GERmanium Detector Array – search for neutrinoless ββ decay

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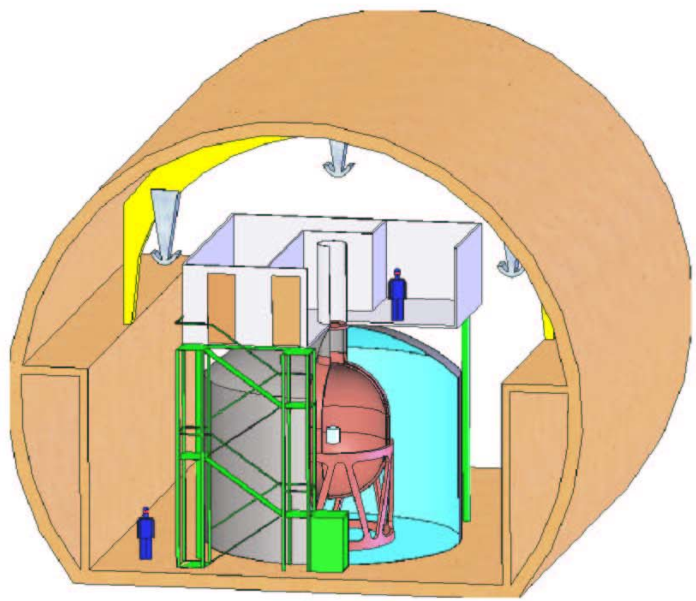

Review of motivation

Status

R&D at the MPI

GERDA

The GERmanium Detector Array for the search of neutrinoless $\beta\beta$ decays of ^{76}Ge at LNGS

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Deputy Spokesperson

Spokesperson

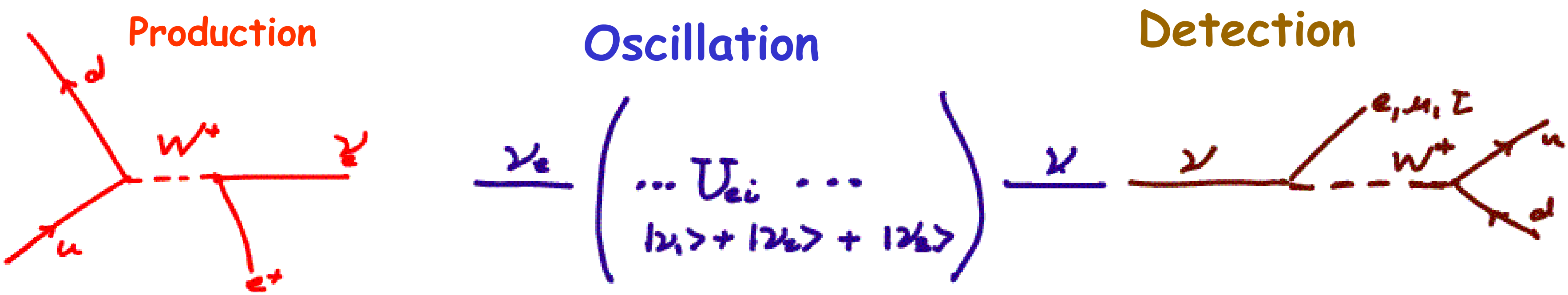
AC Chair of Collab Board

- Collaboration is formed
- Proposal submitted/reviewed by LNGS – positive statement from the SC
- Location ~final

Motivation

We now know that neutrinos have mass, and that weak eigenstates mix.

Mass eigenstates: m_1, m_2, m_3 Weak eigenstates: ν_e, ν_μ, ν_τ



Mixing matrix: U_{ij} can be characterized by three mixing angles, θ_{12}, θ_{13}, θ_{23}, one Dirac CP phase, δ, and two Majorana phases Φ_2, Φ_3 (which don't appear in oscillations)

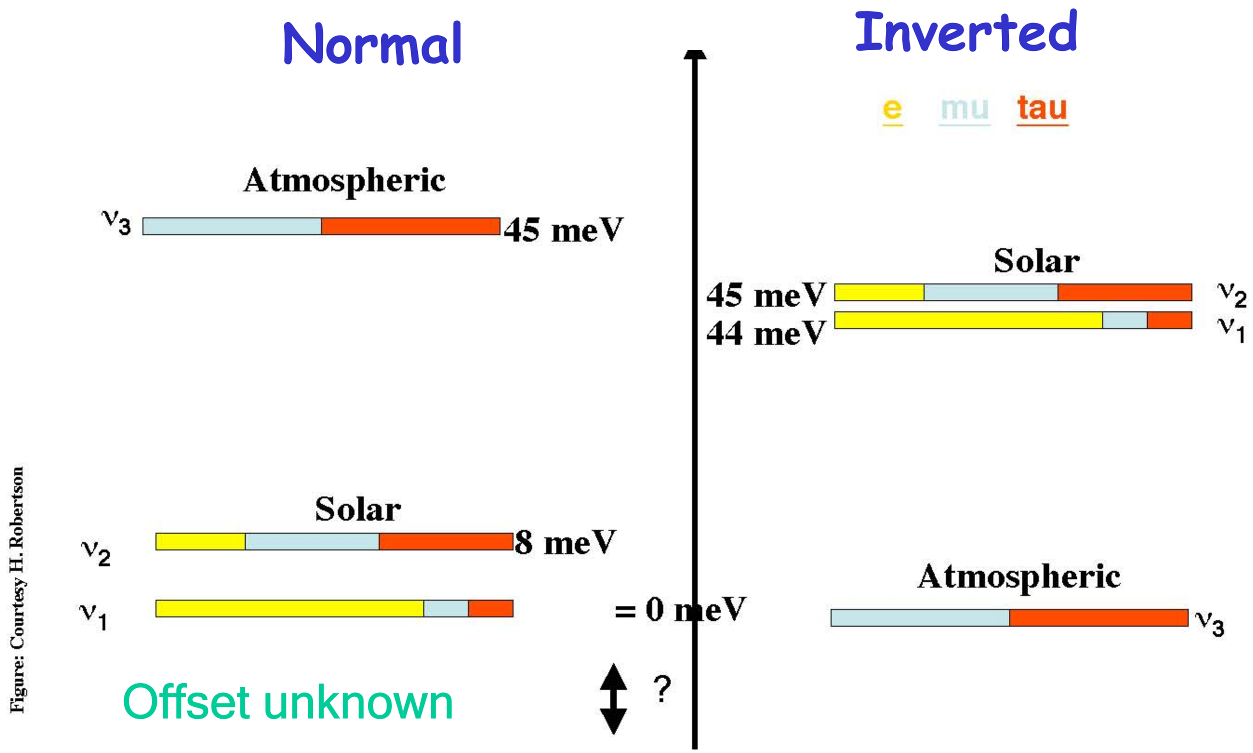
Motivation

Oscillation experiments have determined two mixing angles (θ_{12}, θ_{23}) as well as two (mass)^2 differences (m_2^2-m_1^2, $|m_1^2$-$m_3^2|$). There is an upper limit on the third mixing angle. Still missing:

1. absolute mass scale
2. mass hierarchy
3. nature of neutrino (Majorana, Dirac particle)
4. value of third mixing angle
5. CP phases

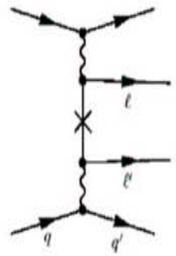
Double beta decay experiment can address 3, and, if neutrinos are Majorana particles, then also a combination of 1,2,5 (see later).

