Title: The DEAP-3600 Detector and Recent Developments at SNOLAB

Date: Mar 11, 2011 01:00 PM

URL: http://pirsa.org/11030112

Abstract: The DEAP-3600 single-phase liquid-argon dark matter detector is under construction at SNOLAB. The fundamental goal of the design is to increase the volume of the detector while having the liquid argon contact the smallest possible surface comprising only clean acrylic and wavelength shifter. Specifically DEAP-3600 is a spherical detector with a 1000 kg fiducial mass and a design background rate less than 0.1 events in the WIMP region of interest in three years of data taking. Design sensitivity to WIMP dark matter at 100 GeV is 10-46 cm2. In order to achieve this ambitious goal an extensive program of background reduction and control is underway for all detector components including the acrylic vessel, process system, photomultiplier tubes and TPB wavelength shifter. Efforts to obtain acrylic with bulk Uranium and Thorium contamination below 0.3 and 1.3 ppt respectively and Pb-210 contamination below 1.1x10-8 ppt will be described. A resurfacer is under development to ensure that the surface contamination of acrylic is removed. Even with these stringent controls fiducialization will be required to reduce surface backgrounds by a factor of 1000. Preliminary studies are promising. We have operated the DEAP-1 prototype detector underground at SNOLAB; results from the DEAP-1 runs will be discussed and the impact of those runs on DEAP-3600 will be discussed. SNOLAB has recently made the Ã¢ÂÂ€ÂÂœphase 2Ã¢ÂÂ€ÂÂ• expansion (including the cryopit and two drifts) part of the clean space. A photo essay showing recent progress in the facility and the experimental program will be presented.

DEAP-3600
Direct Dark-Matter Search

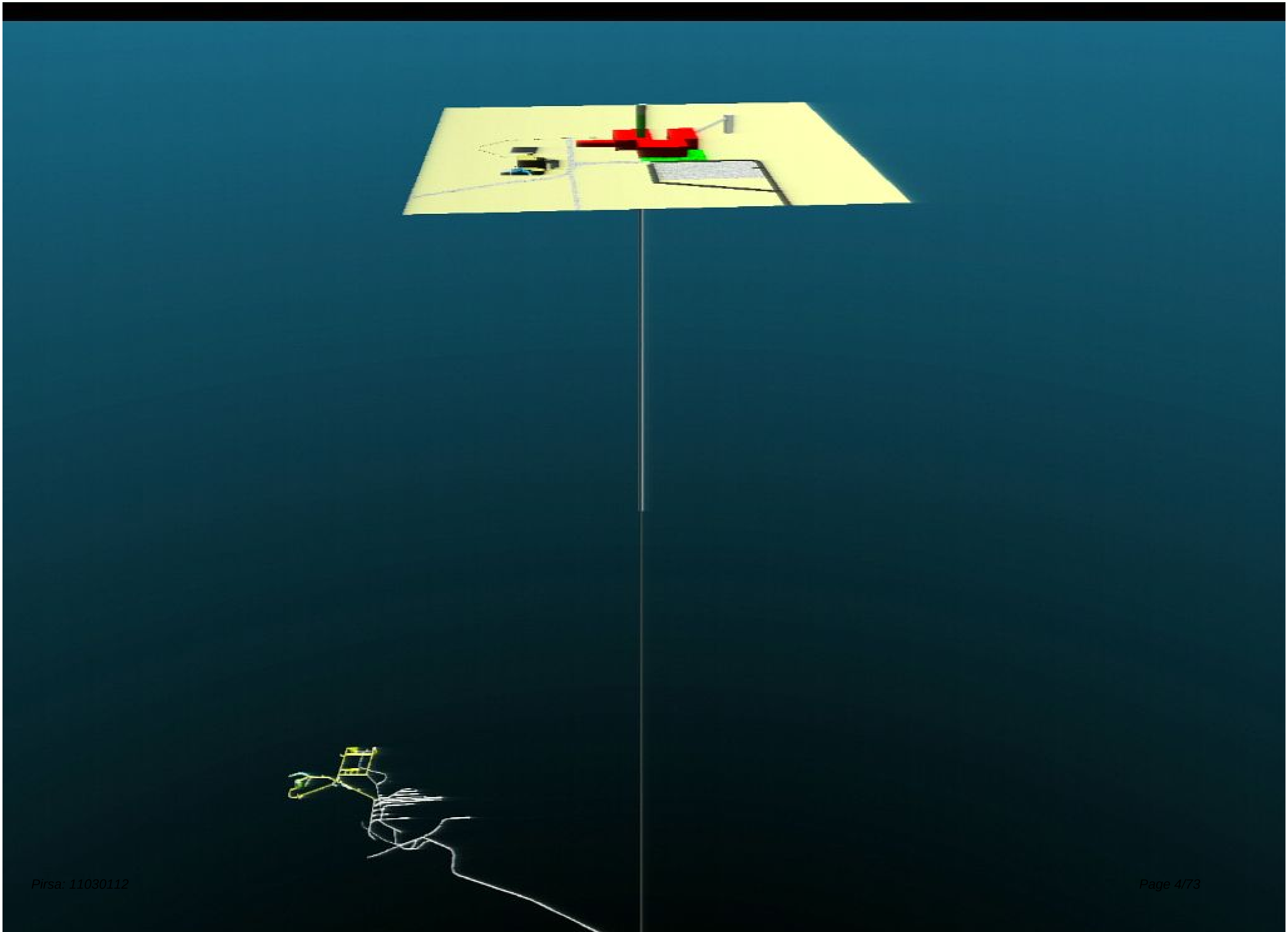
Chris Jillings

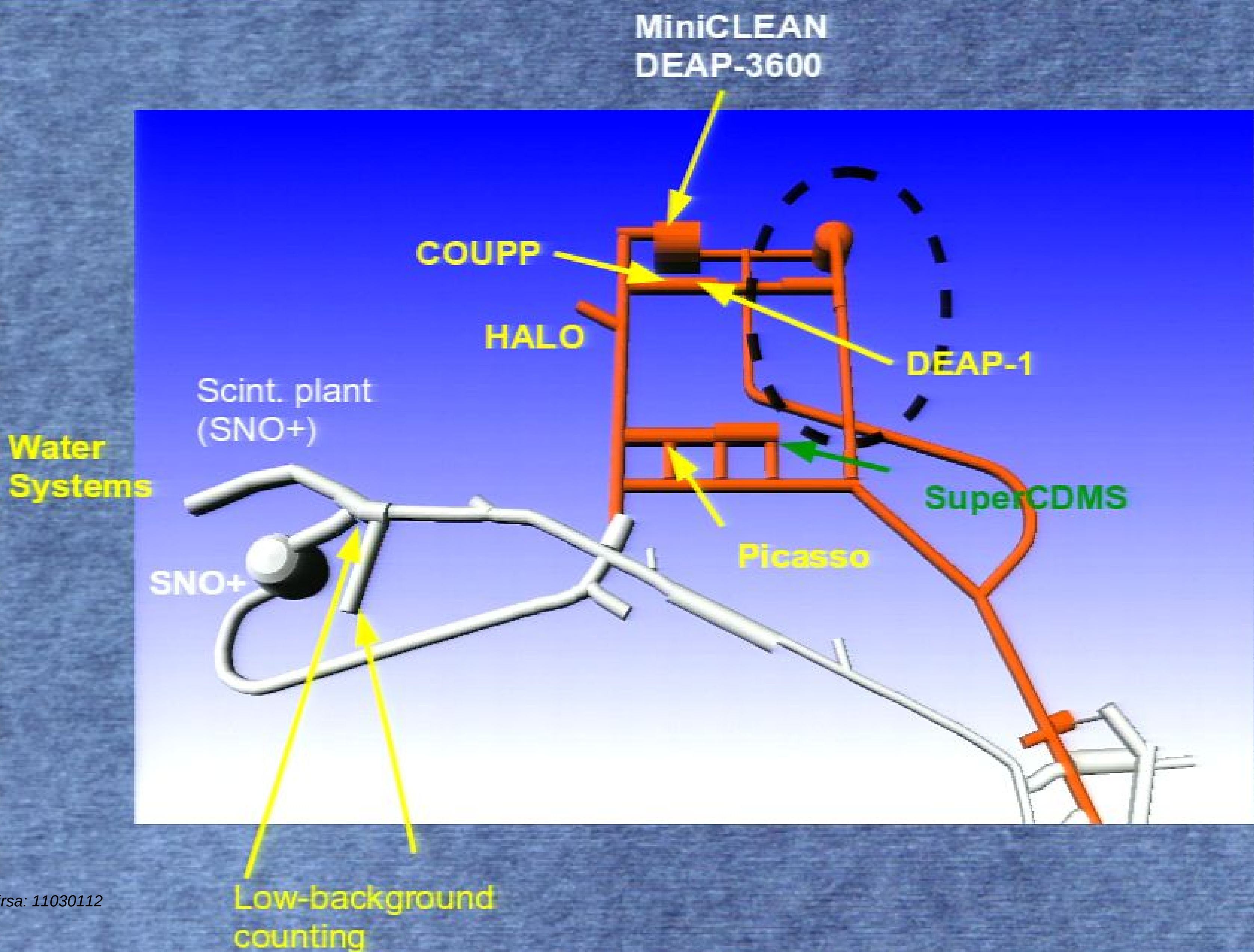
Laurentian University
Université Laurentienne

For the DEAP-3600 Collaboration

Overview

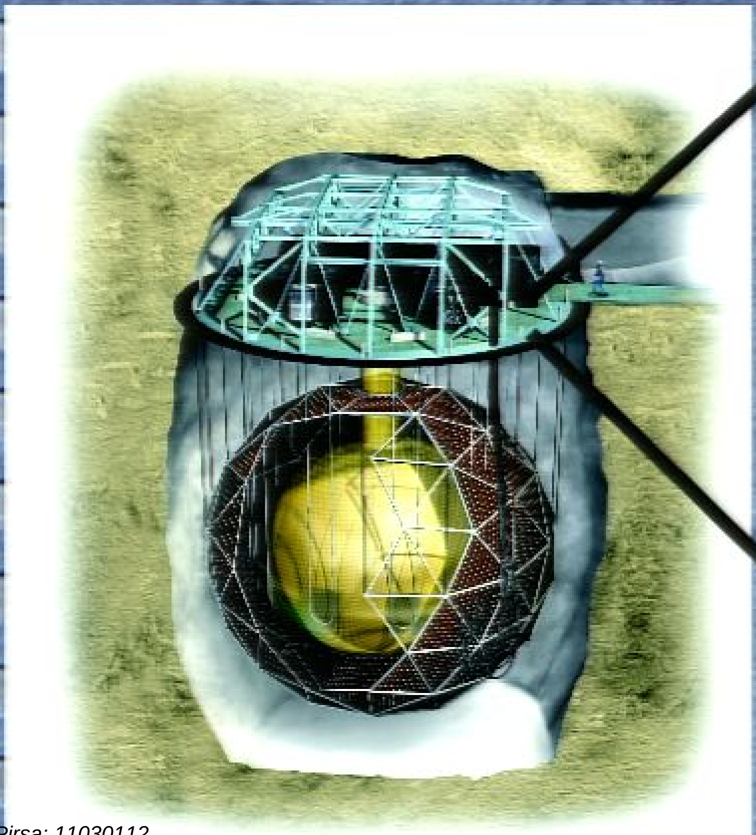
- A slide show showing SNOLAB's recent progress
-
- Dark Matter and Liquid Nobles
- Why DEAP?
- Design Overview
- Sources of backgrounds and control
- Progress with DEAP-1
- What's Next

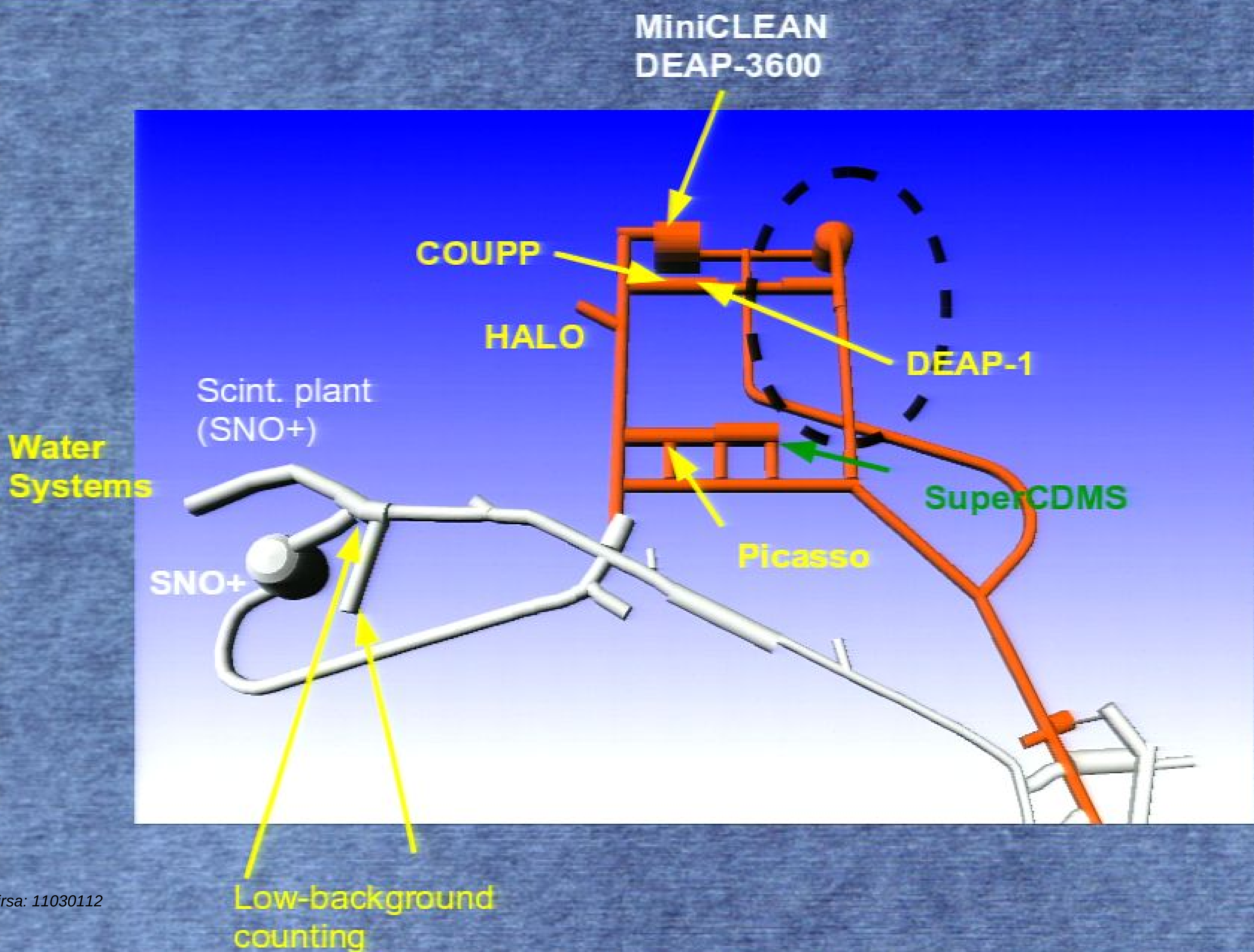



MiniCLEAN
DEAP-3600
COUPP
HALO
DEAP-1
Scint. plant
(SNO+)
Water
Systems
SuperCDMS
Picasso
SNO+
Low-background
counting

SNO+ Cavity

- Anchors to hold down buoyant sphere of L.A.B.

