Neutrino Nuclear Responses For Double Beta Decays And Supernova Neutrinos

INPC2016

Hidetoshi Akimune Konan University

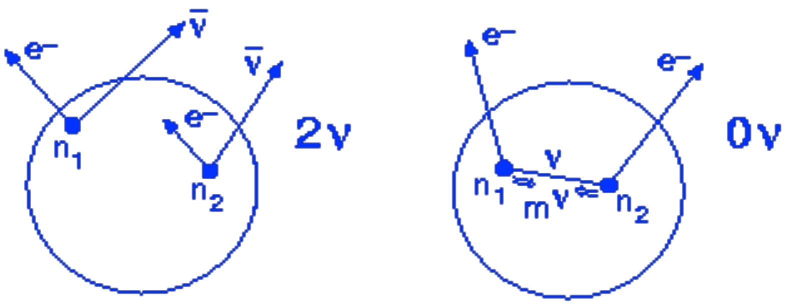
Collaborators

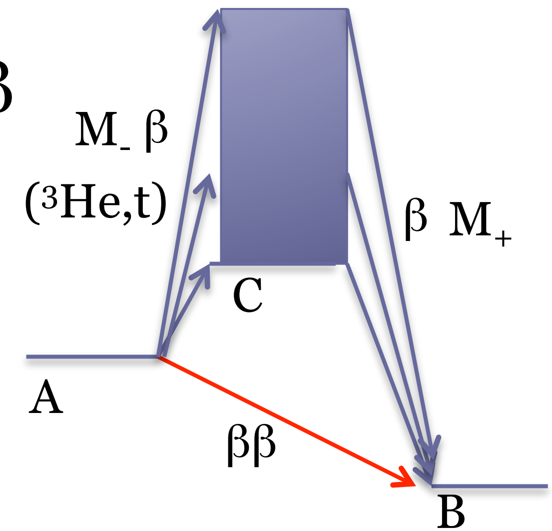
Hidetoshi Akimune	Konan University
Hiro Ejiri	RCNP, Osaka
Dieter Frekers	Universität Münster
Muhsin Harakeh	KVI-CART, Groningen

T. Agodi	INS INFN Catania	N. Kalantar	KVI, Groningen
M. Alanssari	IKP, Univ. Münster	A. Lennarz	IKP, Univ. Münster
F. Cappuzzello	IKP, Univ. Münster	Y. Matsuda	Tohoku CYLIC
D. Carbone	INS INFN Catania	P. Puppe	IKP, Univ. Münster
M. Cavallaro	INS INFN Catania	P. Ries	TV Darmstadt
F. Diel	K¨oln University	C.Rigollet	IKP, Univ. Münster
C. A. Douma	KVI, Groningen	J. Suhonen	Univ. Jyvaskyla
H. Fujita	RCNP Osaka	A. Tamii	RCNP Osaka
Y. Fujita	RCNP Osaka	K. Heguri	Konan University
M. Fujiwara	RCNP Osaka	F. Hattori	Konan University
G. Gey|	RCNP Osaka	J. Gellanki	KVI, Groningen
K. Hatanaka	Osaka University	V. Werner	TV Darmstadt
M. Holl	IKP, Univ. Münster	R. Zegars	NSCL MSU
A. Inoue	RCNP Osaka		

Double beta decay

- $(A,Z) \rightarrow (A,Z+2) + 2\,e^- + 2\bar{\nu}_e$ $2\nu\beta\beta$
- $(A,Z) \rightarrow (A,Z+2) + 2\,e^-$ $0\nu\beta\beta$





- $0\nu\beta\beta$: unique process to measure the characteristics of neutrino
  - Neutrino mass measurement via half-life measurement
  - Requires half-life measurements beyond 10^{20} yrs!!!!

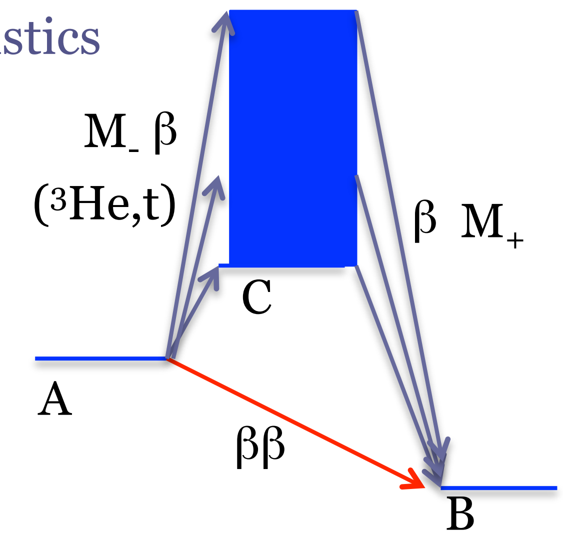
ν-nuclear responses for ββ-ν physics

$$T_{0\nu\beta\beta}^{-1} = G^{0\nu} \left| < m_\nu > \right|^2 \left| M^{0\nu} \right|^2$$

ν-nuclear response$[M^{0\nu}]^2$ is needed for m_ν study [1,2]

$$M^{0\nu} = \sum M_+ M_- \qquad M_\pm = (g_A)^{eff} M_\pm(QPRA)$$

- Nuclear models such as QRPA, IBM… include uncertain renormalization of axial weak coupling in the nuclear medium $(g_A)^{eff}$
  - We need experimental $(g_A)^{eff}$ for $[M^{0\nu}]$
    for relevant states to help theoretical calculations.
    If $(g_A)^{eff}$ changes -10%, $[M^{0\nu}]^2$ changes -40% and
    3 times larger detector is needed for same statistics
  - Experiments,
    - (^{3}He,t) RCNP : present , (p,n)
    - (n,p), (t,^{3}He),(d,^{2}He), (^{7}Li,^{7}Be),,,,
    - μ-capture MuSIC RCNP
    - γ-capture NewSUBARU



