DEAP-3600 Dark Matter Search With Argon

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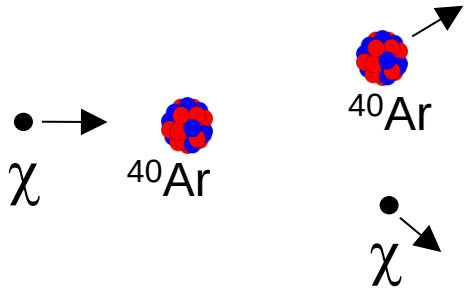
on behalf of the
DEAP Collaboration

TAUP 2013 Asilomar

Liquid Argon as a Scintillation Detector for Dark Matter



Scattered nucleus (with several 10's of keV) is detected via scintillation in liquid argon

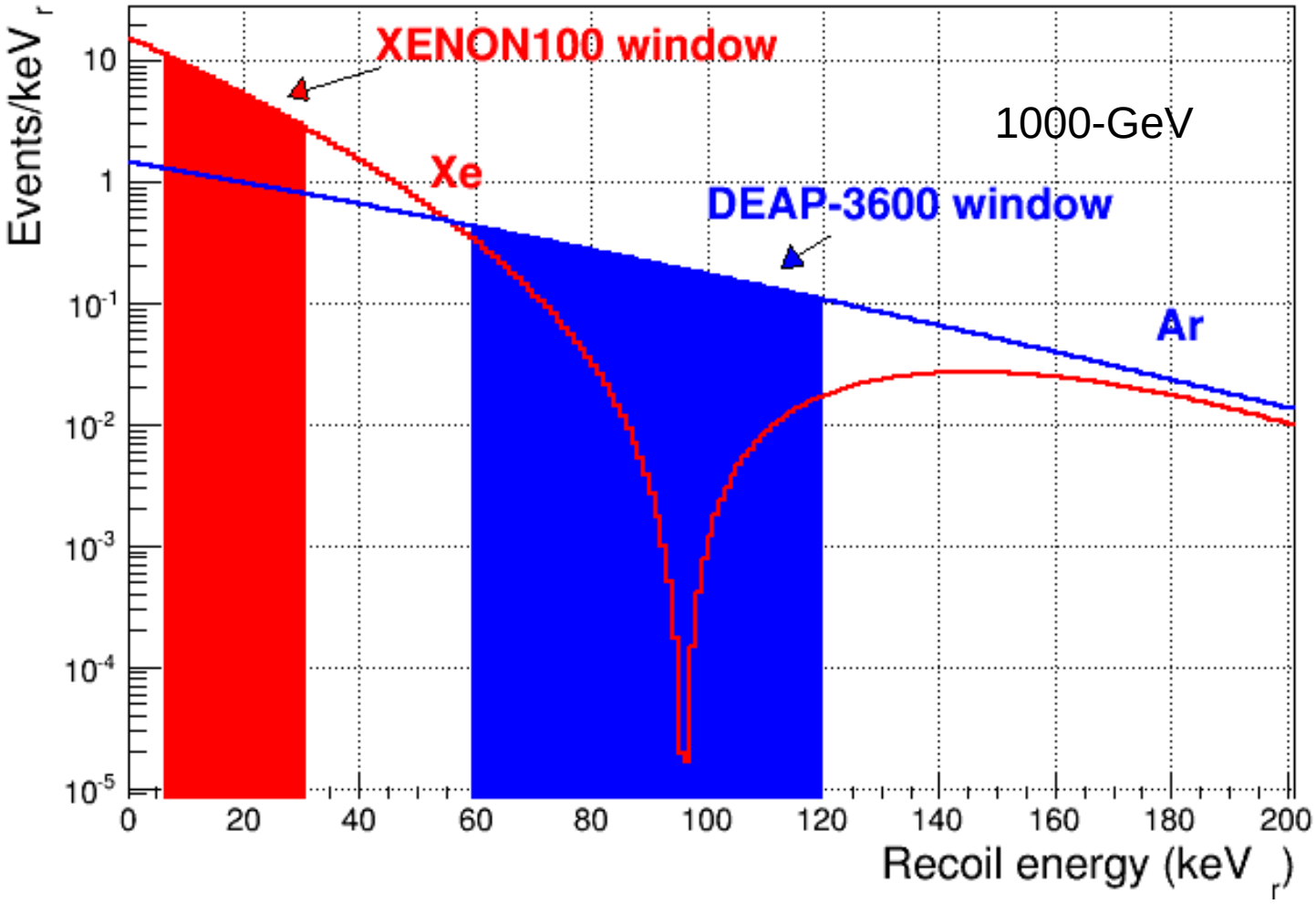
•Well-separated singlet and triplet lifetimes in argon allow good pulse-shape discrimination (PSD) of β/γ's using only scintillation time, projected to 10^{-10} at 15 keV_{ee}
(see Astroparticle Physics 25, 179 (2006) and arxiv/0904.2930)
(Removes β's from ^{39}Ar through to solar neutrino scatters)

•Position reconstruction allows removal of surface events

•Very large target masses possible, since no absorption of UV scintillation photons in argon, and no e-drift requirements (1 tonne to ~hundreds of tonnes)

•**1000 kg** argon target allows **10^{-46} cm^2** sensitivity (SI) for 100-GeV mass WIMP (3 year run)

Xenon and argon for direct WIMP scattering



- Potential for very large and very sensitive searches
- Complementary

DEAP-3600 will be sensitive to much of the remaining SUSY parameter space for the simplest models, similar sensitivity to XENON-1T for high-mass WIMPs

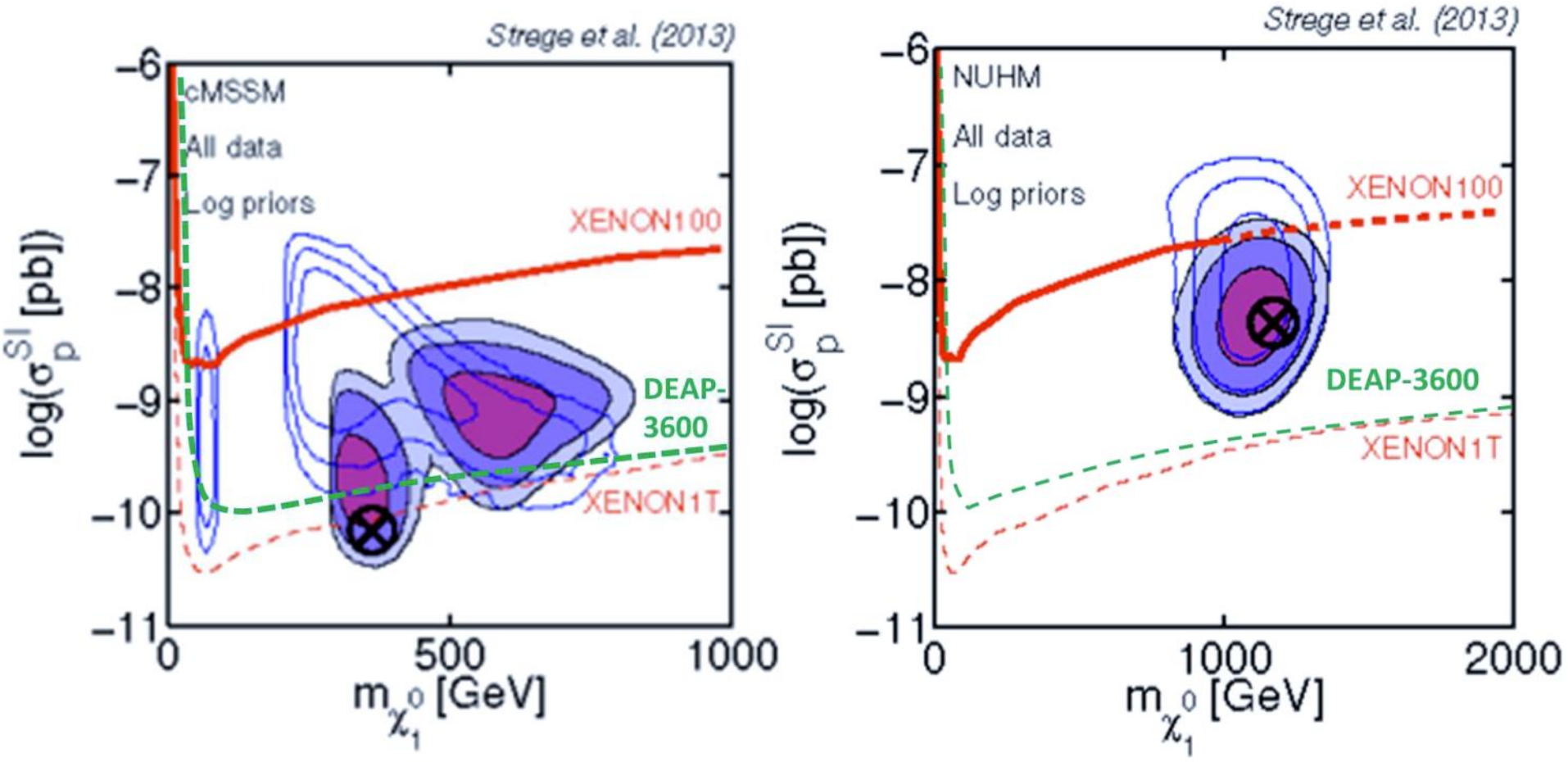


Figure adapted from C. Strege et al., JCAP04(2013)013

DEAP-3600 Background Budget (3 year run)

Background	Raw No. Events in Energy ROI	Fiducial No. Events in Energy ROI	
Neutrons	30	<0.2	Acr+H_2O shield
Surface α's (^{210}Po)	150	<0.2	Resurfacer
^{39}Ar β's (nat. argon)	1.6x10^{9}	<0.2	PSD
^{39}Ar (depleted Ar)	8.0x10^{7}	<0.01	
Total		**<0.6**	

Need to resurface inner vessel and ensure purity of acrylic.

