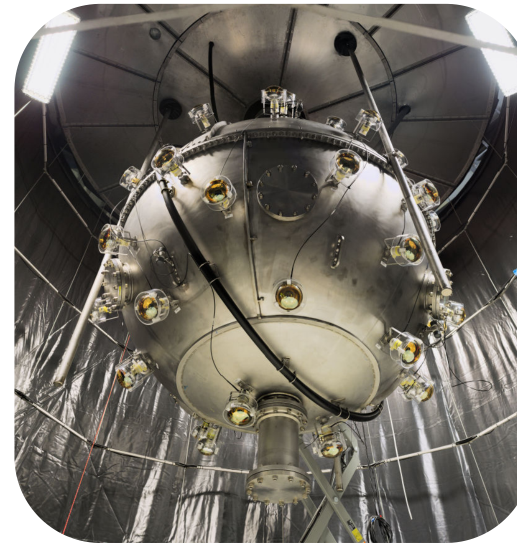
LATEST RESULTS FROM THE DEAP-3600 DARK MATTER SEARCH AT SNOLAB



ROBERT STAINFORTH

ON BEHALF OF THE DEAP-3600 COLLABORATION

FEBRUARY 11TH

LAKE LOUISE WINTER INSTITUTE 2019

DEAP-3600 Collaboration

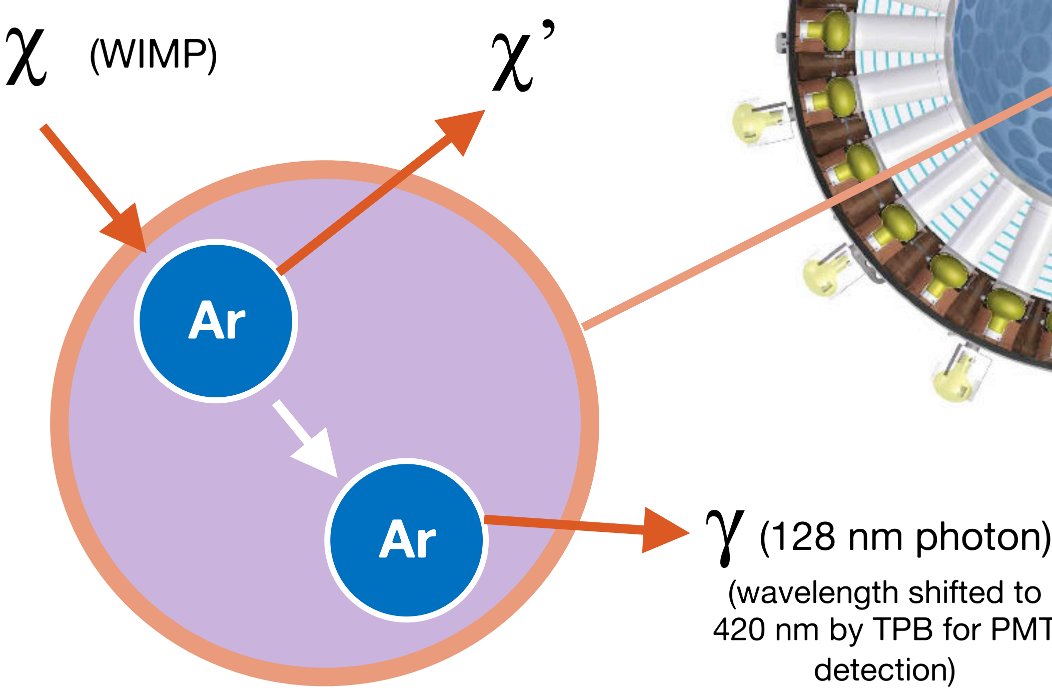
University of Alberta
Carleton University
Laurentian University / Université Laurentienne
Technische Universität München
Queen's University
Royal Holloway University of London
Particle Physics — Rutherford Appleton Laboratory
SNOLAB — Mining for Knowledge / Creuser pour trouver... l'excellence
University of Sussex
Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens
TRIUMF
Instituto de Física
National Research Center "Kurchatov Institute"
INFN — Istituto Nazionale di Fisica Nucleare
Ciemat

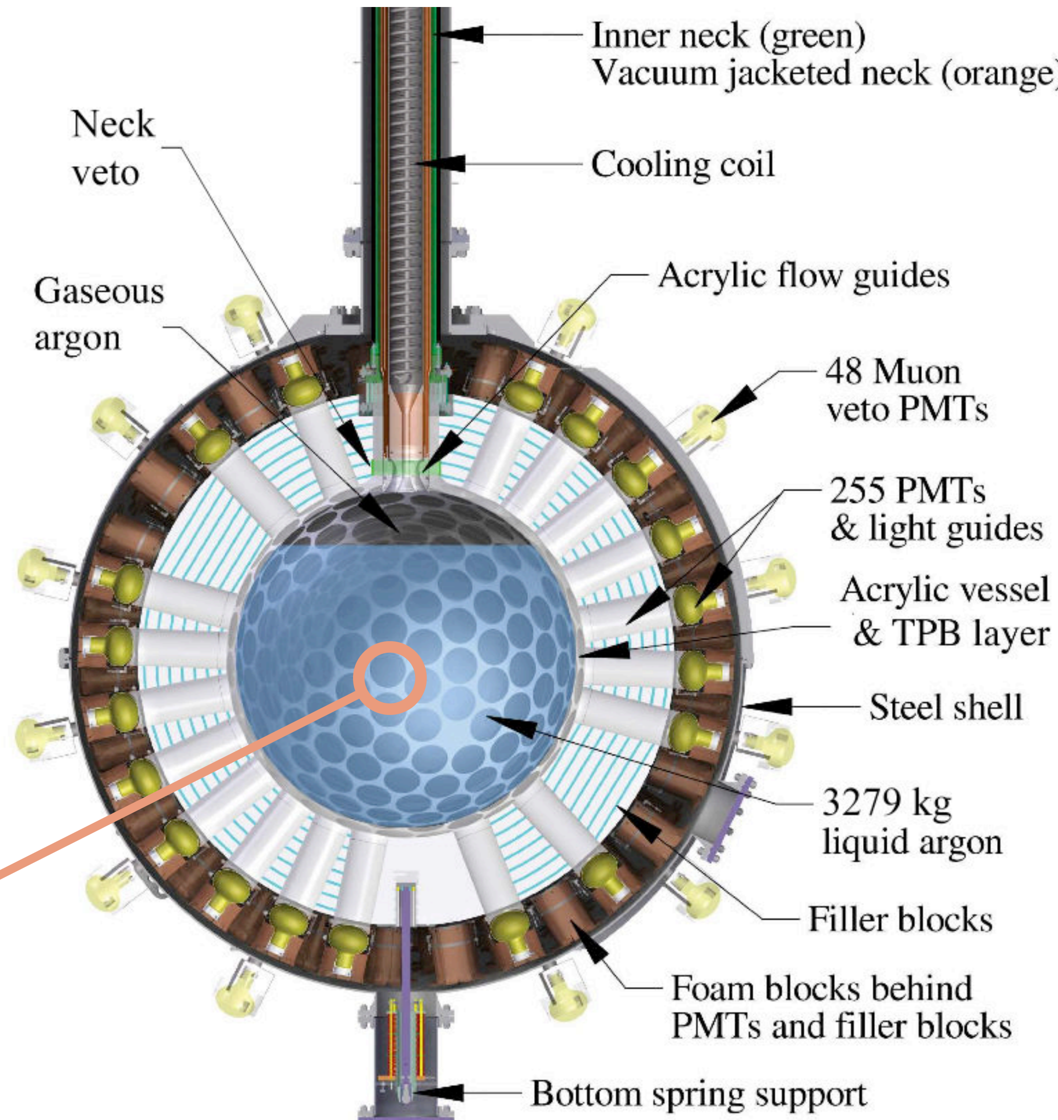
80+ researchers

Detector

Single-phase liquid argon (LAr) scintillation light detector design.

