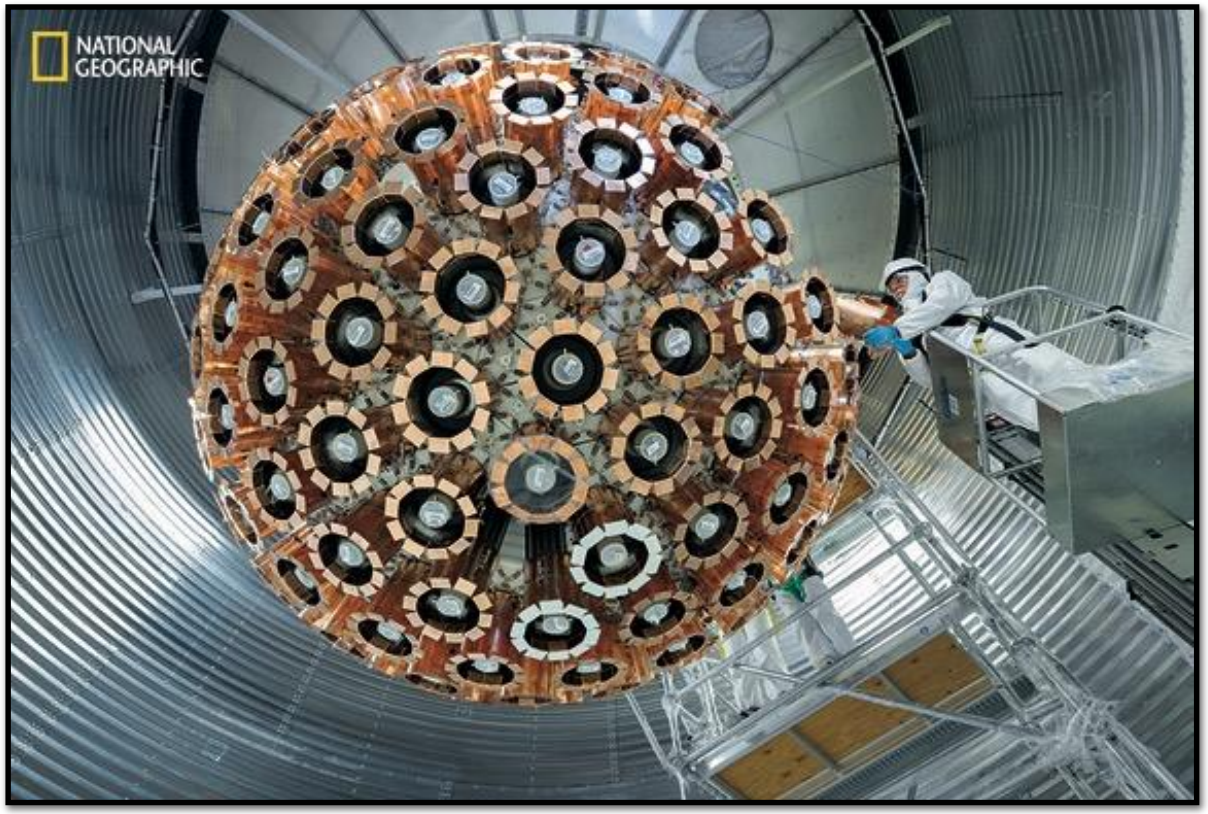
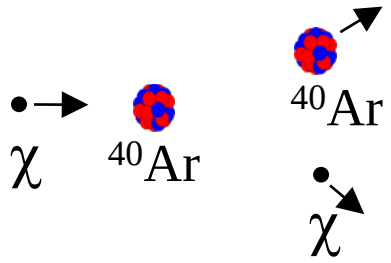
Status of DEAP-3600 at SNOLAB



Mark Boulay
Carleton University

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

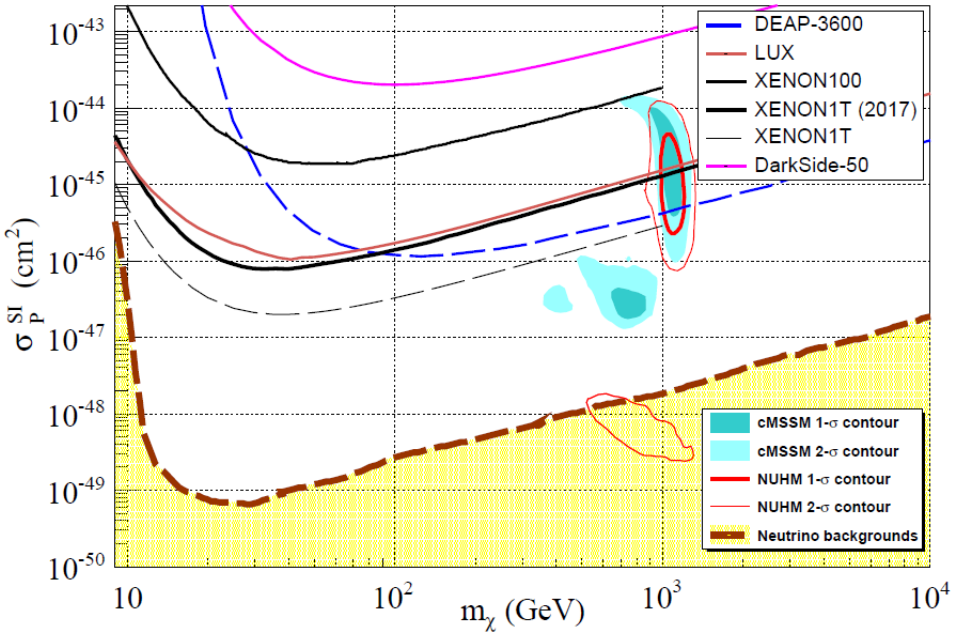
Argon is **easy to purify**

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)

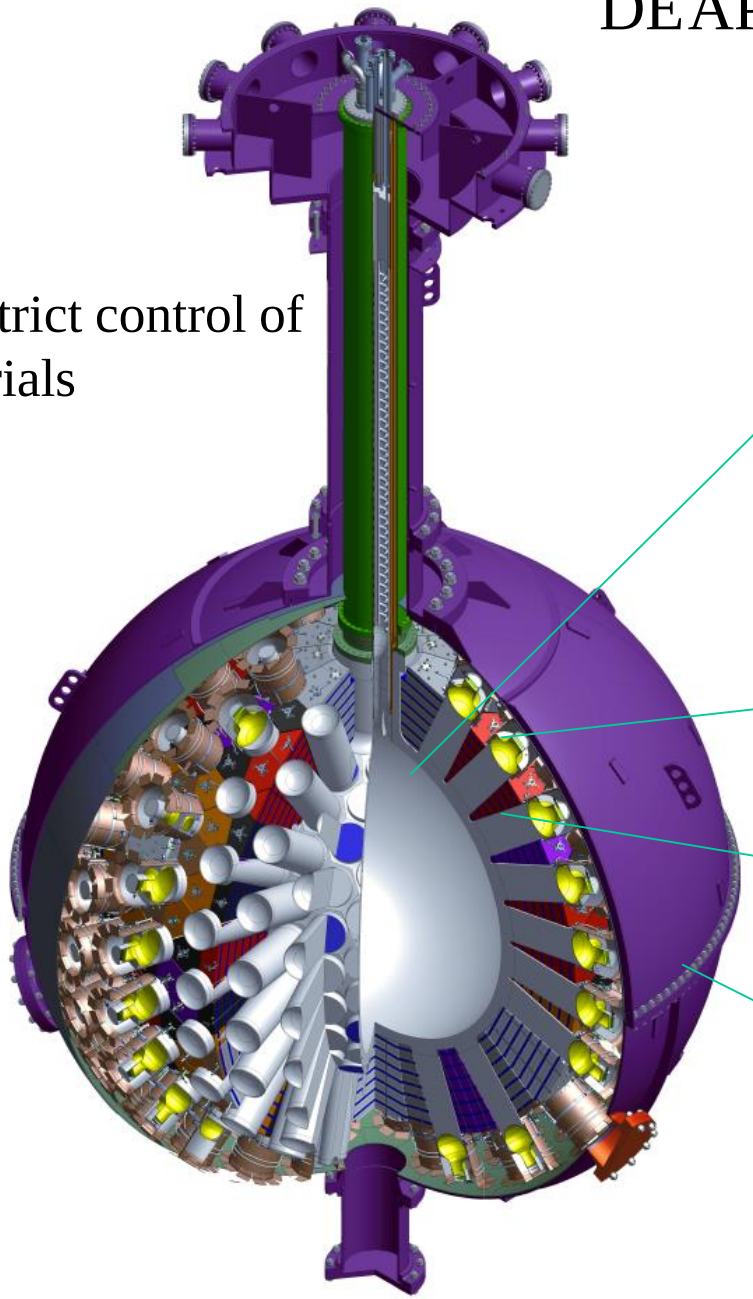
DM Sensitivity

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 (36,000 kg-days). 90%CL corresponds to ~9 events in DEAP

