PICO

Search for Dark Matter with bubble chambers

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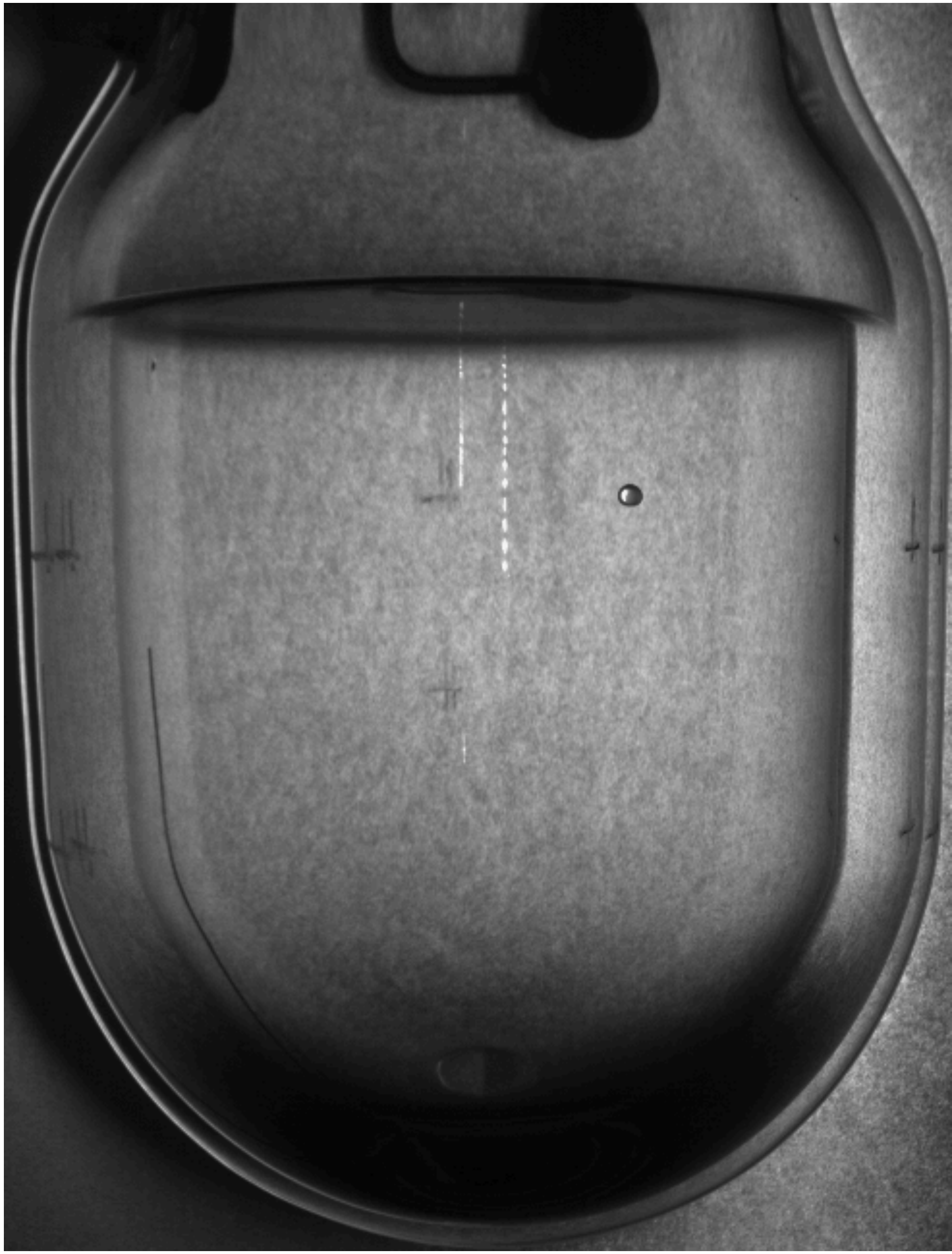
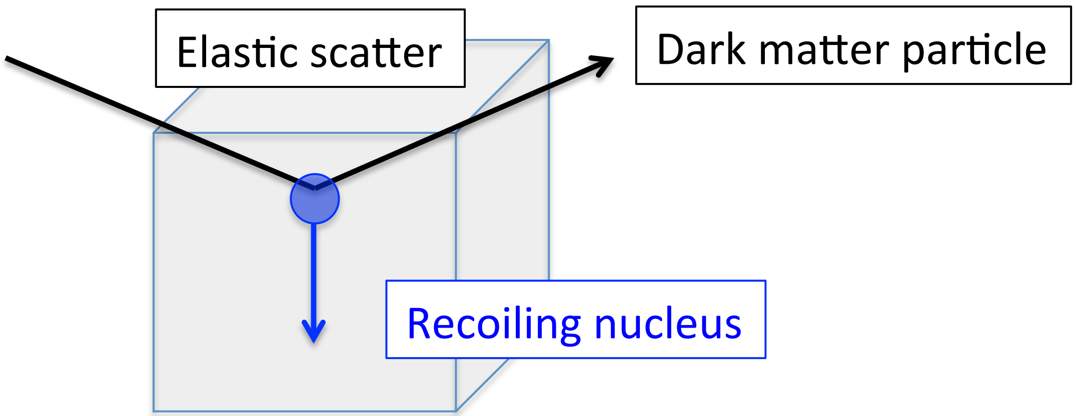
For the PICO Collaboration
at LLWI 2015



Dark matter direct detection



- Interaction rate depends on how the dark matter couples to quarks/gluons in target nuclei
  - Z, higgs, squark exchange, ...
- Model dependent
  - Eg SUSY: is lightest neutralino more bino-like, higgsino-like, what is the sparticle spectrum, etc

Dark matter direct detection

- WIMP-nucleus interaction could be
  - Spin-Independent (SI) (scalar/vector coupling)
    - Coherent scattering
      → enhancement for heavy nuclei: Ge, Xe, I, ...
      → higher sensitivity to WIMP-nucleon cross-section
    - Nonetheless depending on the model the SI cross-section could be small and another type of coupling could dominate...

Dark matter direct detection

- WIMP-nucleus interaction could be
  - Spin-Dependent (SD) (axial-vector coupling)
    - Couples to nuclear spin
      → requires unpaired nucleon, enhancement depends on nuclear shell structure

Isotope	Spin	Unpaired	λ^2
^{7}Li	3/2	p	0.11
^{19}F	1/2	p	0.863
^{23}Na	3/2	p	0.011
^{29}Si	1/2	n	0.084
^{73}Ge	9/2	n	0.0026
^{127}I	5/2	p	0.0026
^{131}Xe	3/2	n	0.0147

← Fluorine is ideal

(Well, multiple targets is ideal!)

