Challenges with Heavy-Ion Double Charge Exchange Reactions at RCNP and RIBF

Motonobu Takaki
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Contents

Double Charge eXchange reaction

Characteristics of DCX:

Isotensor Probe: $\Delta T_z = 2$ or $\Delta(N-Z) = 4$

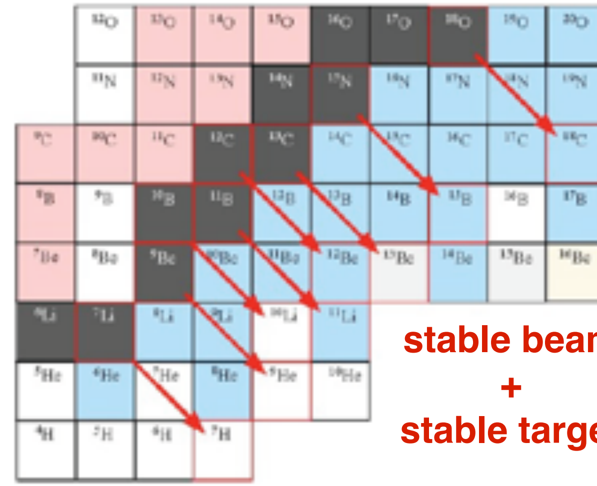
Pion double charge exchange reaction

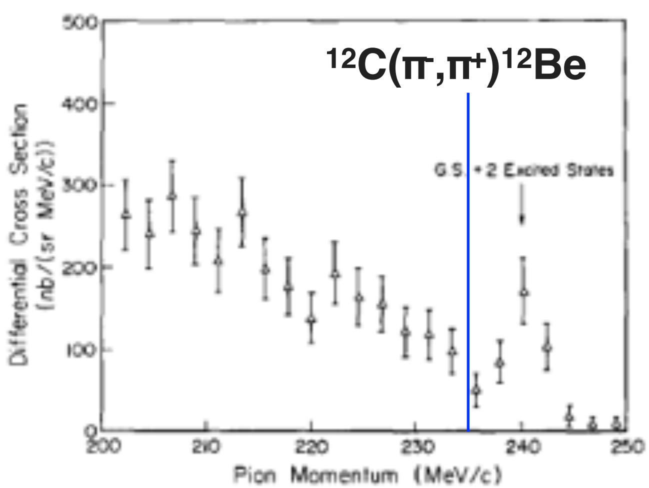
simple

Heavy-ion double charge exchange reaction @ low-energy

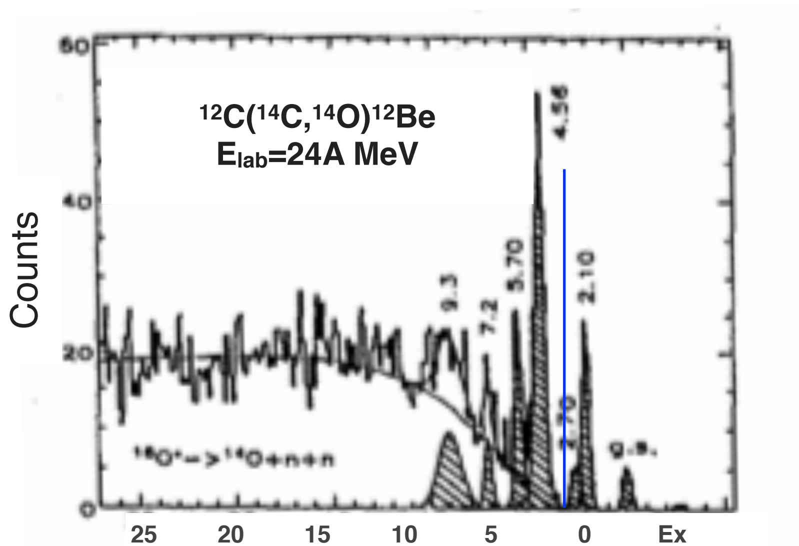
intense beam

high resolution spectroscopy





J.E. Ungar *et al.*, PLB, **144** 333 (1984)



W. Oertzen *et al.*,
NPA, **588** 129c (1995)

Double Giant Resonances via DCX

$\Delta Tz = 2$ is easily identified!

Isotensor transition can be identified!

Pion double charge exchange reaction

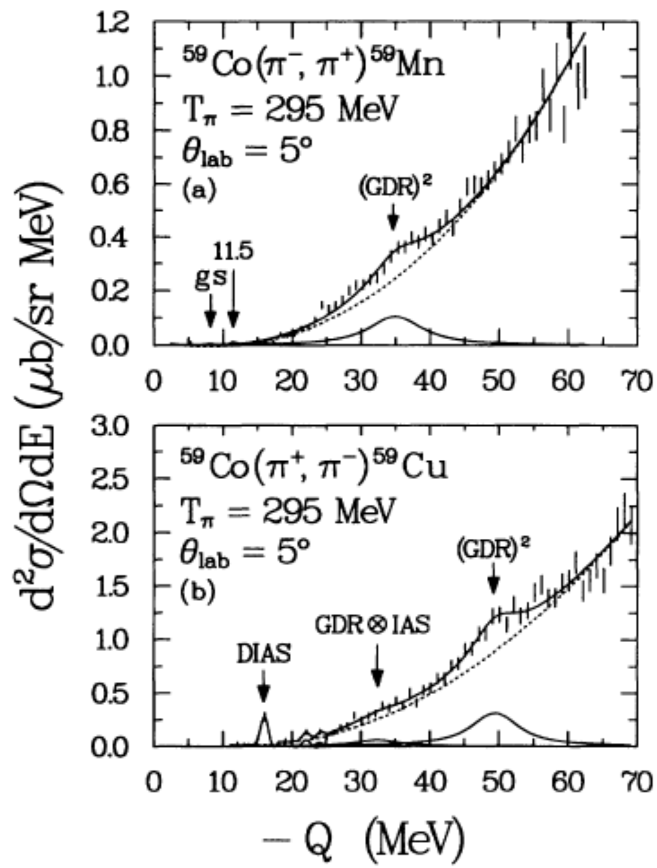
DIAS, DGDR,…

pion: spin zero

How can we access spin excitations?

Heavy-Ion Double Charge eXchange (HIDCX) reaction

($\Delta Tz = 2$) + **($\Delta S = 0$ or 2)**

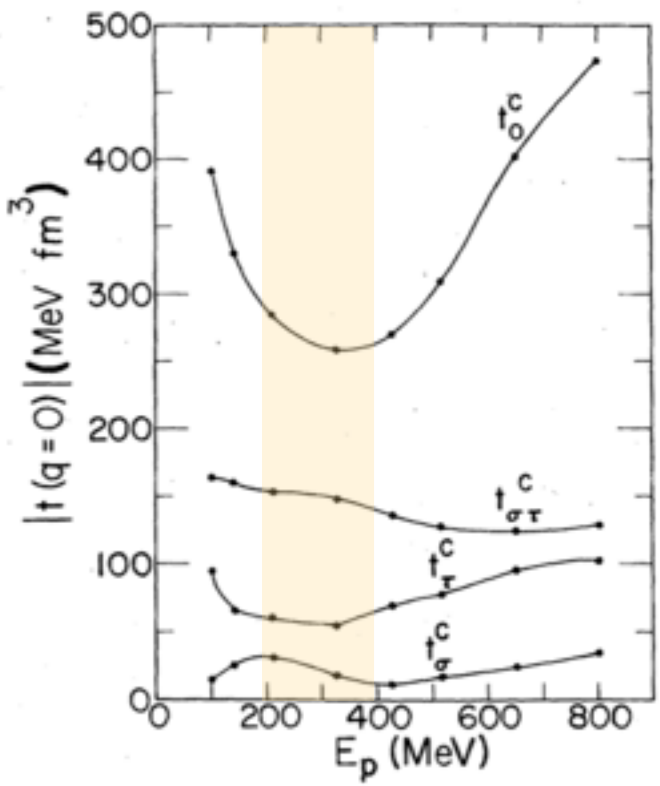


S. Mordechai et al., PRL 60, 408 (1988).

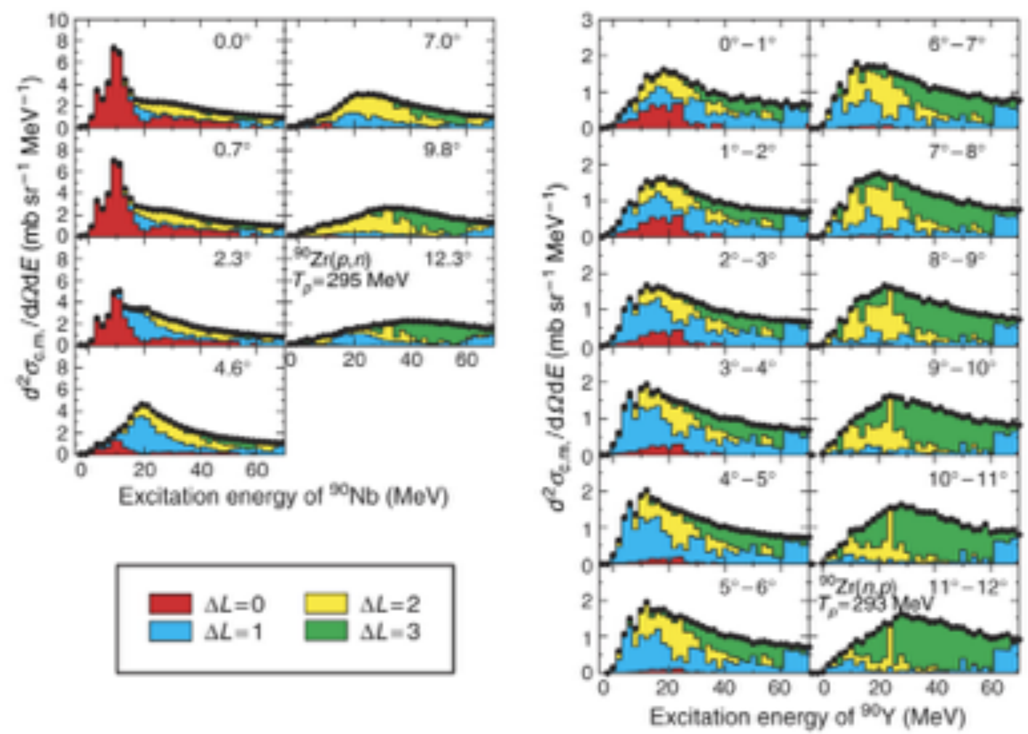
HIDCX @ intermediate energy

Expectation:

- **Simple reaction mechanism**
- **Concrete bases on knowledge of single charge exchange**



