Development of a 50-Tonne Next-Generation Argon Detector at SNOLAB

Scientific Merit
- Argon and xenon for DM searches
- Backgrounds
- Ultimate reach

Project Overview

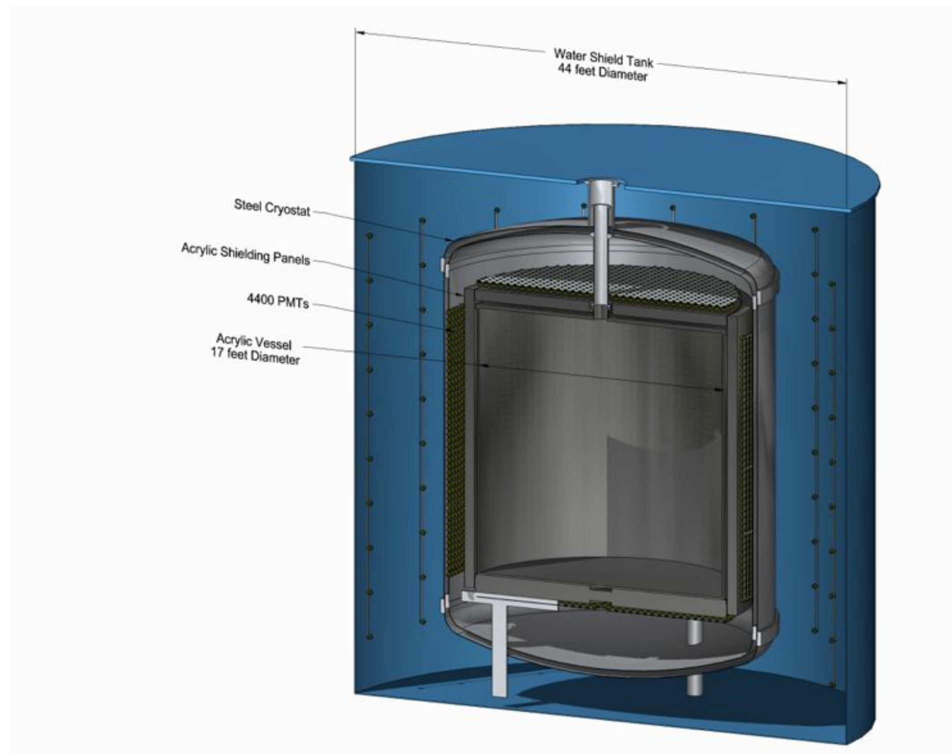
DEAP-3600 Status

Collaboration

Funding Requirements

Schedule

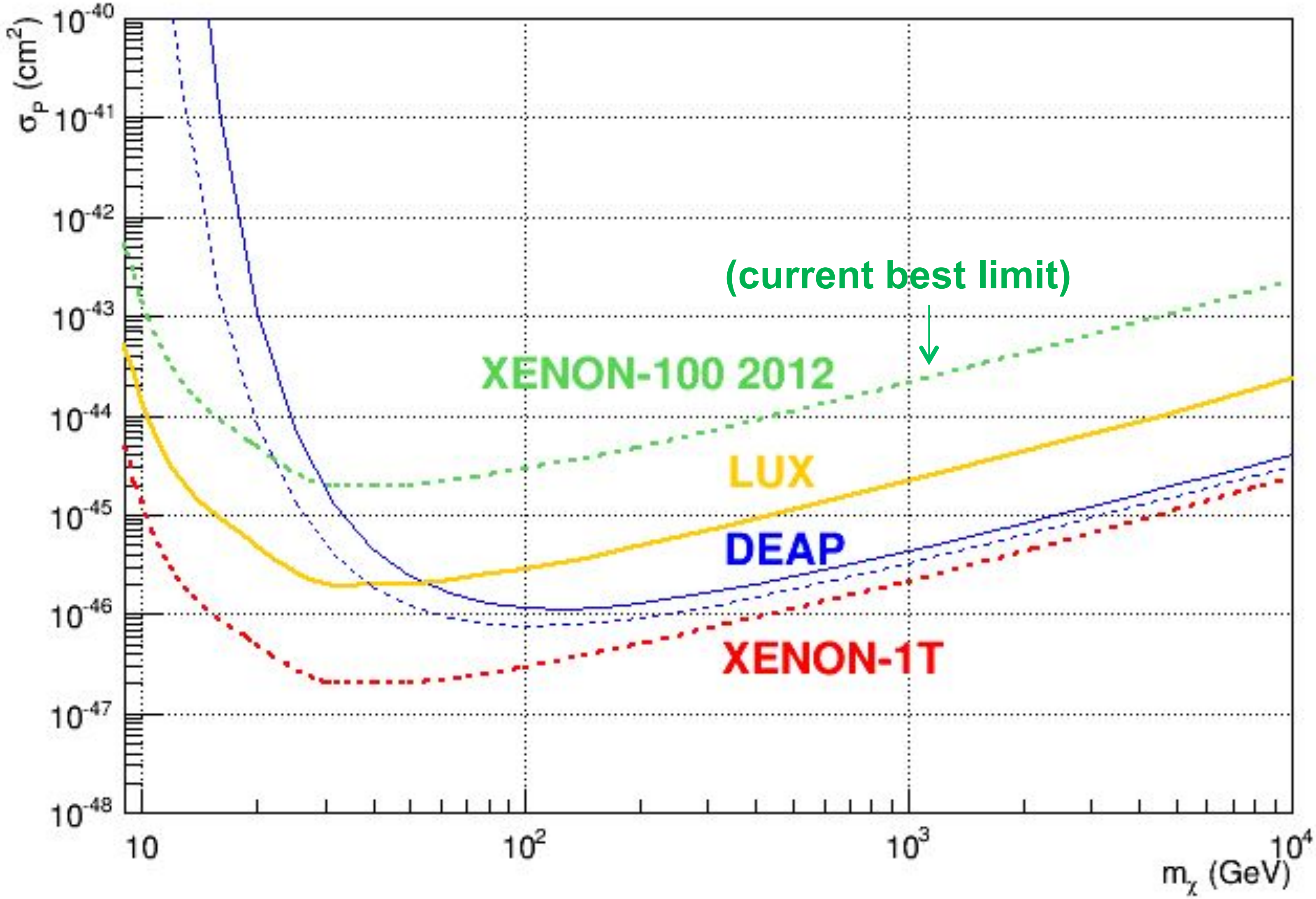
Resource Request from SNOLAB



Mark Boulay
Queen's University, Kingston

SNOLAB Future Projects, Aug 21, 2013

Physics Context: Spin-independent DM Sensitivity



Scientific Merit

- Identification of Dark Matter remains one of the highest science priorities
- Some “hints”:

At low-energies either annual modulation signals (DAMA, CoGent) or excess events (CDMS, CRESST) look like low-mass WIMPs, but either low-statistics or alternate explanations; results in mutual tension. Low mass region should be fully covered shortly, since interaction cross-section relatively high.

- At high-energies, astrophysical measurements (e+/e- fraction, etc.) could be interpreted as high-mass WIMPs, other explanations possible

- Non-observation of Supersymmetry at LHC, combined with observed value for Higgs mass tends to “push” supersymmetry towards heavy WIMPs (> 350 GeV) for simplest remaining models (eg. cMSSM, NUHM; 5/6 parameters), although there is tension at 2-3 sigma levels in fits.

- Current and planned future direct searches (LUX, DEAP-3600, XENON-1T) will explore some of the remaining parameter space, down to 2-3x10^{-45} cm^2 SI at 1000-GeV WIMP mass, but significant space even in the simplest models remains out of reach. SD scattering remains out of reach in these models.

- Detector with sensitivity of order 2x10^{-48} cm^2 SI would be sensitive to full parameter space, capable of seeing or ruling out the simplest SUSY models

DEAP-3600 will be sensitive to much of the remaining SUSY parameter space for the simplest cMSSM and NUHM models,

similar sensitivity to XENON-1T for high-mass WIMPs, best-fit point for cMSSM remains out of reach for both.

