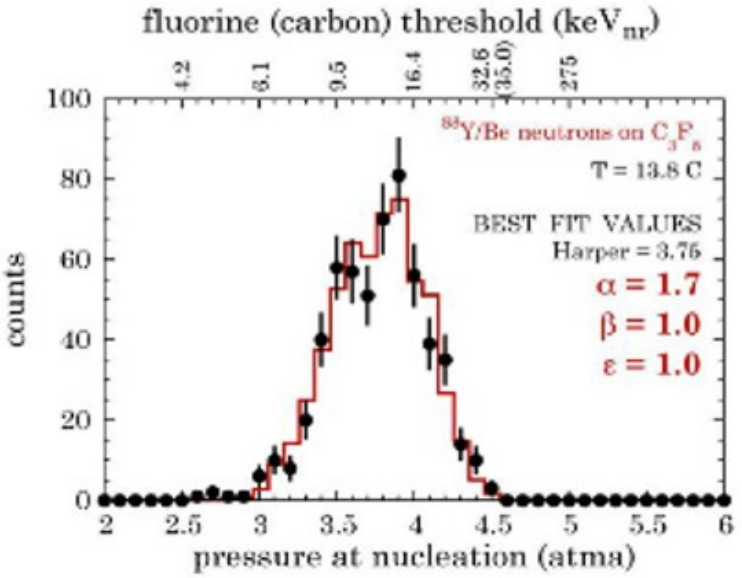
PICO-2L

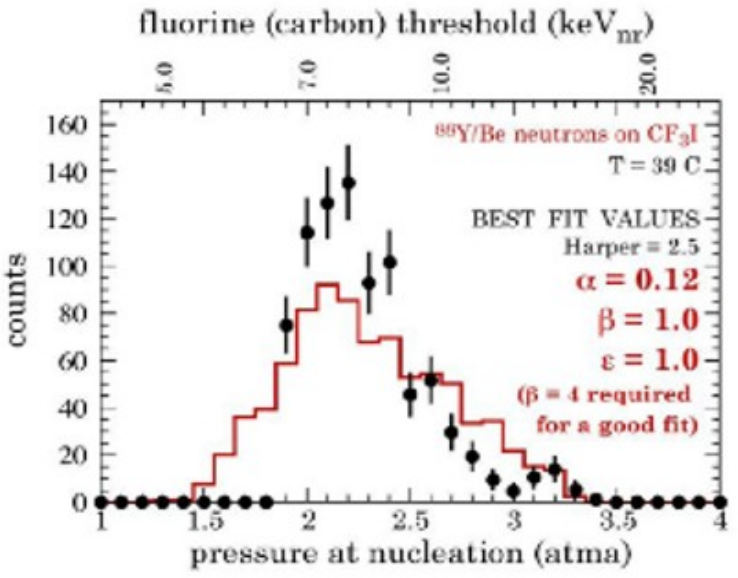
- C3F8 as target material
- Very low threshold achievable: 3 keV
- Excellent for low-mass WIMP studies.
- Excellent for Spin Dependent