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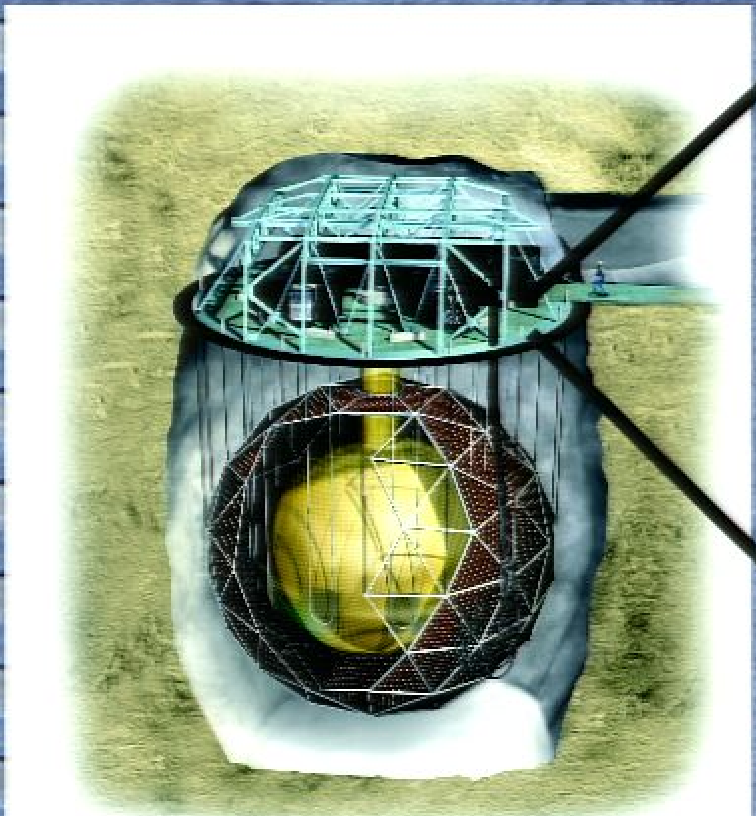
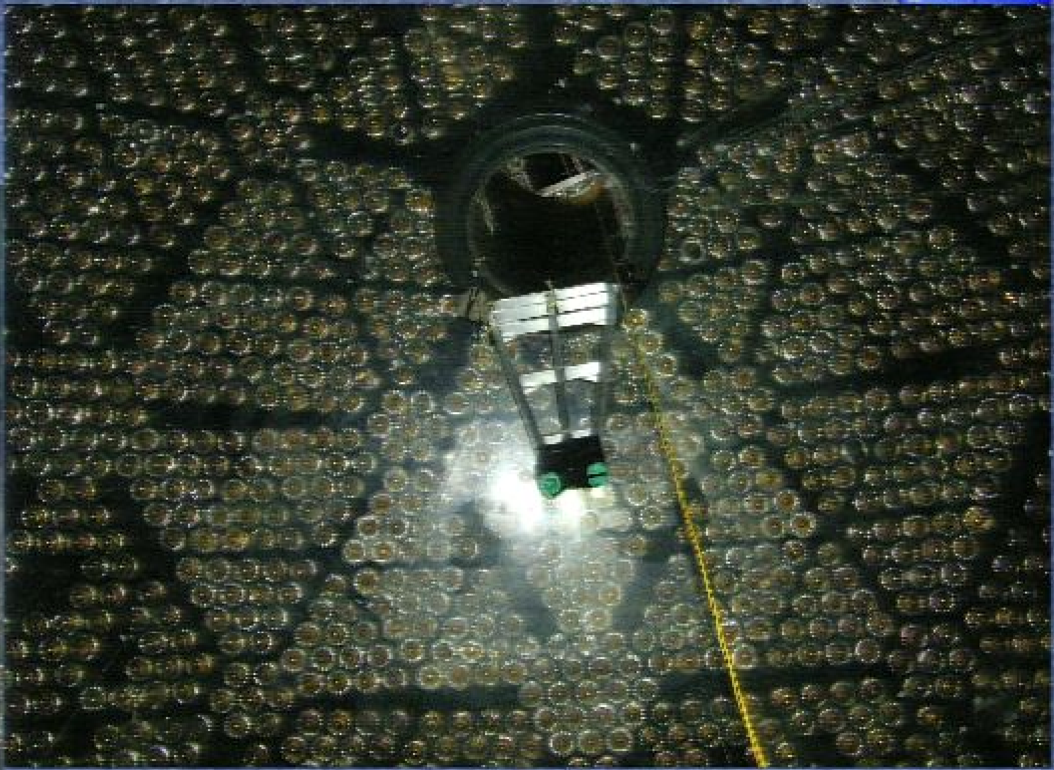
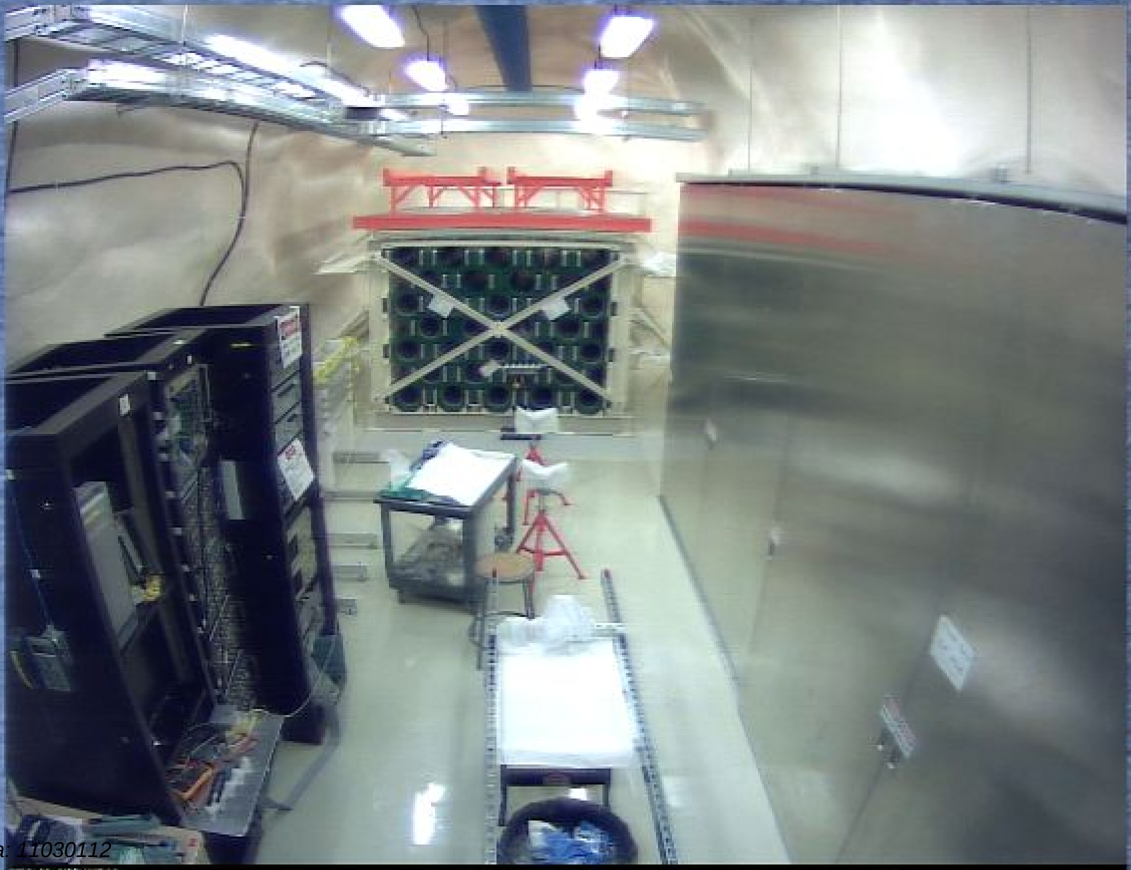


More SNO+



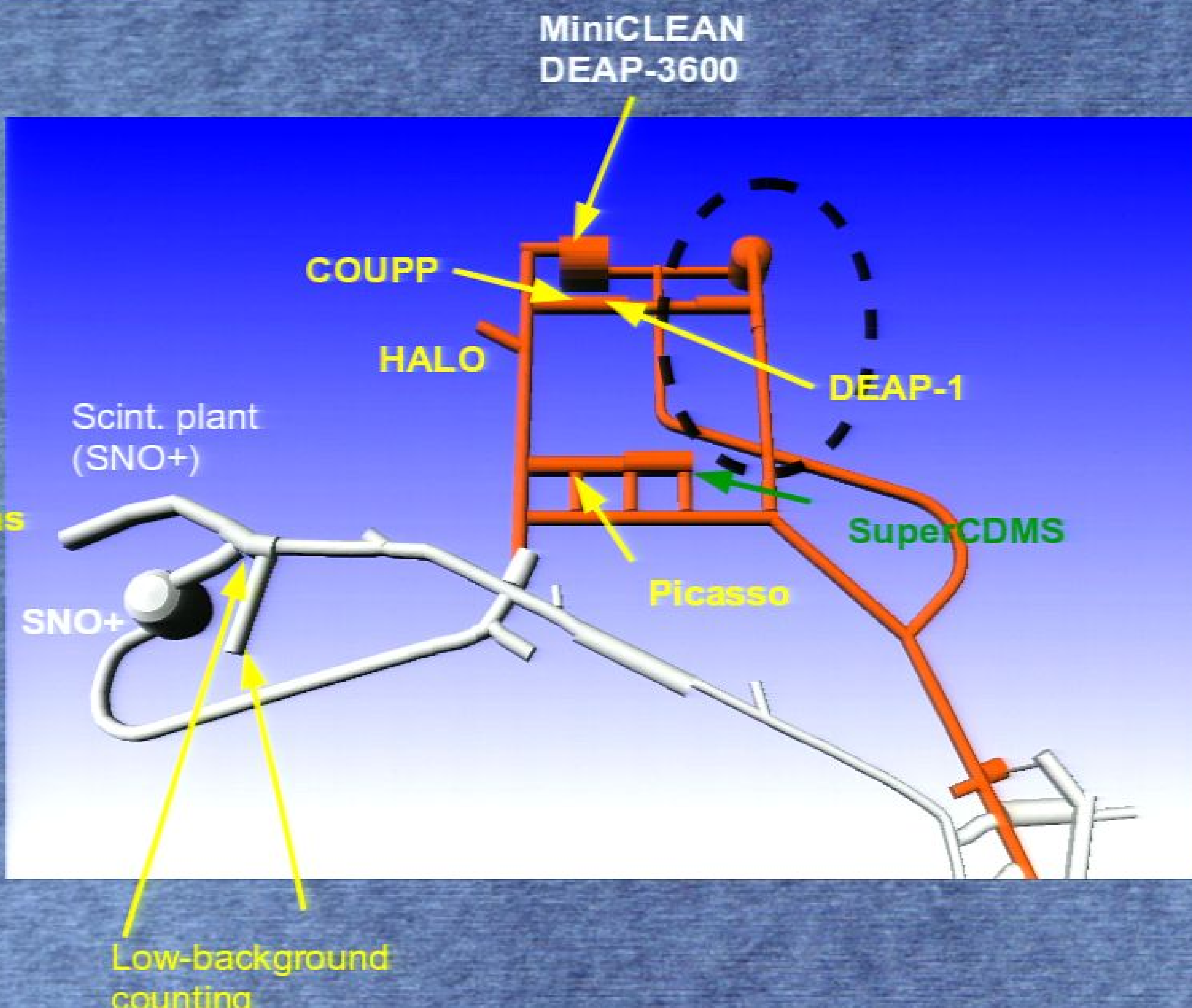
HALO

- A lead supernova detector: Helium And Lead Observatory



Picasso

- Taking Data: Picasso detector with bean-bag WIMP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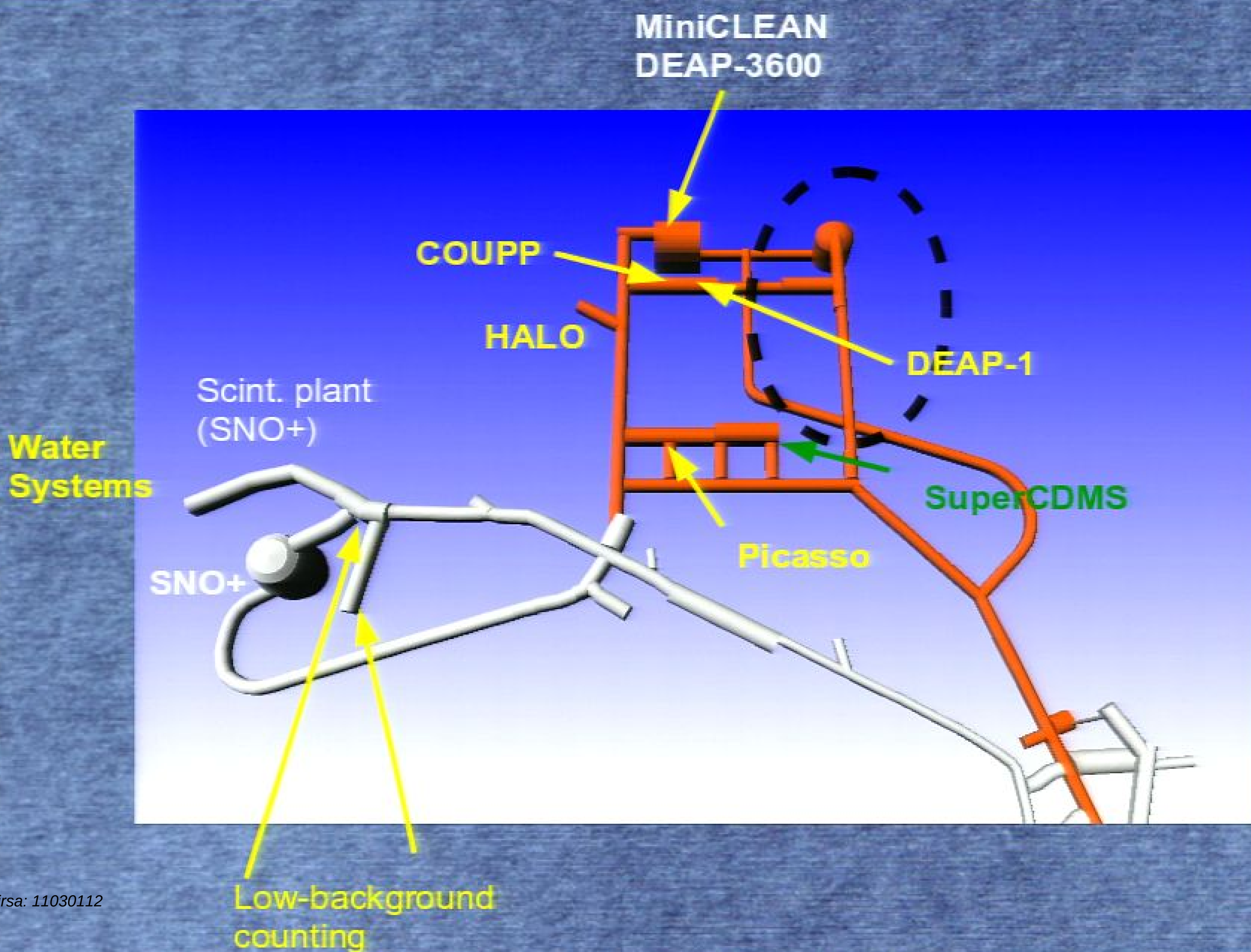
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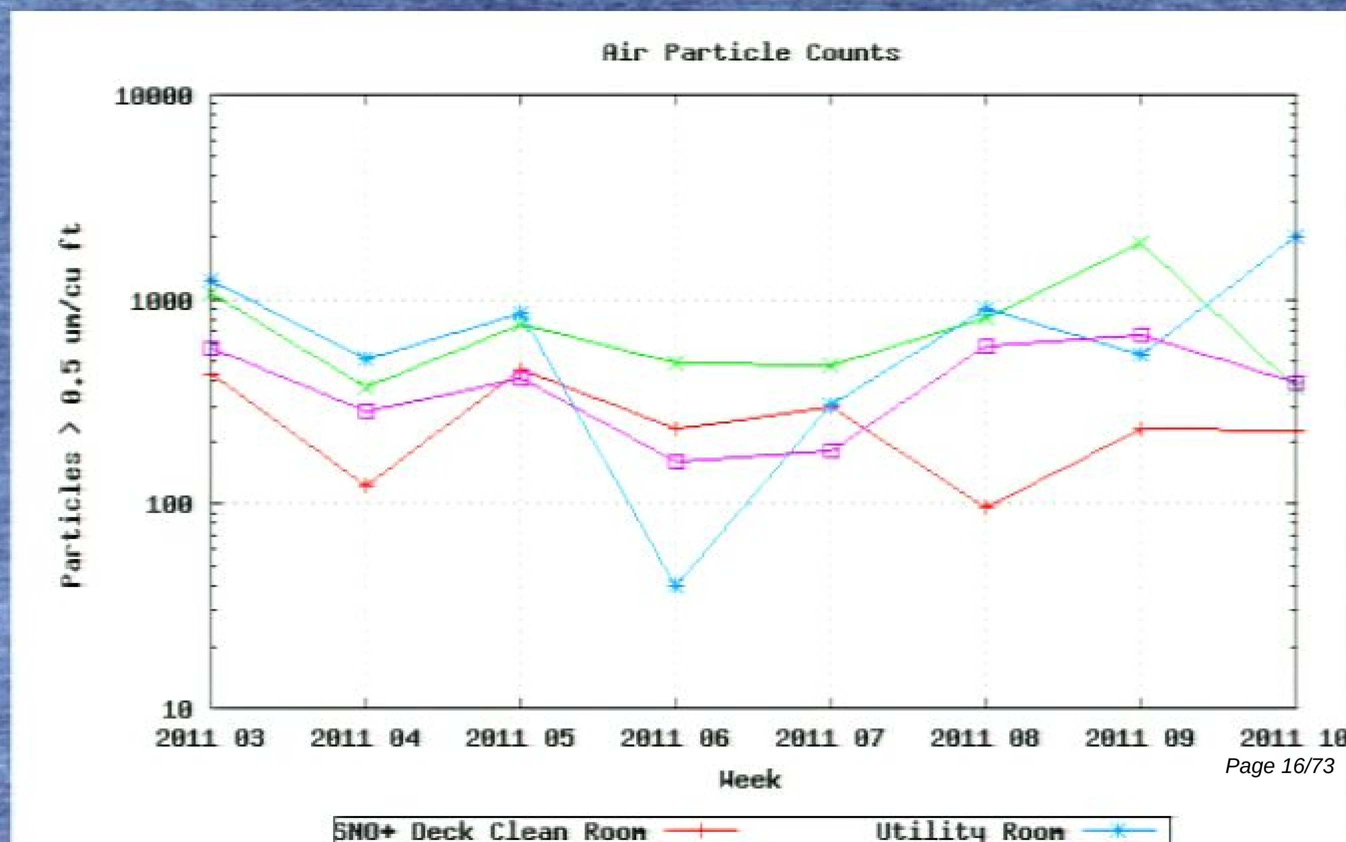
Phase 2 Area Opened in March

As of one week ago the cryopit needed only fire detection and emergency lighting for science to start.

