Bubble Chambers for Direct Dark Matter Searches in COUPP

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SNOLAB

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COUPP Collaboration

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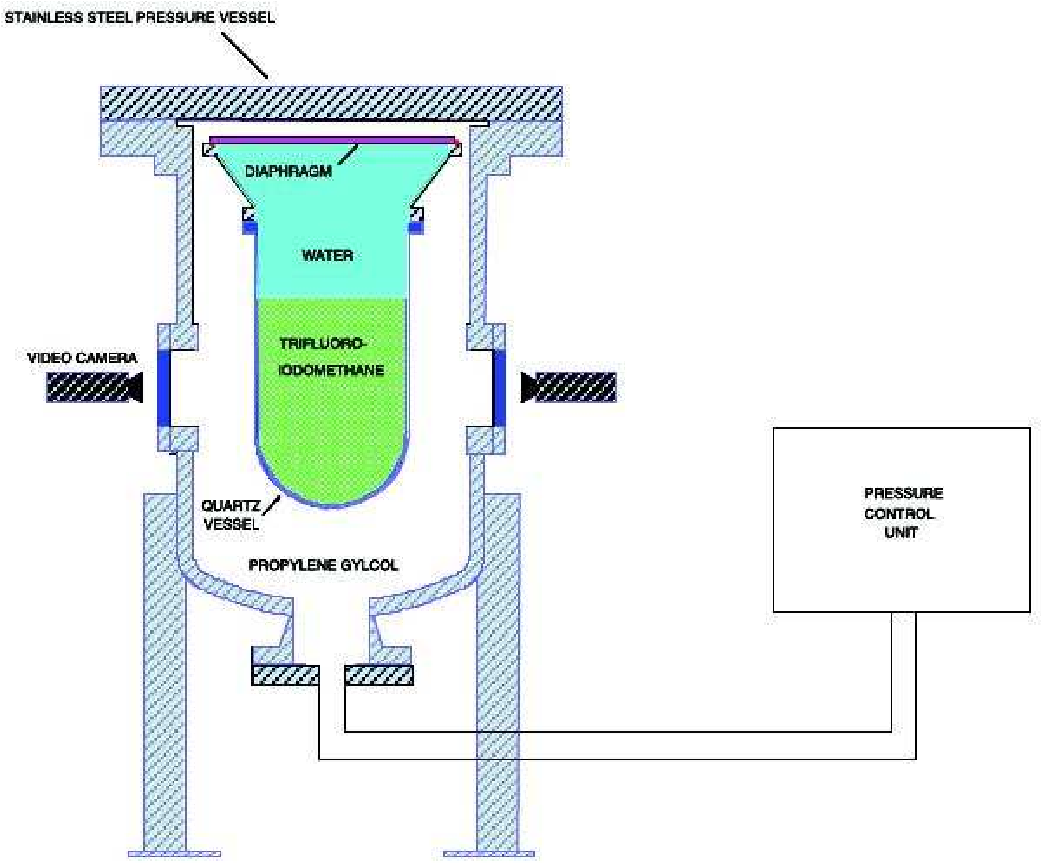
With support from:

COUPP bubble chambers

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



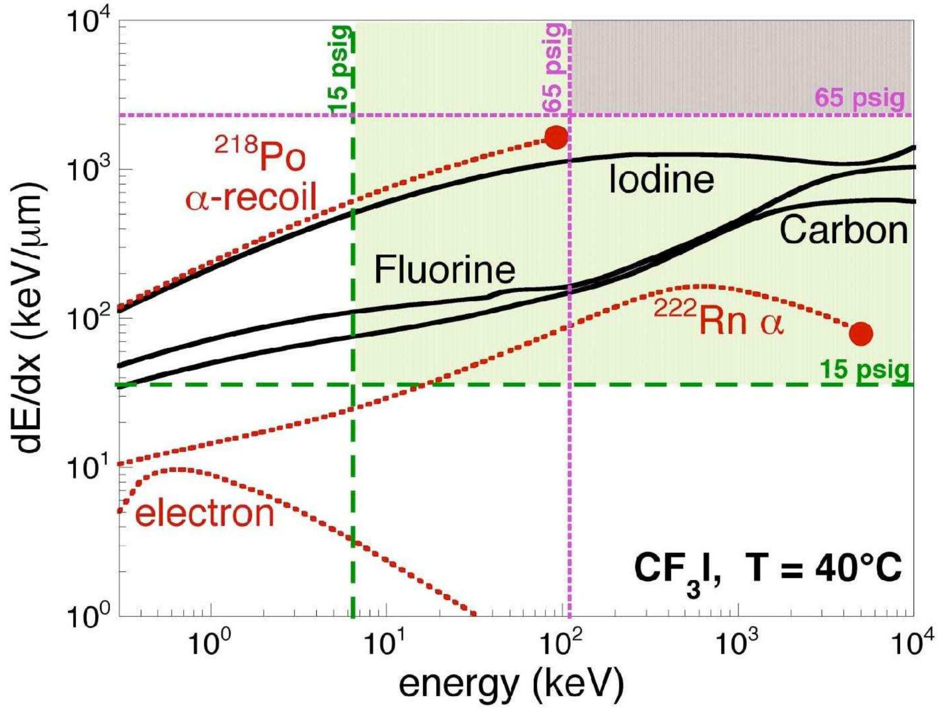
COUPP bubble chambers

- **The ability to reject electron and gamma backgrounds by arranging the chamber thermodynamics such that these particles do not even trigger the detector**
- **The ability to suppress neutron backgrounds by having the radioactively impure detection elements far from the active volume and by using the self-shielding of a large device and the high granularity to identify multiple bubbles**
- **The ability to build large chambers cheaply and with a choice of target fluids**
- **The ability to increase the size of the chambers without changing the size or complexity of the data acquisition**
- **Sensitivity to spin-dependent and spin-independent WIMP couplings**

