Status of the DEAP-3600 Dark Matter Search

Shawn Westerdale
(for the DEAP-3600 Collaboration)
UCLA Dark Matter 2018

Carleton University

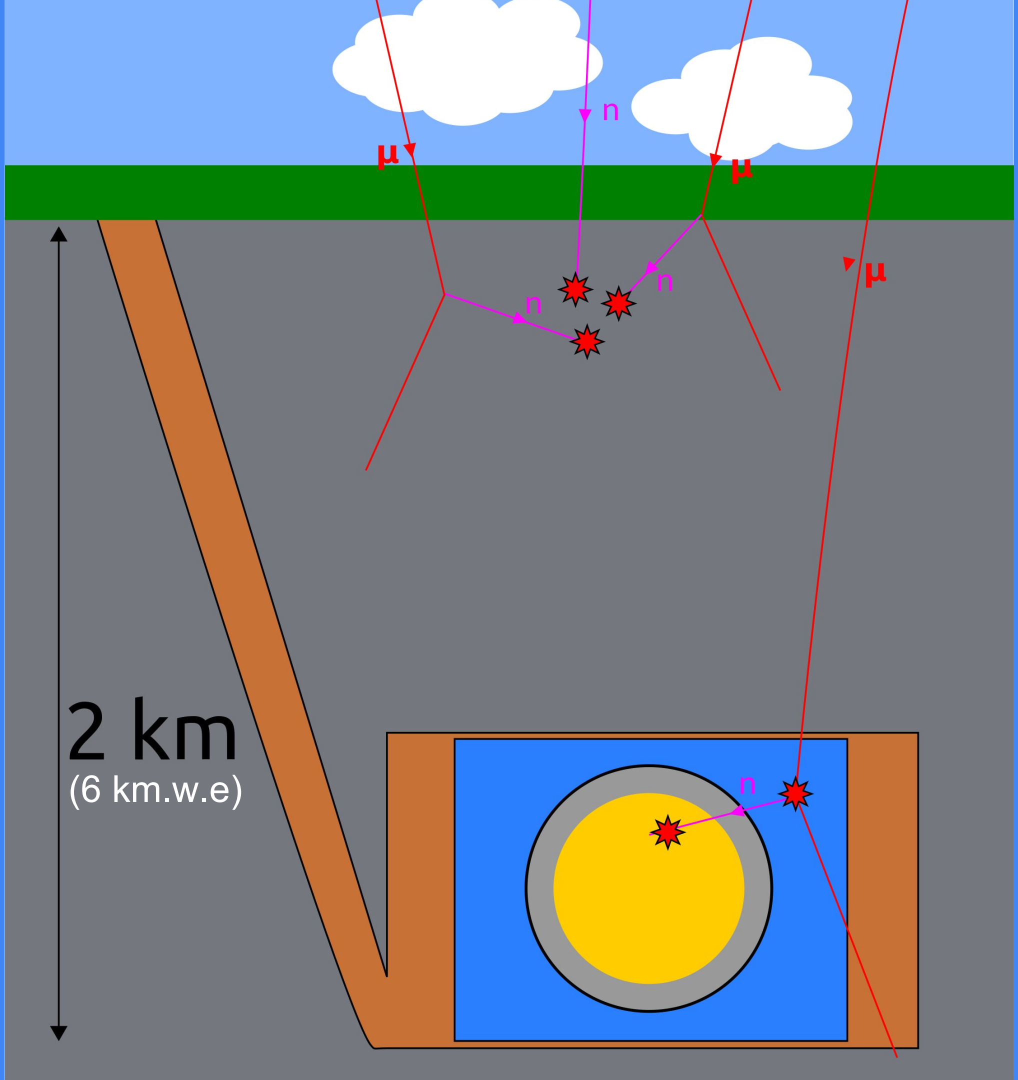
The DEAP-3600 Collaboration

75 researchers across Canada, UK, Germany, and Mexico

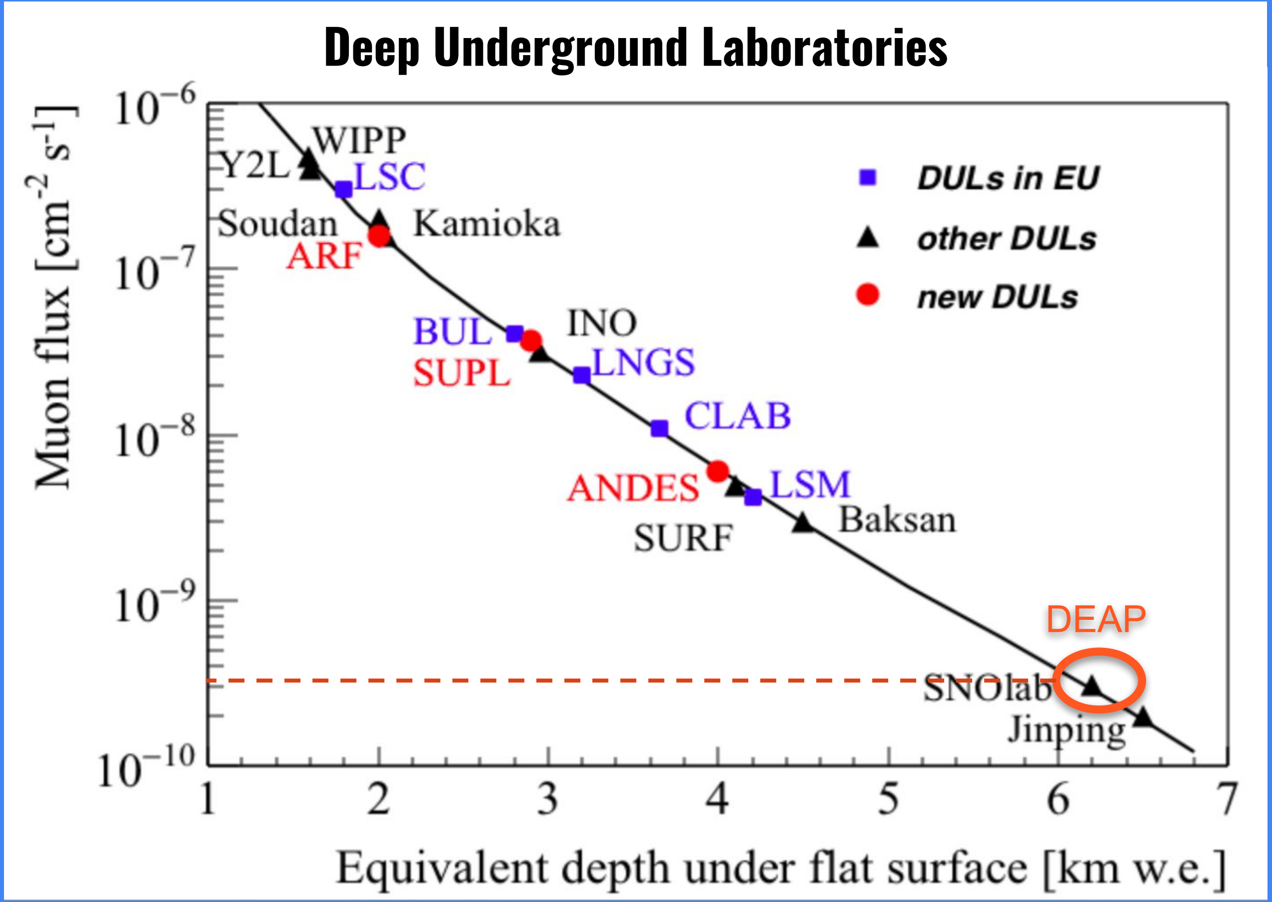
+ future collaborators in Italy and USA

TRIUMF
UNIVERSITY OF ALBERTA
Carleton UNIVERSITY
Queen's UNIVERSITY
ROYAL HOLLOWAY UNIVERSITY OF LONDON
SNOLAB
Canadian Nuclear Laboratories
Laboratoires Nucléaires Canadiens
LaurentianUniversity
UniversitéLaurentienne
Particle Physics
Rutherford Appleton Laboratory
US
University of Sussex
Technical University of Munich
TUM
Instituto de Física

DEAP Under-ground: SNOLAB

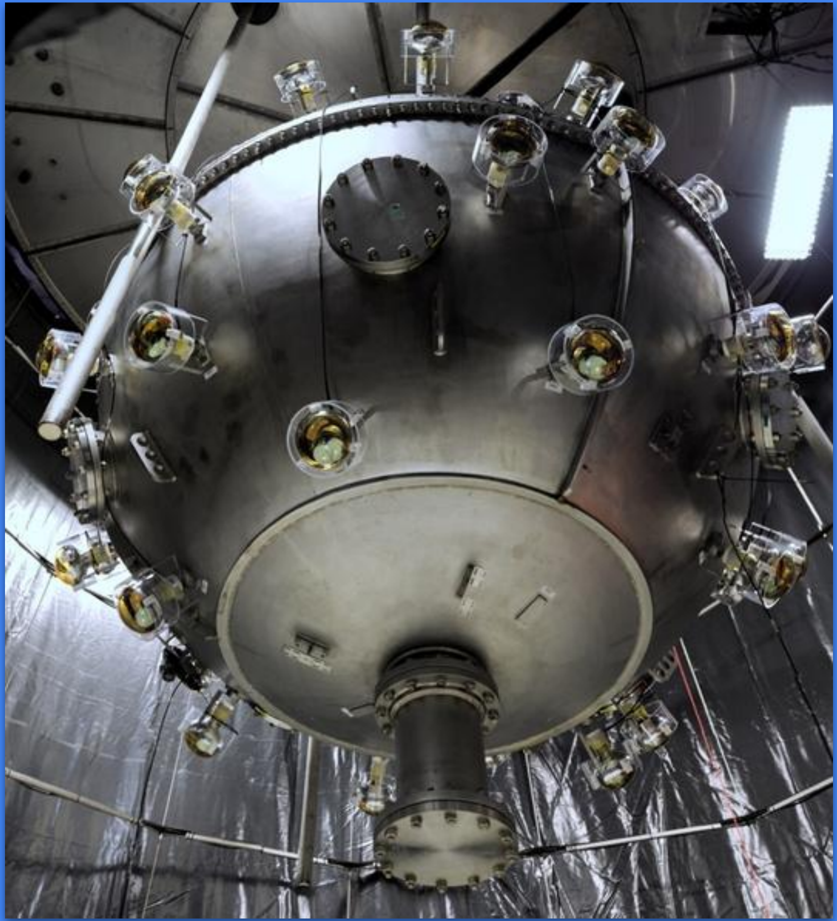


DEAP Underground: SNOLAB

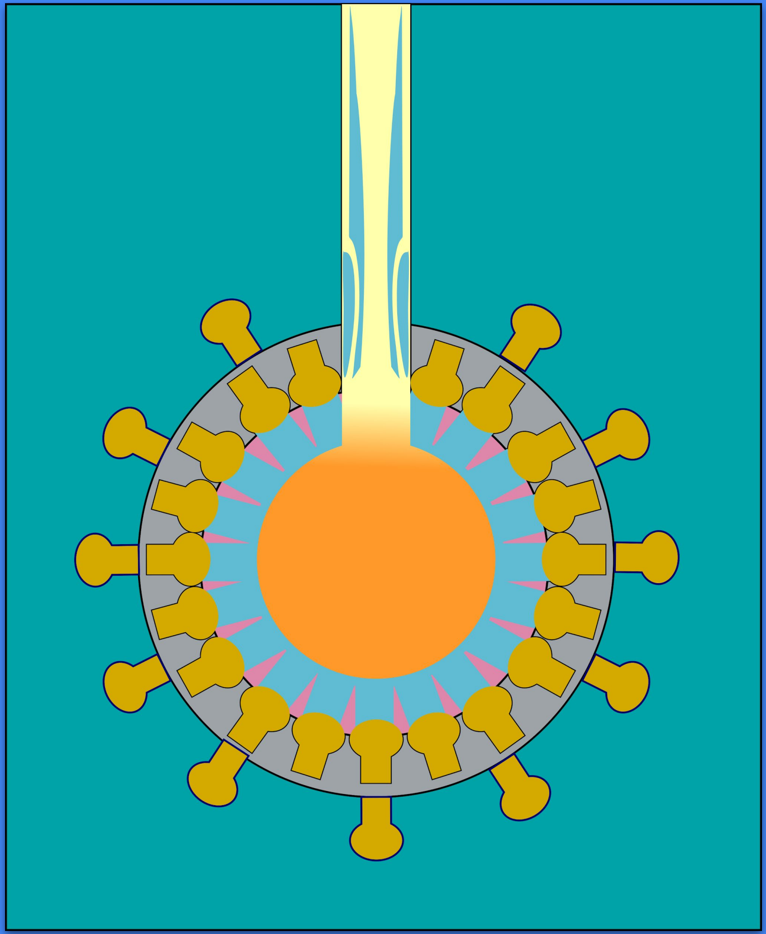


A. Ianni. "Considerations on Underground Laboratories." TAUP 2017

The DEAP detector



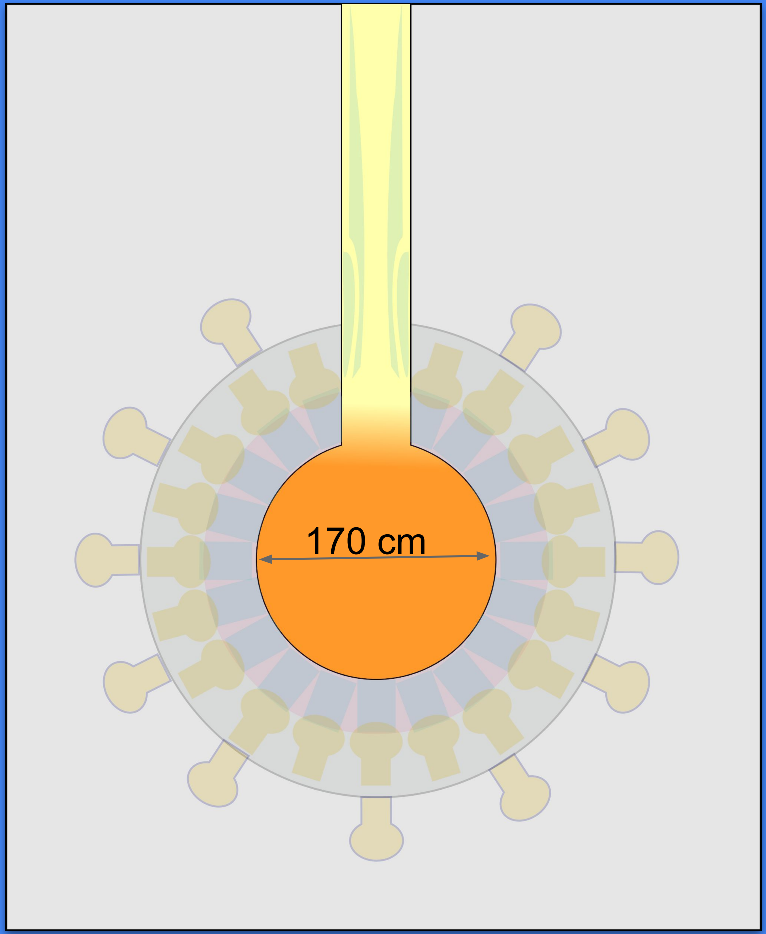
The DEAP detector



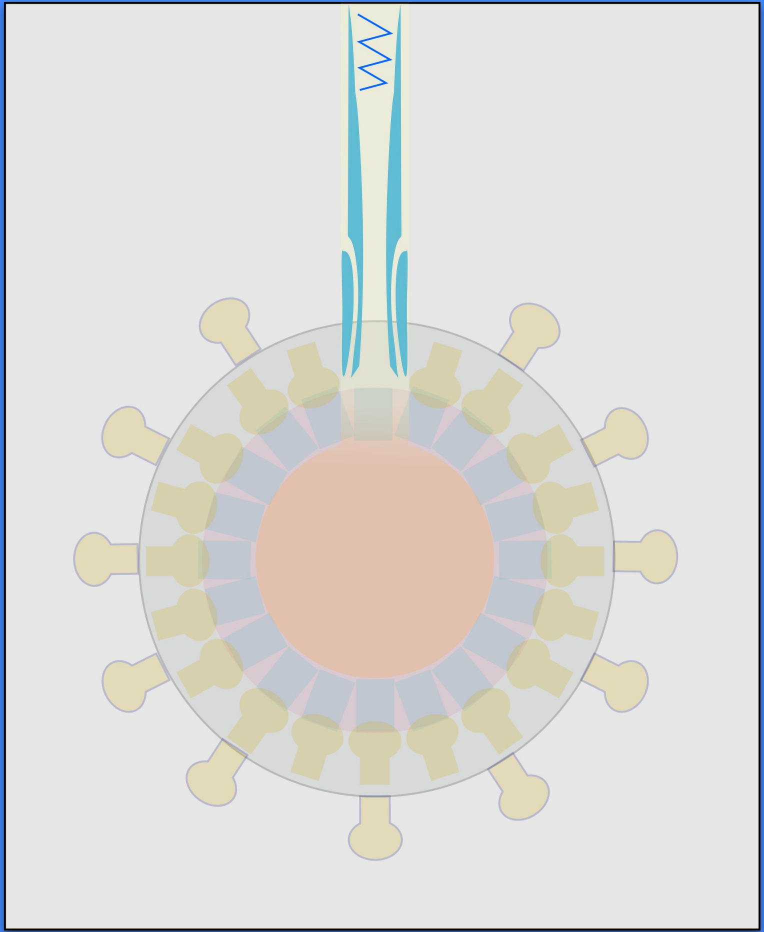
170 cm diameter sphere filled with 3322 kg of LAr

(2.2 tonnes fiducial)

