The DEAP-3600 Experiment

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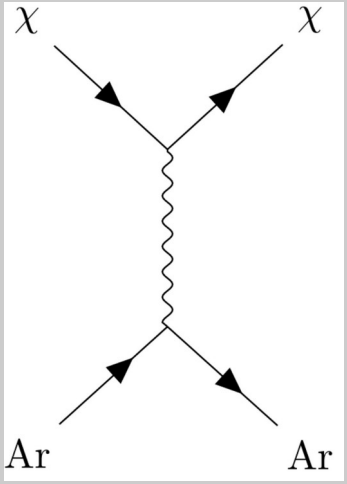
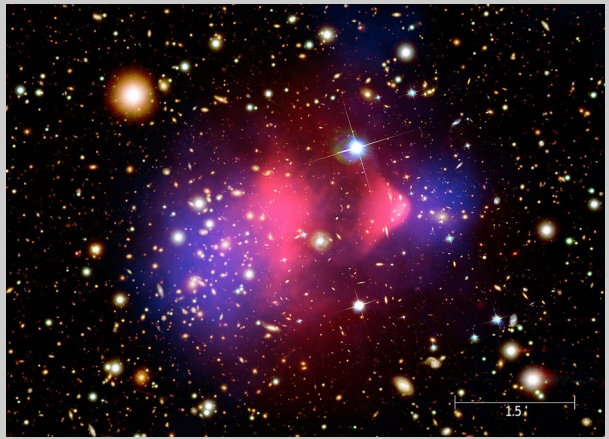
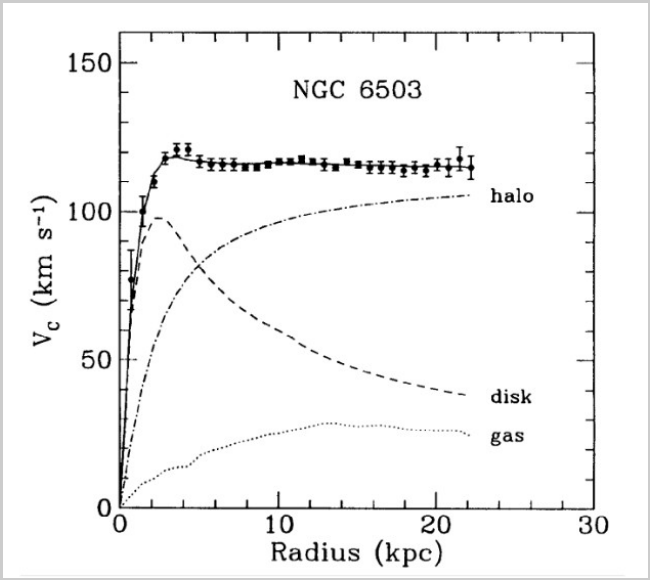
On Behalf of the DEAP-3600 Collaboration
International Cosmic Ray Conference
13th July 2021

Introduction

- DEAP-3600 is a direct detection dark matter search experiment using liquid Argon as a target







https://arxiv.org/abs/0812.4005

DEAP Collaboration

University of Alberta

AstroCeNT
Nicolaus Copernicus Astronomical Center of the Polish Academy of Sciences

Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

Carleton University

INFN
Istituto Nazionale di Fisica Nucleare

Johannes Gutenberg Universität Mainz

National Research Center "Kurchatov Institute"

Gobierno de España
Ministerio de Ciencia, Innovación y Universidades

Ciemat
Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

Laurentian University
Université Laurentienne

IF
Instituto de Física

Princeton University

Technical University of Munich

TRIUMF

Queen's University

Royal Holloway University of London

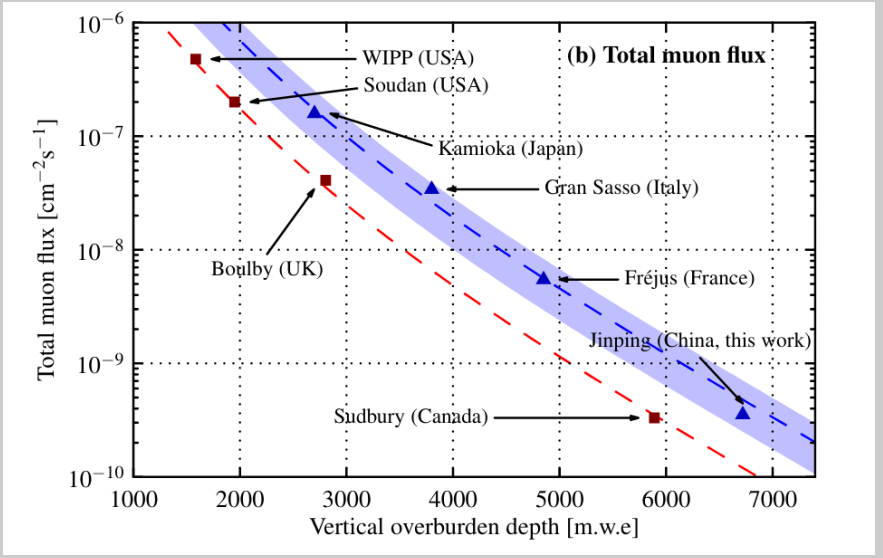
Particle Physics
Rutherford Appleton Laboratory

