DEAP-3600 Dark Matter Search at SNOLAB

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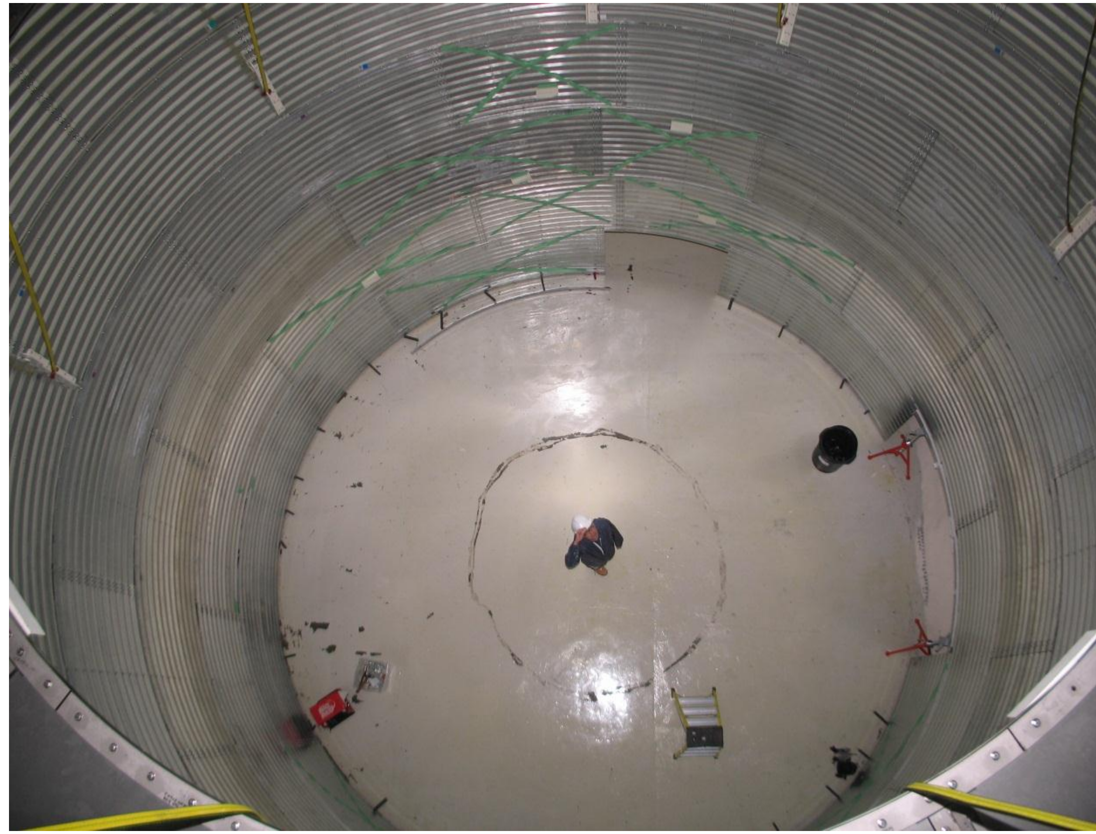

DEAP-3600 H_2O shield tank in SNOLAB Cube Hall

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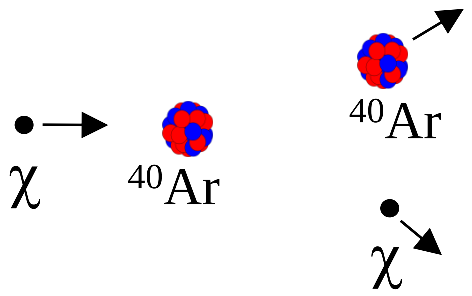
TAUP Munich Sept 8 2011

Direct WIMP detection with liquid argon



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

Pulse-shape discrimination (PSD) is very powerful in argon, allows for suppression of background β/γ events.

Projected pulse shape discrimination (PSD) in argon allows threshold of approx. 20 keV_{ee} (60 keV_r)

1000 kg argon target allows 10^{-46} cm^2 sensitivity (spin-independent) with ~20 keV_{ee} threshold (~65 keVr) threshold, sufficient to mitigate ^{39}Ar

Liquid argon
- is easily purified and has a high light yield
- is well-understood, allows for very simple scintillation detector
- has an easily accessible temperature (85K)
- allows a very large detector mass (~tonne) with uniform response (few % light yield uniformity)

DEAP-1 (7 kg)
DEAP-3600 (3600 kg)

