Prototype p-type Ge detector for GERDA Phase-I at GERDA-Detector-Lab (GDL)

GERDA in general:

- HdMo & IGEX
- GERDA Phase-I Goal

p-type vs. n-type Ge detectors

- semiconductor junction, depletion zone & bias Voltage
- production of p-type detector
- p-type versus n-type

Prototype detector operation

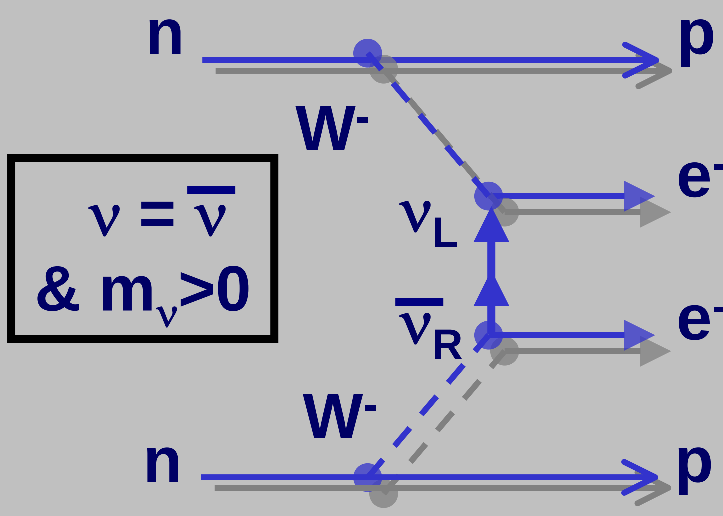
- mount contacts & apply HV
- warm up afterwards

Leakage current problem

CRESST-GERDA(-MuonCooling) student seminar
Xiang Liu, 23/11/2007

$0\nu\beta\beta$ decay → effective Majorana neutrino mass $m_{\beta\beta}$

- $2\nu\beta\beta$ decay:
  $(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\bar{\nu}$
  SM allowed & observed.
- $0\nu\beta\beta$ decay: $\Delta L=2$
  $(A,Z) \rightarrow (A,Z+2) + 2e^-$
  if νs Majorana & have mass.

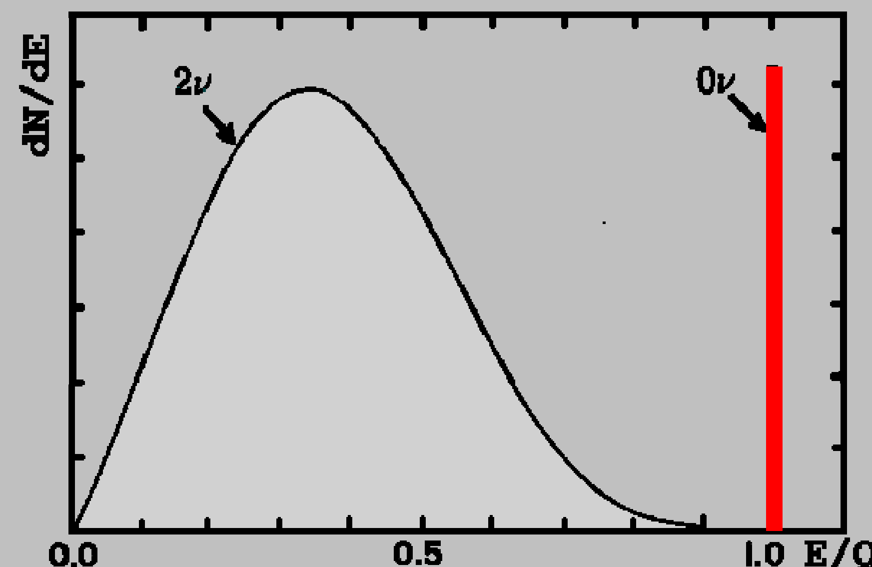


- many isotopes can be used
  to search for $0\nu\beta\beta$.

- measure half-life $T_{1/2}$:

$$T_{1/2}^{-1} = G^{0\nu}(E_0,Z)\left|M^{0\nu}\right|^2 \left\langle m_{\beta\beta}\right\rangle^2$$

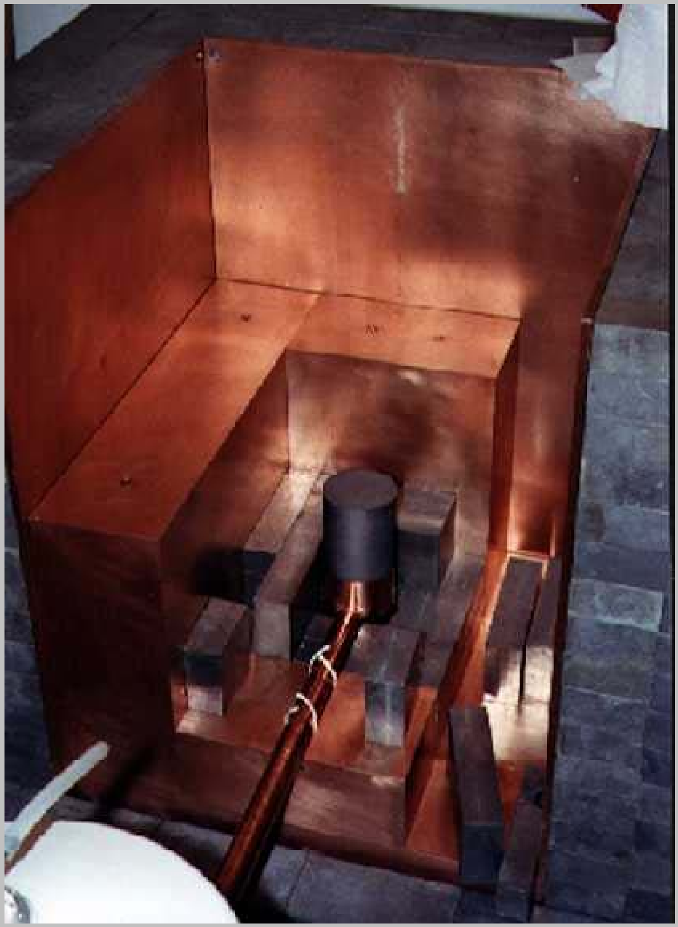
$G^{0\nu}$: phase space integral
$M^{0\nu}$: nuclear matrix element
$\langle m_{\beta\beta}\rangle = \left| \sum U_{ei}^2 \, m_i \right|$
(U_{ei}: neutrino mixing matrix)

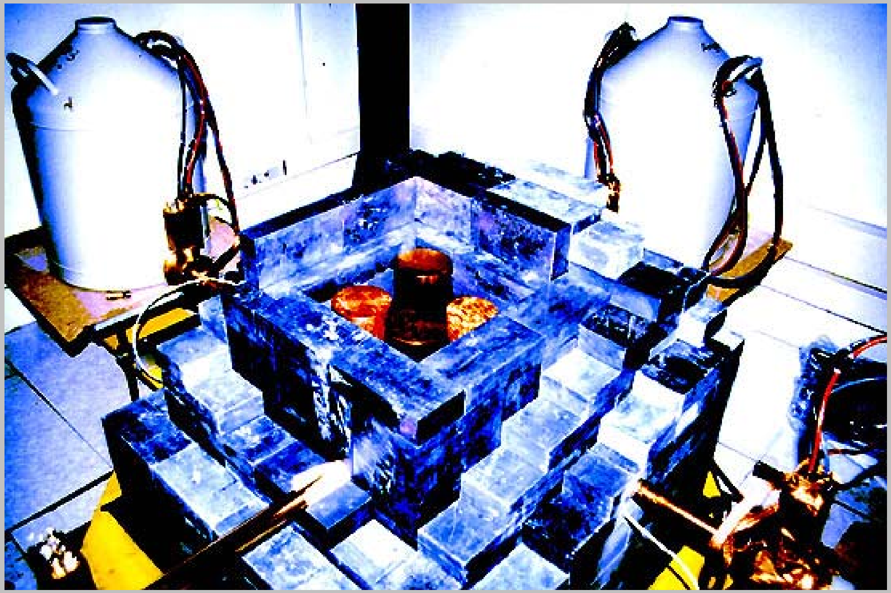


Previous Ge76 experiments

Heidelberg-Moscow experiment:

- 5 p-type ^{76}Ge-enriched detectors
- Cooled through cooling finger
- Operated in Vacuum
- Shielded with Pb & Cu





