Support Experiments for Neutrinoless Double Beta Decay

^{76}Ge in GERDA

Peter Grabmayr

the GERDA Collaboration

Eberhard Karls Universität Tübingen
Germany

Kepler Center for Astro and Particle Physics

Eberhard Karls Universität Tübingen

bmb+f - Förderschwerpunkt
Astroteilchenphysik
Großgeräte der physikalischen Grundlagenforschung

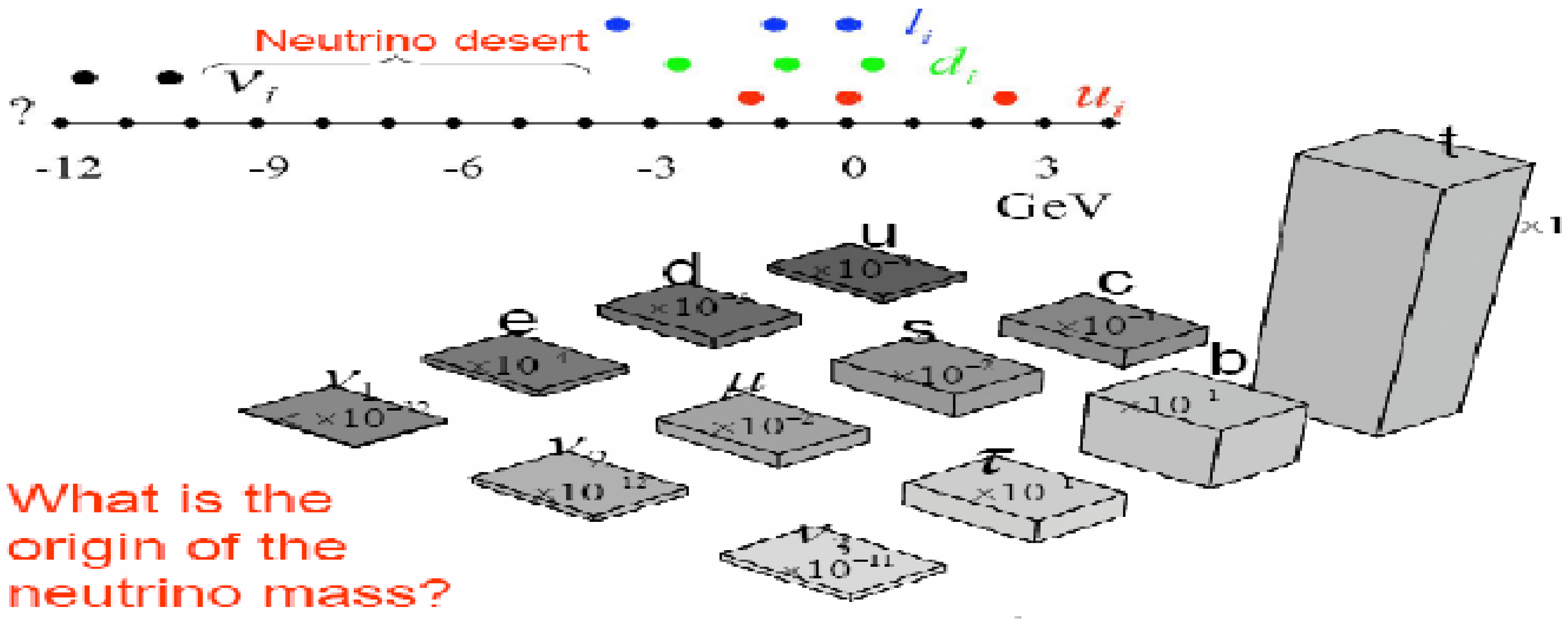
neutrino mass

Oscillations: neutrinos have finite mass !

Neutrinos: Dirac or Majorana particles ?

What is the origin of the neutrino mass ?

Masses in the Standard Model SUSY / Higgs



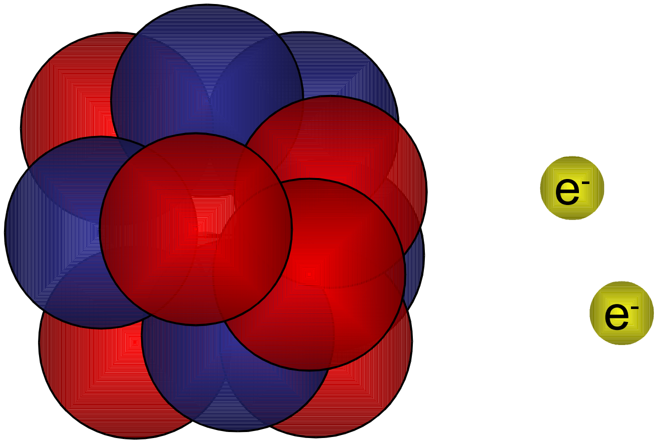
What is the origin of the neutrino mass?

neutrinoless double beta decay

2^{nd} order allowed weak process

$(A,Z) \rightarrow (A,Z+2) + 2e^-$

$(0\nu\beta\beta)$



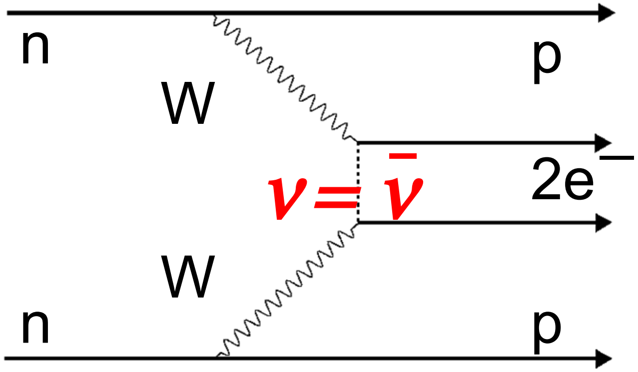
Gamow-Teller and Fermi

$$\left| M_F - (g_a/g_v)^2 \, M_{GT} \right|^2$$

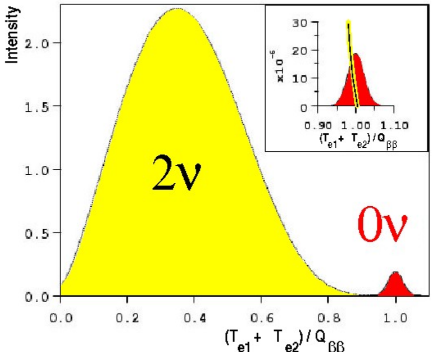
Neutrino = Anti-Neutrino

(Majorana type)

- must have finite mass
- violation of lepton number conservation $\Delta L=2$



signature →



^{76}Ge experiments

previous experiments: HDM (5 det) and IGEX (3 det)

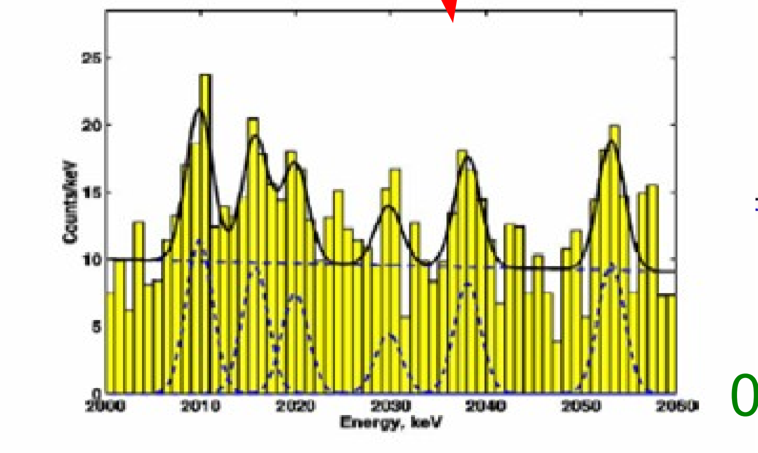
Klapdor-Kleingrothaus et al.

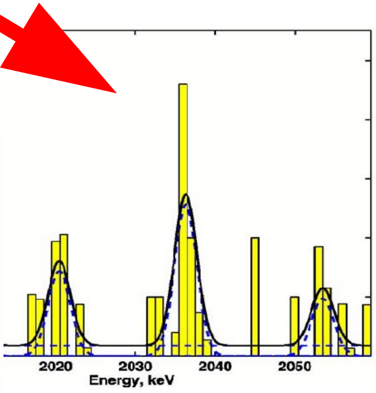
Phys Lett B586 (2004) 198

71,7 kg·y

$T_{1/2} > 1{,}9 \cdot 10^{25}$ y (90%CL)

(0,69 - 4,18)





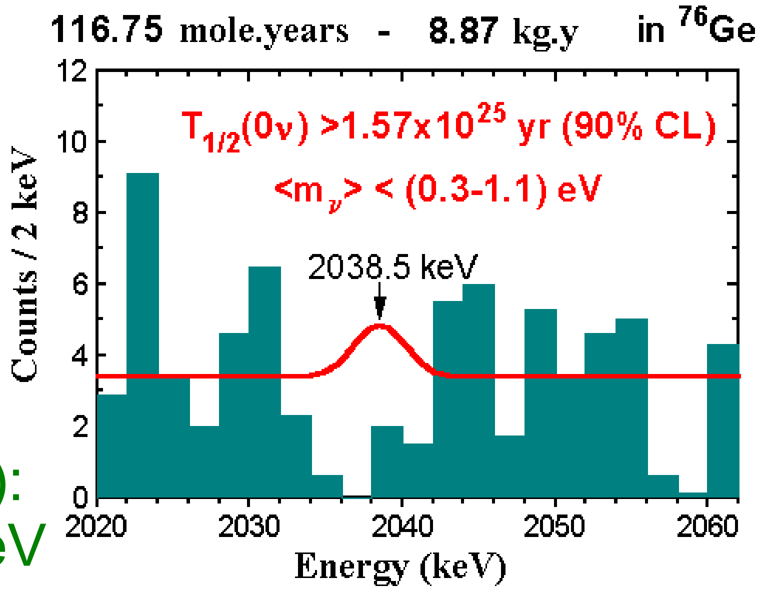
MPLA21 (2006):
0,27< $m_{\beta\beta}$ < 0,4 eV

Aalseth et al.

Phys Rev D65 (2002) 092007

8,9 kg·y

$T_{1/2} > 1{,}6 \cdot 10^{25}$ y (90%CL)



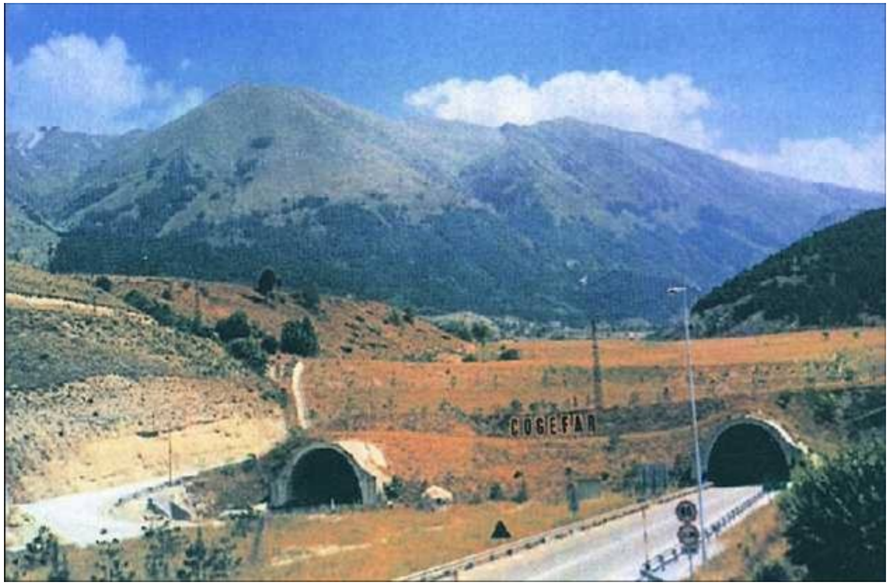
experiments

NEMO/SuperNEMO	^{100}Mo	DC tracking
cuoricino/cuore	^{130}Te	bolometer
Majorana/GERDA	^{76}Ge	ionisation

R. Santorelli, talk D 416, 4.9.@15:45

Candles	^{48}Ca	szintillation
SNOW++	^{150}Nd	szintillation
MOON	^{100}Mo	MWPC+PLfibres
COBRA	CdZnTe	ionisation+track?
EXO	^{136}Xe	TPC

GERDA @ LNGS



Support experiments

- understand (reduce) background contributions
  in laboratory LNGS   3800 m.w.e.
- check on theory of nuclear matrix elements

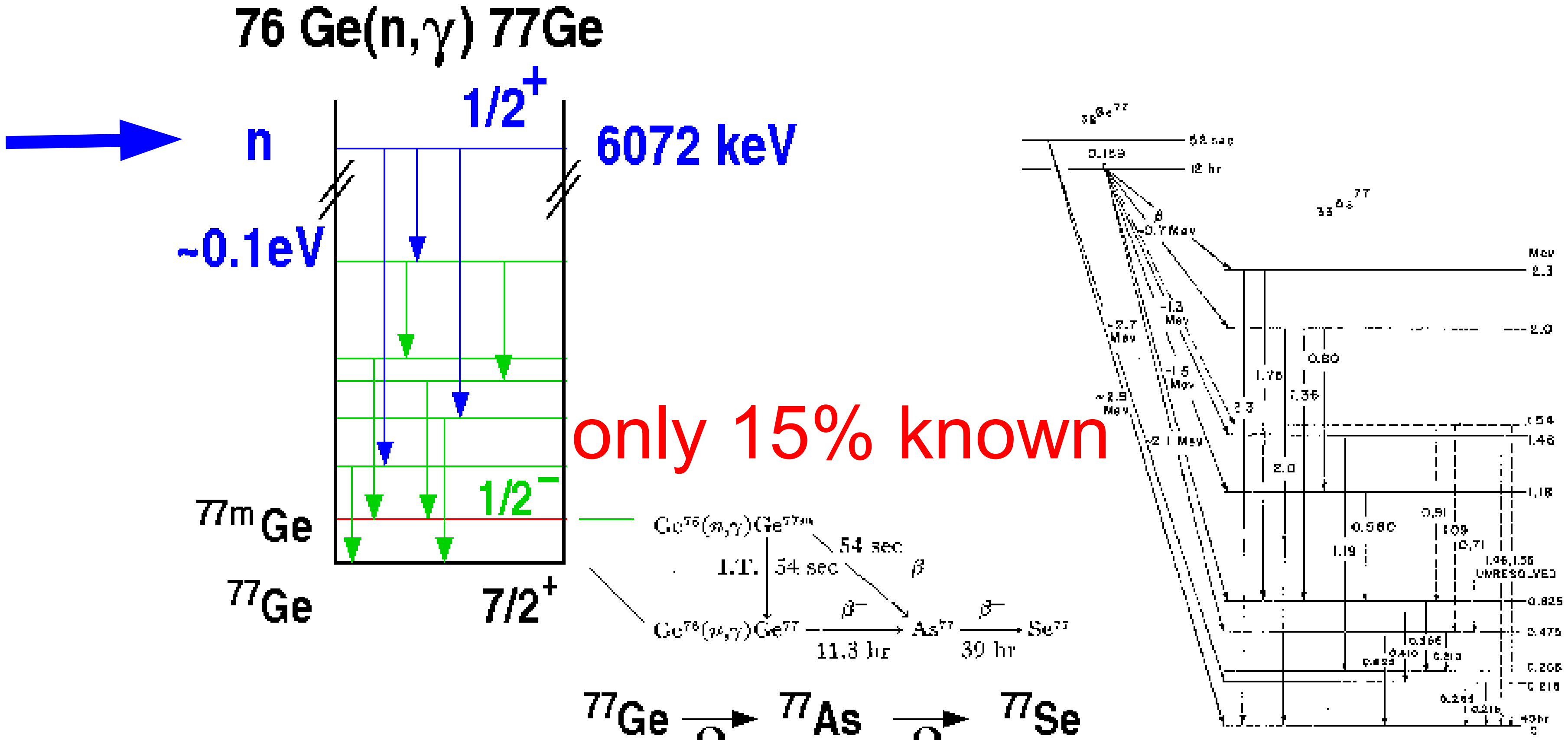
$1/T_{1/2} = PS * ME^2 * (m_\nu / m_e)^2$

- neutron capture (n,γ)
- Charge exchange reactions (d,^{2}He) (^{3}He,t)
- one-nucleon transfer experiments (d,^{3}He)(^{3}He,d)
  (d,p)(p,d)(d,t)..

neutron capture

2 photon lines: 2041(prompt) & 2037 (delayed) keV close to $Q_{\beta\beta}$ = 2039keV

2 experiments: thermal (< meV, FRM-II) & astro (25 keV, FZK)



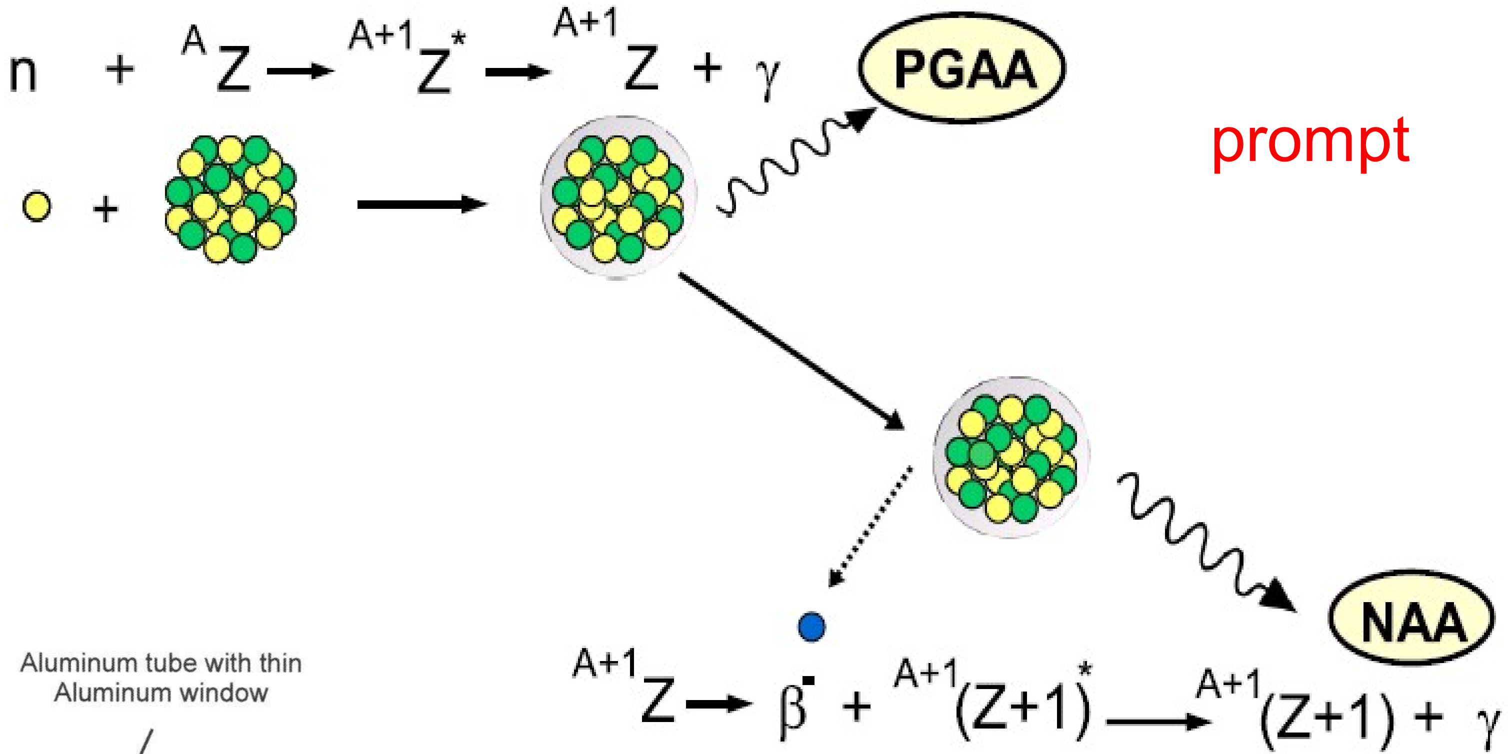
only 15% known

Fig. 6. Decay scheme of $_{32}Ge^{77}$.