PICO-2L

In the first joint COUPP/PICASSO collaboration meeting in February 2013 we decided to deploy a 2 liter C_3F_8 detector to replace COUPP-4 (CF_3I).

- Twice the F density
- Lower threshold
- Improved efficiency
- Lower background hardware

New two-bellows design inner vessel assembly. Silica jar is an exact replica of COUPP-4 jar.

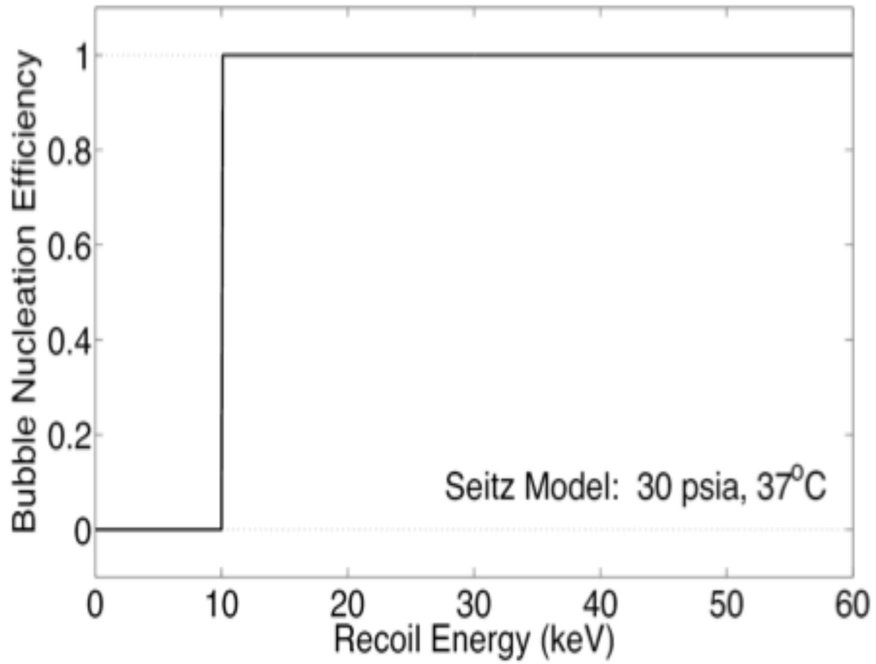
Simplified pressure vessel – ¼ the mass of steel as COUPP-4.

Threshold and efficiency

- Threshold based on theory of Seitz, Phys. of Fluids I, 2 (1958)
- Energy deposition E_{th} within length R_c will nucleate a bubble
- Seitz model assumes step function above threshold, but the track dependence is not fully specified

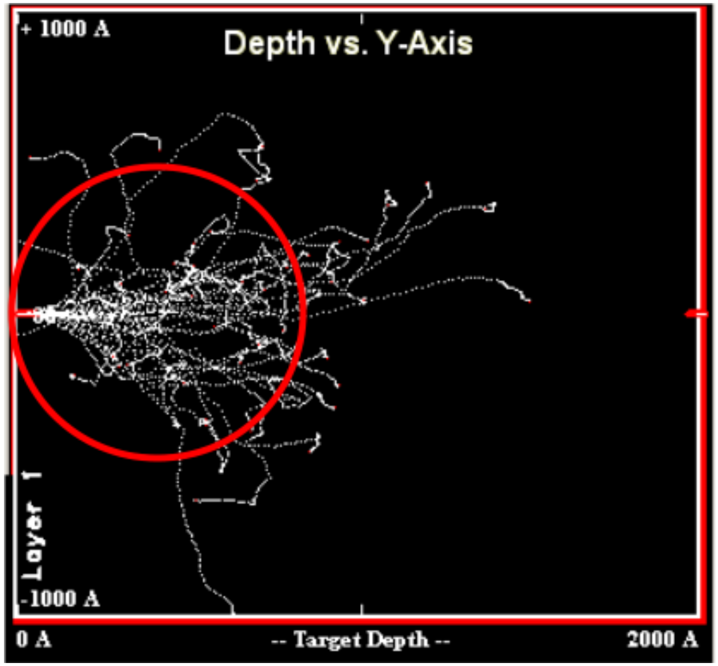
$$p_v - p_l = \frac{2\sigma}{r_c}$$

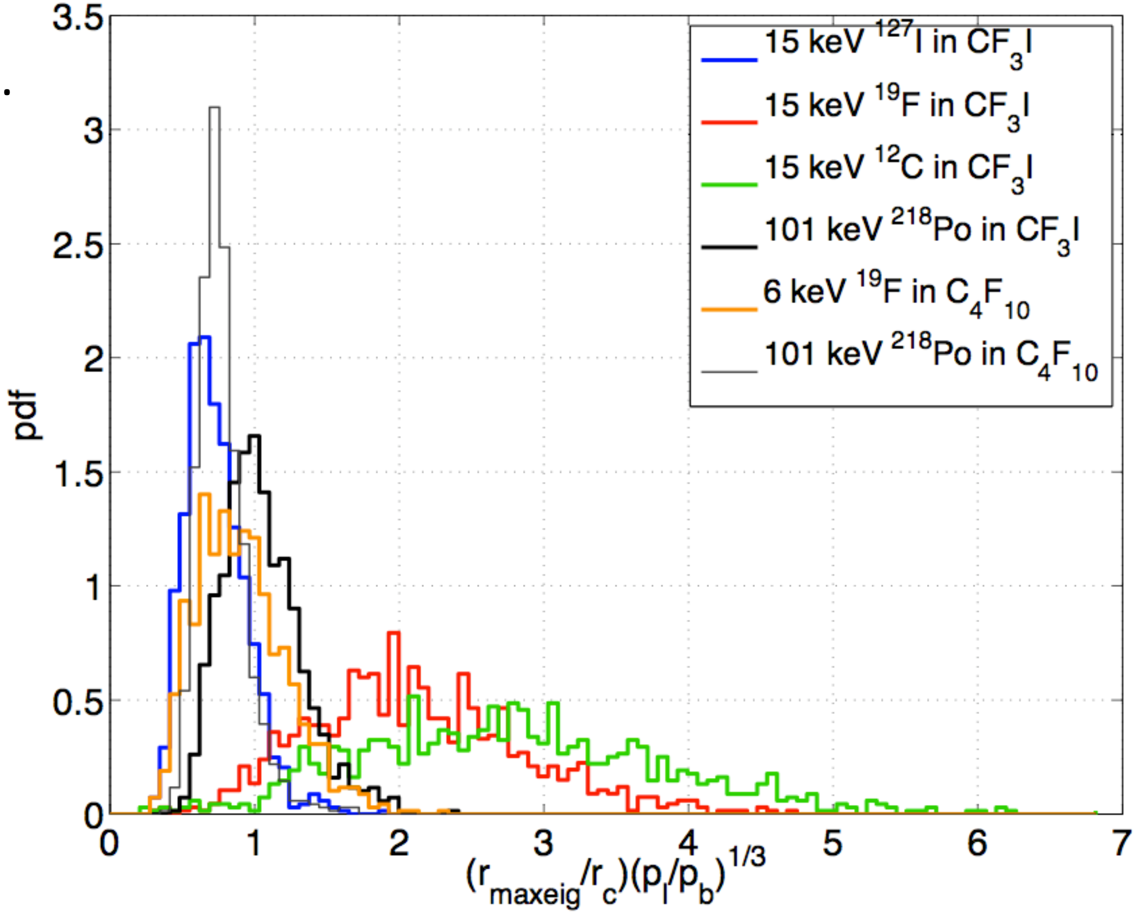
$$E_{th} = \underbrace{4\pi r_c^2 \left(\sigma - T\frac{\partial\sigma}{\partial T}\right)}_{\text{Surface energy}} + \underbrace{\frac{4}{3}\pi r_c^3 \rho_v h}_{\text{Latent heat}}$$



