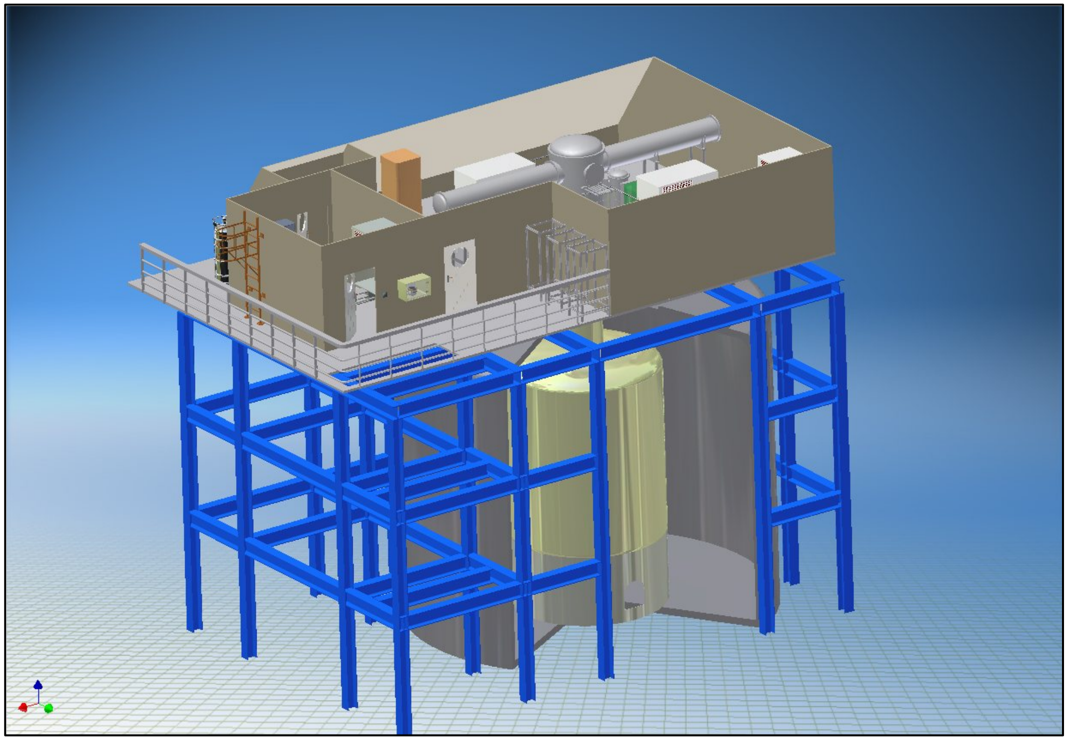
The GERDA experiment



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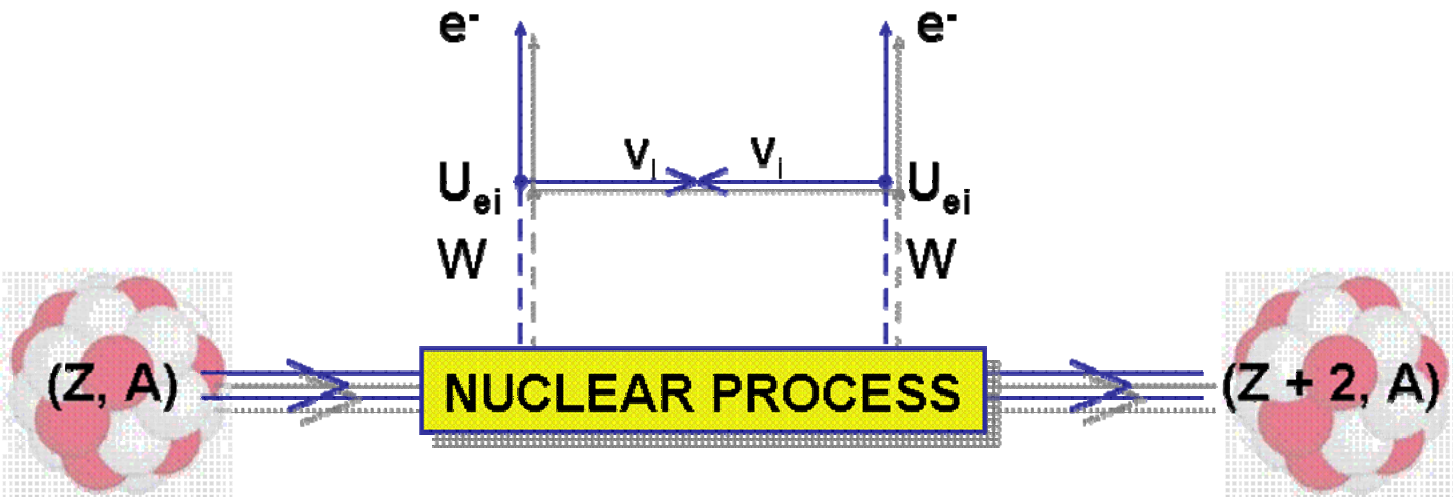
Thanks for further help from: Daniel Kollár, Olaf Reimann, David Fink and the mechanical workshop

OUTLINE

- Motivation: neutrinoless double beta-decay
- The principles of the GERDA experiment
- Status of detector development
- Status of infrastructure



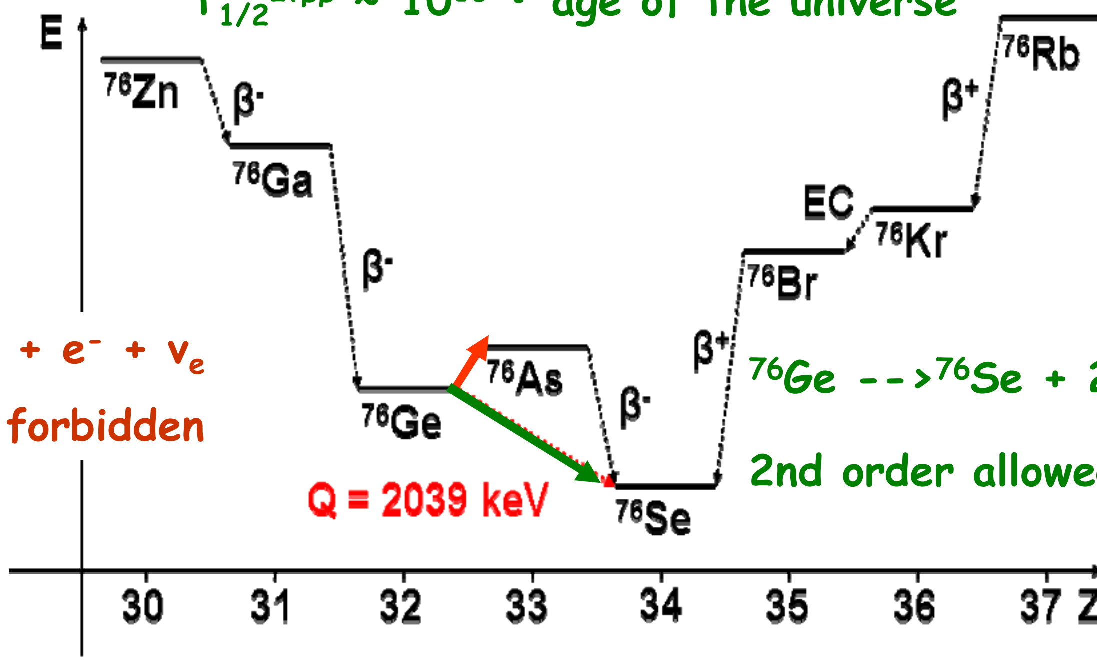
Double Beta Decay (of ^{76}Ge)

