THE GIOVE DETECTOR

High sensitivity germanium spectrometer at shallow depth.

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GERMANIUM SPECTROSCOPY

- High purity germanium crystals can be manufactured into gamma ray detectors with excellent resolution.
  - Typical resolutions of ~0.1%.

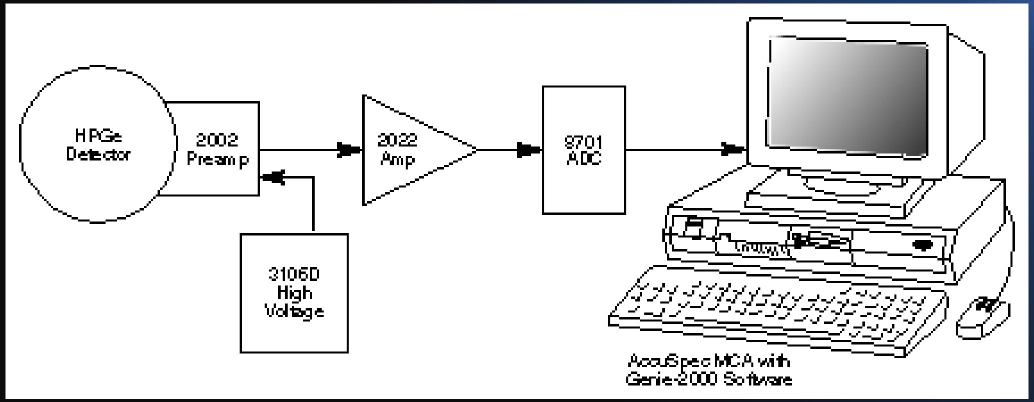
- GIOVE = **High purity Ge (HPGe) detector**
  - Suitable for measuring trace amounts of radioactivity (not high energy radioactive sources).
  - Used to screen materials for radioactivity.

Germanium crystal.

Operation Principle

- Energy of gamma rays can be measured following **energy transfer of photons to electrons in the crystal.**
  - Via the photoelectric effect, Compton scattering, electron-positron pair production – depending on photon energy.

High voltage applied to the crystal. → Electric field in the diode makes it possible to collect electron-hole pairs produced by particles crossing the crystal. → Measure the amount of charge produced by the initial particles – this is proportional to the energy of the particles.



The typical order of operations...

MOTIVATION: ULTRA LOW BACKGROUND EXPERIMENTS

- Gamma ray spectroscopy with Ge detectors an essential tool for **material screening** in rare event physics experiments:
  - Searches for **dark matter, neutrinoless double beta decay, and solar neutrinos.**

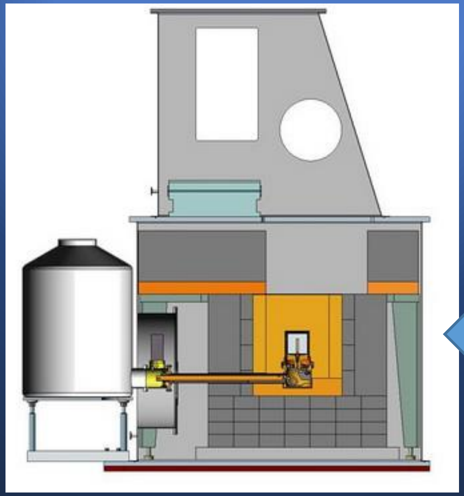
- Such experiments demand the lowest possible radioactivity concentrations – near target or detector array.
  - XENON Dark Matter Project
  - GERDA search for $0\nu\beta\beta$ decay

MOTIVATION: ULTRA LOW BACKGROUND EXPERIMENTS

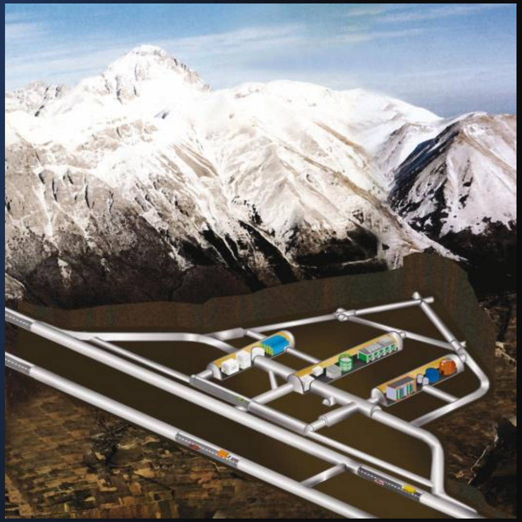
- GeMPI detectors - highest-sensitivity Ge detectors available, located in Gran Sasso National Laboratory (LNGS) in central Italy.
- Achieve detection limits of **10 μ Bq/kg** (U and Th) with 3800m w.e. overburden providing cosmic ray shielding.

