COUPP: Bubble Chambers for Dark Matter Detection

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SNOLAB

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COUPP Collaboration

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COUPP bubble chambers

- Target material: superheated $CF_3I$
  spin-dependent/independent ($C_3F_8$, $C_4F_{10}$)

- 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 \( \sim 20 \text{ cm} \)
  3:1 single-multiple ratio
  in COUPP4

- WIMPs:
  Nuclear recoil
  mean free path > \( 10^{12} \text{ cm} \)
  1 bubble
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
COUPP4 features

- Energy: threshold detector
- Background suppression:
  - UG at SNOLAB
  - Water shielding
  - Clean materials
- Background discrimination:
  - Neutrons:
    - Multiples bubbles
    - Nuclear recoil, $l \sim 20 \text{ cm}$
  - $\alpha$: acoustic parameter
    - Nuclear recoil, $40 \mu\text{m}$ track
- Large target mass: getting there
COUPP4 at SNOLAB

• Installation in summer 2010
• First Physics run begins Nov. 3, 2010
  (second Physics run in 2012)
• Run settings (P=30.5 psia):
  – 17.4 days at 8 keV (39°C)
  – 21.9 days at 10 keV (36°C)
  – 97.3 days at 15 keV (33.5°C)
• 4.048 kg of CF$_3$I
• Calibrations:
  – Neutron calibration runs: AmBe and $^{252}$Cf
  – Continuous source of $^{222}$Rn
COUPP4 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 $82.5 \pm 1.9\%$
COUPP4 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
COUPP4 at SNOLAB: calibrations

Radon fraction = $0.95 \pm 0.05$

$^{222}\text{Rn}$ (101 keV), $^{218}\text{Po}$ (112 keV), $^{214}\text{Po}$ (146 keV)

GEANT and MCNP simulations

- Bubble rate is 50% higher

![Graphs and plots related to calibration results]
COUPP4 at SNOLAB: calibrations

- 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, $CF_3I$

Understand efficiency for 15 keV recoils in $CF_3I$

SRIM $\rightarrow$ TRIM calculation
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% $\alpha$ 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

(Netrions from rock: < 1/year)
COUPP4 at SNOLAB: results

Internal neutron background

- **View-ports:**
  0.5 ppm $^{238}\text{U}$ and 0.8 ppm $^{232}\text{Th}$, ($\sim 5$ events)

- **Piezos:**
  4.0 ppm $^{238}\text{U}$, 1.9 ppm $^{232}\text{Th}$ and $^{210}\text{Pb}$, ($\sim 2$ 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

Hydraulics failed

- Replace more components
- ICP-MS assay

Piezos detached from IV

Refurbishing the detector

Different target material

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COUPP4 at SNOLAB: sensitivity
COUPP60 at SNOLAB

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COUPP60

Engineering run at Fermilab: successful commissioning
COUPP60 moved to SNOLAB

• Ready for physics run by the end of the month
Calibrations

• $\gamma$ and neutron calibrations
  - AmBe and $^{252}$Cf
  - $^{60}$Co and $^{133}$Ba

• COUPP Iodine Recoil Threshold Experiment
  - Low energy Iodine recoils
  - $\pi$ beam and silicon trackers

• $^{88}$Y/Be calibration chamber
  - Understand response to low energy recoils
  - Monochromatic low energy neutrons
**COUPP4-Lite**

- $C_3F_8$ as target material
- Spin-dependent sensitivity
- Low energy threshold
- New hydraulics
- New pressure vessel

*Physics run by mid 2013*
COUPP500

- $> 10^{10}$ $\gamma/\beta$ insensitivity
- $> 99.3\%$ acoustic $\alpha$ discrimination
- Multi-target capability
  SD- and SI-coupling
  High- and low-mass WIMPs
- Easily scalable, inexpensive to replicate
- Growing collaboration
  Newly merged with PICASSO

R&D phase
COUPP sensitivity plots

\[ WIMP \text{ mass} \ [\text{GeV/c}^2] \]

\[ SD \ WIMP-\text{proton cross section} \ [\text{cm}^2] \]

\[ SI \ WIMP-\text{nucleon cross section} \ [\text{cm}^2] \]

- PICASSO 2012
- COUPP 2012
- Super-K (soft)
- Super-K (hard)
- IceCube
- CMS (A-V)

- COUPP−500
- 250L C\(_3\)F\(_8\), 3 keV
- COUPP−4 Lite
- COUPP−500
- 250L C\(_3\)F\(_8\), 15 keV
- COUPP−60

- DAMA
- CRESST
- CDMS
- XENON10/100
- CoGent

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Conclusions

• Physics run at SNOLAB completed for COUPP4
  – Results published in 2012
  – Spin-dependent competitive limit achieved
  – Excellent acoustic alpha rejection: > 98.9%

• COUPP family of detectors making huge improvements
  – COUPP60 at SNOLAB:
    Physics run by the end of the month (with 38kg)
  – Calibrations, calibrations and calibrations:
    CIRTE, $^{88}$Y/Be, gamma, neutron, ...
  – COUPP4-Lite: $C_3F_8$, by mid this year
  – COUPP500 is coming fast
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Stay tuned for more bubbles!

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