Neutrino Masses



If offset large $\Rightarrow$ degenerate neutrino masses

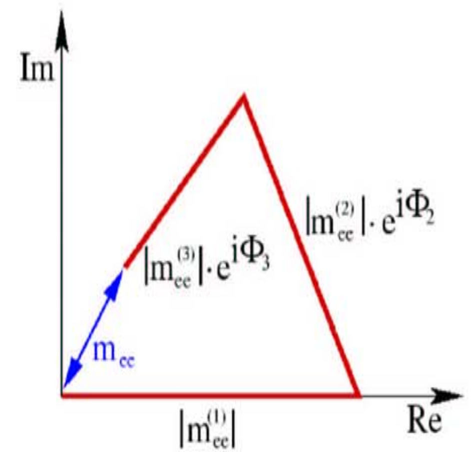
Effective mass in 0ν DBD



$$\propto |\langle \mathrm{m_{ee}} \rangle| \;=\; |\textstyle\sum \mathrm{m_i U_{ei}^2}| \;\leq\; 0.28\ \mathrm{eV}$$

$$m_{ee} = |m_{ee}^{(1)}| + e^{i\Phi_2}|m_{ee}^{(2)}| + e^{i\Phi_3}|m_{ee}^{(3)}|$$

$$|m_{ee}^{(1)}| = |U_{e1}|^2 m_1$$
$$|m_{ee}^{(2)}| = |U_{e2}|^2 \sqrt{m_1^2 + \Delta m_{21}^2}$$
$$|m_{ee}^{(3)}| = |U_{e3}|^2 \sqrt{m_1^2 + \Delta m_{31}^2}$$

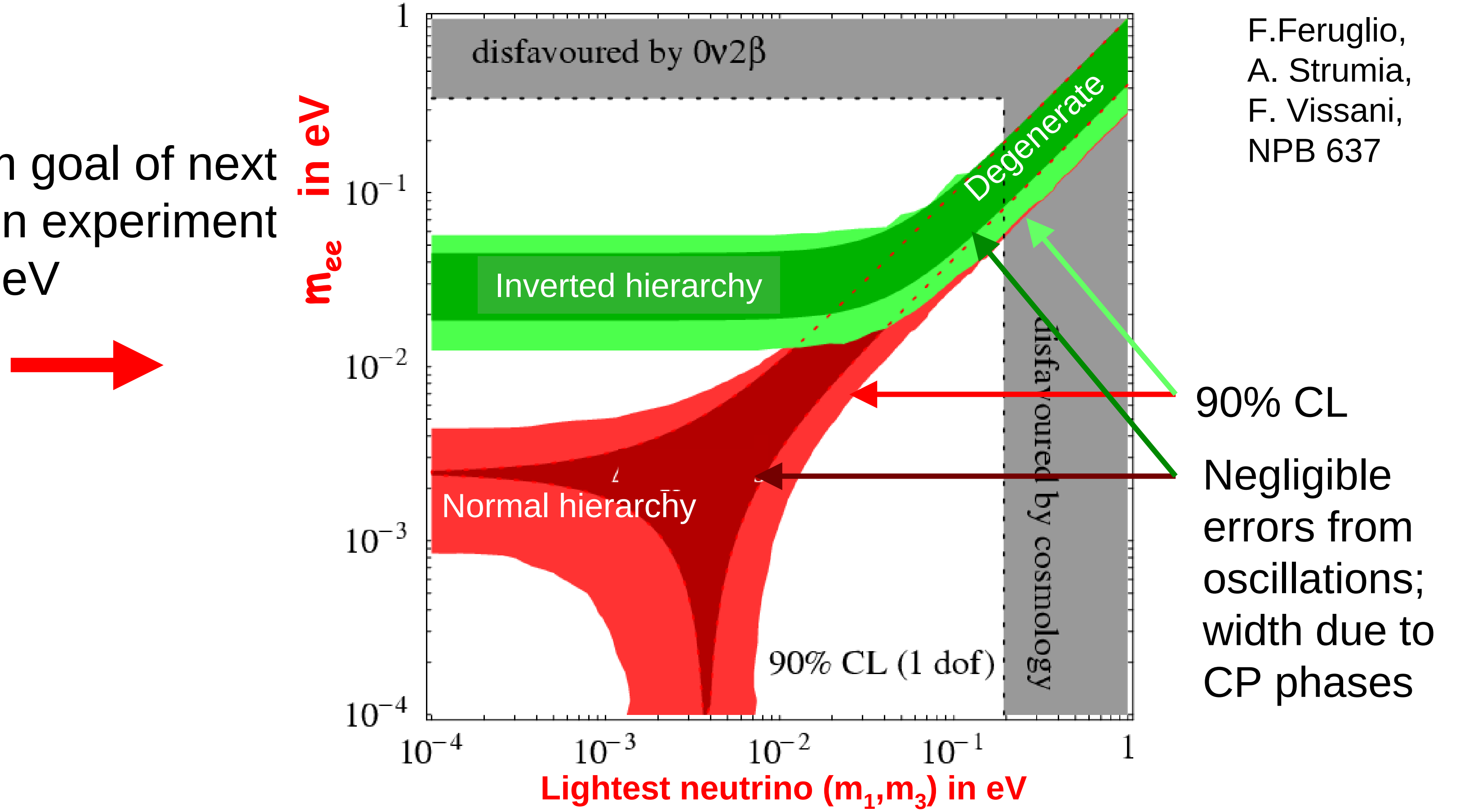


solar $\Rightarrow$ $|U_{e1}|^2, |U_{e2}|^2, \Delta m_{21}^2$ atmosph. $\Rightarrow$ Δm_{31}^2 CHOOZ $\Rightarrow$ $|U_{e3}|^2 < 0.1$

