50 years
of searching for neutrinoless double beta decay with Ge detectors

A.Smolnikov, MPIK Heidelberg / JINR Dubna

HPGe detectors fabricated from germanium enriched in ^{76}Ge isotope (up to 87 %) are simultaneously the ββ decay sources and the 4π detectors.

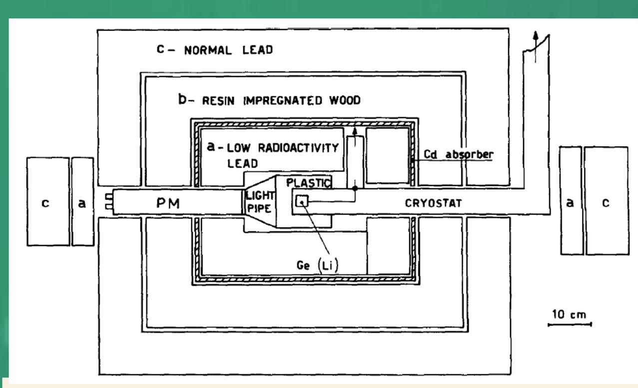
Advantages of such type experiments are due to: 1) the excellent energy resolution (≈ 3 кэВ at 2 MeV) ; 2) the high purity of Ge crystals (very low intrinsic background);3) and the high signal detection efficiency (close to 100%).

Disadvantages: 1) not the highest 0νββ–transiton energy for ^{76}Ge: $Q_{\beta\beta}$ =2039 keV amongst the other promising isotopes, such as Mo-100, Se-82, Nd-150,Ca-48 …; 2) only one characteristic of 0νββ decay - sum energy of two electrons – is possible to detect.

Nevertheless, one of such type currently running experiments (GERDA) is the first experiment that surpasses a sensitivity for the 0νββ half-live of T ½ ~ 10^{26} yr and the first one that operates quasi-background-free thus resulting in a strong discovery potential.

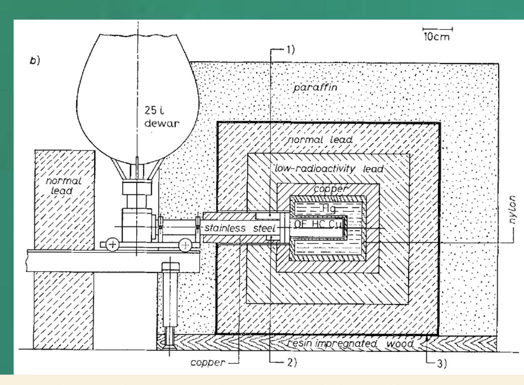
1967 – 1992 (years of the final result publications)

1967



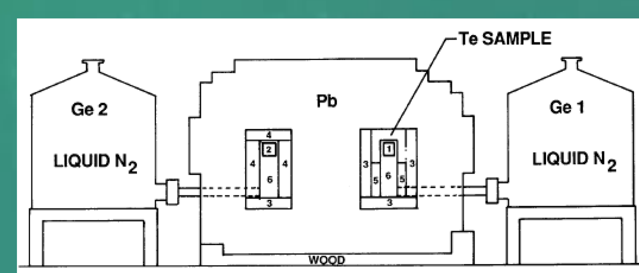
The first Ge experiment performed by the Milan group
Ge(Li) detector of 17 cm³ active
The background counting rate in ROI is **1.1×10^{-2} h^{-1} keV^{-1}**
712 hours of running time
in anticoincidence with the scintillation counter.
$T_{1/2}$ (0νββ) > 3.1×10^{20} yr (68% C.L.)
E. Fiorini, A. Pullia, G. Bertolini, F. Cappelani, and G. Restelli, Phys. Lett. 25B (1967) 602

1973

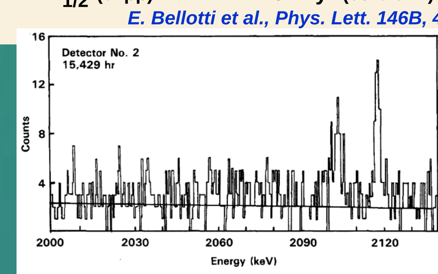


The underground set up of the Milan group in the Mont Blanc tunnel (4200 m w. e.)
Ge(Li) detector of 68.5 cm³ active volume.
The background rate in ROI is **2×10^{-3} h^{-1} keV^{-1}**
(2100 + 2400) hours of running time .
$T_{1/2}$ (0νββ) > 5.0×10^{21} yr (68% C.L.)
E. Fiorini et al., Nuovo Cimento 13A, 747 (1973)

