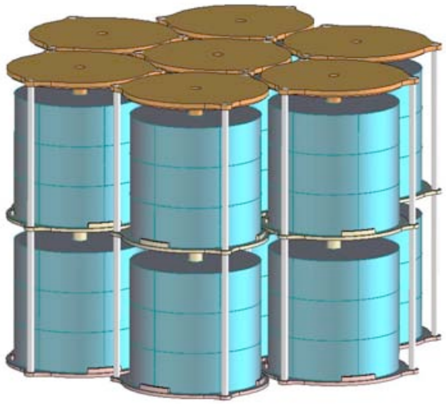
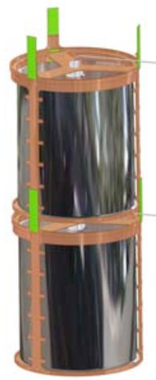
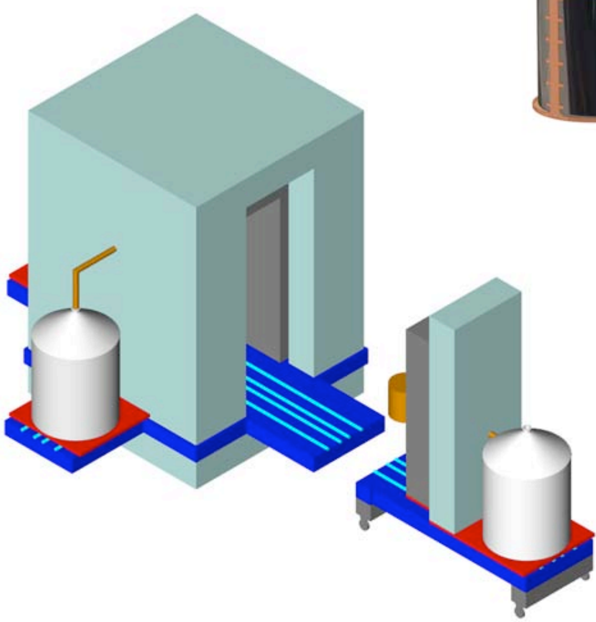
MAJORANA Progress

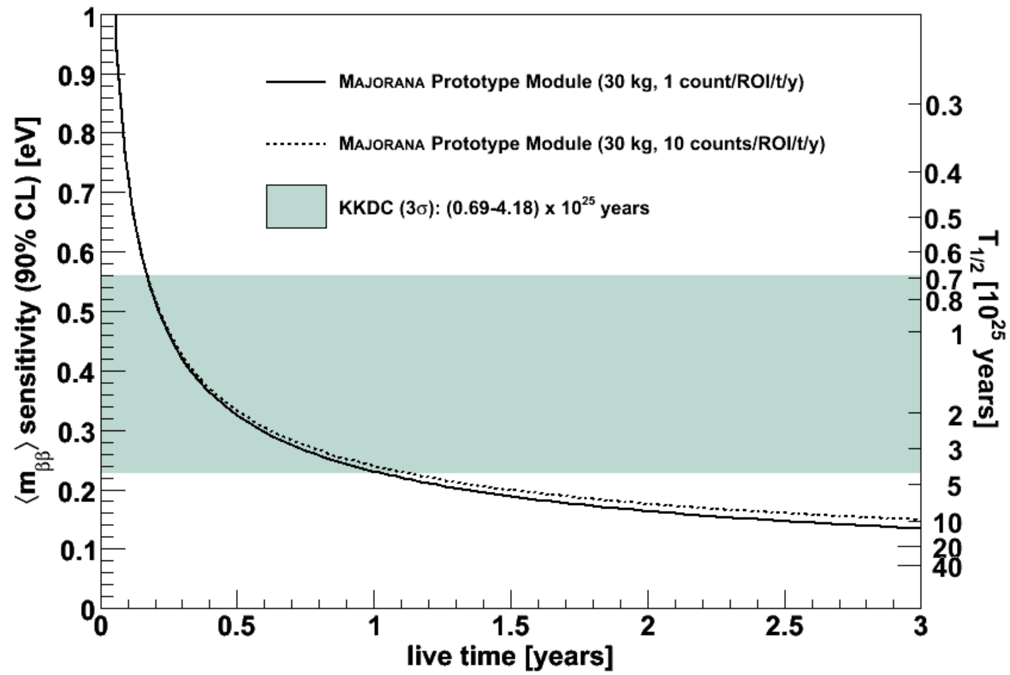
Alan Poon

Berkeley Lab









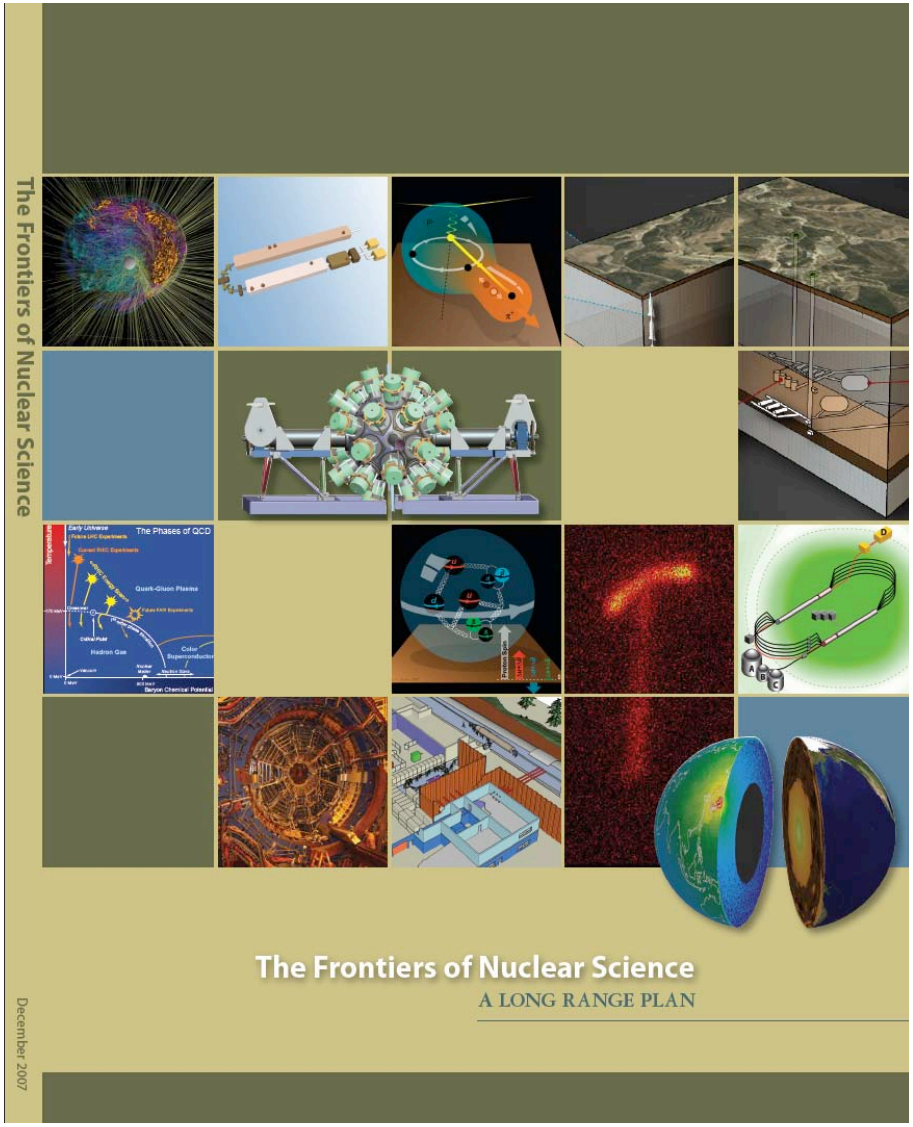
Outline

- US Long Range Planning
  - Just released: HEP P5
- SUSEL/DUSEL Process
- MAJORANA Technical Progress:
  - Overview
  - Detector & module development
  - Lab infrastructure
  - Low background counting
  - Schedule

US Nuclear Physics Long Range Plan

- Finalized in Dec. 07
- Plan recommends support for CUORE and MAJORANA
- Neutrinos now an integral part of the program
- Support for ton-scale experiment anticipated:

  “[MAJORANA] is working in close cooperation with the European GERDA Collaboration…Once the low backgrounds and the feasibility of scaling up the detectors have been demonstrated, the collaborations would unite to pursue an optimized one-ton-scale experiment.”

