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Looking ahead, the production of new Ge diodes

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Goal of GERDA Phase II: increase the sensitivity of the experiment

1. Increase mass of ^{76}Ge (about 2^{x})
2. Decrease detector background

→ one order magnitude in total

- Minimize cosmogenic activation (production of ^{68}Ge and ^{60}Co long-lived isotopes into detector)
- New detector design (segmented and BEGe detectors)

Enriched material for GERDA Phase II: **motivation**

The sensitivity ($T_{1/2}$) ~ δ(enr%)/δ(nat%) =

= (86%/7,61%) = 11

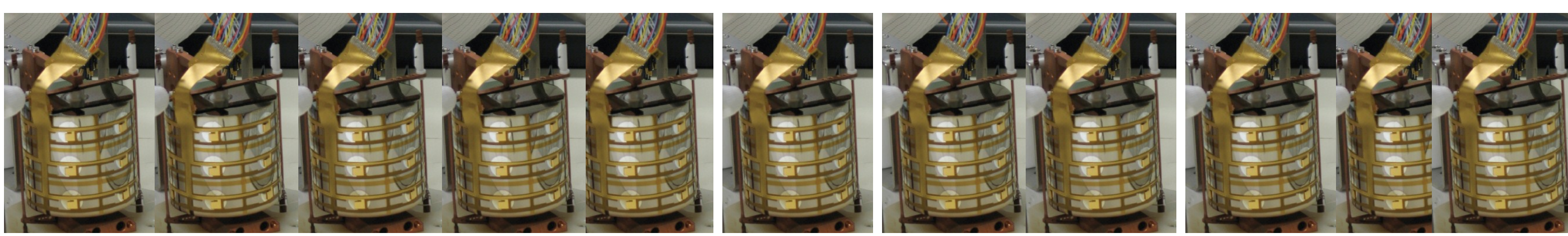
One ^{76}Ge diode $\Rightarrow$ 11 ^{nat}Ge diodes

^{76}Ge diode (δ = 86%)

≡

^{nat}Ge diodes (δ = 7,6%)

1 2 3 4 5 6 7 8 9 10 11



Cosmic ray activation

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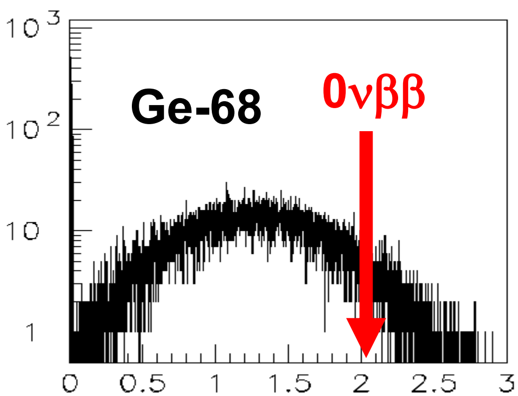
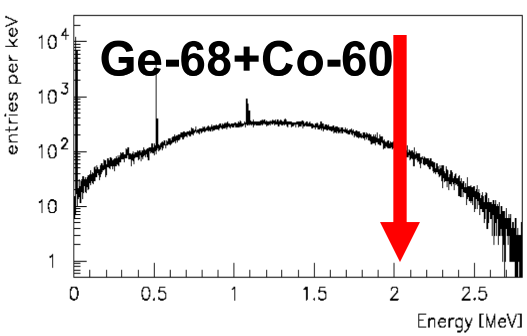
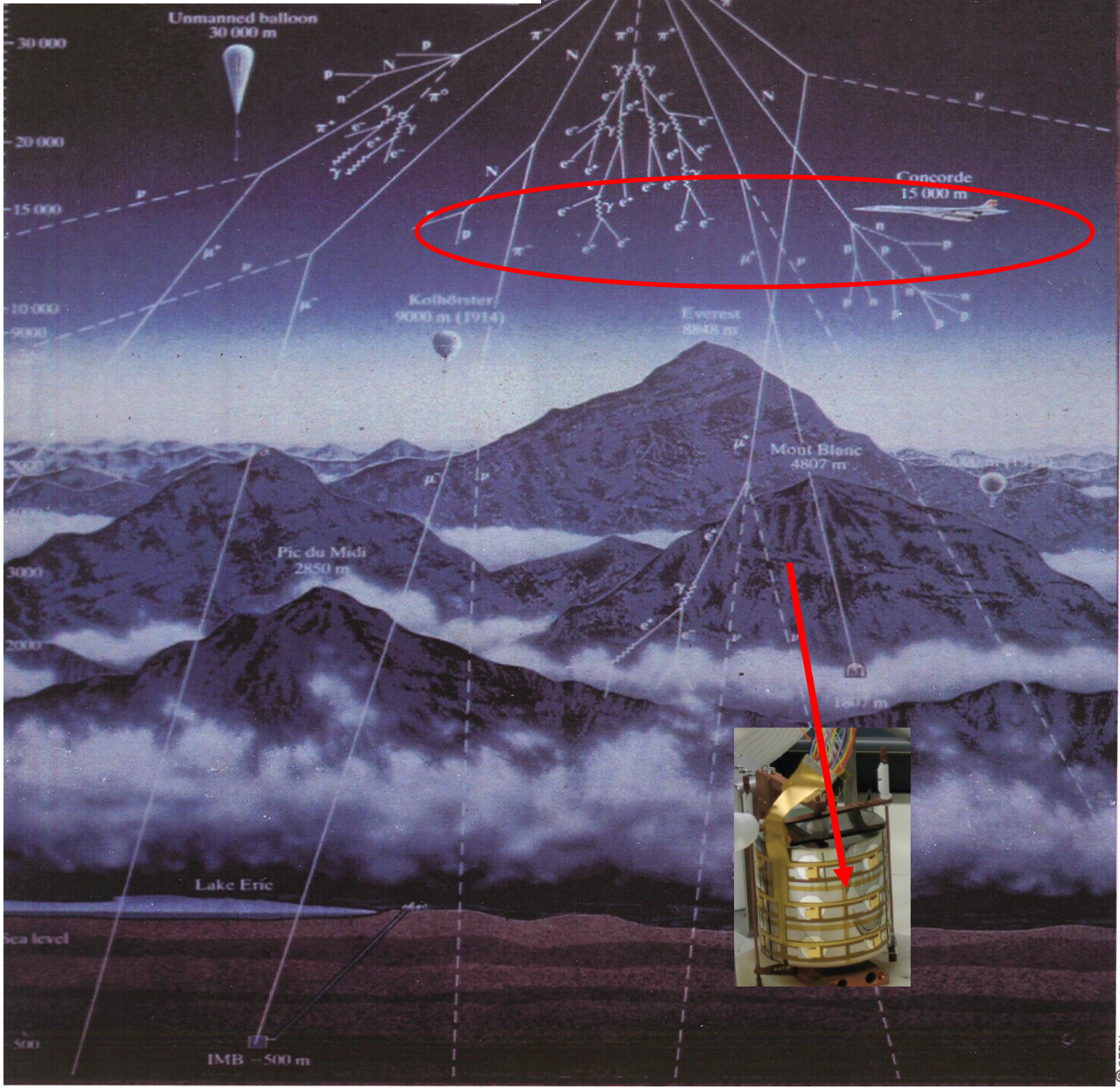
Ge + N component → 60Co and 68Ge