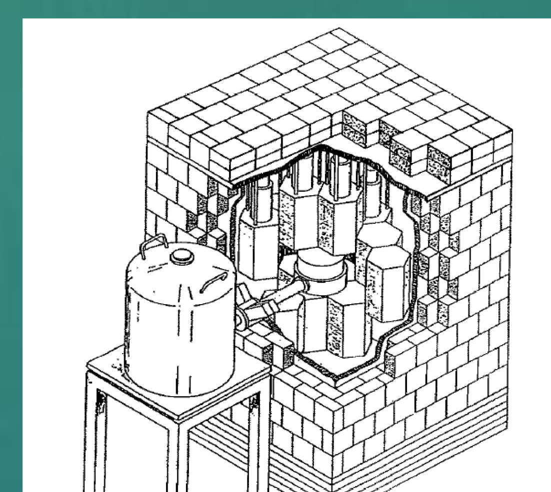
1984



The underground set up of the Milan group with two Ge Li detectors in the Mont Blanc tunnel.
Two Ge(Li) detectors of 125 cm³ and 148 cm³ active volume.
The background counting rate in ROI is **3.7×10^{-4} h^{-1} keV^{-1}**
(20698 + 15429) hours of running time .
$T_{1/2}$ (0νββ) > 1.2×10^{23} yr (68% C.L.)
E. Bellotti et al., Phys. Lett. 146B, 450 (1984)

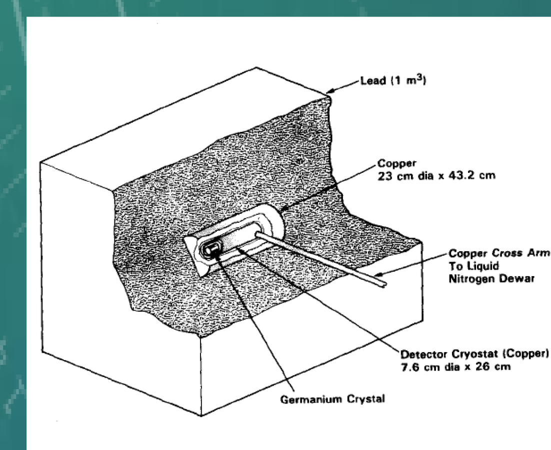


1985



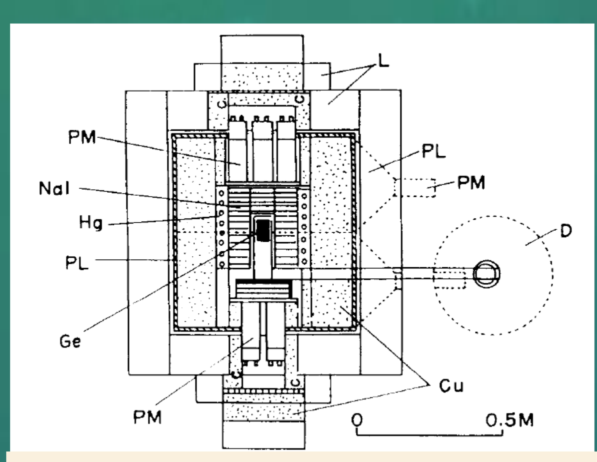
Zaragoza-Bordeaux-Strasbourg set up
in Frejus tunnel (4800 m w. e.)
Four Ge detectors of about 417 cm³ total active volume inside 19 hexagonal NaI detectors.
The background rate in ROI is **2.3 cts/(kg kev yr)**
Exposure 1.6 kg yr
$T_{1/2}$ (0νββ, 0^+- 2^+) > 6×10^{22} yr (68% C.L.)
F. Leccia et al., Nuovo Cimento 85A (1985) 19