Bottom Line

- SNOLAB has 53000 square feet of class 2000 clean-room space. It is not (yet) all allocated.
- Typical dust deposition rates <1 μgram/cm²/month



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irect WIMP Detection Using Scintillation Time Discrimination in Liquid Argon

M.G. Boulay* and A. Hime
Physics Division, MS H803, Los Alamos National Laboratory, Los Alamos, NM 87545
(Dated: November 15, 2004)

Parameter	Ne	Ar	Xe
Yield ($\times 10^4$ photons/MeV)	1.5	4.0	4.2
prompt time constant τ_1 (ns)	2.2	6	2.2
late time constant τ_3	15 μs	1.59 μs	21 ns
I_1/I_3 for electrons	0.12	0.3	0.3
I_1/I_3 for nuclear recoils	0.56	3	1.6
λ(peak) (nm)	77	128	174
Rayleigh scattering length (cm)	60	90	30

Astroparticle Physics 25, 179 (2006)

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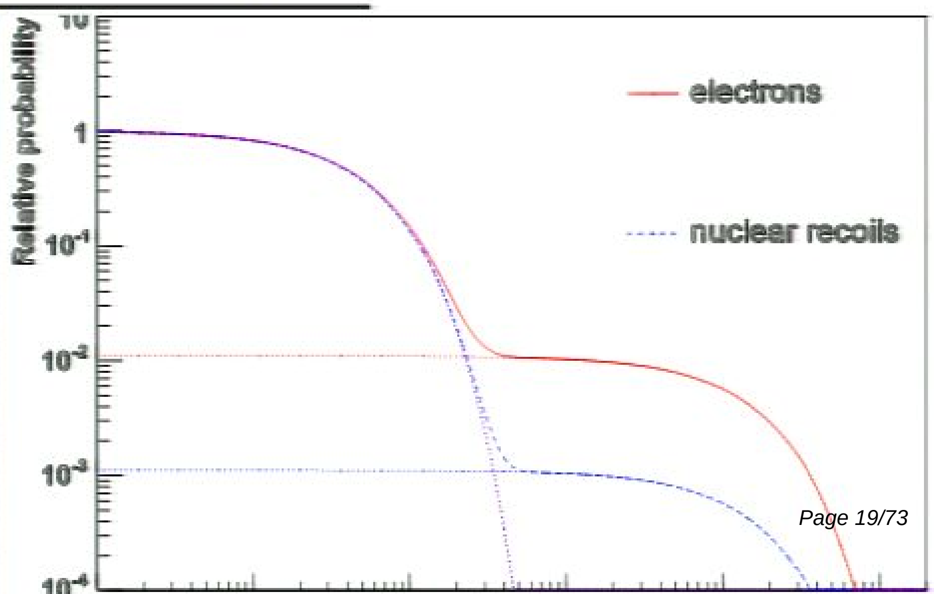
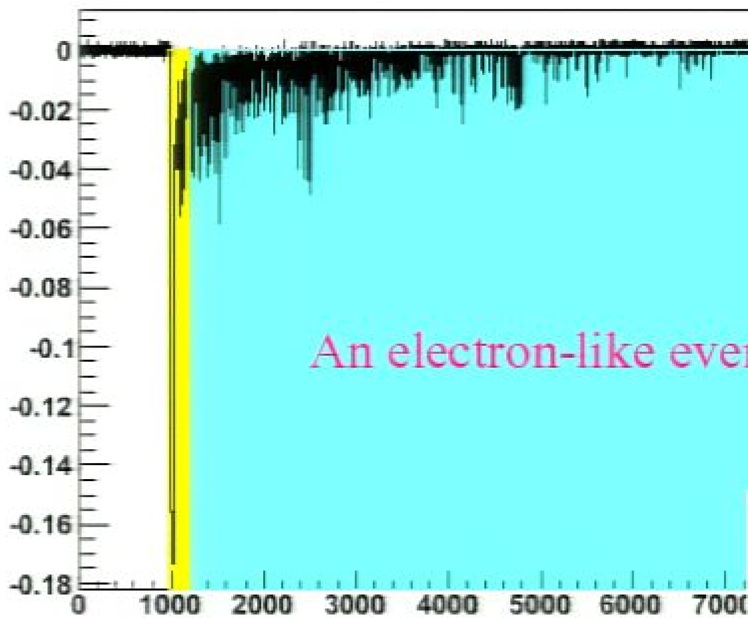
scintillation pulse-shape analysis for discrimination of e- vs nuclear recoils
-> no electron-drift

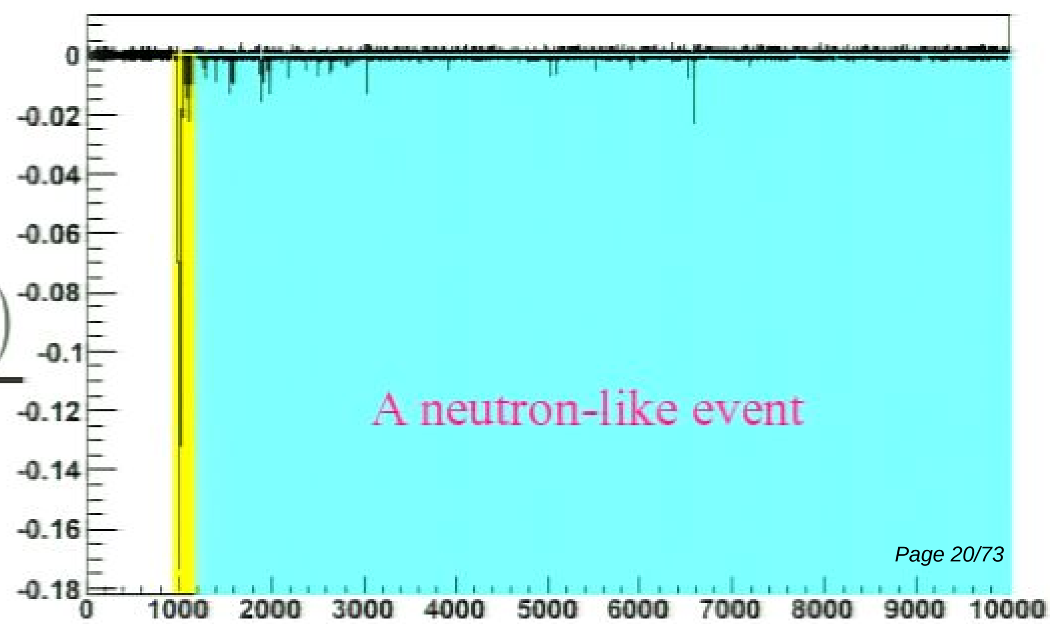


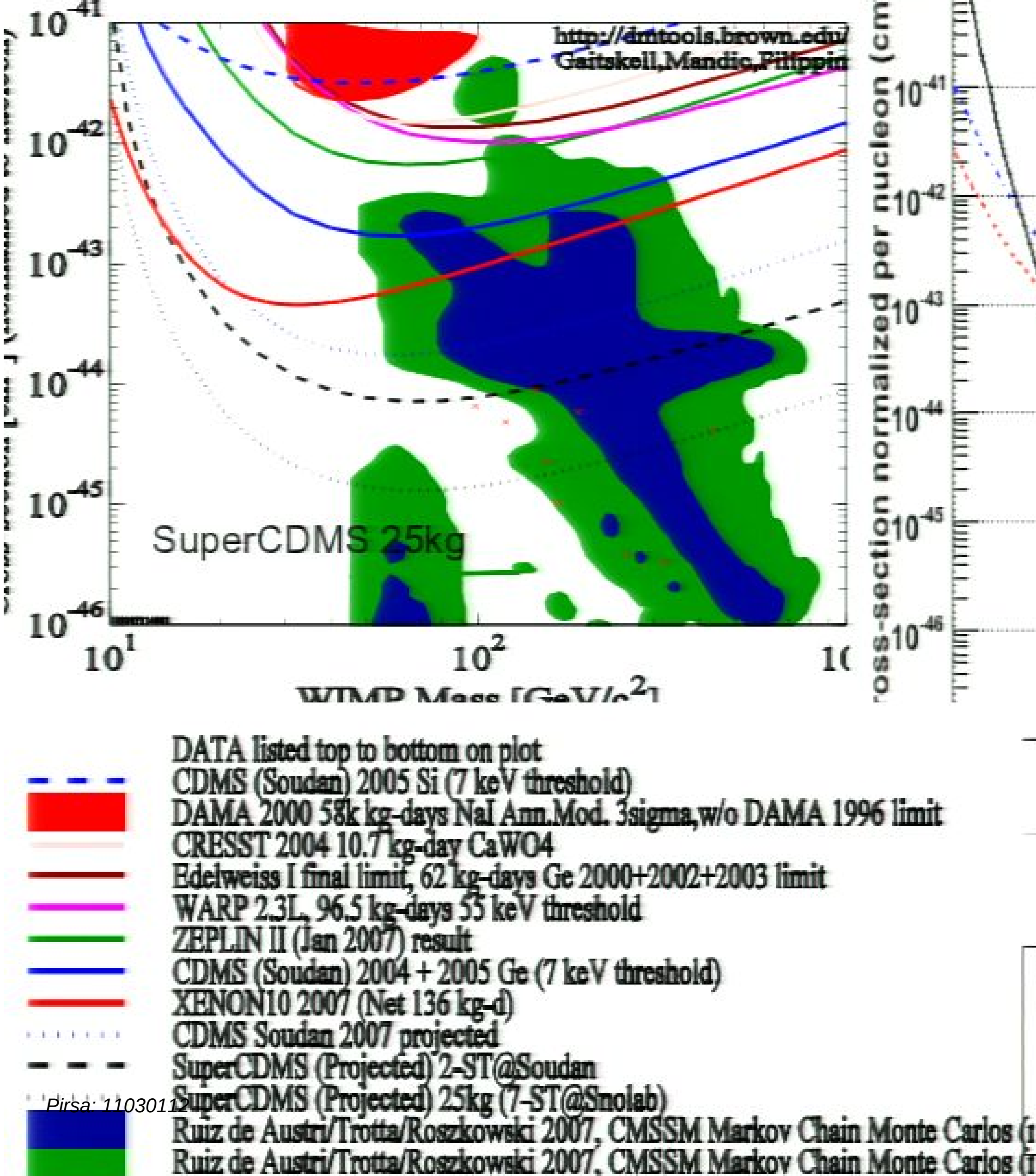
F_{prompt}: the discriminator

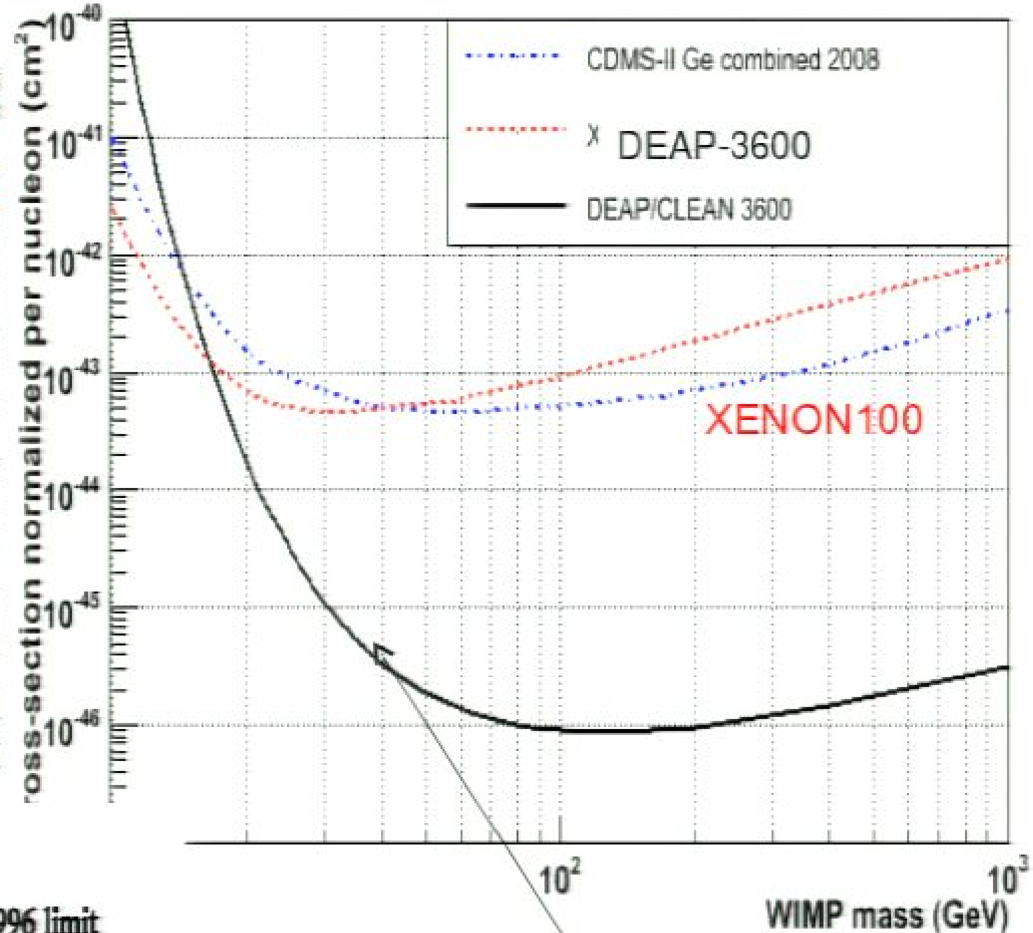


Yellow: Prompt light region
Blue: Late light region

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





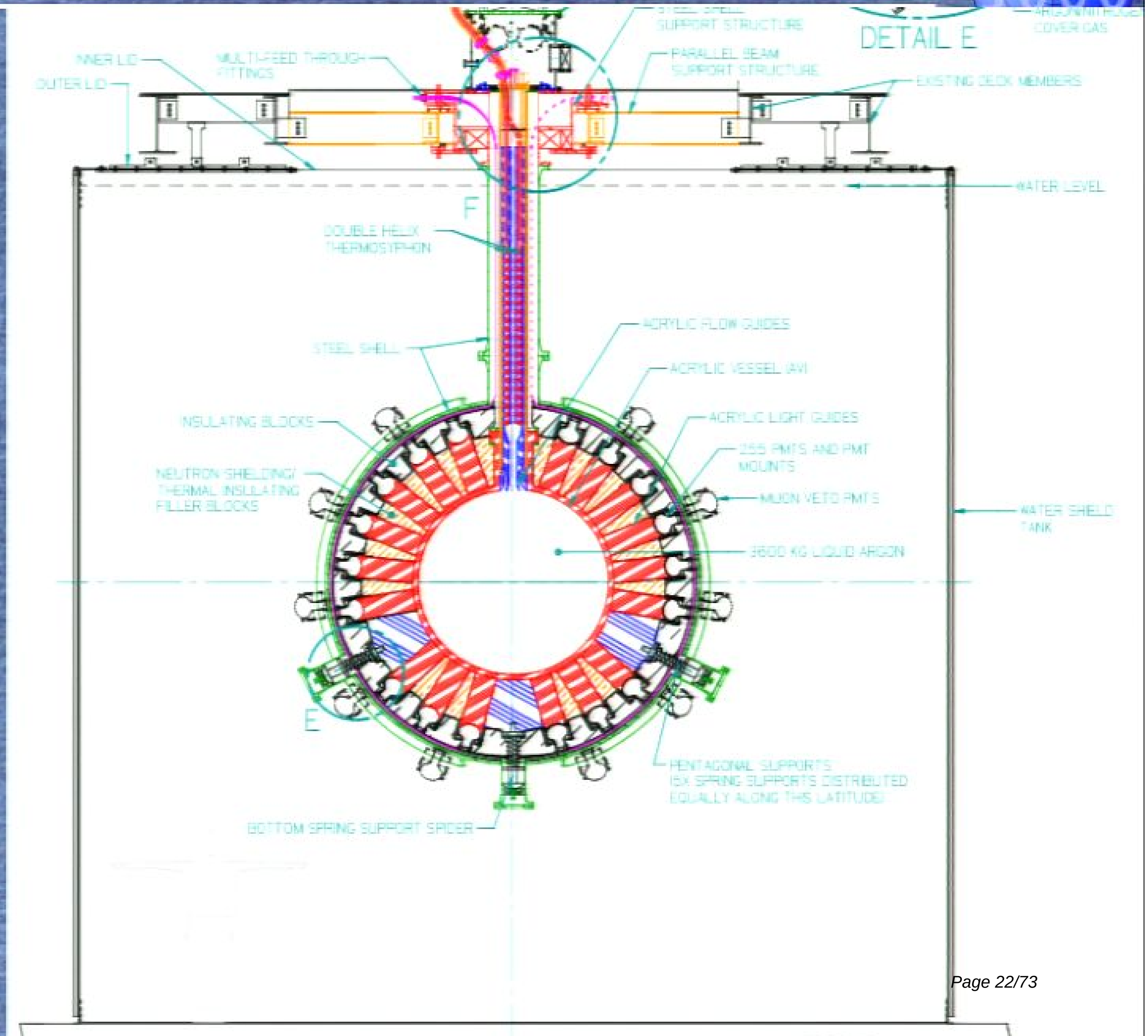


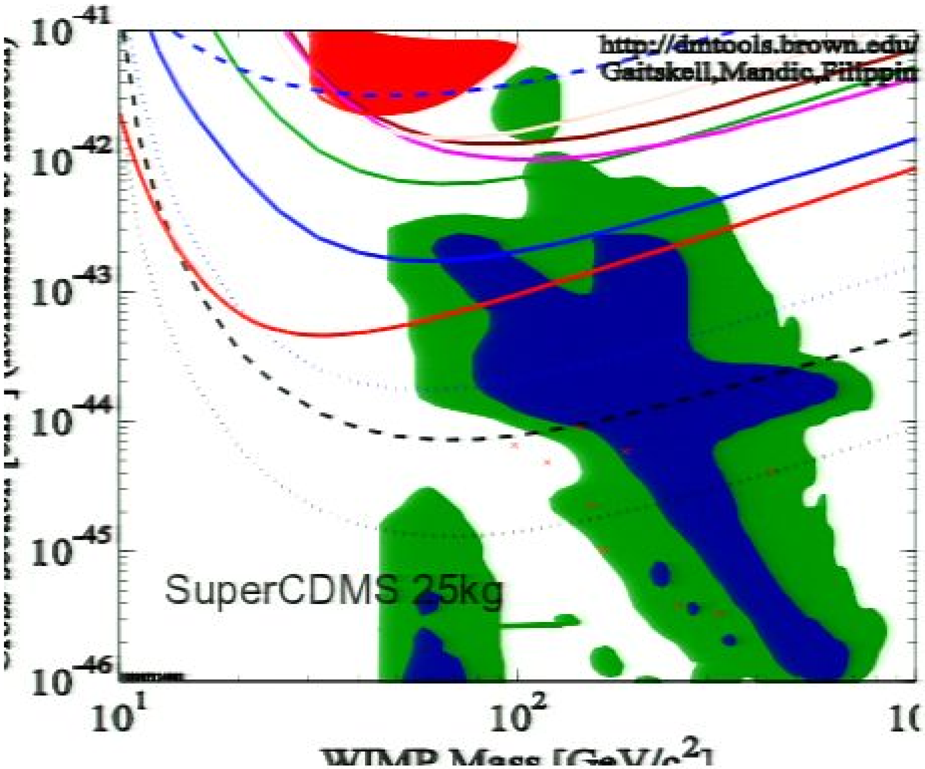
60 keVr threshold, without depletion of argon-39.

