Gamow-Teller transitions from ^{8}He and ^{12}Be

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9th RIBF discussion meeting
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CENTER for NUCLEAR STUDY
THE UNIVERSITY of TOKYO

SHARAQ COLLABORATION

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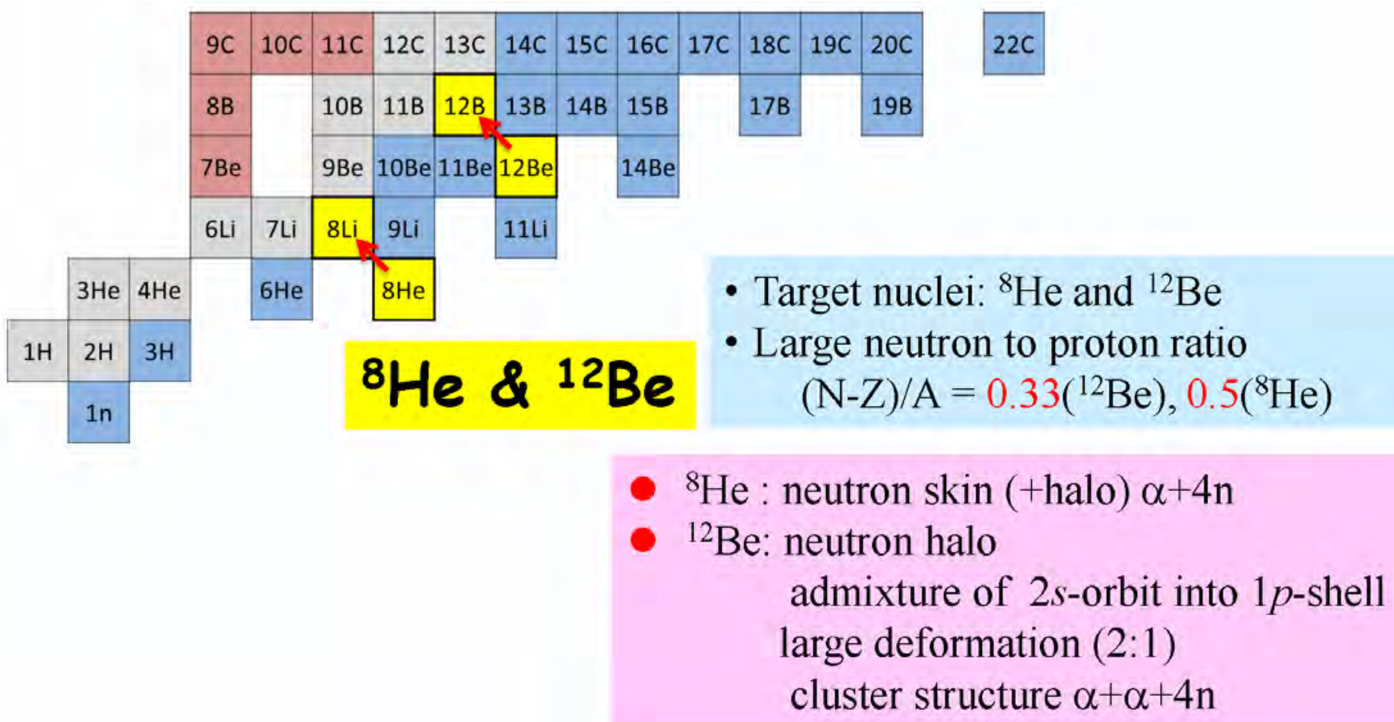
MSU:	M. Sasano, D. Bazin, R. Zegers
Aizu	H. Sagawa
Nihon	T. Suzuki

First RIBF (p,n) measurements in inverse kinematics at RIBF

- ^{8}He, ^{12}Be … light neutron rich nuclei



- WINDS neutron detector array

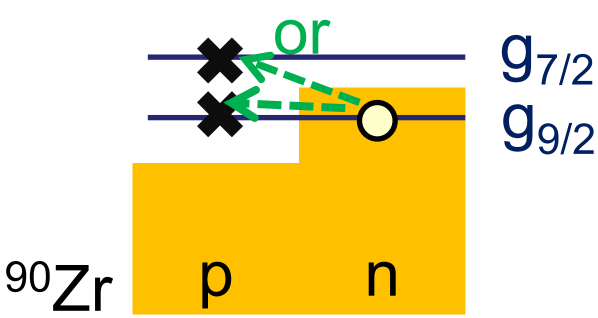
Gamow-Teller transition

GT transition

- ΔS=1, ΔT=1, ΔL=0
- transition operator

$$O_{\mathrm{GT}\pm} = \sum_j \sigma_j t_\pm$$

- configuration



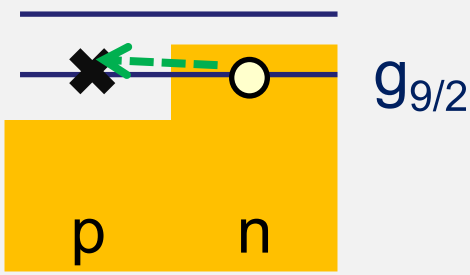
- strength $B(\mathrm{GT}^\pm) = \left|\langle j \| O_{\mathrm{GT}\pm} \| i \rangle\right|^2$
- sum rule

$$\Sigma B(\mathrm{GT}^-) - \Sigma B(\mathrm{GT}^+) = 3(N - Z)$$

Fermi transition

- ΔS=0, ΔT=0, ΔL=0
-

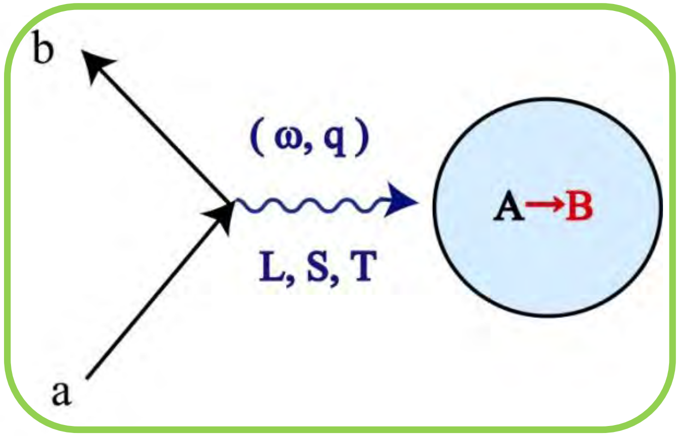
$$O_{\mathrm{F}\pm} = \sum_j t_\pm$$



$$B(\mathrm{F}^\pm) = \left|\langle j \| O_{\mathrm{F}\pm} \| i \rangle\right|^2$$

$$\Sigma B(\mathrm{F}^-) - \Sigma B(\mathrm{F}^+) = N - Z$$

Observation of GTGR …charge exchange reactions



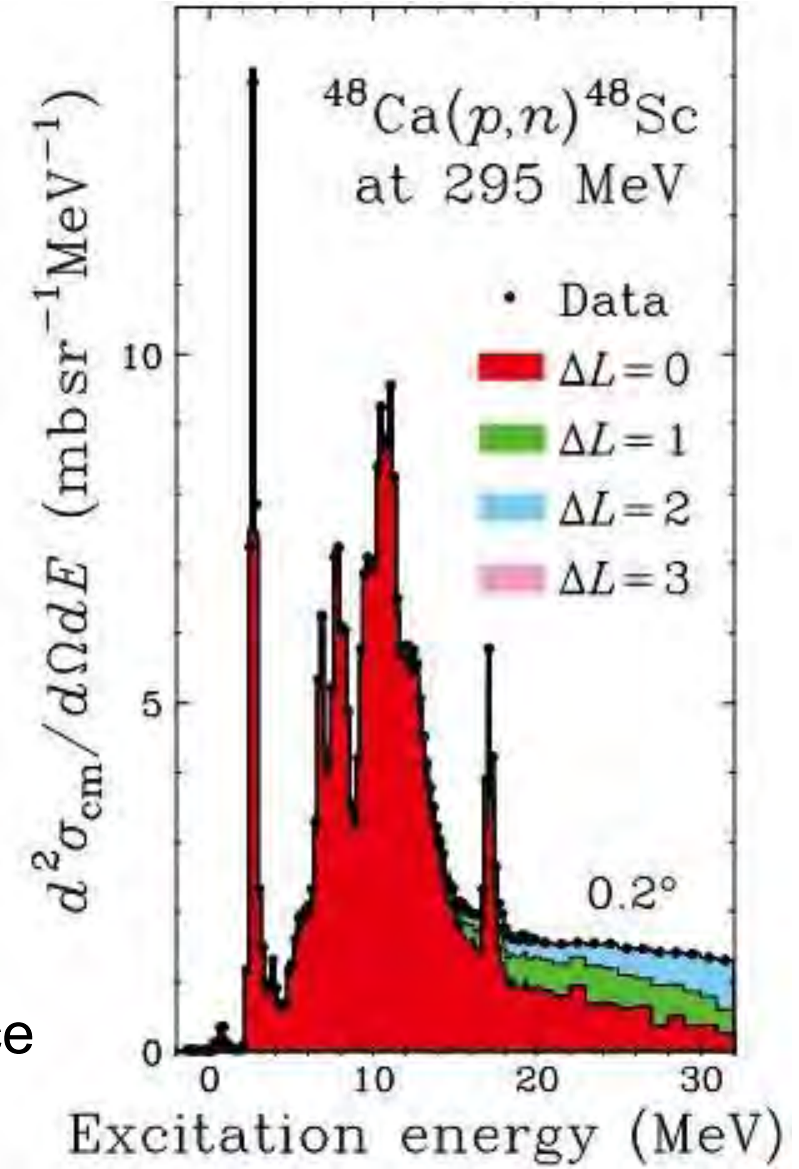
Charge exchange reactions:

a = incoming	b = outgoing
p	n
^{3}He	t
…	…

Observables

- transition strengths: …B(GT)
- Energy and Width of giant resonance

⇒ Essential inputs / constraint to structure theory & astrophysics



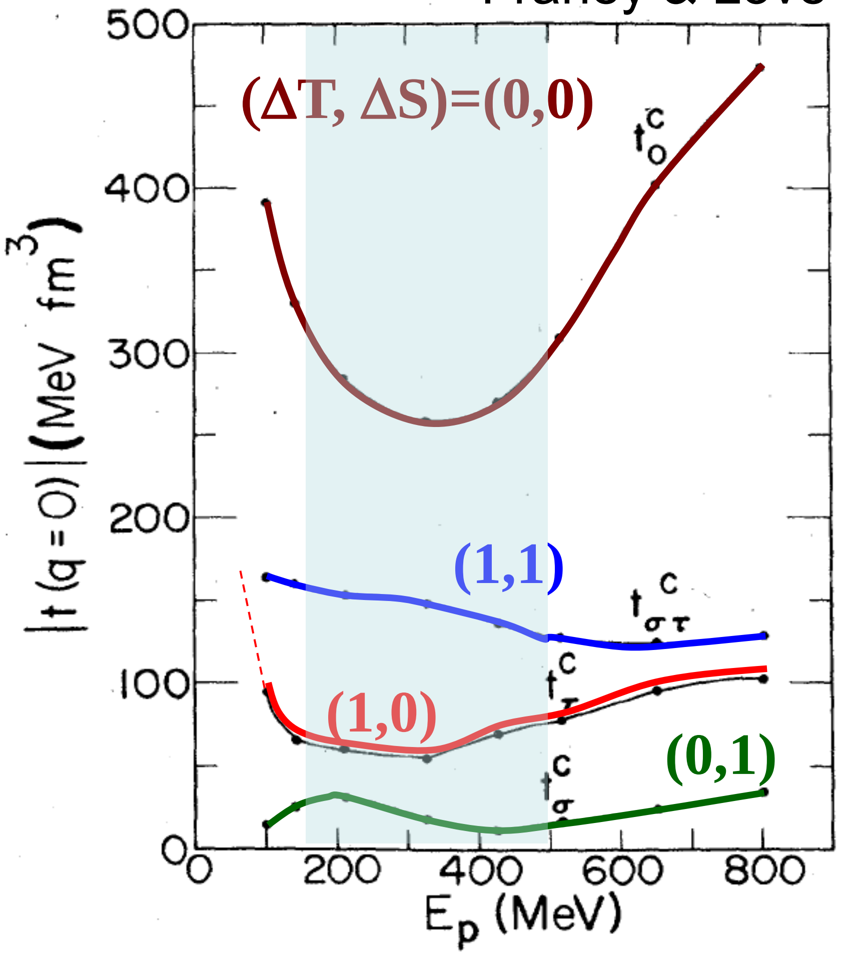
Advantage of intermediate energy

Proportionality

$$\frac{d\sigma}{d\Omega}(0^\circ)_{\Delta L=0} = \hat{\sigma}_{\mathrm{GT}} F(q,\omega) B(\mathrm{GT})$$