DRAWBACKS

- Incovenience
- Cost
- Time (for measuring samples)



GeMPI-I detector at LNGS.



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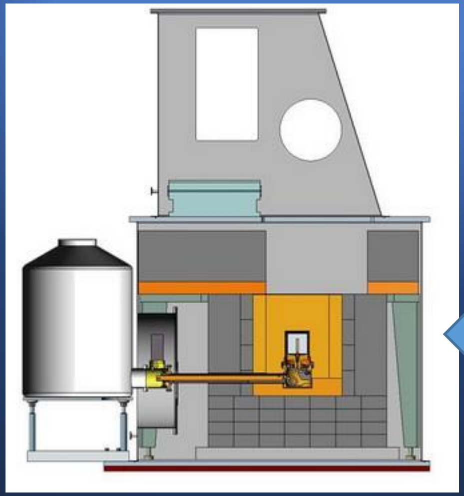

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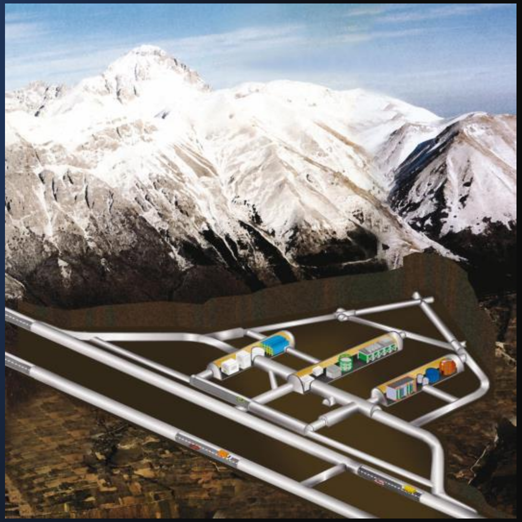

Can we achieve the same sensitivity at just 15m w.e. at MPIK?

Answer: Almost.

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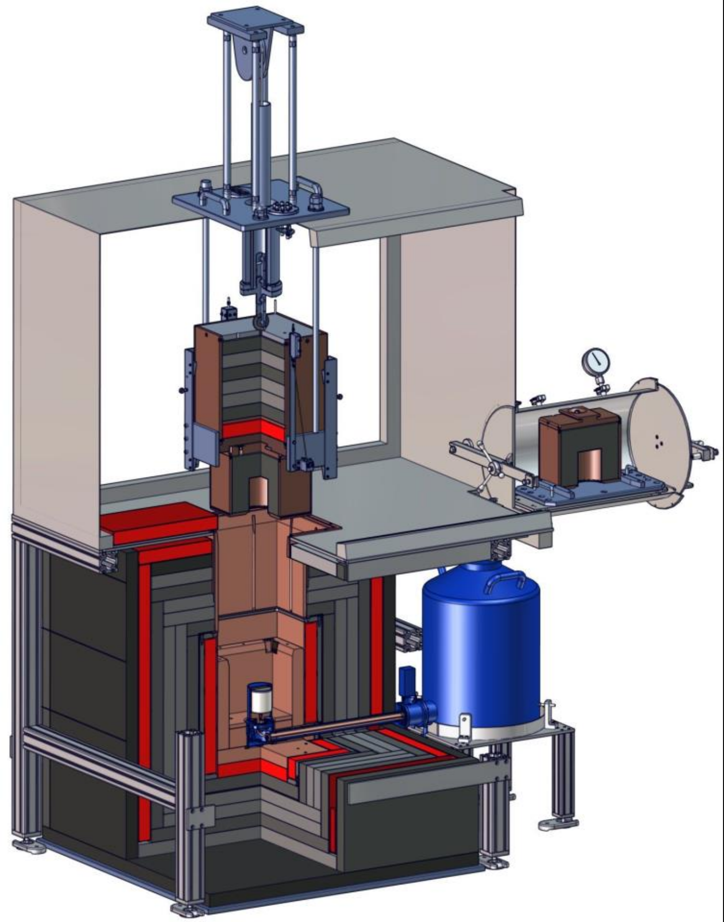
GIOVE = Germanium Inner and Outer Veto

- Located in low-level lab at MPIK at 15m w.e. (= 5.3m rock/soil)

- Muon flux reduced by a factor of ~2-3, compared to 10^6 at LNGS

- Achieves sensitivities in 100 μBq/kg (U and Th) range.