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

LaurentianUniversity
UniversitéLaurentienne

Queen's UNIVERSITY

ROYAL HOLLOWAY UNIVERSITY OF LONDON

Particle Physics
Rutherford Appleton Laboratory

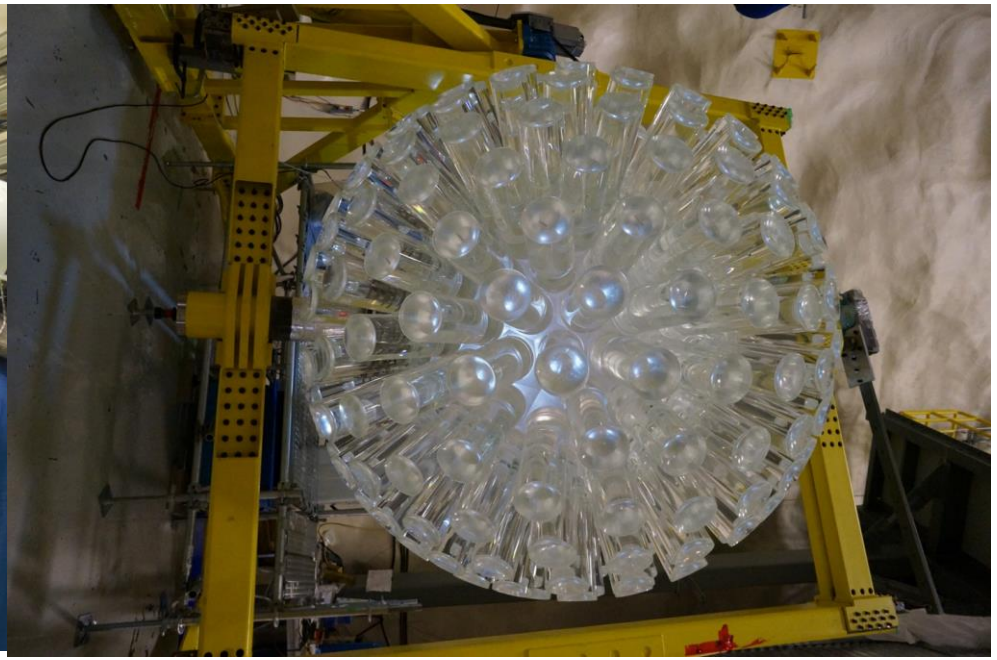
SNOLAB
MINING FOR KNOWLEDGE
CREUSER POUR TROUVER... L'EXCELLENCE

US University of Sussex

TRIUMF

IF Instituto de Física

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

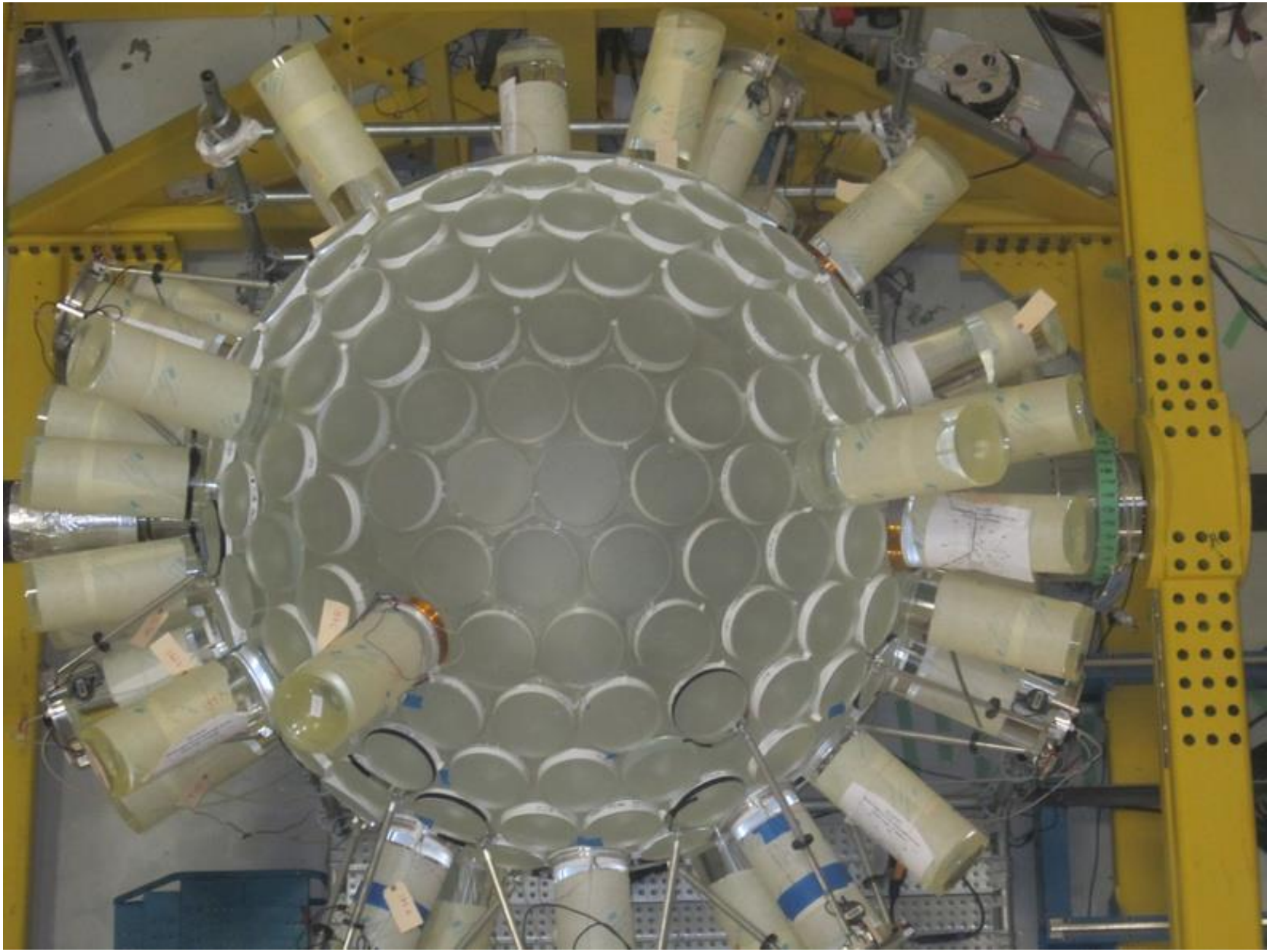
- Fabrication from pure MMA monomer at RPTAsia (Thailand), strict control of radon exposure for all steps, to < 10^{-20} g/g ^{210}Pb (RPT was fabricator of the SNO Acrylic Vessel)

- 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

Bonding light guides to the DEAP AV, underground at SNOLAB



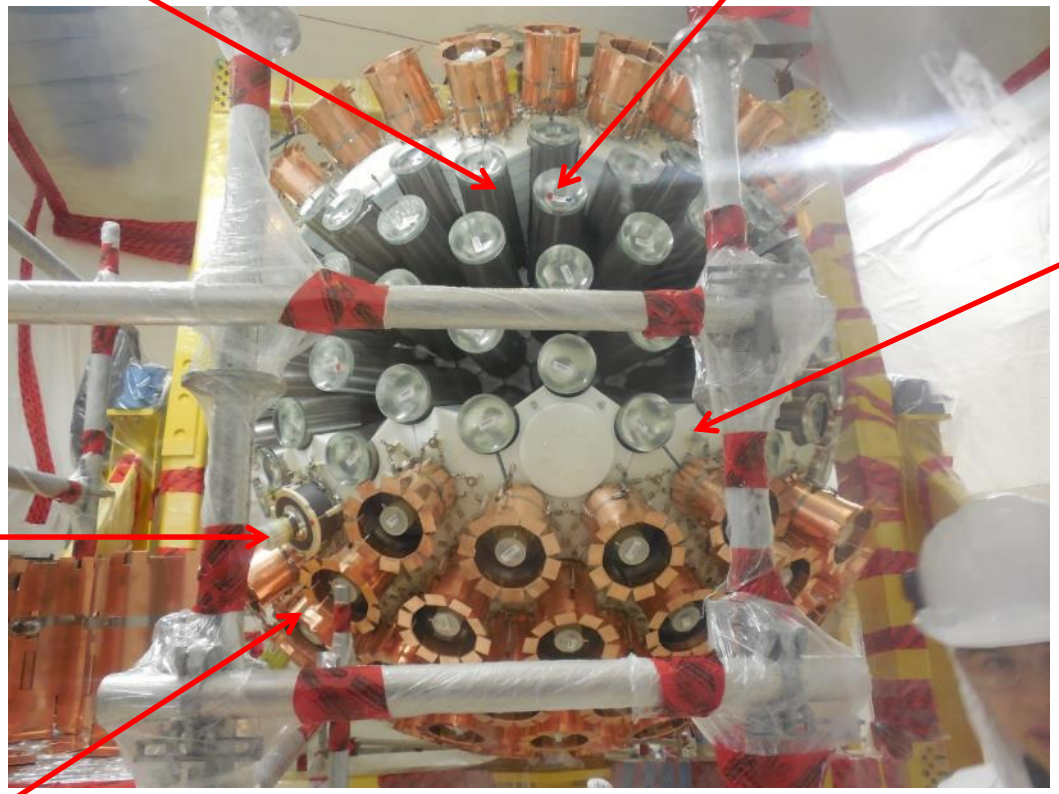
Moving the AV into assembly room

Mark Boulay

DEAP-3600 Detector Assembly

Specular reflector + opaque wrap

Acrylic Light Guide



PE neutron shielding “blocks”

PMT with silicone oil coupling

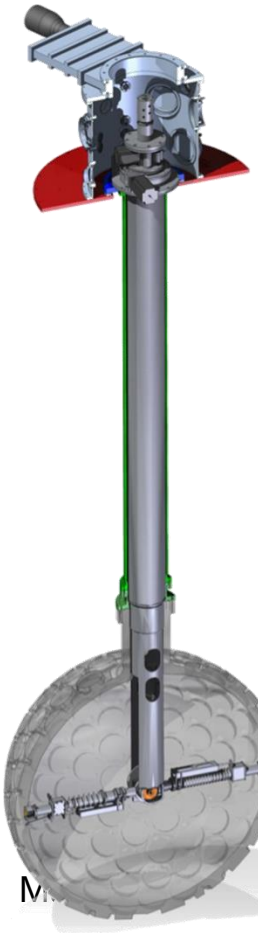
Copper sleeve over PMT

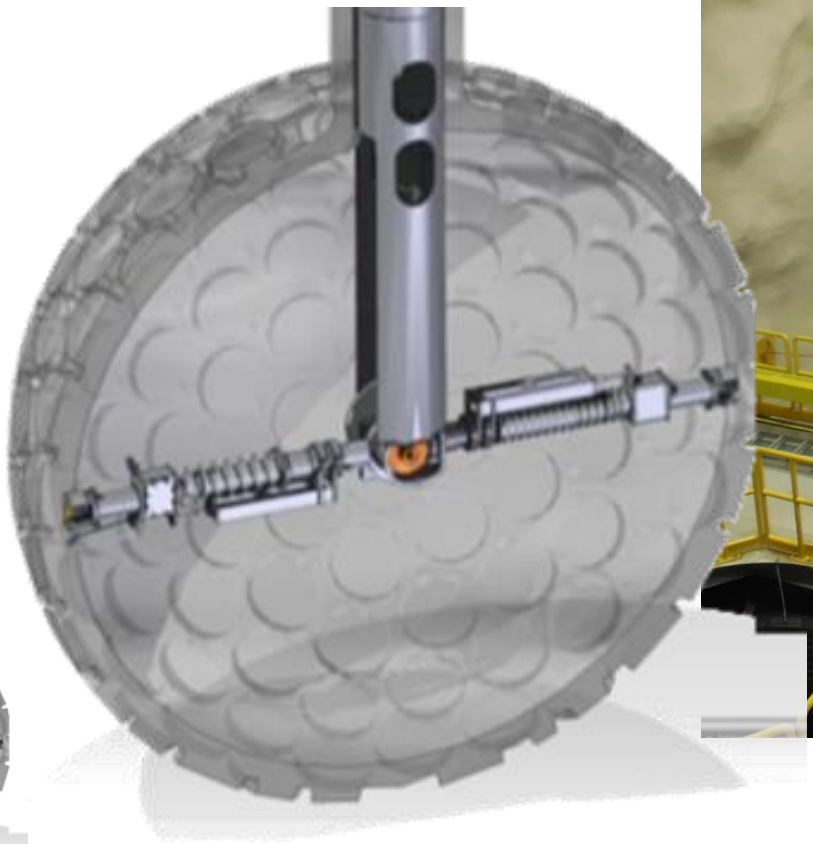
2,500 person-weeks of assembly (students, faculty, PDFs, technicians, engineers)

