GERMANIUM DETECTOR ARRAY

A search for neutrinoless double beta decay

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Neutrino Properties

Simplest explanation for observations by 3-neutrino flavor mixing

Quark Mixings

Weakly interacting and mass eigenstates are independant basis

$$\begin{bmatrix} |d'\rangle \\ |s'\rangle \\ |b'\rangle \end{bmatrix} = \begin{bmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{bmatrix} \begin{bmatrix} |d\rangle \\ |s\rangle \\ |b\rangle \end{bmatrix}$$

$$V_{ij} = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}c_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{bmatrix}$$

Neutrino Properties

Simplest explanation for observations by 3-neutrino flavor mixing

Neutrino Mixings

Weakly interacting and mass eigenstates are independant basis

$$\begin{bmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \end{bmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{bmatrix} |m_1\rangle \\ |m_2\rangle \\ |m_3\rangle \end{bmatrix}$$

$$U_{\nu i} = \begin{bmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta_{13}} \\ -s_{12}c_{23} - c_{12}s_{23}s_{13}e^{i\delta_{13}} & c_{12}c_{23} - s_{12}s_{23}s_{13}e^{i\delta_{13}} & s_{23}c_{13} \\ s_{12}c_{23} - c_{12}c_{23}s_{13}e^{i\delta_{13}} & -c_{12}s_{23} - s_{12}c_{23}s_{13}e^{i\delta_{13}} & c_{23}c_{13} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & e^{i\frac{\alpha_{21}}{2}} & 0 \\ 0 & 0 & e^{i\frac{\alpha_{31}}{2}} \end{bmatrix}$$

Neutrino Properties

Observed Properties

Two mass differences

- $m_2^2 - m_1^2 = \Delta m_\odot^2$
- $|m_1^2 - m_3^2| = \Delta m_{atm}^2$

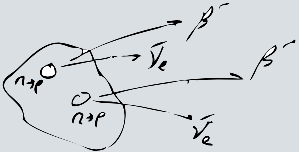
Two mixing angles

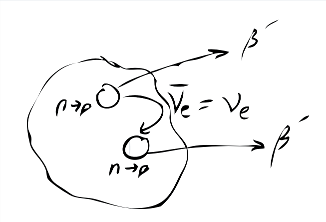
- $\theta_{12} = \theta_\odot$ and $\theta_{23} = \theta_{atm}$

and an upper limit on θ_{13}

Still Missing

- Value of the third mixing angle
- Absolute mass scale
- Mass hierarchy
- CP violating phases
- Nature of the neutrino mass (Majorana or Dirac)





Neutrinoless Double Beta Decay

Effective Majorana Neutrino Mass

$2\nu\beta\beta$ $(A, Z) \rightarrow (A, Z+2) + 2e^- + 2\bar{\nu}_e$

SM allowed and observed in many isotopes.

$0\nu\beta\beta$ $(A, Z) \rightarrow (A, Z+2) + 2e^-$

$\Delta L = 2$

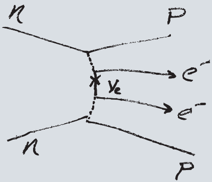
Half-life

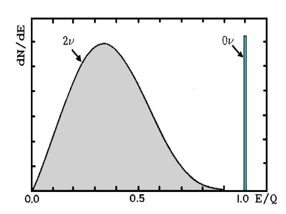
$$(\mathrm{T}^{0\nu}_{1/2})^{-1} = \mathrm{G}^{0\nu} \cdot |\mathrm{M}^{0\nu}|^2 \cdot \langle m_{\beta\beta} \rangle^2$$

$\mathrm{G}^{0\nu}$: Phase space integral

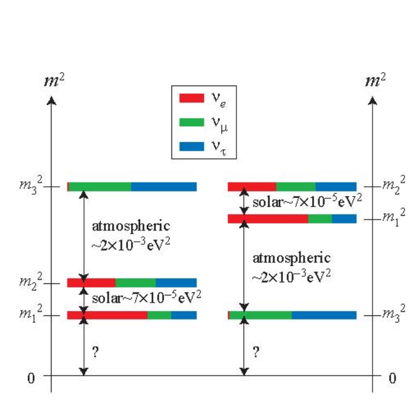
$\mathrm{M}^{0\nu}$: Nuclear matrix elements

