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Reaction studies of Double Gamow-Teller transitions in ββ-decay nuclei

Tomohiro UESAKA

RIKEN Nishina Center

Motonobu Takaki

CNS, University of Tokyo

for RCNP-E429 Collaborations

Starting point

Experimental information on nuclear double Gamow-Teller/ double spin-dipole responses is seriously limited.

Lifetimes of 2νββ nuclei
→ **limited to low lying states (mostly ground states) for ~10 species.**

Single Gamow-Teller/spin-dipole responses
→ **rich data, constraints to structure models. Relationship to double GT/SD responses is not direct.**

Existing data: lifetimes of 2νββ decay nuclei

TABLE 1 Summary of experimentally measured $\beta\beta(2\nu)$ half-lives and matrix elements[a]

Isotope	$T^{2\nu}_{1/2}$ (y)	References	$M^{2\nu}_{GT}$ (MeV^{-1})
^{48}Ca	$(4.2 \pm 1.2) \times 10^{19}$	(55, 56)	0.05
^{76}Ge	$(1.3 \pm 0.1) \times 10^{21}$	(57–59)	0.15
^{82}Se	$(9.2 \pm 1.0) \times 10^{19}$	(60, 61)	0.10
^{96}Zr†	$(1.4^{+3.5}_{-0.5}) \times 10^{19}$	(62–64)	0.12
^{100}Mo	$(8.0 \pm 0.6) \times 10^{18}$	(65–70), (71)†	0.22
^{116}Cd	$(3.2 \pm 0.3) \times 10^{19}$	(72–74)	0.12
^{128}Te[b]	$(7.2 \pm 0.3) \times 10^{24}$	(75, 76)	0.025
^{130}Te[c]	$(2.7 \pm 0.1) \times 10^{21}$	(75)	0.017
^{136}Xe	$>8.1 \times 10^{20}$ (90% CL)	(77)	<0.03
^{150}Nd†	$7.0^{+11.8}_{-0.3} \times 10^{18}$	(68, 78)	0.07
^{238}U[d]	$(2.0 \pm 0.6) \times 10^{21}$	(79)	0.05

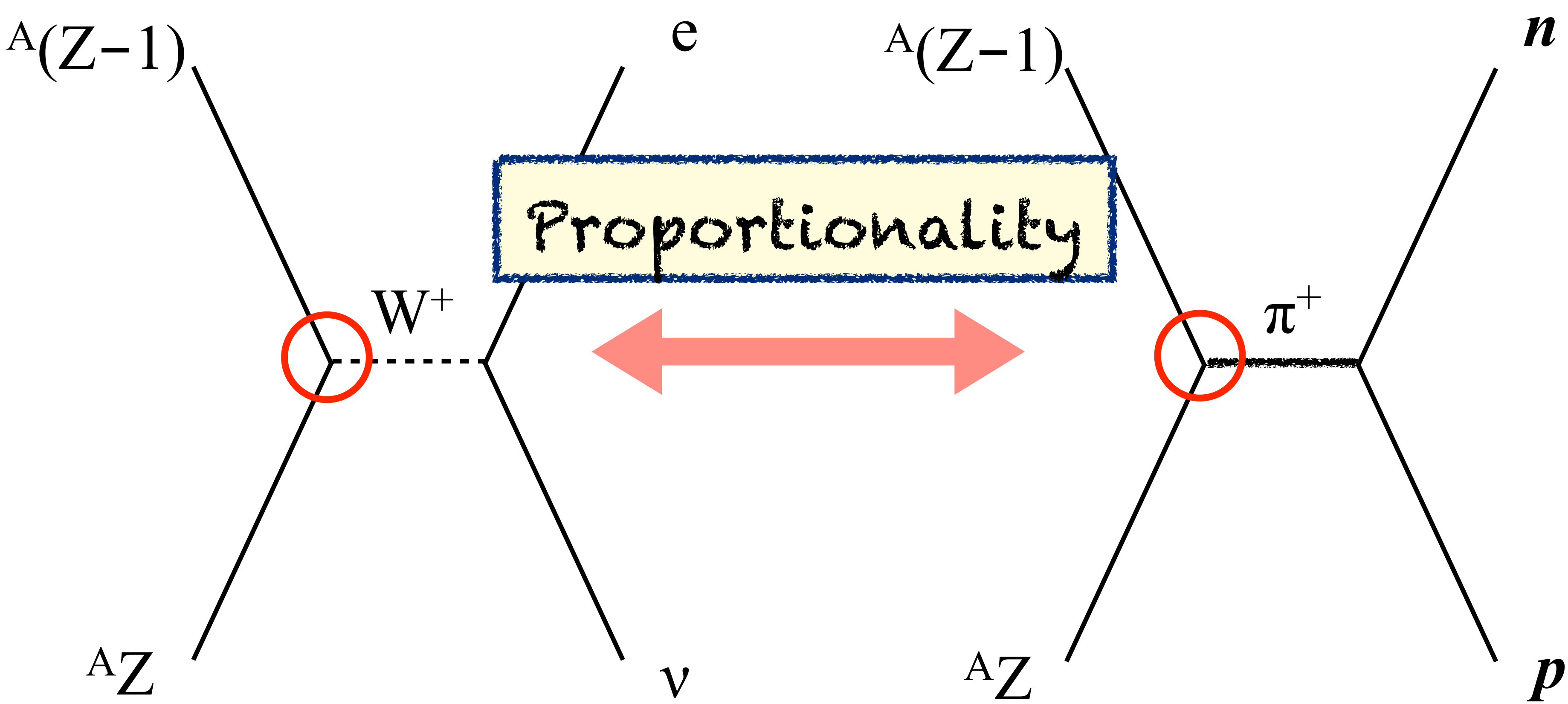
< 10^{-3} of sum rule values

>99.9%: unobserved

Elliot & Vogel (2002)

