荷電交換反応による二重ベータ崩壊核行列要素の研究

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「宇宙の歴史をひもとく地下素粒子原子核研究」研究会

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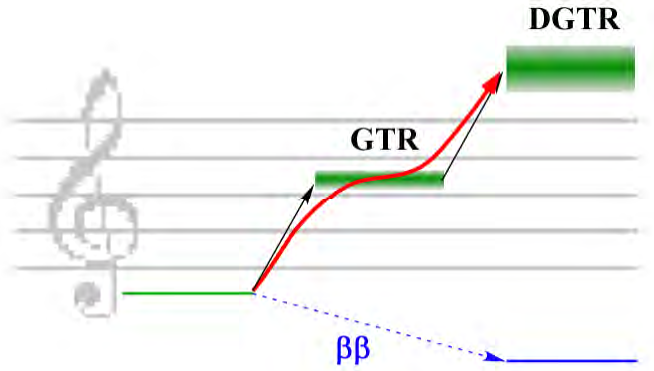
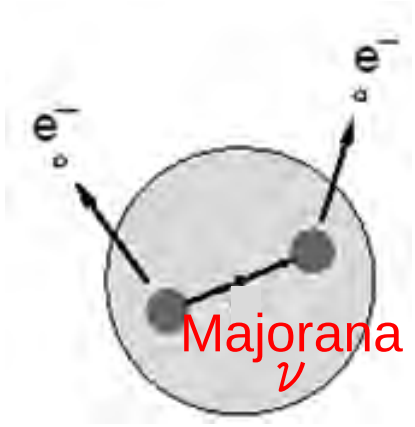
CENTER *for* NUCLEAR STUDY
THE UNIVERSITY *of* TOKYO



0v DBD and Nuclear Matrix Elements



0v double beta decay
- Majorana v is emitted and absorbed.
  Nucleus is kicked by 50~100 MeV/c twice.

0v life time and v mass

Phase space / weak coupling

"nuclear matrix element" (NME)

$$\left(T_{1/2}^{0\nu}\right)^{-1} = G^{0\nu}\left\langle m_{\nu;\beta\beta}\right\rangle^2 \left|M_{\mathrm{GT}}^{0\nu} - M_{\mathrm{F}}^{0\nu}\right|^2 + \ldots$$

nuclear structure calculation
Shell model, RPA,…

effective majorana mass of electron neutrino

NME is important!
- analysis … absolute mass / mass limit of v
- research planning … which nucleus is the best candidate?

$0\nu\beta\beta$ Matrix Element: Decomposition in the pnQRPA

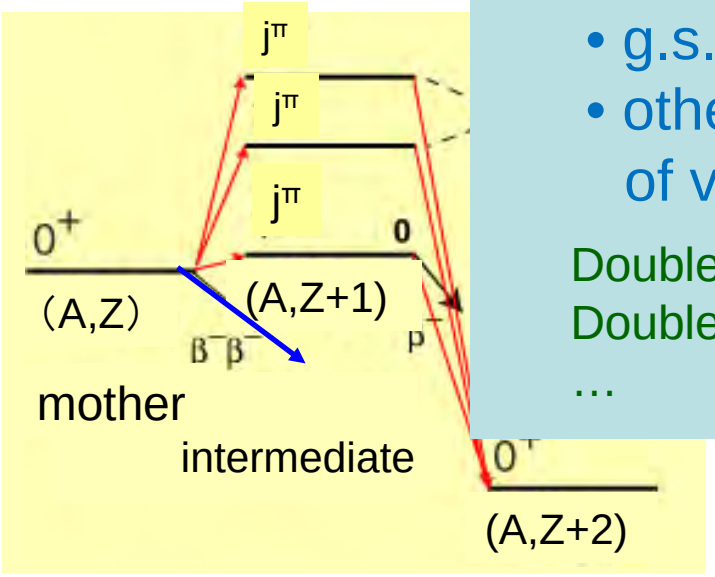
Suhonen, 2005

$$M_{\mathrm{GT}}^{(0\nu)} = \sum_{J^\pi} M_{\mathrm{GT}}^{(0\nu)}(J^\pi)$$

Neutrino potential

$$M_{\mathrm{GT}}^{(0\nu)}(J^\pi) = \sum_{n\lambda} \langle 0_f^+ \| \sum_j \left[\sigma_j F_\lambda(\mathbf{r}_j)\right]_J t_j^- \| J^\pi n \rangle \times \langle J^\pi n \| \sum_j \left[\sigma_j F_\lambda(\mathbf{r}_j)\right]_J t_j^- \| 0_i^+ \rangle$$

