Backgrounds in PICO

Eric Vázquez Jáuregui

SNOLAB

AARM Meeting

Fermilab; Batavia IL, USA; March 19, 2014

PICO
Collaboration

Queen's University — C. Amole, M. Besnier, G. Caria, A. Kamaha, A. Noble, T. Xie

Universitat Politècnica de València — M. Ardid, M. Bou-Cabo

Pacific Northwest National Laboratory — D. Asner, J. Hall

Northwestern University — D. Baxter, C.E. Dahl, M. Jin

Indiana University South Bend — E. Behnke, H. Borsodi, C. Harnish, O. Harris, C. Holdeman, I. Levine, E. Mann, J. Wells

P. Bhattacharjee, M. Das, S. Seth

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

KICP Kavli Institute for Cosmological Physics — J.I. Collar, R. Neilson, A.E. Robinson

Université de Montréal — F. Debris, M. Fines-Neuschild, C.M. Jackson, M. Lafrenière, M. Laurin, L. Lessard, J.-P. Martin, M.-C. Piro, A. Plante, O. Scallon, N. Starinski, V. Zacek

Laurentian University / Université Laurentienne — 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

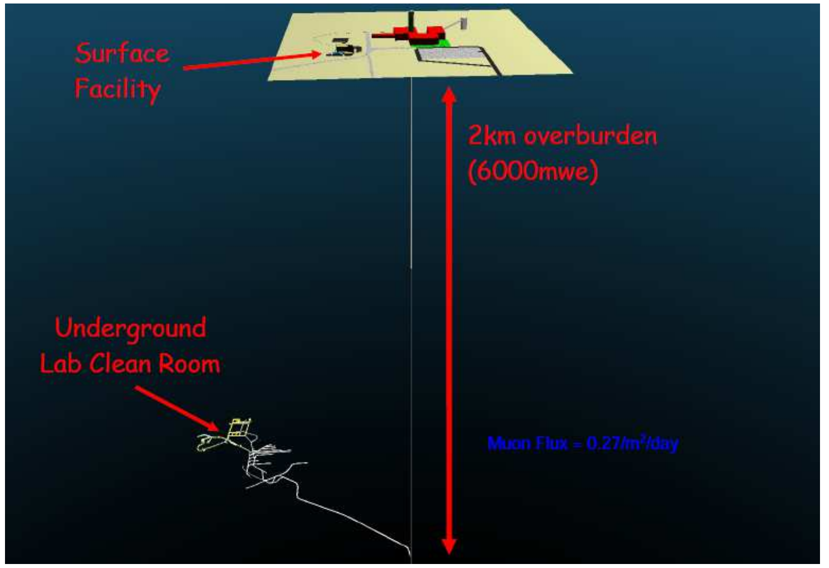
SNOLAB — I. Lawson, E. Vázquez Jáuregui

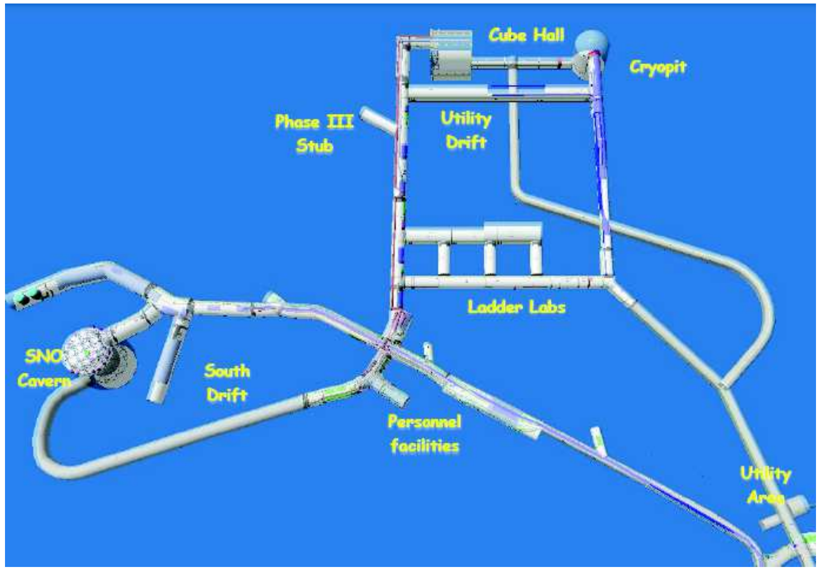
VirginiaTech — D. Maurya, S. Priya

SNOLAB

deepest and cleanest large-space international facility in the world

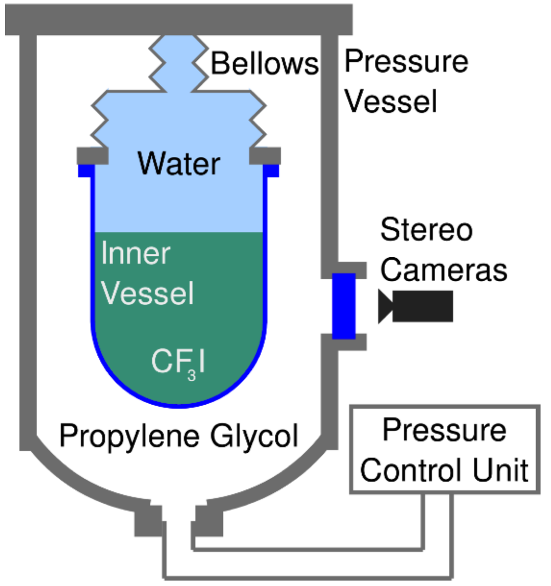
- 2 km underground near Sudbury, Ontario
- ultra-low radioactivity background environment Class 2000
- Physics programme focused on neutrino physics and direct dark matter searches

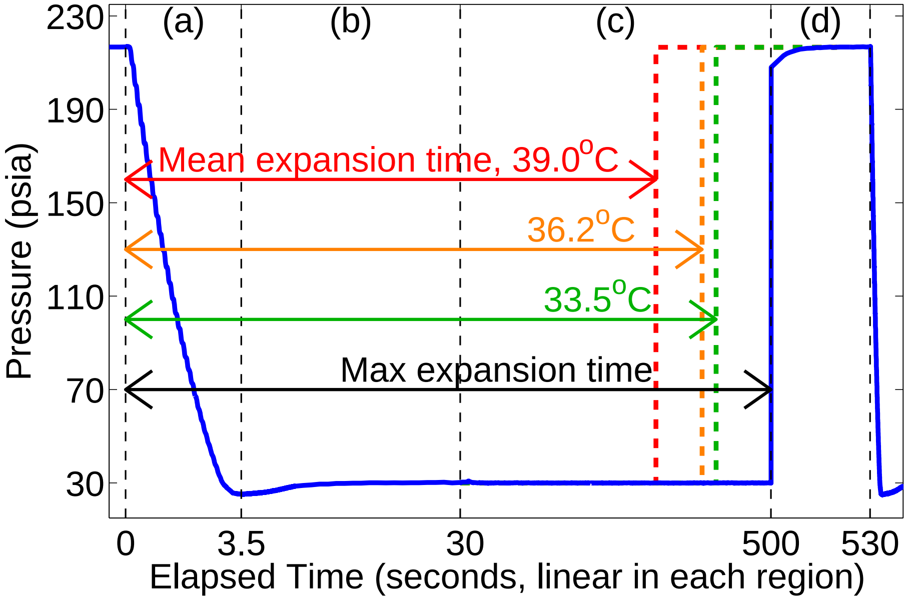




PICO bubble chambers

- Target material:
  superheated CF_3I or C_3F_8
  spin-dependent/independent
- Particles interacting evaporate a small amount of material: bubble nucleation
- Cameras record bubbles
- Piezo sensors detect sound
- Recompression after each event

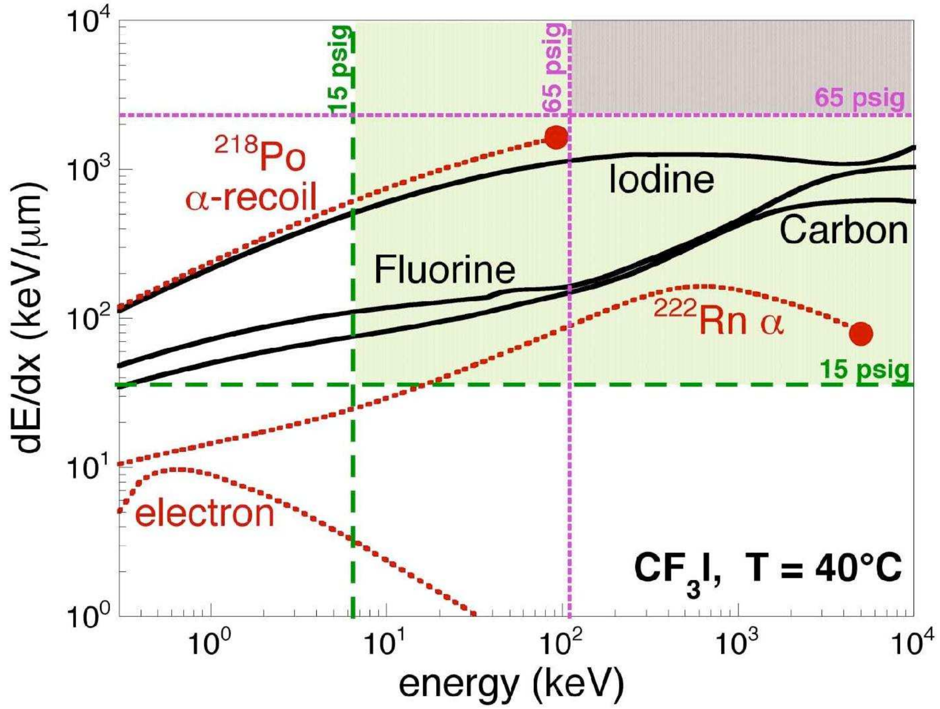




Bubble nucleation

Dependence of bubble nucleation on the total deposited energy and dE/dx

- Region of bubble nucleation at 15 psig
- Backgrounds: electrons, ^{218}Po, ^{222}Rn
- Signal processes of Iodine, Fluorine and Carbon nuclear recoils



