NEWS DBD Hiro Ejiri

Greenary Nimph 翠の精

Fundamental questions of neutrinos

Neutrinos are KEYs for new physics:

1. Lepton number violation

2. Majorana particle ν = anti ν

3. Absolute mass scale and mass spectrum

NH $m_1 < m_2 < m_3$ IH $m_3 < m_1 < m_2$

3. Lepton sector CP phases,

4. Weak interactions with right-handed currents,

5. Susy-exchange mechanism . Majoron mediated weak process.

These fundamental questions of ν are studied by nuclear $\beta\beta$ decays in nuclear femto laboratories.

Unique features of DBD

1. Part. Phys. Neutrinos and weak interactions

   beyond the electro-weak standard model SM

   Majorana nature ν , ν, mass scale and spectrum

   Right weak current. Weak CP phases

   New mechanisms SUSY, Majoron, and others

2. Exp. Low energy (a few MeV) ultra-rare (10^{-36}/sec)

   Ultra high luminosity 10^{83} /cm^2 sec

3. Nucl. Phys. Nuclear matrix elements.

   Sensitive to all nucleonic and non-nucleonic effects

References

- 1. Ejiri H, Suhonen J and Zuber Z 2019 Phys. Rep. 797 1
- 2. Ejiri H 2005 J. Phys. Soc Jpn. 74 2101
- 3. Vergados J, Ejiri H and Simkovic F 2012 Rep. Prog. Phys. 75 106301
- 4. Ejiri H 2019 Frontiers in Physics 10.3389/fphys. 00030
- 5. Ejiri H, 2019 J. Phys. G. Nucl. Part. Phys. 46 125202
- 5. Ejiri H 2019 MEDEX2019, AIP Conf. Proc. 2165 020007

I. Introduction to DBD

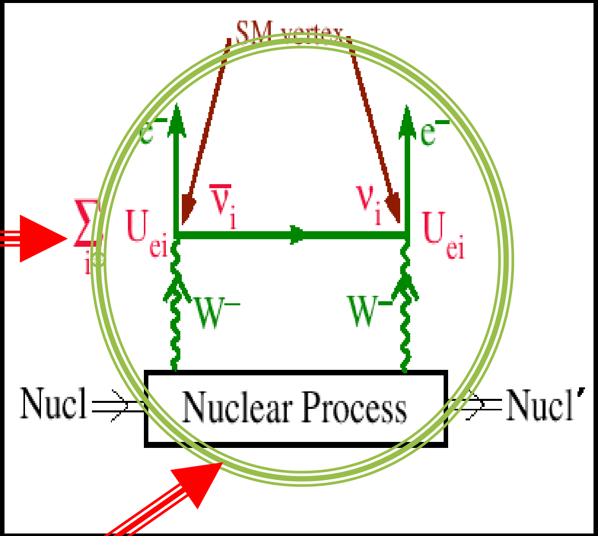
Majorana neutrinos and neutrino-less ββ decays

0νββ A = B + β + β

Lepton number ΔL=2 beyond SM.

Particle astro physics

Majorana ν, m_ν CP, RHC



$$T^{0\nu} = G^{0\nu} [M^{0\nu}\ m_\nu]^2$$

EXP

NNR,
Nucl. phys. g_A
short-range, isobar
&
τ σ correlation

Experimental aspects of DBD ν-mass studies.

I. Neutrino mass and
DBD mass sensitivity (Dec 5th)

II. Nuclear Physics
Nuclear matrix elements. (2020.)

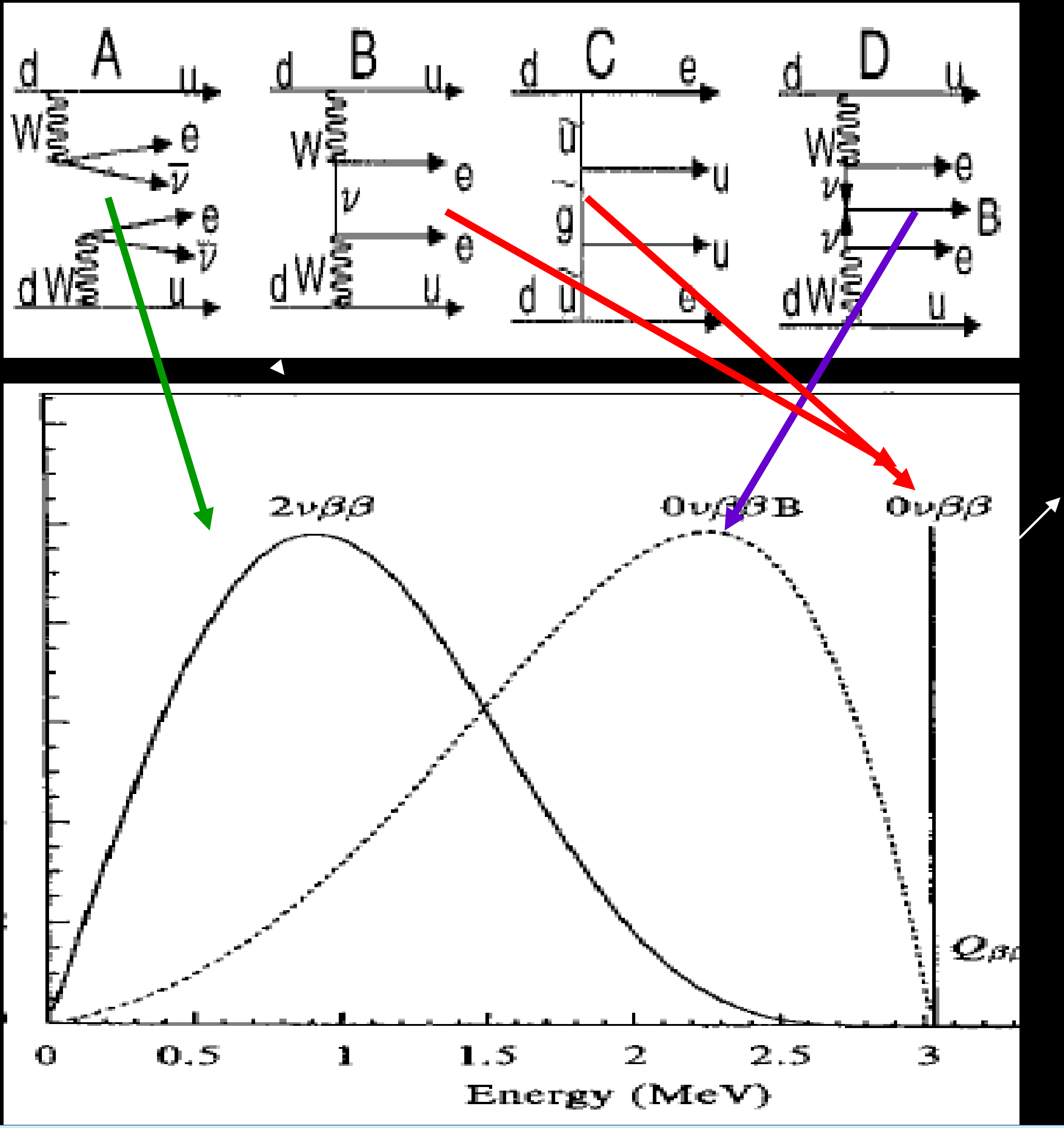
I. Neutrino mass and DBD mass sensitivity

Dec. 5th

- 1. What we learn by ν-less double beta decays (DBD)
- How we identify /study Majorana nature ,
- ν-mass, leptor-sector phases. and DBD mechanisms
- 2. DBD rate and the ν-mass sensitivity
- DBD experiments to access DBD and the ν-mass

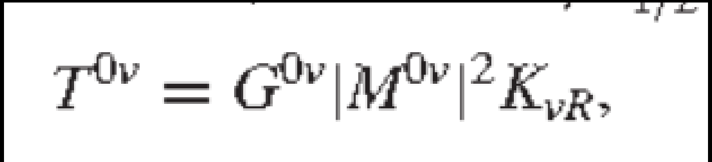
II. What we learn by ν-less DBD

A. 2νββ
B. 0νββ,
D. Mββ -

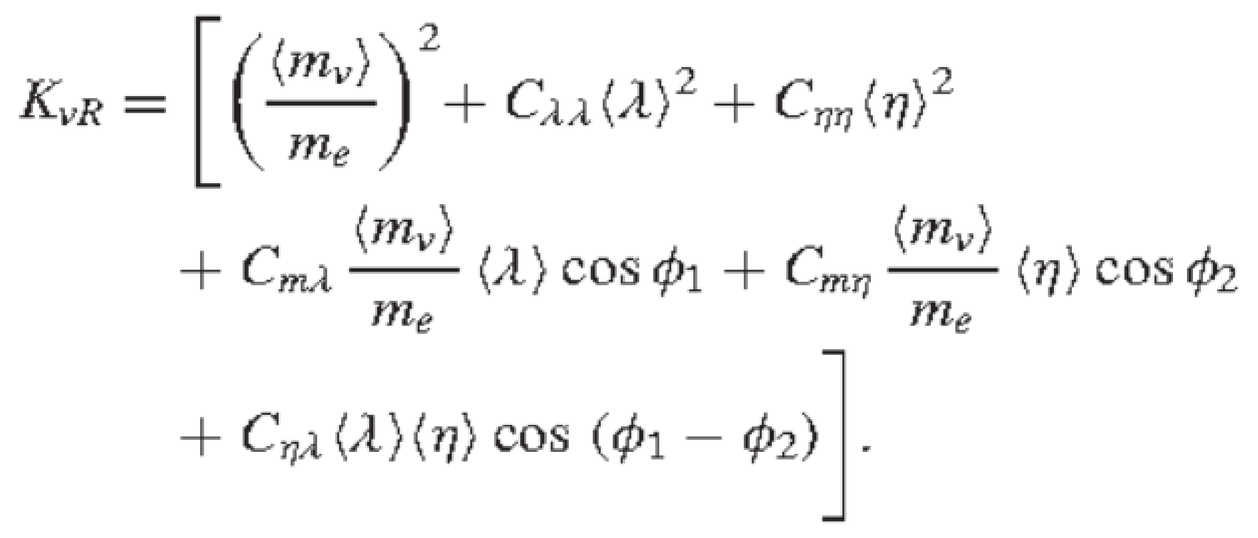


Energy spectra to select the 0νββ 2-body kinematics

L-R symmetric model : Left right weak currents



$$T^{0\nu} = G^{0\nu}|M^{0\nu}|^2 K_{\nu R},$$



$$K_{\nu R} = \left[\left(\frac{\langle m_\nu \rangle}{m_e} \right)^2 + C_{\lambda\lambda} \langle \lambda \rangle^2 + C_{\eta\eta} \langle \eta \rangle^2 + C_{m\lambda} \frac{\langle m_\nu \rangle}{m_e} \langle \lambda \rangle \cos \phi_1 + C_{m\eta} \frac{\langle m_\nu \rangle}{m_e} \langle \eta \rangle \cos \phi_2 + C_{\eta\lambda} \langle \lambda \rangle \langle \eta \rangle \cos (\phi_1 - \phi_2) \right].$$