$^{77}Ge \xrightarrow[\beta]{} {}^{77}As \xrightarrow[\beta]{} {}^{77}Se$

Q_{β} = 2703 690 keV

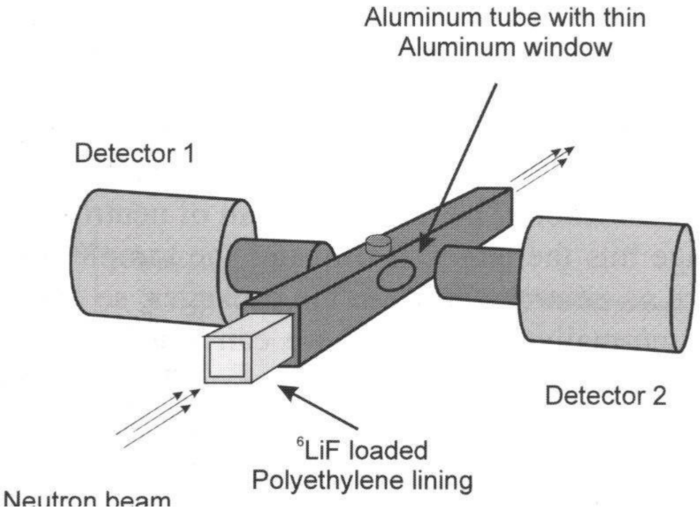
the reaction



$$n + {}^{A}Z \rightarrow {}^{A+1}Z^{*} \rightarrow {}^{A+1}Z + \gamma$$

prompt

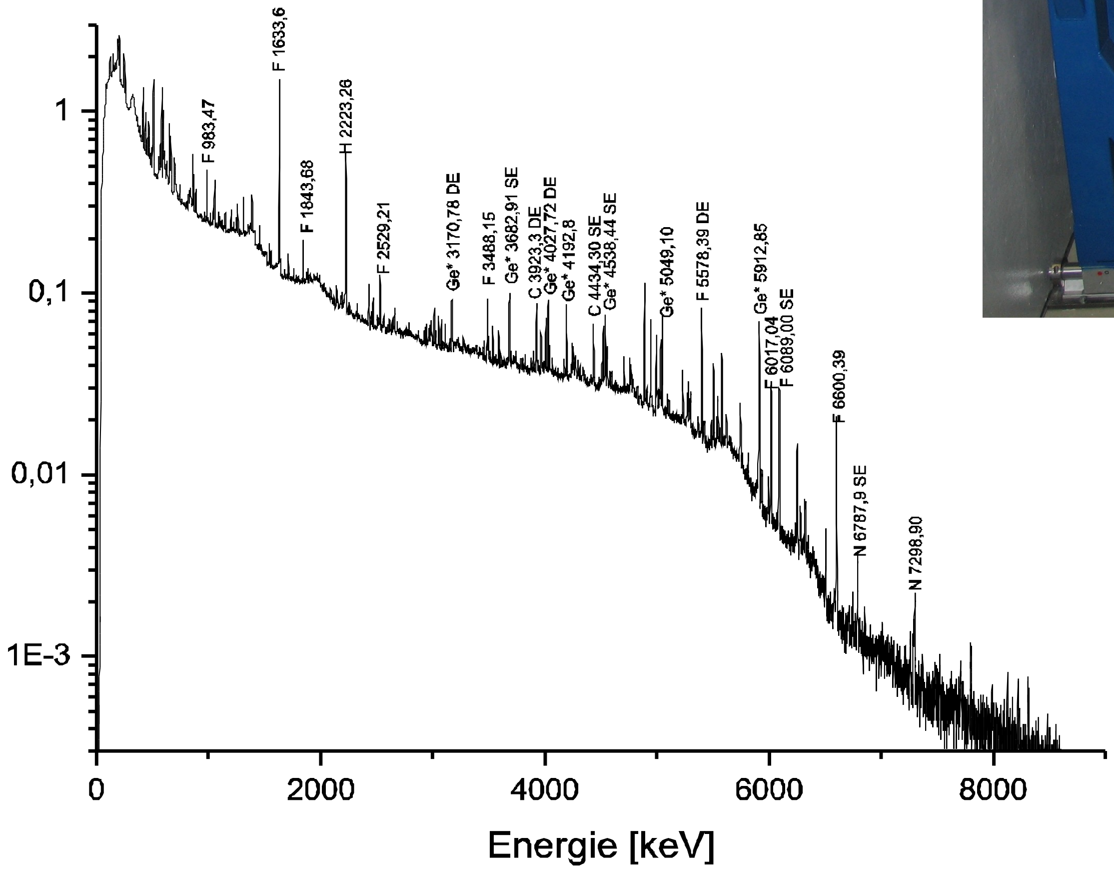
$$^{A+1}Z \rightarrow \beta^{-} + {}^{A+1}(Z+1)^{*} \longrightarrow {}^{A+1}(Z+1) + \gamma$$

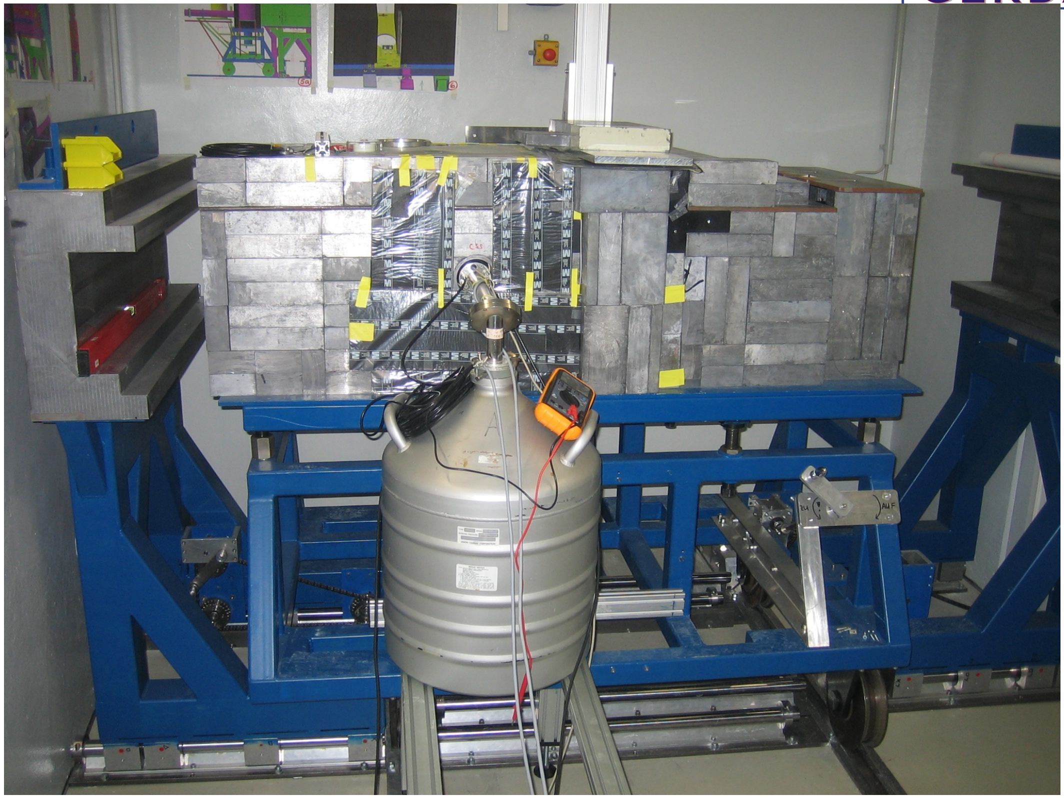


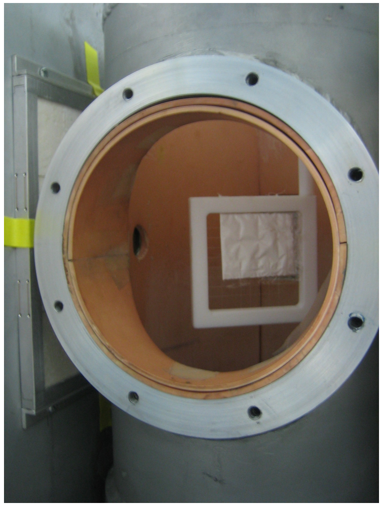
coincidence technique for study of decay schema

the reaction

- m ~ 300 mg of enriched GeO_2
- Irradiation time > 50 000 s

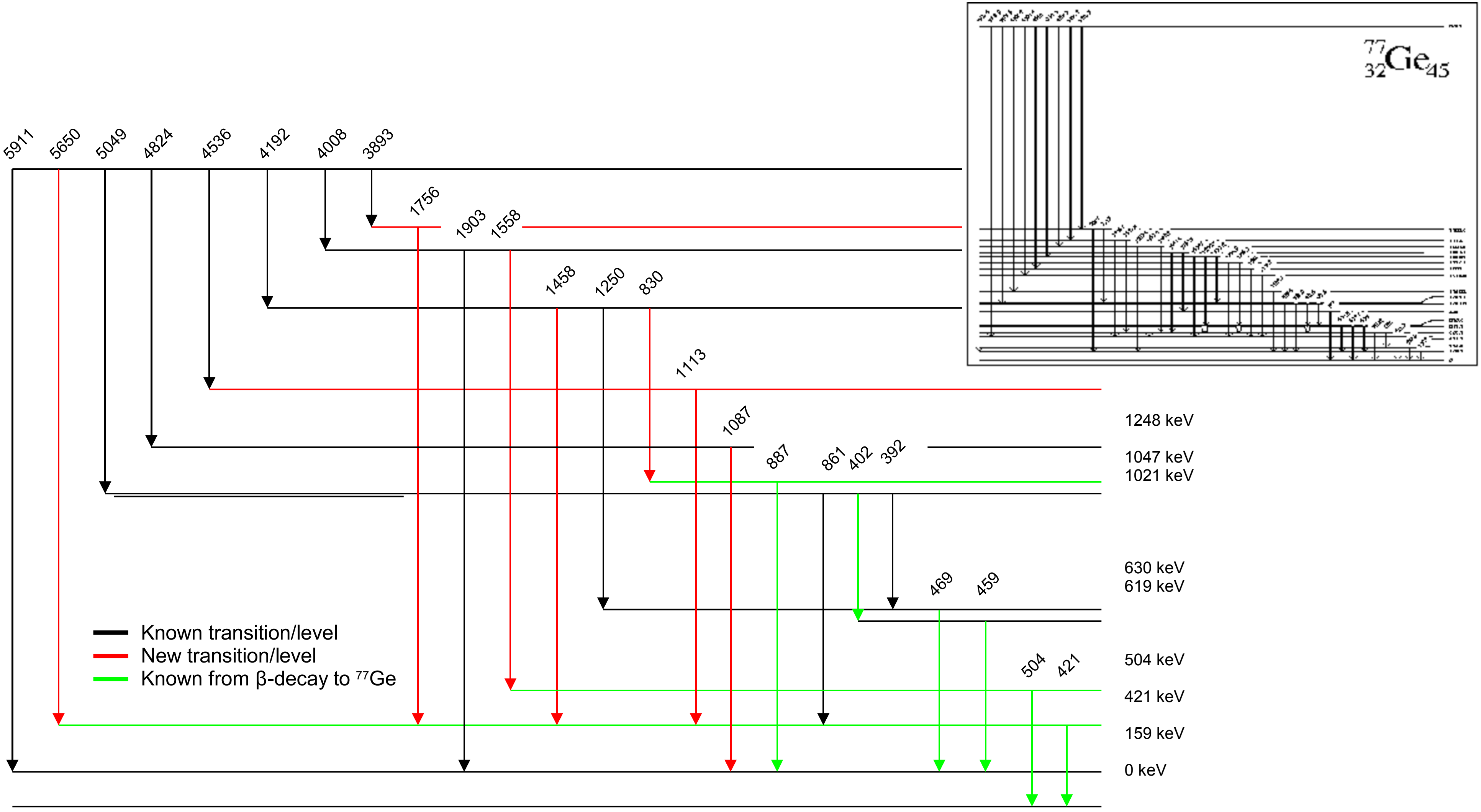




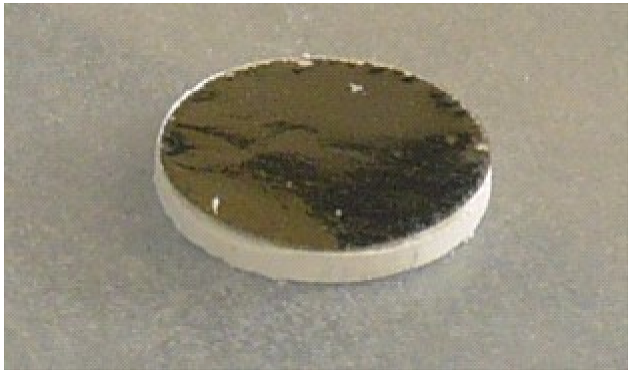


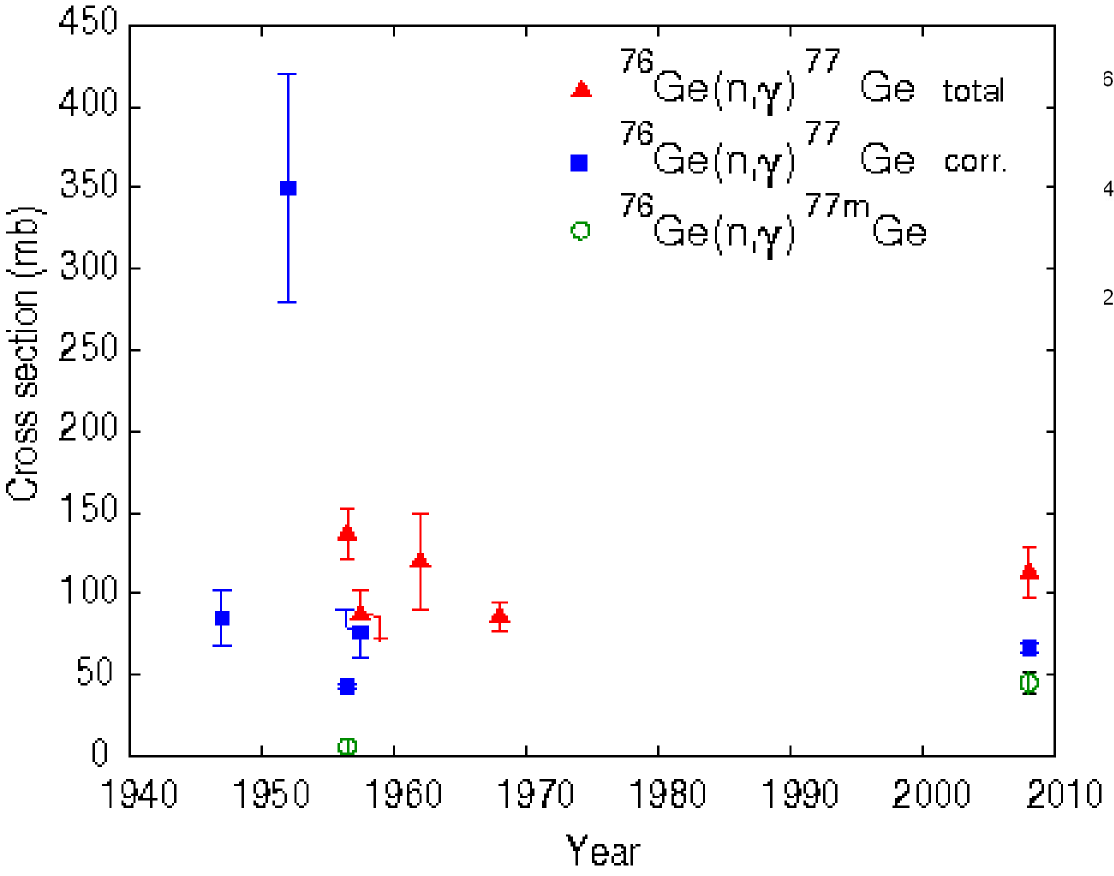
- 7.83×10^9 n/(cm^2 s^1)
- $<\lambda_n>$ = 6.7 Å
- <E> = 1.83 meV

