

Nuclear Data for astrophysics(NRDF/A)

-Evaluation based on nuclear structure model-

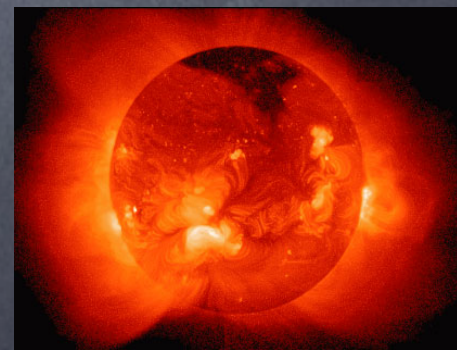
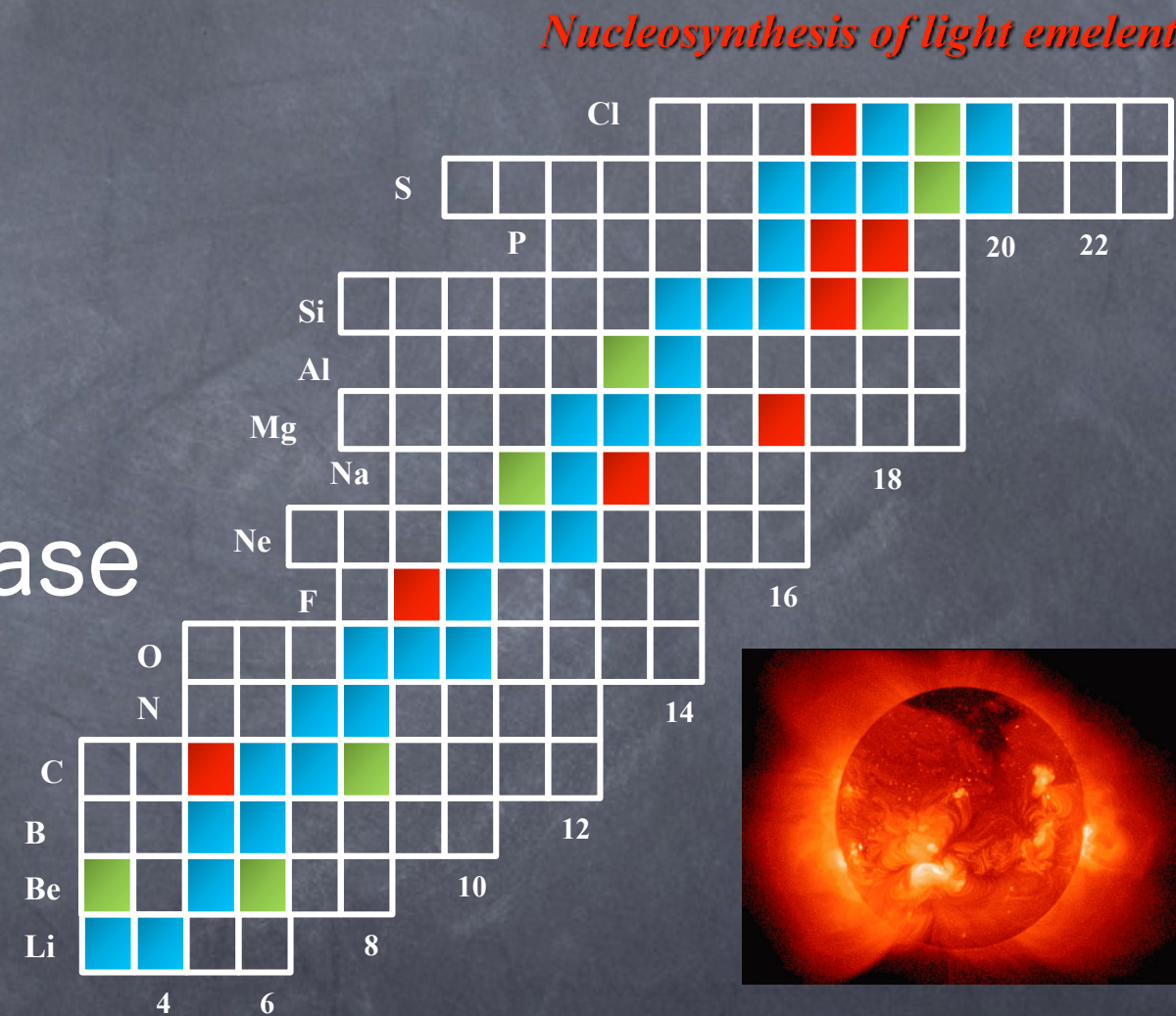
Kazuyuki Yamamoto