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Requirements to the enriched Ge-76

- Enrichment on Ge-76 ≥ 86% (11 times ↑)
- Total quantity of ^{enr}Ge: 37,5 kg
  Cost effective industrial scale production:
  only gas-centrifuge separation
- To decrease Ge-68 and Co-60 production:
  - Depletion of Ge-70 ≤ 0.01% (> 300 ↓)
  - Minimization of exposure of ^{enr}Ge to cosmic rays at Earth surface
- Chemical purity to start HPGe detector production: 6N (99,9999%) electronic grade Ge metal

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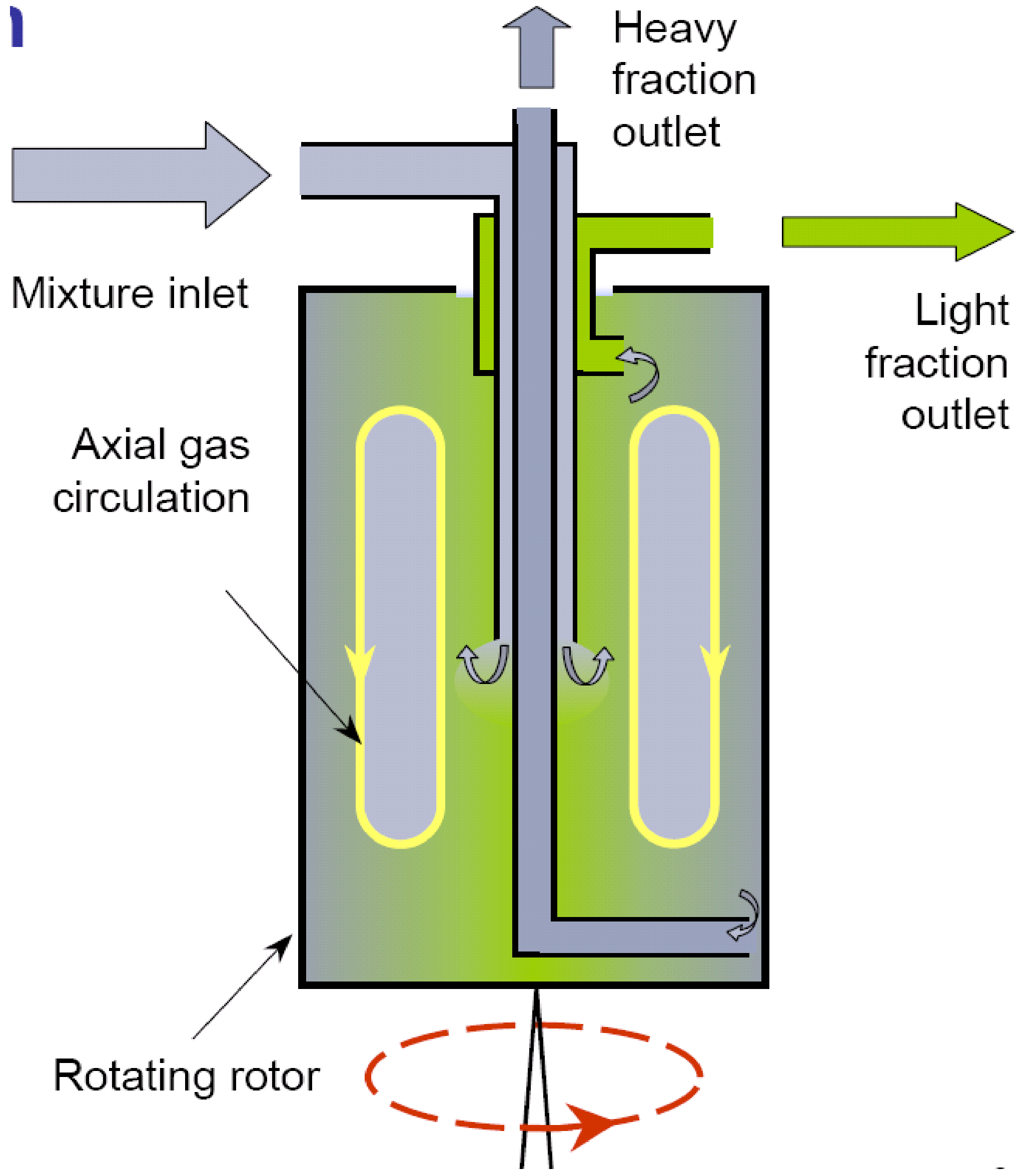
The ECP (Zelenogorsk, Russia): biggest in the world plant for production of stable isotopes by gas-centrifuge method

Zelenogorsk (former Krasnoyarsk-45): the city on Green Mountains

September, Siberia…

Principle of gas-centrifuge isotope separation

Centrifuge acceleration: 500 000 g
Rotation ~ 1500 s^{-1}



Cascade: many hundred and even thousand units

Operation life:
30 years

Enrichment procedure at the ECP for GERDA Phase II

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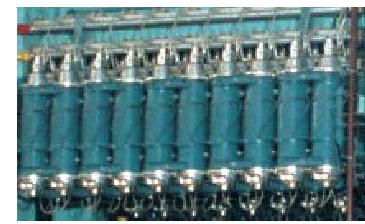
Fluorination: ^{nat}Ge (99,9999%) → $^{nat}GeF4$

Isotopic separation: $^{nat}GeF_4$ → $^{76}GeF_4$ (13 kg → 1kg)

(~ **0,5 tons** of 99,9999% Ge metal → 37,5 kg)



Chemistry: $^{76}GeF_4$ → $^{76}GeO_2$ (99.8% - technical grade)

Storage at shallow depth (underground)

Svetlana Department, ECP

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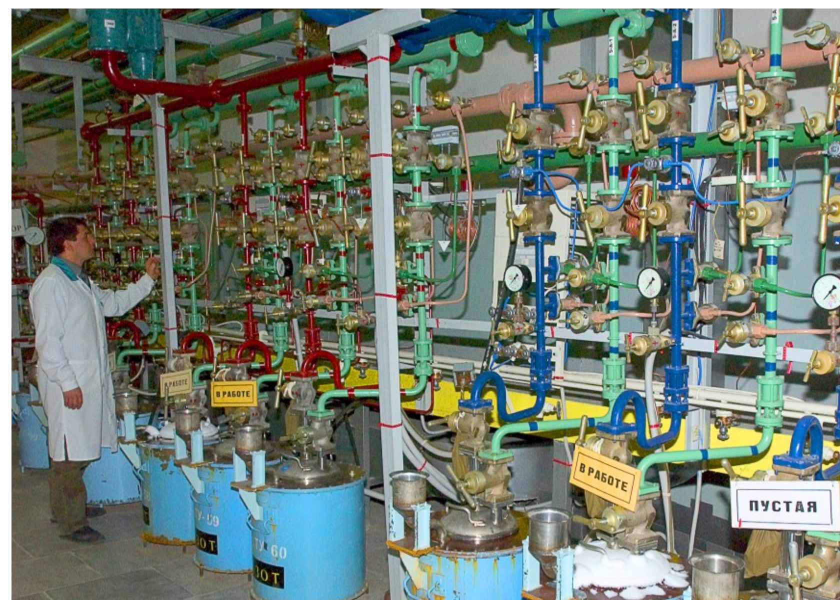
Anatoly Shubin (1939 - 2008)



