Nuclear Data for astrophysics(NRDF/A)

-Evaluation based on nuclear structure model-

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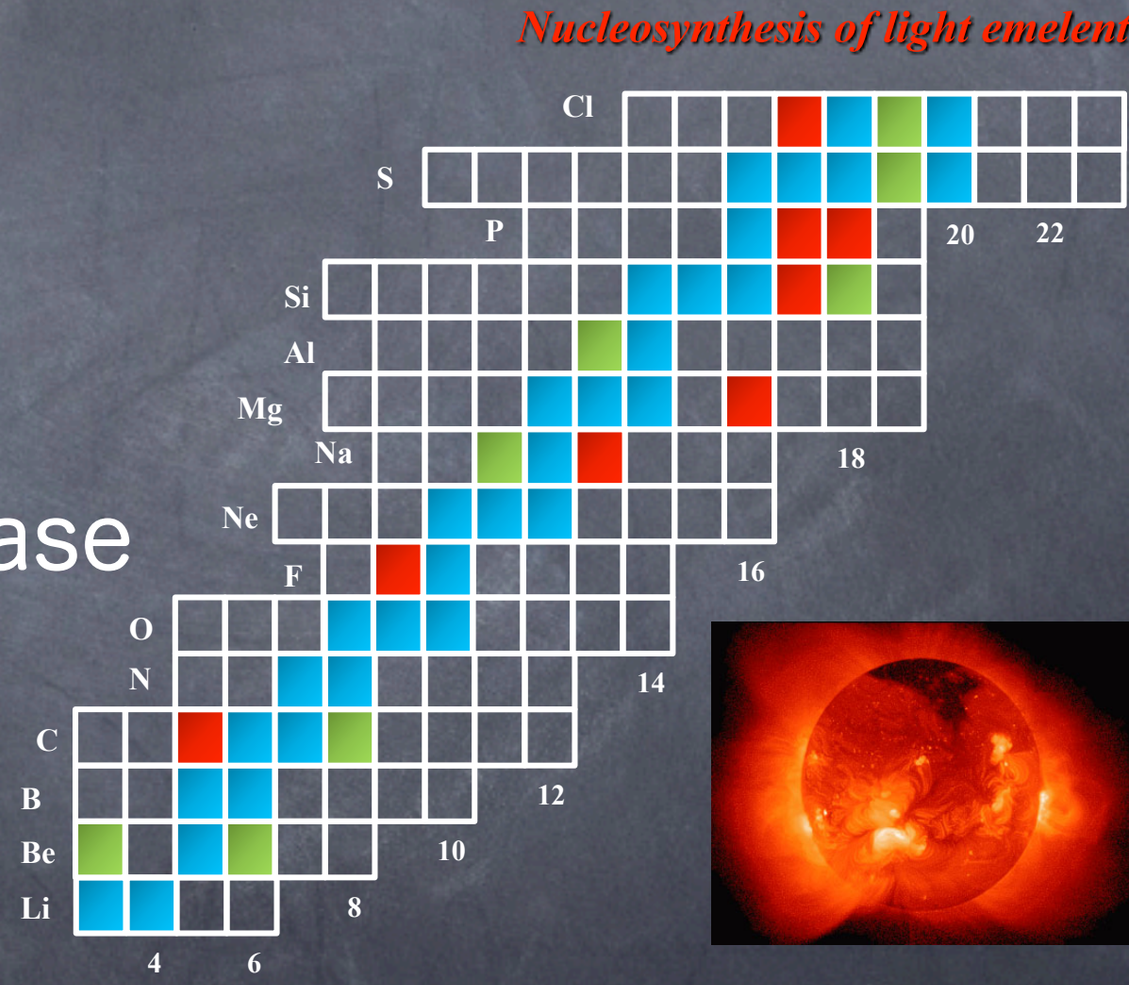
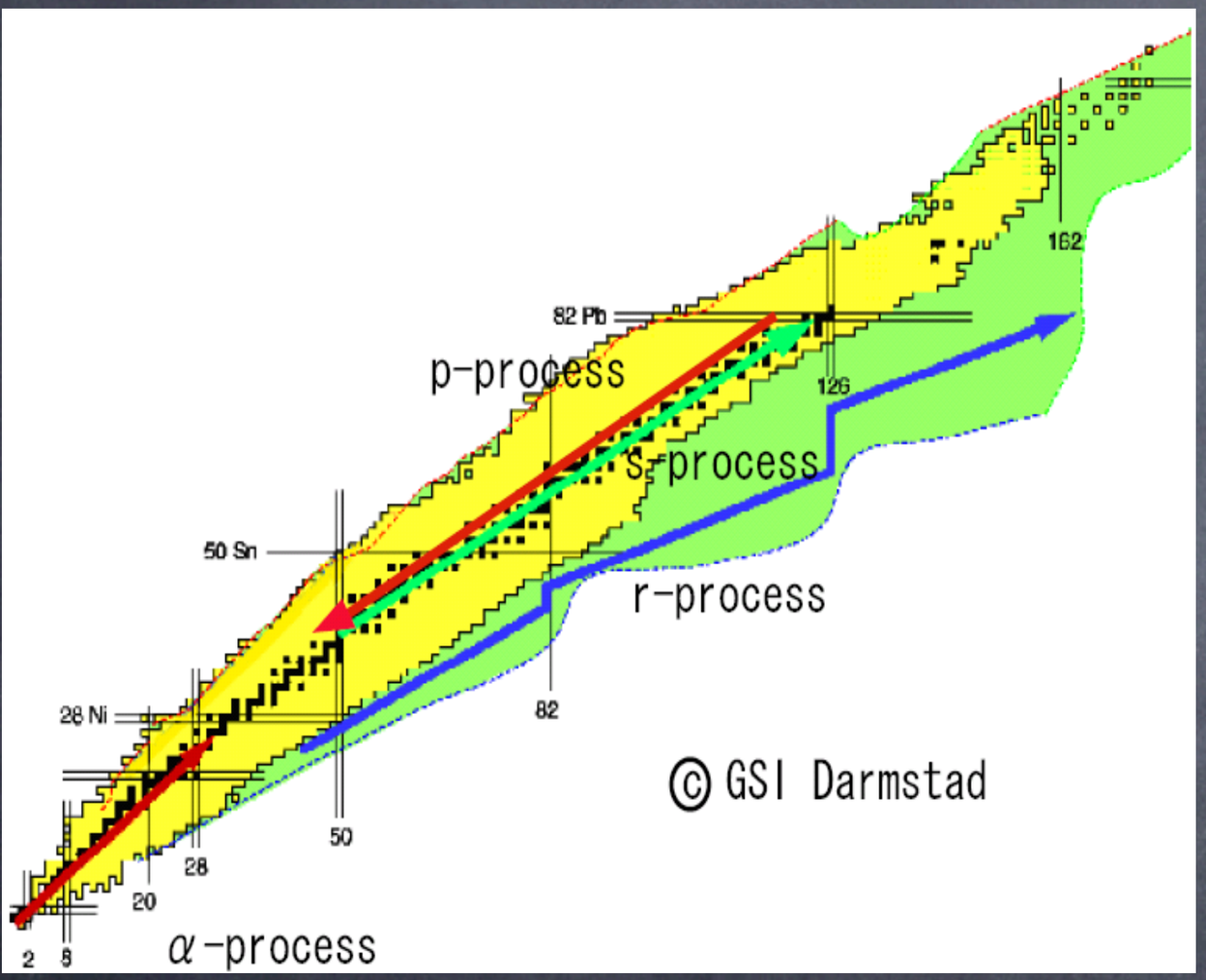
NRDF/A (2006-)

