GERDA Phase II detector assembly - design & performance

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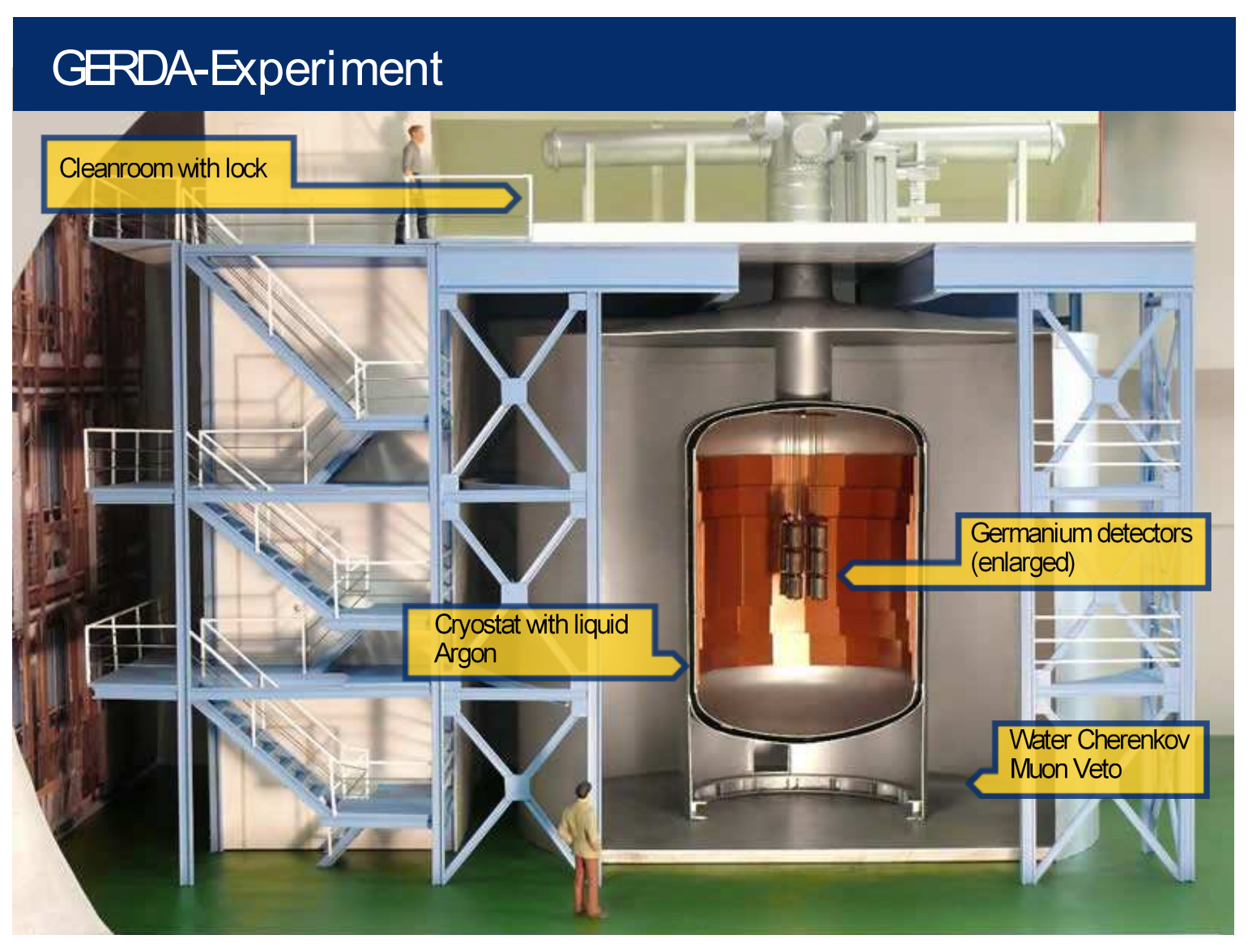
Germanium Detector Array Experiment



Schematic of GERDA Experiment

- **Search for neutrinoless double beta decay ($0\nu\beta\beta$) of ^{76}Ge**
- Operation of bare germanium diodes enriched in ^{76}Ge in liquid argon (LAr)
- Located at Laboratori Nazionali del Gran Sasso (LNGS) under 3400 m.w.e. of rock
- **Best limit for ^{76}Ge**

$$\boldsymbol{T^{0\nu}_{1/2} > 2.1 \cdot 10^{25}\,\mathrm{yr}\ (90\,\%\ \ \mathrm{C.L.})}$$

reached in June 2013 (Phase I)

