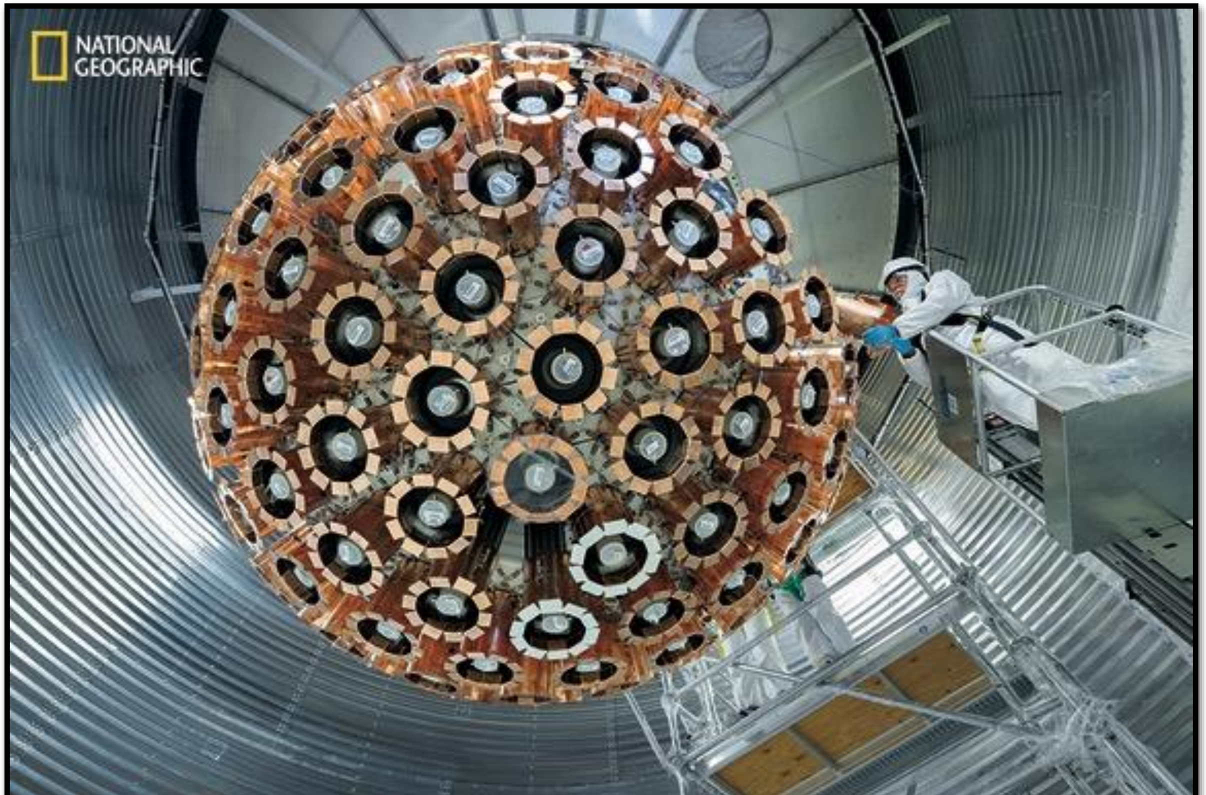
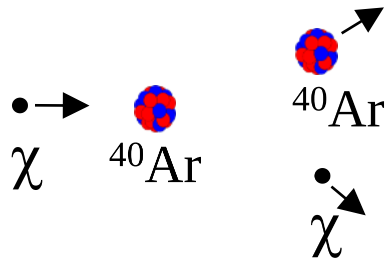
DEAP-3600 at SNOLAB – First Results and Future Plans



Mark Boulay
Carleton University
Queen's University
for DEAP-3600

DEAP-3600 Dark Matter Search

Liquid Argon for DM (Single-phase)



Scattered nucleus detected via scintillation in LAr

Good Pulse-shape discrimination between β/γ and nuclear recoils with scintillation

Argon is **easy to purify**

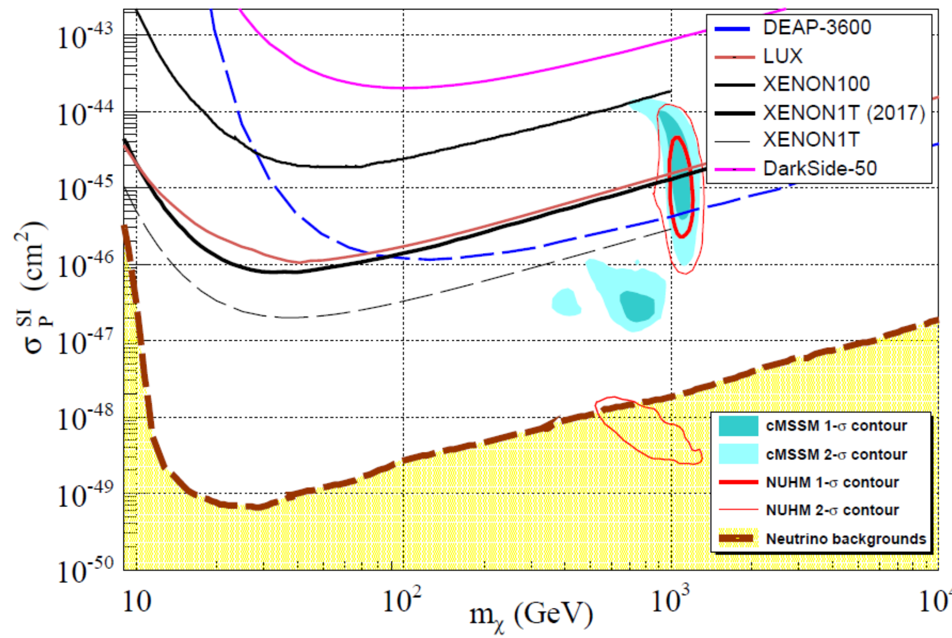
Very large target masses possible, no absorption of UV scintillation photons in argon, no pileup until beyond tonne-scale

Position reconstruction allows surface background removal, based on photon detection (~5 cm resolution allows removal of radon daughter events from analysis)

Very uniform and stable detector response

DM Sensitivity

1 tonne fiducial mass (3.6 tonnes total) designed for < 0.2 background events/year, 3 year run



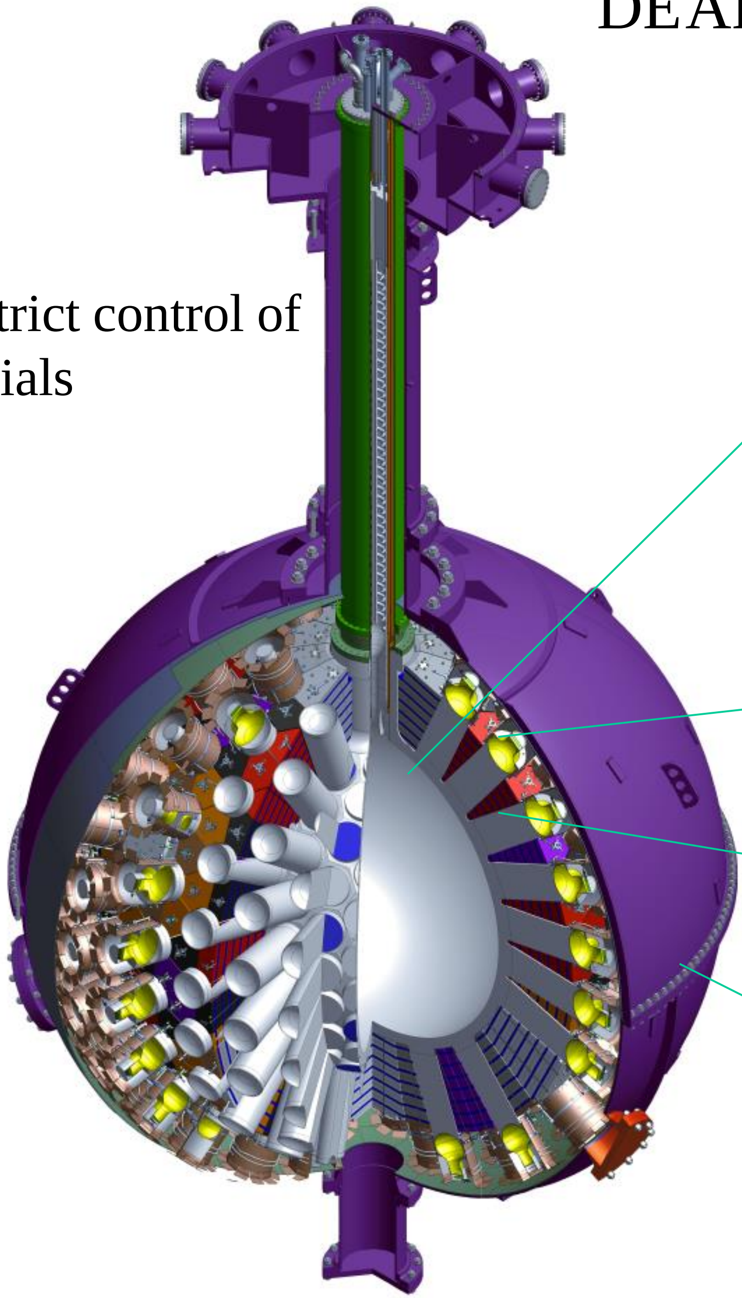
Latest result is from XENON-1T May 2017

Mark Boulay

DEAP-3600 Detector (single-phase)

very strict control of materials

3.5 meters



3600 kg argon in sealed ultraclean Acrylic Vessel (1.7 m ID)

Vessel is “resurfaced” in-situ to remove deposited Rn daughters after construction

255 Hamamatsu R5912 HQE PMTs 8-inch (Light Sensors)

50 cm light guides + PE shielding provide neutron moderation

Steel Shell immersed in 8 m water shield at SNOLAB

DEAP Collaboration: 75 researchers in Canada, UK, and Mexico

UNIVERSITY OF ALBERTA

Carleton UNIVERSITY

Laurentian University Université Laurentienne

Queen's UNIVERSITY

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Particle Physics Rutherford Appleton Laboratory

SNOLAB Mining for knowledge Creuser pour trouver... l'excellence

US University of Sussex

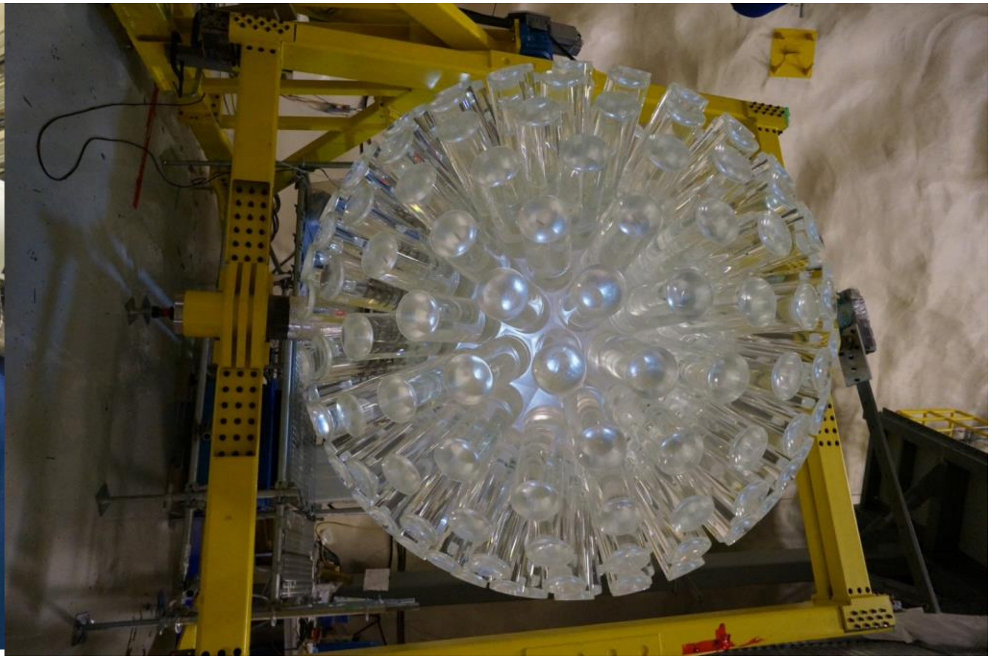
Canadian Nuclear Laboratories / Laboratoires Nucléaires Canadiens