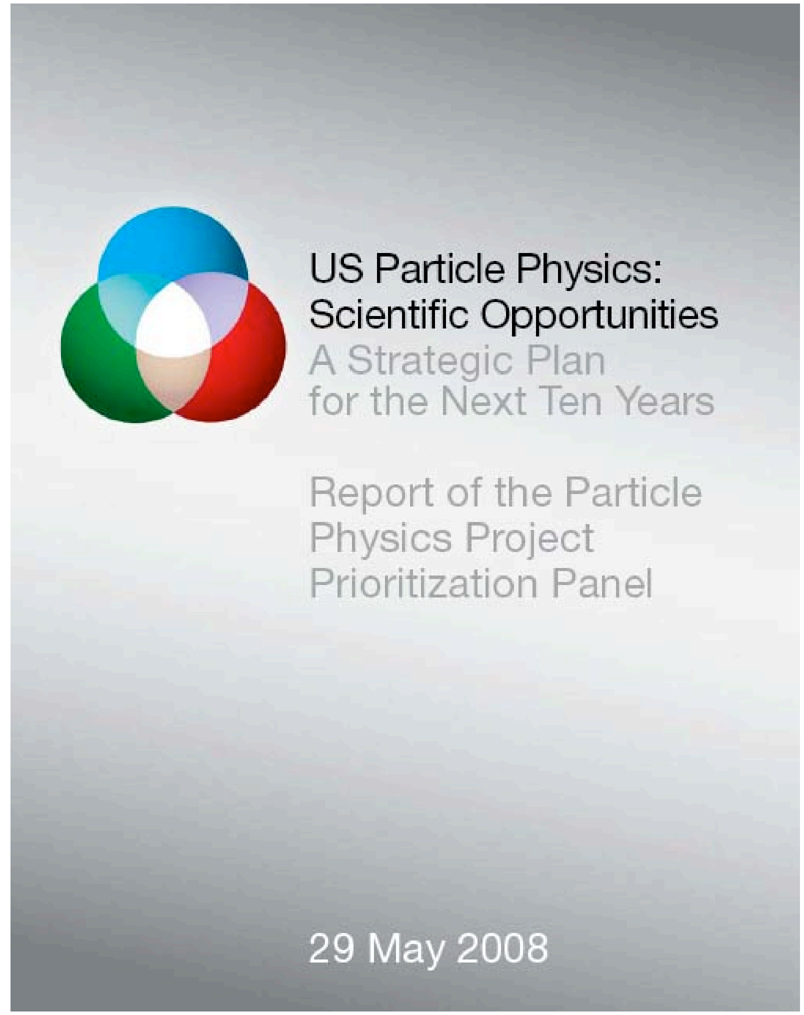


http://www.er.doe.gov/np/nsac/nsac.html

US High Energy Physics P5

- P5:"Particle Physics Project Prioritization Panel"
- Released on May 29
- Various funding scenarios considered
- Overall recommendation:

"The panel recommends a strong, integrated research program for US particle physics at three frontiers: the Energy Frontier, using both hadron colliders and lepton colliders to discover and illuminate the physics of the Terascale; **the Intensity Frontier, comprising neutrino physics and high-sensitivity experiments on rare processes**; and the Cosmic Frontier, probing the nature of dark matter and dark energy and other topics in particle astrophysics."



US High Energy Physics P5

Nonaccelerator Neutrino Experiments

- The reactor experiments, Double Chooz and Daya Bay, are designed to carry out measurements of the mixing angle θ_{13}, an important physics parameter. The panel recommends support for these experiments under any of the funding scenarios considered by the panel.

- Nonaccelerator experiments searching for neutrinoless double beta decay have the potential to make discoveries of major importance about the fundamental nature of neutrinos. The panel recommends support for these experiments, in coordination with other agencies, under any funding scenario considered by the panel.

US High Energy Physics P5

- Tying DUSEL to the HEP program

  - The panel recommends a world-class neutrino program as a core component of the US program, with the long-term vision of a large detector in the proposed DUSEL laboratory and a high-intensity neutrino source at Fermilab.

  - The panel further recommends that in any funding scenario considered by the panel, Fermilab proceed with the upgrade of the present proton source by about a factor of two, to 700 kilowatts, to allow a timely start for the neutrino program in the Homestake Mine with the 700-kilowatt source.

Homestake (SUSEL vs DUSEL)

SUSEL ("Sanford Lab")

• Funded by the state of South Dakota and private donation from Mr. Sanford.

• 4850' Level at Homestake

• This project is funded and moving forward; water is being pumped out; engineering team is establishing lab infrastructure.

• A Physics Advisory Committee to advise on experimental program.

• Space access in early 2009

DUSEL

• A US NSF initiative to build a deep underground lab with support for an initial suite of experiments (ISE).

• "S3": Lab Preliminary Design Report (PDR) funded ($5M/y for 3 y); in progress

• "S4": ISE PDR process yet to be defined.

• NSF panel to evaluate S4 and select ISE.

• Construction start ~2011 if approved by National Science Board.

Sanford Laboratory and DUSEL

- Sanford Laboratory will become DUSEL
- The MAJORANA DEMONSTRATOR is planned for Sanford Laboratory
- The S4 process will provide money for projects to prepare Designs for possible inclusion in the Initial Suite of Experiments (ISE) at DUSEL
- MAJORANA is working with Sanford Lab’s engineering team in specifying the infrastructure needs for the DEMONSTRATOR.
- Plan for an underground electroforming system in 2009.

MAJORANA Status 

- FY2007: NSF and DOE
  - DUSEL R&D funding
- FY2008: NSF and DOE
  - DUSEL R&D funding
  - Demonstrator proposal prepared
  - Being discussed with DOE for submission
  - Demonstrator is planned as part of the early entry at SUSEL
- Additional start-up grant and institutional support for the first cryostat in the DEMONSTRATOR.
- S4 proposal being discussed with GERDA
  - Planning for larger experiment as part of the DUSEL ISE

MAJORANA Collaboration Goals

Actively pursuing the development of R&D aimed at a ~1 tonne scale ^{76}Ge $0\nu\beta\beta$-decay experiment.

- Science goal: build a prototype module to test the recent claim of an observation of $0\nu\beta\beta$. This goal is a litmus test of any proposed technology.
- Technical goal: Demonstrate background low enough to justify building a tonne scale Ge experiment.
- Work cooperatively with GERDA Collaboration to prepare for a single international tonne-scale Ge experiment that combines the best technical features of MAJORANA and GERDA.
- Pursue longer term R&D to minimize costs and optimize the schedule for a 1-tonne experiment.

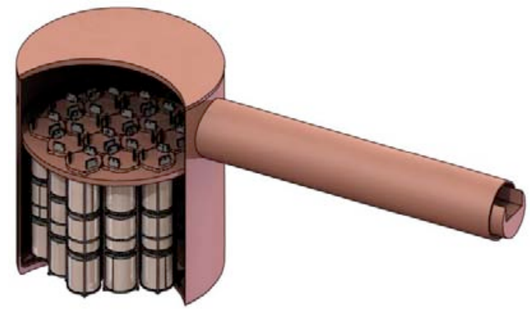
We have been guided by advice from NuSAG, an independent external panel review (Mar. 06), and a DOE NP $0\nu\beta\beta$ pre-conceptual design review panel (Nov. 06)

Support: As a R&D Project by DOE NP & NSF PNA

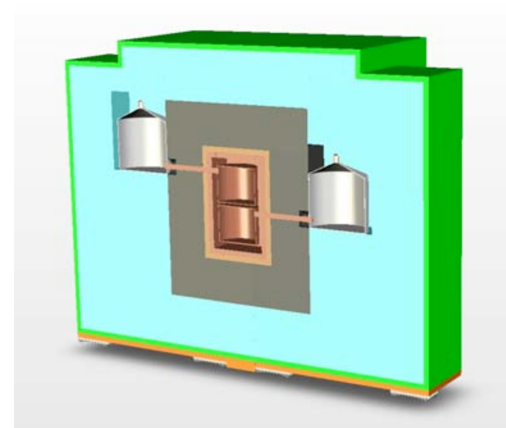
The MAJORANA DEMONSTRATOR Module

^{76}Ge offers an excellent combination of capabilities & sensitivities.

