Dark matter search with DEAP-3600

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(Carleton University)

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DEAP Collaboration: 75 researchers in Canada, UK, Germany, Mexico
(+ future collaborators from Italy, USA)

UNIVERSITY OF ALBERTA

Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens

Carleton UNIVERSITY

Laurentian University
Université Laurentienne

Instituto de Física

Queen's UNIVERSITY

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Particle Physics
Rutherford Appleton Laboratory

Science & Technology Facilities Council

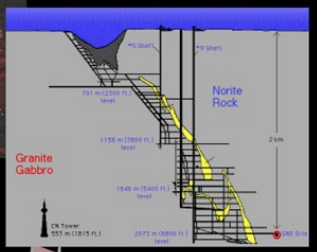
SNOLAB

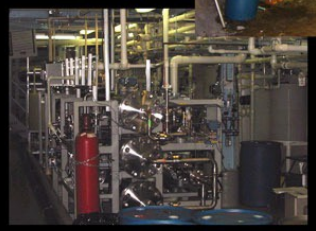
University of Sussex

Technical University of Munich

TRIUMF

Cube Hall
(DEAP-3600, MiniCLEAN)

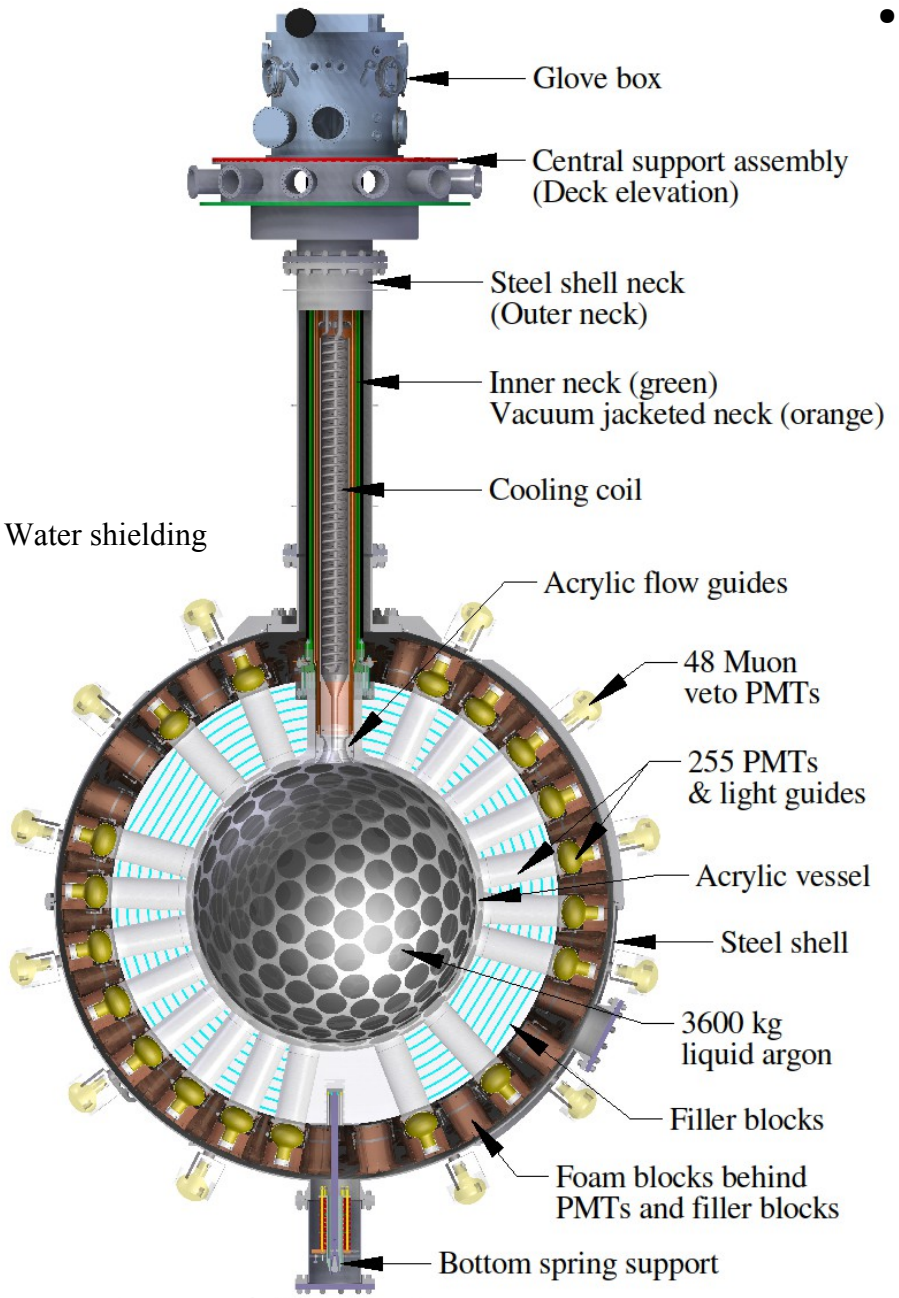




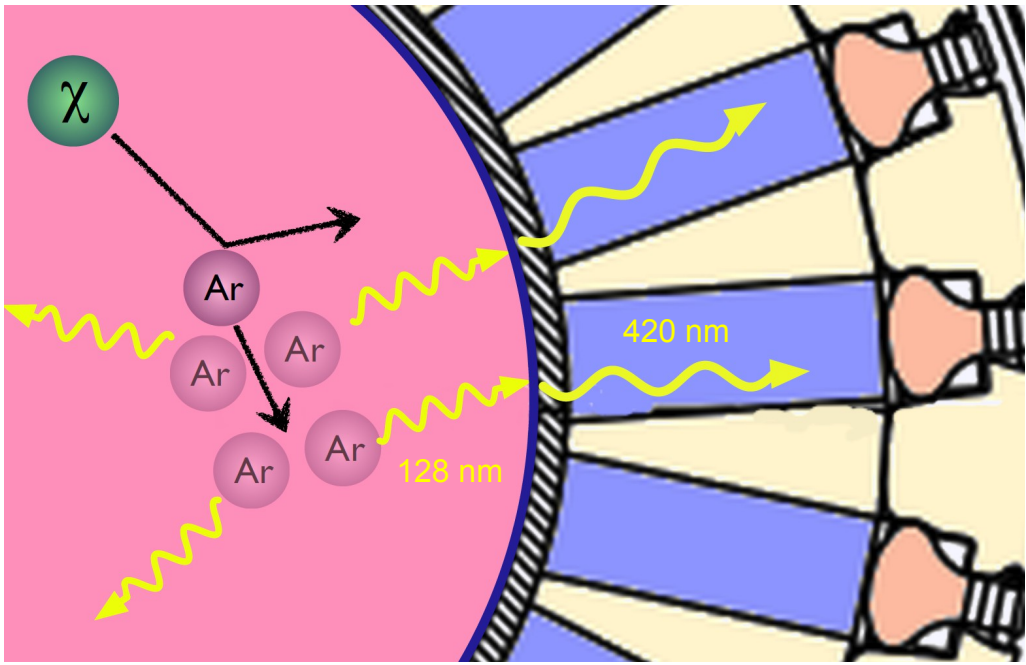
SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

