# News on
# Double Beta Decay Search

# Why ?

## (A, Z) ➔ (A, Z+2) + 2 e$^-$

deep insight in ν physics unaccessible by oscillation measurements

if 0νββ observed ➔ ν is a Majorana particle

if $T^{0\nu}_{1/2}$ is measured ➔ $m_{\beta\beta}$ (ν mass scale) can be extracted

*PNMS (mixing) matrix elements*

$m_{\beta\beta} = \Sigma\, m_j\, U_{ej}^{\;2}$

***Majorana mass of neutrino***

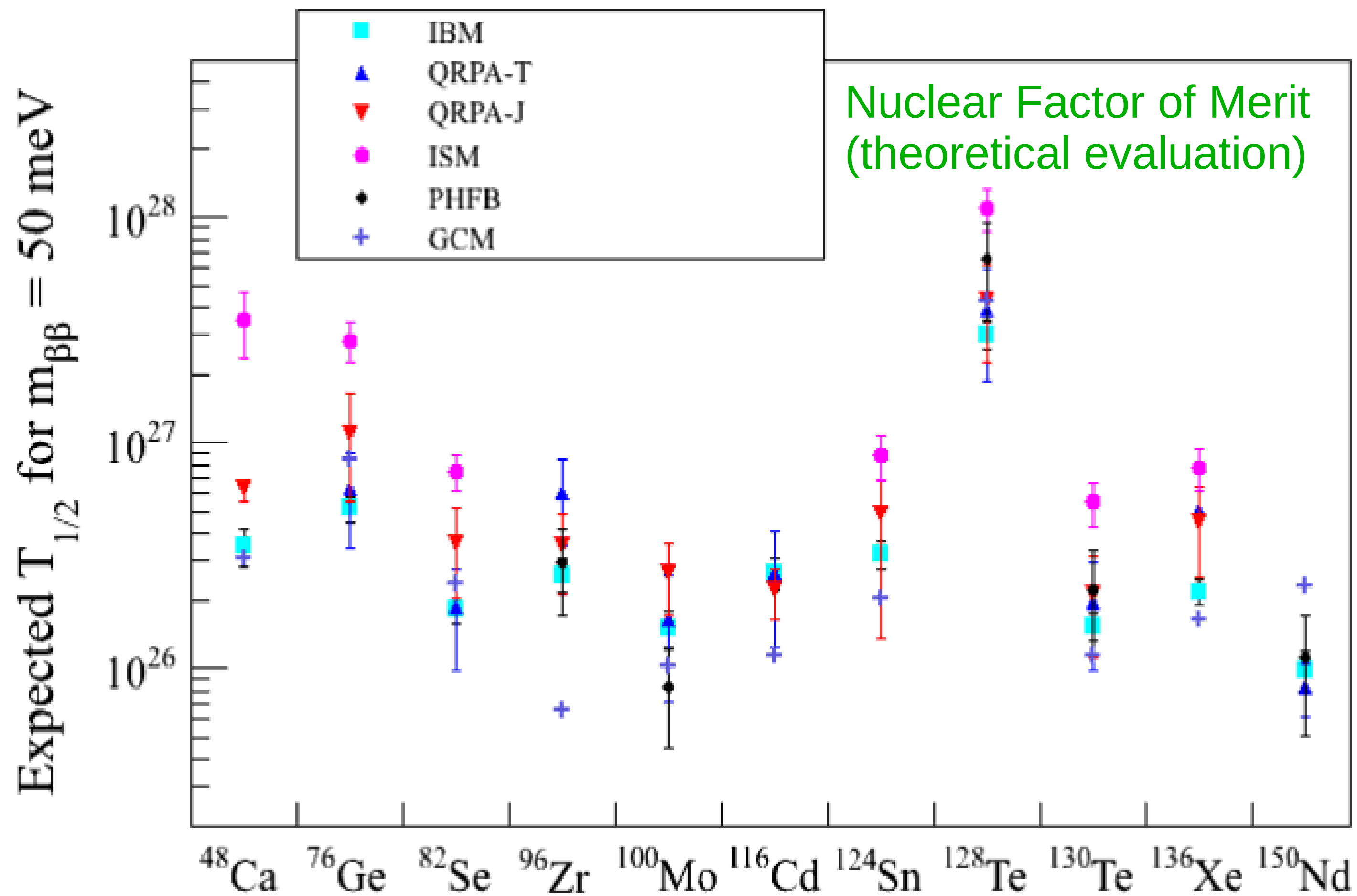
$$\left(T^{0\nu}_{1/2}\right)^{-1} = \boxed{G^{0\nu}(Q,Z)\ \left|M^{0\nu}\right|^2}\ \frac{\left|\langle m_{\beta\beta}\rangle\right|^2}{m_e^2}$$

Nuclear Factor of Merit
(theoretical evaluation)

*…. we neglect here possible contribution to the half-life amplitude from right-handed couplings*

if $T^{0\nu}_{1/2}$ is measured ➔ $m_{\beta\beta}$ value can be extracted

# unfair statement




**few good candidates**

**no BEST candidate**

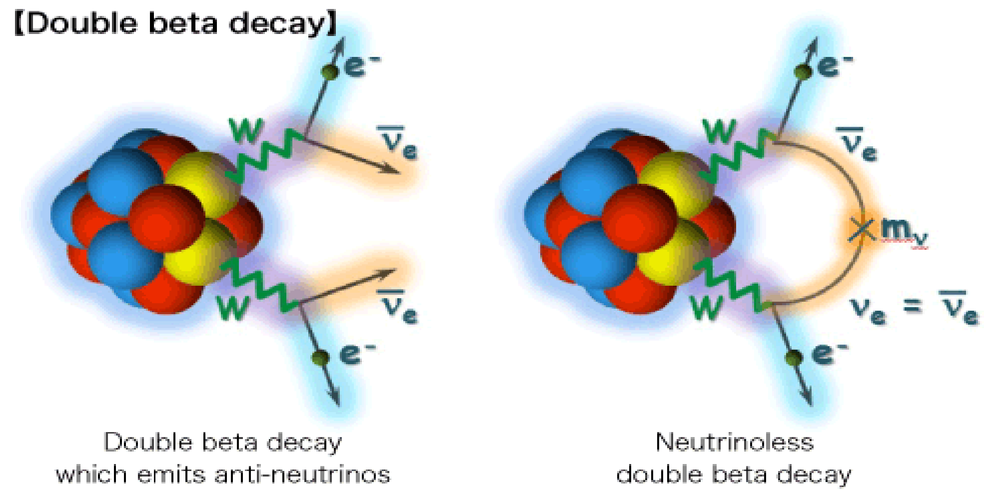
**not simple comparison of $m_{bb}$ results/sensitivities**

**!**

# How ?

$2\nu\beta\beta$

$0\nu\beta\beta$

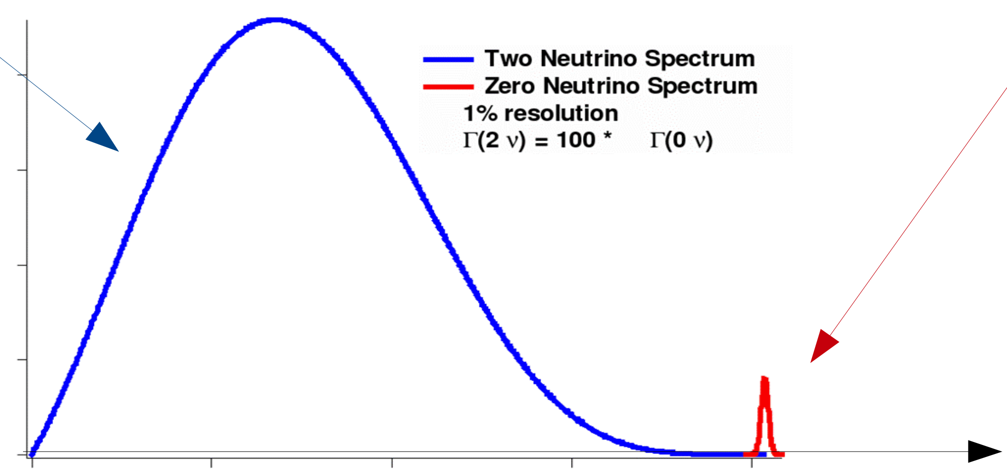



$E_1 + E_2 \leq Q_{\beta\beta}$

$E_1 + E_2 = Q_{\beta\beta}$

this decay is SM "compliant"
(no lepton number violation,
possible also for massless $\nu$)
it is observed $T_{1/2} \sim 10^{20}$ yr

<u>it is a dangerous background
for the obervation of $0\nu\beta\beta$</u>




$E_1+E_2$ = SUM ENERGY OF 2 ELECTRONS

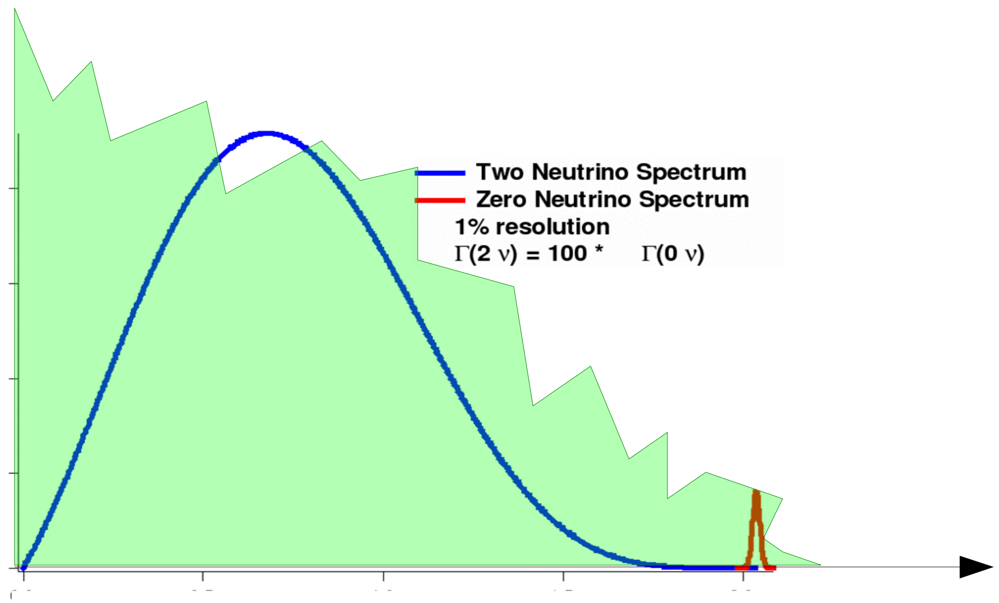
# How ?

**both generally hidden in a huge background due to radioactivity and cosmic rays**

$2\nu\beta\beta$

$0\nu\beta\beta$

**real challenge for future expt.**




$E_1+E_2$ = SUM ENERGY OF 2 ELECTRONS

# Sensitivity

**SCALE** = exposure (number of bb emitters and measuring time)
= ***Isotope Mass*** **x** ***Time***

**PERFORMANCES =** number of background counts in the ROI
***Background Rate*** ***x*** ***detector FWHM***

**0 counts in ROI P=0**
*zero bkg expts*

$S_{0\nu\beta\beta} \propto$ **SCALE** = Mass x Time

**counts in ROI >> 0**

$$S_{0\nu\beta\beta} \propto \sqrt{\frac{\text{SCALE}}{\text{PERFORMANCES}}}$$

# Strategies to improve Sensitivity

**1.** increase the **SCALE**

main problem (cost+time) is isotope enrichment (excluding Te)

**2.** improve the **PERFORMANCES**

➔ **achieve the 0 background** condition where $S_{0\nu\beta\beta} \propto$ time

**high resolution detectors**

**particle identification** (mostly $\alpha$'s rejection)

event classification according to **particle track**: Single Site vs. Multi Site

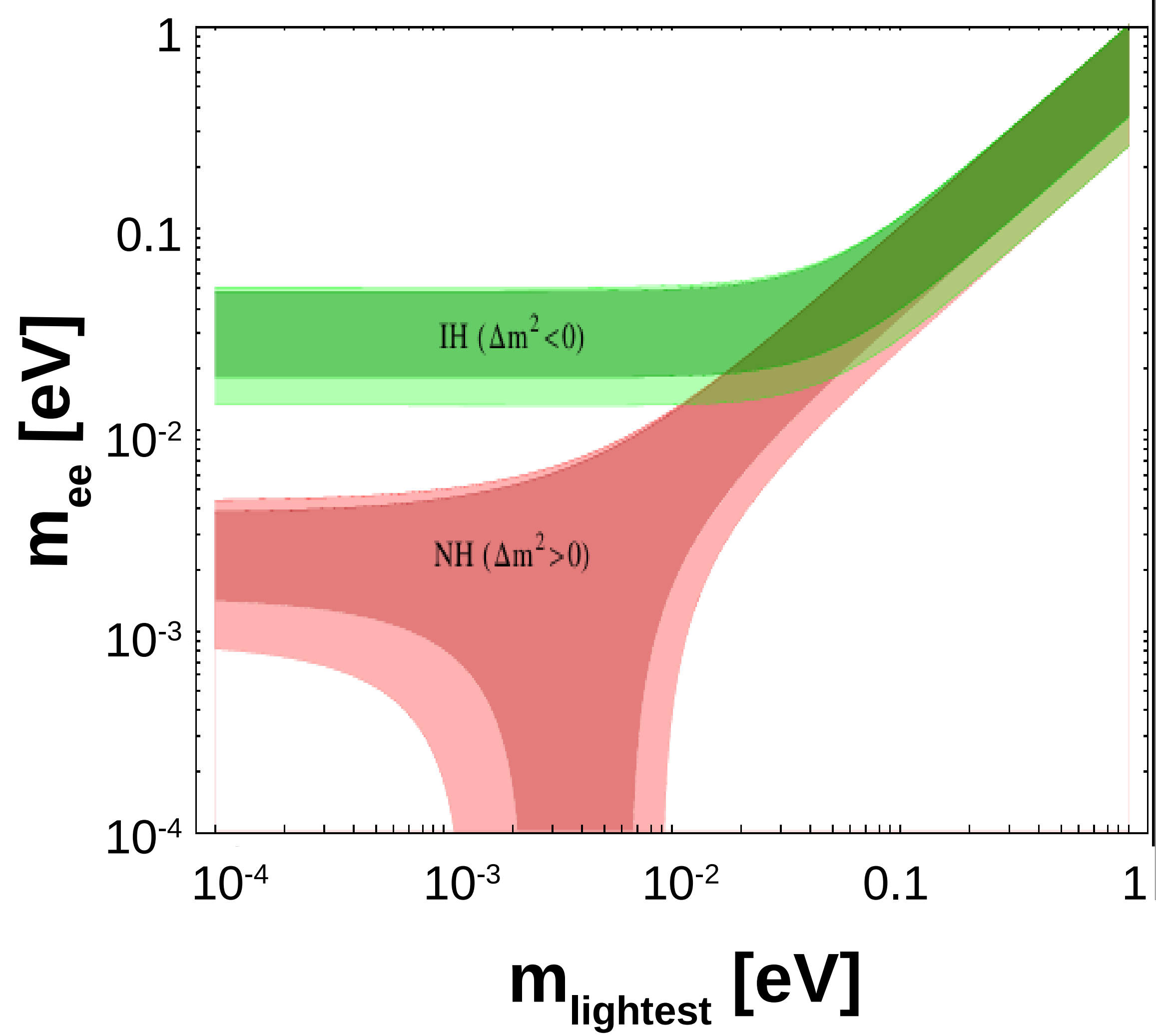
$0\nu\beta\beta$ is mostry SS whereas background events ($\gamma$'s) are often MS