Currently running with 3256 kg

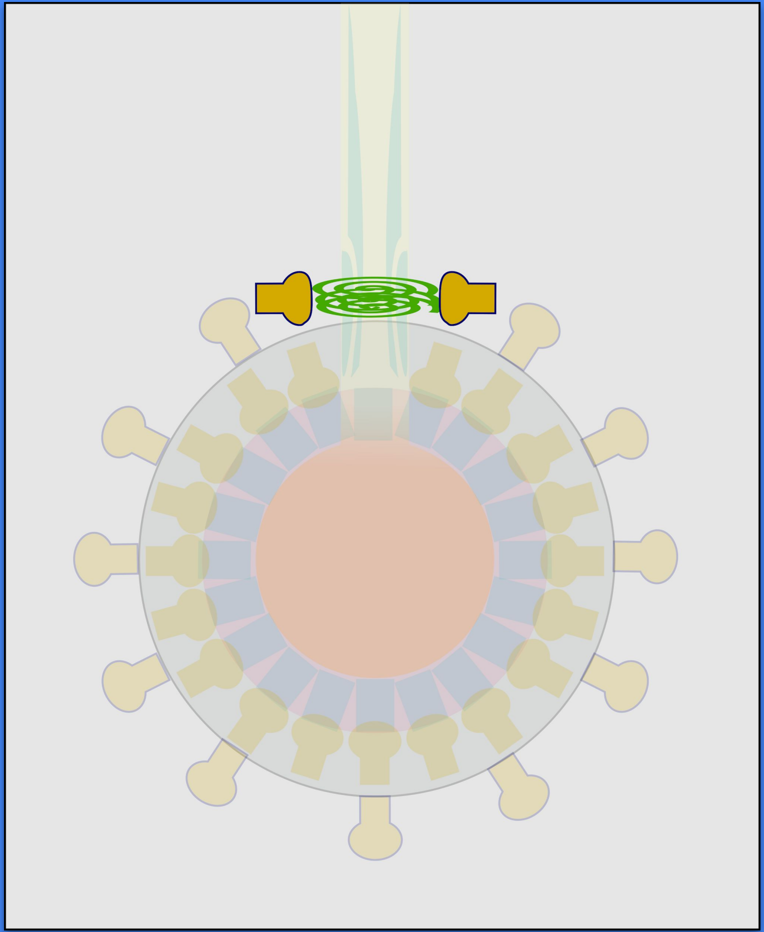


Filled through neck.
LN_2 cooling coil condenses Ar.
Acrylic flow guides control LAr flow

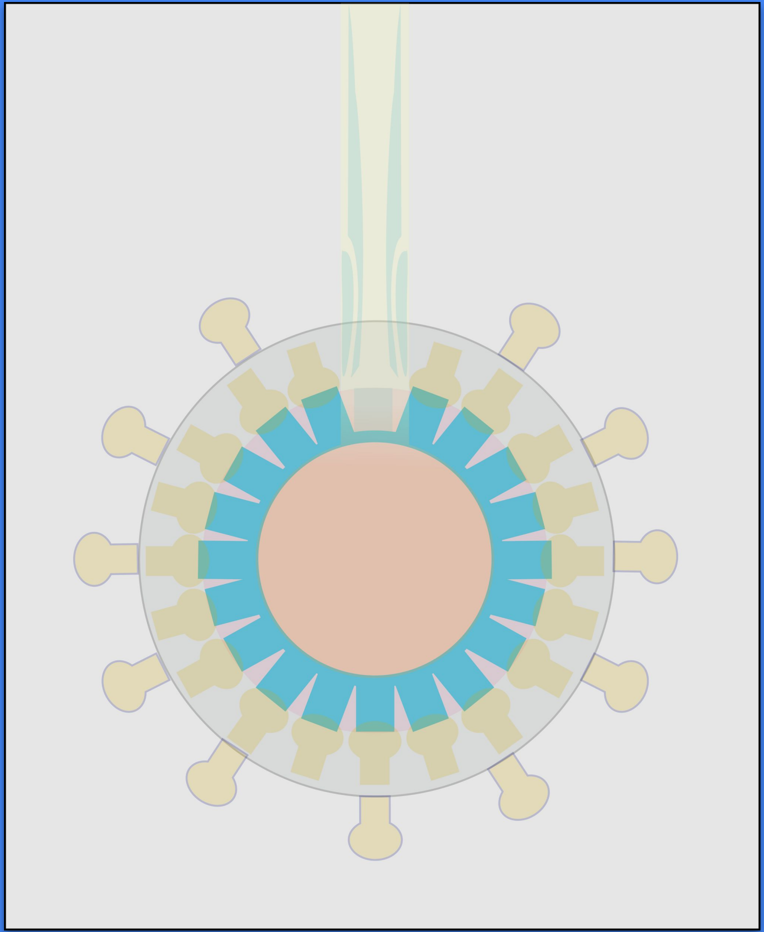


Neck veto:
Optical fiber + 4 PMTs

(3 cm Hamamatsu R7600-300)

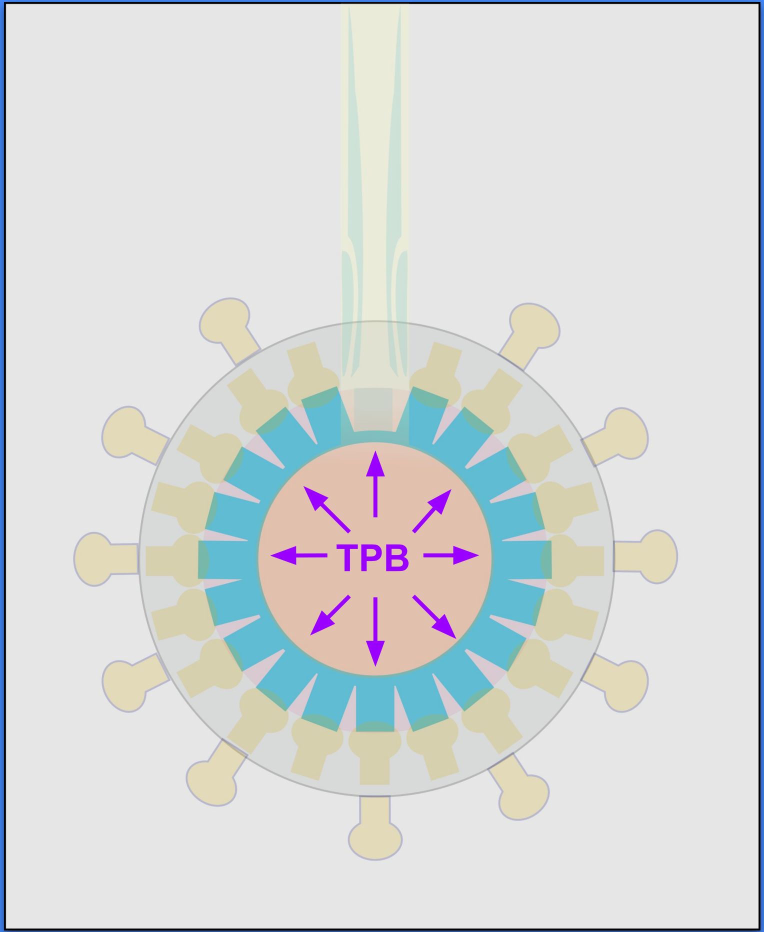


50 cm long light guides & acrylic shell shield LAr from neutrons, keep PMTs warm

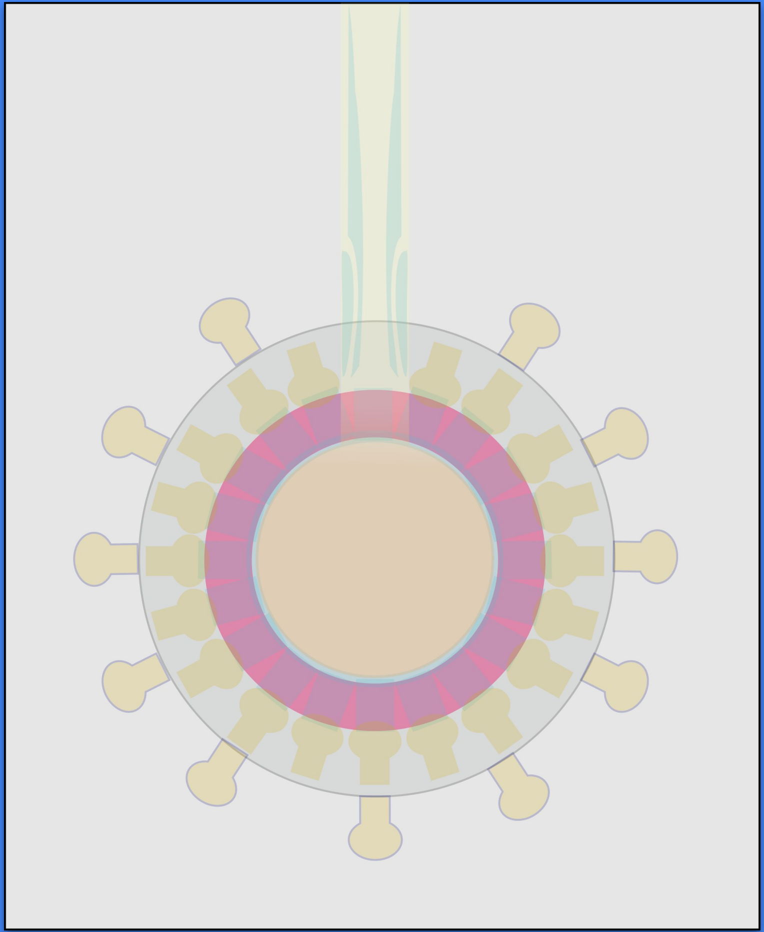


Inner surface sanded to reduce surface backgrounds

TPB layer converts 128 nm LAr scintillation photons to visible

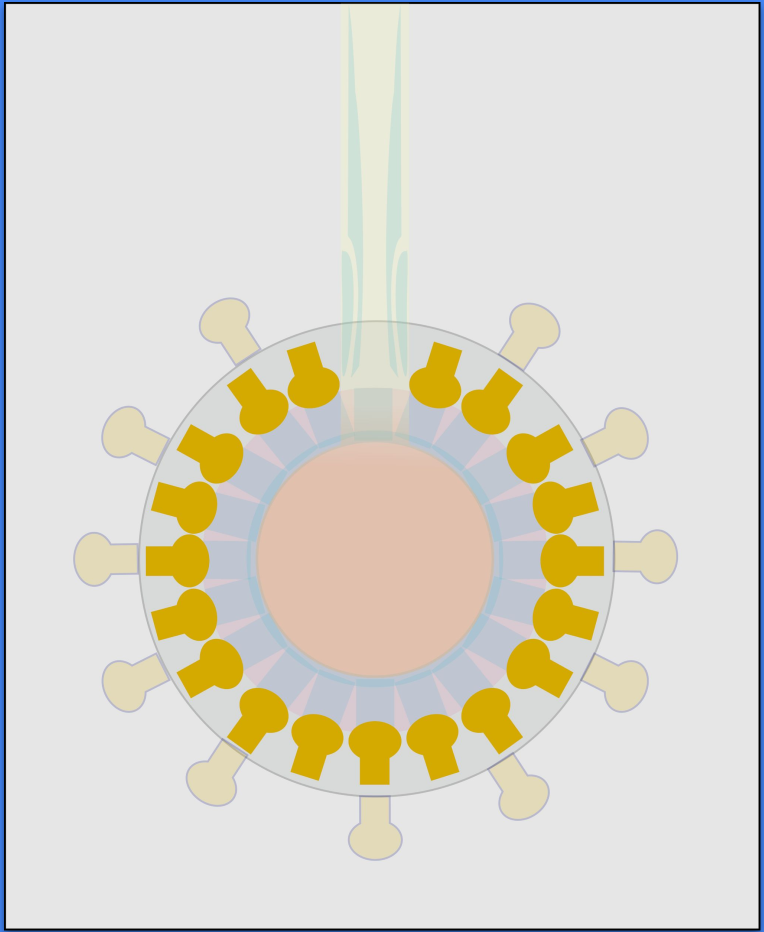


Foam filler blocks provide additional shielding, thermal insulation

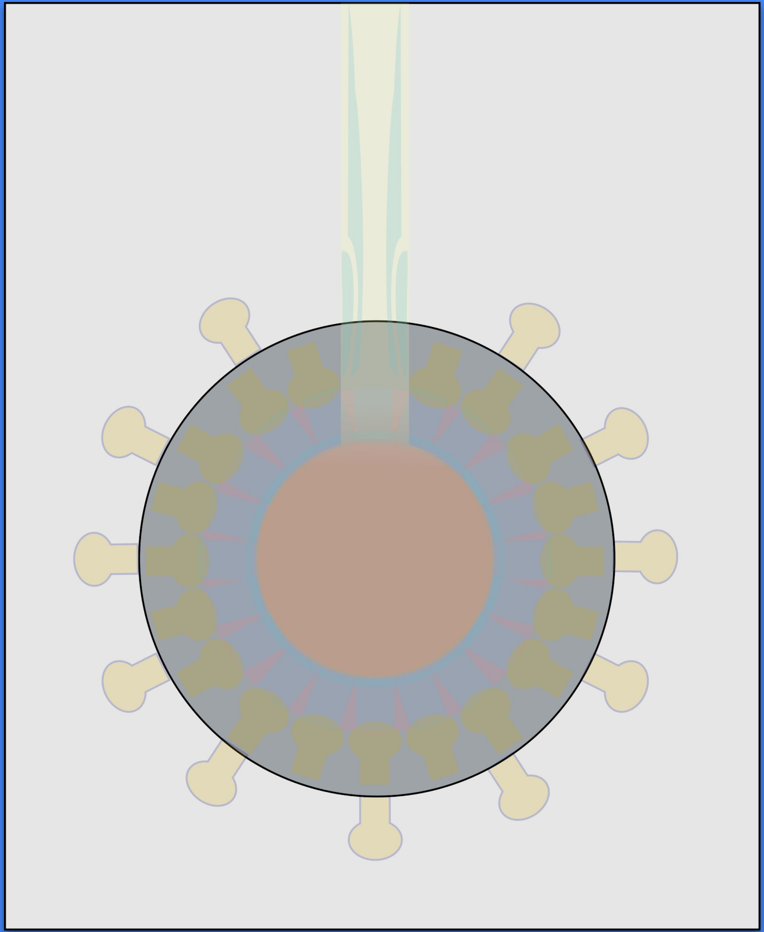


255 PMTs view LAr

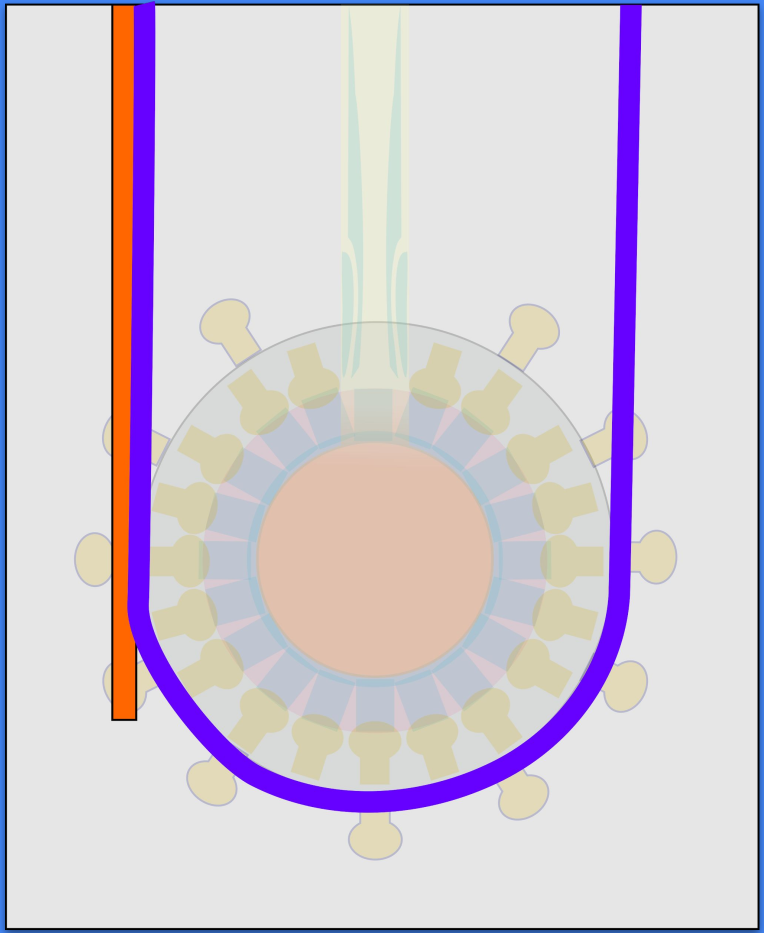
(8" Hamamatsu R5912 HQE LRI)



Stainless steel sphere holds inner detector, maintains N_2 atmosphere

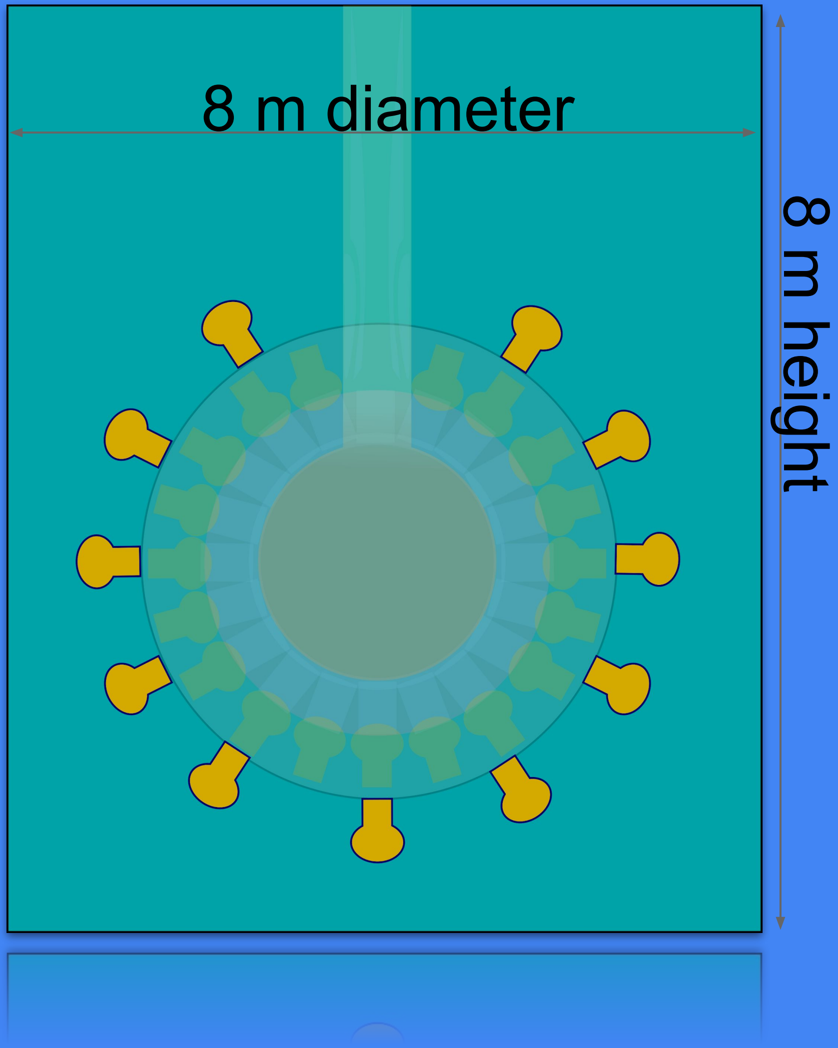


Calibration tubes allow sources to be lowered outside steel shell



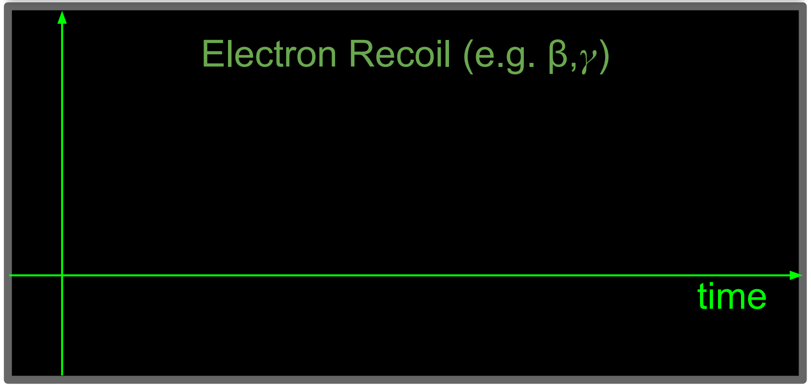
Water Cherenkov muon veto: ~100 tonnes of water viewed by 48 PMTs

