Dark Matter Search at SNOLAB with DEAP-3600

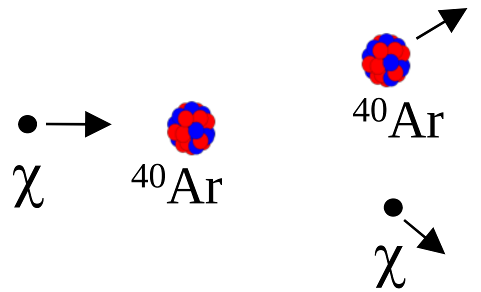
@

- Direct DM search with LAr
- DEAP-3600 design
- Backgrounds
- Project Status

Mark Boulay
Queen's University, Canada

IDM 2010, Montpellier

Liquid argon as a dark matter target



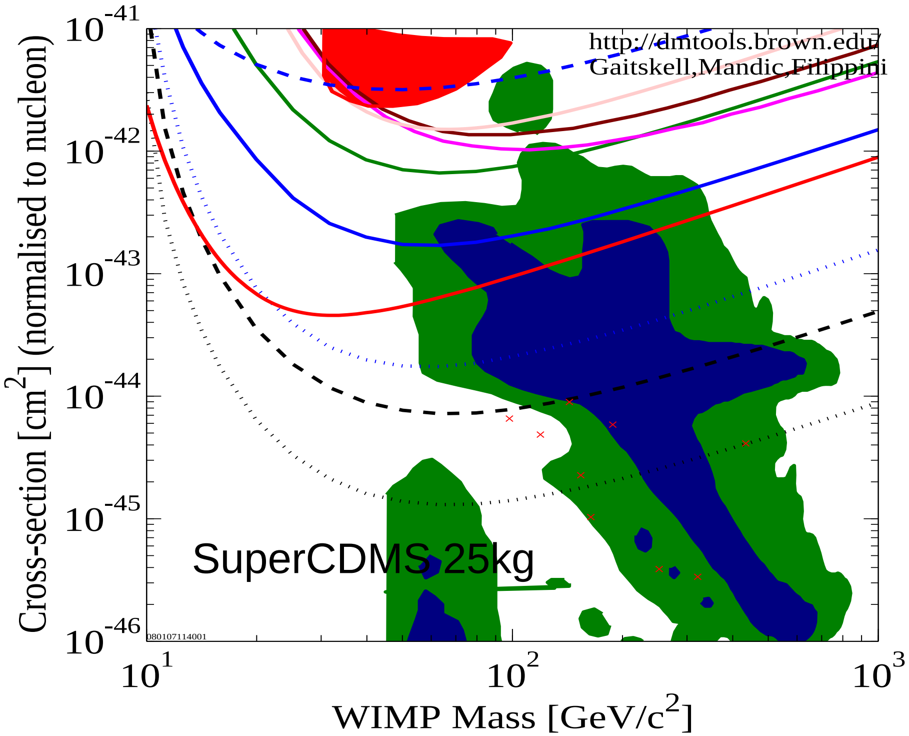
- Less loss of coherence for lighter nuclei, argon can provide useful information even with relatively high energy threshold

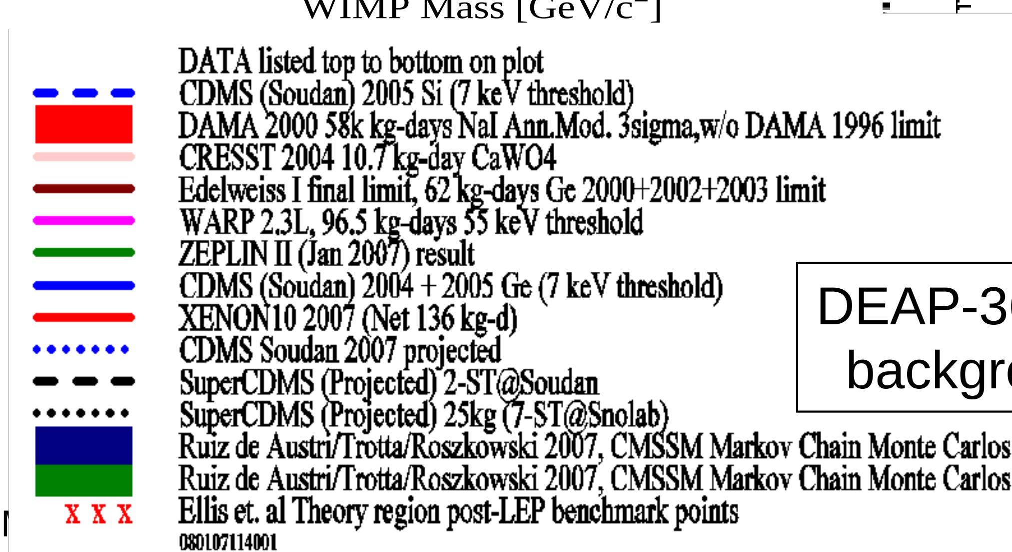
Rate ~ A^2F (coherent)

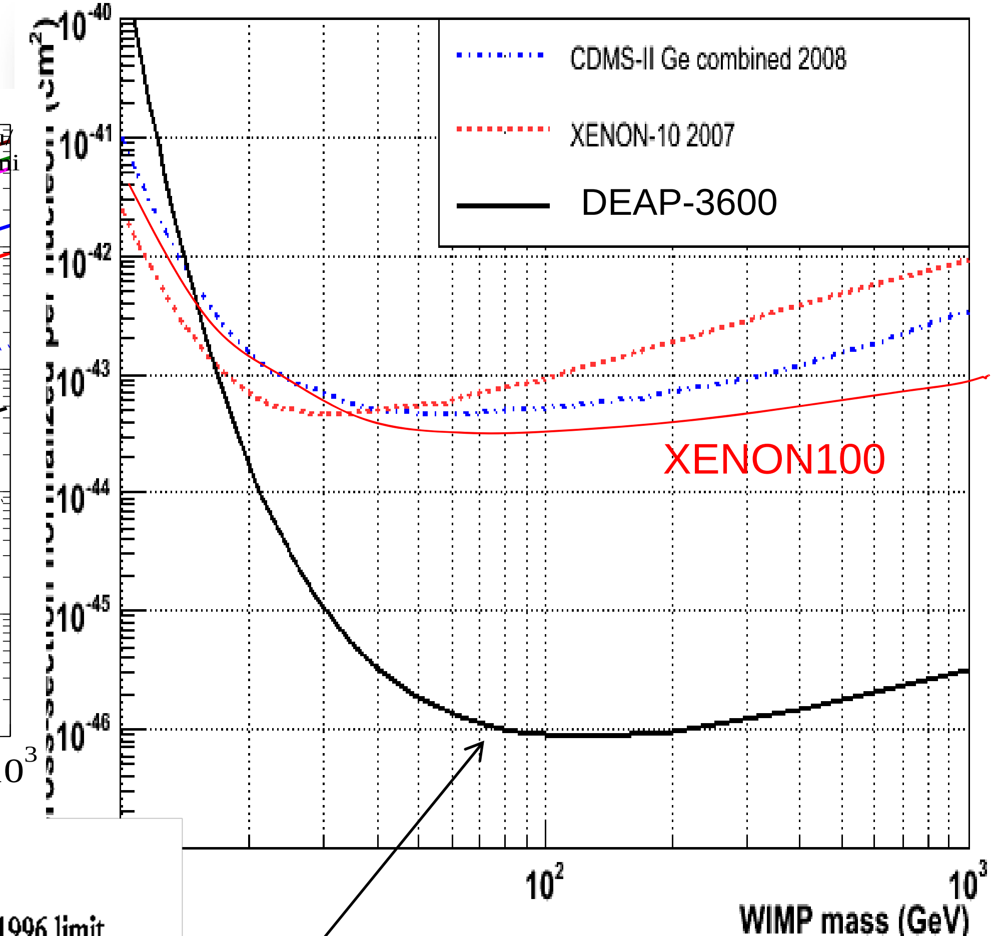
- Well-separated singlet and triplet lifetimes in argon allow for good pulse-shape discrimination (PSD) of β/γ's using only scintillation time information, projected to 10^{-10} at 20 keV_{ee}
  (see Astroparticle Physics 25, 179 (2006) and arxiv/0904.2930)

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

- **1000 kg** argon target allows **10^{-46} cm^2** sensitivity (SI) with ~20 keV_{ee} threshold, 3-year run



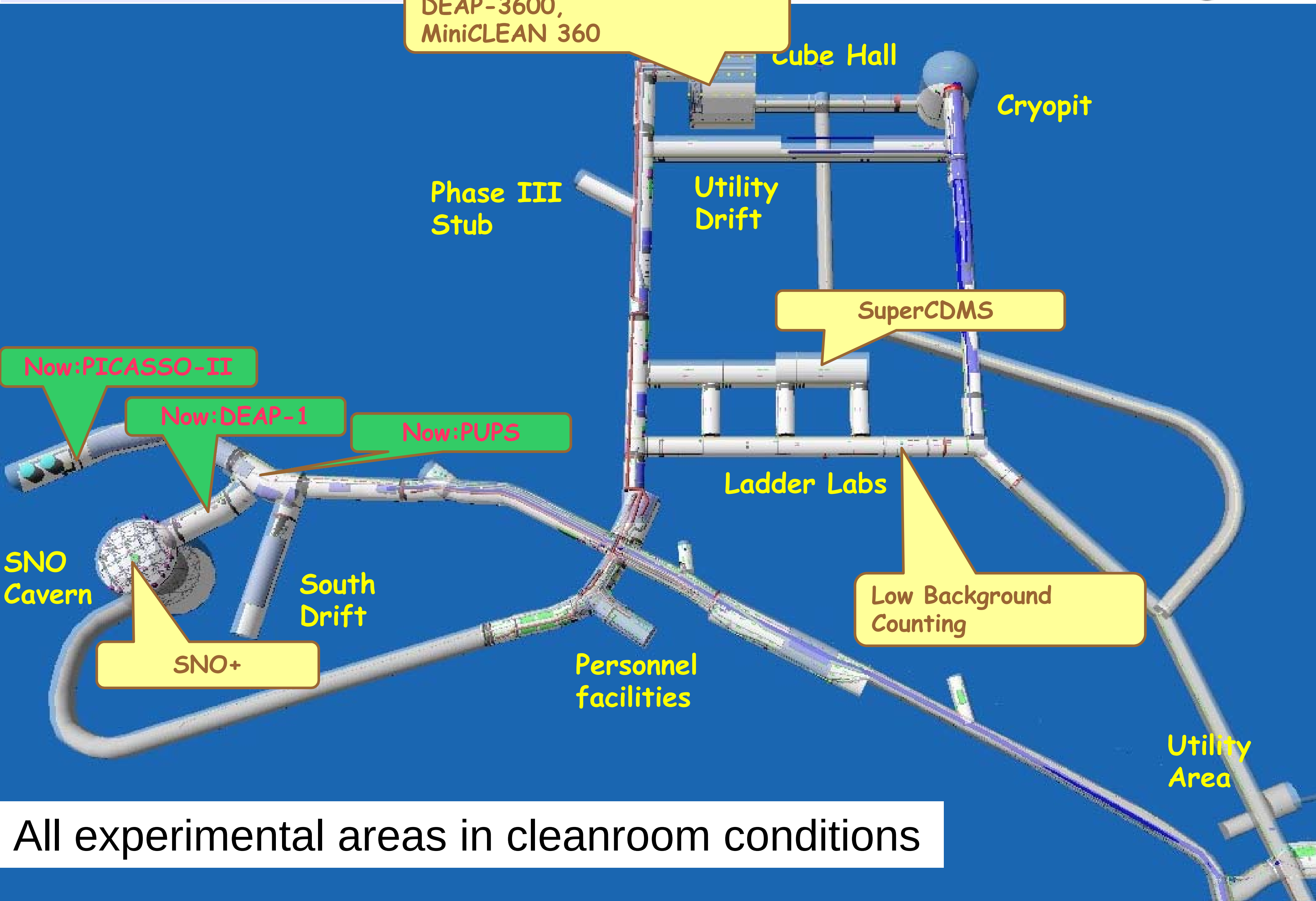




60 keVr threshold, without depletion of argon-39.