RHC L/R weak boson mass ratio λ and mixing θ

$<m>=|\Sigma m_j U_{ej}|$ $<\lambda>=(M_L/M_R)^2|\Sigma U_{ej} V_{ej}|$

$<\eta>=\tan\theta_{LR}|\Sigma U_{ej} V_{ej}|$

C. Θ_{21} and E_{12} correlations to identify LHC/RHC

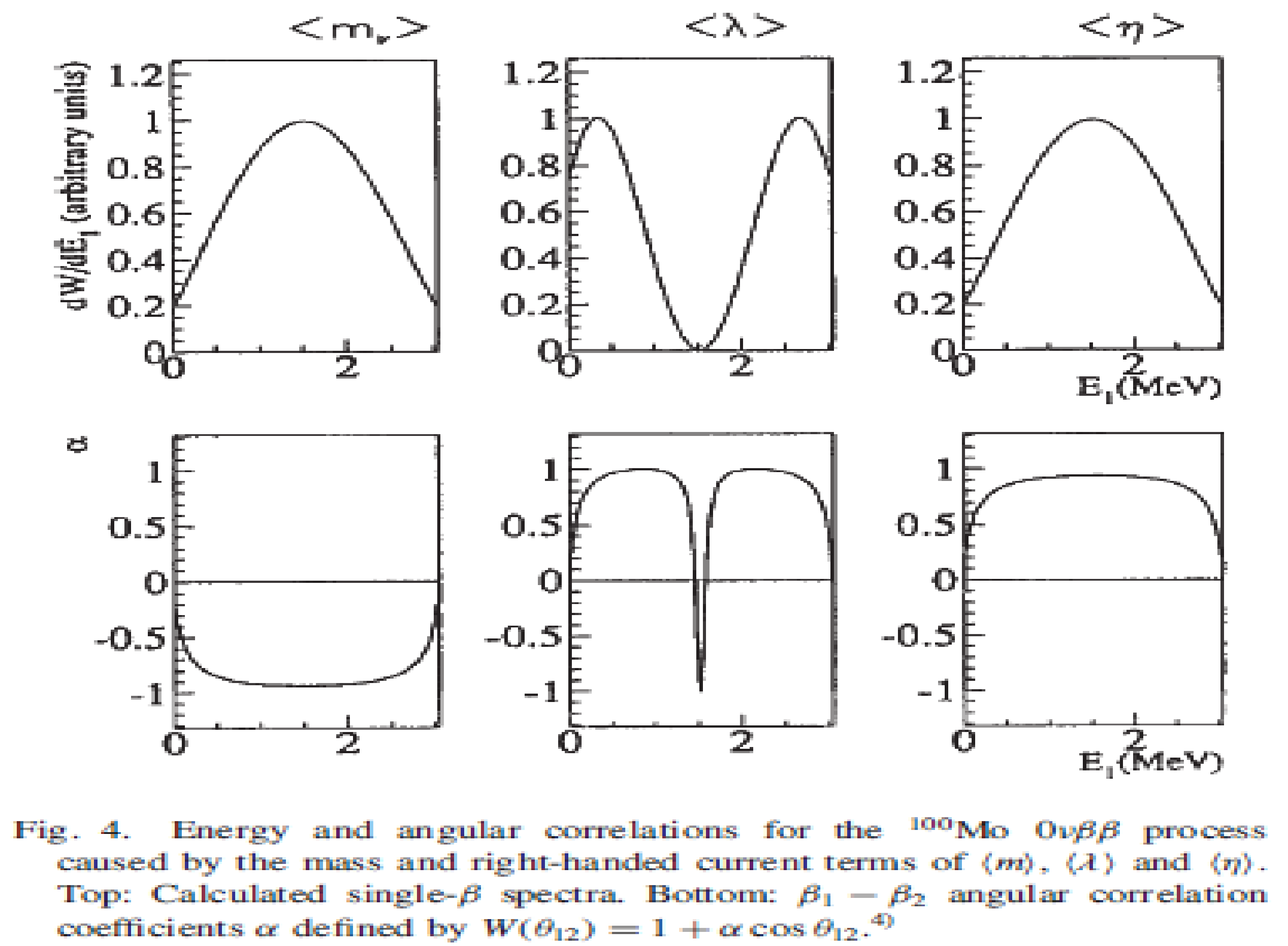


Fig. 4. Energy and angular correlations for the ^{100}Mo $0\nu\beta\beta$ process caused by the mass and right-handed current terms of $\langle m\rangle$, $\langle\lambda\rangle$ and $\langle\eta\rangle$. Top: Calculated single-β spectra. Bottom: $\beta_1-\beta_2$ angular correlation coefficients α defined by $W(\theta_{12}) = 1 + \alpha\cos\theta_{12}$.4)

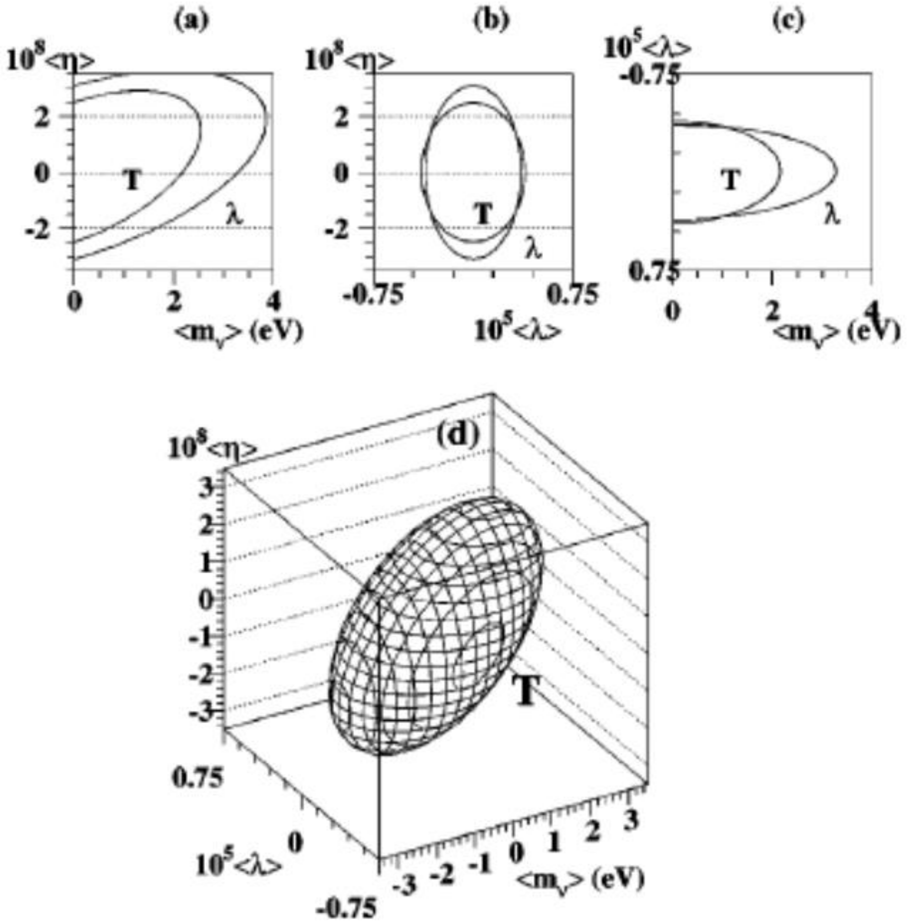
$<m>\sim 0.3$ eV, $<\lambda> \sim 7\ 10^{-7}$, $<\eta> \sim 4\ 10^{-9}$

LIMITS ON THE MAJORANA NEUTRINO MASS AND . . . PHYSICAL REVIEW C **63** 065501

TABLE III. Limits on the effective Majorana neutrino mass and right-handed weak current parameters with 90(68)% C.L. from the $0\nu\beta\beta$ decay of ^{100}Mo for the recent calculation of nuclear matrix element.

	$\langle m_\nu \rangle$ (eV)	$\langle \lambda \rangle$ (10^{-6})	$\langle \eta \rangle$ (10^{-8})
QRPA [a]	4.8(3.5)	4.7(3.3)	2.4(1.9)
QRPA [b]	2.1(1.5)	3.6(2.5)	2.6(1.9)
QRPA SU(3) [c]	2.4(1.7)	3.2(2.2)	2.7(2.0)
RQRPA [d]	2.5(1.8)		
RQRPA [e]	2.8(2.0)		

[a] Reference [28].
[b] Reference [27].
[c] Reference [29].
[d] Reference [4].
[e] Reference [30].



H. Ejiri , N. Kudomi et al ELEGANT
PR C 63 2001 065501
100Mo tracking detector

Left handed currents

Exchanges : light ν mass, heavy ν-mass, Susy

Same kinematics; E & θ distribution

Different isotopes/states with different $Q_{\beta\beta}$, $M^{0\nu}$

to identify

1. $0\nu\beta\beta$ peak/BG and
2. light-ν, SUSY $M^{0\nu} = M(m) + M(SUSY)$

J. Vergados PR 361 02 $\lambda_{111}' < 2 \sim 3 \; 10^{-5}$

A. Faessler,et al PRD 77 (2008) 113012

Neutrino mass and neutrino matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} C_{12}C_{13} & C_{13}S_{12} & S_{13}e^{-i\delta} \\ -S_{12}C_{23}-C_{12}S_{23}S_{13}e^{i\delta} & C_{12}C_{23}-S_{12}S_{23}S_{13}e^{i\delta} & S_{23}C_{13} \\ S_{12}S_{23}-C_{12}C_{23}S_{13}e^{i\delta} & -C_{12}S_{23}-S_{12}C_{23}S_{13}e^{i\delta} & C_{23}C_{13} \end{pmatrix} U_p \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix},$$

$$U_p = \begin{pmatrix} e^{i\alpha_1/2} & 0 & 0 \\ 0 & e^{i\alpha_2/2} & 0 \\ 0 & 0 & 1 \end{pmatrix}.$$