Shelter at ECP (former bomb-proof shelter)

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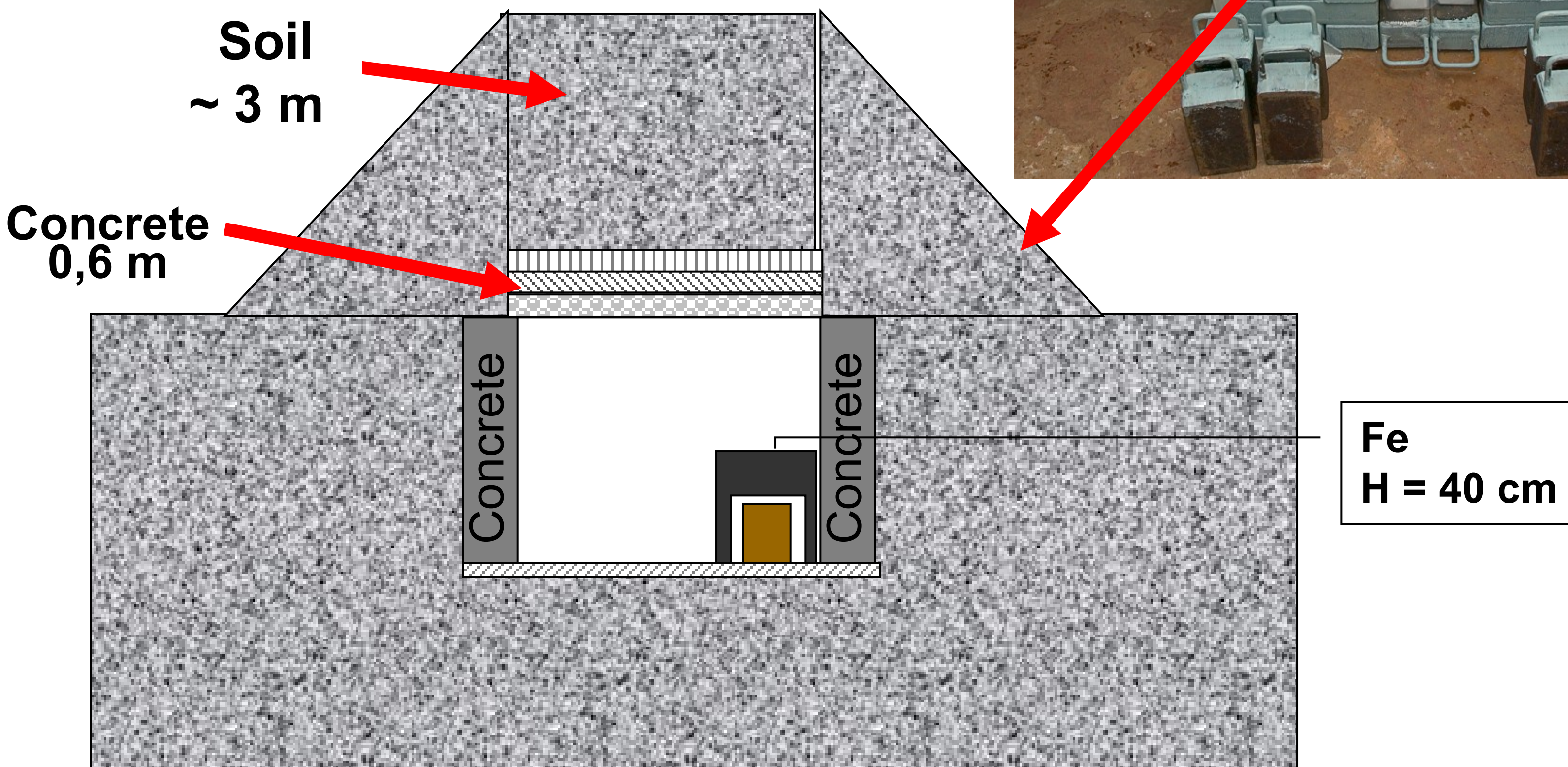
March 2005 till March 2006

Activation reduction:

~ 22 for Ge-68

~ 45 for Co-60



Transportation: Zelenogorsk (Siberia) – Munich, 4700 km

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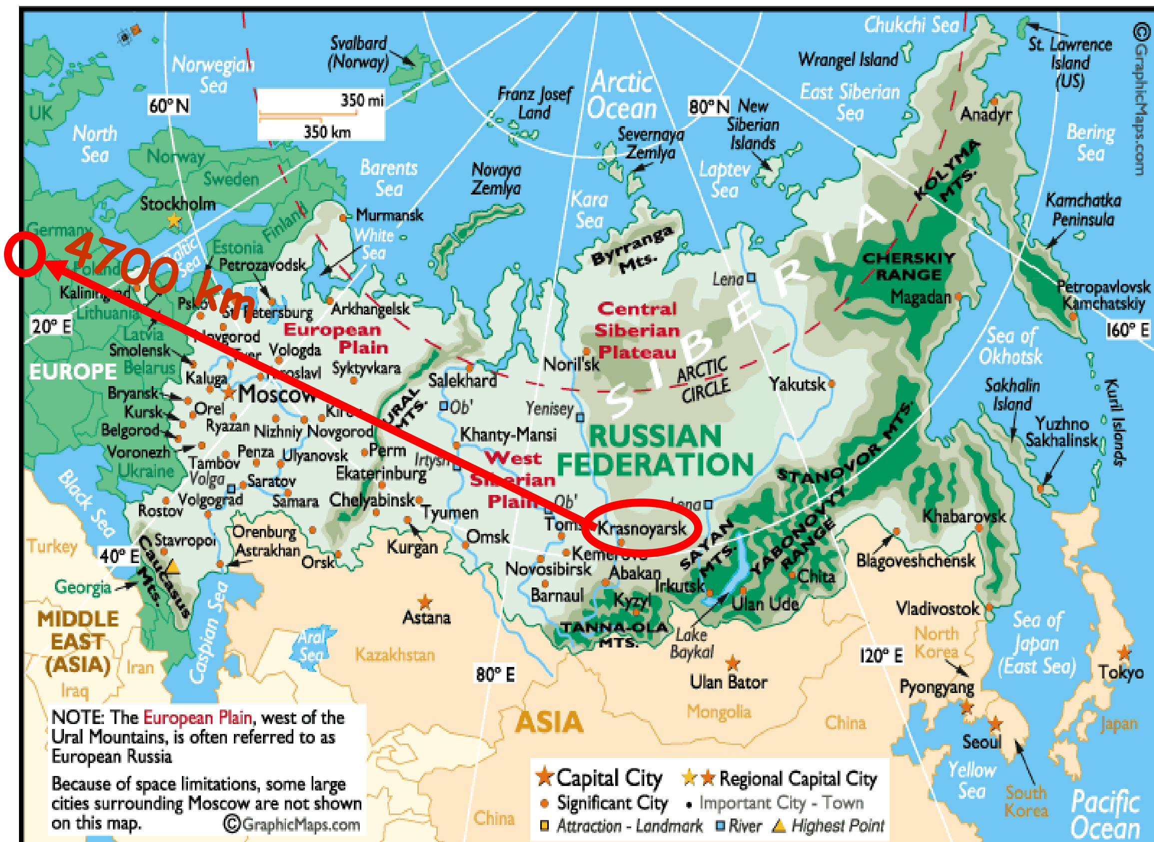
Reduction of cosmic activation

