DEAP-3600 Dark Matter Search at SNOLAB

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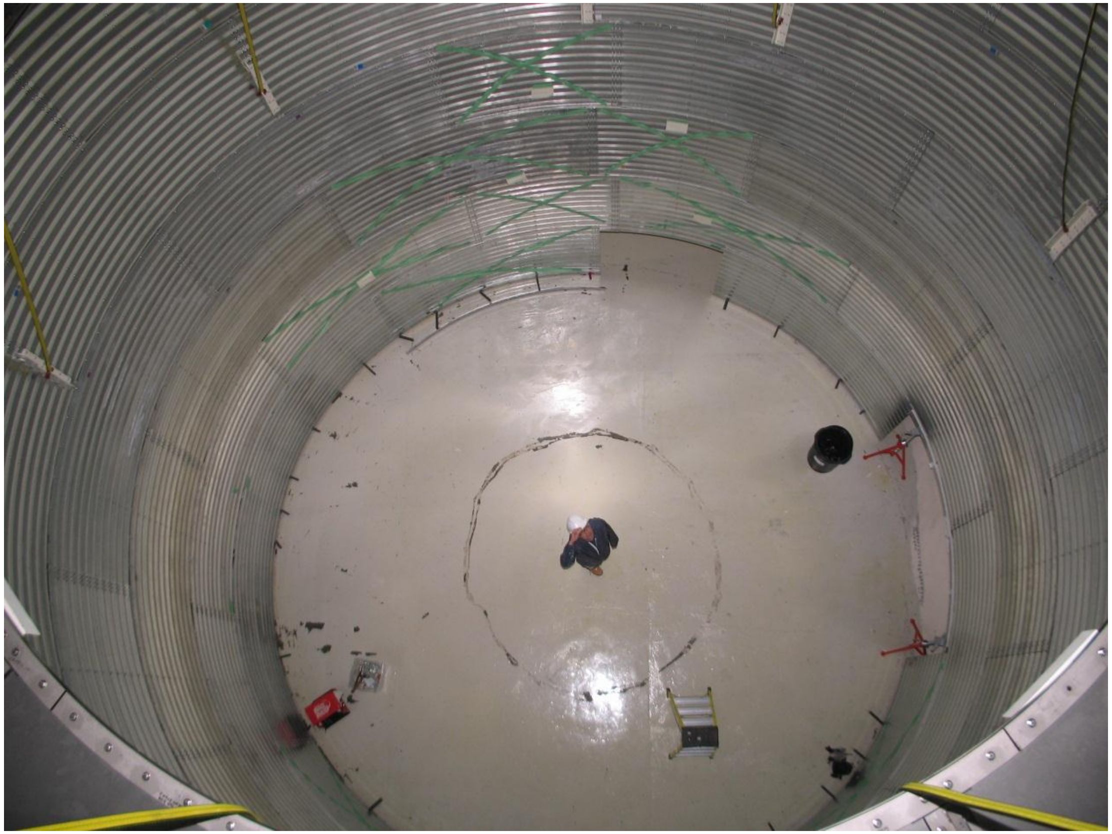

DEAP-3600 H_2O shield tank in SNOLAB Cube Hall

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IDM 2012 July 24, 2012 Chicago KICP

DEAP collaboration

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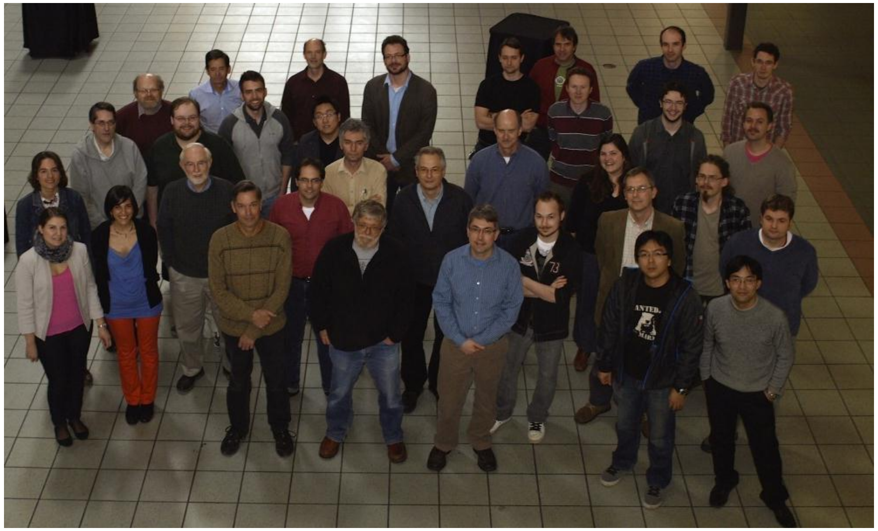
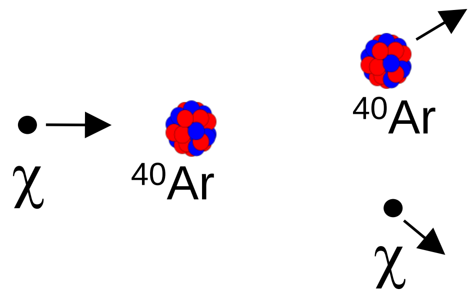


Dark Matter with Liquid Argon



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

  (Astroparticle Physics 25, 179 (2006) and arxiv/0904.2930)

- Very large target masses possible, since no absorption of UV scintillation photons in argon, and no e-drift requirements

- Detector Technology is scalable to very large masses (100 tonnes or more)

- DM search with argon complimentary to xenon, well-separated masses

- **1000 kg** argon target allows ~**10^{-46} cm^2** sensitivity (SI) with ~15 keV$_{ee}$ (60 keVr) threshold, 3-year run

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Backgrounds for Liquid Argon Dark Matter

- **β/γ events:** dominated by ^{39}Ar rate, present in argon at approx. 1 Bq/kg
  - Removal with PSD possible up to ~1000 kg of argon
  - Can also use argon depleted in ^{39}Ar (DAr),
  - Collaborating with Princeton group for DAr for DEAP

- **neutron recoils:** (α,n)+fission, μ-induced
  - Need very strict materials control, and SNOLAB depth + shielding

- **surface events:** Rn daughters and other surface impurities
  - clean surfaces in-situ (resurfacer), position reconstruction, limit radon

DEAP-3600: 1000 kg LAr, 3-year exposure < 0.2 events from each each source (ie 1 background event per 5 Gg-days)