Meme Media Laboratory, Hokkaido University

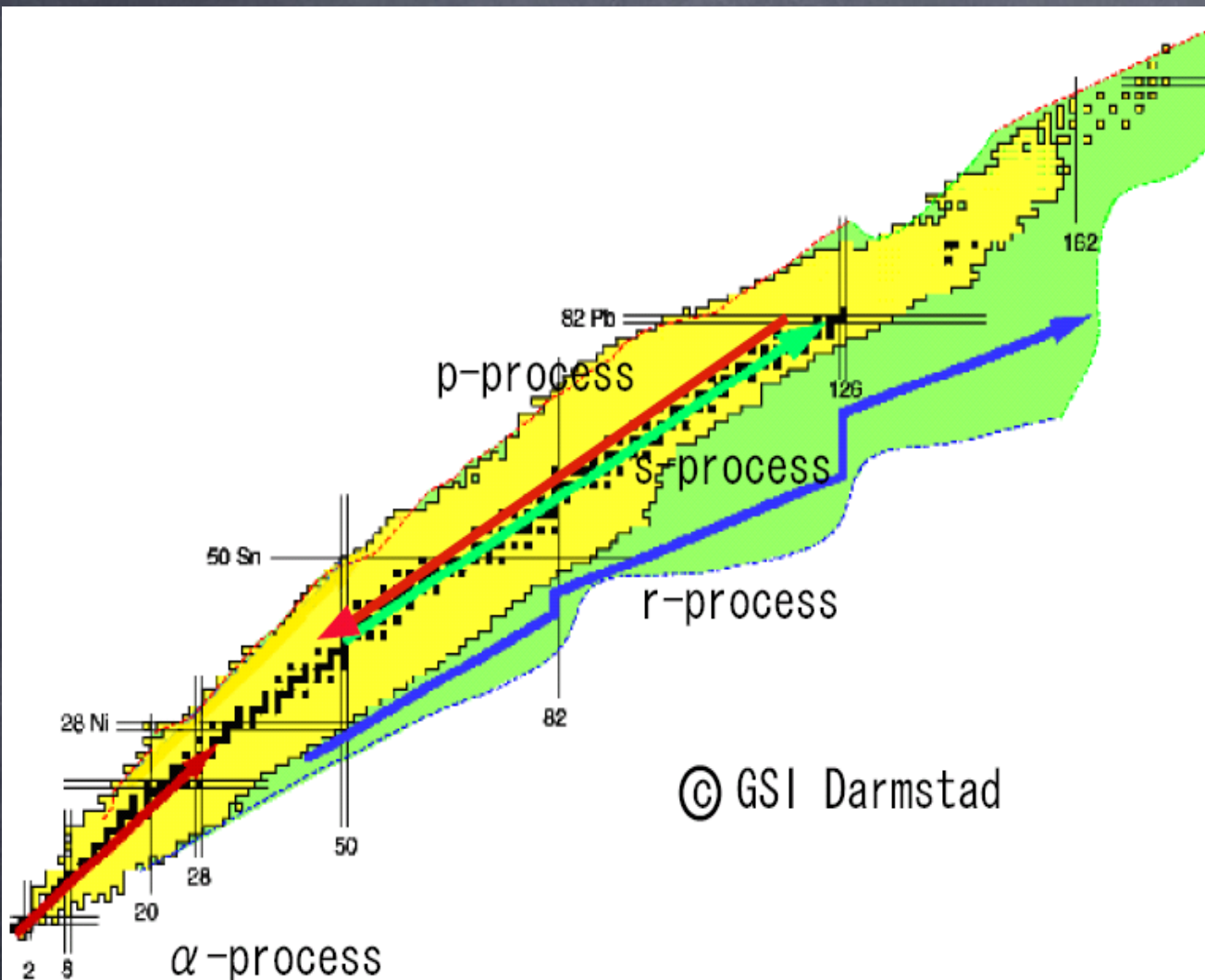
NRDF/A (2006-)

Nuclear Reaction Data File for Astrophysics

- Reaction rates of theoretical evaluation for astro-nuclear reaction
- NRDF/A bibliographic database
- NRDF/A datafile
- Development of publication system for NRDF/A datafile



Nucleosynthesis



Big-bang nucleosynthesis
Light nuclei($A < 8$)

Evolution of star

pp-chain
CNO-cycle
NeNaMgAl -cycle

s-process(Slow)
r-process(Rapid)
p-process(Photon or Proton)

Synthesis of Elements in Stars (1957)

E. M. Burbidge, G. R. Burbidge, W. A. Fowler and F. Hoyle

NRDF/A Astro-nuclear reaction compiled file

Compile Theoretical and Experimental data
in the world

- * Cross section
- * Astrophysical S-factor
- * Reaction rate
- * Resonance width
- * Scattering phase shift
- etc ...
- * H to Si region
- * Particle and
Photo induced
reaction

NRDF/A Bibliographic database (2008-)

北大核データ
JCPRG 北海道大学大学院理学研究部附属
原子核反応データ研究開発センター
Hokkaido University Nuclear Reaction Data Centre

Faculty of Science, Hokkaido University
Nuclear Reaction Data Centre (JCPRG)

JSPS Asia and Africa Science Platform Program
"R&D Platform Formation of Nuclear Reaction Data in Asian Countries" (2010-2013)
Environmental Radiation Dose Monitoring Information is available here.(2011/3-)

Nuclear Reaction Data

1. Introduction
[Data guide / Citation](#)
2. **NRDF** (Japanese charged-particle reaction data)
Search @ [NRDF](#) / [NRDF \(Darpe\)](#) / [NRDF/A](#) / [News](#)
3. **EXFOR** (Experimental nuclear reaction data)
Search @ [JCPRG](#) / [IAEA](#) / [NEA](#) / [News](#)
4. **CINDA** (Bibliography for nuclear reaction works)
Search @ [JCPRG](#) / [IAEA](#) / [NEA](#) /
5. **ENDF/EVA** (Evaluated nuclear reaction data)
Search @ [JCPRG](#) / [JAEA](#) / [IAEA](#) / [NEA](#)

Tools

1. Graph Digitizing System (GSYS, SyGRD)
2. Cross Section Renormalizer (RENORM)
3. On-Line Calculations of Potential Scattering (OLCoPS)
4. RGM Web calculations (WebRGM)
5. High energy reaction evaluation (JoW)
6. Nuclear reaction data editor (HENDEL)
7. IntelligentPad

About us

1. Introduction to JCPRG: [History](#) / [People](#)
2. NRDC Network: [Introduction](#) / [Documents](#)
3. [Album](#)

Documents

1. Annual report (Archive in Jpn.)
2. Publications and presentations
3. Executive committees (in Jpn.)
4. Manuals

NRDF/A Reference Search (2010)

Target :

Reaction :

Year :

Cross Sections and Reaction Rate of Selected Key Reactions (Compiled in 2009)

No	Reaction	Reference	Author	Code	Data	Figure
a0043	d(3He,p)4He	NP/A690(2001)790	M.Aliotta et.al.	Ali2001	EXP	EXP
a0044	d(3He,p)4He	PL/B482(2000)43	H.Constantini et.al.	Cos2000	EXP	EXP
a0045	d(3He,p)4He	ZP/A690(1994)171	P.Prati et.al.	Pra1994	EXP	EXP
a0043	3He(d,p)4He	NP/A690(2001)790	M.Aliotta et.al.	Ali2001	EXP	EXP
a0039	3He(a,g)7Be	PR/C75(2007)065803	F.Confortola et.al.	Con2007	EXP	EXP
a0041	3He(a,g)7Be	PR/L97(2006)122502	D.Bemmerer et.al.	Bem2006	EXP	EXP
a0008	9Be(p,g)10B	NP/A679(2000)199	D.Zahnow et.al.	Zah1995	EXP,CAL	EXP,CAL
a0010	9Be(p,a)6Li+9Be(p,d)8Be	NP/A210(1973)341	A.J.Sierk et.al.	Sie1973	EXP	EXP
a0011	9Be(p,a)6Li	NP/A359(1997)211	D.Zahnow et.al.	Zah1997	EXP	EXP
a0037	9Be(p,a)6Li	PR/C78(2008)035805	Qun-Gang Wen et.al.	Qun2008	EXP,CAL	EXP,CAL
a0011	9Be(p,d)6Li	NP/A359(1997)211	D.Zahnow et.al.	Zah1997	EXP	EXP