- Now updating experimental apparatus to Phase II

Phase II of the GERDA Experiment

- Sensitivity on $T^{0\nu}_{1/2}$ is proportional to

$$\epsilon\, a \sqrt{\frac{M \cdot t}{BI \cdot \Delta E}}$$

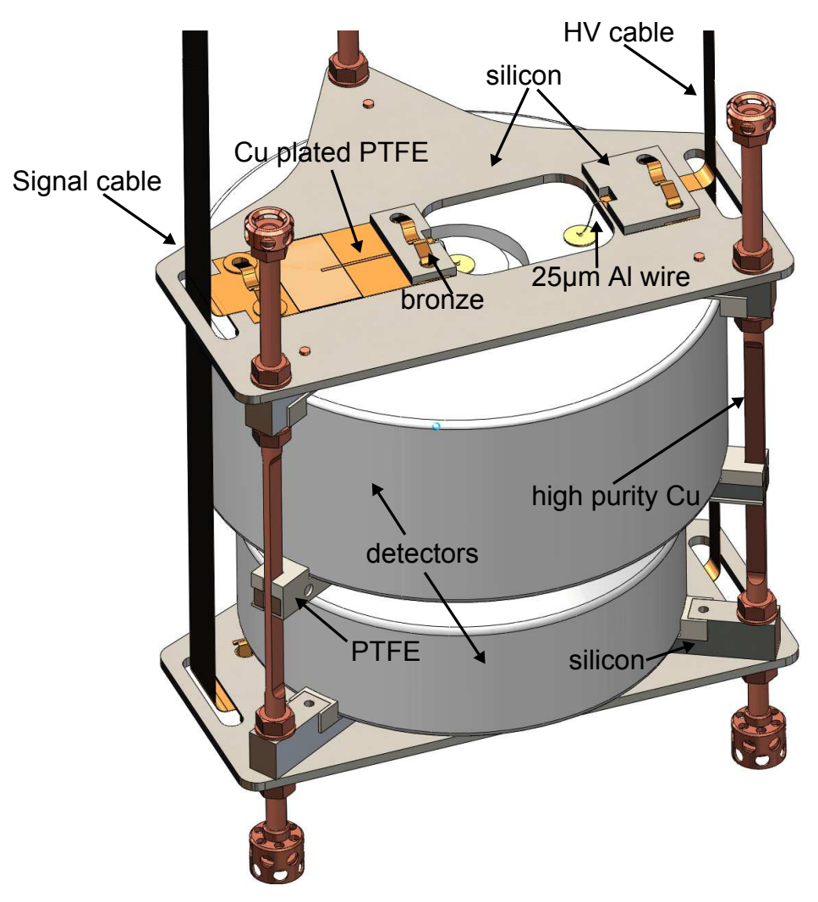
ϵ: detection efficiency, a: abundance of ^{76}Ge, M: target mass [kg], t: exposure [yr], BI: background index [cts/(keV·kg·yr)], ΔE: energy resolution around ROI at $Q_{\beta\beta}$ = 2039 keV

- Efficiency and abundance cannot be increased much more
- Increase of target mass by 20 kg with additional custom made detectors (BEGe)
- Reduction of background index by factor 10 to $< 10^{-3}$ cts/(keV·kg·yr) with
  - Active veto by reading out scintillation light of LAr
  - Improved pulse shape discrimination capabilities of new detectors
  - Use of even more radio-pure materials and reduction of mass close to the detectors, e.g. detector holders and front-end electronics
- Further improvement of energy resolution ΔE by better front-end electronics and new detectors

