Double beta decay experiments: present and future

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OUTLINE

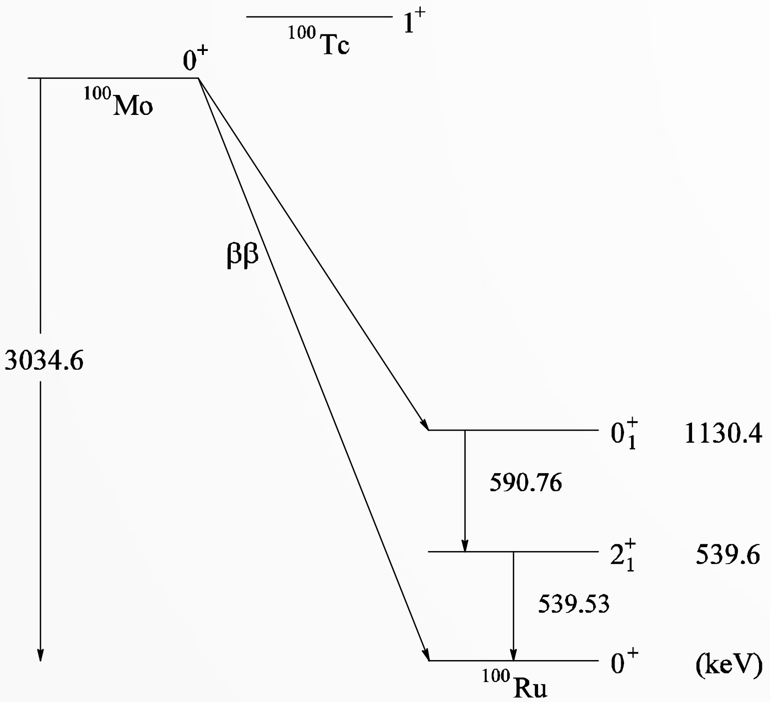
- **Introduction**
- **Present status**
- **Future experiments**

  - near future (2018-2023)

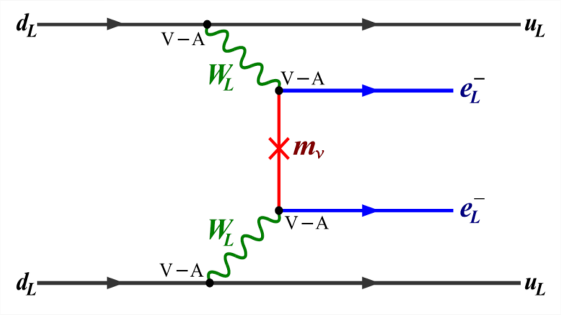
  - far future (2024-...)