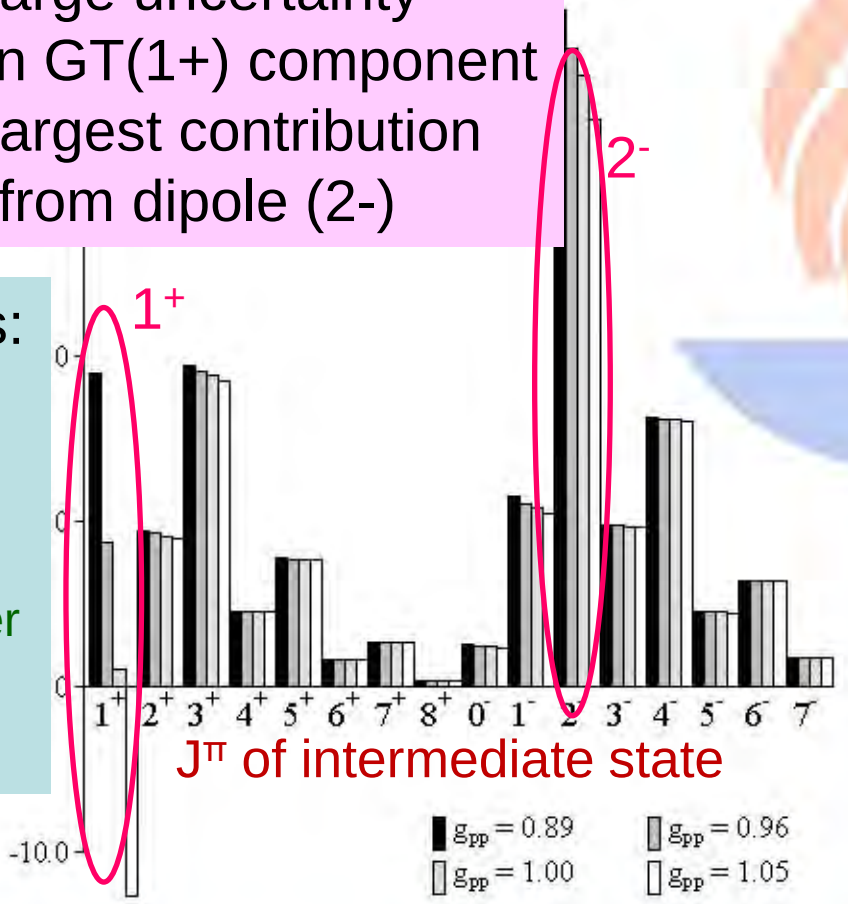
- large uncertainty in GT(1+) component
- largest contribution from dipole (2-)



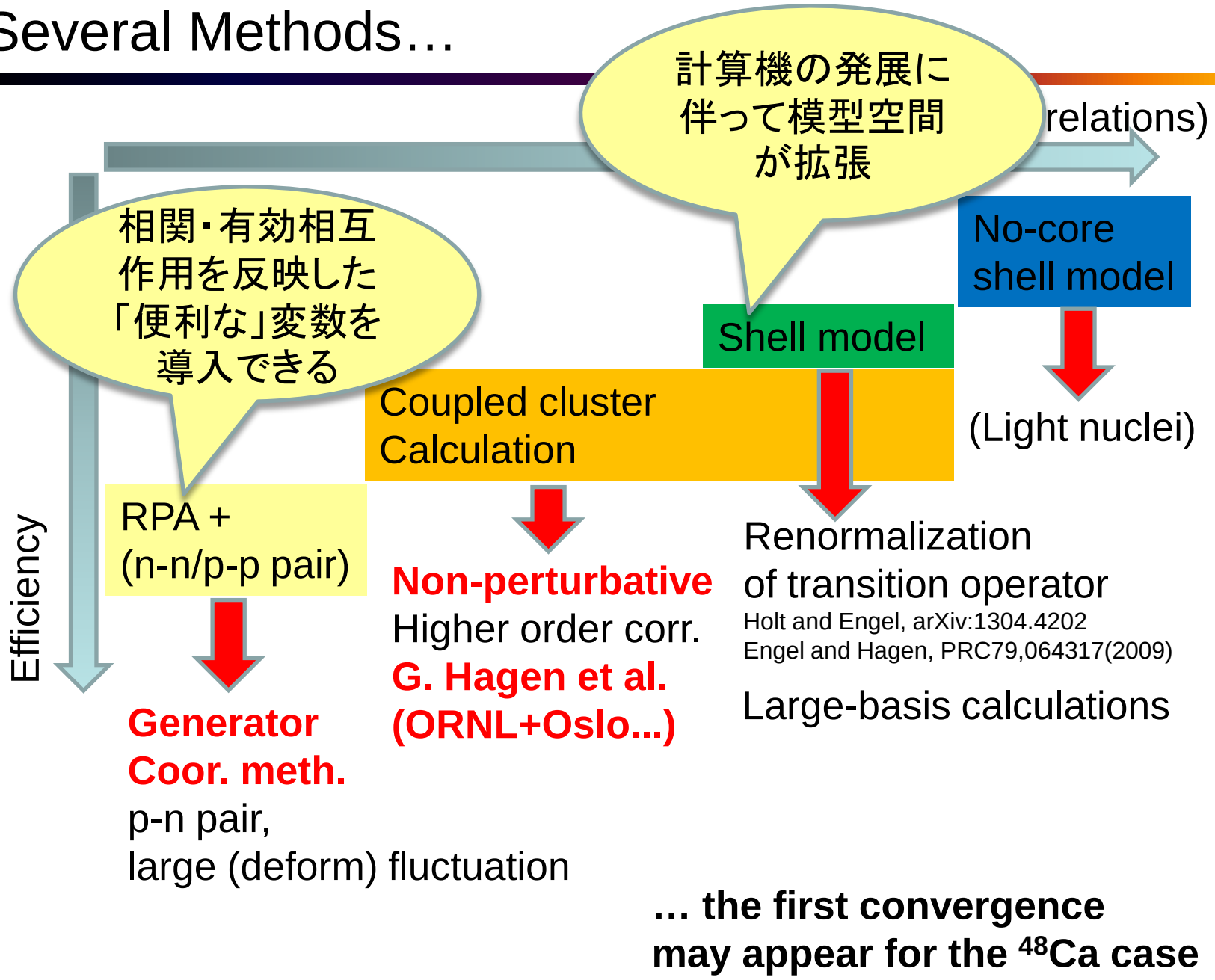
intermediate states:

- g.s.
- other states of various J^π.

Double GamowTeller
Double SpinDipole
…



Several Methods…



Correlations or model spaces?

For example, comparing SM w/ QRPA

- Each has uncertainty of ~ 30%
- SM predictions …

  20-50% smaller than QRPA.
- Concerns…

SM : limited model space

QRPA :

sufficient correlation?

Menendez, PRL100(2008)052503

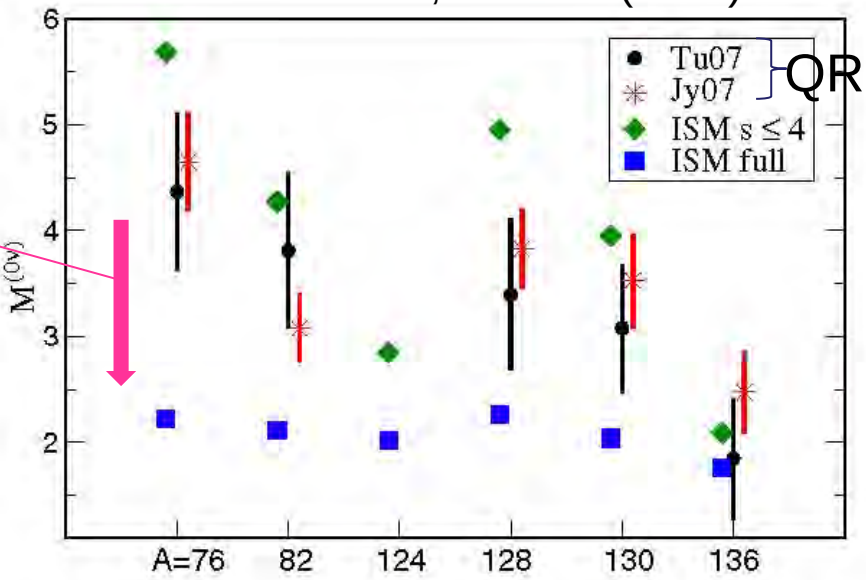


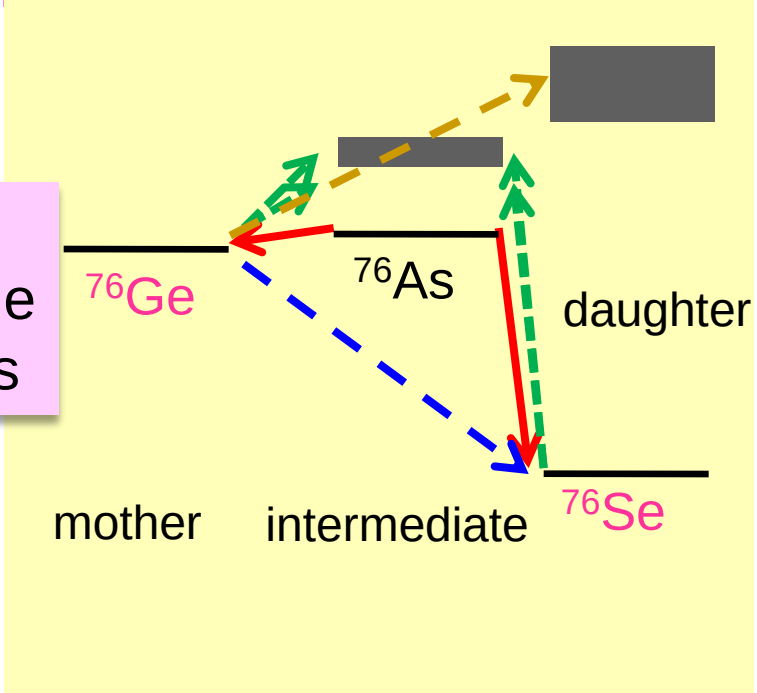
FIG. 3 (color online). The neutrinoless double beta decay NME's; comparison of ISM and QRPA calculations. Tu07; QRPA results from Ref. [20]. Jy07; QRPA results from Ref. [21]. ISM $s \leq 4$ and ISM; present work. The ISM results have uncertainties in the 20% range (see text).