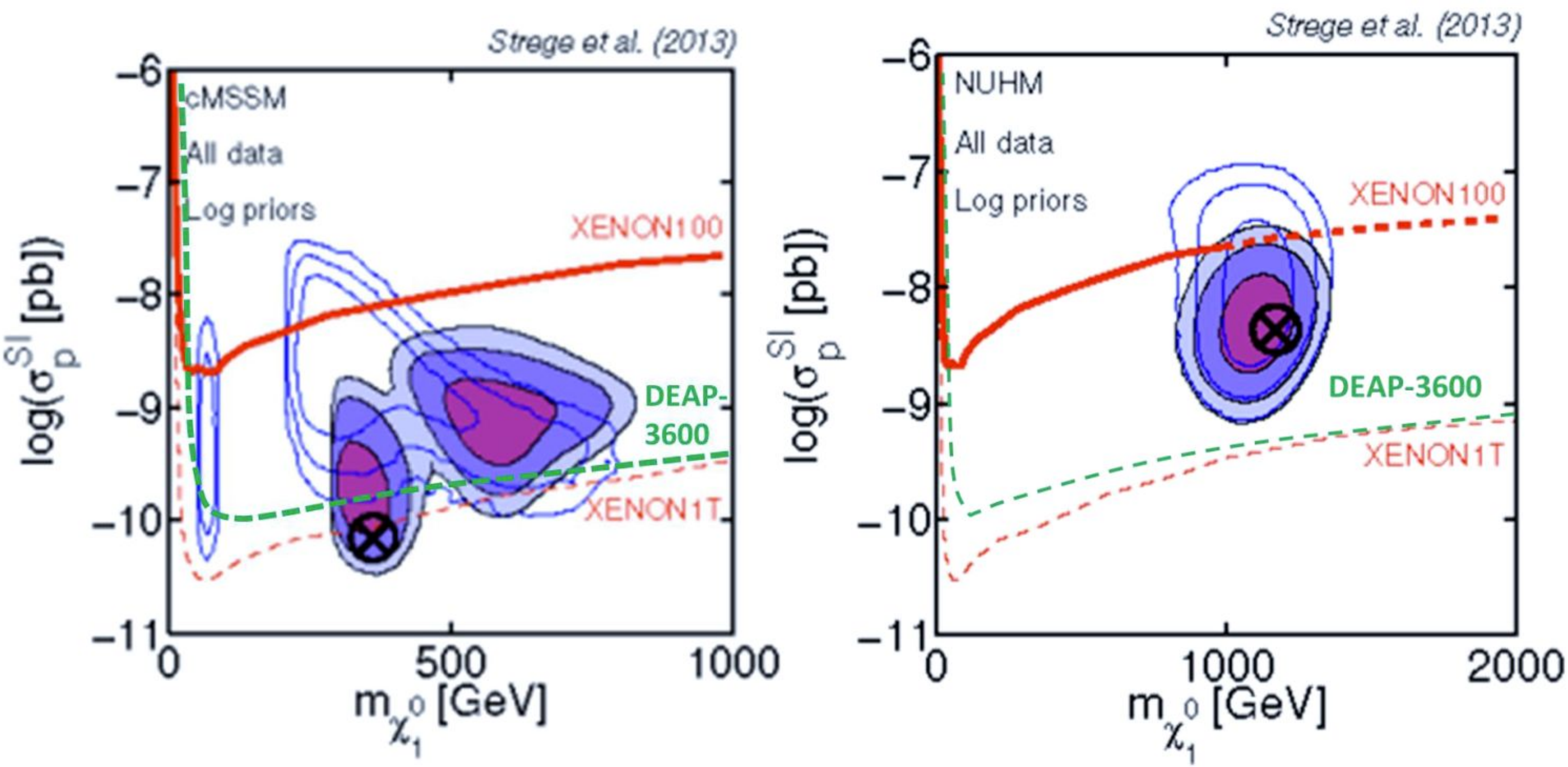
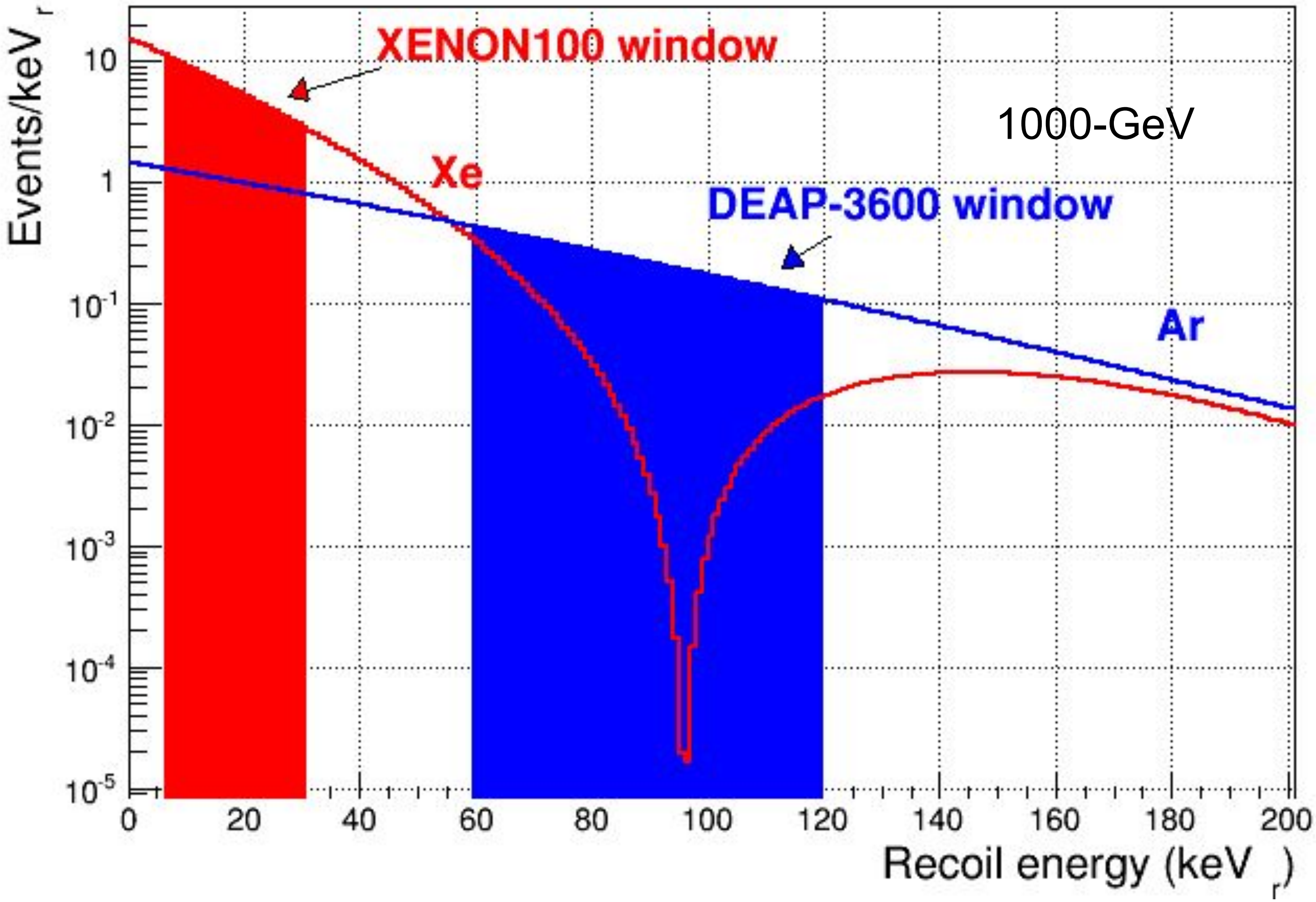


Figure adapted from C. Strege et al., JCAP04(2013)013

Xenon and argon for direct WIMP scattering, two potential targets for v. large mass searches



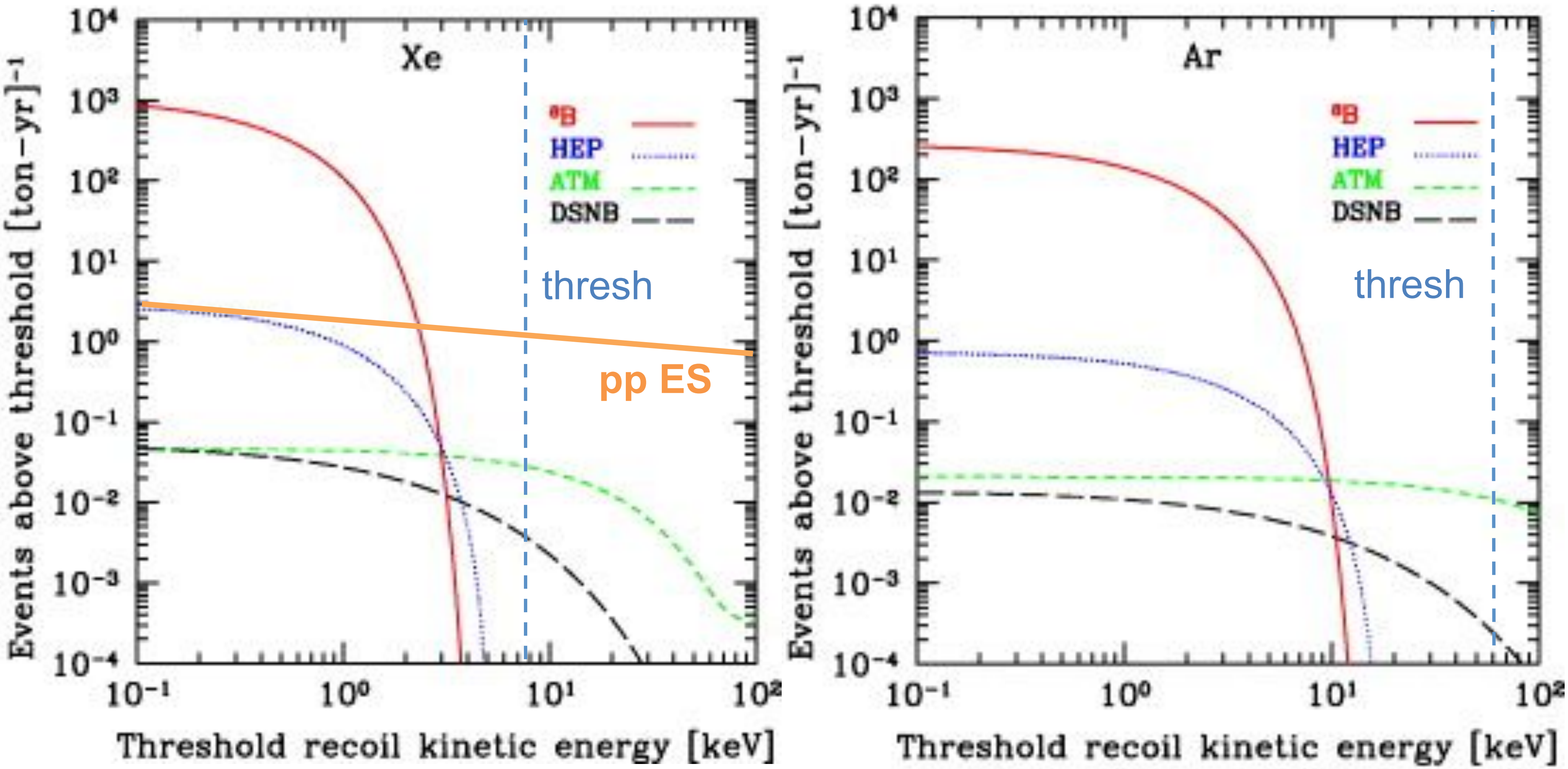
Backgrounds in xenon and argon

All the “regular” radioactive backgrounds

- neutrons, internal, μ-induced
- β/γ leakage
- surface events, α-emitting Rn daughters

Beyond 10^{-46} cm^2, need to consider neutrinos…

Neutrino backgrounds in xenon and argon



Coherent scattering from Strigari, New J. Phys. 11 (2009) 105011
pp elastic scattering, Boulay

0.5 event/tonne-year pp background in xenon, after 0.995 discrimination

Neutrino backgrounds and sensitivity in xenon, argon

Target	Sigma for one WIMP per tonne-year at 100 GeV	N.R. acceptance (in fiducial volume)	Sigma with acceptance for one WIMP per tonne-year at 100 GeV	No. pp events per tonne-year In ROI	Target mass for one pp event detected	Sigma where one pp event is detected
Argon	1.5×10^{-46}	0.9	1.7×10^{-46}	0	N/A	N/A
Xenon	6.8×10^{-48}	0.3	2.3×10^{-47}	0.5	2 tonnes	1×10^{-47}

NOTES: 7 tonnes of argon has equivalent sensitivity to 1 tonne xenon at 100 GeV WIMP mass, fraction is function of energy

With 2 tonnes xenon, expect one pp event in ROI (after E.R. discrimination of 99.5%, measured with XENON-100)

Equivalent to 1×10^{-47} cm^2 cross section for one pp background in xenon

Aside:

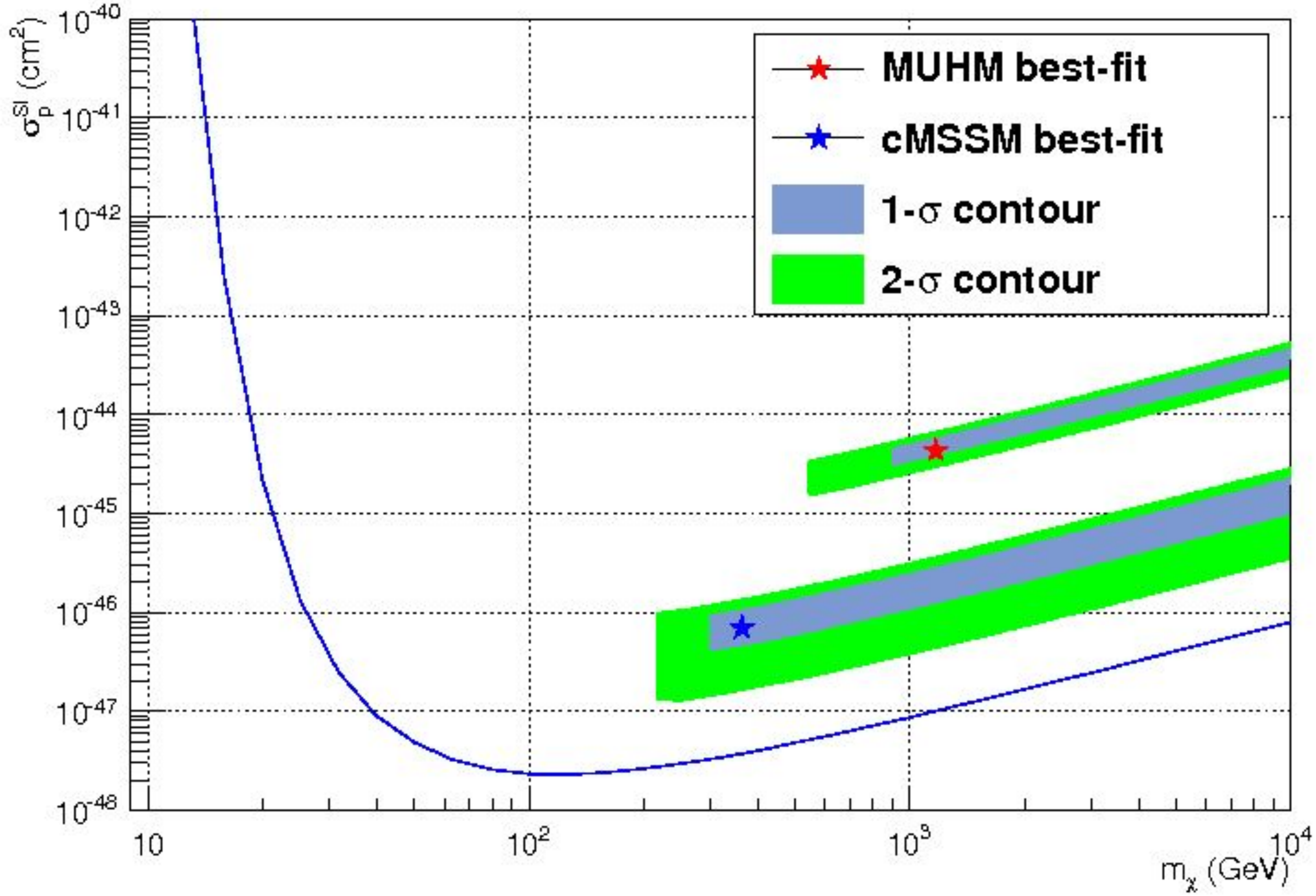
DEAP-3600 holds 3.6 tonnes of argon, or could hold approx. 8 tonnes of xenon

Backgrounds are 0.6 events/3-years, if there was interest could consider filling DEAP-3600 with xenon for pp ES measurement

Cost = approx 10M$ xenon (compare to 4K$ argon !)
+ new purification/cooling (ie SNO+ -scale upgrade)

If xenon purified sufficiently of ^{85}Kr etc., sufficient statistics for 1% pp solar neutrino measurement (15-tonne years, low-background)

Sensitivity with 50-tonnes argon



Science Motivation Summary

Very good motivation to aim for 2×10^{-48} cm^2 SI:

Positive signal predicted for simplest SUSY models, sensitive to full parameter space

Possibility of reconstructing WIMP mass and cross-section

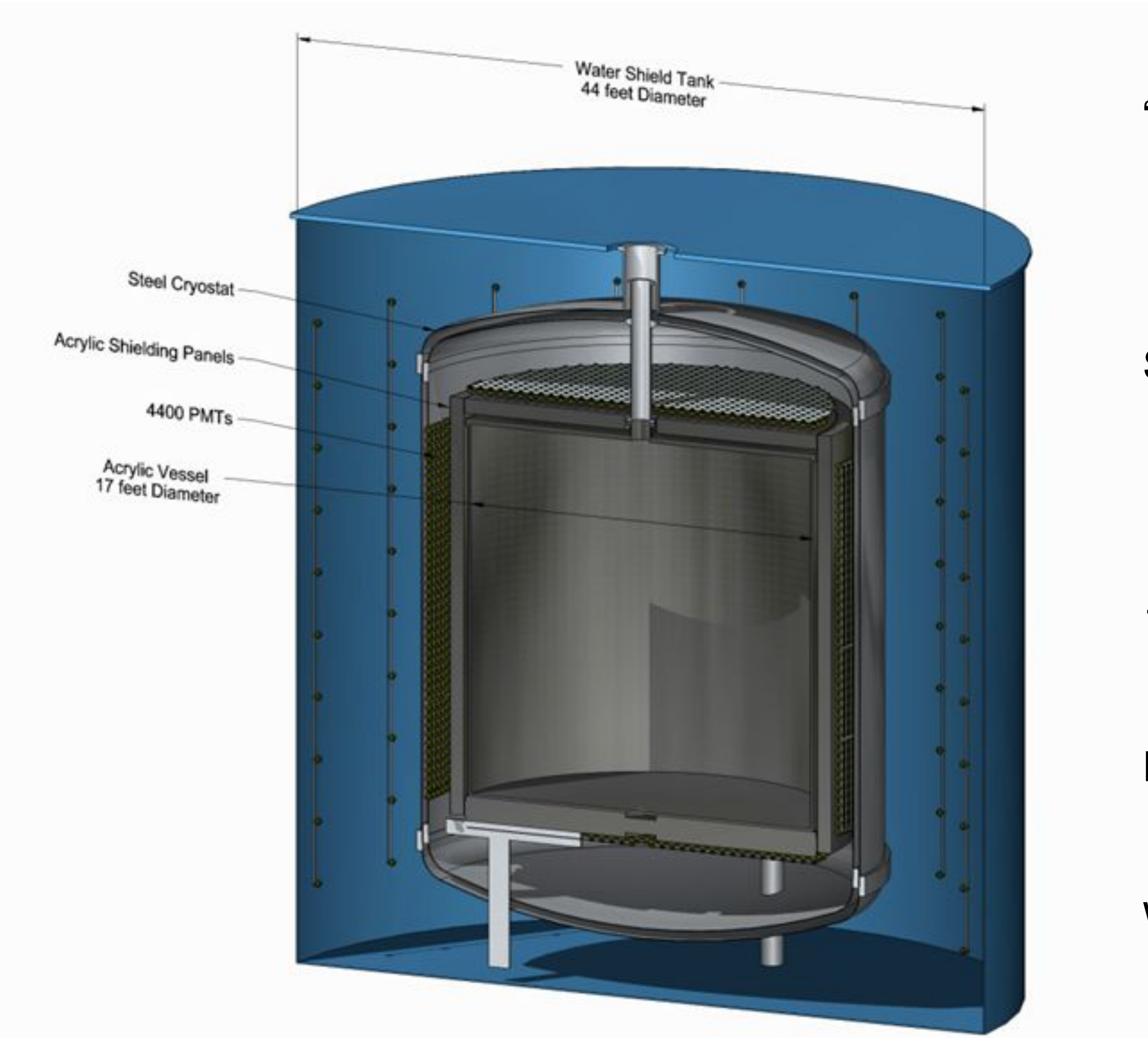
In general model-independent search with sensitivity to relatively high-mass WIMPs, should not ignore these!

Xenon and argon are two potential targets for this sensitivity

Xenon becomes more difficult around 10^{-47} cm^2 due to irreducible pp neutrino ES backgrounds (beyond 10^{-47} cm^2 requires recoil discrimination beyond demonstrated 0.995, at large scale)

Scaling-up single-phase argon technology “relatively” simple;
for very large detector, surface backgrounds become less problematic.

50-Tonne liquid argon detector (conceptual)



"Conventional" ultra-clean acrylic vessel, constructed UG

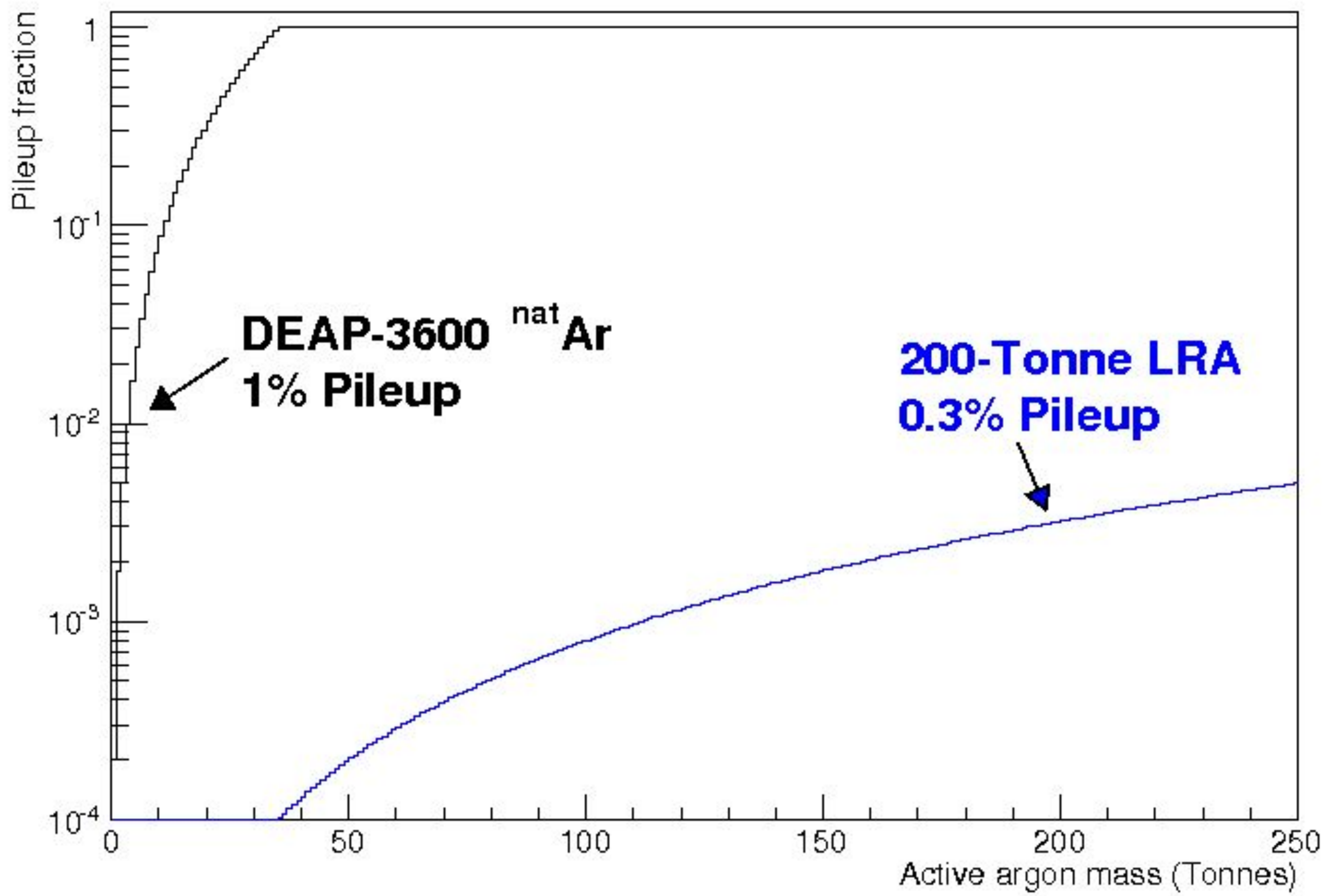
Sanded over ~months to remove deposited daughters, meets requirement