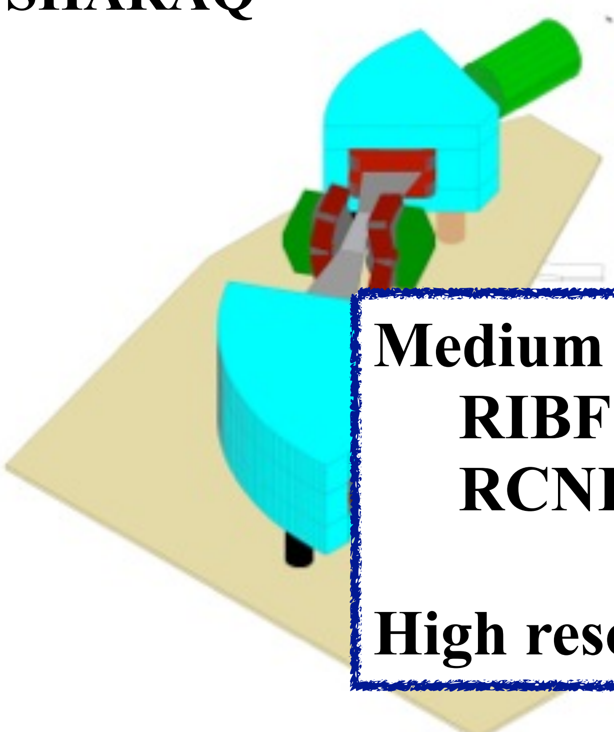
(p,n), (n,p), (d,^{2}He), (^{3}He,t)…



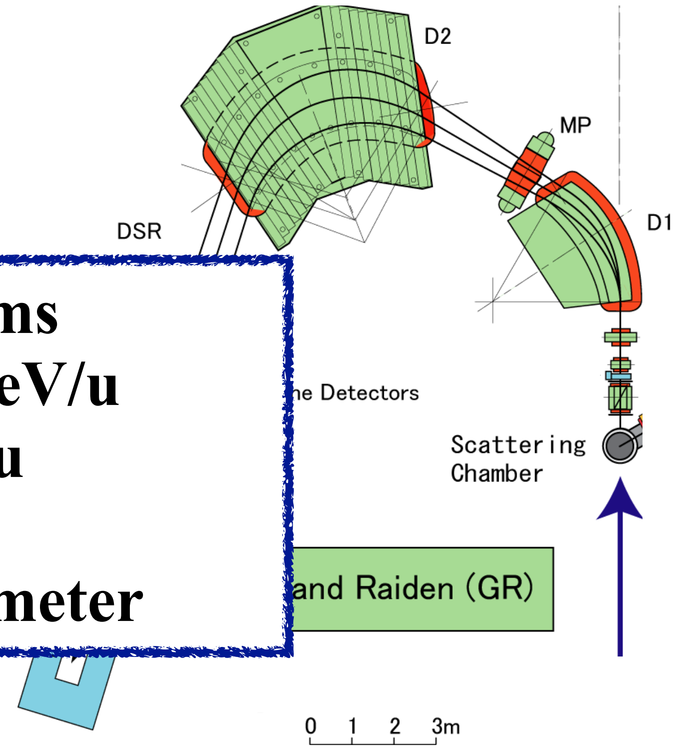
Wakasa, Yako, Sakai et al.

HICX Studies at SHARAQ & Grand Raiden

SHARAQ



Grand Raiden

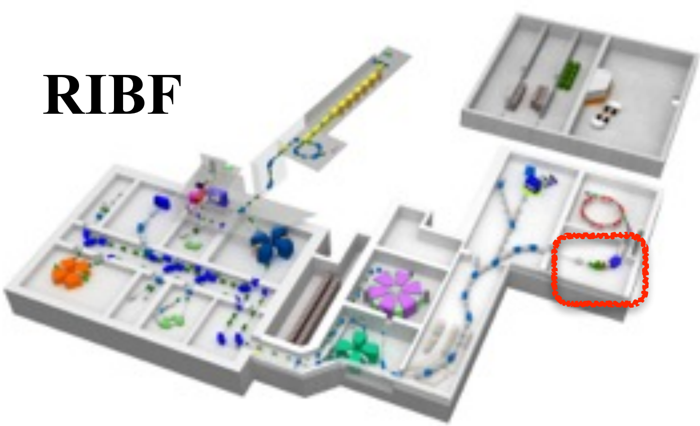


Medium energy HI beams

RIBF	**200–300 MeV/u**
RCNP	**<100 MeV/u**

High resolution spectrometer

RIBF



RCNP

Contents

Introduction:

What is the double charge exchange(DCX) reaction?

Why we use heavy-ion DCX reaction at intermediate energy.

Physics cases:

Our starting point: Study of ^{12}Be via $^{12}C(^{18}O,^{18}Ne)$ @ 80 MeV/u

Production of “Element 0” by employing exothermic DCX

Search for a DGTGR on the ββ-decay nuclei

Plan of Future Experiments to realize:

higher statistics and better S/N

better momentum matching

Summary

What can we do w/ HIDCX?

"Heavy-Ion"
Double Charge Exchange reactions

Δ(N-Z) = 4!

ΔS=0,2 & ΔTz=2!

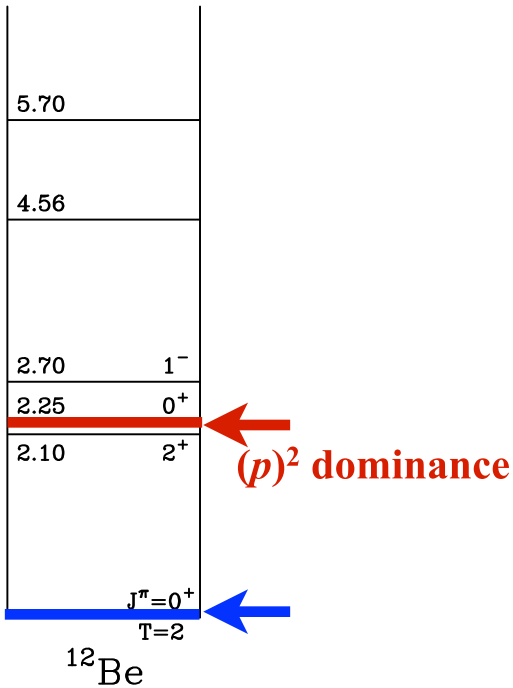
Production and Investigation
Neutron- / Proton-rich isotopes

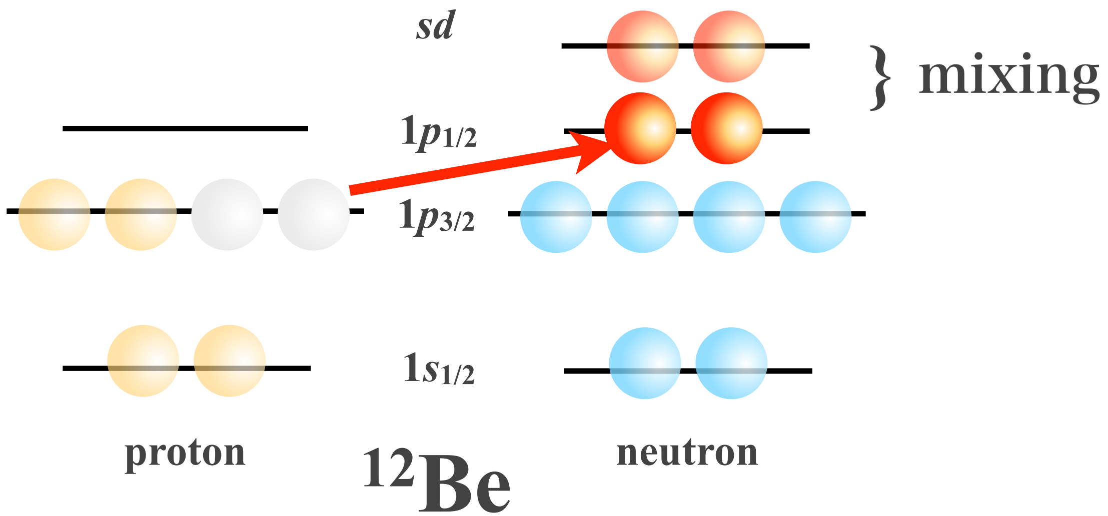
New Aspect of Spin-Isospin physics?
Double Gamow-Teller …
Multi-phonon ex. w/ spin d.o.f.

MT, Uesaka, Matsubara

Symbolic Nucleus ^{12}Be: disappearance of N=8 magic number

Mixing degree between *p*- and *sd*-shell components in 0^+ states of ^{12}Be





The cross section for the two 0^+ states at forward angle

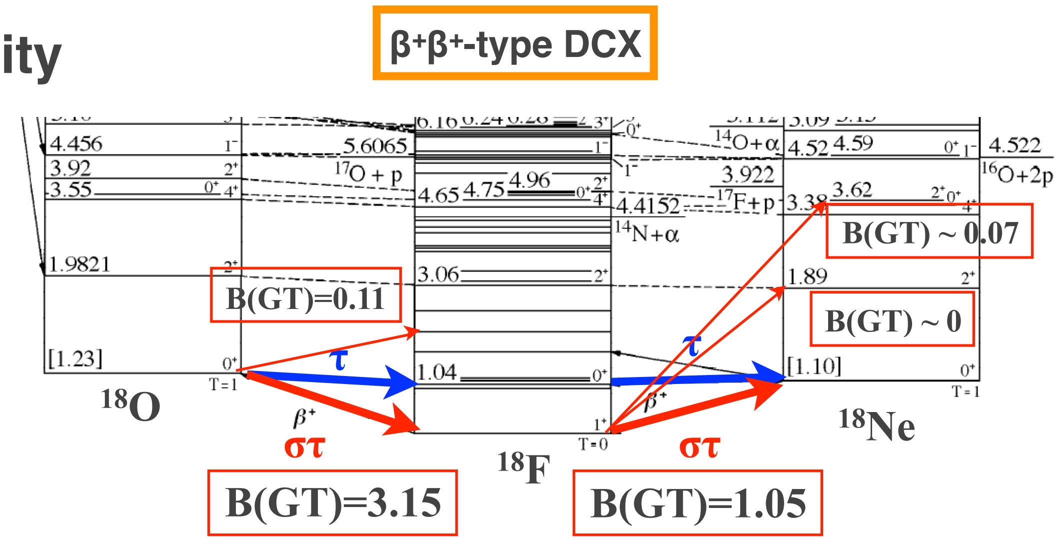
- dominated by double Gamow-Teller transition(ΔL=0, ΔS=0 or 2, ΔT=2).
- mainly reflect **the *p*-shell contribution**.