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

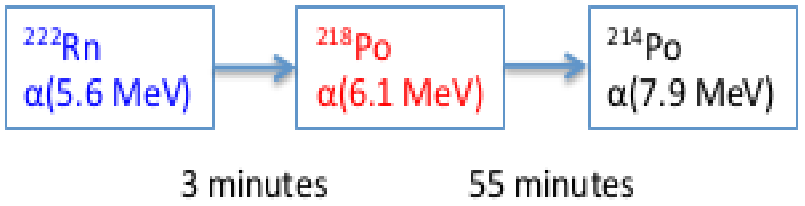


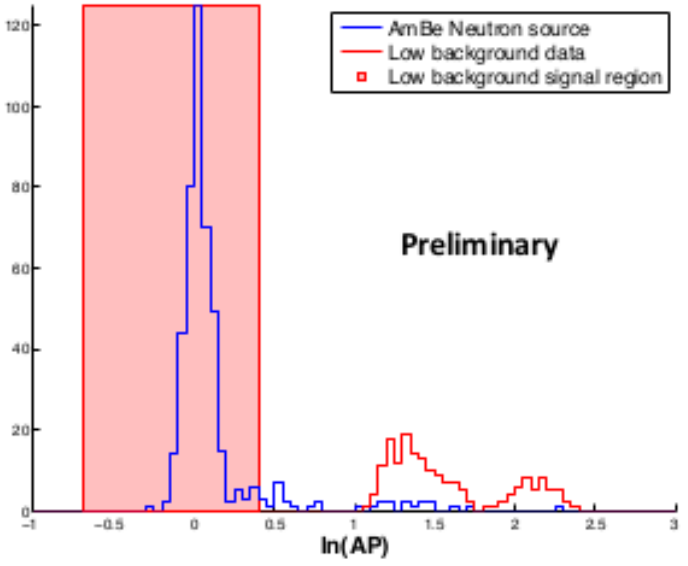


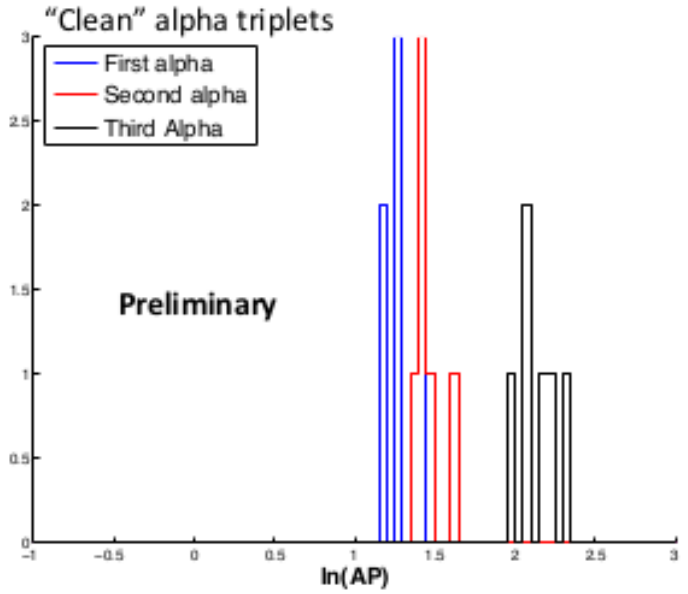


Pico2L: Status

- No multiple bubble events in the low background data.
- Two distinct alpha peaks, clearly separated from nuclear recoils.
- Timing of events in high AP peaks consistent with Radon chain alphas, and indicate that the higher Energy 214Po alphas are significantly louder (a new effect not seen in CF3I)

