Status of current and future neutrinoless double-beta decay experiments

Frédéric Perrot
CENBG / IN2P3 / Bordeaux University

Workshop “Shell Model as a Unified View of Nuclear Structure”

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Plan

- Neutrino physics and double beta decay process
- General considerations in order to built a double beta decay experiment
- Status of some current/future double beta decay experiments
- Summary and outlook

Neutrino physics and double beta decay process

Neutrino Physics

What is known:

- 3 flavors of neutrinos ν_e, ν_μ, ν_τ that can oscillate from one to another family ($\nu_e \leftrightarrow \nu_\mu$, $\nu_\mu \leftrightarrow \nu_\tau$ …)

→ mixture between the flavor and the mass eigenstate of neutrinos

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

PMNS matrix

- Since the end of 90's: precision measurements of mixing angles θ_{12}, θ_{23} and square mass difference Δm^2 (SuperKamiokande, KamLAND, SNO,…)
- Recently: first measurement of θ_{13}=8.8° (Daya-Bay, 2012)
- Oscillations prove a non-zero mass for neutrinos

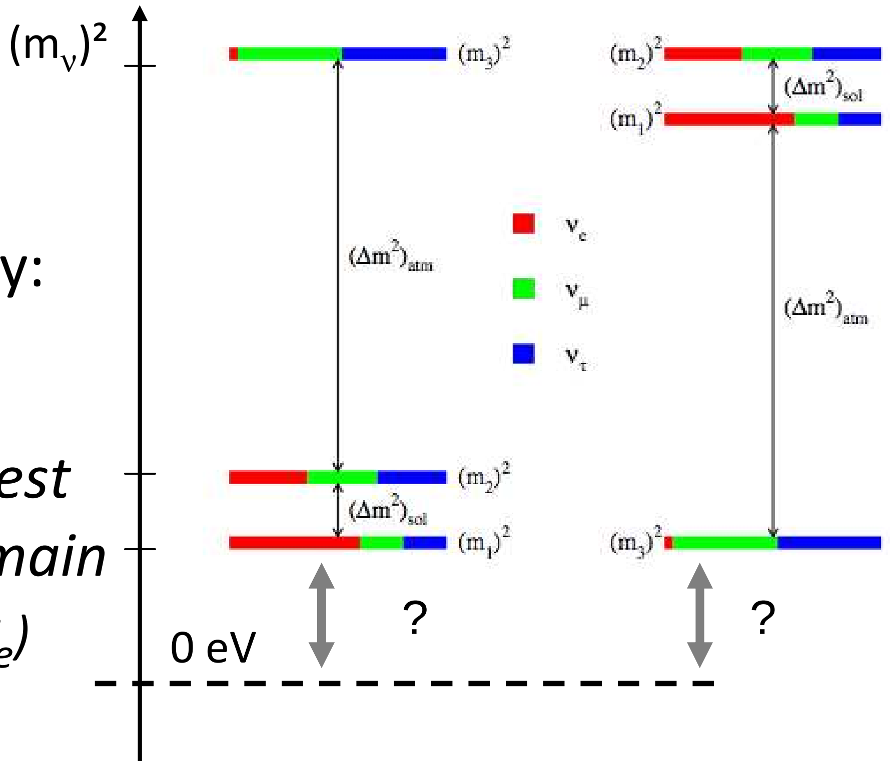
Neutrino Physics

What is still not solved:

- Nature of neutrinos: Dirac ($\nu \neq \bar{\nu}$) or Majorana ($\nu = \bar{\nu}$) ?
- Absolute neutrino mass scale ?

Normal hierarchy:
$m_1 < m_2 < m_3$

(i.e. that the lightest neutrino m_1 is the main component of ν_e)

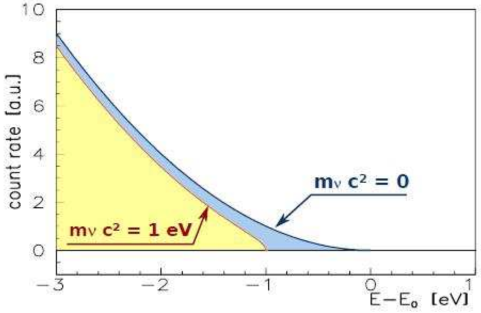


Inverted hierarchy:
$m_3 < m_1 < m_2$

Neutrino Mass Constraints

- Beta decay end-point of ^{3}H:

$$m_\beta = m_{\bar{\nu}_e} = \sqrt{\sum_j m_j^2 U_{ej}^2} < 2.2\ eV$$



KATRIN experiment
goal: < 0.2 eV

- Cosmological constraints on the sum of the neutrino mass eigenstates:

$$\Sigma = \sum_j m_{\nu_j} < 0.44 - 0.76\ eV$$

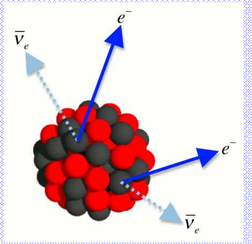
- Neutrinoless double beta decay process sensitive to the effective neutrino mass

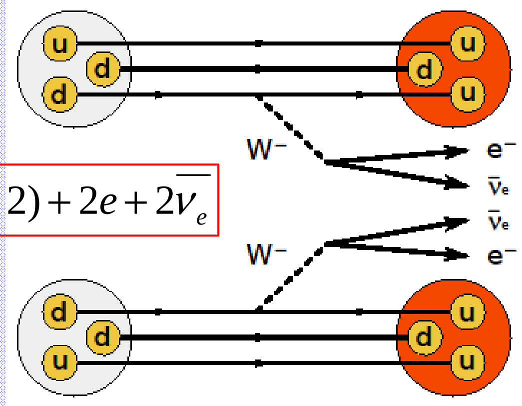
$$< m_{\beta\beta} > = \left| \sum_j m_j U_{ej}^2 \right| = m_1 \left| U_{e1} \right|^2 + m_2 \left| U_{e2} \right|^2 e^{i\phi_1} + m_3 \left| U_{e3} \right|^2 e^{i\phi_2}$$

ϕ_1, ϕ_2: Majorana
phases

Double beta decay: 2νββ and 0νββ

2νββ process

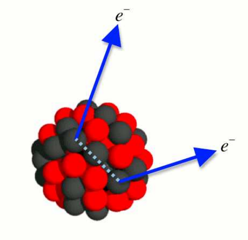


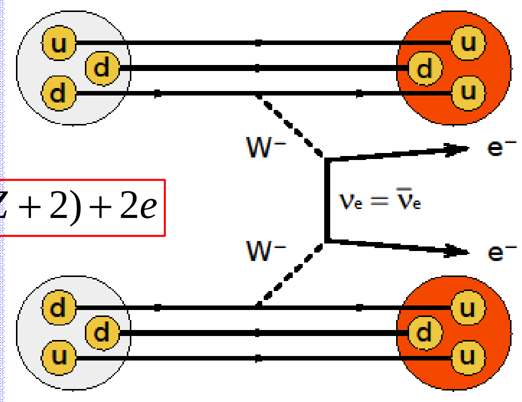


$$(A,Z)\rightarrow(A,Z+2)+2e+2\overline{\nu}_e$$

- Emission of 2 electrons and 2 anti-neutrinos
- ΔL=0: conservation of the leptonic number
- Process allowed by the Standard Model
- $T_{1/2}$ measured at 10^{18} – 10^{22} yr

0νββ process





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

- Emission of 2 electrons only
- ΔL=2: non-conservation of the leptonic number
- Process forbidden by the Standard Model
- $T_{1/2}$ expected > 10^{25} yr

Double beta decay: 2νββ and 0νββ

2νββ process

$$\frac{1}{T_{1/2}^{2\nu}} = G_{2\nu}(Q_{\beta\beta}^{11}, Z)\times\left|M_{2\nu}\right|^2$$

- $G_{2\nu}$: phase space factor (well-known)
- $M_{2\nu}$: nuclear matrix element

Measurement of $T_{1/2}(2\nu)$:

a direct access to the nuclear structure

Recent result for ^{136}Xe 2νββ decay (2011):

- Exp: $M_{2\nu}$ (^{136}Xe) =0.19(2) MeV^{-1} (EXO-200)

- Shell Model: $M_{2\nu}$(^{136}Xe) =0.25 MeV^{-1}

E. Caurier, F. Nowacki, A. Poves, Phys. Lett. B711, 2012

0νββ process

$$\frac{1}{T_{1/2}^{0\nu}} = G_{0\nu}(Q_{\beta\beta}^{5}, Z)\times\left|M_{0\nu}\right|^2\times\boxed{< m_{\beta\beta} >^2}$$

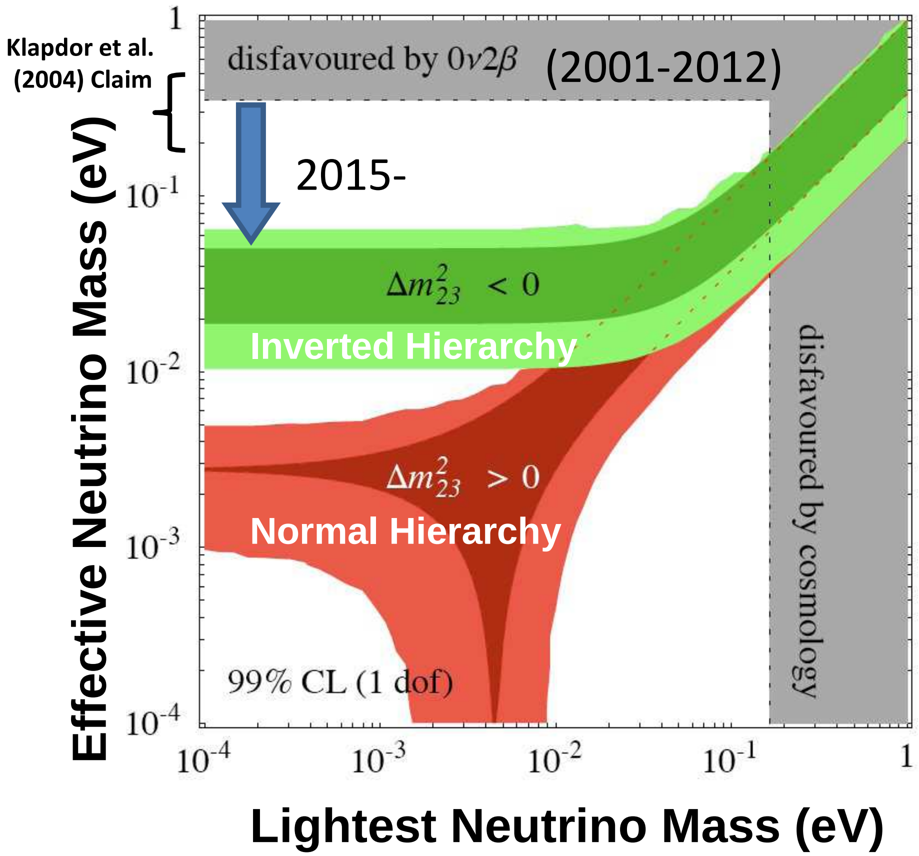
- $G_{0\nu}$: phase space factor (well-known)
- $M_{0\nu}$: nuclear matrix element
- $<m_{\beta\beta}>$: effective neutrino mass

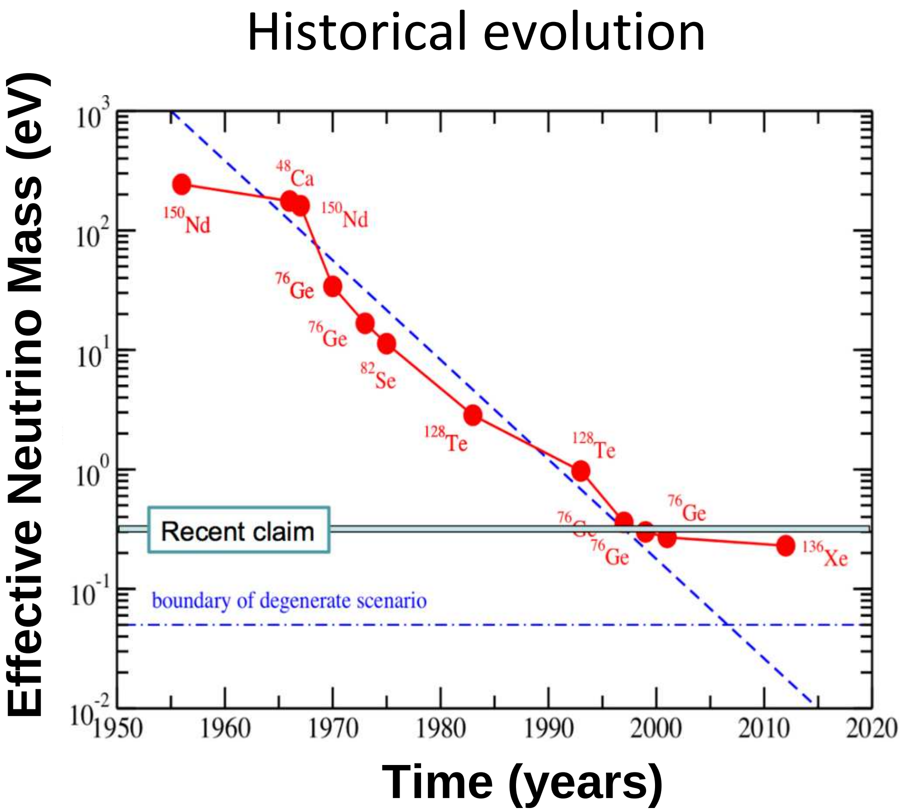
Measurement of $T_{1/2}(0\nu)$:

a direct access to the effective neutrino mass!