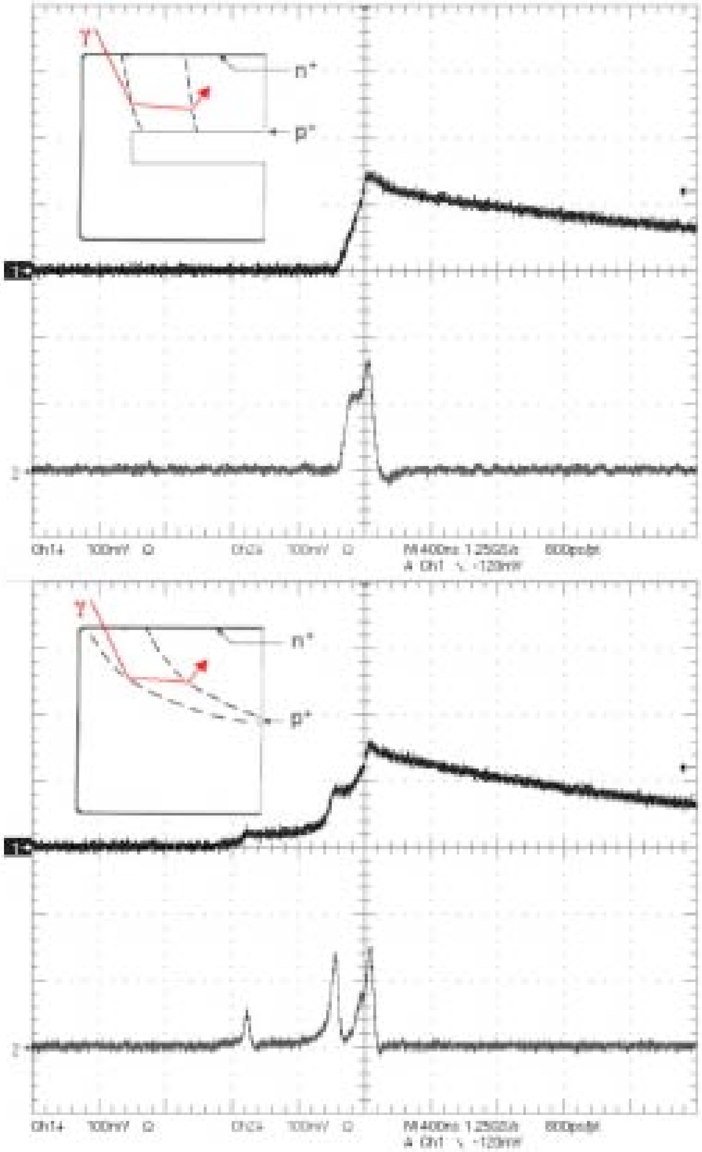
(Excellent energy resolution, intrinsically clean detectors, commercial technologies, best $0\nu\beta\beta$ sensitivity to date)

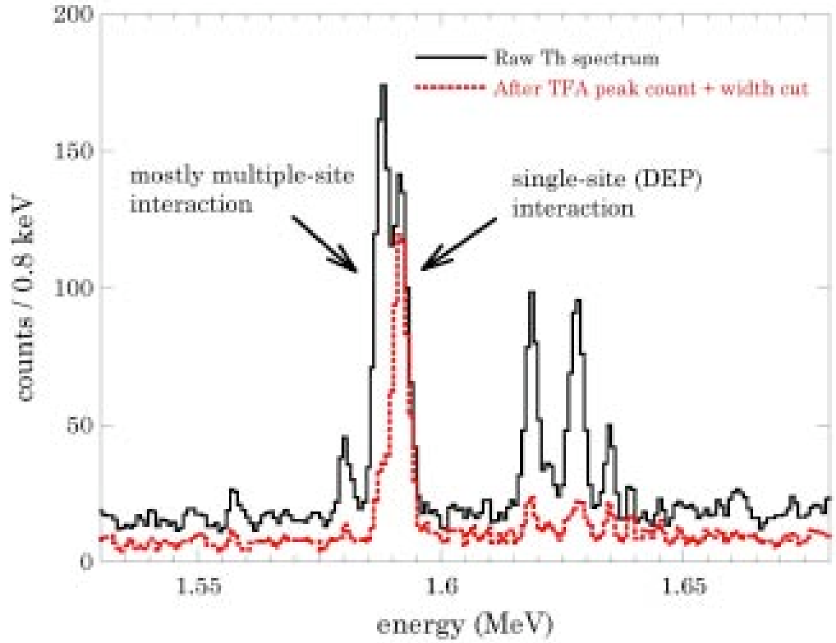


- 60-kg of Ge detectors
  - 30-kg of 86% enriched ^{76}Ge crystals required for science goal.
  - 60-kg required for sensitivity to background goal.
  - Examine detector technology options p- and n-type, segmentation, point-contact.
- Low-background Cryostats & Shield
  - ultra-clean, electroformed Cu
  - Initial module will have 3 cryostats
  - Pursuing a cryostat with natural P-PC
  - naturally scalable
  - Compact low-background passive Cu and Pb shield with active muon veto
- Located underground 4850' level at SUSEL/DUSEL.



Detector — PPC





- **The longer drift distance in the PPC stretches the pulse leading to a clear indication of a multiple site event.**
- **A solid p-type detector: easier to handle, instrument.**
- **But achieves much of advantage of segmented detectors.**

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

PPC Detector Status

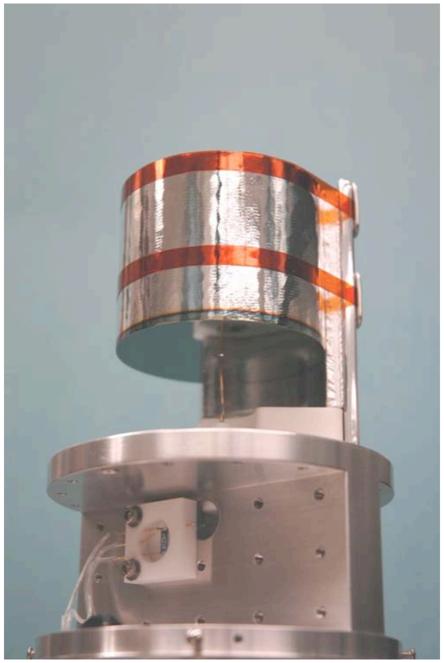
Detectors/crystals already delivered/ordered:

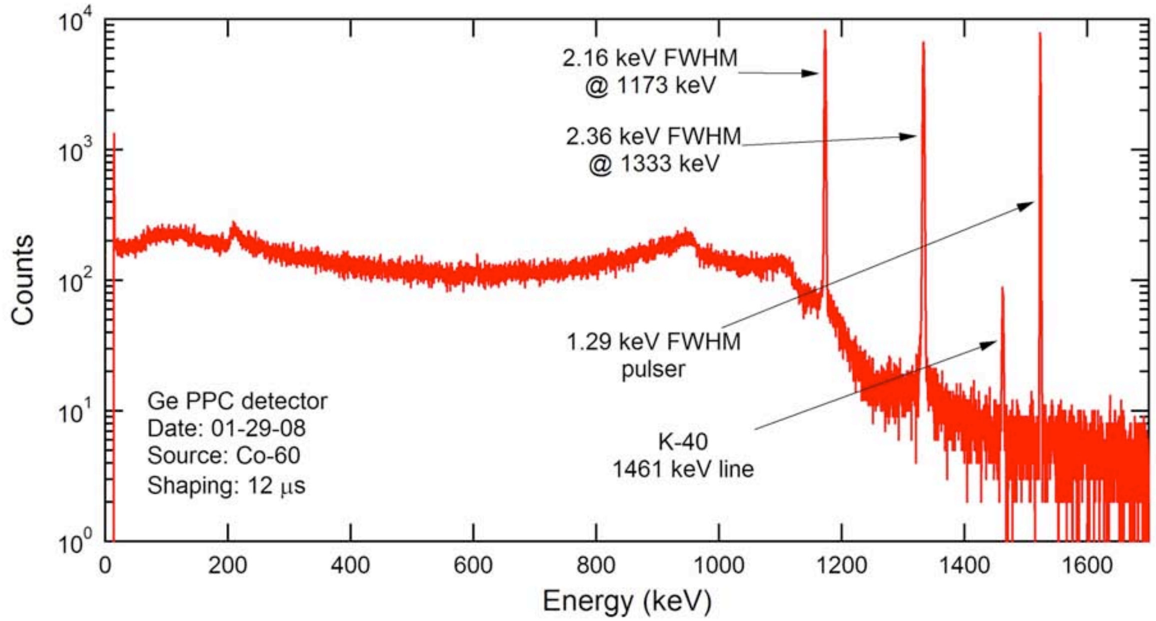
1. U. Chicago, from Eurisys ~50x44 mm
2. PNNL, from Eurisys ~50x50 mm
3. LBNL (Paul Luke), crystal from ORTEC ~62x50 mm, will try segmenting the outer contact
4. LANL, from PHDs (Ethan Hull) ~72x37 mm
5. ORNL, from PHDs (Ethan Hull) ~62x46 mm