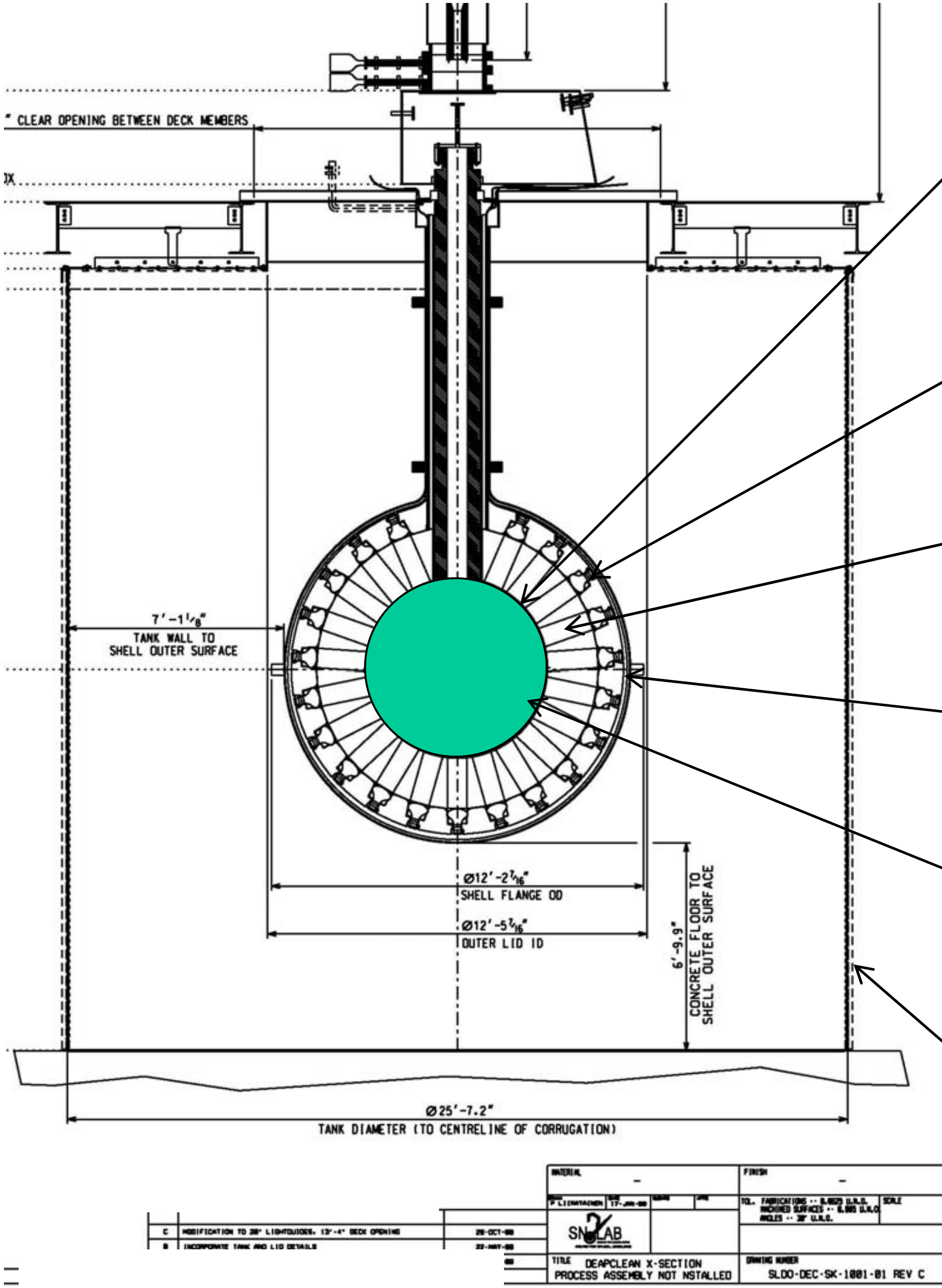
DEAP-3600 projected = 1,000,000 kg-days, background-free sensitivity

SNOLAB Experimental Program



All experimental areas in cleanroom conditions

DEAP-3600 Detector



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

266 8" PMTs
(warm PMTs to increase light efficiency)

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

DEAP collaborators (Canadian groups)

- **University of Alberta**

  D. Grant, P. Gorel, **A. Hallin**, J. Soukup, C. Ng, B. Beltran, K. Olsen
- **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
- **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
- **SNOLAB/Laurentian:** **B. Cleveland, F. Duncan**, **R. Ford**, **C.J. Jillings,** M. Batygov
- **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)

Backgrounds to WIMP interactions

- Beta/gamma interactions
  (dominated by ^{39}Ar for LAr experiments)
  pulse shape discrimination – PSD
  isotopically-reduced argon decreases background rate

  Working with Princeton group to obtain 4 tonnes of depleted argon for DEAP-3600 with 20X depletion factor

- neutron-induced nuclear recoils
  muon suppression underground at SNOLAB
  detector design, clean materials for (α,n) neutrons
  (acrylic vessel+light guides for attenuation)

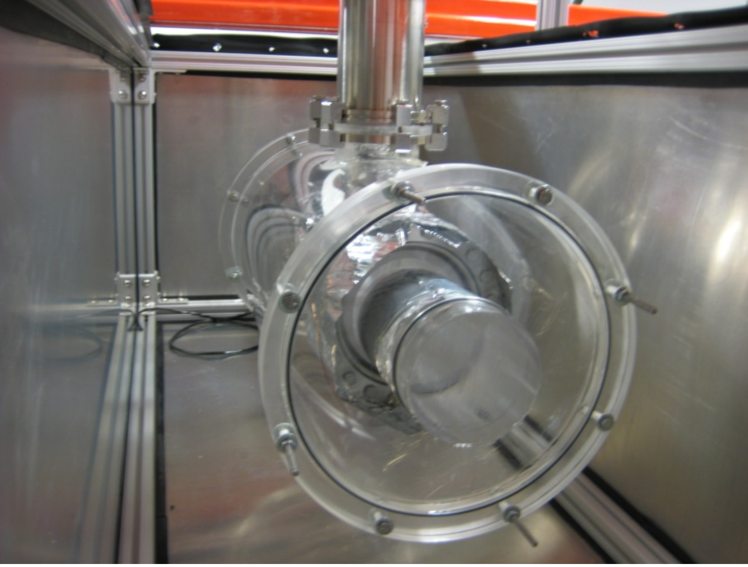
- surface contamination
  clean detector surfaces in-situ (resurfacer device)
  vertex reconstruction for fiducial volume definition
  (10 cm resolution at threshold)

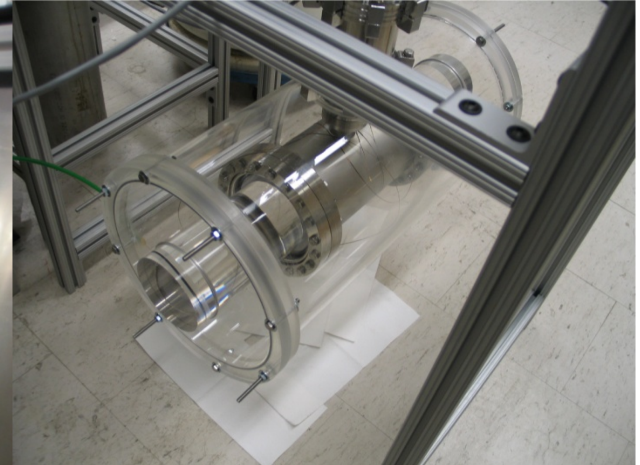
Background	Fiducial No. Events in Energy ROI (3 yrs,1000 kg)	Materials Purity Specification (based on MC calculations)
Neutrons from PMTs	<0.2	70 ppb U, Th in PMTs 50 cm acrylic for n moderation
^{222}Rn/daughters on detector surface	<0.1	^{222}Rn emanation < 5 μBq
^{238}U in acrylic	<0.01	<0.2 ppt ^{238}U in acrylic
^{232}Th in acrylic	<0.01	<0.9 ppt ^{232}Th in acrylic
^{210}Pb in acrylic	<0.01	<6x10^{-21} g/g ^{210}Pb in acrylic

• ^{222}Rn emanation measurements (at Queen's) limited to ~60 μBq, building new lower-background emanation system

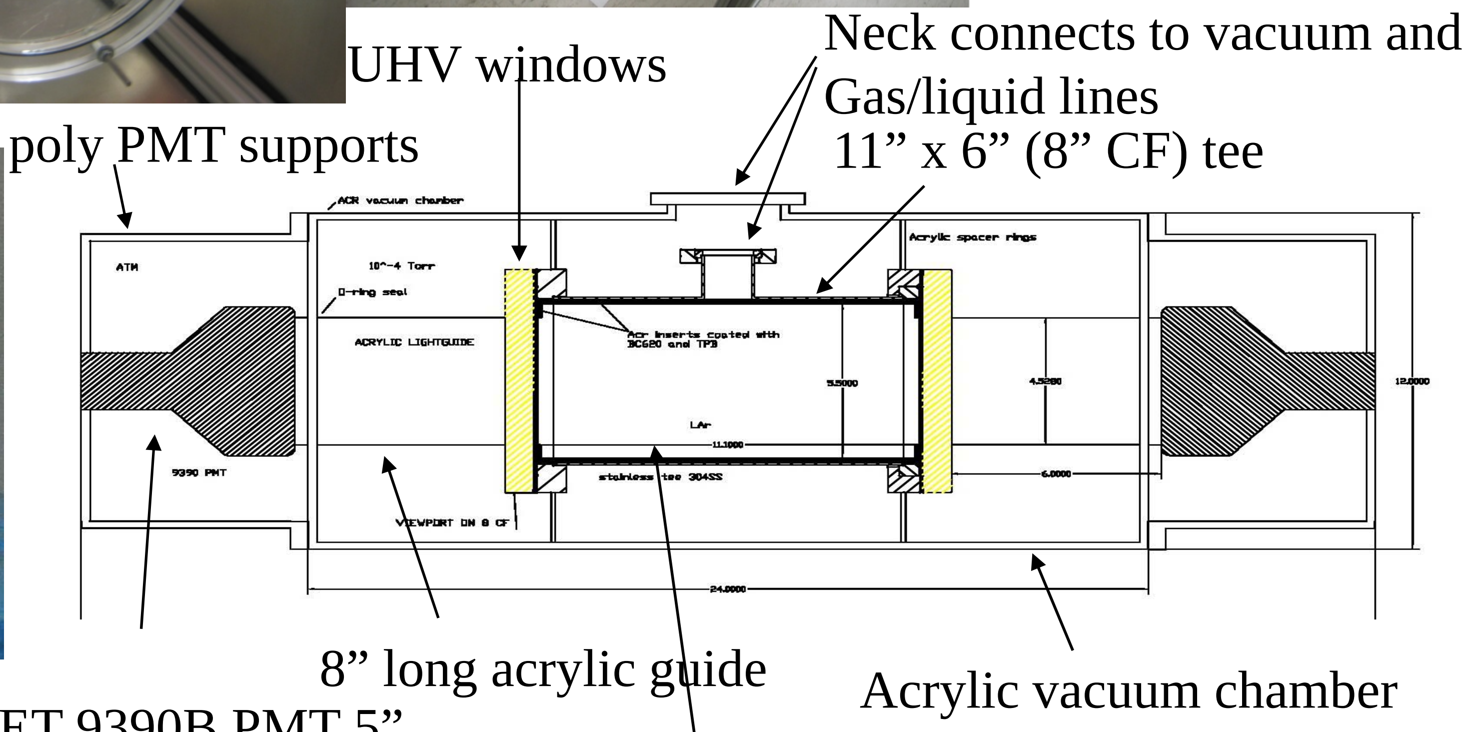
• Requirements for acrylic similar to SNO acrylic vessel, new Ge well-detector purchased for ^{210}Pb assay with required sensitivity (vaporize & count kg's of acrylic)

• Other materials less critical, acrylic moderates external neutrons; not sensitive to γ's.