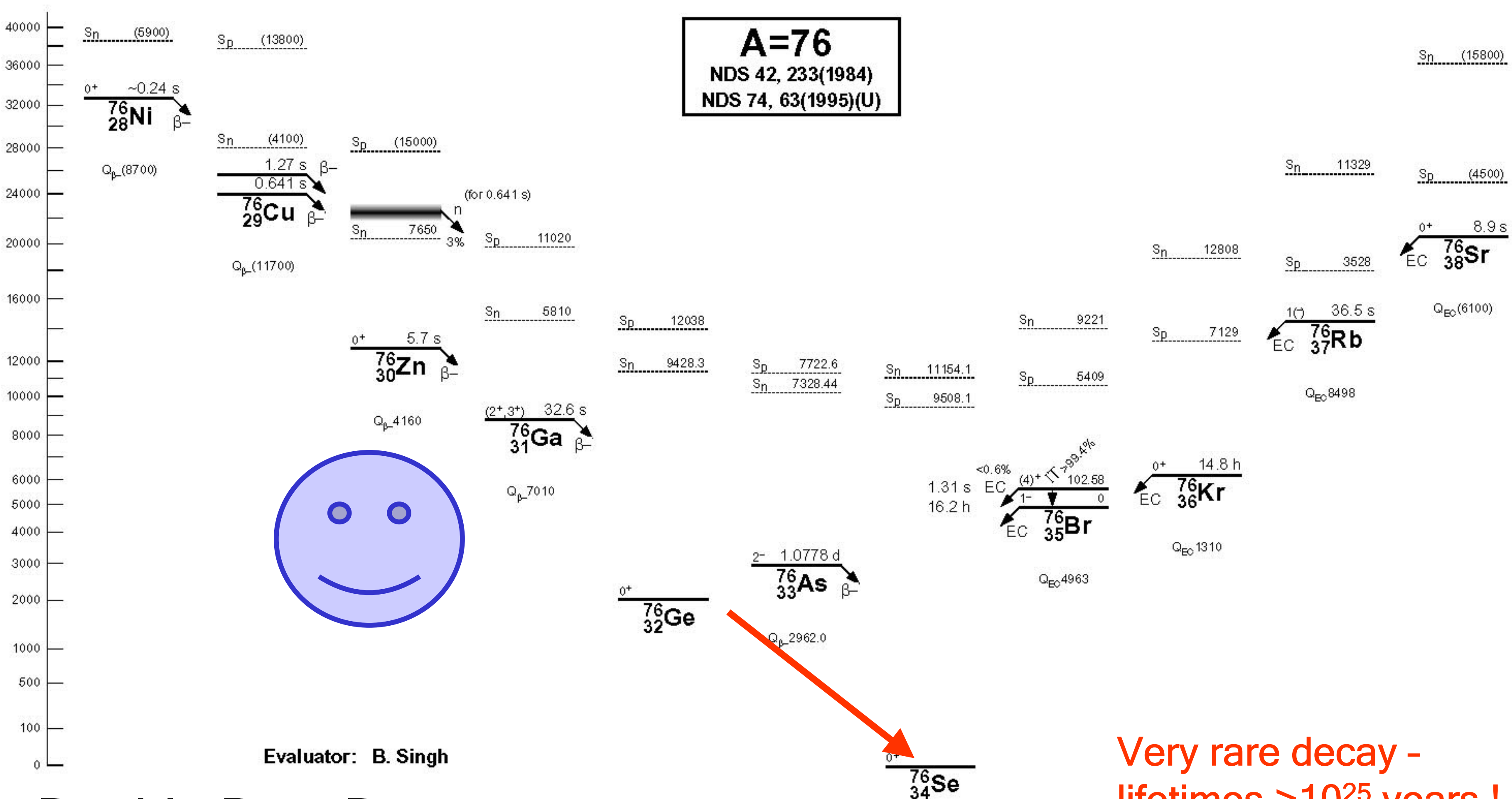
Free parameters: m_1, CP-phases Φ_1, Φ_2

Allowed values of m_{ee}

Long term goal of next generation experiment 10 –50 meV



F.Feruglio, A. Strumia, F. Vissani, NPB 637



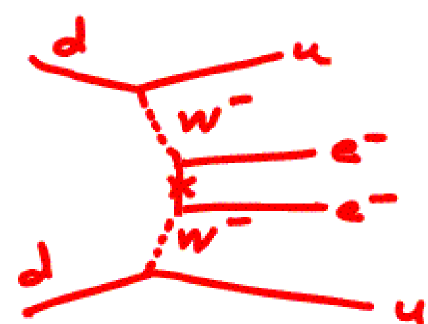
Double Beta Decay:

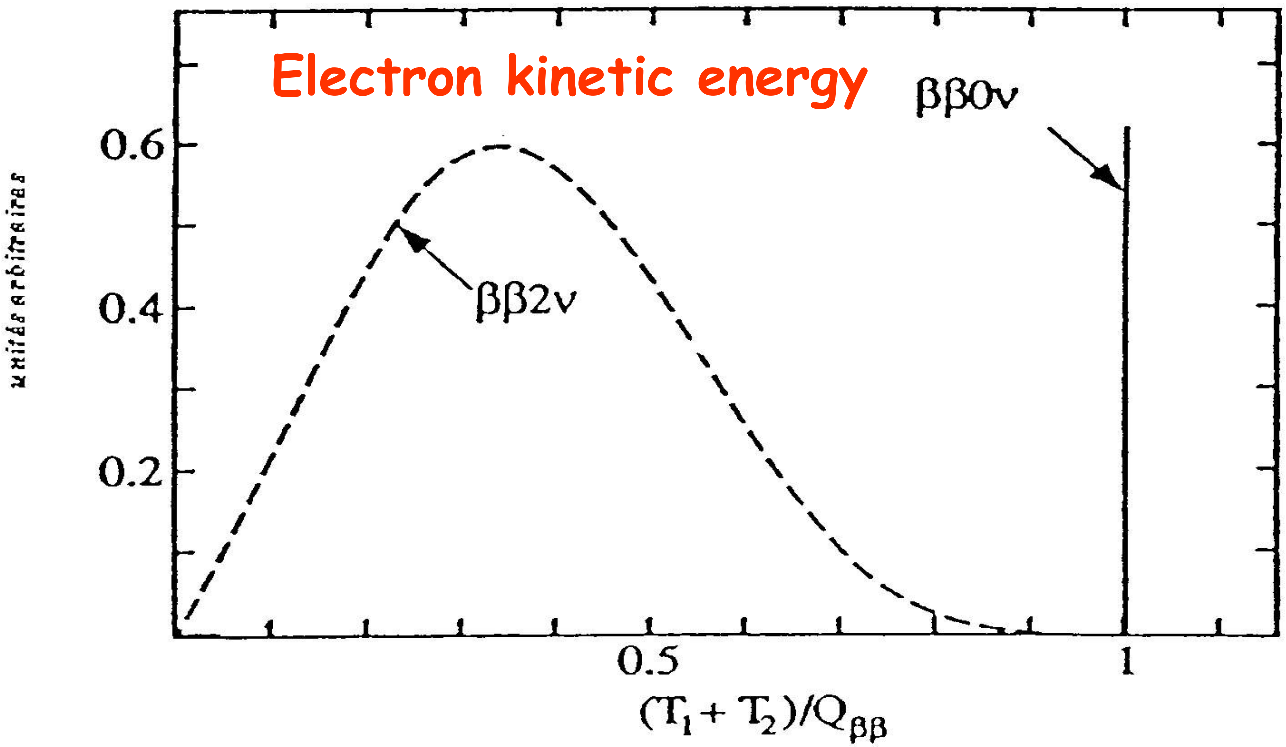
Very rare decay - lifetimes >10^{25} years !