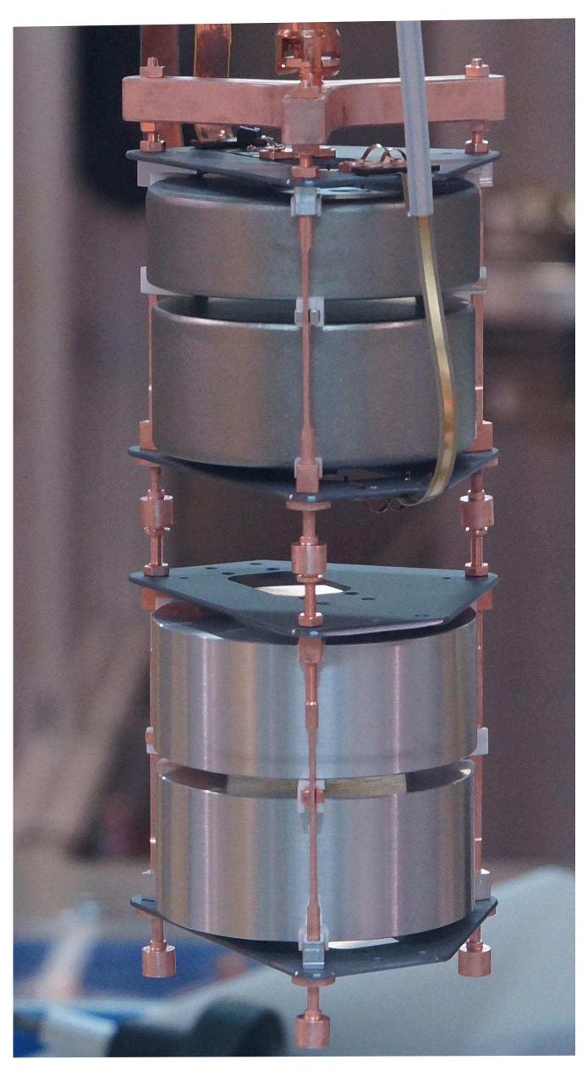
→ **Aim for Phase II sensitivity is**

$$\boldsymbol{T^{0\nu}_{1/2} > 10^{26}}\,\mathrm{yr}$$

Detector holder design



CAD of detector holder

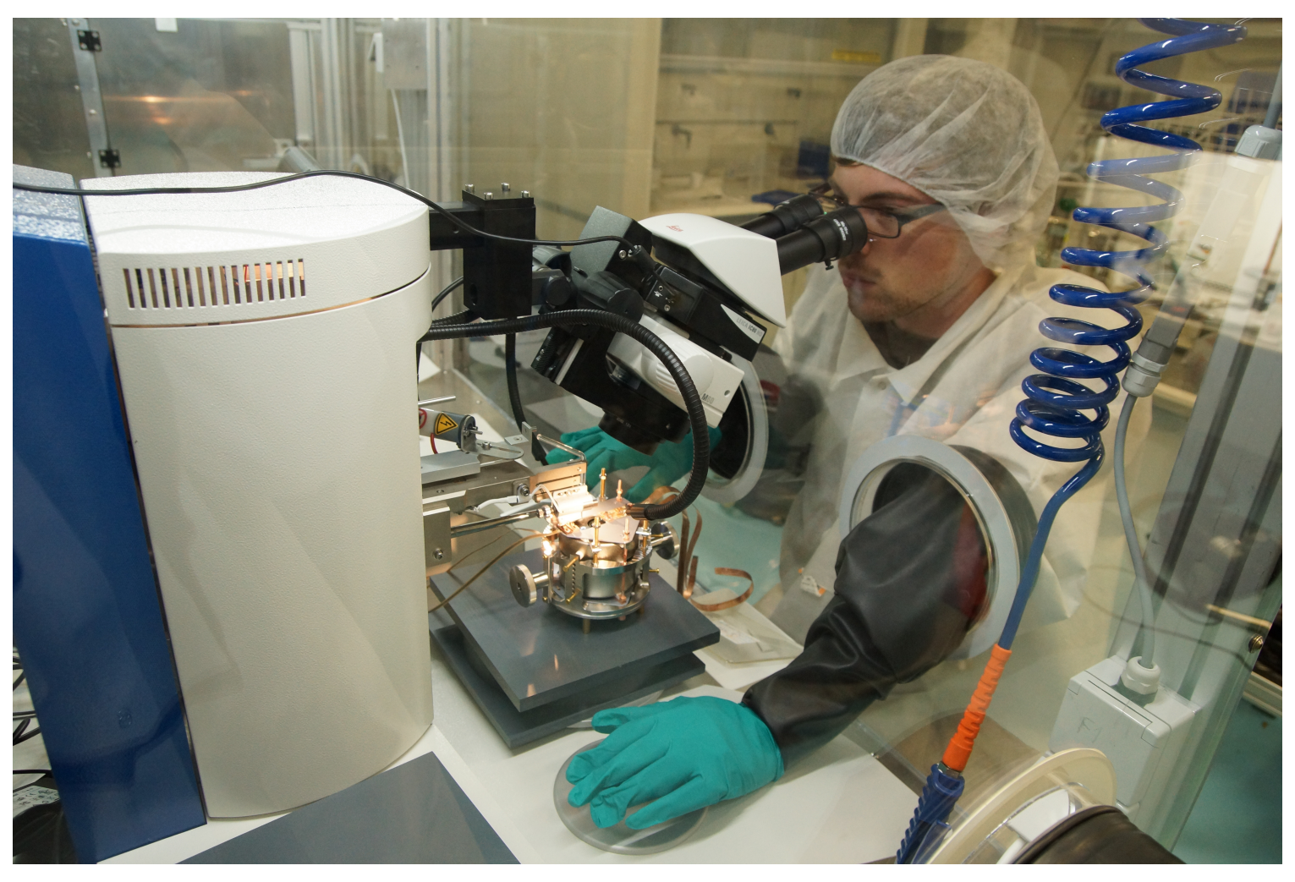


Assembly of two detector pairs

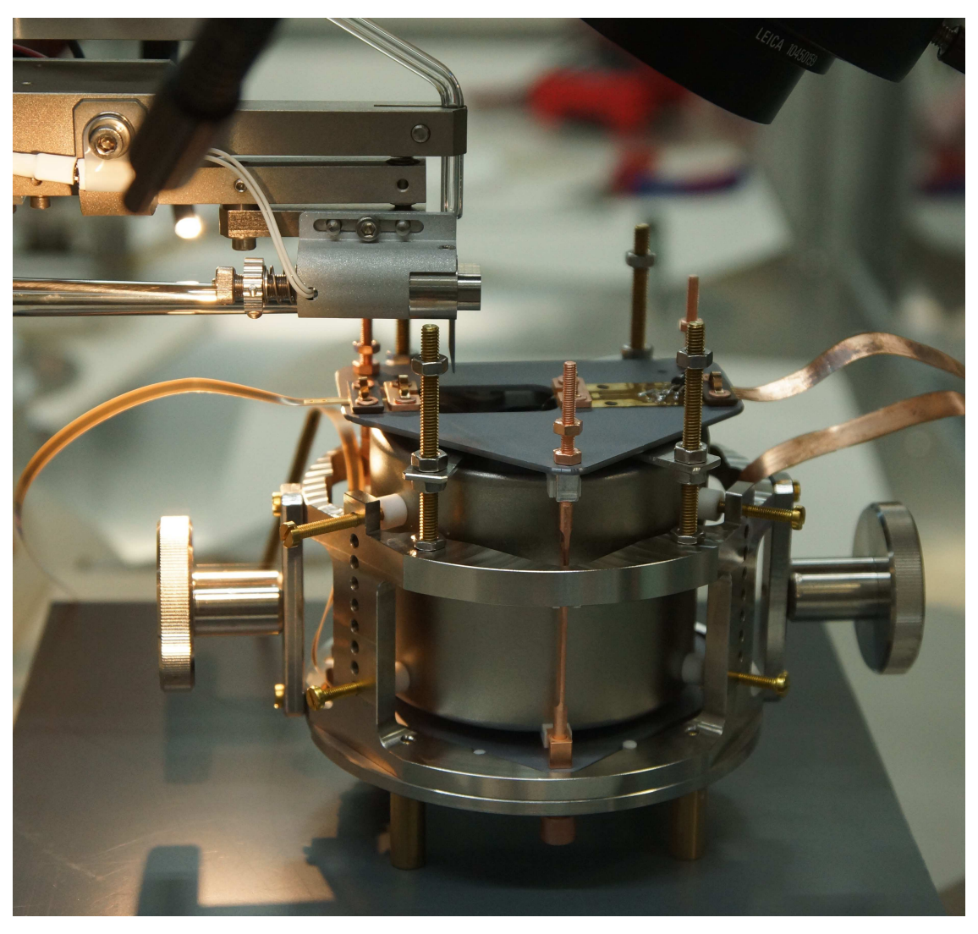
