MAJORANA

Status

Jason Detwiler

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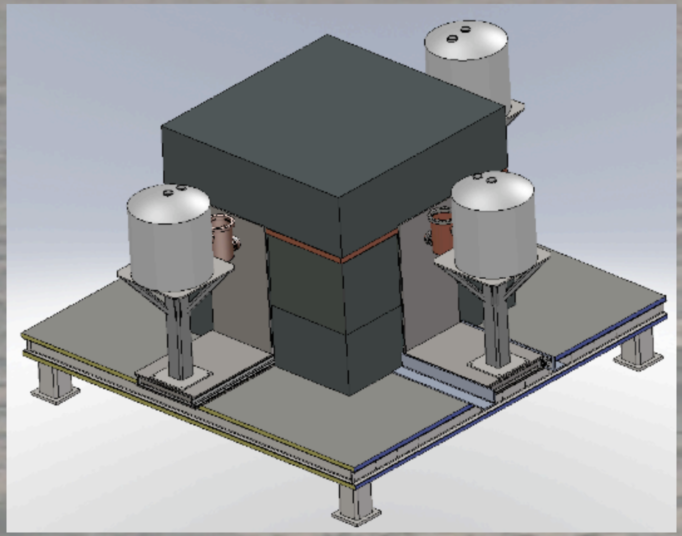
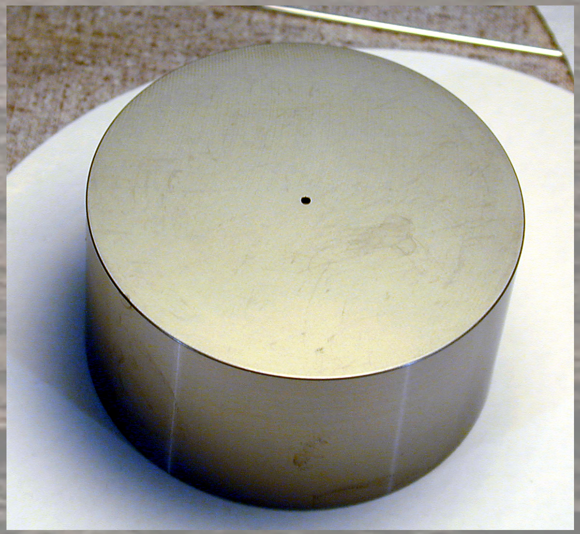


DBD09 / HAW09

Waikoloa, HI

Oct 13, 2009



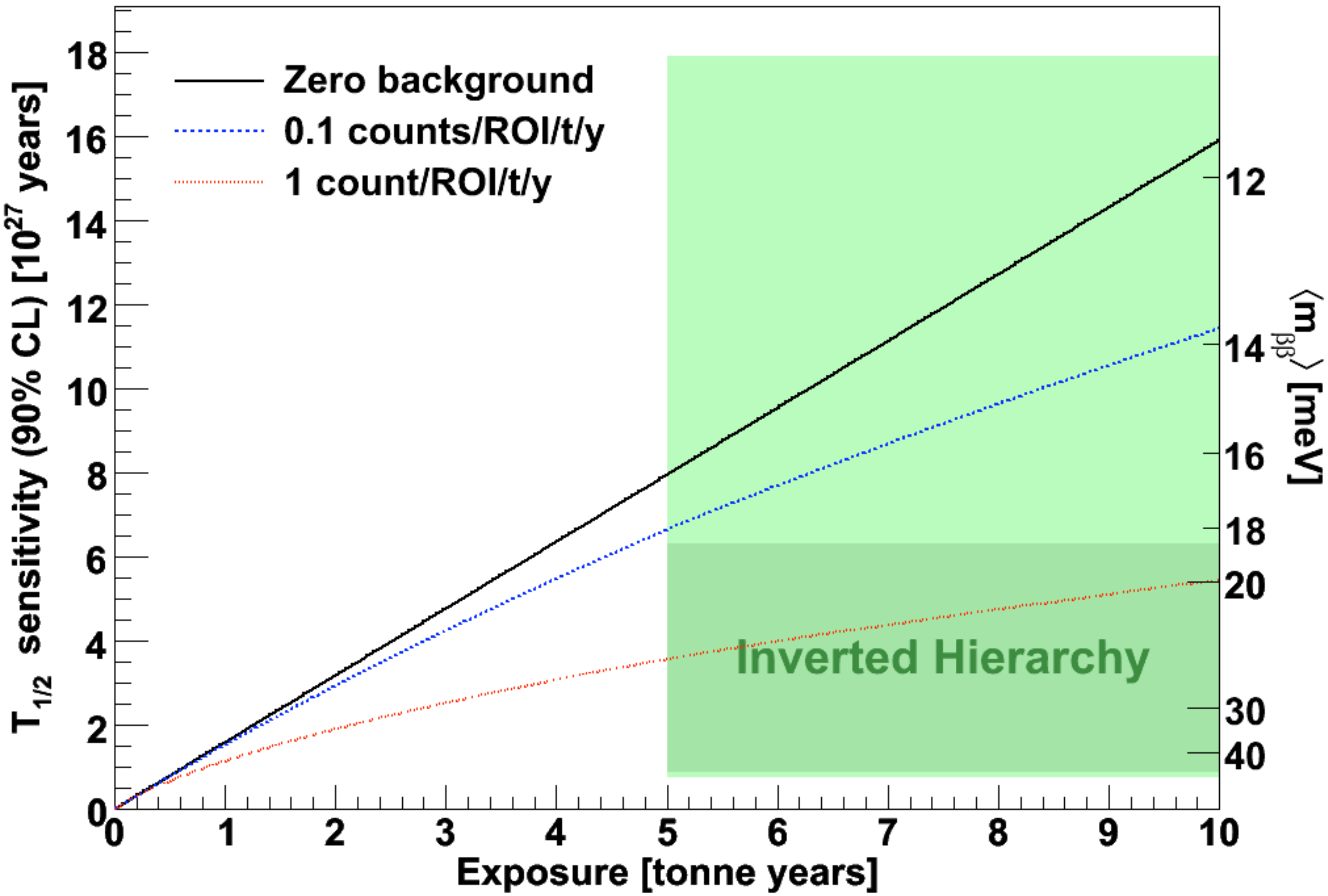
Advantages of ^{76}Ge

- Intrinsic high-purity Ge detectors = source
- Excellent energy resolution: 0.16% at 2039 keV (4 keV ROI)
- Powerful background rejection: segmentation, timing, pulse-shape discrimination
- Demonstrated ability to enrich from 7.44% to ≥86%
- ^{76}Ge has the current best limit:

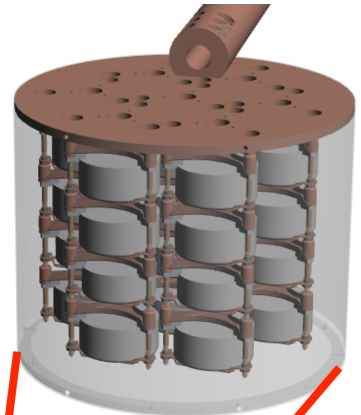
$$T_{1/2}^{0\nu} > 1.9 \times 10^{25}\ \mathrm{y}\ (90\%\ \mathrm{CL})$$

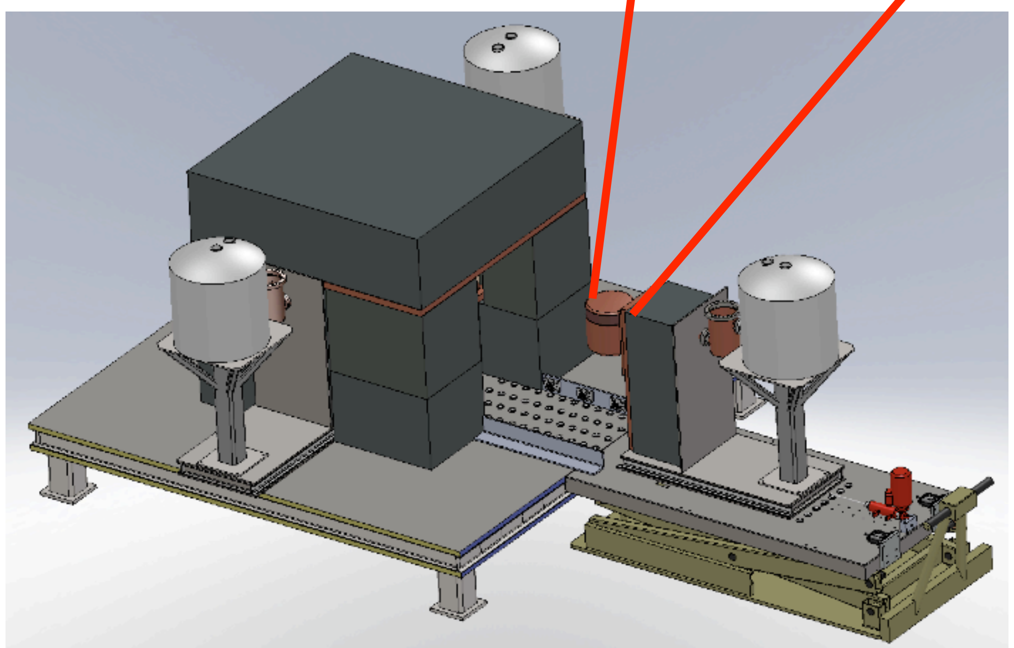
H.V. Klapdor-Kleingrothaus *et al.*, Eur. Phys. J. A **12**, 147, (2001).

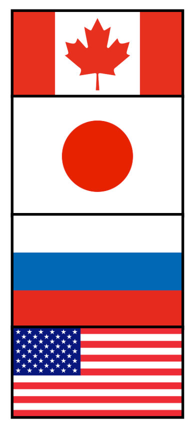
Ton-Scale Sensitivity

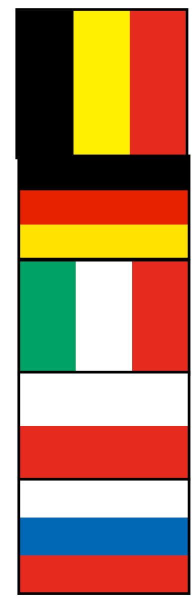


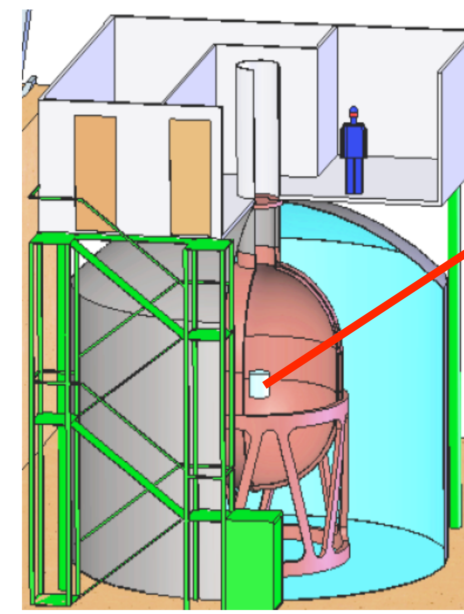
Majorana and GERDA

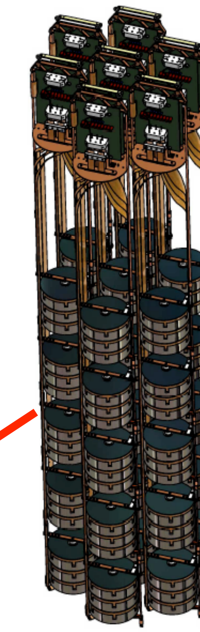












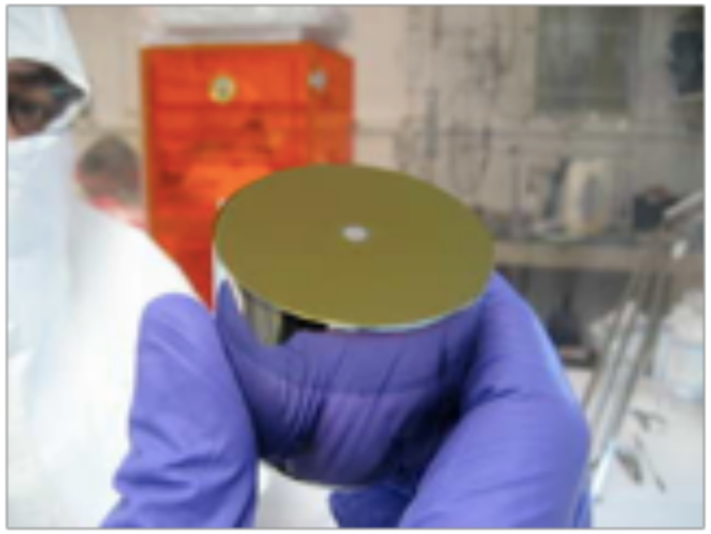
- Modular ^{enr}Ge arrays in electroformed Cu cryostats
- E-formed Cu / Pb passive shielding
- 4π plastic scintillator μ veto

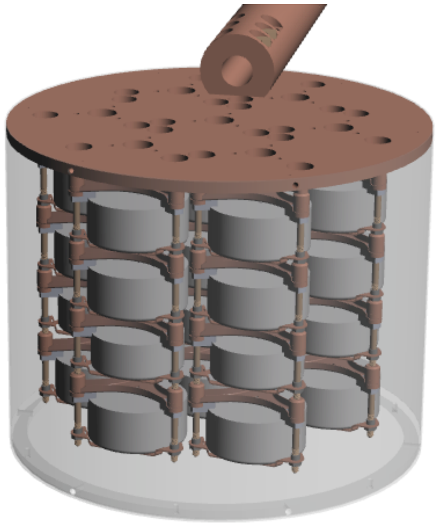
- ^{enr}Ge array submersed in LAr
- Water cherenkov μ veto
- Phase I: ~18 kg (H-M/IGEX xtals)
- Phase II: +20 kg segmented xtals

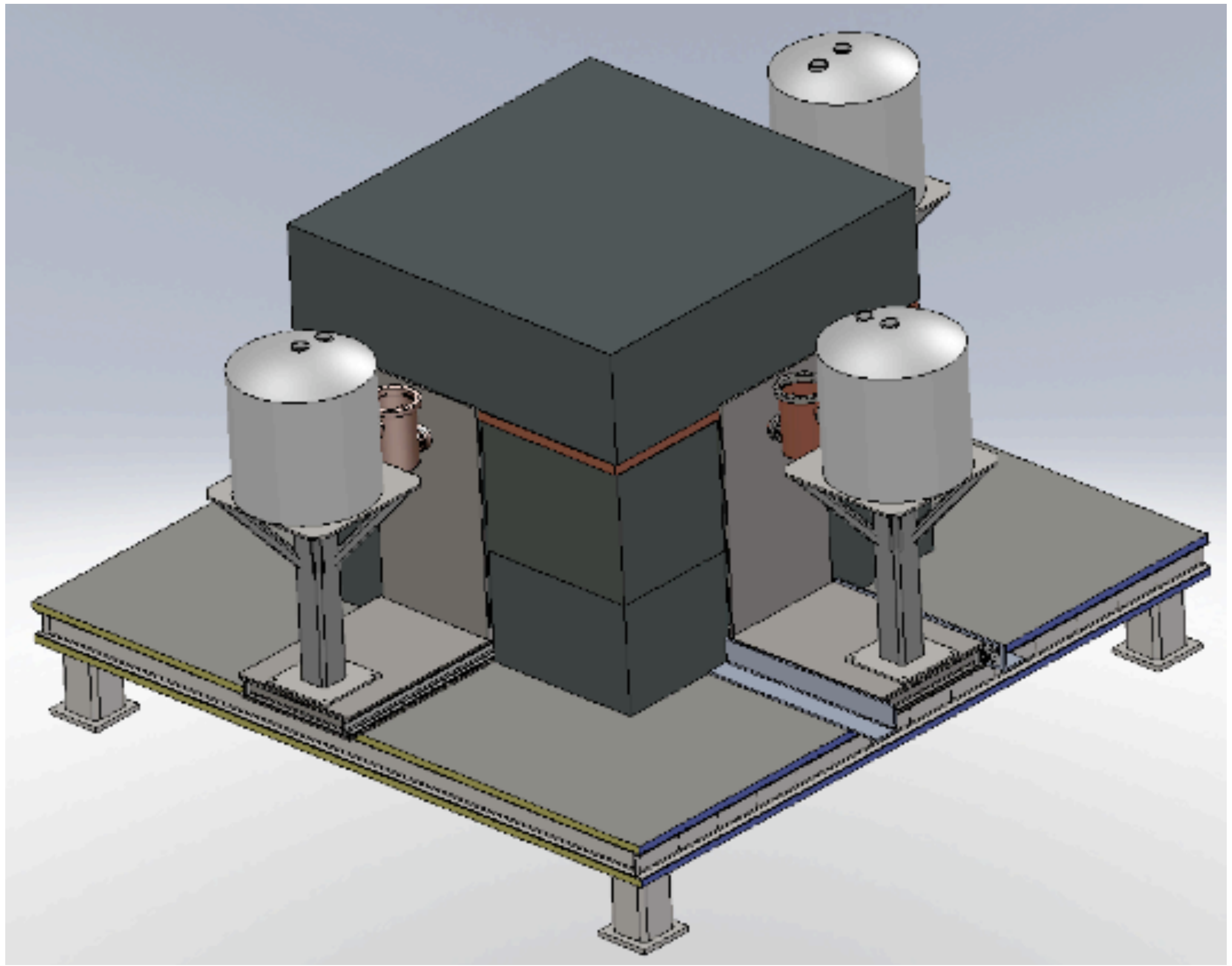
- Open exchange of knowledge and ideas (e.g. MaGe MC)
- Intend to merge for 1-ton experiment using the best techniques

The MAJORANA DEMONSTRATOR

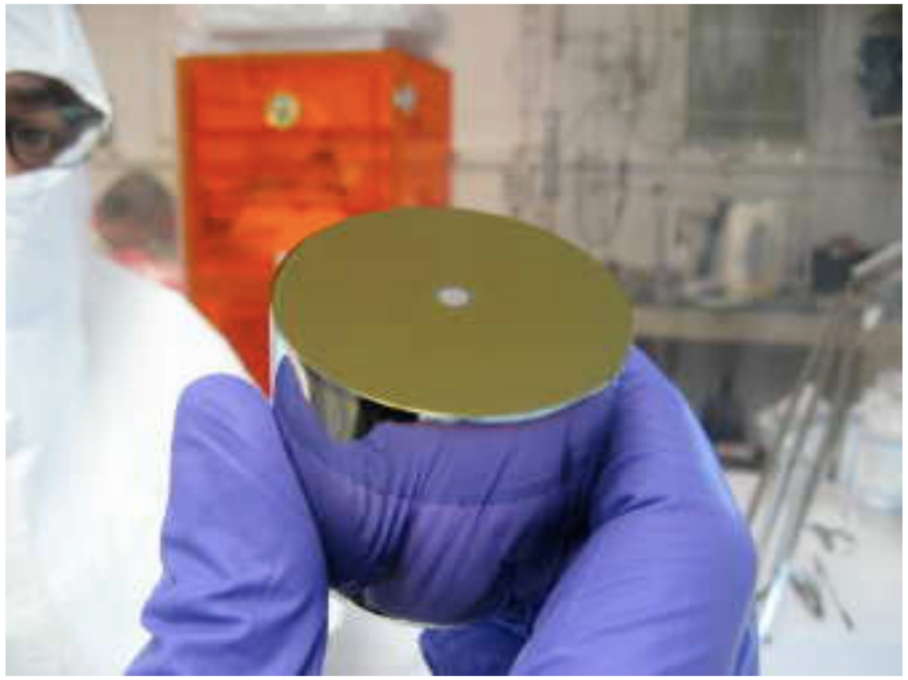
- 60-kg of Ge detectors required for sensitivity to background goal: 1 c/ROI/t/y
- 30-kg of 86% enriched ^{76}Ge crystals required for science goal: test the Klapdor-Kleingrothaus *et al.* claim
- Examine detector technology options: p-type point-contact detectors
- Initial module will have 3 cryostats; fast track 1st module thanks to institutional support
- Located underground at the 4850' level of Sanford Lab.