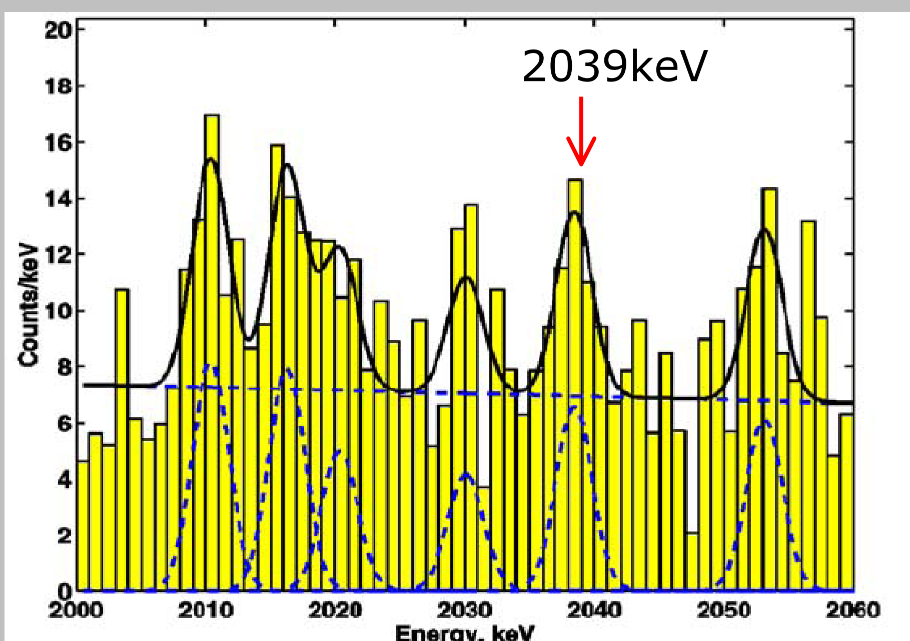
Previous Ge76 experiments

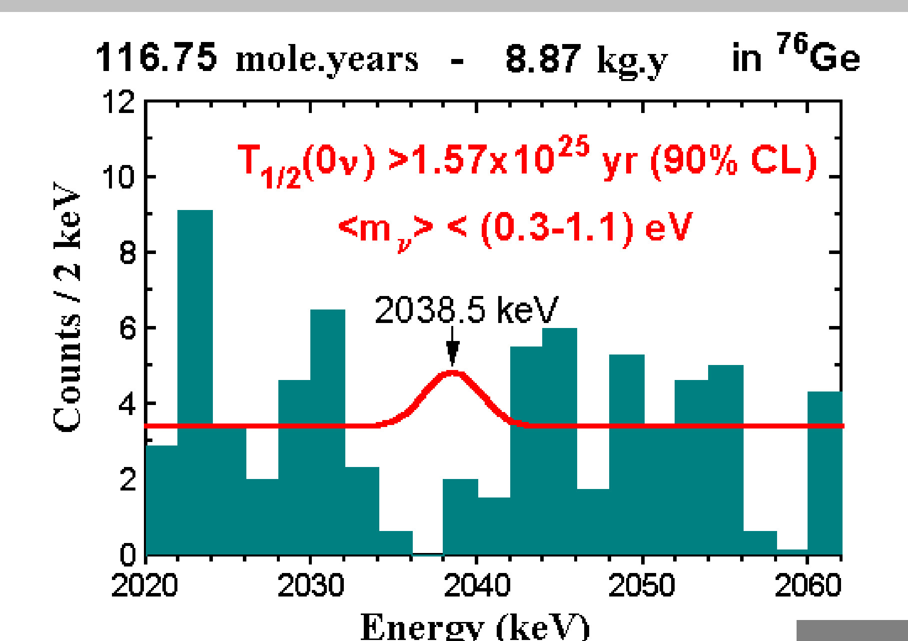
	HdMo	IGEX
exposure[kg·y]	71.1	8.87
B [counts/kg·keV·y]	0.11	0.2
$T_{1/2}$ limit (90%CL)[y]	$1.9 \cdot 10^{25}$	$1.6 \cdot 10^{25}$

"Evidence for $0\nu\beta\beta$" $1.2 \cdot 10^{25}$
H.V.Klapdor-Kleingrothaus, etc., (0.69-4.18 3σ)
Phys. Lett. B 586 (2004) 198-212

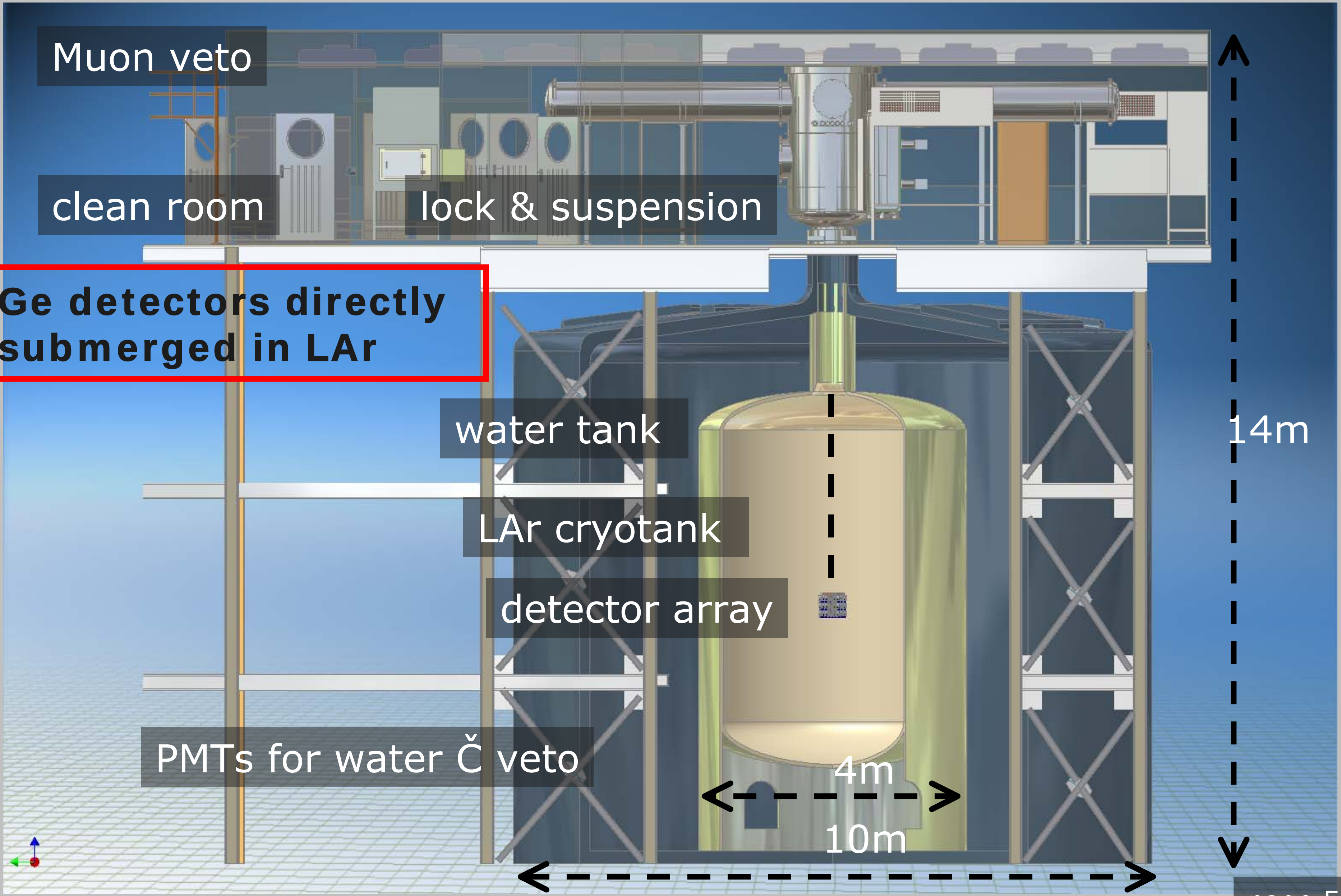
Background index B:
counts/kg·keV·y

kg: Ge mass
keV: energy window
y: exposure time





GERDA design



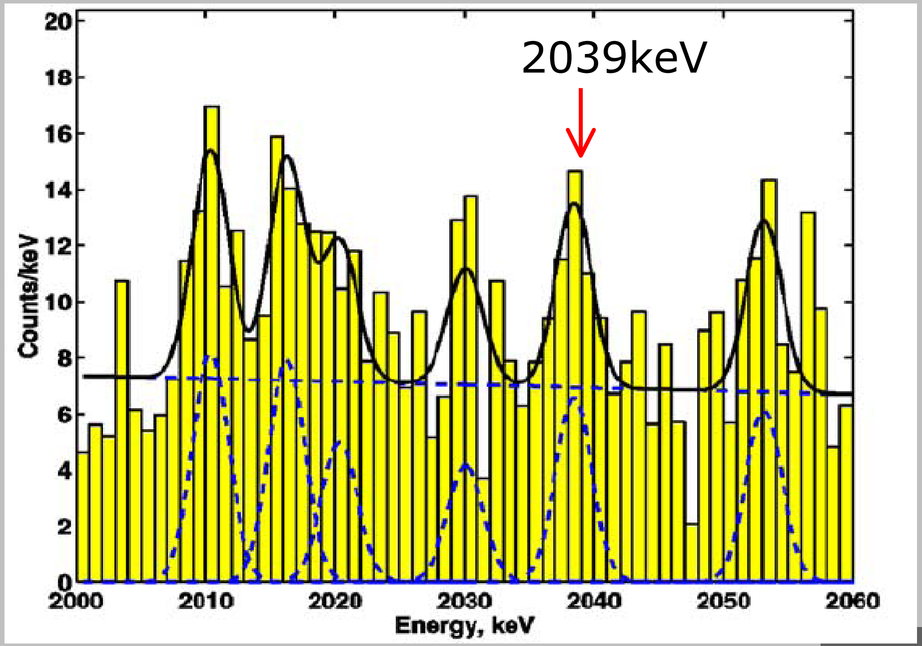
GERDA Phase-I

phase	I	II	III
exposure[kg·y]	30	100	>1000
bg [counts/kg·keV·y]	10^{-2}	10^{-3}	$<10^{-4}$
Limit on $m_{\beta\beta}$ [eV]	0.27	0.13	~0.05

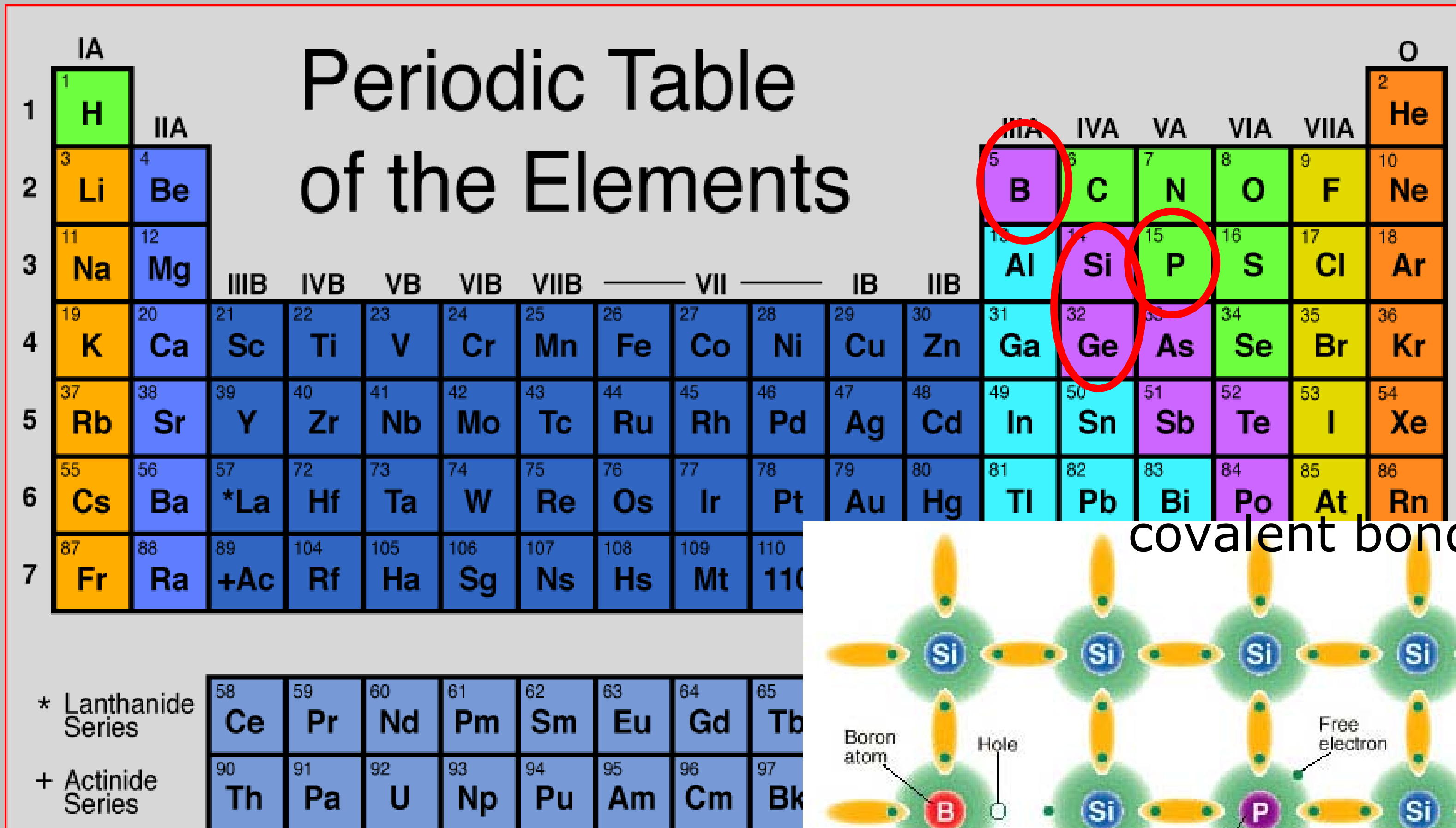
Phase I: 3 IGEX & 5 HdMo detectors, 17.9 kg, non-segmented
(6 non-enriched detectors from Genius-TF for reference)