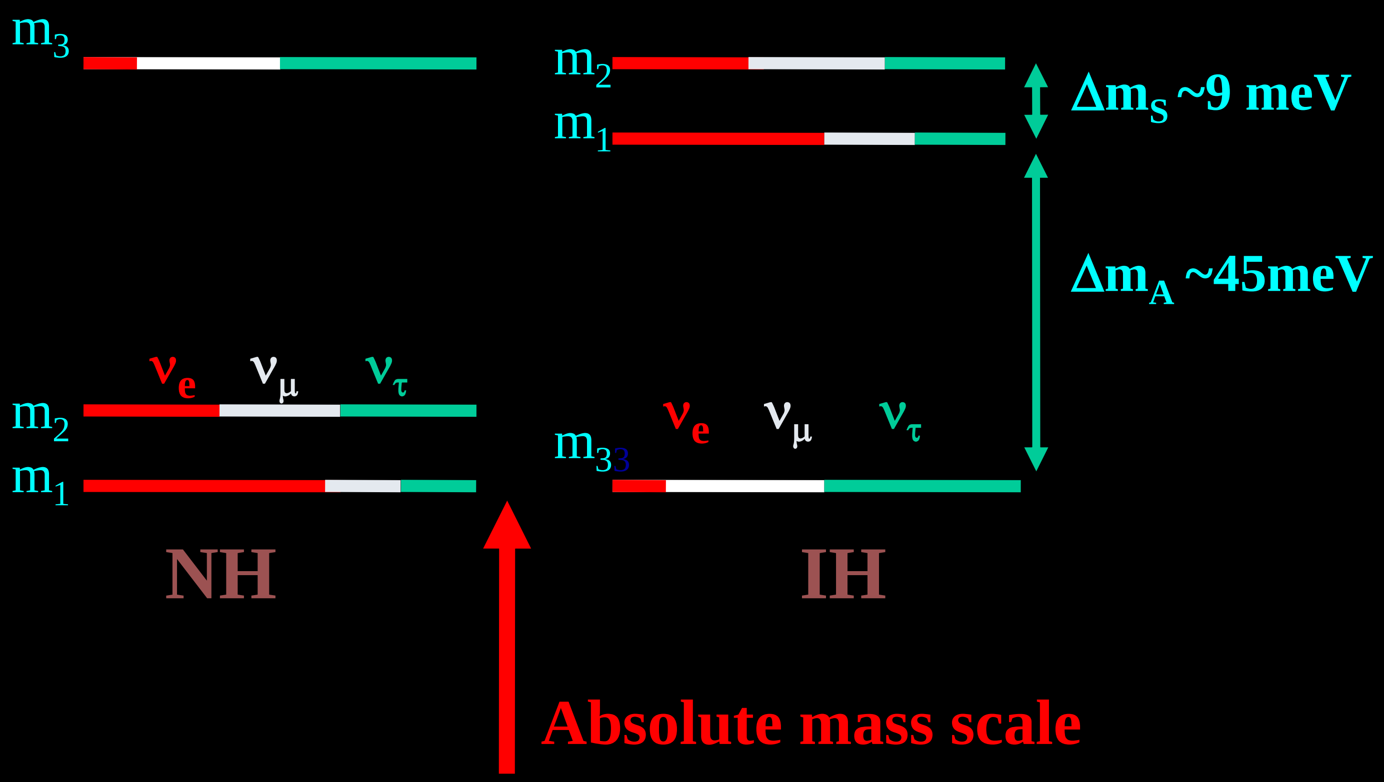
Δm^2（ATM） = $(2.43 \pm 0.13) \times 10^{-3}$ eV

Δm^2（SUN） = $(7.65{+}0.13{-}0.20) \times 10^{-5}$ eV^2

$\tan^2\theta_{12} = 0.452{+}0.035{-}0.033$ $\sin^2 2\theta_{23} > 0.94$

$\sin^2 2\theta_{13} = 0.092 \pm 0.016$ (stat) $\pm$ 0.005 (syst)

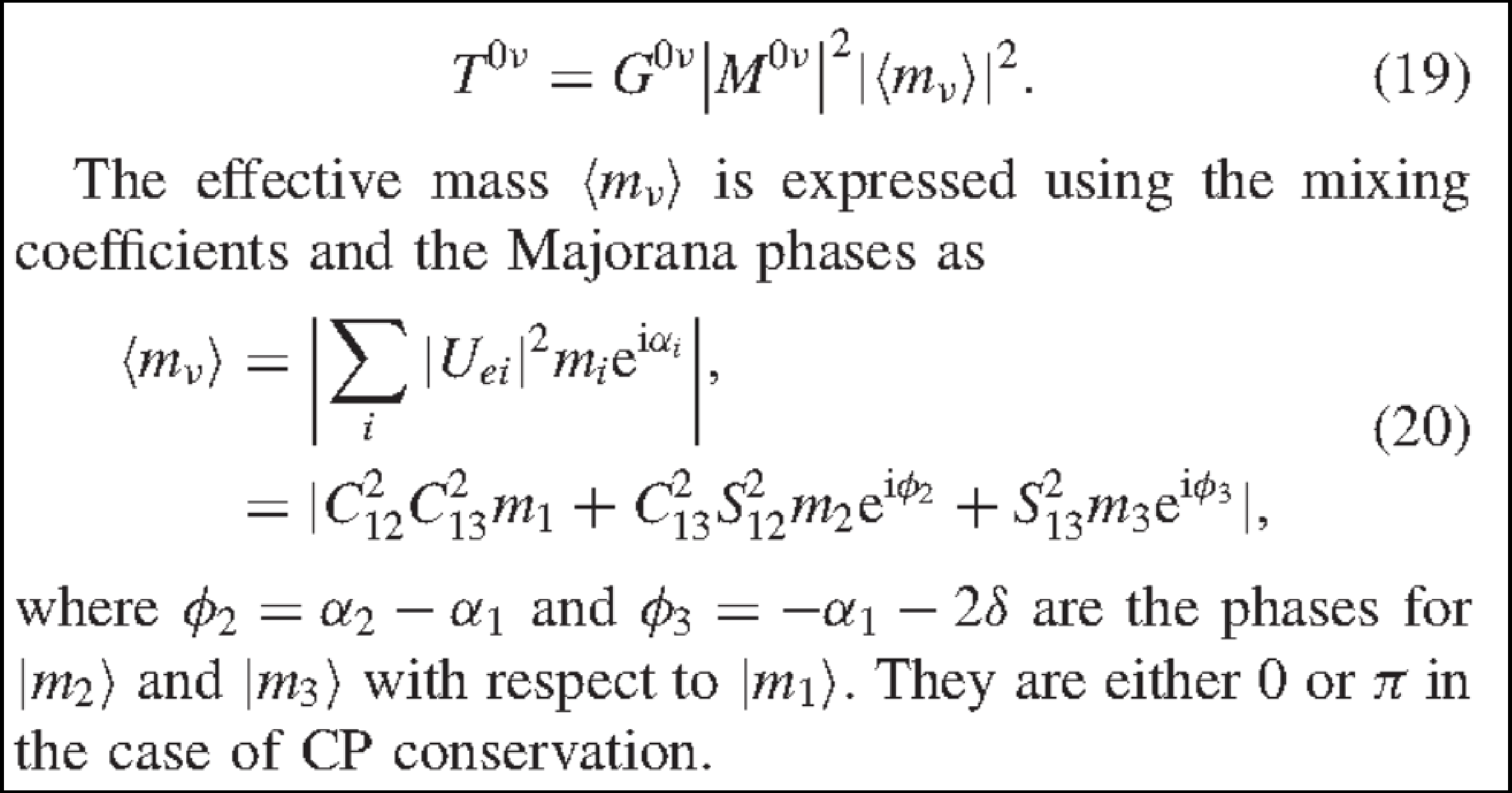
ν–mass spectrum



$$< m_\nu > = |\Sigma\, U_i^2 \; \exp(i\, \phi_i)\, m_i| \qquad \phi_i=\alpha_2-\alpha_1,$$

is given by using U_i Δm_S, Δm_A given by ν oscillations

Vergados Ejiri Somkovic RPP 2012



$$T^{0\nu} = G^{0\nu}\left|M^{0\nu}\right|^2 |\langle m_\nu \rangle|^2. \tag{19}$$

The effective mass $\langle m_\nu \rangle$ is expressed using the mixing coefficients and the Majorana phases as

$$\begin{aligned} \langle m_\nu \rangle &= \left| \sum_i |U_{ei}|^2 m_i \mathrm{e}^{\mathrm{i}\alpha_i} \right|, \\ &= |C_{12}^2 C_{13}^2 m_1 + C_{13}^2 S_{12}^2 m_2 \mathrm{e}^{\mathrm{i}\phi_2} + S_{13}^2 m_3 \mathrm{e}^{\mathrm{i}\phi_3}|, \end{aligned} \tag{20}$$

where $\phi_2 = \alpha_2 - \alpha_1$ and $\phi_3 = -\alpha_1 - 2\delta$ are the phases for $|m_2\rangle$ and $|m_3\rangle$ with respect to $|m_1\rangle$. They are either 0 or π in the case of CP conservation.

IH in case of small m_3

$\langle m \rangle \sim m(\mathrm{ATM})\,(1-\sin^2 2\,\theta_{12}\,\sin^2\alpha_{12})^{½}$

$\theta_{12} \sim 34$ deg $\theta_{13} \sim 8.5$ deg. .

Phase difference $\phi_2 = \alpha_{12}$ = to be measured .