GT unit cross section

kinematical correction by reaction theory



Intermediate energies

… direct reaction

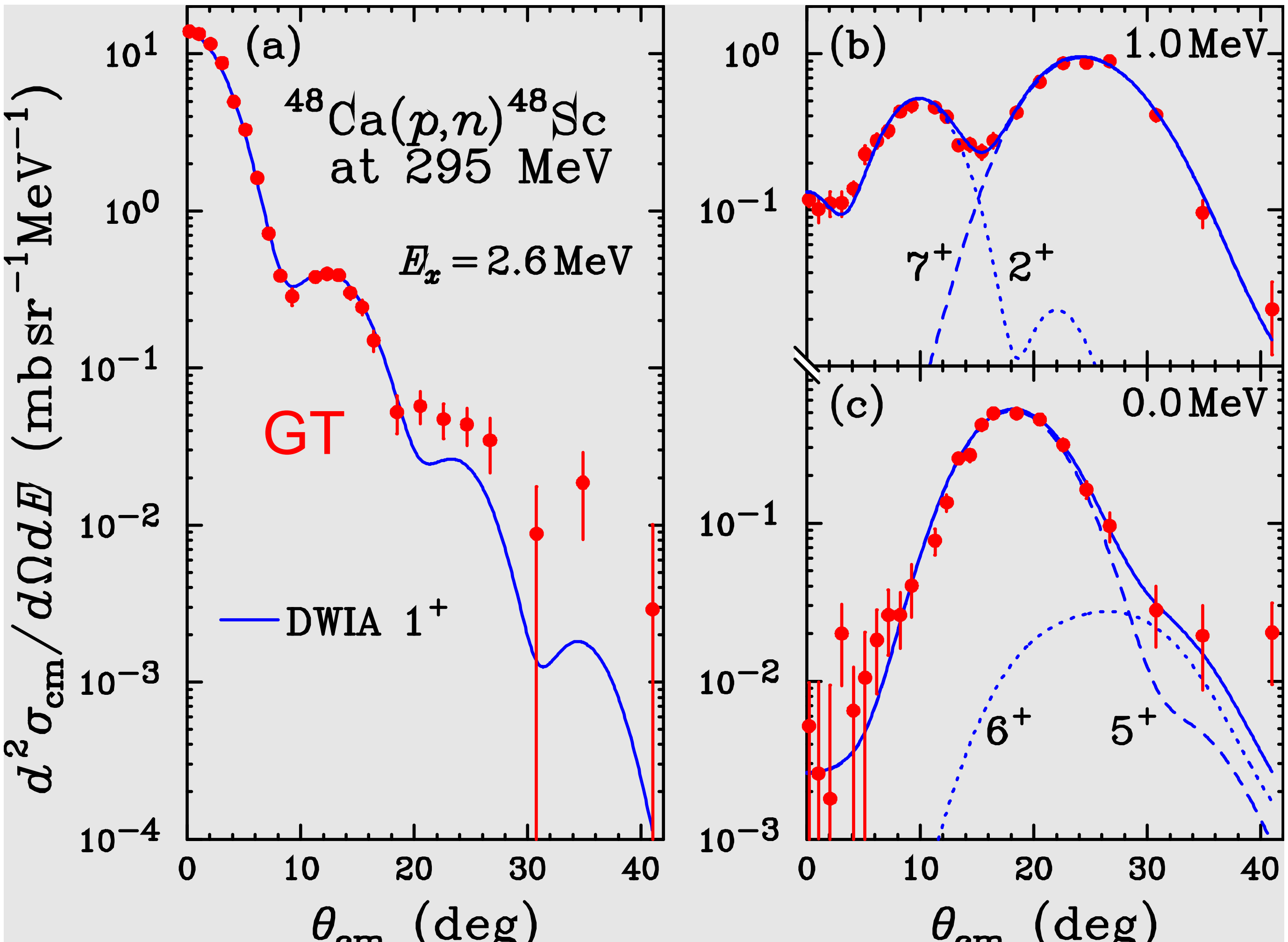
- Simple reaction mechanism
- $t_{\sigma\tau}$ is the largest apart from t_0^C

⇒ GT transitions are most clearly seen.

Reaction theory

DWIA = distorted wave impulse approximation
is doing well.

K.Y., PRL103(2009)012503



Systematics of GT peak energy (「原子核構造論」高田、池田)

表 **3.2** 主な巨大共鳴

名称 など	振動モードの アイソスピン・ 角運動量演算子	全スピン・ パリティ (I^π)	励起エネルギー† (MeV)
アイソスカラー型 ($T=0$)			
単極	1	0^+	$80\,A^{-1/3}$
4 重極	$Y_{2\mu}(\theta,\varphi)$	2^+	$65\,A^{-1/3}$
アイソベクトル型 ($T=1, T_z=0$)			
単極	$\tau_z\cdot 1$	0^+	$170\,A^{-1/3}$
双極	$\tau_z\cdot Y_{1\mu}(\theta,\varphi)$	1^-	$79\,A^{-1/3}$
4 重極	$\tau_z\cdot Y_{2\mu}(\theta,\varphi)$	2^+	$130\,A^{-1/3}$
荷電交換型 ($T=1, T_z=\pm 1$)			
IAS	$\tau_\pm$	0^+	$E_{\rm IAS}=V_{\rm c}$(娘核) $-\,V_{\rm c}$(親核)
GTR	$\tau_\pm\cdot\boldsymbol{\sigma}$	1^+	$E_{\rm IAS}+\bar{\varepsilon}_{ls}-\alpha(N-Z)/A$

† $A>60$ の原子核に対する大まかな表式である．

注：IAS はアイソバリック・アナログ状態の略．IAS は共鳴幅が狭いけれども巨大共鳴の1種と考えてよい．GTR は Gamow-Teller 共鳴の略．

$$\langle E_{GT}\rangle-\langle E_{IAS}\rangle=\Delta E_{ls}-\alpha\frac{N-Z}{A}$$

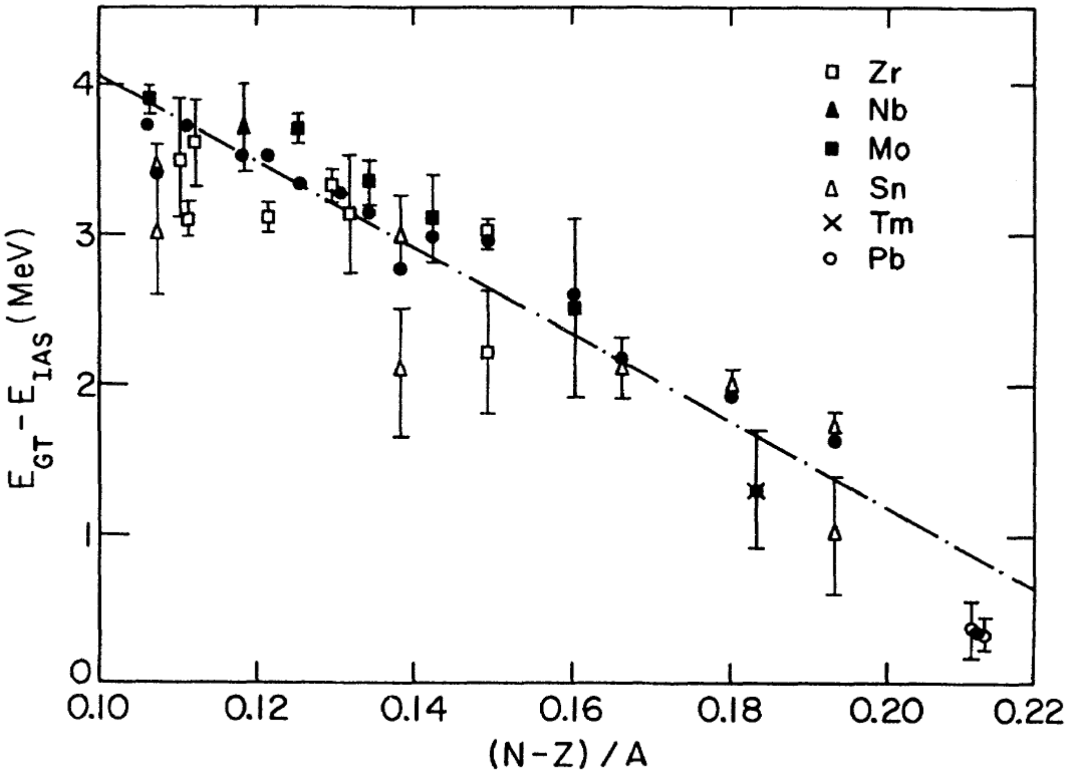
Spin orbit int. (ΔE_{ls})

Spin-dependent central int. (α)

Neutron excess vs E_{GT} - E_{IAS}

$$\langle E_{GT} \rangle - \langle E_{IAS} \rangle = \Delta E_{ls} + 2(\tilde{\kappa}_{\sigma\tau} - \tilde{\kappa}_{\tau}) \frac{N-Z}{A}$$

K.Nakayama et al, PLB114(1982)217.
F.Osterfeld, Rev. Mod. Phys. 64 (1992)491.



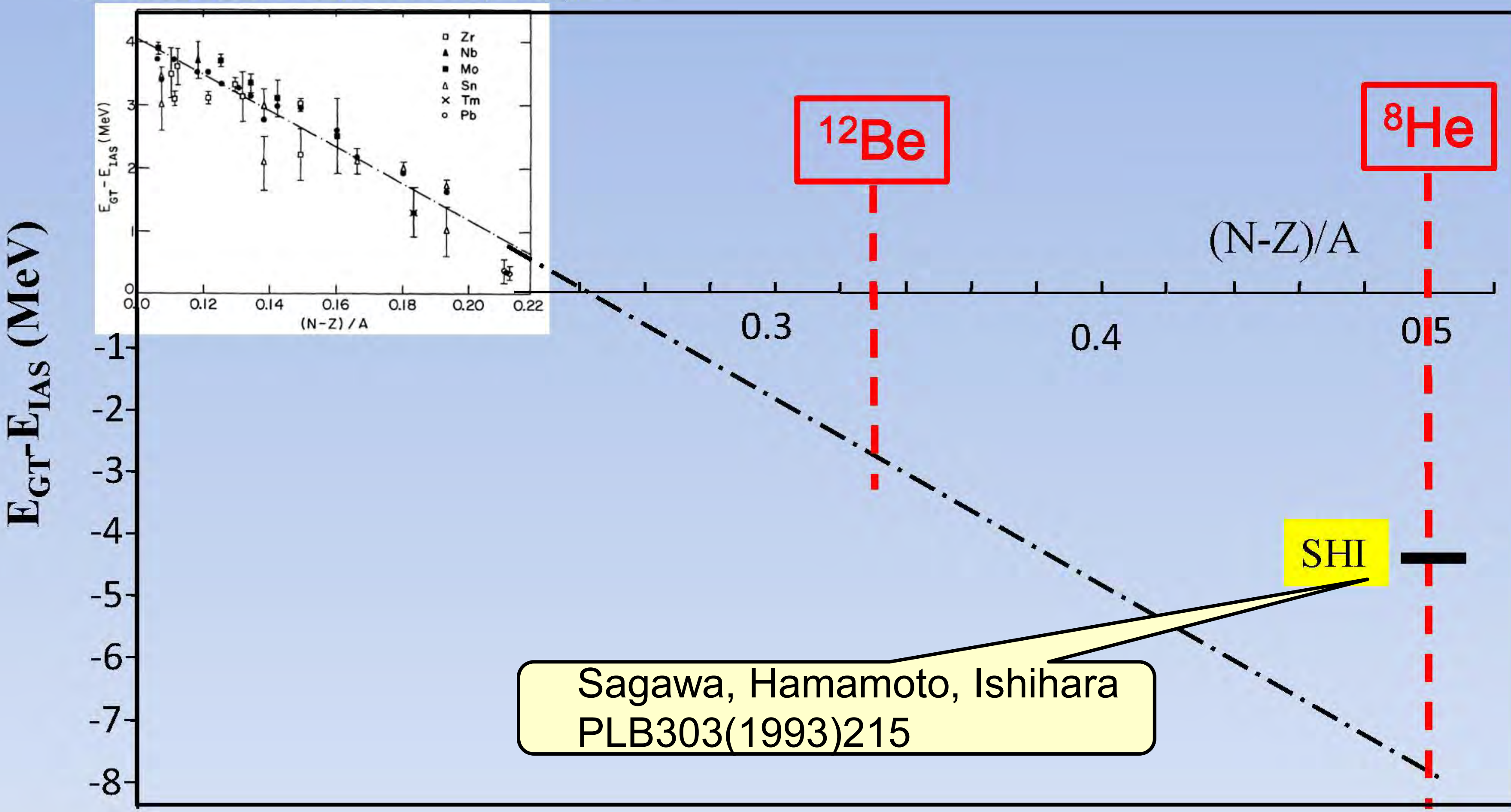
$\Delta E_{ls}=1/2(\varepsilon_{j>} - \varepsilon_{j<})$:
Spin-orbit part of the single-particle energy

$\kappa_{\sigma\tau}(\kappa_{\tau})$:
particle-hole coupling constants
$\kappa_{\sigma\tau} = \tilde{\kappa}_{\sigma\tau}/A$, …

GT states
in light neutron rich nuclei,
H.Sagawa et al, PLB303(1993)215.

Collectivity in (N-Z)/A>0.21:very nuetron rich nuclei

K.Nakayama et al, PLB114(1982)217.