TRIUMF

IF Instituto de Física

Mark Boulay

DEAP Assembly at SNOLAB (2013-2016)



Background	Fiducial No. Events in Energy ROI – 3 live years
Neutrons	<0.2
Surface α's	<0.2
^{39}Ar β's (natural argon)	<0.2

designed for
1-tonne fiducial mass
3 live years

Mark Boulay

Fabrication and Assay of DEAP Acrylic

- Fabrication from pure MMA monomer at RPTAsia (Thailand), strict control of radon exposure for all steps, to < 10^{-20} g/g ^{210}Pb (RPT was fabricator of the SNO Acrylic Vessel)

- Assay of production acrylic < 2.2×10^{-19} g/g ^{210}Pb
  (Corina Nantais M.Sc. Thesis 2014, <0.2 bkg events/3 years)

Monomer cast at RPT Asia, 2010

Thermoformed Panel at RPT Colorado

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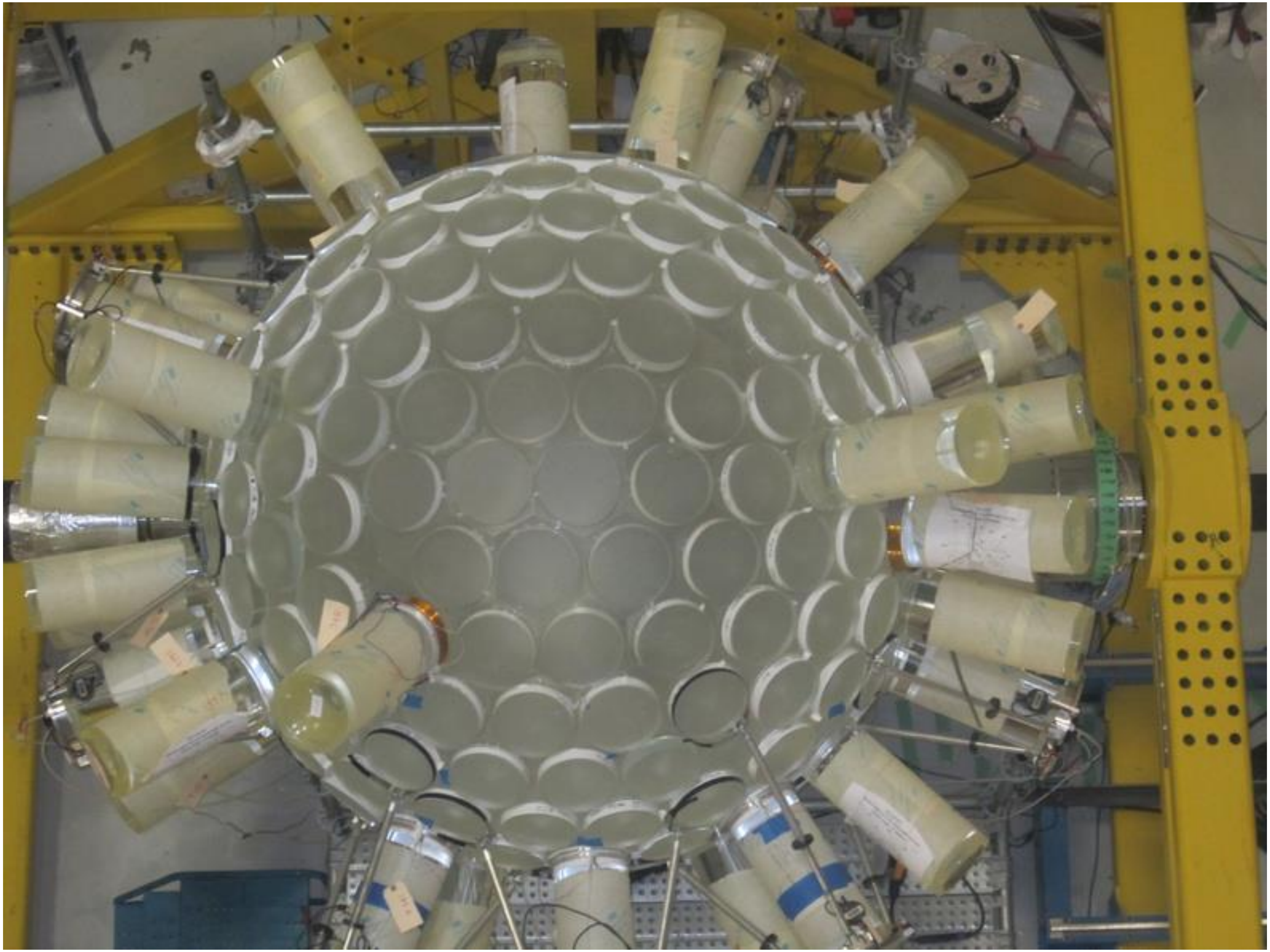
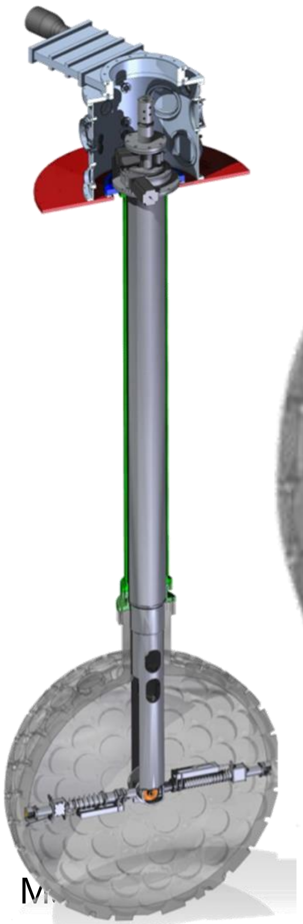
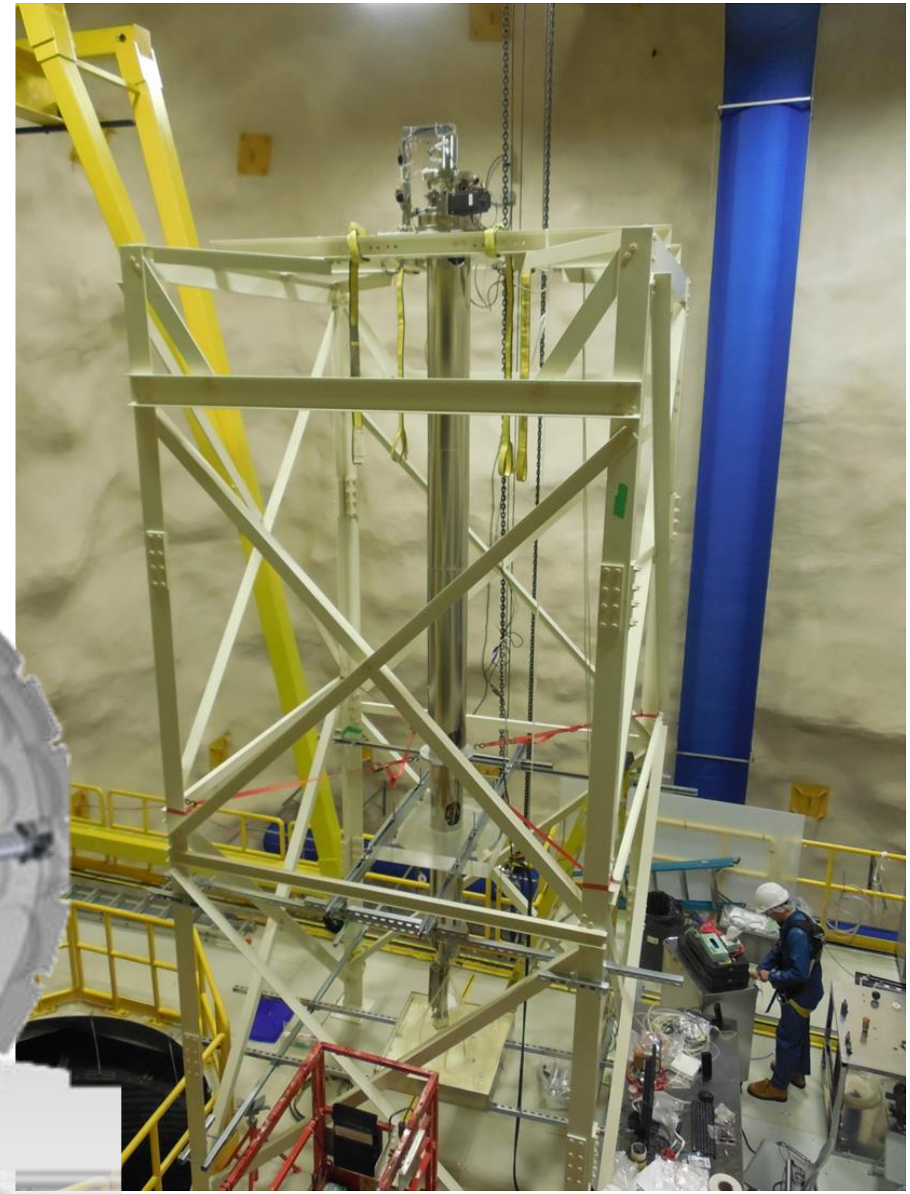
Bonding light guides to the DEAP AV, underground at SNOLAB



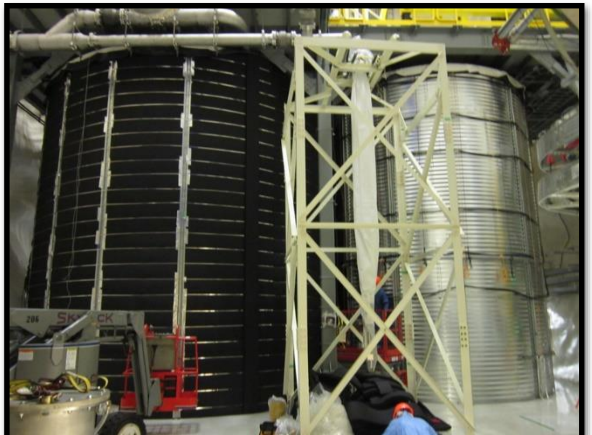
Acrylic Vessel Resurfacer

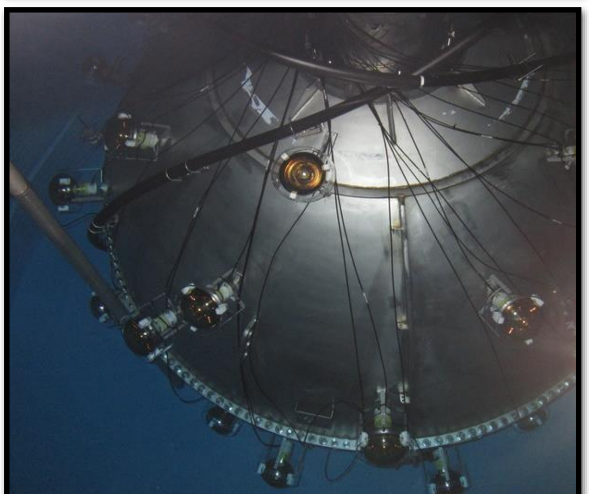
- Mechanical sander to clean inner surface
- Components selected for low radon emanation
- Remove 0.5-mm surface *in situ* with N_2 purge
- Cleans surface to bulk-level impurities
  (order 100,000 cleaner than SNO vessel)