But need to know NME precisely…

0νββ process and neutrino mass



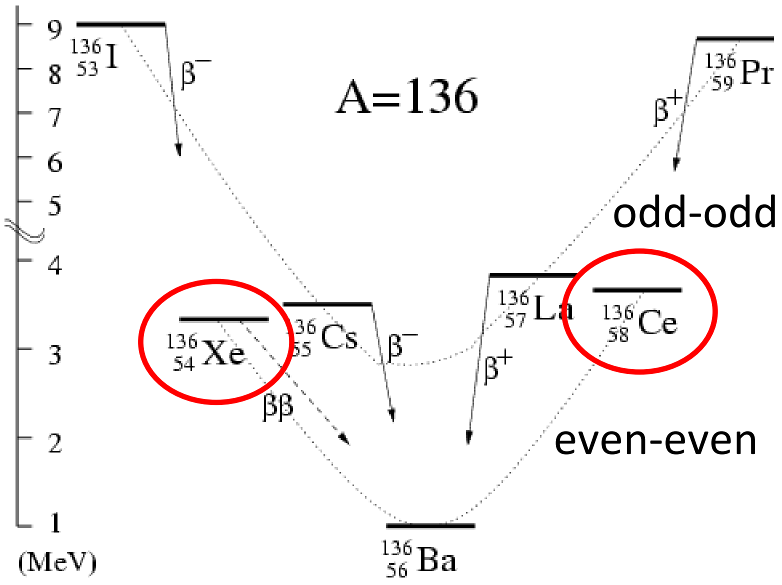


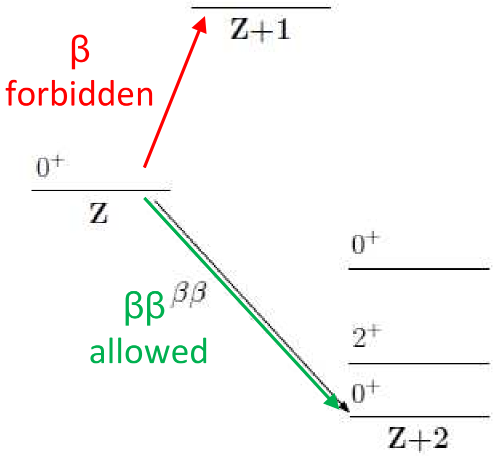
If neutrino is a Majorana particle, 0νββ process will test soon the inverse hierarchy of the neutrino mass

General considerations in order to built a double beta experiment

Origin of the double beta decay process

Example of the isobaric chain A=136





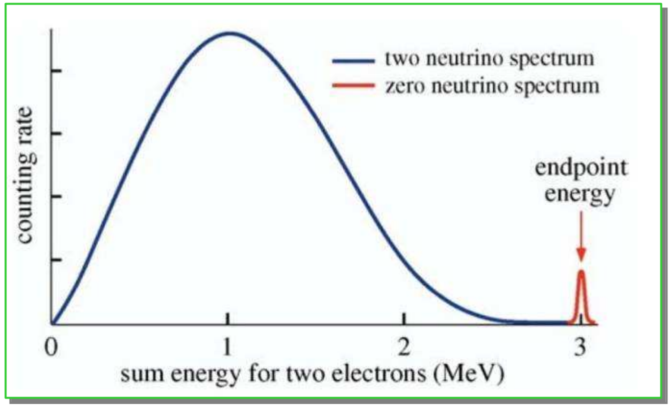
- Pairing interaction between nucleons (even-even nuclei more bound)
- ^{136}Xe and ^{136}Ce are stable against β decay but unstable against ββ decay ($\beta^-\beta^-$ for ^{136}Xe and $\beta^+\beta^+$ for ^{136}Ce)

There are 35 $\beta^-\beta^-$ and 6 $\beta^+\beta^+$ emitters in the nature

0νββ observables

$$^{136}_{54}Xe \rightarrow ^{136}_{56}Cs + 2e^-$$

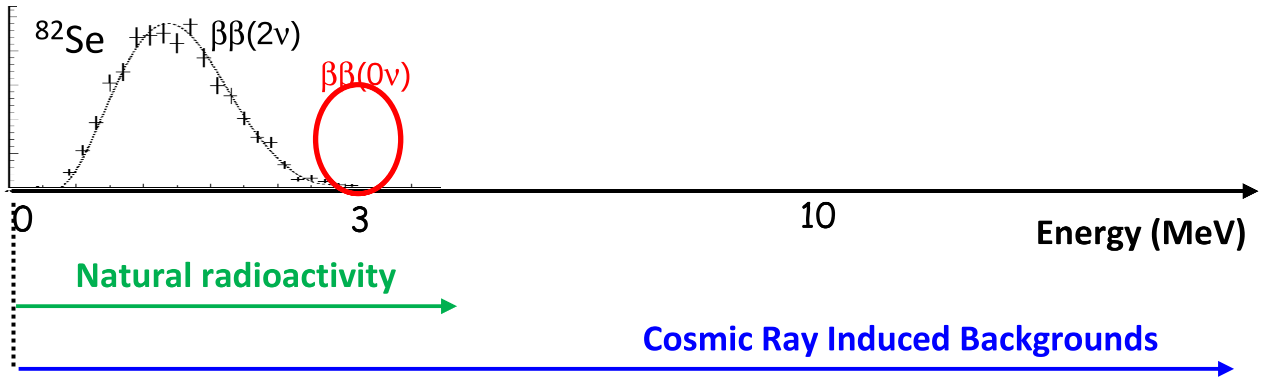
- Energy sum of the 2 electrons for 0νββ process → Peak at $Q_{\beta\beta}$



- Angular distribution of the 2 electrons
- Gamma emission in case of ββ decay in excited states
- Identification of daughter nucleus

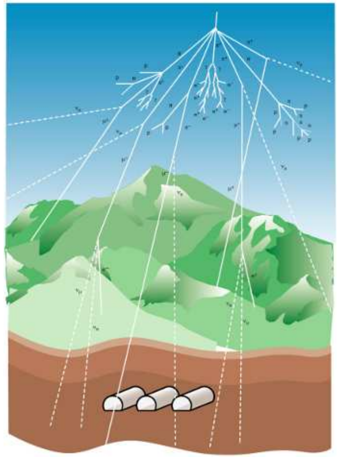
Question of background

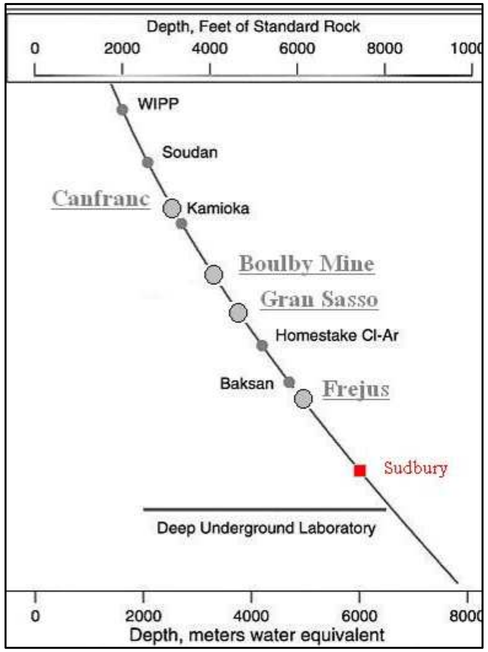
Sources of background in the $0\nu\beta\beta$ energy window



Natural radioactivity

Cosmic Ray Induced Backgrounds

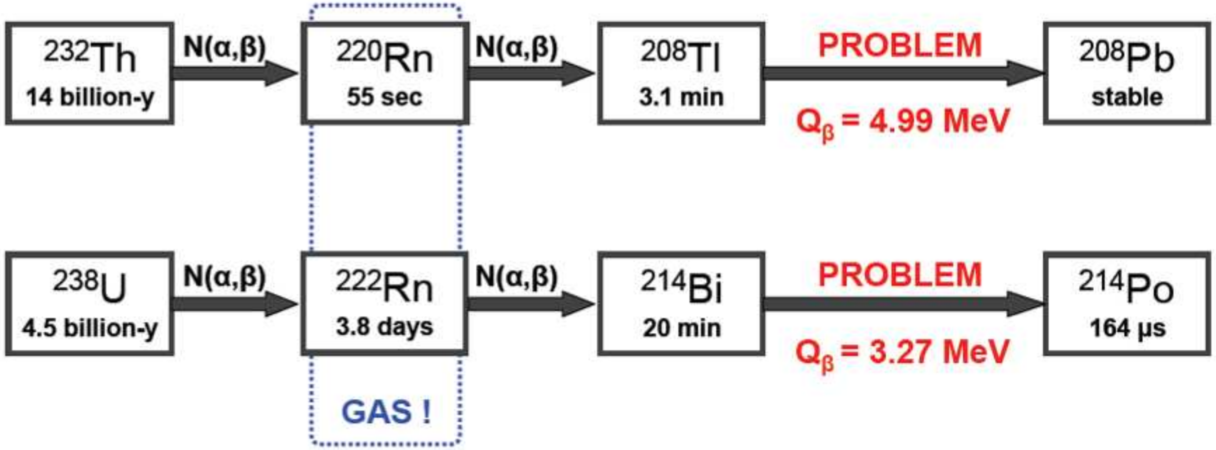




- Cosmic rays: necessity to be in an underground laboratory
- Natural radioactivity (radioactive chains from ^{238}U and ^{232}Th) : necessity to select the materials
- Background from the $2\nu\beta\beta$ decay itself: good energy resolution and isotope choice

Natural radioactivity

Main background: ^{232}Th and ^{238}U natural radioactive chains



What to do against?

- To purify the ββ sources
- To control the radiopurity of the surrounding materials
- To prevent Radon diffusion from outside using efficient barriers or traps
- To use tagging/identification techniques to distinguish between α, β and γ and single site (SS) or multiple sites (MS)

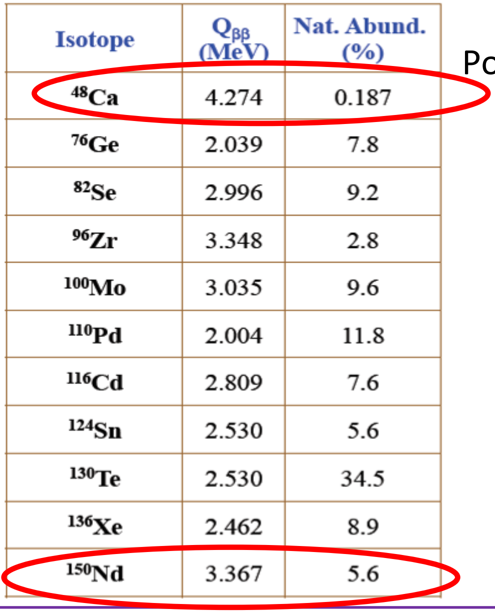
Isotope choice

« Theoritical » requirements:

- Favoured nuclear matrix element
- High phase space factor

Experimental requirements:

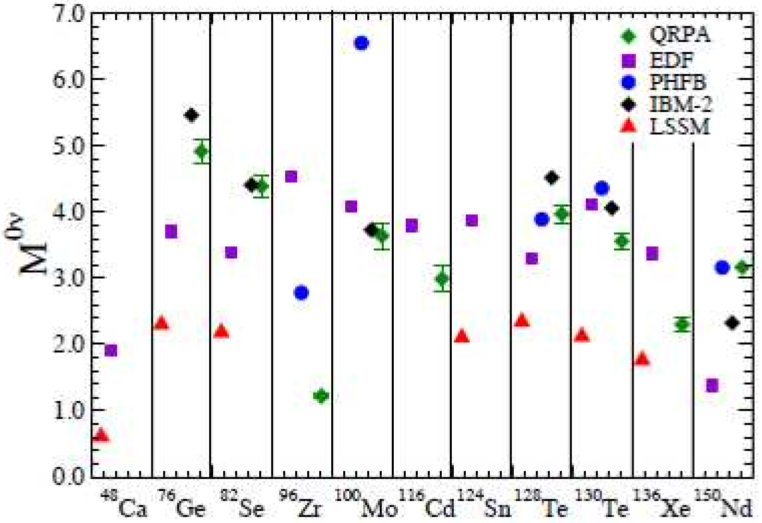
- High $Q_{\beta\beta}$ value (background)
- Reasonable abundance (mass)



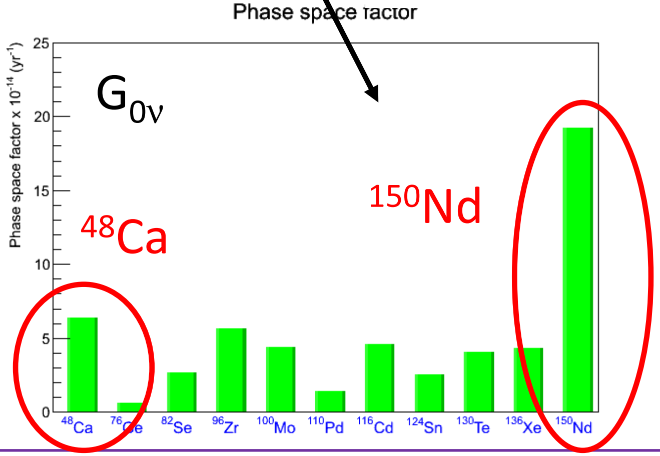
Isotope	$Q_{\beta\beta}$ (MeV)	Nat. Abund. (%)
^{48}Ca	4.274	0.187
^{76}Ge	2.039	7.8
^{82}Se	2.996	9.2
^{96}Zr	3.348	2.8
^{100}Mo	3.035	9.6
^{110}Pd	2.004	11.8
^{116}Cd	2.809	7.6
^{124}Sn	2.530	5.6
^{130}Te	2.530	34.5
^{136}Xe	2.462	8.9
^{150}Nd	3.367	5.6