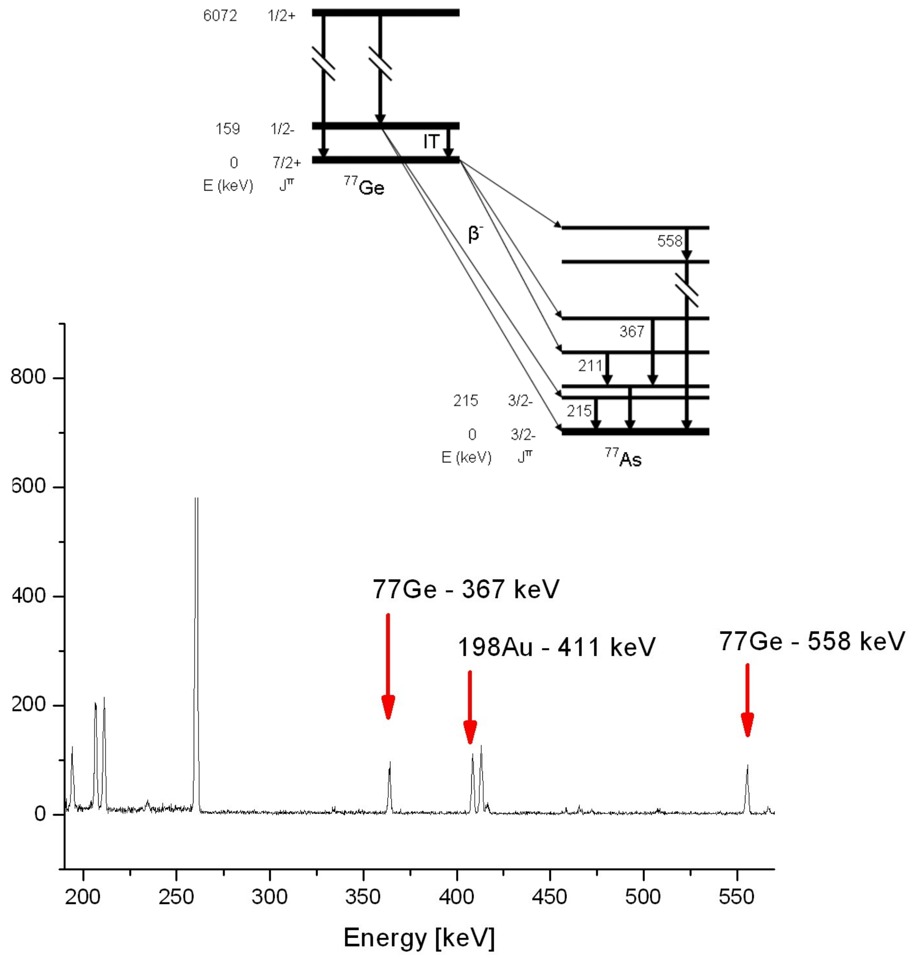
first look at coincidence data



total capture cross section







G.Meierhofer et al., EPJ A (2009)

neutron capture

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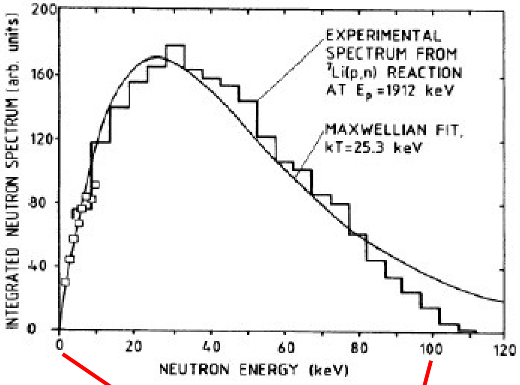
IOP PUBLISHING JOURNAL OF PHYSICS G: NUCLEAR AND PARTICLE PHYSICS

J. Phys. G: Nucl. Part. Phys. 35 (2008) 014022 (5pp) doi:10.1088/0954-3899/35/1/014022

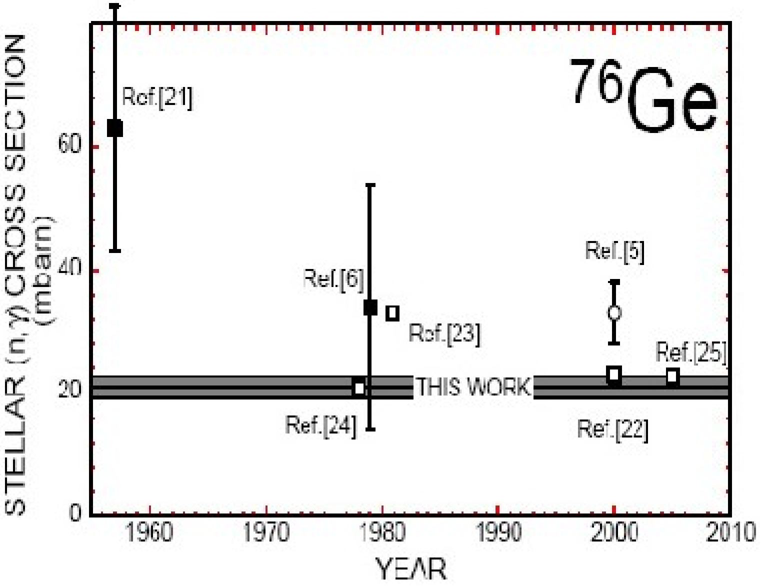
Neutron capture cross section of ^{76}Ge

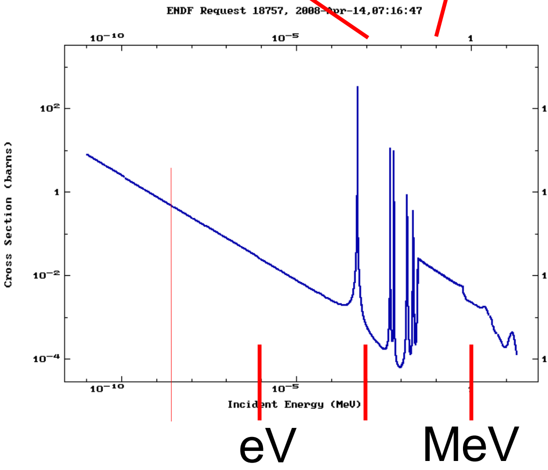
J Marganiec[1,2], I Dillmann[1], C Domingo Pardo[1], P Grabmayr[3] and F Käppeler[1]



2nd publication in PRC

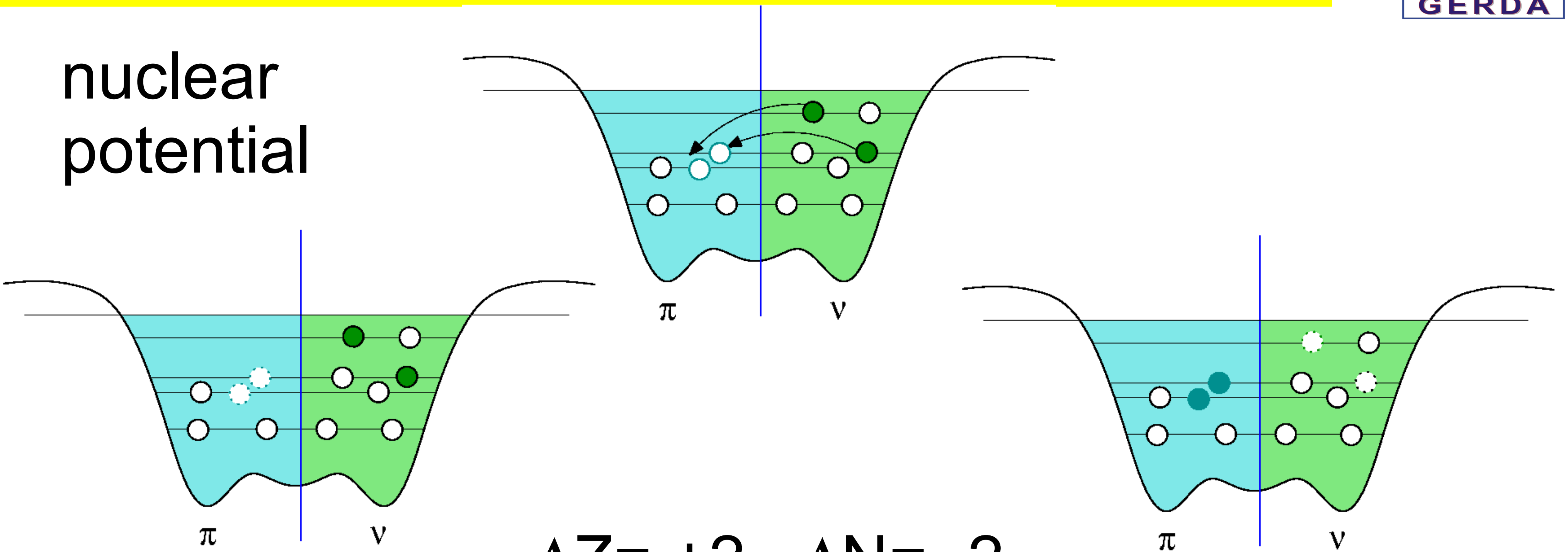
$\sigma^{gs} + \sigma^{m}$





ββ-decay in the Shell Model

nuclear
potential



$\Delta Z = +2 \quad \Delta N = -2$

$^{76}\text{Ge}_{44} \longrightarrow {}^{76}\text{Se}_{42}$

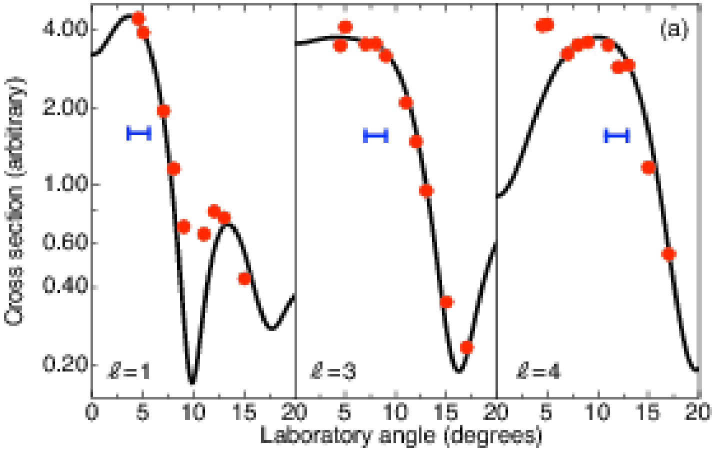
V. Rodin: calculations of ME

no reaction for direct comparison

clarify structure of initial and final nucleus

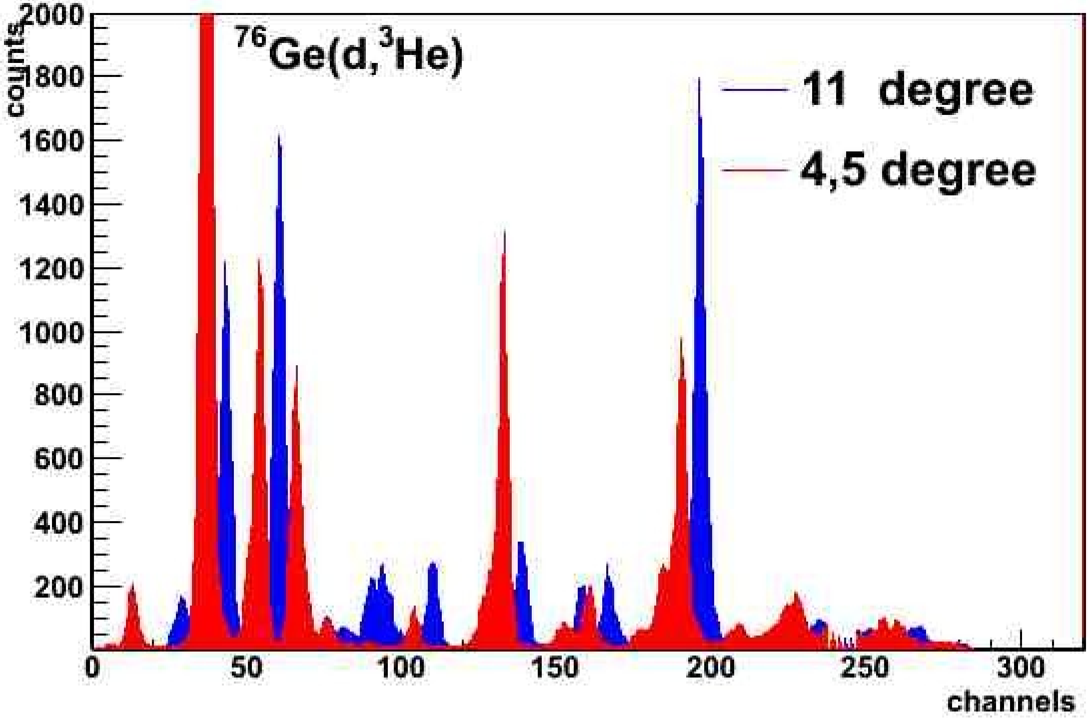

RCNP Osaka

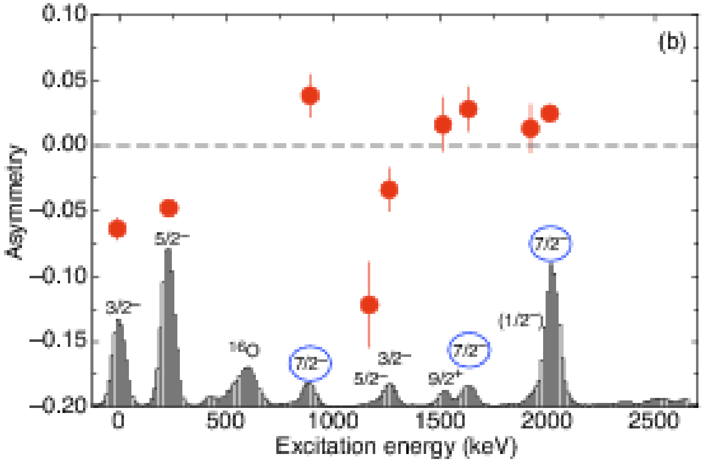
proton transfer



B.Kay, J. Schiffer, S. Freeman,PG

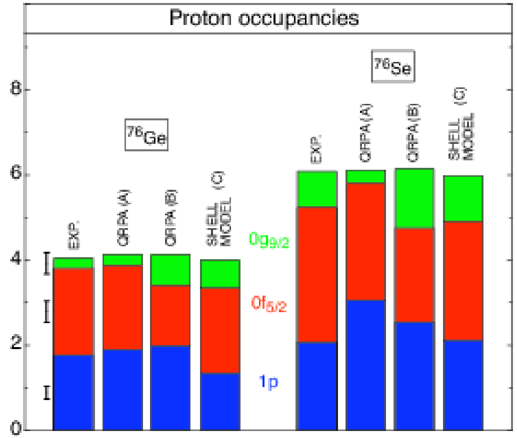
Phys. Rev. C 79 (2009) 021310





in (^{3}He,d) not the full strength found

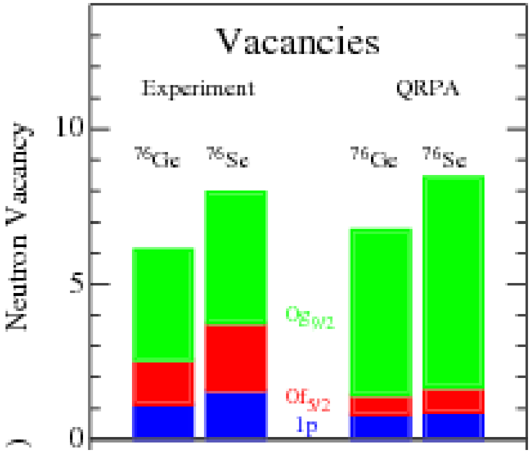
differences in occupancy



A) V.A. Rodin etal
NPA766 (2006) 107

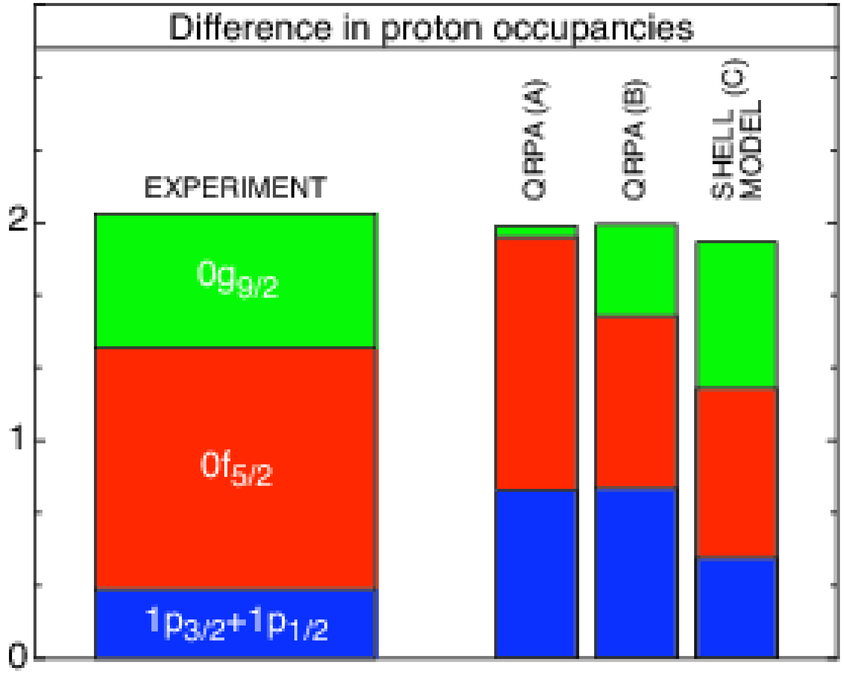
B) J. Suhonen and O. Civitarese
PLB668 (2008) 277

