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Seattle

Study of Spin-isospin Responses in the Continuum by Charge-Exchange Reactions

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Contents

1 How reliable are the spin-isospin responses in the continuum extracted by the nucleon CHEX reactions ?

- Measurement, analysis and associated uncertainties
  - ✓MDA
  - ✓unbound transition (shallow binding approx.) ?
  - ✓L=0, L=2 and their interference effect ?
  - ✓interference between GT and IVSM ?
  - ✓proportionality ?

2 How are they in the case of composite projectiles ?

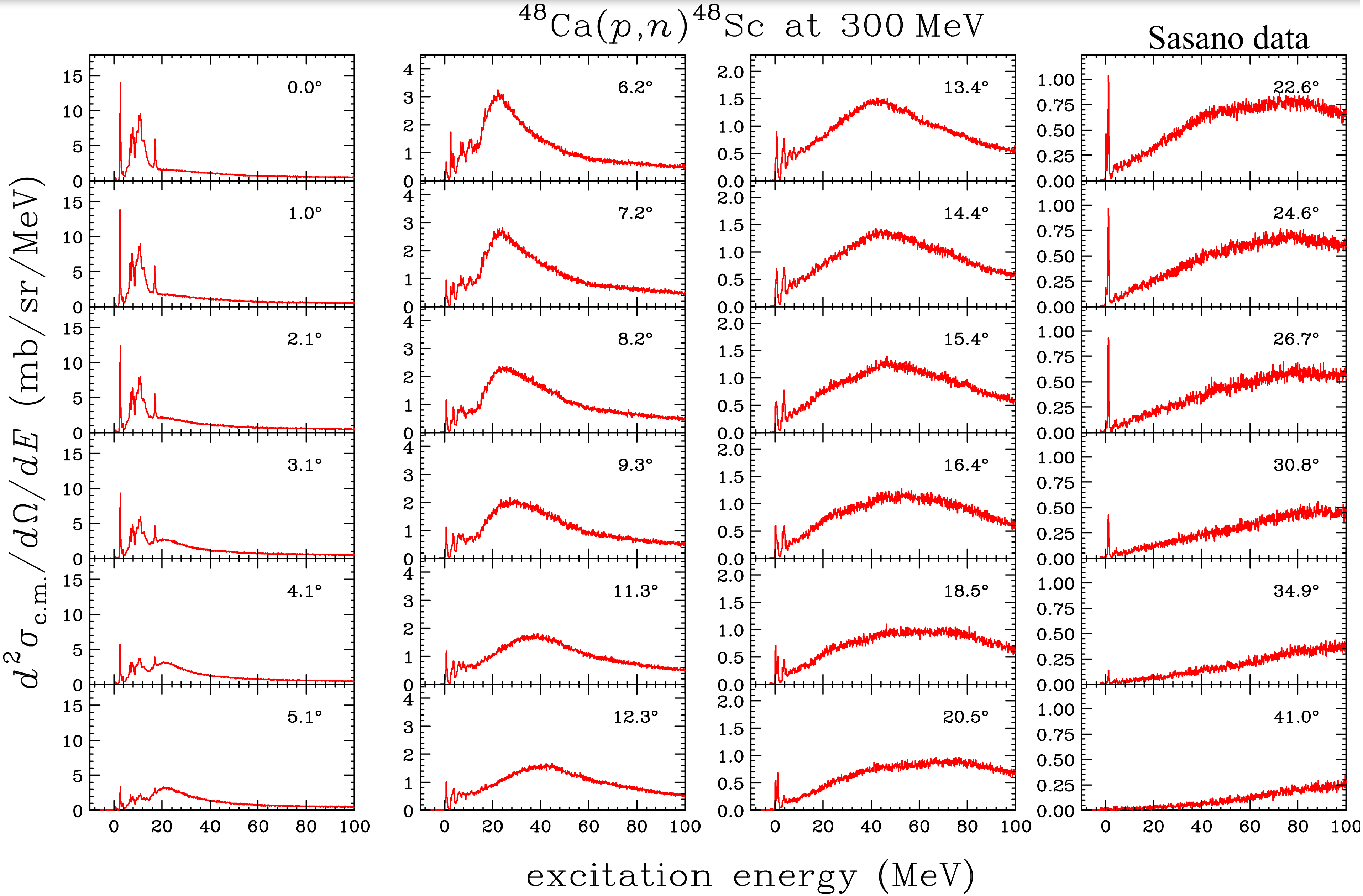
- (t,^{3}He,) reaction: measurement by Miki
  - ✓Exchange effects
- (^{12}N,^{12}C) reaction: measurement by Noji
  - ✓Ambiguities by optical potentials(imaginary part)

3 Brand-new: measurement of the exothermic ^{12}Be(p,n) reaction in inverse-kinematics at 200 MeV/A by Yako

- *– observation of GT giant resonance and SDR –*

4 Summary and home works for theorists

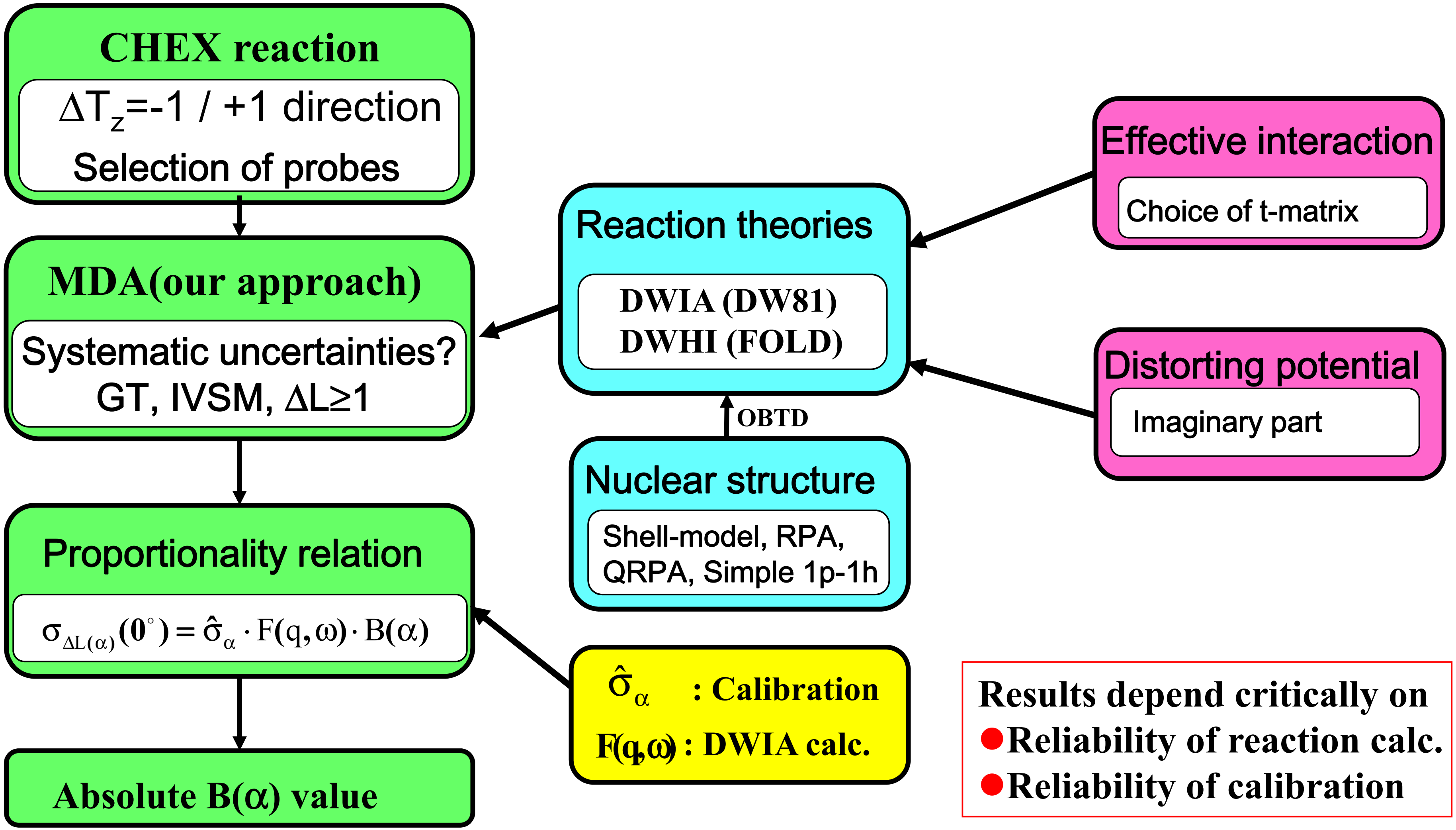
$^{48}Ca(p,n)$ data



48Ca(p,n)48Sc at 300 MeV
Sasano data
d2σc.m./dΩ/dE (mb/sr/MeV)
excitation energy (MeV)
0.0°
1.0°
2.1°
3.1°
4.1°
5.1°
6.2°
7.2°
8.2°
9.3°
11.3°
12.3°
13.4°
14.4°
15.4°
16.4°
18.5°
20.5°
22.6°
24.6°
26.7°
30.8°
34.9°
41.0°

How to cook the continuum ?

Example: spin-isospin responses



Multipole Decomposition Analysis

$$\sigma^{\exp}(\theta_{cm}, E_x) \approx \sum_{J^\pi} a_{J^\pi} \sigma^{calc}_{ph;J^\pi}(\theta_{cm}, E_x)$$

DWIA

$$\Delta L = 0, 1, 2, 3 \quad [J^\pi = 1^+, (0^-, 1^-, 2^-), (2^+, 3^+), 4^-]$$

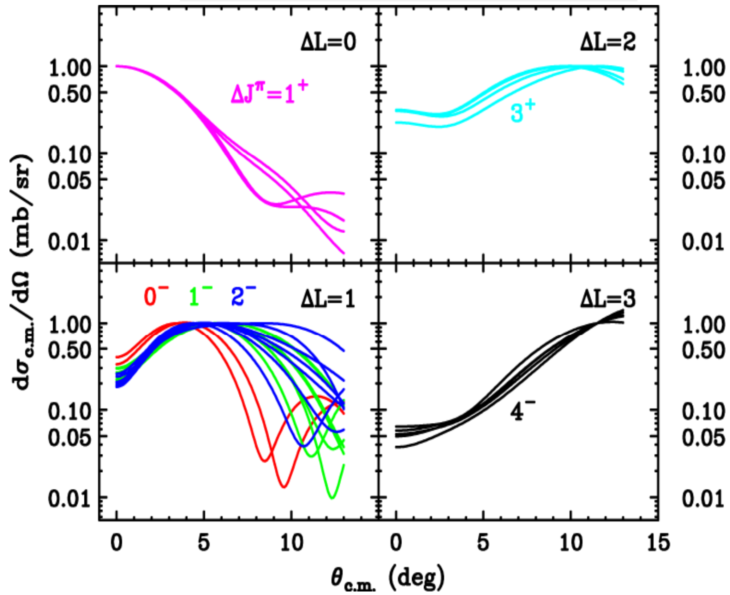
DWIA inputs

- NN interaction:
  t-matrix by Franey & Love @325 MeV
- optical model parameters:
  Global optical potential
  (phenomenological, Cooper et al.)
- one-body transition density:
  pure 1p-1h configurations

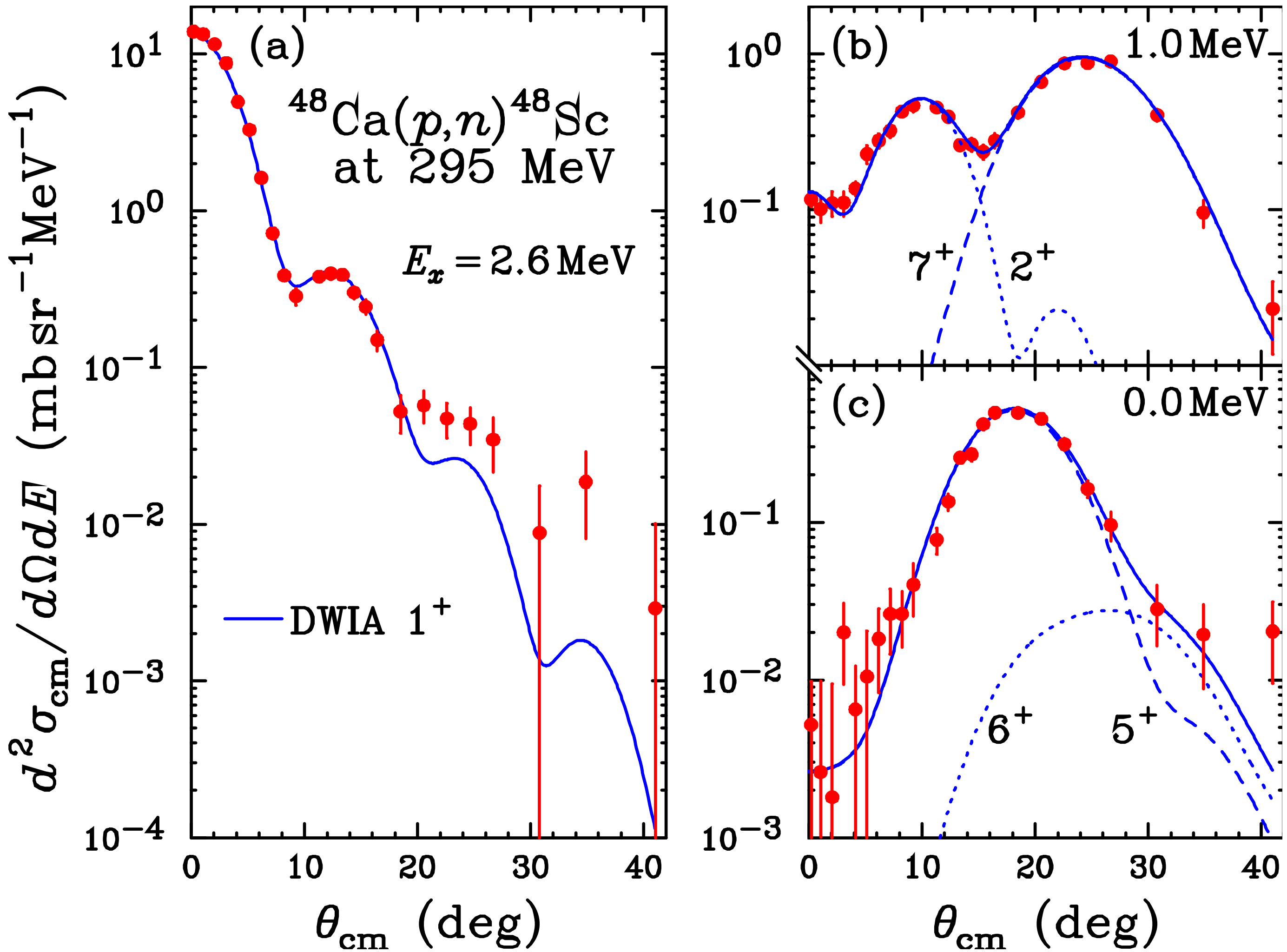
Particle:	1f, 2p, 1g, 2d, 3s, 1h11/2
Hole:	1p, 1d, 2s, 1f

radial wave functions … W.S. / H.O.

^{48}Ti(n,p) angular dist.
E_x = 20 MeV

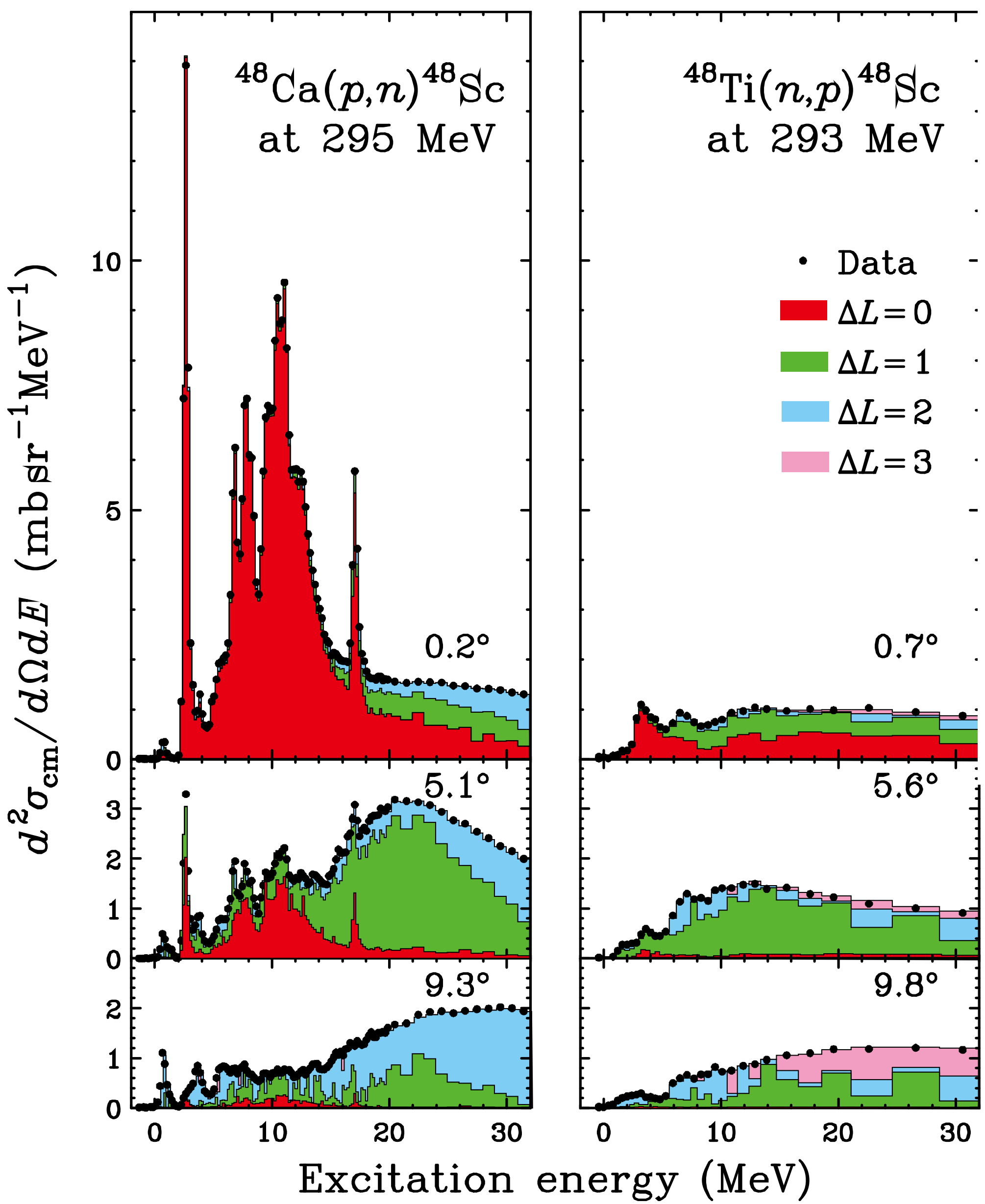


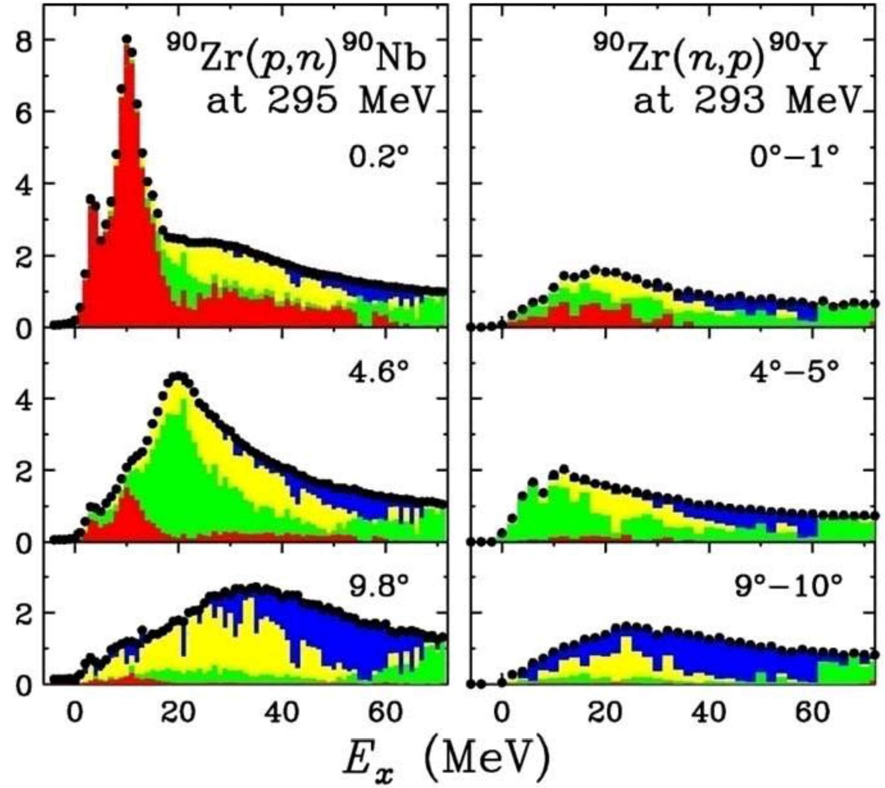
How well does DWIA reproduce data ?

