

Title: Dark matter search at SNOLAB with DEAP-3600

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Abstract: DEAP-3600 is a dark matter experiment using 3600 kg of liquid argon for direct WIMP search, with a target sensitivity to the spin-independent WIMP-nucleon cross-section of 10^{-46} cm 2 . The detector is currently under construction at SNOLAB, located 2 km underground in Sudbury. In this single-phase liquid argon experiment, discrimination of beta/gamma backgrounds from the WIMP-induced nuclear recoil signal will be achieved by analyzing the pulse shape of scintillation light. A prototype 7-kg liquid argon detector has been taking data at SNOLAB since 2007 and has allowed extensive background studies, including significant radon and surface contamination reduction. The status of the experiment and of background reduction studies will be presented.

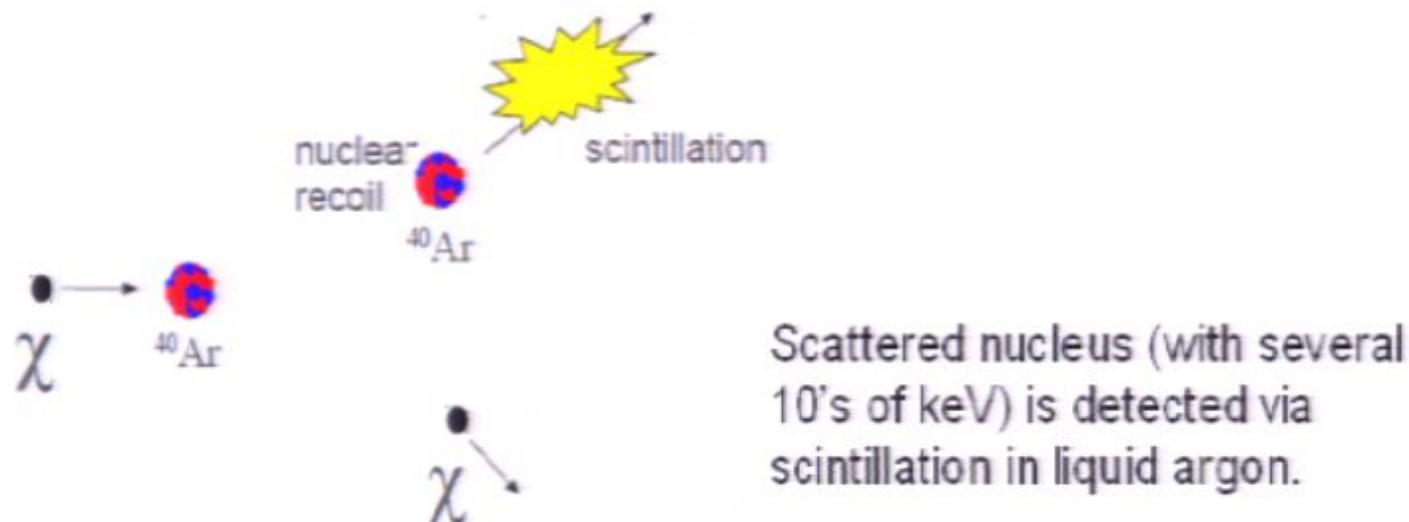


Dark Matter Search at SNOLAB with DEAP-3600

Bei Cai
For the DEAP collaboration
Queen's University

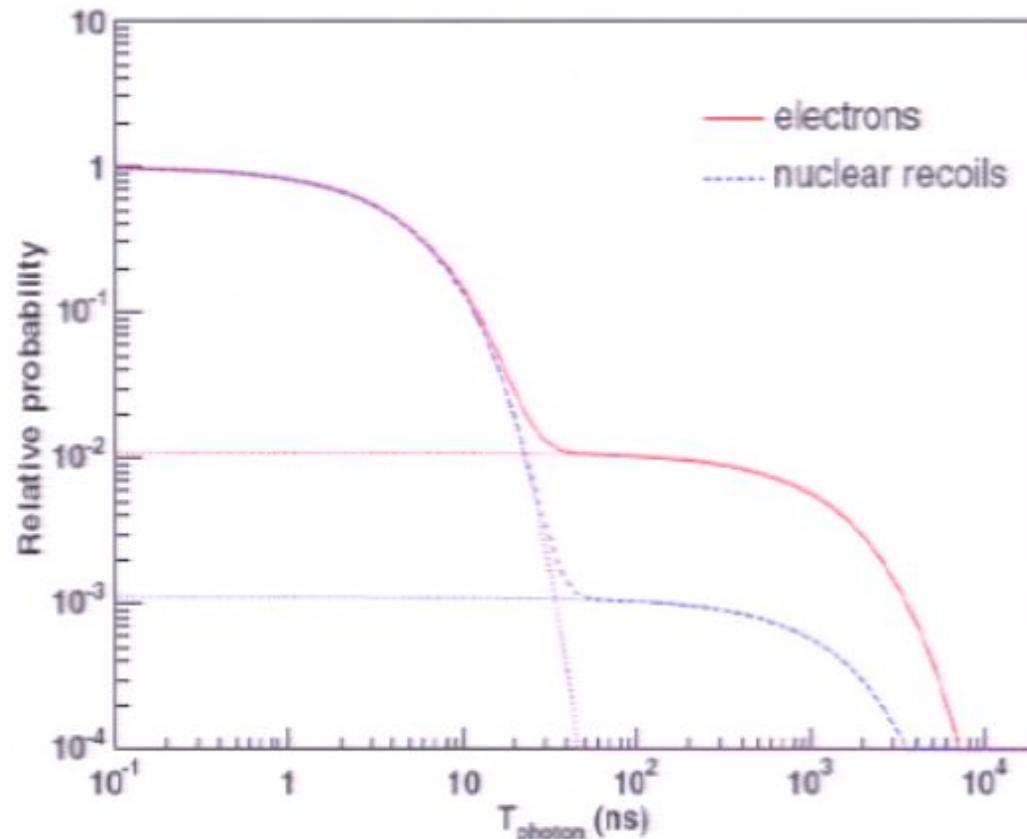
Dark Matter Experiment with Liquid Argon using Pulse-Shape Discrimination

Direct WIMP detection with liquid argon



- Excellent pulse-shape discrimination (PSD) in liquid argon between electron recoils and nuclear recoils
- Good scintillator (40 photons/keV)
- Inexpensive and easy to purify
- Single-phase detector, easy to scale up

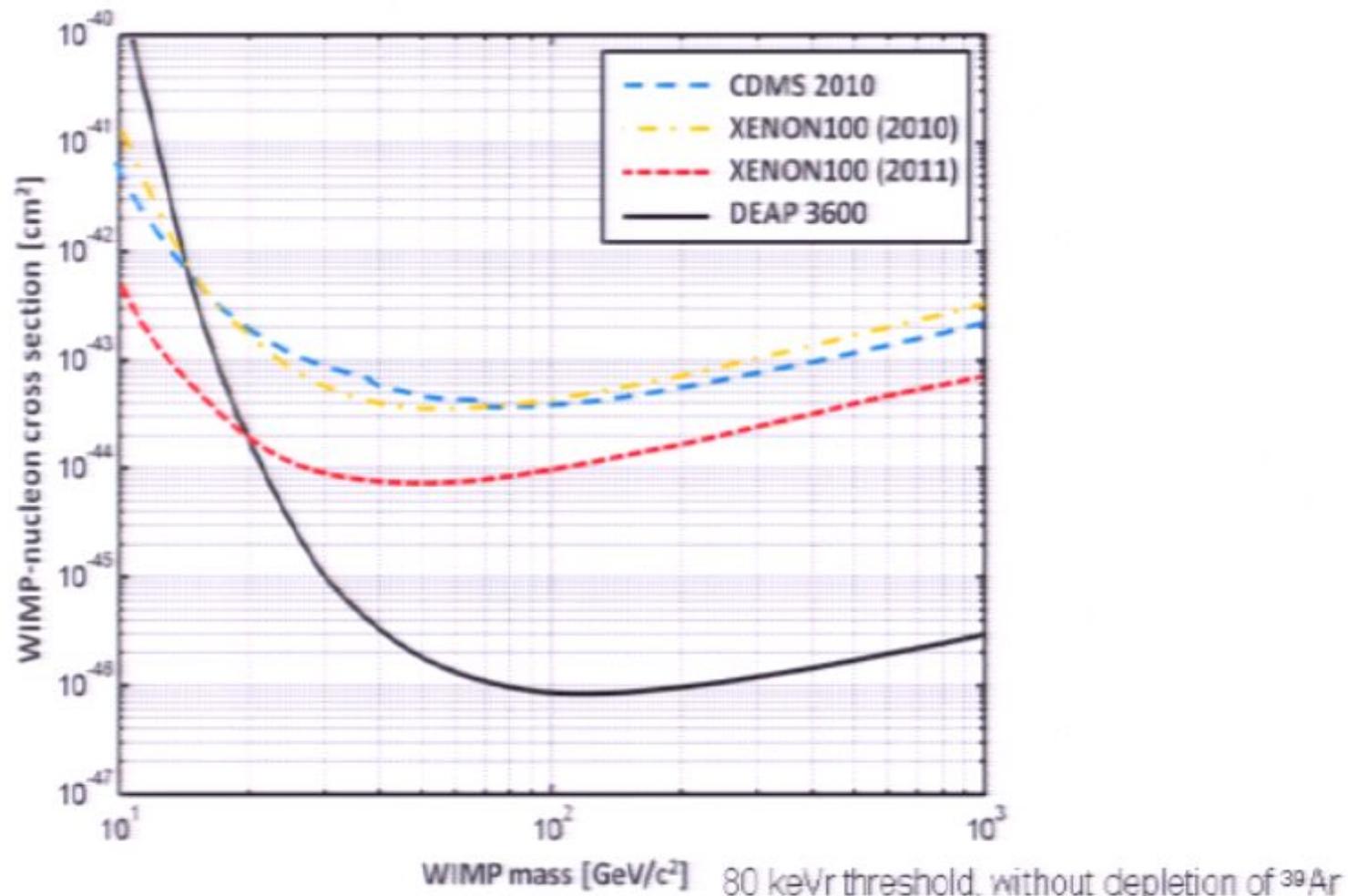
Pulse-shape discrimination



Astroparticle Physics 25, 179 (2006)

- Pulse-shape discrimination in argon allows threshold of ~ 20 keVee
- 1000 kg argon target allows 10^{-46} cm^2 sensitivity (spin-independent)

DEAP-3600 sensitivity (spin-independent)



CDMS 2010:

612 kg-days (Ge)