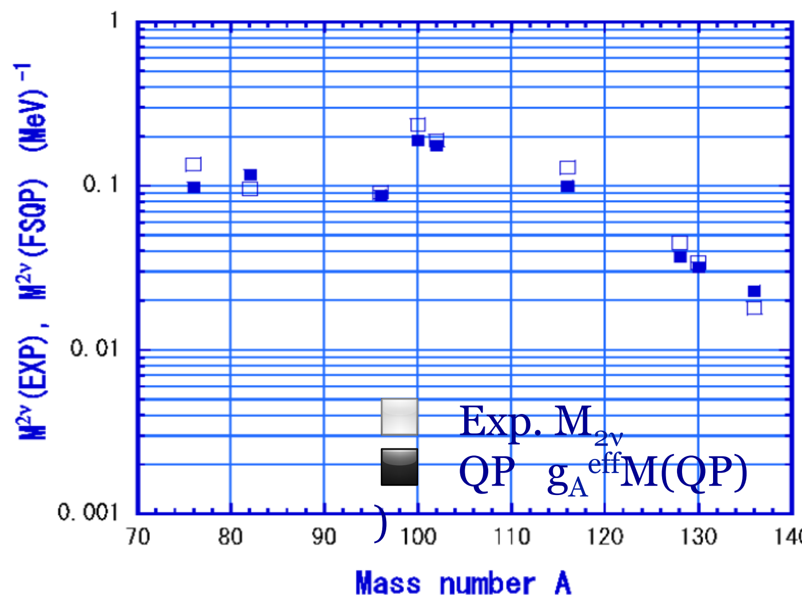
[1] H. Ejiri, Phys. Rep. 338 (2000), JPSJ 74 (2005).
[2] J. Vergados, H. E, F. Simkovic, Rep. Prog. Phys. 75 (2012).

(^{3}He,t) reaction at RCNP Osaka

- High energy resolution ($\Delta E \sim 30$ keV) is essential to separate intermediate states in DBD nuclei,
- At E/u = 140 MeV, relatively large $V_{\sigma\tau}$ and small V_o
- We have good data for Gamow -Teller and Spin-Dipole state on DBD nuclei [5]
- So far, $M^{2\nu}$ for $2\nu\beta\beta$

$$M^{2\nu} = \sum M_+(GT1^+) M_-(GT1^+)$$

  - 2 real ν are in s-wave
  - $M^{2\nu}$ are well reproduced[6]. using $M_\pm = (g_A)^{eff} M_\pm(QRPA)$
- Next step, $M^{0\nu}$ for $0\nu\beta\beta$
  - To study ν-mass



[5] H.Ejiri D. Frekers, N. Harakeh, H.A., et al., PRC 88 054329 (2013), C 86, 044603 (2012) C 84, 051305 (2011), C 77, 024307 (2008), C 74, 034333 (2006), C 74, 024309 (2006), C 70, 034318 (2004), C68, 064612 (2003), C64, 067302 (2001), PRL. 99 202501(2007), 85, 4442 (2000), 82, 3216 (1999), PLB 706, 134 (2011) .394B, 23 (1997)

[6] H. Ejiri. JPSJ 78 (2009) 74201, 81 (2912) 33201

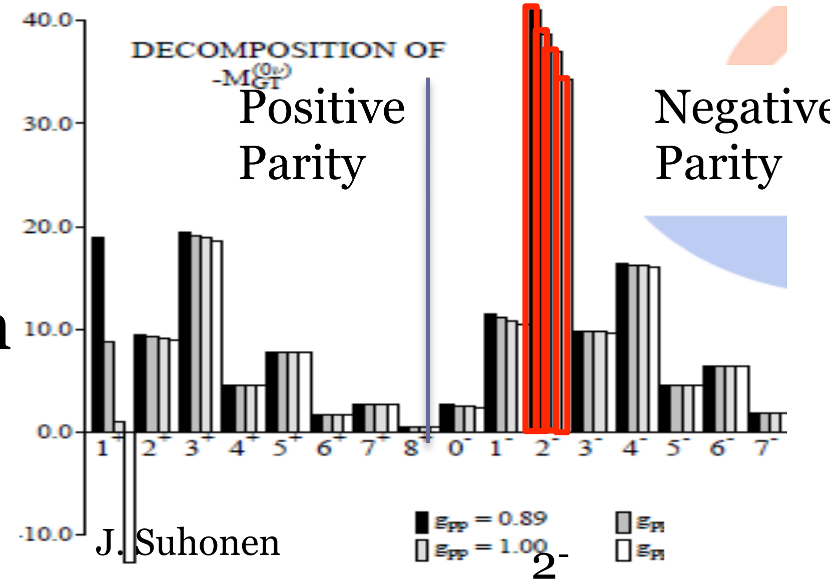
Spin Dipole (SD) 2^- for $0\nu\beta\beta$

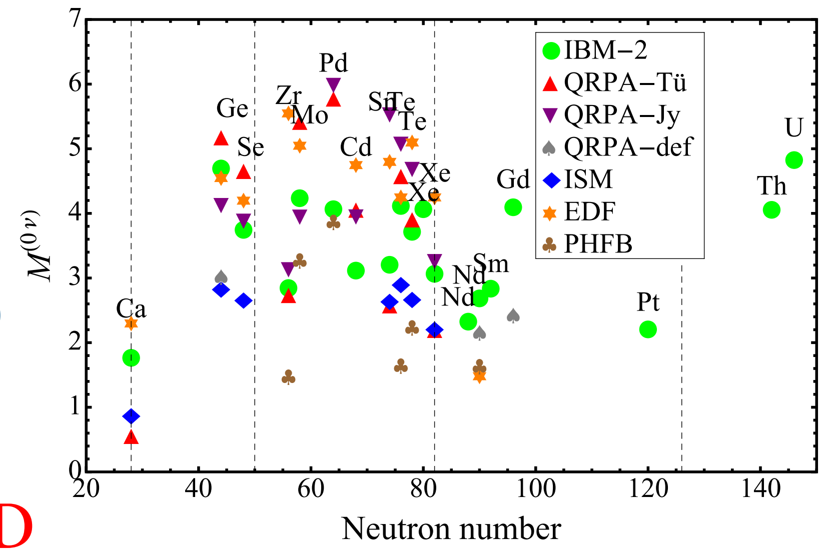
- $0\nu\beta\beta$: virtual ν exchange inside nuclei
  - $q \sim 1/r = 1\text{-}0.3\ \mathrm{fm}^{-1}$, $rq = L \sim 1\text{-}2$
  - $J_\pi = 2^-$ is the major component
- Cross Section for (^{3}He,t) reaction

$$\sigma(SD) = KF(q,\omega)\left|J_{SD}\right|^2 B(SD)$$

$$M(SD) = g_A \tau\left[\sigma \times f(r) Y_1\right]_2 \qquad B(SD) = \frac{\left|M(SD)\right|^2}{2J_i + 1}$$