- Two new detectors are assembled as a pair
- First stage of front-end electronics & HV strip integrated into holder assembly
- Reduction of holder mass per kg detector mass is important since BEGe's are smaller than semi-coaxial detectors
- Most of the copper replaced by intrinsically pure monocrystalline silicon (known from neutron activation analysis)
- **New contacting scheme (wire bonding)** allows a holder with reduced mass and material strength, i.e. silicon

Detector contacting

Wire bonding



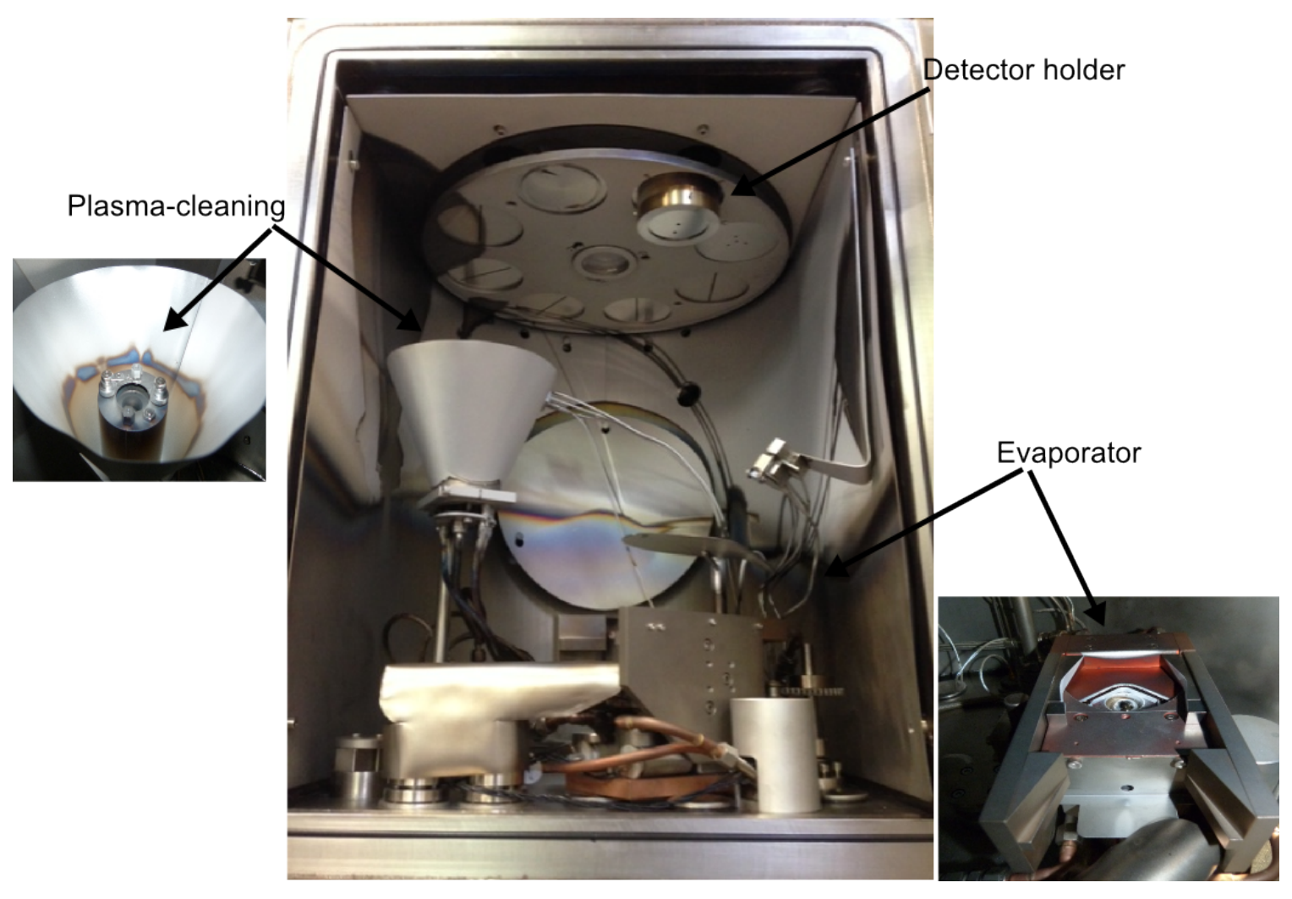
Bonding machine located in Germanium Detector Lab



