DEAP-3600 Collaboration.
DEAP-3600 is located 2km underground at the SNOLAB Facility in Sudbury ON, Canada.
Overview of the DEAP-3600 experiment.

- Single phase LAr, 3.6 tonne (1 tonne fiducial).
- Spherical ultra-pure acrylic vessel (AV).
- 255 HQE Hamamatsu PMTs, coupled via acrylic light guides.
- Foam and polyethylene provide further shielding.
- 3 um layer of wavelength shifter (TPB) converts 128 nm scintillation light into the visible range.
- AV enclosed inside Steel Shell, immersed in 403 m³ water tank with 45 veto PMTs.

L. Roszkowski et al., JHEP 1408 (2014) 067
The inner vessel was covered with two types of reflector materials to maximize light collection.

- Vacuum Jacketed Neck
- Cooling Coil
- Acrylic Vessel (AV)
- 3600 Kg Liquid Argon
- 255 PMTs & Light Guides
- Steel Shell
- Foam and polyethylene Filler Blocks

Pietro Giampa, Queen’s University, LRT 2017
Construction of the experiment was completed in early January 2016.

Pietro Giampa, Queen’s University, LRT 2017
Electron-recoil backgrounds are mitigated with PSD, DEAP-3600 has a projected rejection power of $10^{10}$.

**Pulse Shape Discrimination (PSD)**

$$F_{\text{prompt}} = \frac{\text{Prompt light}}{\text{Total Light}}$$

**Prompt Light (150 ns)**

**Late Light**

**Total Light = Prompt + Late**

*M. Kuzniak et al., Nuc Phys B Proc Sup 00 (2014) 1–7*
Alpha particles are particularly challenging for DEAP-3600, as degraded decays occurring on the surface could mimic the expected WIMP signal.

In a single-phase detector position reconstruction is quite challenging. It is important to reduce the surface contamination to a minimum in order to match the requirement of 0.2 events / 3 years tonne (fiducial volume).
Acrylic is optimal for low-background experiments as it can be produced with very low intrinsic radioactivity.

The acrylic used for the AV was carefully fabricated in a low Rn environment, with a control to \( <10^{-20} \text{ g/g } ^{210}\text{Pb} \) from Rn exposure.

\[
d = \varepsilon SC \\
F = -D \frac{\partial C}{\partial x}
\]

A sanding robot, the Resurfacer, was designed to remove the inner-most layer of acrylic from the AV.

- 18 ft. tall extension structure, with main body sited at the center of the AV.
- The full system was vacuum rated (multiple tests during commissioning).
- Two rotating sanding arms each dedicated to a specific hemisphere (N/S).
- Two spinning motors to control the Theta and Phi motion of the arms, located outside of the AV seal.
- Full electrical and fluid systems, with components methodically selected to match the background budget.
- 20 ft. tall canister was used to insert and extract the robot in a Rn reduced environment.
Uniform sanding across the AV sphere is achieved by designing the arms with a series of spring-loaded sections.

- Spring loaded system maintains a constant 12-lb force onto the AV.
- Can handle a relative displacement of 2 cm,
- Sanding Pad: 3M Flexible Diamond 690 QRS Cloth Sheet 6002J M74 [<120 mBq/kg].
- All electrical equipment is enclosed in water resistant housing.
- Arm features a position sensor which measures the travel of the telescopic section.
- Measured removal rate of $12.0 \pm 0.5 \text{ g/Hr}$. 
A dedicated system delivers and extracts the needed UPW for the sanding procedure via stainless steel piping.
Custom designed cover gas system for the delivery of ultra-purified N$_2$ gas, with radio-purity of 0.39 $\mu$Bq/m$^3$.

- 200L Cryofab CFN-200 modified Dewar.
- 75g LN$_2$ immersed activates charcoal trap.
- Up to 4.37 kg/Hr output rate.
- System designed to keep AV pressure at 3 psig.
The Resurfacer was ran in-situ for over 200 hours, with an estimated removed radial depth of 500 microns.

- Remote operation was absolutely essential to complete resurfacing in a timely fashion. (Software was very robust).
- There were a few challenges that required stopping operation for short period of time, but they were all handled promptly.
- Total integrated sanding time for each hemisphere is **200 hours**, with an estimated removed radial depth of **500 microns** (within target).
- The resurfacer was extracted through the deployment canister (under ultra-purified N₂ purge gas) without exposing the AV to lab air.
From the collected physics data we estimated the surface $^{210}$Po contamination to be 0.89±0.04 mBq.

$^{210}$Po alpha decays from the surface of the experiment are particularly dangerous as they can not be identified using standard time delay coincidence analysis tools.

Region 1 - $^{210}$Po (Surface Activity)
Region 2 - $^{222}$Rn (LAr Bulk Activity)
Region 3 - $^{218}$Po (LAr Bulk Activity)
Region 4 - $^{214}$Po (LAr Bulk Activity)
Conclusions

• Acrylic can be produced with very low intrinsic radioactivity, making it an ideal vessel material for low-background experiments.

• Any introduced radioactivity in the acrylic had to be reduced in-situ with a custom designed sanding robot.

• Uniform sanding for long periods of time can be achieved with the designed previously discussed.

• Complex system, not just the robot but a fluid system and a gas system are also needed. All components have to be carefully selected to keep radioactivity to a minimum.

• Described in details the custom designed cover gas system, which delivers $N_2$ purified-gas at $0.39 \, \mu Bq/m^3$ at a rate of 4.3 Kg/Hr.

• The resurfacer was successfully ran in-situ for over 200 hours, with an estimated removed radial depth of 500 microns (within target).
Back-Up
Currently liquid noble detectors lead the >10 GeV WIMP searches, while solid state detectors prime in the few GeV range.
Interactions between subatomic particles and argon nuclei generate UV (128 [nm]) scintillation light.

Early Photons: 7 ns
Late Photons: 1.6 μs

Wavelength Shifter (UV to Visible)

Photo-sensors Array
Argon scintillation via excitation can be produced in two different states (singlet & triplet), with distinct lifetime ~7 [ns] vs ~1.6 [us].

![Diagram of Ar2* excited states and potentials](image)
The AV was coated in-situ with 3 microns of TPB

- Deployed source at the center of the AV, with the detector under high vacuum. Uniformly evaporated the TPB onto the AV inner surface.
A stainless steel cooling coil, charged with LN2, provided the 1000 [W] of cooling needed to cool-down the AV to 87 K.
Both the GloveBox and Canister were kept under constant ultra-purified N2 purge gas flow.
Delayed time coincidence analysis is used to identify decay pairs from the Uranium and Thorium chains.

<table>
<thead>
<tr>
<th>Tag</th>
<th>Half-Life</th>
<th>Time Window</th>
<th>Tag Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>222Rn-218Po</td>
<td>183 [s]</td>
<td>350 [s]</td>
<td>73%</td>
</tr>
<tr>
<td>220Rn-218Po</td>
<td>0.16 [s]</td>
<td>0.5 [s]</td>
<td>90%</td>
</tr>
<tr>
<td>214Bi-214Po</td>
<td>164 [μs]</td>
<td>500 [μs]</td>
<td>88%</td>
</tr>
</tbody>
</table>
Aug 17\textsuperscript{th} incident

- During 1st fill liquid Ar reached the neck level
- Clean Rn-scrubbed N\textsubscript{2} leaked into LAr
  - Seal at the acrylic-steel interface got too cold and failed
  - 100 ppm level contamination
    - 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
    - 2nd fill expected to be completed in Oct. 2016

Finalizing analysis of the data collected with partially full detector:
280 kg-yr total exposure (before cuts).