Search for Double Gamow-Teller Giant Resonance via heavy-ion double charge exchange reaction

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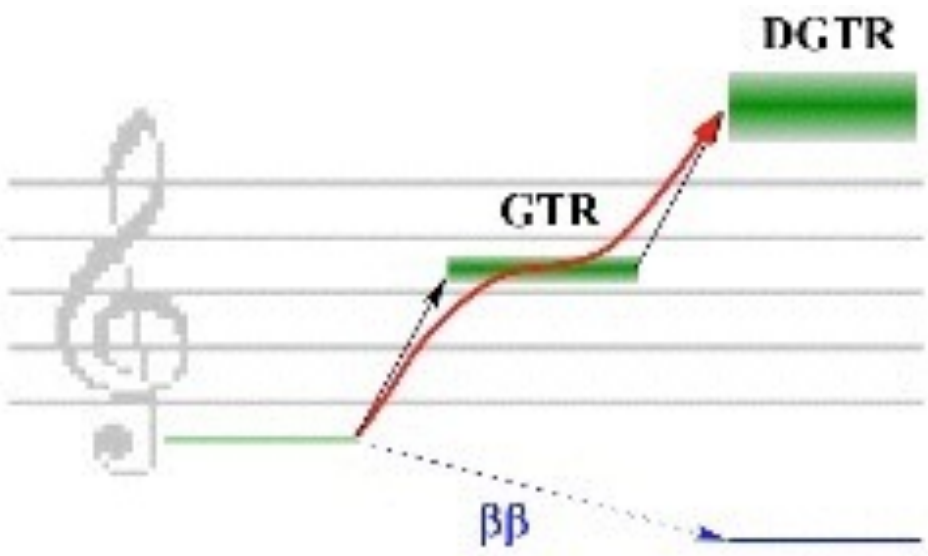
Introduction & Motivations

Studies of Gamow-Teller transitions stem a core of nuclear physics research

Quenching problem
High-resolution GT spectroscopy
Nuclear weak responses
relevant to astrophysics
New excitation modes in Unstable nuclei



The goal of our project is
to extend the GT studies to TWO-phonon space
by discovering double GT giant resonances
(DGTGR).

Basic questions to be answered are:

Are GT responses linear?
The centroid energy is twice of GTGR? How about its width?
How much is a quenching factor for DGT response?

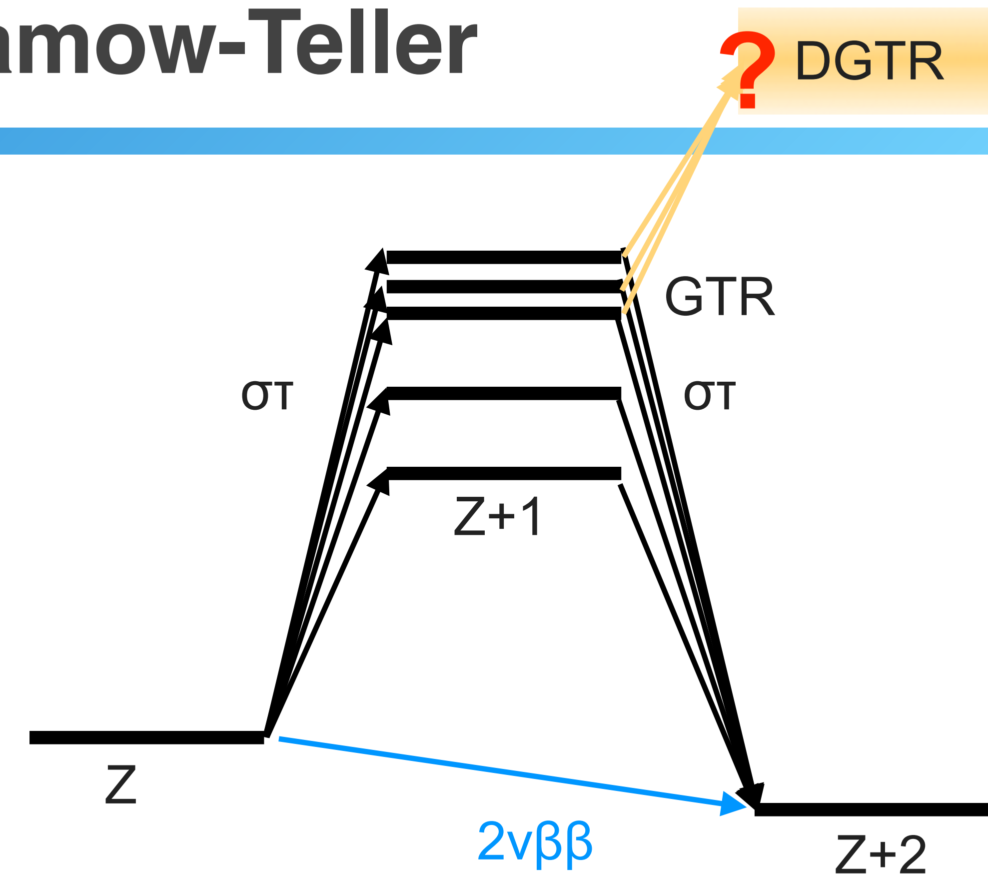
How reliable are nuclear structure calculations for ββ-decay matrix elements?