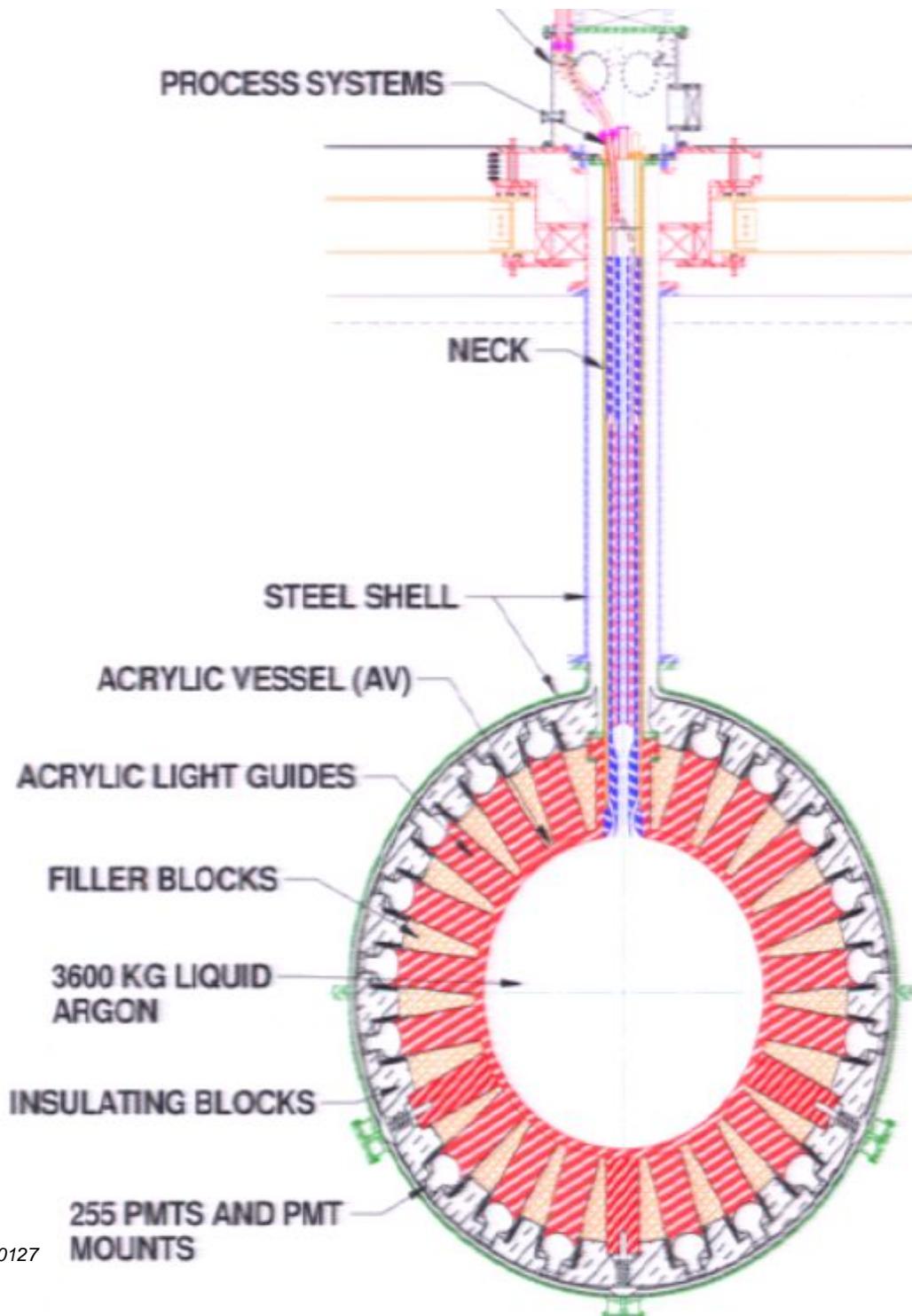
XENON100 2011:

1471 kg-days (Xe)

DEAP-3600:

1,000,000 kg-days (LAr)

background free sensitivity



DEAP-3600 detector

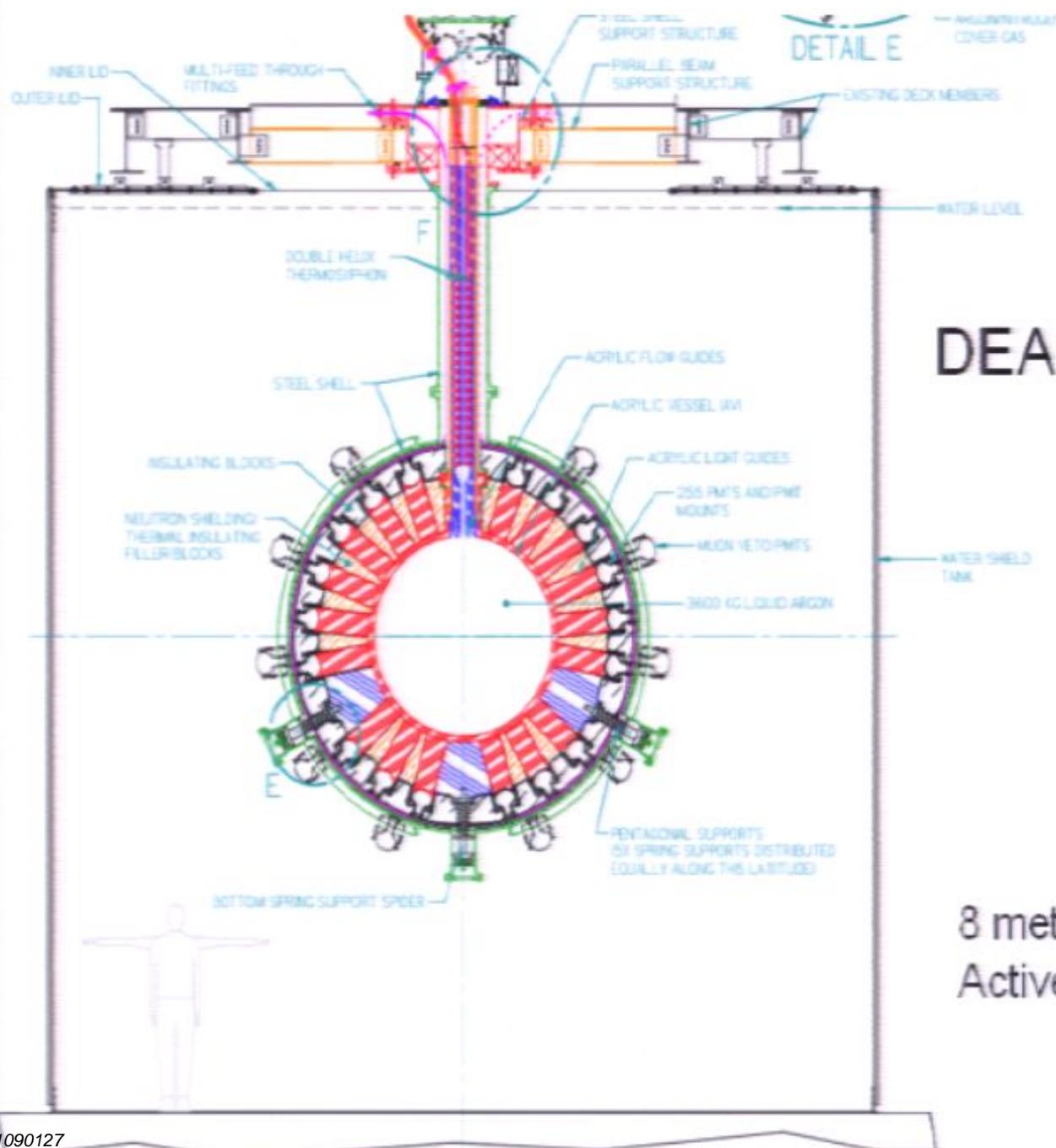
85 cm radius acrylic sphere
contains 3600 kg LAr
(55 cm, 1000 kg fiducial)

255 8" PMTs (warm)

50 cm acrylic light guides and
fillers for neutron shielding
(from PMTs)

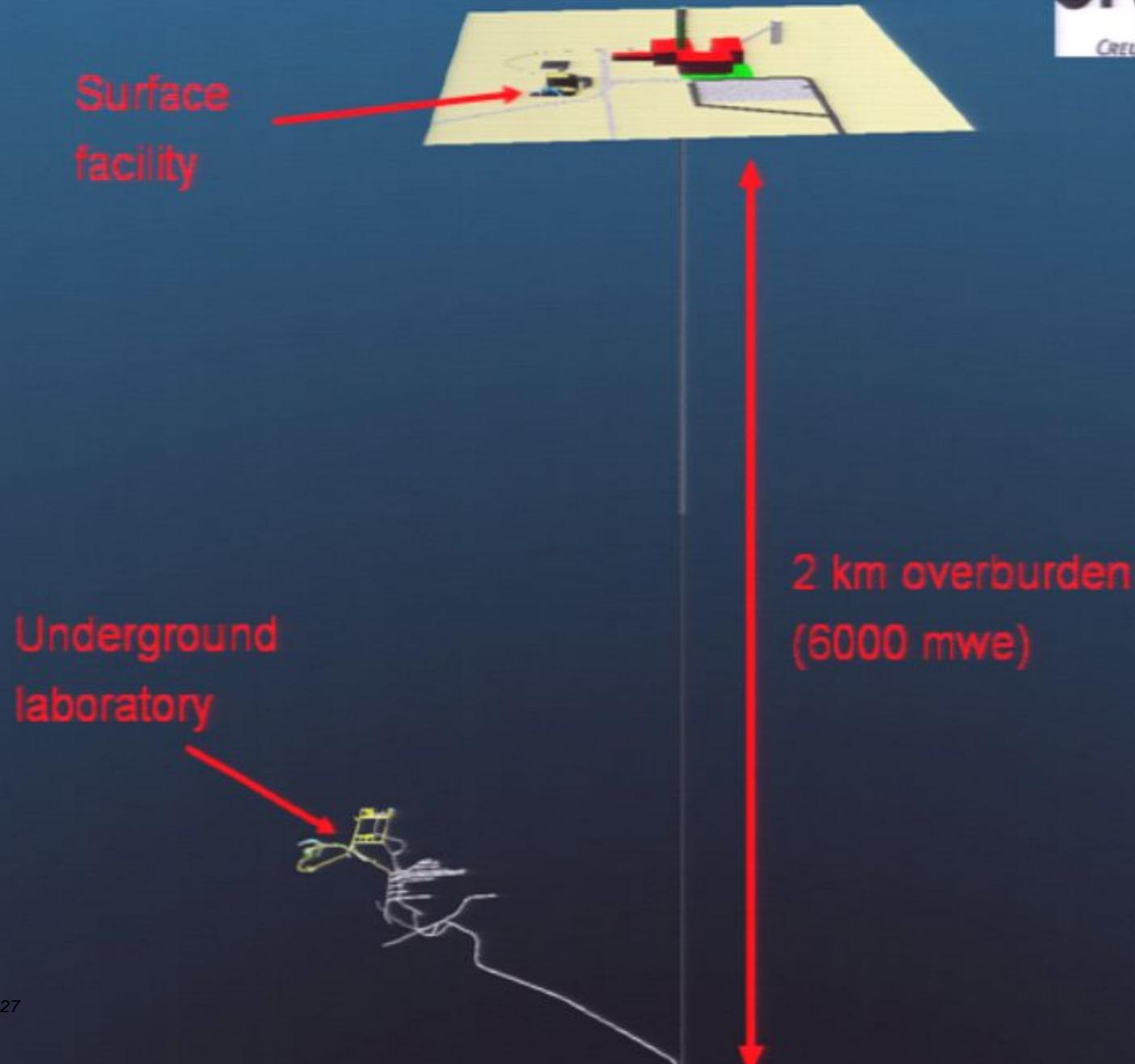
Steel shell for safety to prevent
cryogen/water mixing (AV
failure)

Only LAr, acrylic, and
WLS (30 g) inside of neutron
shield



DEAP-3600 detector

8 meter water shielding
Active muon veto



DEAP-3600 &
MiniCLEAN

DEAP-1

COUPP

PICASSO

SNO+

SuperCDMS

SNOLAB
Cube Hall

SNOLAB

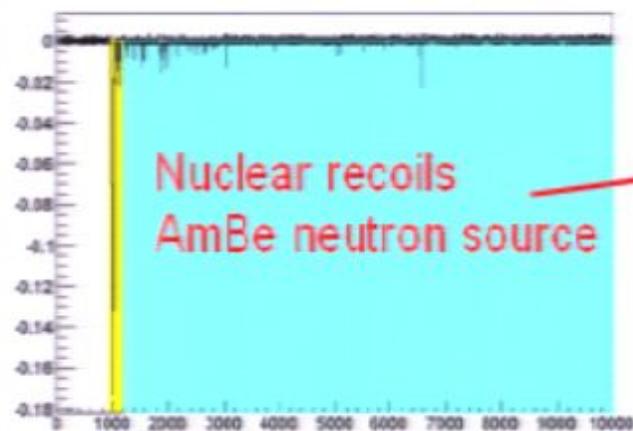
Backgrounds in DEAP-3600

- β,γ backgrounds
 - Pulse-shape discrimination
- Neutron backgrounds
 - Muon suppression at SNOLAB
 - Clean materials and shielding
- Surface contamination
 - Clean detector surface (resurfacer device)
 - Vertex reconstruction for fiducial volume
- ^{39}Ar is the largest source of background
- Expect 10^9 events in 3 years in (20-40) keVee
- Working with Princeton group to get depleted argon (>50 times depletion)