DEAP-1 prototype (7 kg LAr)



ET 9390B PMT 5”

7 kg LAr

inner surface 97% diffuse reflector,
Covered with TPB wavelength shifter

Mark Boulay, Queen’s

DEAP-1 detector in water shield

50 cm water for neutron and γ shielding
(Operating at SNOLAB since 2007)

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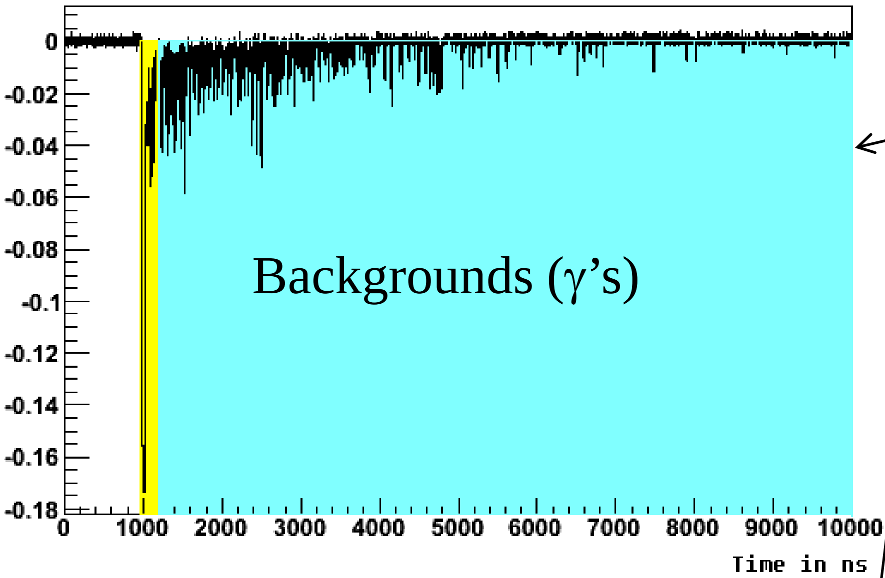
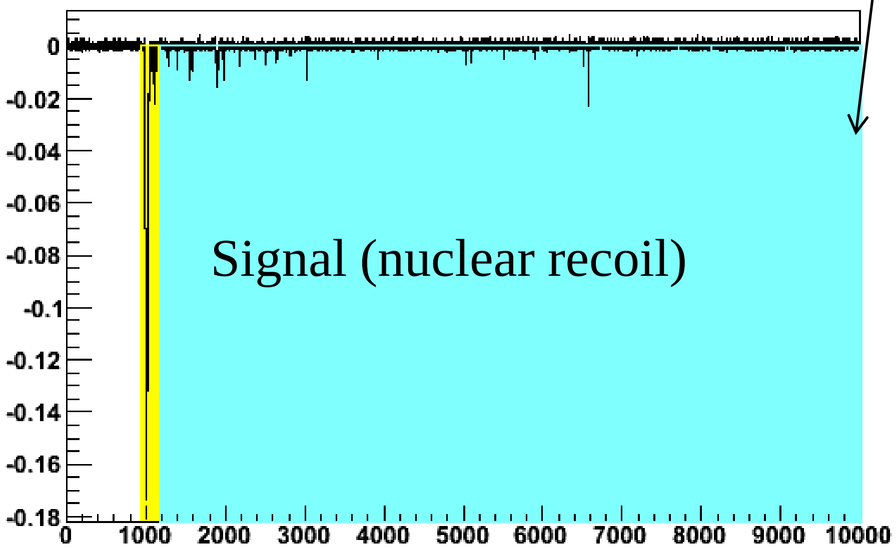
DEAP-1

Pulse-Shape Discrimination in Liquid Argon



PMT signals

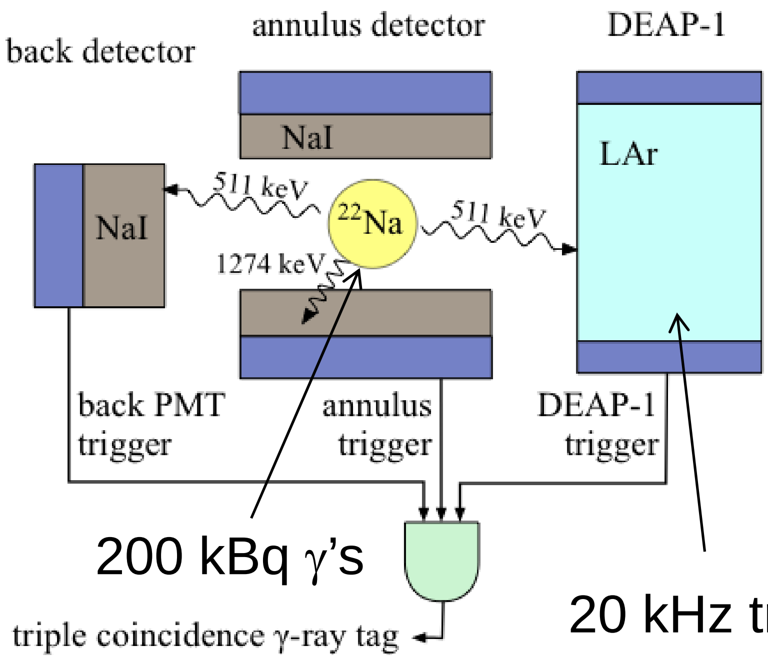


$$F_{prompt} = \frac{\text{PromptPE } (150ns)}{\text{TotalPE } (9\mu s)}$$

Yellow: Prompt light region
Blue: Late light region

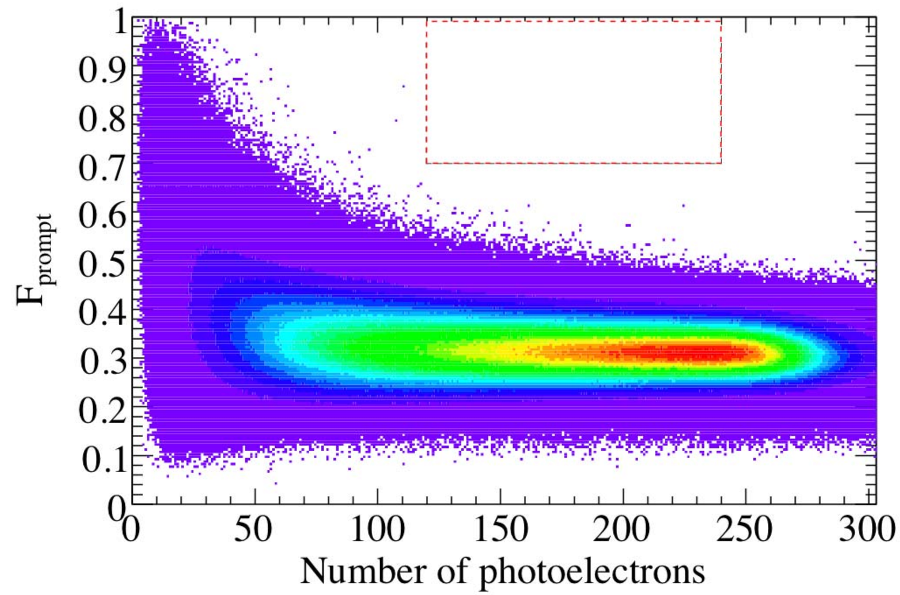
Tagged γ Calibration

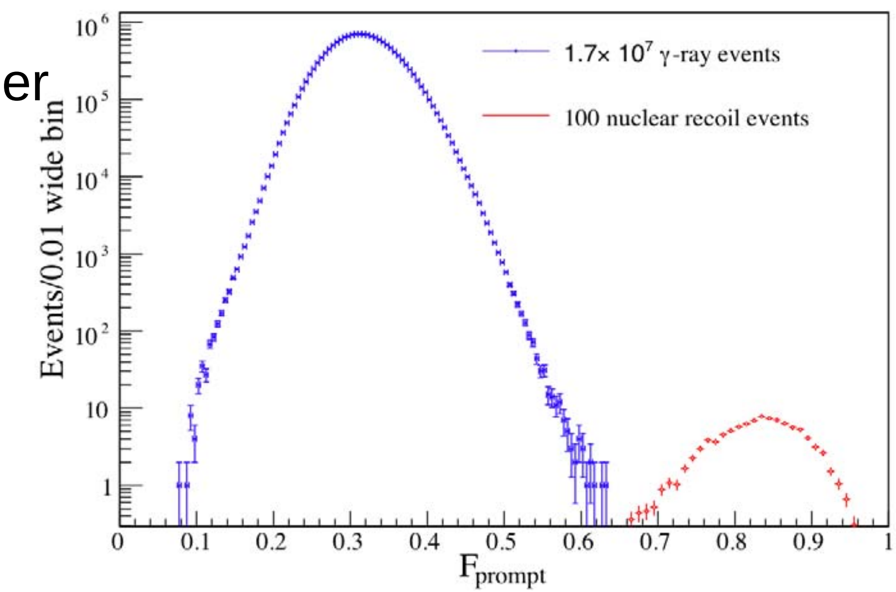
Triple-coincidence Na-22 calibration



200 kBq γ's

20 kHz trigger Rate (γ's)





β/γ leakage (statistics limited) $<6\times10^{-8}$

arXiv.org: 0904.2930

Background rates in DEAP-1 (low-energy region 120-240 p.e.)

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 couting)
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 μBq	***Clean v1*** **chamber at SNOLAB**	Glove box preparation of inner chamber (reduce Rn adsorption/implantation on surfaces)
March 2009	150 μBq	***Clean v2*** **chamber at SNOLAB**	Sandpaper assay/selection, improved purging, PTFE instead of BC-620 reflector (from Rn emanation measurements), Rn diffusion mitigation, UP water in glove box, documented procedures; Rn Trap@SNOLAB for filling.
March 2010		***Clean v3*** **chamber at SNOLAB**	Acrylic monomer purification for coating chamber. TPB purification.

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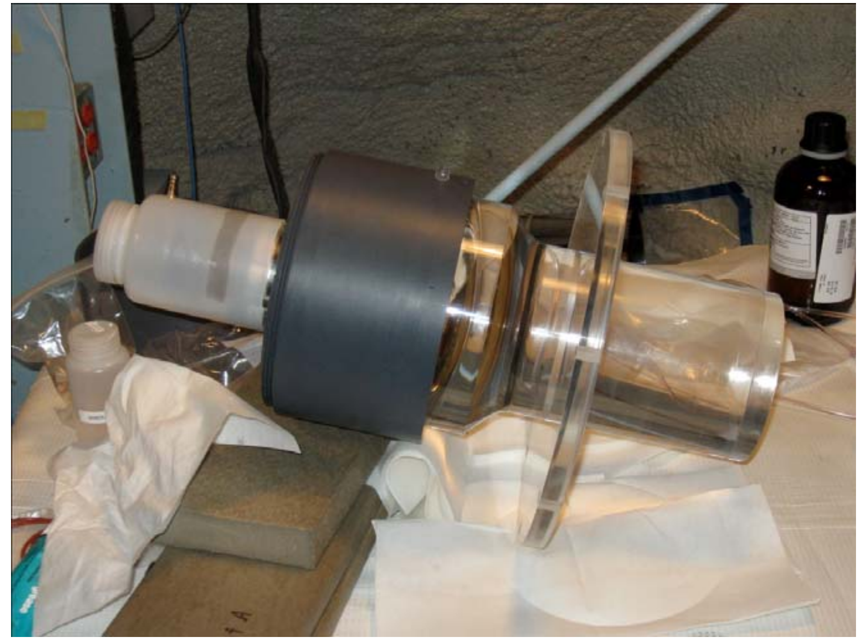
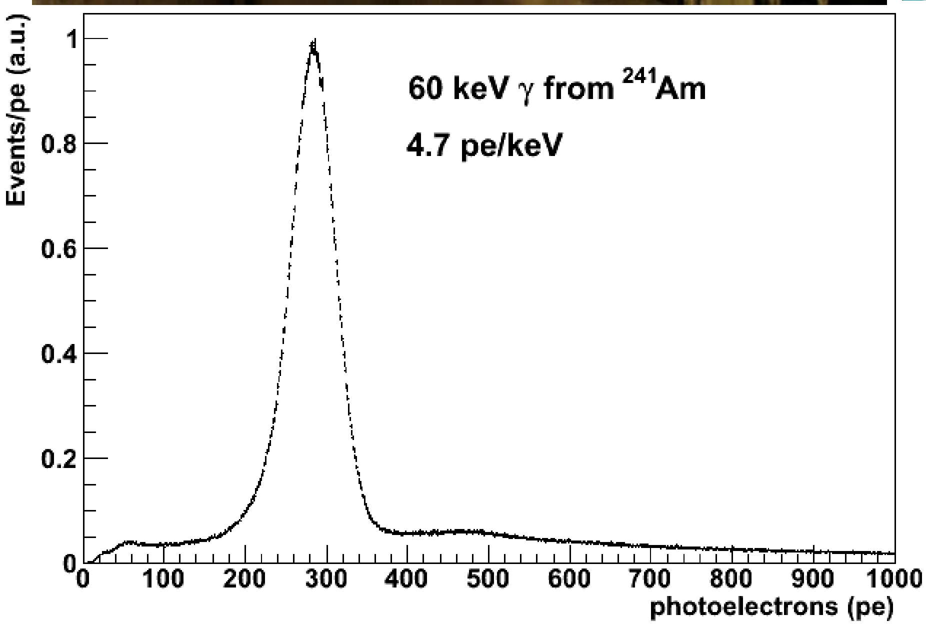
Light yield in DEAP-1 with Hamamatsu R5912 HQE PMTs