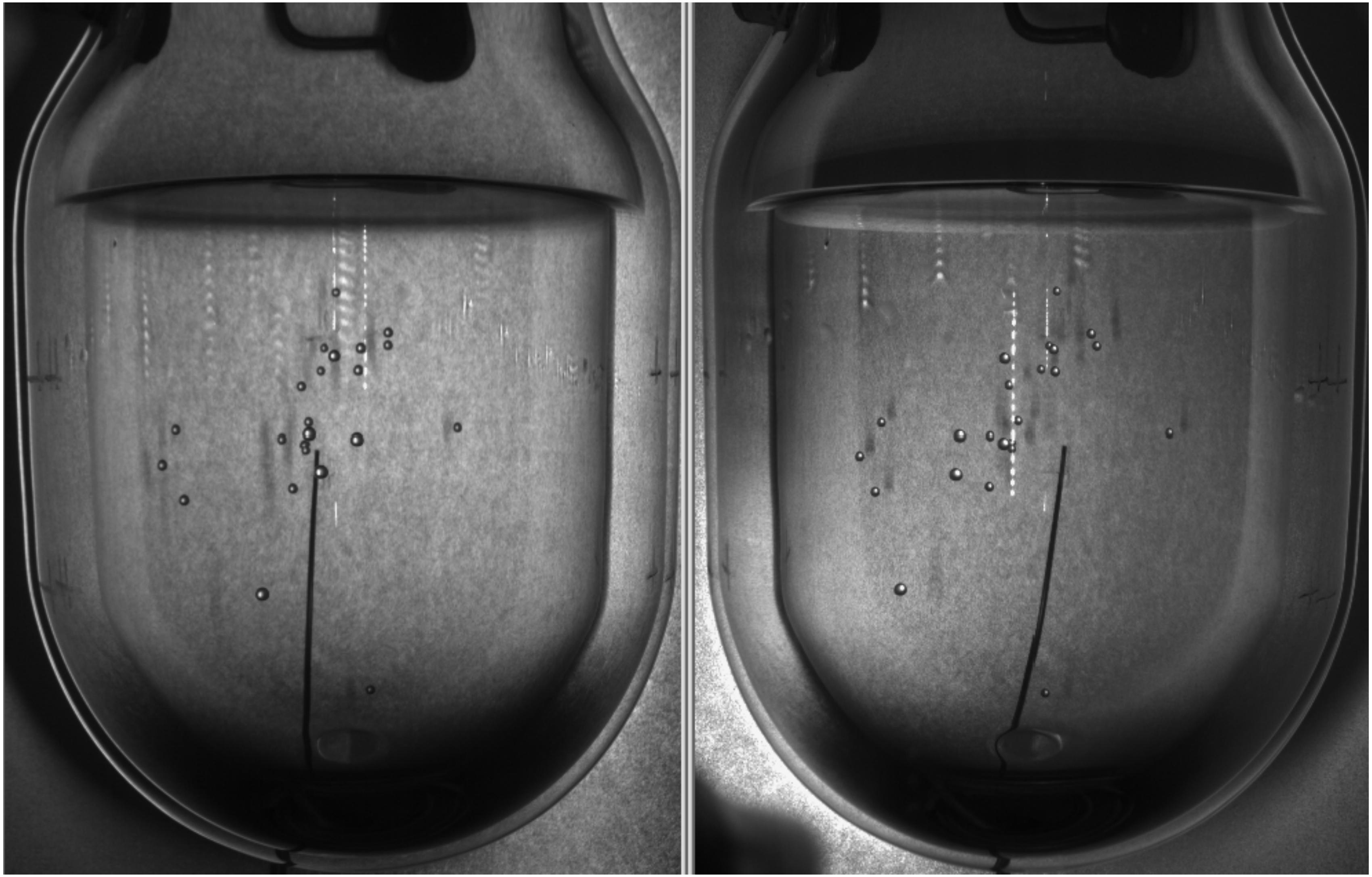
Understanding efficiency of F, C recoils

SRIM simulation of 15keV F recoils.