K = 8 ↓ for ^{68}Ge

K = 13 ↓ for ^{60}Co



Ø140 cm x 126.5 cm (H)

Weight is 15 tons

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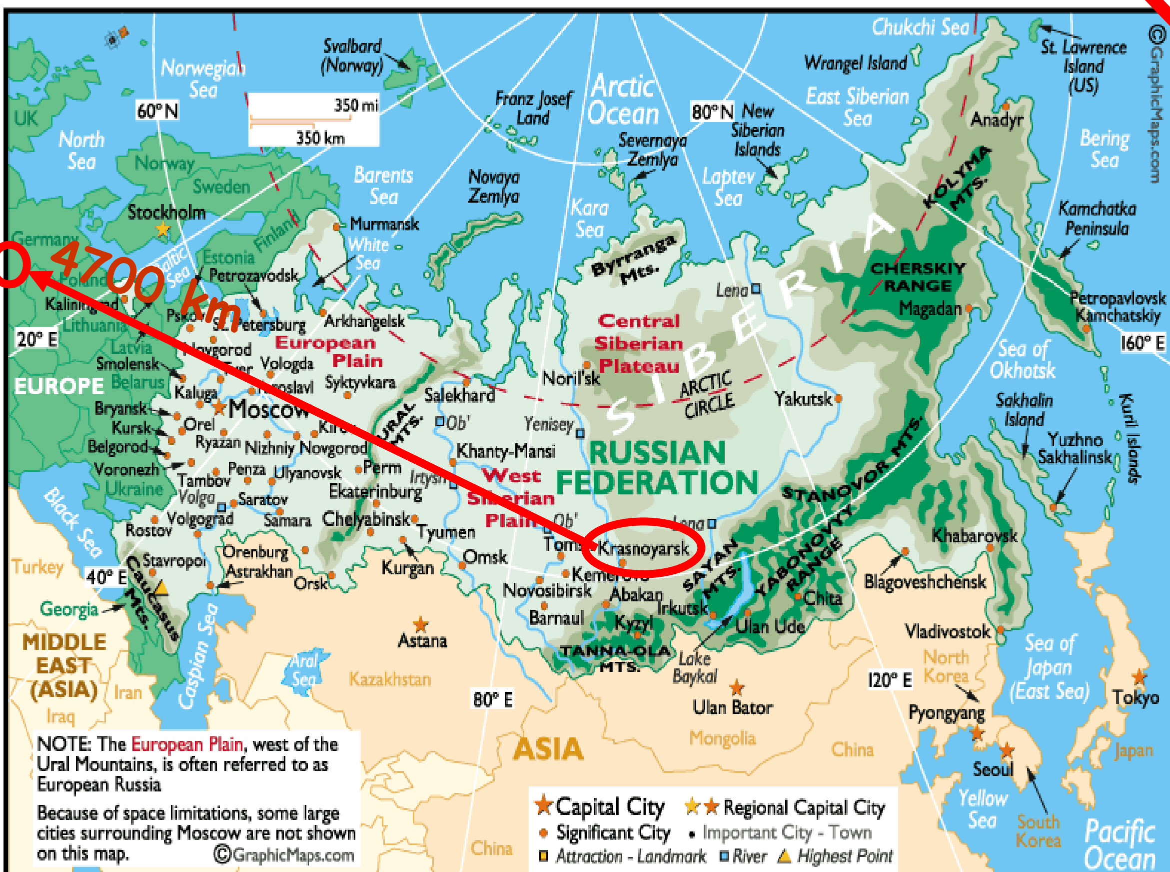
Transportation:
Zelenogorsk (Siberia) – Munich, 4700 km

Possible question at customs:
just 54 kg of Ge oxide inside 15 tons “”pile of metal”?



Test Run first (15 kg of natGe): Feb. – March 2005

Run 2 (37,5 kg of 76Ge): March-April 2006

Transport container arrived at MPP: Rally Zelenogorsk – Munich is over

$^{76}GeO_2$ inside

^{76}Ge in Munich: celebration with VODKA®

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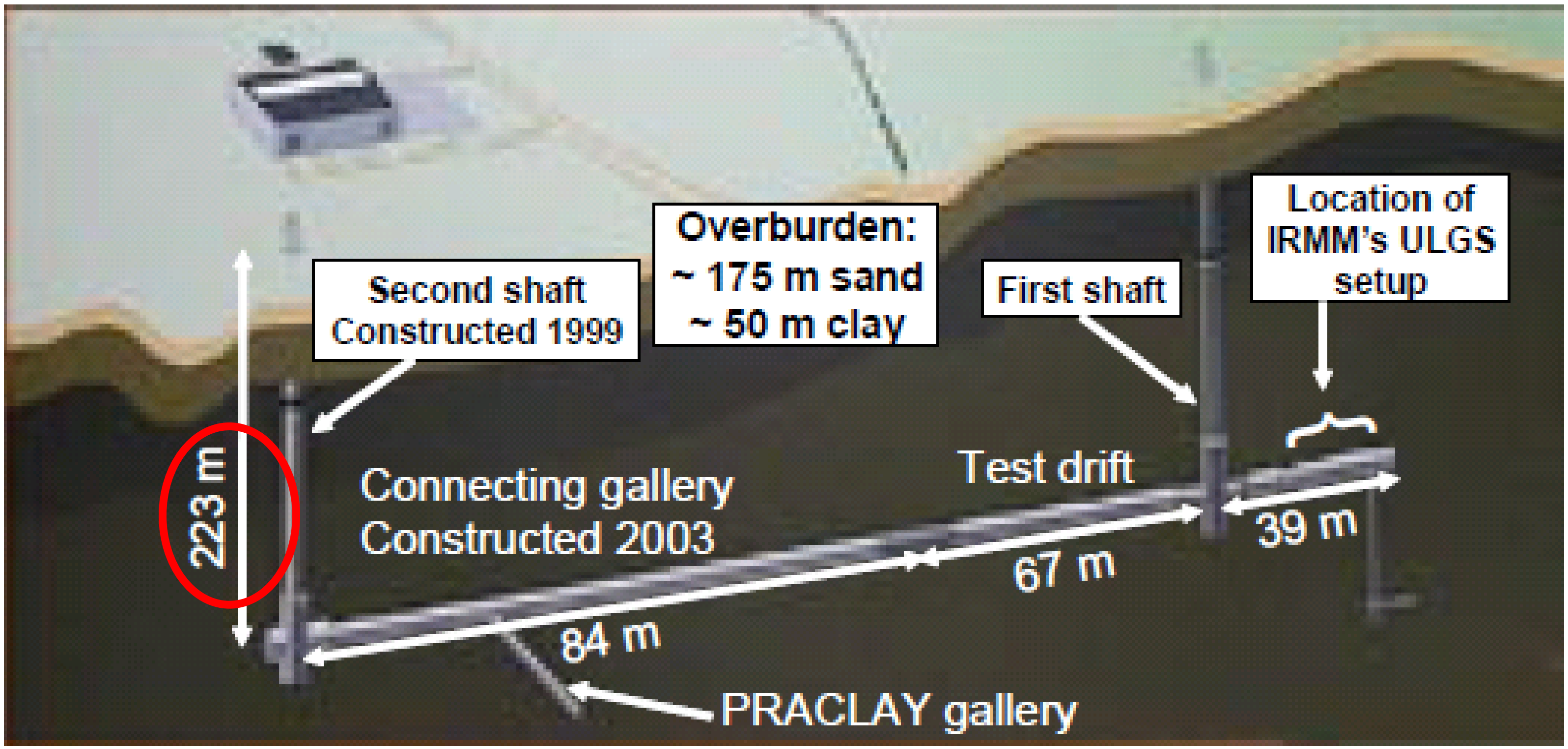
HADES underground lab (Geel, Belgium): storage of $^{76}GeO_2$ during 4 years