2070 m underground

DEAP-3600

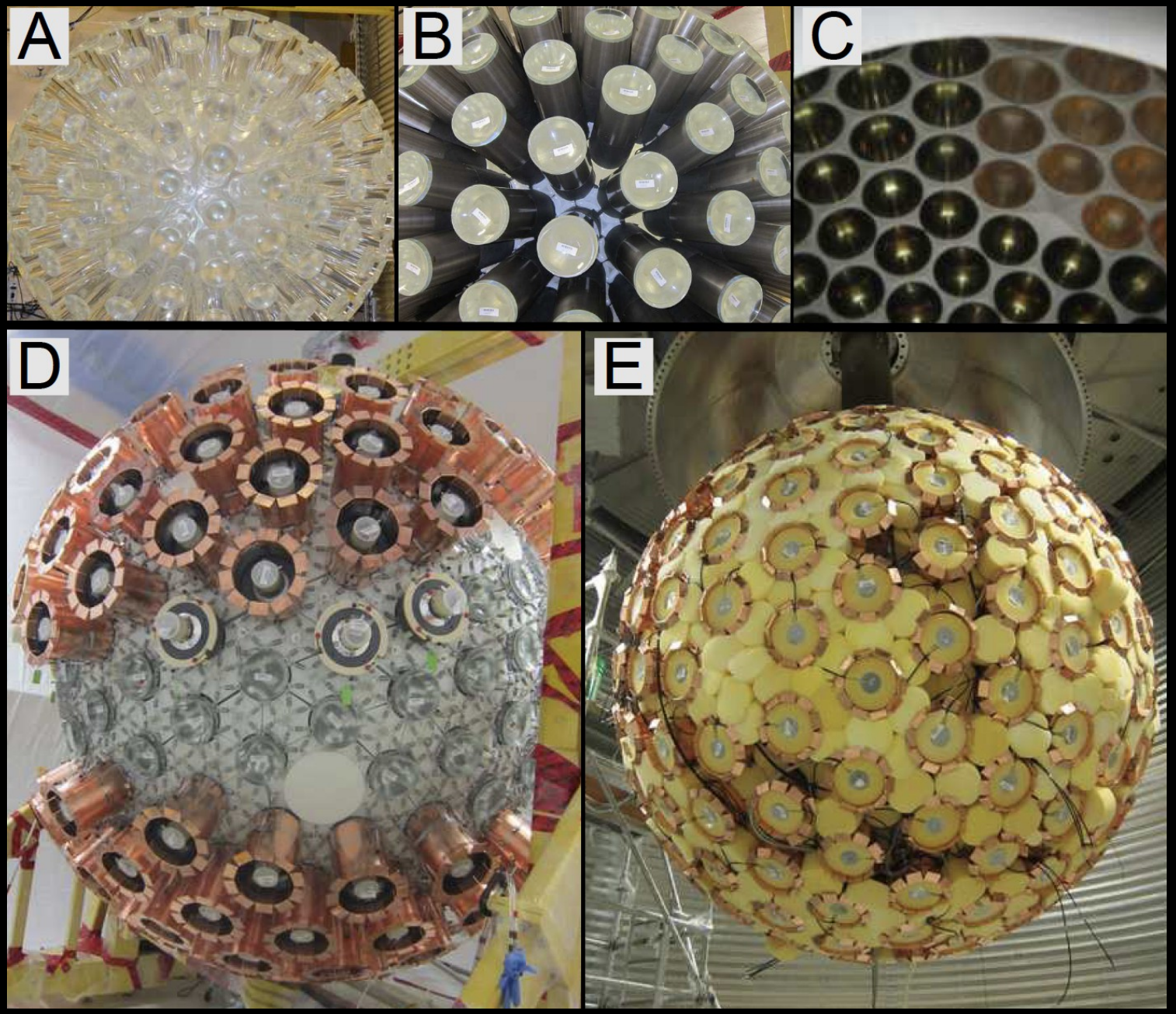


- **D**ark matter **E**xperiment using **A**rgon **P**ulse-shape discrimination
  - Design mass: 3600 kg of liquid argon (LAr)
    - Largest acrylic cryostat ever built
  - Goal: Detect dark matter particles colliding with argon nuclei



  - UV scintillation light from LAr nuclear recoils is wavelength-shifted to visible at TPB layer, then collected by photomultiplier tubes (PMT)

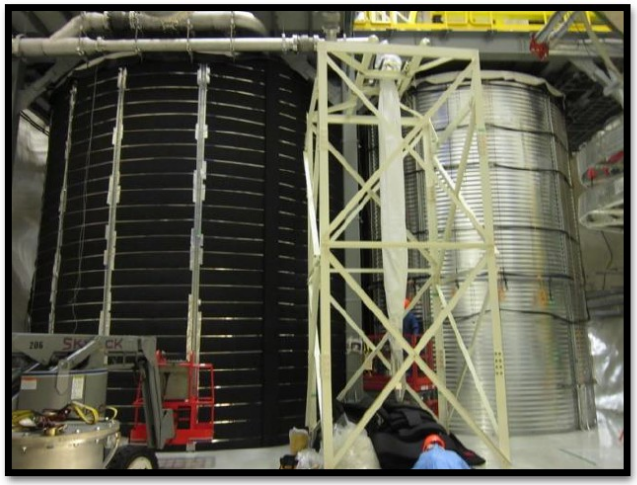
Light guides Reflectors Inside view

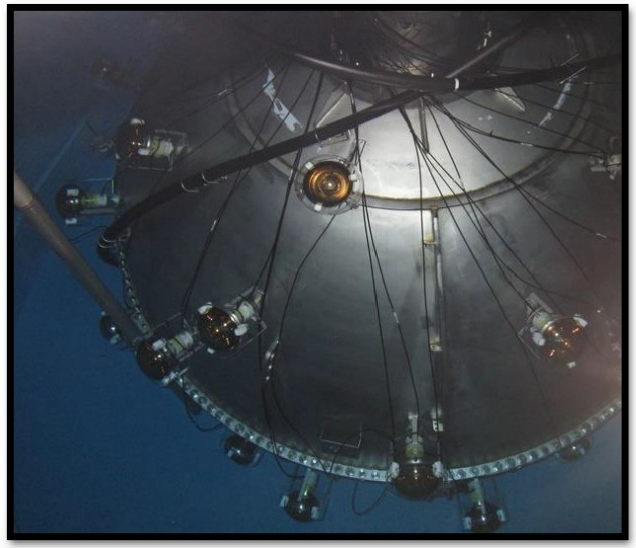


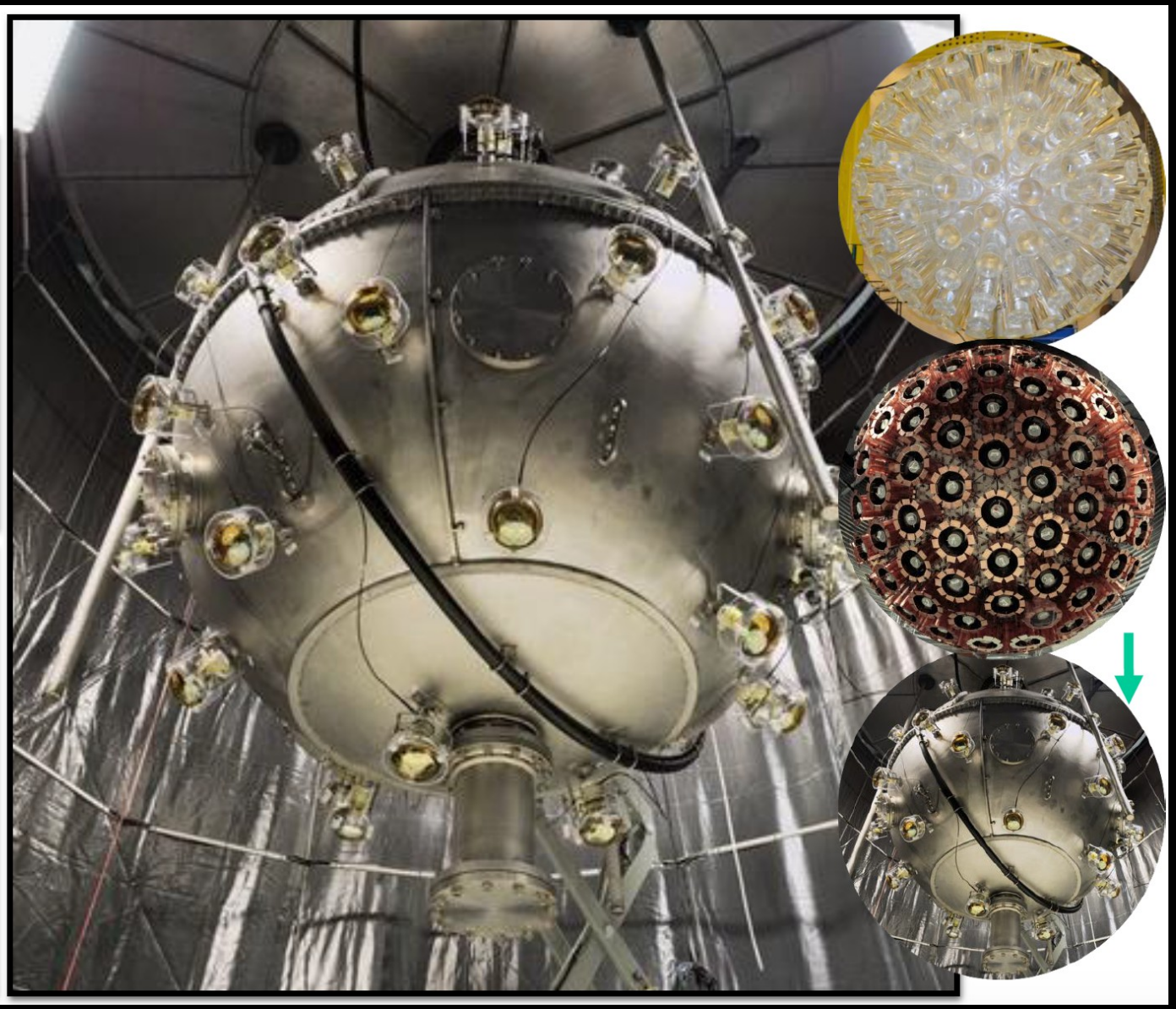
PMT installation Backing foam installation