  - IO and NO
- **Conclusion**

I. INTRODUCTION



$Q_{\beta\beta}$ = 3.033 MeV



$^{100}Mo \Rightarrow$ $^{100}Ru + 2e^-$

$^{100}Mo \Rightarrow$ $^{100}Ru + 2e^- + \chi^0\ (+\chi^0)$

$^{100}Mo \Rightarrow$ $^{100}Ru + 2e^- + 2\nu$

There are 35 candidates for $2\beta^-$-decay

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

What one can extract from 2β-decay experiments? →

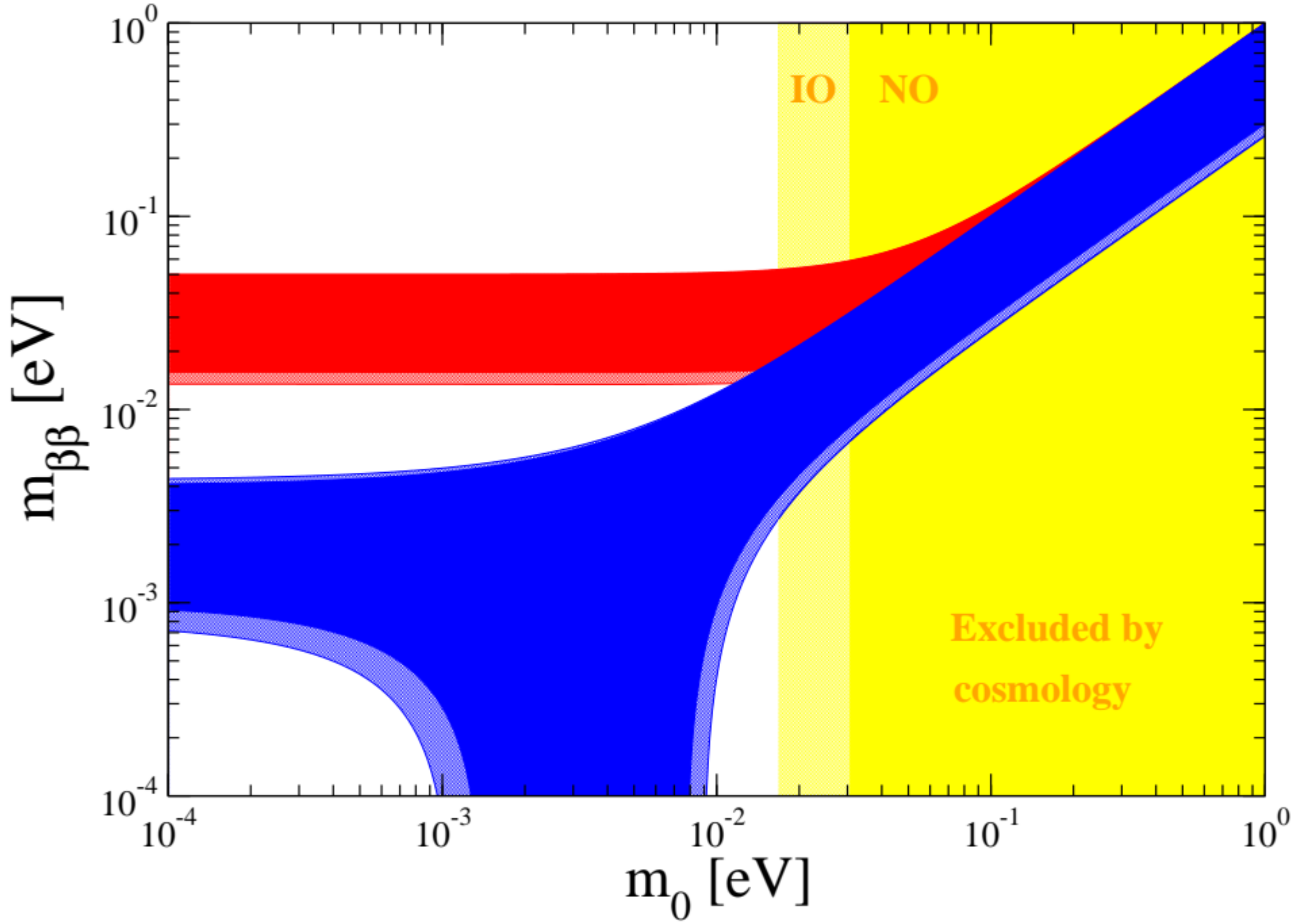
- **Lepton number non-conservation (ΔL=2)**
- **Nature of neutrino mass (Dirac or Majorana?)**
- **Absolute mass scale**
- **Type of mass ordering (normal or inverted)**
- **CP violation in the lepton sector**