^{12}C(^{18}O,^{18}Ne)^{12}Be reaction experiment @ 80 AMeV was performed

(^{18}O,^{18}Ne) reaction

Ground states of ^{18}O and ^{18}Ne are among the **same super-multiplet**:

- simple transition process
- **large transition probability**
  - **B(GT^2) ~ 3.5**



A primary ^{18}O beam is employed

- **high intensity (> 10 pnA)**

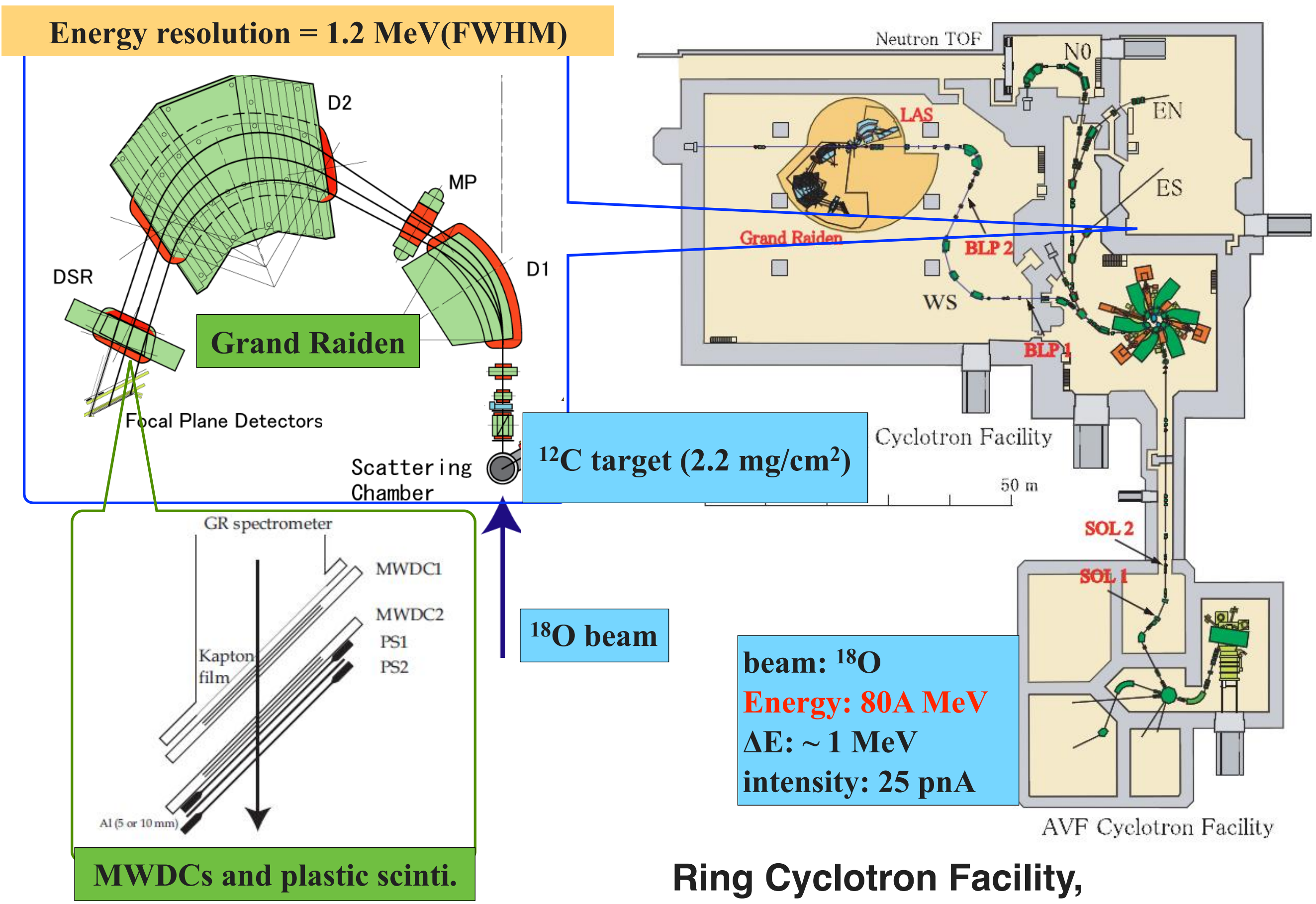
Experiment can be performed at RCNP with GR spectrometer

- high quality data with high energy resolution

Our 1st HIDCX exp. @ RCNP

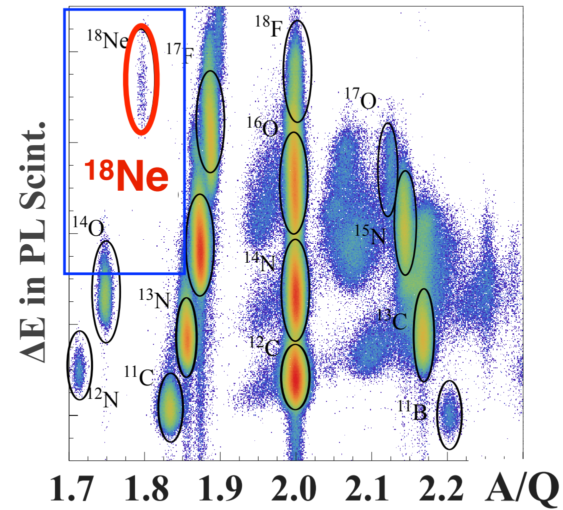
$^{12}C(^{18}O,^{18}Ne)^{12}Be$ @ 80 MeV/u

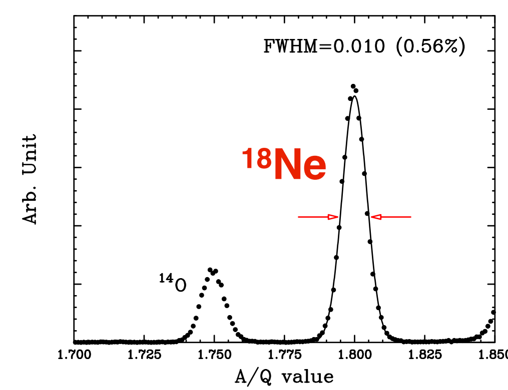
To study the low-lying states of ^{12}Be



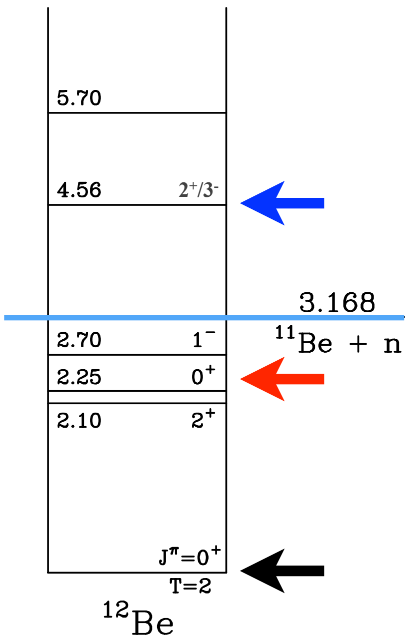
Ring Cyclotron Facility, Research Center for Nuclear Physics, Osaka University

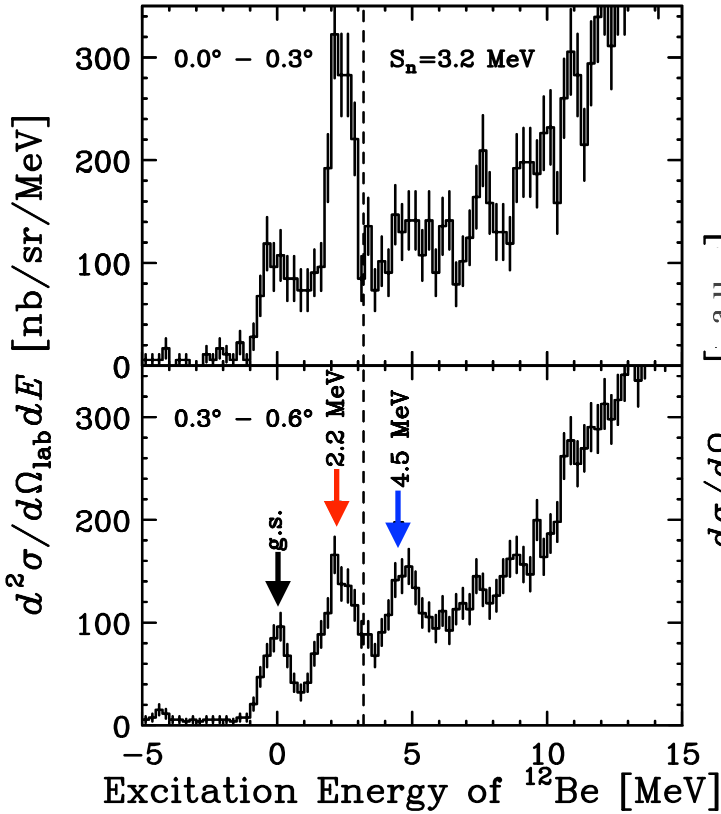
Good PID resolution

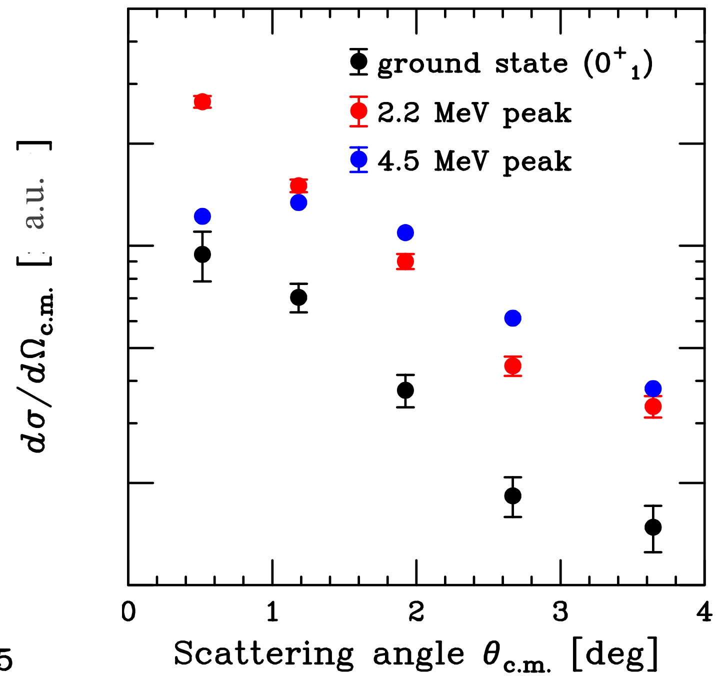




Our 1st result of HIDCX @ RCNP







- **The 2.2 MeV peak has a larger cross section than the g.s.**
- **Different angular distribution of the 4.5 MeV peak.**

What can we do w/ HIDCX?

"Heavy-Ion" Double Charge Exchange reactions

Δ(N-Z) = 4!

ΔS=0,2 & ΔTz=2!

Production and Investigation
Neutron- / Proton-rich isotopes

New Aspect of Spin-Isospin physics?
Double Gamow-Teller …
Multi-phonon ex. w/ spin d.o.f.