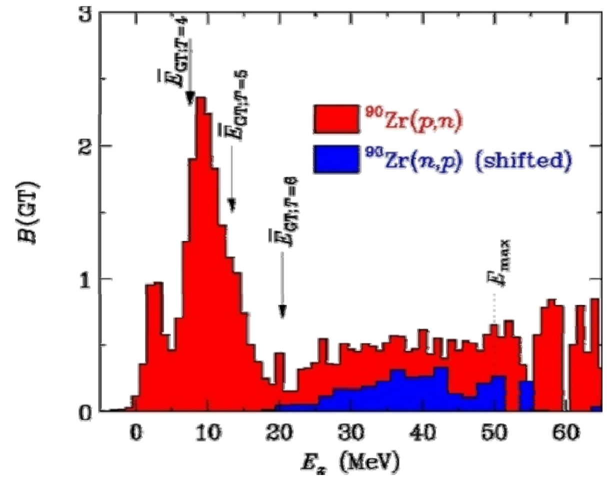


Reproduce very well at least low Ex !

Decomposed spectra







Uncertainties in GT strength by Yako

^{90}Zr(p,n)/(n,p) cases

		S^- (30.6)	S^+ (3.0)	$S^- - S^+$ (27.6)	Q (0.92)
statistical		0.5	0.4	0.6	0.02
systematic	c.s. data	1.3	0.3	1.4	0.05
	unit c.s.	1.5	0.1	1.4	0.05
	MDA*	0.5	0.3	0.3	0.01
	IVSM*	0.9	0.3	0.7	0.02

* : estimated within the 'standard' DWIA framework

- optical models: (contribution = 0.2 for S^- MDA)
  phenomenological… EDAIZr(Cooper), n-global(Shen),
  folding… RH-RIA(Horowitz), DParis(von Geramb)
- radial w.f.:(0.2)
  Woods-Saxon, Harmonic Oscillator, wine-bottle shapes
- effective NN interaction:(0.3)
  Franey-Love @ 325 MeV & 270 MeV

Uncertainties besides cross section of data

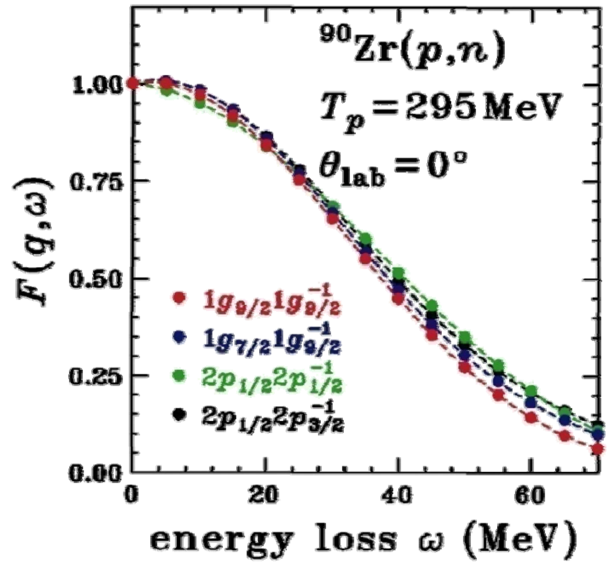
- unit cross section
- proportionality?
- unbound transition (shallow binding approx.) ?
- L=0, L=2 and their interference effect ?
- interference between GT and IVSM ?

Proportionality (relation between $\sigma_{\Delta L=0}$ and B(GT))

$$\sigma_{\Delta L=0}(0^\circ) = \hat{\sigma}_{GT} \cdot F(q,\omega) \cdot B(GT)$$

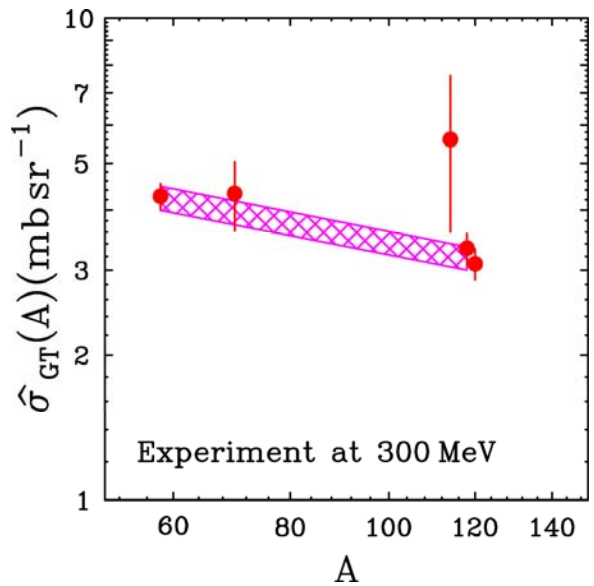
$$\sigma_{\Delta L=0}(q,\omega) \rightarrow B(GT)$$

- **F(q,w): kinematical correction**
  (q,w) → (0,0)
  estimated by DWIA calc.



- **$\hat{\sigma}_{GT}$: GT unit cross section**
  should be measured, not easy
  systematic study by Sasano
  PRC 79, 024602 (2009)

$$\hat{\sigma}_{GT}(A=48) = 4.69 \pm 0.40 \text{ mb/sr}$$



Same $\hat{\sigma}_{GT}$ is used for both (p,n) / (n,p).

Proportionality test by Sasano

$$\sigma_{\Delta L=0}(0^\circ) = \hat{\sigma}_{GT}\cdot F(q,\omega)\cdot B(GT)$$

Proportionality test by shell model

Exercise by using:

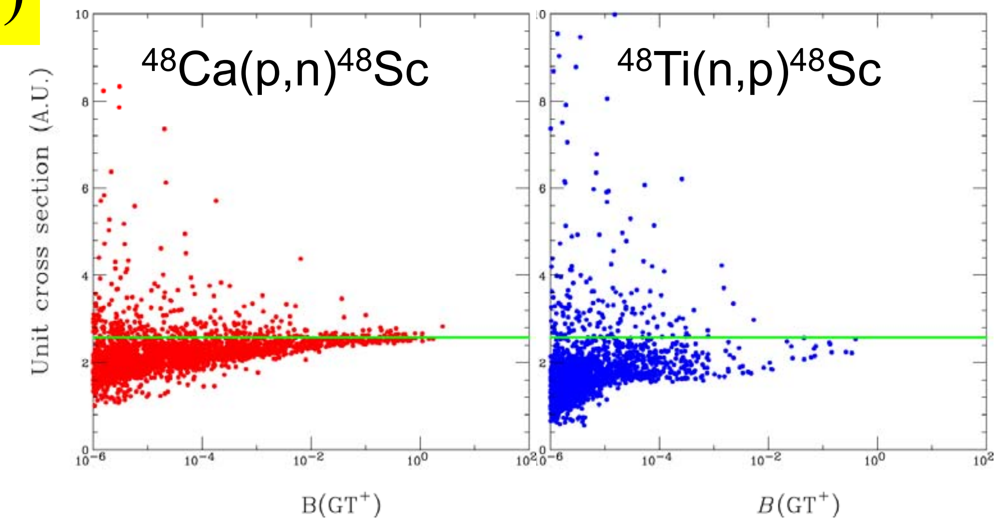
- ^{48}Ca--^{48}Ti system
- Shell model calculations
- Standard DWIA calc.

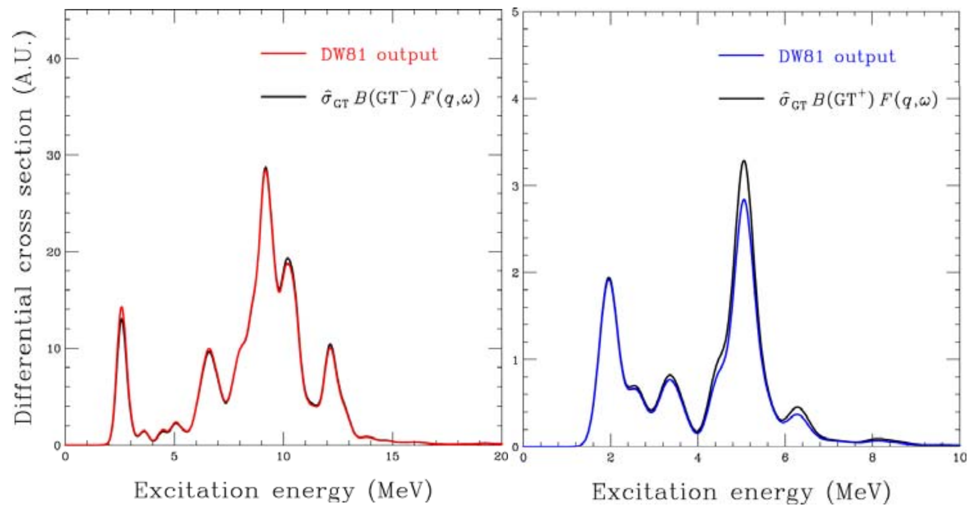
Deviations are large for small B(GT) for both sides.

↓

Averaging could work.

Retain the proportionality (optimistic hope ?!).



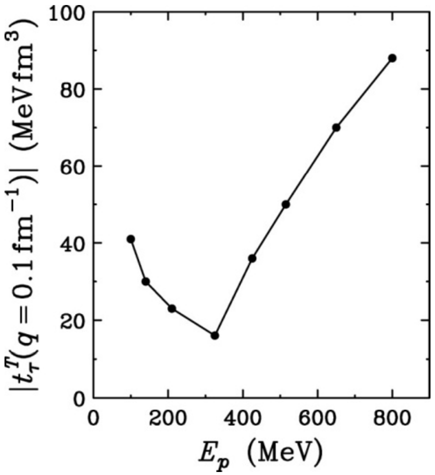


Proportionality test-2 by Sasano

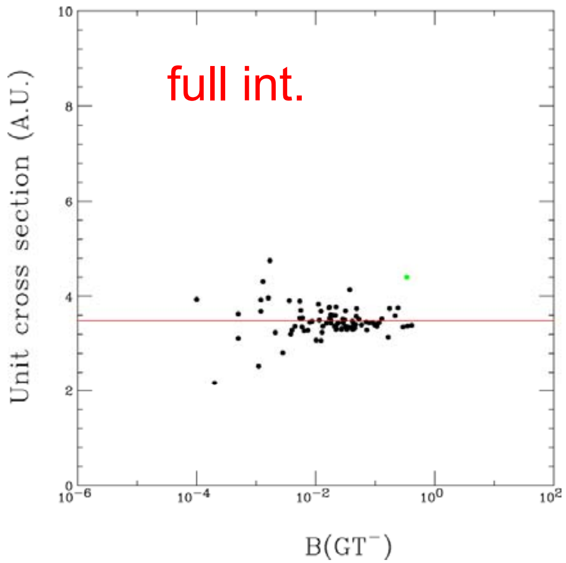
Effects by tensor interaction

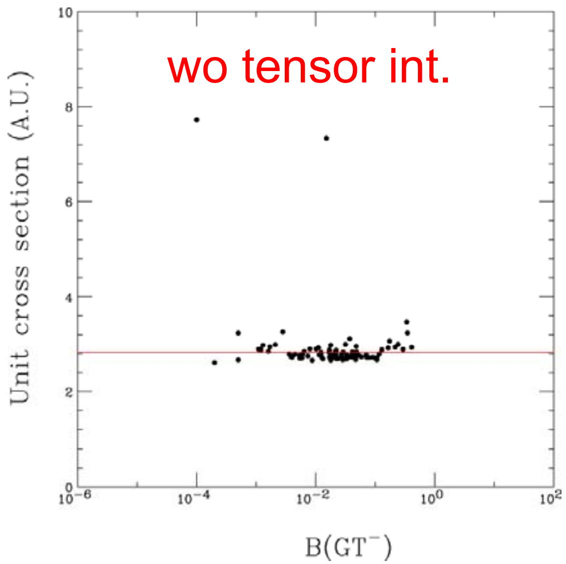
Exercise by using:
- ^{58}Ni system
- Shell model calculations
- Standard DWIA calc.
  with / without tensor interactions

Deviations are mainly due to the tensor interactions.



MDA might work best at 200-400 MeV.





Shallow binding approximation (exercise by Wakasa)

Continuum → unbound transition density

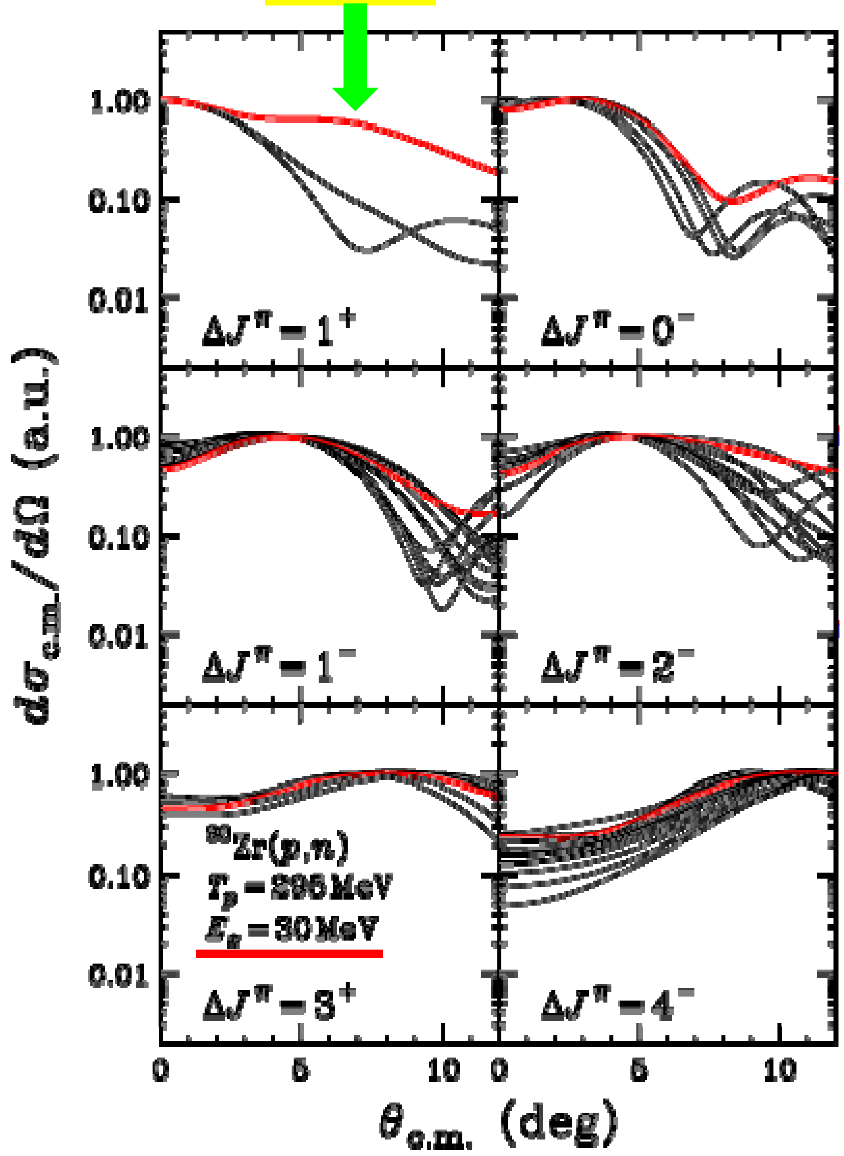
Customary shallow binding approx. is used.

Need to check the validity

- **crdw code by Ichimura et al.**
  Phys.Rev. C 63, 044609 (2001).
  - **DWIA + continuum RPA**

Shallow binding approx. seems to work well.

IVSM



Interferences

GT vs. IVSM

$$\sigma_{\Delta L=0} \propto \left| \langle \varphi_f | \langle \chi_f | V_{int} | \chi_i \rangle | \varphi_i \rangle \right|^2$$

$$\propto \left| \langle \varphi_f | C_{GT} O_{GT} + C_{IVSM} O_{IVSM} | \varphi_i \rangle \right|^2$$

$$\propto \underbrace{\left| \langle \varphi_f | C_{GT} O_{GT} | \varphi_i \rangle \right|^2}_{\sigma_{GT}} + \underbrace{\left| \langle \varphi_f | C_{IVSM} O_{IVSM} | \varphi_i \rangle \right|^2}_{\sigma_{IVSM}} + \underbrace{2\,\mathrm{Re}\left(\langle \varphi_i | C^*_{IVSM} O^*_{IVSM} | \varphi_f \rangle \langle \varphi_f | C_{GT} O_{GT} | \varphi_i \rangle \right)}_{\sigma_{int'f}\text{ : interference}}$$

● **1^+ state consists of:**

$$\left| 1^+ \right\rangle = \left| \mathrm{GT}; \Delta S = 1, \Delta L = 0(2),\ 0\hbar\omega \right\rangle$$
$$+ \left| \mathrm{IVSM}; \Delta S = 1, \Delta L = 0,\ 2\hbar\omega \right\rangle$$
$$+ \left| \mathrm{SQR}; \Delta S = 1, \Delta L = 2,\ 2\hbar\omega \right\rangle$$

Strictly speaking:
$|0\ \hbar\omega>$ and $|2\ \hbar\omega>$ are
not orthogonal.