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

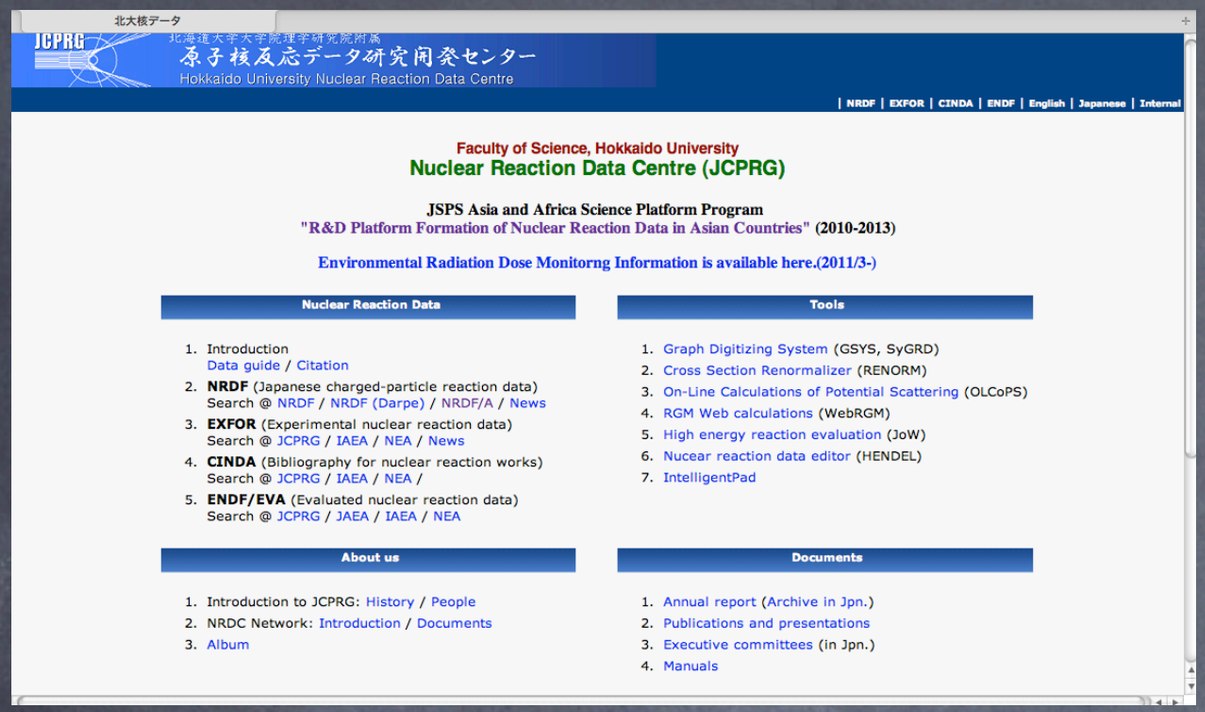
Compile Theoretical and Experimental data in the world

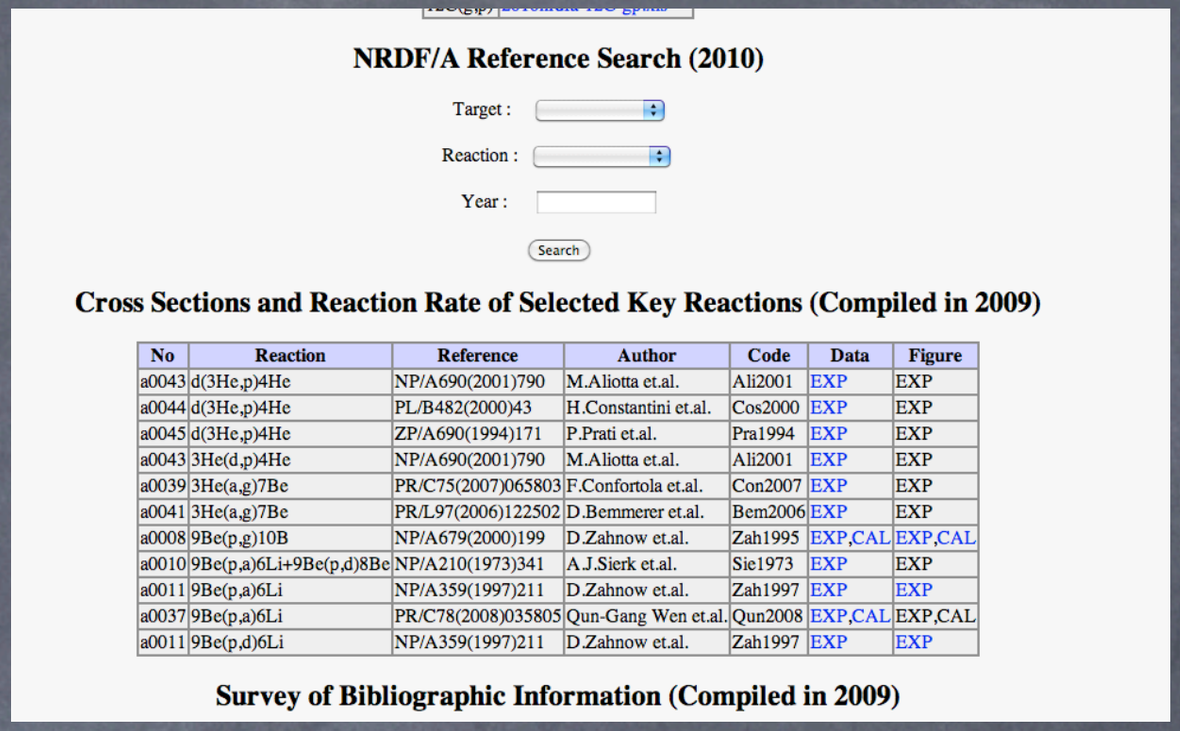
* Cross section
* Astrophysical S-factor
* Reaction rate
* Resonance width
* Scattering phase shift

etc ...

