BRIEF REVIEW OF DOUBLE BETA DECAY EXPERIMENTS

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OUTLINE

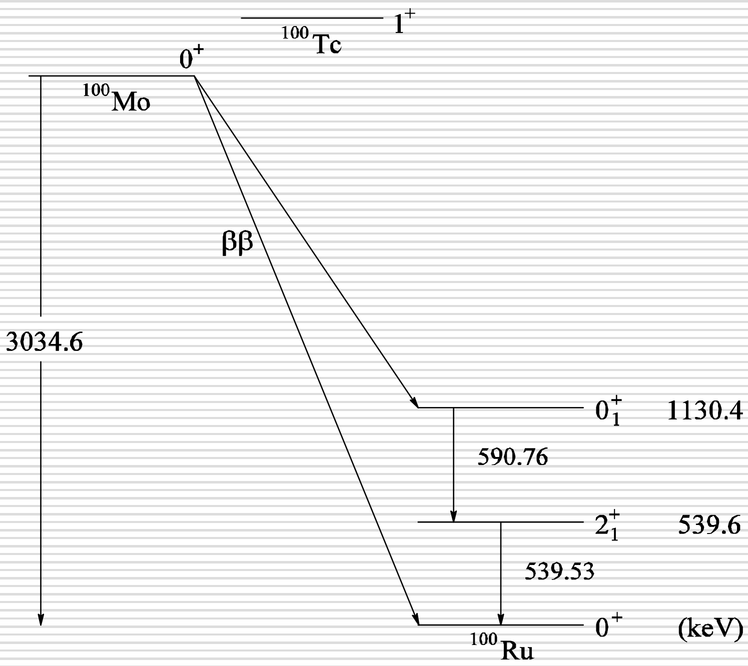
- **Introduction**

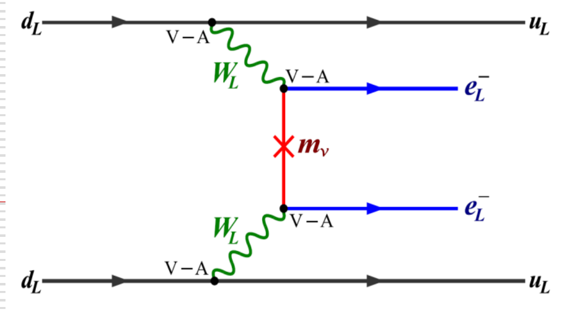
- **Best recent results:**
- **- KamLAND-Zen (Xe-136);**
- **- GERDA-II (Ge-76).**

- **Future experiments:**
- **- near future (2017-2019);**
- **- far future (2020-…).**

- **Conclusion**

1. Introduction





^{100}Mo ⇒ ^{100}Ru + 2e-

^{100}Mo ⇒ ^{100}Ru + 2e- + χ0 (+χ0)

^{100}Mo ⇒ ^{100}Ru + 2e- + 2ν

There are 35 candidates for 2β-decay

W ~ Q^5 (0ν); W ~ Q^7 ($0\nu\chi^0$)
W ~ Q^{11} (2ν)

What one can extract from 2β-decay experiments?

