A DEAP & CLEAN Program for the Direct Detection of Dark Matter

Andrew Hime
Physics Division, MS H803
Los Alamos National Laboratory
Los Alamos, NM 87545
ahime@lanl.gov

INFO 2009
Santa Fe, NM
July 6-10, 2009

DEAP/CLEAN Collaboration

University of Alberta
Aksel Hallin
Boston University
Ed Kearns
Carleton University
Kevin Graham
Harvard University
John Doyle
Los Alamos National Laboratory
Andrew Hime
MIT
Joe Formaggio & Jocelyn Monroe
NIST - Boulder
Kevin Coakley
University of New Mexico
Dinesh Loomba

University of North Carolina
Reyco Henning
University of Pennsylvania
Josh Klein
Queens University
Mark Boulay and Art McDonald
University of South Dakota
Dongming Mei
SNOLAB
Fraser Duncan
Syracuse University
Richard Schnee
TRIUMF
Fabrice Retrieve
Yale University
Dan McKinsey

16 Institutions with ~80 Participants

Institutional Representatives + Students + PDs + Engineers + Technicians

Outline

Evidence for Dark Matter

Challenges & Goals for Direct Detection Searches

Single Phase Scintillation in LAr & LNe

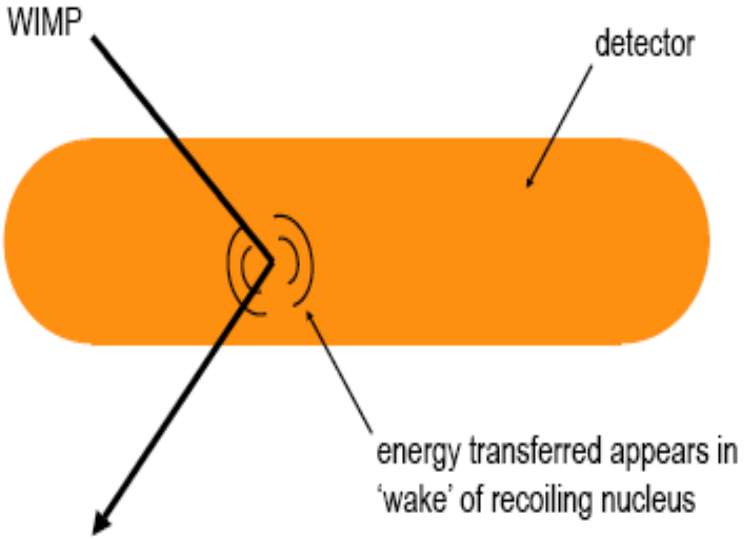
… a somewhat pedagogical approach

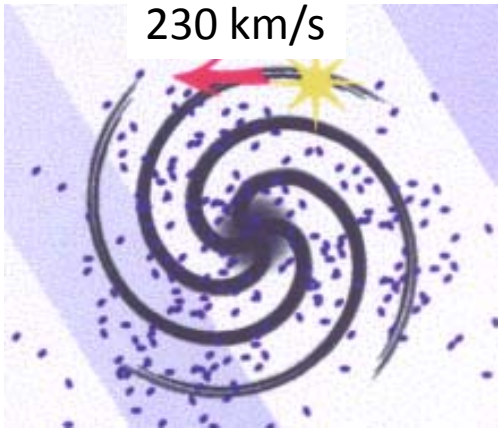
A Family of DEAP & CLEAN Detectors

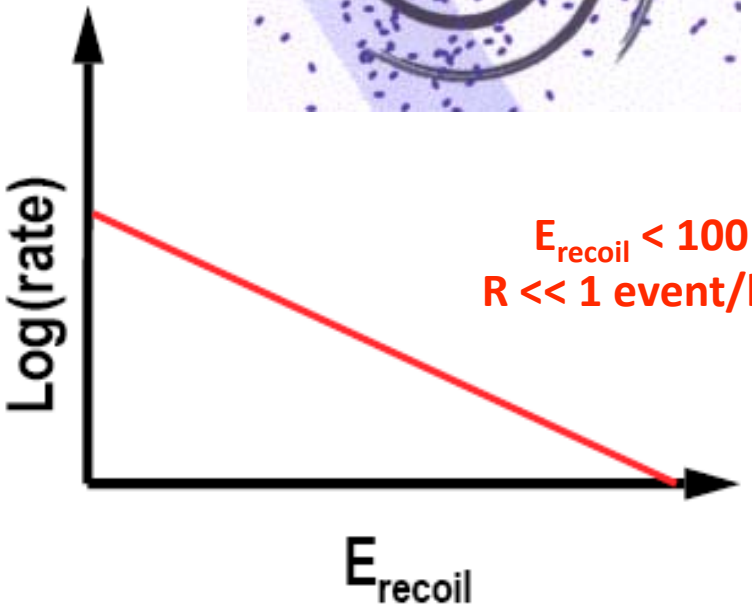
Building Mini-CLEAN

WIMP Sensitivity & Reach

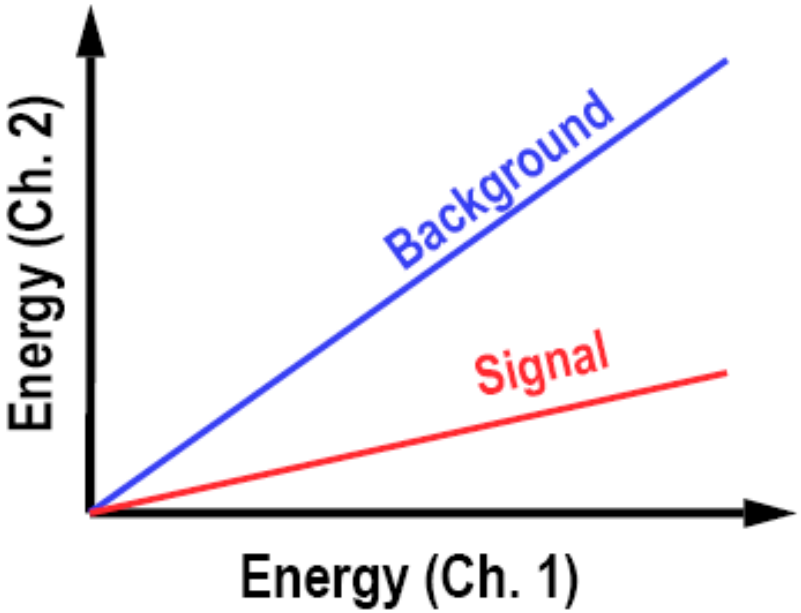
Surfing Through the WIMP-WIND



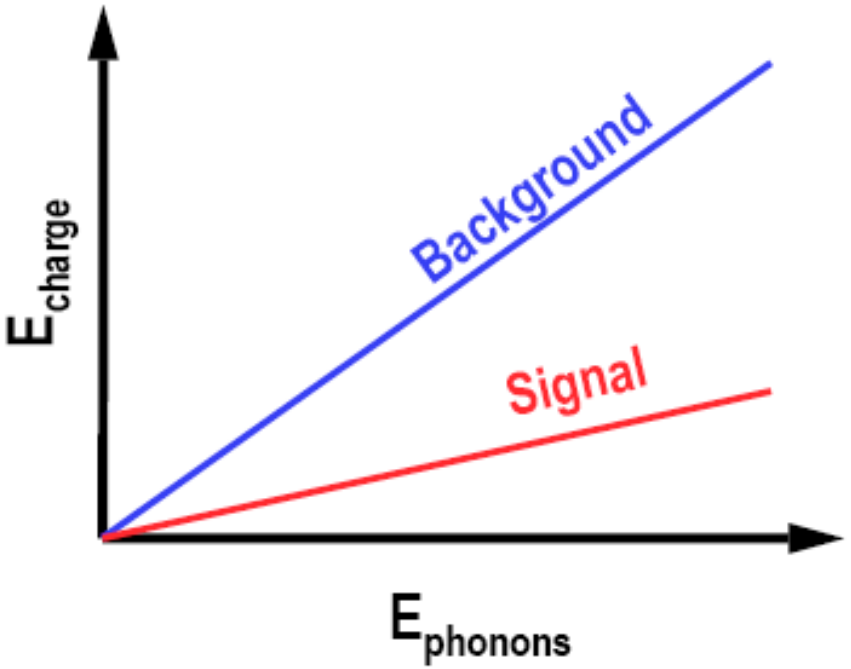


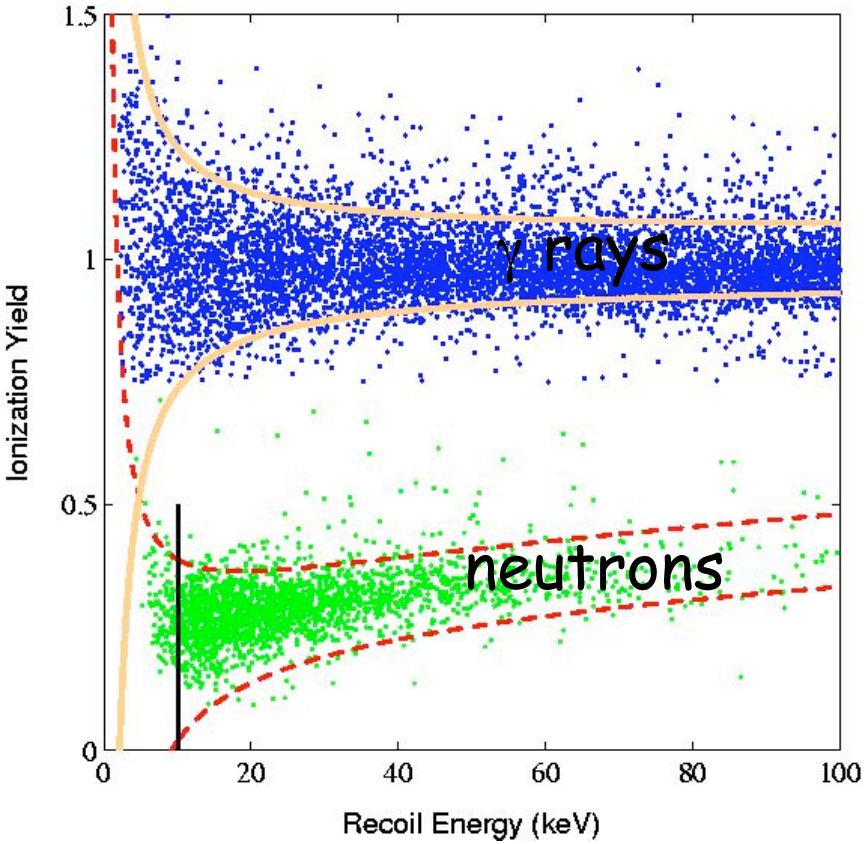


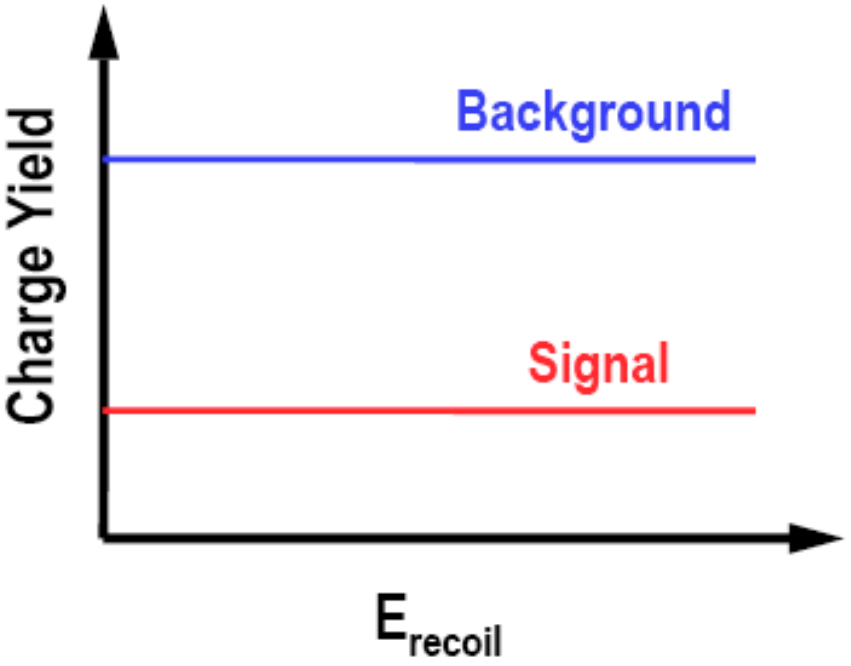
$E_{recoil} < 100$ keV
R << 1 event/kg/day



