The DEAP Search for Dark Matter

SUSY 2016

5th July 2016

Dr Joseph Walding
Royal Holloway, University of London

On behalf of the DEAP-3600 Collaboration
Current Dark Matter Picture

• Dark matter proposed to explain astronomical observations

• Planck* measurement recently increased amount of dark matter in the Universe to 27%!

• Weakly interacting massive particles (WIMPs) are a leading candidate

• Require very low and well understood backgrounds

*arXiv:1303.5076 to be published in Astronomy and Astrophysics
What is DEAP-3600?

- Dark matter Experiment using Argon Pulse-shape discrimination

- DEAP-3600: Liquid Argon (LAr) detector
  - 3600 kg LAr, 1000 kg fiducial mass
  - SNOLAB – Sudbury, Ontario
  - 6800 feet underground = 6000 m.w.e
  - Single phase detector

- Single phase – No gaseous amplification region
  - No electron drift requirements
  - $4\pi$ PMT coverage
  
  ➔ Detector scalability to $O(\text{kTonne})$

- Why Argon?
  - Ar transparent to 128nm scintillation photons
    - Large fiducial masses
  - Well separated singlet and triplet state lifetimes
  - Easy to purify and inexpensive

---

1000 kg argon target & 3 year run allows $\sim 10^{-46} \, \text{cm}^2$ sensitivity (SI) with $\sim 15 \, \text{keVee} \ (60 \, \text{keVr})$ threshold (bkgd limit)
How does DEAP-3600 fit in?

- Will set a world's best spin independent measurement on a competitive timescale:
  - $10^{-46} \text{ cm}^2$ for 100 GeV WIMP mass (3 years)


DEAP-3600
Who are DEAP-3600?

- University of Alberta
- Carleton University
- Queens University
- SNOLAB/Laurentian
- SNOLAB
- TRIUMF
- Rutherford Appleton Laboratory
- Royal Holloway, University of London
- University of Sussex
- Instituto de Fisica, UNAM

65 collaborators
DEAP-3600 Detector

- LAr housed in sealed ultraclean acrylic vessel
- 255 8-inch Hamamatsu R5912 HQE PMTs
  - 32% QE, 75% coverage
- Acrylic vessel & light-guides provide PMT neutron shielding
- Tetraphenyl-butadiene (TPB) used as wavelength shifter (128nm to 430nm)
- Cosmic veto
  - SNOLAB (2km underground)
  - Detector submerged in 8m diameter water tank
DEAP-3600 Signal

- What do we see?
  - Ionisation from recoiling nucleus
- Ar singlet and triplet excited states have well separated lifetimes (7ns vs. 1.5us)
- Electronic and nuclear recoils produce different ratios of singlet and triplet states therefore...

Electronic recoil
DEAP-1 data

Nuclear recoil
DEAP-1 data
DEAP-3600 Signal

• What do we see?
  – Ionisation from recoiling nucleus

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

• Electronic and nuclear recoils produce different ratios of singlet and triplet states therefore...

• Pulse Shape Discrimination (PSD):
  – Separate electronic and nuclear recoils using timing
  – \( F_{\text{prompt}} = \frac{P_{\text{prompt}}}{P_{\text{total}}} \)
  – Prompt window: 200 ns

arXiv:0904.2930

DEAP-1 data

Na-22 gammas

AmBe neutrons

05/07/2016

SUSY 2016 - The DEAP-3600 Experiment
Dr. Joseph Walding
DEAP-3600 Backgrounds

• **β/γ events:**
  – Ar-39 dominant rate – 1 Bq/kg. Removal using PSD
  – Leakage scales with light yield

• **Neutron recoils:**
  – (α,n) - very strict material controls: achieved with ex-situ material assays
  – Muon induced – SNOLAB ~2km underground + active cosmic veto

• **Surface alphas:**
  – Rn daughters and other surface impurities.
  – Clean acrylic surface in-situ, fiducial volume cuts, limit radon