23 bubble AmBe neutron event

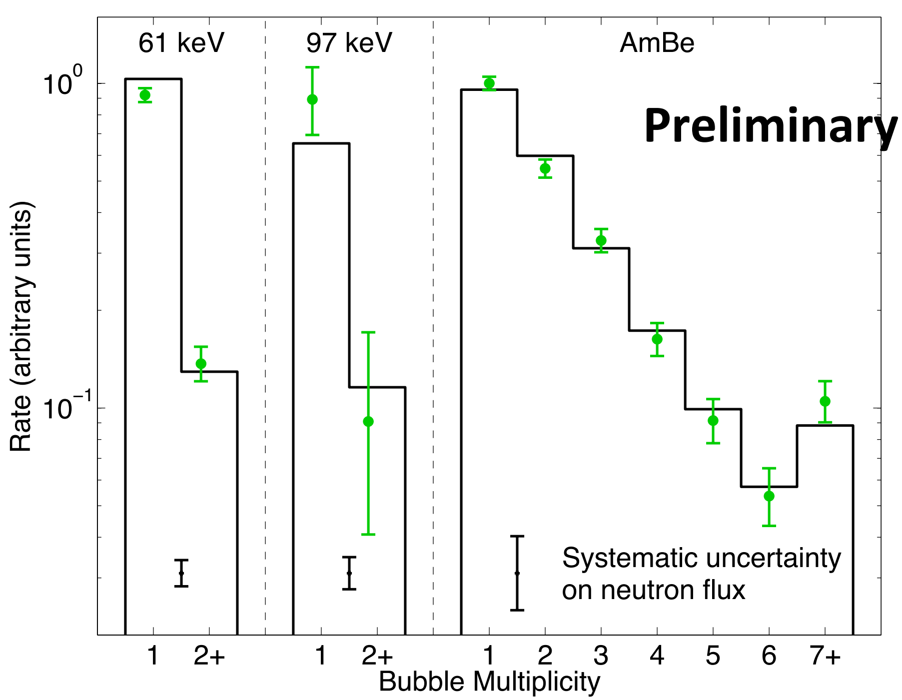


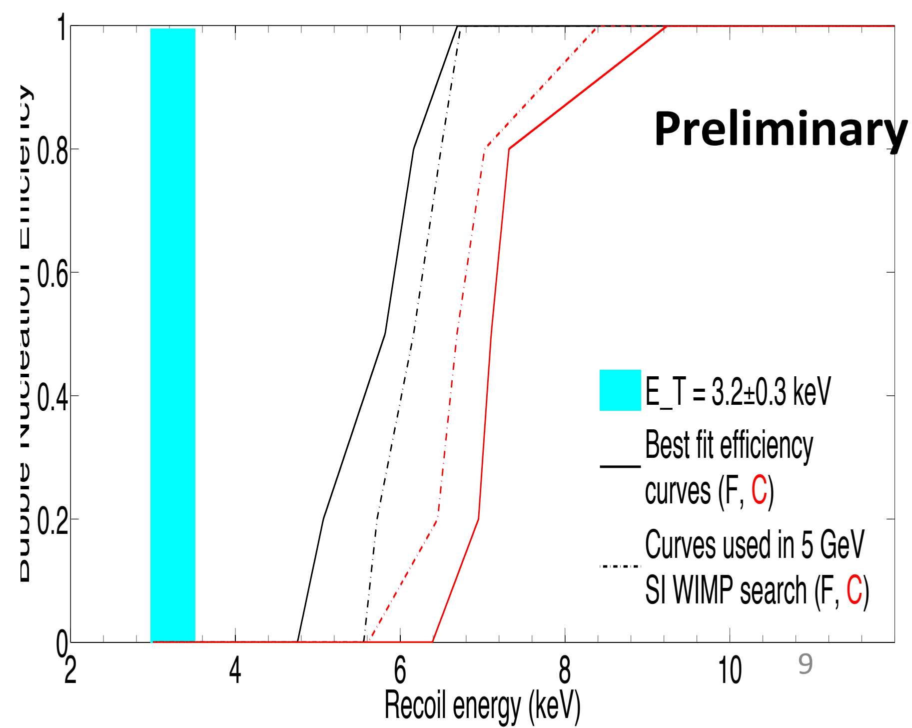
High multiplicity is a result of high bubble nucleation efficiency; 60% of neutron calibration events are multiples (compared to 25% in CF_3I).

C_3F_8 Sensitivity Calibrations

In addition to in-situ AmBe we calibrate the nuclear recoil response of C_3F_8 with 61 & 97 keV neutrons at U. of Montreal → probe very low energy recoils (12 & 20 keV max)

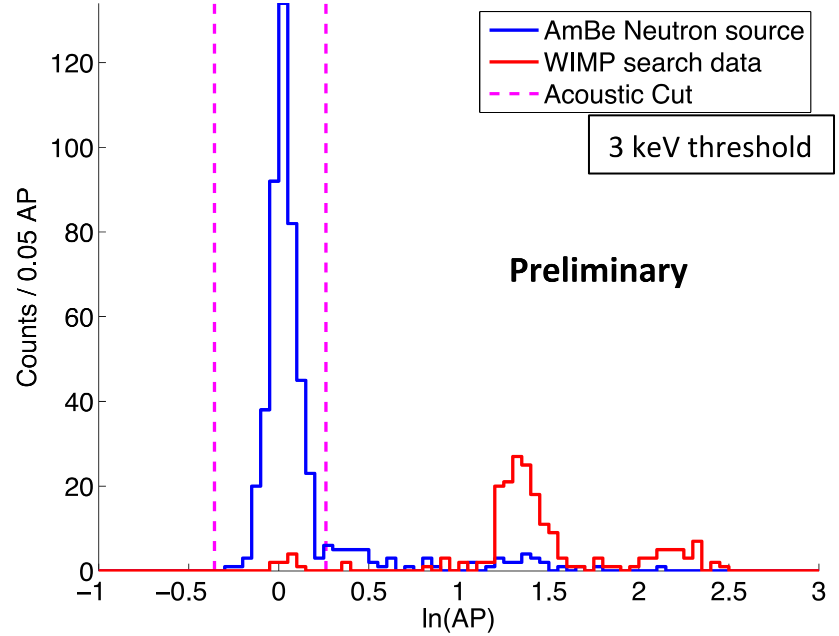
The shape of the efficiency curve is constrained at low energy, with agreement across calibrations. Conservative approach: choose least sensitive pair of eff curves 1σ consistent with calibrations



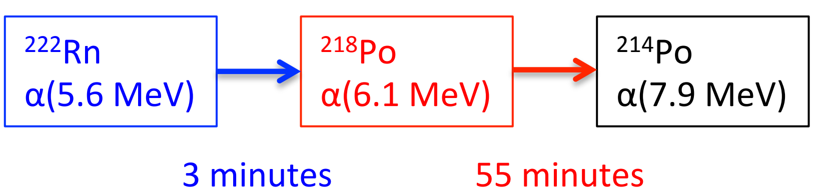


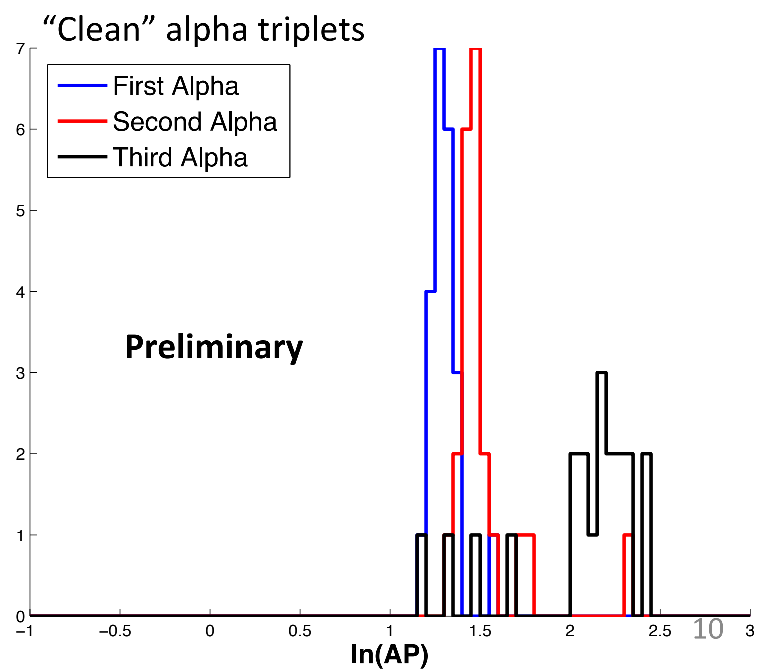
PICO-2L
Acoustic discrimination

- 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 ^{214}Po alphas are significantly louder (a new effect not seen in CF_3I) **("Acoustic calorimetry")**