**identification of daughter nucleus**

**$2\nu\beta\beta$ is the ultimate irreducible background**

importance of energy resolution - choice of proper candidate

# Goals



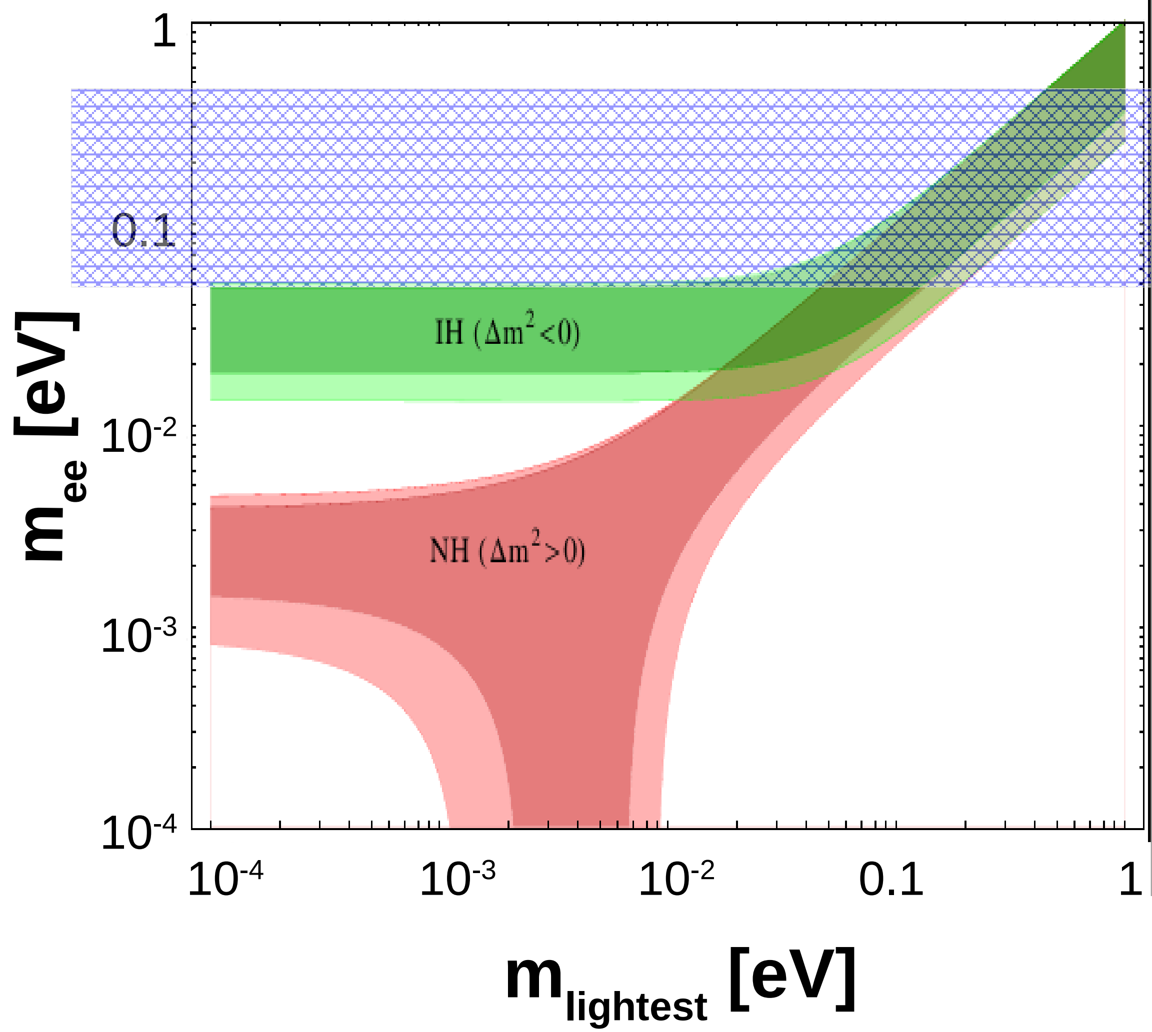
1
0.1
10^-2
10^-3
10^-4
m_ee [eV]
IH (Δm²<0)
NH (Δm²>0)
10^-4
10^-3
10^-2
0.1
1
m_lightest [eV]

# Goals

***"present generation"***

**starting/running experiments will be able to <u>approach</u> the IH**

***generally the mass is too small to see events when $m_{\beta\beta}$ is in IH band***

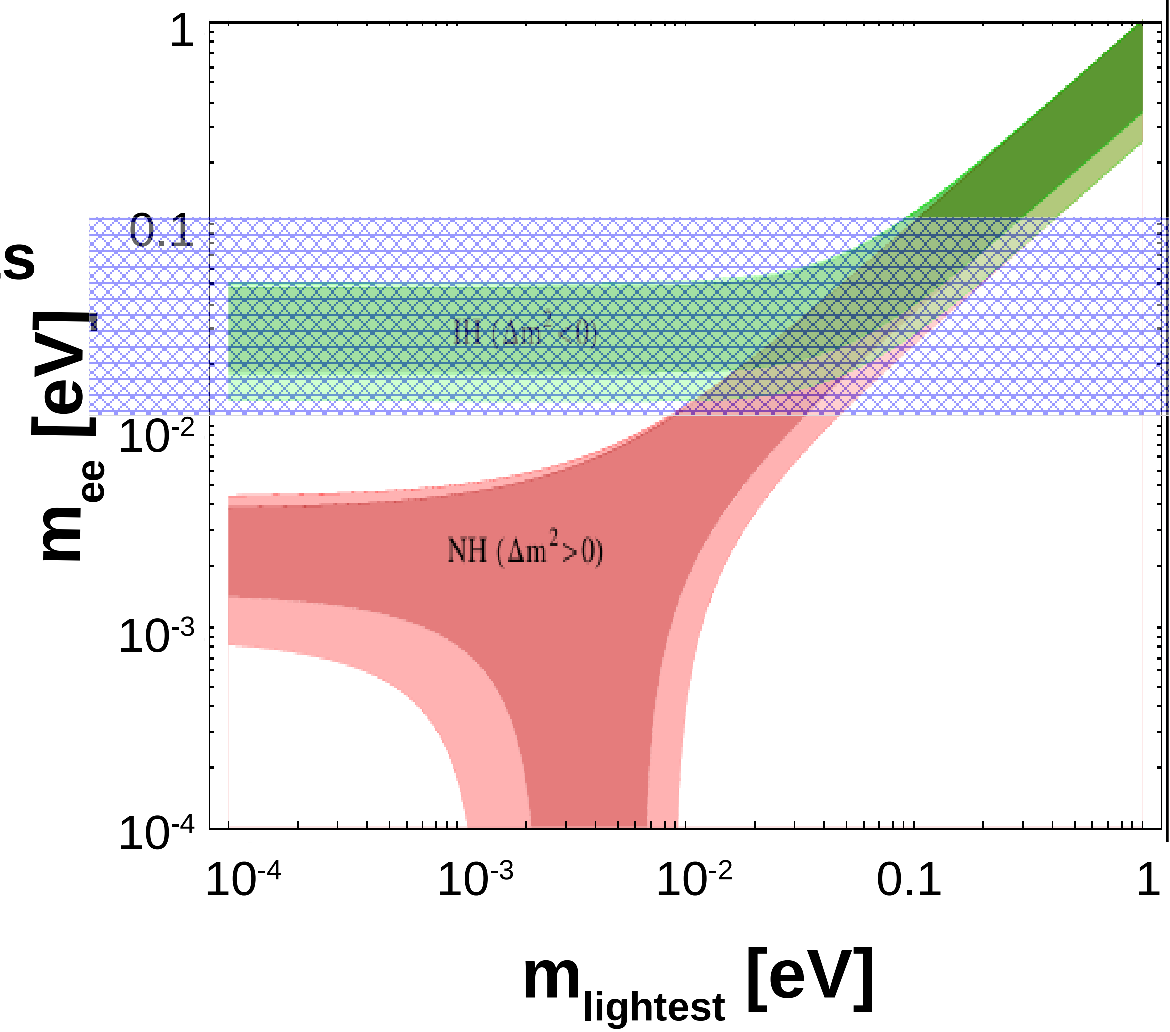


# Goals

***"future generation"***

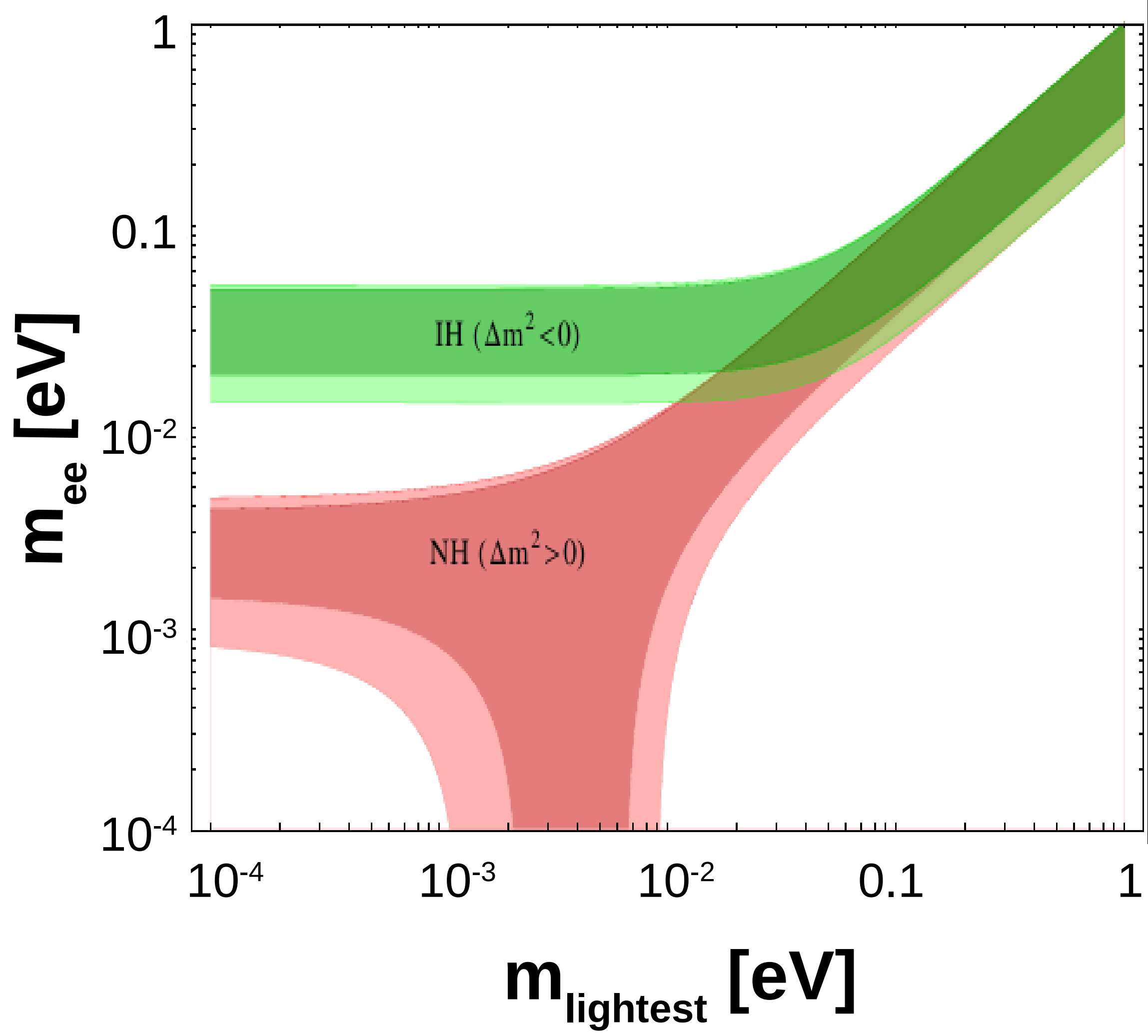
**planned /dreamed experiments aim at fully explore the IH**

***the required mass is***
***1-10 ton of isotope (if not more)***



# Goals

**or … find 0νββ somewhere !!**



# Plenty of experiments and techniques

| ***Techniques*** | ***Experiments*** |
| --- | --- |
| TPC | **EXO** NEXT |
| Inhomogeneous Tracking Detectors | SuperNEMO MOON ... |
| Bolometric Detectors | **CUORE** … AMORE LUCIFER LUMINEU... |
| Semiconductors | **GERDA** MAJORANA COBRA |
| Liquid Scintillators | **KamLAND-ZEN** SNO+ |

I chose only few of them …
those reporting new results or
construction achievements in the latest months