1986



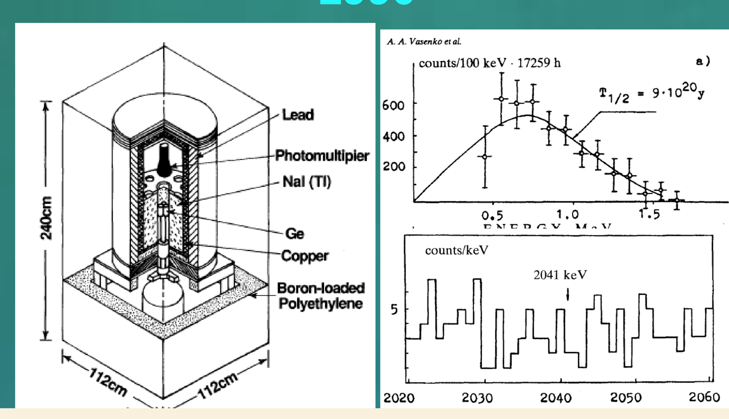
PNL-USC set up
in the **Homestake gold mine (1438 m of rock)**
Ge detector 135 cm³ volume
The background rate in ROI is **1.7 cts/(kg kev yr)**
8089 hours
$T_{1/2}$ (0νββ) > 1.4×10^{23} yr (68% C.L.)
F.Avignone et al., Phys. Rev. C34, 666 (1986))

1987



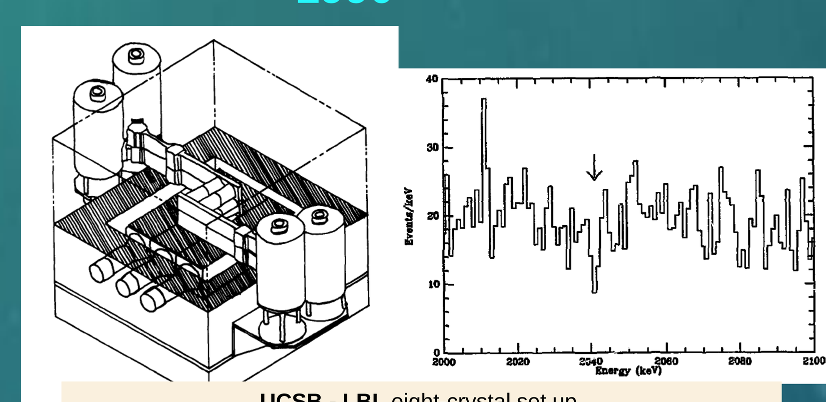
ELEGANTS set up
at the **Kamioka underground laboratory (2700 m w. e.)**
171 cm³ HPGe detector surrounded by 4π NaI (Tl)
The background rate in ROI is **5.5 cts/(kg kev yr)**
8621 hours of running time
$T_{1/2}$ (0νββ) > 7.3×10^{22} yr (68% C.L.)
H.Ejiri et al., J. Phys. G: Nucl. Phys. 13 (1987) 839

1990



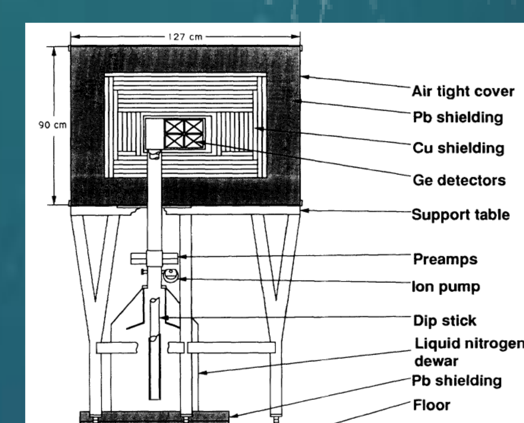
The first Ge experiment with enriched in ^{76}Ge detectos
The **ITEP- Yerevan** array of three Ge-detectors inside a NaI(Tl) active shield.
The detector set with **2 enriched in ^{76}Ge crystals**, 106 cm³ and 109 cm³ , and one of natural germanium, 115 cm³, operated in the Avan salt mine (645 m.w.e.), Armenia.
The background rate in ROI is **2.6 cts/(kg kev yr)**, Exposure 0.87 kg yr(^{76}Ge)
$T_{1/2}$ (0νββ) > 1.3×10^{24} yr (68% C.L.)
A.Vasenko et al., Modern Physics Letters A, V. 5, N.17 (1990) 1299