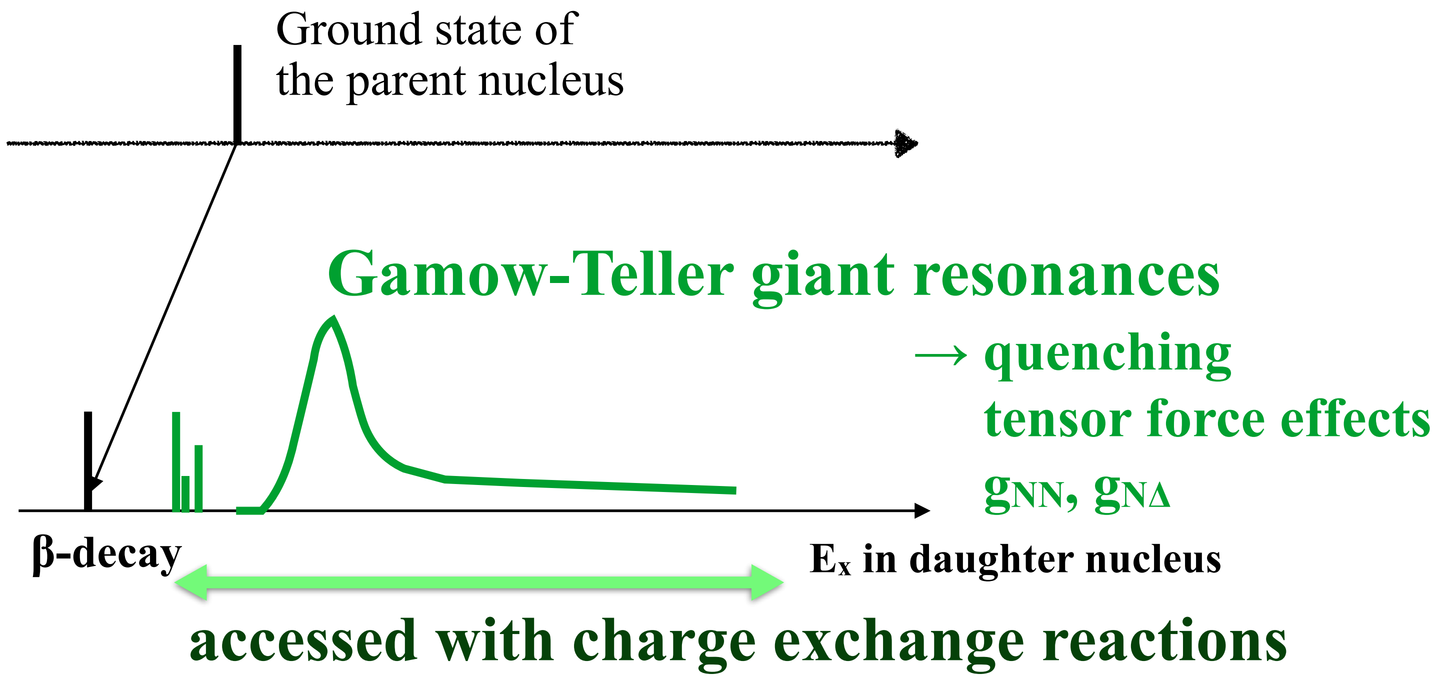
Reaction studies of nuclear weak responses

Charge exchange reaction : driven by STRONG interaction
(p,n), (^{3}He,t), (d,^{2}He) . . .