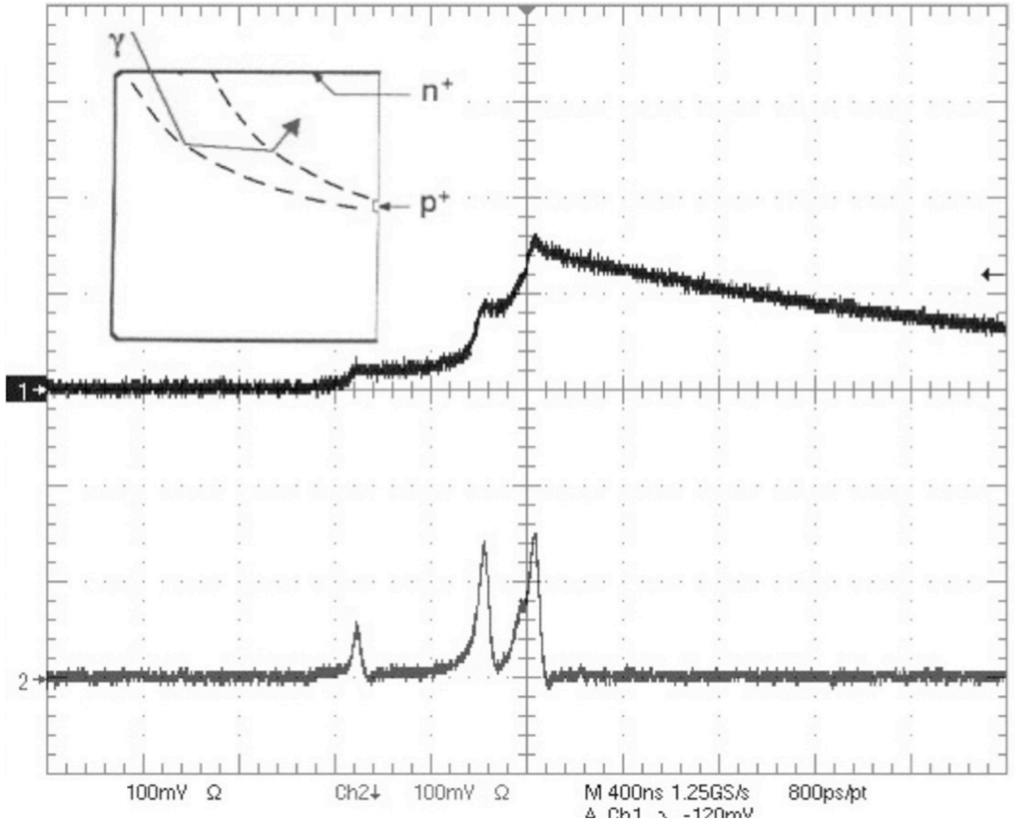




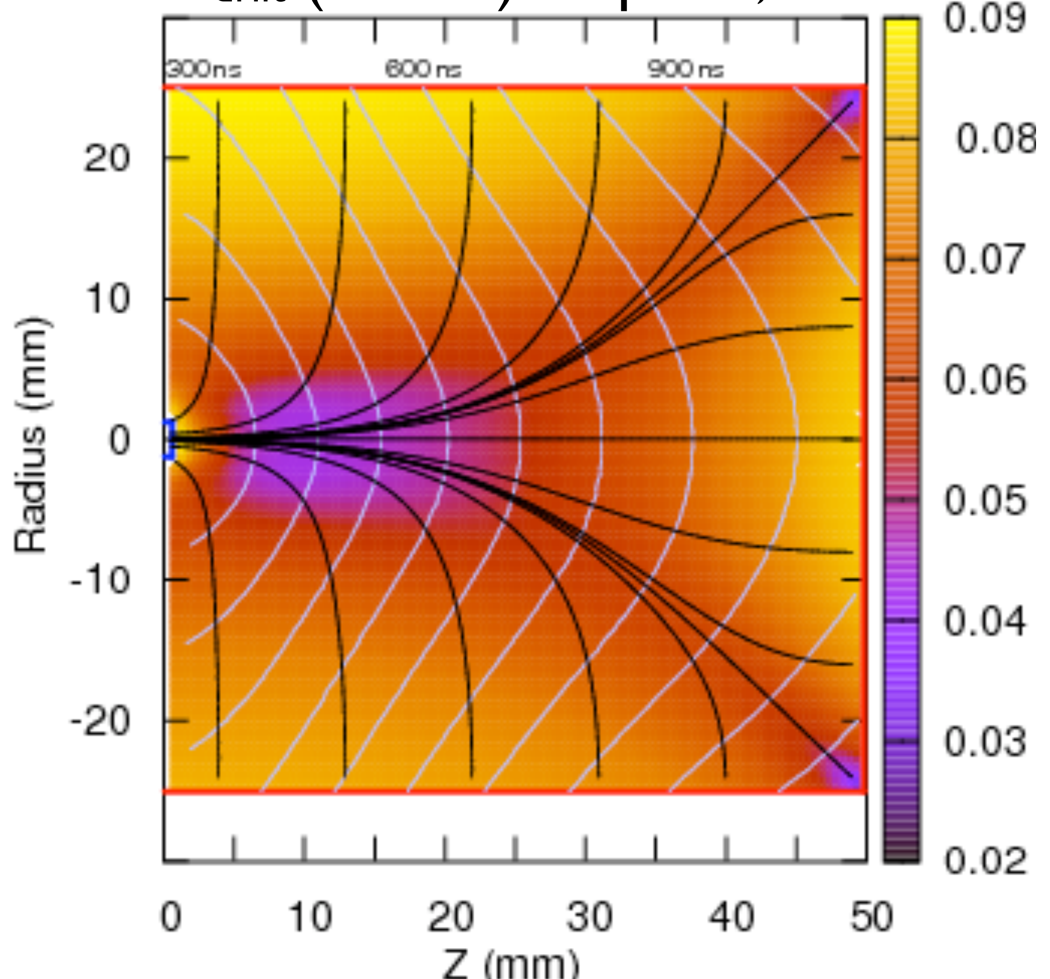


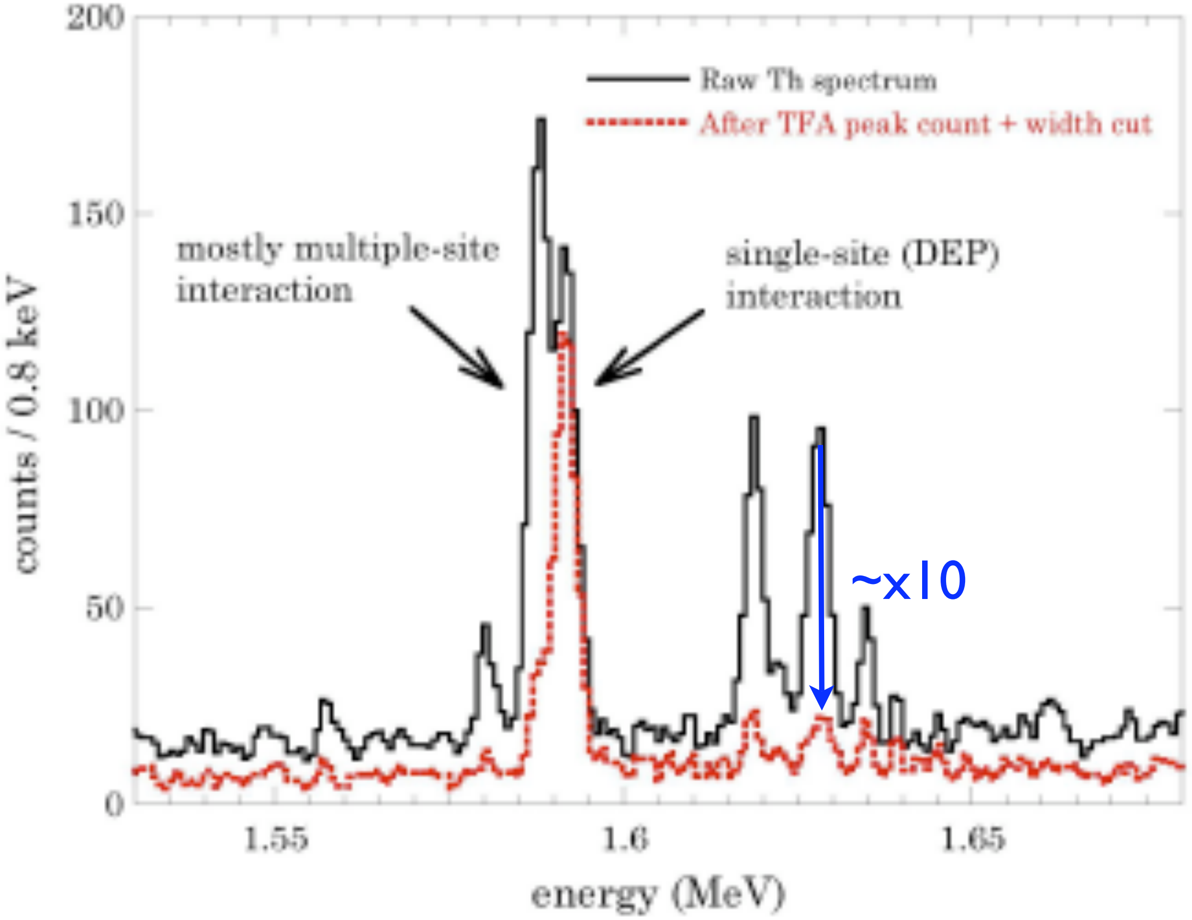
Point Contact Detectors





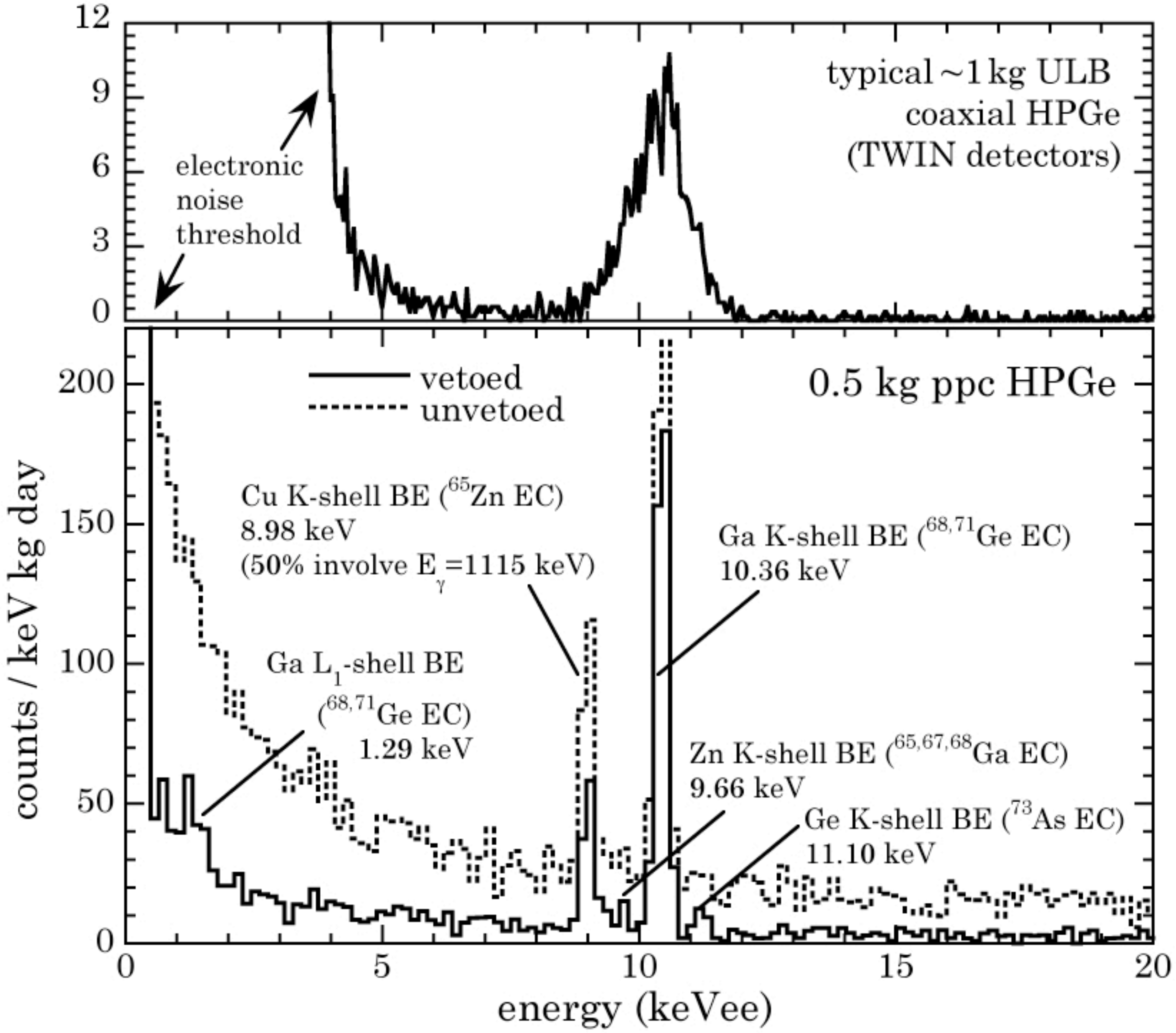
Hole v_{drift} (mm/ns) w/ paths, isochrones

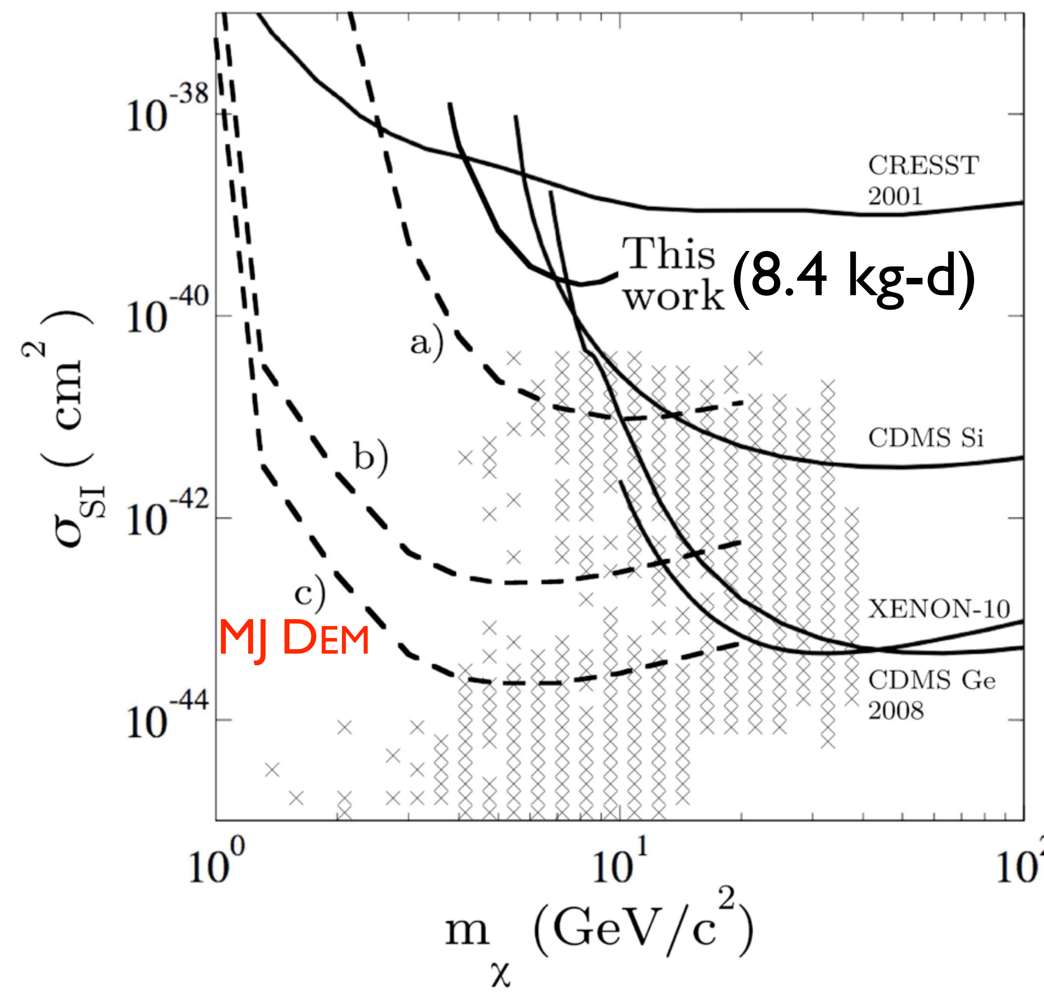


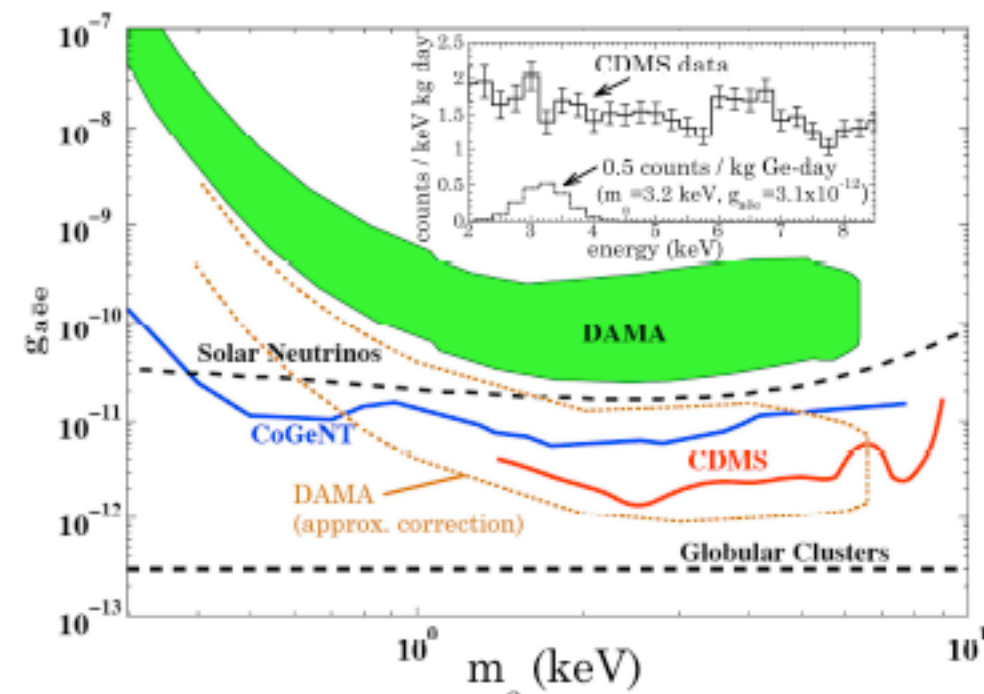


Barbeau et al., JCAP 09 (2007) 009; Luke et al., IEEE trans. Nucl. Sci. 36 , 926(1989).

Point Contact Detectors







- CvNS (Reactor, SN, solar ν...)
- DM (light/slow WIMPs, Q-balls)
- Axions
- e⁻ decay

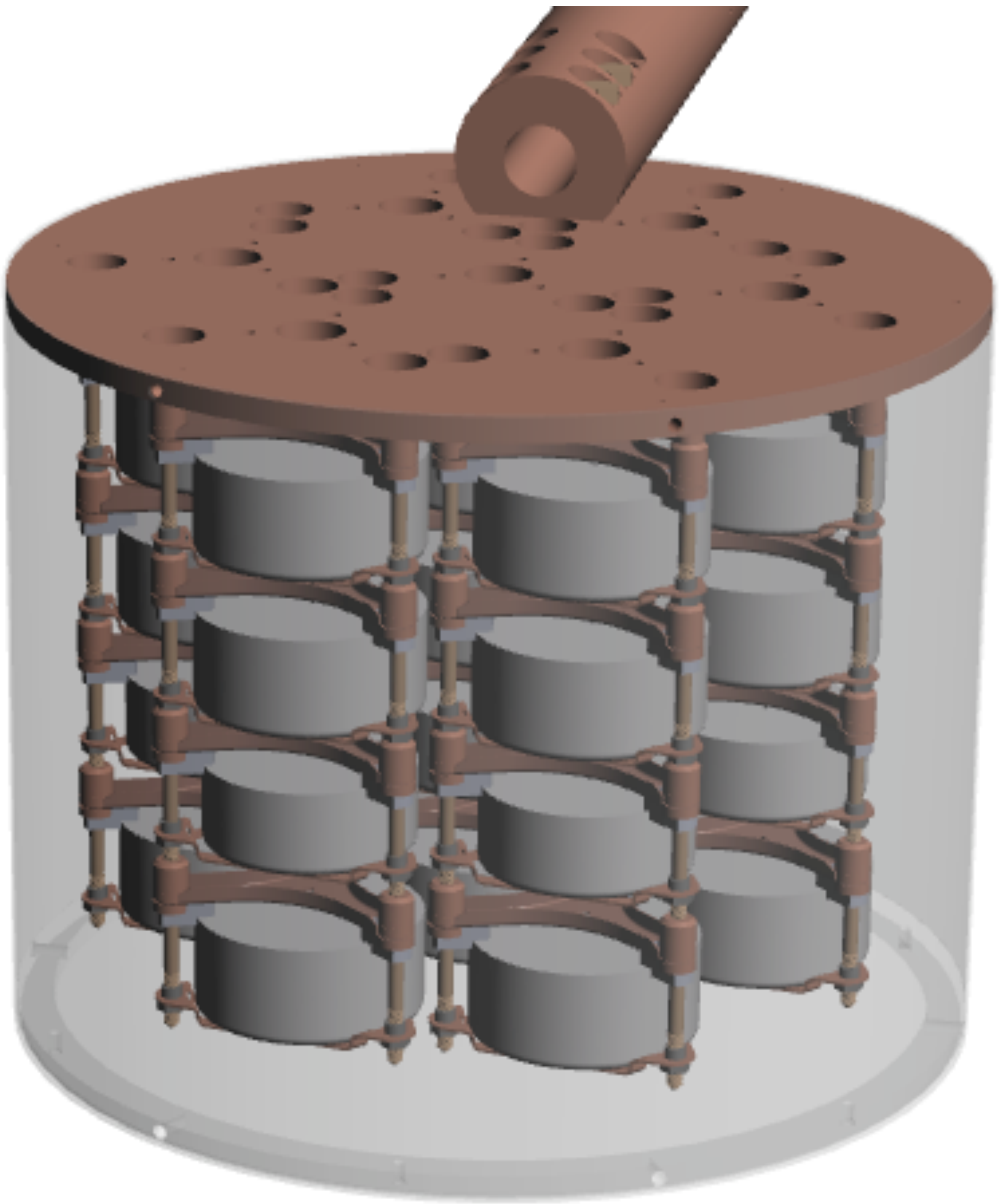
C. E. Aalseth *et al.*, Phys. Rev. Let. **101**, 251301 (2008); Z. Ahmed *et al.*, arXiv:0902.4693 [hep-ex], J.I. Collar and M. G. Marino, arxiv:0903.5068 [hep-ex]

PPCs Studied / In Hand

Institution (Detector Name)	Dimensions	Mass	Resolution (1.33 MeV)	Manufacturer (Crystal Grower)	Impurity Gradient
U Chicago (PPC I)	50 mm Ø x 44 mm	460 g	1.82 keV	Canberra	2.8
PNNL (PPC II)	50 mm Ø x 50 mm	527 g	2.15 keV	Canberra	1.6
LBNL (SPPC)	62 mm Ø x 44 mm	800 g	2.11 keV	LBNL (AMETEK)	1.7
LANL (MJ70)	72 mm Ø x 37 mm	800 g	2.15 keV	PHD's (UMICORE)	0.8
ORNL (MJ60)	62 mm Ø x 46 mm	740 g	4-4.5 keV	PHD's (UMICORE)	1.2
U Chicago (BEGe)	"standard"	450 g	<2 keV	Canberra	
LBNL (Mini-PPCs)	20 mm Ø x 10 mm	17 g		LBNL (AMETEK)	
ORNL (Big BEGe)	90 mm Ø x 25 mm	850 g	1.95 keV	Canberra	
LANL (MJ BEGes)	70 mm Ø x 30 mm	579 g	<2.2 keV	Canberra	
LANL	60 mm Ø x 50 mm	770 g		ORTEC	