Arrival from Munich: 11 April 2006



Departure from Geel to the Rammelsberg mine in Goslar near PPM Pure Metals: 08 March 2010

T_{exp} = 6 hours

Reduction and Purification of ^{enr}Ge

- **Main issue:** reduction $^{enr}GeO_2$ to ^{enr}Ge metal and purification from 99,98% → 99,99999999% (10N)

  with no isotopic dilution...
- **2 years of R&D with depleted GeO_2** after enrichment process at various sites in Russia and Germany

  2 batches of **$^{dep}GeO_2$ powder** (50 kg + 34 kg) that has the same properties and purity **as $^{enr}GeO_2$** were bought from ECP
- **In 2009:** we chose PPM Pure Metals (Germany) as industrial partner for reduction & purification
- **In 2010:** Reduction & purification of ^{enr}Ge (37,5 kg) was made

PPM Pure Metals (Langelsheim, Germany)

Reduction & Purification at PPM Pure Metals (Langelsheim, Germany)

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1) 50+34 = 84 kg of $^{dep}GeO_2$

2) 54 kg of $^{enr}GeO_2$

Reduction

- ➢ 98% yield

Zone refinement (ZR)

Yield

- ➢ 94%(^{enr}Ge)

^{enr}Ge in form of metal bars

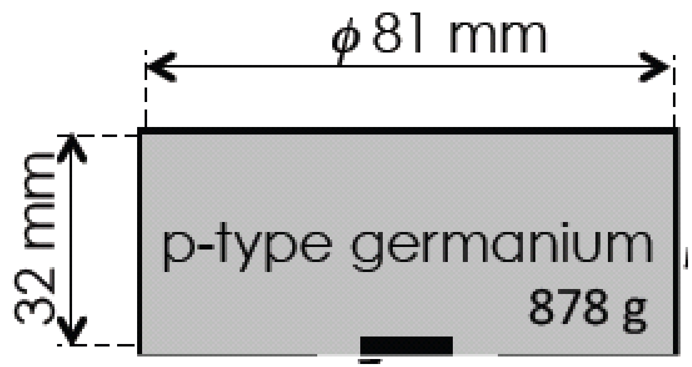
ZR: 37,2 kg → 35,45 kg purified + 1,161 kg (< 50 Ohm*cm)

- Total exposure = 5,25 days, including transportation
- 94% overall yield

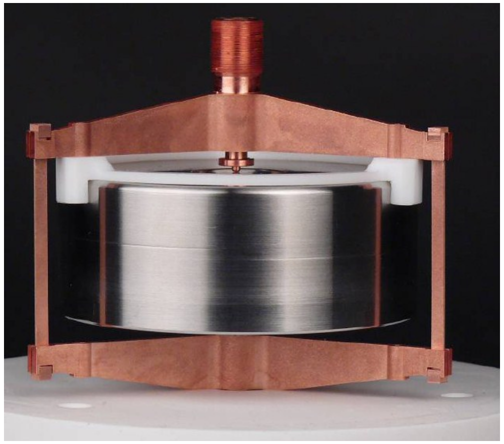
Next steps depend on the detector technology we will choose

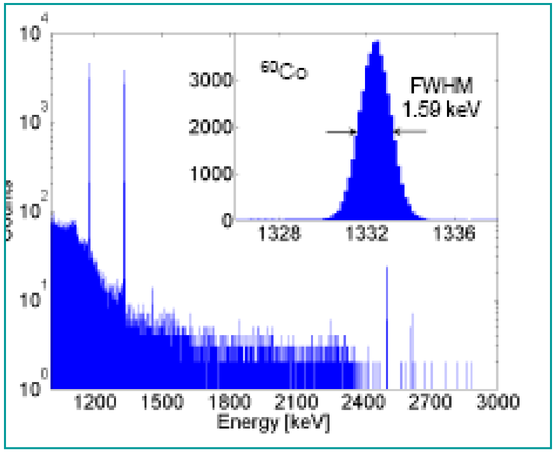
Two technologies of detector production: n-type segmented and p-type BEGe