$(A,Z) \rightarrow (A,Z+1)+e+\nu$ energetically forbidden

$(A,Z) \rightarrow (A,Z+2)+2e+2\nu$ is allowed.

Then, for Majorana particle $(A,Z) \rightarrow (A,Z+2)+2e$ possible



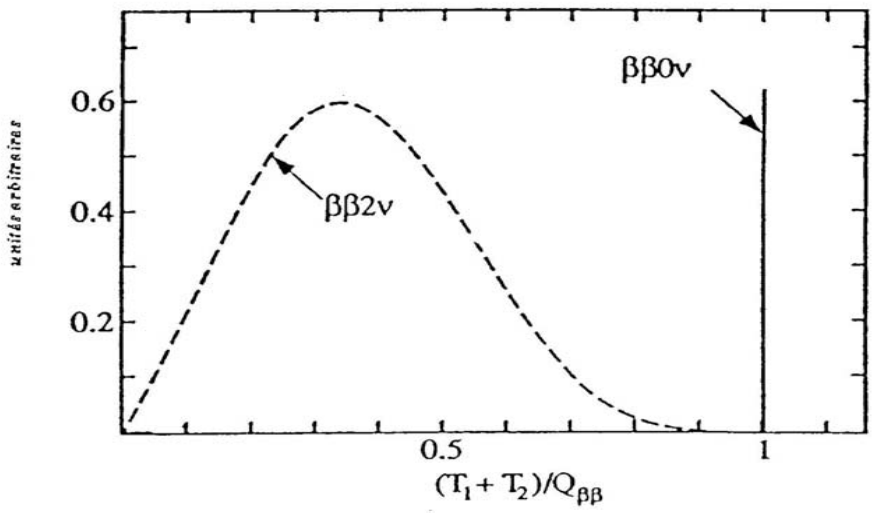


The measurement is conceptually simple – we look for a sharp peak at the end of the two-electron energy spectrum. Biggest issue is background. Need to reduce background in the energy range of interest to 10^{-3} event/kg/year !

Why Germanium

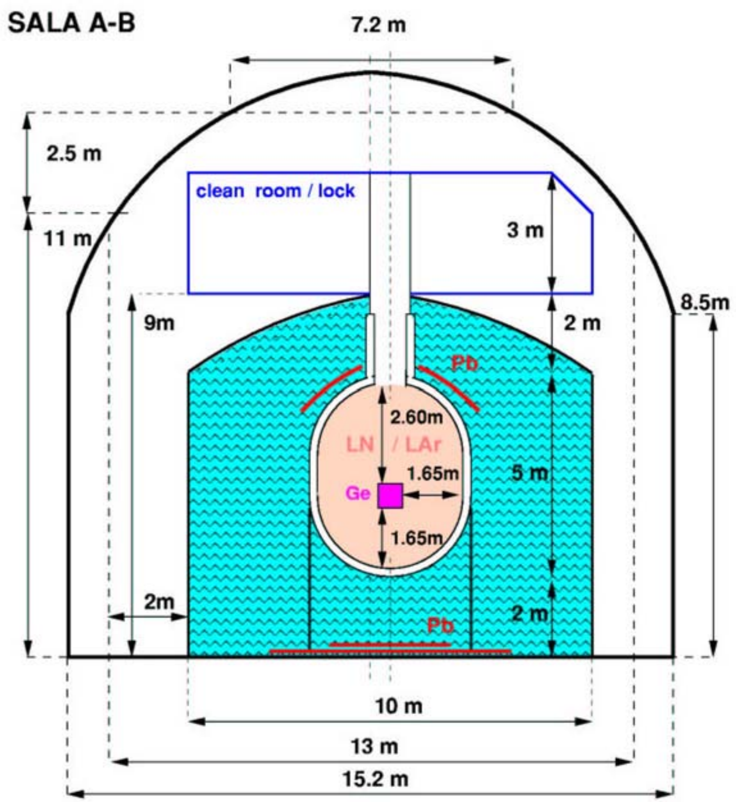
Germanium is a good choice because:

• excellent energy resolution (0.1% at 2MeV). Allows finer binning, so less background. There is always the irreducible background from allowed 2ν mode which can only be distinguished via energy resolution.



• considerable experience worldwide
• enrichment possible (but expensive)
• possibilities for further development - there is interest in more finely segmented detectors in nuclear physics, astrophysics, so detector development ongoing.

Biggest Issue - backgrounds



Liquid Nitrogen can be purified such that there are ~no dangerous isotopes. Nitrogen acts as shield against radiation from walls, containment vessel. Possibility to use Argon instead of Nitrogen. Switch to water for outside layer to make cryogenic vessel more compact. Water acts as Muon Veto.

Example: cosmogenic ^{68}Ge production

cosmogenic production in ^{76}Ge at sea level: about 1 ^{68}Ge / (kg day) (Majorana white book, simulation + measurement). Considering experiments to measure cosmogenic activation.

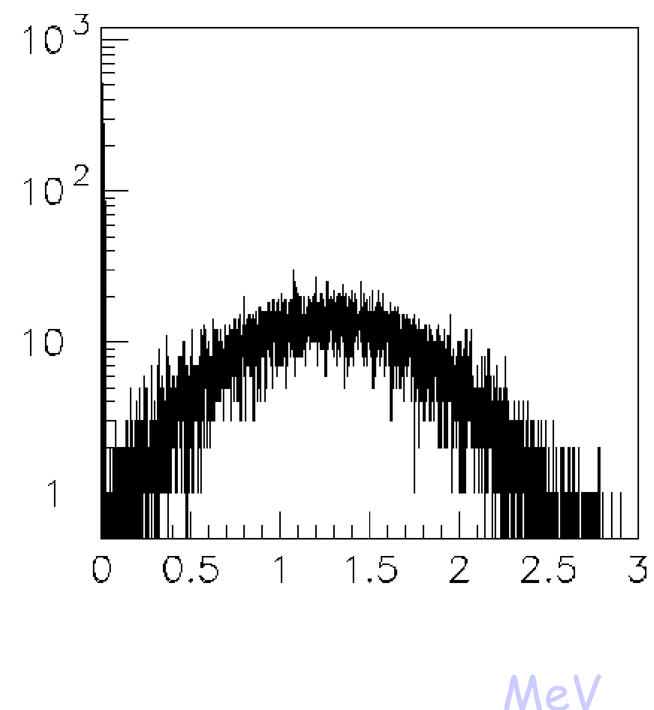
From B. Swchingenheuer MPI-K

Dominant decay chain:

^{68}Ge → ^{68}Ga via EC (10.6 KeV γ)
τ=271 days

^{68}Ga → ^{68}Zn via β^+ (90%, 1.9 MeV)
+ γ (0.511 MeV)
+ γ (0.511 MeV)
τ=68 minutes

Possibility to distinguish 2.0 MeV $\beta + \gamma$(s) from 2x1.0 MeV β^- ?

