Search for
Double Gamow-Teller Giant Resonance
via
Heavy-Ion Double Charge Exchange Reaction

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Double Gamow-Teller resonance

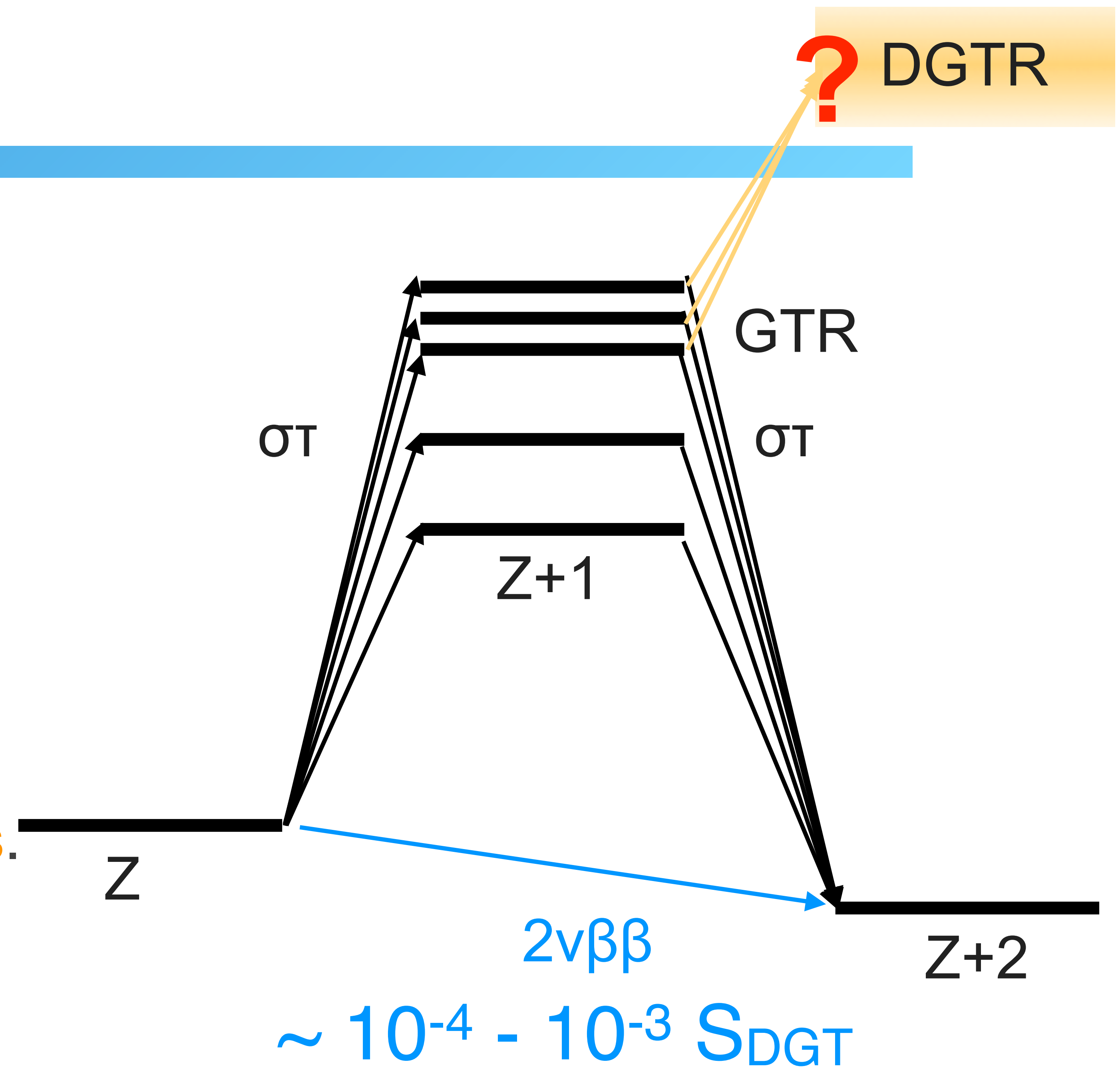
Double Gamow-Teller resonance (DGTR) consists of two GT resonances induced by the spin-isospin operator, στστ.

Through the DGTR study, we would like to answer.

- Is the DGTR just superposition of the GTRs, or, do the nuclear (spin-dependent) correlations cause further changes to structure and responses of double GT states?

DGTR can be another benchmark for nuclear structure calculation of ββ-decays.

- The calculation only rely on the 2νββ results.



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).

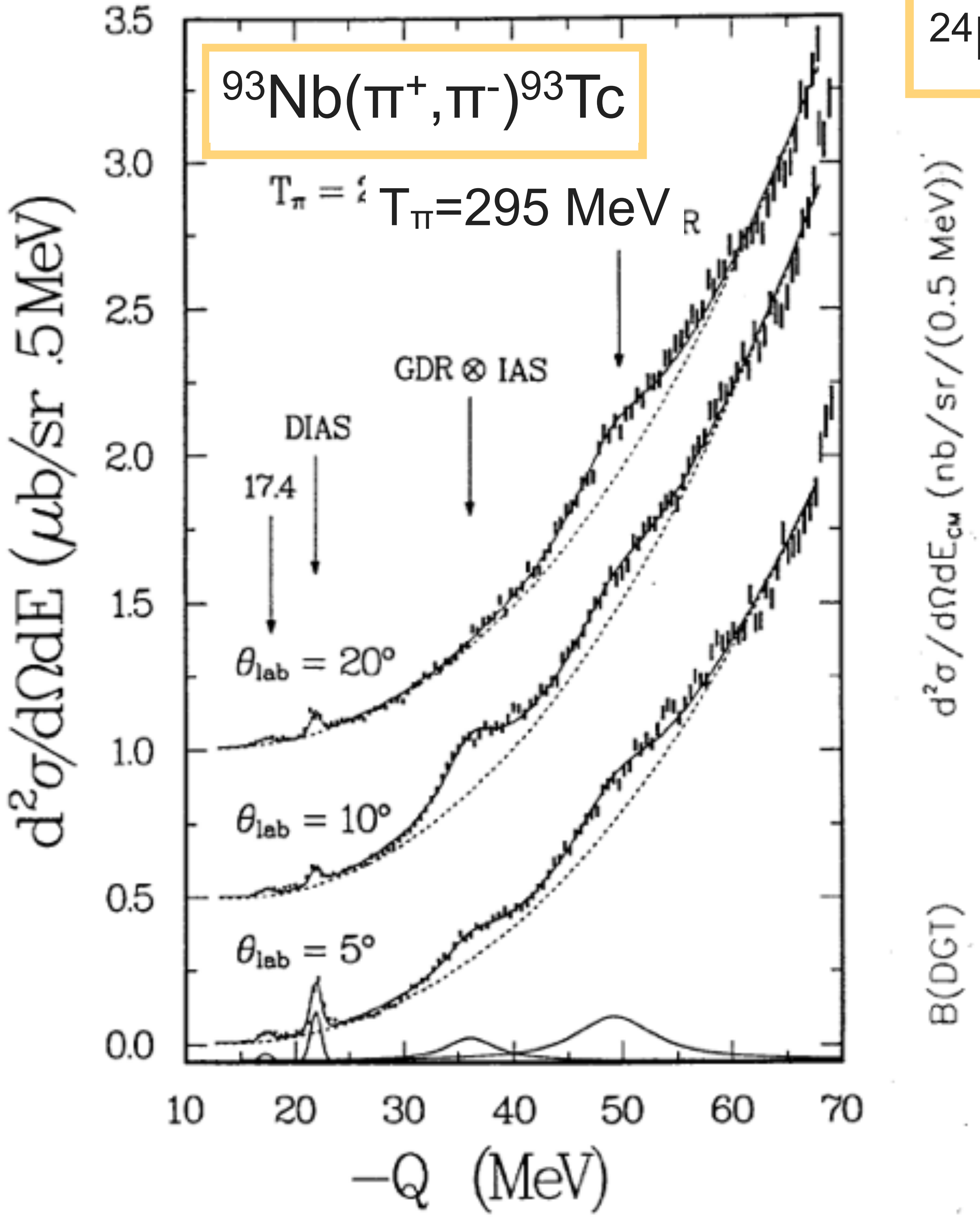
DGTR has been left to be discovered!

Limitation of experimental access to DGT

A few experiment have been attempted.

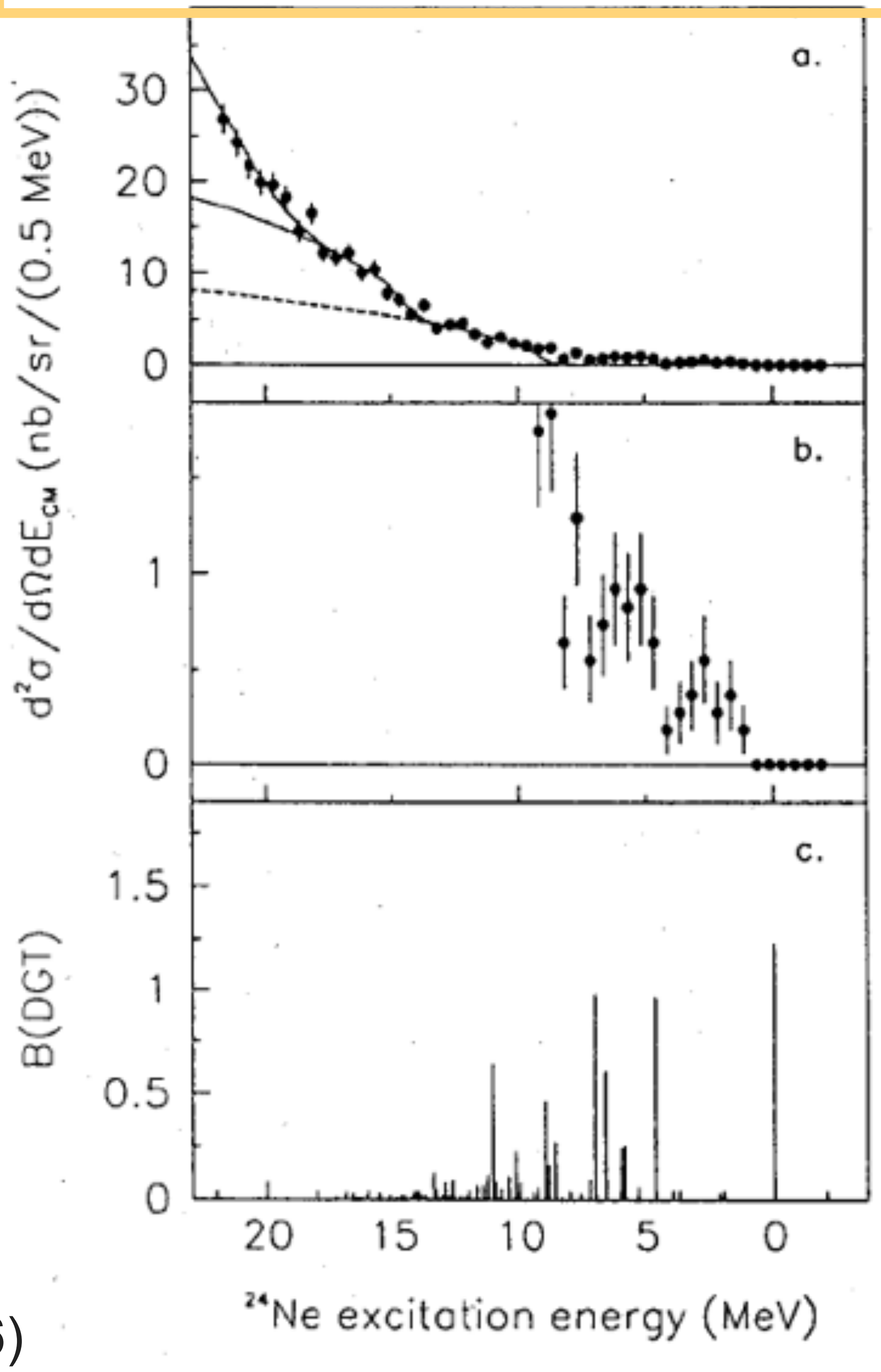
$^{93}Nb(\pi^+,\pi^-)^{93}Tc$

T_π=295 MeV



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)

Some strengths were found.