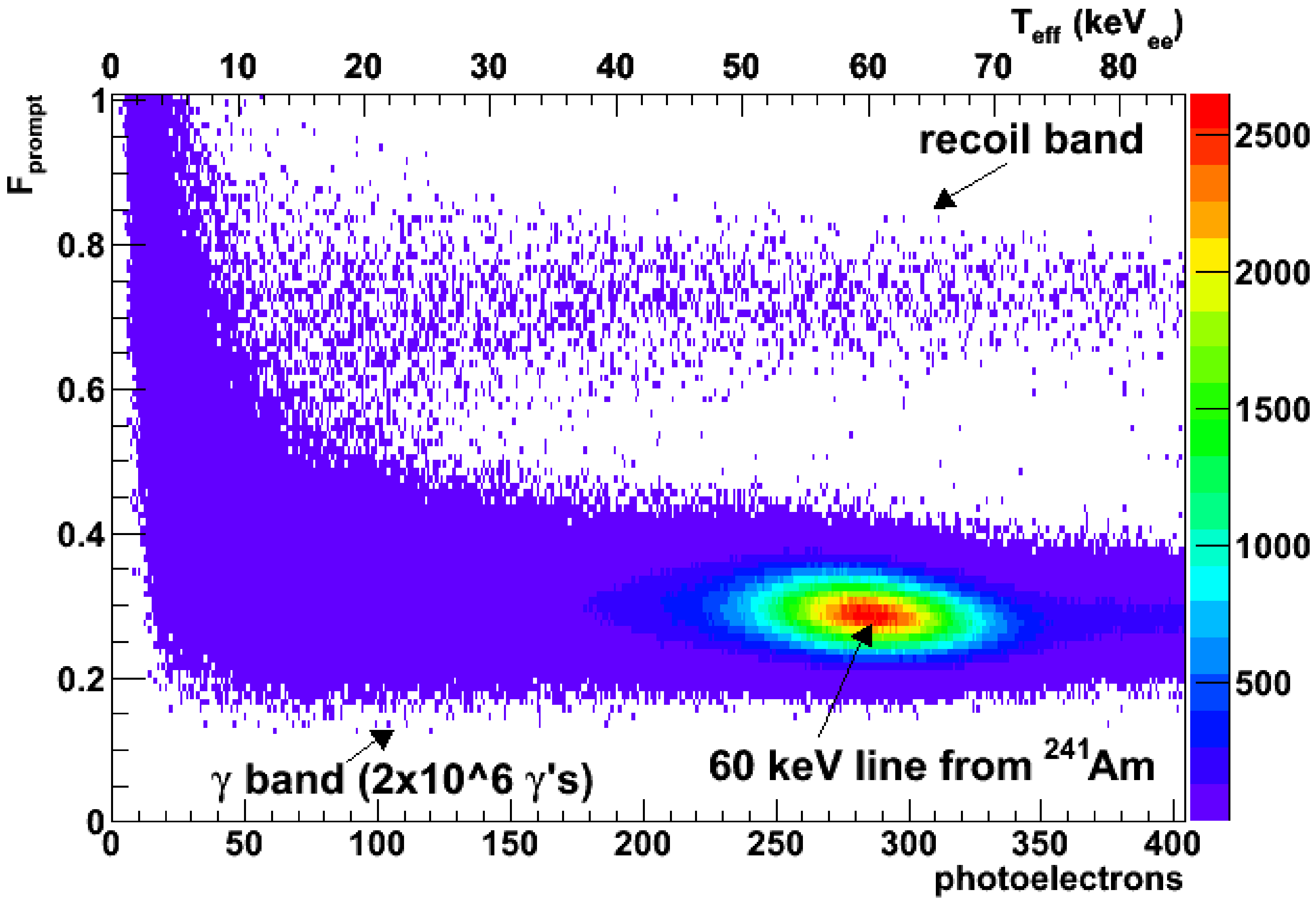


4.7 pe/keV in DEAP-1

expect higher light yield in DEAP-3600 (greater PMT coverage, 75% vs 20%)

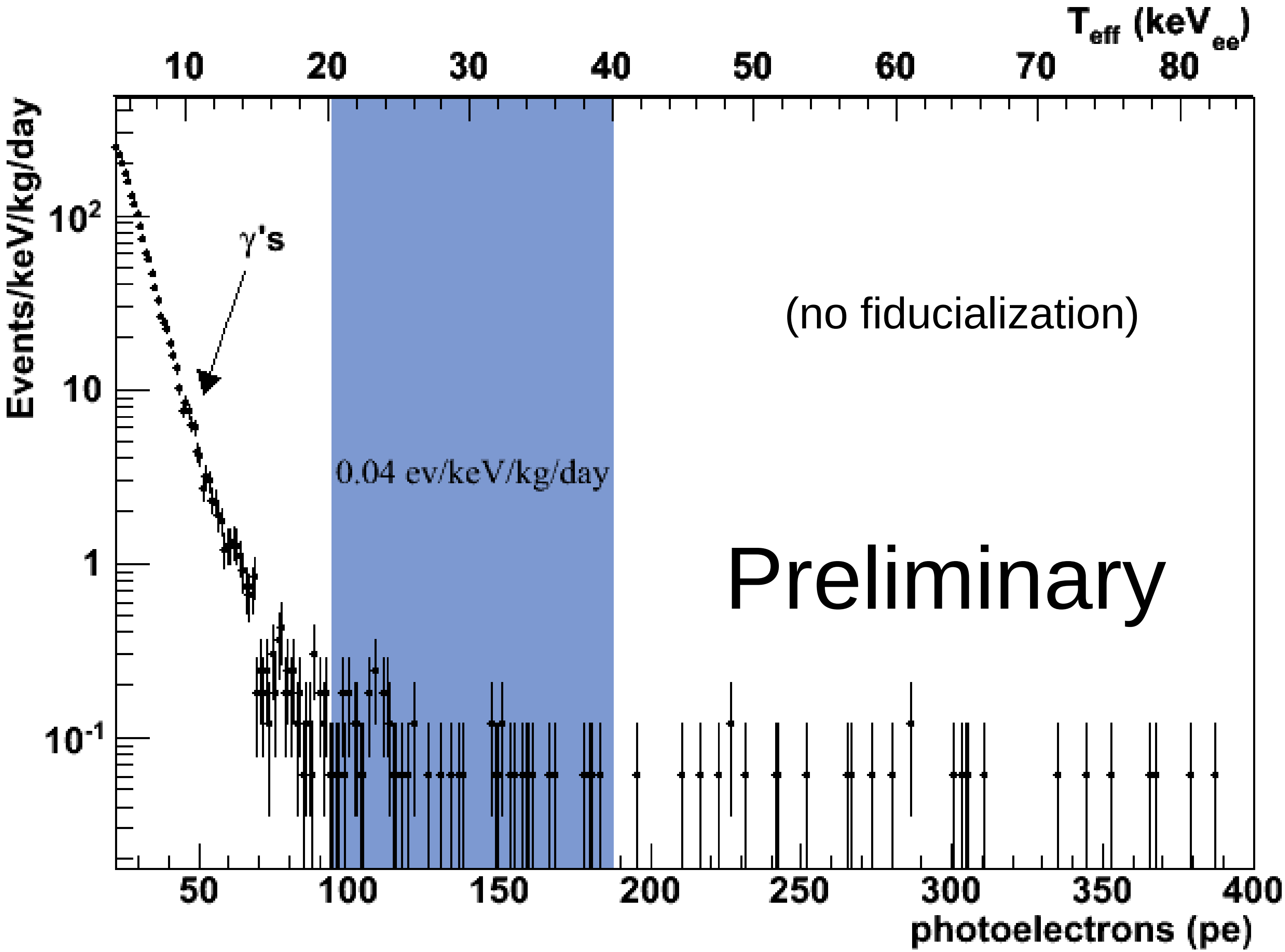
MC simulations (ratio of DEAP-3600 to DEAP-1) show > **8 pe/keV** in DEAP-3600, design goal was 6 pe/keV.

Calibration of DEAP-1 with AmBe neutron source



(preliminary –electronics and analysis being "tuned" for R5912's)

Data from DEAP-1 at SNOLAB (June 2010)



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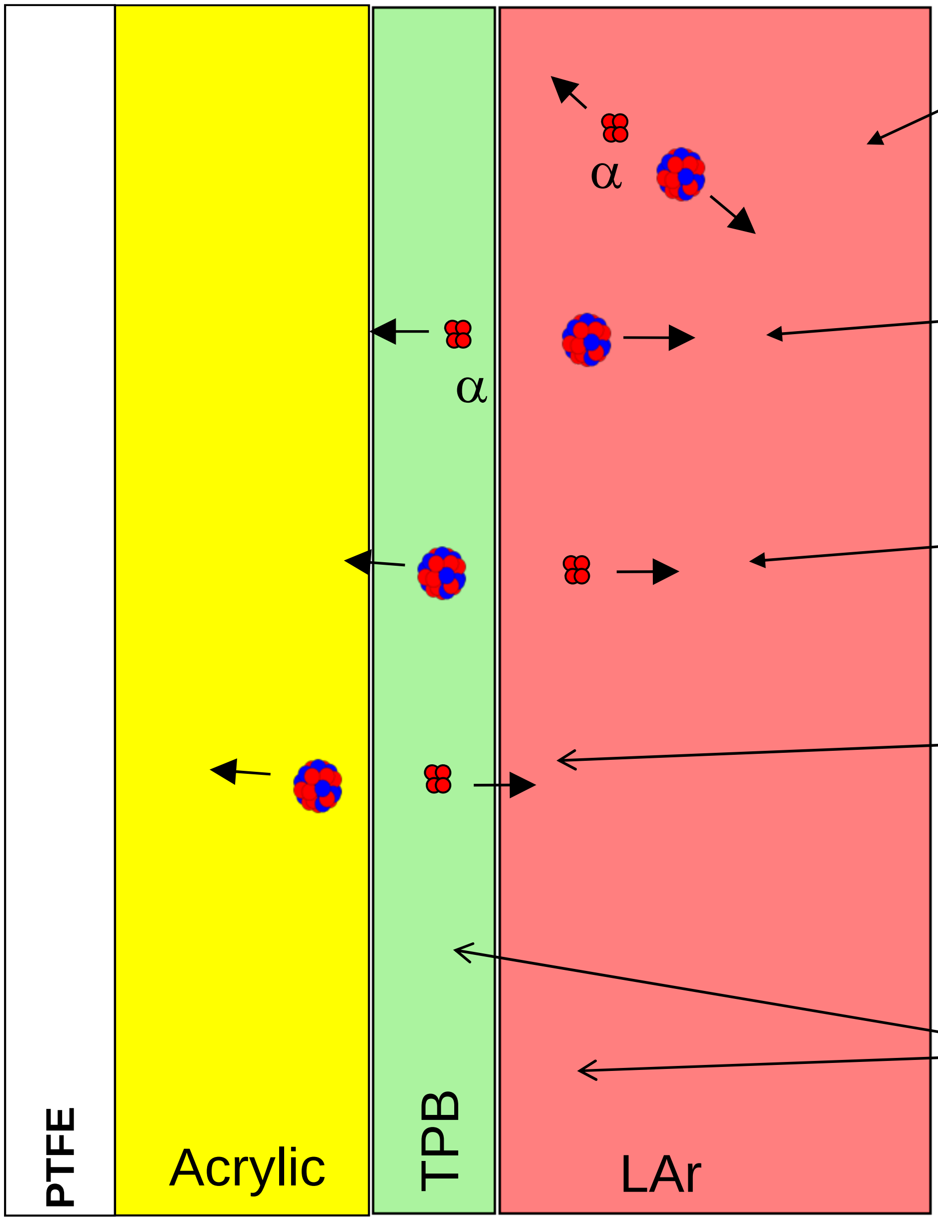
α Backgrounds in Liquid Argon