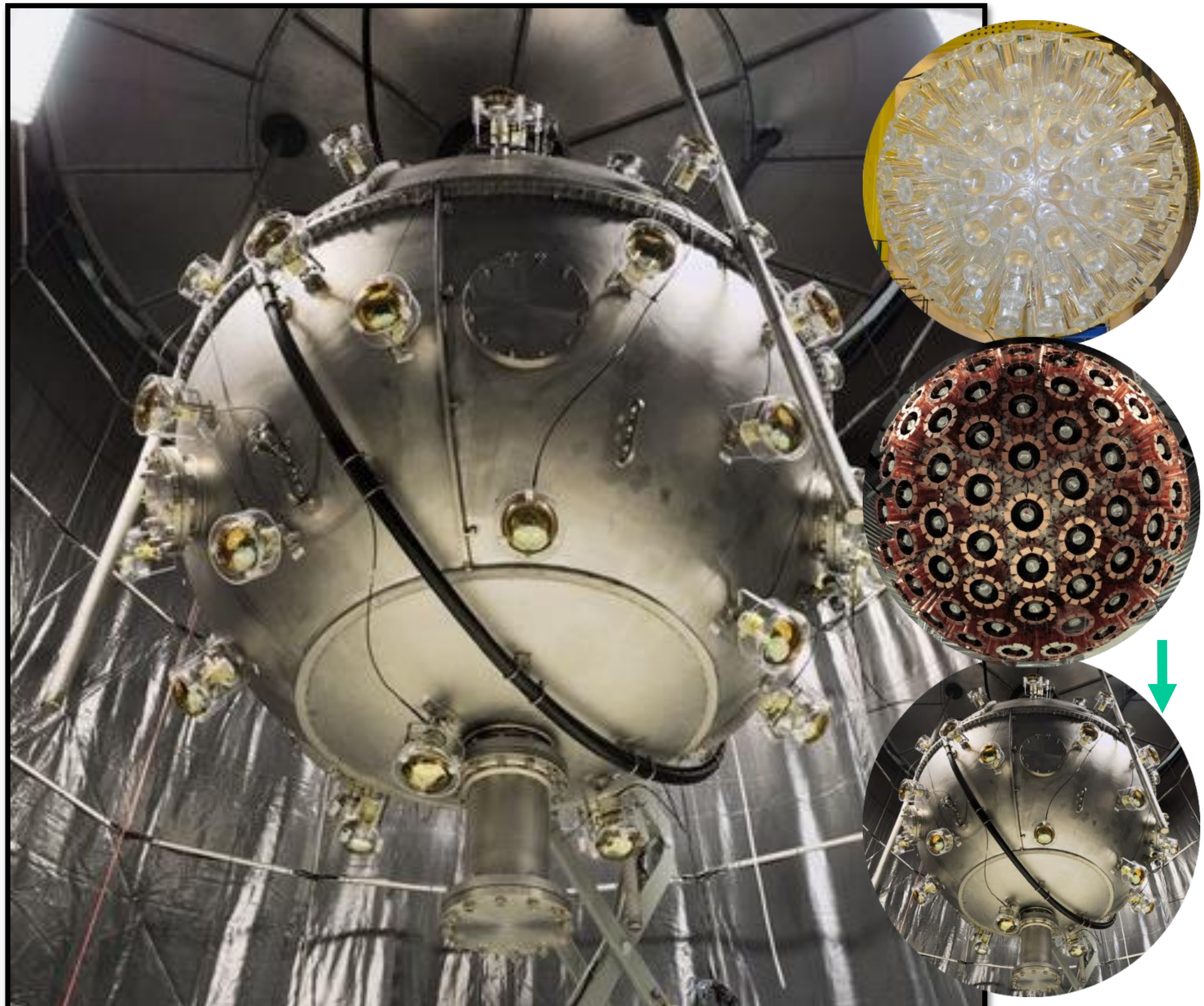




Construction of DEAP-3600 was completed in early 2016



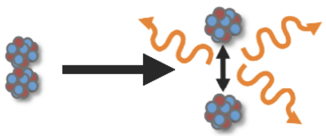




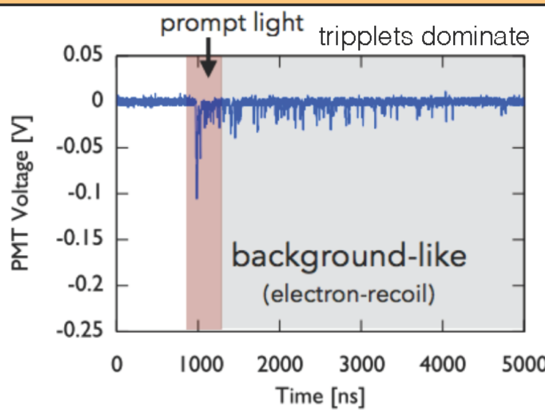
Experimental Signatures

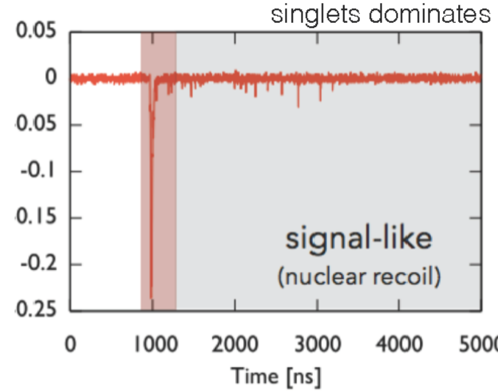
Ar scintillation:

- excimers are create



- singlet: 6 ns
- tripplet: 1500 ns
- wavelength: 128 r

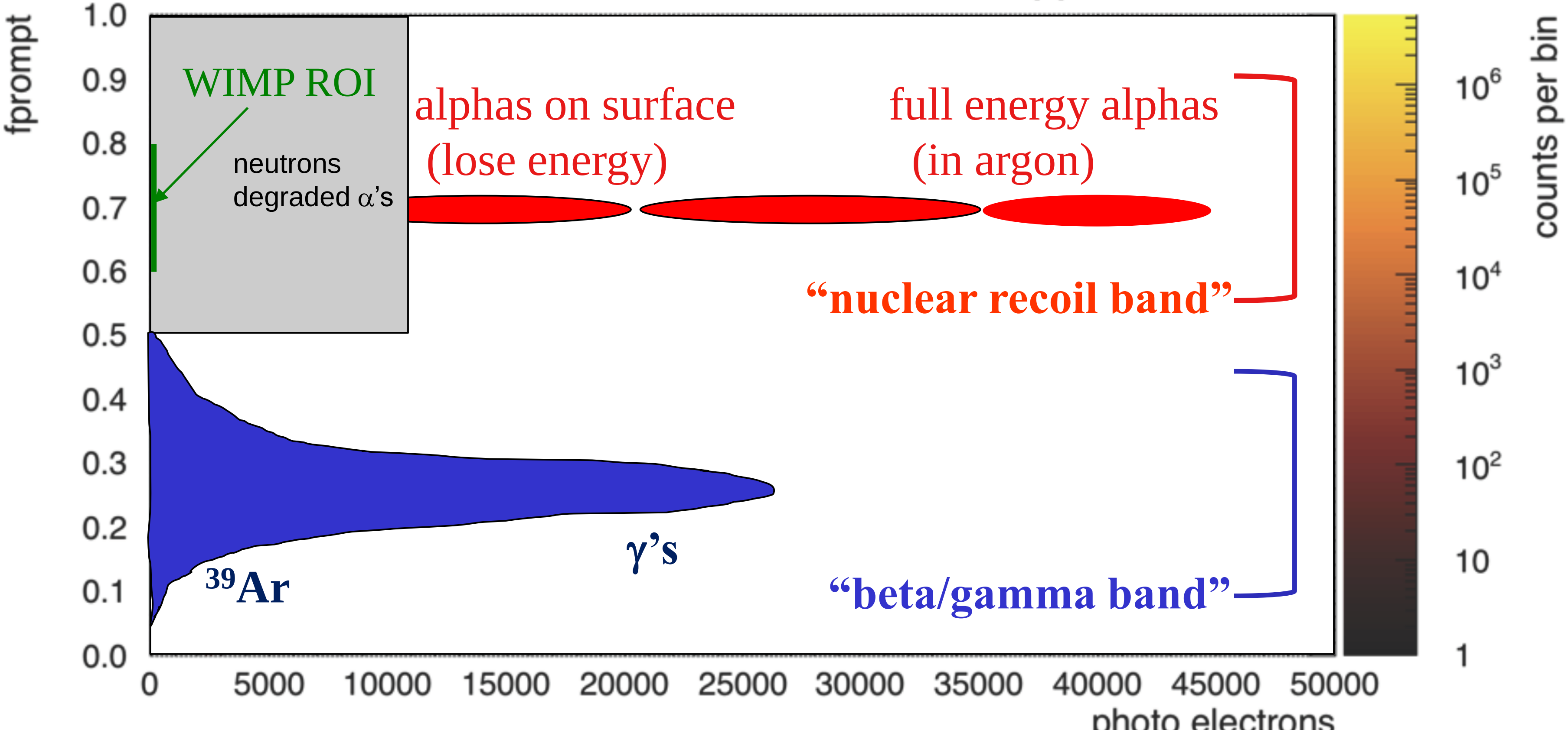




Pulse shape discrimination (PSD) parameter:

fprompt =

$$\frac{\textbf{prompt light (150 ns)}}{\textbf{total light (10000 ns)}}$$



DEAP 3600 commissioning data

Calibrating DEAP-3600

Before liquid argon fill:

deployed "laserball" source inside AV

20 optical fibers connected to PMTs allow "continuous monitoring"

After argon fill:

20 optical fibers

external cal. sources:
γ's from Th, ^{22}Na;
n's from AmBe source

internal backgrounds:
^{39}Ar β decays
U/Th chain γ's and α's

Relative PMT efficiency

PMT timing offsets

Energy response

Event position reconstruction

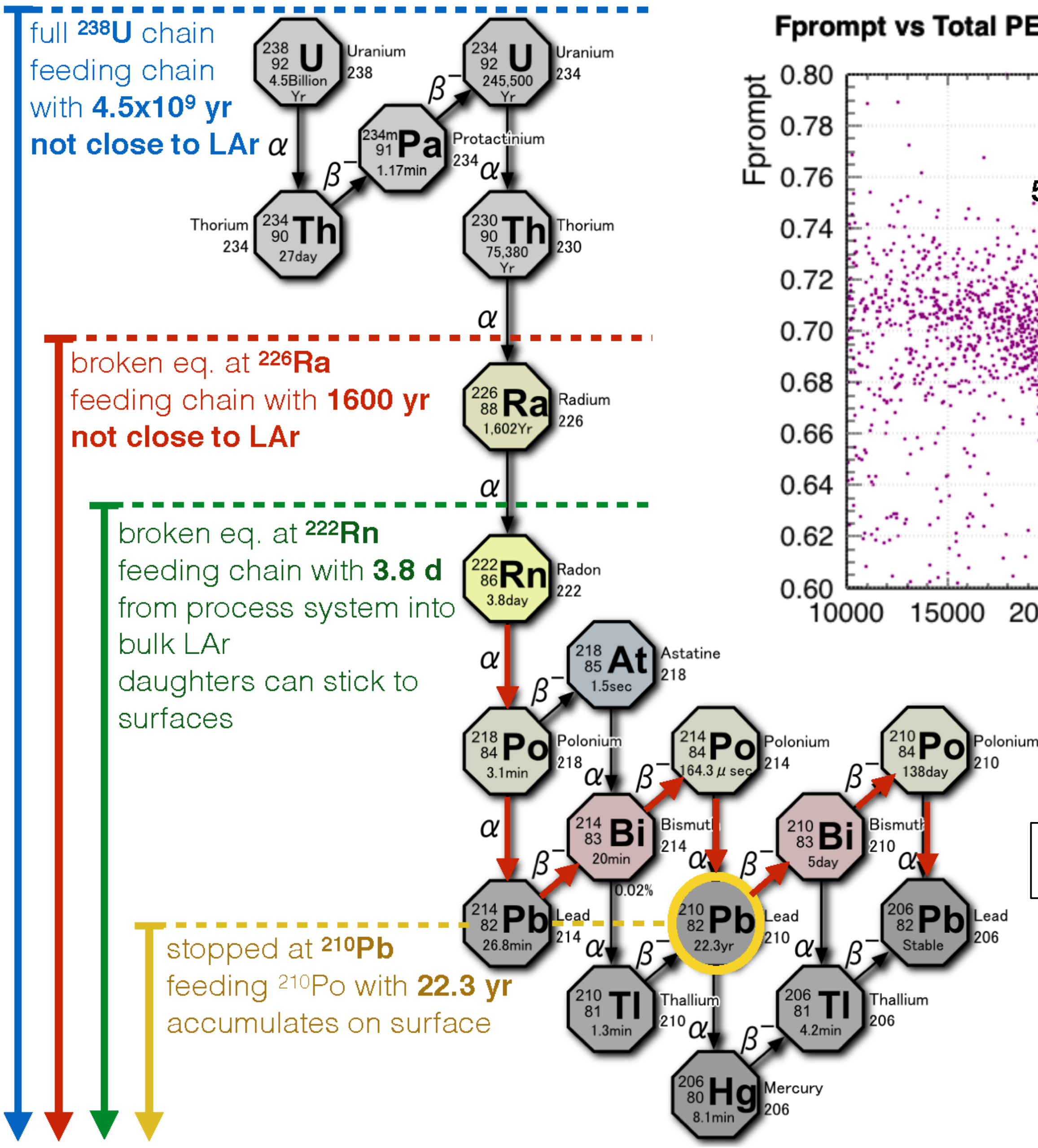
Neutron response

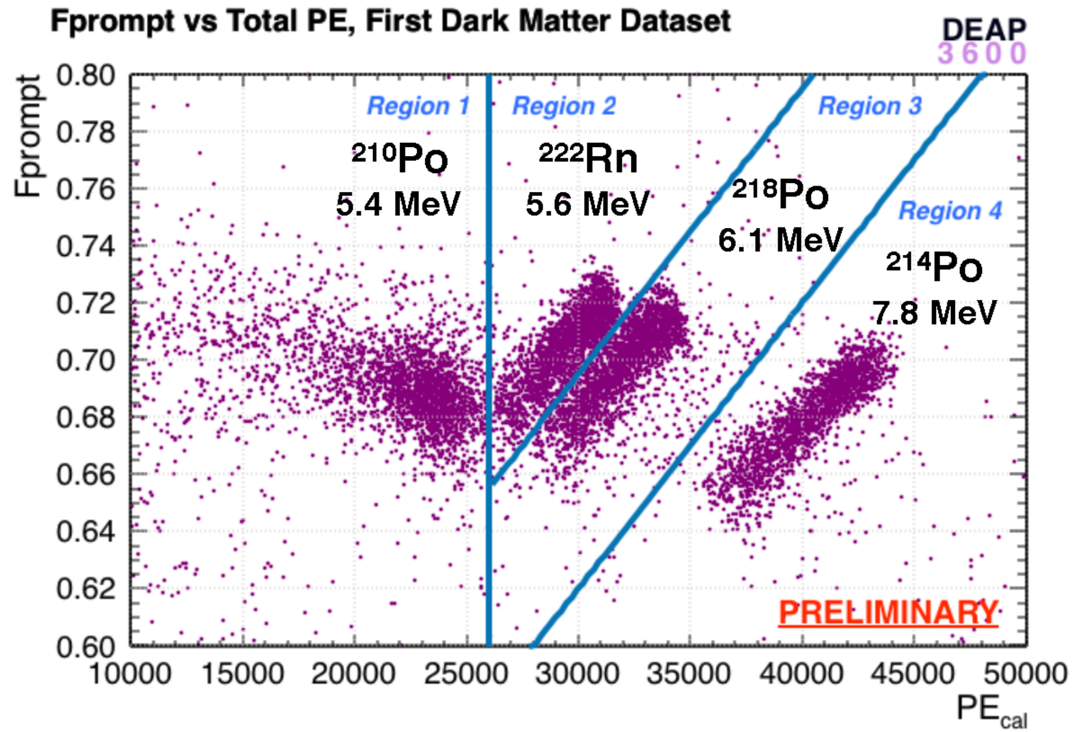
Cut acceptance

Single nuclear recoil response from MC, compare AmBe data to MC (includes multiple recoil events)

Mark Boulay

^{238}U Decay Chain





- DEAP DAQ is designed for low energy WIMP interactions. Events at alpha energies saturate DAQ

Bjoern Lehnert's talk on Monday

- ^{210}Po on surface:
  - Equal detector response
- ^{222}Rn, ^{218}Po, ^{214}Po in LAr bulk:
  - Detector response depends on radius

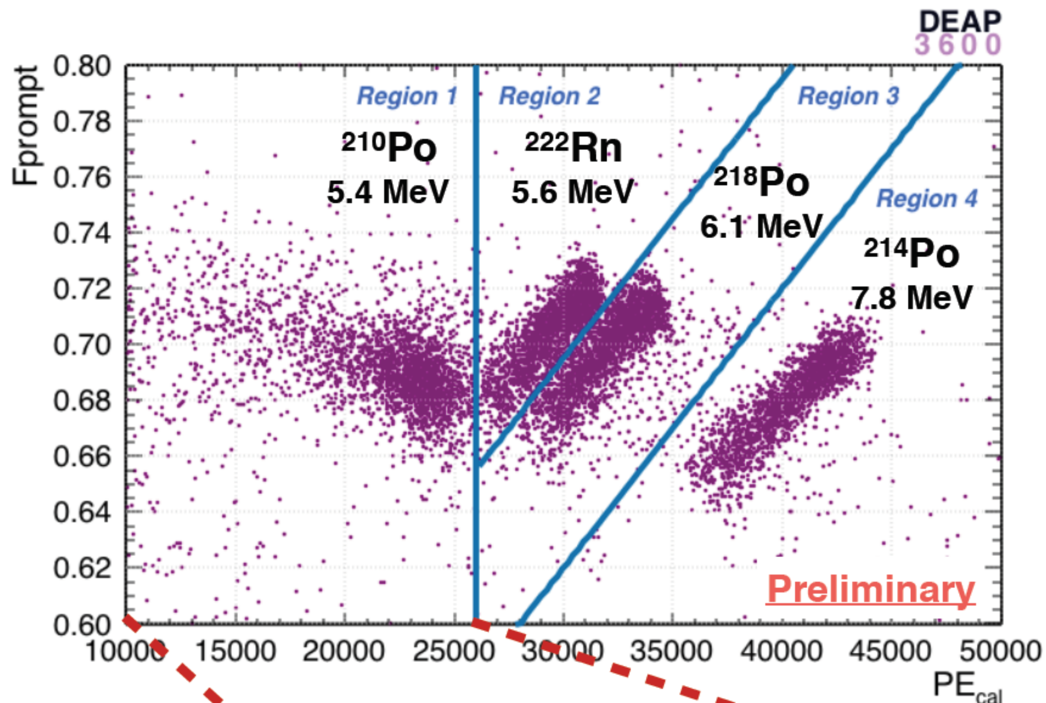
Alpha Background Summary

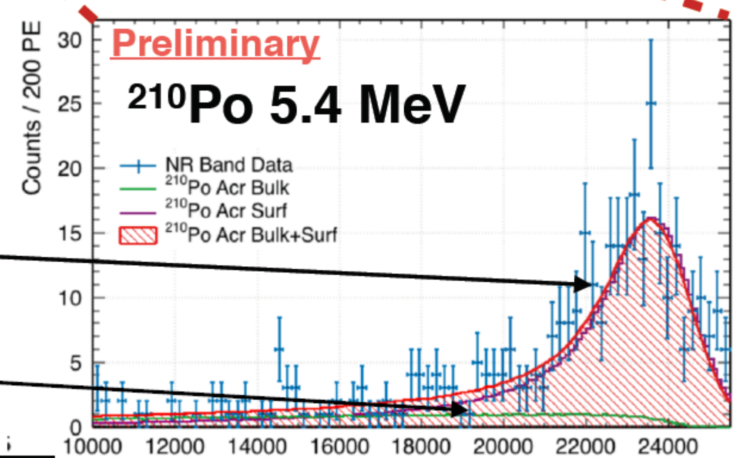
- Measuring the ^{222}Rn content in the bulk LAr shows the very competitive results
- Conclusion: ^{222}Rn induced background within expectations

^{222}Rn in Dark Matter experiments:

Experiment	Activity / rate	Target
DEAP-3600	≈0.2 µBq / kg	LAr
PandaX-II	6.6 µBq / kg	LXe
LUX	66 µHz / kg	LXe
XENON1T	10 µBq / kg	LXe

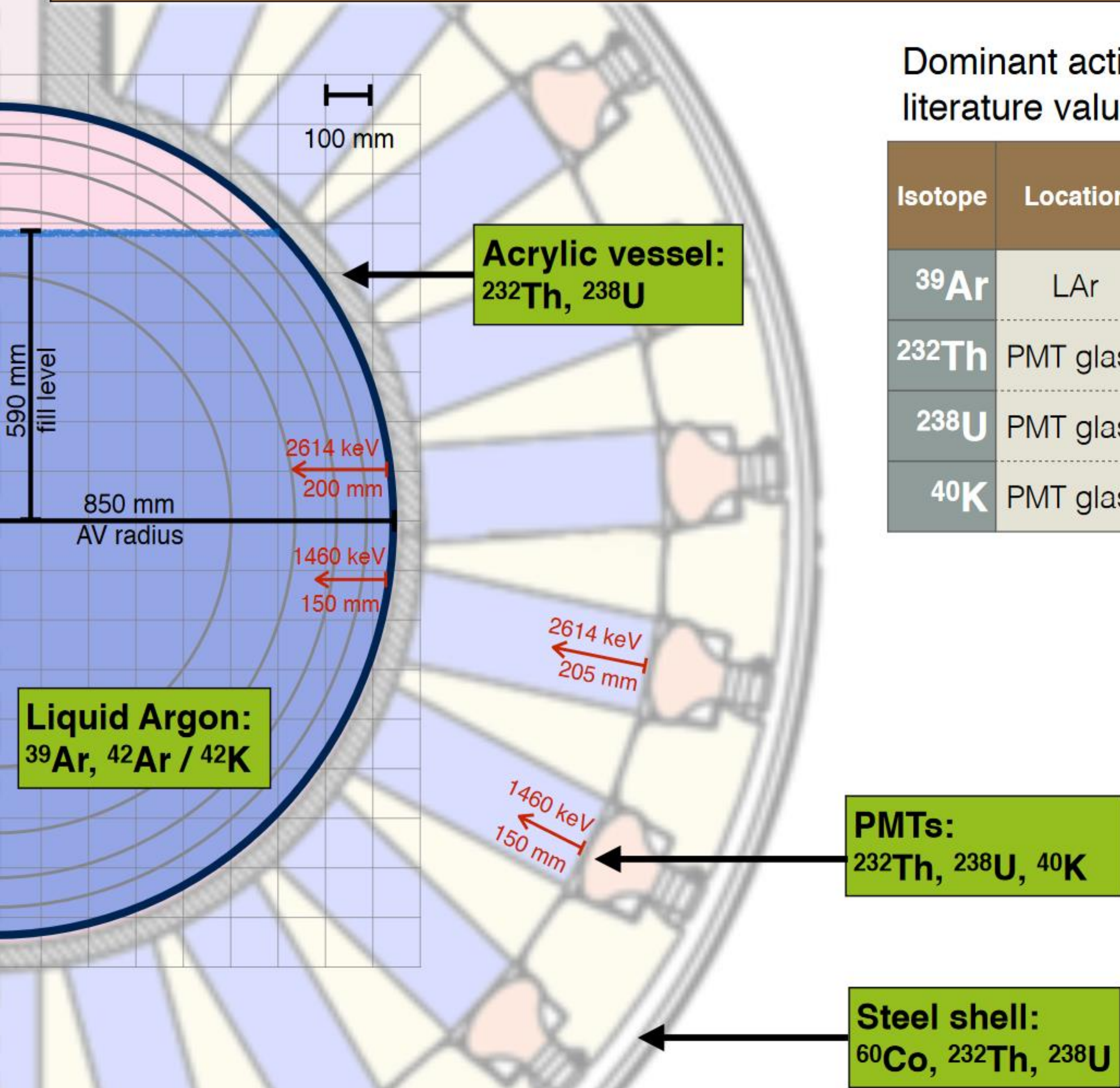
- PandaX-II: PHYSICAL REVIEW D 93, 122009 (2016)
- LUX: Physics Procedia 61 (2015) 658 – 665
- XENON1T: XeSAT 2017 talk [link]





- **Majority (0.2 mBq/m²) of ^{210}Po decays on TPB - acrylic interface**
- **Indication (<2 mBq) of ^{210}Po in 80 μm acrylic bulk (green)**