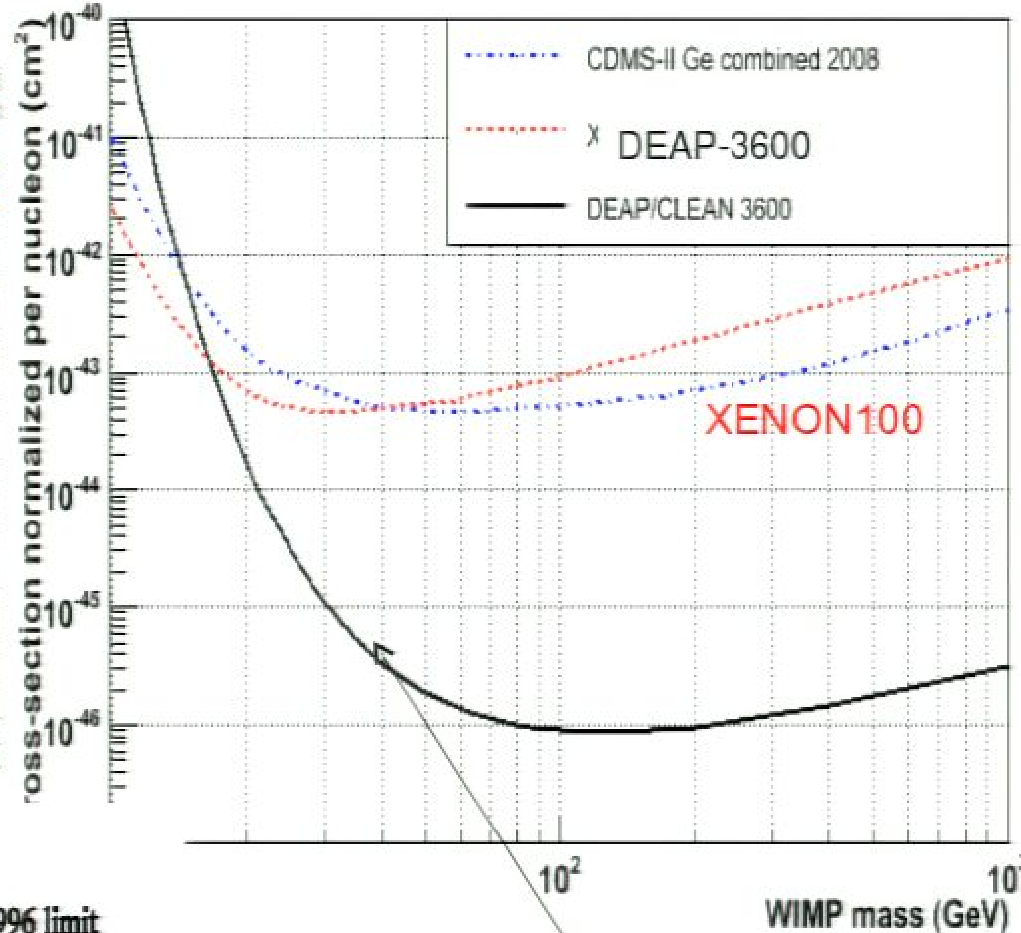
DEAP-3600 design sensitivity, 1,000,000 kg-days, background-free

DEAP-3600 Design

- 1000 kg fiducial mass
- 3600 kg Liquid Argon
- Wavelength shifter (TPB)
- Acrylic sphere
- Acrylic light guides / Filler blocks
- 255 Hamm R5912 HQE PMTs
- Steel shell (safety)
- Water Ch. Muon veto







DATA listed top to bottom on plot
CDMS (Soudan) 2005 Si (7 keV threshold)
DAMA 2000 58k kg-days NaI Ann.Mod. 3sigma,w/o DAMA 1996 limit
CRESST 2004 10.7 kg-day CaWO4
Edelweiss I final limit, 62 kg-days Ge 2000+2002+2003 limit
WARP 2.3L, 96.5 kg-days 55 keV threshold
ZEPLIN II (Jan 2007) result
CDMS (Soudan) 2004 + 2005 Ge (7 keV threshold)
XENON10 2007 (Net 136 kg-d)
CDMS Soudan 2007 projected
SuperCDMS (Projected) 2-ST@Soudan
SuperCDMS (Projected) 25kg (7-ST@Snolab)
Ruiz de Austri/Trotta/Roszkowski 2007, CMSSM Markov Chain Monte Carlos (
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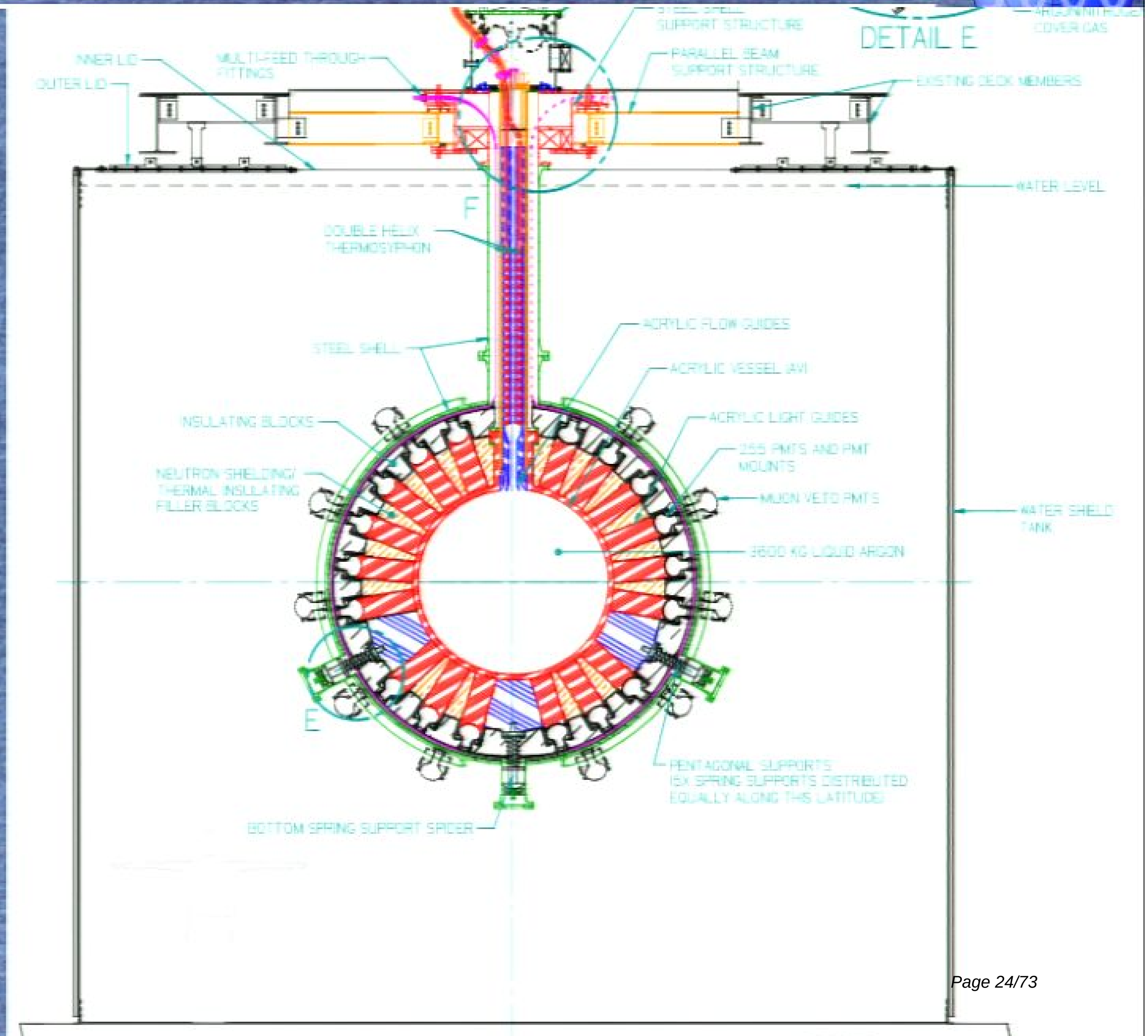


Summary of Backgrounds

Goal: 0.1 background events in 1 tonne in 3 years

Surface Events: Alphas and nuclear recoils from surface activity in acrylic and TPB.

- Automatic resurfacing under pure gas to remove any radon daughter activity
- Control contamination in acrylic & TPB
- Reconstruction

Radon: Emanation from process system components.

- Charcoal filter at ~ -150C
- Seamless tubing
- Careful control of valves

Summary of Backgrounds (2)

Neutrons: Fast neutrons from (α,n) in acrylic, PMT glass, steel shell or rock wall.

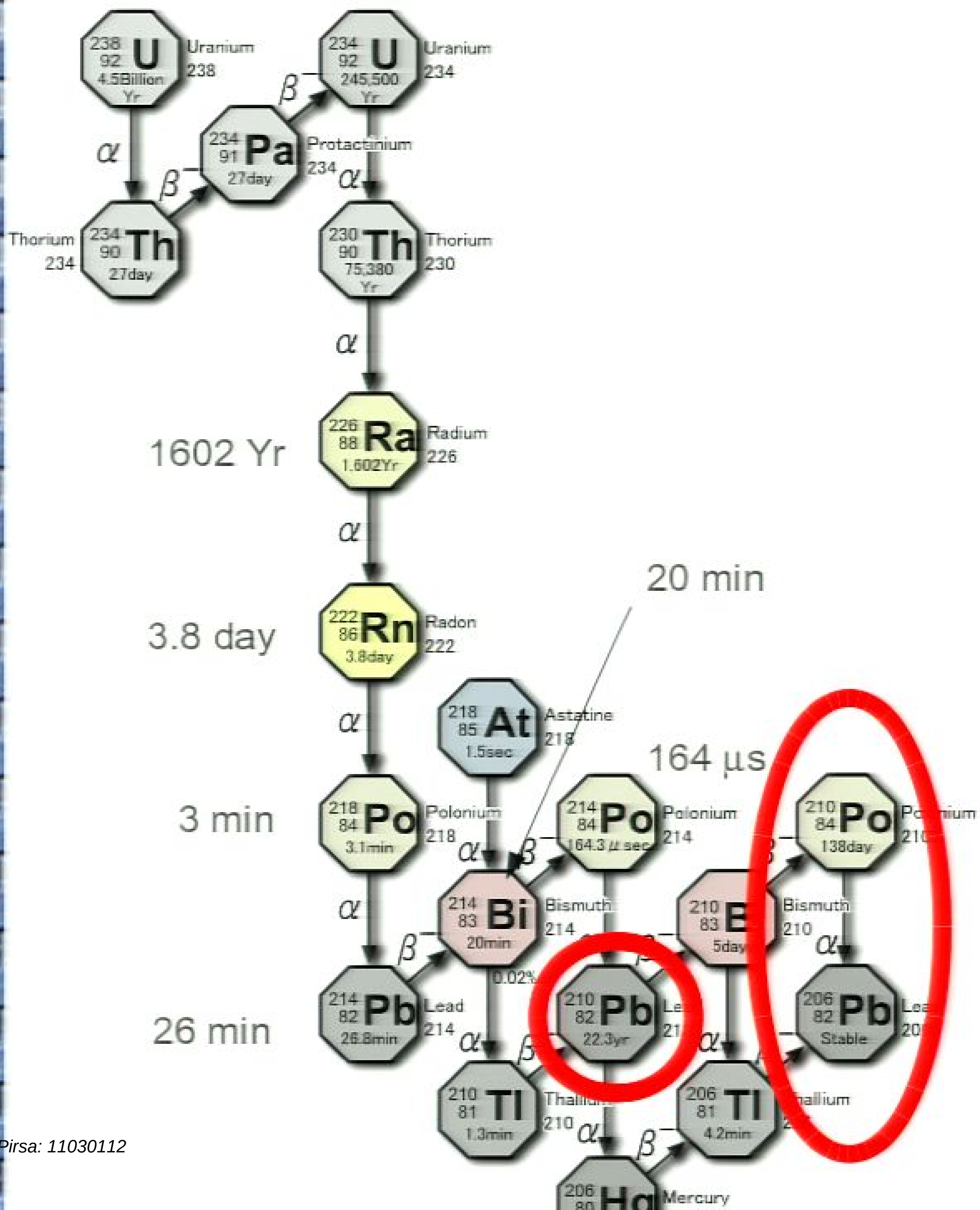
- Control contamination in acrylic
- Long light guides and acrylic filler to shield
- Water tank shielding

Cosmic-ray induced neutrons: Fast neutrons from cosmic rays

- 6000 mwe flat overburden at SNOLAB
- Active muon veto

Electromagnetic Events: Betas from Argon-39 and other gamma sources

- PSD – requires high light yield: Improved with better optics in acrylic, ie shorter light guides
- Water shielding

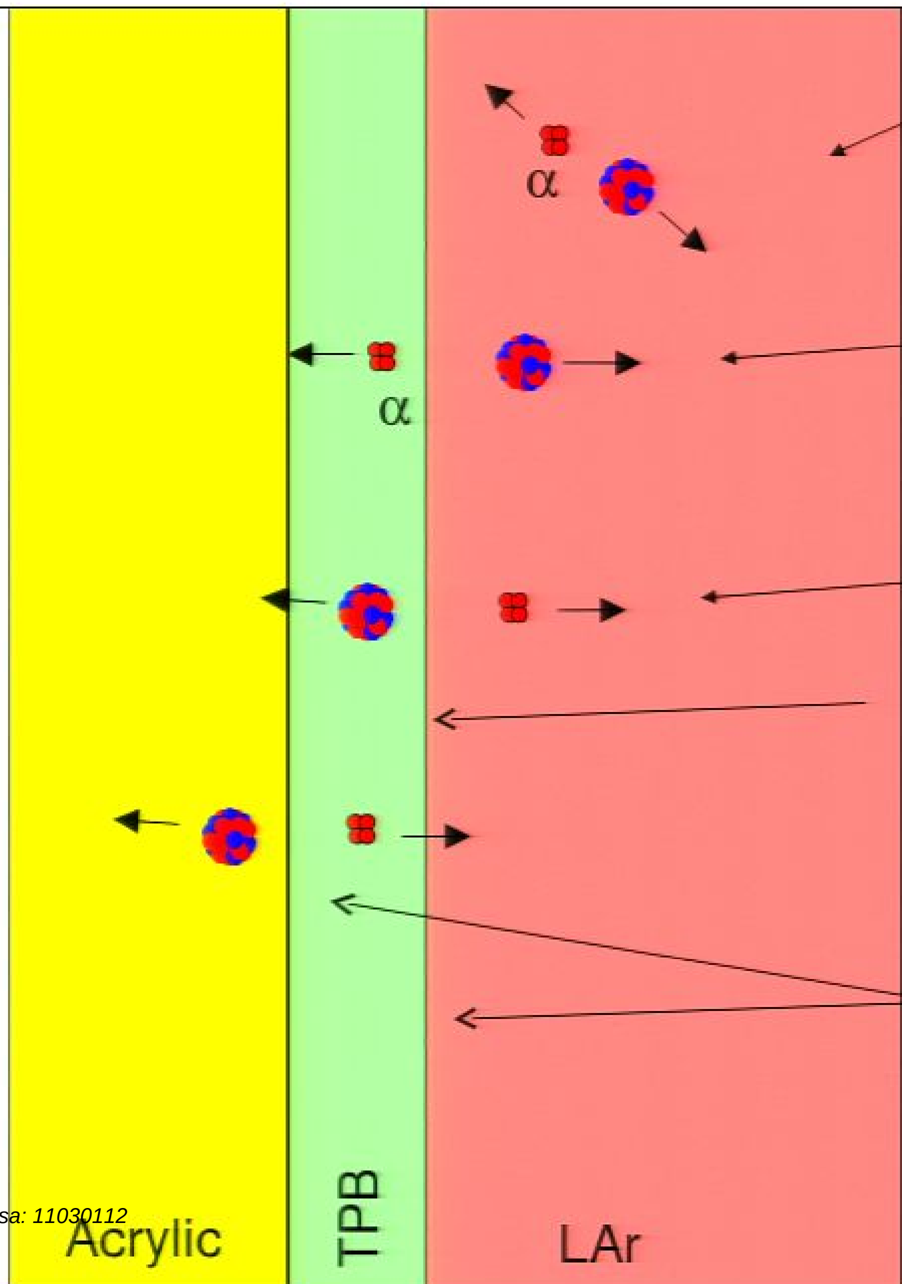


The **22-year** half life of Pb means it is there "forever".

We must keep Radon away from the inner surface.

Scraping away the inner surface with a resurfacer can remove all Pb-210 made after manufacture but it cannot eliminate Pb-210 in the bulk.

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)

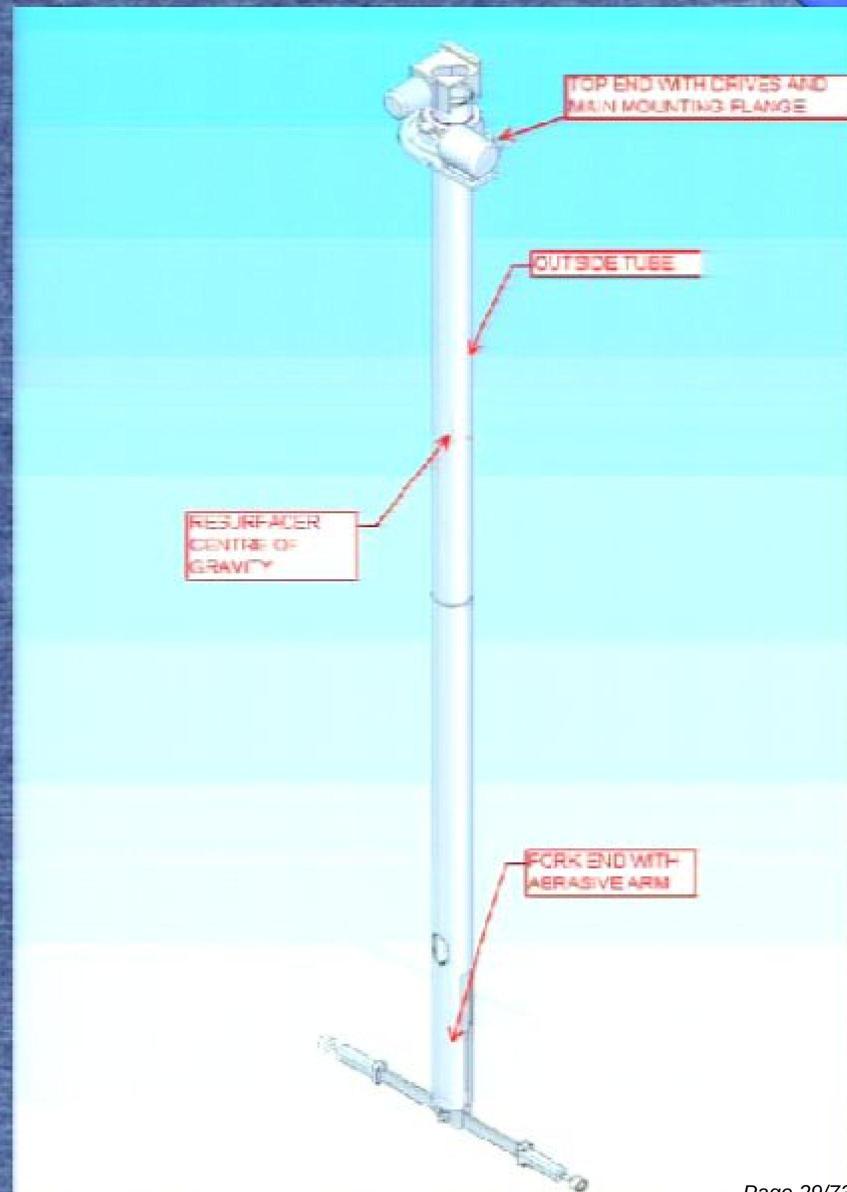
both TPB and LAr scintillate

The Resurfacer

After the AV is completely built and before the TPB is applied the resurfacer will be introduced inside the acrylic vessel.

Radon penetrates approximately 0.1mm into acrylic. Thus it must be able to remove about 1mm of acrylic to remove radon daughters from the air in SNOLAB during construction.

The surface contamination remaining is simply the bulk contamination.