Beyond the Drip Line!

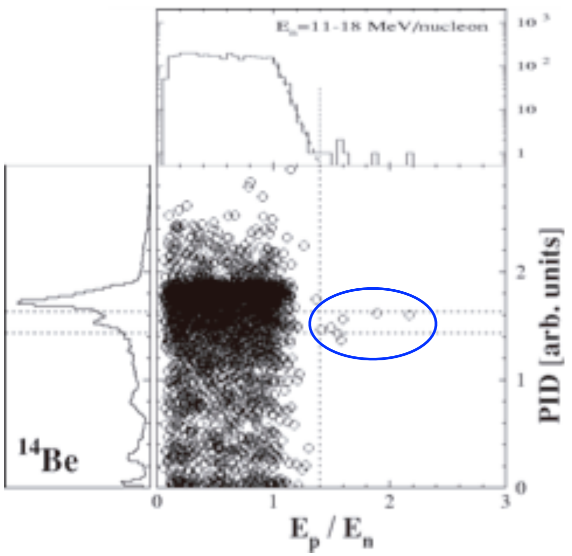
Production and Investigation "Element 0"

Kisamori (RIKEN) & Shimoura (CNS)

Tetra-neutron system

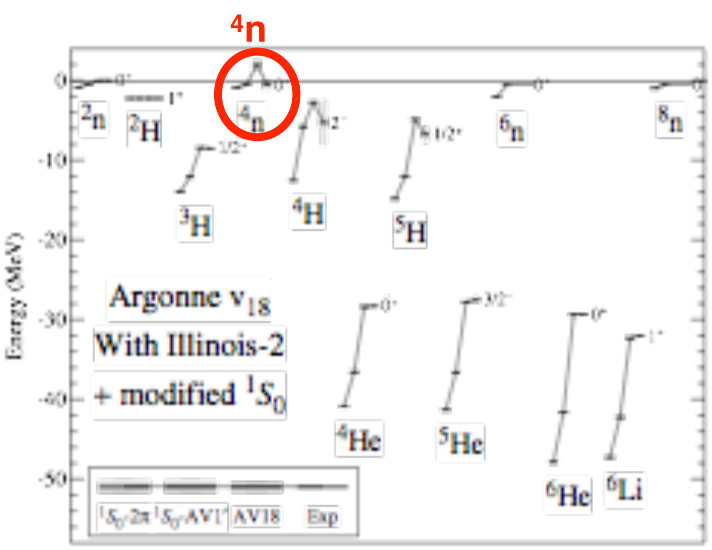
Pure neutron system
information on multi-neutron forces

Fission of Uranium
J.P. Shiffer Phys. Lett. 5, 4, 292 (1963).
$^4He(\pi^-,\pi^+)$ reaction
J.E. Unger, et al., Phys. Lett. B 144, 333 (1984).



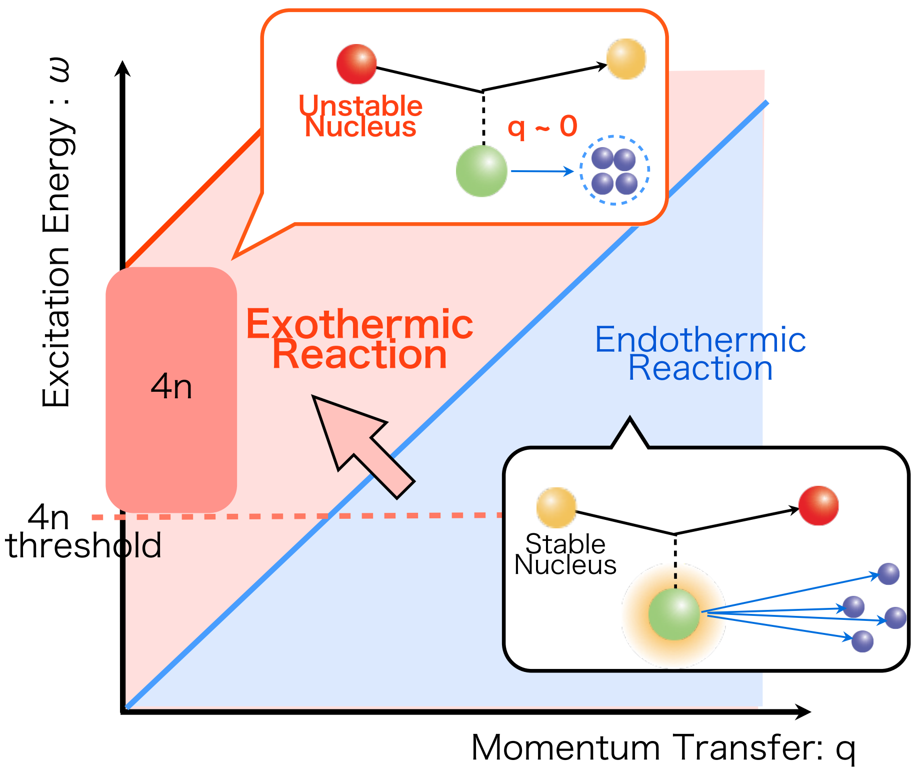
Candidates of bound tetra-neutron in breakup of ^{14}Be
F.M. Marques, et al., PRC 65, 044006 (2002)

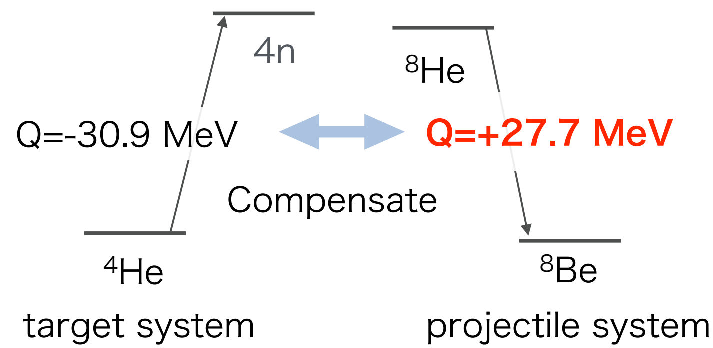
Theoretical work
ab-initio type calculation (NN, NNN interaction)
S.C. Piper, PRL 90, 252501 (2003)
Possible existence of resonance state ~2 MeV



New approach: Exothermic DCX

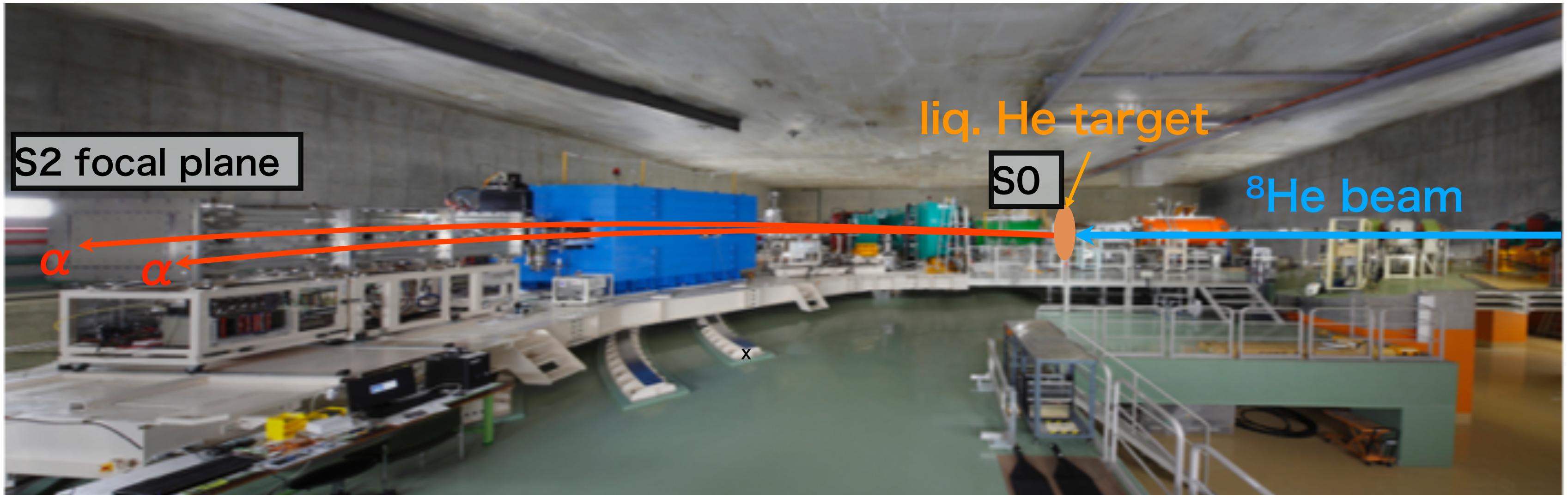
- Double-charge exchange (DCX) reaction $^{4}He(^{8}He,^{8}Be)4n$
  - Exothermic reaction
    → 4n system with **small momentum transfer.**
    (almost recoil less condition)





This reaction has an sensitivity at low excitation energy region of 4n system.

Experiment with SHARAQ spectrometer



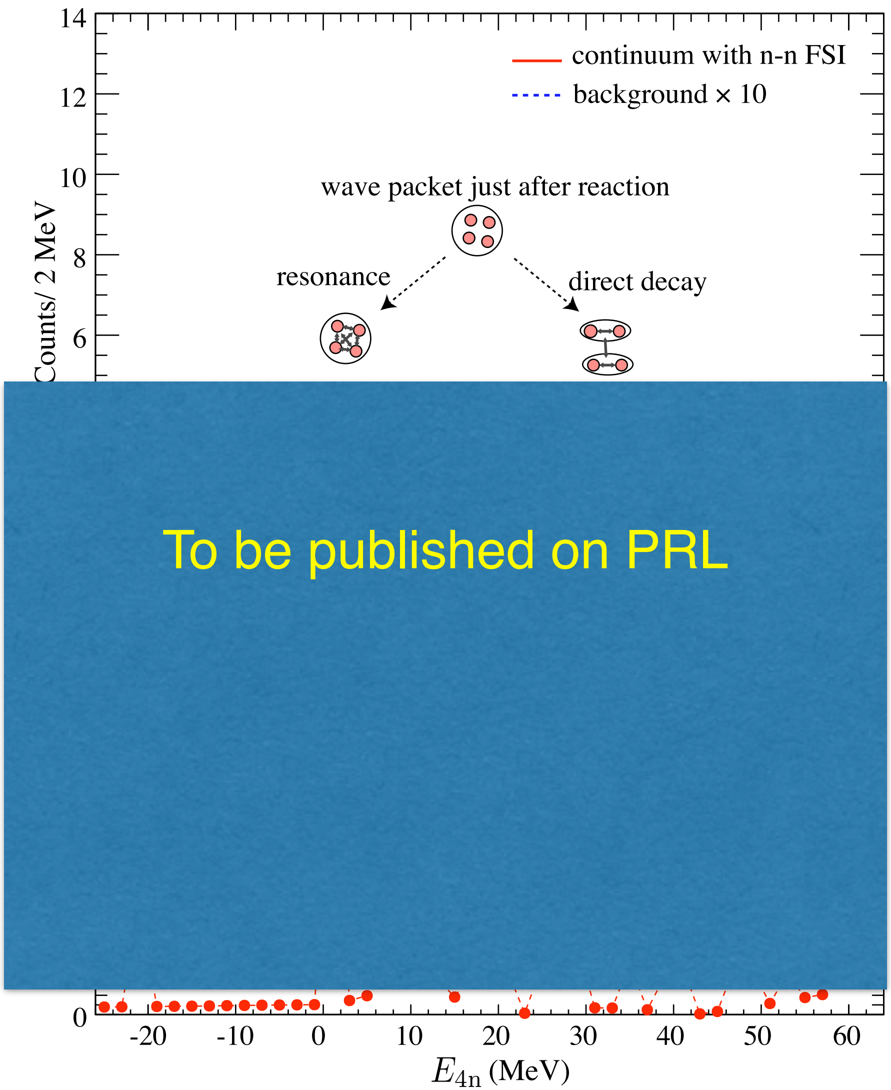
- Ion optical transport: Large Momentum Acceptance mode