- removal of 1 mm acrylic
- ^{210}Pb < 1.1x10^{-19} g/g for 0.1 events/3 years
  (strict control of Rn exposure)

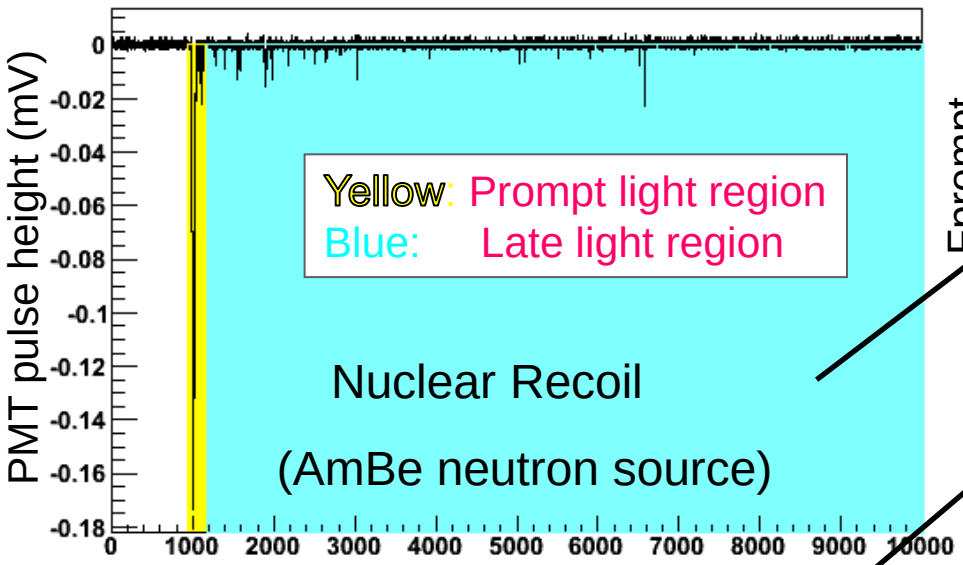
All materials have been assayed/controlled (2007-2013)

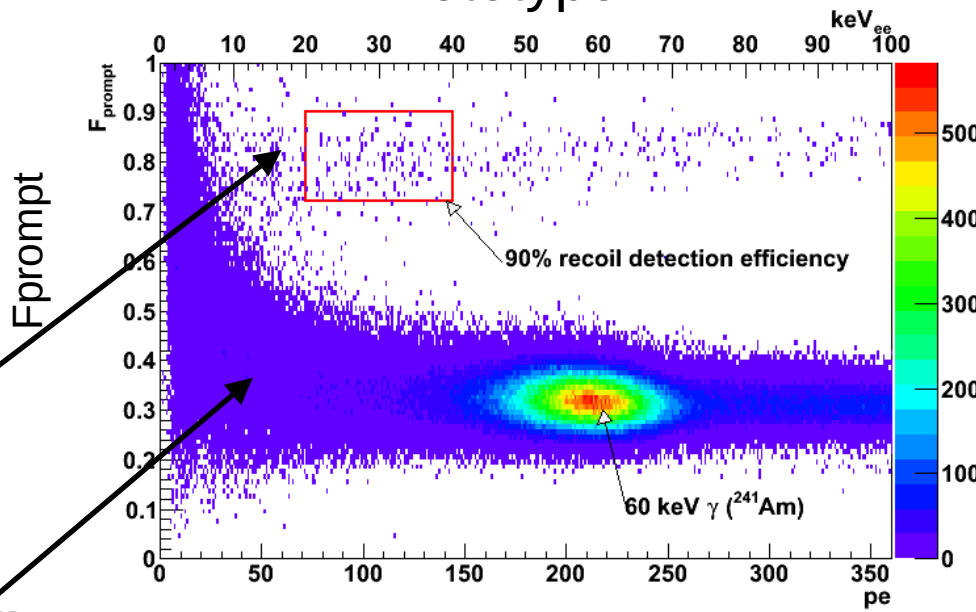
DEAP-3600 Design Parameters and Background Target Levels

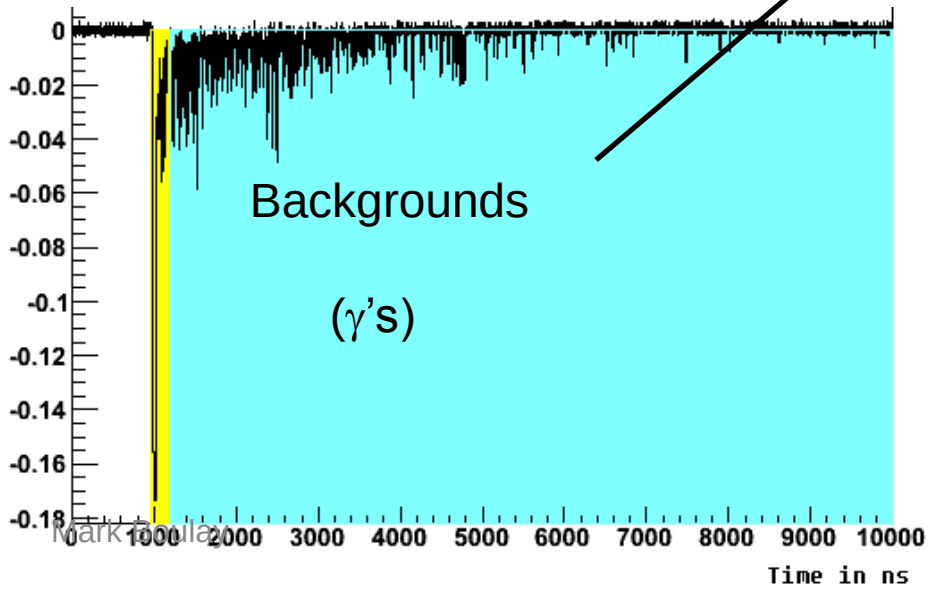
Parameter	Value
Light Yield	8 photoelectrons per keV_{ee}
Nuclear Quenching Factor	0.25
Analysis Threshold	15 keV_{ee}, 60 keV_r
Total Argon Mass (Radius)	3600 kg
Fiducial Mass (Radius)	1000 kg
Position Resolution at threshold (conservative, design spec)	10 cm
Position Resolution at threshold (ML fitter)	5 cm
Background	**Target**
Radon in argon	< 1.4 nBq/kg
Surface α's (tolerance using conservative pos. resolution)	< 0.2 $\mu Bq/m^2$
Surface α's (tolerance using ML position resolution)	< 100 $\mu Bq/m^2$
Neutrons (all sources, in fiducial volume)	< 2 pBq/kg
Bg events, dominated by ^{39}Ar	< 2 pBq/kg
Total Backgrounds	**< 0.6 events in 3 Tonne-y**

arXiv/1203.0604

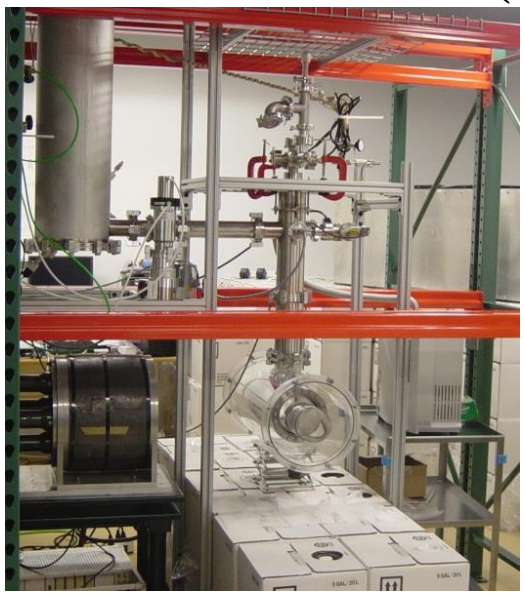
Background suppression with PSD in DEAP-1 Prototype