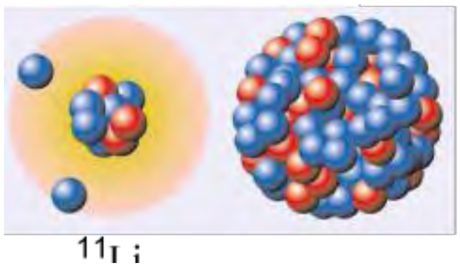
(p,n) measurement
on neutron-rich nucleus ^{12}Be

Aim:

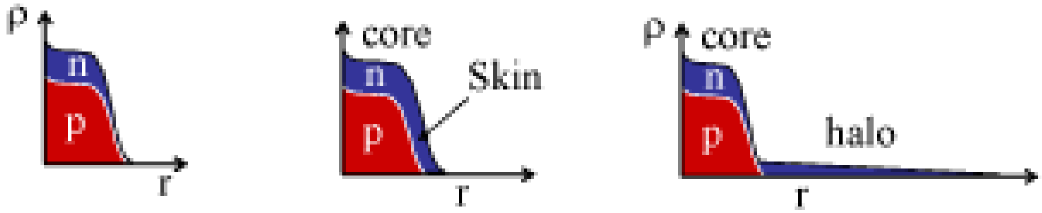
- to establish the (p,n) measurement on unstable nuclei @ RIBF

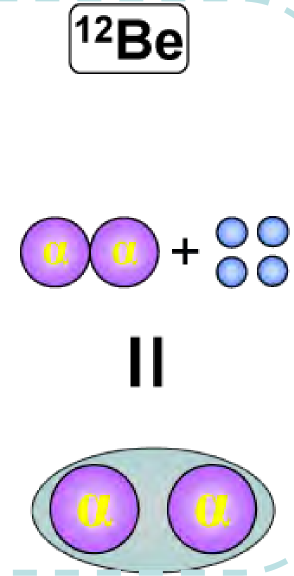
^{12}Be … interesting?

- Large isospin asymmetry: (N-Z) / A = 0.33



N=8 is not a magic number in n-rich nuclei …





Interpretations

- halo
- cluster
- deformation: ellipsoid ratio
  … long:short = 2:1
- 40% admixture of sd-orbits into p-orbits

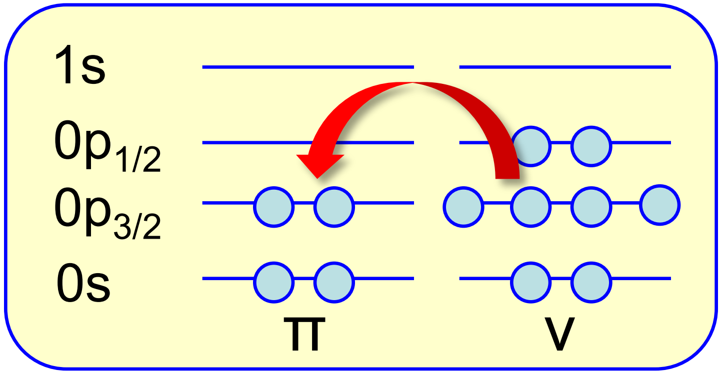
Effects on GT?

Shell-model prediction: GT excitations

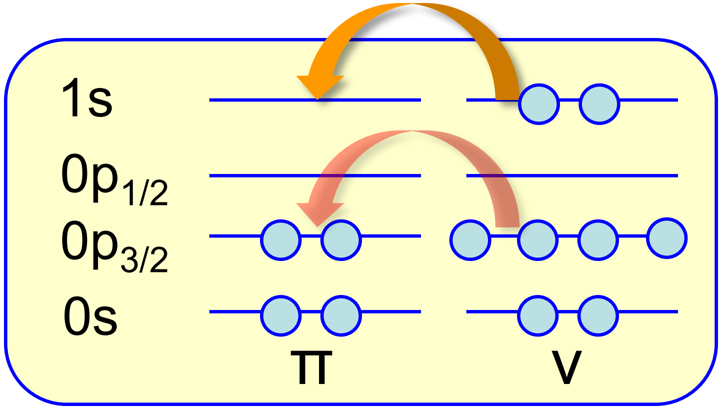
- Model space: p-sd
- $\Delta\varepsilon_{1s}$= —3.4 MeV
  logft value is reproduced.

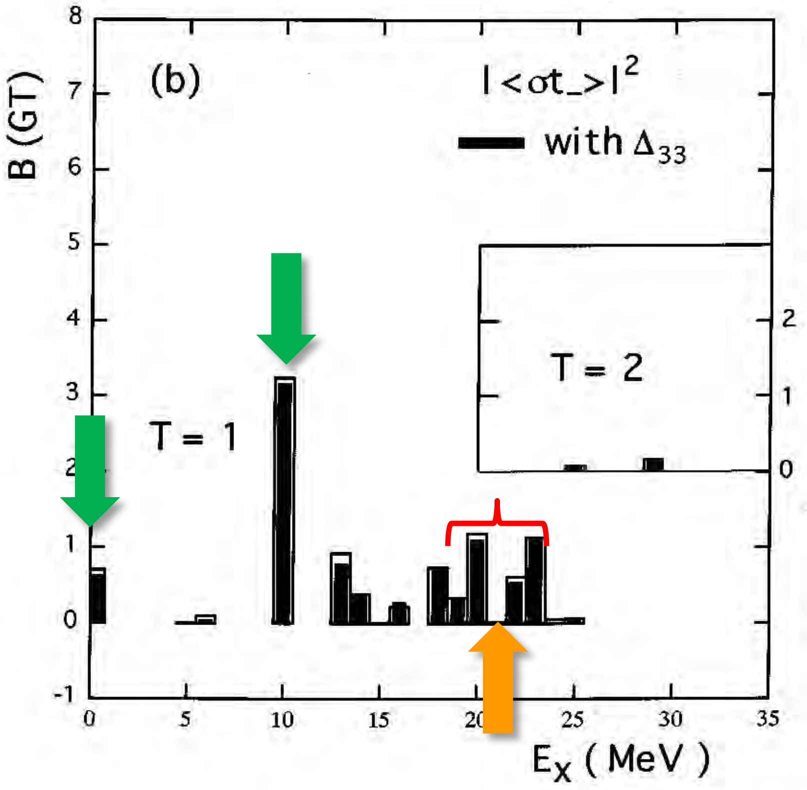
Suzuki & Otsuka, PRC56(1997)847

$(0p)^2$
40%



$(1s)^2$
60%

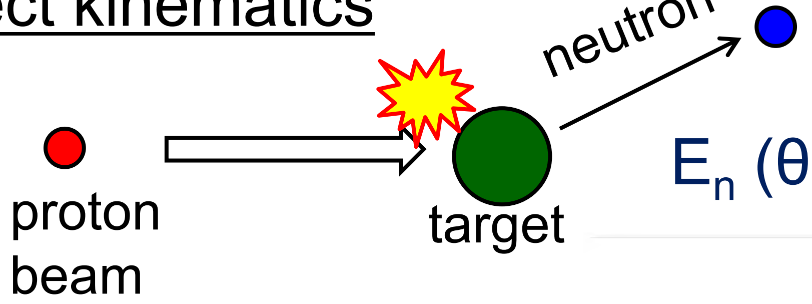




…Deformation-difference?
…Cluster model?

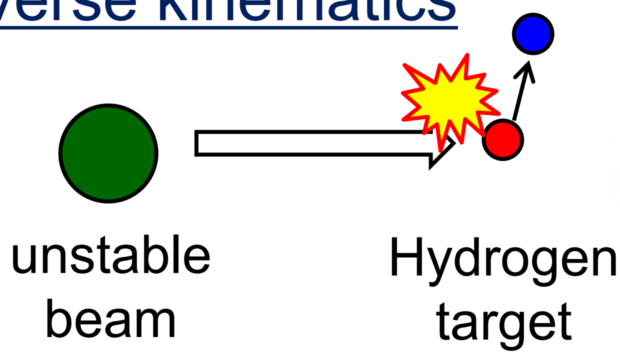
Inverse kinematics

direct kinematics

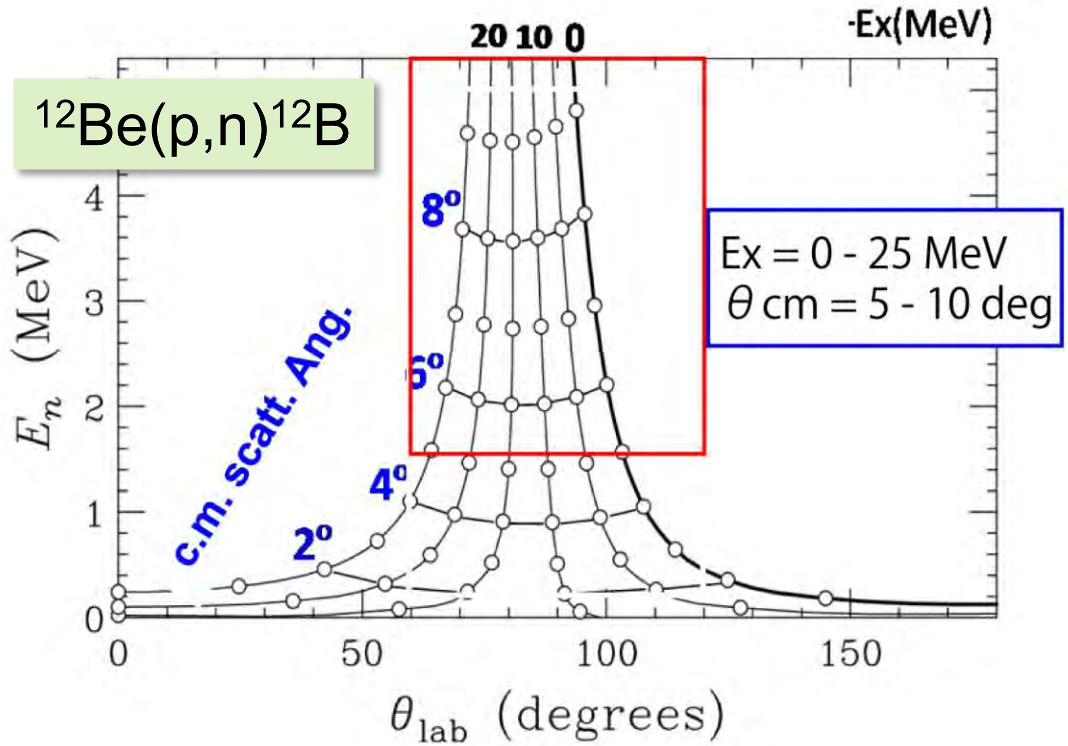


$E_n\ (\theta_{cm} \approx 0) \sim E_{beam}$

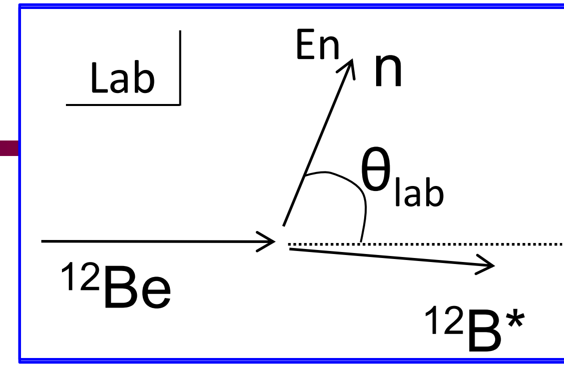
Inverse kinematics



$E_n\ (\theta_{cm} \approx 0)$: small

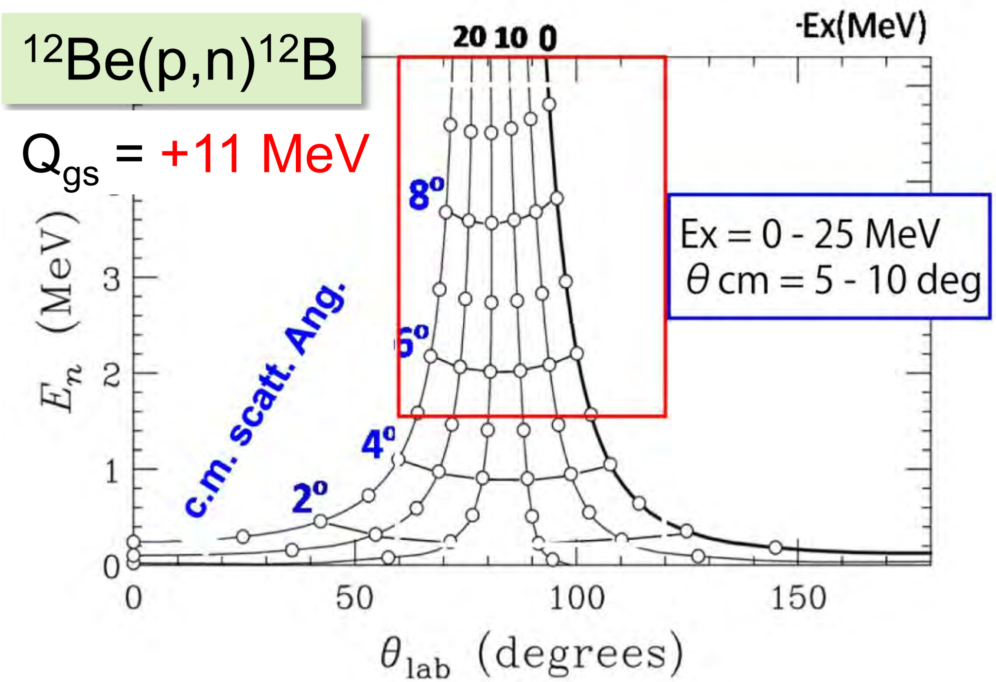


^{12}Be(p,n) measurement



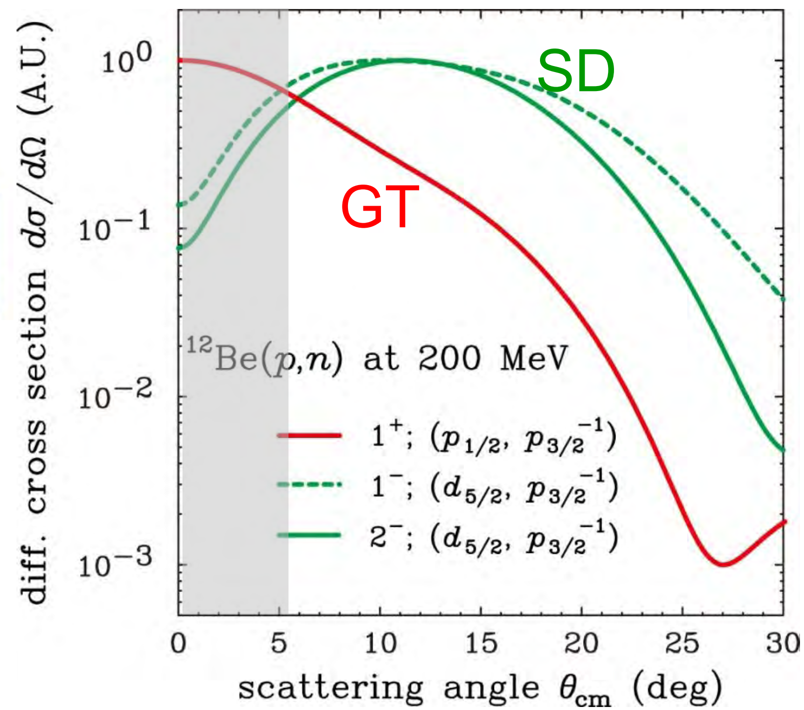
- resolution $\delta E_x \sim 1$ MeV, $\delta\theta_{cm} \sim 1$ deg
- missing mass : $(E_n, \theta_{lab}) \rightarrow (E_x, \theta_{cm})$
  E_n …Time-of-flight