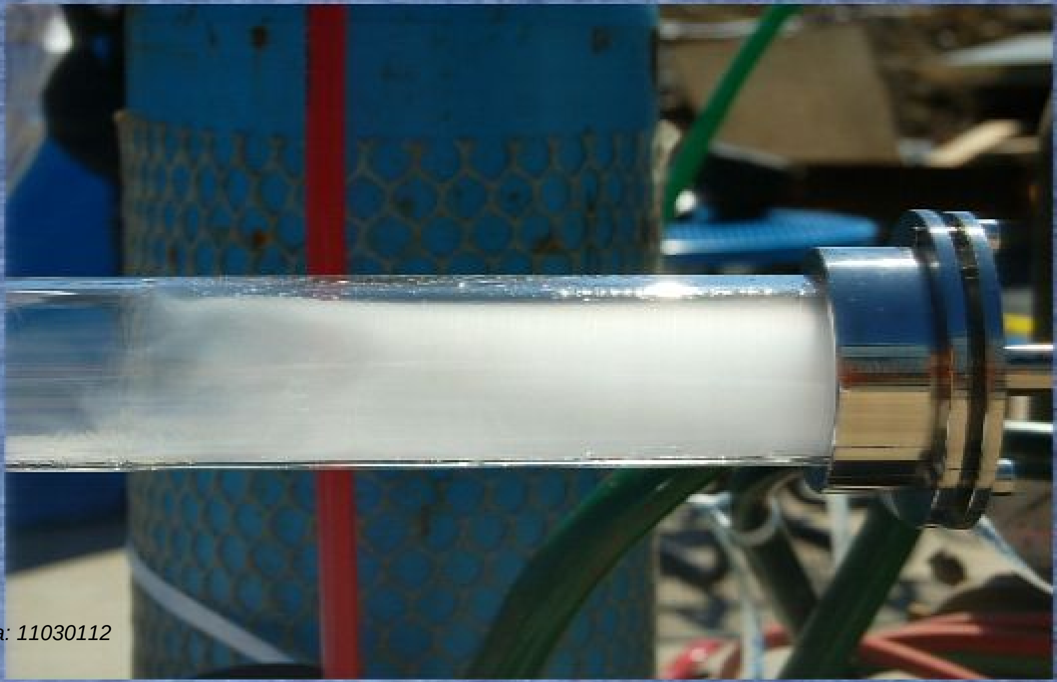


Acrylic Purity Requirements

^{238}U	0.3 ppt
^{232}Th	1.3 ppt
^{210}Pb	1.1×10^{-8} ppt

Acrylic Assay

- With our low-background Ge counter we can get to about 10ppt U and Th for assay simply by counting acrylic.
- Concentrate the contaminant by vaporizing ~ 10 kg acrylic in a clean quartz tube oven.
- The Pb-210 requires the clean oven and sophisticated clean chemistry and alpha counting or IC-PMS



This small test setup is now being replaced with a multi-kg version.

Some Notes About Acrylic

- Acrylic is a polymer: PMMA or Poly Methyl MethAcrylate.
- Used to protect your laptop screen, in paints, ...
- MMA is a liquid made in the petroleum industry.

This is a photo of (now half of) the ThaiMMA plant. The final stage of MMA production is distillation.

This is why acrylic can be so radiopure.

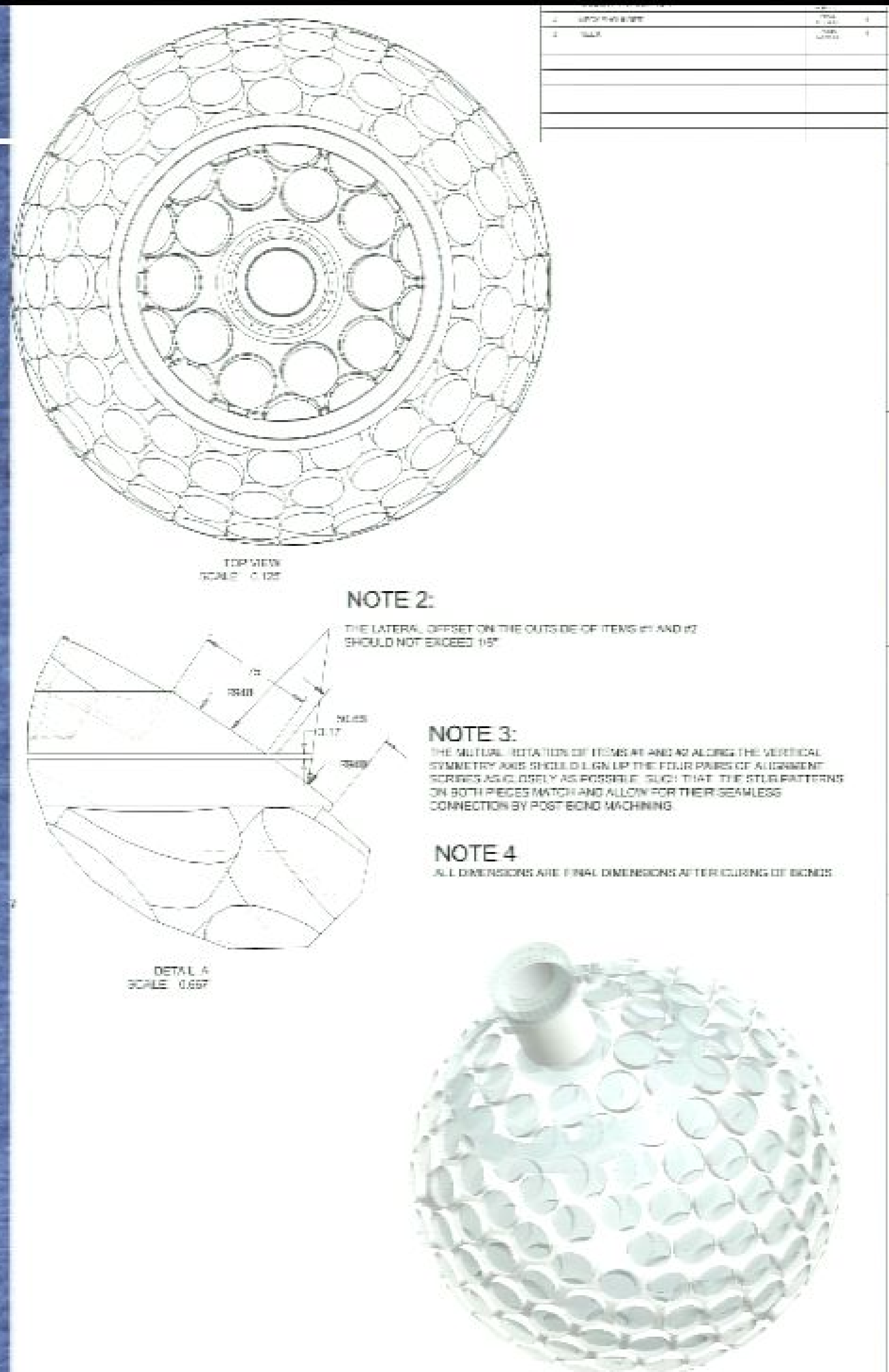
Making PMMA Panels

- The MMA is poured into molds with (less than 0.2% additives) and cured under heat.
- The process system must be free from dust and other sources of Uranium and Thorium.
- But even worse, it must be low in **Radon**.
- Once the panels are made radon exposure is OK.
- We have visited one candidate factory and it was good enough.
- Acrylic purchase out for public bid.

The AV will be made of a sphere formed from five rectangular panels thermoformed into orange slices

And a collar

And a Neck



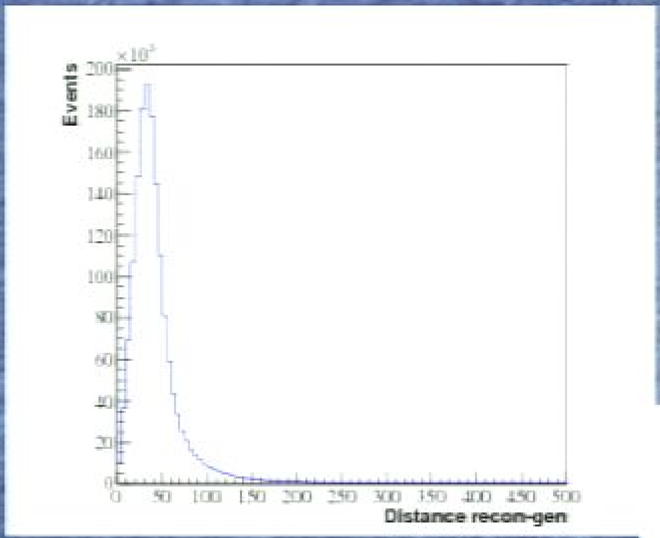
Machining at University of Alberta

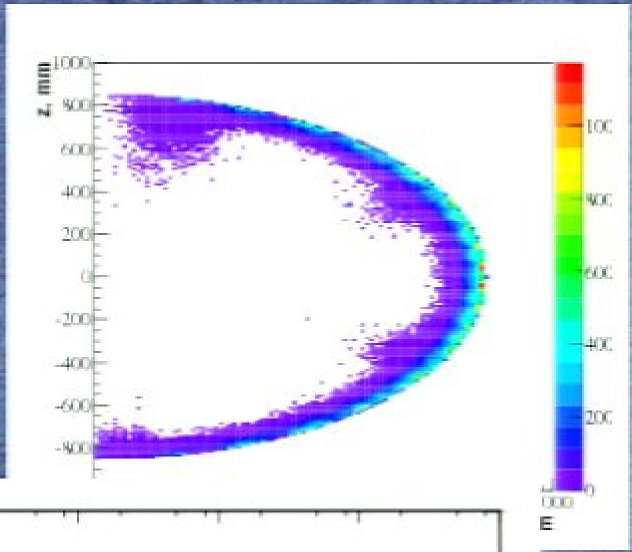
Fiducialization

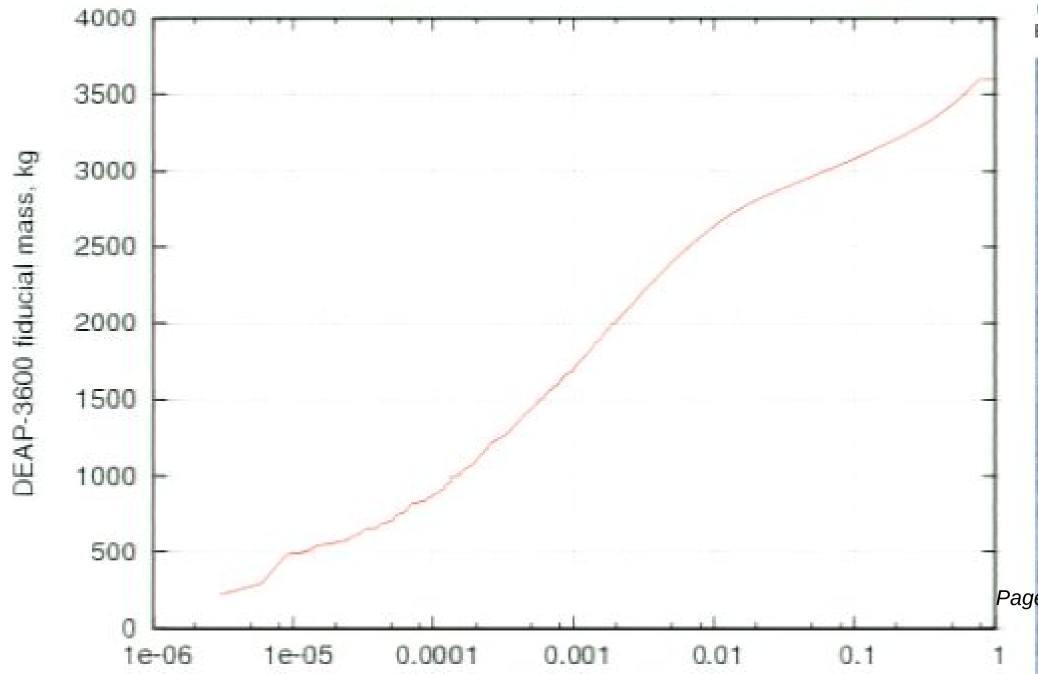
- Even with this high level of purity we require a further 10^3 reduction from fiducialization.
- Full radius = 85cm
- Fiducial radius = 55 cm
- Require an "effective resolution" of 10 cm.
- Charge-based M-L fitter (Does not yet contain all physics)
  - Optimistic: no time information
  - Pessimistic: Electronics and PMT charge smearing not included.

Very Preliminary Recon Results

Simulation of events on surface with 120-240 detected photons



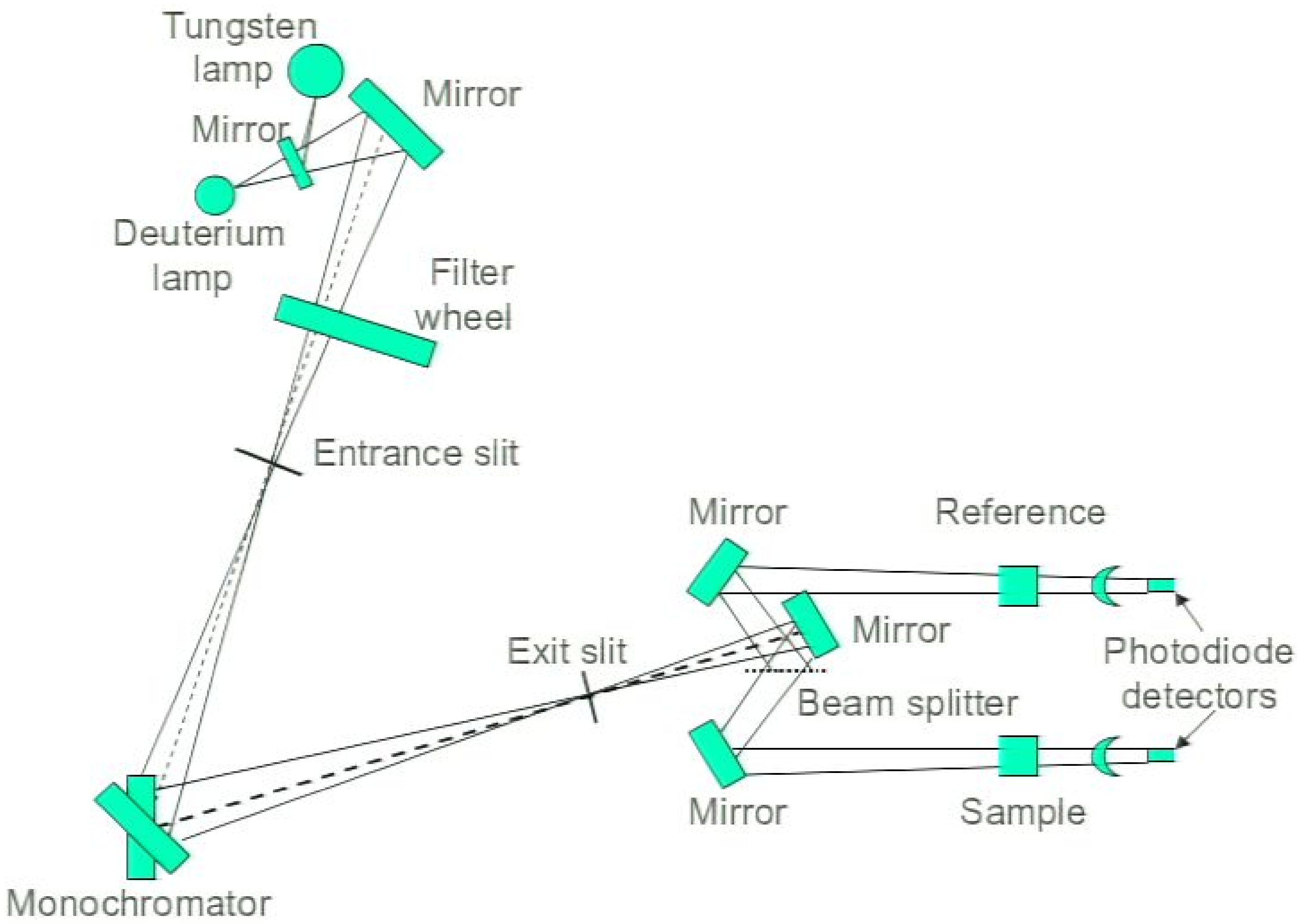




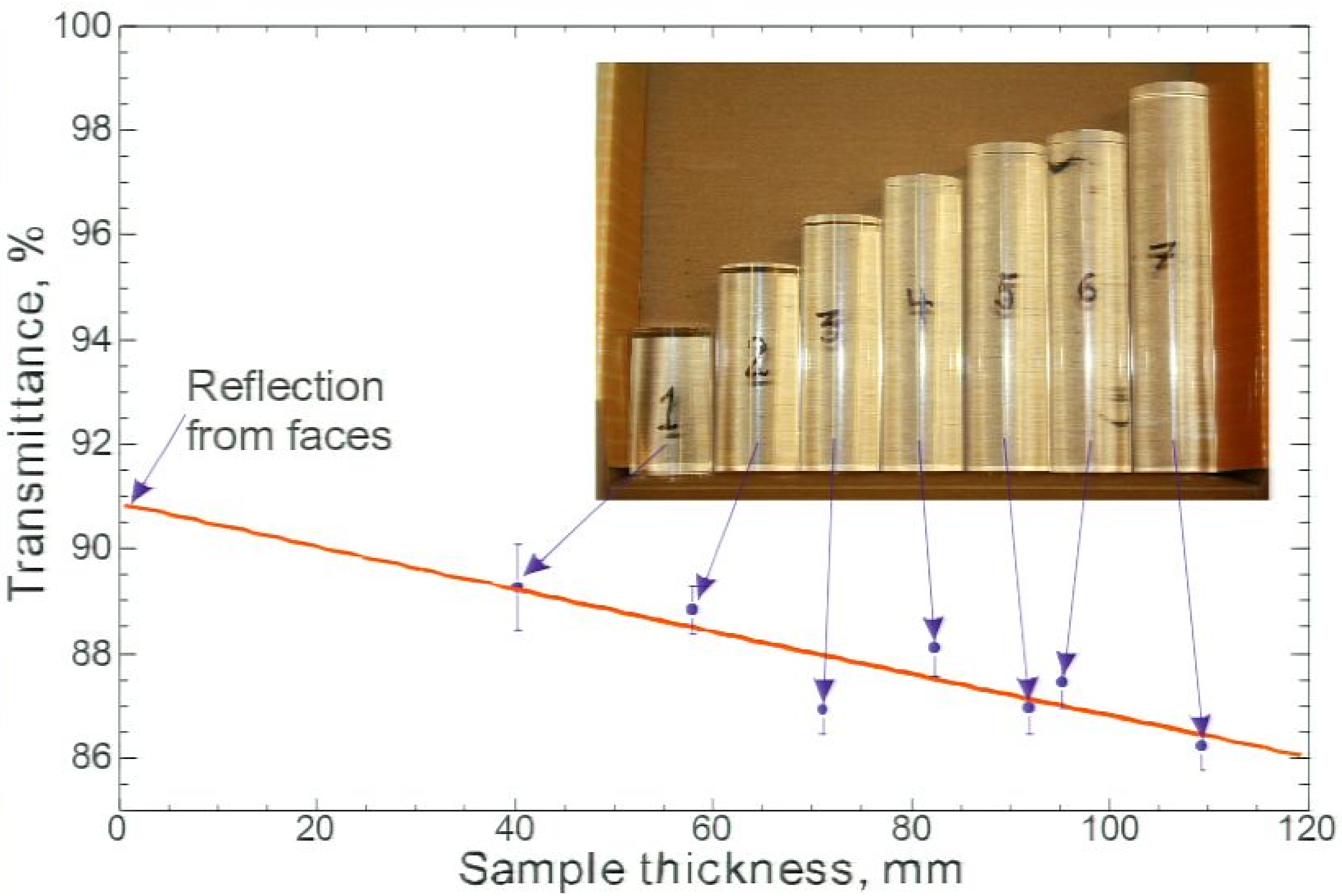
Optics

- Need good photon counting statistics for PSD
- Need 120 photoelectrons to do PSD at the 10^{-10}
- To have 20 keV_{ee} threshold need, require 6pe/keV.
- The acrylic light guides must be transparent.
- We want an attenuation length at least 4 meters integrated over the TPB spectrum
-