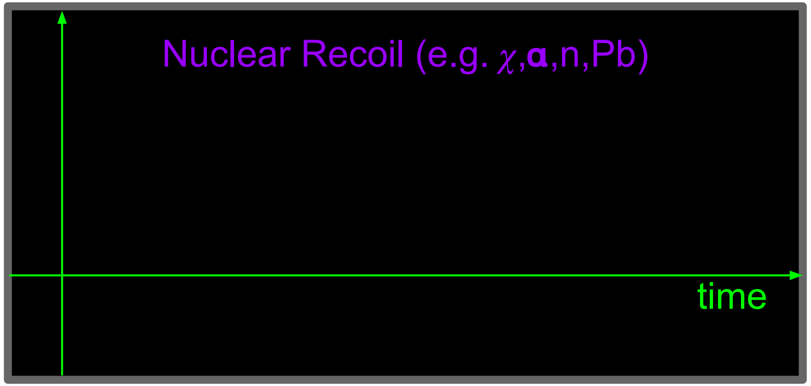
(8” Hamamatsu R1408)

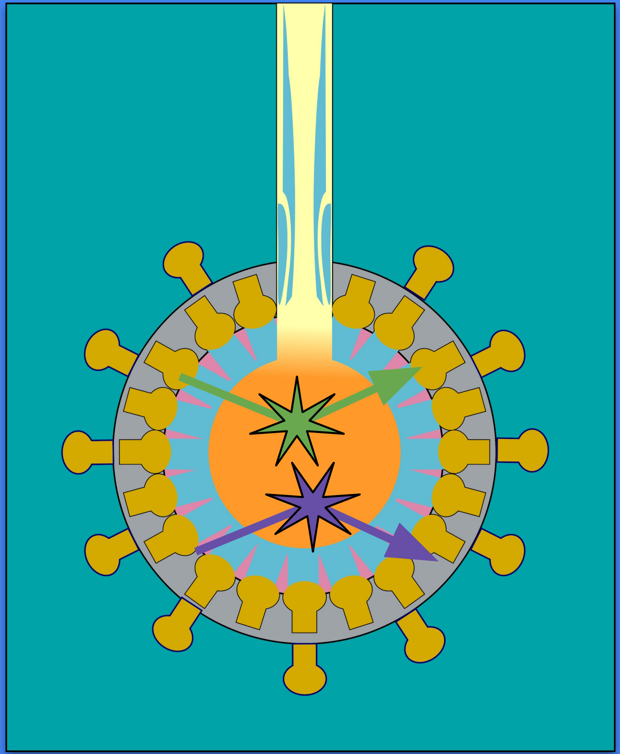


An event occurs

Oscilloscope Readout

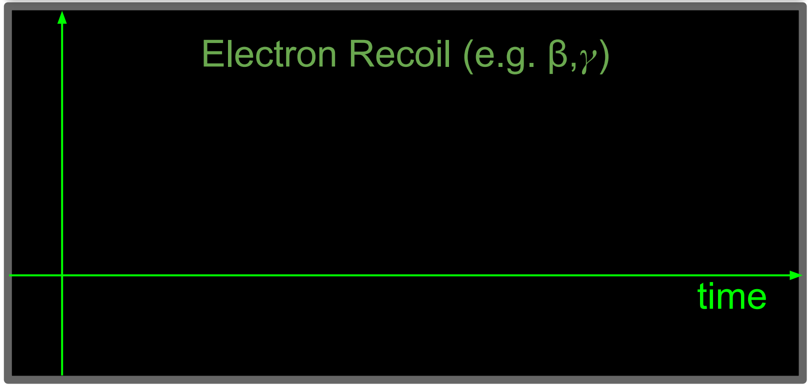


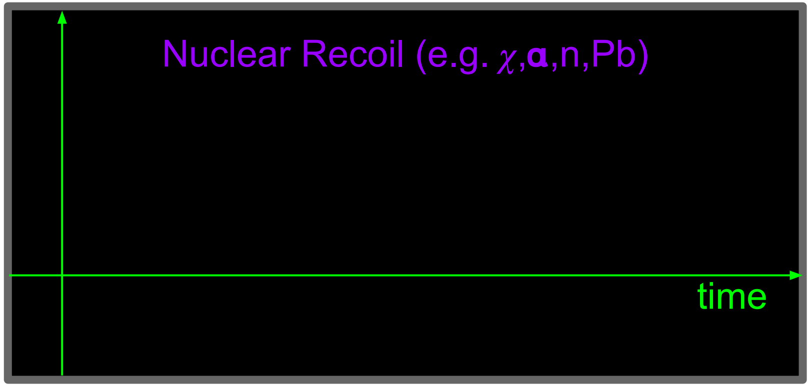


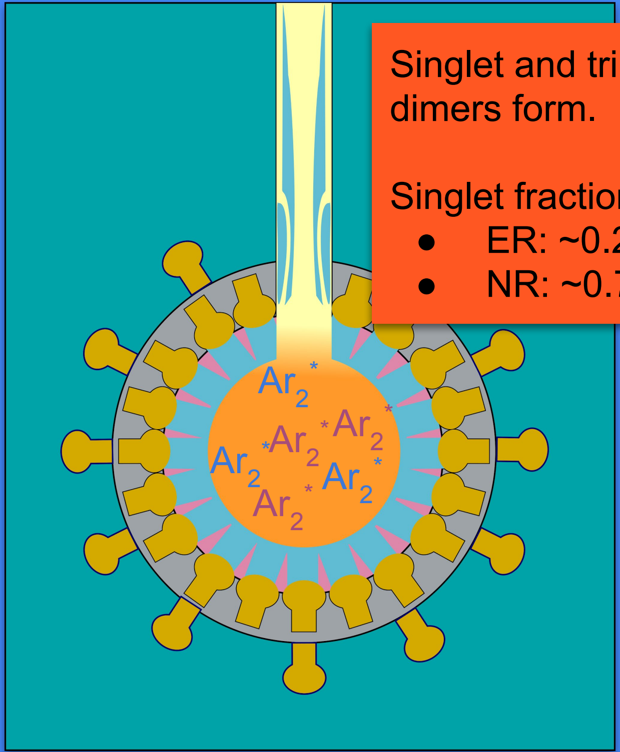


Argon dimers form

Oscilloscope Readout





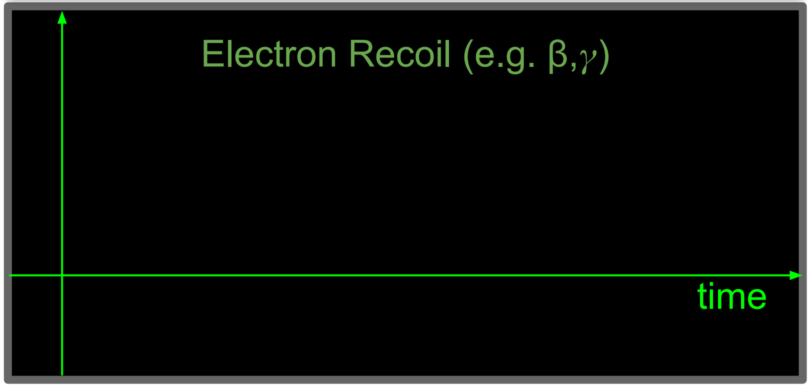


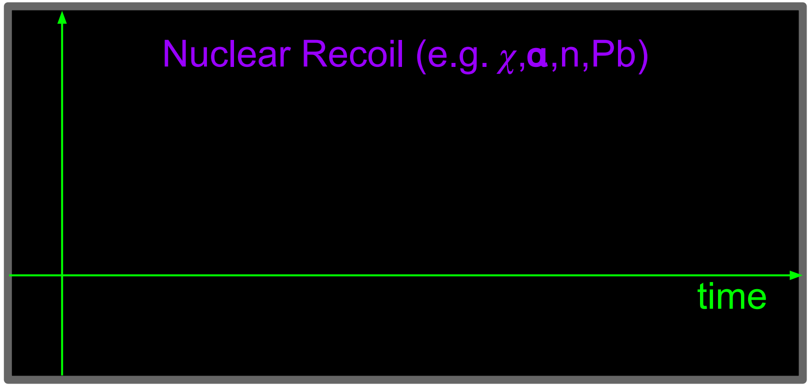
Singlet and triplet dimers form.

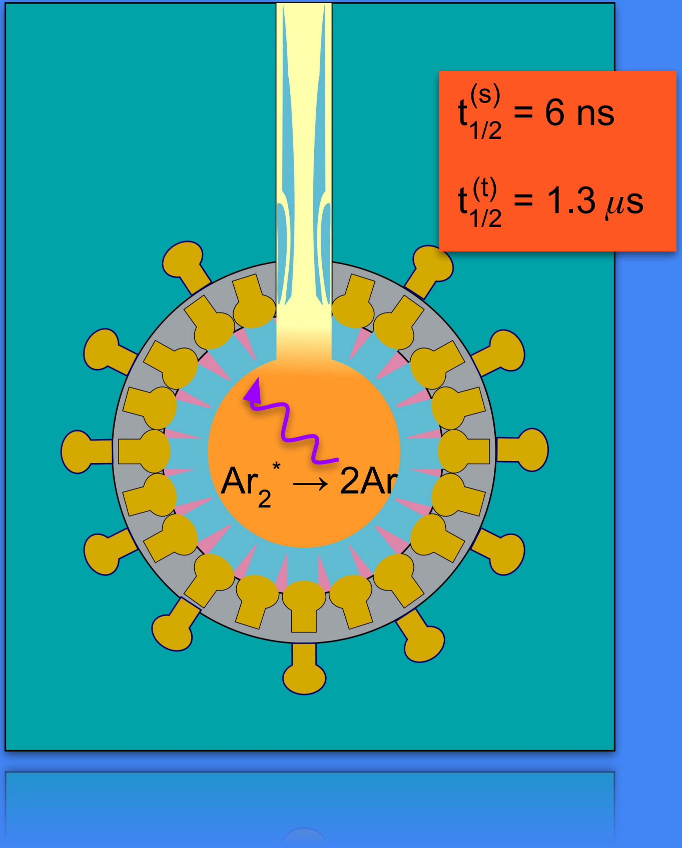
Singlet fraction
- ER: ~0.25
- NR: ~0.70

