The DEAP Search For Dark Matter

49th Rencontres De Moriond: Cosmology

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28th March 2014
On Behalf of the DEAP-3600 Collaboration

Outline
• The DEAP Program
• Calibration Systems & first ex-situ data
• Construction Status
• Outlook
Collaboration

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

70 collaborators

Me
Yesterday morning at breakfast...

Me: *Hello*

Jack Steinberger: *Hello, are you QCD?*

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JS: Oh, so you know nothing then!
Me: *hangs head*
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

DATA listed top to bottom on plot
- DAMA region, 90% C.L., Hooper PRD 2010
- CRESST-II (Soudan Silicon SI Result, R125-128, contour 90% C.L.)
- 2-sigma Allowed Region part 1, 730kg-days data
- XENON10 2007, measured Left from Xe cube
- Edelweiss II Final result (March 25 2011)
- Xenon 100 (2011)
- LUX (2013) 90% U.L.

*arXiv:1303.5076
What is DEAP-3600?

- **Dark matter Experiment** using **Argon Pulse**-shaped 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 $\sim 10^{-46}$ cm$^2$ sensitivity (SI) with $\sim 15$ keVee ($60$ keVr) threshold (bkgd limit)
How does DEAP-3600 fit in?

- Will set a worlds best spin independent measurement on a competitive timescale:
  - $10^{-46}$ cm$^2$ for 100 GeV WIMP mass (3 years)
  - Current best limit: LUX 2013
  - 1 month to exceed Xe-100
  - 1 year to exceed LUX projected final sensitivity
DEAP-3600 Signal

• What do we see?
  – Ionisation from recoiling nucleus
  – 128nm light wavelength shifted before detection by photomultipliers

• 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...
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• 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
  – $F_{\text{prompt}} = \frac{PE_{\text{prompt}}}{PE_{\text{total}}}$
  – Prompt window: -50 ns $\Rightarrow$ 150 ns
DEAP-1: 7kg LAr Prototype Detector
DEAP-1

- PSD (*Updated result of arXiv:0904.2930*):
  - 3x10^-8 suppression (stat. limited) of γ’s seen in DEAP-1 (25 keVee)
  - light yield of ~4 PE/keV
  - Region of interest: 100 – 160 PE, Fprompt > 0.7

- Backgrounds (*arXiv:1211.0909*):
  - Principle backgrounds from Rn-222 decay chain coming from Uranium decay chain
    - Rn-222: 3.83 day lifetime (~20 minute Ar cycling)
  - Surface background < 100 μBq/m² achieved in DEAP-1
    - Material assays x10 lower limit in DEAP-3600

DEAP-1 results used to project DEAP-3600 sensitivity
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 Backgrounds

• $\beta/\gamma$ events:
  – Ar-39 dominant rate – 1 Bq/kg. Removal using PSD
  – Leakage scales with light yield

• Neutron recoils:
  – $(\alpha,n)$ - 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.
  – Resurface acrylic surface in-situ, fiducial volume cuts, limit radon (trap)

For $10^{-46}\text{cm}^2$ sensitivity over 3 year exposure (1000 kg fiducial volume) requires < 0.6 background events

<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 $\alpha$’s</td>
<td>&lt; 100 $\mu$Bq/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>
</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
Neutron Calibration Ex-situ data

- Tagged 74 MBq AmBe source
  \[ \text{Am}^{241} \rightarrow \text{Np}^{237}\ast + \alpha \]
  \[ \alpha + \text{Be} \rightarrow \text{C}^{12}\ast + n \]
  4.4MeV from \( \text{C}^{12}\ast \) de-excitation

- Two 5x4cm NaI crystals encapsulate source
- Simulation estimate: 100 hours to get 10,000 single neutron scatters in DEAP
- Expect ~20% gammas (AmBe) to deposit > 500keV energy in NaI crystal
- Ex-situ measurement of efficiency in agreement with simulation

\[ \text{Cs-137 Spectrum (ex-situ data)} \]
\[ \text{AmBe Spectrum (ex-situ data)} \]
Vacuum testing the steel sheel

Bonding lightguides to the acrylic vessel

Completed acrylic vessel – lightguide assembly
Attaching magnetic shields

Installing the filler blocks

PMT Installation

Installed LED fibre system reflector
Conclusions and Outlook

• May 7\textsuperscript{th}: DEAP-3600 PMT installation completed and detector sealed
  – Start resurfacing
  – Start calibration commissioning of the detector with the optical fibre system
• Fill with gAr July
• 5 weeks to cooldown
• Commissioning May - September
• Begin physics run October 2014

First result early 2015!
Full sensitivity 3 years $10^{-46}\text{cm}^2$
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Me: ... Yet!
Thank you

Stay tuned!
Backup