Study of weak-coupled states in ^{23}Al via inelastic scattering

-- Using low-energy RI beam at CNS --

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Outline

- Introduction
- Experiment

  Method, RIB prod. & Setup
- Results

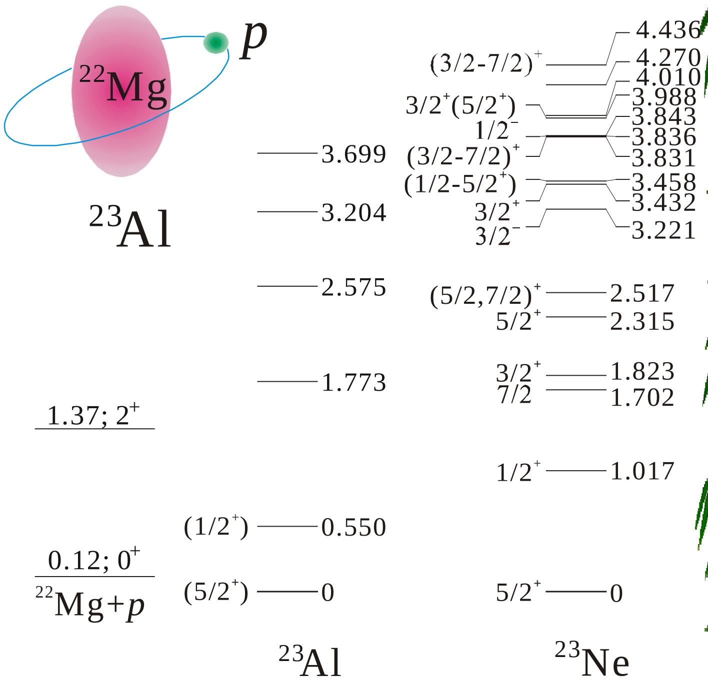
  Spectra, inelastic analysis, new level scheme
- Model Calculations

  R-matrix analysis & Shell model calc.
- Summary

Introduction

(1) Aim: Weak-coupled structure in ^{23}Al

S_p (^{23}Al) = 0.125 MeV, S_p (^{22}Mg) = 5.502 MeV
β_2 (^{23}Al) ≈ 0.3 ~ 0.6, β_2 (^{22}Mg) ≈ 0.56



(2) Status: Structure in ^{23}Al

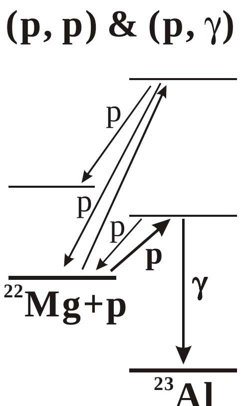
(a) ^{24}Mg(^{7}Li, ^{8}He) @MSU;

(b) β-delayed proton decay of ^{23}Si @GANIL;

(c) Coul. Dissoc. of ^{23}Al @ RIKEN

Conclusion: Several levels were observed without spin-parity assignments.

(3) Present work



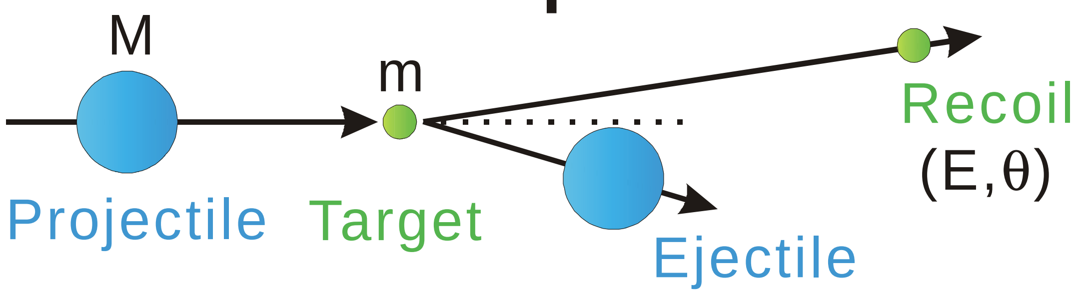
E_{cm} (^{23}Al) up to 4 MeV (by resonant elastic & inelastic scattering)