SNOLAB

US
University of Sussex

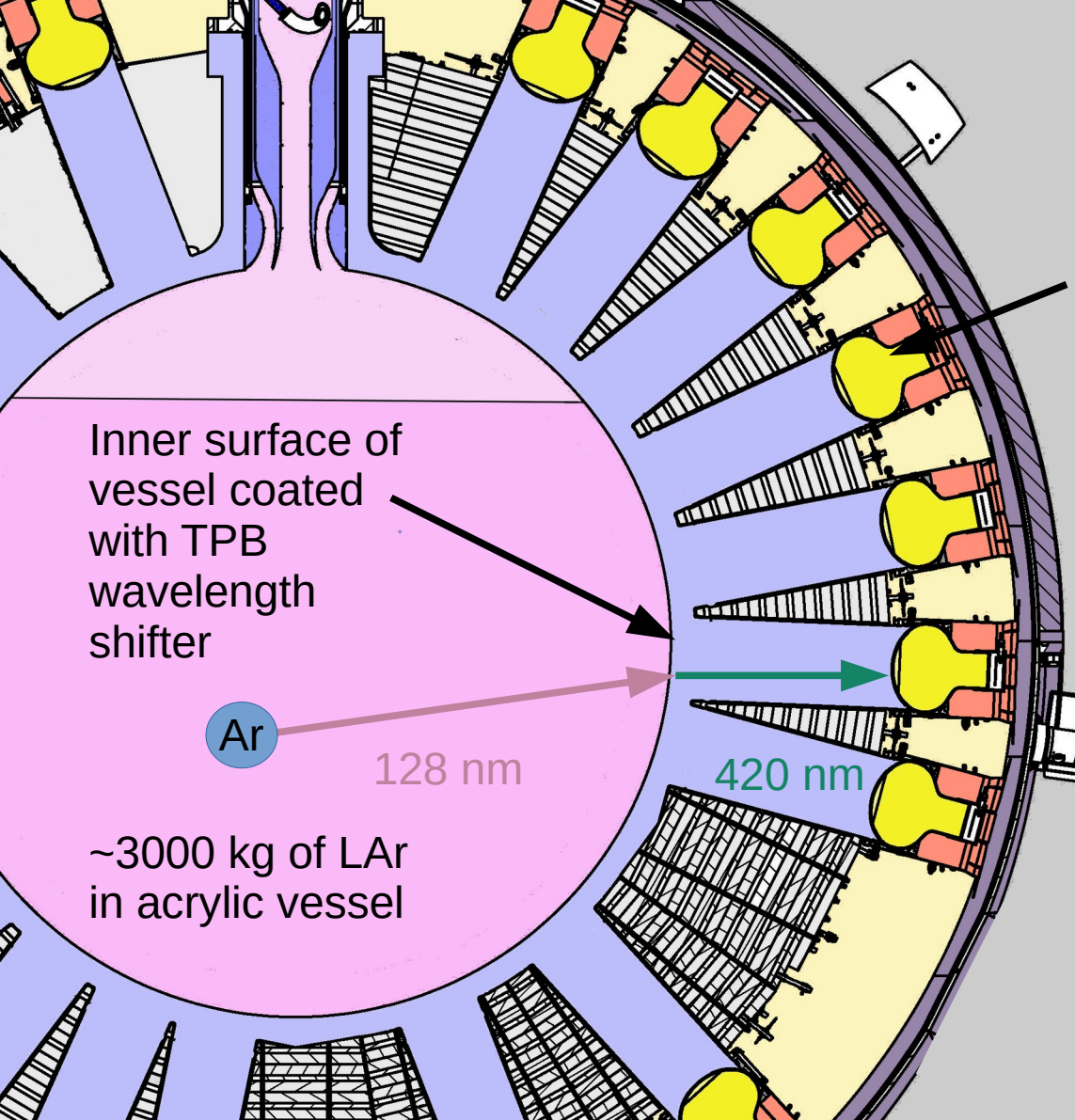
Location

- The detector is located at SNOLAB in Sudbury Ontario
- Provides a ~6 k.m.w.e overburden