Dimers split → 128 nm photons

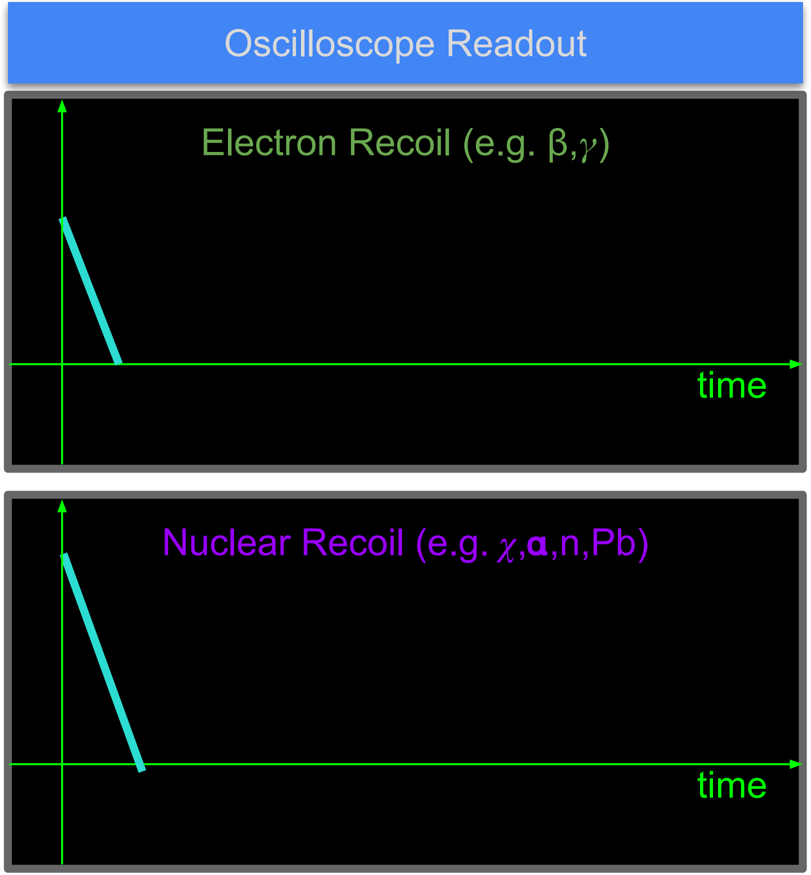
Oscilloscope Readout

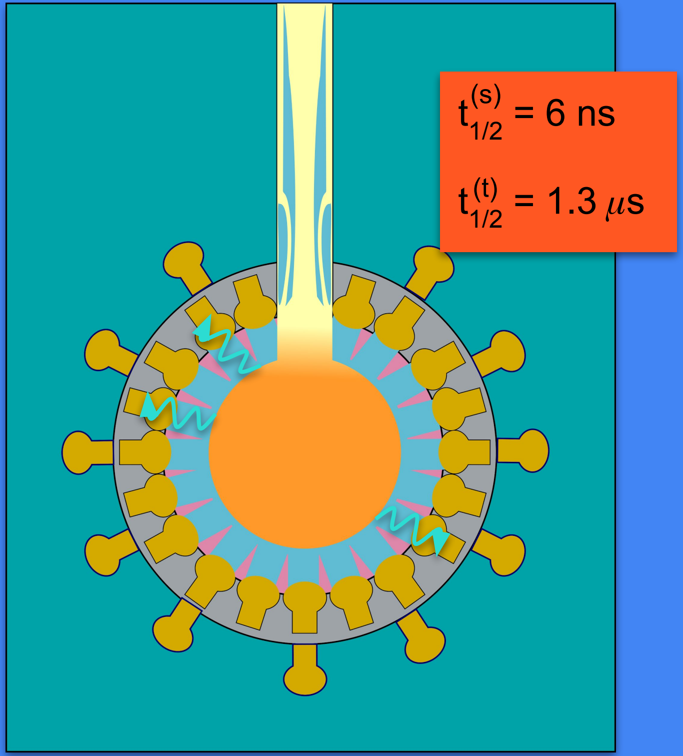






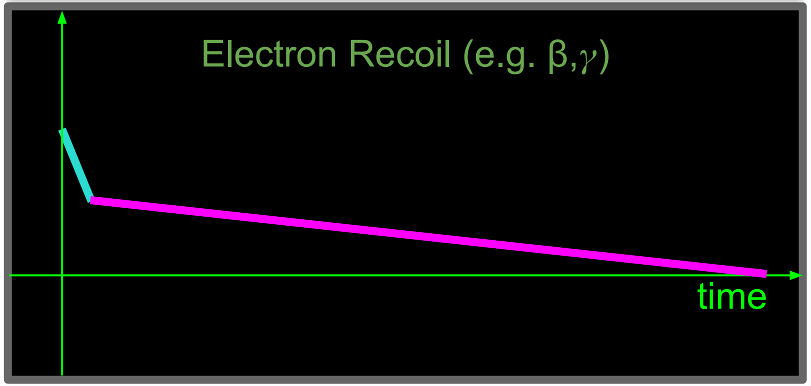
Singlet light shifted by TPB, detected

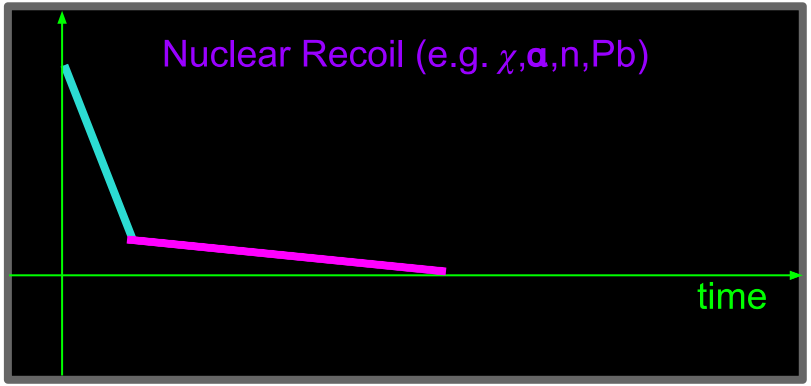


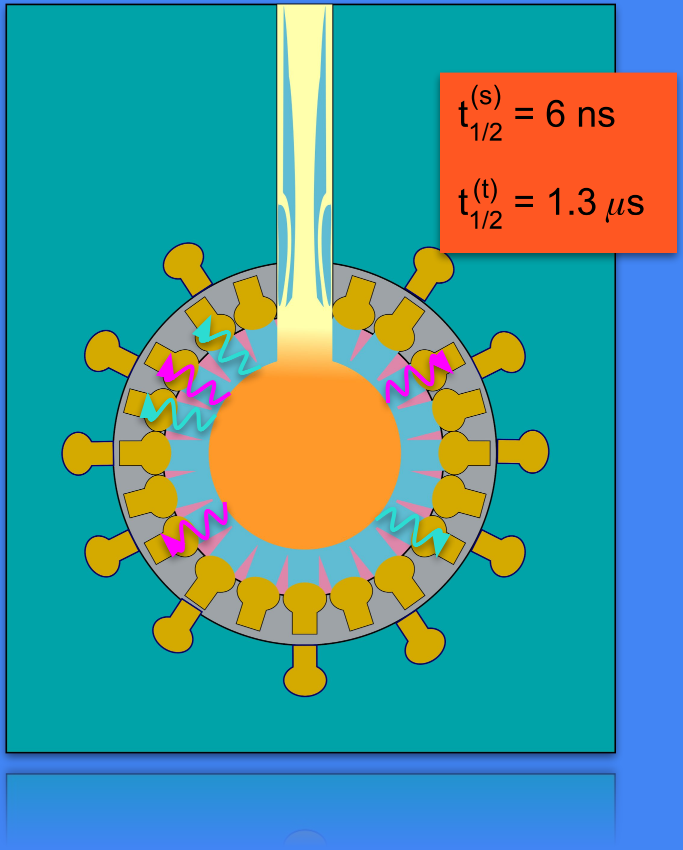


Triplet light shifted by TPB, detected

Oscilloscope Readout

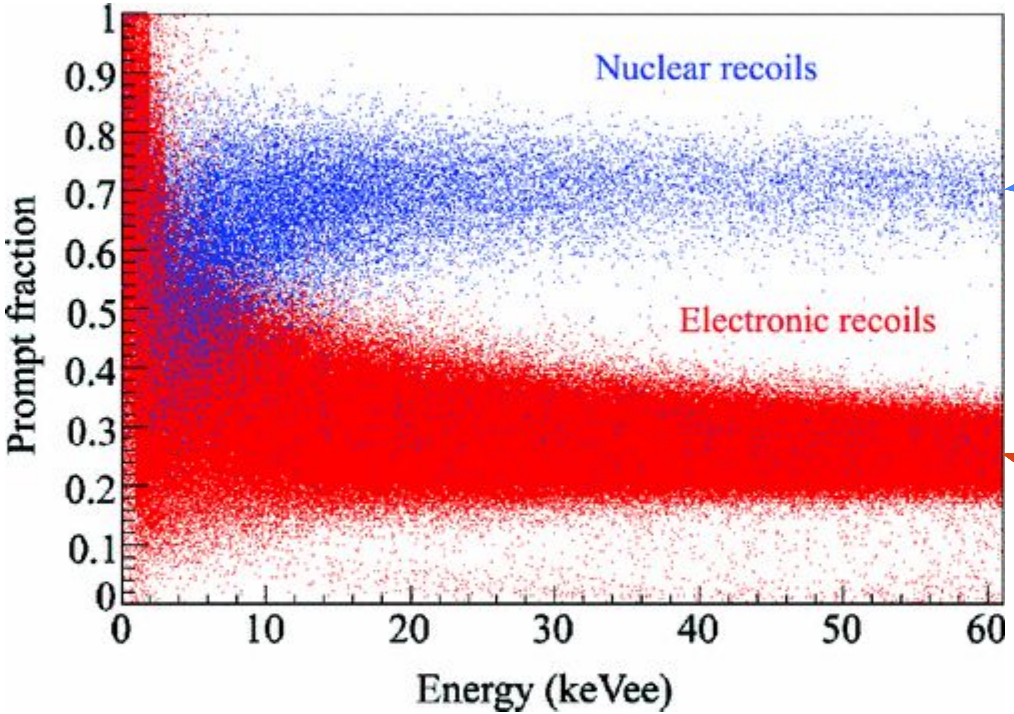


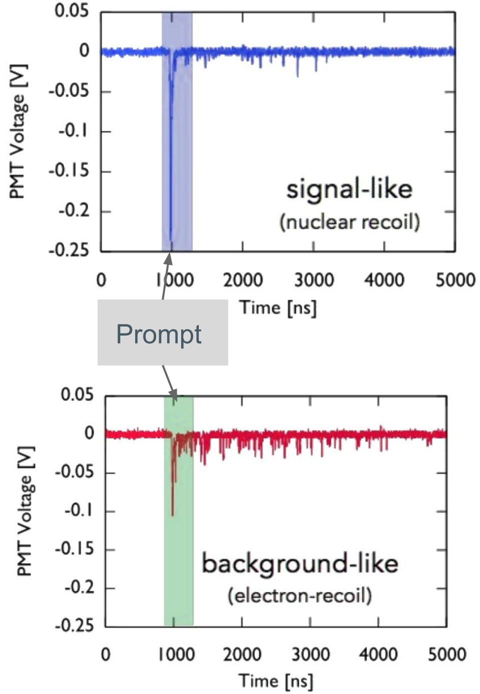




Pulse Shape Discrimination: Powerful separation between ER and NR

$$F_{prompt} = \frac{\text{Prompt PE}}{\text{Total PE}}$$





W. H. Lippincott, *et al*. Phys. Rev. C 78, 035801.

P.A.Amaudruz, *et al*. Astropart. Phys. 85 (Dec 2016), pp 1-23

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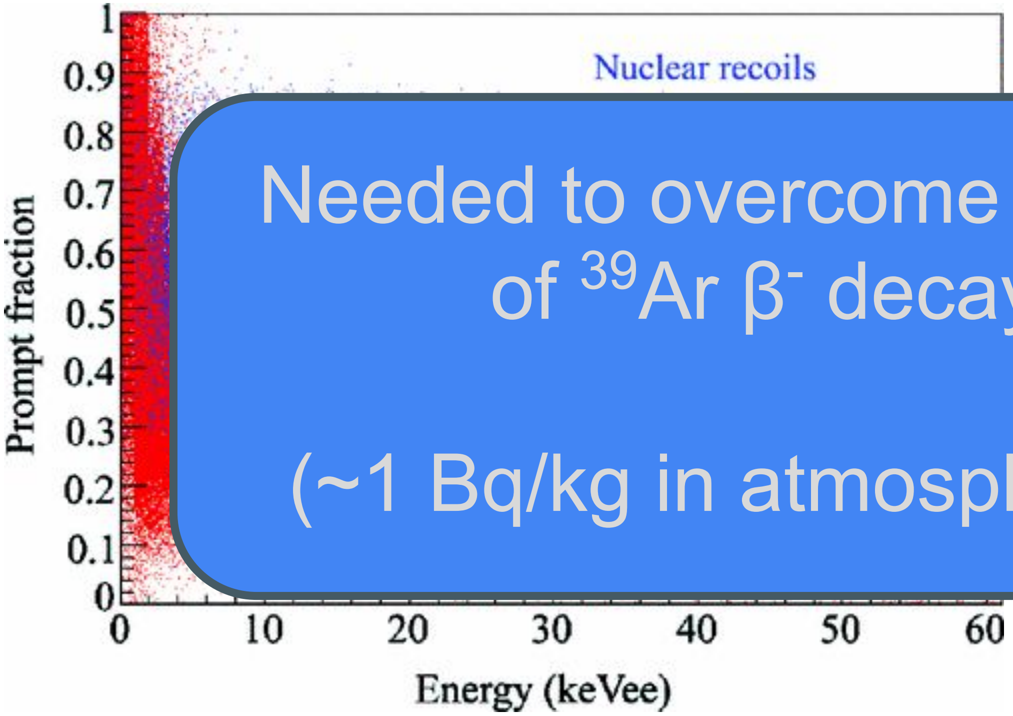
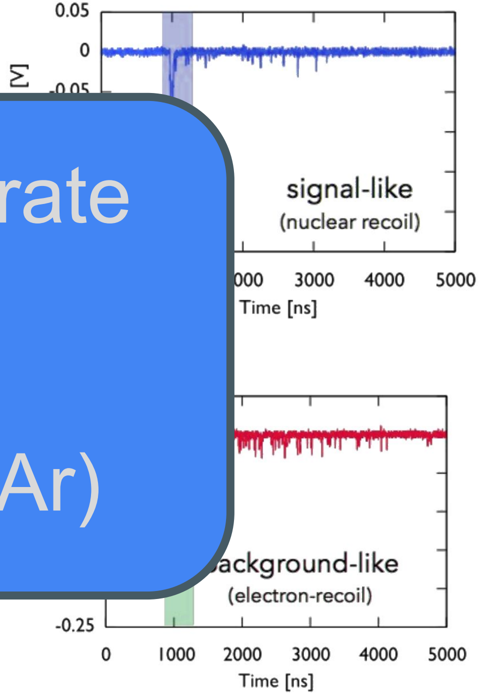


Needed to overcome high rate of ^{39}Ar β^- decays!

(~1 Bq/kg in atmospheric Ar)



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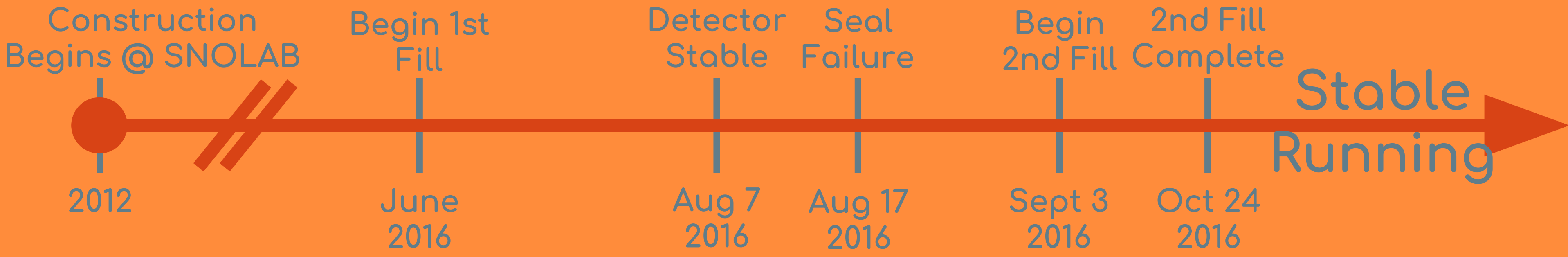
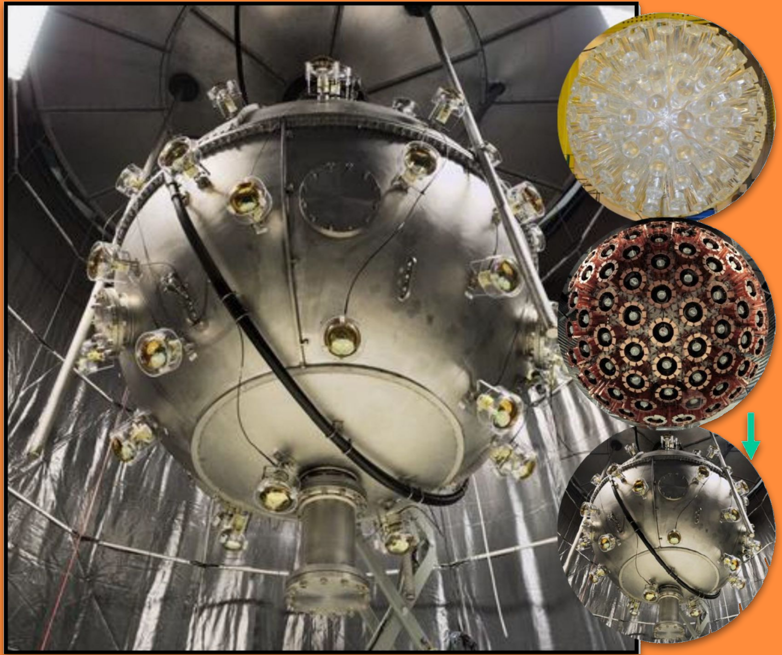
P.A.Amaudruz, *et al*. Astropart. Phys. 85 (Dec 2016), pp 1-23

Timeline


Construction Begins @ SNOLAB
2012
Begin 1st Fill
June 2016
Detector Stable
Aug 7 2016
Seal Failure
Aug 17 2016
Begin 2nd Fill
Sept 3 2016
2nd Fill Complete
Oct 24 2016
Stable Running

Timeline



Construction of parts, as early as 2009

Construction Begins @ SNOLAB — 2012

Begin 1st Fill — June 2016

Detector Stable — Aug 7 2016

Seal Failure — Aug 17 2016

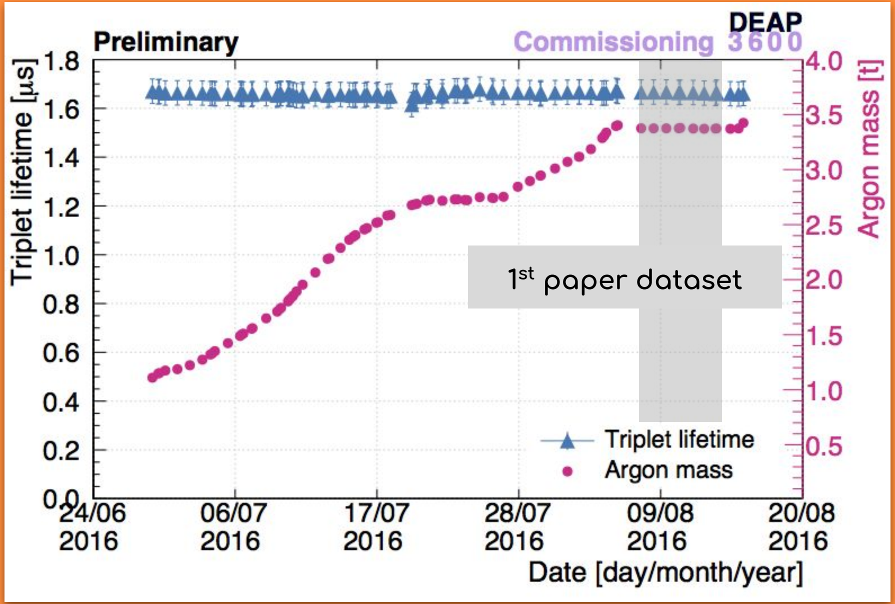
Begin 2nd Fill — Sept 3 2016

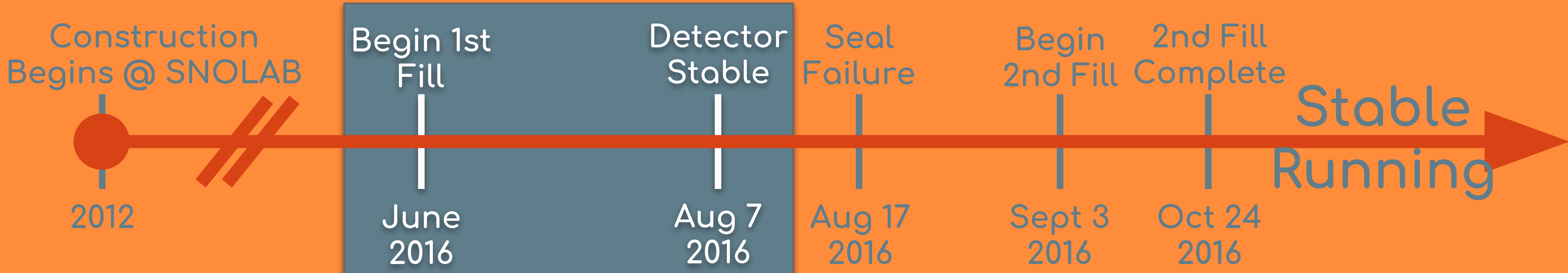
2nd Fill Complete — Oct 24 2016

Stable Running

Details in DEAP-3600 detector paper: arXiv:1712.01982

Timeline


Preliminary
DEAP Commissioning 3600
Triplet lifetime [μs]
Argon mass [t]
1st paper dataset
Triplet lifetime
Argon mass
24/06 2016
06/07 2016
17/07 2016
28/07 2016
09/08 2016
20/08 2016
Date [day/month/year]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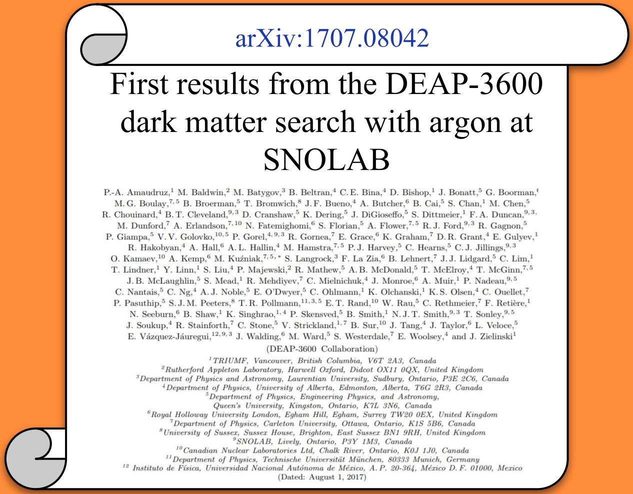


arXiv:1707.08042

First results from the DEAP-3600 dark matter search with argon at SNOLAB

P.-A. Amaudruz,[1] M. Baldwin,[2] M. Batygov,[3] B. Beltran,[4] C.E. Bina,[4] D. Bishop,[1] J. Bonatt,[5] G. Boorman,[6] M. G. Boulay,[7,5] B. Broerman,[5] T. Bromwich,[8] J.F. Bueno,[4] A. Butcher,[6] B. Cai,[5] S. Chan,[1] M. Chen,[5] R. Chouinard,[4] B.T. Cleveland,[9,3] D. Cranshaw,[5] K. Dering,[5] J. DiGioseffo,[5] S. Dittmeier,[1] F.A. Duncan,[9,3,] M. Dunford,[7] A. Erlandson,[7,10] N. Fatemighomi,[6] S. Florian,[5] A. Flower,[7,5] R.J. Ford,[9,3] R. Gagnon,[5] P. Giampa,[5] V.V. Golovko,[10,5] P. Gorel,[4,9,3] R. Gornea,[7] E. Grace,[6] K. Graham,[7] D.R. Grant,[4] E. Gulyev,[1] R. Hakobyan,[4] A. Hall,[6] A.L. Hallin,[4] M. Hamstra,[7,5] P.J. Harvey,[5] C. Hearns,[5] C.J. Jillings,[9,3] O. Kamaev,[10] A. Kemp,[6] M. Kuźniak,[7,5,*] S. Langrock,[3] F. La Zia,[6] B. Lehnert,[7] J.J. Lidgard,[5] C. Lim,[1] T. Lindner,[1] Y. Linn,[1] S. Liu,[4] P. Majewski,[2] R. Mathew,[5] A.B. McDonald,[5] T. McElroy,[4] T. McGinn,[7,5] J.B. McLaughlin,[5] S. Mead,[1] R. Mehdiyev,[7] C. Mielnichuk,[4] J. Monroe,[6] A. Muir,[1] P. Nadeau,[9,5] C. Nantais,[5] C. Ng,[4] A.J. Noble,[5] E. O'Dwyer,[5] C. Ohlmann,[1] K. Olchanski,[1] K.S. Olsen,[4] C. Ouellet,[7] P. Pasuthip,[5] S.J.M. Peeters,[8] T.R. Pollmann,[11,3,5] E.T. Rand,[10] W. Rau,[5] C. Rethmeier,[7] F. Retière,[1] N. Seeburn,[6] B. Shaw,[1] K. Singhrao,[1,4] P. Skensved,[5] B. Smith,[1] N.J.T. Smith,[9,3] T. Sonley,[9,5] J. Soukup,[4] R. Stainforth,[7] C. Stone,[5] V. Strickland,[1,7] B. Sur,[10] J. Tang,[4] J. Taylor,[6] L. Veloce,[5] E. Vázquez-Jáuregui,[12,9,3] J. Walding,[6] M. Ward,[5] S. Westerdale,[7] E. Woolsey,[4] and J. Zielinski[1]