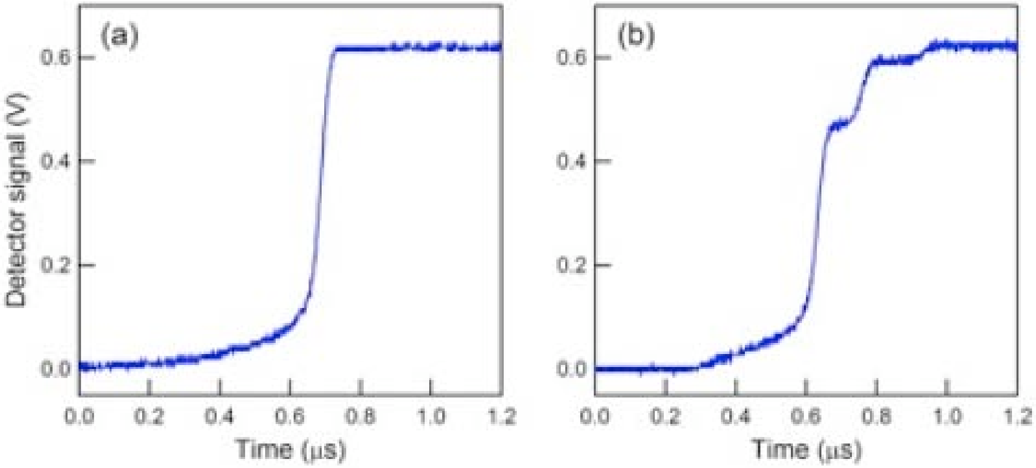
PPC Detector Status

	Chicago	PNNL	LBNL (SPPC)	LANL (MJ70)	ORNL (MJ60)
Dimension	50mm ϕ x 44mm	50mm ϕ x 50mm	62mm ϕ x 50mm	72mm ϕ x 37mm	62mm ϕ x 46mm
Mass (g)	460	527	800	800	740
Point contact	5.4mm ϕ x ?mm		2mm ϕ x 0.75mm	1.5mm ϕ x 2mm	1.5mm ϕ x 2mm
Impurity (1e10/cm^3)			1.2 to 0.7	0.48 to 0.63 ?	0.50 to 0.43
Depletion (V)	2400		2800	2000	
Energy resolution @1.33 MeV	1.82keV	2.15 keV	2.36 keV	<2.15 keV	
Pulser	140 eV		1.29	< 0.94 keV	
Capcitance (pF)	1.8				
Manufacturer	Canberra/Eurisys	Canberra/Eurisys	ORTEC/Luke	UMICORE/PHDs	UMICORE/PHDs

Segmented PPC - Phase I







<u>Collaboration-fabricated</u>

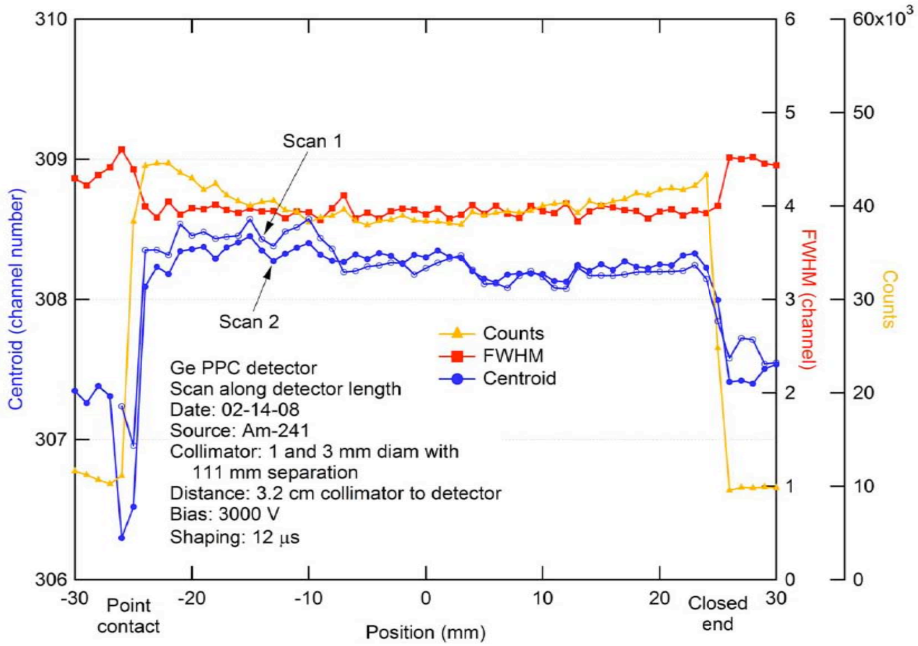
- **Bought crystal - 0.8 kg**
- **Machined and applied contacts at LBNL**
- **Works well**
- **To be segmented**

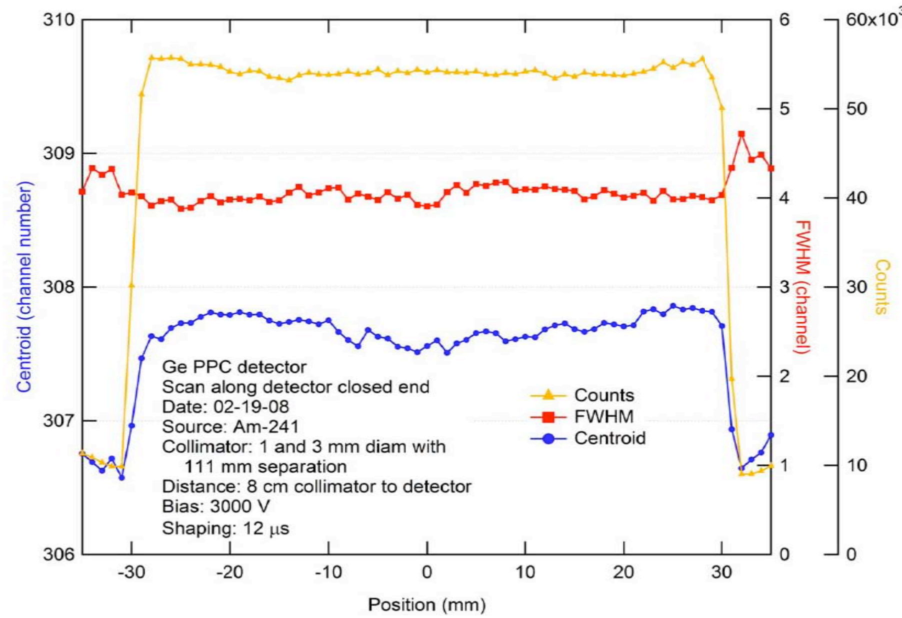
Segmented PPC - Phase I

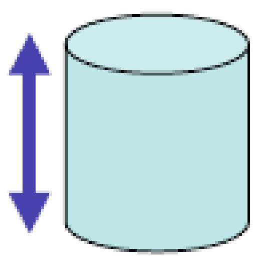
Low energy gamma source scanning studies

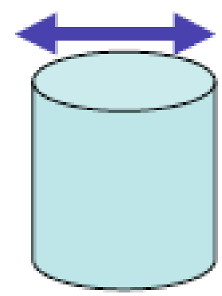
Labview driven *automated* 2-D scanner.
Can do both “side” or “top” scans, with collimated sources.