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)

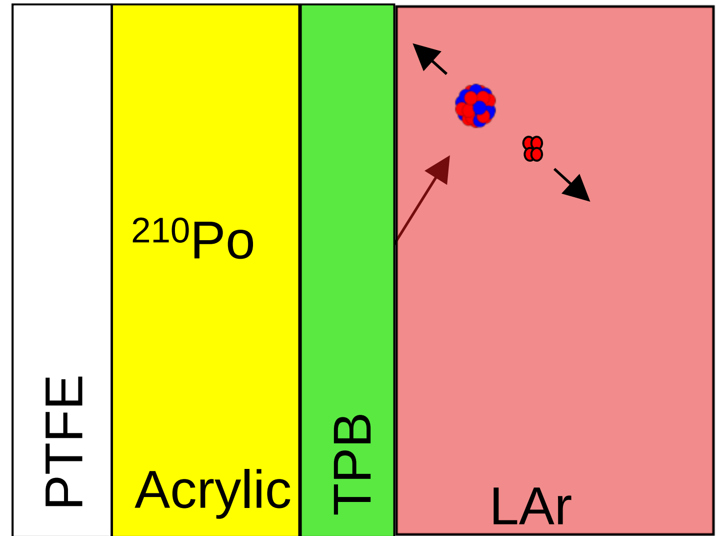
Decay from **TPB surface** releases α in argon and recoil nucleus in TPB
(see mostly α-particle, high energy)

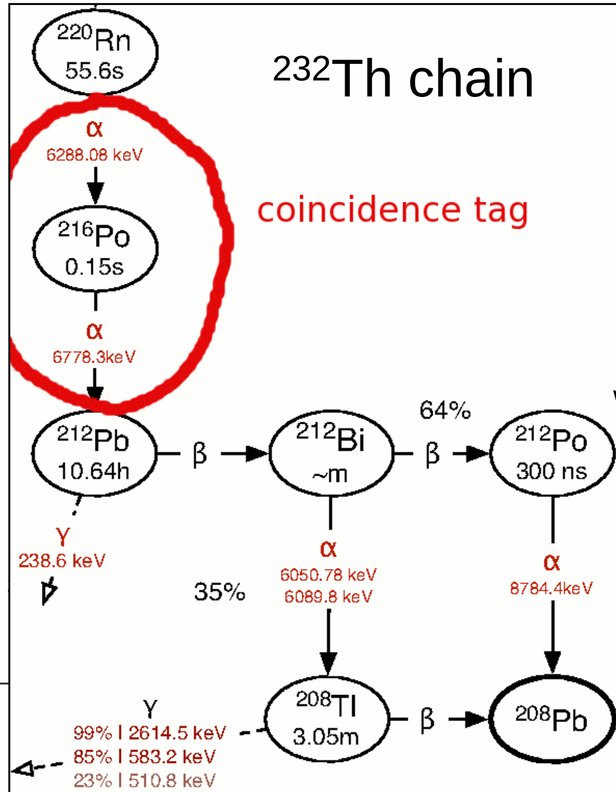
Decay from **inside TPB or acrylic** releases α which may also enter LAr.
Could see
(a) Light from TPB only (prompt) or
(b) Light from LAr (range of energies)

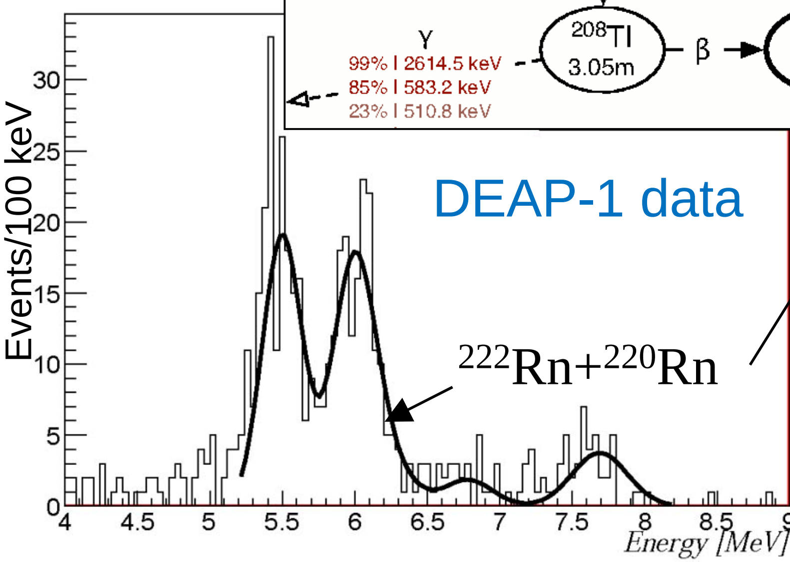
both TPB and LAr scintillate

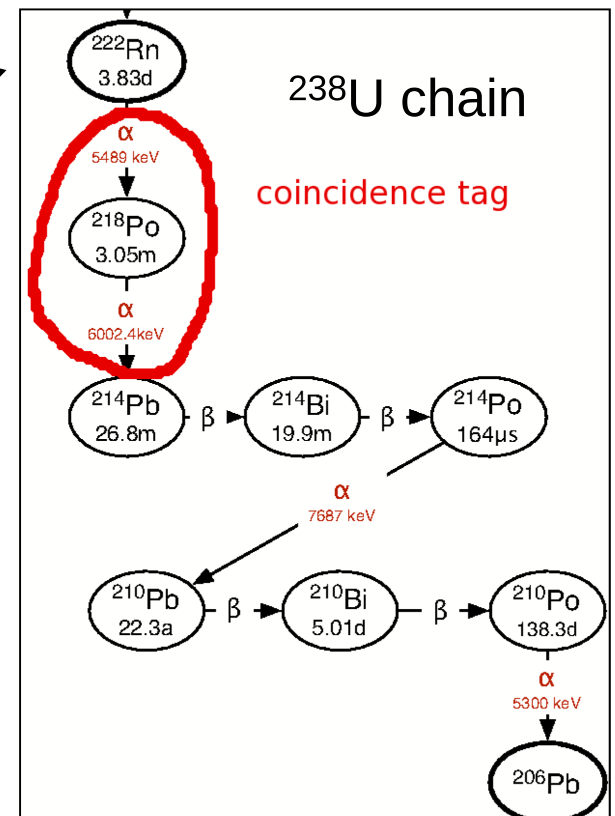
DEAP-1 and DEAP-3600 surface profile

α Backgrounds in LAr (DEAP-1)









In DEAP-1:

100 μBq ^{222}Rn

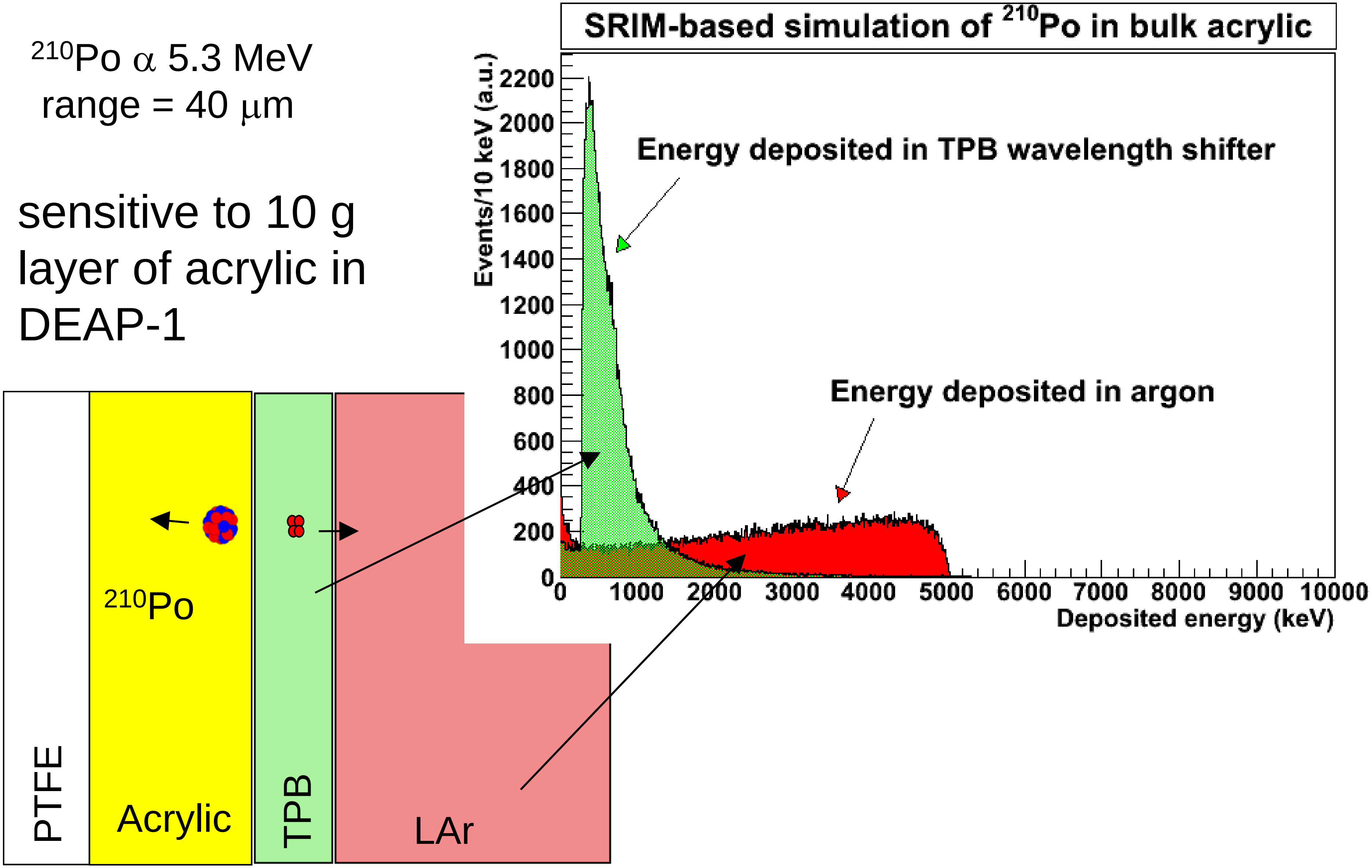
20 μBq ^{220}Rn

α backgrounds in acrylic or TPB

T. Pollman (Queen's)

^{210}Po α 5.3 MeV
range = 40 μm

sensitive to 10 g layer of acrylic in DEAP-1



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Surface Backgrounds in DEAP

A “pessimistic” upper limit on the surface background rate is
$< 150\ \mu\text{Bq} / 0.2\ \text{m}^2$ ($750\ \mu\text{Bq/m}^2$)