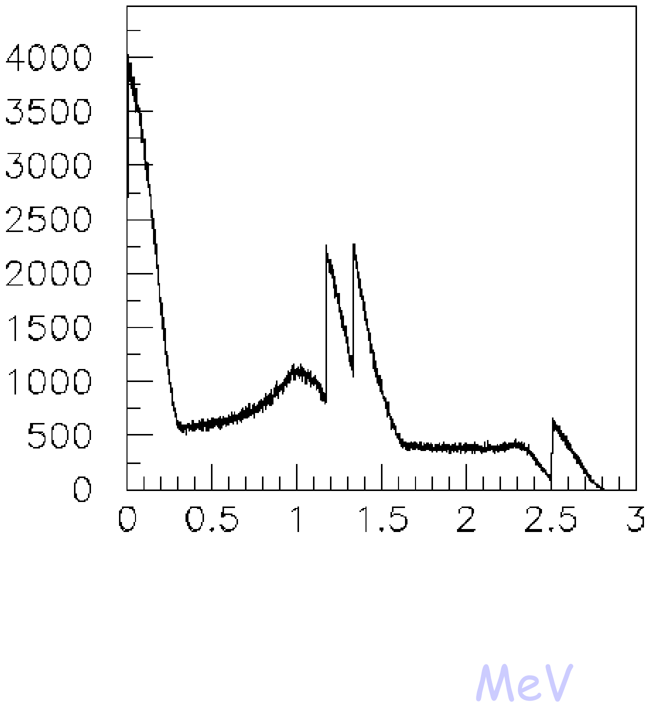


Example: ^{60}Co activity

after 10 days of activation and 3 years of storage 0.18 mBq/kg → 5.4 decays/(kg y)

Dominant decay chain:
$^{60}Co \rightarrow {}^{60}Ni$ via
β^- (0.316 MeV)
+ γ (1.17 MeV)
+ γ (1.33 MeV)
τ= 5.27 years

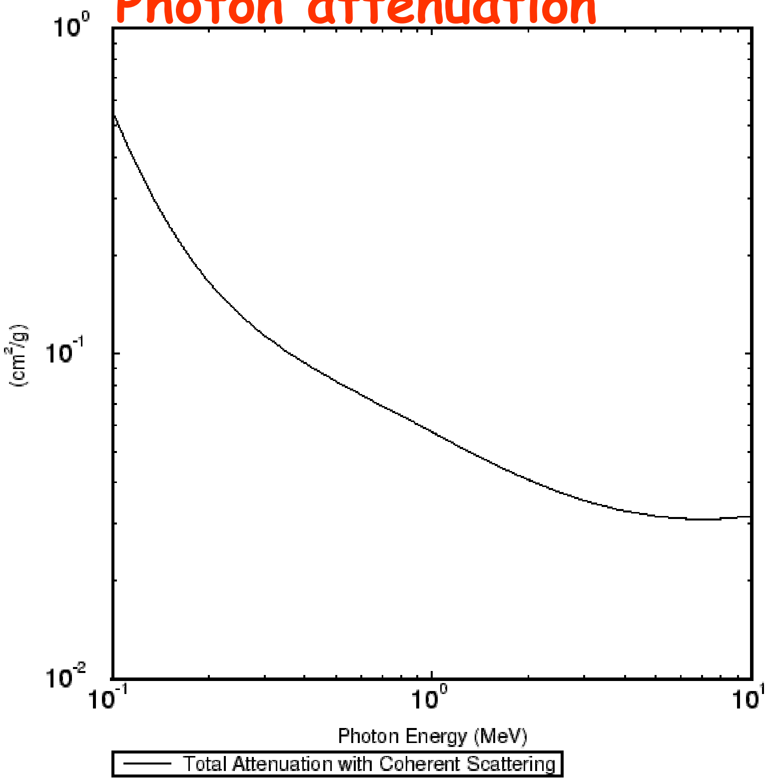
Possibility to distinguish gammas from electron ?



Pulse shape, segmentation

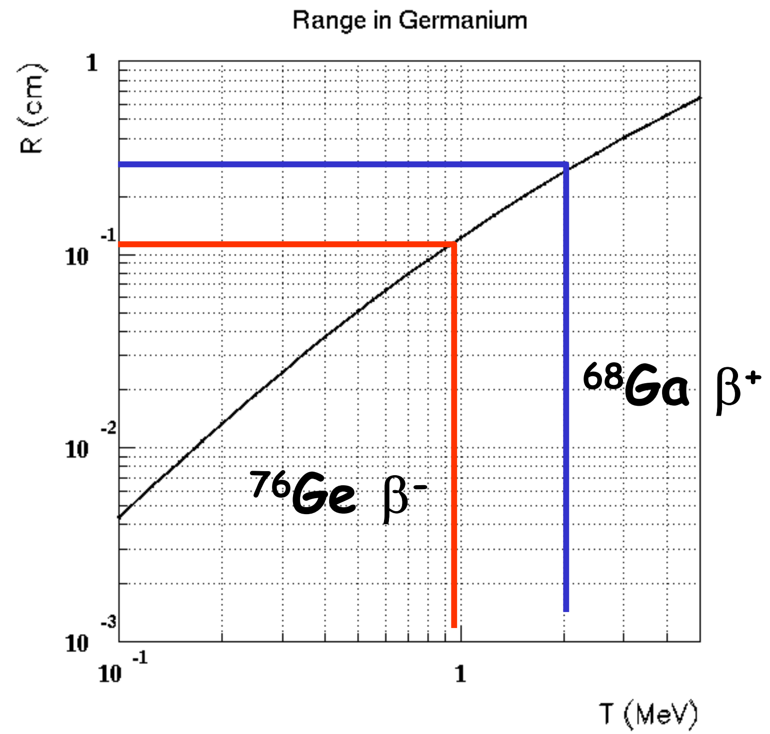
Can we distinguish single versus multiple energy deposits ? Tools: pulse timing, segmentation. Field simulation in Ge important.