	LMA mode	standard
Momentum resolution	1/10000	1/14700
Angular acceptance		
- vertical	± 1.5 deg	± 1.7 deg
- horizontal	± 2.9 deg	± 3.0 deg
Solid angle	4.3 msr	4.8 msr
Momentum acceptance	±1.8 %	±1 %

Center for Nuclear Study

ICHOR

Results: Possible Existence of Resonance state



Energy resolution: 1.2 MeV
Uncertainty of calibration: ±1.3 MeV
Background: 0.02 events/2 MeV

Candidate of Resonance state
4.9σ significance revel
E_{4n} = 0.83 ± 0.65 (stat.) ± 1.25 (syst.) MeV
upper limit of Γ = 2.6 MeV (FWHM)
cross section : 3.8 nb
(int. up to θ_{CM} < 5.4 degree)

Submitted to PRL
Accepted!

Courtesy of Dr. K. Kisamori (RIKEN)

What can we do w/ HIDCX?

"Heavy-Ion"
Double Charge Exchange reactions

Δ(N-Z) = 4!

ΔS=0,2 & ΔTz=2!

Production and Investigation
of
Neutron- / Proton-rich isotopes

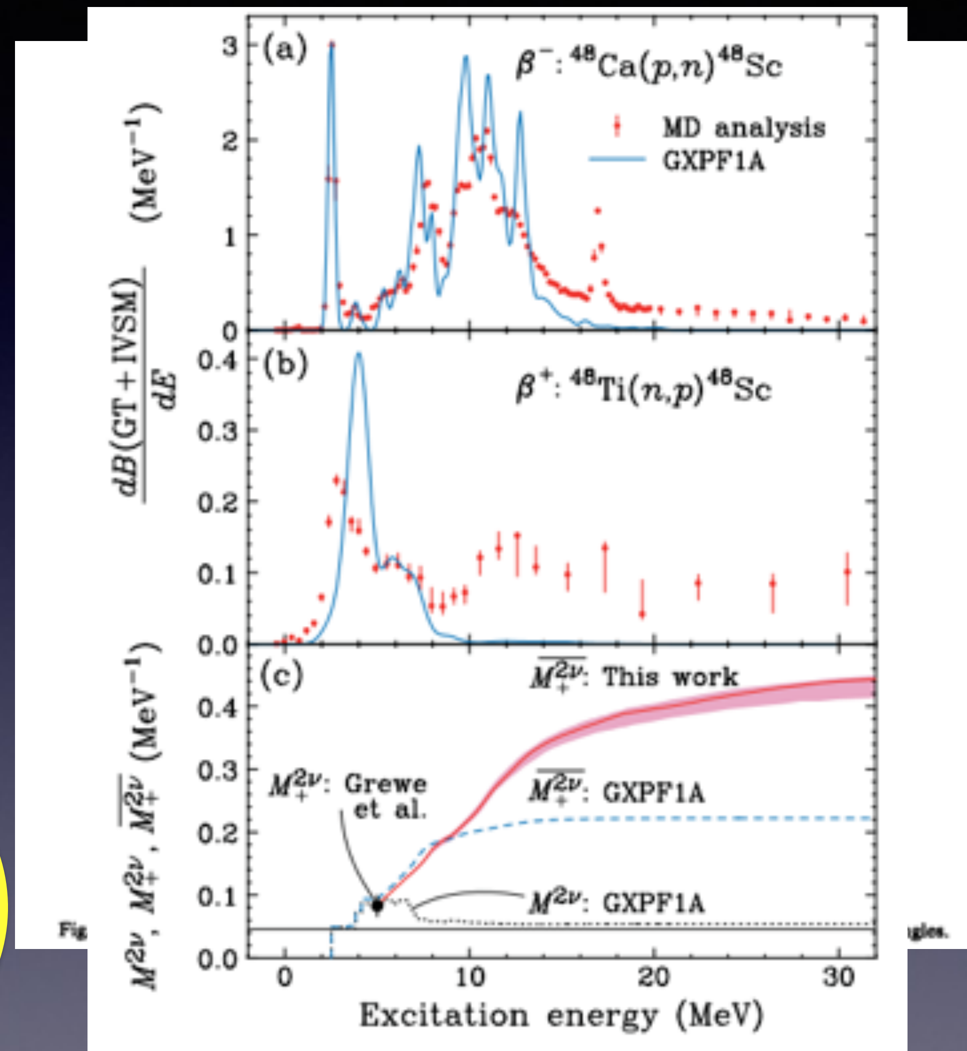
- New Aspect of
  Spin-Isospin physics?
- Double Gamow-Teller …
- Multi-phonon ex. w/ spin
  d.o.f.

Excellent works with single charge exchange

β-decay

CX probe
Observation of GTGR

- Tensor correlation in g.s.
- GT strength distributions
- Nuclear weak response
  relevance to Astro physics
  and so on…



E.-W. Grewe et al. (2007)
K. Yako et al. (2009)

Motivation: Extend the GT studies

β-decay

CX probe
Observation of GTGR

- Tensor correlation in g.s.
- GT strength distributions
- Nuclear weak response
  relevance to Astro physics
  and so on…

Motivation: The DGT studies

ββ-decay

$B(GT^2) \sim 0.01$
↓
$B(GT^2) > 100$

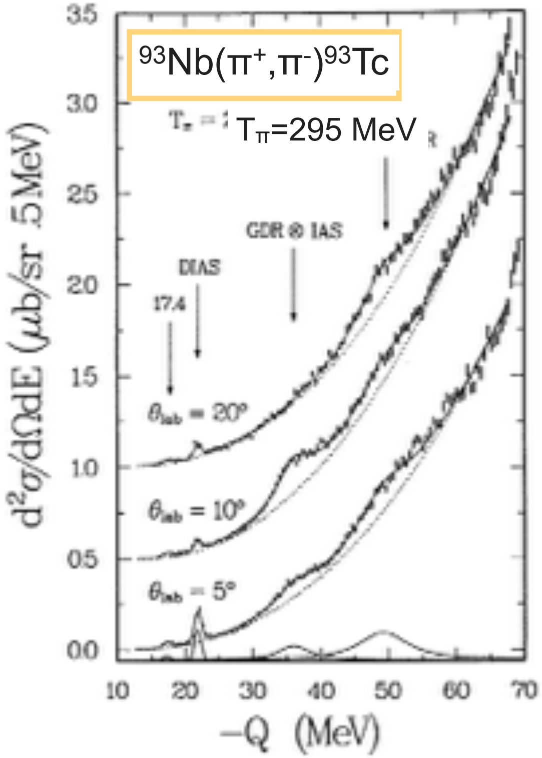
DCX probe
Observation of DGTGR

- Correlation of GTRs?
  or just superpositions of GTRs?
- DGT strength distributions?
- Alternative calibrator for DBD MEs?

and so on…

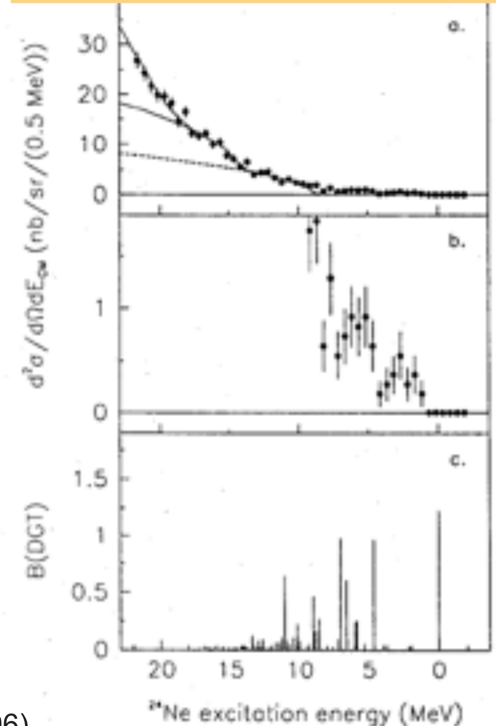
How can we study the DGTR?

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)

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

What can we do w/ HIDCX?

“Heavy-Ion”
Double Charge Exchange reactions

Δ(N-Z) = 4!

ΔS=0,2 & ΔTz=2!

Our starting point
$^{12}C(^{18}O,^{18}Ne)^{12}Be$

- **New Aspect of Spin-Isospin physics?**
- **Double Gamow-Teller …**
- **Multi-phonon ex. w/ spin d.o.f.**

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

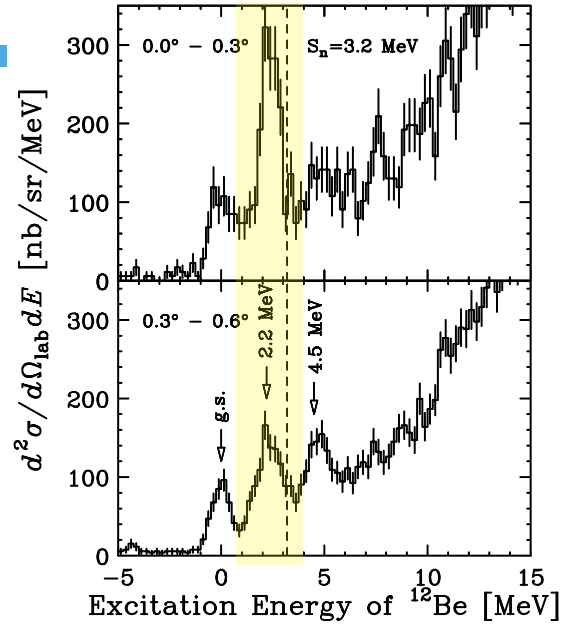
^{12}C(gnd)→^{12}Be(0_2^+) transition is strong.