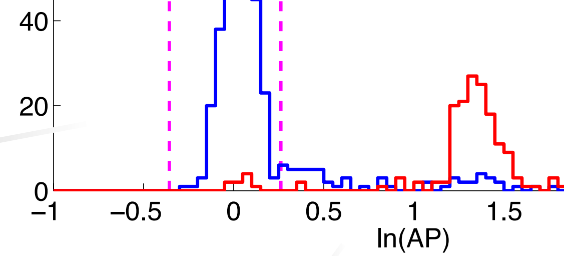


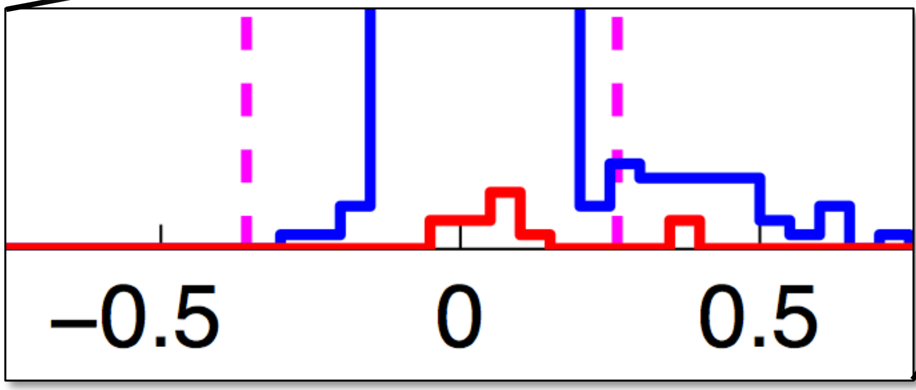
Radon chain alphas





PICO-2L results





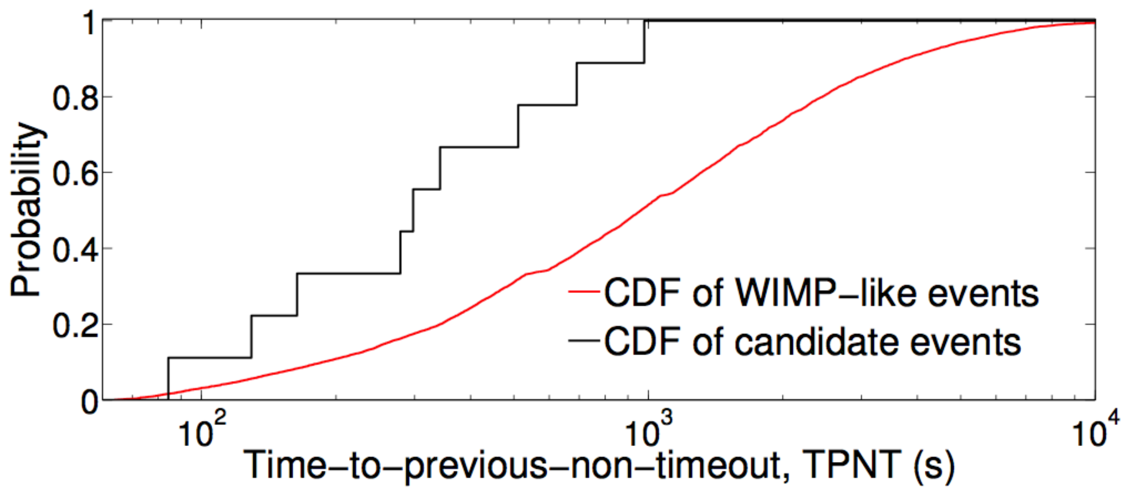
- 12 candidate events in 211.6 kg-days of exposure

Seitz threshold, E_T (keV)	Livetime (d)	WIMP exposure (kg-d)	Candidates
$3.2 \pm 0.2(\text{exp}) \pm 0.2(\text{th})$	32.2	74.8	9
$4.4 \pm 0.3(\text{exp}) \pm 0.3(\text{th})$	7.5	16.8	0
$6.1 \pm 0.3(\text{exp}) \pm 0.3(\text{th})$	39.7	82.2	3
$8.1 \pm 0.5(\text{exp}) \pm 0.4(\text{th})$	18.2	37.8	0

- Expected ~1 background event (neutrons)