150-tonnes DAr in AV 50-tonne fiducial

Requires UG storage of argon target

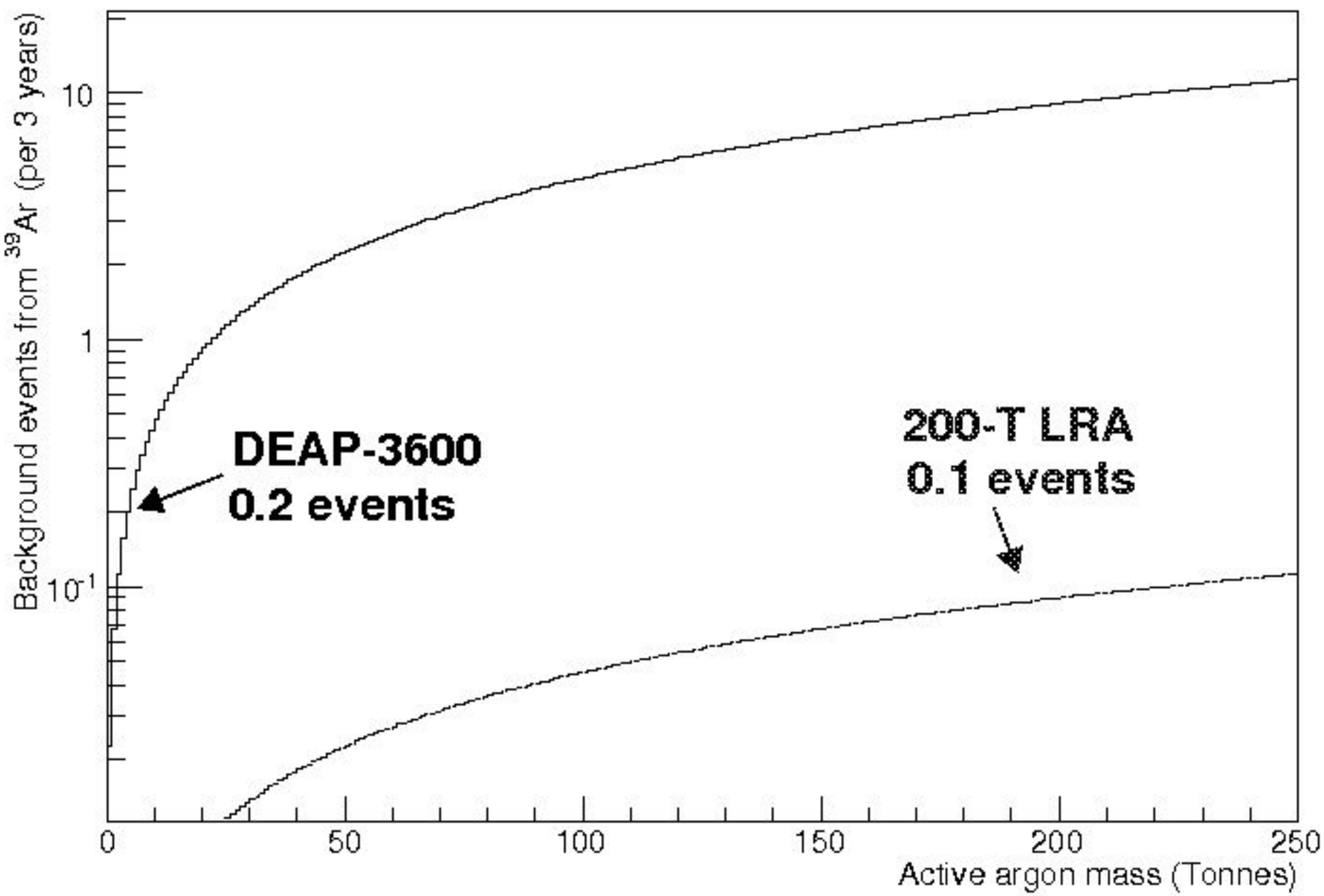
Will investigate PMTs versus SiPMs

The downside: ^{39}Ar in Ar at 1 Bq/kg



Need argon depleted in ^{39}Ar beyond ~few tonnes

Expected background from ^{39}Ar after PSD



PSD requirement less for 50-tonne detector with X200 depleted argon

Depleted argon

^{39}Ar maintained in the atmosphere through cosmogenic production ^{40}Ar (n,2n) ^{39}Ar and similar reactions

Pioneering work by Galbiati, Calaprice (Princeton) demonstrated the possibility of obtaining low-radioactivity argon from underground sources

Underground argon activity varies depending on geology, depth due to production underground:

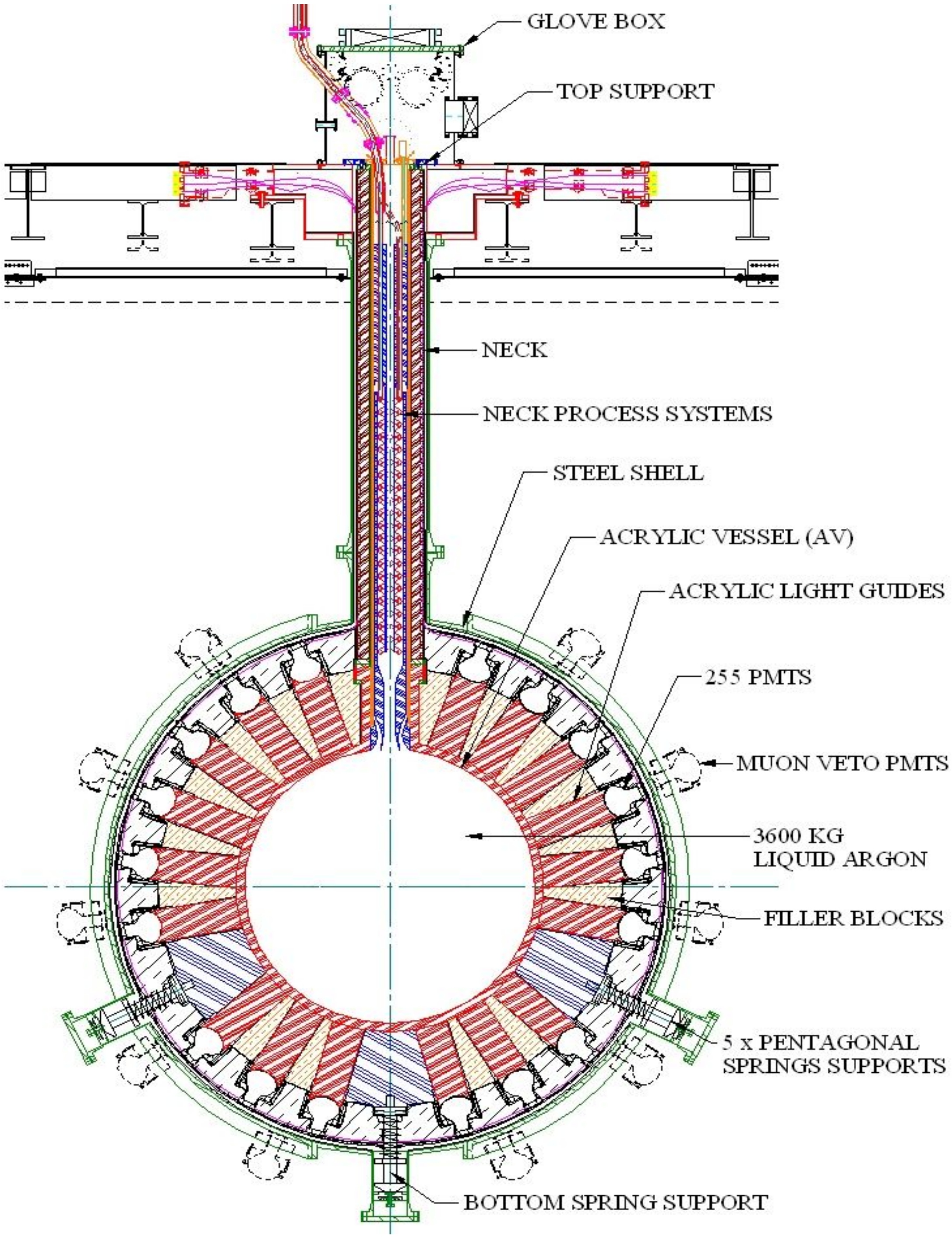
- (α,n) neutrons from U/Th underground
- $^{39}K(n,p)^{39}Ar$

Site in Colorado developed for extraction, in support of both DarkSide and DEAP-3600 (4 tonnes to be produced for DEAP-3600)

Several tonnes of low-radioactivity argon per day are being extracted along with CO_2; Princeton currently separating on the order of kg/day from the stream

Would need to scale up to order 100 kg/day for proposed detector, significant effort

DEAP-3600 Detector



3600 kg argon target
(1000 kg fiducial)
in sealed ultraclean
Acrylic Vessel

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

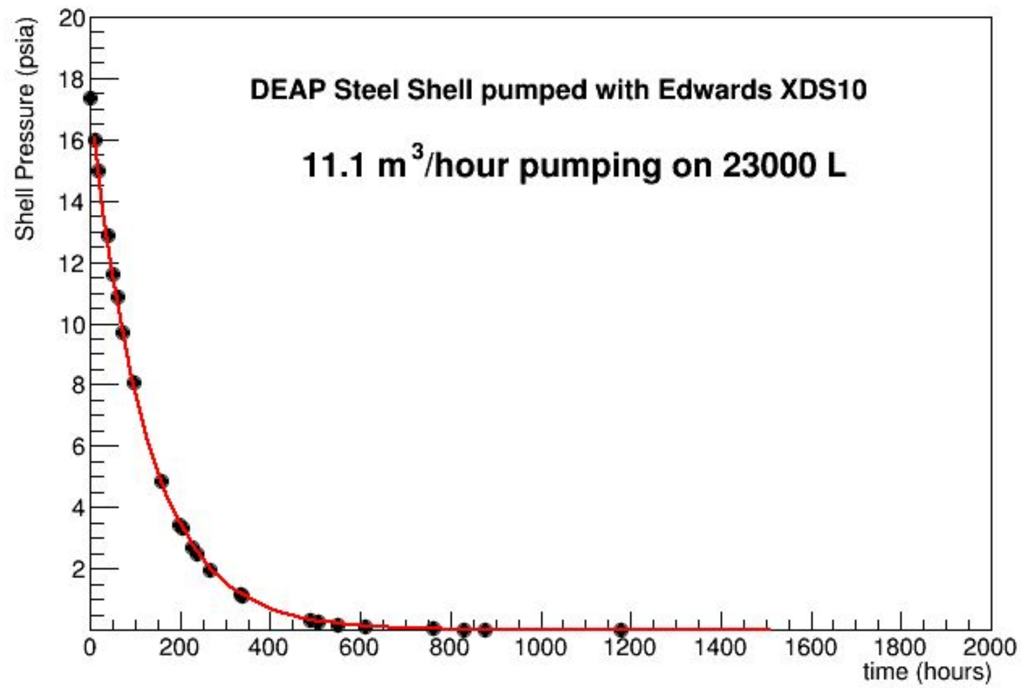
255 Hamamatsu
R5912 HQE PMTs 8-inch
(32% QE, 75% coverage)