<table>
<thead>
<tr>
<th>Background (in Fid Vol)</th>
<th>DEAP-3600 Goal</th>
</tr>
</thead>
<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/m²</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>
</tr>
</tbody>
</table>

For $10^{-46}$ cm² sensitivity over 3 year exposure (1000 kg fiducial volume) requires < 0.6 background events
Can we build it...
...yes we can!
Commissioning/Calibrating DEAP

Extensive calibration program
• Begun in 2015 (once PMTs ramped up)

5 calibration handles
• Two optical systems:
  – Acrylic-Aluminium Reflector Fibre System (AARFs)
  – Laserball
• Two external sources:
  – 1 MBq tagged Na-22 source
  – 74 MBq tagged AmBe source
• And Ar-39!

<table>
<thead>
<tr>
<th>Detector state</th>
<th>Calibration Systems Used</th>
<th>Calibration Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-TPB (vacuum)</td>
<td>AARF</td>
<td>PMT calibration/monitoring</td>
</tr>
<tr>
<td>Post-TPB (vacuum)</td>
<td>AARF, Laserball</td>
<td>Timing, LG-PMT efficiencies, TPB deposition</td>
</tr>
<tr>
<td>Gaseous Ar (GAr)</td>
<td>AARF, AmBe, Na-22</td>
<td>Detector monitoring, Detector nuclear/gamma response</td>
</tr>
<tr>
<td>Partial Fill (LAr/ GAr)</td>
<td>AARF, AmBe, Na-22</td>
<td>As above</td>
</tr>
<tr>
<td>Full (LAr)</td>
<td>AARF, AmBe, Na-22</td>
<td>As above</td>
</tr>
</tbody>
</table>
Commissioning/Calibrating DEAP

Extensive calibration program
- Begun in 2015 (once PMTs ramped up)

5 calibration handles
- Two optical systems:
  - Acrylic-Aluminium Reflector Fibre System (AARFs)
  - Laserball
- Two external sources:
  - 1 MBq tagged Na-22 source
  - 74 MBq tagged AmBe source
- And Ar-39!

**Detector state** | **Calibration Systems Used** | **Calibration Goals**
--- | --- | ---
Pre-TPB (vacuum) | AARF | PMT calibration/monitoring
Post-TPB (vacuum) | AARF, Laserball | Timing, LG-PMT efficiencies, TPB deposition
Gaseous Ar (GAr) | AARF, AmBe, Na-22 | Detector monitoring, Detector nuclear/gamma response
Partial Fill (LAr/ GAr) | AARF, AmBe, Na-22 | As above
Full (LAr) | AARF, AmBe, Na-22 | As above
AARFs and Laserball

• AARFs:
  – Detector monitoring system
  – Monitor PMT efficiencies, SPE charges and detector timing*
  – 20 AARFs distributed about the detector
AARFs and Laserball

• Laserball:
  – One time deployment (post TPB deposition)
  – Ex-situ characterisation
  – Two wavelengths: 445nm and 375nm, three deployment positions (z = -55, 0, +55 cm)
  – Used to measure optical properties of acrylic light-guides and TPB
  – Determine absolute T₀ (channel timing offsets)
  – Used to set absolute calibration scale for AARFs
AARF and Laserball

• Low occupancy AARF data used to calibrate SPE charges for each PMT

• PMT efficiencies measured using AARF and laserball
  – Very good agreement for both systems
AARF and Laserball

- Channel-to-channel time offsets ($T_0$) extracted using
- Post calibration channel-to-channel jitter < 1 ns
- TPB non-uniformity, and detector optical characterisation using laserball and AARFs ongoing
Conclusions & Outlook

• Started data collection in detector commissioning phase in 2015
• Extensive calibration program, with lot’s of work ongoing
• Began cool-down on February 17th 2016
• Liquid fill began 1 month ago
• DEAP-3600 almost full, first physics run is about to begin!
A high energy event

Run: 9406
Subrun: 3  Event: 300460

Total energy: 1520 PE

High event rate: ~1 event/day
Expected muon rate: 1.6 muons/day

preliminary

Thank you, stay tuned!