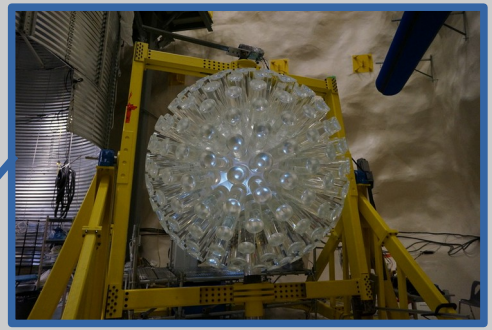


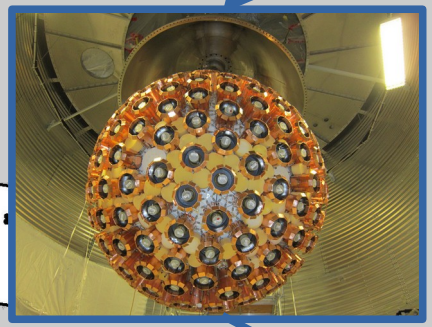
https://arxiv.org/abs/2007.15925

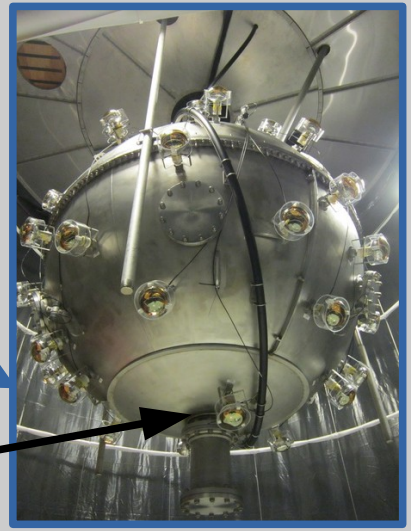
DEAP-3600



255 HQE PMTs connected via acrylic light guides



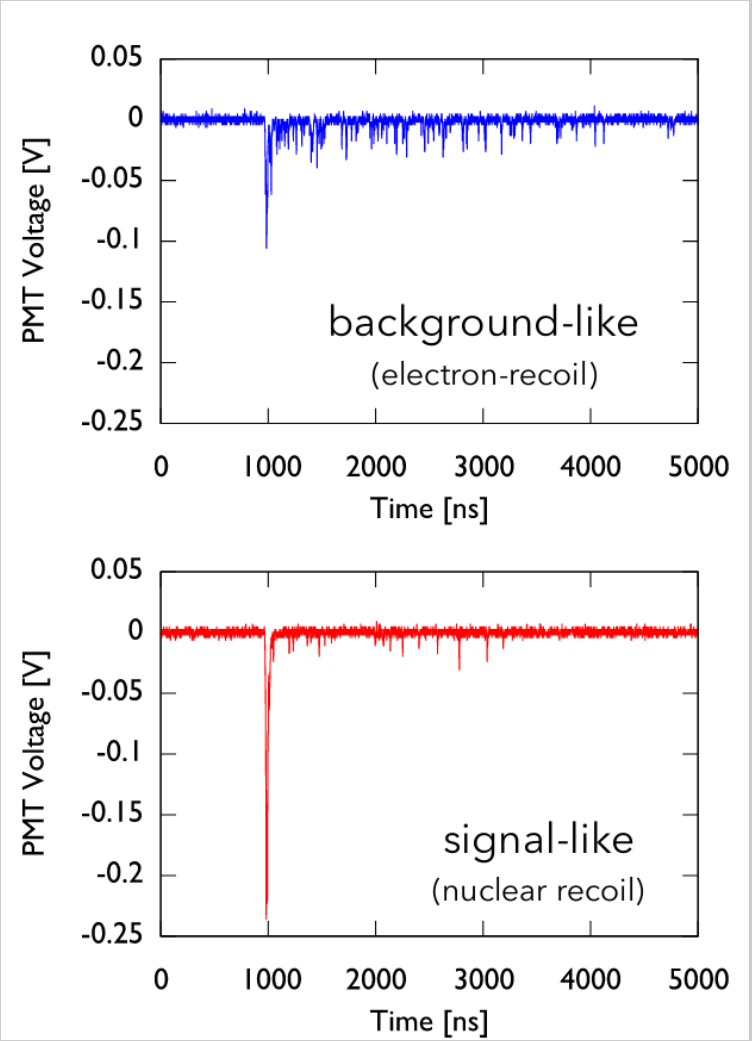




Veto PMTs external to steel shell

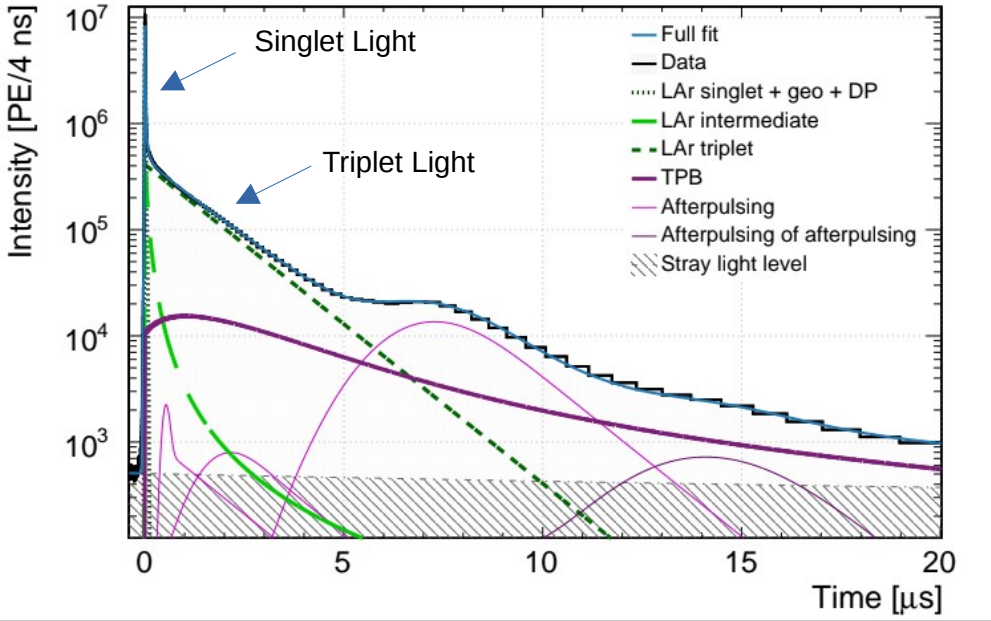
Use of Liquid Argon

- Argon is chosen as:
  - It has a good scintillation light yield (40,000 photons/MeV)
  - Transparent to its scintillation light (128 nm)
- Scintillation time profile of Argon allows removal of backgrounds
  - Nuclear Recoils (NR)
    i.e. (WIMP, α, n) → Singlet State (6 ns)
  - Electron Recoils (ER)
    i.e. (β, μ, γ) → Triplet State (1.4 μs)
- **Signal events have much more light earlier in the event**

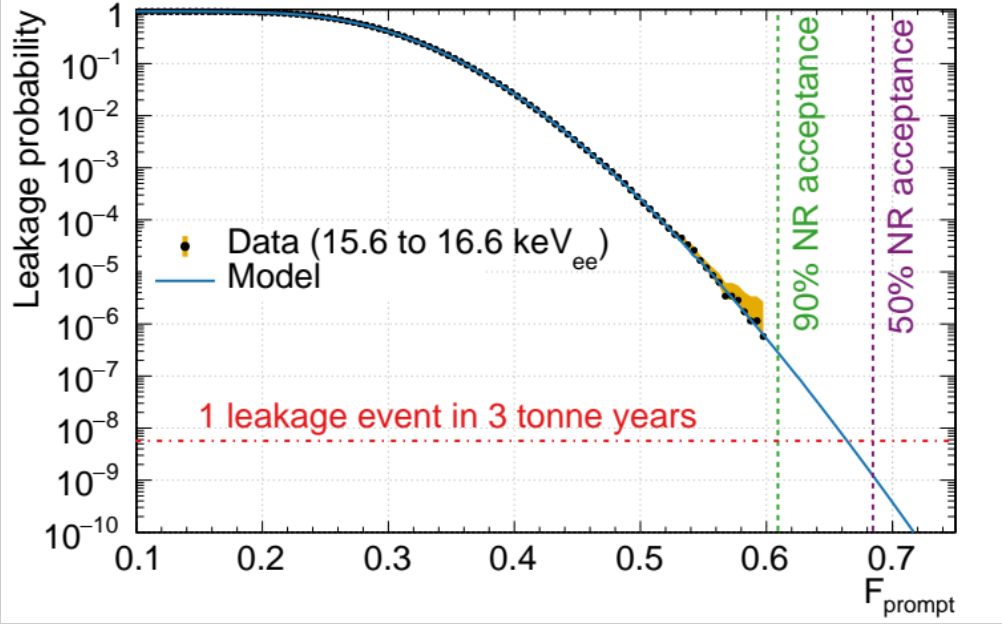


Pulse shape discrimination

https://arxiv.org/abs/2001.09855



https://arxiv.org/abs/1902.04048



Highly accurate model to account for detector effects i.e. TPB response and AP developed

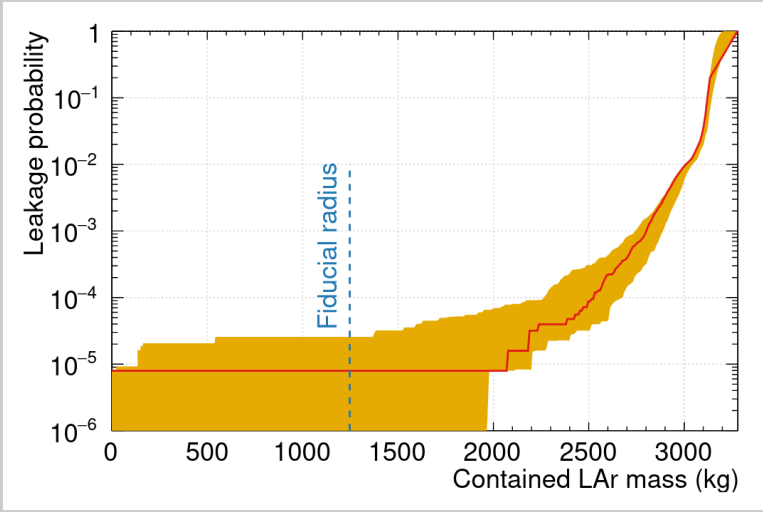
$$\mathrm{F_{prompt}} = \frac{\sum_{-28\ \mathrm{ns}}^{60\ \mathrm{ns}} \mathrm{PE}(t)}{\sum_{-28\ \mathrm{ns}}^{10\ \mu\mathrm{s}} \mathrm{PE}(t)}$$