2νββ decays: One of the Double Gamow-Teller

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

Eliot&Vogel, (2002)



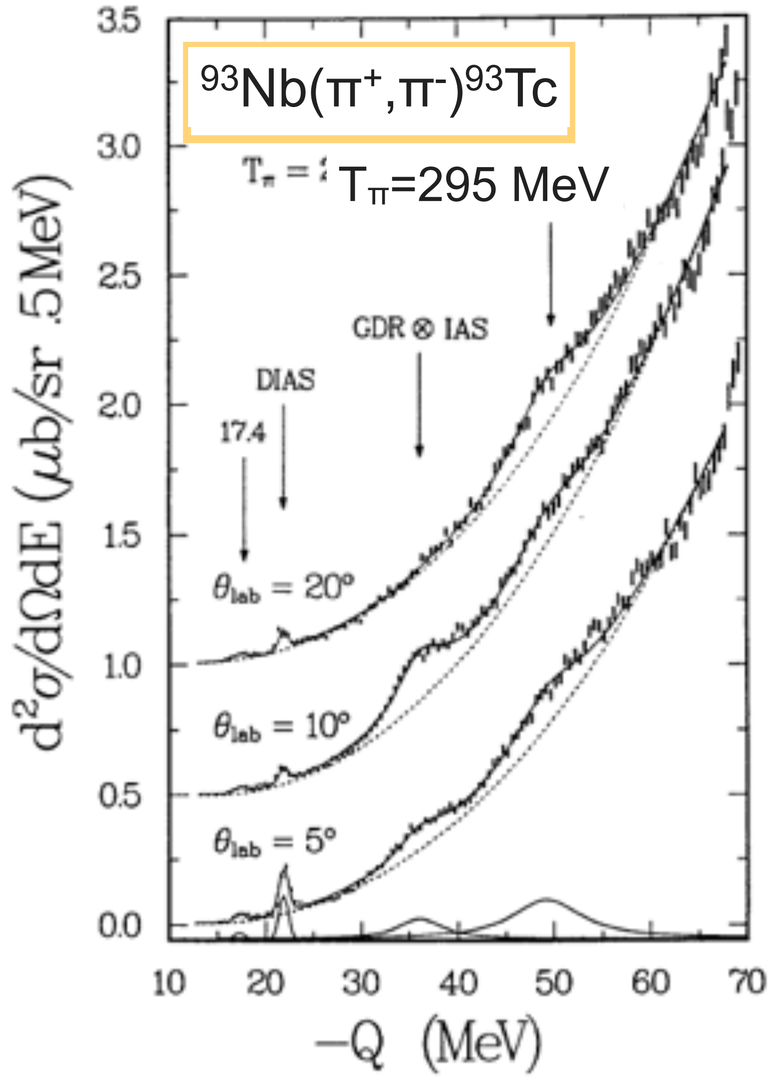
$\sim 10^{-4} - 10^{-3}\ S_{DGT}$

A unique calibration of nuclear structure calculation for the ββ-decay.

> ***The (ββ-decay) matrix element, however, still remains very small and accounts for only a 10^{-4} to 10^{-3} of the total DGT sum rule. A precise calculation of such hindered transition is, of course, very difficult and is inherently a subject of large percent uncertainties. At present there is no direct way to "calibrate" such complicated nuclear structure calculations involving miniature fractions of the two-body DGT transitions. By studying the stronger DGT transitions and, in particular, the giant DGT states experimentally and as we do here, theoretically, one may be able to "calibrate" the calculations of ββ-decay nuclear elements.***
>
> **N. Auerbach, L. Zamick, and D. Zheng, Annals of Physics 192, 77 (1989).**

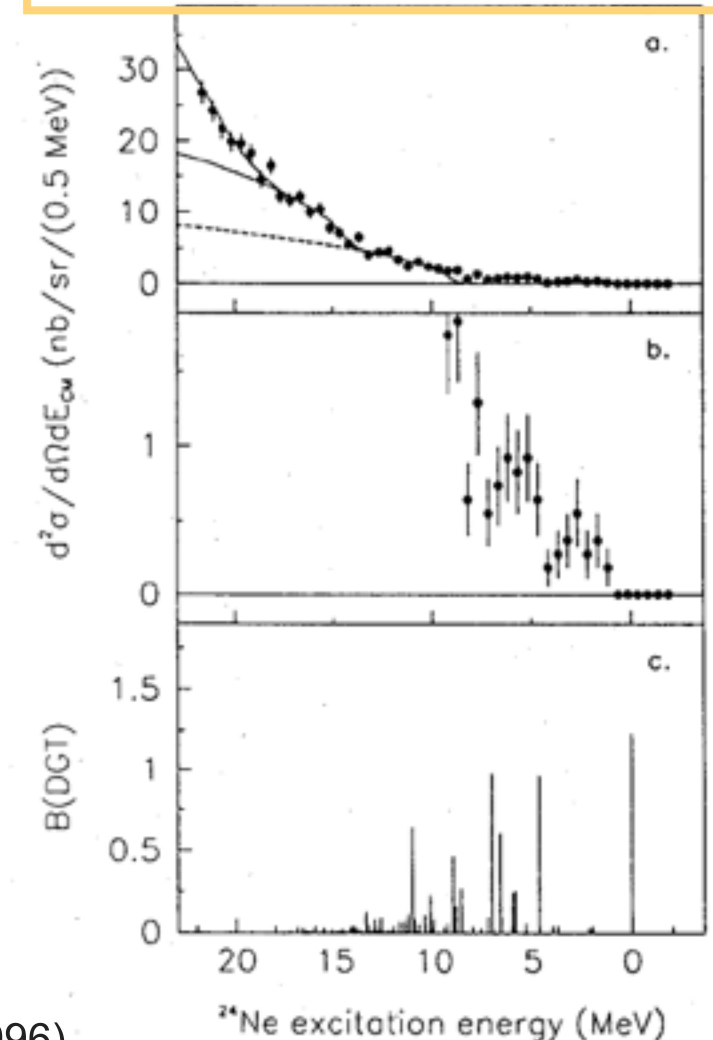
How can we study the DGT?