B(GT^2) ~ 0.3

^{12}C(^{18}O,^{18}Ne) experiment →

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

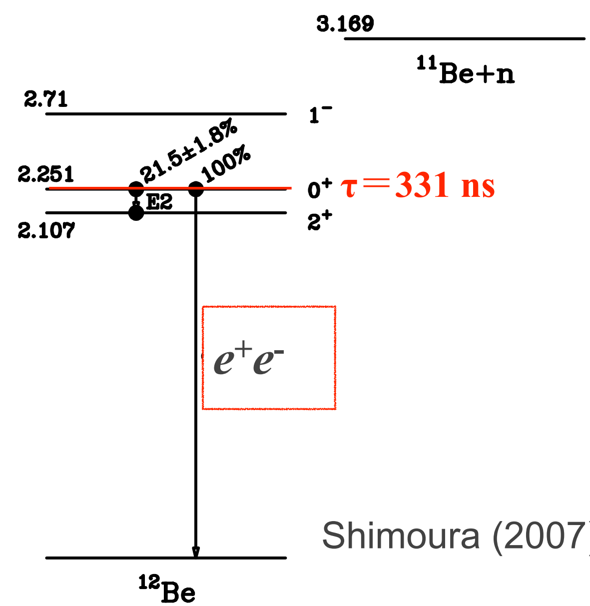
- This is because all of the initial ^{12}**C($0^+_{g.s.}$)**, intermediate ^{12}**B($1^+_{g.s.}$)** and final ^{12}**Be(0^+_2)** state are **dominated by 0ħω configuration**.



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.**

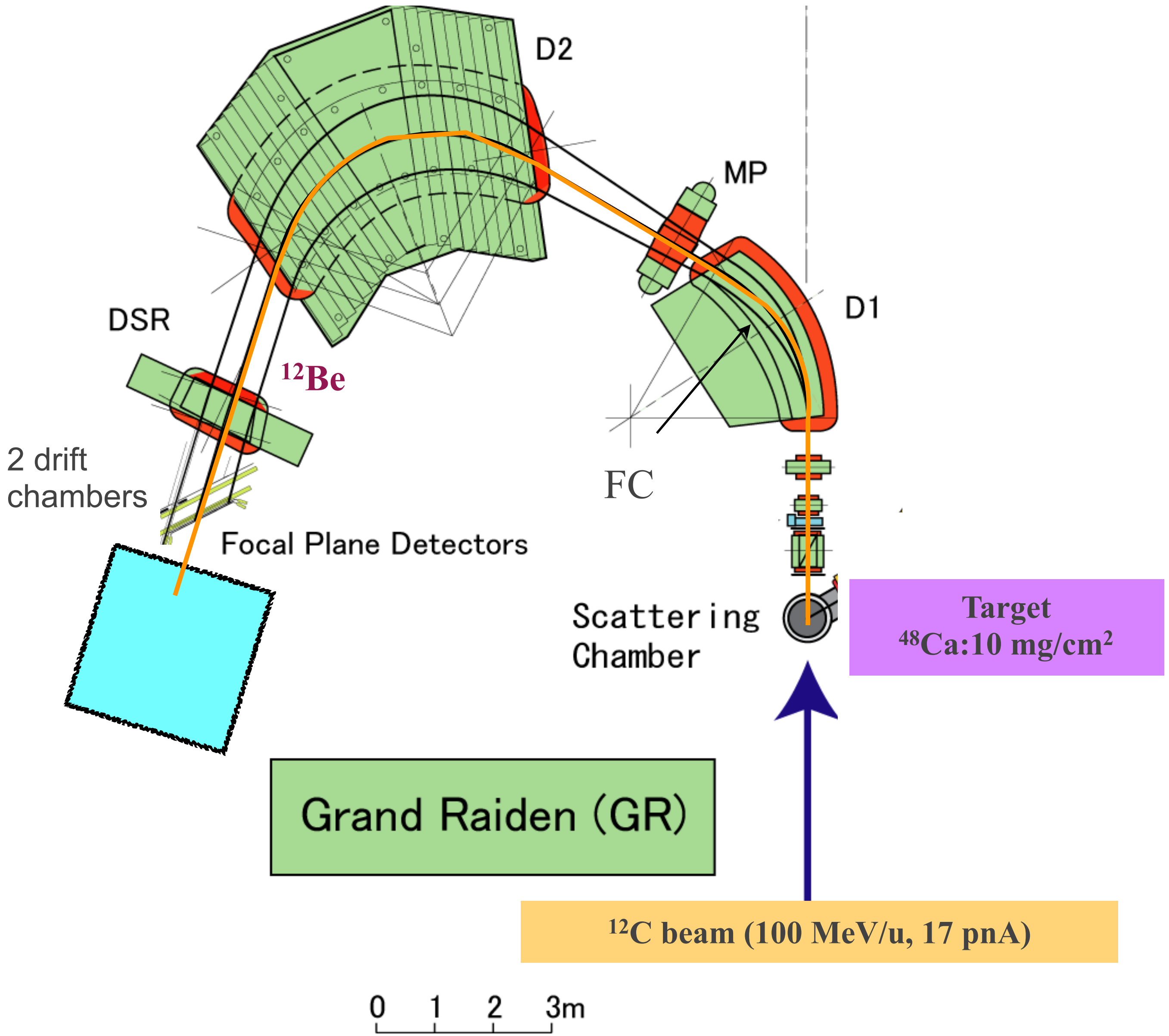


Shimoura (2007)

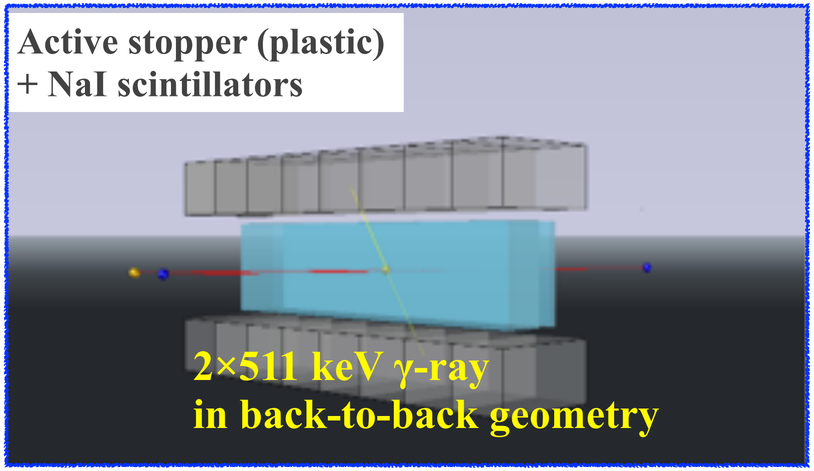
Those two characteristics make this reaction specially effective in DGT studies.

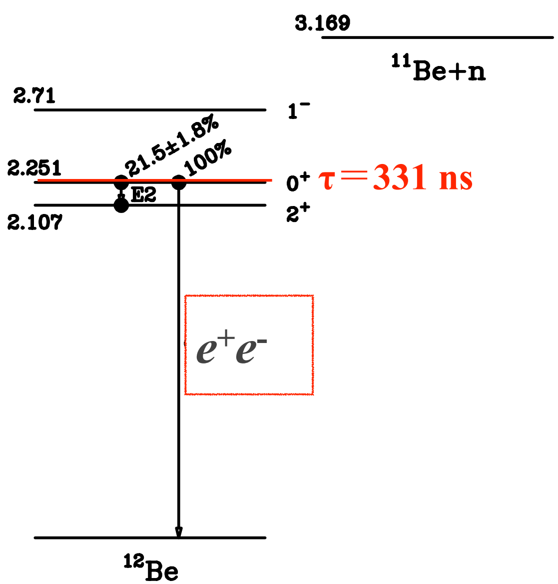
First application: ^{48}Ca(^{12}C,^{12}Be(0^+_2)) experiment