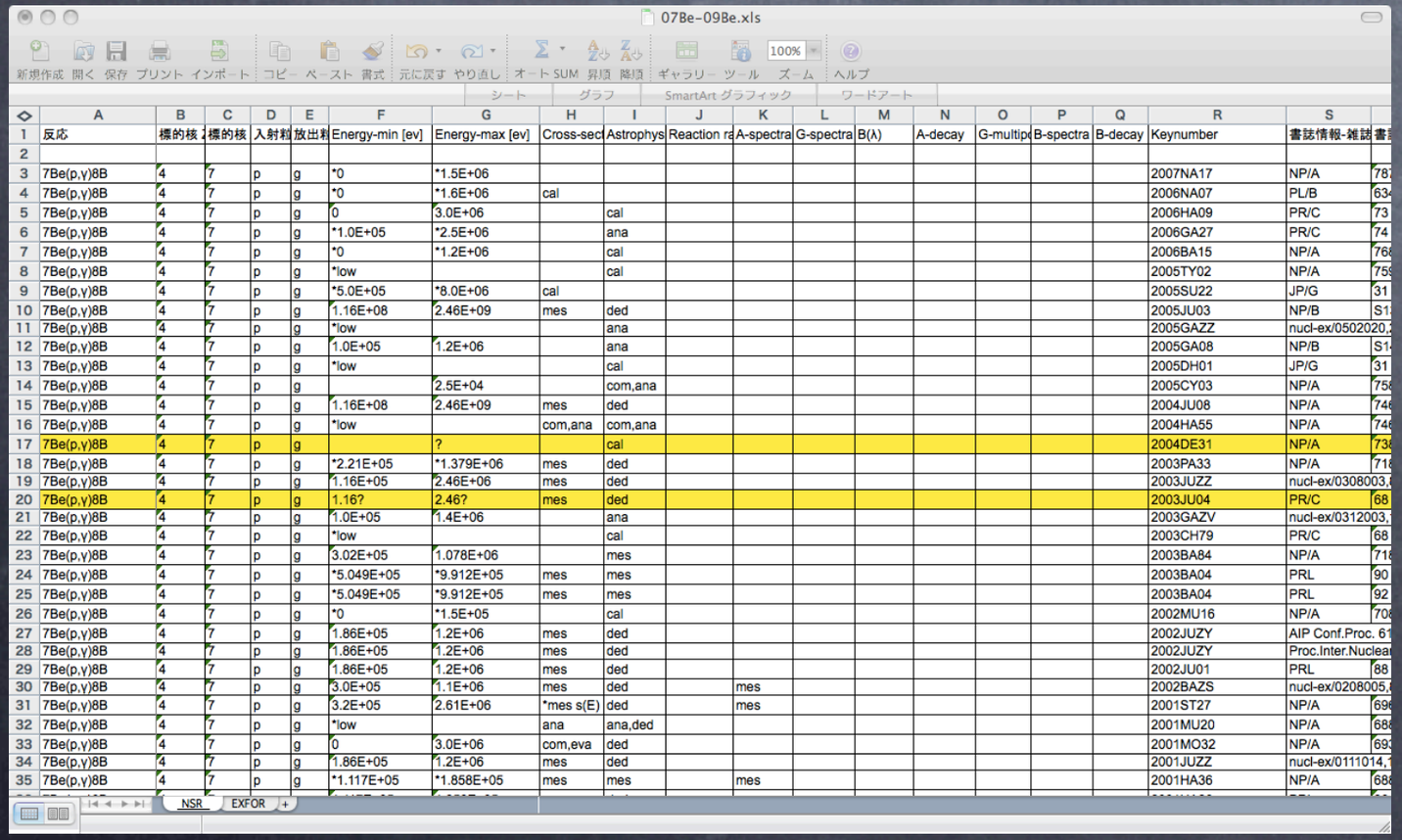
* H to Si region
* Particle and Photo induced reaction

NRDF/A Bibliographic database (2008-)