for **10^{-46} cm^2 sensitivity**

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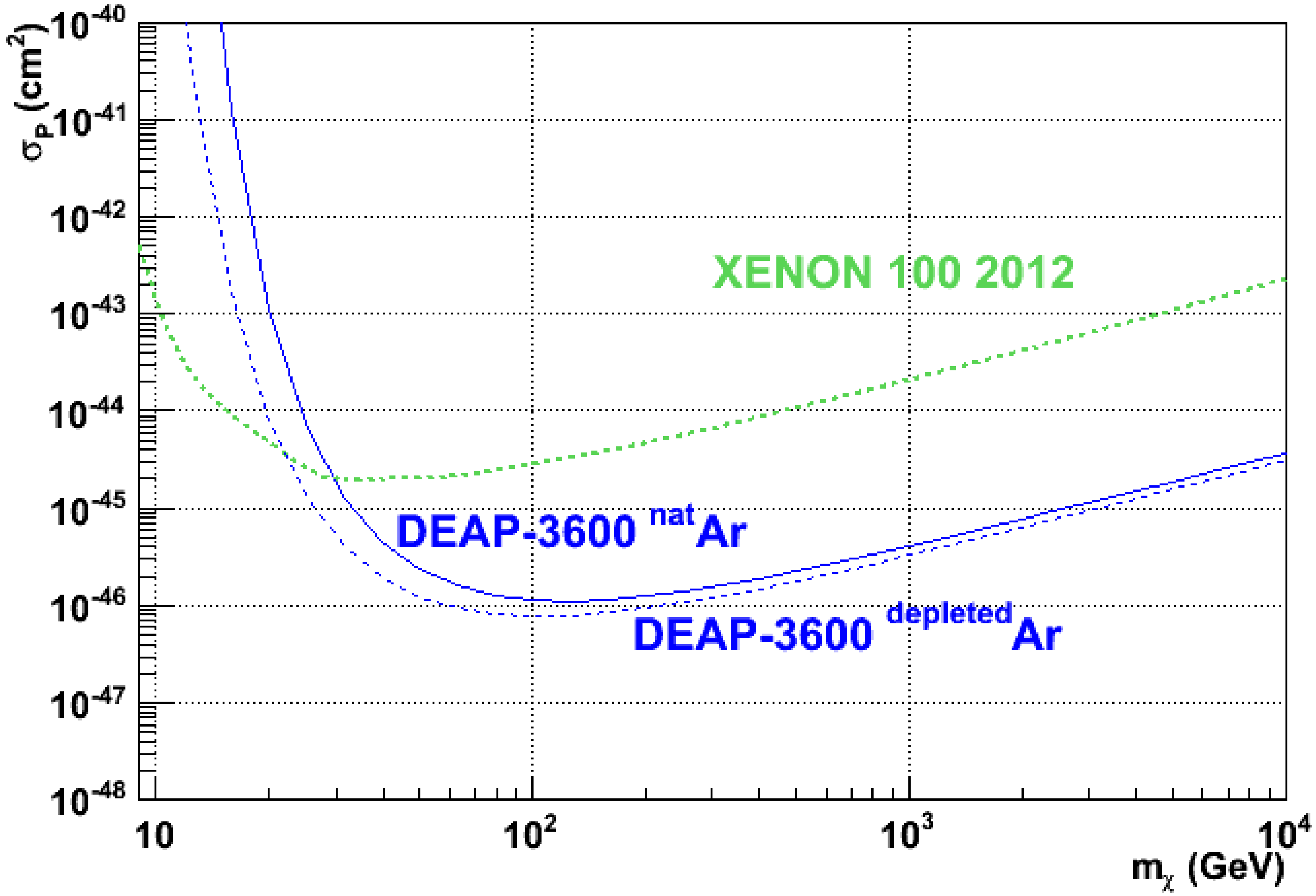
DEAP-3600 Sensitivity (Spin-Independent)



Ultimate sensitivity of DEAP-3600 is 8x10^{-47} cm^2

Shown is “cuts-based” analysis. DAr allows enhanced sensitivity to light WIMPs.

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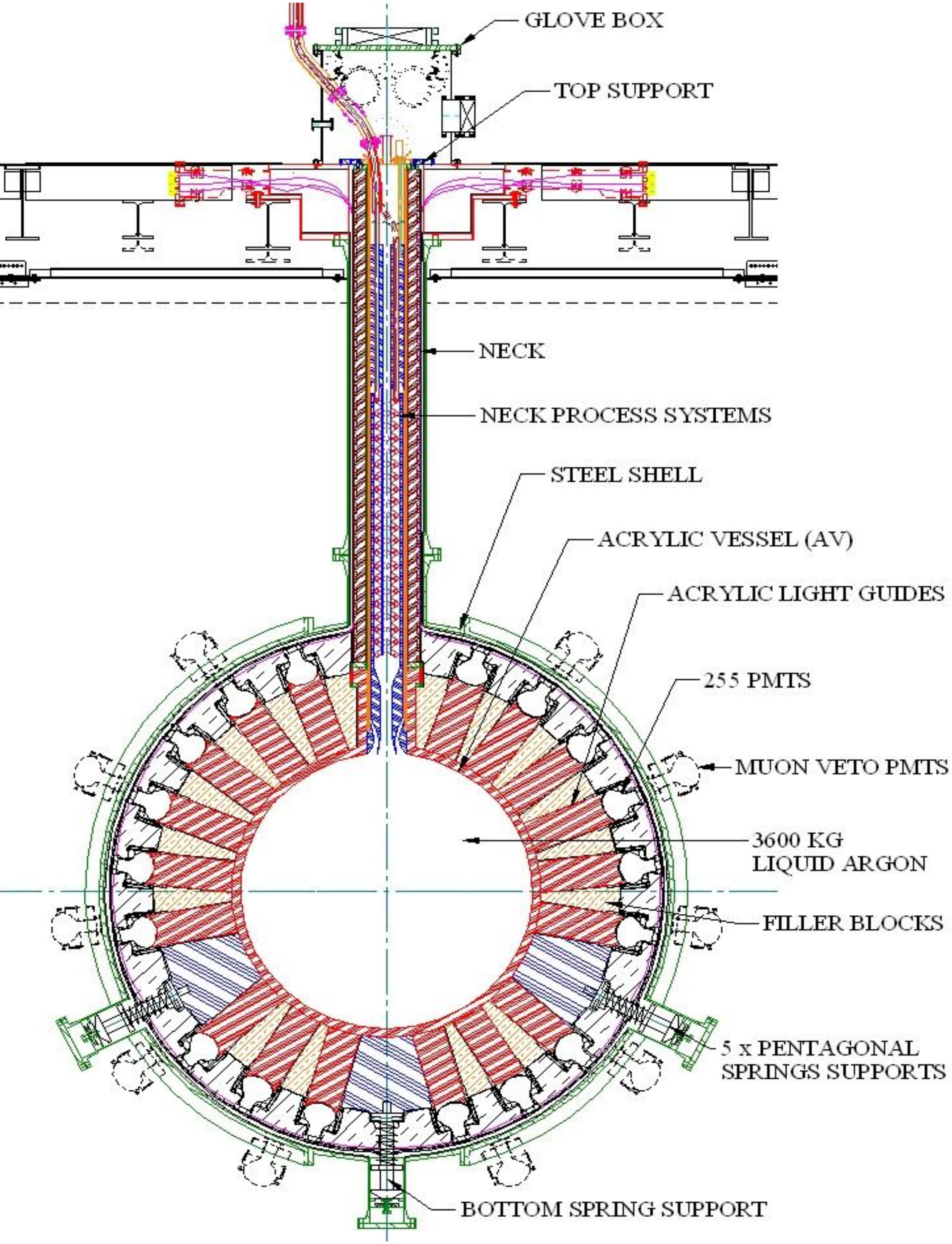
DEAP-3600 Detector



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

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

Large area vacuum deposition source for TPB wavelength shifter deposition

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

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

See Astroparticle Physics 25, 179 (2006)

and arXiv 0904.2930

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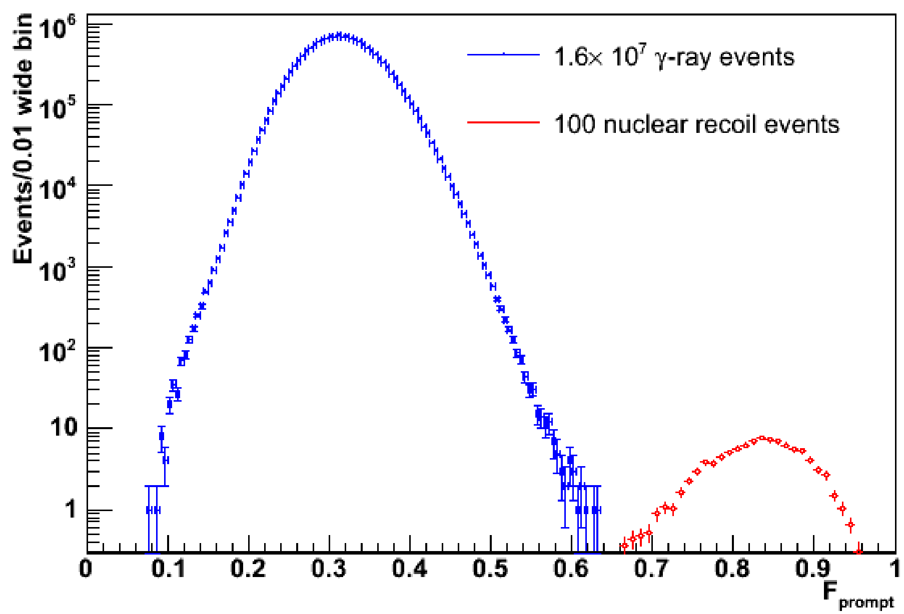
β/γ rejection from recoils with PSD