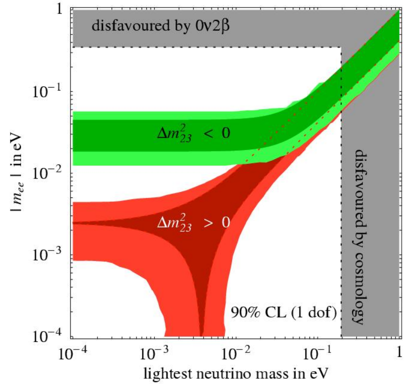
$\langle m_{\beta\beta} \rangle^2 = |\sum_i U_{ei}^2 m_{\nu_i}|^2$





The Hierarchy Problem



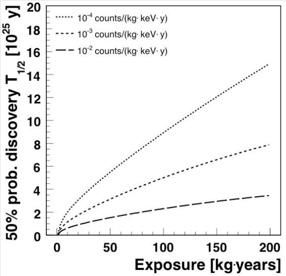


F. Feruglio *et al.*, Nucl. Phys. B 637(2002)

Searching in ^{76}Ge

Experimental Design Considerations

- Large target mass & long exposures
- Extreme low background levels
- High signal efficiency



Advantages of Germanium

- Source $\leftrightarrow$ Detector
  High signal efficiency $\sim$ 85–95%
- Ultrapure material, High Purity Ge
- High resolution (FWHM $\sim$0.1-0.2%)
  Helps to reduce background from $2\nu\beta\beta$
  and avoid γ's from the Compton continuum.
- Vast experience base

http://periodictable.com

Disadvantages

- $Q_{\beta\beta}$=2039 keV, still plenty of γ's
- Enrichment is possible, but expensive!
- Limited sources of crystal & detector manufacturers

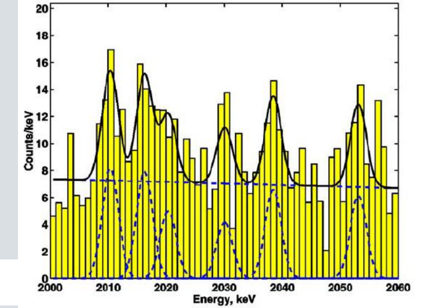
GERDA

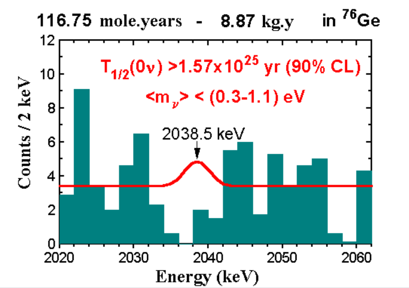
Previous ^{76}Ge Experiments

	HdMo	IGEX		
Location	LNGS	Homesteak	Baksan	Canfranc
Overburden [m.w.e.]	3800	4000	660	2450
Exposure [kg · yr]		2.4	2.5	4.0
	71.1		8.9	
Bg [counts/kg·keV·yr]	0.11		0.17	
$T_{1/2}$ limit (90% CL)[yr]	1.9×10^{25}		1.57×10^{25}	