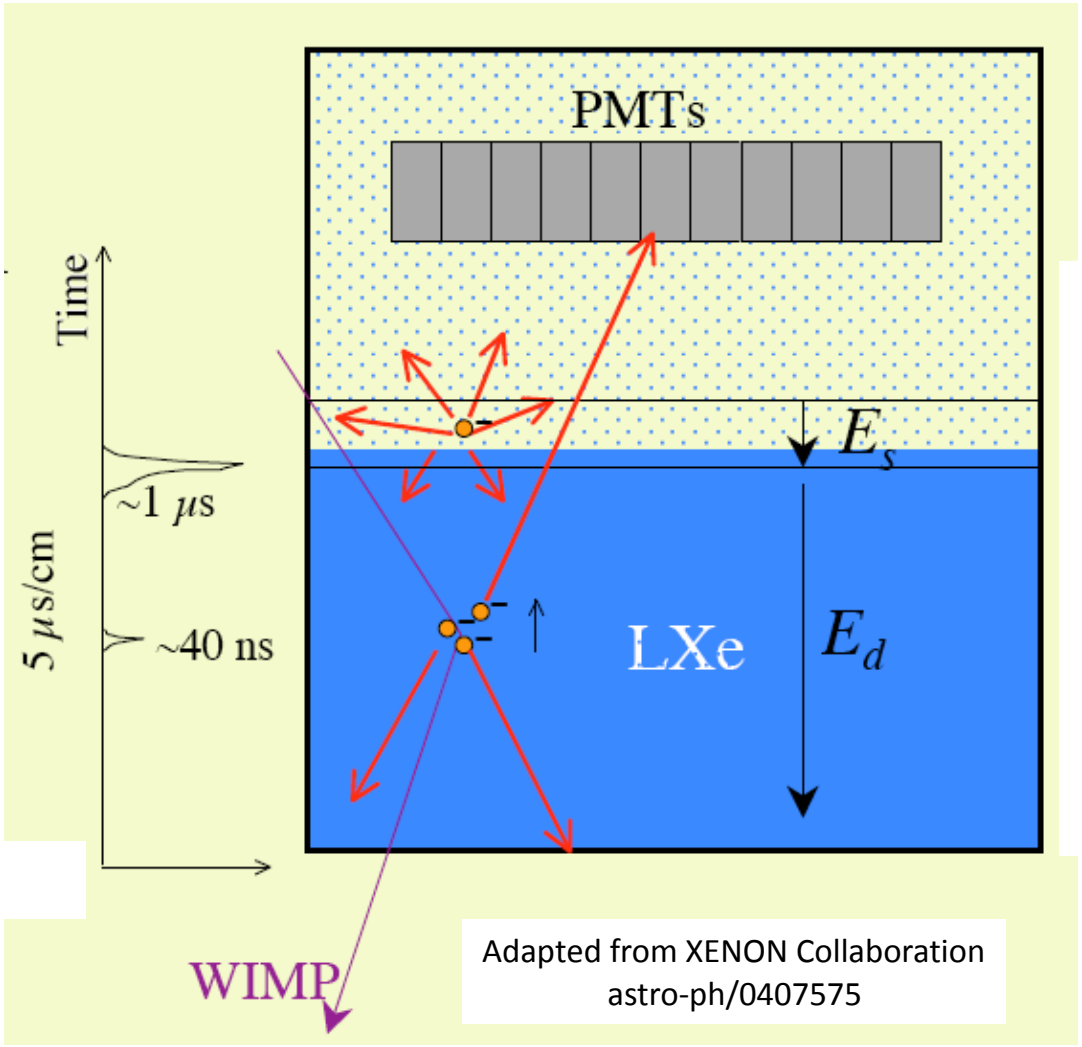

CDMS


Background
Signal
E_{charge}
$E_{phonons}$

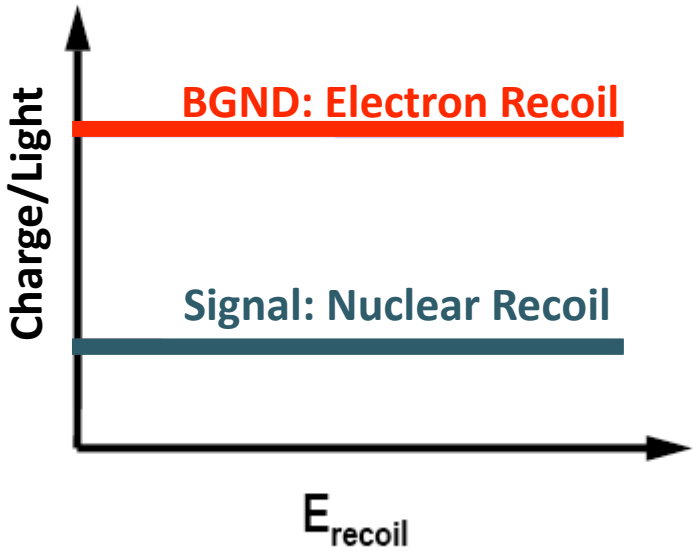

Ionization Yield
Recoil Energy (keV)
γ rays
neutrons
0
0.5
1
1.5
0
20
40
60
80
100


Charge Yield
Background
Signal
E_{recoil}

Background Discrimination in a “Dual-Phase” LXe Detector

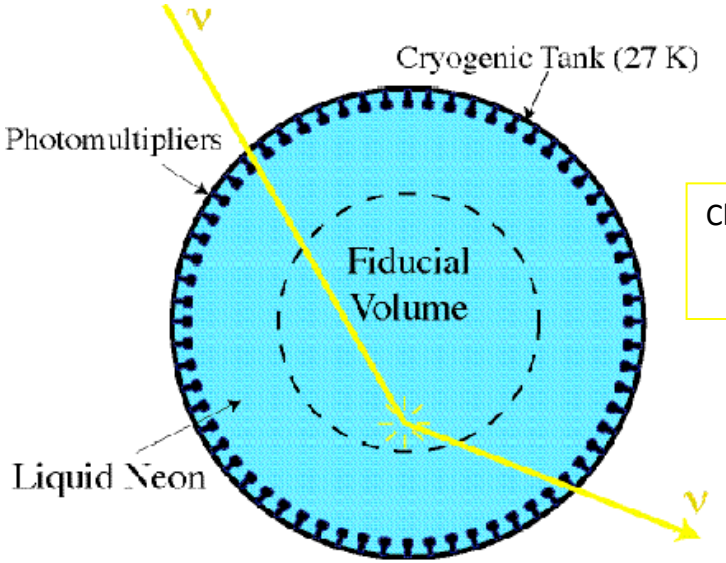


Adapted from XENON Collaboration
astro-ph/0407575



CLEAN: Cryogenic Low Energy Astrophysics with Neon

McKinsey & Doyle, J. Low Temp. Phys. **118**, 153 (2000)
McKinsey & Coakley, Astroparticle Physics **22**, 355 (2005)
Boulay, Hime, & Lidgard, **nucl-ex**/0410025



Clean & Large Fiducial Volume

Prepare an Ultra-Pure, Massive, and Low-Energy Threshold Fiducuial Volume of LNe for the Direct Detection of pp-Solar Neutrinos and WIMP Dark Matter

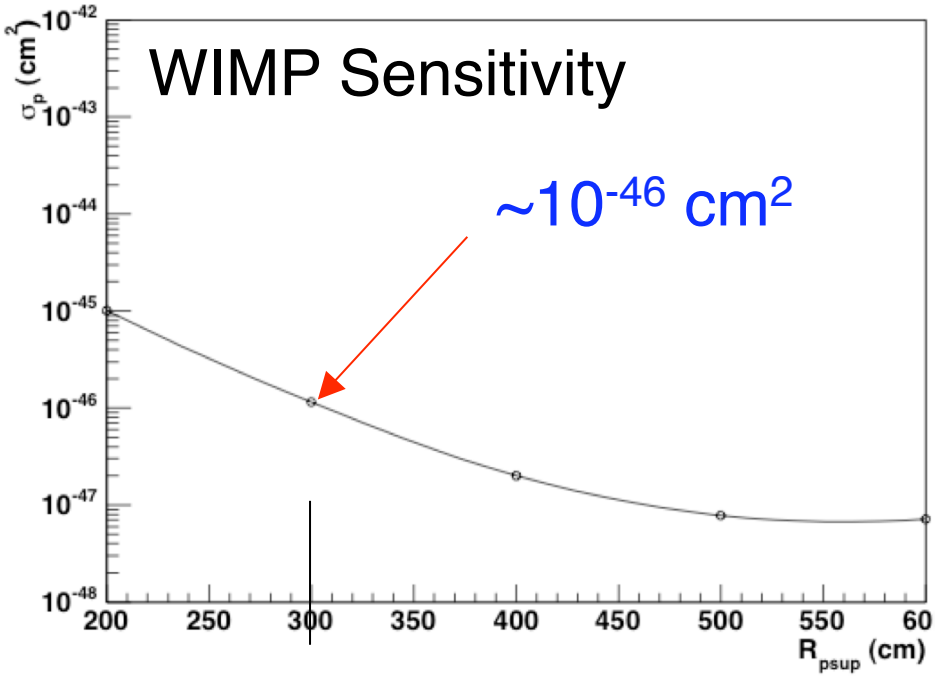
- LNe contains no long-lived radioactive isotopes and is easily purified of ^{39}Ar & ^{85}Kr using conventional cold-traps.
- LNe is transparent to its own scintillation light and dense enough to act as a self-shielding medium.
- Position reconstruction via PMT charge & time distributions allows fiducialization of the central volume while avoiding the PMT background wall.
- LNe scintillates brightly in the EUV with ~30000 photons/MeV.

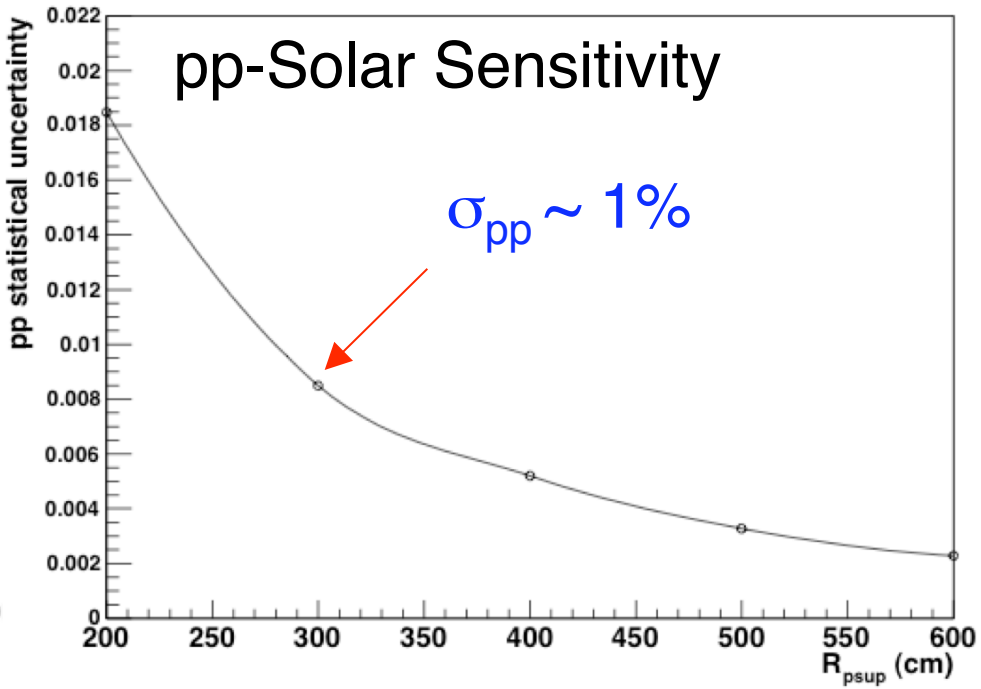
Low-Energy Threshold

- Pulse-Shape-Discrimination is possible using two distinct states of scintillation light, making possible a truly dual-purpose detector of low-energy solar neutrinos and WIMP dark matter

Sensitivity to WIMPs and Neutrinos with Liquid Neon

M.Boulay, A.Hime, and J.Lidgard (nucl-ex/0410025)