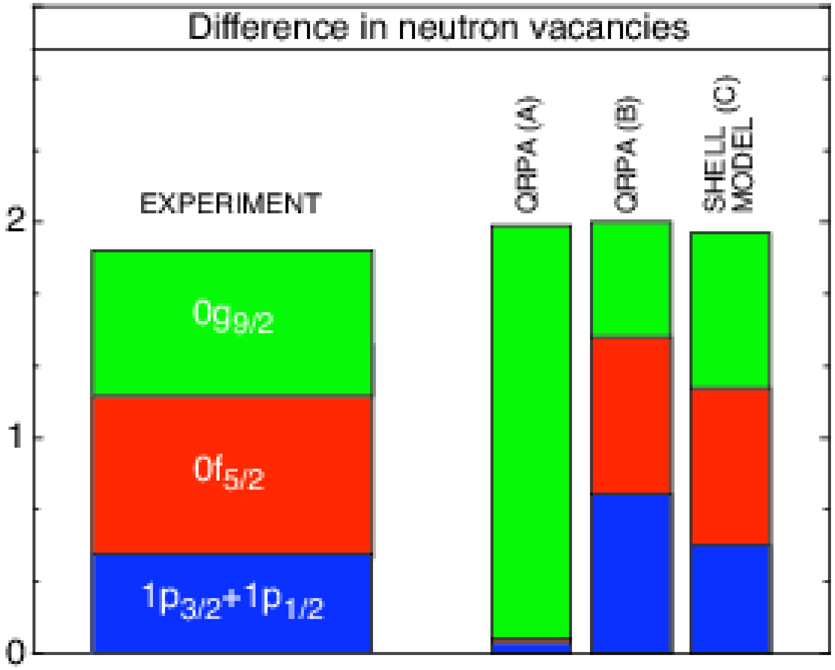
C) E. Caurier etal
PRL 100 (2008) 052503
+ A.Poves (priv.comm.)



protons

neutrons

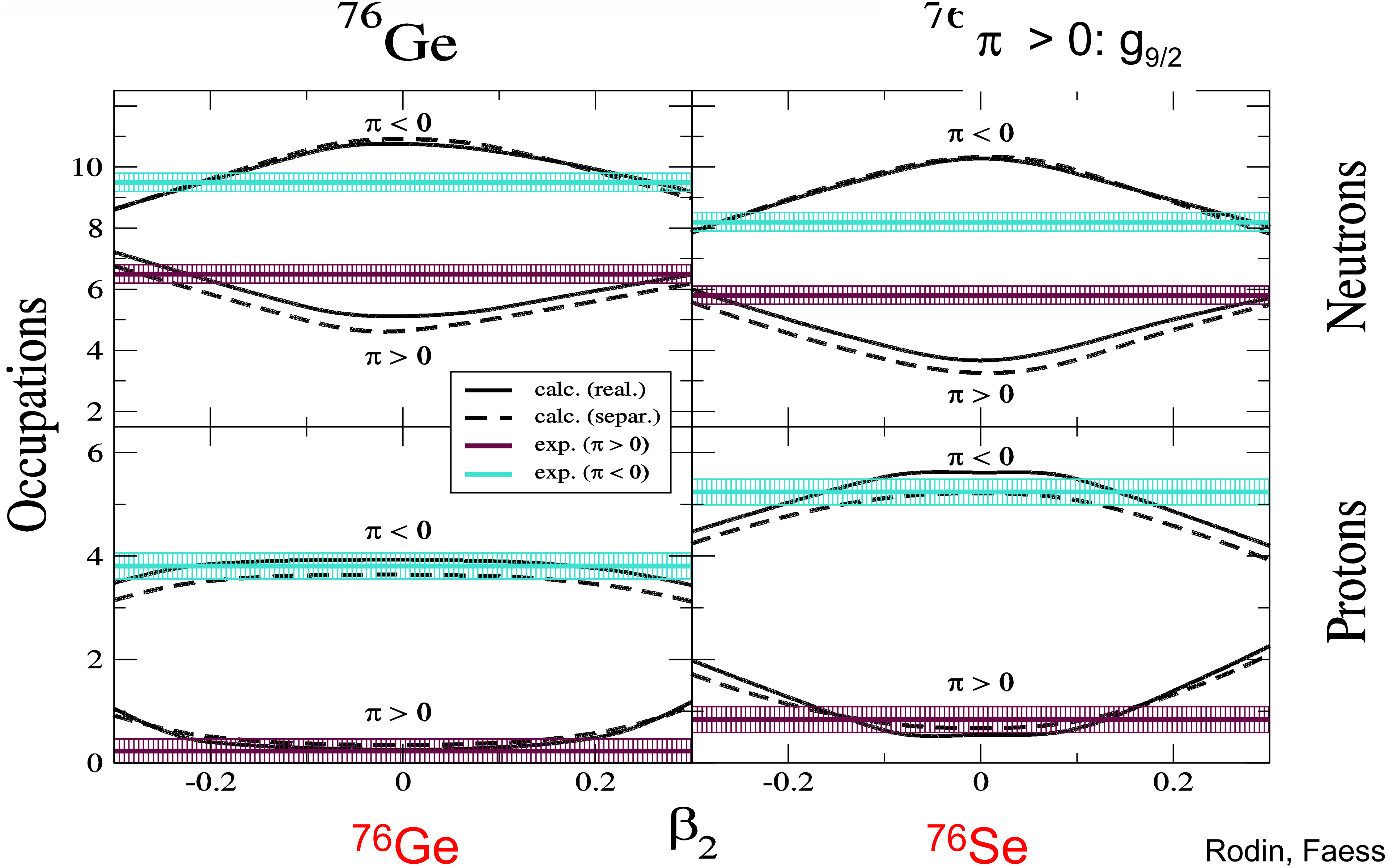




Deformation affects the occupation Probabilities of neutrons mainly.

Parity π < 0:
$p_{1/2}$, $p_{3/2}$,$f_{5/2}$

π > 0: $g_{9/2}$



^{76}Ge

^{76}Se

Rodin, Faessler,

summary

Finish setup by fall 2009

verify background level of
$< 10^{-2}$ cts/(keV·kg·y)

wait one year with 17.9 kg ^{76}Ge
for first result on **$0\nu\beta\beta$**
……… if he is right

Phase III: GERDA+Majorana

other experiments:

limit for 0νECEC on ^{36}Ar $T_{1/2} > 1{,}9 \cdot 10^{18}$ y ; 68% CL

n-capture, nucleon-transfer for nuclear structure

phase space

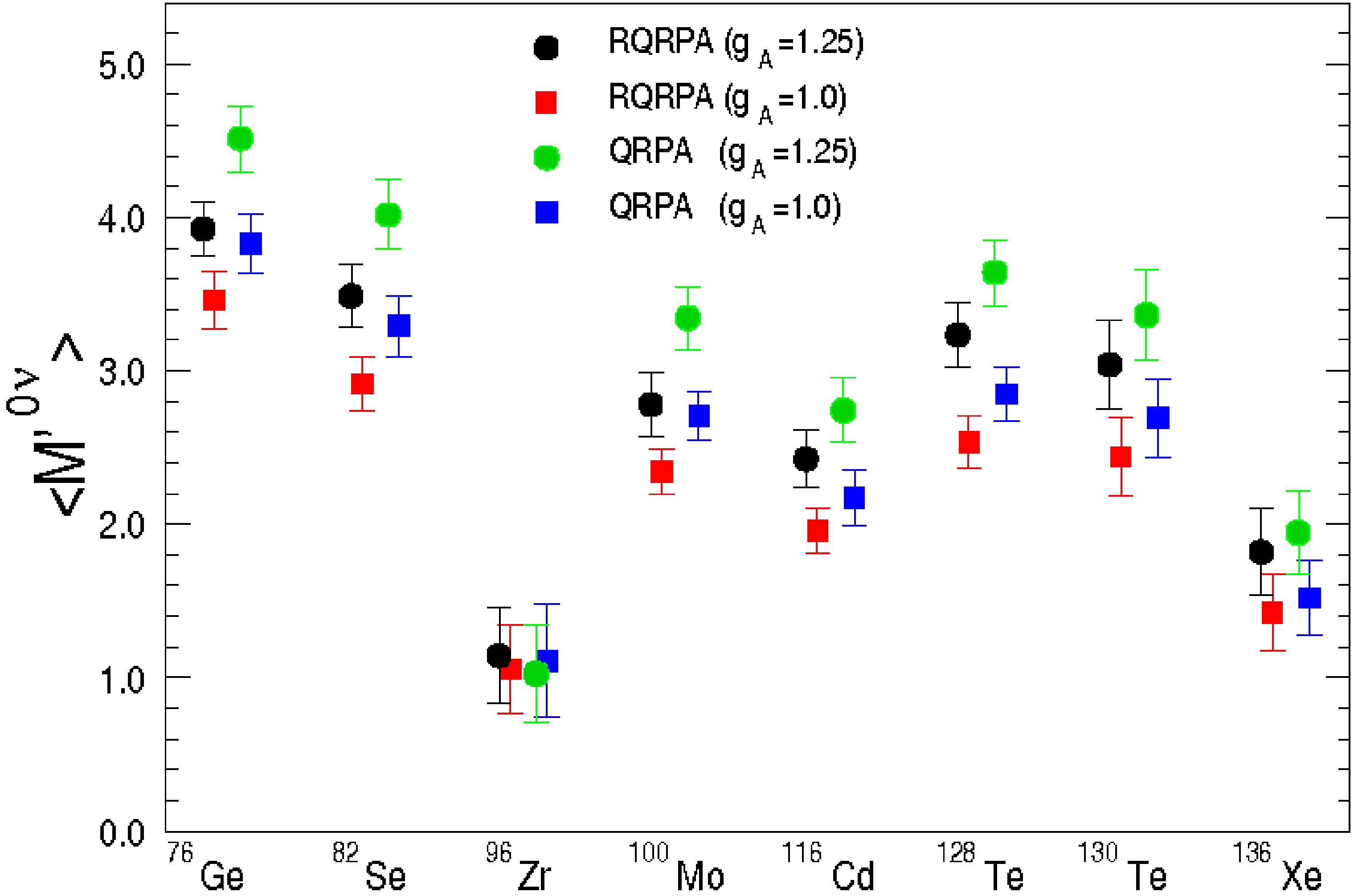
$0\nu\beta\beta$ decay rate scales with Q^5
$2\nu\beta\beta$ decay rate scales with Q^{11}

Isotope	Q-value (keV)	Nat. abund. (%)	$(PS\ 0\nu)^{-1}$ ($yrs \times eV^2$)	$(PS\ 2\nu)^{-1}$ (yrs)
Ca 48	4271	0.187	4.10E24	2.52E16
Ge 76	2039	7.8	4.09E25	7.66E18
Se 82	2995	9.2	9.27E24	2.30E17
Zr 96	3350	2.8	4.46E24	5.19E16
Mo 100	3034	9.6	5.70E24	1.06E17
Pd 110	2013	11.8	1.86E25	2.51E18
Cd 116	2802	7.5	5.28E24	1.25E17
Sn 124	2288	5.64	9.48E24	5.93E17
Te 130	2529	34.5	5.89E24	2.08E17
Xe 136	2479	8.9	5.52E24	2.07E17
Nd 150	3367	5.6	1.25E24	8.41E15

natural α decay : 2615 keV

Nuclear Matrix Elements

QRPA: A. Faessler, F.Simkovic, V. Rodin NPA 766 (2006) 107 corr



Shell Model: Strassbourg-Madrid; Caurier, Poves

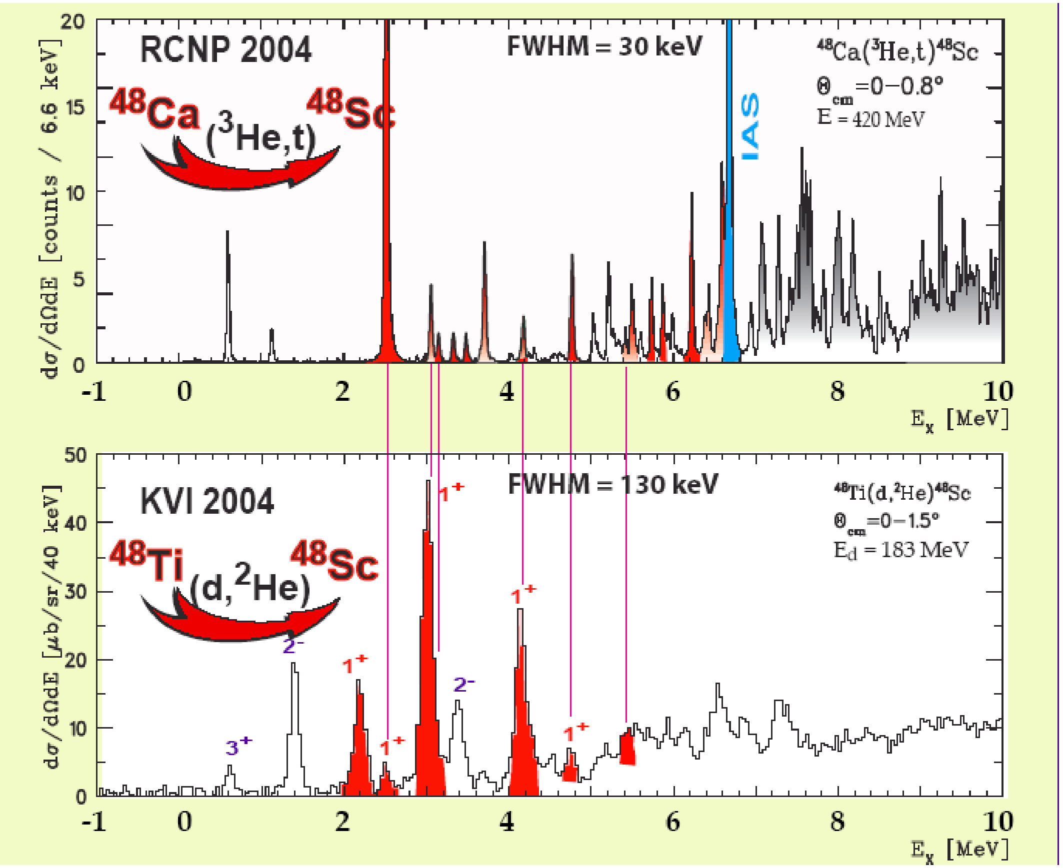
Charge exchange reactions

2νββ: Only intermediate 1⁺ states contribute

Supportive measurements from accelerators

Done for ^{48}Ca and ^{116}Cd
more needed

D. Frekkers, K. Zuber



Currently: (d,^{2}He) and (^{3}He,t)

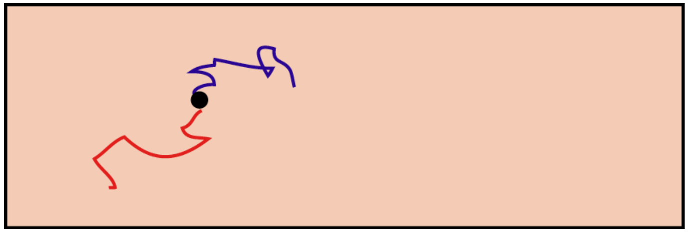
better resolution than (n,p) or (p,n)

methods

aim at 100 meV scale ⇒ B < 10^{-3}/(keV kg yr)

two orders of magnitude better than now

calorimetric:



source = detector

Measure sum energy with calorimetric techniques

Ge semiconductor, bolometers

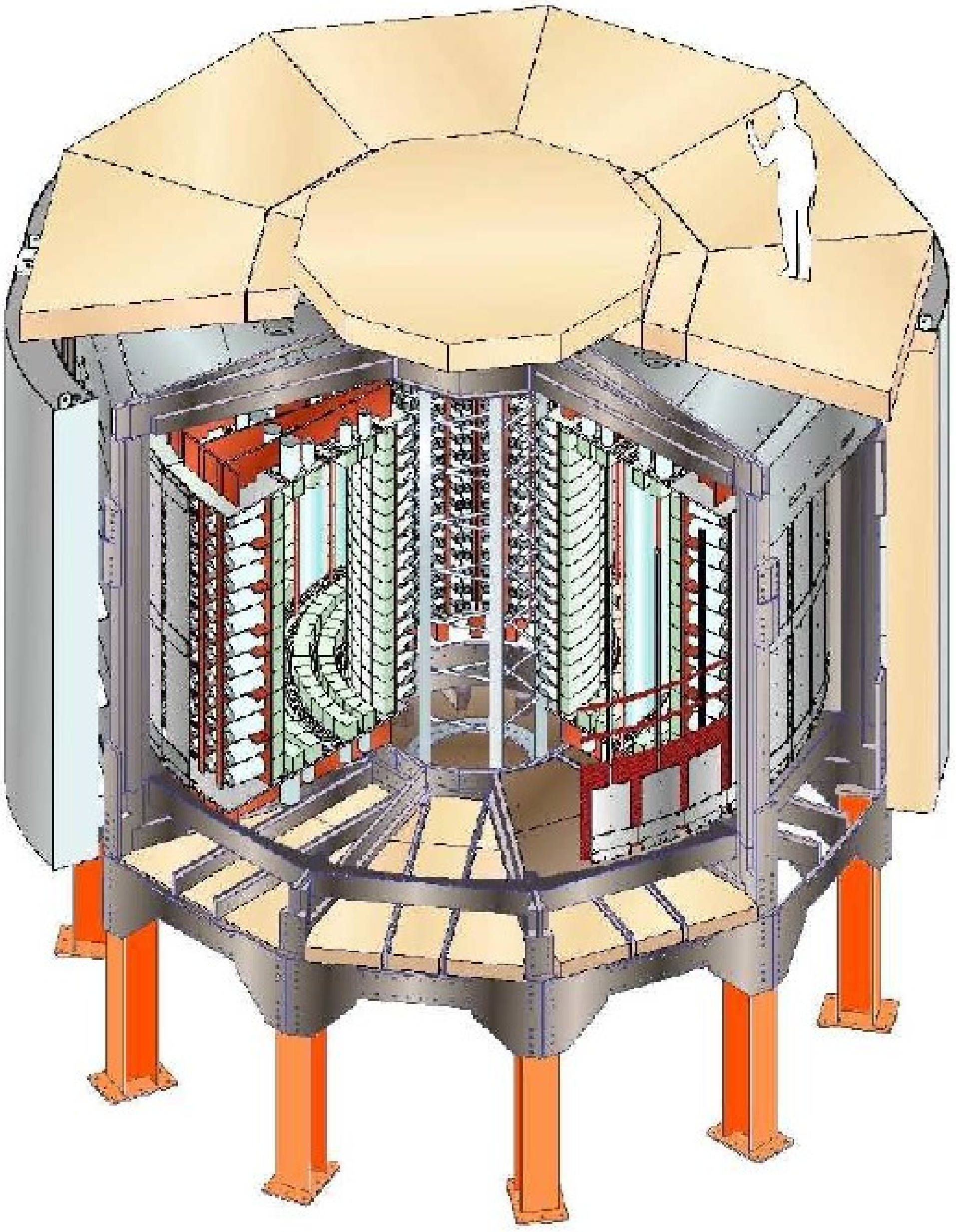
+ very clean materials
+ very large sensitive masses
  several 100 kg:
    CUORICINO/CUORE, bolometers
    GERDA, MAJORANA Ge diodes
+ per-mille energy resolution

tracking:

source ≠ detector

+ background suppression via event reconstruction,
  but $2\nu2\beta$
– **energy resolution (to distinguish $2\nu2\beta$)**
– “dilute” detectors, need large space
+ several nuclides possible (⇒select high Q)
  NEMO3: tracking, calorimetry, **B**-field,
  ⇒ $T_{1/2} > 5.8\ 10^{23}$ y ⇒ $M_{ee} < 0.4 - 1.4$ meV
  ⇒ Future: SuperNEMO