…Guides from Experiments are necessary.

Experimental attempts to guide the calculation

1. Static properties: particle occupation / vacancy
2. Single transitions
   - Single beta decay
   - GT transitions
   - Other transitions
3. Double transitions
   - 2νββ decay ($M^{2\nu}$)
   - Double GT resonance?

Charge-exchange reactions



GT strength distributions…comparison with shell model

Shell model …

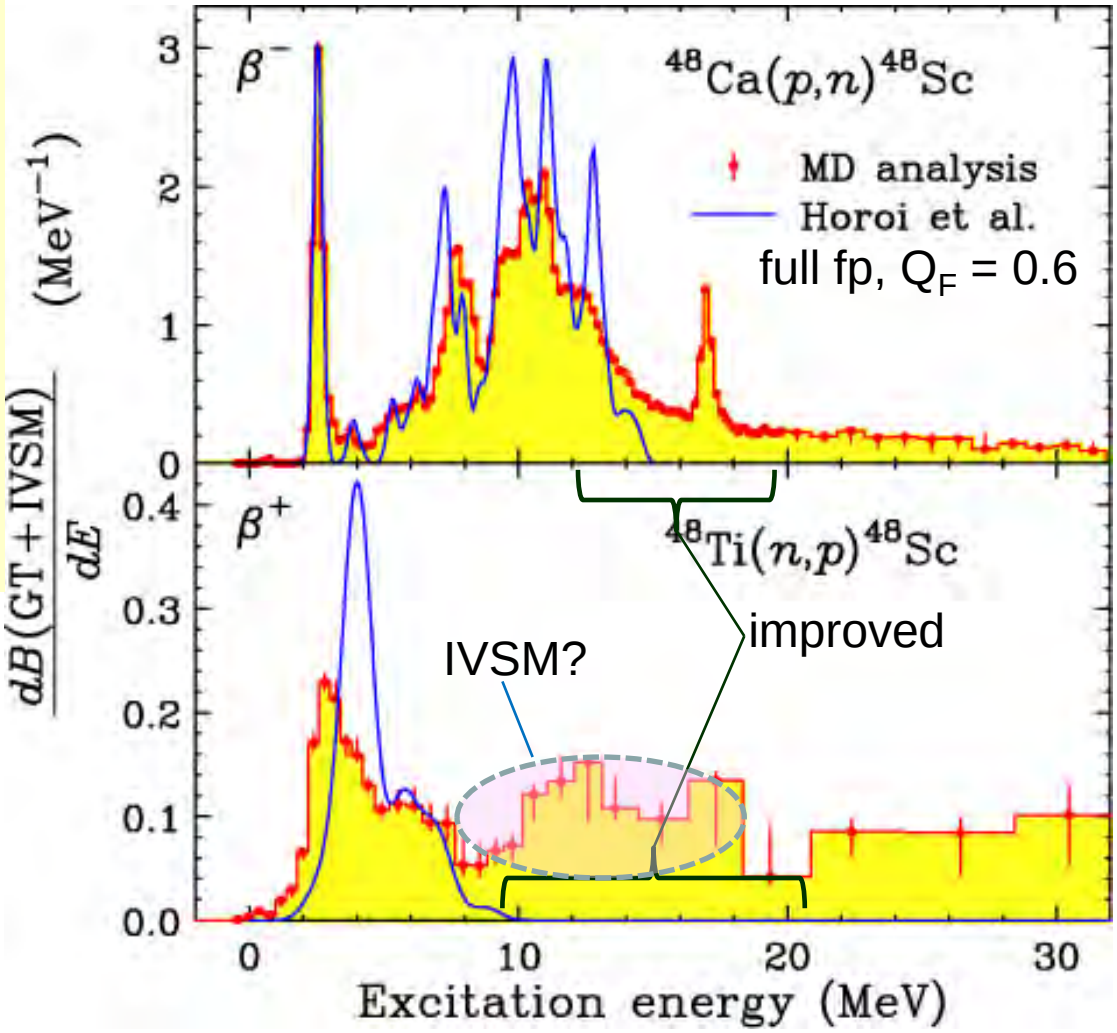
with quenched operator

Spectra agree qualitatively up to …

(p,n) : E_x = 15 MeV

(n,p) : 8 MeV

Strengths beyond … underestimated.