Poor abundance

Improvement of NME calculations: differ only by a factor 2-3



Bilenky, Giunti: arXiv:1203.5250v2



How to build a 0νββ experiment

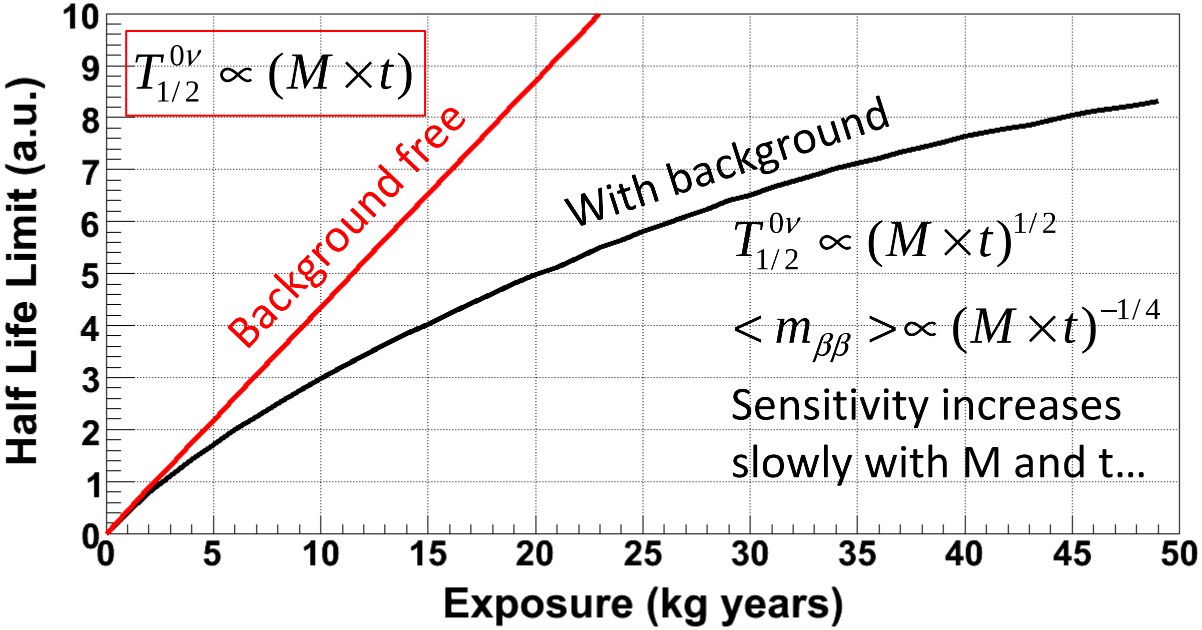
Maximise efficiency (ε) and isotope abundance (a)

Maximise exposure=mass(M) x time (t)

$$T_{1/2}^{0\nu}(90\%\ C.L.) = 2.54\times10^{26}\, y \left(\frac{\varepsilon\times a}{W}\right)\sqrt{\frac{M\times t}{b\times\Delta E}}$$

W: atomic weight

Minimise background (b) and energy resolution (ΔE)



$$T_{1/2}^{0\nu} \propto (M\times t)$$

$$T_{1/2}^{0\nu} \propto (M\times t)^{1/2}$$

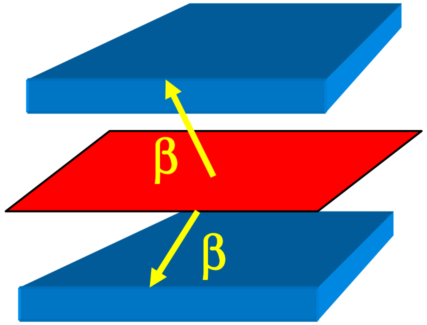
$$< m_{\beta\beta} > \propto (M\times t)^{-1/4}$$

Sensitivity increases slowly with M and t…

Experimental approach

Tracko-calo

Source ≠ Detector



Advantages:

- Full event topology information
- Clear signature of 0νββ event
- Can probe different mechanisms
- Isotope flexibility

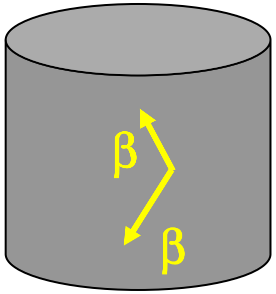
Elements of both

Gazeous Xe TPC

Pixelated CdZnTe

Calorimeter

Source = Detector



Advantages:

- High energy resolution
- High efficiency
- Compact

Techniques:

- Semiconductor
- Bolometer
- Scintillator

Current and future experiments

Tracker

Tracko-calo
N_{Bckg} , isotopes
^{82}Se (^{150}Nd,^{48}Ca)
→ **SuperNEMO**

Pixellized CdZnTe
ε, N_{Bckd}
^{116}Cd
→ **COBRA**

TPC
ε, N_{Bckd}
^{136}Xe, ^{150}Nd
→ **MTD**
EXO-gas
NEXT

Calorimeter

Ge diode
ε, ΔE
^{76}Ge
→ **GERDA**
MAJORANA

Bolometers
ε, ΛE
^{130}Te,^{82}Se,^{100}Mo
→ **CUORE**
LUCIFER
ZnMo4

Liquid Xe
ε,M,(N_{bckd})
^{136}Xe
→ **EXO**

Scintillator
ε, M
^{136}Xe, ,^{48}Ca,
^{150}Nd, ^{100}Mo
→ **KamLAND-Zen**
CANDLES
SNO+
Borexino
CdWO4
AMoRE

Experiments in the world

Status of some current/future 0νββ experiments

Tracko-calo experiments:

NEMO3-SuperNEMO (^{100}Mo, ^{82}Se and others)

NEXT: optical gazeous TPC (^{136}Xe)

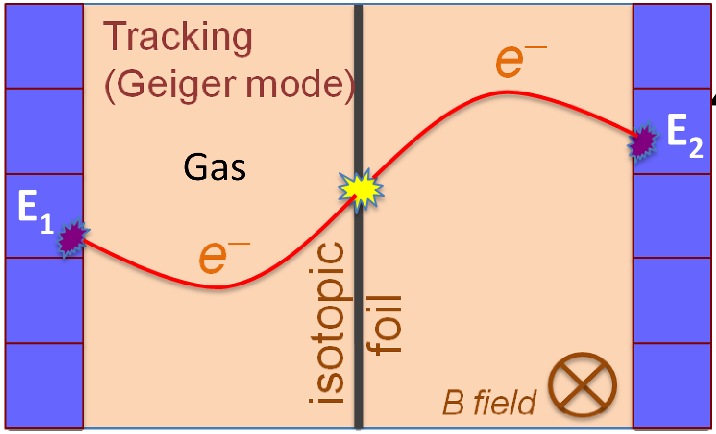
NEMO

Neutrino **E**ttore **M**ajorana **O**bservatory

- ββ isotope: ^{100}Mo, ^{82}Se and 5 others for NEMO3 and ^{82}Se for SuperNEMO
- Technique: tracko-calo
- Data taking: 2003-2010 (NEMO3)
- Location: LSM (Modane, France)

Detector design:

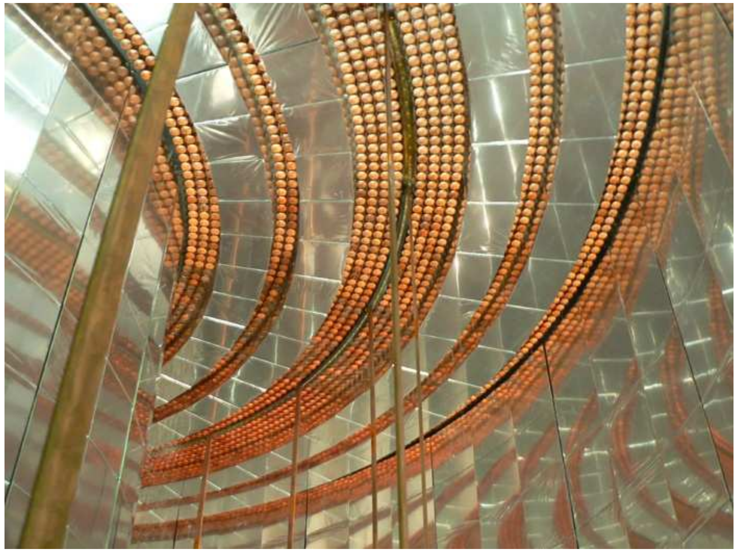
- Source: isotopic foils
- Tracking detector: drift wire chamber in Geiger Mode
- Calorimeter (E): plastic scintillators with low-background PMTs
- Magnetic field: to distinguish electron from positron

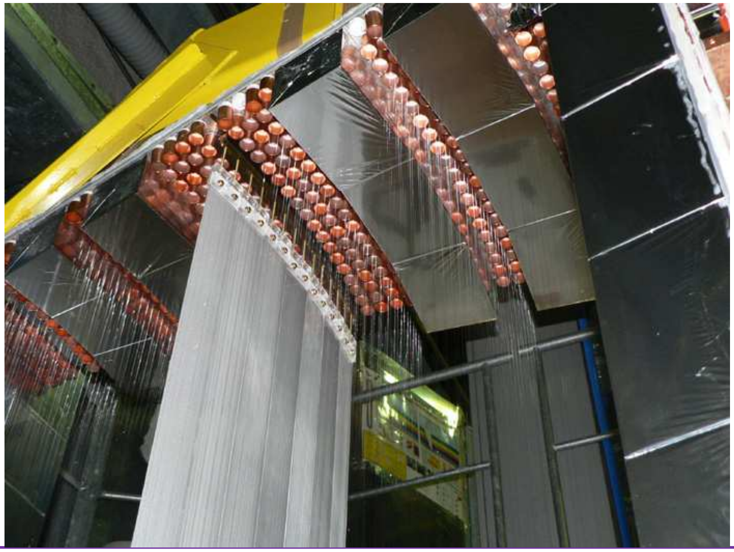


Plastic scintillator
+ PMT

Particle identification
e^-, e^+, α, γ
+ energy measurement

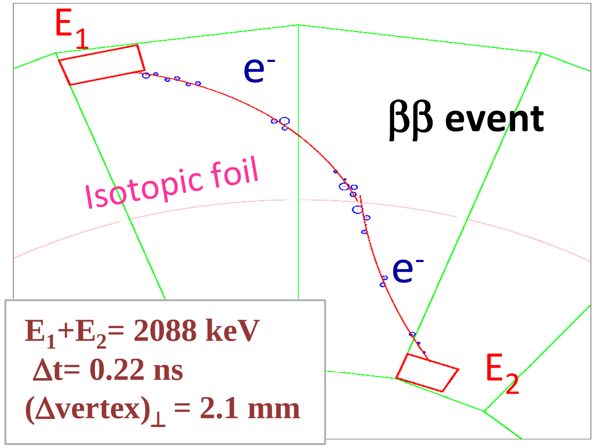
NEMO3





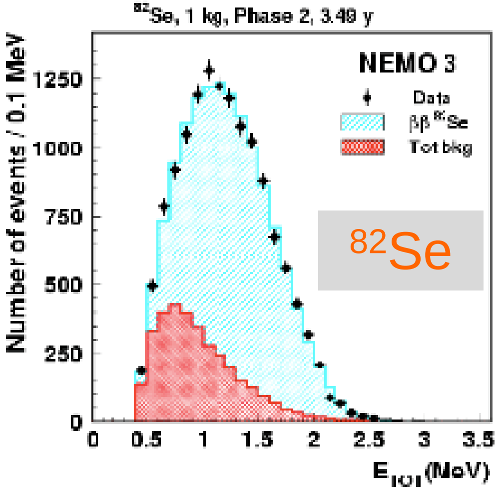
Unique feature

Measurement of all kinematic parameters: individual energies and angular distribution

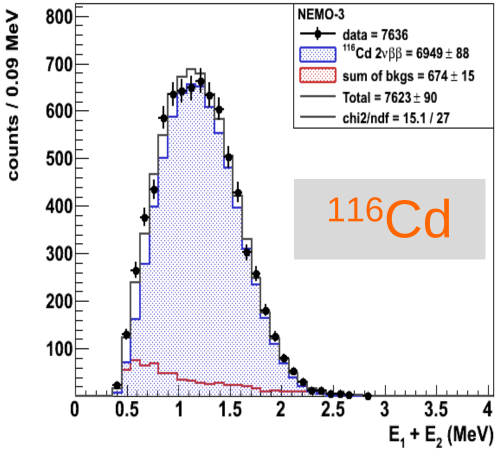


E_1+E_2= 2088 keV
Δt= 0.22 ns
$(\Delta\text{vertex})_\perp$ = 2.1 mm

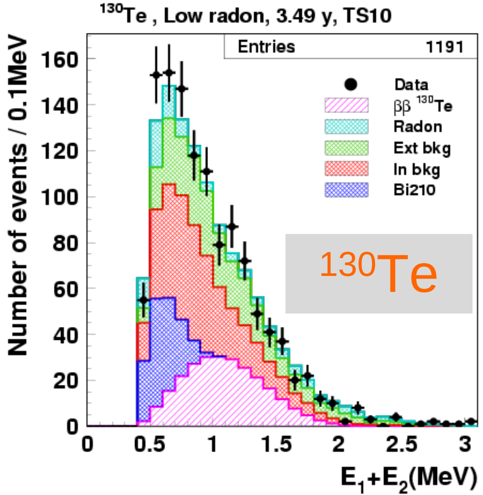
NEMO3: 2νββ results (not final)



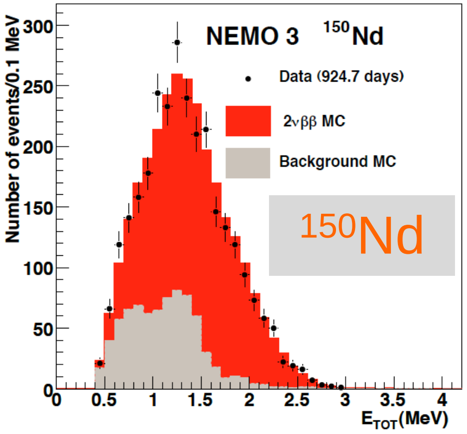
[9.6 ± 0.1 $_{(stat)}$ ± 1.0 $_{(syst)}$] x 10^{19} y



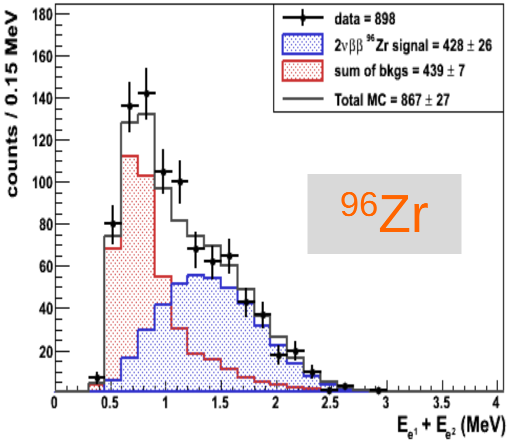
[2.88 ± 0.04$_{(stat)}$ ± 0.16$_{(syst)}$] x 10^{19} y