The GIOVE detector.

BACKGROUND IN GIOVE

Source

Cosmic ray muons

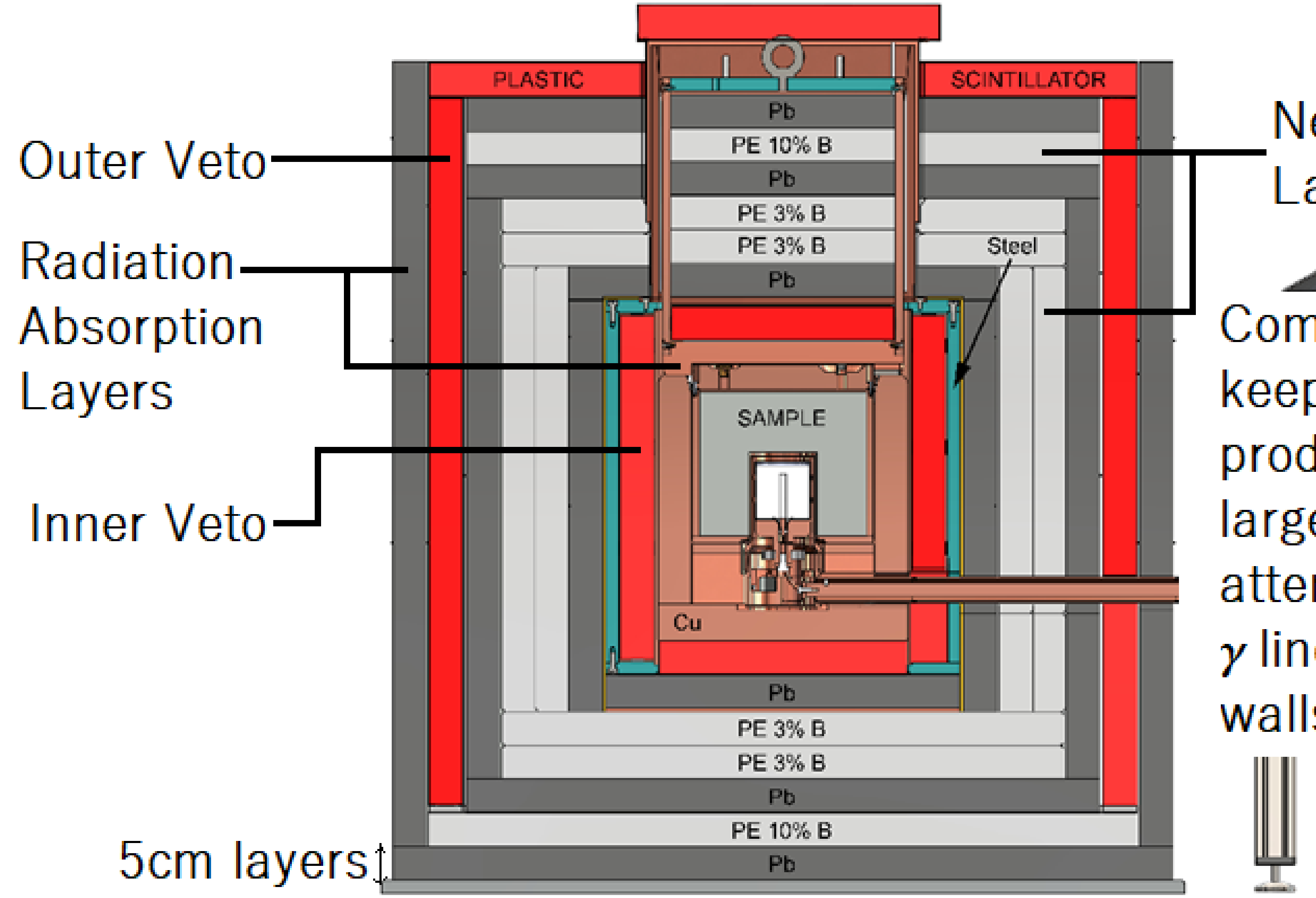
Environmental radiation from surrounding lab and shield materials.

