DEAP-3600 Dark Matter Experiment

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For the DEAP-3600 collaboration

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DEAP-3600

- Single phase liquid argon (LAr) dark matter detector
- Located in Vale’s Creighton mine at Sudbury, ON, Canada
- 2070 m underground
The best-fit WIMP parameters in the cMSSM and NUHM models are within sensitivity of the upcoming class of experiments (DEAP-3600 and XENON1T), while possibly evading detection at the LHC, even for the future 14 TeV run because of the very high allowed superparticle masses. A number of more general models, e.g. p9MSSM, lead to similar conclusions, although the best-fit parameters can vary.

2. The DEAP-3600 detector

DEAP-3600, located at SNOLAB, will perform a dark matter particle search on liquid argon with sensitivity to the spin-independent WIMP-nucleon cross-section of $10^{-46} \text{cm}^2$, a factor of approximately 20 increase over current experiments, as shown in Fig. 1.

![Figure 1: Dark matter sensitivity of liquid argon expressed as a limit on spin-independent WIMP-nucleon scattering cross-section. Shown are the current experimental limits from the CDMS-II, XENON100, and LUX detectors, and the expected sensitivity for 3 tonne-years of natural liquid argon with a 15 keV ee threshold, and with a 12 keV ee threshold for low-radioactivity argon (LRA) that has been depleted in $^{39}$Ar by a factor of 100.](image)

- **DEAP-3600**
  - 3600 kg LAr target (1000 kg fiducial volume)
  - Ultraclean Acrylic vessel (AV)
    - Resurfaced in-situ to remove Rn daughters after construction
  - Deposit TPB uniformly on AV surface before filling with LAr
  - 255 PMTs (8”)
  - Shielding against
    - Neutrons: Light guides and polyethylene filler blocks
    - Gammas and cosmic muons: 8 m diameter ultra pure water veto tank, instrumented with PMTs, surrounds the steel spherical shell

![Figure 2: The DEAP-3600 detector. The acrylic vessel has an inner radius of 85 cm and holds 3600 kg of liquid argon, which is viewed by 255 8-inch diameter high quantum efficiency Hamamatsu R5912-HQE PMTs through 50-cm long lightguides.](image)
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LAr as dark matter target

- WIMP signal: ionization from $^{40}\text{Ar}$ recoiling nucleus
- Projected light yield: 8 pe/keVee
- 128 nm light wavelength (shifted to 425 nm by TPB before detection by PMTs)
- Most sensitive to high mass WIMPs (60-120 keVr energy ROI)
- Ar singlet and triplet excited states have well-separated lifetimes (7ns versus 1.5 μs)

- Electronic and nuclear recoils produce different ratios of singlet and triplet states

**Excellent pulse shape discrimination (PSD)**

Single phase LAr: scintillation channel is sufficient no ionisation is needed
Background

• β/γ events: $^{39}$Ar
  - Rate: 1 Bq/kg
  - PSD reduces $^{39}$Ar by $>10^{-9}$

• Neutron recoils: $(\alpha, n)$ fission and μ-induced
  - Strict material screening and assay
  - Shielding

• Surface events: Rn daughters and other surface contamination
  - Sanded 200 μm off inner AV surface
  - Position reconstruction + fiducialization
  - Limited exposure to radon

<table>
<thead>
<tr>
<th>Background (in Fid Vol)</th>
<th>DEAP-3600 Goal</th>
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<tbody>
<tr>
<td>Radon in Ar</td>
<td>&lt; 1.4 nBq/kg</td>
</tr>
<tr>
<td>Surface α’s</td>
<td>&lt; 100 μBq/m$^2$</td>
</tr>
<tr>
<td>Neutrons (all sources)</td>
<td>&lt; 2 pBq/kg</td>
</tr>
<tr>
<td>Ar-39</td>
<td>&lt; 2 pBq/kg</td>
</tr>
<tr>
<td>Total (3 tonne-yr)</td>
<td>&lt; 0.6 events</td>
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such as supersymmetry (SUSY). The two leading SUSY models, the cMSSM and NUHM, fit all of the currently available data including indirect searches, Planck results, recent SUSY searches and the Higgs discovery at the LHC as well as dark matter exclusions from direct detection experiments, with the leading upper limit from LUX \[5\]. To accommodate the global data, these models predict relatively heavy WIMPs, with central values between a few hundred GeV and about 1 TeV \[6, 7, 8, 9\].