n-type detectors with
18-fold segmented electrodes
m = 1.6 kg

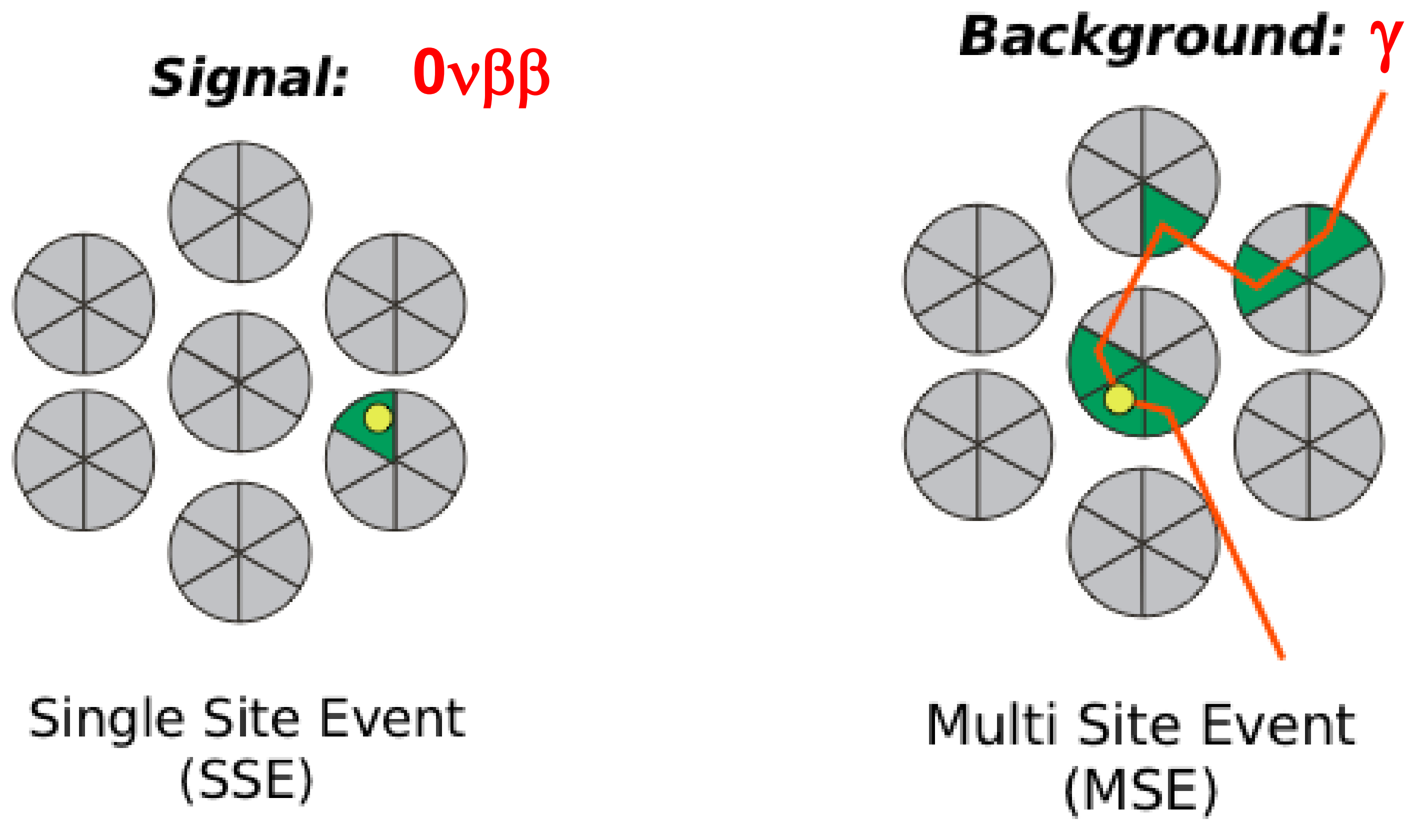


Commercial p-type BEGe detectors
with advanced 0νββ signal recognition
& background suppression; **m = 0,9 kg**





Further background suppression in Phase II – segmented detector (1)



Crystal and segment anti-coincidence possible

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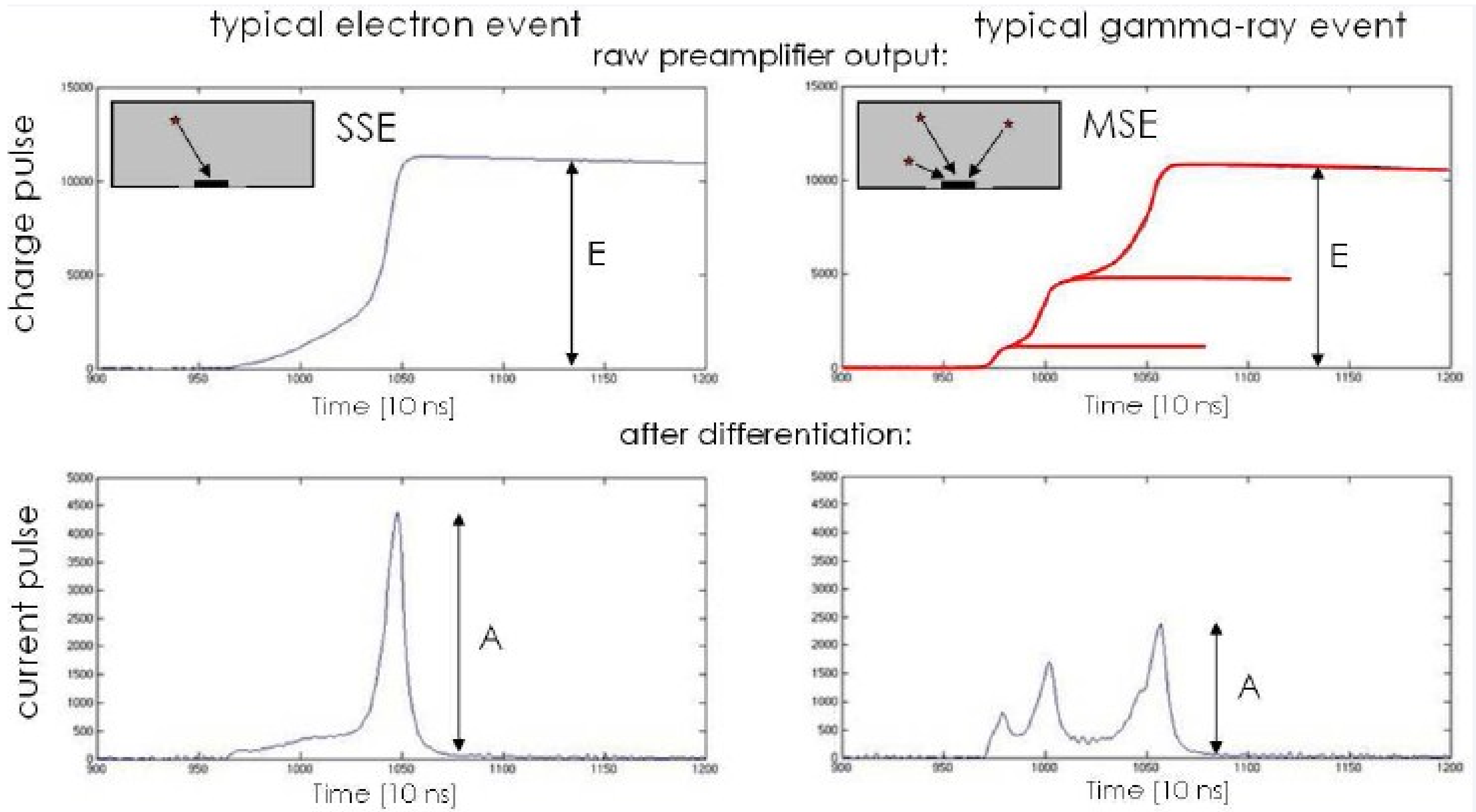
Further background suppression in Phase II – BEGe detector (2)

Pulse Shape Discrimination

$0\nu\beta\beta$ γ



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Crystal pulling and detector production for Phase II: status and future

n-type crystal

- No **industrial** manufacturer
- R&D with Leibniz-Institut für Kristallzüchtung (Berlin)

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- purity of 12 N achieved (99,9999999999%)
- still need to reduce impurities by one order of magnitude
- Canberra-Lingolsheim for detector manufacture

p-type crystal

- Since 2008, Canberra Oak Ridge and Canberra Olen as industrial partners. Industrial BEGe detector as nominal option for Phase II