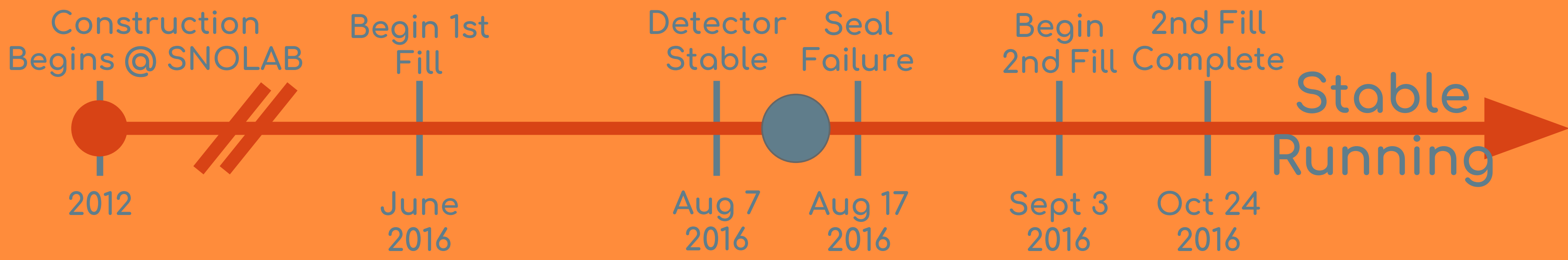
(DEAP-3600 Collaboration)

[1] *TRIUMF, Vancouver, British Columbia, V6T 2A3, Canada*
[2] *Rutherford Appleton Laboratory, Harwell Oxford, Didcot OX11 0QX, United Kingdom*
[3] *Department of Physics and Astronomy, Laurentian University, Sudbury, Ontario, P3E 2C6, Canada*
[4] *Department of Physics, University of Alberta, Edmonton, Alberta, T6G 2R3, Canada*
[5] *Department of Physics, Engineering Physics, and Astronomy, Queen's University, Kingston, Ontario, K7L 3N6, Canada*
[6] *Royal Holloway University London, Egham Hill, Egham, Surrey TW20 0EX, United Kingdom*
[7] *Department of Physics, Carleton University, Ottawa, Ontario, K1S 5B6, Canada*
[8] *University of Sussex, Sussex House, Brighton, East Sussex BN1 9RH, United Kingdom*
[9] *SNOLAB, Lively, Ontario, P3Y 1M3, Canada*
[10] *Canadian Nuclear Laboratories Ltd, Chalk River, Ontario, K0J 1J0, Canada*
[11] *Department of Physics, Technische Universität München, 80333 Munich, Germany*
[12] *Instituto de Física, Universidad Nacional Autónoma de México, A.P. 20-364, México D.F. 01000, Mexico*

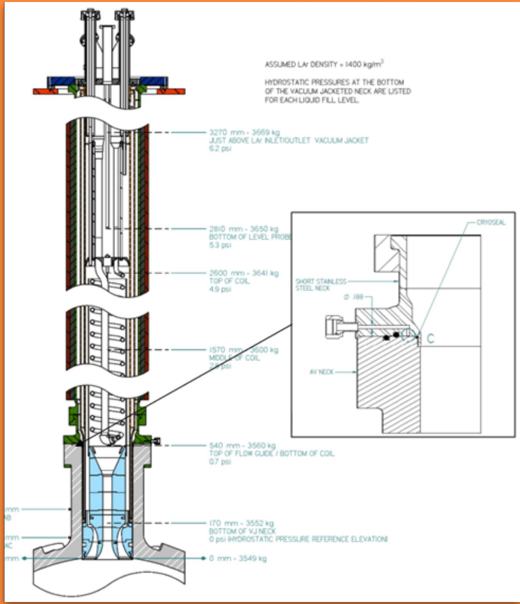
(Dated: August 1, 2017)

Main focus of this talk

- First paper data taken now
- 4.4 live days with stable operating conditions



Timeline

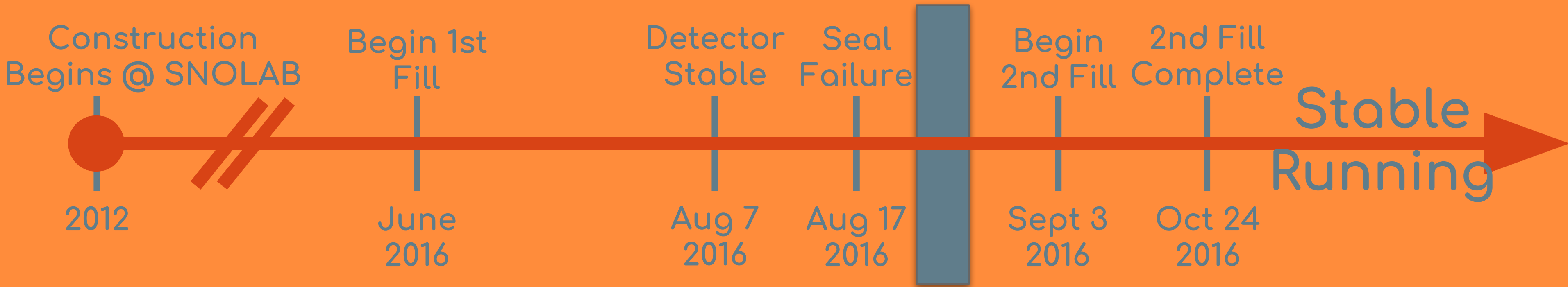


- LAr reached neck
- Seal at acrylic-steel interface got too cold and failed
- Introduced 100 ppm level contamination of Rn-scrubbed N_2

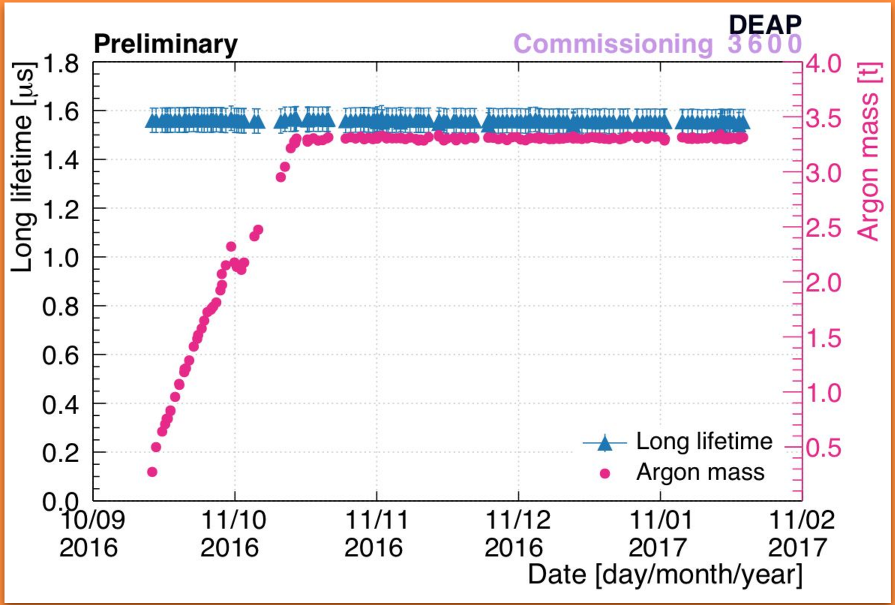
- Construction Begins @ SNOLAB — 2012
- Begin 1st Fill — June 2016
- Detector Stable — Aug 7 2016
- **Seal Failure — Aug 17 2016**
- Begin 2nd Fill — Sept 3 2016
- 2nd Fill Complete — Oct 24 2016
- Stable Running

Timeline

- Vented N_2-contaminated Ar
- Refilled detector
- Left ~35cm clearance between LAr and flow guides
- Stable operating for over 1 year and going



Timeline



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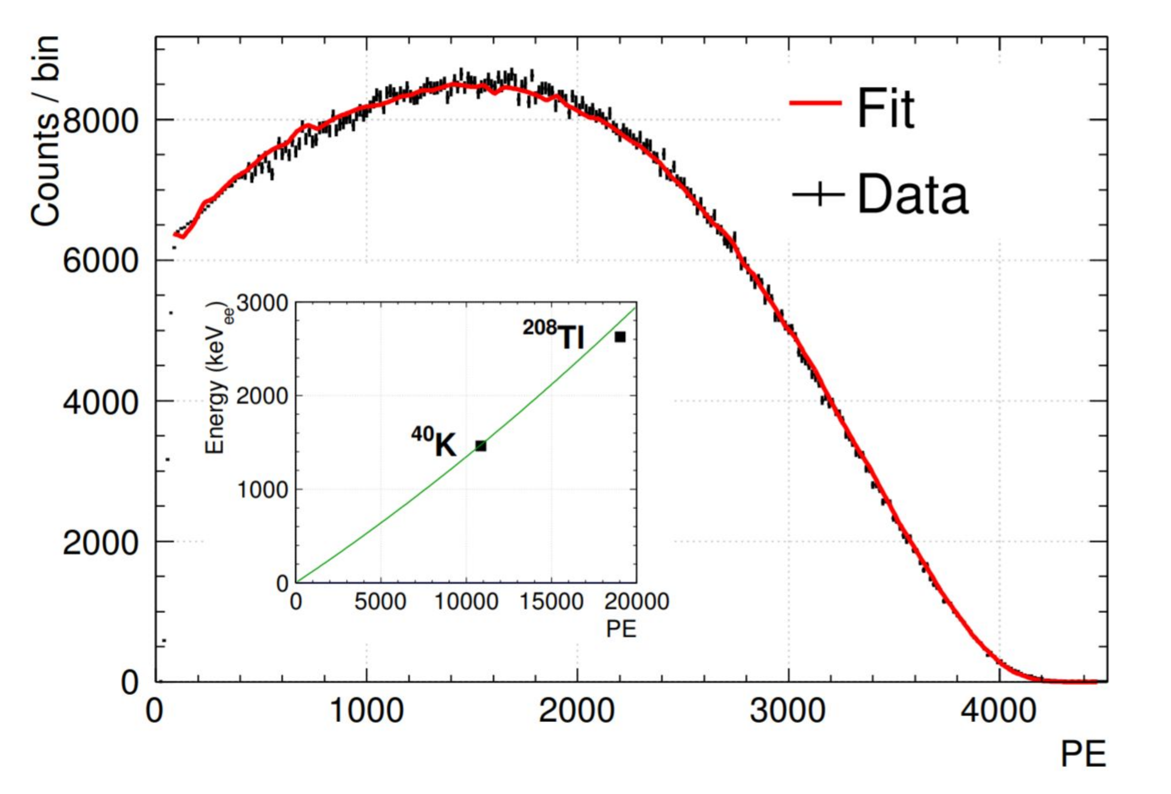
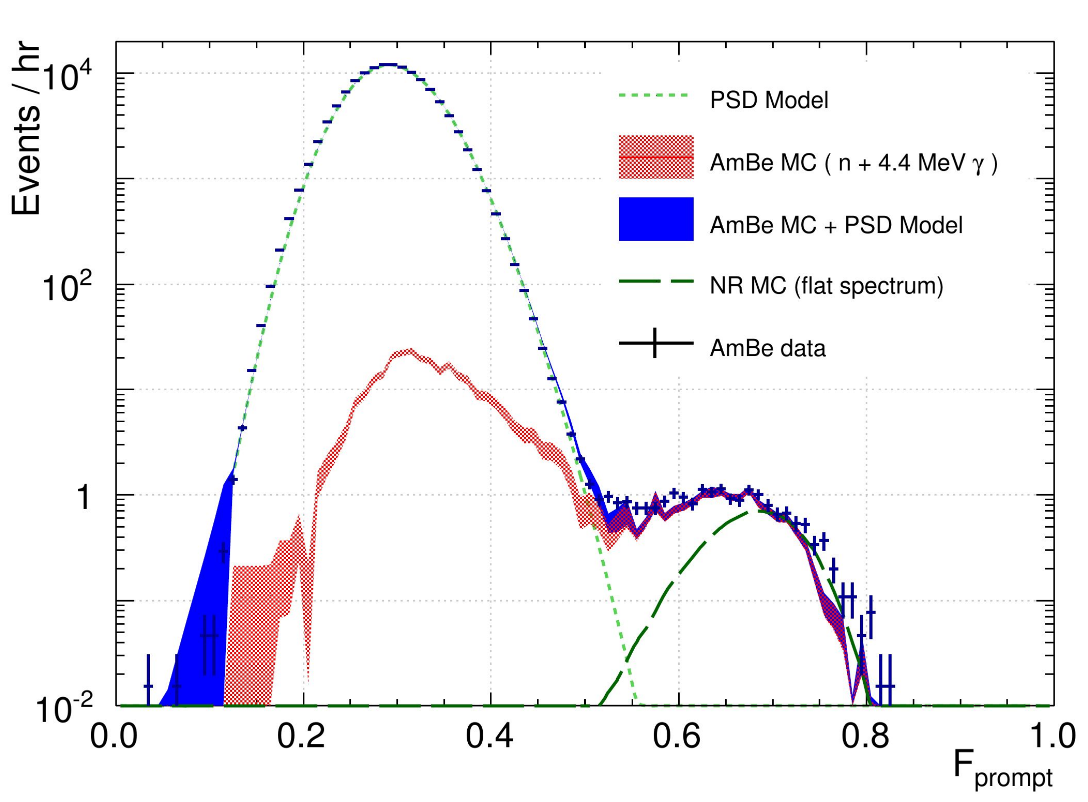
Determine light yield from ^{39}Ar β^- spectrum



- 1st fill dataset: energy calibration with ^{39}Ar spectrum
- Confirmation with comparisons between ^{22}Na and ^{39}Ar data in the 2nd fill

Agreement between AmBe data and MC

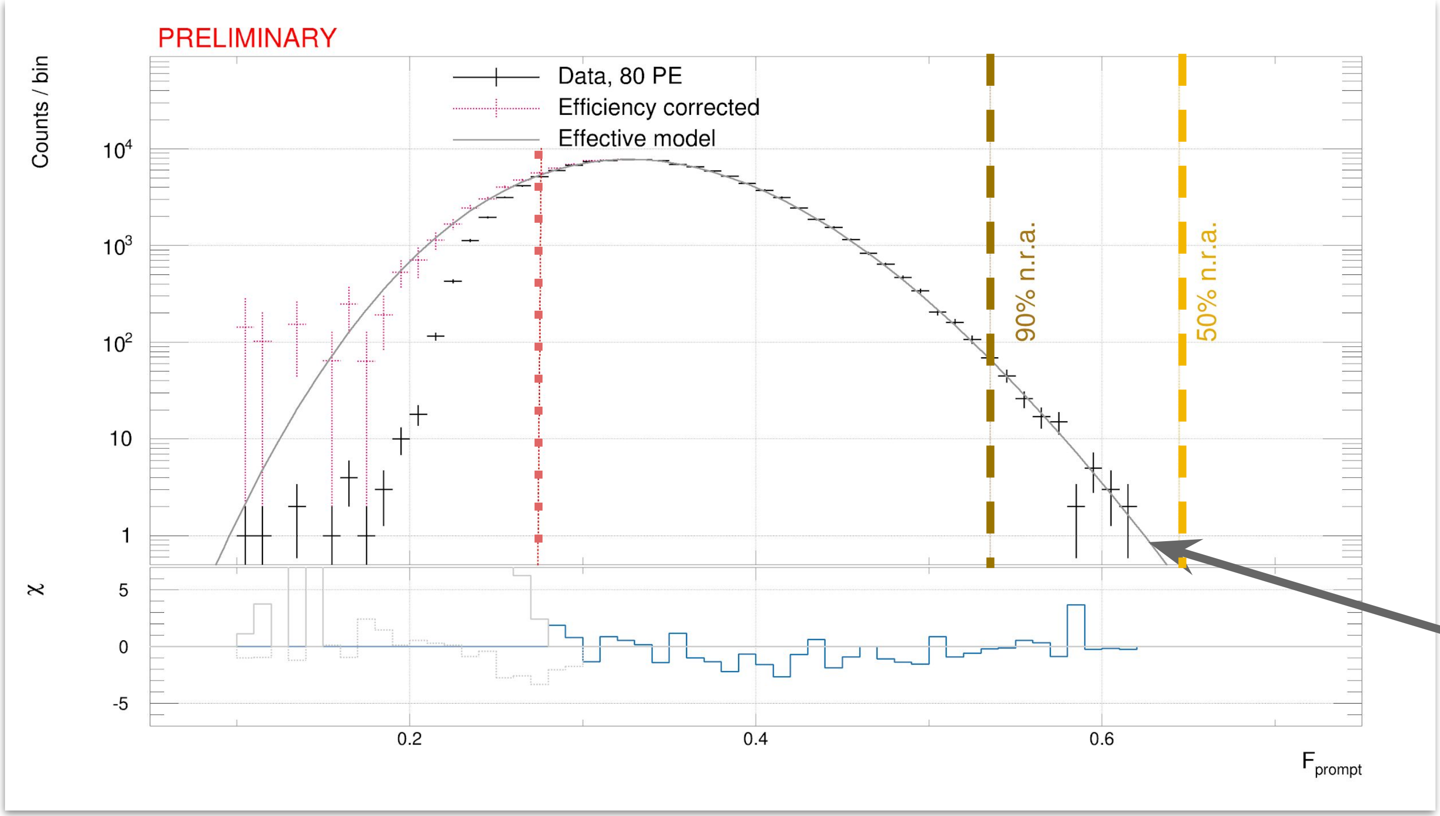


Nuclear recoil band generated from singlet/triplet ratios and quenching factors consistent with SCENE data.