NEMO



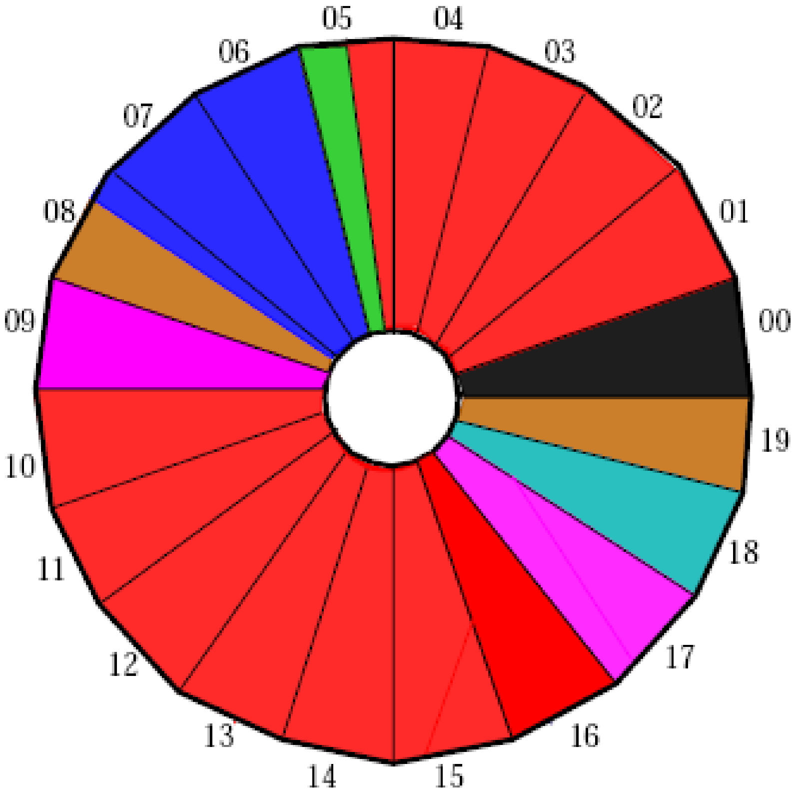
20 segments with thin foils
3D readout drift chambers
surrounding 1940 plastic szint.
B = 30G   (ε_{track} = 98%)

Mo (6,9kg), Se(0,9kg),Te(0,45kg)
Cd(0,40kg),Nd(36g)

Modane : 4800 mwe

$\boldsymbol{\varepsilon}$ = 50% @ 1 MeV
ΔE = 11-14% FWHM

NEMO



^{100}Mo 6.914 kg $Q_{\beta\beta}$ = 3034 keV

^{82}Se 0.932 kg $Q_{\beta\beta}$ = 2995 keV

ββ0ν search

ββ2ν measurement

^{116}Cd 405 g $Q_{\beta\beta}$ = 2805 keV

^{96}Zr 9.4 g $Q_{\beta\beta}$ = 3350 keV

^{150}Nd 37.0 g $Q_{\beta\beta}$ = 3367 keV

^{48}Ca 7.0 g $Q_{\beta\beta}$ = 4272 keV

^{130}Te 454 g $Q_{\beta\beta}$ = 2529 keV

^{nat}Te 491 g

Cu 621 g

External bkg measurement

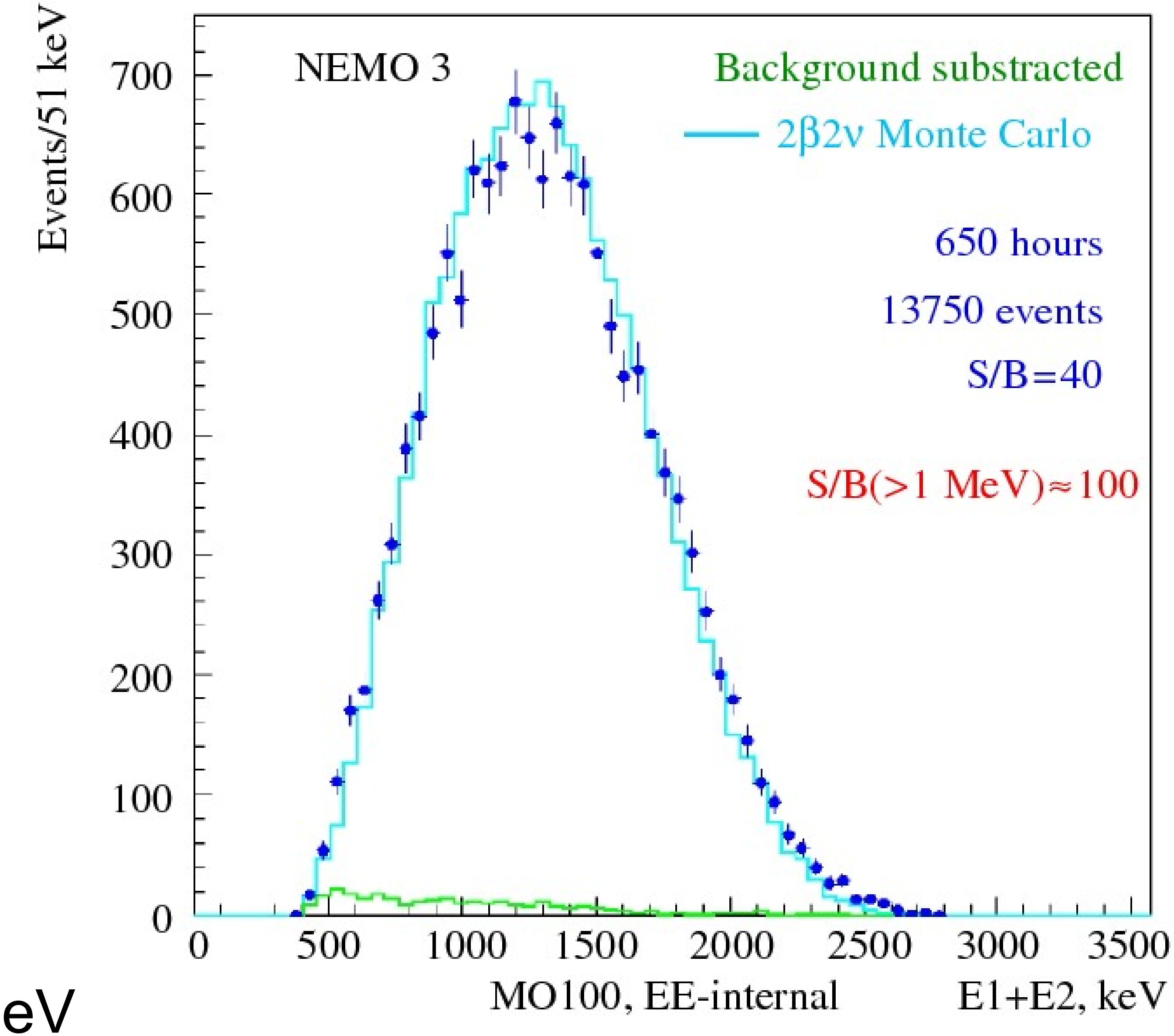
(All the enriched isotopes produced in Russia)

NEMO

^{100}Mo

Q = 3034 keV

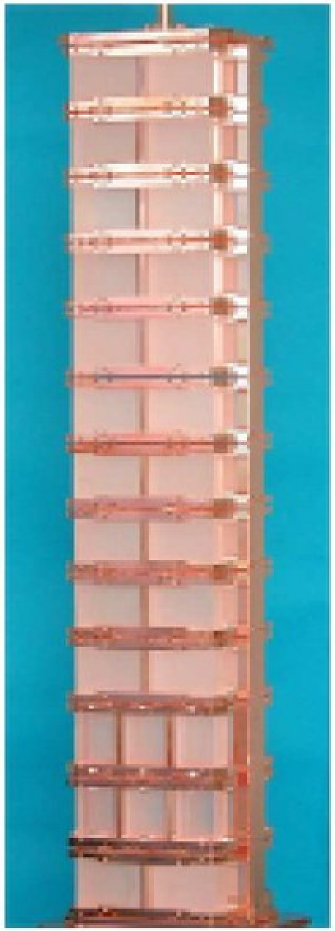
$T_{1/2}^{2\nu} = 7{,}8 \cdot 10^{18}$ y



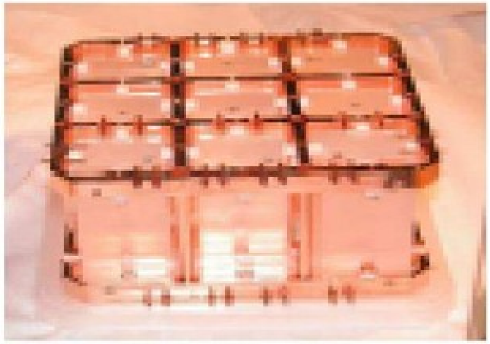
ΔE = 250 keV @ 3MeV

CUORICINO/CUORE

62 crystals in 13 planes



$5 \times 5 \times 5$ cm^3



$3 \times 3 \times 6$ cm^3

2 enriched

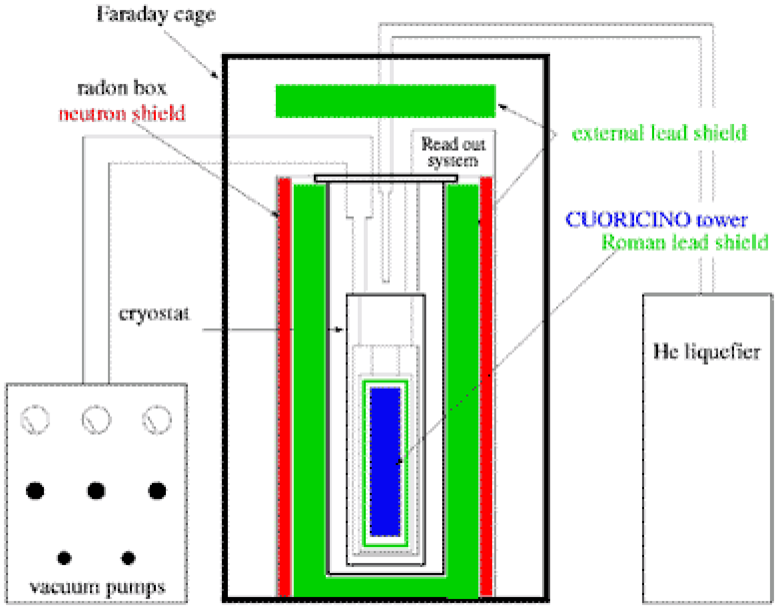
^{128}Te and ^{130}Te

TeO_2 bolometers: M ~ 30kg

OFHC Copper & Teflon

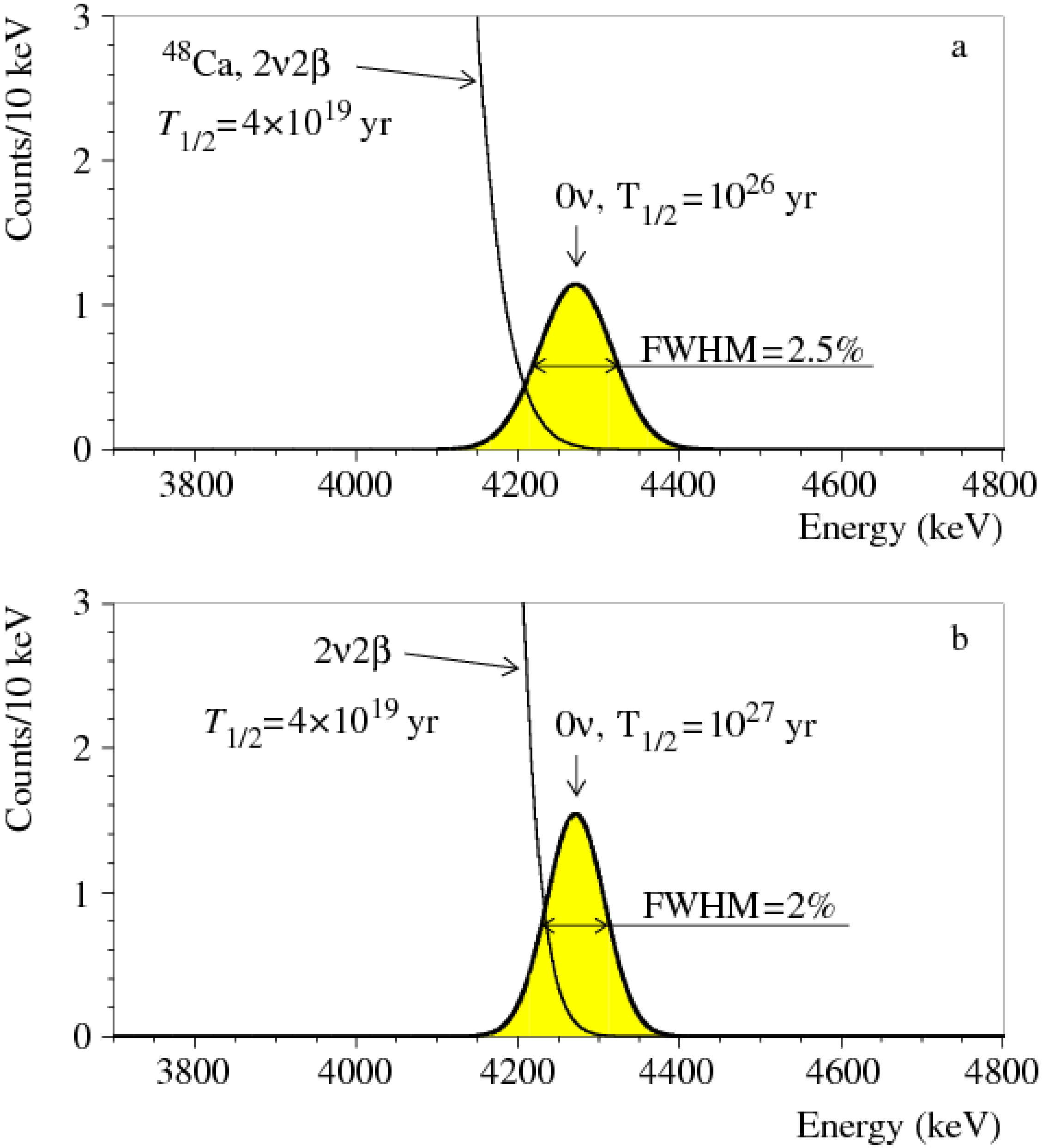
T = 8 mK

b =0,2 cts/(keVkgy)