High energy cosmic muon
Back up
External Source Calibration

- Only just begun external source calibration campaign
- Using AmBe GAr data to isolate nuclear single scatters
- First partial fill AmBe data taken last week, being used to help define ROI for first WIMP search
Commissioning and Calibration
Commissioning & Calibration

- High energy Cherenkov event rate
Calibrating DEAP

<table>
<thead>
<tr>
<th>Detector state</th>
<th>Calibration Systems Used</th>
<th>Calibration Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-TPB (vacuum)</td>
<td>AARF</td>
<td>PMT calibration/monitoring</td>
</tr>
<tr>
<td>Post-TPB (vacuum)</td>
<td>AARF, Laserball</td>
<td>Timing, LG-PMT efficiencies, TPB deposition</td>
</tr>
<tr>
<td>Gaseous Ar (GAr)</td>
<td>AARF, AmBe, Na-22</td>
<td>Detector monitoring, Detector nuclear/gamma response</td>
</tr>
<tr>
<td>Partial Fill (LAr/GAr)</td>
<td>AARF, AmBe, Na-22</td>
<td>As above</td>
</tr>
<tr>
<td>Full (LAr)</td>
<td>AARF, AmBe, Na-22</td>
<td>As above</td>
</tr>
</tbody>
</table>
Optical Calibration

- 3 systems:
  - LED fibre system
  - LED/Laser-ball
  - Neck laser

- PMT timing & gain calibration/monitoring
  - Fast rise time (1 clock tick = 4ns)
  - AV/light guide monitoring
  - Run during commissioning and physics run

First data from LED system
Gamma & Neutron Calibration

- Tagged Na-22 and AmBe-neutron sources
  - Na-22: Map detector with well understood gamma spectrum
    - Cal F loops around detector
  - AmBe: Populate detector with WIMP-like recoil events

Scintillator response to AmBe Gamma Spectrum

- Double-Escape Peak
- Single-Escape Peak
- Compton Edge

Energy (keV)

Counts
Neutron Calibration Ex-situ data

- Tagged 74 MBq AmBe source

\[ \text{Am}^{241} \rightarrow \text{Np}^{237*} + \alpha \]
\[ \alpha + \text{Be} \rightarrow \text{C}^{12*} + n \]
4.4MeV from C^{12*} de-excitation

- Two 5x4cm NaI crystals encapsulate source

- Simulation estimate: 100 hours to get 10,000 single neutron scatters in DEAP

- Expect \sim 20\% gammas (AmBe) to deposit \textgreater 500keV energy in NaI crystal

- Ex-situ measurement of efficiency in agreement with simulation

\[ \text{AmBe Spectrum (ex-situ data)} \]

\[ \text{Cs-137 Spectrum (ex-situ data)} \]
DEAP-1: 7kg LAr Prototype Detector
DEAP-1

- PSD ([Updated result of arXiv:0904.2930]):
  - $3 \times 10^{-8}$ suppression (stat. limited) of $\gamma$’s seen in DEAP-1
  - Light yield of $\sim 4$ PE/keV
  - Region of interest: 100 – 160 PE, $F_{\text{prompt}} > 0.7$

- Backgrounds ([arXiv:1211.0909]):
  - Principle backgrounds from Rn-222 from Uranium decay chain
    - 3.83 day lifetime
  - In region of interest measured to be $< 100 \, \mu\text{Bq/m}^2$

**DEAP-1 results used to project DEAP-3600 sensitivity**
How does DEAP-3600 fit in?

- Will set a worlds best spin independent measurement on a competitive timescale.

---

**WIMP Mass [GeV/c^2]**

**Cross-section [cm^2]**

---

**dmtools.brown.edu**

---

6 - The DEAP-3600 Experiment - Dr. Joseph Walding
Current Dark Matter Picture

- Dark matter proposed to explain astronomical observations
- Planck* measurement recent amount of dark matter in the
- Weakly interacting massive particles are a leading candidate
- Require very low and well understood backgrounds

*arXiv:1303.5076 to be published in Astronomy and Astrophysics