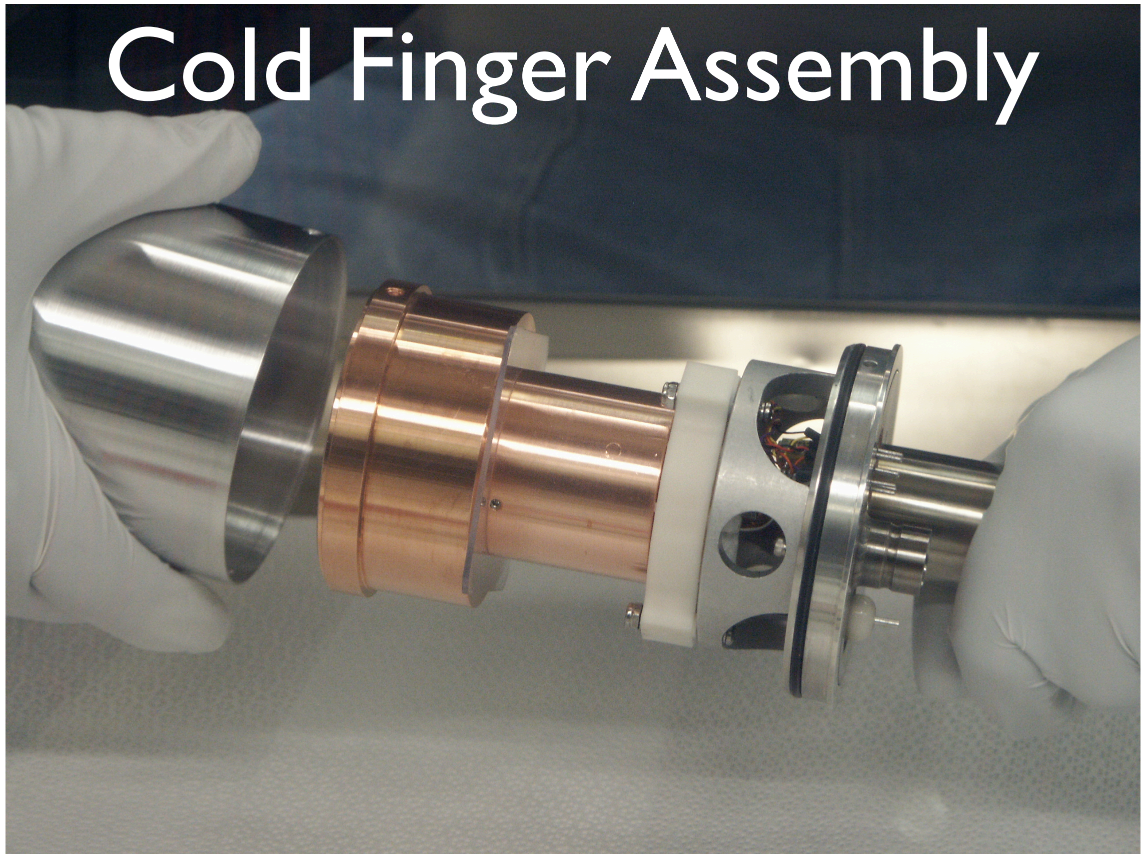
First Module

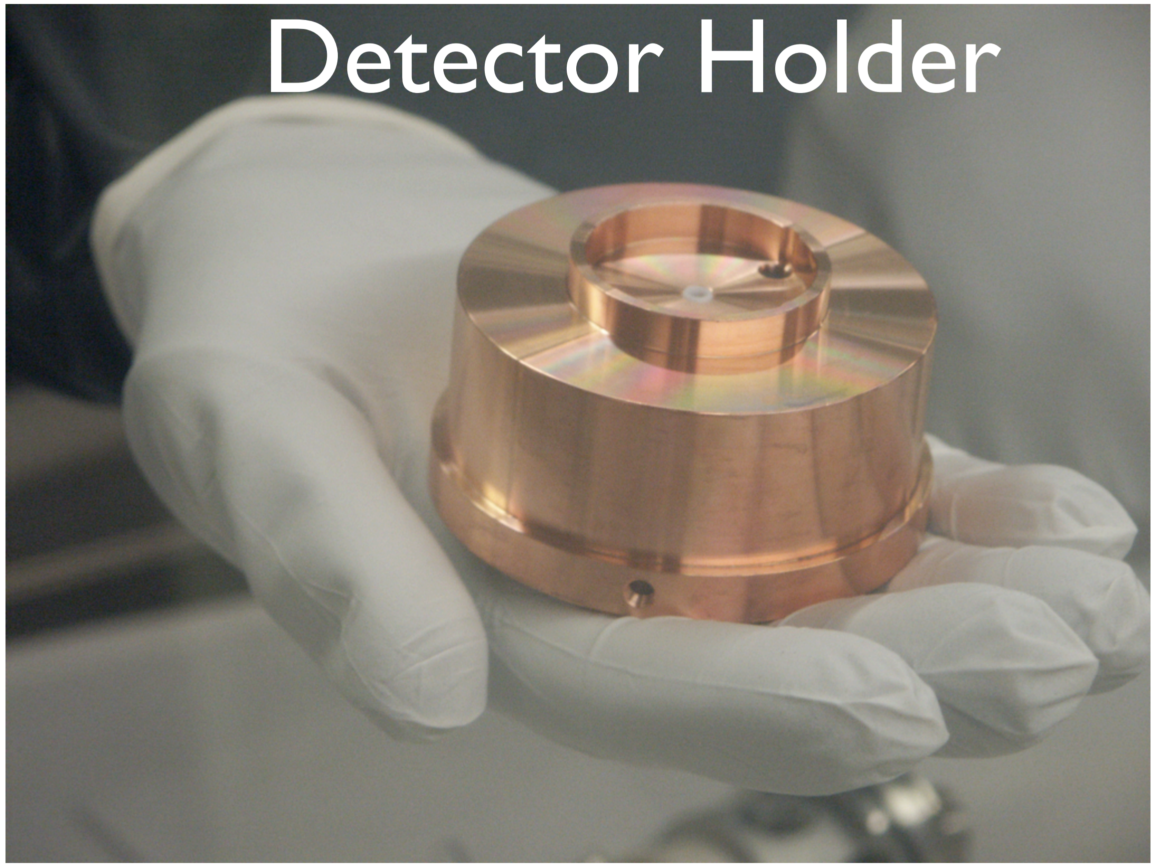
- 18 natural-Ge Canberra BEGe's
  - ∅ = 70±2.5 mm, h = 30±2.5 mm
  - 579 g active mass
  - contact r < 6.5 mm (5 mm nom.)
  - Front surface metalized for HV
  - ~4 crystals per string
- Full scale demonstration of MAJORANA configuration
- Start counting $0\nu\beta\beta$ backgrounds
- Low-E physics



The First 18 BEGes

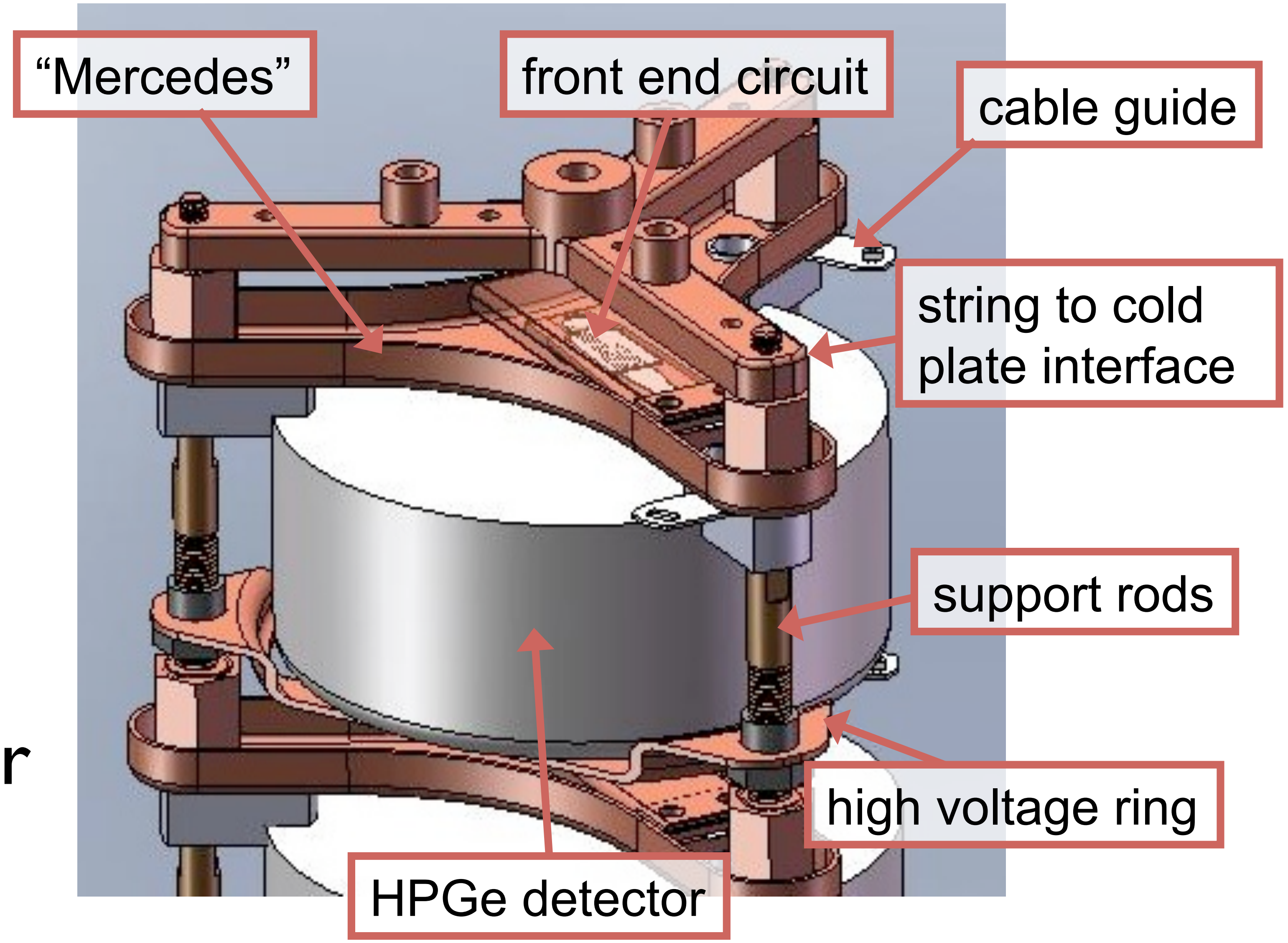
- 17 detectors delivered, accepted; 1 returned for refurbishment
- Storage system fabricated and used
- See talk by Gehman (DJ1)





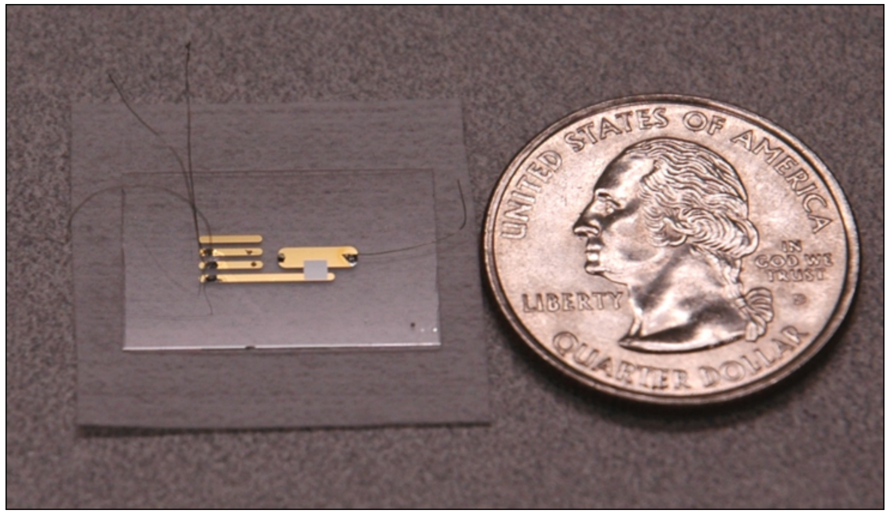
Detector Mounts

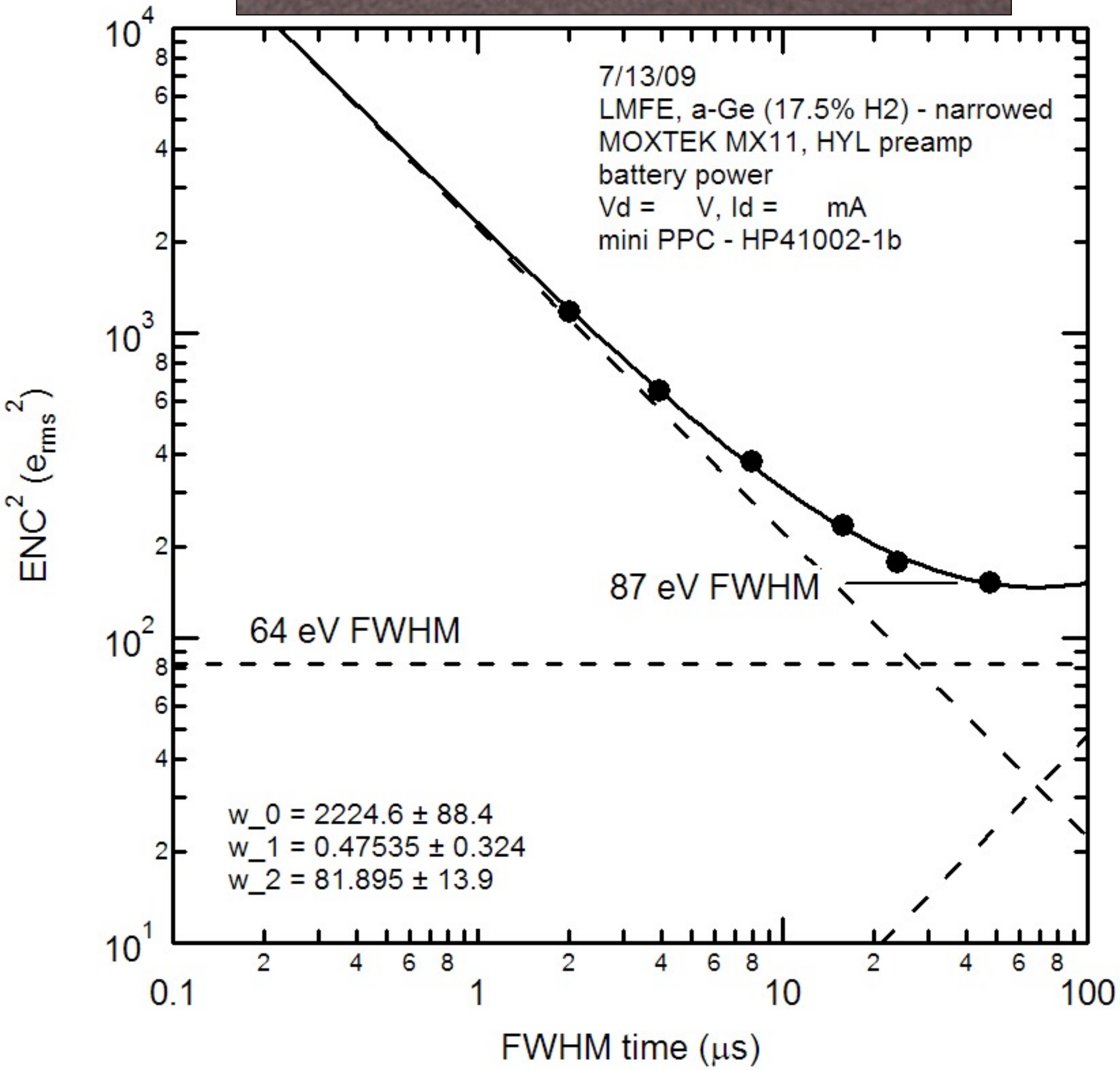
- EFCu and plastic, minimizing part count
- Thermally shorted to coldplate
- HV on outer contact; possibly integrated filter capacitor



- Contact spring integrated into mount or front end board
- Currently iterating design and prototyping

Front Ends: Resistive Feedback

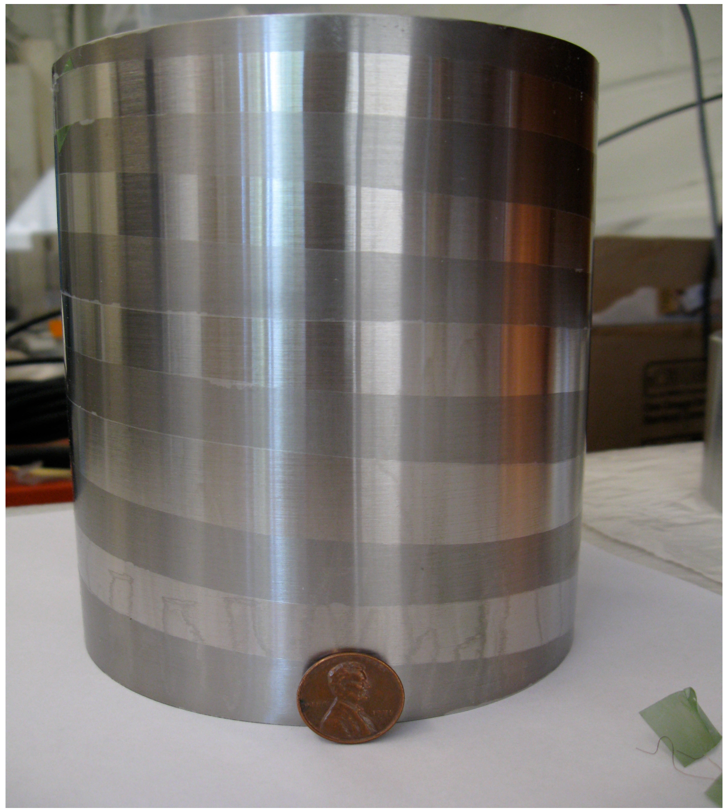


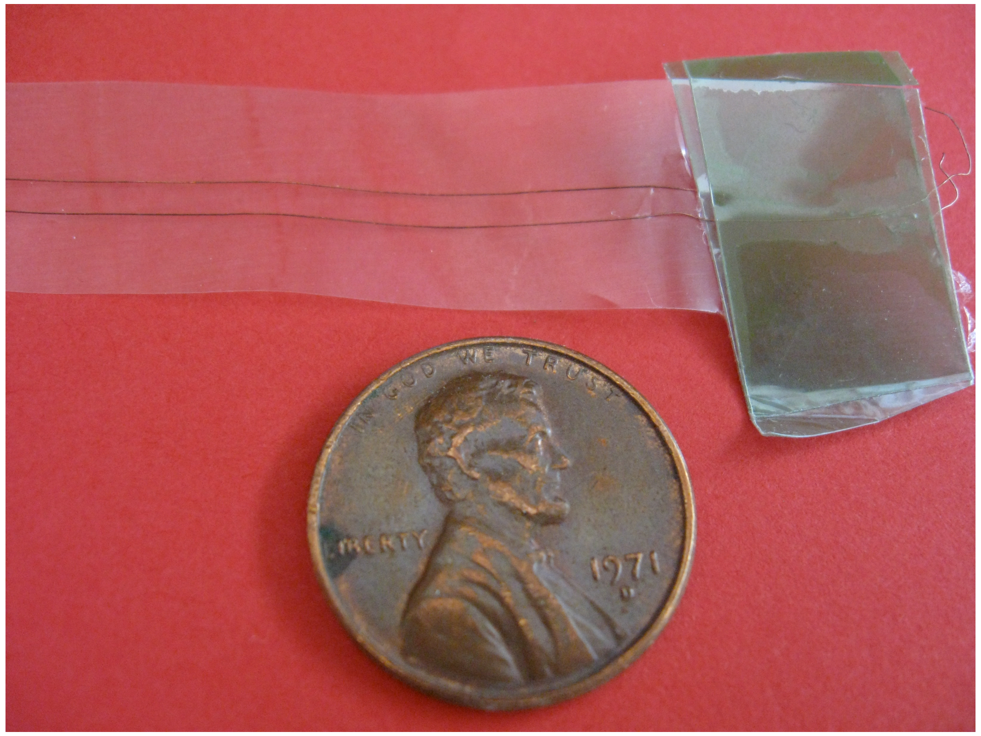


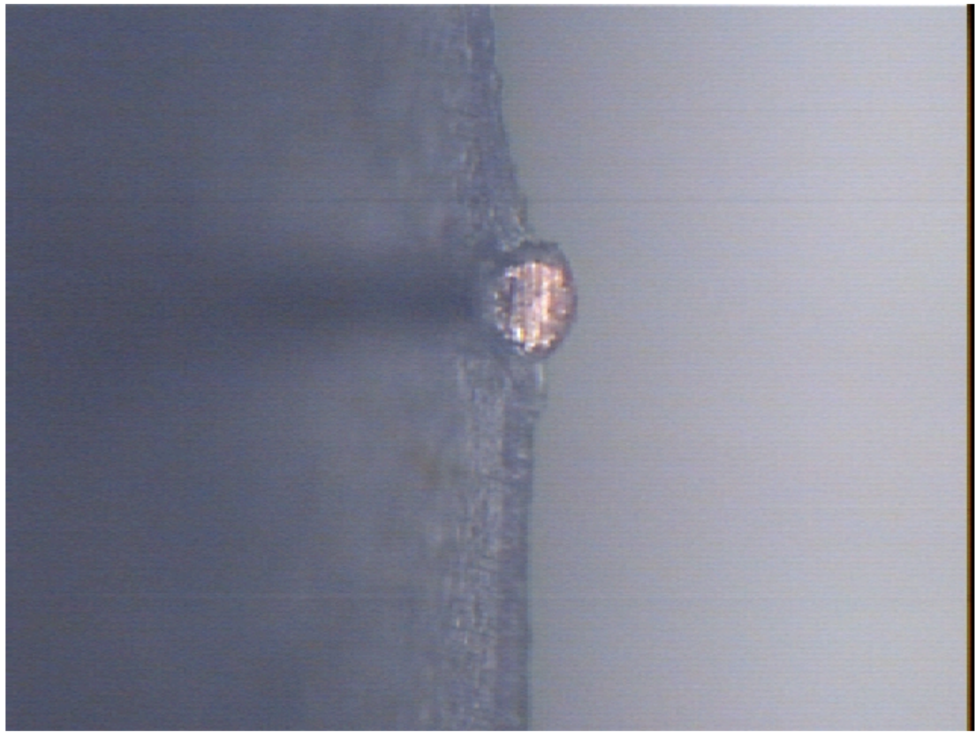
- Trace proximity provides ~1 pF capacitance
- Silica or sapphire substrate provides thermal control
- Amorphous Ge resistor: deposit in H environment gives proper R at low T
- MX-11 FET, custom low-noise preamp
- Have achieved possibly world record low-noise for this kind of circuit