Sensitive to nuclear recoils **(NRs)** induced by dark matter particles such as **weakly interacting massive particles (WIMPs).**





DEAP-3600 detector

DEAP-3600 Timeline

Time

2006

Initial design phase

May, 2016

Fill detector with purified atmospheric argon

Aug, 2016

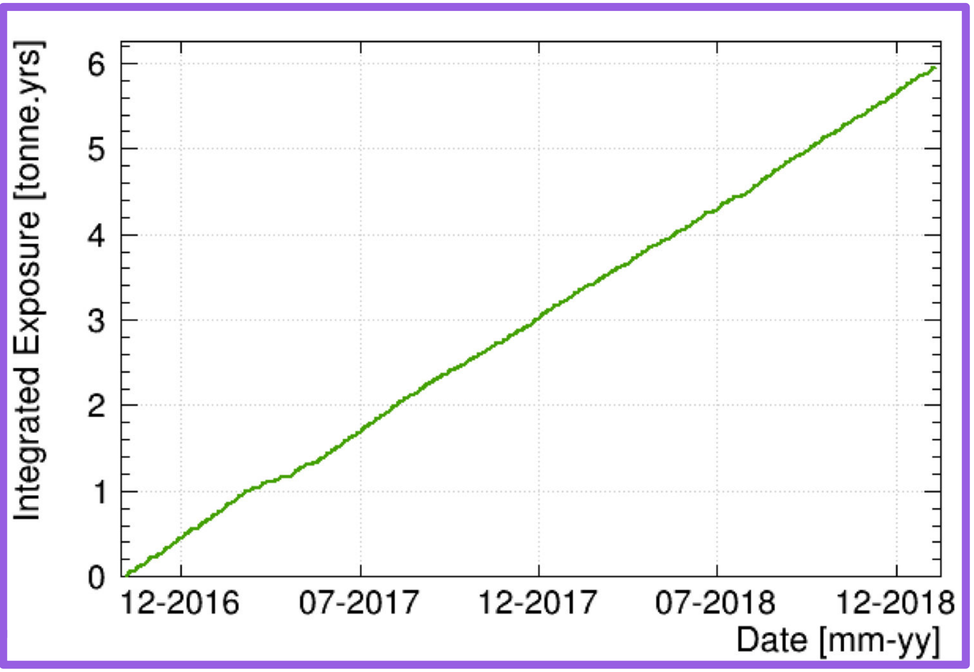
Collect first physics data for dark matter search

Nov, 2016 – Dec 2017

Collect physics data (open dataset)

Jan 2018 – present.

Collect physics data with blinding scheme (20% open).



To date, have collected a run time of ~ **6 tonne years** physics data.

Updated Results

Previously: Reported result from **4.4 live time day dataset** collected in August 2016.
Phys. Rev. Lett. 121, 071801

Today: Report updated result from **231 live time day dataset** collected in the period Nov 2016 – October 2017
Submitted to arXiv **today [Feb 11th, 2019]**
(to be submitted to Phys. Rev. D.)

Reaching Low Backgrounds

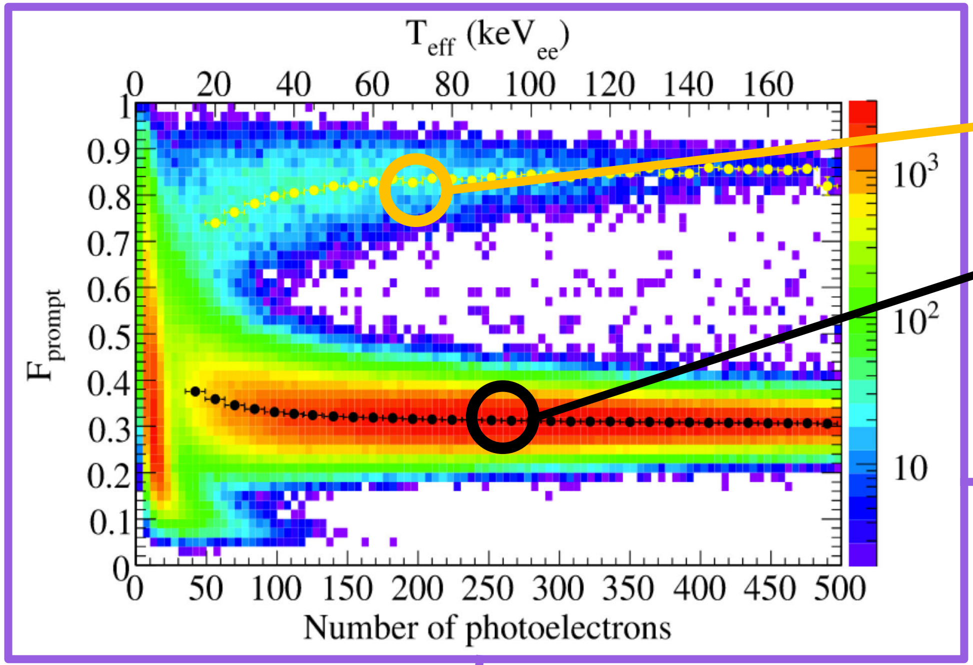
Dark matter searches **require very low background rates.**

Design: Careful material selection and assay of all detector components

- **Construction:** Resurfacing of components in contact with LAr
- **Analysis:** Discrimination of WIMP NRs from interactions of other particles (e.g. β, α, n).

Atmospheric argon contains Ar39, a β-decaying isotope ~ 1 Bq/kg

Corresponds to 3.1 kHz in DEAP-3600



Discrimination of electronic recoils from Ar39 with nuclear recoils from neutrons.
Result from DEAP-1: ***[Astro. Part., Vol 85, Dec 2016 p1-23]***