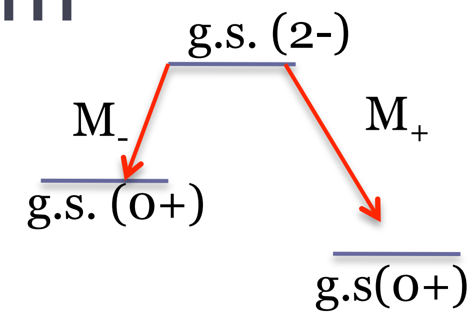
- We aim
  - to experimentally provide $\left|J_{SD}\right|^2$ to get M(SD) from σ (SD)
  - $M(SD) = (g_A)^{eff} M(QPRA)$ for strong SD states observed in DBD nuclei
  - to help theories such as QRPA
  - to test feasibility of (^{3}He,t) for SD



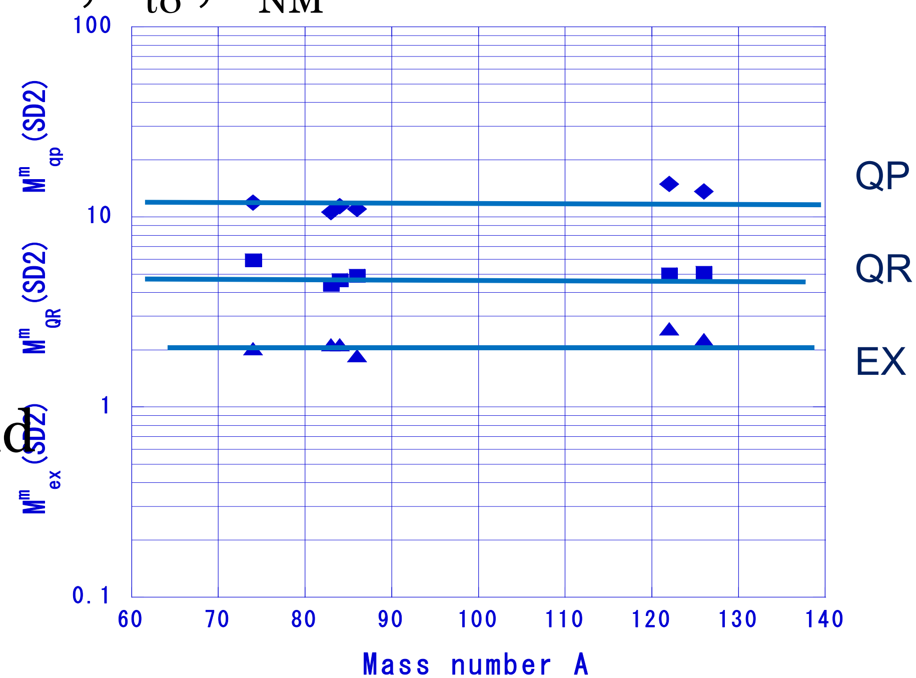


J. Barea et al. PRC 91 034304 (2015)

Keys for ν response are (1) τσ correlation and (2) g_A^{eff} in nuclear medium



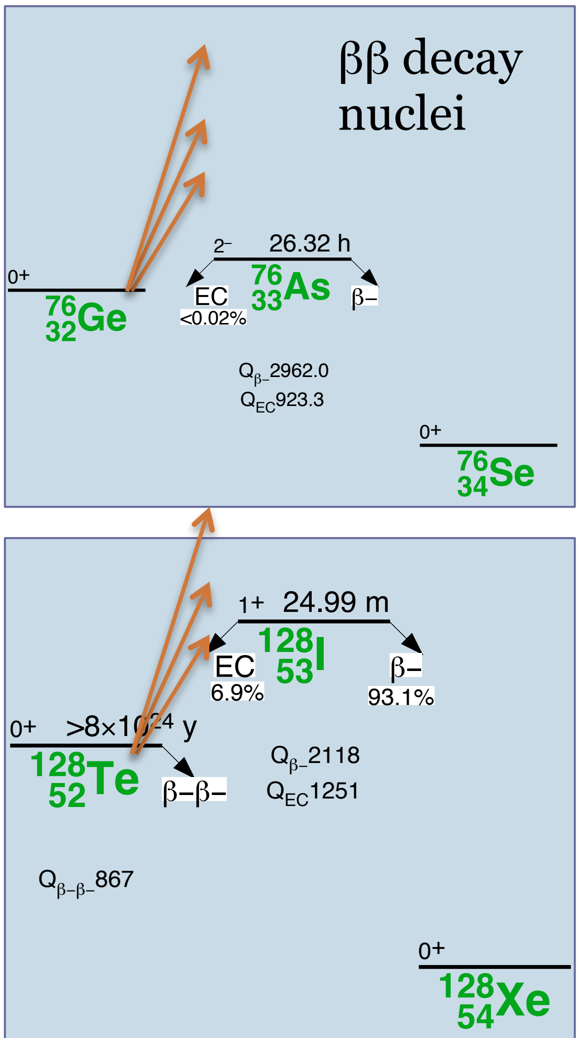
- M^m for Single $2^- \to 0^+$ β decay
  - Here $M^m=[M_+M_-]^{1/2}$
    - M^+ for A(Z,N) ⇄ A(Z+1,N−1)
    - M^- for ⇆ A(Z−1,N+1)
- Phenomenological reduction factor k , $k_{\tau\sigma}$, k_{NM}
  - M^m(EXP) = k M^m(QP)
    - $k = k_{\tau\sigma} k_{NM} \sim 0.2$
  - M^m(QRPA) = $k_{\tau\sigma}$ M^m(QP)
    - $k_{\tau\sigma} \sim 0.4$ τσ correlation
  - M^m(EXP) = k_{NM} M^m(QRPA)
    - $k_{NM} \sim 0.5 = g_A^{eff}$ n-medium
- Are these reductions generally valid
  for SD ground /excited states
  in DBD nuclei ?