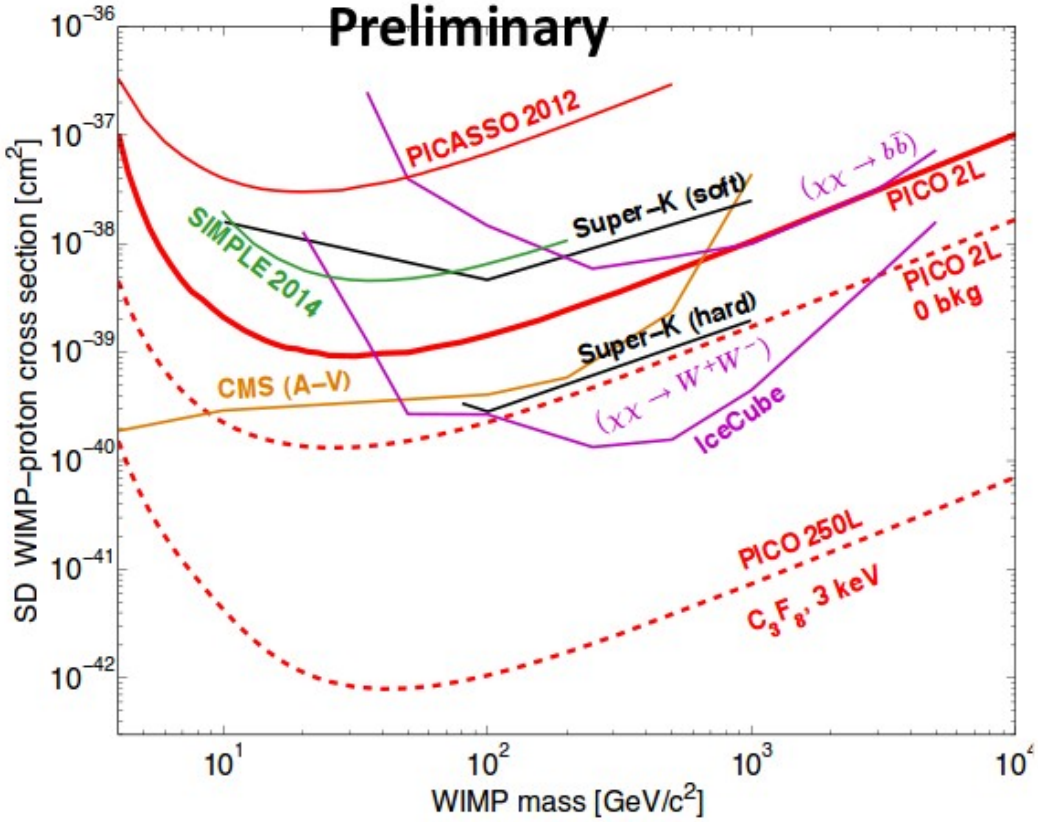


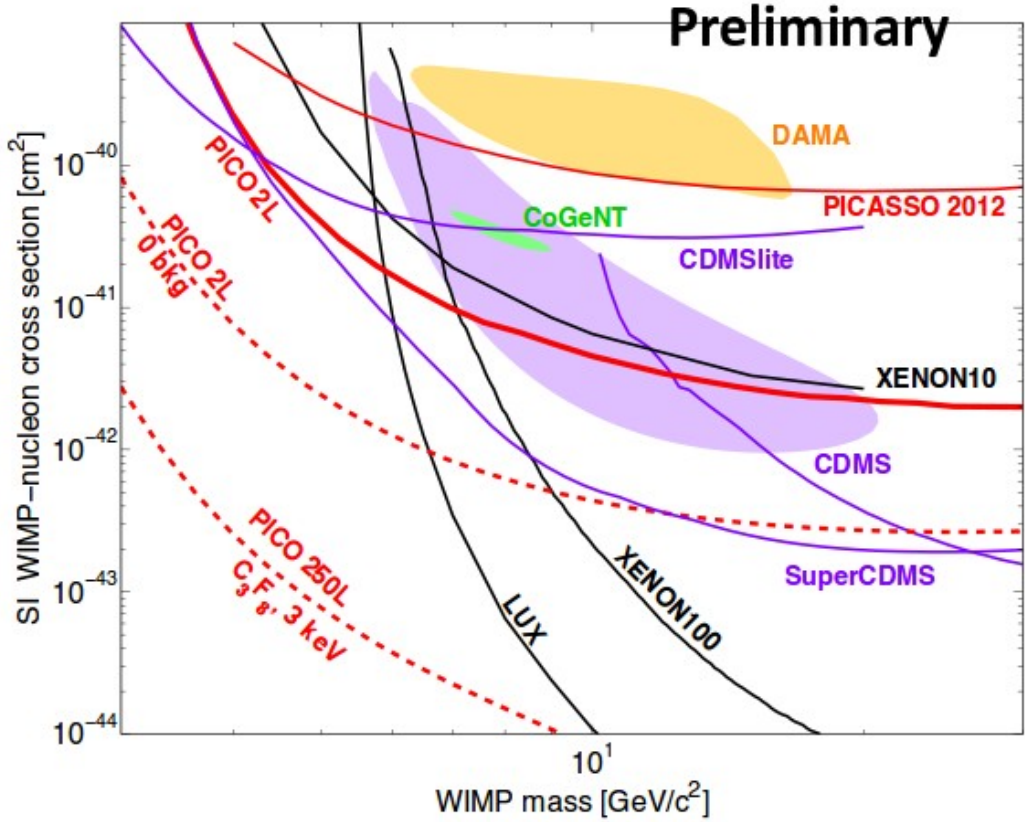