Particle Discrimination

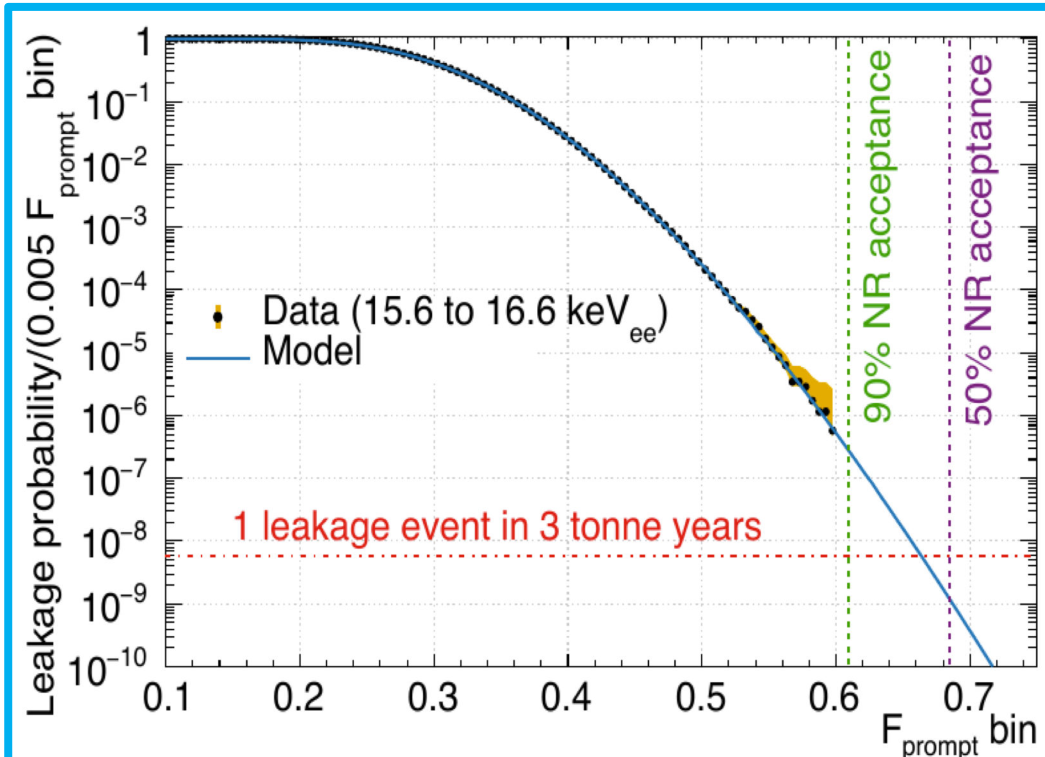
Arrival time of photons at PMTs dependent on particle type generating LAr scintillation **(e.g. β, α, n).** Integrating PE over time allows for **pulse shape discrimination (PSD).** Define '**Fprompt**' parameter.

Pulse Shape Discrimination (PSD)

Minimizing ER Leakage

Energy region of interest **(ROI)** for WIMPs: **95-200 PE** equiv. **15.6 – 32.8 keVee**. Have achieved best ever PSD between ERs and NRs in this analysis. Strongly suppress dominant source of detector events from the WIMP search.

Energy [keVee]	PSD leakage probability
15.6 (WIMP ROI threshold)	$2.8^{+1.3}_{-0.6}\times10^{-7}$ (90% NR acc.) $1.2^{+0.7}_{-0.3}\times10^{-9}$ (50% NR acc.)
15.6-32.8 (WIMP ROI Energy range)	**Average Value** $4.1^{+2.1}_{-1.0}\times10^{-9}$ (90% NR acc.) $3.5^{+2.2}_{-1.0}\times10^{-11}$ (50% NR acc.)

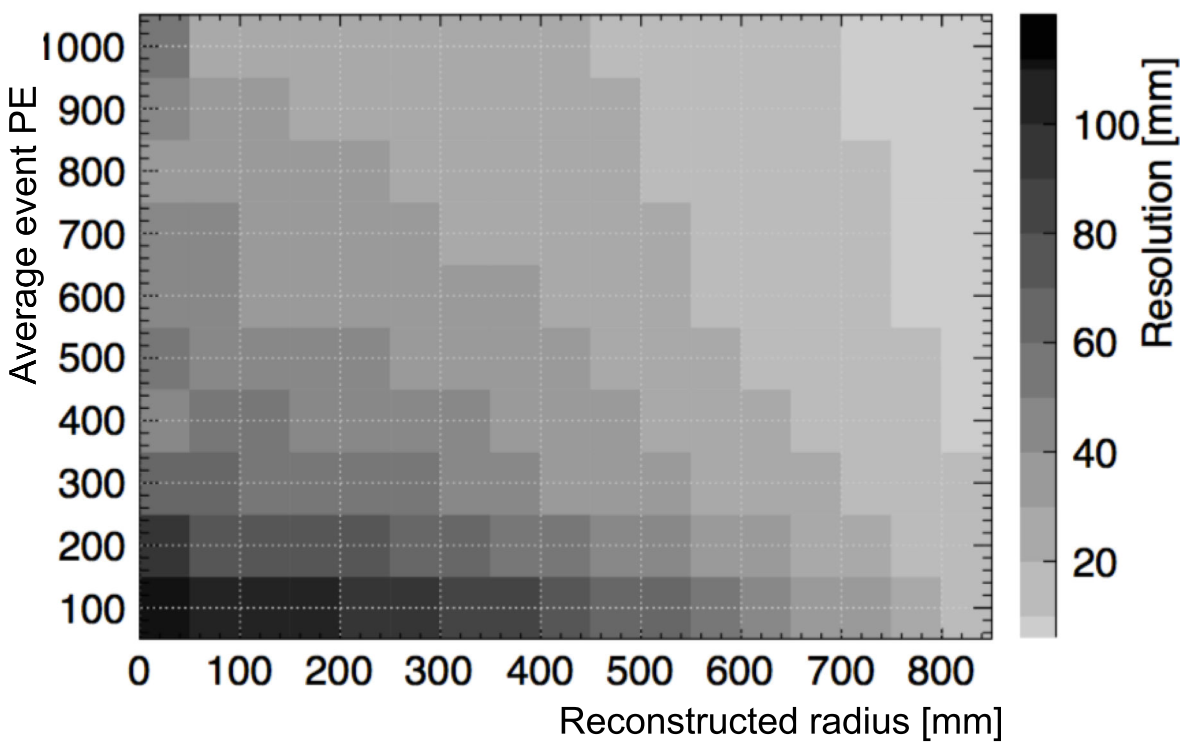


Left: Probability of an ER event being detected above a given Fprompt value at the WIMP threshold of 15.6 keVee in DEAP-3600.

Position Reconstruction

Use both **PMT-hit patterns** and **time** to **reconstruct and verify position** of scintillation events in the detector. Developed **two** position reconstruction algorithms (1) **PE-based,** (2) **PE+timing-based.**

- First-ever demonstration of position reconstruction in a single-phase liquid argon detector
- Position resolution of **~20 mm for events near detector surface** in WIMP energy ROI. Provides **excellent background rejection of surface events.**



Fiducial radius to mitigate external neutron, Cherenkov and surface background sources:
R < 630 mm

Left: Position resolution using **PE-based algorithm** on Ar39 ERs.