Cables

- Parylene coated extruded Cu flex cables
- Other options: picocoax, CuFlon / PEN / Kapton-based flex cables, parylene-coated twisted pairs
- Cable connection options: wire (fusion) bond, dimpled pressure connection, conducting adhesive, e-beam welding

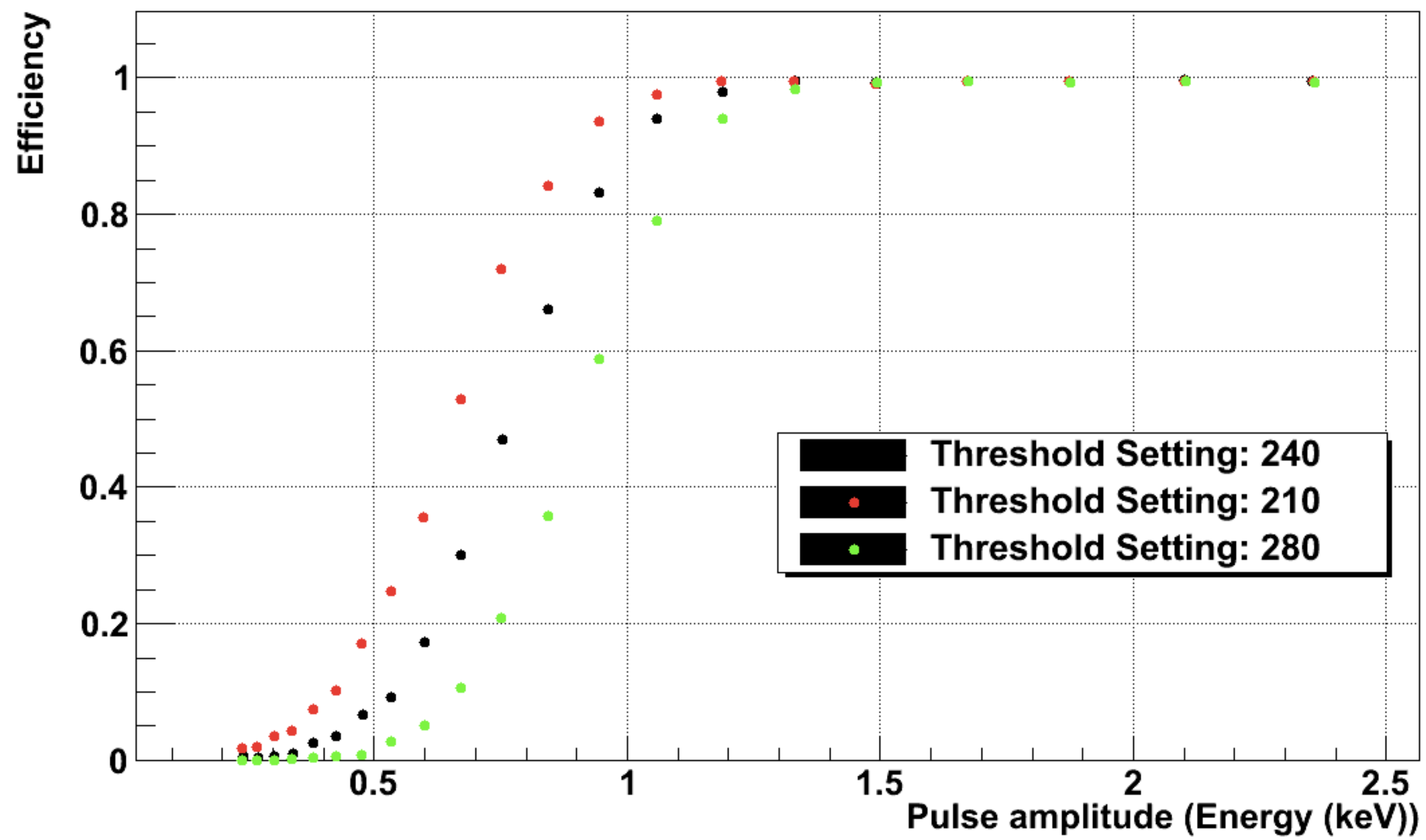


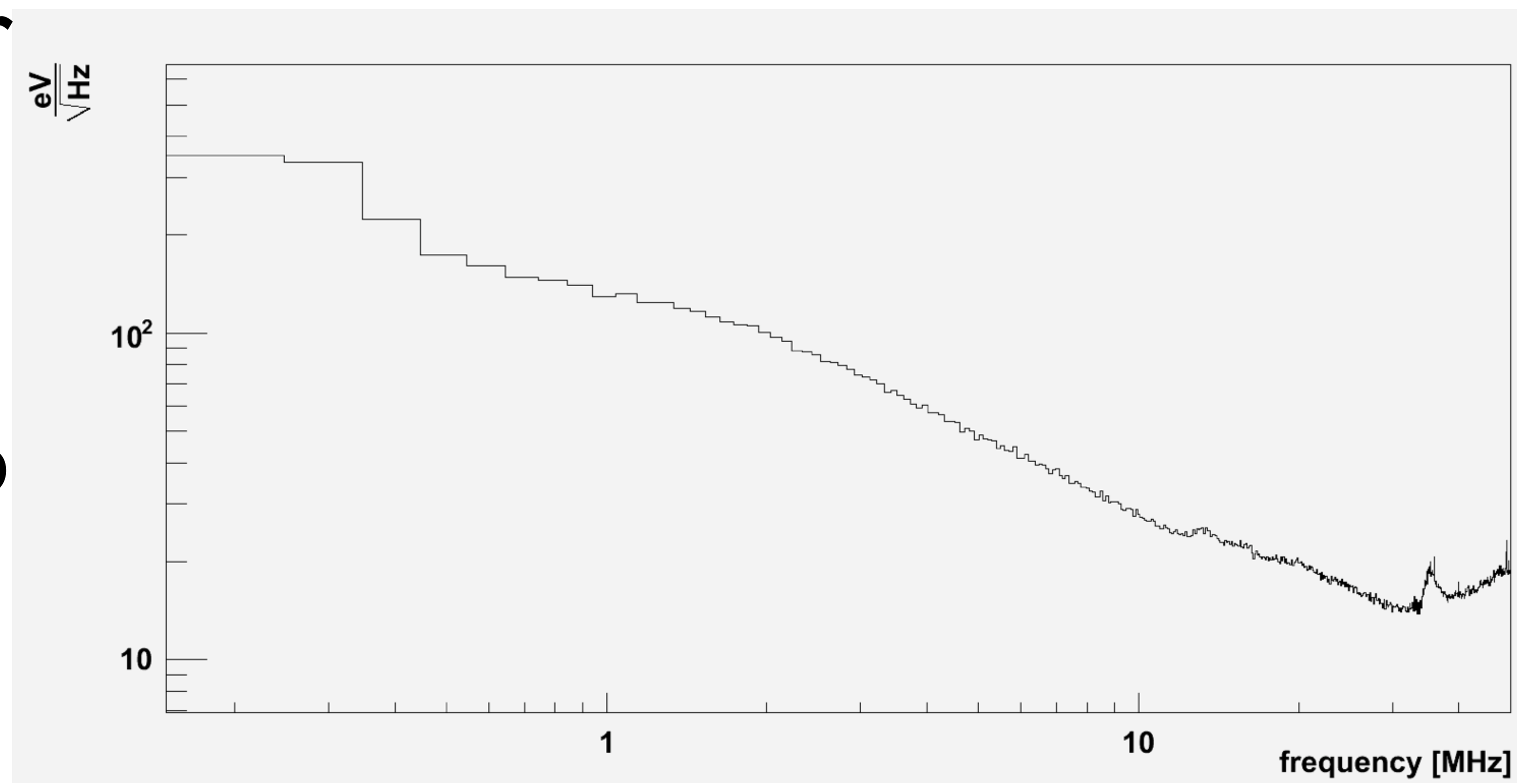




DAQ

- Investigating noise / triggering at low-E
- Upgrade GRETINA card FPGA to increase integration time, trigger off of energy
- Exploring SIS alternatives as a backup

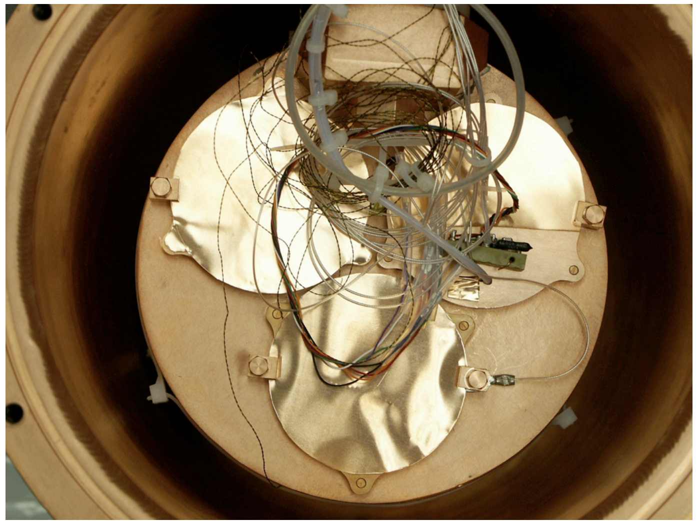


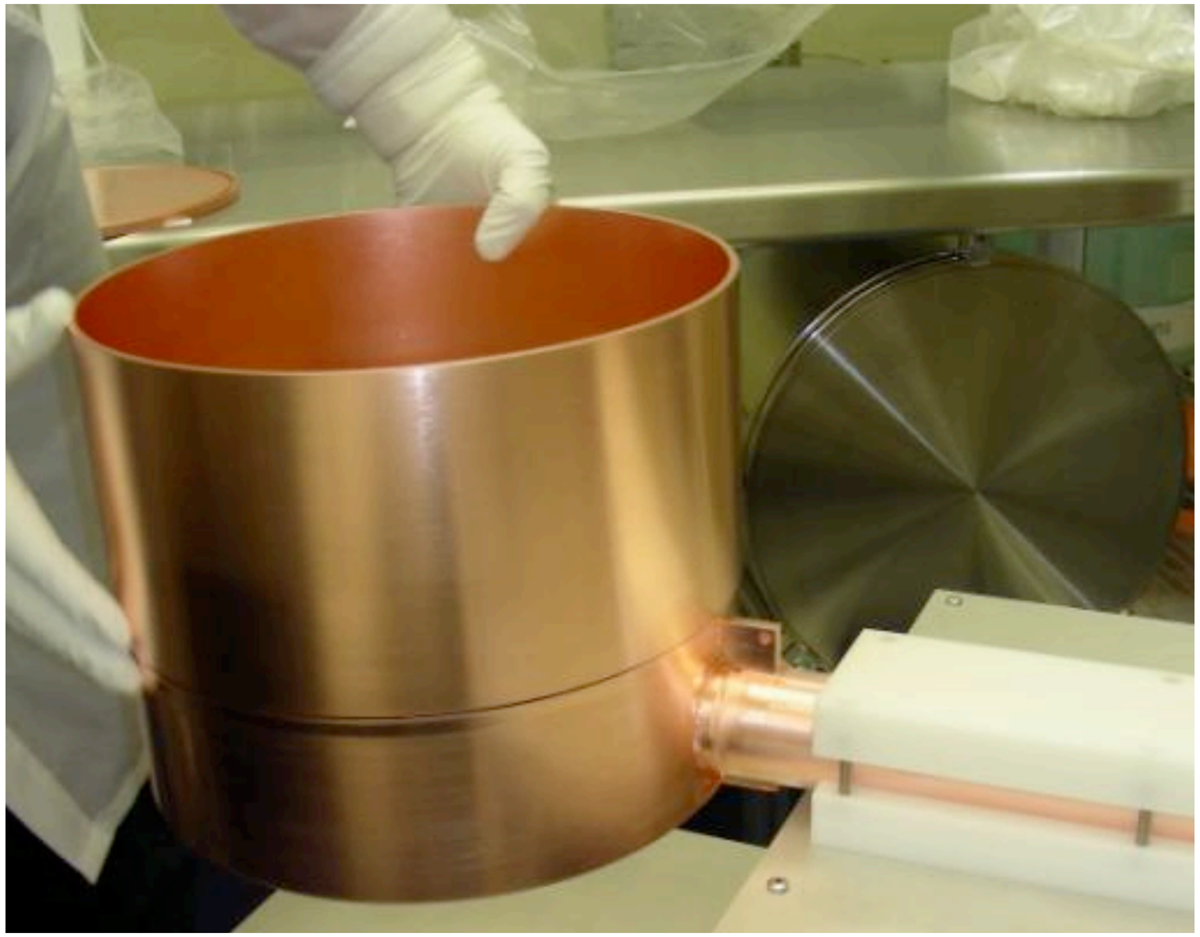


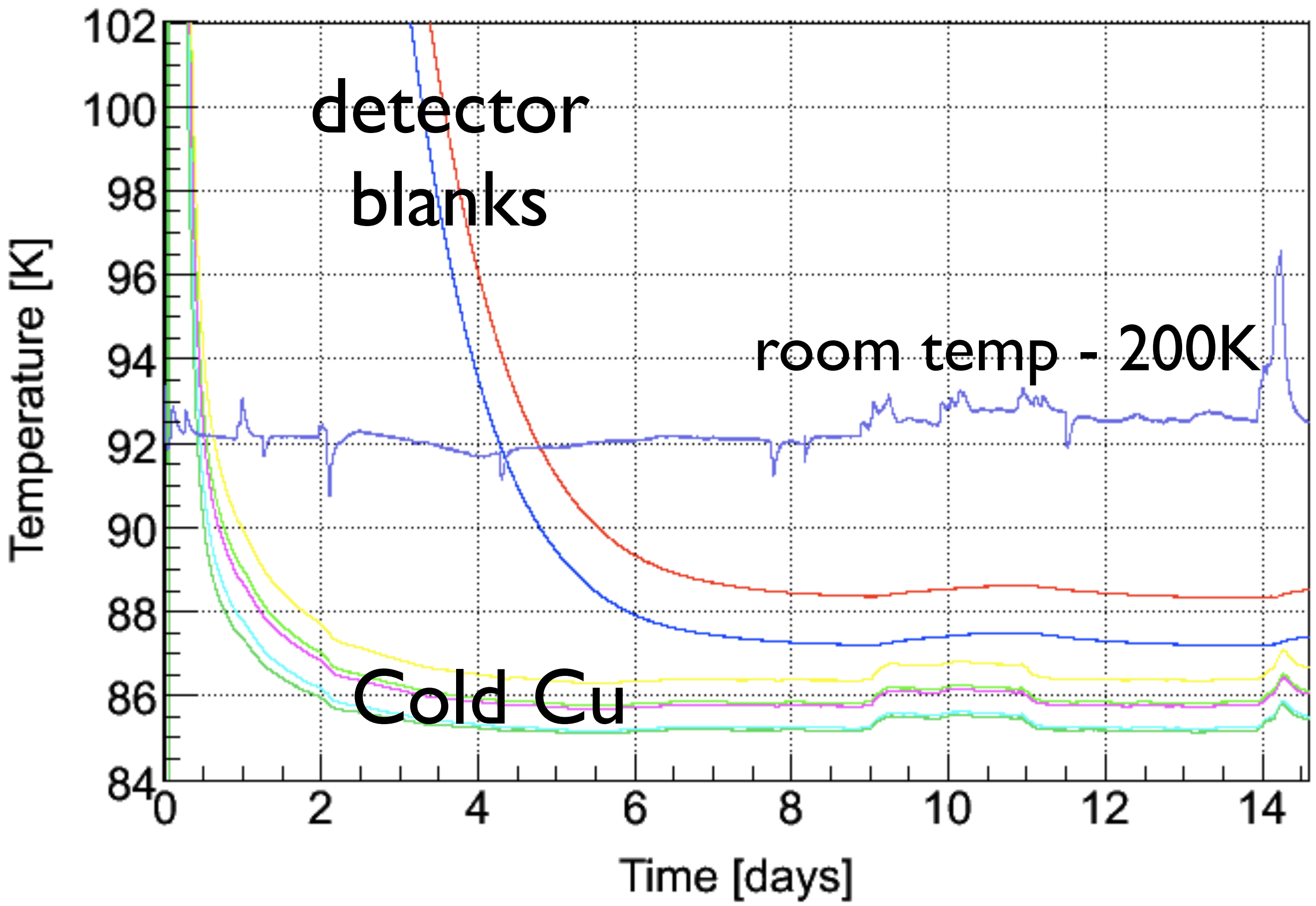
Cryostat

- Coldplate / cryostat design and prototyping underway
- Thermal / mechanical / electrical testing and integration in the LANL Canary Cage