$0\text{–}\pi/2$: m= 50-15 meV need $\Delta m \sim 5$ meV, and NME $\Delta M \sim 15$ % to get the phase difference $\pi/4$

NH in case of small m_1

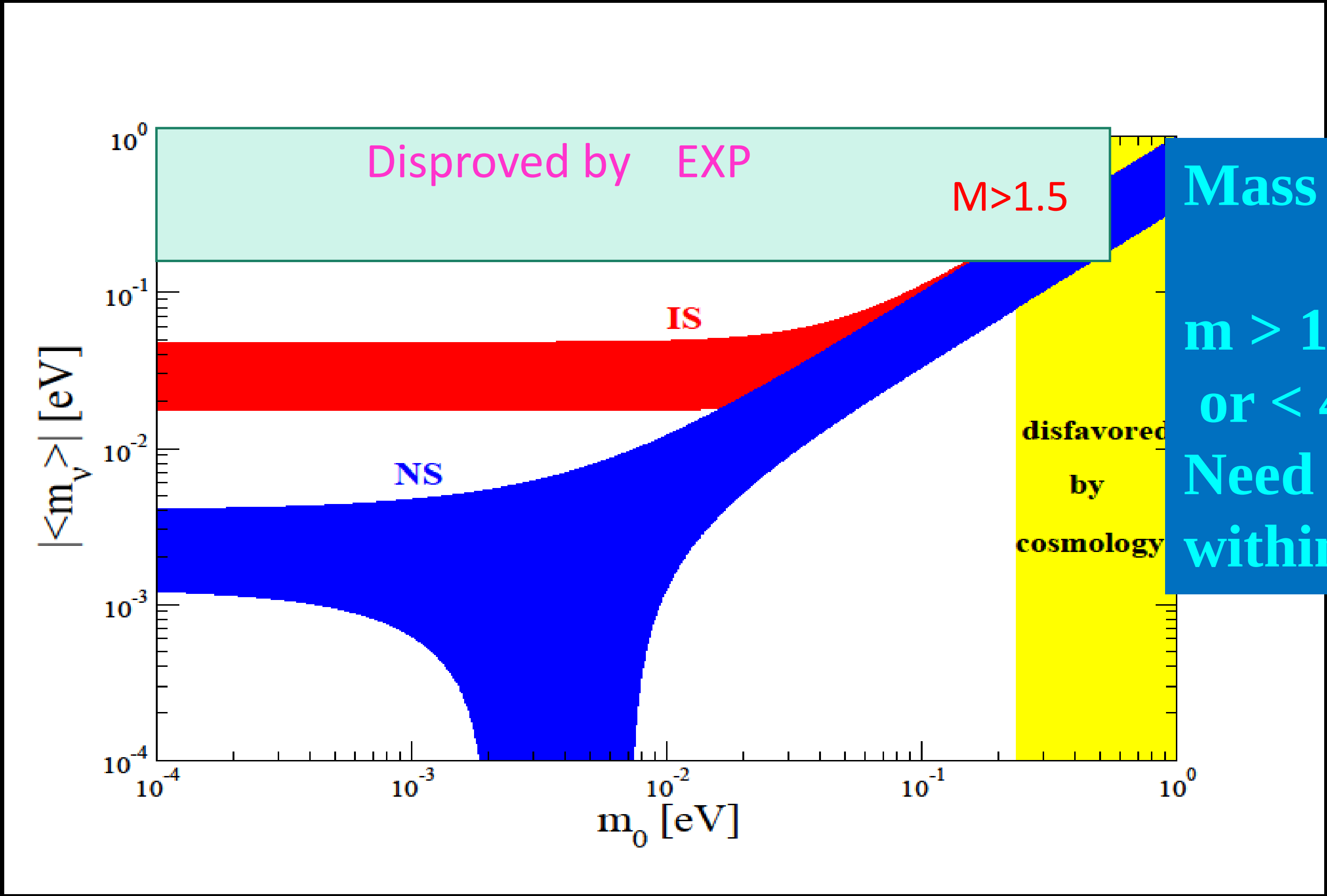
$\langle m \rangle \sim m(\mathrm{Sun})\,(\sin^2\theta_{12})$

$m(\mathrm{ATM})\,(\sin^2\theta_{13})\,\exp(-2\alpha_2) = 1.5\text{ -}4$ meV

Phase difference α_2 : m= 4-1.3 meV need $\Delta m \sim$ meV, and NME $\Delta M \sim 15$ % to get the phase α_2

$< m_\nu > = |\Sigma U_i^2 \ \exp(i\ \phi_i)\ m_i| \qquad \phi_2=\alpha_2-\alpha_1, \quad \phi_3 = -\alpha_2-2\delta$

is given by using U_i Δm_S, Δm_A given by ν oscillations.



Mass hierarchy

m > 15 meV
or < 4 meV
Need m or M within a factor 3

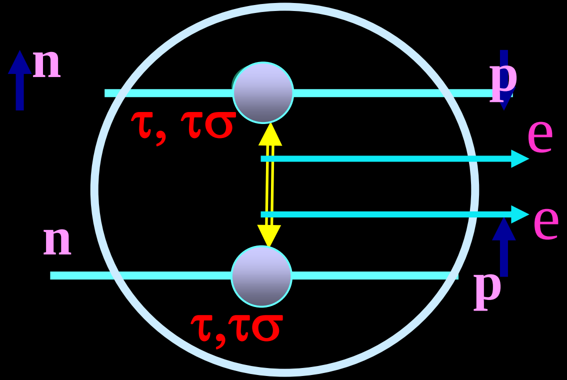
J. Vergados, H. Ejiri, F. Simkovic, Rep. Prog. Phys. 75 (2012) 106301.

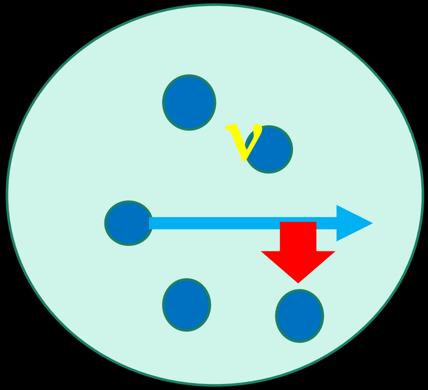
H. Ejiri, J. Phys. Soc. Jpn. 74 (2005) 2101.

Why DBD : $\sigma \sim 10^{-83}$ cm^2 T$\sim 10^{-36}$/sec

A femto (10^{-15}cm) nuclear collider

Luminosity L$\sim 10^{76}$/cm^2 /sec = 3 10^{83}/cm^2 /y





3 ton 10^{30} nutrons with 1/3 light velocity in a bahn area

Cross section = 10^{-83} cm^2 in case of IH 20 meV M=2

III DBD mass sensitivity and DBD exps to access the ν-mass

Key Elements for DBD

$T^{0\nu} = G^{0\nu}[M\ m]^2$ m= light Majorana ν mass

Experiment gives a limit or a value for $[M\ m]$

or $M \longleftrightarrow m$ if M or m is known

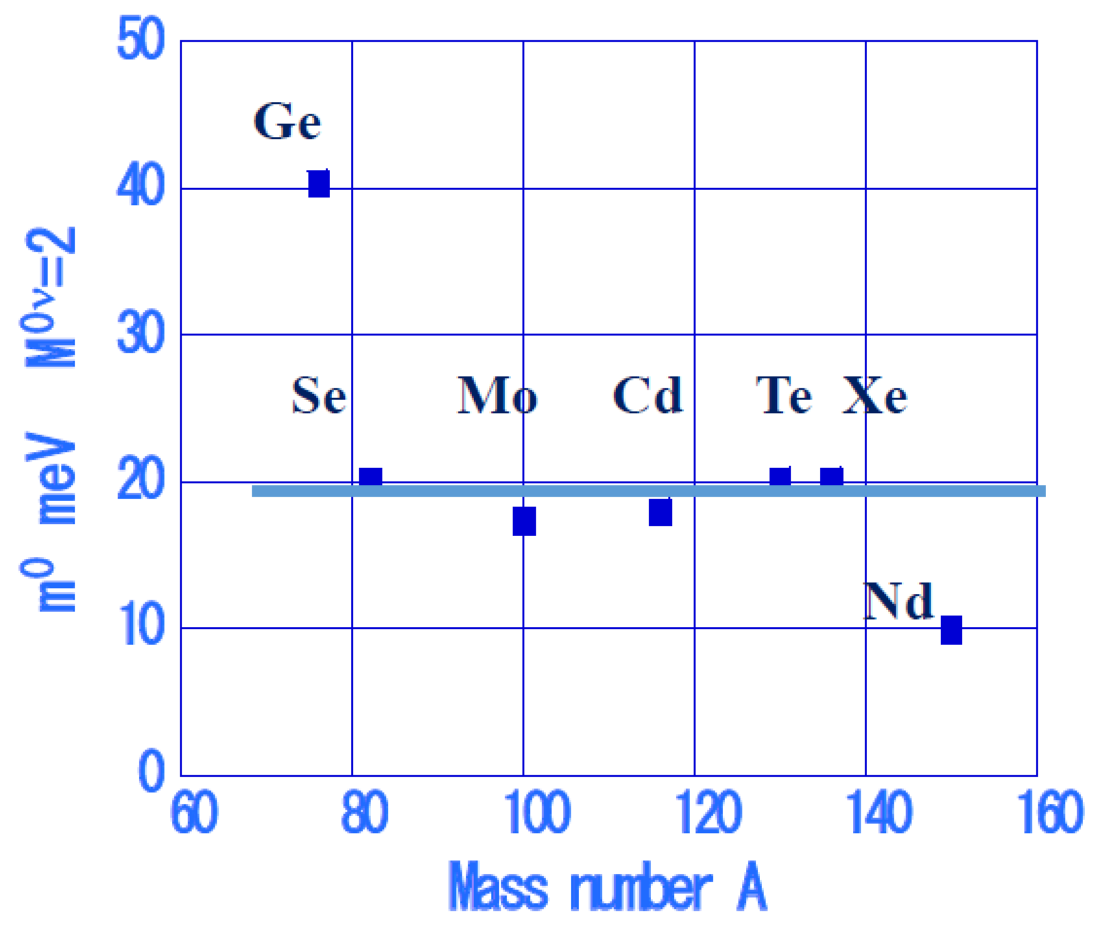
$T^{0\nu} = [m/m_0]^2$ m_0 = unit mass to give 1 /ton year

$=k/[M\,(G^{0\nu})^{1/2}]$

$\sim$ 20-40 meV $(2/M)$

$(T)^{-1}=(m/m_0)^2$ Rate /t y $m=m_0 = k/M$ M=NME

In case of M=2 : Ton scale is required, 2n ,isobar ?



Key Elements for DBD

m_m = Neutrino mass to be detected.