Background in detector

- Bremsstrahlung photons and electrons in high density materials (e.g. Pb).
- Neutrons, via muon capture, photonuclear interactions and spallation.
  - Can produce photons/electrons which are captured by germanium atoms, lines from excited germanium ions will be seen in the detector.

Lines from isotopes can be directly seen in the detector, e.g. at 2.6MeV for U-232.

THE GIOVE SHIELD



Compact enough to keep muonic neutron production low, but large enough to attenuate the 2.6 MeV γ line emitted from lab walls.

INNER AND OUTER MUON VETO

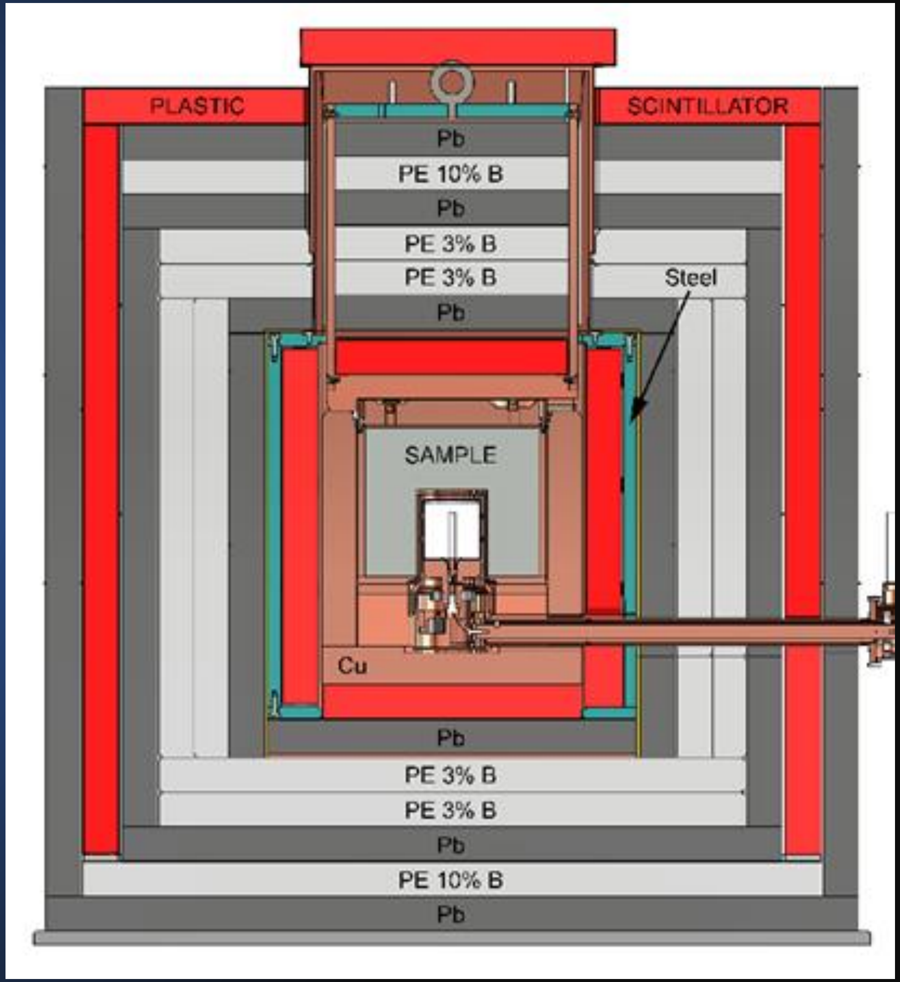
Plastic scintillator plates: high photon yield + fast signal response

- Similar neutron thermalization power as moderator, polyethylene (PE)

PMTs installed in scintillator layers record muon events => Detector stops taking data for 300 μs so that secondary particles are not detected.

Two Layer Structure:

- Inner plates can record muons escaping detection by outer plates.
- Coincidence set-up: Simultaneous events in both scintillator layers considered muon-induced.