Photon attenuation



R=1/ρx = 4 cm for 1 MeV γ

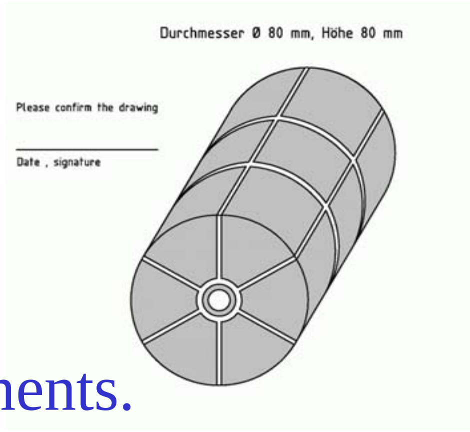
Range of electrons in Germanium (from NIST tables)



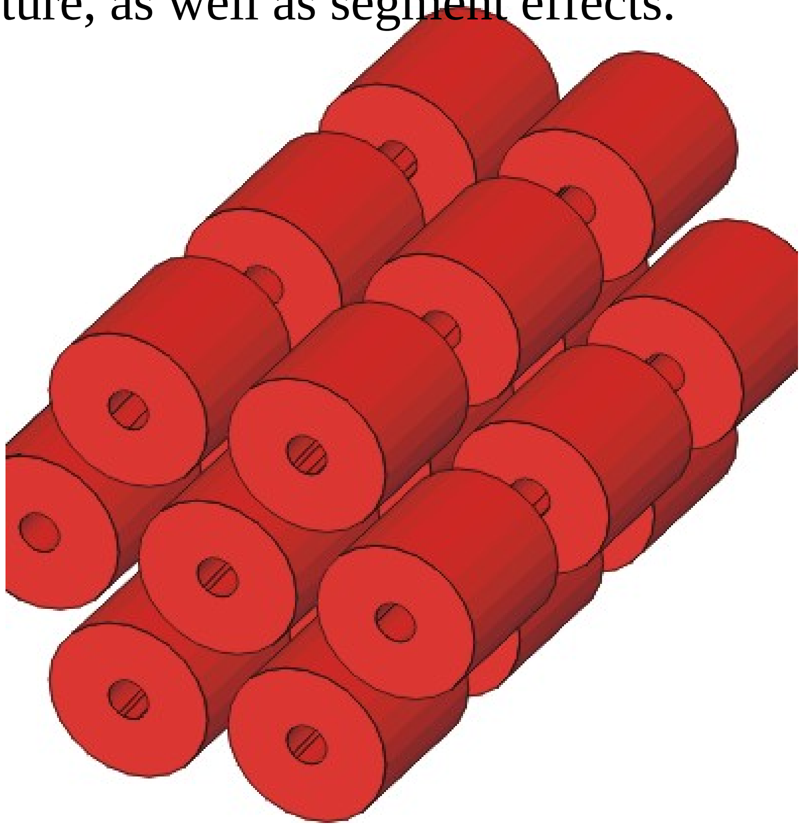
MaGe: MC for Gerda & Majorana

- **Gerda & Majorana MC groups collaborate on a single MC package. Based on previous Majorana framework.**
- **Both groups have their own geometry, share same physics processes.**
- **Avoid redundant work, more developers and users for cross check.**
- **A first version is available.**

✓Gerda preliminary geometry, with water & liquid N2 shielding.
✓21 crystals, each 8cm high, 8cm in diamete
✓MPI-Munich studies bg. in supporting structure, as well as segment effects.

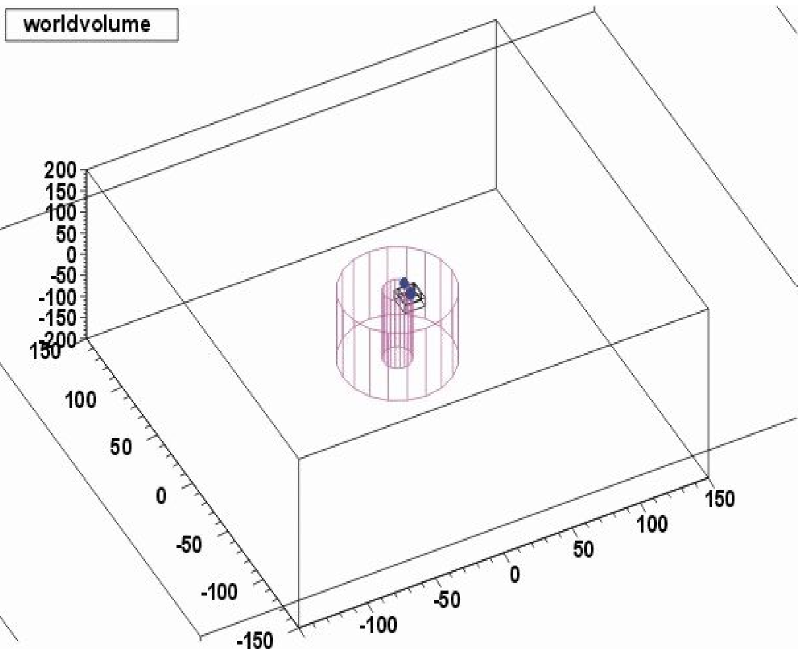


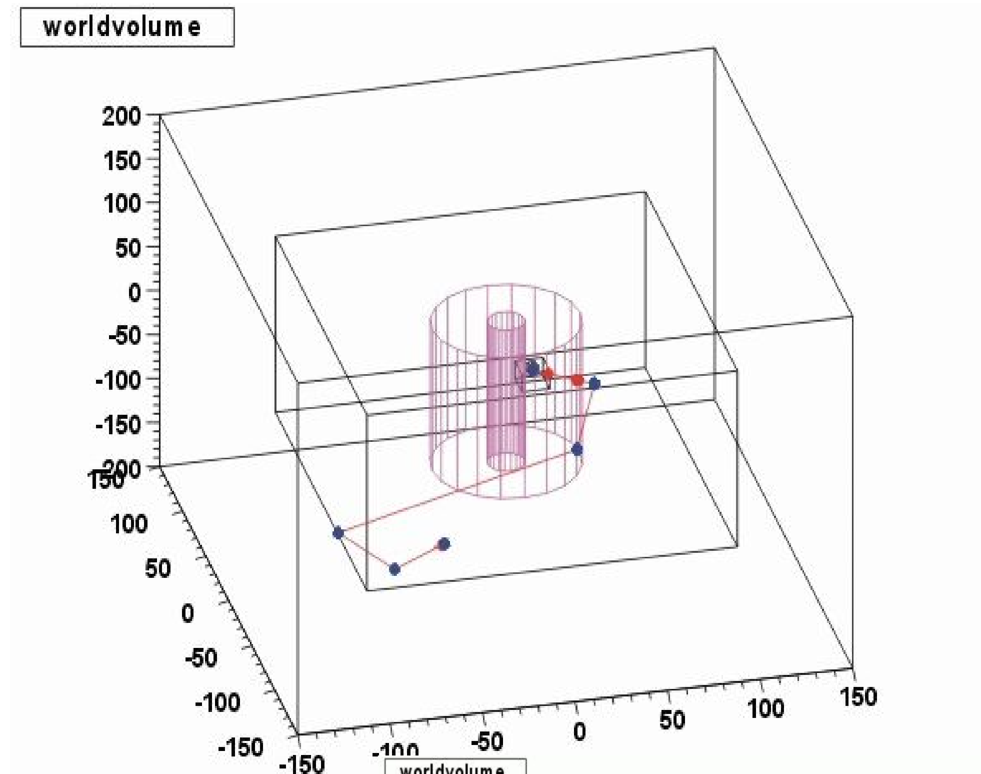
3x6 segments.