50 cm light guides +
PE shielding provide
neutron moderation

Detector in 8 m water
shield at SNOLAB

Top and Bottom Steel Shell Hemispheres in SNOLAB Cube Hall (Dec. 2012)

Steel Shell Installation and Vacuum Testing



Steel Shell in final installation position, hanging from deck

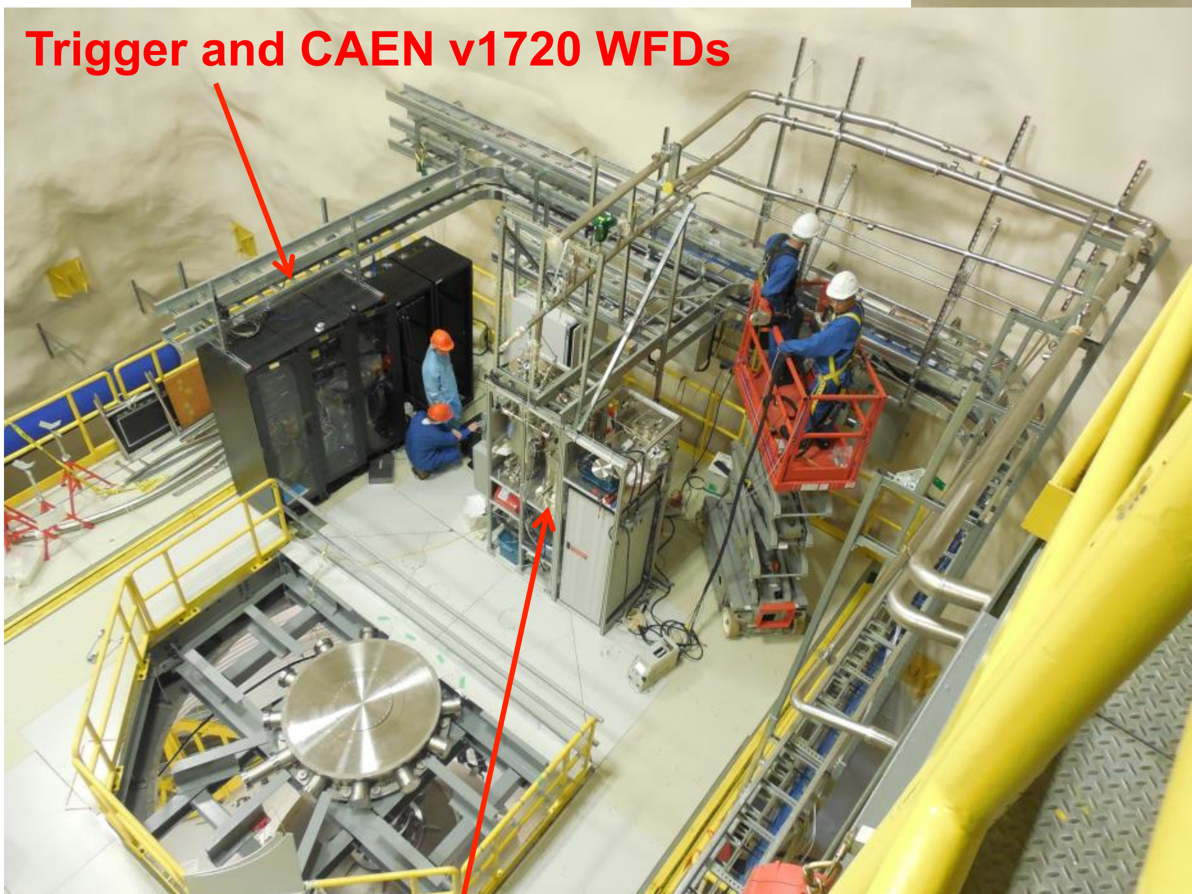

JM
Johns Manville
CAUTION

Preparing Stirling Coolers for System Commissioning (July 2013)

Electronics, Trigger, Purification and Cryogenics Installed

3500L LN_2 dewar with 3KW cryocoolers, for cooling argon

Trigger and CAEN v1720 WFDs



150 LPM purification system (ultralow radon) and Rn scrubber

3000 LAr dewar for target storage

DEAP-3600 Background Budget (3 year run)

Background	Raw No. Events in Energy ROI	Fiducial No. Events in Energy ROI
Neutrons	30	<0.2
Surface α's	150	<0.2
^{39}Ar β's (natural argon)	1.6×10^{9}	<0.2
^{39}Ar β's (depleted argon)	8.0×10^{7}	<0.01

Neutrons: Acr+H_2O shield

Surface α's: Resurfacer

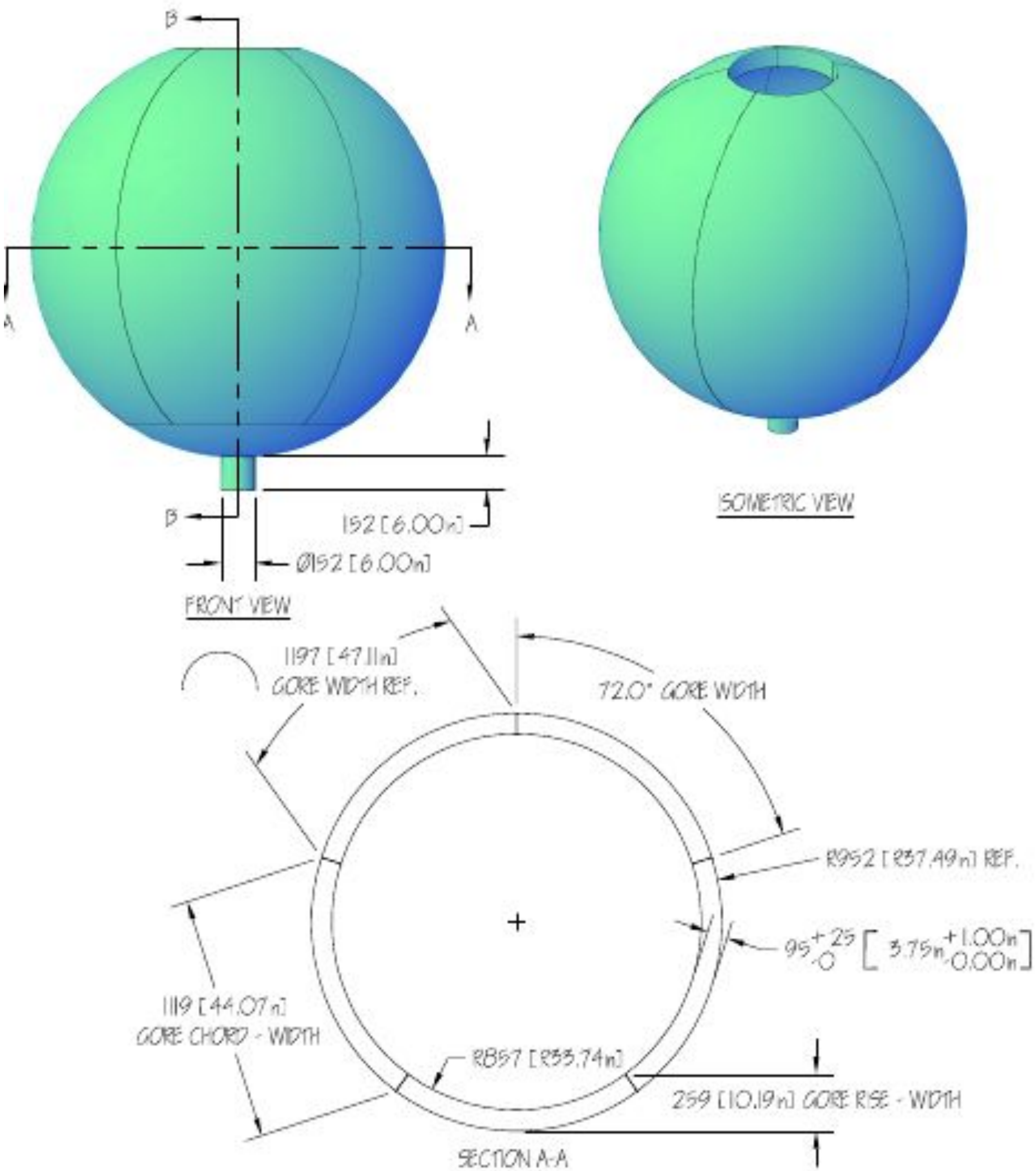
^{39}Ar β's: PSD

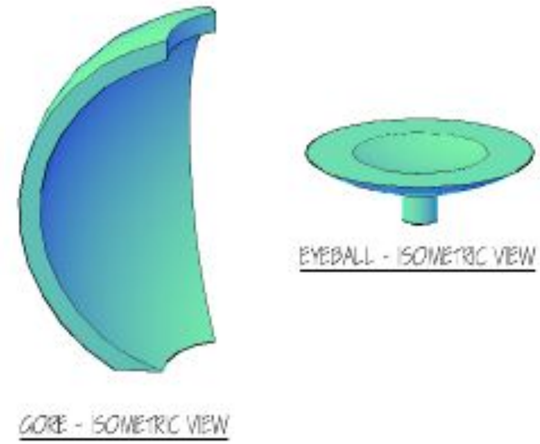
Surface α's → Need to resurface inner vessel and ensure purity of acrylic.