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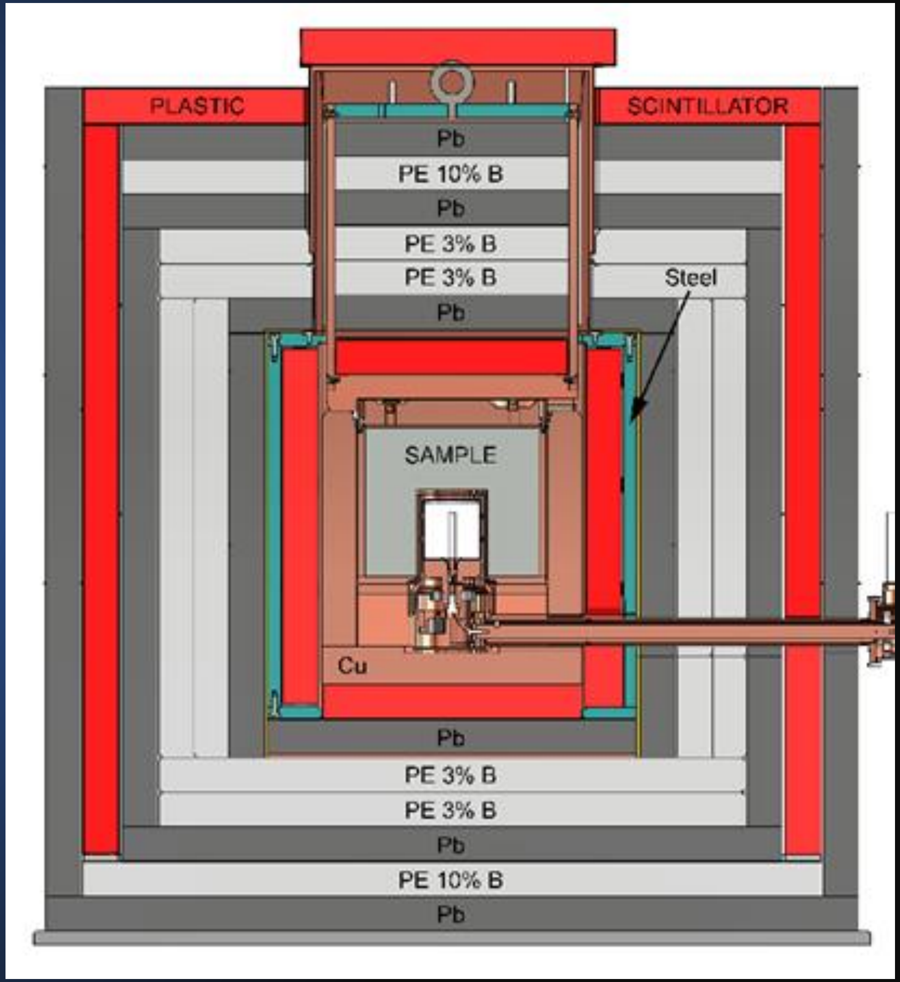
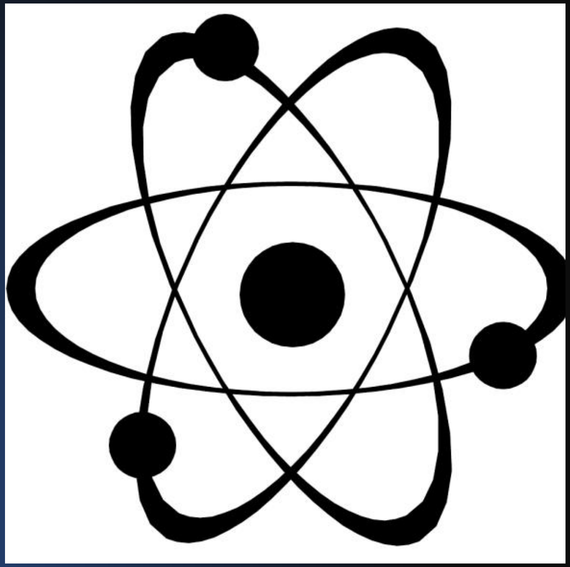


Result: ≥99% muon tagging efficiency.

NEUTRON ATTENUATION



To stop neutrons efficiently, need compact neutron **moderators** and **absorbers.**

Moderator → **Polyethylene** (and plastic scintillator plates).

Slows neutrons to the appropriate speed for capture.