DEAP-3600 background budget (3 year run)

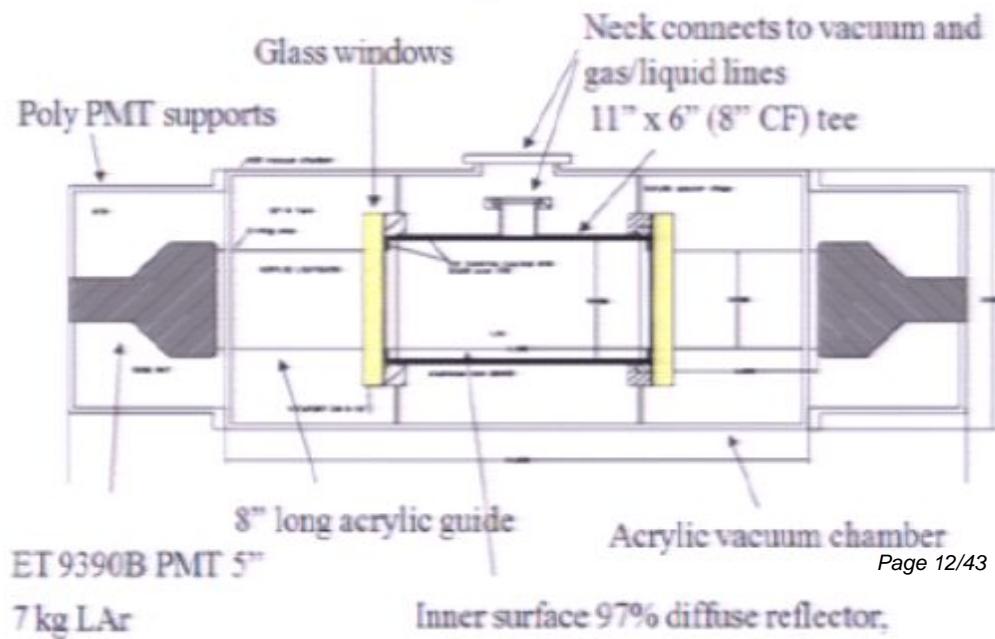
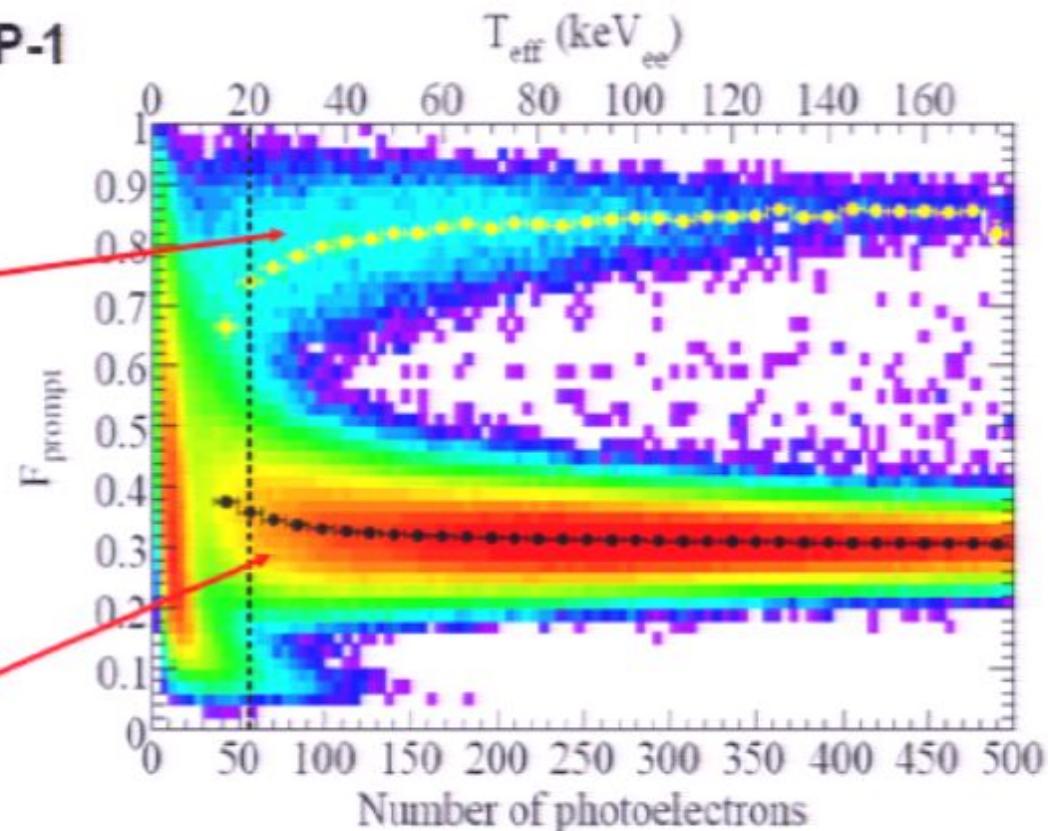
Background	Raw No. Events in Energy ROI	Fiducial No. Events in Energy ROI	
^{39}Ar β 's (natural argon)	1.6×10^9	< 0.2	PSD
^{39}Ar β 's (depleted argon)	8.0×10^7	< 0.01	
Neutrons	30	< 0.2	Acrylic/ H_2O shield
Surface α 's	150	< 0.2	Resurfacser

PSD in liquid argon with DEAP-1

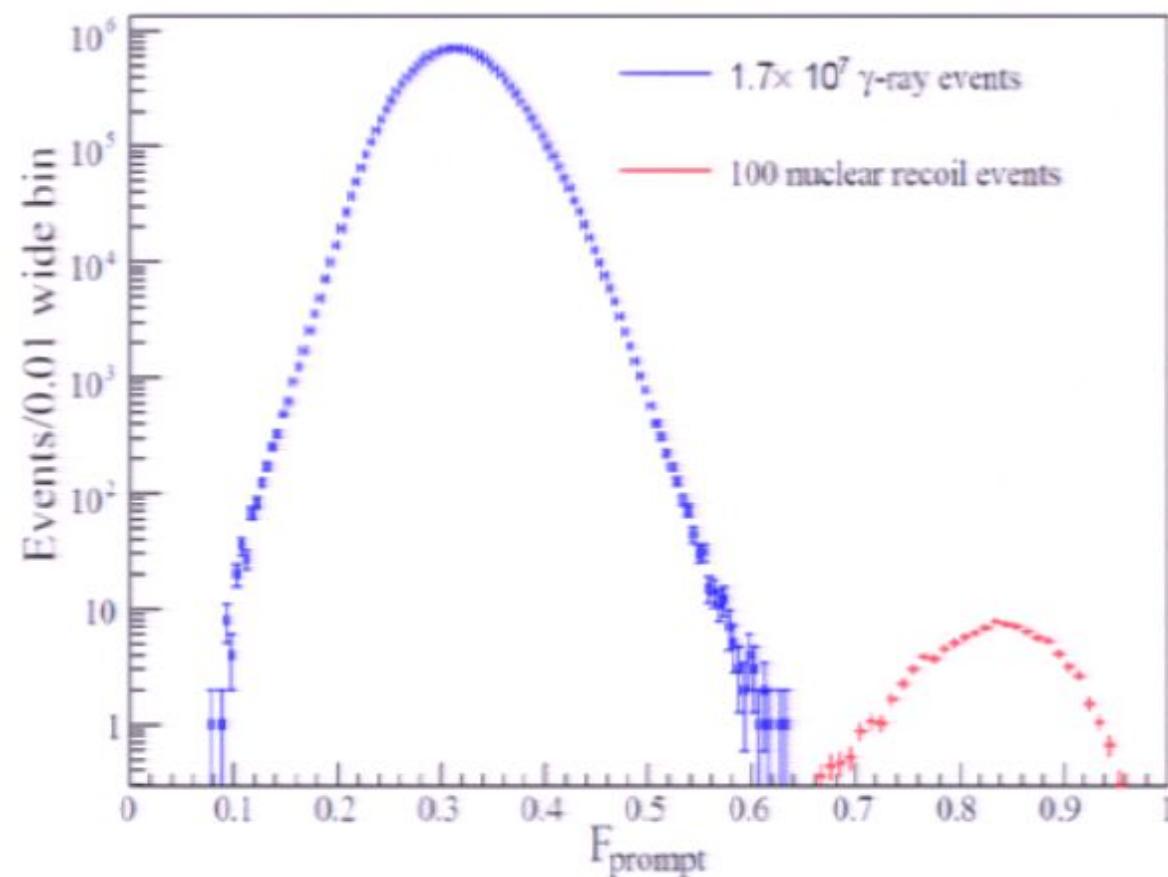


Yellow: Prompt light region
Blue: Late light region

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



β/γ background suppression in liquid argon

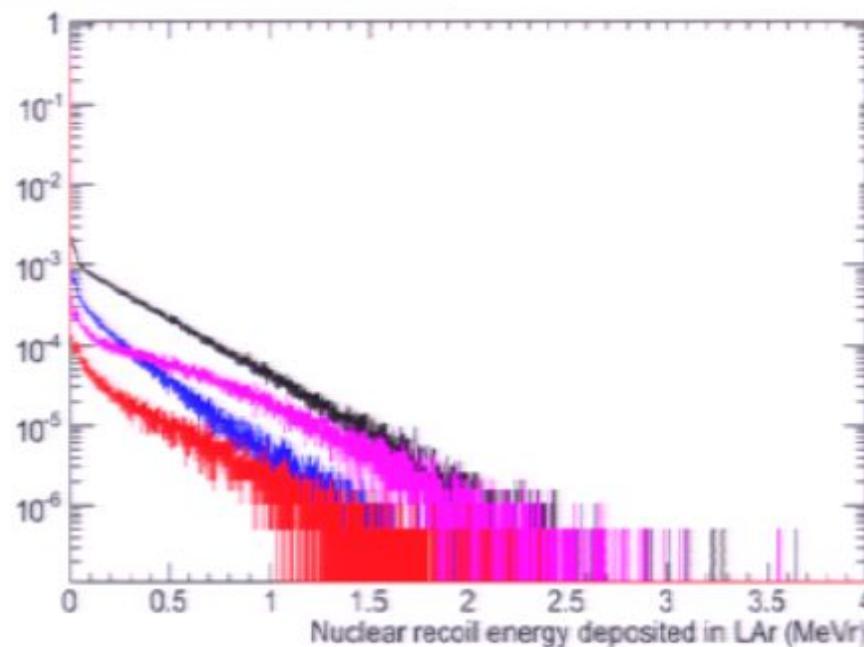


- γ suppression better than 6×10^{-8} (45-88 keVee, Queen's)
- 3×10^{-8} now achieved at SNOLAB, studies ongoing with improved light yield, lower threshold
- Simple model of photon statistics predicts 10^{-10} suppression at 120 pe (20 keVee threshold DEAP-3600)

Neutron backgrounds

- (α, n) neutrons
 - α 's from ^{238}U , ^{232}Th , ^{210}Pb decay chains
 - α 's from radons emanated from the detector materials and then decay on detector surface
- Fission neutrons
 - 0.439 n/y/g/ppm ^{238}U
 - Small from ^{235}U and ^{232}Th
- ~26 muons in shield water per day and can be efficiently vetoed