X. Liu co-coordinator

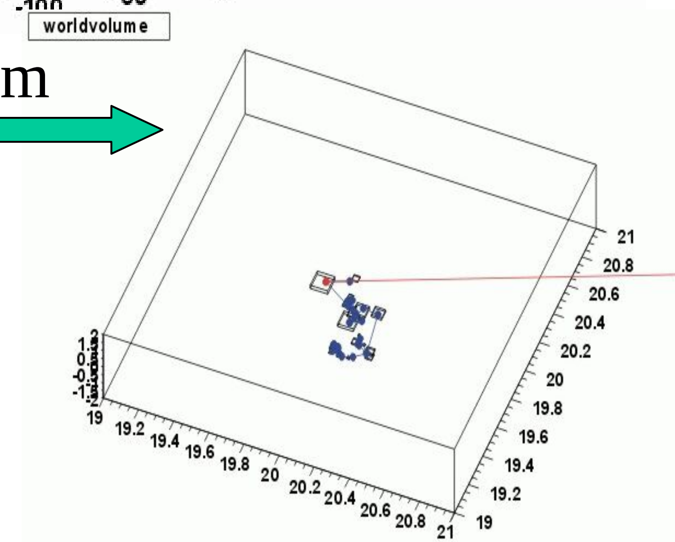
Single electron events





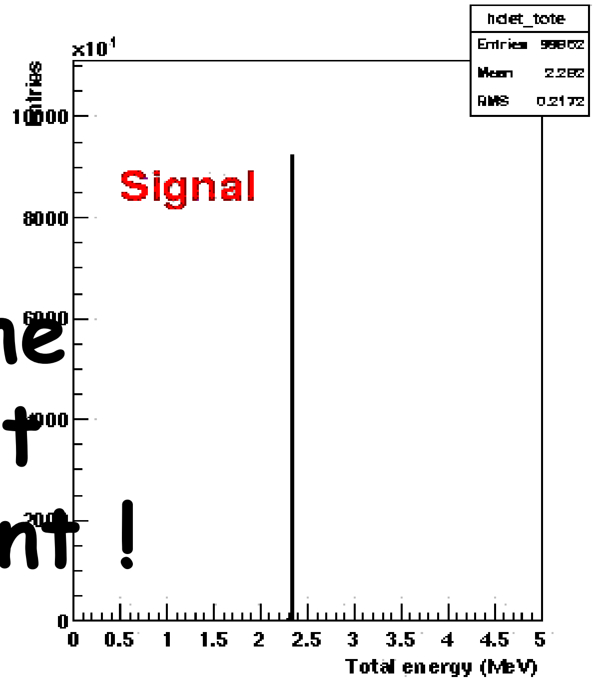
✓Most single-e events deposit energy locally.
✓A small fraction deposit energy in 2 Ge crystal, since a hard photon is generated at early stage.

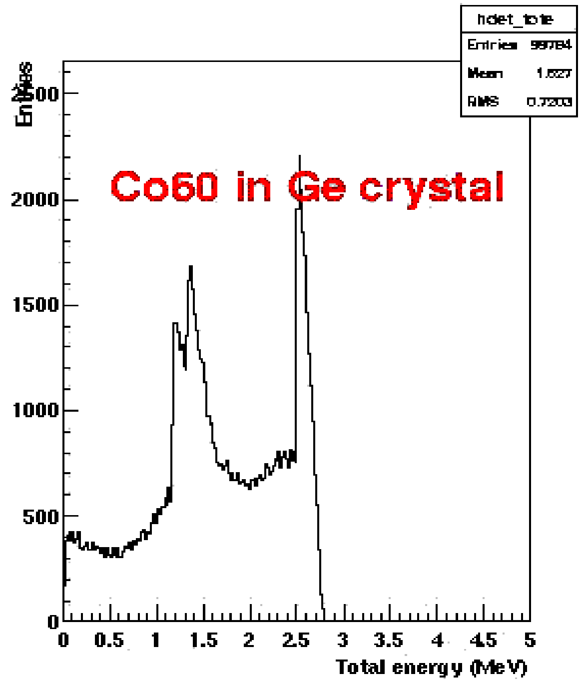
Zoom

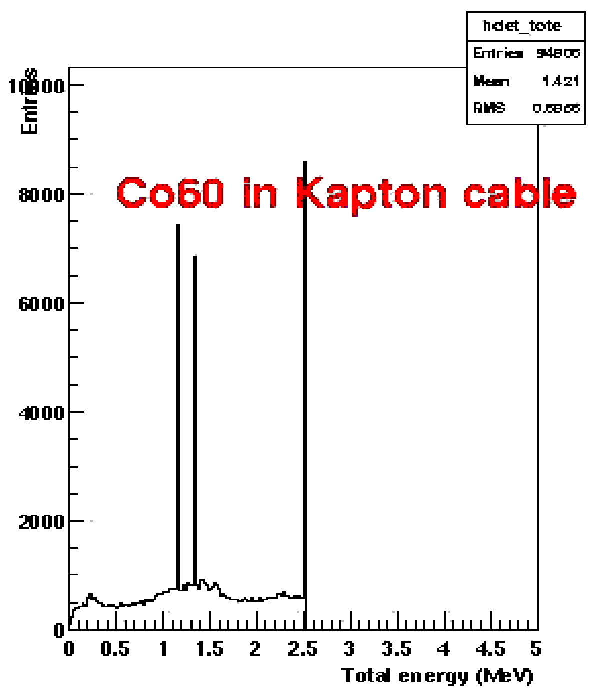


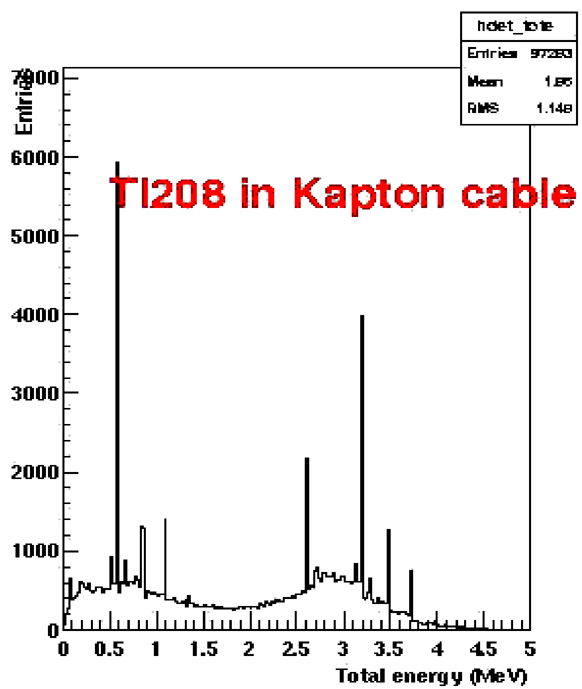
Blue: electron trajectory
Red: photon trajectory

Not the correct endpoint !