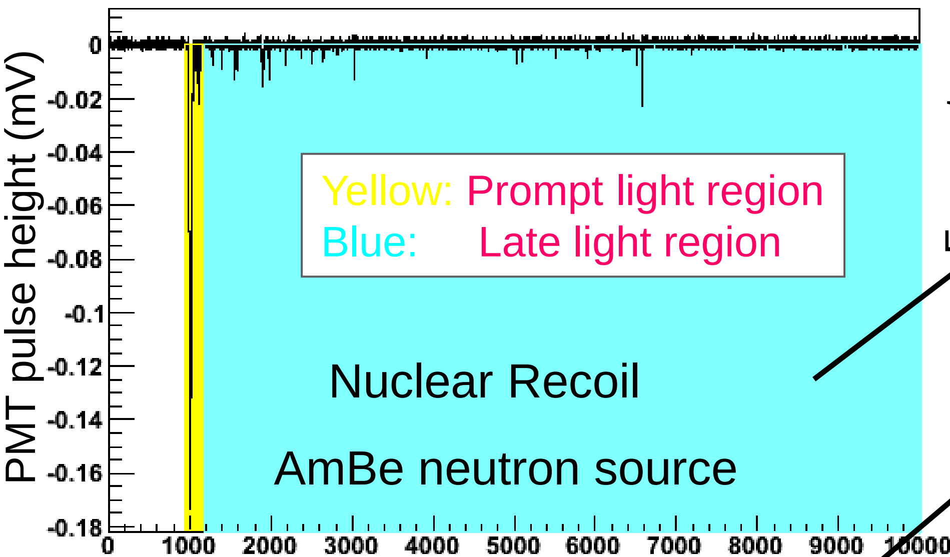
F_{prompt} = fraction of "prompt"/total light

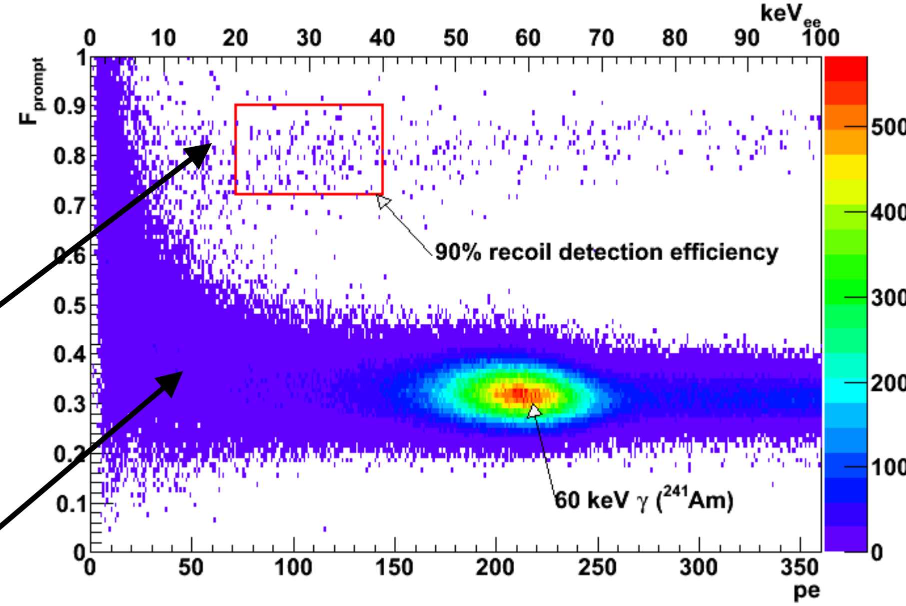
Simple statistical model (no free parameters) predicts 10^{-10} discrimination for 120-240 pe analysis window (60 keVr threshold with 8 pe/keVee)

Model agrees over 8 orders of magnitude tested

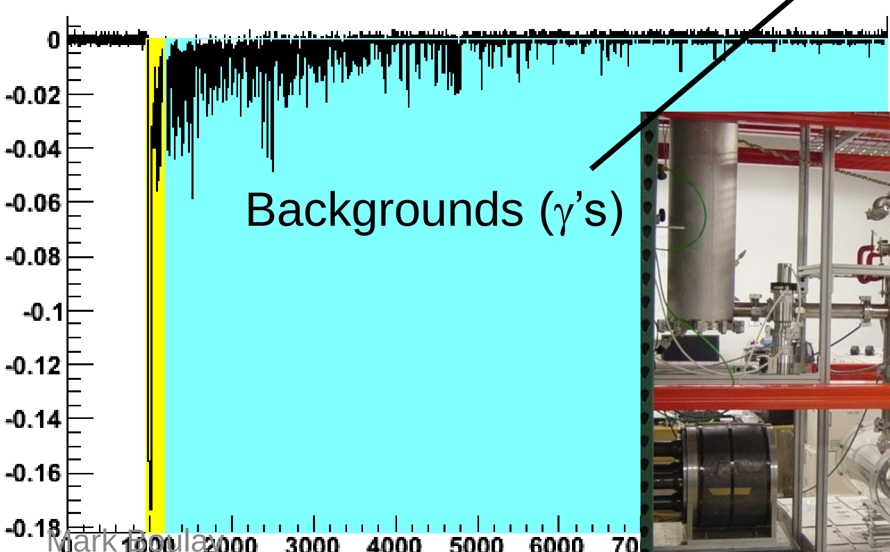


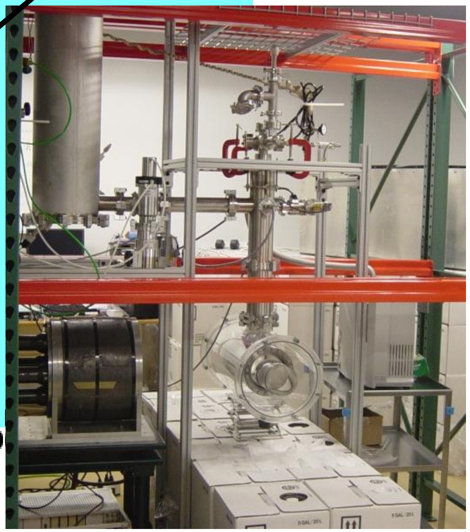
Background suppression with PSD in DEAP-1





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





γ suppression better than 3×10^{-8} (45-89 keV$_{ee}$, 120-240 pe) using tagged γ source