Survey of Bibliographic Information (Compiled in 2009)

07Be-09Be.xls																
新規作成 開く 保存 プリント インポート コピー ペースト 書式 元に戻す やり直し オート SUM 昇順 降順 ギャラリー ツール ズーム ヘルプ																
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
1	反応	標的核	標的核	入射粒	放出粒	Energy-min [eV]	Energy-max [eV]	Cross-sec	Astrophys	Reaction ra	A-spectra	G-spectra	B(A)	A-decay	G-multip	B-spectra
2																
3	7Be(p,γ)8B	4	7	p	γ	*0	*1.5E+06								2007NA17	NP/A
4	7Be(p,γ)8B	4	7	p	γ	*0	*1.6E+06	cal							2006NA07	PL/B
5	7Be(p,γ)8B	4	7	p	γ	0	3.0E+06		cal						2006HA09	PR/C
6	7Be(p,γ)8B	4	7	p	γ	*1.0E+05	*2.5E+06		ana						2006GA27	PR/C
7	7Be(p,γ)8B	4	7	p	γ	*0	*1.2E+06		cal						2006BA15	NP/A
8	7Be(p,γ)8B	4	7	p	γ	*low			cal						2005TY02	NP/A
9	7Be(p,γ)8B	4	7	p	γ	*5.0E+05	*8.0E+06	cal							2005SU22	JP/G
10	7Be(p,γ)8B	4	7	p	γ	1.16E+08	2.46E+09	mes	ded						2005JU03	NP/B
11	7Be(p,γ)8B	4	7	p	γ	*low			ana						2005GAZZ	nucl-ex/0502020.2
12	7Be(p,γ)8B	4	7	p	γ	1.0E+05	1.2E+06		ana						2005GA08	NP/B
13	7Be(p,γ)8B	4	7	p	γ	*low			cal						2005DH01	JP/G
14	7Be(p,γ)8B	4	7	p	γ		2.5E+04		com,ana						2005CY03	NP/A
15	7Be(p,γ)8B	4	7	p	γ	1.16E+08	2.46E+09	mes	ded						2004JU08	NP/A
16	7Be(p,γ)8B	4	7	p	γ	*low			com,ana	com,ana					2004HA55	NP/A
17	7Be(p,γ)8B	4	7	p	γ	?			cal						2004DE31	NP/A
18	7Be(p,γ)8B	4	7	p	γ	*2.21E+05	*1.379E+06	mes	ded						2003PA33	NP/A
19	7Be(p,γ)8B	4	7	p	γ	1.16E+05	2.46E+06	mes	ded						2003JUZZ	nucl-ex/0308003.6
20	7Be(p,γ)8B	4	7	p	γ	1.16?	2.46?	mes	ded						2003JU04	PR/C
21	7Be(p,γ)8B	4	7	p	γ	1.0E+05	1.4E+06		ana						2003GAZV	nucl-ex/0312003.1
22	7Be(p,γ)8B	4	7	p	γ	*low			cal						2003CH79	PR/C
23	7Be(p,γ)8B	4	7	p	γ	3.02E+05	1.078E+06		mes						2003BA84	NP/A
24	7Be(p,γ)8B	4	7	p	γ	*5.049E+05	*9.912E+05	mes	mes						2003BA04	PRL
25	7Be(p,γ)8B	4	7	p	γ	*5.049E+05	*9.912E+05	mes	mes						2003BA04	PRL
26	7Be(p,γ)8B	4	7	p	γ	*0	*1.5E+05		cal						2002MU16	NP/A
27	7Be(p,γ)8B	4	7	p	γ	1.86E+05	1.2E+06	mes	ded						2002JUZY	AIP Conf.Proc. 6
28	7Be(p,γ)8B	4	7	p	γ	1.86E+05	1.2E+06	mes	ded						2002JUZY	Proc.Inter.Nuclea
29	7Be(p,γ)8B	4	7	p	γ	1.86E+05	1.2E+06	mes	ded						2002JU01	PRL
30	7Be(p,γ)8B	4	7	p	γ	3.0E+05	1.1E+06	mes	ded		mes				2002BAZS	nucl-ex/0208005.6
31	7Be(p,γ)8B	4	7	p	γ	3.2E+05	2.61E+06		*mes s(E)	ded		mes			2001ST27	NP/A
32	7Be(p,γ)8B	4	7	p	γ	*low			ana	ana,ded					2001MU20	NP/A
33	7Be(p,γ)8B	4	7	p	γ	0	3.0E+06		com,eva	ded					2001MO32	NP/A
34	7Be(p,γ)8B	4	7	p	γ	1.86E+05	1.2E+06	mes	ded						2001JUZZ	nucl-ex/0111014.1
35	7Be(p,γ)8B	4	7	p	γ	*1.117E+05	*1.858E+05	mes	mes		mes				2001HA36	NP/A

Reaction : about 190
Light nuclei reaction
Record : about 7000

URL <http://www.jcprg.org/>

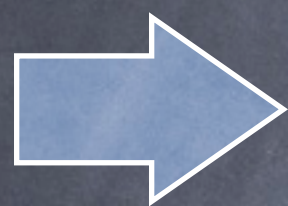
Reaction, NSR key number, Doi, Ref, Author, Title, Key word...

NRDF/A Evaluation (2009-)

1. Evaluation based on nuclear structure model

Orthogonality Condition Model(OCM)

+
Complex Scaling Method(CSM)^{1,2}



When reaction cross section is not measured by the experiment, it is necessary to evaluate the cross section for **theoretical approach in astrophysical reaction.**

2. Evaluation based on reaction theory

Continuum-Discretized Coupled-Channels method
(CDCC)³

Ref. [1] T. Myo, K. Kato, S. Aoyama and K. Ikeda, PRC 63 (2001).

[2] S. Aoyama, T. Myo, K. Kato and K. Ikeda, PTP 116 (2006).

