Search for Dark Matter with bubble chambers

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Bubble chamber: theory

- In a superheated fluid, bubbles will collapse unless they are large enough \((r_c)\) to overcome surface tension: must deposit \(E_{th}\) in a radius less than \(r_c\)
  \[E_{th} \& \frac{E_{th}}{r_c} = \frac{dE}{dx}\] threshold
- Threshold based on theory of Seitz (Phys. of Fluids I, 2 (1958))
  For a given fluid:
  Classical Thermodynamics gives \(E_{th}, r_c\) in terms of \(P, T\)
Pressure & temperature → min energy, dE/dx threshold
→ sensitive to nuclear recoils but not electron recoils

1950s-1970s

Neutron calibration event
Gamma/Beta Backgrounds

Gamma Rejection by Chamber

Various PICO Detectors

Aim for this level for 1 year exposure
Nuclear target

- Big advantage of bubble chambers is the ease of changing nuclear target (lot’s of candidate refrigerants)
- Previously used CF$_3$I (I for SI sensitivity, F for SD sensitivity), now using C$_3$F$_8$ (focusing on SD sensitivity, low mass)

A. L. Fitzpatrick, see also: 0908.2991, 1203.3542, 1211.2818, 1308.6288
Pressure expansion puts target fluid in superheated state

Wait for particle interaction to nucleate a bubble, recompress
Cameras capture stereoscopic bubble images @ 100 fps (primary trigger)

Acoustic sensors & fast pressure transducer capture sound & pressure rise from bubble growth
Acoustic discrimination of α’s

- Clear acoustic signature of single nuclear recoil (track < ~μm)
- Sound emission peaks at $r_{\text{bubble}} \approx 10$ μm
- $\alpha$ track much larger (~40 μm) → separate nucleation sites → $\alpha$’s several times louder
The PICO program

- PICO: merger of PICASSO and COUPP collaborations
- PICO-2L $C_3F_8$ (2014-17)
  - C. Amole et al.,
- PICO-60 CF$_3$I (2013)
  - Phys. Rev. D 93, 061101 (2016)
- PICO-60 $C_3F_8$ (2016-17)
- PICO-40L (2017-18)
- PICO-500 (future)
PICO-60 Cleaning

- Every component touching the inner volume was cleaned against MIL-STD-1246C level 50

**Post-Filtration Particulate Size Distribution**

- Filter Sample Normalized by Flow
PICO-60 run with blinded acoustics

- Filled with 52 kg $C_3F_8$ in June, 2016
  - Blind analysis on data from November 2016 and January 2017
    1167-kg-days at 3.3 keV threshold
- 106 bulk singles in WIMP search dataset
  - Consistent with $^{222}\text{Rn}$ decay rate
- Expected Neutron Background
  - 3 multiple bubbles in the physics data
  - 3:1 multiples to singles ratio from calibration and simulation
  - 0-3 bulk singles would be consistent with neutrons and no anomalous background

C. Amole et al., arXiv:1702.07666
No events in signal region!

Radon chain alphas
Spin-dependent Limits

C. Amole et al., arXiv:1702.07666
Moving forward: PICO-40L

Eliminate buffer fluid

Purpose of buffer liquid is to isolate the active liquid from the stainless parts.

Thermal gradient can ensure that target fluid near stainless parts is not active.

PICO-60

PICO-40L
Summary

• PICO bubble chambers at the 40L scale are background-free
• PICO dominates the search for spin-dependent WIMP-proton coupling
• PICO-40L: Design changes expected to further improve bubble chamber stability and lower neutron background, deployment this year
• Ton-scale PICO-500 in engineering stage, goal: data taking in 2019
BACKUP
Long term

- Coherent neutrino background much lower for light target compared to Xe
Nucleon Coupling Limits

Limits on neutron vs proton spin-dependent coupling

See Tovey for details:
Comparison to Collider

Axial-vector mediator, Dirac DM
\( g_q = 0.25 \), \( g_{\text{DM}} = 1 \)

C. Amole et al., arXiv:1702.07666