# a long standing tradition

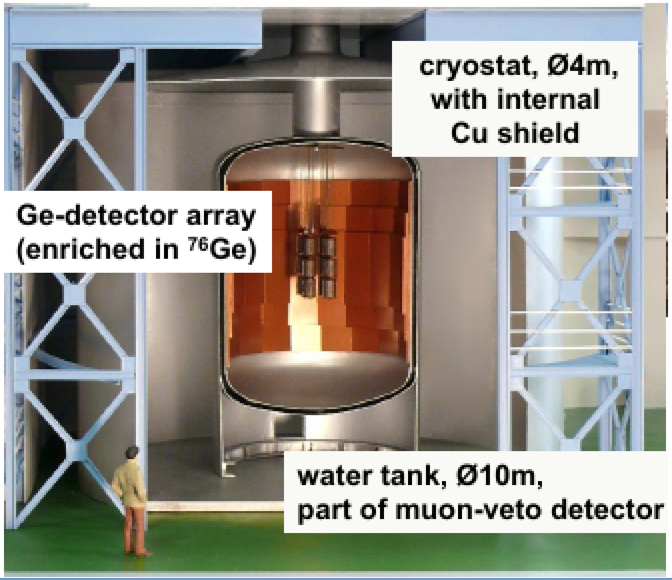
# GERDA and MAJORANA

**$^{76}$Ge – enrichible – $Q_{\beta\beta}$ = 2039 keV**

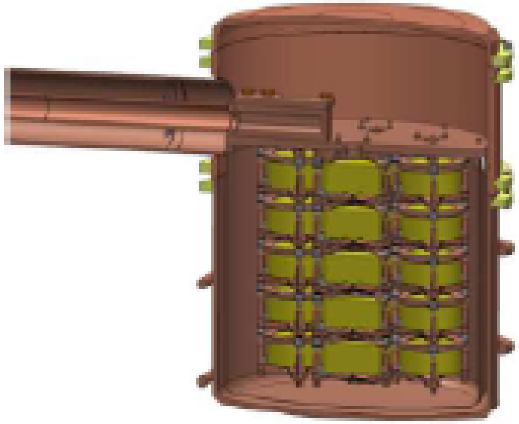
widely used technique for $\gamma$ spectroscopy

two different strategies

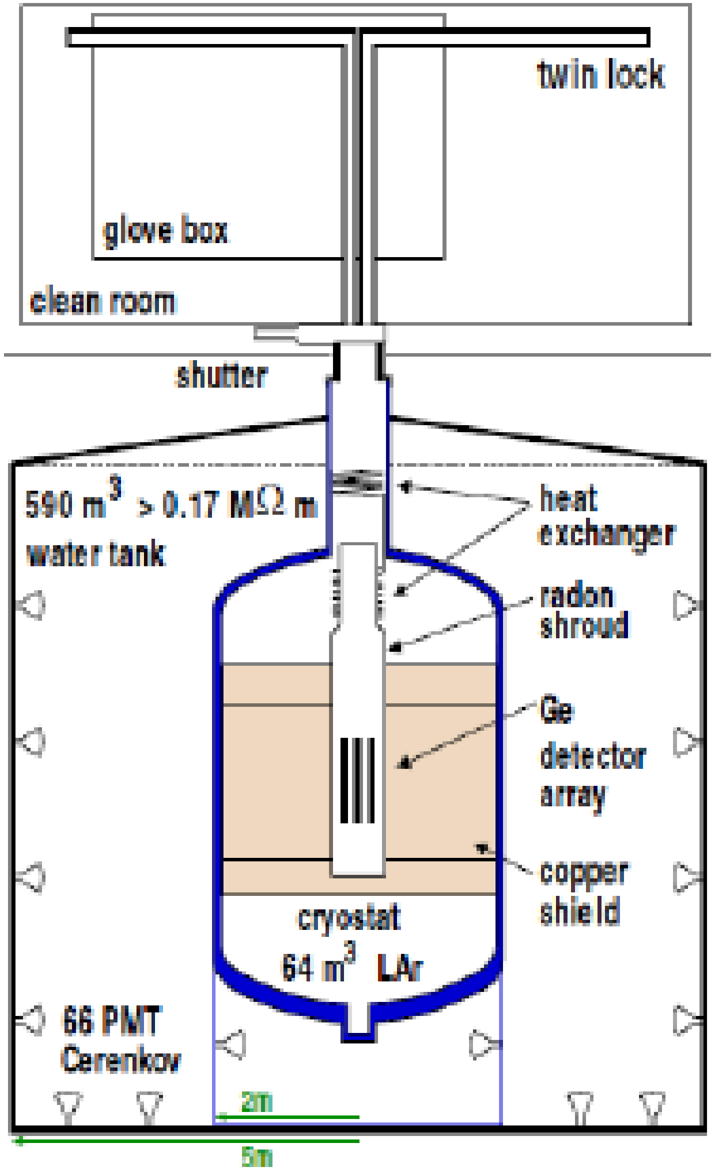
in **GERDA** *(running)*




**MAJORANA Demonstrator**
*(under construction)*



# GERDA




## experimental set-up

- $^{76}$Ge enriched HPGe detectors operated in a LAr
- water Cherenkov tank
- LNGS 3800 m.w.e. overburden

## strategies

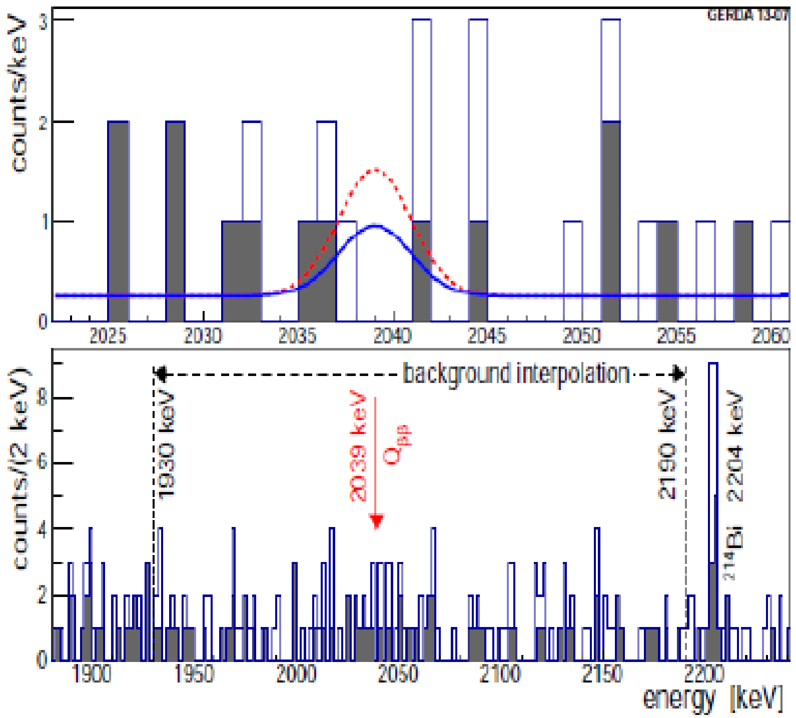
- **well defined phased program** (mass increase and detector improvement)
- **ionization signal FWHM at $Q_{\beta\beta}$ ~ 2-4 keV**
- PSA for background rejection (SS vs MS)
- extremely radioclean environment (liquid generally easly purified)
- active shield
  - phase I water Cherenkov
  - phase II LAr scintillation

# GERDA – phase I

| | |
|---|---|
| **Exposure 21.6 kg x y** | refurbished coaxial HPGe (10.9 kg) + new BEGe (3.6 kg) |
| **Background Index** Coaxial | **1.7 $10^{-2}$ counts/(keV kg yr)** |
| BEGe | **3.6 $10^{-2}$ counts/(keV kg yr)** |

**0νββ result** **$T^{0\nu}_{1/2}$ > 2.1 $10^{25}$ yr at 90% C.L.**

**Klapdor claim ~ ruled out !**




**BEGe bkg is 30 times higher than what needed for Phase II**

**main background sources**

$^{42}K$ + $^{222}Rn$ in LAr
($^{42}K$ unexpected and partially already mitigated)

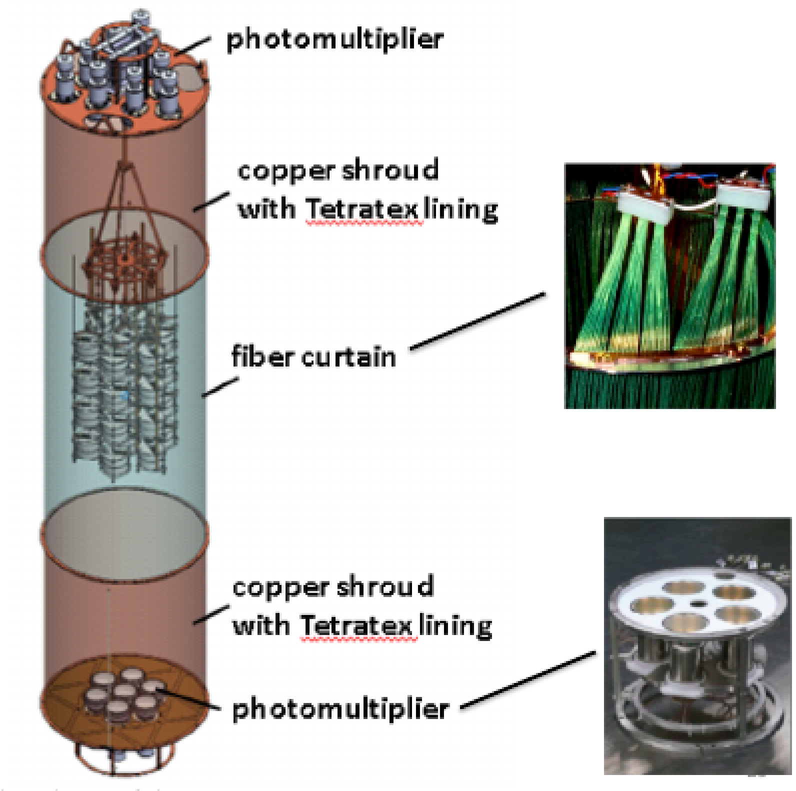
$^{214}Bi$+$^{228}Th$ in detector assembly
surface alphas

# GERDA – toward phase II

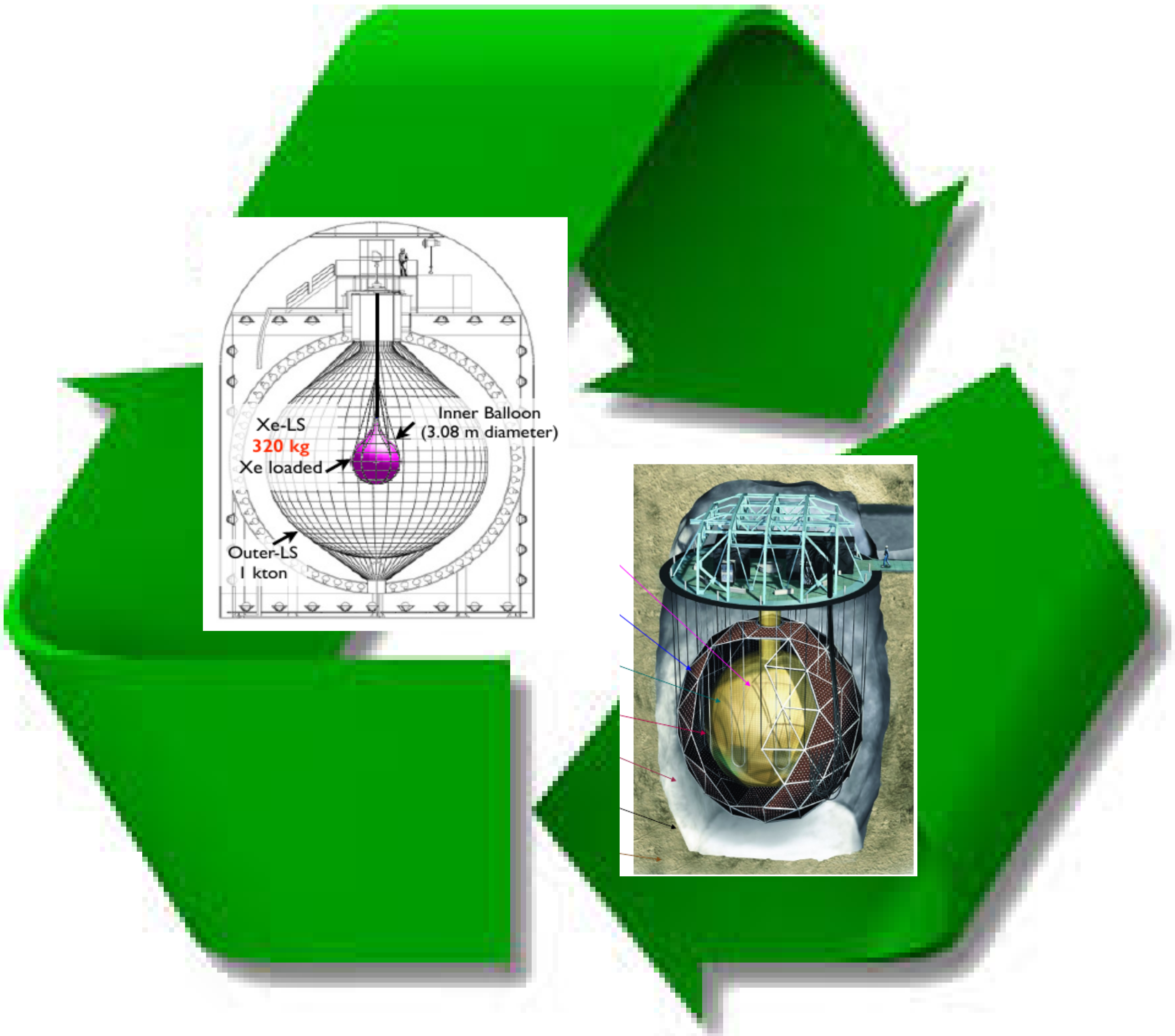
- Transition to Phase II ongoing:
  - Increase of target mass (+20 kg; total ≈40 kg of Ge detectors)
  - New custom made BEGe detectors with enhanced pulse shape discrimination
  - Liquid argon instrumentation
  - Background ≤ $10^{-3}$ cts /(keV kg yr)

