Energy response and position reconstruction at DEAP-3600
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The experiment:

- Pixelated detector
- Detection of WIMPs via nuclear recoils
- Designed for 3600 kg LAr
- 255 PMTs to measure energy and position of events in the LAr
- AV coated with wavelength shifter TPB
- Located at SNOLAB
- Taking physics data since 2016
- Target sensitivity to WIMP-nucleon cross section $10^{-46} \text{ cm}^2$ at WIMP masses of 100 GeV
The experiment:

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Discriminating the $^{39}$Ar signal using PSD:

- $^{39}$Ar Dimer states with different life times:
  - Singlet $\tau \approx 6$ ns - predominantly nuclear recoils
  - Triplet $\tau \approx 1500$ ns - predominantly electromagnetic events

- $^{39}$Ar:
  - $\beta^-$ emitter with $Q = 565$ keV
  - From cosmic ray interaction on $^{40}$Ar
  - Isotropically distributed in LAr

$\rightarrow$ Percentage of light signal in prompt light as indication of singlet state population
Single Photon counting:

Ideal measurement: single photon counting correcting for PMT effects
De-excitation photons (128 nm) → TPB (420 nm) → Photoelectron cascades in PMTs

• Translation of PMT pulses to number of photoelectrons observed using charge division (qPE)

arXiv:1705.10183
Correction of different effects necessary:

Effects to correct on PE estimator:

- **PMT effects:**
  - After-pulse (AP): caused by back-scatter of electrons on PMT dynodes
  - Saturation of PMTs
  - Dark noise

- **Other effects:**
  - Pile-up of two or more events in same event window

arXiv:1705.10183
Understanding the energy response using $^{39}$Ar:

- Light yield uniformly scaled to match the simulation to data

Cool down phase, before fill

Gas phase calibration with $^{39}$Ar
Understanding the energy response using $^{39}$Ar:

- Light yield uniformly scaled to match the simulation to data

Simulation, after finishing fill

LAr phase calibration with $^{39}$Ar
External $^{22}\text{Na}$ source allows tagged gamma rays:

![Diagram of Na source, LYSO crystals, and PMTs]

**Preliminary**

**MC simulations**

**Energy deposited in argon (MeV)**

- 0.511 MeV
- 0.511 MeV
- 1.27 MeV
External $^{22}$Na source allows tagged gamma rays:

Preliminary

MC simulations

Energy deposited in argon (MeV)
Photoconversion of incoming $\gamma$ on the acrylic:

- at few tens of keV photoelectric effect dominant effect over Rayleigh and Compton scattering
- Once gammas are degraded to a few tens of keV, they travel very short distance before being photoabsorbed
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Measurement of well defined energy deposit at known position
Fit of the low energy peak in LAr data:

- Peak of photoconversion at AV surface from gammas
- Also observed in simulation
- Fit with uniformly scaled light yield to match the simulation to data

![Graph showing fit of the low energy peak in LAr data](image-url)
Comparing $^{39}$Ar and low energy $^{22}$Na:

WIMP ROI: 120 – 240 PE

Very preliminary results!
Measurement of event position:

Two main approaches possible:
- Time-based
- Charge-based
Measurement of event position:

Two main approaches possible:
- Time-based

- Finite speed of light
- PMT hit time proportional to source distance from PMT
- Absolute vertex resolution uniform across volume
- Dependent on scintillator response times, PMT transit time, DAQ quality
Measurement of event position:

Two main approaches possible:

- Charge-based

- Charge patterns of the PMTs
- Point-like source: closer PMTs expected to have more photon hits and charges
- Pattern detector dependent
- Vertex resolution improved towards the edge of the detector
Measurement of event position:

Two main approaches possible:
- Time-based
- Charge-based

DEAP-3600 small enough for charge-based vertex reconstruction to deliver the better position resolution
How it is done:

MC

- MC model of the detector with optics
- Simulation with high statistics of isotropically distributed source
- MC truth position in detector
- PMT charge pattern
- Look-up table

Data

- PMT charge pattern
- Minimisation algorithm
- Fitted event position

Work in progress!
Fiducialisation and de-biasing using $^{39}$Ar:

- Isotropic $^{39}$Ar distribution
- Map true radius to reconstructed radius
- Account for energy dependence
- Determine fiducial mass by determining $^{39}$Ar rate

Work in progress!

MC

MC model of the detector with optics
Simulation with high statistics of isotropically distributed source
MC truth position in detector
Reconstructed position
Map at different energies of corrected position vs truth position

Data

Fitted event position
Applying correction map
Corrected event position

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Work in progress!
Na studies to understand surface backgrounds:

Work in progress
The Deap-3600 collaboration:

around 60 collaborators in Canada, the UK and Mexico

The speakers operational support was provided by NSERC
Back Up
# DEAP-3600 calibration program:

<table>
<thead>
<tr>
<th>Calibration Source</th>
<th>Calibration goal</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laserball</td>
<td>Optical (PMT) calibration</td>
<td>vacuum runs only</td>
</tr>
<tr>
<td>LED Light Injection</td>
<td>Optical (PMT) calibration, monitoring</td>
<td>used in all run phases</td>
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<tr>
<td>$^{22}$Na</td>
<td>Energy and position reconstruction, gamma response</td>
<td>Argon phase</td>
</tr>
<tr>
<td>AmBe</td>
<td>Energy calibration, gamma and neutron response</td>
<td>Argon phase</td>
</tr>
<tr>
<td>$^{39}$Ar</td>
<td>Intrinsic, energy and position reconstruction</td>
<td>Argon phase</td>
</tr>
</tbody>
</table>

- Argon phase: gas phase (GAr), partial fill phase, liquid argon phase (LAr)
- LED Light Injection system with fibres installed on PMTs
- External calibration sources: $^{22}$Na (1 MBq) and AmBe (74 MBq)
- Intrinsic calibration source: $^{39}$Ar (expected 1.01 Bq/kg)