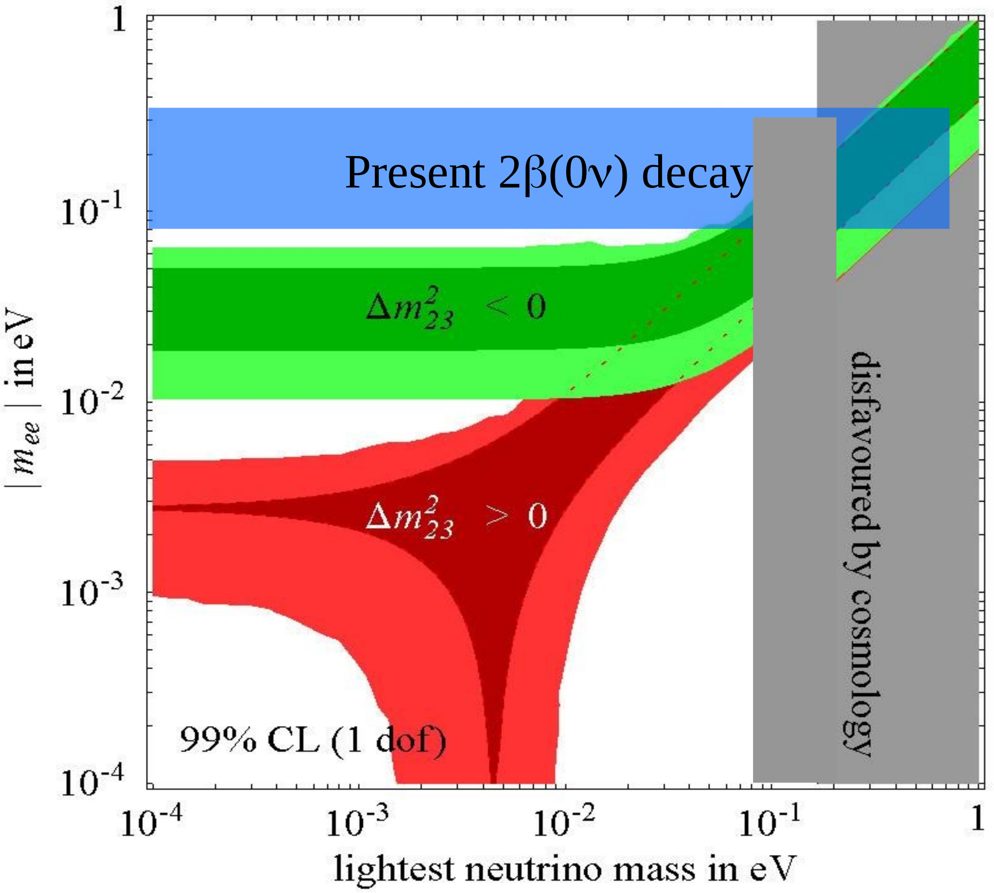
- **Lepton number nonconservation ($\Delta L=2$)**
- **Nature of neutrino mass (Dirac or Majorana?).**
- **Absolute mass scale (value or limit on m_1).**
- **Type of hierarchy (normal, inverted, quasi-degenerated).**
- **CP violation in the lepton sector**

Best present limits on $<m_\nu>$

Nucleus	$T_{1/2}$, yr	$<m_\nu>$, eV QRPA + others	Experiment
^{76}Ge	$>5.2 \cdot 10^{25}$ ($>3.5 \cdot 10^{25}$)	< 0.17-0.39 (< 0.20-0.48)	GERDA-II
^{136}Xe	$>1.07 \cdot 10^{26}$ ($>0.5 \cdot 10^{26}$)	< 0.06-0.19 (< 0.09-0.28)	KamLAND-Zen
^{130}Te	$>4 \cdot 10^{24}$	< 0.31-0.75	CUORE0 + CUORICINO
^{100}Mo	$>1.1 \cdot 10^{24}$	< 0.33-0.62	NEMO-3

Conservative limit on $<m_\nu>$ is 0.3 eV

DBD and neutrino mass hierarchy



Degenerate: can be tested

Inverted: can be tested by next generation of **2β** experiments.

Normal: inaccessible (new approach is needed)

β: m_ν < 2 eV

2β: $\langle m_\nu \rangle$ < 0.3 eV

Cosmology : Σm_ν < 0.12-0.18 eV

QUENCHING OF g_A IN NUCLEAR MATTER (g_A PROBLEM)

$$\left(T_{1/2}^{0\nu}\right)^{-1} = \left|\frac{m_{\beta\beta}}{m_e}\right|^2 g_A^4 \left|M_\nu^{0\nu}\right|^2 G^{0\nu}$$

⇒ $m_{\beta\beta} \sim 1/g_A^2$

g_A = 1.27 from free neutron decay

$g_A^{eff} \approx$ 0.3-0.9 (from β^- and $2\beta^-(2\nu)$ decay)

⇓

~ (2-15) times lower sensitivity to $m_{\beta\beta}$?!