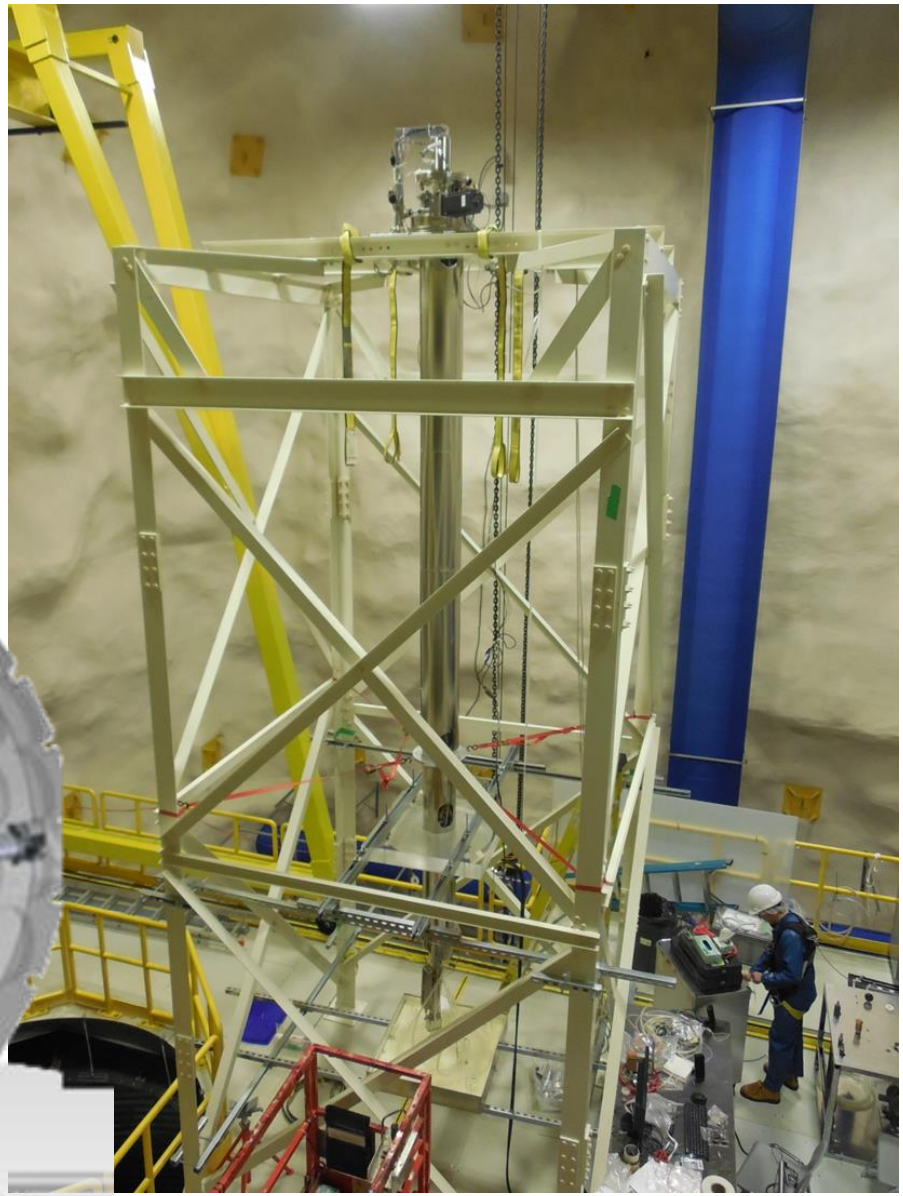
Mark Boulay

Acrylic Vessel Resurfacer

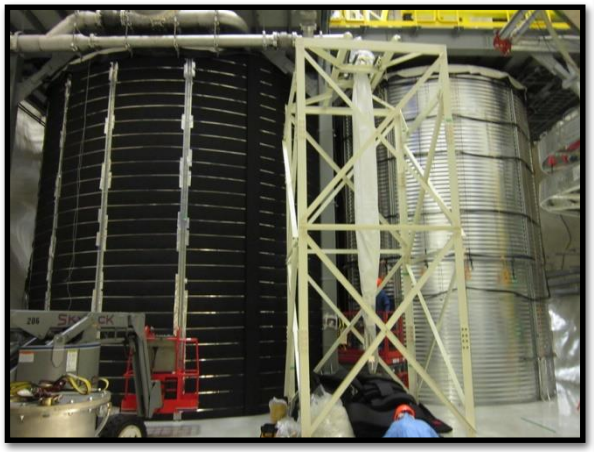
- Mechanical sander to clean inner surface
- Components selected for low radon emanation
- Remove 0.5-mm surface *in situ* with N_2 purge
- Cleans surface to bulk-level impurities
  (order 100,000 cleaner than SNO vessel)

