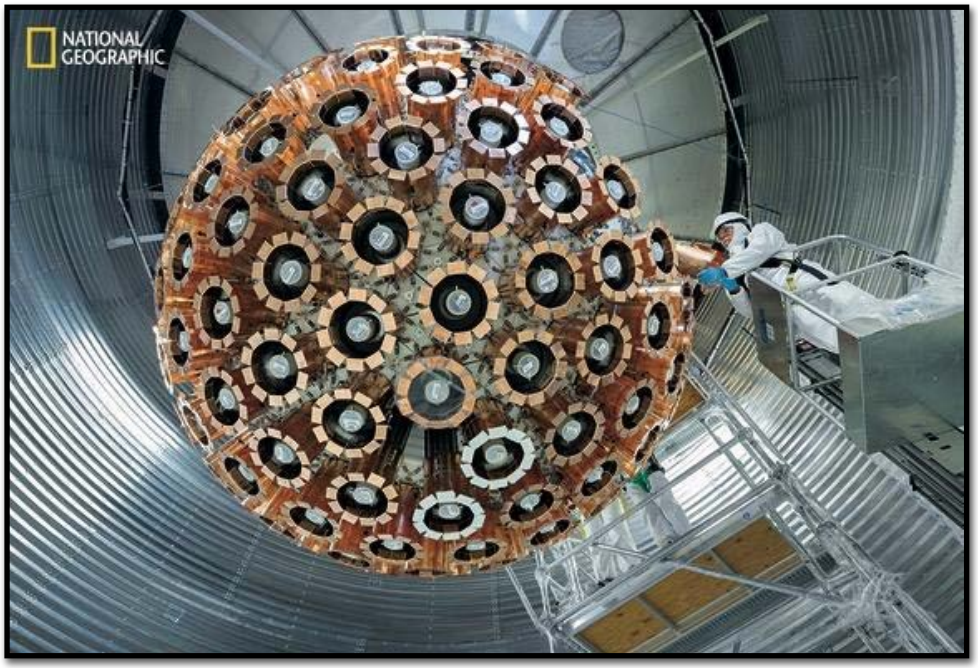
DEAP-3600 Project Overview

Outline

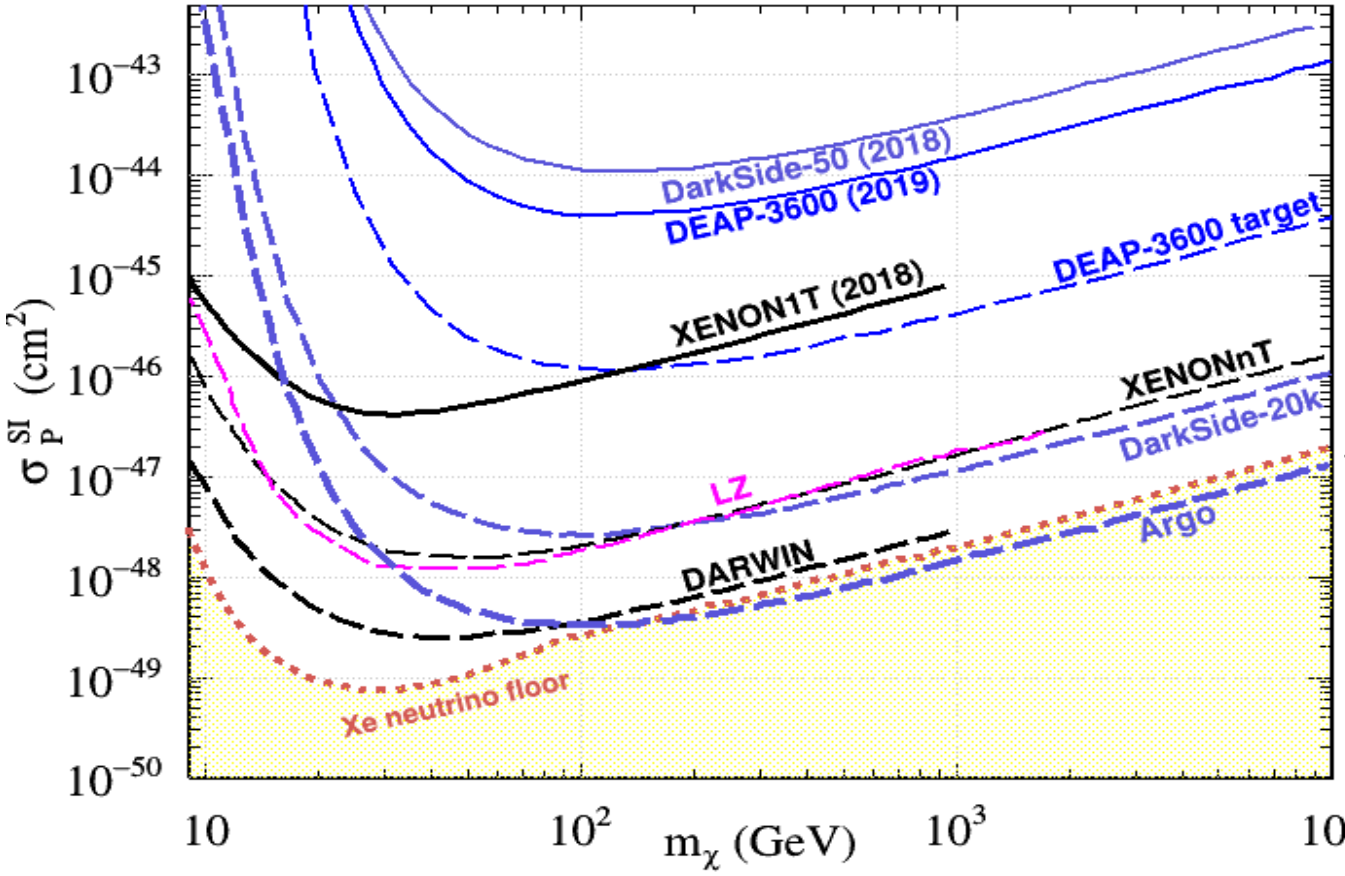
- The search for Dark Matter
- DEAP Collaboration
- DEAP-3600 running to date
  - Overview of detector
  - Summary of results
  - Physics sensitivity
  - Limitations
- DEAP-3600 Hardware Upgrades
  - Summary
  - Future experimental program



Mark Boulay,
Carleton University,
on behalf of
the DEAP Collaboration

IPP Town Hall July 15, 2020