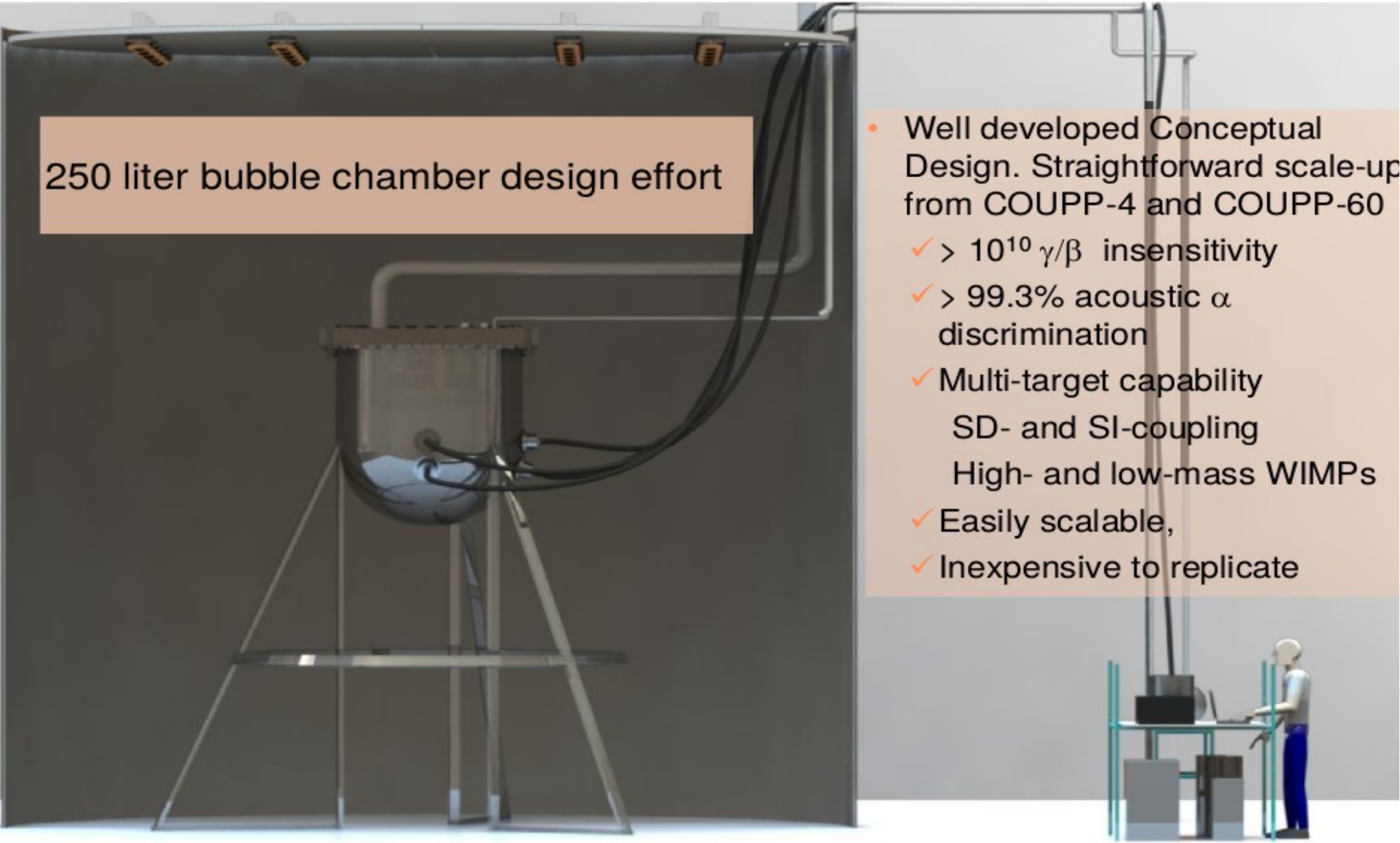
Pico2L: Limits

- Projection limits considering Pico 2L data.