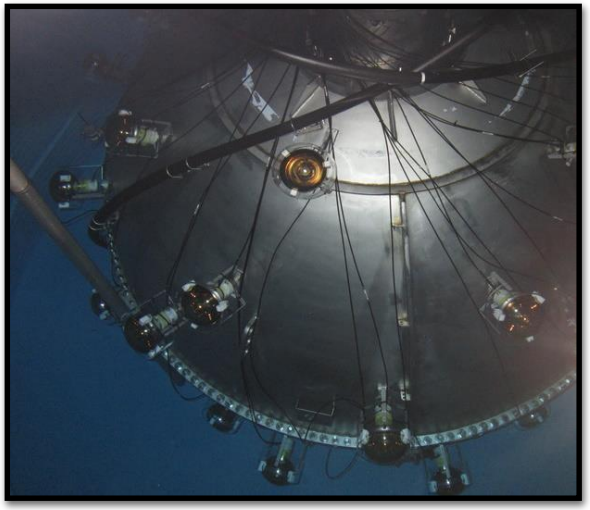


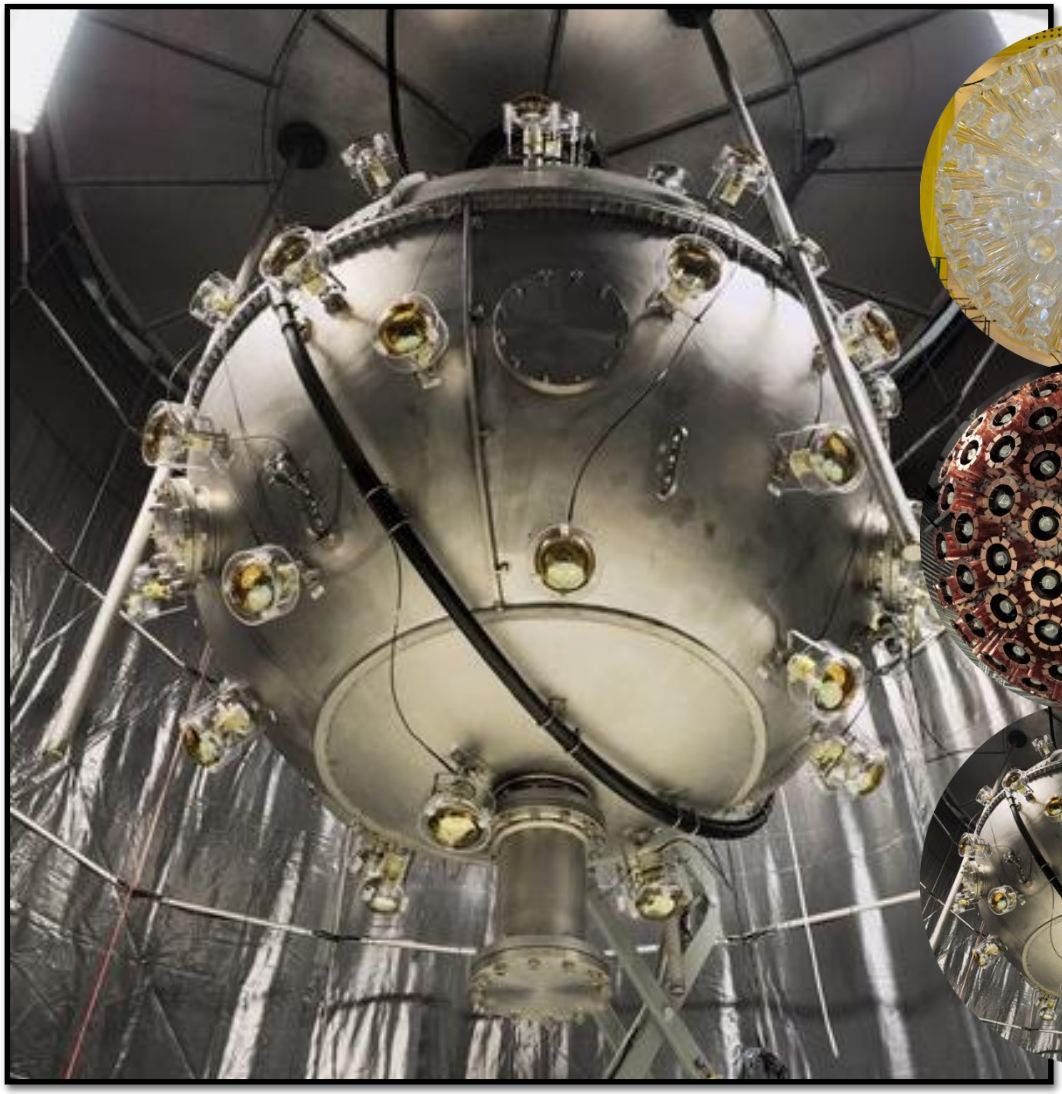


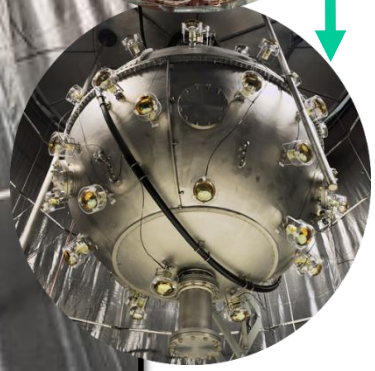


Construction of DEAP-3600 was completed in early 2016







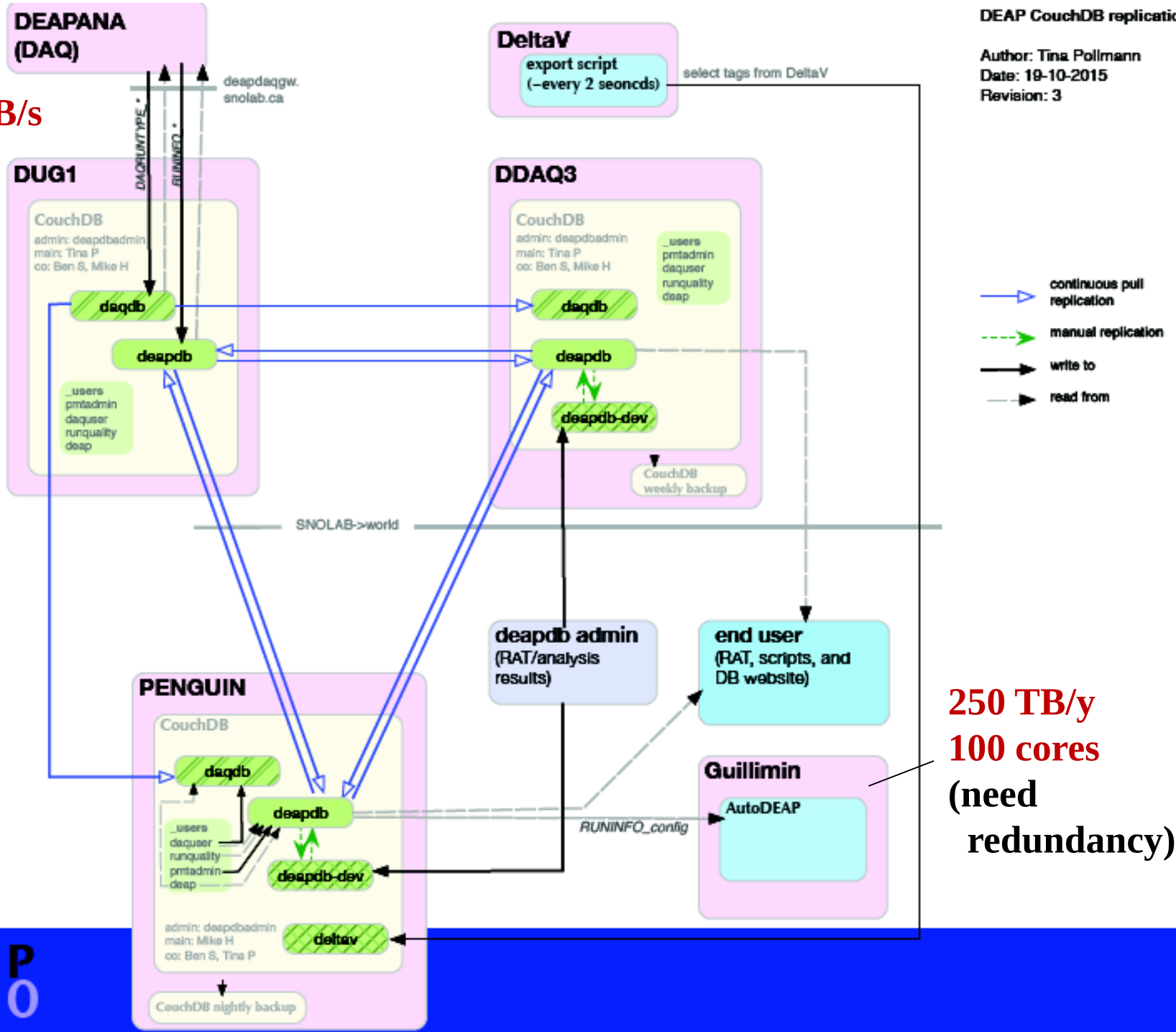


Mark Boulay

DEAP-3600 status

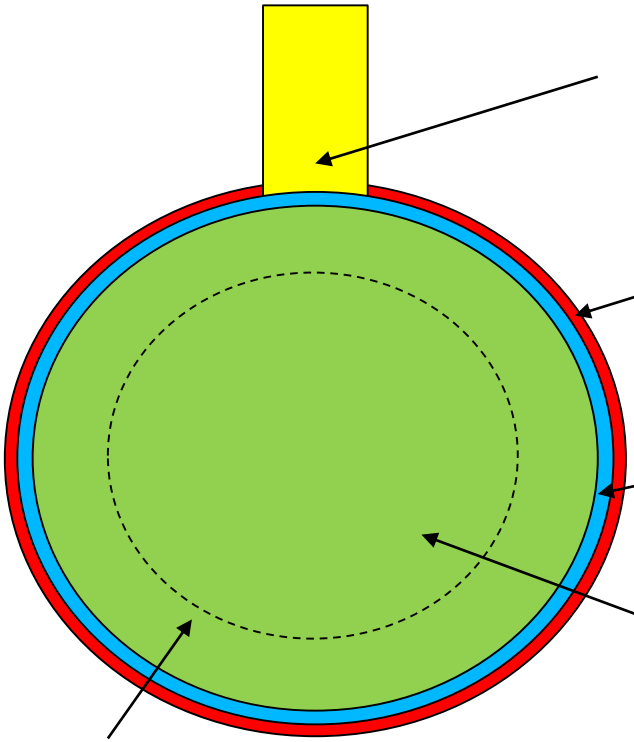
- First cooldown/fill Feb-August 2016 (gas contamination on August 17th, drained and refilled)
- Detector (re-)filled since Nov 1, 2016, now with ~3300 kg
- Collecting DM search data, approx 80% livetime fraction corresponds to 24,000 kg-days per month exposure.
- So far stable performance, good light yield
- Taking physics and calibration data, plan to continue data collection for ~4 years
- Working on the first analysis from the 1st fill data
- In-situ backgrounds analysis in-progress, in particular calibration of position reconstruction, finalizing cuts

DB infrastructure.



DEAP-3600 Background Reduction

First step is detector design, low-background materials, then…



fiducial boundary

α decays from neck region - shadowed
(**position reconstruction, hit spatial/time pattern**;
alpha decays in neck degraded in light yield)

α decays from inner surface
(**position reconstruction, hit spatial/time pattern**
^{222}Rn daughters on surface, degraded energy)

neutron scatters
(**position reconstruction, external μ-veto**)

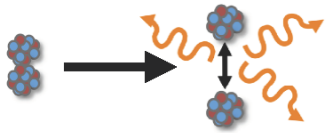
internal events
- **outside of energy ROI** (full energy α's)
- inside energy ROI: electron/γ - **PSD** (^{39}Ar)
- WIMPs

Current status: α backgrounds, neutron backgrounds, PSD analyses well advanced, in-situ measurements of background levels, finalizing position reconstruction and cuts (in progress). Many details will be presented at CAP.

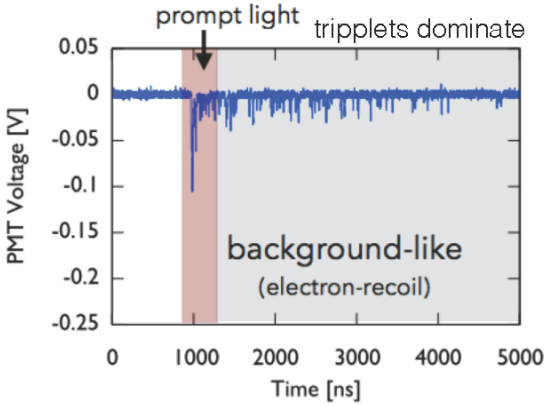
Experimental Signatures

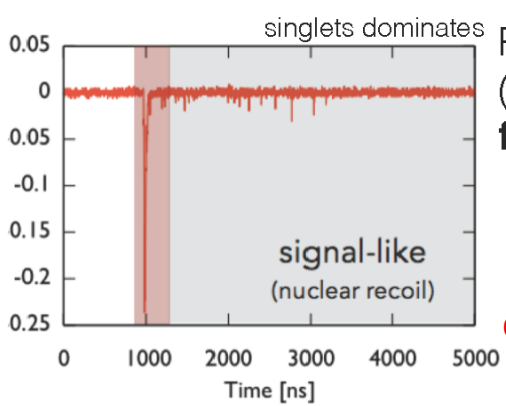
Ar scintillation:

- excimers are create



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



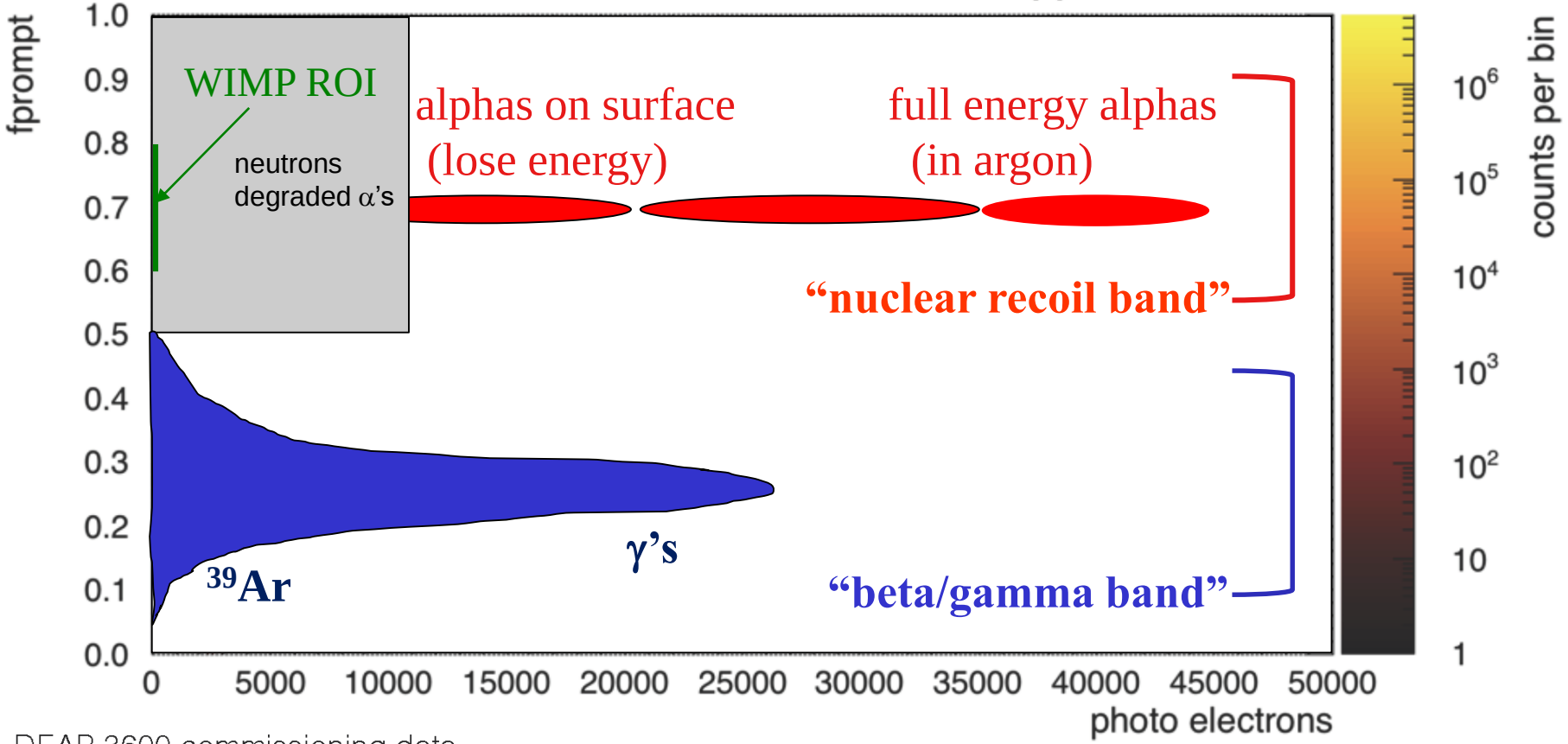


Pulse shape discrimination (PSD) parameter:

fprompt =

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

overview of backgrounds: see Bjoern Lehnert R1-5



DEAP 3600 commissioning data

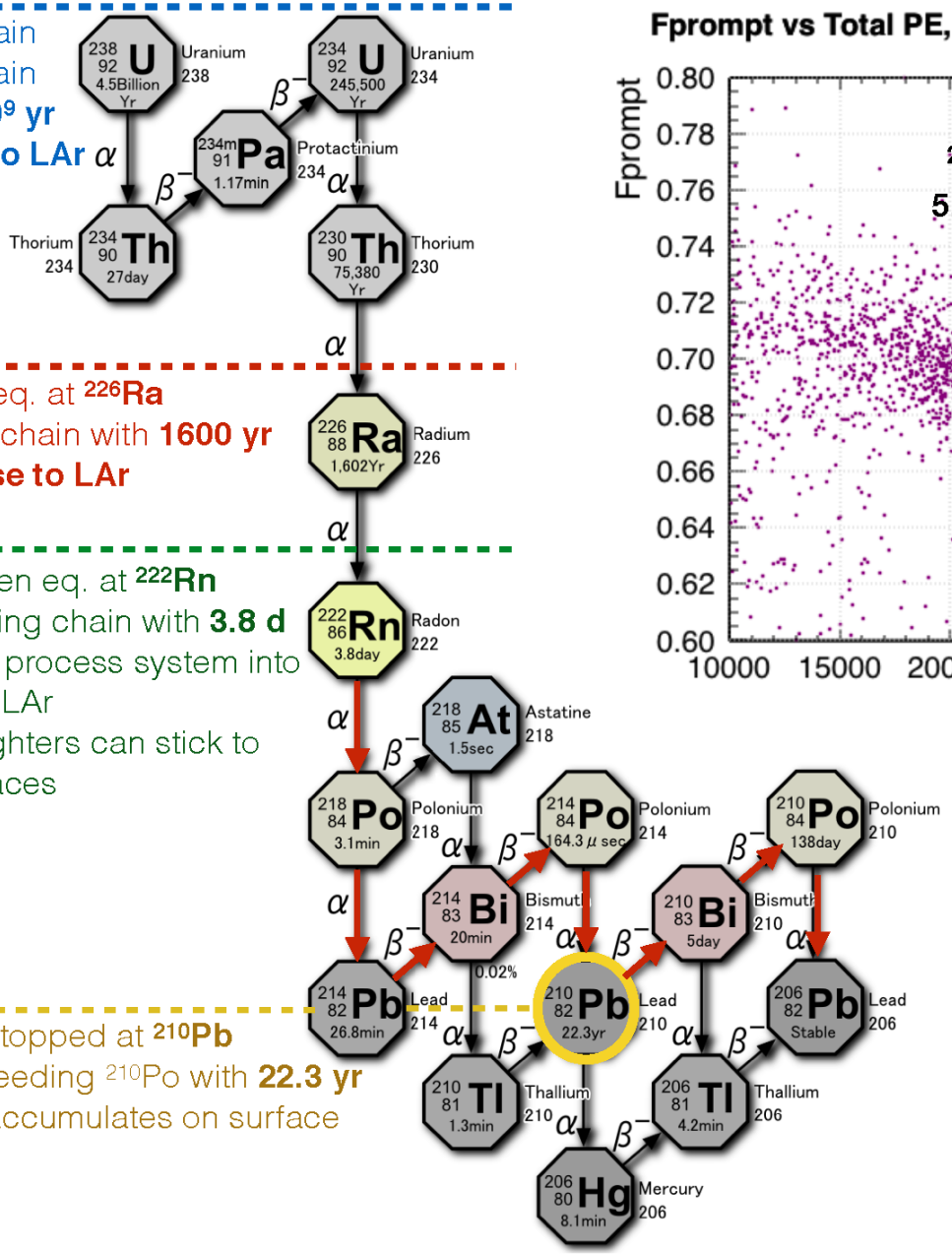
^{238}U Decay Chain

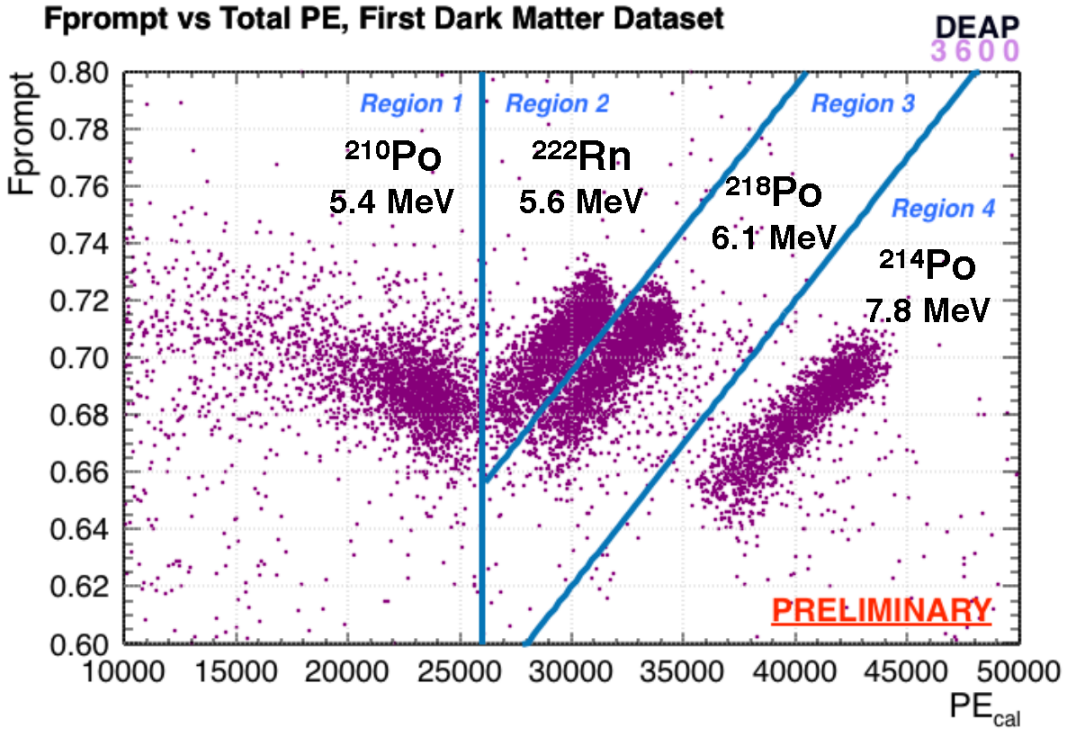
full ^{238}U chain feeding chain with **4.5x10^9 yr** **not close to LAr**

broken eq. at ^{226}Ra feeding chain with **1600 yr** **not close to LAr**

broken eq. at ^{222}Rn feeding chain with **3.8 d** from process system into bulk LAr
daughters can stick to surfaces

stopped at ^{210}Pb feeding ^{210}Po with **22.3 yr** accumulates on surface





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

Talk M4-3
J. McLaughlin

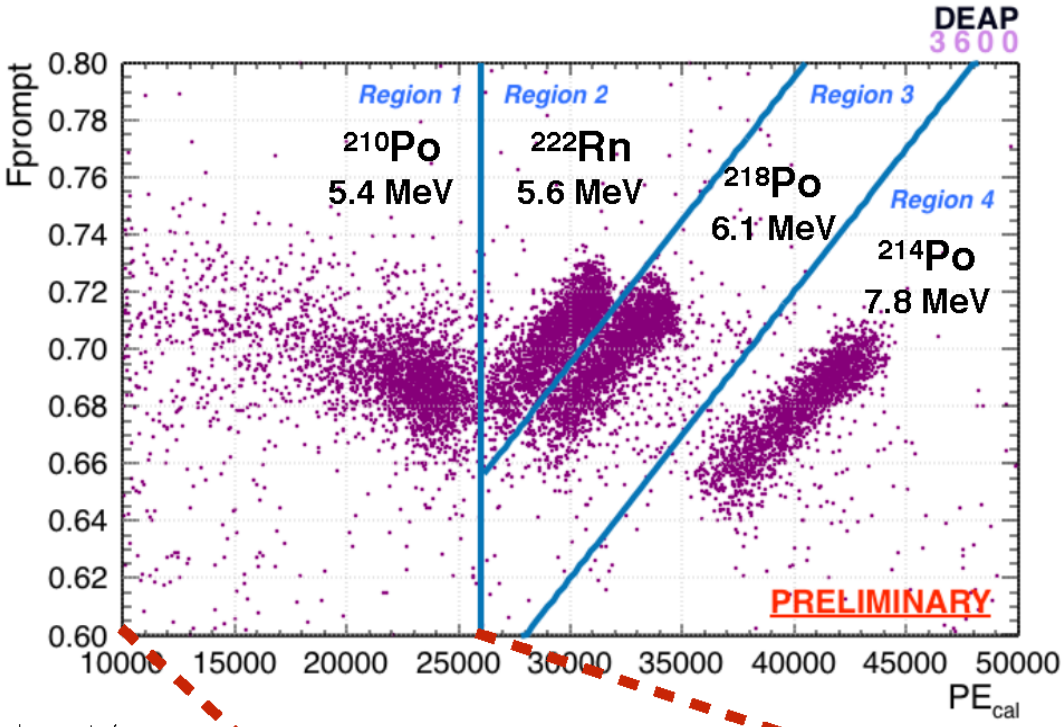
- ^{210}Po on surface:
  - Equal detector response
- ^{222}Rn, ^{218}Po, ^{214}Po in LAr bulk:
  - Detector response depends on radius