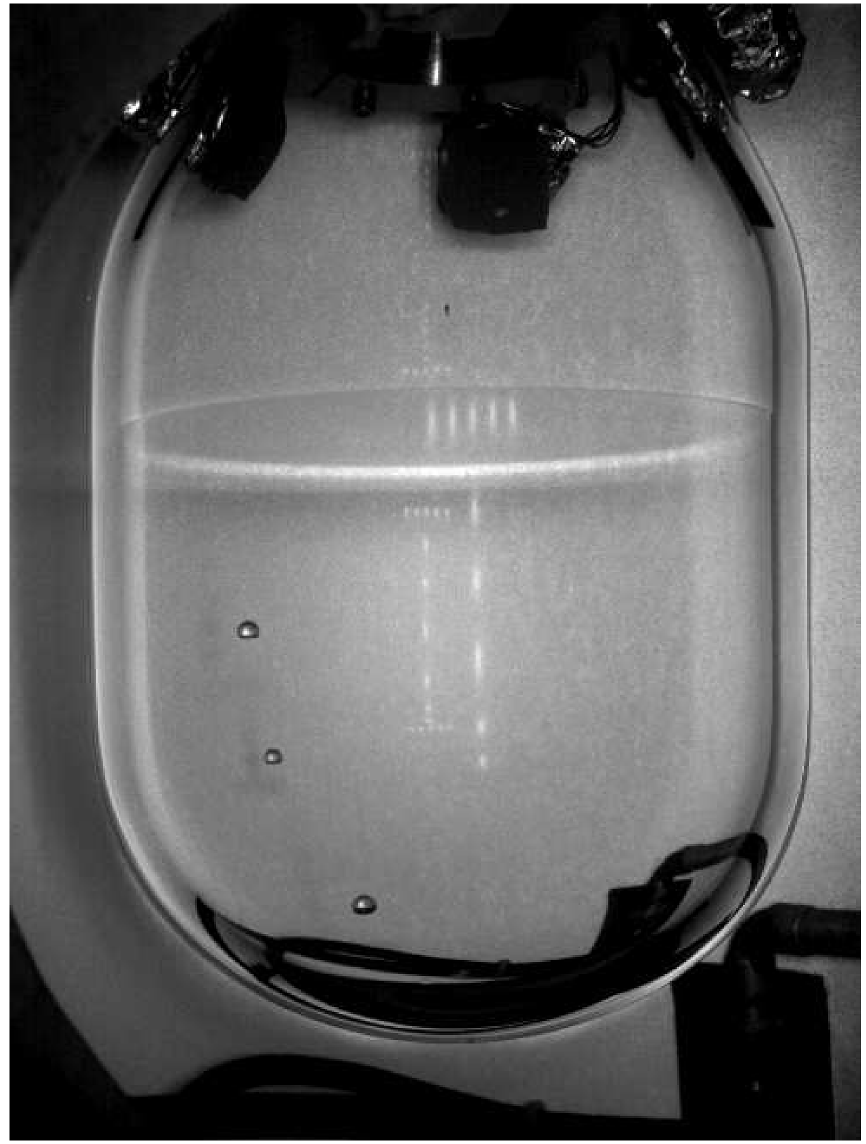
insensitive to electrons and gammas

PICO bubble chambers

- **Alpha decays:**
  Nuclear recoil and
  40 μm alpha track
  1 bubble

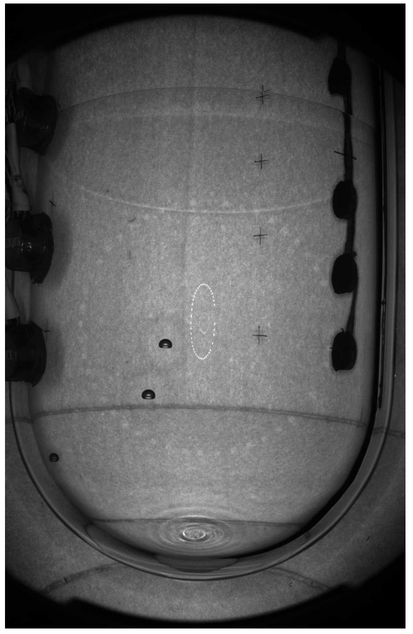
- **Neutrons:**
  Nuclear recoils
  mean free path $\sim$20 cm
  3:1 (1:1) single-multiple ratio in COUPP4 (COUPP60)

- **WIMPs:**
  Nuclear recoil
  mean free path $> 10^{12}$ cm
  1 bubble

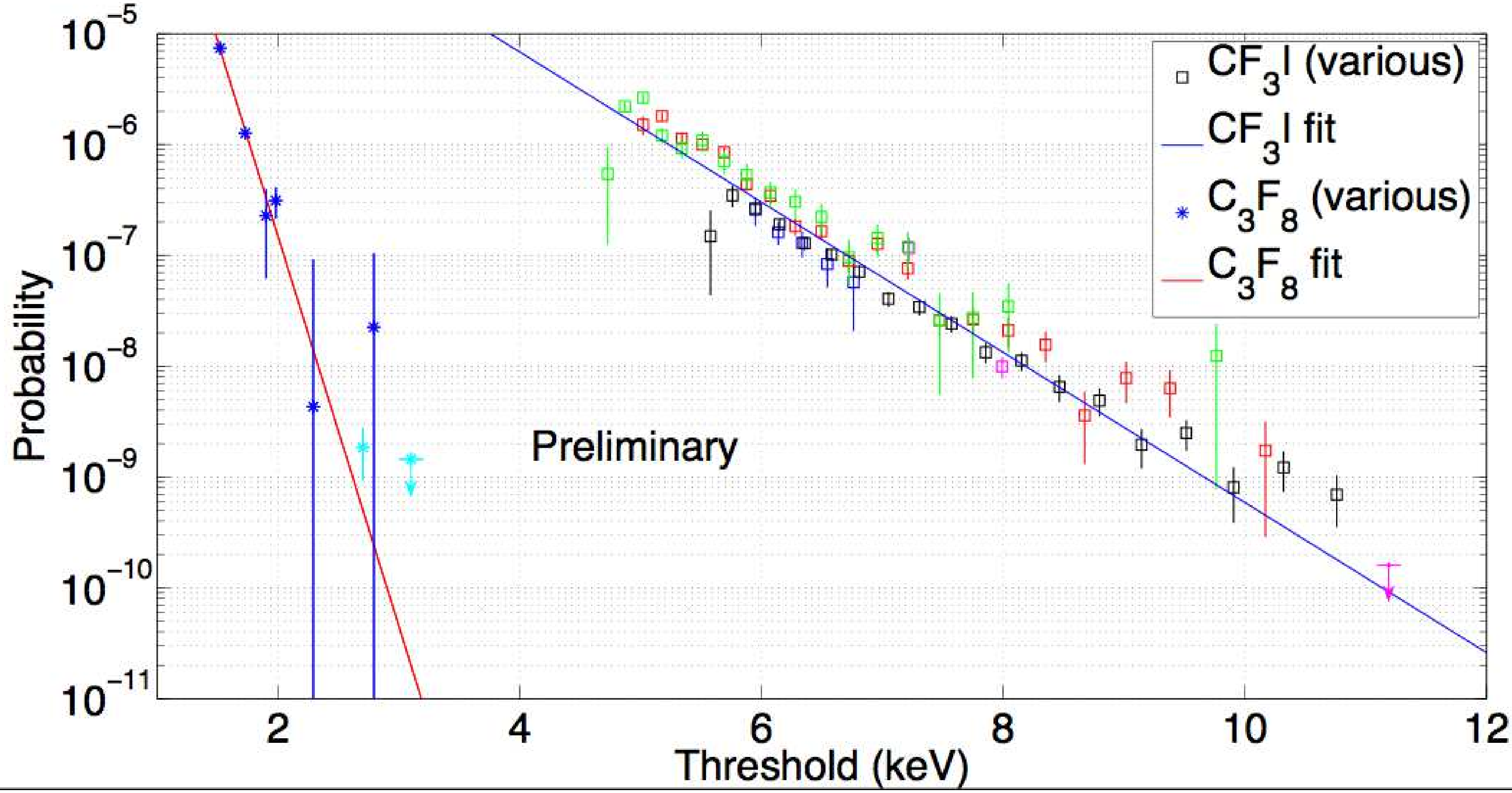


PICO features

- Energy: threshold detector
- Background suppression:
  - UG at SNOLAB
  - Water shielding
  - Clean materials
- Background discrimination:
  - Neutrons:
    multiples bubbles
    Nuclear recoil, $l \sim 20$ cm
  - α: acoustic parameter
    Nuclear recoil, 40 μm track
- Large target mass:
  COUPP4, COUPP60
  PICO-2L, PICO-250L