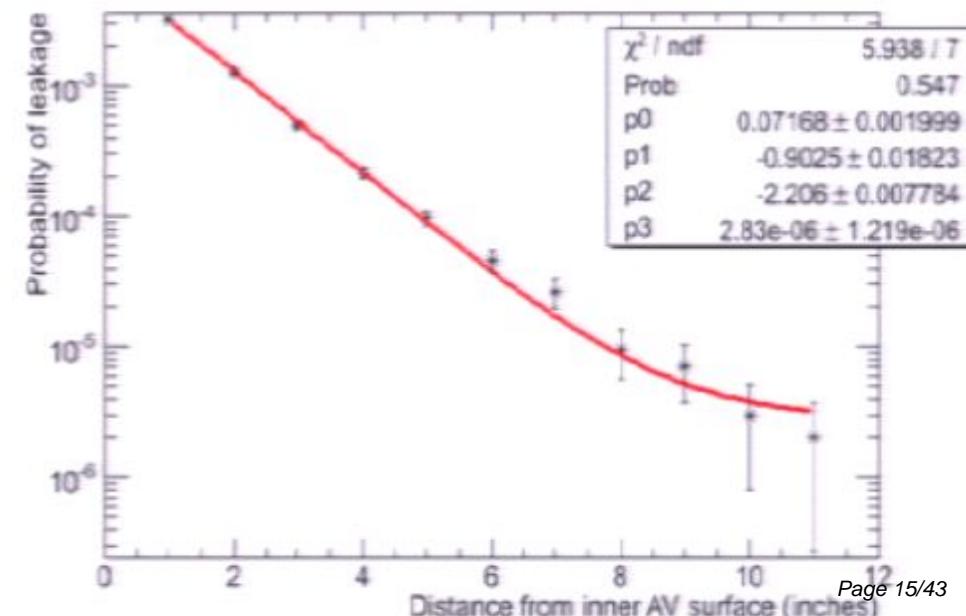
Uranium (α , n) neutrons in the AV



- Black --- No cuts
Blue --- Fiducial cut
Purple --- Prompt cut
Red --- Both cuts

Nuclear recoil energy deposited in LAr (GEANT4 simulations)

Uranium (α , n) neutrons in acrylic ($[0] * \exp([1]*x+[2])+[3]$)

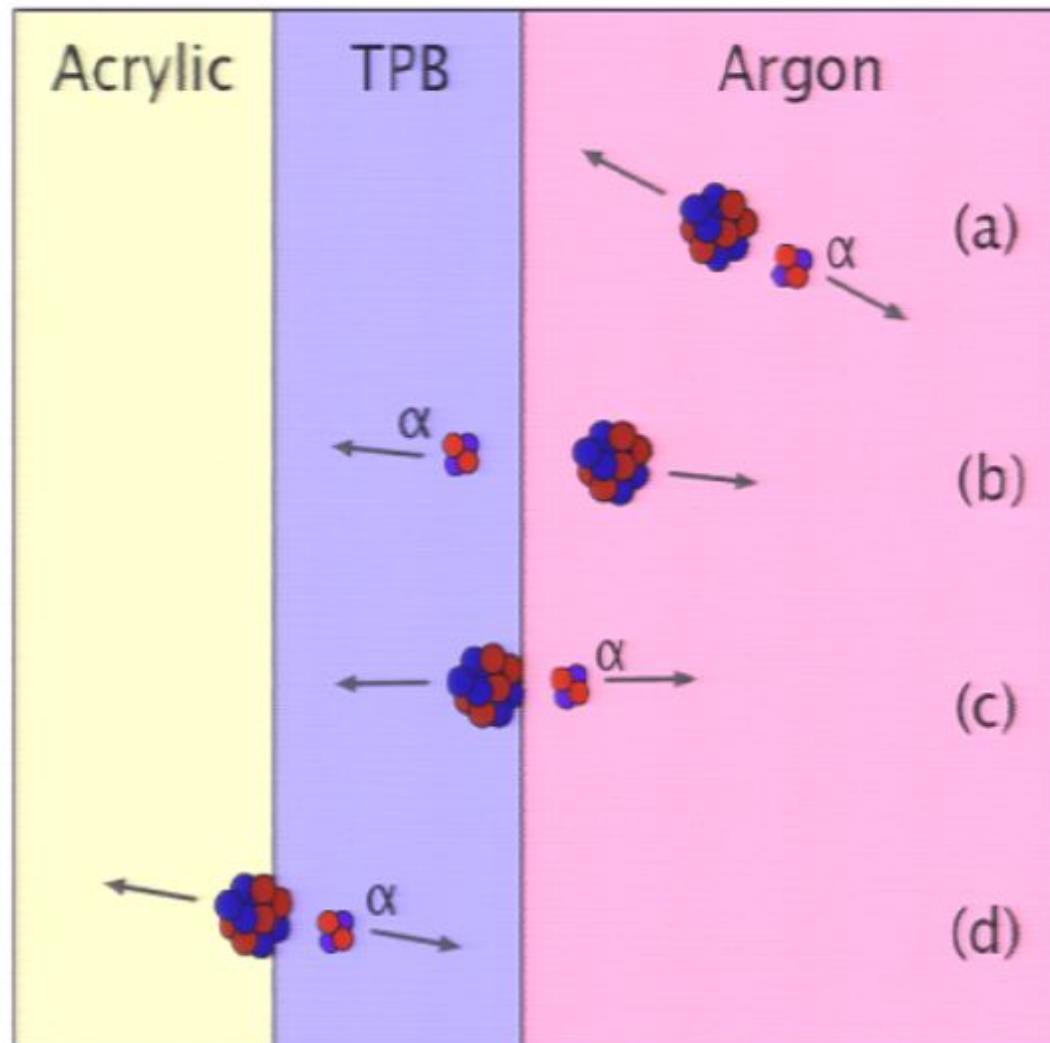


Radio-purity requirements

	^{238}U	^{232}Th	^{210}Pb	
Acrylic light guides	0.12	0.16	3	(mBq/kg)
PMTs	0.08	0.05	0.96	
PMT cable	0.25	0.18	4.52	(Bq/kg)
Steel shell	0.16	0.23	101.7	

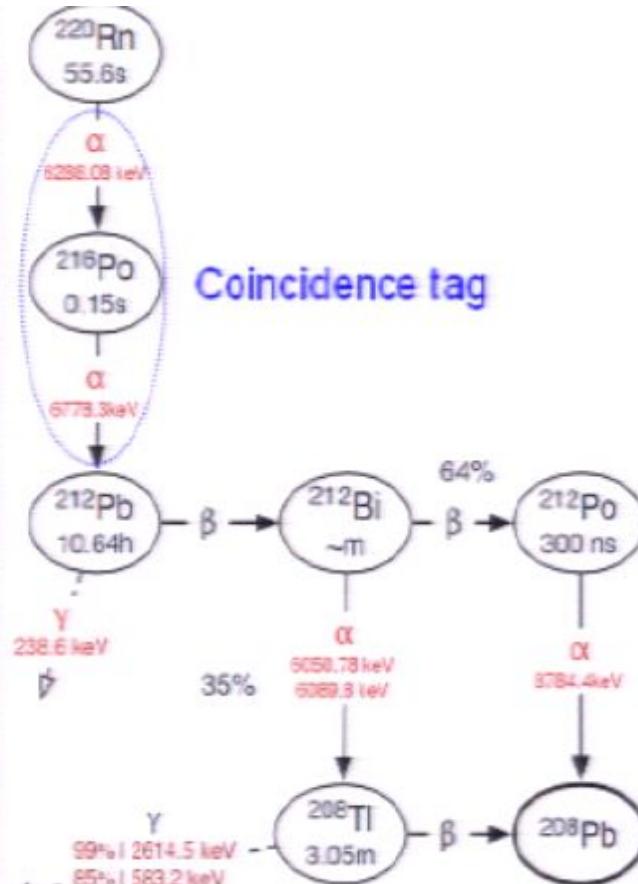
- Limits correspond to 0.01 WIMP-like background events in 3 years
- PMT gamma assay gives 0.92 Bq/kg ^{238}U and 0.14 Bq/kg ^{232}Th , which correspond to <0.2 backgrounds in 3 years

Surface contamination: alpha backgrounds



Alphas may lose most of their energies in acrylic, scintillate in either TPB or LAr or both, and produce signals in WIMP ROI

Both TPB and liquid argon scintillate

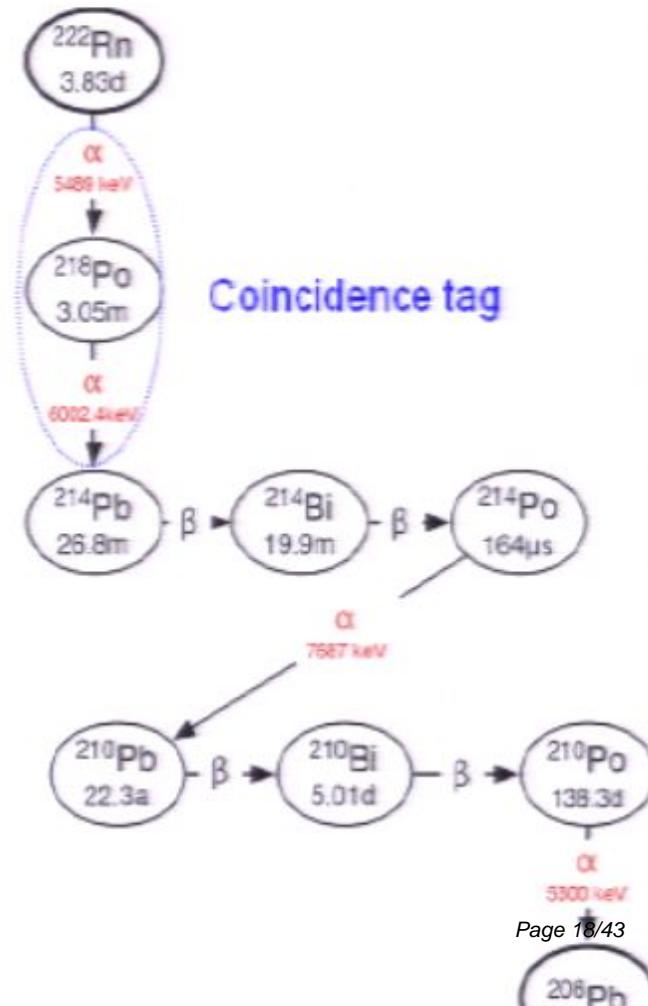


Coincidence tag

α Backgrounds in DEAP-1

χ^2/ndf	1175 / 89
Prob	0.02317
number of ^{222}Rn	189.4 ± 9.7
resolution	0.02515 ± 0.00135
number of ^{220}Rn	28.93 ± 4.81
Po214 divider	3.143 ± 0.445
Po214 resolution	0.04608 ± 0.00512
Po218 resolution	0.02755 ± 0.00683

$180 \mu\text{Bq} ^{222}\text{Rn}$
 $20 \mu\text{Bq} ^{220}\text{Rn}$



Sources of alpha backgrounds in DEAP-3600

^{238}U , ^{232}Th , and ^{210}Pb in the bulk acrylic of the AV (inner 80 microns)