- removal of 1 mm acrylic
- $^{210}Pb < 1.1 \times 10^{-19}$ g/g for 0.1 events/3 years (strict control of Rn exposure)

Mark Boulay, Queen's

DEAP-3600 Acrylic Vessel Construction





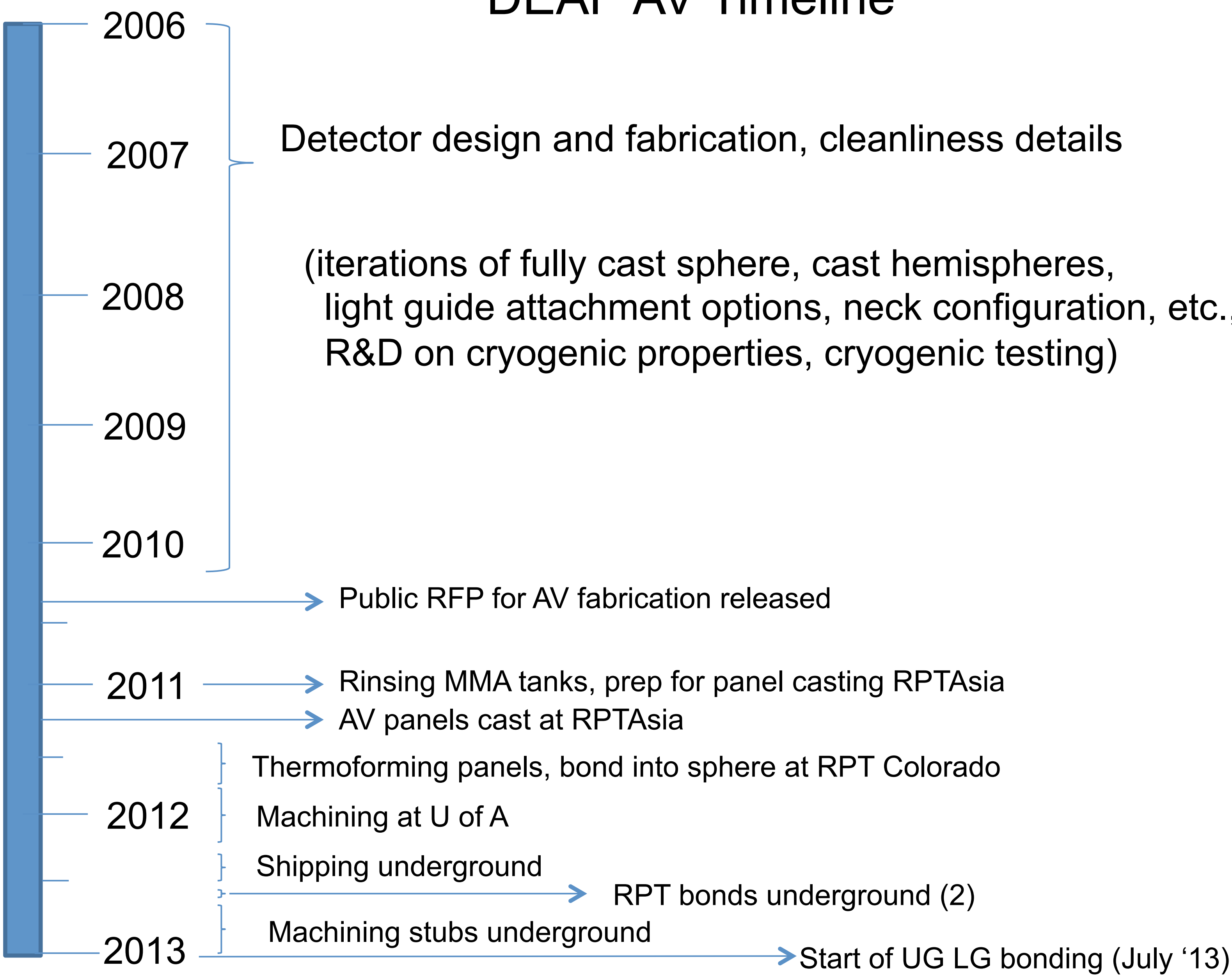
Thermoform 4”-thick panels cast from pure MMA monomer
(too much Rn in polymer beads)
Test thermoforming Nov 29, 2011
Panels to RPT December 2011

Bond into sphere
(Reynolds Polymer Tech.)

Machine with light guide ‘stubs’

Bond light guides UG at SNOLAB

DEAP AV Timeline



Production of Panels for AV Sphere

<u>MMA at ThaiMMA</u>

Production: 12 t/hr with 15m^3/hr air

+ 1.25 units contamination

Watched loading of truck

+ 1 unit contamination

<u>Receiving at RPT Asia</u>

PE lined hose.

All fittings carefully cleaned

+1 unit contamination

A(^{222}Rn) = 6.3 +/- 3.5 Bq/m^3

Mould Preparation

- Moulds are prepped in a HEPA-filtered clean room made especially for DEAP.
- Glass sheets with nylon dams.

Expected ^{210}Pb Loads

	AV Shell	Light Guides
	Thai MMA	Lucite
Distillation [cont. units]	1.25	0.09
Storage [cont. units]	0	1..500
Truck [cont. units]	1	1
A(^{222}Rn) [mBq/m^3]	3.5	10 (est.)
Expected ^{210}Pb [mBq/tonne]	9.25	10 - 500
	RPT Asia	Spartech
MMA Storage tank [cont. units]	1	1
Reactor Vessel [cont. units]	0.5	0.1
Post-reactor storage [cont. units]	1	1
Moulds [cont. units]	1	1
A(^{222}Rn) [mBq/m^3]	6.3 to 10.8	5 (est.)
Expected ^{210}Pb [mBq/tonne]	22.8	5
Total ^{210}Pb [mBq/tonne]	**32 (<8x10^{-21} g/g)**	**15 - 500**

Assay

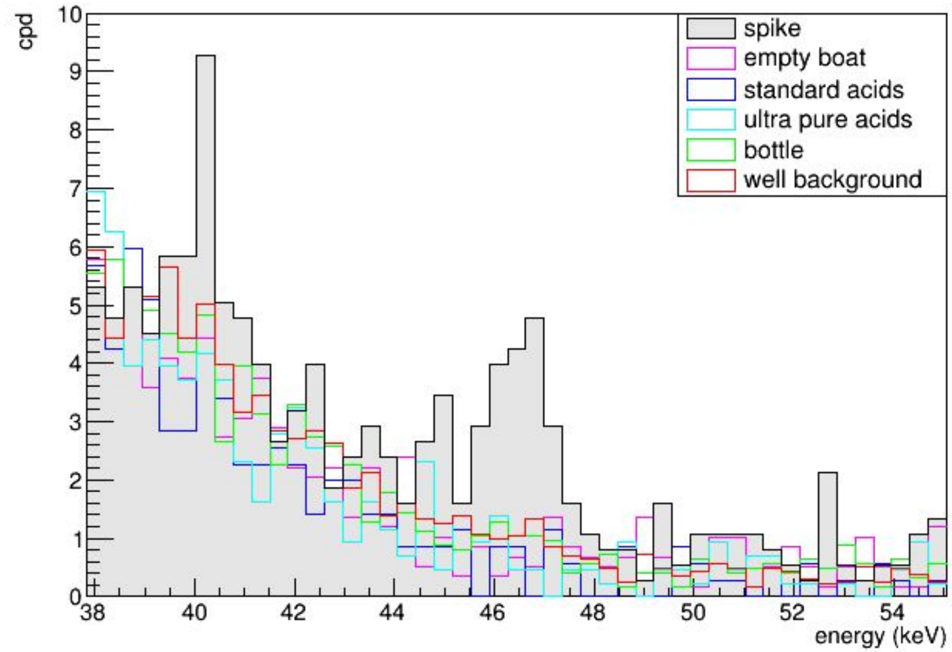
- Want to assay acrylic at levels of 10^{-20} g/g ^{210}Pb
- Requires vapourization to concentrate contaminants followed by chemical extraction followed by counting in a Germanium well detector.

New Furnace and extraction system developed for acrylic assay

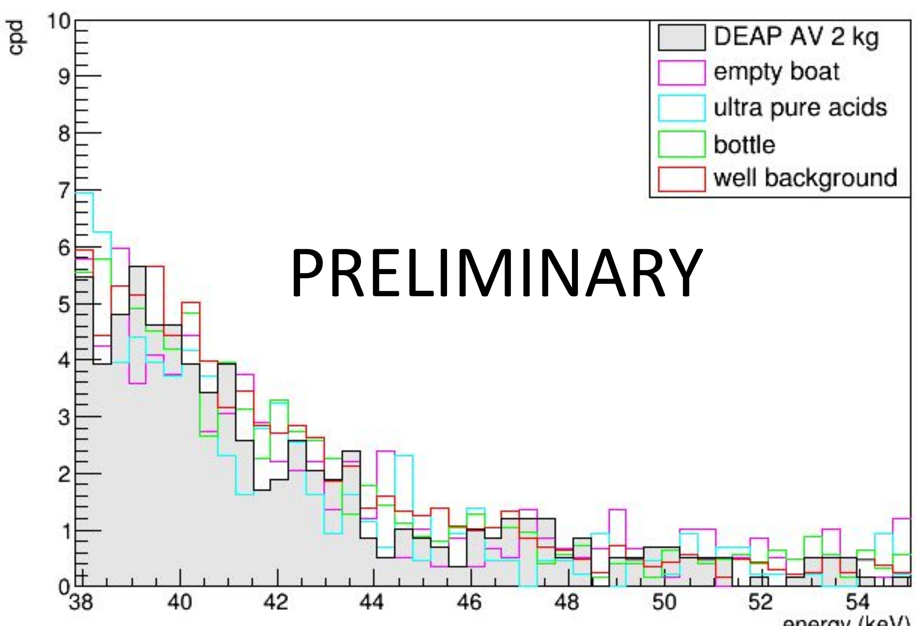
New Ge-well detector purchased/installed UG (~few counts per day for 46 keV line)

Also directly α-count ^{210}Po daughters after depositing on nickel

Spike with ^{222}Rn into acrylic cylinder



DEAP AV acrylic assay and backgrounds



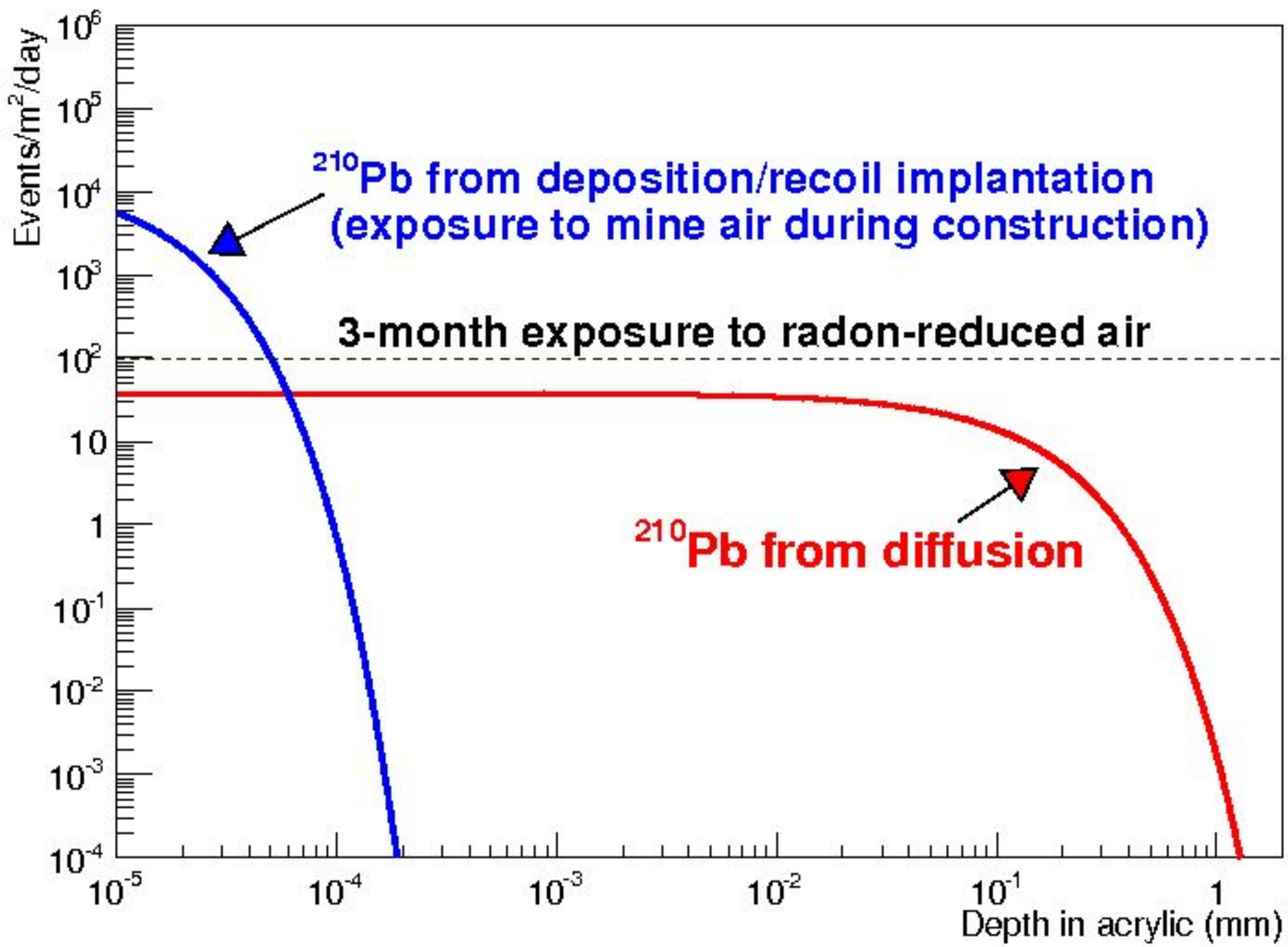
PRELIMINARY assay result:

^{210}Pb : $< 8 \times 10^{-19}$ g/g

Nominal <0.8 bkd events in 3 years

(results from Corina Nantais, M.Sc. thesis work)

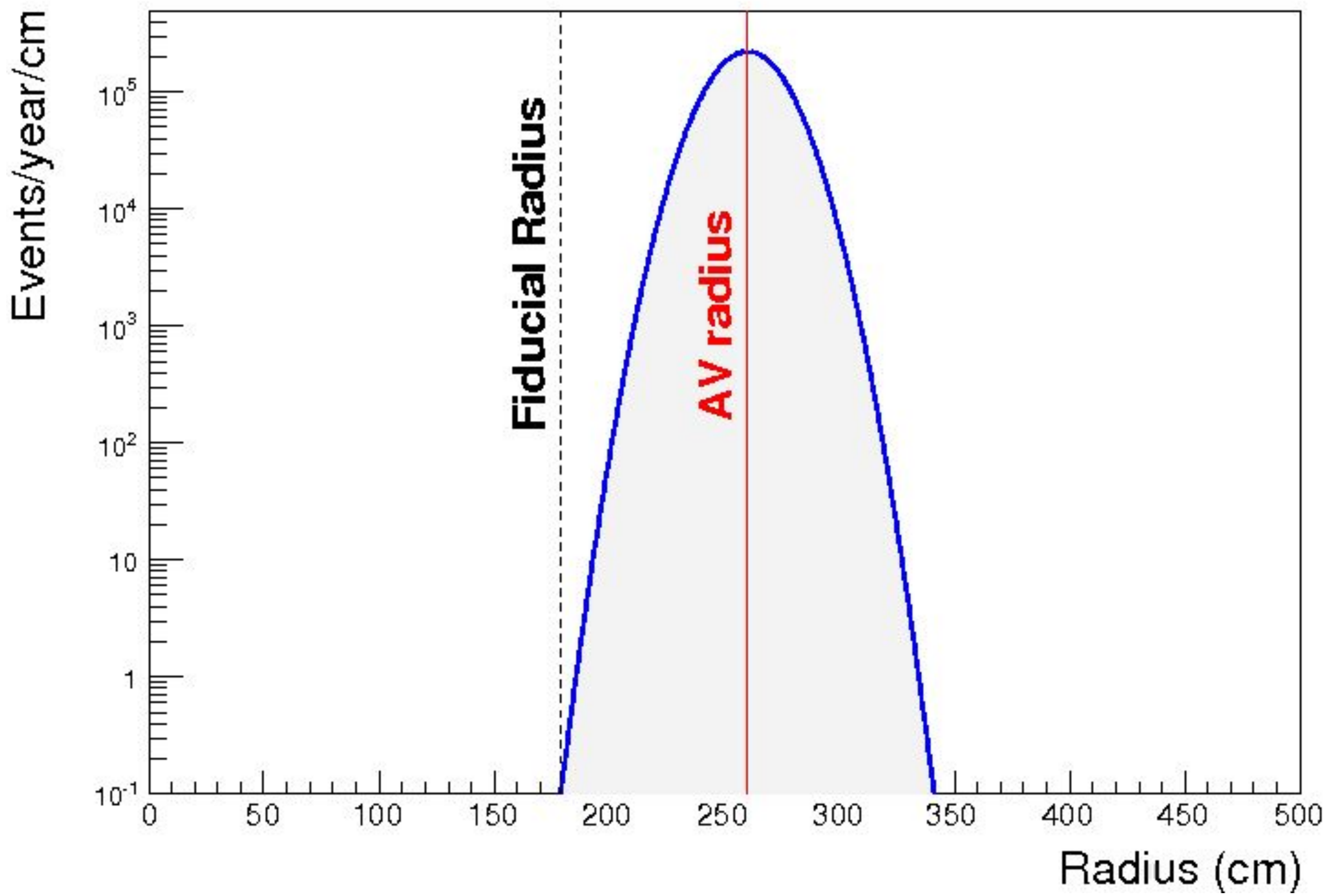
^{210}Pb distribution in acrylic from deposition, diffusion after acrylic casting



DEAP-3600 "small" enough that we need to remove 1 mm to get to target level

50-tonne detector only needs deposited radon removed

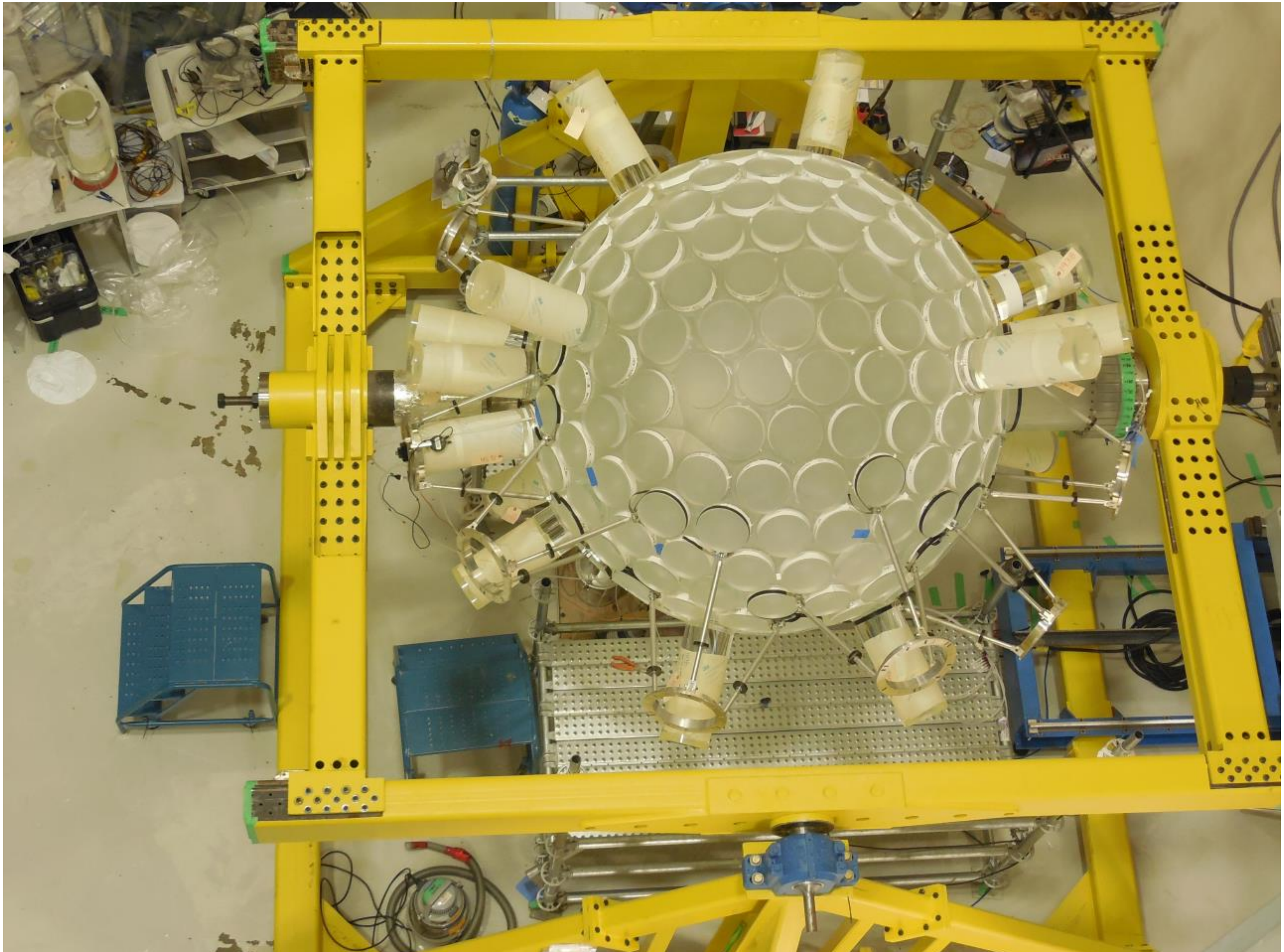
“Toy” calculation estimating backgrounds in 50-tonne detector, deposited radon (only) removed



Setup for AV Neck Bond (Reynolds Polymer, Tech. at SNOLAB Jan 2013)