[3] M. Kamimura, M. Yahiro, Y. Iseri, Y. Sakuragi, H. Kameyama and M. Kawai, PTP Suppl. 89 (1986), 1

☆ Orthogonal condition model(OCM)

OCM take into account the Pauli principle.

Schrodinger eq.

$$H_{rel}\chi = E\chi \qquad \langle \chi | \chi_F \rangle = 0$$

To satisfy the Pauli principle.

Hamiltonian

$$H_{rel} = \sum_{i=1} T_i - T_{cm} + V_N + V_C + \lambda V_F$$

☆ Complex scaling method(CSM)

$$Ur \rightarrow re^{i\theta}$$

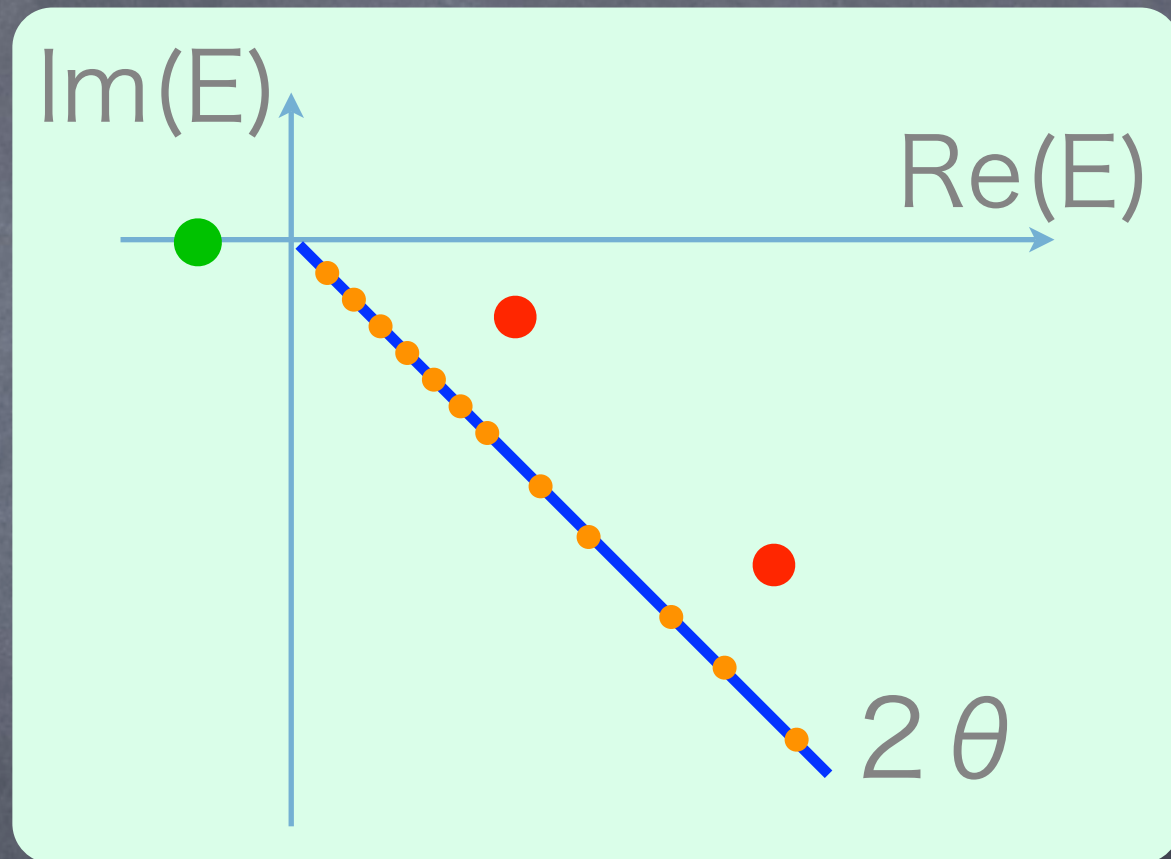
$$Uk \rightarrow ke^{-i\theta}$$

$$H(\theta) = U(\theta)HU^{-1}(\theta)$$

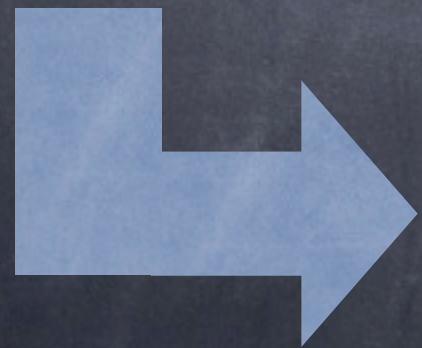
$$\Phi(\theta) = U\Phi = e^{i\frac{3}{2}\theta}\Phi(re^{i\theta})$$

$$H(\theta)\Phi^\theta = E^\theta\Phi^\theta$$

$$E^\theta = E_{re} - i\Gamma/2$$



Solution of Hamiltonian



{ Bound state
Unbound state

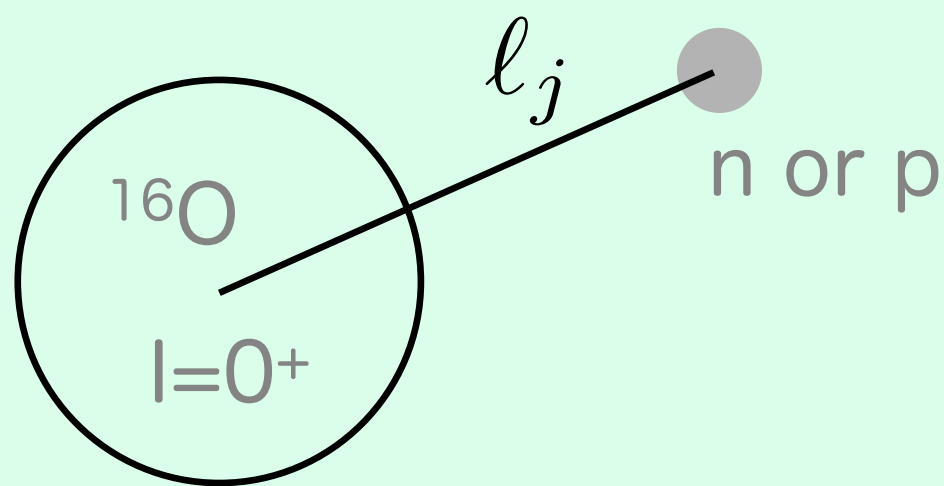


{ Resonant st.
Continuum st.

