DEAP-3600 Dark Matter Search at SNOLAB

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+ Close links with the MiniCLEAN collaboration
Outline

- WIMP dark matter search status
- Latest projections for simple SUSY models
- Liquid argon as a target
- DEAP-3600 detector
- Background mitigation
- Irreducible neutrino backgrounds
- Prospects for a multi-tonne single-phase LAr detector
- Summary
All dark matter so far...

A number of anomalous signals or controversial claims have been reported...

However, no clear generally accepted evidence yet

adapted from Adam Falkowski's figure:
http://resonaances.blogspot.com/2014/03/weekend-plot-all-of-dark-matter.html

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Current searches

- Unclear situation and significant tension at low energies
- Since recently, dominance of liquid noble gas detectors

Adapted from LUX Collaboration, PRL112,091303 (2014)
Latest experimental results favour \(~1\text{TeV}\) WIMPs (cMSSM and NUHM)

(includes LHC and the recent LUX limit)

\(\Rightarrow\) see talk by A. Williams (Tue afternoon, session B)

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Within reach for 1-tonne detectors

Adapted from L. Roszkowski, E.M Sessolo, A.J. Williams, arXiv:1405.4289v1
(includes LHC and the recent LUX limit)

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Other models...

- A fairly robust prediction, with a number of other *simple* models giving a preferred mass of ~few hundred GeV - ~1 TeV
  - ...
- A variety of other (*more complex*) models giving predictions at rather low ~1-10 GeV WIMP mass
- (And of course other dark matter candidates are there, too)
Well-separated singlet and triplet lifetimes in argon allow for good pulse-shape discrimination (PSD) of $\beta/\gamma$'s using only scintillation time information.

- **PSD to $10^{-8}$ demonstrated with DEAP-1**

- For DEAP-3600 projected to $10^{-10}$ at 15 keVee, sufficient to remove background from cosmogenic $^{39}$Ar.

- Very large target masses possible, since no absorption of UV scintillation photons in argon, and no e-drift requirements.

- **1000 kg** argon target allows $10^{-46}$ cm$^2$ sensitivity (SI) with ~15 keVee (60 keVr) threshold, 3-year run.
Pulse shape discrimination (PSD)

Ar singlet and triplet excited states have well separated lifetimes (7ns vs. 1.5us)

Electric signal from PMT: Photoelectron counting:

\[
FP_{\text{prompt}} = \frac{N_{\text{prompt}}}{N_{\text{prompt}} + N_{\text{Late}}}
\]

Neutron (AmBe)

\(\gamma^{(22\text{Na})}\)

Prompt: 0-150ns
Late: 150ns-10\(\mu\)s

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Xe and Ar for direct WIMP scattering

- Potential for very large and very sensitive searches
- Complementary
- For high WIMP masses Ar is very competitive with Xe

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DEAP-3600 detector

3600 kg argon target (1000 kg fiducial) in sealed ultraclean Acrylic Vessel

Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction

255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)

50 cm light guides + PE shielding provide neutron moderation

Detector immersed in 8 m water shield, instrumented with PMTs to veto muons

Located 2 km underground at SNOLAB

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SNOLAB Subury Ontario Canada

**Running:** HALO
- Const: DEAP-3600
- MiniCLEAN

**Const:** COUPP-60

**HALO Stub**

**Cube Hall**

**Cryopit**

**Running:** DAMIC

**J-Drift**

**Running:** PICASSO

**201..?: CDMS-TE**

**Paused:** DEAP-1

**South Drift**

**SNO Cavern**

**Personnel facilities**

**Const:** SNO+
# Backgrounds budget

<table>
<thead>
<tr>
<th>Background</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radon in argon</td>
<td>&lt; 1.4 nBq/kg</td>
</tr>
<tr>
<td>Surface α’s (tolerance using conservative pos. resolution)</td>
<td>&lt; 0.2 μBq/m²</td>
</tr>
<tr>
<td>Surface α’s (tolerance using ML position resolution)</td>
<td>&lt; 100 μBq/m²</td>
</tr>
<tr>
<td>Neutrons (all sources, in fiducial volume)</td>
<td>&lt; 2 pBq/kg</td>
</tr>
<tr>
<td>Bg events, dominated by 39Ar</td>
<td>&lt; 2 pBq/kg</td>
</tr>
<tr>
<td><strong>Total Backgrounds</strong></td>
<td><strong>&lt; 0.6 events</strong></td>
</tr>
<tr>
<td><em>(3 Tonne-year in fiducial volume and Region of Interest)</em></td>
<td></td>
</tr>
</tbody>
</table>

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Background mitigation

- **b/g events**: dominated by $^{39}$Ar rate, 1 Bq/kg
  PSD is very powerful in liquid argon, distinguish from recoils

- **neutron recoils**: $(\alpha,n)$+fission, $\mu$-induced
  NO neutrons! SNOLAB depth, clean detector materials
  (strict material screening & assay, quality assurance / co-operation with suppliers), shielding

- **surface events**: Rn daughters and other surface contamination
  Clean surfaces in-situ, position reconstruction, limited exposure to radon
PSD with DEAP-1

- PSD of $\sim 10^{-10}$ required to beat down backgrounds from $^{39}$Ar (a beta emitter).