studies planned with higher light yield

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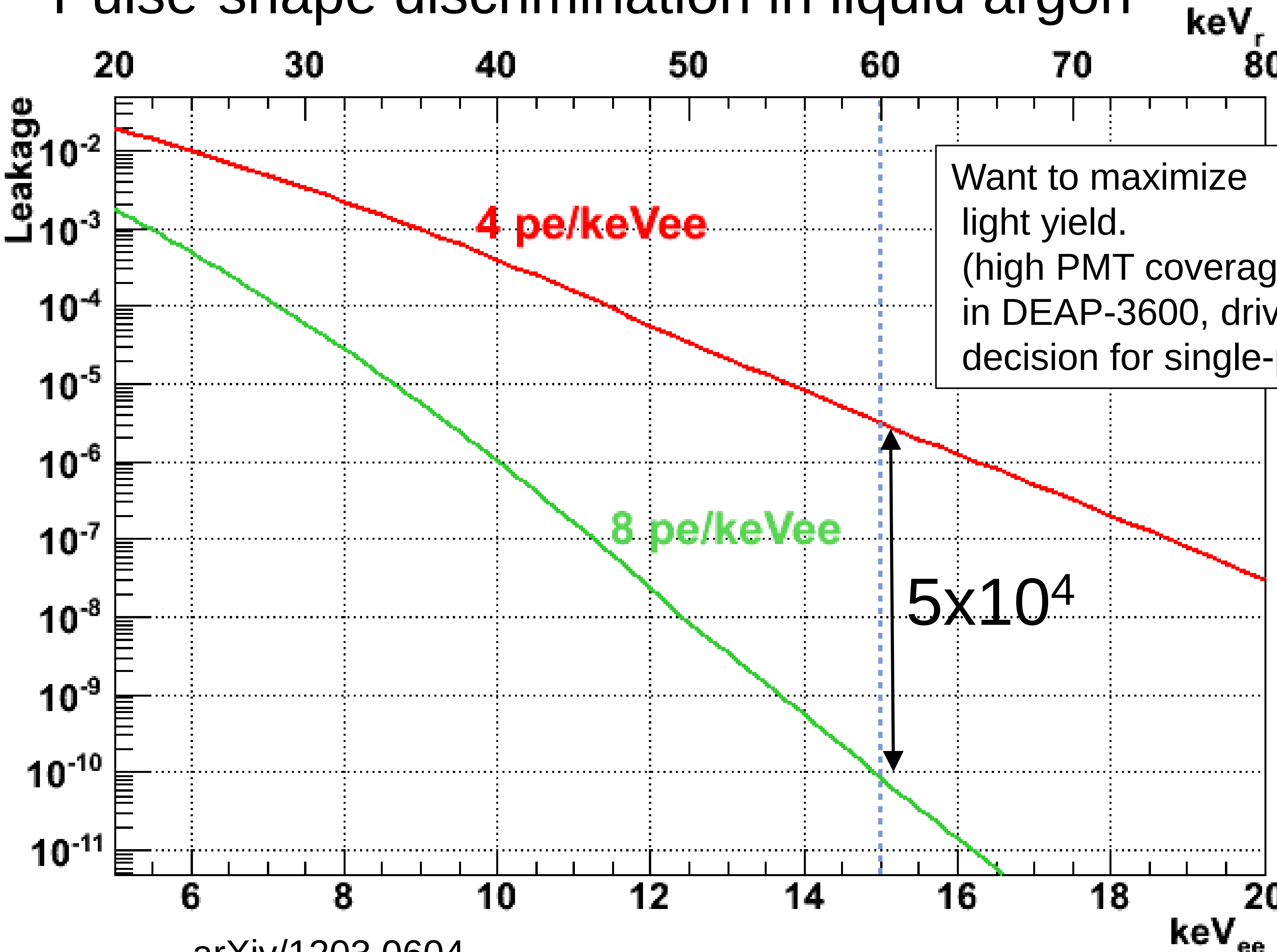
Pulse-shape discrimination in liquid argon



Want to maximize light yield. (high PMT coverage in DEAP-3600, drives decision for single-phase)

arXiv/1203.0604

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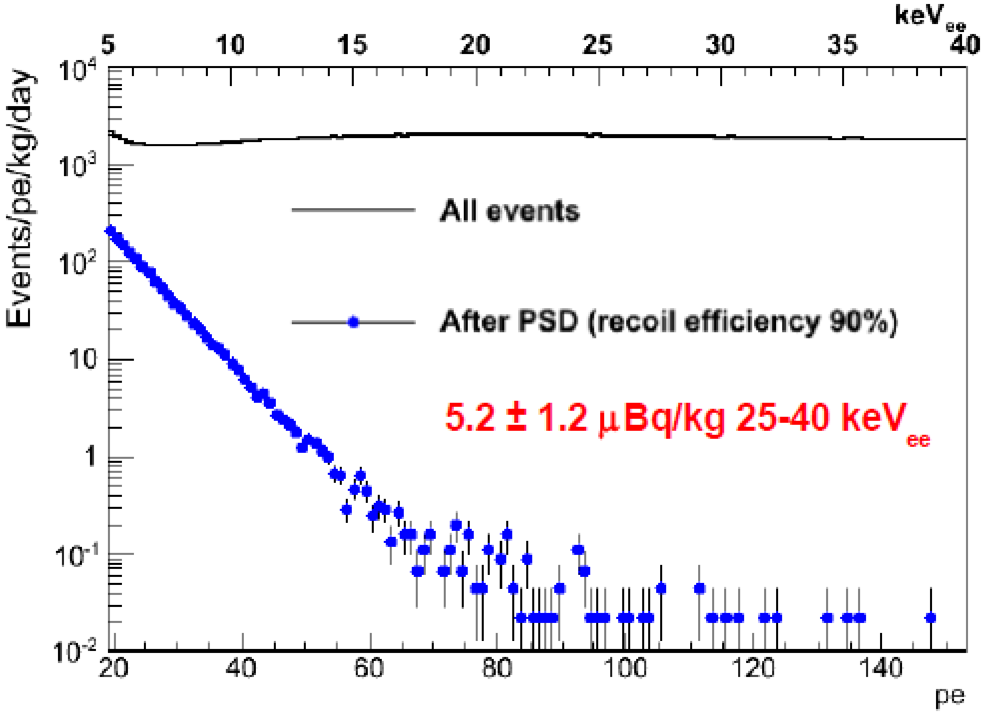
Low-background data from DEAP-1 at SNOLAB (7 kg liquid argon)



Background < **~100 μBq/m²** demonstrated

DEAP-3600 design specification assumed conservative 10-cm position resolution

Detailed Maximum-likelihood fitter analysis predicts x 2 improvement on resolution

Improved resolution + surface backgrounds predict < 0.03 surface backgrounds events in DEAP-3600 run

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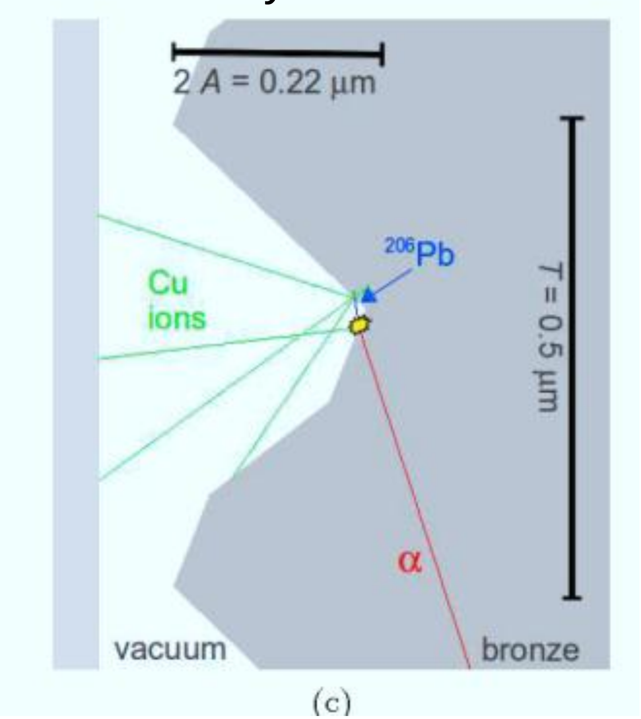
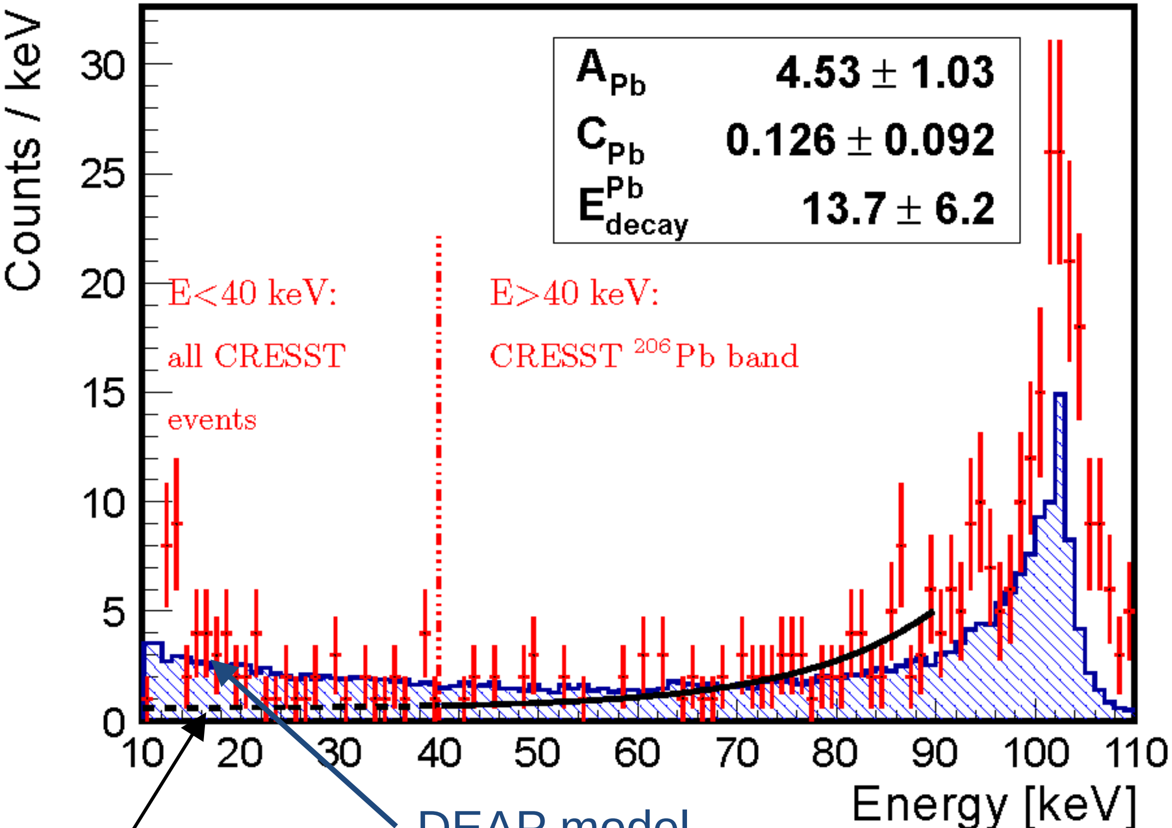
Aside: Surface Backgrounds and Low Energy Events