No clear evidence for DGTR 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?

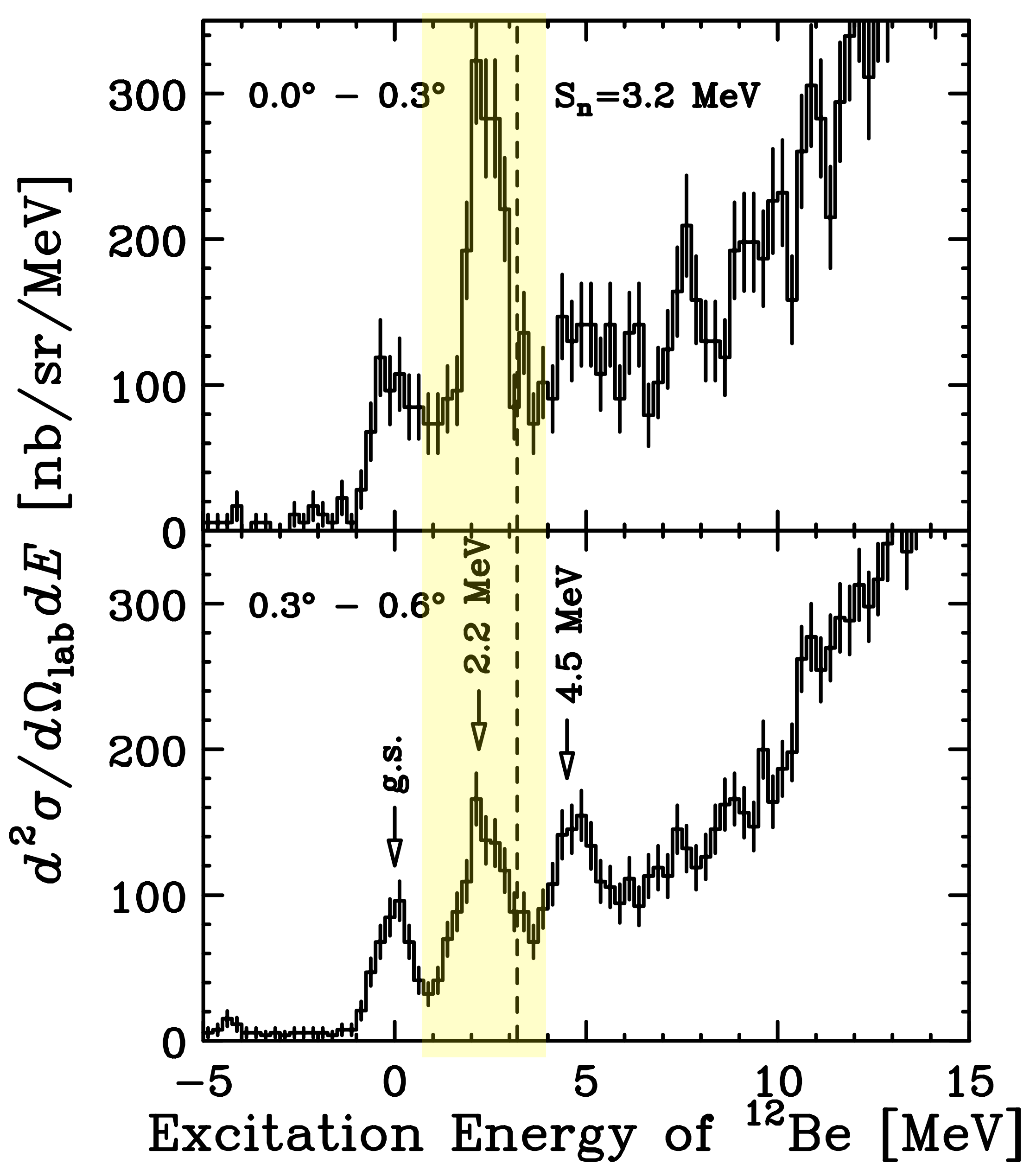
DGT: ΔL=0, ΔS=0 or 2, ΔT_z=2

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 →

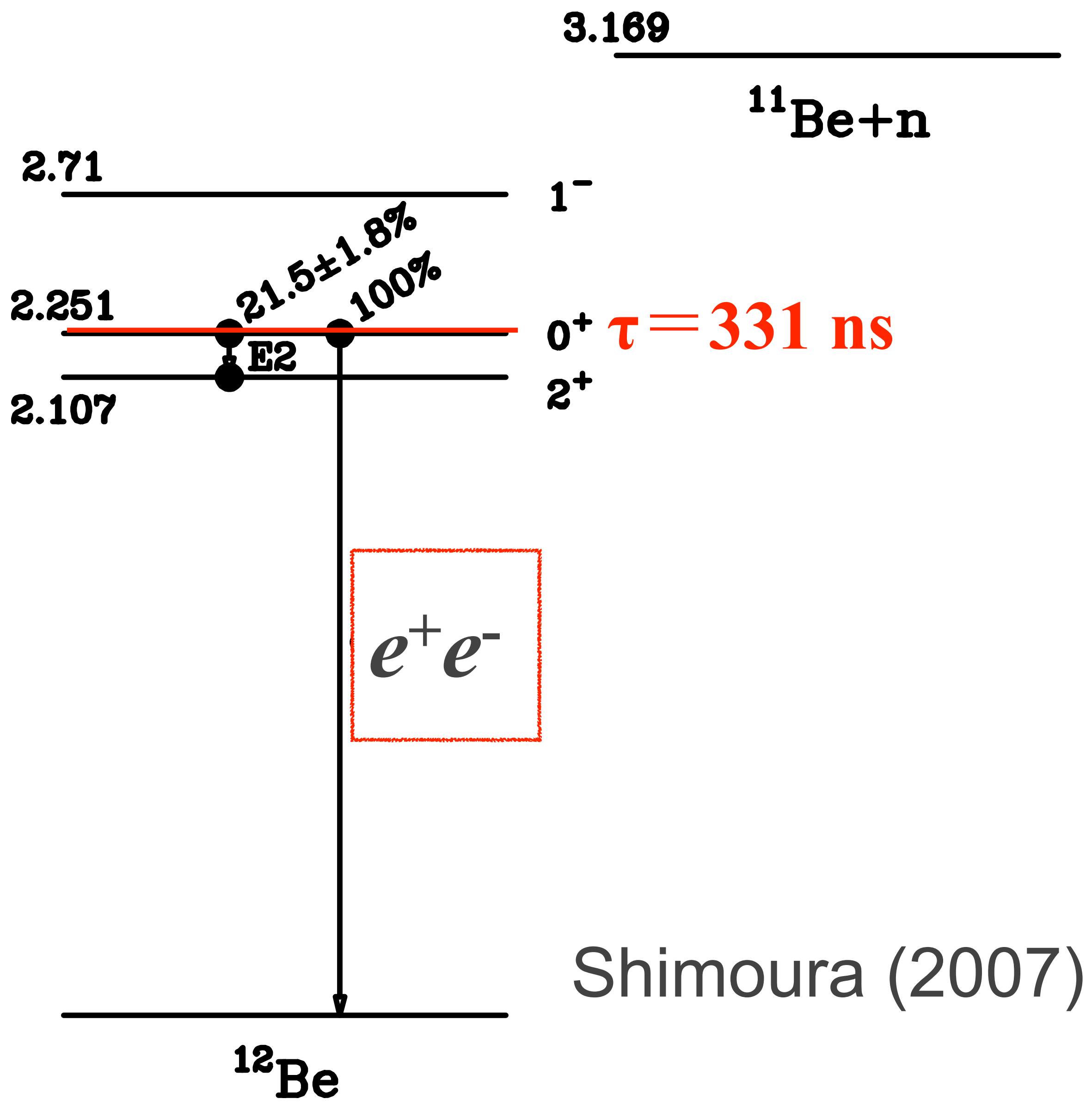
Matsubara, Uesaka, MT et al.,
Few-Body Syst. **54**, 1433 (2013).

- 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.**

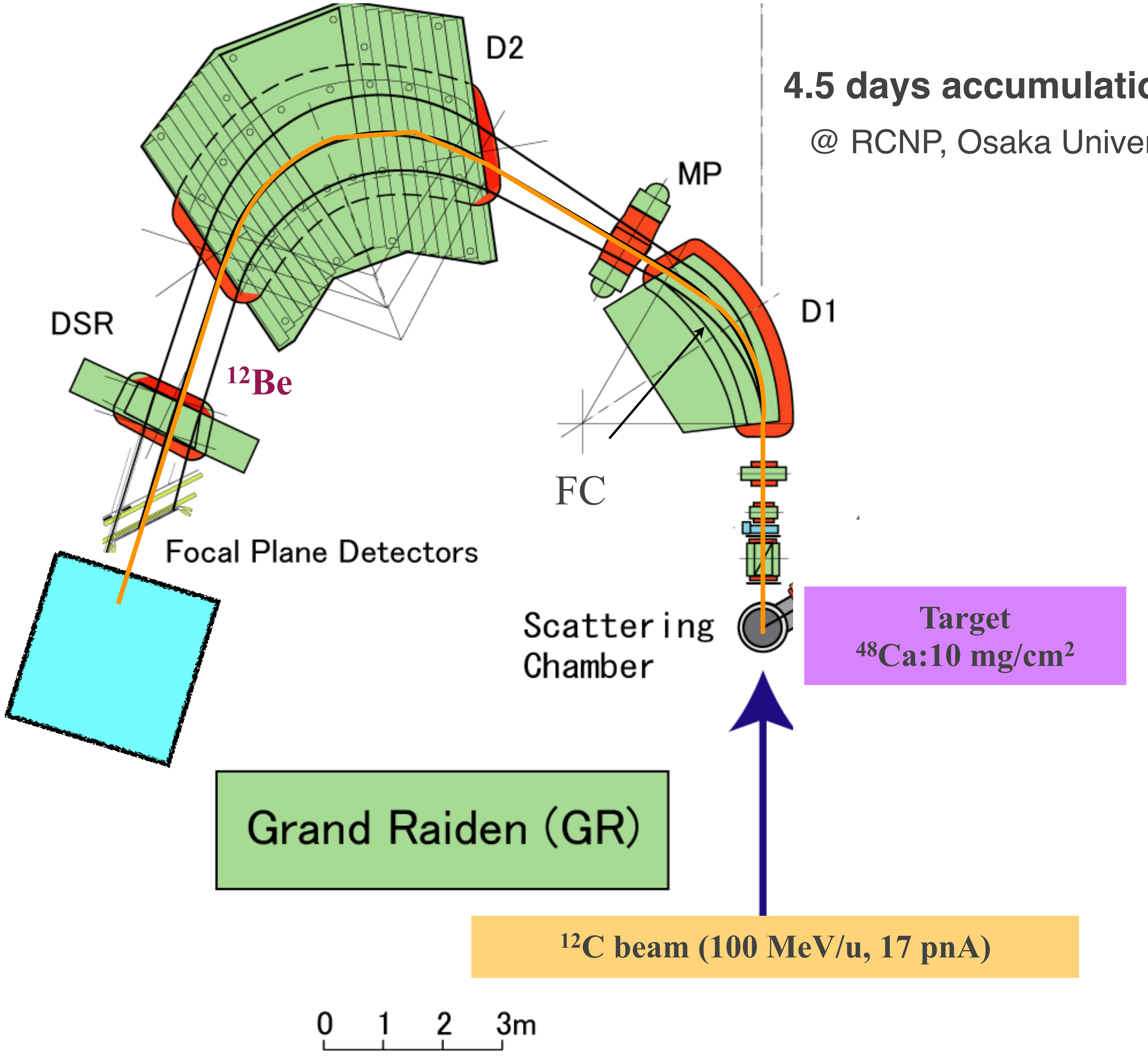


Shimoura (2007)