-Measured with a tagged gamma source using DEAP-1 at SNOLAB.

P.-A. Amaudruz et al., submitted to Astroparticle Physics
Surface backgrounds

High energy spectrum, fitted with Radon daughters

Low energy spectrum in ROI

Low energy cut off + improved PSD => NO α background in WIMP window

Detailed surface background model, suggested a 'conventional' explanation to the excess of events seen by CRESST-II, see:
Construction highlights: acrylic vessel

RPT Colorado

University of Alberta, Edmonton
Underground bonding
Vacuum testing the steel sheel

Bonding lightguides to the acrylic vessel

Completed acrylic vessel – lightguide assembly
Reflector & PMT installation
Picture taken from the inside of the detector after the reflector and PMT installation

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Time scale

- Some delay with respect to the plot: ~6 months
- Next installation steps:
  - Resurfacing
  - Wavelength shifter deposition
  - Cooldown
- Commissioning starts then
- Competitive limits after ~2 months of data taking

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Single phase Ar limited by coherent scattering of atmospheric neutrinos

Superior PSD in Ar allows to get rid of contribution from elastic scattering of pp neutrinos on electrons.

Adapted from L.E. Strigari, New J. Phys. 11 (2009) 105011

- Our current focus on DEAP-3600
- But already starting to think about a competitive next generation detector
- Very attractive possibility for a precision mass measurement

(if a signal at $\sim 10^{-46}$ cm$^2$ is seen)
WIMP mass sensitivity

- Technology can be scaled to very large target masses, > 100 tonnes or $10^{-48} \text{ cm}^2$ sensitivity
- Larger detector allows for better position reconstruction, which makes surface contamination easier to mitigate
- Relaxed targets on surface contamination significantly simplify many aspects of construction and assembly (compared to DEAP-3600)
- Large detector will require Depleted Argon

Chosen parameters:
- 44’ diam. water tank
- 24’ diam. Steel Shells
- 4400 8” HQE PMTs
- 12” acrylic shielding panels
- 17’ diam. 2” thick acrylic
- vessel with flanged lid
- 150 tonnes argon in AV (50 tonnes fiducial)

- Modest R&D underway
Within reach for 1-tonne detectors

Large detector can conclusively probe the allowed CMSSM parameter space and most of the NUHM allowed parameter space.

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Summary

- ~1 TeV WIMPs favoured by the simplest and most widely considered models (cMSSM and NUHM). Within reach for the upcoming round of direct detection experiments.

- DEAP-3600 construction is nearly complete.

- Detector online later this year, with competitive sensitivity for WIMP masses >150 GeV.

- We have demonstrated sufficient control over surface backgrounds and excellent PSD in DEAP-1.

- Some conceptual effort on the next generation detector.

- In the single-phase technology, larger scale makes life much easier.

- Attractive way towards a precision WIMP mass measurement (if a WIMP signal is seen by 1 tonne scale experiments). Single-phase LAr is ideally suited for this purpose.

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Stay tuned!
Backup
CMSSM parameter space

CMSSM, $\mu > 0$
Posterior pdf
Log Priors

inner contour: $1\sigma$
outer contour: $2\sigma$
dashed: KRS (2013)

ATLAS ($20 \text{ fb}^{-1} \sqrt{s} 8 \text{ TeV}$)

CMSSM, $\mu < 0$
Posterior pdf
Log Priors

inner contour: $1\sigma$
outer contour: $2\sigma$

ATLAS ($20 \text{ fb}^{-1} \sqrt{s} 8 \text{ TeV}$)

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DEAP-1: Good understanding of surface backgrounds

- Find $^{214}\text{Po}$ “sticks” to wall

**$^{222}\text{Rn}$**
- 3.83 d
- 5480 keV
- 3.05 m

**$^{218}\text{Po}$**
- $\alpha$
- 6002.4 keV
- 26.8 m

$^{222}\text{Rn}$:
- 120 µBq in DEAP-1

Compare for example:
- 360 µBq in EXO-200
  - [PRL 109 032505 (2012)]
Non-trivial effects due to surface roughness

- Coupled with surface contamination it can lead to tails at low energies
- It is impossible to account for surface roughness using simple tools such as SRIM
- Can be properly simulated using Geant4 with one of its common extensions:
  => physics list from example “TestEm7” in the standard distribution

- Possible explanation of the CRESST-II event excess at low energies


Geant4 + realistic surface + TestEm7