This current background level would allow 250 kg background-free, sensitivity to SI-scattering of $4\text{x}10^{-46}\ \text{cm}^2$
(<0.2 events in 3 years, using 10-cm position resolution, 35 cm fiducial cut)

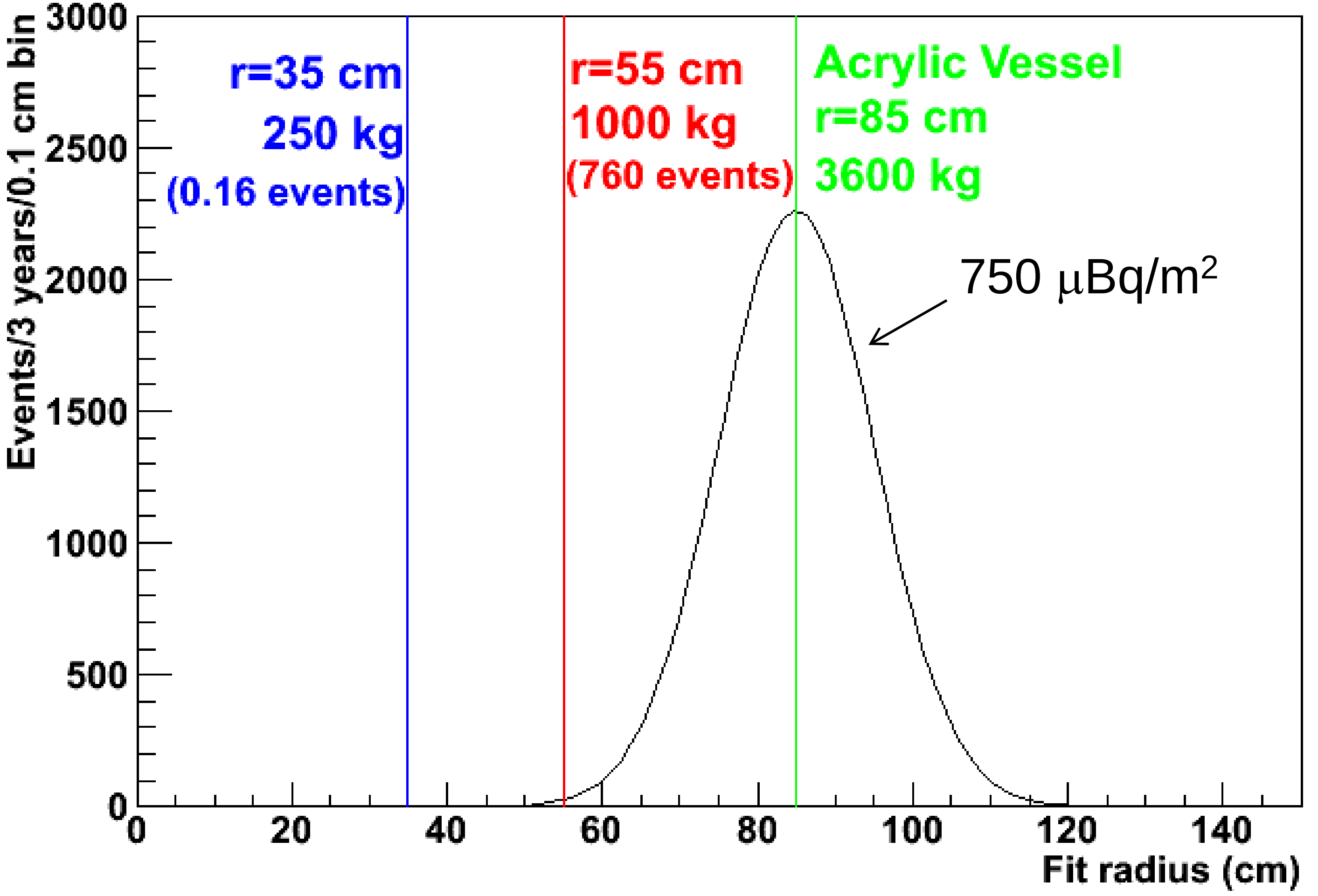
Several possibilities to further reduce backgrounds:

- Reduce Rn emanation (weld passivation, etching, and exposure control)

- TPB purification

- Tags in analysis:
    - PMT hit distribution (large pulses for PMTs directly in front of alpha event)
    - α/recoil pulse shape discrimination (recent measurements of scintillation in TPB wavlength shifter show promise)

3-years of DEAP-3600 scaled to current backgrounds achieved in DEAP-1



Even current surface background rates from DEAP-1 would allow 250 kg "background-free" in DEAP-3600 (4×10^{-46} cm^2) sensitivity.

Several improvements planned to further reduce backgrounds.

SNOLAB Cube Hall (DEAP-3600 area) September 2009

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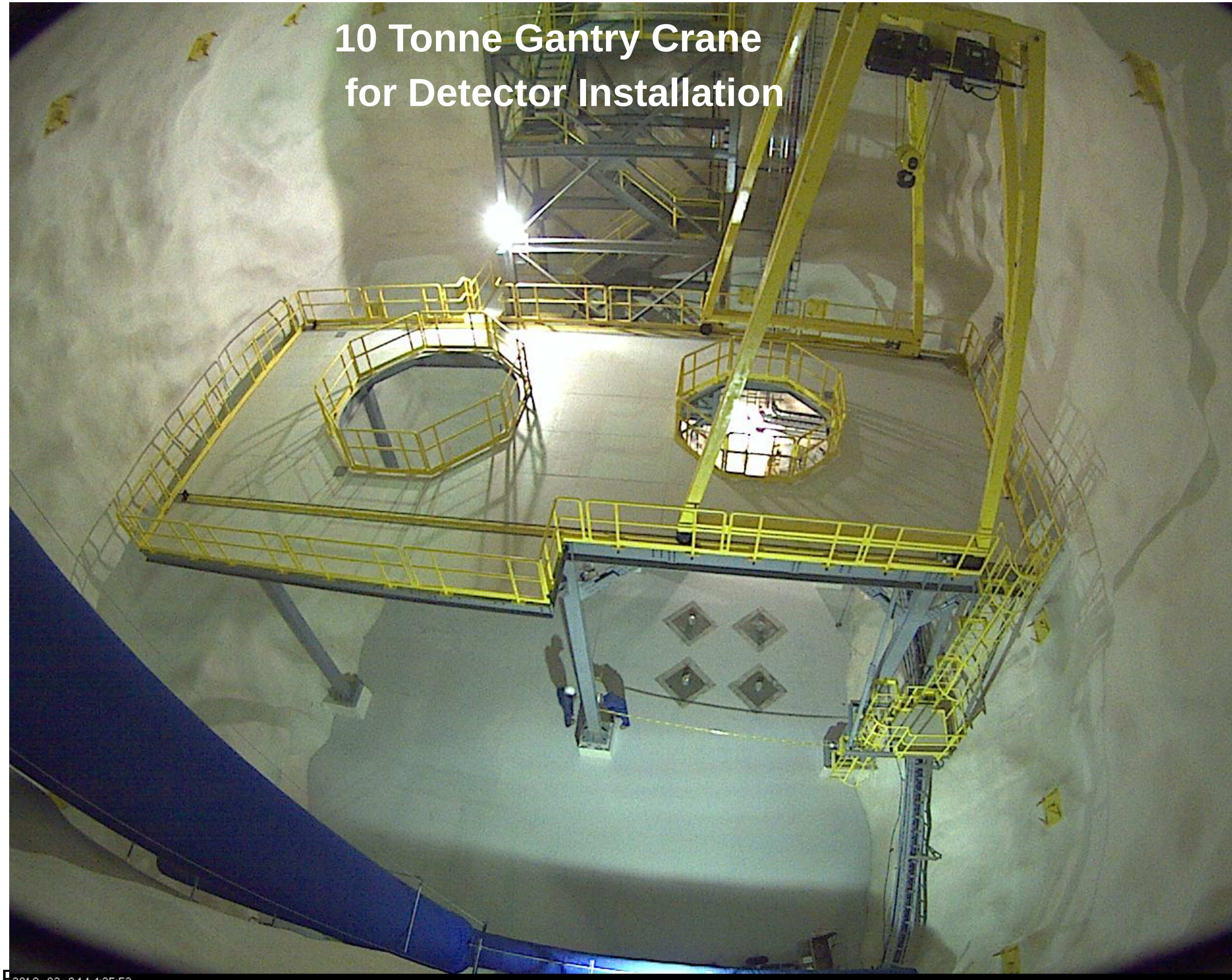
Feb 2010, Cube Hall now part of SNOLAB cleanroom

10 Tonne Gantry Crane for Detector Installation



DEAP-3600 schedule

Early 2010

Completed deck installation in Cube Hall, water tank components shipped UG

Rest of 2010

Install shield tank, water systems, electrical, infrastructure
Prepare sub-system and safety reviews
Prepare fabrication-ready drawings, prototyping of cryogenic systems, DAQ, 50-cm test vessel
Continued background studies with DEAP-1

2011 Construct and ship AV and components to site, complete process systems, electronics, QA, detector assembly

2012 Commission and Run

Summary

- DEAP-3600 targeting background-free exposure of 1000 kg LAr, 10^{-46} cm^2 sensitivity

- Current background levels and detector response demonstrated with DEAP-1 would allow "background-free" 250-kg search with DEAP-3600, on-going efforts for surface background reduction techniques (and PSD studies) with DEAP-1

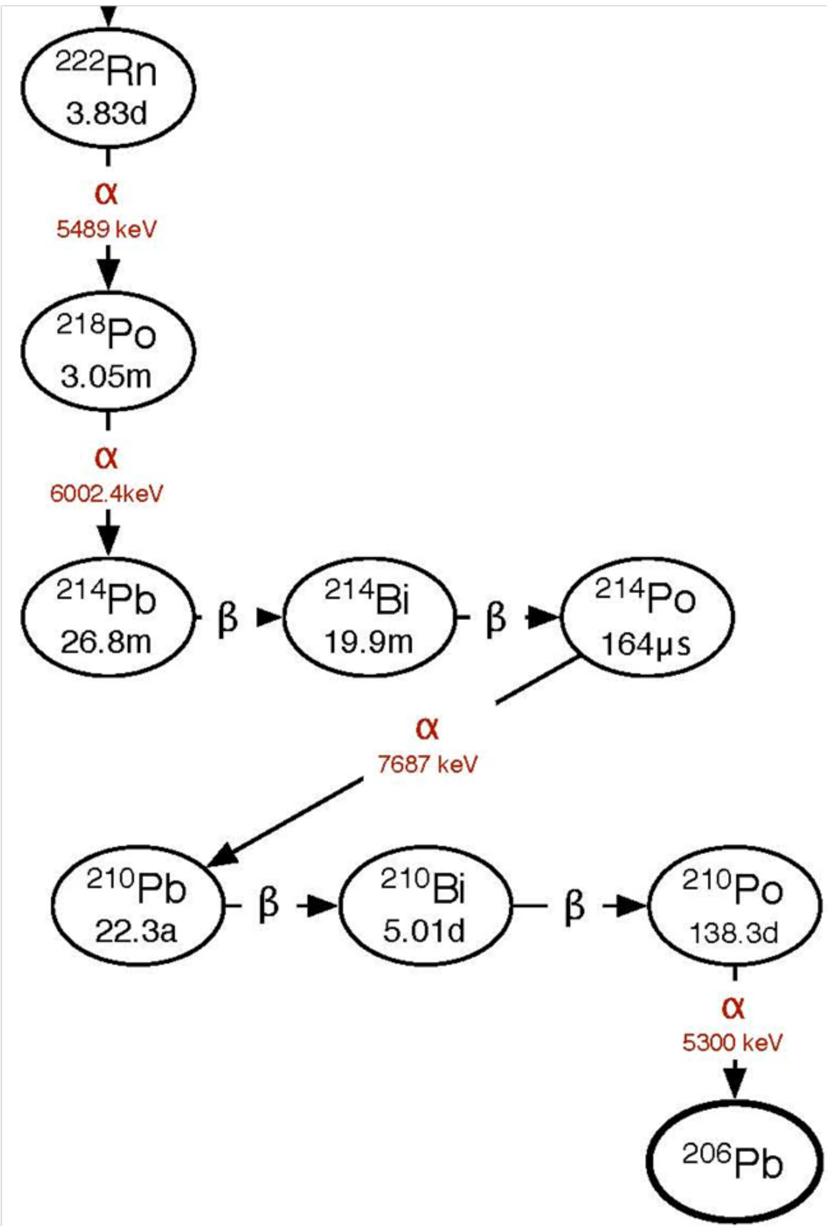
- Construction effort underway at SNOLAB, first running planned for 2012

