Dark matter and Mini-CLEAN

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CLEAN collaboration
Collaborating Institutes:

- Boston University: E. Kearns, D. Gastler
- Carleton University: K. Graham
- NIST, Boulder: K. Coakley
- University of North Carolina: R. Henning
- Queen's University: M. Boulay, A. Hallin
- SNOLAB: F. Duncan, I. Lawson, C. Jillings
- University of South Dakota: D. Mei
- University of Texas, Austin: J. Klein, S. Seibert, R. Hegde
CLEAN:

- Cryogenic
- Low Energy
- Astrophysics
- Noble Gases

A
A+
A*
A2+

2 excited molecular states: singlet and triplet

ionization
excitation

A2*

dissociation

A2

uV photon (77/128 nm)

collisions
recombination
Why Neon and Argon?

* Easy to purify; neon with charcoal, argon with a getter
* Transparent to own scintillation light
* Inexpensive
* Good pulse shape discrimination
* Can swap argon for neon to characterize backgrounds and test for WIMP signal without changing detector
CLEAN detectors:

- Pico-CLEAN: 100 ml test apparatus
  - measurements of scintillation efficiencies and demonstrate pulse shape discrimination
- Micro-CLEAN: 3 litre active volume R+D system
  - measurements of scintillation efficiencies and quantify pulse shape discrimination in argon
  - soon to switch to neon
- Mini-CLEAN: 100 litre active volume
  - will be installed underground as a dark matter detector
- CLEAN: 100 tonne
  - p-p solar neutrino and dark matter detector
Pico-CLEAN

2 x 75 mm PMTs

5 cm diameter inner volume

5 cm tall inner volume

Active volume fully coated with TPB

Photomultiplier tube

Wavelength shifter

Teflon tube

Liquid Neon

Glass window

Sapphire window

LNe in

Photomultiplier tube

LNe out
Electronic Recoil Calibration: 0.93 pe/keV (neon in pico-CLEAN)

- 511 keV Compton edge
- 1274 keV Compton edge
- 0.93 pe/keV

Counts vs. Electronic recoil signal (pe)
Nuclear Recoils:

\[ E_{\text{recoil}} = \frac{2E}{(1+A)^2} \left[ 1 + A - \cos^2(\theta) - \cos(\theta)\sqrt{A + \cos^2(\theta) - 1} \right] \]

Require:
- Delayed time of flight
- Minimal asymmetry between PMTs viewing cell
- PSD in organic scintillator

(neon in pico-CLEAN)
Nuclear Recoil Scintillation Efficiency:
(neon in pico-CLEAN)

Nuclear recoil scintillation efficiency of 0.26±0.11 at 291 keV
Example Traces:

- Nuclear Recoil
- Electronic Recoil

(neon in pico-CLEAN)
Time Dependence:

$F_{\text{prompt}} = \frac{\text{Signal (t<100ns)}}{\text{Total Signal}}$

(100 photoelectron events)

Electronic Recoils

Nuclear Recoils

(neon in pico-CLEAN)
Discrimination power: (neon in pico-CLEAN)

Electronic recoils rejection exceeds 1:1400 (>99.9%) for 100 pe events.
Micro-CLEAN Results

- 2 x 200 mm PMTs
- 20 cm diameter inner volume
- 10 cm tall inner volume
- Active volume fully coated with TPB
- Argon
Electronic Recoil Calibration: (argon in micro-CLEAN)

- $^{57}$Co -- 122 keV γ
- $^{22}$Na -- 511 keV γ

- 4.5 pe/keV
Nuclear Recoils:

\[ E_{\text{recoil}} = \frac{2E}{(1+A)^2} [1 + A - \cos^2(\theta) - \cos(\theta)\sqrt{A + \cos^2(\theta) - 1}] \]

Require:
- Delayed time of flight
- Minimal asymmetry between PMTs viewing cell
- PSD in organic scintillator

2.8 MeV argon in micro-CLEAN
Nuclear Recoils: (argon in micro-CLEAN)

Energy (keV)

Counts

0 20 40 60 80 100

Energy (keV)

Counts

0 20 40 60 80 100

Energy (keV)

Counts

0 20 40 60 80 100

Energy (keV)

Counts

0 10 20 30 40 50

238.6 keV

210.1 keV

86.2 keV

66.9 keV

44.5 keV

32.6 keV

27.7 keV

19.0 keV

14.5 keV

PRELIMINARY
Nuclear Recoil Scintillation Efficiency:

(argon in micro-CLEAN)

LAr (Mini-CLEAN collaboration, Summer 2006)
LXe (Aprile et al., Phys. Rev. D 72, 072006 (2005).)
Example Trace: (argon in micro-CLEAN)
Time Dependence:

280 photoelectron events

Electronic Recoils

Nuclear Recoils

\[ F_{\text{prompt}} = \frac{\text{Signal (t<100ns)}}{\text{Total Signal}} \]

(argon in micro-CLEAN)
Discrimination power:

Nuclear Recoils

Electronic Recoils
Discrimination power: 

(argon in micro-CLEAN)

15-18 keVee events (54-64 keVr)

Electronic recoil acceptance: $1.4 \times 10^5$ (99.999% rejection)

Projected:
- $1 \times 10^{-4}$ at 2pe/keV
- $6 \times 10^{-8}$ at 4pe/keV
- $3 \times 10^{-11}$ at 6pe/keV
Discrimination power: (argon in micro-CLEAN)

Electronic Recoil Acceptance vs. Energy (keVr)

2 pe/keV
4 pe/keV
6 pe/keV
Micro-CLEAN Data (4 pe/keV)
Estimated Micro-CLEAN Background

Solid lines indicate projected level assuming 50% NR acceptance

99%
99.9%

desired level for Mini-CLEAN

PRELIMINARY
Mini-CLEAN

32 x 200 mm PMTs

54 cm diameter inner volume

Designed WIMP cross section limit: \(10^{-45} \text{ cm}^2\) for 1 year
BG free
Position reconstruction:

(K. Coakley)

(Mini-CLEAN)
### Background Study: (Mini-CLEAN)

<table>
<thead>
<tr>
<th>Component</th>
<th>Material</th>
<th>U/Th</th>
<th>Yield (n / yr)</th>
<th>Yield in Target (n / kg /yr)</th>
<th>Yield in ROI (n / kg /yr)</th>
<th>Yield in ROI* (n / kg /yr)</th>
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</thead>
<tbody>
<tr>
<td>Fiducial Sphere</td>
<td>15 kg Quartz</td>
<td>3 ppb</td>
<td>19.1</td>
<td>0.090</td>
<td>0.029</td>
<td>0.004</td>
</tr>
<tr>
<td></td>
<td>5 kg SS</td>
<td>3 ppb</td>
<td>4.0</td>
<td>0.009</td>
<td>0.003</td>
<td>0.001</td>
</tr>
<tr>
<td>PMT Sphere</td>
<td>20 kg SiO$_2$</td>
<td>30 ppb</td>
<td>255</td>
<td>0.055</td>
<td>0.018</td>
<td>0.003</td>
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<td></td>
<td>4 kg B$_2$O$_3$</td>
<td>30 ppb</td>
<td>2295</td>
<td>0.495</td>
<td>0.162</td>
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<tr>
<td></td>
<td>85 kg SS</td>
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<td>Outer Cryostat</td>
<td>125 kg SS</td>
<td>3 ppb</td>
<td>101</td>
<td>0.033</td>
<td>0.013</td>
<td>0.002</td>
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<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>2743</strong></td>
<td><strong>0.706</strong></td>
<td><strong>0.235</strong></td>
<td><strong>0.034</strong></td>
</tr>
</tbody>
</table>

*Background Study: (Mini-CLEAN)*

D-M. Mei & A. Hime

PRELIMINARY
Summary

* New pulse shape discrimination results in LAr (preliminary). Discrimination measurements currently limited by ambient neutron backgrounds in above-ground laboratory

* Preliminary new nuclear recoil scintillation efficiency results for argon

* Will be filling micro-CLEAN with neon soon

* Currently commissioning Mini-CLEAN
PMT Testing

Single photo-electron peaks at various temperatures
Gain Curves

![Graph showing gain curves for single photo-electron area vs. temperature](image)
Quantum Efficiency

![Graph showing the relationship between temperature (K) and relative quantum efficiency. The graph displays a trend where the relative quantum efficiency increases with increasing temperature.](image-url)
Neon Purification with Charcoal

Adsorption Constants onto Charcoal

Temperature (K)

Adsorption Coefficient (l/kg)

Argon
Hydrogen
Nitrogen
Krypton

50 100 150 200 250 300 350

1×10^18
1×10^15
1×10^12
1×10^9
1×10^6
1×10^3
1×10^0

50 100 150 200 250 300 350

Temperature (K)