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



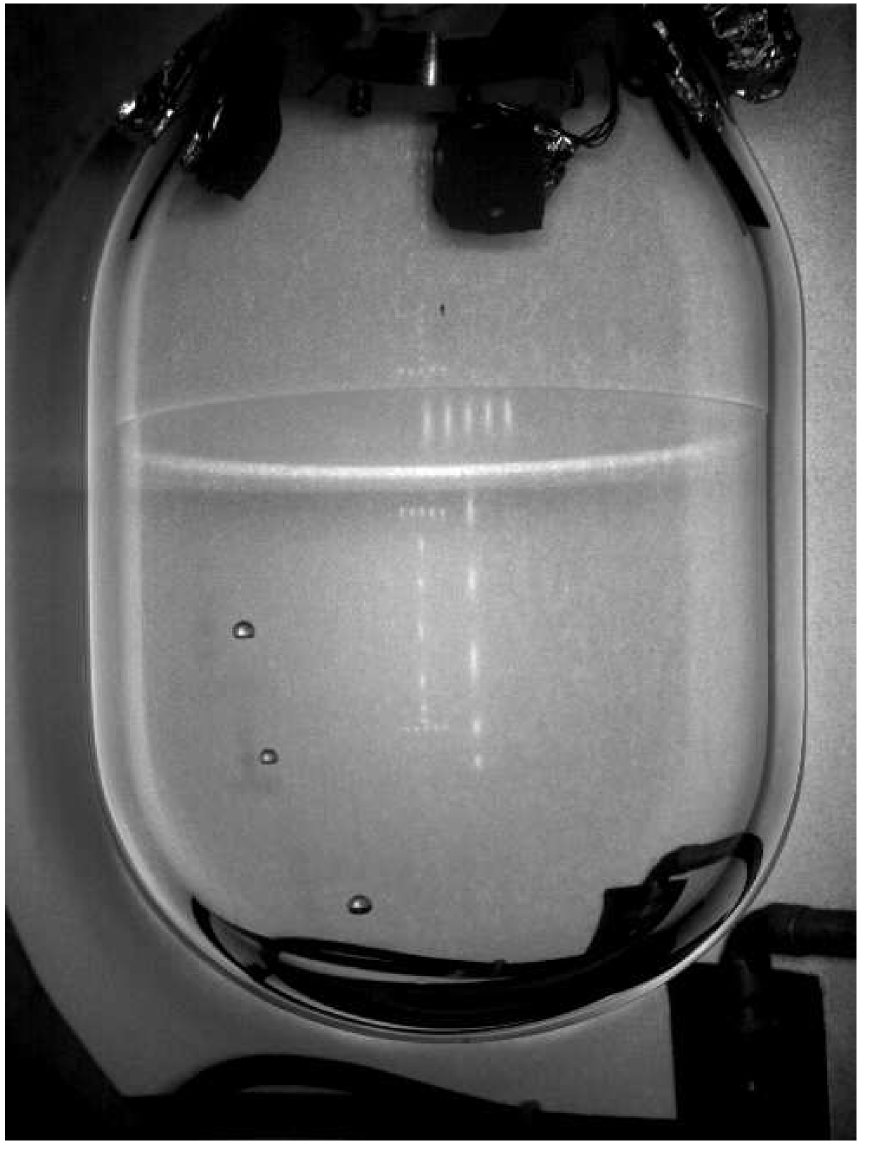
insensitive to electrons and gammas

COUPP bubble chambers

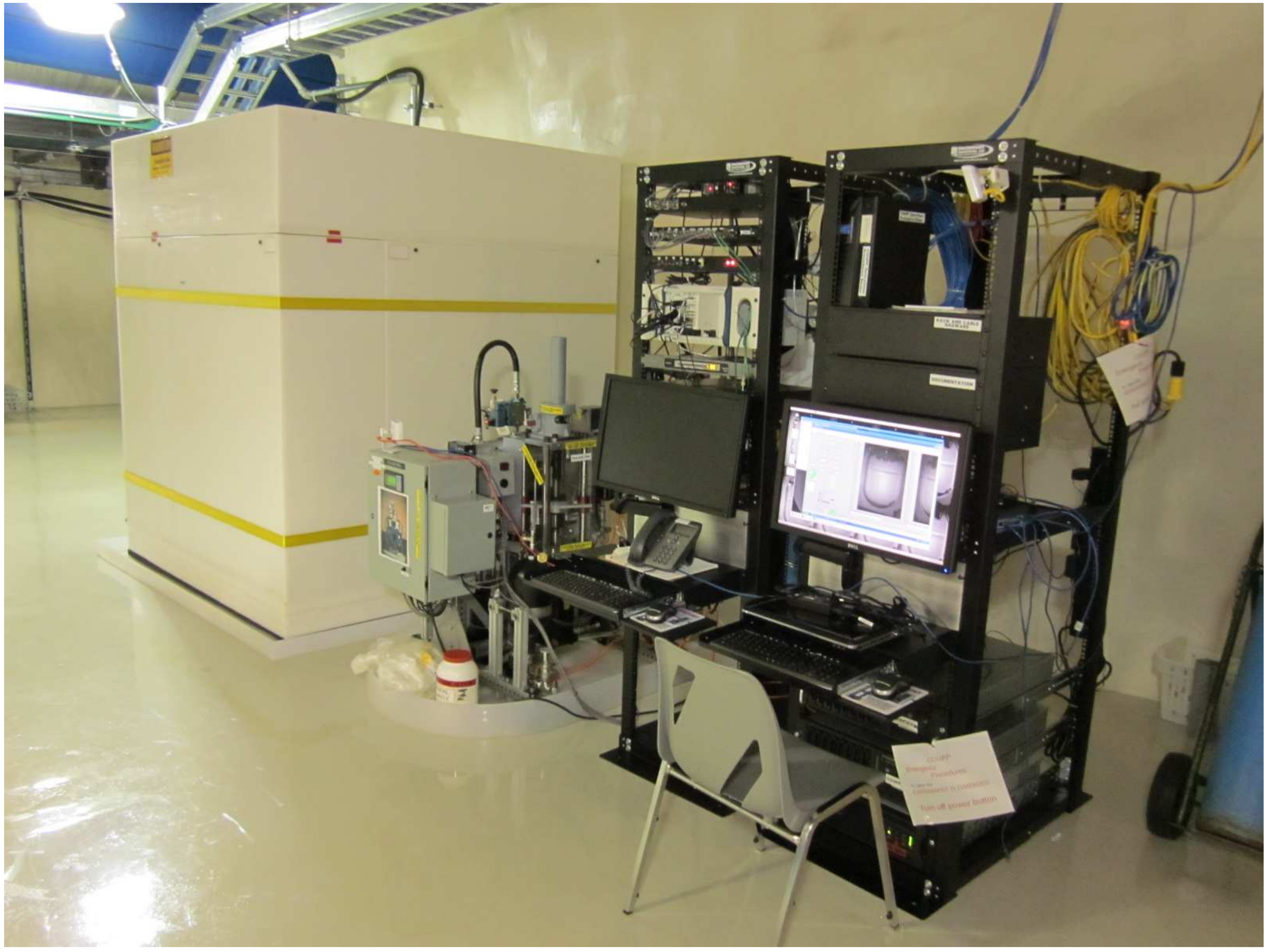
- **Alpha decays:**
  Nuclear recoil and
  40 μm alpha track
  1 bubble

- **Neutrons:**
  Nuclear recoils
  mean free path $\sim$20 cm
  3:1 single-multiple ratio
  in COUPP 4kg

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



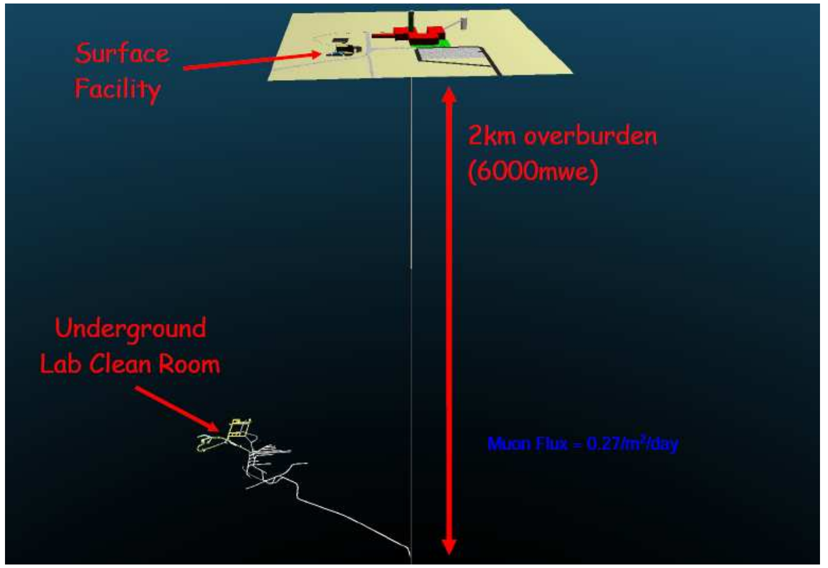
COUPP-4kg

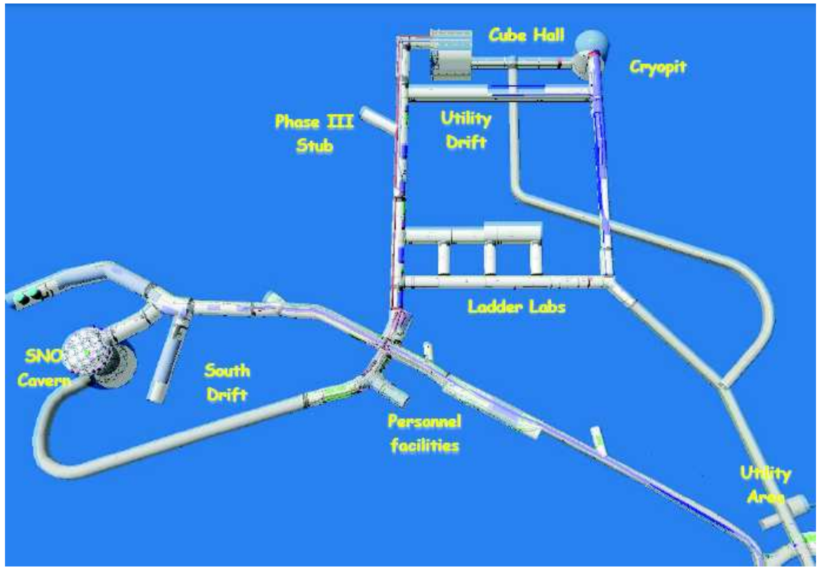


SNOLAB

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

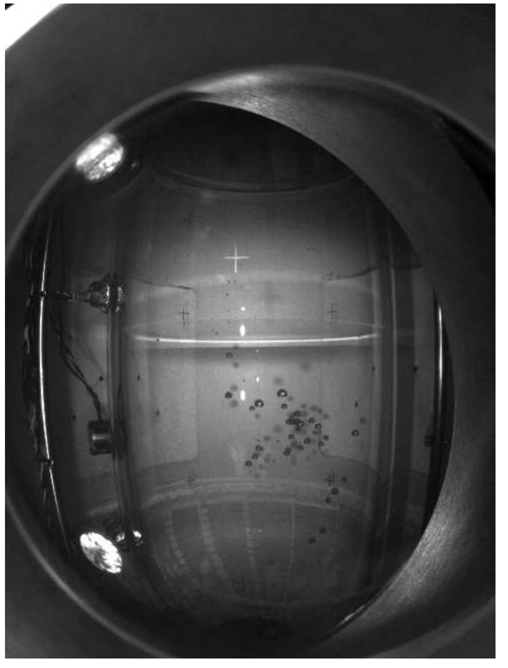




COUPP at SNOLAB

COUPP-4kg features

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

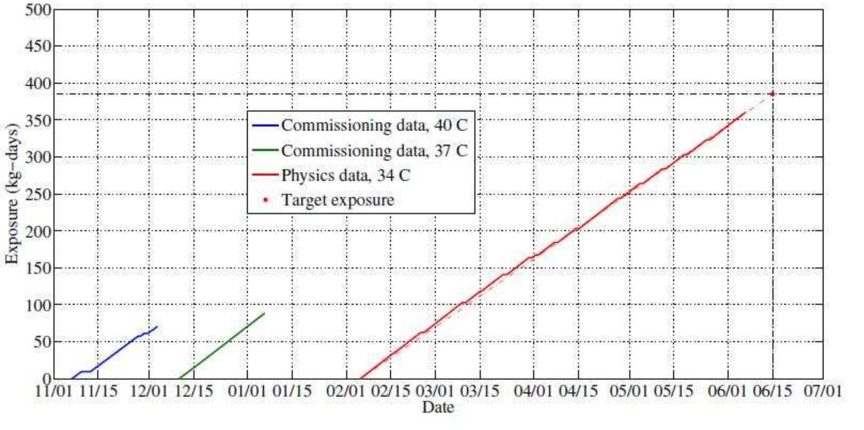


COUPP-4kg more features

- Thermodynamics: two temperature sensors and pressure transducers
- Fast AC-coupled pressure transducer for bubble growth
- Four lead zirconate piezoelectric acoustic transducers
- Two VGA resolution CCD cameras
  (20-degree stereo angle, 100 frames per second)
- Main trigger: frame-to-frame differences
  - compression within 20 ms of a bubble nucleation
  - 500 secs of expansion without a bubble $\longrightarrow$ compress to 215 psia for 30 secs
  - live-time: starts 30 secs after an expansion