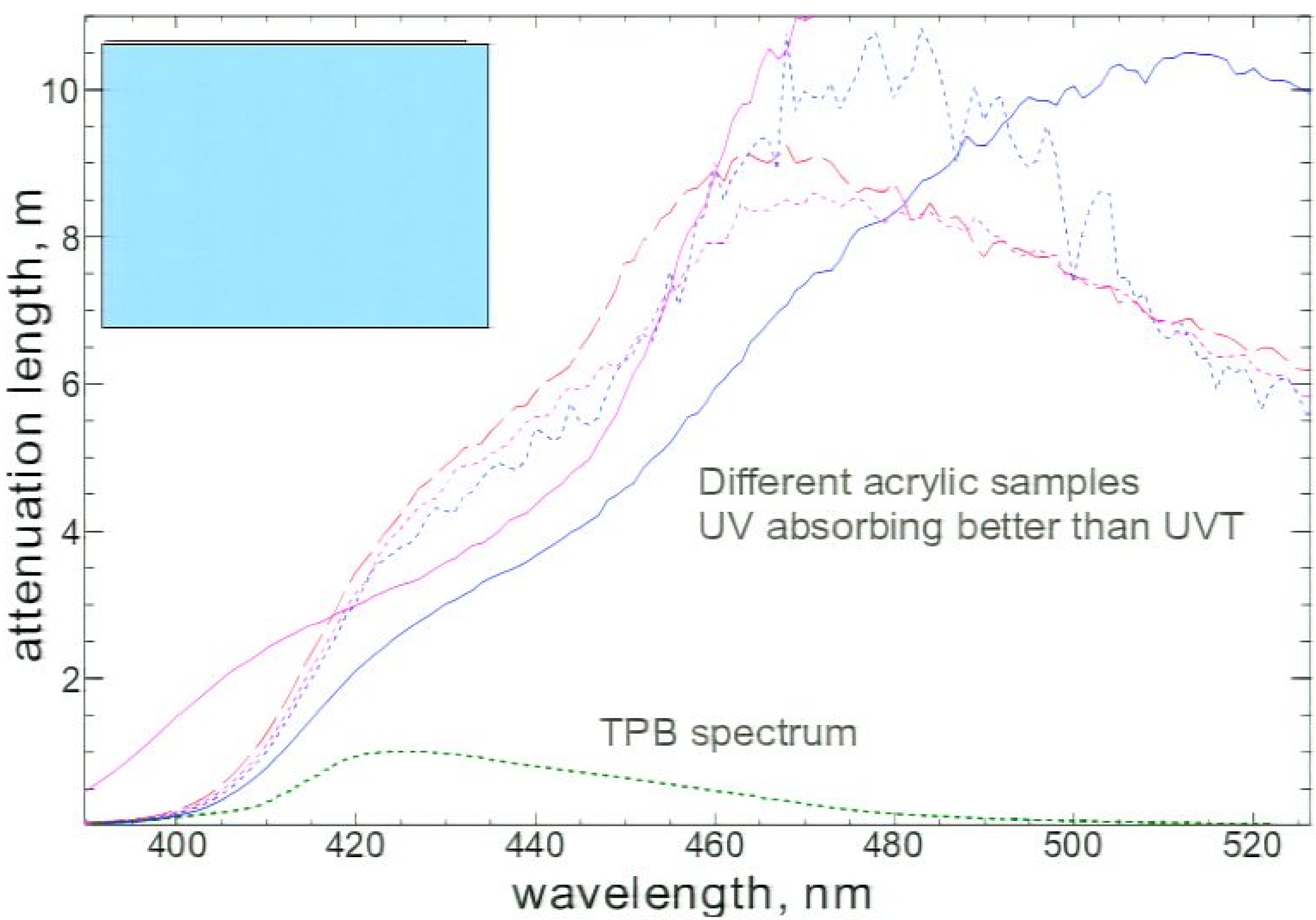
Dual beam Spectral Photometer



Sample Optics Result (405 nm)



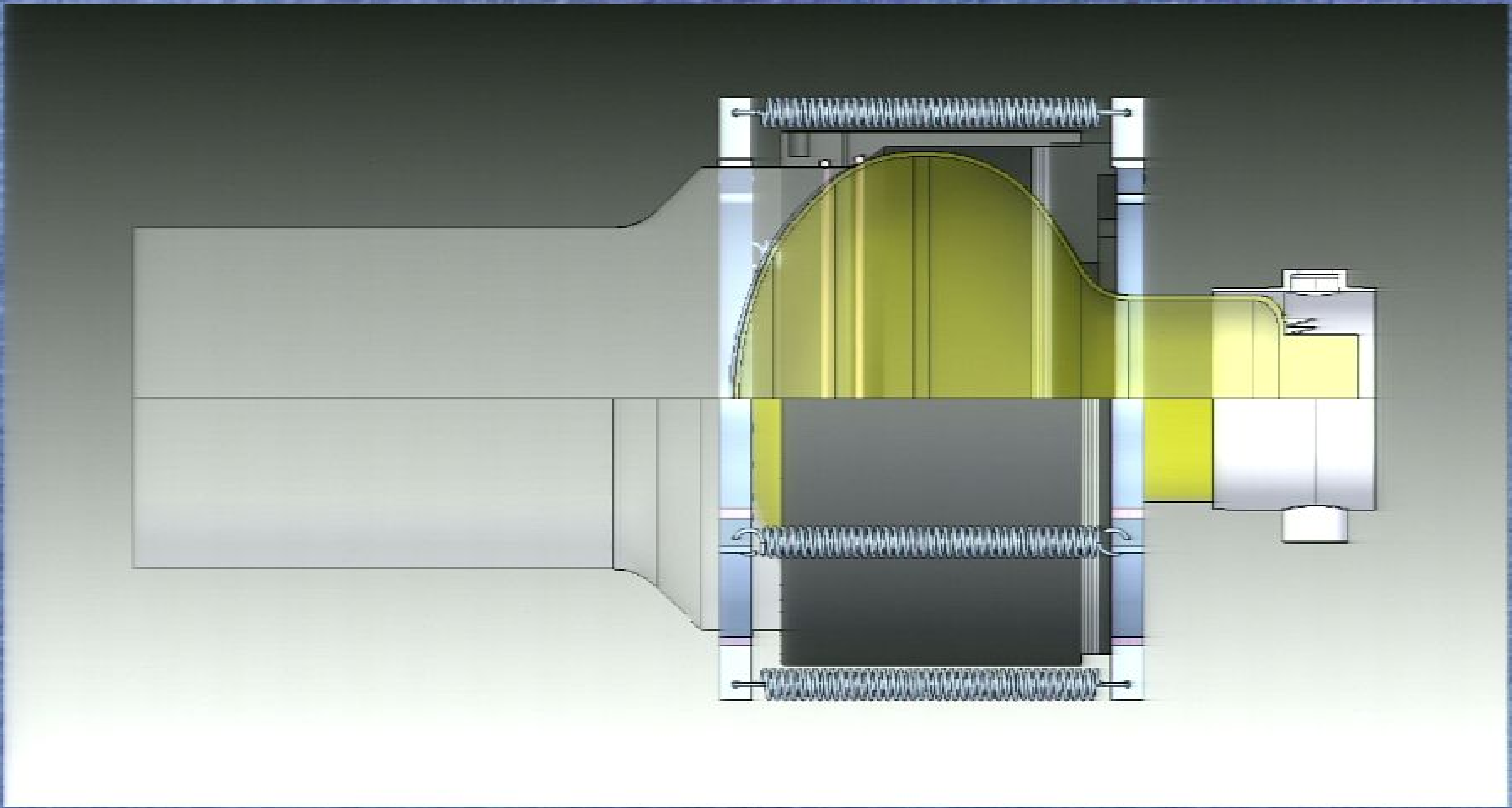
Some Complete Test Results



Good News on the Light Guides

- We have samples of acrylic with the required attenuation length.
- The contamination requirements are ten times less severe and are based on $^{13}C(\alpha,n)$
- (This process is described with rigor and elegance in the PhD thesis of Sanshiro Enimoto of Tohoku University. This is the background to the KamLAND geoneutrino measurement.)
- The light guides are out for public bid.
- The light guides will be bonded to the acrylic vessel.
- The PMTs will be coupled to the light guides with mineral oil and sealed with Orings

Light Guide/PMT Coupling



DEAP-1 prototype version

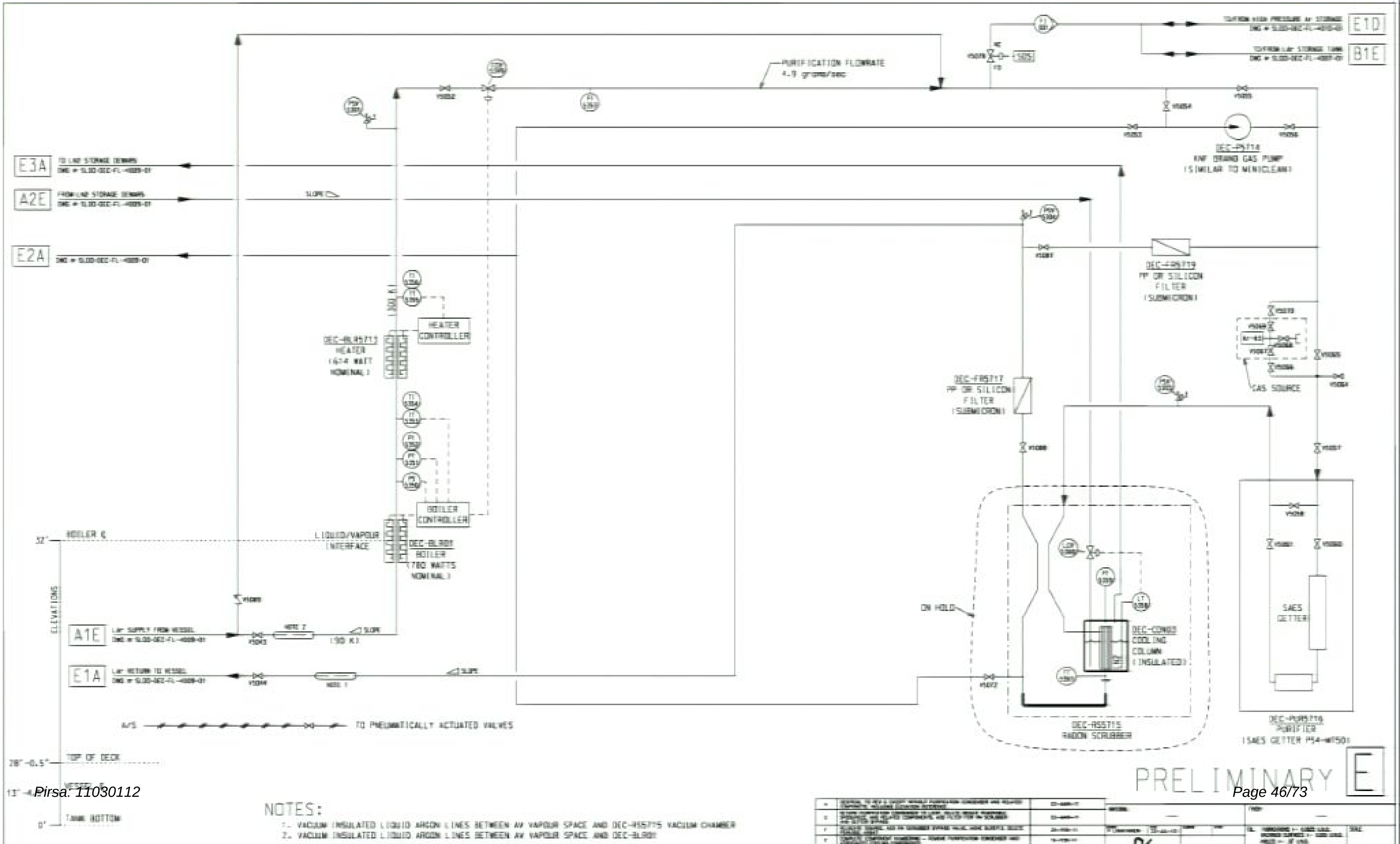
PMTs and Electronics

- We will use 255 Hamamatsu R5912 HQE PMTs
- (About 35% peak photocathode efficiency)
- Read out with 250 MHz waveform digitizers.
- CAEN V1720 is used on DEAP-1.
- Out for public bid.

Calibration

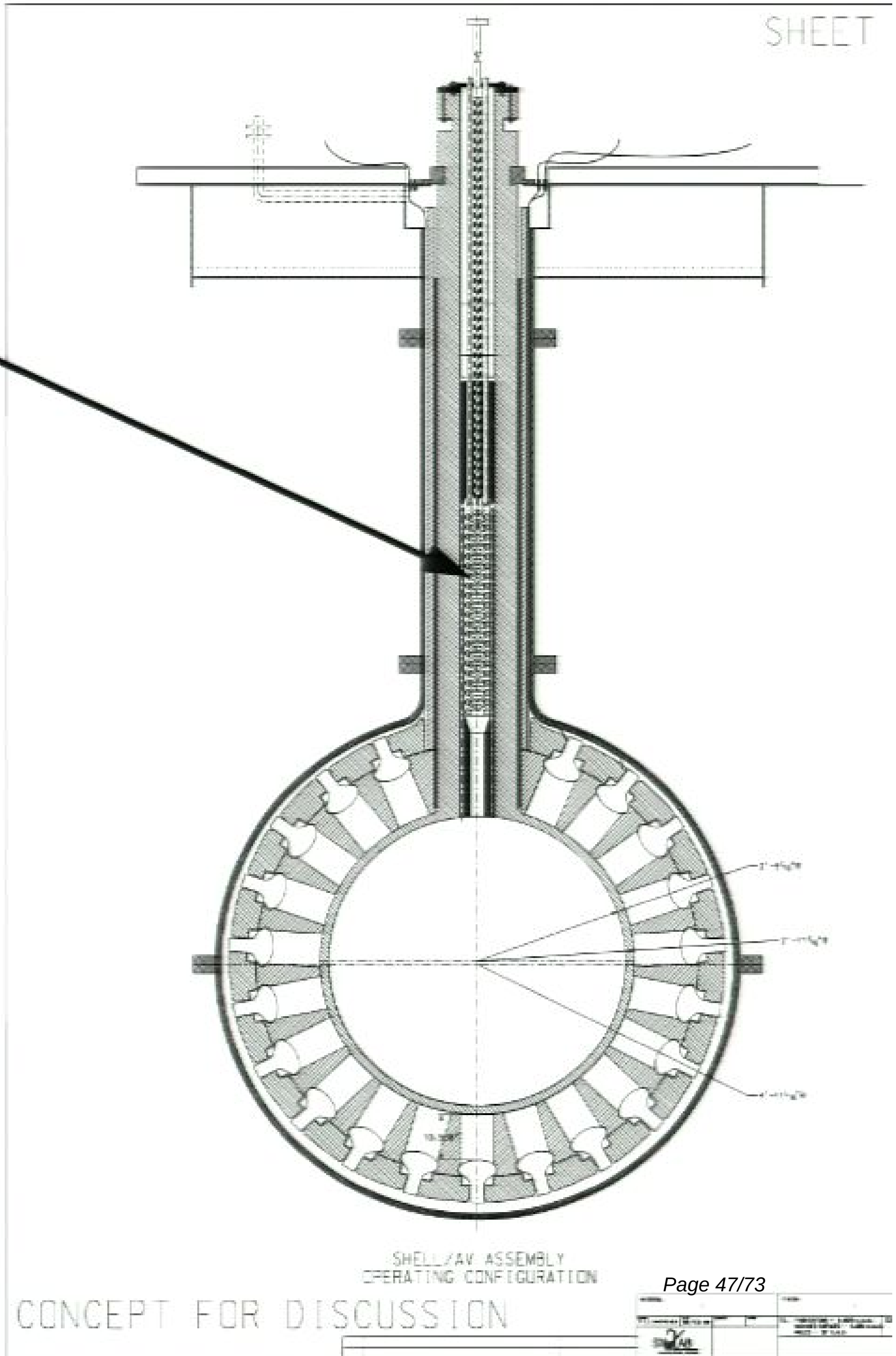
- First Do No Harm: Inserting sources will contaminate. No source insertion until end of run.
- Use Ar-39
- Use surface events
- Use External sources
- Use a 266nm laser shone down the neck to spot illuminate TPB at he bottom.

Process Systems



Cooling

- Sealed copper coils charged with Liquid nitrogen
- One end in LAr
- Other end in LN2 dewar
- Heat from argon transferred into LN2 latent heat
- Dewar kept cold using cryo-coolers
- LN2 buffer in dewar lasts ~4 days with no power.