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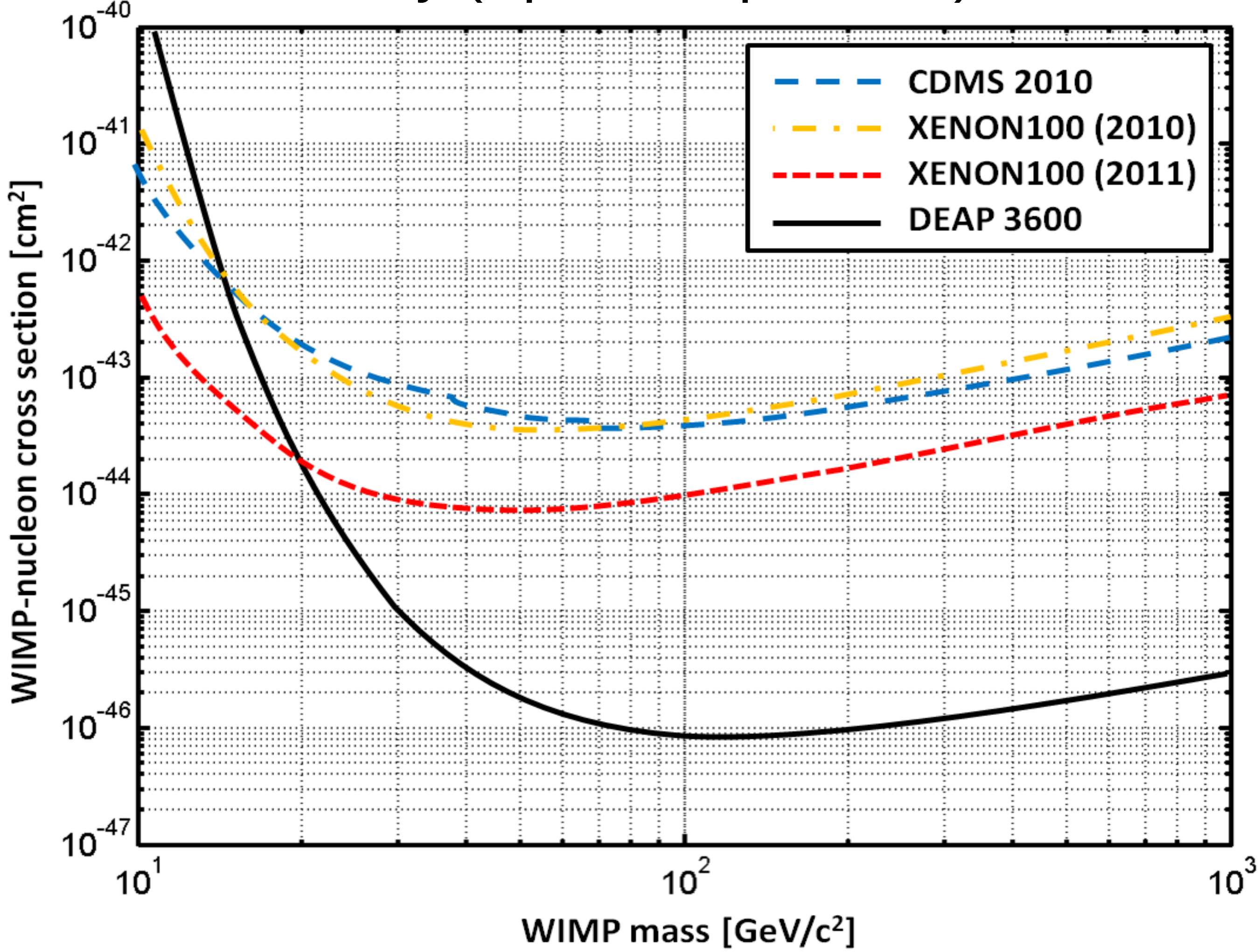
DEAP-3600 Sensitivity (Spin-Independent)

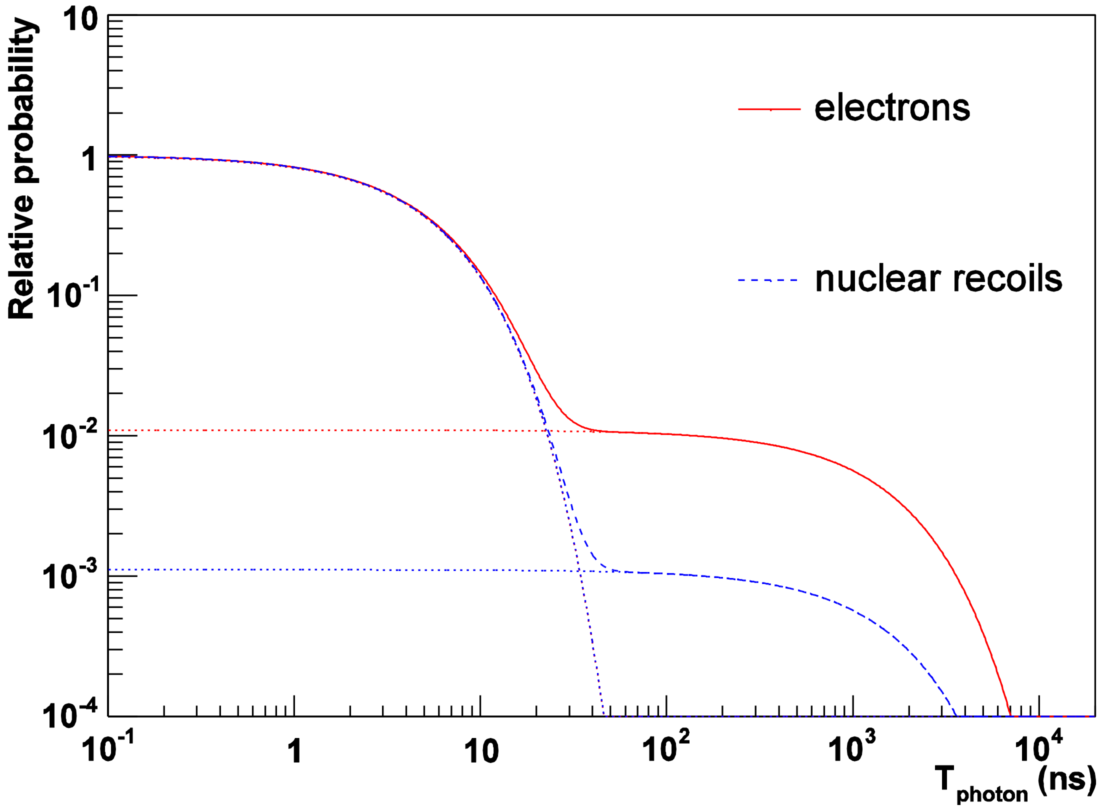


Above: 1000 kg 3 year run sensitivity 20 keV_{ee} threshold, atmospheric argon

Collaboration with Princeton group to produce 3600 kg target of argon depleted by factor of 25 or more in ^{39}Ar

Pulse-shape discrimination for β/γ rejection in liquid argon

Parameter	Ar	Xe
Yield (x10^4 photons/MeV)	4	4.2
Prompt time constant τ_1	6 ns	2 ns
Late time constant τ_3	**1.5 μs**	21 ns
I_1/I_3 for electrons	0.3	0.3
I_1/I_3 for nuclear recoils	3	1.6
λ(peak) nm	128	174
Rayleigh scattering (cm)	90	30



Astroparticle Physics 25, 179 (2006)

PSD can reject ^{39}Ar events (typically 1 Bq/kg argon)

scintillation pulse-shape analysis for discrimination of e- vs nuclear recoils
➡ no electron-drift