"Evidence for $0\nu\beta\beta$" $0.69 - 4.18 \times 10^{25}$ [yr] 3σ

H.V. Klapdor-Kleingrothaus, *et. al*, Phys. Lett. B 586 (2004) 198-212



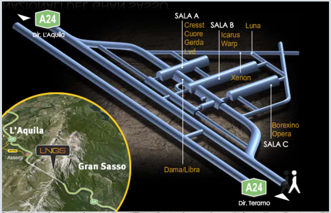


GERDA Collaboration

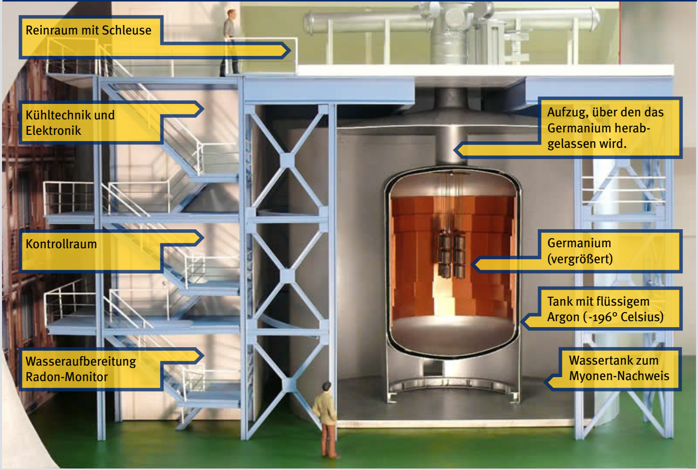
INFN Laboratori Nazionali del Gran Sasso, Assergi, Italy
Institute of Physics, Jagellonian University, Cracow, Poland
Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Germany
Joint Institute for Nuclear Research, Dubna, Russia
Institute for Reference Materials and Measurements, Geel, Belgium
Max-Planck-Institut für Kernphysik, Heidelberg, Germany
Dipartimento di Fisica, Universitá Milano Bicocca, Milano, Italy
INFN Milano Bicocca, Milano, Italy
Dipartimento di Fisica, Universitá degli Studi di Milano e INFN Milano, Milano, Italy
Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, Russia
Institute for Theoretical and Experimental Physics, Moscow, Russia
Russian Research Center Kurchatov Institute, Moscow, Russia
Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany
Physik Department E15, Technische Universität München, Germany
Dipartimento di Fisica dell'Universitá di Padova, Italy
INFN Padova, Padova, Italy
Shanghai Jiaotong University, Shanghai, China
Physikalisches Institut, Eberhard Karls Universität Tübingen, Germany
Physik Institut der Universität Zurich, Switzerland

100 Members
19 Institutes
7 Countries

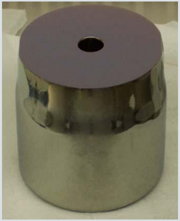
GERDA Experiment at LNGS

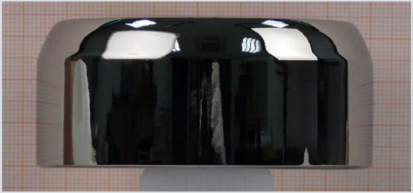


GERDA-Experiment



GERDA Detectors





Phase I

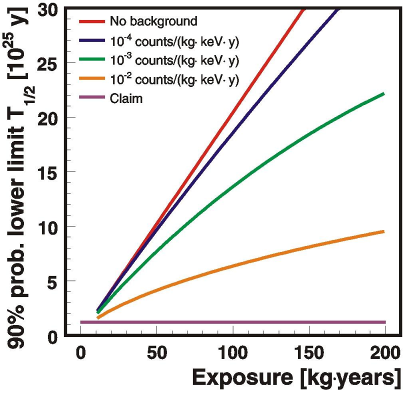
- 3 IGEX & 5 HdMo Detectors 17.9 kg
- (6 non-enriched Genius-TF for reference)

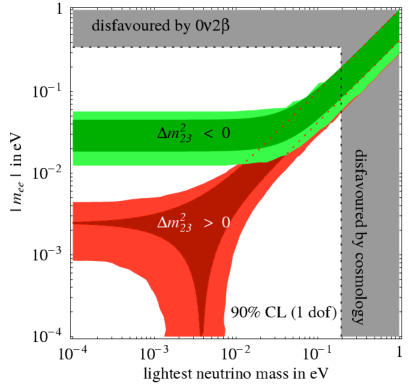
Phase II

- 35 kg 6N enriched Ge Metal
- 18 kg Detector slices expected for BEGe diode production
- IKZ Crystal pulling R&D for segmented detectors