Backgrounds in PICO: γ rejection

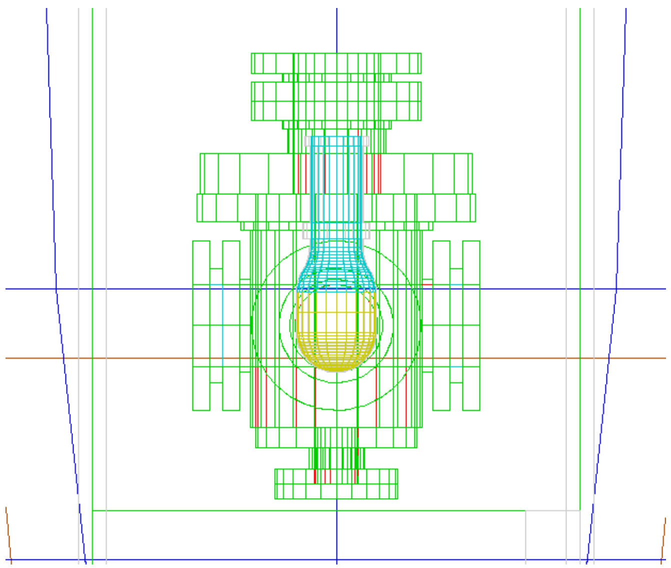


Bubble nucleation probability from gamma interactions in C_3F_8 and CF_3I

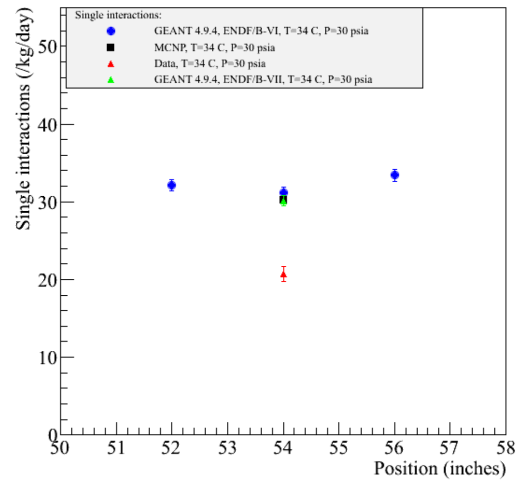
COUPP4 at SNOLAB: simulations

GEANT and MCNP simulations

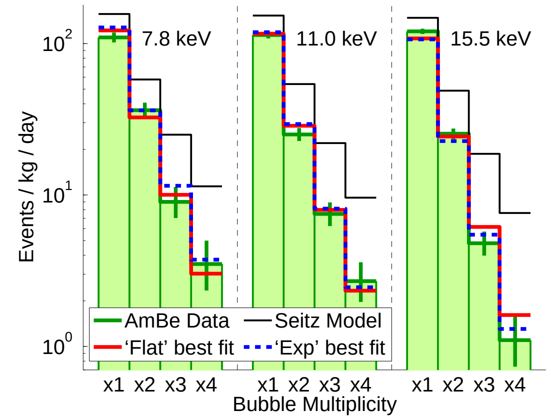
- Compare predicted rates of single and multiple bubble events with observation



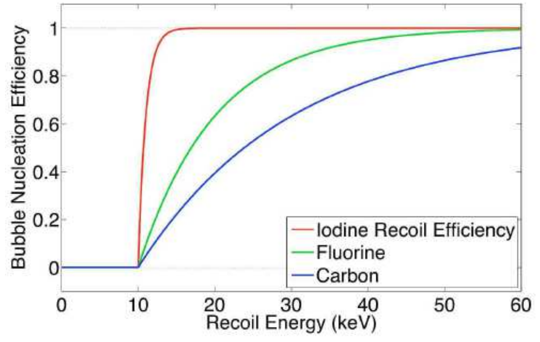
Threshold is determined using Seitz 'Hot Spike' Model, Phys. Fluids 1, 2 (1958).



Data show a shortfall of events compared to simulation of the Seitz Model



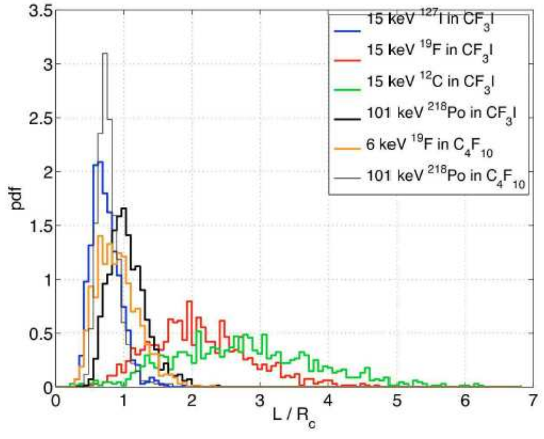
- Lower efficiency for ^{19}F and ^{12}C recoils
- Seitz model for ^{127}I recoils

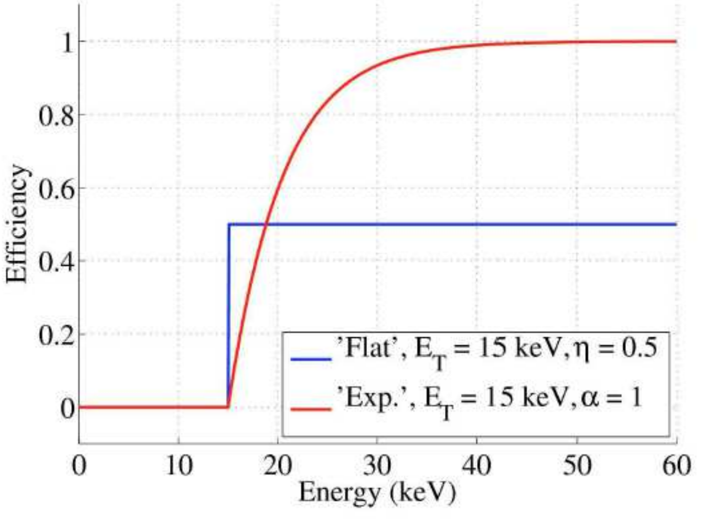


Seitz model:

- 6 keV ^{19}F recoils, C_4F_{10} (PICASSO)
- 101 keV ^{218}Po recoils, C_4F_{10} (PICASSO)
- 101 keV ^{218}Po recoils, CF_3I

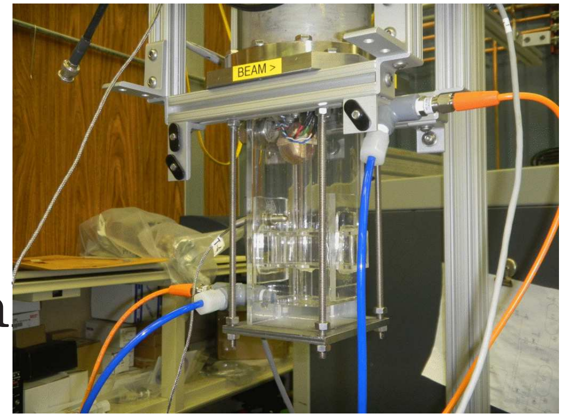
SRIM → TRIM calculation

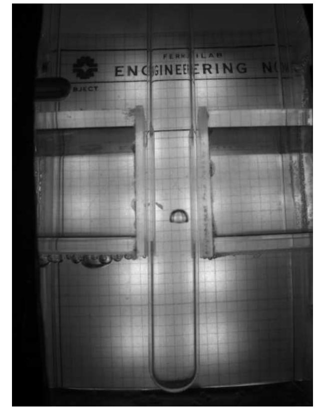




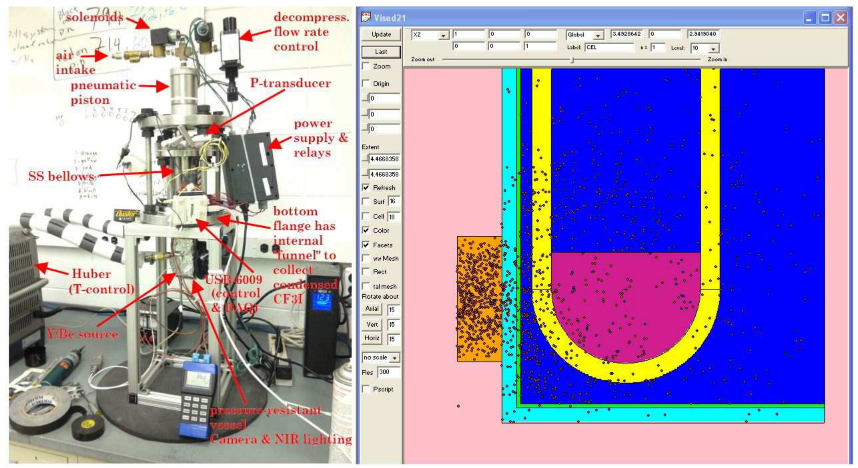
Calibrations

- γ and neutron calibrations
  - AmBe and ^{252}Cf
  - ^{60}Co and ^{133}Ba
  - Neutron beam at Montrea





- COUPP Iodine Recoil Threshold Experiment
  - Low energy Iodine recoils
  - π beam and silicon trackers
- ^{88}Y/Be calibration chamber
  - Understand response to low energy recoils
  - Monochromatic low energy neutrons

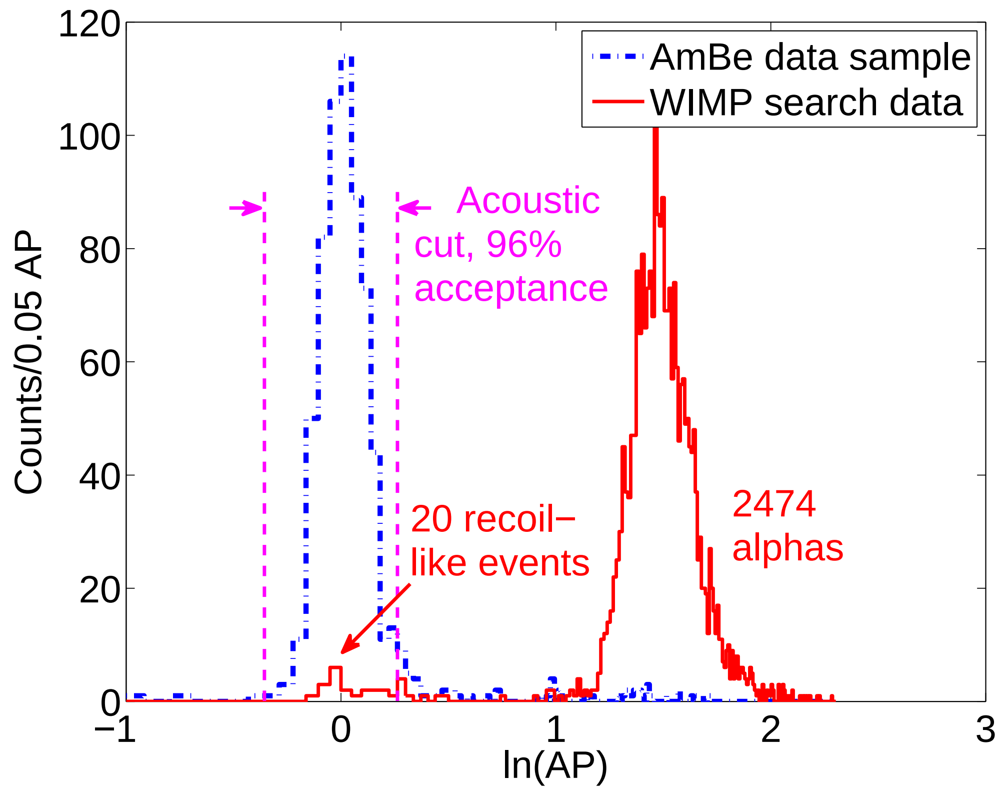


COUPP4 at SNOLAB: results

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)