^{238}U , ^{232}Th , and ^{210}Pb in the TPB

^{210}Pb and ^{210}Po deposited on the AV inner surface from ^{222}Rn exposure

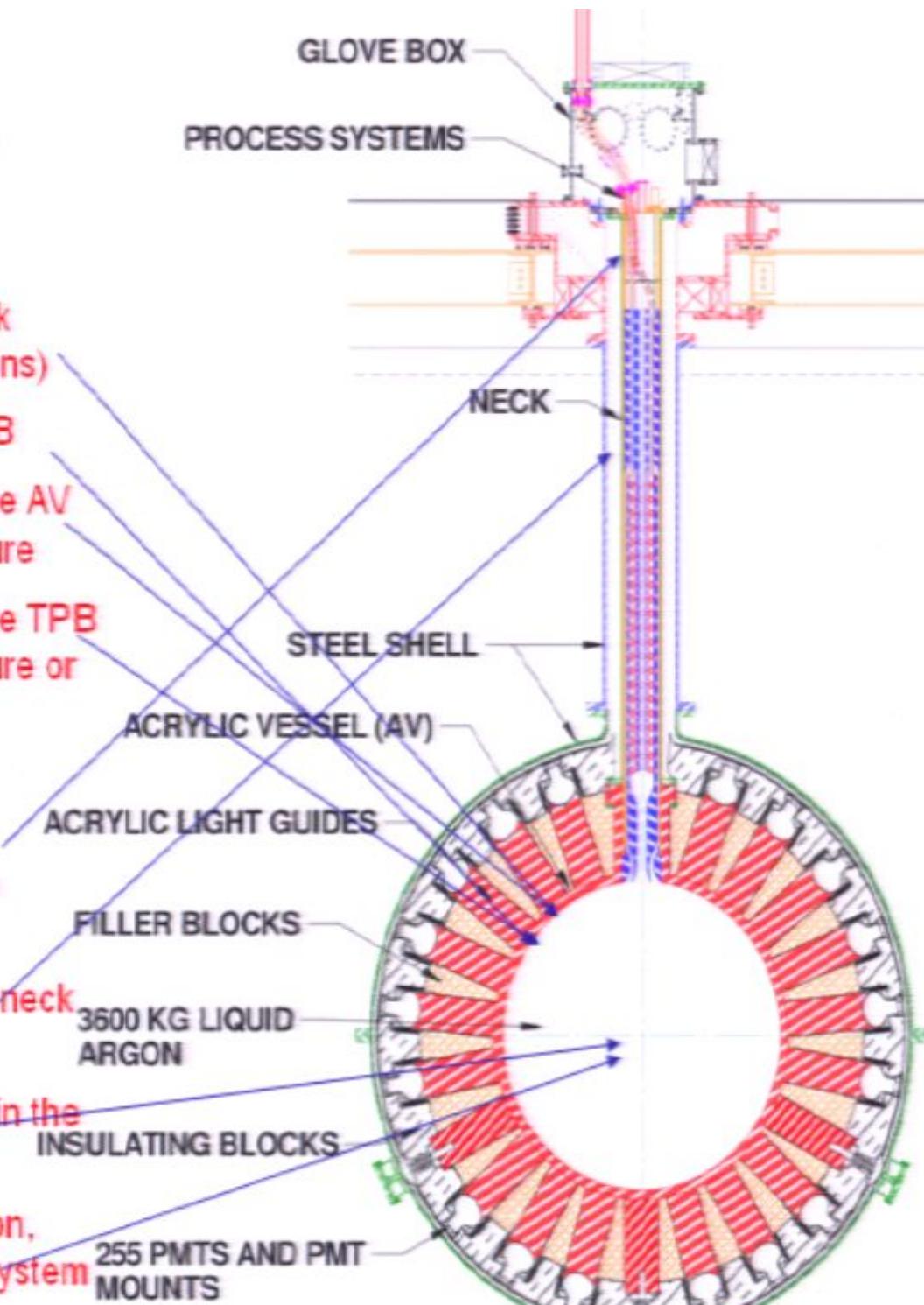
^{210}Pb and ^{210}Po deposited on the TPB inner surface from ^{222}Rn exposure or radon emanation

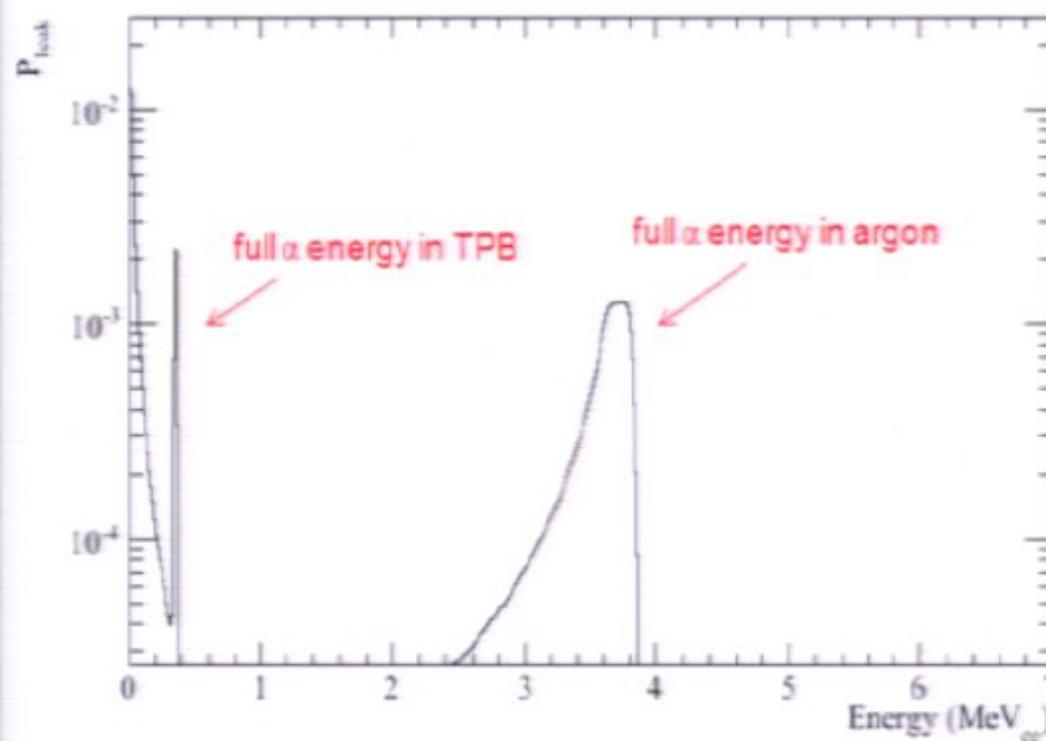
^{210}Pb and ^{210}Po desorbed from the process system or other components that later adsorb to the inner detector surface

Alpha decays from the detector neck region

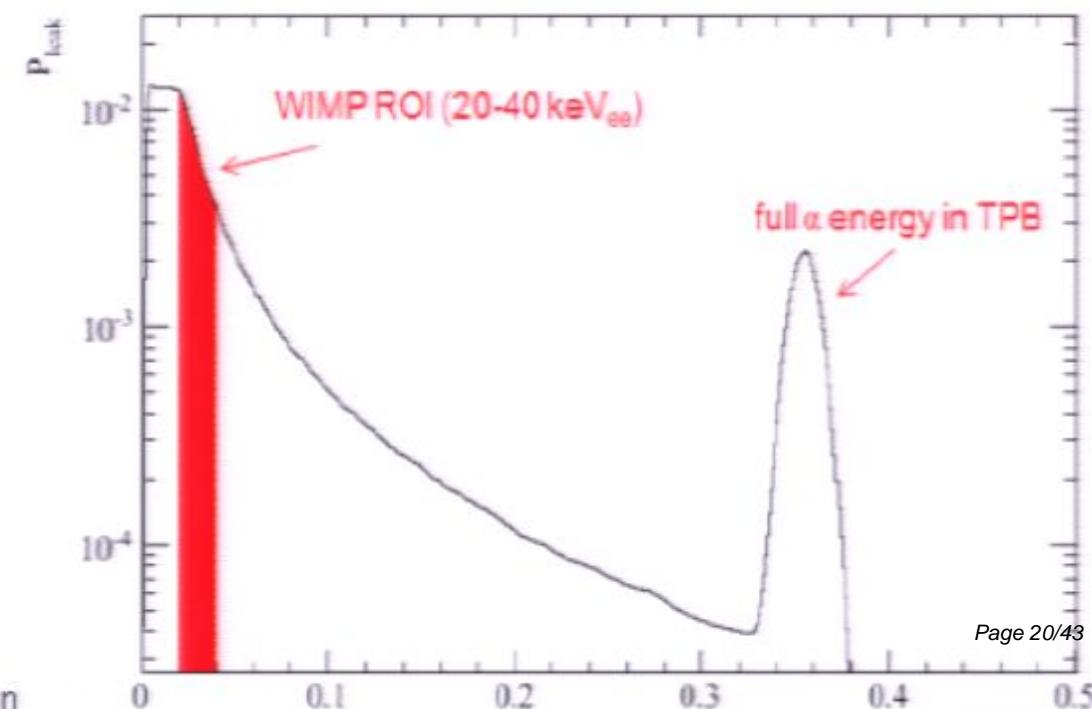
Alpha decays from particulates in the liquid argon

Leaching of Th and Ra into argon, i.e., from welds in the process system





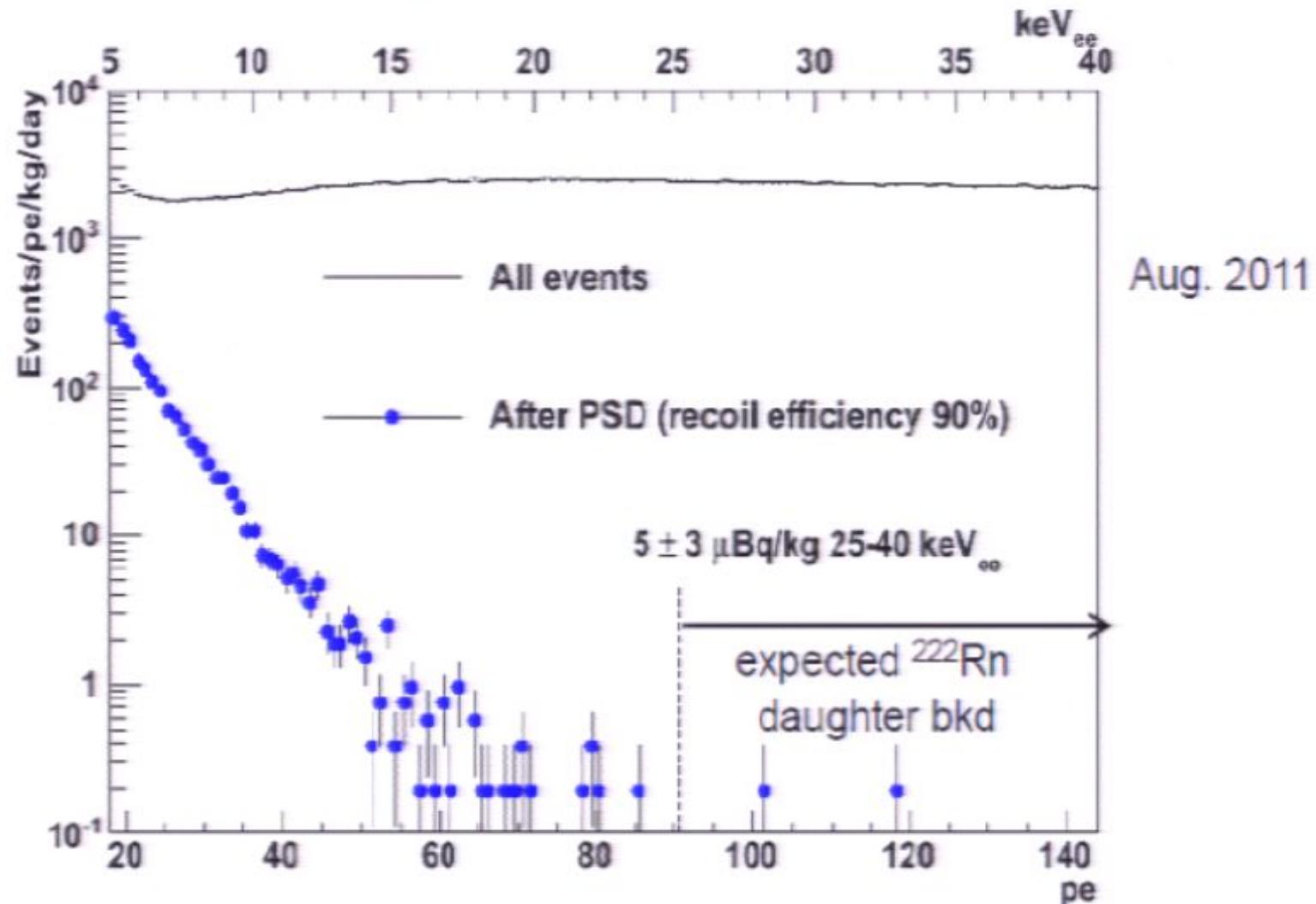
^{210}Po on TPB inner surface produces WIMP-like events