Gamma and Beta Background



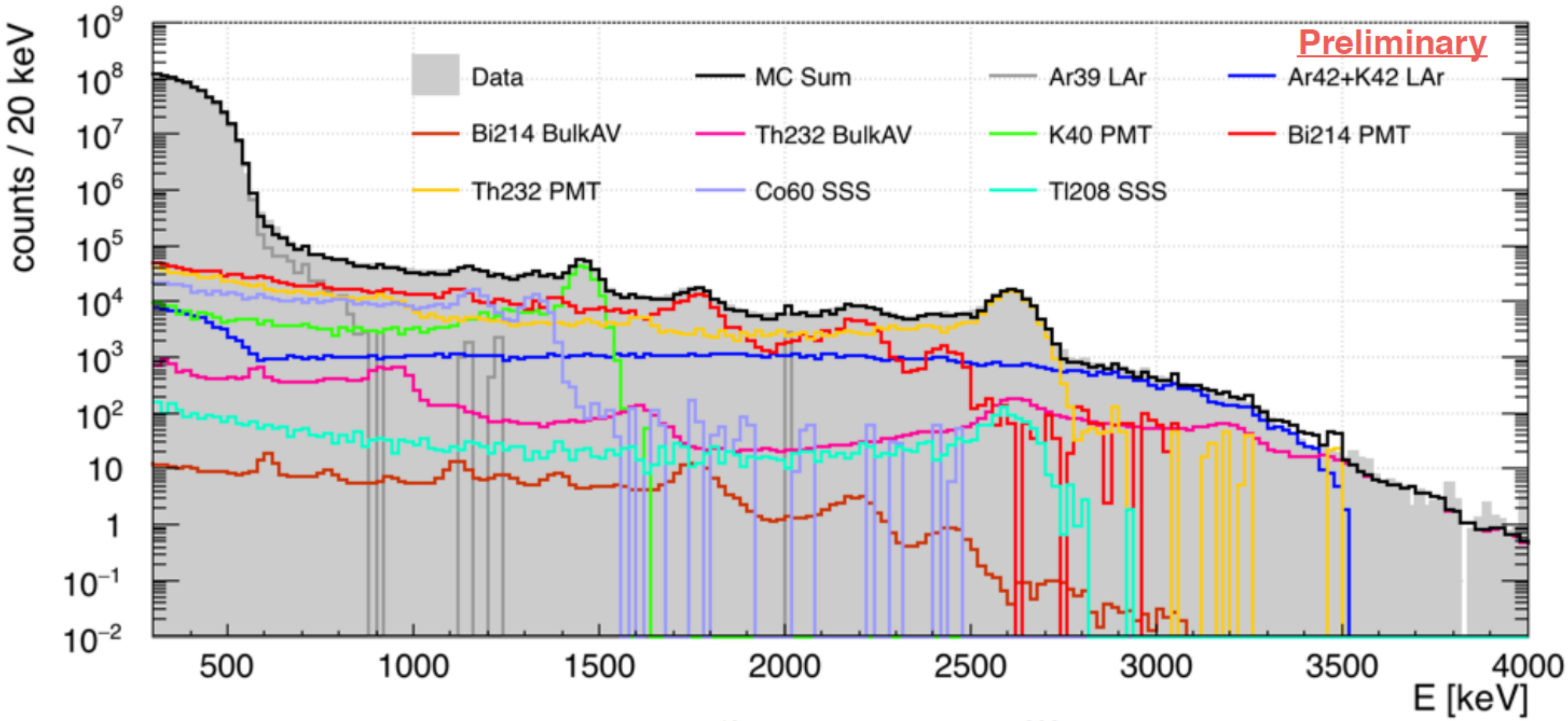
Dominant activities from screening or literature values (approximate)

Isotope	Location	Activity [Bq]	specific activity [mBq/kg]	Concentration [ppb]
^{39}Ar	LAr	3300	1010	
^{232}Th	PMT glass	26	139	34
^{238}U	PMT glass	169	921	75
^{40}K	PMT glass	100	546	18

simulated background components

Gamma and Beta Background Model

Background Model in ER Band (0.2 < fprompt < 0.4) MC components scaled to radioassay data



- Empiric energy calibration based on 1460 keV (^{40}K) and 2614 keV (^{208}Tl) peak
- Scaling of MC simulations to known screening / literature values (this is not a fit)
- Low energy region (< 0.5 MeV) dominated by ^{39}Ar
- Mid energy region (0.5 - 2.6 MeV) dominated by gammas from outside components (mainly PMT glass)
- High energy region (> 2.6 MeV) dominated by ^{42}K and by close ^{208}Tl sources

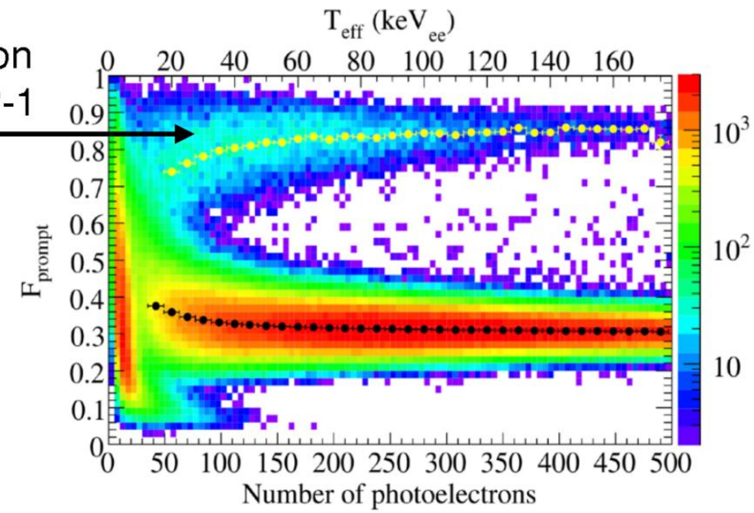
- Gamma line measurements can be used to constrain (α,n) neutron production within a factor of 2

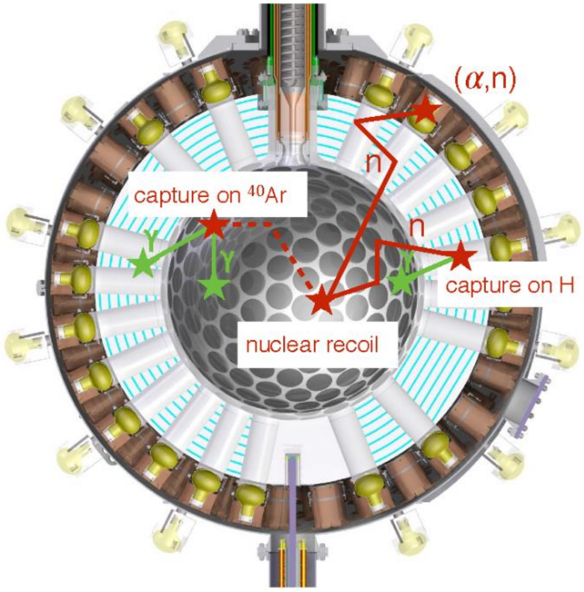
Bjoern Lehnert's talk on Monday

Neutron Background

- Neutrons produced by
  - (α,n) reactions in close and far material
  - fission neutrons
  - cosmogenic neutrons (muon induced)
- Extensive neutron MC campaign using radio-purity assays and (α,n) yields from SOURCES-4C
  - Dominant source is (α,n) in PMT glass (≈70%)
  - Well constrained from γ-background and consistent with target values

neutron calibration in DEAP-1



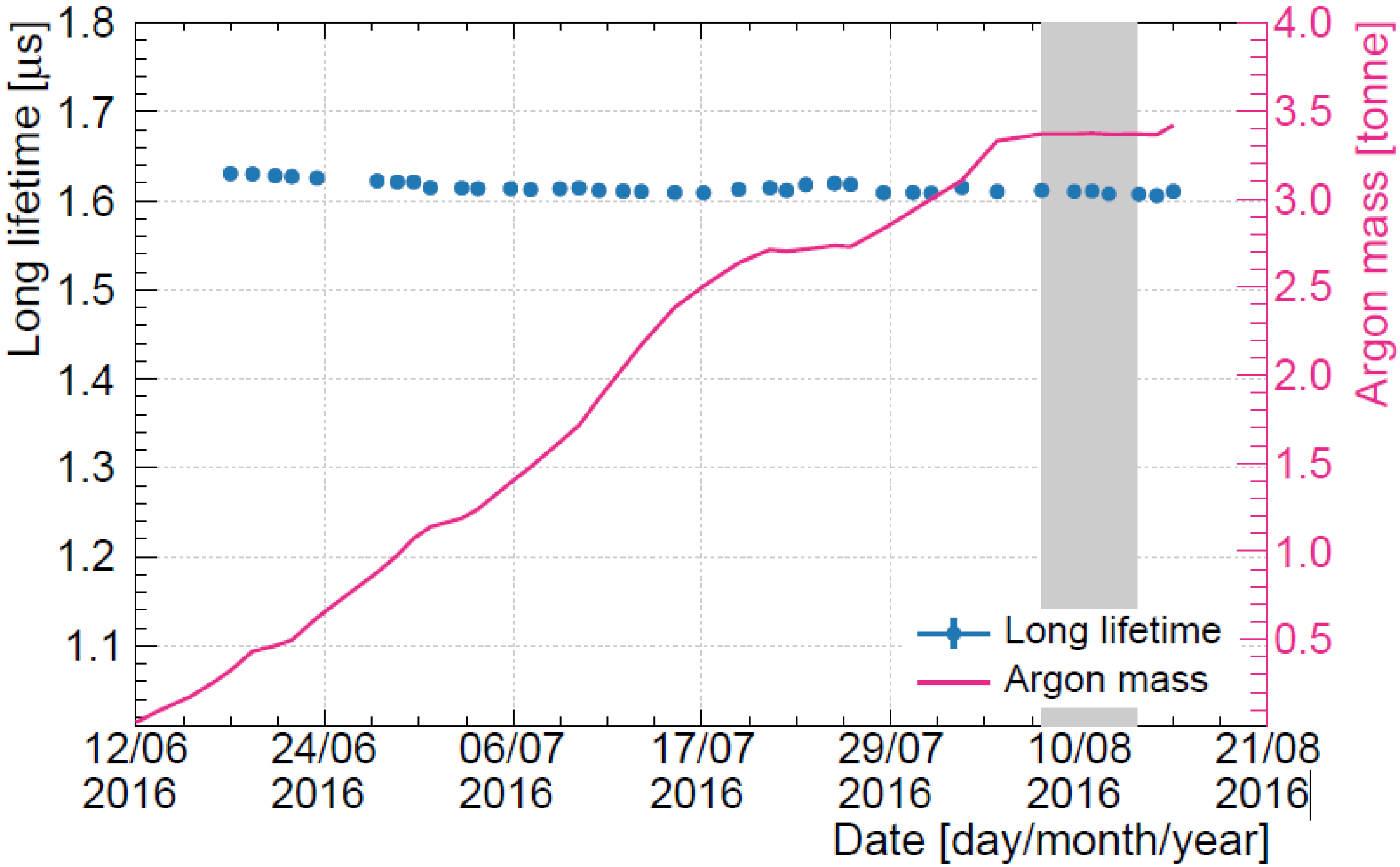


Data driven limit on neutron interactions:

- **Idea:** Eventually all neutrons capture and leave gamma signature
  - 2.2 MeV γ form ^{1}H in acrylic
  - 6.1 MeV γ-cascade from ^{40}Ar in LAr
  - Search for n - γ coincidences
- **Preliminary result:**
  - No coincidence found above expected random background
  - Limit on neutron interactions consistent with target value