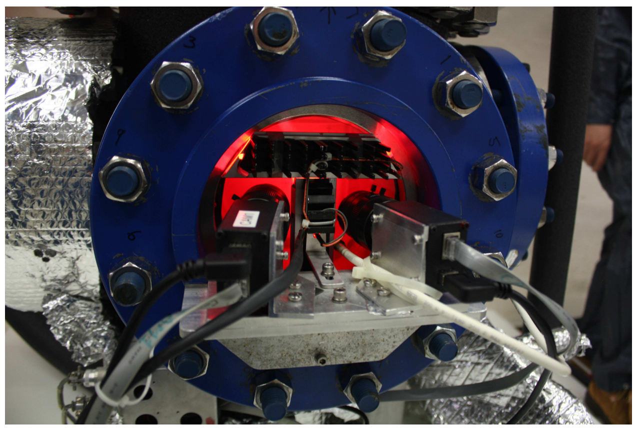
20 WIMP candidates

(Neutrons from rock: < 1/year)

Internal neutron background

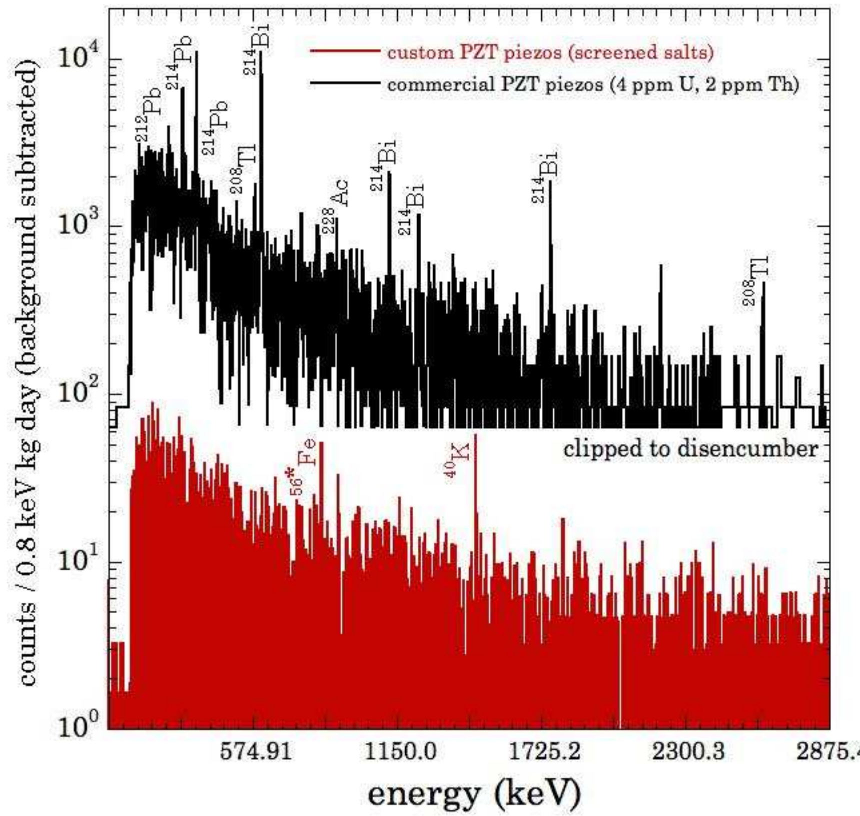
- View-ports:
  0.5 ppm ^{238}U and 0.8 ppm ^{232}Th, ($\sim$ 5 events)
- Piezos:
  4.0 ppm ^{238}U, 1.9 ppm ^{232}Th and ^{210}Pb, ($\sim$ 2 events)

Fission and (α,n) on light elements



New piezos built (low background salts)

New view-ports (synthetic silica)

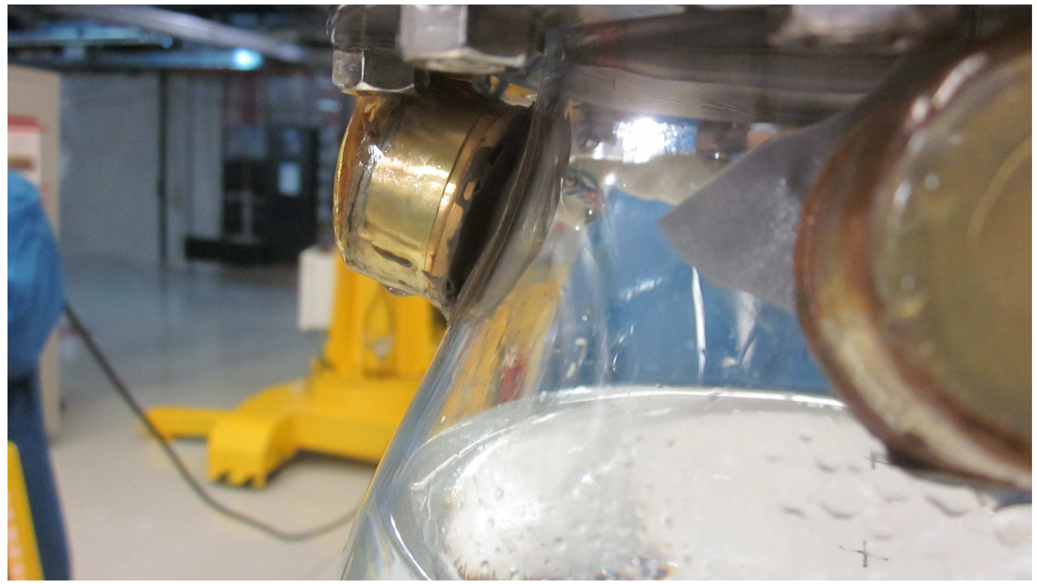


COUPP4 at SNOLAB: Physics run II

- New physics run in 2012
- 8 singles, 1 double, 1 triple
- Replace more components
- ICP-MS assay