Inverse kimenatics



$\delta E_n \sim 0.8$ MeV, $\delta\theta_{lab} \sim 1.3$ deg

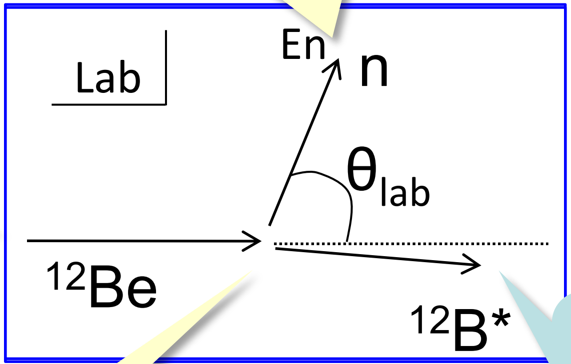
Angular distribution



Measurement

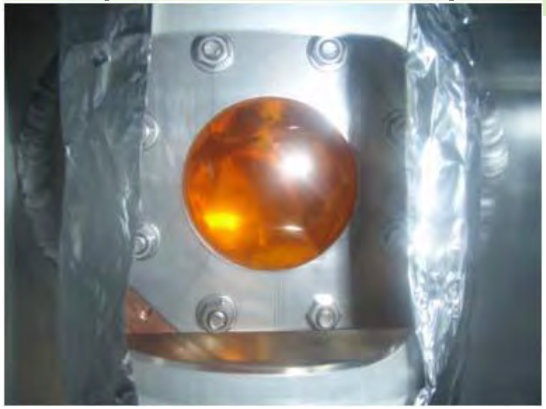
Neutron detector
“WINDS”
TOF

^{18}O beam + Be
Achromatic transport



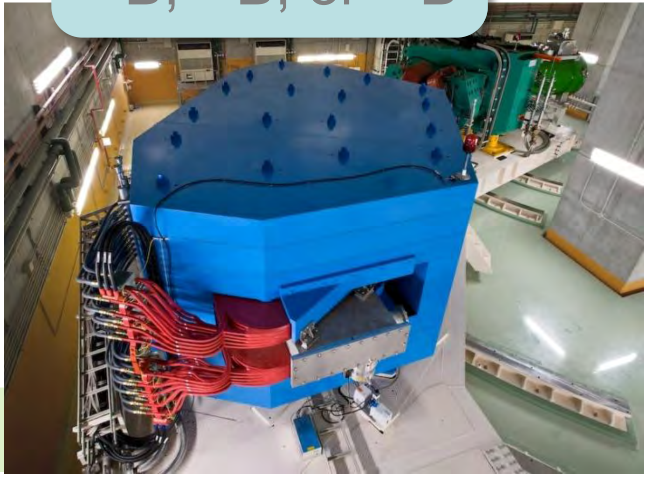
SHARAQ
^{12}B, ^{11}B, or ^{10}B

14 mm^{t}, 40 mmΦ
Kapton wndw 25 μm^{t}

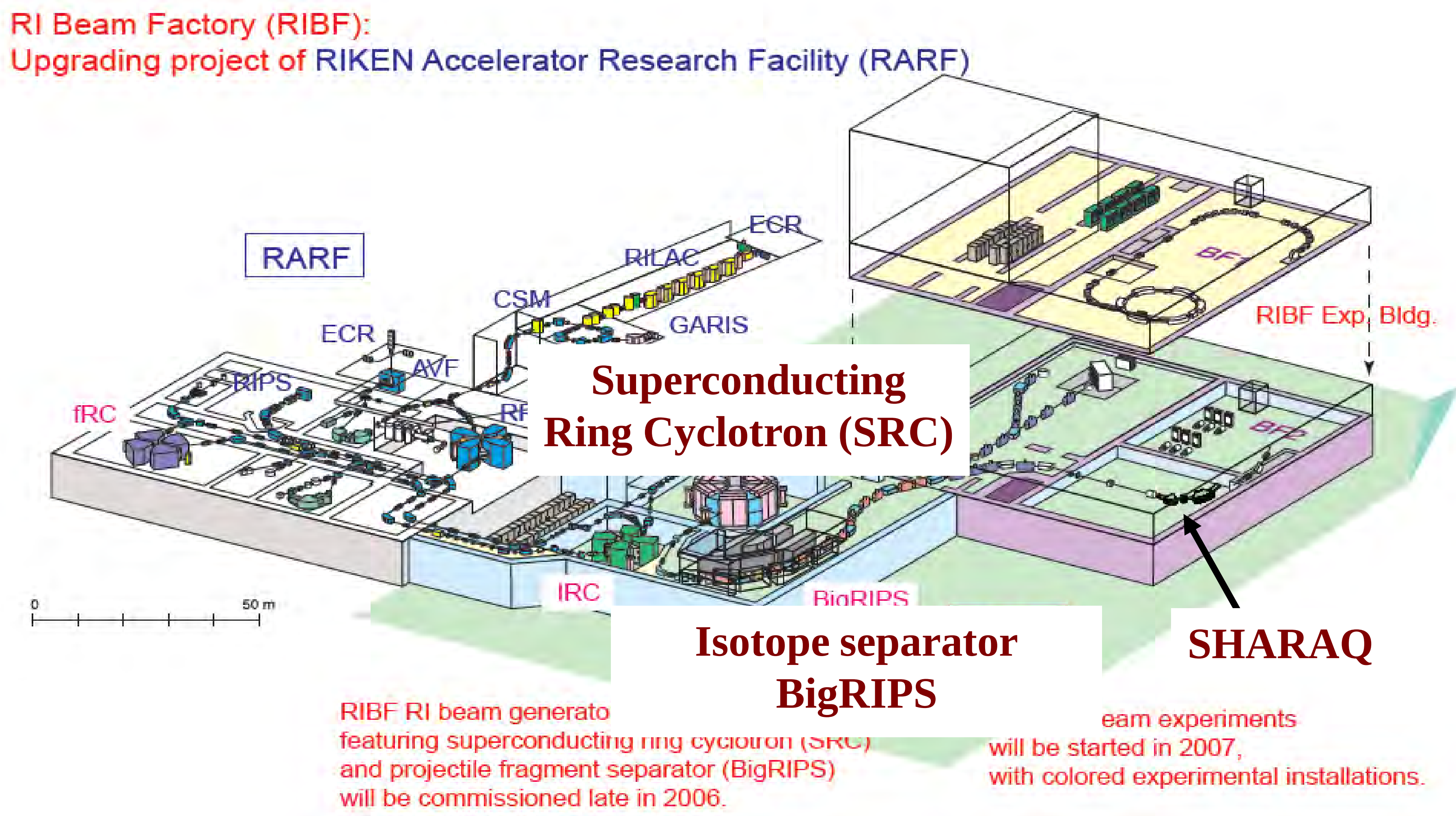


LiqH$_2$
target

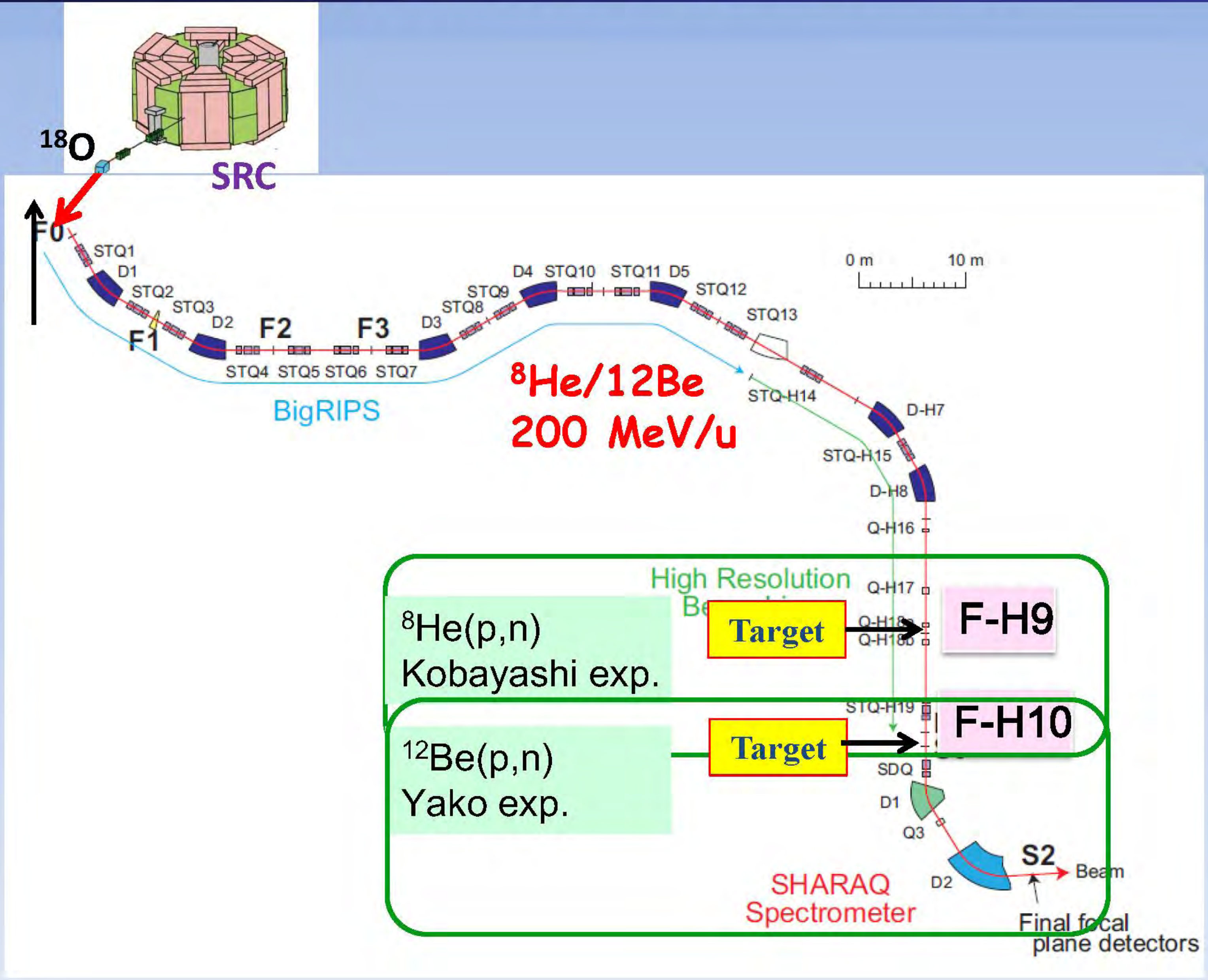
|δ| < 1%, ~5 msr



RI beam factory @ RIKEN

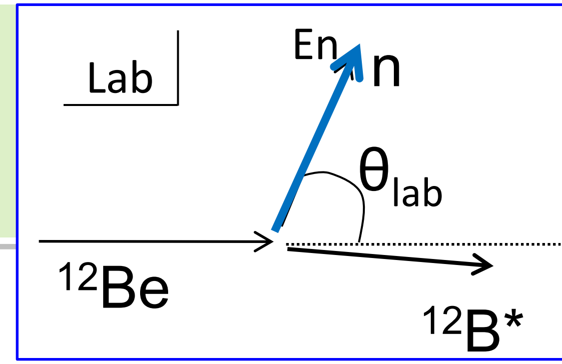


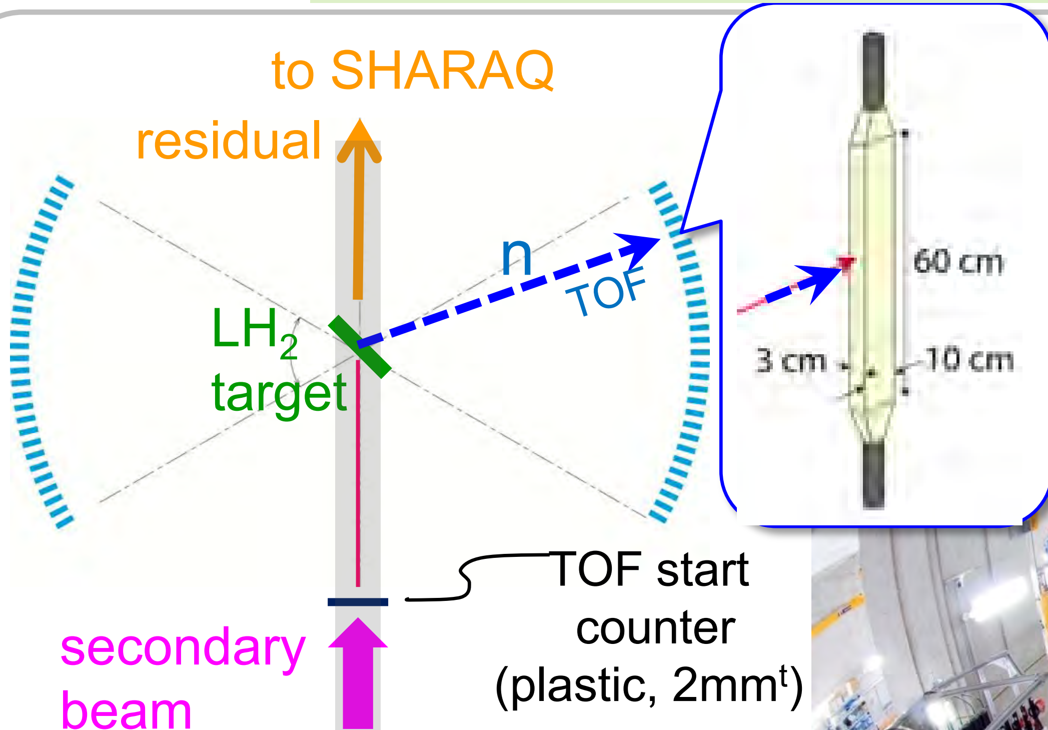
^{8}He/^{12}Be(p,n) measurements at RIBF