Canary Cage

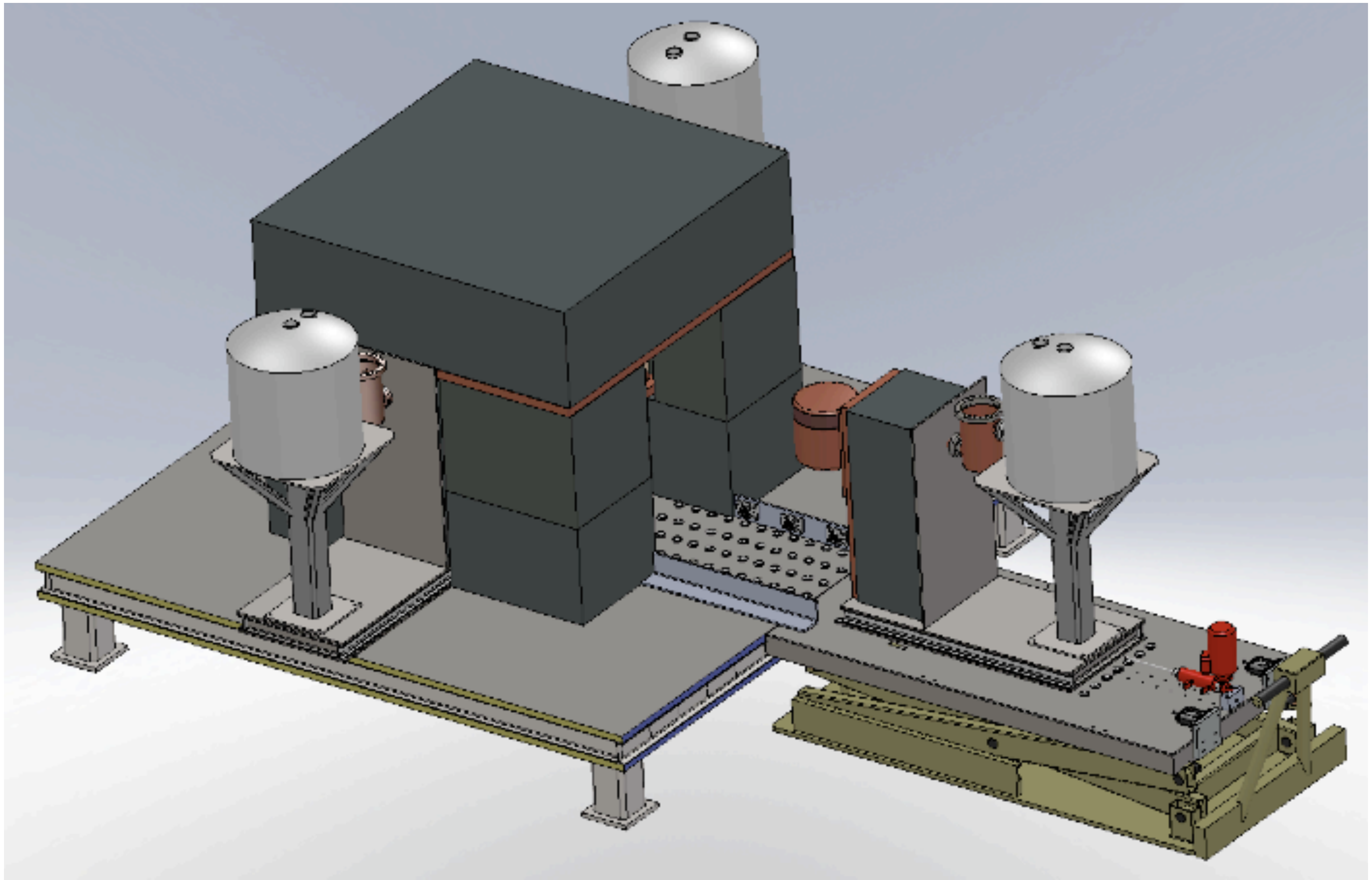






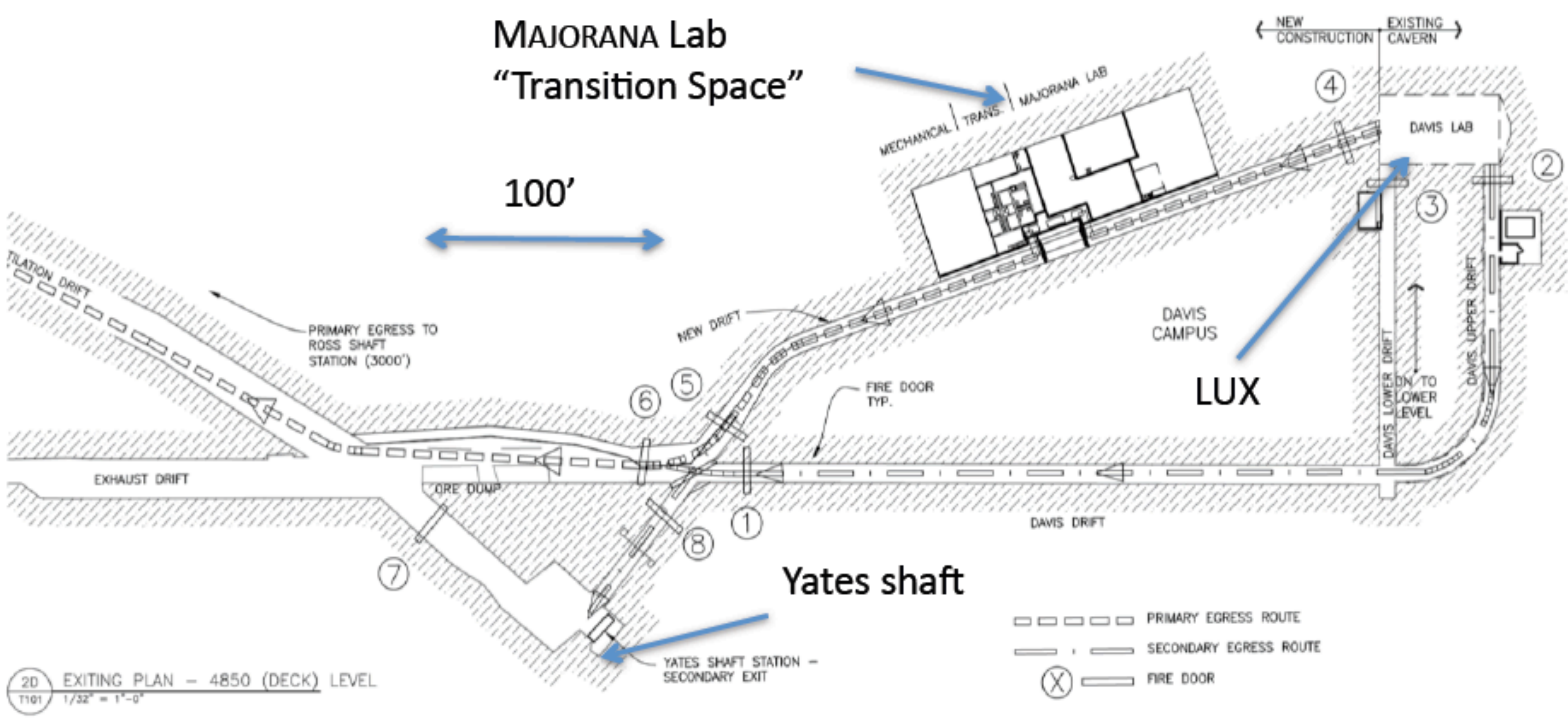
Mechanical Systems

- Shield and monolith engineering underway
- 86% of Pb is in hand



Site Facilities

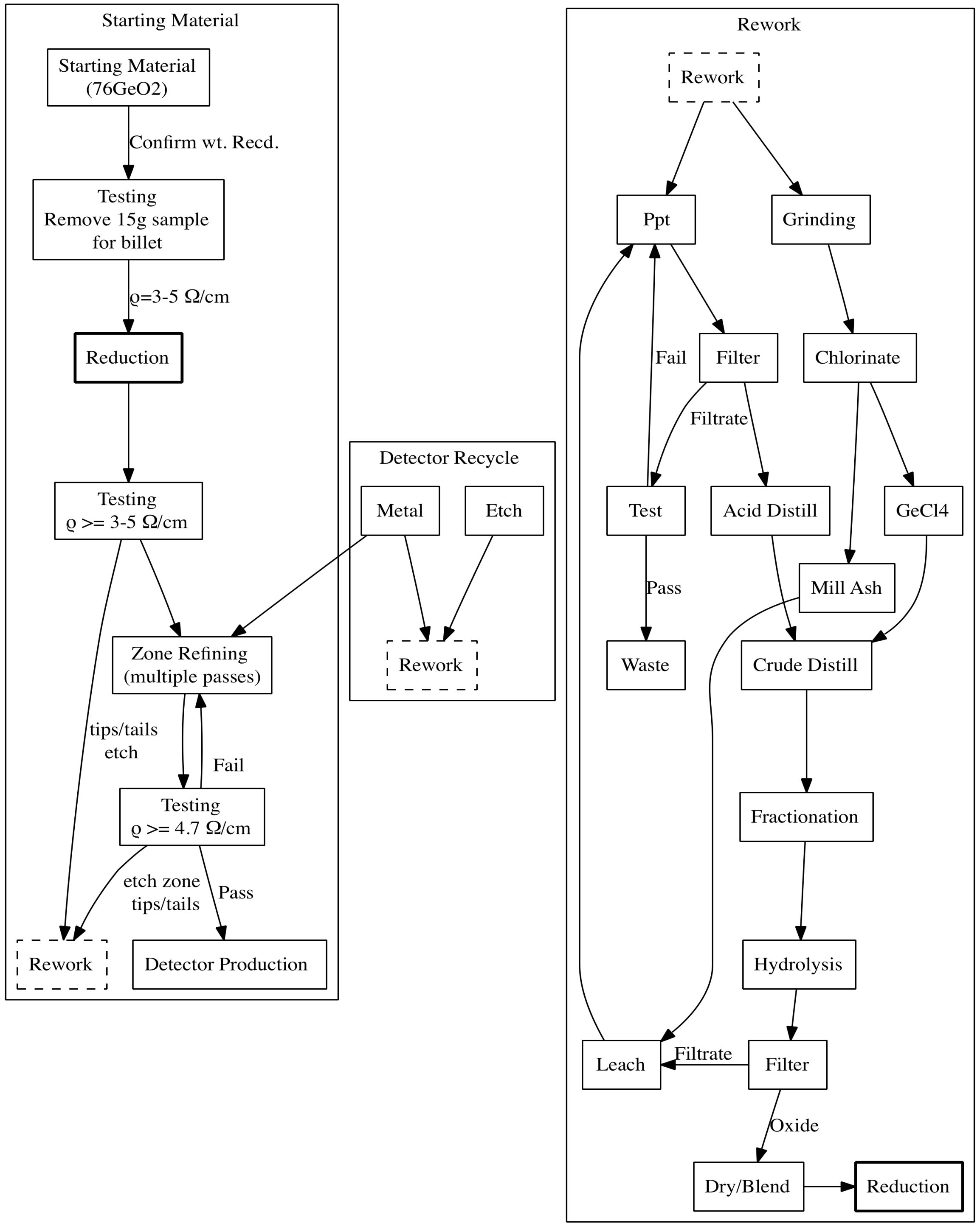
- Current layout: EFCu, detector facilities, and machine shop in one campus at 4850’ level in new drift to Davis cavity (LUX)
- Excavation underway; beneficial occupancy anticipated April 2010
- Temporary lab for EFCu starting Jan 2010, funded by NSF



Davis Campus, 4850’ level, near Yates shaft

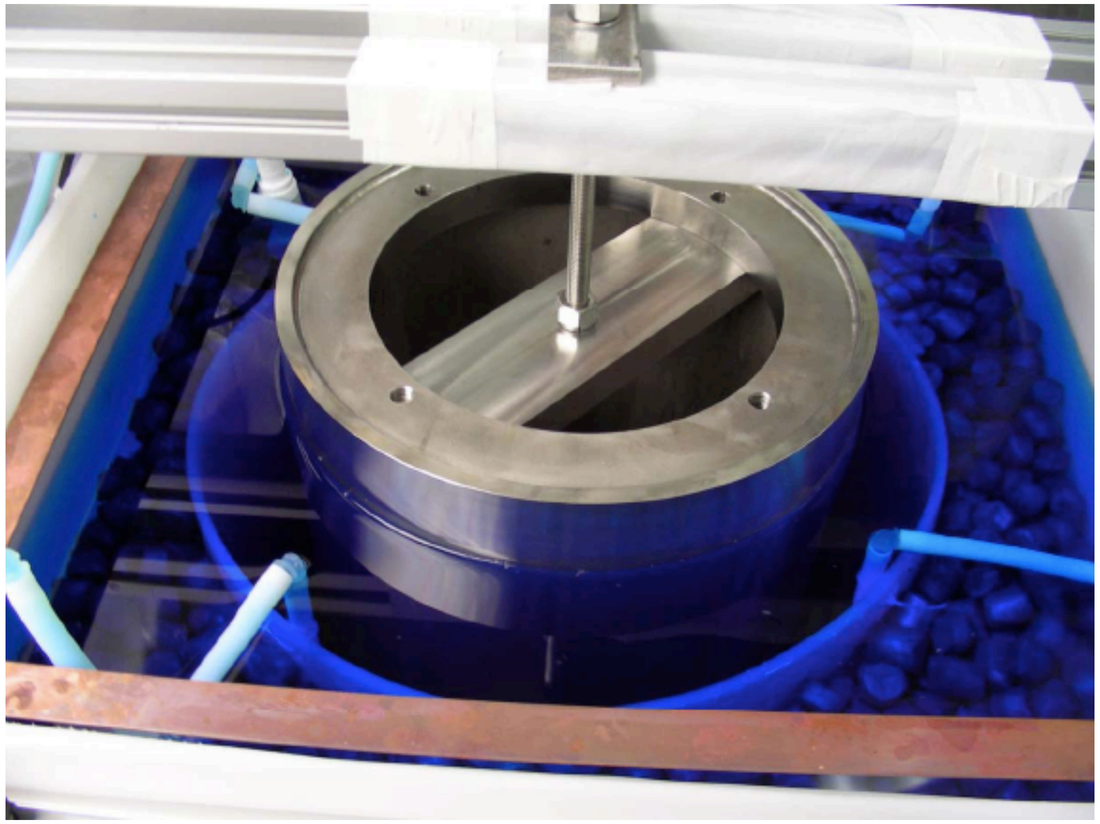
Enriched Germanium

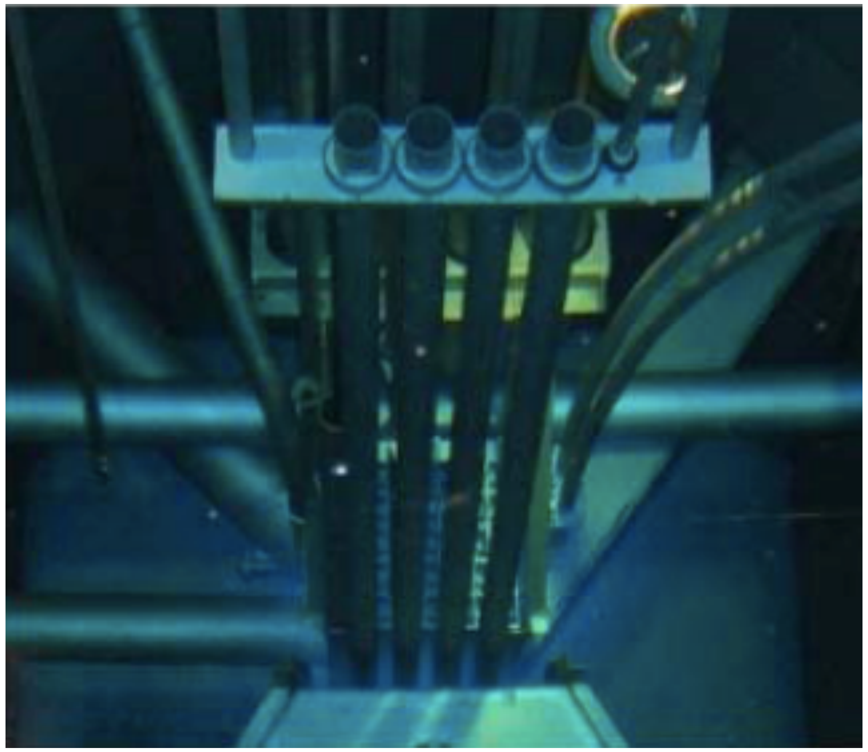
- UMICORE not interested in processing enriched Ge
- Fully costed plan to establish a small processing facility in Oak Ridge. Working with contractor team
- USD received SD funding for a UG crystal pulling lab
- Continue to monitor alternative enrichment methods, but gas centrifuge is still (highly) favored



Materials and Assay

- Campaign to further reduce limits on backgrounds in EFCu (previous best: ~0.7 µBq/kg ^{232}Th, addressing bath purity)
- Procured enough NXT-85 plastic for detector supports; verified purity via INAA
- Cables and electronics materials screening by ICPMS in Russia (now)
- Most Pb in-hand, gamma counting / ICPMS program planned.

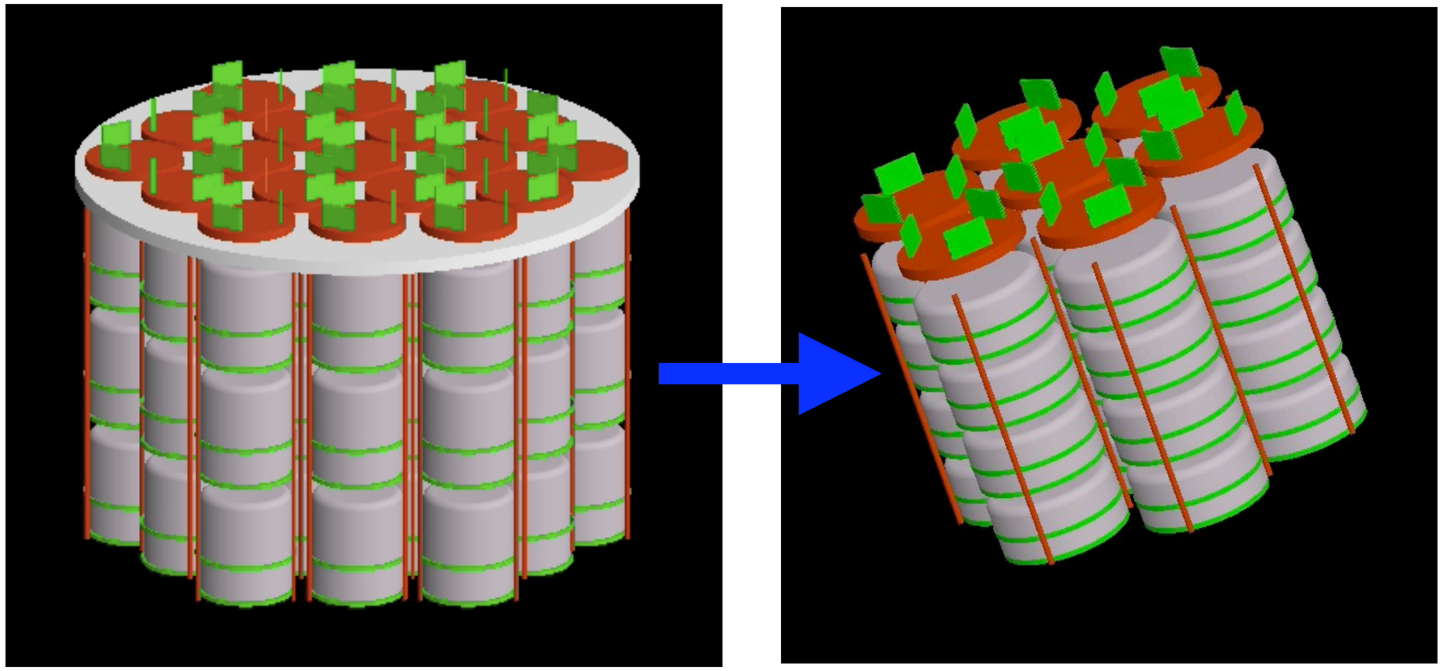




Materials Specifications

Material	Uses	Contaminant Goals	Equivalent Achieved Assay	Reference
Germanium	Detectors	<100 days ^{68}Ge exp. <30 days ^{60}Co exp.	N/A	[Avi92]
Electroformed Copper	Detector Mounts, Cryostat, Inner Cu Shield	<0.1 μBq/kg ^{208}Tl <0.3 μBq/kg ^{214}Bi	0.2 ± 0.1 μBq/kg	[Hop09]
Commercial Copper	Outer Cu Shield	<0.3 μBq/kg ^{208}Tl <3 μBq/kg ^{214}Bi	<0.3 μBq/kg <36 μBq/kg	[Hop09], [Leo08]
Lead	Lead Shield	<1 μBq/kg ^{208}Tl <10 μBq/kg ^{214}Bi	<1 μBq/kg <10 μBq/kg	[Leo08]
Plastic	Detector Mounts, Insulation	<0.4 μBq/kg ^{208}Tl <10 μBq/kg ^{214}Bi	<0.4 μBq/kg <10 μBq/kg	[Bac09], [Leo08]
Small Components	Front-End Electronics, Contacts	<3 nBq/chan. ^{208}Tl <20 nBq/chan. ^{214}Bi	<3 nBq/chan. <20 nBq/chan.	[Loa09], [Leo08]
Cables	Signal, High-Voltage	<30 μBq/kg ^{208}Tl <160 μBq/kg ^{214}Bi	<30 μBq/kg <160 μBq/kg	[Det08], [Hop09], [Leo08]

Background Model



- Updates from 2006:
  - Lower granularity (x2)
  - Internal front-ends
  - Increased internal Cu
  - Backgrounds from new components / materials
- Background Simulation Campaign: Winter 2009-2010
  - DEMONSTRATOR geometry
  - Full-spectrum background model
- Low-Energy Backgrounds:
  - Cosmogenics (Ge isotopes, ^{65}Zn, ^{73}As, ^{3}H...)
  - Low-E compton from U, Th, K
  - ^{210}Pb bremsstrahlung
  - ... learn more with the MJDEM.

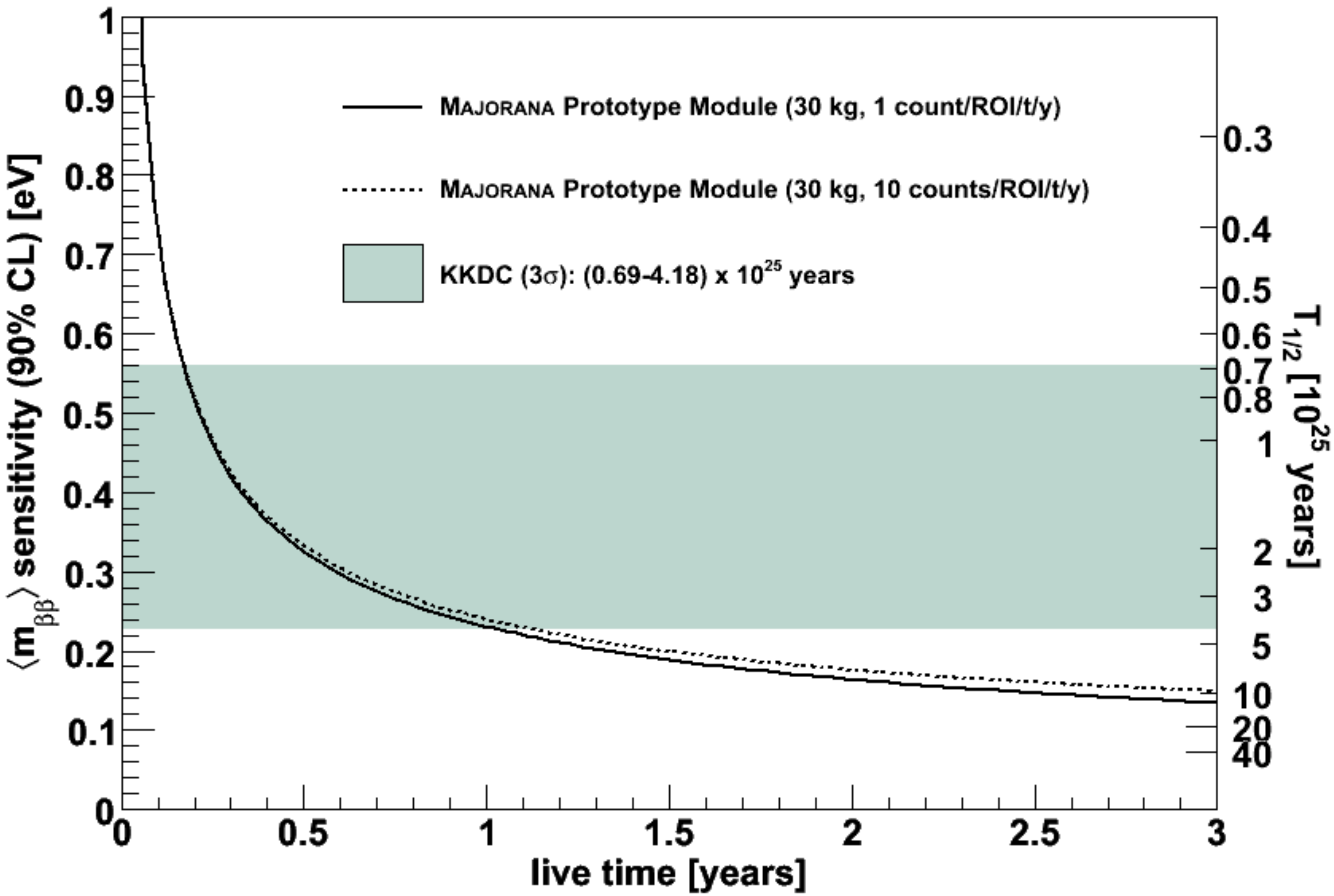
Background Budget (cont.)

Background Source	Radioactive Isotope [counts/ROI/t/y]			Total Background [c/ROI/t/y]
Enriched Germanium Crystals	**^{68}Ge**	**^{60}Co**	**^{232}Th/^{238}U**	0.92
	0.56	0.06	0.30	
Natural Germanium Crystals	**^{68}Ge**	**^{60}Co**	**^{232}Th/^{238}U**	77
	~75	~2	0.3	
Detector Mounts	**^{208}Tl**	**^{214}Bi**		0.05
	0.03	0.02		
Front-Ends, Contacts	**^{208}Tl**	**^{214}Bi**		0.02
	0.01	7×10^{-3}		
Cables	**^{208}Tl**	**^{214}Bi**	**^{60}Co**	0.03
	0.02	7×10^{-3}	6×10^{-3}	

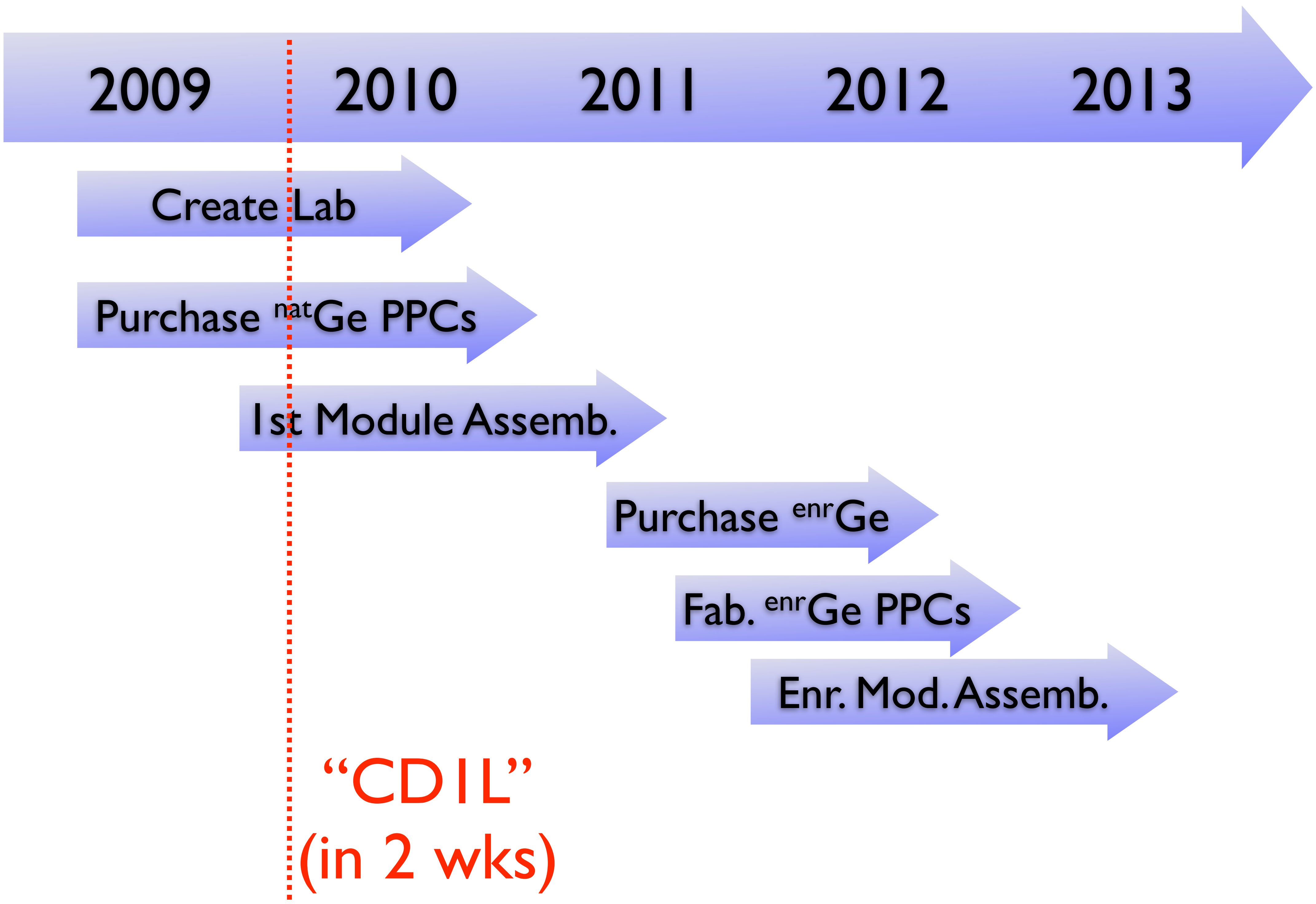
Background Budget (cont.)