Claim of evidence
signal: 28.75±6.86 events
bg level: 0.11 cts/ kg·keV·y
H.V.Klapdor-Kleingrothaus, etc., Phys. Lett. B 586 (2004) 198-212

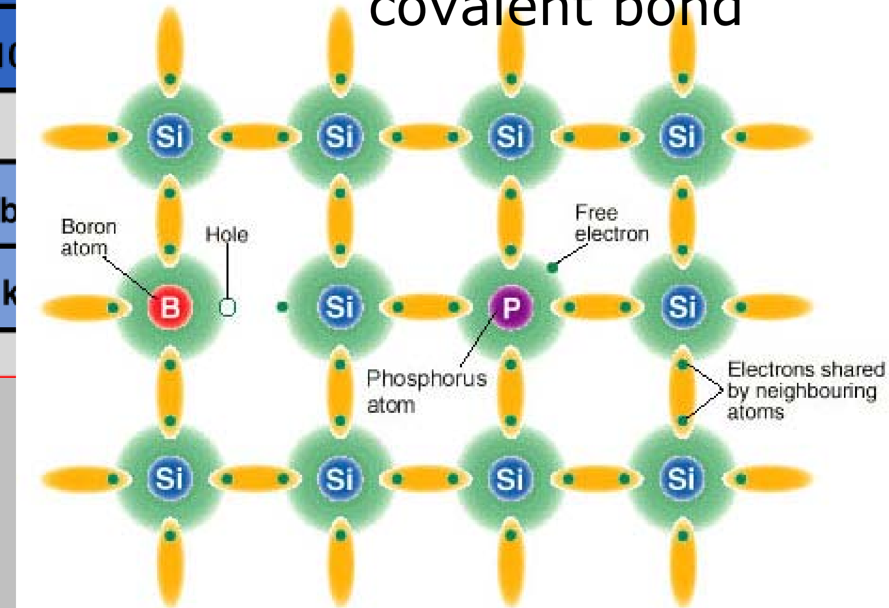
If claim true, phase-I will see:
signal: ~13 events
bg: 3 events in 10keV window at 2MeV



n-type & p-type semiconductors

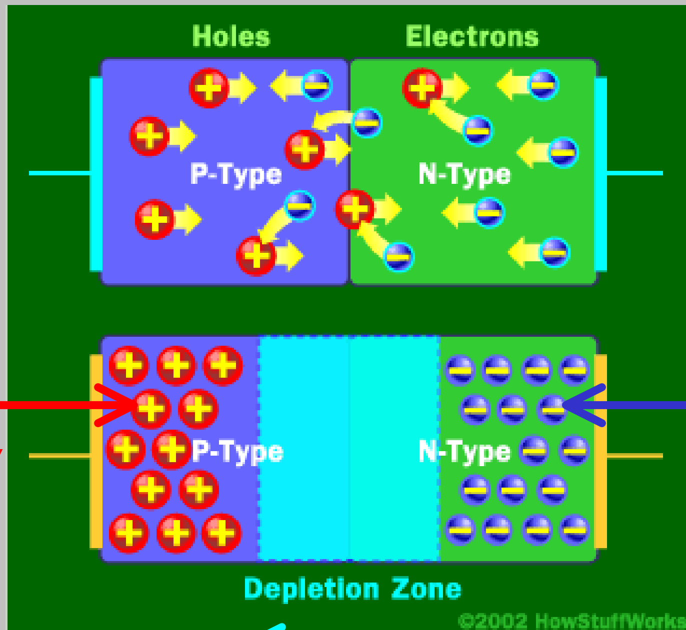


covalent bond



p-doped n-doped

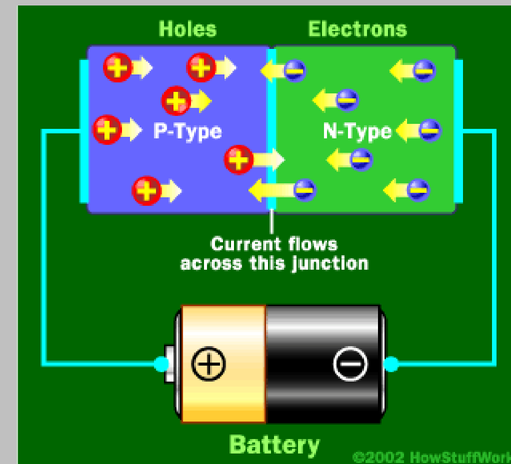
p-n junction, depletion zone & bias voltage