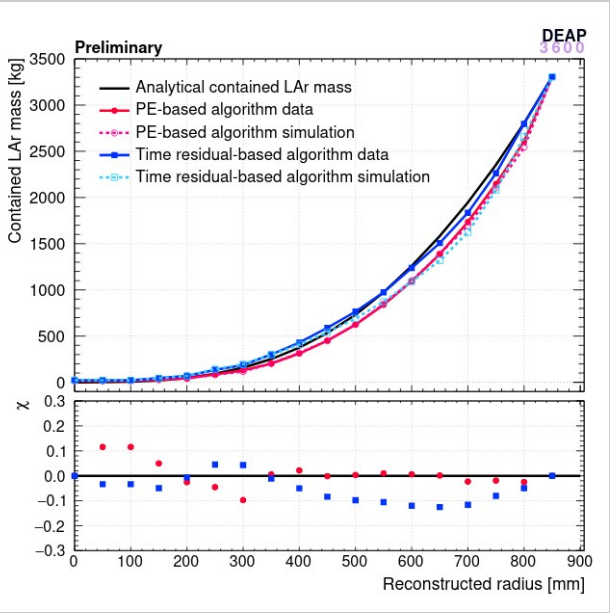
NR (Signal) = More Singlet Light
ER (Background) = More Triplet Light

NR events have a higher Fprompt value

Surface Backgrounds

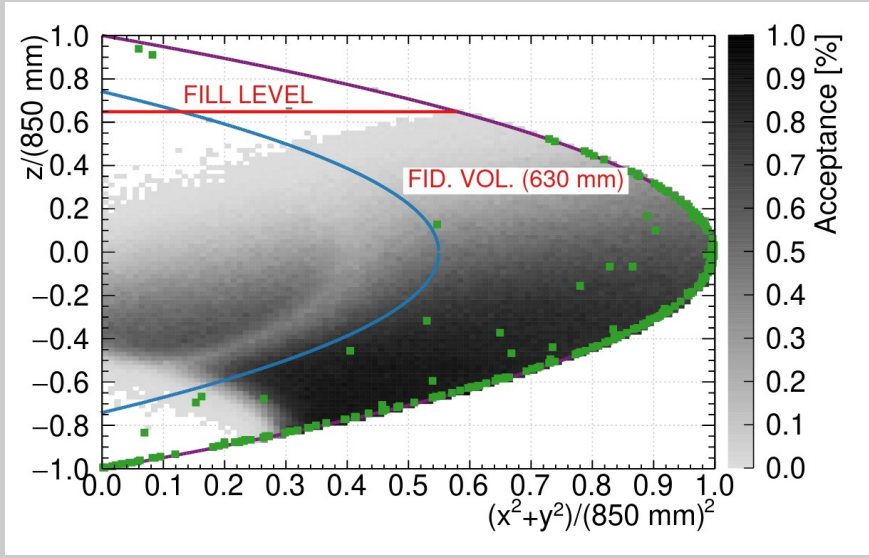
- Other backgrounds exist after energy and fprompt cuts
  - i.e. alphas on the surface of the AV
- Surface backgrounds constrained by fiducial cut