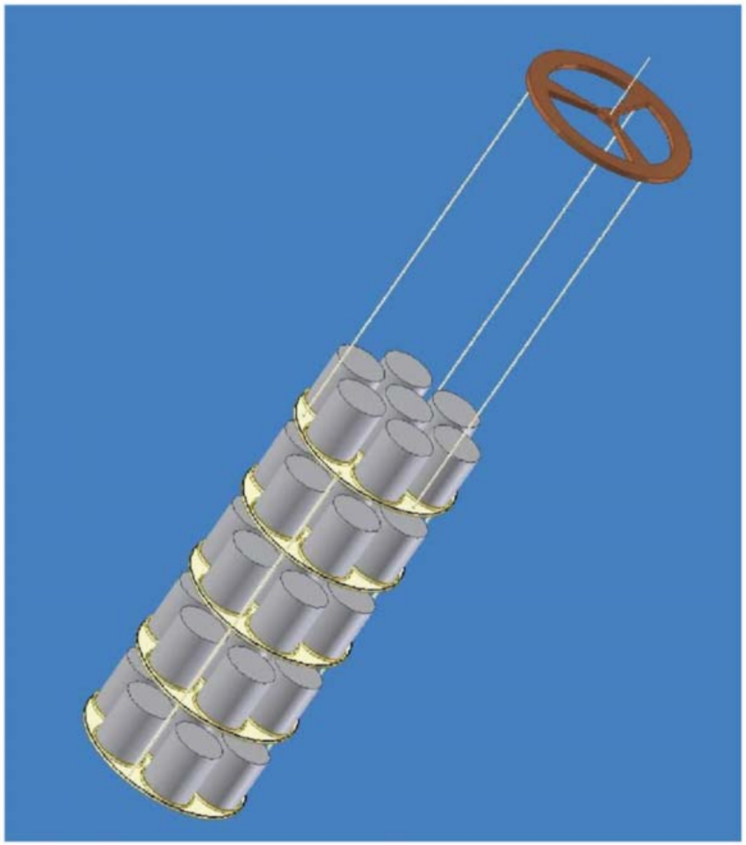




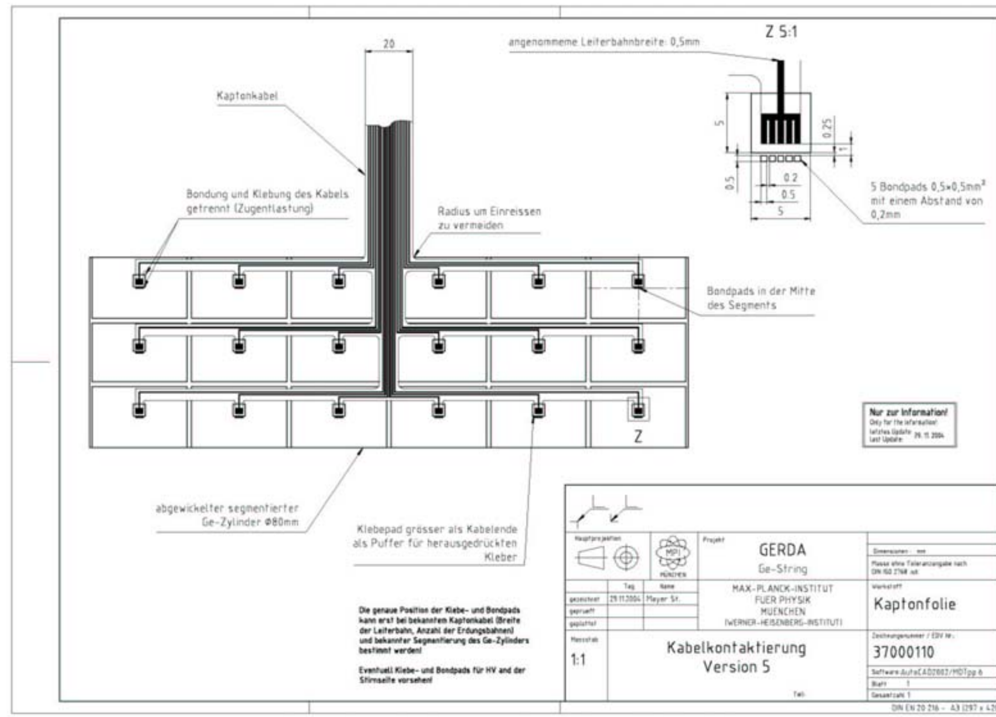


fraction	Only 1 Ge crystal	1 Ge & energy in 10keV window	Only 1 seg-ment	1 seg. & energy in 10keV window
signal	94%	90%	86%	82%
Co60 in Ge	18%	2* 10E-4	6%	2* 10E-5
Co60 in support. cable	26%	1* 10E-4	13%	< 10E-5
Tl208 in cable	20%	1* 10E-4	10%	3* 10E-5

Detector Supports, Clean Room, Lock



A detail – Kapton cables



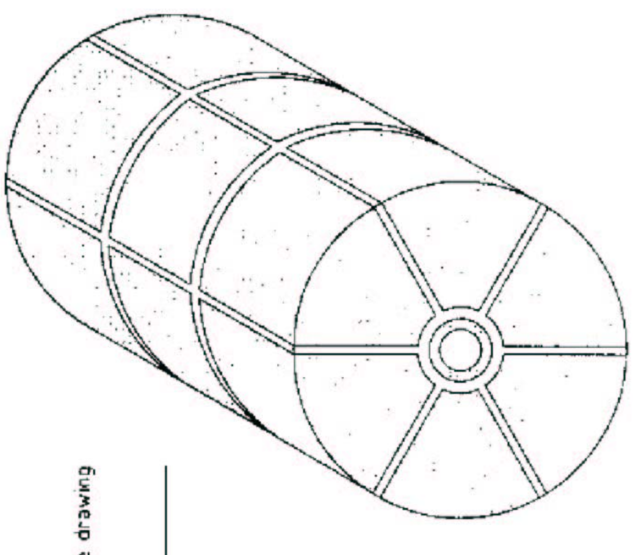
Detector support scheme in the LN_2. We try to minimize the amount of support material.

I. Abt, Coordinator

New Detectors

New detector geometries:

18-fold segmented detector – prototypes ordered from DSG and Canberra



New ^{76}Ge detectors for Phase II

- Contract for 15 kg natural Ge + transport container
- Contract for 30 kg ^{76}Ge
- Visits to DSG, Canberra, Umicore

A. Caldwell coordinator

Timeline, Funding

• The funding for Phase I,II 80% available

• The approval of the experiment by the LNGS director requires technical director's OK. This is ~finalized.

• Many ongoing activities at MPI – WHI (mechanical engineering, MC simulations, detector optimization, ^{76}Ge acquisition). Want to add effort in ee but will depend on manpower.

• MPI-K is leading the cryogenic tank design & construction

• Italian groups want to design & build water tank+readout electronics.

• Russian groups provide expertize, muon veto

• So, we are making progress !