END

DEAP-3600 Surface α's/recoils budget

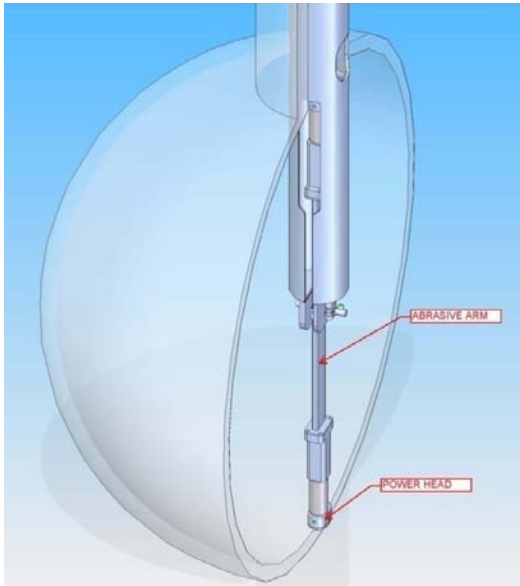
Source	Rate	Source	Events in ROI/3y
Total surface events in energy ROI	<1.6 μBq	All sources	<0.2
^{222}Rn in Ar		emanation	
^{220}Rn in Ar		emanation or Th, Ra leaching	
^{210}Pb in WLS		Rn diffusion into WLS	
^{210}Pb **on** WLS		leaching in ^{210}Pb from plumbing, surfaces	
^{210} Pb in acrylic		Rn diffusion into beads	
U in WLS		Impurity	
U in acrylic		Impurity	
Th in WLS		Impurity	
Th in acrylic		Impurity	
Particulates (mine dust)		Impurity, Rn emanation load	

DEAP-3600 Acrylic Vessel Resurfacer (Florian, Queen’s Engineer)



Mechanical resurfacer removes surface Contamination in inert environment

Debris is flushed and removed with ultrapure water



Resurfacer components are low Rn emanation materials and cleaned of ^{210}Pb

Resurfacer inserted and removed through sealed glove box

All materials that see argon need to be cleaned : low radon emanation, no ^{210}Pb, etc. leaching (weld passivation, etching, …)

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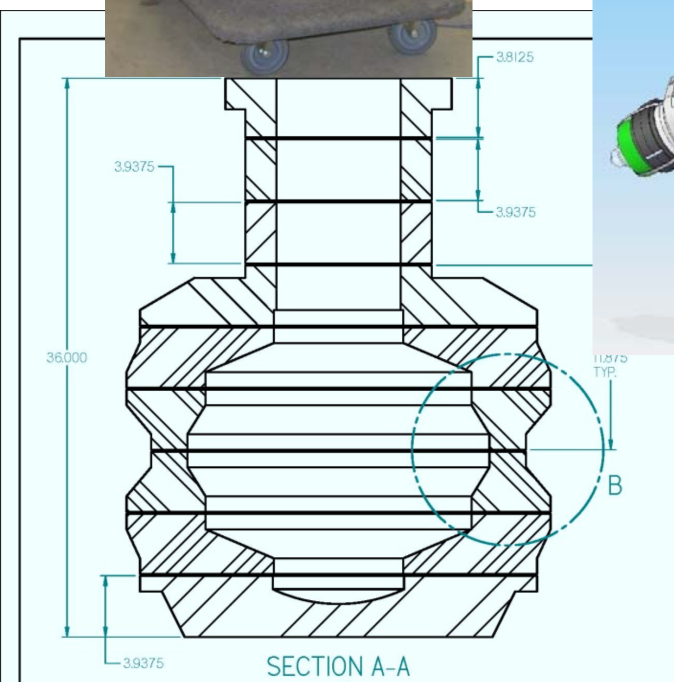
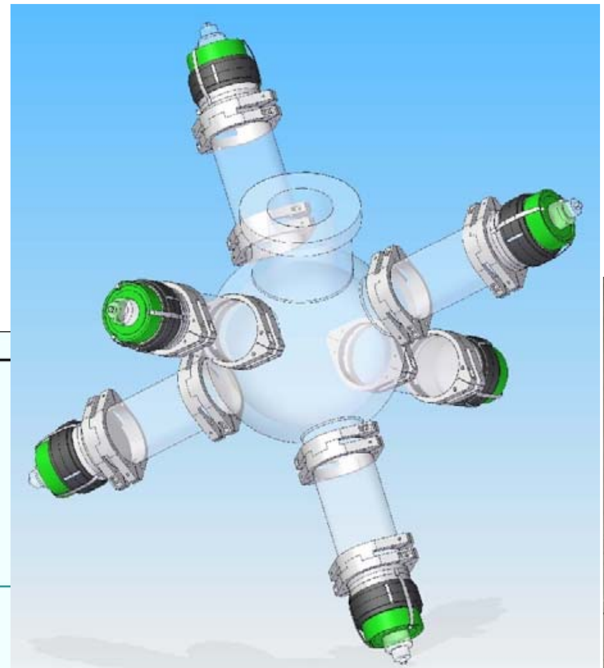
50-centimeter test vessel

Constructing a small test acrylic vessel to qualify machining/bonding of acrylic, and prototype some sub-systems





vessel is constructed from bonded 4” rings

Rings after bonding at Reynolds Polymer (Colorado)

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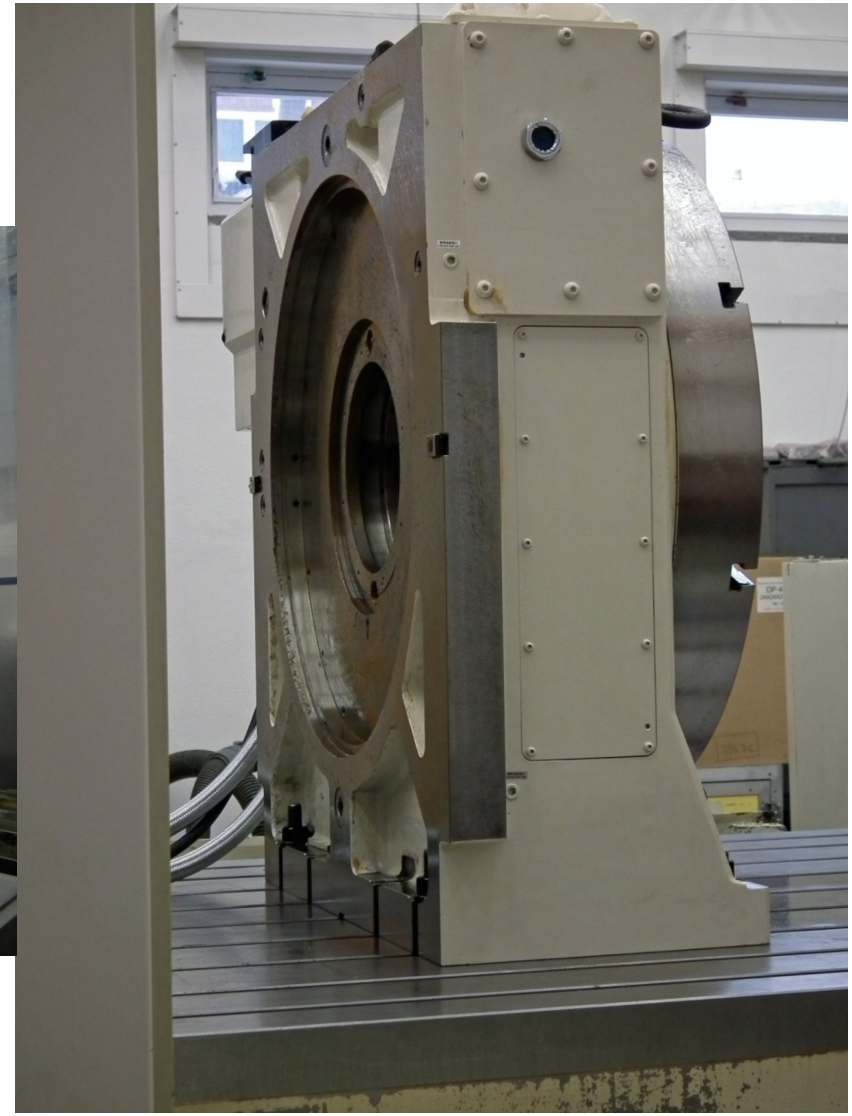
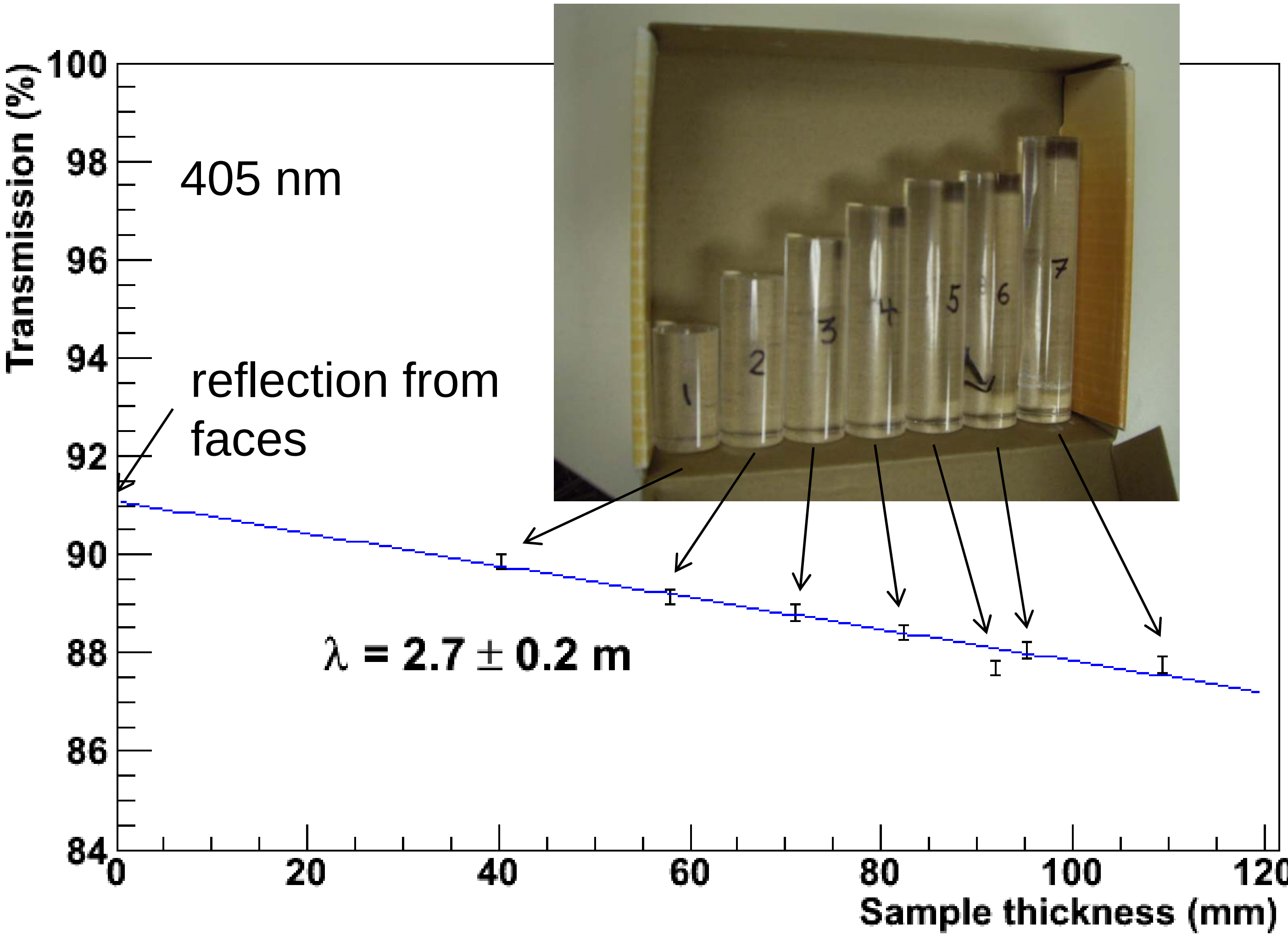
DEAP Acrylic Vessel Machining Setup (University of Alberta)