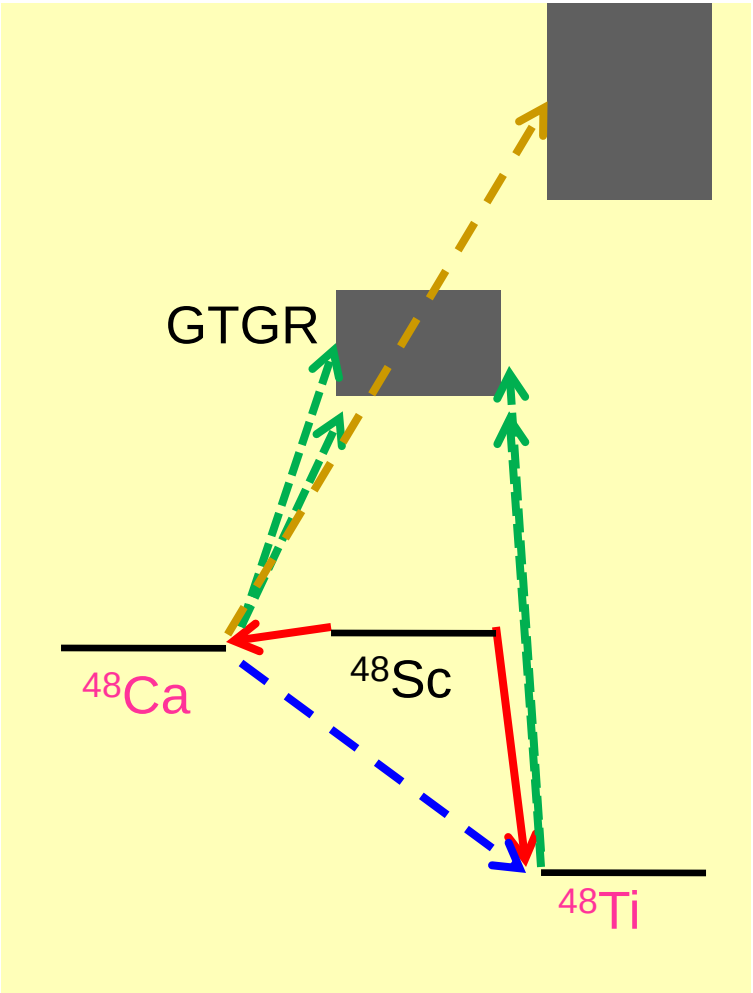
Necessity of larger model space? Correlations?, …

Double GT resonance…Challenge by experimentalist

Constraint of
double transition
(in addition to $M^{2\nu}$)
… Double GT resonance

Sum rule:
ΣB(DoubleGT)
= 6(N-Z)(N-Z-1)
= 336 for ^{48}Ca

Only 0.02 is going
to g.s. of ^{48}Ti



Giant
resonance?
DGTGR
336(?)

0.02

10 days of experiment was fully approved at RCNP BPAC, Mar2014

Search for Double Gamow-Teller Giant Resonances in ^{48}Ti via the Heavy-Ion Double Charge Exchange ^{48}Ca(^{12}C, ^{12}Be(0_2^+)) Reaction

Motonobu Takaki (CNS, University of Tokyo)

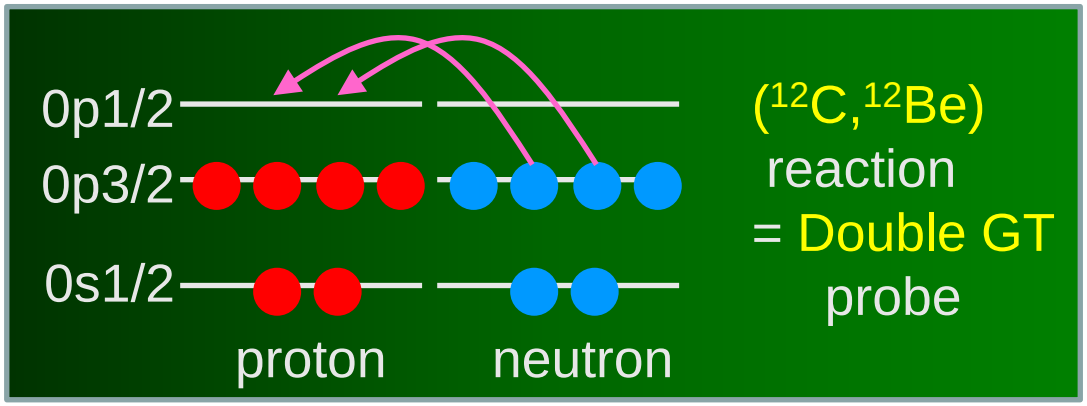
&

Tomohiro Uesaka (RIKEN Nishina Center)