Two reconstruction algorithms based on charge and hit times of PMTs

Resolution is 30-45 mm at 630 mm for lower energy events

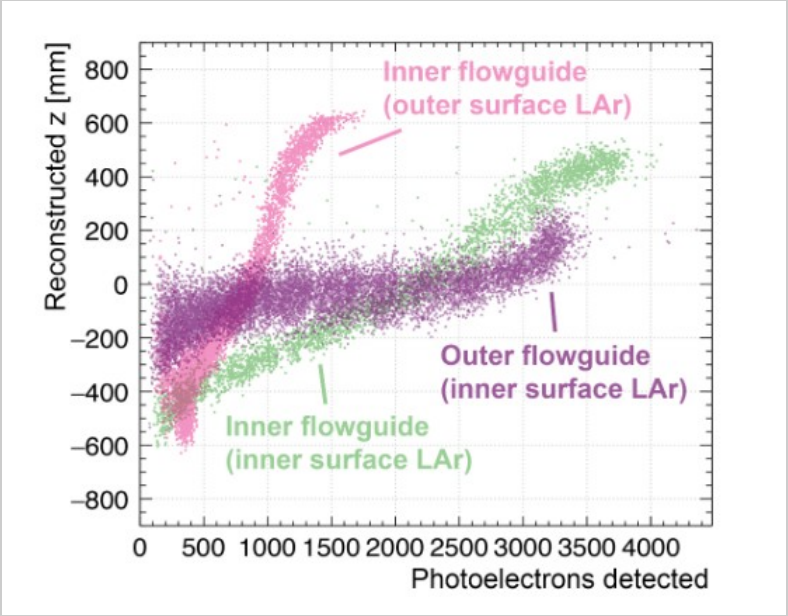


https://arxiv.org/abs/2004.02058

https://arxiv.org/abs/1902.04048

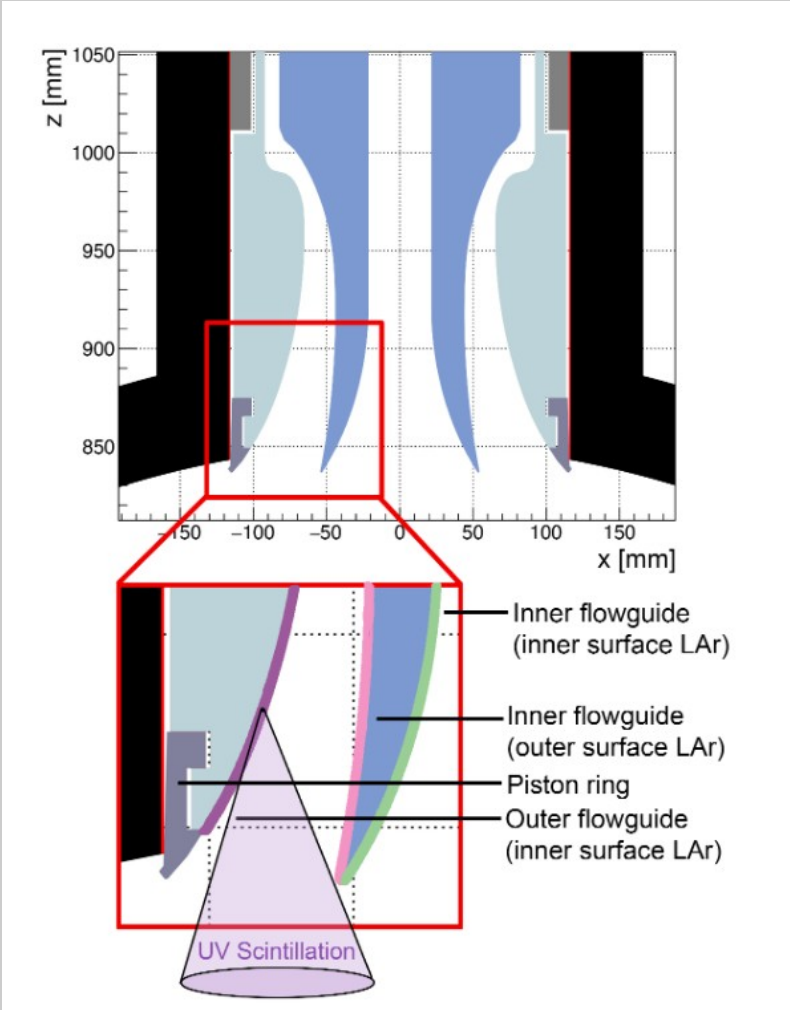
Neck Backgrounds

Remaining significant backgrounds are due to shadowed/degraded alpha decays

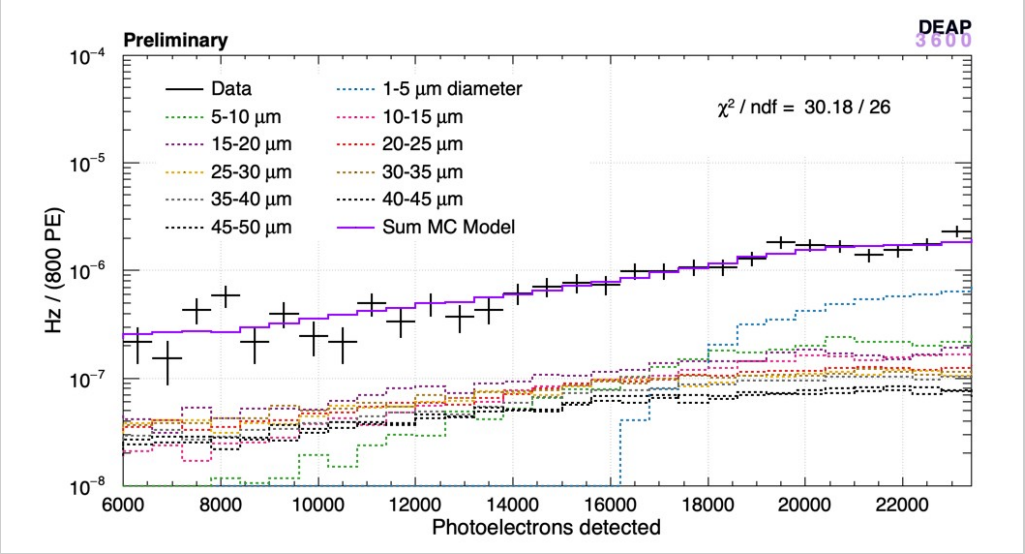


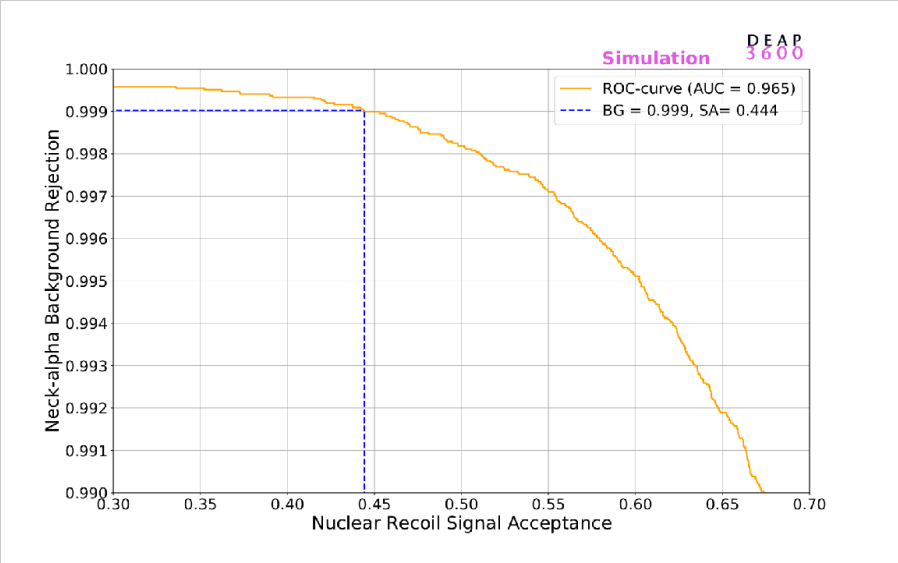
Shadowed alpha decays on the surface can misreconstruct within the fiducial volume

Alpha decays on the surface of the acrylic can deposit energy in thin argon layer on the surface – event will have high fprompt.



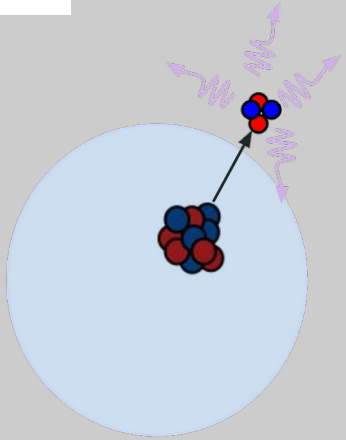
Dust Backgrounds





Shadowed dust events – Particulate size distribution modelled by a power law.

