The MiniCLEAN
Dark Matter Experiment

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Scintillation in Noble Liquids

Energy deposition in noble liquids produces short lived excited diatomic molecules in singlet and triplet states.
### Pulse Shape Analysis

<table>
<thead>
<tr>
<th></th>
<th>Singlet</th>
<th>Triplet</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>He</strong></td>
<td>~10ns</td>
<td>13 s</td>
</tr>
<tr>
<td><strong>Ne</strong></td>
<td>&lt;18.2 ns</td>
<td>14.9 μs</td>
</tr>
<tr>
<td><strong>Ar</strong></td>
<td>7 ns</td>
<td>1.60 μs</td>
</tr>
<tr>
<td><strong>Xe</strong></td>
<td>4.3 ns</td>
<td>22 ns</td>
</tr>
</tbody>
</table>

- **Electronic recoil**
- **Nuclear Recoil**

*Triplet state highly suppressed!*
Rejecting Electron-like Events

- Discriminate with ratio of prompt to total light
- Reject beta and gamma backgrounds with greater than $10^8$ efficiency
Single Phase Ar/Ne Detectors

Advantages:

- Target material is relatively inexpensive (and swappable in MiniCLEAN)
- No need for electric fields to drift charge.
- Simpler detector design
- Able to use a spherical geometry
- Does not require $^{39}$Ar-depleted argon for large detectors
- Neon is clean enough to use for pp solar neutrinos

Disadvantages:

- Lower $A^2$ reduces coherent scattering enhancement
- Self-shielding from external backgrounds worse than other materials
- Atmospheric argon contains $^{39}$Ar, a high rate beta decay isotope (1 Bq/kg)
The DEAP and CLEAN Family of Detectors

**DEAP-0:**
Initial R&D detector
- 7 kg LAr
- 2 warm PMTs
- At SNOLab 2008

**DEAP-1:**
- 7 kg LAr
- 2 warm PMTs
- At SNOLab 2008

**picoCLEAN:**
Initial R&D detector
- 4 kg LAr or LNe
- 2 cold PMTs
- surface tests at Yale

**microCLEAN:**
- 4 kg LAr or LNe
- 2 cold PMTs
- surface tests at Yale

**MiniCLEAN:**
- 500 kg LAr or LNe (150 kg fiducial mass)
- 92 cold PMTs
- At SNOLAB mid-2011

**DEAP-3600:**
- 3600 kg LAr (1000 kg fiducial mass)
- 266 warm PMTs
- At SNOLAB 2012

**50-tonne LNe/LAr Detector:**
- pp-solar ν, supernova ν, dark matter <10^{-46} cm^2
- At DUSEL ~2016?
MiniCLEAN Goals

- **Demonstrate** the technical features of a $4\pi$ single-phase detector using both liquid argon and neon.

- **Characterize** detector response to produce signal and background distributions using combination of calibration and Monte Carlo. Leverage this knowledge in our analysis.

- **Perform** a WIMP dark matter search competitive and complementary to next generation experiments with $O(100 \text{ kg})$ fiducial mass.

- **Develop** the experience and verified simulation tools to design a 50 ton CLEAN experiment.
A Less Simple View

Outer Vessel

Inner Vessel

LAr/LNe

92 PMTs

TPB @ R=43 cm

PMTs @ R=81 cm

Courtesy J. Griego
Optical Cassettes

R5912-02-MOD:
14 dynodes
Pt photocathode underlayer

Courtesy J. Griego
Water Shielding

Outer Vessel

Inner Vessel

Water Shield Tank

Deck

Veto PMTs

Courtesy J. Griego
SNOLAB

Surface Facility

Underground Laboratory

2 km of rock (6000 mwe)

Sudbury, Ontario, Canada
Construction Progress:
Outer Vessel
Construction Progress: Inner Vessel

Courtesy F. Lopez
Construction Progress: Cube Hall

Insert MiniCLEAN here

Courtesy F. Duncan
MiniCLEAN WIMP Analysis

Perform a blind analysis with signal box in three reconstructed observables:

- Energy
- Radius
- Fprompt

Use calibration data, simulation, and systematic uncertainties to optimize the final box.
Energy

- A spherical $4\pi$ detector has very uniform energy response.
- We obtain the “electron equivalent” kinetic energy (keVee), as nuclear recoils have $\sim 25\%$ quenching factor.
- Nominal energy region of interest is 20-50 keVee.