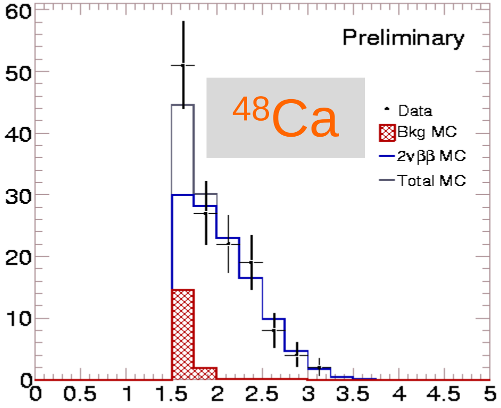
[7.0± 0.9$_{(stat)}$ ± 1.1$_{(syst)}$] x 10^{20} y



[9.11 $^{+0.25}_{-0.22}$ (stat) ± 0.63$_{(syst)}$] x 10^{18} y

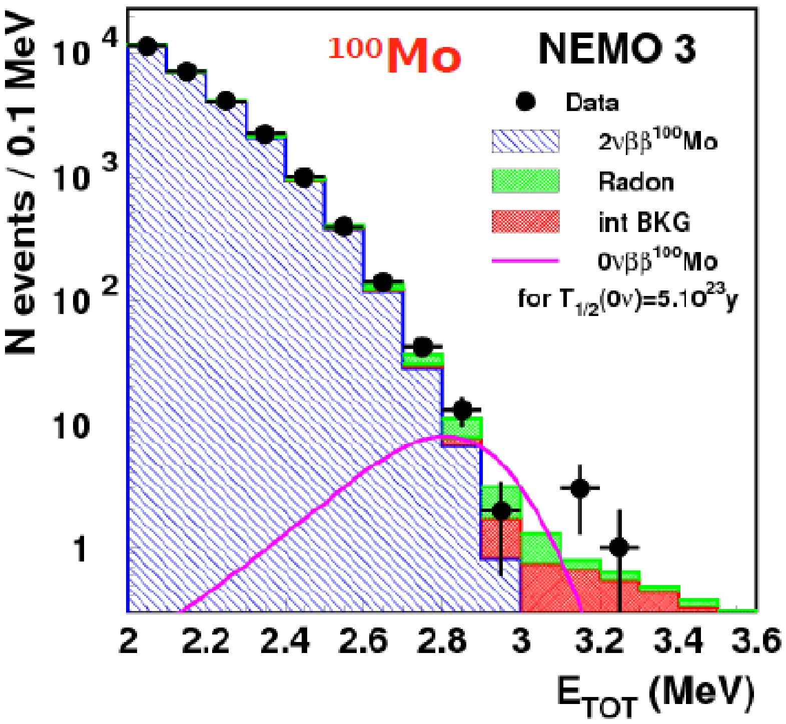


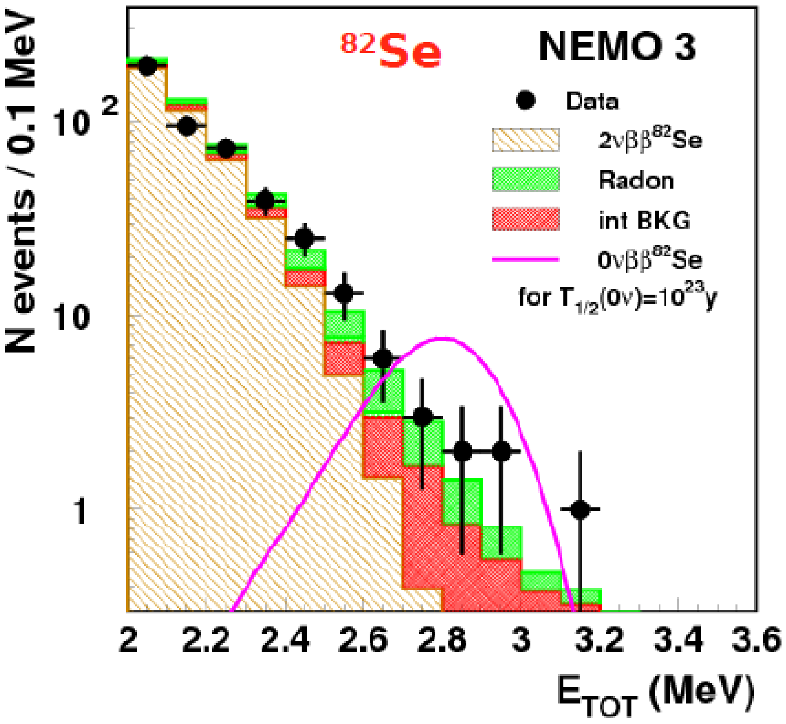
[2.35 ± 0.14$_{(stat)}$ ± 0.16$_{(syst)}$] x 10^{19} y



[4.4 $^{+0.5}_{-0.4}$ stat () ± 0.4 $_{(syst)}$] x 10^{19} y

NEMO3: 0νββ Results (not final)





^{100}Mo (for exposure of 31.2 kg.yr)

$T_{1/2}$ (0νββ) > 1.0 x 10^{24} y (90% C.L.)

$<m_{\beta\beta}>$ < 0.31 – 0.96 eV

^{82}Se (for exposure of 4.2 kg.yr)

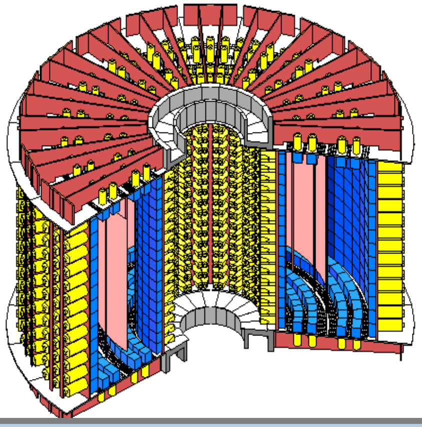
$T_{1/2}$ (0νββ) > 3.2 x 10^{23} y (90% C.L.)

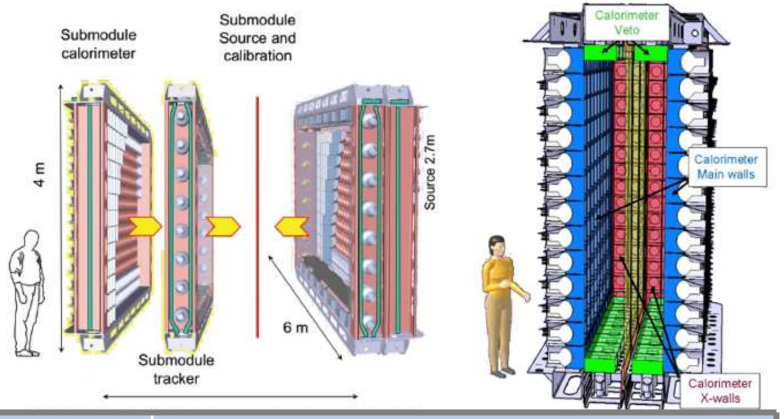
$<m_{\beta\beta}>$ < 0.94 – 2.6 eV

From NEMO3 to SuperNEMO

20 sectors: 10 kg of 7 isotopes

20 planar modules, each 5-7 kg of isotope
Can do different isotopes & locations





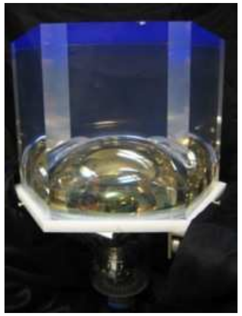
NEMO-3	→	**SuperNEMO**
^{100}Mo, ^{82}Se, ^{150}Nd, ^{130}Te, ^{116}Cd, ^{96}Zr, ^{48}Ca	**Isotope**	**^{82}Se, …^{150}Nd, ^{48}Ca**
7 kg	**Mass**	**100 kg (7 kg Demonstrator)**
15% at 1 MeV	**Energy resolution**	**8% at 1 MeV**
$T_{1/2}(0\nu\beta\beta) >$ 2 x 10^{24} y $\langle m_{\beta\beta}\rangle$ < 0.3 – 0.9 eV	**Sensitivity**	**$T_{1/2}(0\nu\beta\beta) >$ 1 x 10^{26} y $\langle m_{\beta\beta}\rangle$ < 0.04 – 0.10 eV**

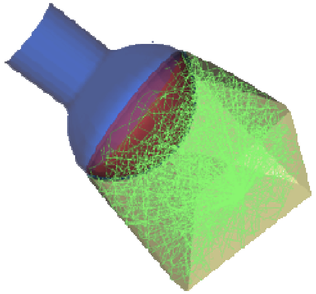
SuperNEMO R&D results

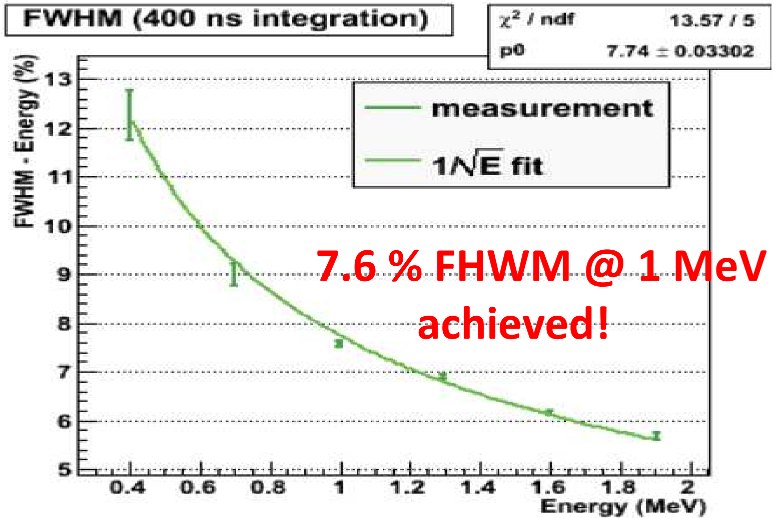
Calorimeter

Scintillator PVT size: 25.6 x 25.6 x 12 cm^3

8’’ Hamamatsu PMT







7.6 % FHWM @ 1 MeV achieved!

Tracker

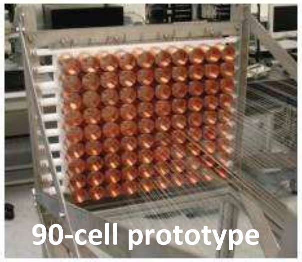
Size cell: l=3.7 m, ϕ=44 mm

Transverse spatial resolution: 0.7 mm,

Longitudinal spatial resolution: 1cm

Efficiency > 98%

Wiring Robot



90-cell prototype

Radon concentration line for tracker gas

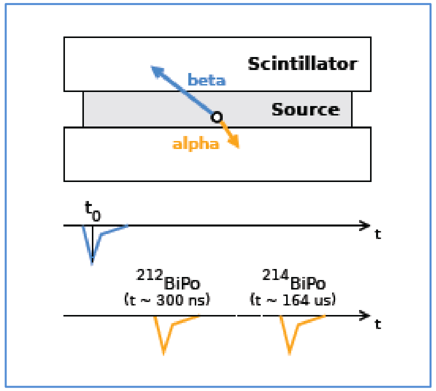
Must be sensitive to 0.15 mBq/m^3 in Radon

SuperNEMO R&D results

BiPo detector

Goal: to measure the radiopurity of the $\beta\beta$ foil in ^{214}Bi (^{238}U) and ^{208}Tl (^{232}Th)

Technique: measure the e/α coincidence in plastic scintillators



Sensitivity achieved in 6 months

A(^{208}Tl) ≤ 2 µBq/kg

A(^{214}Bi) ≤ 10 µBq/kg

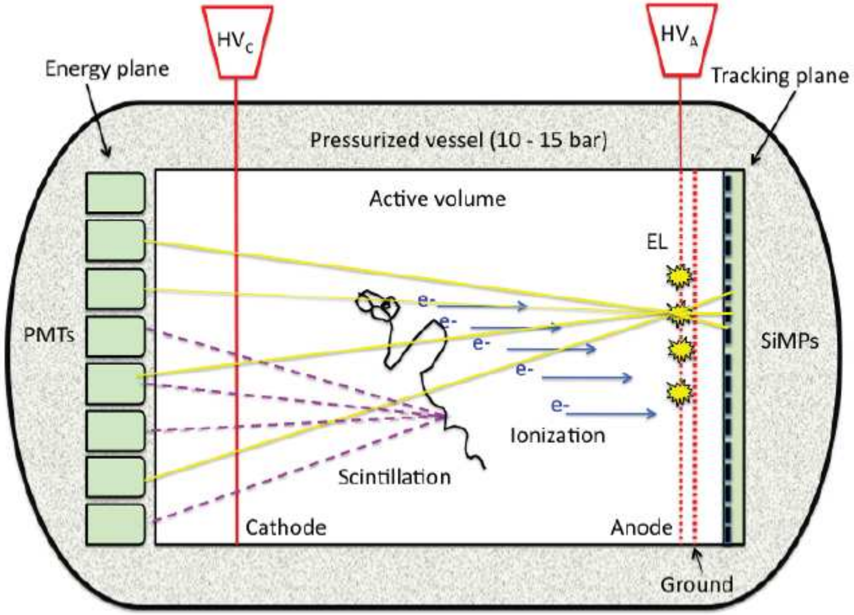
SuperNEMO schedule

- Construction started in the laboratories
- Installation and commissioning of the demonstrator at LSM Fréjus in 2013-2014
- Data taking in 2015
- No background expected
- Sensitivity after 2 years:
  $T_{1/2} > 6.6\ 10^{24}$ y and $<m_{\beta\beta}> < 0.2$-0.4 eV
- Full SuperNEMO detector with 100kg of ^{82}Se and 5 years data taking:
  $T_{1/2} > 1.0\ 10^{26}$ y and $<m_{\beta\beta}> < 0.04$-0.11 eV