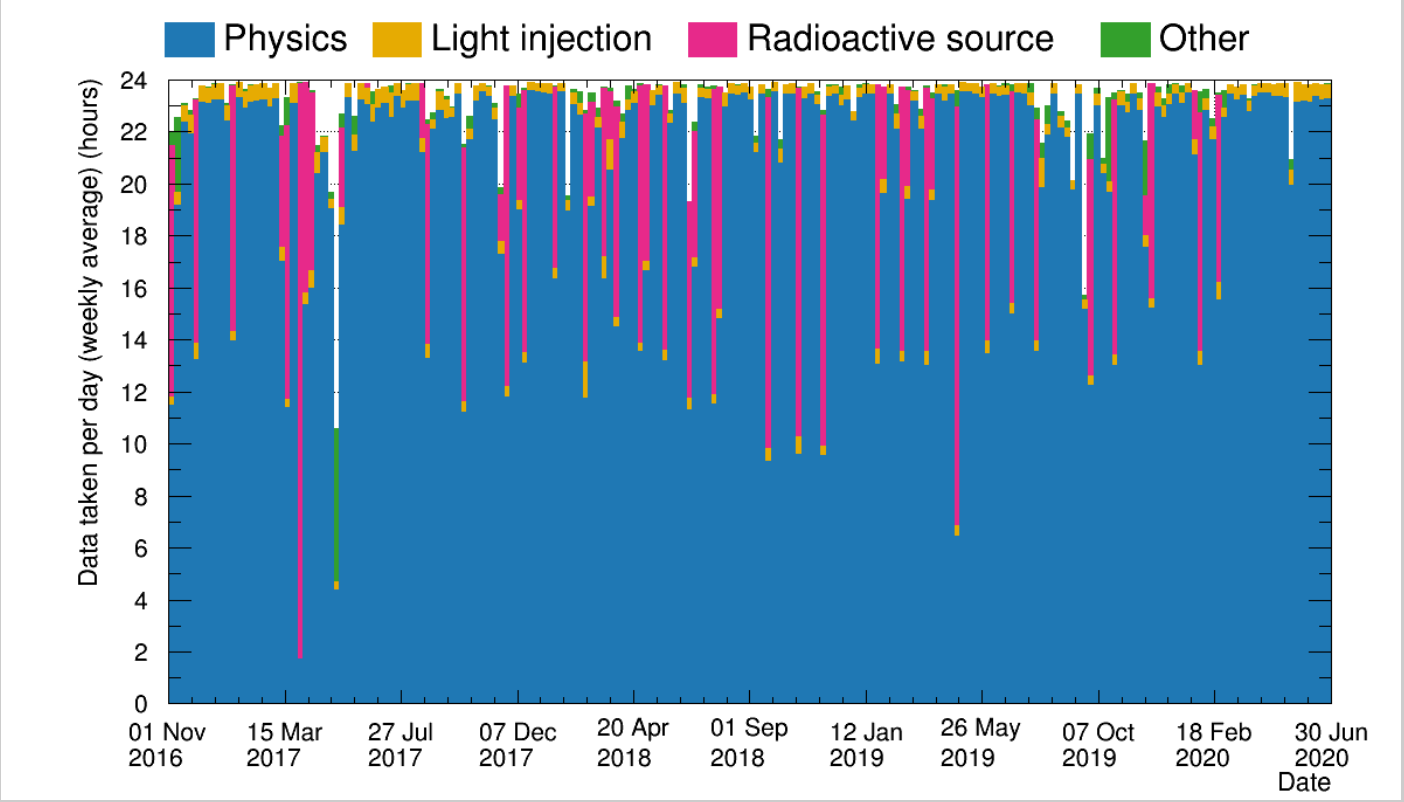
Dust particles shadow the scintillation light and degrade energy of the alpha particle



Machine Learning techniques applied to discriminate neck/dust events and signal events – work in progress

Dataset

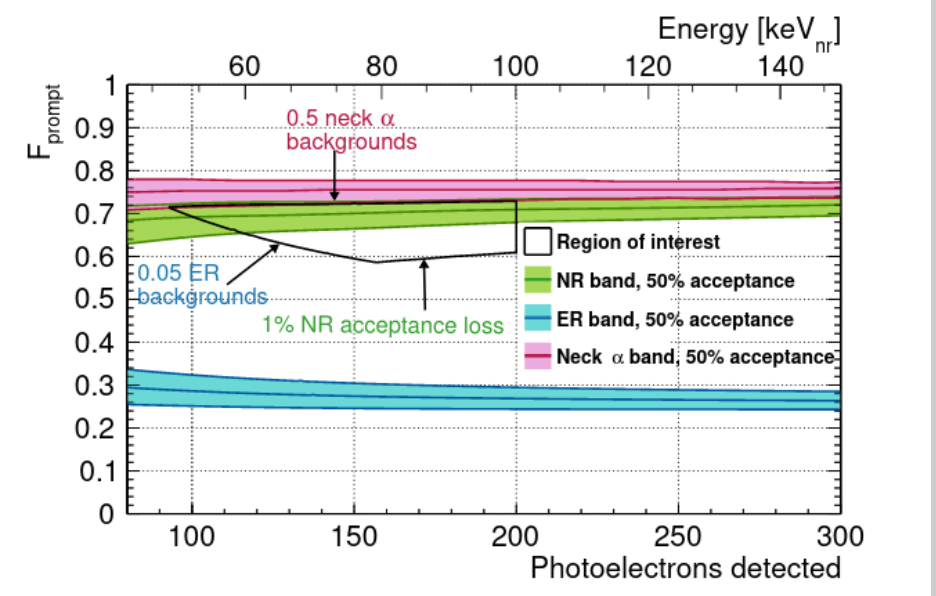
- Experiment has been running in current configuration since November 2016
- Since 1st of January 2018 80% of data is blinded
- Detector was drained on 28th March 2020 for upgrades
- Currently taking data with no LAr



Searching For WIMPs

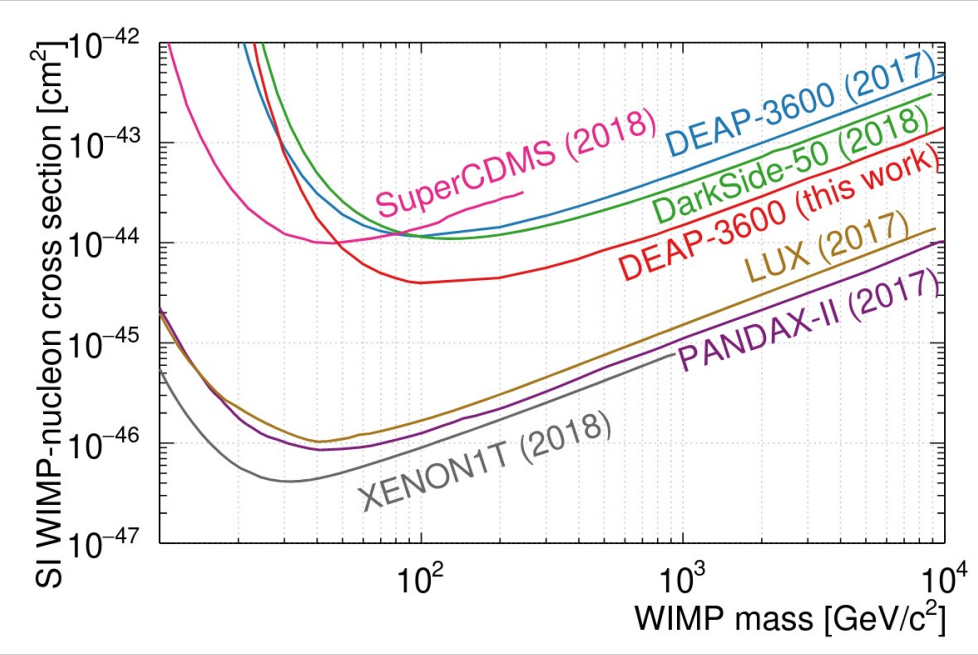
- Most Recent search used 231 days of livetime
- No MVA techniques used

	Background rejection cut	WIMP accept. [%]	$N_{\mathrm{bkg}}^{\mathrm{ROI}}$	$N_{\mathrm{obs}}^{\mathrm{ROI}}$
Cherenkov	Neck veto	$92.0^{+1.0}_{-0.1}$	$9.2^{+4.4}_{-3.5}$	29
α-decays in neck	Early pulses in GAr PMTs	$45.4^{+1.5}_{-0.1}$	$2.3^{+1.1}_{-0.9}$	2
	Position fitter consistency	$35.4^{+2.5}_{-0.1}$	$0.62^{+0.31}_{-0.28}$	0
	Total	$35.4^{+2.5}_{-0.1}$	$0.62^{+0.31}_{-0.28}$	0