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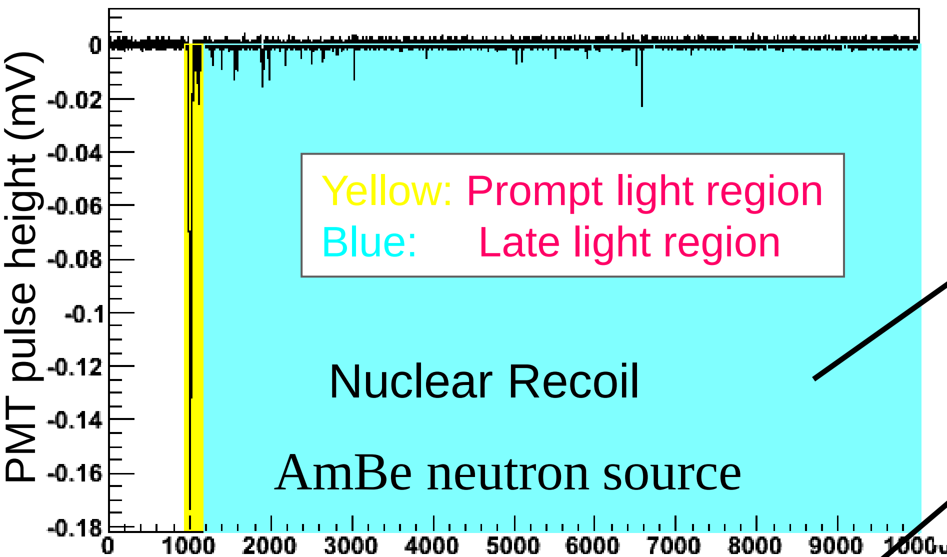
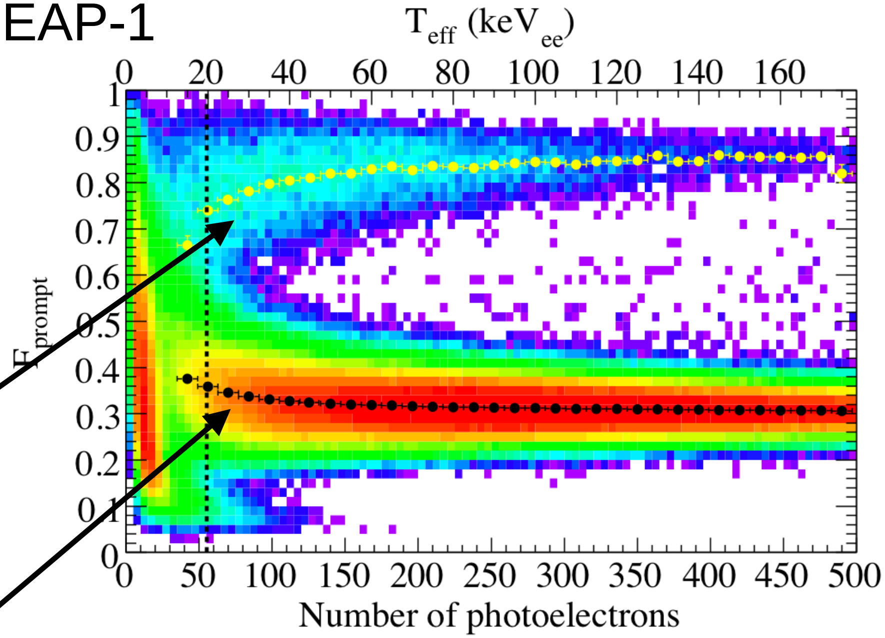
Background suppression with PSD in DEAP-1



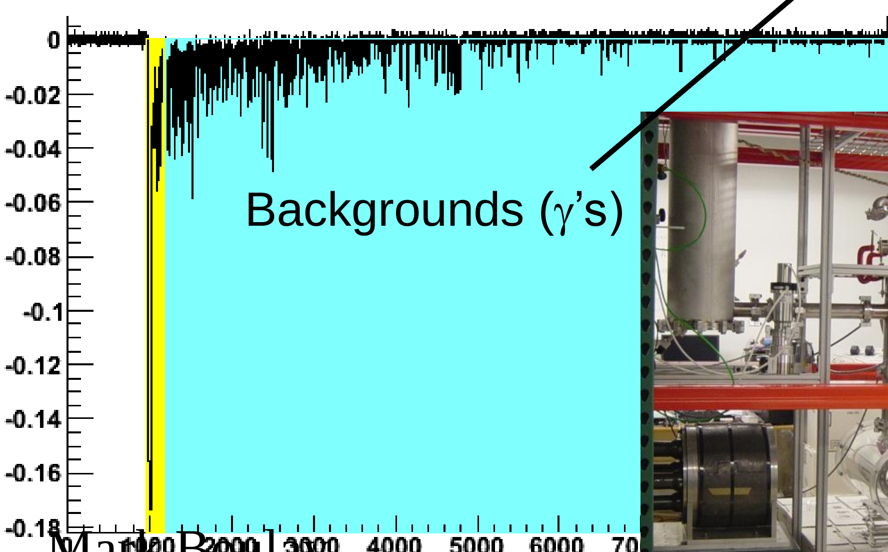


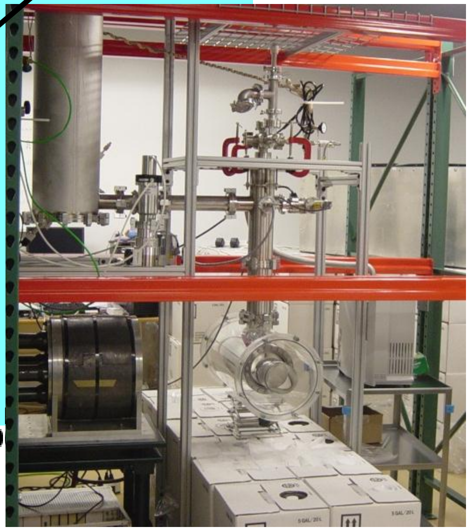
$$F_{prompt} = \frac{PromptPE(150ns)}{TotalPE(9\mu s)}$$

γ suppression better than 6×10^{-8} (45-88 keV$_{ee}$, Queen's)

3×10^{-8} now achieved at SNOLAB, studies ongoing with improved LY, lower threshold

Simple model of photon statistics predicts 10^{-10} suppression at 120 pe (20 keV$_{ee}$ threshold DEAP-3600)