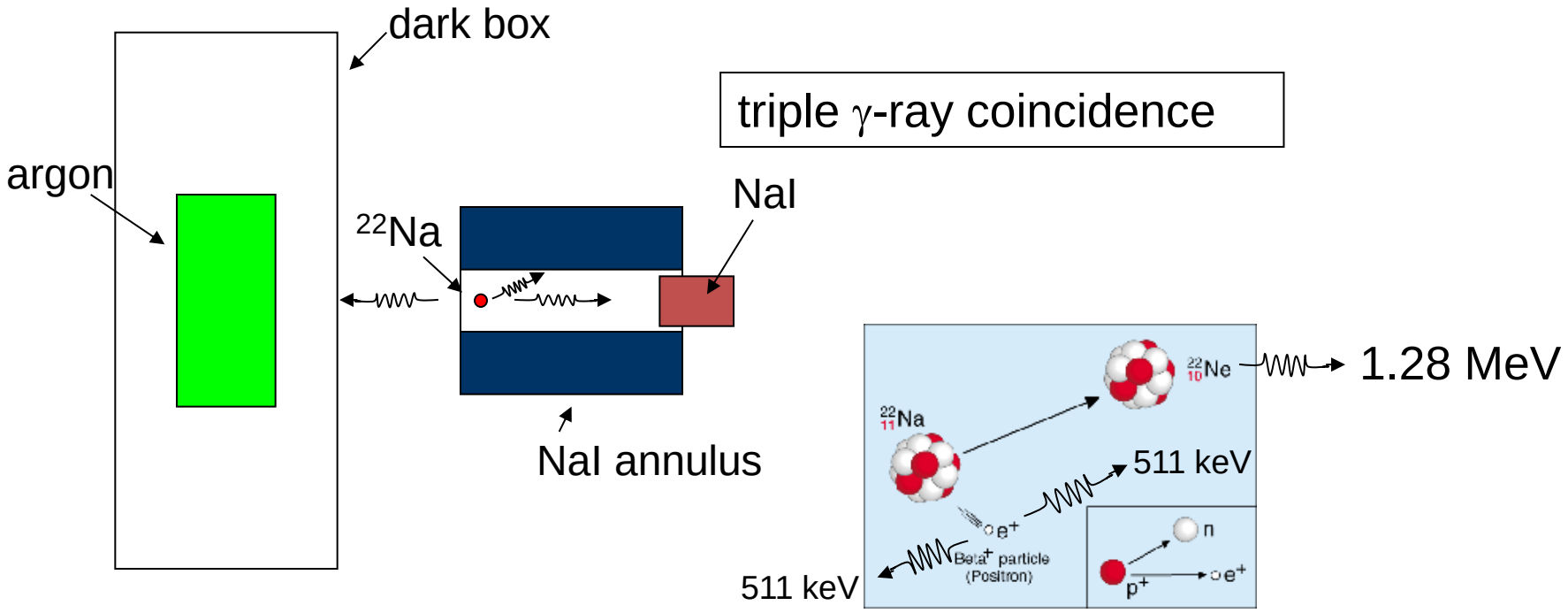




$$F_{prompt} = \frac{PromptPE(150ns)}{TotalPE(9\mu s)}$$

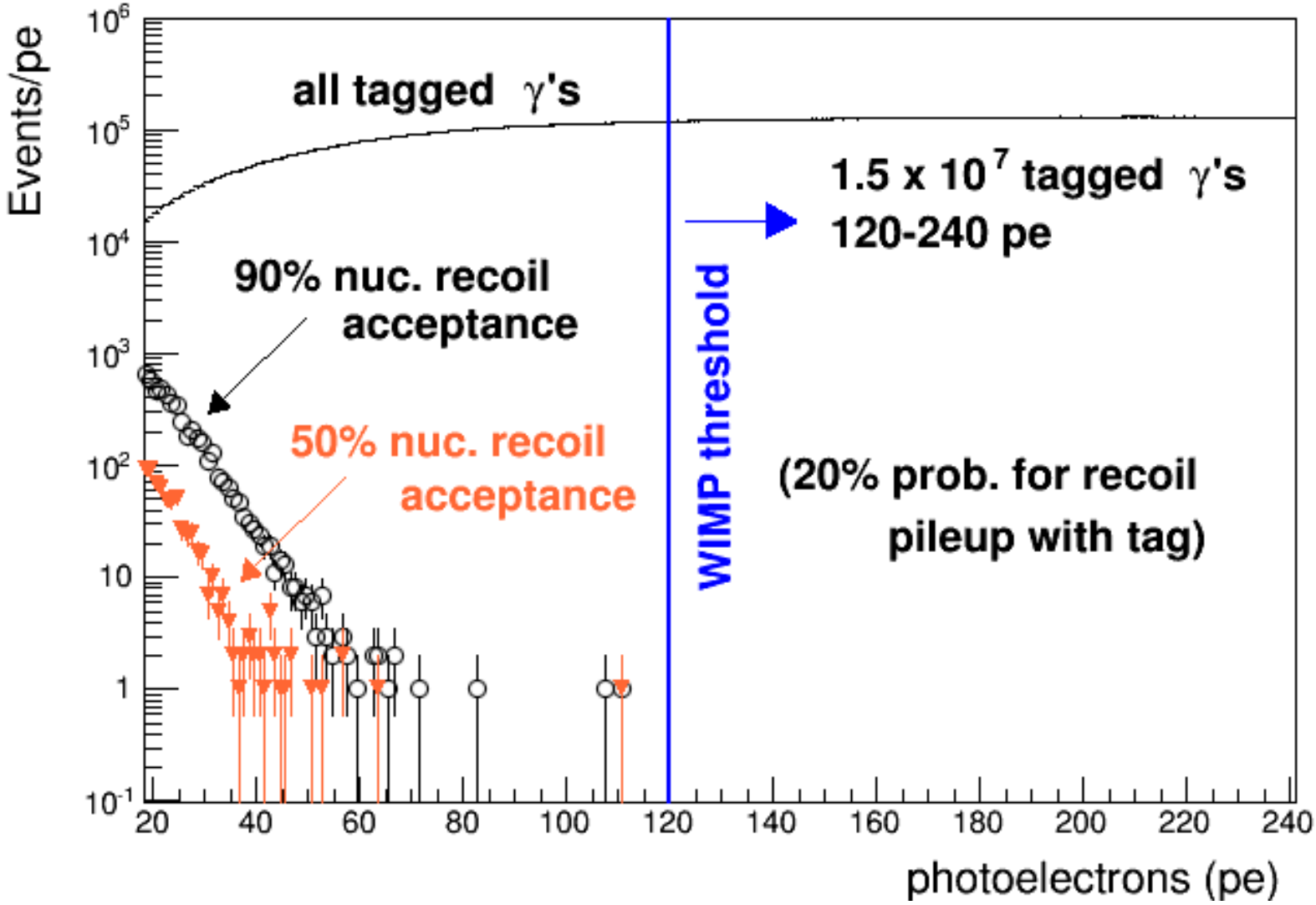


PSD studies with tagged ^{22}Na source in DEAP-1



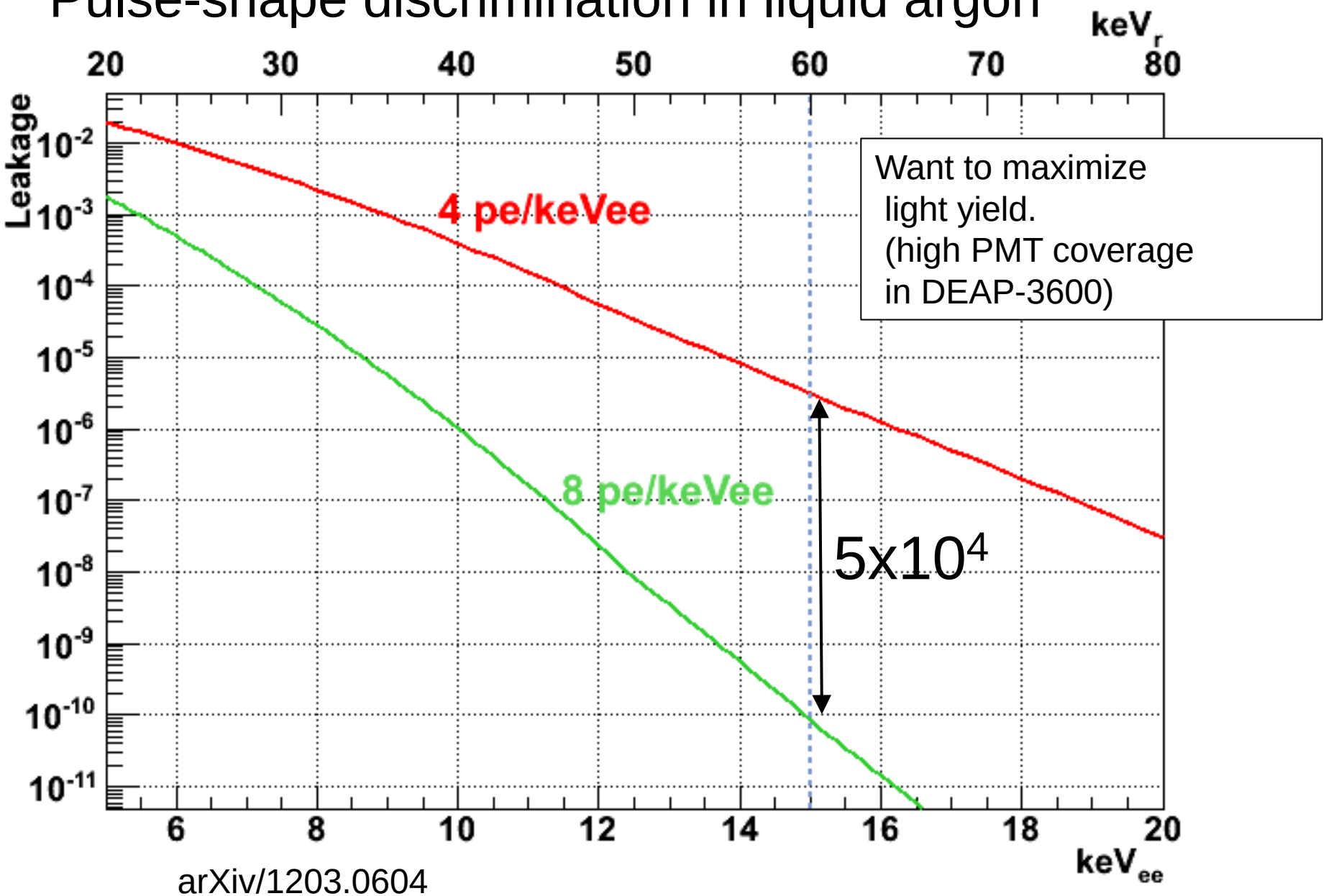
Expect order 10^8 events before random pileup of nuclear recoil backgrounds (in small detector) with tag