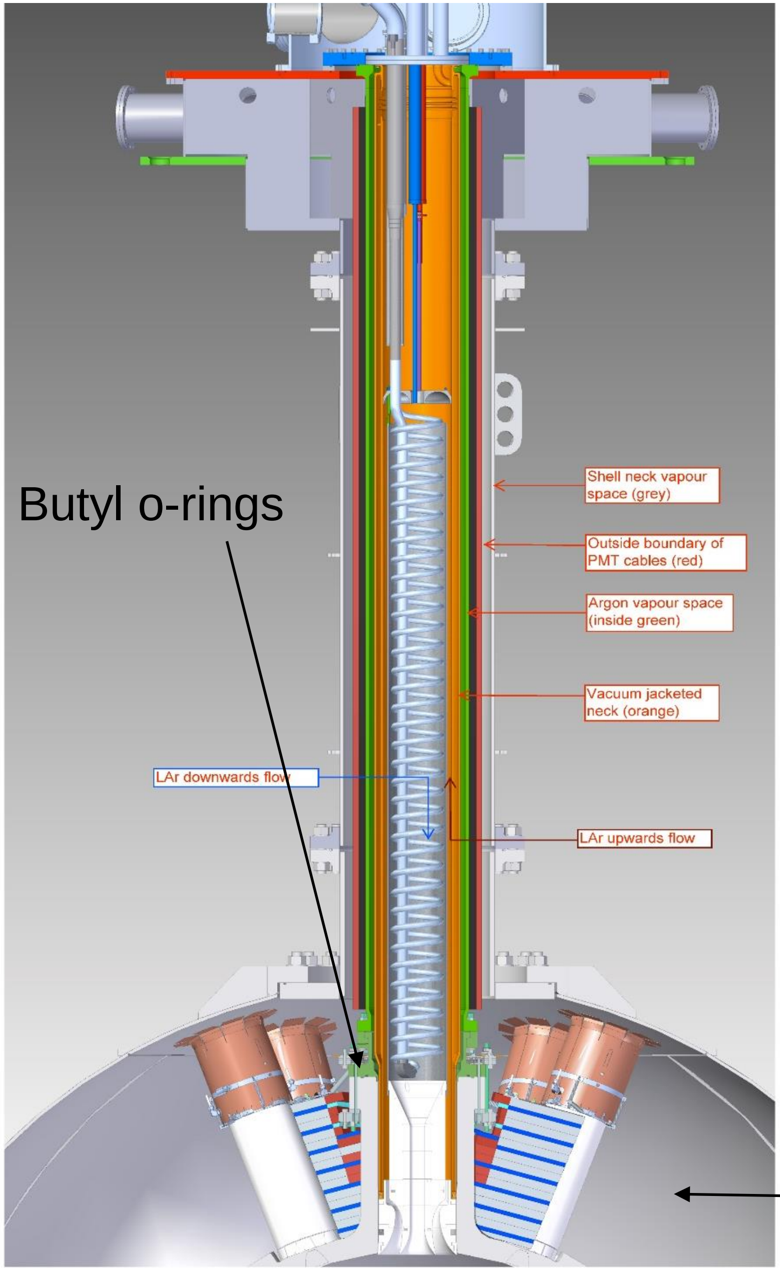
See Shawn Westerdale's talk 5 PM today for details

DEAP-3600 detector filling



First analysis presented here from data collected in August 2016 at end of first LAr fill

August 17, 2016 Incident



Butyl o-rings

Leak developed between Butyl o-rings and Steel Shell region

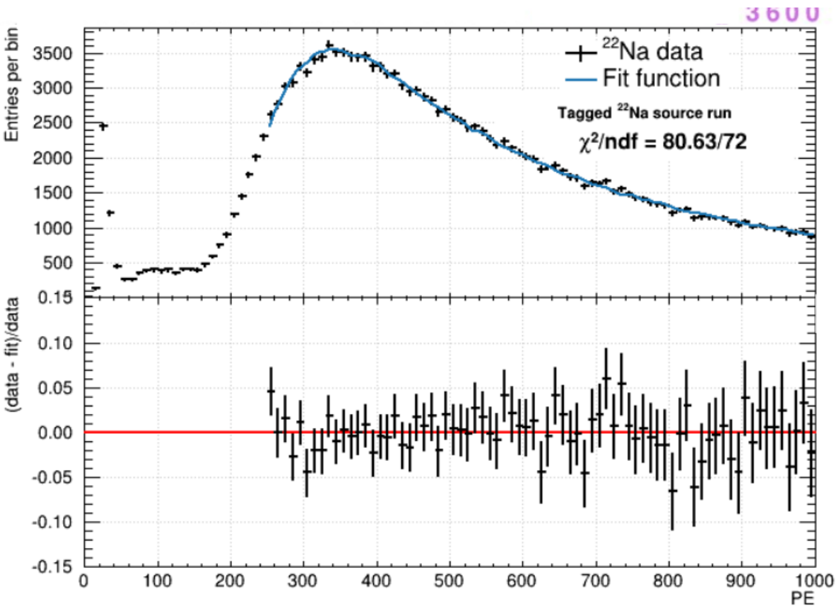
~100 ppb N_2 into LAr

Drained and refilled to slightly lower LAr level by October 2016

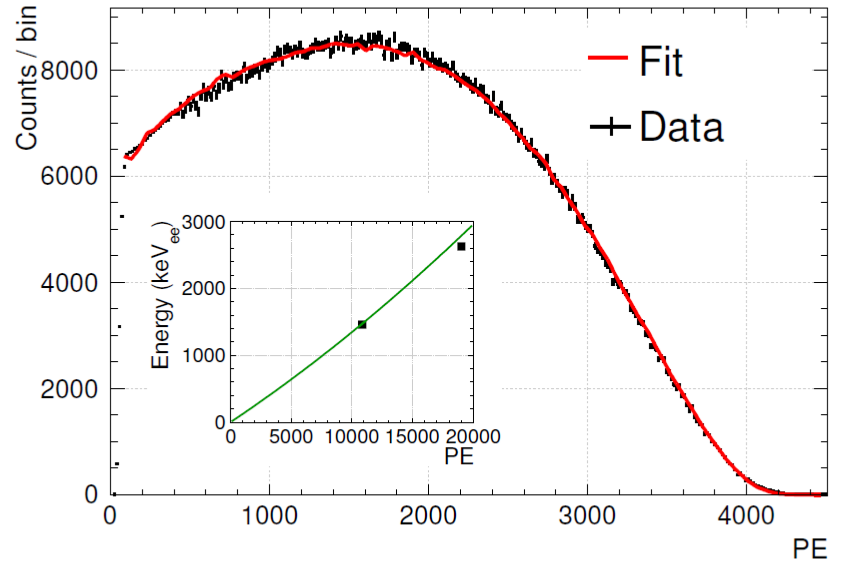
Continued collecting data at new level since Nov 1, 2016 – 3322 kg

Rn-scrubbed N2 gas in Steel Shell

Energy Calibration in DEAP-3600



low energy with external ^{22}Na feature



higher energies with ^{39}Ar and γ lines

Saturation effects at high energies not yet accounted for

WIMP ROI: $80 - 240$ PE

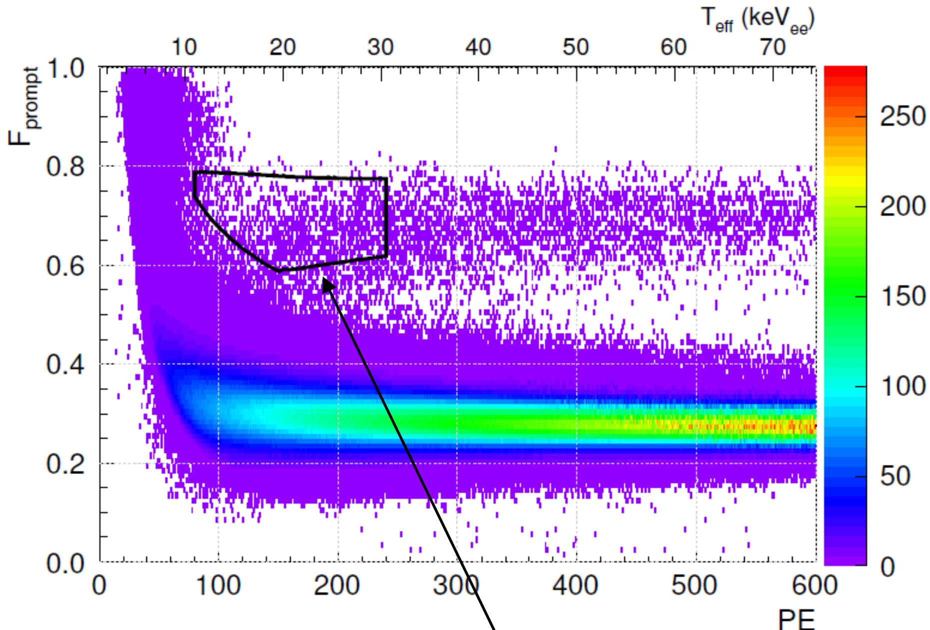
$c_0 + c_1\text{PE} + c_2\text{PE}^2$

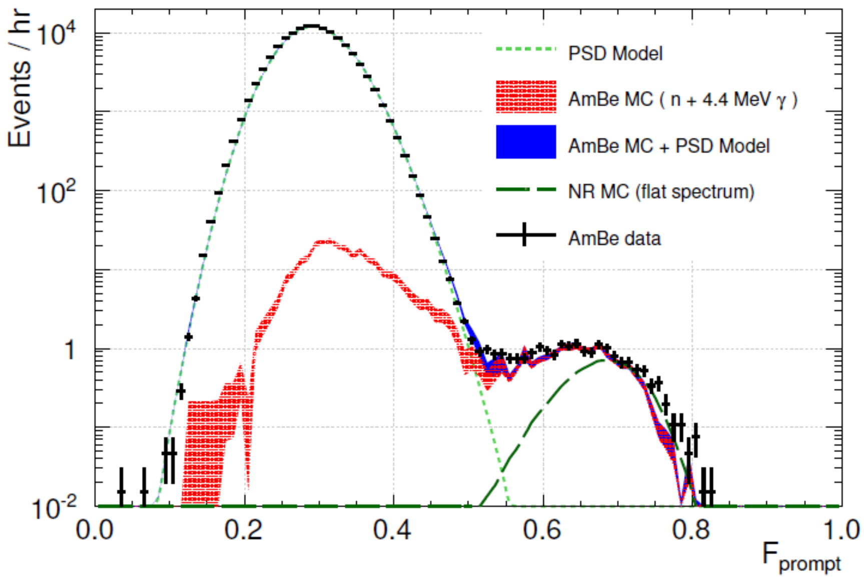
Preliminary light yield:

$$LY = 7.36^{+0.61}_{-0.52}(\text{fit syst.}) \pm 0.22(\text{SPE syst.})\text{PE/keV}_{ee}\ @80\,\text{PE}$$

Stefanie Langrock’s talk Monday for details

Neutron calibration with AmBe source in DEAP-3600



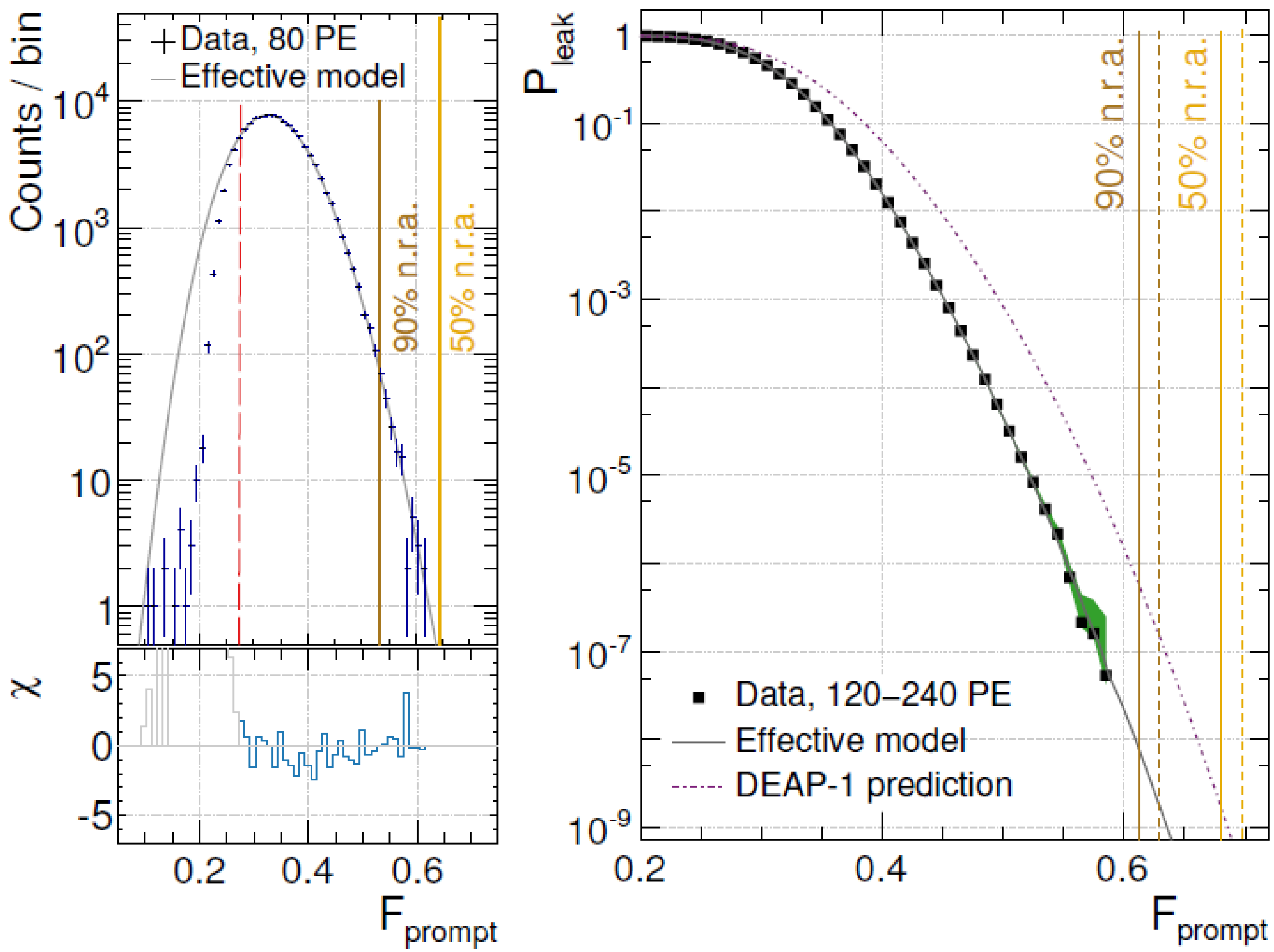


140-240 pe

WIMP search ROI

- AmBe neutron source deployed outside of Steel Shell
- Detect neutrons and gammas from source (+ capture gammas)
- Used data for cross-check of simulation
- Simulation used to evaluate single-recoil response