A few experiment have been attempted.



Mooderchai et. al., NPA 599, 159c (1996)

^{24}Mg(^{18}O,^{18}Ne)^{24}Ne @ 76 A MeV



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

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

Takahisa, Ejiri et al.,

AIP Proc. Conf. **915**, 815 (2007)

No clear evidence so far…

It is difficult to find a good probe

(π^+,π^-): spin 0 probe
(^{18}O,^{18}Ne): $\beta^+\beta^+$ -type probe
(^{11}B,^{11}Li): small overlap?

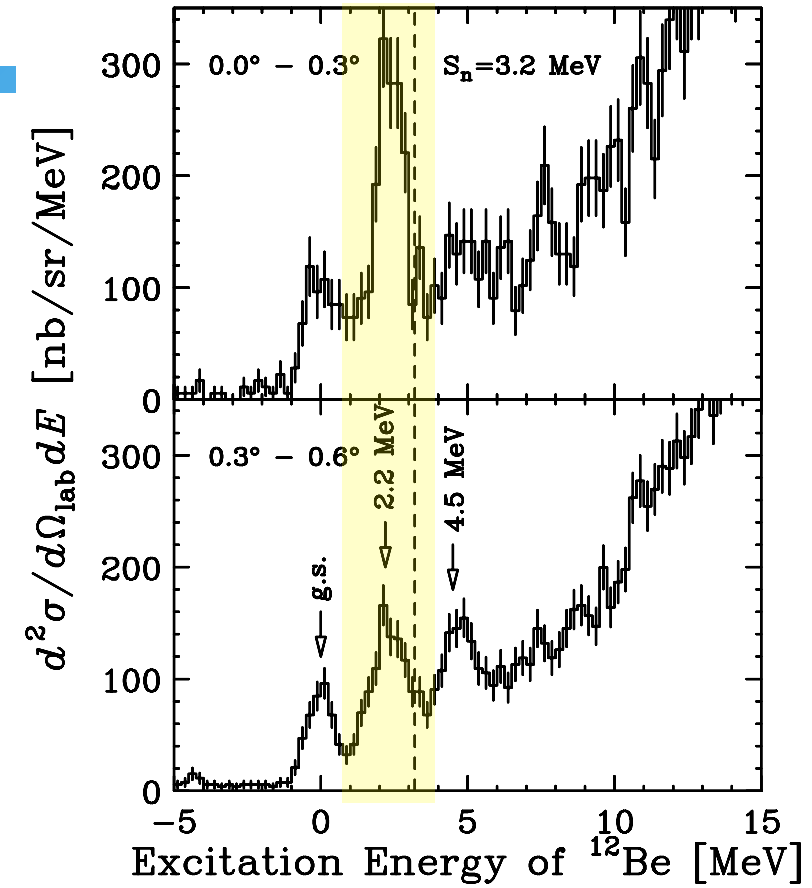
DGT: ΔL=0, ΔS=0 or 2, ΔT=2

Spin and Isospin flips is necessary.

Heavy-ion double charge exchange (HIDCX) reaction

$\beta^-\beta^-$ -type DGT probe is effective for medium or heavy mass nuclei

New idea: (^{12}C,^{12}Be(0^+_2)) reaction



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

B(GT^2) ~ 0.3

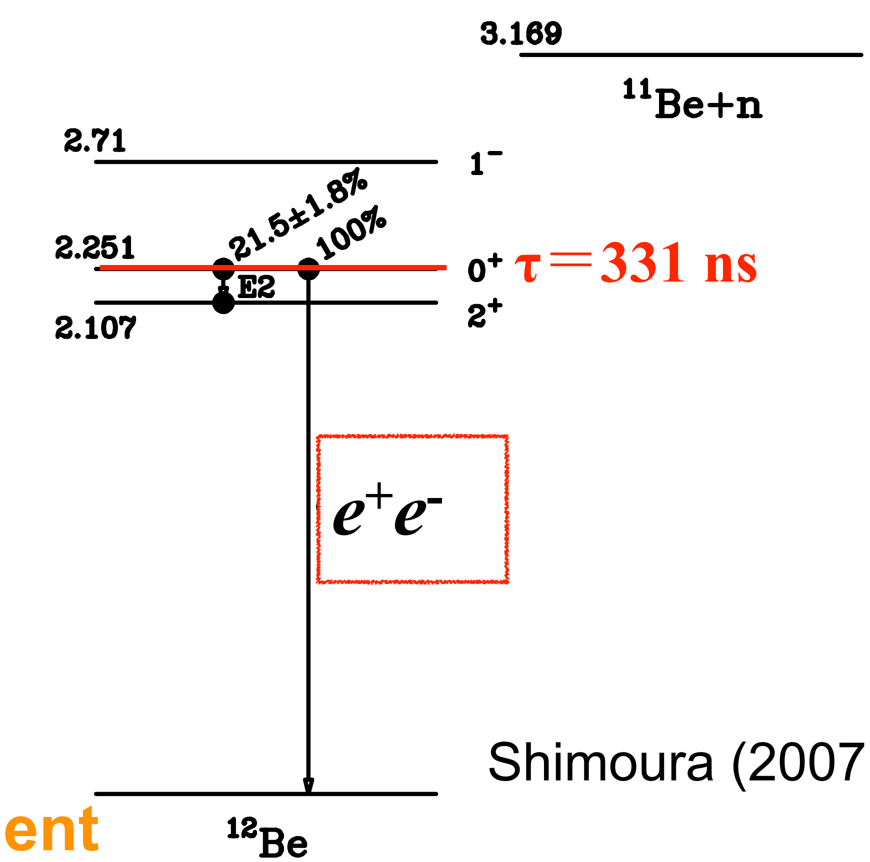
^{12}C(^{18}O,^{18}Ne) experiment →

Matsubara, Uesaka, MT et al.,
Few-Body Syst. **54**, 1433 (2013).