↓

- good quality crystals,
- and the detectors made of ^{dep}Ge tested **as good as** BEGe detectors from standard production

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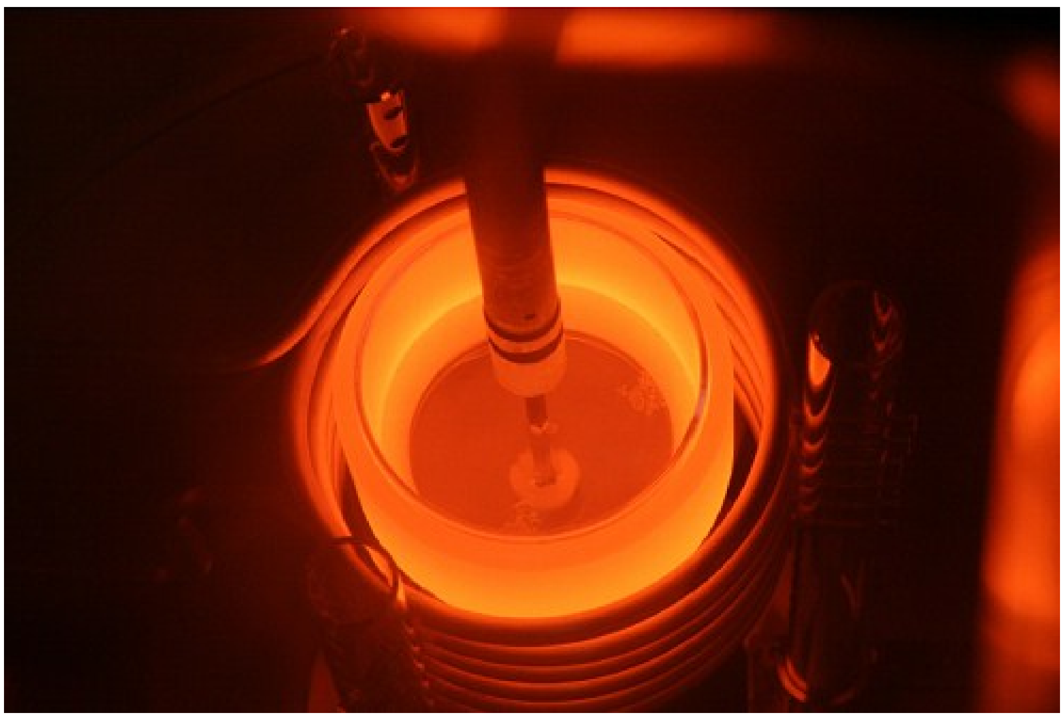
Institut für Kristallzüchtung (IKZ, Berlin): crystal puller EKZ 2000

Crystal pulling (purity 99.9999999999 % Ge) some of the purest material in the world – impurities at the level of 10^{-12} /atom



BEGe detectors for GERDA Phase II

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- **Four crystal based on ^{dep}Ge** were pulled by **Canberra Oak Ridge** and **five detectors** were produced by **Canberra Olen**.

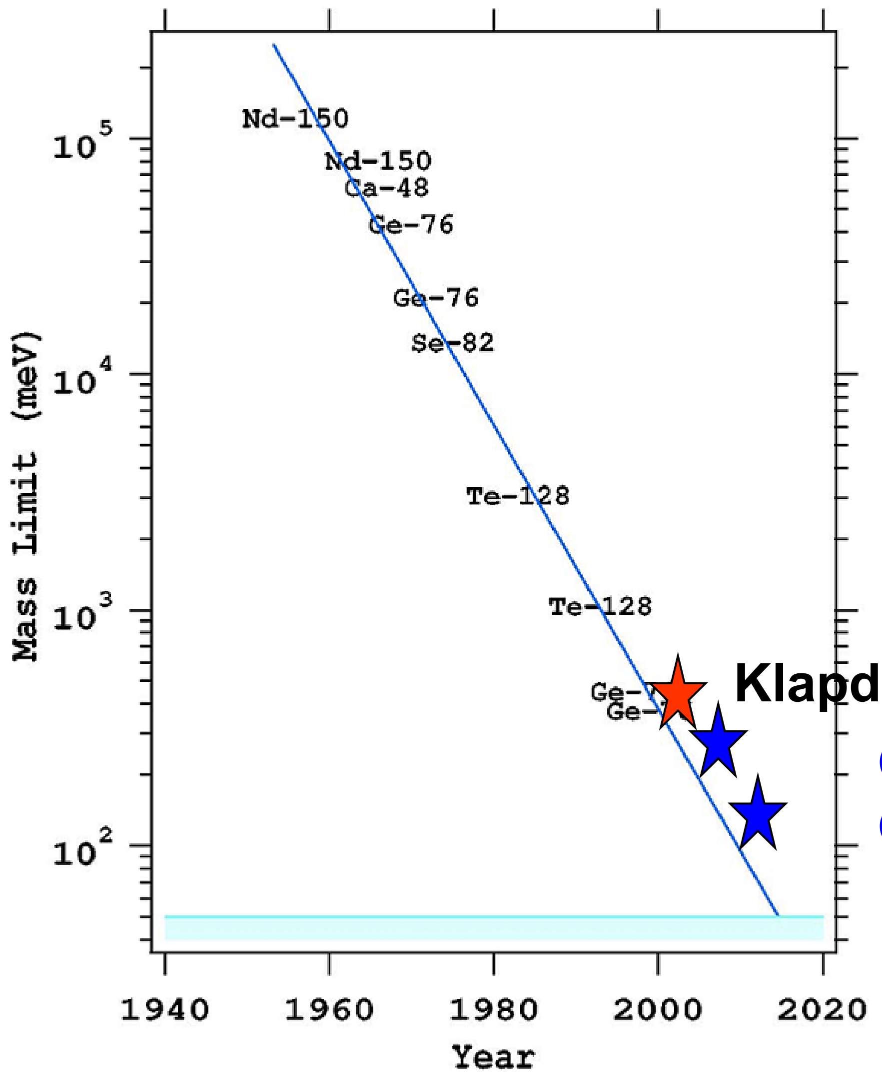
- The detectors tested **as good as** BEGe detectors from standard production.

- Excellent performance both for energy resolution and background suppression via PSA.

- **Expect first batch of Phase II enriched detectors the end of 2011 (early 2012)**

History and perspectives of Searches for 0νββ decay

There is a long history to the search for neutrinoless double beta decay, including claims of positive results.