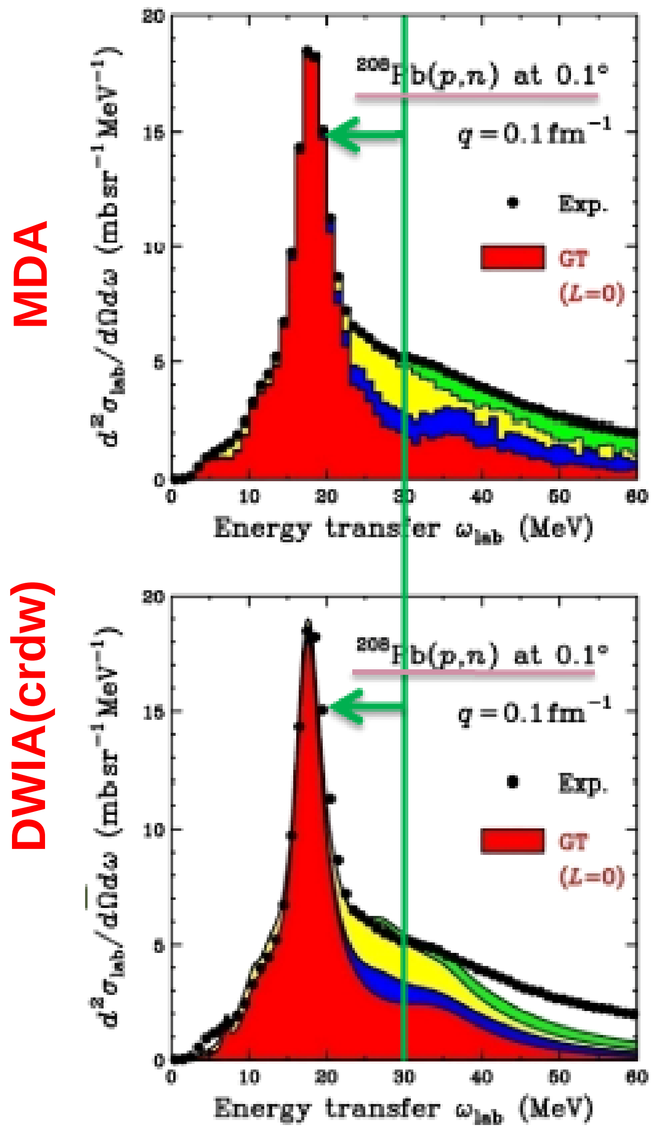
→In principle they all interfere!
→Two sources of interferences

1 △L=0 and △L=2 within a mode
2 mode interference; GT vs. IVSM

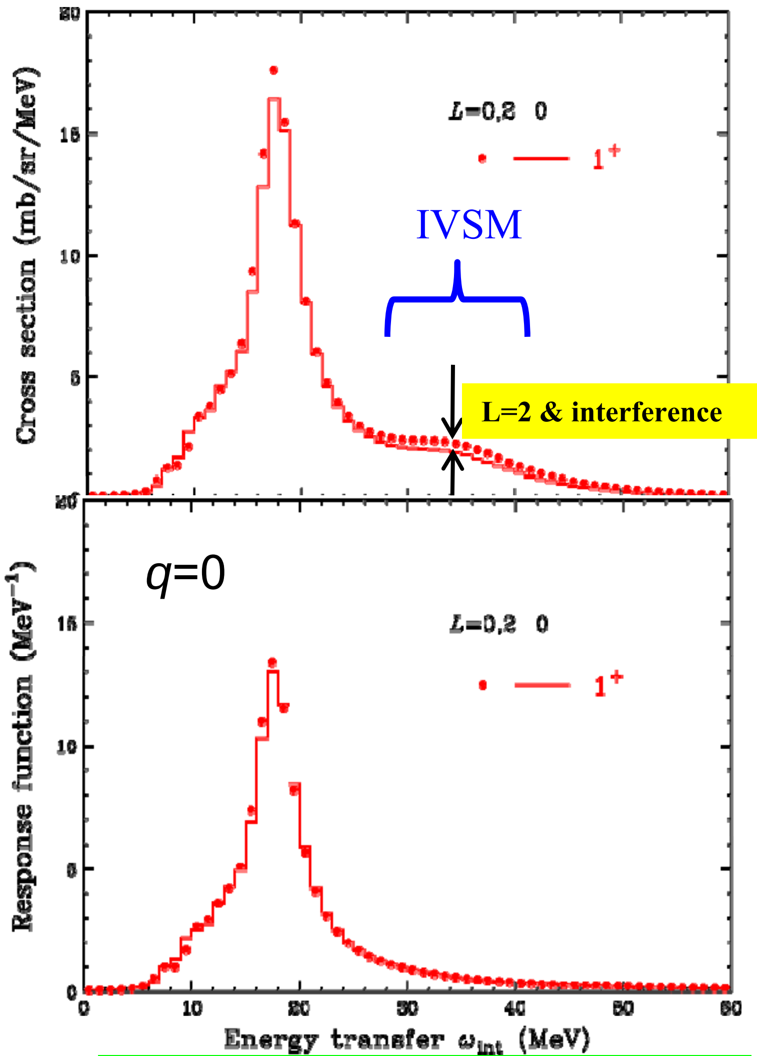
● **How to disentangle experimentally?**

L=0, L=2 and their interference (exercise by Wakasa)

MDA vs. DWIA for ^{208}Pb(p,n) 300 MeV



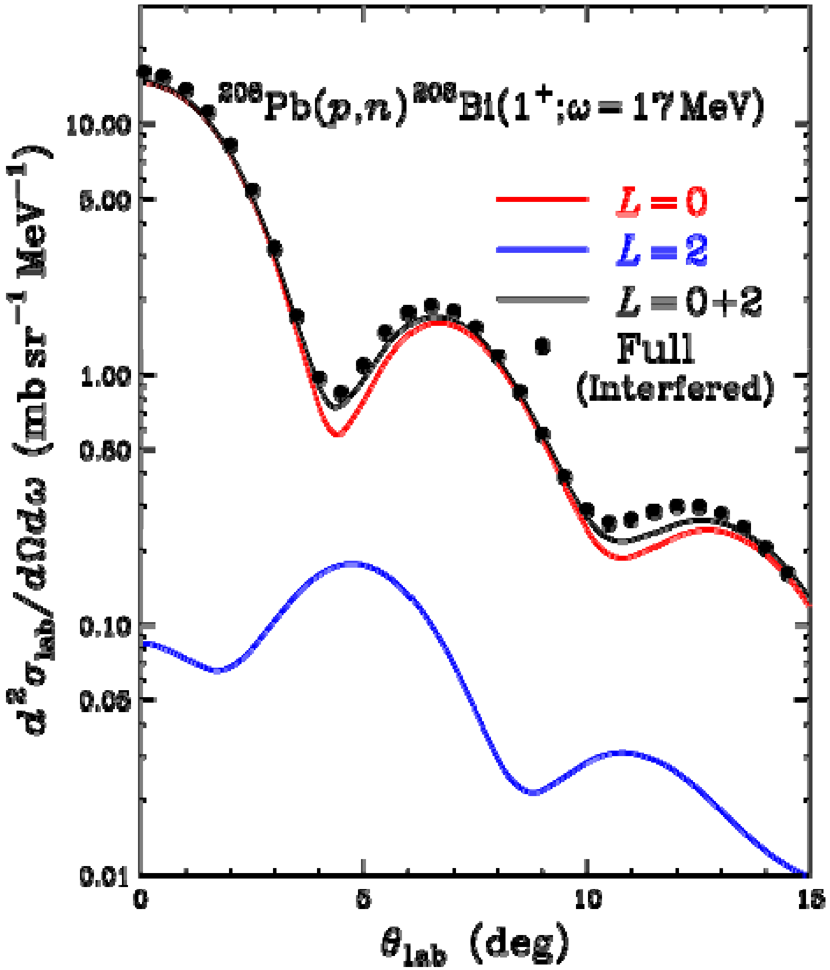
L=0, L=2 and interference



$J^{\pi}=1^{+}$ response consists of GT + IVSM + interference !

L=0, L=2 and their interference (exercise by Wakasa)

L=0, L=2 and interference



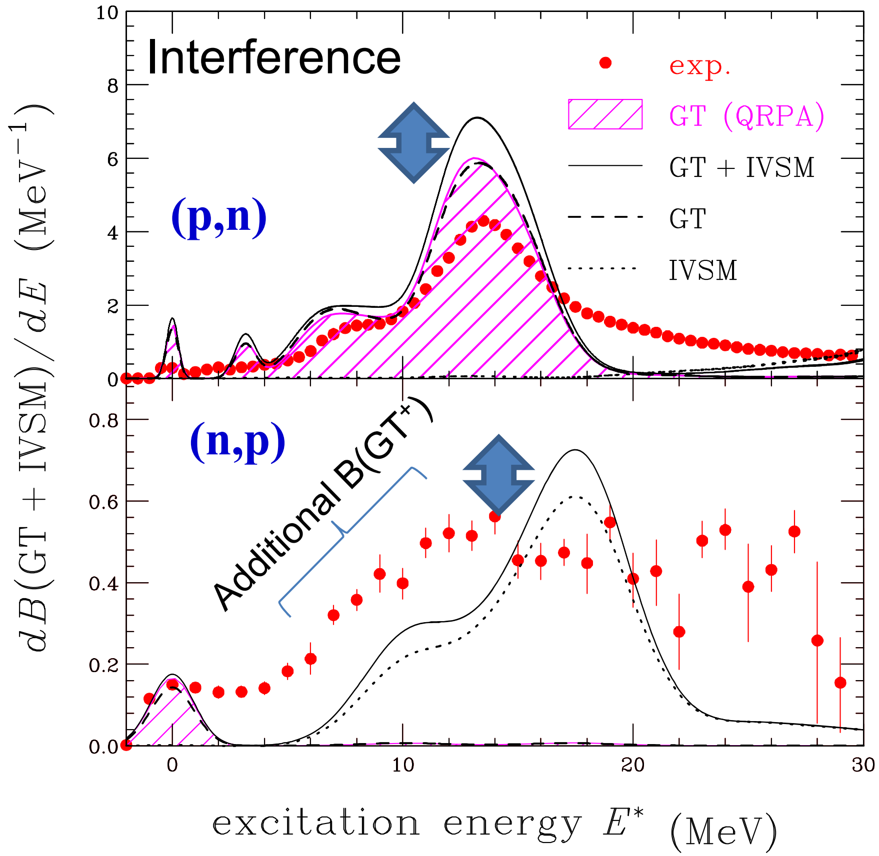
Few % effect by interference is seen.

Interference between GT+IVSM (Sasano data and calc.)

- $^{116}Cd(p,n)^{116}In$ at 300 MeV
- $^{116}Sn(n,p)^{116}In$

Scat. amp.: $T = T_{0hw}(GT) + T_{2hw}(IVSM)$

$$|T|^2 = |T_{0hw}|^2 + |T_{2hw}|^2 + 2\,\mathrm{Re}\,(T_{0hw}^{*}\ T_{2hw})$$



QRPA (GT + IVSM)
(Rodin et al., Tuebingen Univ.)
Large model space (34 levels)
⇒ 2hw
quenching factor, 0.843
& $g_{pp} = 0.5$

	Theo.			Exp.
	GT	IVSM	GT+IVSM	GT+IVSM
β+	0.4	5.4	6.8	11±1
β-	42	4	52	45±8

Strengths around 10 MeV are partly reproduced, but still underestimated in the calculation.

Summary for (p,n)/(n,p) and some DWIA exercises

- **Unit cross section**
  - **Must be experimentally calibrated**

- **Proportionality : recover (?) for the continuum**
  - **Poor ΔE helps? (average over ΔE)**

- **MDA**
  - **Shallow binding treatment seems to work**

- **Interference (exercise)**
  - **between L=0 and L=2(IVSQ) : seems to be small**
  - **between GT and IVSM : ?**

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- ($t,^{3}He$,) reaction: measurement by Miki
  - ✓Exchange effects
- ($^{12}N,^{12}C$) reaction: measurement by Noji
  - ✓Ambiguities by optical potentials(imaginary part)

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- *– observation of GT giant resonance and SDR –*

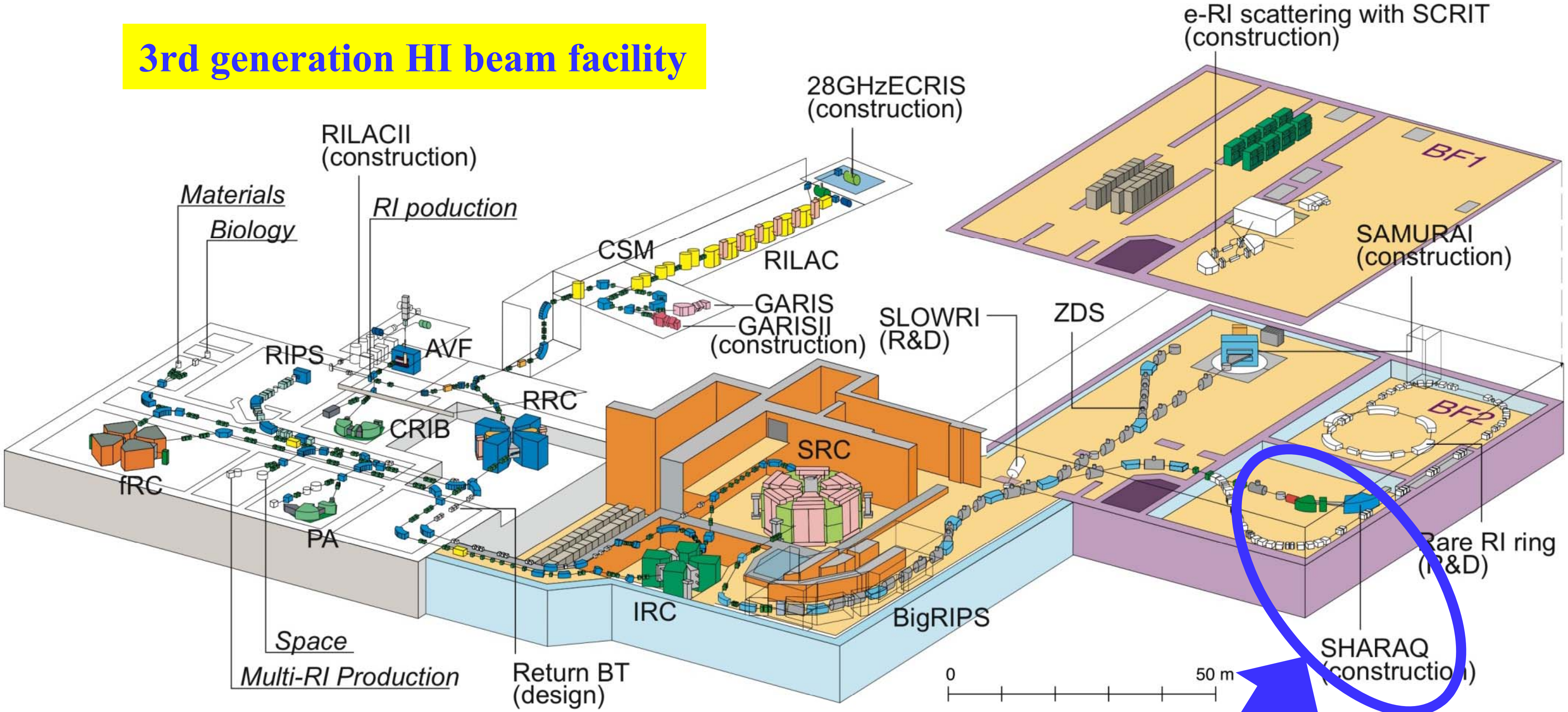
4 Summary

Studies on spin-isospin responses by composite projectiles

- β^+ IVSM search by (t,^{3}He) reaction
- β^- IVSM search by (^{12}N, ^{12}C) reaction

RI Beam Facility of RIKEN

3rd generation HI beam facility



SHARAQ

ICHOR and SHARAQ

SHARAQ magnetic spectrometer :

Constructed by Uiv. Tokyo under ICHOR project

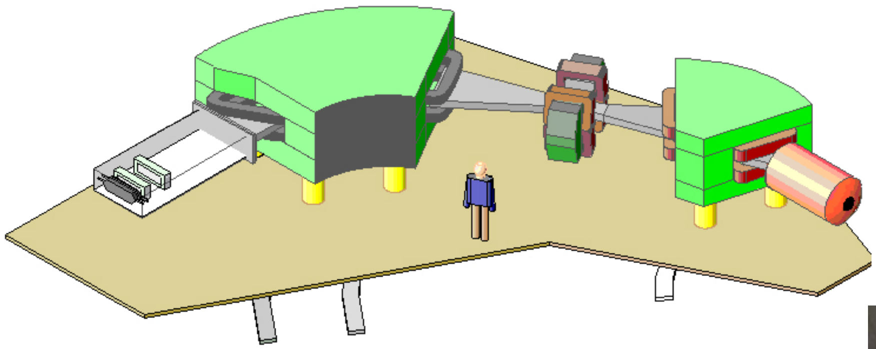
Sharaku

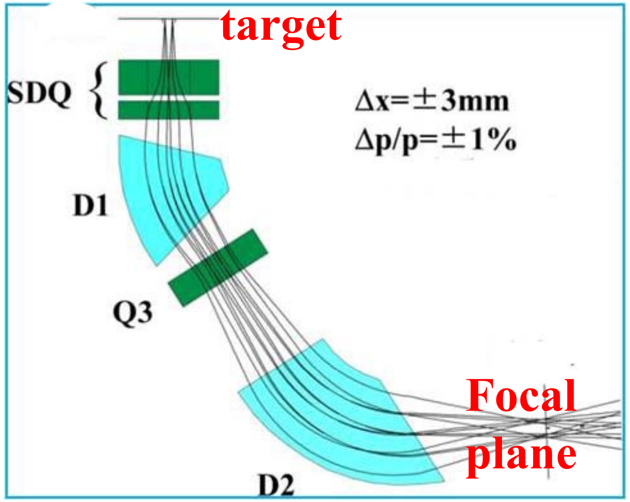
- Isospin-spin responses in CHarge-exchange exOthermic Reactions (ICHOR)
- Under the Grant-in-Aid for Specially Promoted Research of MEX
- Spokesperson: H. Sakai (University of Tokyo)
- Approved at 2005 for 5 years.
- Total budget: about $5M.

ICHOR

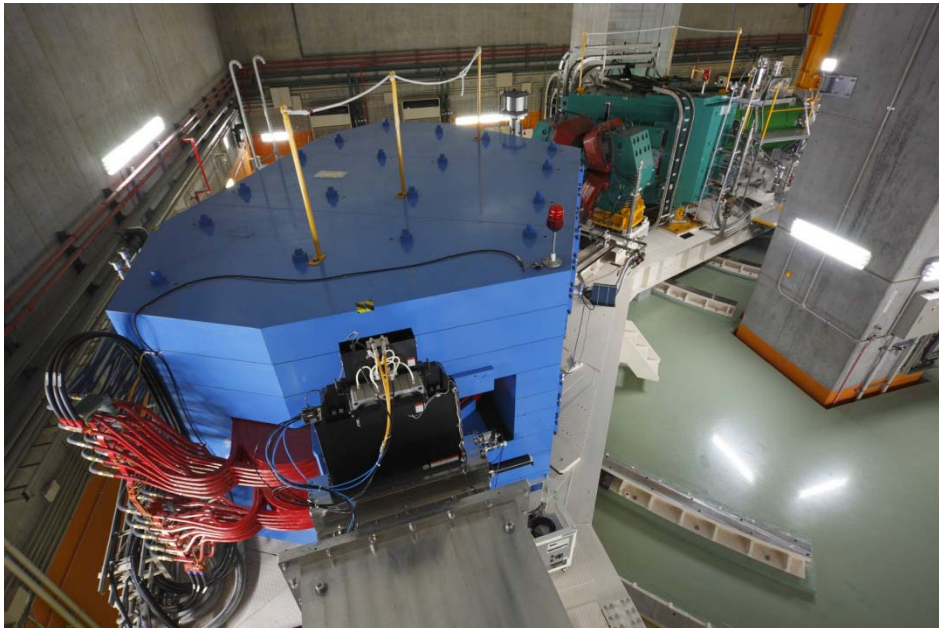
SHARAQ Characteristic

Dedicated to the missing mass spectroscopy by unstable RI beams.





- QQDQD type
- Maximum rigidity 6.8 Tm
- $\delta p/p = 1/14700$
- Dispersion matching $(x|\delta)$, $(\theta|\delta)$
- Angular resolution < 1 mrad
- Solid angle 2.7 msr
- Rotatable (-2 to 15 degree)
- Weight 500 tons



Experiments at SHARAQ since 2009

- Measurement of the spin isovector monopole resonance via the (t,^{3}He) reaction at 900 MeV (approved)
  Spokesperson: K. Miki
  Done in 2009. (First experiment!)