Segmented PPC - Phase I

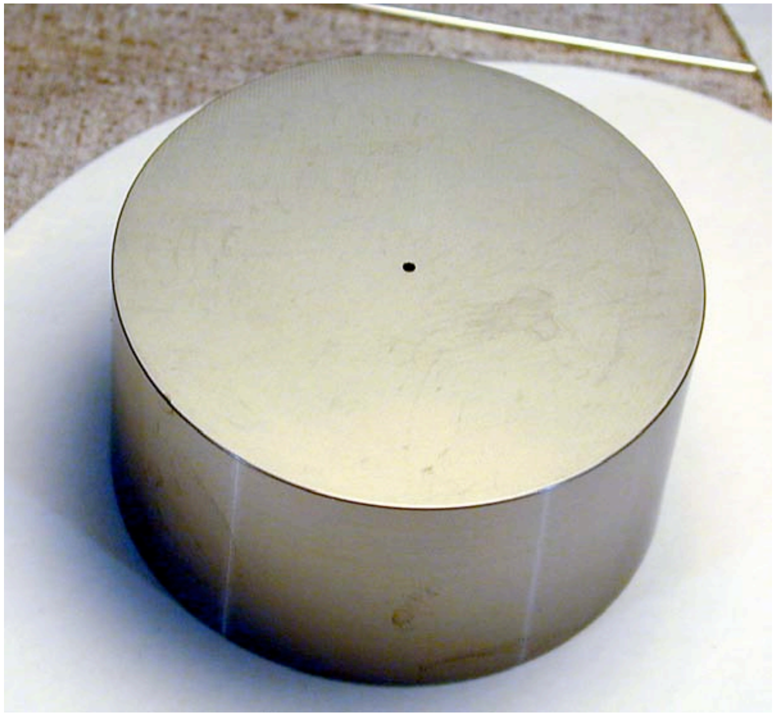




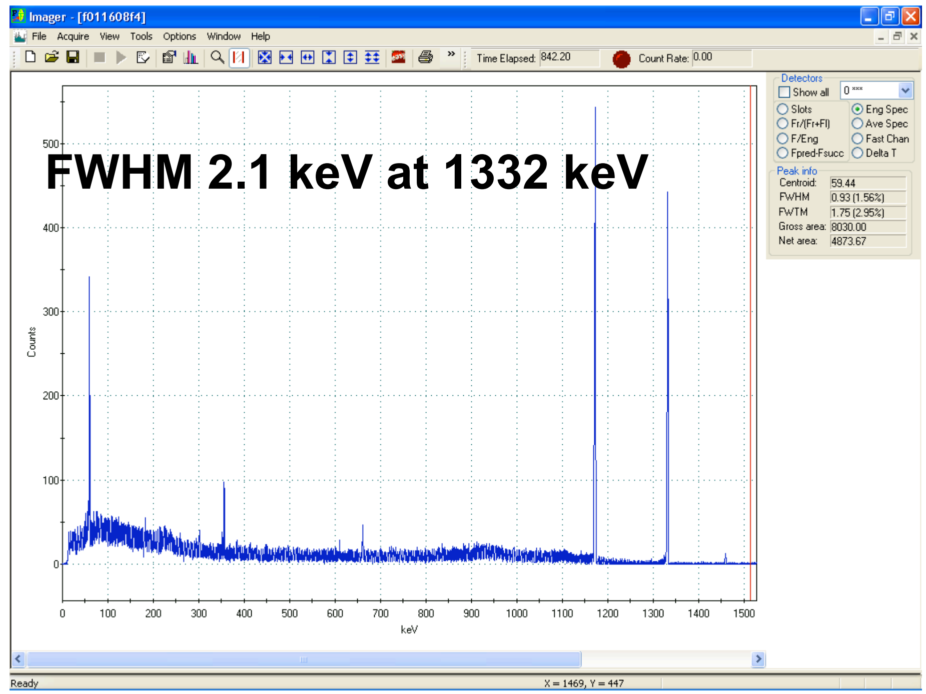




MJ70 Detector from PhDs Inc.



Diameter = 72.2 mm
Length = 37.3 mm
Hole = 1.5 mm diameter
2.0 mm deep

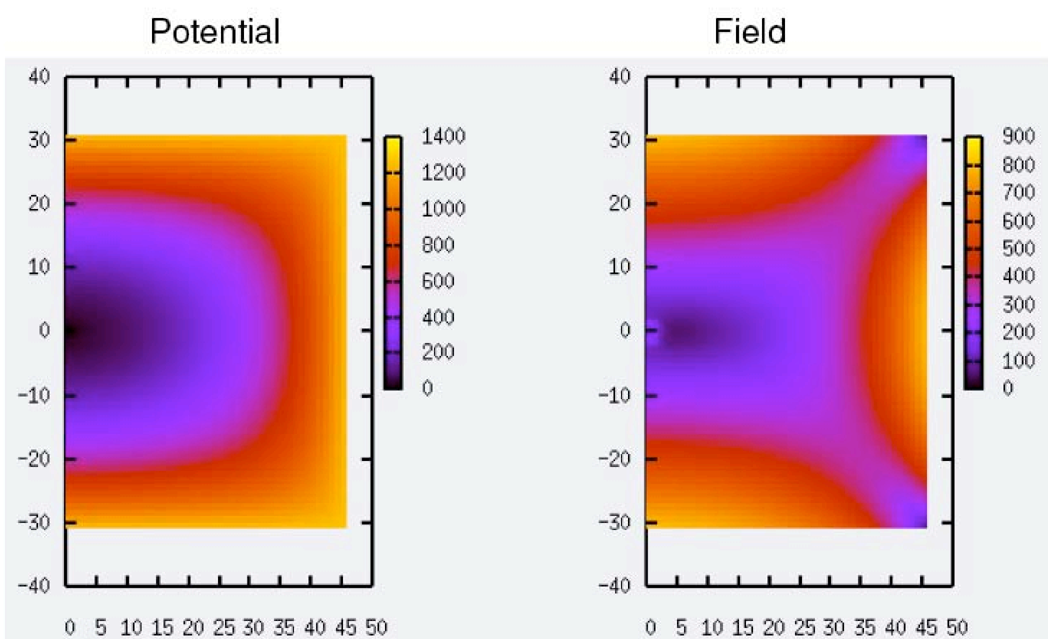


- Worked well initially
- Failed to hold bias voltage after the manufacturer mounted it for shipment to LANL
- Detector delivered recently

Calculating Field & Weighting Potential

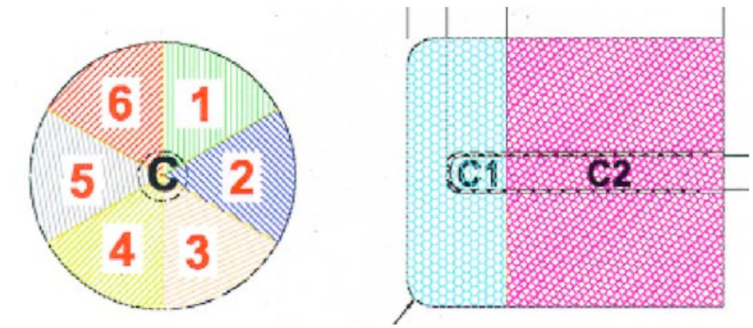
- Charge trapping prediction reliable
- Can optimize designs based on field and impurity gradient

Example: MJ60:
depletes at 1220V

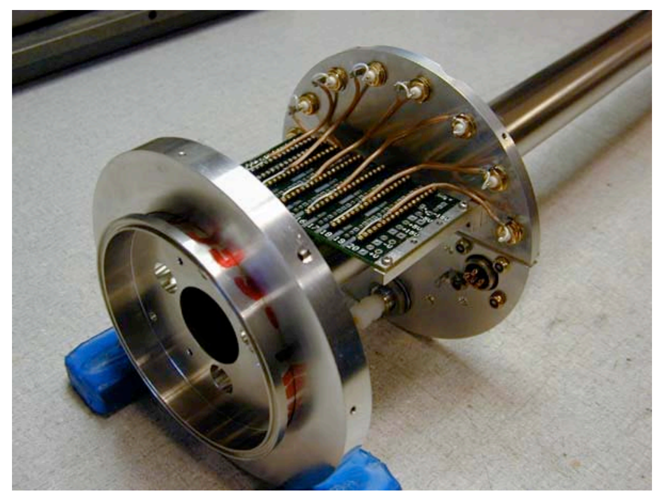


N-Type Segmented — SEGA

- SEGA detector
  - Crystal description
    - N-type ^{76}Ge detector (86%)
    - 12 segments - 6 outer X 2 inner
  - Currently in temporary cryostat
  - Mounting crystal in low background cryostat for background studies; working with ORTEC on remounting
  - Mount designed; mechanical prototype built (not electroformed)
  - Status
    - Planning to install underground in the coming year