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



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	反応	標的核	標的核	入射粒	放出粒	Energy-min [ev]	Energy-max [ev]	Cross-sect	Astrophys	Reaction ra	A-spectra	G-spectra	B(λ)	A-decay	G-multipo	B-spectra	B-decay	Keynumber	書誌情報-雑誌
2																			
3	7Be(p,γ)8B	4	7	p	g	*0	*1.5E+06											2007NA17	NP/A
4	7Be(p,γ)8B	4	7	p	g	*0	*1.6E+06	cal										2006NA07	PL/B
5	7Be(p,γ)8B	4	7	p	g	0	3.0E+06		cal									2006HA09	PR/C
6	7Be(p,γ)8B	4	7	p	g	*1.0E+05	*2.5E+06		ana									2006GA27	PR/C
7	7Be(p,γ)8B	4	7	p	g	*0	*1.2E+06		cal									2006BA15	NP/A
8	7Be(p,γ)8B	4	7	p	g	*low			cal									2005TY02	NP/A
9	7Be(p,γ)8B	4	7	p	g	*5.0E+05	*8.0E+06	cal										2005SU22	JP/G
10	7Be(p,γ)8B	4	7	p	g	1.16E+08	2.46E+09	mes	ded									2005JU03	NP/B
11	7Be(p,γ)8B	4	7	p	g	*low			ana									2005GAZZ	nucl-ex/0502020
12	7Be(p,γ)8B	4	7	p	g	1.0E+05	1.2E+06		ana									2005GA08	NP/B
13	7Be(p,γ)8B	4	7	p	g	*low			cal									2005DH01	JP/G
14	7Be(p,γ)8B	4	7	p	g		2.5E+04		com,ana									2005CY03	NP/A
15	7Be(p,γ)8B	4	7	p	g	1.16E+08	2.46E+09	mes	ded									2004JU08	NP/A
16	7Be(p,γ)8B	4	7	p	g	*low		com,ana	com,ana									2004HA55	NP/A
17	7Be(p,γ)8B	4	7	p	g		?		cal									2004DE31	NP/A
18	7Be(p,γ)8B	4	7	p	g	*2.21E+05	*1.379E+06	mes	ded									2003PA33	NP/A
19	7Be(p,γ)8B	4	7	p	g	1.16E+05	2.46E+06	mes	ded									2003JUZZ	nucl-ex/0308003
20	7Be(p,γ)8B	4	7	p	g	1.16?	2.46?	mes	ded									2003JU04	PR/C
21	7Be(p,γ)8B	4	7	p	g	1.0E+05	1.4E+06		ana									2003GAZV	nucl-ex/0312003
22	7Be(p,γ)8B	4	7	p	g	*low			cal									2003CH79	PR/C
23	7Be(p,γ)8B	4	7	p	g	3.02E+05	1.078E+06		mes									2003BA84	NP/A
24	7Be(p,γ)8B	4	7	p	g	*5.049E+05	*9.912E+05	mes	mes									2003BA04	PRL
25	7Be(p,γ)8B	4	7	p	g	*5.049E+05	*9.912E+05	mes	mes									2003BA04	PRL
26	7Be(p,γ)8B	4	7	p	g	*0	*1.5E+05		cal									2002MU16	NP/A
27	7Be(p,γ)8B	4	7	p	g	1.86E+05	1.2E+06	mes	ded									2002JUZY	AIP Conf.Proc. 61
28	7Be(p,γ)8B	4	7	p	g	1.86E+05	1.2E+06	mes	ded									2002JUZY	Proc.Inter.Nuclea
29	7Be(p,γ)8B	4	7	p	g	1.86E+05	1.2E+06	mes	ded									2002JU01	PRL
30	7Be(p,γ)8B	4	7	p	g	3.0E+05	1.1E+06	mes	ded		mes							2002BAZS	nucl-ex/0208005
31	7Be(p,γ)8B	4	7	p	g	3.2E+05	2.61E+06	*mes s(E)	ded		mes							2001ST27	NP/A
32	7Be(p,γ)8B	4	7	p	g	*low		ana	ana,ded									2001MU20	NP/A
33	7Be(p,γ)8B	4	7	p	g	0	3.0E+06	com,eva	ded									2001MO32	NP/A
34	7Be(p,γ)8B	4	7	p	g	1.86E+05	1.2E+06	mes	ded									2001JUZZ	nucl-ex/0111014
35	7Be(p,γ)8B	4	7	p	g	*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

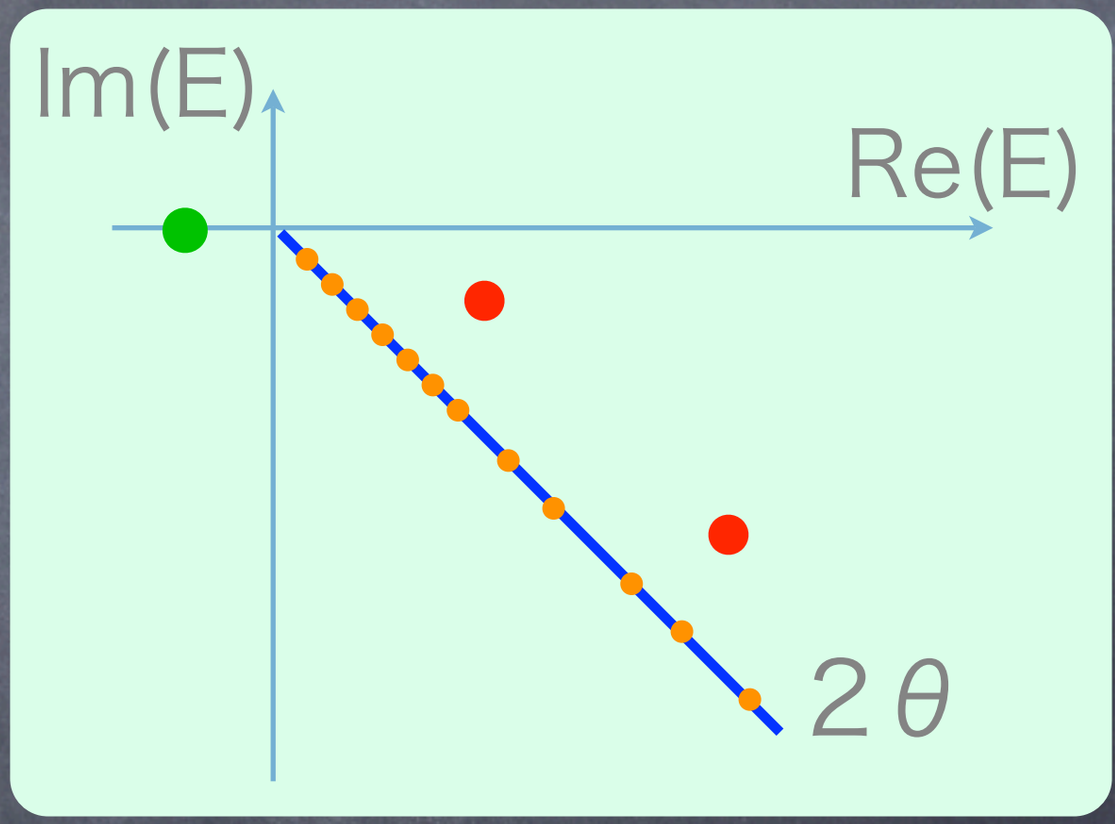
$$H_{rel} = \sum_{i=1} T_i - T_{cm} + V_N + V_C + \lambda V_F$$

☆ Complex scaling method(CSM)

$$Ur \to re^{i\theta}$$
$$Uk \to ke^{-i\theta}$$

$$H(\theta) = U(\theta)HU^{-1}(\theta)$$
$$\Phi(\theta) = U\Phi = e^{i\frac{3}{2}\theta}\Phi(re^{i\theta})$$

$$H(\theta)\Phi^{\theta} = E^{\theta}\Phi^{\theta}$$
$$E^{\theta} = E_{re} - i\Gamma/2$$