Direct Dark Matter Searches and Sensitivities



end 2022

~2023

~end 2020's or beyond

Extremely interesting to identify Dark Matter (of course)

At high-masses (above 100 GeV), still 3-orders of magnitude to go before reaching the ultimate "neutrino floor" defined by CNNS of either solar or atmospheric neutrinos

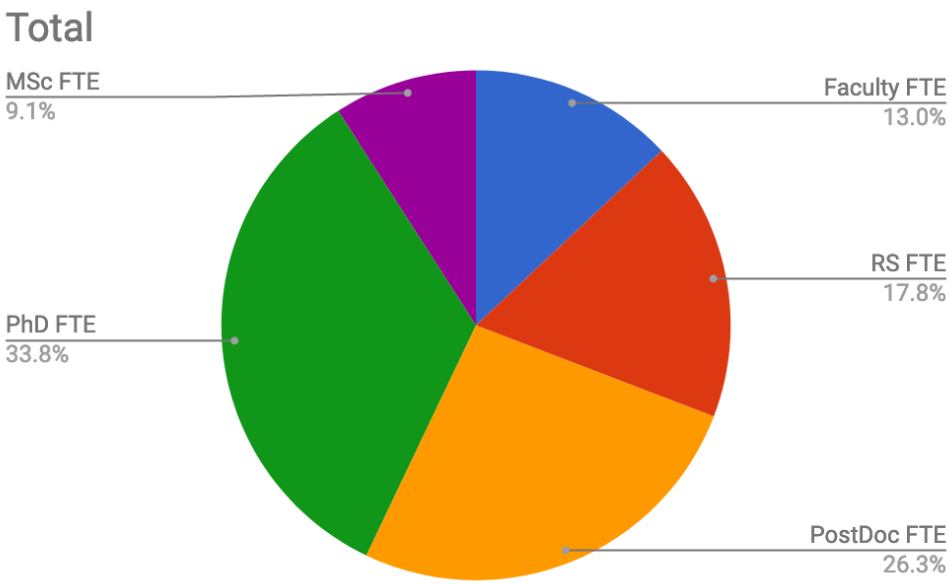
Good news: we know how to get there, this drives the long-term argon program in Canada