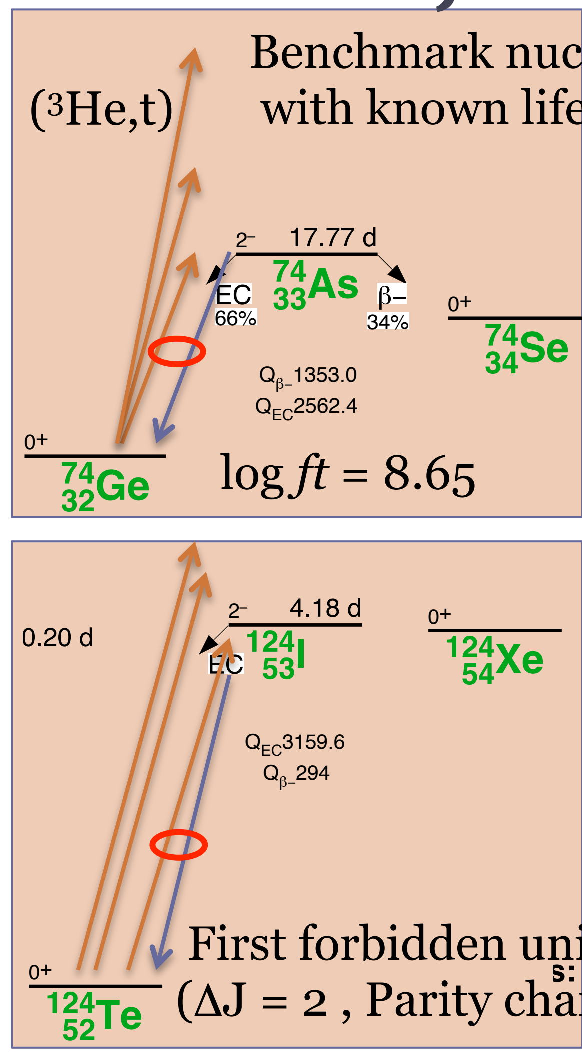
[8] H. Ejiri, Proc. MEDEX 13, APS conf. series, proc. 1572 (2013) 40.
[9] H. Ejiri, N. Soukouti, and J. Suhonen, Phys. Lett. B 729 (2014) 27.

Level diagrams for DBD nuclei and Benchmark nuclei with known *ft*

ββ decay nuclei



Benchmark nuclei with known lifetime



First forbidden unique transition
(ΔJ = 2 , Parity change)

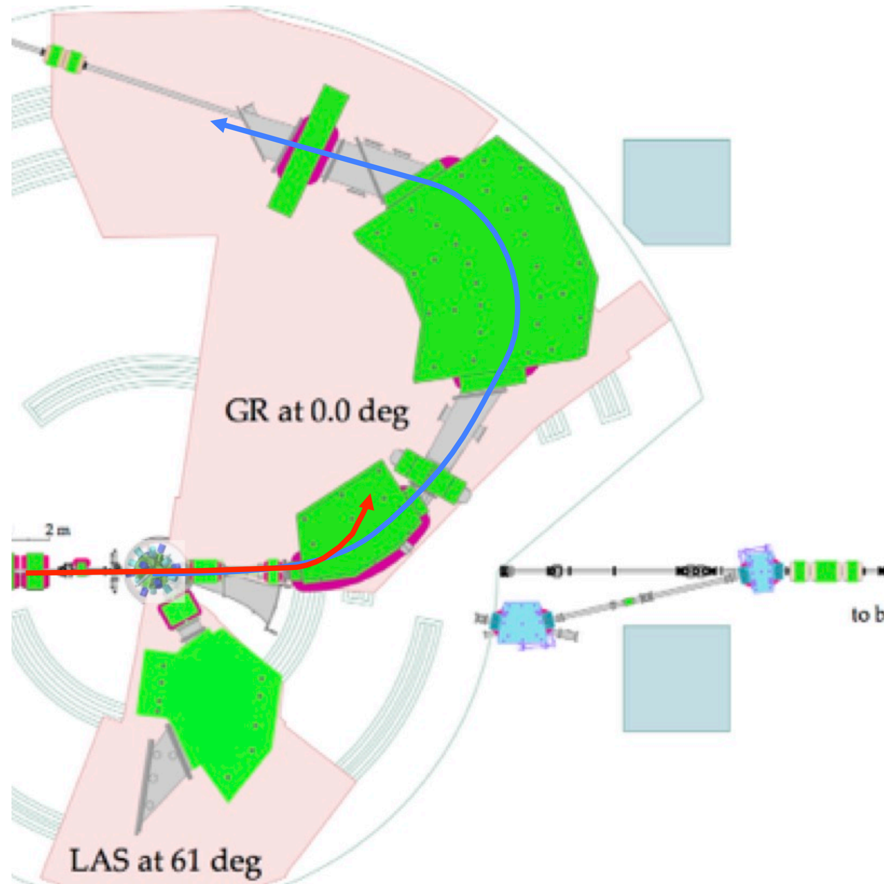
^{74}Ge(^{3}He,t) ^{74}Ge, ^{122}Sn(^{3}He,t) ^{122}Sb, ^{124}Te (^{3}He,t) ^{124}I

- In May 2016, we performed (^{3}He,t) experiment as benchmark for M(SD)
- Nuclei with large response (M^m(SD)) known from β decays.
- Unique σ, τ, l flip transitions
  - $[\sigma Y_1]_2 >> \delta p\ [\sigma Y_3]_2$
  - ΔJ=2, parity change
- Neighbor to DBD nuclei. σ(SD)'s were measured so far.
  - ^{76}Ge, ^{128,130}Te
- ^{74}Ge and ^{124}Te: to see if any mass dependence of $|J_{SD}|^2$
- ^{122}Sn (semi-magic) and ^{124}Te with similar A and QP: to see if any nuclear structure effects and to confirm

$$\sigma(SD) = KF(q,\omega)\left|J_{SD}\right|^2 B(SD)$$

Experiment at RCNP Osaka Univ.