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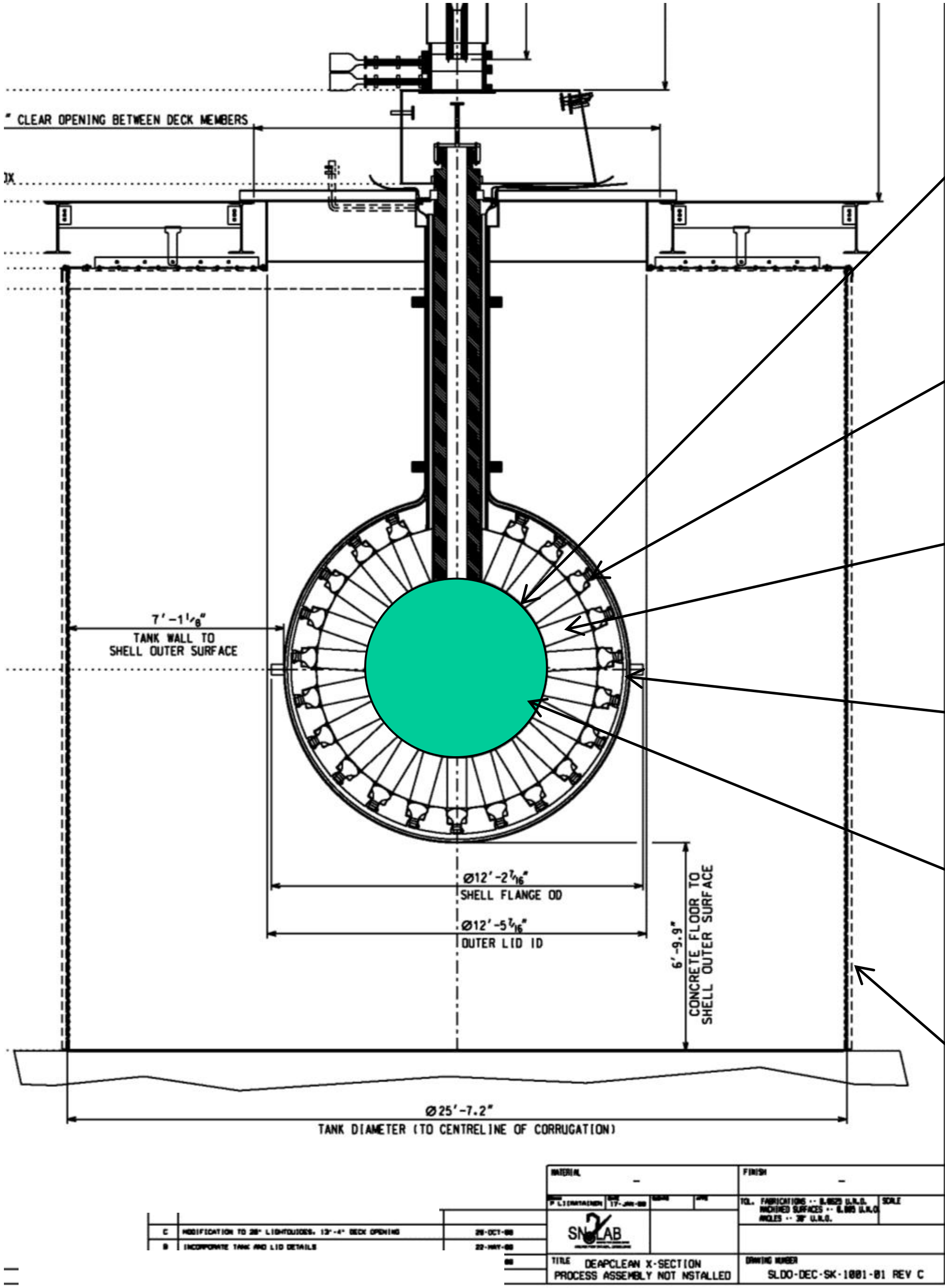
DEAP-3600 Detector



85 cm radius acrylic sphere contains 3600 kg LAr
(55 cm, 1000 kg fiducial, sealed vacuum vessel to control backgrounds)

255 8" PMTs
(Hamamatsu R5912 HQE)

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 (10 g) inside of neutron shield

8.5 m diameter water shielding sized for reduction of (α,n) from rock

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DEAP-3600 materials radiopurity requirements

Component	Material	^{238}U g/g	^{232}Th g/g	^{210}Pb g/g	Rate
Acrylic Vessel	acrylic	2×10^{-12}	9×10^{-12}	10^{-20}	
Light Guides	acrylic	1×10^{-11}	4×10^{-11}	10^{-18}	
PMTs (255)	glass +	75×10^{-9}	30×10^{-9}		
Rn emanation					5 μBq
Internal surface					0.2 μBq/m^2

Detailed G4 MCs set light guide length = 50 cm for neutron moderation

Neutron production cross-checked with SOURCES (and SNO codes), neutron detection and shielding efficiency verified with DEAP-1 LAr detector

Active assay program (U/Th/Pb/Rn emanation). Most other materials require ~ppb

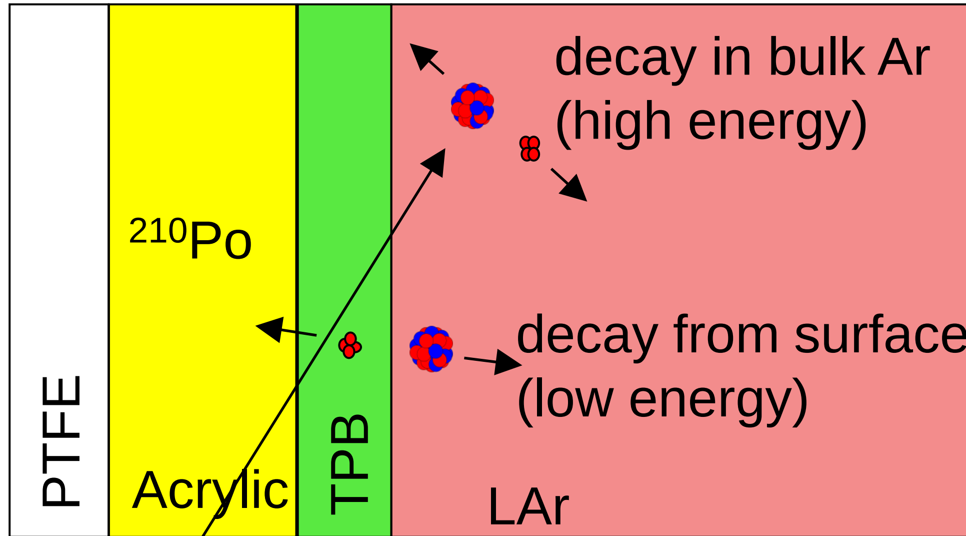
Developed system to vaporize many kg's of acrylic and count residue with Ge well detector for ^{210}Pb assay