- Initial state nucleus has to be bound less than final state nucleus, but stronger than intermediate.
- Only possible in even-even nuclei.
- 35 isotopes decay via $2\nu\beta\beta$

$T_{1/2}^{2\nu\beta\beta} \sim 10^{10} \cdot$ age of the universe

$^{76}Ge \rightarrow ^{76}As + e^- + \nu_e$

energetically forbidden



$^{76}Ge \rightarrow ^{76}Se + 2e^- + 2\nu_e$

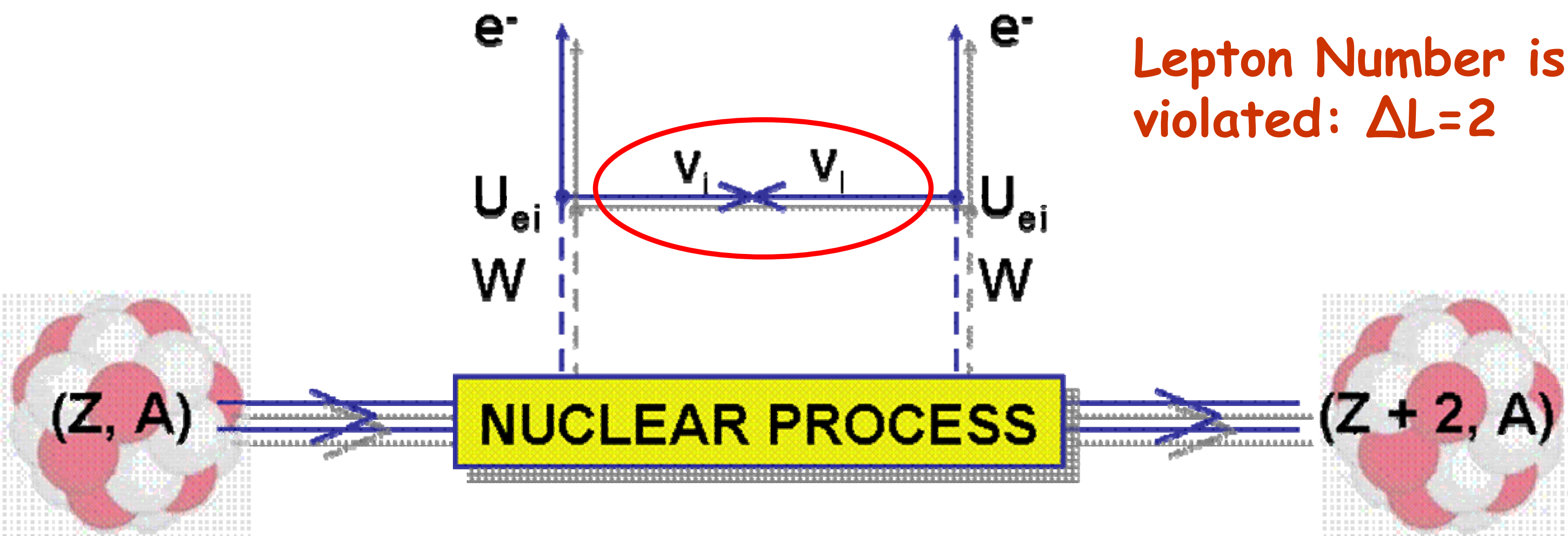
2nd order allowed weak process

Neutrinoless Double Beta Decay

- Neutrino is identical with its antiparticle (Majorana particle)
- Neutrino is massive (helicity flip required)

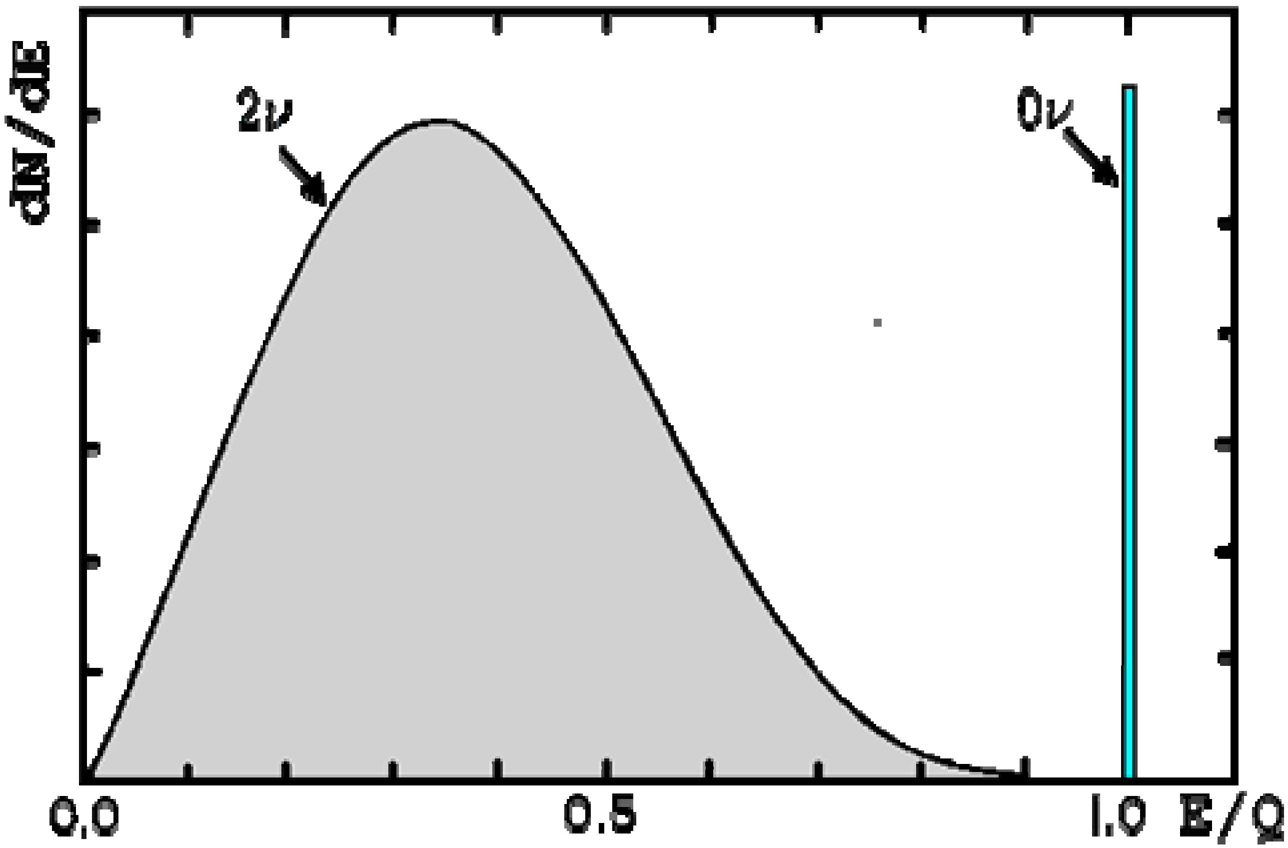
$$1/\tau = G(Q,Z)\ |M_{nucl}|^2\ \langle m_{ee}\rangle^2$$