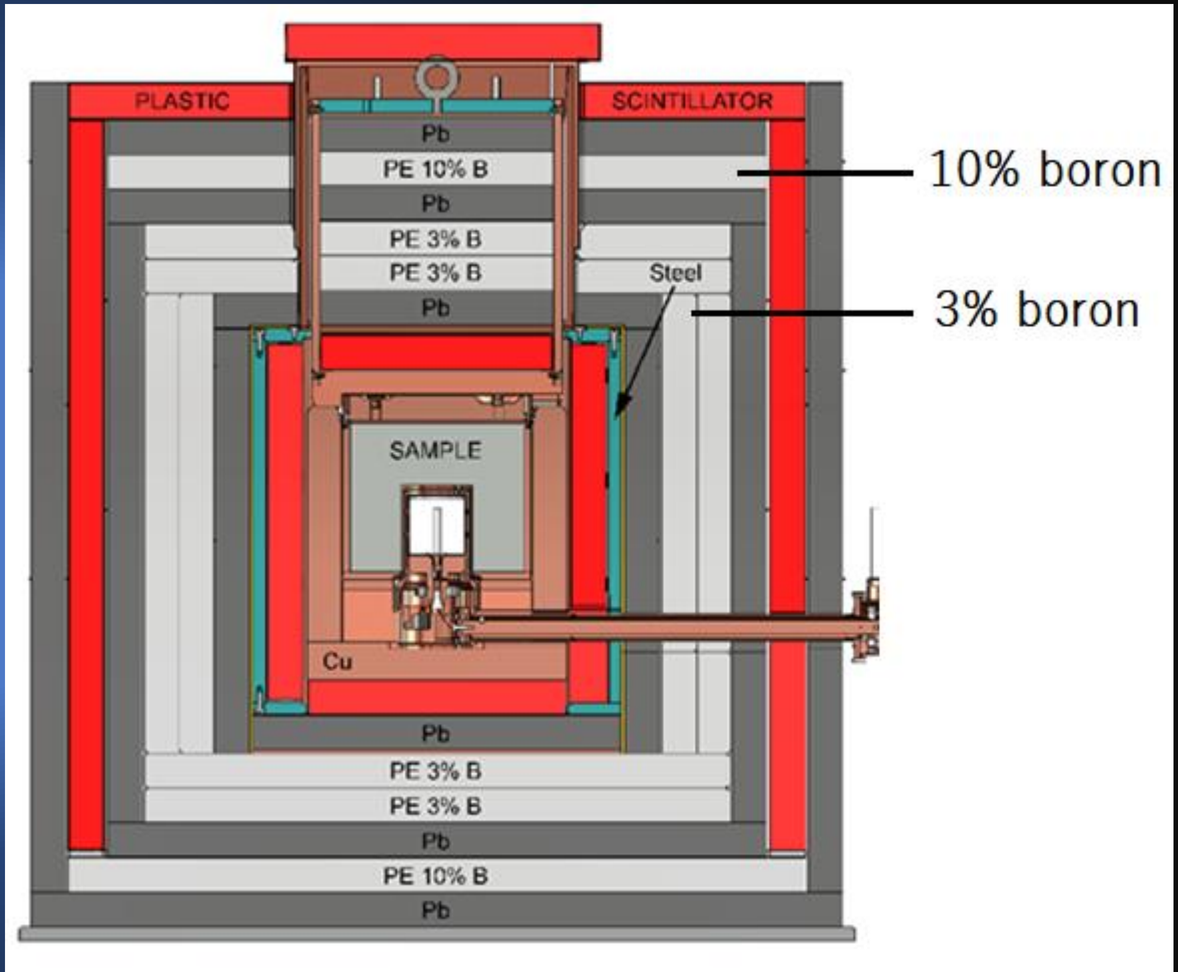
Absorber → **Boron**

Thermal neutron capture cross-section ~ 767 b

NEUTRON ATTENUATION

- Tests demonstrated **3% to 10% B-loaded PE** was the optimal ratio for neutron flux attenuation (thermal and fast) for the inner layers.
  - Percentage of B in PE decreases with proximity to detector.

- Final layer of Pb surrounds the Cu sample chamber due to potential radio-impurities in B.