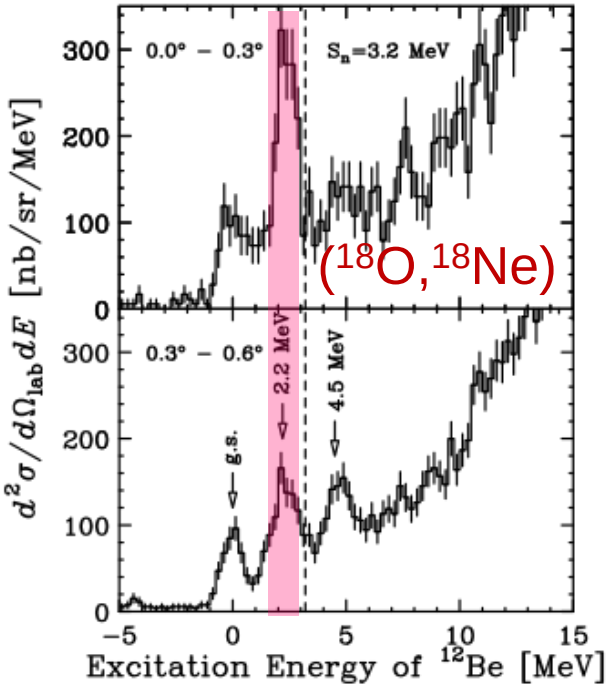
Exp by Takaki

New Idea: (^{12}C,^{12}Be(0^+_2)) Reaction

^{12}C(gnd)→^{12}Be(0_2^+) transition is strong.

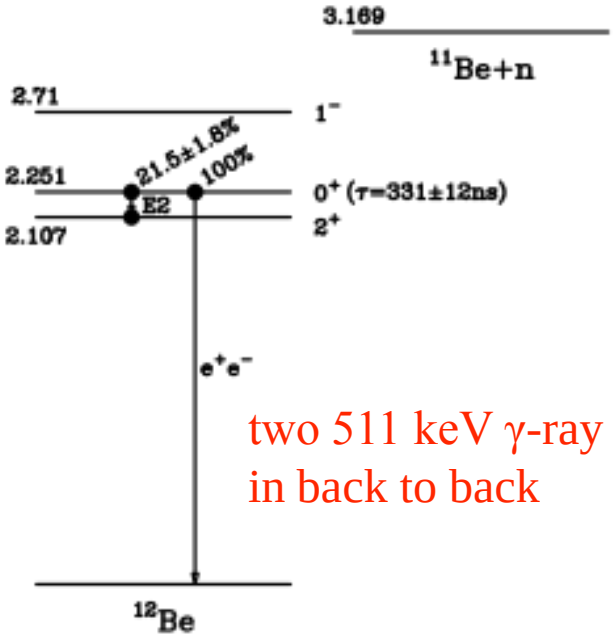


… Effective in Double GT excitation.

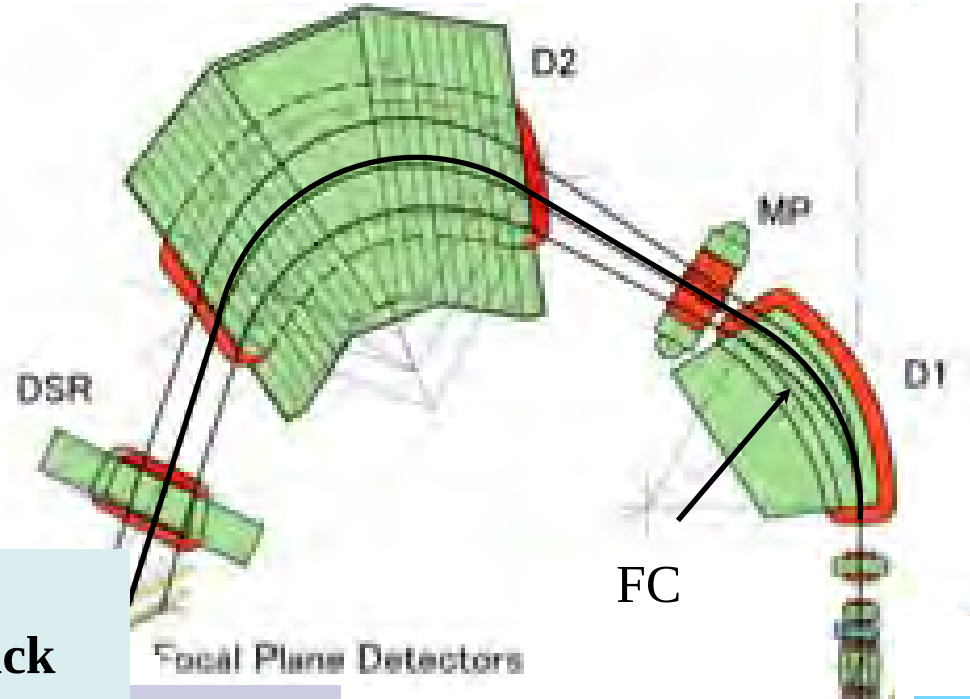


Delayed-γ tagging enables clear event identification.