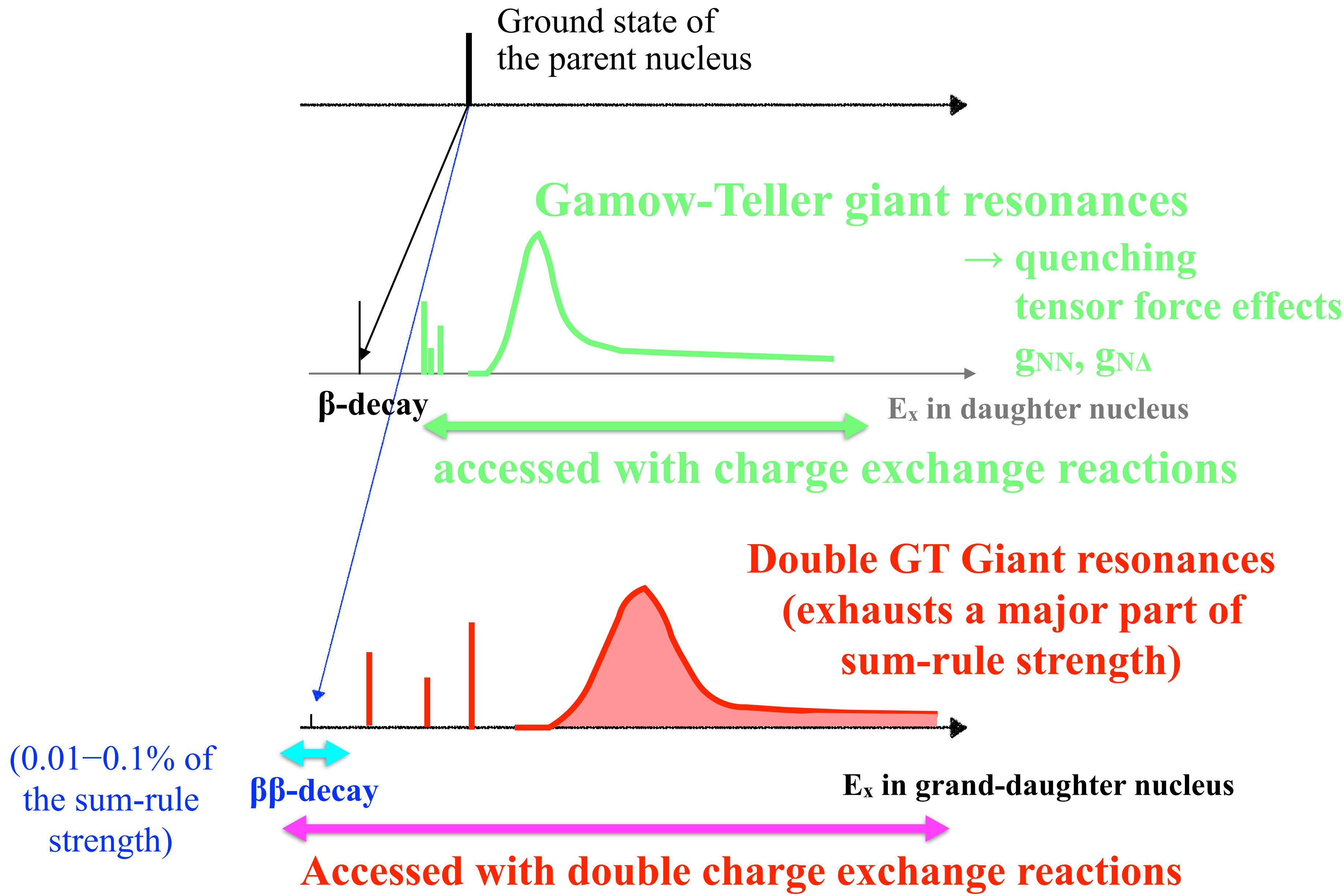


C.D. Goodman et al., Phys. Rev. Lett. **44**, 1755 (1980)

Our understanding of GT responses



Our understanding of GT^2 responses

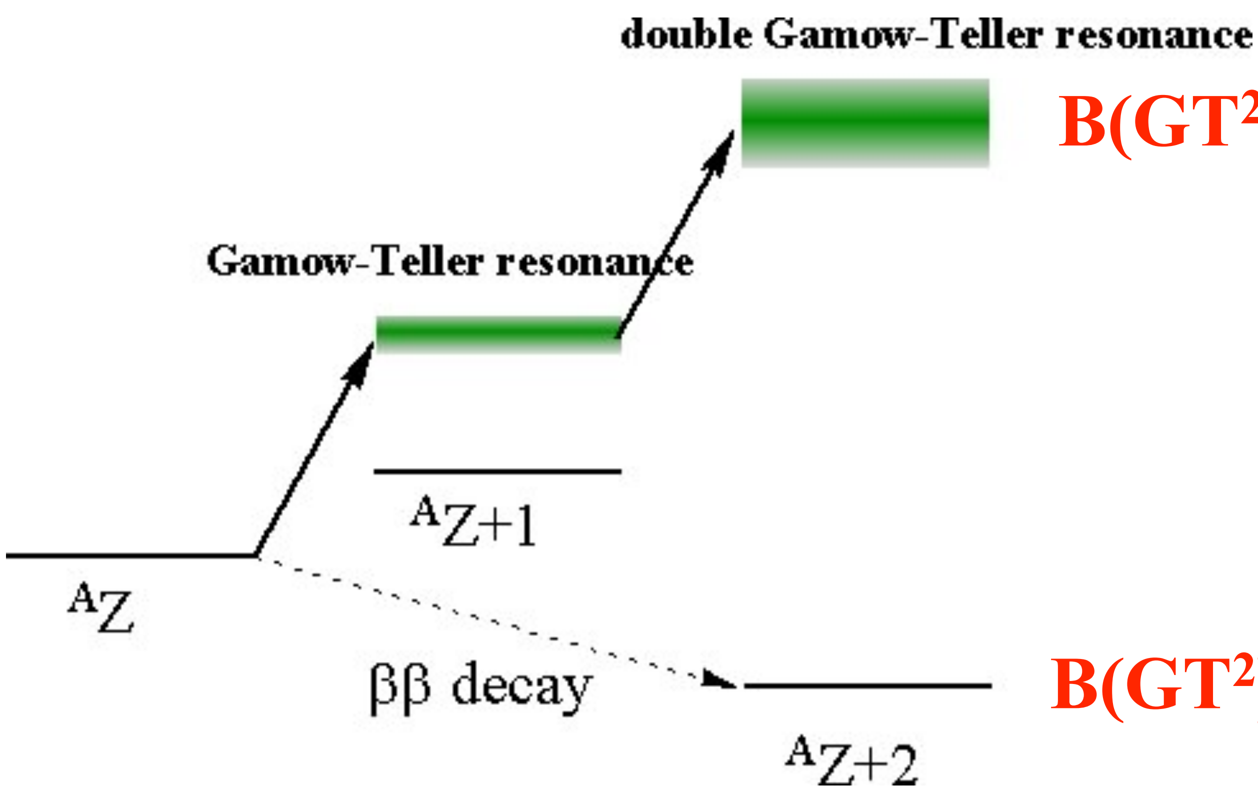


Double Gamow-Teller Giant Resonances

Gamow-Teller resonance built on a Gamow-Teller resonance exhausts a major part of the $(GT)^2$ strength

⇔ 2νββ decay

Auerbach, Zamick, Zheng, Ann. Phys. **192**, 77 (1989).