GERDA Physics Goal

Phase	I	II	Ton Scale
Exposure [kg·yr]	15	100	$>$1000
Bg [counts/kg·keV·yr]	10^{-2}	10^{-3}	10^{-4}
Upper limit $m_{\beta\beta}$[eV]	0.23-0.39	0.09-0.15	$\sim$0.05
A. Smolnikov, P. Grabmayr			Merge
PRC 81 028502(2010)			with Majorana

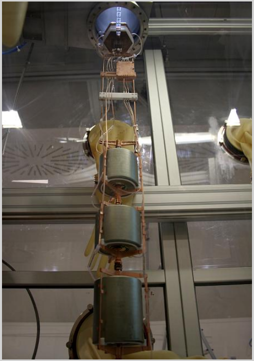




Background Measurements

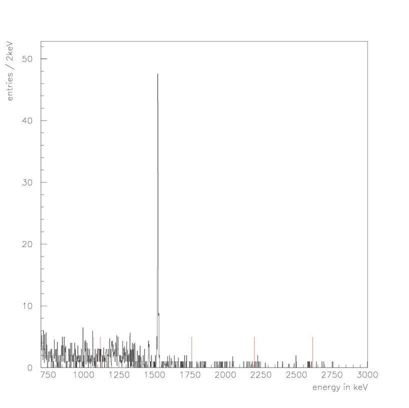
Commissioning Lock PLC

Natural Genius-TF Detectors



Background Measurements

First Discovery!



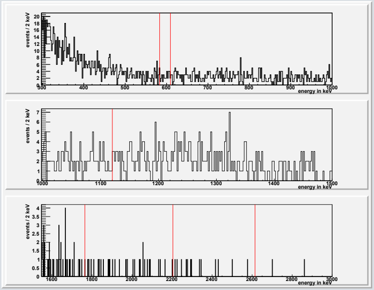
Sum of two detectors (5.3 kg) for 1 month

Red lines indicate U/Th chain line energies, $< 10^{-3}$cts/kg·keV·yr

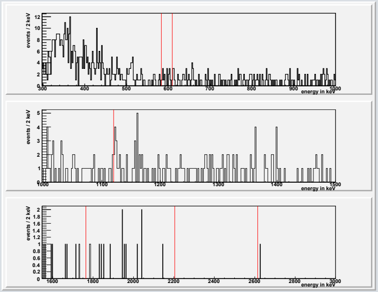
line rate 2.1 counts/kg·day, evidence of ^{42}K ions $\sim$ 50 times expected

Background Measurements

Outer shroud: 760 mm ϕ copper foil
Inner shroud: 113 mm ϕ copper foil



Outer: Floating Voltage

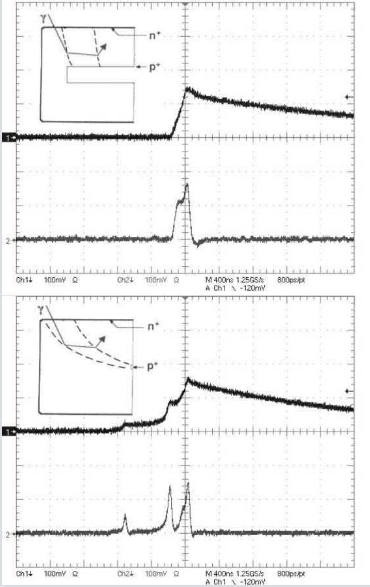


Outer @ -400V ; Inner @ 0 V
BG index 0.08$\pm$0.03 cnt/kg$\cdot$yr$\cdot$keV

$\sim$17 days sum of three detectors (7.6 kg)
Red lines indicate dominant gamma energies from U/Th chains