0νββ Decay rate	Phase space factor (~Q^5)	Matrix element	Effective Majorana Neutrino mass



Lepton Number is violated: ΔL=2

Neutrinoless Double-Beta Decay Signature



Signature: Sharp peak at Q-value of the decay (2039 *keV* for ^{76}Ge)

Neutrinos: Unanswered Questions

We know that neutrinos must have a mass, but:

1. What is the absolute mass scale?
2. Which hierarchy do neutrino masses have?
3. Is the neutrino a Majorana type or Dirac type particle?
4. What are the CP phases in the mass matrix?
5. What is the mixing angle Θ_{13}?

Questions 1.-3. and partly question 4. could be solved with the help of neutrinoless double-beta decay

Sensitivity of 0νββ-experiments

The observable of neutrinoless double beta decay experiments is its half-life. $T_{1/2}^{0\nu\beta\beta} \gtrsim 10^{15} \cdot$ age of the universe

Figure of merit for a limit sensitivity for experiment with background:

$$T_{1/2} \propto a\,\varepsilon\sqrt{\frac{M\,t}{b\,\delta E}}$$

M	active target mass of the experiment	Increase target mass
b	background of the experiment	Minimize and select material
a	enrichment of isotope under consideration (< 1.0)	Use isotope with high natural abundance or enrich material
ε	signal detection efficiency (<1.0)	
δE	Energy resolution	
t	Measuring time (< 20y)	

Most dangerous background sources

Cosmic Rays: muons and products from showers

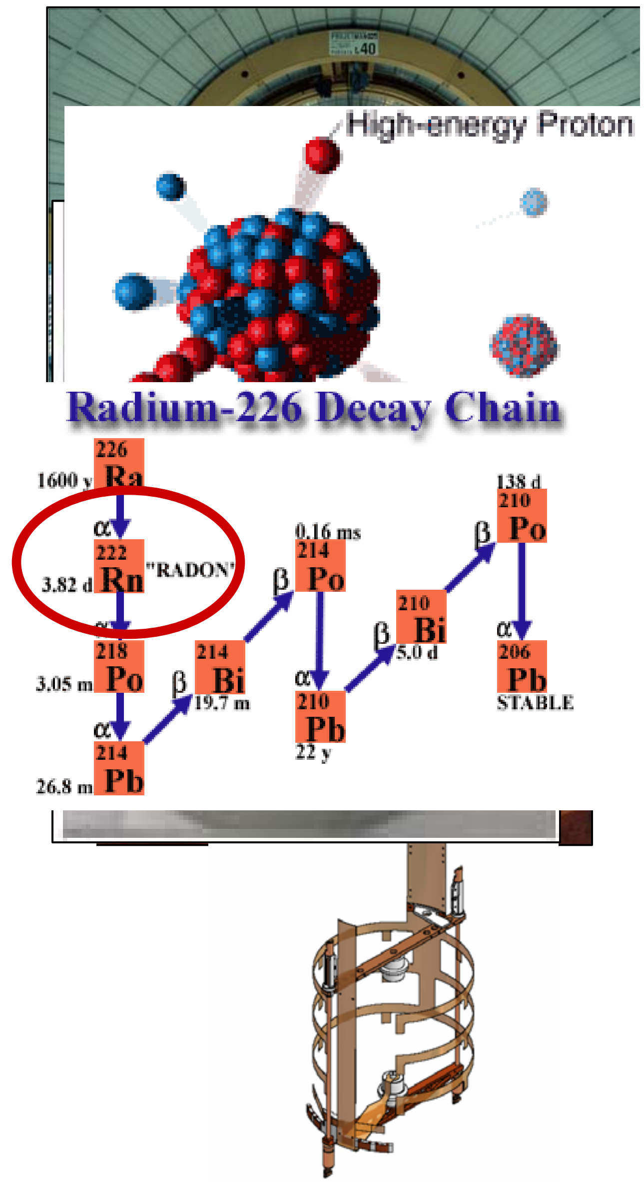
Natural radioactivity from the surrounding: Gammas and neutrons from rock, etc.

Natural radioactivity of the materials used for infrastructure and detector system: Gammas

Internal and surface contaminations of the detector: Gammas, betas, alphas

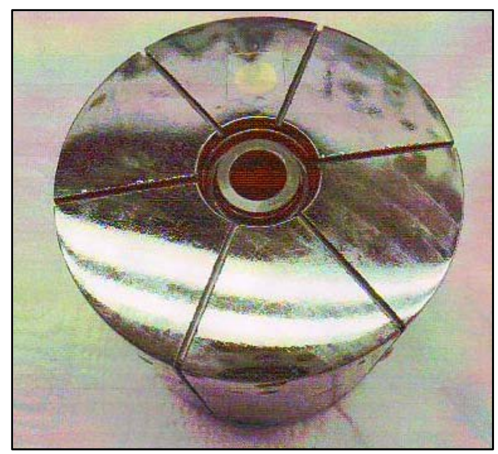
Cosmogenically produced long lived isotopes inside the germanium and the surrounding materials

Radon from the tunnel air



High Purity Germanium detectors

Very good energy resolution	Background due to 2νββ decay negligible
Source = Detector	High signal detection efficiency (95%)
Very high purity of detector material (zone refinement)	Very low intrinsic background
Considerable experience	Well known and reliable, improvements possible
Natural abundance of ^{76}Ge 7,44%	Enrichment necessary



Results from HPGe experiments

Heidelberg-Moscow Experiment:

11.5 kg of enriched Ge detectors

71.7 kg yrs of data

0.11 Counts/(kg keV y) around 2040 keV

--> Upper limit:

$T_{1/2} \geq 1.9 * 10^{25}$ years (90% C.L.)

4.2 σ claim: $T_{1/2} = 1.19 * 10^{25}$ years

--> $\langle m_{ee} \rangle$ = 440 *meV* (KK matrix el.)