NEXT-100

<u>N</u>eutrino **<u>E</u>**xperiment with a **<u>X</u>**enon **<u>T</u>**PC

- ββ isotope: ^{136}Xe
- Technique: optical TPC (tracking+calorimeter)
- Completion of R&D
- Location: LSC lab. (Canfranc, Spain)



Detection principle:

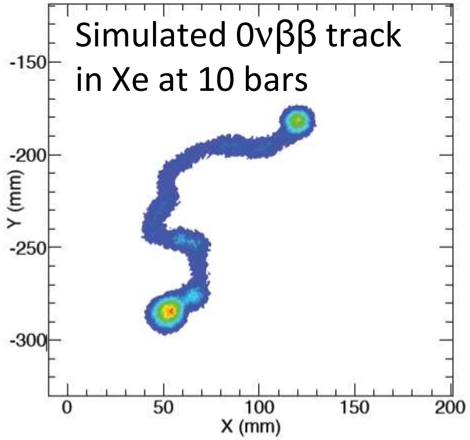
- TPC filled with gazeous Xe at 10-15 bars
- up to 150 kg of ^{enr}Xe (90.9% enrichment)
- Use ionization and excitation
  - excitation: prompt UV emission (scintillation) used as a start t_0
  - ionization: converted (with high E field) in scintillation light and used for energy measurement

  → ElectroLuminescent (EL) TPC

NEXT-100

Recent progress

- 0.5-1% FWHM at $Q_{\beta\beta}$ demonstrated
- Tracking and event topologies underway



Sensitivity expected:

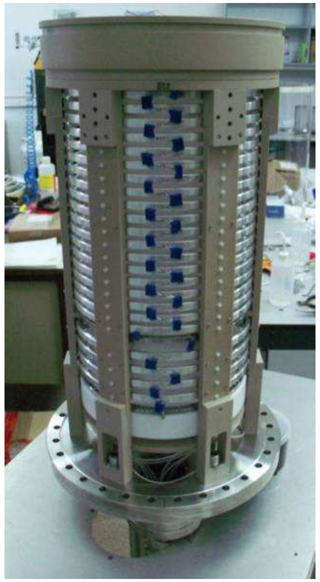
- Assuming 100kg of ^{136}Xe and 5 years operation:

$T_{1/2}(0\nu) > 6.10^{25}$ yr (90% C.L.)

$\langle m_{\beta\beta} \rangle < 0.1$ eV

Schedule:

- 2013: NEXT-100 construction
- 2014: NEXT-100 commissioning with non-enriched Xe
- 2015: start physics run with enriched Xe



Time Projection Chamber of the NEXT-DEMO prototype

Calorimeter experiments:

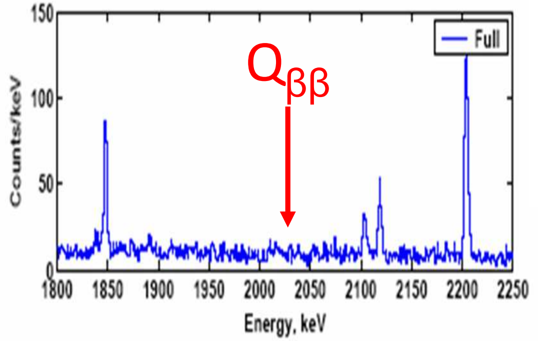
Semiconductors: GERDA (^{76}Ge)

Bolometer: CUORE (^{130}Te)

Inorganic scintillator: CANDLES III (^{48}Ca)

Scintillator: EXO-200 and KamLAND-Zen (^{136}Xe)

^{76}Ge Ionisation Detectors



Advantages:

- Well-known technique (High-Purity Germanium)
- Very good energy resolution (0.16% at $Q_{\beta\beta}$ = 2038 keV, i.e. 3.3 keV)
- Direct test of Klapdor claim (same isotope): $<m_{\beta\beta}>$ = 0.24-0.58 eV

Disadvantages:

- Difficult to discriminate between electron (single site) and γ (multi-site) events
- Complex backgrounds (e.g. cosmogenics)

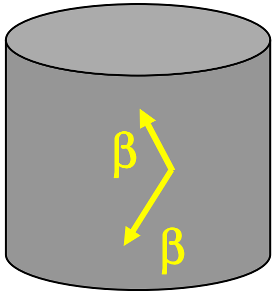
2 projects:

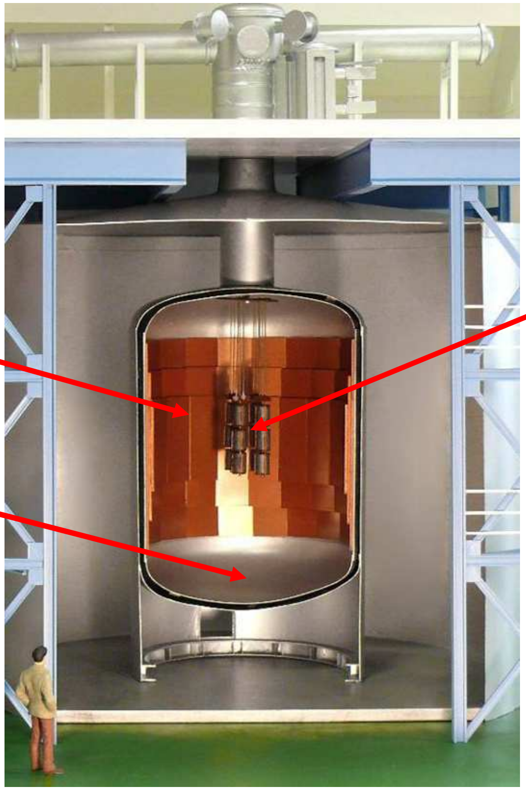
- GERDA experiment running since Nov. 2011
- MAJORANA experiment in completion of R&D phase

GERDA

<u>GER</u>manium **<u>D</u>**etector **<u>A</u>**rray (installed in Gran Sasso):

- bare Ge-diodes array immerged in liquid argon (LAr)
- shielding (high-purity LAr + H_2O)





Cu shield

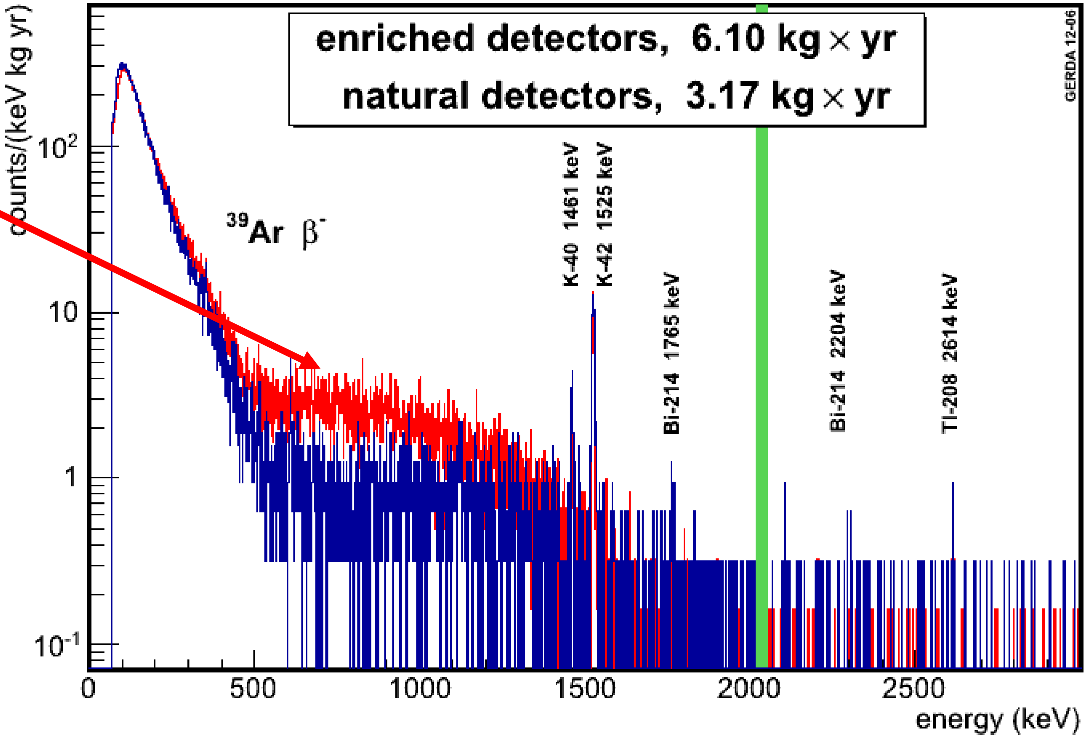
Cryostat filled with LAr

Ge detectors

GERDA Phase I

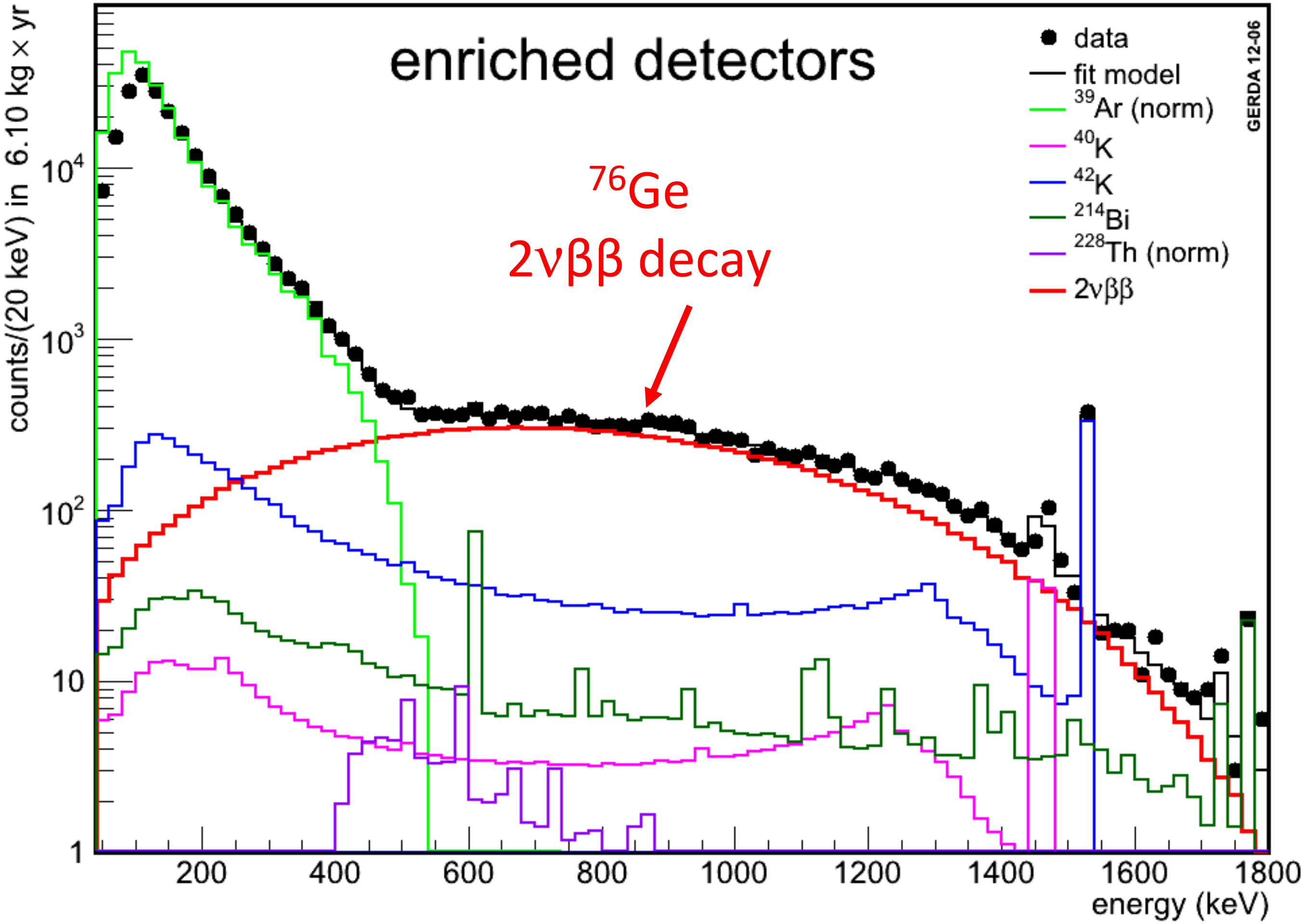
Phase I (started in Nov. 2011)

- 14.6 kg of ^{enr}Ge (86% of ^{76}Ge) from previous experiments (HM and IGEX)
- 7.6 kg of ^{nat}Ge from GTF



Excess of events due to 2νββ decays

GERDA: first $2\nu\beta\beta$ result for ^{76}Ge

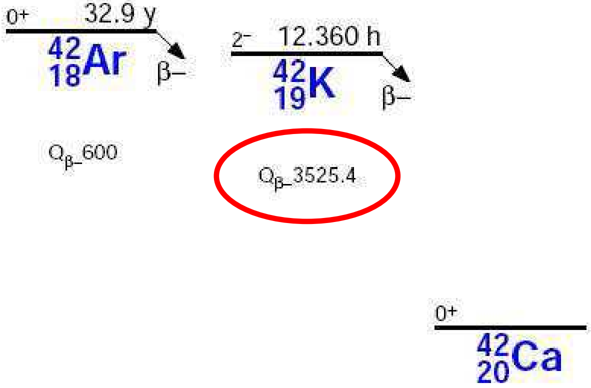


$T_{1/2}(2\nu)=[1.88\pm0.10].10^{21}$ yr

GERDA

Phase I (to be completed by early 2013)

- Region of interest (2038 ± 20 keV) is blinded
- Background Index (BI) is 0.02 count/keV/kg/year (without PSA)
- Problem of the ^{42}Ar background to be solved



Phase II (start by spring 2013)

- 40 kg of ^{enr}Ge
- P-type detectors and R&D with Majorana
- Expected BI: 0.001 count/keV/kg/year → Less than 1 background event expected in 3 years!
- Sensitivity (3 years):