J. Soukup, Alberta

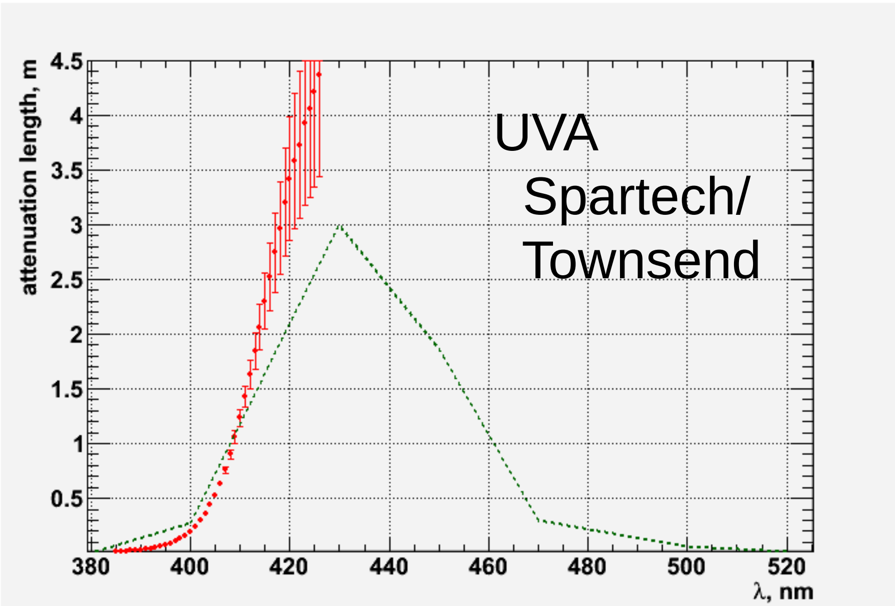
Acrylic optical attenuation lengths

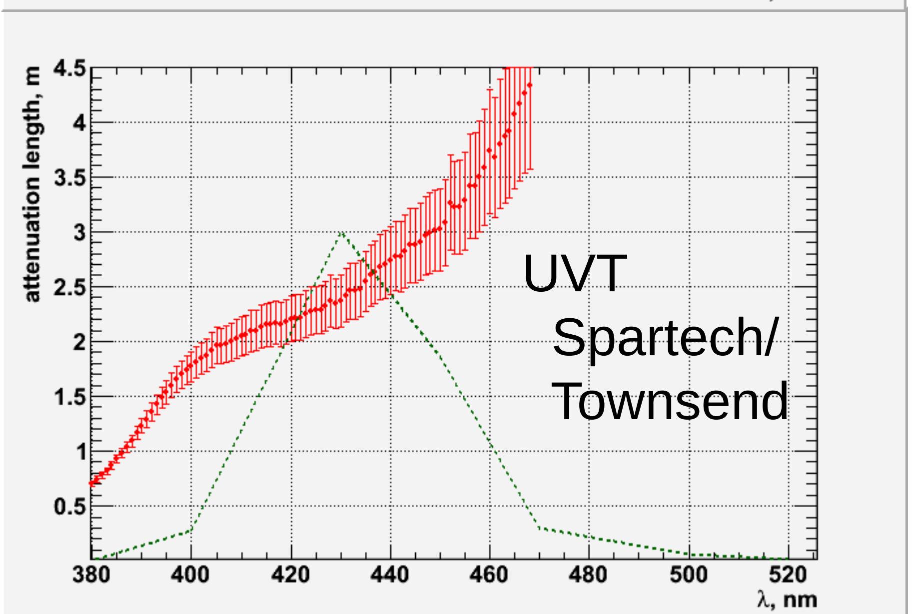


Carefully machined sets of acrylic rods, measured transmission with Lambda UV-VIS spectrometer to fit attenuation length, for several acrylic suppliers, with and without UV absorbers in acrylic (UVA or UVT)

(Data from V. Golovko, Queen's)

Acrylic attenuation length measurements





We consistently find that acrylic with UV absorber is much better at long wavelengths (> 400 nm)

Working with Spartech to "tailor" the UV absorber for best light transmission

Acrylic Sample	Average atten. length (m)
RPT-UVA	3.5
RPT-UVT	2.2
CS Hyde	4.1
Evonic-Rohm-UVT	4.8
Polymer Plastic UVT	2.4
Bicron-UVA	1.8
Spartech-UVA	5.2
Spartech-UVT	2.3
CS Hyde 2	>10

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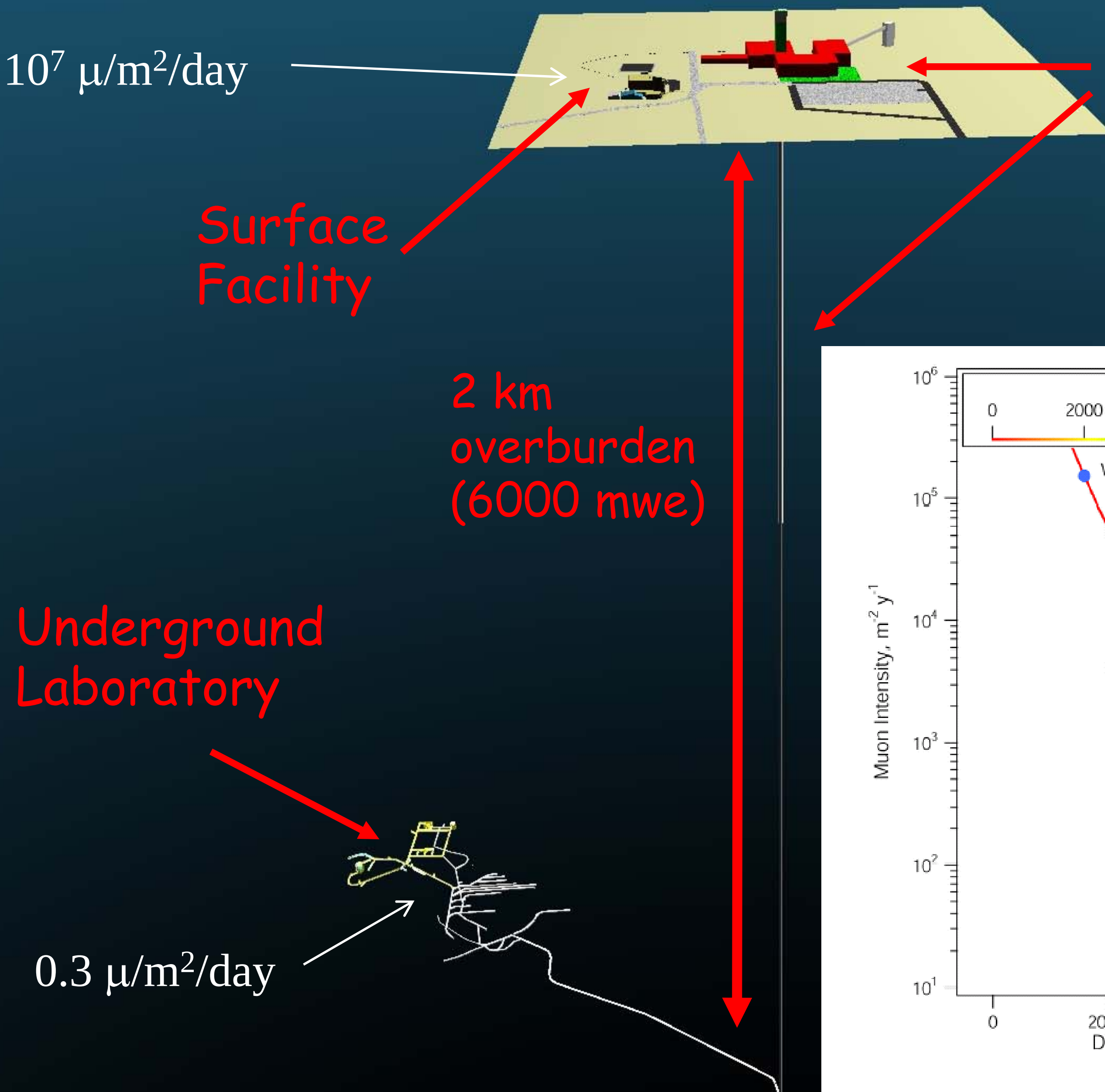
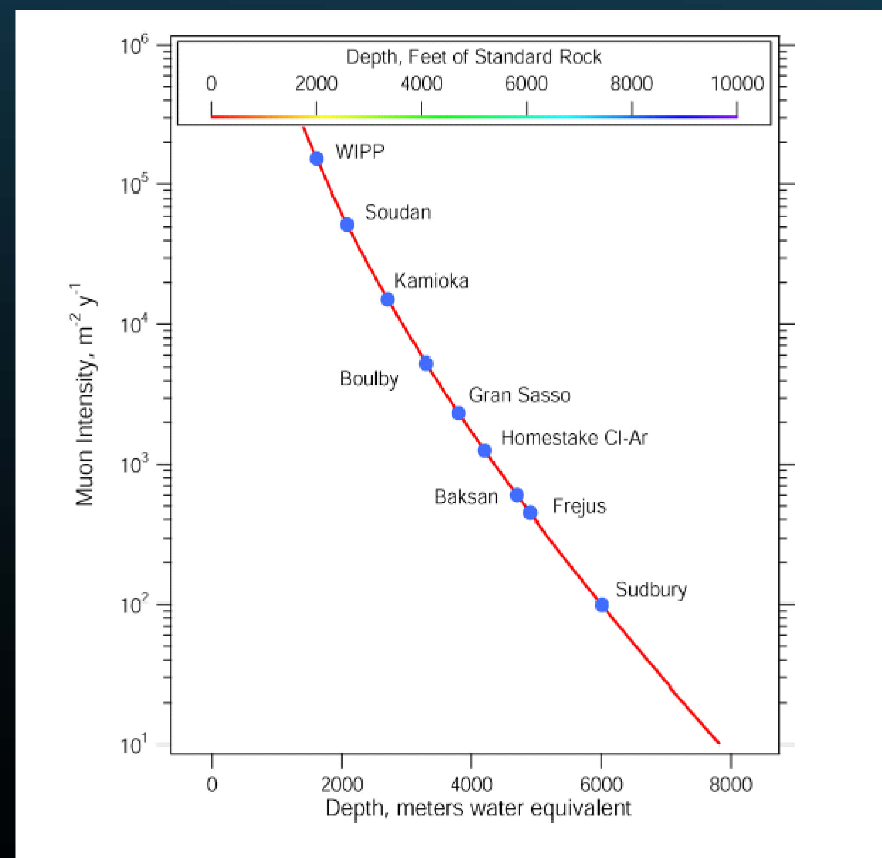
SNOLAB



10^7 μ/m²/day
Vale-INCO Creighton Mine near Sudbury, Ontario
Surface Facility
2 km overburden (6000 mwe)
Underground Laboratory
0.3 μ/m²/day



Depth, Feet of Standard Rock
0
2000
4000
6000
8000
10000
WIPP
Soudan
Kamioka
Boulby
Gran Sasso
Homestake Cl-Ar
Baksan
Frejus
Sudbury
Muon Intensity, m⁻² y⁻¹
10⁶
10⁵
10⁴
10³
10²
10¹
Depth, meters water equivalent