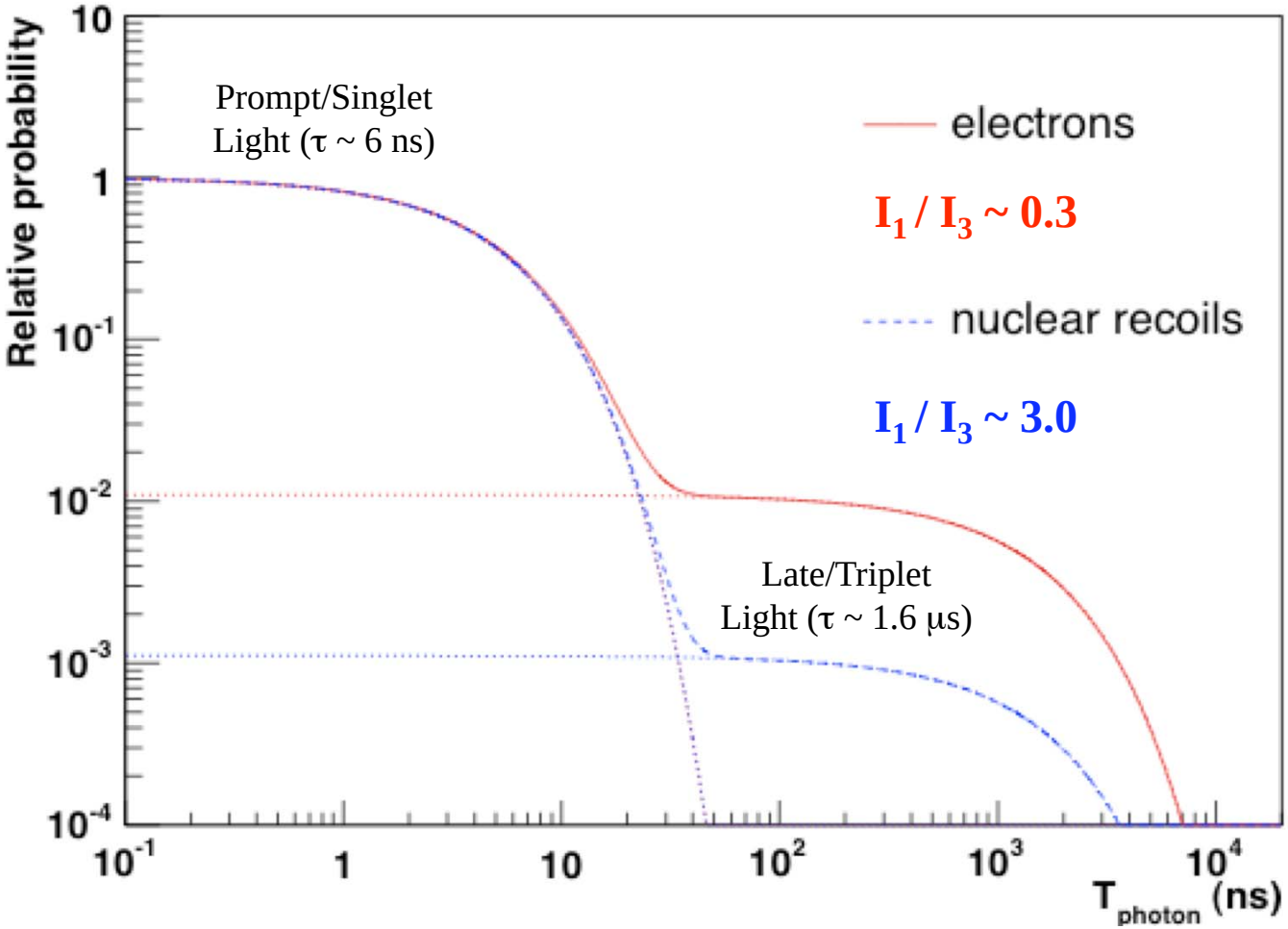


300 cm

Detector size →

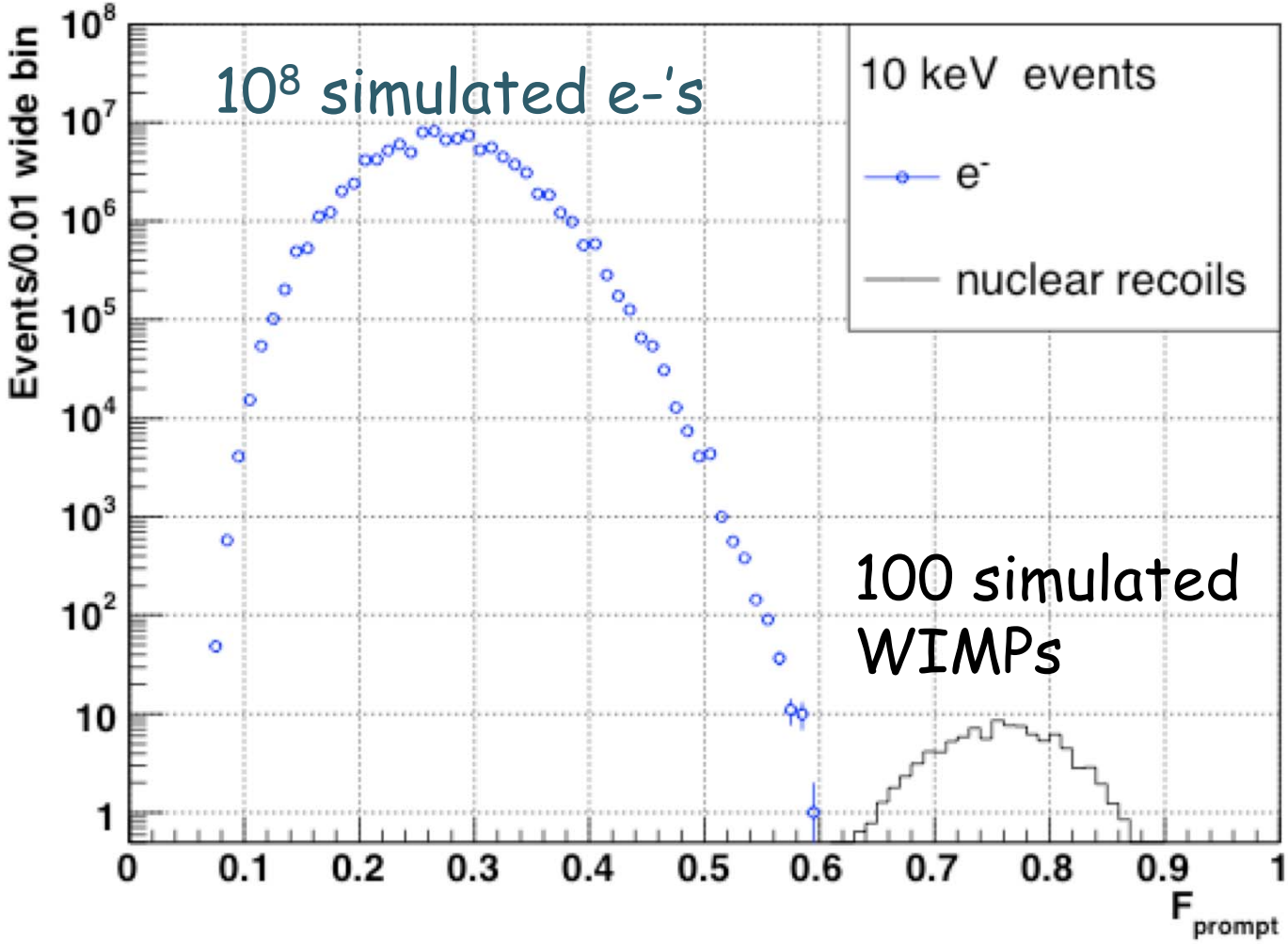
Pulse Shape Discrimination in LAr

M.G.Boulay and A.Hime, Astroparticle Physics 25, 179 (2006)

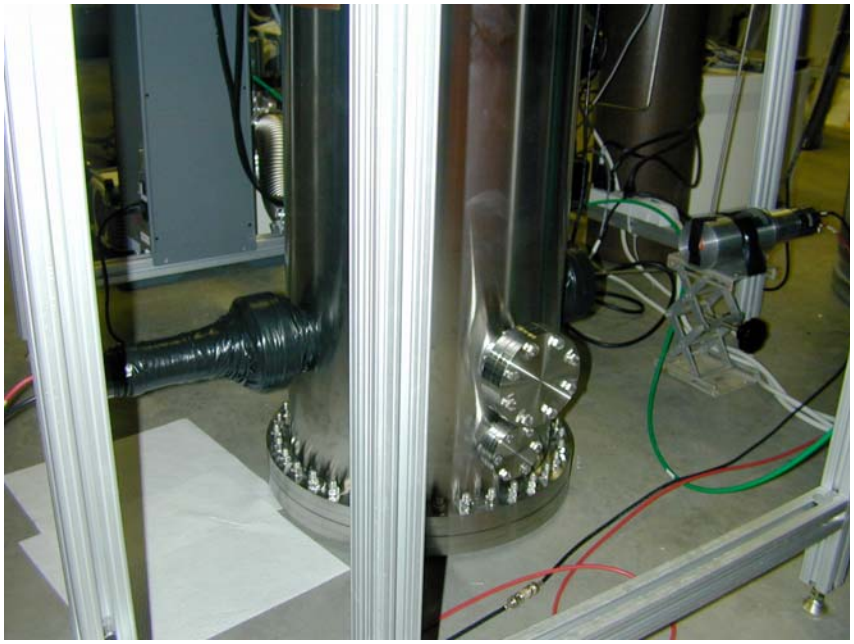


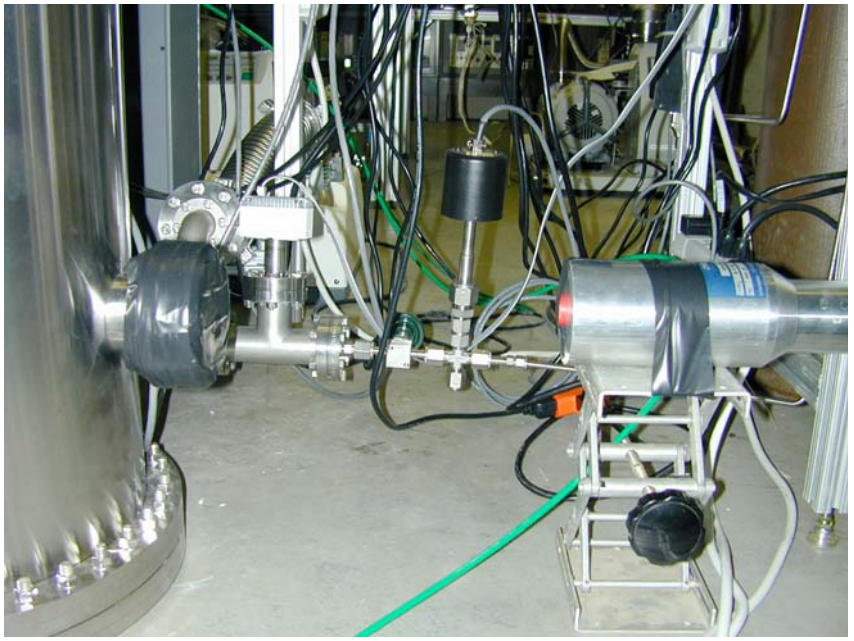
Background rejection with LAr (simulation)

M.G.Boulay and A.Hime, Astroparticle Physics 25, 179 (2006)

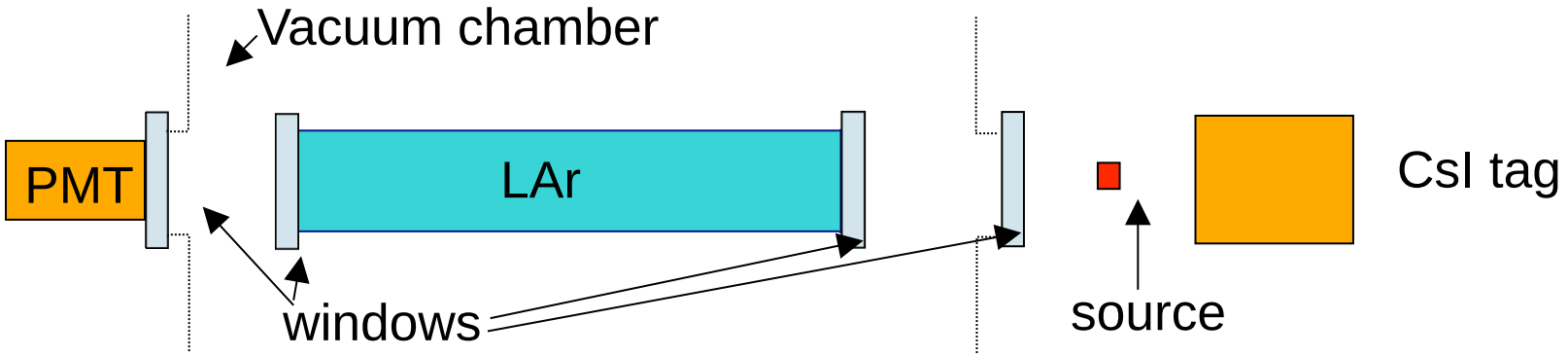


DEAP-0 Test Calibration at LANL





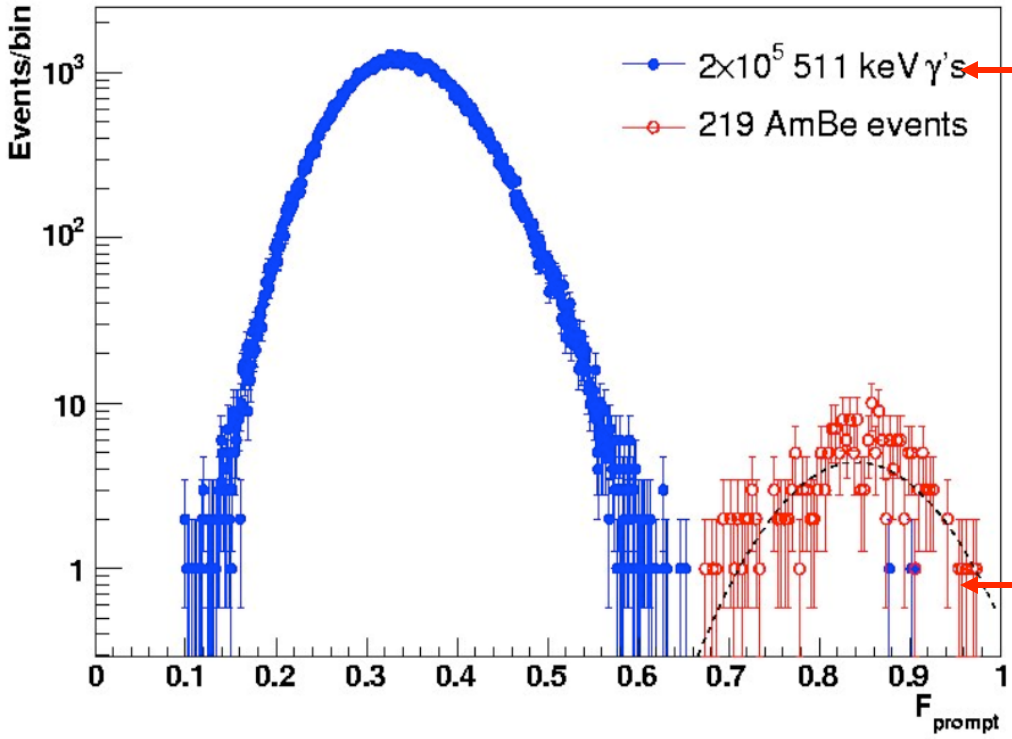
PMT coupled to LAr cell through chamber window



DEAP-0 Results & Projections for PSD in LAr

Avg. No. p.e.	Measured Leakage	Background Leakage	Projected PSD
50	$(2.4 \pm 0.6) \times 10^{-5}$	$(2.1 \pm 1.0) \times 10^{-5}$	1×10^{-10}
60	$(1.4 \pm 0.4) \times 10^{-5}$	$(1.5 \pm 0.9) \times 10^{-5}$	2×10^{-13}
70	$(1.0 \pm 0.4) \times 10^{-5}$	$(2.5 \pm 1.1) \times 10^{-5}$	1×10^{-17}