1990

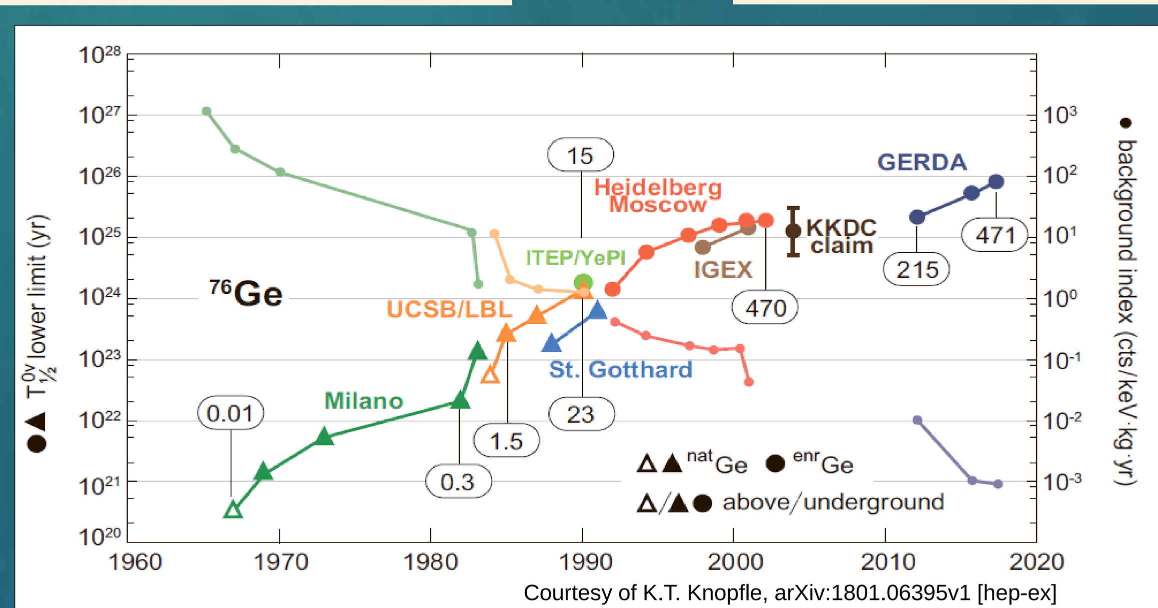


UCSB - LBL eight-crystal set up.
8 Ge detectors with fiducial volumes of about 160 cm³ each operating inside NaI(Tl) shield.
Located 600 m.w.e. deep in the California dam.
The background rate in ROI is **1.2 cts/(kg kev yr)** Exposure 21 kg yr.
$T_{1/2}$ (0νββ) > 1.2×10^{24} yr (68% C.L.)
D.Caldwell et al., Nuclear Physics 13, 547 (1990)

1992



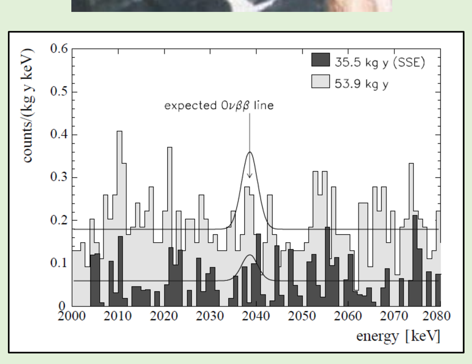
Set up of the **Caltech-SIN-Neuchatel** group
in the **St.Cotthard tunnel (3000 m w. e.)**
8 HPGe detectors totaling 1095 cm³ fiducial volume
The background rate in ROI is **2.4 cts/(kg kev yr)**
15058 hours = 10 kg yr
$T_{1/2}$ (0νββ) > 6.0×10^{23} yr (68% C.L.)
D. Reusser, et al., Phys.Rev.D45, 2548 (1992)



History of T1/2 lower limits (68%CL, 90%CL since 1990) and background indexes.
Framed numbers show exposures in mol(76Ge)·yr [arXiv:1801.06395v1].