- This is because all of the initial **^{12}C($0^+_{g.s.}$)**, intermediate **^{12}B($1^+_{g.s.}$)** and final **^{12}Be(0^+_2)** state are **dominated by 0ħω configuration**.

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.**

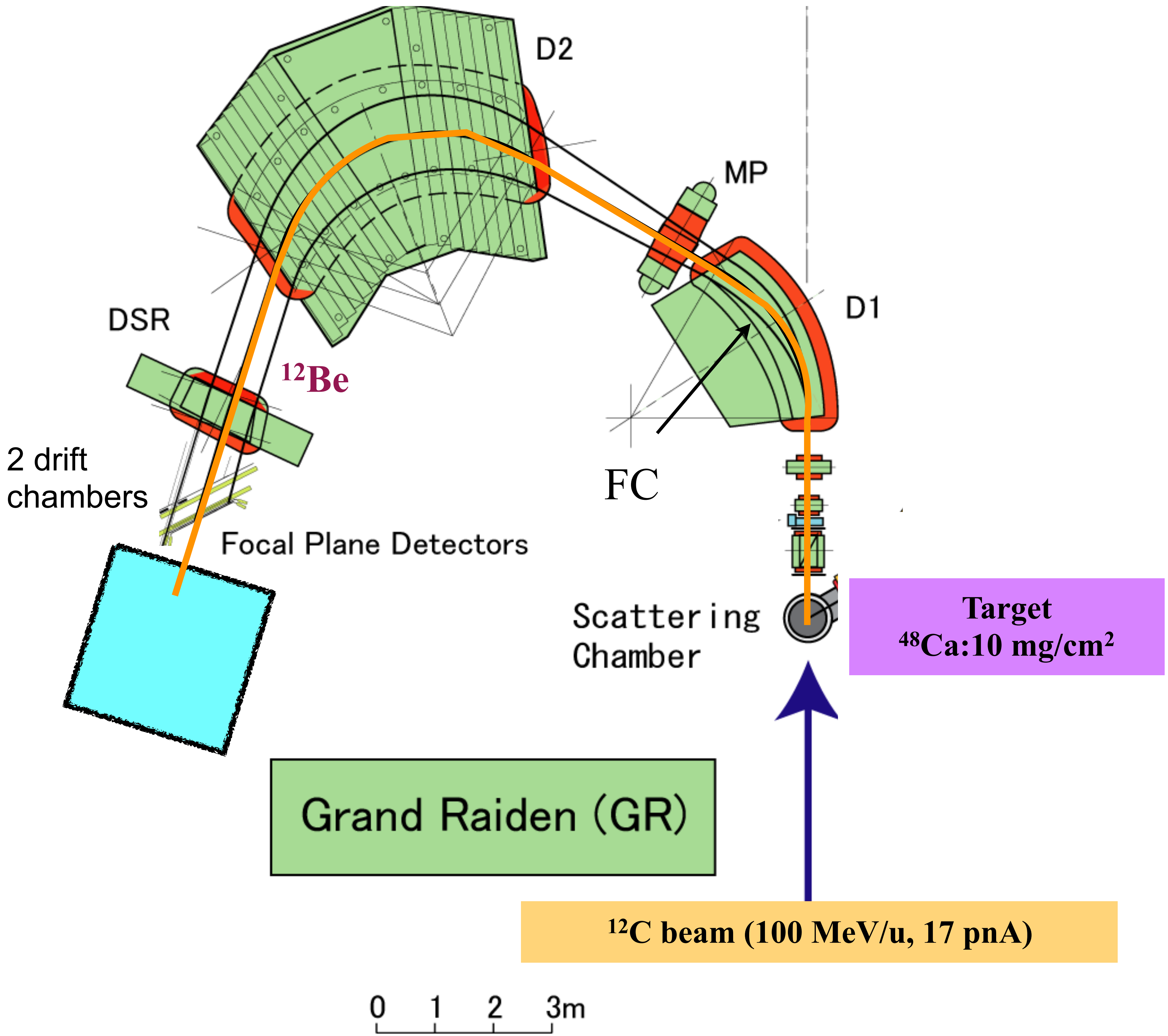


Shimoura (2007)

Those two characteristics make this reaction specially effective in DGT studies.

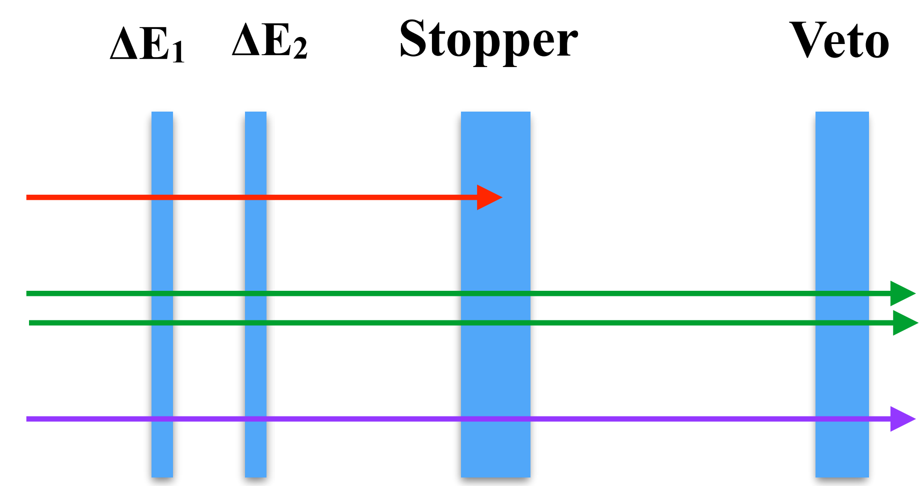
First application: ^{48}Ca(^{12}C,^{12}Be(0^+_2)) experiment