IGEX Experiment:

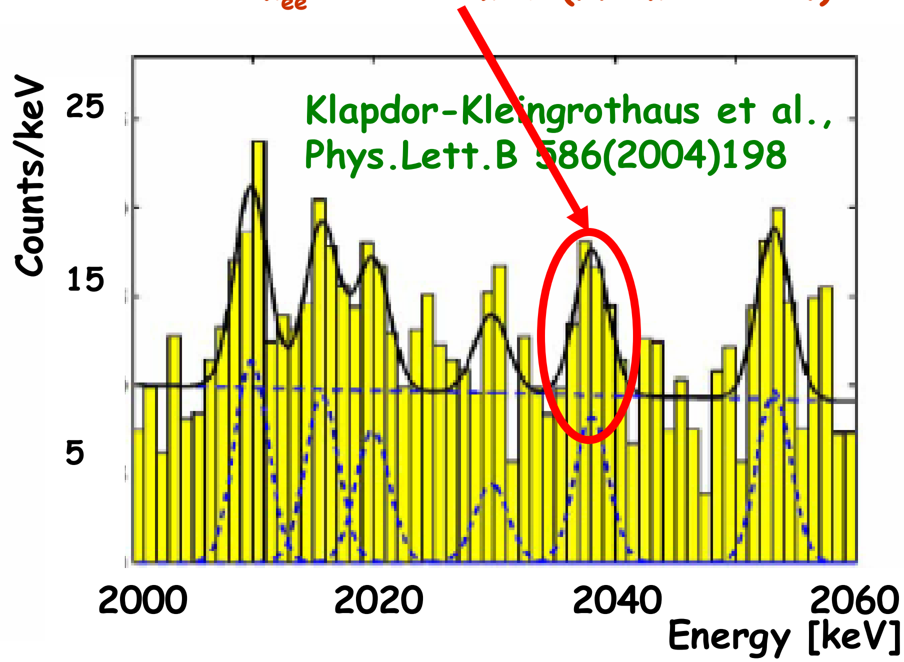
6.8 kg of enriched Ge detectors

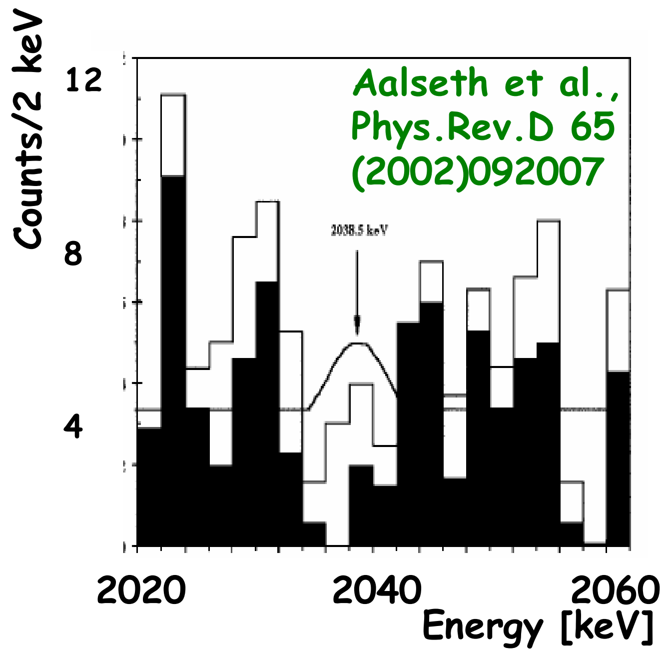
117 mol yrs of data

0.17 Counts/(kg keV y) around 2040 keV

--> Upper limit:

$T_{1/2} \geq 1.6 * 10^{25}$ years (90% C.L.)





GERmanium Detector Array: GERDA

Increase sensitivity in order to confirm or refute the claim

--> Reduce bkg-index by at least two orders of magnitude to 10^{-3} Cts/(kg keV year)

--> Increase target mass

The principle idea of the GERDA experiment:

Use the cryo-liquid as cooling medium and shield simultaneously:

--> Radioactive background can be drastically reduced

- LN and LAr can be produced with very high purity
- Material of conventional cryostat is removed from detector surrounding