Background Identification

- Time structure of the charge signal: Pulse Shape Analysis



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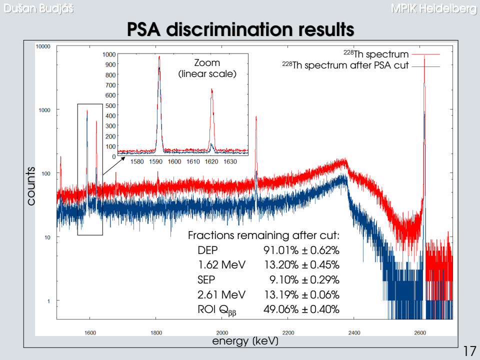

D. Budjáš *et al.*, J INST 4 P10007(2009)

- Granulation/Segmentation: 18 fold-segmented n-type detectors
- Liquid Argon Veto Instrumentation

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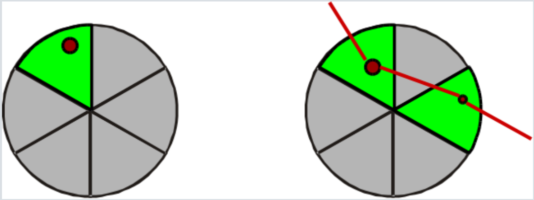

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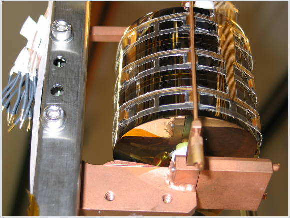

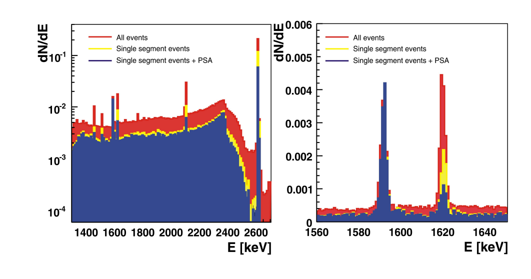

I. Abt *et al.* EPJ C 52(2007)
I. Abt *et al.* NIM A 583(2007)

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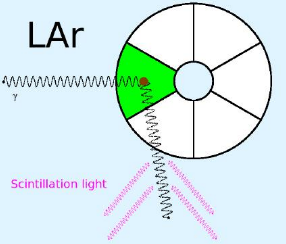

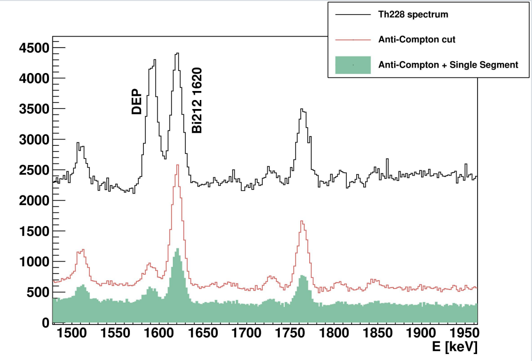

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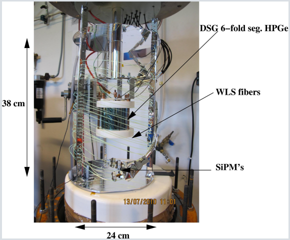
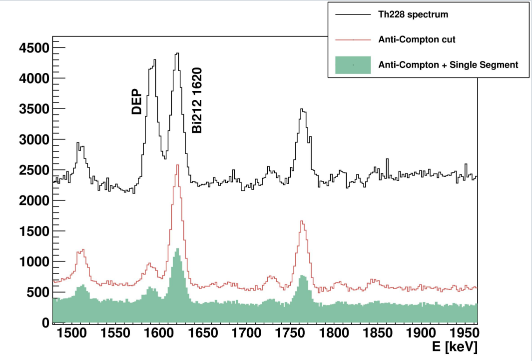