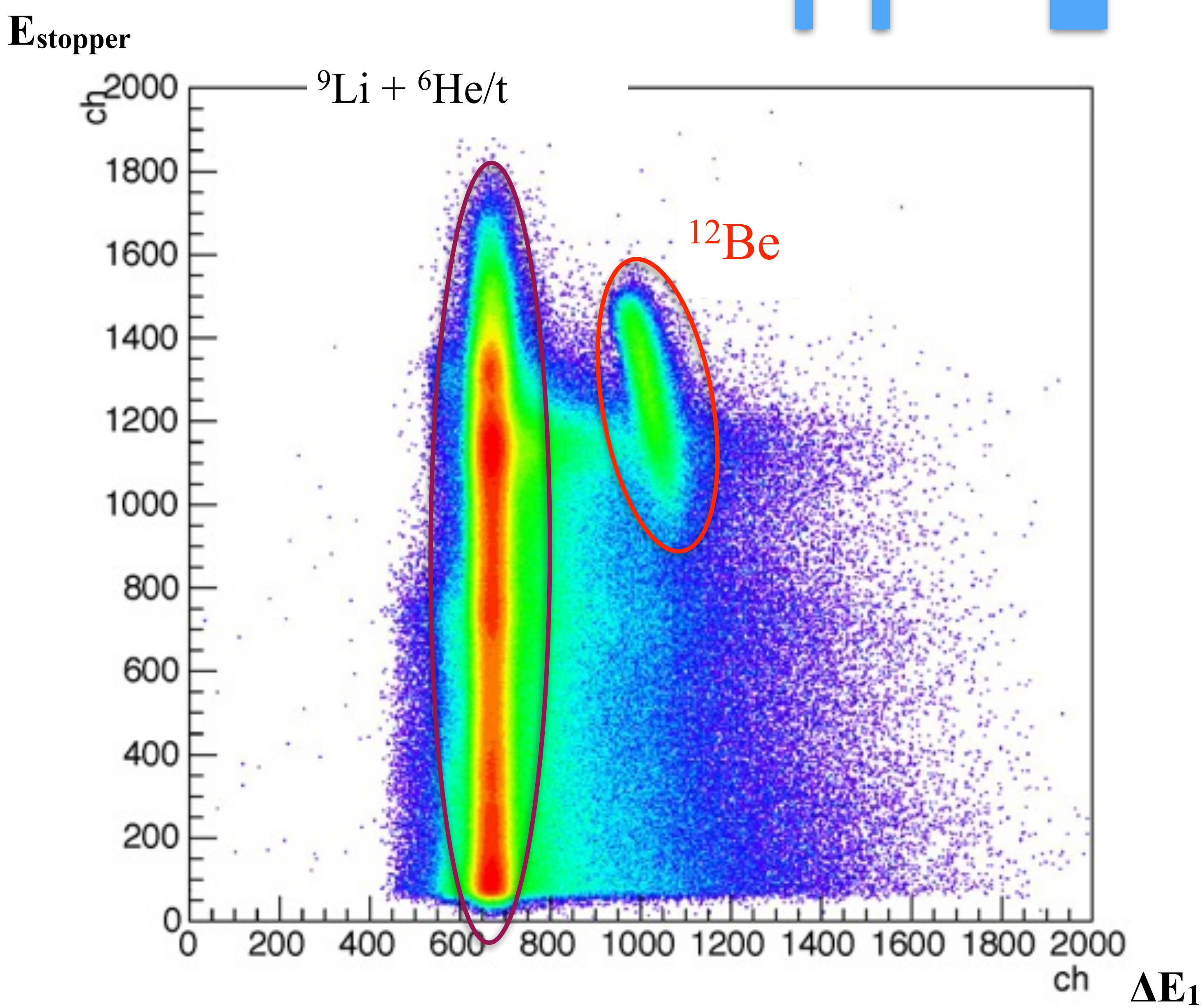
Experimental setup



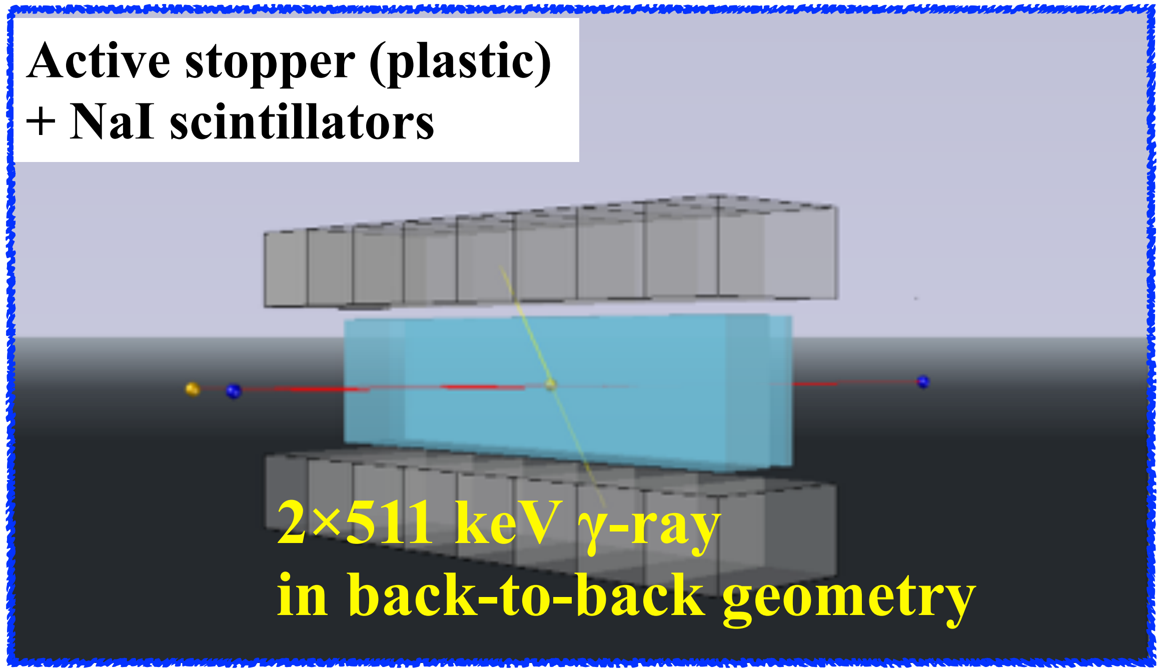