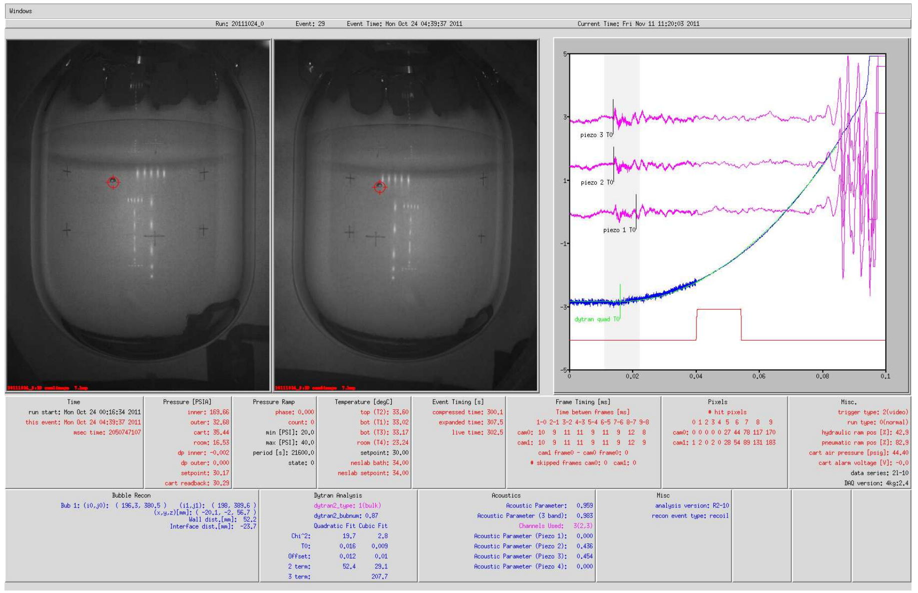
COUPP-4kg at SNOLAB

- Installation in summer 2010
- Physics run begins Nov. 3, 2010
- 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:
  - 12 neutron calibration runs: AmBe and ^{252}Cf
  - Continuous source of ^{222}Rn



COUPP-4kg at SNOLAB: 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 $82.5 \pm 1.9\%$

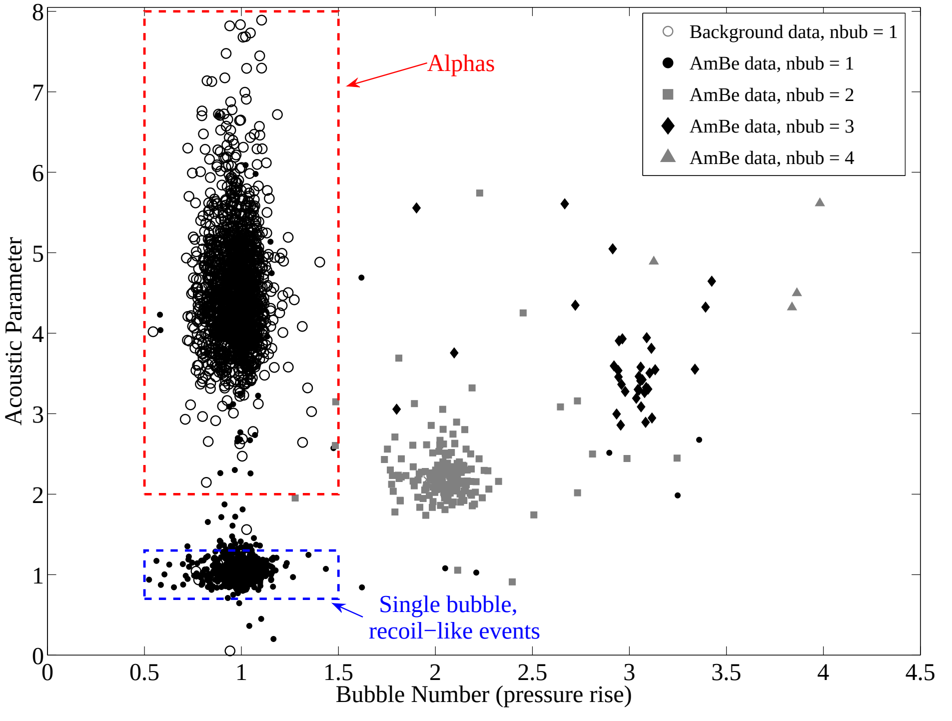
COUPP-4kg at SNOLAB

Acoustic transducer signals digitized with a 2.5 MHz sampling rate and recorded for 40 ms for each event

The nuclear recoil acceptance of the AP cut $95.8 \pm 0.5\%$

3 ways of counting:

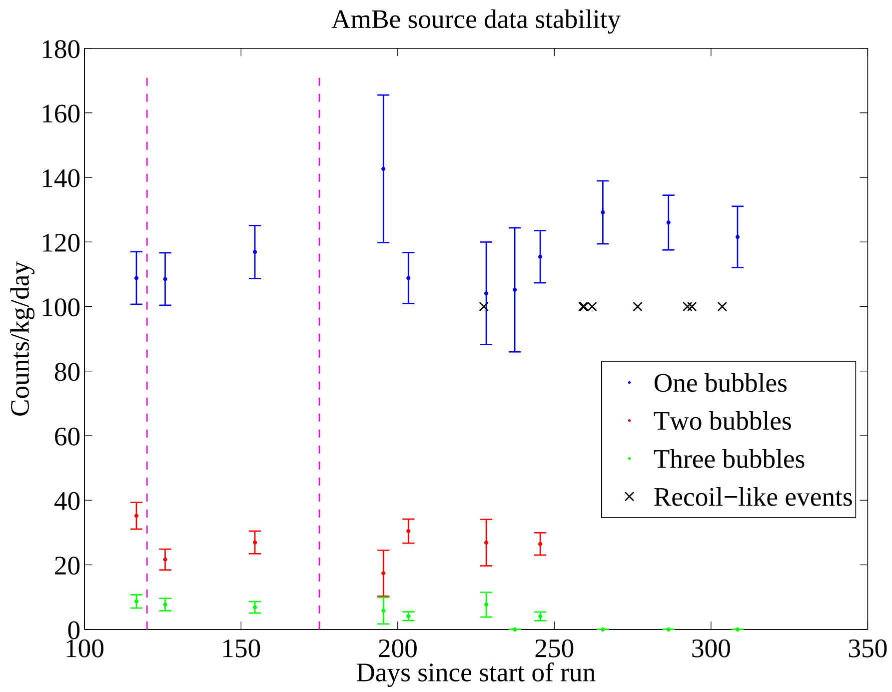
- Images: cameras
- Pressure rise: transducer
- Acoustic parameter: piezos

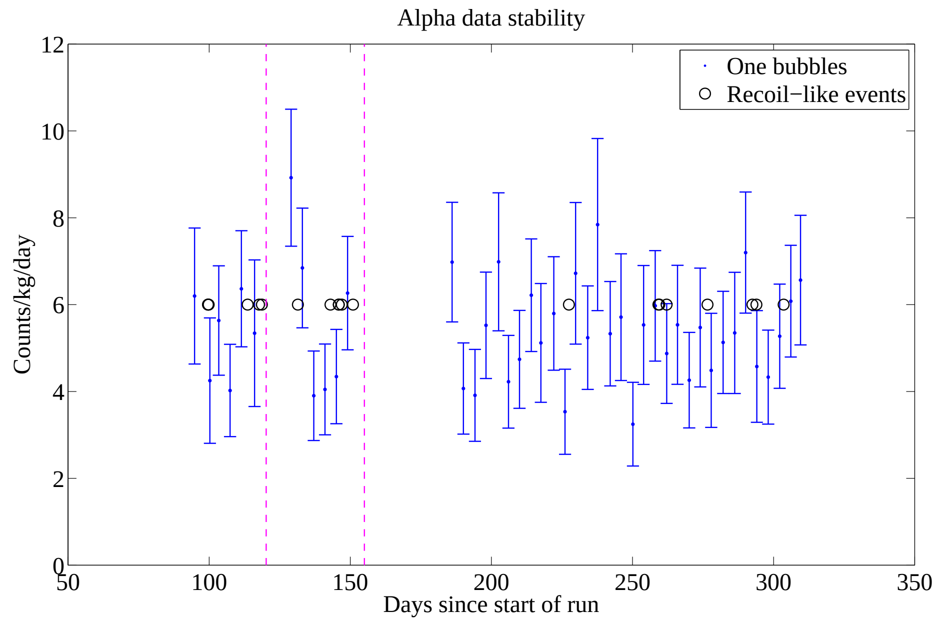


COUPP-4kg at SNOLAB: calibrations

Neutron calibrations:

- AmBe
- ^{252}Cf





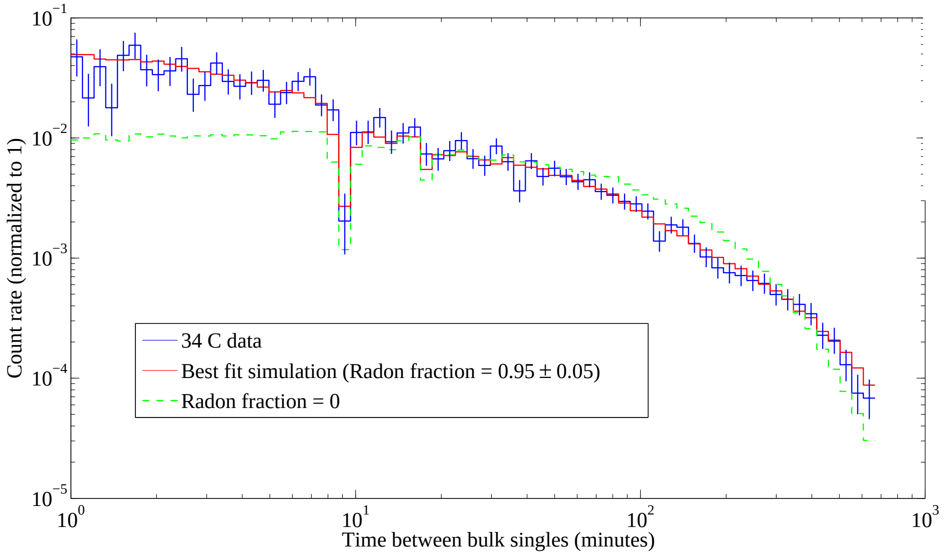
Alpha calibration: ^{222}Rn

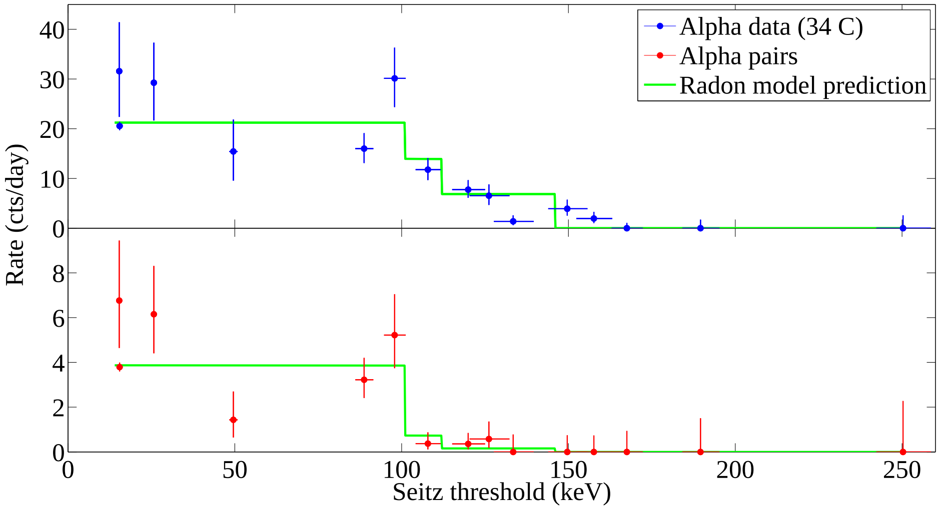
- Test Seitz model threshold
- Absolute bubble nucleation efficiency
- Characterize acoustic signature of α decays