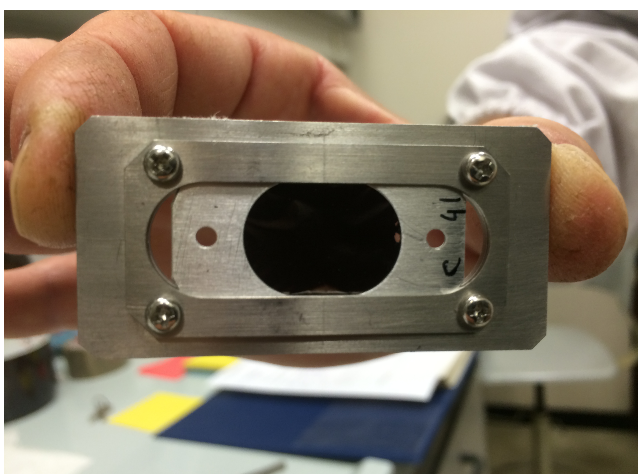
- (^{3}He,t) reaction at 420 MeV
  - High resolution spectrometer "Grand Raiden"
  - $\Delta E < 50$ keV
  - $\theta = 0$ to 5^o

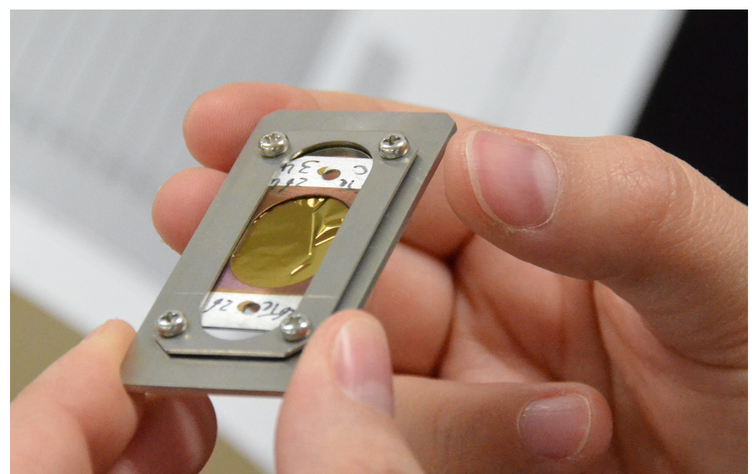


Target

- Germanium and Tellurium are known as materials which are very difficult to make thin foil: Hard and fragile.
- In order to achieve high resolution ($\Delta E \sim 30$ keV), very thin (less than 1 mg/cm^2) foil is required.
- Vapor deposition on thin carbon foil
  - Carbon foil ~40 μg/cm^2
  - ^{74}Ge, ^{124}Te ~ 250 μg/cm^2

