First light from DEAP-3600, a single phase liquid argon detector for dark matter search

Fabrice Retière on behalf of the DEAP collaboration
DEAP-3600 physics reach

- **Target**
  - 1,000kg fiducial of liquid Argon
  - Background < 1 count over 3 years

Very competitive in TeV range and beyond
DEAP-3600 concept

- 3,600kg of liquid Argon
  - Enclosed in 85 cm radius acrylic ball
  - 1,000kg fiducial

- Scintillation only
  - Aka single phase
  - Light viewed by 255 photo-multiplier tubes
    - HQE Hamamatsu R5912
DEAP-3600 through its background mitigation technique
  - Neutron background mitigation
  - $\gamma$ and $\beta$ rejection by pulse shape discrimination
  - Surface $\alpha$ background mitigation

Beyond DEAP-3600
  - Reaching the coherent scattering neutrino limit
neutron mitigation

2073 m Underground (6010 mwe) => 0.27 muon/m²/day
Shielding with acrylic

- Inside a water tank
- ~50cm of light guide acrylic and filler blocks
- Ultra-low radioactivity acrylic
- PMT dominant source of neutrons

- TPB wavelength shifter
- Acrylic vessel
- Filler block
- Acrylic light guide
- PMT
Acrylic work

- Acrylic ball and light guide bars manufacturing by Reynolds Polymer
  - Radiopurity control at each manufacturing steps
- Stub machining at U. Alberta
- Light guide machining at TRIUMF
- Light guide bonding underground at SNOLAB
Then adding PMTs, reflectors and filler blocks
And embed the whole assembly in a water tank

- Calibrations tubes (x3) (AmBe, 5000n/s)
- Water tank with liner
- Magnetometers
- Magnetic field compensation coils (x4)
- Calibration tube ($^{22}$Na, 3.7MBq)

Rate with vacuum in AV primarily due to $\gamma$ interactions in light guides
Détecteur est dans la phase de mise en service.
Poudre fluorescente déposée dans le vaisseau.
Citerne en phase de finition.
Début de la prise de données dans quelques mois.

Calibration source
Deployment system

Ar purification
Getter + Charcoal trap (Rn)

Wavelength shifter (TPB) evaporation
Deployment system + Glove box
Starting to fill with liquid Argon early June

Quick increase in data rate
- Due to $^{39}$Ar decay occurring at $\sim$1Bq/kg
- As seen by trigger system

What the trigger sees
... in the region I am allowed to show
Pulse shape discrimination for eliminating e- recoil

Critical for rejecting huge $^{39}$Ar background ($\sim 3.5$ kHz)

$$F_{\text{Prompt}} = \frac{N_{\text{prompt}}}{N_{\text{prompt}} + N_{\text{Late}}}$$

arXiv:0904.2930

Nuclear recoil (neutron/WIMP)

Electron ($\gamma/\beta$)
Where does it come from? scintillation in LAr

- **Excitation**
  - Production independent of energy density
  - Populate mainly triplet state

- **Ionization + recombination**
  - Production higher for high energy density
  - Populate mainly singlet state

- **Pulse shape discrimination**
  - $\tau_{\text{singlet}} \sim 6\text{ns}$, $\tau_{\text{triplet}} \sim 1600\text{ns}$
  - e- recoil, 35% singlet, 65% triplet
  - Nuclear recoil, 75% singlet, 25% triplet

Excitation: $Ar^* \ (1)$

\[
Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar
\]

\[
Ar_2^* \rightarrow 2Ar + \gamma
\]