Example : $^{16}\text{O} + \text{N}$

$^{16}\text{O} + \text{N}$ Hamiltonian

$$H_{rel} = T + V_N + V_C + \lambda V_F$$



T : kinetic operator

V_N : Nuclear potential

V_C : Coulomb potential

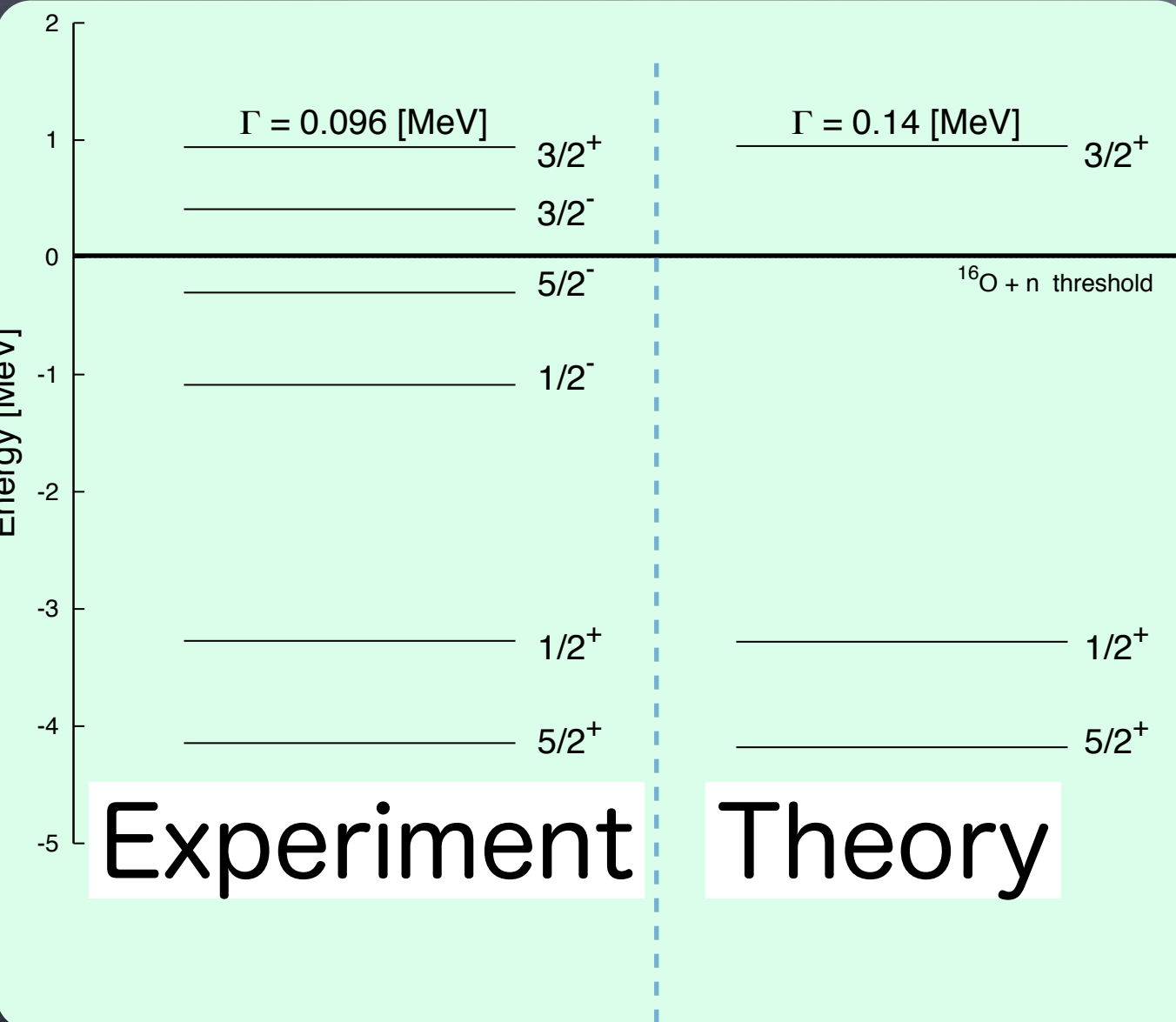
V_F : Pauli pseudo-potential

core-n folding potential is defined as following :