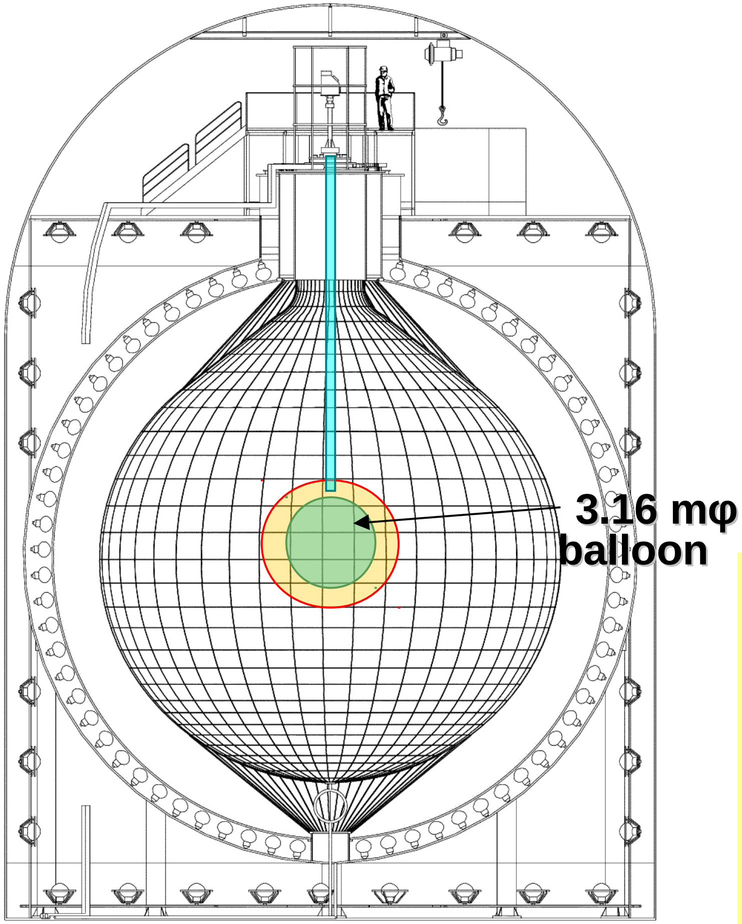
(but $g_A^{eff}(2\nu) \neq g_A^{eff}(0\nu)$?!)

2. BEST RECENT RESULTS

- **KamLAND-Zen (^{136}Xe)**
- **GERDA-II (^{76}Ge)**

KamLAND-Zen

(Original idea of R. Ragavan, PRL 72 (1994) 1411)



1st phase enriched Xe 400kg

R=1.7 m balloon

$V=20.5m^3, S=36.3m^2$

LS : C10H22(81.8%)+PC(18%) +PPO+Xe(~2.5wt%)

ρLS : 0.78kg／ℓ

high sensitivity with low cost

24 of September 2011 - beginning of data tacking – June 2012 (Phase I)