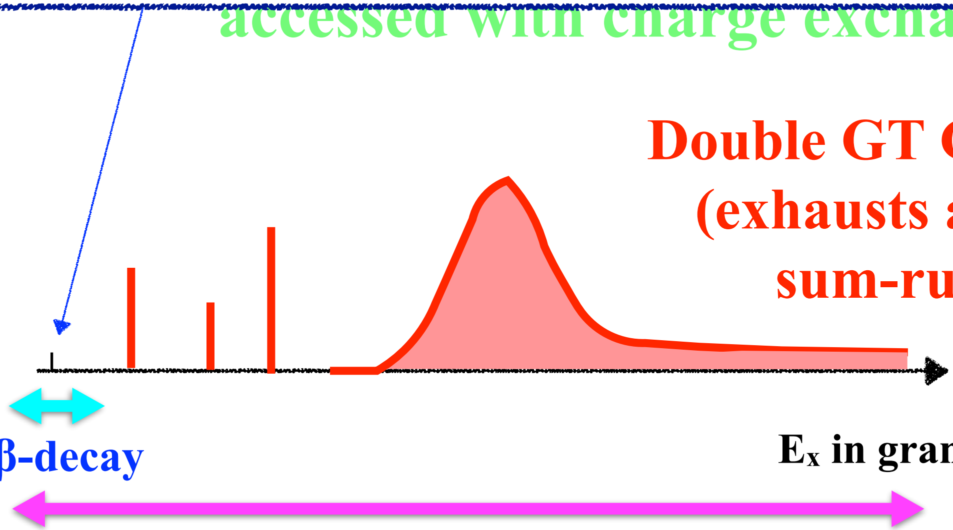


$B(GT^2) \sim 100$

$B(GT^2) \sim 0.1$

Reaction studies of DGT responses will open

- Extension of DGT studies to
  - wider range of excitation energies (no Q-value restriction)
  - any nuclei (not limited to ββ nuclei)
- Quenching of the GT^2 strength
- Nature of DGTGR
  - Is the DGTGR a simple superposition of single GT?
- Momentum-transfer dependence of ββ-decay ME



Which double charge-exchange reaction should be used?

Previous attempts to observe DGTR: (π^+, π^-)

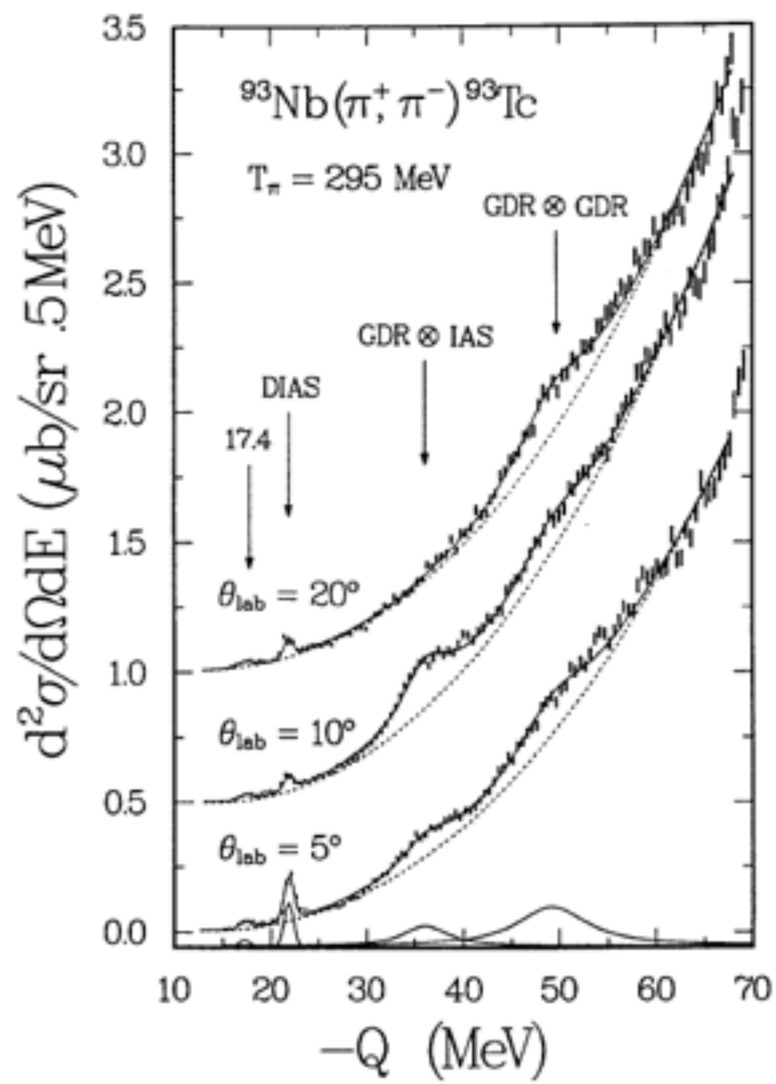
(π^+,π^-) @ 292 MeV LAMPF

S. Mordechai et al., PRL **60**, 408 (1988).

Double IAS & Double GDR ○

Double GT ×

(π^+,π^-) populates spin-flip states only weakly



Previous attempts to observe DGTR: (^{18}O, ^{18}Ne)