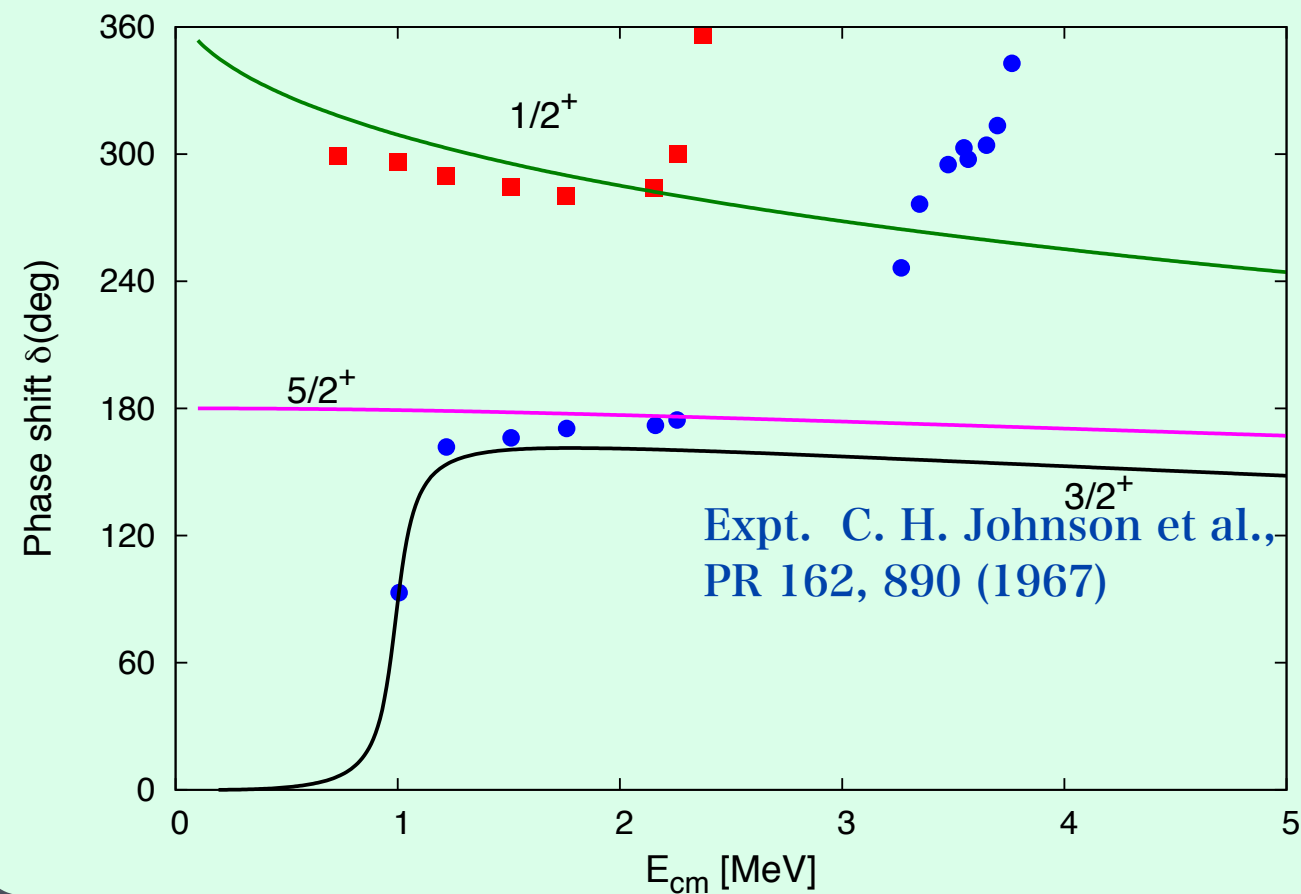
$$V_N = V(r) + V(\mathbf{r}, \mathbf{r}') + V_{ls}(r)$$

Results of $^{16}\text{O}(n, \gamma)^{17}\text{O}$ reaction

Energy level for ^{17}O



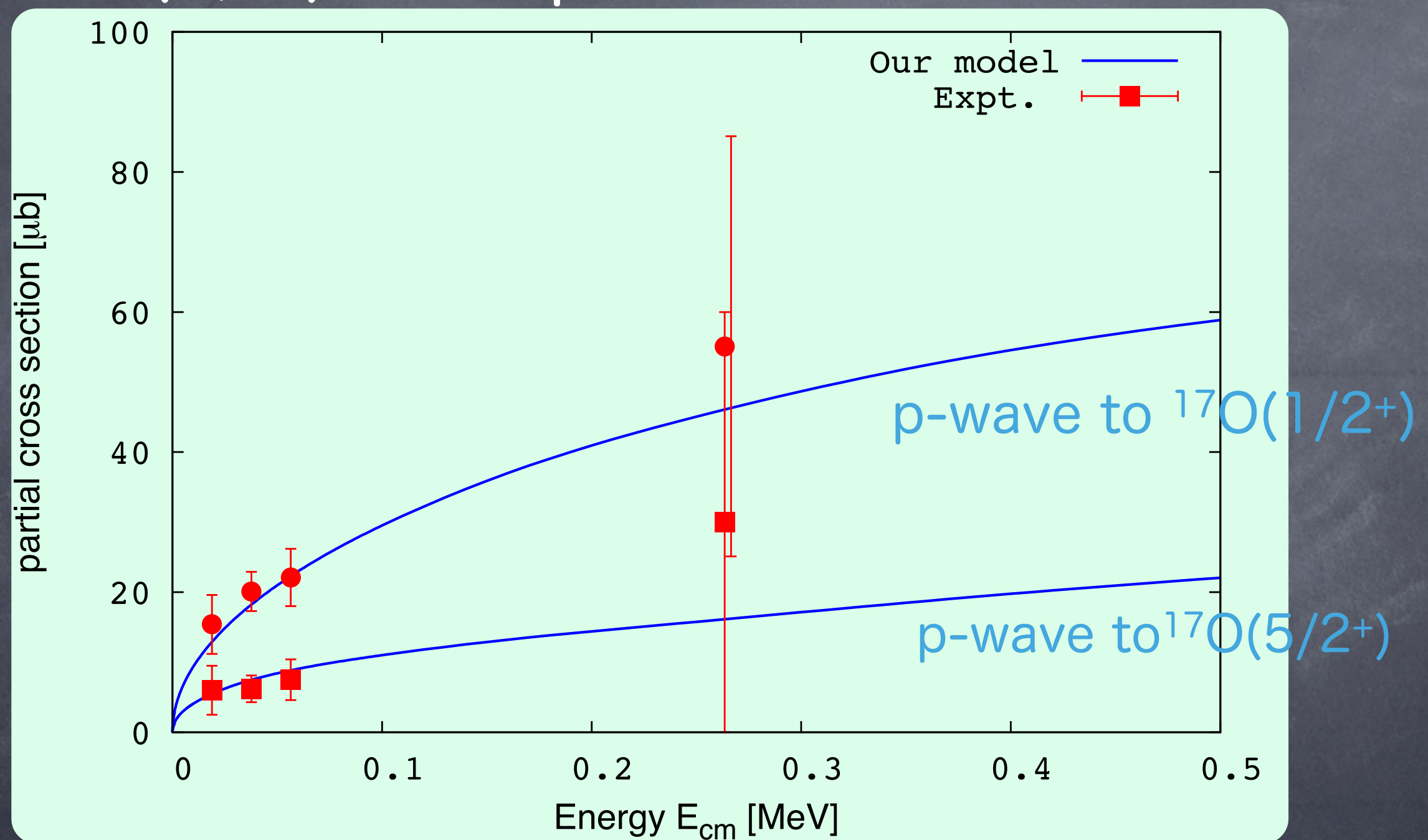
Elastic scattering phase shift for $^{16}\text{O}+n$



The core+n potential is reliable for the low-lying positive-parity states.

Ref: K.Y, H. Masui, K. Kato, T. Wada and M. Ohta, PTP 121 (2009), 375.