  Search for IVSM β^+ direction

- Studies of isovector non-spin-flip monopole resonance via the super-allowed Fermi type charge exchange reaction
  Spokesperson: Y. Sasamoto
  Done in 2010.

  Search for IVM β^- direction

- Development of Exothermic charge-exchange reaction as a new spin-isospin probe and its application to the observation of the isovector spin monoploe resonance in ^{90}Nb
  Spokesperson: S. Noji
  Done in 2010.

  Search for IVSM β^- direction

- Direct mass measurement of neutron-rich Calcium isotopes at N~34
  Spokesperson: S. Michimasa
  (approved)

  High resolution of SHARAQ

- Tetra-neutron system produced by exothermic double-charge exchange reaction
  Spokesperson: S. Shimoura
  (approved)

  Tetra-neutron

- Spin-isospin excitations of ^{12}Be via the (p,n) reaction in inverse kinematics
  Spokesperson: K. Yako
  Done in June 2011. 2 months ago!

  (p,n) in inverse-kinematic

Search for the β^+ IVSM by (t,^{3}He) reactions at 300 MeV/A

Spokesperson: K. Miki, Univ. Tokyo

β^+ Iso-Vector Spin-Monopole Resonance

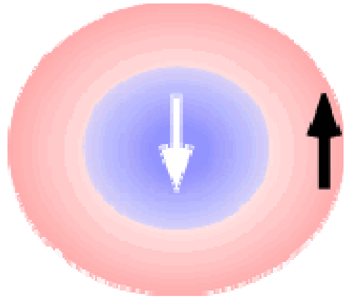
- Purpose : search for IVSMR(β^+)

  Isovector compression mode with spin

  <u>Previous Exp.</u>

  IVSMR(β^-) – a few signatures

  IVSMR(β^+) – no clear signature



ΔL=0, ΔS=1

2ħω

- Experiment

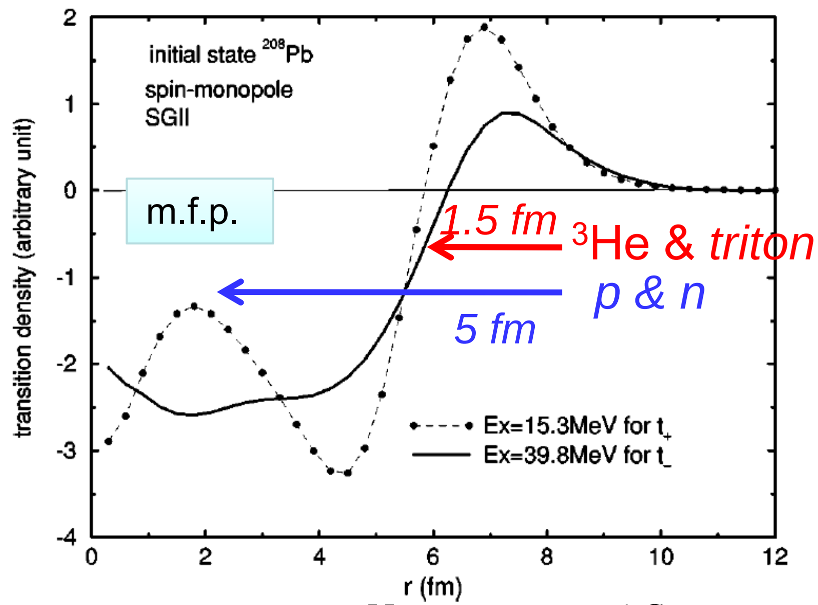
  (t,^{3}He) reaction at 300 MeV/u for ^{208}Pb and ^{90}Zr

  BigRIPS + SHARAQ

- Why (t,^{3}He) reaction at 300MeV/u ?

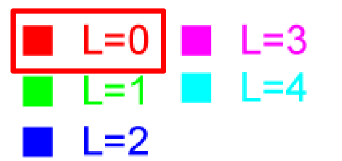
  Why ^{208}Pb and ^{90}Zr targets ?

  1. strong spin-isospin excitation
  2. large absorption effect
  3. strong Pauli-blocking effect

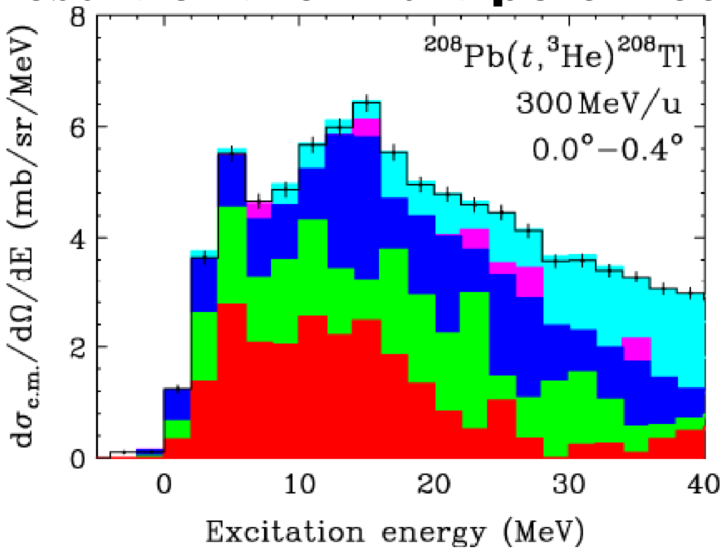


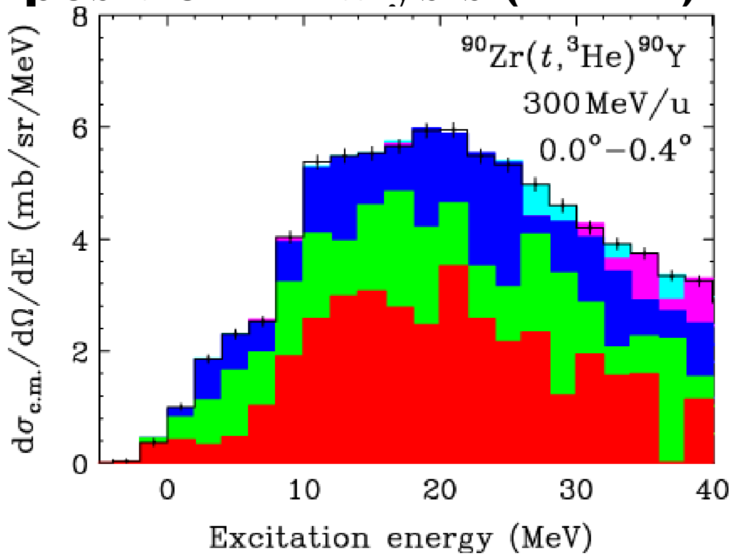
Hamamoto and Sagawa
PRC 62 (2000) 024319

IVSM study by (t,^{3}He) reaction

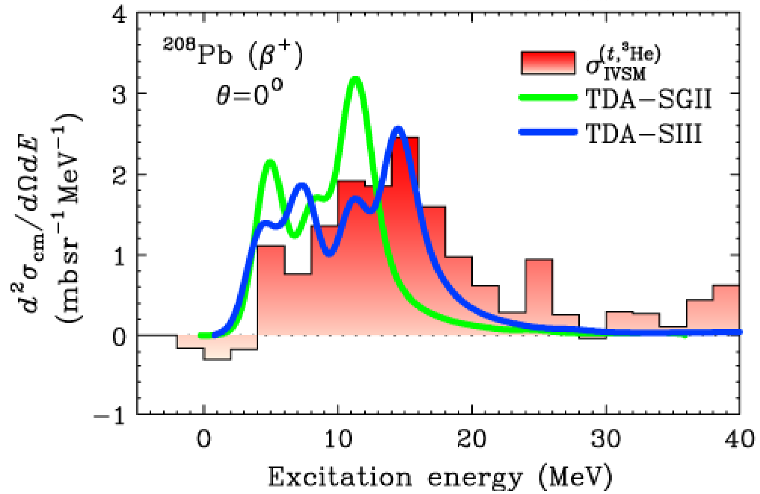


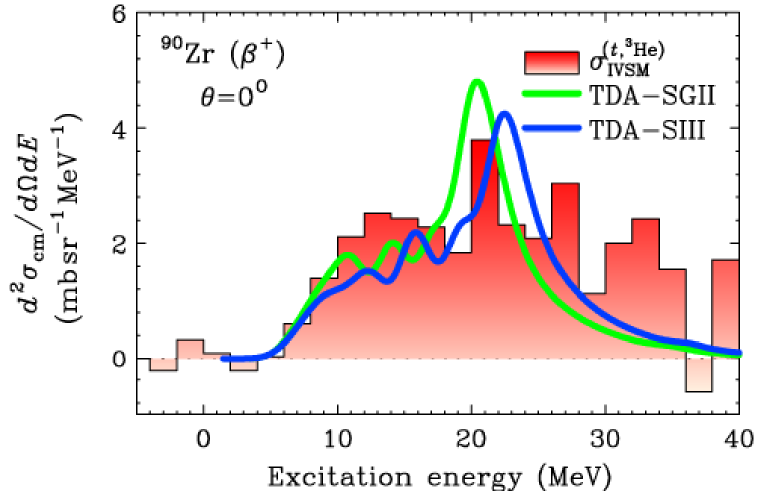
- **Result of the Multipole Decomposition Analysis (MDA)**





$\sigma^{(t,{}^3\mathrm{He})}_{\mathrm{IVSM}}$





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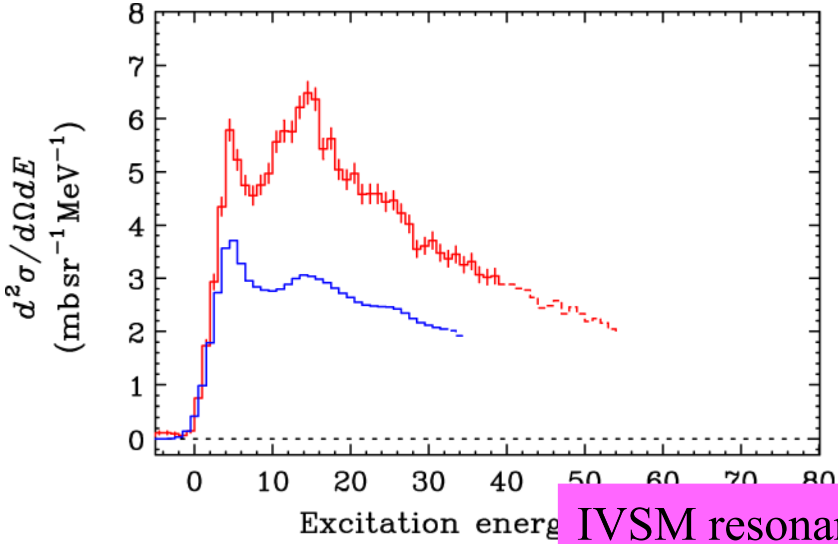
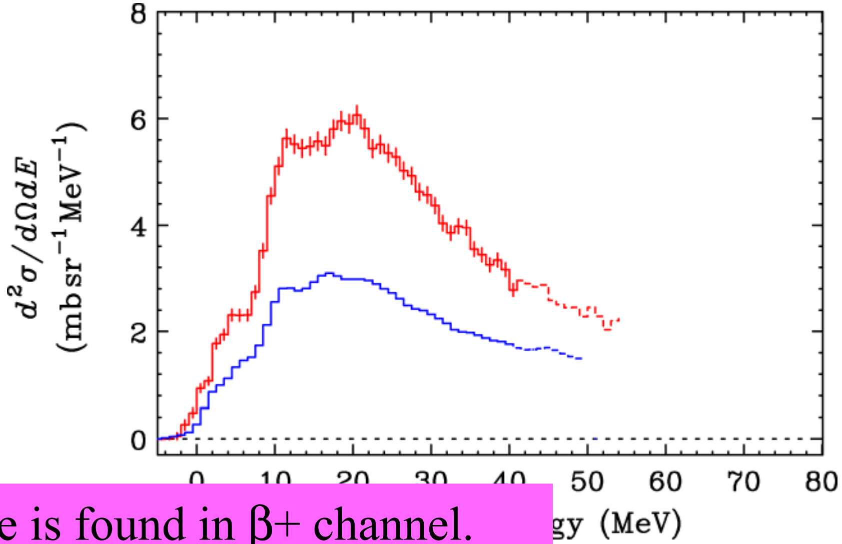
Comparisons (t,^{3}He)/(n,p) vs. (^{3}He,t)/(p,n)

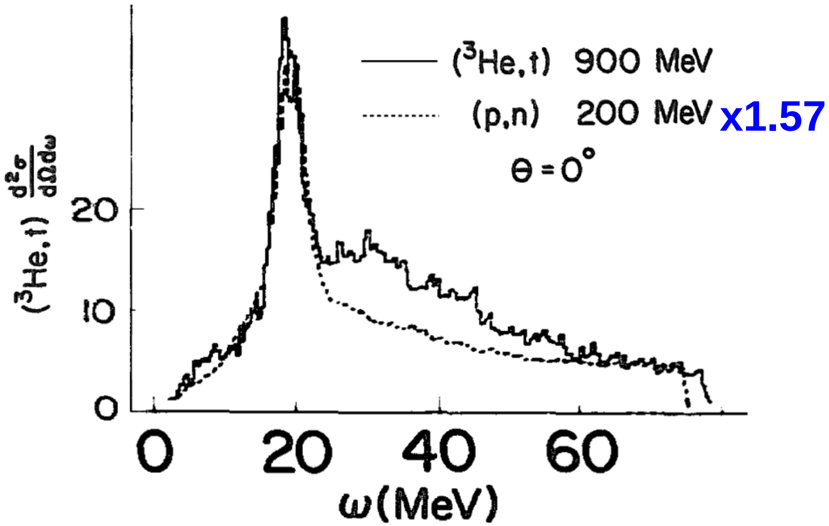
^{208}Pb(*t*,^{3}He) 300MeV/u 0.0°-0.4° (RIBF)
^{208}Pb(*n*,p) 200MeV 0.0°-1.8° (TRIUMF) x1.57

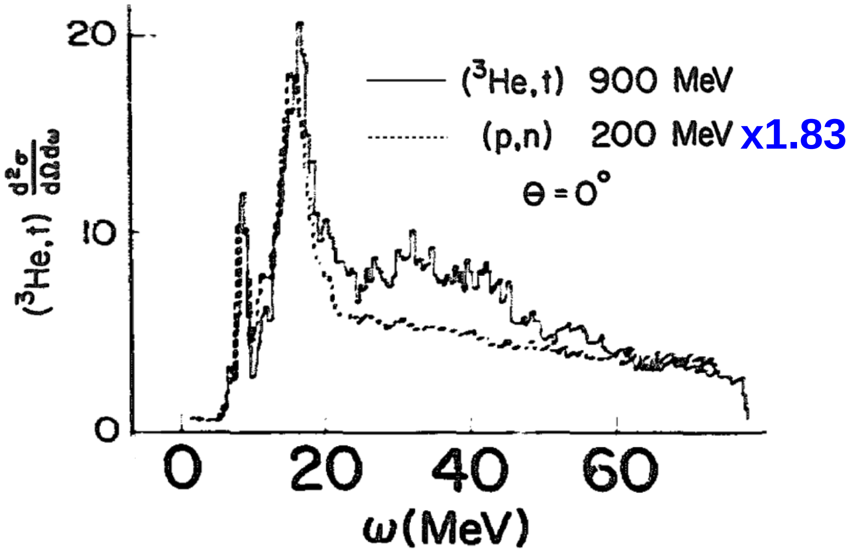


^{90}Zr(*t*,^{3}He) 300MeV/u 0.0°-0.4° (RIBF)
^{90}Zr(*n*,*p*) 300MeV 0.0°-1.0° (RCNP) x1.83



IVSM resonance is found in β+ channel.





Exchange effects

- comparison between (p,n) and (3He,t) reactions

Anti-symmetrization (A simple case : *N-N* system wo spin,isospin)

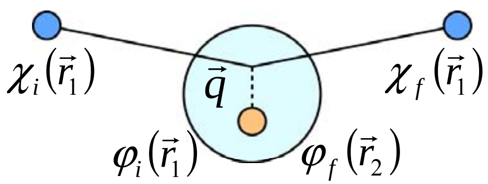
$\chi_{i,f}(\vec{r})$ --- Scattering wave function (proj, eject)

$\chi_f(\vec{r}_1)$ --- single-particle wave function (target)

$$\Psi_i = \frac{1}{\sqrt{2}} \begin{vmatrix} \chi_i(\vec{r}_1) & \varphi_i(\vec{r}_1) \\ \chi_i(\vec{r}_2) & \varphi_i(\vec{r}_2) \end{vmatrix}, \quad \Psi_f = \frac{1}{\sqrt{2}} \begin{vmatrix} \chi_f(\vec{r}_1) & \varphi_f(\vec{r}_1) \\ \chi_f(\vec{r}_2) & \varphi_f(\vec{r}_2) \end{vmatrix}$$

$$T = \langle \Psi_f | V_{\rm int} | \Psi_i \rangle$$
$$= \int d\vec{r}_1 \int d\vec{r}_2\, \chi_f^*(\vec{r}_1) \varphi_f^*(\vec{r}_2)\, V_{\rm int}\, \chi_i(\vec{r}_1) \varphi_i(\vec{r}_2) \quad - \quad \int d\vec{r}_1 \int d\vec{r}_2\, \chi_f^*(\vec{r}_1) \varphi_f^*(\vec{r}_2)\, V_{\rm int}\, \chi_i(\vec{r}_2) \varphi_i(\vec{r}_1)$$

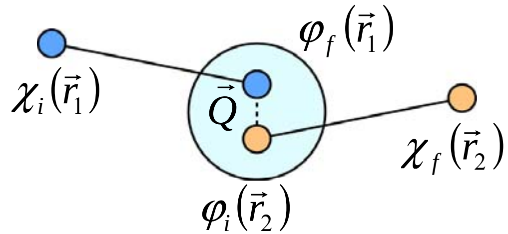
Direct



⇩

Reducible down to
2-dim. radial integral (easy)

Exchange (knock-on)