Hydraulics failed

Piezos detached from IV

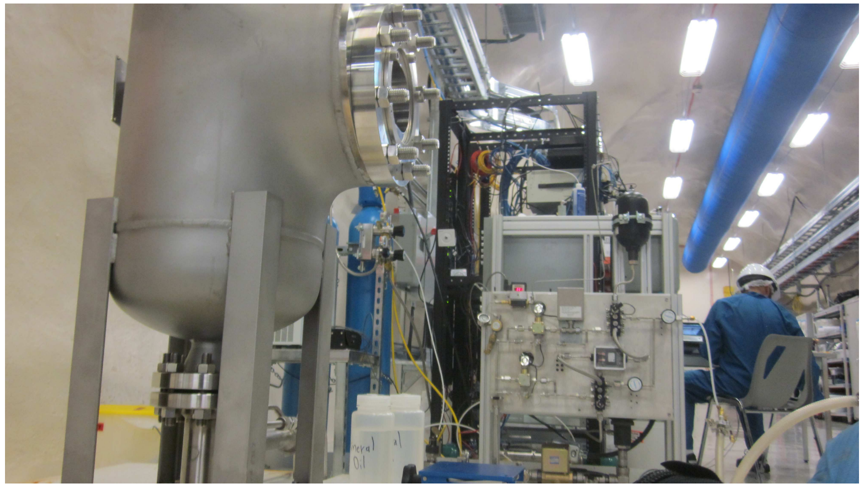


Refurbishing the detector

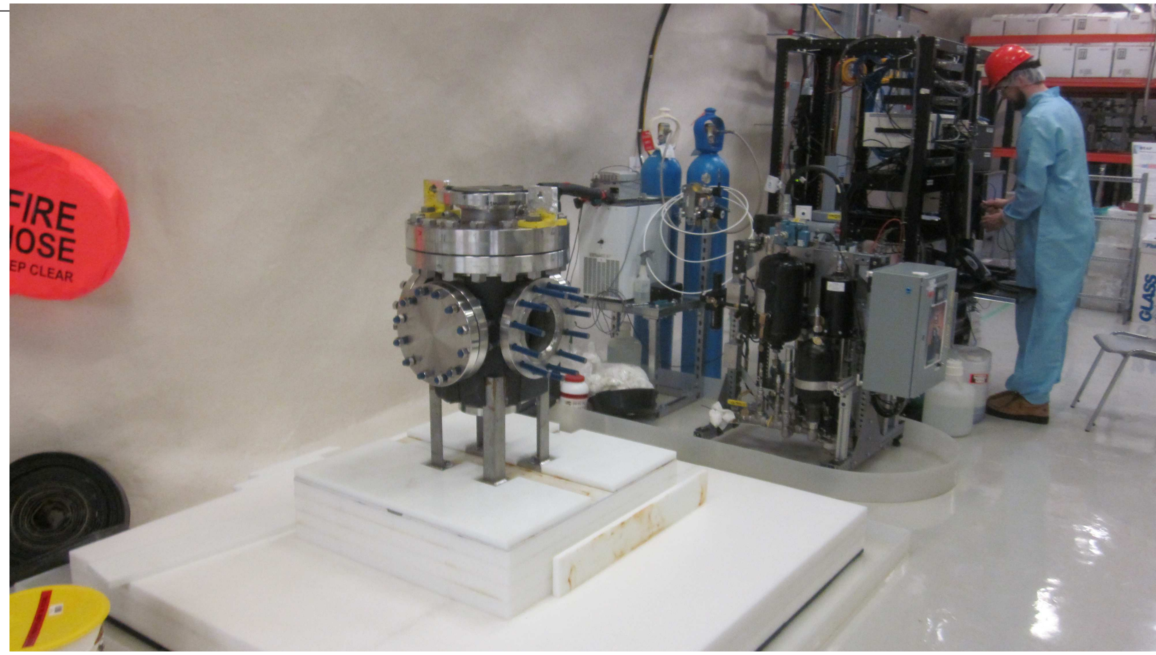
Different target material

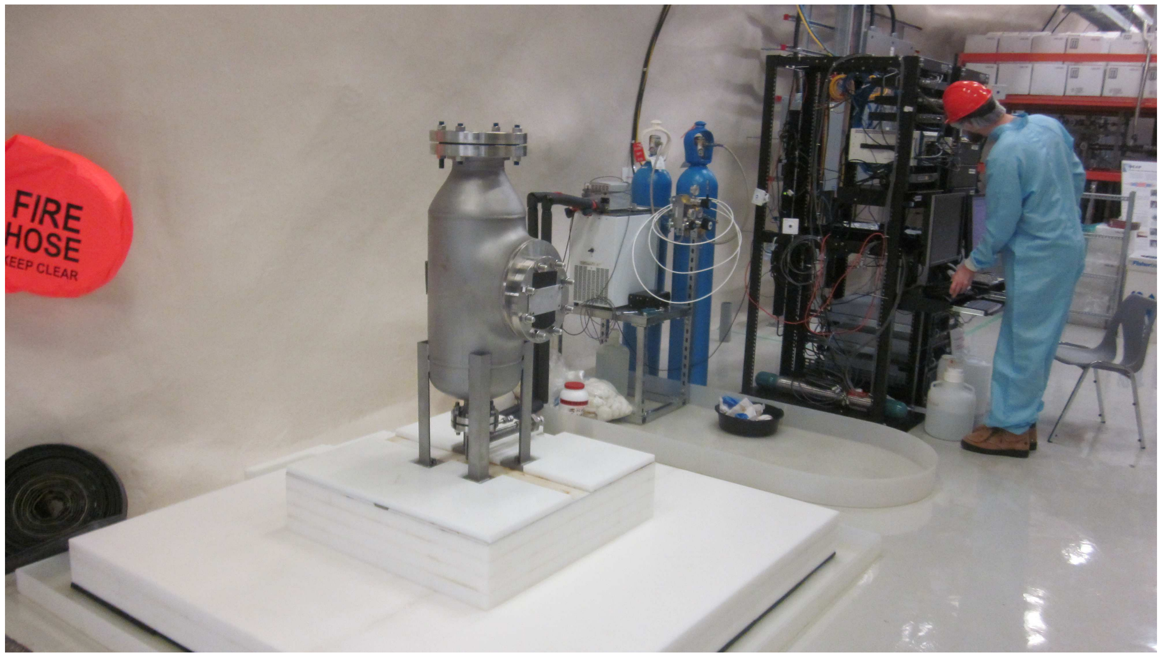
PICO-2L

- C_3F_8 as target material
- spin-dependent sensitivity
- Low energy threshold
- new hydraulics
- new pressure vessel

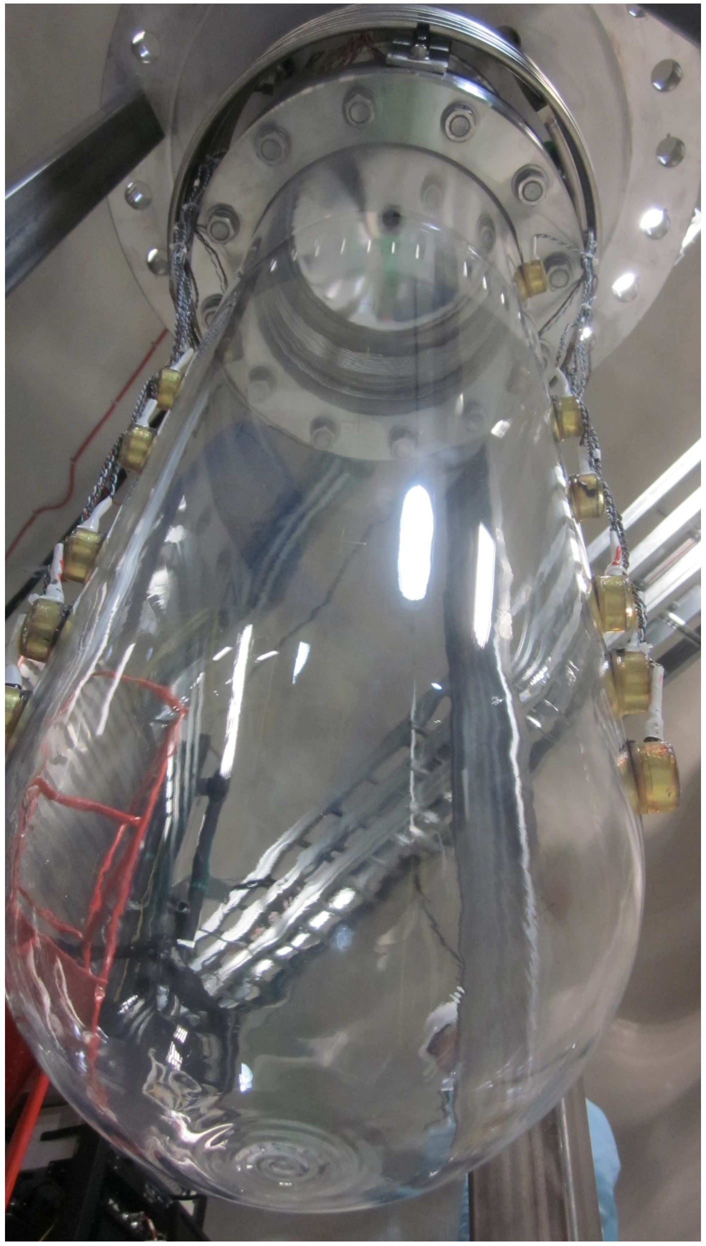


From COUPP4 to PICO-2L

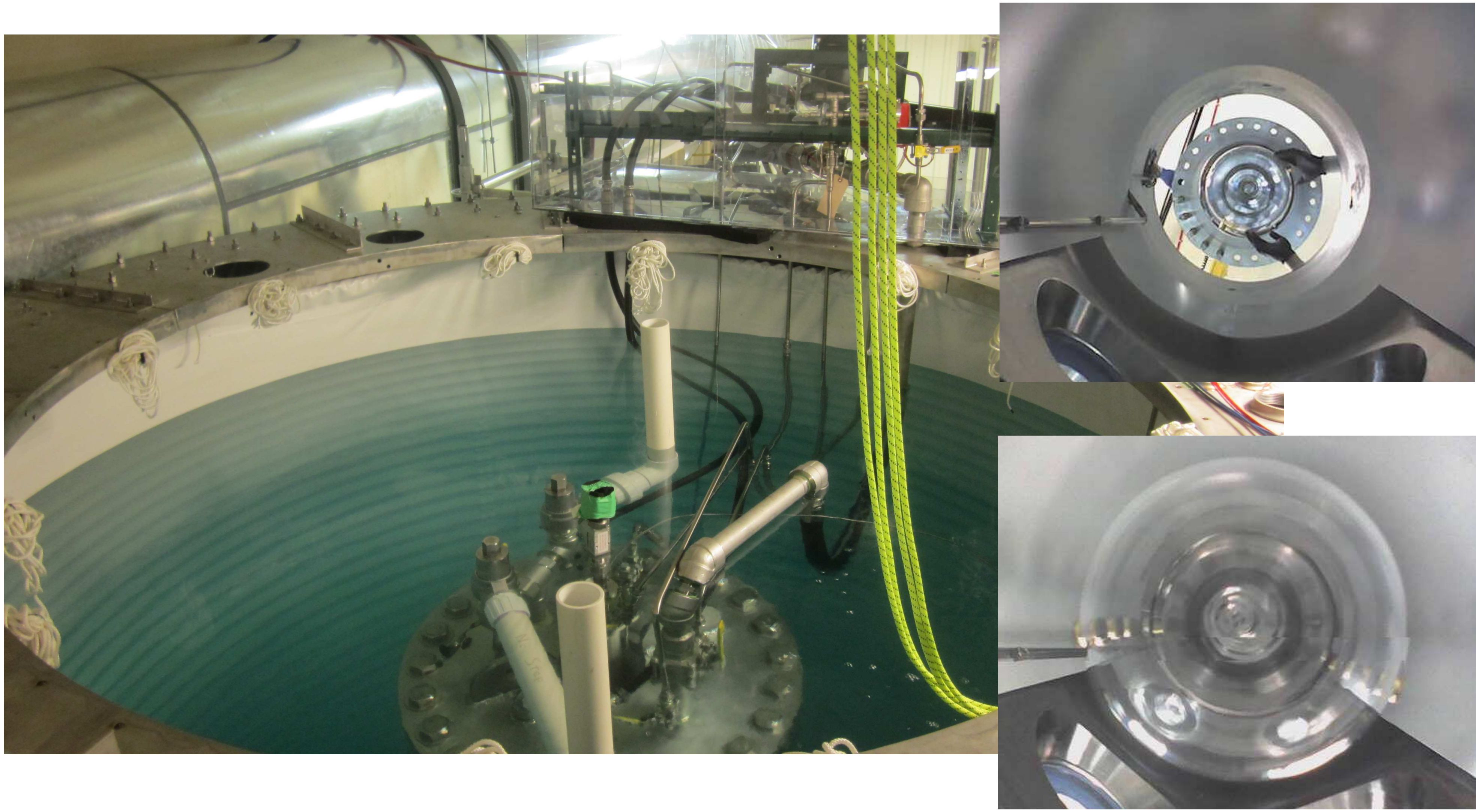




COUPP60 at SNOLAB

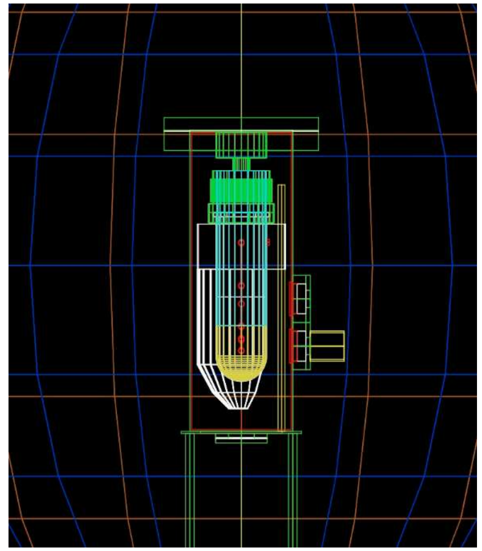


COUPP60 at SNOLAB



Running in the ladder labs at SNOLAB

- First bubble on May 1, 2013 (radon decay)