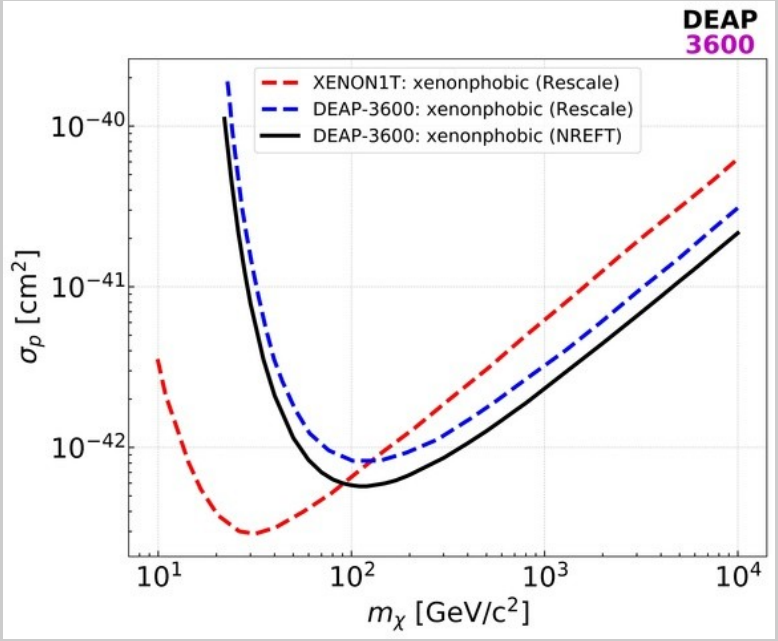


- WIMP search region defined by ROI
- ROI is defined such that expected number of events in ROI is < 1

Sensitivity (231 Day Dataset)



Current sensitivity of DEAP-3600 to WIMPs (90% CL) Assuming standard DM halo model (Phys. Rev. D 82, 023530) – No MVA techniques applied



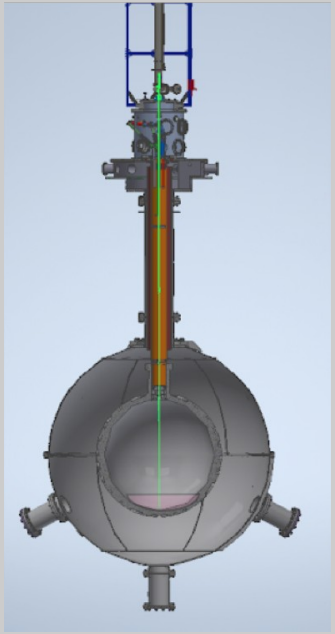
Can explore isopin-violating couplings – World leading sensitivity for certain configurations
https://arxiv.org/abs/2005.14667
https://arxiv.org/abs/1902.10256
Can also study sensitivities for various halo substructures

Detector Upgrades

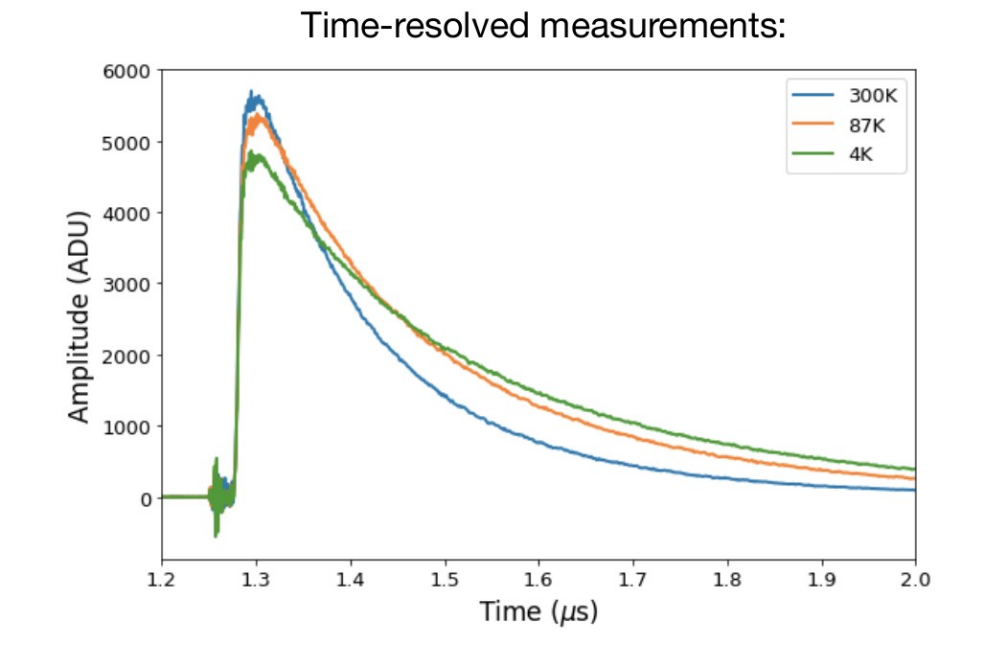
Upgrades are specifically designed to remove the neck and dust backgrounds.

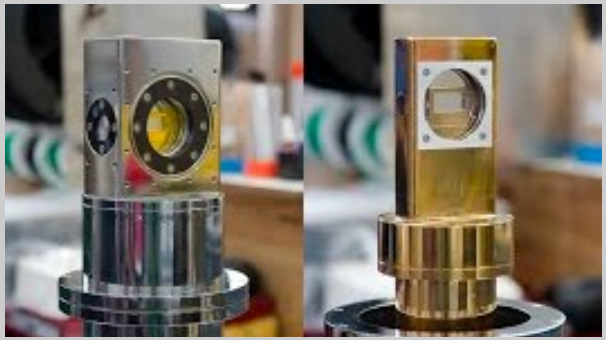
- **Alternate cooling system**
  - Allows warming of the neck – no LAr condensate on flow guides
  - Filtering of the LAr during cooling – removes dust particles

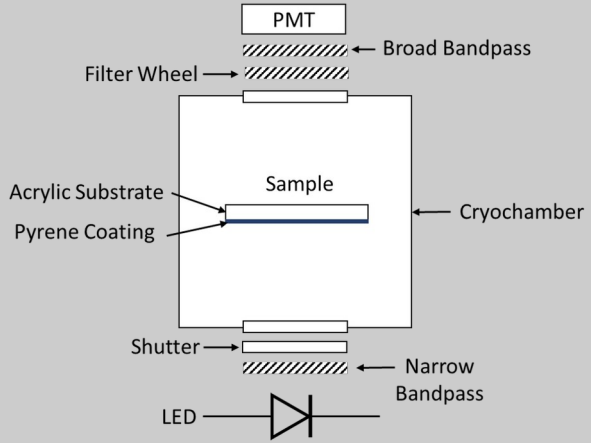
- **Flow guide coating**
  - Coat flowguides with long decay time wavelength shifter – alpha decays will then have low fprompt