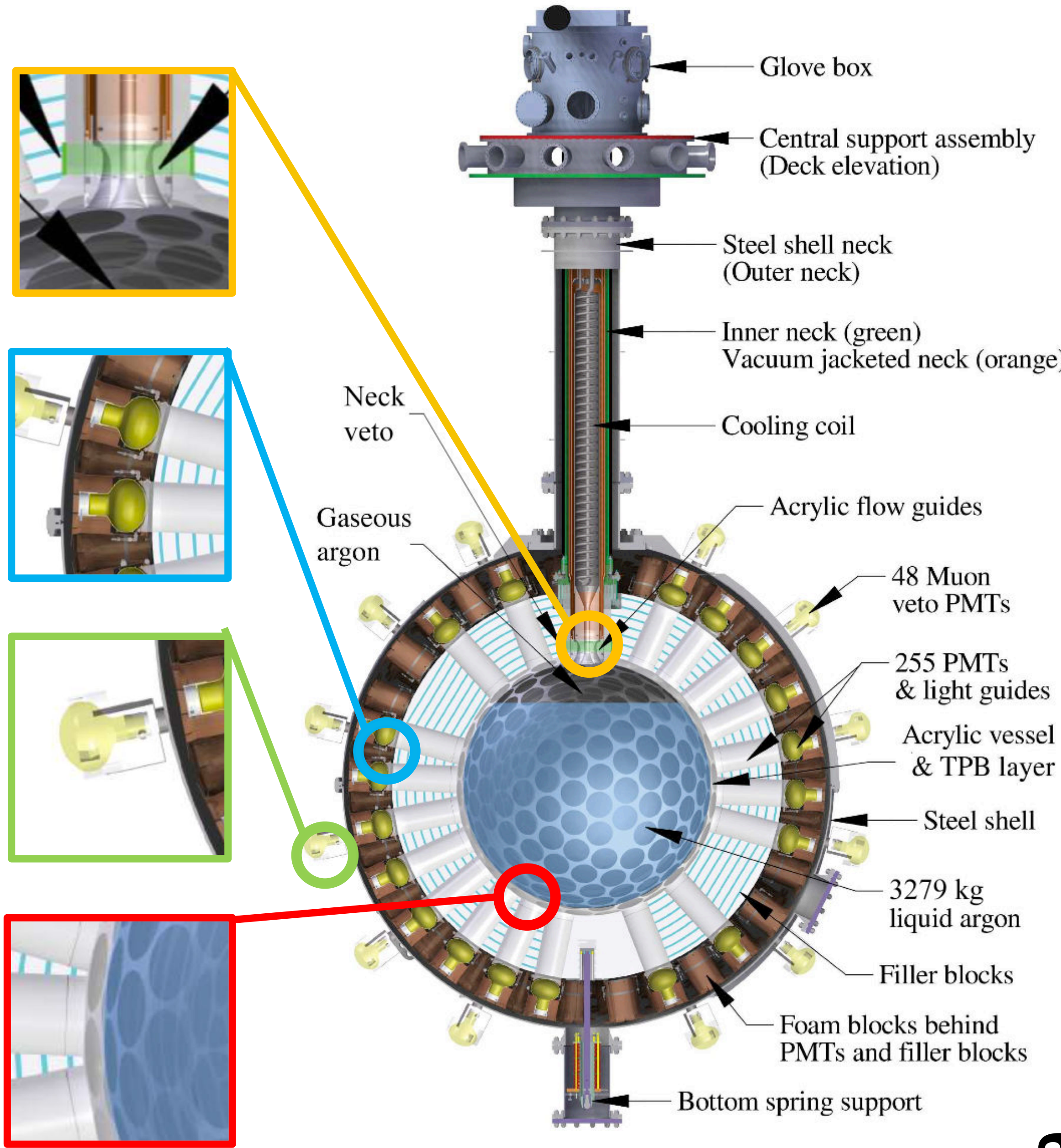
Backgrounds - Overview

Neck flowguides: Long-lived Rn222 progeny (e.g. Pb210) result in Po210 **α-decays** through LAr close to surface of acrylic flowguides.

PMTs: Primary source of **radiogenic neutrons** amongst other detector components. **β's & γ's** produced in PMT glass and **light guide acrylic** produce **Cherenkov** in acrylic.

External (Water & Rock): Cosmogenic induced neutrons produced inside water & rock.

AV surface: Po210 generates **α-decays** with degraded energy.
LAr: Ar39 ERs & α-decays from Rn222/Rn220 & their progeny

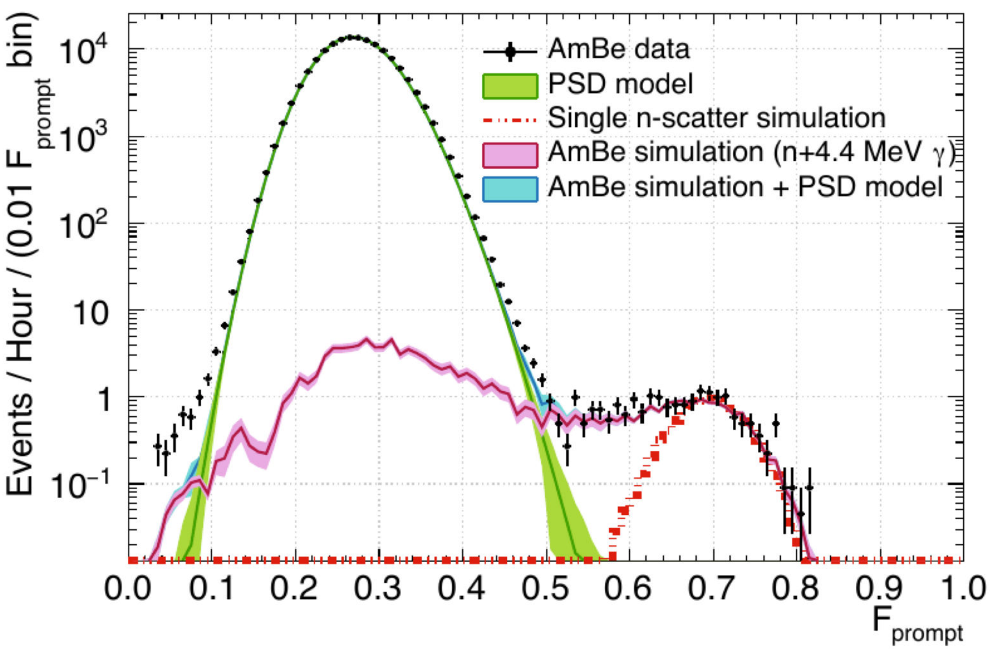


Backgrounds - Neutrons & Cherenkov

Deployed calibration sources used to **validate model for nuclear recoils induced by neutrons** and the detector response to **Cherenkov light.**

Cosmogenic Neutrons: SNOLAB depth of 2km shields against cosmogenic muons.
Background expectation: < 0.11 (90% C.L.) events in ROI
Radiogenic Neutrons: Based on Geant4/RAT simulations **normalized to material assay values**.
Validated via in-situ neutron tagging analysis on physics data and with an AmBe calibration source.
Background expectation: $0.10^{+0.10}_{-0.09}$ events in ROI

AmBe neutron calibration data



Cherenkov
Data collected with U232 calibration source (2.6 MeV γ's) informs cuts to remove Cherenkov.

Sideband analysis on physics data yields upper limit:
Background Expectation: < 0.14 (90% C.L.)

Left: Fprompt distribution in the 120-200 PE range for various neutron data & MC samples. Shown also is the ER Fprompt model (green).

Backgrounds – Alphas (AV Surface, LAr)

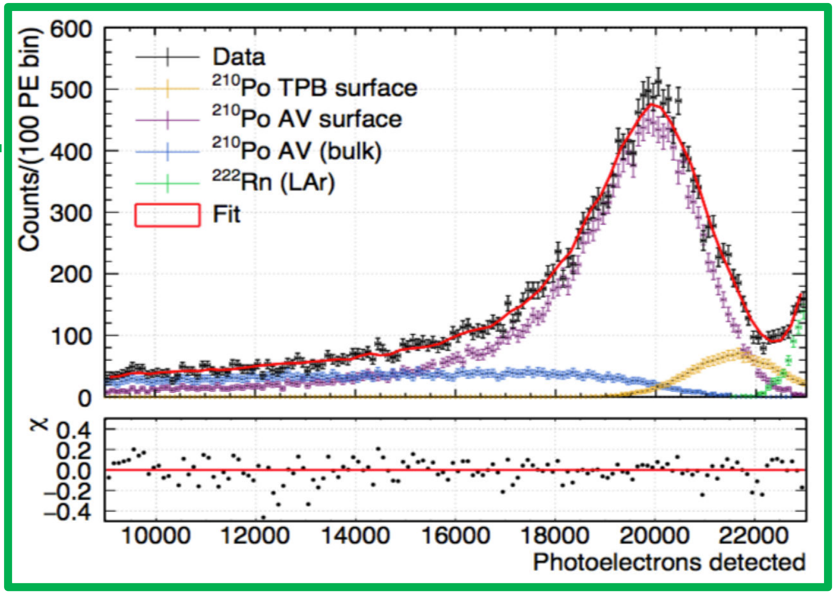
AV surface: Residual long-lived Pb210 nuclei on the AV surface result in **degraded Po210 α-decays.**
Background expectation: < 0.08 (90% C.L.) events in ROI

