Dark Matter Search with the DEAP-3600 experiment

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ICHEP 2018: International Conference on High Energy Physics
Seoul, Korea; July 4-11, 2018
DEAP Collaboration: 75 researchers in Canada, UK, Germany, Mexico (+ future collaborators from Italy, USA)
Dark matter Experiment with Argon and Pulse-shape discrimination:

- Scattered nucleus detected via scintillation
- Pulse shape discrimination for suppression of $\beta/\gamma$ events
- LAr advantages:
  - Is easily purified and high light yield
  - Is well understood
  - Has an easily accessible temperature ($85K$)
  - Allows a very large detector mass with uniform response
- Detectors:
  - DEAP-1: prototype, 7 kg LAr, 2 PMTs
  - DEAP-3600: 3600 kg LAr, 255 8” PMTs
DEAP-1

Demonstrate discrimination between electromagnetic events and nuclear recoils

- Measurement of the scintillation time spectra and pulse-shape discrimination of low-energy $\beta$ and nuclear recoils in liquid argon with DEAP-1, Astroparticle Physics 85 (2016) 1-23


Argon singlet and triplet excited states have well separated lifetimes (7ns vs 1.6µs)

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**DEAP-3600**

- **Single phase liquid argon:**
  simple, scalable, inexpensive

- **Capacity of up to 3600 kg argon**
  (1000 kg fiducial)
  in ultra-clean AV

- **Vessel is “resurfaced” in-situ**
  to remove Rn daughters

- **TPB wavelength shifter**
  deposition: in-situ vacuum evaporation

- **255 Hamamatsu R5912**
  HQE 8” PMTs
  (32% QE, 75% coverage)

- **50 cm light guides and**
  PE shielding for neutron moderation

- **Detector immersed in 8 m water**
  shield tank in Cube Hall
DEAP-3600 is located at SNOLAB

SNOLAB

deepest and cleanest large-space international facility in the world

● 2 km underground near Sudbury, Ontario
● Ultra-low radioactivity background environment Class 2000
● Physics programme focused on neutrino physics and direct dark matter searches

Home of the SNO experiment 2015 Nobel prize in Physics
DEAP-3600: construction
DEAP-3600: construction

[Images of the DEAP-3600 detector being constructed]
A First Glimpse of the Hidden Cosmos

As scientists map the universe, what they can’t see—dark energy and dark matter—is key.

FIRST TO CAPTURE DARK MATTER ON EARTH? DEAP-3600, maybe the most sensitive dark matter detector yet, was installed last year more than a mile underground in a nickel mine in Ontario. Its spherical array of light sensors points inward, toward a core full of liquid argon. The hope is that dark matter particles striking argon atoms will trigger tiny flashes of light.
DEAP-3600 resurfer

- Sanding robot deployed in the AV
- $500 \ \mu m$ of acrylic removed from the AV inner surface
- Goal to reduce surface alpha backgrounds in the ROI to projected 0.2 events per year.
Backgrounds

- $\beta/\gamma$ events: dominated by $^{39}$Ar beta decay rate, 1 Bq/kg
- Pulse Shape Discrimination (PSD)

- Neutron recoils: $(\alpha,n) +$fission, cosmogenic $\mu$-induced

- Depth and water Cerenkov $\mu$ veto, clean detector materials, shielding

- Surface events: Rn daughters and other surface contamination

Surfaces sanded in-situ, limited exposure to Rn, position reconstruction & fiducialization
Calibration

- Laserball optics calibration (once before argon filling)
- Calibration sources: 241AmBe, 22Na, 228Th (1 d per month)
- Light injection via fibers (1 hour per day)
- Background sources: 39Ar, 40K, 208Tl $\gamma$-lines (constant monitoring)

See Pietro Giampa’s talk for details
Results from first dataset

1st LAr fill: Jun - Aug 2016:
- Detector filled with 3322 kg liquid argon
- 10 day stable period selected as dataset
- 4.4 live day dataset (9.9 tonne-days fiducial exposure)
DEAP-3600 ROI definition

ROI definition:

- (A) = 0.2 leakage events from $^{39}$Ar in dataset
- (B) NR acceptance > 5% at lowest energy @80 PE = 11 keVee = 39 keVr (nominal design was 120 PE)
- (C) Low $F_{\text{prompt}}$ cut removing 5% NR acceptance
- (D) High $F_{\text{prompt}}$ cut removing 1% NR acceptance
- (E) Highest energy @240 PE = 33 keVee = 111 keVr to reduce backgrounds

PSD projection:

< $10^{-8}$ @ 90% NR acceptance and < $10^{-10}$ @ 50% NR acceptance

PSD performance:

- Best demonstrated ER leakage using pulse shape discrimination in LAr: < $1.2 \times 10^{-7}$ @ 90% NR acceptance
No events observed in ROI within 4.4 live days (1.4 \times 10^9 total triggers)

Setting limit on dark matter:
- Dominant expected background source is 0.2 events from 39Ar
- Conservative assumption:
  0 background events expected, 0 events observed
DEAP-3600 limits

Results of 4.44 days of data (arXiv 1707.08042), updated plot (2018)
DEAP-3600: for the 2nd dataset

- More than one year dataset recorded (3256 kg of LAr in detector)

- All available experimental data combined still consistent with the simplest versions of SUSY (cMSSM, NUHM), remaining parameter space is directly probed by direct WIMP searches with tonne scale detectors: DEAP-3600, XENON1T, LUX/LZ
Future plans

Argon collaboration formed: DarkSide, DEAP, MiniCLEAN, ArDM
- Completion of current science and R&D programs by each collaboration (DS-50, DEAP-3600, MiniCLEAN, ArDM)
- Joint collaboration on DS-20K at LNGS, 20 tonnes of underground Ar in two-phase TPC (operation starting 2021) and SiPM photodetectors
- Joint collab. on multi-hundred-tonne detector, site TBD (mid-2020s)

DS-20K concept with proto-Dune Cryostat (from C. Galbiati):

See Pietro Giampa’s talk for details
Final remarks

- DEAP-3600 searches for dark matter with liquid argon
- Pulse shape discrimination demonstrated at the order of $10^{10}$
- First results of 4.4 days of commissioning data sets a limit on WIMP-nucleon spin-independent cross section of $< 1.2 \times 10^{-44} cm^2 @100 GeV/c^2 (90\%CL)$
- Detector is operating for more than one year with 3256 kg of LAr, data taking until 2020 (3 tonne-year exposure)
- Analysis in preparation: tuning of optical model, more detector calibrations, blinding scheme implemented,...

Stay tuned for very exciting results from DEAP-3600!