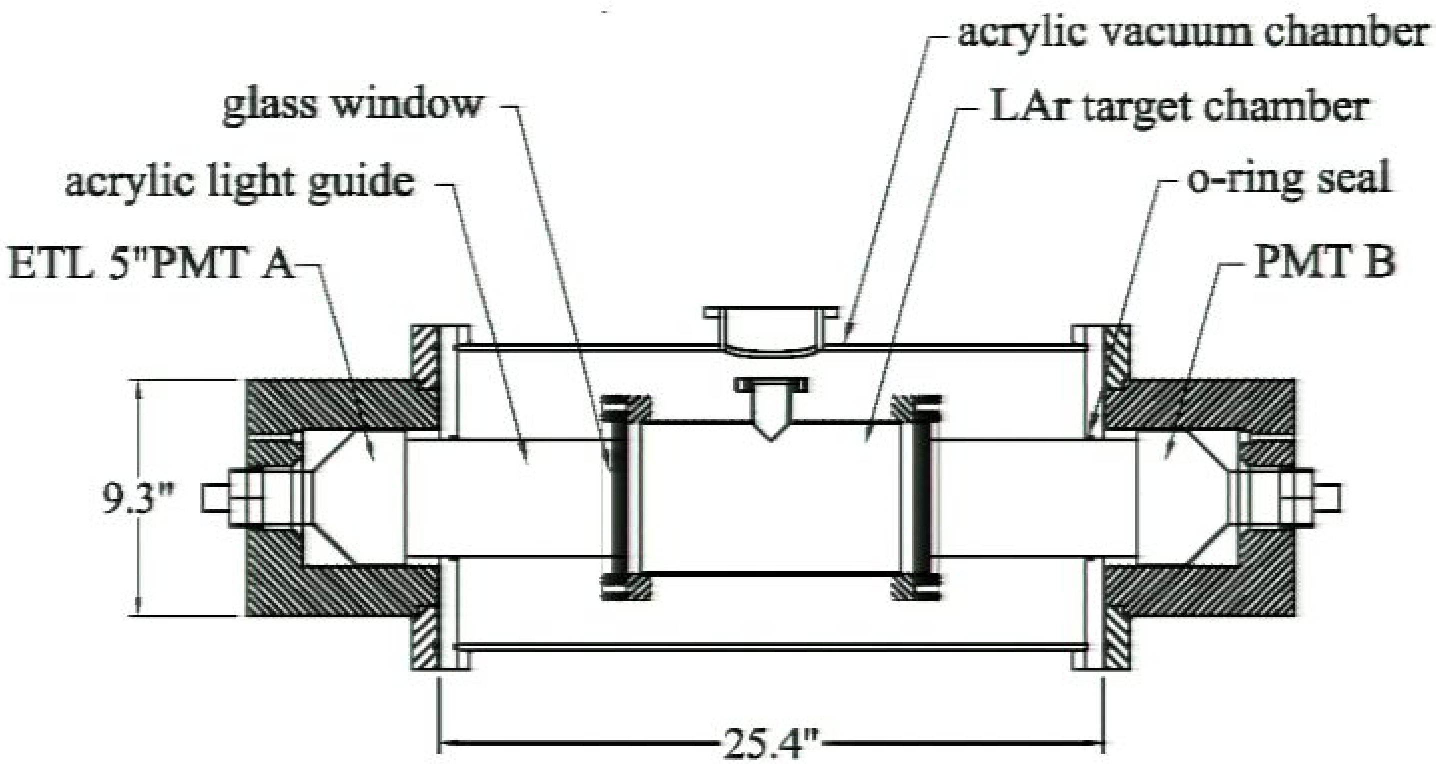


DEAP-1

- Our prototype 7-kg detector undergound
- Has tested
  - PMT/digitizers
  - Background levels
  - Pulse-shape discrimination
  - Light yield
  - Neutron-shielding calculations
  - Prototype radon scrubber

DEAP-1

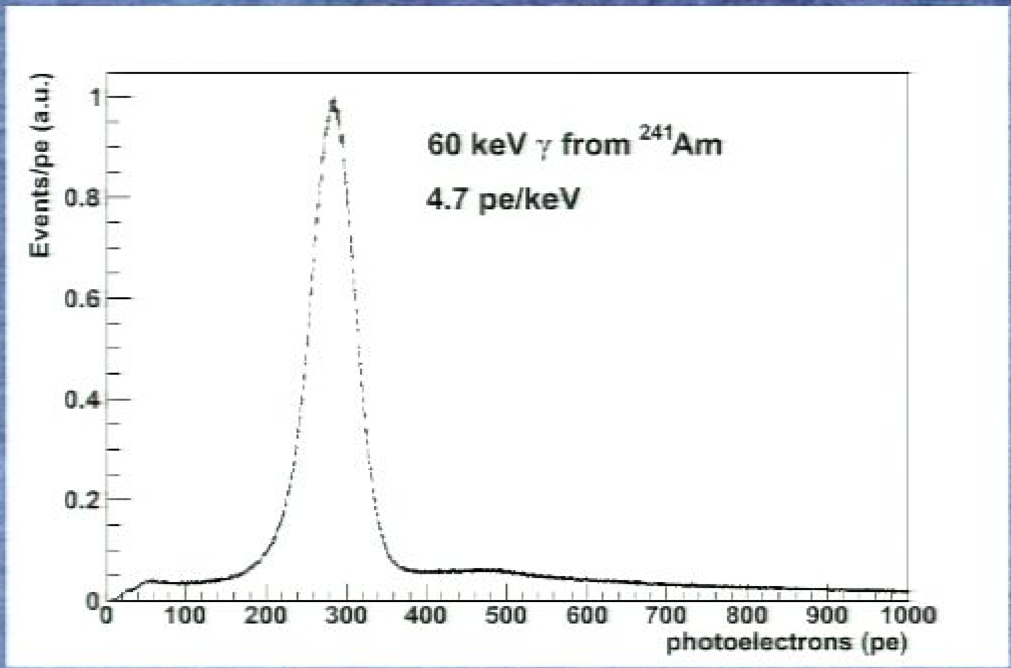
DEAP-1



PMTS replaced with Ham R5912

Light Yield

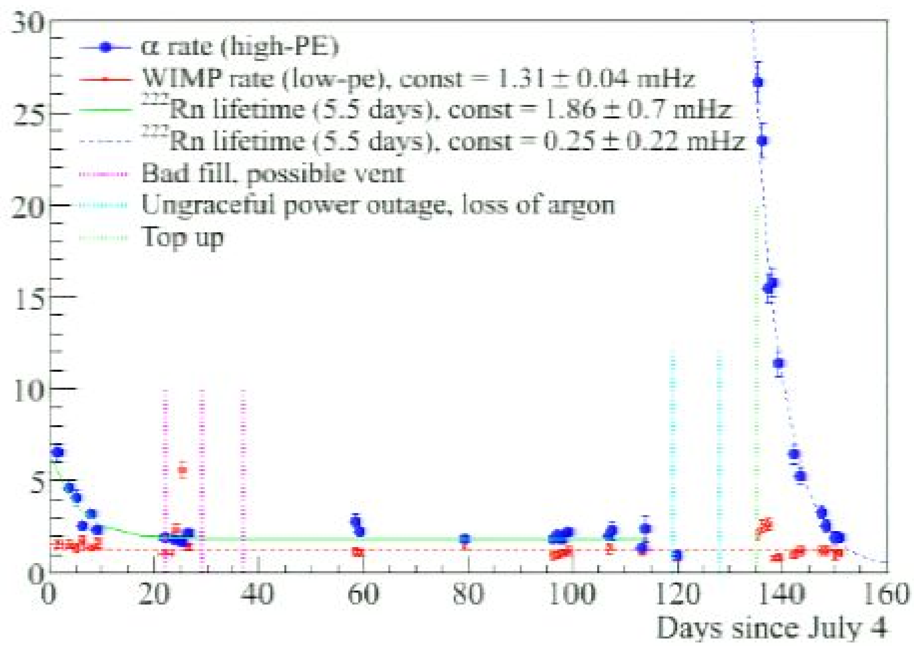
From generation 3 run: R5912 HQE PMTs and new light guides.



Prototype Radon Scrubber

- Cooled with ethanol-ice slush
- >1000 m^2 surface area charcoal
- The Vanderwaals binding energy of the Rn on charcoal is greater than kT

Background Rates



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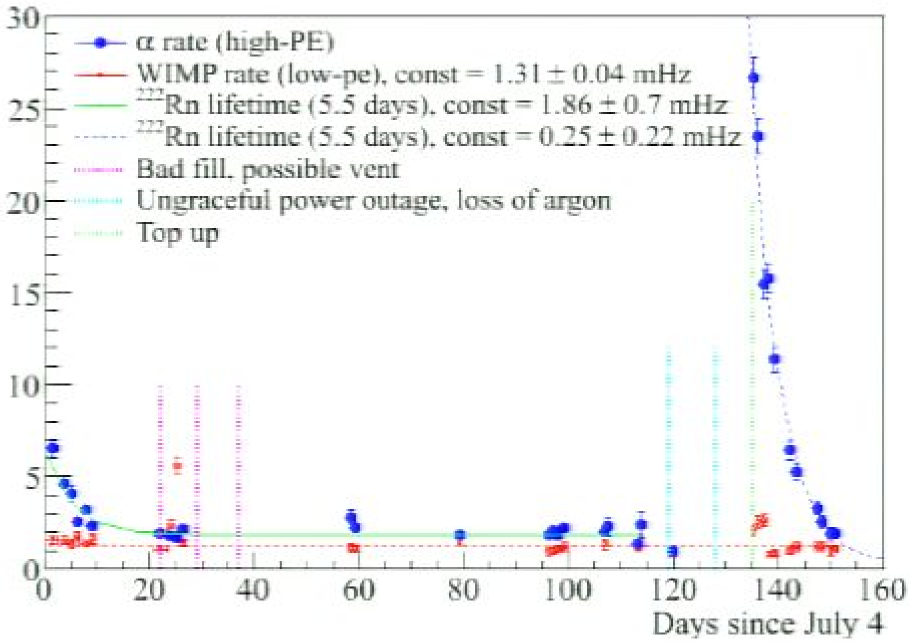

July 4, 2008 Run

2-4 mHz steady state

Top-up added large ^{222}Rn spike

Used to develop U-chain tags

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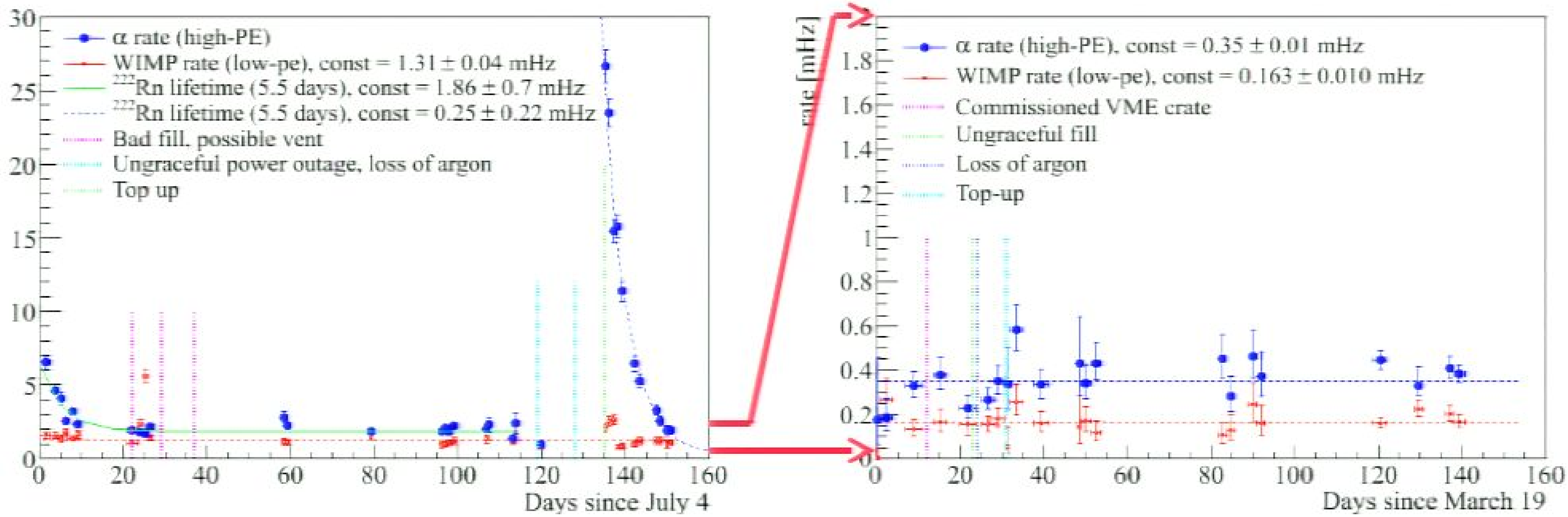

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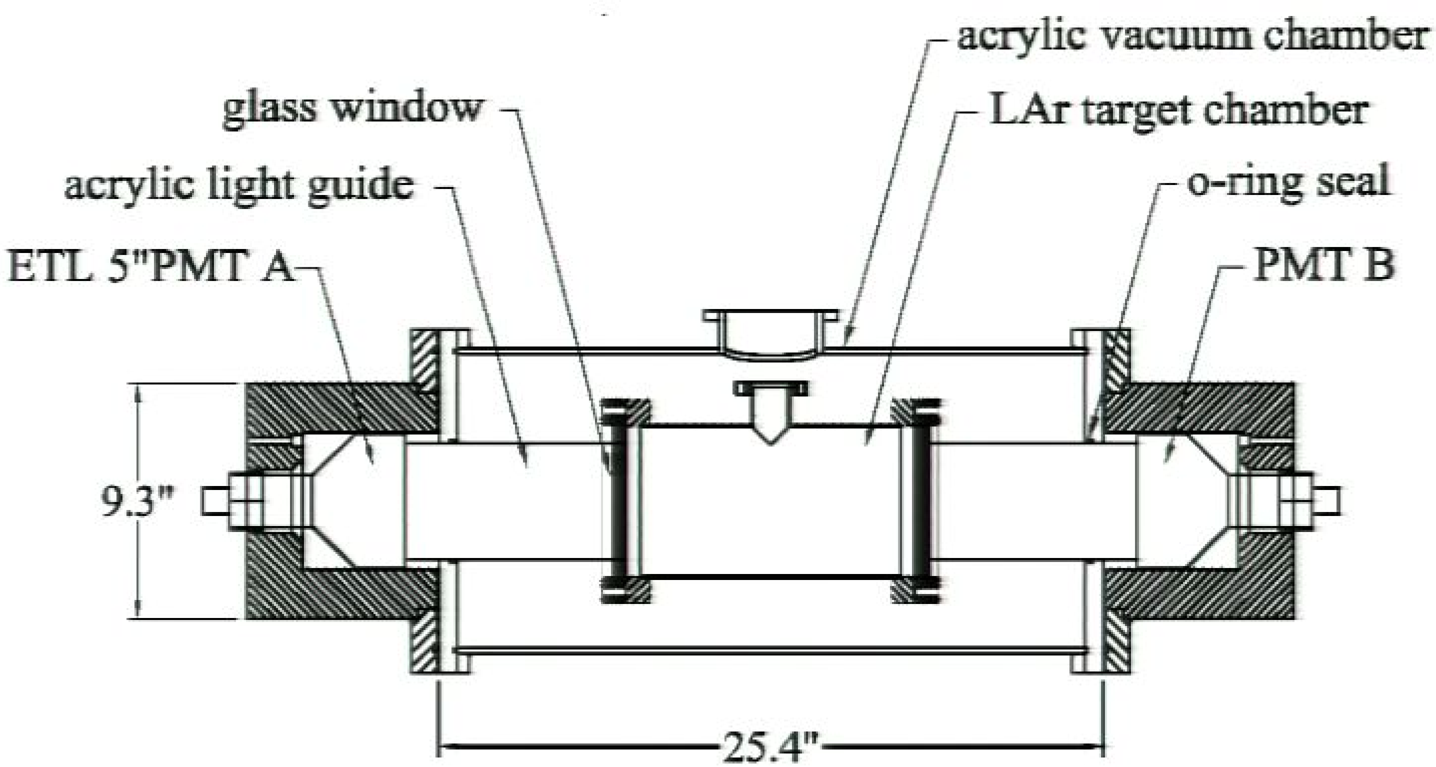
Zfit