DEAP Collaboration

Recently admitted two new institutions (Astrocent and St. Petersburg NPI)

DEAP Collaboration: Membership (November 2019)

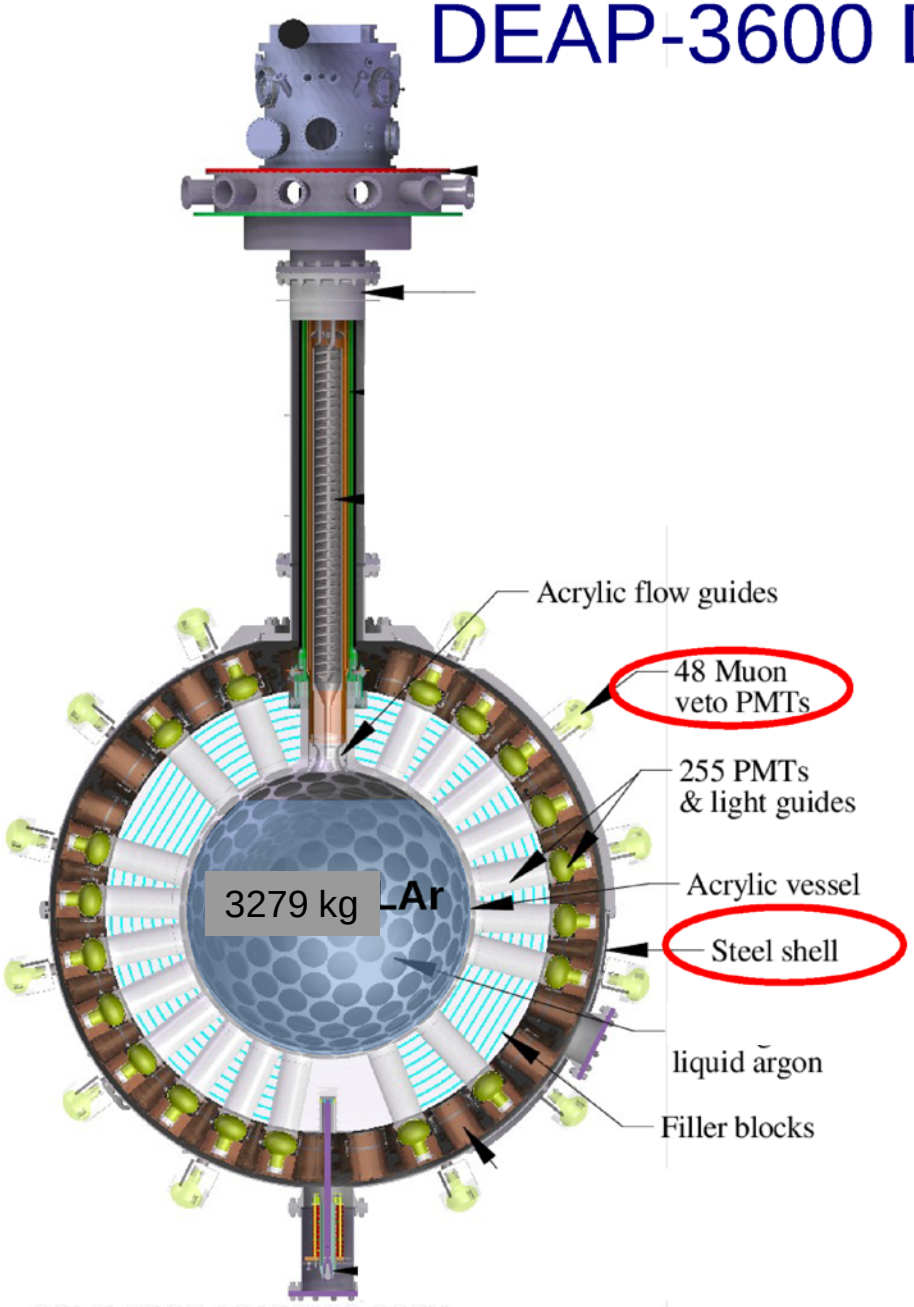
	Canada	Canada FTE	Total	Total FTE
Graduate students	12	12.0	22	16.5
Postdocs	12	8.1	20	10.1
Research scientists	17	5.1	32	6.9
Faculty members	8	3.6	23	5.0
Total	49	28.8	**97**	**38.5**