Background Source	Radioactive Isotope [counts/ROI/t/y]			Total Background [c/ROI/t/y]
Cryostat and Inner Copper Shield	^{208}Tl	^{214}Bi		0.50
	0.37	0.13		
Outer Copper Shield	^{208}Tl	^{214}Bi	^{60}Co	0.20
	0.06	0.10	0.03	
Lead Shield	^{208}Tl	^{214}Bi		0.26
	0.10	0.16		
Prompt Cosmogenics	(n,n'γ)	Ge(n,n)	Direct μ, Other	~1
	~0.8	~0.1	~0.1	
Other	Surface α	External γ, (α,n)	$2\nu\beta\beta$, n, Other	0.16
	0.05	~0.1	~0.01	
			Total for enriched Ge:	3.2

DEMONSTRATOR Sensitivity



DEMONSTRATOR Schedule

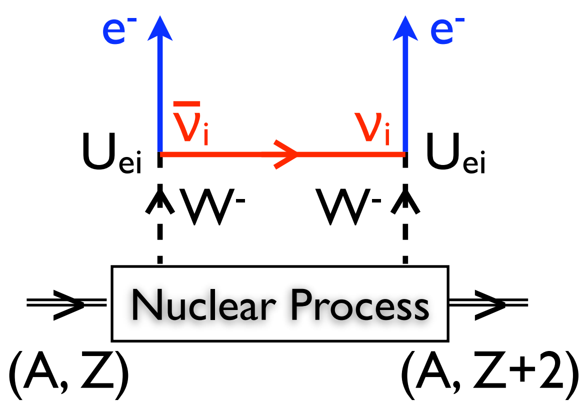


Summary

- Institutional support has propelled us into motion over the last year
- Making progress on technical designs, background goal
- On track for full DOE support starting this fiscal year

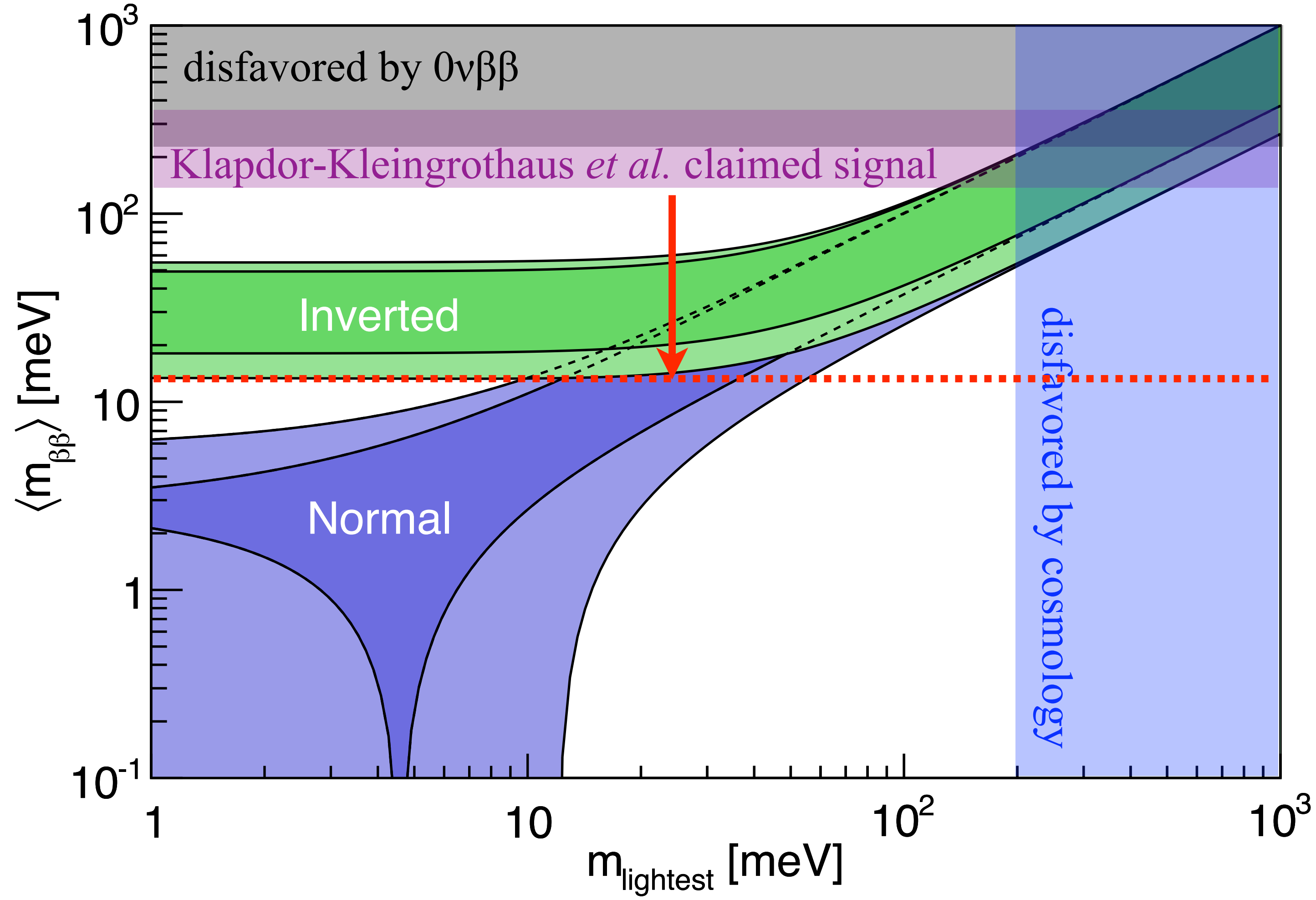
Extra Slides

Neutrinoless Double-Beta Decay



$$T_{1/2}^{0\nu} = \left(G^{0\nu} \, |M^{0\nu}|^2 \, \langle m_{\beta\beta} \rangle^2 \right)^{-1}$$

$$\langle m_{\beta\beta} \rangle \equiv \left| \Sigma \, m_i \, U_{ei}^2 \right|$$

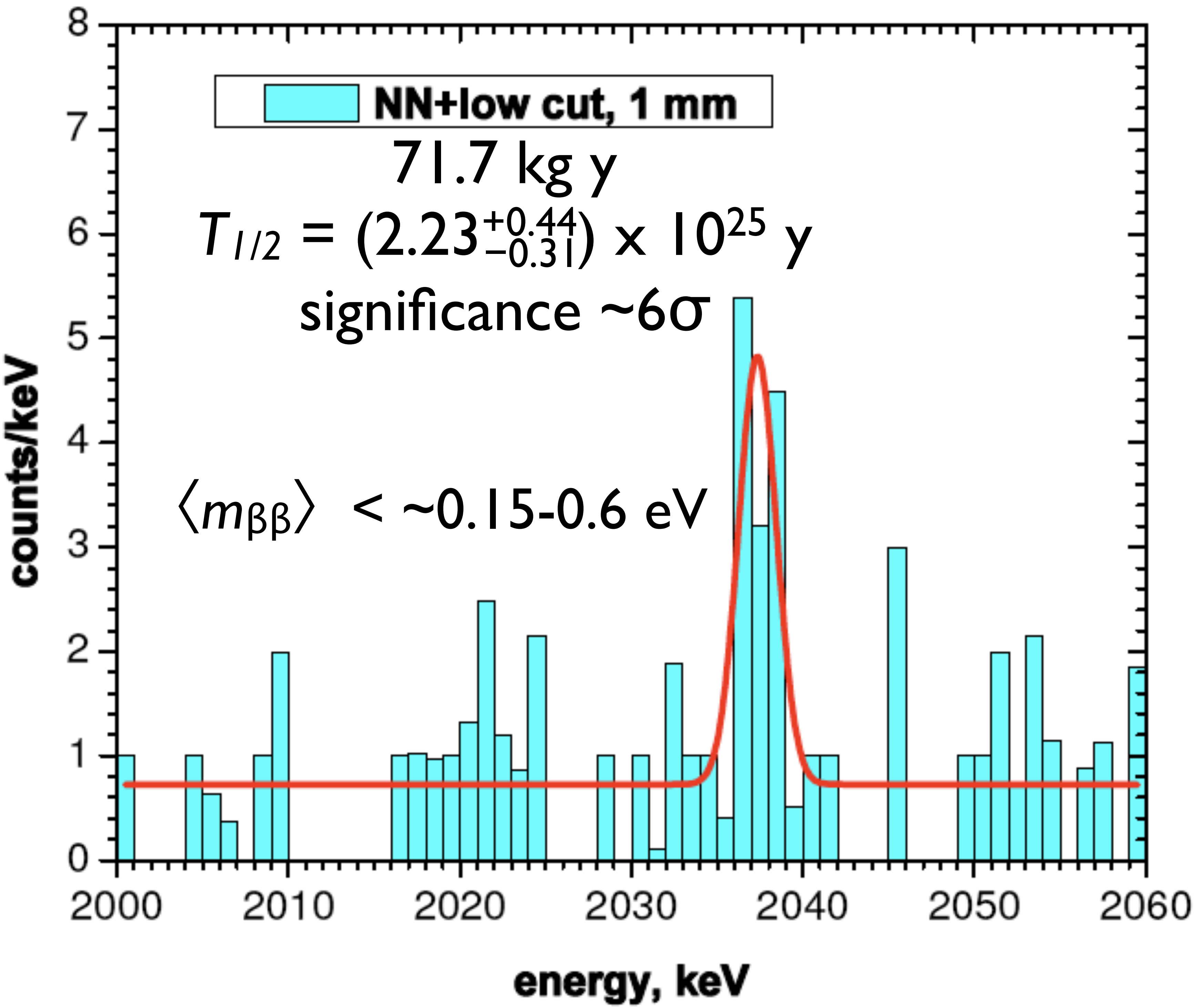


$\nu = \bar{\nu} \rightarrow$ Lepton number violation $\rightarrow$ Leptogenesis

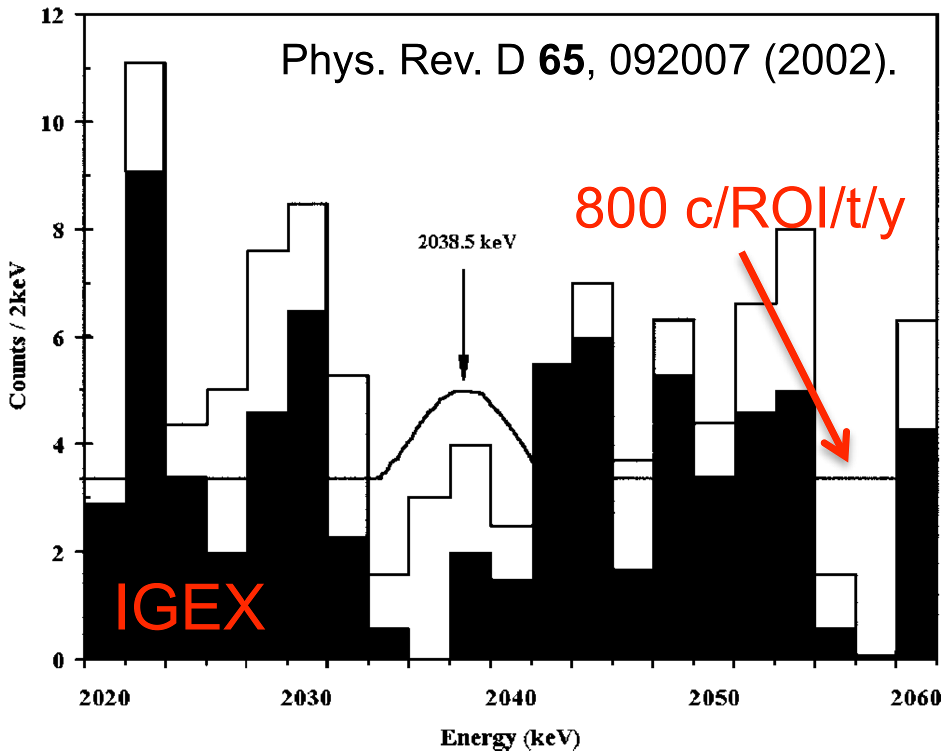
Double-beta decay is currently the only practical method of determining if ν are Majorana particles.

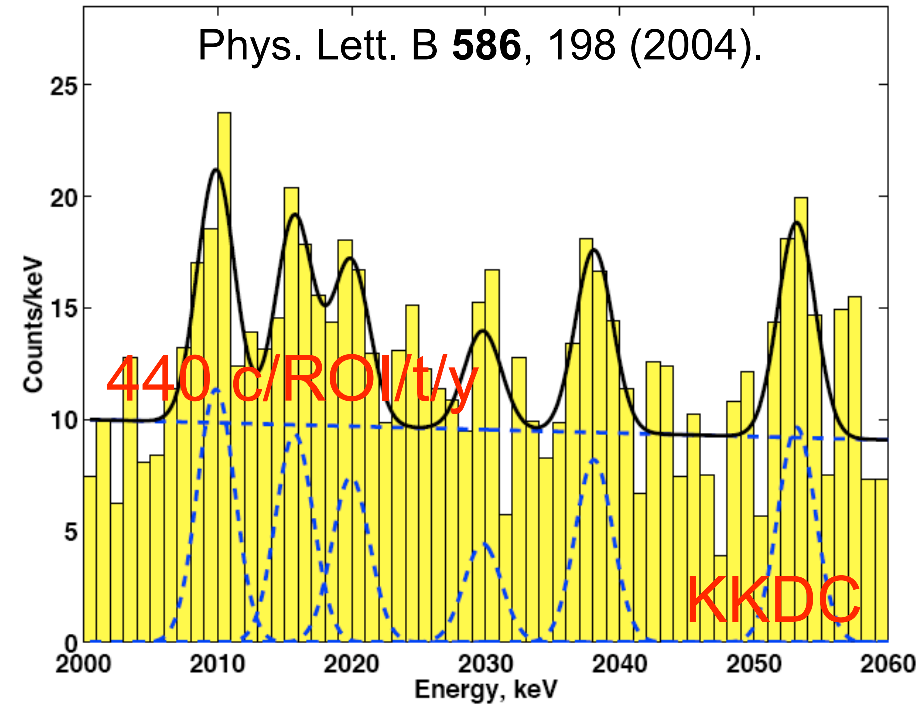
Claimed Observation

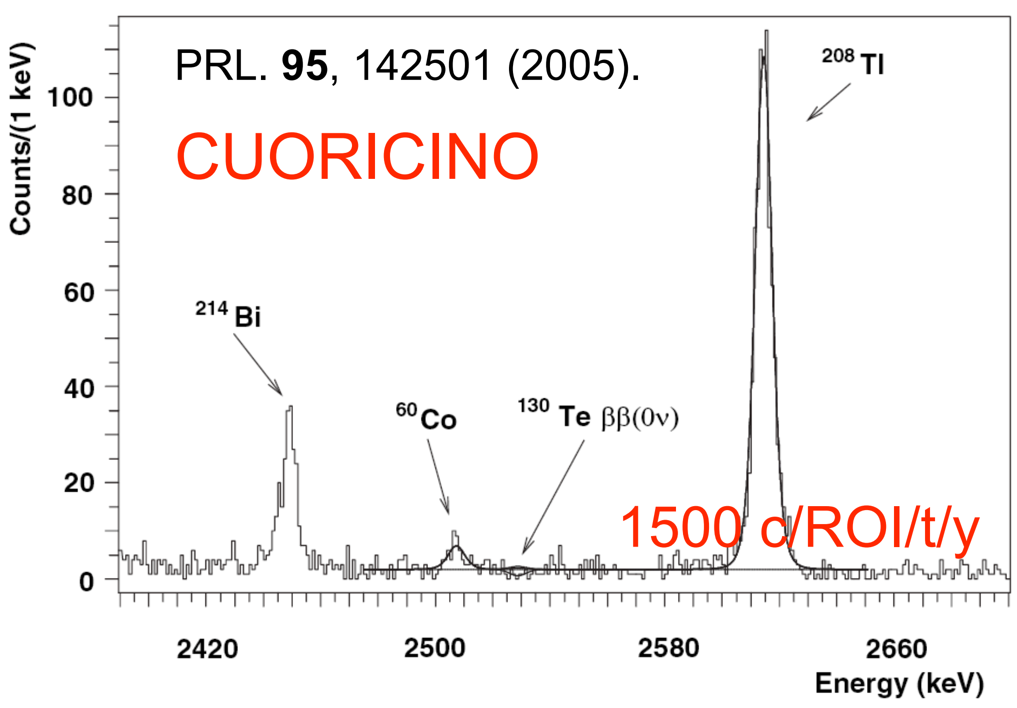
Klapdor Kleingrothaus *et al.*, Mod. Phys. Lett. A **21** (2006) p 1547.