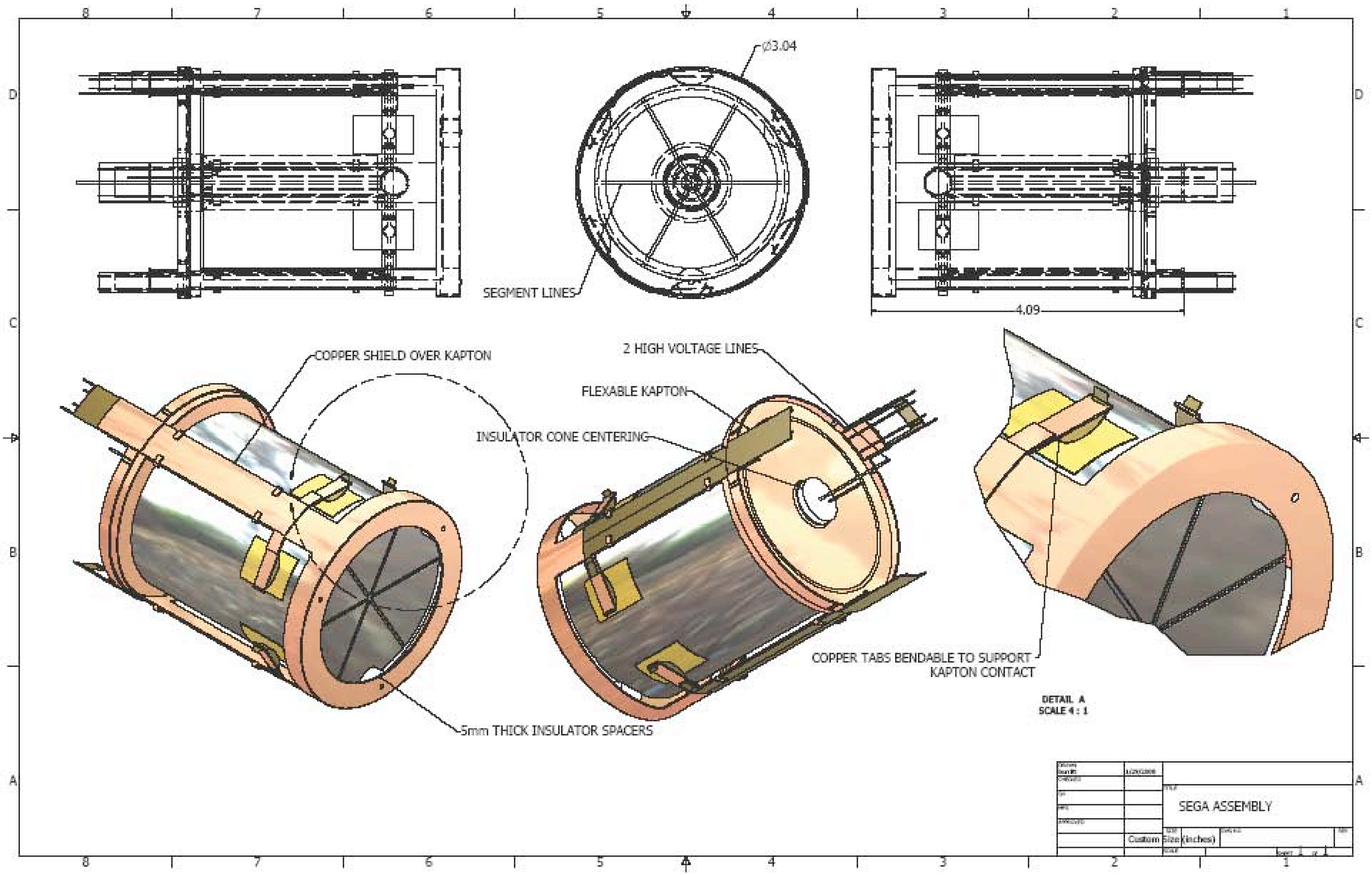


SEGA segmentation

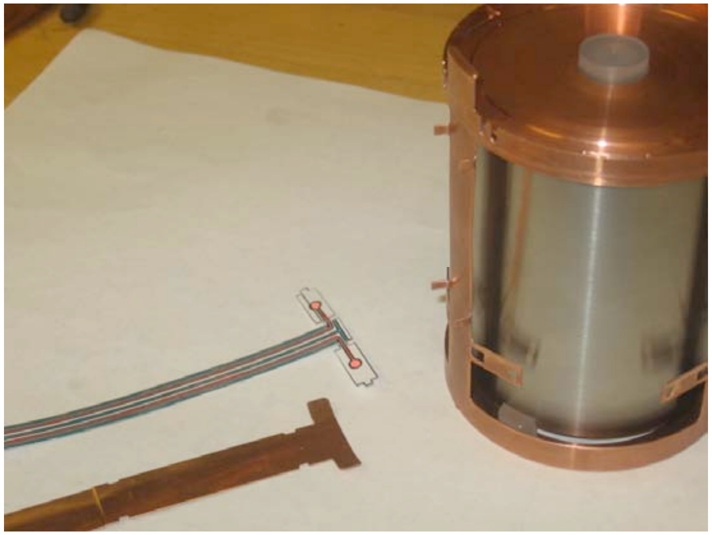


Test cryostat

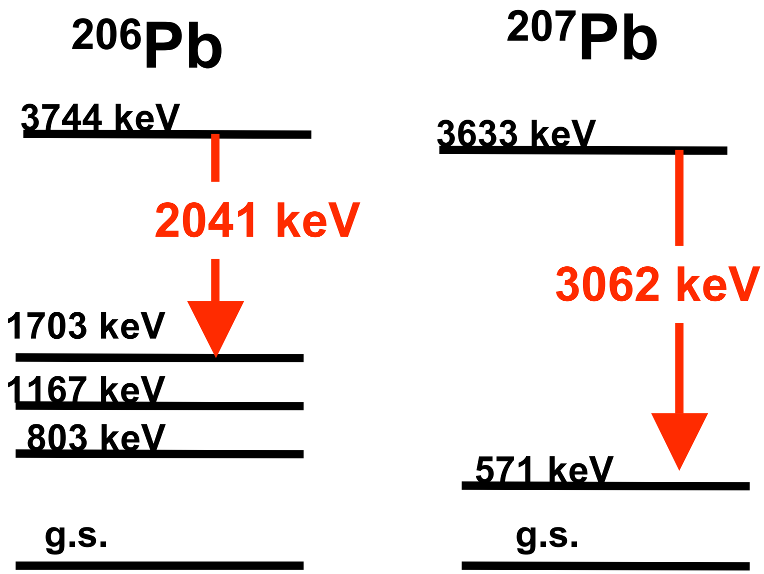
SEGA Mounting Structure

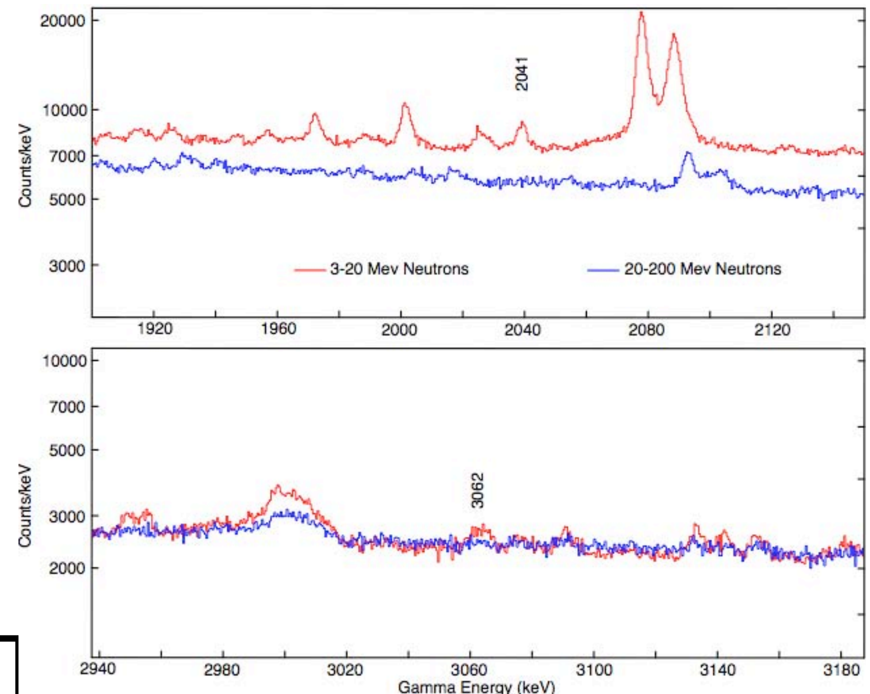


SEGA - Mount Prototype



New Levels of Sensitivity - New Backgrounds





Specific Pb γ rays are problematic backgrounds

^{206}Pb has a 2040-keV γ ray, and ^{207}Pb has a 3062-keV γ ray, backgrounds very close to the 2039-keV of 0νββ in ^{76}Ge

1. **Neutron interactions in Pb excite these levels**
2. **The DEP of the 3062 is a single-site energy deposit similar to 0νββ, hard to reject**
3. **Cross sections are poorly known and hence simulation codes poorly describe them**