Not included here:

- Engineers
- Technicians
- Admin

DEAP-3600 Dark Matter Search



- **Single phase liquid argon** approach: simple, scalable, inexpensive
- 3.3 tonne target (1000 kg fiducial) in sealed ultraclean Acrylic Vessel
- Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction
- In-situ vacuum evaporated TPB wavelength shifter (~10 m^2 surface)
- Bonded 50 cm long light guides + polyethylene shielding against neutrons
- 255 Hamamatsu R5912 HQE PMTs 8-inch (32% QE, 75% coverage)
- Detector immersed in 8 m water shield, instrumented with PMTs to veto muons
- Located 2 km underground at SNOLAB

Highlights

Concept developed in Canada with R&D starting in 2005; first operation at SNOLAB started in 2016

First physics running November 2016 – April 2020
shutdown for detector upgrades April 2020

First published analyses on first year “non-blind” data, currently analyzing blinded data with more sophisticated techniques (multi-variate, ML, etc.) for improved sensitivity

Several innovations:

Large cryogenic acrylic vessel (Alberta)

Large-area in-situ acrylic vessel sanding robot (Queen’s/Carleton)

Ultralow-background and large area wavelength-shifter coatings (Queen’s/Carleton)

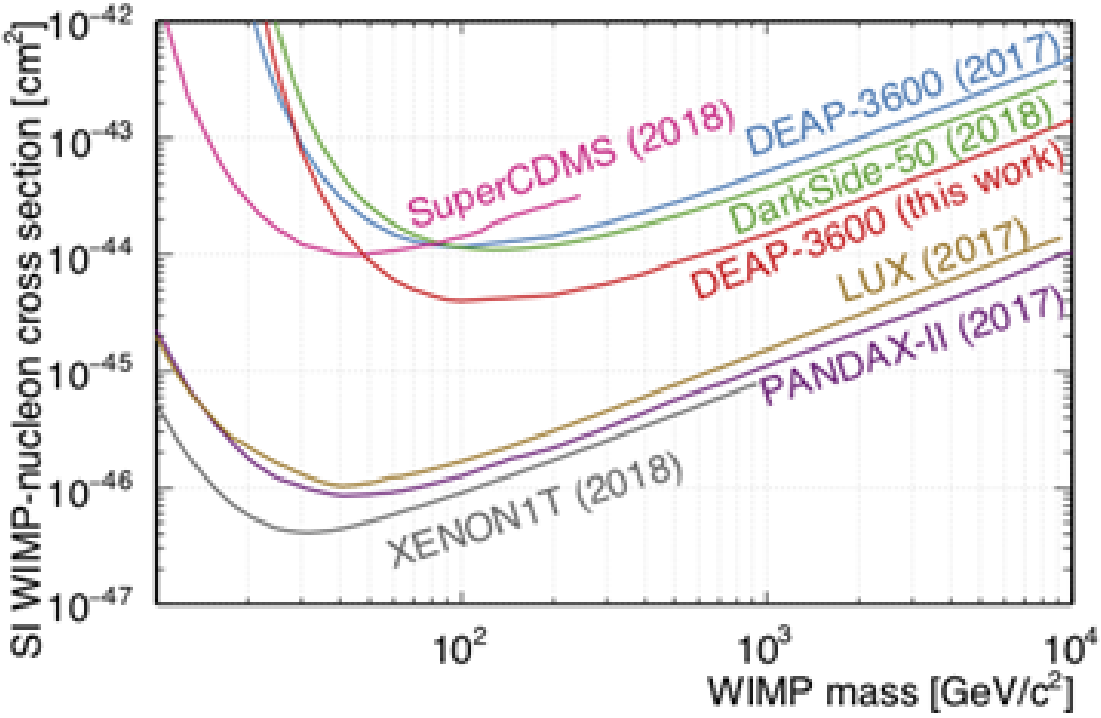
Strict materials control, lowest-ever achieved 210Pb concentrations in acrylic (SNOLAB and Laurentian, Queen’s/Carleton)