PSD with triple-tagged γ's in DEAP-1



run at Queen's, 2.8 pe/keVee

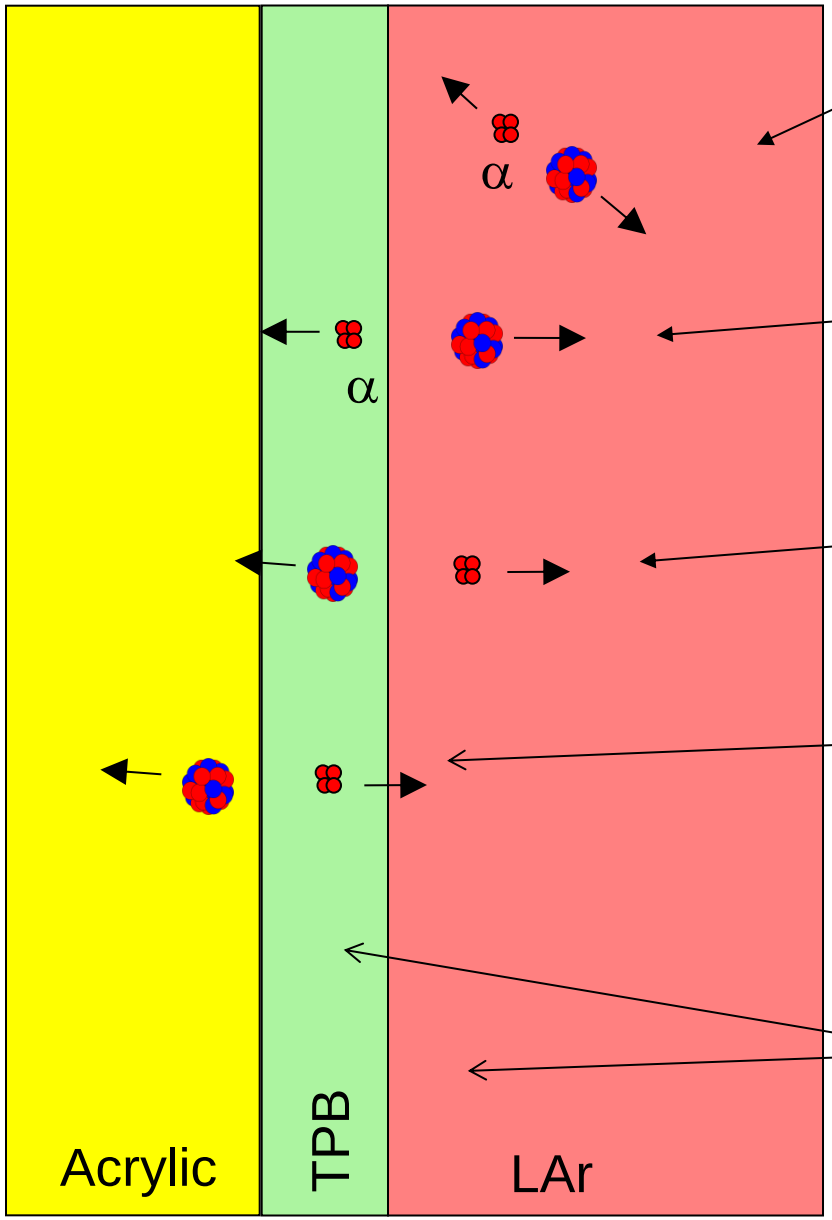
Pulse-shape discrimination in liquid argon



Want to maximize light yield. (high PMT coverage in DEAP-3600)

arXiv/1203.0604

α and Surface Backgrounds in Liquid Argon



Decay in **bulk argon** tagged by α-particle energy

Decay from **TPB surface** releases untagged recoiling nucleus in argon and α in TPB (see both with low energy)

Decay from **TPB surface** releases α in argon and recoil nucleus in TPB (see mostly α-particle, high energy)

Decay from **inside TPB or acrylic** releases α which may also enter LAr. Could see
(a) Light from TPB only (prompt) or
(b) Light from LAr (range of energies)

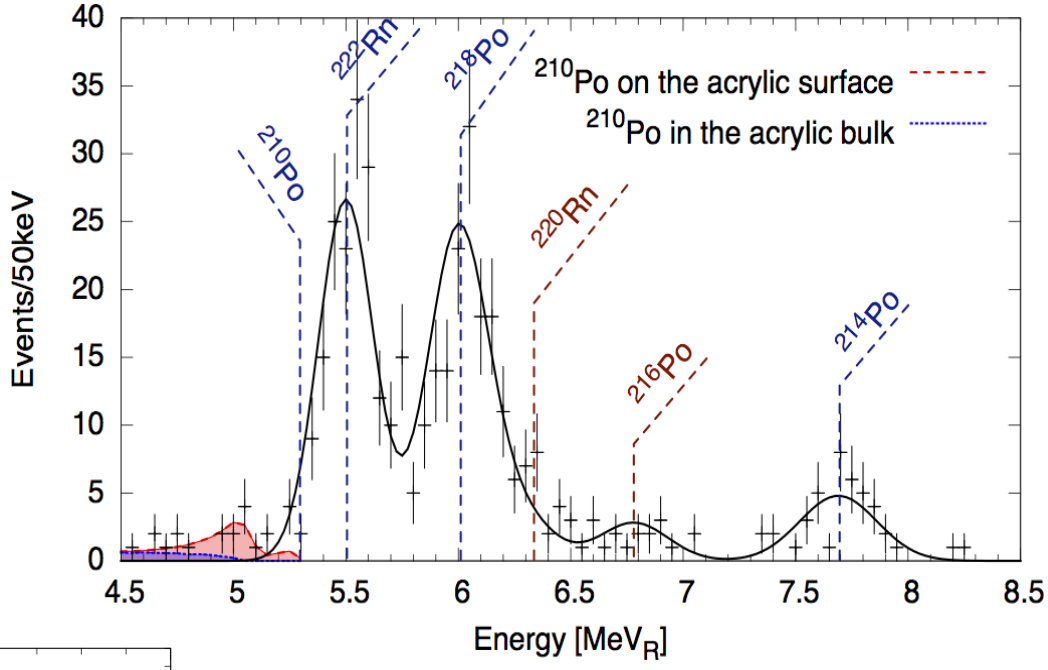
both TPB and LAr scintillate

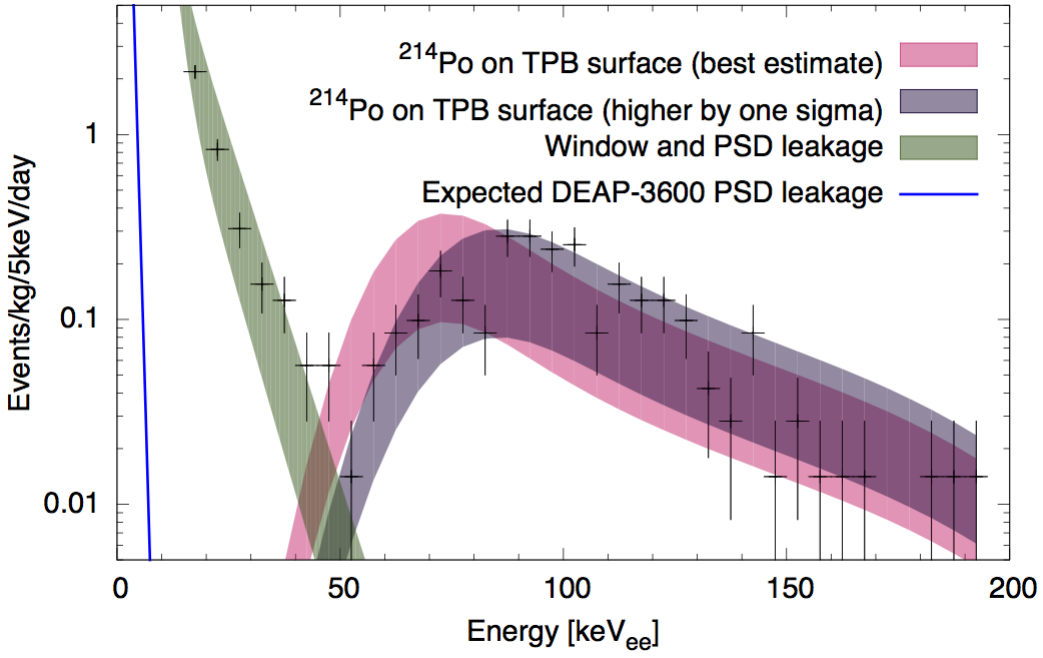
DEAP-1 and DEAP-3600 surface profile

α Backgrounds in LAr (DEAP-1)