Neck Coating







Pyrene coating selected for DEAP-3600

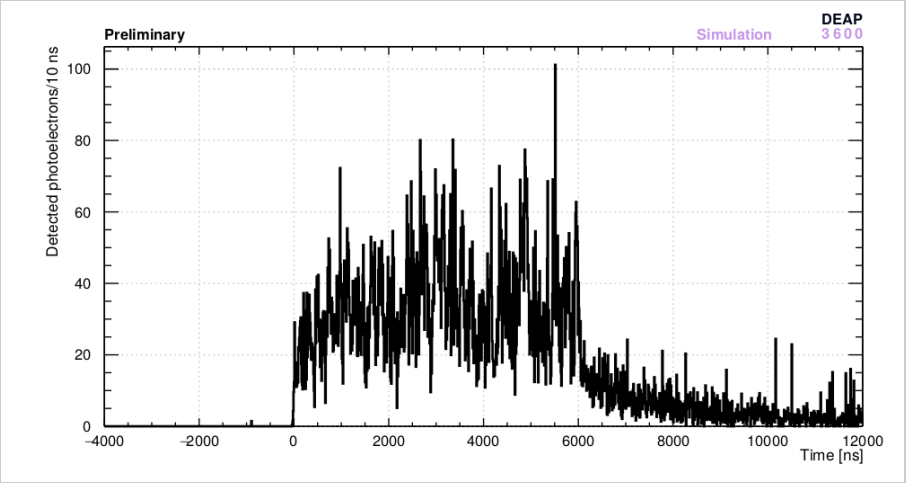
Long decay time of pyrene means neck events will have lower fprompt.

Ex-situ measurements characterising coatings performed

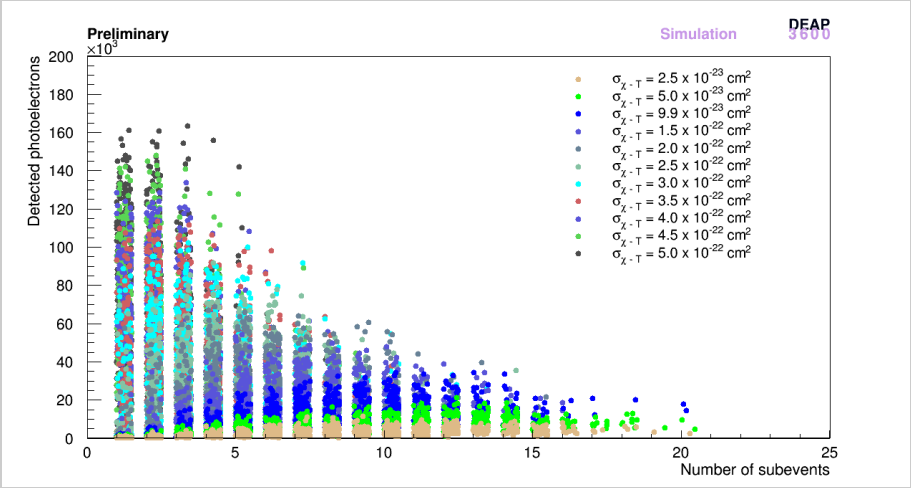
Search for Multiple Interacting Massive Particles

MIMPs are dark matter particles with large cross sections – scatter multiple times as they traverse the detector.

MIMPs have much higher masses – projected sensitivity of DEAP-3600 up to the Planck Mass



Simulated signal from a MIMP passing through the detector. Size of DEAP gives good sensitivity

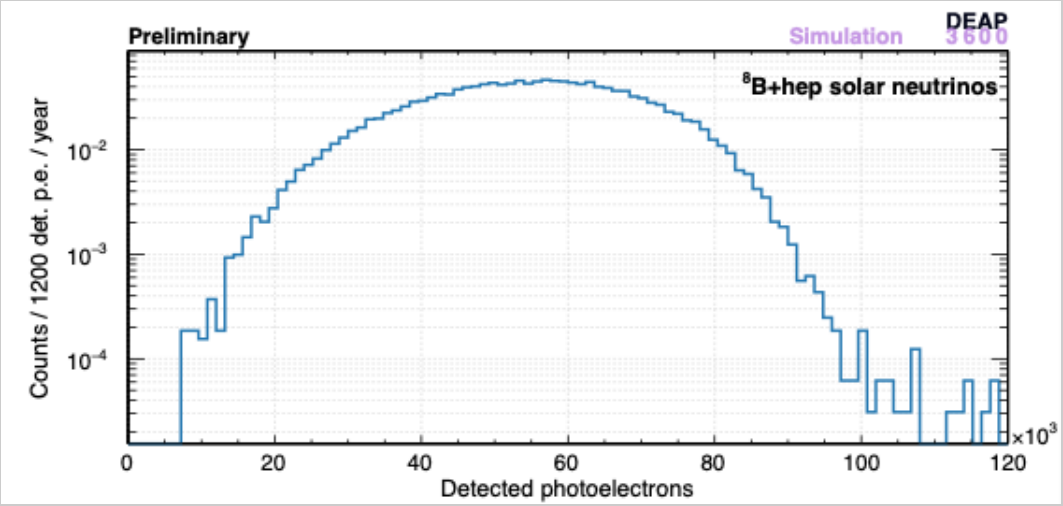


Expected signal from MIMPs for various cross sections.

For high cross section MIMPs unable to resolve individual scatterings

Solar neutrino absorption

$$^{8}\mathrm{B} \rightarrow ^{8}\mathrm{Be} + e^{+} + \nu_{e}$$ Q=18 MeV



Expected signal from neutrino absorbtion events (After trigger/tagging/nuclear decay corrections)

Look for ^{8}B solar ν_e via:

$$\nu_{e} + ^{40}\mathrm{Ar} \rightarrow ^{40}\mathrm{K}^{*} + e^{-}$$

$$E_{\nu_e} > 3.9\ \mathrm{MeV}$$

Golden Channel - 30% of the time excited state of ^{40}K decays via 1.64 MeV γ emission with mean lifetime of 480 ns

Expect up to 16 interactions in three years of live data. After various efficiency corrections expect 5-10 events in three years

Conclusions

- Original configuration of DEAP-3600 ran until March 2020
  - WIMP search data is currently blinded – analysis underway
  - MVA techniques being applied to reduce some backgrounds
- Detector Upgrades underway
  - Should significantly reduce degraded alpha backgrounds.
- The detector can also be used to perform other physics analyses
  - MIMPs
  - Solar Neutrinos