Signal > BG

$T^{0\nu}\ NT = [m_m/m_0]^2\ NT > (BG)^{1/2} = (BNT)^{1/2}$

NT= Isotope ton and year B= BG/ton year

$m_m = m_0\ d$

$d = 2\ [B/NT]^{1/4}$ detector sensitivity, $\varepsilon \sim 0.5$

$m_m = 2\ m_0\ [\ B/NT]^{1/4}$ in case of $\varepsilon = 0.5$

$m_0 = k/M = 20$, $M=2$, $B=1$, $NT=16$, $m_m = 20$ meV

Why Nuclear Matrix element M

1. Get ν-mass $m = [1/M]\,[T_{1/2}\,G]^{-1/2}$
2. Detector mass sensitivity

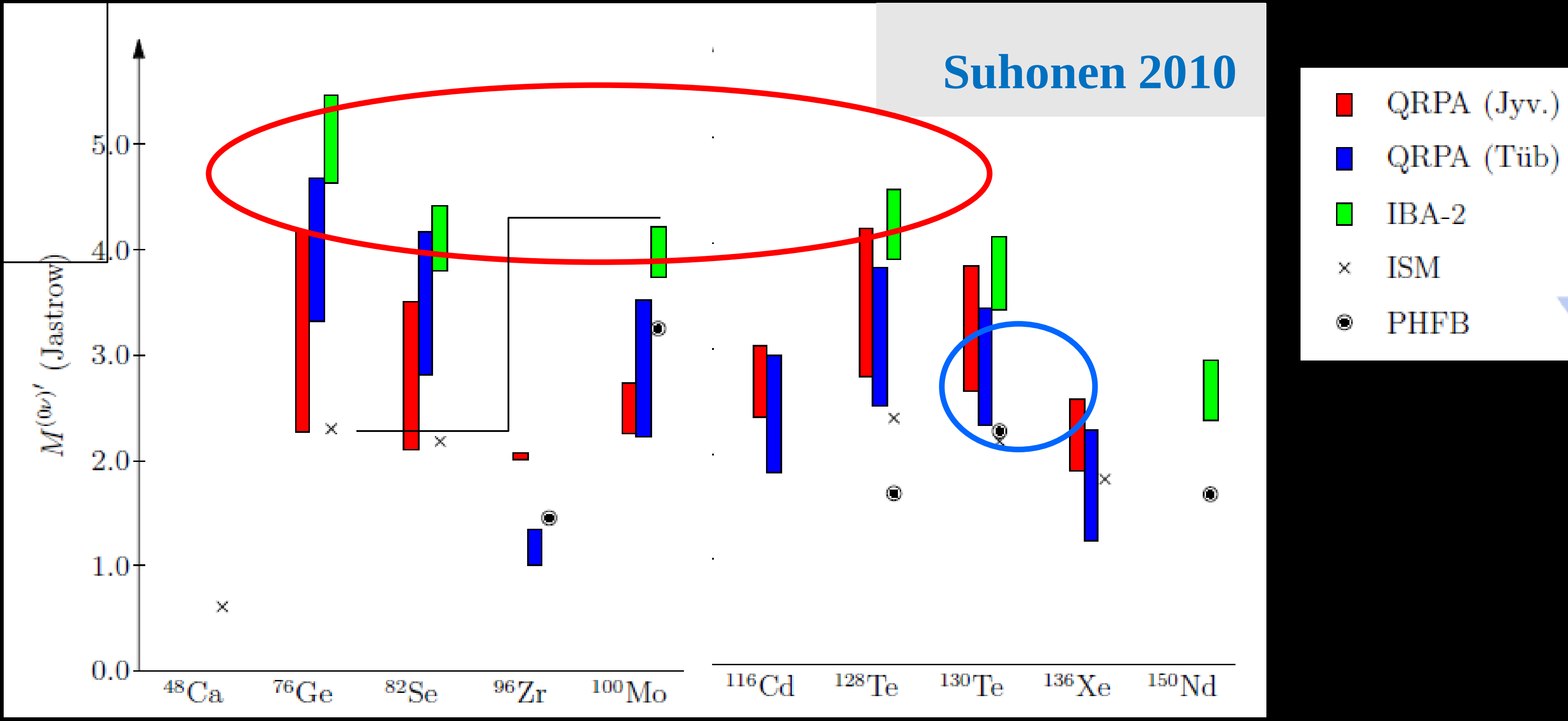
$m = k\,m_0\,/M\,[\,B/N]^{1/4}$ m_0 for S=1/ty

- M = NME, B=BG/ty N=Isotope mass ton
- M Factor 3 in M is equivalent to
- Factors 100 less in BG or 100 more in N tons

3. Theoretical M: factor 10 uncertainty

- Need experimental input to M

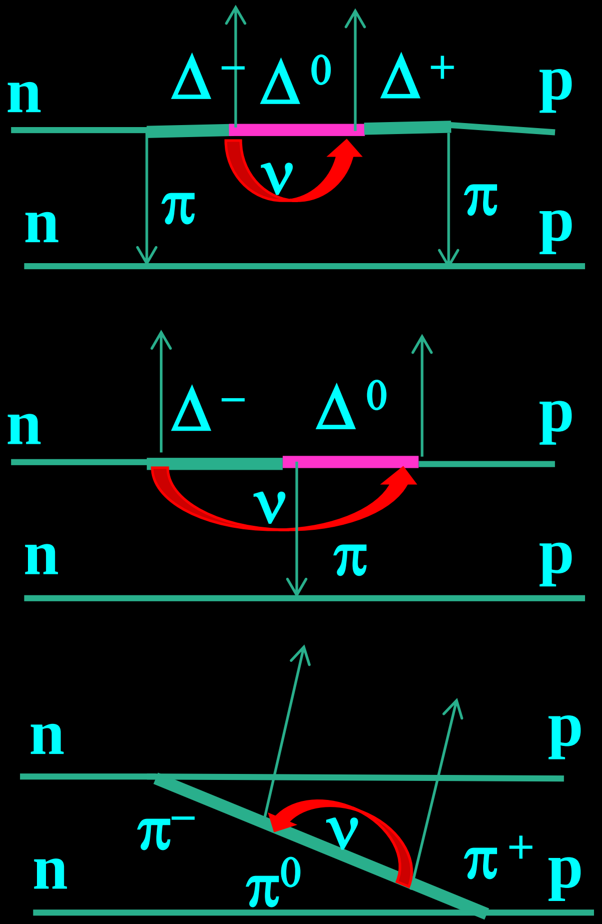
NMEas are very sensitive to nuclear models and parameters



Suhonen 2010

Experimental imputs are crucial, NEXT NEWS in Jan

Hadronic (Δ, π) *



Effect on low ββ 0^+ - 0^+

$P(\Delta)^2 \sim (10^{-2})^2 \sim 10^{-4}$

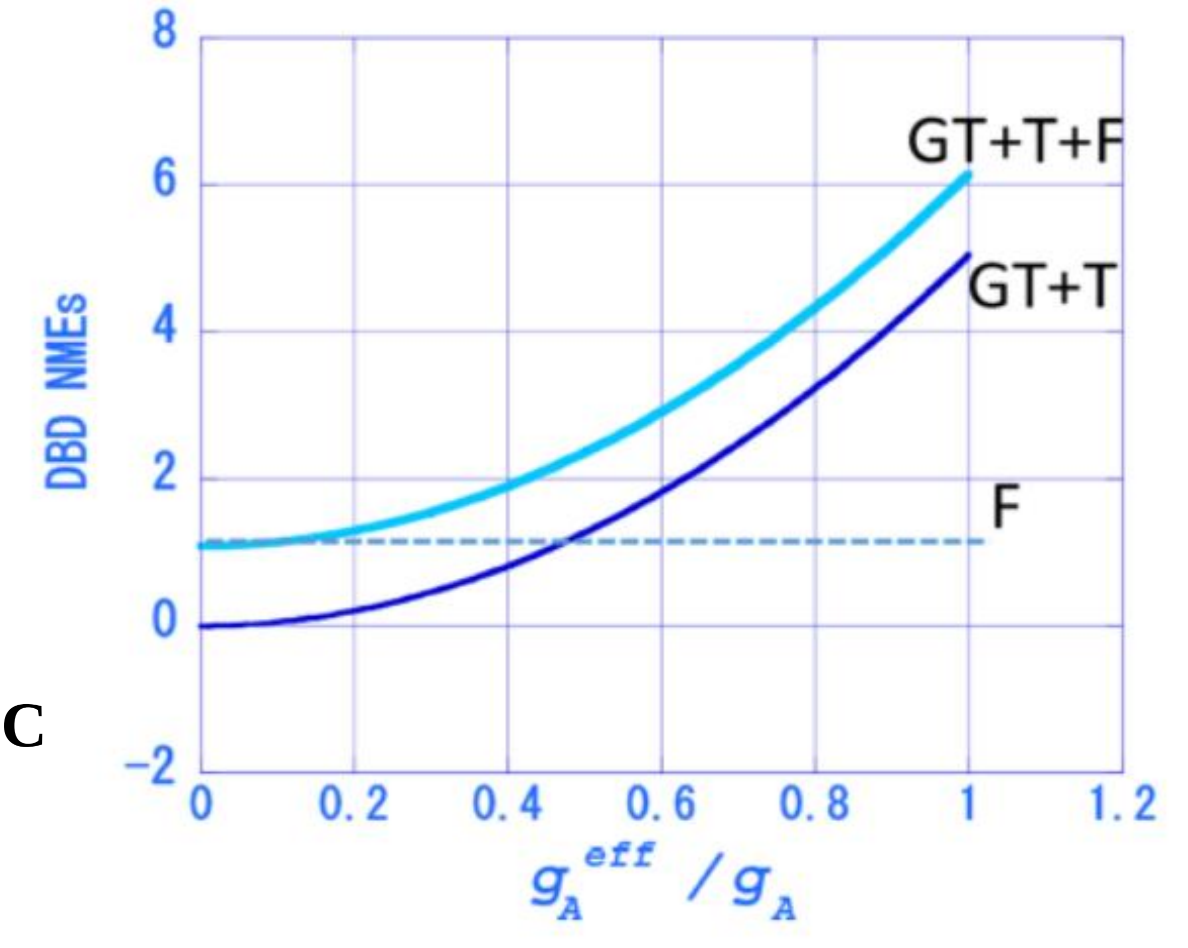
*Pontecorvo; Haxton, Stephenson, Kotani Doi .

$$M^{0\nu} = [\frac{g_A^{eff}}{g_A}]^2[M_M^{0\nu}(GT) + M_M^{0\nu}(T)] + [\frac{g_V}{g_A}]^2 M_M^{0\nu}(F),$$