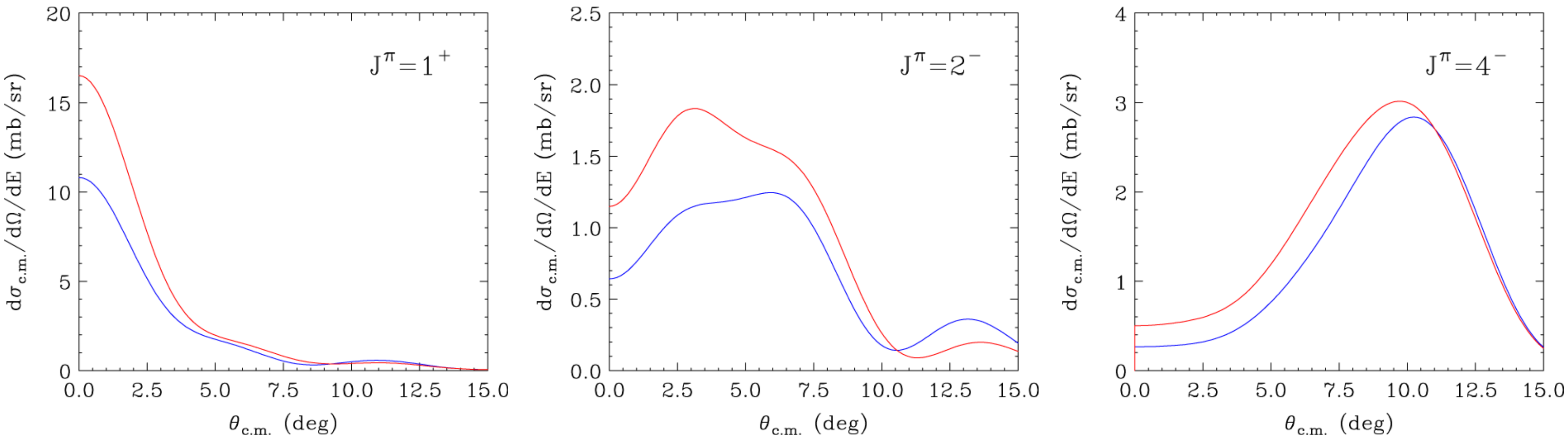


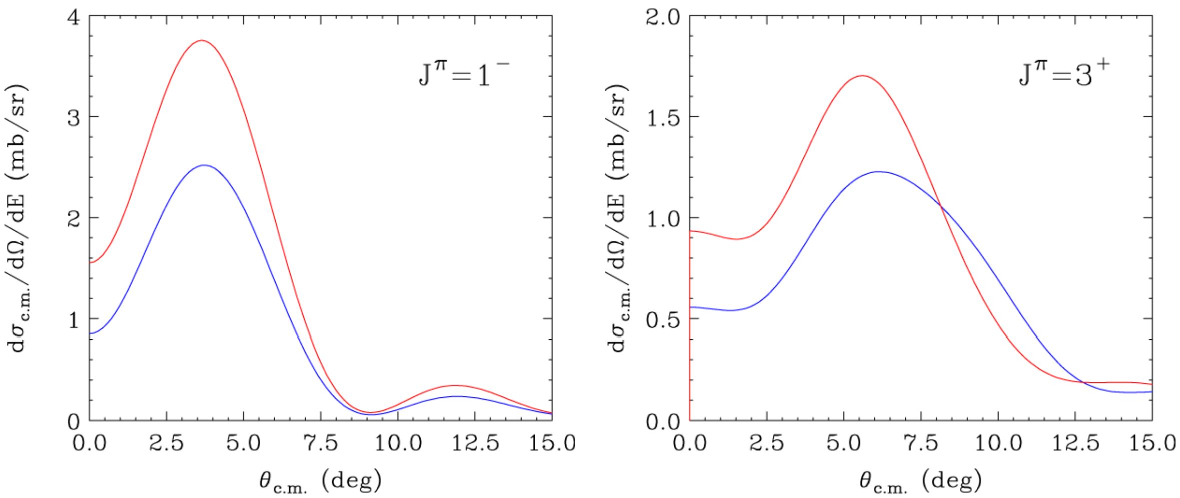
⇩

Irreducible…
6-dim. integral (difficult)
→ approx. : short-range, central only, …

208Pb(n,p) at 300MeV as an example

^{208}Pb(n,p) at 300MeV
Computer Code : DW81 (“Knock-on exchange is calculated exactly”)
N-N interaction : Franey-Love 325MeV





Direct+Exchange
Direct Only

Contribution from exchange is large (≳50%).

Indispensable for the discusssion of absolute cross section.

Direct and exchange effects in (^{3}He,t)

- DWHI+FOLD : rather difficult to calculate exchange effects
- DCP-1 code : includes knock-on exchange effects

(Distorted wave impulse approximation code for Composite-Particle scattering)

Udagawa, Schulte and Osterfeld, NP A474 (1987) 131.

Contributions from the Exchange Term in ^{12}C(p,n) and (h,t) Reactions

1$^+$, 0^o

Reaction	E(MeV)	ℓ_t	σ(D)	σ(E)	σ(D+E)	σ(D+E)/σ(D)
(p,n)	200	0	14.0	1.02	7.46	0.53
		2	0.03	0.002	0.037	1.38
		0+2	14.0	1.02	7.50	0.54
(h,t)	600	0	47.4	0.028	27.5	0.58
		2	0.272	0.039	0.501	1.84
		0+2	47.7	0.067	28.0	0.59
	300	0	4.59	0.426	6.10	1.33
		2	0.037	0.002	0.104	2.79
		0+2	4.63	0.428	6.20	1.34
	900	0	16.2	1.40	20.3	1.25
		2	0.293	0.078	0.662	2.26
		0+2	16.5	1.48	21.0	1.27

Large exchange effects !
→ However …..

Energy dependent! Very subtle
→(p,n)~(3He,t), if this is a general feature, then ….

Computer Codes for DWBA,DWIA

- Computer Codes (for experimentalist ?)

* Only for KNOCK-ON exchange.
No code available for FULL exchange.

	Author/Maintainer	N-A	A-A	Exchange (*)	Note.
DWUCK4	Kunz	O	△	Short-range approx.	
TWOFNR	Igarashi et.al.	O	△	Short-range approx.	
DW81	Comfort, Love	O	△	Exact	
DWBA98	Raynal et.al.	O	△	Exact	
DCP-1	Udagawa et.al.	O	O	Exact	Lost…?
FOLD	Zegers et.al.	O	O	Short-range approx.	Developing…?

Double folding

→ **Wanted** : Code for **A-A** scattering with **Exact** treatment of **Exchange**.

Search for the β^{-} IVSM search via (^{12}N,^{12}C) reactions

Spokesperson: S. Noji, Univ. Tokyo

Experimental condition & setup

^{90}Zr(^{12}N,^{12}C)^{90}Nb

BigRIPS + SHARAQ

pri. beam: ^{14}N 250*A* MeV, 400 pnA

sec. beam: ^{12}N 176*A* MeV, 1.6 Mcps

reaction target: ^{90}Zr 150 mg/cm^2

Detectors

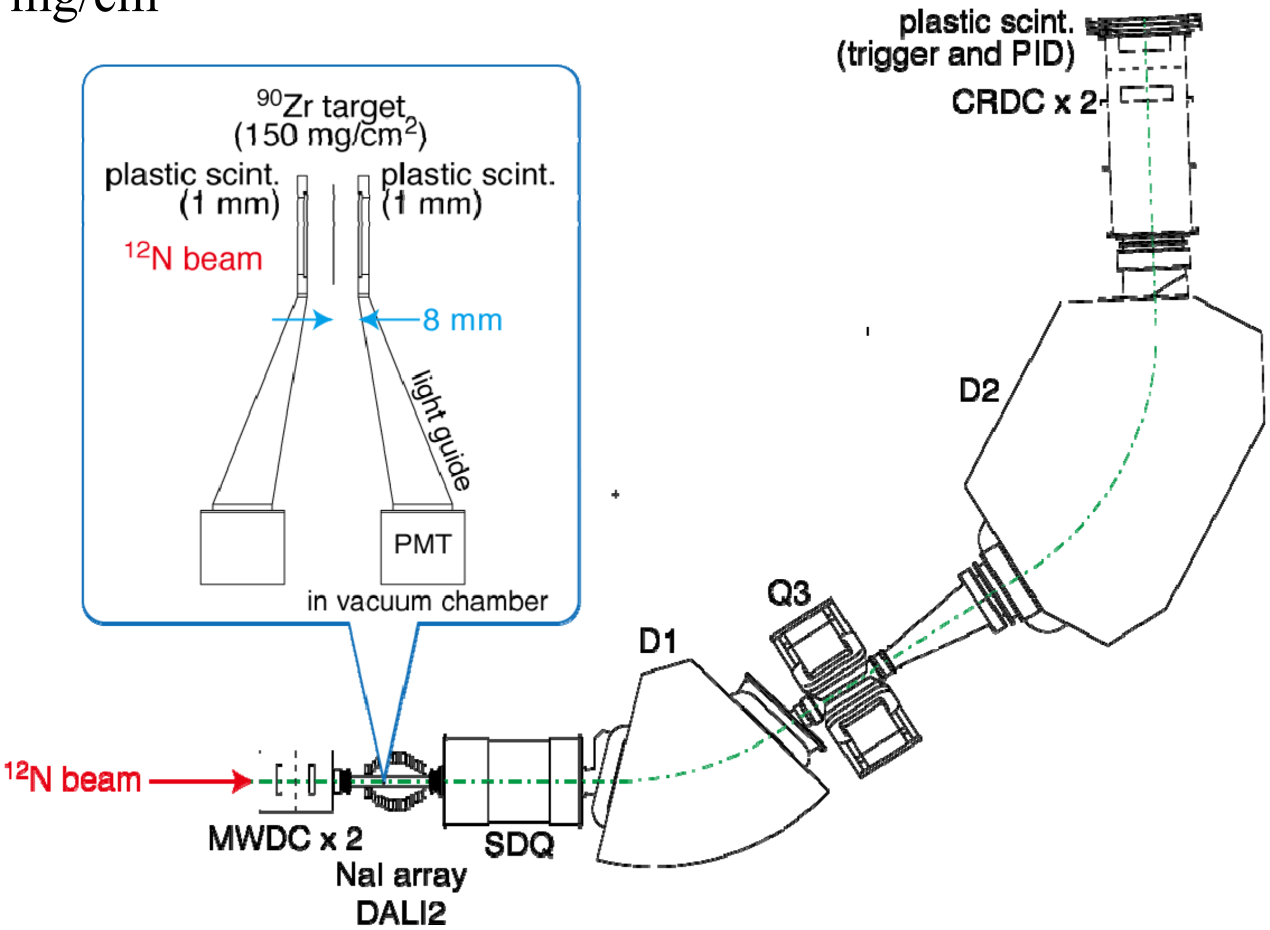
track of incoming beam
MWDC x2

track of reaction product
CRDC x2

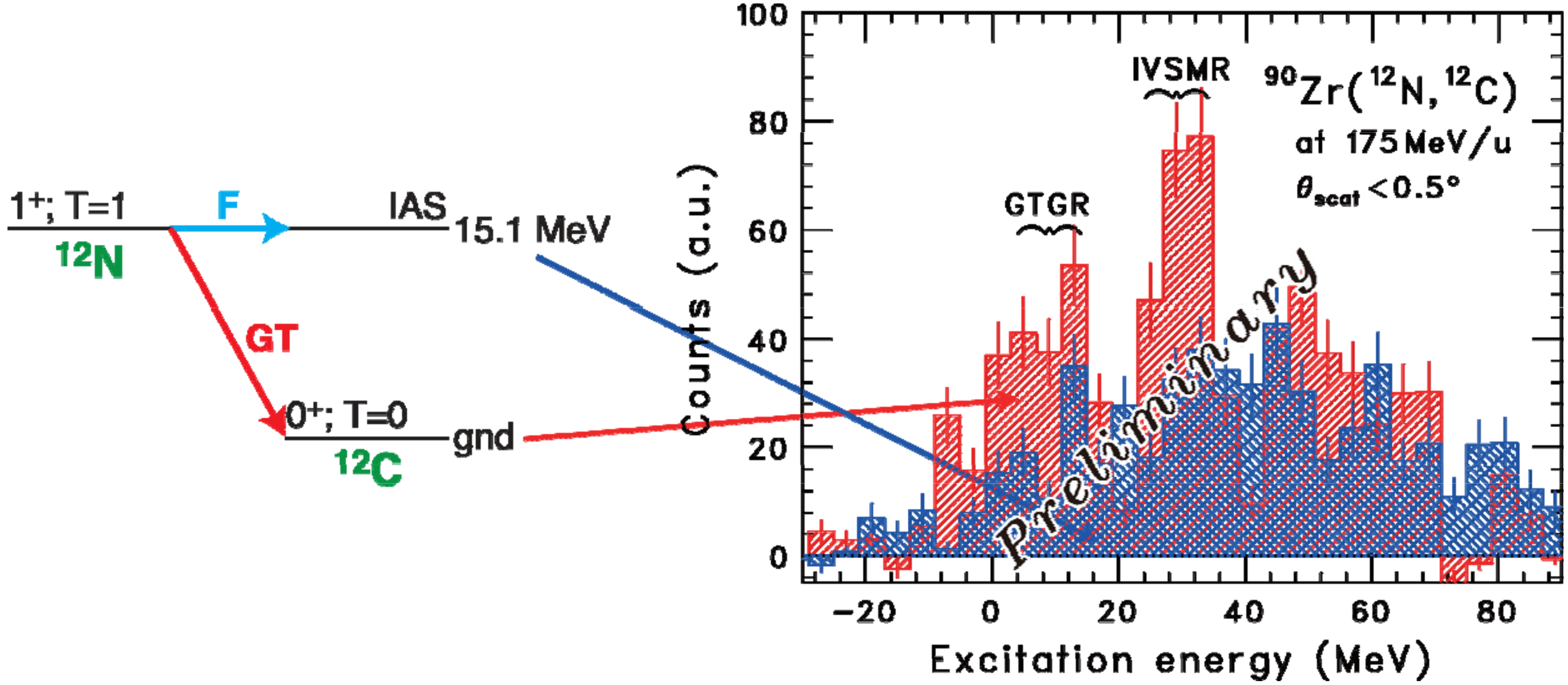
trigger & PID
focal plane scint.

ID of β decay events
target scint.

de-exc. γ rays from ^{12}C*
NaI array DALI2



Very very preliminary result by Noji



Optical potentials

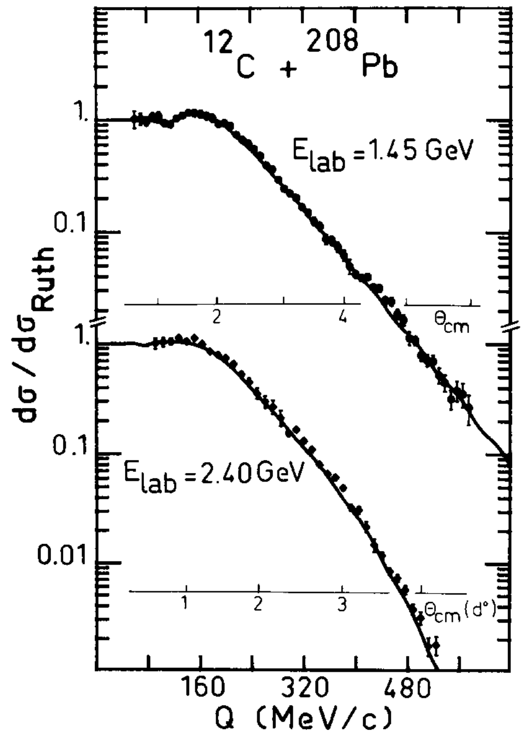
Nuclear Physics A490 (1988) 441–470
North-Holland, Amsterdam

ELASTIC AND INELASTIC SCATTERING OF ^{12}C IONS AT INTERMEDIATE ENERGIES

J.Y. HOSTACHY, M. BUENERD, J. CHAUVIN, D. LEBRUN and Ph. MARTIN
ISN Grenoble, 53, Avenue des Martyrs, 38026 Grenoble Cedex, France

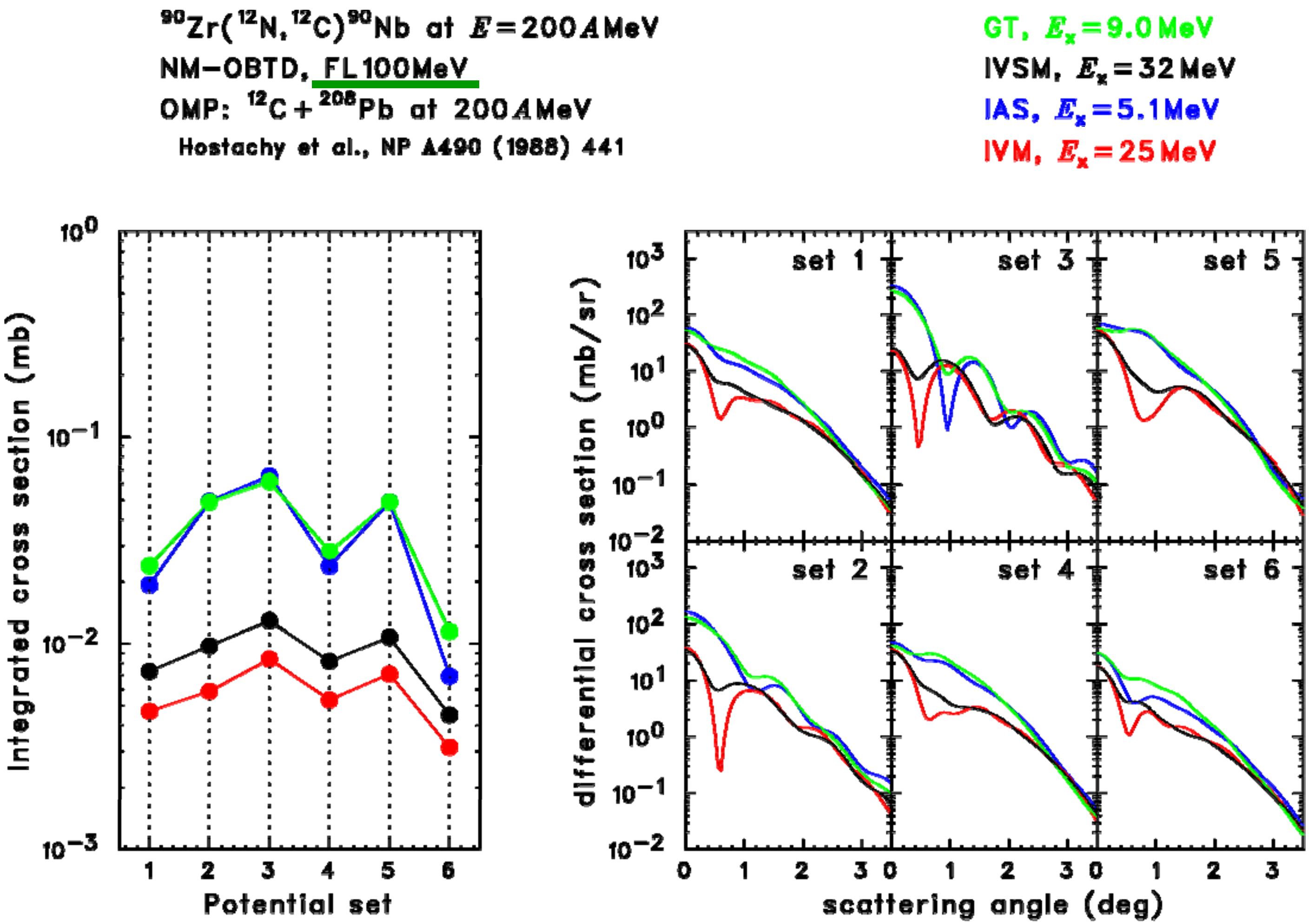
J.C. LUGOL, L. PAPINEAU, P. ROUSSEL and N. ALAMANOS
DPhN, CEN Saclay, 91191 Gif-sur-Yvette Cedex, France