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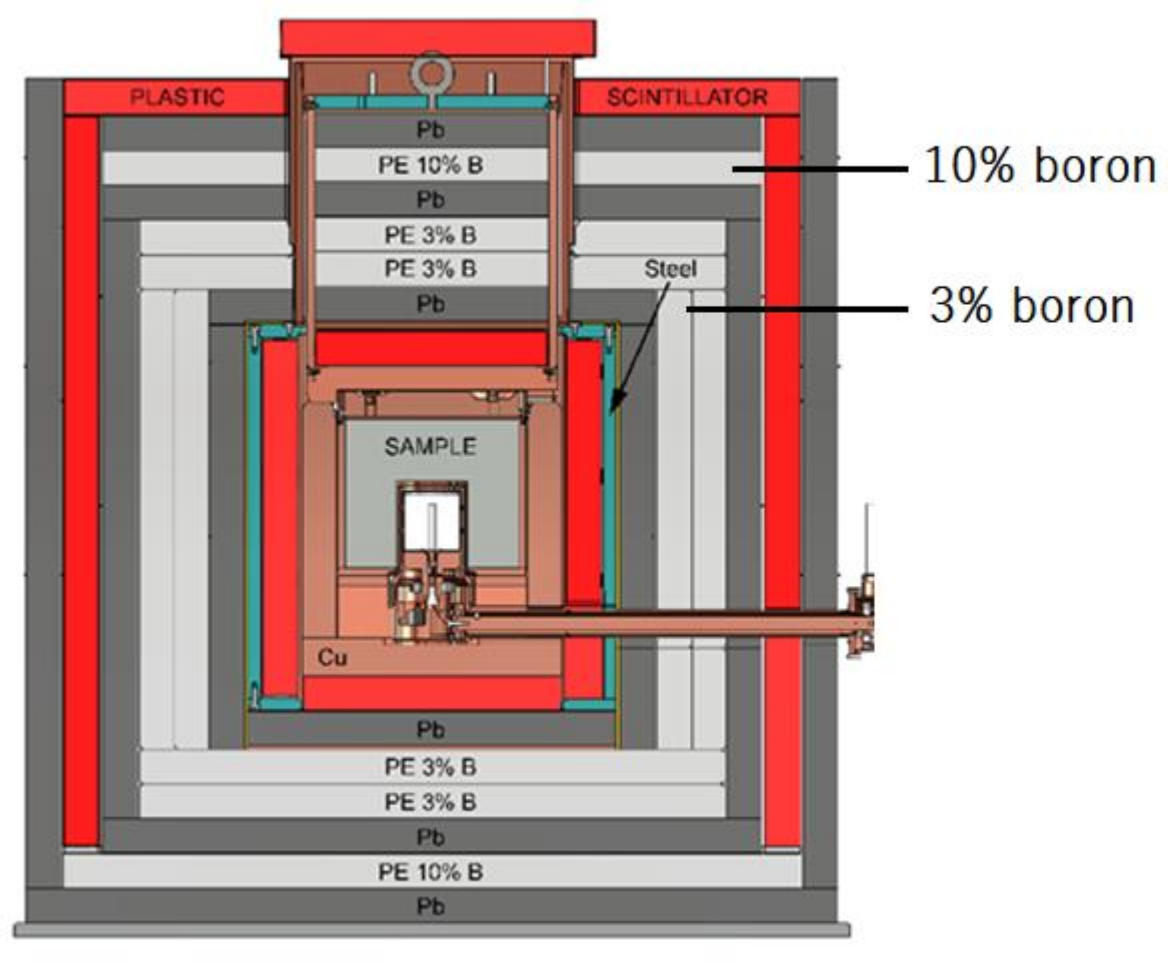

Result: ~70% reduction in neutron-induced signals.

CONCLUDING REMARKS

- Shallow-depth Ge spectroscopy a valuable tool for rare-event experiments – e.g. searches for dark matter and **$0\nu\beta\beta$** decay.

- GIOVE combines a novel active muon veto system and highly radio-pure passive shielding to suppress background components.
  ➡ Achieving sensitivities in **100 μBq/kg range.**

- Inner-outer muon veto system achieves efficiency of ≥ 99% for muons and muon-induced signals.

- B-loaded PE moderator layers attenuate neutron flux by ~70% in detector.

CONCLUDING REMARKS

Can we do better?

MC simulations of new materials and new configurations of existing shield layers indicate background in detector may be further reduced.

- Different arrangements of current Pb and moderator layers.
- Alternative higher density and radio-pure materials to replace Pb layers.
- Neutron absorbers with larger neutron capture cross section and greater radiopurity.

Thank you for your attention!

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SOURCES

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