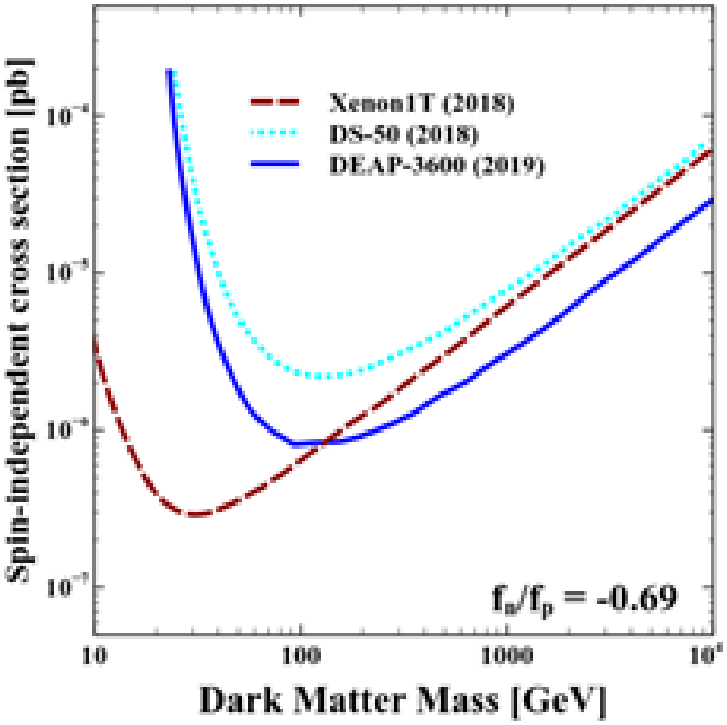
Large-scale liquid argon purification system with lowest-ever achieved internal radon concentration (Queen’s/Carleton)

Development of low-noise, low-deadtime electronics, trigger and DAQ system (TRIUMF)

Best-ever achieved PSD discrimination of low-energy ER events from NR events (collaboration)

Results from DEAP-3600 DM Search (PRD 100 022004 2019)





arxiv.org/abs/1902.10256
also 2005.14667 (2020)
isospin-violating DM

Complementarity between xenon and argon, for example sensitivity to isospin-violating DM

Background reduction in argon

Significant advantage with Ar: discrimination of “ER” events with Pulse-Shape Discrimination (PSD) can completely remove this component *:

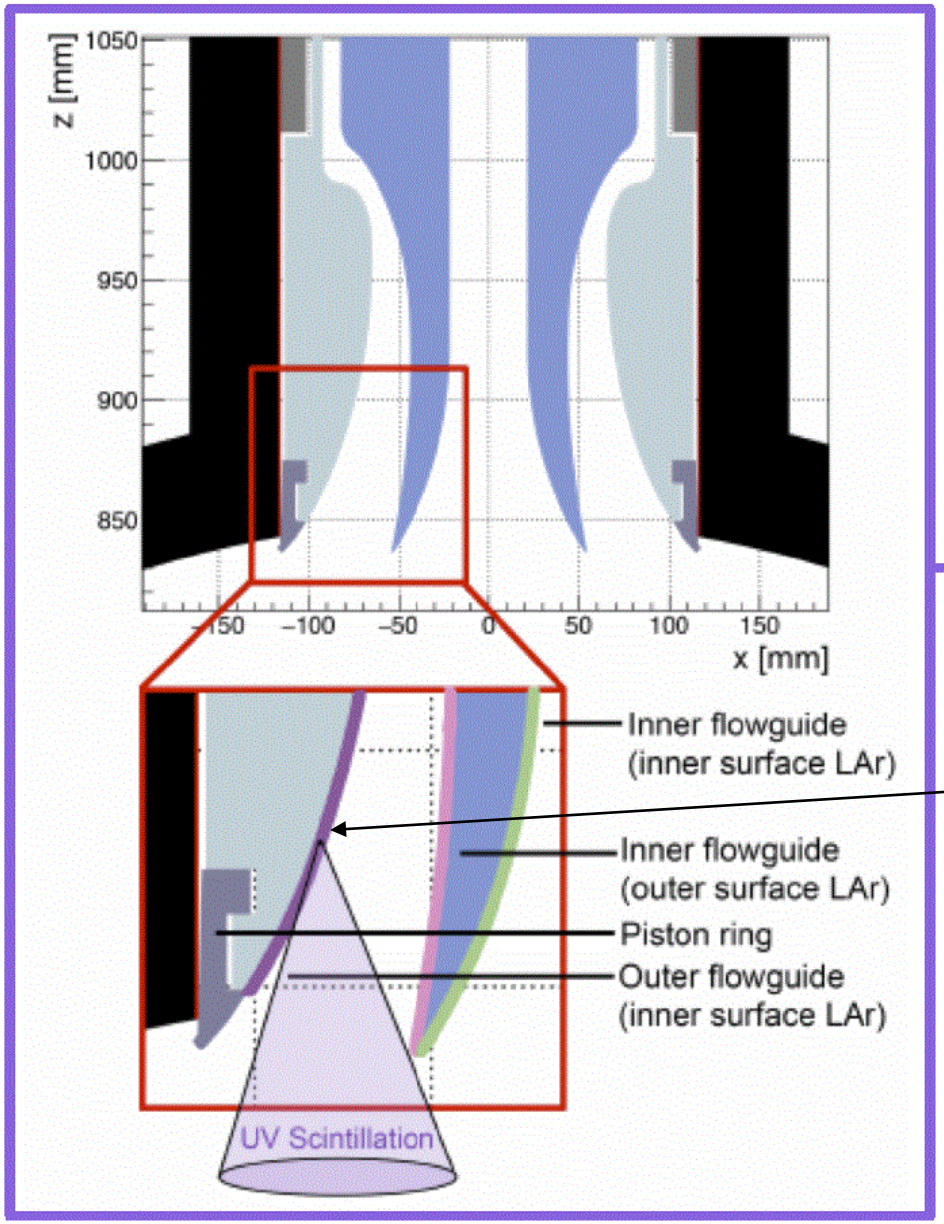
DEAP-3600 showed PSD “leakage” of ER events of 1.2×10^{-9} compared to 5×10^{-3} for Xe (reason: larger difference of singlet/triplet lifetimes in Ar)

Consequence is that ER backgrounds can be completely removed in large-scale argon experiments (unlike in Xe experiments), sensitivity in Ar is limited by backgrounds from CNNS of atmospheric neutrinos; Xe expected to be dominated by ER from pp neutrino-e scattering

Goal for DEAP-3600 is to reach background-free exposure, currently limited by other low-level backgrounds (see next slide):

*rates need to be low enough to avoid significant pileup:
1-tonne target mass OK with atmospheric argon (1 Bq/kg ^{39}Ar β decays)
larger experiments require low ^{39}Ar: underground argon source from Colorado (“Urania” extraction plant) is reduced by factor ~1400

Backgrounds – Alphas (Neck)



Shadowed α decays from liquid argon in neck region lead to low-energy backgrounds

^{210}Po decays at the flowguide-LAr interface

DEAP-3600 Hardware Upgrades

Summary:

Installation of new deployment system for cooling tube (allows operation with warm flowguides; no LAr film on flowguides = no neck events)

Coating flowguides with a “slow” wavelength shifter, to remove neck events with PSD (see NIM A 968, 163631 2020 Boulay & Kuzniak)

Various upgrades to cryogenic and purification system for more stable operation

Implemented by end of 2020

Funding Summary

2007 & 2009 CFIs for capital construction
(total $27.2 M)

Strong support from SNOLAB and partner institutions

Strong support from various MRS's and from McDonald Institute

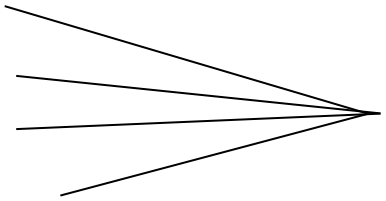
2017 CFI IF ($9M) towards future noble liquid detector development and light readout
(Carleton/TRIUMF/McGill/Sherbrooke)

NSERC-supported since 2005

Global Argon Dark Matter Program (see Aksel's talk)