Solution of Hamiltonian

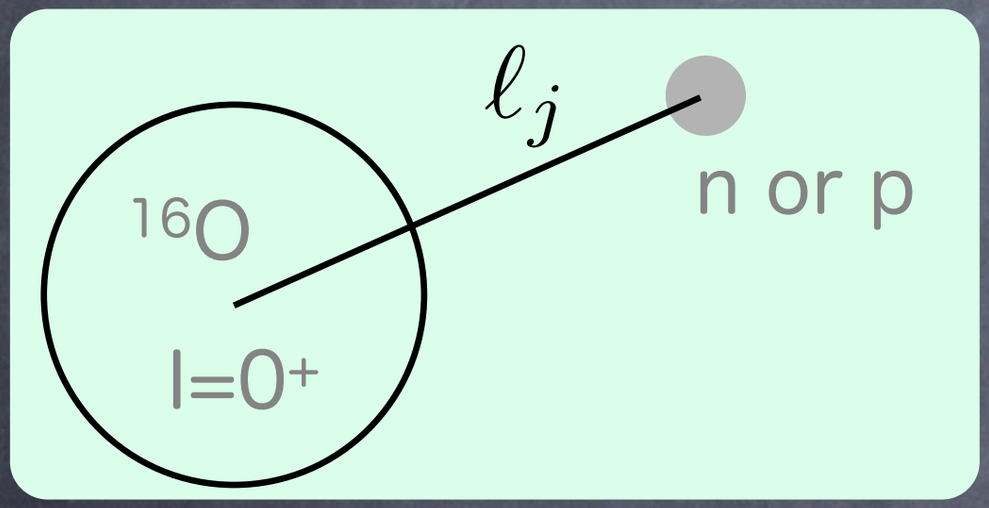
- Bound state
- Unbound state
  - Resonant st.
  - Continuum st.

Ref. S. Aoyama, T. Myo, K. Kato and K. Ikeda, PTP 116 (2006).

Example : ^{16}O + N

^{16}O+N Hamiltonian

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



T : kinetic operator

VN : Nuclear potential

VC : Coulomb potential

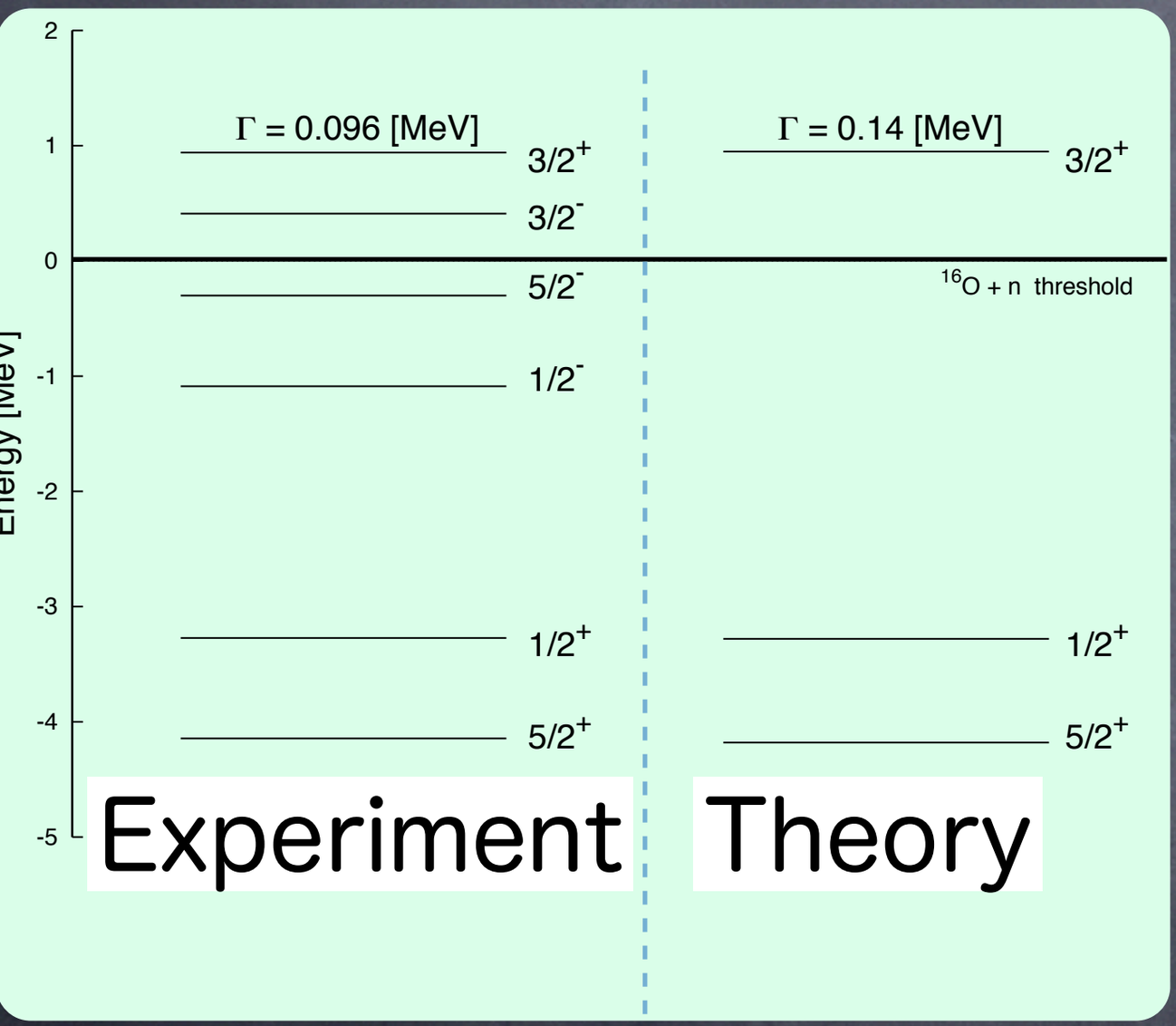
VF : Pauli pseudo-potential

core-n folding potential is defined as following :