Ionization: $Ar^+ \ (2)$

\[
Ar^+ + Ar \rightarrow Ar_2^+
\]

\[
Ar_2^+ + e^- \rightarrow Ar^{**} + Ar
\]

\[
Ar^{**} \rightarrow Ar^* + \text{heat}
\]

\[
Ar^* + Ar + Ar \rightarrow Ar_2^* + Ar
\]

\[
Ar_2^* \rightarrow 2Ar + \gamma
\]
The power of PSD

- **DEAp-1** measure e-recoil suppression better than $3 \times 10^{-8}$
- **Model predicts** $10^{-10}$ suppression allowing for sufficient background rejection of $^{39}$Ar in DEAP-3600
Triplet lifetime during the fill.
Stable and high!
Dealing with PMT nuisances

- Gain drift and fluctuation
- Dark noise
- After-pulsing

Measured very precisely in situ
Measuring after-pulsing in-situ

β/γ mitigation

Electron backscatter

After-pulsing

Time-Charge Distribution of Afterpulsing

Charge (pC)

10^2

10

1

DeltaT (ns)

1000 2000 3000 4000 5000 6000 7000 8000
Radon and its annoying daughters

- Rn + daughter decays in LAr not an issue
  - Too high energy
  - Issue, decay with “missing” energy

- Solutions:
  - Minimize radon emanation with filters and a trap
  - AV resurfacing: shave a mm off the surface
    - Then TPB (wavelength shifter) deposition
  - Position reconstruction

http://arxiv.org/abs/1211.0909

Developed by Queen's U.

TevPA 2016
Simulations of surface events

Partial fill reconstruction

Fiducial mass ~ 1 out of 3.6 tons
### Projected physics reach

<table>
<thead>
<tr>
<th>Background</th>
<th>Target count for a 3tonne-year exposure</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neutron</td>
<td>&lt;0.2</td>
<td>Shielding: 6000 mwe (SNOLAB), Active water shield, light guides and filler blocks Material selection</td>
</tr>
<tr>
<td>In 1t LAr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>β &amp; γ</td>
<td>&lt;0.2</td>
<td>Pulse shape discrimination Material selection (for γ)</td>
</tr>
<tr>
<td>In 1t LAr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radon</td>
<td>negligible</td>
<td>Material selection, SAES getter, cold charcoal radon trap <em>High energy events, not in ROI</em></td>
</tr>
<tr>
<td>In 1t LAr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Surface α</td>
<td>&lt;0.2</td>
<td>Material selection (acrylic), sanding of AV (1mm removal), fiducialization.</td>
</tr>
<tr>
<td>In 1t LAr</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

So far, backgrounds appear to be close to target
Aug 17th incident

- Liquid Argon in the neck
- Seal failure at the acrylic – steel interface
  - Seals got too cold
  - Nitrogen leaked into the argon → 100ppm
    ➤ More than the purification system can handle
- Remedy
  - Vent Argon
    ➤ Completed by end of Aug.
  - Refill with fresh argon up to the edge of the neck in Sep-Oct
    ➤ Physics data taking expected to start in Oct. 2016

280kg-day exposure before incident before fiducialization and other cuts
If DEAP-3600 background manageable

- Upgrade to 5 tons?
- Go all the way to n floor
  - Need at least 200 tons

A 50tons concept

- That is too small...
- With obsolete technology
Tackling the photo-detection challenge

- ~150m² of photo-detector required for a 200 tons single phase detector
  - DEAP-3600 ~8 m² (with PMT), nEXO ~ 4m² with SiPMs
- SiPMs compelling because
  - Low radioactivity
  - Highly tilable
  - Perform better cold
  - High efficiency (>50% in blue) and currently 10% at 125nm
  - High timing resolution
  - However many issues
    - Scaling to very large area
    - Cost?

- A compelling solution: 3DdSiPMs

U.Sherbrooke (QC, Canada) & Teledyne-DALSA
DEAP-3600 construction phase is over

Data taking with liquid argon has started
- Current exposure competitive with other LAr experiment
  - First look at data look promising. Backgrounds and light yield more or less as expected
- Set-back of a few months due to neck incident
- Physics data taking starting in October

(already) thinking about the future
- To reach the neutrino floor
- Need new technologies