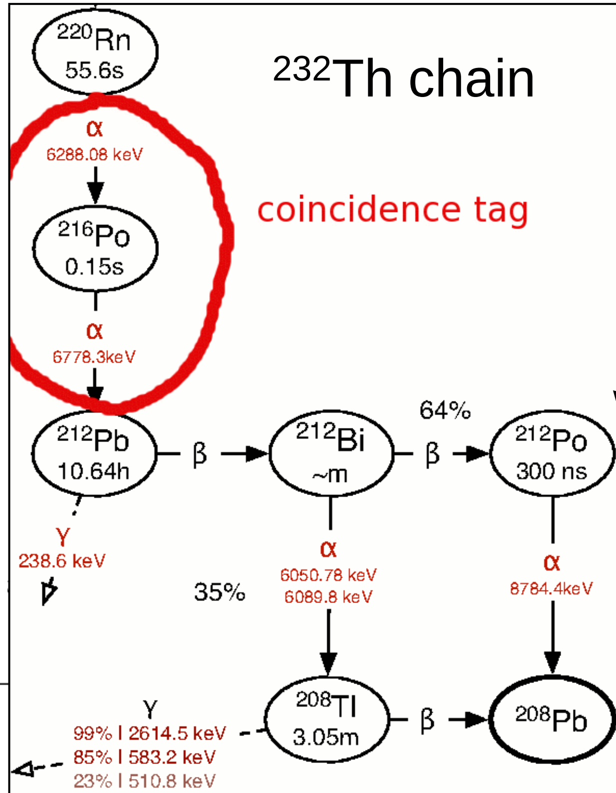
Target levels are for 1 background event or less per 15 tonne-yr in energy ROI, total background budget is < 0.6 events in 3 tonne-years from all sources

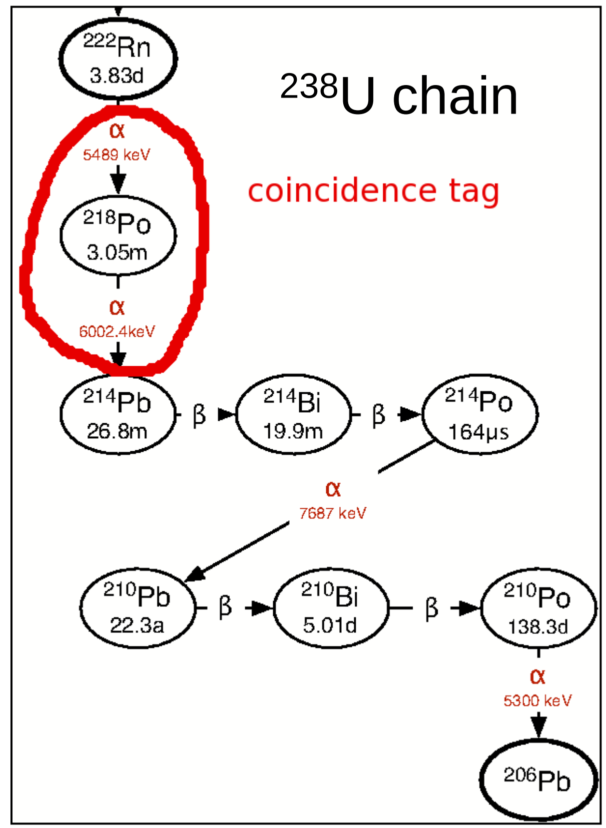
Construction and Prototyping of DEAP-3600 Components

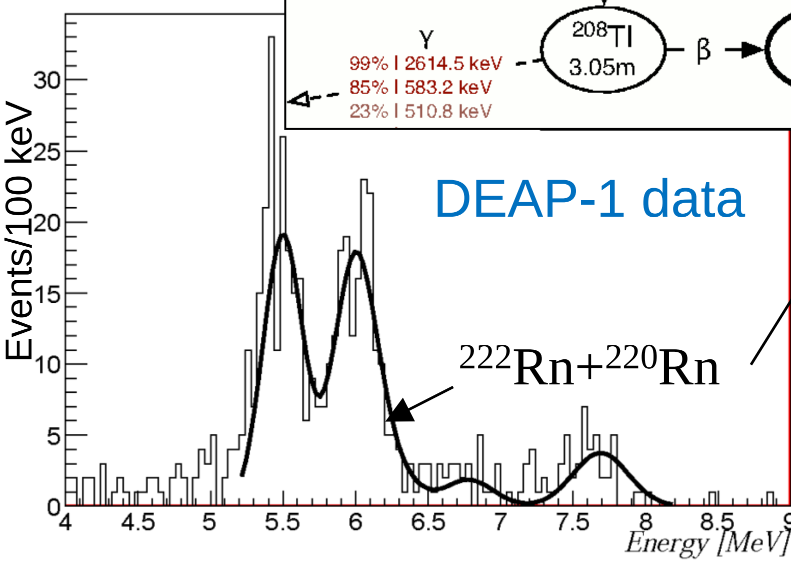
Rn/α Backgrounds in LAr (DEAP-1)