Backgrounds in PICO

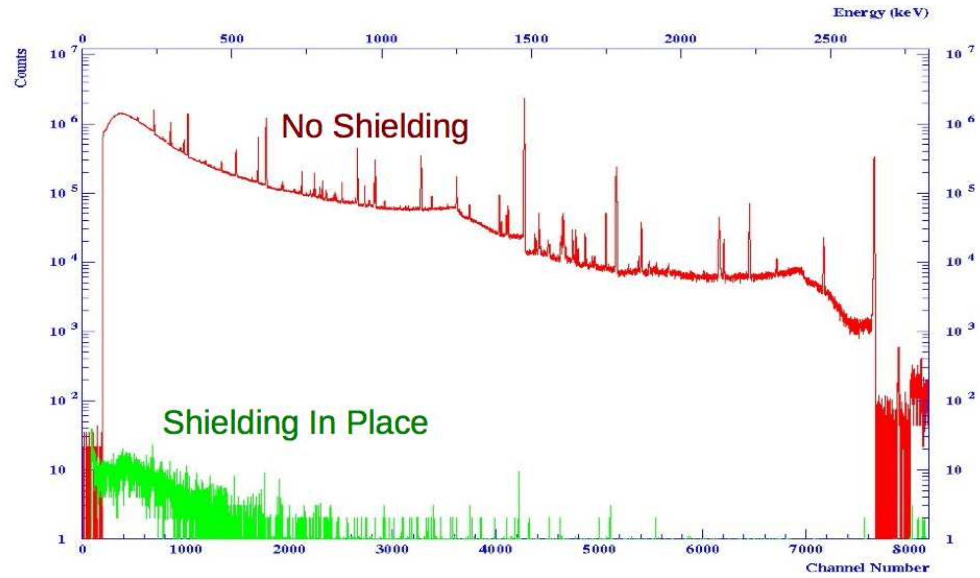
- Each part (or set of similar parts) contributes at most 10% of the total background budget (0.05 single-site events per live-year)
- Require fewer than 0.1 total events, including multi-site events, per live-year for each part

- University of Chicago germanium counter
- SNOLAB germanium counters
- ICPMS counting at PNNL
- Radon emanations at SNOLAB

HPGe at SNOLAB

HPGe detector:

- Measure activity in materials
- Data used as input for simulations.
  Ex: (α,n), (γ,n) spontaneous fission



Talk by I. Lawson tomorrow
"Low Background Counting
at SNOLAB"

SNOLAB Low Background Counting Facility

Descriptions of the SNOLAB PGT and Canberra HPGE detectors

- A Description of the SNOLAB PGT HPGe detector, presented at SNOLAB Workshop V
- Status of the SNOLAB PGT Ge detector (Report)
- Presentation at AARM S4 Collaboration Meeting June 2012.
- Presentation at LRT 2013, includes details of the PGT and Canberra Well detectors.
- Presentation at Laurentian University October 8, 2013
- Photographs of the PGT Detector(View Photos)
- Photographs of the Canberra Well Detector(View Photos)

Technical Details of the SNOLAB HPGE detector and material containers

- Drawing of the Geometry of the Ge detector and 1 litre Marinelli beaker, courtesy of James Loach.
- Description of the standard 1L Marinelli beaker from Ga-Ma Associates.
- Description of the 4 L Marinelli beaker from Ga-Ma Associates.
- Description of the 500 mL Marinelli beaker from Ga-Ma Associates.
- Description of the 180mL Marinelli beaker from Ga-Ma Associates.

Technical Details of the SNOLAB Canberra Well detector and material containers

- Description of the 3mL Cowie Sample bottle.

Radioactivity Measurements of Various Materials Using the SNOLAB PGT HPGE Coax Detector

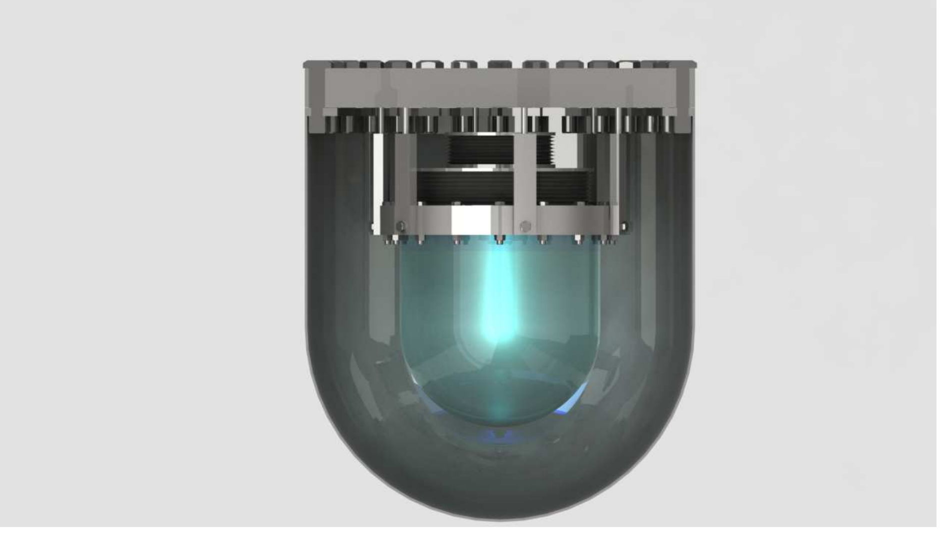
The most sensitive detection region for gammas using this detector is from 100 to 2700 keV.

- Summary Table for ALL measurements (Web Page and XLS Format) [last updated on 2014/03/18]
- Summary Table for COUPP measurements (Web Page and XLS Format) [last updated on 2013/08/09]

PICO-250L

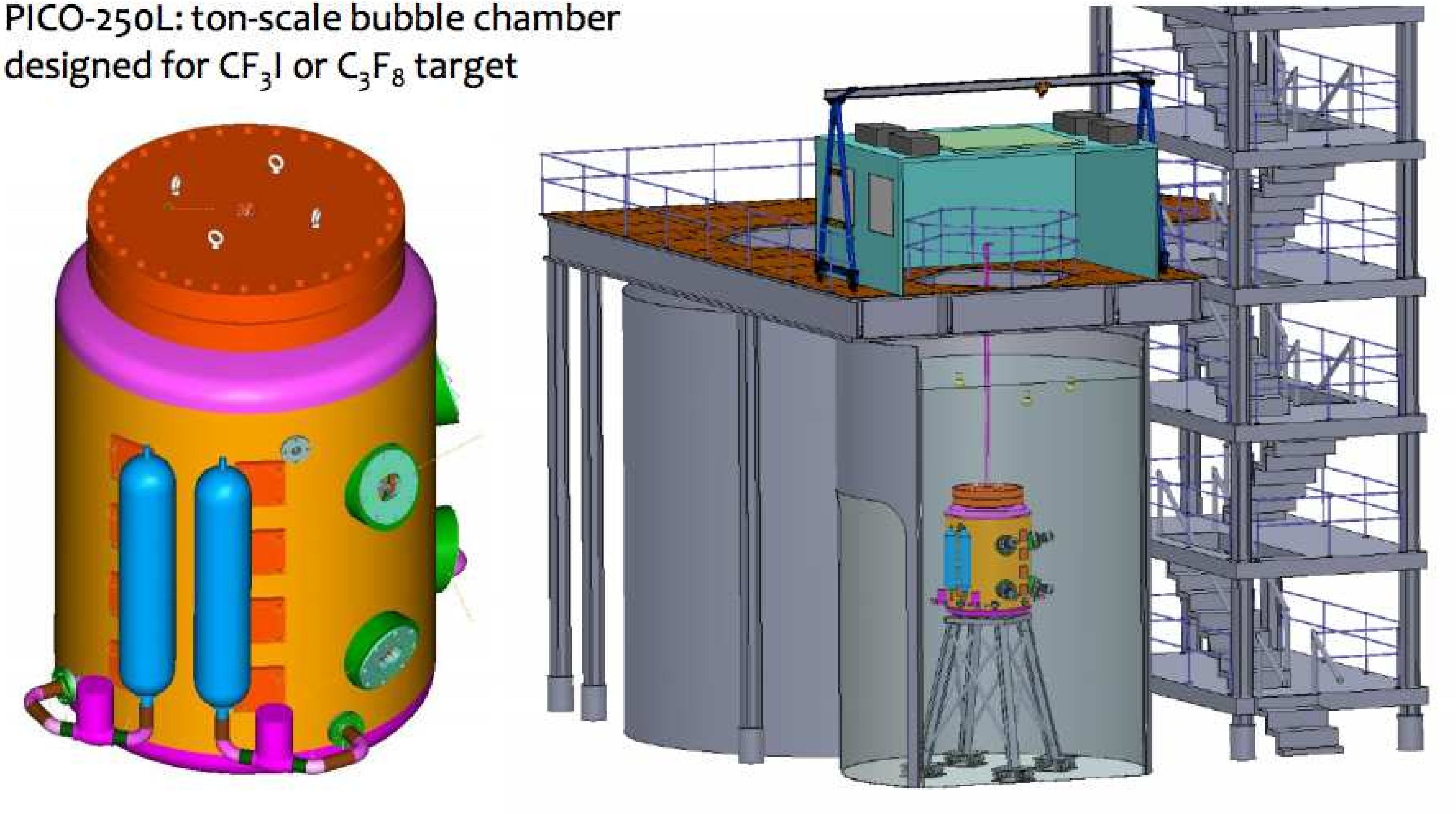
- $> 10^{10}$ γ/β insensitivity
- $> 99.3\%$ acoustic α discrimination
- Multi-target capability
  SD- and SI-coupling
  High- and low-mass WIMPs
- Easily scalable, inexpensive to replicate
- First effort: PICO-2L