Steel shell, Veto PMTs

Water tanks in Cube Hall

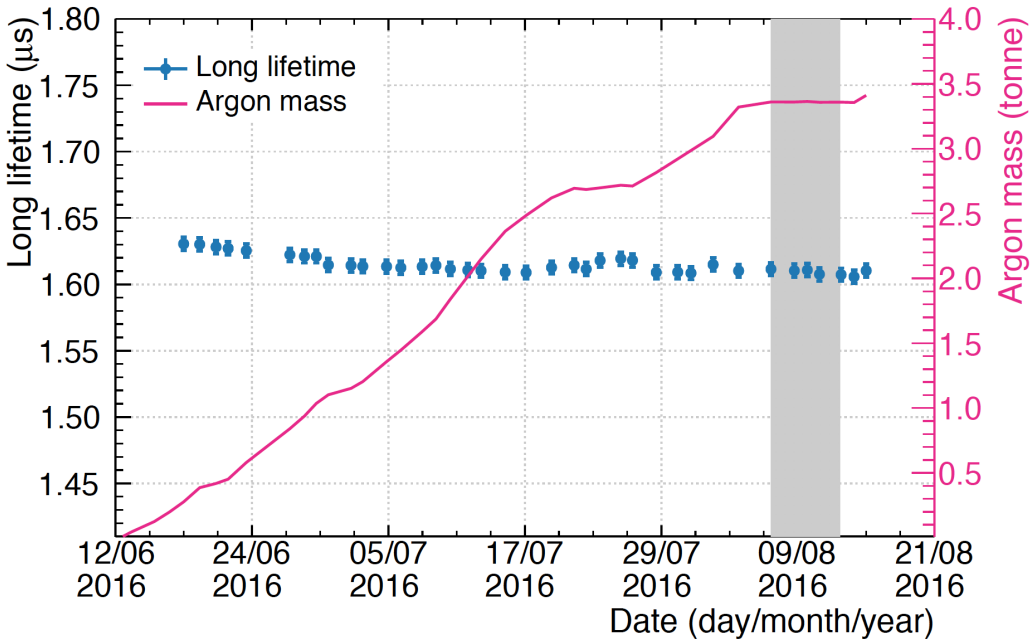




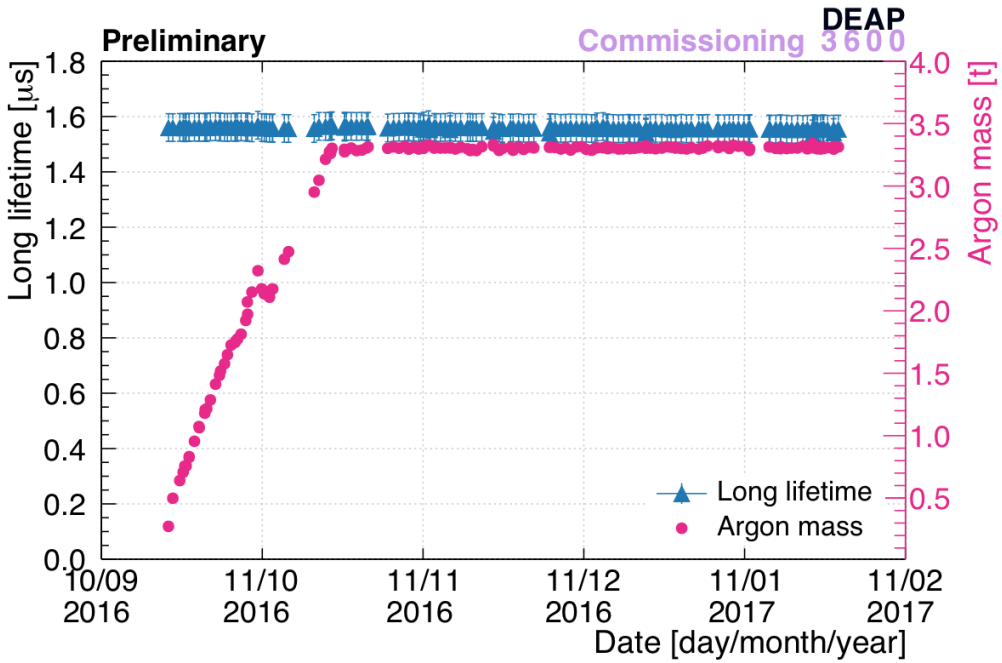


All details now available in the DEAP-3600 detector paper! arXiv:1712.01982

DEAP-3600: Datasets



First fill: June – August 2016



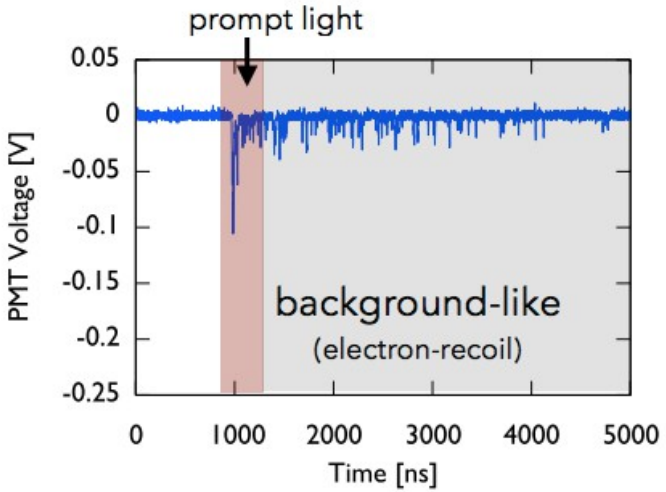
Second fill: September – October 2016

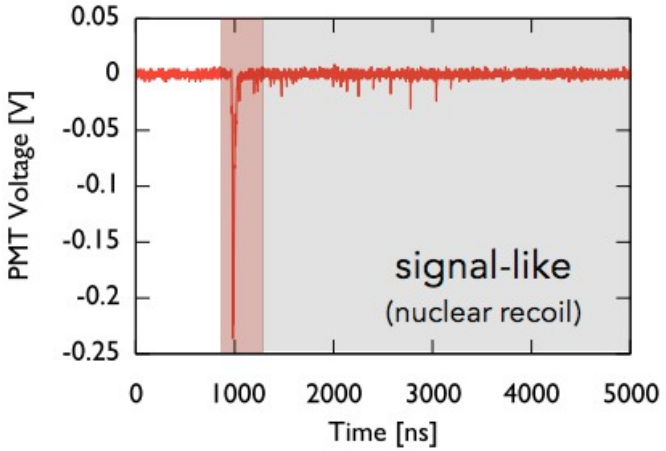
- Detector filled up to 3322 kg of LAr in summer 2016
  - Collected 9.1 days of data (**4.4 live days** passing DQ) → Our first dark matter search!
  - Incident on August 17, 2016: a leak in neck region let about 100 ppb N_2 into LAr volume
    - Decided to drain and re-fill to slightly lower level
- DEAP-3600 now taking data with 3256 kg of LAr since November 1st, 2016

Pulse-Shape Discrimination

- Liquid argon is suitable for very large targets
  - Transparent to its own scintillation light
  - Easy to purify
  - Much lower cost compared to xenon
- ... but there is **^{39}Ar**: β decays around 1 Bq/kg in natural argon
- Solution: **Pulse-shape discrimination** (PSD)
  - Scintillation via two lowest excited states, with very different lifetimes
    - Singlet state: **6 ns** (“prompt light”)
    - Triplet state: **1.3 µs** (“late light”)
  - Nuclear recoils excite predominantly the singlet state → **signal events have more prompt light** !
- Further, long-term solution: Argon depleted in ^{39}Ar

  DarkSide: Masayuki Wada's talk on Wednesday

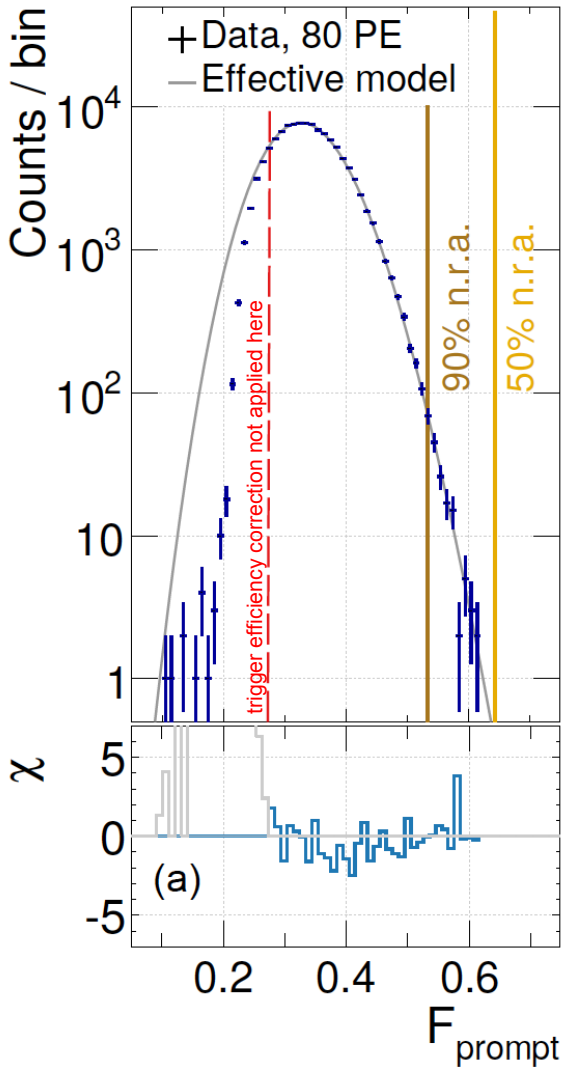


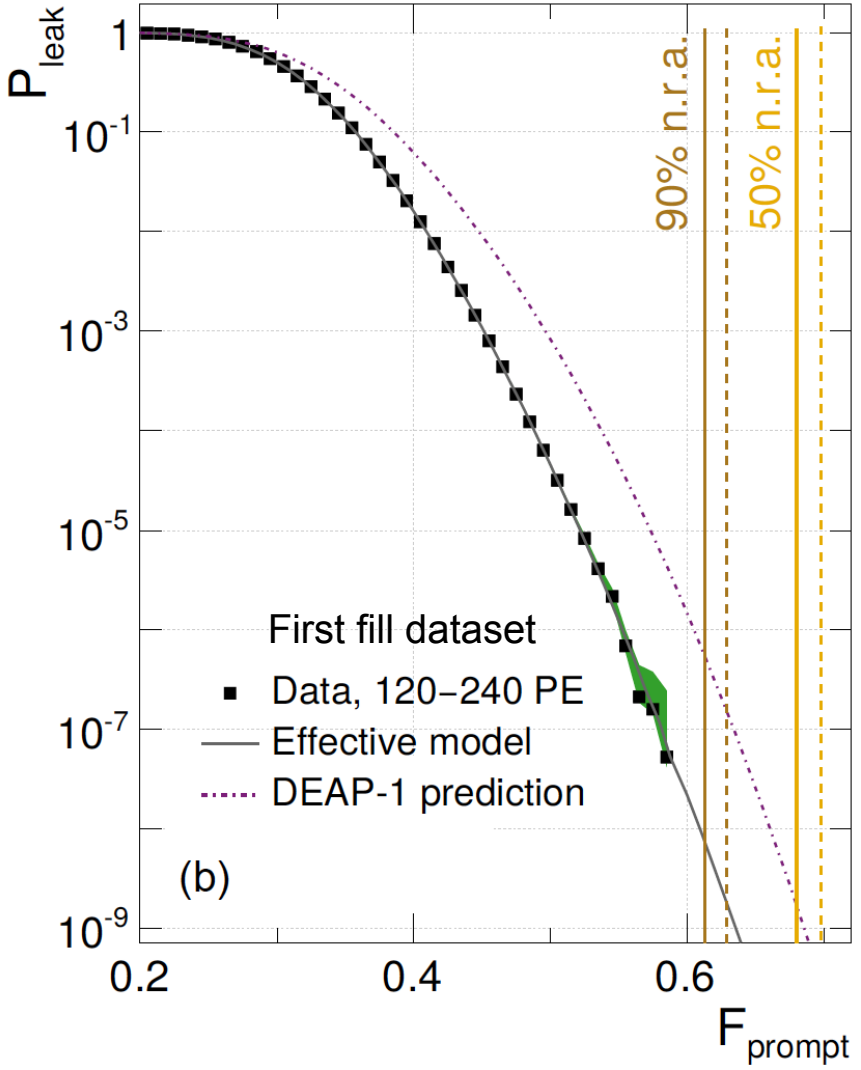


$$F_{prompt} = \frac{Q\ prompt}{Q\ total}$$

Pulse-Shape Discrimination

- Electron recoil background events are rejected very effectively!
  - Leakage probability as low as **10^{-8}** for 90% nuclear recoil acceptance in region of interest