For the reaction, reliable wave function $^{16}\text{O}(n, \gamma)^{17}\text{O}$ capture cross section

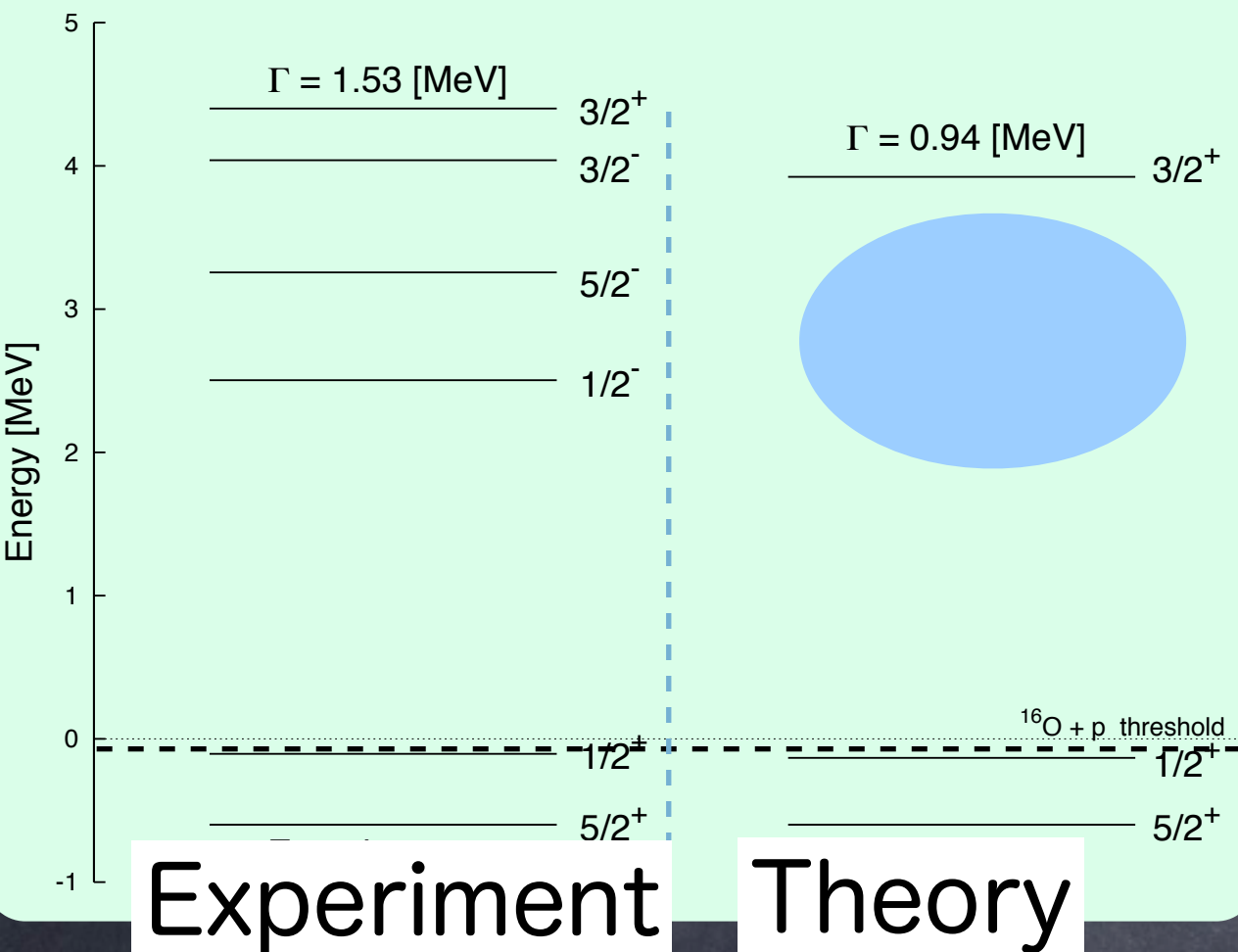


The wave function of the p-scattering and bound states are reliable.

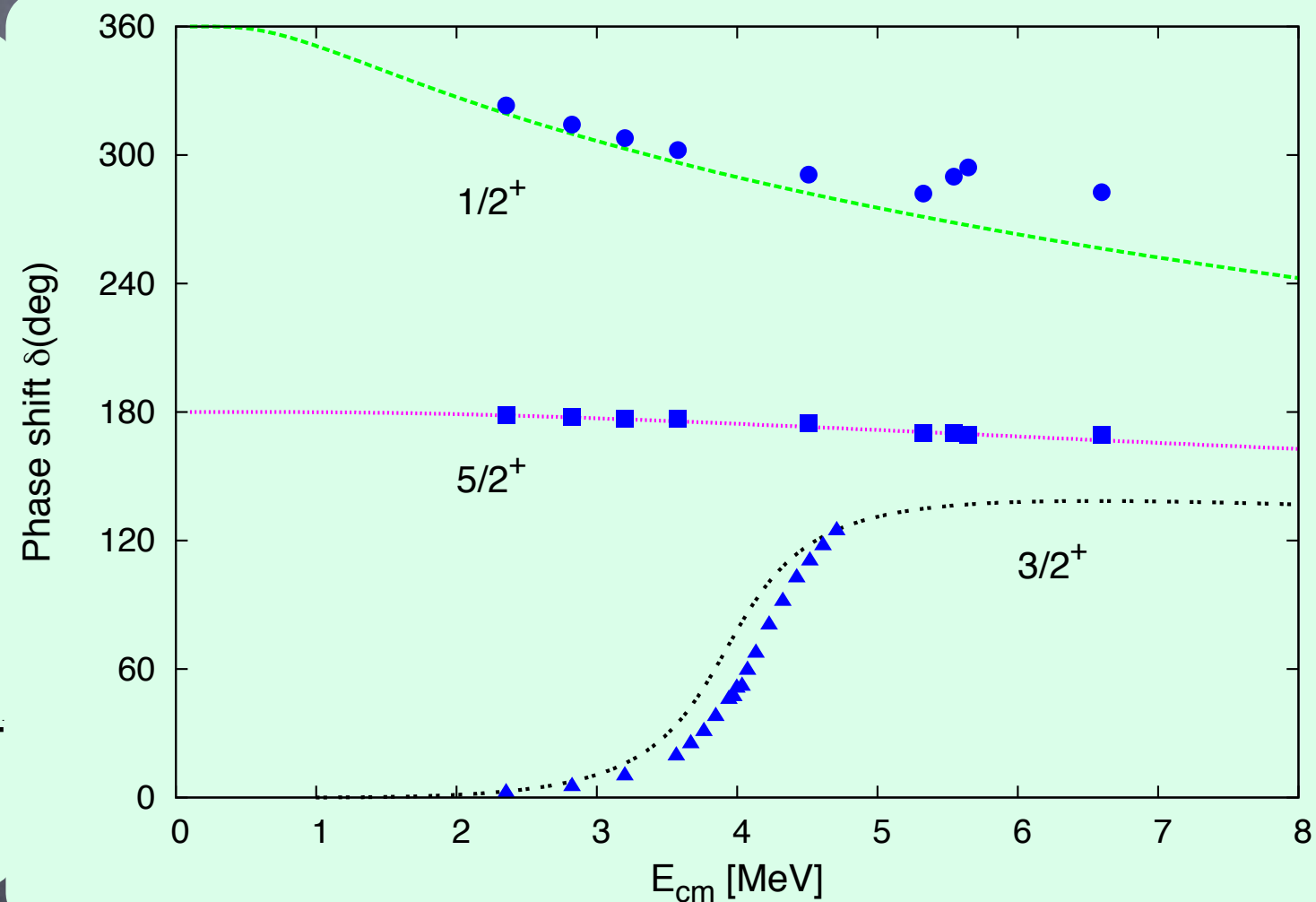
Ref: K.Y, H. Masui, K. Kato, T. Wada and M. Ohta, PTP 121 (2009), 375.