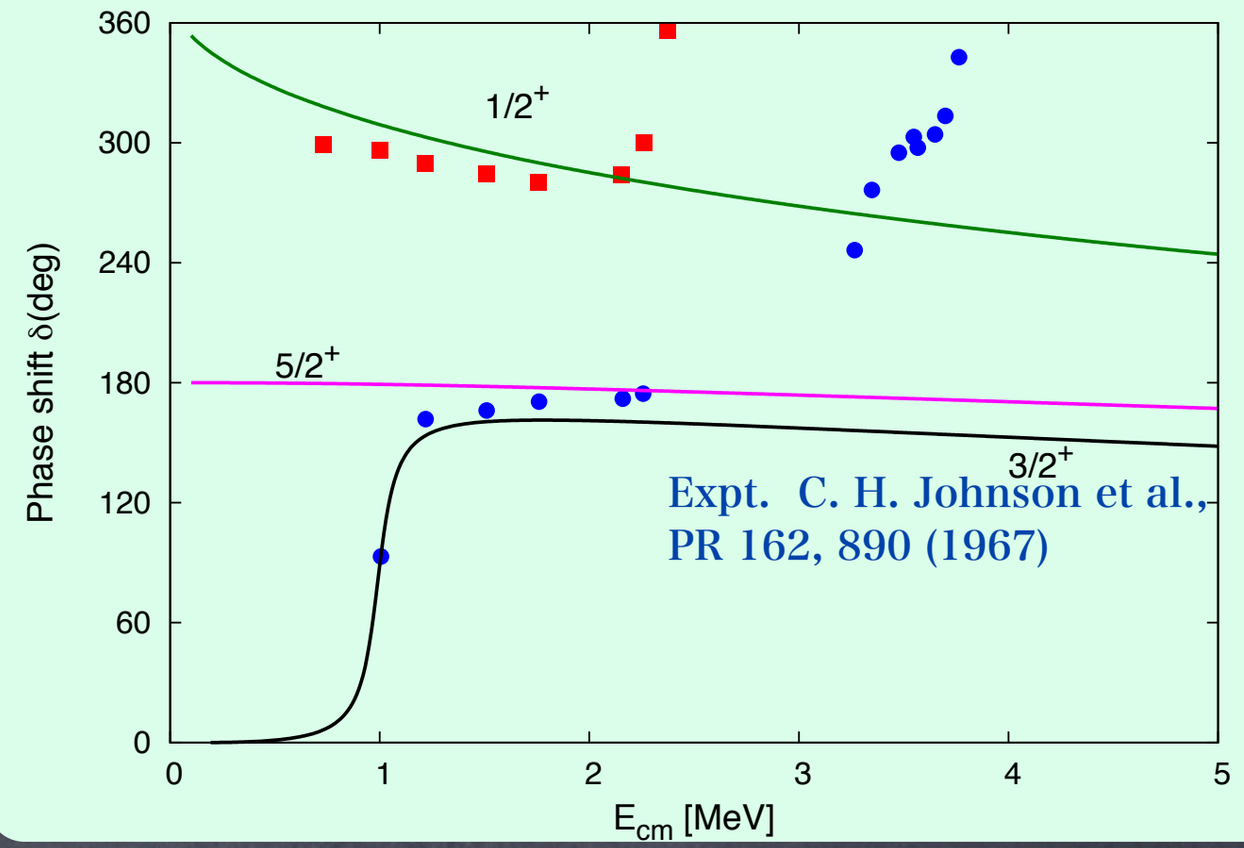
$$V_N = V(r) + V(\boldsymbol{r}, \boldsymbol{r}') + V_{ls}(r)$$

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

Energy level for ^{17}O



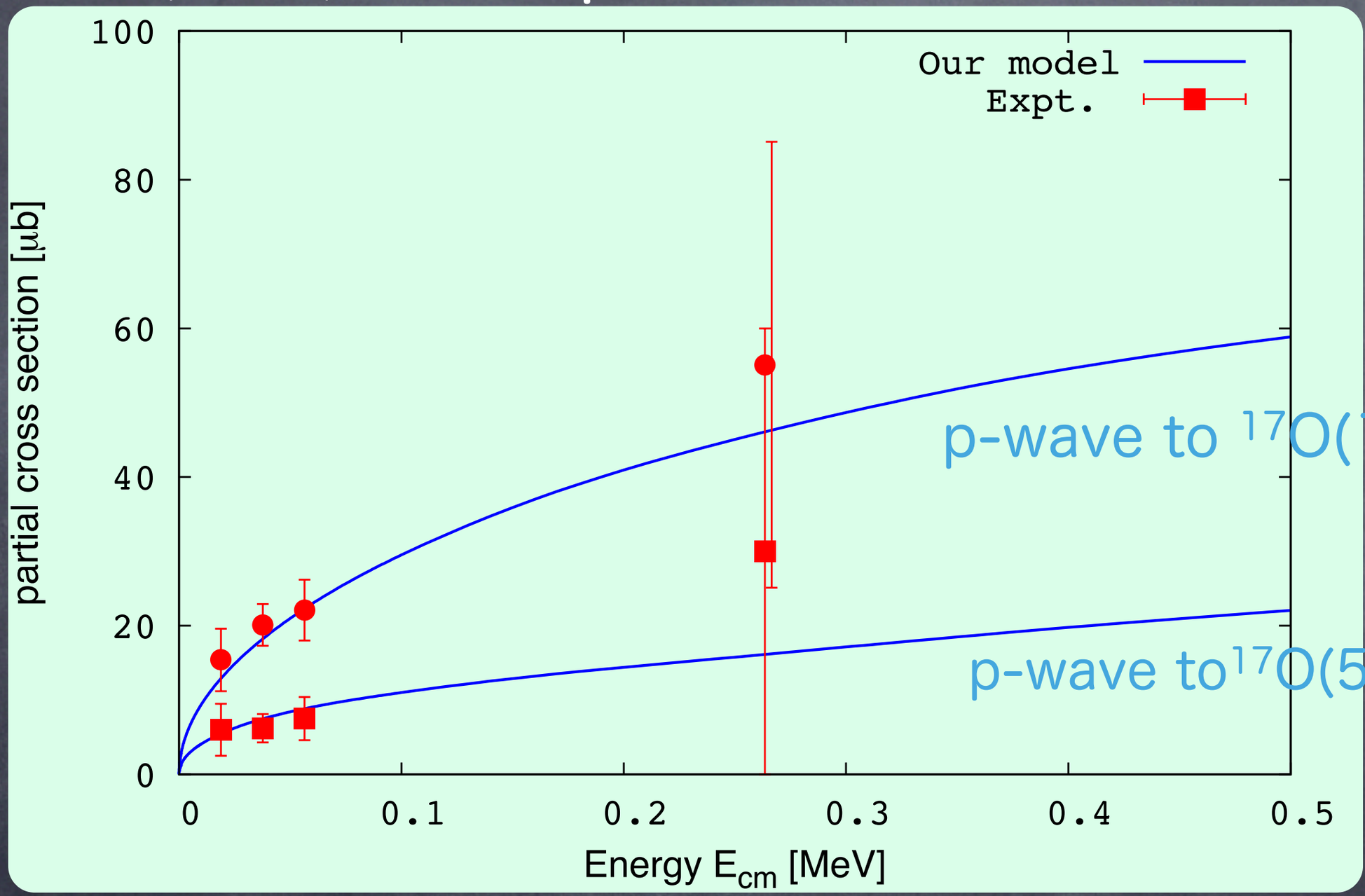
Elastic scattering phase shift for ^{16}O+n