**Phase II Goal**

**Sensitivity $S^{0\nu}_{1/2}$ ~ $10^{26}$ yr**

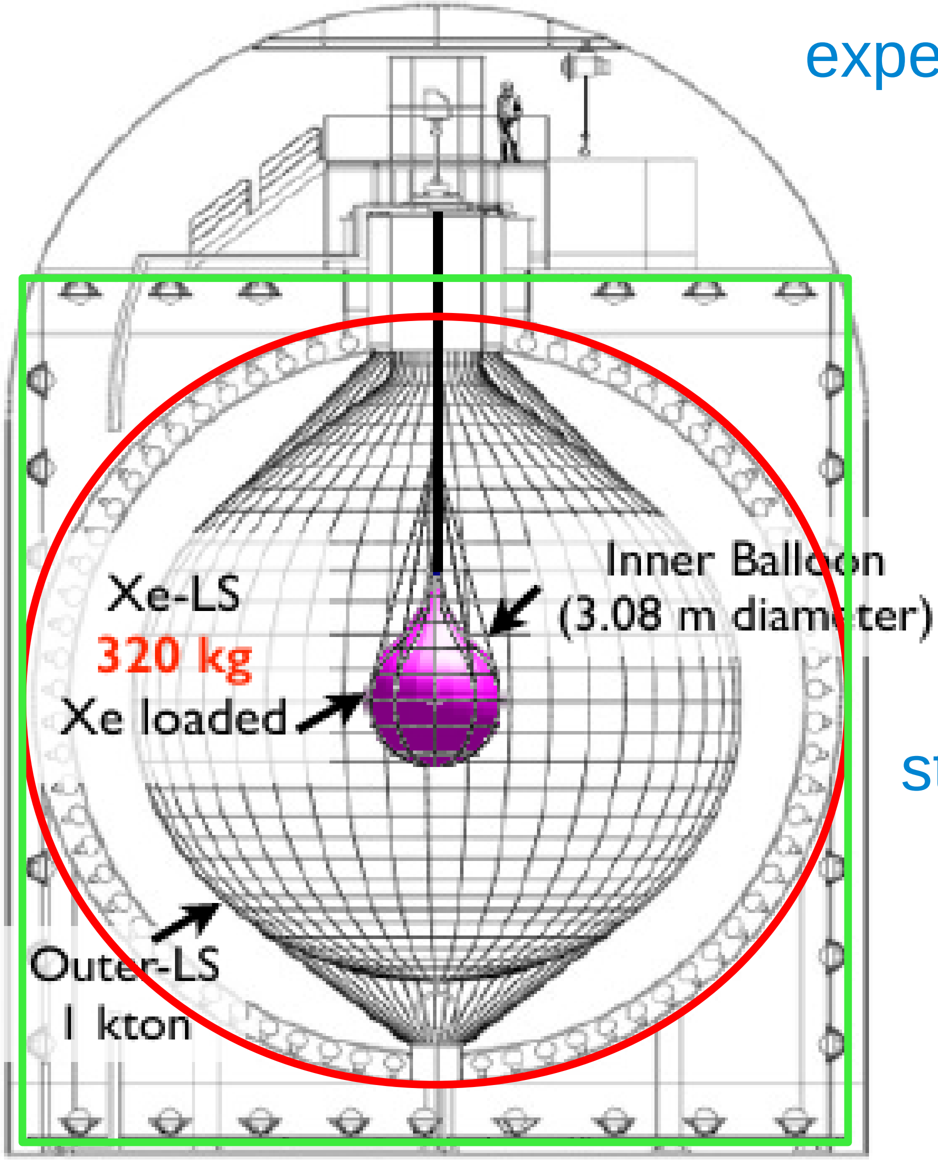


# Recycling


Xe-LS
320 kg
Xe loaded
Inner Balloon
(3.08 m diameter)
Outer-LS
1 kton

# Kamland-ZEN

## $^{130}$Xe – enrichible – $Q_{\beta\beta}$ = 2458 keV




## experimental set-up

**Inner Balloon** = Xe loaded liquid scintillator
DBD source 320 kg Xe (290 kg $^{136}$Xe)
increased to 383 kg Xe in phase II

**Outer Balloon** = liquid scintillator
active shield for external gammas

**Water Cherenkov** detector muon veto

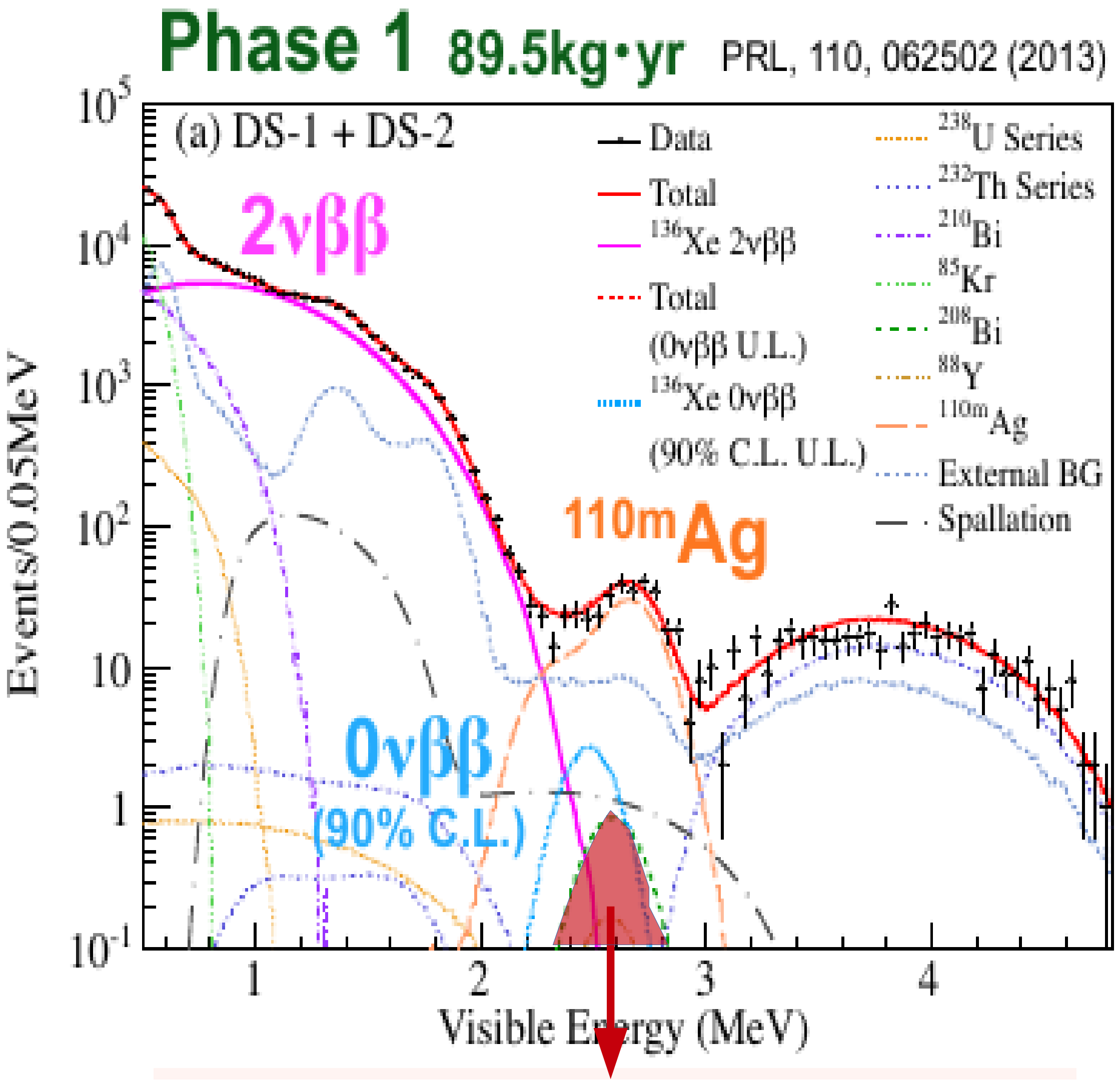
2700 m.w.e. Kamioka

## strategies

**scintillation signal** FWHM at $Q_{\beta\beta}$ ~ 240 keV

different **cuts used to reject bkg events**
Fiducial Volume changed over the analyses

# Kamland-ZEN – phase I data




$Q_{\beta\beta}$ = 2458 keV

fiducial volume

179 kg first data-set
125 kg second data set

dominant background from $^{110}$Ag (Fukushima fallout or p interaction on Xe)

$T^{0\nu}_{1/2}$ > 1.9 $10^{25}$ yr (90% C.L.)

# Kamland-ZEN – toward phase II

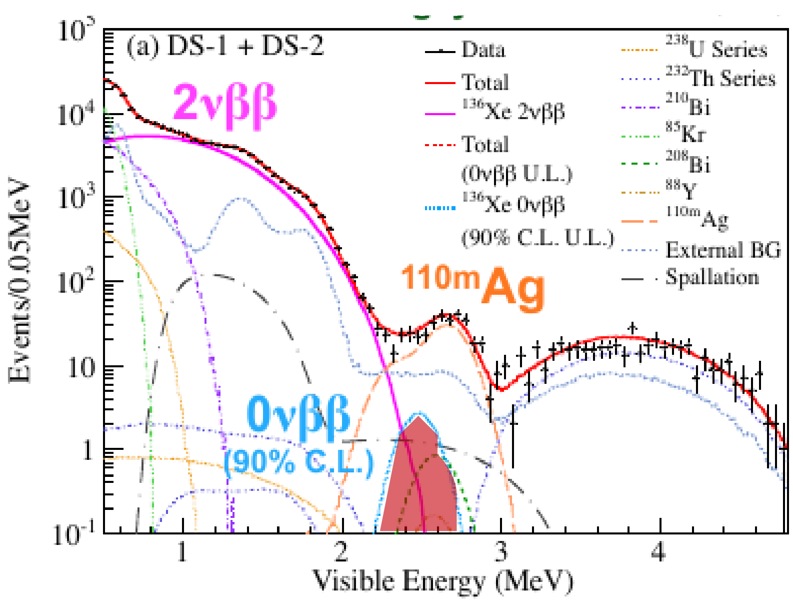
purification of both Xe and LS — $^{110}$Ag reduced by a factor 10

increase in Xe concentration

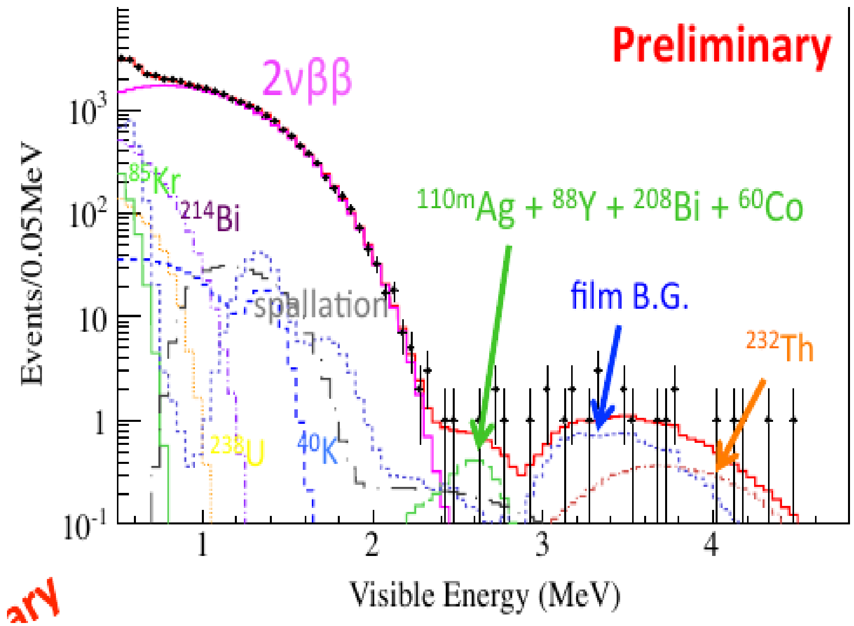
| phase 1 | | phase 2 |
|---|---|---|
| (2.44 ± 0.01) wt% | → | (2.96 ± 0.01) wt% |

optimization of background rejection cuts

**phase I**




**phase II**



# Kamland-ZEN – phase II

*preliminary*

| | |
|---|---|
| Phase 1 (213 days) | $T^{0\nu}_{1/2} > 1.9 \times 10^{25}$ yr |
| Phase 2 (115 days) | $T^{0\nu}_{1/2} > 1.3 \times 10^{25}$ yr |
| Combined | $\mathbf{T^{0\nu}_{1/2} > 2.6 \times 10^{25}}$ **yr** |

$$\downarrow$$

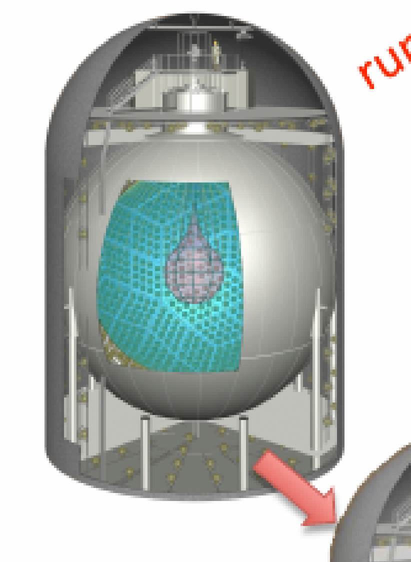
$\langle m_{\beta\beta} \rangle < 0.14\text{-}0.28$ eV (QRPA)

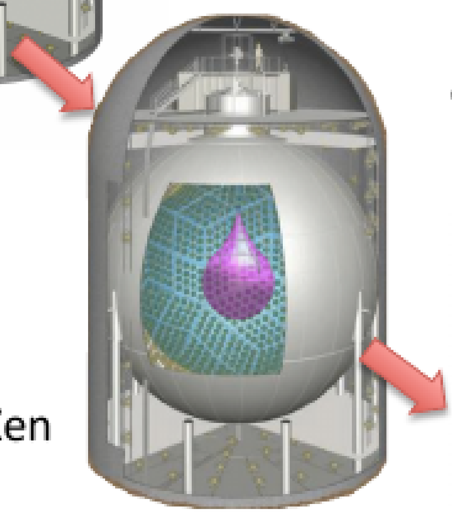
*Neutrino 2014 - Itaru Shimizu for Kamland-ZEN*