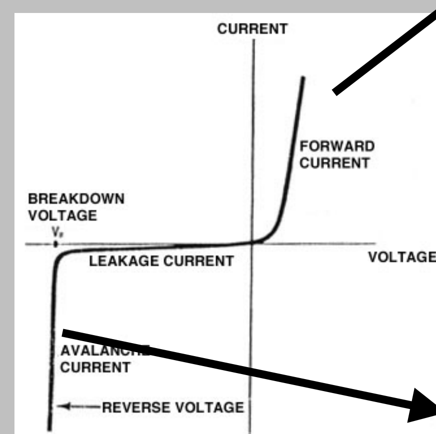
"free" holes

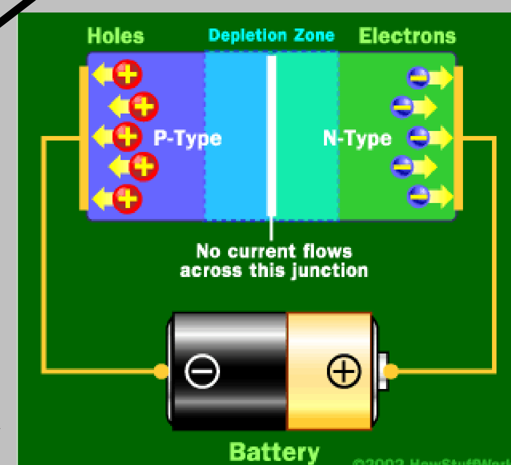
"free" electrons

E field in depl. zone



forward bias

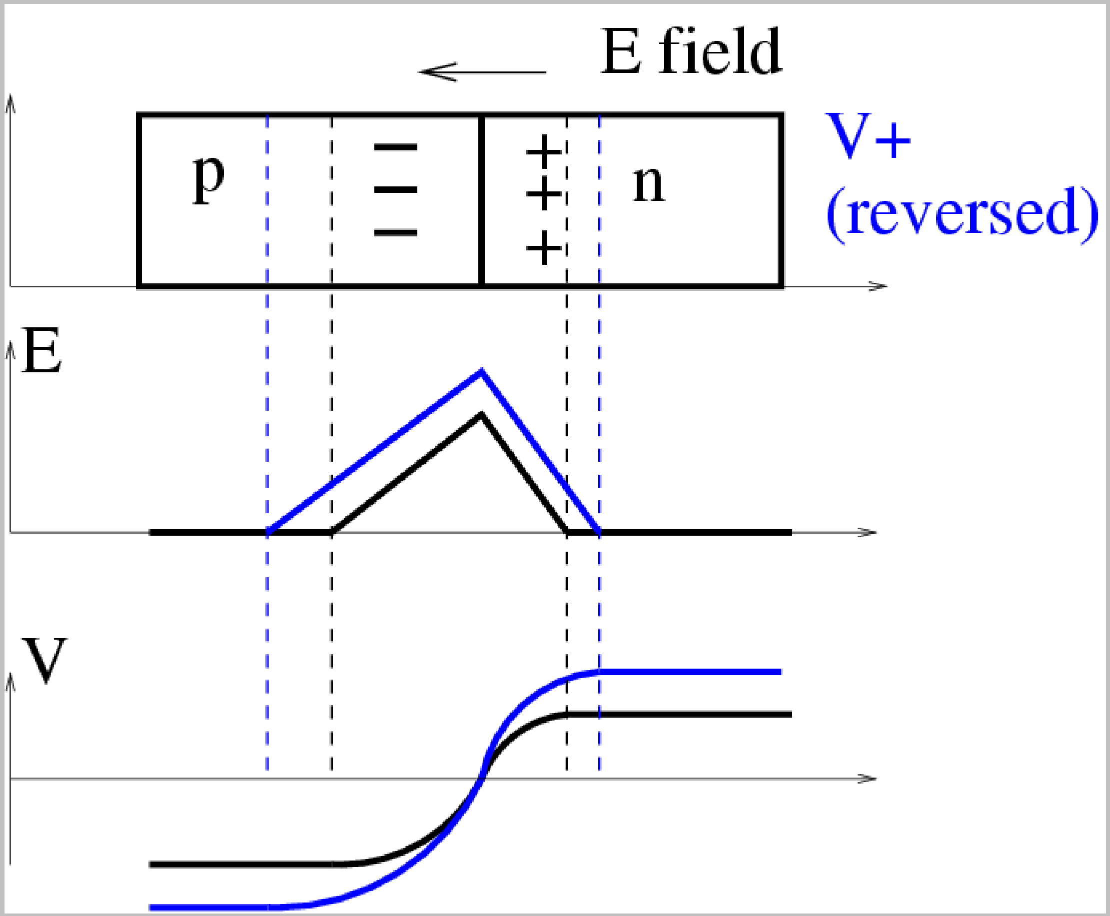




reversed bias

Depletion zone
is active volume

p-n junction, depletion zone & bias voltage

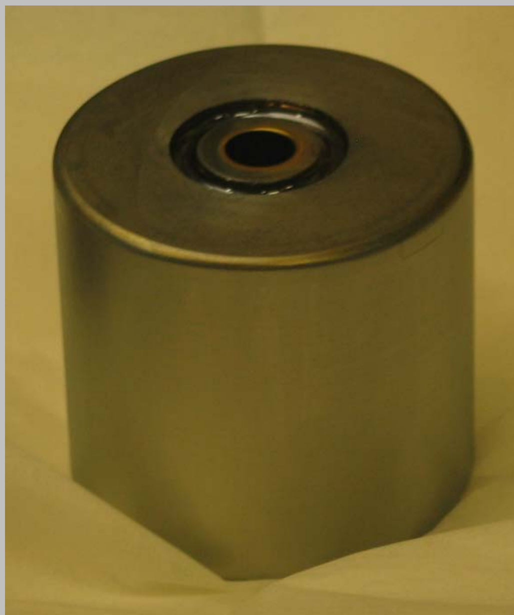


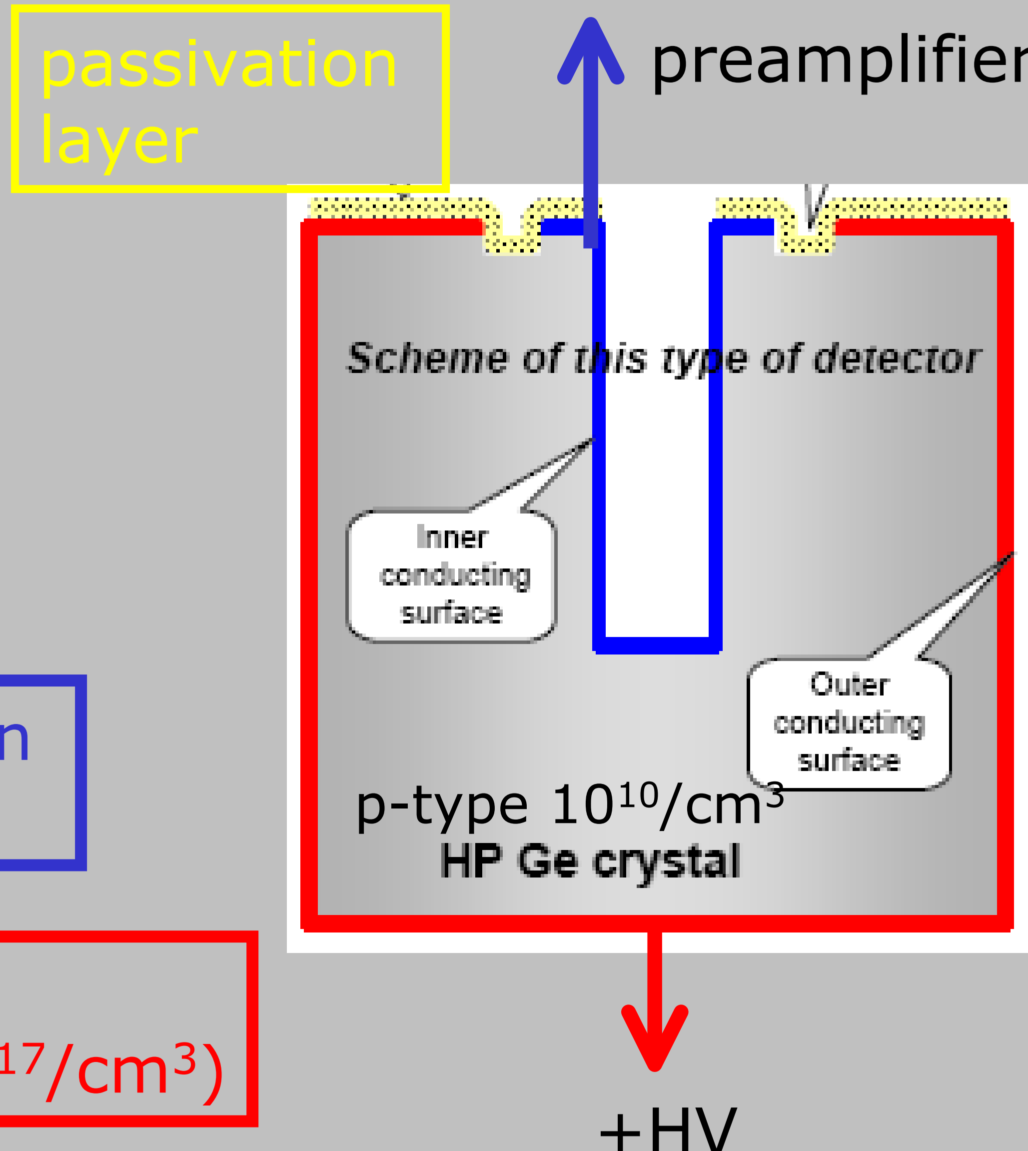
✓Depletion zone is the active volume.

✓Depletion zone depth anti-proportional to doping concentration, proportional to voltage.

$$D \propto \sqrt{\frac{V}{N}}$$

HdMo p-type Germanium detectors

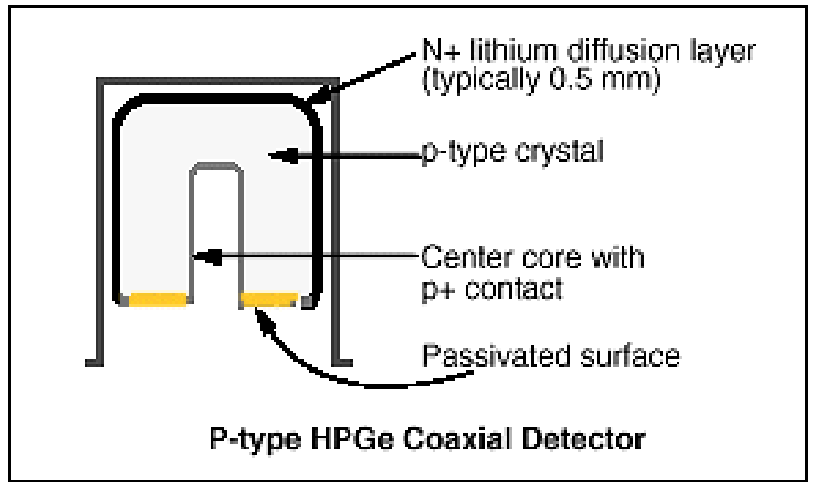


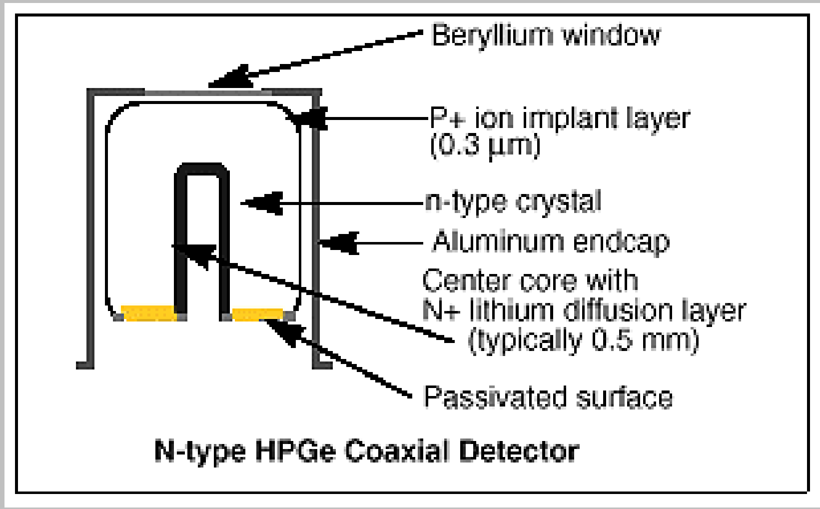


p+ B implantation layer 0.3 μm

n+ Li diffusion layer 0.5mm ($10^{17}/cm^3$)