10 keV_{ee}
with 5 p.e./keV

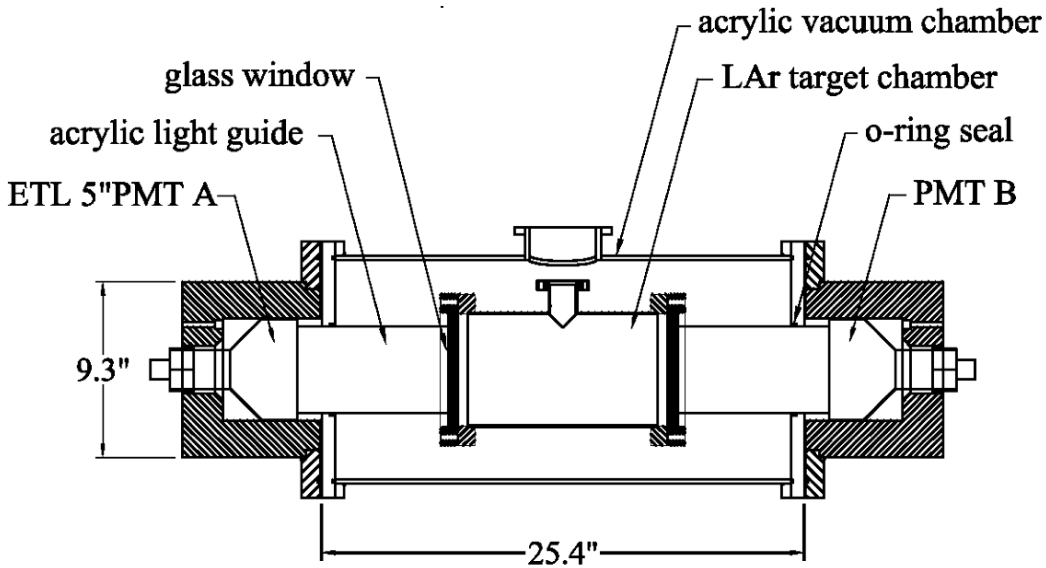


High Energy

Neutron BGND

DEAP-1

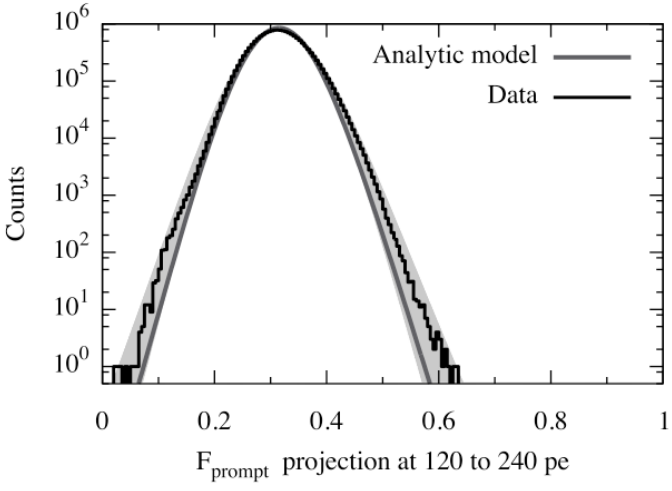
A 7 kg single-phase LAr detector

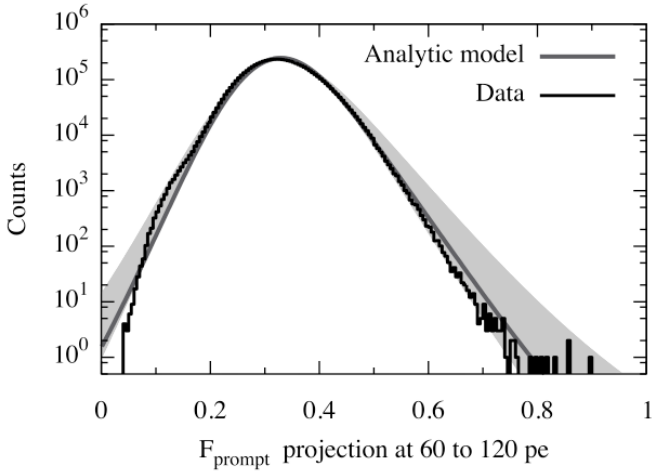


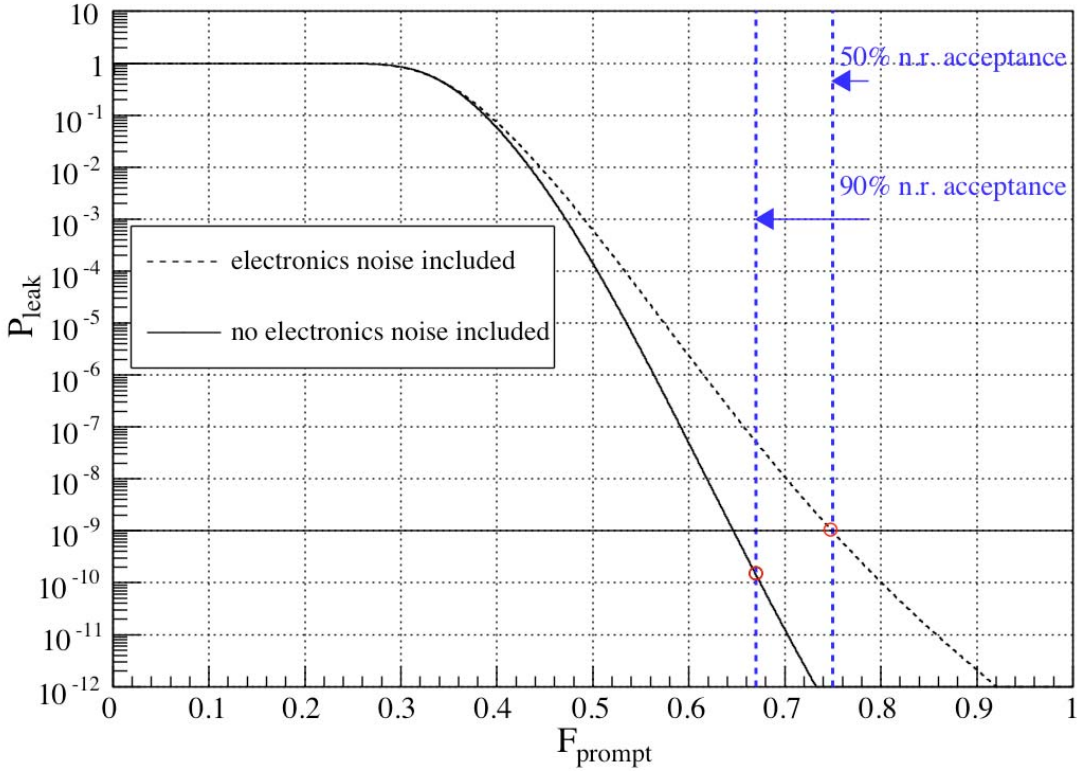
- Development of liquid-argon methods
- Prove pulse-shape discrimination
- Develop background-reduction techniques
- Dark Matter sensitivity to ~10^{-44} cm^2 at 100 GeV

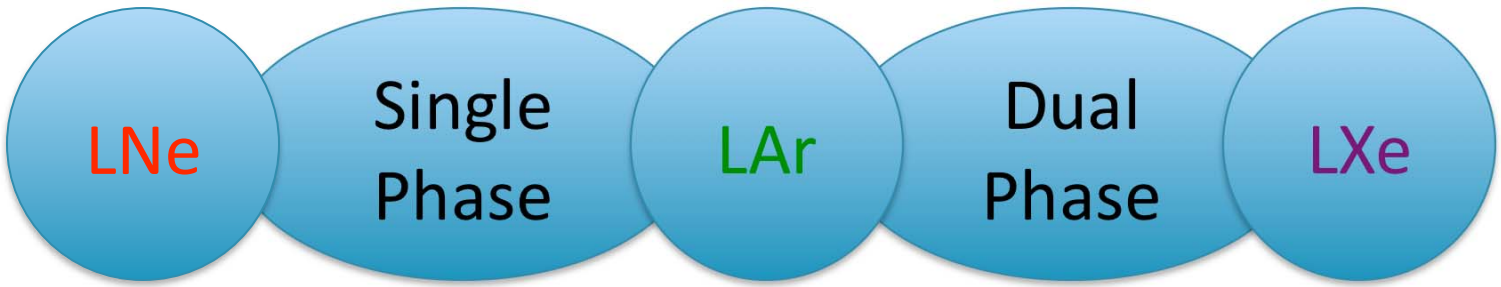
DEAP-1

Model of PSD from DEAP-1

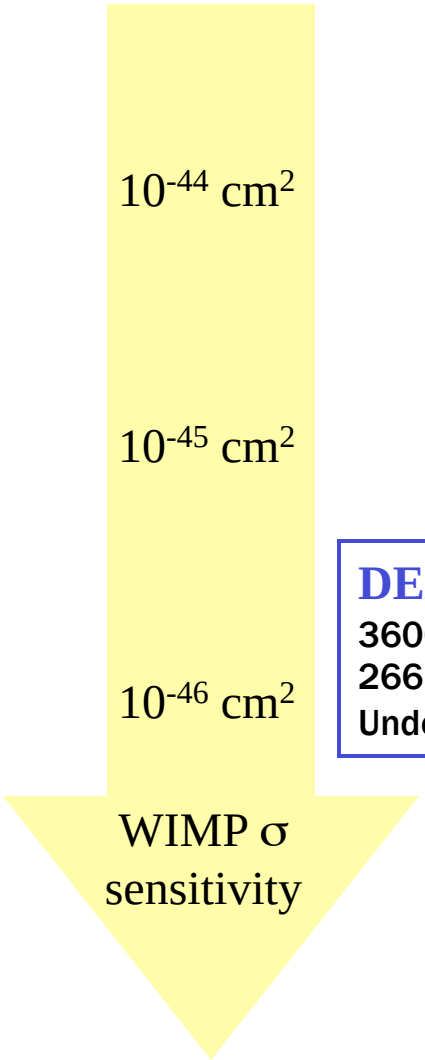







LNe
Single Phase
LAr
Dual Phase
LXe

DEAP and CLEAN Family of Detectors



DEAP 0
initial R&D detector

DEAP 1
7 kg LAr
2 warm PMTs
SNOLab 2008

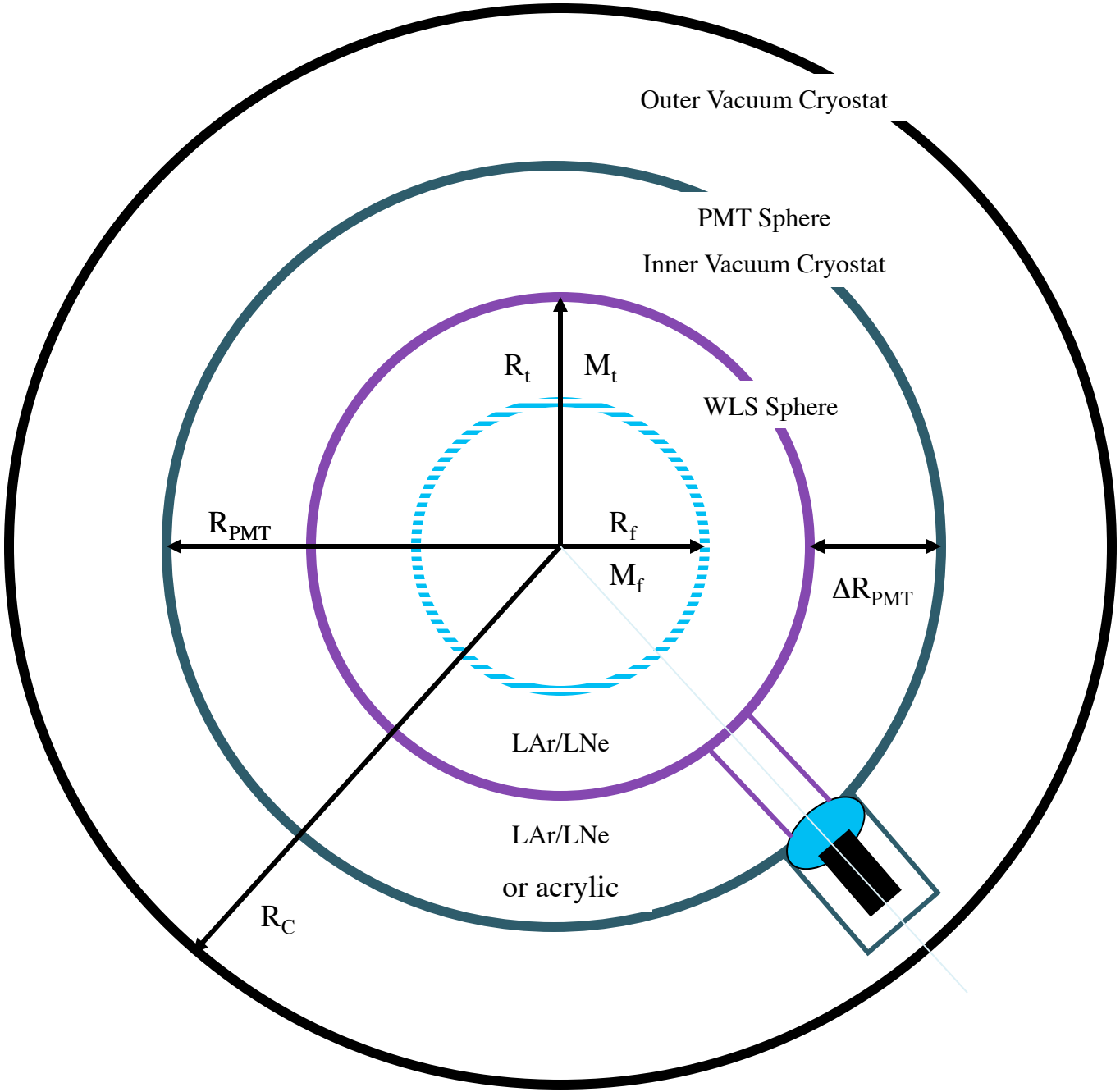
Pico-CLEAN
initial R&D detector

Micro-CLEAN
4 kg LAr and LNe
2 cold PMTs
surface tests at Yale

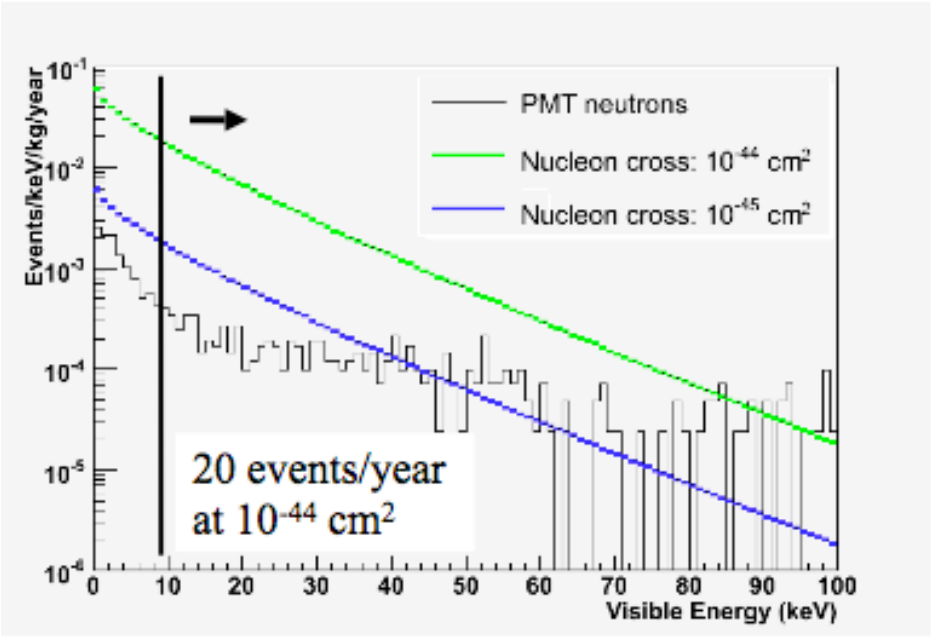
Mini-CLEAN
400 kg LAr/LNe (150 kg fiducial mass)
92 cold PMTs
Underground at SNOLab 2009