COUPP-4kg at SNOLAB: calibrations

Radon fraction $= 0.95 \pm 0.05$

^{222}Rn (101 keV)
^{218}Po (112 keV)
^{214}Po (146 keV)

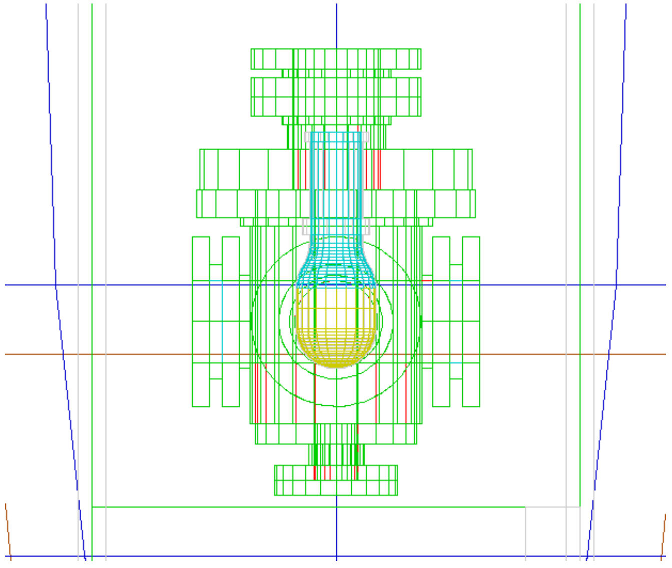


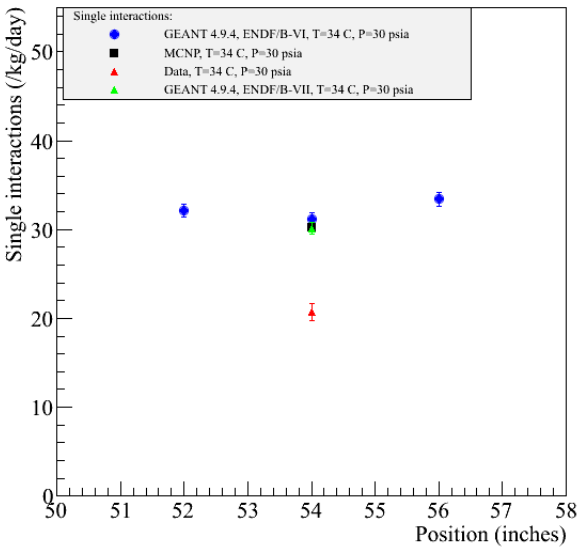


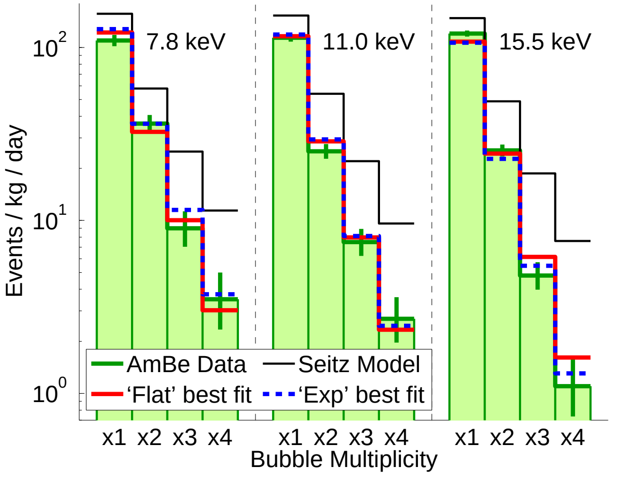
COUPP-4kg at SNOLAB: calibrations

GEANT and MCNP simulations

- Bubble rate is 50% higher
- Multiple bubbles rate also higher



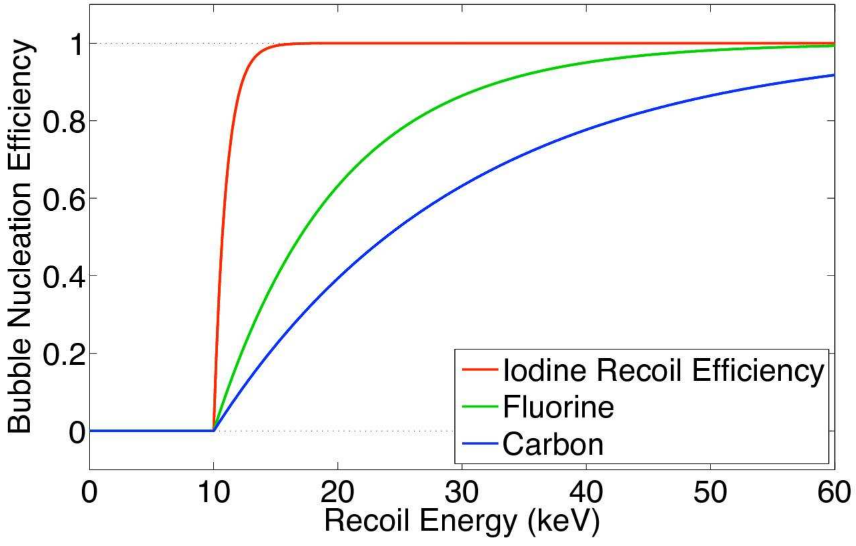


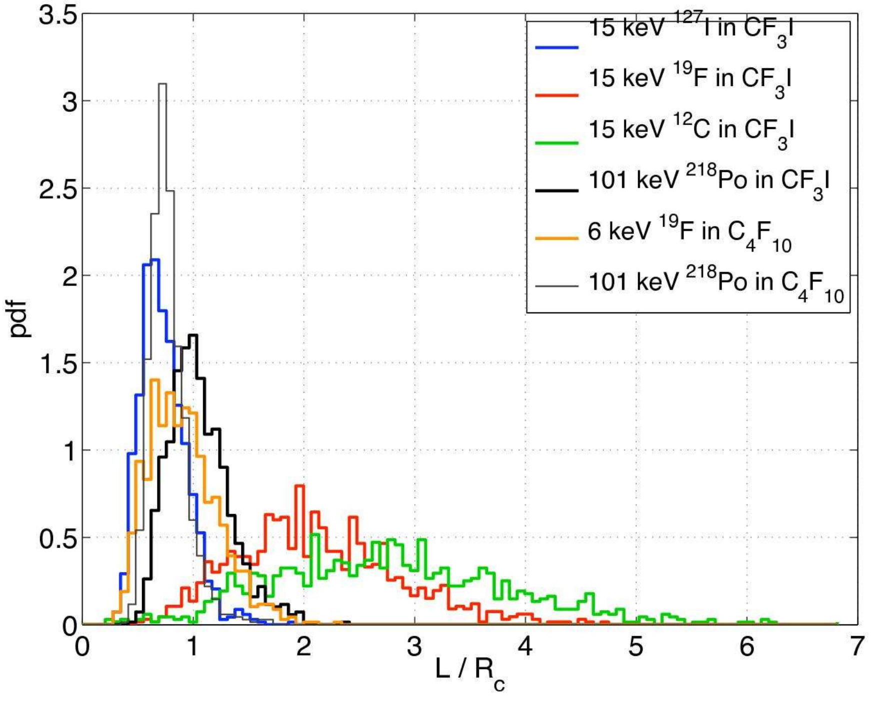


COUPP-4kg at SNOLAB: calibrations

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

SRIM → TRIM calculation





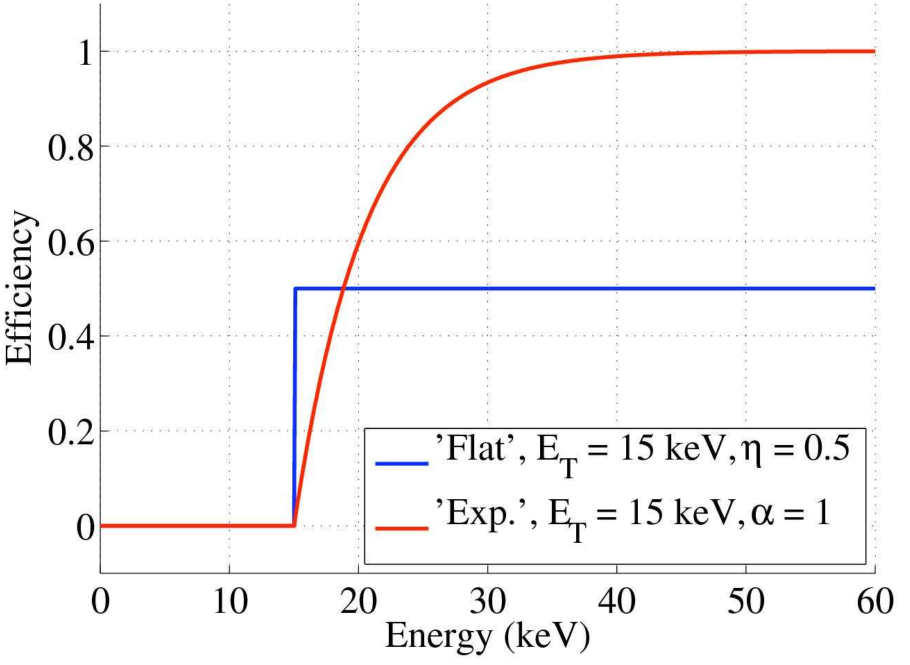
COUPP-4kg at SNOLAB: calibrations

Seitz model:

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

Understand efficiency for 15 keV recoils in CF_3I

Measurements have been performed



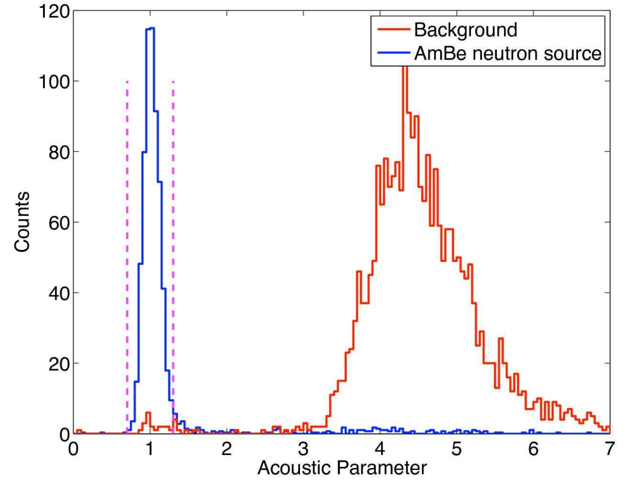
COUPP-4kg at SNOLAB: results

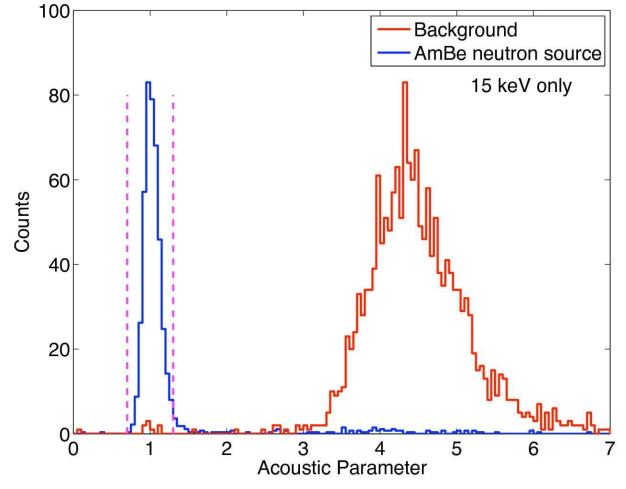
456 kg-days

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)