High-energy spectrum described by

^{222}Rn (15 μBq/kg) and
^{220}Rn (3 μBq/kg)





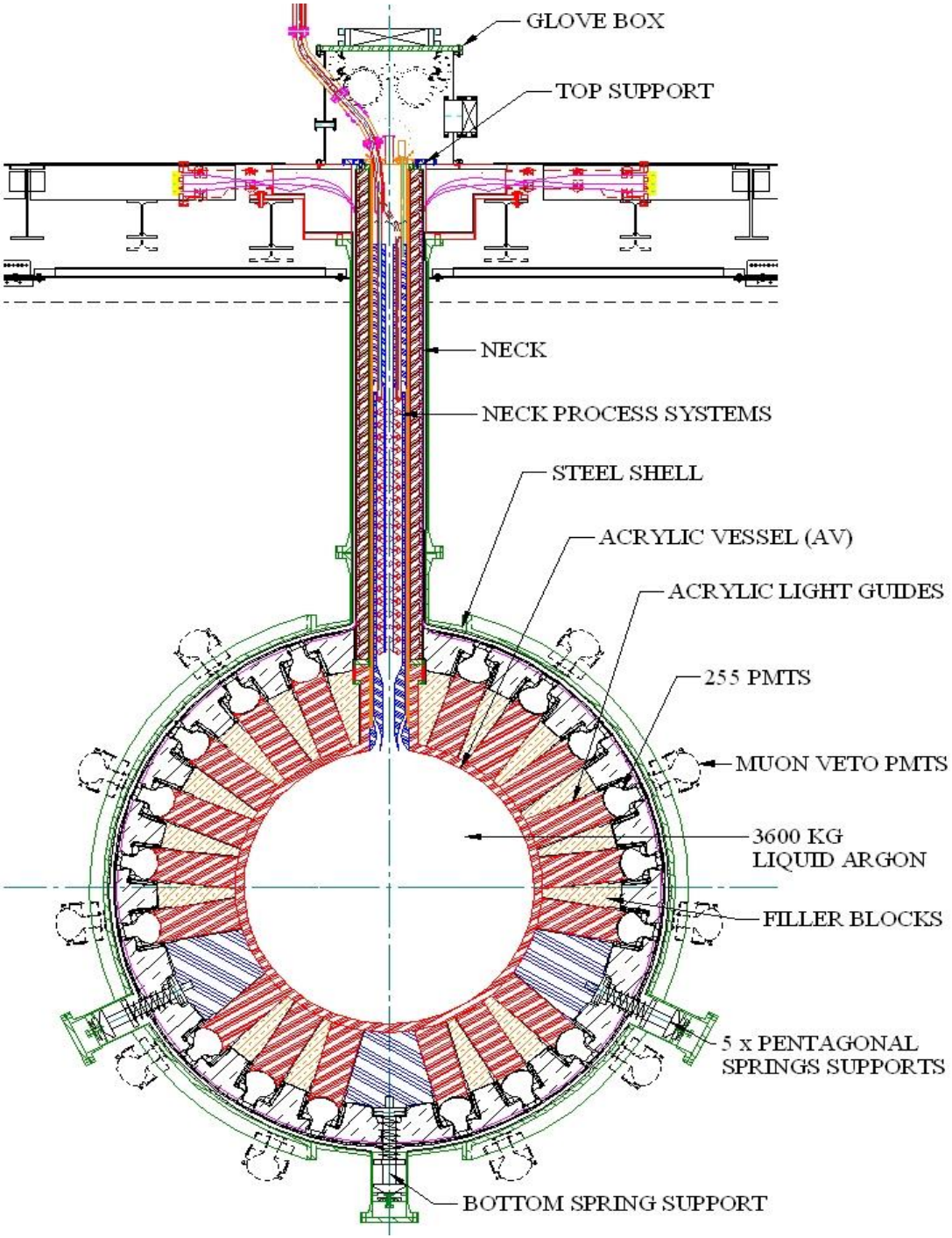
Low-energy peak described by surface events

Expect upper cutoff **above** WIMP window

PSD leakage due to lower light yield (4 pe/keVee)

arXiv:1211.0909 (under revision)

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

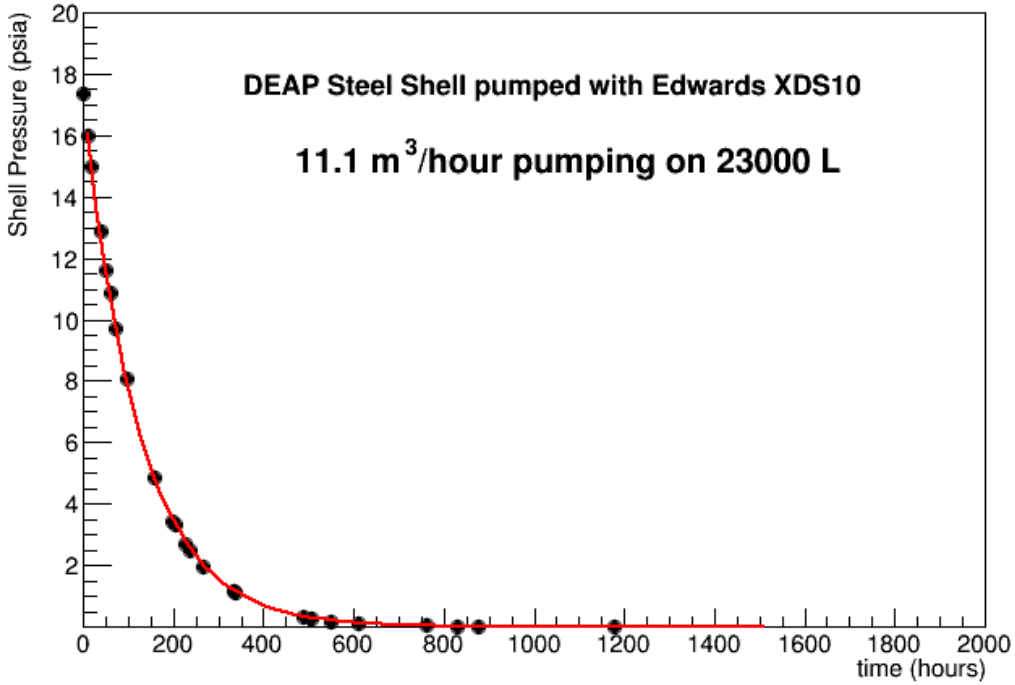
Top and Bottom Steel Shell Hemispheres in SNOLAB Cube Hall (Dec. 2012)
23,000 L vacuum vessel

Cleaning Electropolished “Steel Shell” Vessel

Steel Shell Installation and Vacuum Testing

Steel Shell in final installation position, hanging from deck

"Bag" for helium leak test of large equatorial O-ring seal, welded together underground