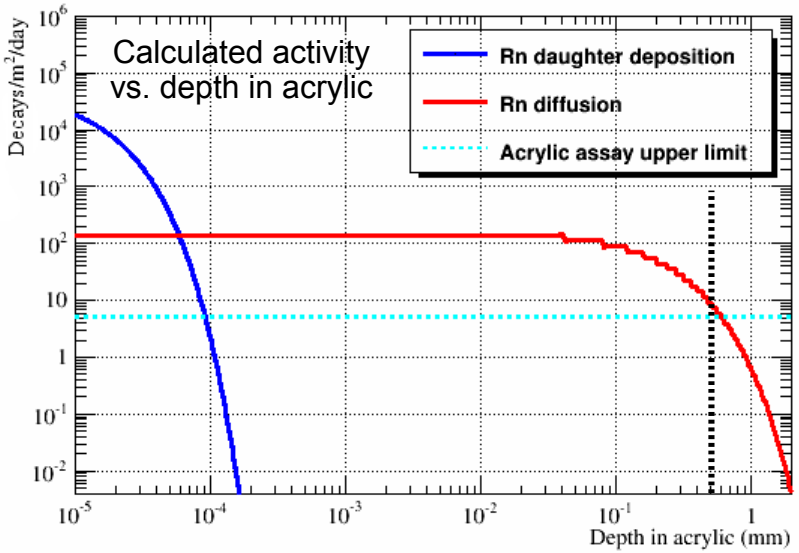




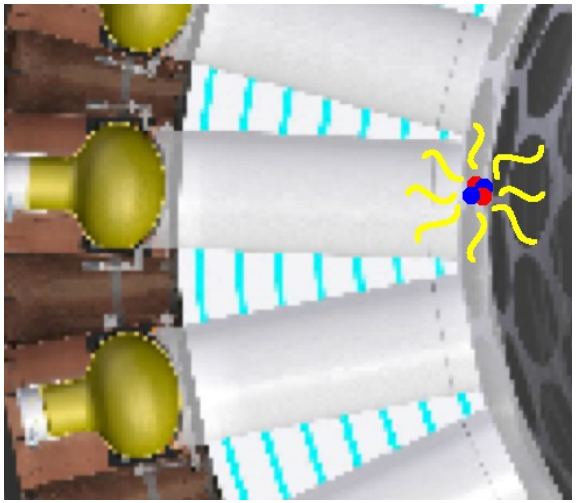
Alpha Backgrounds

- **Alpha** particles emitted from surface impurities cause nuclear recoils
  - Energy deposited typically much higher than for WIMP-nuclear recoils, but may enter region of interest if only a small fraction is detected
  - Mitigation:
    - Strict radon controls during construction
    - Acrylic vessel resurfacing: measured surface activity 0.22 ± 0.04 mBq / m^2
    - Fiducial region definition: Max scintillation PE fraction per PMT

      [Position reconstruction algorithms to be used for longer-exposure search]



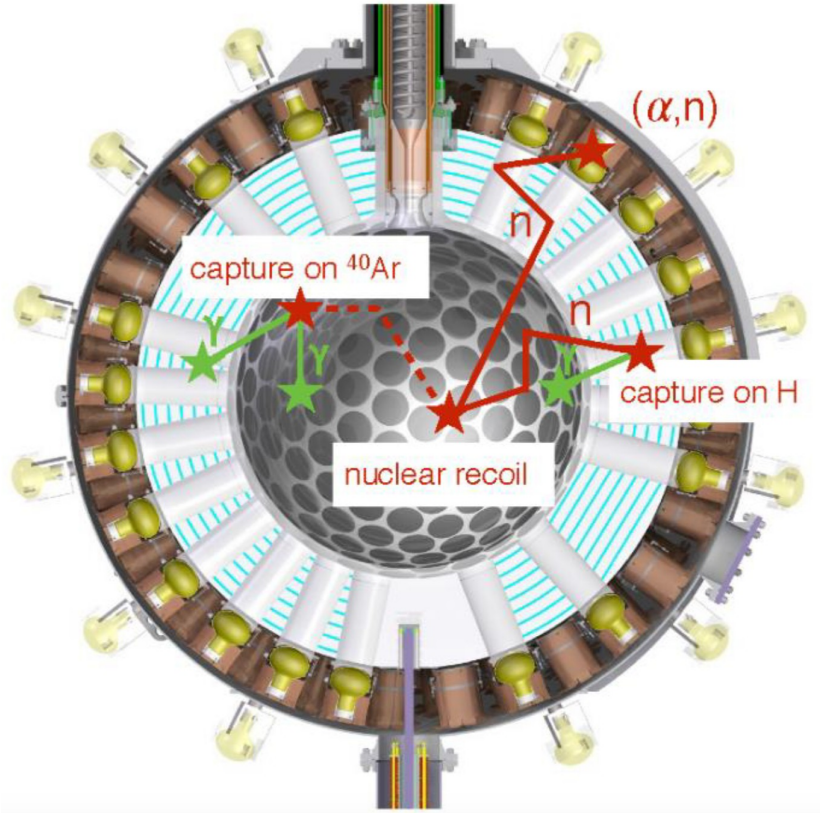
Resurfacing removed
500 ± 50 μm of acrylic surface