Close-up of bonding arm & detectors in mounting jig

- Wire bonding well established in chip industry & for Si detectors, but not regularly used with large volume germanium diode detectors
- Small masses of bonding wire (25 µm wire thickness) ensure low background contribution
- **Challenges:**
- Bonds have to be stable during immersion in LAr & warming up ✓
- Bonding must not damage sensitive read-out electrode ✓
- Usage of bonding machine in glove box ✓

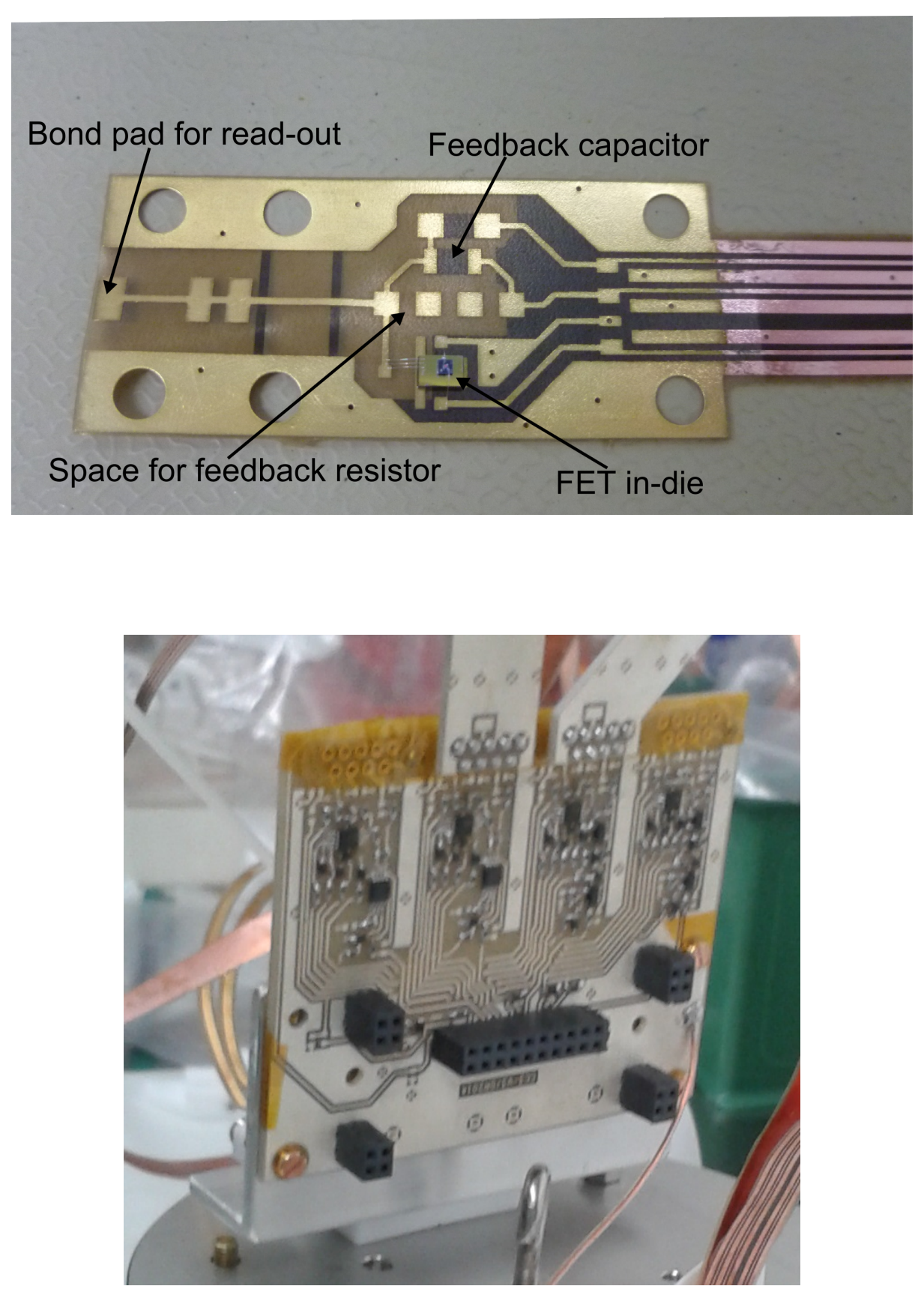
Metalization of detectors



Thin film deposition machine

- Metalization of read-out & HV electrodes needed for **ohmic contact at cryogenic temperatures & reliable wire bonding**
- Aluminum e-gun evaporation chosen as high quality deposition process
- Screened high purity material (6N) and film thickness (600 nm) ensure small background
- **Process developed at TUM** and integrated into production process in close collaboration with detector vendor Canberra SNV, Olen

Front-end electronics



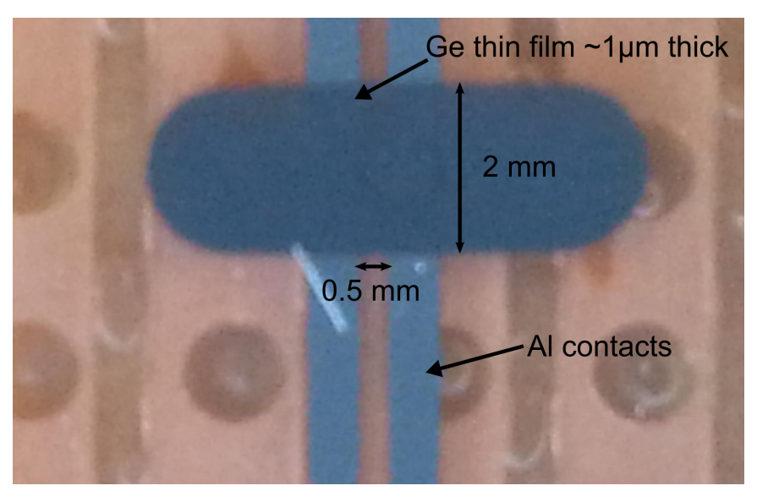
1st & 2nd stage of front-end electronics

- Concept of GERDA Phase II front-end electronics is **separation of 1st & 2nd stage of charge sensitive pre-amplifier**
- Close-by 1st stage (6 mm) reduces noise due to additional capacitances & pick up
- Electronically more complex 2nd stage put far away from detectors (~50 cm) to reduce background contribution

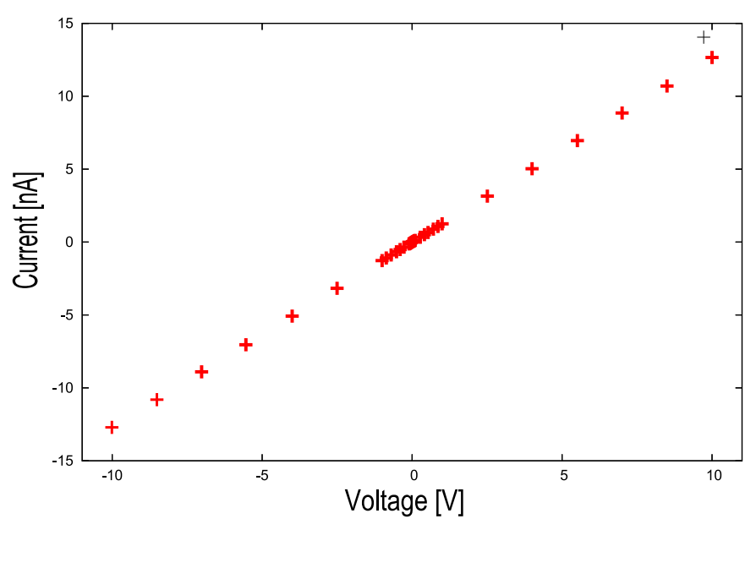
Description of 1st stage

- Components integrated on signal cable
- FET in-die with low capacitance
- Stray capacitance of traces as feedback capacitor
- Radiopure resistor with high resistance (~GΩ) still to be chosen