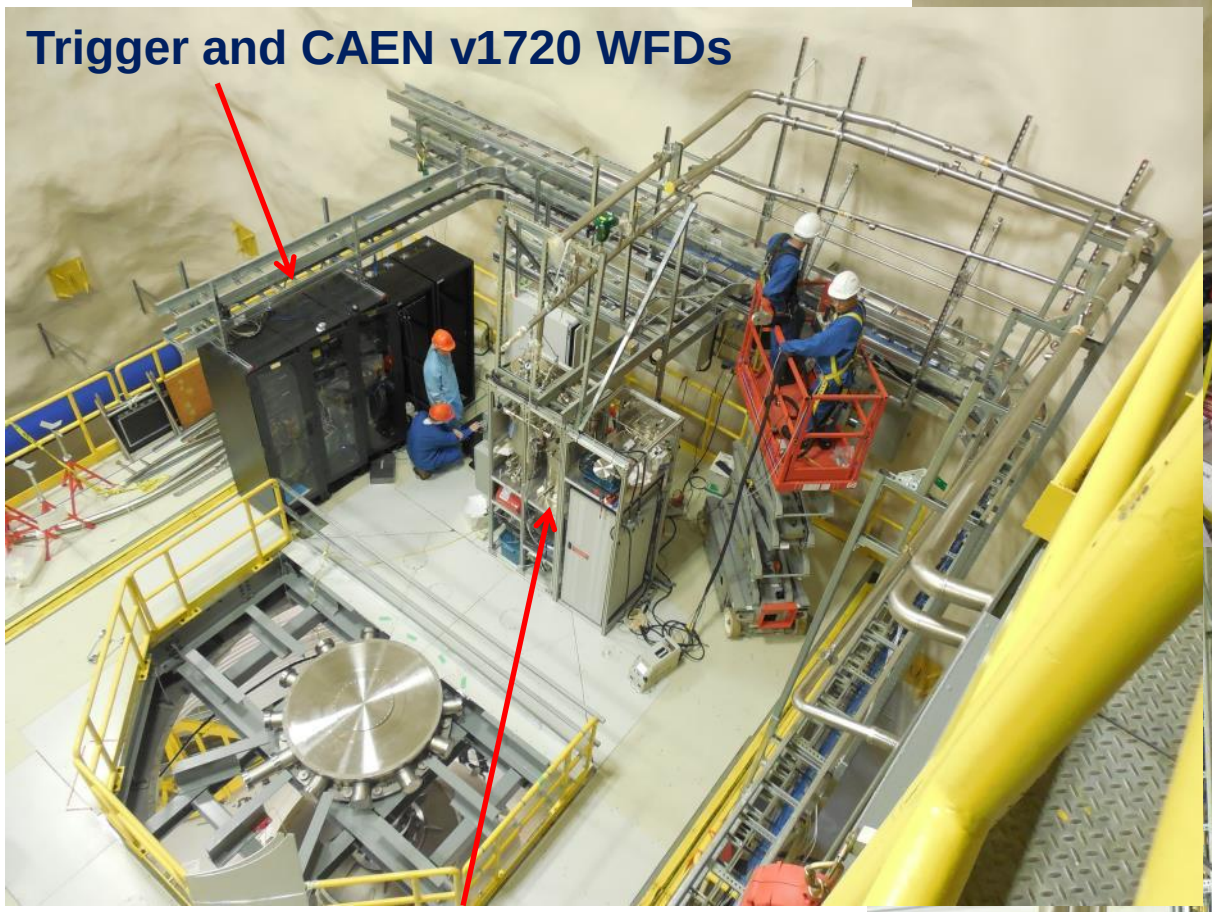


Purification rack on deck (installed May 2013)

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 Acrylic Panel Production

Strict control of exposure to Radon, with collaboration oversight of production. Panels cast in 2011.

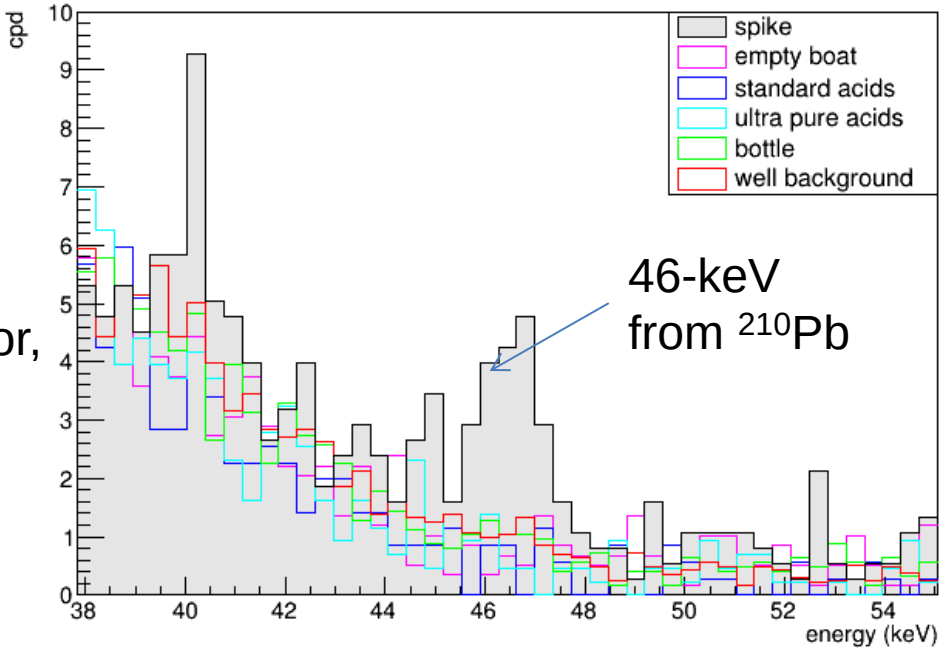
Pure-monomer cast panels for AV (RPT-Asia) and Light Guides (Spartech, USA)

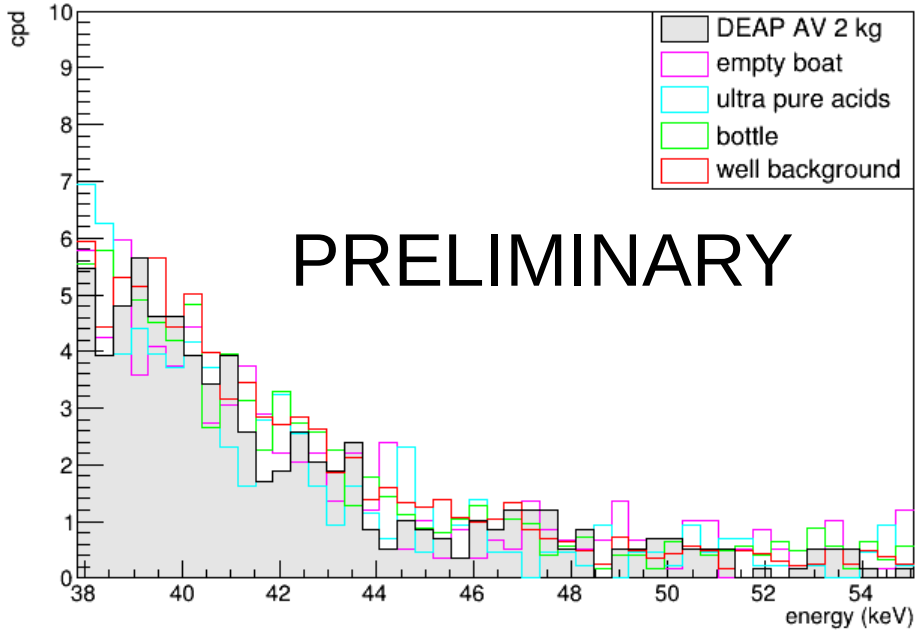
Acrylic Assay for ^{210}Pb

Developed system to vaporize kg's acrylic

Extract and count residue (Ge well detector, α counter for ^{210}Po)

Spike with ^{222}Rn into acrylic cylinder





DEAP AV acrylic assay and backgrounds

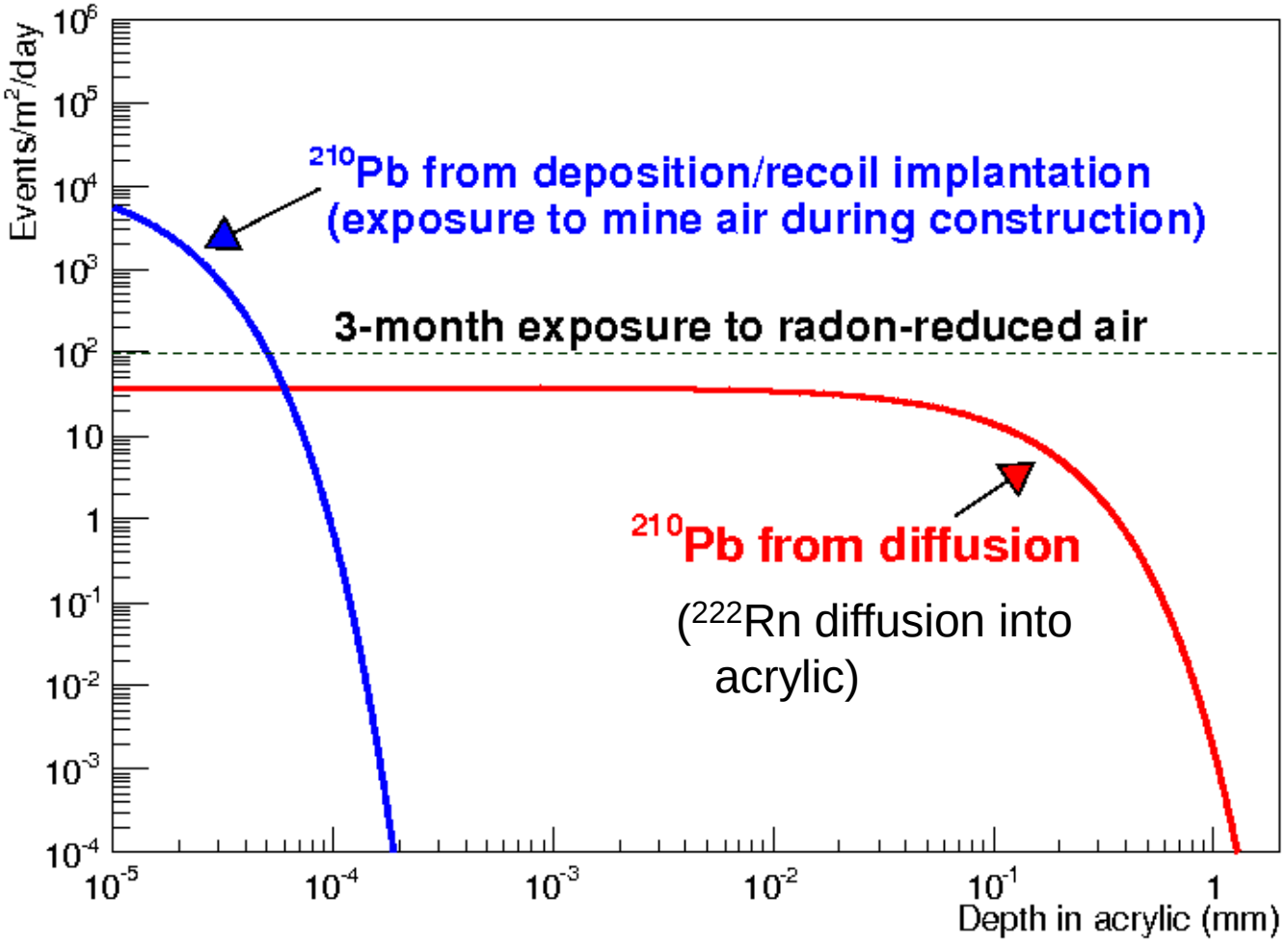
PRELIMINARY assay result:

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

Nominal < 0.8 bkd events in 3 years

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

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



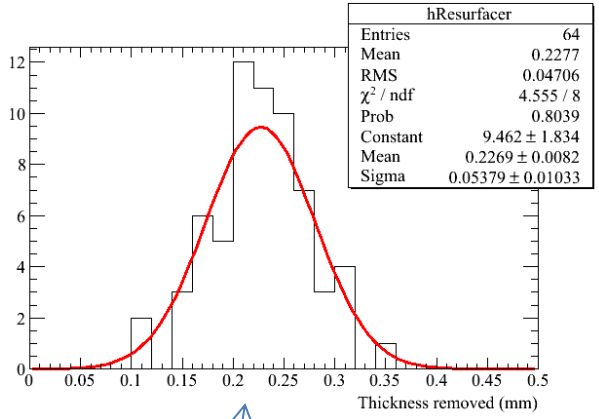
Will remove 1mm with Resurfacer

DEAP-3600 Acrylic Vessel Resurfacer

Removes 1 mm acrylic in-situ after construction

Radon-scrubbed N_2 purge gas and UPW flushing to extract residue

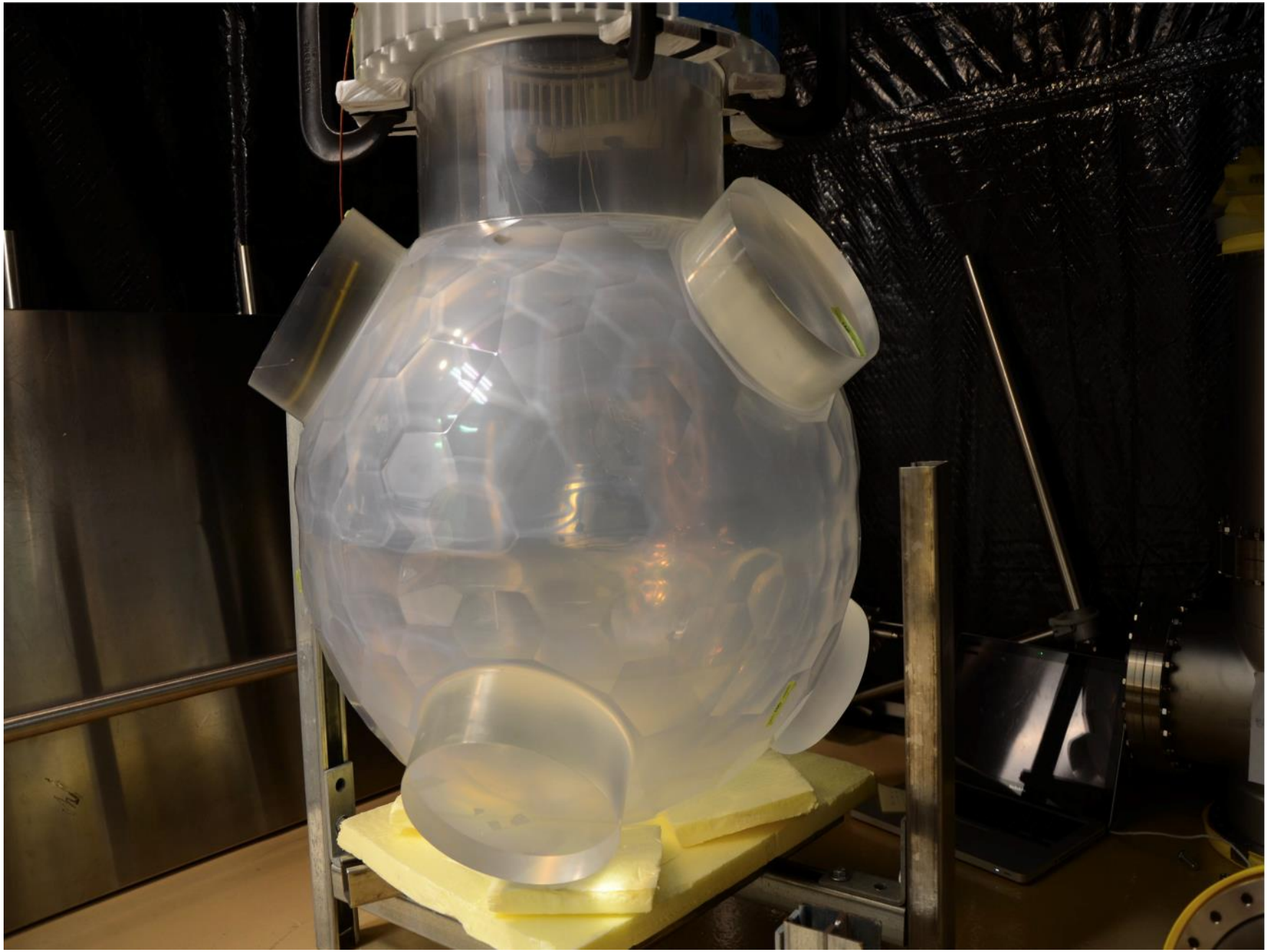
Surface contamination returns to bulk purity level



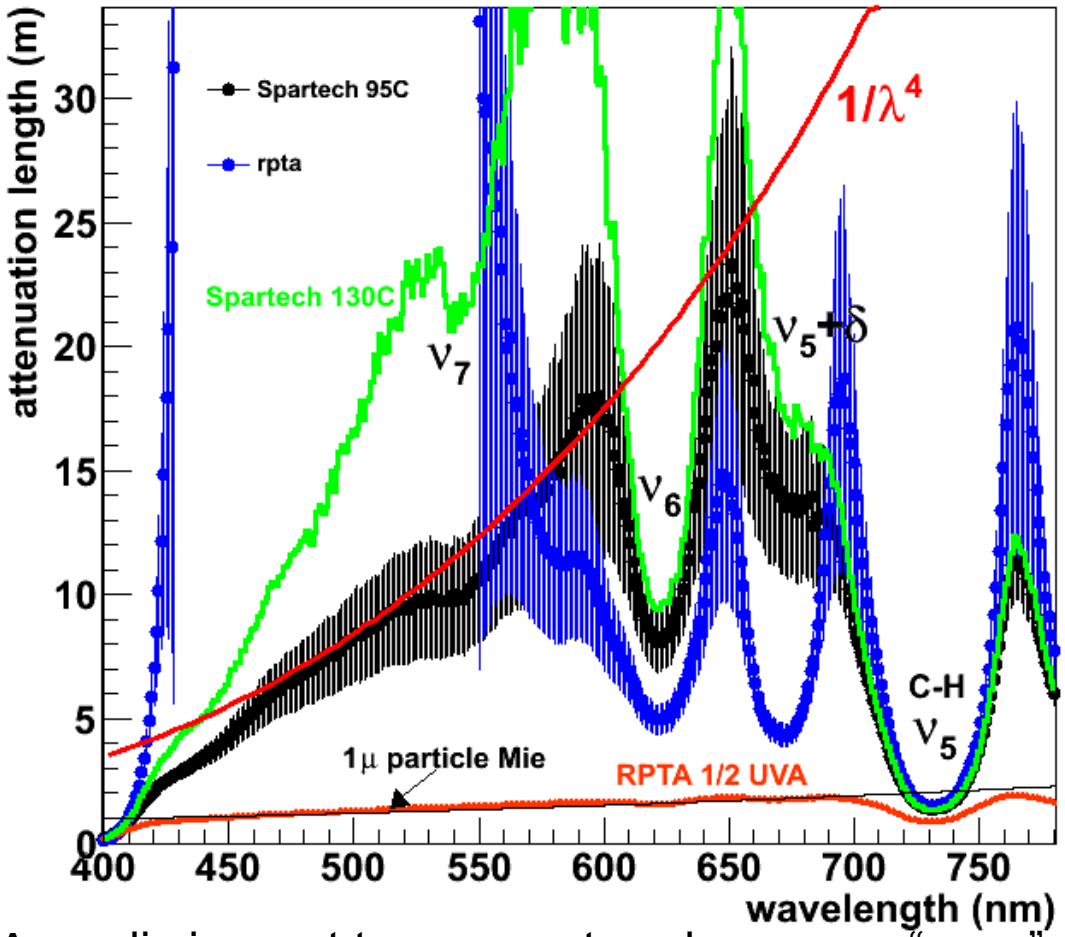
24% uniformity demonstrated

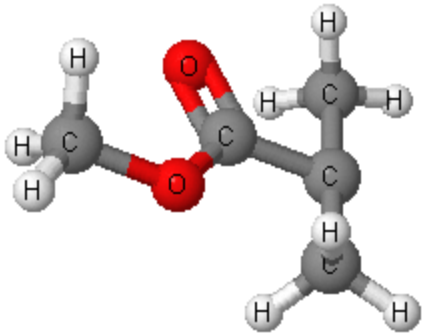
4π TPB (Organic WLS) deposition source developed for DEAP-3600