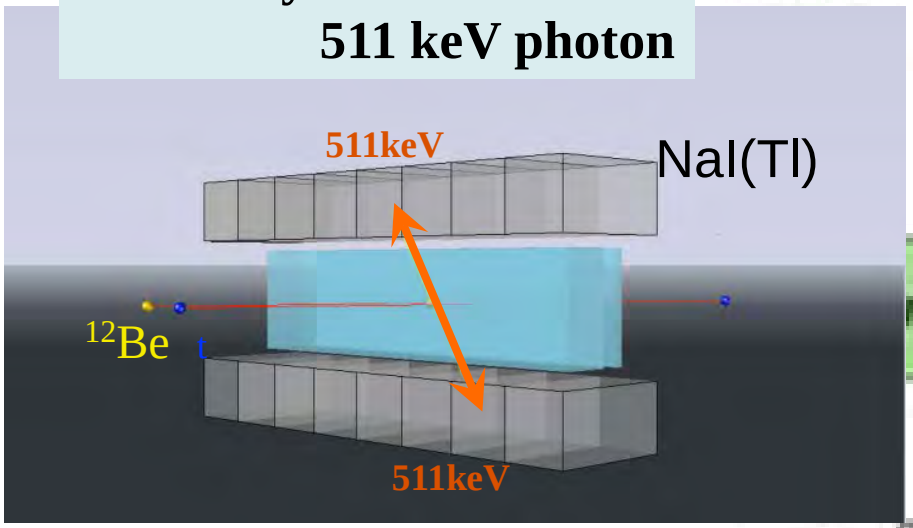
- $\tau(^{12}\mathrm{Be}(0_2^+)) = 330$ ns $\gg$ TOF ~ 150 ns
- ~ 70% of the ^{12}Be(0^+_2) state can survive until reaching the GR F.P.



Experimental setup



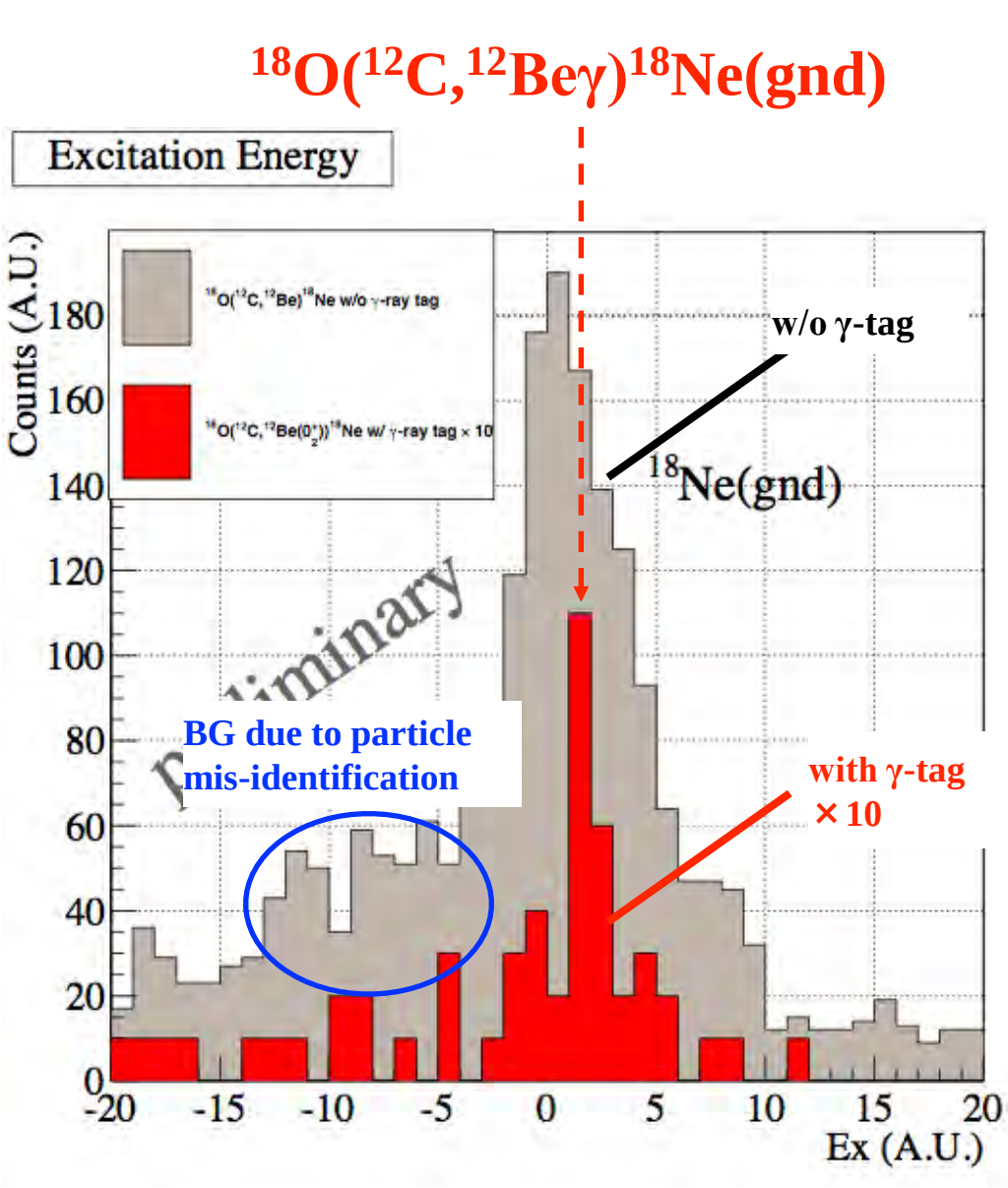
Plastic + 16 NaI(Tl)
→ identify back-to-back 511 keV photon