E_R, J^π, Γ_p ($\Gamma_{p'}$) ➔ Weak-coupled structure of ^{23}Al

Experiment

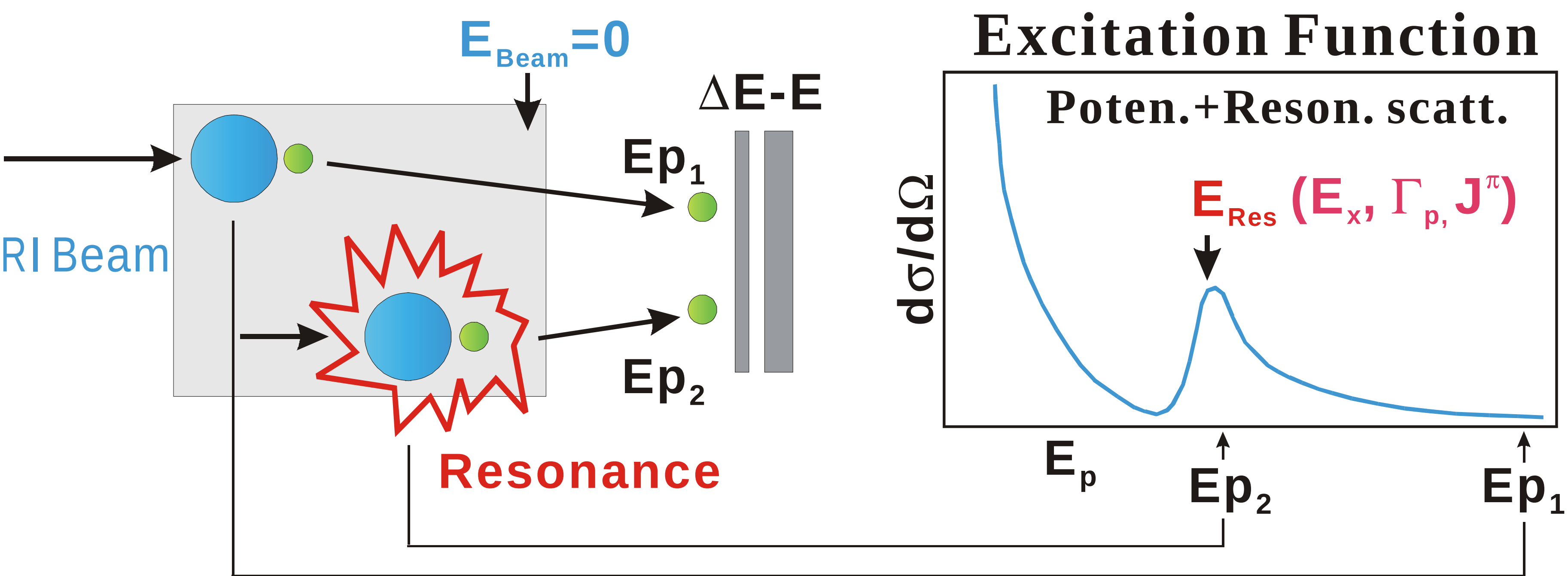
(1) Experimental Method

As for proton elastic scattering



$$E_{cm} = \frac{A+1}{4A*\cos^2(\theta_{lab})} * E_p$$

$$E_x = E_{cm} + Q$$



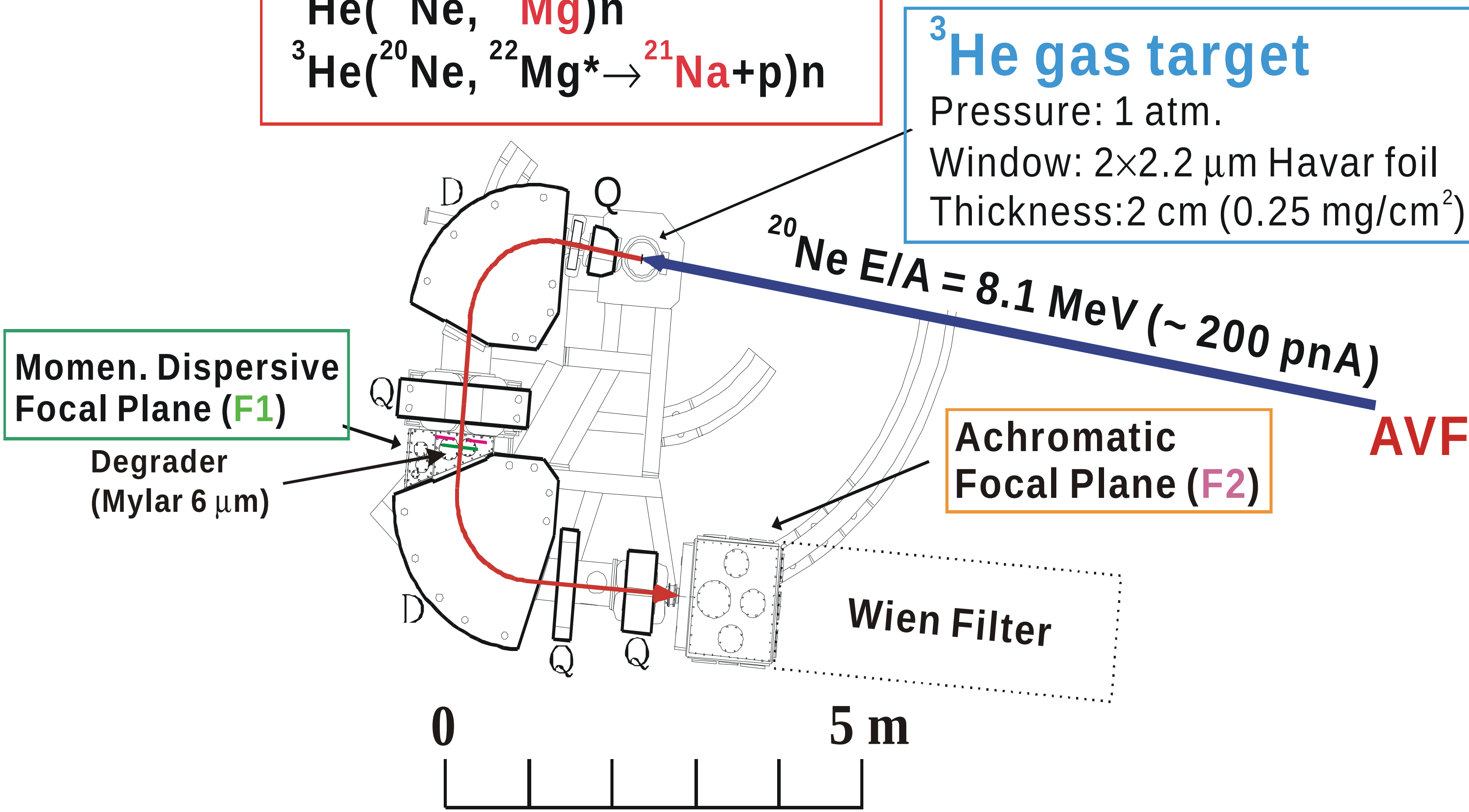