Resolution @
20 keVee = 15%
Radius: Position Reconstruction

- No photon in MiniCLEAN can travel from event vertex to a PMT!
- We have developed a hybrid analytic/Monte Carlo based maximum likelihood position reconstruction called ShellFit.
- Includes all major optical effects.
ShellFit: Radial Bias

Average bias [fit - true radius] (mm)

20 keV electrons
ShellFit: Resolution (Cartesian)

Average X resolution (mm)

20 keV electrons

(True radius/439 mm)³
Fprompt

- Designed to be the simplest possible pulse shape discriminant.

- $F_{\text{prompt}} =$ Charge in prompt window (150 ns) divided by total charge. Ranges from 0 to 1.
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Backgrounds

Major:

- $^{39}$Ar: 1 Bq per kg of atmospheric argon
- PMT Neutrons
- Rn daughters on surfaces

Sub-dominant:

- External gammas from steel and rock
- External neutrons from rock and cosmic ray spallation
Mitigating Backgrounds

- $^{39}$Ar: Cut with Fprompt
- PMT Neutrons: Low activity glass, pull PMTs back from fiducial volume, acrylic shielding, position reconstruction, timing distribution
- Rn daughters on surfaces: Modular design to assemble cassettes in gloveboxes, position reconstruction
- External gammas from steel and rock: Low activity steel, water shield, cut with Fprompt
- External neutrons from rock and cosmic ray spallation: Water shield, active cosmic ray veto.
Controlling Radon

- Goal of 1 decay per m$^2$ per day on the TPB surface.
- Creating a model of Rn deposition to understand how to achieve this goal during assembly.
Neutron Cross-Sections

- Modeling of neutrons is important for detector design and optimization.
- Carefully studying GEANT4 neutron simulations in argon/neon and making new measurements.

Selected Neutron Inelastic Cross Sections on $^{40}$Ar

### Conclusions
- Optical model has been shown to work very well for medium mass and heavy nuclei (Hodgson, *Nuclear Reactions and Nuclear Structure*).
- Depends strongly on (N-Z)/A.
- Na-22 approximates Ne-20 for now.

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**Graphs:**
- Neutron cross-sections for $^{20}$Ne and $^{22}$Na.
- Comparison of simulation and experimental data.

**Figures:**
- Graphs showing cross-sections vs energy and angle.
- Data from Na-22 (NNDC) and Ne-20.

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**References:**
- K.J. Palladino
- S. MacMullin, et al.
Calibration

Developing a calibration plan to understand detector response and model it in our Monte Carlo

Sources:

- $^{39}$Ar (natural and spike)
- $^{57}$Co
- $^{22}$Na
- AmBe
- $^{83}$Kr$^m$
- d-d neutron generator
- Light injection (visible and UV)
WIMP Sensitivity

![Graph showing WIMP sensitivity with different lines representing various experiments such as XENON10 (2007), CDMS (2008), MiniCLEAN, LUX, CLEAN, Ne, CLEAN, natural Ar, and CLEAN, depleted Ar.](image)

Events / 10 kg / yr
Events / 100 kg / yr
Events / 1000 kg / yr
Schedule

- **September 2010**: Underground infrastructure completed

- **Winter 2010**: Outer vessel in shield tank on stand

- **May 2011**: Inner vessel fabrication completed

- **Summer 2011**: Cassette assembly and installation into inner vessel

- **Fall 2011**: Detector commissioning and initial calibrations

- **Winter 2011**: Liquid argon dark matter run begins (projected lifetime: 2 years, followed by neon run)
Conclusion

• Single phase noble liquid detectors offer a highly scalable option for dark matter and neutrino detection.

• MiniCLEAN extends the DEAP/CLEAN series of detectors to 150 kg fiducial volume with liquid argon and neon.

• Broad R&D program studying Ne/Ar scintillation, cold PMTs, TPB properties, radon deposition, acrylic optics, and neutron cross-sections on argon and neon.

• Will perform a dark matter search and also demonstrate the techniques to be used in a future 50 ton detector.

• Construction is underway, with detector commissioning scheduled for fall 2011.
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