Optical MC propagates detector optics into F_{prompt} distribution, including afterpulsing.

$$F_{\text{prompt}} \equiv \frac{\sum_{\{i|t_i \in (-28 \text{ ns}, 150 \text{ ns})\}} Q_i}{\sum_{\{i|t_i \in (-28 \text{ ns}, 10 \text{ µs})\}} Q_i},$$

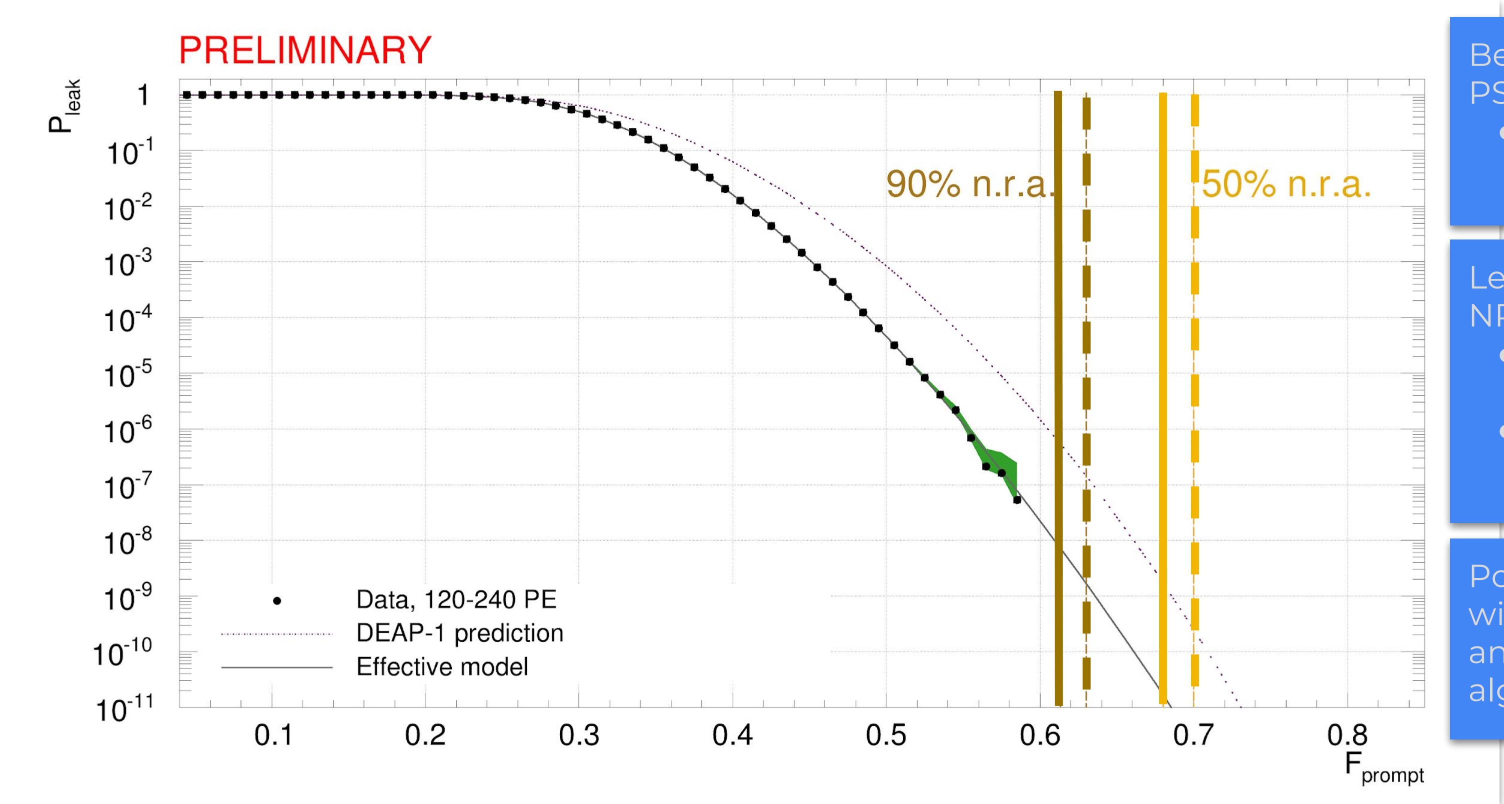
Agreement between PSD model and data at threshold



Reduce ER backgrounds with F_{prompt} cut in each PE bin to achieve leakage rate of 0.2 events during exposure

Gaussian ∗ Gamma

Powerful ER rejection with good NR acceptance



Best demonstration of PSD in LAr to date!

- Better than DEAP-1 prediction

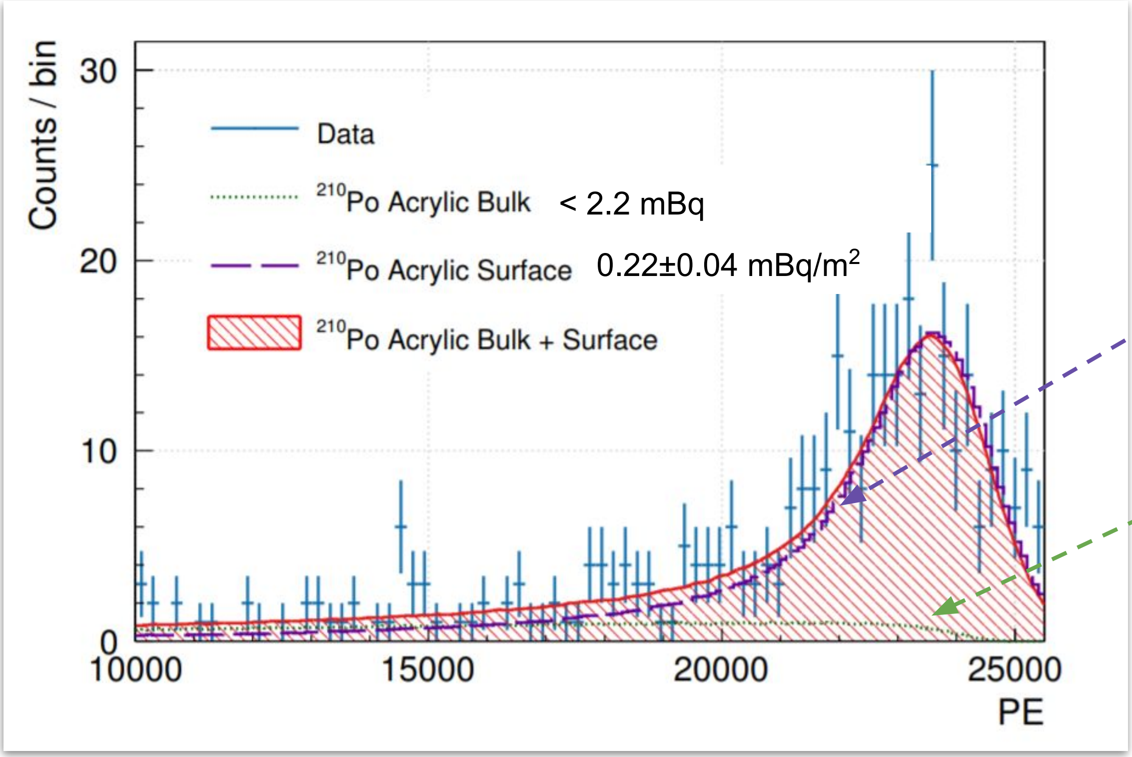
Leakage prob <10^{-7} (90% NR acceptance)

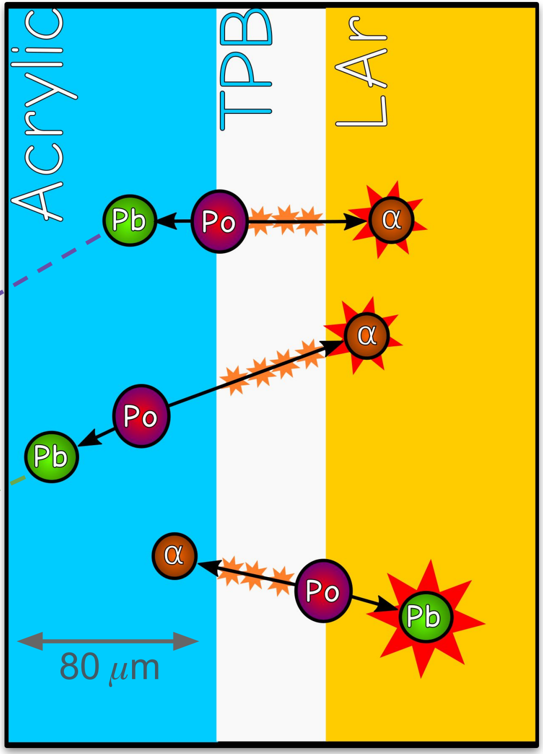
- 90% N.R.A. projection: 10^{-8}
- 50% N.R.A. projection: 10^{-10}

Possible improvements with more optimization and afterpulse removal algorithms

Surface radon contamination levels

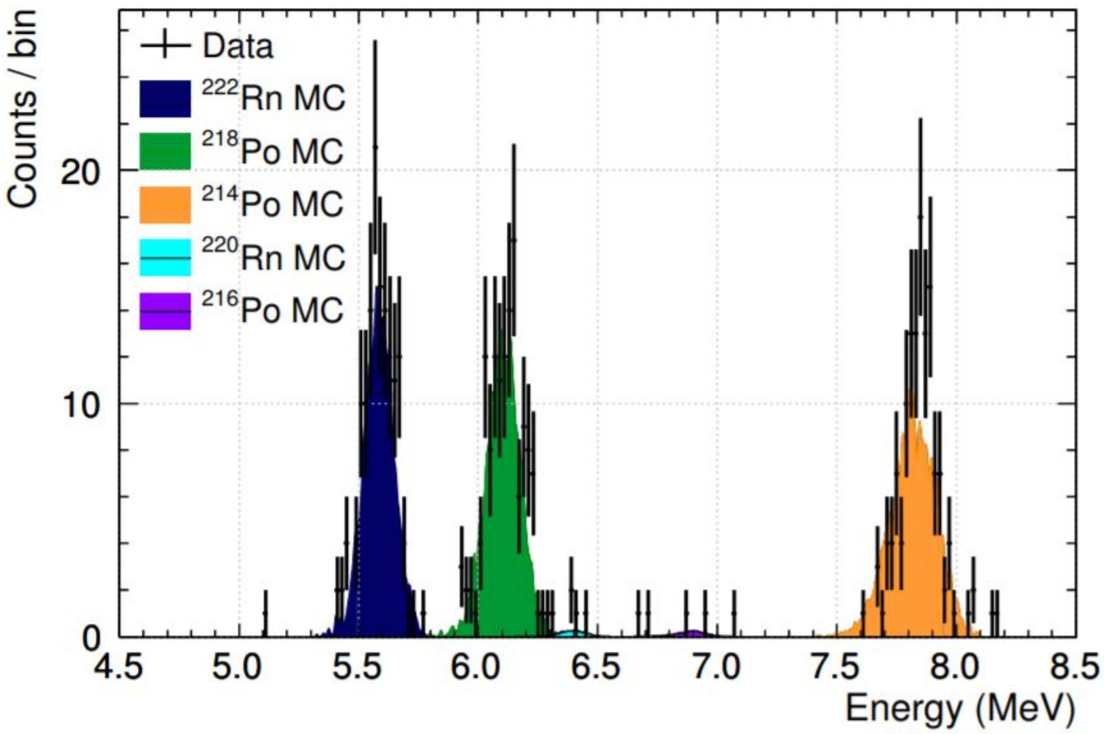
Degraded α particles and recoiling lead nuclei may make NRs on inner surface of detector





Radon contamination in bulk LAr

May stick to surfaces and become surface backgrounds



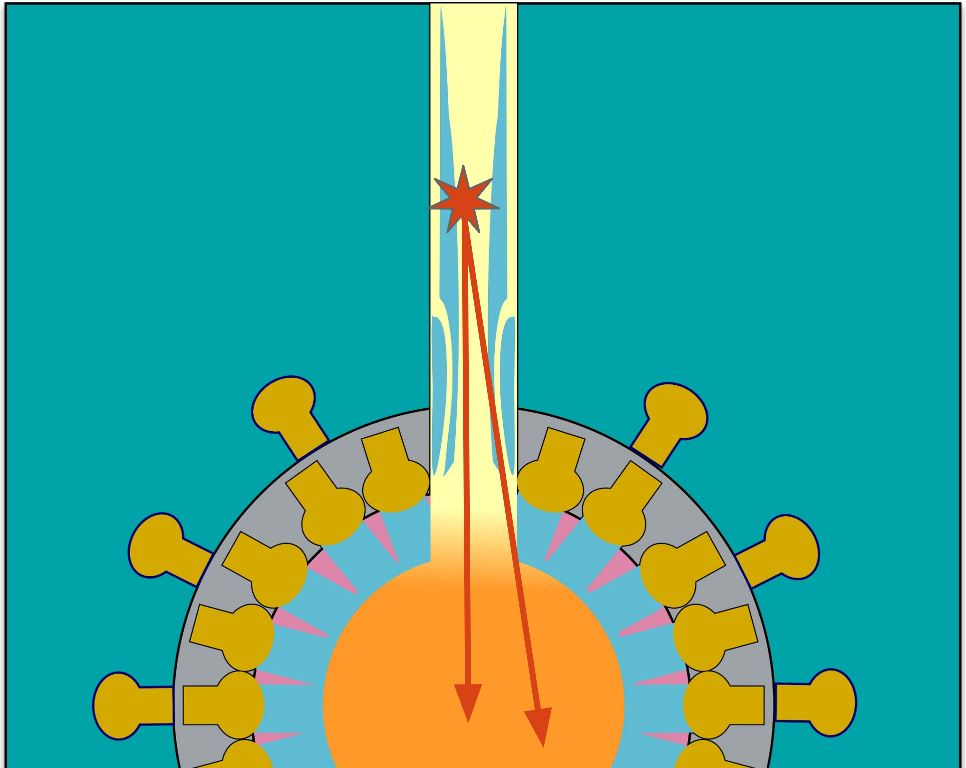
Measured activities

- ^{222}Rn: $(1.8\pm0.2)\times10^{-1}$ μBq/kg
- ^{214}Po: $(2.0\pm0.2)\times10^{-1}$ μBq/kg
- ^{220}Rn: $(2.6\pm1.5)\times10^{-3}$ μBq/kg

Lowest Rn contamination of any noble liquid dark matter experiment!

Radon contamination in neck

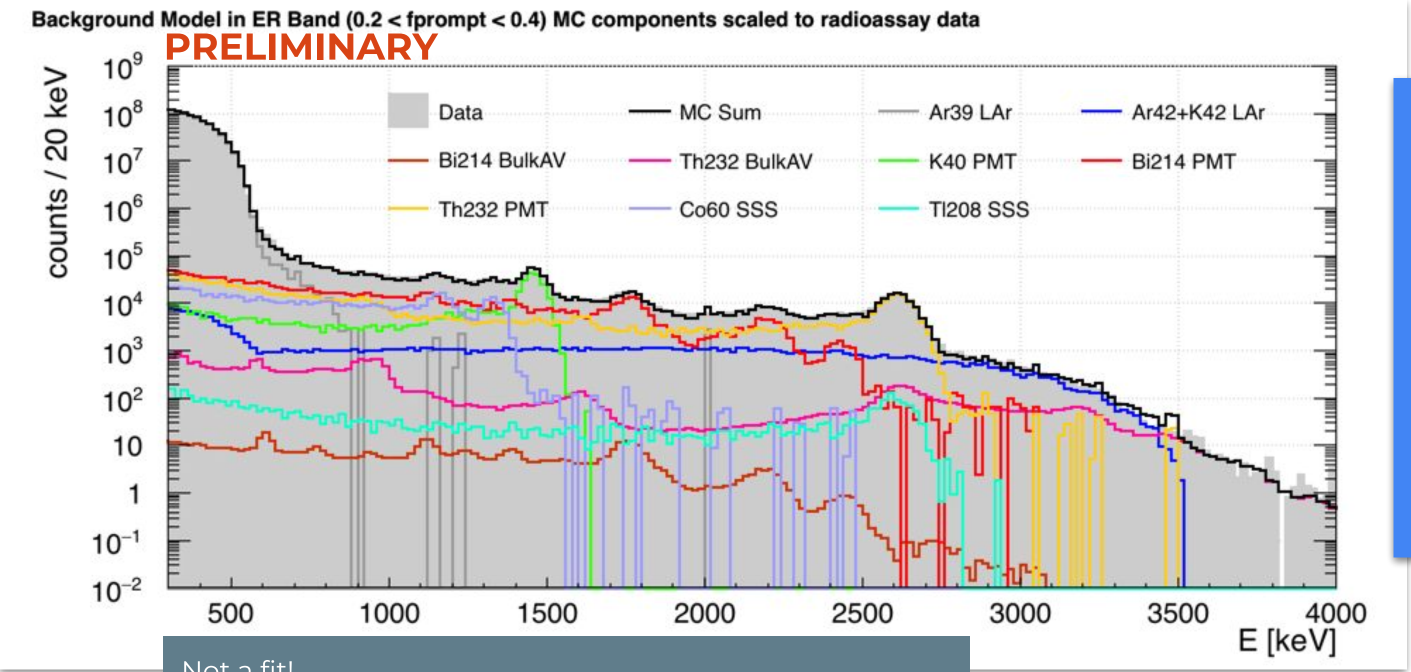
α decays in a LAr film on the flow guides may lose light due to solid angle and appear in ROI



Still working on understanding these backgrounds and how to discriminate them in larger dataset

ER backgrounds consistent with screening

U and Th within factor of 2 of expectations → Radiogenic neutron rate consistent w/ design goal