June 2010





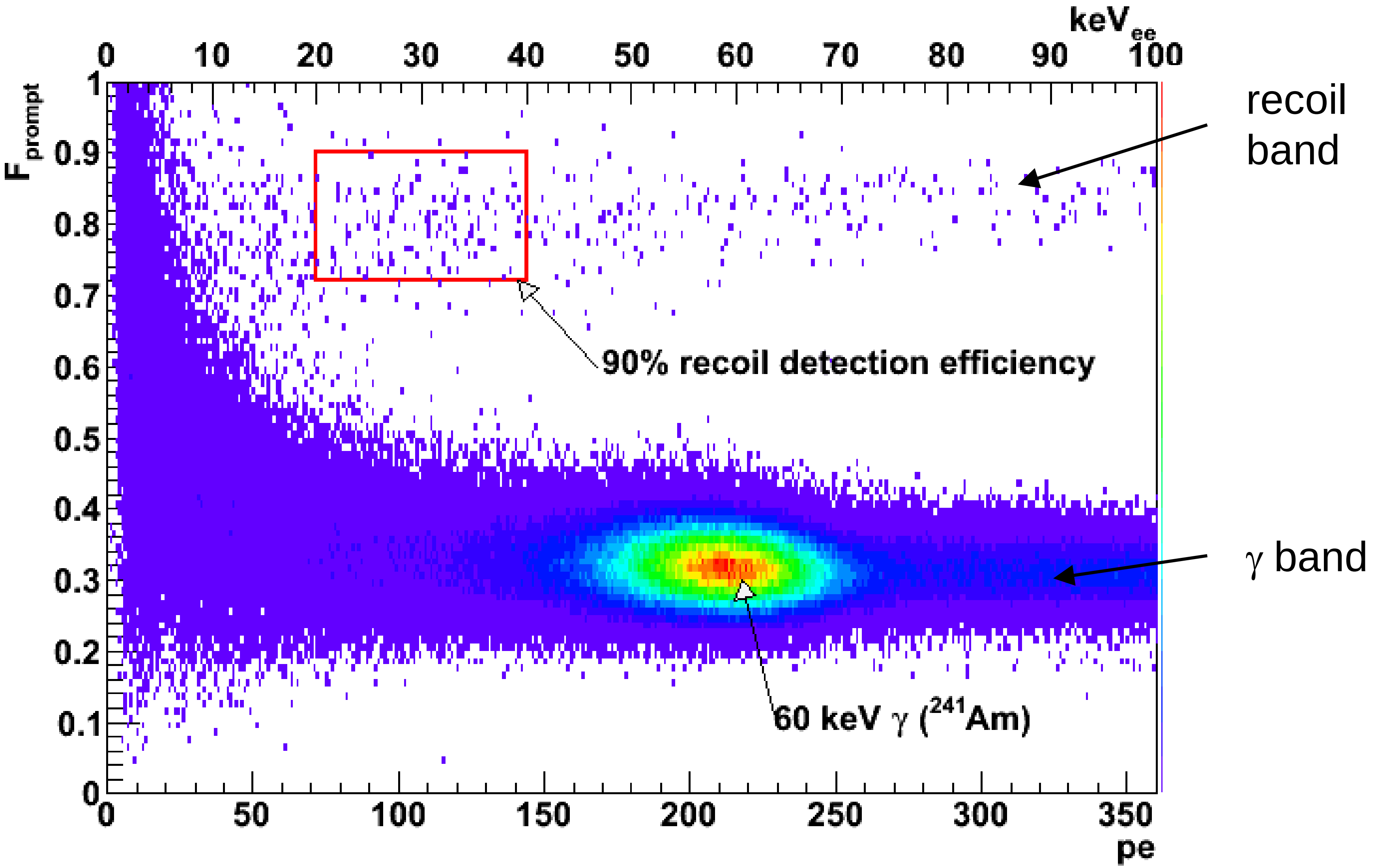




14 µBq/kg ^{222}Rn
3 µBq/kg ^{220}Rn

total rate
100 µBq ^{222}Rn
20 µBq ^{220}Rn

Calibration with DEAP-1 at SNOLAB (7 kg liquid argon)



Nuclear recoil calibration with neutrons from (α,n) Am-Be source

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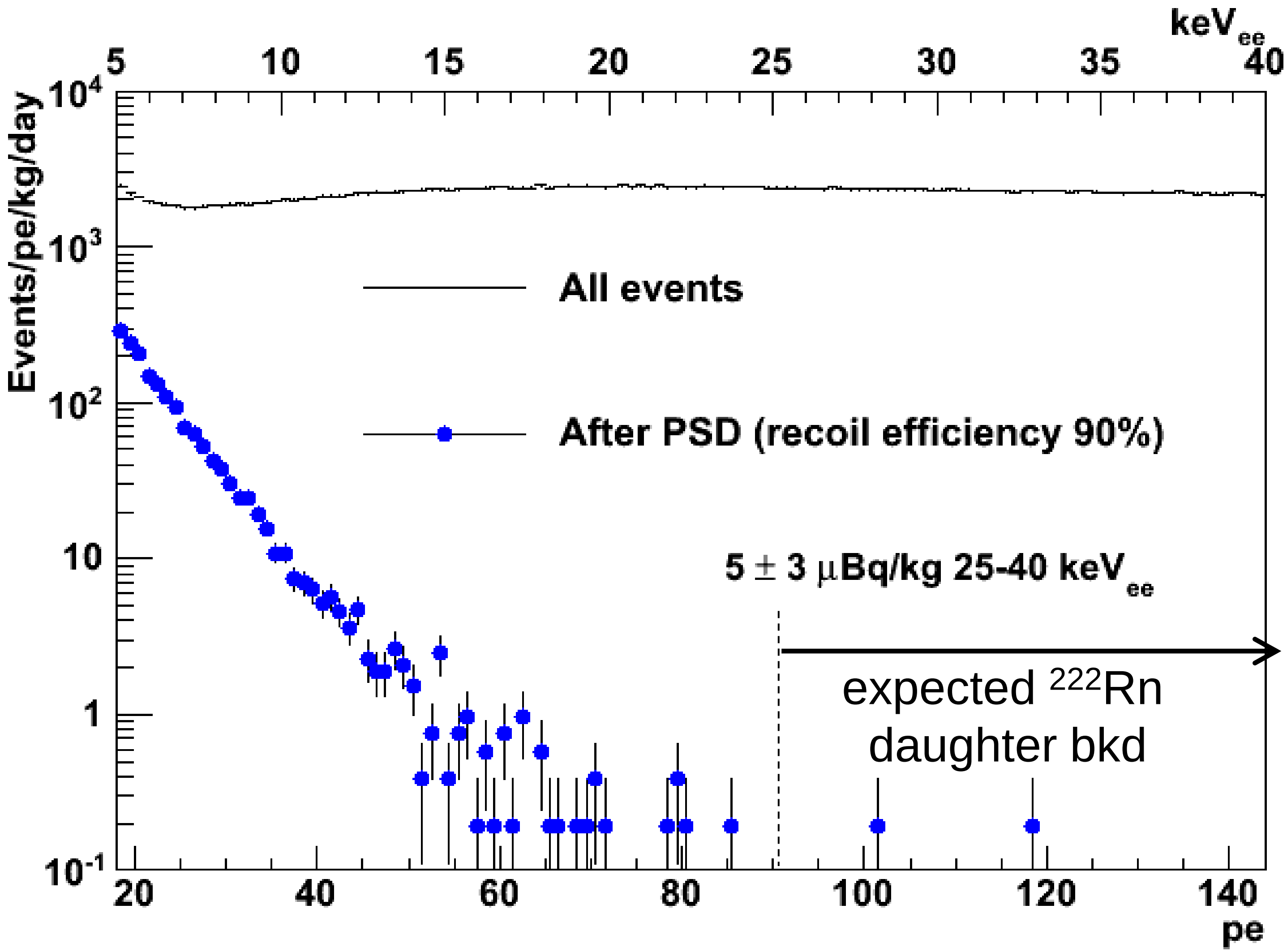
Low-background data from DEAP-1 at SNOLAB (7 kg liquid argon)