Identification of ^{12}Be

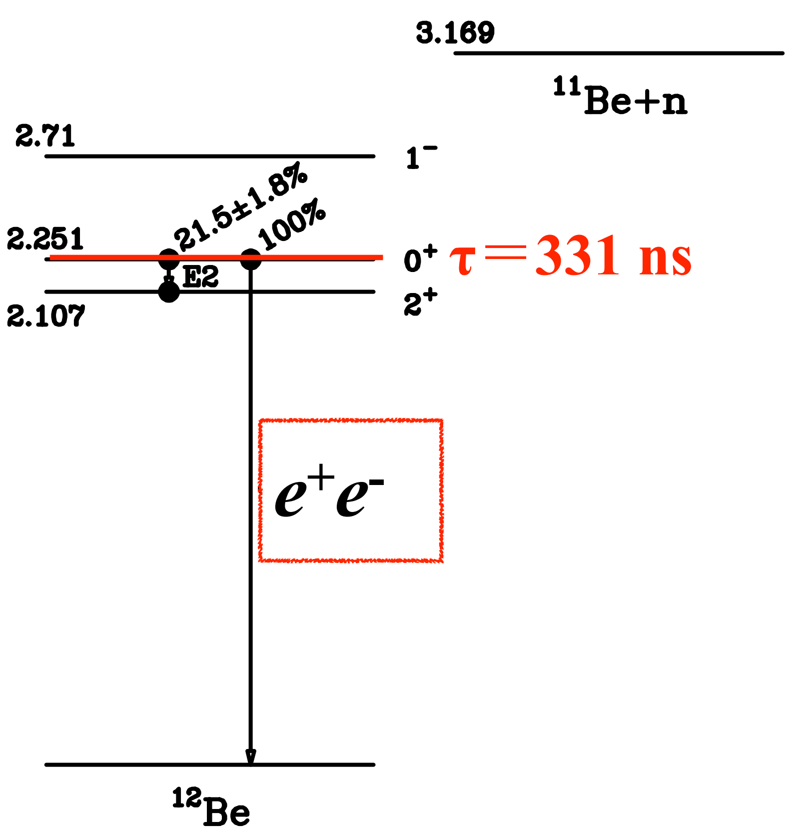
^{12}Be	~	0.1	Hz
^{6}He, ^{9}Li	~	1000	Hz
t	~	100000	Hz