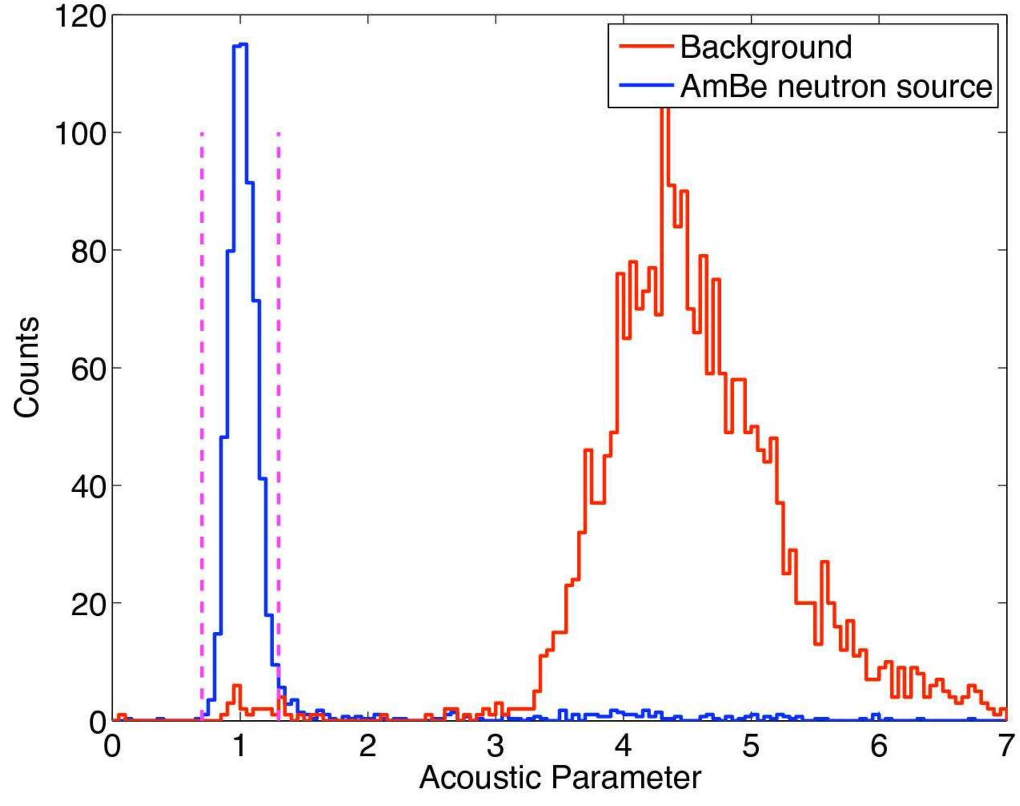


COUPP-4kg at SNOLAB: results

20 WIMP candidates

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

Neutrons from rock:
$< 1/\text{year}$



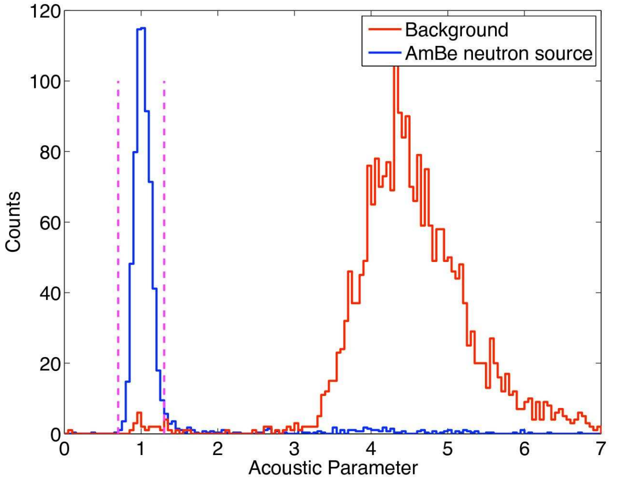
COUPP-4kg at SNOLAB: results

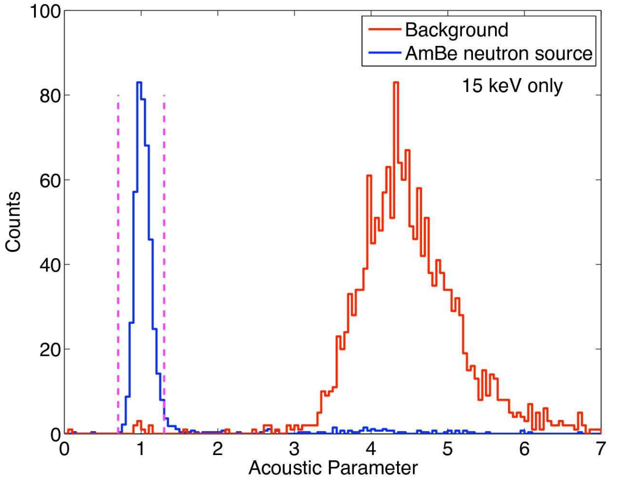
Some events with high AP

- 4 events at 8 keV
- 2 events at 10 keV

Clustered:
3 high-AP events
in one hour
at 8 keV

Significant fraction
correlated in time

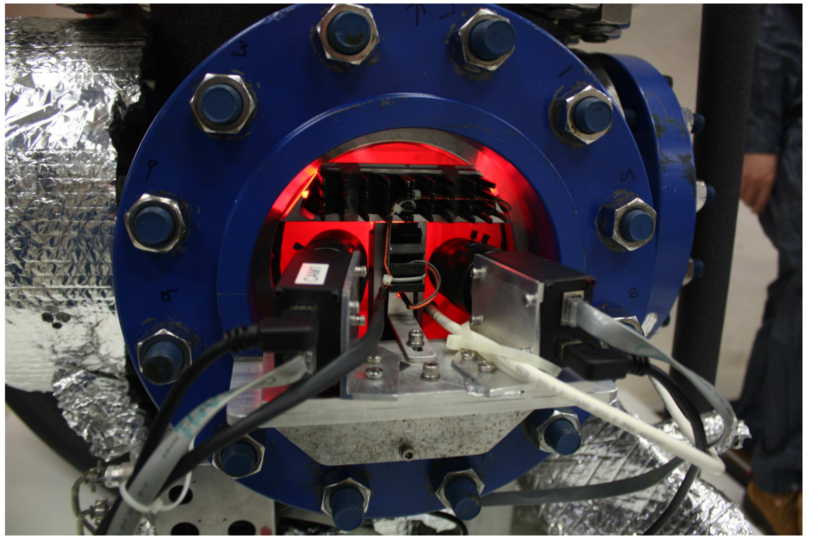


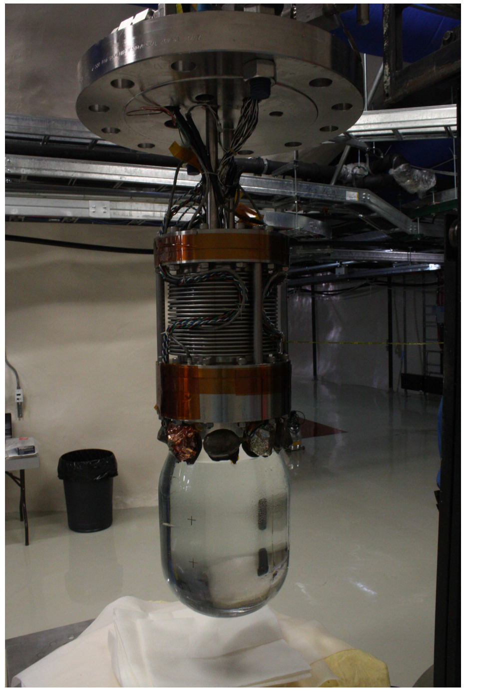


Internal neutron background

- 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

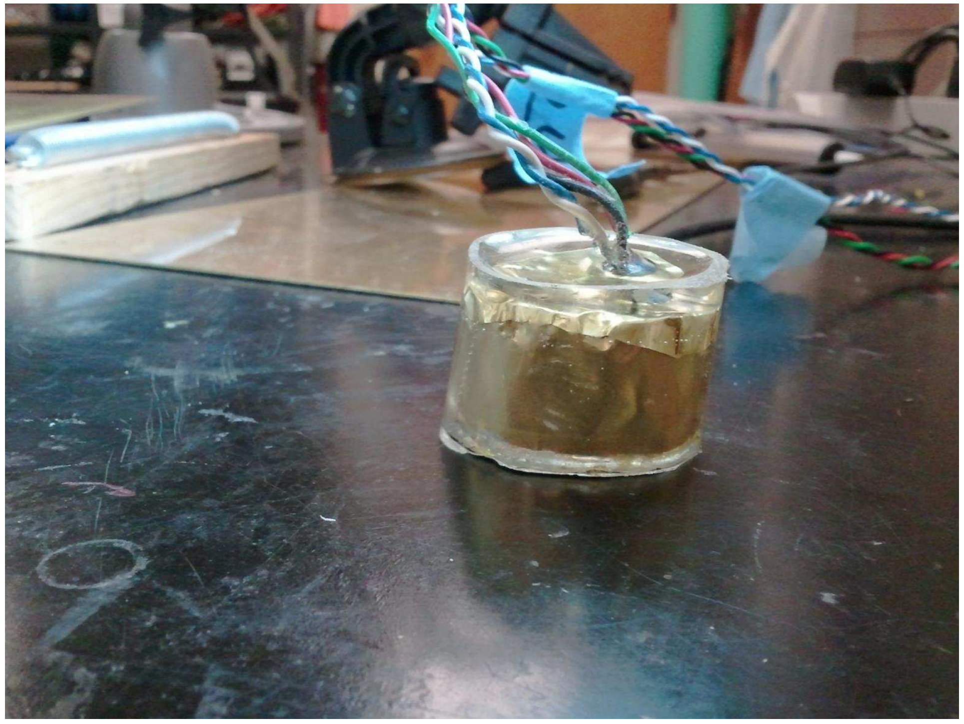


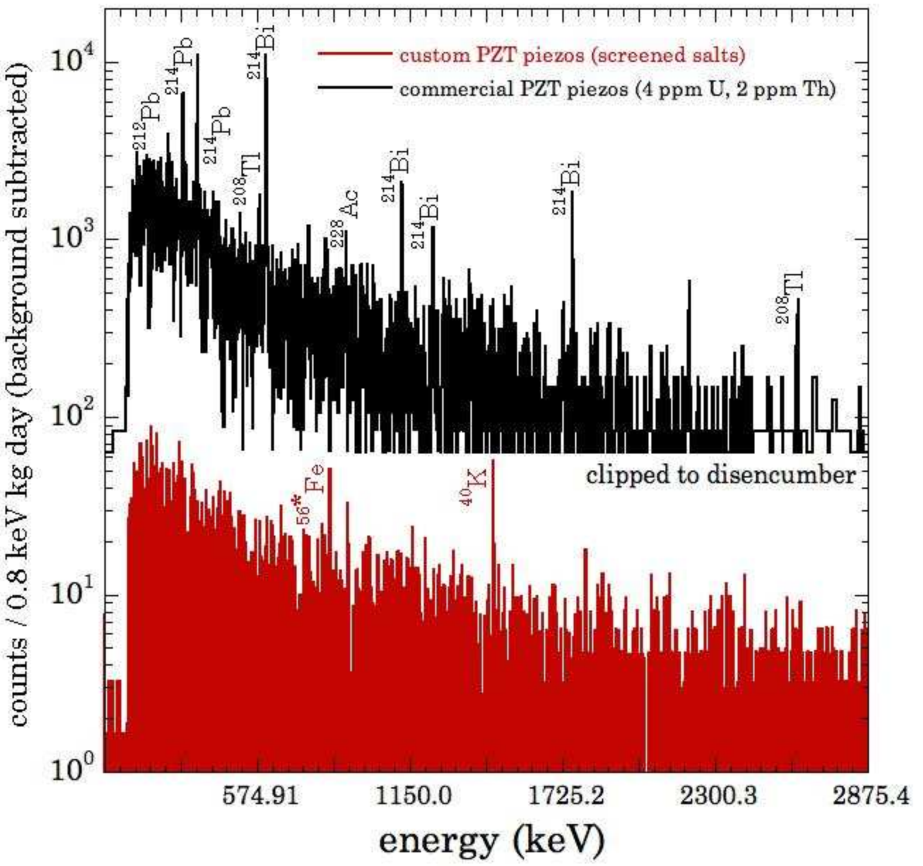


COUPP-4kg at SNOLAB: upgrades

New piezos built
(low background salts)

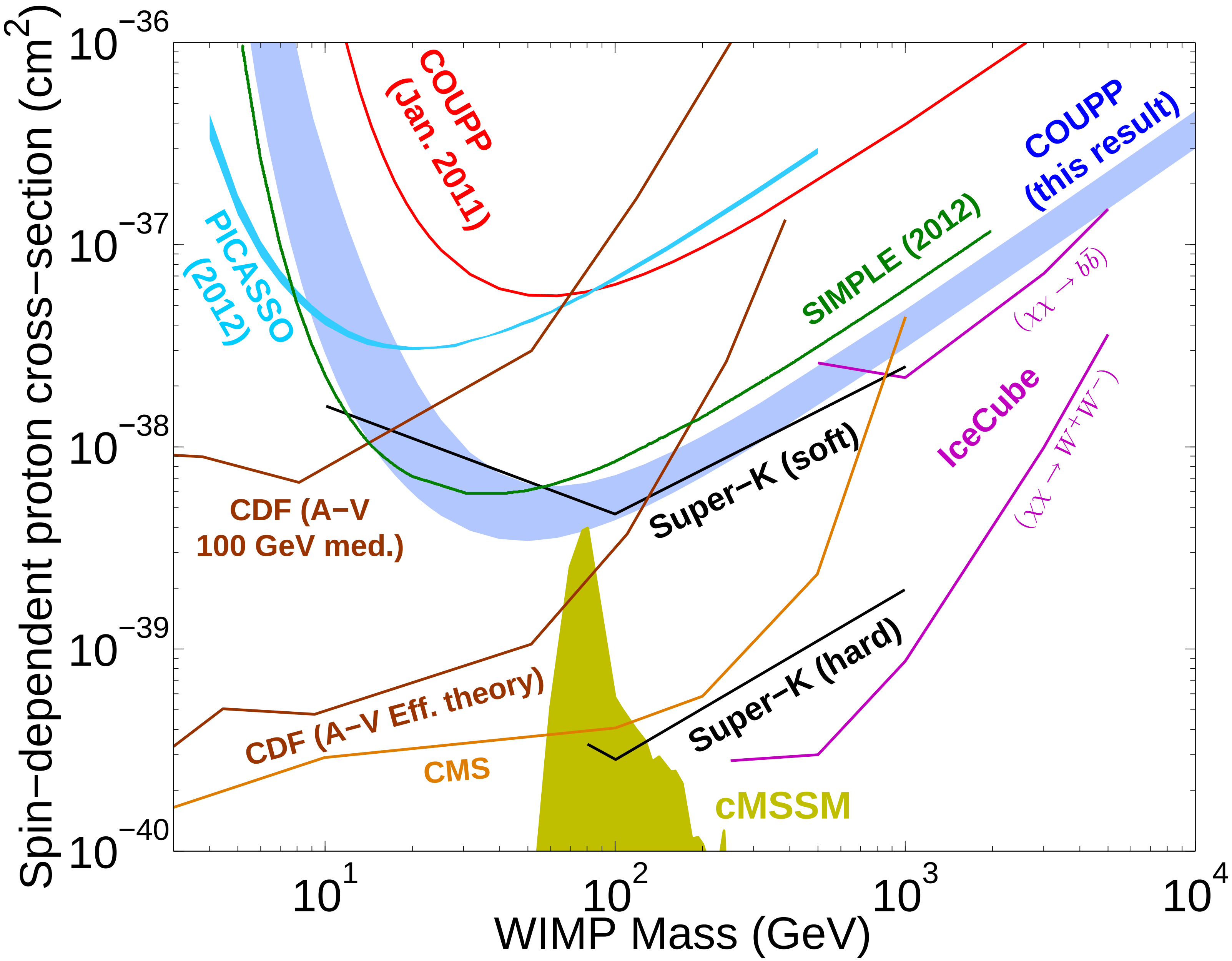
New view-ports
(synthetic silica)





Physics run restarted last month!