Surface backgrounds

- Acrylic vessel radio-purity requirements:
 - 4, 5, 31 $\mu\text{Bq}/\text{kg}$ ^{238}U , ^{232}Th , and ^{210}Pb , respectively
- Existing assay of RPT acrylic gives <0.4 WIMP-like events in 3 years in fiducial volume
- No measurements on ^{210}Pb yet (evaporation of acrylic and counting in low-background HPGe well counter)
- To reduce surface backgrounds
 - Acrylic QA
 - Remove radon-exposed dirty surface with resurfacer
 - TPB purification
 - Data analysis in DEAP-3600: PMT hit pattern with large signals when PMTs are directly in front of an alpha
 - Alpha pulse-shape discrimination

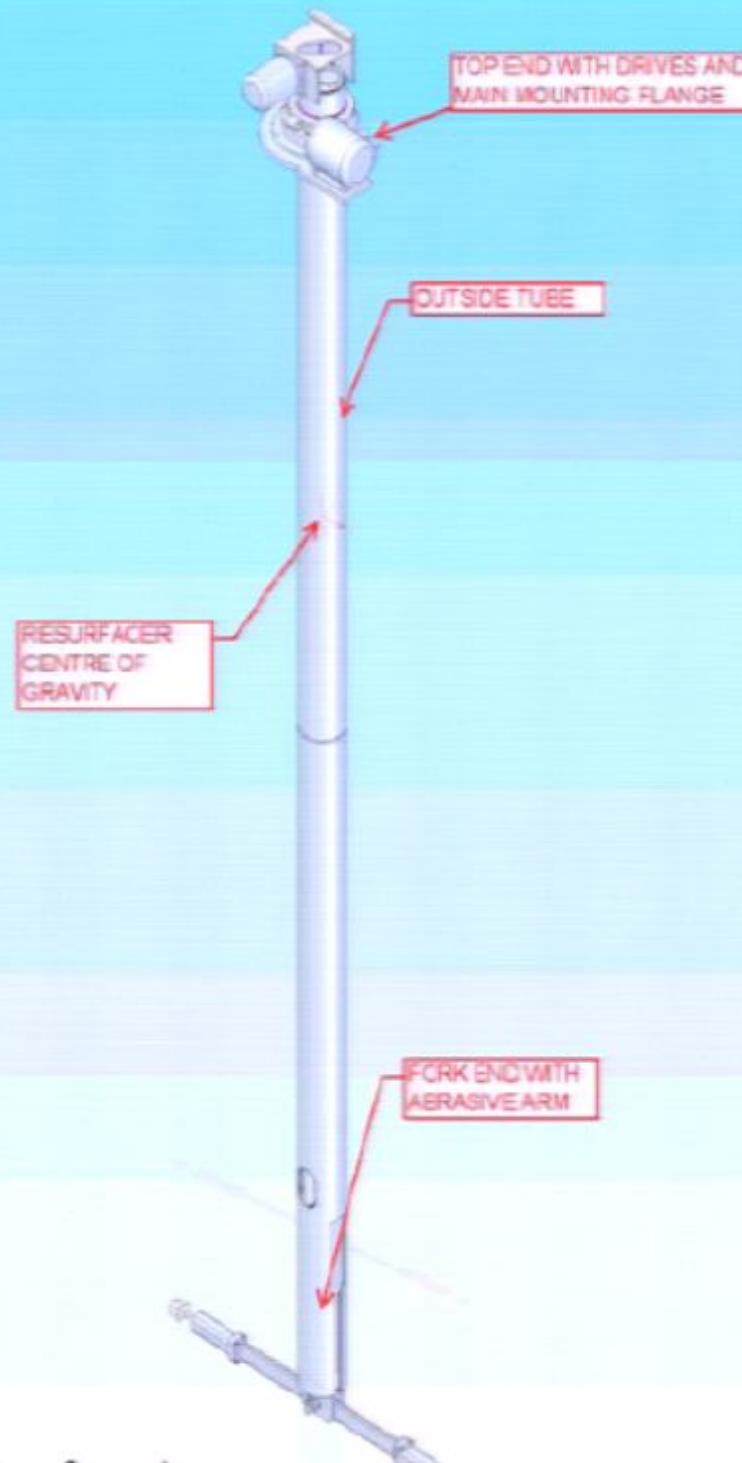
DEAP-1 low background data with and without PSD



- DEAP-1 light yield: 3.6 pe/keV
- DEAP-3600 expected light yield >6 pe/keV, would allow 20 keV_{ee} threshold at 120 pe

Background rates in DEAP-1 (120-240 pe)

Date	Background Rate (in WIMP ROI)	Configuration	Improvements for this rate
April 2006	20 mBq	First run (Queen's)	Careful design with input from materials assays (Ge γ counting)
August 2007	7 mBq	Water shield (Queen's)	Water shielding, some care in surface exposure (< a few days in lab air)
January 2008	2 mBq	Moved to SNOLAB	6000 m.w.e. shielding
August 2008	400 μ Bq	Clean v1 chamber at SNOLAB	Glove box preparation of inner chamber (reduce Rn adsorption/implantation on surfaces)
March 2009	150 μ Bq	Clean v2 chamber at SNOLAB	Sandpaper assay/selection, PTFE instead of BC-620 reflector ,Rn diffusion mitigation, UP water in glove box, documented procedures; Rn Trap.
March 2010	130 μ Bq	Clean v3 chamber at SNOLAB	Acrylic monomer purification for coating chamber. TPB purification.
Feb 2011	~10 μ Bq	Clean v4 chamber at SNOLAB	Inner chamber redesign to remove "Neck Light" events



Resurfacer

Mechanical resurfacer removes surface contamination in inert environment.

Debris is flushed and removed with ultrapure water.

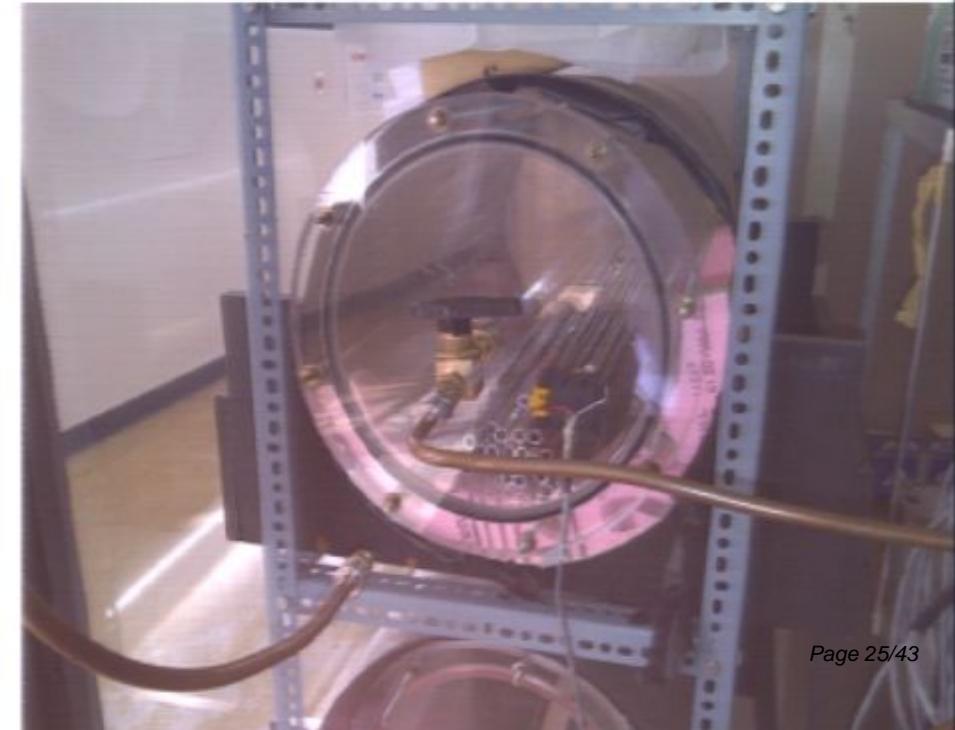
Resurfacer inserted and removed through sealed glove box

Resurfacer components are low-emission materials

Design has been finalized and some components are out for fabrication

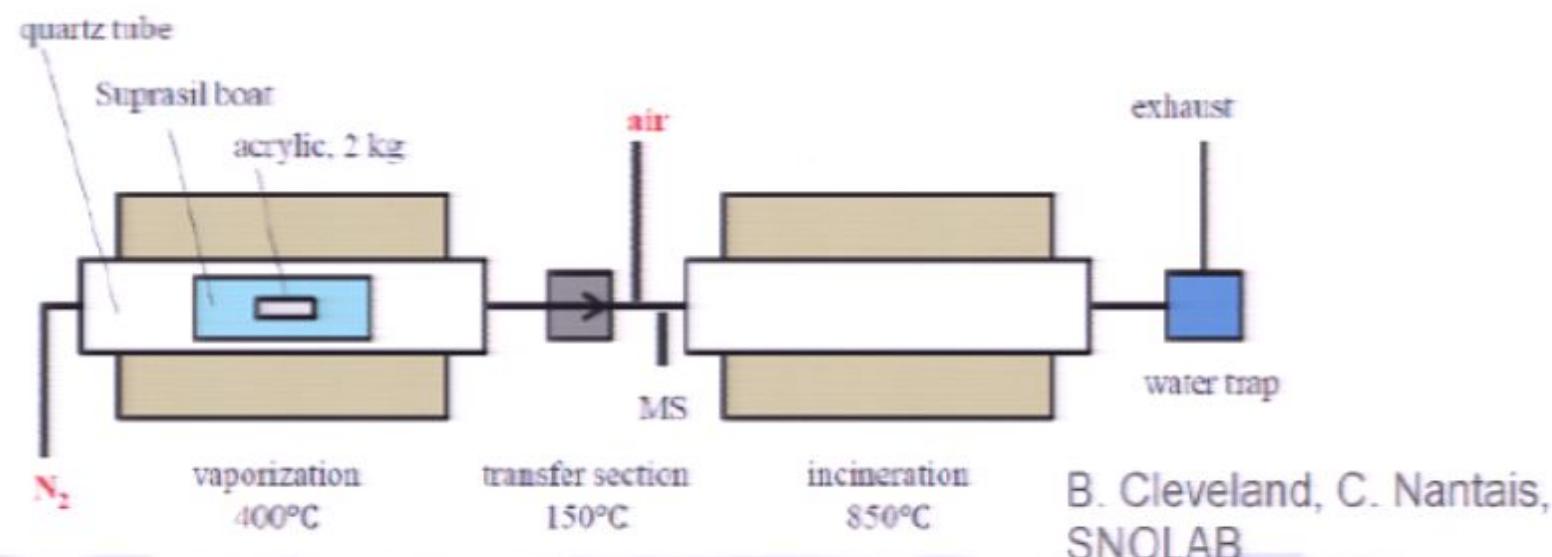
Radon control in argon process system

- During and after resurfacing, the detector is sealed and has no contact with ^{222}Rn containing air
- All-metal argon process system with low-background radon emanation
- Study of emanation from 1200 sample welds in electropolished $\frac{1}{2}$ " tubing found emanation of $25 \pm 4 \mu\text{Bq}/\text{m}^3$.
- Working on passivating and cleaning to reach target of $\sim 1 \mu\text{Bq}/\text{m}^3$.