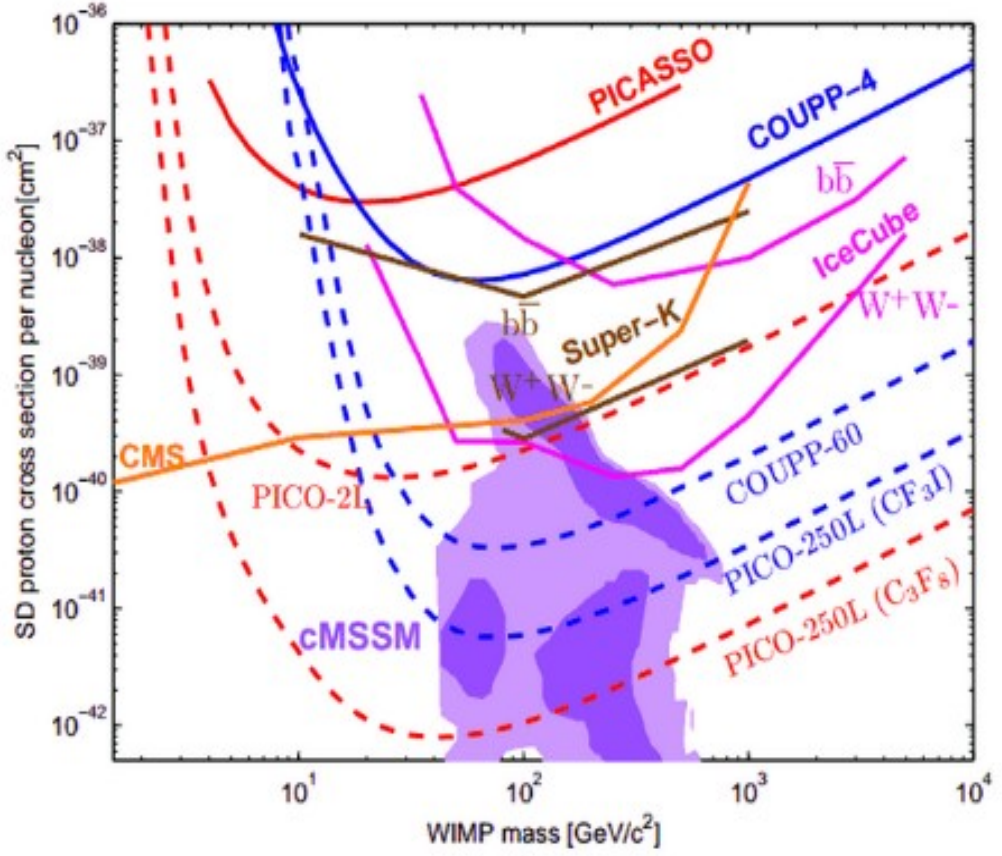


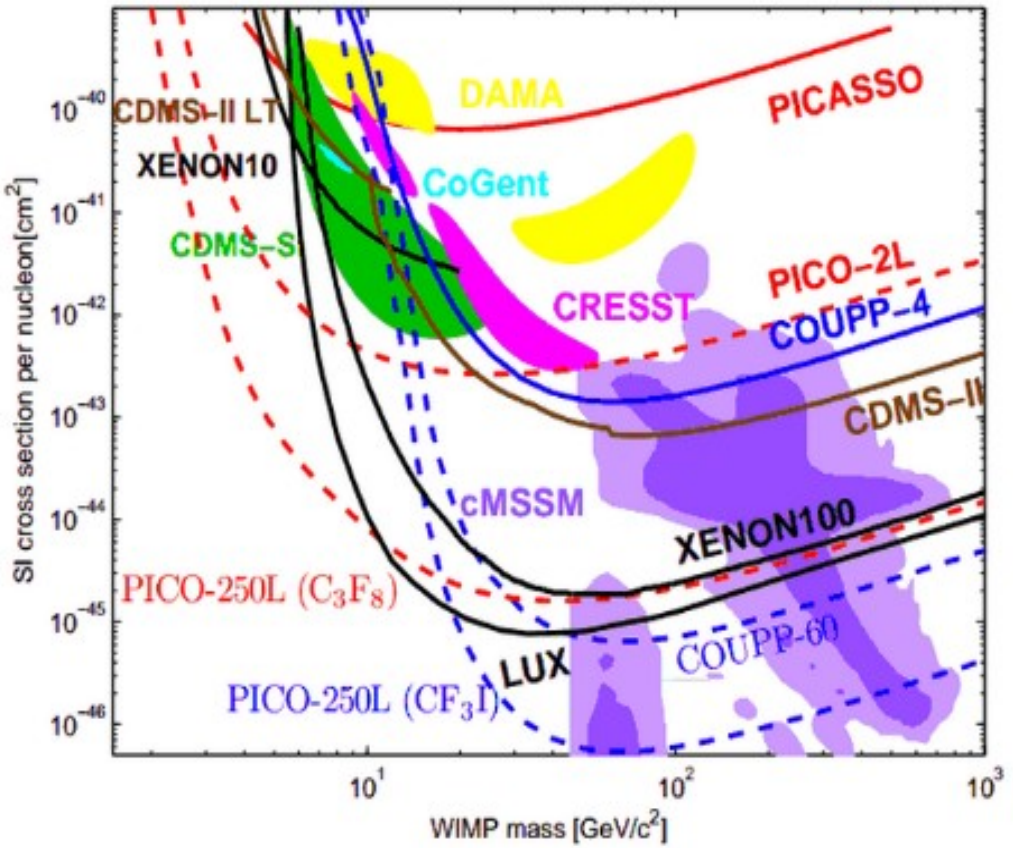
Pico250L:



- 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

Sensitivity projections





cMSSM model space from Roszkowski et. al., JHEP 0707:075 (2007).

MOSCAB

- Probably new dark matter detector comming soon MOSCAB.
- MOSCAB is a superheated liquid based detector, using geyser technique.
- First prototype were tested at Milano – Biccoca University.