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

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

Experimental setup

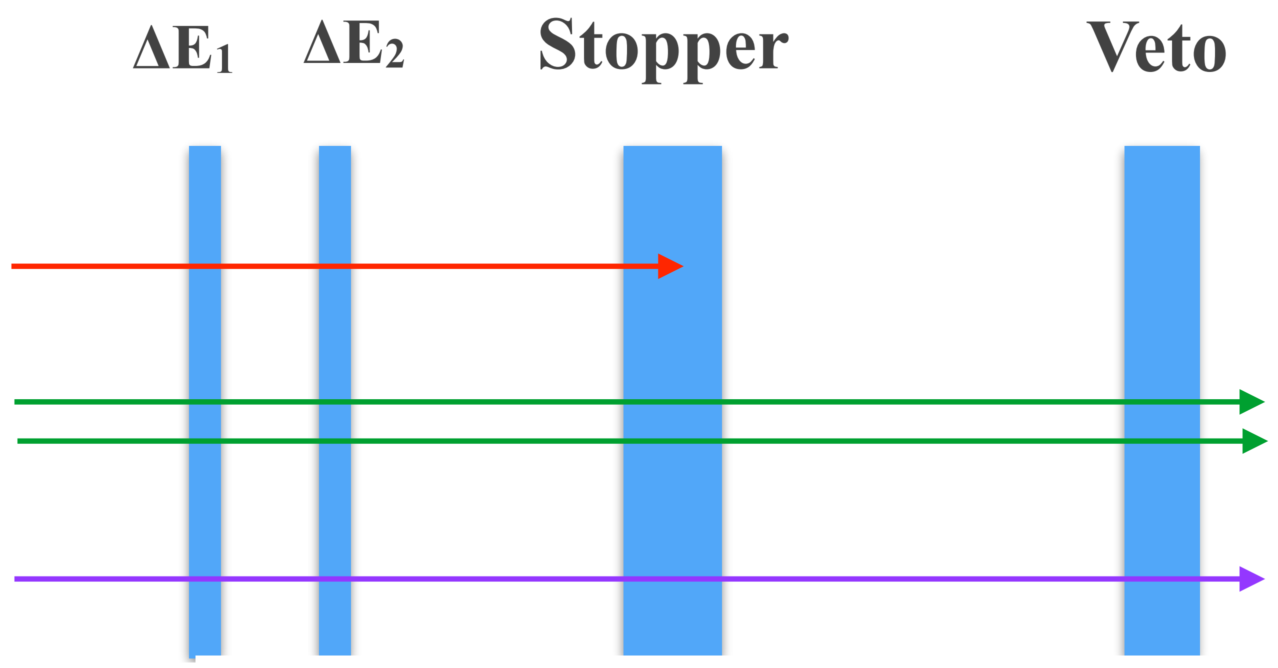


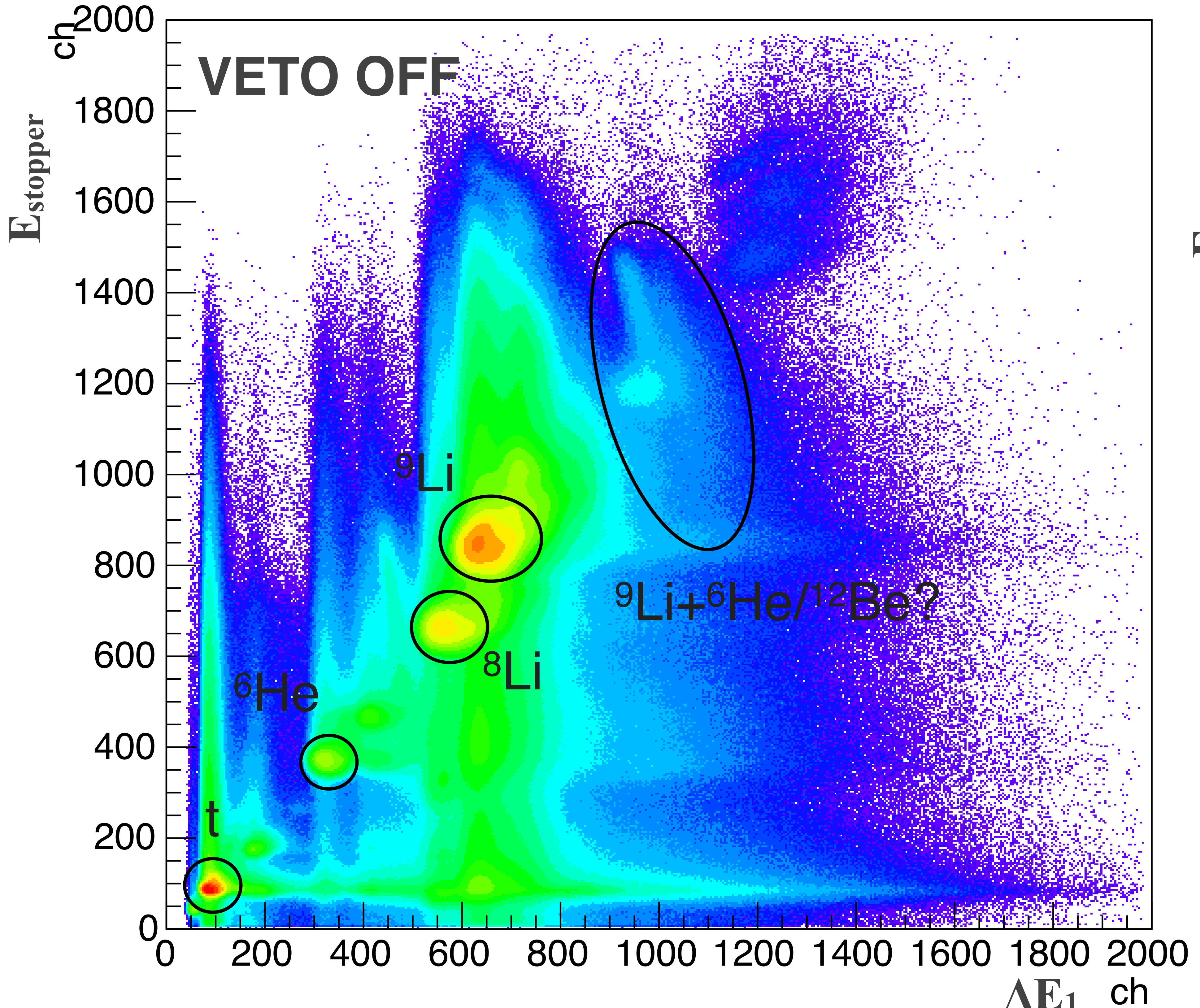
4.5 days accumulation

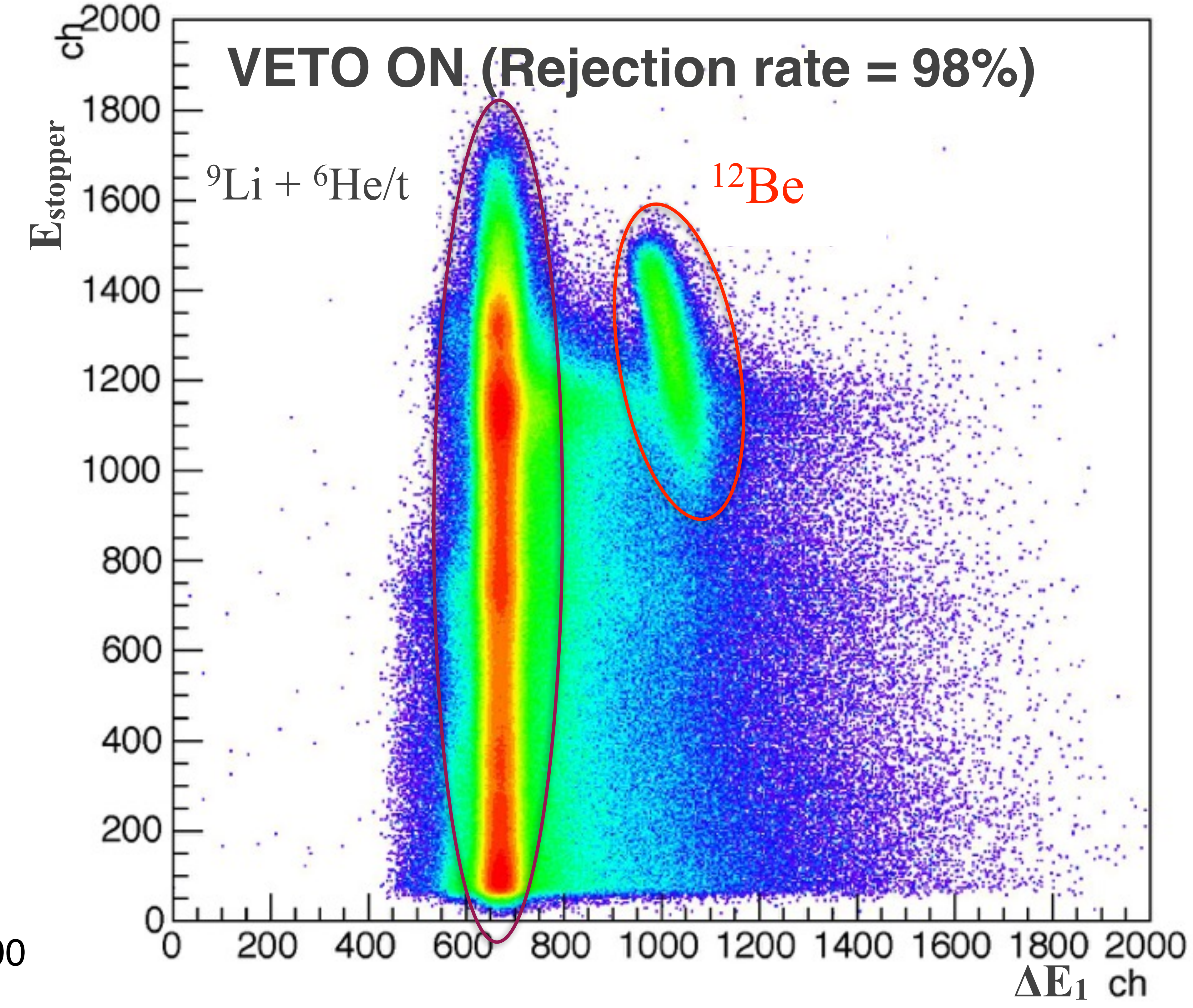
@ RCNP, Osaka University, Japan

Identification of ^{12}Be

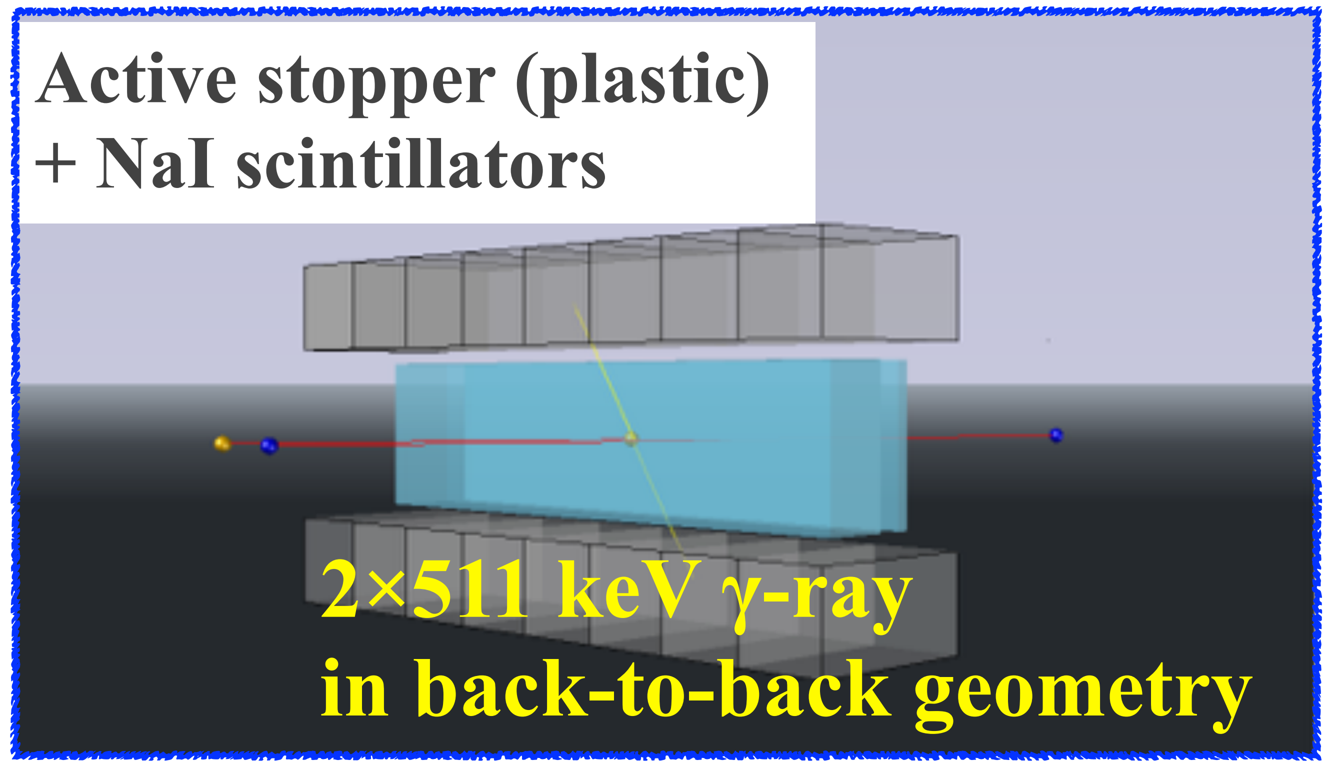
^{12}Be	~ 0.1	Hz
^{6}He, ^{9}Li	~ 1000	Hz
t	~100000	Hz