WINDS

"WINDS"
= Wide-angle Inverse-kinematics Neutron Detectors for SHARAQ





T_n (MeV)	1	10
TOF (ns)	130	30
Req. on δTOF (ns)	3.5	1.5

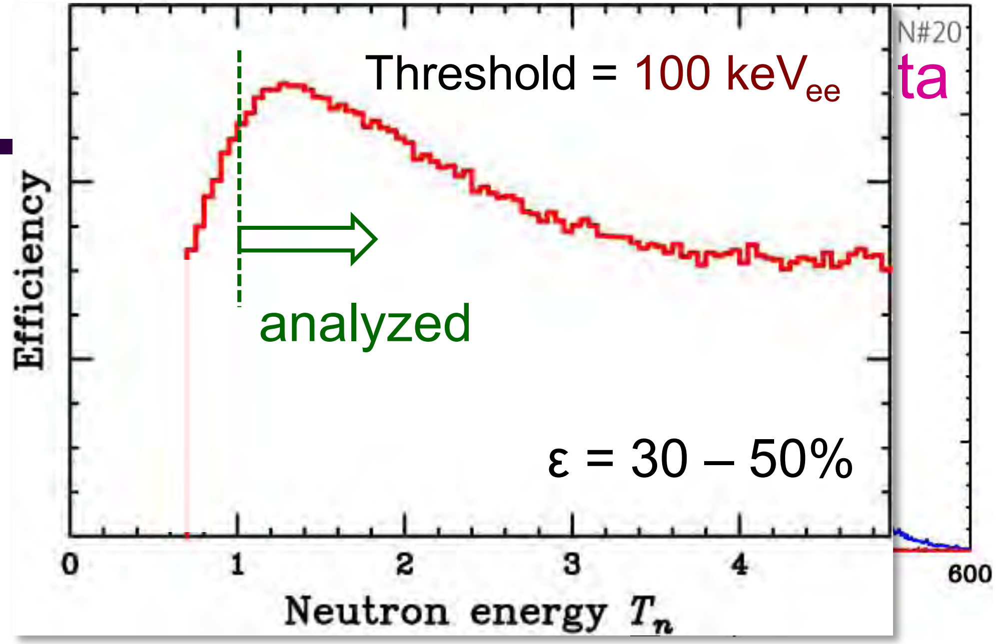
- 59 plastic scintillators (H7195 + BC408, 60 x 10 x 3 cm^3)
- θ = 60-120° , FPL = 180 cm

δTOF(WINDS): ~ 1.5 ns

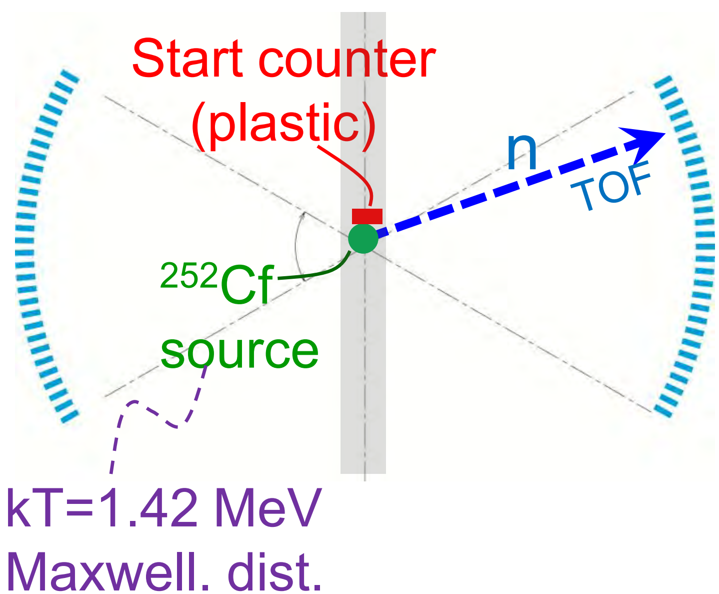
Calibration

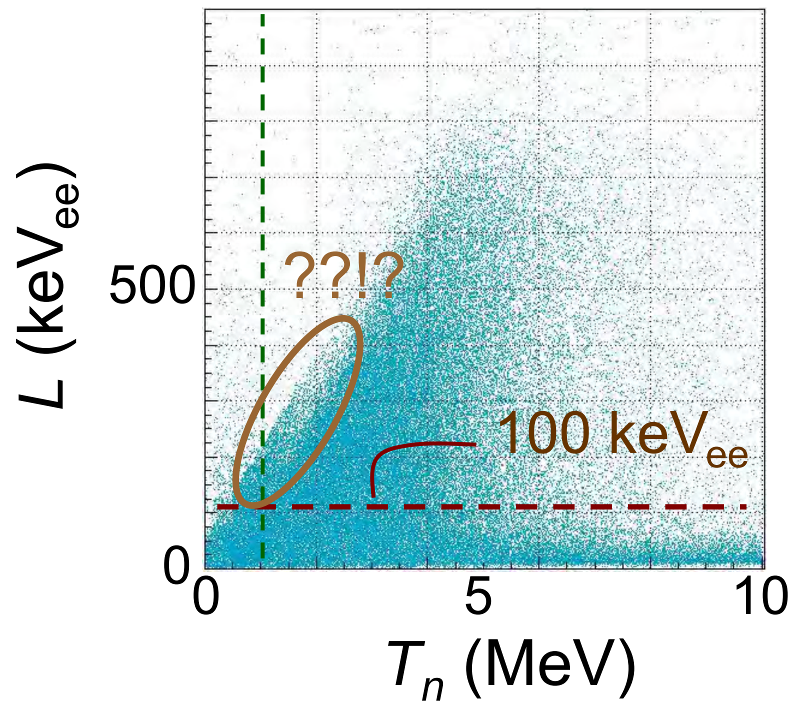
- Light output

$$L = \sqrt{Q_{up} Q_{down}}$$



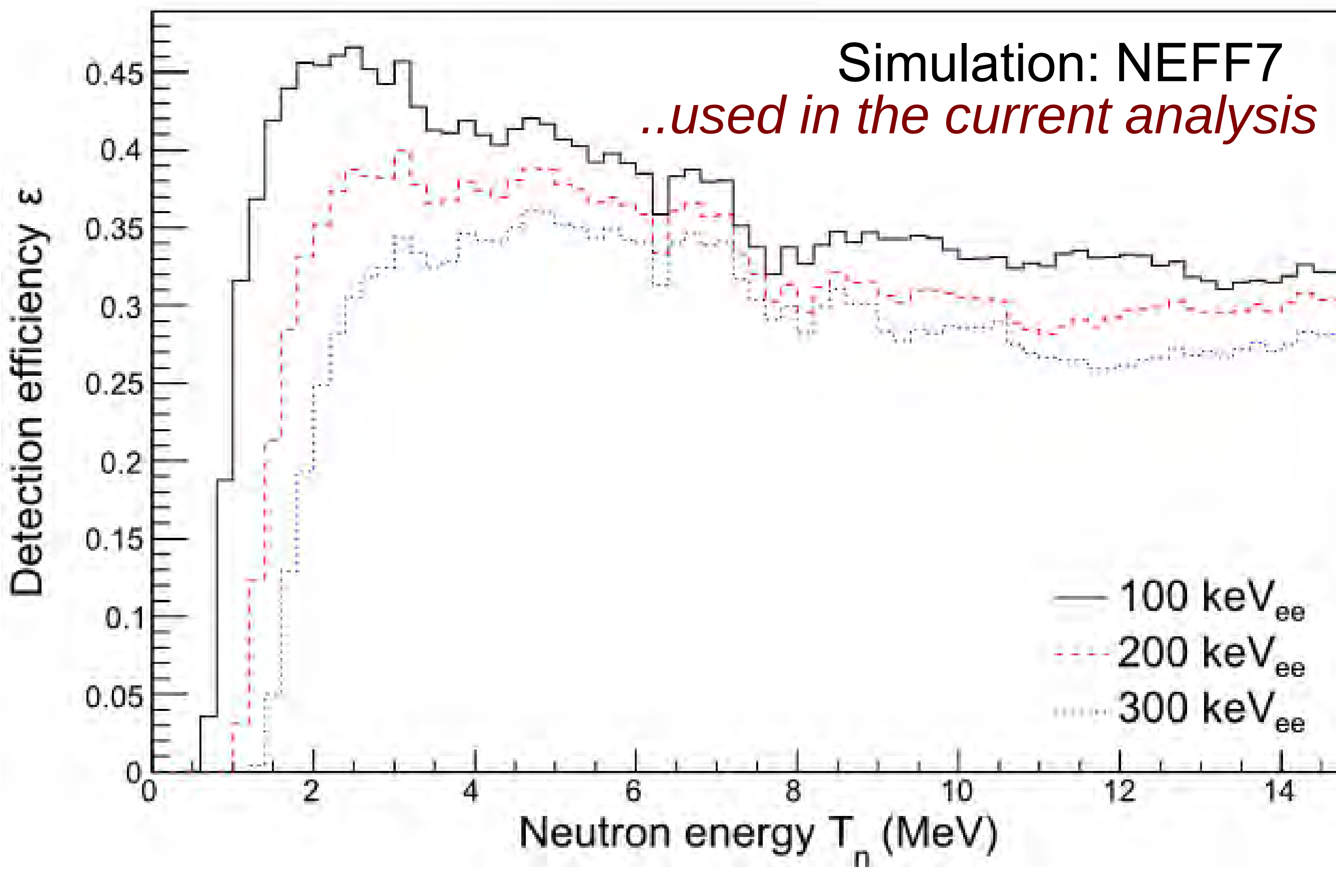
- Efficiency (^{252}Cf)

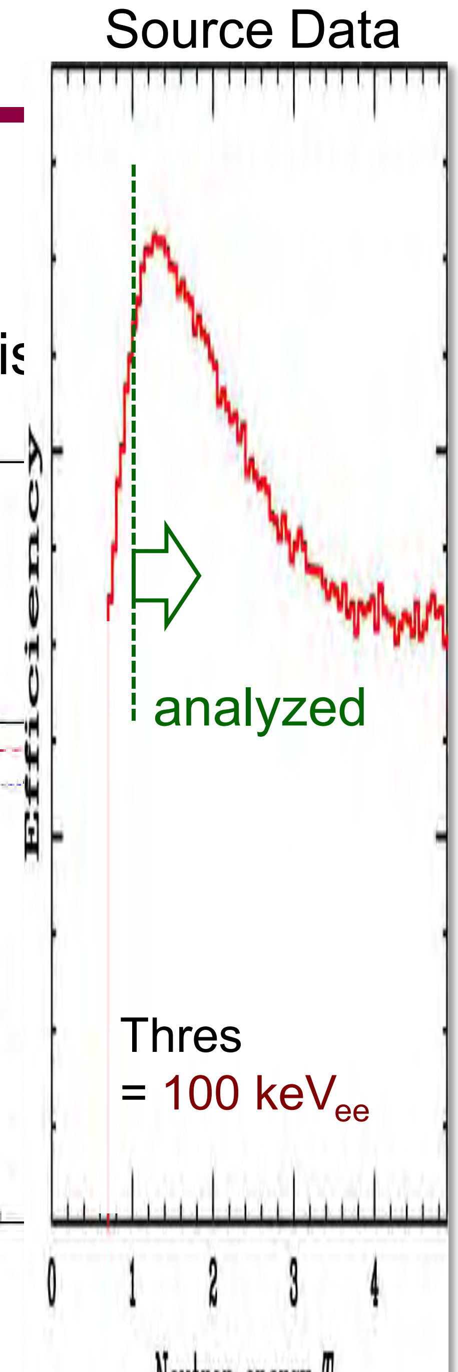




Efficiency … not well understood.