Aug. 2011

Low-energy backgrounds in DEAP-1 with and without PSD (3.6 pe/keV$_{ee}$)
Light collection in DEAP-3600: 6 pe/keV$_{ee}$ (20 keV$_{ee}$ threshold at 120 pe)

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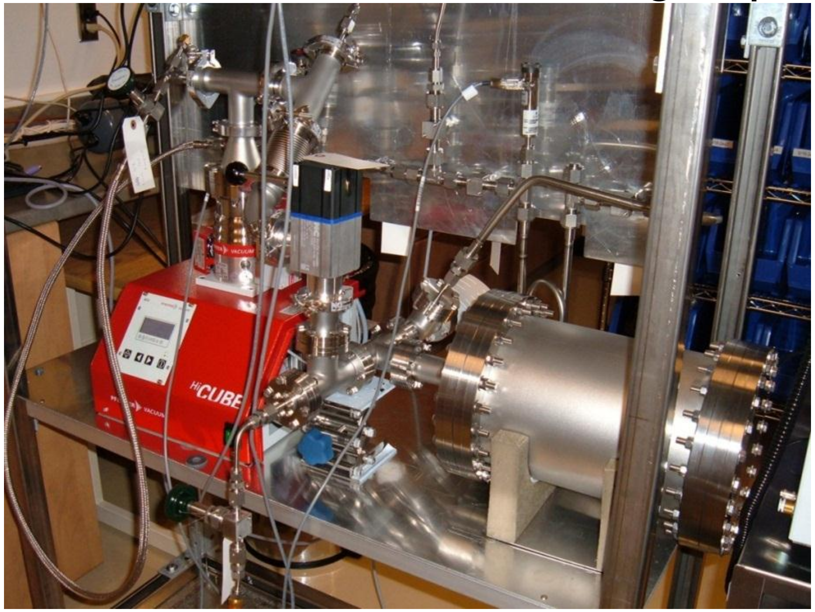
Radon control in DEAP-3600 argon purification loop



Purification loop components (tubing, valves, etc.) selected for low Rn emanation

Orbital welder with radiologically qualified tips used in cleanroom for assembly of purification loop

All-metal emanation system (built with components selected for DEAP purification loop) for low-background radon emanation

Study of emanation from 1200 sample welds in electropolished ½" tubing found emanation of 25 +/- 4 μBq/m. Working on passivating/cleaning to reach target of ~1 μBq/m.

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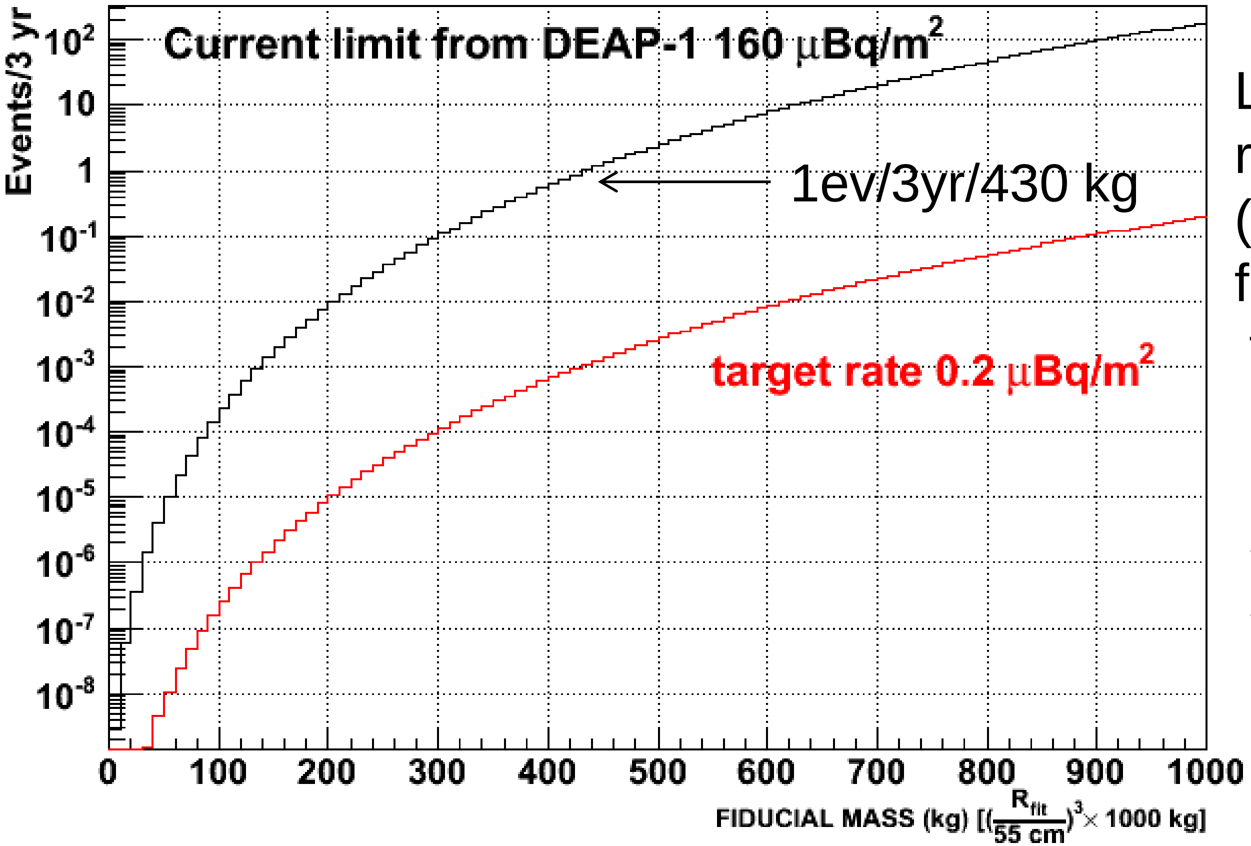
Surface background control in DEAP-3600