Automated Light Guide bonding system setup

Light Guide Bonding onto Acrylic Vessel



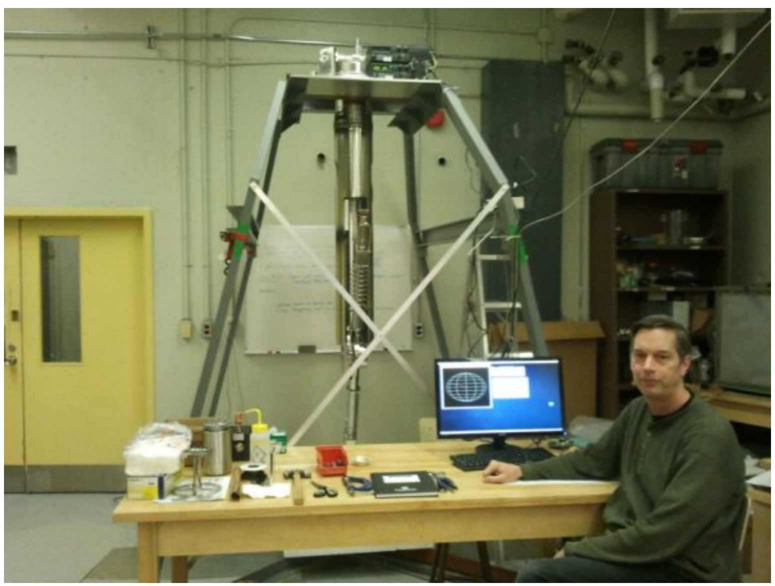
Acrylic Vessel Resurfacer

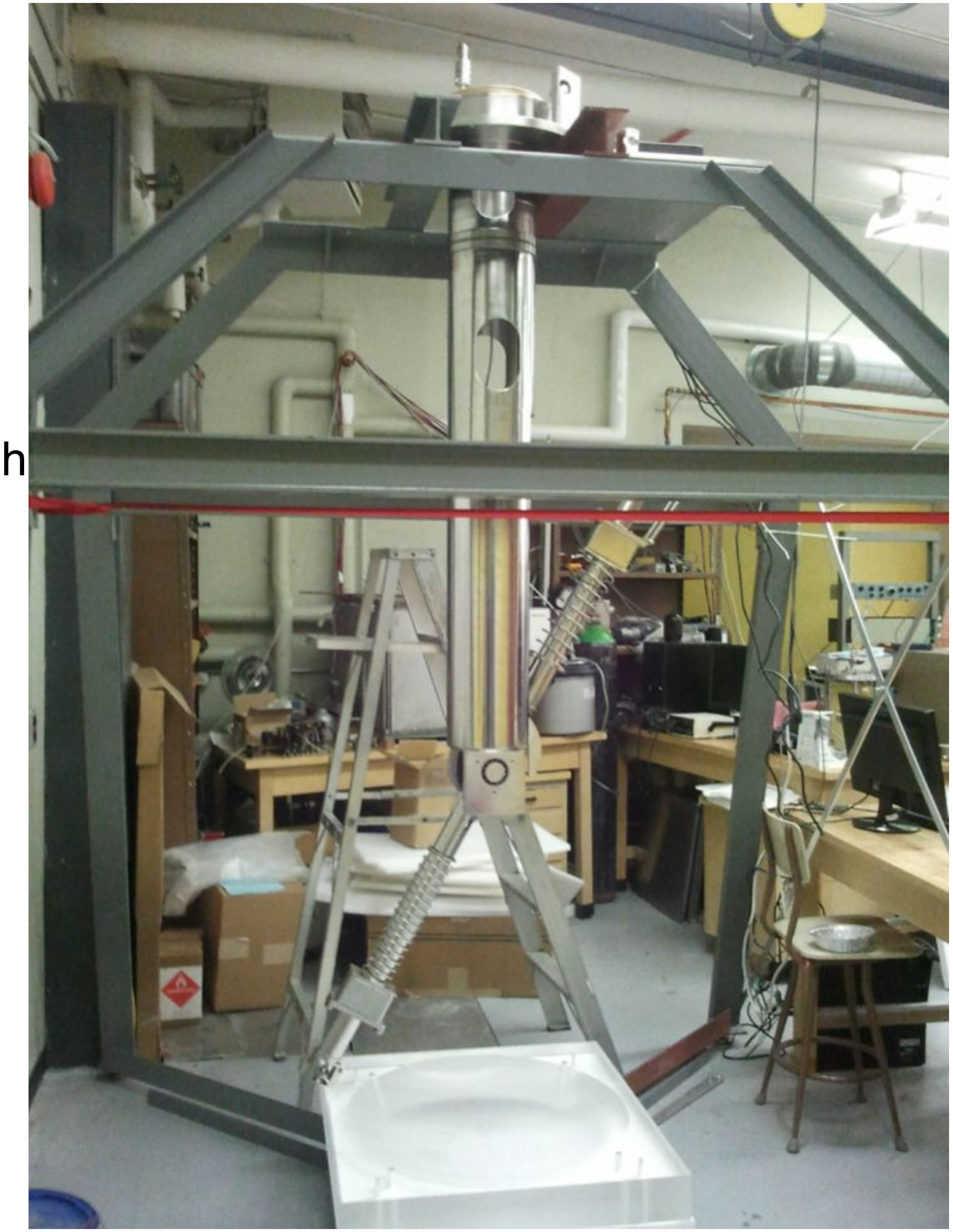
Assembled and Tested at Queen's for ~18 months

All components low-Rn emanation

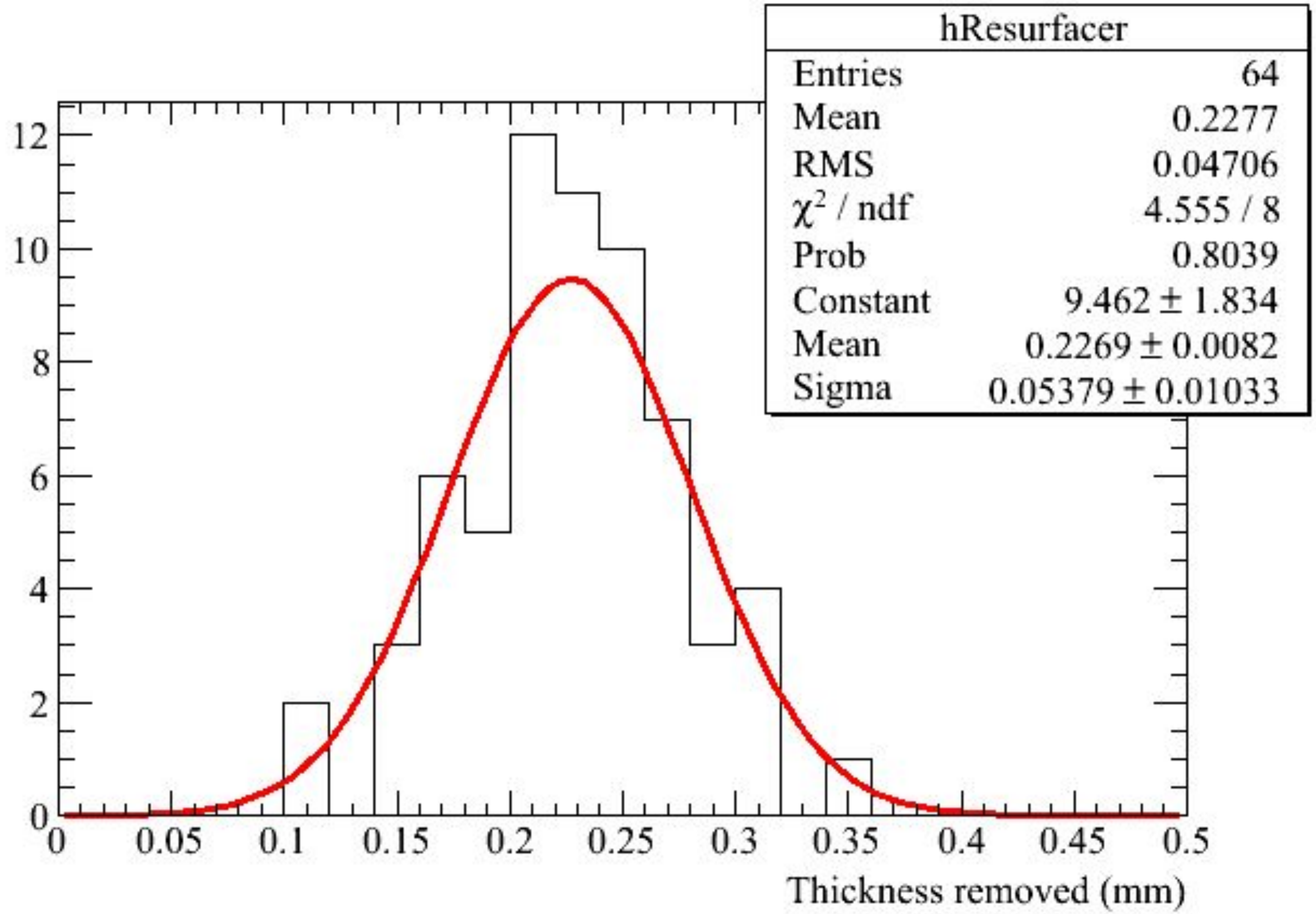
Removes 1 mm of acrylic surface after acrylic vessel installed and sealed, flush with UPW and extract residue

Removes implanted and diffused radon daughters





Acrylic removal and uniformity, 60 hours resurfacer running (tests at Queen's)



24% uniformity (meets specification)

“Status of Progenitor Systems”

~5 years running DEAP-1 (7-kg scale)

PSD 10^{-8}

Radon purification system, achieved ~15 μBq/kg ^{222}Rn

Expertise with backgrounds in argon, low-radon systems

Physics emphasis was DEAP-3600, no fiducialization in DEAP-1

DEAP-3600

First tonne-scale dark matter experiment, construction nearing completion

Will have world-leading sensitivity, 50X current

Demonstrated “clean” acrylic fabrication, in particular ^{210}Pb

Anticipate first results (from 3600) before full-scale proposal demonstrating technique

Significant experience with large-scale project management, design, construction, reviews, etc.

Preliminary project budget (not including DAr)

Component	M$ CAD	Comments
AV	5	Estimate for 2” thick vessel with flange
Acrylic shield	2.2	180 4x8’ sheets, cost from DEAP
Support and Deck	1.5	Estimated from DEAP
PMTs	12.9	Scaled from DEAP
Electronics	12.4	Scaled from DEAP
Steel Shells	3.4	Scaled from DEAP
Water shield	0.95	Scaled from DEAP
Cryogenics/Storage	5.5	
Purification	3	Scaled from DEAP,X2
Slow Control	0.5	Scaled from DEAP,X4
Calibration	2	
RRA Cleanroom	1	
DAr delivery	2.5	
Project Management/Admin	6	
Installation Labour	1.8	50K/month x 36
Installation costs	1.8	50K/month x 36
Engineering design	3	5x125K/year x 5 years
Preliminary engineering for safety, costing	0.06	Requesting from SNOLAB
Total	**65**	

Collaboration

Project will require significant collaboration (40+ faculty?)

17 faculty currently joined LOI
(14 in Canada, 3 UK)

Significant interest from additional groups, discussions underway (Berkeley, Penn, McMaster) and additional interest from existing groups

Expect to grow collaboration significantly after first DEAP-3600 results / demonstration of single-phase argon

Letter of Interest - Development of a 50-Tonne Next-Generation Liquid Argon Detector at SNOLAB

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SNOLAB and Laurentian University

J. Monroe, J. Nikkel, and J. Walding

Department of Physics, Royal Holloway, University of London

S. Peeters

Department of Physics, University of Sussex

August 6, 2013

Tentative Project Schedule

2013,2014:

Conceptual design/safety analysis, develop budget
Identify space requirements, submit space request
and development requests
(Start DEAP-3600 Data collection, focus of effort)

2014,2015:

More detailed engineering for budgeting
Design/plans for depleted argon storage and delivery

2015-2017:

Detailed engineering for contracts/fabrication
Implementation of DAr storage and argon collection start

2017-2020:

Construction and Installation
Continued DAr collection/storage
(End DEAP-3600 Data collection)

2020-2025:

Operation

Outstanding R&D/Development

Demonstrated cleanliness of acrylic, could
design and go out for bids for AV, Steel Shell, Shield tank, Purification
and cooling systems, etc. once
conceptual design is completed (commercial bids, no R&D)

Require safety/siting analysis to understand feasibility and requirements

Planning R&D on SiPM vs PMTs, ongoing at TRIUMF during next year
Need to develop plan/technique for WLS coating
Need detailed MC and backgrounds budget
Need to further pursue delivery and storage of large quantity of DAr

Requesting from SNOLAB order 9 months engineering at 30% effort
(2 x 0.3 FTE for 9 months) to allow us to develop additional funding requests

and space allocation request.

END