- Efficiency for low energy neutron seems to be underestimated.
- Current data analysis at T_n< 2 MeV (< 6 deg) is not reliable.





First experiment: ^{12}Be(p,n) reaction

- Beam line: BigRIPS + SHARAQ
- Primary beam: ^{18}O 250A MeV, 100-200 pnA
  - ¼ -freq. buncher @RILAC… pulse separation of 122 ns
- Primary target: Be, 20 mm^t
- Secondary beam: ^{12}Be 200A MeV,
  0.5 – 1 Mcps on target
  beam size Δx = 7 mm (in σ)
  Δy = 5 mm
- Secondary target: Liq H_2, 14 mm^t

SHARAQ

SHARAQ …high-resolution magnetic spectrometer constructed at RIBF by UT - RIKEN collaboration.

Maximum rigidity

6.8 Tm

Momentum resolution

d*p*/*p* = 1/14700

Angular resolution

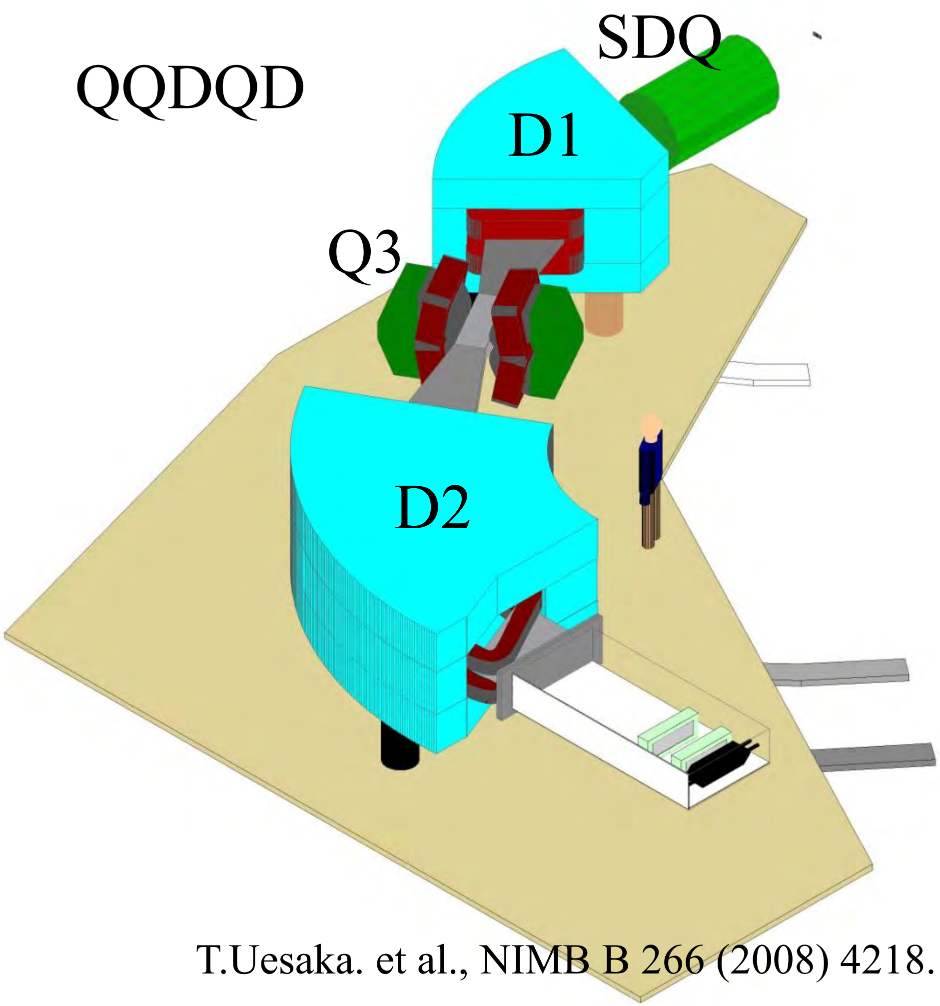
~ 1 mrad

Momentum acceptance

± 1%

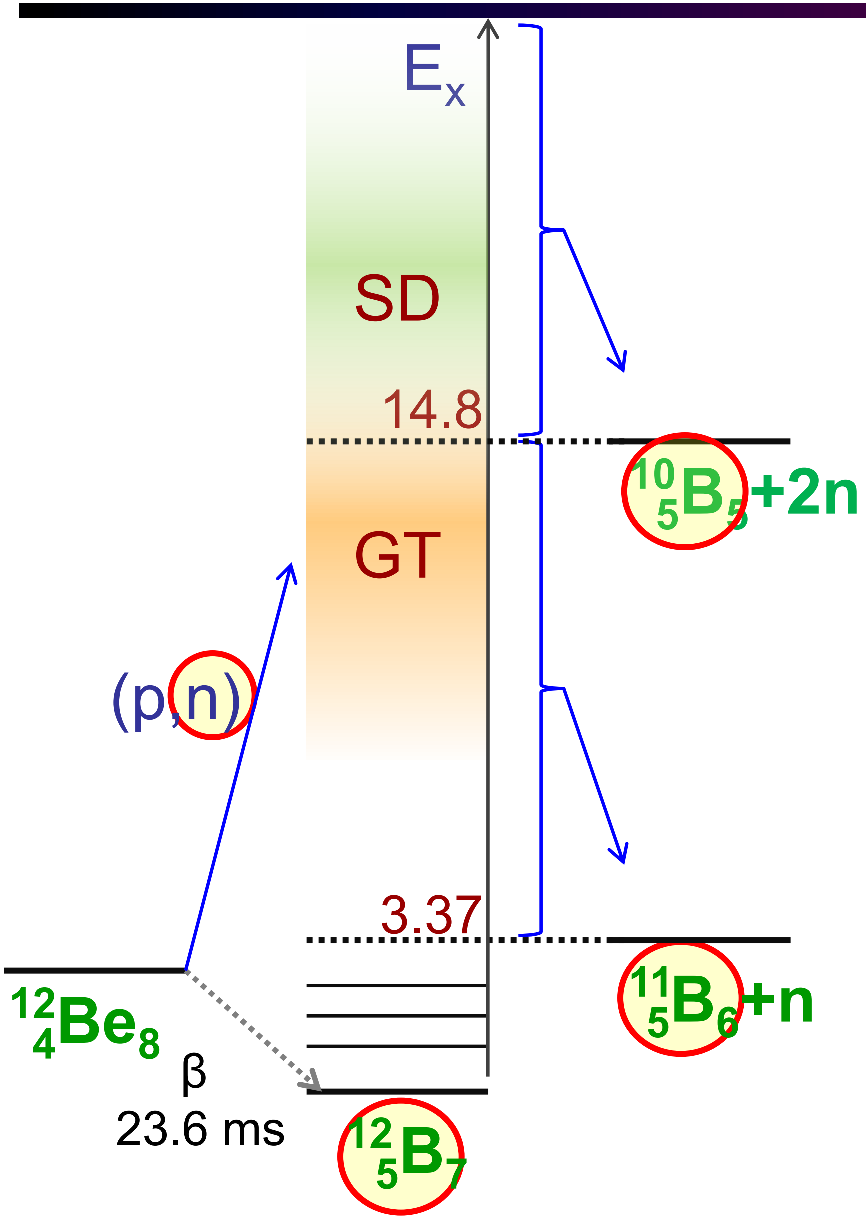
Angular acceptance

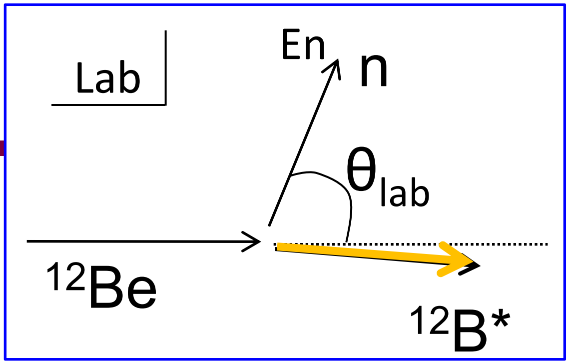
~ 5 msr



T.Uesaka. et al., NIMB B 266 (2008) 4218.

Coincidence measurement



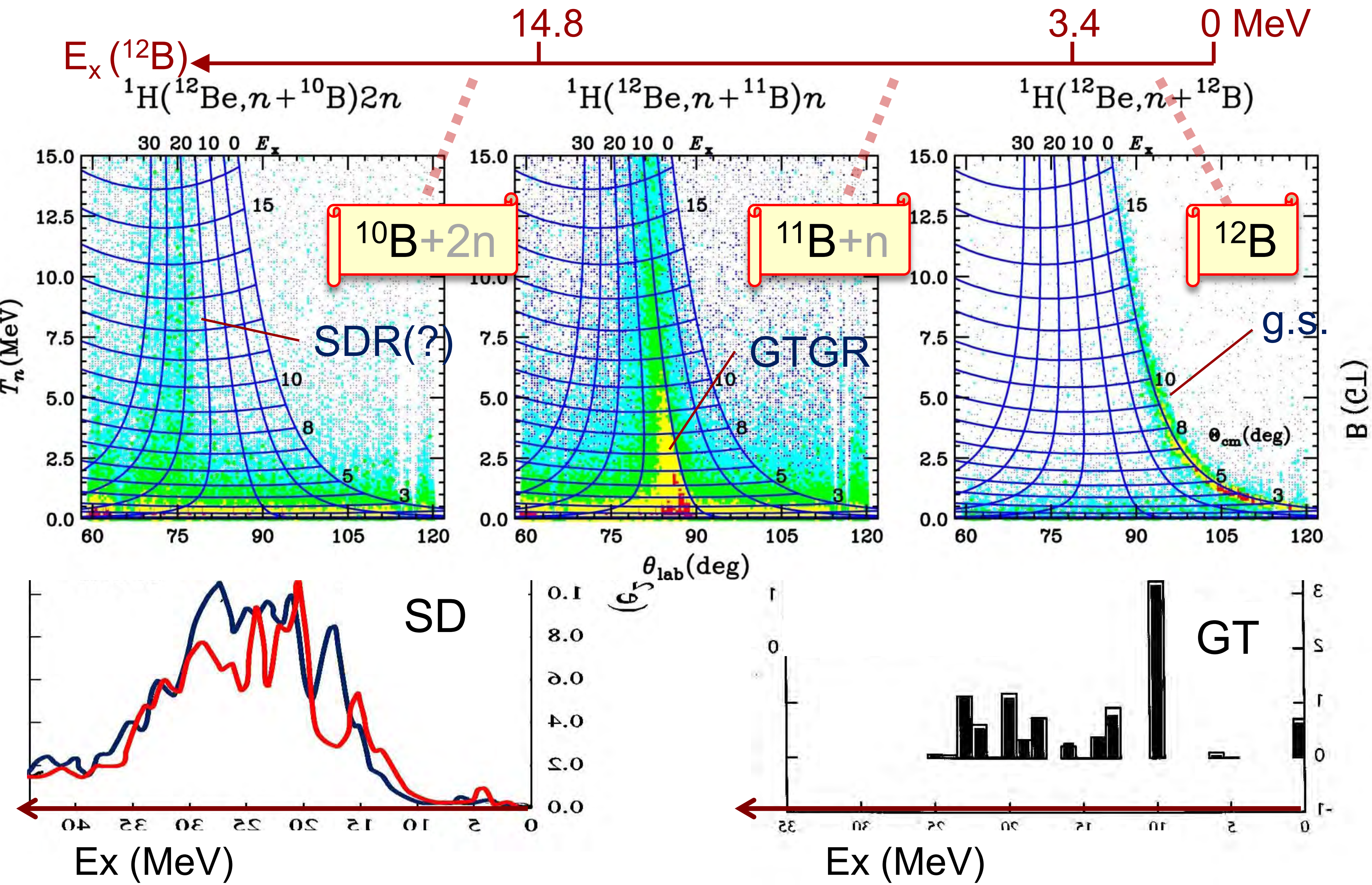


Improvement of S/N :

Coincidence with the residual particle

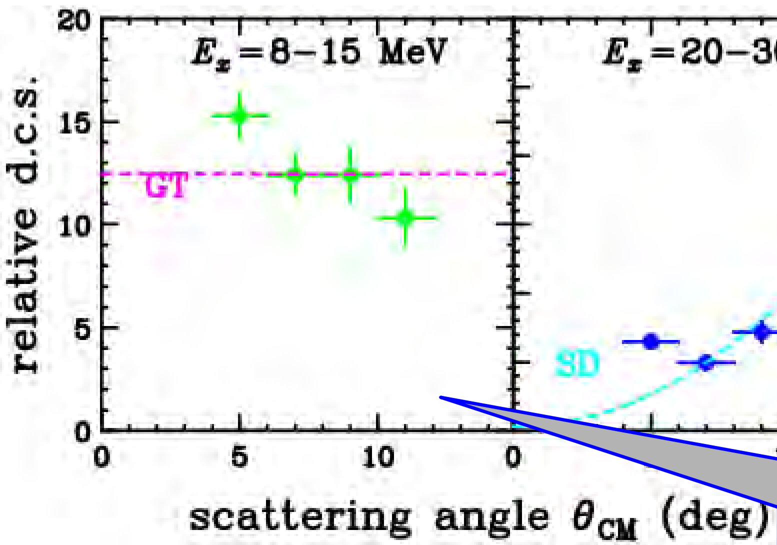
- $0 < E_x < 3.4$ MeV → ^{12}B & n
- $3.4 < E_x < 14.8$ MeV → ^{11}B & n
- $E_x > 14.8$ MeV → ^{10}B & n