Best present limits on $\langle m_\nu \rangle$

Nucleus	$T_{1/2}$, yr; 90% CL	$\langle m_\nu \rangle$, eV QRPA, ISM, IBM-2, PHFB, ...	Experiment
^{136}Xe	$> 5.6 \times 10^{25}$ ($> 1.07 \times 10^{26}$)	**< 0.08-0.23** (< 0.06-0.16)	KamLAND-Zen
^{76}Ge	$> 5.8 \times 10^{25}$ ($> 8 \times 10^{25}$)	< 0.14-0.37 (< 0.12-0.31)	GERDA-I + GERDA-II
^{130}Te	$> 7 \times 10^{24}$ ($> 1.5 \times 10^{25}$)	< 0.19-0.74 (< 0.13-0.50)	CUORICINO + CUORE0 + CUORE
^{100}Mo	$> 1.1 \times 10^{24}$	< 0.33-0.62	NEMO-3
^{82}Se	$> 2.4 \times 10^{24}$	< 0.4-0.9	CUPID-0/Se

Conservative limit on $\langle m_\nu \rangle$ is 0.23 eV

DBD and neutrino mass ordering



Inverted ordering (IO):

$\langle m_\nu \rangle$ = 14-50 meV

(Can be tested by next generation of **2β**-decay experiment)

Normal ordering(NO):

$\langle m_\nu \rangle$ = 0-30 meV

Limiting case → **$\langle m_\nu \rangle$** = **1-4 meV**

β: $\langle m_\nu \rangle$ < 2 eV

2β: $\langle m_\nu \rangle$ < 0.23 eV

Σm_ν < 0.12 eV (PLANCK'2018)

Global analysis prefer NO (3-3.5σ); NO – Σmν > 0.06 eV, IO - Σmν > 0.1 eV

Best current experiments (+starting in 2018-2019)

Experiment	Isotope	M, kg	Sensitivity $T_{1/2}$,yr; 90% CL	Sensitivity $<m_\nu>$, meV	Status
CUORE	^{130}Te	200	$9.5x10^{25}$	53-200	current
GERDA-II	^{76}Ge	35	$1.5x10^{26}$	90-230	current
Majorana-D	^{76}Ge	30	$1.5x10^{26}$	90-230	current
EXO-200	^{136}Xe	200 (100)	$5.7x10^{25}$	85-225	current
CUPID-0/Se	^{82}Se	5	$6x10^{24}$	250-590	current
KamLAND-Zen	^{136}Xe	750	$2x10^{26}$	**45-120**	Start in 2018
SNO+-I	^{130}Te	1300	$2x10^{26}$	**36-140**	Start in 2019
NEXT	^{136}Xe	100	$6x10^{25}$	83-220	Start in 2019
CUPID-0/Mo	^{100}Mo	4	$1.5x10^{25}$	90-170	Start in 2019
AMoRE-I	^{100}Mo	2.5	$\sim 10^{25}$	110-210	Start in 2019
SuperNEMO-D	^{82}Se	7	$6.5x10^{24}$	240-560	Start in 2019

Indicated sensitivity will be reached in ~ 3-5 years from now, 2021-2023

Sensitivity is not enough to investigate IO region

Most developed and promising projects for next generation experiments

Experiment	**Isotope**	**M, kg**	**Sensitivity $T_{1/2}$, yr; 90% CL**	**Sensitivity $\langle m_\nu \rangle$, meV**	**Status**
LEGEND	^{76}Ge	200 1000	~ 10^{27} ~ 10^{28}	34-90 **11-28**	R&D
nEXO	^{136}Xe	5000	9×10^{27}	**8-22**	R&D
CUPID	^{130}Te, ^{100}Mo, ^{82}Se, ^{116}Cd	~ 200-500	$(2\text{-}5) \times 10^{27}$	**6-17**	R&D
KamLAND-Zen	^{136}Xe	1000	6×10^{26}	25-70	R&D
SNO+-II	^{130}Te	8000	7×10^{26}	20-70	R&D
AMoRE-II	^{100}Mo	100	5×10^{26}	15-30	R&D
SuperNEMO	^{82}Se	100-140	$(1\text{-}1.5) \times 10^{26}$	50-140	R&D
PandaX-III	^{136}Xe	200 1000	~ 10^{26} ~ 10^{27}	65-170 20-55	R&D

The experiments will start ~ **5-10** years from now and will need ~ **5-10** years for measurements → final results in **2028-2033.**