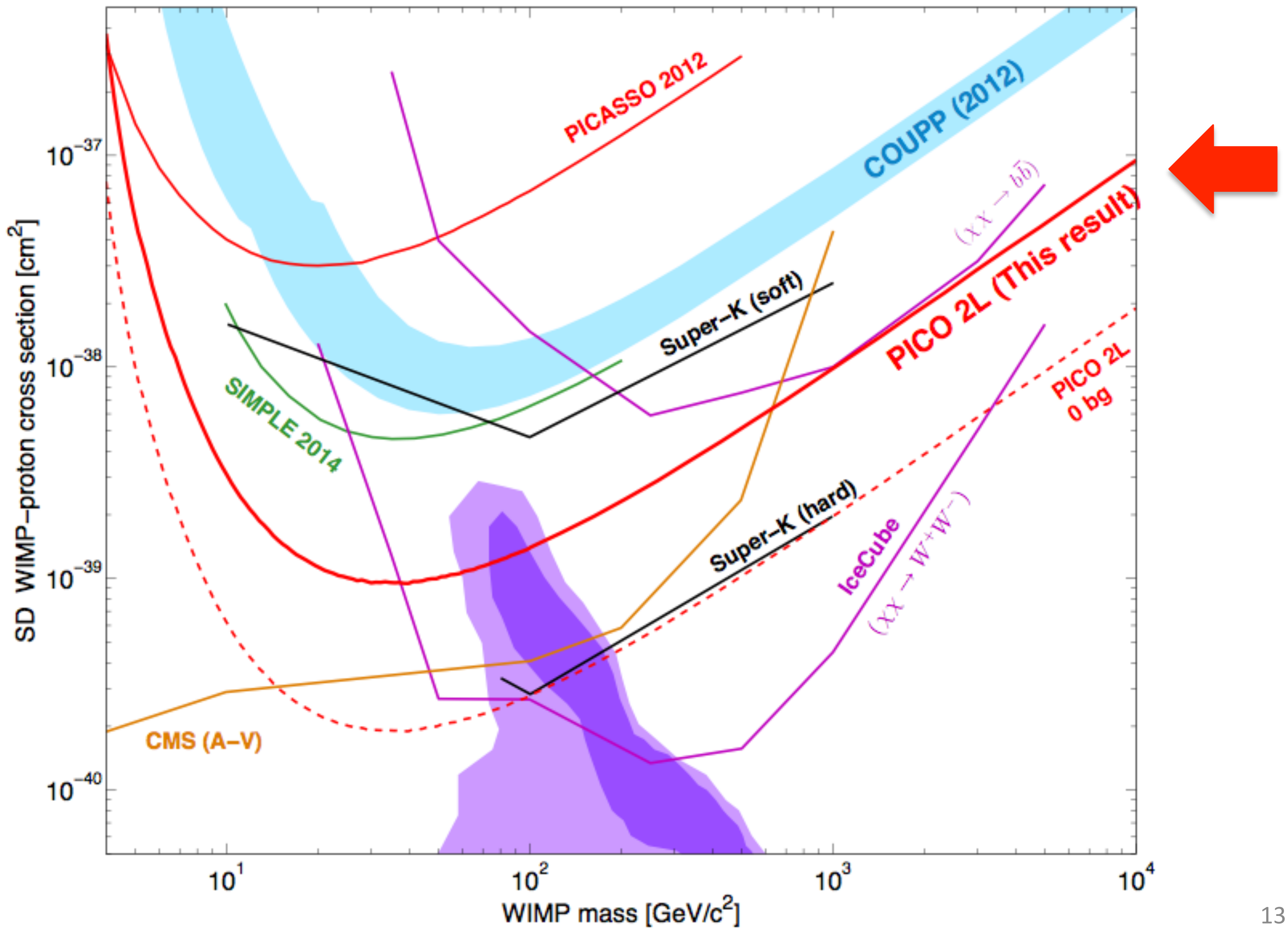
PICO-2L results

- However:
  – Post-run samples show evidence of particulate contamination (see previous talk)
  – Candidate events have timing correlations inconsistent with WIMPs or neutrons

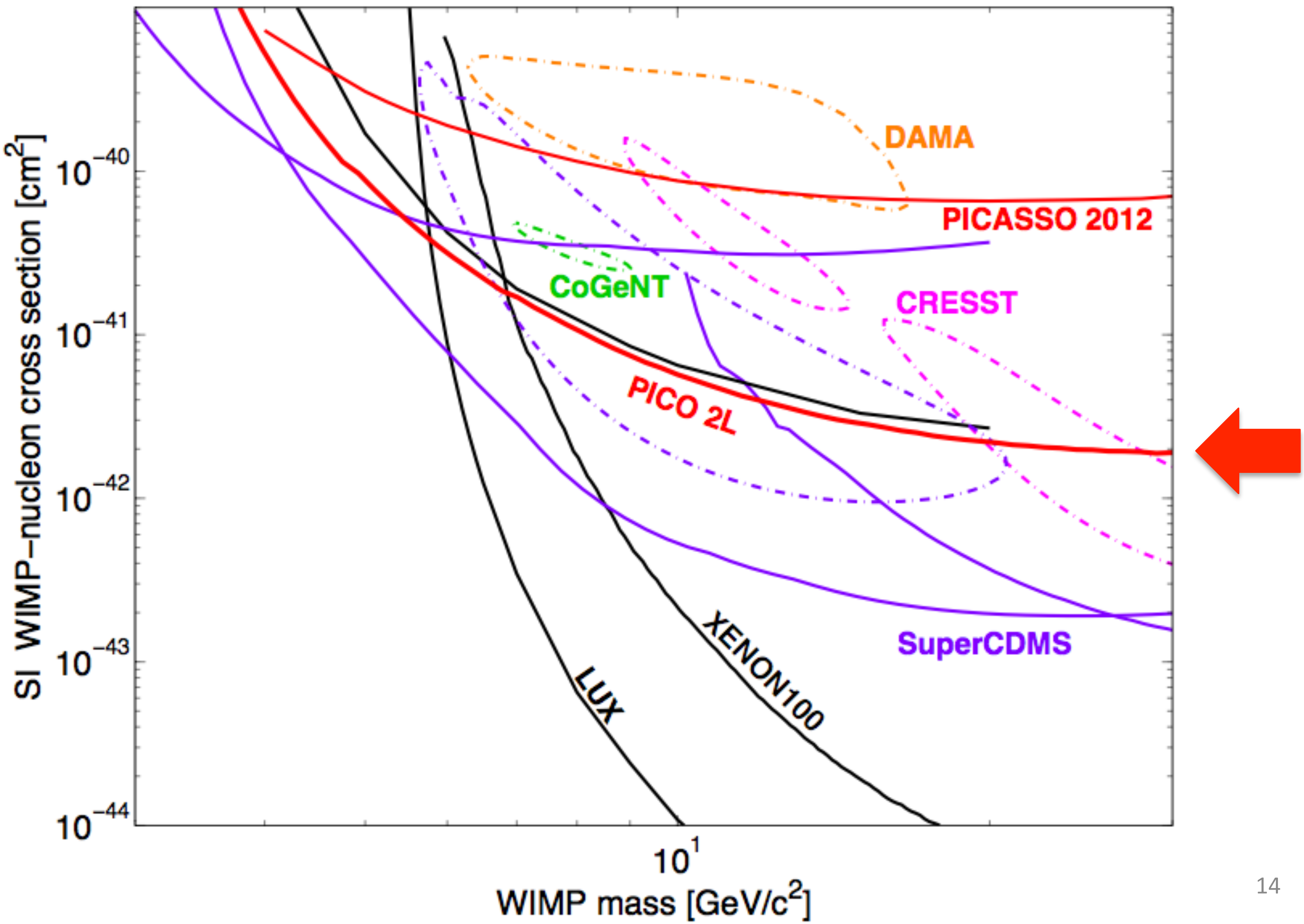


  – Timing becomes a cut variable, method similar to optimum interval of Yellin, PRD 66.032005 (2002)

PICO-2L limits



PICO-2L limits



Summary

- 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 (C_3F_8) PICO-2L has demonstrated:
  - Successful operation at 3keV nuclear recoil threshold
  - No neutron background observed
  - Good acoustic rejection of alphas
  - Detailed Fuorine and Carbon-recoil efficiency calibrations
  - **PICO-2L has a new world-best SD WIMP-proton limit**