Over 350 researchers from

- DarkSide
- DEAP
- ArDM
- MiniCLEAN



DS-20K @LNGS → multi-hundred-tonne ARGO@SNOLAB

collaborating on future program:

- Completion of current science and R&D programs by each collaboration
- Joint collaboration on DS-20k at LNGS (100 to 200 tonne-year exposure)
- Extraction of ~60 tonnes of low ^{39}Ar underground argon for DS-20k, then ~400 tonnes for future detector (storage facility at SNOLAB: ARGUS).
- Joint collaboration on future multi-hundred-tonne LAr detector to reach neutrino floor at SNOLAB, ARGO (~202X+)
- Continued development of DEAP enables long-term program

Funding Summary going forward

Submitted 2020 CFI IF application ($22.6 M):

- DEAP-3600 upgrades
- DS-20k Acrylic TPC and low-background coatings
- DS-20k Electronics and DAQ
- Development of ARGUS: ARGon Underground Storage at SNOLAB (100-tonnes towards 400 tonne ARGO+background assay capability)

2020 NSERC for DS-20k activities (see Aksel's talk for details, development now, running ~2024 for 5+ years)

Planning 2021 NSERC submission towards R&D for ARGO: conceptual design (single phase), background budget at SNOLAB, light readout R&D. Concept 2021-2023, engineering 2024-2026, then construction+10 y data.

Plan to explore potential uses of DEAP-3600 detector after 2022 towards future R&D, in upcoming grant period.

Summary

DEAP-3600 is currently the most sensitive argon DM search experiment, demonstration of extremely low background levels and background suppression with PSD. Expect to increase sensitivity with further analysis.

Complementarity with xenon, e.g. leading sensitivity for Isospin-violating models, will continue to improve with further sensitivity increases

Plan for upgrades to mitigate limiting background sources in hardware

Excellent training ground and track record for training of HQP, also needed for future experimental efforts.

Planning for phased approach with argon with increasing sensitivity to neutrino floor:

DEAP-3600 -> DS-20k -> ultimate 400 tonne experiment at SNOLAB (ARGO)

Key contributions to DS-20k from Canadian groups (acrylic TPC, low-background surface coatings, electronics, trigger and underground argon)

EXTRA

DEAP publications: Objectives for 2020

- This year, we are prioritizing a list of 7 publications:
  - Pulse-shape discrimination with DEAP-3600 (published, Eur.Phys.J.C 80 (2020) 4,303
  - Ar39 specific activity measurement (advance draft prepared)
  - Muon veto instrumentation and muon flux measurement
  - 5.5 MeV solar axion search
  - Constraints on dark matter-nucleon couplings (Effective Field Theory) and non-thermal halo components (submitted, arxiv 2005.14667)
  - Dark matter search on 231 live-day dataset with profile likelihood ratio method
  - **Dark matter search with 2016-2019 dataset**

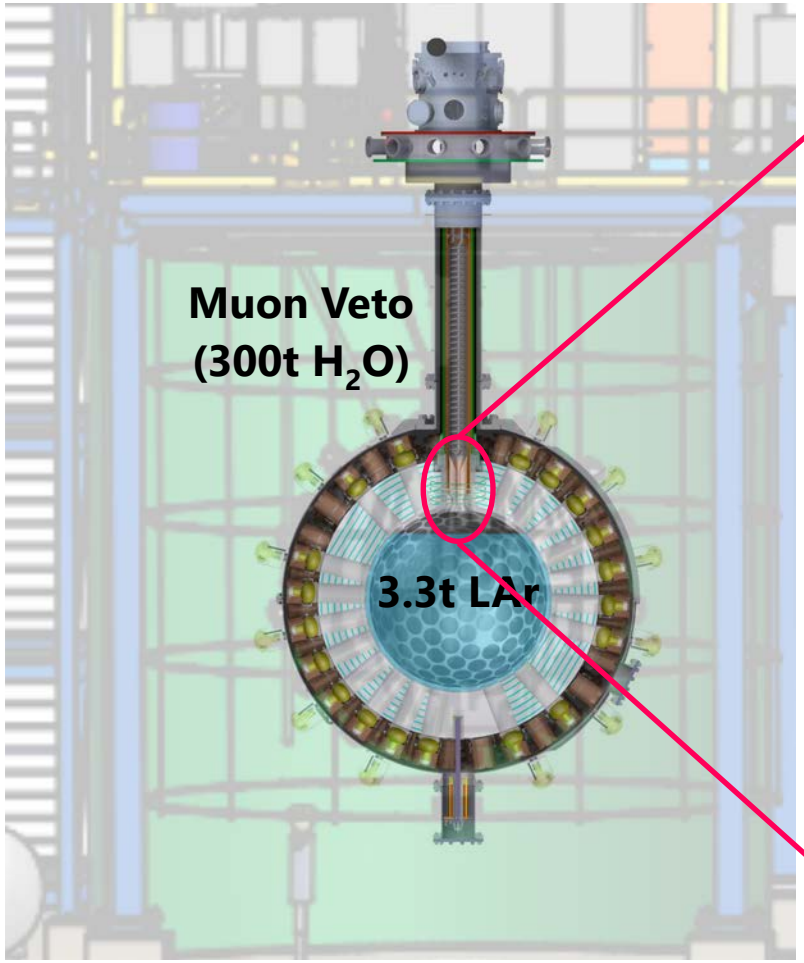
- We have a rich physics programme, limited mainly by person-power