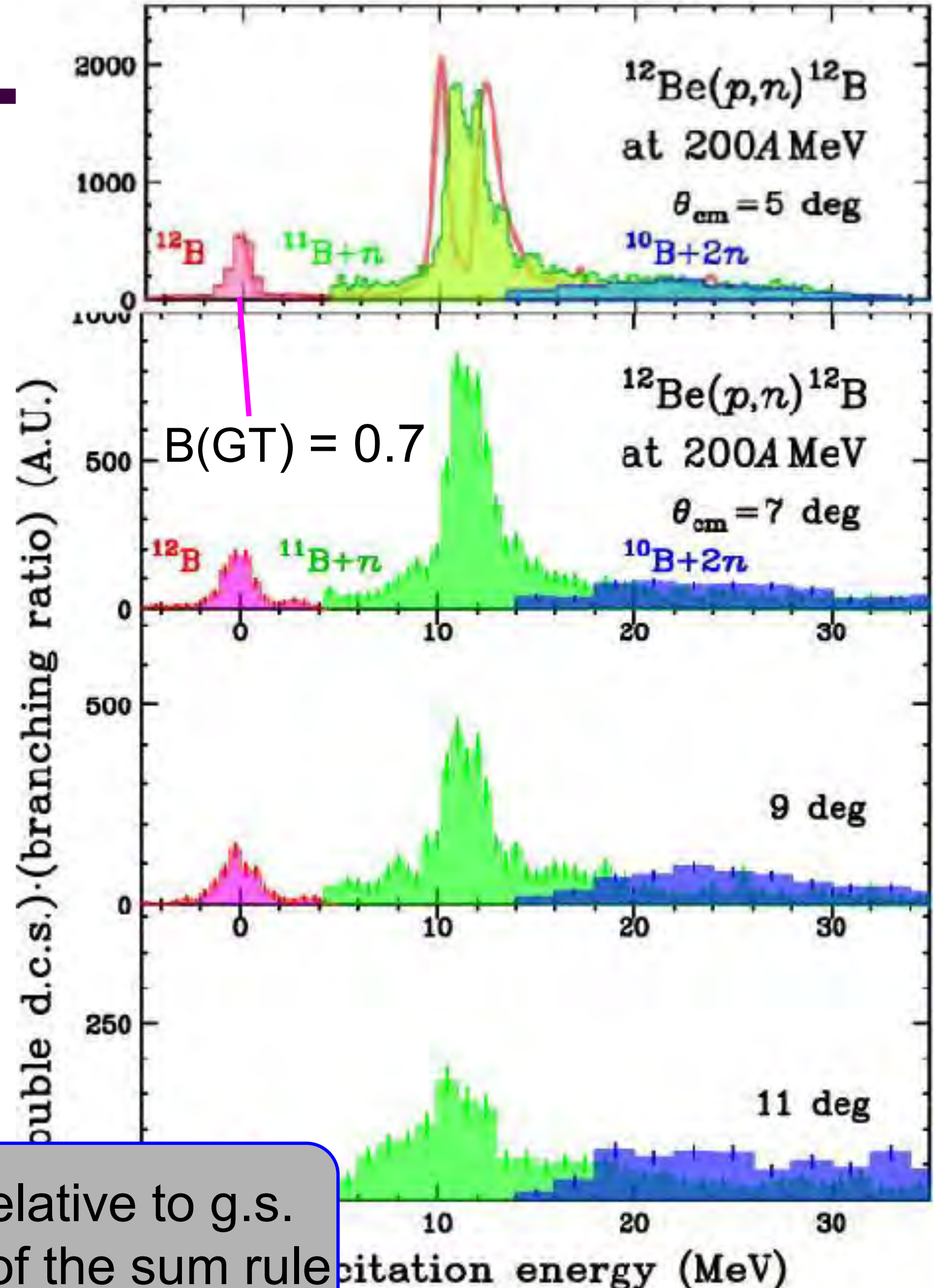
Semi-Online spectra



^{12}Be(p,n) Spectra

- GTGR at E_x = 10-14 MeV
- SM calculation: (Suzuki-san)
  SFO' $\Delta s_{1/2}$ = -0.3, 4ħω
- E_x = 20-30 MeV region contains SD (ΔL=1) component.



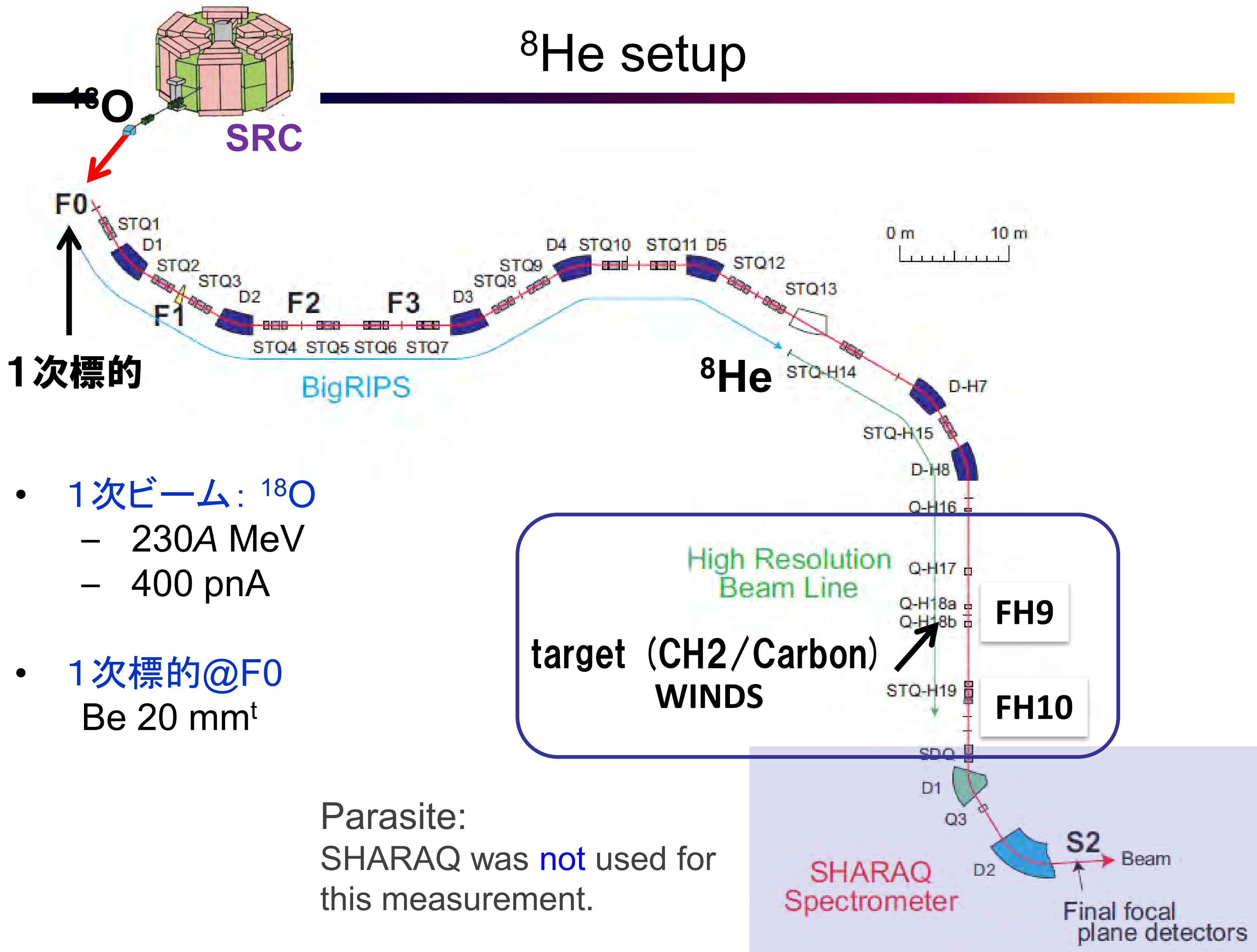


c.s. relative to g.s.
~80% of the sum rule

^{8}He

M. Kobayashi, S. Shimoura

^{8}He setup



- 1次ビーム: ^{18}O
  - 230*A* MeV
  - 400 pnA
- 1次標的@F0
  Be 20 mm^{t}

Parasite:
SHARAQ was not used for this measurement.