(π^+,π^-) @ 292 MeV LAMPF

populates spin-flip states only weakly

S. Mordechai et al., PRL **60**, 408 (1988).

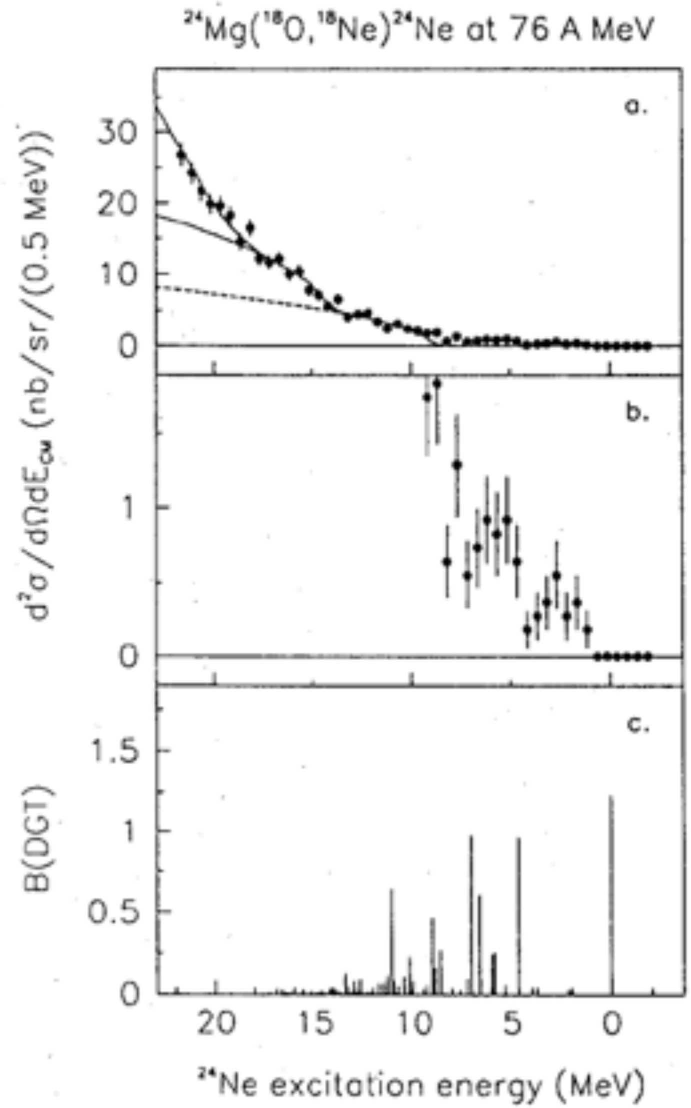
(^{18}O,^{18}Ne) @76MeV/A MSU, GANIL

J. Blomgren et al., PLB **362**, 34 (1995).

(^{18}O,^{18}Ne) induces $\beta^+\beta^+$ transitions

β^+ is ×10 weaker than β^-

due to Pauli blocking



Previous attempts to observe DGTR: (^{11}B, ^{11}Li)

(π^+,π^-) @ 292 MeV LAMPF

populates spin-flip states only weakly

S. Mordechai et al., PRL **60**, 408 (1988).

(^{18}O,^{18}Ne) @76MeV/A MSU, GANIL

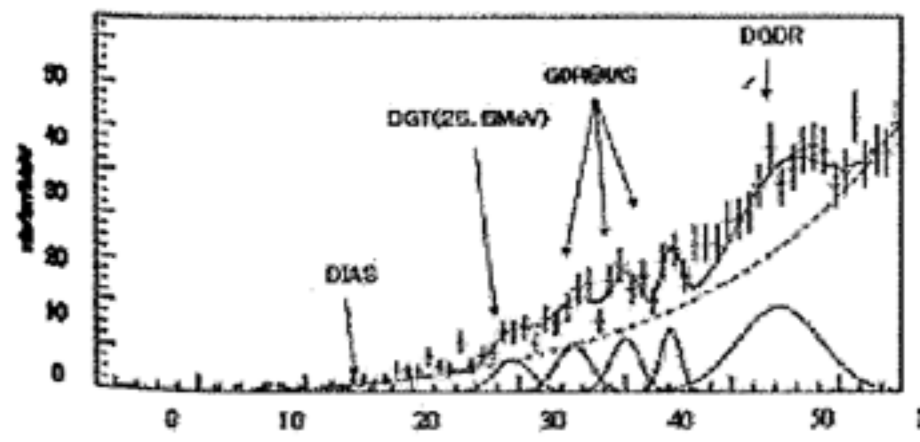
J. Blomgren et al., PLB **362**, 34 (1995).

β^+ is ×10 weaker than β^- due to Pauli blocking

(^{11}B, ^{11}Li) @69MeV/A RCNP

Lightest projectile

Small overlap in projectile?



Takahisa, Ejiri et al., AIP Proc. Conf. **915**, 815 (2007)

What does "good" double exchange reaction mean

	(π^+, π^-)	$(^{18}O, ^{18}Ne)$	$(^{11}B, ^{11}Li)$
Large production yield			
Large cross section	×	×	?
Large luminosity (high-intensity beam)	×	○	○
Clear event identification	○	△	○

New idea to use (^{12}C, $^{12}Be\gamma$) reaction

&

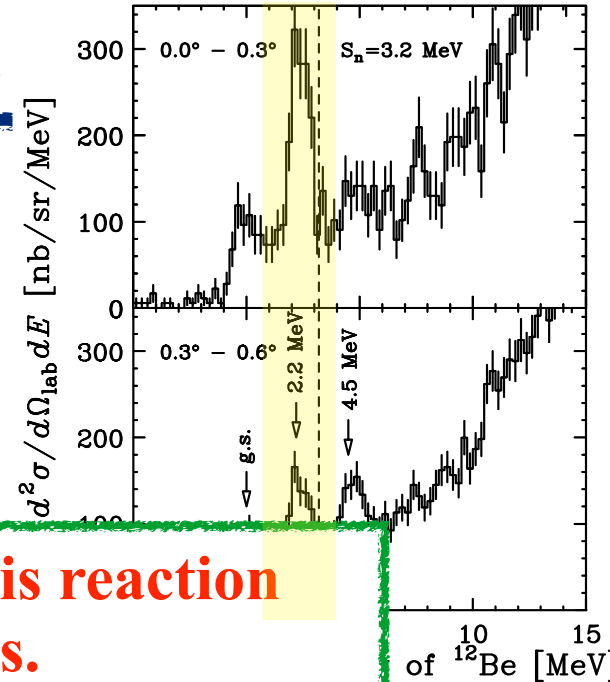
First experimental results on ^{48}Ca

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

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

B(GT^2) ~ 0.3

^{12}C(^{18}O,^{18}Ne) experiment →
Matsubara, Takaki, TU et al.,
Few-Body Syst. **54**, 1433 (2013).