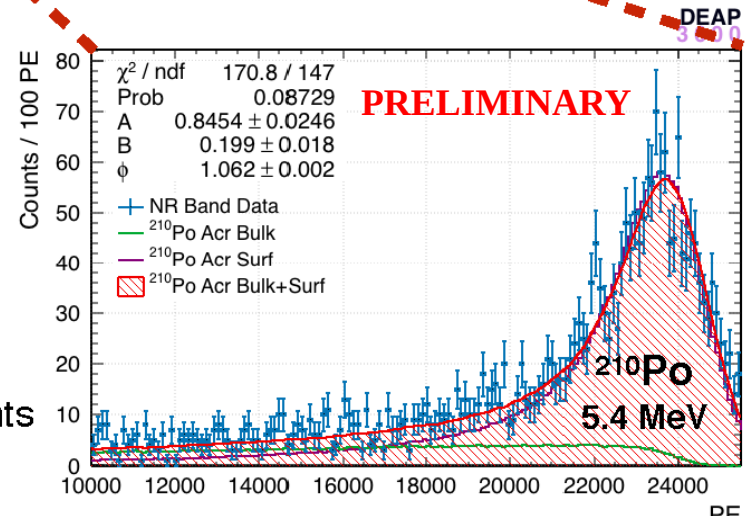
Alpha Background

- Measuring the ^{222}Rn content in the bulk LAr shows the well very competitive results
- **Preliminary** ^{222}Rn activity

^{222}Rn in Dark Matter experiments:

Target	Experiment	Activity [mBq]
LAr	DEAP-3600	≈0.5
LXe	Xenon1T	5.7
LXe	PandaX	3.9
LXe	LUX	17.9

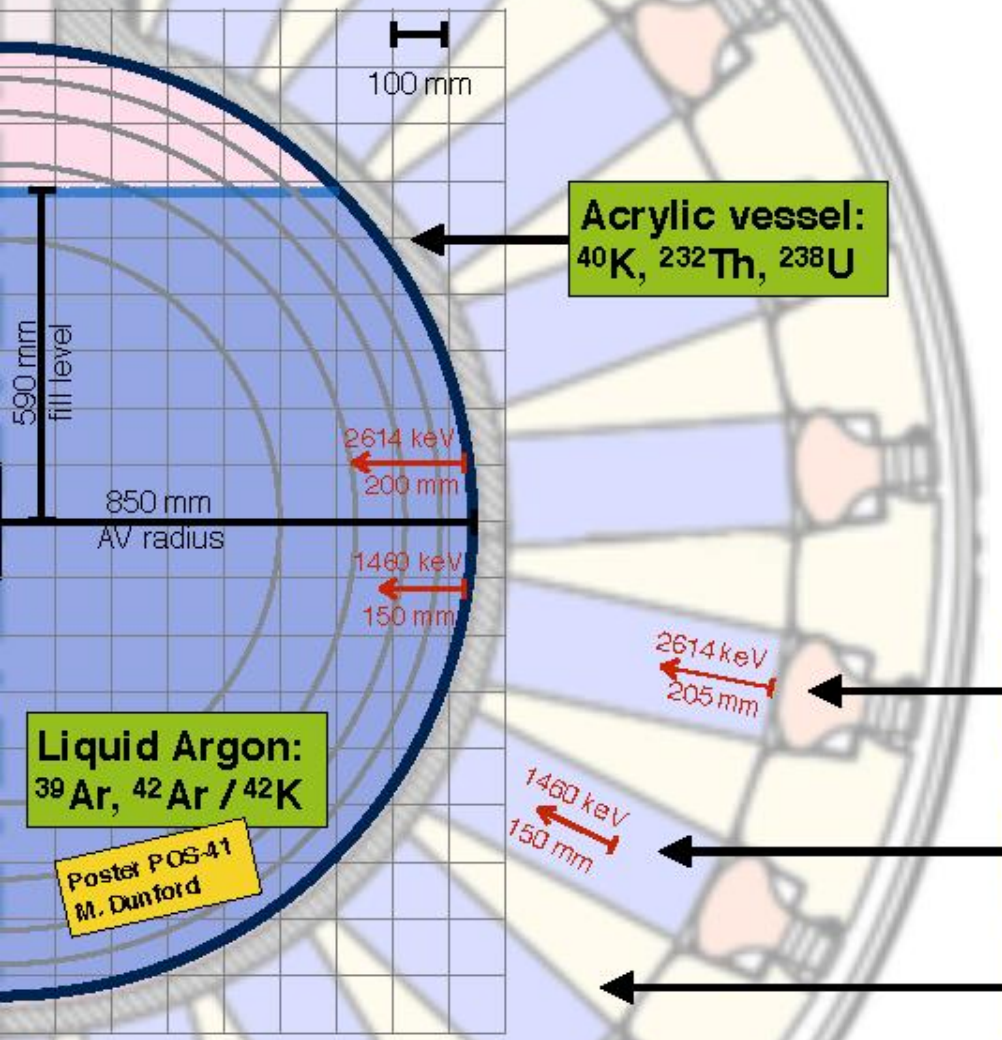




Majority of ^{210}Po events on the acrylic surface

- https://indico.cern.ch/event/432527/contributions/1071738/attachments/1321292/1981557/ICHEP2016_EthanBrown_v1.pdf
- "Krypton and radon background in the PandaX-i dark matter experiment," JINST 2, 2017.
- "Radon-related backgrounds in the LUX dark matter search," Phys. Procedia, vol. 658, 2015.

Gamma and Beta Background



Acrylic vessel:
^{40}K, ^{232}Th, ^{238}U

2614 keV
205 mm

PMT glass:
^{232}Th, ^{238}U

1460 keV
150 mm

Light guides:
^{40}K

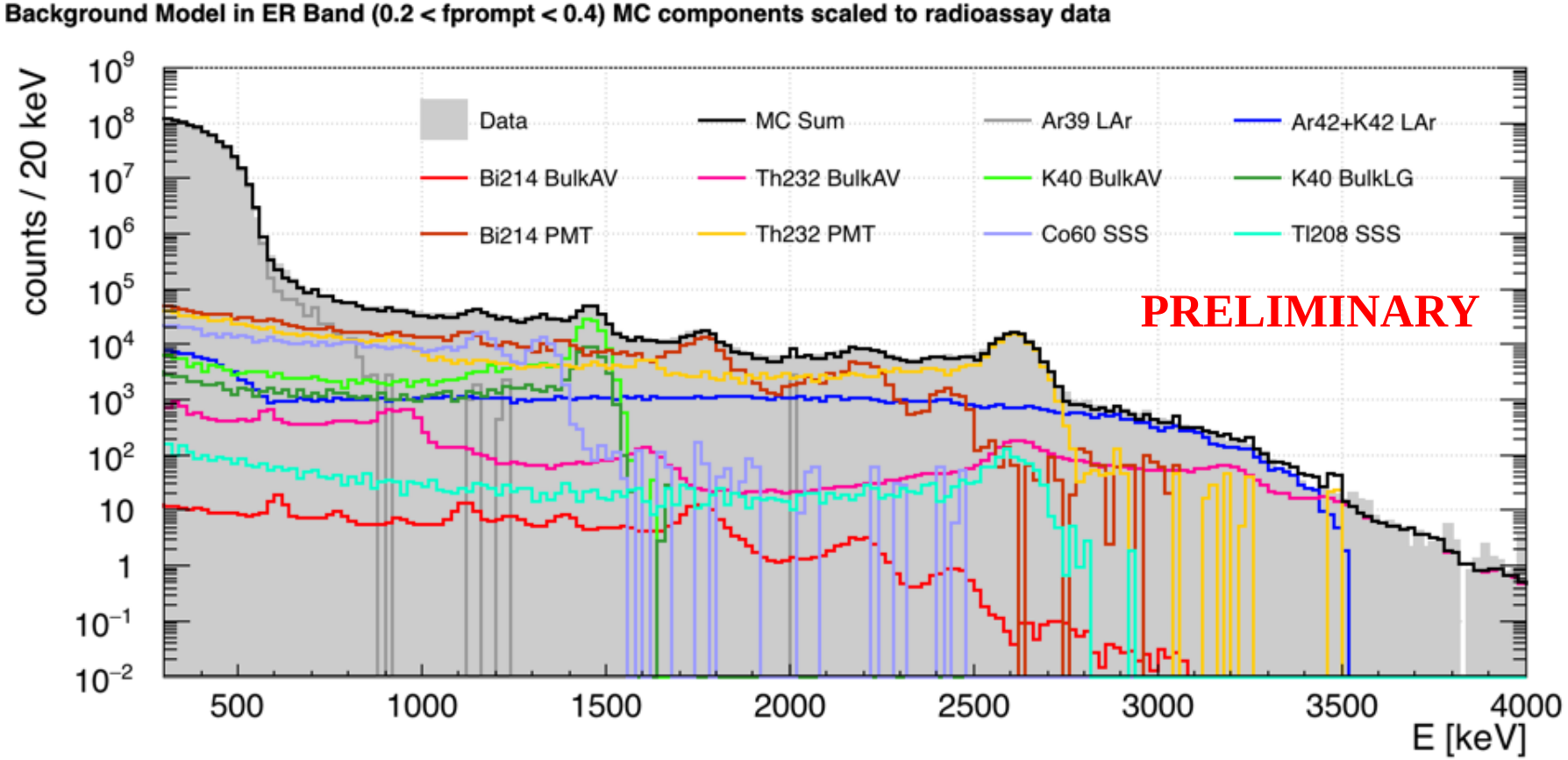
Filler blocks:
^{40}K

Steel shell:
^{60}Co, ^{232}Th, ^{238}U

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	acrylic	7.5	≈2	70

Electron Recoil Band Background Model



- 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 gamma from outside components (mainly PMT glass)
- High energy region (> 2.6 MeV) dominated by ^{42}K and beta components from very close ^{208}Tl sources