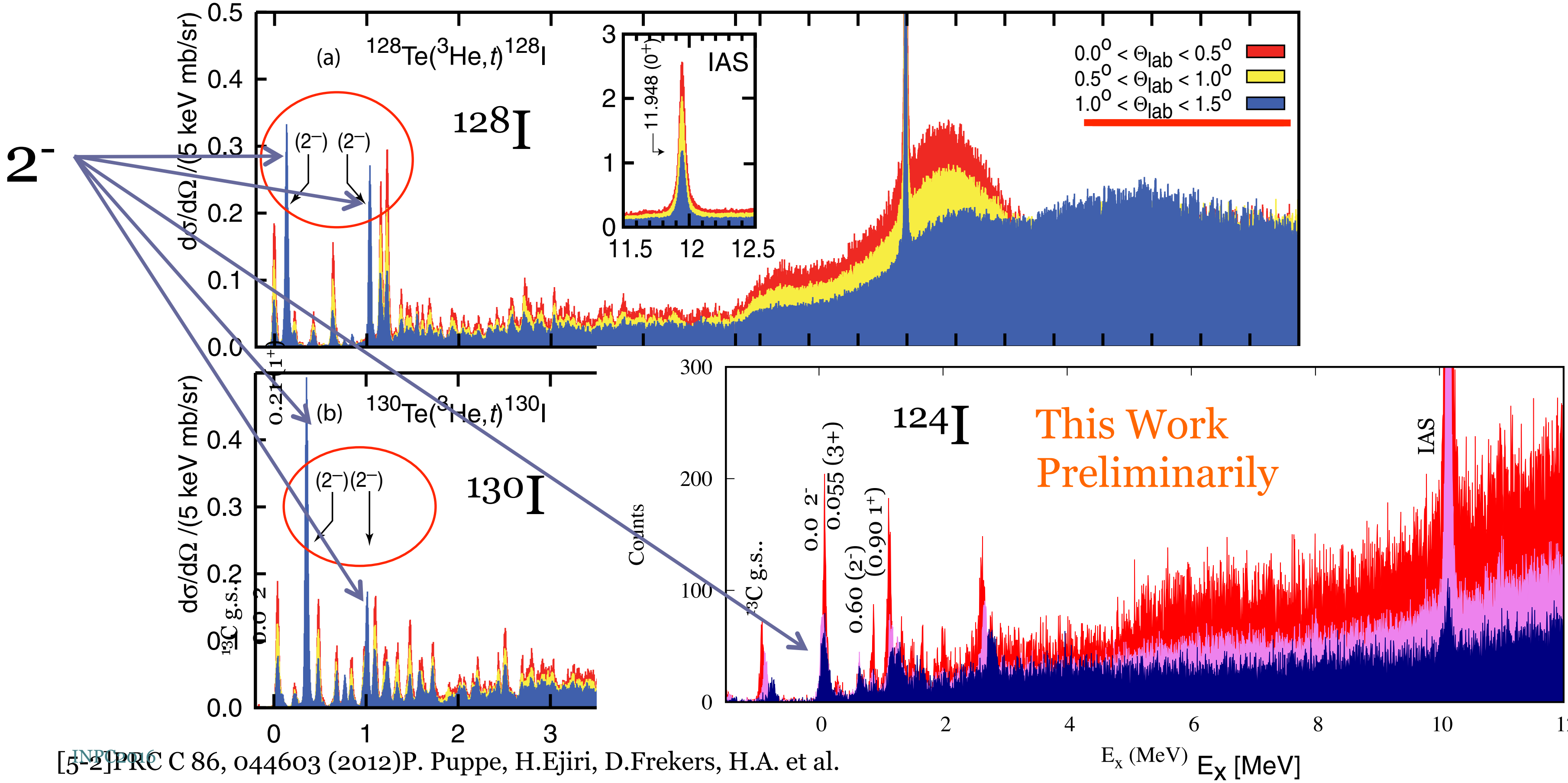
INS INFN Catania ITALY





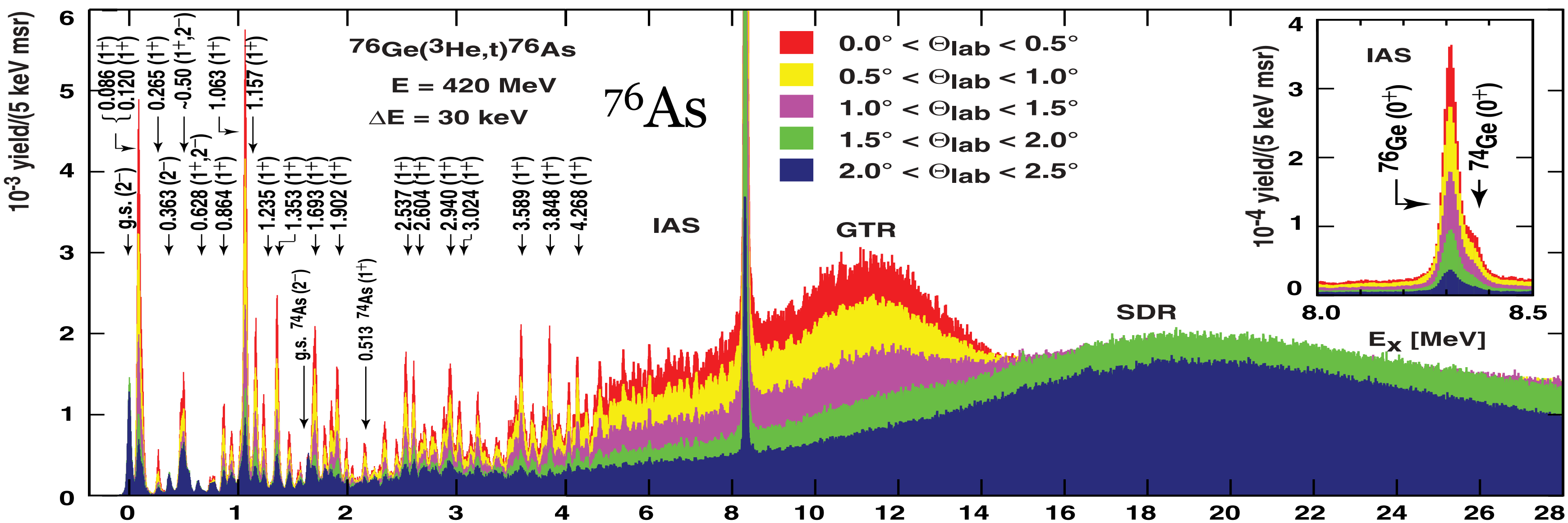
^{128,130}Te (ββ nuclei) and ^{124}Te (benchmark) show clear GT and SD states

- RCNP high resolution system is the unique and only opportunity

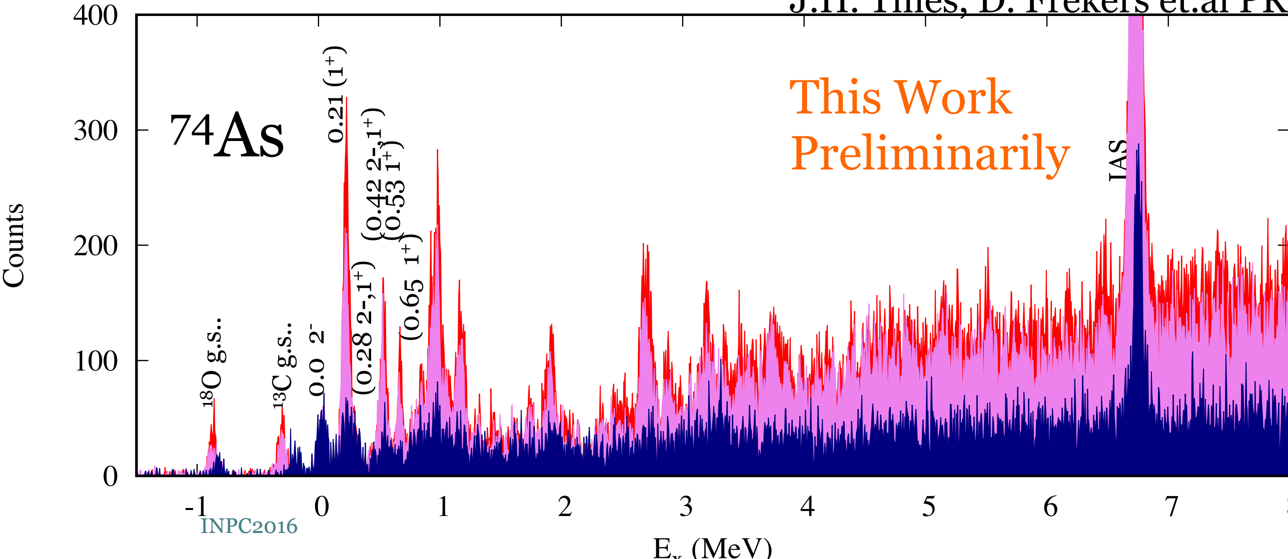


[5-2]PRC C 86, 044603 (2012)P. Puppe, H.Ejiri, D.Frekers, H.A. et al.

^{76}Ge ($\beta\beta$ nuclei) and ^{74}Ge (benchmark)

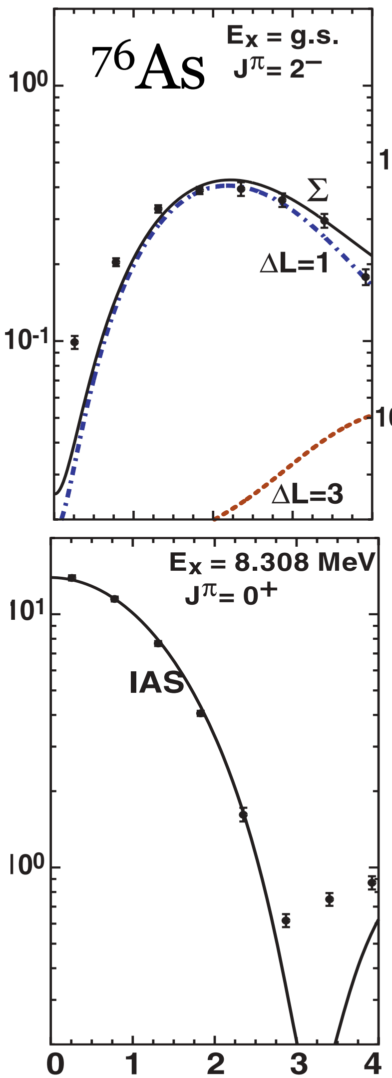


J.H. Thies, D. Frekers et.al PRC86 014304(2012)