DEAP-3600
3600 kg LAr (1000 kg fiducial mass)
266 cold PMTs*
Underground at SNOLab late 2010

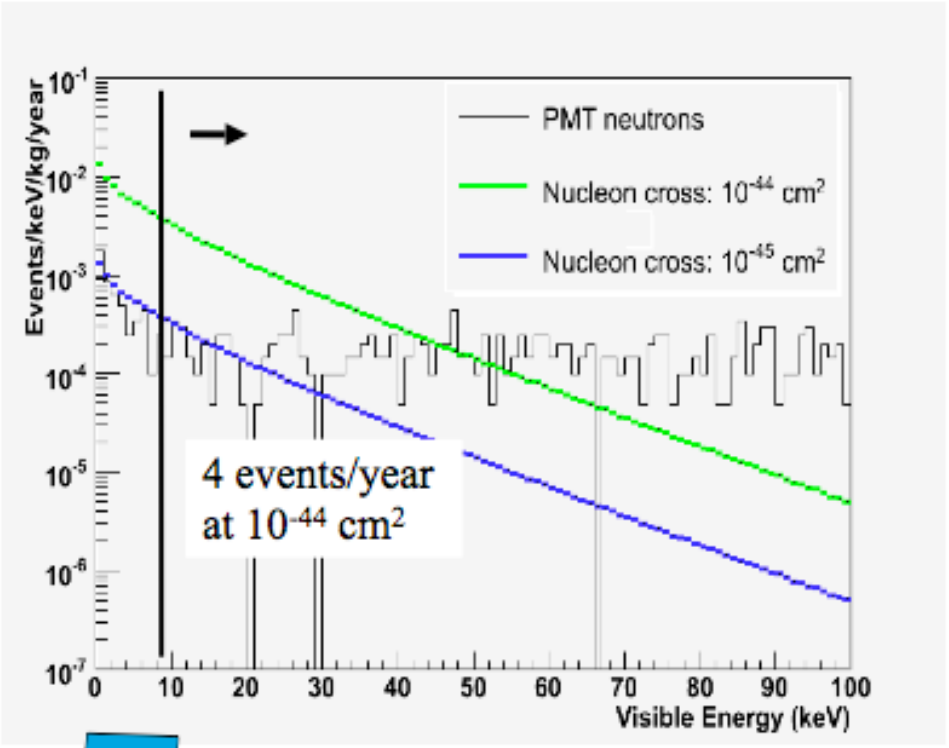
50 ton LNe/LAr Detector
pp solar ν, supernova, dark matter < 10^{-46} cm^2
DUSEL ISE ~ 2012


Outer Vacuum Cryostat
PMT Sphere
Inner Vacuum Cryostat
WLS Sphere
R_t
M_t
R_{PMT}
R_f
M_f
ΔR_{PMT}
LAr/LNe
LAr/LNe
or acrylic
R_C

100kg Mini-CLEAN-LAr



100kg Mini-CLEAN-LNe

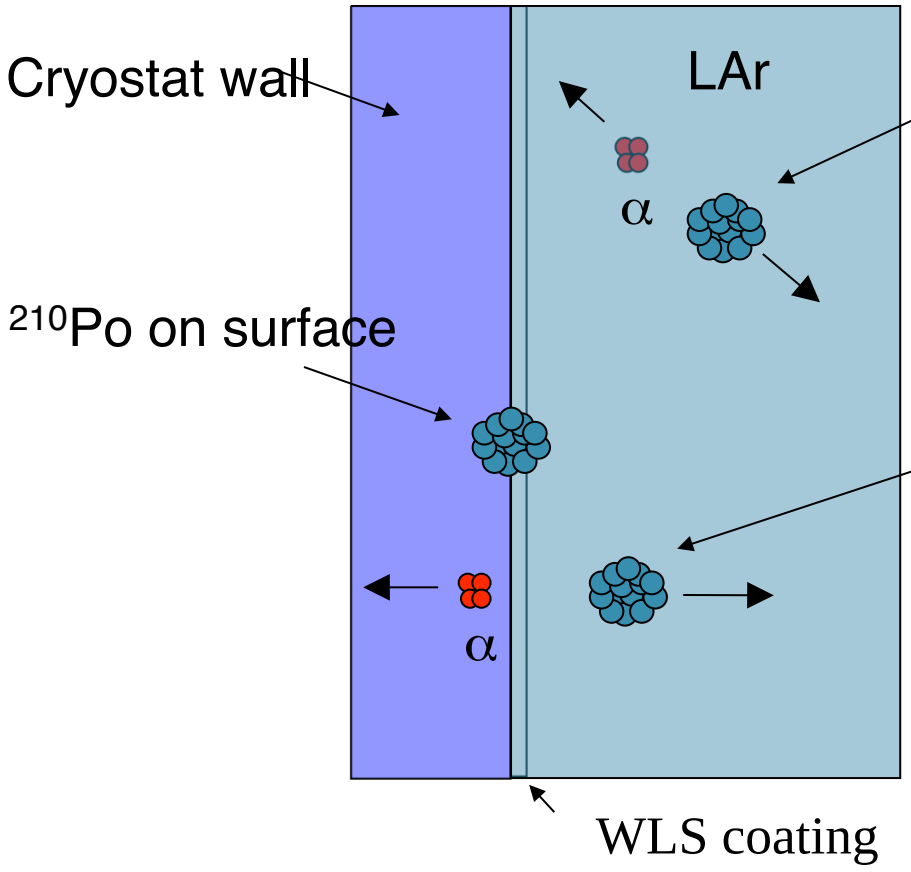


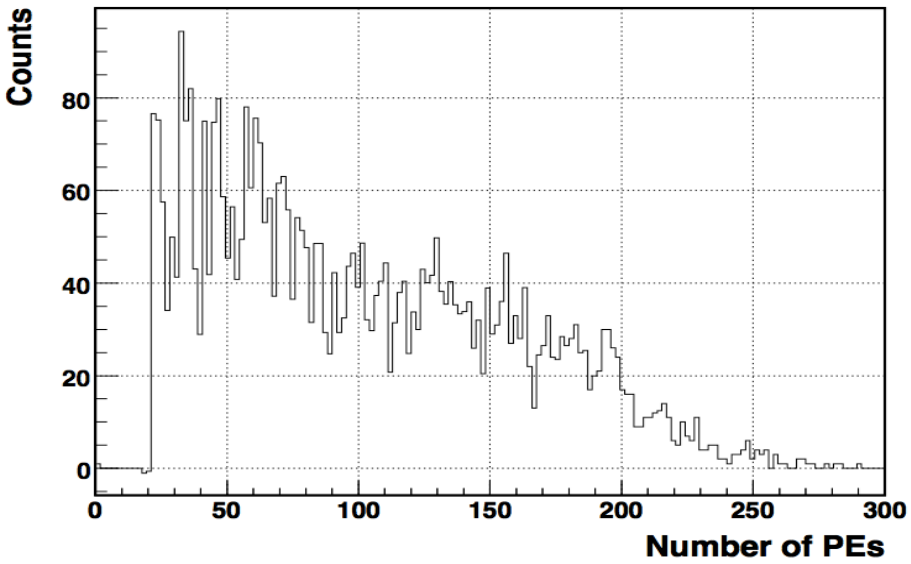
Exchange Target in Identical Detector to "Exercise" Signal v.s. BGND

assuming a 100 GeV WIMP $\left\{ \begin{array}{c} S_{Ar} \sim 5 \times S_{Ne} \\ B_{Ar} \sim B_{Ne} \end{array} \right\}$ **& similar energy threshold**

Hime & Mei

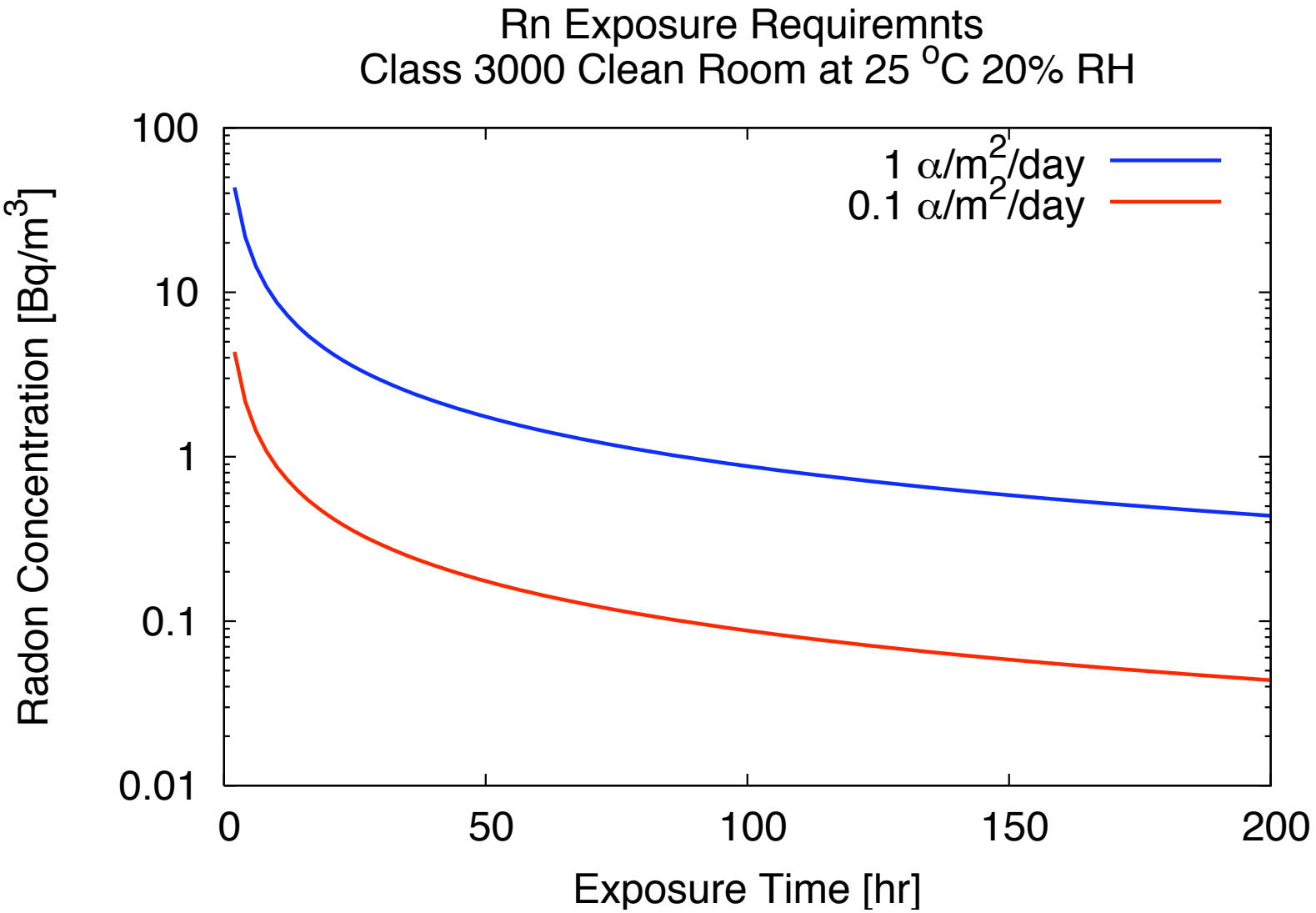
Surface Radon Daughters Present a Challenging Problem





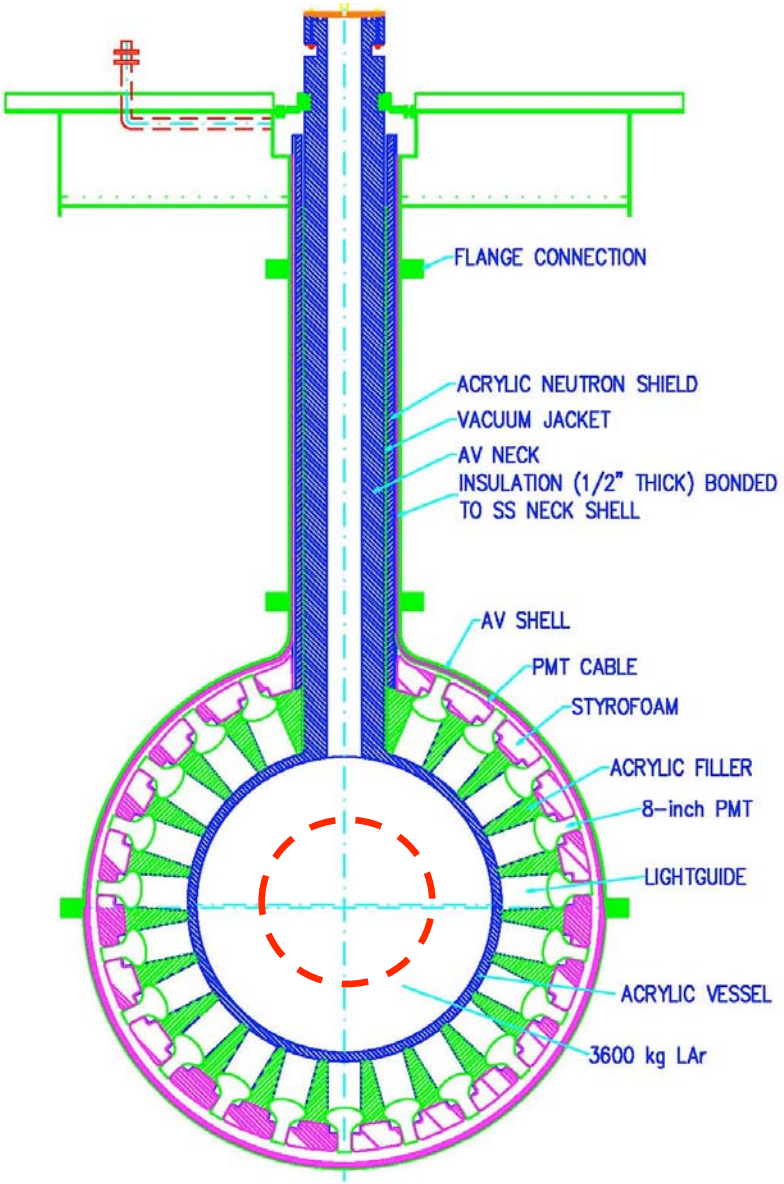
Alpha particles scintillate in WLS coating and "boost" the nuclear-recoil background out of WIMP energy window of interest.