Objectives for 2020

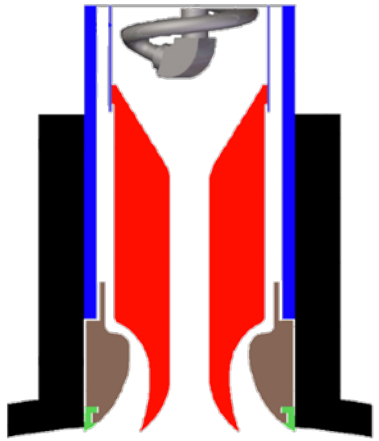
Full list of DEAP publications in progress

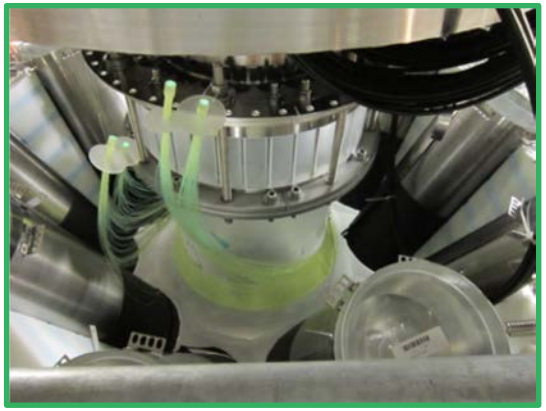
- Dark matter searches
  - **WIMP search with 2016-2019 dataset**
  - WIMP search on 231 live-day dataset with profile likelihood ratio method
  - Constraints on dark matter-nucleon couplings and non-thermal halo components
  - 5.5 MeV solar axions
  - 10-100 keV-scale hidden photons and axion-like particles
  - Low-mass WIMP search via annular modulation
  - Low-mass WIMP search using low-threshold data
  - Super-heavy multiply interacting massive particles
  - Boosted dark matter
  - Sterile neutrinos
- Other searches
  - Ar36 0vECEC
  - Short-lived cosmogenic isotope production in LAr
  - Inverse beta decay with boron-8 neutrinos
- Measurements
  - Ar39 specific activity
  - Ar39 half-life
  - Ar39 decay spectrum and nuclear parameters
  - Alpha scintillation in LAr
- Pulse-shape discrimination
  - Likelihood-based vs. prompt fraction
  - PSD model paper (with DarkSide)
  - Wavelength shifter long time constants
- Detector papers
  - Muon veto instrumentation and muon flux
  - Position reconstruction
  - PMT saturation and digitizer clipping corrections
  - LAr optical model
  - GAr pulse shapes and lifetimes
  - Detector stability

DEAP-3600 Neck Flowguides



Flow guides





Neck Veto

Comments on long-term running plan

to Aug 2020	preparing for upgrades
May/June 2020	detector warmup
(moved forward to March/April)	
July-Aug 2020	no access – calibration
Aug-Oct 2020	implement HW upgrades
Nov-Dec 2020	cooldown and fill
Jan 2021-	recommissioning and data collection