^{136}Xe: 320 kg, enrichment – 91%

ΔE/E(FWHM) = 9.5% at 2.5 MeV

11 December 2013 – 27 October 2015 Phase II with 383 kg of ^{136}Xe (Phase II)

^{238}U : 0.2~2.2×10^{-18} g/g

^{232}Th : 1.9~4.8×10^{-17} g/g

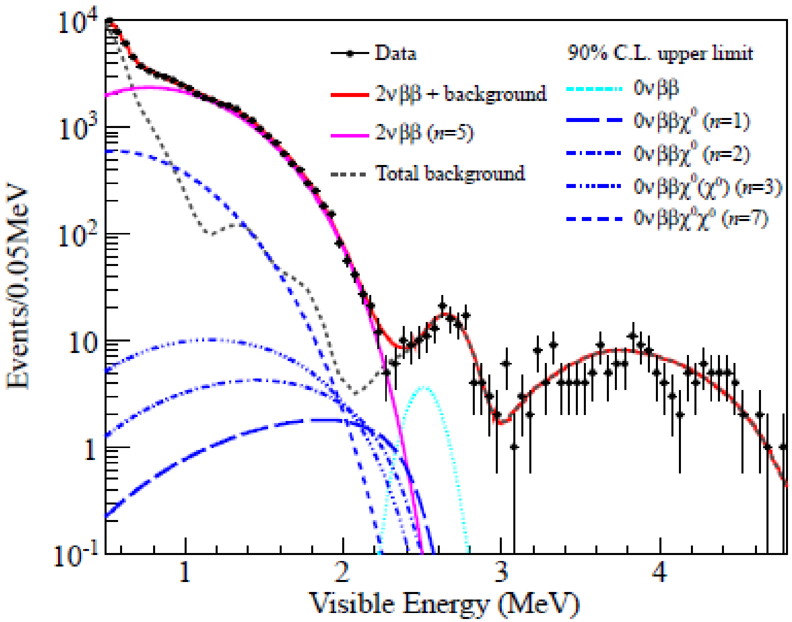
KamLAND-Zen results

(Phase 1, 89.5 kg · yr of ^{136}Xe)

- **$T_{1/2}(2\nu) = 2.30 \pm 0.02(\text{stat.}) \pm 0.12(\text{sys.}) \times 10^{21}$ yr**
- **(PRC 86 (2012) 021601R; in agreement with EXO-200)**

$T_{1/2}(0\nu) > 1.9\text{x}10^{25}$ yr (90% CL) $\Rightarrow$ $\langle m_\nu \rangle < 0.14\text{-}0.34$ eV

(PRL 110 (2013) 062502)



Ordinary (spectral index n = 1) Majoron-emitting decay of ^{136}Xe

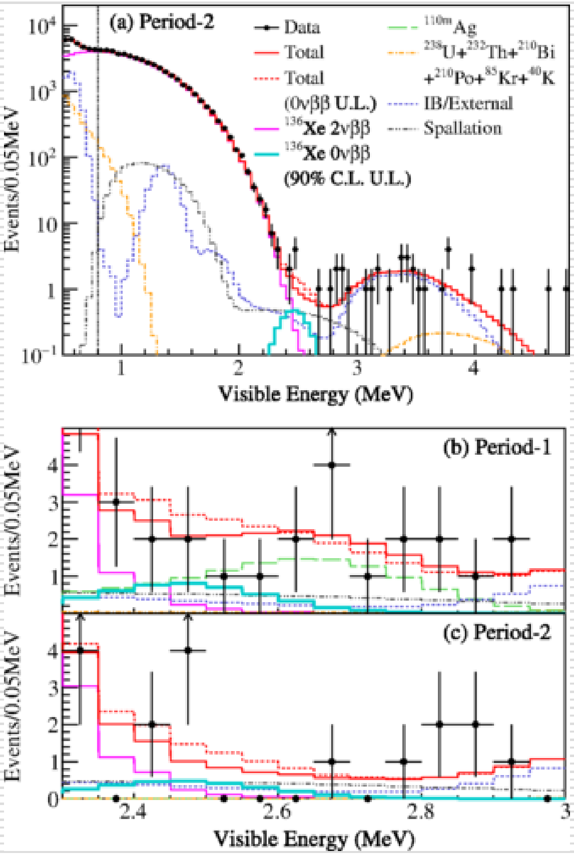
$T_{1/2} > 2.6\times10^{24}$ yr

$\langle g_{ee} \rangle < (0.8\text{-}1.6)\times10^{-5}$

Background is ~ 100 times higher than in KamLAND
BI ~ 10^{-4} c/keV · kg · yr
(Fukushima isotopes)

Sensitivity will be ~ 10 better if background problem will be solved

New data with KamLAND-Zen: Phase-II (11 December 2013 – 27 October 2015)



Period-1: 270.7 days
Period-2: 263.8 days
Σ = 534.5 days (504 kg·yr ^{136}Xe)

Phase I $T_{1/2}(0\nu) > 1.9\text{x}10^{25}$ yr
Phase II $T_{1/2}(0\nu) > 9.2\text{x}10^{25}$ yr