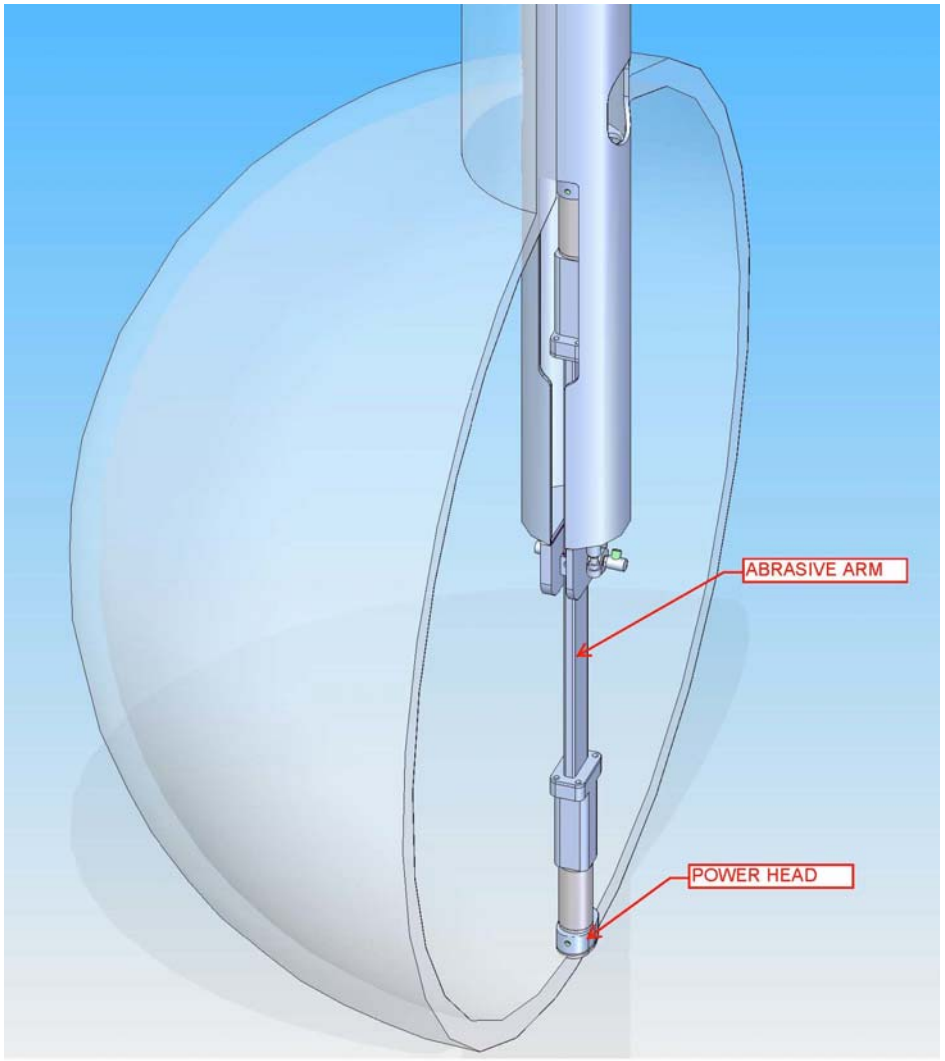
Mark Boulay

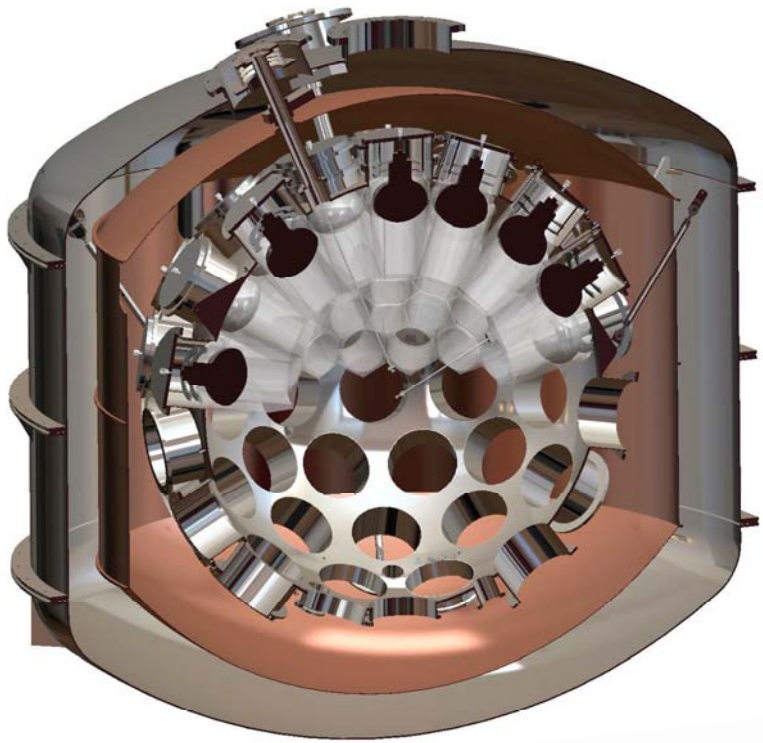


Vince Guiseppe

DEAP-3600 (Monolithic Acrylic Vessel with *in situ* Surface Cleaning)

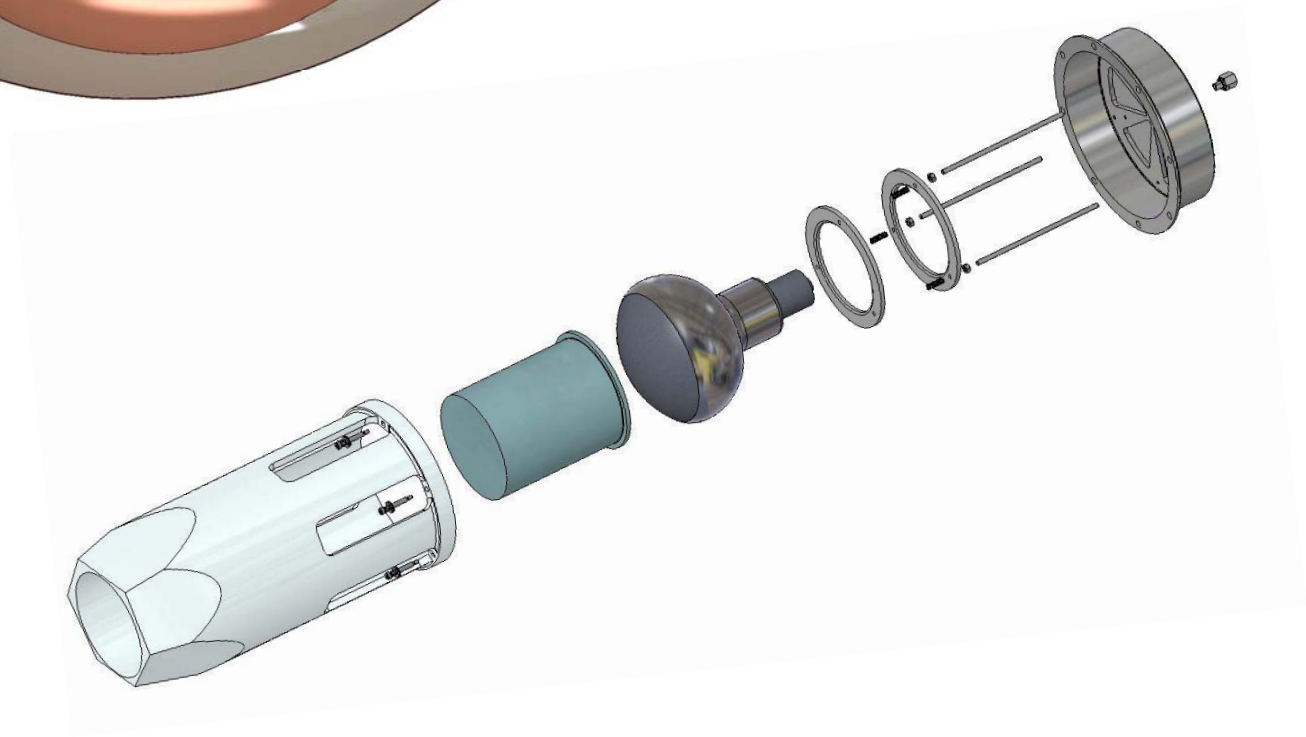






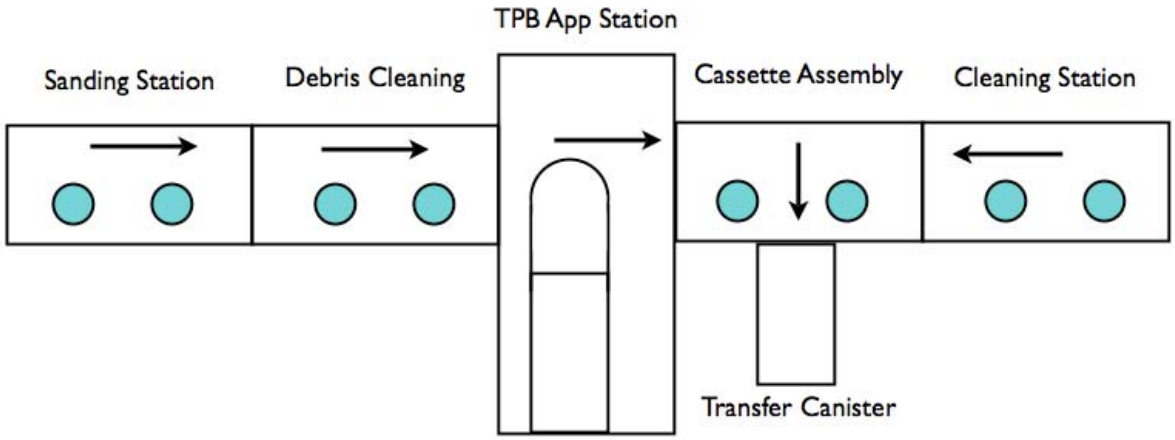
Mini-CLEAN

A Modular Approach with Radon-Free Assembly



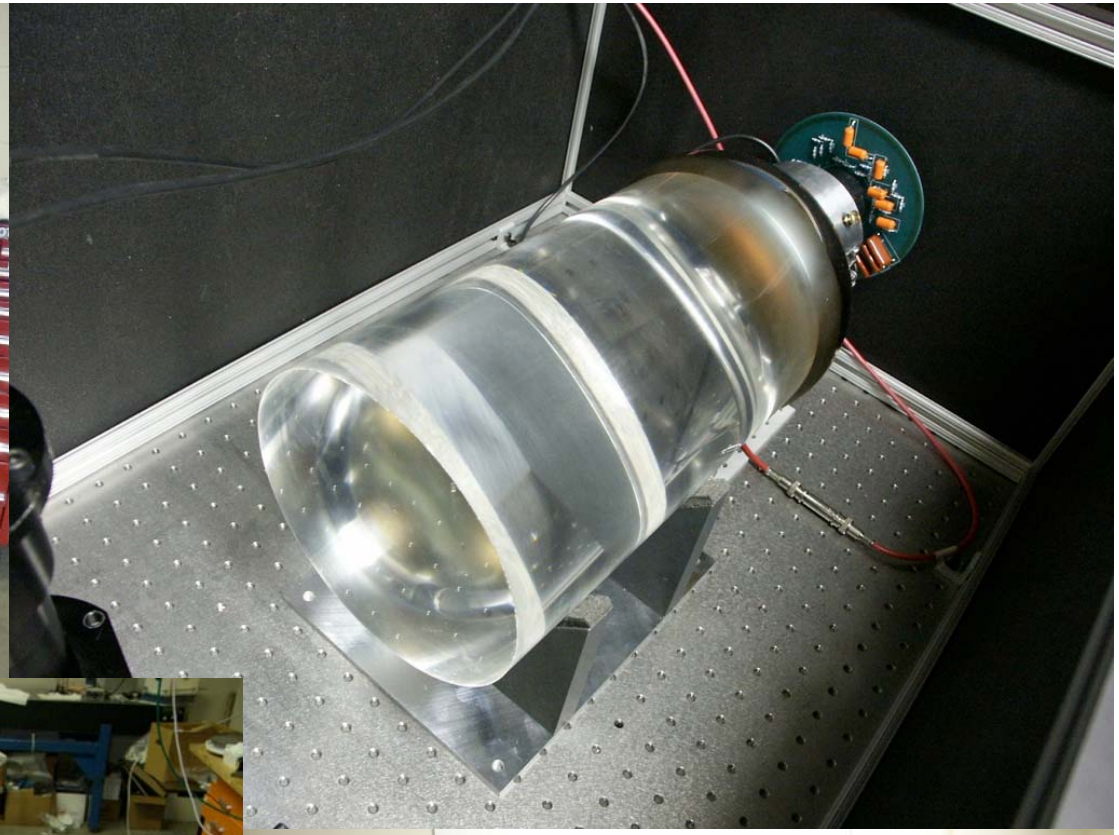
PMT Cassette Assembly

- Done in Clean Assembly Room (or Research Lab) above ground at SNOLAB
- Shooting for Class 100, low radon environment
- Six stations: sand acrylic, clean debris, coat light guide with TPB, clean other parts, assembly, put in transfer canister for shipment UG
- QA needed at all steps of process