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 $^{16}O(n,\gamma)^{17}O$ capture cross section

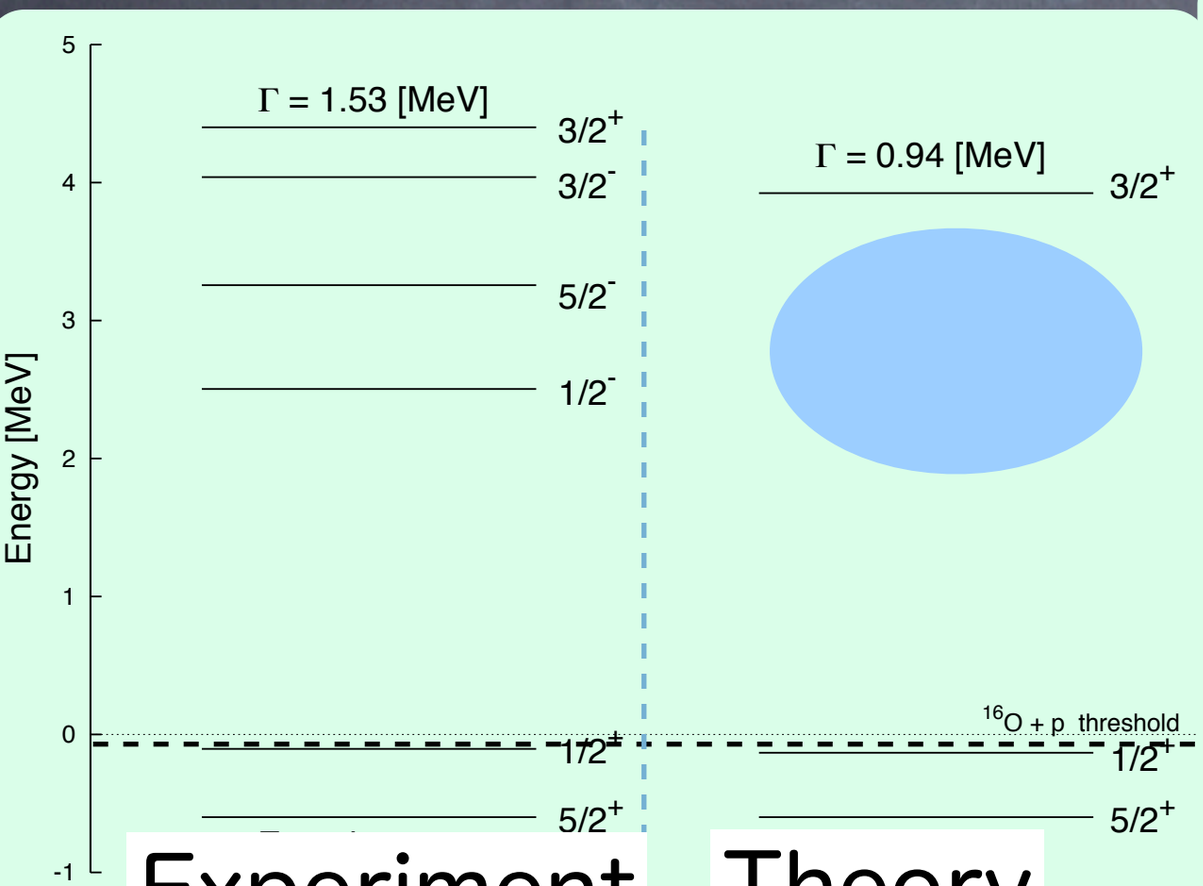


The wave function of the p-scattering and bound states are reliable.