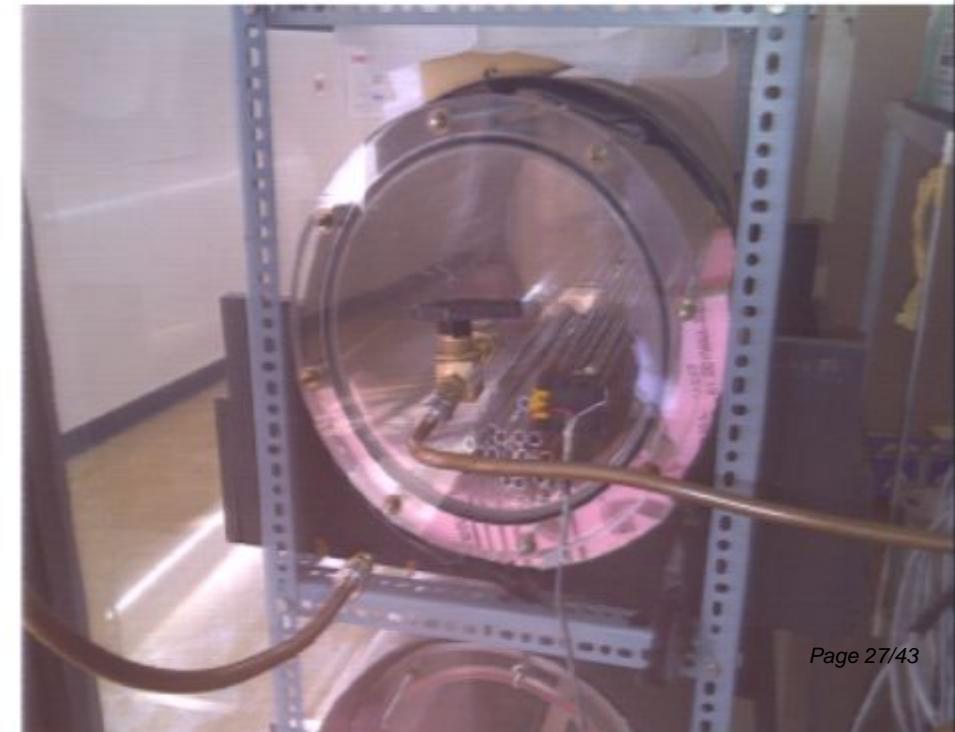
Acrylic Quality Assurance

- Acrylic is made of a liquid monomer MMA, which can be purified by distillation
- Extremely high purities achievable
- Working closely with RPT to ensure the product will meet the requirements
- Will assay vaporized acrylic in high-purity Ge well detector



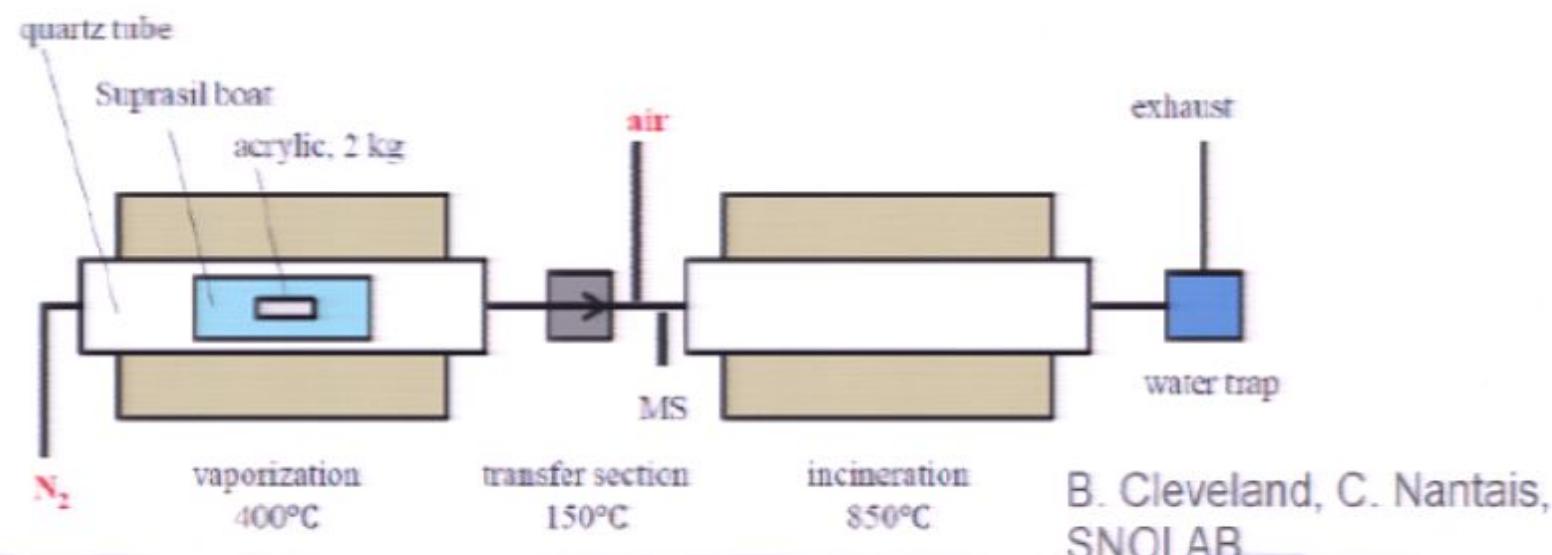
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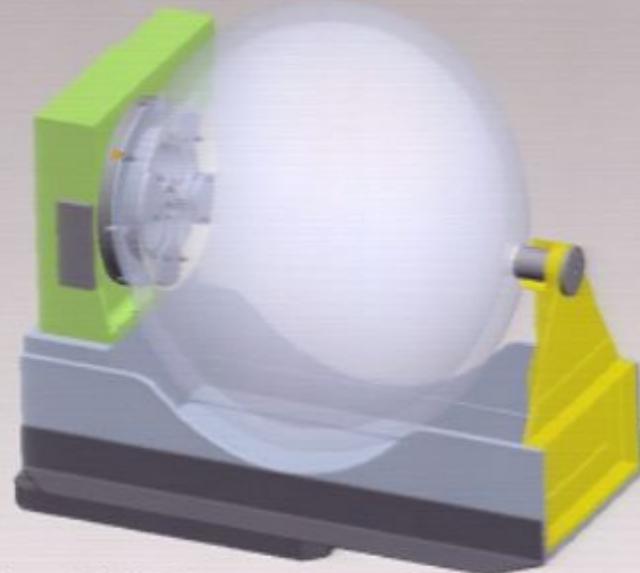


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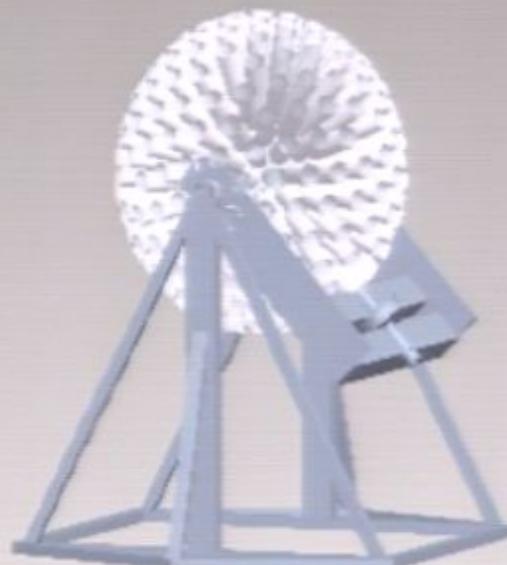
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DRAWINGS FOR DEAP AV SHELL STUB MACHINING TOOLING