$T_{1/2}(0\nu) > 2.10^{26}$ y, $\langle m_{\beta\beta} \rangle < 0.11$ eV

Phase III

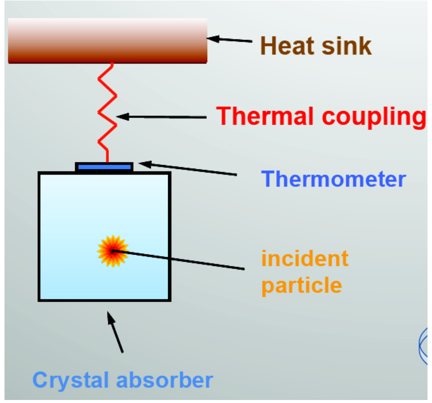
- Goal of the ton scale of ^{enr}Ge joint with Majorana

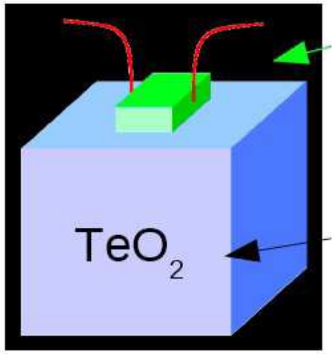
CUORE

Cryogenic **U**nderground **O**bservatory for **R**are **E**vents

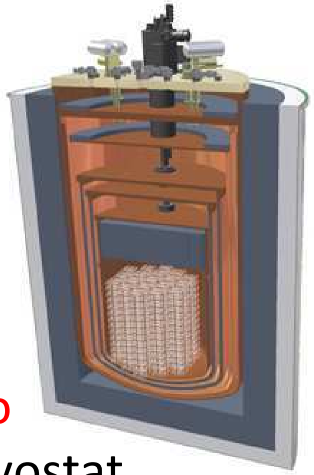
- ββ isotope: ^{130}Te ($Q_{\beta\beta}$=2527 keV)
- Technique: calorimeter (bolometer)
- Completion of R&D
- Location: LNGS lab. (Gran Sasso,Italy)

Bolometric technique





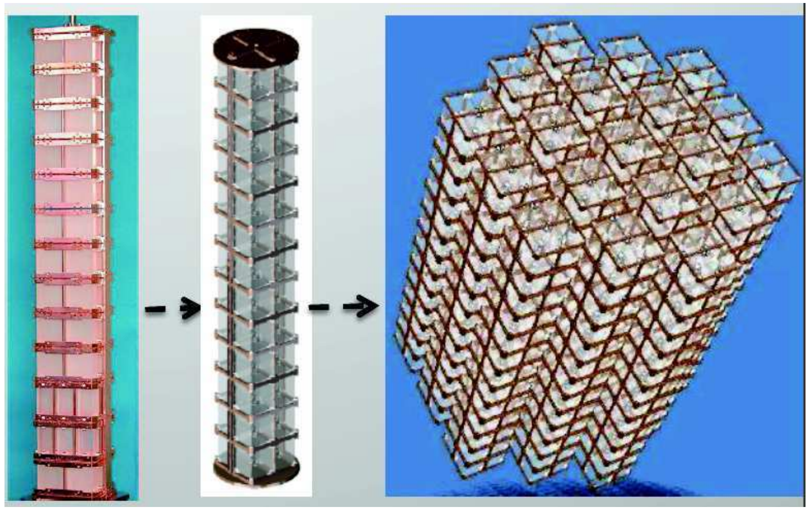
- TeO_2 absorb energy deposited by particle
- Energy E registered by a thermistor (NTD Ge) as T increase
- Signal: ΔT=E/C, C thermal capacity
- Need low T~mK
- Very good energy resolution: ~5keV at $Q_{\beta\beta}$ (2527 keV), i.e. FWHM/E=0.2%



Detector and cryostat

- TeO_2 crystals cooled down to ~10mK with He in a copper cryostat
- Isotopic natural abundance of ^{130}Te: 34.1% (no enrichment!)

Scaling of the CUORE project



1) Cuoricino: CUORE demonstrator (2003-2008)

- 1 tower, 62 crystals, 11.3kg of ^{130}Te
- Achieved background: 0.169 cts/keV/kg/yr
- Sensitivity achieved (90% C.L.):
- $T_{1/2}(0\nu) > 2.8 \times 10^{24}$ yr, $<m_{\beta\beta}> < 0.30\text{-}0.71$ eV

2) CUORE-0 (2012-2014)

- 1 of the 19-tower Cuore assembly, 52 crystals, 11kg of ^{130}Te
- Control detector-production chain
- As stand alone experiment: improve background down to 0.11-0.05 cts/keV/kg/yr

3) CUORE (2014-2019)

- 19 towers, 988 crystals, 206 kg of ^{130}Te
- Goal background : 0.01 cts/keV/kg/yr
- Sensitivity expected with 5 years running (90% C.L.)
- $T_{1/2}(0\nu) > 1.6 \times 10^{25}$ yr, $<m_{\beta\beta}> < 0.04\text{-}0.09$ eV

CANDLES

CAlcium fluoride for studies of **N**eutrino and **D**ark matters by **L**ow **E**nergy **S**pectrometer

- ββ isotope: ^{48}Ca ($Q_{\beta\beta}$=4.27 MeV)
- Technique: calorimeter (scintillator)
- Data taking: since June 2011
- Location: Kamioka mine (Japan)

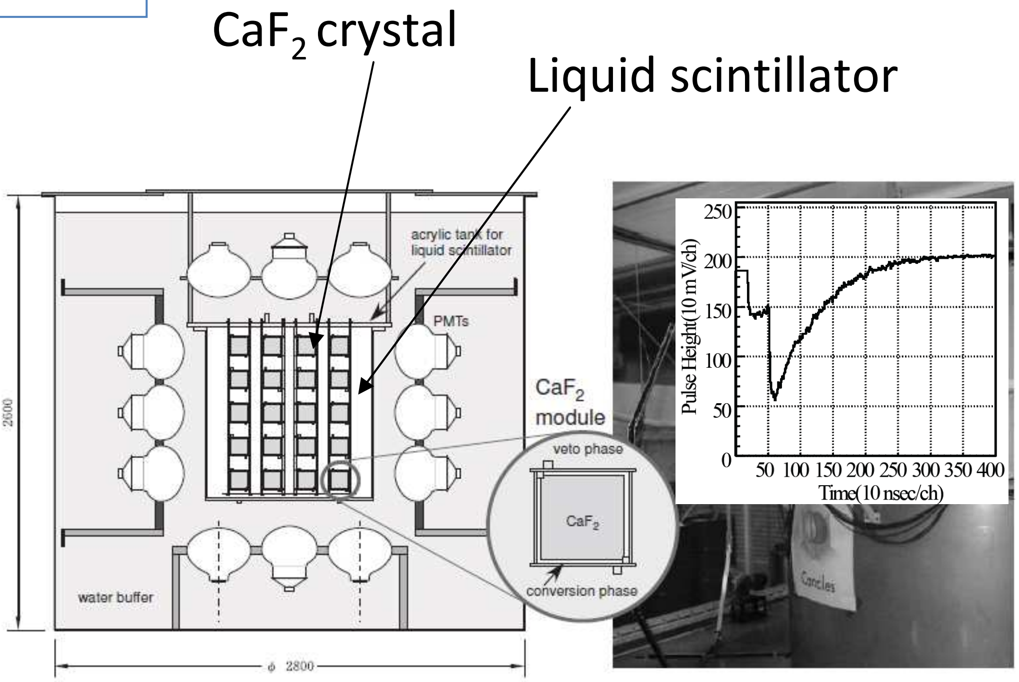
Previous experiment: ELEGANT VI

$T_{1/2}(0\nu) > 5.8 \times 10^{22}$ year (90% C.L.)

$<m_{\beta\beta}> < 3.5\text{-}22$ eV

Detector design of CANDLES III:

- 96 CaF_2 crystals (10x10x10cm^3): 305 kg
- only 0.3kg of ^{48}Ca (0.187% abund.)
- CaF_2 immerged in liquid scintillator:
  - 4 π active shield
  - passive shield
- distinguish ββ signal in CaF_2 (slow scintillation component) from muons and ext. γ/β in LS (fast component)



CANDLES III

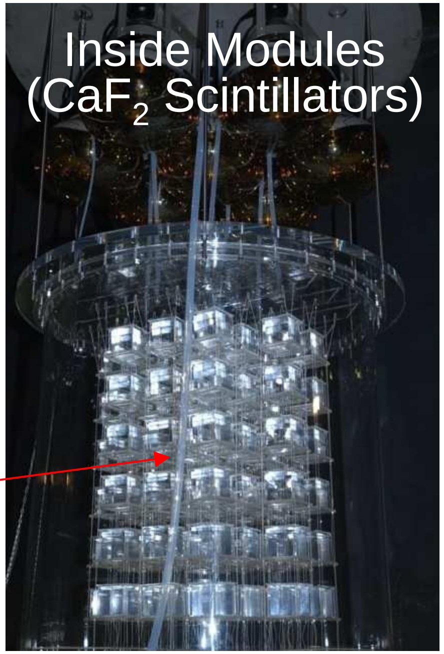
CANDLES I : background rejection (proof of principle)

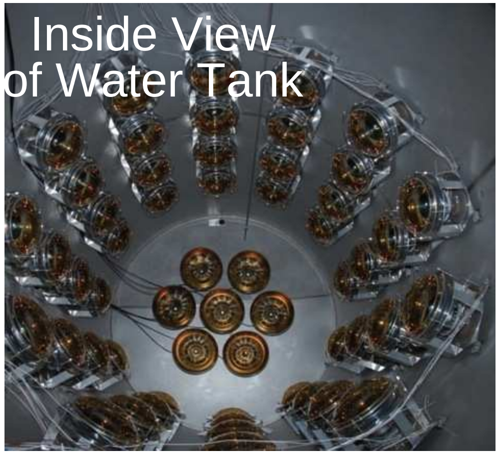
CANDLES II : prototype with 2 PMT 15’’

CANDLES III: start of the measurement in June 2011

CANDLES Futur to reach $T_{1/2}(0\nu)>10^{26}$ years:

- 1^{st} step : from 300 kg to a few ton
- 2^{nd} step : ^{48}Ca enrichment from 0.19% to 2%

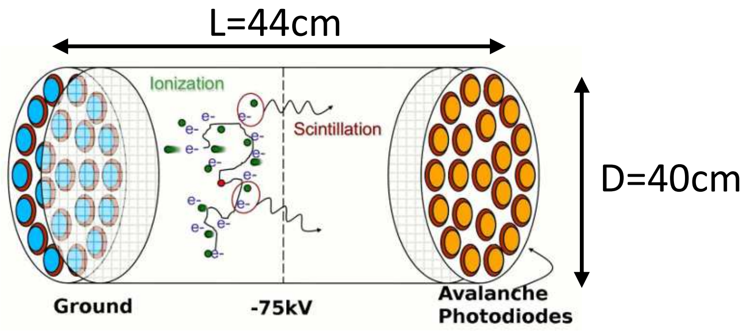

Inside Modules (CaF_2 Scintillators)


Inside View of Water Tank

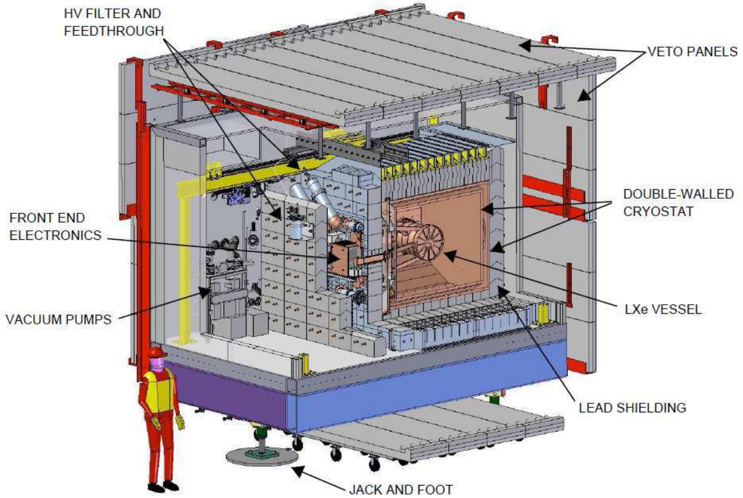
EXO-200

Enriched **X**enon **O**bservatory
- $\beta\beta$ isotope: ^{136}Xe ($Q_{\beta\beta}$ =2458 keV)
- Technique: calorimeter (scintillation)
- Data taking: since May 2011
- Location: WIPP lab. (USA)

Detector design:
- TPC filled with Liquid Xenon (LXe)
- 175 kg of ^{enr}Xe (80.6% of ^{136}Xe)

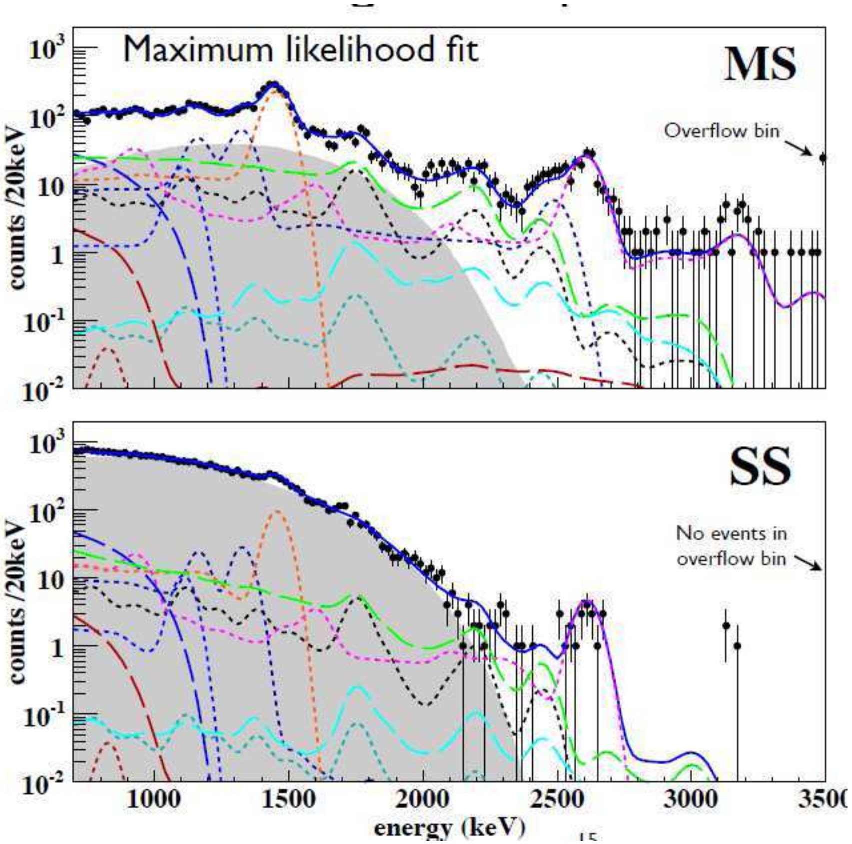


- Use of both ionisation and scintillation
→ discrimination of α from β/γ
- Drift time measurement
→ position reconstruction (18mm in XY and 6mm in Z)
→ distinguish SS (β,ββ) from MS (γ's) events



Background reduction:
- Lead shield
- 4 plastic scintillators (muon vetos)
- 700m overburden (1600 m w.e.)