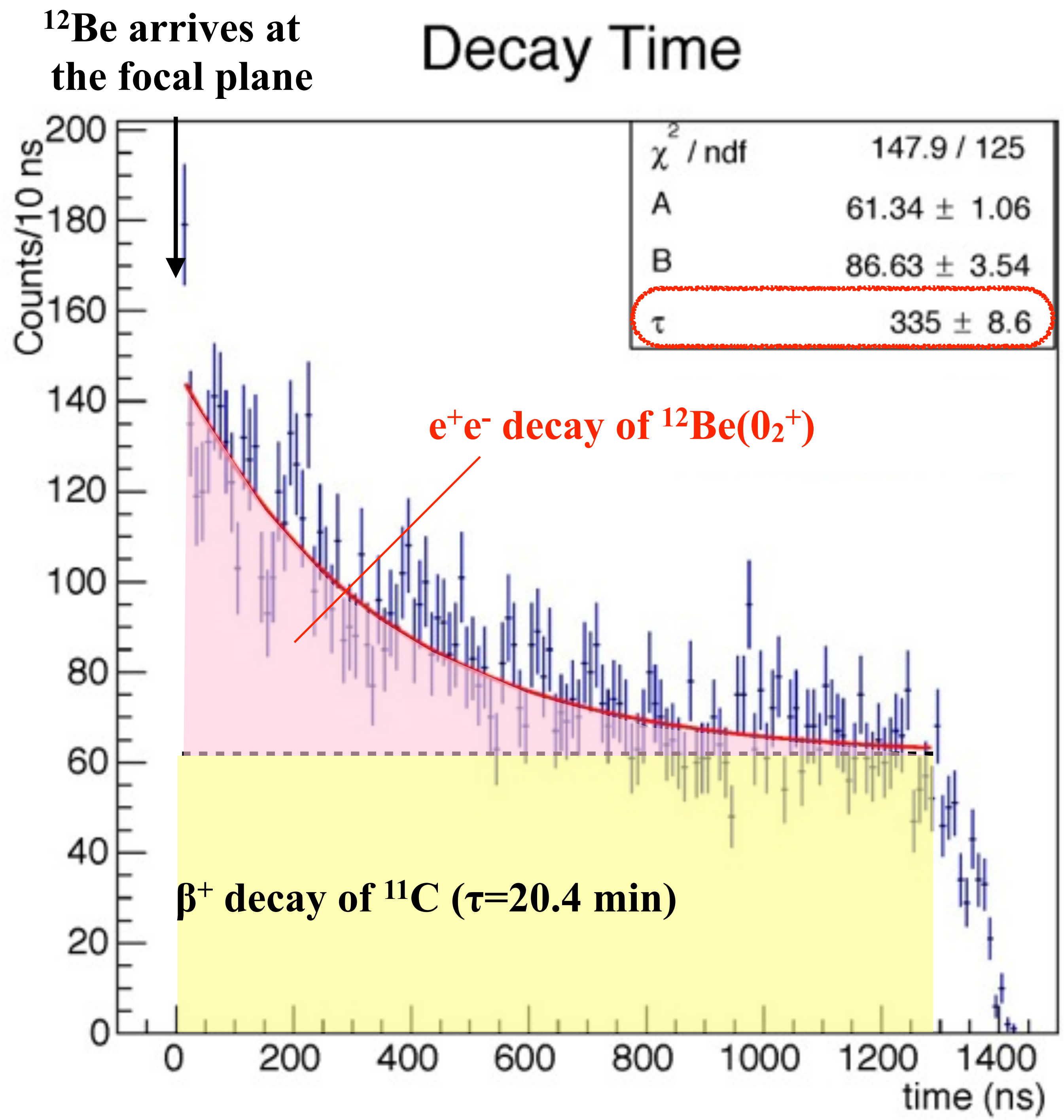




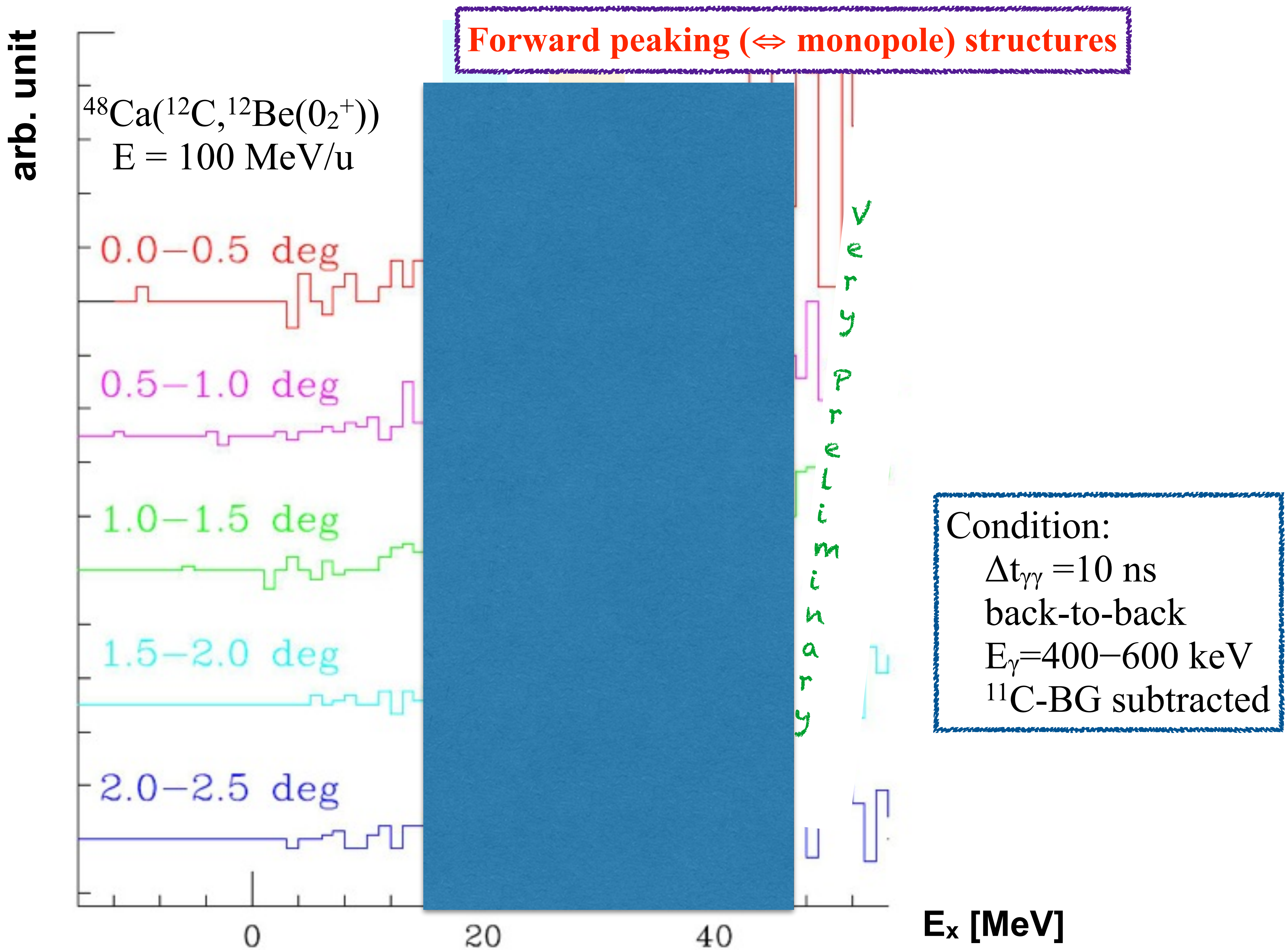
Identification of $^{12}Be(0^+_2)$ with γ-ray tagging