PICO

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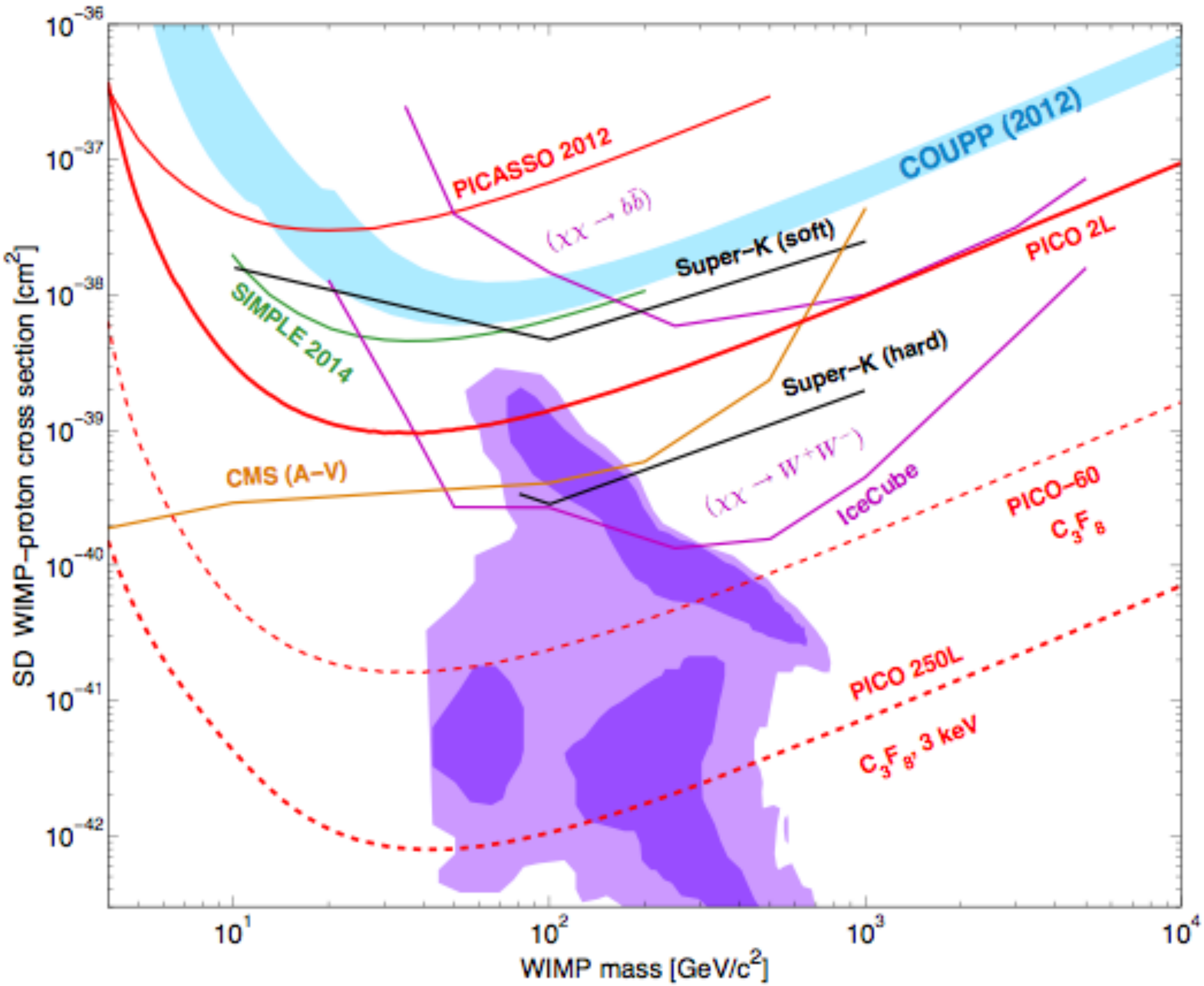
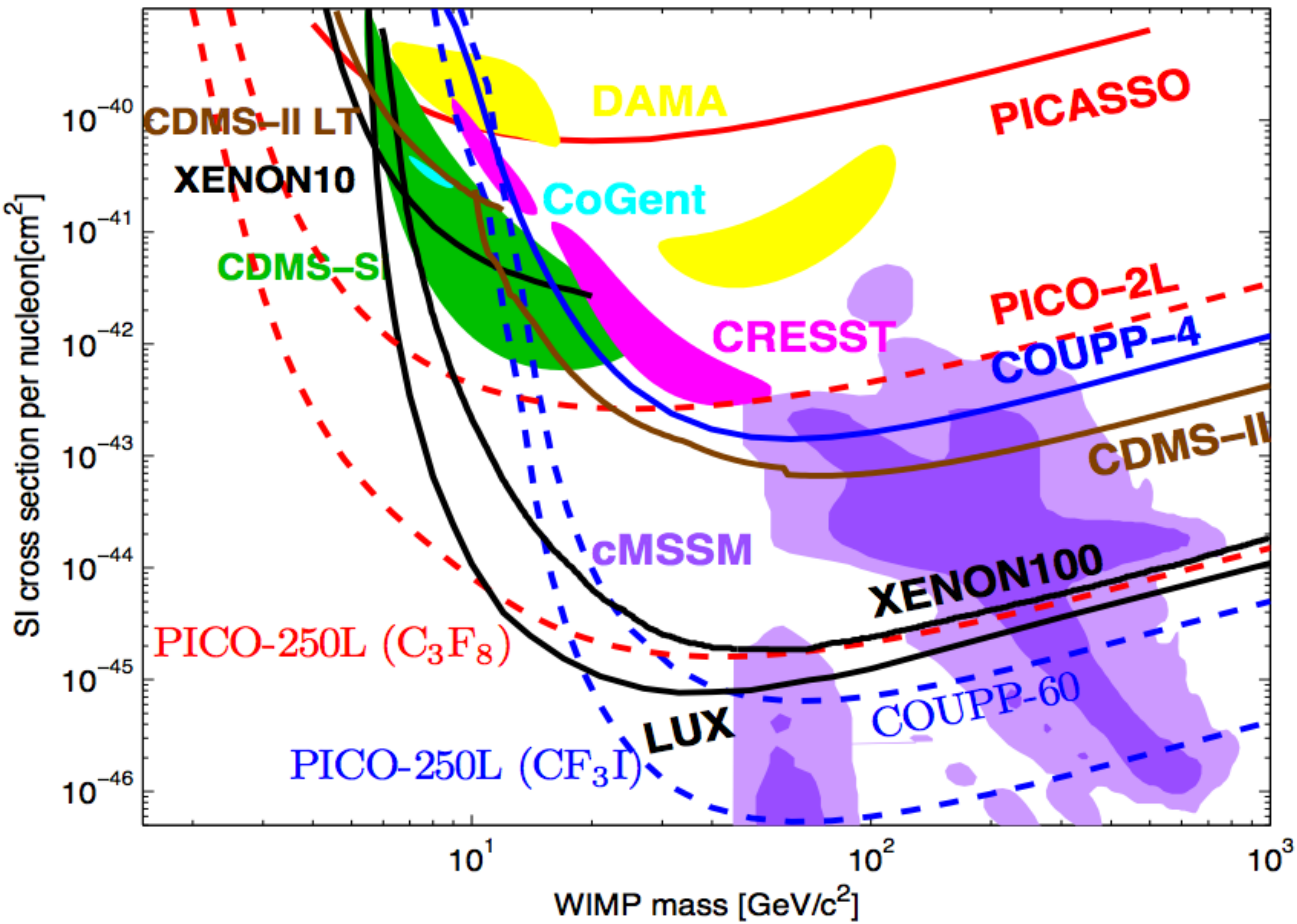
BACKUP