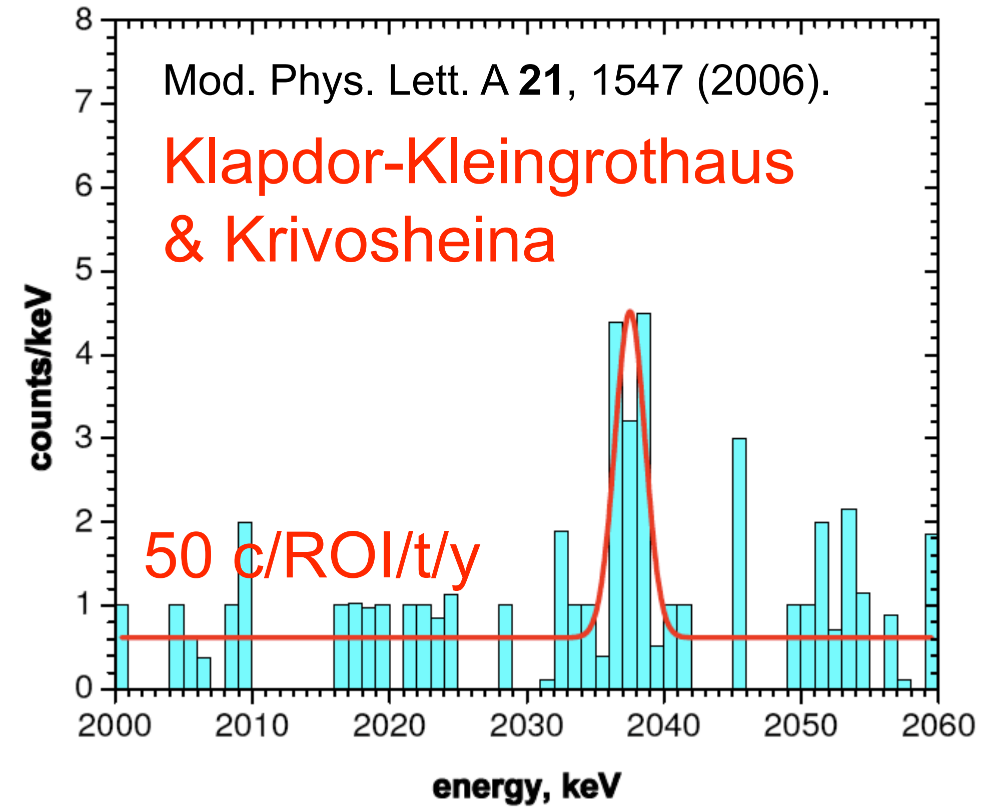


Recent Experiments



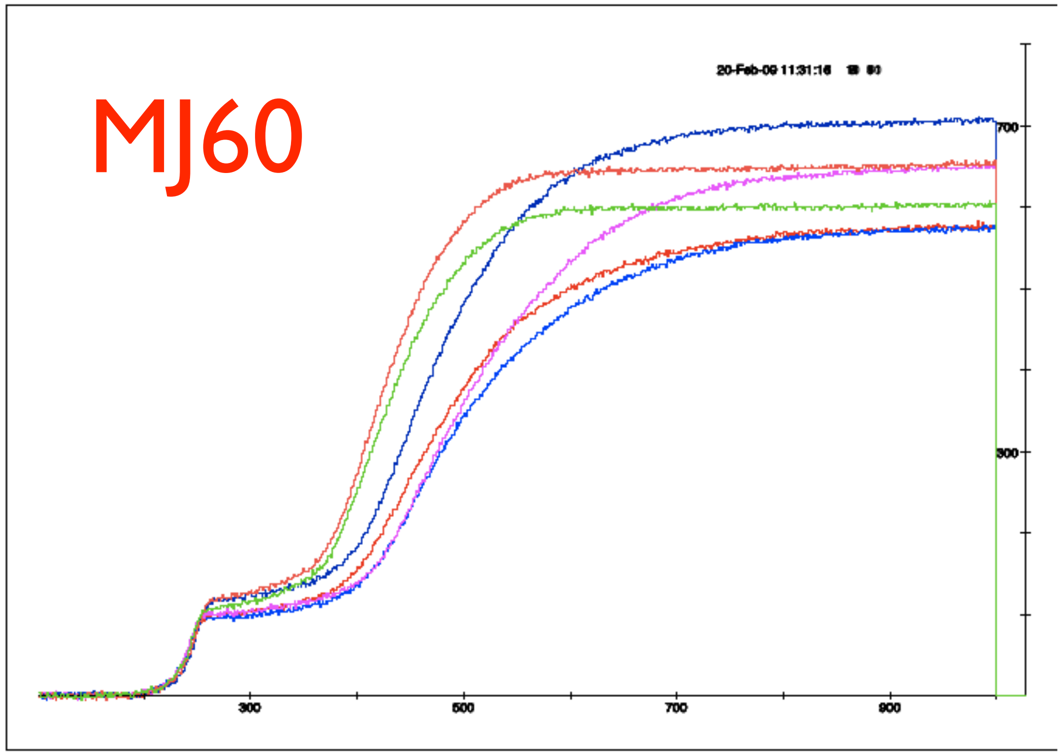


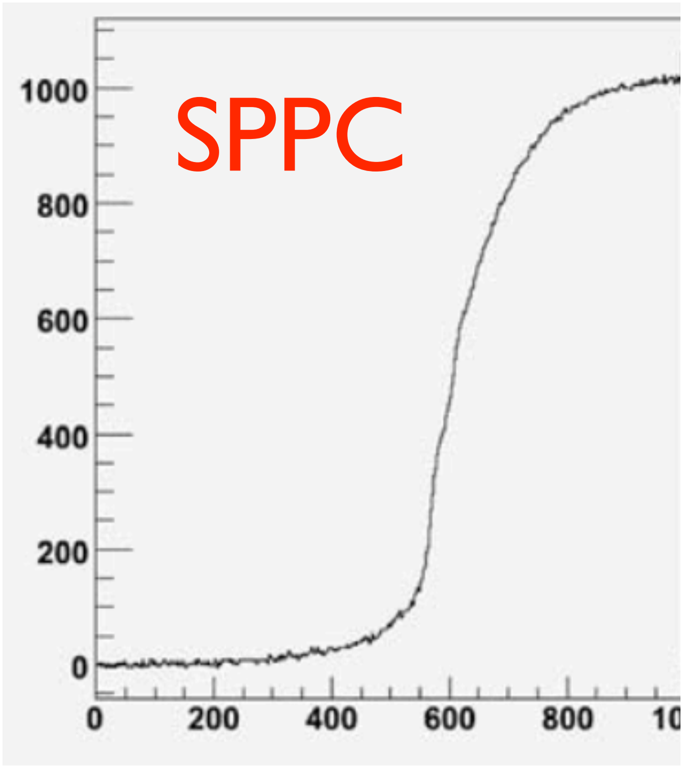


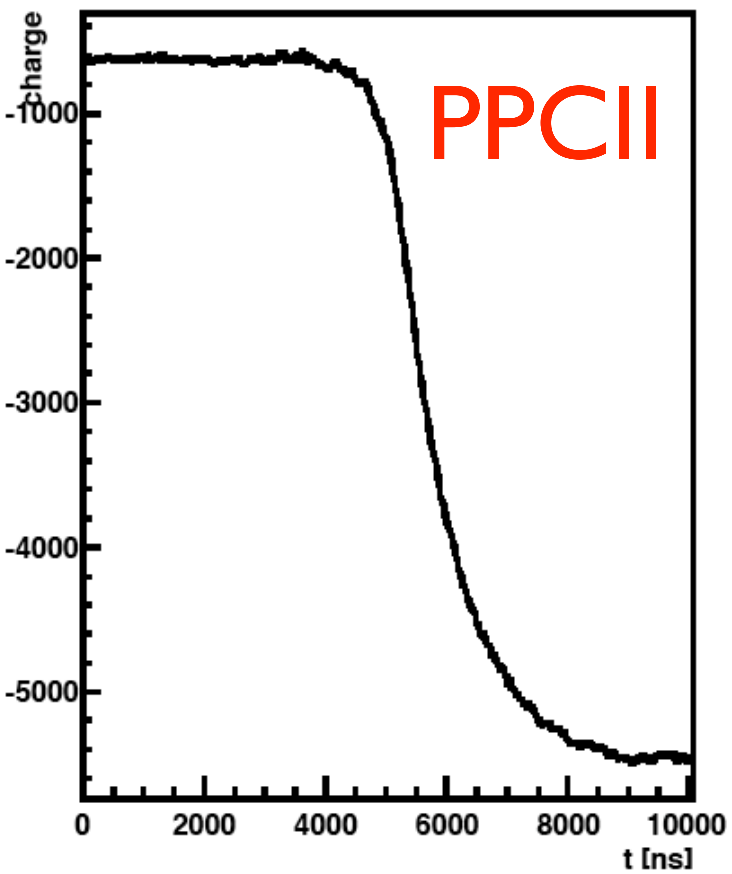


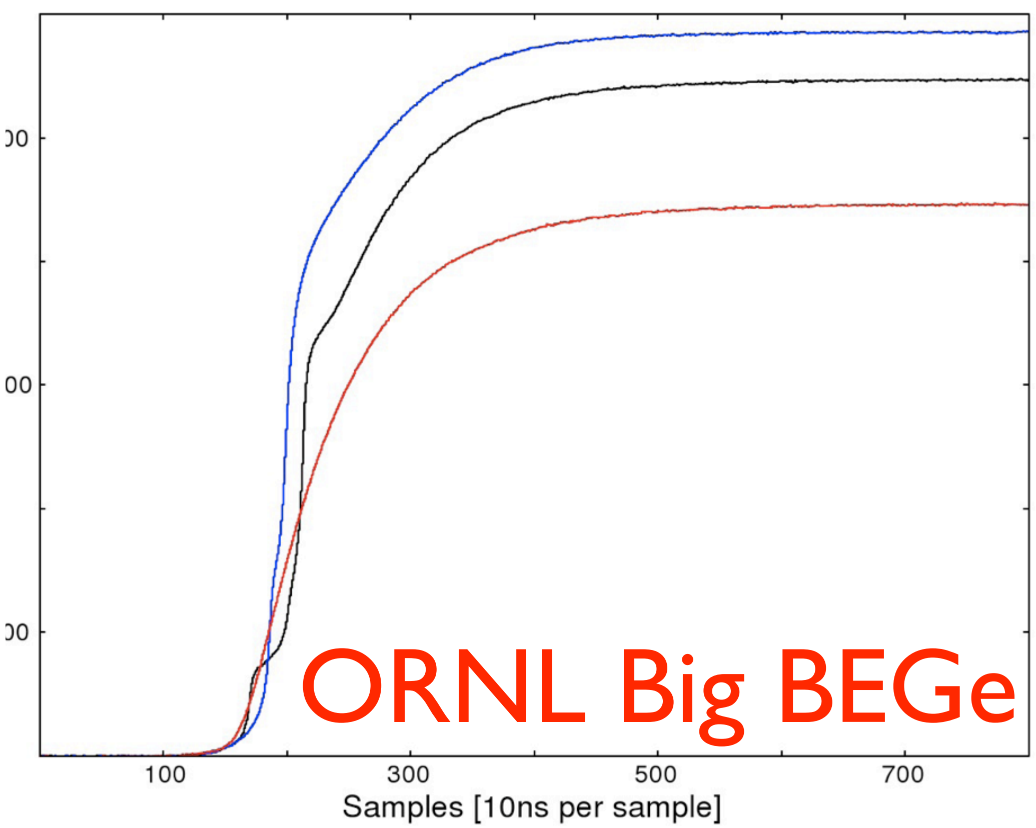
Slow-Rise Pulses

- Small percent of pulses with slow roll-up, possibly ubiquitous in PC detectors
- Kinked slow-roll pulses in MJ60 consistent with charged open surface with slower hole mobility
- Energy-, position-, surface-prep-dependence under investigation



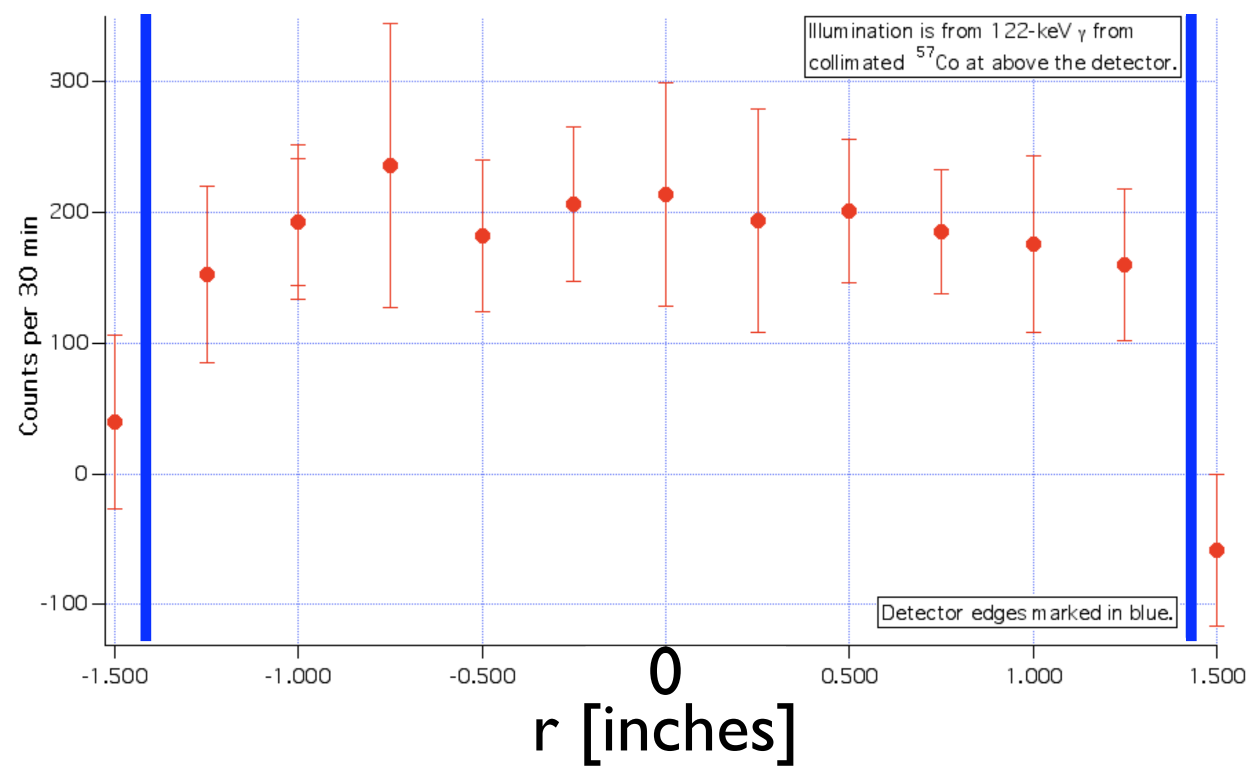


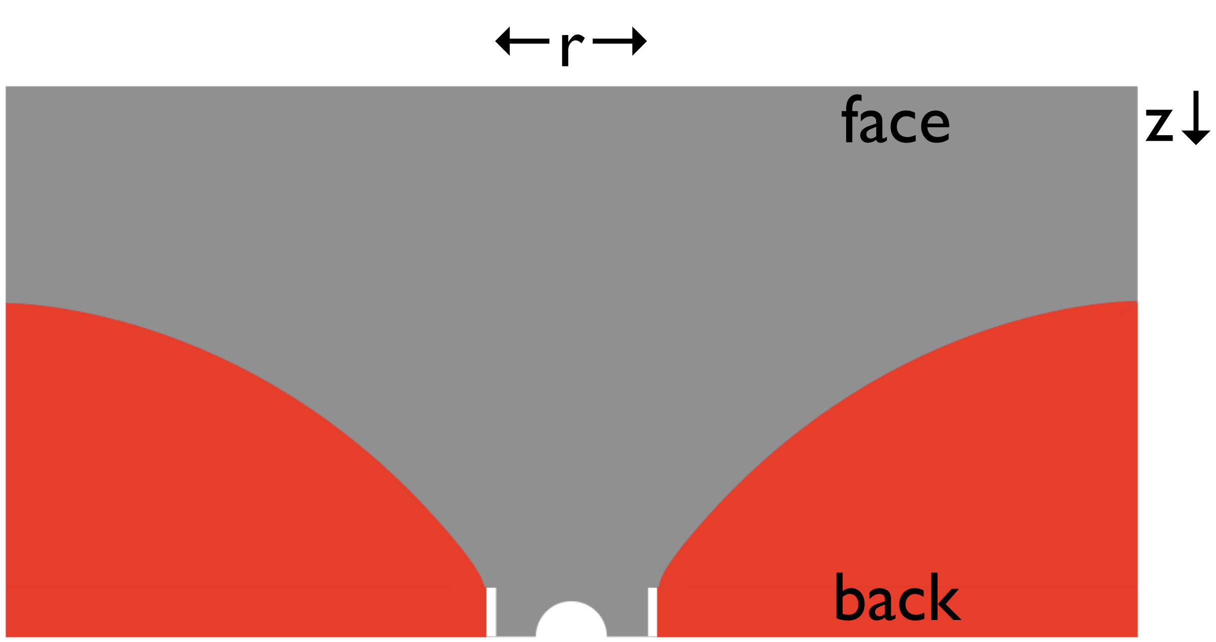


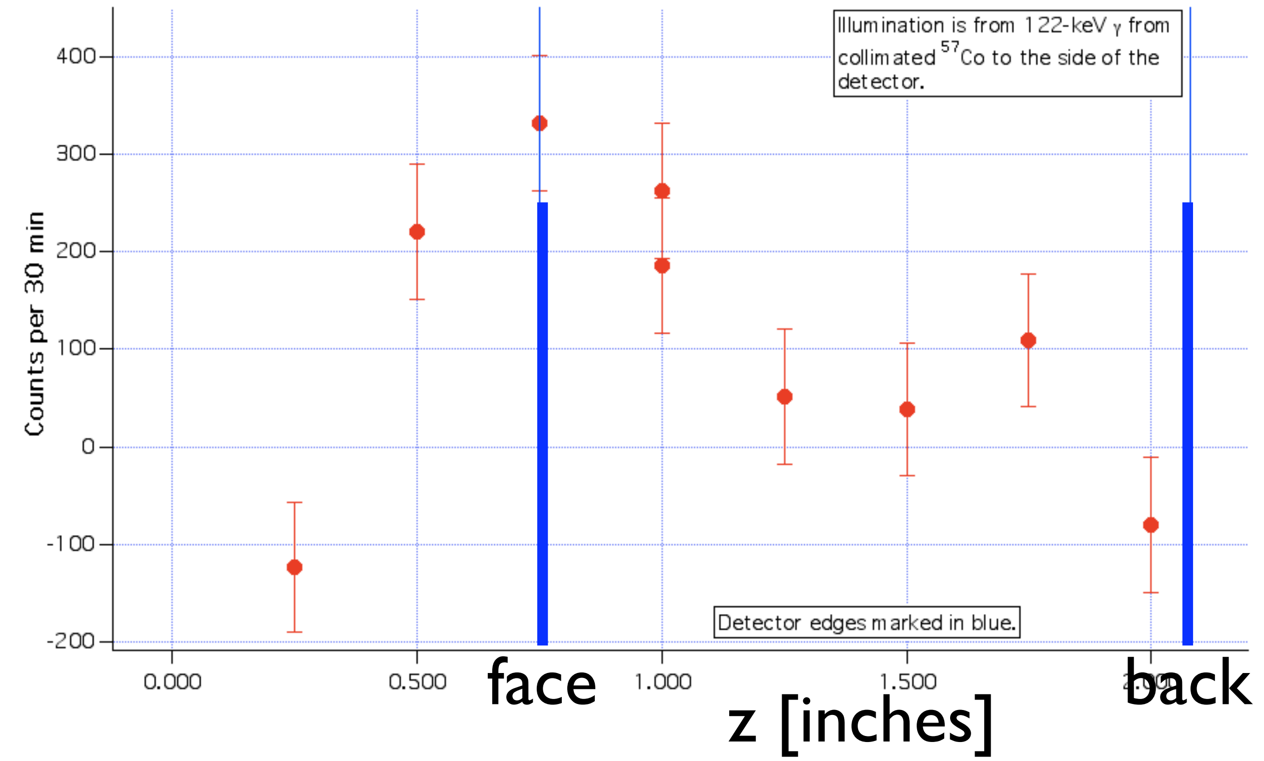


PPC Charge Collection R&D

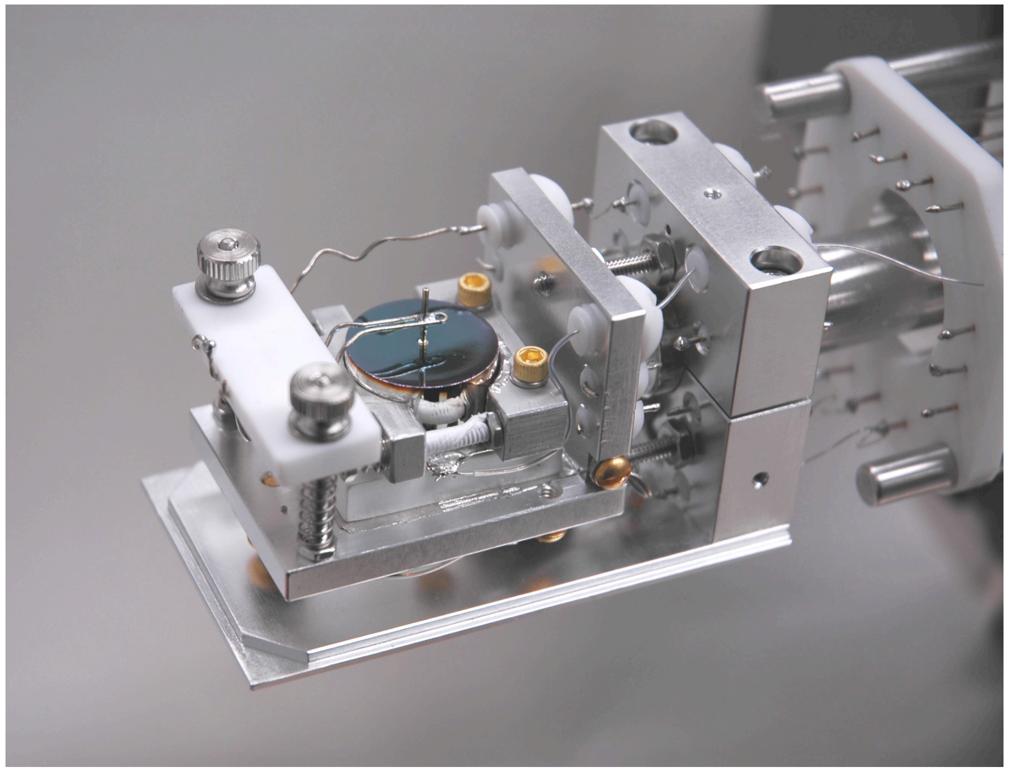
- ^{57}Co scan shows rapidly dropping efficiency near the detector back
- Consistent with drift trajectories being “blocked” by ditches