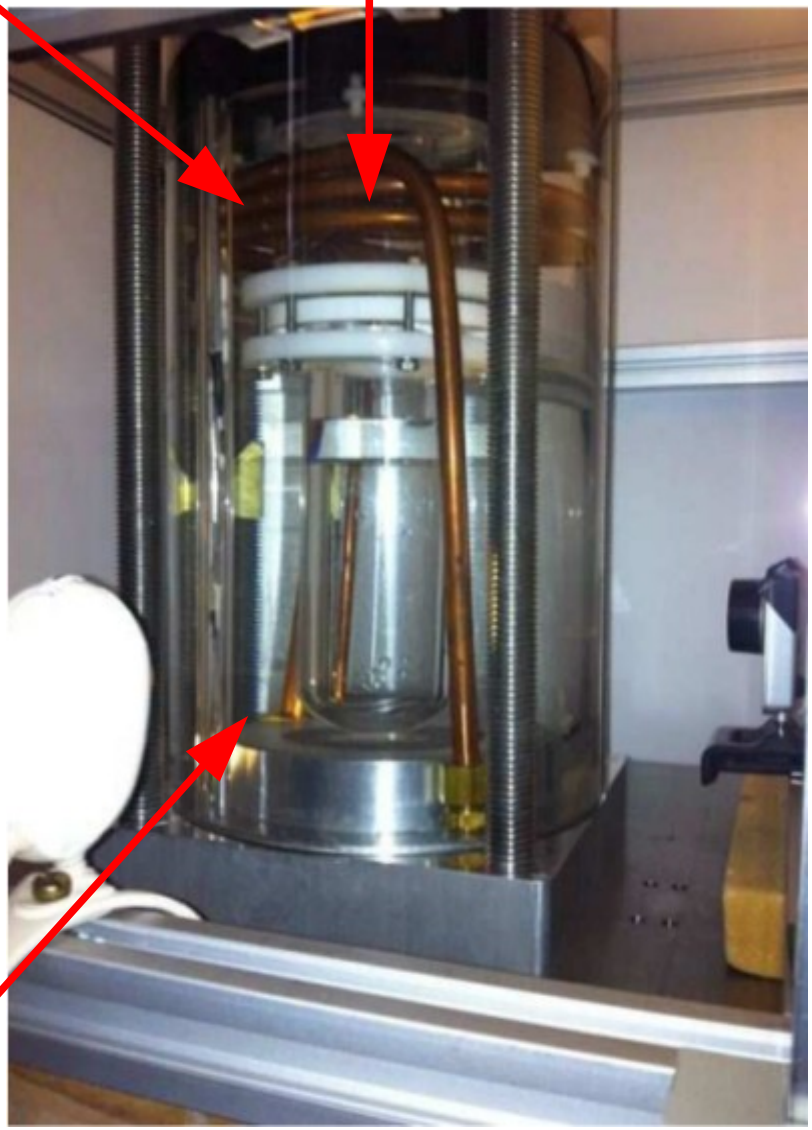
Pressurized vessel
Tipically 6bar.

Cold C3F8 condensate bubbles

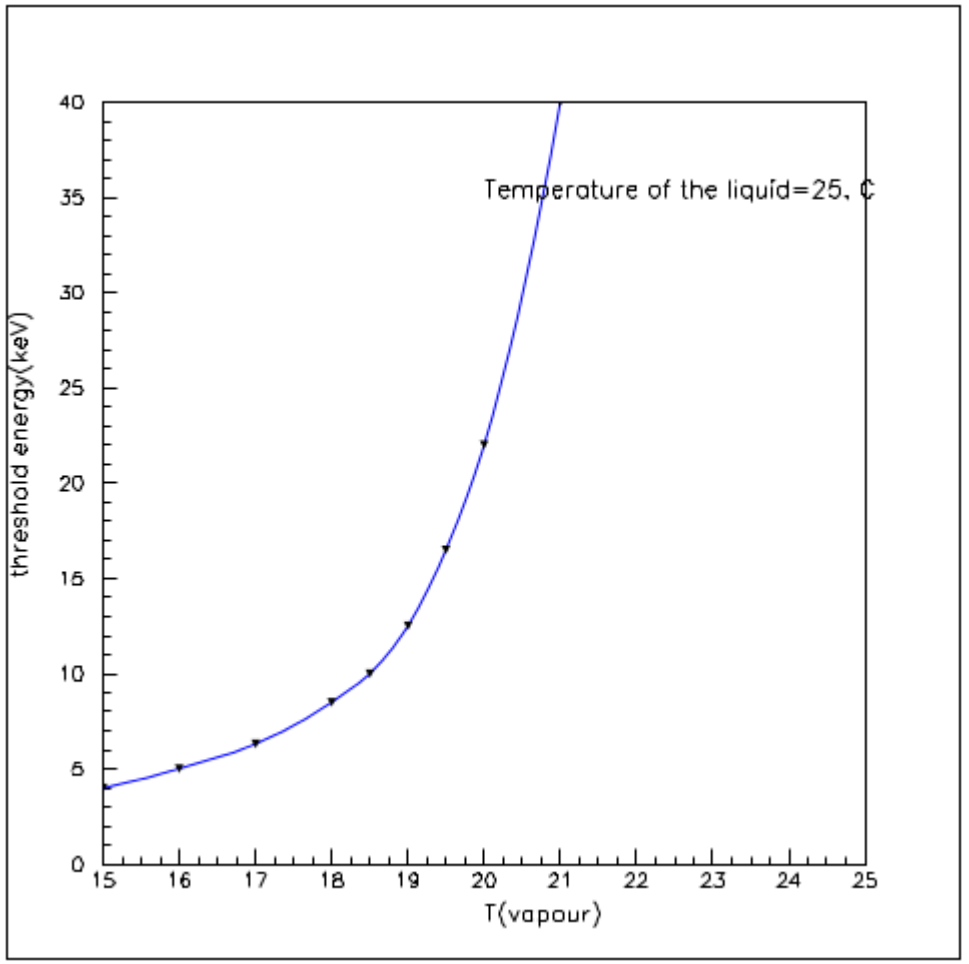
Generated a delta T, bubble are recondensed.