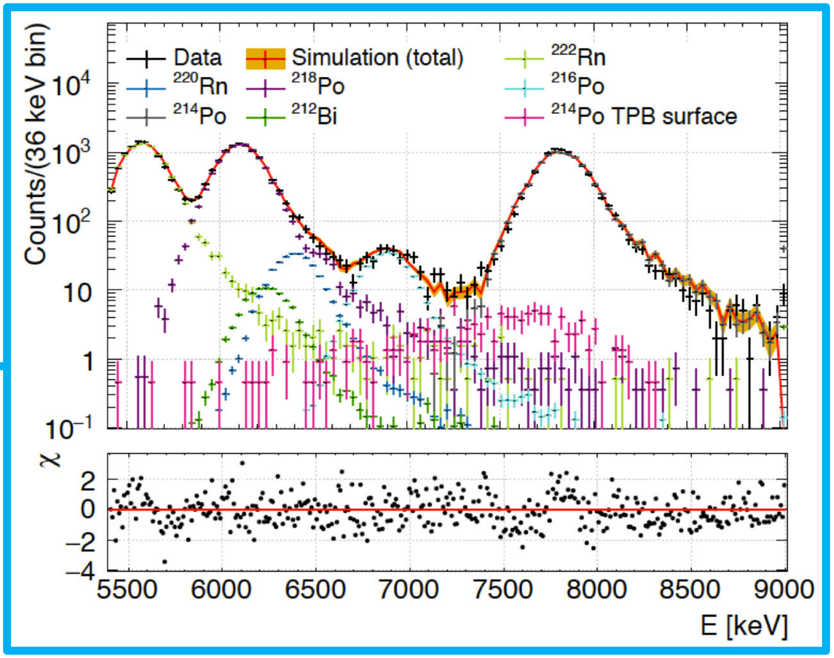
LAr Target: **α-decays** generated by **Rn222/Rn220 progeny** in **the LAr target trigger high energy events.** These do not impact the WIMP search.

Lowest reported Rn backgrounds for a dark matter experiment

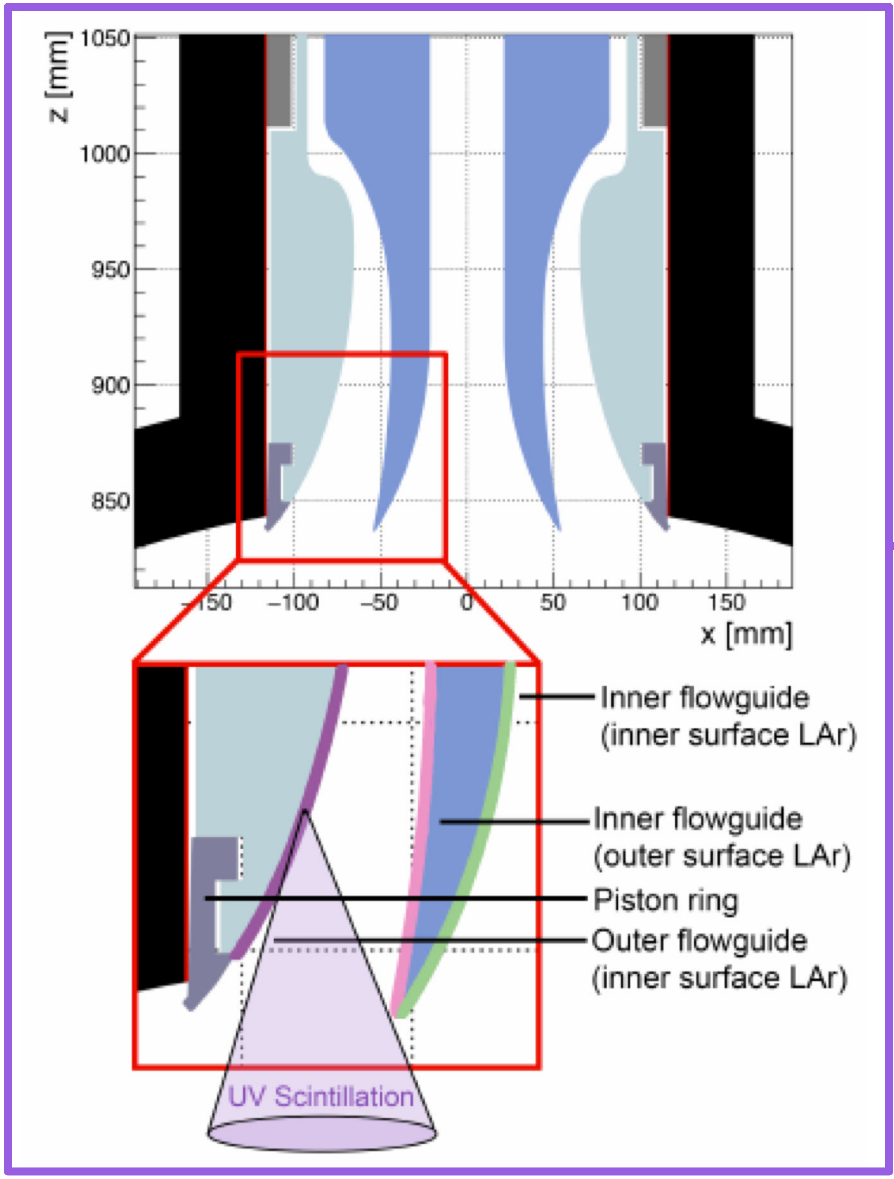
Component	Activity
^{222}Rn LAr	(0.153 ± 0.005) µBq/kg
^{218}Po LAr	(0.159 ± 0.005) µBq/kg
^{214}Po LAr	(0.153 ± 0.005) µBq/kg
^{214}Po TPB surface	< 5.0 µBq/m^2
^{220}Rn LAr	(4.3 ± 1.0) nBq/kg
^{216}Po LAr	(4.5 ± 0.4) nBq/kg
^{212}Bi LAr	< 5.6 nBq/kg
^{212}Po LAr	(3.4 ± 1.1) nBq/kg
^{210}Po TPB & AV surface	(0.26 ± 0.02) mBq/m^2
^{210}Po AV (bulk)	(2.82 ± 0.05) mBq

Summary of measured α-emitter activities





Backgrounds – Alphas (Neck)

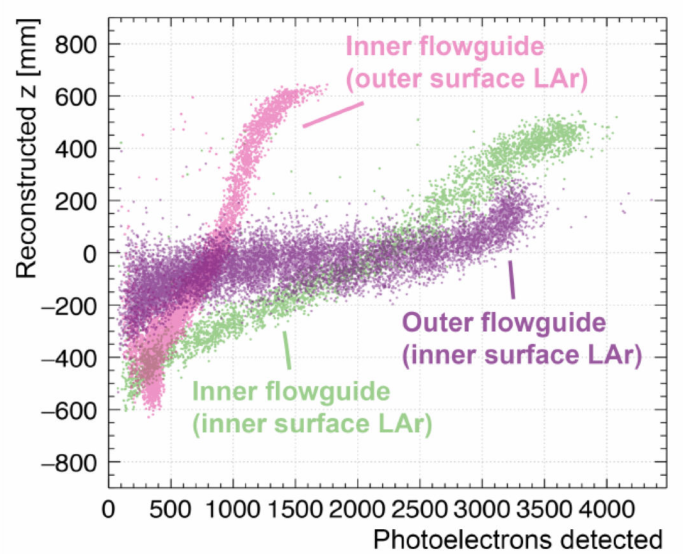


Po210 α-decays from the **surface of acrylic flowguides located in the neck** contribute to the background rate at low PE. **Requires LAr** located in close proximity to flowguide surfaces (e.g. a thin LAr film).