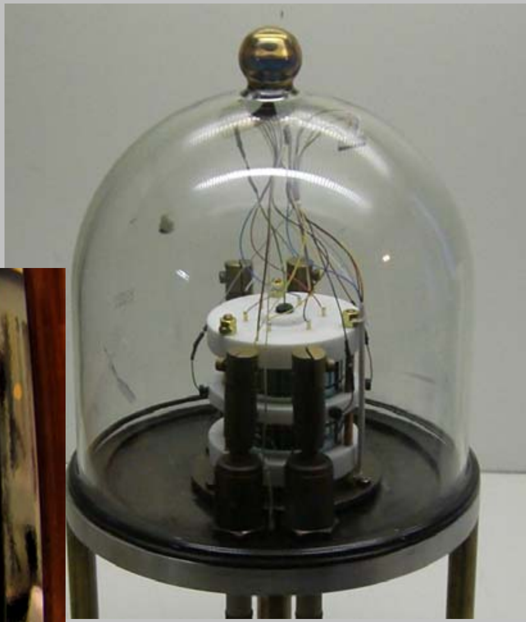
p-type & n-type Germanium detectors



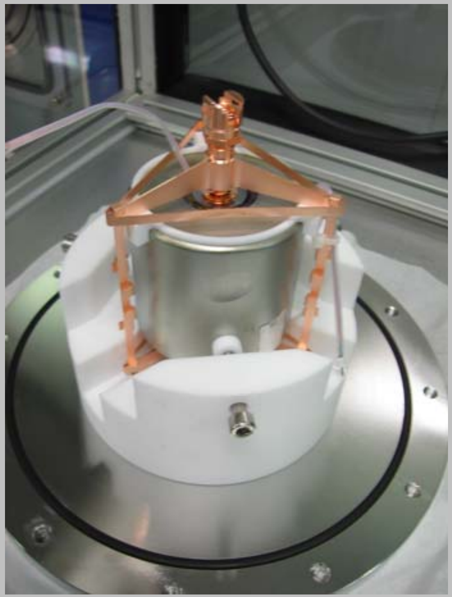


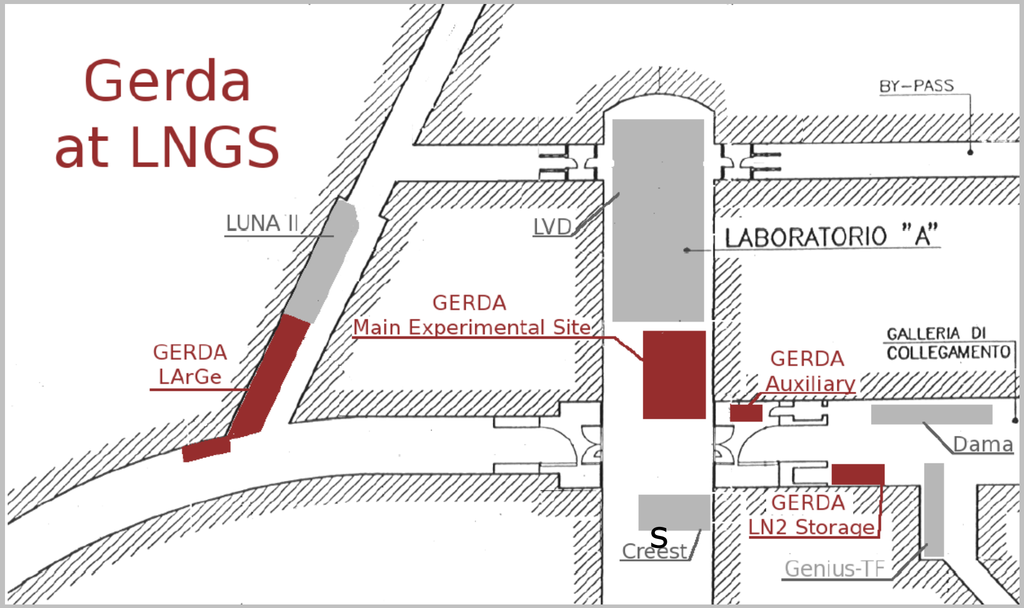
P-type: thick deadlayer outside
→ "robust"

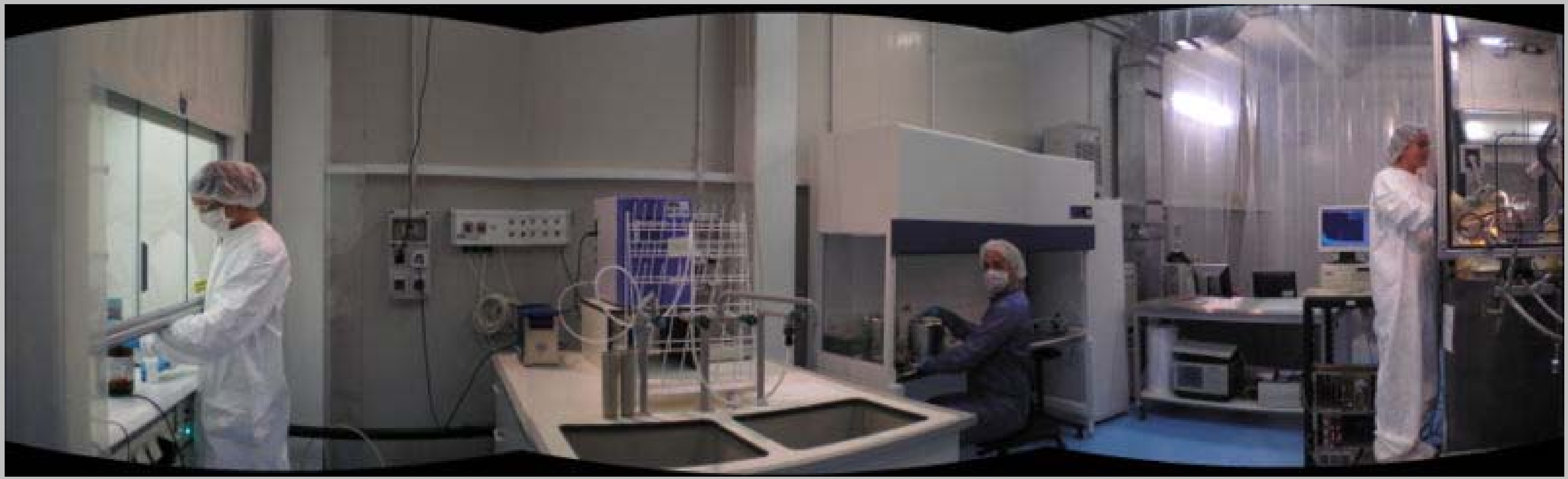
→ Ge in deadlayer wasted
→ non-uniform field, especially for segmented detector.