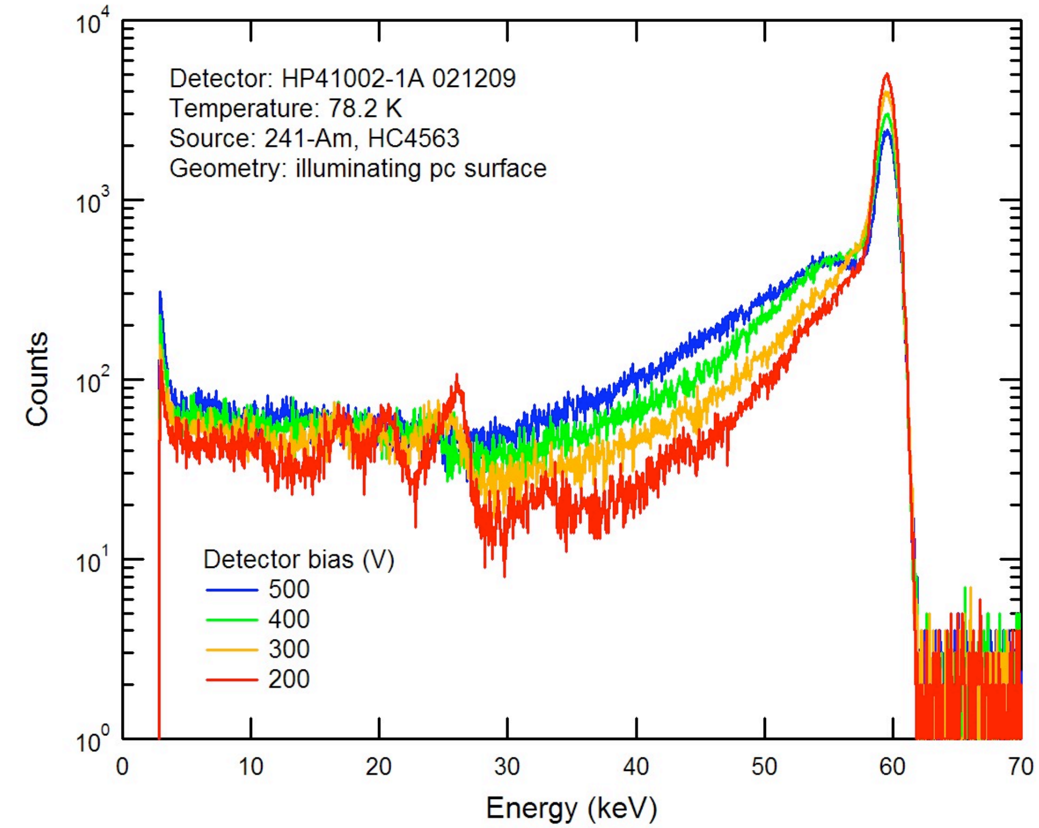




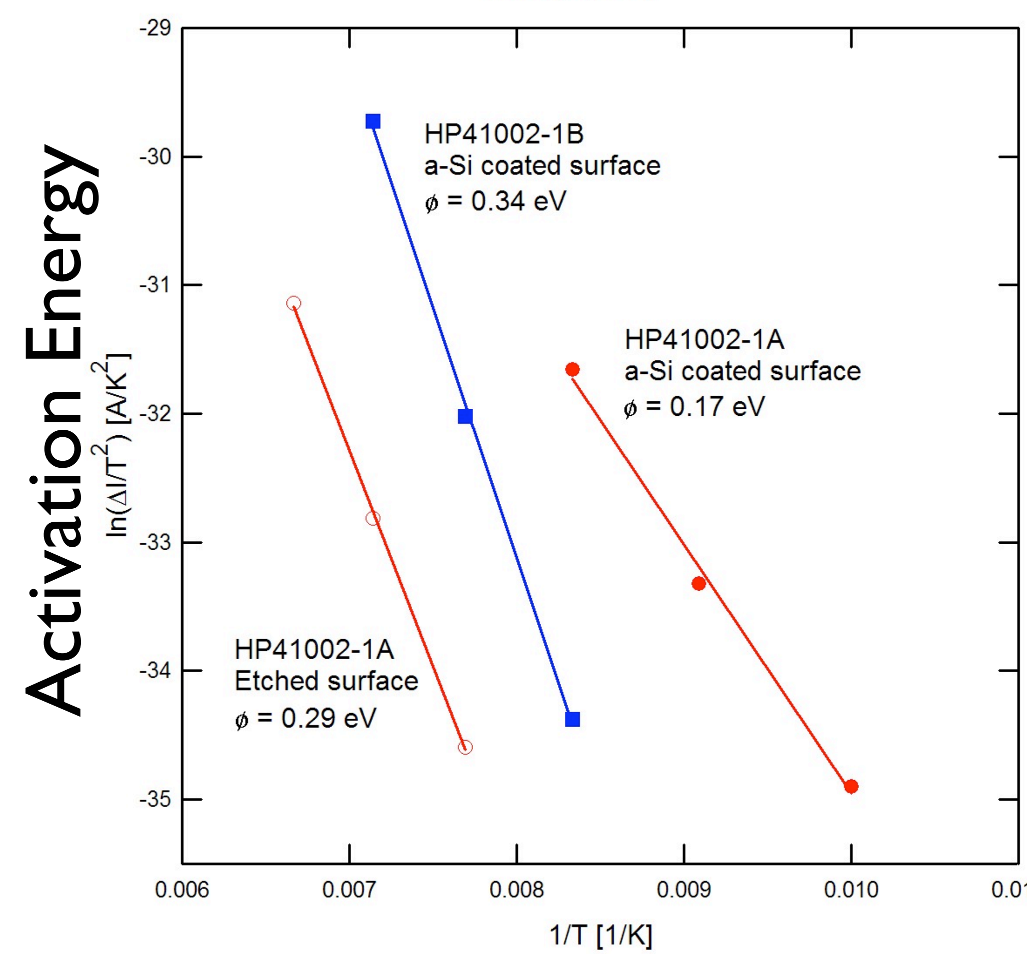


Surface Passivation R&D





- Mini-PPCs in T-variable cryostat
- Surface passivation recipe that didn't work for SPPC works for mini PPC, but gives different performance on identical mini PPCs
- Spectral variations consistent with charge trapping on passivated surface
- Investigate as a function of passivation recipe



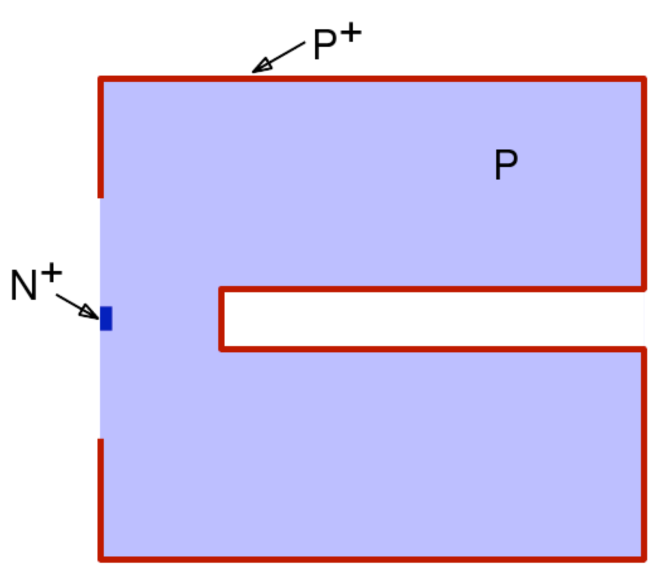
Point Contact Detector R&D

Detectors studied / in hand:

Institution (Detector Name)	Dimensions	Mass	Resolution (1.33 MeV)	Manufacturer (Crystal Grower)	Impurity Gradient
U Chicago (PPC I)	50 mm Ø x 44 mm	460 g	1.82 keV	Canberra	2.8
PNNL (PPC II)	50 mm Ø x 50 mm	527 g	2.15 keV	Canberra	1.6
LBNL (SPPC)	62 mm Ø x 44 mm	800 g	2.11 keV	LBNL (AMETEK)	1.7
LANL (MJ70)	72 mm Ø x 37 mm	800 g	2.15 keV	PHD's (UMICORE)	0.8
ORNL (MJ60)	62 mm Ø x 46 mm	740 g	4-4.5 keV	PHD's (UMICORE)	1.2
U Chicago (BEGe)	"standard"	450 g	<2 keV	Canberra	
LBNL (Mini-PPCs)	20 mm Ø x 10 mm	17 g		LBNL (AMETEK)	
ORNL (Big BEGe)	90 mm Ø x 25 mm	850 g	1.95 keV	Canberra	
LANL (MJ BEGes)	70 mm Ø x 30 mm	579 g	<2.2 keV	Canberra	
LANL	60 mm Ø x 50 mm	770 g		ORTEC	

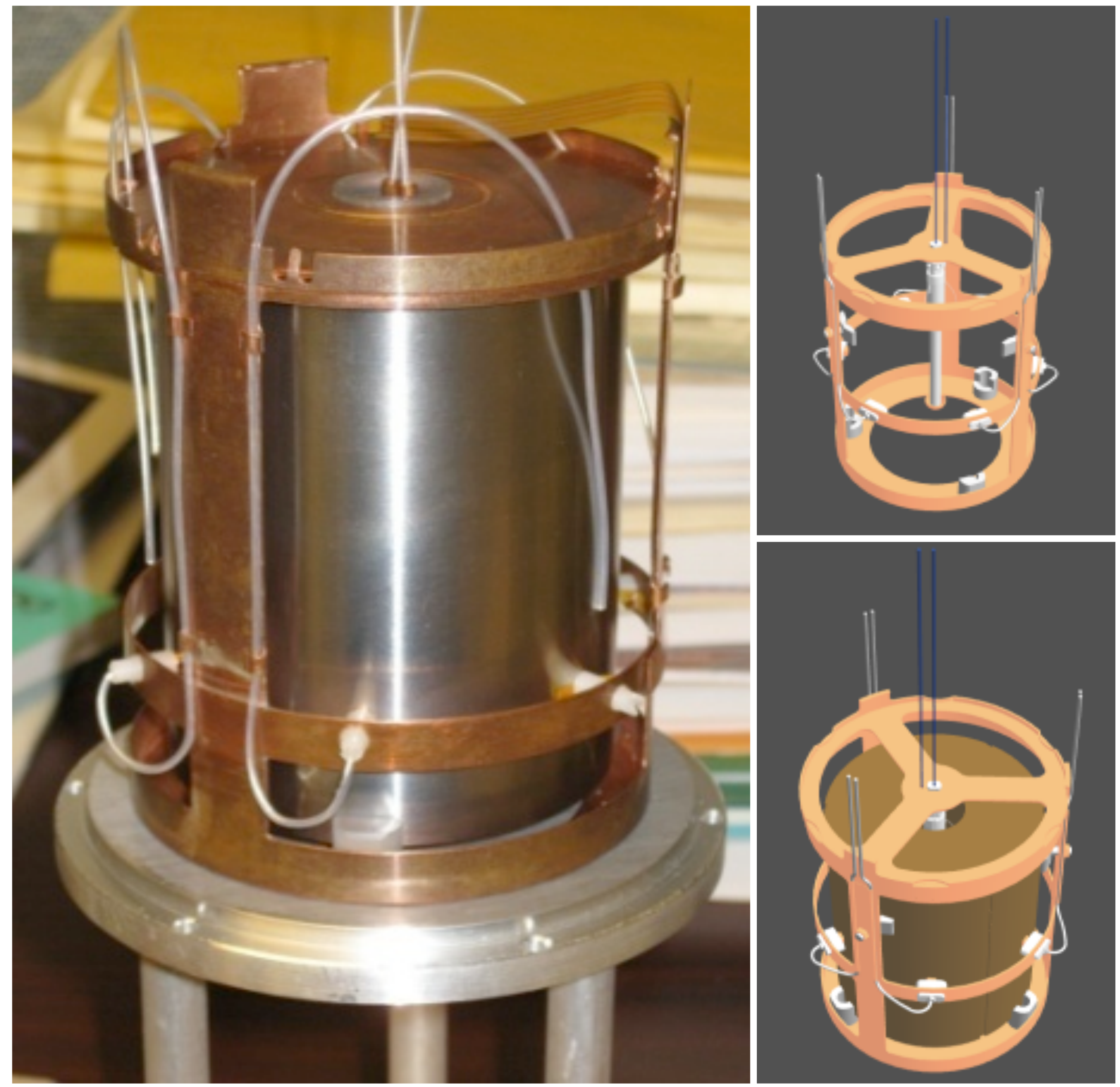
Further planned PPCs for R&D

- Canberra BEGe for low-BG low-E studies
- Inverted-coax PPC ⟶
- MJ "first module"-like BEGe for testing



SEGA

- 4x2 segmented n-type ^{enr}Ge detector
- Electroforming detector mount components at PNNL; baths functional, maybe making parts now
- WIPP visit, training
- Install in WIPP ASAP



Other R&D

- Neutron interaction simulations
- Cross-beam characterization
- Rn deposition on crystal surfaces
- Surface alpha background characterization
- Homestake backgrounds characterization

Chao's G4 bug report 1058

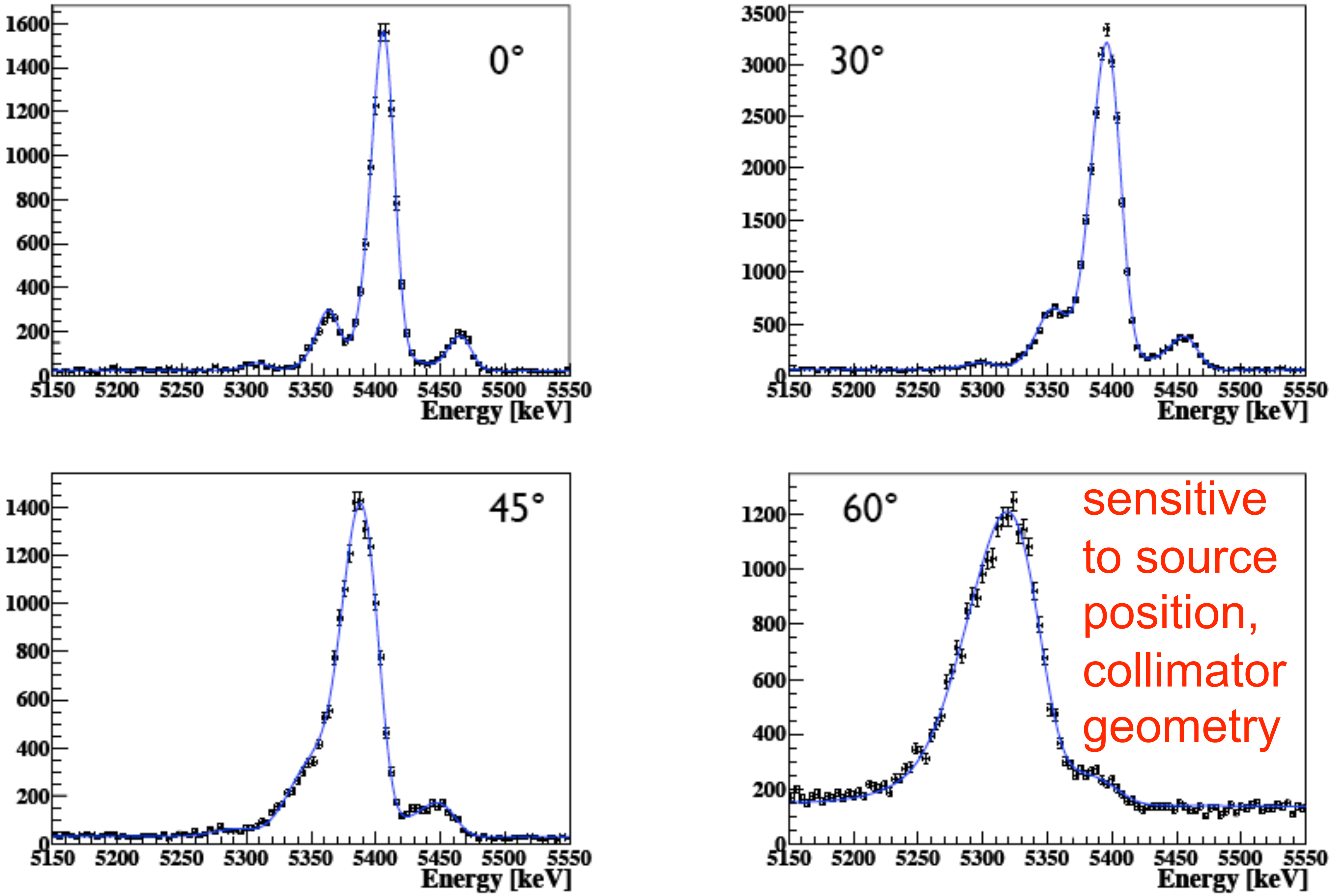
```
*****************************************************************************************
* G4Track Information:   Particle = neutron,   Track ID = 1,   Parent ID = 0
*****************************************************************************************

Step#    X       Y       Z      KineE   dEStep  StepLeng  TrakLeng   Volume     Process
    0  -10 cm    0 fm    0 fm    2 MeV   0 eV     0 fm      0 fm       Air   initStep
    1   -5 cm    0 fm    0 fm    2 MeV   0 eV     5 cm      5 cm       Air  Transportation
    2  8.01 mm    0 fm    0 fm    0 eV    0 eV    5.8 cm   10.8 cm  Germanium  NeutronInelastic
    :----- List of 2ndaries - #SpawnInStep=  6(Rest= 0,Along= 0,Post= 6), #SpawnTotal=  6 ----------
    :  8.01 mm    0 fm    0 fm  1.38 MeV  neutron
    :  8.01 mm    0 fm    0 fm  27.8 keV Ge74[0.0]
    :  8.01 mm    0 fm    0 fm   596 keV   gamma
    :  8.01 mm    0 fm    0 fm   370 eV    gamma
    :  8.01 mm    0 fm    0 fm  10.7 eV    gamma
    :  8.01 mm    0 fm    0 fm  10.7 eV    gamma
    :----------------------------------------------------------- EndOf2ndaries Info ---------------
```

unexpected gamma lines

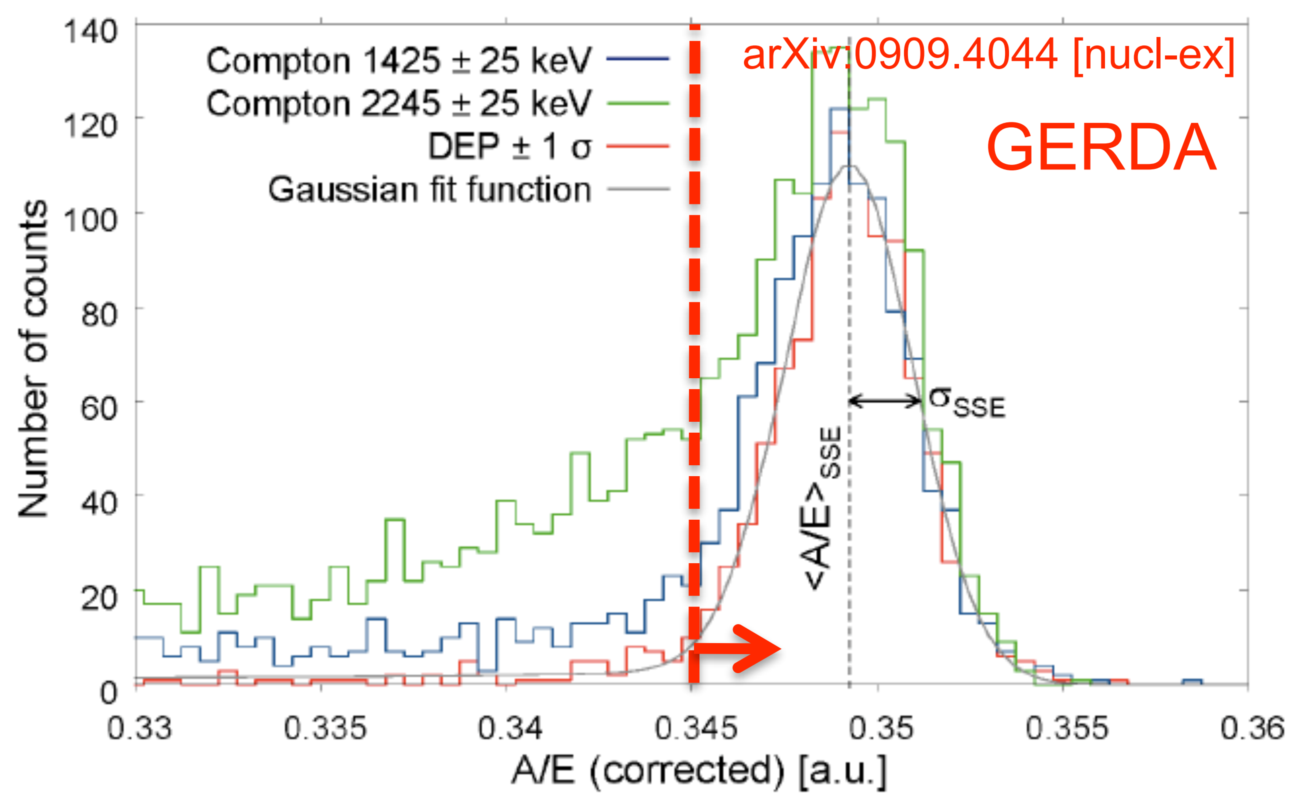
Surface Alphas

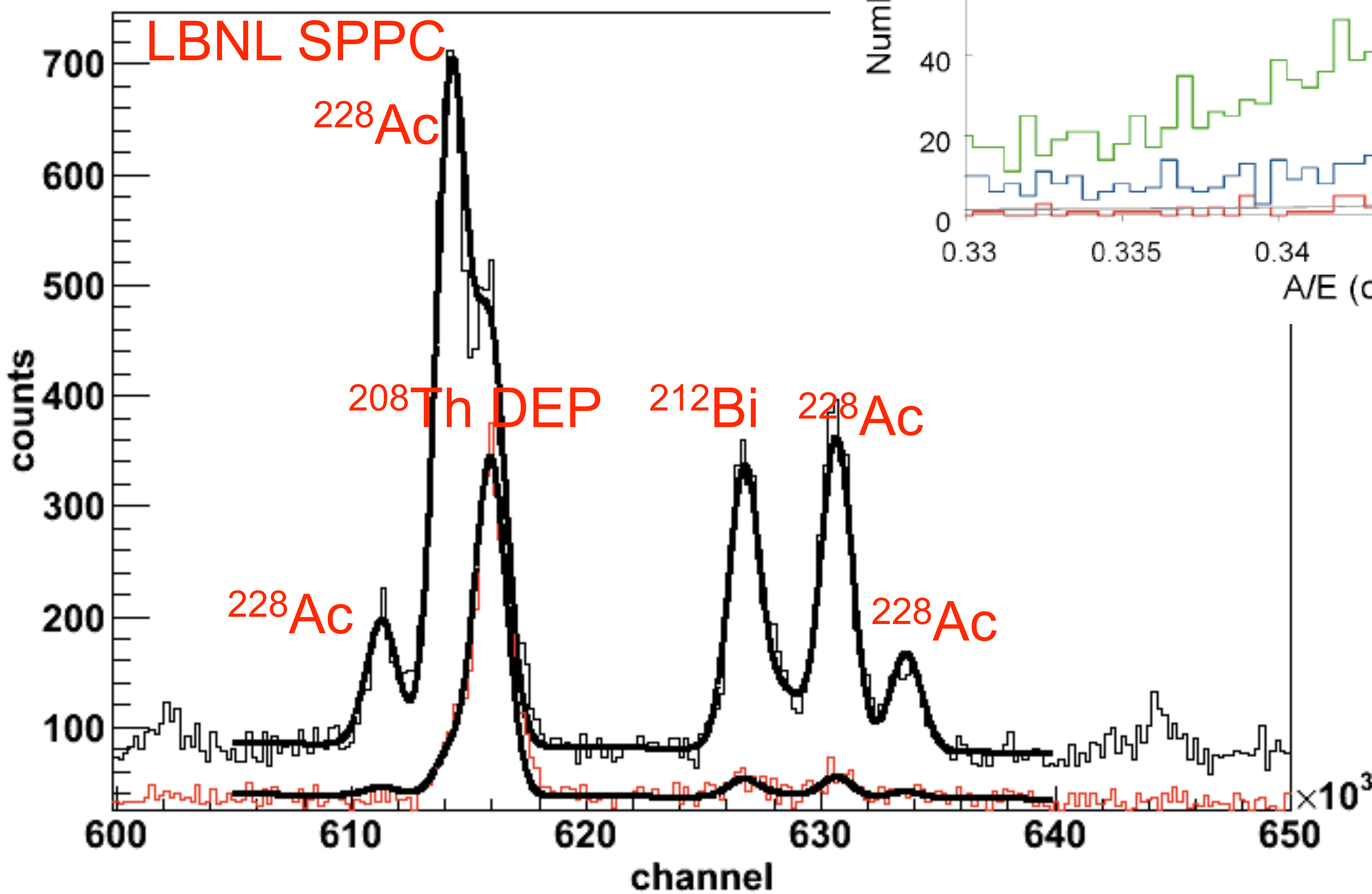
N-type detector, collimated ^{241}Am source data



Pulse-Shape Analysis

- **I_{max}/E PSD**





χ^2-Based Pulse-Shape Analysis

- **Single-site event basis:**
  - **γ coincidence**
  - **cross-beam data**
  - **flood field data**
  - **simulation**