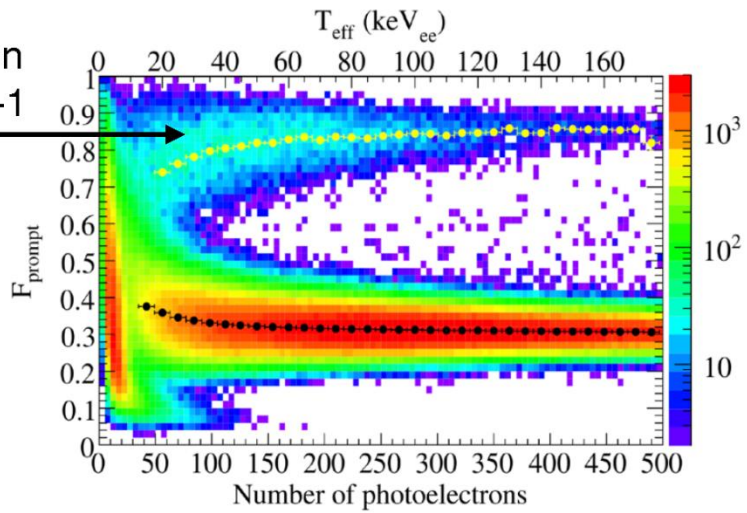
- **Gamma line measurements can be used to constrain (α,n) neutron production**

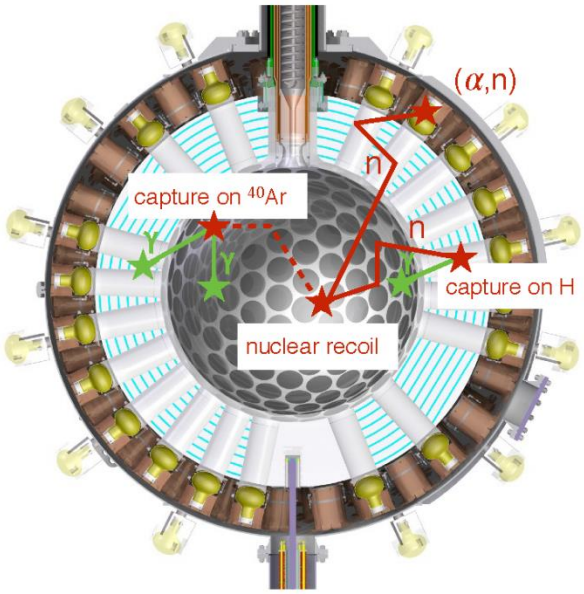
Neutron Background

- 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:

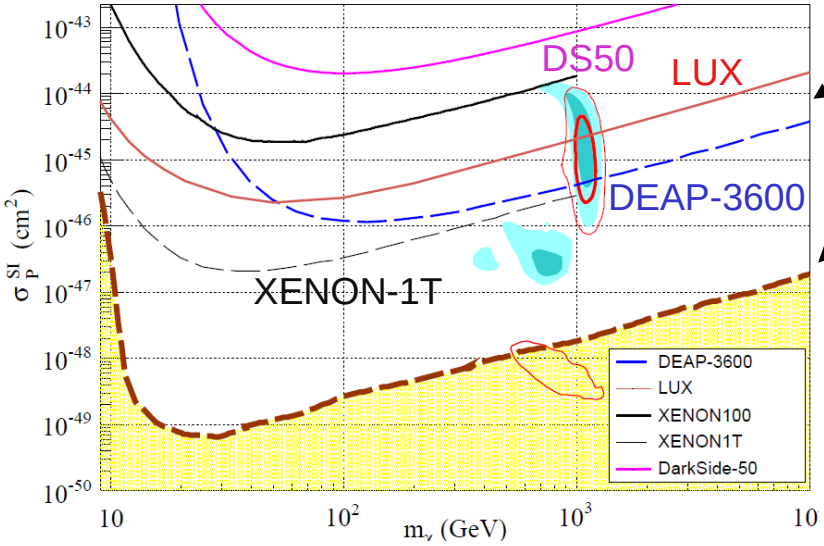
- **Idea:** Eventually all neutrons capture and leave gamma signature
  - 2.2 MeV γ form ^{1}H in acrylic
  - 6.1 MeV γ-cascade from ^{40}Ar in LAr
  - Search for n - γ coincidences
- **Preliminary result:**
  - No coincidence found above expected random background
  - Limit on neutron interactions consistent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

DEAP Talks at CAP 2017

Presenter	Talk/Session
Bjoern Lehnert	Backgrounds overview/R1-5
Robert Stainforth	Cleaning Data for Dark Matter Search/R2-3
Shawn Westerdale	TPB fluorescence tails/W3-5
Carl Reithmeier	Position reconstruction and MC tuning/POS-40
Stefanie Langrock	Energy and position response/R1-5
Matthew Dunford	Argon Isotopes in DEAP-3600/POS-41
Colin Moore	Veto of Seismicity induced events/W3-5
Ben Broerman	TPB deposition in DEAP-3600/T3-3
Andrew Erlandson	Instrumental events and cosmic ray muons/POS-37
Conner Stone	Machine learning algorithms/T3-3
Joseph McLaughlin	PMT signal saturation correction/M4-3

M

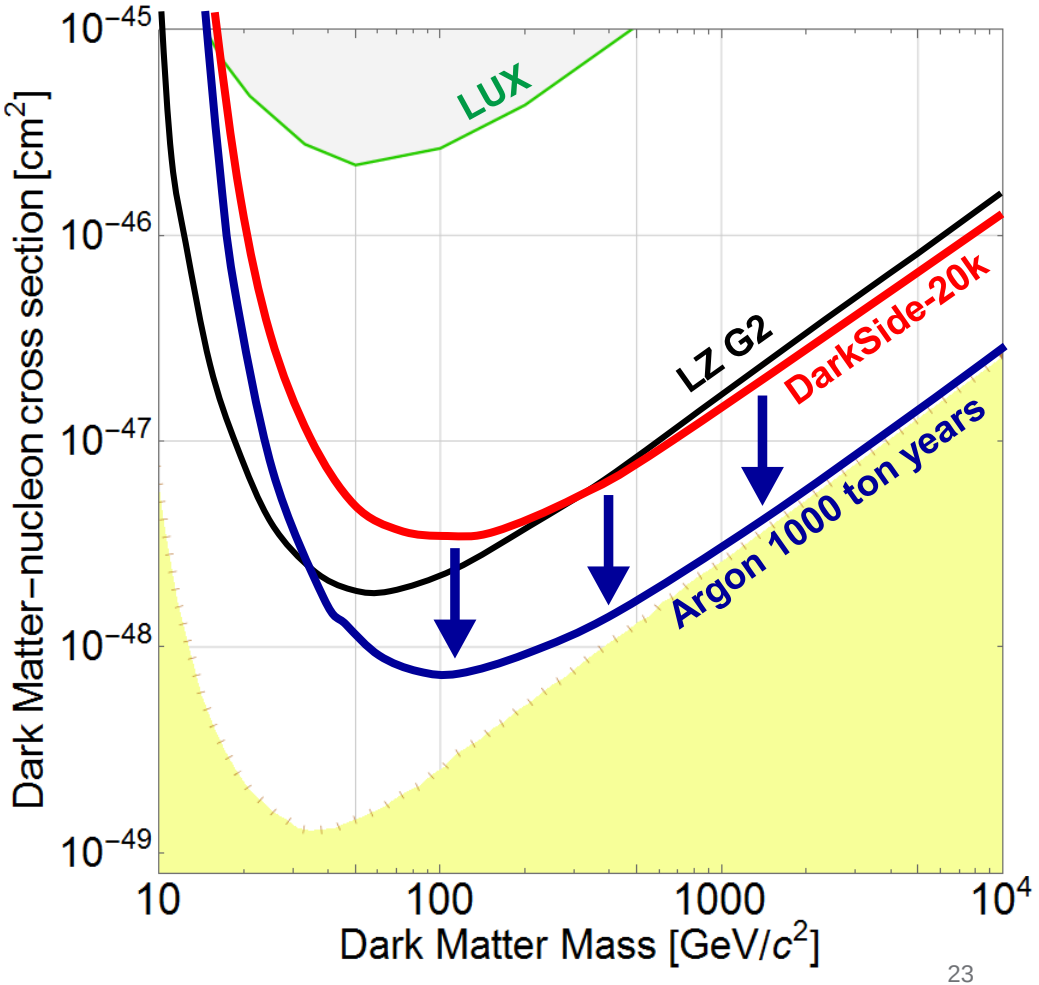
Beyond DEAP-3600: Sensitivity with Argon



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

β/γ discrimination: solar pp neutrino ES background not a concern – in xenon expected dominant bkg at ½ event per tonne-year after recoil discrimination

New global argon collaboration forming

- Significant international collaboration forming for future argon DM searches (350+ researchers)

- Complementary to LHC searches (exploration of v. high masses with direct search). Complimentary to xenon, will want positive detection in at least two targets.