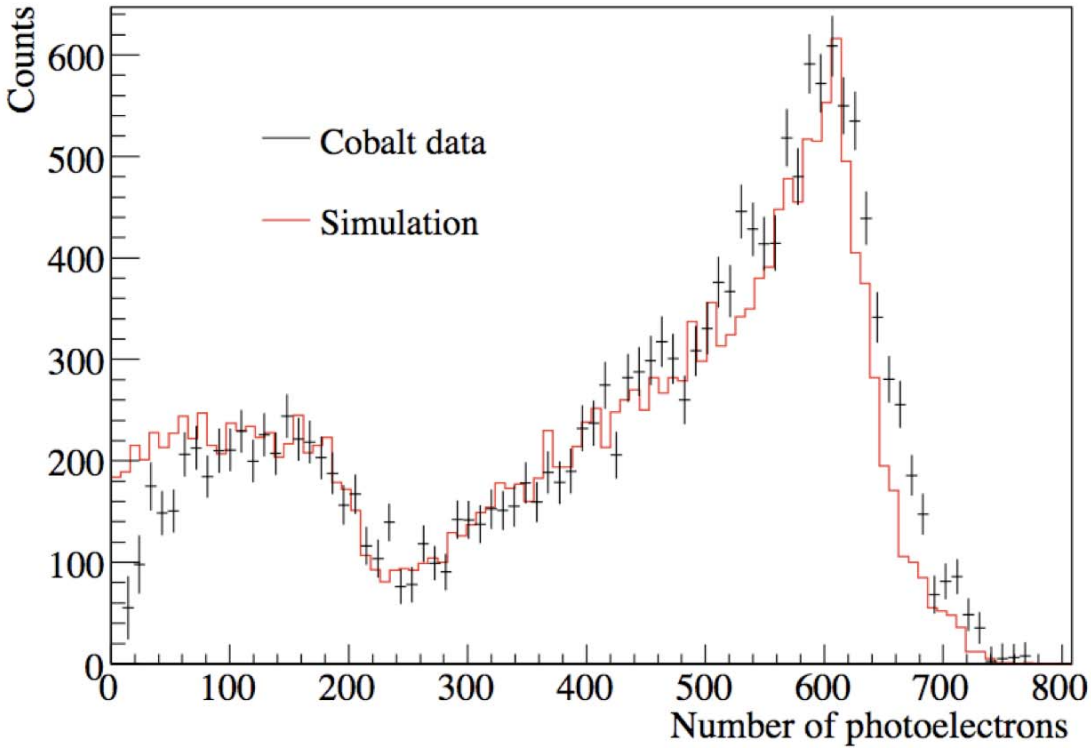


Cassette Insertion into IV

- Take cassette out of transfer canister via an interlock and into insertion glove box
- Mate insertion glove box to IV nipple, remove flange, insert cassette, tighten
- Need windows, two sets of gloves, vacuum environment



Micro-CLEAN



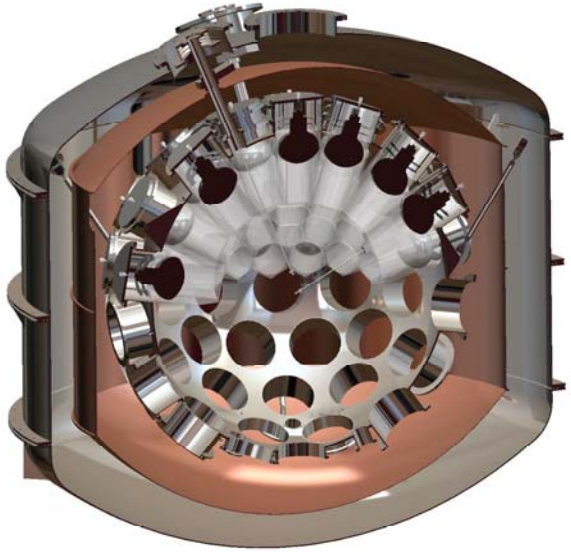
Expected Mini-CLEAN
Light Yield: 6-7 pe/keV

MINI-CLEAN 360 DETECTOR ASSEMBLY

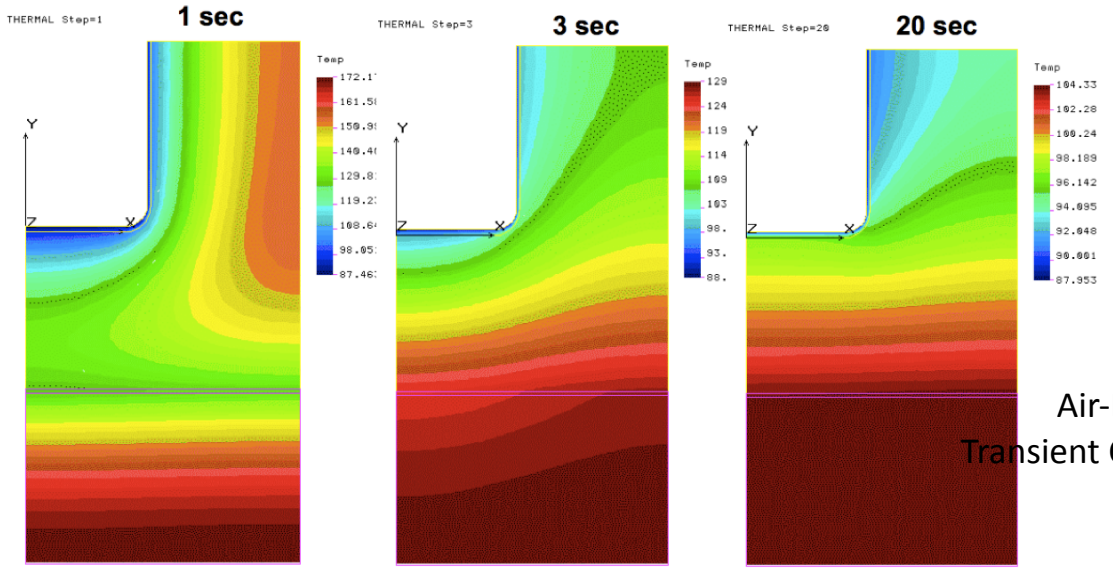
MINI-CLEAN 360 DETECTOR ASSEMBLY (View from above)

LANL Engineering
Mini-CLEAN Detector Concept

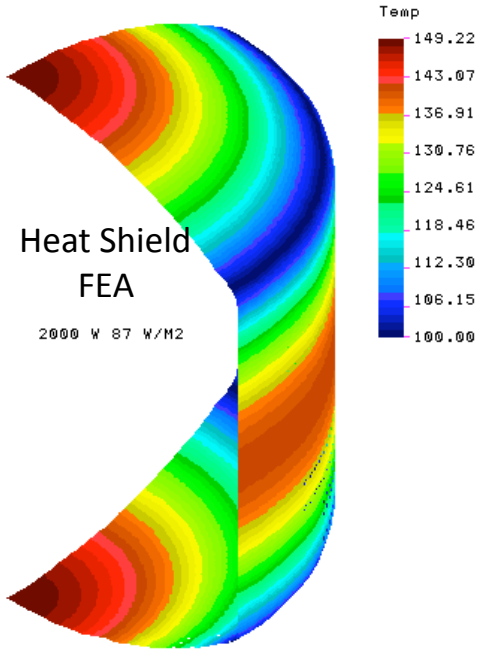
MINI-CLEAN 360 OUTER VACUUM VESSEL (With support structure)