Surface Roughness required to understand low-energy/high-energy ratio in DEAP-1

^{210}Po decay from surface



partial shadowing shifts
events to low energy



DEAP model

CRESST-II model (dashed line)

arXiv:1203.1576, Kuzniak et al, accepted for publication in Astroparticle Physics

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

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DEAP-3600 Radiopurity Requirements for Neutron Backgrounds

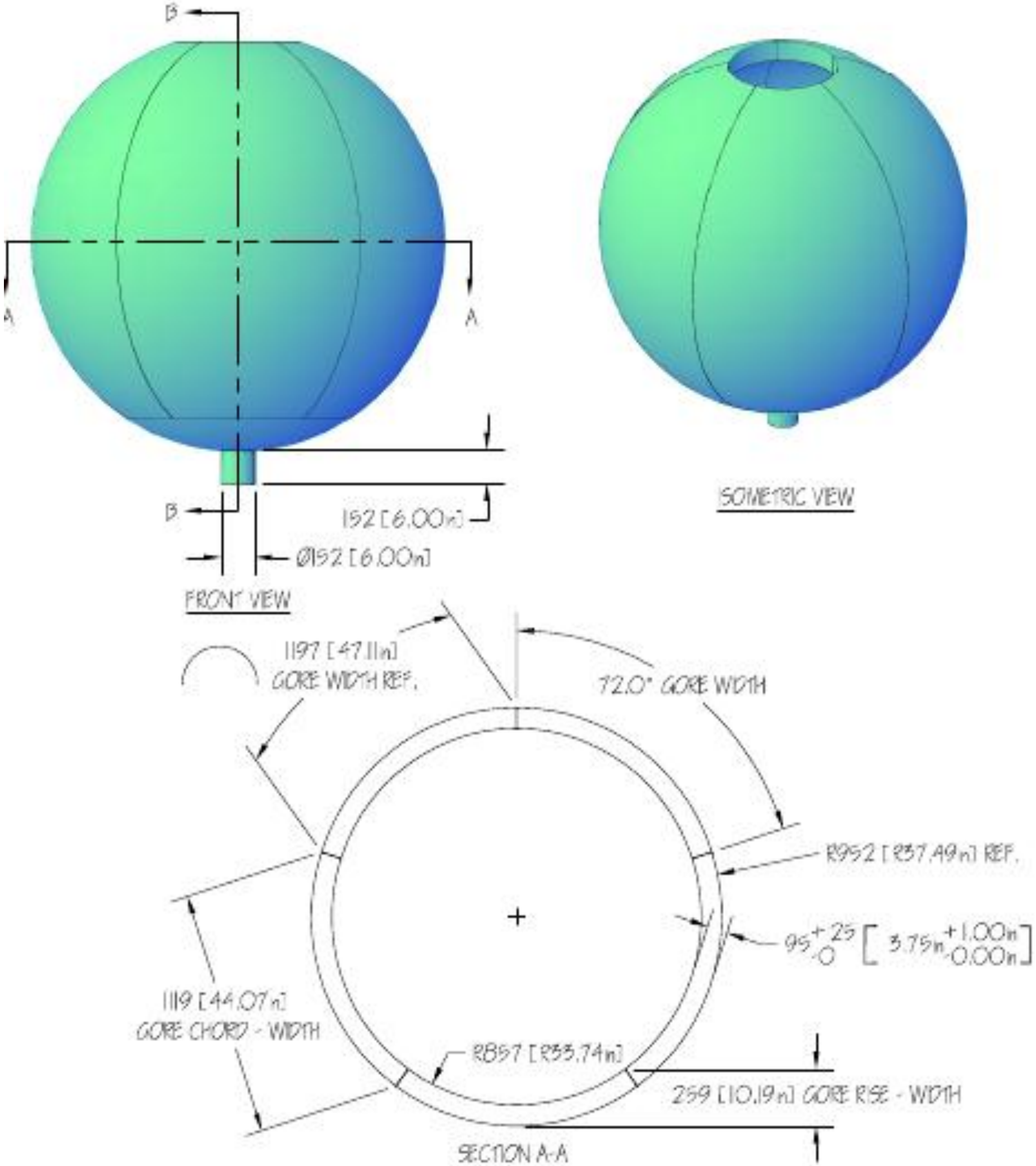
- GEANT-4 Monte-Carlo sets light guide length = 50 cm for neutron moderation
- Neutron production cross-checked with SOURCES (and SNO codes), neutron detection and shielding efficiency verified with DEAP-1 LAr detector
- Active assay program (U/Th/Pb/Rn emanation)
- At our target levels, exposure of materials to radon (in particular acrylic and PE with ppt U, Th) can lead to ^{210}Pb significantly out of equilibrium with ^{238}U
- Strict control of Radon exposure to detector materials
- Extensive QA program to control Radon exposure of acrylic and monomer during all fabrication steps

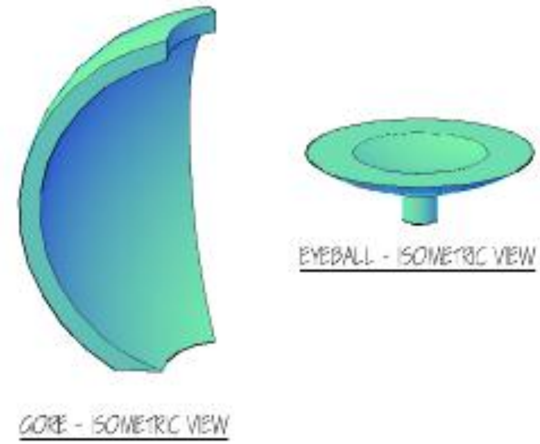
Neutron backgrounds in DEAP-3600 (held extensive internal review in 2011)

(In 3 years)	# of neutrons (produced)	Events in ROI
Acrylic vessel	<44 (Ge γ-assay) <2 (SNO result)	<0.096 <0.004
Light guides	<127 (Ge γ-assay) <5 (SNO result)	<0.015 <0.0006
Filler blocks	<173 (Ge γ-assay)	<0.034
PMTs	$2.6x10^5$	0.140
PMT mounts	7565	0.010
Rn emanation	<44	<0.081
Rn deposition (3 months construction)	38	0.010
Other sources		0.04
Total **(SNO results)**	**<$2.7x10^5$**	**<0.35** **< 0.3**

Above limits use conservative 10-cm position resolution, upper limits for acrylic contamination (assays in progress)

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 arrived RPT Dec, 2011

Bond into sphere
(Reynolds Polymer Tech.)

