Searching for dark matter with COUPP

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TIPP
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The COU PP Collaboration

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- **Indiana University South Bend**: Ed Behnke, Joshua Behnke, Tonya Benjamin, Austin Connor, Cale Harnish, Emily Grace Kuehnemund, Ilan Levine (PI), Timothy Moan, Thomas Nania
- **Fermilab**: Steve Brice, Dan Broemmelsiek, Peter Cooper, Mike Crisler, Jeter Hall, Martin Hu, Hugh Lippincott, Erik Ramberg, Andrew Sonnenschein, Fermilab Engineers and Technicians
- **SNOLAB**: Eric Vazquez Jauregui
- **Virginia Tech**: Shashank Priya
Dark matter

- We think dark matter exists
- We are looking for dark matter particles
How do we find it?

- WIMPs can scatter elastically with nuclei, and the recoil can be detected directly
  - The energy deposited by dark matter in an elastic collision is \(~10\text{-}100 \text{ keV}\)
  - Looking for a handful of events per year
How do we find it?

- WIMPs can scatter elastically with nuclei, and the recoil can be detected directly
  - The energy deposited by dark matter in an elastic collision is $\sim 10\text{-}100$ keV
  - Looking for a handful of events per year

Integrated rate above threshold, 100 GeV WIMP, $\sigma_0 = 10^{-45}$ cm$^2$
COUPP bubble chambers

- Superheated fluid, CF$_3$I or other
  - F for spin-dependent
  - I for spin-independent
  - Other - e.g. C$_3$F$_8$ for a light WIMP search

- Particle interactions nucleate bubbles
- Cameras see the bubbles
- Recompress the chamber to start over
Why bubble chambers?

- A lot of effort goes into discriminating electronic recoils produced by electrons and gamma rays from nuclear recoils produced by neutrons and WIMPs.

- Xenon S1/S2 discrimination.

- Charge and timing parameters in CDMS.
Why bubble chambers?

- A lot of effort goes into discriminating electronic recoils produced by electrons and gamma rays from nuclear recoils produced by neutrons and WIMPs

- Bubble nucleation depends on both total energy deposited and the density of energy deposition
  - Two thresholds for nucleation: $E$ and $dE/dx$

- By choosing superheat parameters (temperature and pressure), bubble chambers are blind to electronic recoils
Why bubble chambers?

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Why bubble chambers?

- Easy to identify multiple scatter events → Neutron backgrounds
- Relatively easy DAQ and analysis chain
  - Two cameras
  - Piezo acoustic sensors
  - Slow control
- No PMTs, no high voltage
Are there any drawbacks?

- Bubble chambers are threshold detectors - no energy resolution
  - Harder to distinguish backgrounds based on spectral information
    - Alpha backgrounds were big concern
  - Understanding energy threshold - calibrations are complicated and important
- Bubble chambers are slow - \( \sim \) 30 s of deadtime for every event
  - Must keep overall rate low
About those alphas...

  - Alphas deposit their energy over tens of microns
  - Nuclear recoils deposit theirs in tens of nanometers
- In COUPP bubble chambers, alphas are several times louder
The COUPP program

- COUPP-4: A 2-liter chamber - shallow site in 2009, at SNOLAB since September, 2010
- COUPP-60: A 30-liter chamber commissioning at Fermilab, goal is to move to SNOLAB within a year
COUPP-4 at Minos in 2009

- First demonstration of acoustic discrimination in COUPP bubble chamber

- AP - "Acoustic Parameter"
  - Measure of acoustic energy deposited in event

- nuclear recoil cut (88% acceptance)
- Untagged plus pre-veto
- Tagged nuclear recoils (sAmBe, NuMI, or cosmic)
- $^{222}\text{Rn}$ daughters ($\Delta t<3.1\text{min, days 5–20}$)
COUPP-4 at Minos in 2009

- 3 "WIMP" candidates
- Unvetoed 2 bubble event
- At least 74% alpha discrimination
COUPP-4 at Minos in 2009 (PRL, 106:021303, 2011)

* 3 months with zero background
COUPP-4 at Minos in 2009  
(PRL, 106:021303, 2011)
COUPP-4 at SNOLAB

➢ To SNOLAB at 6800 ft below
COUPP-4 at SNOLAB

- To SNOLAB at 6800 ft below
COUPP-4 at SNOLAB

- 17.4 live-days at 7 keV threshold
- 21.9 live-days at 10 keV threshold
- Physics run at 15 keV threshold since February 2, ending June 15
Improvements: the “dytran”