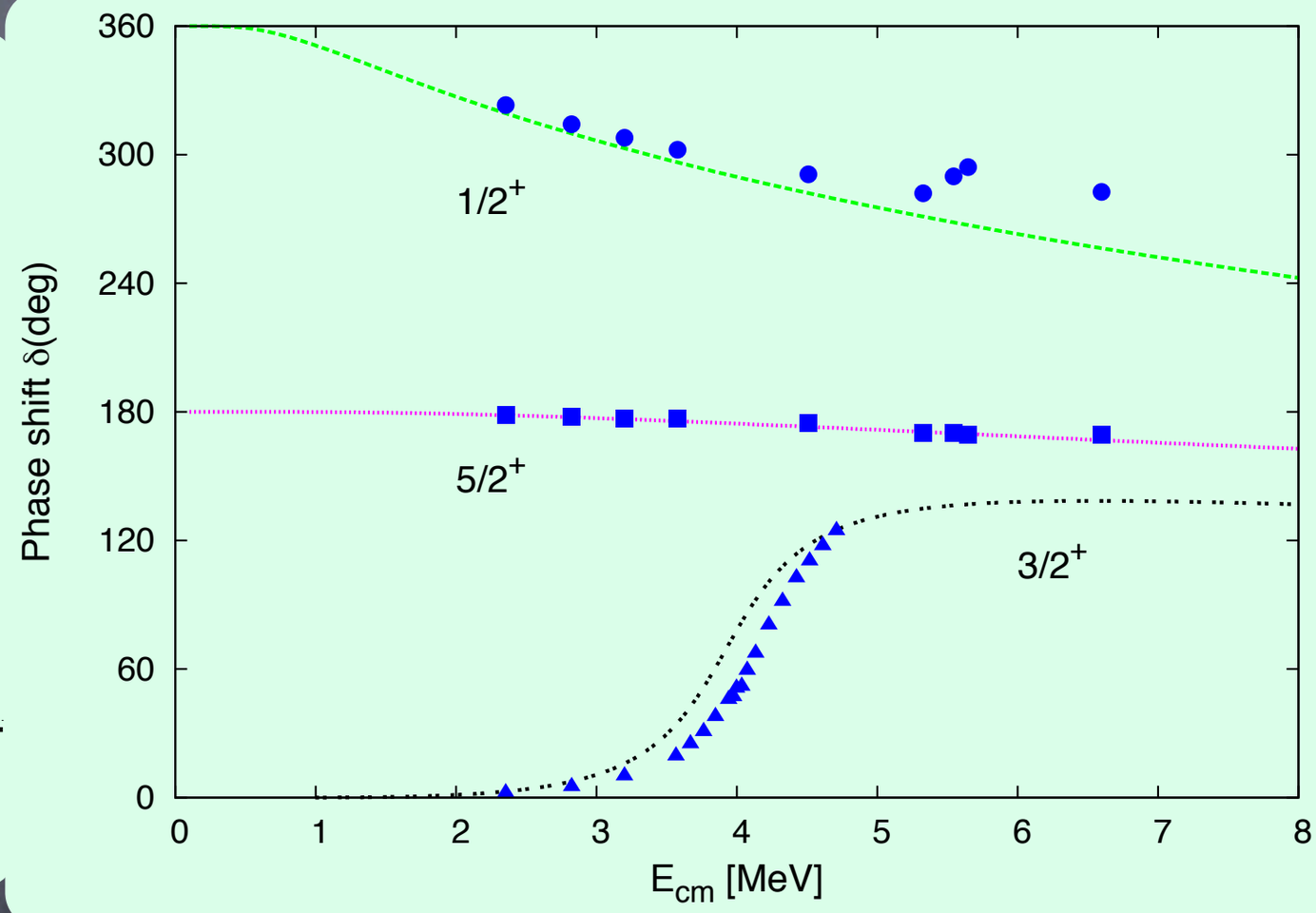
Ref: K.Y, H. Masui, K. Kato, T. Wada and M. Ohta, PTP 121 (2009), 375.

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

Energy level for ^{17}F

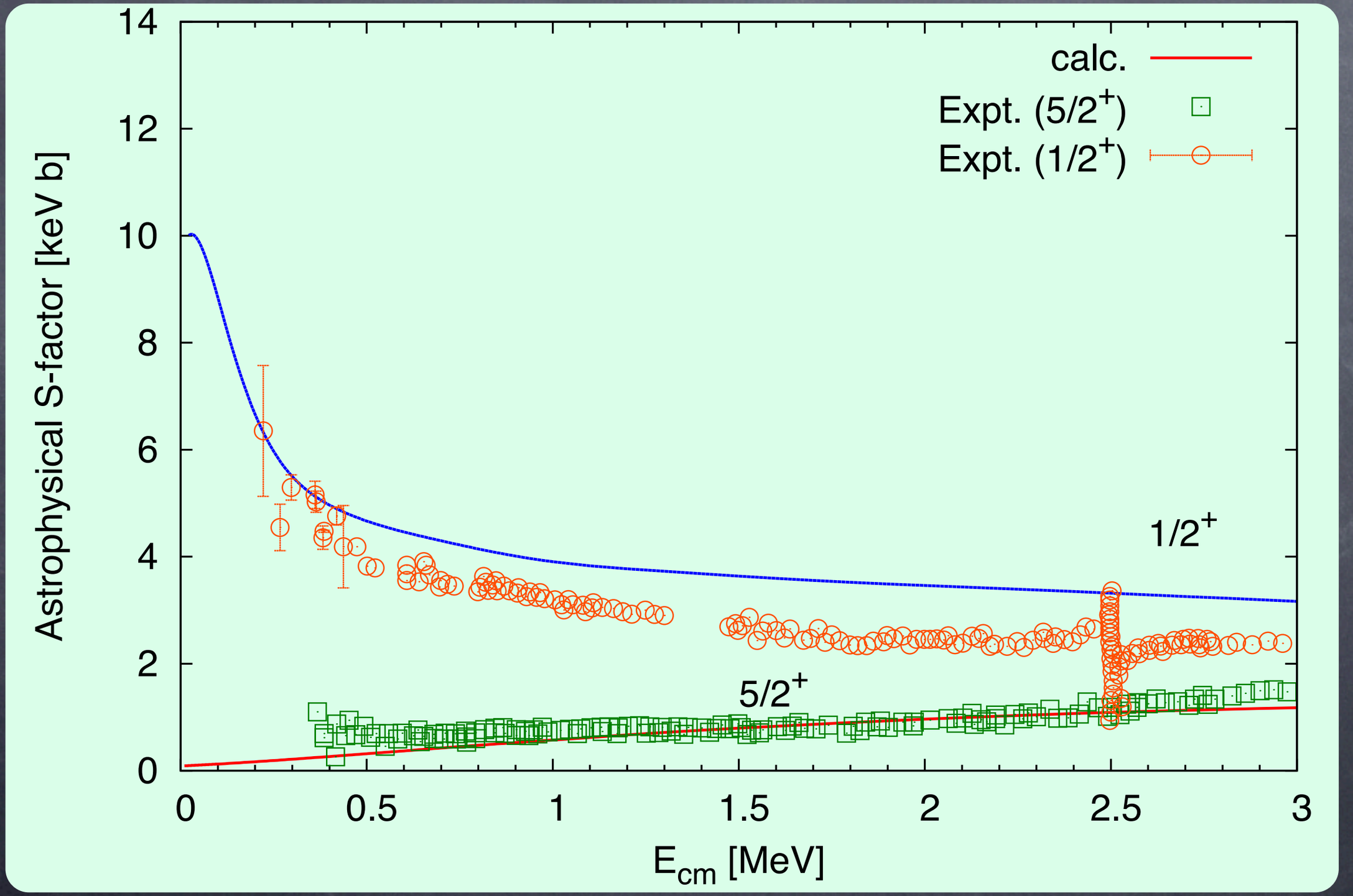


Elastic scattering phase shift for ^{16}O+p



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.

$a+a+a \rightarrow {}^{12}C$ $a+a+n \rightarrow {}^{9}Be$ $a+a+p \rightarrow {}^{9}B$

Thank you for your attention