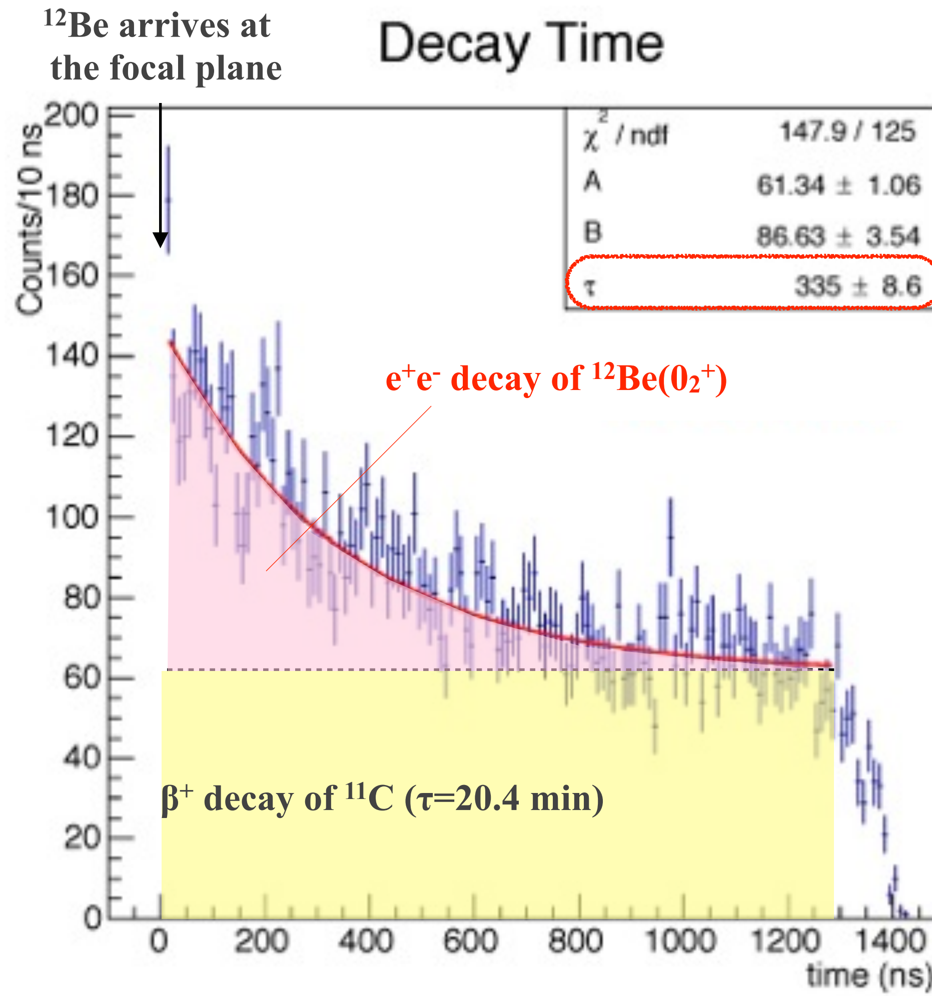
Experimental setup



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

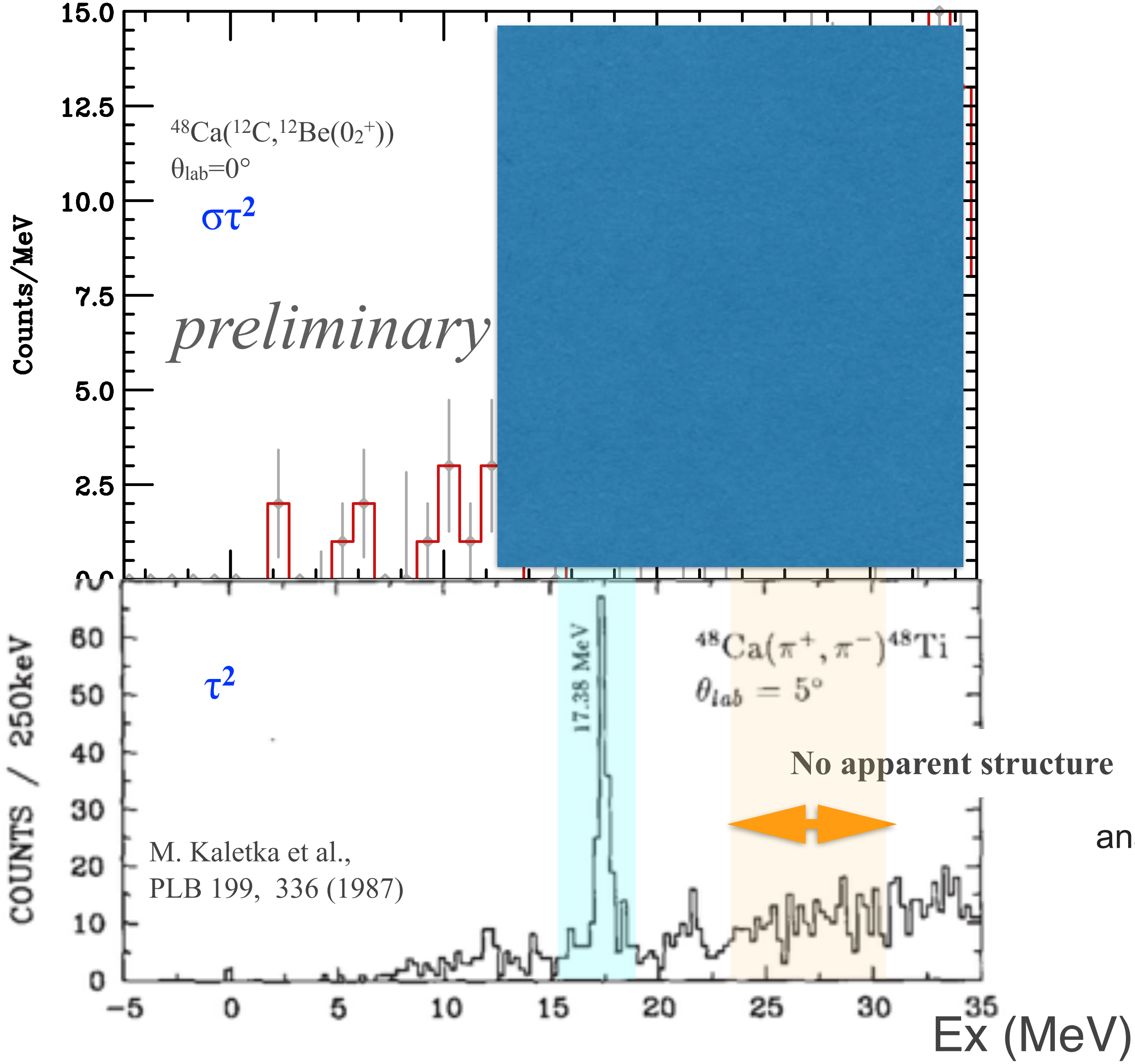






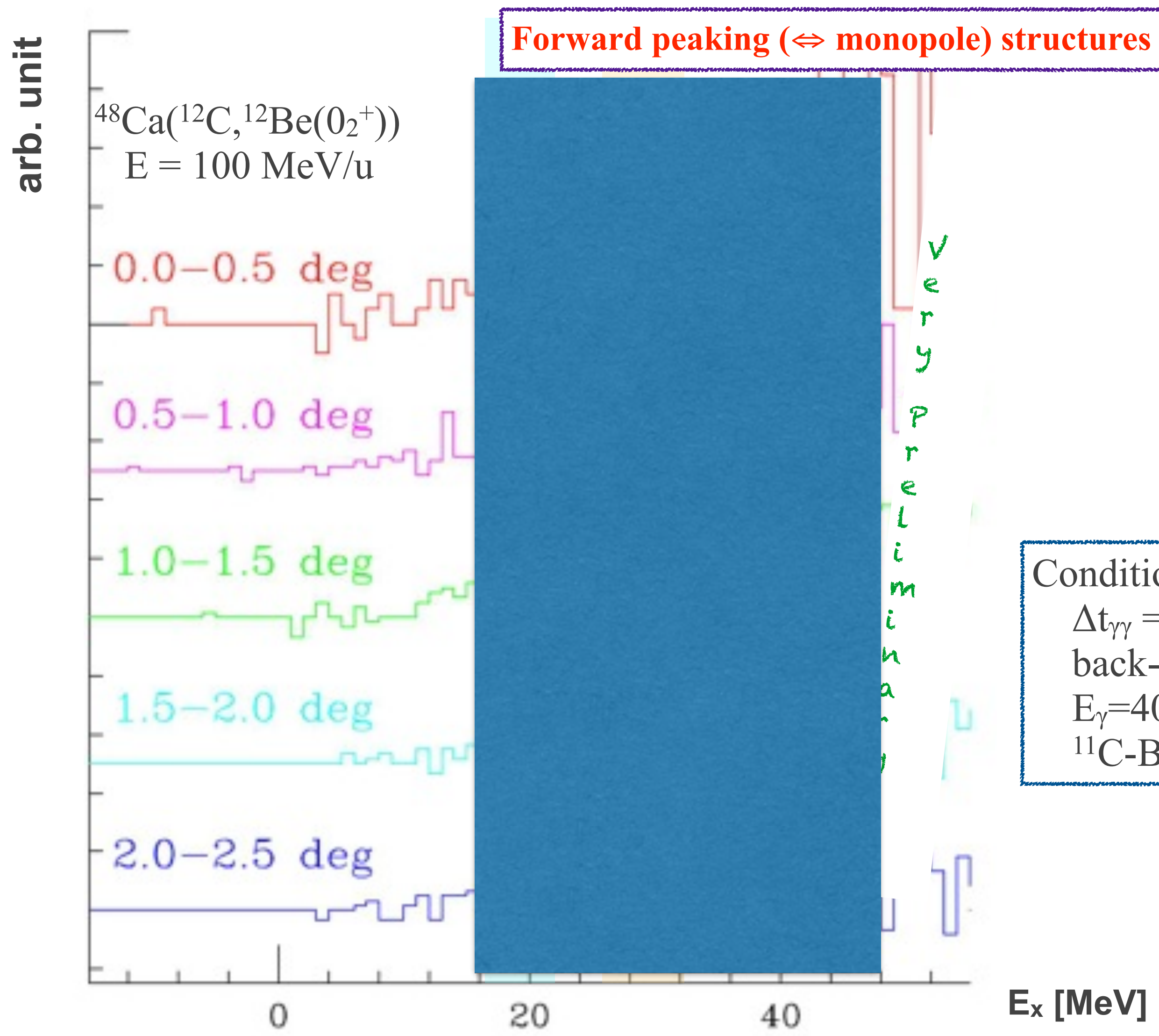
Result: comparison with πDCX data

4.5 days experiment w/ 17 pnA beam intensity



analysis is ongoing…

Result: Excitation energy spectra



Condition:
- $\Delta t_{\gamma\gamma}$ =10 ns
- back-to-back
- E_γ=400–600 keV
- ^{11}C-BG subtracted

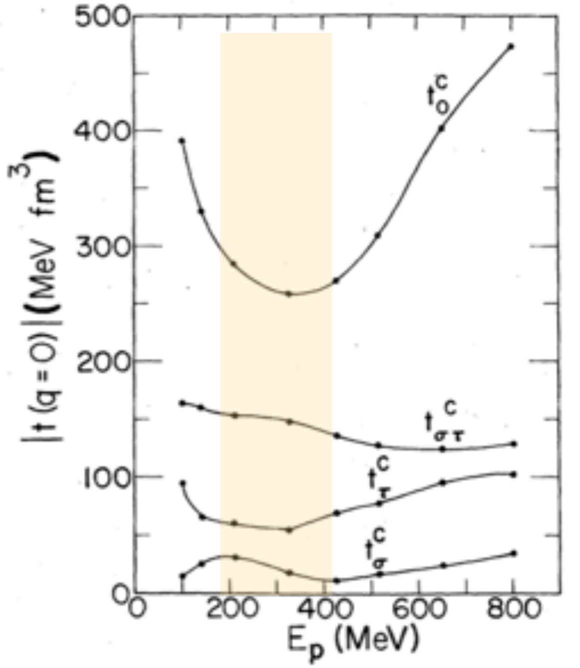
Contents

Go beyond and more effective

Move to RIBF

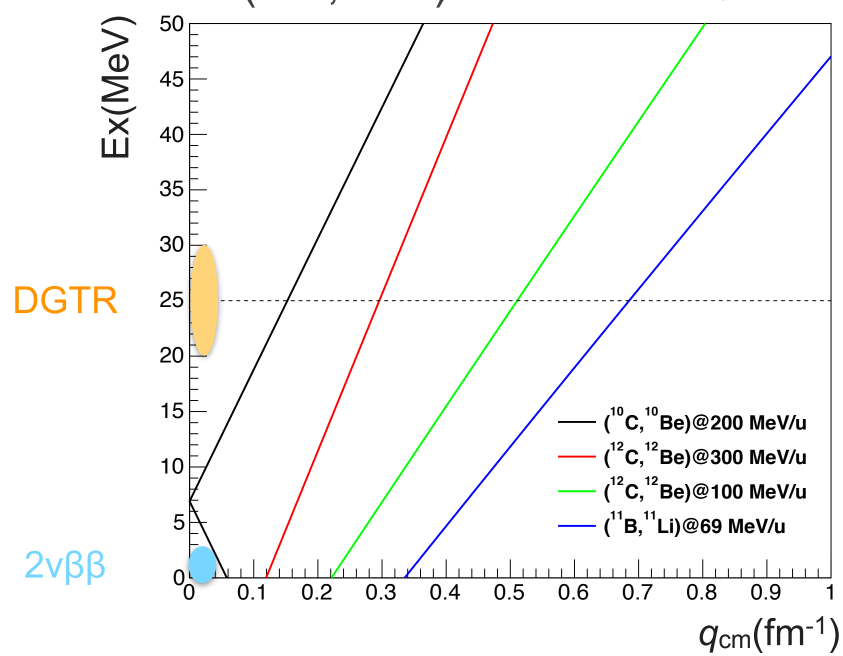
- **200 - 300 MeV/u**
- **Higher intensity**
- **lower *q***