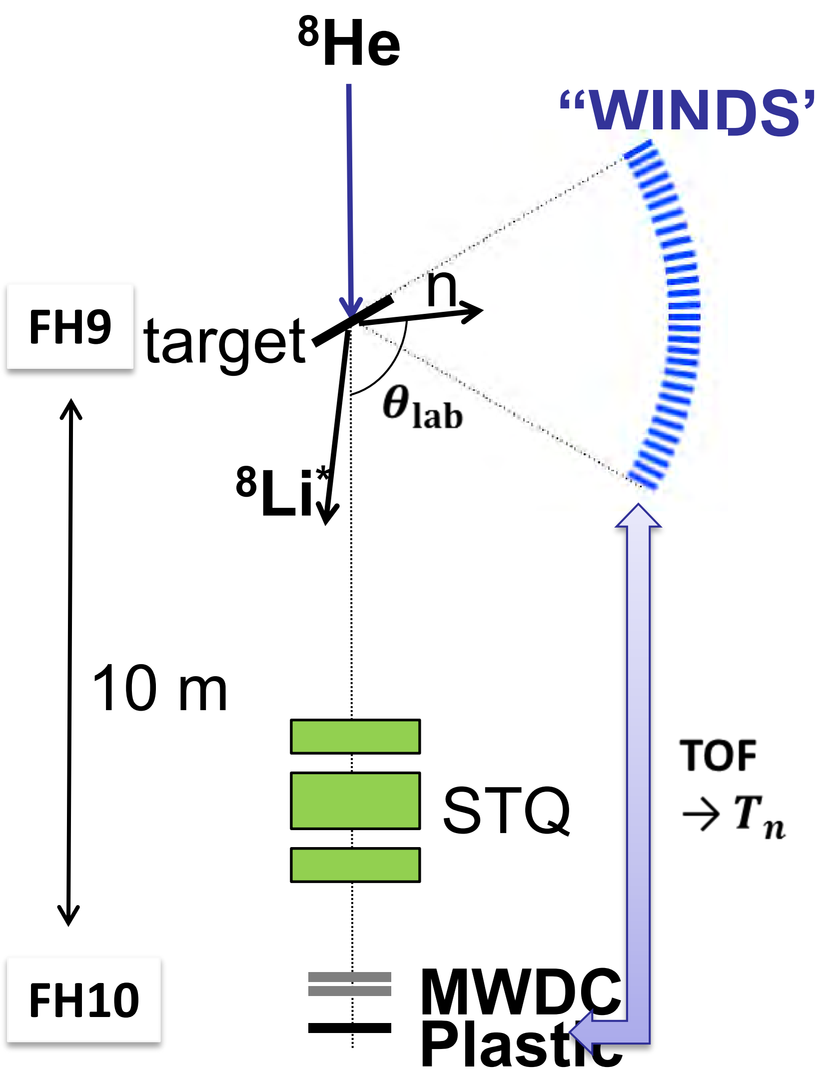
Targets, detection of residuals…

- Secondary beam: ^{8}He

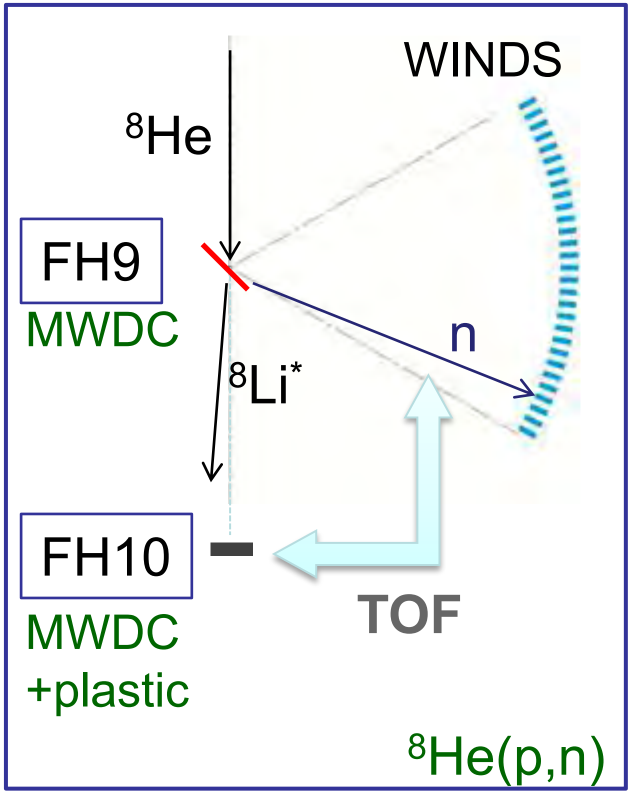
Energy	190A MeV
Beam intensity	2 Mcps

- Secondary target @FH9

Polyethylene (CH_2)	0.39 g/cm^2
Carbon	0.46 g/cm^2



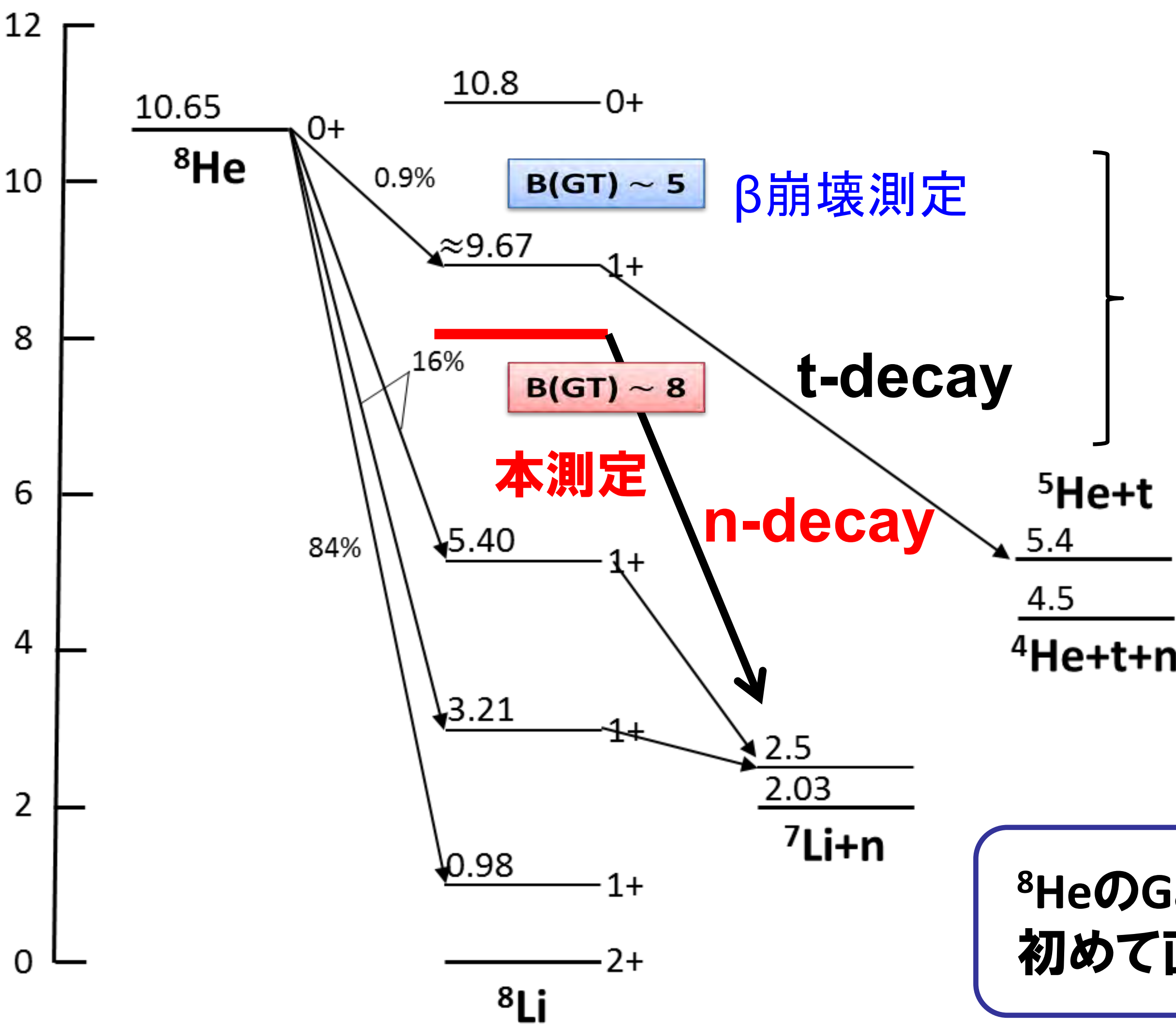
Difficulties overcome by Kobayayashi-san



- ☑ Only half of the WINDS counters
  → moved downstream by 3 cm
- ☑ Identification of residual: SHARAQ
  → Beamline detectors
- ☑ Beam prescaling: Hardware
  (= 1/4-freq. buncher)
  → software cut
- ☑ Secondary Target: LH_2 → (polyethylene)
  - (Carbon)

… allows
parasite measurements.

Gamow-Teller Resonance



cf. 和則値

$$3(N-Z)=12$$

GT遷移強度の大部分が Ex~ 8 - 9 MeV の共鳴状態に集中

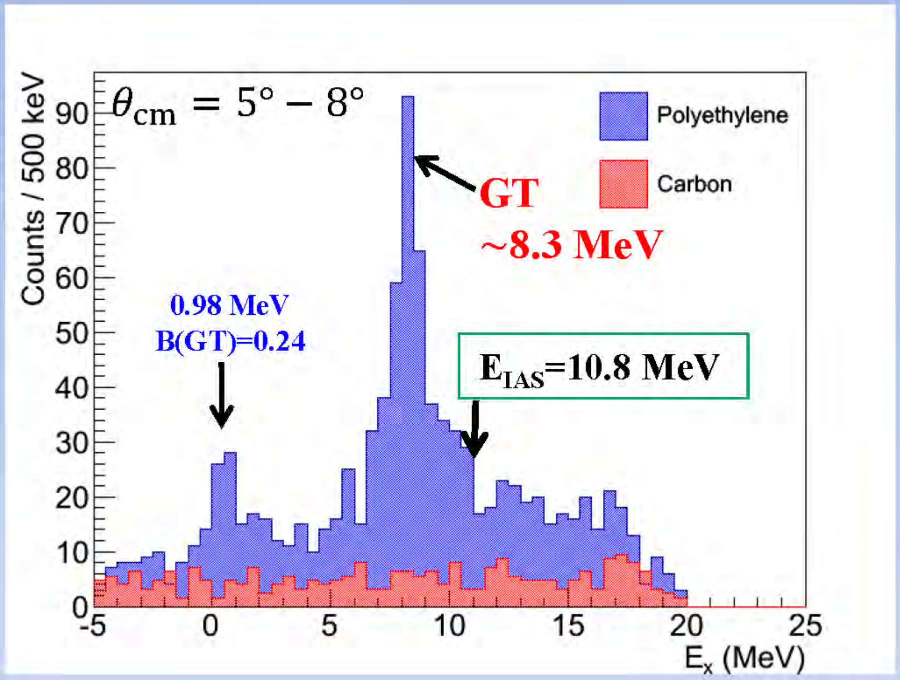
↓

Gamow-Teller Resonance

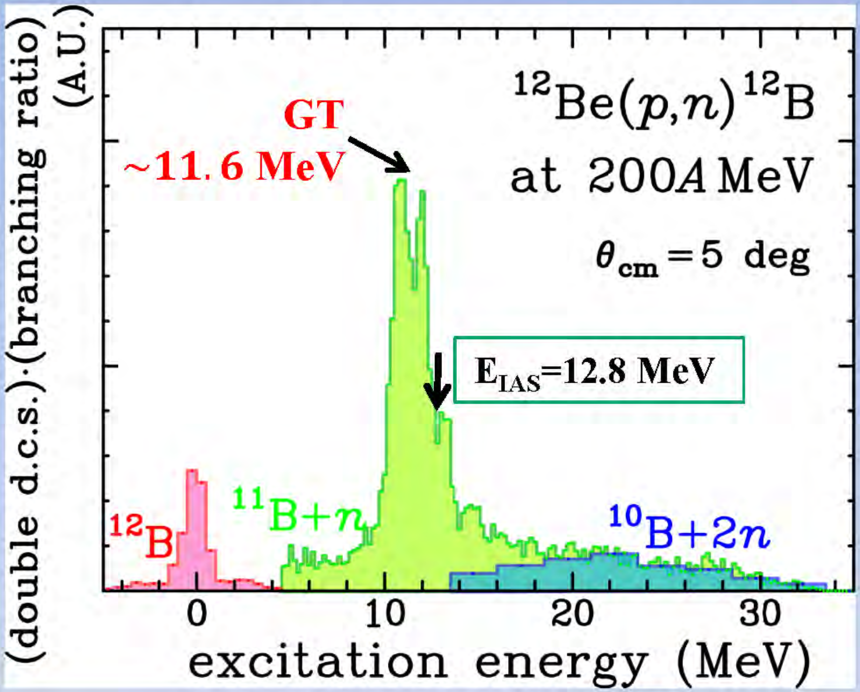
^{8}HeのGamow-Teller Resonanceを初めて直接的に観測した

Results

- $^{8}He(p,n)$ at 200 MeV/u



- $^{12}Be(p,n)$ at 200 MeV/u

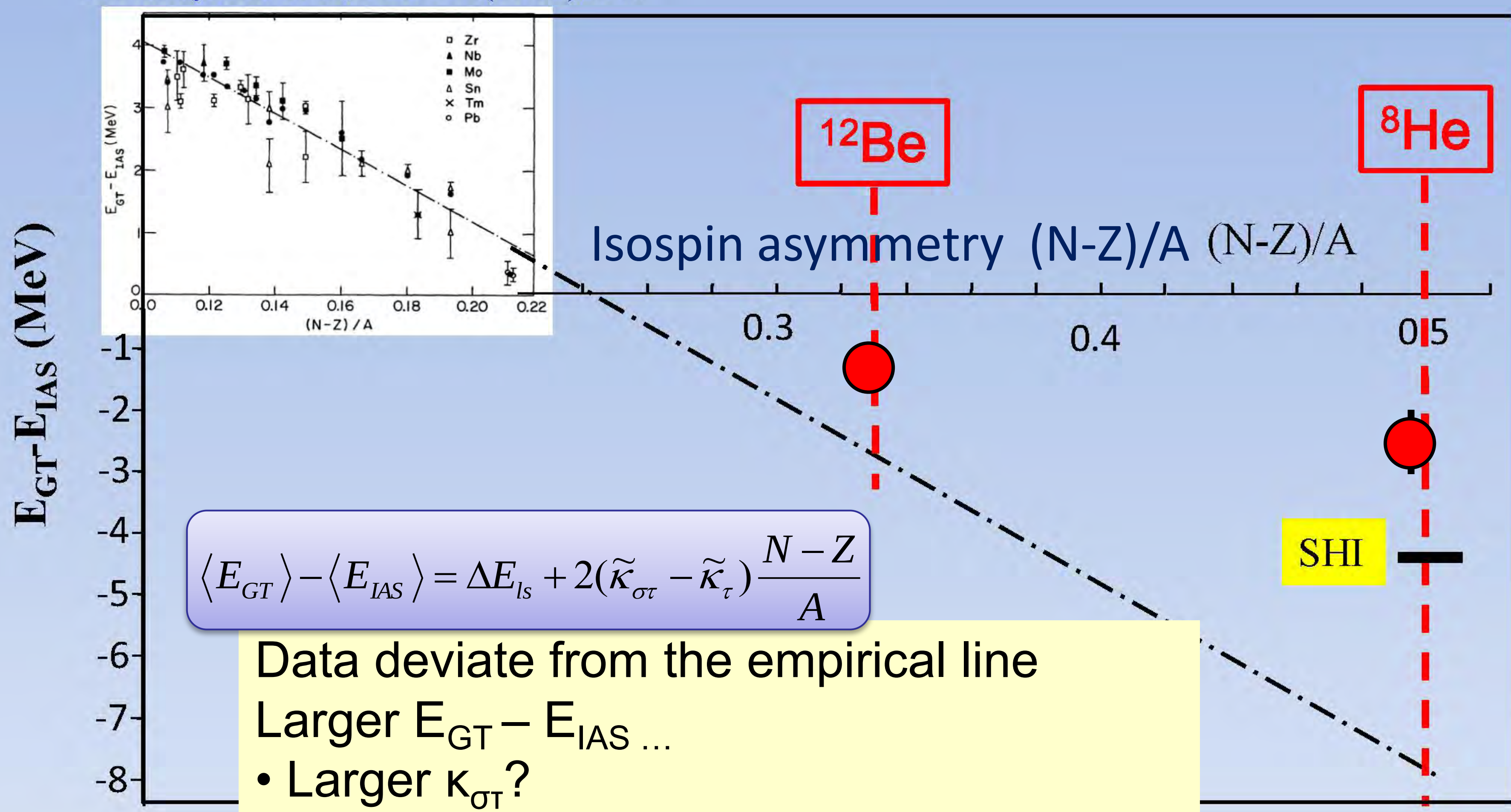


$$E_{GT} - E_{IAS} = -2.5 \pm 0.5 \text{ MeV}$$

$$E_{GT} - E_{IAS} = -1.2 \pm 0.4 \text{ MeV}$$

Collectivity in (N-Z)/A > 0.21: Very neutron rich nuclei

K.Nakayama et al, PLB114(1982)217.



$$\langle E_{GT} \rangle - \langle E_{IAS} \rangle = \Delta E_{ls} + 2(\tilde{\kappa}_{\sigma\tau} - \tilde{\kappa}_{\tau}) \frac{N-Z}{A}$$

Data deviate from the empirical line

Larger $E_{GT} - E_{IAS}$ …

- Larger $\kappa_{\sigma\tau}$?
- Is ΔE_{ls} (= - 20l·sA$^{-2/3}$ MeV) treated right?
- Some structural effects not described in the model

Summary

- GTGRs were measured for ^{8}He and ^{12}Be at SHARAQ-WINDS.

- GTGRs for these nuclei were observed for the first time.
  - E_{GT}-E_{IAS} = -2.5 MeV (^{8}He), -1.2 MeV(^{12}Be)
    …negative values
  - Data deviate from the empirical line by Nakayama.

Inverse kinematics (p,n) measurements at RIBF

Measurement done

- ^{8}He, ^{12}Be
- ^{132}Sn (SAMURAI) Sasano-Zegers

Beamtime approved

- ^{48}Cr (SAMURAI) Sasano

Planned~suggested

- ^{52}Fe(12+) isomer
- ^{14}Be((N-Z)/A = 0.43), $^{20,\,22}$C(0.40, 0.46), ^{24}O(0.33) (Sakai)
- ^{22}O, ^{24}O, and more (Sasano)