Feedback resistor development at TUM



Amorphous germanium resistor sample



Linearity curve of sample resistor

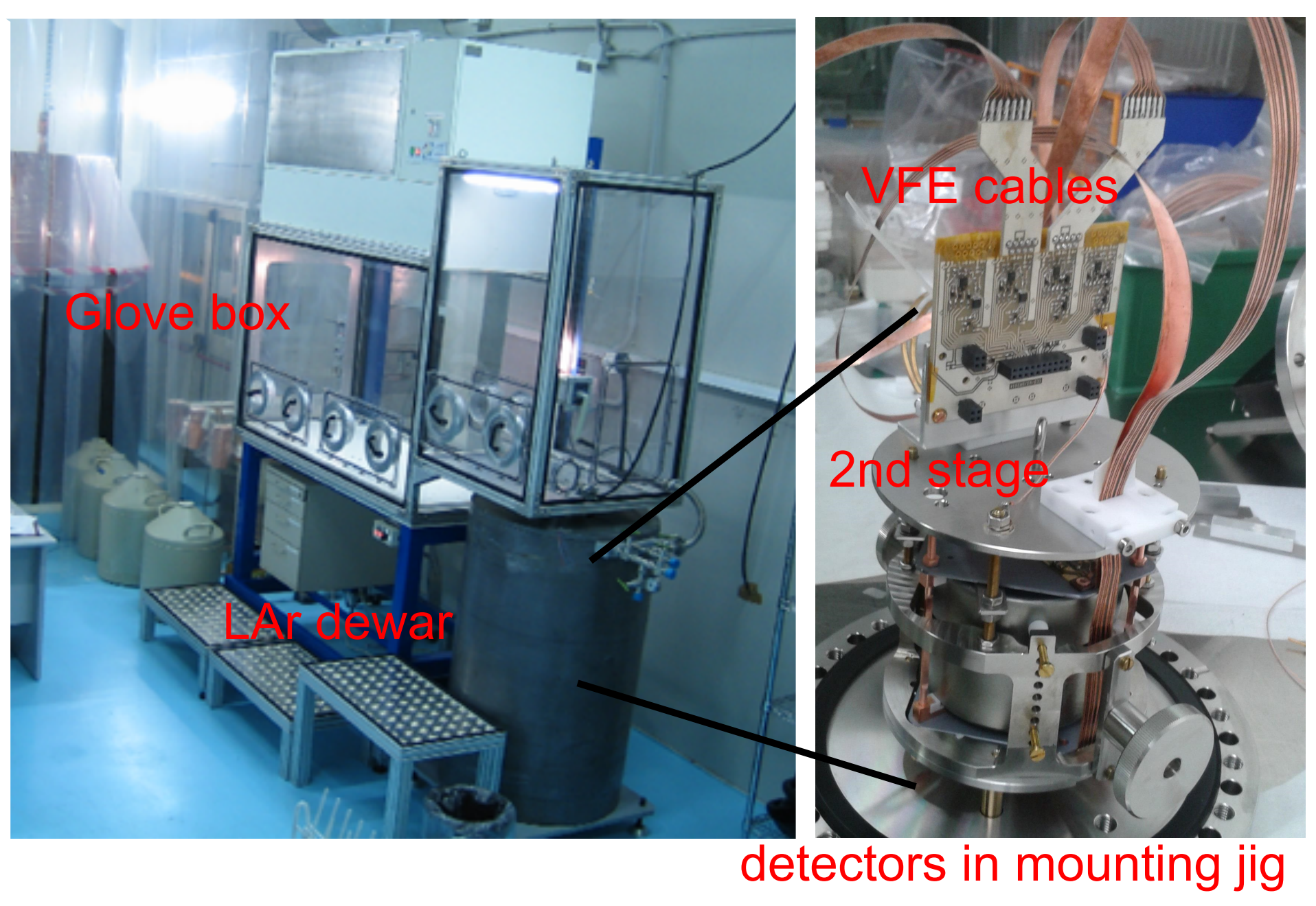
- Amorphous germanium (a-Ge) is radio-pure & higly resistive at LAr temperature
- MAJORANA Experiment uses a-Ge resistors
- High resistance reduces thermal noise component
- Thin film deposition techniques used for production
- High purity quartz as substrate

Status:

- Achieved correct resistance values with high reproducibility ✓
- Verified linearity of a-Ge over wide voltage range ✓
- Resistance increases over time when stored in room atmosphere
- Impact of possible cryogenic or inert atmosphere storage being investigated