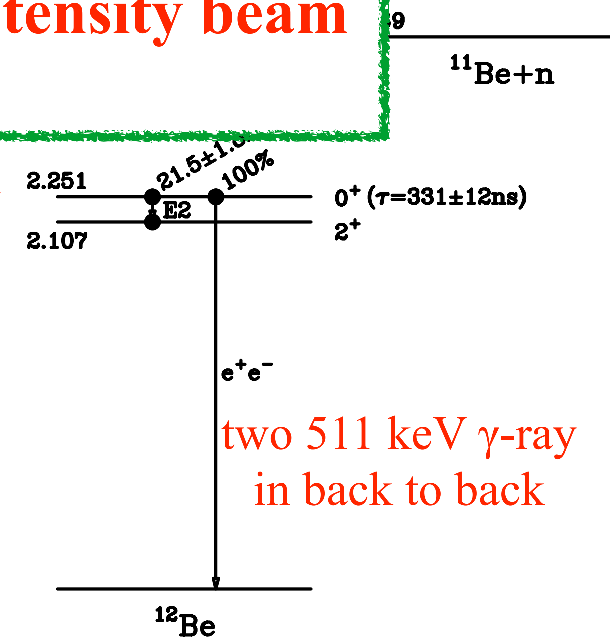


- This is
  interme
  are dom

These two characteristics make this reaction specially effective in DGTR studies.

Large cross section & high-intensity beam
Clear event identification

Delayed-γ tagging enables clear event identification.

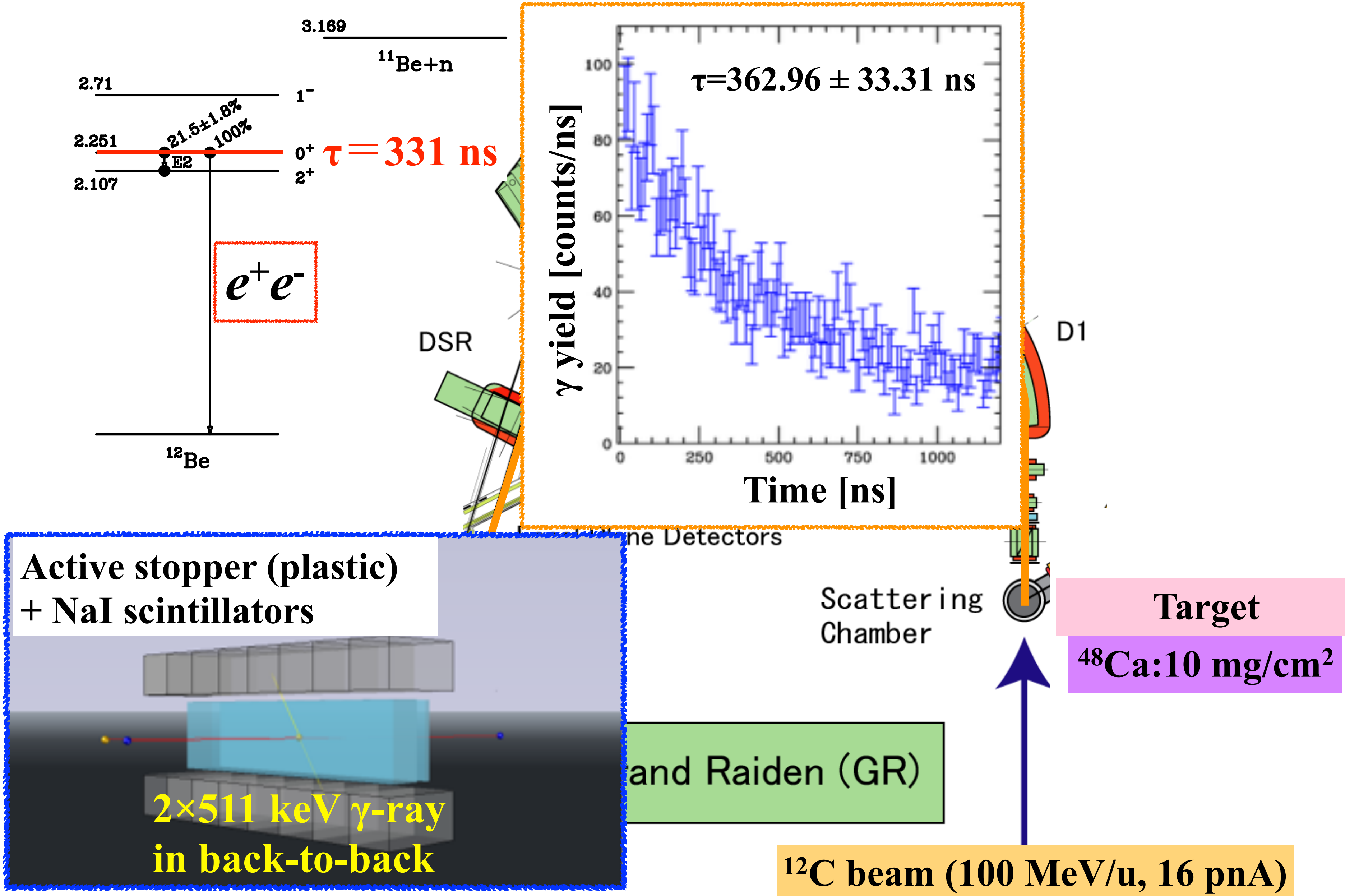


- τ(^{12}Be(0_2^+)) = 331 ns
  ≫ TOF ~ 150 ns (Grand Raiden)