Data taking by 2016



PICO-250L

PICO-250L: ton-scale bubble chamber designed for CF_3I or C_3F_8 target

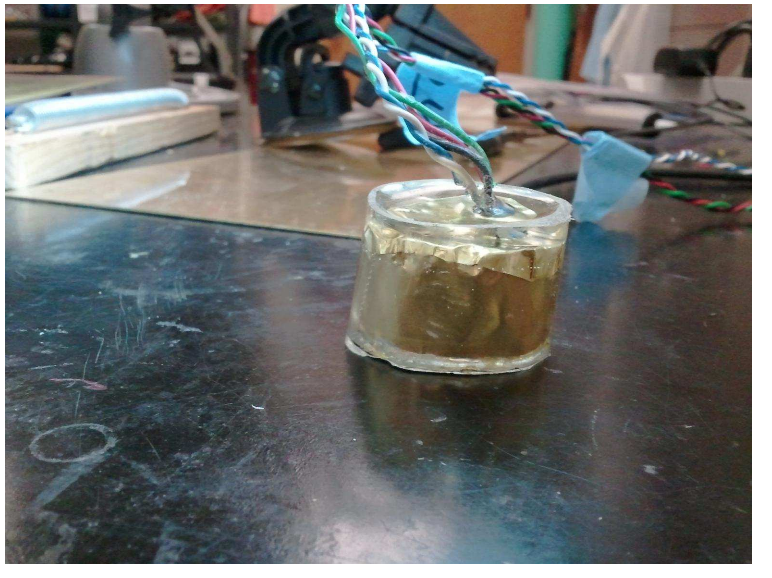


PICO-250L design

- Target fluid:
  - C_3F_8
  - CF_3I
- Inner vessel assembly: ultra-high-purity synthetic fused silica jar
- Outer vessel: Stainless steel (ϕ= 60 inches)
- Acoustics sensors: piezoelectric acoustic transducers

PICO-250L design

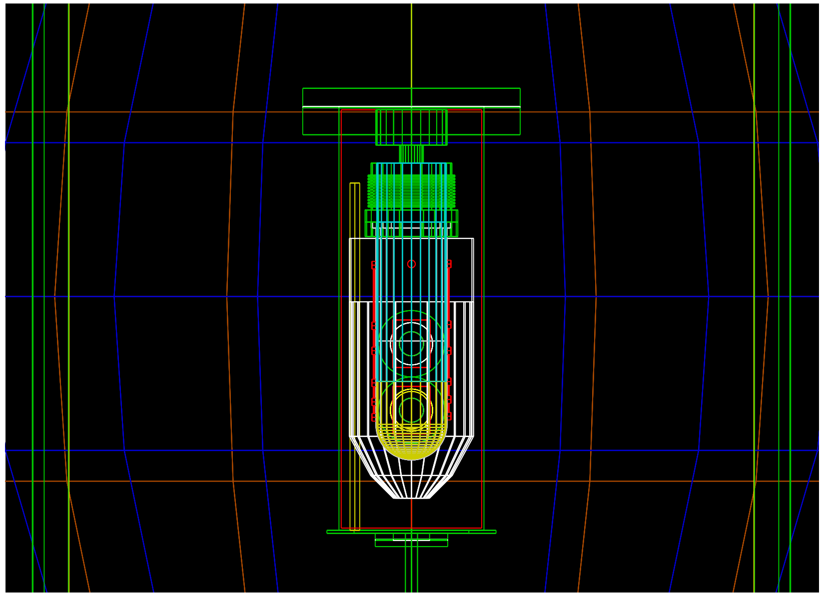
- Outer neutron shielding:
  - neutron moderator
  - muon veto
- Pressure control unit:
  - expand and recompress the chamber
  - regulate chamber pressure
- Data acquisition:
  - T and P sensors
  - machine vision cameras
  - acoustic transducers

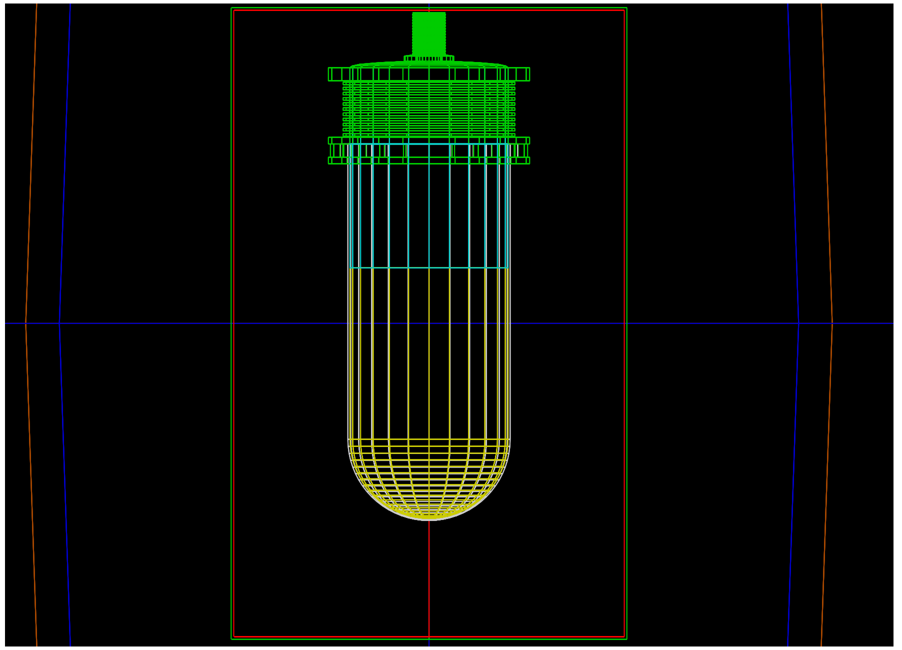


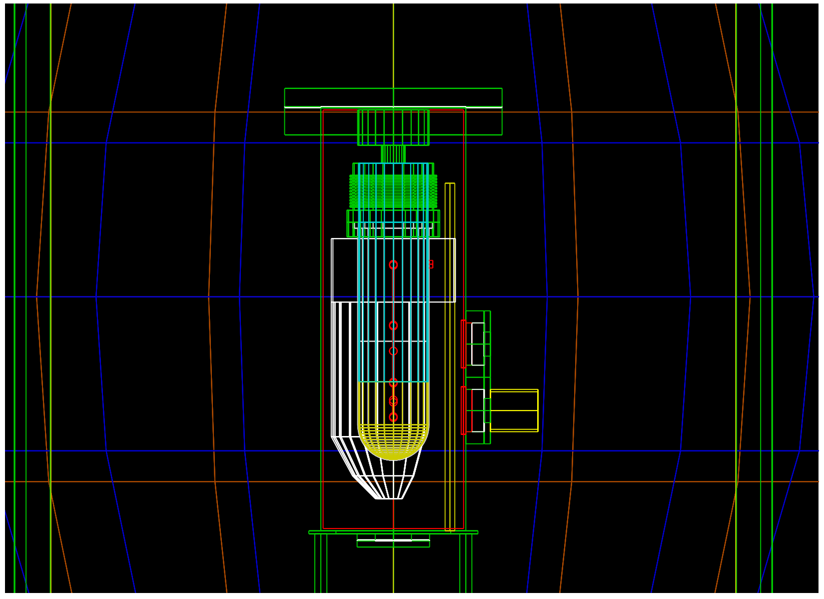
PICO-250L simulations

- **External backgrounds:**
  - **Rock neutrons**
  - **Muon induced neutrons**
  - **(γ,n) reactions**
- **Internal backgrounds:**
  - **U and Th: fission and (α,n) on light elements: SOURCES-4C and SNO code**
  - **^{238}U direct decay**
    - **Materials: SS, quartz, cabling,...**
    - **Fluids: water, LAB, glycol, CF_3I/C_3F_8**
    - **Radon**
    - **Mine dust, veto PMTs**
    - **Acoustic transducers**

Detectors in GEANT







COUPP60 and PICO-250L GEANT4 models

PICO-250L: external neutrons

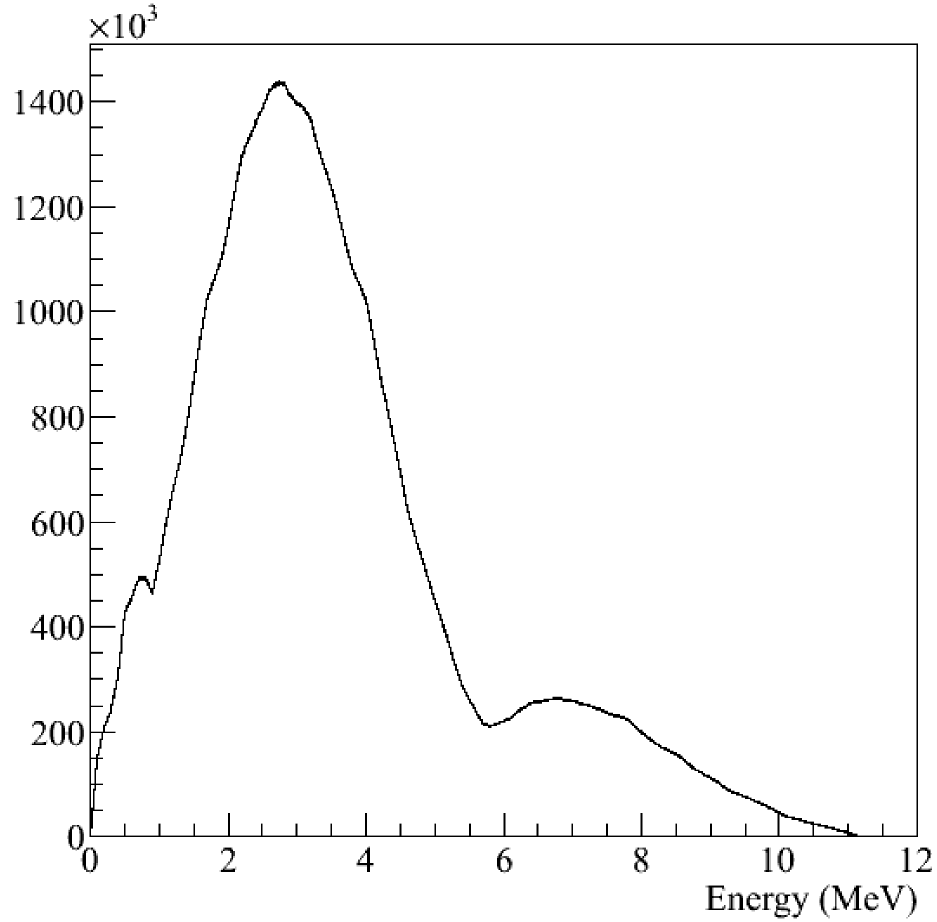
Fast neutrons from norite:
4000 n/m^2/day