Combined $T_{1/2}(0\nu) > 1.07\text{x}10^{26}$ yr
(Sensitivity ~ $0.5\text{x}10^{26}$ yr)

$\langle m_\nu \rangle$ < 0.06-0.19
(< 0.09-0.28)

PRL 117 (2016) 082503; 109903

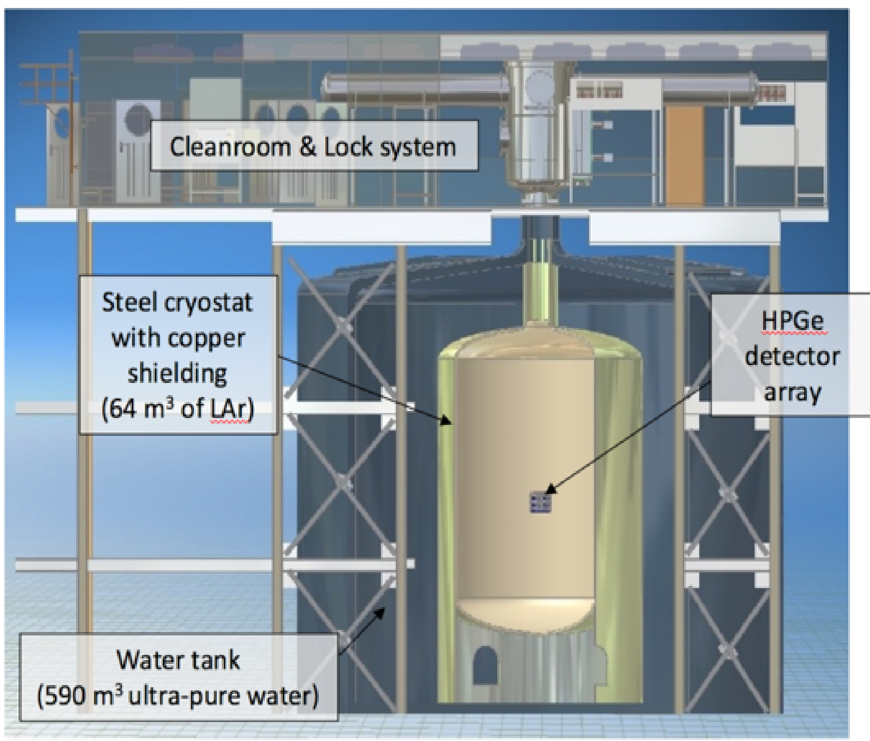
$T_{1/2}(2\nu)$= 2.21± 0.02(stat)± 0.12(syst) x 10^{21} yr

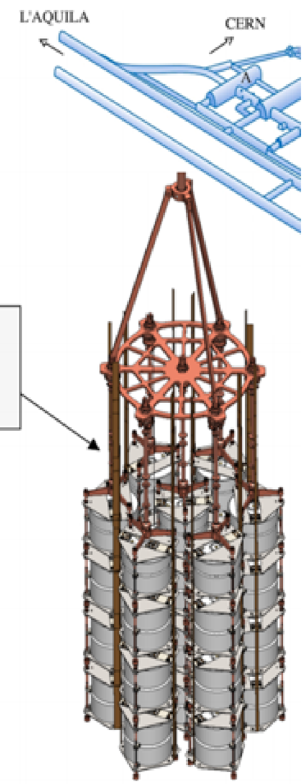
GERDA-II (Gran Sasso)

Detector type: enriched Ge diodes in LAr

- active target: ~ 35 kg
- σ_E /E: ~0.15-0.2% @ Q value
- pulse shape, LAr and coincidence veto
for bkg reduction: 7-35x10^{-4} c/keV/kg/y

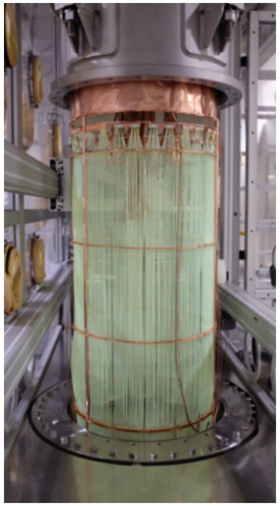
Phase II deployed in Dec 2015





[EPJC 73 (2013) 2330]