Results of $^{16}\text{O}(p, \gamma)^{17}\text{F}$ reaction

Energy level for ^{17}F

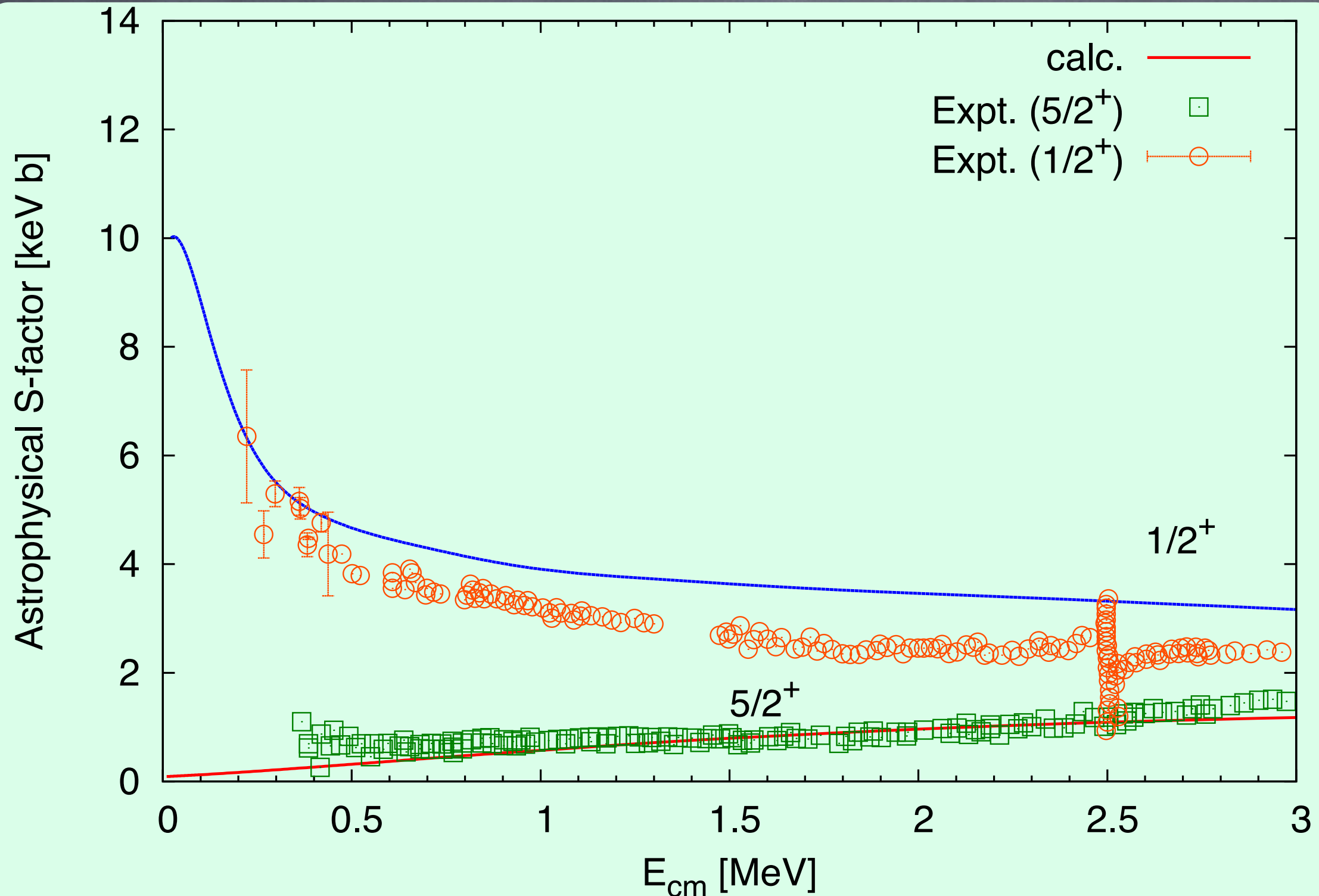


Elastic scattering phase shift for $^{16}\text{O}+p$



Ref: K.Y, H. Masui, K. Kato, T. Wada and M. Ohta, PTP 121 (2009), 375.

Astrophysical S-factor



Ref: K.Y, H. Masui, K. Kato, T. Wada and M. Ohta, PTP 121 (2009), 375.

Summary and Future plans

- Our method well reproduce the experimental data at low-energy.
- We will perform the systematic evaluation for isotope and isotone using OCM+CSM.
- We evaluate the 3-body reaction.
 $a+a+a \rightarrow {}^{12}\text{C}$ $a+a+n \rightarrow {}^9\text{Be}$ $a+a+p \rightarrow {}^9\text{B}$

Thank you for your attention