Muon induced neutrons in:
rock, water, stainless steel

Water tank dimensions:

- $\phi = 6.8$ m
- L = 7.4 m

$\sim$ **67 muons/day**



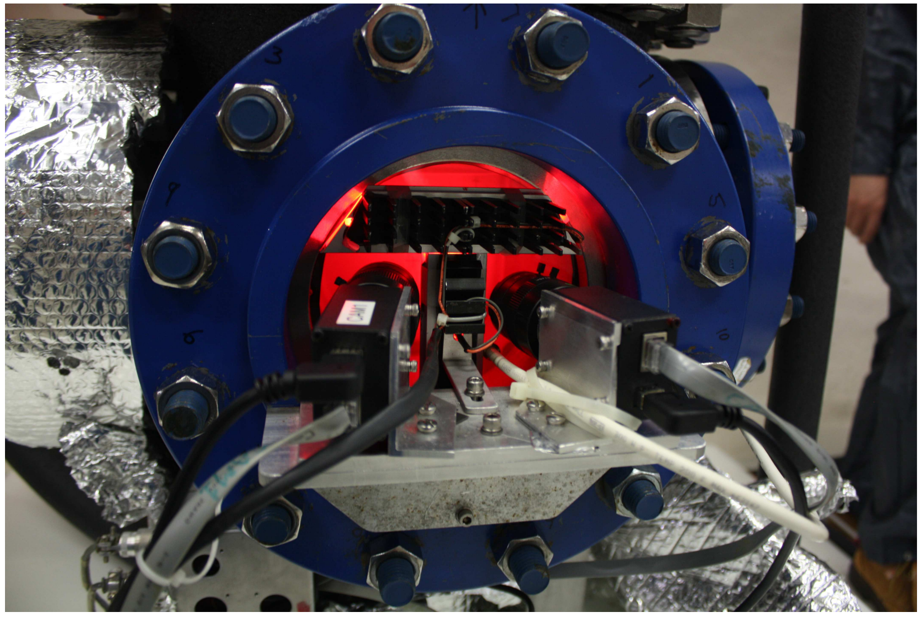
Neutron energy for (α,n) reaction in norite

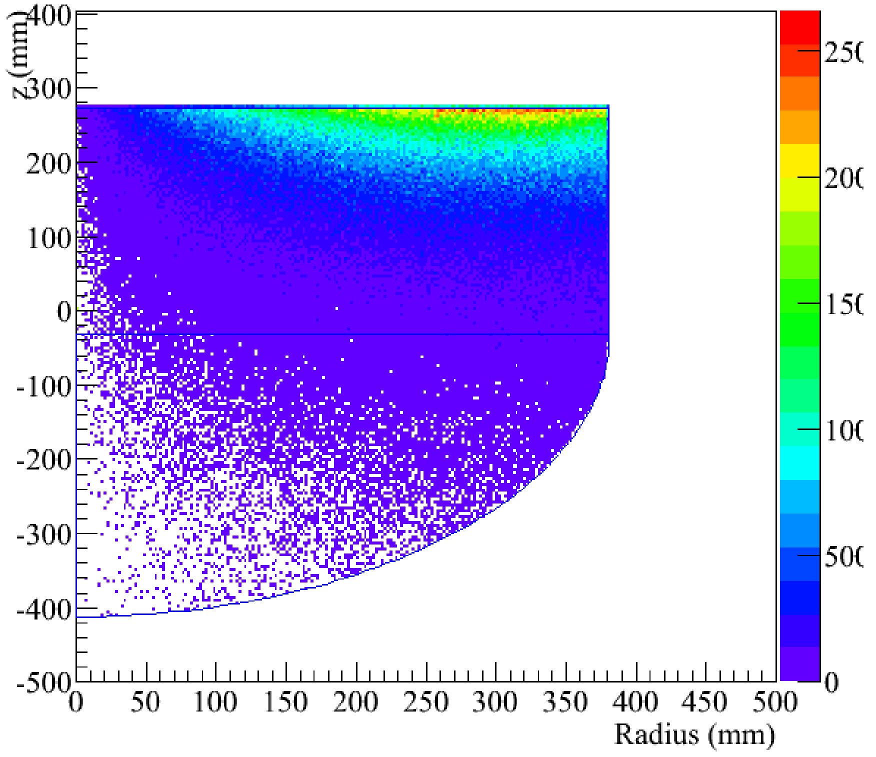
PICO-250L: fission and (α,n)

Stainless steel, quartz

Water/LAB (buffer and tank), propylene glycol

- ^{238}U, ^{232}Th, ^{235}U





Other backgrounds:

- Mine dust
- veto PMTs

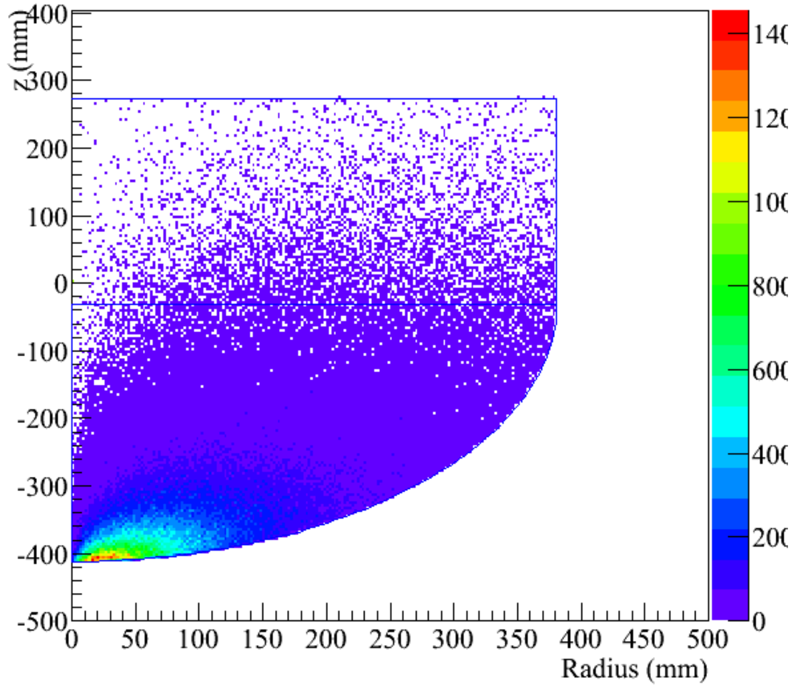
PICO-250L: acoustic transducers

Two positions simulated:

(10 ppb ^{238}U and ^{232}Th
0.1 ppb ^{235}U, 10 Bq/kg ^{210}Pb)

- side only, 25g
  2×10^{-8} events/kg-day
- bottom only, 25g
  3×10^{-7} events/kg-day

Acoustic simulation in progress
for design optimization



screening for salts used in the manufacture of piezoelectric transducers

around 15 samples
(high purity germanium detector at SNOLAB)

PICO-250L: fluid purity

α decays
and neutrons from (α,n):

0.0159 ppt ^{238}U
0.0488 ppt ^{232}Th
0.0025 ppt ^{235}U
25 μBq/kg ^{222}Rn
25 μBq/kg ^{210}Pb

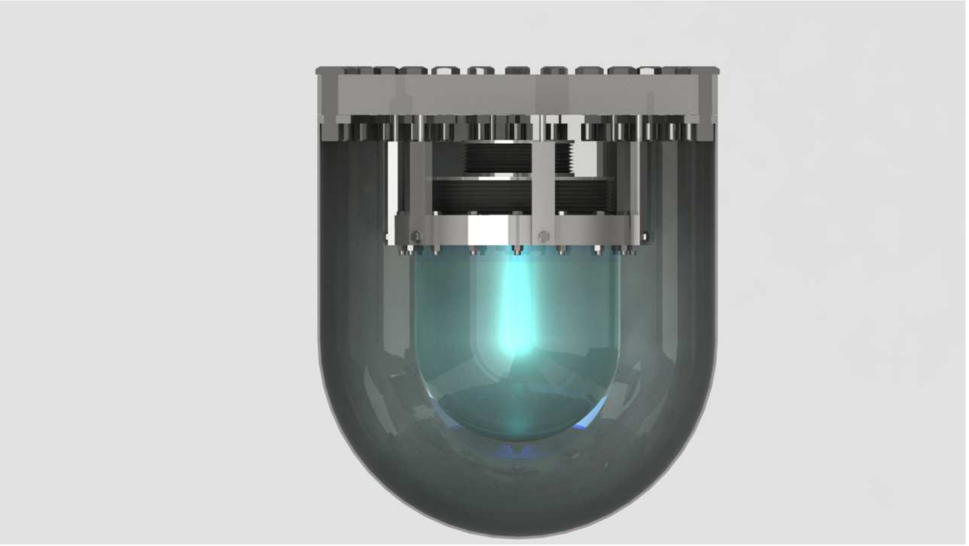
6×10^{-6} events/kg-day

vetoable: alpha + neutron

PICO-250L: radon

Radon deposition and
emanation on all surfaces

Radon diffusion in all fluids



Conclusions

Backgrounds in PICO-250L:

- **Learning from COUPP4 backgrounds**
- **Good control of backgrounds in COUPP60 and PICO-2L**
- **PICO-250L programme to keep backgrounds under control:**
  - **Material screening, in-situ measurements**
  - **Simulations: GEANT and MCNP (independent groups within the collaboration)**

Compute Canada: $\sim 10^5 - 10^6$ livetime years simulated