J. ARVIEUX and C. CERRUTI
Laboratoire National Saturne, F-91191 Gif-sur-Yvette, France

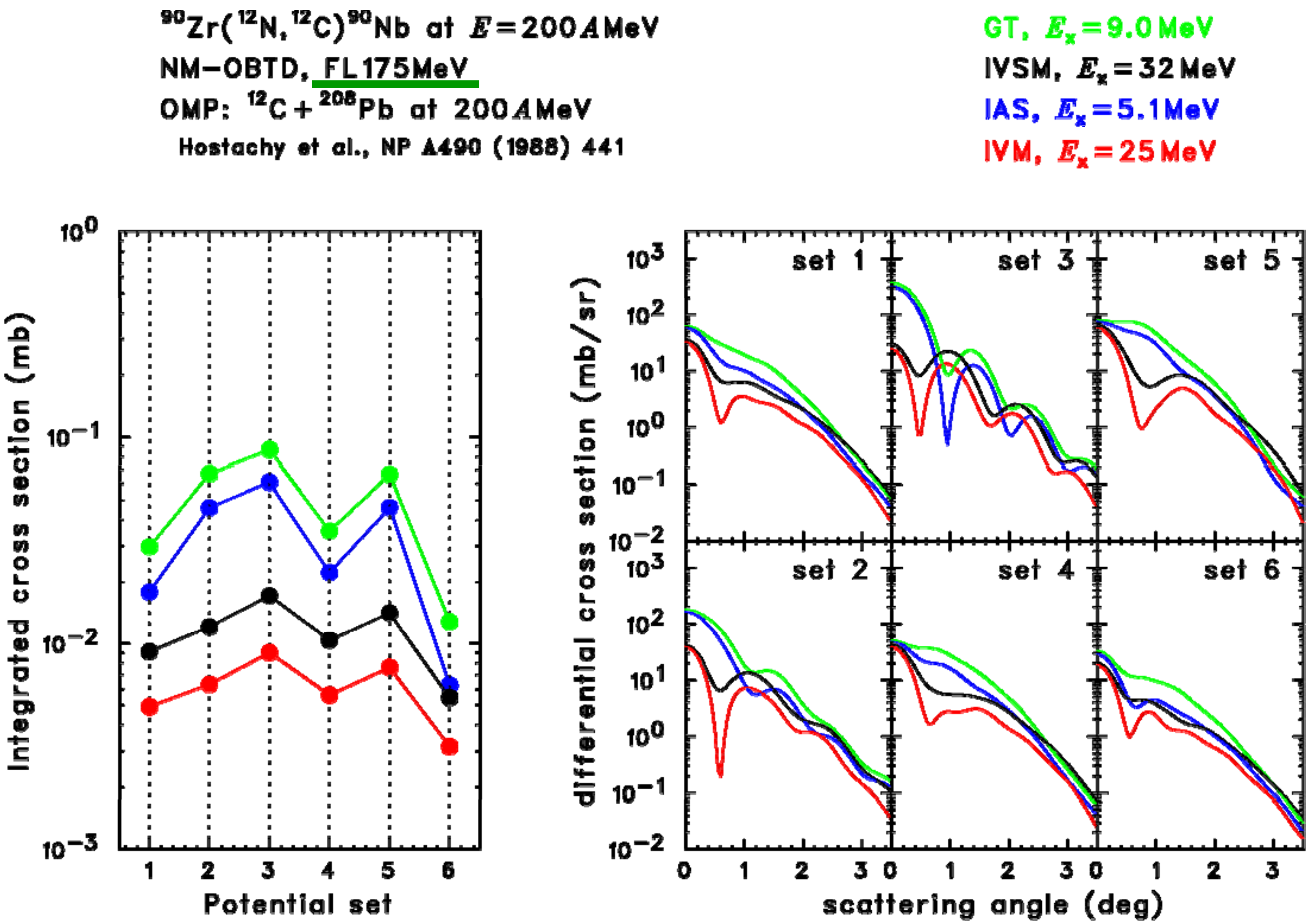


E/A (MeV/u)	V_0 (MeV)	r_R (fm)	a_R (fm)	W_0 (MeV)	r_I (fm)	a_I (fm)	σ_r (mb)	χ^2/N
200	10	0.803	0.815	35.82	0.991	1.186	3.61	1.87
	20	0.869	0.345	16.59	1.234	0.739	3.58	1.50
	35.68	0.900	0.466	14.06	1.238	0.743	3.47	1.45
	40	0.748	0.649	26.17	1.080	1.063	3.59	1.64
	50	0.889	0.508	14.85	1.226	0.788	3.51	1.79
	72.15	0.195	1.275	95.28	0.692	1.526	3.75	1.92

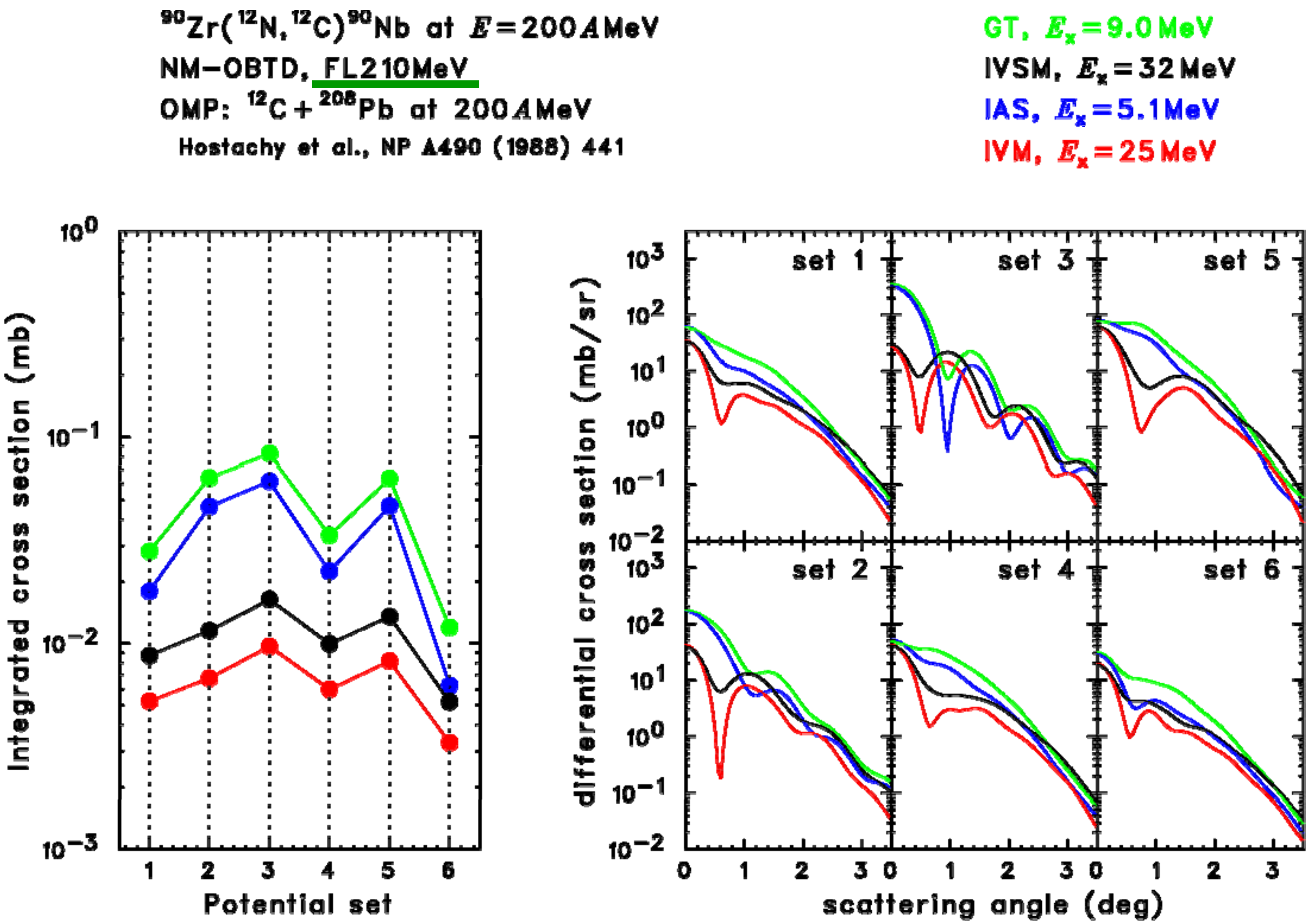
Ambiguities by V_{eff} and optical potentials



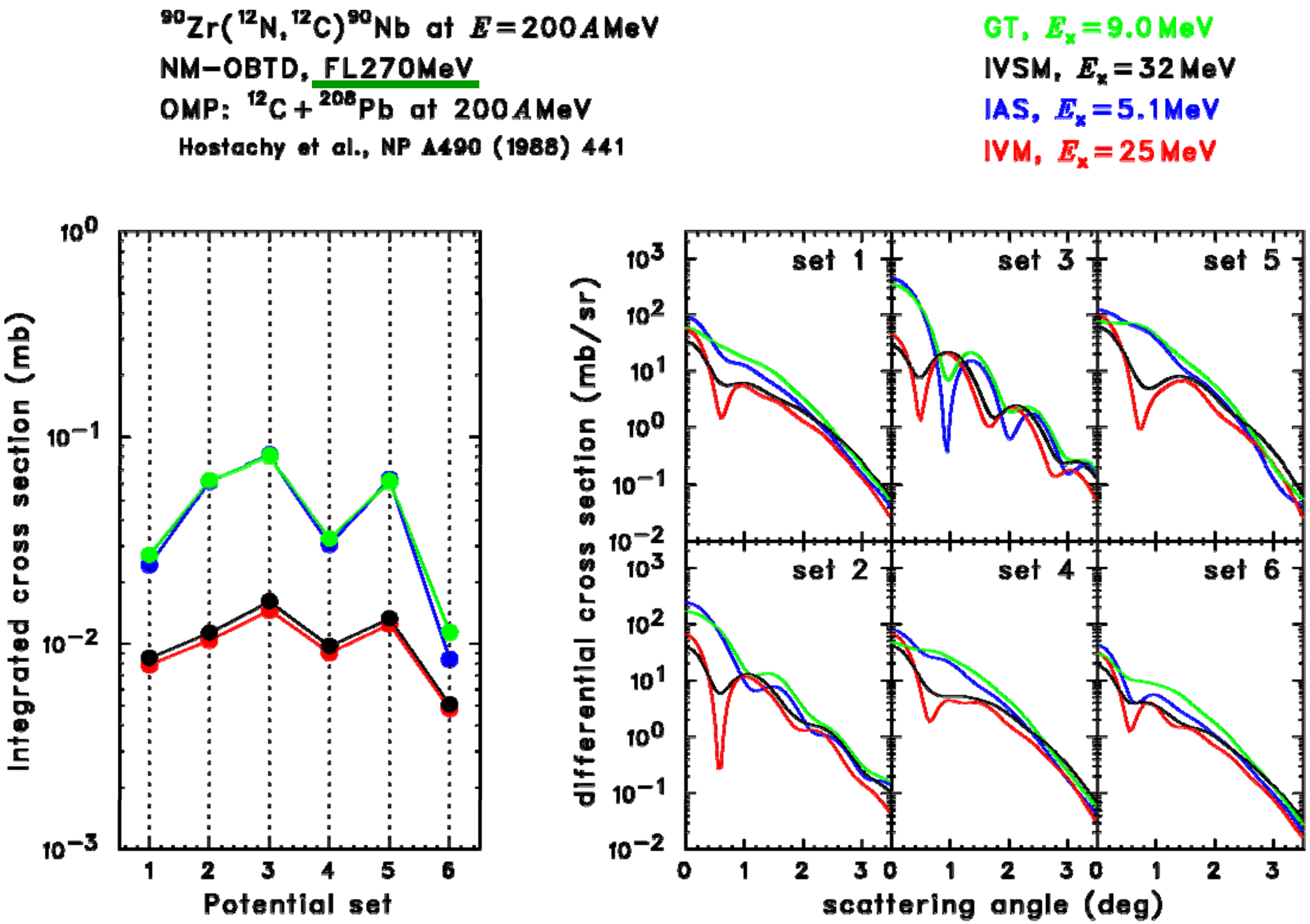
Ambiguities by V_{eff} and optical potentials



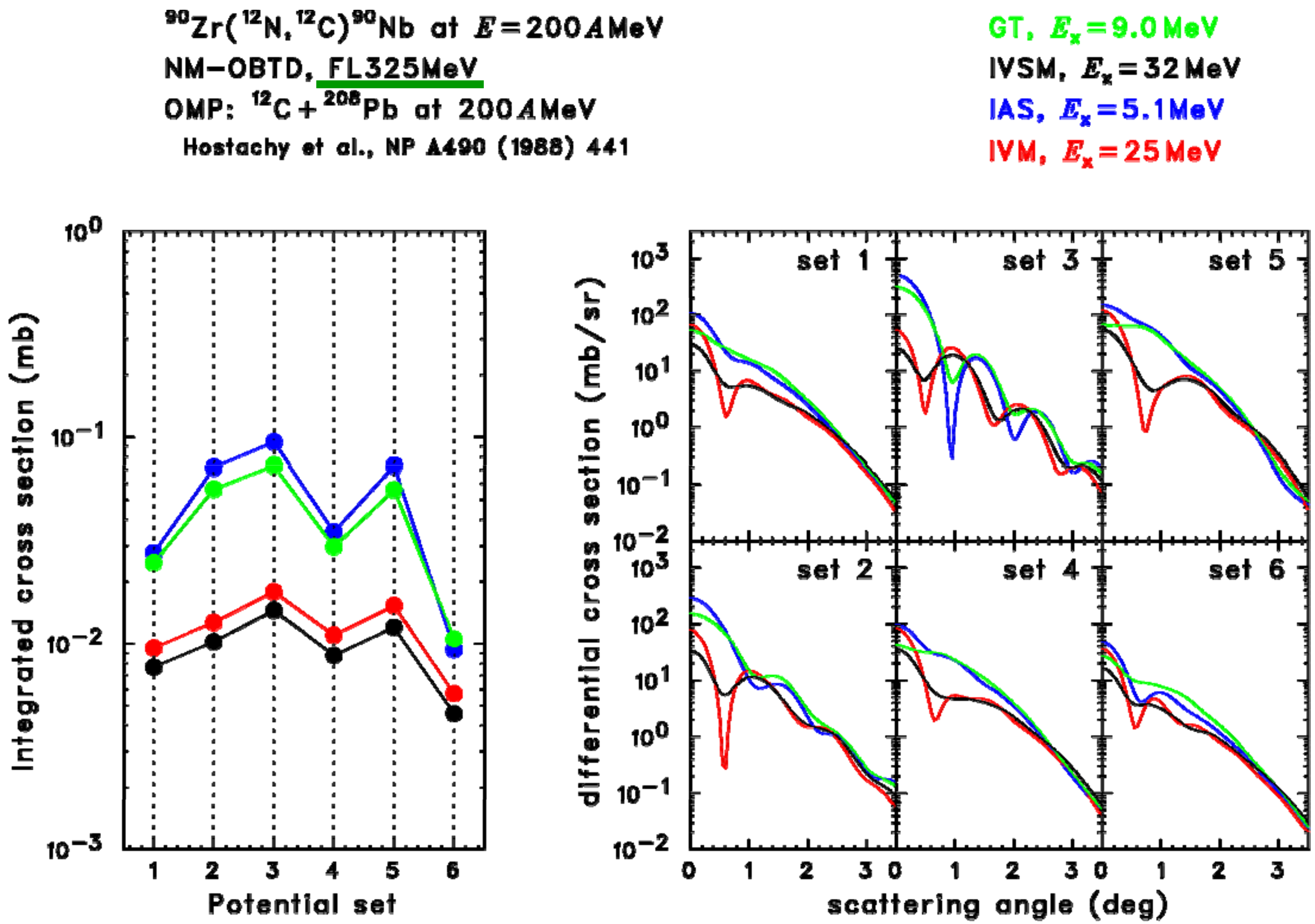
Ambiguities by V_{eff} and optical potentials



Ambiguities by V_{eff} and optical potentials



Ambiguities by V_{eff} and optical potentials



Lessons by exercise

- Effective interaction dependence is rather small.
- An order of magnitude difference depending on optical pot. sets.
- Even angular distributions are different.
- How to choose optical potentials? → show a guidline

Contents

1 How reliable are the spin-isospin responses in the continuum extracted by the nucleon CHEX reactions ?

- Measurement, analysis and associated uncertainties
  - ✓MDA
  - ✓unbound transition (shallow binding approx.) ?
  - ✓L=0, L=2 and their interference effect ?
  - ✓interference between GT and IVSM ?
  - ✓proportionality ?

2 How are they in the case of composite projectiles ?

- (t,^{3}He,) reaction: measurement by Miki
  - ✓Exchange effects
- (^{12}N,^{12}C) reaction: measurement by Noji
  - ✓Ambiguities by optical potentials(imaginary part)

3 Brand-new: measurement of the exothermic ^{12}Be(p,n) reaction in inverse-kinematics at 200 MeV/A by Yako

- – *observation of GT giant resonance and SDR* –

4 Summary

First measurement of the exothermic ^{12}Be(p,n) reaction

in inverse-kinematics at 200 MeV/A

Spokesperson: K. Yako

What is interesting in ^{12}Be ?

①large neutron asymmetry

$$\varepsilon = \frac{(N-Z)}{A} = 0.33$$

②disappearance of closed shell N=8

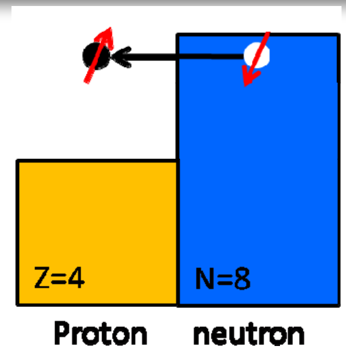
- 40% admixture of sd-orbits into p-orbits
- Effects on to GT transitions?
- Large effects on SDR transition?

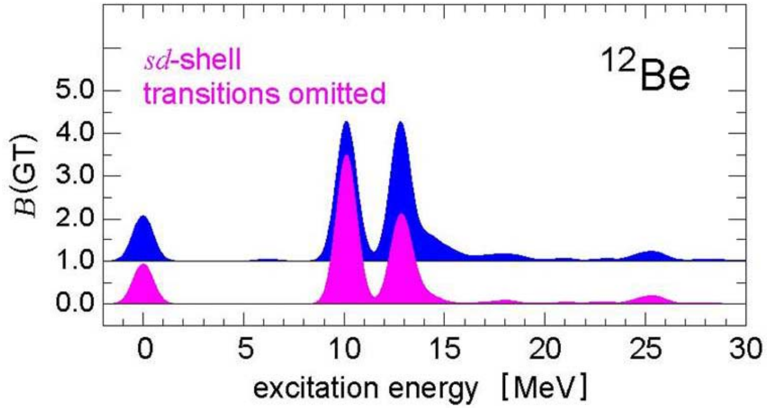
$$O^{\pm}_{1\mu}(GT) = \sum_i \sigma_\mu(i)\, t_\pm(i)$$

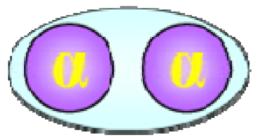
$$\hat{O}^{\pm}(SDR) = \sum_{im\mu} t^i_\pm \sigma^i_m r_i Y_1^\mu(\hat{r}_i)$$

③huge deformation(cluster structure)

- Ellipsoid ratio; long : short=2:1 !
- Large effects on SDR transition?
- Effects on GT transition?







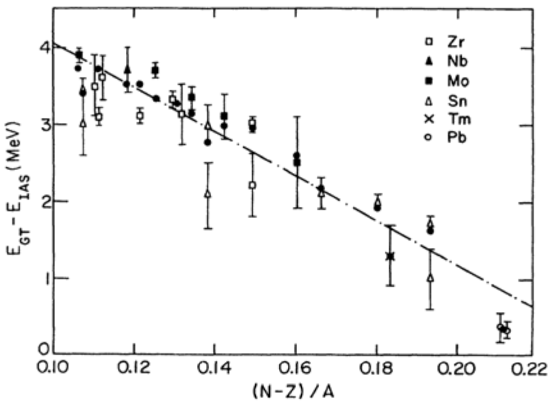
Aim: GT/SDR search in neutron rich nucleus ^{12}B
⇒collectivity of GT state
⇒breaking of closer structure by SDR
⇒establish of new spectroscopic tool by unstable beams

GTGR exists in light neutron-rich nuclei ?