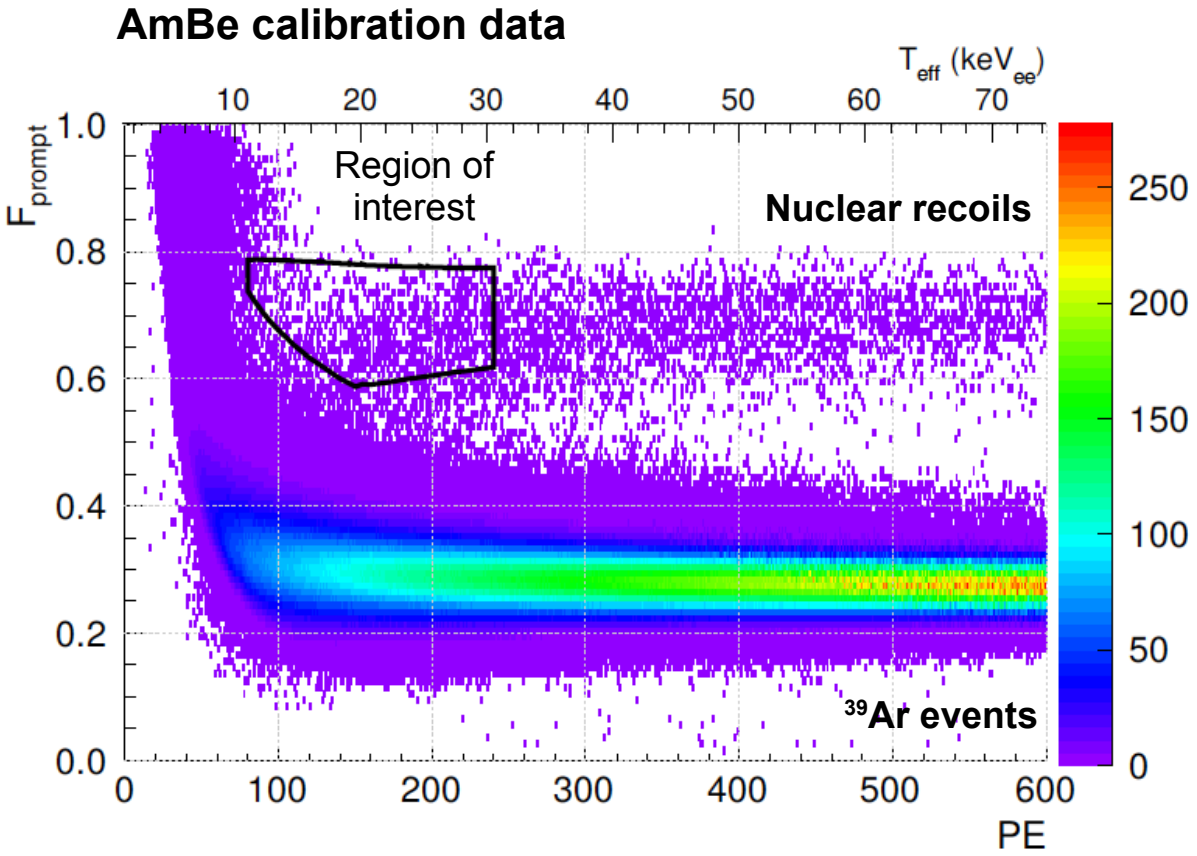


Surface events send a high fraction of the light towards a single PMT

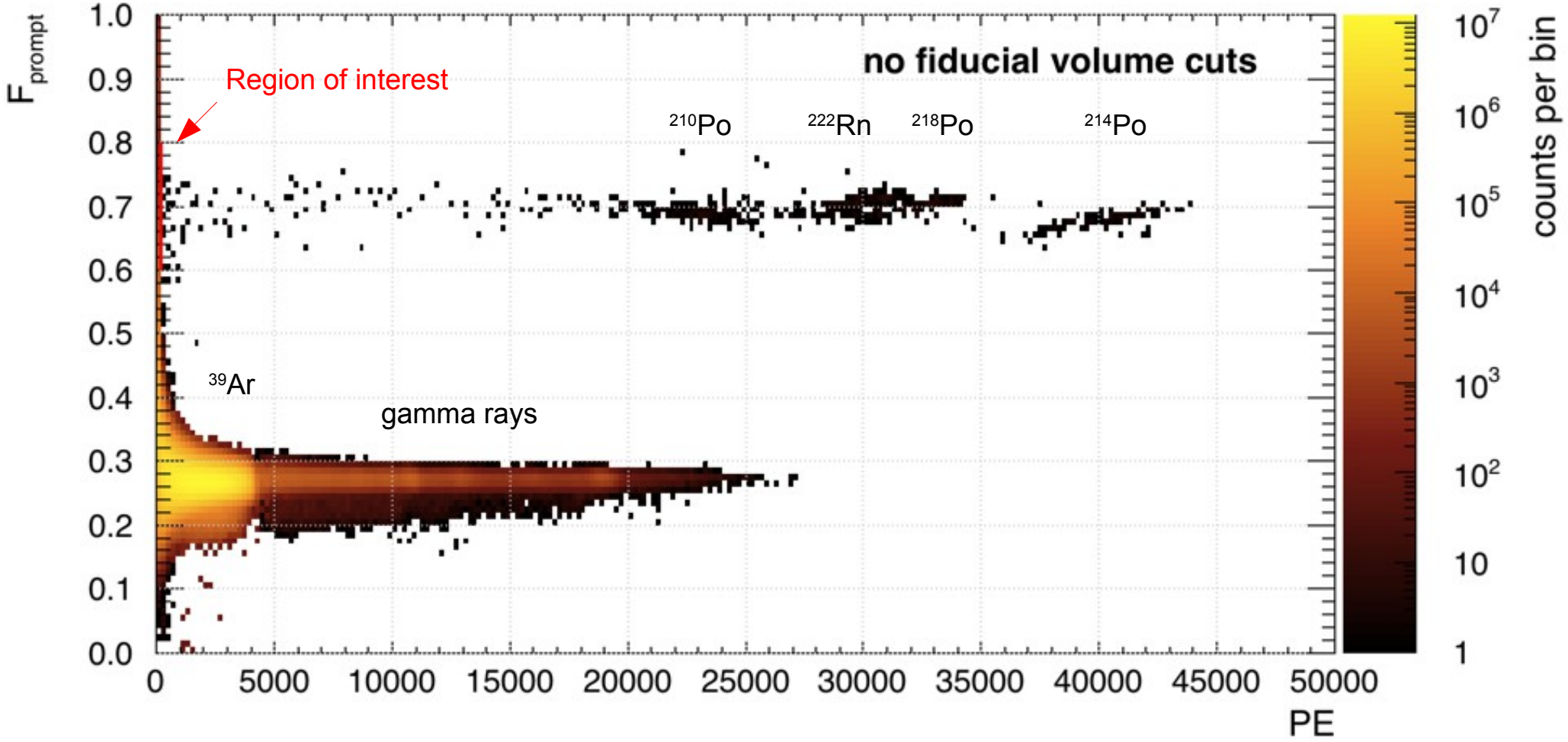
Neutron Backgrounds

- **Neutrons** also cause nuclear recoils that may enter the region of interest
  - Main sources: (α,n) in PMT glass, Fission products, Muon-induced neutrons
  - Mitigation: Material controls, Shielding, Event coincidence cuts
- Total background in fiducial region from all sources **< 0.2 / tonne / year (goal)**





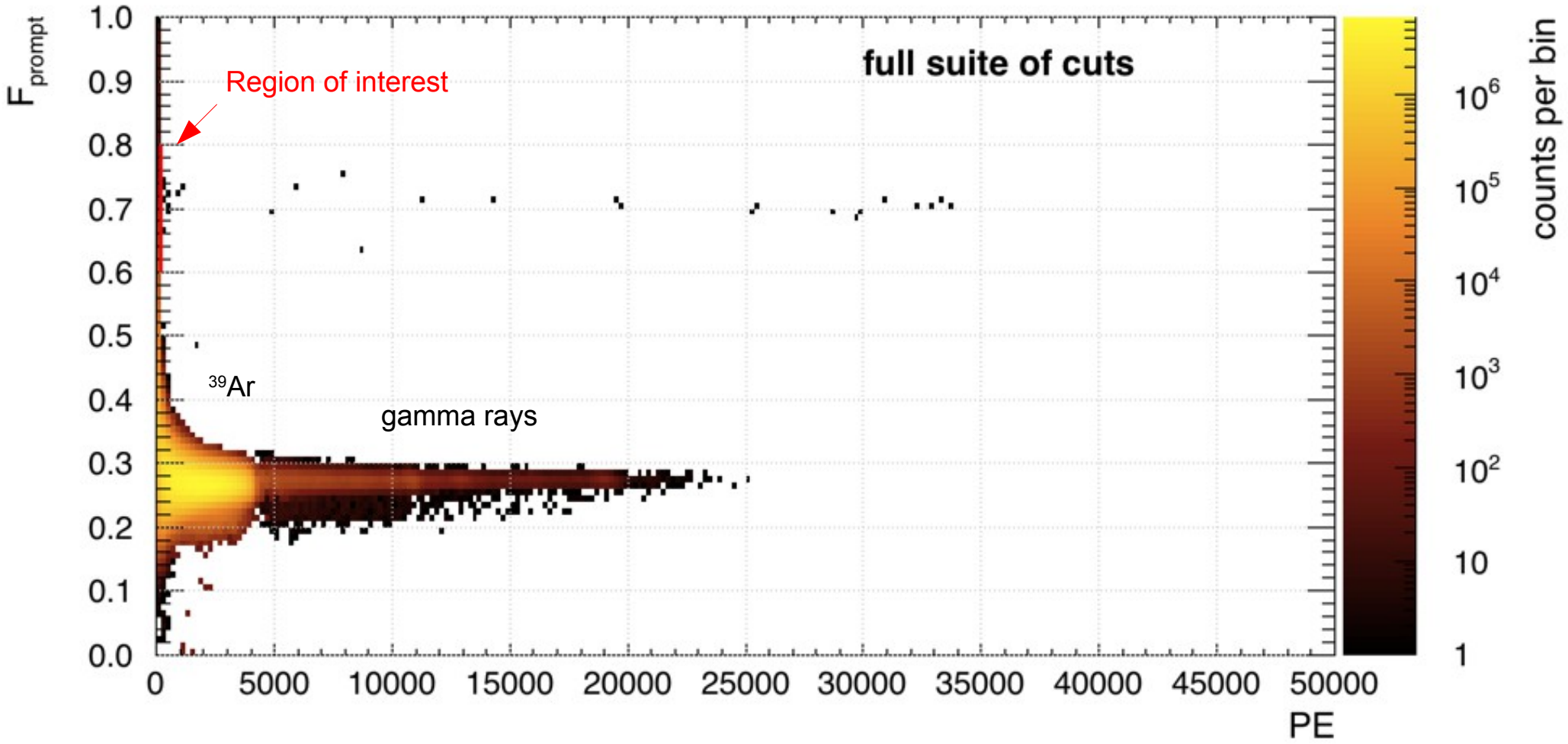
Results



Dark Matter Search (4.4 live days)

arXiv:1707.08042

Results



Dark Matter Search (4.4 live days)