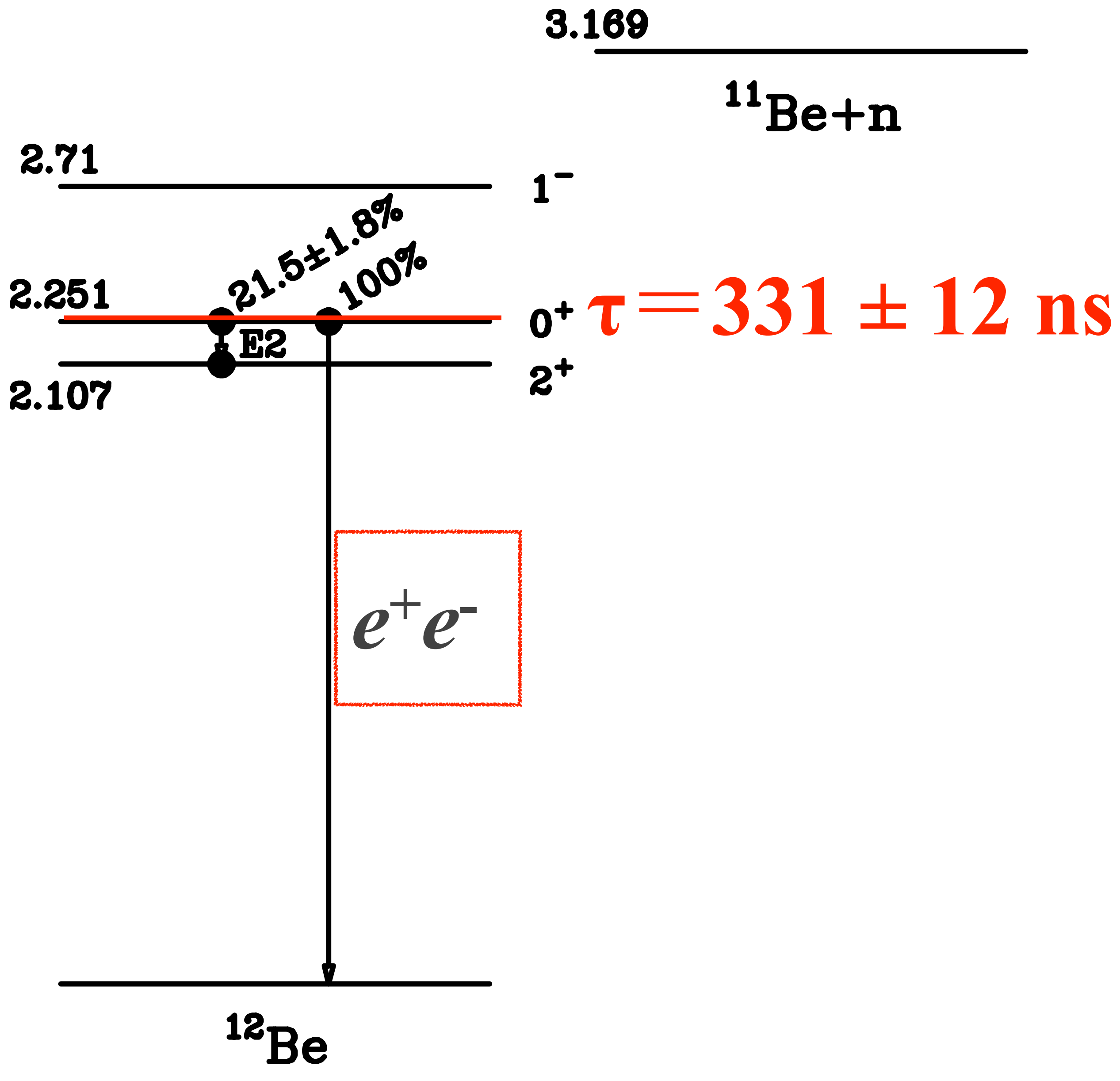


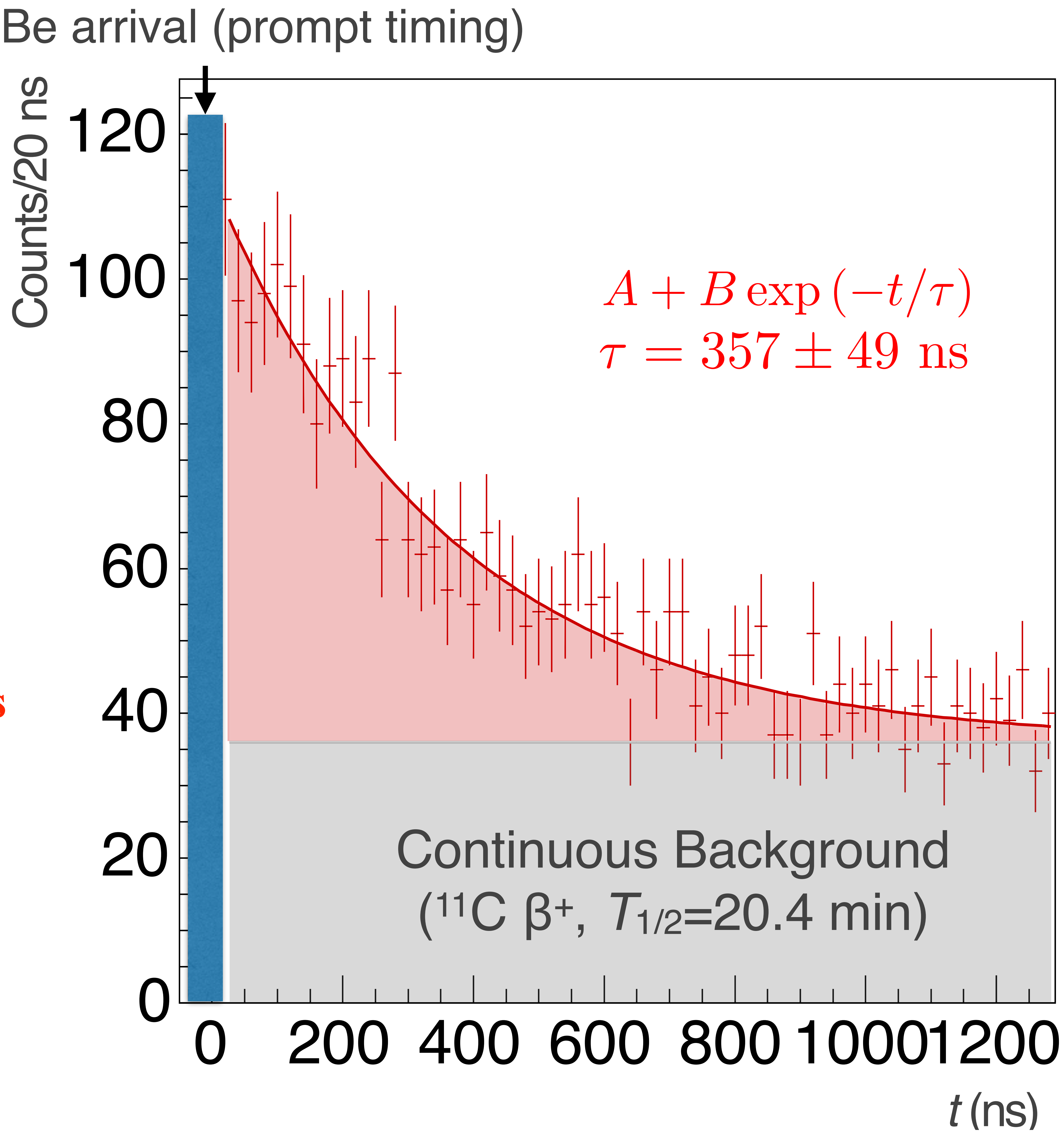




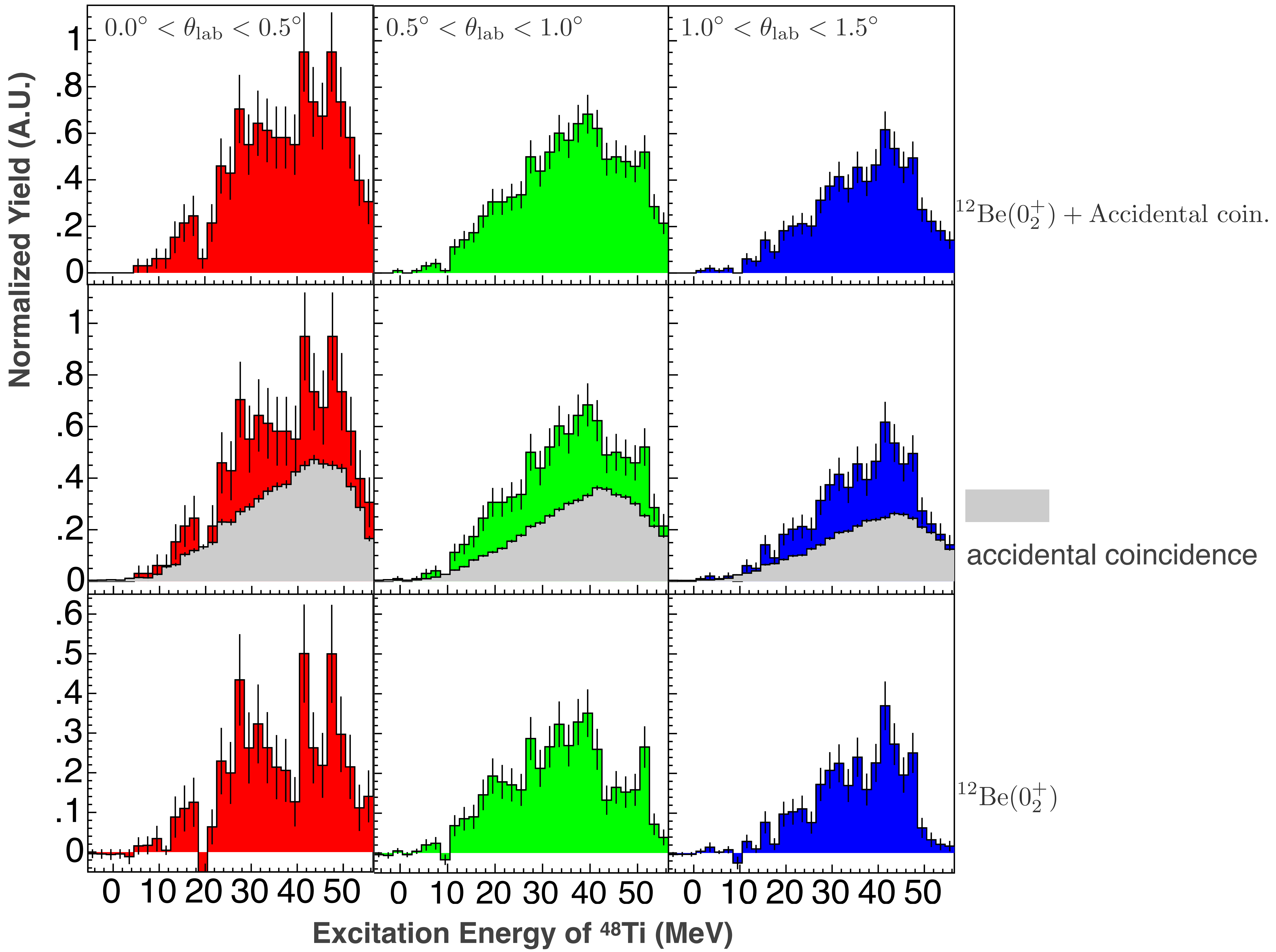
Identification of ^{12}Be(0^+_2) with γ-ray tagging