Integration test & first results

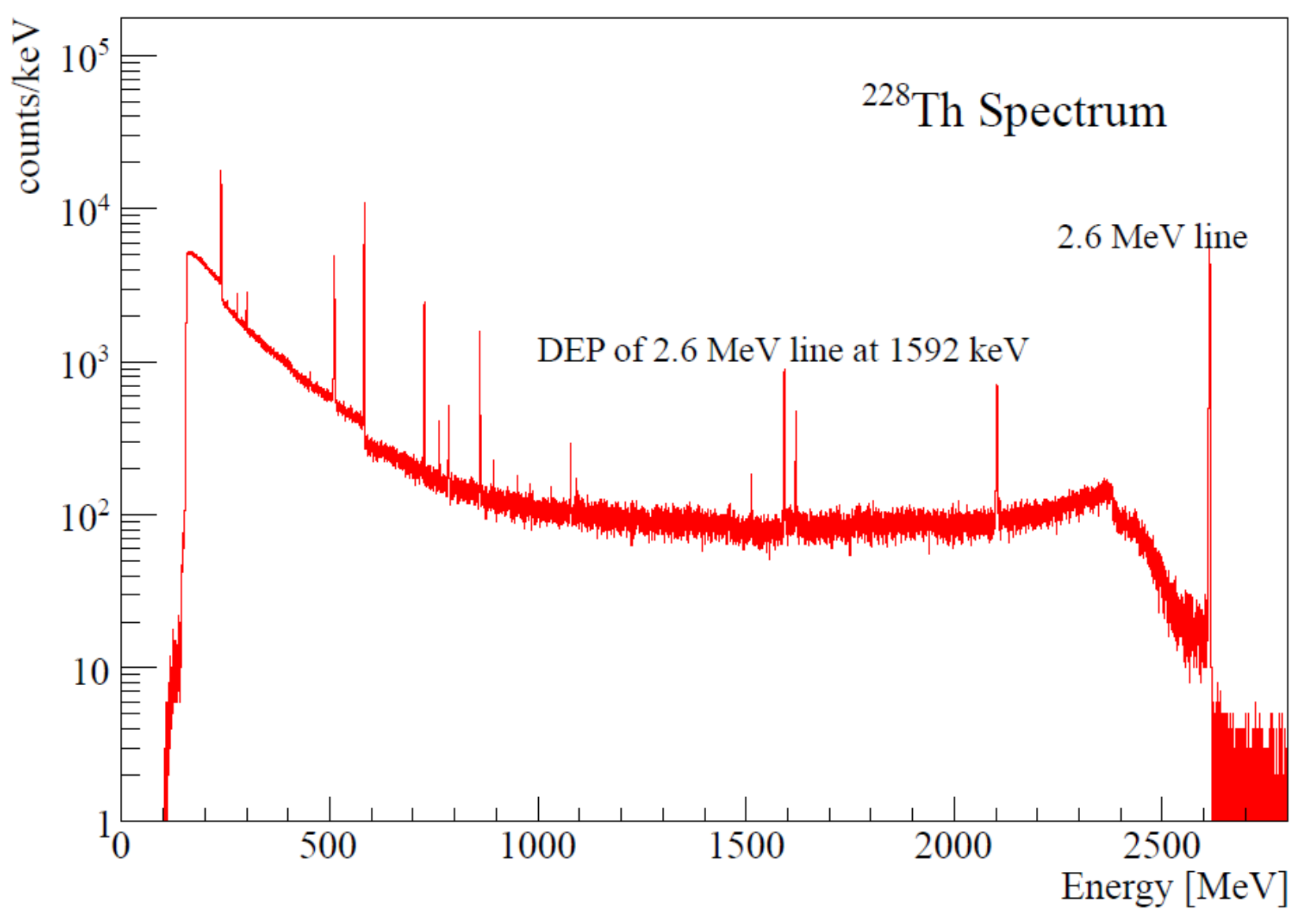
- Test of complete assembly in liquid argon cryostat
- Detector assembly built up in glove box
- Use of prototype detectors (from non-enriched material)
- Investigation of **noise**✓, **microphonics**✓, **handling**, **stability**, **energy resolution**✓, **pulse shape discrimination performance** ongoing
- Test of new front-end electronics in close to final setup with realistic VFE cable length
- Measurements with ^{228}Th source for energy resolution and pulse shape performance testing



Testing apparatus in underground Germanium Detector Lab (GDL)

- Energy resolution of BEGes in **Phase I with not close VFE** (CC2): **3 keV** @ 2.6 MeV during calibrations
- With **new VFE** and **2nd stage** (CC3) during integration tests in **LAr** and **final cable length**: **2.7 keV** @ 2.6 MeV
- Resolution in **vacuum cryostat** (under ideal conditions): **2.4 keV** @ 2.6 MeV
- Pulse shape capabilities at least as good as in Phase I - still being investigated

→ **Excellent energy resolution in ultra low background setup is main advantage of germanium detectors**



Peak [keV]	Fitted peak pos. [keV]	FWHM [keV]	Rel. resolution [%]
583.191	583.09 ± 0.00	1.49 ± 0.00	0.26
1592.537	1592.17 ± 0.01	2.14 ± 0.02	0.13
1620.500	1620.03 ± 0.01	2.12 ± 0.03	0.13
2614.533	**2614.20 ± 0.00**	**2.71 ± 0.01**	**0.10**

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