# **Kamland-ZEN** – future prospects

KamLAND-Zen Phase II

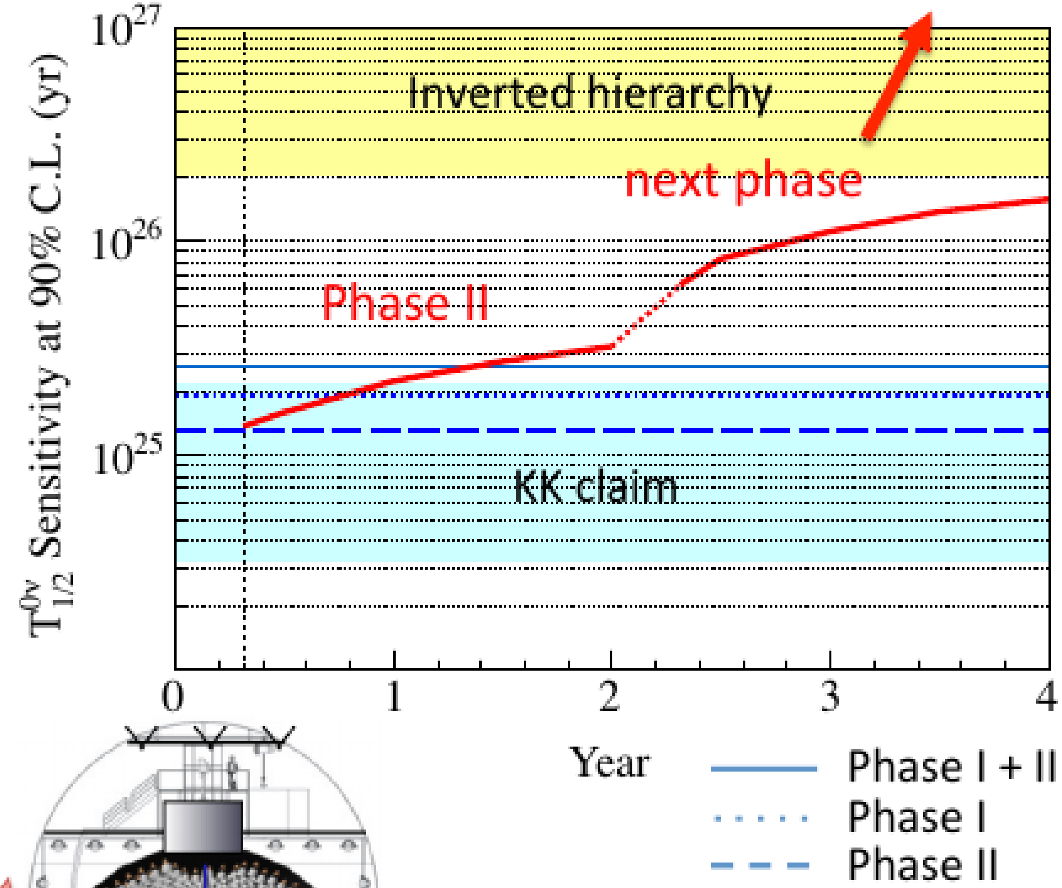
running

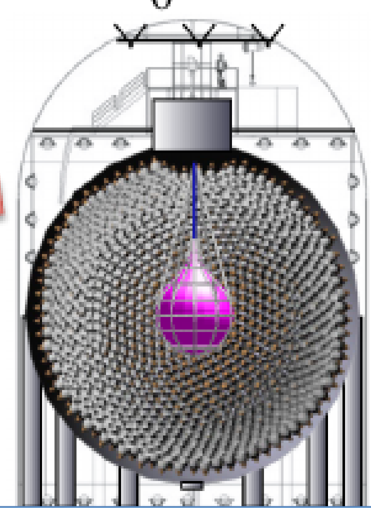




KamLAND-Zen
next phase
new inner balloon with
700 – 800 kg Xe

funded



KamLAND2-Zen
high Energy resolution
pressurized xenon

planning

# the very popular $^{136}$Xe !!

beside Kamland-ZEn other two experiment are based on $^{136}$Xe – why ?

the **only gaseous DBD candidate**

- good NME
- easily enrichable
- easily purified
- high $Q_{\beta\beta}$ (2458 keV)

allows **application of TPC technique**

- **EXO** LXe working
- **NEXT** pressurized Xe under construction

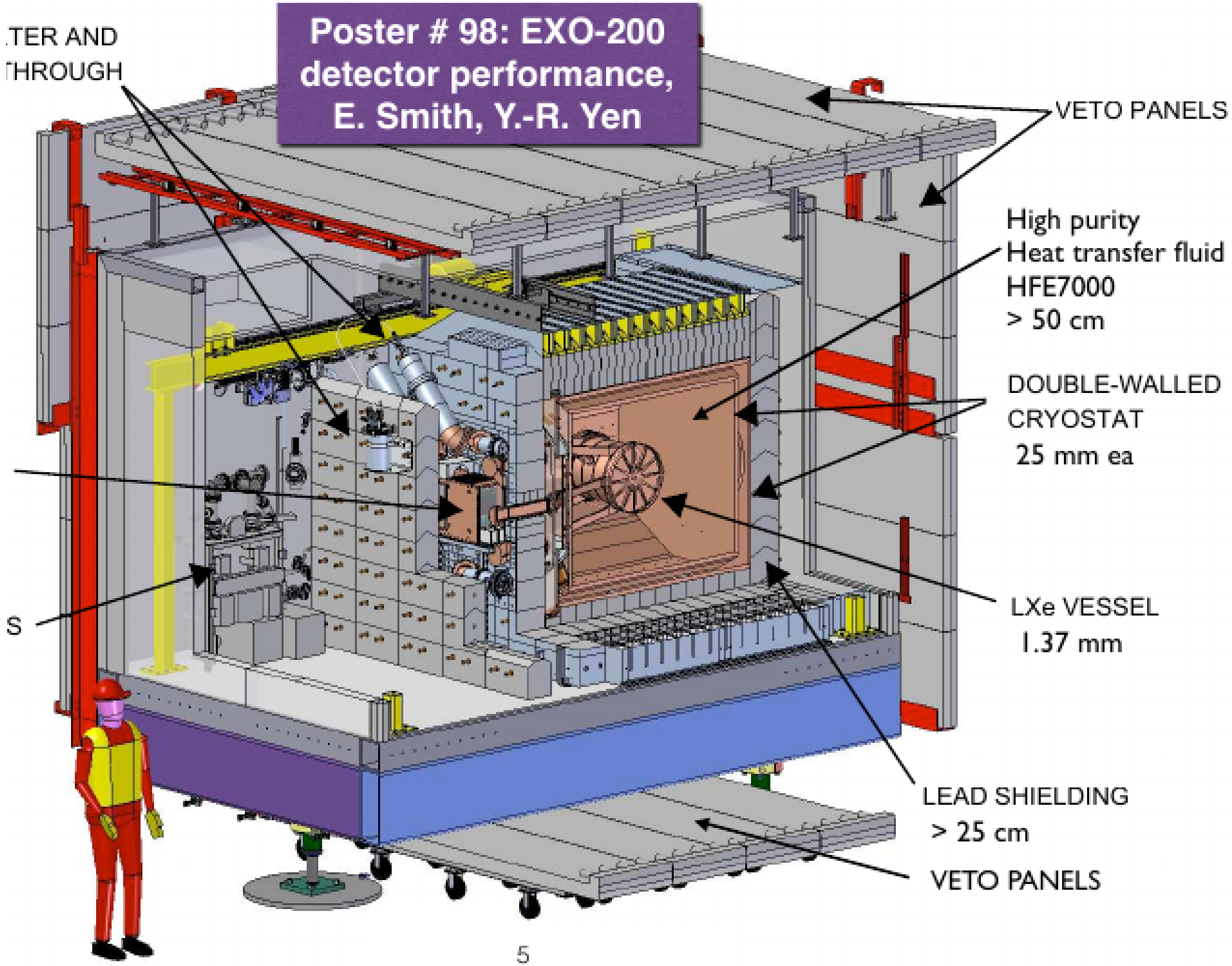
# EXO-200

## experimental set-up

liquid Xe TPC
80.6% enriched $^{136}$Xe

heavvy shielded

WIPP New Mexico 1587 m.w.e.



# EXO-200

strategies

ionization

scintillation

X-Y-Z position

event classification in SS single-site / MS multi-site
most of DBD are SS whereas bkg is often MS

Fiducial Volume cut (bkg events induced by contamination in vessel ...)

energy measurement **FWHM 88 keV**

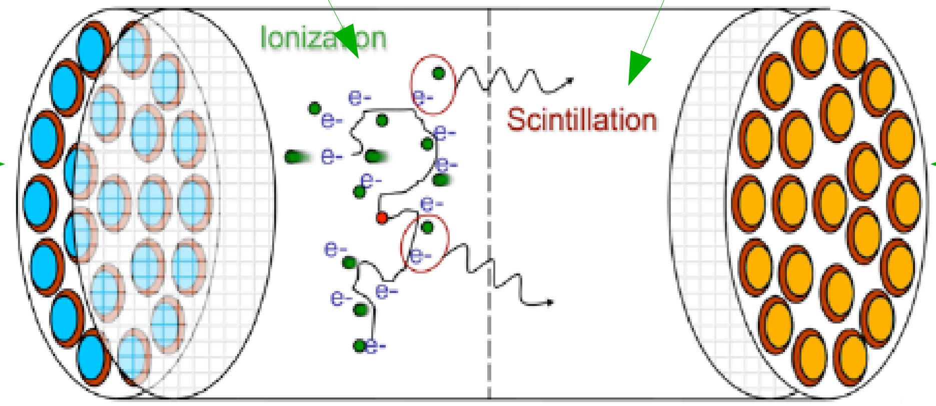
ionization/scintillation alpha rejection

*cathode*

*drift region I*

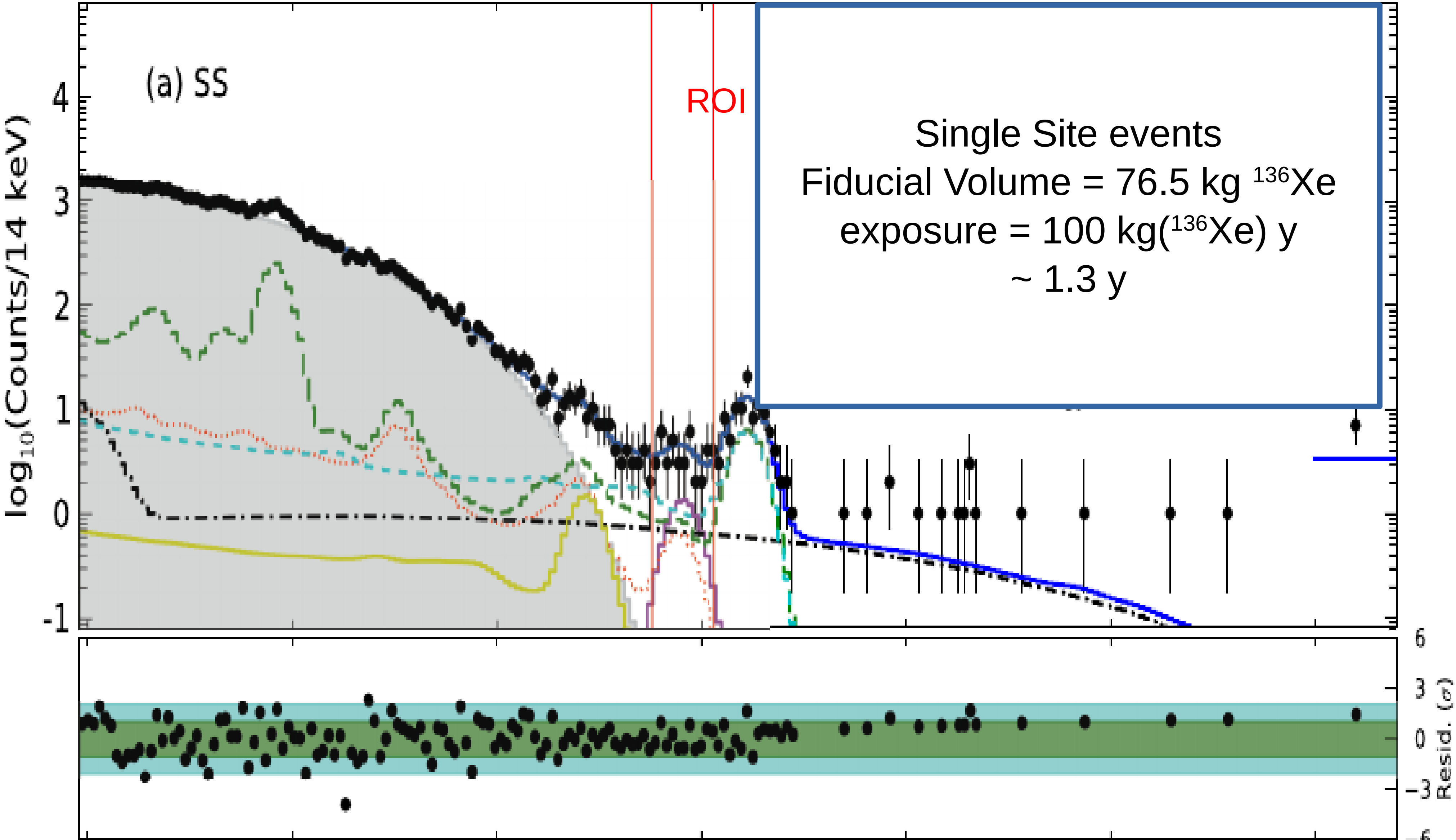
*drift region II*

*APD = Avalanche Photo-Diodes (light collection)*




*APD = Avalanche Photo-Diodes (light collection)*

# EXO-200 – $T_{1/2}^{0\nu} < 1.1 \times 10^{25}$ y




Single Site events
Fiducial Volume = 76.5 kg $^{136}$Xe
exposure = 100 kg($^{136}$Xe) y
~ 1.3 y