Machine with light guide ‘stubs’

Bond light guides UG at SNOLAB

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Attenuation in DEAP Qualification and Production Acrylic Sheets

Supplier	Attenuation length (m)	Relative Transmission (%)	Origin	
RPT-UVA	3.7	77		1" slab
RPTA-UVA M&Ch	6.5	87	Thailand	1" slab
RPTA-UVA Standard	2.4	67	Thailand	1" slab
RPTA-UVA 0.5 UVA	0.9	33	Thailand	1" slab
Spartech UVA	5.4	84	USA	
Spartech UVA co-cast (short)	5.0	83	USA	6.5" slab
Spartech UVA co-cast (long)	5.0	83	USA	6.5" slab
Spartech UVA	5.6	85	USA	1" slab
DEAP PRODUCTION ACRYLIC				
RPTAsia (Acrylic Vessel)	Almost no attenuation!	~100%	Thailand	4.5" sheet
Spartech USA (LGs)	3.3 m	74%	USA	4" sheet

After a lot of investigation, found that
Polymerization of acrylic below glass transition temperature (105C) can lead to excess Rayleigh scattering from small-scale inhomogeneous strain (see for example Polymer Journal 34 (6) 2002 p 466)

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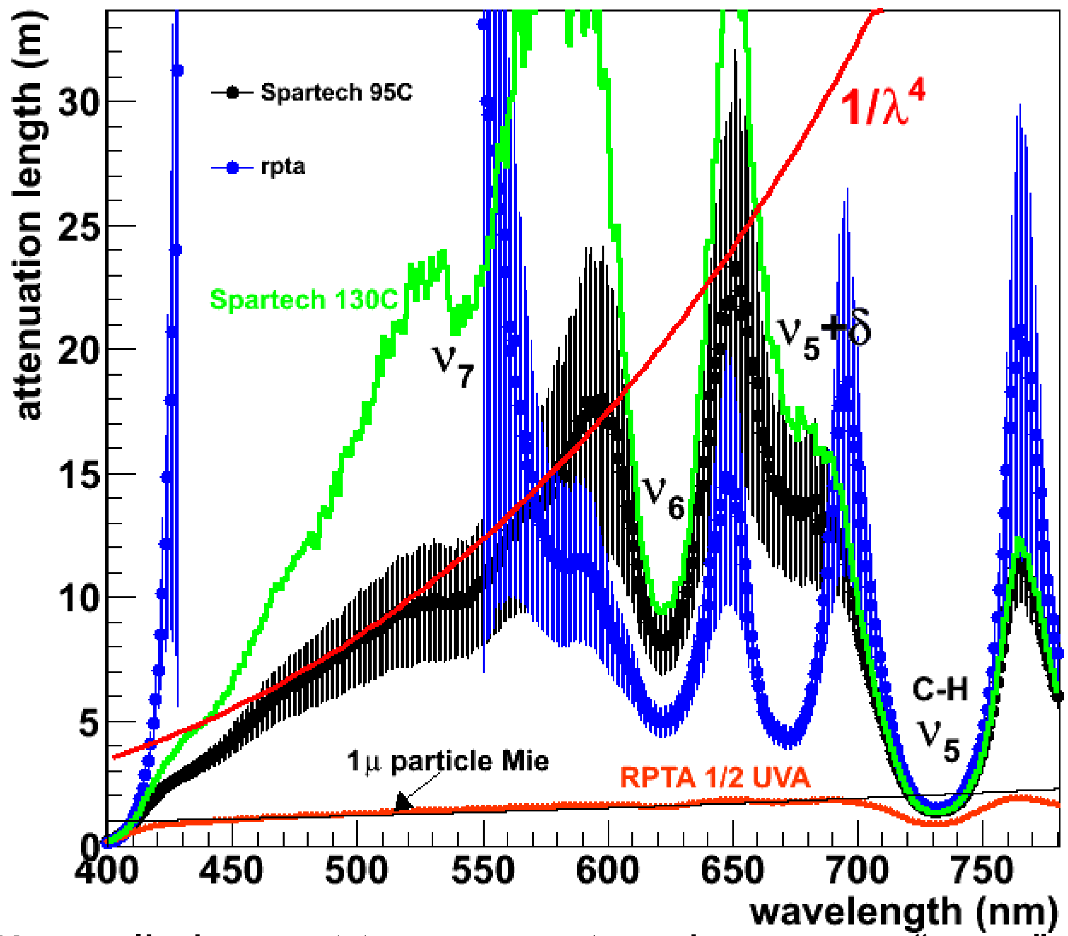
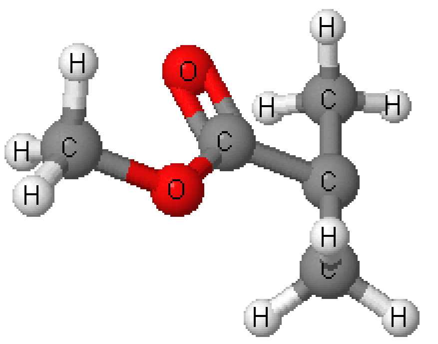
Spartech and RPTA samples – Transparency of DEAP production acrylic





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 is also clean, with excess Rayleigh scattering (but we can fix!)

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

Thermoforming sheets for DEAP Acrylic Vessel
Reynolds Polymer, Colorado

Thermoforming tool

Successfully thermoformed panel

- Thickness/radius of curvature ratio larger than had been attempted
- R&D contract with Reynolds Polymer to develop thermoforming technique
- Special mold/stamping tool designed and fabricated
- R&D Completed early 2012