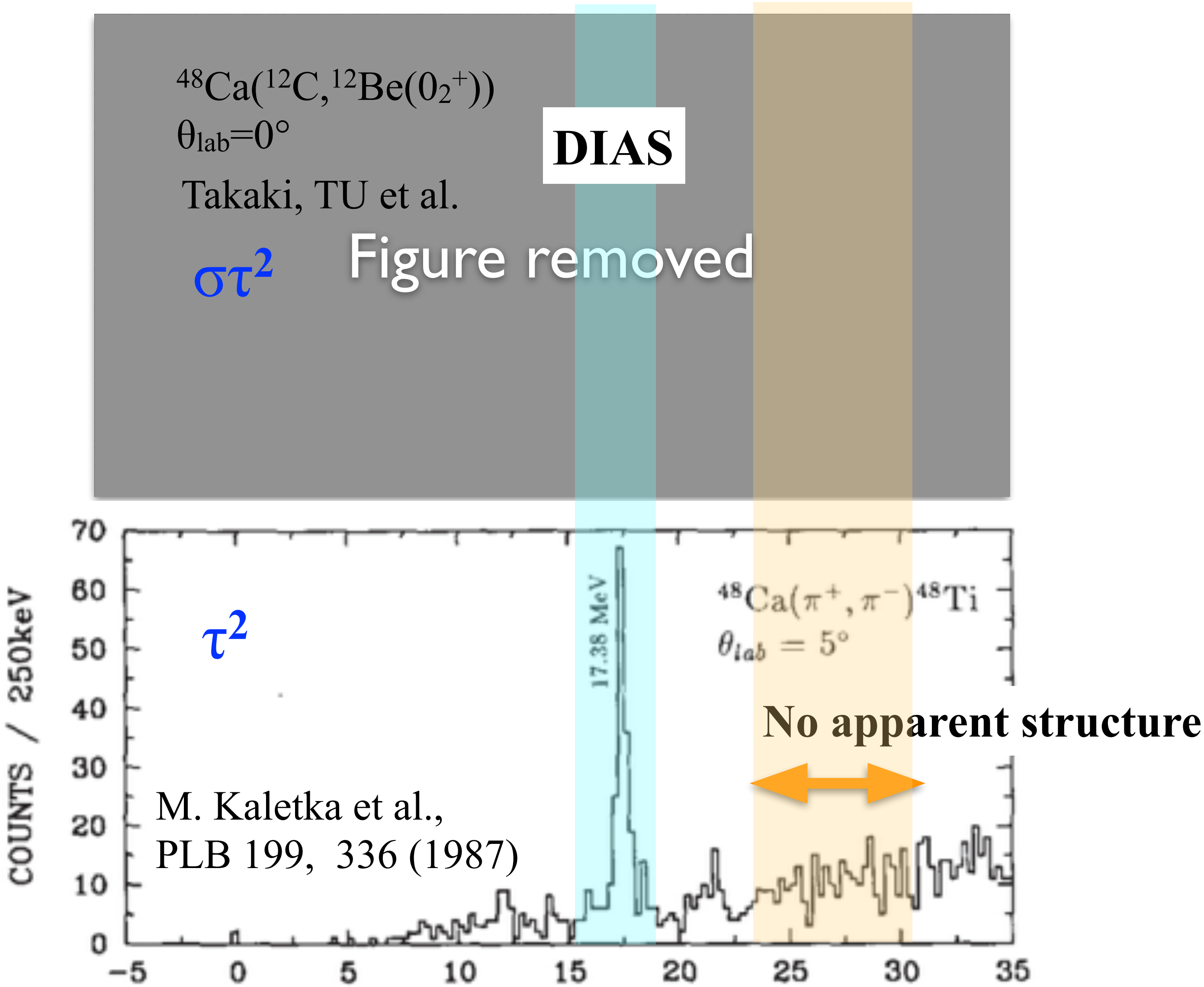
- ~ 70% of the ^{12}Be(0^+_2) state can
  survive and reach the focal plane.

Experiment @ Grand Raiden (RCNP)

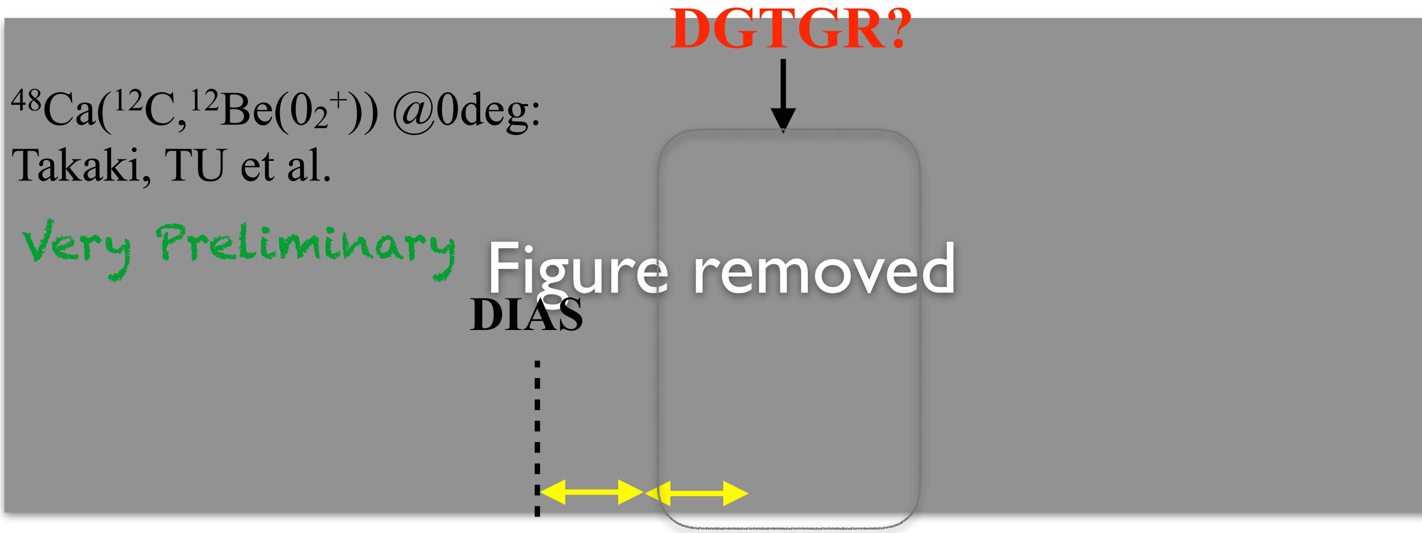
Takaki, TU et al.