EXO-200 : first 2νββ half-life of ^{136}Xe

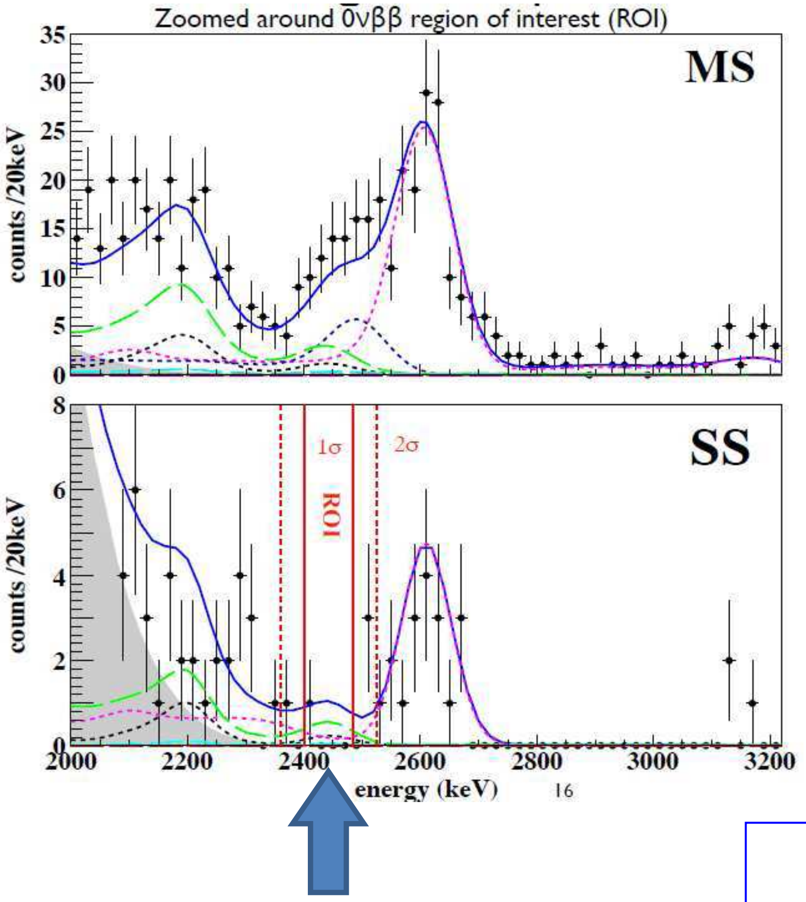


- Rejection of surface contamination → definition of a fiducial volume (56% of the total LXe volume)
- Active mass of ^{136}Xe : 98.5 kg
- 22000 2νββ events measured above 0.7 MeV (S/B ratio ~10)

$T_{1/2}(2\nu)=[2.23\pm0.02(\mathrm{stat})\pm0.22(\mathrm{syst})].10^{21}$ yr

arXiv:1205.5608 (May 2012)

EXO-200: limit for 0νββ half-life of ^{136}Xe



Search for 0νββ signal

- ^{136}Xe: $Q_{\beta\beta}$ =2458 keV
- Energy resolution: 4.5% at $Q_{\beta\beta}$
- Observed background around the 0νββ region of interest: 5 events at 2σ

→ BI: 0.0015 cts/keV/kg/yr (within specs!)

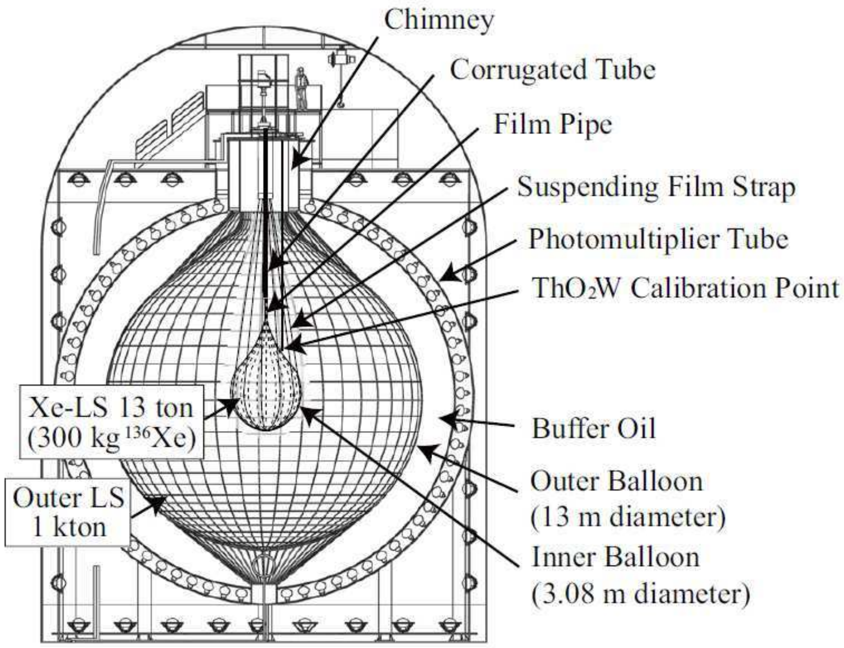
$T_{1/2}(0\nu) > 1.6 \times 10^{25}$ yr (90% C.L.)

$\langle m_{\beta\beta} \rangle < 0.14\text{-}0.38$ eV

KamLAND-Zen

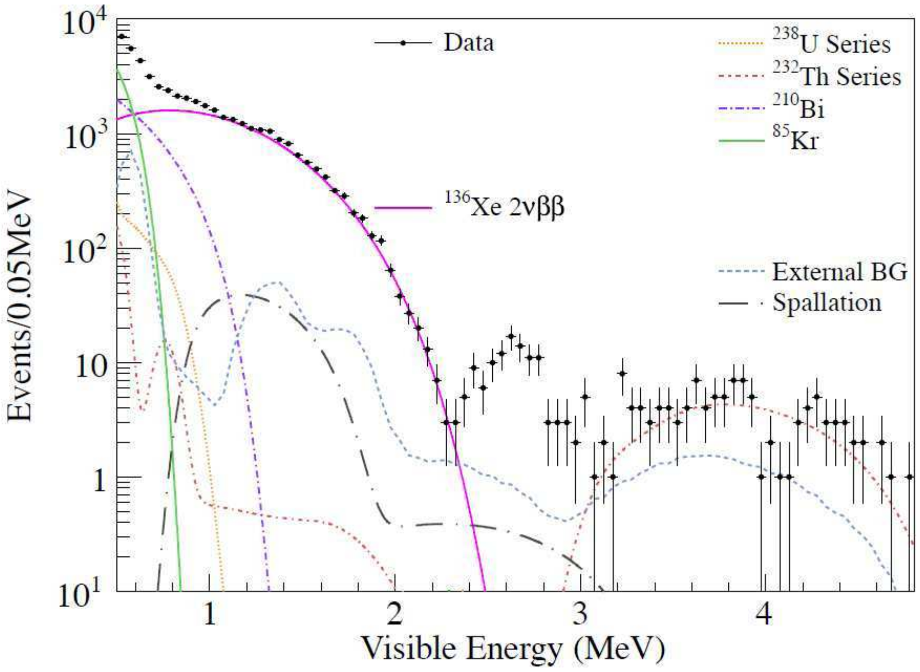
KamLAND Zero neutrino experiment
- ββ isotope: ^{136}Xe
- Technique: calorimeter (LS)
- Data taking: since Oct.2011
- Location: Kamioka mine (Japan)

Detector design:
- Inner balloon (R=1.54m) filled with 13t of Xe-loaded Liquid Scintillator (LS)
- High solubility of Xe gas in LS
- 2.5% weight of ^{enr}Xe (~300 kg of ^{136}Xe)



Background reduction:
- Outer LS sphere (R=6.5m, 1000t): active shield against ext. γ's and int. γ's
- Water tank (3200t): neutron moderation and muon Cherenkov detector
- High purification of LS in ^{238}U/^{232}Th and daughter nuclei

KamLAND-Zen: 2νββ half-life of ^{136}Xe



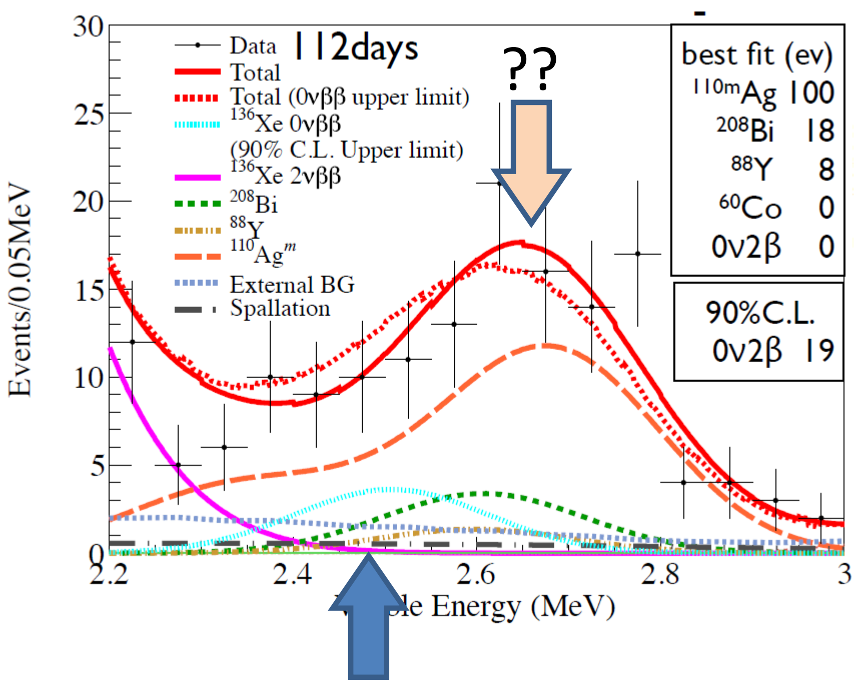
- Fiducial volume with R=1.2m (43% of the inner balloon volume)
- Active mass of ^{136}Xe : 129 kg
- 35500 2νββ events selected between 0.5-4.8 MeV

$T_{1/2}(2\nu)=[2.38\pm0.02(\mathrm{stat})\pm0.14(\mathrm{syst})].10^{21}$ yr

arXiv:1201.4664 (April 2012)
Gando *et al.,* PRC **85**, 045504, 2012

→ consistent with the EXO-200 result

KamLAND-Zen: limit for 0νββ half-life



Search for 0νββ signal

- Unexpected peak at 2.6 MeV
- Rate stable in time: non short-lived radioisotope
- Non-compatible with ^{136}Xe $Q_{\beta\beta}$
- Check ‘all’ nuclei and decay paths
- Remaining candidates: ^{110m}Ag, ^{208}Bi, ^{88}Y and ^{60}Co (some of them may come from the Fukushima fallouts)

$T_{1/2}(0\nu) > 6.2 \times 10^{24}$ yr (90% C.L.)

$<m_{\beta\beta}> < 0.3\text{-}0.6$ eV

arXiv:1201.4664 (April 2012)
Gando *et al.*, PRC **85**, 045504, 2012

Summary of recent results

S.R.Elliott, arXiv: 1203.1070v1 (March 2012)