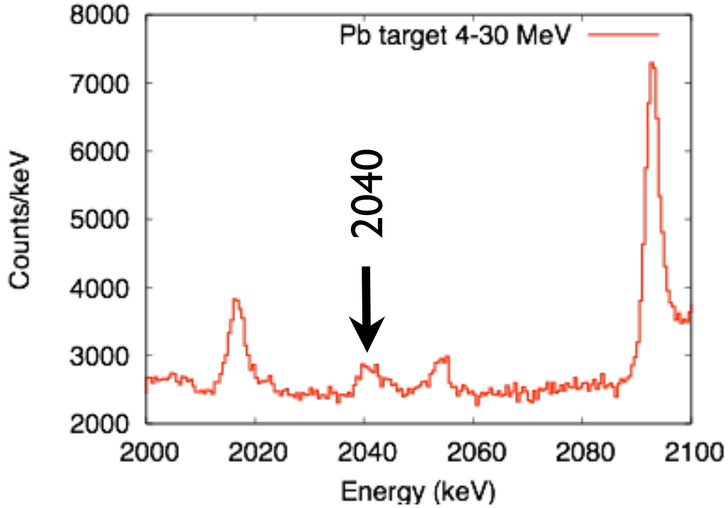
Neutron reaction studies

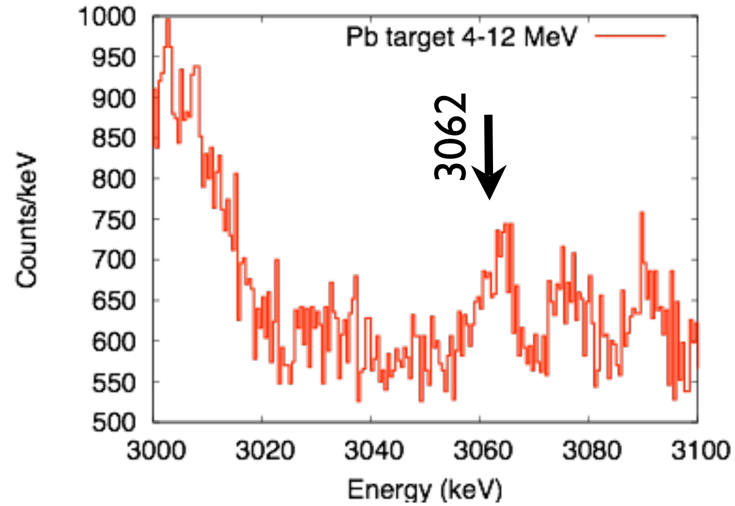
We discovered the lines and recognized their potential for creating background (arXiv:0704.0306)

We estimated the cross section

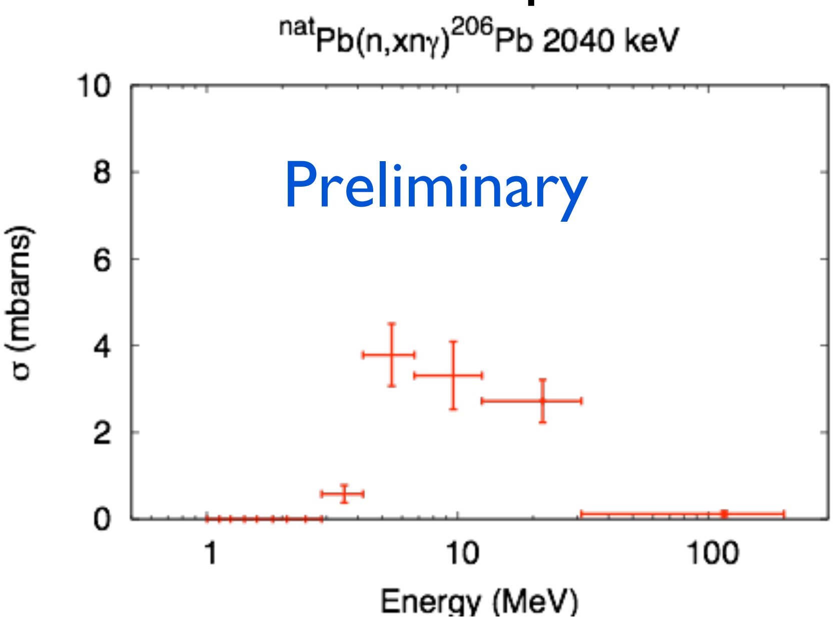
We initiated studies at LANSCE and TUNL to measure the cross sections with neutrons up to ~200 MeV in Pb, Cu and enriched Ge

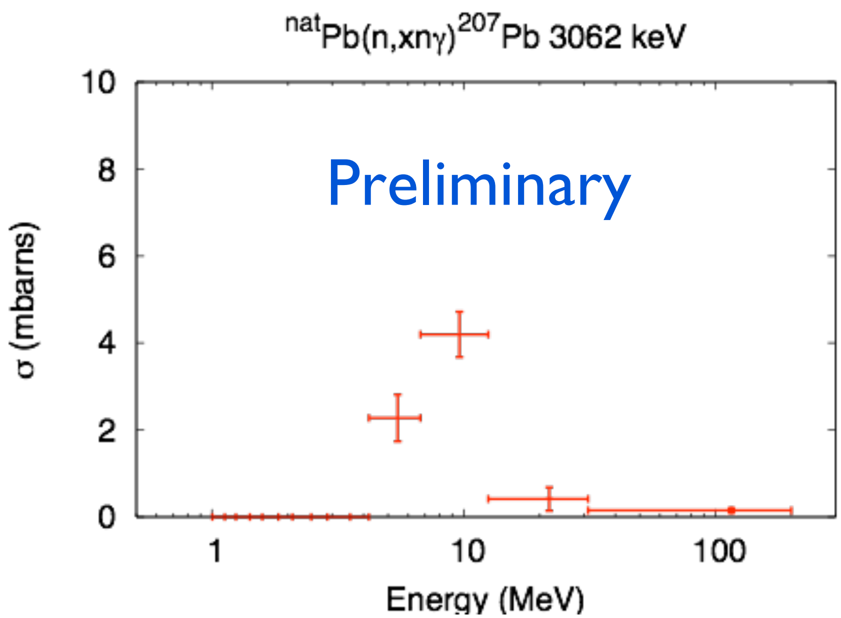
Neutron-induced backgrounds in Pb





Specific transitions in Pb evident





Material Screening

- Assay program progress
  - Ge low-background counters
    - Facilities identified.
    - Cross calibrating with “Table Mountain” rocks.
    - Micro-coax wire assayed (being analyzed).
    - HV vacuum feedthrough assayed (being analyzed).
    - Electroformed Cu to be counted at LNGS.
  - Neutron activation
    - Facilties identified.
    - Sample preparation procedures.
    - Irradiation of “standard pottery” and Parylene at UCD and NCSU.
    - Cross calibration.
  - ICPMS
    - Facilities identified

Material Screening - Gamma Facilities

Facility	Depth (mwe)	Detectors	Shielding	Volume[1]	Sensitivity/BG	Available	Sample Prep	Cost/Turn around time	Contact
LBNL Surface	0	115% n-type	Outer Pb, inner Cu, special 4π shielded room	7"x7"x12"	6-8 mBq/kg U/Th	Now	On-site, use Marinelli	\$200-\$500 ~days	Yuen-dat Chan Brian Fujikawa
LBNL Oroville	180	85% p-type	Low activity Pb, Cu UG > 12 yrs	7"x7"x12"	0.6-0.8 mBq/kg U/Th	Now	On-site, use Marinelli	\$600 ~weeks	Yuen-dat Chan Brian Fujikawa
WIPP	1600	22% n-type	8 in Pb in current setup[2]	6"x6"x12"	45 µBq/kg Ge @ 2615 keV	Now	TBD	\$800 (est) ~weeks	Steve Elliott Rob Johnson
PNNL	0	Detector 6B - 40% PNNL 17a - 29.1%	6B – commercial Pb, Cu 17a – LB Cu cryostat, Pb, Compton veto	17a: ~6"x6"x6" 6B: TBD	60 mBq/kg	6B – Now 17a – "Now"	On-site	\$500 (est) ~days	Elwood Lepel (6B) Marty Keillor (17a)
UW	0	53, 55% n-type	6 in Pb, 1 in Cu plate roof	7"x10"x16"	10s of mBq/kg U/Th (est)	Soon	On-site	Shipping & Handling ~days	Peter Doe Alexis Schubert
KURF	1450	Melissa – 52.2% VT1 – 35%	6 in Pb, Cu lining soon, possible Rn purge in future	Melissa: 16"x16"x18" VT1: TBD	9.4 mBq/kg Ge @ 1500-2500 keV 1.2 mBq/kg @ 2615 keV[3]	May 2008 (est)	TBD	Shipping & Handling ~weeks	Reyco Henning Padraic Finnerty Henning Back
LNGS[4]	3500	GeMPI-2 99%	>8in Pb, Rn purge, Cu lining, all have Cu cryostat, SS enclosure	Contact Matthias Laubenstein	30.9 µBq/kg Ge @ 100-2730 keV 0.45 µBq/kg @ 2615 keV	Now	You	Shipping & Handling ~wk-mon.	Matthias Laubenstein Henning Back