COUPP-4kg at SNOLAB: sensitivity



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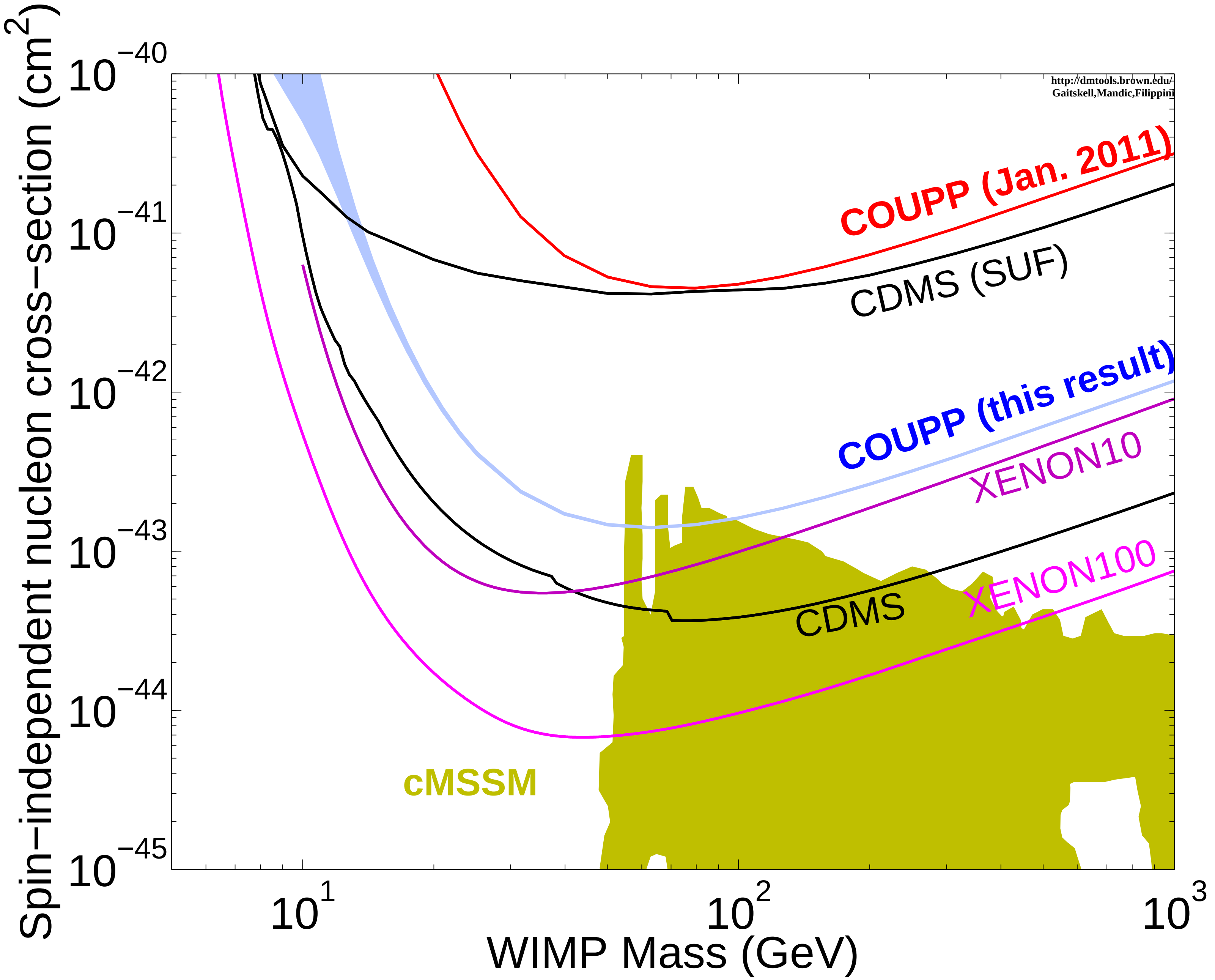
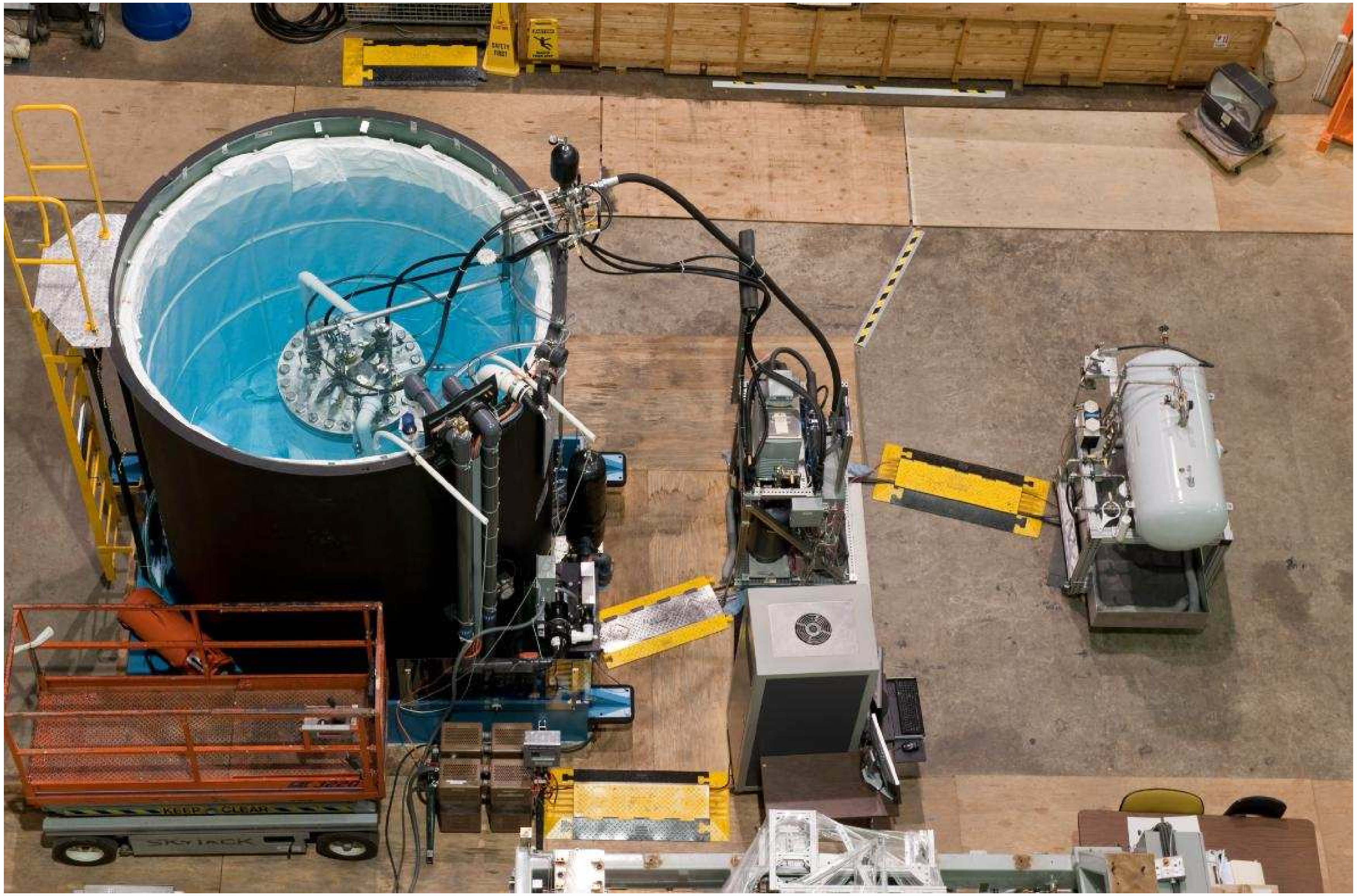
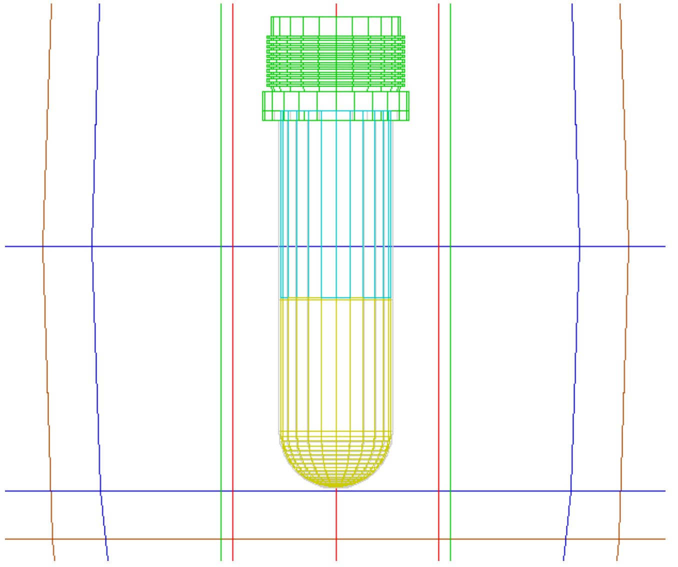


COUPP-60kg



COUPP-60kg

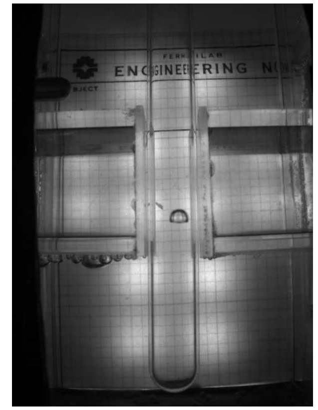
Engineering run at Fermilab: successful commissioning COUPP-60kg is moving to SNOLAB

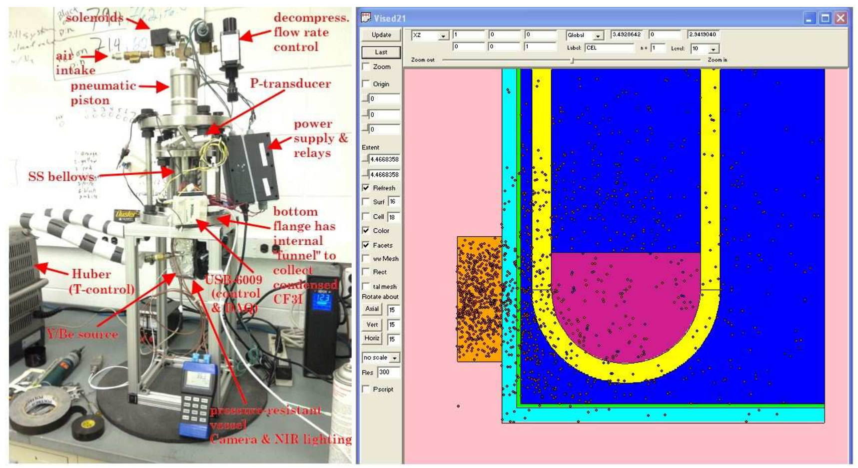


- Ready for physics run by the end of this year

Calibrations

- γ and neutron calibrations
  - AmBe and ^{252}Cf
  - ^{60}Co and ^{133}Ba
- 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