J. Janisckó-Csáthy *et al.*, arXiv:1011.2748v1 [physics.ins-det]



Phase II Detector Production

- Purchase Enriched $^{76}GeO_2$: ECP Zelenogorsk, RU

- Metal Reduction and Zone Refinement: Langelsheim, DE 08.03.2010 to 30.4.2010
- Crystal Pulling at Canberra: Oakridge, TN, USA
- BEGe Detector Diode Production: Olen, BE
- Crystal Pulling Institut für Kristallzüchtung: Berlin, DE
- Segmented Detector Diode Production: Lingolsheim, Fr

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  35.5 kg Enriched HPGe 6N material
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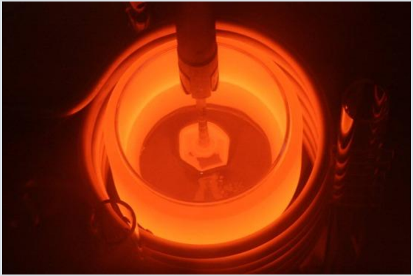

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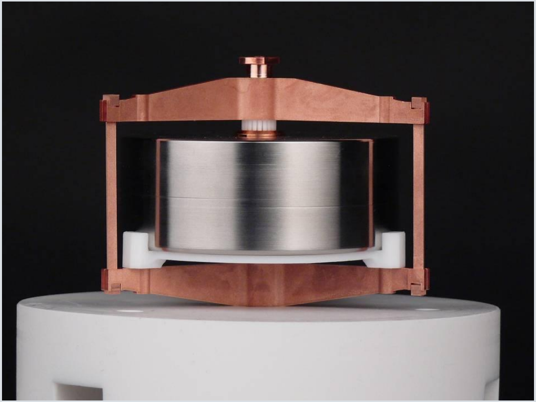

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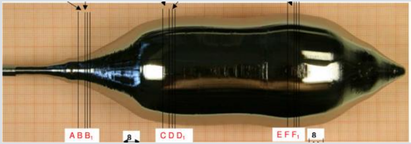

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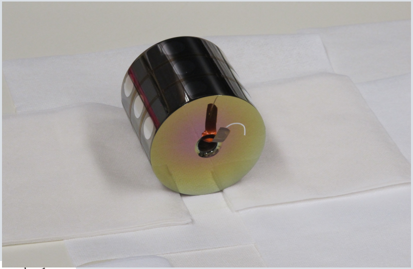
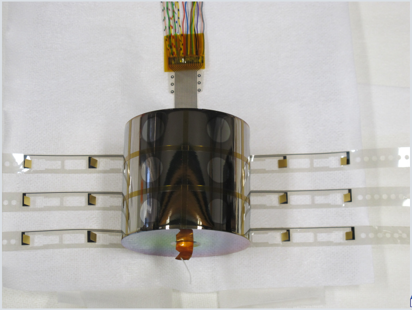
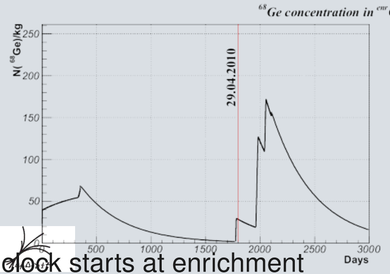
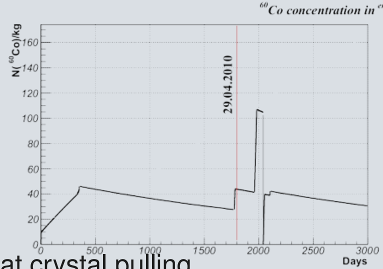




Production Chain Worldwide



clock starts at enrichment



at crystal pulling

Production Chain Worldwide

Conclusions

- Phase I well on the way to confirming or refuting the $0\nu\beta\beta$ claim
- Phase II will show the feasibility of a ton scale experiment by demonstrating the following techniques:
  - Shielding $\rightarrow$ a graded approach with detectors operated bare in LAr
  - Selection $\rightarrow$ Careful screening of all materials placed inside the cryostat.
  - Identification $\rightarrow$ PSA/Segmentation/Active veto
- In the case of a null result the GERDA and Majorana experiences will be combined for the ton scale experiment.