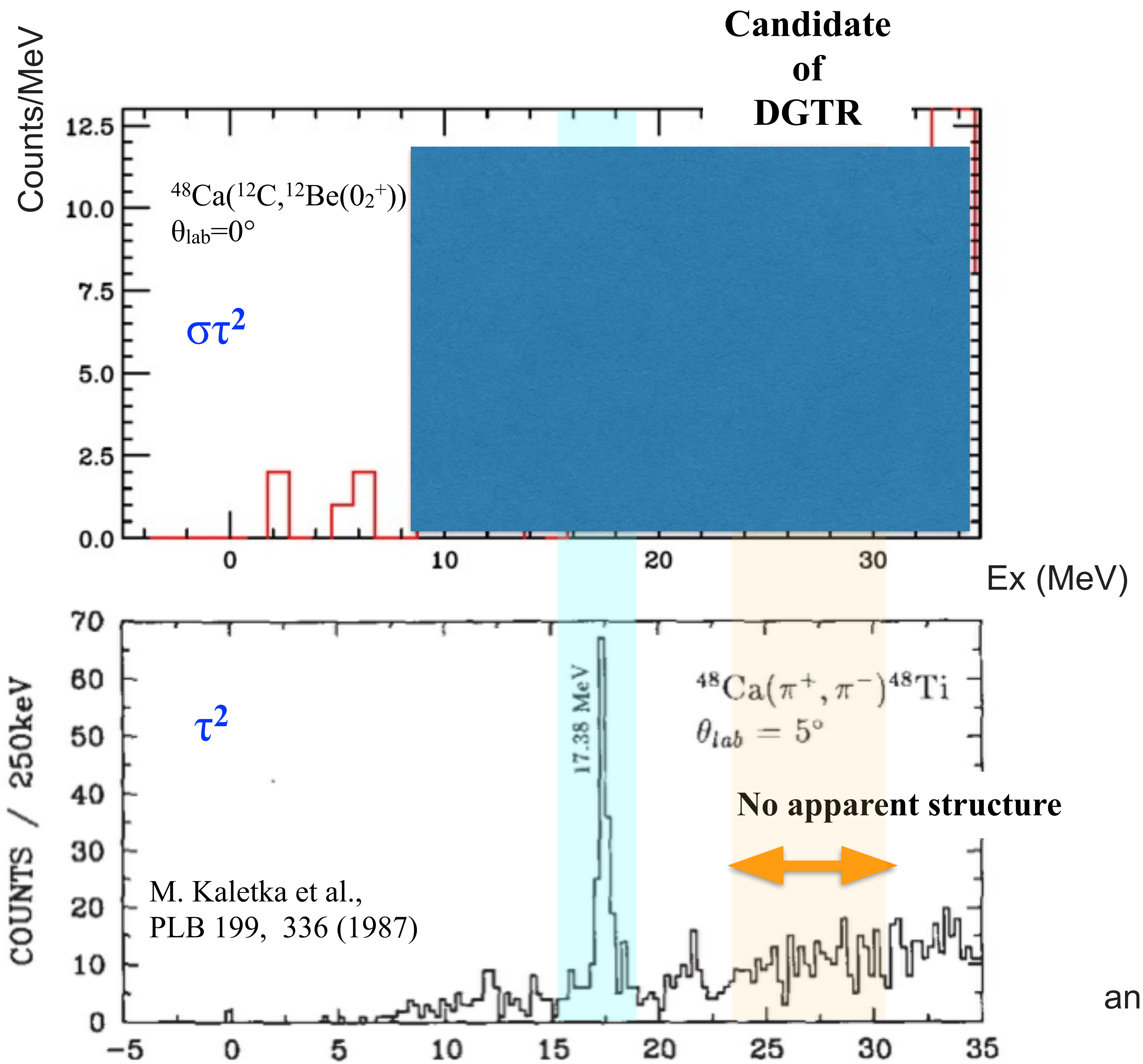




Excitation energy spectra in ^{48}Ti



Comparison with (π+,π-) spectrum



analysis is ongoing…

Summary

Double Gamow-Teller Resonances

will open research opportunity on GT$\times$GT excitations

can serve as a test case for nuclear models of $0\nu\beta\beta$

Experimental access has been quite limited.

New idea: (^{12}C,$^{12}Be(0^+_2)$) reaction

Strong transition in the projectile ($^{12}C \rightarrow {}^{12}Be(0_2^+)$)

Event identification capability via delayed-γ tagging

The first physics case : ^{48}Ca

→ Applications to other ββ-decay nuclei

Collaborators

E358 experiment

H. Matsubara[2], T. Uesaka[3], N. Aoi[4], M. Dozono[1], T. Hashimoto[4], T. Kawabata[5],
S. Kawase[1], K. Kisamori[1], Y. Kubota[1], C.S. Lee[1], J. Lee[3], Y. Maeda[6], S. Michimasa[1],
K. Miki[4], S. Ota[1], M. Sasano[3], T. Suzuki[4], K. Takahisa[4], T.L. Tang[1], A. Tamii[4],
H. Tokieda[1], K. Yako[1], R. Yokoyama[1], J. Zenihiro[3], and S. Shimoura[1]

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[5]Department of Physics, Kyoto University
[6]Department of Applied Physics, University of Miyazaki

E429 experiment

T. Uesaka, 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,

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Gamma-ray 2D spectrum