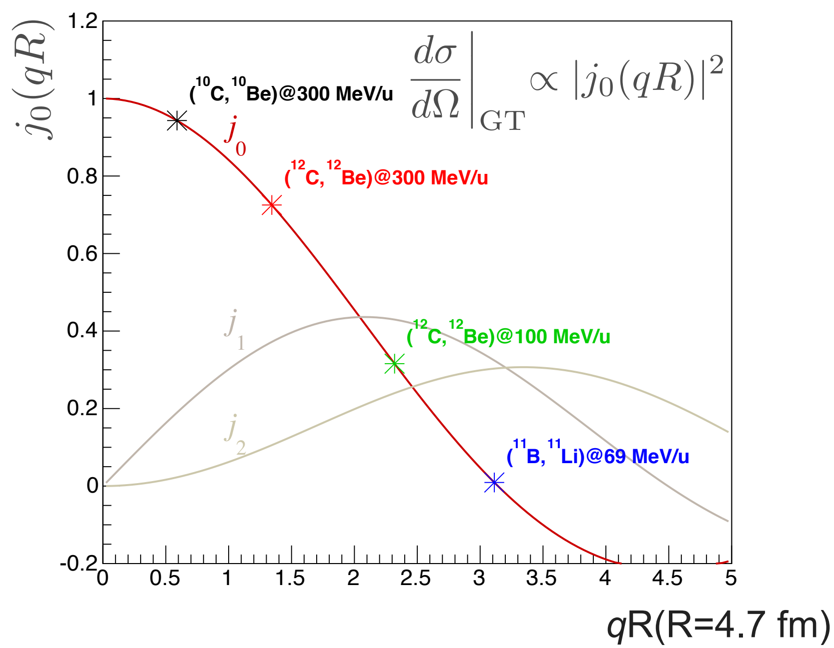
More Suitable for double Gamow-Teller excitation modes



Future plan:

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



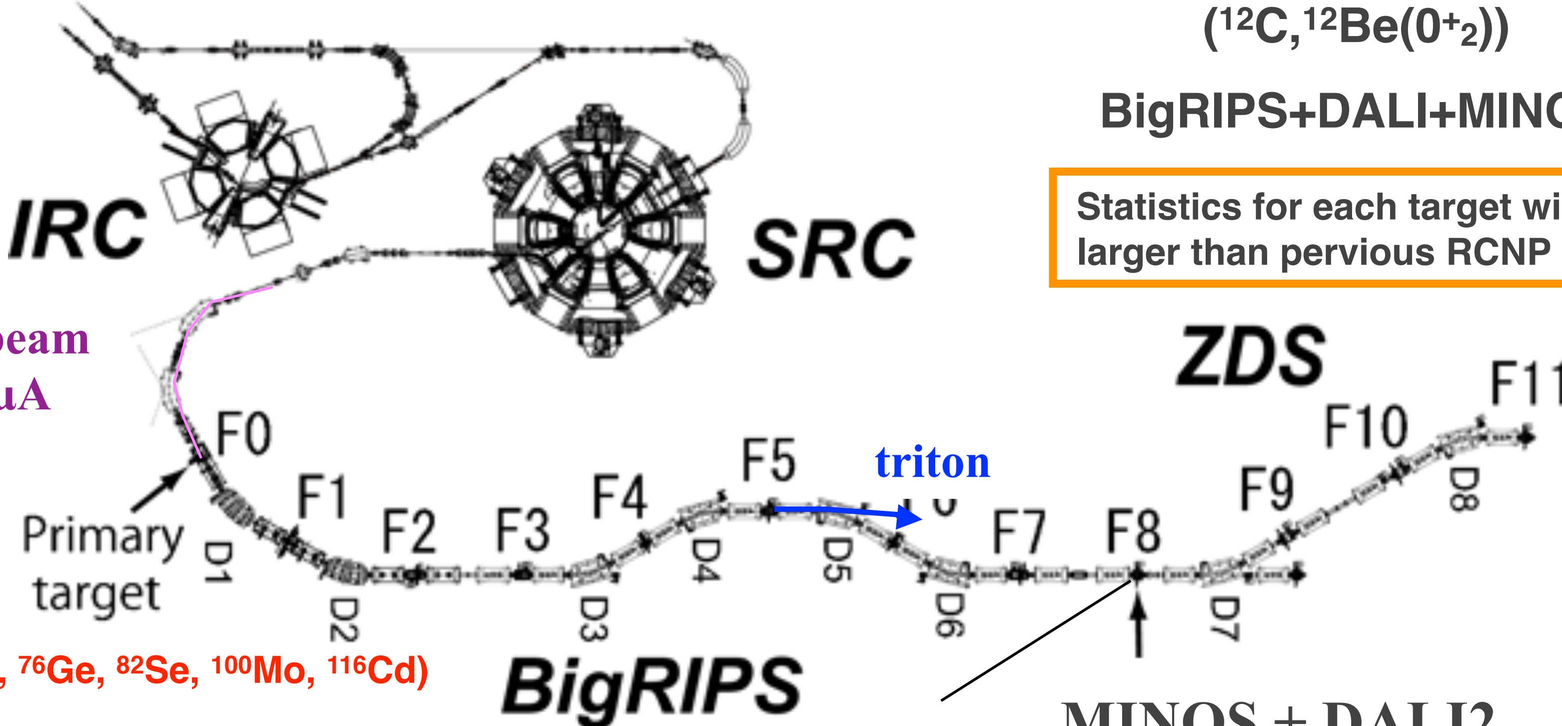


$(^{12}C, ^{12}Be(0^+_2))$

BigRIPS+DALI+MINOS

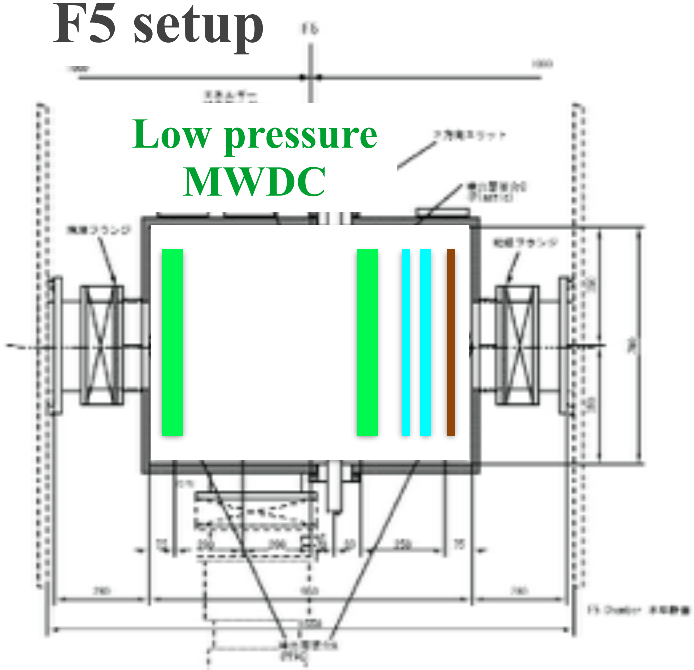
Statistics for each target will be larger than pervious RCNP exp.

^{12}C beam 1pμA

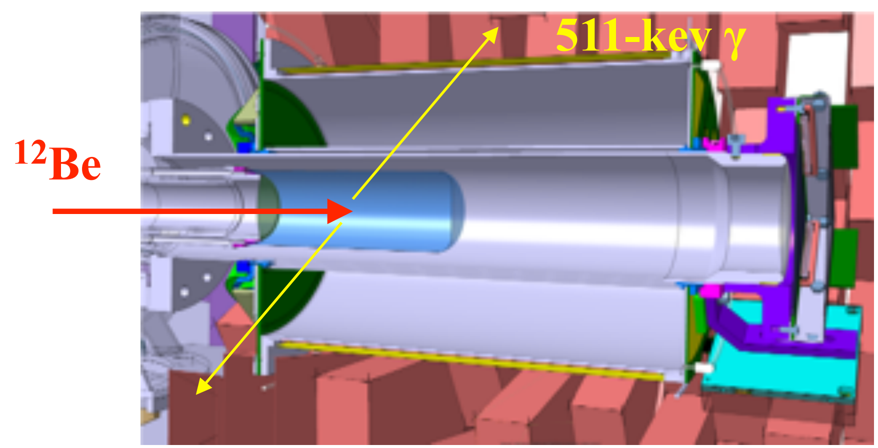


$(^{48}Ca, ^{76}Ge, ^{82}Se, ^{100}Mo, ^{116}Cd)$

F5 setup



MINOS + DALI2



stopping ^{12}Be and detecting delayed γ.

Summary

The characteristics of HIDCX reactions are:

ΔTz = 2, Δ(N-Z) = 4
Spin degrees of freedom and selectivity
Controllable kinematical condition

We performed three experiments:

$^{12}C(^{18}O,^{18}Ne)^{12}Be$ reaction experiment
lead **new idea of a probe for DGTGR** and
will be **a benchmark for reaction models**.

Search for Tetra-neutron system with exothermic DCX reaction
found **a candidate of the resonance state of Tetra-neutron**.

Search for DGTGR on ^{48}Ca via $(^{12}C,^{12}Be\gamma)$ reaction
found structures at 17 MeV and **25 MeV.**
The latter one is most likely DGTGR.

Collaborators

CNS, Tokyo	S. Shimoura, M. Dozono, M. Kobayashi, K. Yako, S. Michimasa, S. Ota, Y. Sasamoto, M. Matsushita, S. Kawase, H. Tokieda, H. Miya, Y. Kubota, C.S. Lee, R. Yokoyama, A. Saito, K. Nakanishi, H. Matsubara, Y. Kikuchi
RIKEN Nishina Center	T. Uesaka, K. Kisamori, M. Sasano, H. Sakai, L. Stuhl, J. Zenihiro, H. Baba, T. Ichihara, K. Itahashi
RCNP, Osaka	A. Tamii, C. Iwamoto, N. Aoi
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LPC Caen, Konan, Tokyo Tech, Tohoku, Miyazaki, Notre Dame, TU Darmstadt. . . . .