Material Screening - NAA

Facility	MNRC at UC Davis	Pulstar reactor at NCSU
Reactor Power	2 MW	1 MW
Neutron Flux	1.5×10^{13}	$4\text{-}8 \times 10^{12}$
Irradiation time	33 min	24 h
Sample Preparation	At Davis / LBNL	Anywhere
Cost per Sample	$674 + Gamma Counting	

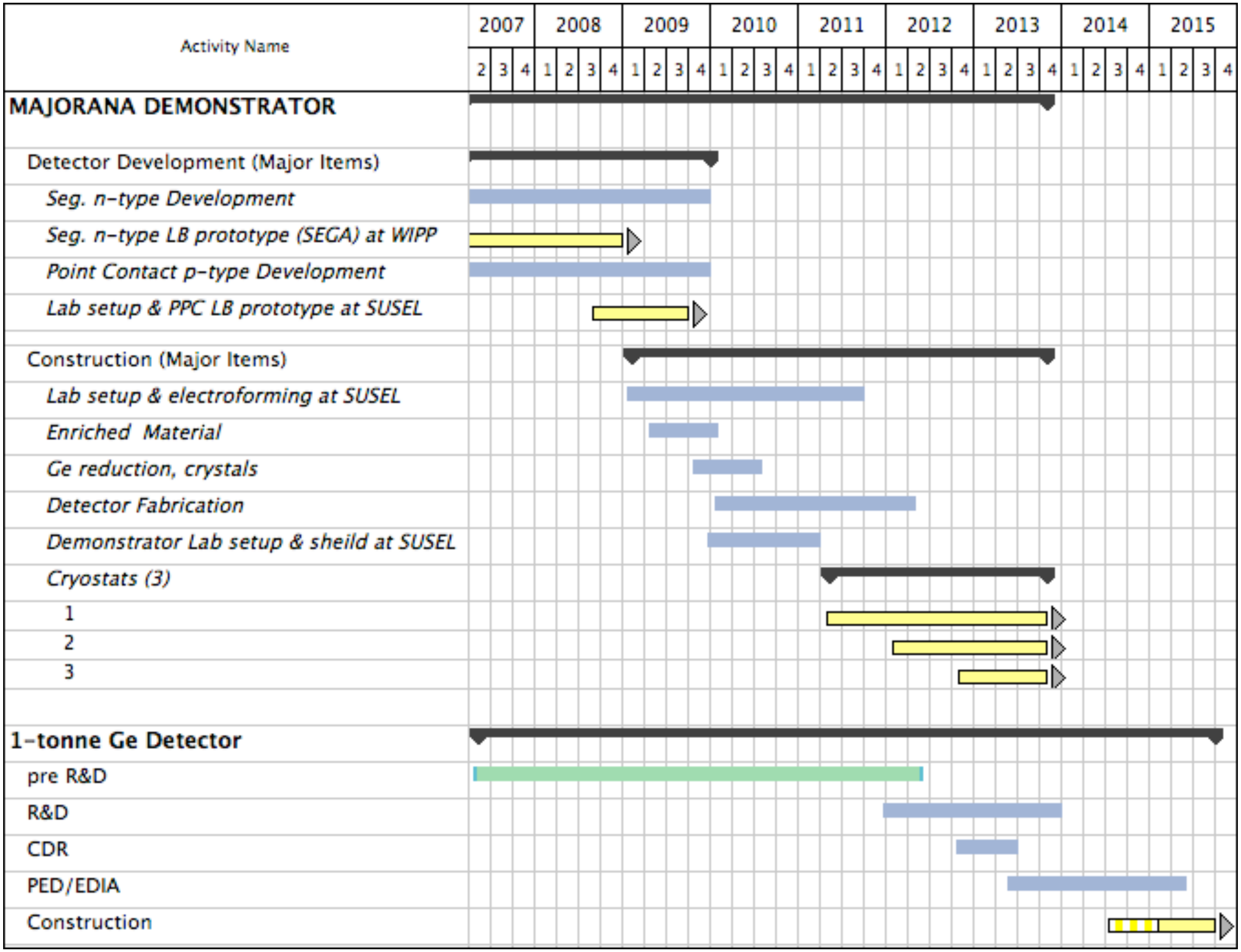
Material Screening - ICPMS

Facility	PNNL	Institute of Microelectronics Technology and High Purity Materials Russian Academy of Sciences	Institute for National Measurement Standards National Research Council of Canada
Location	USA	Russia (Chernogolovka)	Canada
Apparatus	ICP-MS, SIMS, LA-ICP-MS, ICP-OES	ICP-MS, SS-MS, ICP-AES	ICP-MS**,** GD-MS
Sensitivity	0.15 pg/g Th, U	6 ppt (Th), 2 ppt (U)	ICP-MS EXO Lead: 1.5 ppt (Th), 0.5 ppt (U) GD-MS EXO Lead: 4.0 ppt (Th), 4.0 ppt (U)
Cost per sample	$3000	~$100 + ~$150 FedEx/DHL	GD-MS Costs: 635 $CDN ICP-MS Costs: TBD

Ge Processing

- Discussions with UMICORE held
  - to assist MAJORANA in setting up a facility to purify the enriched Ge, and make the first zone refinement to intrinsic Ge bars to deliver to the crystal pulling facility
- We are permitted to get former employees of Eagle Picher (bought by UMICORE) to share their experience.
- A meeting on refinement is being organized at ORNL for next month.
- Our intention is to build our own line.

MAJORANA Projected Schedule
(optimal funding)



The MAJORANA Collaboration

Note: Red text indicates students

Duke University, Durham, North Carolina , and TUNL
James Esterline, Mary Kidd, Werner Tornow

Institute for Theoretical and Experimental Physics, Moscow, Russia
Alexander Barabash, Sergey Konovalov,
Igor Vanushin, Vladimir Yumatov

Joint Institute for Nuclear Research, Dubna, Russia
Viktor Brudanin, Slava Egorov, K. Gusey, S. Katulina,
Oleg Kochetov, M. Shirchenko, Yu. Shitov, V. Timkin,
T. Vvlov, E. Yakushev, Yu. Yurkowski

Lawrence Berkeley National Laboratory, Berkeley, California and the University of California - Berkeley
Yuen-Dat Chan, Mario Cromaz, Jason Detwiler, Brian Fujikawa, Bill Goward, Donna Hurley, Kevin Lesko, Paul Luke,
Alan Poon, Gersende Prior, Craig Tull

Lawrence Livermore National Laboratory, Livermore, California
Dave Campbell, Kai Vetter

Los Alamos National Laboratory, Los Alamos, New Mexico
Steven Elliott, Gerry Garvey, Victor M. Gehman, Vincente Guiseppe, Andrew Hime, Bill Louis, Geoffrey Mills, Kieth Rielage, Larry Rodriguez, Laura Stonehill, Richard Van de Water, Hywel White, Jan Wouters

North Carolina State University, Raleigh, North Carolina and TUNL
Henning Back, Lance Leviner, Albert Young

Oak Ridge National Laboratory, Oak Ridge, Tennessee
Cyrus Baktash, Jim Beene, Fred Bertrand, Thomas V. Cianciolo, David Radford, Krzysztof Rykaczewski, Chang-Hong Yu

Osaka University, Osaka, Japan
Hiroyasu Ejiri, Ryuta Hazama, Masaharu Nomachi, Shima Tatsuji

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Craig Aalseth, James Ely, Tom Farmer, Jim Fast, Eric Hoppe, Brian Hyronimus, David Jordan, Marty Keillor, Jeremy Kephart, Richard T. Kouzes, Harry Miley, John Orrell, Jim Reeves, Robert Runkle, Bob Thompson, Ray Warner, Glen Warren

Queen's University, Kingston, Ontario
Fraser Duncan, Art McDonald

University of Alberta, Edmonton, Alberta
Aksel Hallin

University of Chicago, Chicago, Illinois
Phil Barbeau, Juan Collar, Charles Greenberg, Brian Odom, Nathan Riley

University of North Carolina, Chapel Hill, North Carolina and TUNL
Melissa Boswell, Padraic Finnerty, Reyco Henning, Michael Ronquest

University of South Carolina, Columbia, South Carolina
Frank Avignone, Richard Creswick, Horatio A. Farach, Todd Hossbach

University of South Dakolta, Vermillion, South Dakota
Tina Keller, Dongming Mei, Zhongbao Yin

University of Tennessee, Knoxville, Tennessee
William Bugg, Yuri Efremenko

University of Washington, Seattle, Washington
John Amsbaugh, Tom Burritt, Peter J. Doe, Jessica Dunmore, Alejandro Garcia, Mark Howe, Rob Johnson, Michael Marino, R. G. Hamish Robertson, Alexis Schubert, Brent VanDevender, John F. Wilkerson