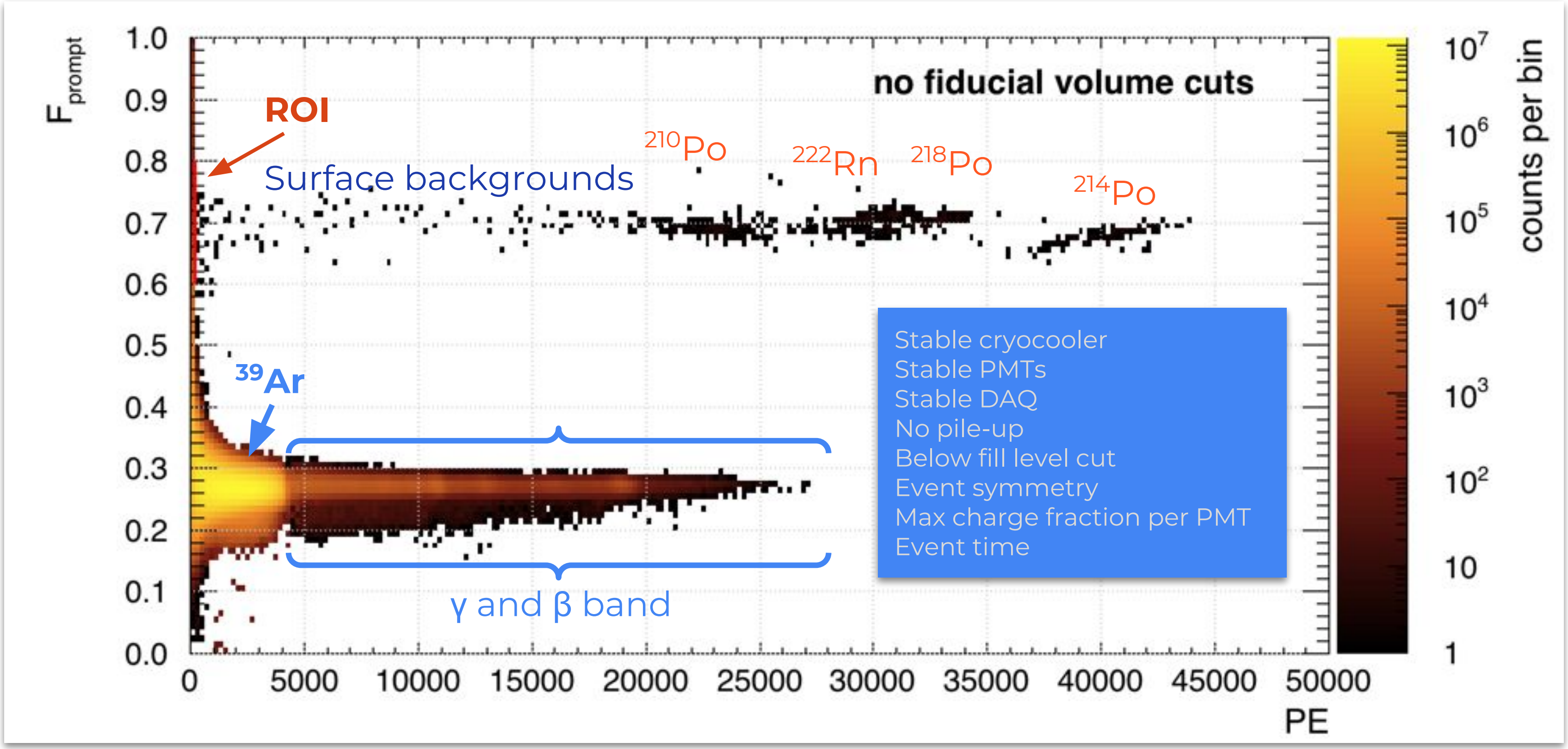


Not a fit!
Energy resolution and pileup rates tuned to match data

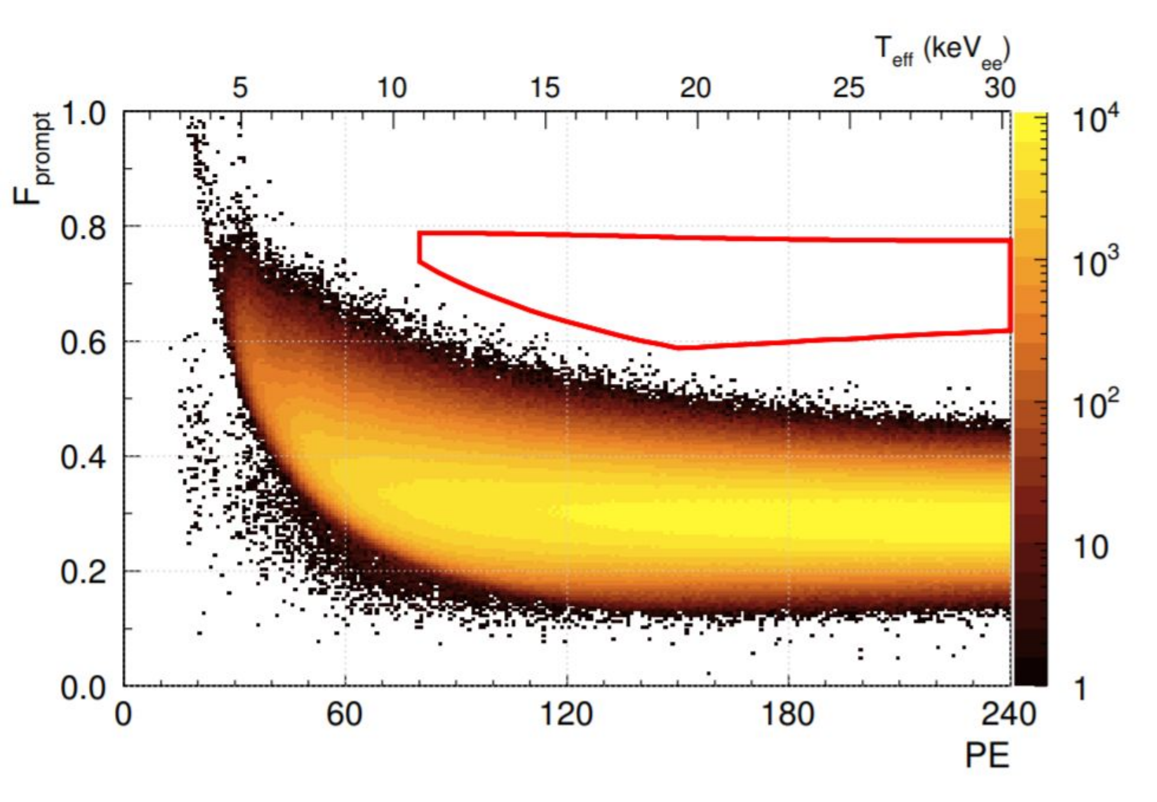
Searches for neutron capture γ's are consistent with expected radiogenic neutron production rate

Target is < 0.2 events in fiducial volume after all cuts

First paper dataset (4.4 d), partial cuts



In the region of interest, after all cuts



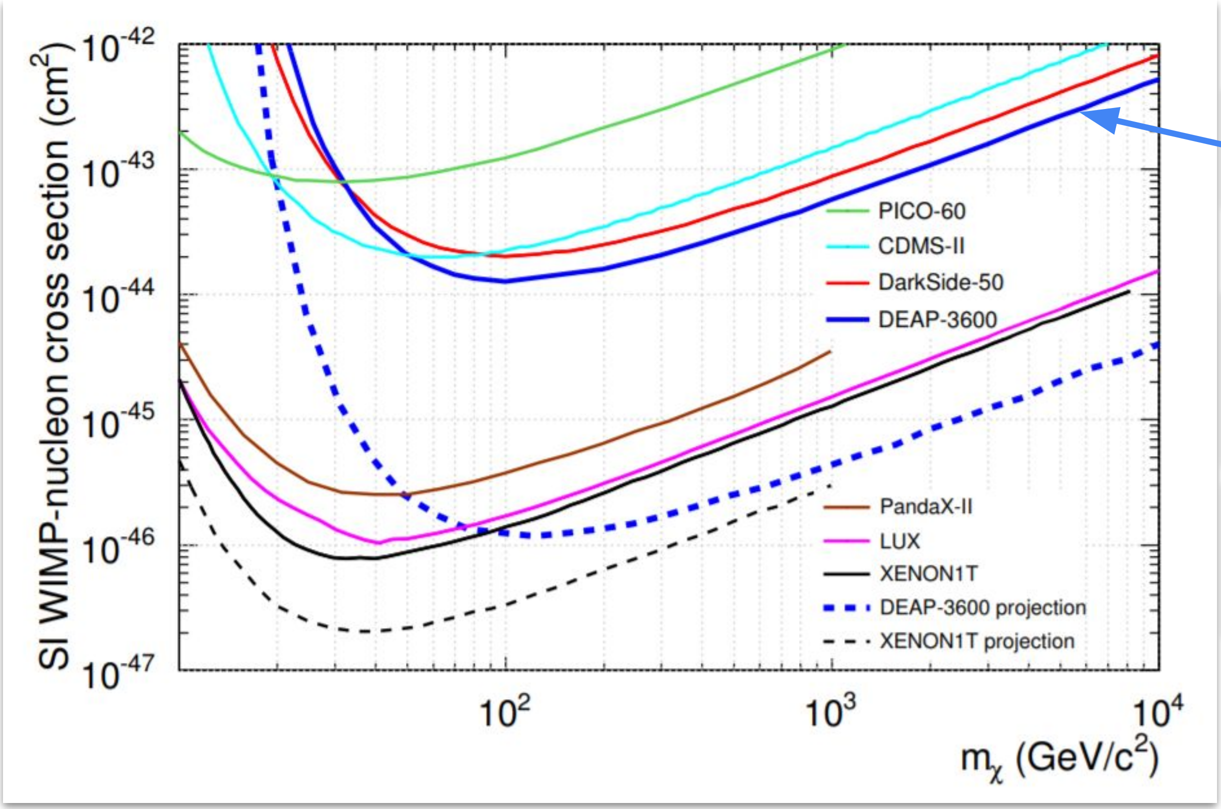
See our first physics paper: arXiv:1707.08042

ROI definition:

- Total of 0.2 PSD leakage events
- < 95% (99%) NR acceptance per bin from below (above)

Live time: 4.4 days
Fiducial mass: 2223 kg
Events in ROI: 0

Excluded WIMP-nucleon cross-sections



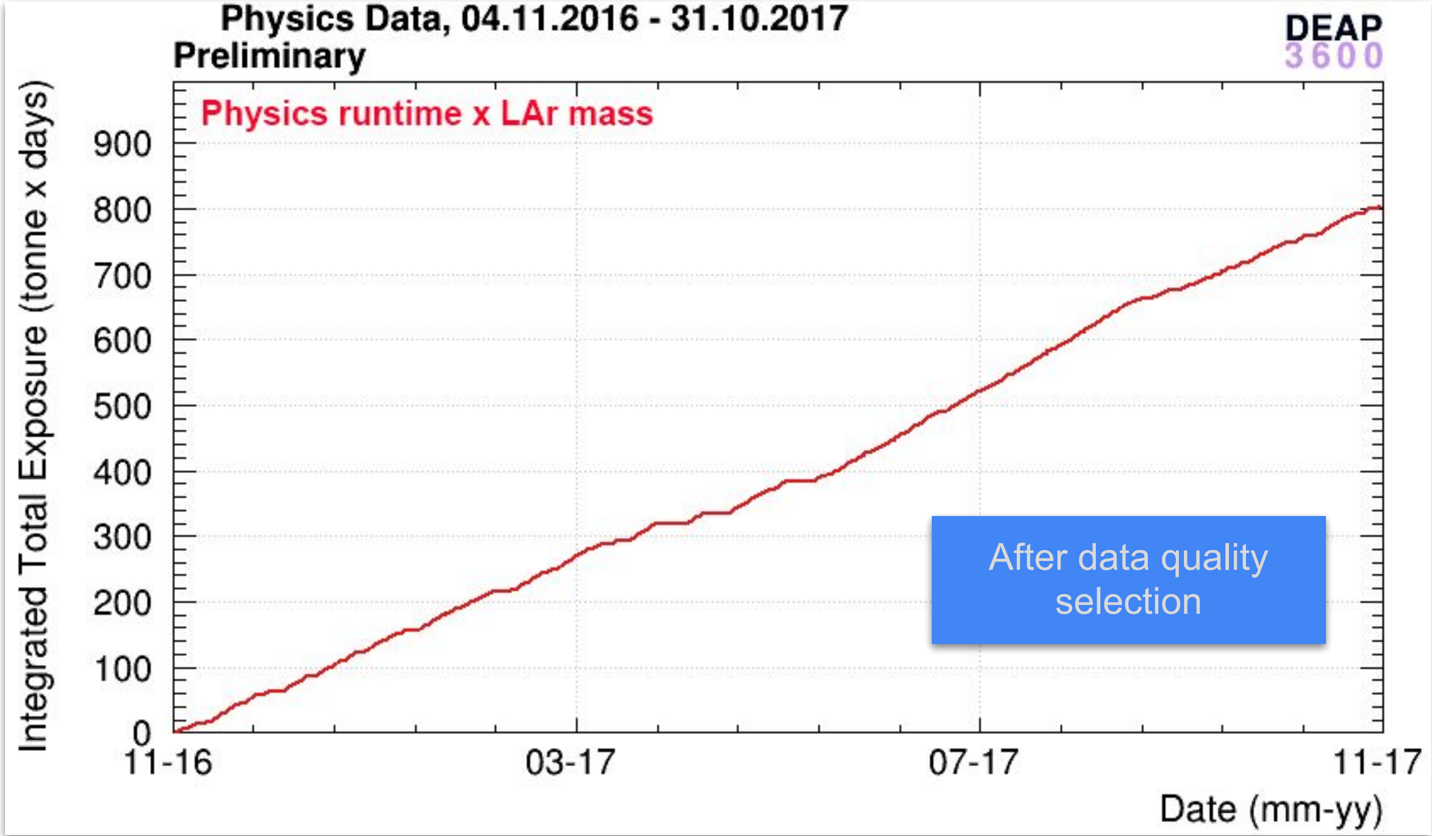
See our first physics paper: arXiv:1707.08042

Live time: 4.4 days
Fiducial mass: 2223 kg
Events in ROI: 0

At m_χ = 100 GeV/c^2 :

σ_{SI} < 1.2 ·10^{-44} cm^2 at 90% C.L.

Cumulative live time with second fill



247 live days

Before fiducial & analysis cuts

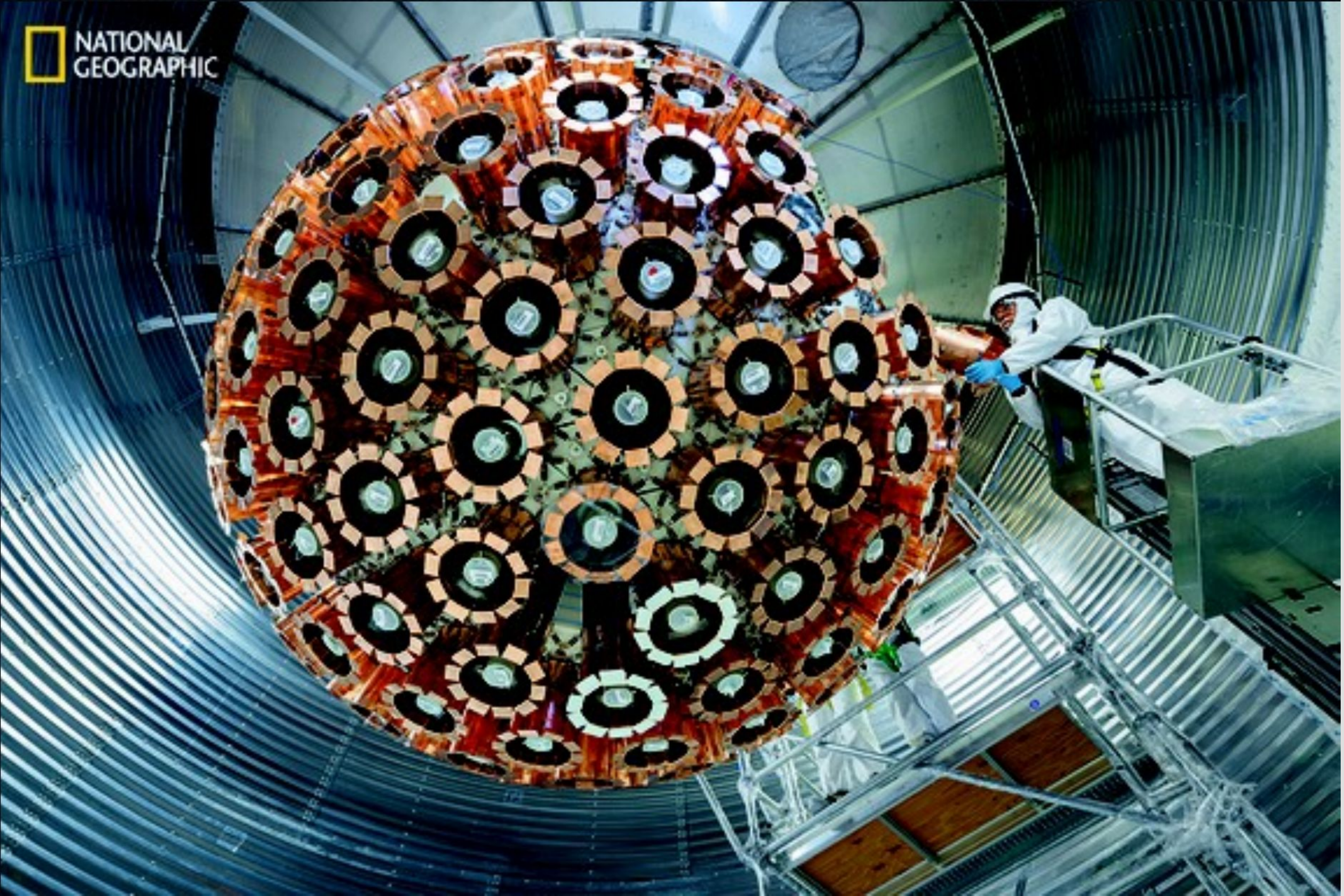
and increasing!

Keep your eyes out for paper #2!