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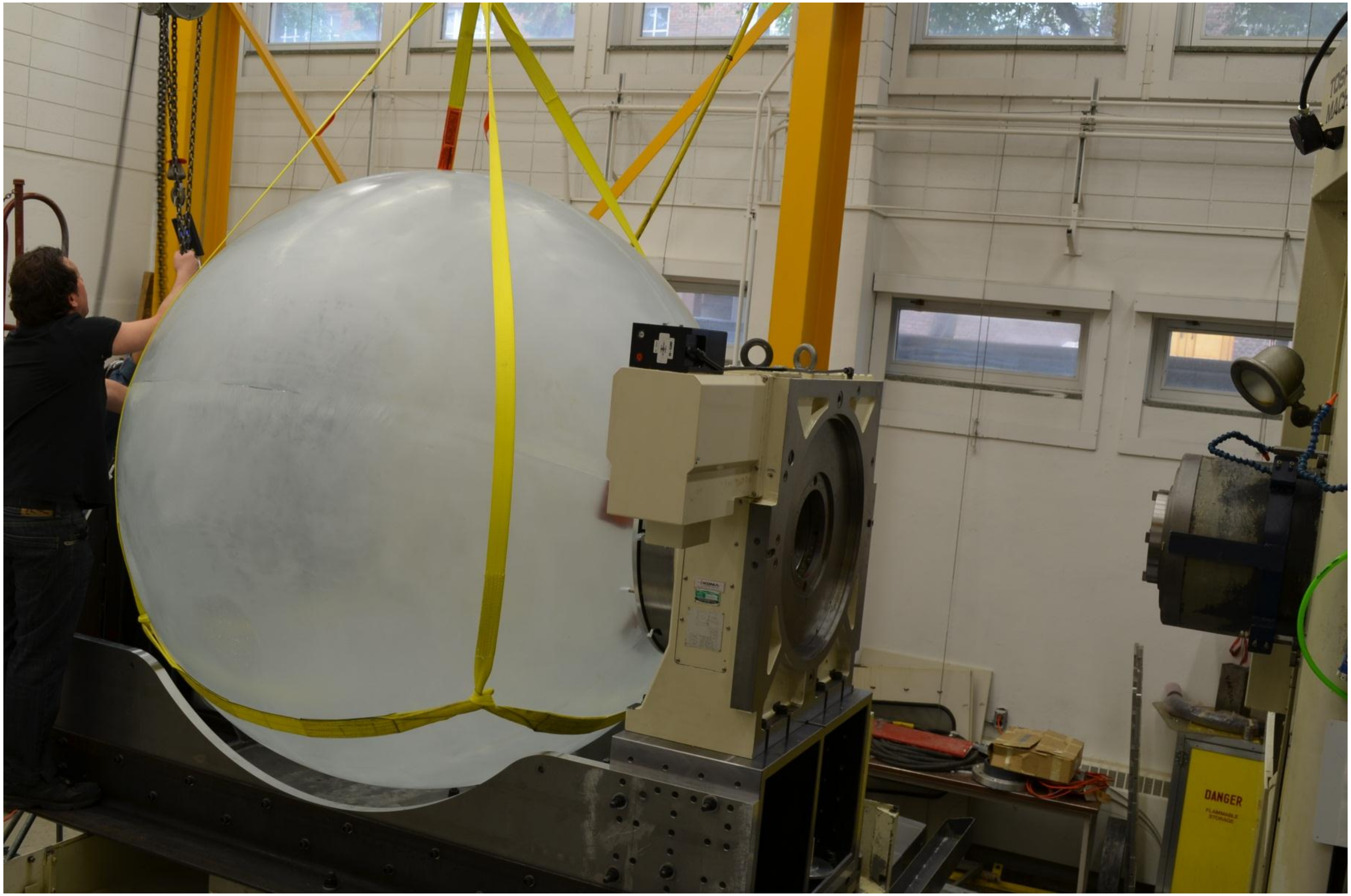
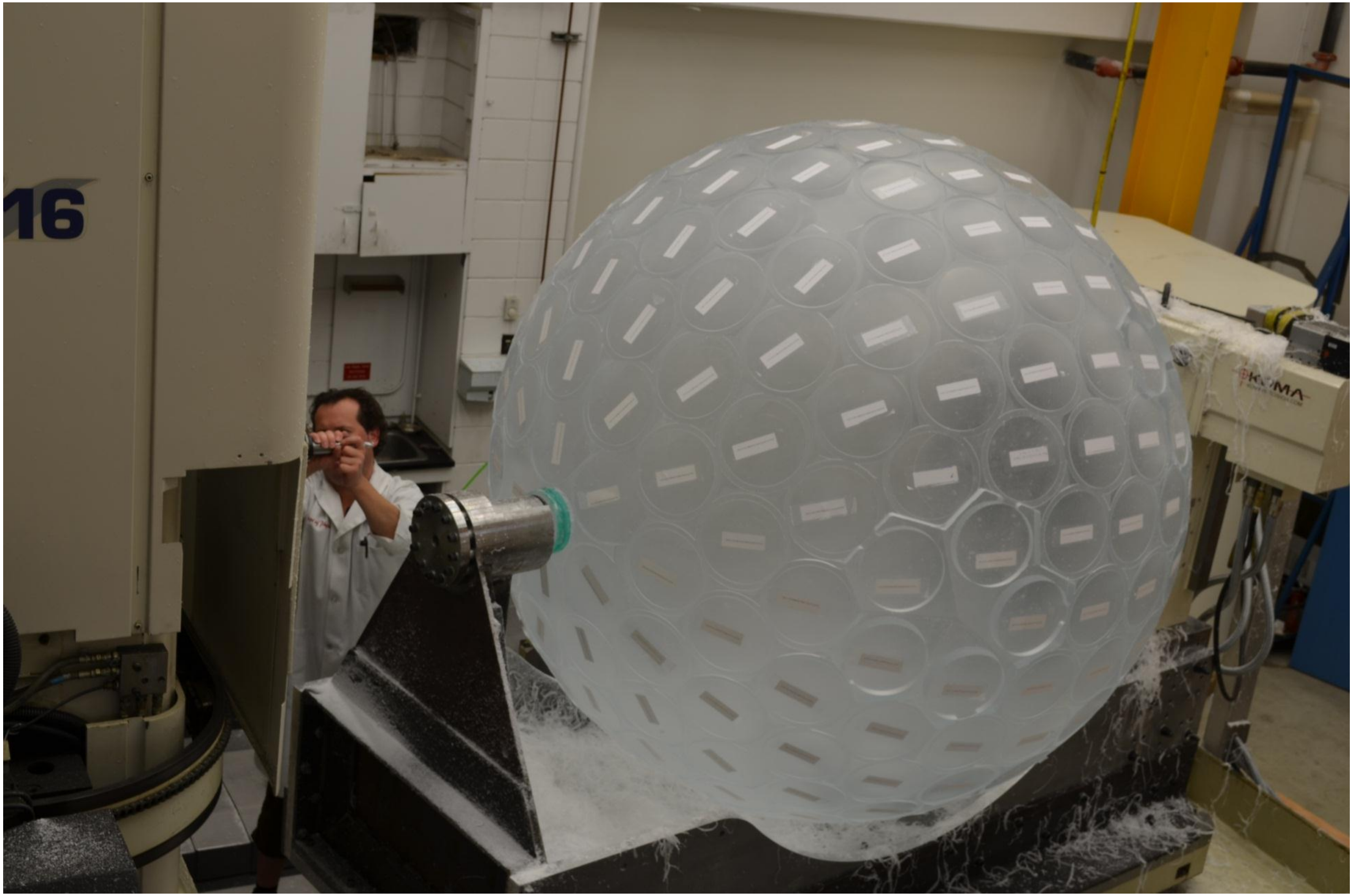
DEAP Acrylic Vessel, Panel Sections at Reynolds Polymer, Colorado

Pre-Bond Dry Fit of sections for DEAP Acrylic Vessel (Reynolds Polymer, Colorado)

Bonded acrylic sphere (From Reynolds Polymer, Colorado)