Vga Camera record the bubble growth inside.

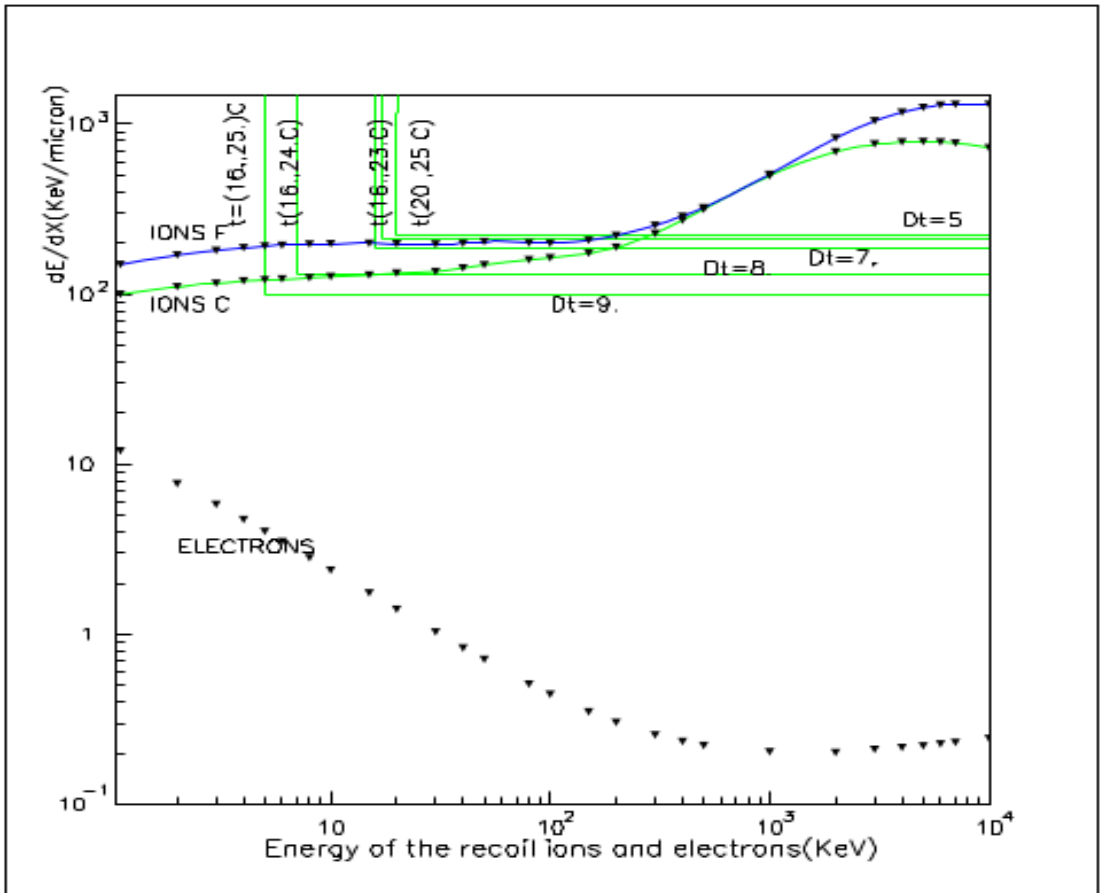
Hot C3F8 as a target material (superheated state)