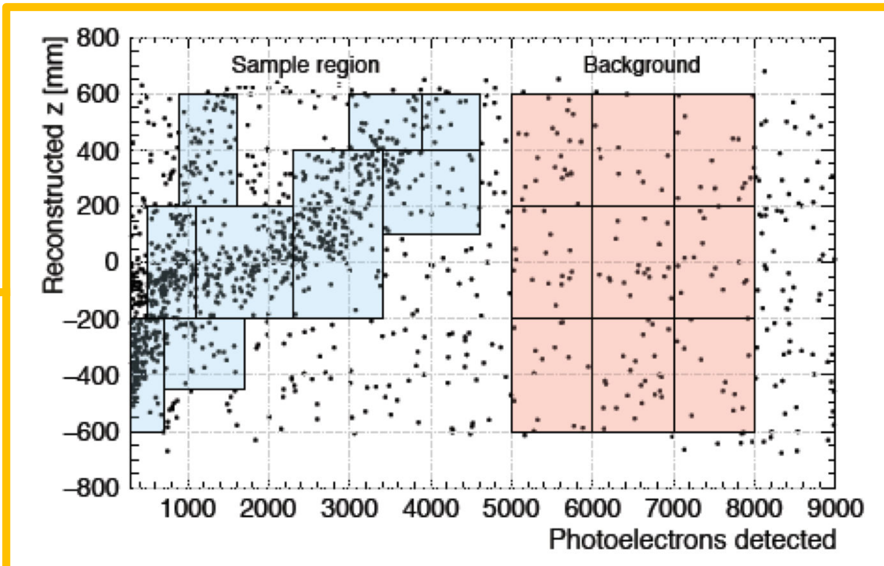
Acrylic absorbs most of the UV scintillation, resulting in ***shadowing*, generating low PE events** that reconstruct inside the fiducial volume.

Three distinct flowguide surfaces:
Inner flowguide, inner Surface
Inner flowguide, outer Surface
Outer flowguide, inner Surface

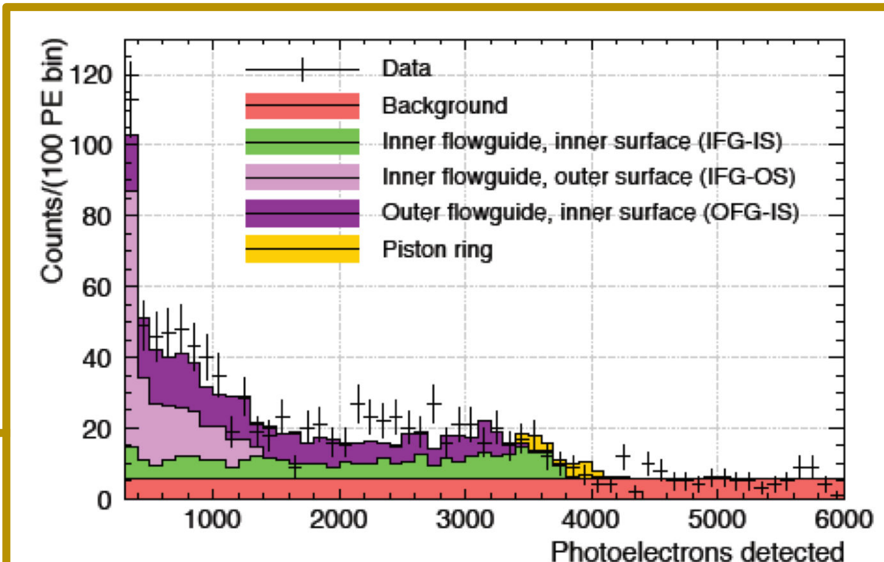
Backgrounds – Alphas (Neck)



Simulations of these neck events predict **distinct correlations between reconstructed z-position vs. PE.**



Features identified in data.



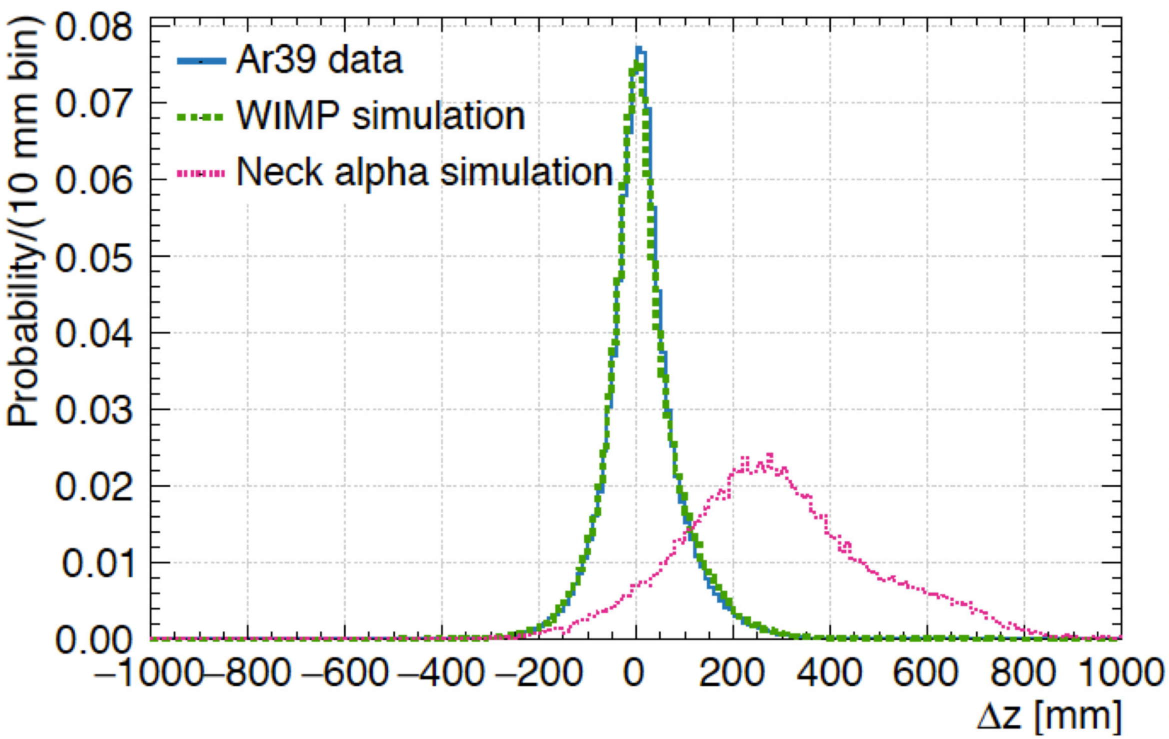
Fit to determine the rate of each component.