Projected limits

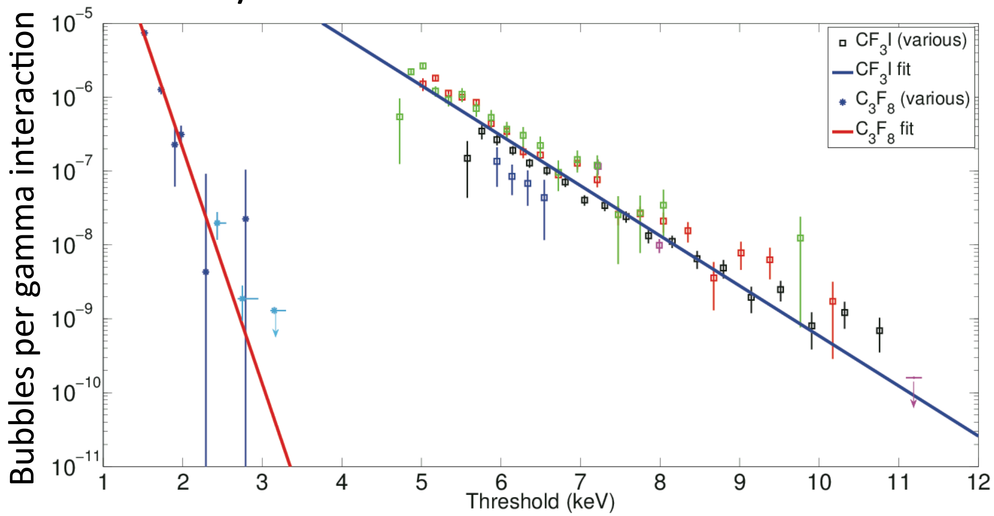


SI projections

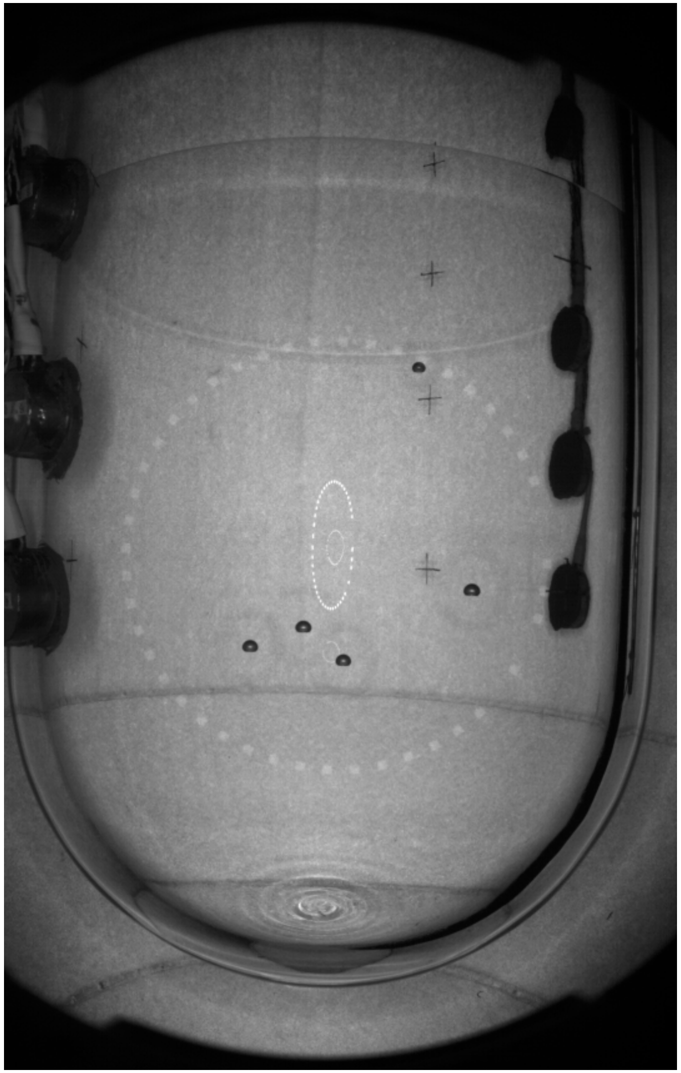


Background Rejection

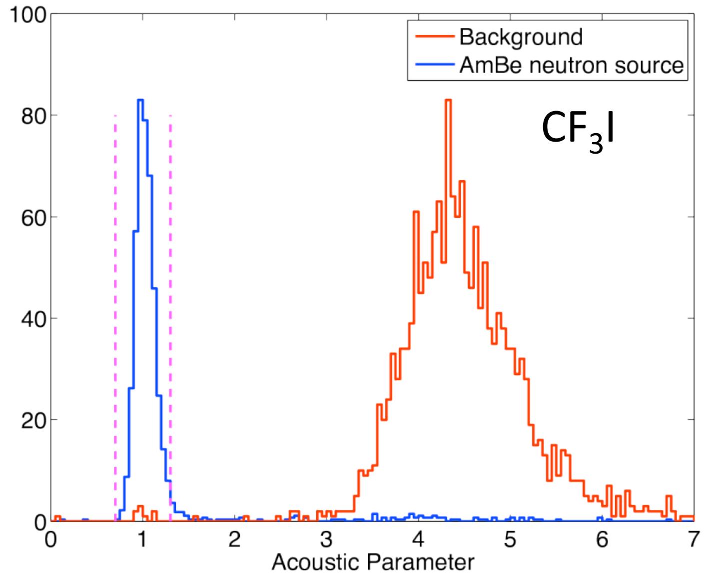
Gamma/Beta



Neutron



Alpha-decay
>99.3% Rejection



COUPP/PICO fast compression bubble chambers

- 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
  - Acoustics used to identify alphas
- Recompress to reset chamber