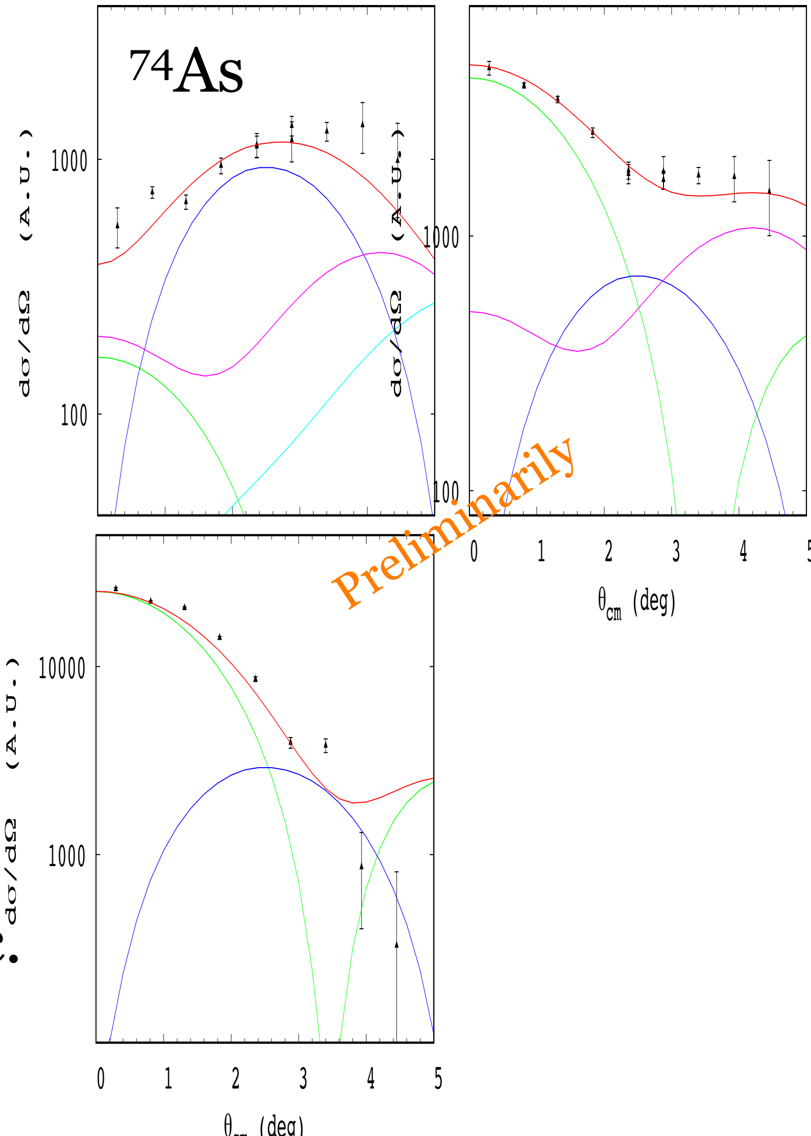
- ^{76}Ge: although g.s. is 2-
  - log *ft* is not know because of low Q
- ^{74}Ge: g.s. is 2-

$^{74,76}Ge(^{3}He,t)^{74,76}As$ Angular distribution



- 2- SD
- 1+ GT
- 0+ IAS

DWBA calc.



Estimation of M(SD2-)

- ^{76}As(g.s. 2^-) -^{76}Ge(g.s. 0^+)
  - B(F) = N-Z = 12
  - B(SD) = 0.564 β-decay
  - M(SD) = 1.68
- ^{74}As(g.s. 2^-) -^{74}Ge(g.s. 0^+)
  - B(F) = N-Z = 10
  - B(SD) = 0.610±0.02
  - M(SD)= 1.75±0.04

Preliminarily
Only statistical error

$$\sigma_{SD}(q,\omega) = KF(q,\omega)\left|J_{SD}\right|^2 \mathrm{B}(SD2^-)$$

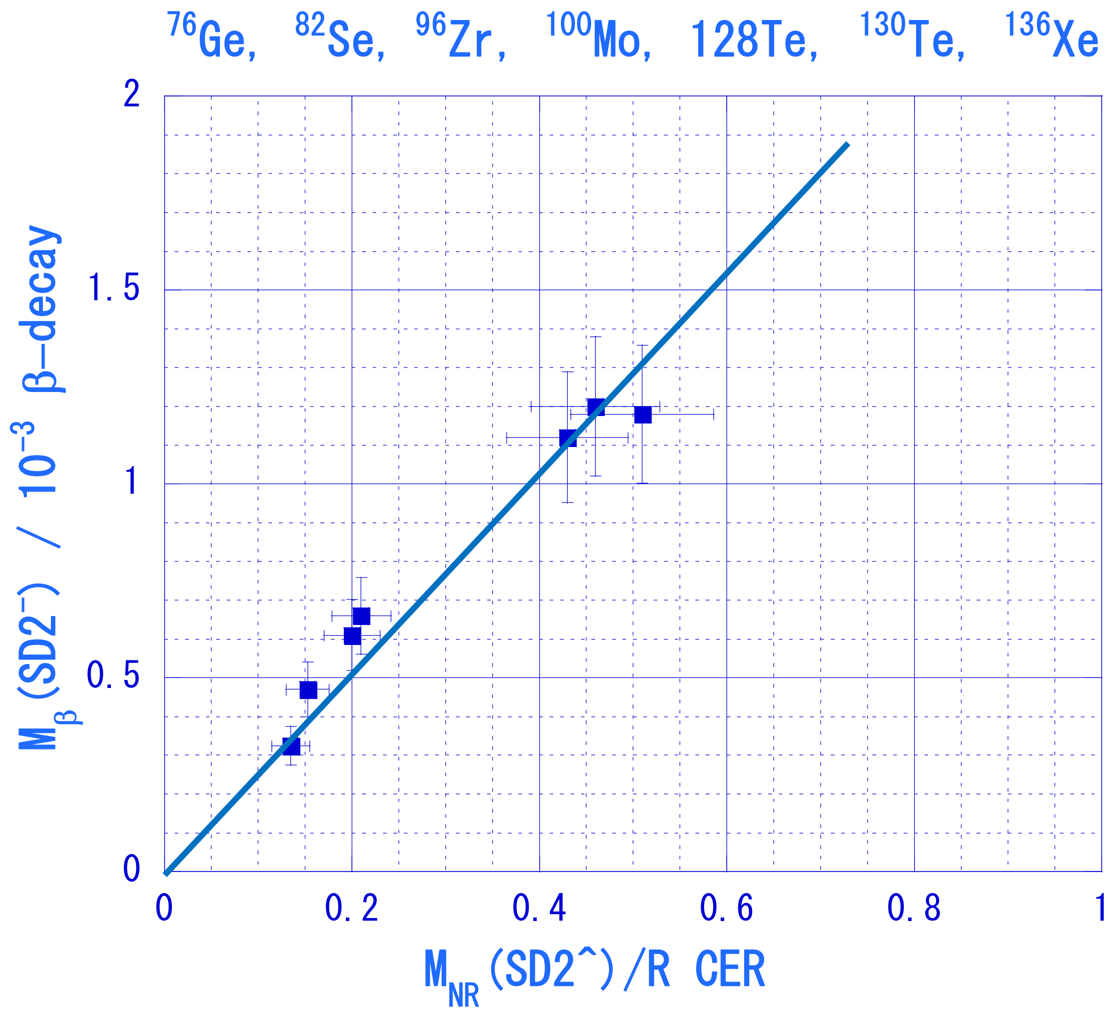
$$\sigma_{IAS}(q,\omega) = KF(q,\omega)\left|J_{\tau}\right|^2 \mathrm{B}(F)$$