Blinding scheme in place for data after Jan 2, 2018

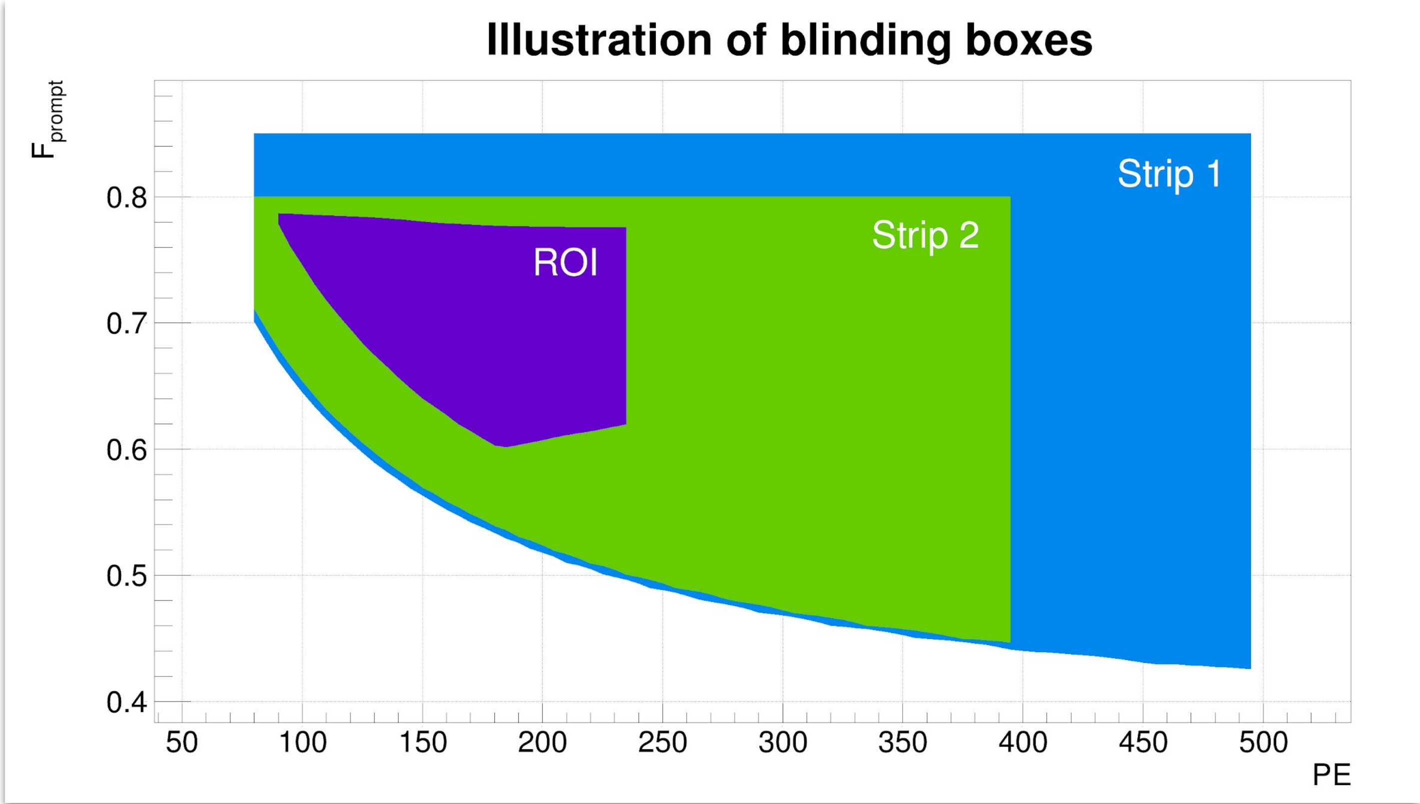
Future plans

- With about a year of data, moving towards a second paper!
- Plans to improve our energy calibration with ^{83m}Kr calibration source
- Internal ^{220}Rn calibration source to model neck events
- Target: 3 tonne-year fiducial exposure
- It's an exciting time for DEAP!
    - Best demonstration of PSD, with plans to improve
    - Lowest Rn contamination of any noble liquid dark matter experiment
    - Most sensitive LAr dark matter detector currently running
- Next generation detector:
    - Joining the Global Argon Dark Matter Collaboration for DarkSide-20k
    - Future multi-hundred tonne LAr detector
    - R&D for new silicon photomultiplier (SiPM) technology



END

Blinding data as of 2018

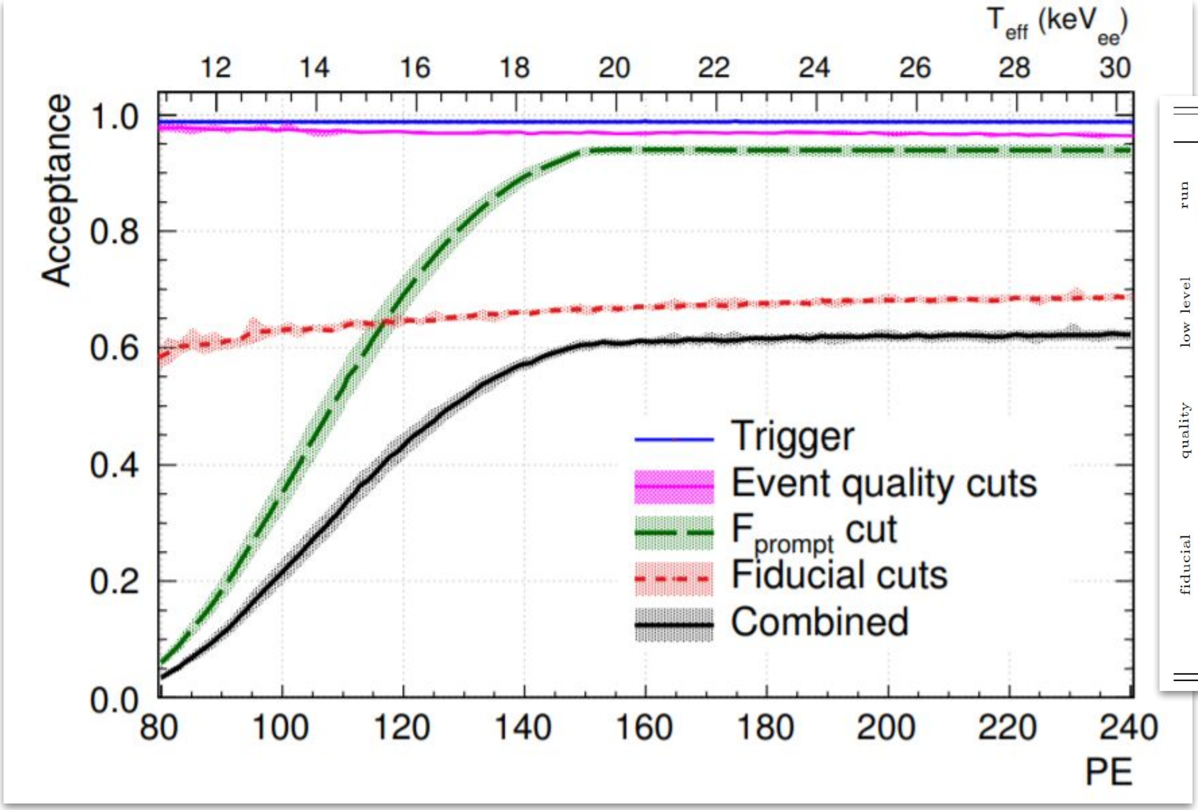


Contents of each box are hidden from analysis

Strips will be removed one at a time to confirm background model

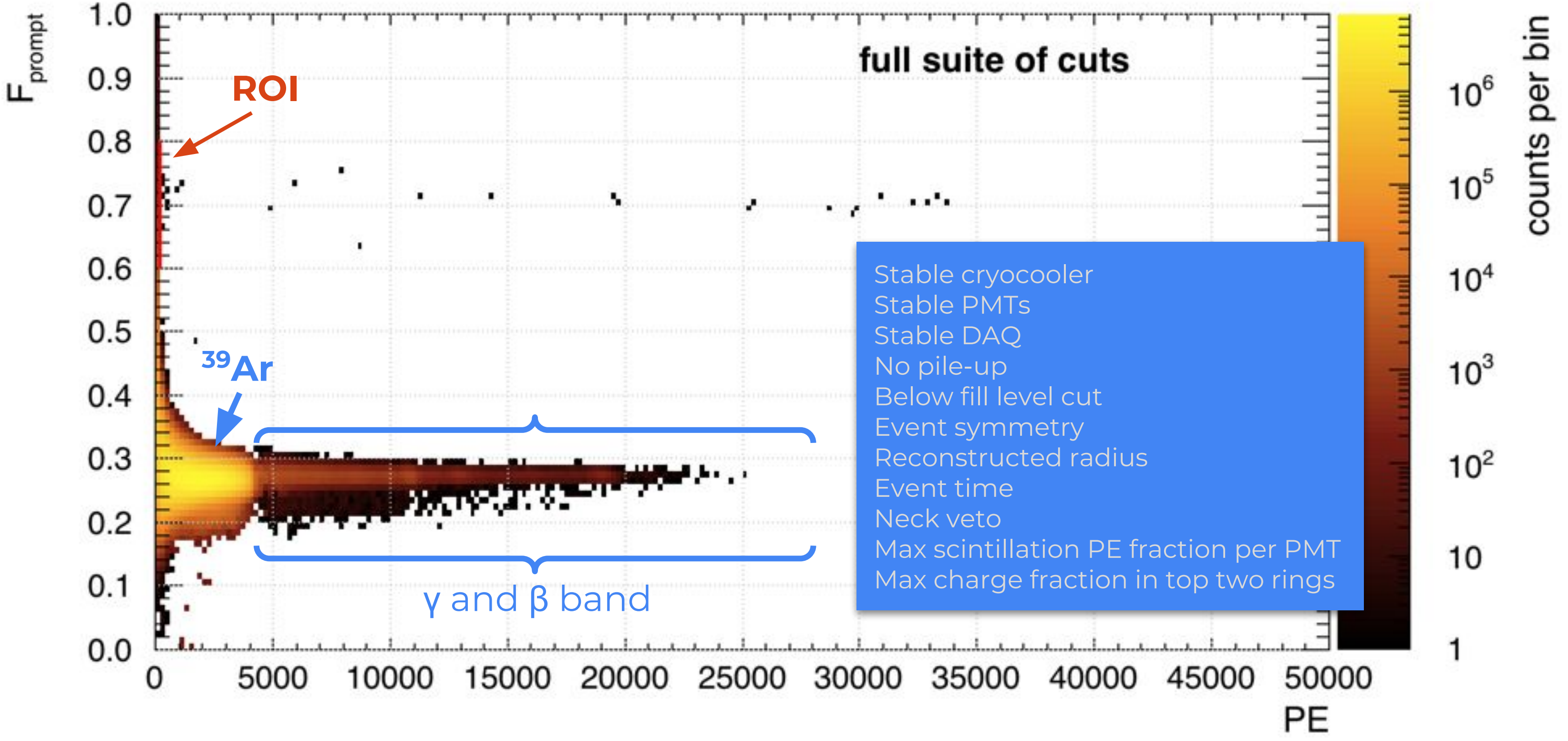
All calibration and special run data and 20% of physics data left open

Cut acceptance



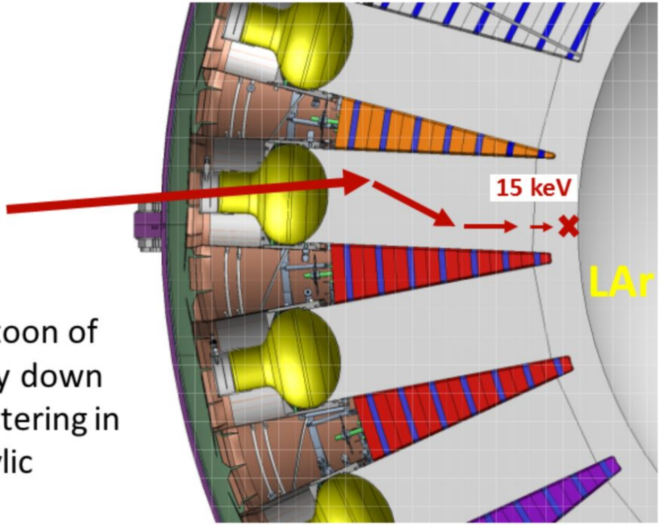
	Cut	Livetime	Acceptance %		$\#_{evt.}^{ROI}$
run	Physics runs	8.55 d			
	Stable cryocooler	5.63 d			
	Stable PMT	4.72 d			
	Deadtime corrected	4.44 d			119181
low level	DAQ calibration				115782
	Pile-up				100700
	Event asymmetry				787
quality	Max charge fraction per PMT		99.58±0.01		654
	Event time		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

First paper dataset after all cuts

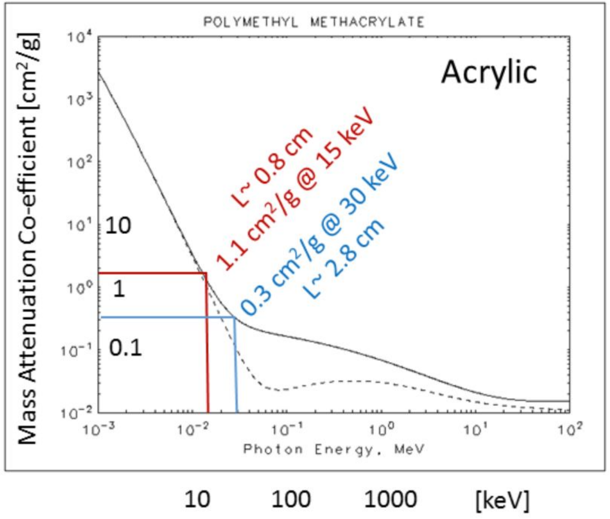


- Stable cryocooler
- Stable PMTs
- Stable DAQ
- No pile-up
- Below fill level cut
- Event symmetry
- Reconstructed radius
- Event time
- Neck veto
- Max scintillation PE fraction per PMT
- Max charge fraction in top two rings

^{22}Na low energy feature



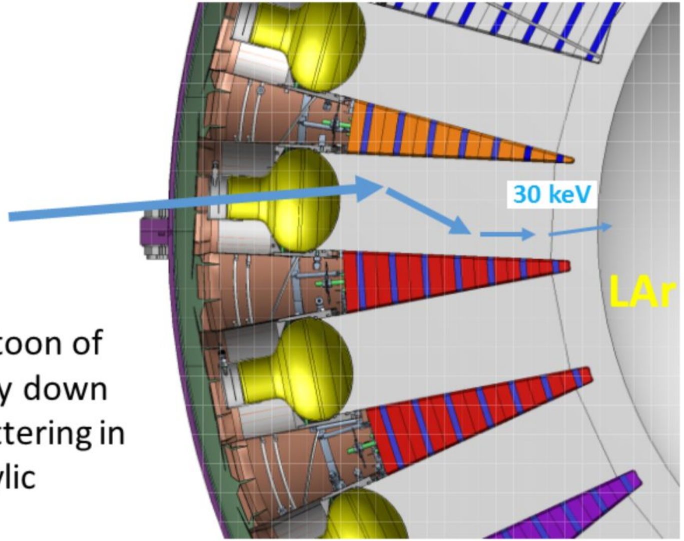
Cartoon of
γ-ray down
scattering in
acrylic

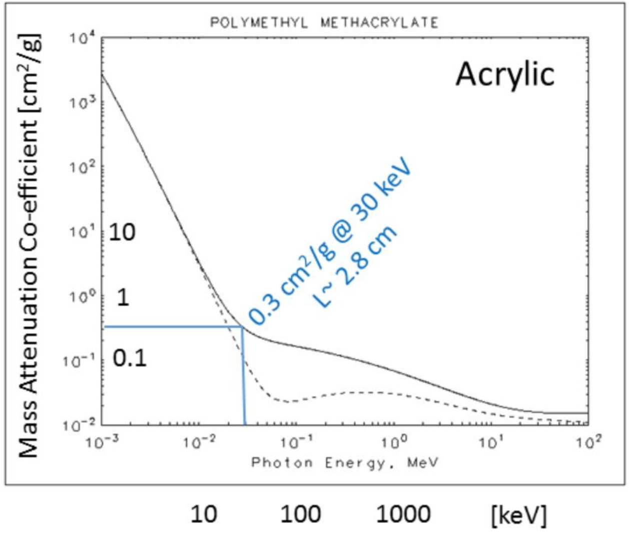


Plot and data from NIST.gov
X-ray mass attenuation coefficients

^{22}Na low energy feature

Cartoon of γ-ray down scattering in acrylic



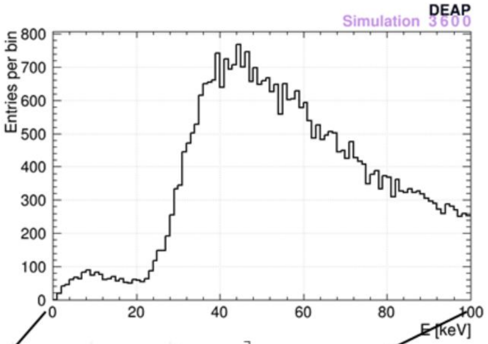


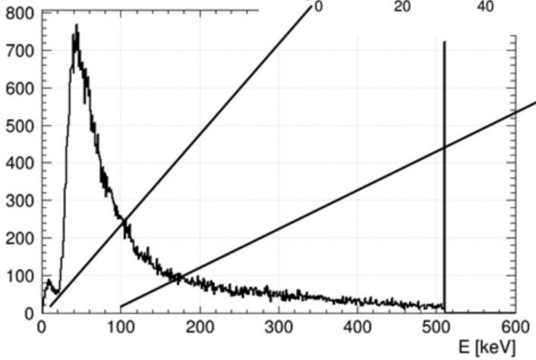
Plot and data from NIST.gov
X-ray mass attenuation coefficients

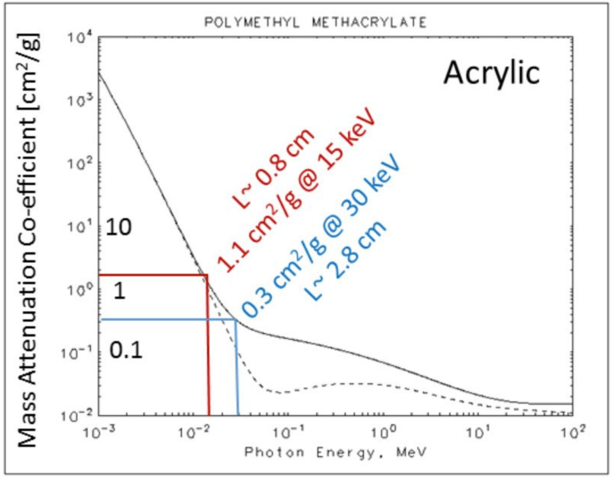
^{22}Na low energy feature

Both the Rising and Falling Edge in Distribution Energy Deposit Arise from Electromagnetic Physics

Example: 511 keV γ
Simulated energy deposit in liquid argon.







Plot and data from NIST.gov
X-ray mass attenuation coefficients

^{22}Na low energy calibration