M(α) by

pnQRPA

^{76}Ge



g_A^{eff} / g_A= 0.5 leads to reductions 0.25 for M(GT),

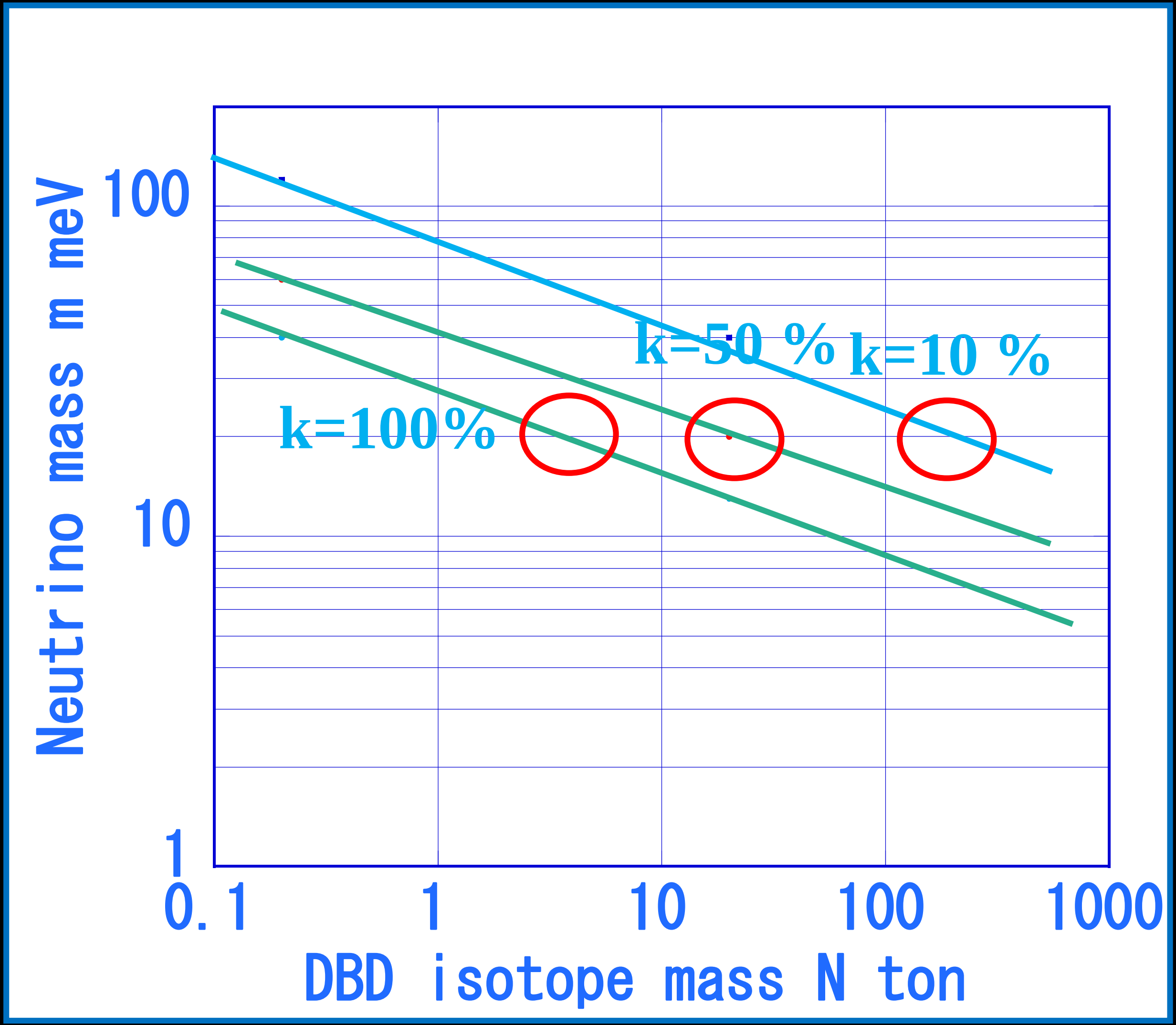
0.4 for $M^{0\nu}$, 0.16 for DBD rate, ~ 40 for detector mass

Detectors to access the IH mass

2019/12/6

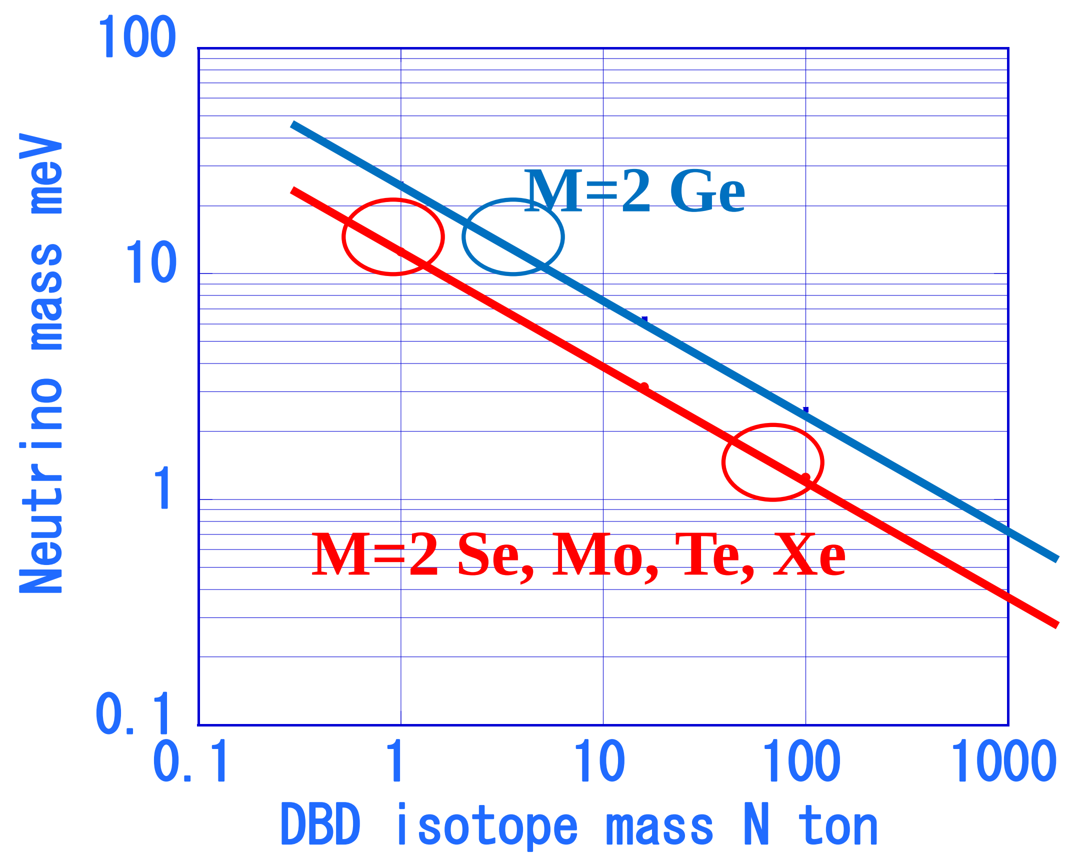
Enrichment k $m=2m_0\ k^{-1/2}\ (B/NT)^{1/4}$