Backgrounds – Alphas (Neck)

A set of cuts are applied to mitigate neck alpha backgrounds. These cuts are based on charge and early time information in PMTs close to the neck. **These PMTs are sensitive to reflected UV photons at the GAr/LAr interface.**

Due to the origin of UV light from these events being from high up in the neck, a cut based on comparing the PE-based and PE+timing based position fitters is used to **test for mis-reconstruction and mitigate this background.**

Background expectation: $0.49^{+0.27}_{-0.26}$ events in ROI

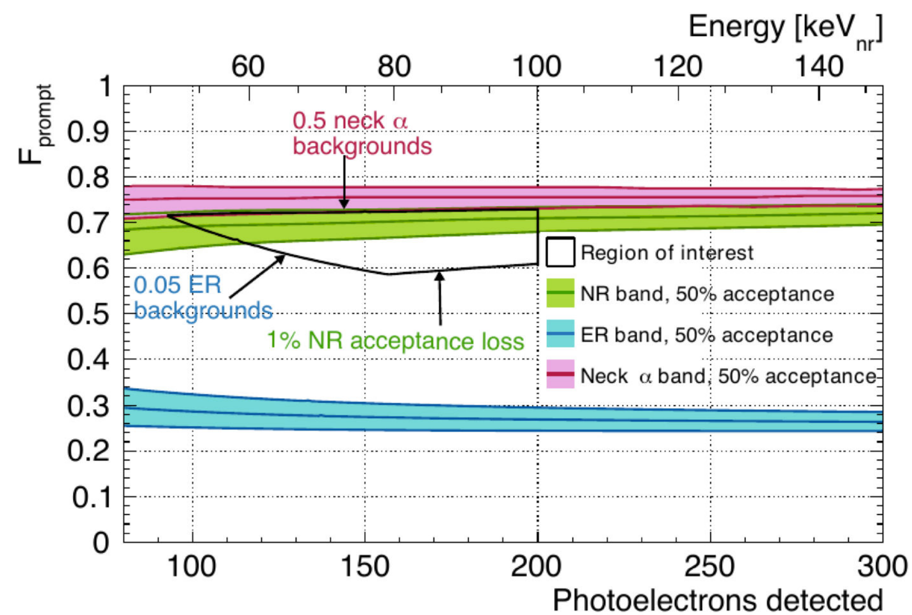


Left: Difference between the reconstructed z-position returned by the time residual-based fitter and the PE fitter (shown: z(time) – z(PE)).

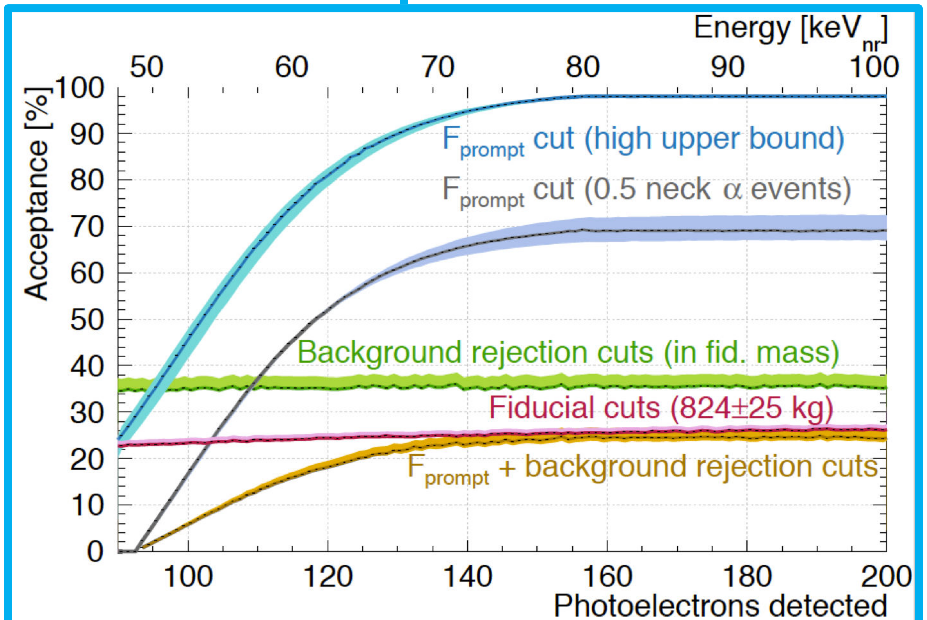
The PE+timing-based fitter is more sensitive to the origin of the early photons, reconstructing systematically higher along the z-axis.

Expectations & Cuts

Fiducial and background rejection cuts tuned on MC models characterized by physics & calibration data to reduce total number of expected background events to **< 1 event. This includes PSD of NRs from both ERs and α-decays.**