resolution

^{48}Ca



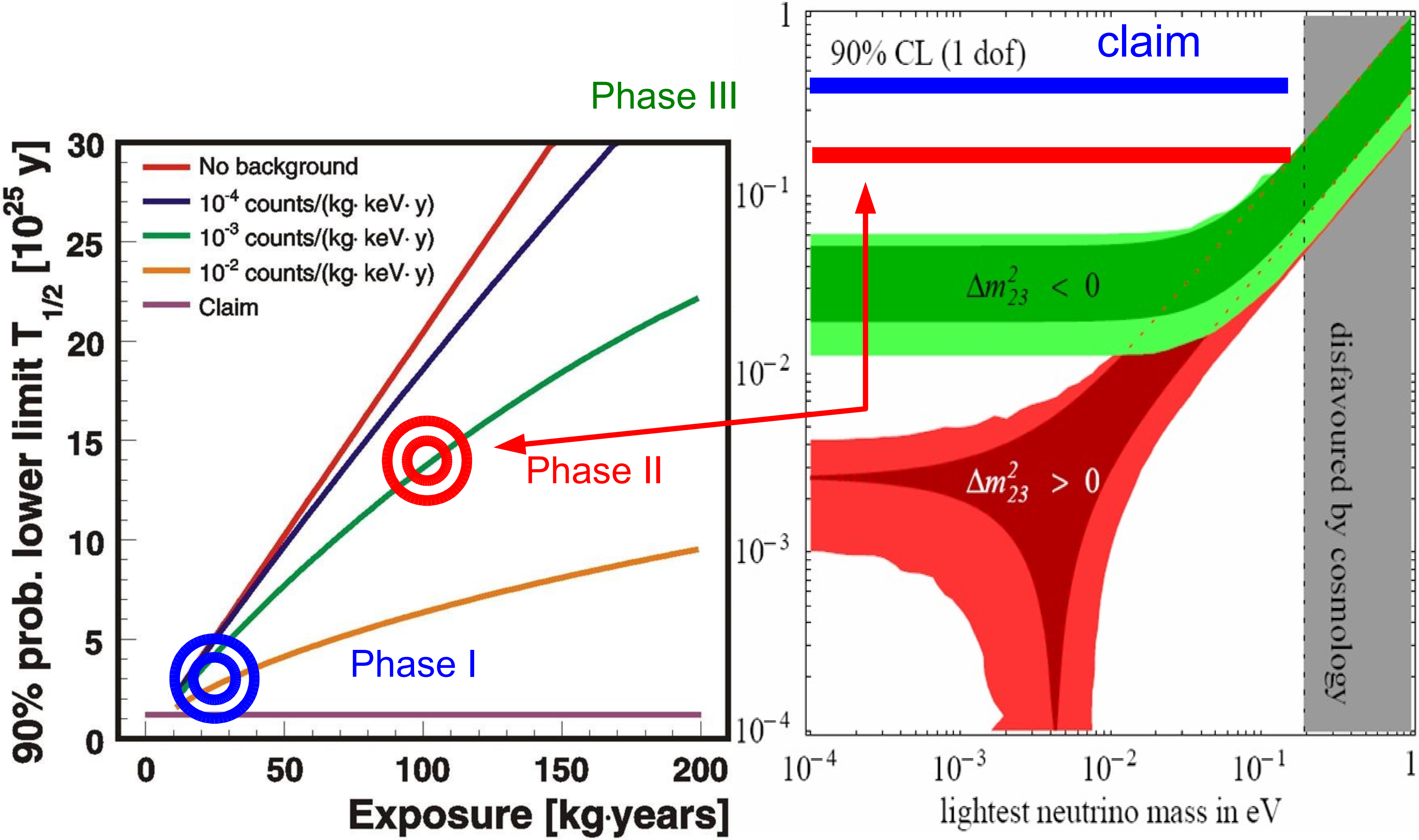
FWHM = 2,5 %

$T_{1/2}$ = 10^{26} yr

FWHM = 2,0 %

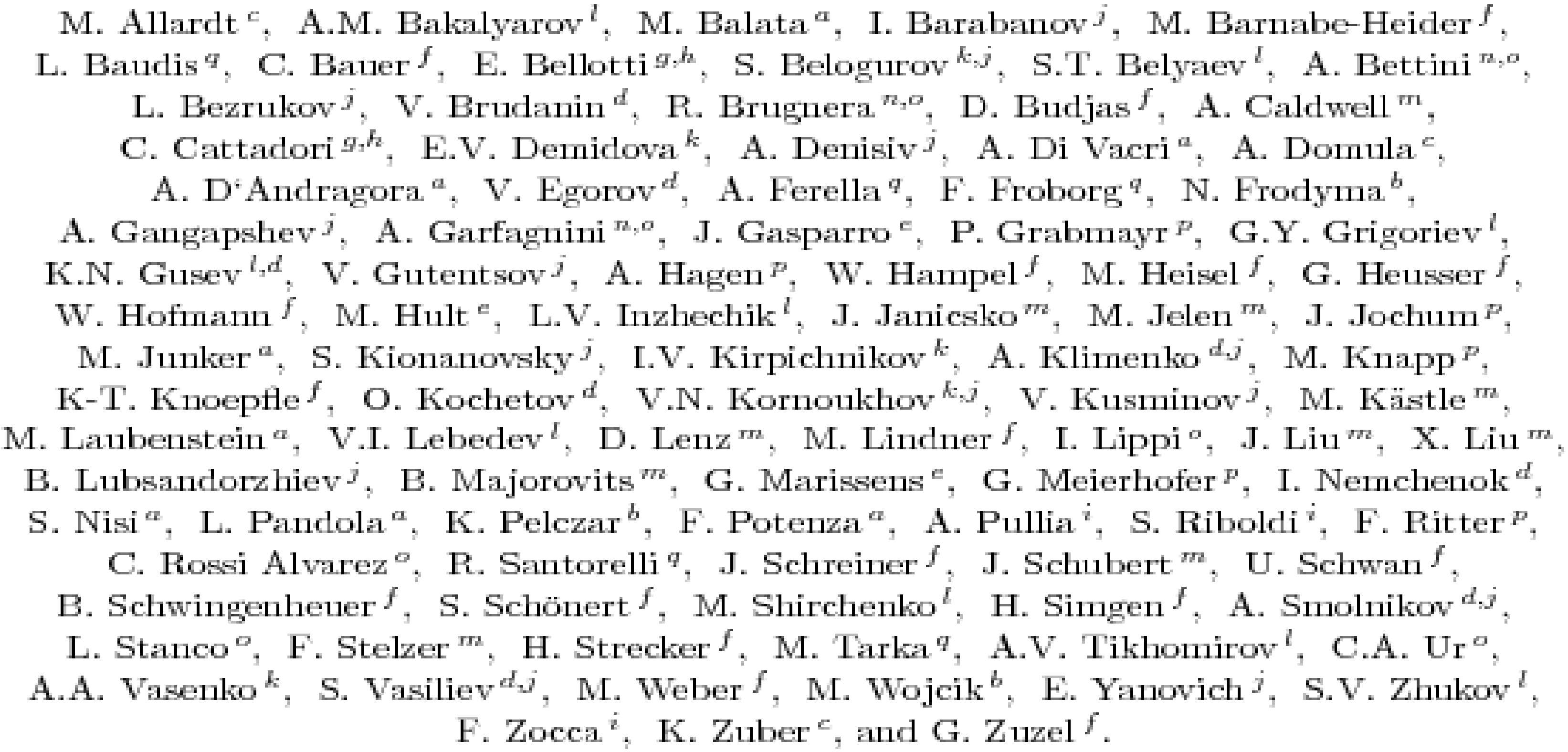
$T_{1/2}$ = 10^{27} yr

sensitivity of GERDA



<M> = 2,4 c.f. NPA 766 (2006) 107

GERDA – the collaboration



M. Allardt[c], A.M. Bakalyarov[l], M. Balata[a], I. Barabanov[j], M. Barnabe-Heider[f],
L. Baudis[q], C. Bauer[f], E. Bellotti[g,h], S. Belogurov[k,j], S.T. Belyaev[l], A. Bettini[n,o],
L. Bezrukov[j], V. Brudanin[d], R. Brugnera[n,o], D. Budjas[f], A. Caldwell[m],
C. Cattadori[g,h], E.V. Demidova[k], A. Denisiv[j], A. Di Vacri[a], A. Domula[c],
A. D'Andragora[a], V. Egorov[d], A. Ferella[q], F. Froborg[q], N. Frodyma[b],
A. Gangapshev[j], A. Garfagnini[n,o], J. Gasparro[e], P. Grabmayr[p], G.Y. Grigoriev[l],
K.N. Gusev[l,d], V. Gutentsov[j], A. Hagen[p], W. Hampel[f], M. Heisel[f], G. Heusser[f],
W. Hofmann[f], M. Hult[e], L.V. Inzhechik[l], J. Janicsko[m], M. Jelen[m], J. Jochum[p],
M. Junker[a], S. Kionanovsky[j], I.V. Kirpichnikov[k], A. Klimenko[d,j], M. Knapp[p],
K-T. Knoepfle[f], O. Kochetov[d], V.N. Kornoukhov[k,j], V. Kusminov[j], M. Kästle[m],
M. Laubenstein[a], V.I. Lebedev[l], D. Lenz[m], M. Lindner[f], I. Lippi[o], J. Liu[m], X. Liu[m],
B. Lubsandorzhiev[j], B. Majorovits[m], G. Marissens[e], G. Meierhofer[p], I. Nemchenok[d],
S. Nisi[a], L. Pandola[a], K. Pelczar[b], F. Potenza[a], A. Pullia[i], S. Riboldi[i], F. Ritter[p],
C. Rossi Alvarez[o], R. Santorelli[q], J. Schreiner[f], J. Schubert[m], U. Schwan[f],
B. Schwingenheuer[f], S. Schönert[f], M. Shirchenko[l], H. Simgen[f], A. Smolnikov[d,j],
L. Stanco[o], F. Stelzer[m], H. Strecker[f], M. Tarka[q], A.V. Tikhomirov[l], C.A. Ur[o],
A.A. Vasenko[k], S. Vasiliev[d,j], M. Weber[f], M. Wojcik[b], E. Yanovich[j], S.V. Zhukov[l],
F. Zocca[i], K. Zuber[c], and G. Zuzel[f].

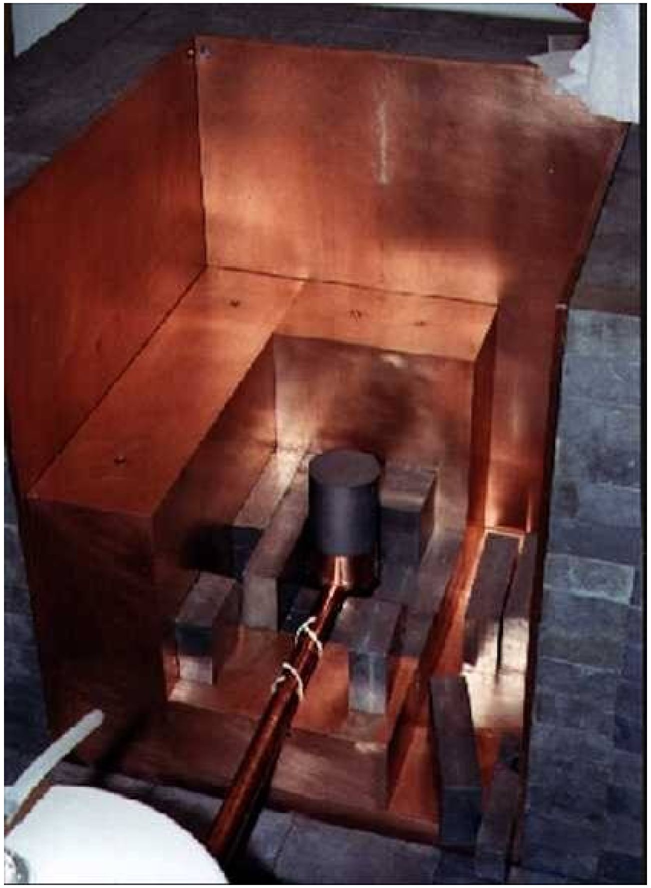
~40 FTE

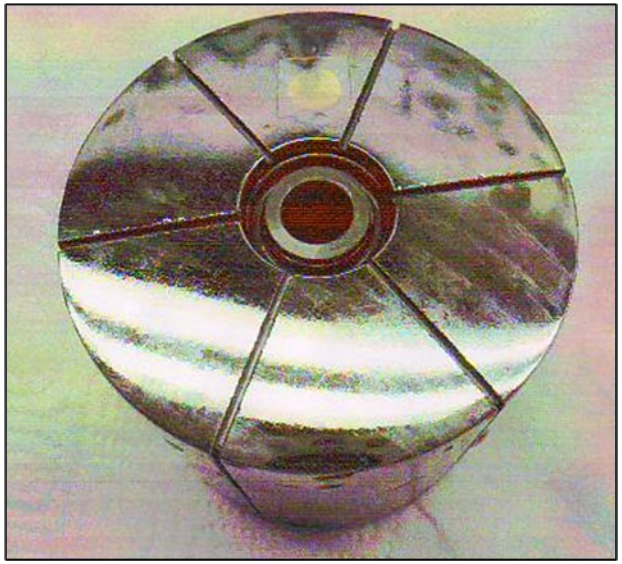
INFN LNGS, JINR Dubna, MPI Kernphysik Heidelberg, Jagellonian U. Cracow, U. Milano-Bicocca, INR Moscow, ITEP Moscow, Kurchatov Institute, MPI Physik München, U. Padova, U. Tübingen, TU Dresden,IRMM Geel, ETH Zurich

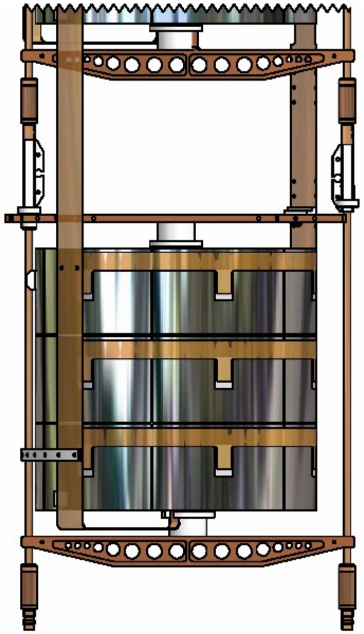
HdM/Majorana vs. GERDA

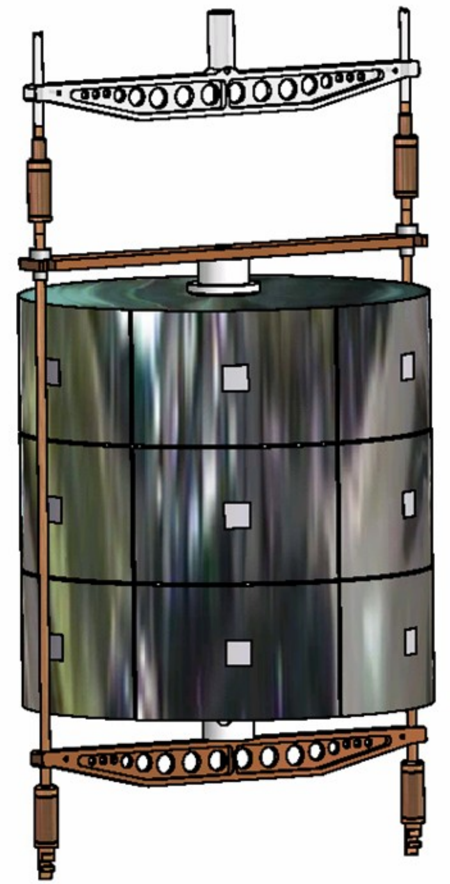
HdM

non-enriched prototype









~ 12 g vs. ~ 2 kg

^{76}Ge experiment GERDA

^{76}Ge: Source == Detector — GERDA:

$Q_{\beta\beta}$ = 2039 keV

large mass of enriched material 7,44% -> ~86%

high energy resolution <4 keV

separate $0\nu\beta\beta$ from $2\nu\beta\beta$

set smaller ROI

low background $<10^{-3}$ cts/(kg·y·keV)

passive : LNGS @ 3800 m.w.e. (reduce μ)

Watertank, LAr (avoid n,cosmogenic)

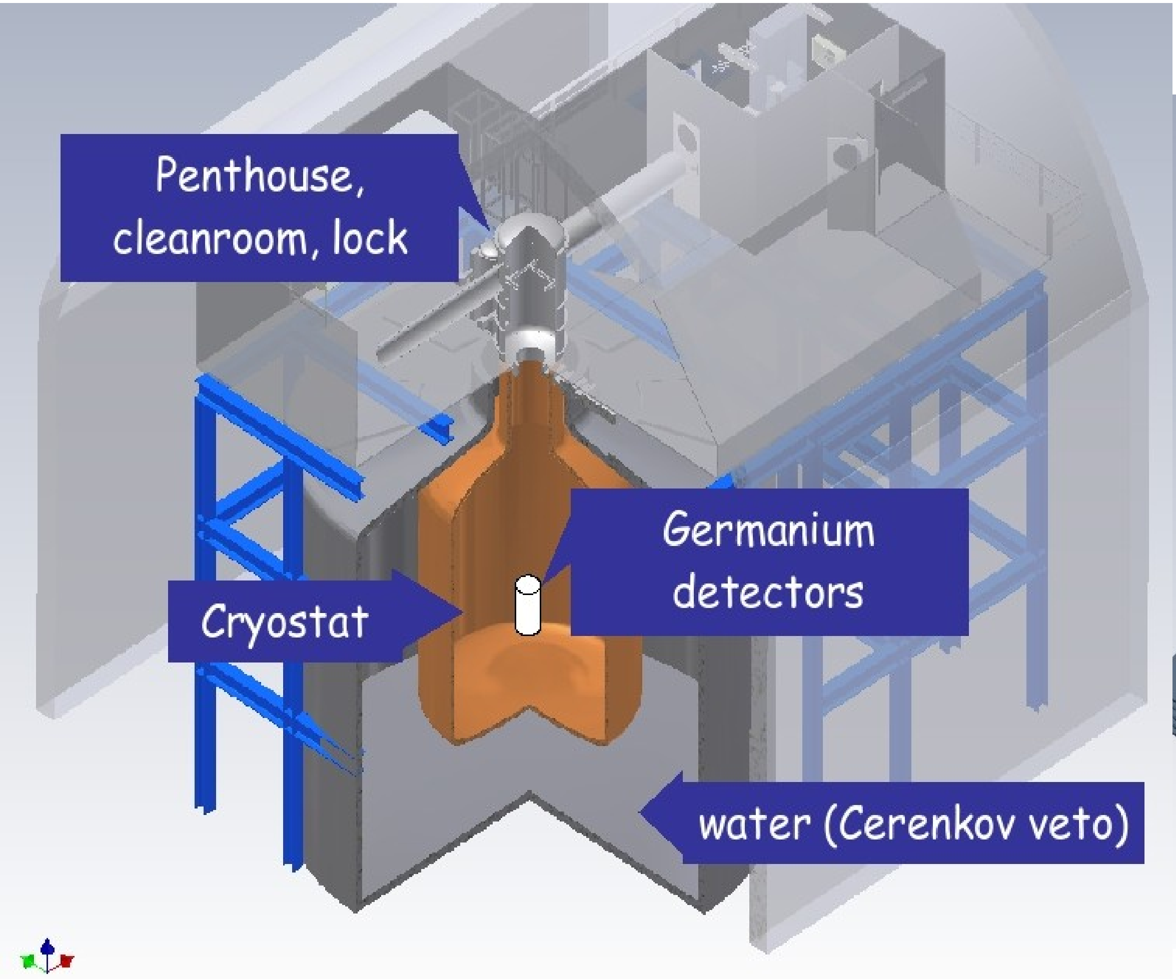
selection of material (reduce Th,U)