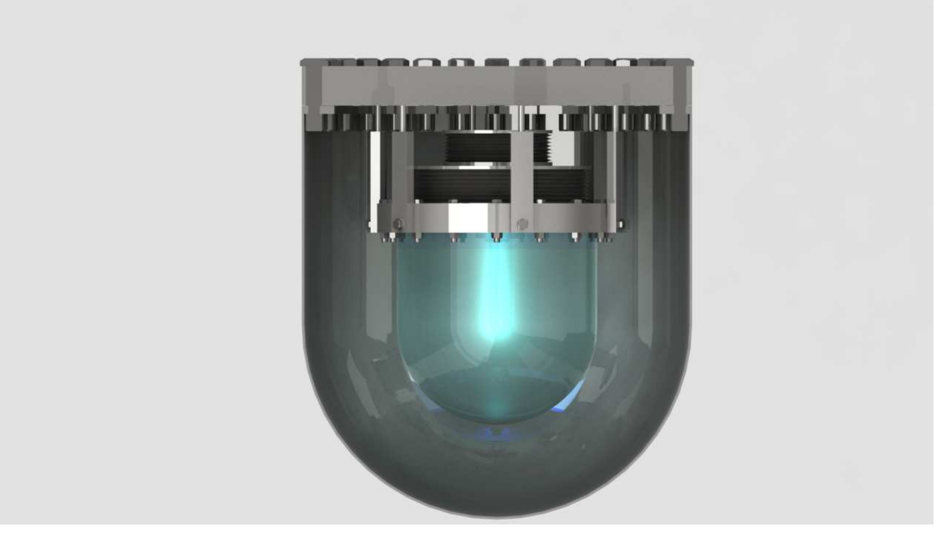




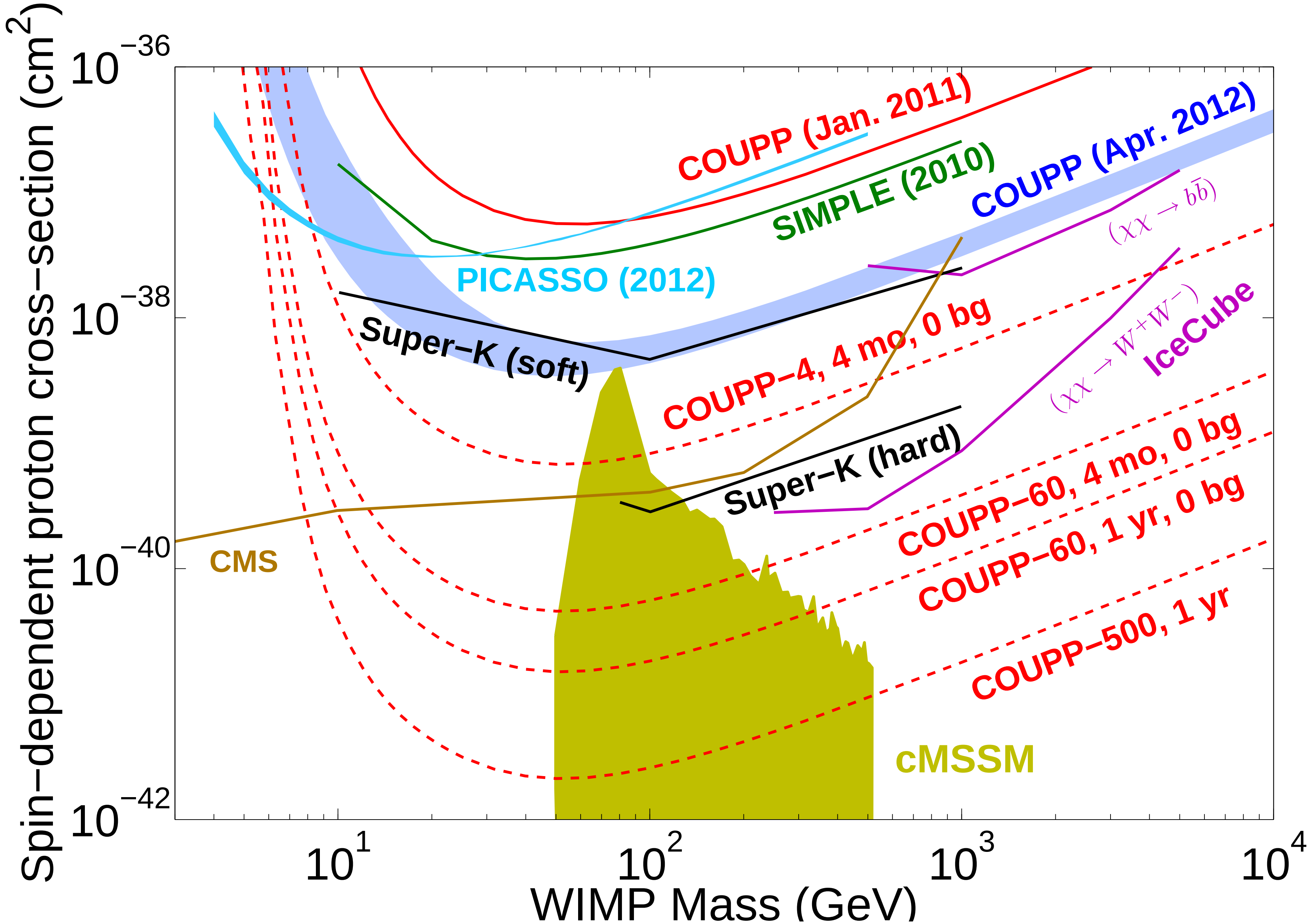
COUPP-500kg

- A tonne scale detector
- spin-independent sensitivity $9 \times 10^{-47} cm^2$, background-free year running
- Beyond next generation (G2) device
- <5M total cost
- Possible to use alternative fluids (C_4F_{10})

R&D phase



COUPP-60kg-500kg expected sensitivity at SNOLAB



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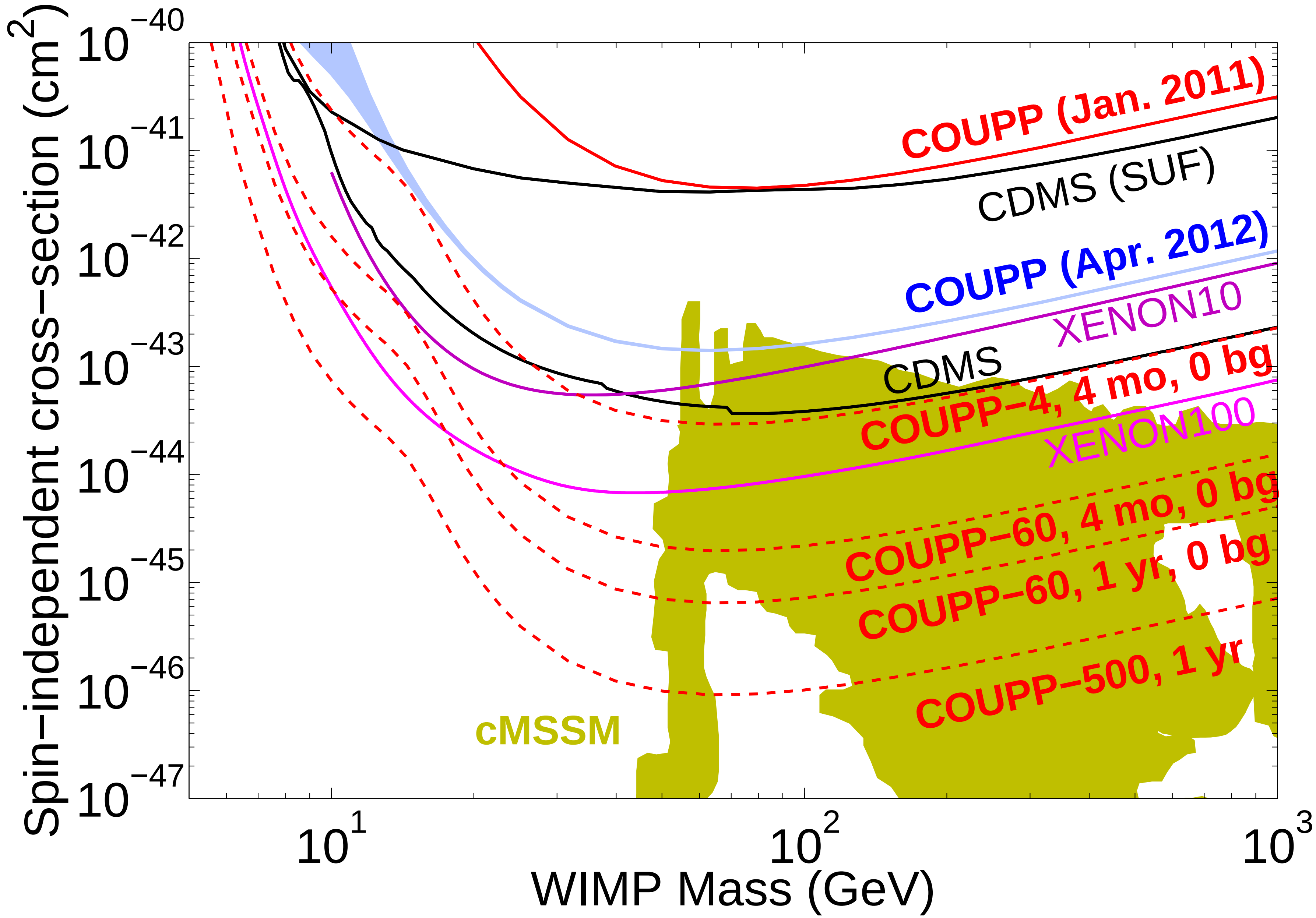

Conclusions

- **First physics run at SNOLAB completed for COUPP-4kg**
  - **Results submitted for publication**
  - **Spin-dependent competitive limit achieved**
  - **Excellent acoustic alpha rejection**
  - **Upgraded detector running**

- **COUPP family of detectors making huge improvements**
  - **COUPP-60kg getting to SNOLAB, Physics run by the end of the year**
  - **Calibrations, calibrations and calibrations: CIRTE, ^{88}Y/Be, ...**
  - **COUPP-500kg is coming fast**

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Stay tuned for more bubbles!