# EXO – future prospects

| | limit | sensitivity |
|---|---|---|
| PRL 2012 | 1.6 $10^{25}$ y | 0.7 $10^{25}$ y |
| Nature 2014 | 1.1 $10^{25}$ y | 1.9 $10^{25}$ y |

**EXO-200**

5 year sensitivity ~ 4 $10^{25}$ y
simply scaling the sensitivity with time sqrt (5/1.3)

**EXO-n (5000 kg ?)**

increase in mass (increase also self-shielding)
better SS/MS (improved spatial resolution)

**daughter nucleus identification ??**

Identification of Ba ion :
$^{136}Xe \rightarrow {}^{136}Ba^{++} + 2e^-$
by laser fluoresence

# BOLOMETERS

**operate at 10 mK**

**solid state detectors** competitive (similar FWHM) with Ge diodes
energy resolution FWHM ~ 5 keV at 3 MeV

can be made of **various ββ candidates**:
$^{82}$Se, $^{100}$Mo, $^{116}$Cd, $^{130}$Te

**particle identification possible**

# CUORE $^{130}Te$ – nat. i.a. ~34% – $Q_{\beta\beta}$ = 2528 keV

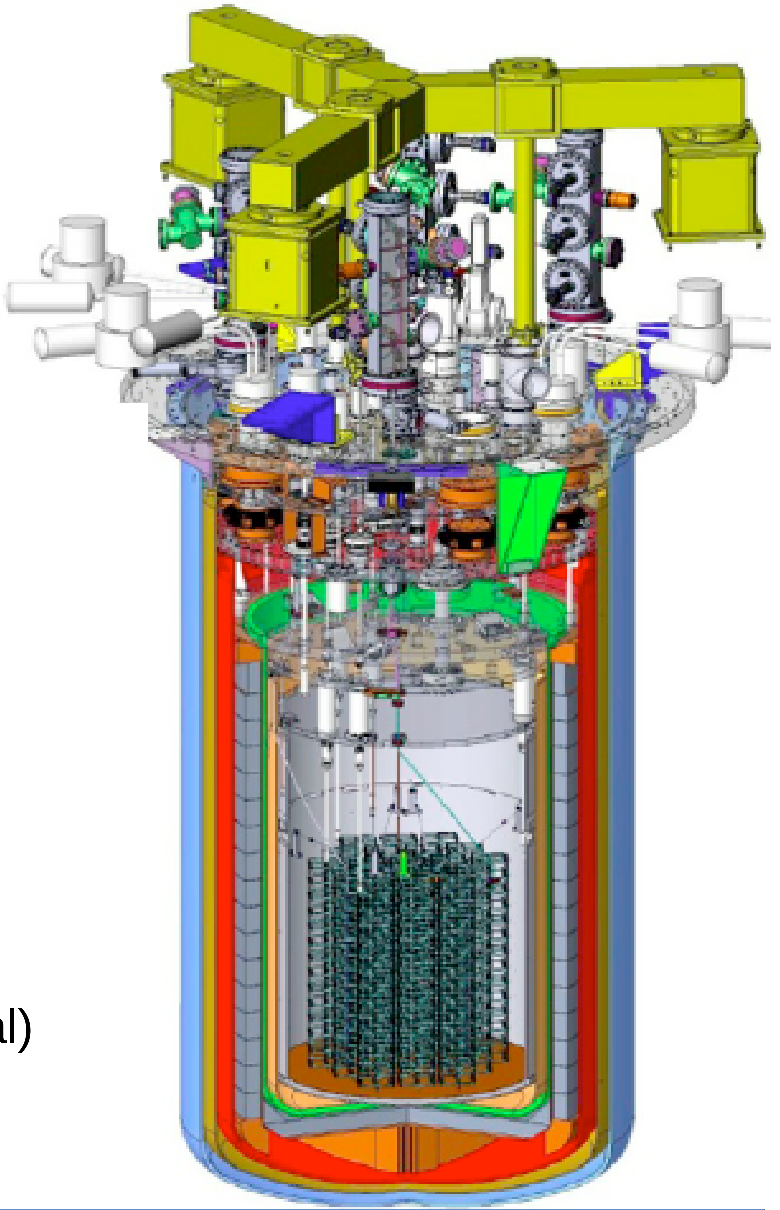
## experimental set-up

**detector** = 988 $TeO_2$ crystals operated as bolometer
= 741 kg = **206 kg $^{130}Te$**

**10 mK refrigerator** specially designed low activity

**internal/external** Pb shields + neutron shield

LNGS 3800 m.w.e. overburden

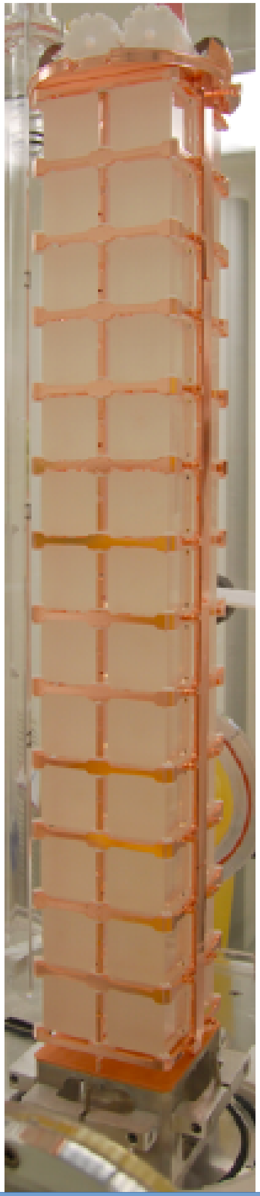


## strategies

**thermal signal** FWHM at $Q_{\beta\beta}$ ~ 5 keV

**background rejection** obtained operating the detectors in anticoincidence (DBD signal fully contained in 1 crystal)

# CUORE – the demonstrator = CUORE-0



**1 CUORE tower mounted in the old Cuoricino cryostat**
**52 $TeO_2$ crystals = 39 kg = 11 kg $^{130}Te$**

**CUORE-0 demonstrator – CUORE goals are**

(I) resolution **5 keV FWHM at $Q_{\beta\beta}$**

(II) background **$10^{-2}$ c/keV/kg/y**

→ **Sensitivity $S^{0\nu}_{1/2}$ ~ $10^{26}$ yr**

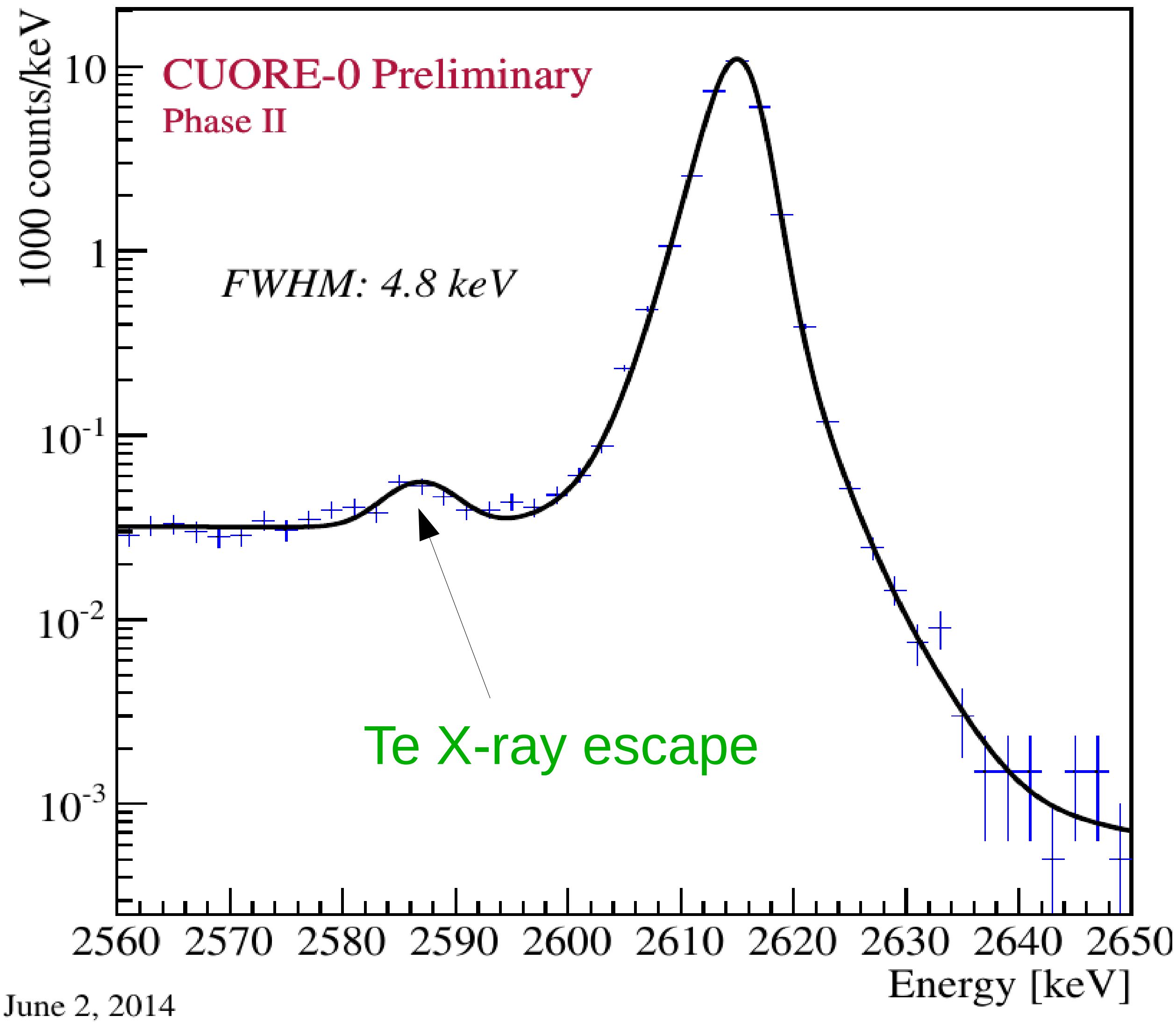
**$^{130}Te$ DBD experiment**

**running** - June 2014 background exposure 18.06 kg.y or 5.02 kg($^{130}Te$).yr.

presently blinded data in the DBD region

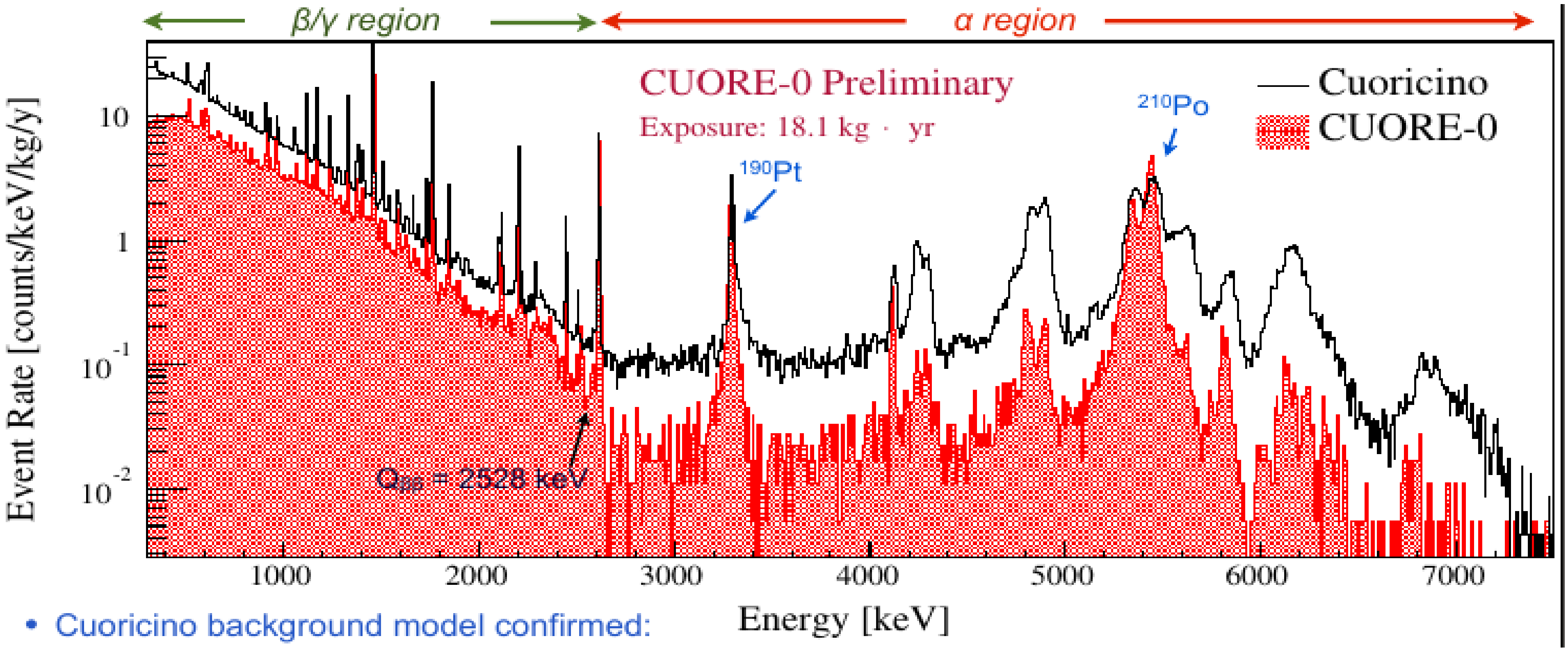
# CUORE – the demonstrator = CUORE-0

CUORE-0 Calibration Spectrum (Phase II)