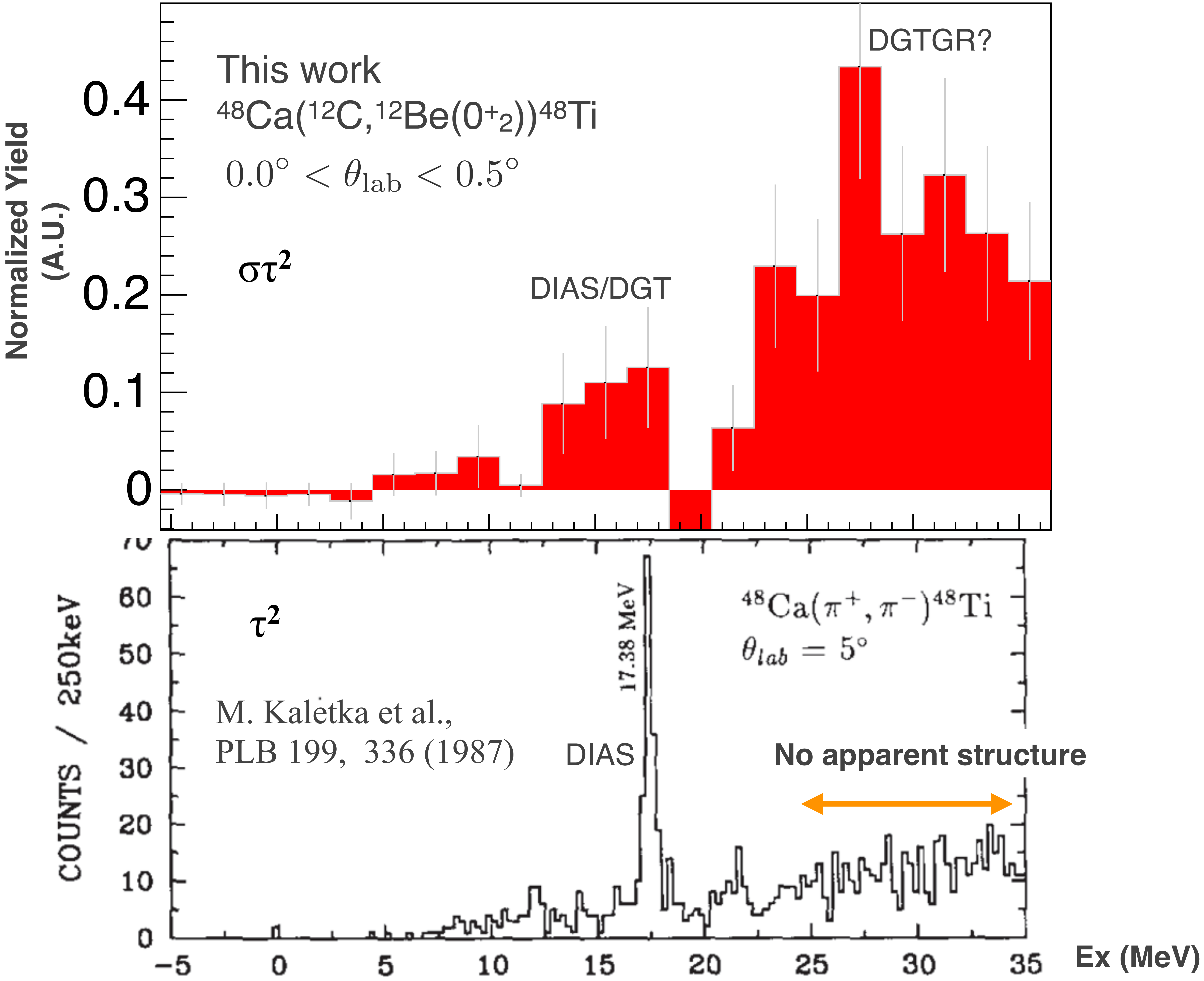




Preliminary Results: Excitation energy spectra



comparison with (π^+,π^-) spectrum



Summary

Double Gamow-Teller Resonances

will open the research opportunity on GTR×GTR correlation.

can serve as another test bench of nuclear models relevant to ββ-decay.

Experimental access has been limited.

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

We started with ^{48}Ca(^{12}C,$^{12}Be(0^+_2)$) reaction @ 100 MeV/nucleon.

We found strengths which not appear in $^{48}Ca(\pi^+,\pi^-)^{48}Ti$ reaction.

The analysis to confirm the DGT strength in ^{48}Ti is in progress.

In near future, we will achieve

higher statistics with a new experiment at RIBF.

to other ββ-decay nuclei (^{76}Ge, ^{100}Mo, ^{116}Cd, ^{130}Te …)

Collaborators

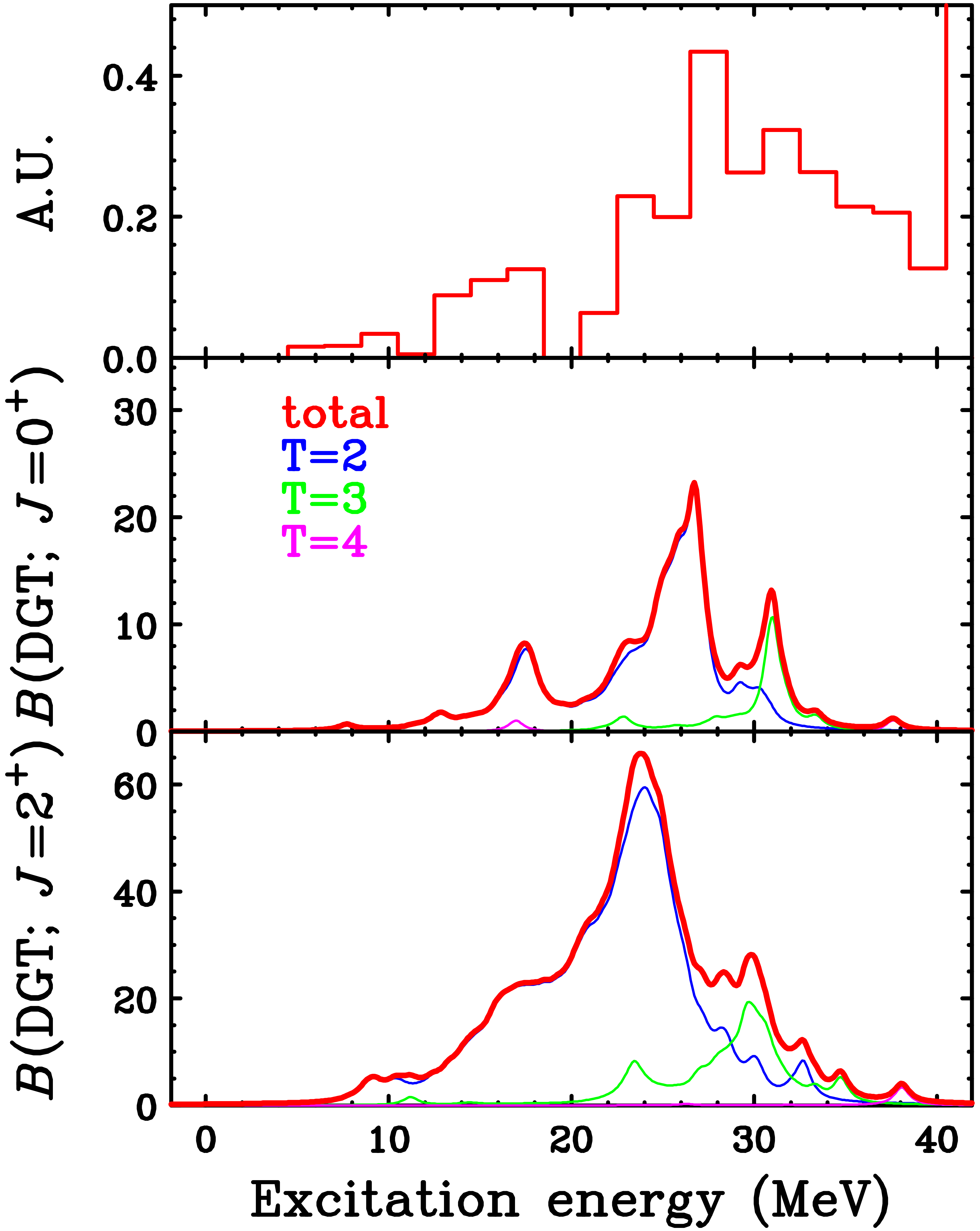
CNS, Tokyo	S. Shimoura, M. Dozono, M. Kobayashi, K. Yako, S. Michimasa, S. Ota, M. Matsushita, S. Kawase, H. Tokieda, Y. Kubota, C.S. Lee, R. Yokoyama, H. Matsubara
RIKEN Nishina Center	T. Uesaka, K. Kisamori, M. Sasano, L. Stuhl, J. Zenihiro
RCNP, Osaka	A. Tamii, C. Iwamoto, Y. Matsuda, N. Aoi
Kyoto	T. Kawabata, T. Furuno, M. Tsumura
Miyazaki	Y. Maeda, S. Gotanda, S. Yamamoto

Comparison with Shell mode calculation

Code: Oxbash

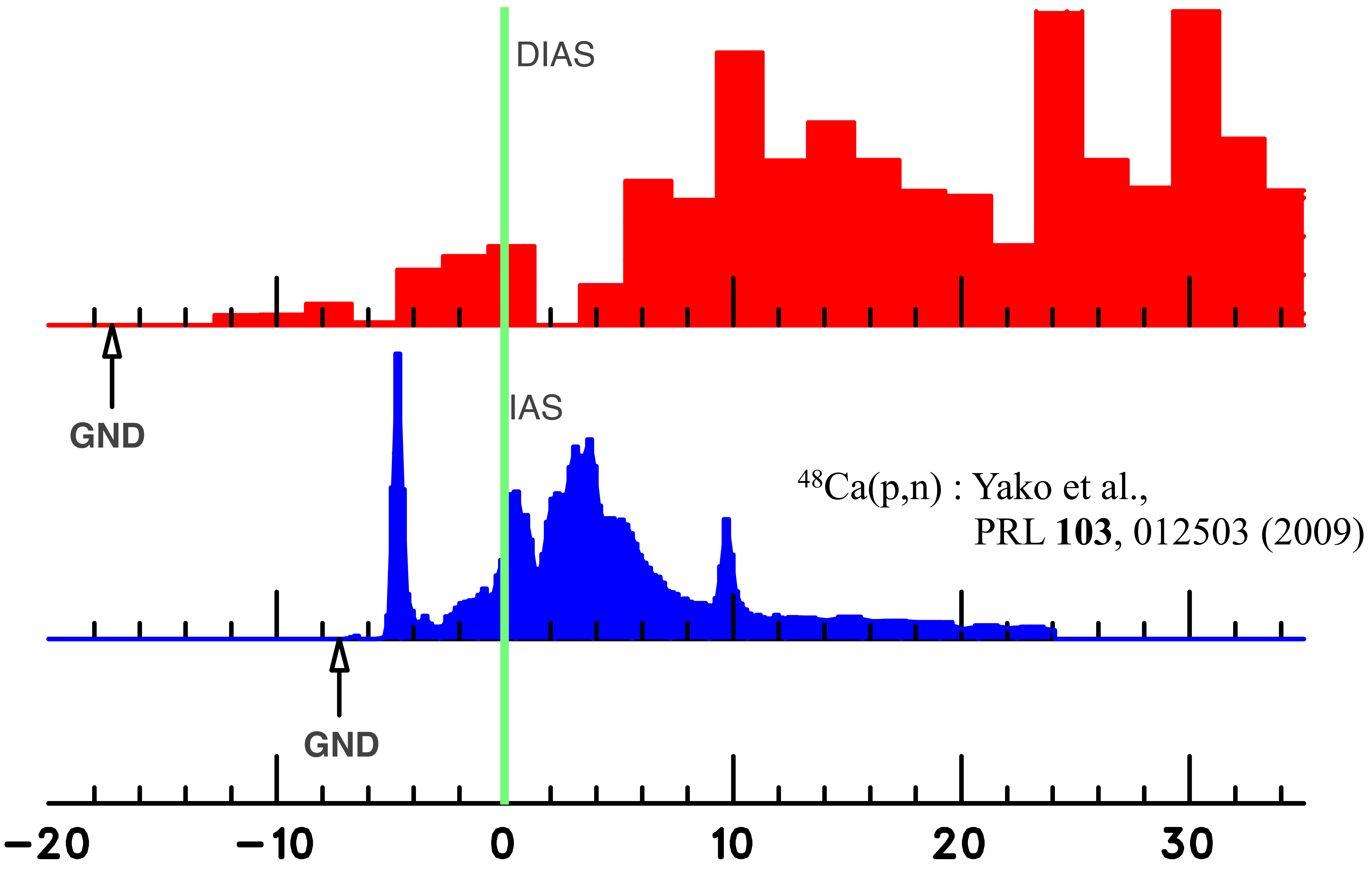
GXPF1a interaction

2n -> 2p (in f-shell)