G. Heusser, Ann. Rev. Nucl. Part. Sci. 45(1995)543

The GERDA collaboration

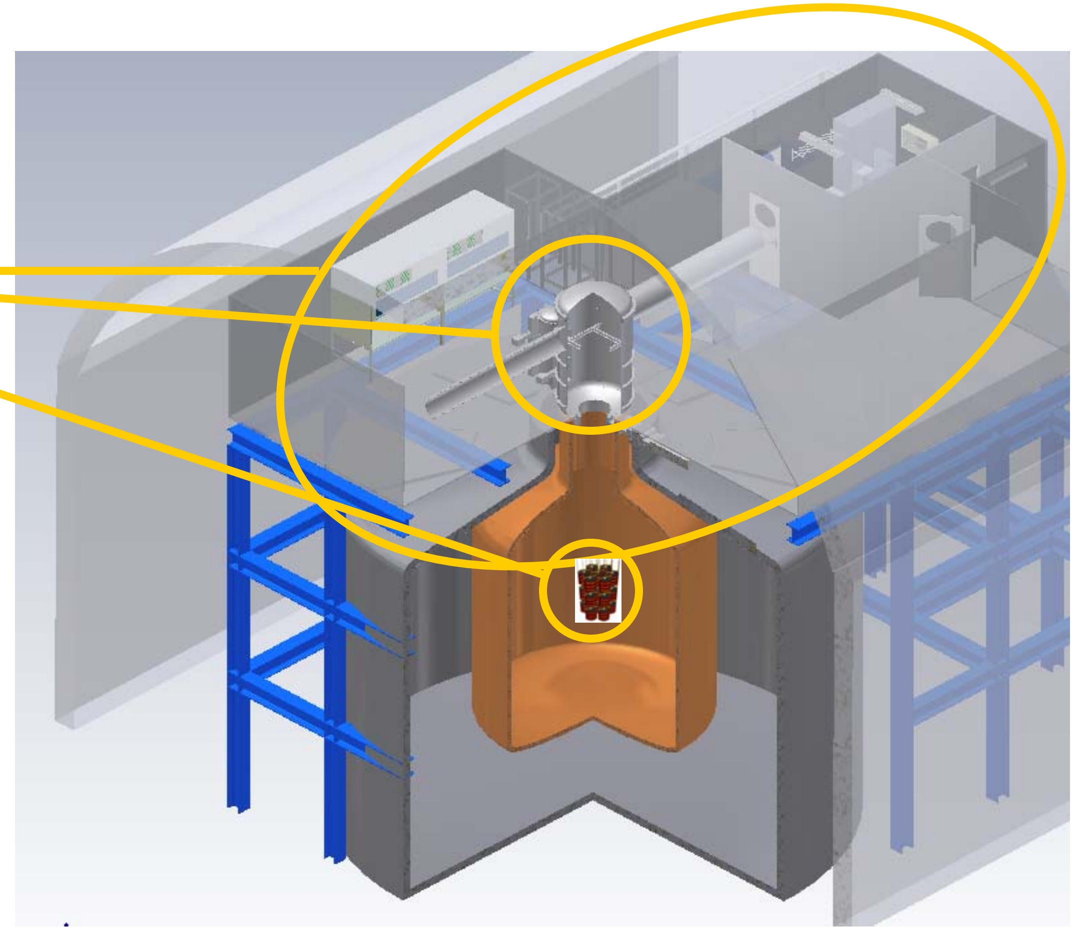
Belgium:
IMMR, Geel, Belgium

Germany:
MPIK, Heidelberg
Univ. Köln
MPI, München
Univ. Tübingen

Italy:
INFN LNGS, Assergi
Univ. di Milano e INFN
Univ. di Padova e INFN

Poland:
Jagiellonian University, Krakow

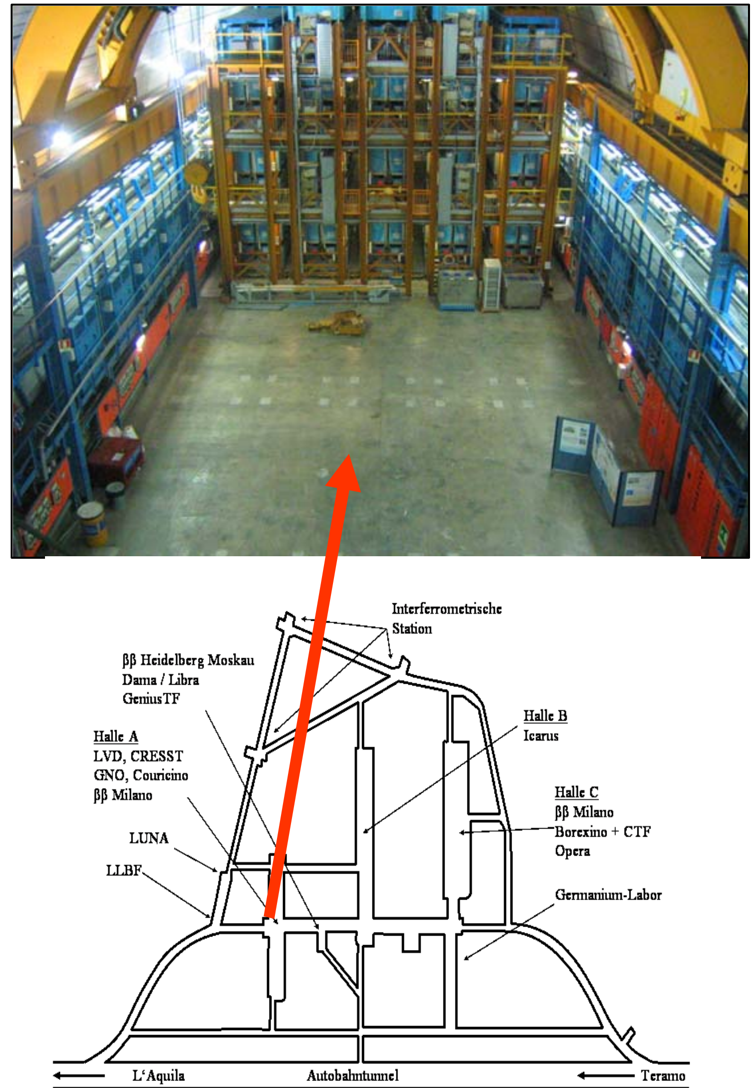
Russia:
INR, Moscow
JINR Dubna
ITEP Physics, Moscow
Kurchatov Institute, Moscow



GERDA location: Gran Sasso, Italy

1400 m rock overburden : 3800 mwe

View from the CRESST hut :



LNGS-INFN: Experiment approved

Construction work has started (hall A)

GERmanium Detector Array: GERDA

	Phase I	Phase II
Target mass of enriched material [kg]	18 kg from Hd-Mo and IGEX detectors	Additional 20 kg
Envisioned background [Counts/(kg keV y)]	0.01 (limited by cosmogenic ^{60}Co)	0.001 (improvement by segmentation and further material selectinos)
Exposure	15 kg y	100 kg y
	Confirm or refute claim	Push sensitivity Discov. potential: $T_{1/2} \approx 5 \cdot 10^{25}$ yrs, Limit setting: to $1.5 \cdot 10^{26}$ yrs. For Rodin et al. matrix element, mass sensitivity about 200 meV

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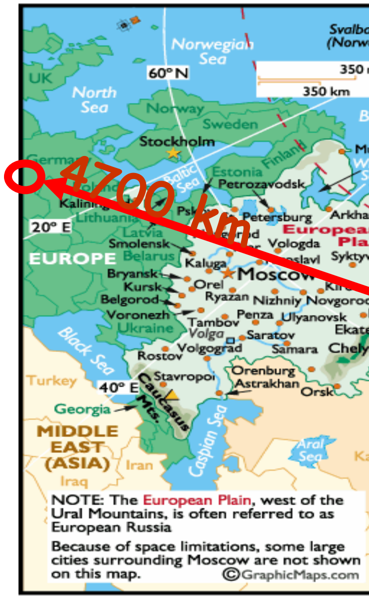
Phase II: 37.5 kg of enriched ^{76}Ge

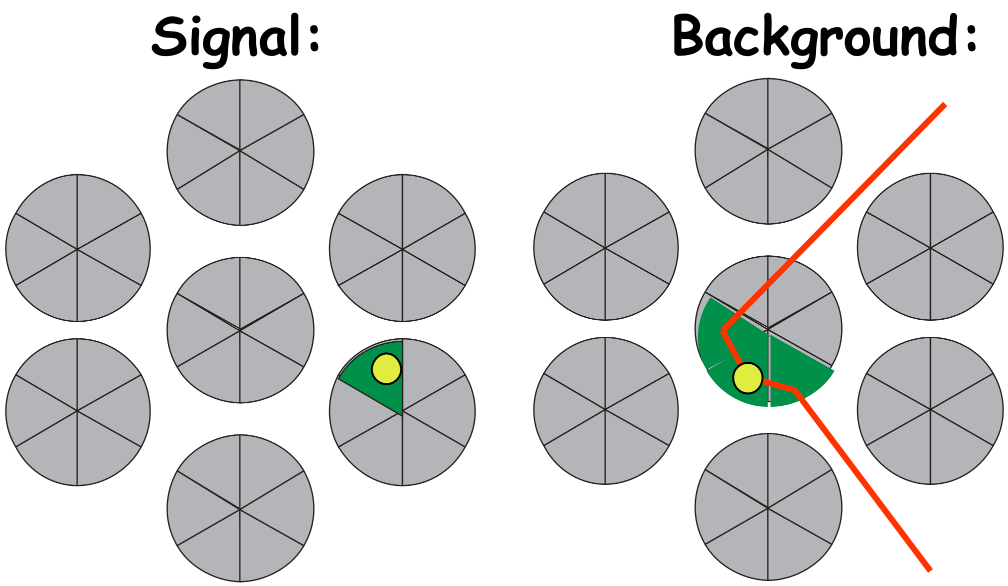
37,5 kg of enriched ^{76}Ge have been shipped to Munich and are now stored underground