Gamow-Teller state

$$|GTR\rangle = \sum_{i=1}^{A} \tau_-^{(i)} \sigma_-^{(i)} |0\rangle$$

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



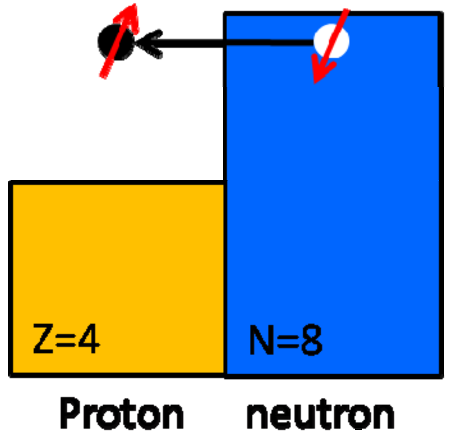
$\Delta E_{ls} = 1/2(\varepsilon_{j>} - \varepsilon_{j<})$:
Spin-orbit part of the single-particle energy

$\kappa_{\sigma\tau}(\kappa_{\tau})$:
particle-hole coupling constants

Nothing known beyond 0.22.

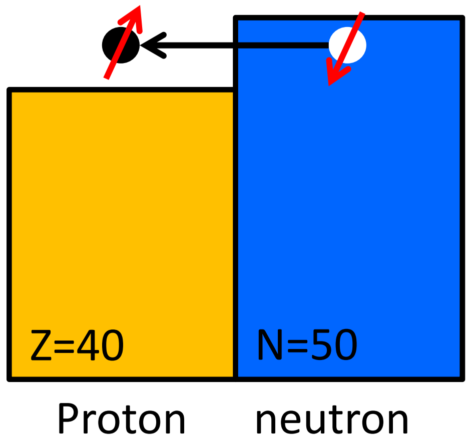
^{12}Be

$$\frac{N-Z}{A} = 0.33$$



^{90}Zr

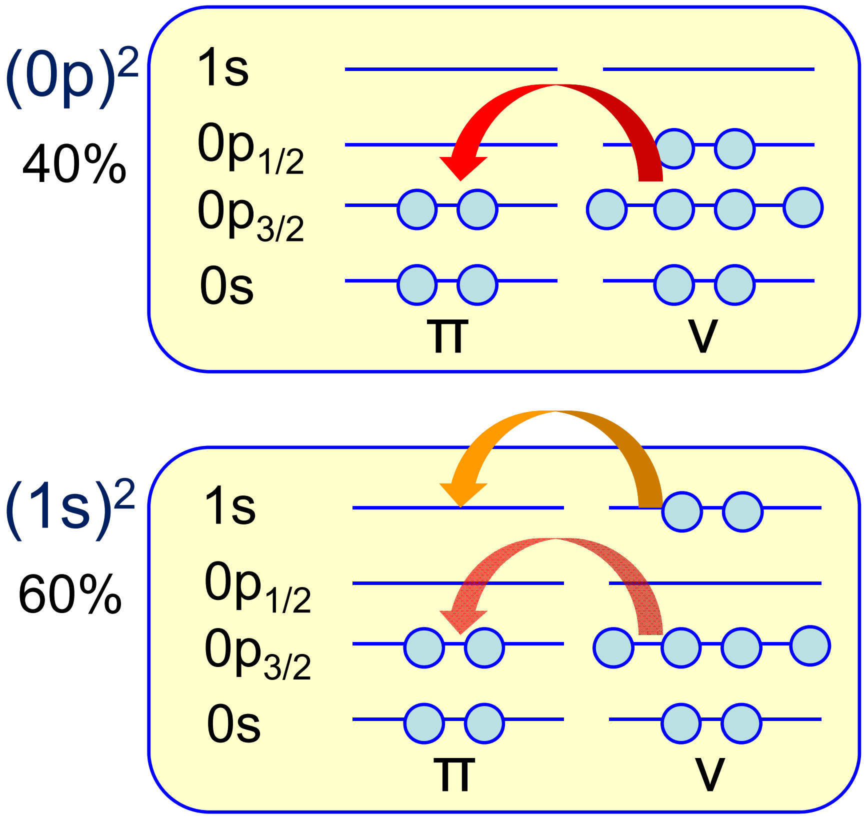
$$\frac{N-Z}{A} = 0.11$$

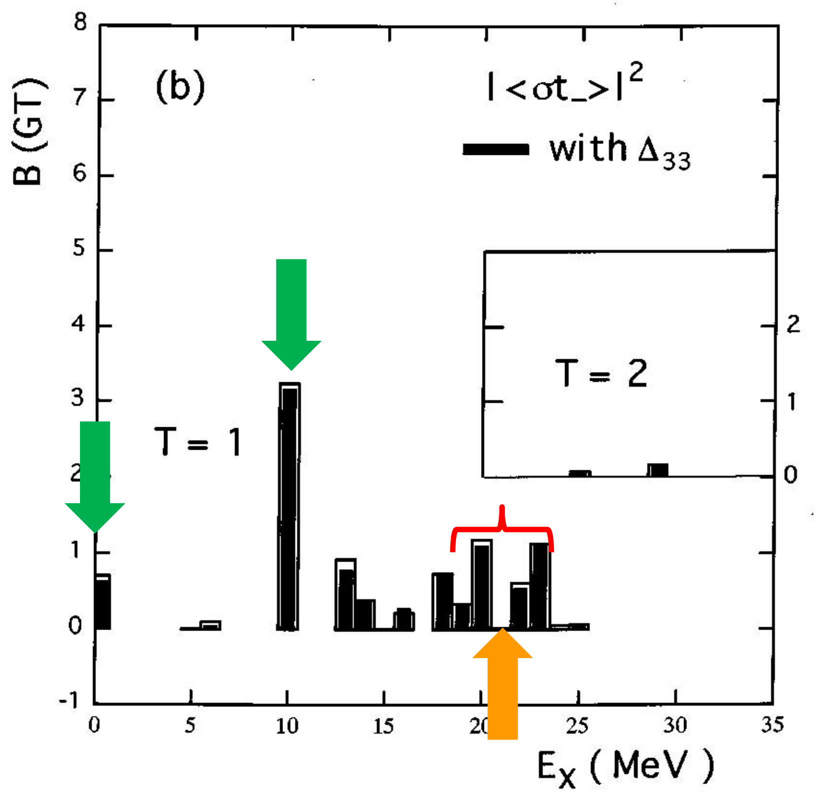


Shell-model prediction: GT excitations

Suzuki & Otsuka, PRC56(1997)847

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

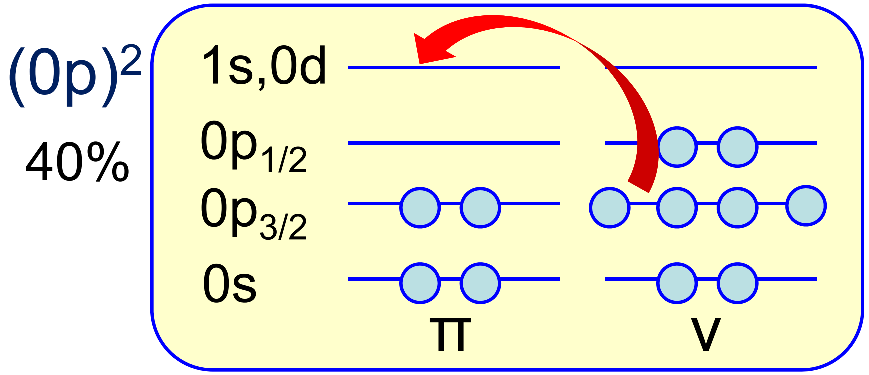


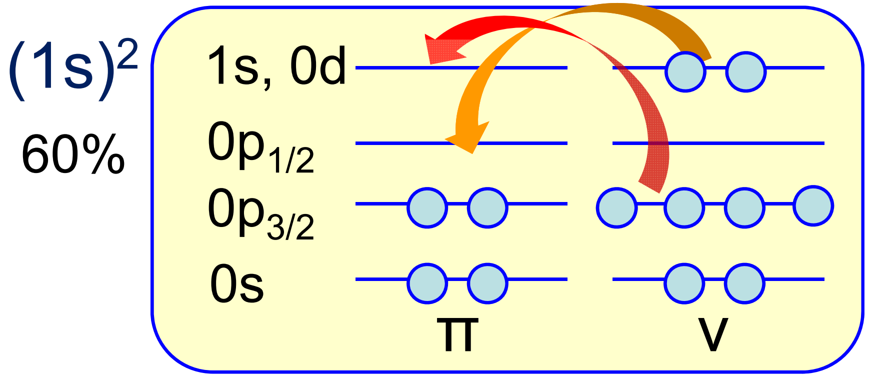


…Deformation-difference?
…Cluster model?

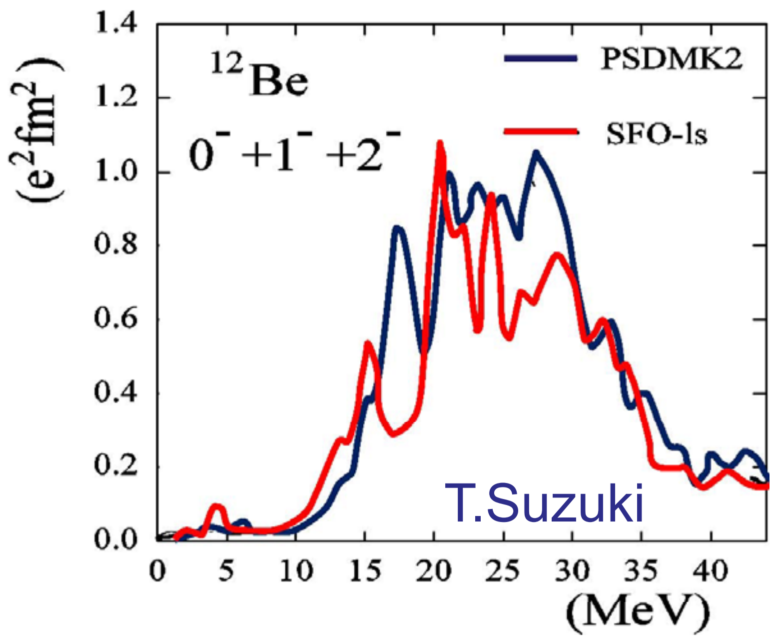
SD excitations

•Spin dipole … ΔL = 1, 1ħω
change in L → qualitative change in strength distribution



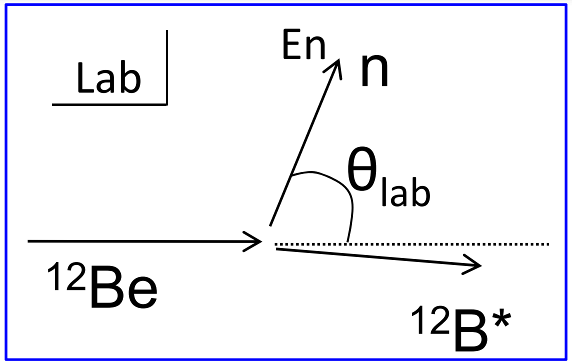


•Degeneracy between
p- and sd- shell can be seen?
•SD excitations in low E_x region?



^{12}Be(p,n) ^{12}B measurement

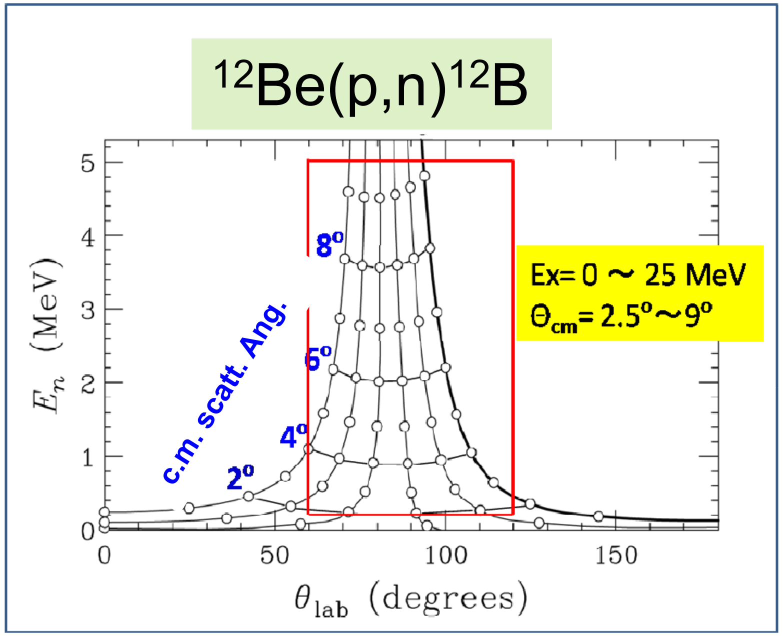
Exothermic reaction in inverse kimenatics!



Q_{gs} = +11 MeV

- 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

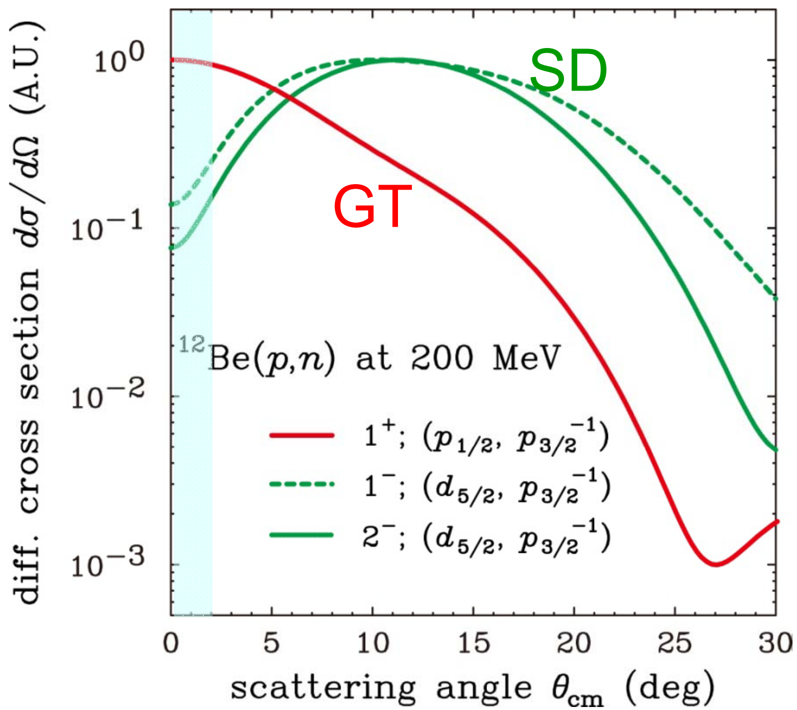


$\delta E_n \sim 0.8$ MeV, $\delta\theta_{lab} \sim 1.3$ deg

θ_n ⟷ Ex of ^{12}B

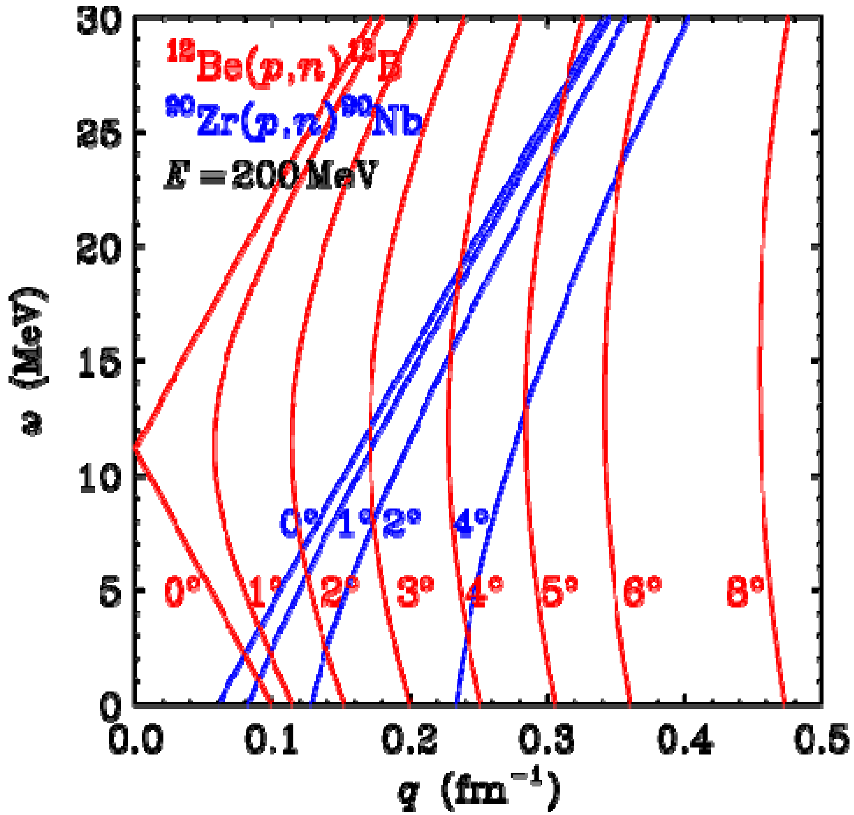
E_n ⟷ θ_{CM}

Angular distribution



Merit of exothermic ^{12}Be(p,n) ^{12}B reaction

^{12}Be(p,n)^{12}B reaction : Q_{gs} = +11 MeV



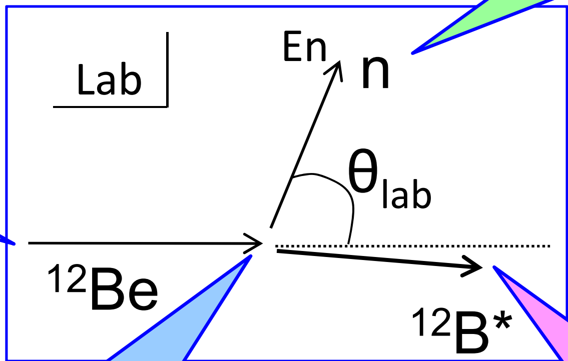
- q=0.0 fm^{-1} is achieved even at ω=11 MeV!
- q=0.2 fm^{-1} is achieved even at 3 degrees.