GERDA-II (Gran Sasso)



Deployed in Dec 2015:

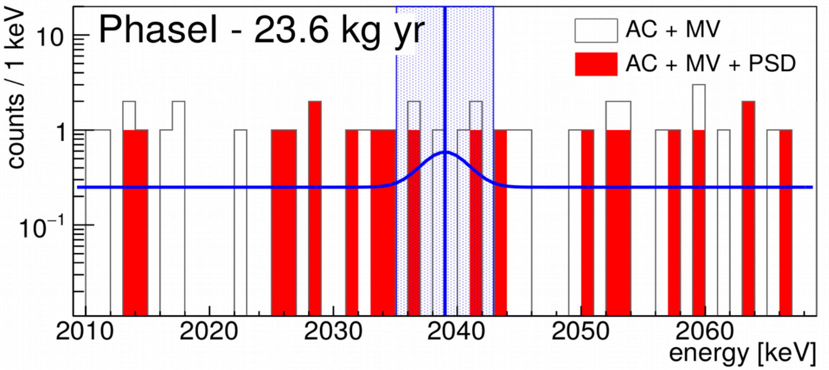
- 30 enriched BEGe (20 kg)
- 7 enriched Coax (15.8 kg)
- 3 natural Coax (7.6 kg)

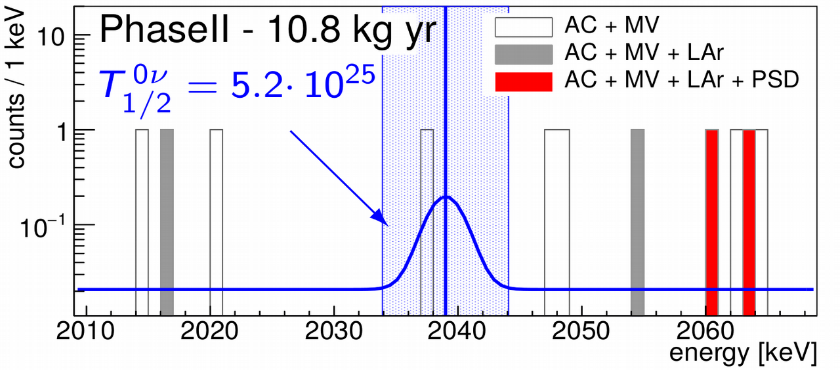
⇒ 35.8 kg of enr detectors

Dec 2015 - May 2016:

- **82% average duty cycle**
- **exposure used for analysis:**
5.8 kg·yr for enriched BEGe;
5.0 kg·yr for enriched coax.
- **blinding window Q ββ ±25 keV**

Statistical analysis





	profile likelihood 2-side test-stat	Bayesian flat prior on cts
$0\nu\beta\beta$ cts best fit value [cts]	0	0
$T_{1/2}^{0\nu}$ lower limit [10^{25} yr]	>5.2 (90% CL)	>3.5 (90% CI)
$T_{1/2}^{0\nu}$ median sensitivity [10^{25} yr]	>4.0 (90% CL)	>3.0 (90% CI)

preliminary!

- unbinned profile likelihood: flat background (1930-2190 keV) + Gaussian signal
- frequentist test-statistics and methods *Cowan et al.*, EPJC 71 (2011) 1554
- ϵ_{coax}^{PSD} to be finalized

III. FUTURE EXPERIMENTS

- **Main goal is:**

To reach a sensitivity ~ **0.01-0.1 eV** to **$<m_\nu>$** (inverted hierarchy region)

- Strategy is:

- to investigate **different** isotopes (**>2-3**);

- to use **different** experimental technique

Here I have selected a few propositions which I believe will be realized in the nearest future