1990 – 2018 (years of operation and result publications)

Heidelberg-Moscow 1990- 2003



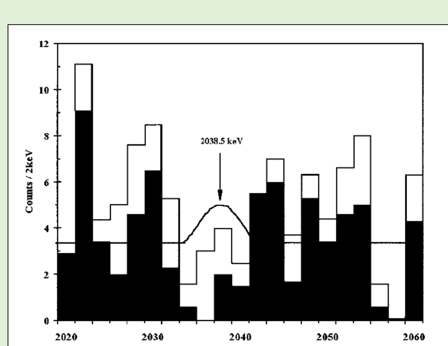
11.5 kg of enriched in ^{76}Ge detectors,
0.11 counts/(kg keV y) around 2040 keV
$T_{1/2}$ (0νββ) > 1.9×10^{25} yr (90% C.L.)
Eur.Phys. Jurn. A 12 (2001) 147

KKDC (part of HDM) claim
to have observed (28.8+/- 6.9) decays
$T_{1/2}$ = (1.19+0.37- 0.23)x10^{25} yr (68% C.L.)
Phys. Lett. B 586, 198 (2004)
(Later $T_{1/2}$ = 2.23x10^{25} yr
Phys. Lett A 21,1547 (2006)

IGEX – Baksan 1992 -> now

IGEX – Canfrank 1993- 2002

6.8 kg of enriched in ^{76}Ge detectors,
0.17 counts/(kg keV y) around 2040 keV
$T_{1/2}$ (0νββ) > 1.6×10^{25} yr (90% C.L.)
Phys. Rev. D65, 092007 (2002)

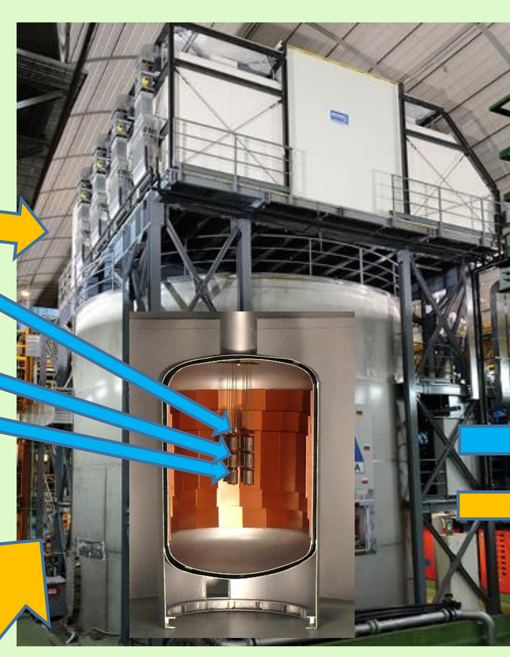


At the end of the 20th century the Heidelberg-Moscow and IGEX not only yield the best current limits on m_ν, they also provided most of the technology needed for future ^{76}Ge experiments

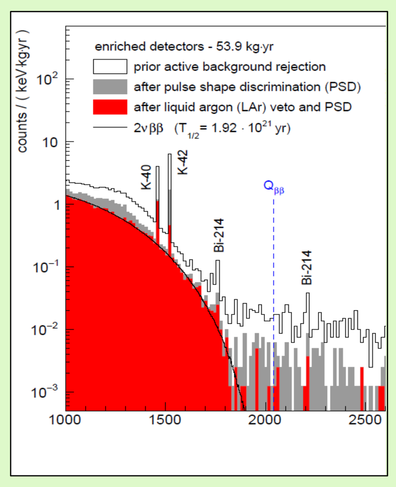
Detectors

Experience

GERDA - I 2006 - 2013

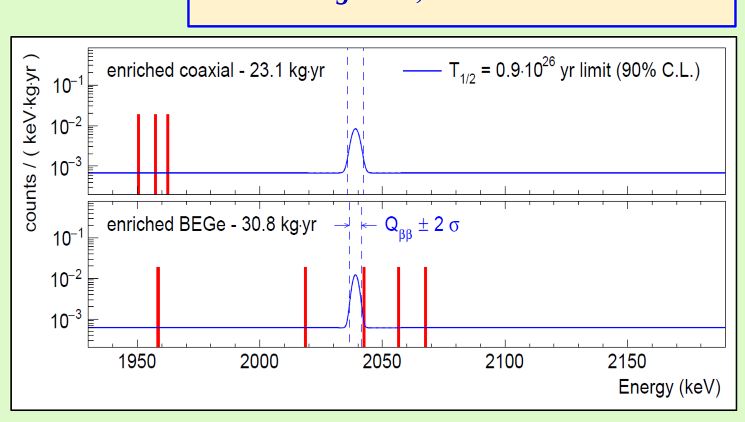


17.7 kg of enriched in ^{76}Ge detectors
0.01 cts/(kg keV y) near 2039 keV
$T_{1/2}$ (0νββ) > 2.1 x10^{25} yr (90% C.L.)
PRL 111, 122503 (2013)
$T_{1/2}$ (2νββ)=(1.926 ± 0.094)×10^{21} yr
Eur. Phys. J. C 75 (2015) 416