There is a chance to detect 2β decay

Normal ordering

The following ranges of **$<m_\nu>$** can be distinguished:

- **10-30 meV** – next generation experiments
- **3-10 meV** – detectors with ~ 1-10 tons of isotope
- **1-3 meV** – detectors with 10-100 tons of isotopes
- **< 1 meV** – not available for observation in foreseeable future

Requirements for 10 tons detector (far future)

- High efficiency (**~100%**)
- Good energy resolution (**FWHM < 1-2%**)
- Low background in ROI (**~ 10^{-6}-10^{-7} c/keV·kg·yr**)
- Low enough cost of isotope

(see A.S.B. Int. J. Mod. Phys. A 33 (2018) 1843001)

Approximate price of ββ isotopes obtained by centrifugation

Isotope	**Abundance**	**Price per kg (k$)**	**Cost of 10 tons (Mln.$)**
^{76}Ge	7.61	~ 80	800 (640)[a]
^{82}Se	8.73	~ 80	800 (640)[a]
^{100}Mo	9.63	~ 80	800 (640)[a]
^{116}Cd	7.49	~ 180	1800 (1440)[a]
^{124}Sn	5.79	~ 300	3000 (2600)[a]
^{130}Te	34.08	**~ 20**	**200 (160)[a]**
^{136}Xe	8.87	**~ 5-10**	**50-100 (40-80)[a]**
^{150}Nd	5.6	> 300	> 3000

[a] Taking into account possible 20% price reduction in the mass production case.

Up to now ~ 1000 kg of ^{136}Xe, ~120 kg of ^{76}Ge and ^{100}Mo have been produced

10 tons detector (far future)

Most suitable experimental techniques are:

- **Gas Xe TPC** (^{136}**Xe**) – nest step for nEXO, NEXT and PandaX-III type detectors
- **Low-temperature scintillation bolometers** (^{130}**Te,** ^{100}**Mo**) -next step for COURE, CUPID and AMoRE type detectors
- **HPGe** (^{76}**Ge**) – next step for LEGEND type detector

Other mechanisms for 2β decay

- **RHC**
- **Super-symmetry**
- **H^{--}**
- **Sterile neutrino**
- **Heavy neutrino**
- **Majoron**
-