- **CUORE** (^{130}**Te**, cryogenic thermal detector)
- **GERDA** (^{76}**Ge**, HPGe detector)
- **MAJORANA** (^{76}**Ge**, HPGe detector)
- **EXO** (^{136}**Xe**, TPC + Ba^{+})
- **SuperNEMO** (^{82}**Se or** ^{150}**Nd**, tracking detector)
- **KamLAND-Zen** (^{136}**Xe**, liquid scintillator)
- **SNO+** (^{130}**Te**, liquid scintillator)

Other proposals: CANDLES, XMASS, NEXT, LUCIFER, AMORE, COBRA …

SUMMARY TABLE

Experiment	Isotope	Mass, kg	$T_{1/2}$, y	$<m_\nu>$, meV	Status
CUORE	**^{130}Te**	200	$9.5 \cdot 10^{25}$	**63-150**	Funded
GERDA	**^{76}Ge**	I. 17 II. 35 III.1000	$2.1 \cdot 10^{25}$ $1 \cdot 10^{26}$ $6 \cdot 10^{27}$	 **120-280** **15-40**	Done Funded R&D
MAJORANA	**^{76}Ge**	I. 30 II. 1000	$1 \cdot 10^{26}$ $6 \cdot 10^{27}$	**120-280** **15-40**	Funded R&D
EXO	**^{136}Xe**	200 5000	$4 \cdot 10^{25}$ 10^{27}-10^{28}	**100-320** **10-50**	Funded R&D
SuperNEMO	**^{82}Se**	7 100-200	$6.5 \cdot 10^{24}$ $(1\text{-}2) \cdot 10^{26}$	**200-400** **40-110**	Funded R&D
KamLAND-Zen	**^{136}Xe**	750 1000	$\sim 2 \cdot 10^{26}$ $\sim 6 \cdot 10^{26}$	**40-140** **25-80**	Funded R&D
SNO+	**^{130}Te**	800 8000	$\sim 9 \cdot 10^{25}$ $\sim 7 \cdot 10^{26}$	**65-158** **23-57**	Funded R&D

NEAR FUTURE (2017-2019)

1. **GERDA-II (35 kg of ^{76}Ge; ~ 1×10^{26} yr).**
2. **MAJORANA-DEMONSTRATOR**

   (30 kg of ^{76}Ge; ~ 1×10^{26} yr).

   ^{76}Ge - ~ 1.5×10^{26} $\langle m_\nu \rangle$ ~ 0.1-0.23 eV

3. **KamLAND-Zen (750 kg of ^{136}Xe; ~ 2×10^{26} yr).**

   ^{136}Xe - ~ 2×10^{26} $\langle m_\nu \rangle$~ 0.04-0.14 eV

4. **CUORE (741 kg of ^{nat}Te; ~ $7\cdot10^{25}$ yr).**
5. **SNO+ (800 kg of ^{nat}Te; ~ $7\cdot10^{25}$ yr).**

   ^{130}Te - ~ 1×10^{26} $\langle m_\nu \rangle$ ~ 0.06-0.15 eV

Other experiments: EXO, Super-NEMO-Demonstrator, LUCIFER, NEXT,…

FAR FUTURE (2020-....)

	Start of data taking
KamLAND2-Zen (1000 kg ^{136}Xe)	~ 2020
SNO+ (8000 kg of ^{nat}Te)	~ 2020
CUPID (^{100}Mo, ^{82}Se, ^{116}Cd, ...)	~ 2022
NG-^{76}Ge (200 kg ^{76}Ge)	~ 2022-2025
nEXO (5000 kg ^{136}Xe)	~ 2025-2030
NG-^{76}Ge (1000 kg ^{76}Ge)	~ 2025-2030

$\Downarrow$

$\langle m_\nu \rangle \sim$ 10-50 meV (but g_A problem!?)

CONCLUSION

1. Present conservative limit on $<m_\nu>$ is $<m_\nu> < 0.3$ eV
2. In a new experiments (in ~ 3 years) sensitivity will be increased up to ~ (0.05-0.15) eV
3. Sensitivity ~ (0.01-0.05) eV will be reached in ~ 5-10 years from now.
4. g_A problem has to be solved.