MINI-CLEAN 360 DETECTOR - SECTION VIEW

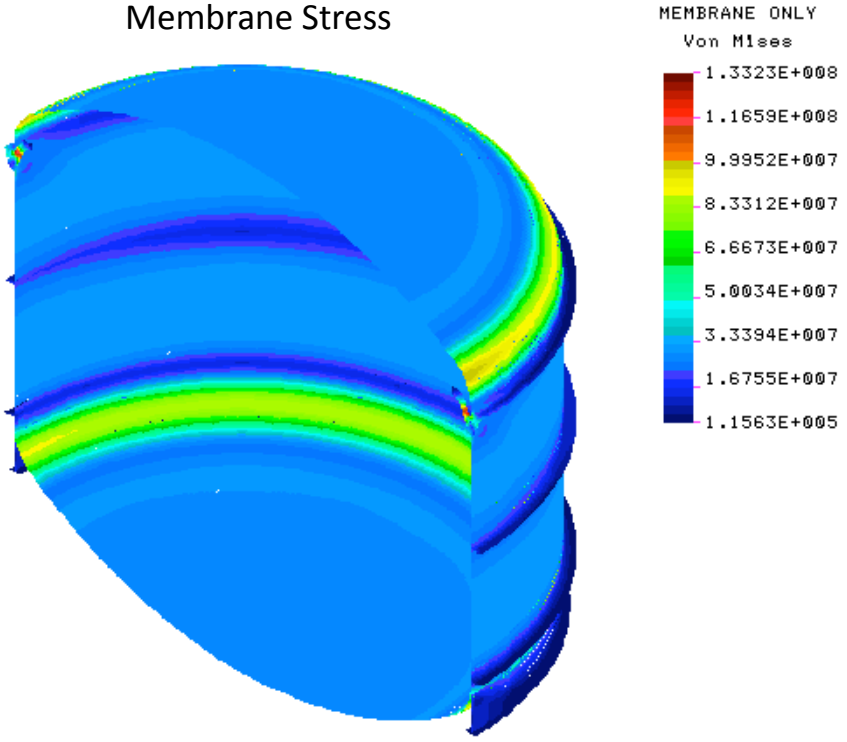


Air-Leak
Transient Cool-Down

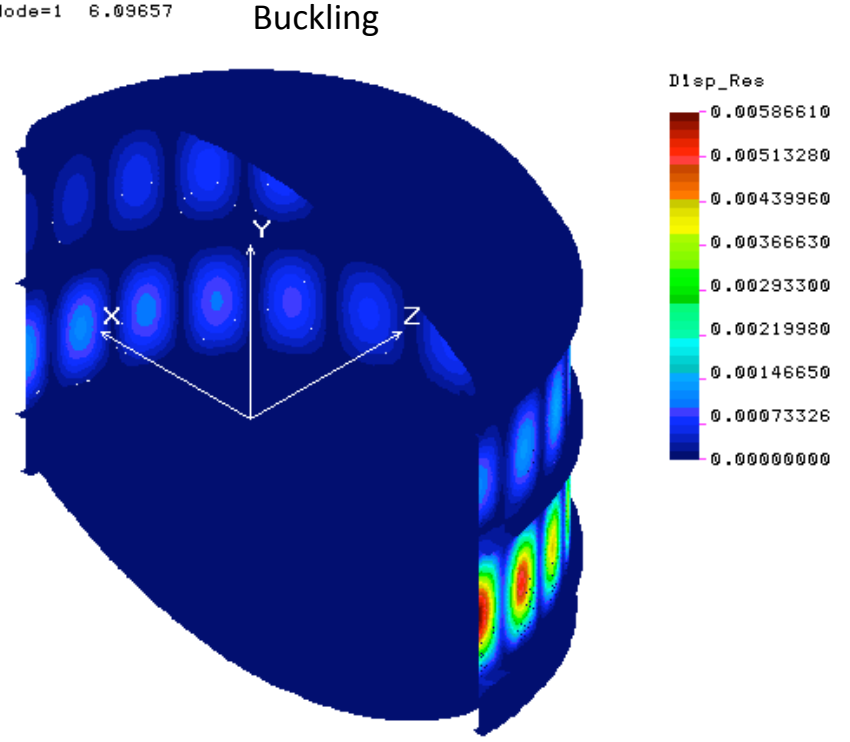


LANL Engineering - Fault Analyses & Mitigation

Membrane Stress



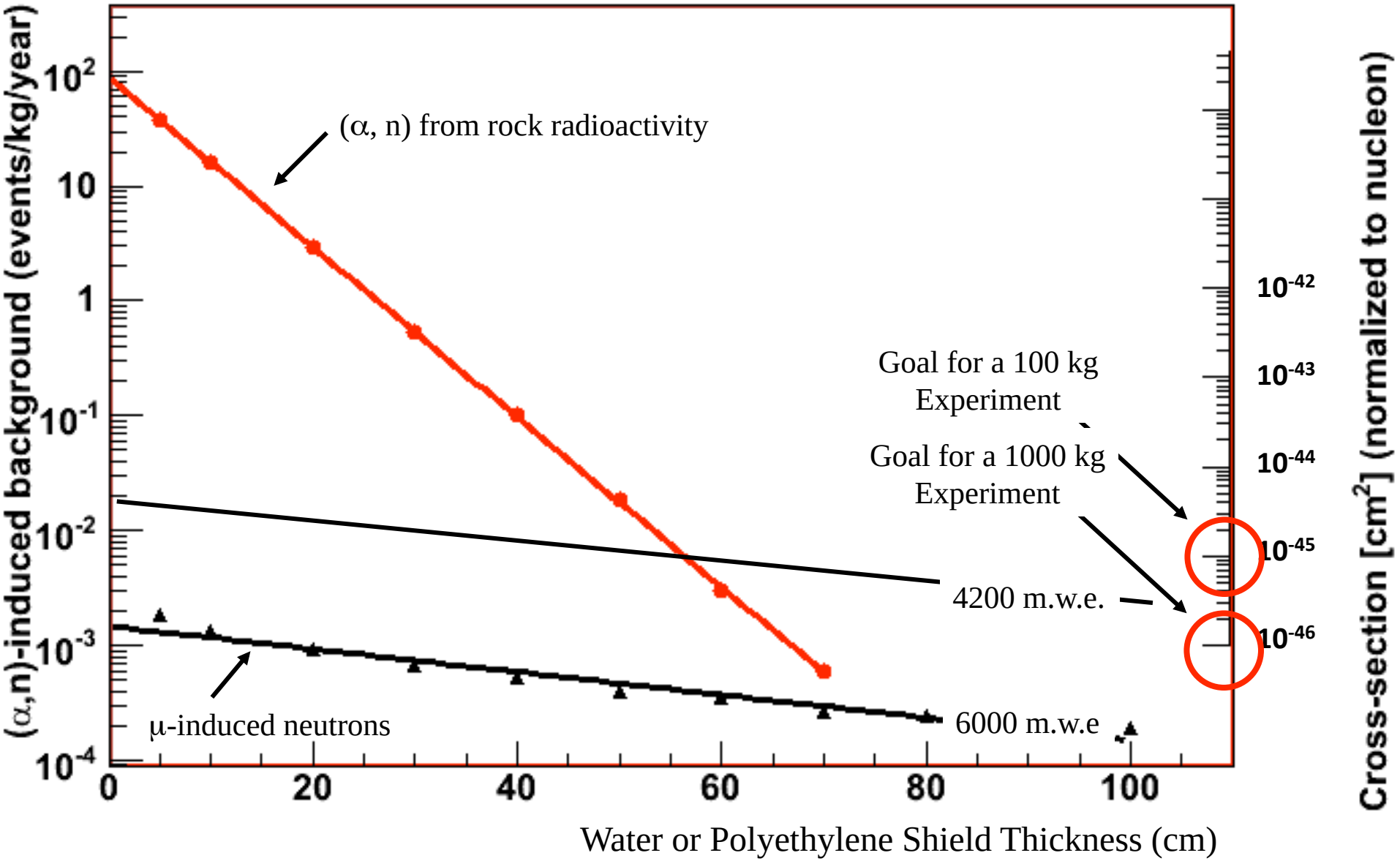
Buckling

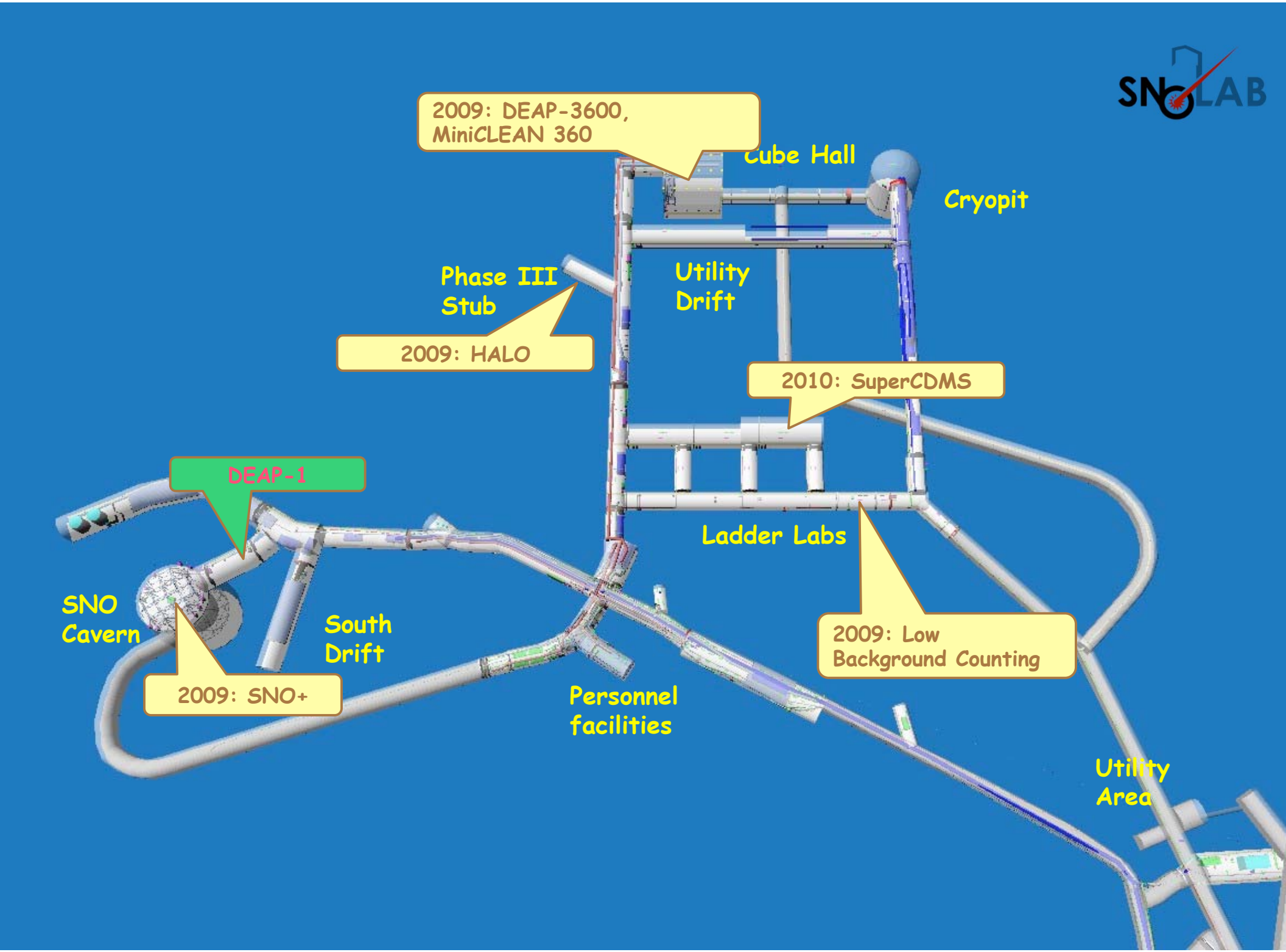


Mini-CLEAN Outer Vessel Under Fabrication

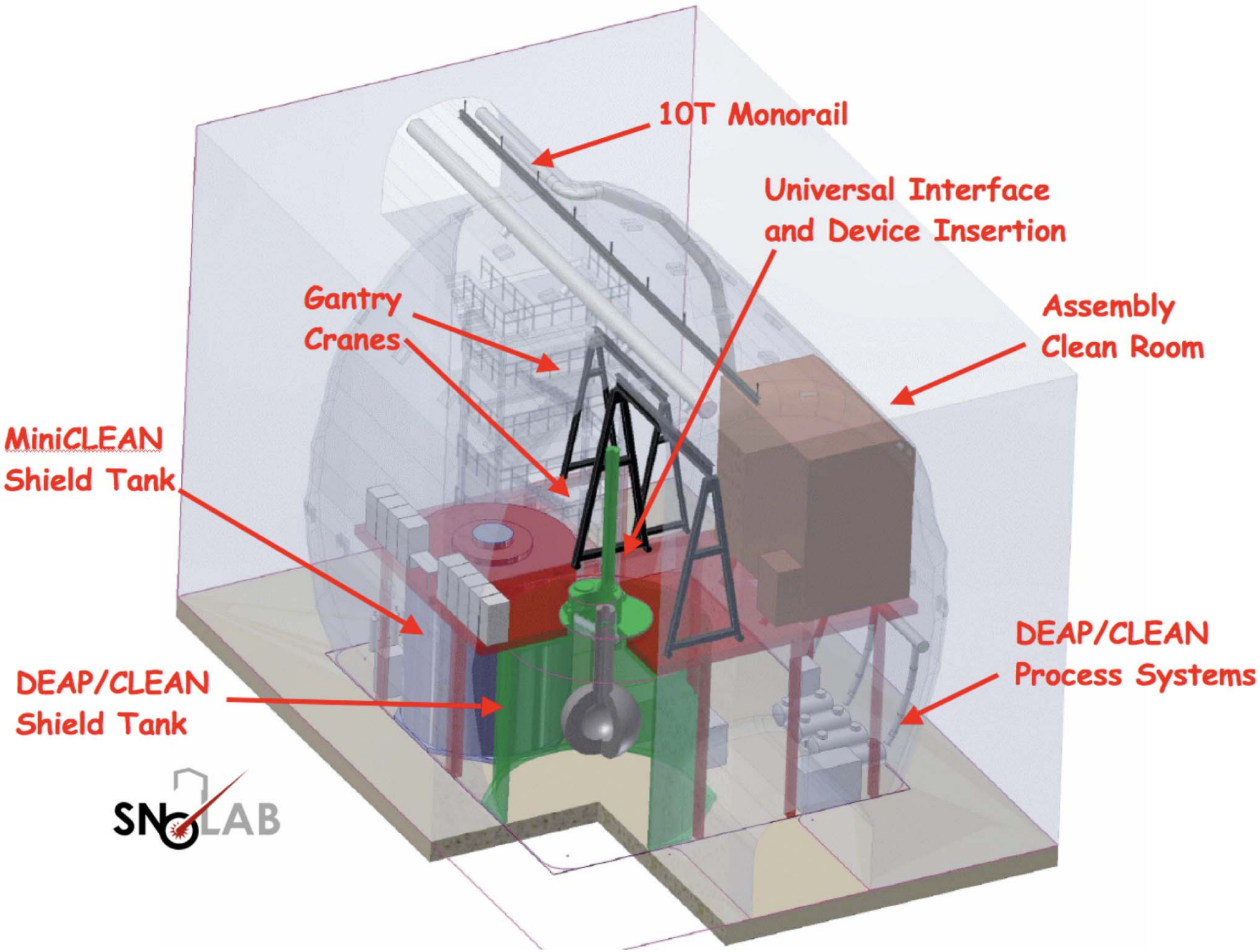
External Neutron Shielding Requirements for LAr-MiniCLEAN

Mei & Hime … Following from PRD **73**, 053004 (2006)

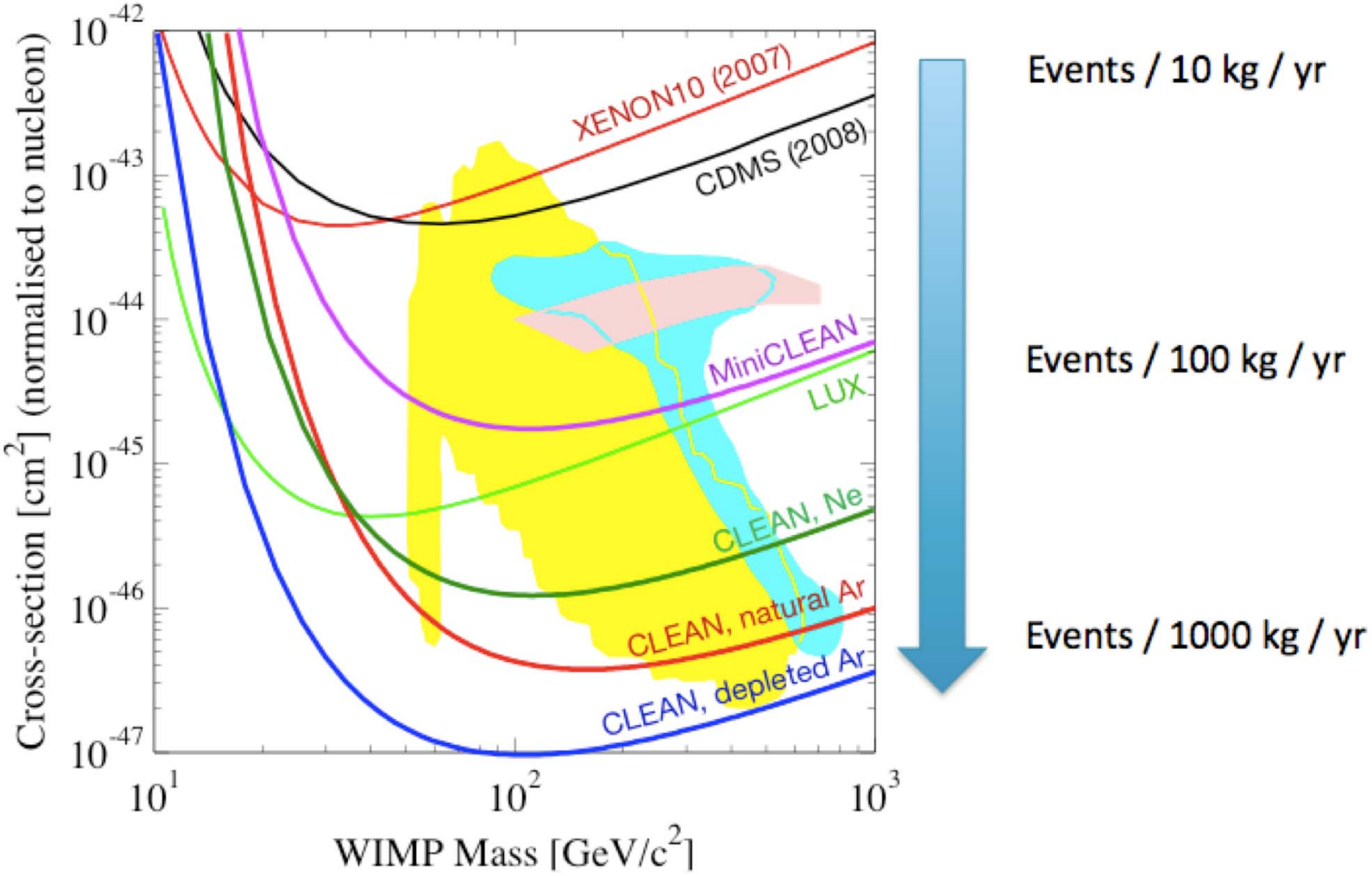



2009: DEAP-3600,
MiniCLEAN 360
Cube Hall
Cryopit
Phase III
Stub
Utility
Drift
2009: HALO
2010: SuperCDMS
DEAP-1
Ladder Labs
SNO
Cavern
South
Drift
2009: Low
Background Counting
2009: SNO+
Personnel
facilities
Utility
Area


Cube Hall at SNOLAB


10T Monorail
Universal Interface
and Device Insertion
Gantry
Cranes
Assembly
Clean Room
MiniCLEAN
Shield Tank
DEAP/CLEAN
Process Systems
DEAP/CLEAN
Shield Tank
SNOLAB

Progress requires Scalable & Background-Free Detectors



go DEAP & get CLEAN

Thank You