$B=1/ty$ $T=5$ y $m_0=20$ meV, IH 20 meV



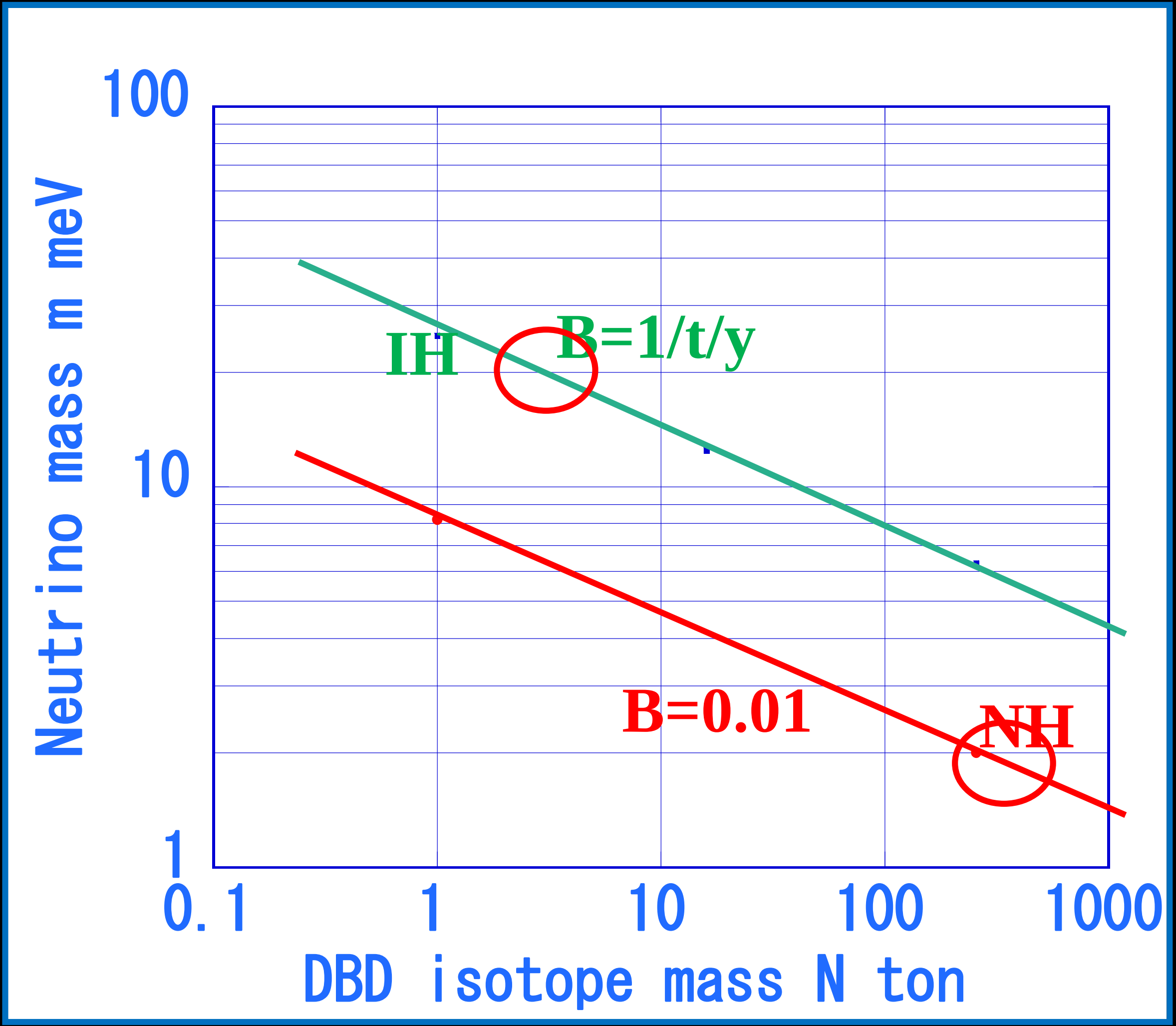
5 % 300 ton is equivalent to 90 % 1 ton

N ton and m meV in T=5 year Y=3 counts, B=0



N ~ 1 to cover IH and N~100 for NH even BG=0

N for M=2 T=5 year BG=1 /ty B=0.01 / t y

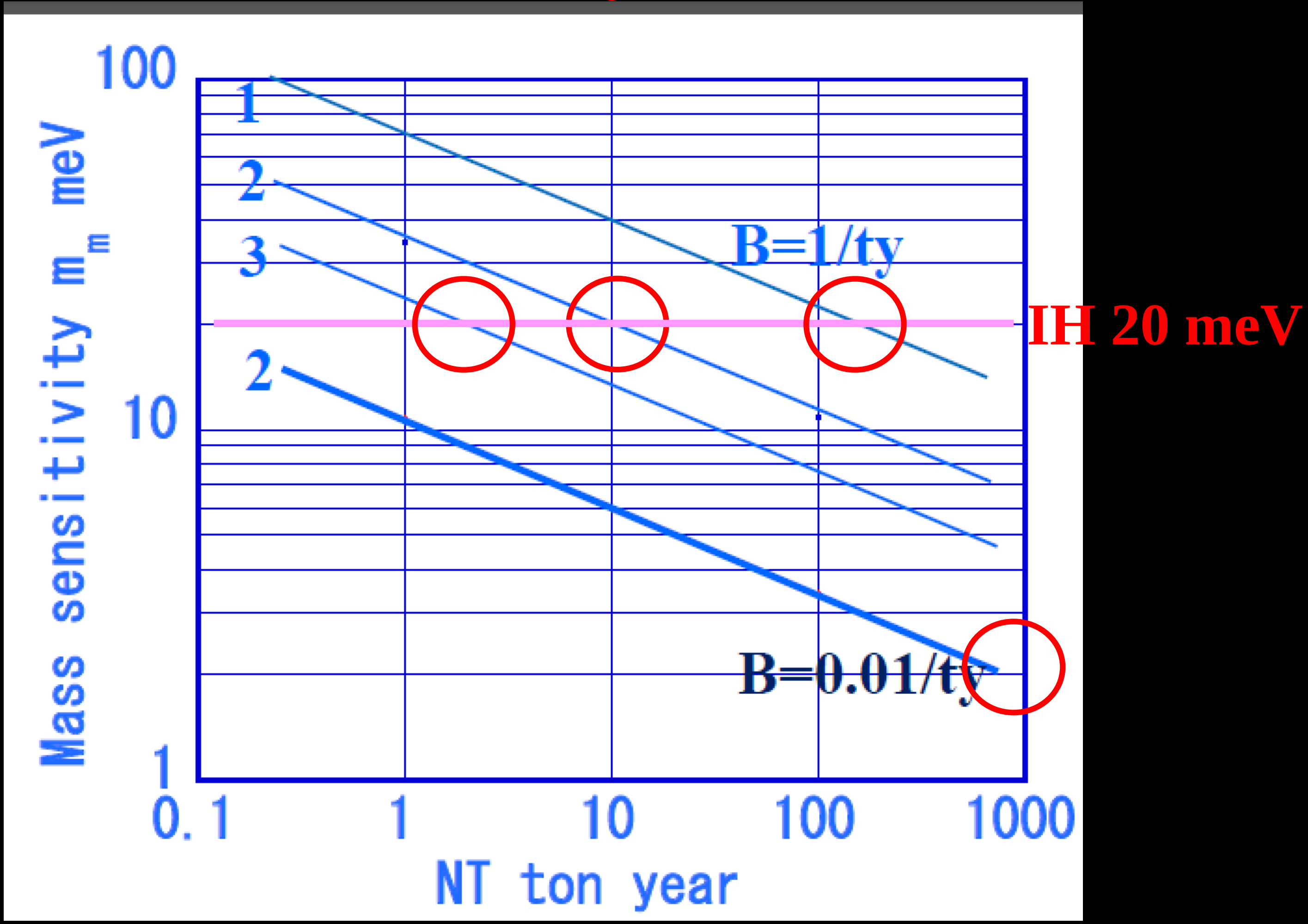


If B is 10 times larger, N should be 10 times more

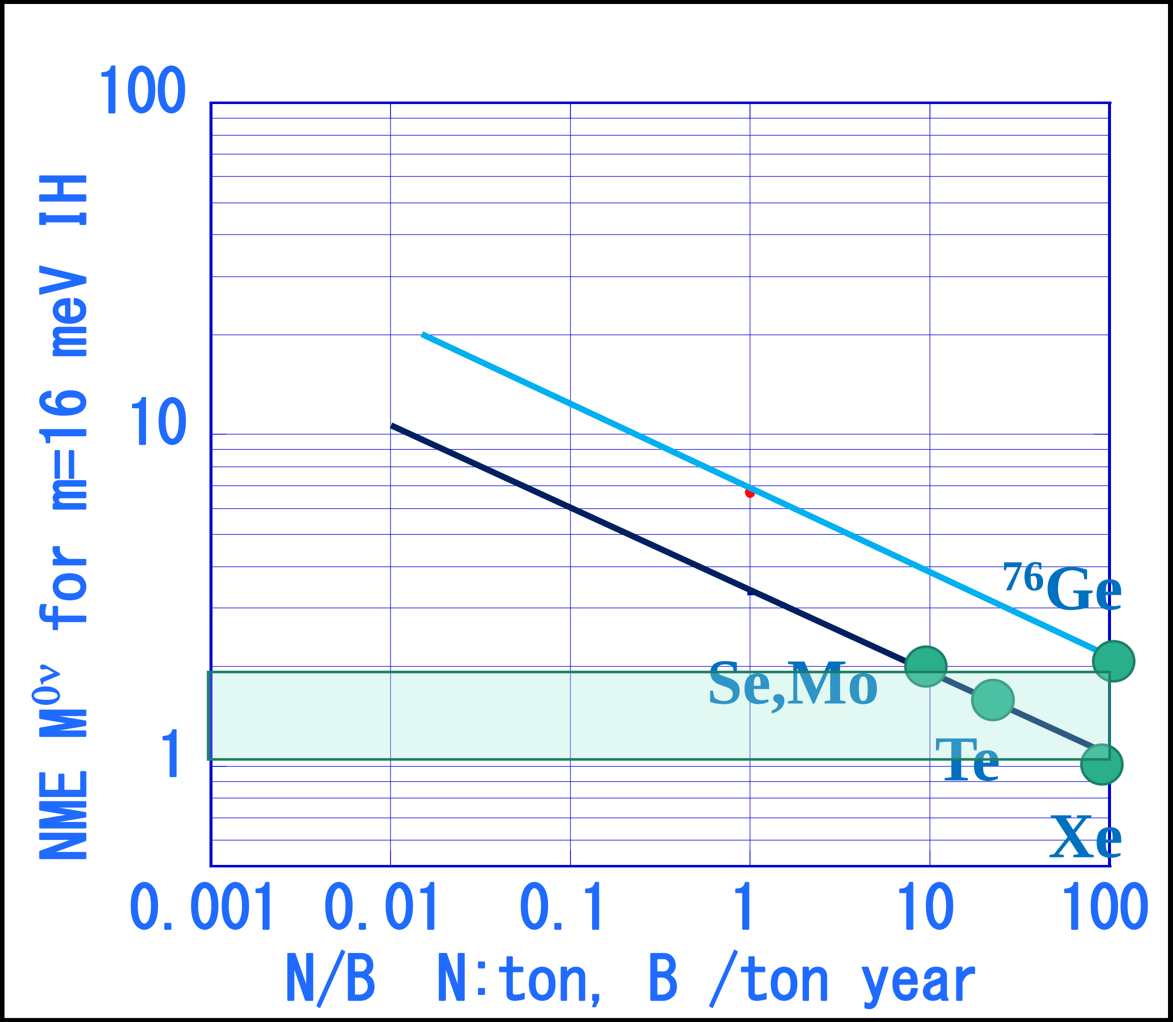
DBD $0\nu\beta\beta$ NMEs and DBD mass sensitivity

$$m = k\,[m_0]\,[B/N]^{1/4}$$

$M^{0\nu}=k^2$ M(QRPA) ~ 2 , m_0 =18 meV ε~0.5



NME versus N Isotope and B (BG) for IH=16 meV T=5 y exp.