- Sensitivity increase from 1 tonne × yr → 1,000 tonne × yr

- Beyond DEAP-3600: DS-20K (20 tonnes argon) – first step

  Future multi-100T detector – "ultimate" ν floor sensitivity

- Two crucial technologies

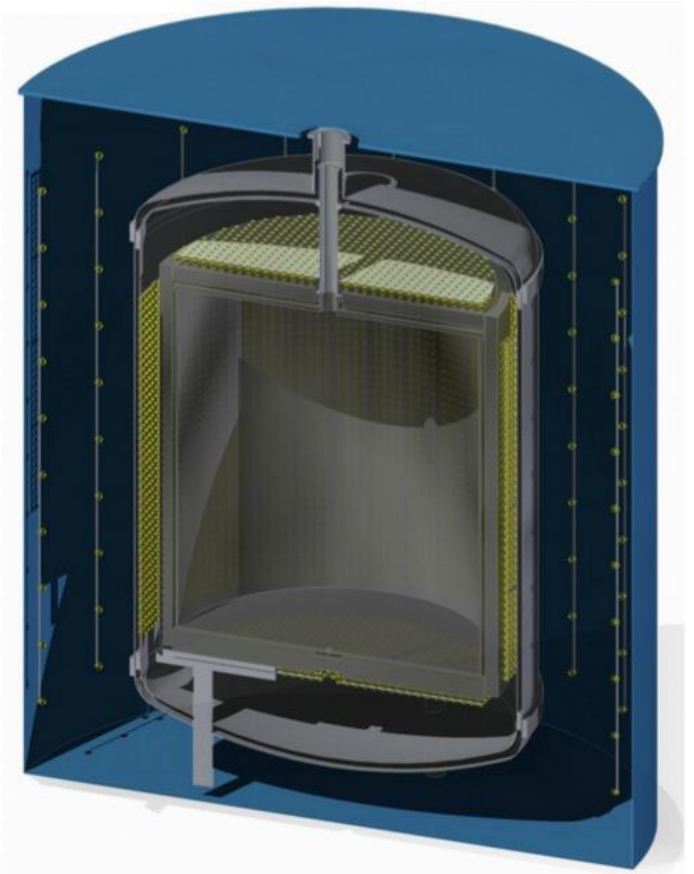
  - Liquid argon target depleted in the radioactive ^{39}Ar (underground argon: Urania and isotopic purification: Aria)

    (Underground argon: scale up facility to ~150 kg/day; total gas stream at current facility is ~3 tonnes per day)

  - SiPMs replacing cryogenic PMTs, in development, R&D

After DS-20K (Argo/DEAP-nT)

- Collaboration will pursue integrated program/common design allowing ktonne-year exposure (single-phase/dual phase both options considered)
- Plan for operation with low-radioactivity argon
- Sensitivity to neutrino floor for high-mass WIMPs
- Timescale follows DS-20K (so mid-2020's)
- Site TBD
- Possibility for solar neutrino measurements
- Some R&D started in Canada, new Cryogenics Facility at Carleton, CAD development of digital SiPM array, some overlap with SiPM development for nEXO (2017 CFI IF request, Carleton, McGill, Sherbrooke, TRIUMF)



Summary

DEAP-3600 collecting data since late 2016!

Preliminary internal background measurements show components are understood. First analysis underway, finalizing calibration of position reconstruction and cuts

11 HQP presentations at CAP – please attend for details!

Full DEAP-3600 run ~4 years, to ~2020

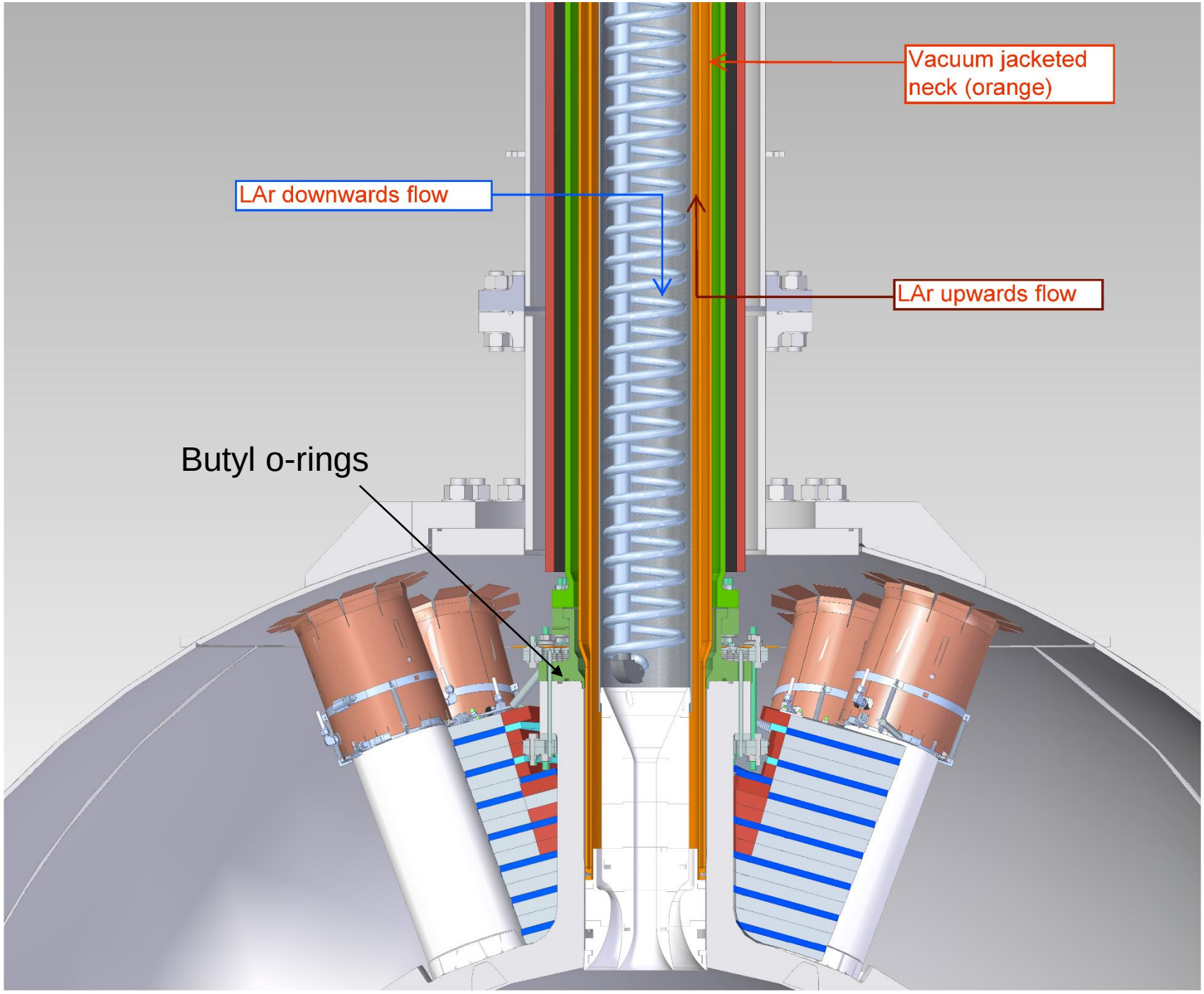
Beyond DEAP-3600:

Significant global collaboration with extensive skills/experience forming toward:

DS-20K at LNGS (20 tonnes argon, 2021 operation)

Future multi-hundred-tonne detector to ν floor (mid-2020's, site TBD)

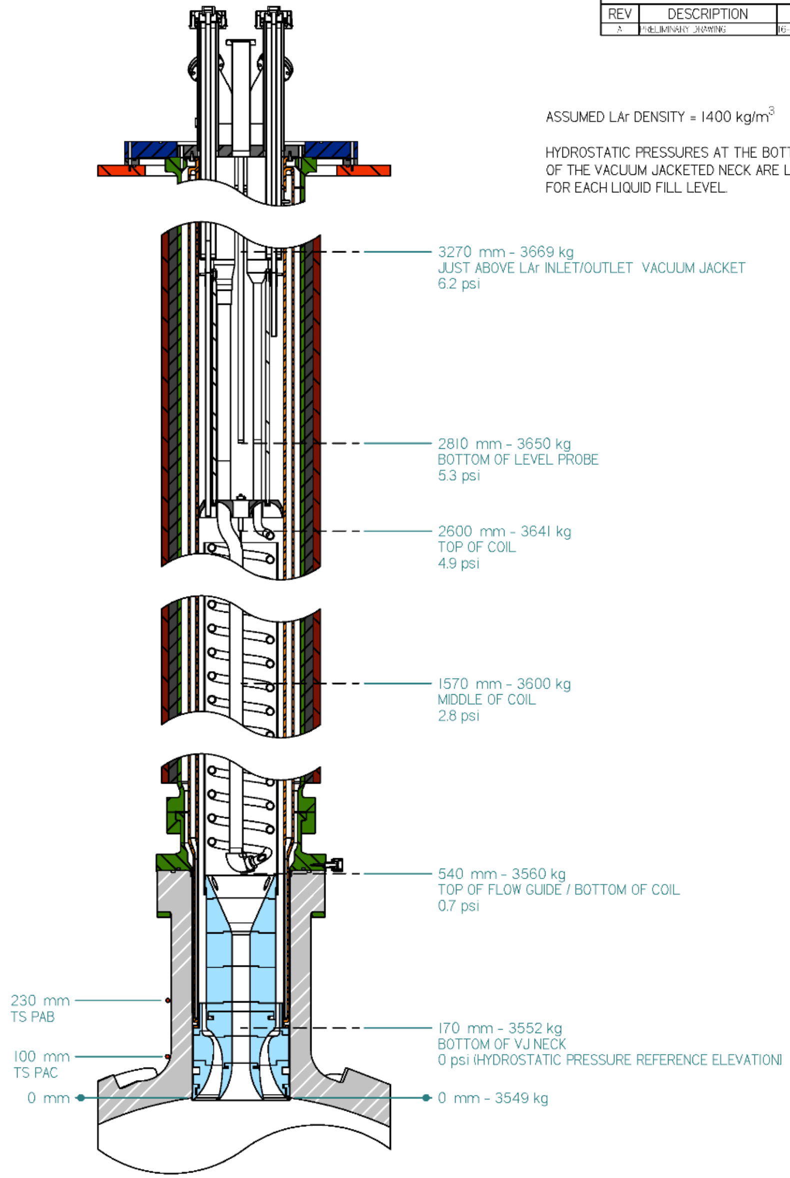
END


Vacuum jacketed neck (orange)
LAr downwards flow
LAr upwards flow
Butyl o-rings

REVISION HISTORY		
REV	DESCRIPTION	DATE
A	PRELIMINARY DRAWING	16-AUG-2015

ASSUMED LAr DENSITY = 1400 kg/m^3

HYDROSTATIC PRESSURES AT THE BOTTOM OF THE VACUUM JACKETED NECK ARE LISTED FOR EACH LIQUID FILL LEVEL.



SECTION A-A

SHEET 3 NECK FILL

DRAWN: KOBY DERING	DATE: 14-JUNE-2016	
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES DECIMALS XX ± 0.01 XXX = 0.005 ANGLES = 1° ROUNDS AND FILLETS 0.313 INCHES SURFACE FINISH 125 μINCHES		**DEAP** *Queen's University, Physics Department* TITLE: AV TEMPERATURE SENSORS AND ARGON FILL LEVELS SIZE B · DWG NO: QUDO-DEC-SK-xxxx-3 · REV A SCALE: AS SHOWN · WEIGHT: · SHEET 3 OF 3