$^{232}$Th calibration of Cuore-0 array

# CUORE – the demonstrator = CUORE-0

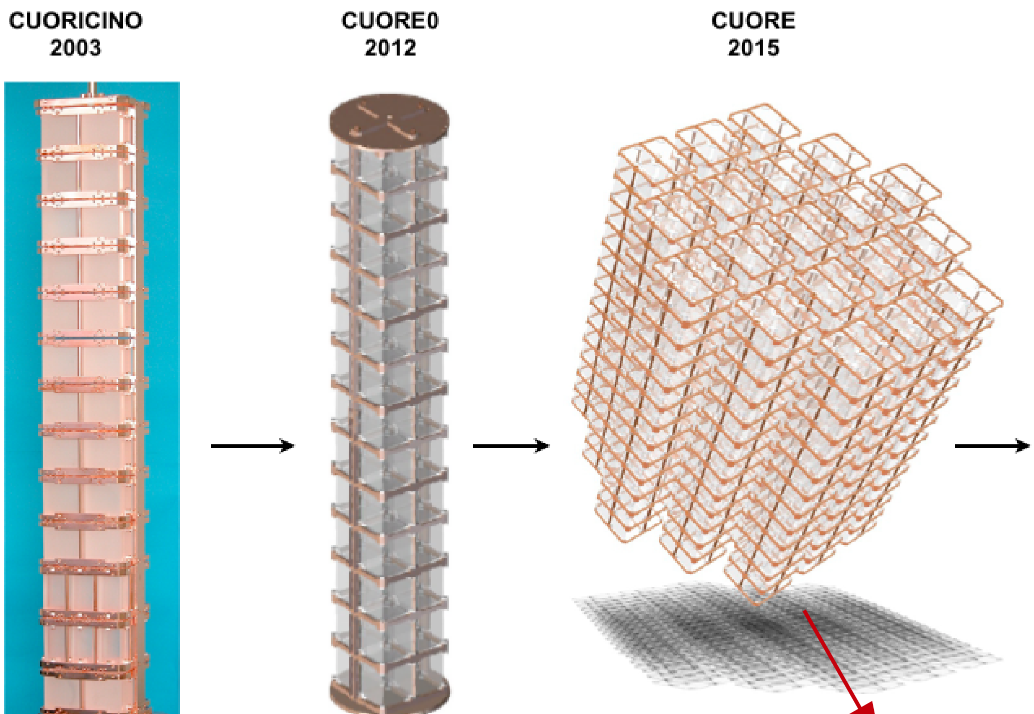



- Cuoricino background model confirmed:

extrapolating CUORE-0 result to CUORE
(less radioactive cryostat + more effective anticoincidence cut)

**$10^{-2}$ c/keV/kg/y is feasible**

# CUORE – future prospects




**among future possibilities**

- **scintillating bolometers**
- **$TeO_2$ enriched bolometers**
- **$TeO_2$ + Cerenkov light read-out**

**data taking in 2015**
**5 y sensitivity $10^{26}$ y**

**unblinding in 2015**
**sensitivity 2 $10^{24}$ y**

# Conclusions

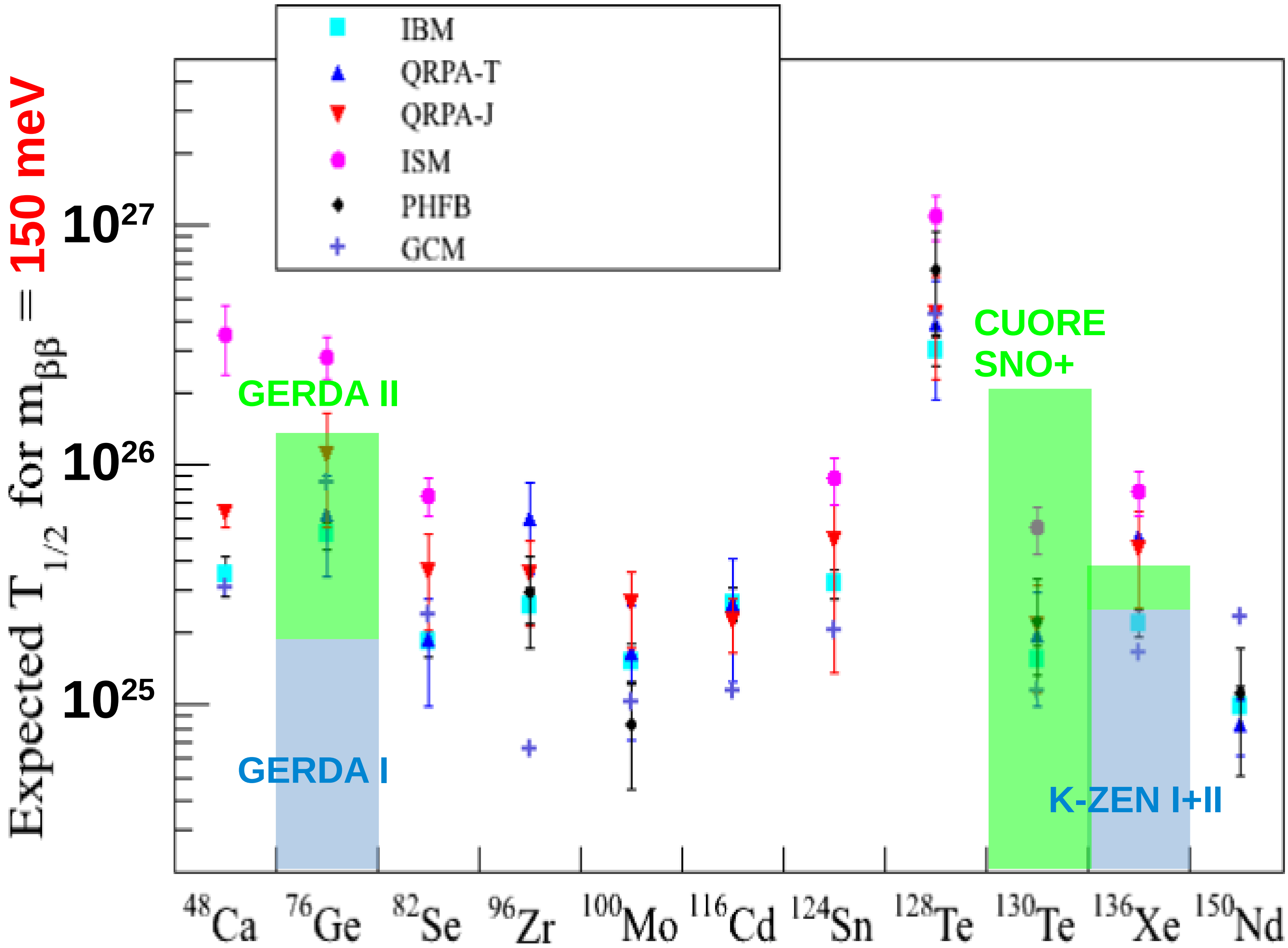
present generation experiments running or nearly (within 1-2 years) running aim at approaching the IH region

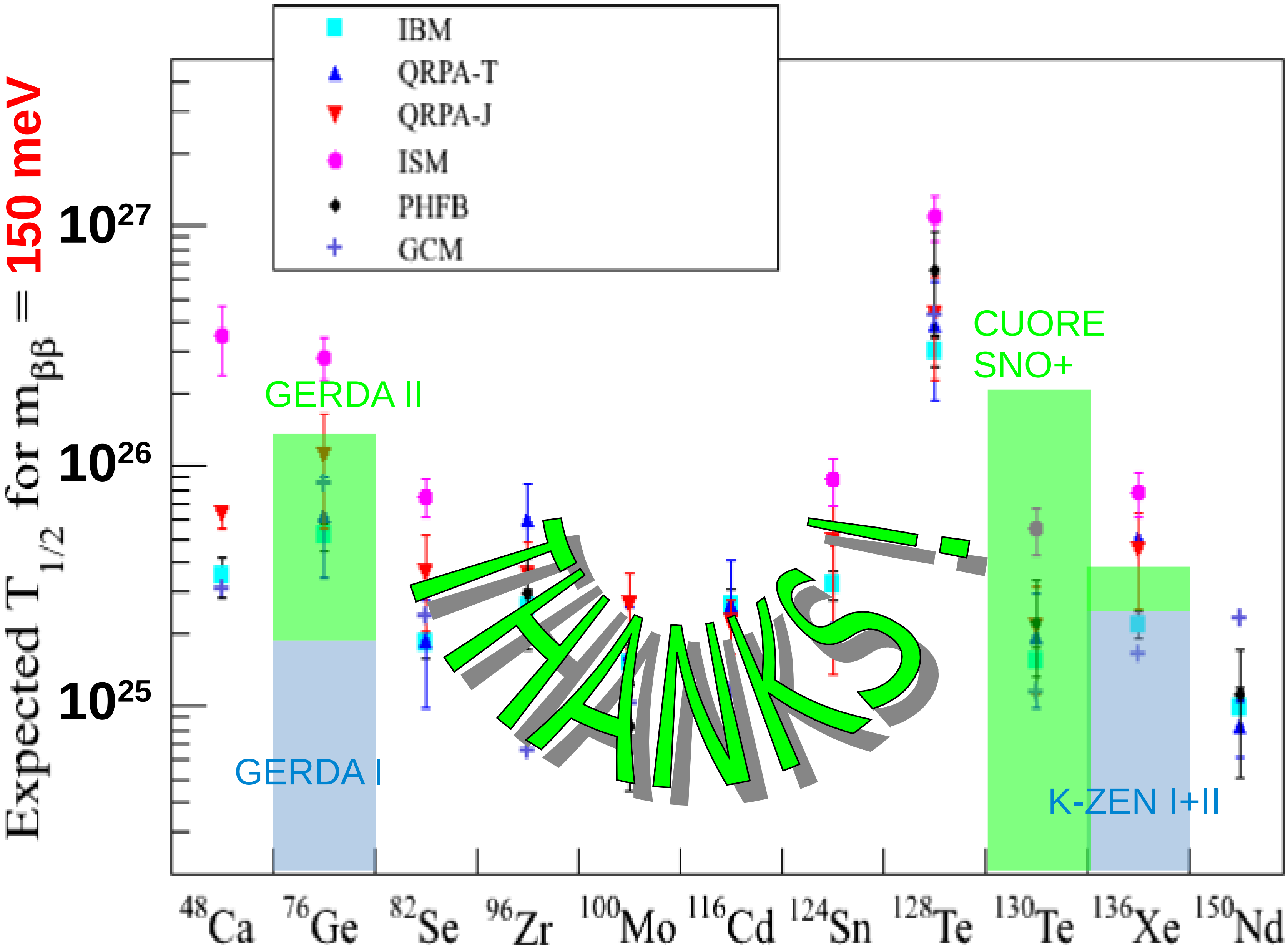
various technical efforst toward improvement of techniques

the challenge of net generation is to be able to (nearly) fully cover the IH

- huge masses (procurement of isotope may be a big issue)
- zero background detectors

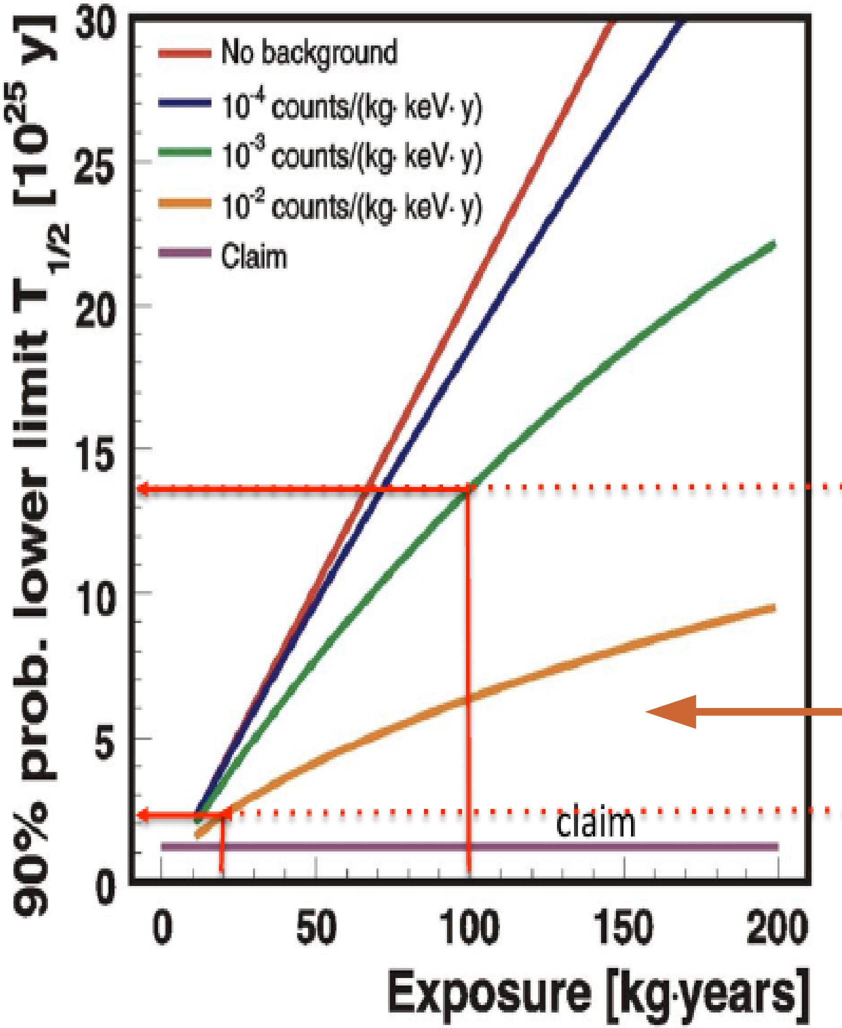
**just to understand how number now discussed compares among each other ….**


IBM
QRPA-T
QRPA-J
ISM
PHFB
GCM
Expected $T_{1/2}$ for $m_{\beta\beta}$ = 150 meV
$10^{27}$
$10^{26}$
$10^{25}$
GERDA II
GERDA I
CUORE
SNO+
K-ZEN I+II
$^{48}$Ca $^{76}$Ge $^{82}$Se $^{96}$Zr $^{100}$Mo $^{116}$Cd $^{124}$Sn $^{128}$Te $^{130}$Te $^{136}$Xe $^{150}$Nd