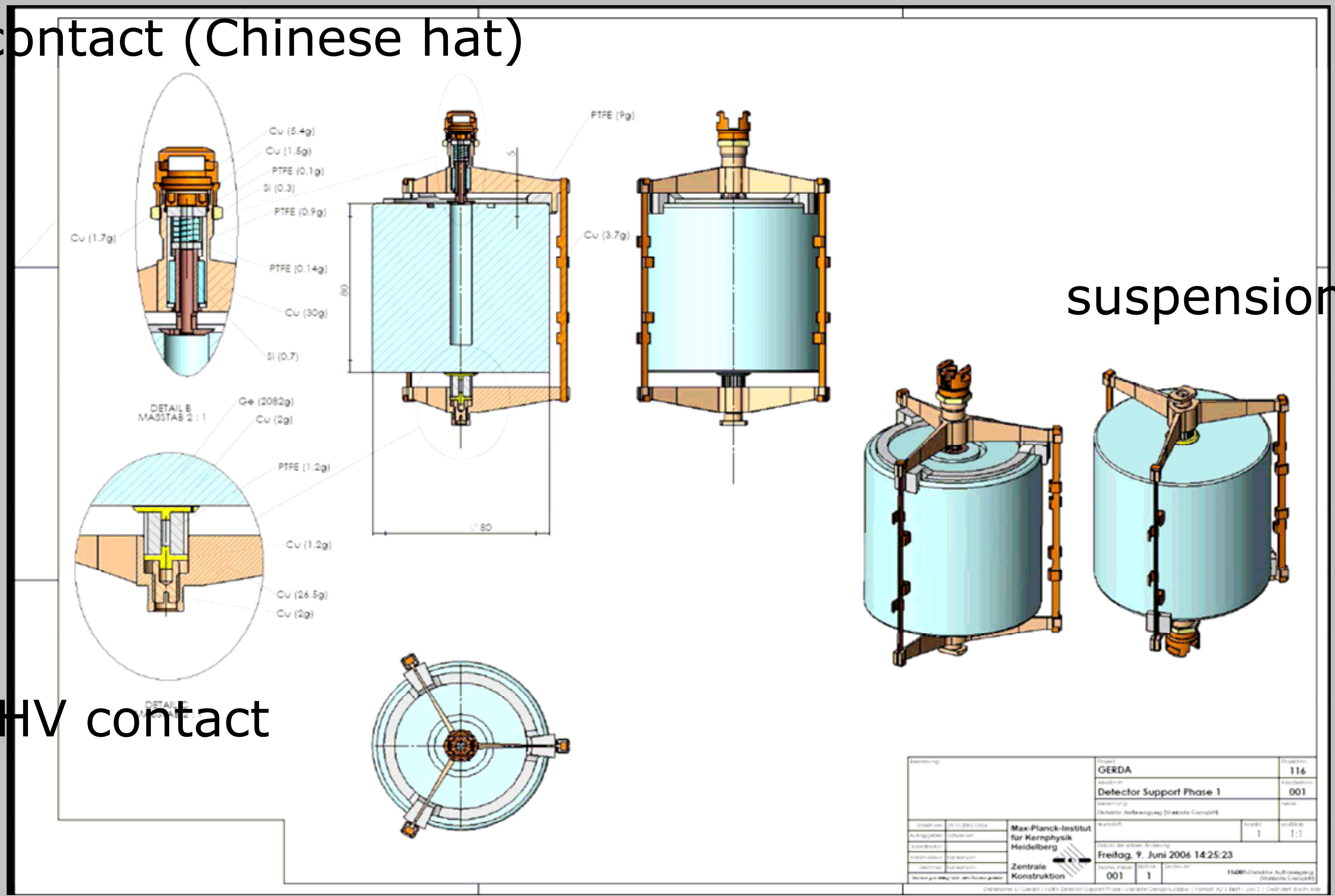
Prototype p-type Ge detector at GDL





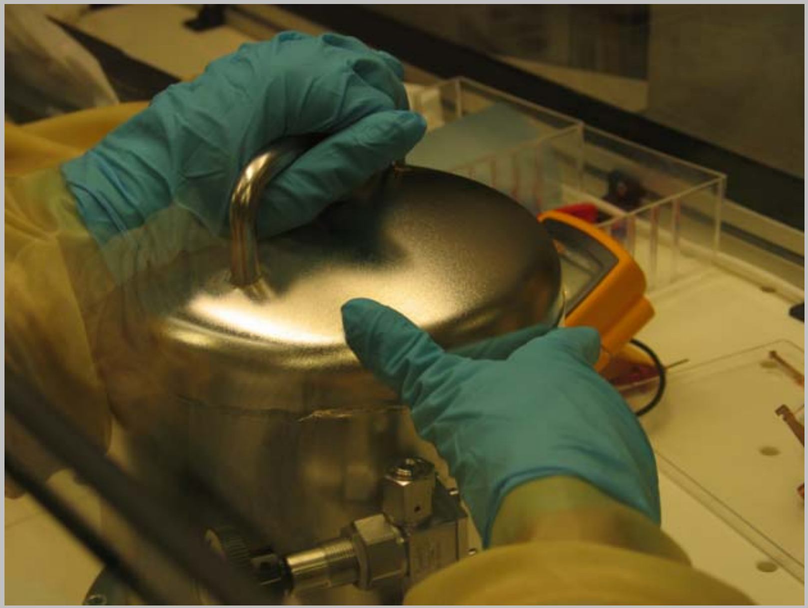


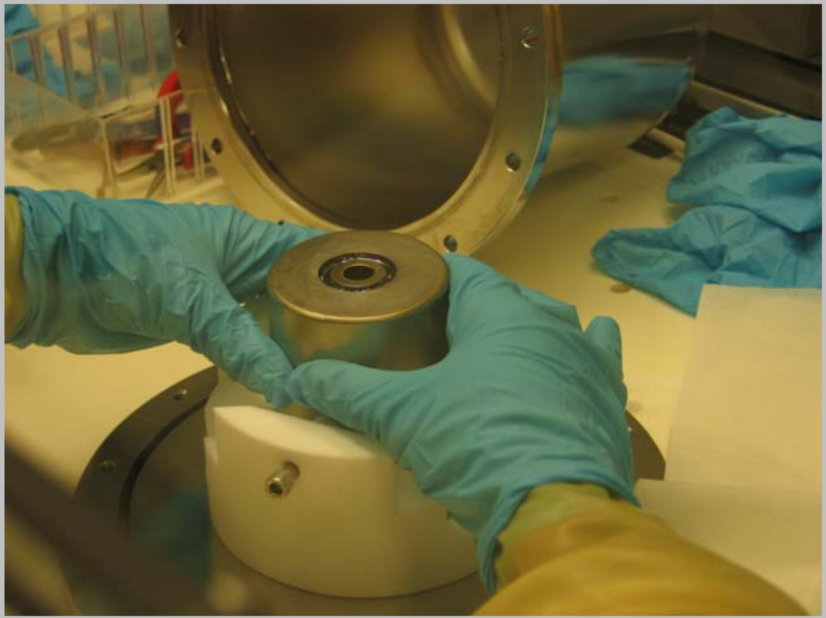
Prototype detector

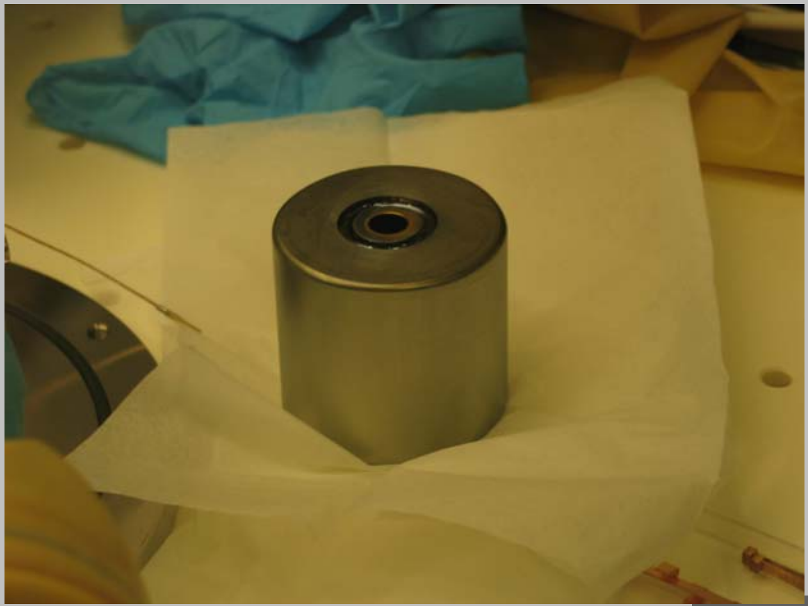


Operating prototype detector in liquid Argon

1. Take detector out of storage can
2. Mount readout contact (Chinese hat)
3. Mount support
4. Mount HV contact
5. Mount detector to suspension
6. Lower detector to LAr, apply HV







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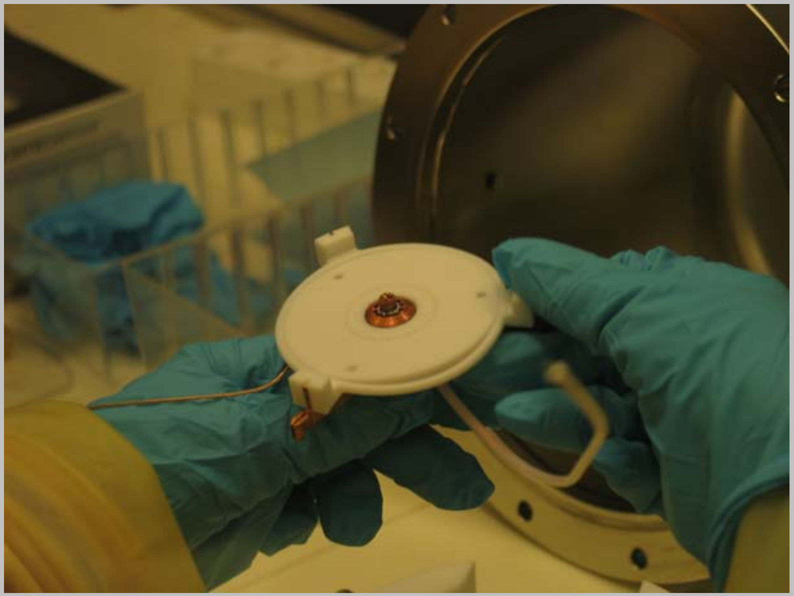

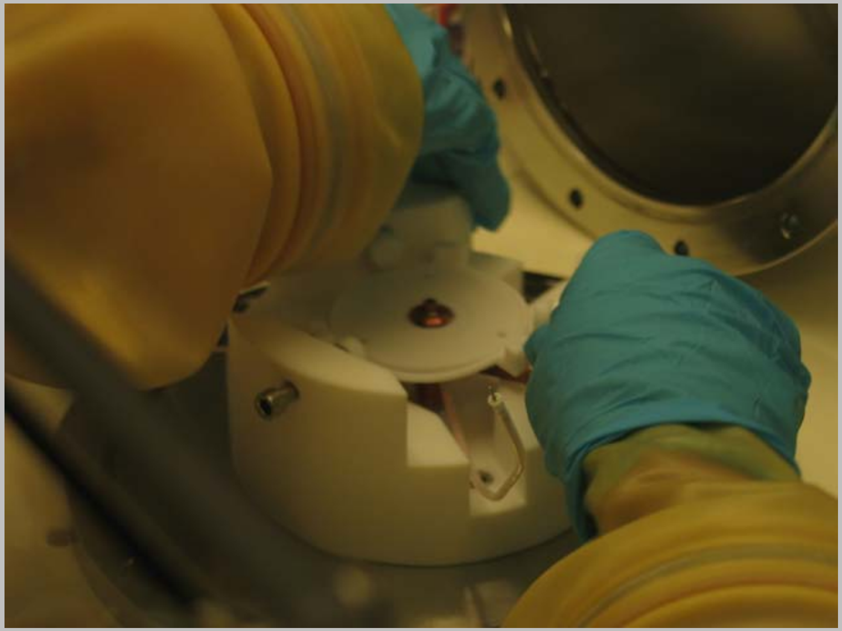

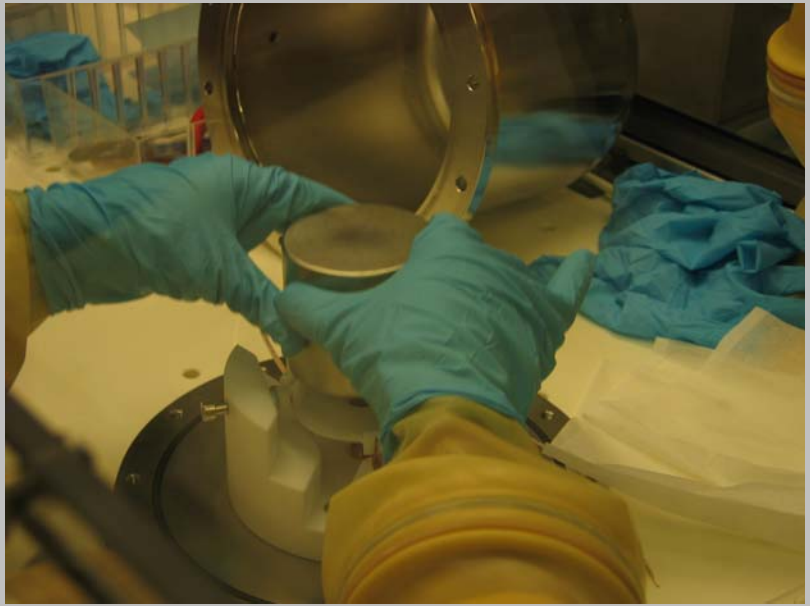

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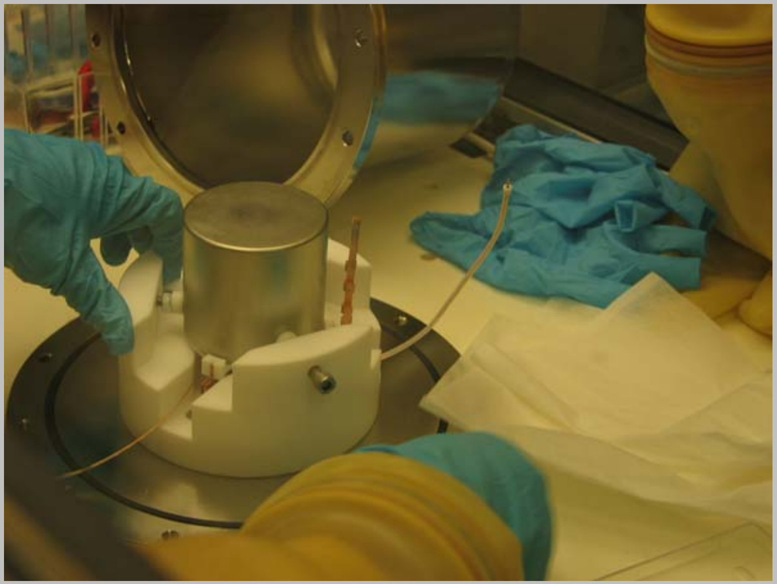