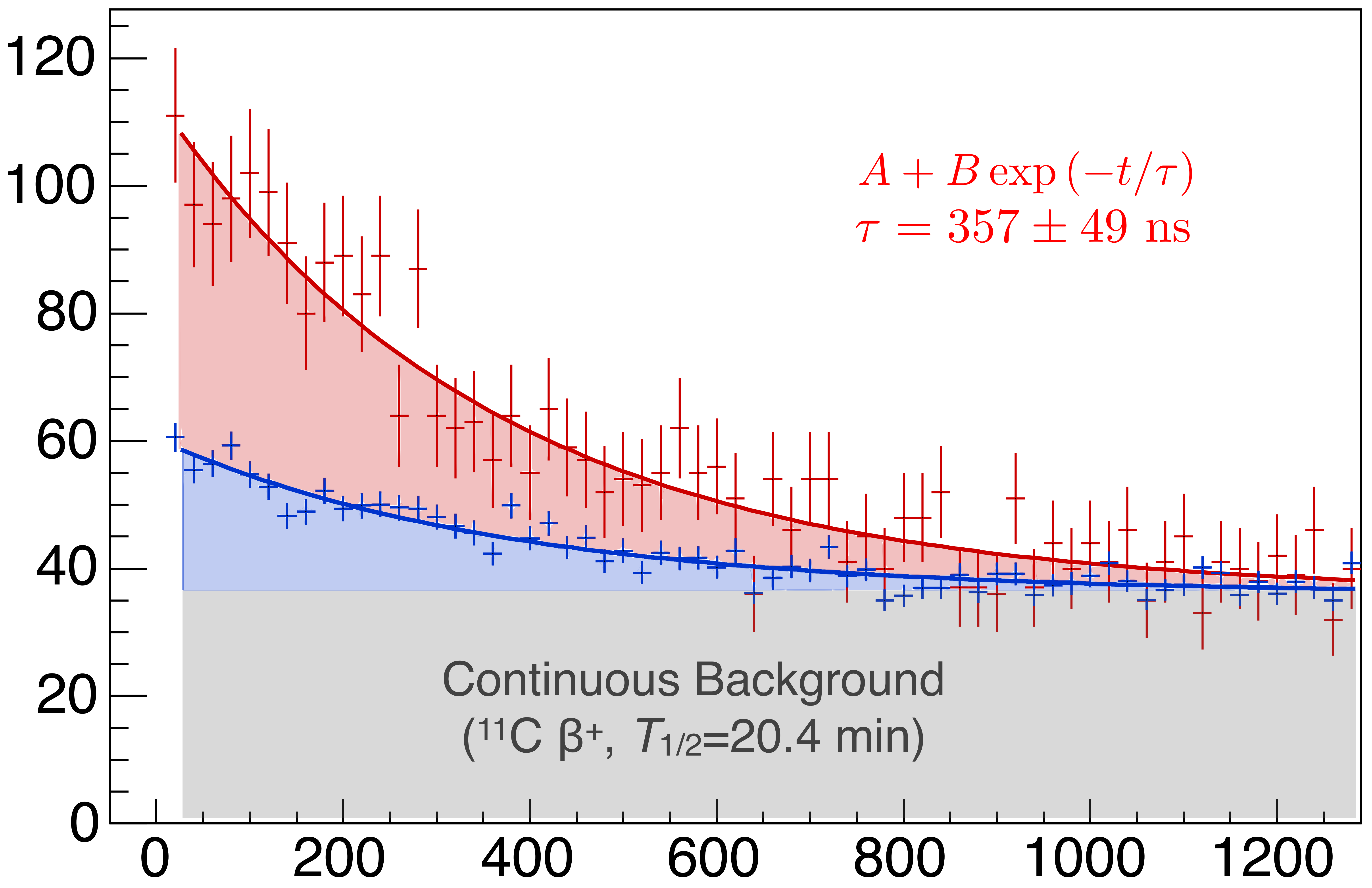


Calculation:
K. Yako, private communication

$(\sigma\tau)^2$ spectrum in ^{48}Ti



Accidental coincidence evaluation

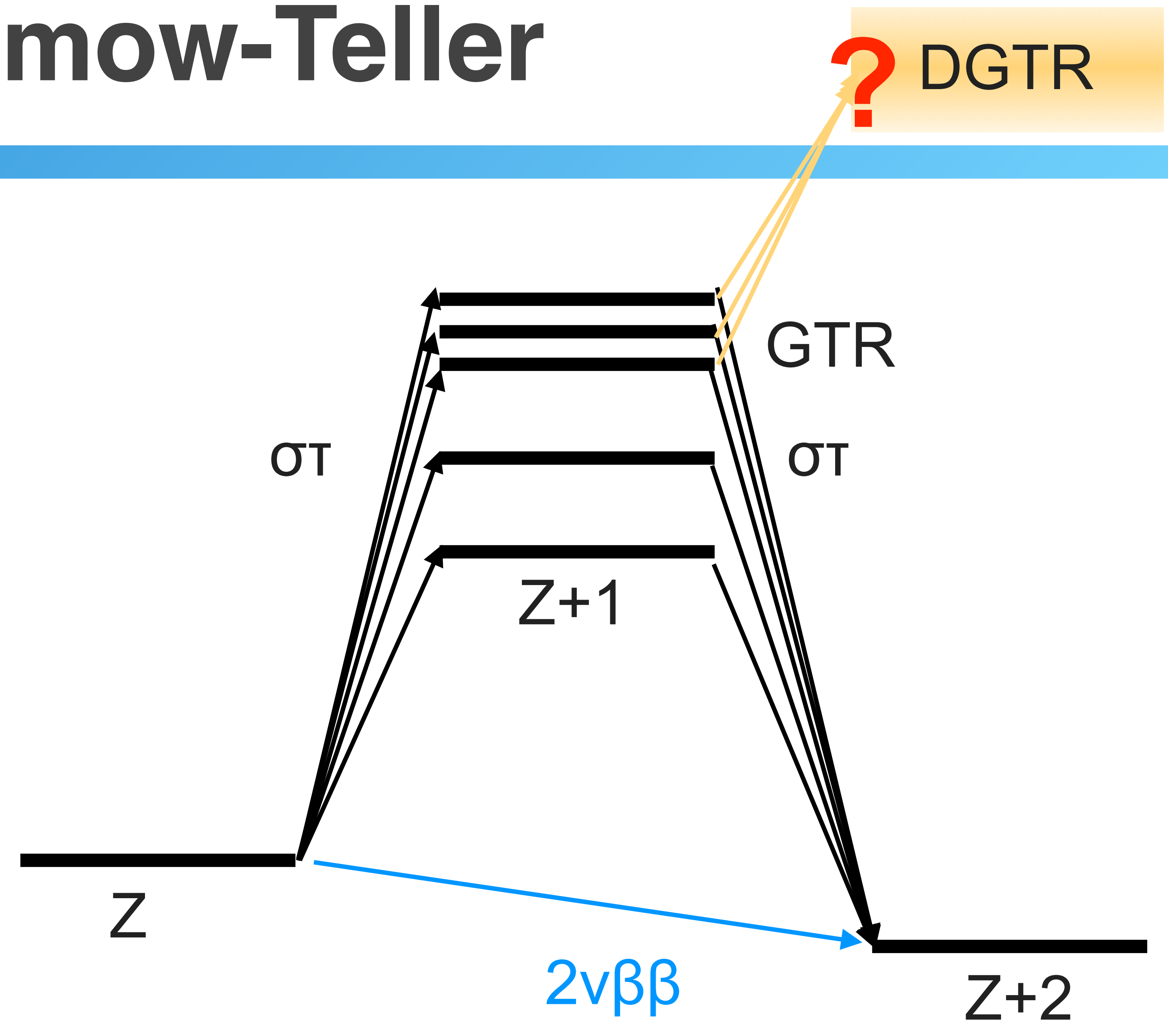


2νββ decays: One of the Double Gamow-Teller

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)



~ 10^{-4} - 10^{-3} S_{DGT}

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N. Auerbach, L. Zamick, and D. Zheng, Annals of Physics 192, 77 (1989).

Single charge exchange reaction on ^{48}Ca

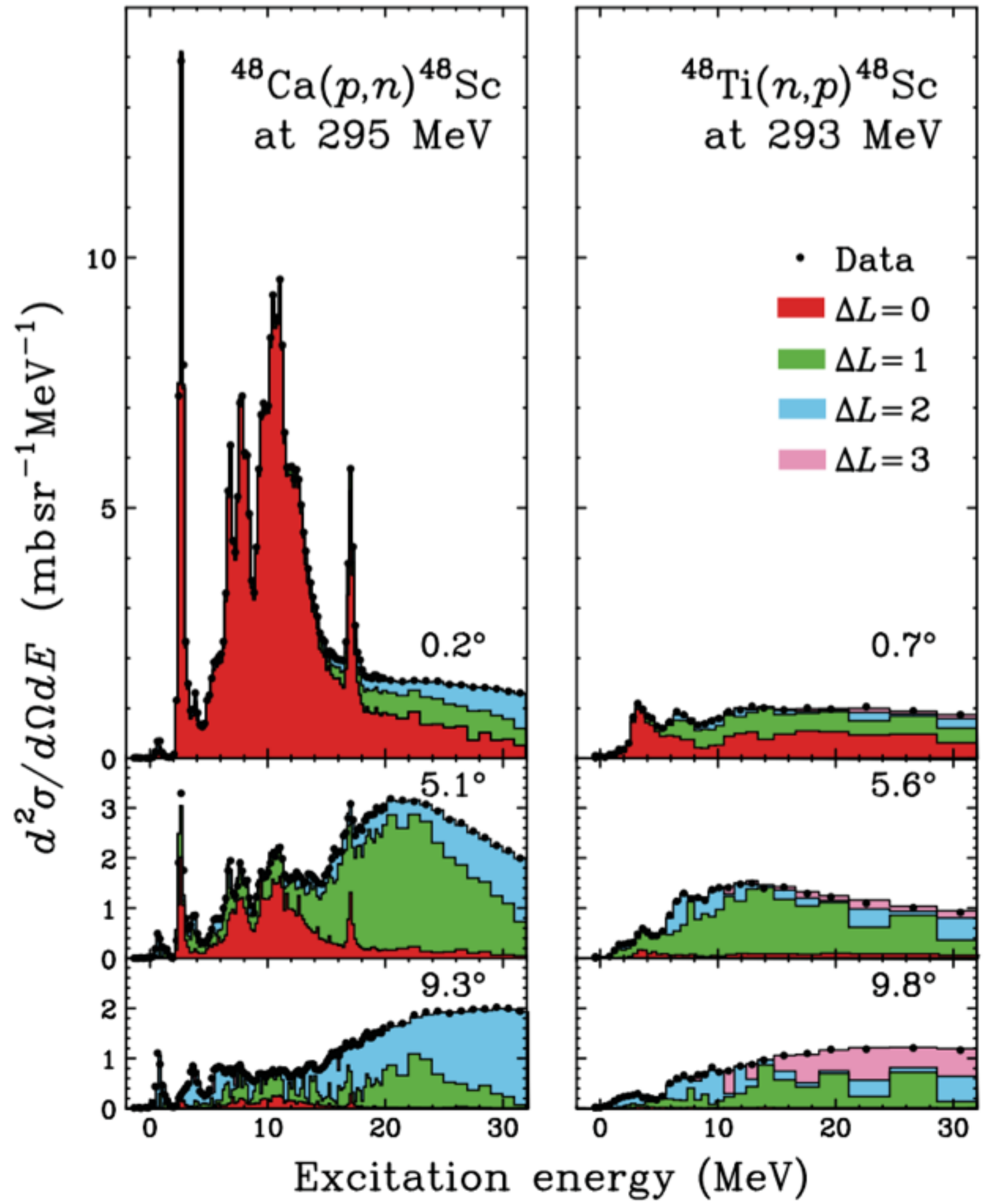


FIG. 1 (color). Double-differential cross sections for the ^{48}Ca$(p,n)^{48}$Sc (left-hand panel) and ^{48}Ti$(n,p)^{48}$Sc (right-hand panel) reactions. The histograms show the MD analysis results.