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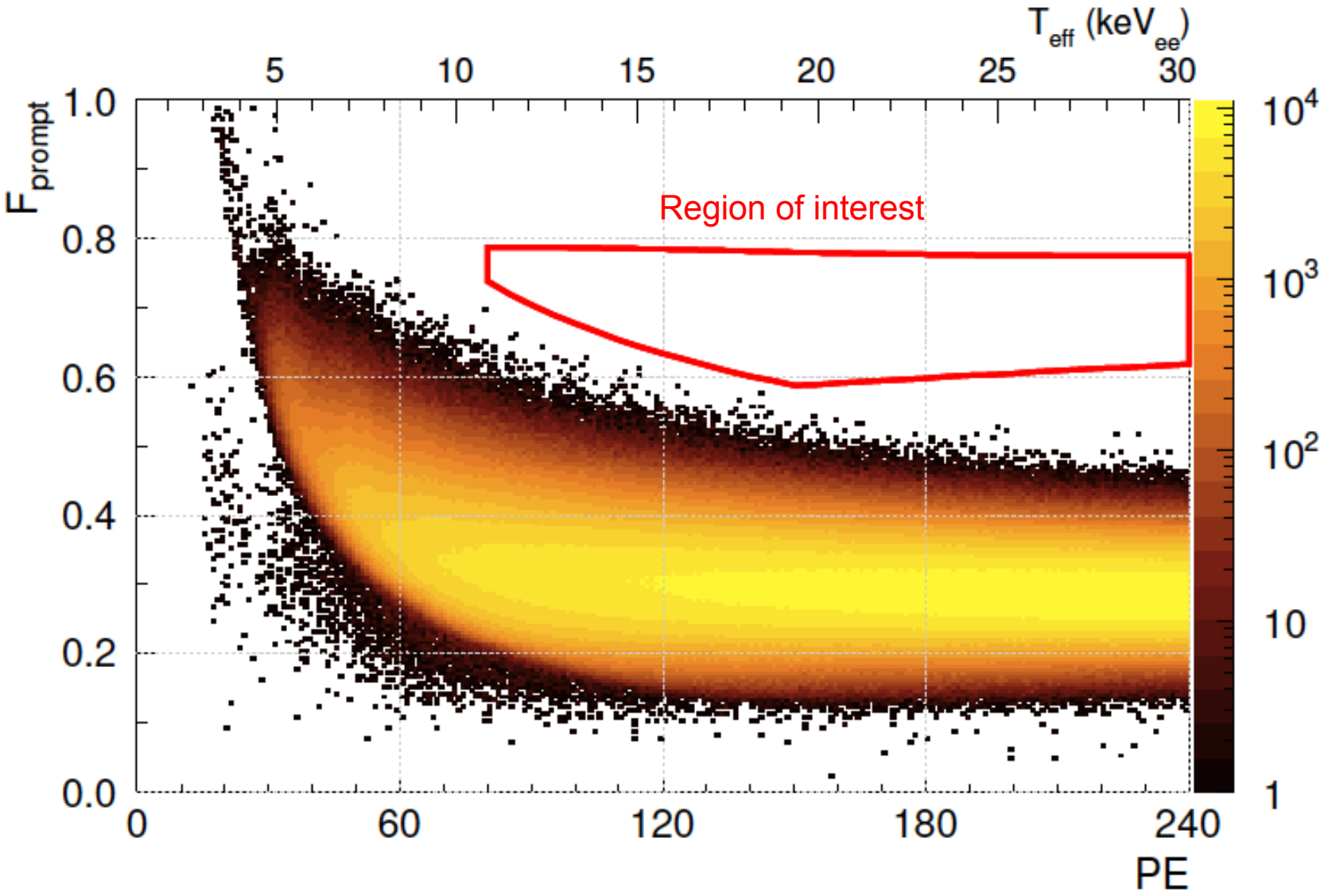
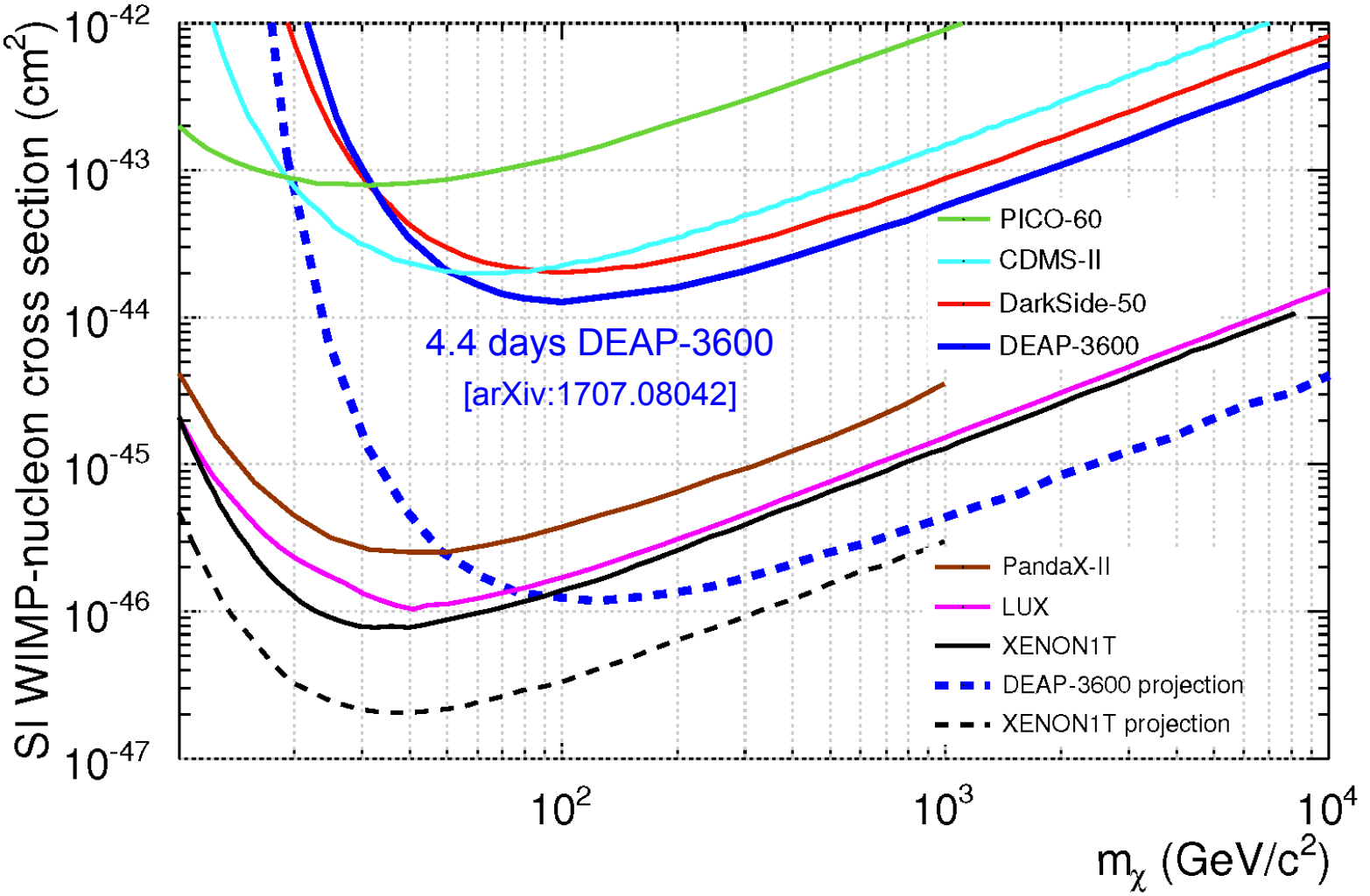
Results



Dark Matter Search (4.4 live days, 2223 kg fiducial)

arXiv:1707.08042

Dark Matter Search Results from DEAP-3600



- DEAP-3600 expected final exclusion sensitivity: 10^{-46} cm^2 for m_χ = 100 GeV/c^2
- How to maximize sensitivity with next-generation experiments? **Think BIG!**

Sensitivity of Future Dark Matter Searches

- Sensitivity to spin-independent nuclear interactions with high-mass dark matter
  - **Global Argon Dark Matter Collaboration** formed, to reach coherent vN scattering floor with a multi-hundred tonnes liquid argon detector