At a fiducial mass of 824 kg, average WIMP efficiency is 35.4%

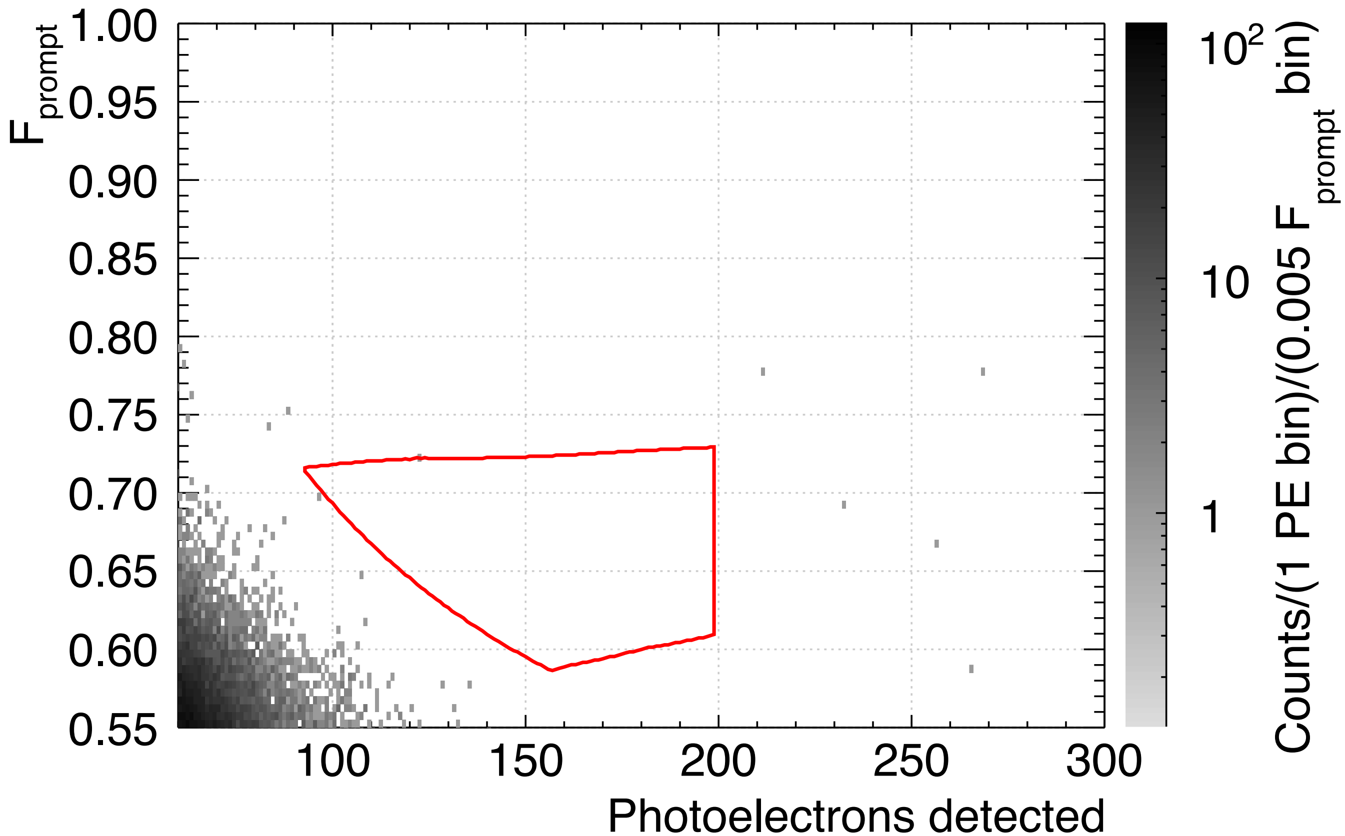


	Source	N^{ROI}
β/γ's	ERs	0.03 ± 0.01
	Cherenkov	< 0.14
n's	Radiogenic	$0.10^{+0.10}_{-0.09}$
	Cosmogenic	< 0.11
α's	AV surface	< 0.08
	Neck FG	$0.49^{+0.27}_{-0.26}$
	Total	$0.62^{+0.31}_{-0.28}$

Summary of background expectations

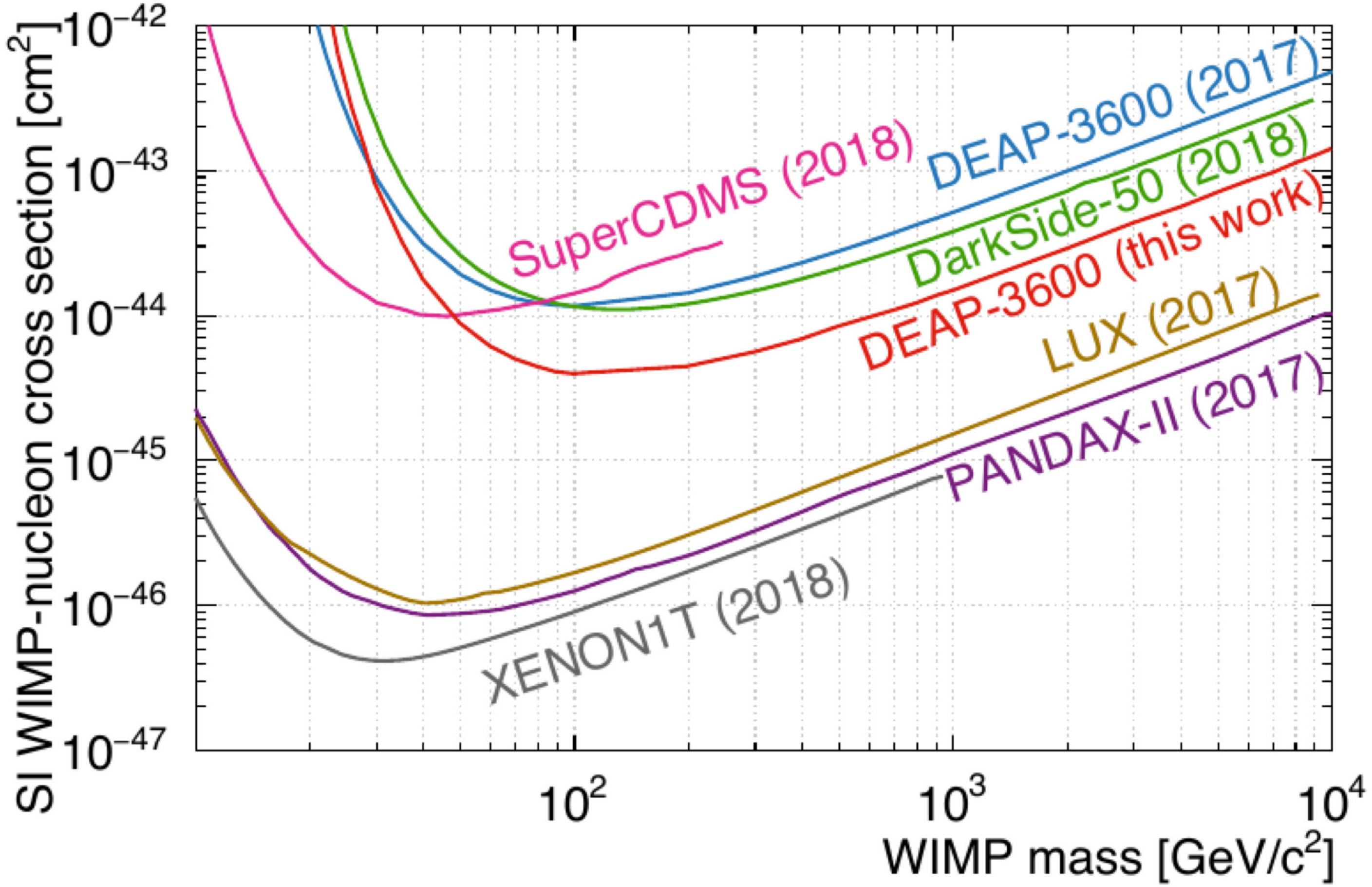
WIMP ROI

After applying all cuts, zero events remain in the ROI.



WIMP Sensitivity

This analysis excludes spin-independent WIMP nucleon cross sections above 3.9×10^{-45} cm^2 @ 100 GeV WIMP mass (90% C.L.). This is a leading result for argon detectors and complementary to the results obtained from Xe-based experiments.



Conclusion & Future Prospects

- DEAP-3600 updated results to excludes spin-independent WIMP nucleon cross sections above **$3.9\times10^{-45}\ cm^2$ @ 100 GeV WIMP mass (90% C.L.).**
- Most powerful demonstration of pulse shape discrimination (PSD) between electronic recoils (ERs) and nuclear recoils (NRs).
- Demonstrated PE-based and PE+timing based position reconstruction in single phase LAr detector for mitigation of external backgrounds.
- Lowest reported Rn222 (Rn220) backgrounds in LAr: **0.15 μBq/kg (4 nBq/kg).**

- Experiment collecting **blind data since January 2018** onwards with 20% unblinded for study.
- Backgrounds from the AV neck are currently the limiting factor. Working on ways to improve WIMP sensitivity through **multivariate analyses.**
- Will collect data **until at least end of 2020**, updating sensitivity calculations for as-measured detector response.
- Developing **new calibration sources** to reduce uncertainty on detector response enabling the more sensitive multivariate analysis.
- Participating in the **DarkSide-20k experiment** and developing plans for future **300-tonne detector at SNOLAB** to increase sensitivity a further factor of ~500, to the neutrino floor.

END

Backup: WIMP ROI and Surrounding Events

Region A
Predict: $0.46^{+0.13}_{-0.18}$
Observe: 1
P(X≥1): 36%

Region B
Predict: $1.25^{+0.26}_{-0.42}$
Observe: 4
P(X≥ 4): 3.8%

ROI
Predict: $0.62^{+0.31}_{-0.28}$
Observe: 0
P(X= 0): 55%

- Predicted neck alpha events more dependent on uncertainty in modelling the light yield for events originating in the AV neck.
- Large variations in the neck alpha light yield and position reconstruction response required to predict event rates consistent with the observation in this region.
- Does not significantly affect the WIMP exclusion analysis presented here.

- Observed excess over the nominal model also extends to regions above 300 PE.
- Aim of future analyses will explore the inclusion of additional background sources, above the upper PE bound of the WIMP ROI. Further constraints on the relevant response functions will also be a focus.