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Backup slides

Phase-II detector candidate # 2:
BeGe (broad-energy) detector

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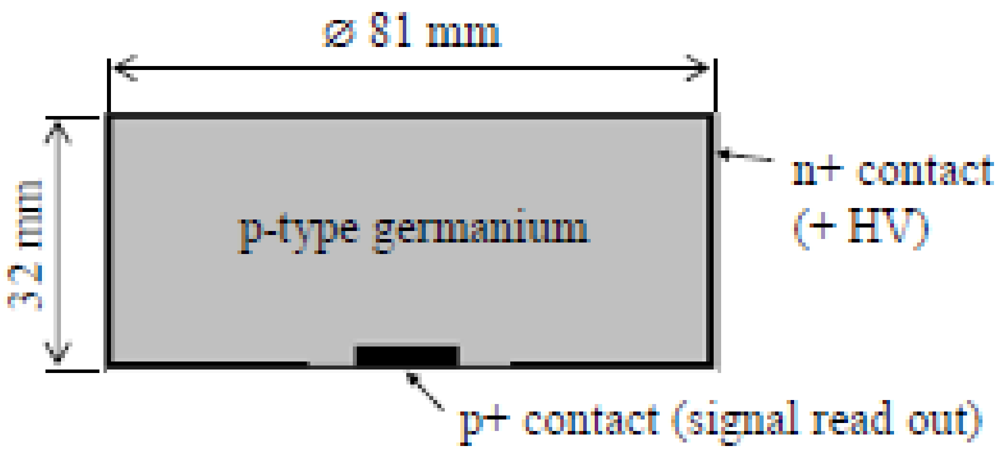
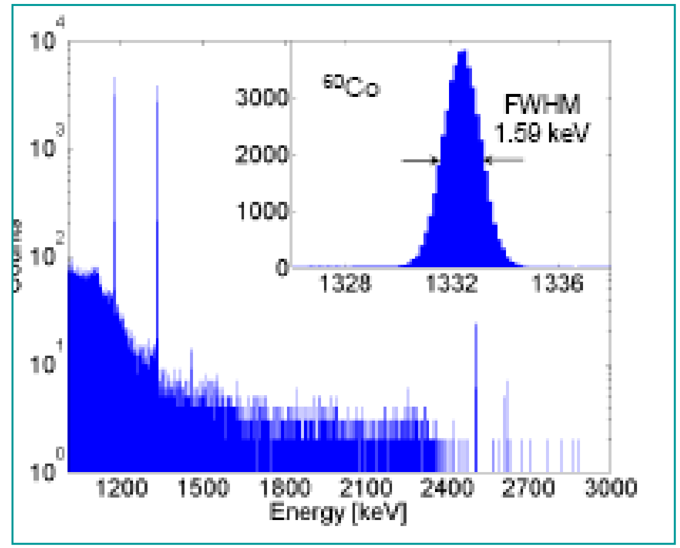
modified model BE5030

energy range 3 keV - 3 MeV
enhanced efficiency for low-energy gammas
low capacitance (⇒ low noise)

the largest BEGe detector
commercially available from Canberra Semiconductor, N.V. Olen





Specifications from Canberra:	
depletion voltage	4000 V
FWHM @ 122 keV	0.63 keV
FWHM @ 1.33 MeV	1.8 keV
mass	870 g

Parameters obtained during R&D for GERDA:	
depletion voltage	3800 V
FWHM @ 59.5 keV	0.49 keV
FWHM @ 1.33 MeV	1.59 keV
mass	878 g

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Steps:

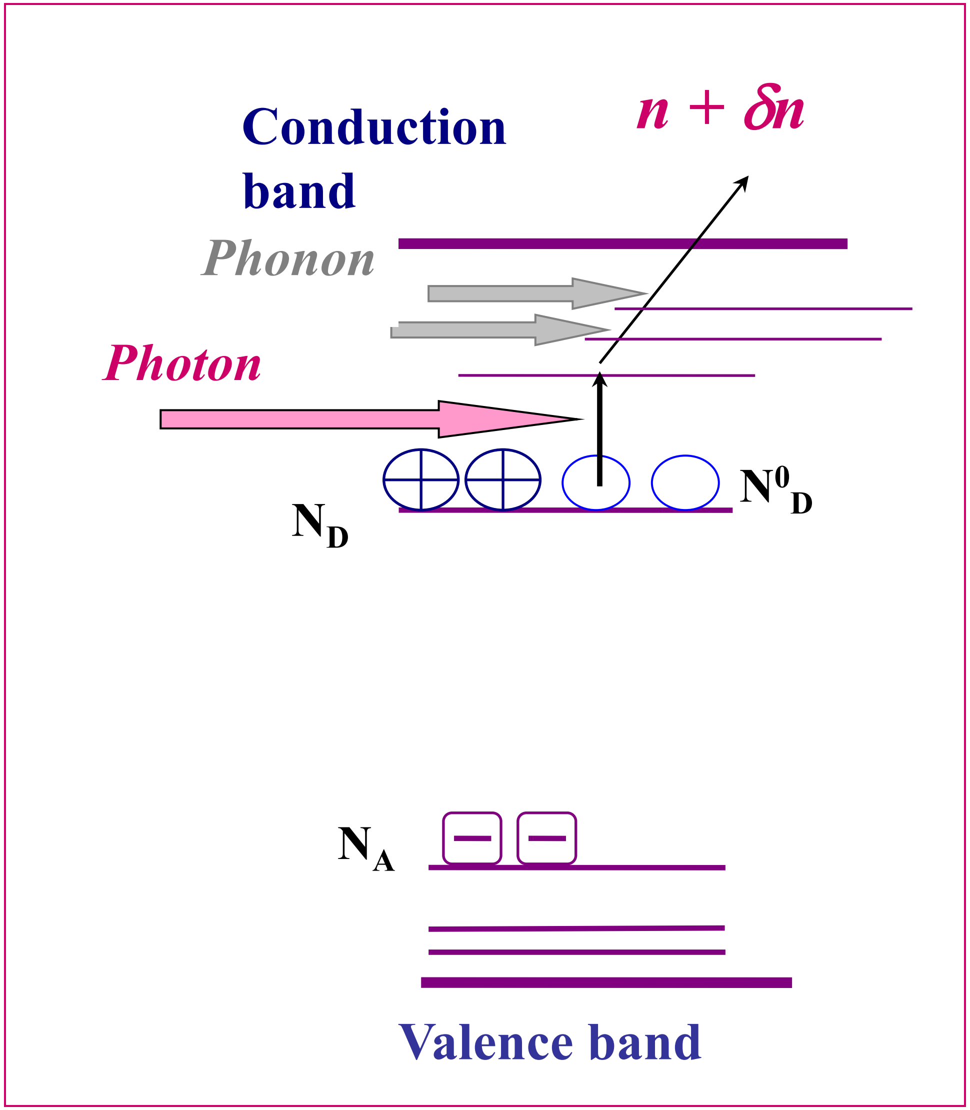
1. **Enrich in ^{76}Ge (>86%) (This step completed -37.5 kg in underground storage)**
   - **Suppression of internal backgrounds**
   - **Cost**
   - **Signal/background**

2. **Zone refining (purity 99.9999-99.99999999 % Ge)**

3. **Crystal pulling (purity 99.9999999999 % Ge) some of the purest material in the world - impurities at the level of 10^{-12}/atom**

4. **Detector manufacture**

5. **In parallel - development of support and cabling system**


Conduction band
$n + \delta n$
Phonon
Photon
N_D
N^0_D
N_A
Valence band