- We can use center of charge to reconstruct events along the axis of DEAP-1



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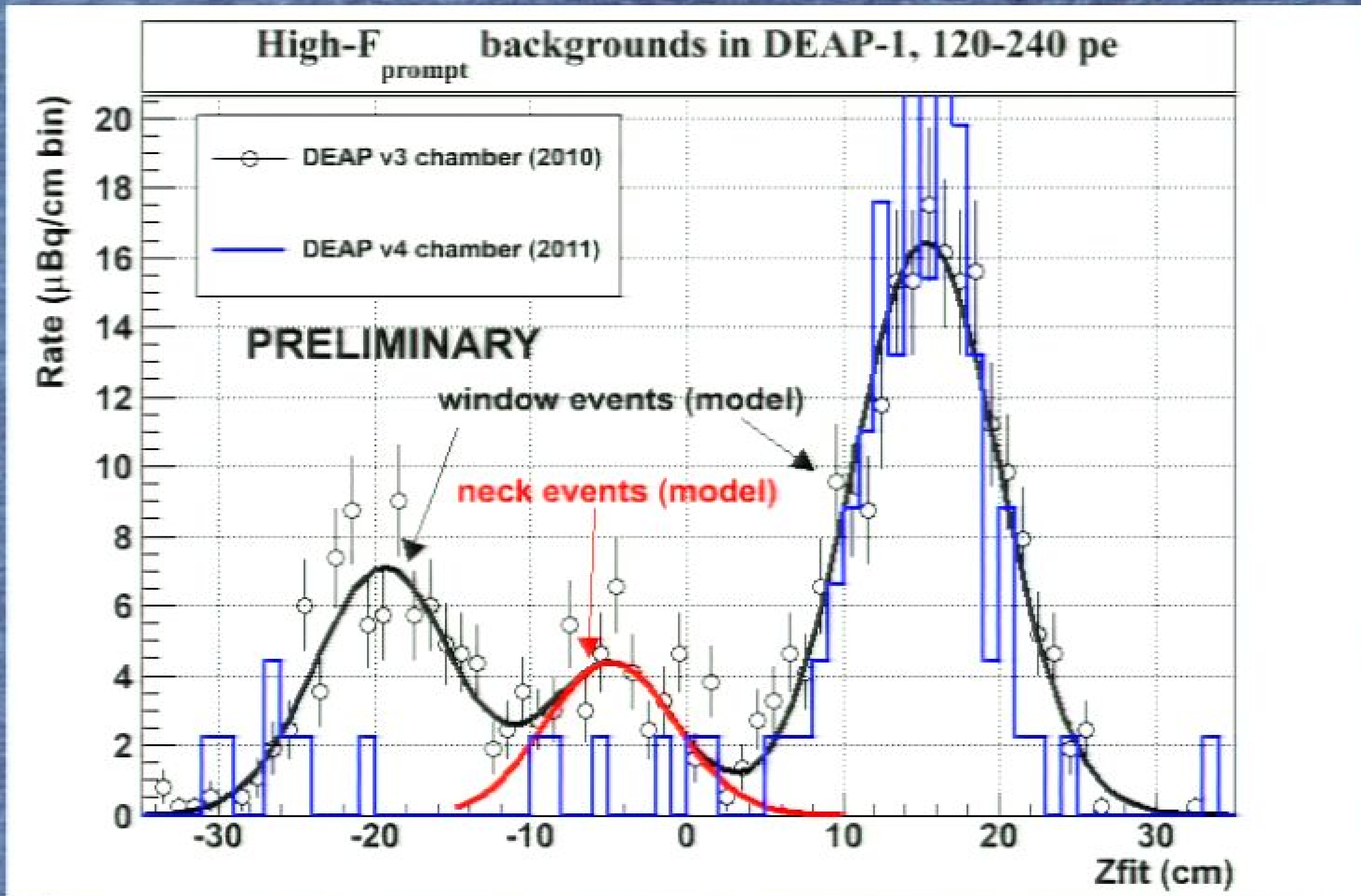
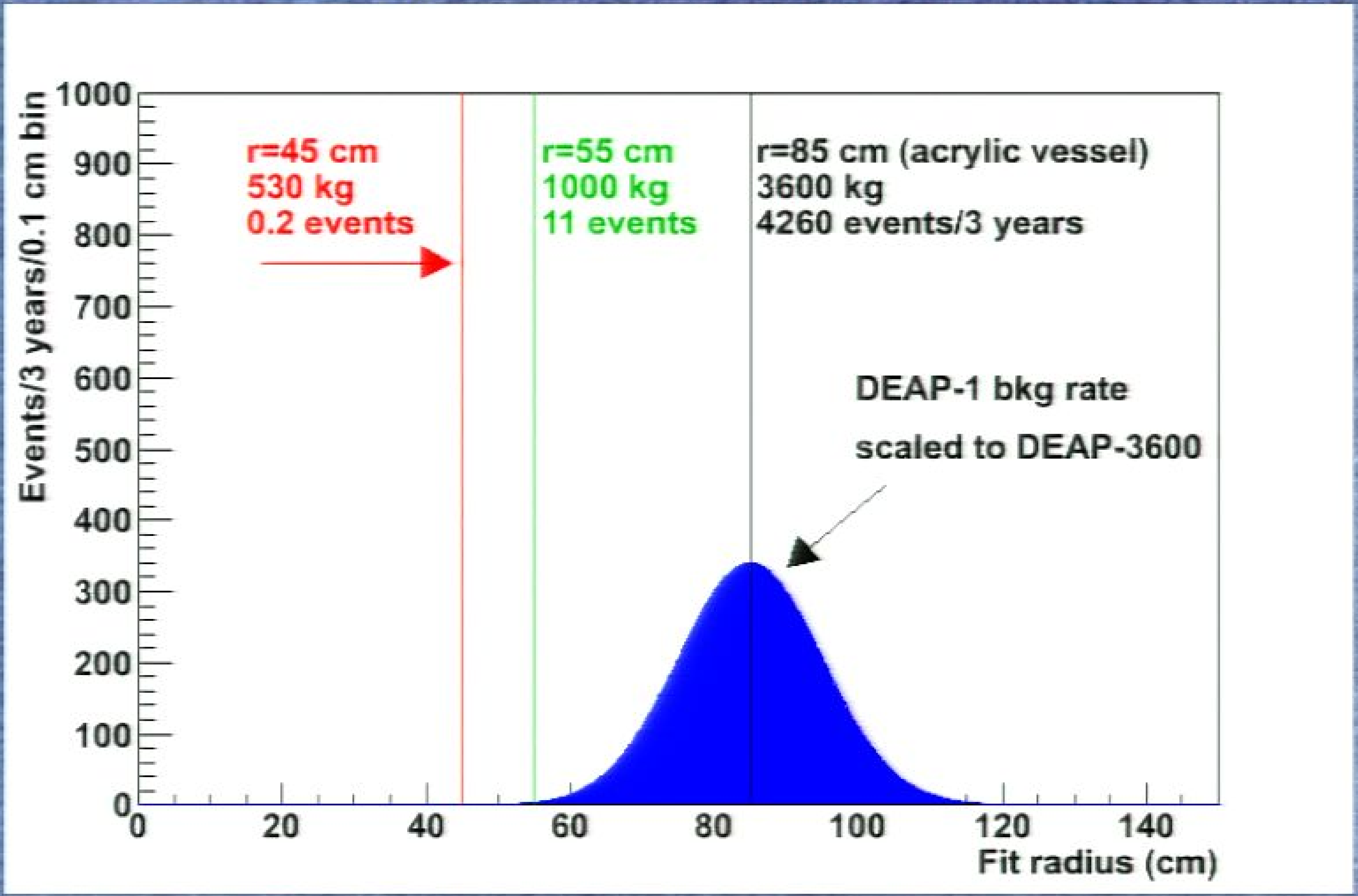


Background Summary

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, PTFE instead of BC-620 reflector ,Rn diffusion mitigation, UP water in glove box, documented procedures; Rn Trap.
March 2010	**130 μBq**	***Clean v3* chamber at SNOLAB**	Acrylic monomer purification for coating chamber. TPB purification.
Feb 2011	**~10 μBq (PRELIMINARY)**	***Clean v4* chamber at SNOLAB**	Inner chamber redesign to remove "Neck Light" events

DEAP-1 to DEAP-3600

- If we make no further progress we reach $2x10^{-46}$ cm^2 in three years



Depleted Argon

- We have signed an MOU with Princeton University to obtain depleted argon.
- This will make the DAQ easier and it will reduce the PSD requirements.
-

Where Are We?

- Short answer: procurement
- Construction starts soon
- Time to make it happen

What I Haven't Mentioned

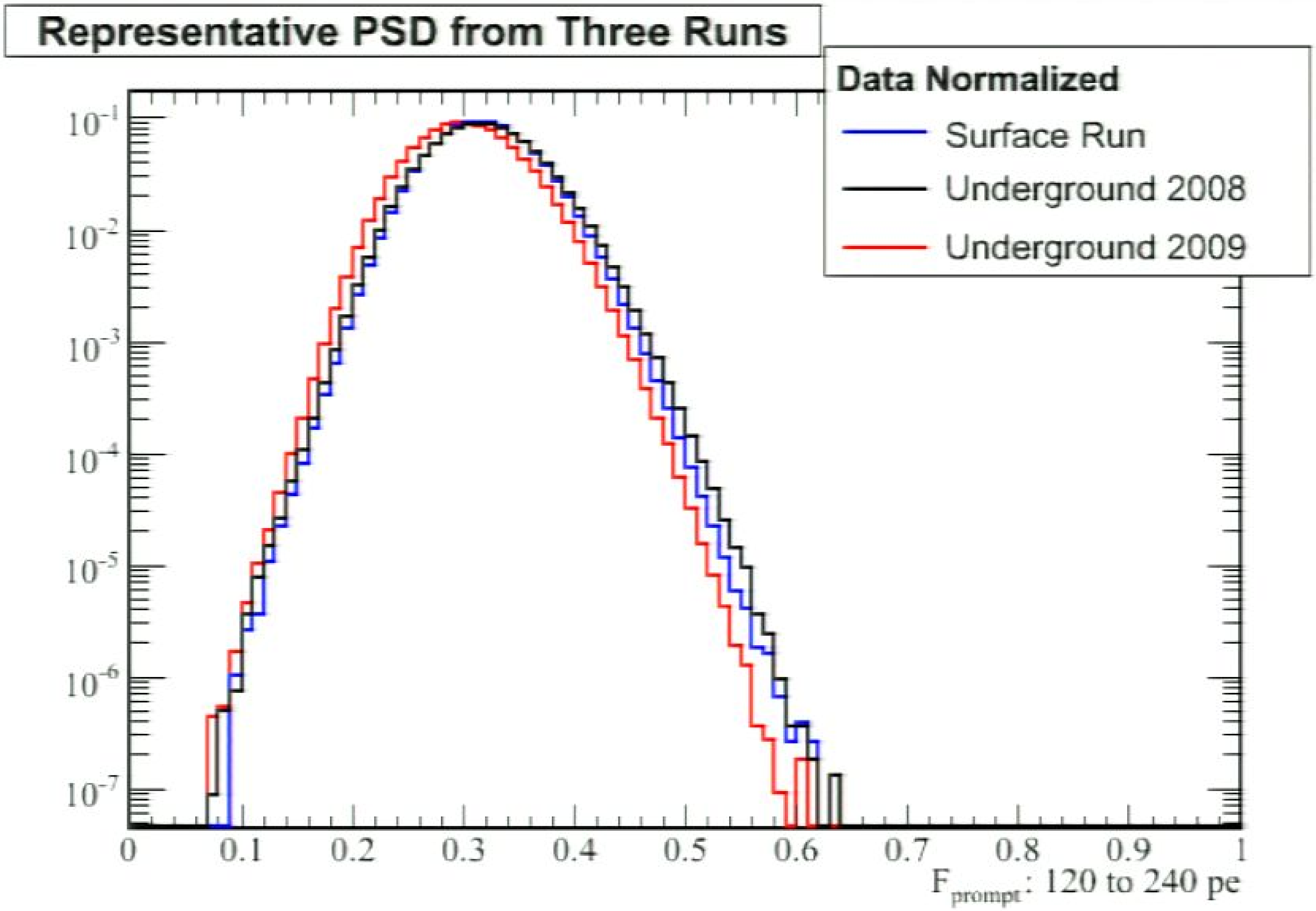
- Construction plans
- Oxygen deficiency hazards (ODH)
- Fire safety
- Procurement
- DAQ development

PSD Underground

DAQ	Sampling	Data Rate Ev/sec	Data Rate Mbyte/sec	Bottleneck
Scope	500 MHz 10 μsec	<~150 /s	1	Scope readout
V1720 & MIDAS	250 MHz 16 μsec	~350 /s	8	Source strength

- PSD is a huge data-reduction effort
- Depends low-noise electronics
- We have 16 TeraBytes of MIDAS data.

Sample PSD Data

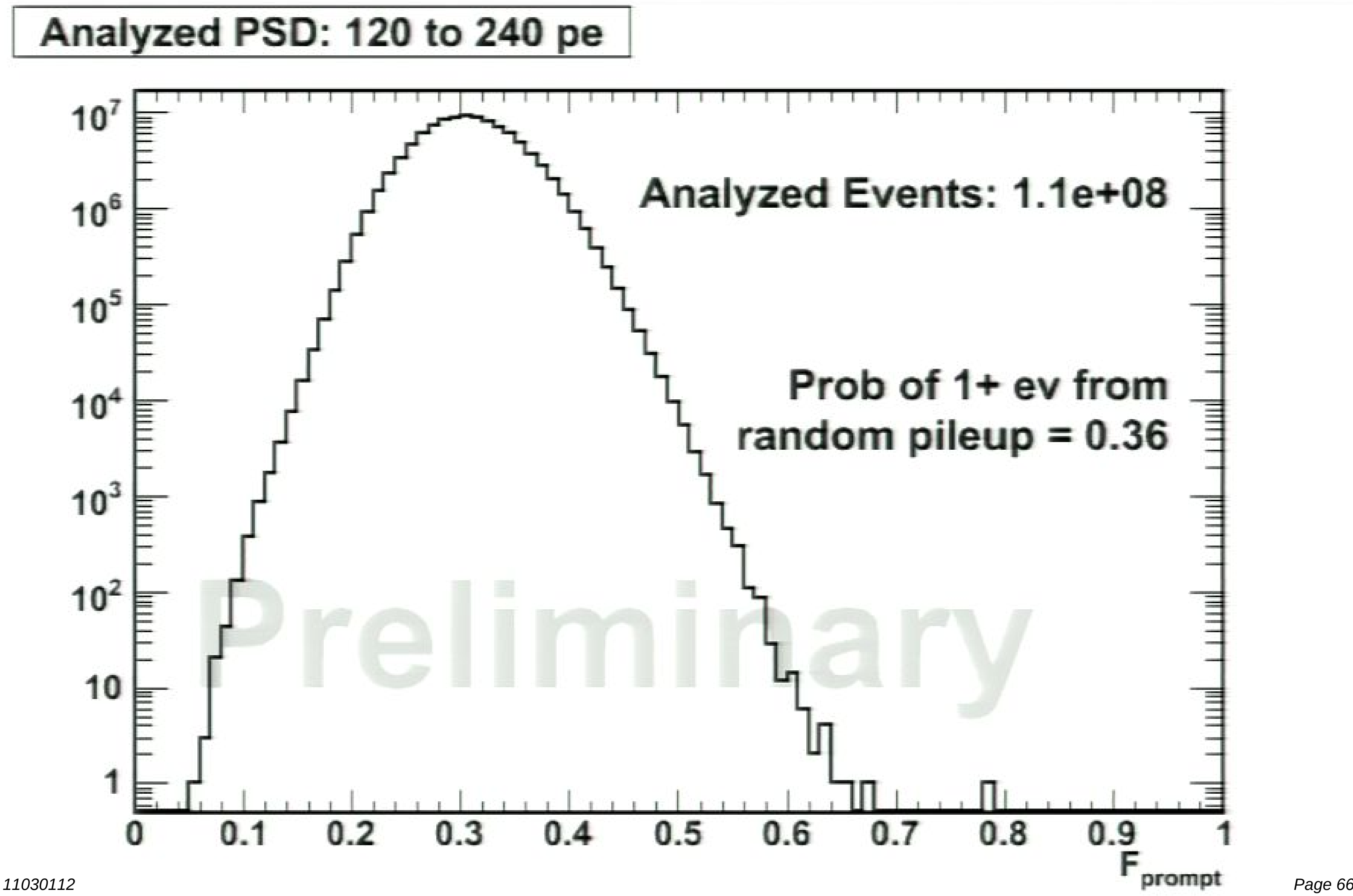


Background To PSD

- The detector high-F_{prompt} background rates have some probability of being coincident with a valid tag as described in the DEAP-1 Surface paper (arXiv:0904.2930).
- Depends on rate of tags and the time window imposed in analysis.
- We expect:

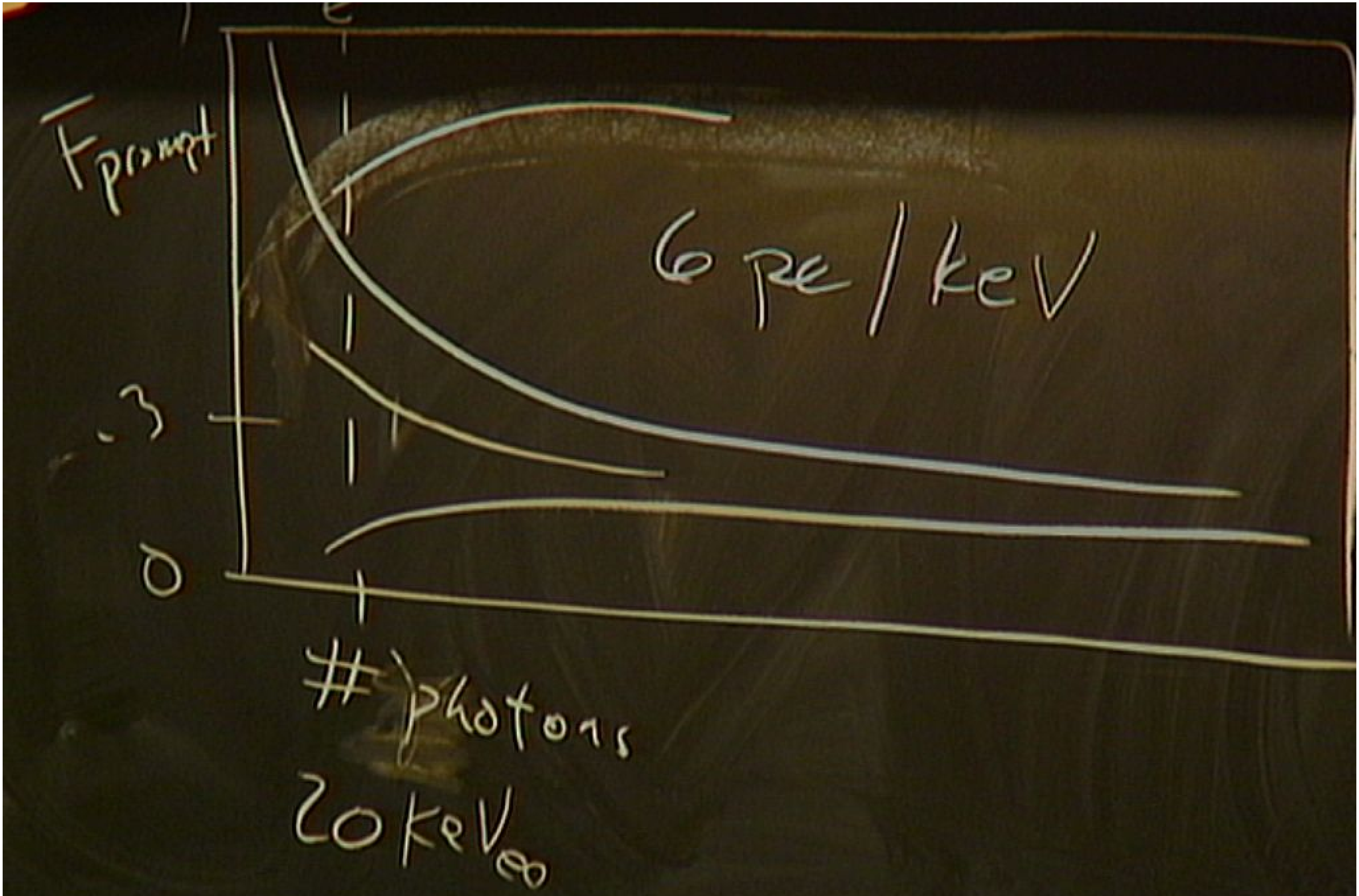
Run	PSD Entries	Expected # pile-up events
Surface	17 M	0.26
U/G 2008 (scope)	22 M	0.16 (preliminary)
U/G 2009 (MIDAS)	70 M	0.13 (preliminary)
Total	**109 M**	**0.45**

Analyzed PSD



DEAP-1 and DEAP-3600

- Given our current understanding of backgrounds in DEAP-1 we could build DEAP-3600 at current background levels and have a ~500 kg fiducial mass


Fprompt
.3
0
6 pe / keV
photons
20 keVee

DEAP-1 and DEAP-3600

- Given our current understanding of backgrounds in DEAP-1 we could build DEAP-3600 at current background levels and have a ~500 kg fiducial mass

DEAP collaborators (Canadian groups)

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CAD groups primarily focused on DEAP-3600

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