Inner acrylic detector surface will be cleaned (removed) in-situ after detector construction. Sanding device deployed in inert Rn-free gas to clean surfaces to bulk U/Th/Pb target levels.

Residual surface events from ^{222}Rn progeny and other sources will be rejected in DEAP-3600 using position reconstruction (~10 cm resolution at threshold).



Left: background rates versus fiducial mass (after pos. reconstruction) for
target surface backgrounds (red)
and
scaled to DEAP-1 surface rates (black)

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Project Status and Timeline

Funded as R&D project since 2006, full capital funding end of 2010 (start of construction at SNOLAB)

R&D and QA to meet acrylic radiopurity and transparency requirements until 2011; Contracts now let with Reynolds Polymer and Spartech Polycast for fabrication of Acrylic Vessel and Light Guide acrylic (first batches now cast). Attenuation length of ~5 m

Acrylic Vessel machining at U of Alberta, shipped to SNOLAB for installation spring 2012

Cryocooler system (3 Stirling SPC1+3000L dewar) to SNOLAB Jan 2012

Deck structure and shielding tank installed at SNOLAB

PMTs, HV system, digitizing electronics (CAEN 1720), slow controls etc. delivered - construction planned throughout 2012

Start of operation with liquid argon, 2013

Summary

Single-phase liquid argon allows for simple, well-understood detector. Relatively high threshold imposed by PSD requirement for β/γ reduction overcome by v. large target mass for good sensitivity

DEAP-3600 designed for very low background rates from all known sources (external/internal neutrons, β/γ's, surface contamination from Rn exposure, ^{210}Pb deposition, Rn emanation). Active materials screening program

Design sensitivity 10^{-46}cm^2 SI for ~100 GeV WIMP

Detector construction to continue throughout 2012

Running with liquid argon at SNOLAB 2013

DEAP collaborators (Canadian groups)

- **University of Alberta**

  D. Grant, P. Gorel, **A. Hallin**, J. Soukup, C. Ng, B. Beltran, K. Olsen, R. Chouinard, T. McElroy, S. Crothers, S. Liu, P. Davis, and A. Viangreiro
- **Carleton University**

  K. Graham, C. Ouellet
- **Queen's University**

  M. Boulay, B. Cai, D. Bearse, K. Dering, **M. Chen**, S. Florian, R. Gagnon, V.V. Golovko, M. Kuzniak, J.J. Lidgard, **A. McDonald**, **A.J. Noble**, E. O'Dwyer, P. Pasuthip, T. Pollman, **W. Rau**, T. Sonley, P. Skensved, M. Ward
- **SNOLAB/Laurentian**

  B. Cleveland, F. Duncan, **R. Ford**, **C.J. Jillings,** M. Batygov, E. Vazquez Jauregui
- **SNOLAB**

  I. Lawson, K. McFarlane, P. Liimatainen, O. Li
- **TRIUMF**

  F. Retiere, Alex Muir

DEAP/CLEAN collaborators

- **University of Alberta:** P. Gorel, **A. Hallin**, J. Soukup, C. Ng, B. Beltran, K. Olsen
- **Boston University:** D. Gastler, **E. Kearns**
- **Carleton University:** **K. Graham**, C. Ouellet
- **Harvard:** **J. Doyle**
- **Los Alamos National Laboratory:** C. Alexander, S.R. Elliott, V. Gehman, V. Guiseppe, W. Louis, **A. Hime**, **K. Rielage**, S. Siebert, J.M. Wouters
- **MIT:** **J. Monroe, J. Formaggio**
- **University of New Mexico:** F. Giuliani**, M. Gold**, **D. Loomba**
- **NIST Boulder:** **K. Coakley**
- **University of North Carolina:** **R. Henning**, M. Ronquest
- **University of Pennsylvania:** **J. Klein**, A. Mastbaum, G. Orebi-Gann
- **Queen's University**: **M. Boulay**, B. Cai, D. Bearse, K. Dering, **M. Chen**, S. Florian, R. Gagnon, V.V. Golovko, M. Kuzniak, J.J. Lidgard, **A. McDonald**, **A.J. Noble**, E. O'Dwyer, P. Pasuthip, T. Pollman, **W. Rau**, T. Sonley, P. Skensved, M. Ward
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- **SNOLAB:** I. Lawson, K. McFarlane, P. Liimatainen, O. Li
- **University of South Dakota:** **D.-M. Mei**
- **Syracuse University:** **R. Schnee**, M. Kos, B. Wang
- **TRIUMF:** **F. Retiere,** A. Muir
- **Yale University:** W. Lippincott, **D.N. McKinsey**, J. Nikkel

CAD groups primarily focused on DEAP-3600

US groups: miniCLEAN (includes LNe target, solar neutrino R&D)