- A fast pressure transducer measures the pressure rise during bubble expansion
- The shape gives position information

A bulk event is quadratic
Improvements: the ”dytran”

- A fast pressure transducer measures the pressure rise during bubble expansion
- The shape gives position information

- A surface event turns over
Improvements: the "dytran"

- A fast pressure transducer measures the pressure rise during bubble expansion
- The shape gives position information

- A wall event blows up
Improvements: the "dytran"

- A fast pressure transducer measures the pressure rise during bubble expansion
- The shape gives position information
Improvements: AP

- Larger calibration data set
- Improved handle on frequency vs. position dependence
  - Events near the center $\rightarrow$ more power at high frequencies
  - Events near the walls $\rightarrow$ more power at low frequencies
Status through Jan 6, 2011

- Better separation
- More robust to bubble position

146 kg days to Jan 6, 2011
Status through Jan 6, 2011

- 750 alphas - 5.1/kg/day
  - > 80% from $^{222}$Rn and daughters
  - > 98% alpha rejection

146 kg days to Jan 6, 2011
Status through Jan 6, 2011

- Single bubble background of ~0.08 events/kg/day
- 2 three-bubble events in this dataset confirms neutron background

![Graph showing acoustic parameter counts and background](image-url)
Piezo-acoustic sensors made of lead zirconate titanate
  - Both fission and \((\alpha,n)\) neutrons

High pressure viewport also contributor
Evidence for 2nd source?

- Clusters of 3 and 5 events in 3 and 9 hours respectively
- Weighted to high end of AP distribution

Status through Jan 6, 2011

146 kg days to Jan 6, 2011
COUPP-4 at SNOLAB

- Current run ends in less than a week (June 15)
- First direct detection experiment limited by internal neutrons
  - A known neutron background that can be removed

* 3 months with zero background
** 1 year with zero background
COUPP-60 Update

- Commissioning at shallow site last summer and fall
- Achieved background goals
  - 2.2 alphas/kg/day, identified by acoustic signature
COUPP-60 Update

- Commissioning at shallow site last summer and fall
- Achieved background goals
  - 2.2 alphas/kg/day, identified by acoustic signature
- \( \sim 1 \) recoil-like event/kg/day - piezos are closer to the fluid
Fluid turned red due to the release of iodine
  - Photodissociation
  - Impurities
Recreated on test stand
Solutions to be tested on new commissioning run this month
  - Sodium sulfite in water to draw out iodine
  - Infrared illumination to limit photodissociation
COUPP-60 Update - Chemistry issues

- Surface boiling
  - Carbon dioxide discovered in post-run fluid analysis
  - New purification step using molecular sieve and SAES getter produces levels comparable to current, stable COUPP-4 run at SNOLAB
COUPP-60 Plans

- Second commissioning run beginning this month
  - Demonstrate stability of optics
  - Absence of surface boiling?
    - If not, still work to do on understanding chemistry

- Begin move to SNOLAB
  - Study of safety requirements
  - Replace high radioactivity components
  - Pack up and move
Other considerations

- Calibrations - we need a better understanding of our threshold and efficiency

- Comparing rate of single and multiple bubble events from a calibrated neutron source with MC simulation

  - Agreement with theory at high temperatures (44 C)
  - $\sim 50\%$ efficiency between 30 and 40 C
  - Can fit data with wide range of efficiency curves
  - What other calibrations can we do?
Other considerations

- Calibrations - we need a better understanding of our threshold and efficiency
- Test chamber at Argonne for neutron source studies
- Pion scattering at test beam at Fermilab
- Gamma-n reaction using High Intensity Gamma Source at North Carolina
Conclusions

- COUPP-4 producing strong results
  - Approaching the world leaders in spin independent sensitivity
  - Clear way forward on current limiting backgrounds
  - Potential to address light WIMP controversy with low threshold running
- COUPP-60 slowly getting to SNOLAB
  - Testing solutions for limiting problems
  - Moving to SNOLAB as soon as possible
- Calibration efforts ongoing
Conclusions

PRELIMINARY

Spin–independent nucleon cross-section (cm$^2$)

WIMP Mass (GeV)

COUPP (MINOS 2009)
COUPP (SUF)
COUPP (SNOLAB so far…)
XENON10
COUPP (4kg deep*)
CDMS
XENON100
COUPP (4kg deep)
COUPP (60kg deep**)

* 3 months with zero background
** 1 year with zero background