DCX Spectrum and comparison with (π^+,π^-)



“Double Gamow-Teller” Spectrum in ^{48}Ti



gnd

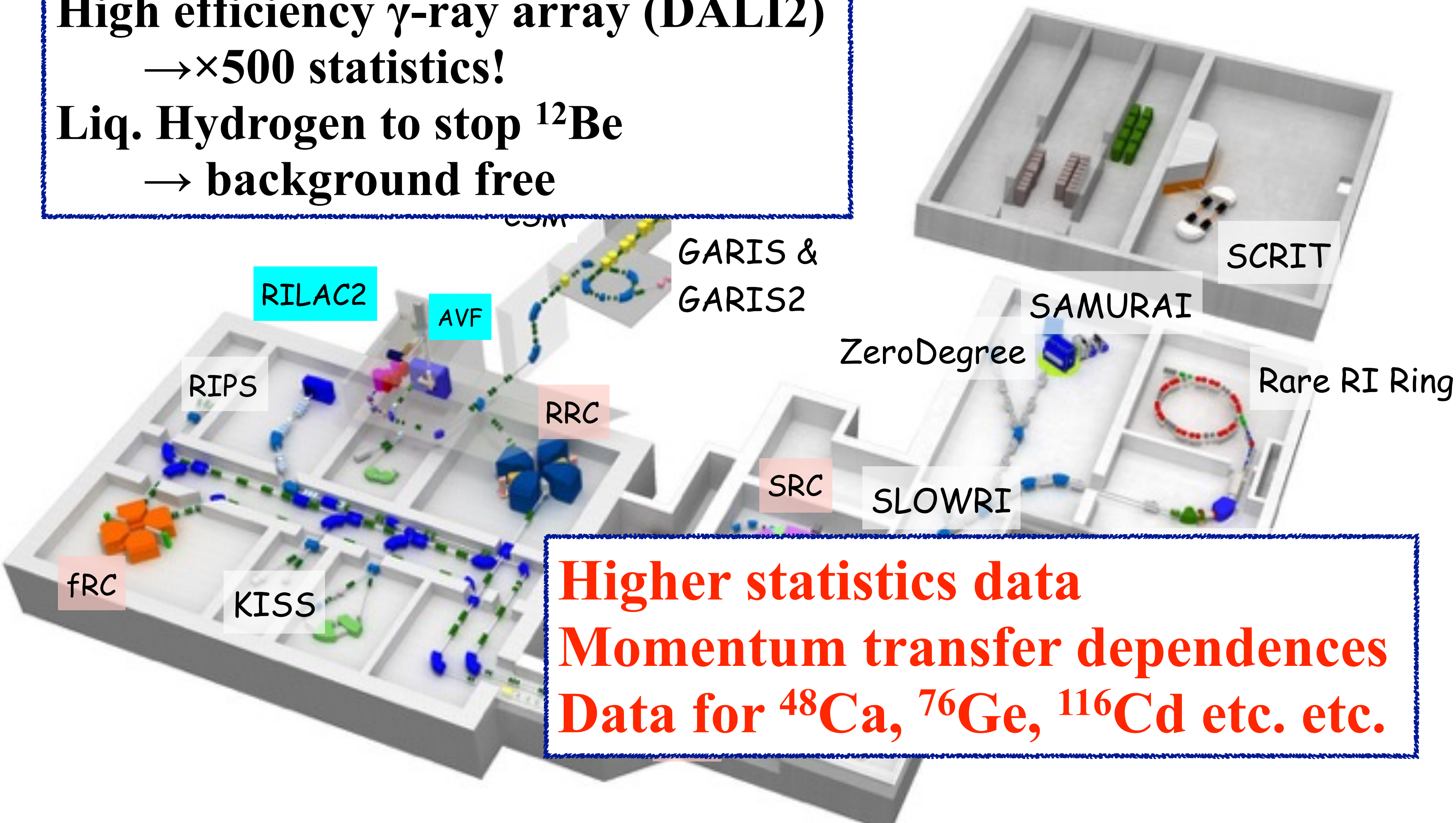
Definitely there is something.
Usefulness of (^{12}C,$^{12}Be\gamma$) is proved.
But limited statistics prevent us from drawing final conclusion.

gnd

(near) Future Plan

Future experiment @RI Beam Factory, RIKEN

High intensity ^{12}C beam (<1pμA)
High efficiency γ-ray array (DALI2)
→×500 statistics!
Liq. Hydrogen to stop ^{12}Be
→ background free



Higher statistics data
Momentum transfer dependences
Data for ^{48}Ca, ^{76}Ge, ^{116}Cd etc. etc.

Summary

Reaction study with heavy-ion double charge exchange reactions can extend our reach to double GT/SD states

to a wider range of excitation energy

to a variety of nuclei

One flagship is observation of DGT giant resonances.

(^{12}C, ^{12}Beγ) can be a good probe to investigate the DGT states.
Results from the first RCNP experiment indicate existence of DGT giant resonances in ^{48}Ti.

★Reliable reaction theory for the double charge exchange should be established for quantitative discussions.

Collaborators

M. Takaki, N. Aoi, M. Dozono, T.Furuno, C. Iwamoto, T. Kawabata, M. Kobayashi, Y. Matsuda, M. Matsushita, S. Michimasa, S. Ota, M. Sasano, S. Shimoura, L. Stuhl, A. Tamii, R. Yokoyama, J. Zenihiro,

CNS, University of Tokyo

RIKEN Nishina Center

RCNP, Osaka University

Department of Physics, Kyushu University

Department of Physics, Konan University