Pulse-Shape Discrimination in DEAP-3600

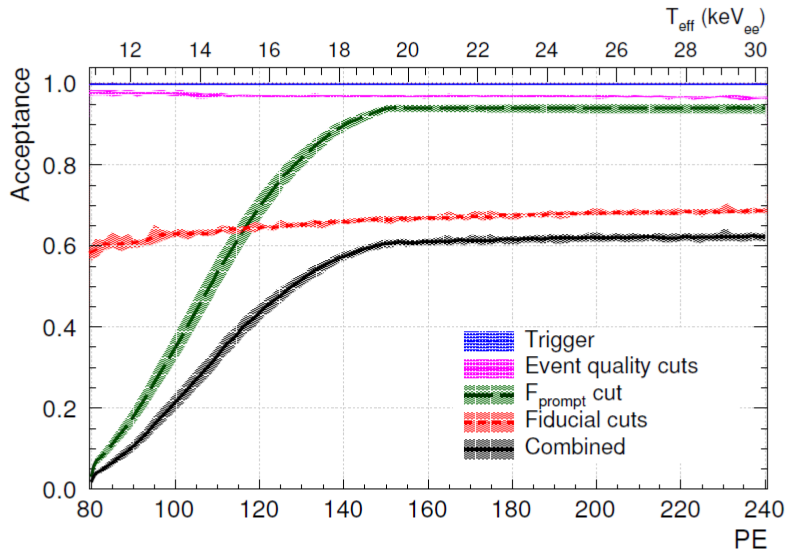


We observe good PSD of beta events down to 11 keVee

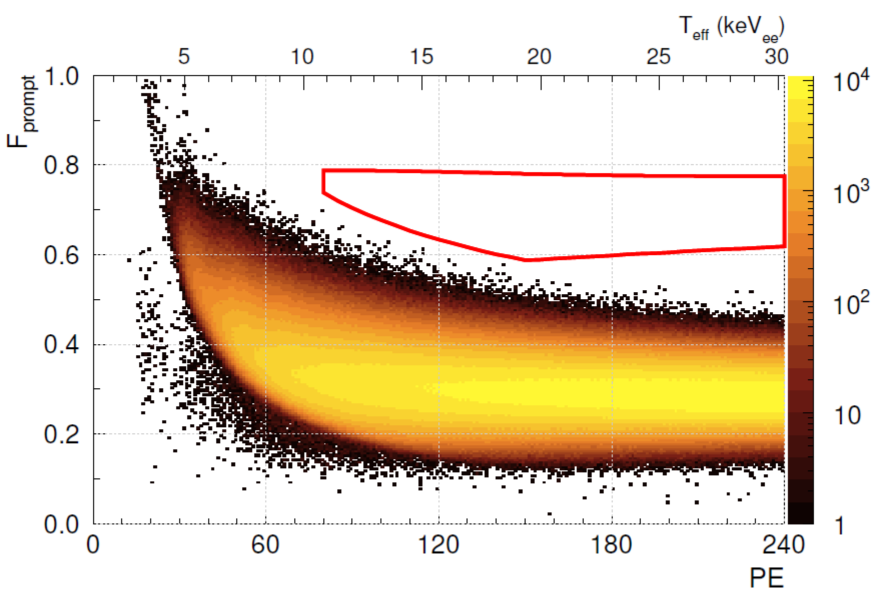
Best ever demonstrated at low energy

expect to meet design goal for full sensitivity run

First Dark Matter Search with DEAP-3600 – 9,870 kg-days



	Cut	Livetime	Acceptance %		#ROI 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



4.44 live days

Selected ROI for < 0.2 leakage from β's

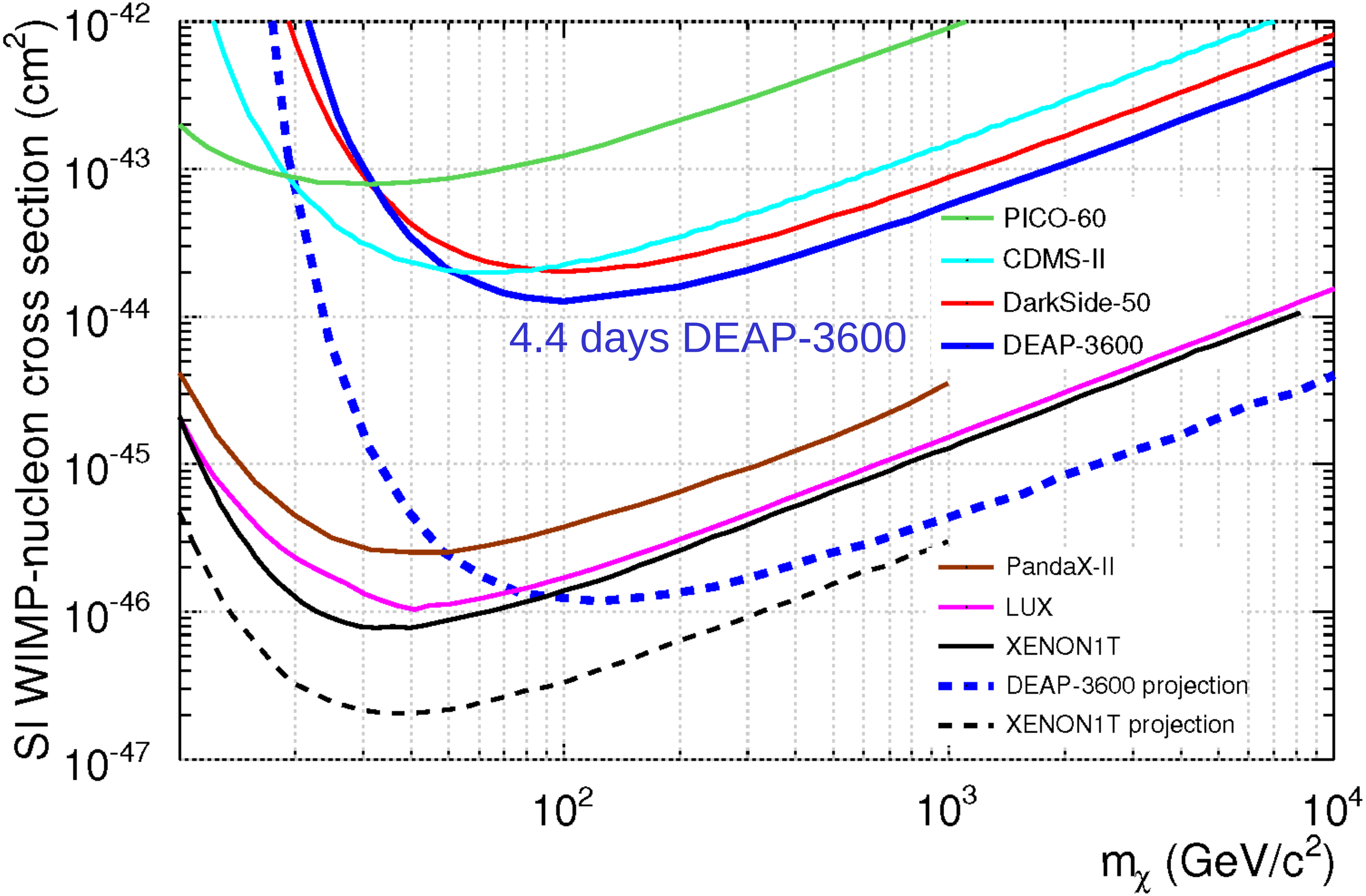
Developed prelim. cuts for instrumental and external-source events