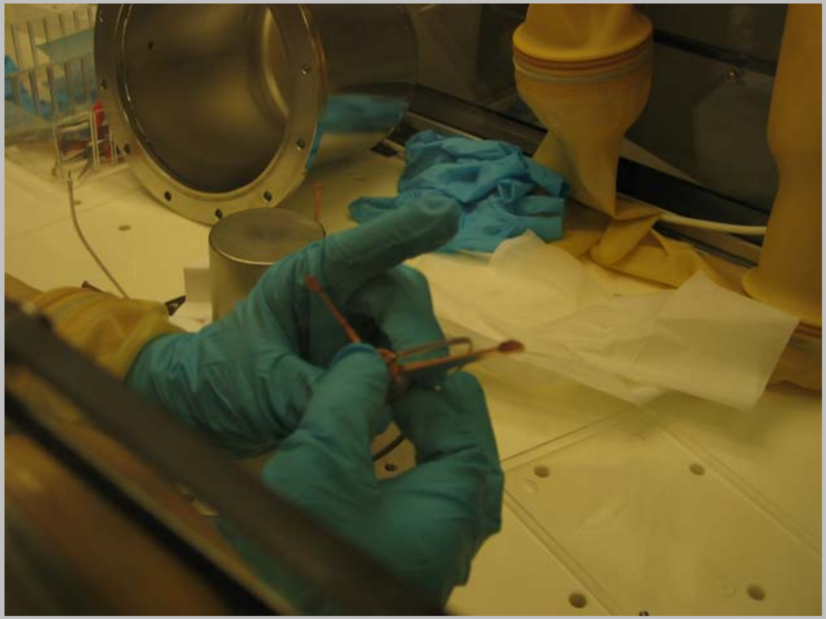

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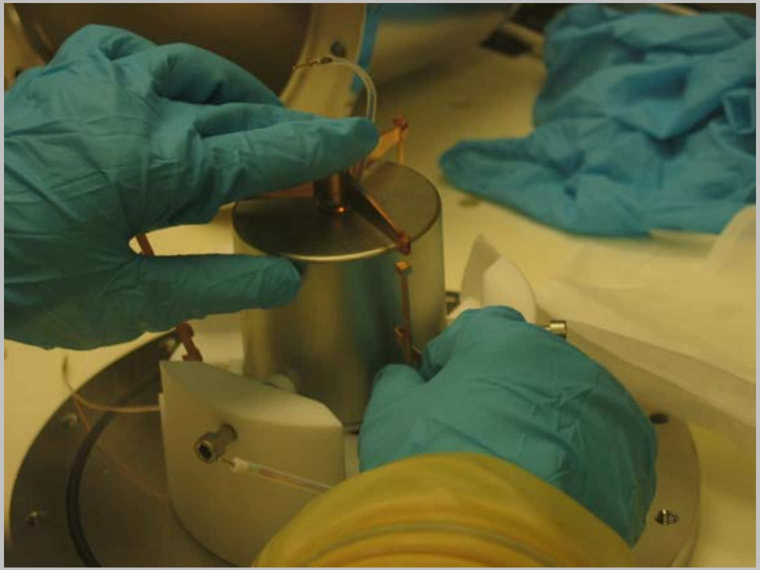

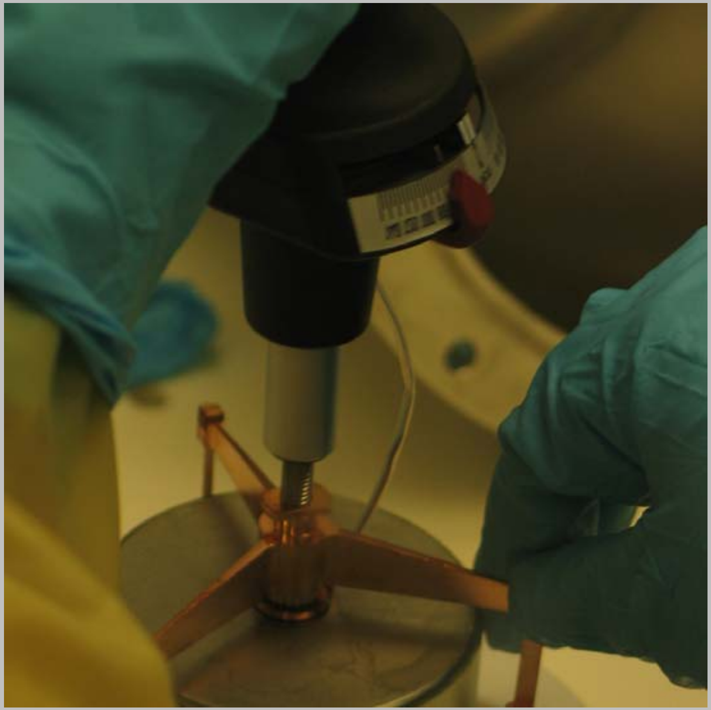

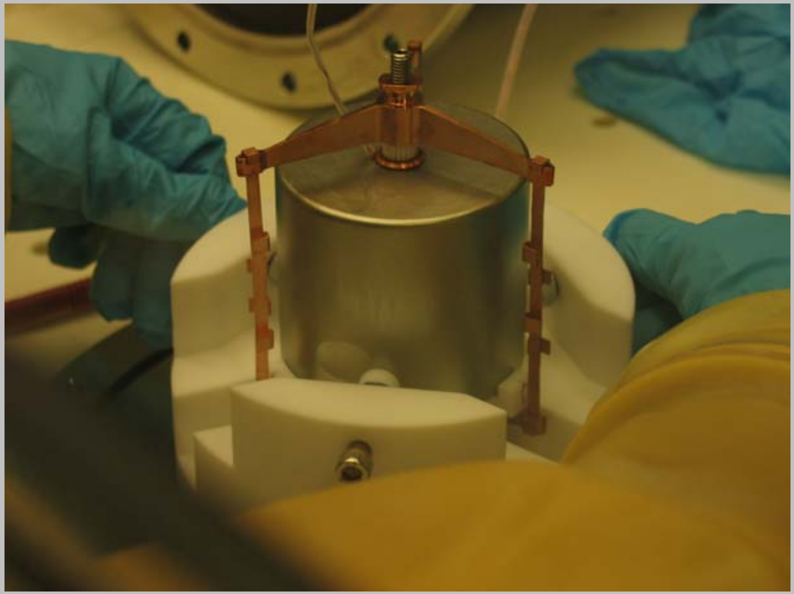

Operating prototype detector in liquid Argon

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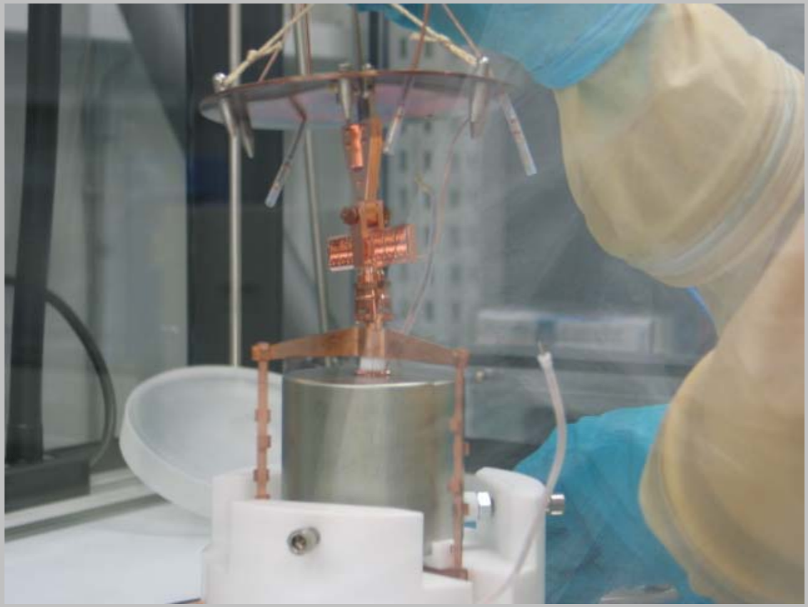

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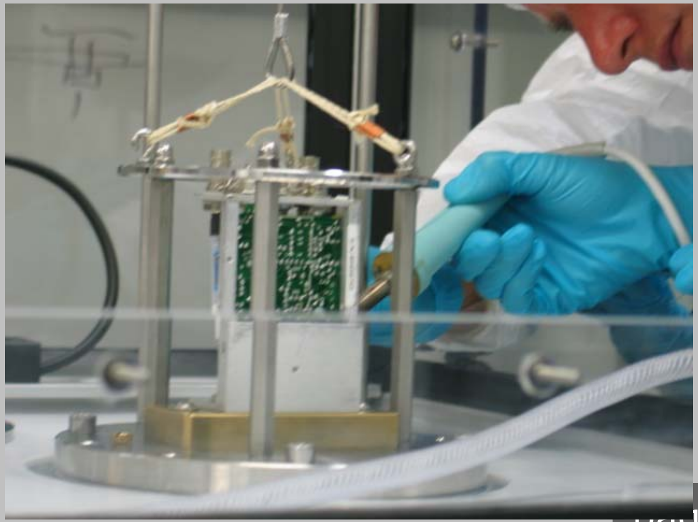

warming up dector

1. Take detector out of storage can
2. Mount readout contact (Chinese hat)
3. Mount support
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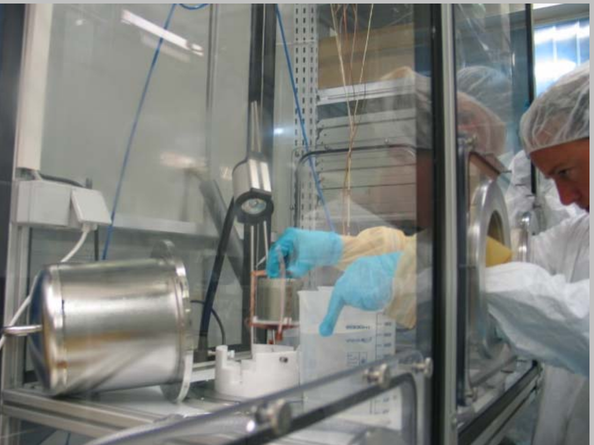
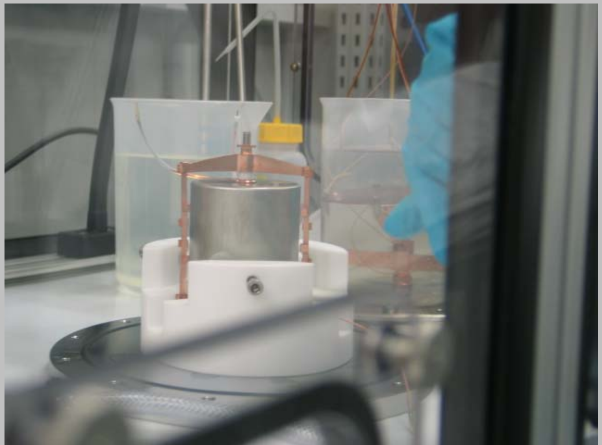
5. Mount detector to suspension
6. Lower detector to LAr, apply HV
7. Warming up after measurement





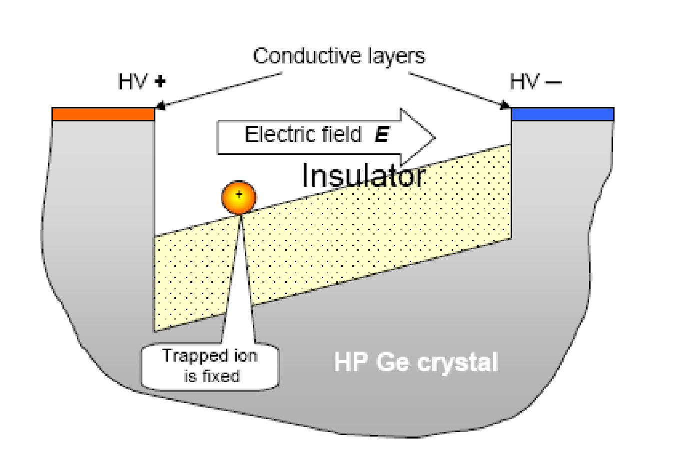
conclusion

GERDA Phase-I: p-type detectors
Phase-II: n-type detectors

Although Ge detectors are a big diode,
fabrication complicated,
detector fragile,
operating intricate.