20-inch test vessel, 1/3 scale



Spartech and RPTA samples – Transparency of DEAP production acrylic





PMMA chain segment

Mean wavelength in DEAP: 440 nm

DEAP RPTA acrylic is most transparent we have ever "seen", close to Rayleigh limit

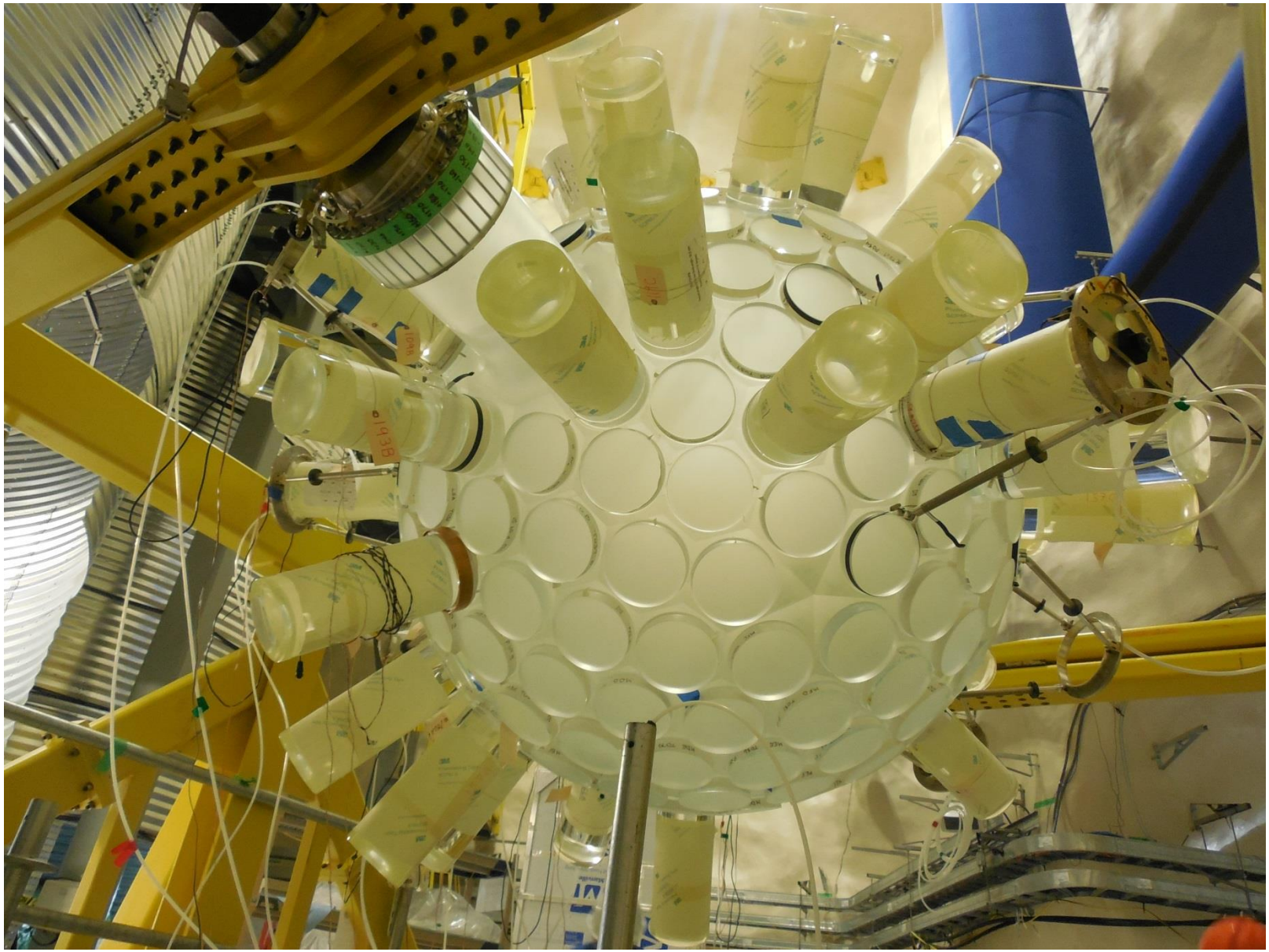
DEAP Spartech acrylic also clean, but excess Rayleigh scattering (anneal to correct)

At high wavelengths, only C-H features seen, expected from PMMA itself

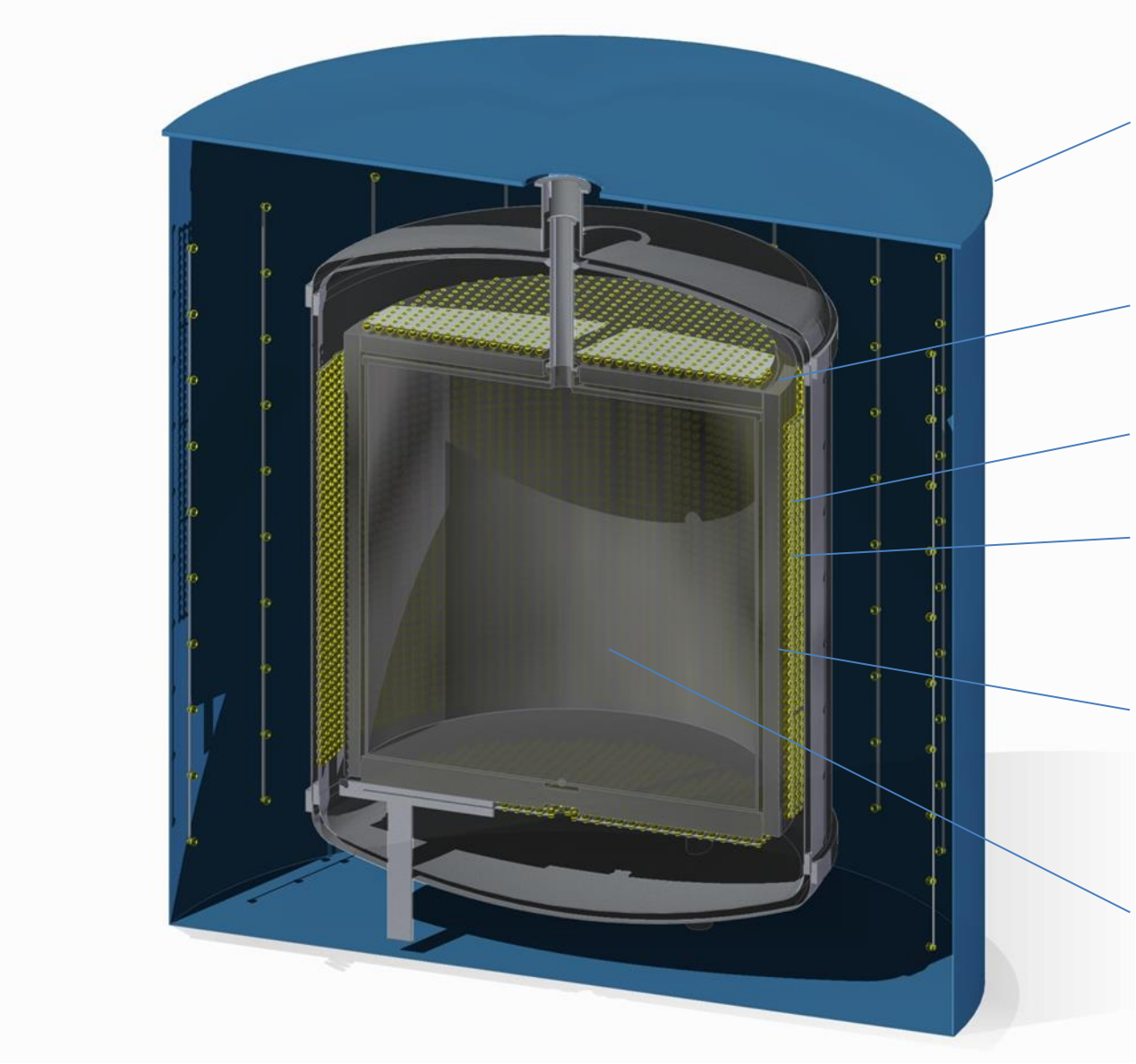
AV Fabrication (RPT Colorado and University of Alberta) 2011 to present

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

Vessel sealed and purged, approx. 50 LGs bonded (September 2013)



Large LAr Detector (Conceptual) 10^{-48} cm^2 Sensitivity…



44’ diam. water tank

24’ diam. Steel Shells
(inner and outer)

4400 8” HQE PMTs

12” acrylic shielding panels

17’ diam. 2” thick acrylic
vessel with flanged lid

150 tonnes argon in AV
(50 tonnes fiducial)

Requires low ^{39}Ar activity

Summary

- DEAP-3600 construction nearing completion, 1000-kg fiducial liquid argon with < 0.2 background events/year background budget
- Extensive backgrounds and assay program, in particular ultralow background acrylic inner vessel and low radon emanation inner detector and purification system
- 10^{-46} cm^2 sensitivity for 100-GeV WIMP (first run natural argon, then DAr)
- Assembly will be “mostly” complete end of 2013, commissioning/filling by Spring 2014
- Potential for v. large target mass with argon, 50-tonnes for 10^{-48} cm^2 sensitivity, precision measurements…