IAS: σ_{IAS} is peaked at 0 deg.
SD: σ_{SD} is peaked at 2.1 deg.
for (^{3}He,t) at 140 MeV/u

$$\frac{\sigma_{SD}(2.1\,\mathrm{deg},{}^{74}\mathrm{Ge})}{\sigma_{IAS}(0.0\,\mathrm{deg},{}^{74}\mathrm{Ge})} \Big/ \frac{\sigma_{SD}(2.1\,\mathrm{deg},{}^{76}\mathrm{Ge})}{\sigma_{IAS}(0.0\,\mathrm{deg},{}^{76}\mathrm{Ge})} = \frac{\mathrm{B}(SD2^-,{}^{74}\mathrm{Ge})}{\mathrm{B}(F,{}^{74}\mathrm{Ge})} \Big/ \frac{\mathrm{B}(SD2^-,{}^{76}\mathrm{Ge})}{\mathrm{B}(F,{}^{76}\mathrm{Ge})}$$

Summary

- We will perform experiment on (^{3}He,t) reaction from nuclei with known ft values of the first forbidden beta decay.
- We determined M(SD2-) from angular distribution of SD2- states in ββ nuclei (^{74}Ge)
- We aim to establish a method to estimate $M^{0\nu}$ for 0ν double beta decay



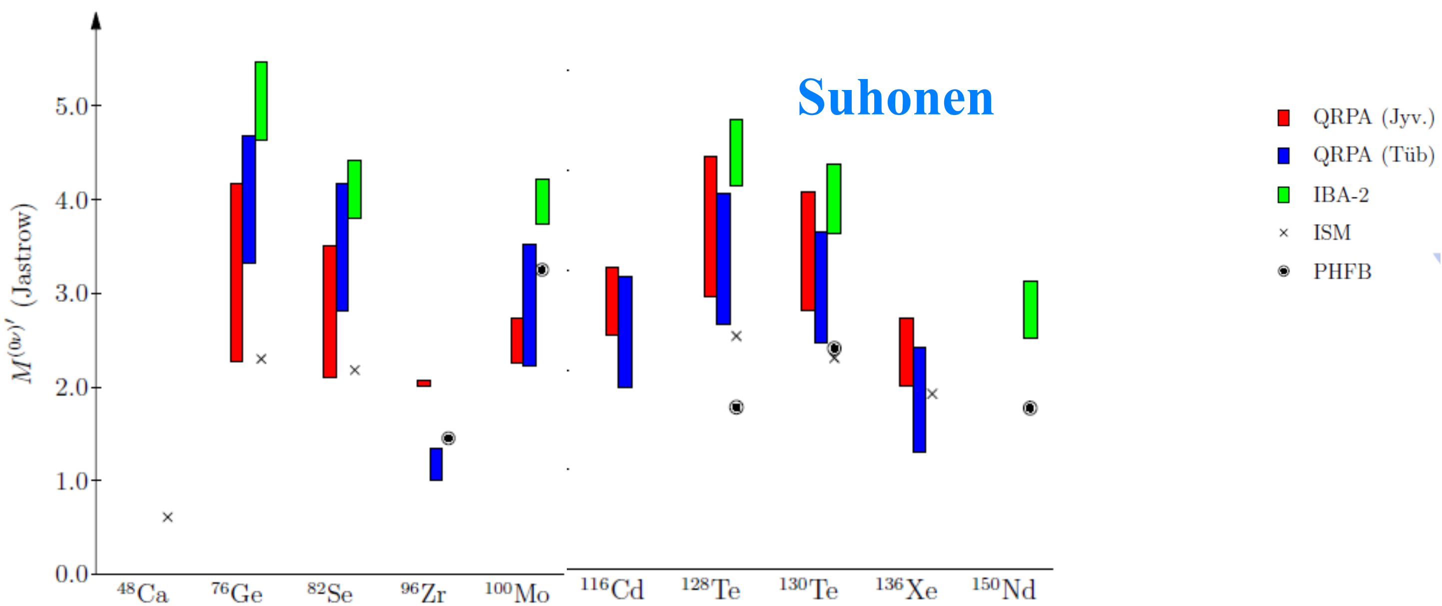
X axis CER 2- cross sections corrected for distortions used for GT
by Ejiri, Frekers, Harakeh, H.A. et al PRC 2010-2013.

Y axix M(SD) calcurated by using experimental g A from ft data in neighboring nuclei by Ejiri

Motivation

1. ν-nuclear responses for ββ−ν & astro-ν studies

$T = G\,[m_\nu M_{\beta\beta}]^2$ Nuclear response= $[M_{\beta\beta}]^2$ for m_ν study



$M^{0\nu}$ values depend on models (g_A) by a factor 3 , equivalent to 100 in detector volume. Which is right ? or all are not right ??. We need experimental data to support and/or confirm theories.

[1] H. Ejiri, Phys. Rep. 338 (2000) 265.
[2] J. Vergados, H. Ejiri, F. Simkovic, Rep. Prog. Phys. 75 (2012) 106301.
[3] H. Ejiri, J. Phys. Soc. Jpn. 74 (2005) 2101.

SN ν_e, ν_x oscillation