DEAP Acrylic Vessel with Light Guide “Stubs” July 2012

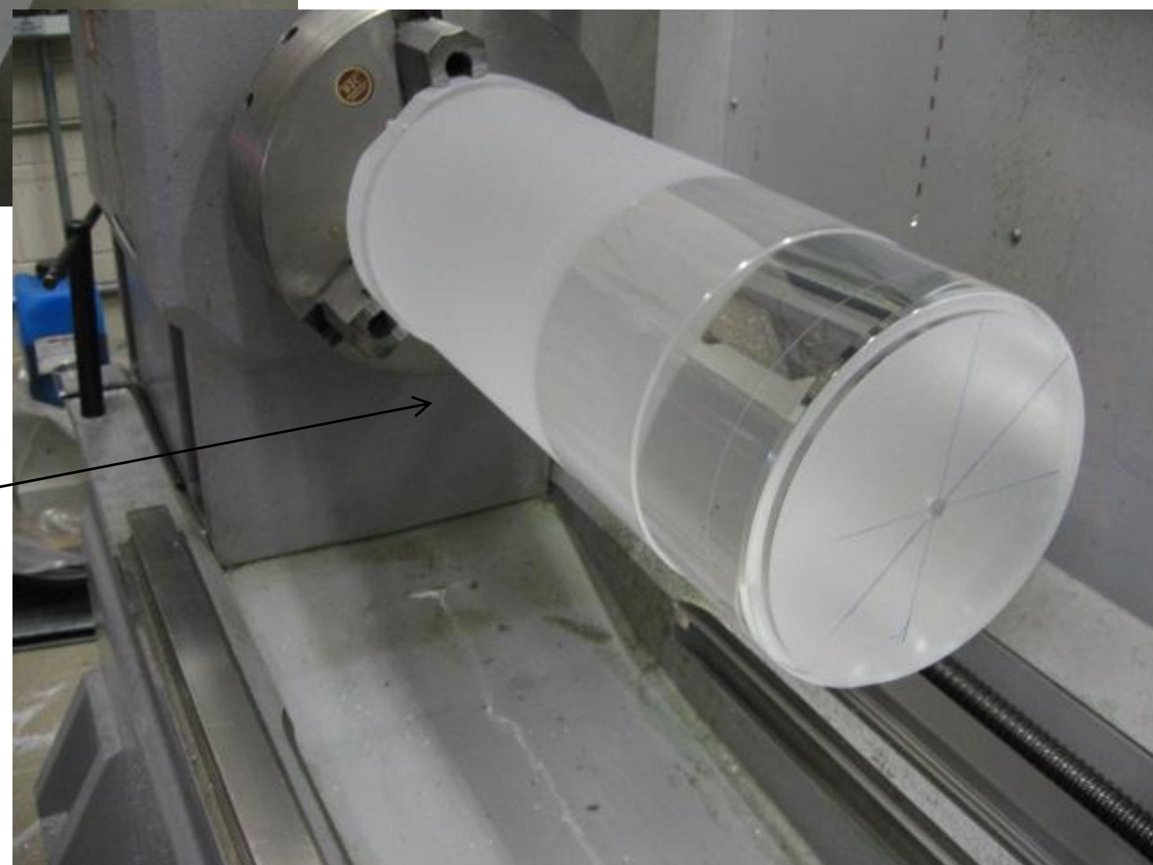


Radiopure acrylic (Spartech) bonded into 8” blocks at Reynolds Colorado

Shipped to TRIUMF Jan 2012

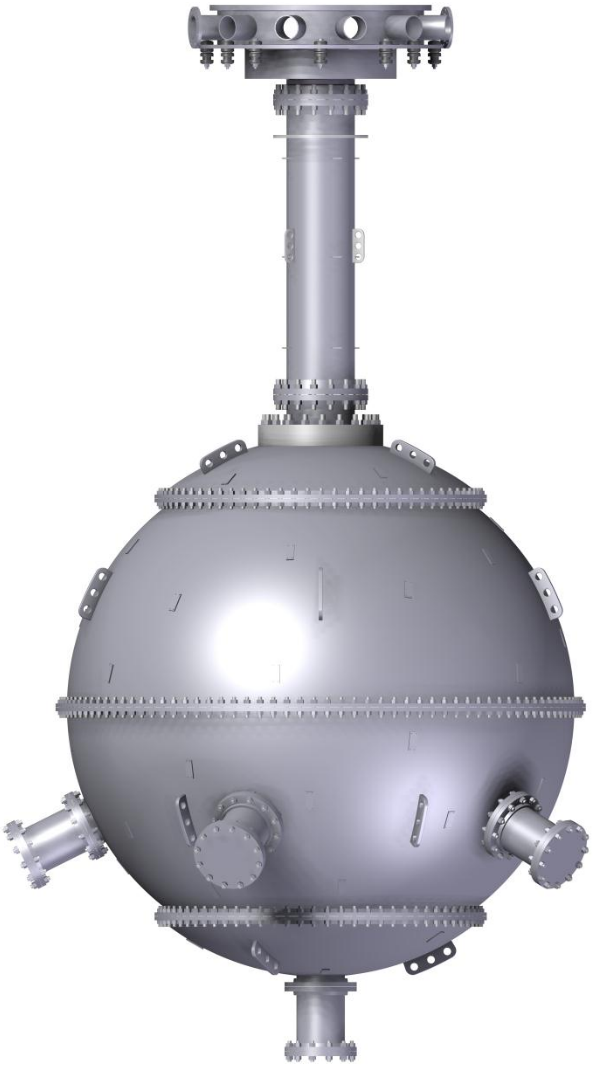
Machining Light Guide in TRIUMF Scintillator Shop

Production LGs now being machined



DEAP-3600 Steel Shell

- 11-foot diameter Section VIII Pressure Vessel
- Electropolished interior for low radon emanation
- Equatorial Flange (O-Ring) for Detector Assembly
- Delivery to SNOLAB July 2012 (9 pieces)
- Final Welds To Be Completed UG Aug 2012



DEAP-3600 Acrylic Vessel Resurfacer

- Resurfacer will be inserted after detector assembly underground, through sealed glove box.
- Resurfacer removes up to 1 mm layer of acrylic, including all diffused or adsorbed radon daughters.
- Residue flushed and extracted with UPW
- Construction is EP stainless steel, low-radon emanation components
- After resurfacing, in-situ large area vacuum deposition source will be used to coat inner surface with TPB wavelength shifter

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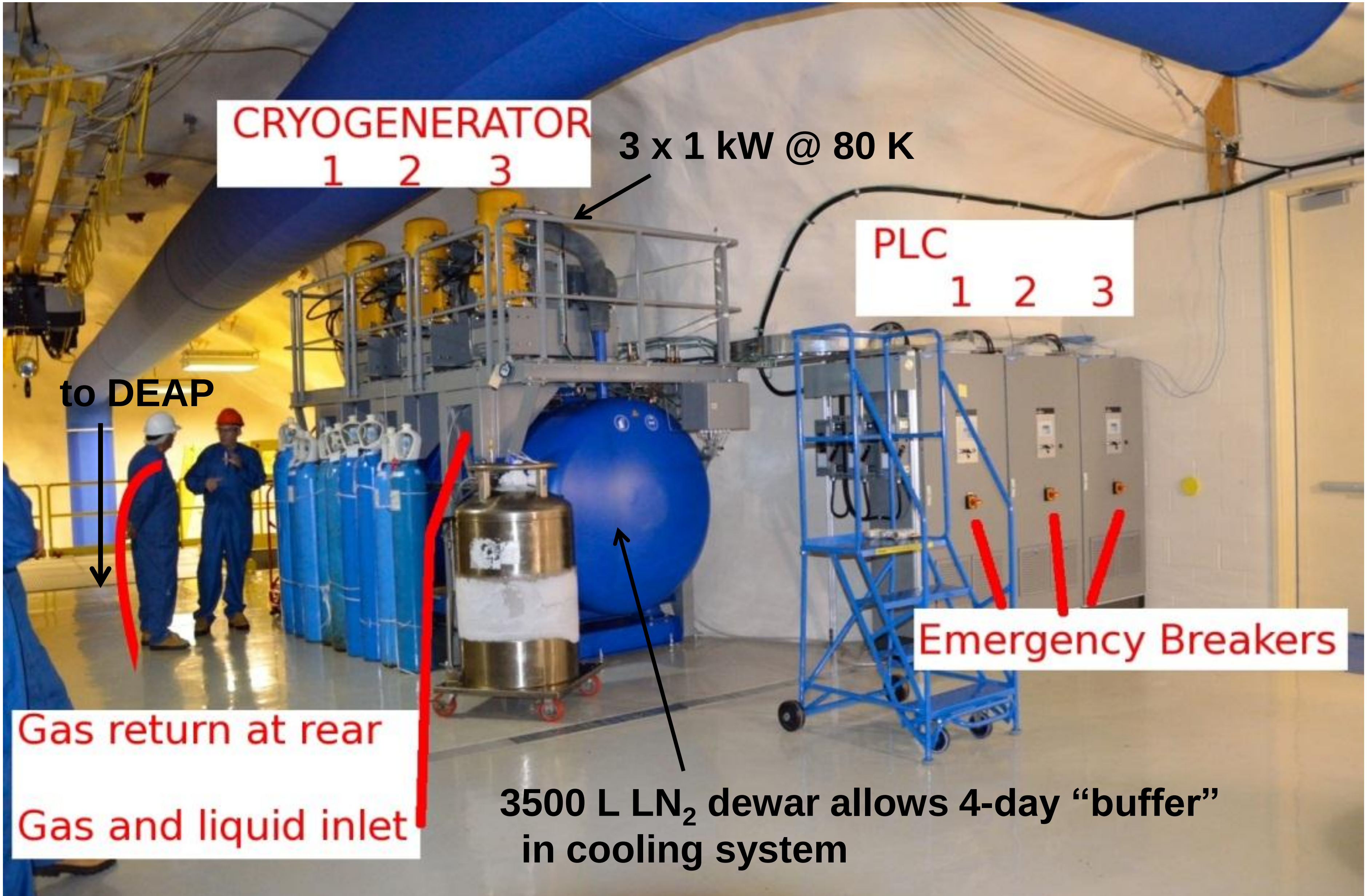
DEAP-3600 Cryocooler System Installed May 2012



Summary

- DEAP-3600 has good physics sensitivity, $8x10^{-47}$ cm^2 (conservative cuts-based analysis, more sophisticated analysis and Depleted Argon allow enhanced low mass sensitivity)

- Extensive radiopurity control and QA program for all components, in particular all fabrication steps of inner Acrylic Vessel

- Most detector components at SNOLAB in September 2012

- Detector Installation, Assembly and Commissioning until late 2013

- Technology can be scaled to very large target masses, > 100 tonnes or 10^{-48} cm^2 Sensitivity. Current focus on DEAP-3600 commissioning, some modest R&D underway

- Surface contamination easier to mitigate with larger detector (using Position Reconstruction)

- Larger detector (100's tonnes) will require Depleted Argon