We need to understand how Ge detector works, but our main focus is still on particle physics.

Possible explanation



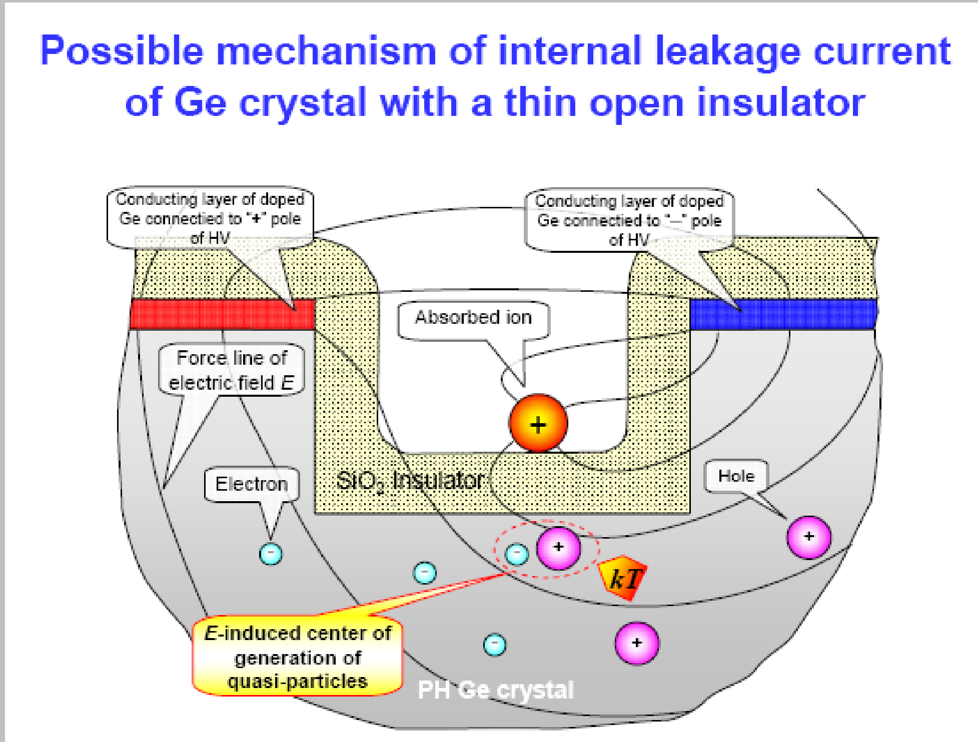
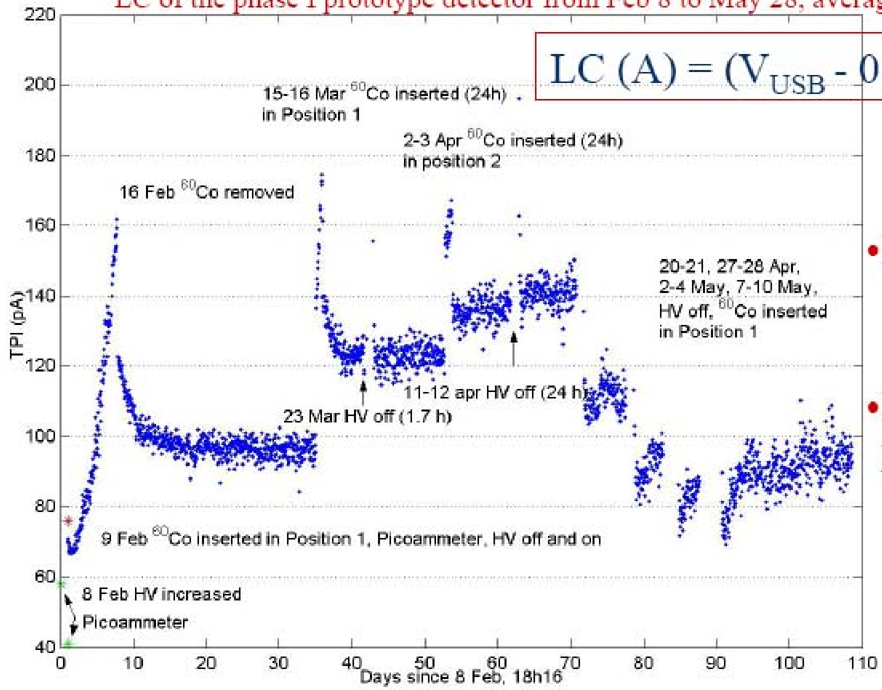


Fig. 3. Thermal generation of the charged quasi-particles in the HP Ge. A ion absorbed on the insulator outer surface, induces extra electric field E in the Ge crystal. It results in local distortion of Ge zone structure. This distortion works like impurity center producing free electrons and holes owing to thermal fluctuations.

Leakage current increase under radiation

Results – Leakage current (LC)

LC of the phase I prototype detector from Feb 8 to May 28, average/hour

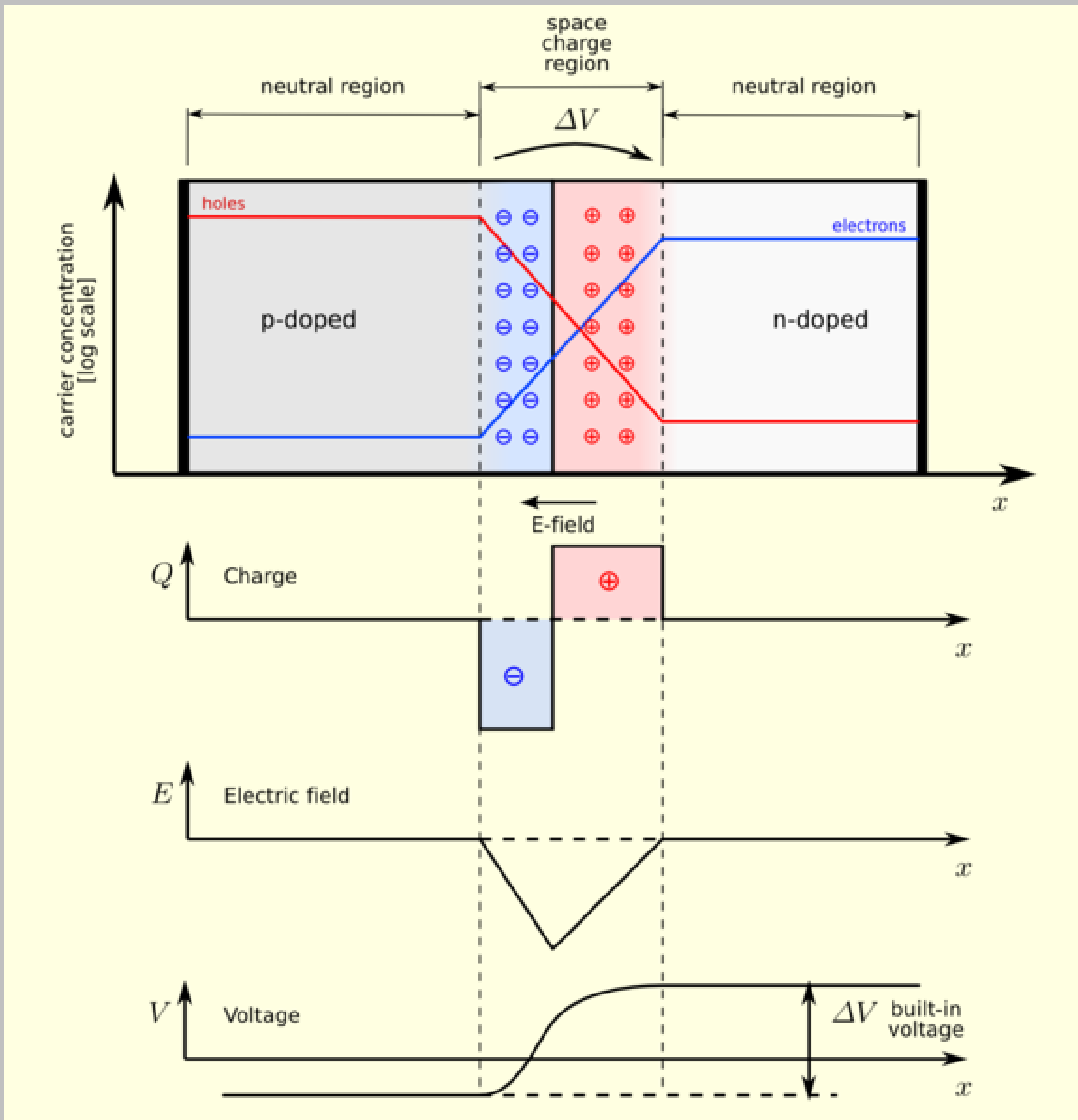


LC (A) = (V_{USB} - 0.495 V) · 1.17/2 (

- $I_{Bulk} = \dfrac{C < E >}{(2.95\ eV/e^-)}$
- $LC_{ave/h}$Error~7 pA

GERDA general meetings, Geel, June 11-13, 2007

p-n junction



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✓Depletion zone depth anti-proportional to doping concentration, proportional to voltage.

$$D \propto \sqrt{\frac{V}{N}}$$