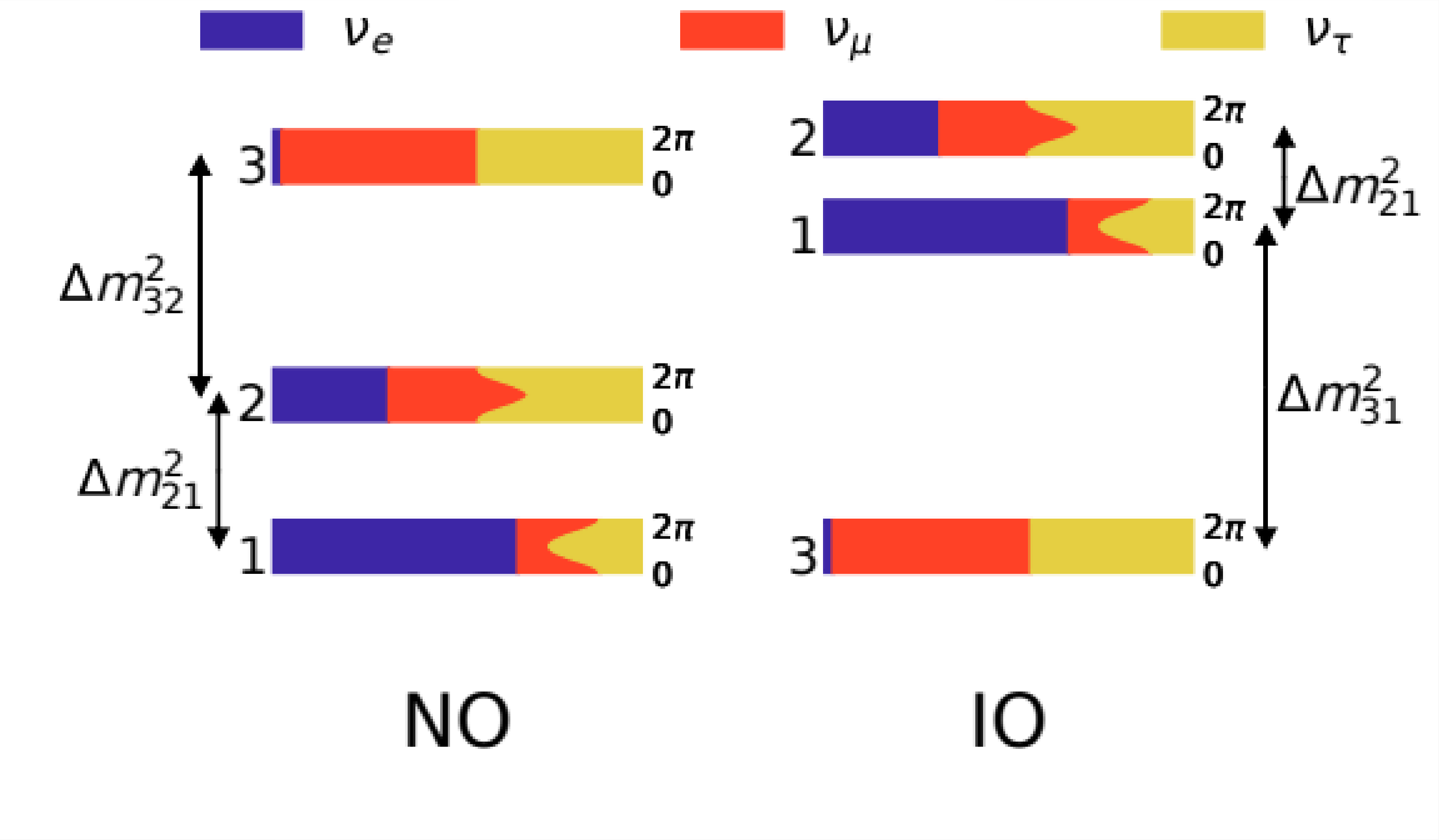
In this case <m_ν> can be very small, but probability of 2β decay can be high enough

CONCLUSION

- Present conservative limit on $<m_\nu>$ is 0.23 eV
- In ~ 3-5 years sensitivity of current experiments will reach the value ~ 0.04-0.2 eV (not enough to investigate IO region)
- Sensitivity ~ 0.01-0.05 eV will be reached by new generation experiments (~10-15 years from now; IO and partially NO regions will be investigated)
- To reach sensitivity ~ 0.001-0.01 eV detectors with 10 tons (or more) of isotope will be needed
- If $<m_\nu> < 1$ meV 2β-decay is not available for observation in foreseeable future
- There is always a chance to detect the 2β-decay if other mechanisms play a role (RHC, super-symmetry,...).

Back-up slides

Neutrino mass ordering



P.F. De Salas et al., hep-ph/1806.11051

Candidates with $Q_{2\beta}$> 2 MeV

Nuclei	$Q_{2\beta}$, keV	Abundance, %
1. ^{48}Ca	4267.98	0.187
2. ^{150}Nd	3371.38	5.6
3. ^{96}Zr	3355.85	2.8
4.^{100}Mo	3034.40	9.63
5. ^{82}Se	2997.9	8.73
6. ^{116}Cd	2813.50	7.49
7. ^{130}Te	2527.52	34.08
8. ^{136}Xe	2457.83	8.87
9. ^{124}Sn	2292.64	5.79
10. ^{76}Ge	2039.00	7.61
11. ^{110}Pd	2017.8	11.72

Natural γ-rays background – E ≤ 2.615 MeV.
So, there are **6 gold** and **5 silver** isotopes.