MOSCAB:Results

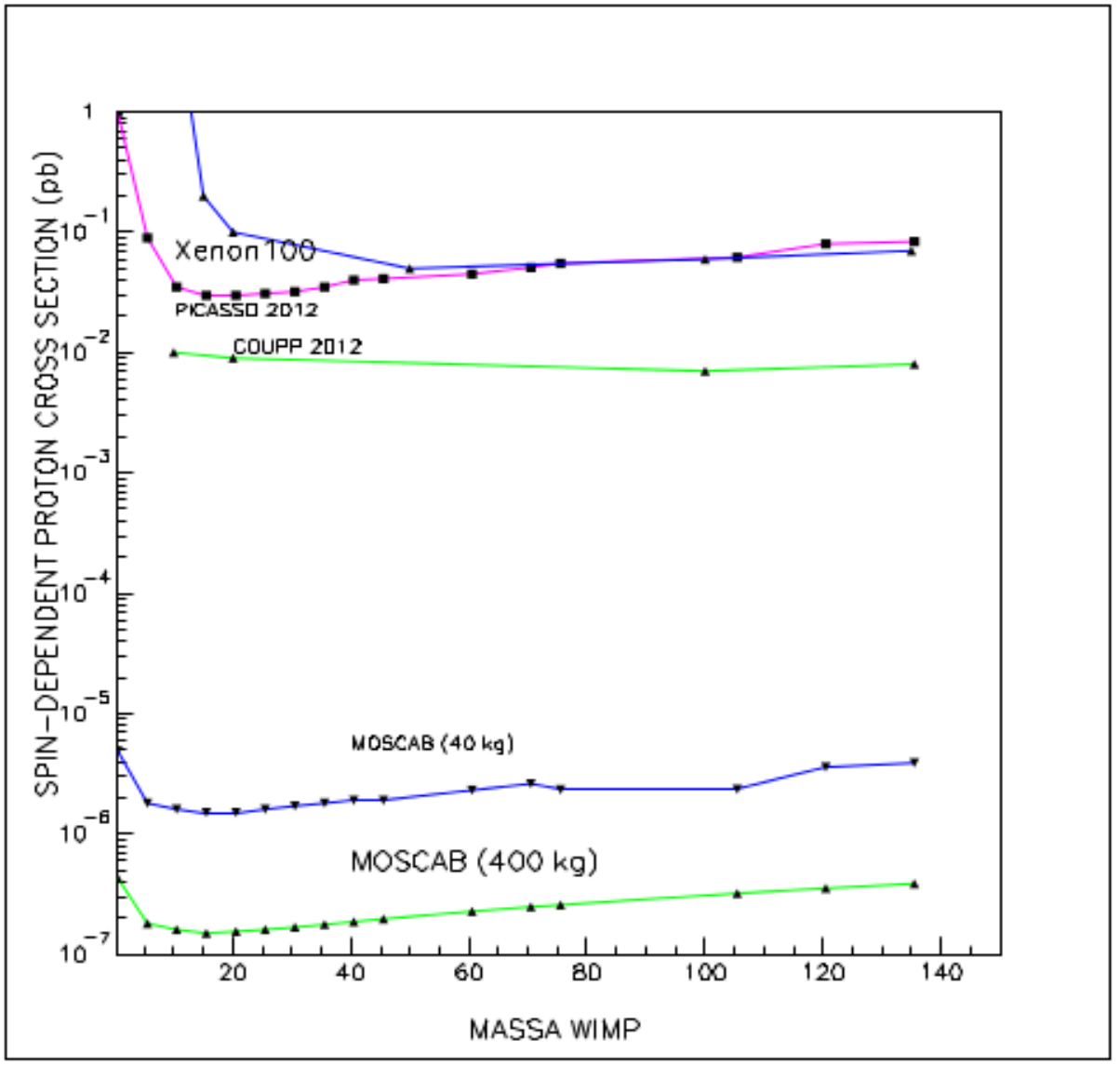


Threshold achievable by MOSCAB could explore low mass wimps zone.



Detector is not sensible to electron recoils.

Moscab: Limits



- Calculated limits, SD of MOSCAB detector.

(Assuming zero background).

Conclussions

- Analysis of COUPP-60 data ongoing. A source of background is present, collaboration is working to understand/eliminate. Improved analysis may allow to reject this background with high efficiency (acoustic / statistical techniques).
- PICO-2L is the first experiment for the new PICO collaboration, formed from the merger of COUPP and PICASSO. With a brand new target fluid (C3F8), PICO-2L has projected world leading spin-dependent sensitivity for 3-10 GeV WIMPs
- Successful operation at 3keV nuclear recoil threshold, detailed calibrations ongoing.
- No neutron background observed and acoustic rejection of alphas demonstrated to be similar to CF3I.
- PICO-2L also acts as a prototype for PICO-250L, a G2 dark matter experiment currently being designed for data taking in 2017.
- MOSCAB:
- Publication about the first test of the technique has been published

  R. Bertoni et al. “A new technique for direct investigation of dark matter”, Nucl Inst & Methods Sect A Volume 744, April 2014, 61– 68.