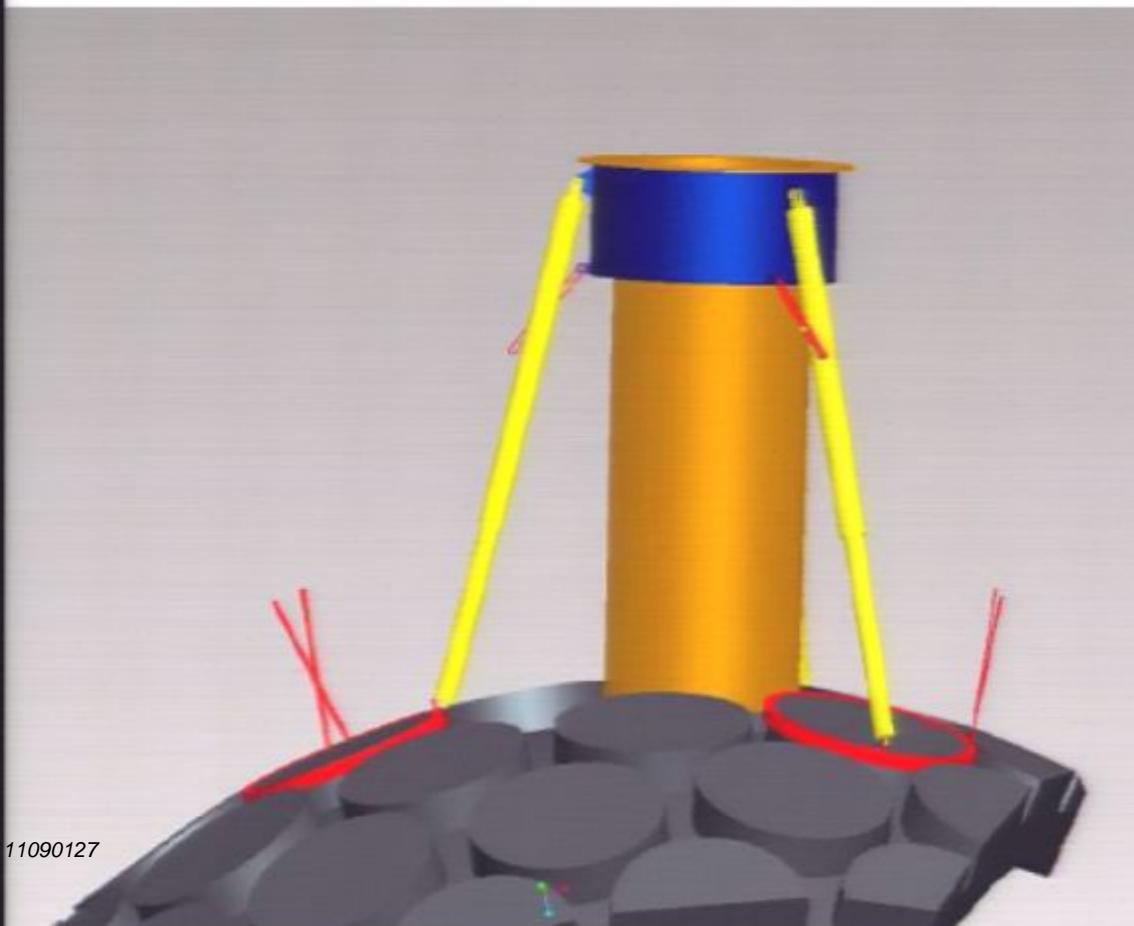
Jan Soukup, U of Alberta



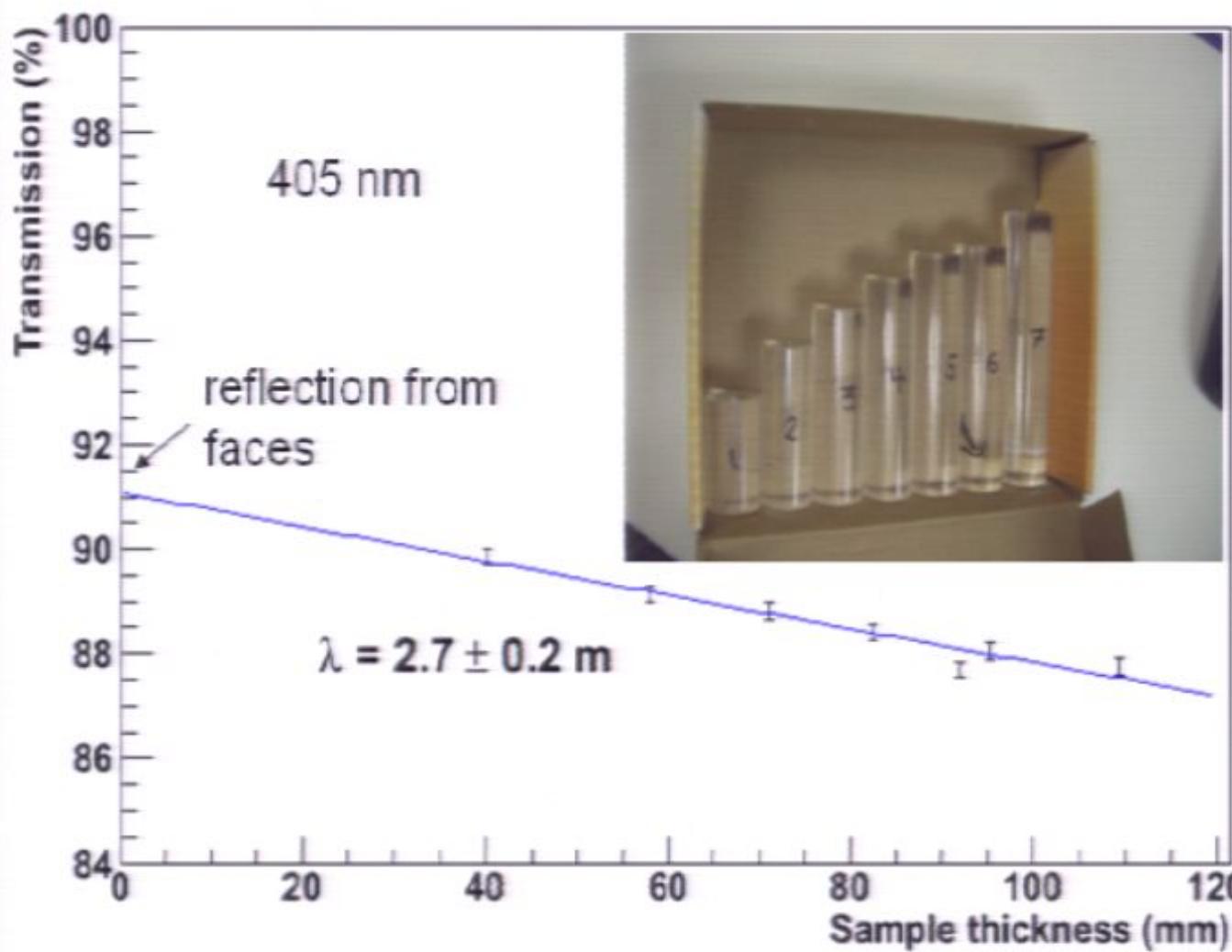
- Acrylic vessel will be machined at the University of Alberta
- Bonding of neck collar, neck, and light guides to happen underground at SNOLAB

Light guide bonding at Alberta

- Developed well-controlled bonding system
- Bond parameters are monitored to ensure consistency
- Cryogenic tests of the bonds for QA



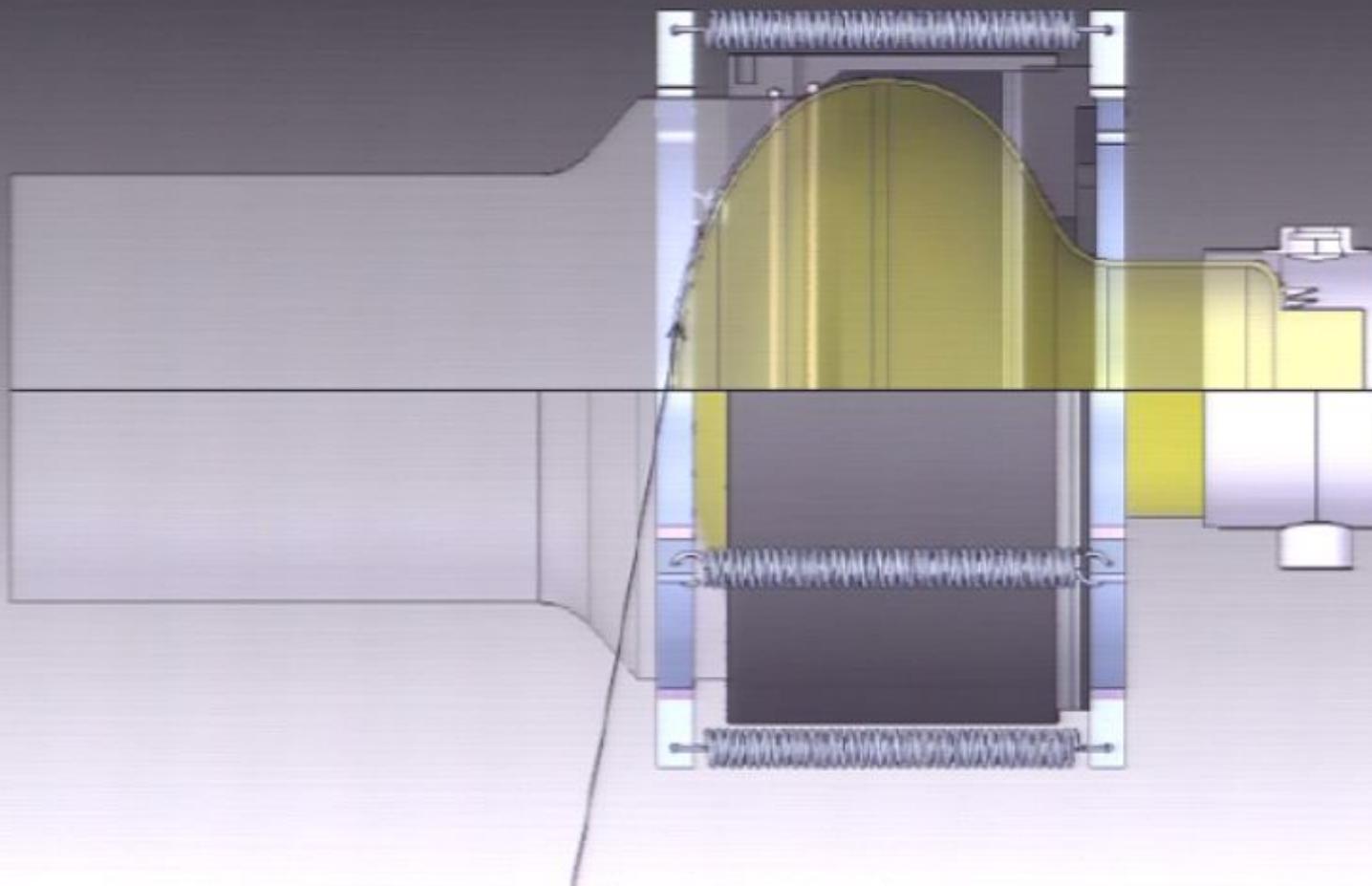
Light attenuation in acrylic



Measured transmission with Lambda UV-VIS spectrometer on carefully machined sets of acrylic rods for several acrylic suppliers

UV absorber acrylic from Spartech has been selected as light guides

PMT attachment



mineral oil optical coupling



Project status

- Critical procurement including acrylic vessel with Reynolds Polymer and light guides with Spartech Polycast in place
- Deck structure and shielding tank installed at SNOLAB
- PMTs, HV system, digitizing electronics (CAEN 1720), slow controls etc. delivered
- Cryocooler system to SNOLAB Jan 2012
- Acrylic vessel installation in spring 2012



DEAP collaboration

- University of Alberta
 - P. Gorel, A. Hallin, J. Soukup, C. Ng, B. Beltran, K. Olsen, D. Grant
- Carleton University
 - K. Graham, C. Ouellet
- Queen's University
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- SNOLAB/Laurentian
 - B. Cleveland, F. Duncan, R. Ford, C.J. Jillings, M. Batygov
- SNOLAB
 - I. Lawson, K. McFarlane, P. Liimatainen, O. Li
- TRIUMF
 - P.A. Amaudruz, A. Muir, F. Retiere

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R. Henning, M. Ronquest

University of South Dakota

D. Mei

University of Pennsylvania

J. Klein, A. Mastbaum, G. Orebi-Gann

Yale University

W. Lippincott, D. McKinsey, J. Nikkel

Summary

- Single-phase liquid argon allows for simple, well-understood detector
- DEAP-3600 has spin-independent sensitivity 10^{-46} cm^2 for 100 GeV WIMP
- The detector is designed for very low backgrounds (less than 0.6 background events in 3-year run)
- Construction has begun and will continue throughout 2012
- Data-taking expected in 2013

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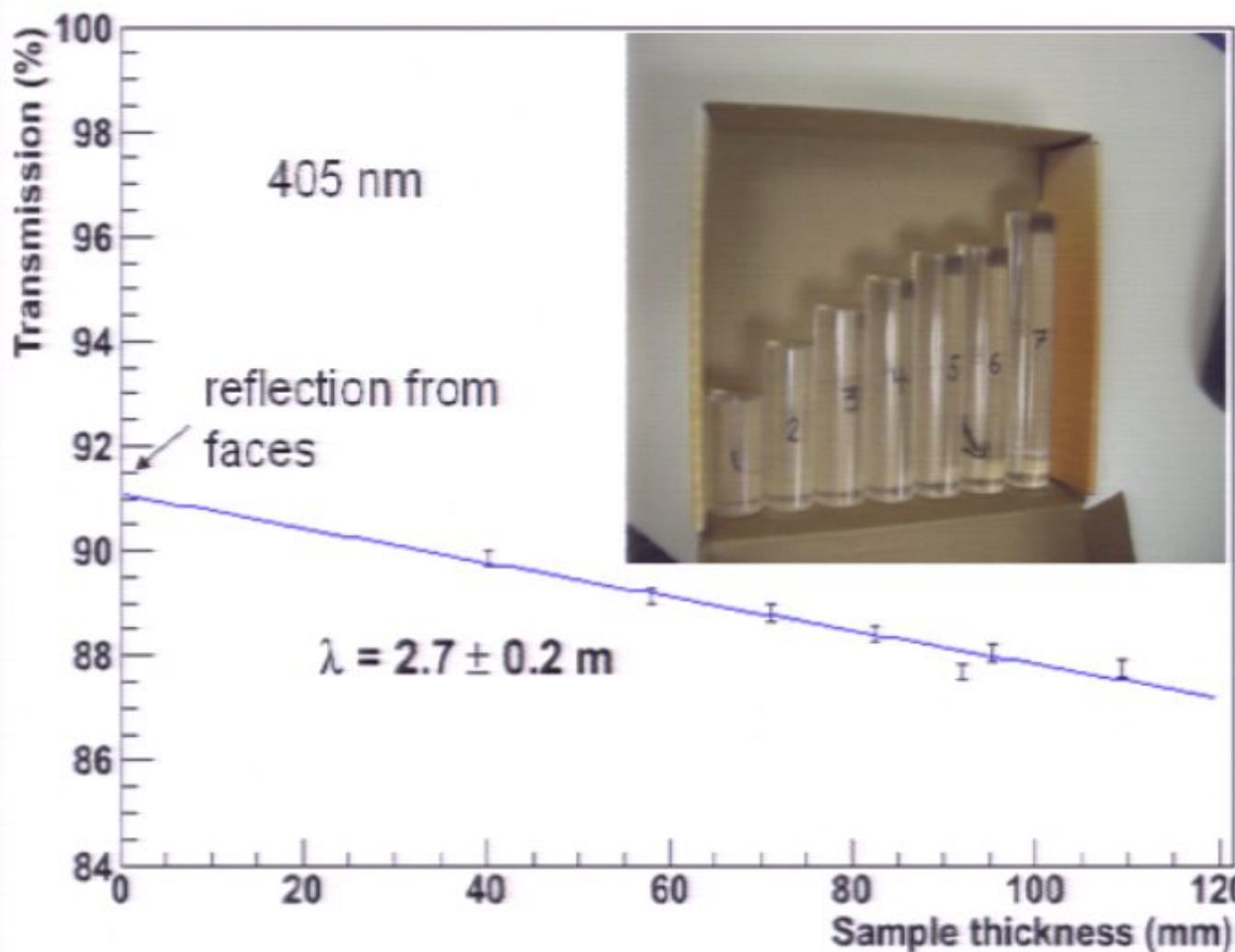


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