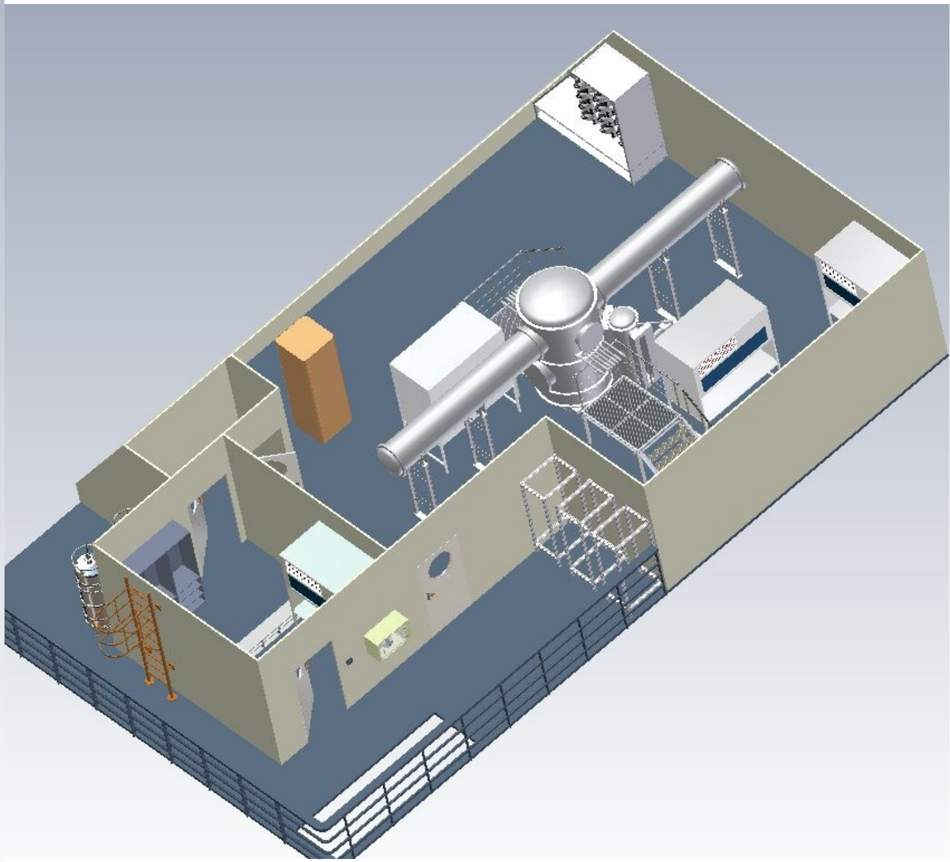
active : Muon veto

segmentation, anti-coincidence

PSA

Super-structure and Watertank



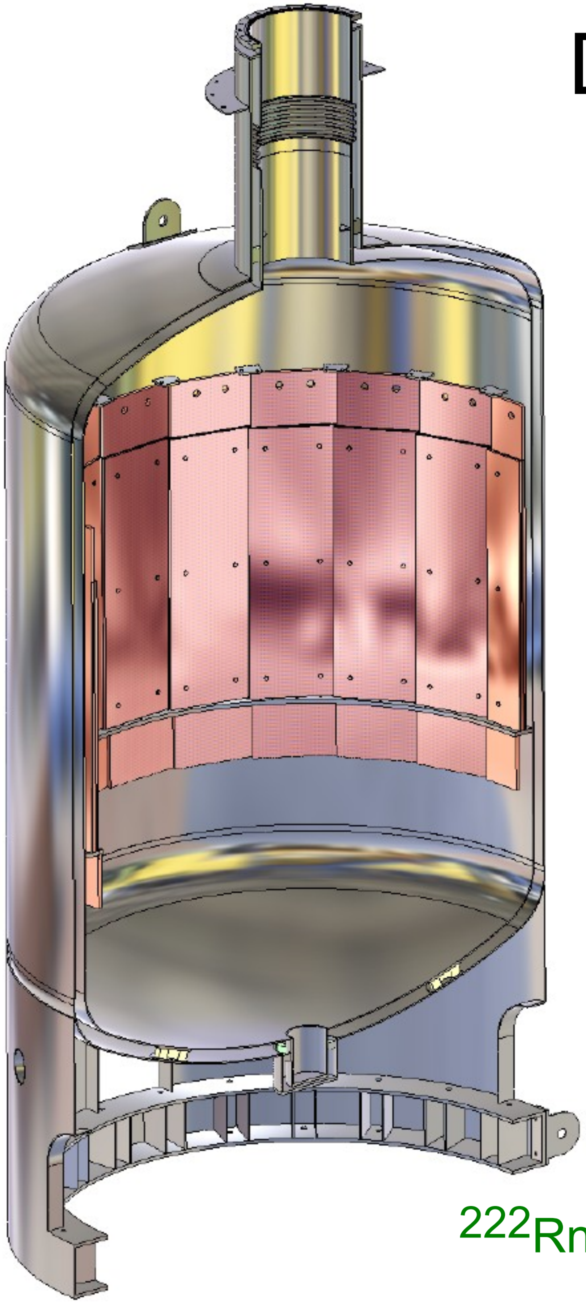


Hall A @ LNGS clean room on top

water tank as active muon veto (66 PMTs)

SS cryostat with copper shield, filled with LAr (~65m^3)

Stainless Steel Cryostat



Double walled SS container

reduce Cu shield from 40 to 16 t

(1t ~ 8000 €)