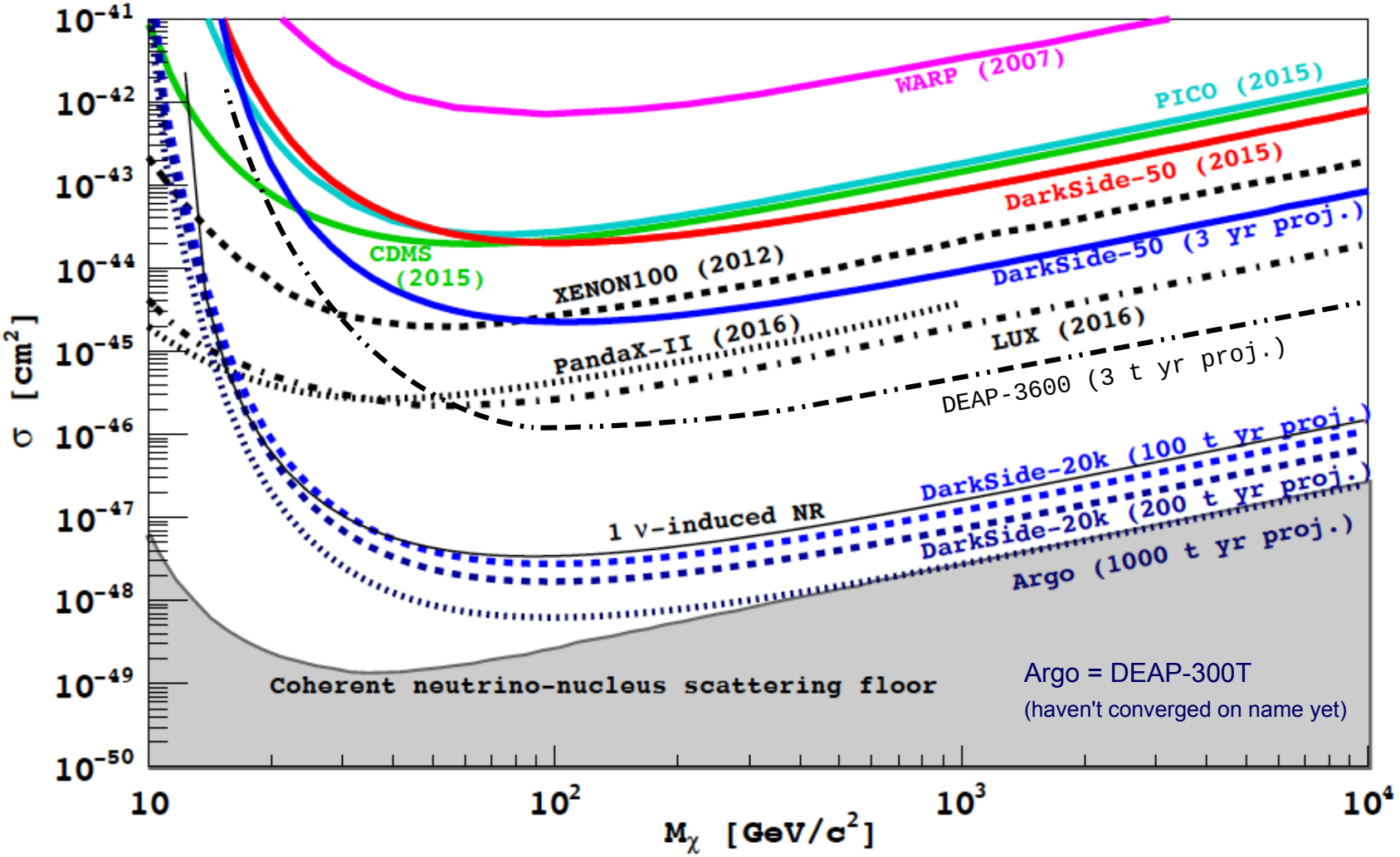


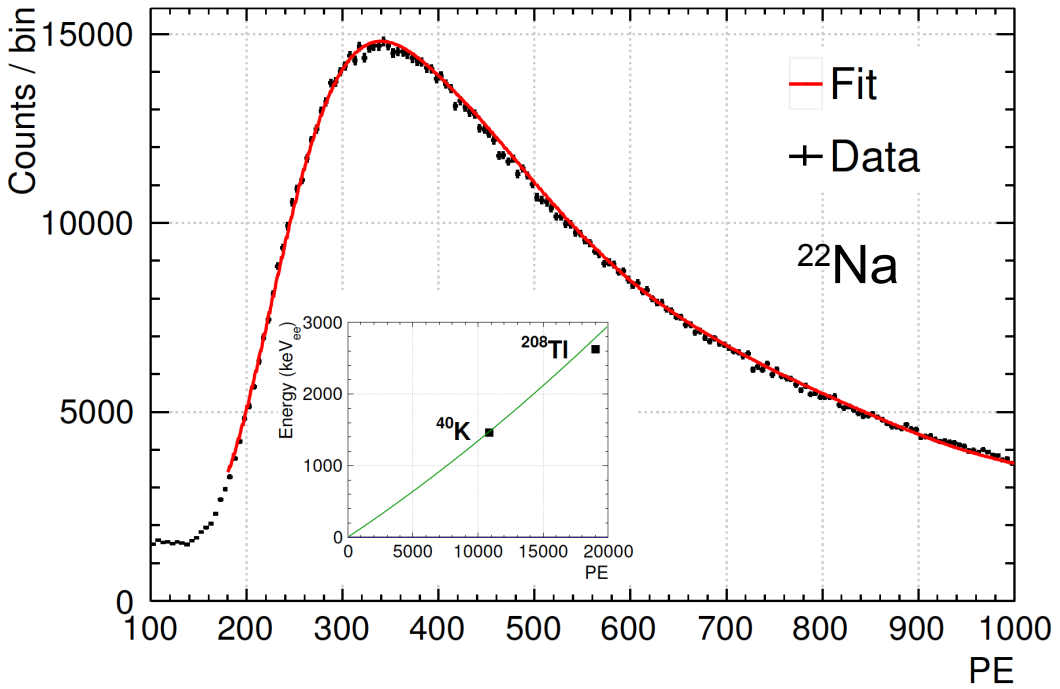
Figure credit: DarkSide-20k, arXiv:1707.08145 (DEAP-3600 expected limit added by hand)

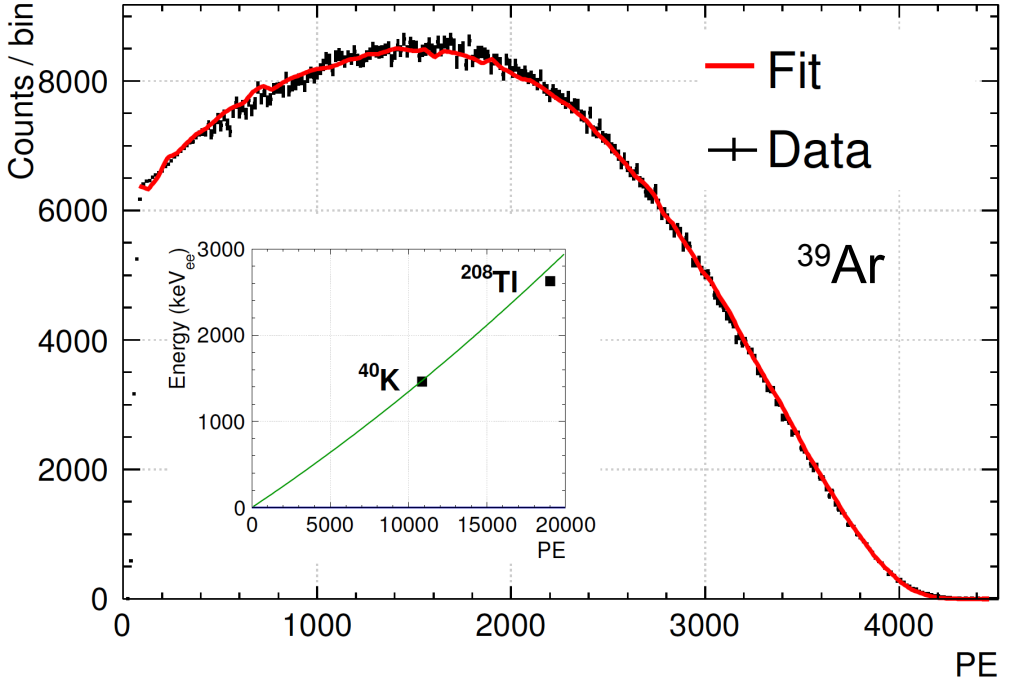
Conclusion

- **DEAP-3600** performed a first dark matter search with first fill dataset
  - Excellent pulse-shape discrimination (PSD)
  - Spin-independent WIMP-nucleon $\sigma < 1.2 \cdot 10^{-44}$ cm^2 at 90% C.L. for $m_\chi = 100$ GeV/c^2
- Second fill dataset: Already collected more than one year of data!
  - Stable detector performance
  - Working hard on thoroughly understanding all rare background events
  - Full calibration of detector response: energy, PSD, position reconstruction
  - Plan to reach a 3 tonne-year fiducial exposure
- Technological challenges for **next-generation** particle detectors are compelling
  - Global Argon Dark Matter Collaboration
  - Depleted argon for DarkSide-20k and a future multi-hundred tonnes LAr detector
  - R&D program for new silicon photomultipliers (SiPM)
- Will dark matter be discovered at **SNOLAB**? Let's find out!

BONUS SLIDES

Energy Calibration



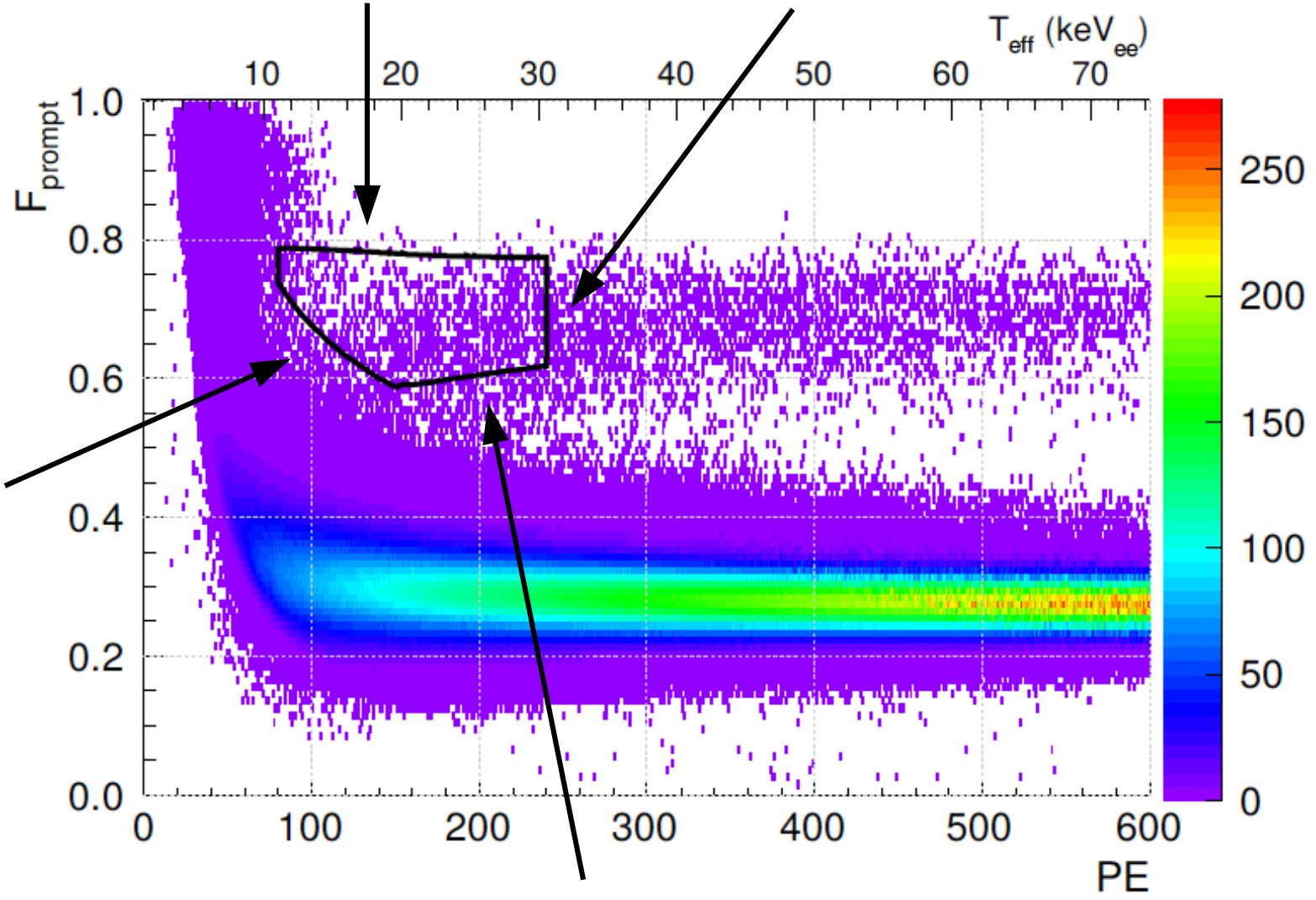


- Fit to ^{22}Na and ^{39}Ar data
  - T_{eff} [keV$_{ee}$] = (1.15 ± 0.50) + (0.121 ± 0.004) PE + (1.32 ± 0.08)·10^{-6} PE^2
- Cross-check at high energy with ^{40}K and ^{208}Tl gamma lines
  - Diverges from fit function because of PMT and DAQ saturation effects