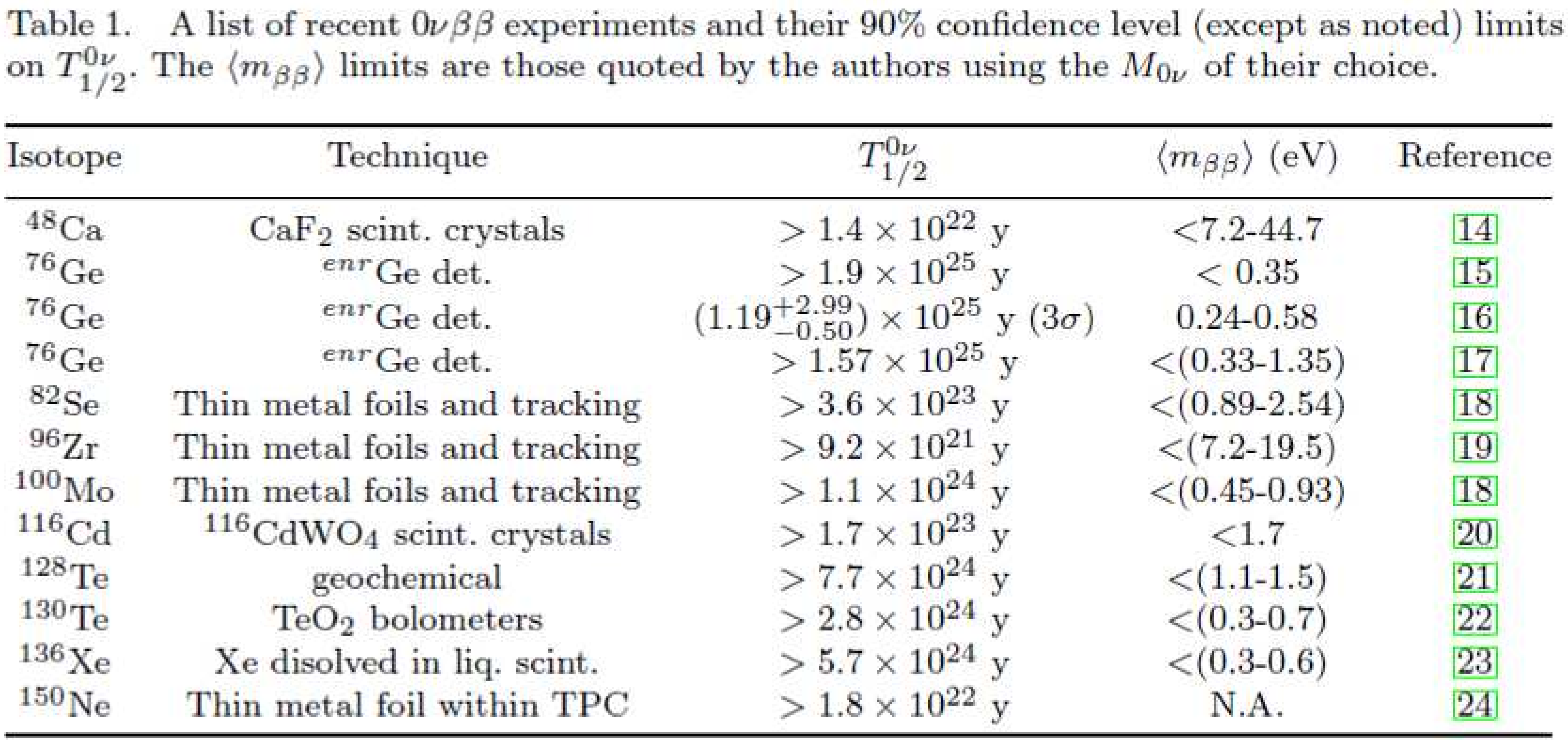


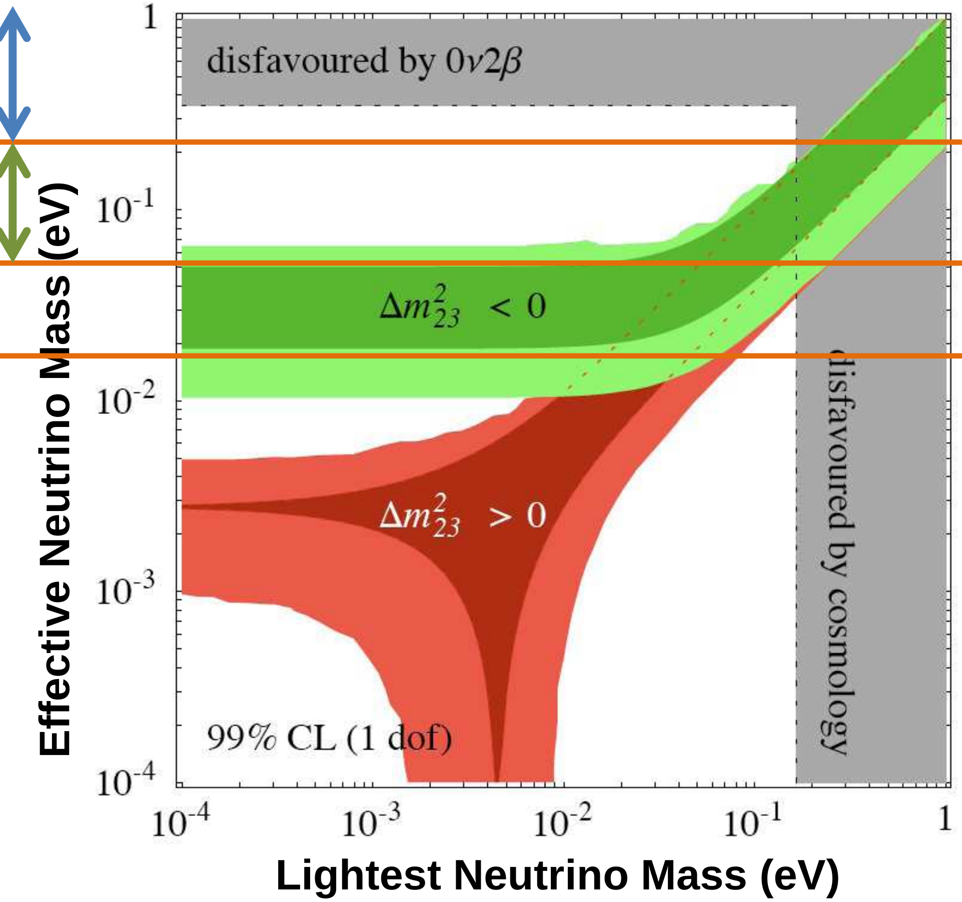
Table 1. A list of recent $0\nu\beta\beta$ experiments and their 90% confidence level (except as noted) limits on $T^{0\nu}_{1/2}$. The $\langle m_{\beta\beta}\rangle$ limits are those quoted by the authors using the $M_{0\nu}$ of their choice.

Isotope	Technique	$T^{0\nu}_{1/2}$	$\langle m_{\beta\beta}\rangle$ (eV)	Reference
^{48}Ca	CaF$_2$ scint. crystals	$> 1.4 \times 10^{22}$ y	<7.2-44.7	14
^{76}Ge	^{enr}Ge det.	$> 1.9 \times 10^{25}$ y	< 0.35	15
^{76}Ge	^{enr}Ge det.	$(1.19^{+2.99}_{-0.50}) \times 10^{25}$ y (3σ)	0.24-0.58	16
^{76}Ge	^{enr}Ge det.	$> 1.57 \times 10^{25}$ y	<(0.33-1.35)	17
^{82}Se	Thin metal foils and tracking	$> 3.6 \times 10^{23}$ y	<(0.89-2.54)	18
^{96}Zr	Thin metal foils and tracking	$> 9.2 \times 10^{21}$ y	<(7.2-19.5)	19
^{100}Mo	Thin metal foils and tracking	$> 1.1 \times 10^{24}$ y	<(0.45-0.93)	18
^{116}Cd	^{116}CdWO$_4$ scint. crystals	$> 1.7 \times 10^{23}$ y	<1.7	20
^{128}Te	geochemical	$> 7.7 \times 10^{24}$ y	<(1.1-1.5)	21
^{130}Te	TeO$_2$ bolometers	$> 2.8 \times 10^{24}$ y	<(0.3-0.7)	22
^{136}Xe	Xe disolved in liq. scint.	$> 5.7 \times 10^{24}$ y	<(0.3-0.6)	23
^{150}Ne	Thin metal foil within TPC	$> 1.8 \times 10^{22}$ y	N.A.	24

Goal of the next generation of experiment

Isotope mass

Required background Level in the ROI



~ 10 kg 2012 **100 – 1000 cts/yr/ton**

~ 100 kg 2015 **1 – 10 cts/yr/ton**

~ 1000 kg **0.1 – 1 cts/yr/ton**

Future experiments

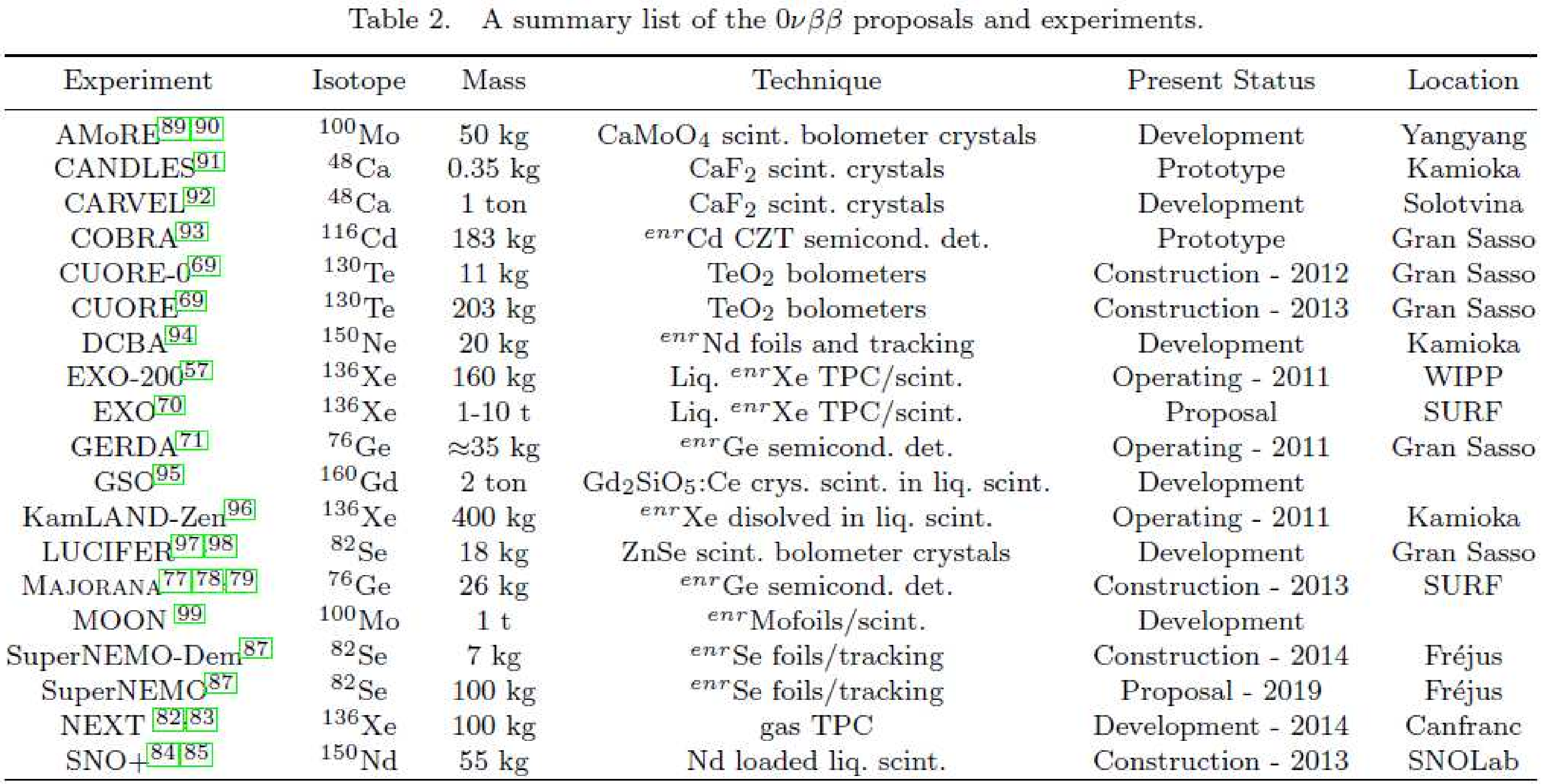


Table 2. A summary list of the $0\nu\beta\beta$ proposals and experiments.

Experiment	Isotope	Mass	Technique	Present Status	Location
AMoRE[89,90]	^{100}Mo	50 kg	CaMoO$_4$ scint. bolometer crystals	Development	Yangyang
CANDLES[91]	^{48}Ca	0.35 kg	CaF$_2$ scint. crystals	Prototype	Kamioka
CARVEL[92]	^{48}Ca	1 ton	CaF$_2$ scint. crystals	Development	Solotvina
COBRA[93]	^{116}Cd	183 kg	^{enr}Cd CZT semicond. det.	Prototype	Gran Sasso
CUORE-0[69]	^{130}Te	11 kg	TeO$_2$ bolometers	Construction - 2012	Gran Sasso
CUORE[69]	^{130}Te	203 kg	TeO$_2$ bolometers	Construction - 2013	Gran Sasso
DCBA[94]	^{150}Ne	20 kg	^{enr}Nd foils and tracking	Development	Kamioka
EXO-200[57]	^{136}Xe	160 kg	Liq. ^{enr}Xe TPC/scint.	Operating - 2011	WIPP
EXO[70]	^{136}Xe	1-10 t	Liq. ^{enr}Xe TPC/scint.	Proposal	SURF
GERDA[71]	^{76}Ge	≈35 kg	^{enr}Ge semicond. det.	Operating - 2011	Gran Sasso
GSO[95]	^{160}Gd	2 ton	Gd$_2$SiO$_5$:Ce crys. scint. in liq. scint.	Development	
KamLAND-Zen[96]	^{136}Xe	400 kg	^{enr}Xe disolved in liq. scint.	Operating - 2011	Kamioka
LUCIFER[97,98]	^{82}Se	18 kg	ZnSe scint. bolometer crystals	Development	Gran Sasso
MAJORANA[77,78,79]	^{76}Ge	26 kg	^{enr}Ge semicond. det.	Construction - 2013	SURF
MOON [99]	^{100}Mo	1 t	^{enr}Mofoils/scint.	Development	
SuperNEMO-Dem[87]	^{82}Se	7 kg	^{enr}Se foils/tracking	Construction - 2014	Fréjus
SuperNEMO[87]	^{82}Se	100 kg	^{enr}Se foils/tracking	Proposal - 2019	Fréjus
NEXT [82,83]	^{136}Xe	100 kg	gas TPC	Development - 2014	Canfranc
SNO+[84,85]	^{150}Nd	55 kg	Nd loaded liq. scint.	Construction - 2013	SNOLab

Summary and outlook

- Running experiments are using various $\beta\beta$ isotopes (^{48}Ca, ^{76}Ge, ^{82}Se, ^{100}Mo, ^{130}Te, ^{136}Xe…) with typical sensitivity $T_{1/2} > 10^{24}$-10^{25} y, i.e. $<m_{\beta\beta}> < 0.15$-0.5 eV
- Claim of the Heidelberg-Moscow experiment in 2004 ($<m_{\beta\beta}> =$ 0.24-0.59 eV) will be tested in 2013-2015
- Next generations of experiment need to use at least 100kg of enriched isotope (started with Xe experiments) with also background improvements
- Goal: to test the inverted hierarchy mass region with $<m_{\beta\beta}> <$ 0.02-0.08 eV ($T_{1/2} > 10^{26}$-10^{27} y)
- Nuclear Matrix Elements: crucial to reach the right effective neutrino mass and the Shell Model is very predictive for several $0\nu\beta\beta$ candidates (except the very interesting ^{150}Nd…)