Sketch of experiment

- (p,n) reaction in Inverse kinematics
- Beam preparation
- Target
- Neutron(TOF)
- Residual nucleus(SHARAQ)

Neutron detector
TOF method

^{18}O beam + Be
Achromatic transport

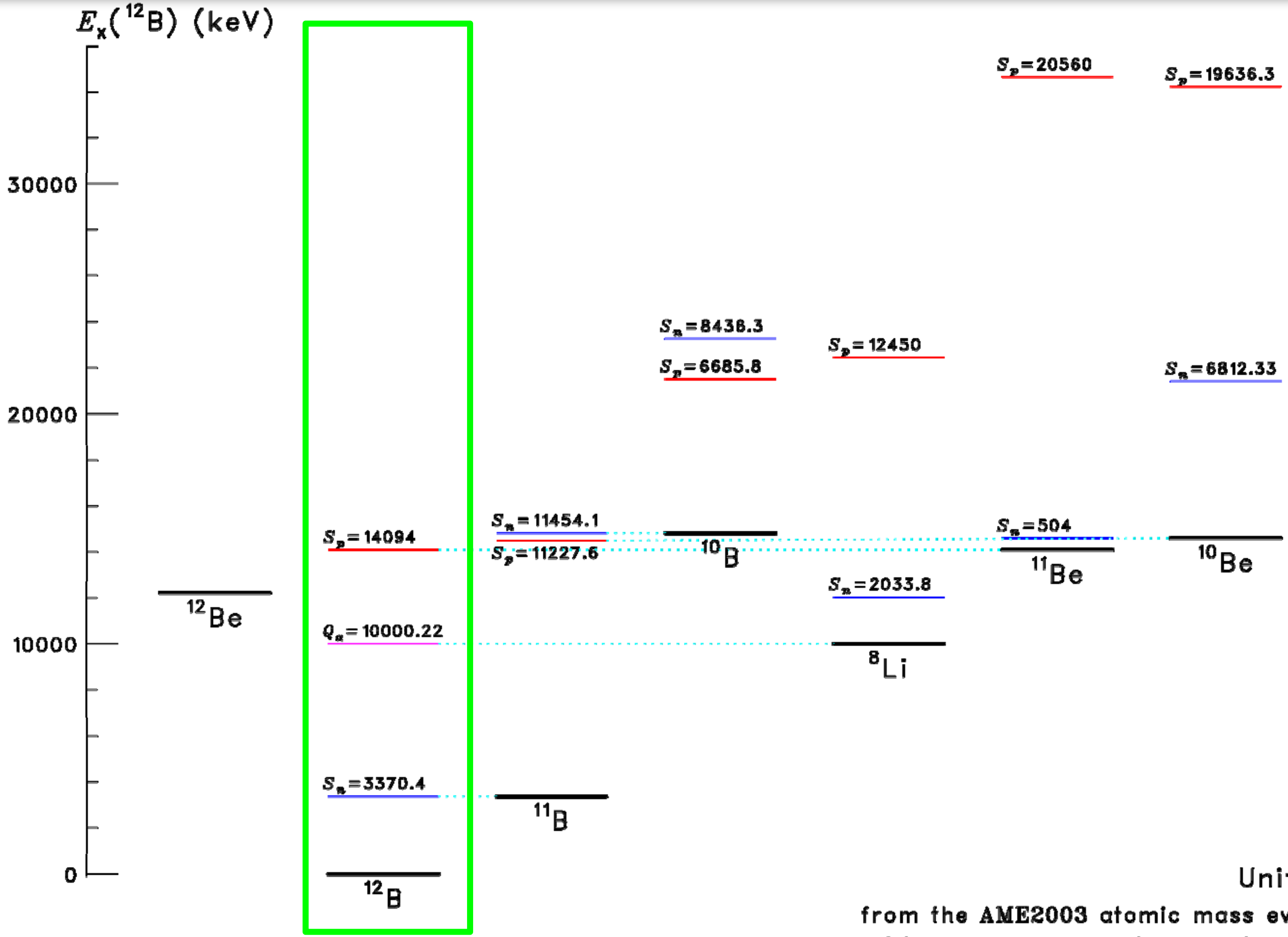


Liquid hydrogen target

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

- **Acceptances**
  $|\delta| < 1\%$
  $|\theta| < 36$ mr, $|\Phi| < 68$ mr

Masses around ^{12}Be

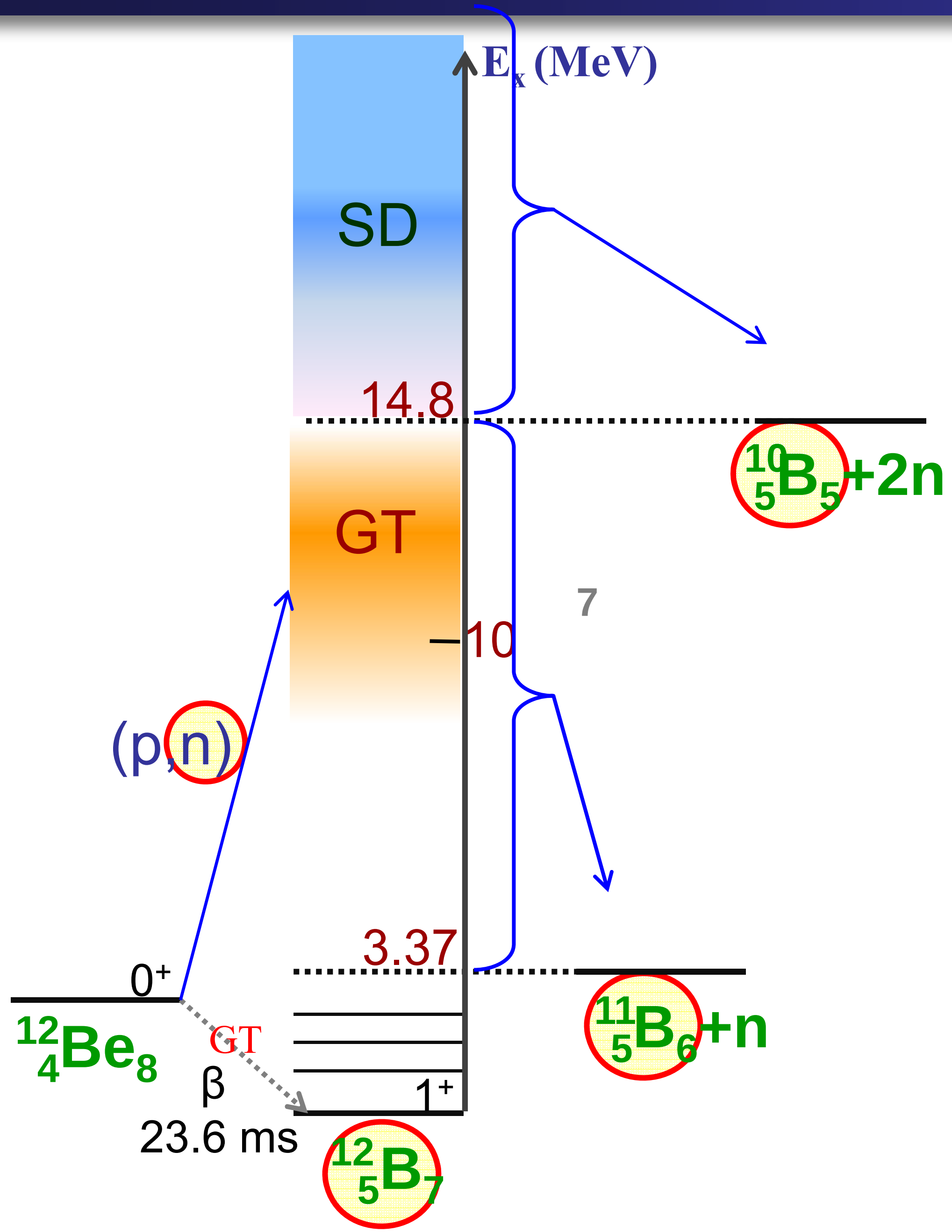


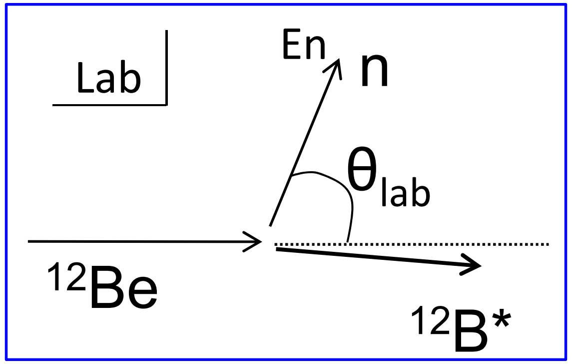
Units: keV

from the AME2003 atomic mass evaluation

http://www.nndc.bnl.gov/masses/rct2.mas03

Coincidence measurement





Neutron and residual particle coincidence meas.

3 settings of SHARAQ

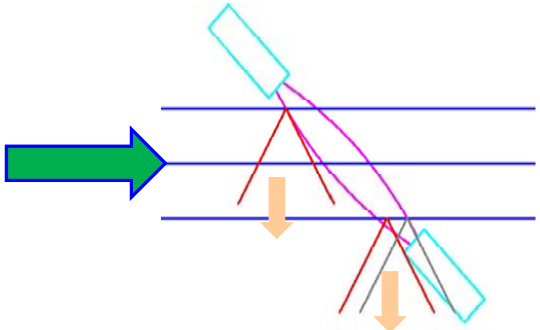
- $0<E_x< 3.4$ MeV
  → ^{12}B & n
- $3.4<E_x<15$ MeV
  → ^{11}B & n
- $15<E_x<22$ MeV
  → ^{10}B & n

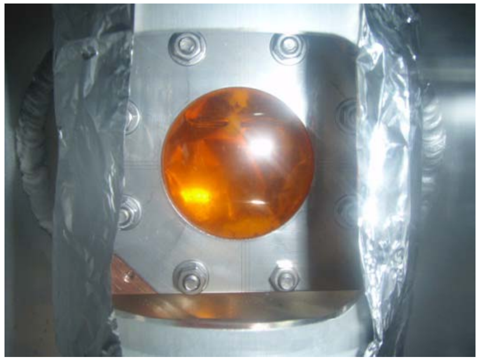
→ improves S/N

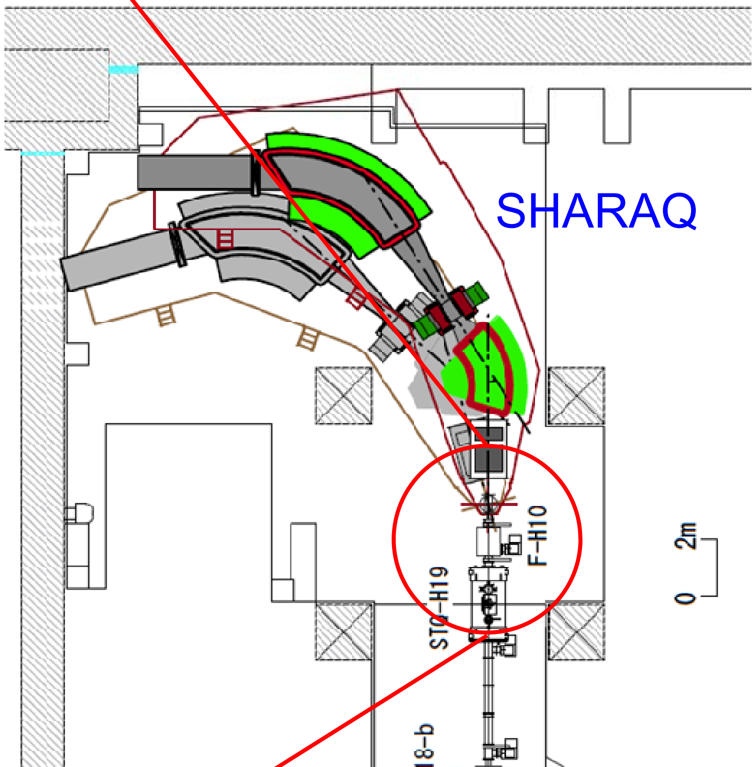
Liquid Hydrogen target

- LH_2 target
  - 14 mm^t
  - 40 mmΦ
  - Kapton window 25 μm

Beam size:
Δx = 7 mm (in σ)
Δy = 5 mm

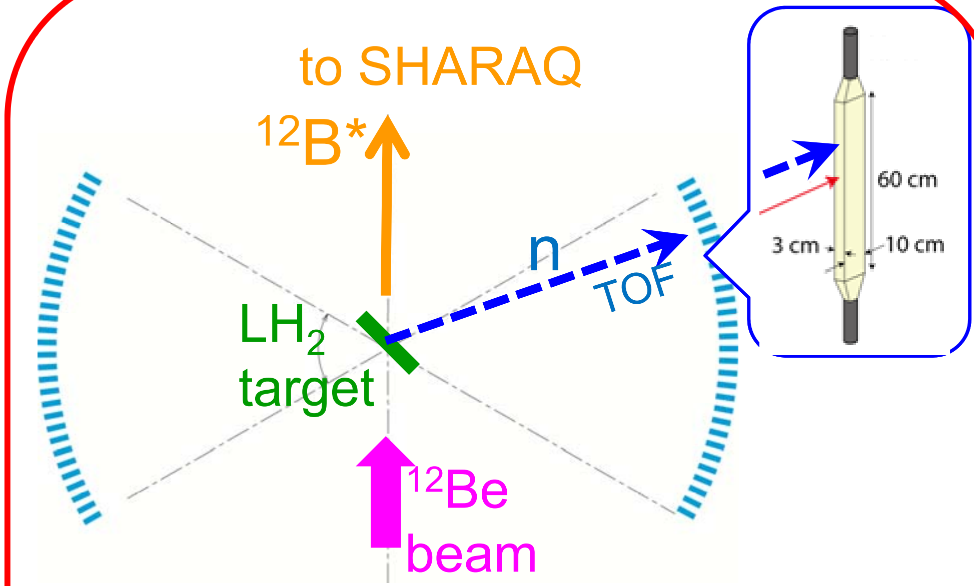




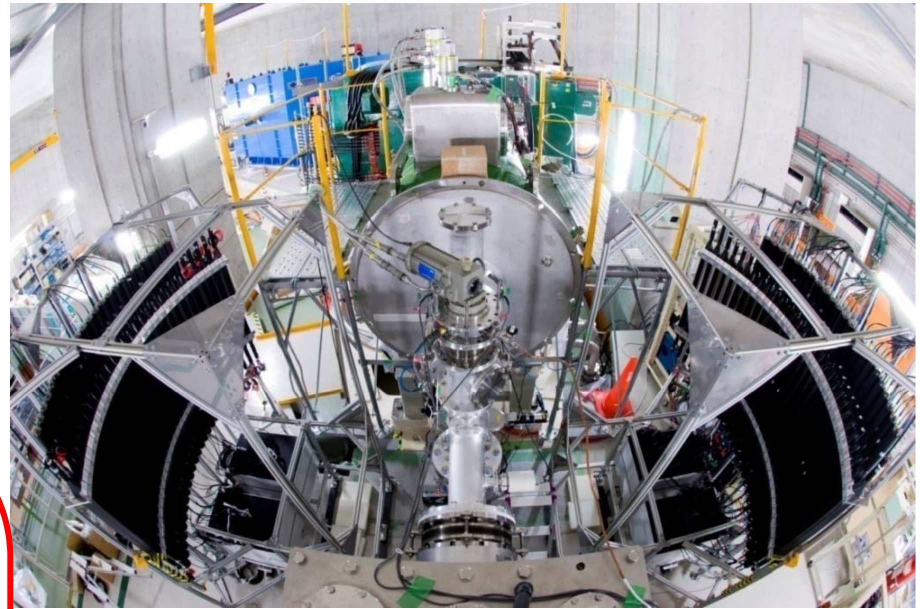


WINDS (neutron counter array)

Wide-angle
Inverse-kinematics
Neutron
Detectors for
SHARAQ



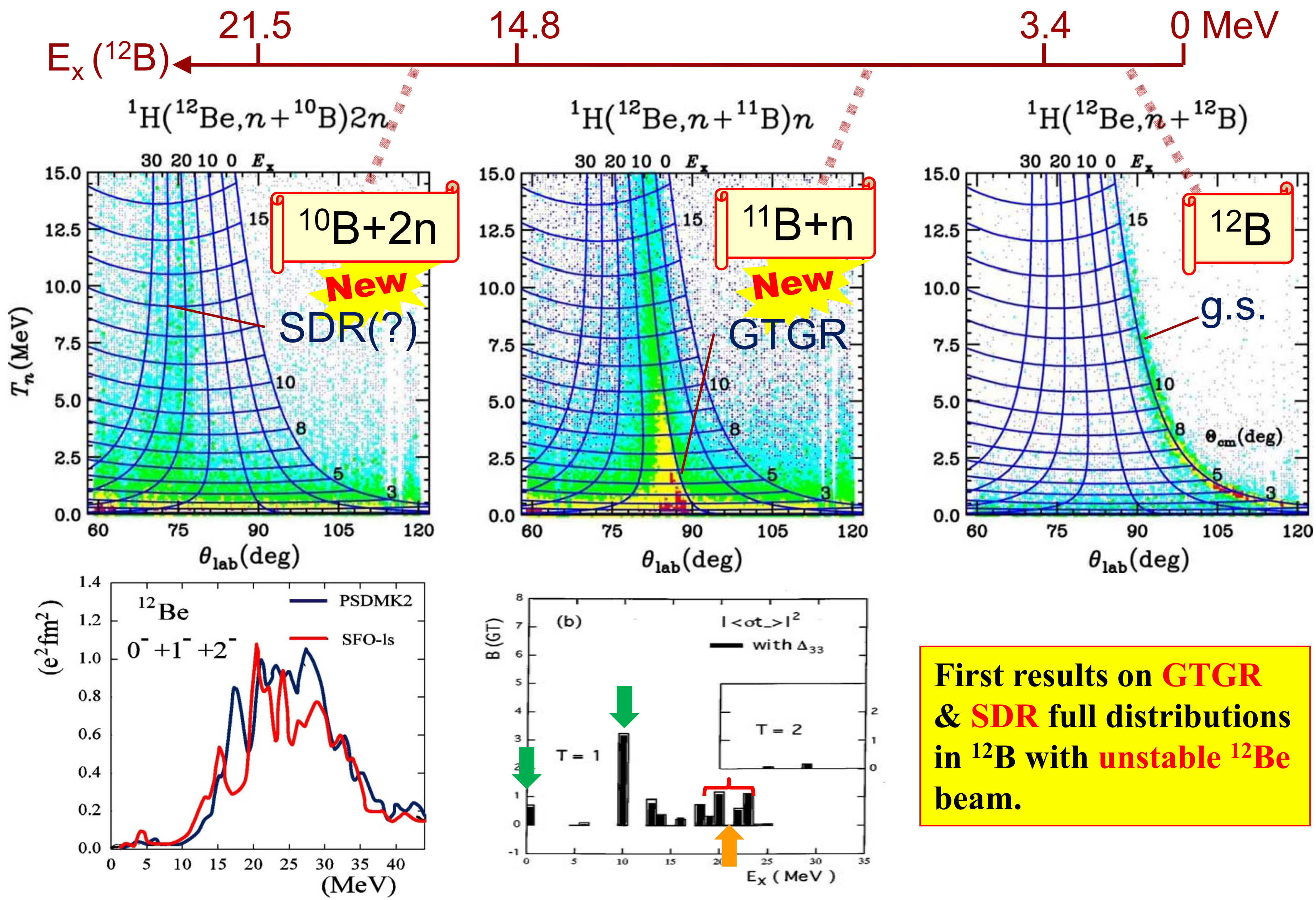
- 59 plastic scintillators (BC408)
  (H7195 + BC408, 60 x 10 x 3 cm^3)
- θ = 60-120° , FPL = 180 cm



Measurement condition

- **Experiment : 6-12 June, 2011**
- **Primary beam: ^{18}O 250A MeV, 100-200 pnA**
  - **¼ -freq. buncher … pulse separation of 122 ns**
- **Primary target: Be, 20 mm^t**
- **Secondary beam: ^{12}Be 200A MeV, 500 kcps on target**
  → contains few % isomer in ^{12}Be
- **Secondary target: Liq H_2, 14 mm^t**

Result



First results on GTGR & SDR full distributions in ^{12}B with unstable ^{12}Be beam.

Summary

1 reliability of extracting the spin-isospin responses in the continuum

- **Unit cross section, proportionality, MDA(shallow binding)**
- **Interferences: L=0 vs. L=2 and GT vs. IVSM**

2 composite projectiles

- **(t,^{3}He,) reaction: measurement by Miki**
  - **Large exchange effects**
- **(^{12}N,^{12}C) reaction: measurement by Noji**
  - **Large ambiguities by optical potentials(imaginary part)**

3 Brand-new: measurement of the exothermic 12Be(p,n) reaction in inverse-kinematics at 200 MeV/A by Yako

- **Please stay tuned**

Home works for theorists

- **Mode interference (GT vs. IVSM)**
  - How to disentangle?
  - Should compare in terms of cross sections ?
  - Requires structure + reaction collaboration
  - Provide us the predictions in terms of cross sections
  - Then, dilemma . . .

- **Exchange effects**
  - Please develop the reaction code which can handle the exchange

- **Optical potentials**
  - Indispensable for the quantitative analysis
  - Hard to carry out exp. for rare-isotopes
  - Please create a global OP

The End

Helps by K. Yako, K. Miki, S. Noji and M. Sasano are acknowledged.