LN_2 test

evaporation

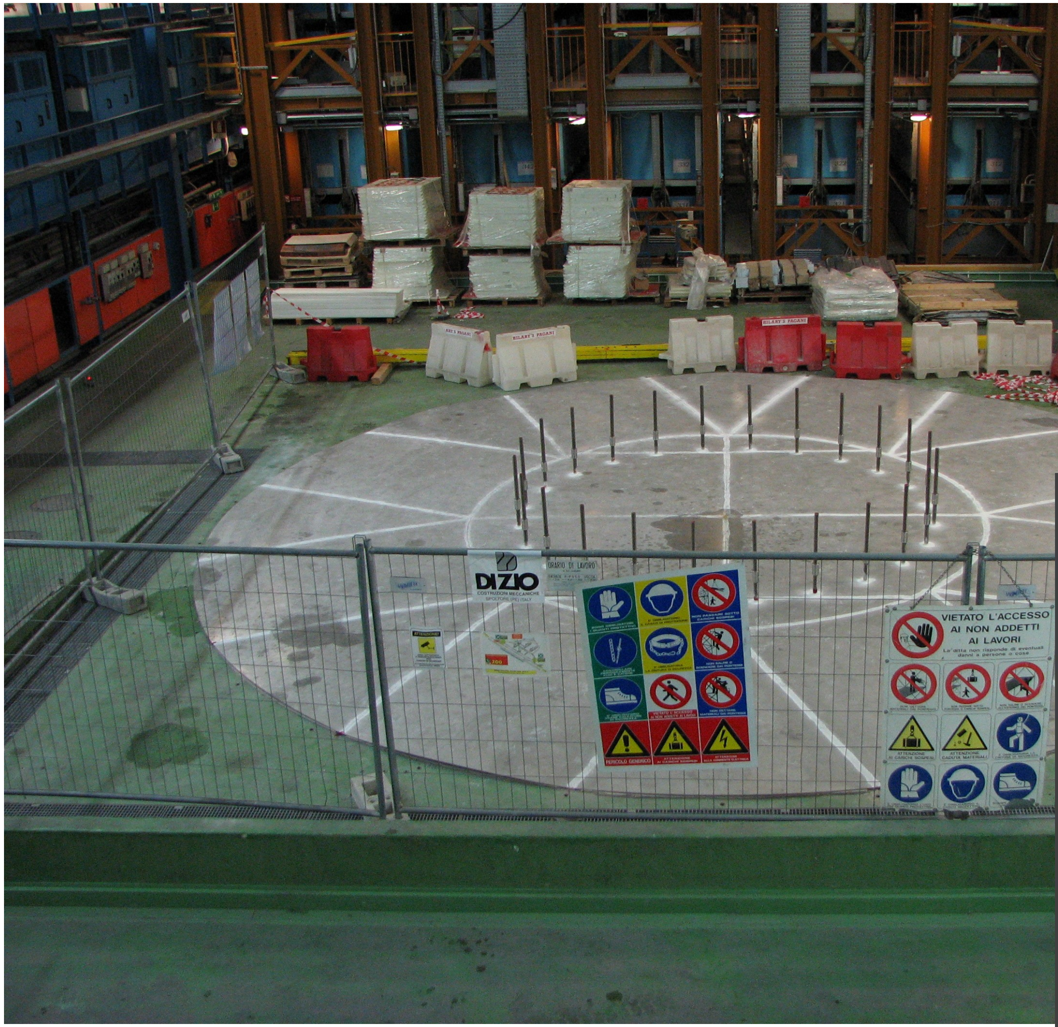
< 4Nm^3/h

300 W

^{222}Rn: 14 → 30 mBq

construction @ LNGS

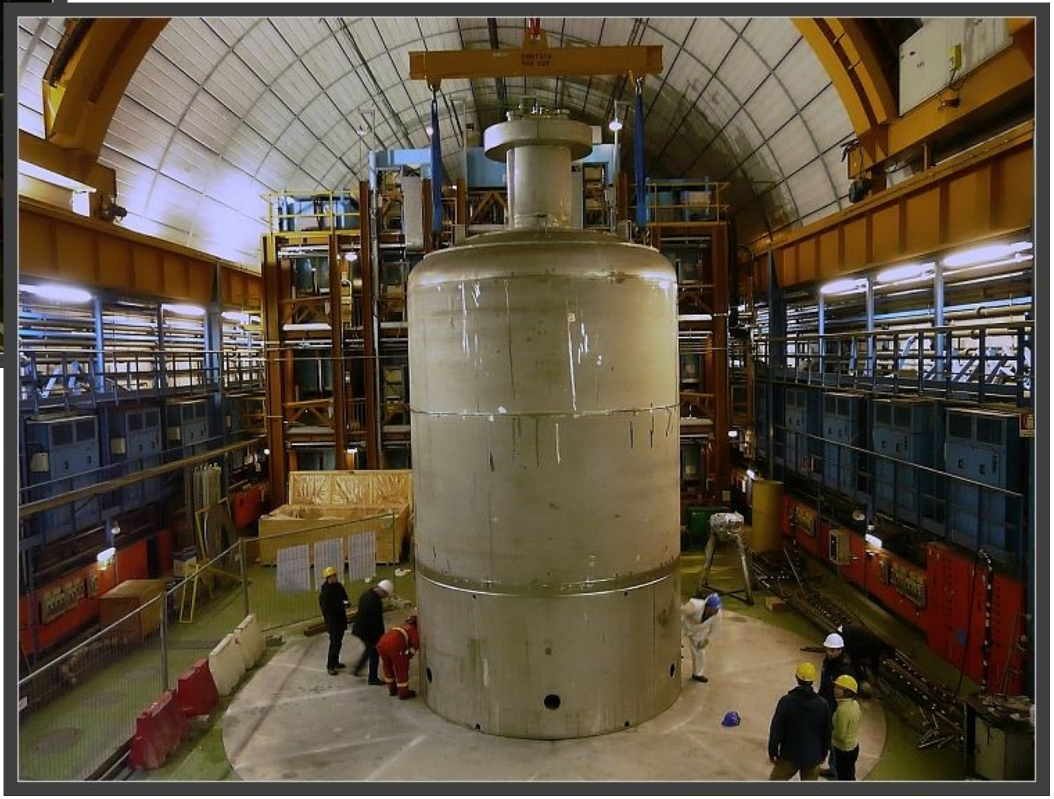
February 2008



March 2008

construction @ LNGS

March 2008



construction @ LNGS

May 2008

construction @ LNGS

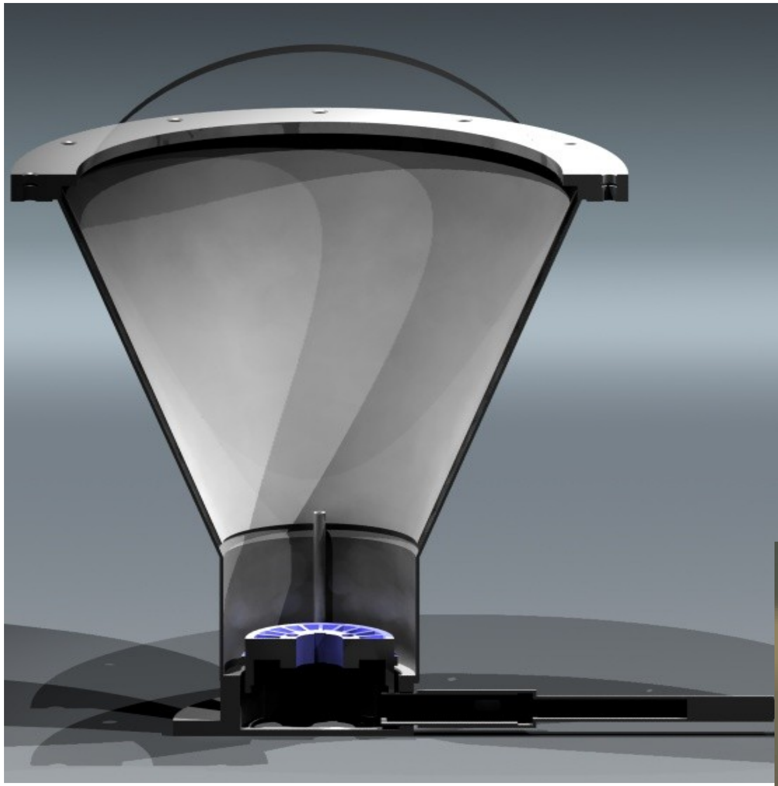
March 2009

Clean room, lock

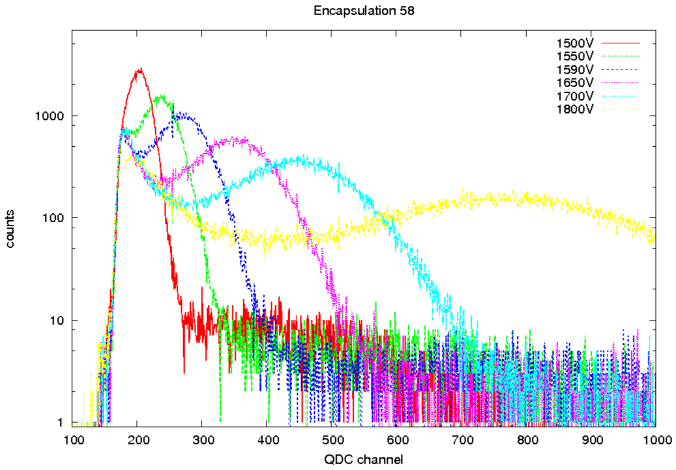
cryogenic
infra structure

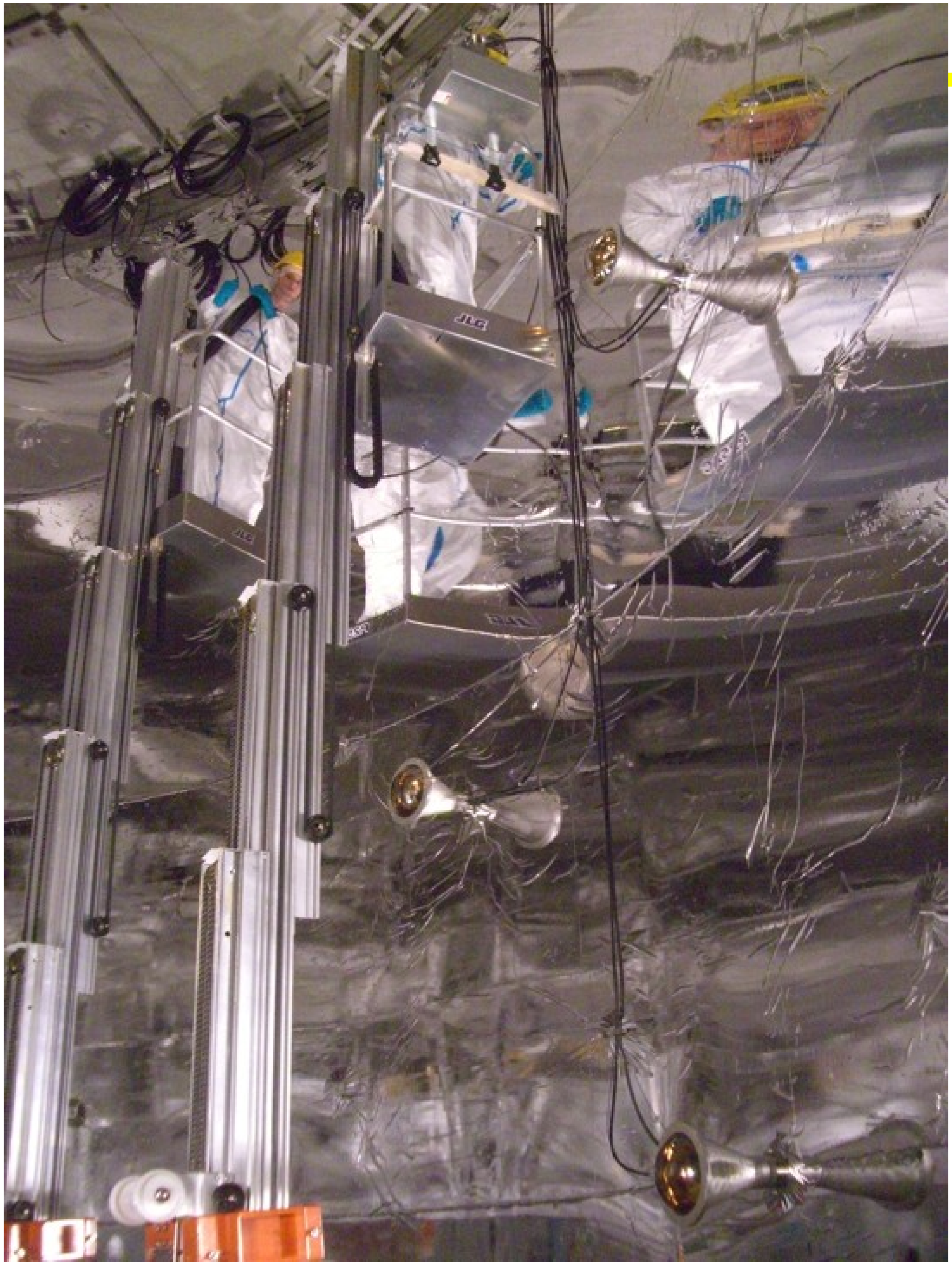
setup of pulley

Cerenkov myon veto in water tank

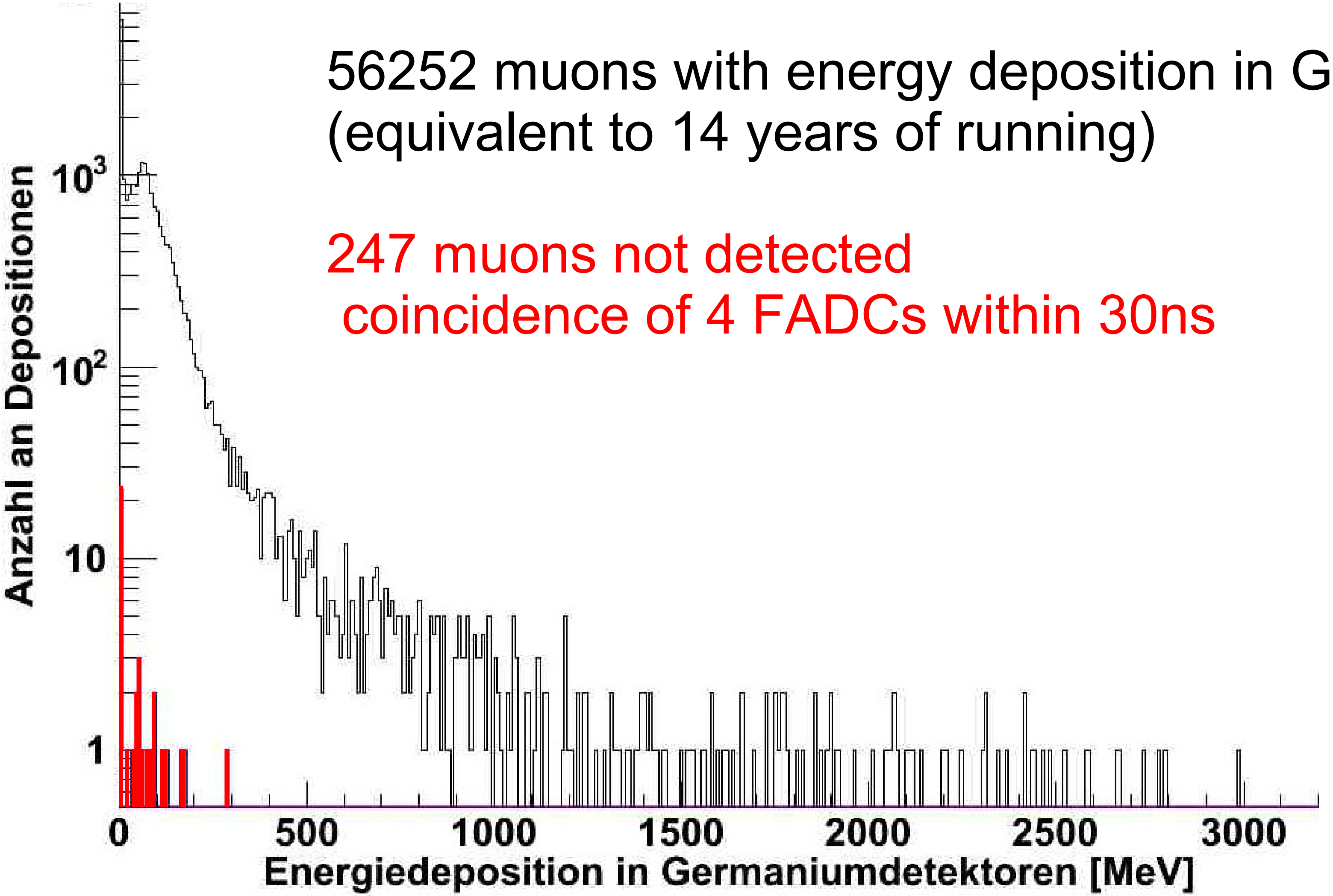


ETL9350





Monte Carlo



56252 muons with energy deposition in Ge
(equivalent to 14 years of running)

247 muons not detected
coincidence of 4 FADCs within 30ns

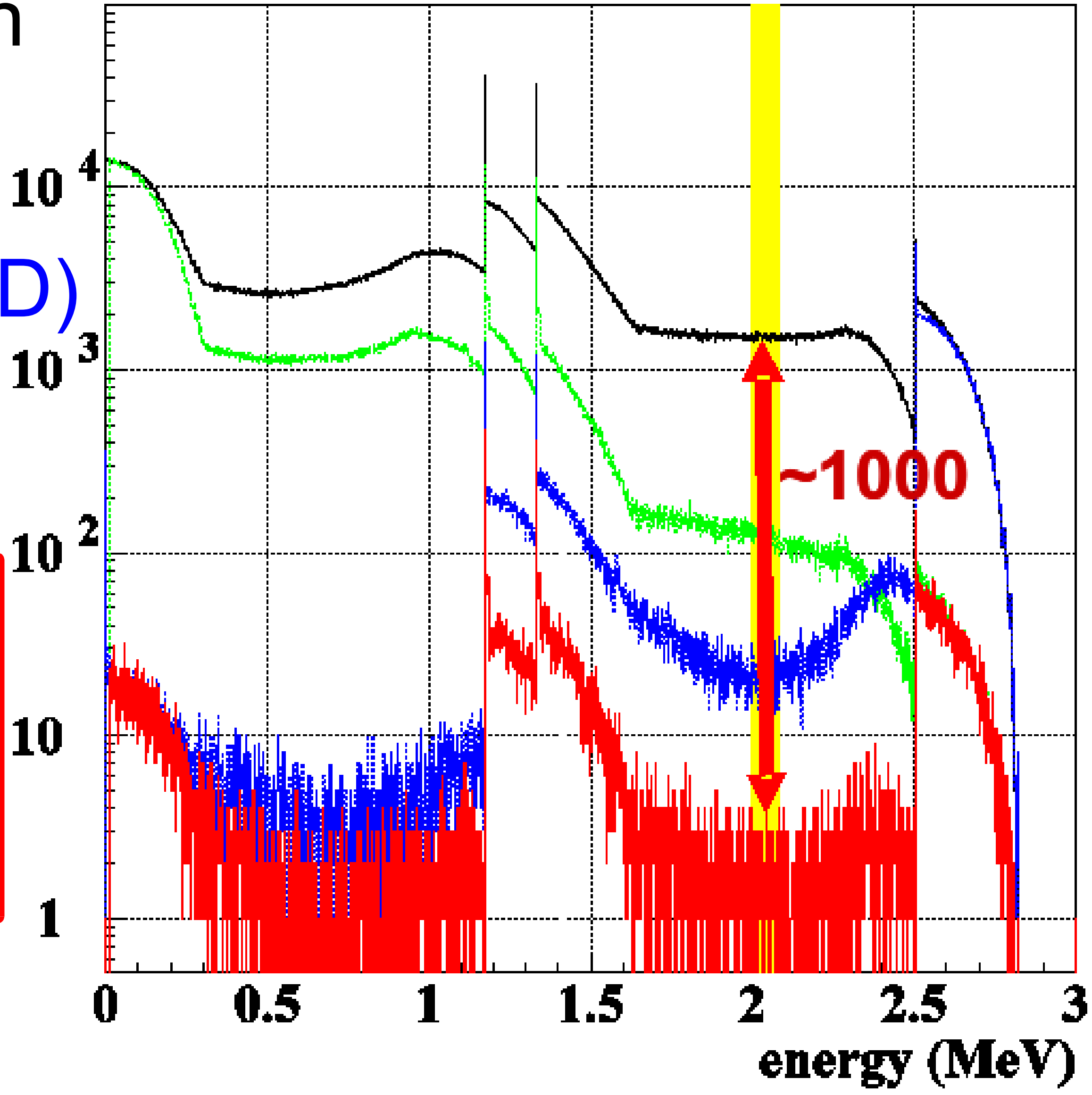
veto through scintillation in LAr

MC simulation of background reduction through segmentation and scintillation in LAr (R&D) and the combination of both methods.

factor 1000

in ROI @ 2039 keV

^{60}Co



neutrino mass

mass and flavor eigenstates of the neutrinos PMNS matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix} \Rightarrow \frac{m_i^2}{2E_\nu} \Rightarrow \begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix}$$

$$U = \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha_1} & 0 \\ 0 & 0 & e^{i\alpha_2} \end{pmatrix}$$

solar

$\sin\theta_{13} \neq 0 \rightarrow$ CPviolation

atmospheric

Majorana

$$U = U_{PMNS} \ \mathrm{diag}(1, e^{i\alpha 1}, e^{i\alpha 2})$$

mass of the neutrino I

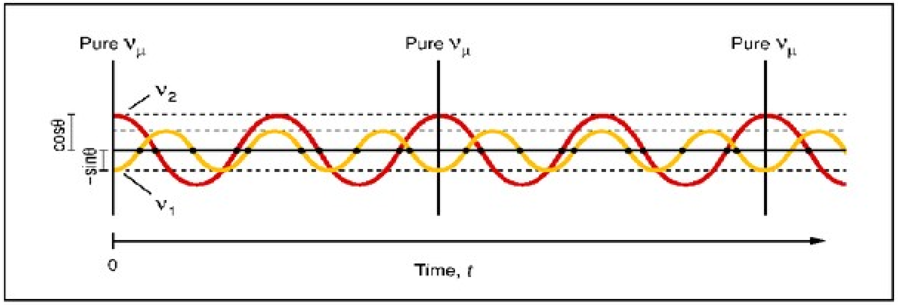
Neutrino oscillations:

mass is finite

(Suzuki, INPC07)

$\Delta m^2_{solar} = 8{,}2\ 10^{-5}\ eV^2$

$\Delta m^2_{atm} = 2{,}7\ 10^{-3}\ eV^2$

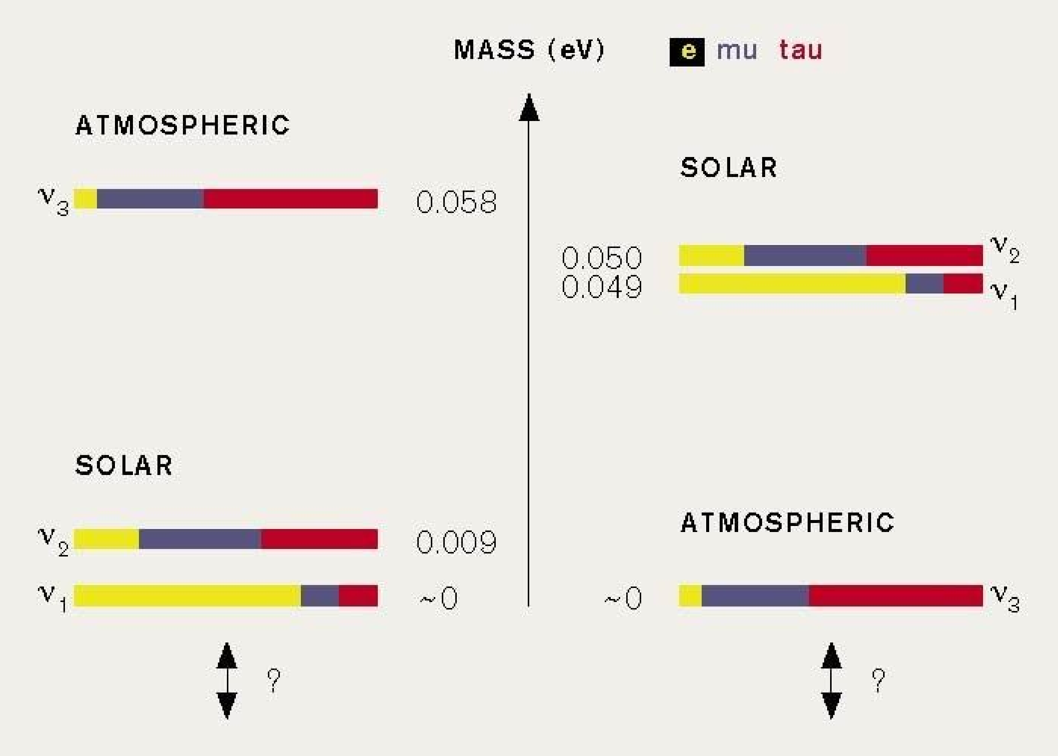


$\Delta m^2_{23} > 0$ normal

$\Delta m^2_{23} < 0$ inverted

still need:

- absolute mass scale
- hierachy



degenerate

hierarchy and limits

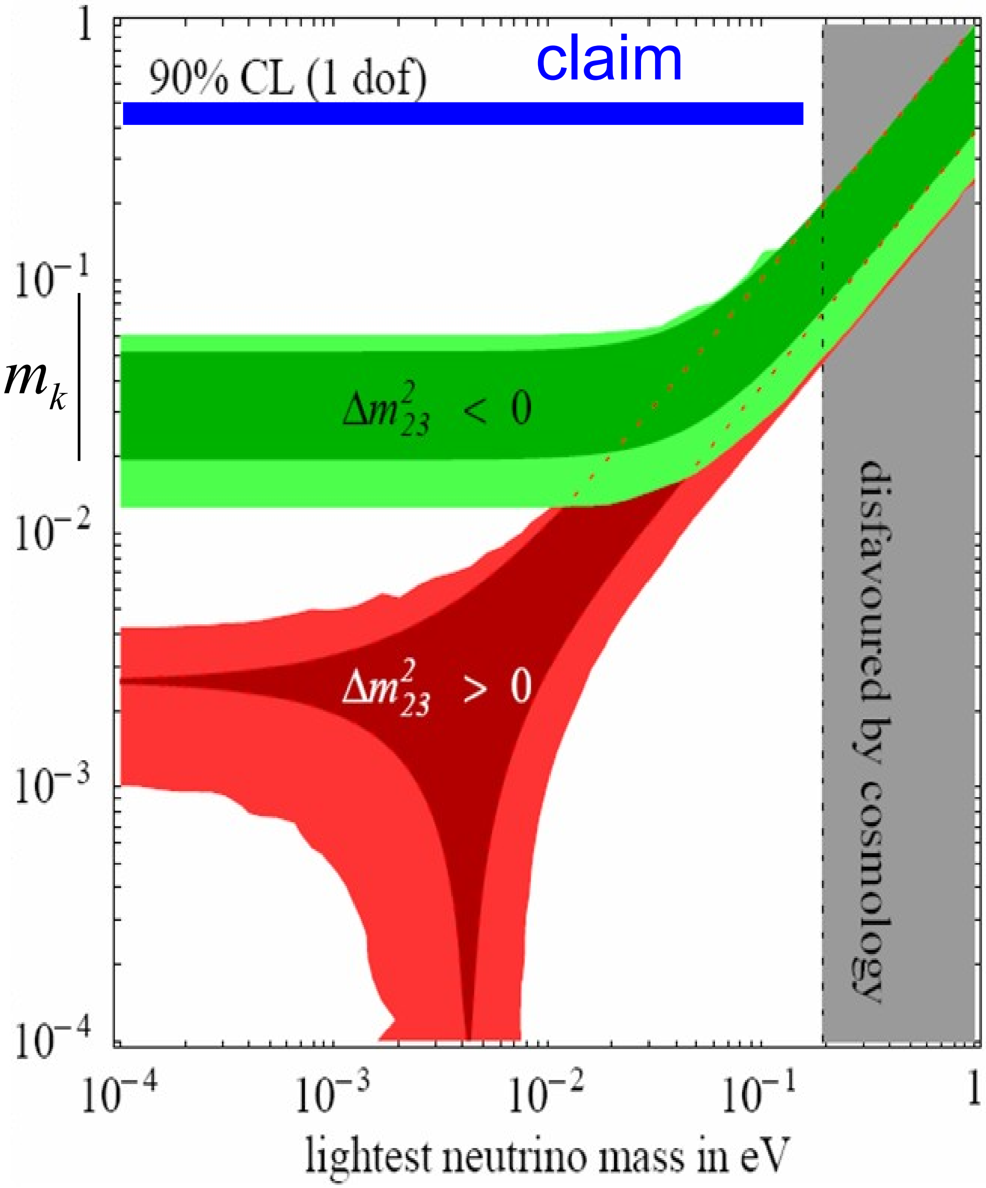
Tritium β decay : < 2,2 eV
Cosmology : < 1,0 eV
ββ decay : < 0,4 eV

$$\langle m_\nu \rangle \equiv m_{ee} = \left| \sum_k U_{ek}^2 m_k \right| = \left| \sum_k |U_{ek}|^2 e^{i\alpha_{ek}} m_k \right|$$

PMNS - Matrix

ββ decay likely to give the most stringent limit on mass

β decay : $m_\nu = \sum_k |U_{ek}|^2 m_k$



history

1934: E. Fermi theory of weak interaction

1935: M. Goeppert-Mayer discussed $2\nu\beta\beta$

1938: E. Majorana two component neutrino

1939: W.H. Furry discussed $0\nu\beta\beta$

1949: First half-life limits (Fireman, Fremlin,...)

1967: First geochemical evidence for $2\nu\beta\beta$

1987: First laboratory evidence for $2\nu\beta\beta$

200x: First laboratory evidence for $0\nu\beta\beta$???

2009: commissioning of GERDA