PhaseII: Segmentation of detectors:

Germanium detectors can be segmented

--> Background identification through identification of multiply Compton-scattered photons by coincidences



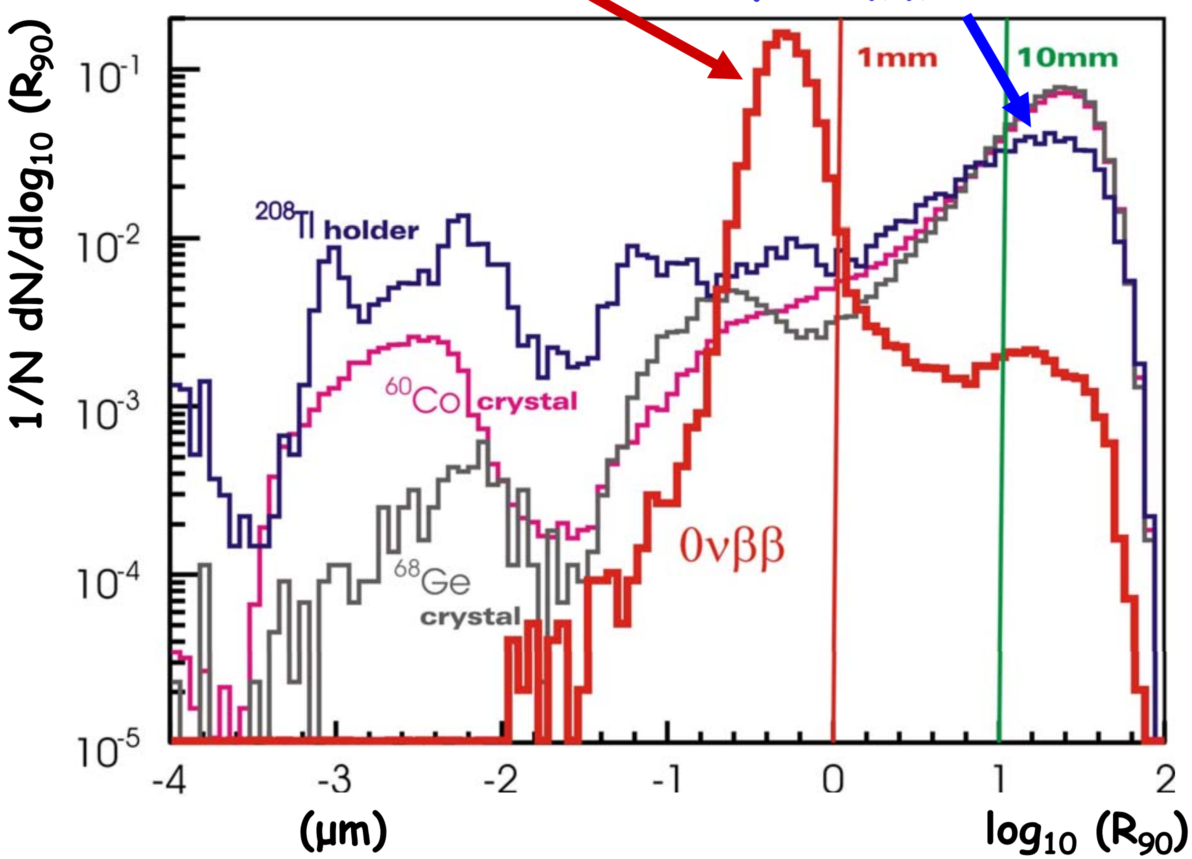
Phase II detectors will be 18 fold segmented:

3-fold in height, 6-fold in φ

PhaseII: Segmentation of detectors:

Most of the electrons deposit their energy on a scale of < 1mm

Most of the ^{208}Tl, ^{68}Ge and ^{60}Co gammas deposit their on an area > few mm



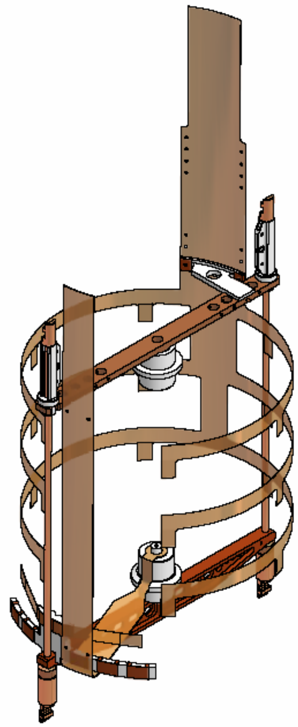
Source	Red.
^{208}Tl (in Ge)	13
^{60}Co (in Ge)	38
^{68}Ge (in Ge)	18
^{210}Pb (α on Ge surface)	1
^{208}Tl (in holder)	5
^{60}Co (in holder)	157
^{208}Tl (in cable)	5

Reduction factors estimated using a GEANT4 Monte Carlo simulation

I. Abt et al, NIM A 2006, doi:10.1016/j.nima.2006.10188

Phase II Detectors: Contacts and Holder

Detector holder made of 31g of copper and 7g of PTFE only.



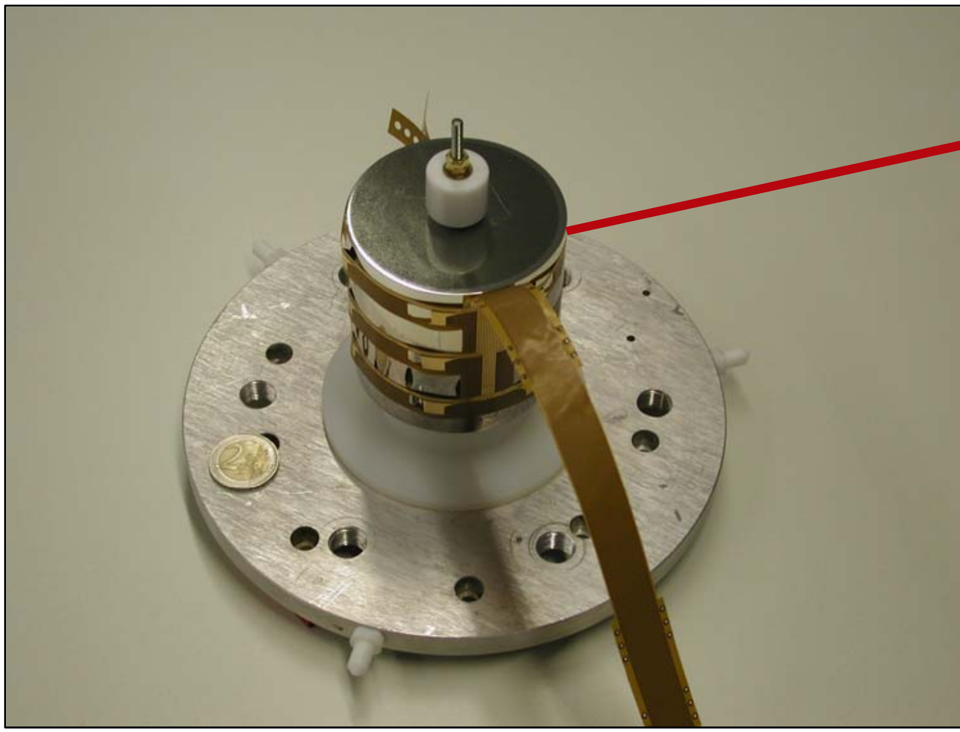
Stress test of holder with 20 kg material hanged in liquid nitrogen.