2223 kg fiducial mass

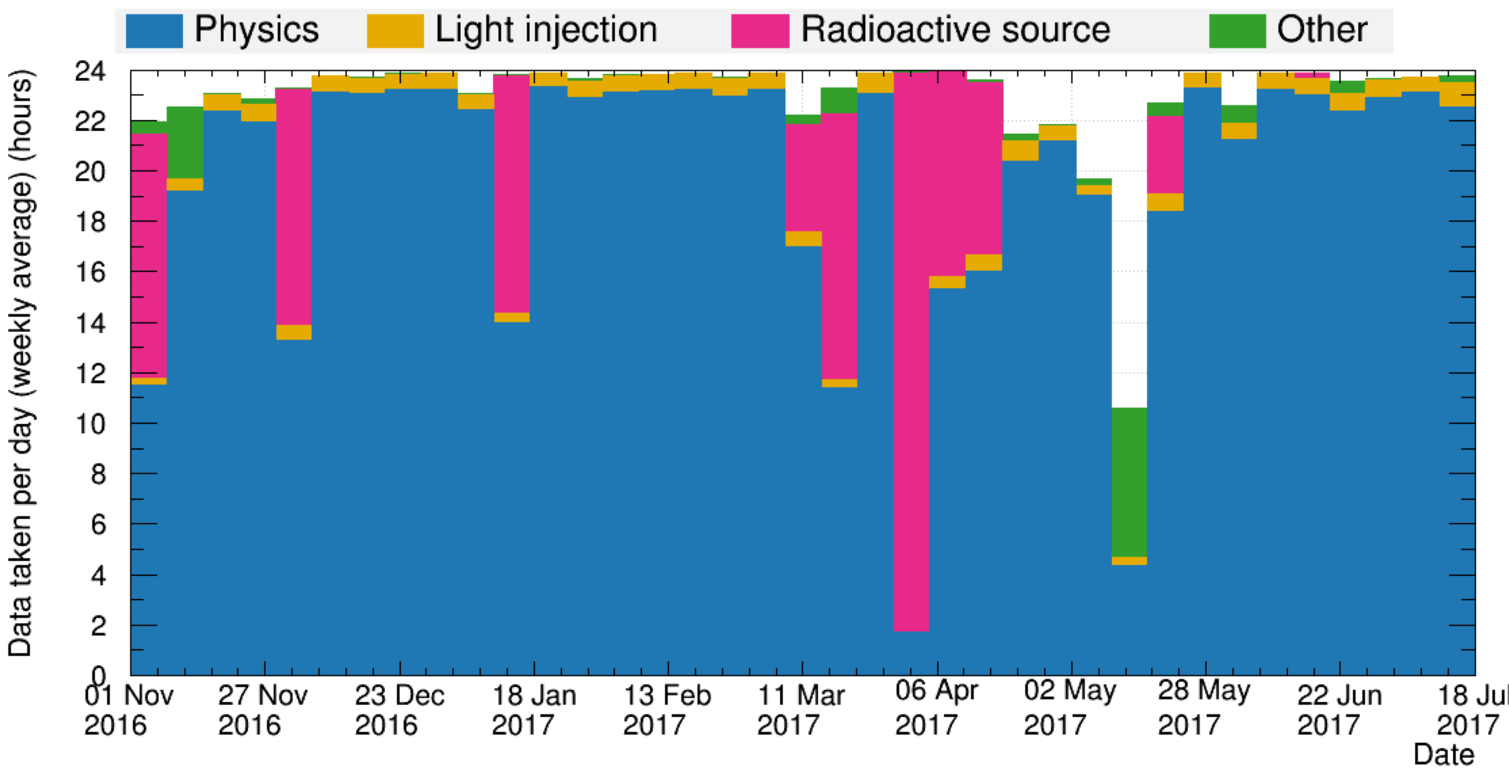
9,870 kg-day exposure

No events observed in ROI

WIMP exclusion with DEAP-3600



DEAP-3600 Continued Running and Plans

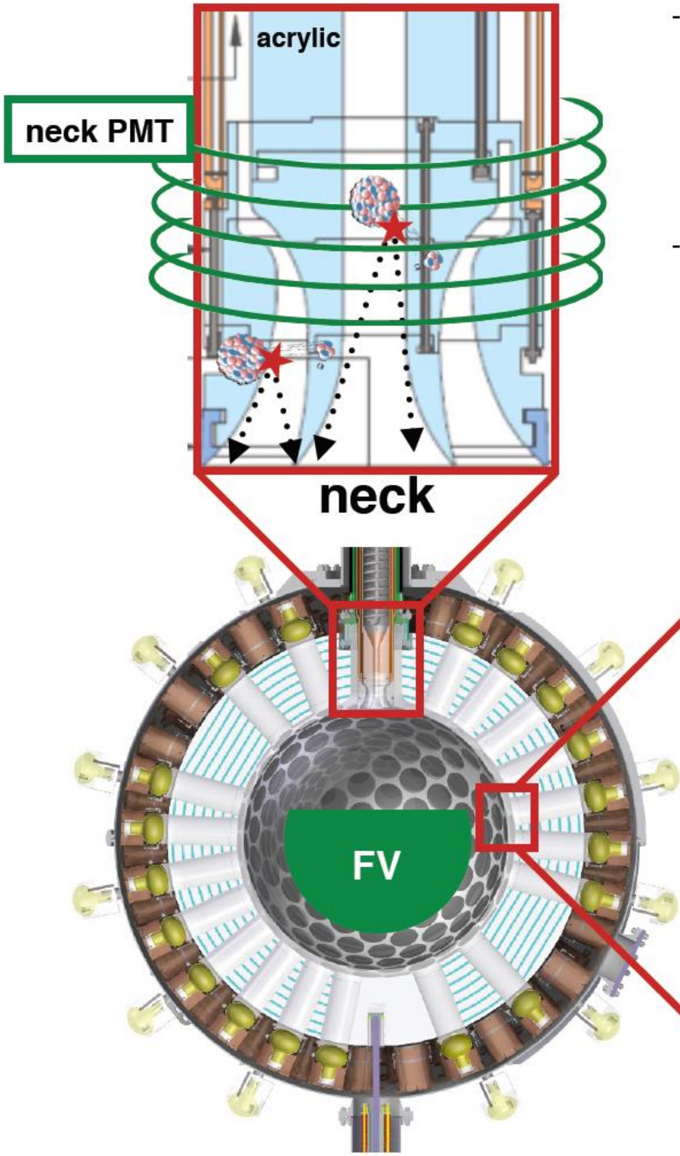


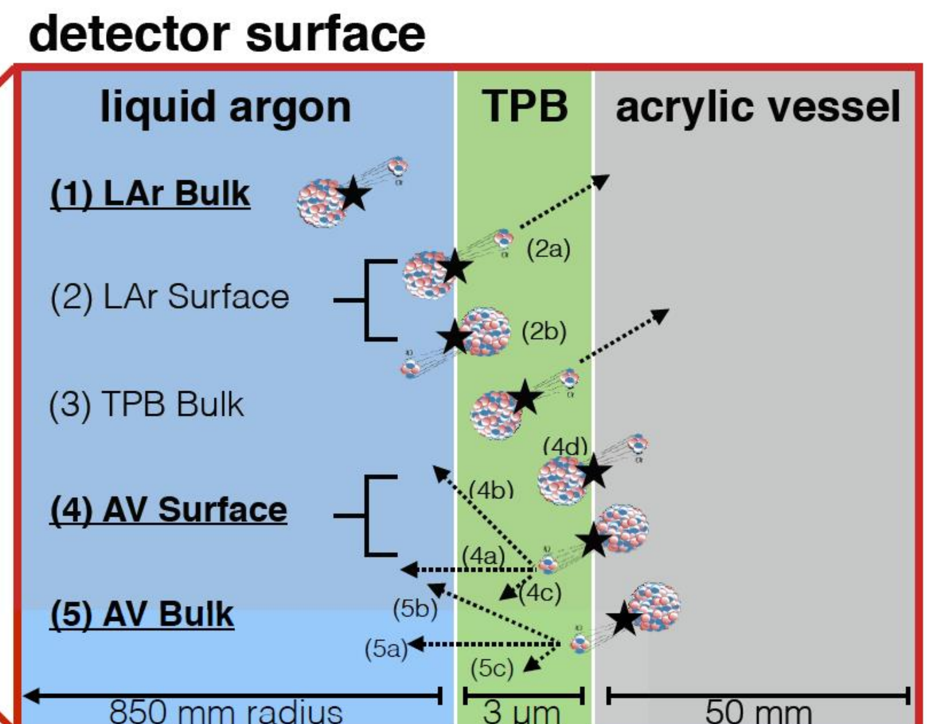
- Collecting DM and Calibration data since Nov 2016
- 82% DM search data
- Already collected ~220 days data, 20-40X first analysis depending on run selection (not yet completed). Will run until 2020.
- Developing model and understanding of all detector backgrounds for more sensitive analysis (incl. neck events, Cherenkov, etc.); full calibration of detector response incl. position reconstruction

Alpha Background Topologies

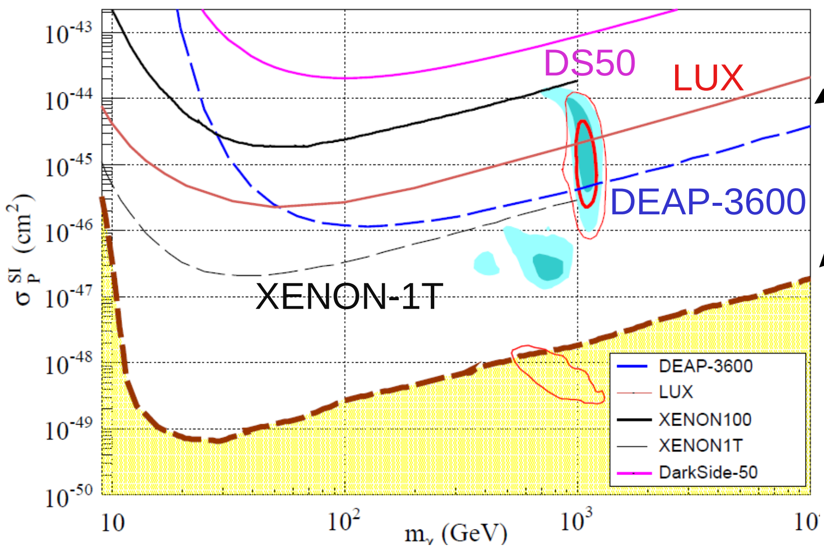
- Alphas result in a low energy event if:
  - Part of energy is deposited in a dead surface (e.g. acrylic)
  - Energy is deposited in medium with less scintillation (TPB)
  - Scintillation light is lost due to shadowing

- Mitigation in analysis:
  - Fiber ("neck") veto (sensitive to visible light in neck)
  - Fiducial volume (FV) cut
  - PMT topology cuts based on charge and timing





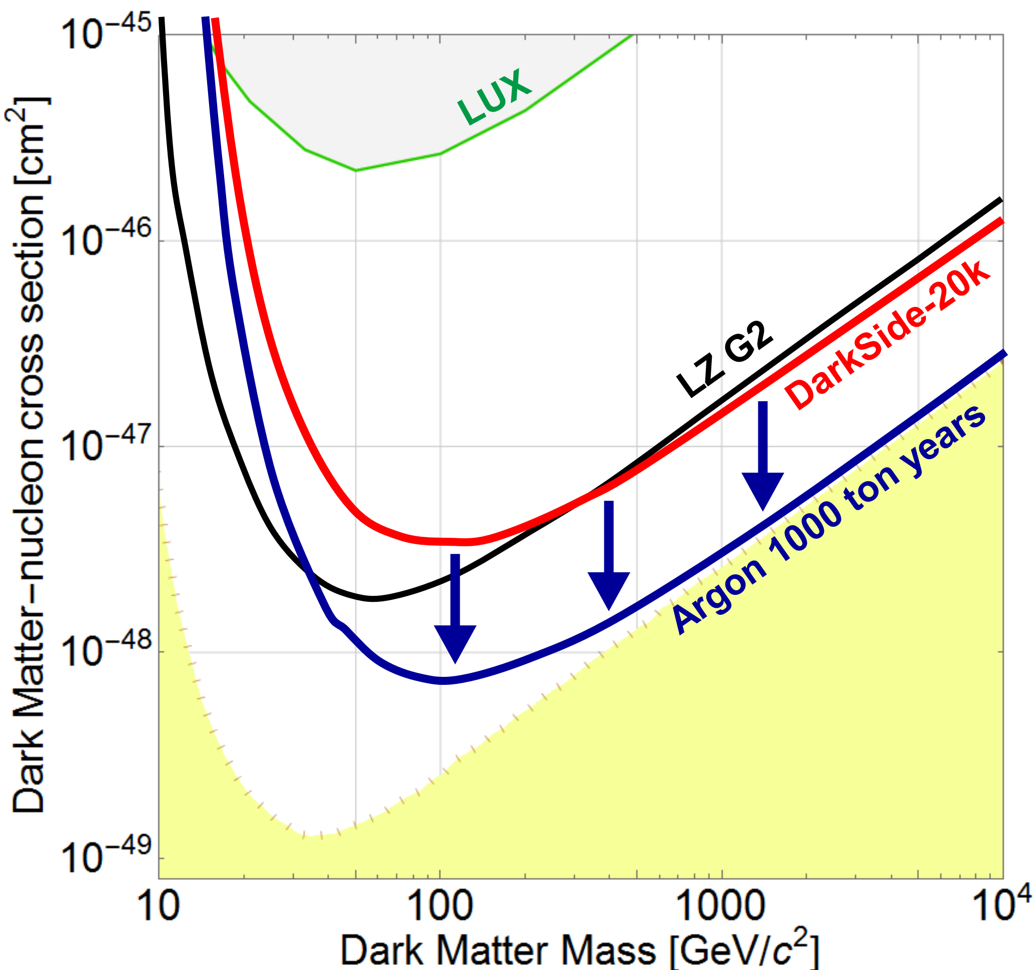
Beyond DEAP-3600: Sensitivity with Argon



we are currently here

want to get here

Spin-Independent ***High-Mass*** Region



Argon has good sensitivity in high-mass region

DS-20K (20 tonnes argon) competitive with LZ
– start operation 2021

1000-tonne years (future detector) reaches down to neutrino floor

Complimentary to xenon – only other target allowing such large exposure

Global collaboration forming for future argon DM program (Darkside, DEAP, miniCLEAN, ArDM)

Mark Boulay

Summary

DEAP-3600 collecting data since 2016

This analysis used approximately 5 live days of data collected in August 2016:

- stable performance & good uniformity (~5% LY variation across detector)
- good light yield and good PSD – best ever demonstrated at low threshold in argon and better than projected from DEAP-1
- preliminary analyses of internal background components – full background model being developed
- lowest achieved ^{222}Rn background of 0.2 μBq/kg (30 to 300X lower than PandaX, LUX, XENON1T)

No events observed in WIMP ROI allows best-ever limit on WIMP-nucleon cross-section at high mass in argon

Data collection ongoing; so far have collected approx. 0.6 M kg-days total exposure = 20-40X this exposure; will run to 2020

Beyond DEAP-3600:
Significant global collaboration for argon DM:
DS-20K at LNGS & future multi-hundred tonne detector

END