Expected $T_{1/2}$ for $m_{\beta\beta}$ = 150 meV
$10^{27}$
$10^{26}$
$10^{25}$
IBM
QRPA-T
QRPA-J
ISM
PHFB
GCM
GERDA II
GERDA I
CUORE
SNO+
K-ZEN I+II
THANKS !
$^{48}$Ca
$^{76}$Ge
$^{82}$Se
$^{96}$Zr
$^{100}$Mo
$^{116}$Cd
$^{124}$Sn
$^{128}$Te
$^{130}$Te
$^{136}$Xe
$^{150}$Nd

# BACKUP

# GERDA




Goal:

'background free' operation

$T^{0\nu}_{1/2}$ scales with exposure

*cooperation with MAJORANA*

Phase II:

Add new enr. BEGe detectors (+20 kg)

BI ≈ 0.001 cts / (keV kg yr)

Sensitivity after 100 kg yr

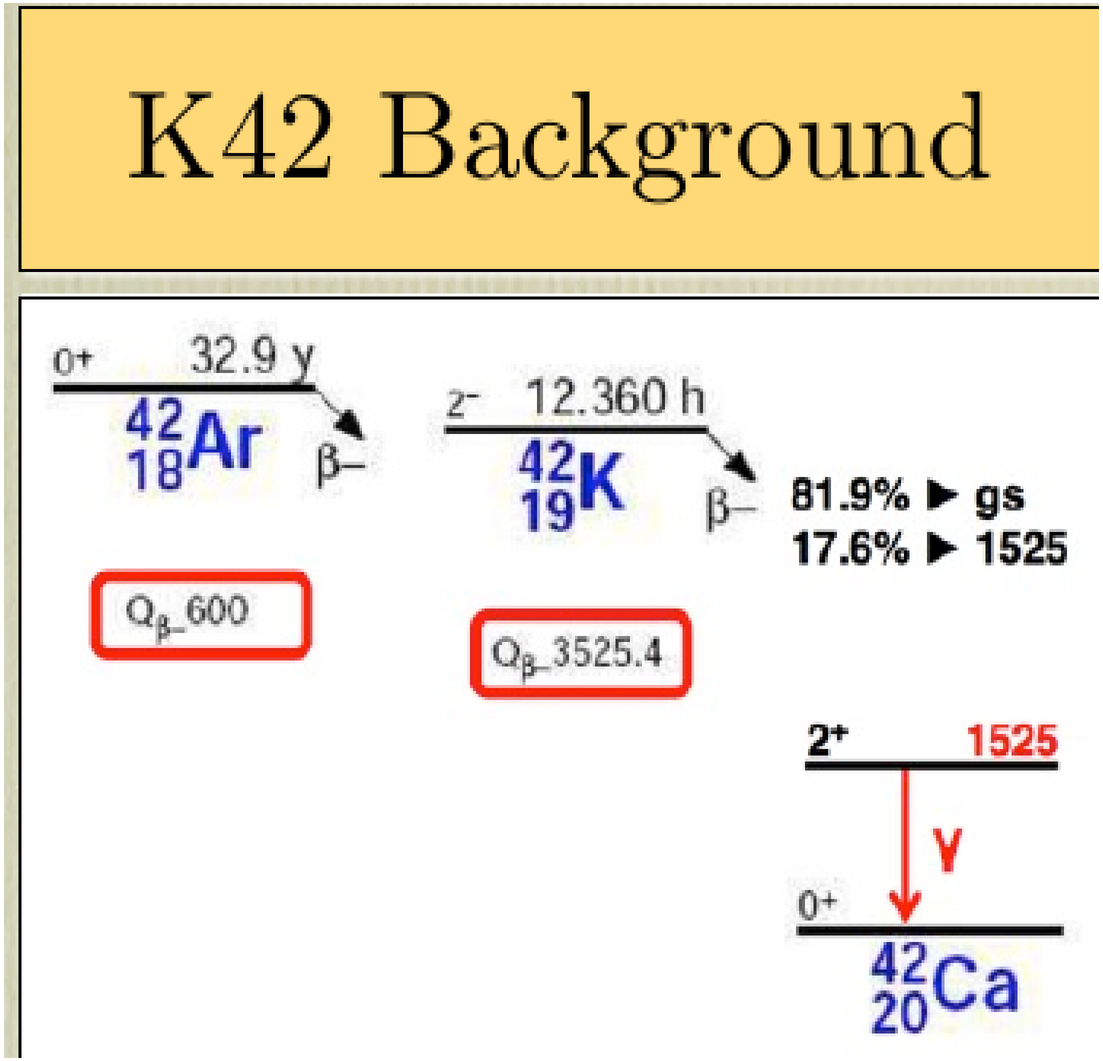
Phase I:

Use refurbished HdM & IGEX (18 kg)

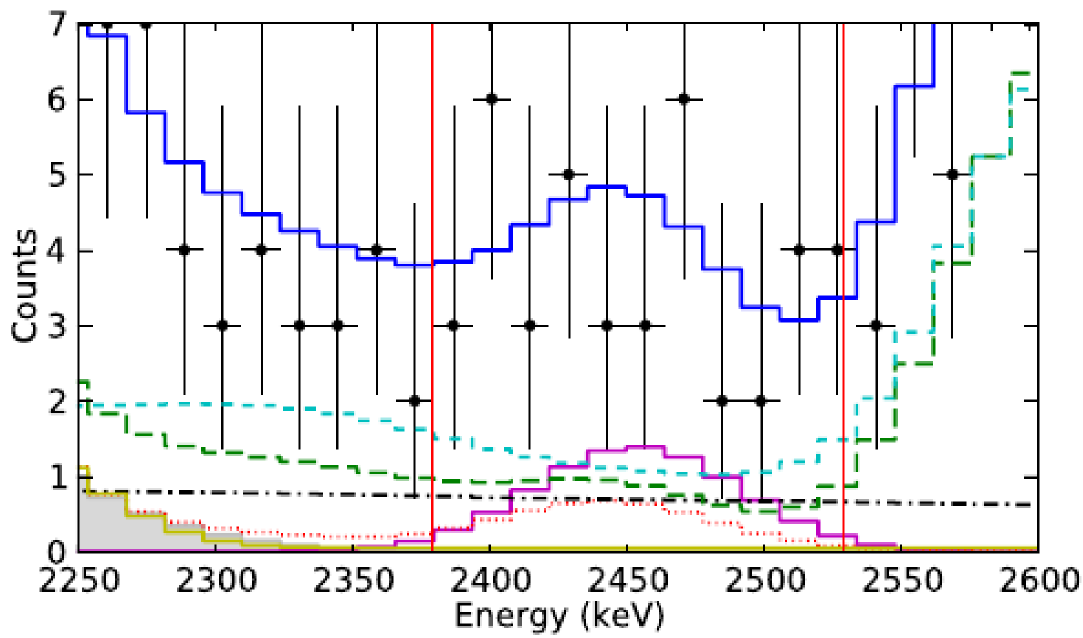
BI ≈ 0.01 cts / (keV kg yr)

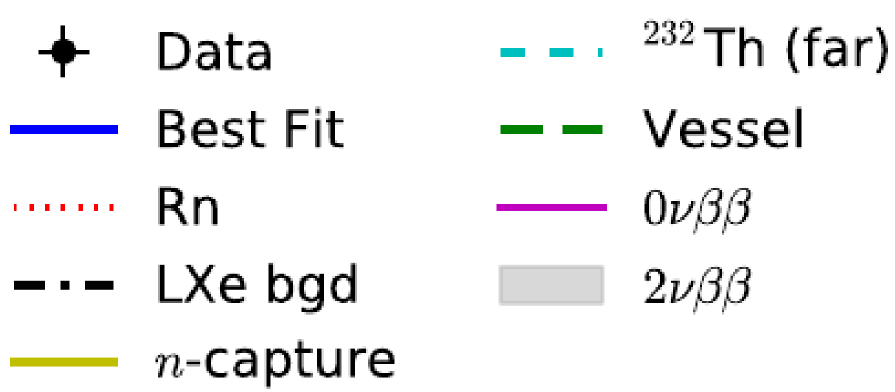
Sensitivity after 20 kg yr

# GERDA


K42 Background
0+
32.9 y
42 18 Ar
β–
Qβ– 600
2⁻
12.360 h
42 19 K
β–
81.9% ▶ gs
17.6% ▶ 1525
Qβ– 3525.4
2+
1525
γ
0+
42 20 Ca

# EXO-200 – bkg in the ROI $(1.7 \pm 0.2) \cdot 10^{-3}\ \mathrm{keV^{-1}\ kg^{-1}\ yr^{-1}}$




~ 50% from $^{232}$Th
(near and far contamination)

~ 25% from $^{238}$U
(near contamination)

~ 25% from $^{137}$Xe
(produced by n-capture)

**From profile likelihood:**

$T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25}$ yr
$\langle m_{\beta\beta} \rangle < 190 - 450$ meV
(90% C.L.)

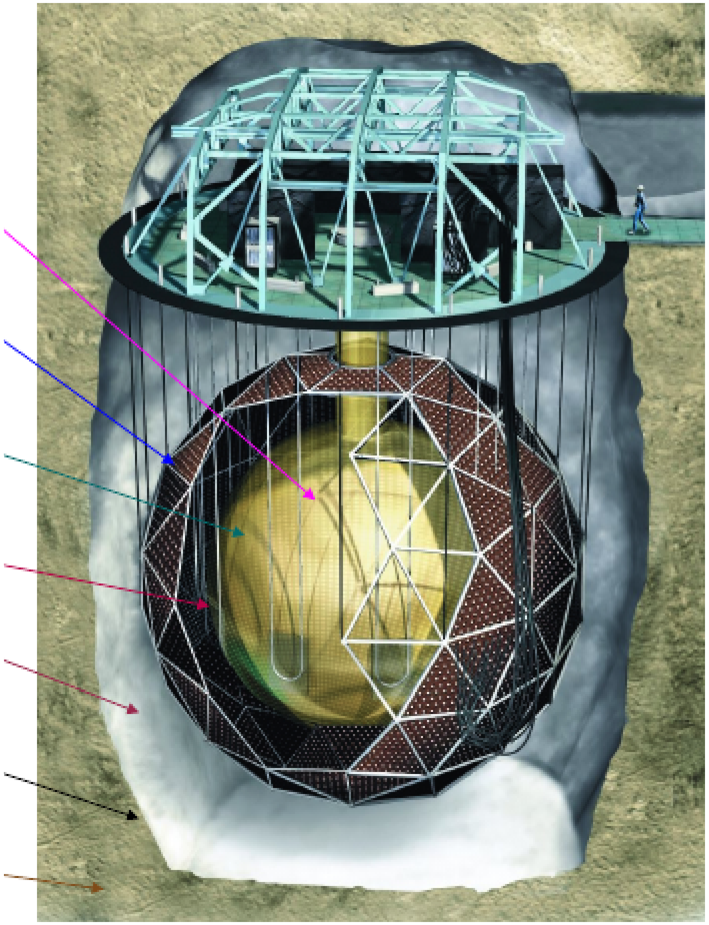
***Nature* (2014)**
**doi:10.1038/nature13432**

M.G. Marino 21 6 June 2014, Nu 2014

# SNO+

use SNO apparatus replacing heavy water with a liquid scintillator doped with a DBD candidate: **Te**

## experimental set-up



**Sphere** = 780 ton of Liquid Scintillator
to be doped with ββ active nucleus

**Geodesic Structure** = support structure for PM

**Water Cherenkov** detector muon veto

6000 m.w.e. Sudbury

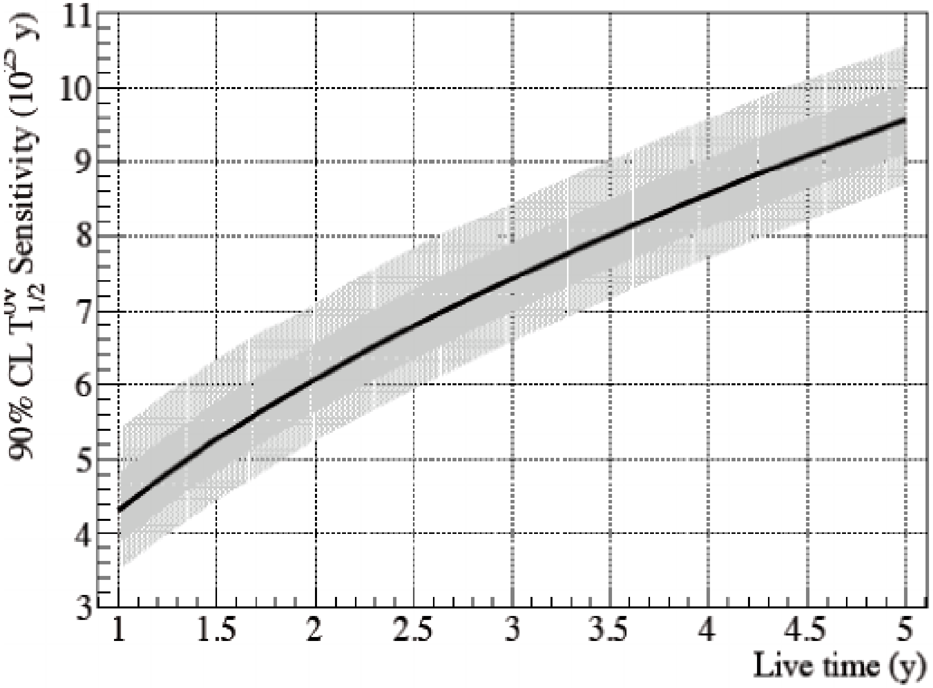
## strategies

**scintillation signal** FWHM at $Q_{\beta\beta}$ ~ 250 keV

**rejection of bkg events**
Fiducial Volume + delayed coincidences

# SNO+ - prospects

- 2014: water fill and water commissioning
  - nucleon decay physics
  - Backgrounds analysis
  - Supernovae neutrinos
- 2015: start liquid scintillator fill
  - background analysis
  - reactor- and geo- antineutrinos
  - Supernovae neutrinos
  - low energy solar neutrinos
- 2016: 0.3% Te loading
  - neutrinoless double beta decay
  - reactor- and geo- antineutrinos
  - Supernovae neutrinos




Half-life sensitivity @90%CL

down to the IH region
by (hopefully) an increase
in LS doping