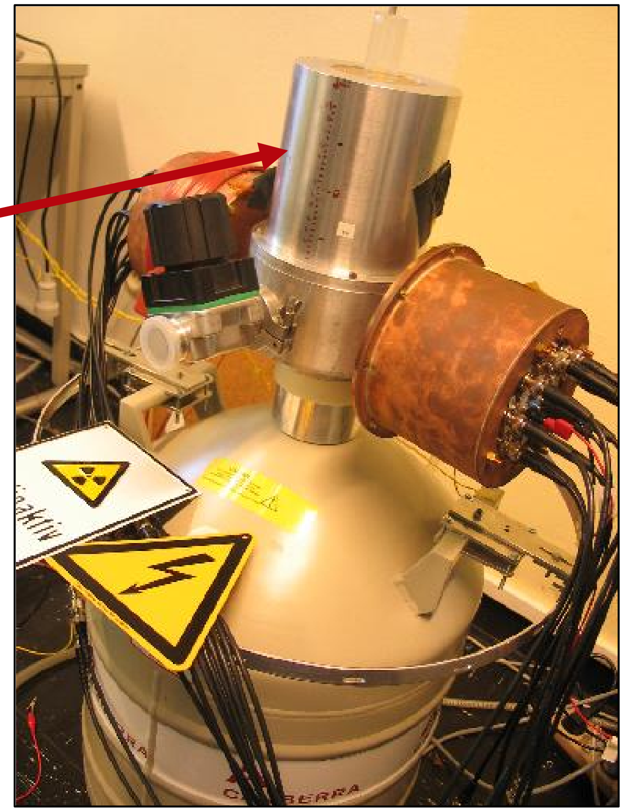
Novel low mass contacting scheme with Cu on Kapton. No additional materials needed.

Phase II: Results with prototype-detectors:

18-fold segmented prototype detector works fine. New contacting scheme verified in conventional surrounding:

Good energy resolution for core and 18 all segments:
3 keV @ 1.3 MeV --> 0.2%



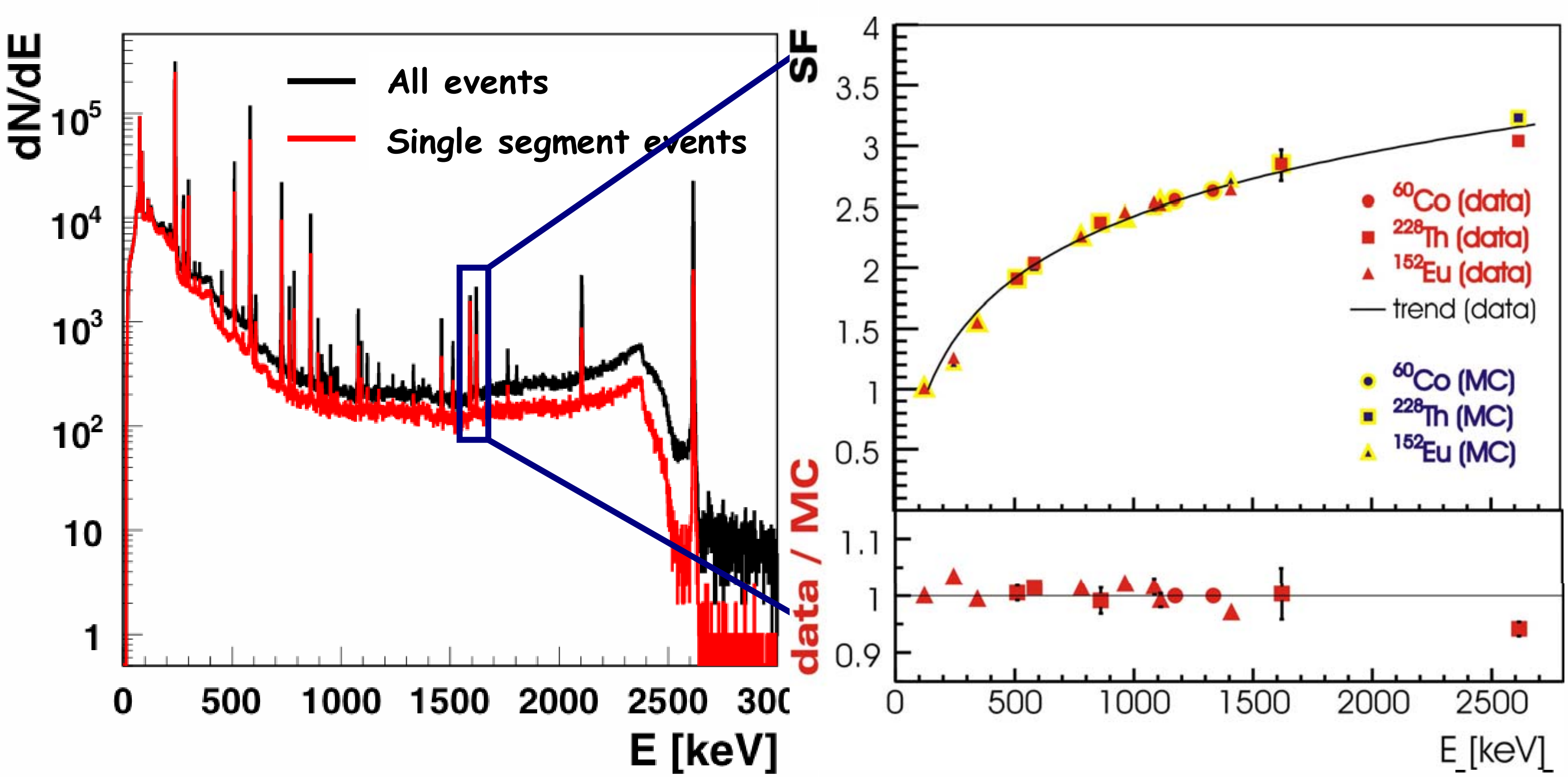


Phase II: Results with prototype detectors:

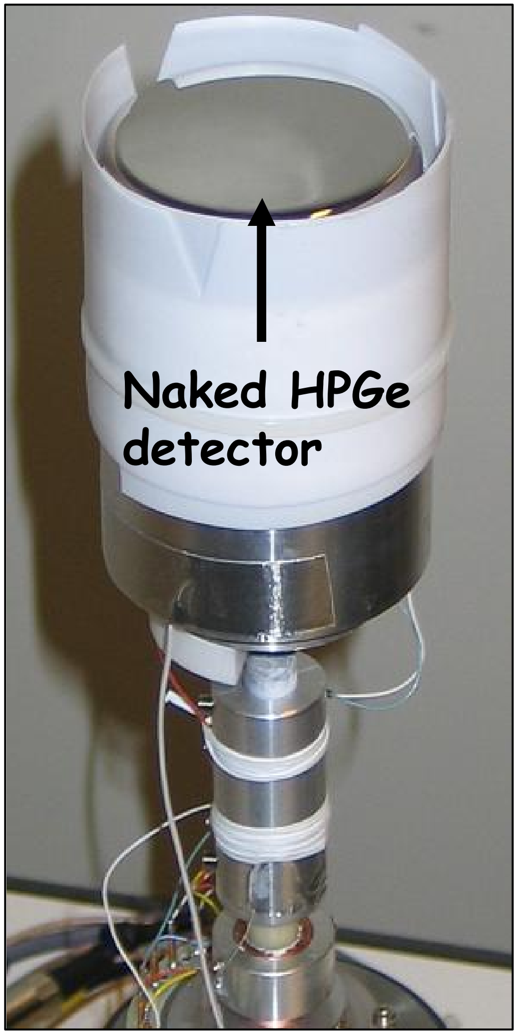
Compton Background recognition works as expected:

Photon Peak is reduced in single segment spectrum, whereas Double Escape Peak remains

Suppression factors (SF) as expected from MC

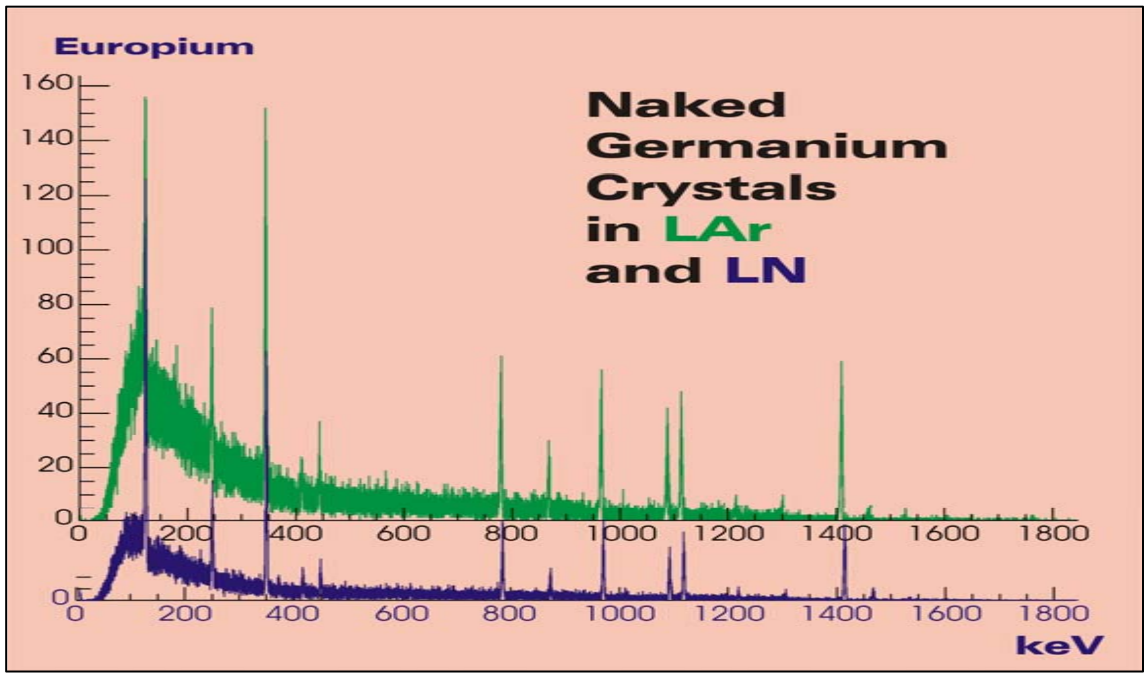


Phase II: Results with prototype detectors:



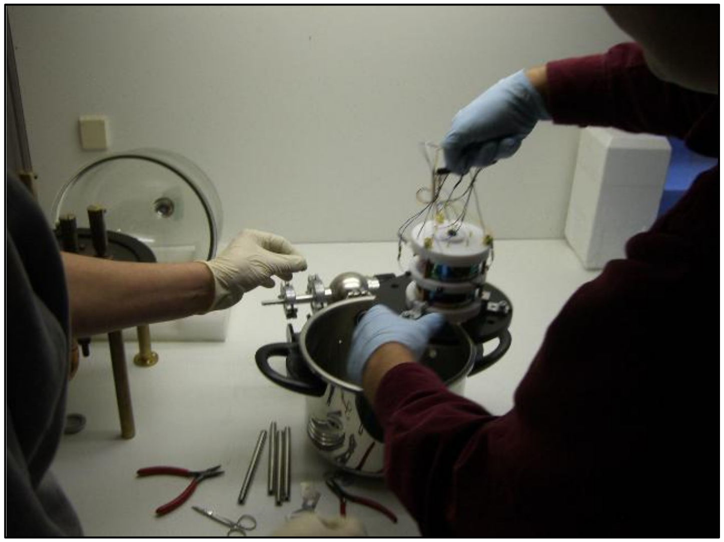
Prototype detectors were cycled:
> 20 times in LN without problem

Spectra were taken also in LAr



Phase II prototype detector

18-fold segmented true coax p-type HPGe detector from DSG: 12th of December 2006



Phase II detector transport

Maximum safety for necessary journeys envisioned

→ **Use same system as for most precious thing transported in cars:**

System successfully tested: prototype-detector safely transported from Mainz to Munich

Phase II Deliverables:

1. Enrichment	2. Purification	3. Crystal growing	4. Detector Fabrication
✓	✗	✗	✓
ECP,Russia 	**Germanyi, Russia** •isotopic dilution, •low yield. **PPM, Germany** 20% World supply High yield promised Test with depleted Ge in 2007	**UMICORE:** •large homel.sec. order ($1.5 billion) •Delivery of few dets until 2008? **IKZ, Berlin** R&D Contract near signing Test crystals in 2007	**Canberra-France** 
Delivered 2006	2008	Few detectors in 2008 , Rest ?	Prototype delivered 2006

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Internal Rail system:

Summary:

- 0vbb experiments have high physics potential
- GERDA will be able to confirm or refute KK-claim
- Enriched material delivered
- Prototype n-type 18-fold segmented detector works well
- Infrastructure on top of tank is on the way