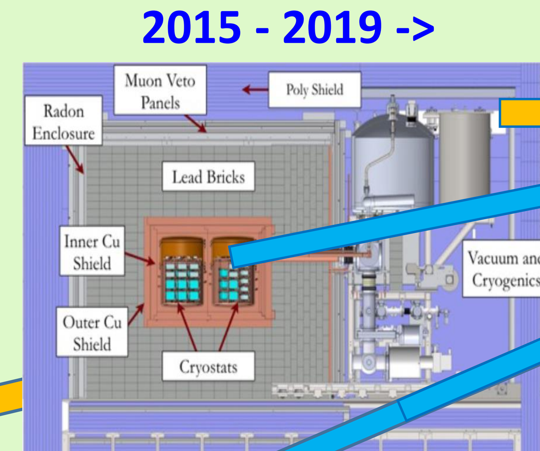


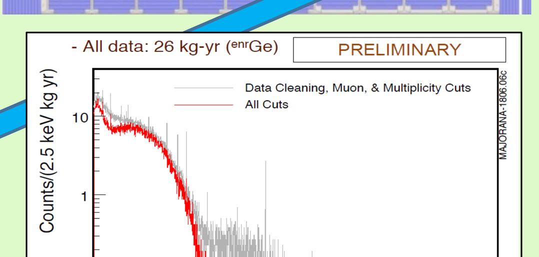
GERDA - II 2014 - 2019 ->

35.6 kg of enriched in ^{76}Ge detectors
LAr scintillation Veto,
0.0006 counts/(kg keV y) near ROI
$T_{1/2}$ (0νββ) > 0.9 x10^{26} yr (90% C.L.)
at sensitivity 1.1 x 10^{26} yr
$m_{\beta\beta}$ < 0.11- 0.26 eV
exposure 831 mole yr (Phases I+II)
for data release May 2018
A. Zsigmond, Talk at NEUTRINO'18

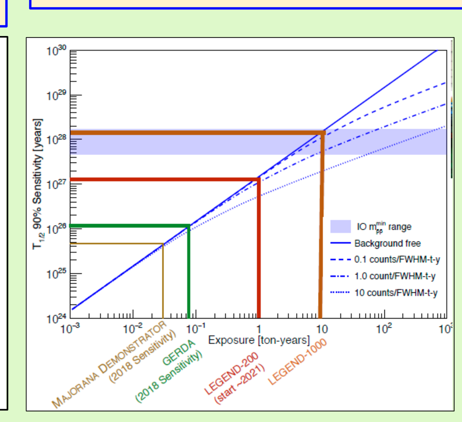


MAJORANA - D 2015 - 2019 ->





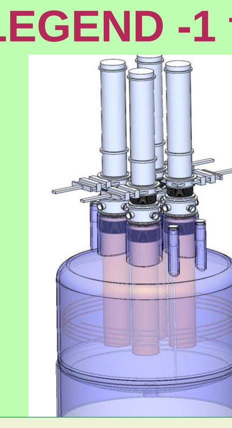
29.7 kg of enriched in ^{76}Ge detectors
0.005 counts/(kg keV y) near ROI
$T_{1/2}$ (0νββ) > 2.7 x10^{25} yr (90% C.L.)
at sensitivity 4.8 x 10^{25} yr
exposure 26 kg yr
for data release April 2018
V. Guisepper, Talk at NEUTRINO'18



LEGEND-200 2020 ->

200 kg ^{76}Ge in upgrade of existing GERDA infrastructure,
BG goal 0.1 cts/(ton kev yr),
$T_{1/2}$ goal ~10^{27} yr
- Will use existing GERDA & MAJORANA detectors (65 kg), plus new detectors (135 kg)

LEGEND -1 ton



$T_{1/2}$ goal ~10^{28} yr
for probing <$m_{\beta\beta}$ >down to 10 meV
to completely cover inverted mass ordering