Definition of the Region of Interest

Reject Cherenkov events
(99% NR acceptance)

Reduce potential backgrounds
from surface alphas



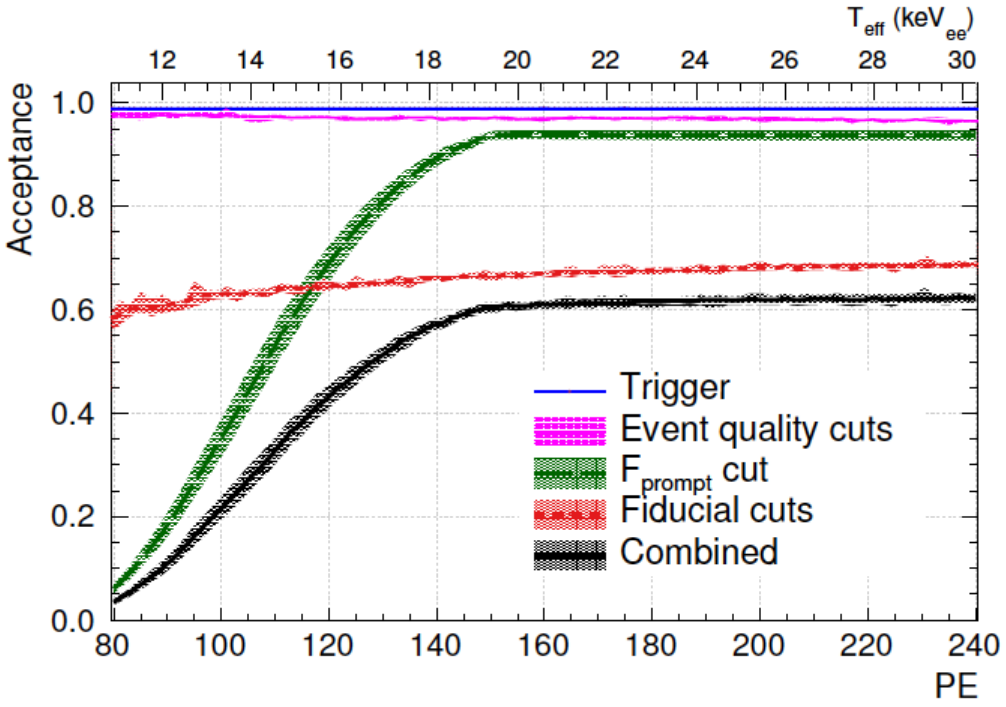
Allow 0.2 events
expected from
^{39}Ar, based on
PSD model

Reduce potential multiple-interaction backgrounds
(95% NR acceptance)

Event Selection and Signal Acceptance

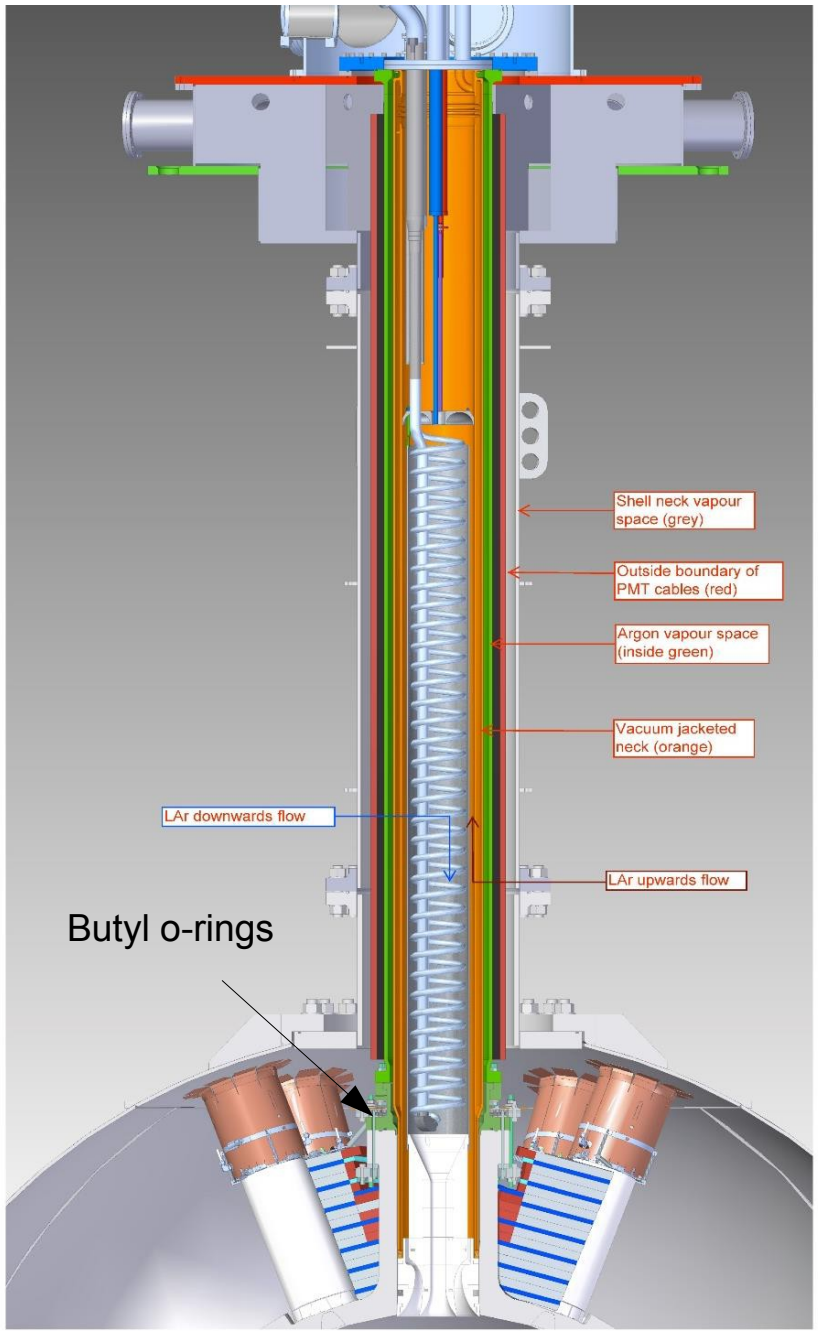
	Cut	Livetime	Acceptance %		$\#^{\mathrm{ROI}}_{\mathrm{evt.}}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
	Pile-up				100700
	Event asymmetry				787
quality	Max charge fraction per PMT		99.58 ± 0.01		654
	Event time		99.85 ± 0.01		652
	Neck veto		$97.49^{+0.03}_{-0.05}$		23
fiducial	Max scintillation PE fraction per PMT			$75.08^{+0.09}_{-0.06}$	7
	Charge fraction in the top 2 PMT rings			$90.92^{+0.11}_{-0.10}$	0
	Total	4.44 d	96.94 ± 0.03	$66.91^{+0.20}_{-0.15}$	0

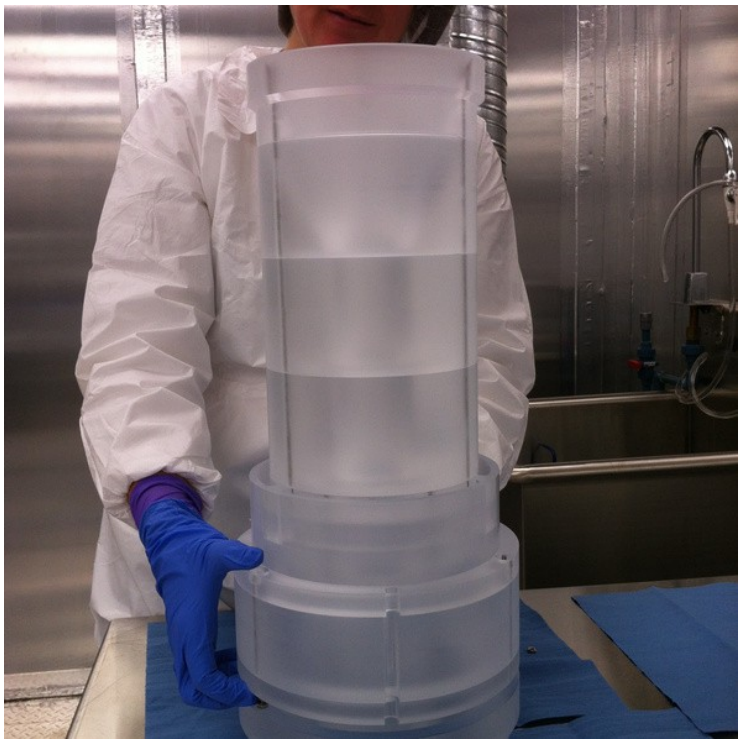
TABLE I: Run selection criteria and cuts with their effects on livetime, integrated acceptance, the fiducial fraction, and the number of events left in the ROI. The acceptance is calculated individually for each run and then weighted by livetime to provide an overall acceptance with the uncertainties taken as maximum and minimum variations about this weighted mean from each run. See text for details about the fiducial fraction determination. The total number of triggers before any cuts was 1.38×10^9, out of which 6.47×10^7 in 80-240 PE window.



- First fill data analysis
  - Fiducial mass: 2223 kg
  - 4.44 live days
  - No event in region of interest

Neck of DEAP-3600





Flow guide

Neck veto