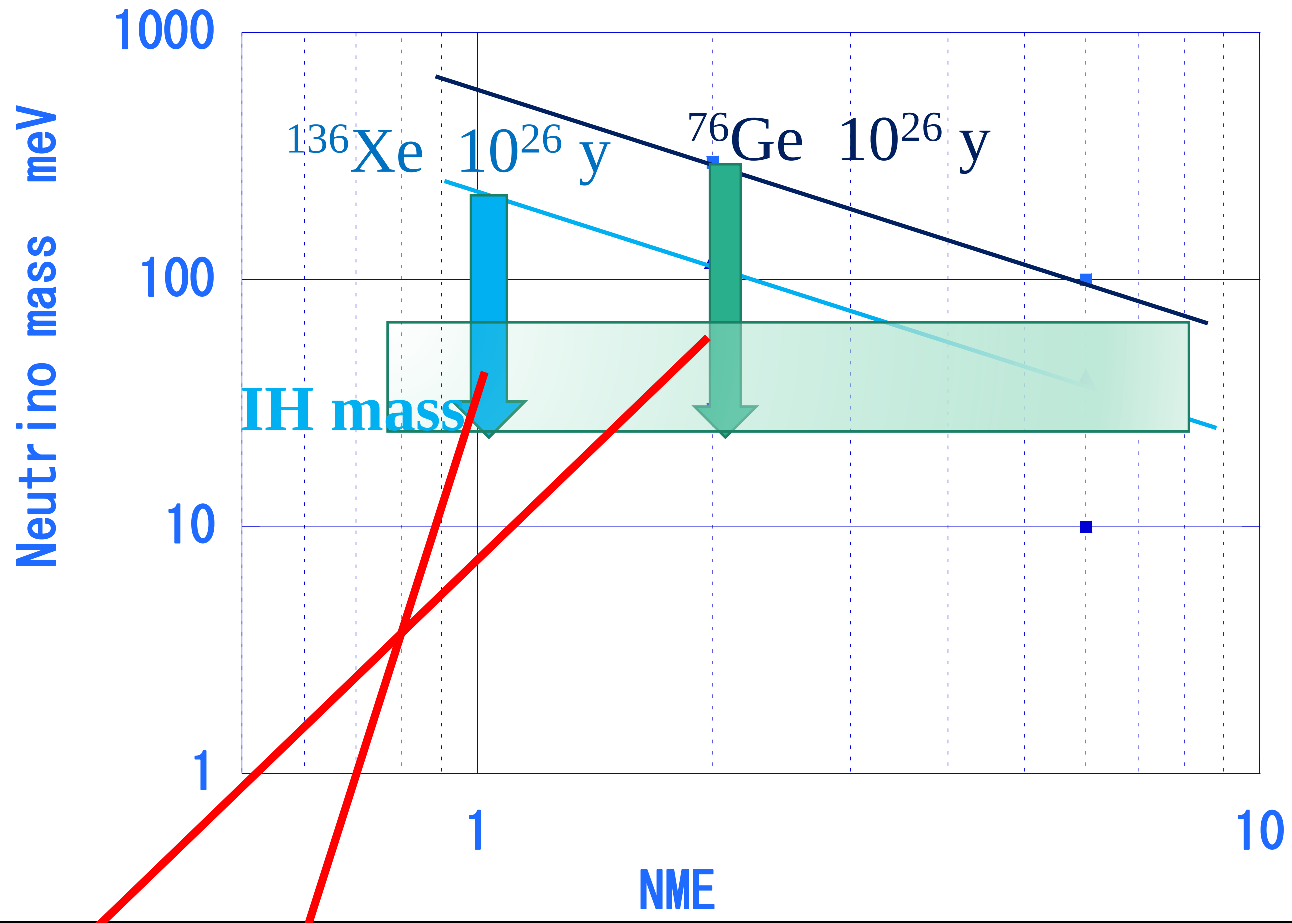


^{76}Ge M~2 N/B~100 N~10 t B~0.1 /t y

Se,Mo M~2 N/B~10 N~30 t B~0.3 / t y

Xe M~1 N/B=100 N~30 t B~0.3 / t y

Limits on [Mass × NME] < $k/T_{1/2}$

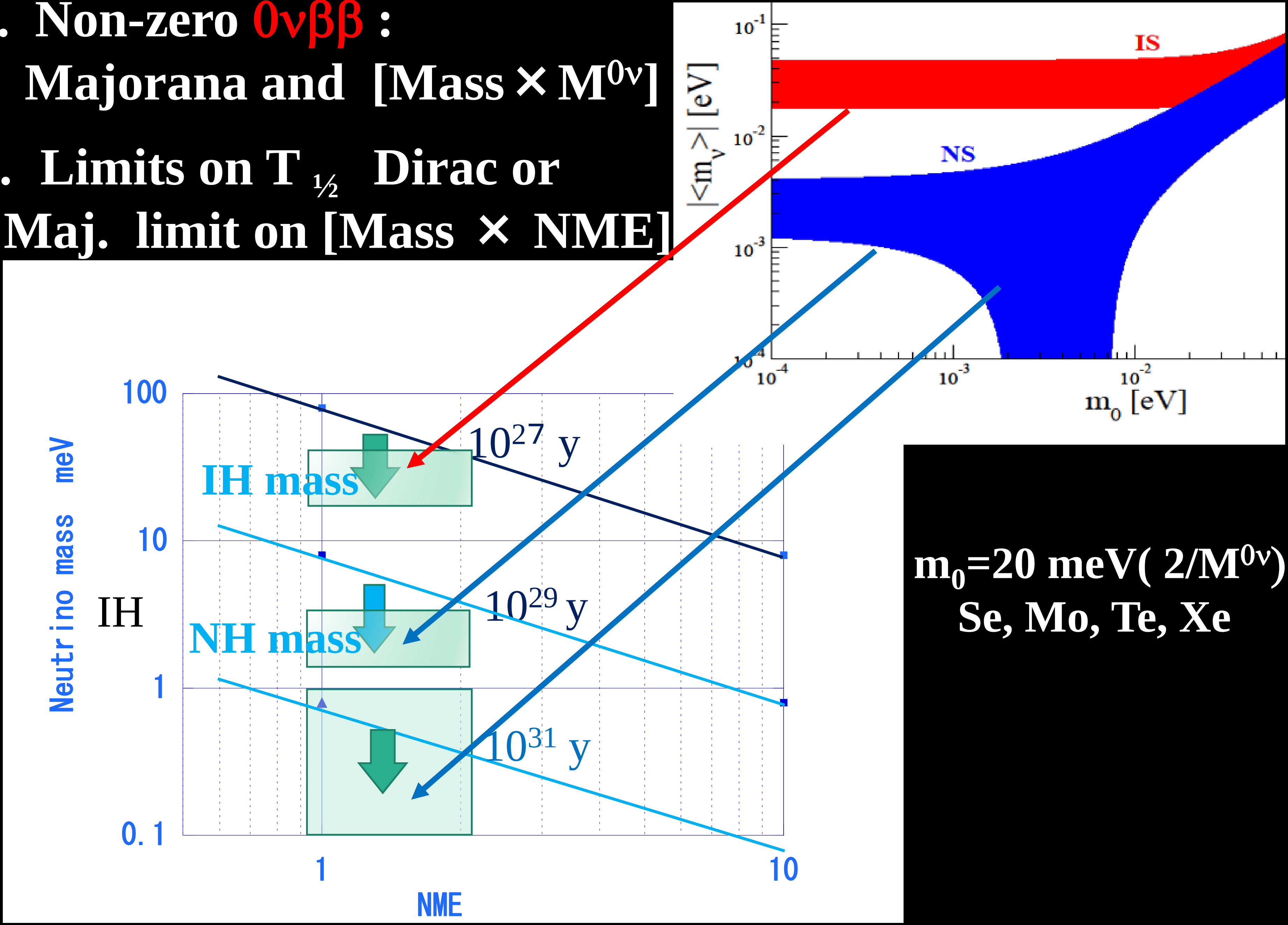


To reach IH mass = 16 meV,

factor 20 and 12.5 in mass and 1.6 10^5 and 2.4 10^4 in NT/B

A. Non-zero 0νββ :
Majorana and [Mass × $M^{0\nu}$]

B. Limits on $T_{1/2}$ Dirac or
Maj. limit on [Mass × NME]



m_0=20 meV(2/$M^{0\nu}$)
Se, Mo, Te, Xe

Detectors to access the IH mass

Isotope Ton Centrifulgal separation

Ge, Se, Mo, Xe

Sub.ton Laser separation Nd

BG per ROI= Energy resolution

B < 0.1/t y Ge R=0.1 %

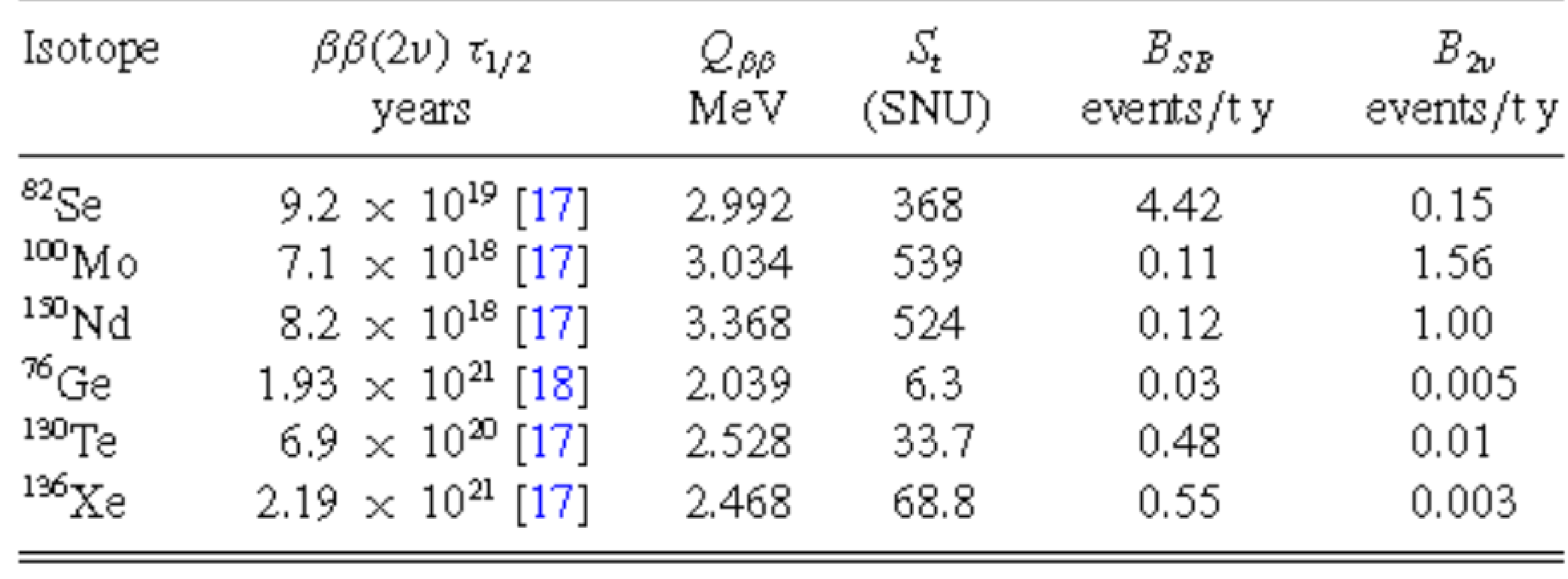
B< 1 /t y Bolometer R=0.5 %

NME M= 2 -1 Ge, Mo, Te, Xe

Solar and $2\nu\beta\beta$ BG Ejiri Elliott Phys, Rev, C 95 055501 2017

Lig. Scintilator B~ 1/R / t y R is concentration %

Ejiri Zuber 2016 J. Phys. G. 43 045201



Isotope	$\beta\beta(2\nu)$ $\tau_{1/2}$ years	$Q_{\beta\beta}$ MeV	S_t (SNU)	B_{SB} events/t y	$B_{2\nu}$ events/t y
^{82}Se	9.2×10^{19} [17]	2.992	368	4.42	0.15
^{100}Mo	7.1×10^{18} [17]	3.034	539	0.11	1.56
^{150}Nd	8.2×10^{18} [17]	3.368	524	0.12	1.00
^{76}Ge	1.93×10^{21} [18]	2.039	6.3	0.03	0.005
^{130}Te	6.9×10^{20} [17]	2.528	33.7	0.48	0.01
^{136}Xe	2.19×10^{21} [17]	2.468	68.8	0.55	0.003

Possible DBD detector with IH mass 20 meV

Yes Majorana and IH and mass No Dirac or NH

- m= k m_0 /M [B/N] ¼ m_0 for S=1/ty
- M = NME=$g_A{}^2$M(QRPA)
- B=BG/ty N=Isotope mass ton

m_0	In case M	BG/t y	N ton /5y	Isotope A
40	2	0.1	3	Ge 76
20	1.5	1	6	Se 82
20	2	1	2	Mo 100
20	1-2	1	30-2	Xe 136

Search for the rare peak/events among huge BGs

Very low energy very rare evets and multi mechanisms

I Energy sum spectrum E=E(β1)+E(β2) with good E resolution
Find 0νββ peak (discovery potential) for lepton number 2

Huge single β BG peak in ROI (region of interest)

Two DBD isotopes to avoid accidental coincidence with BG peak

II Two beta E and angle correlations (like ELEGANT, MOON)
Identify β1 and β2 , left-handed / right–handed currents
One DBD isotope suggested by I sum spectrum

What to do : Concentration of DBD powers

1. Enriched isotopes k>80 % multi-tons

   Centrifugal separation

2. E resolution < 1 % to avoid 2νββ and solar

   and single-β BG

3. Select two isotopes , one from Se/Mo and one

   from Te/Xe to identify the peak.

4. Experimental studies of NMEs with p~80

   MeV/c by (^{3}He,t) and (μ,xn) CERs

5. R&D for MOON/ELEGANT for 2 β and L/R.

Thanks for your attension