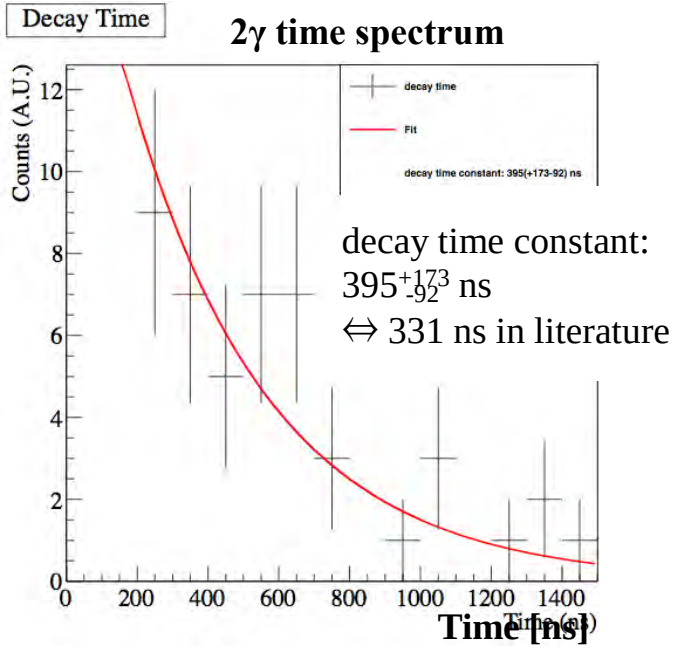


Target
^{48}Ca:10 mg/cm^2
$H_2{}^{18}O$:20 mg/cm^2

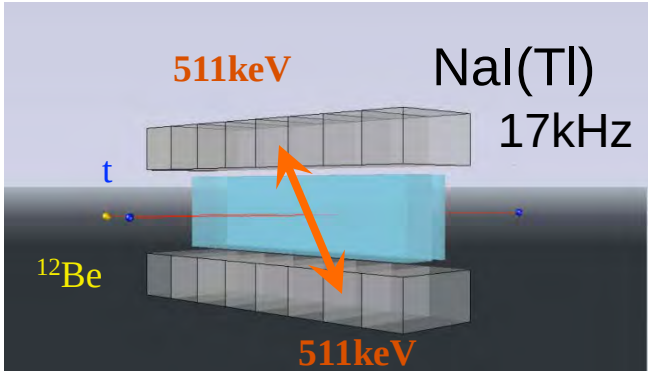
^{12}C beam (100 MeV/u, 30 pnA)

Test Experiment





decay time constant:
395^{+173}_{-92} ns
⇔ 331 ns in literature



Exp vs. Theory

item		Exp	Theory
static	Occupation No.	○	△
single transition	Beta decay	◎/ ○	○
	B(GT) dist. at Low Ex	◎	△
	High Ex	○	×
	Dipole: 0^-, 1^-, 2^-	△/○	△
double trans	M^{2v}	◎	○/ 拘束条件
	Double GT	×	×
	Double SD	×	×

Occupation No. を良く記述するよう理論計算のインプットを調整
-> QRPA と Shell model との M^{2v}予言値 がほぼ一致
J. Menéndez, PRC 80（2009）048501.
… 新たな実験データは計算信頼度の向上に役立っている。

Summary

- 0v nuclear matrix element $M^{0\nu}$ is necessary to deduce the majorana v mass from the 0v half life.
- Prediction of $M^{0\nu}$ depends on the models of nuclear structure

  → Guiding data are needed.

- B(GT) distributions in the $^{48}Ca(p,n)^{48}Sc$ / $^{48}Ti(n,p)^{48}Sc$
  - B(GT; β+) is underestimated

    … correlations/model space is not enough.
- Search for double GT resonance in $^{48}Ca(^{12}C,^{12}Be)$ reaction

  … main component of the double GT transition is studied.