The best-fit WIMP parameters in the cMSSM and NUHM models are within sensitivity of the upcoming class of experiments (DEAP-3600 and XENON1T \[10\]), while possibly evading detection at the LHC, even for the future 14 TeV run because of the very high allowed superparticle masses. A number of more general models, e.g. p9MSSM \[11\], lead to similar conclusions, although the best-fit parameters can vary.

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- Order of magnitude increase in sensitivity over current results at 100 GeV
- 2 months to achieve current LUX sensitivity
- 1 year to exceed LUX projected full sensitivity
Construction milestones

- Summer 2014
- Fall 2013
- Fall 2014
- Winter 2015
Calibration systems

- $^{22}$Na ($\gamma$) and AmBe (n) sources and their deployment systems are fabricated (RHUL, RAL)

- The delivery of the sources are imminent and the deployment systems are already at site and integrated with DAQ
• External optical calibration system (Sussex) is installed

•Injecting light to 20 PMTs

•First data with 253/255 PMTs mid-March
Calibration systems

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- Injecting light to 20 PMTs
- First data with 253/255 PMTs mid-March

DEAP-3600 first commissioning data (Preliminary)
Next..

- TPB deployment
- Internal laserball calibration (Sussex, RHUL)
  - Complementary to the reflector and fibre optics system
- Cool down

LAr process system
Conclusion

• DEAP-3600 will be the first large scale single-phase LAr dark matter detector

• DEAP-3600 construction is almost complete

• Commissioning of the process systems, PMTs, electronics and external optical calibration has started
  - TPB deployment and LAr fill within the next few months

• Physics summer 2015!
DEAP-3600 collaboration

Carleton University
Queen’s University
Laurentian University
University of Alberta
TRIUMF
SNOLAB

Rutherford Appleton Laboratory
Royal Holloway University of London
University of Sussex
Back up
From Eq. (17) the expected discrimination is $10^{-12}$ for a dark matter particle search with natural argon. To achieve an analysis threshold of approximately 15 keV, a rate of decays of approximately 1 Bq per kg [9].

After assuming the detector is constructed of clean material, the dominance of recoil backgrounds has been mitigated, the dominant systematic uncertainties of the model are shown (gray shaded area). The red solid curve is the distribution modeled for an example set of parameters chosen to match the data, i.e. 9% more single photoelectrons.

The curve shows the expected backgrounds in the measurements from an individual contamination event, and analytic models with and without additional noise parameters for 120–240 photoelectrons. The dominant systematic uncertainties of the model are shown (gray shaded area). The blue dashed and dotted lines are the distribution for such a detector given by a statistical model.

The expected background limit could be achieved.

Figure 31 shows the 90% C.L. sensitivity versus WIMP mass for both natural and depleted argon cases, computed assuming a large target mass detector. We have obtained argon that has been sequestered underground and is depleted in the lighter isotopes.

Equation (19) is shown in Fig. 30 and is based on the following parameters:

- $P_{\text{prompt}}$: by varying mean $F_{\text{prompt}}$ the expected background limit could be achieved.
- $P_{\text{drift}}$: by varying mean $F_{\text{drift}}$ the expected background limit could be achieved.
Resurfacing AV

Placed the resurfacer in its deployment frame. Started preparing all the internal hosing for the inlet and outlet UPW and all electrical wiring. Resurfacer fully secured onto the deployment frame.

Deployment Frame

Sanding Arms

UPW Hoses

South Arm

North Arm