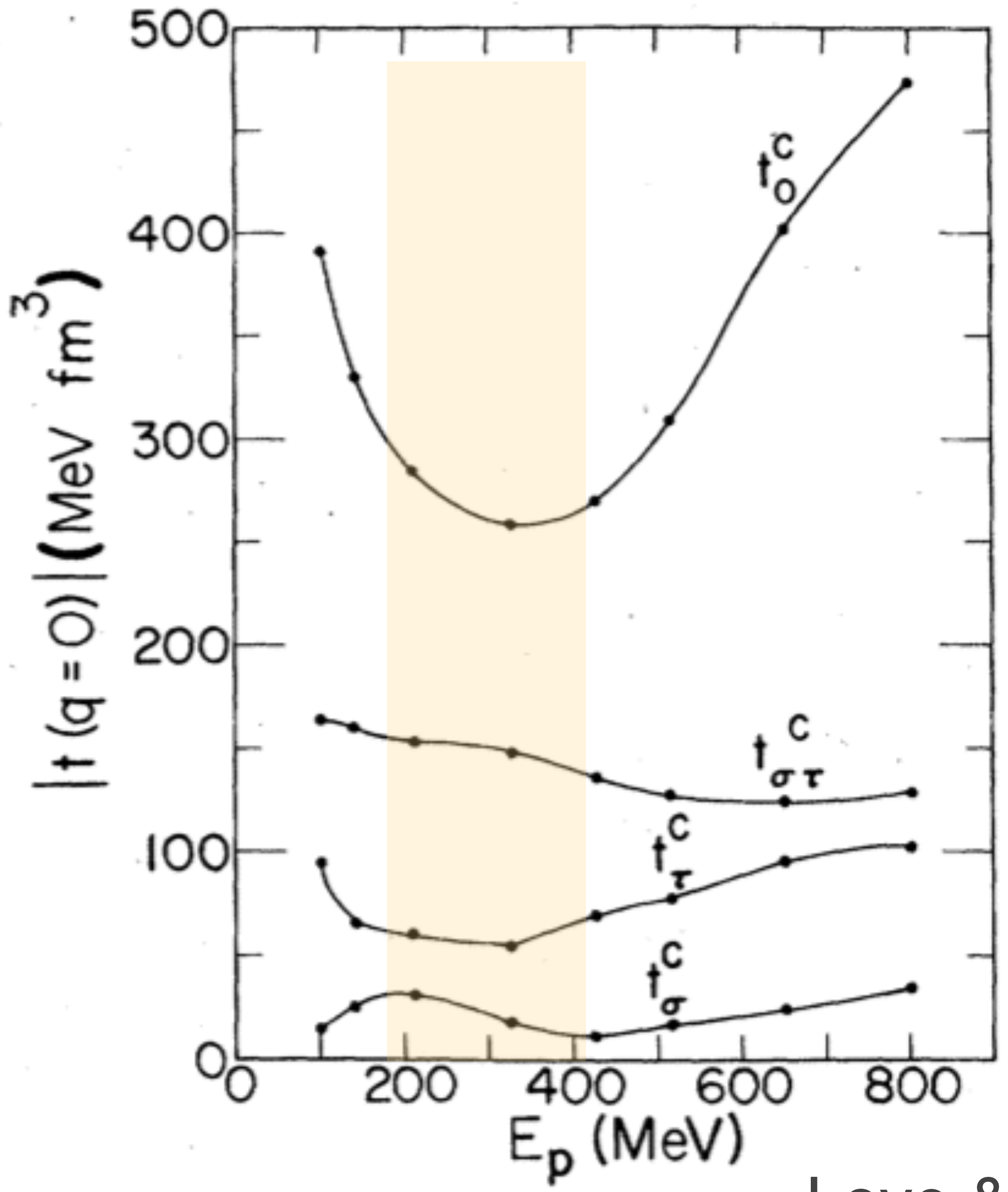
^{48}Ca(p,n) : Yako et al., PRL **103**, 012503 (2009)

Go beyond and more effective

Move to RIBF

- **200 - 300 MeV/u**
- **Higher intensity**
- **lower *q***

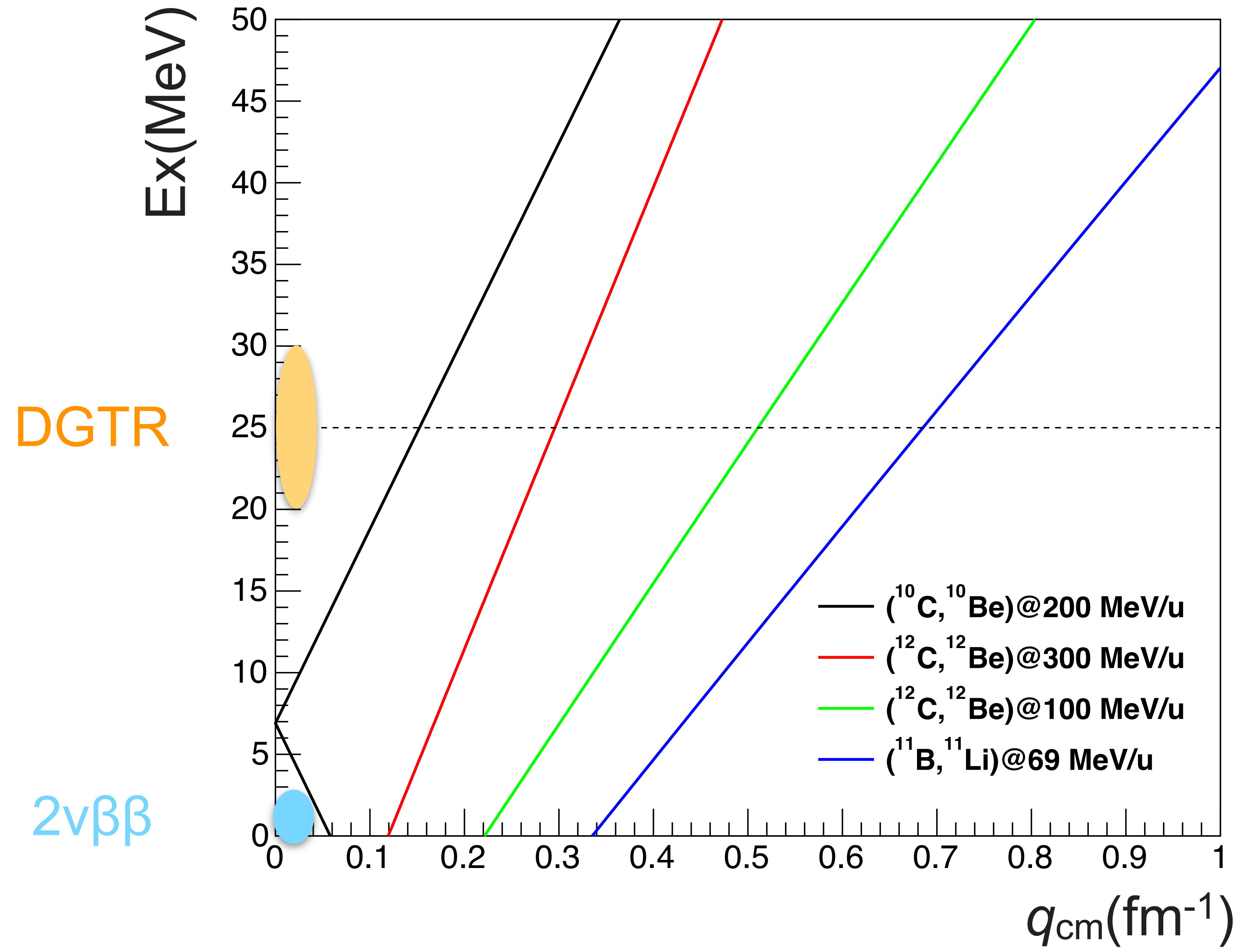
More Suitable for double Gamow-Teller excitation modes

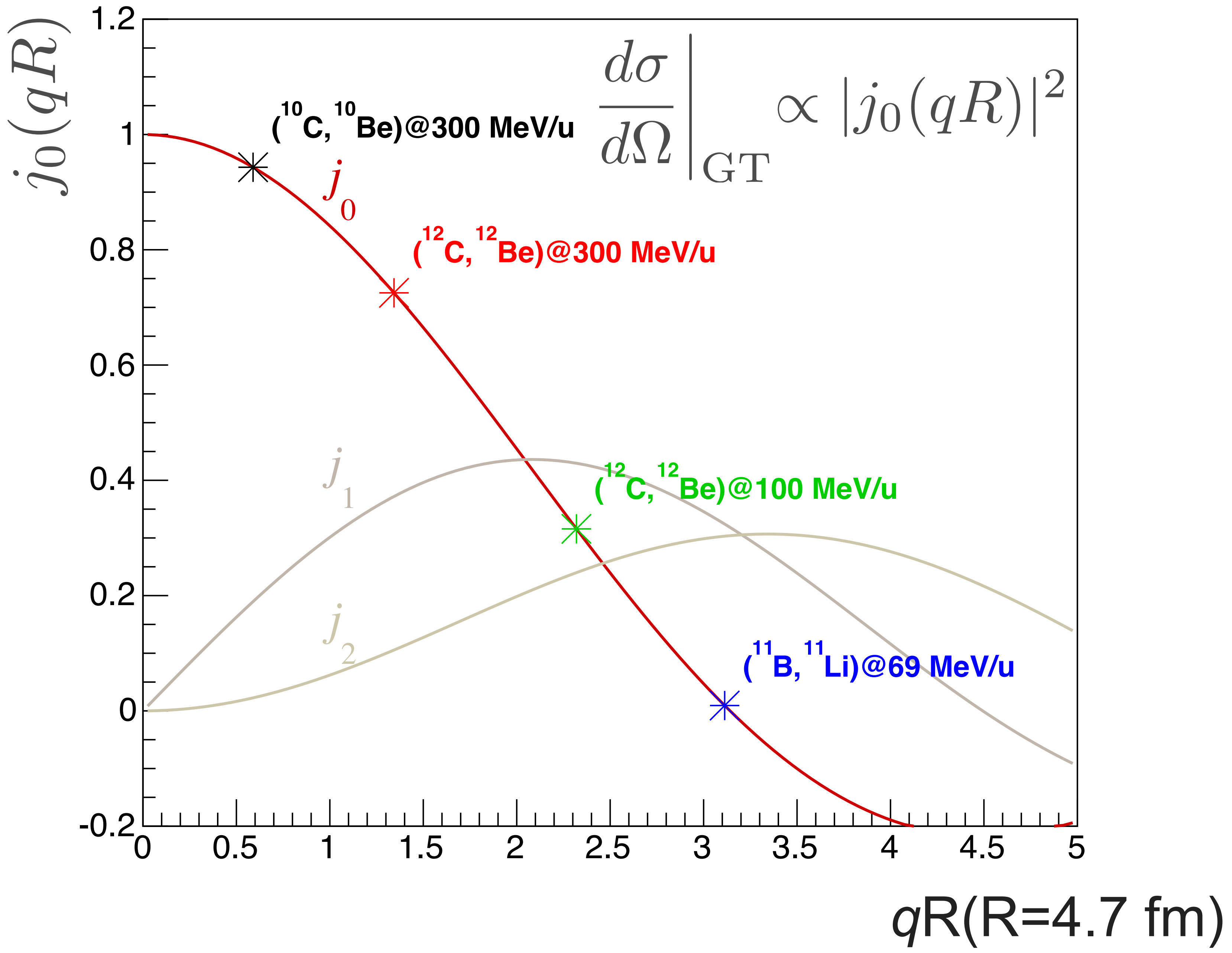


Love & Franey

Future plan:

- (^{12}C,^{12}Be(0^+_2)) w/ BigRIPS+DALI+MINOS
- (^{10}C,^{10}Be) w/ SHARAQ

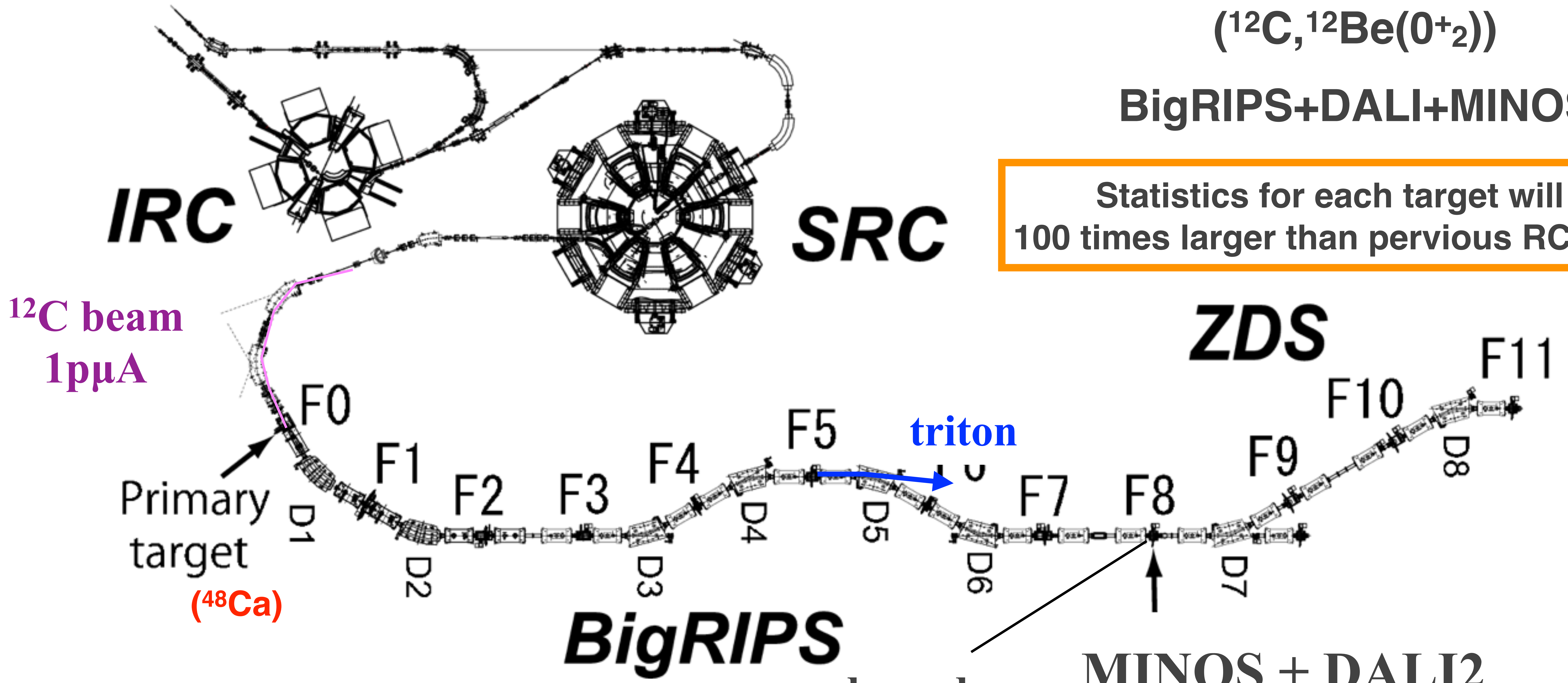




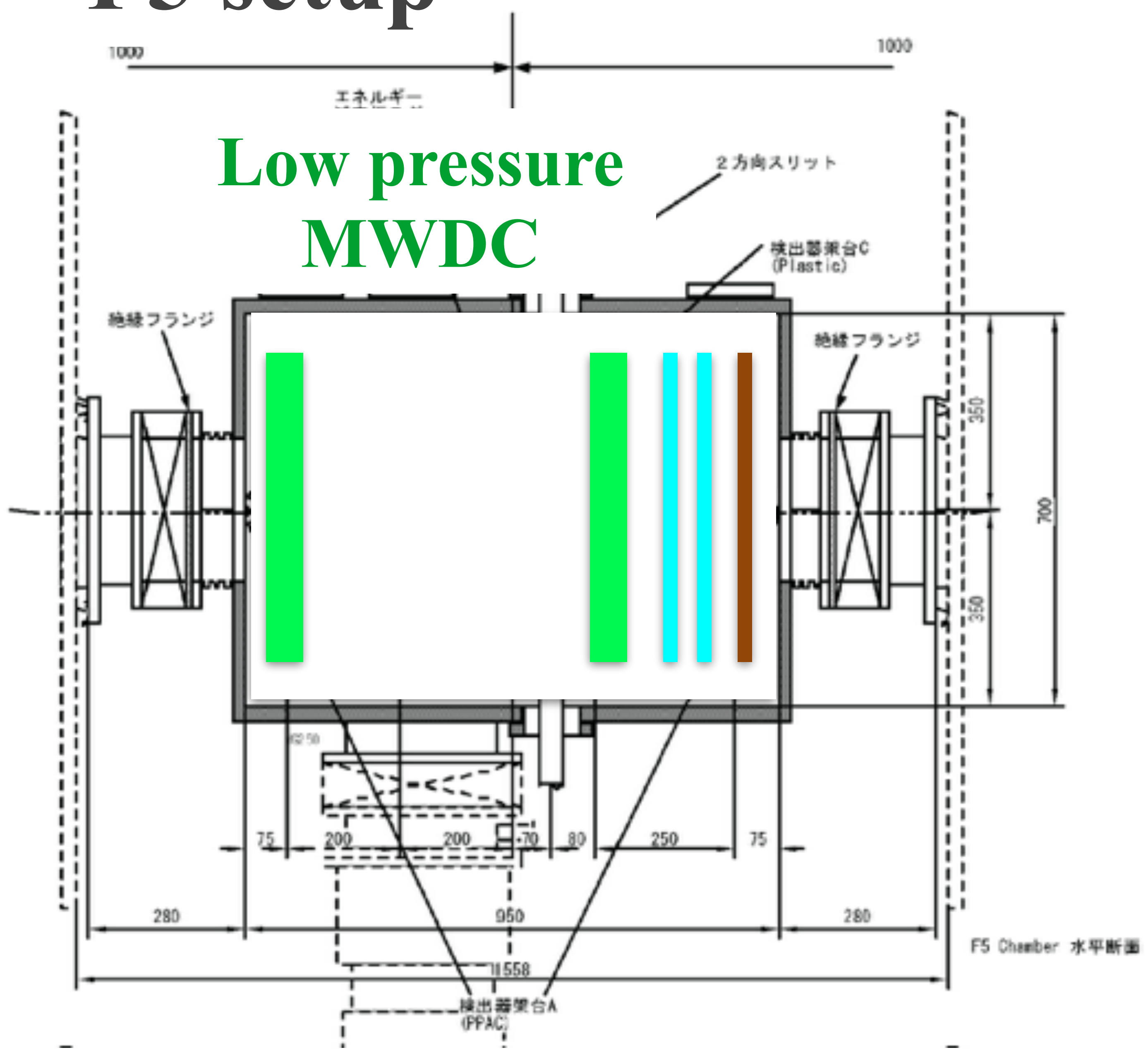
(^{12}C,^{12}Be(0^+_2))

BigRIPS+DALI+MINOS

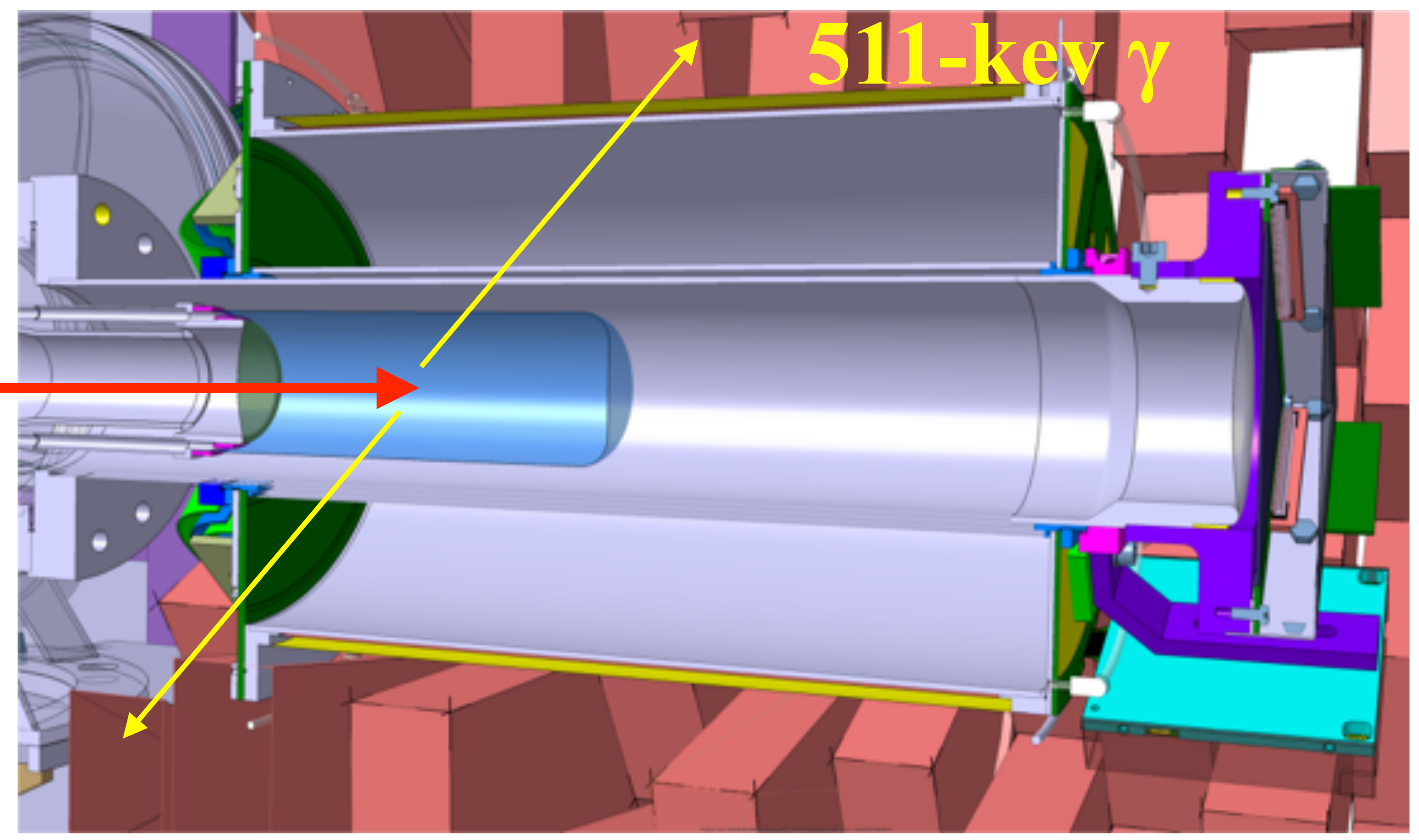
Statistics for each target will be 100 times larger than pervious RCNP exp.



F5 setup



MINOS + DALI2



stopping ^{12}Be and detecting delayed γ.