(2) RI Beam Production

CNS RI Beam Separator (CRIB)

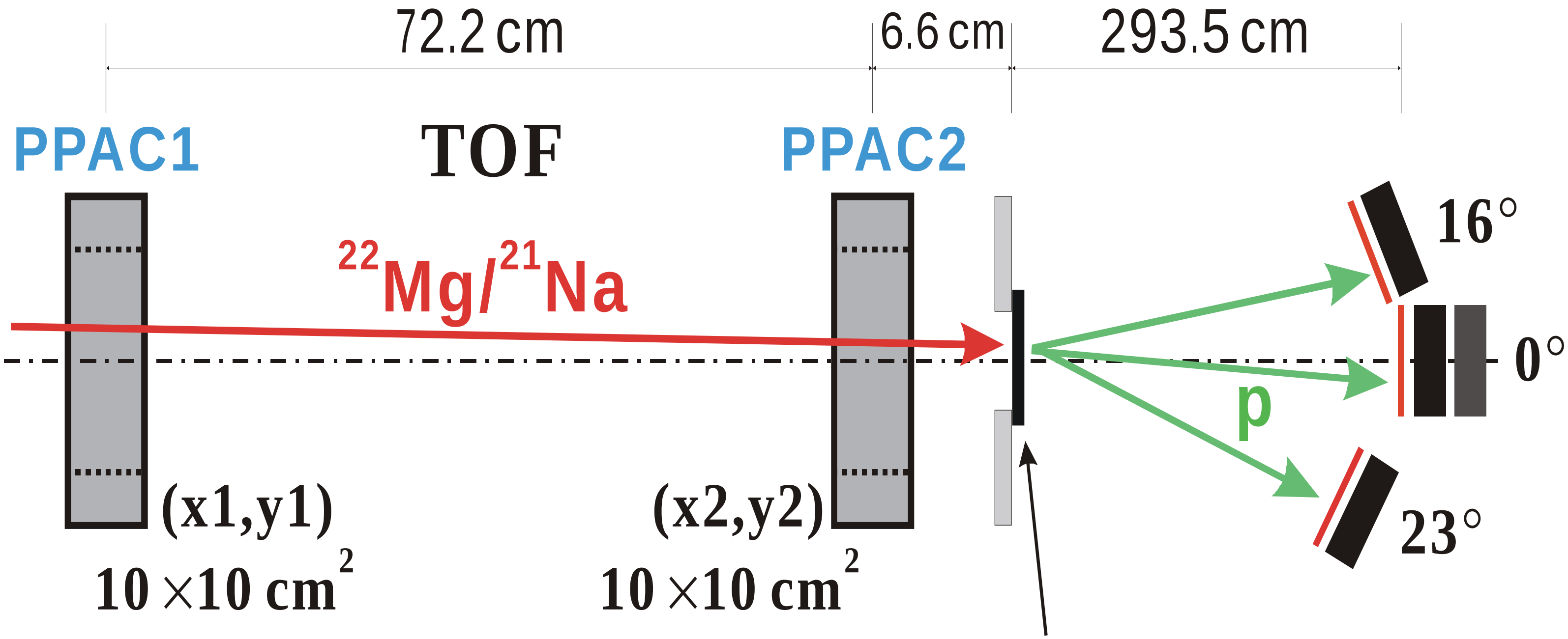
Production Reactions

^{3}He(^{20}Ne, ^{22}Mg)n

^{3}He(^{20}Ne, ^{22}Mg*$\rightarrow$^{21}Na+p)n



(3) Setup for Elastic Scattering



After PPAC2

^{22}Mg: 4.4 AMeV
6.6 kaps (3%)

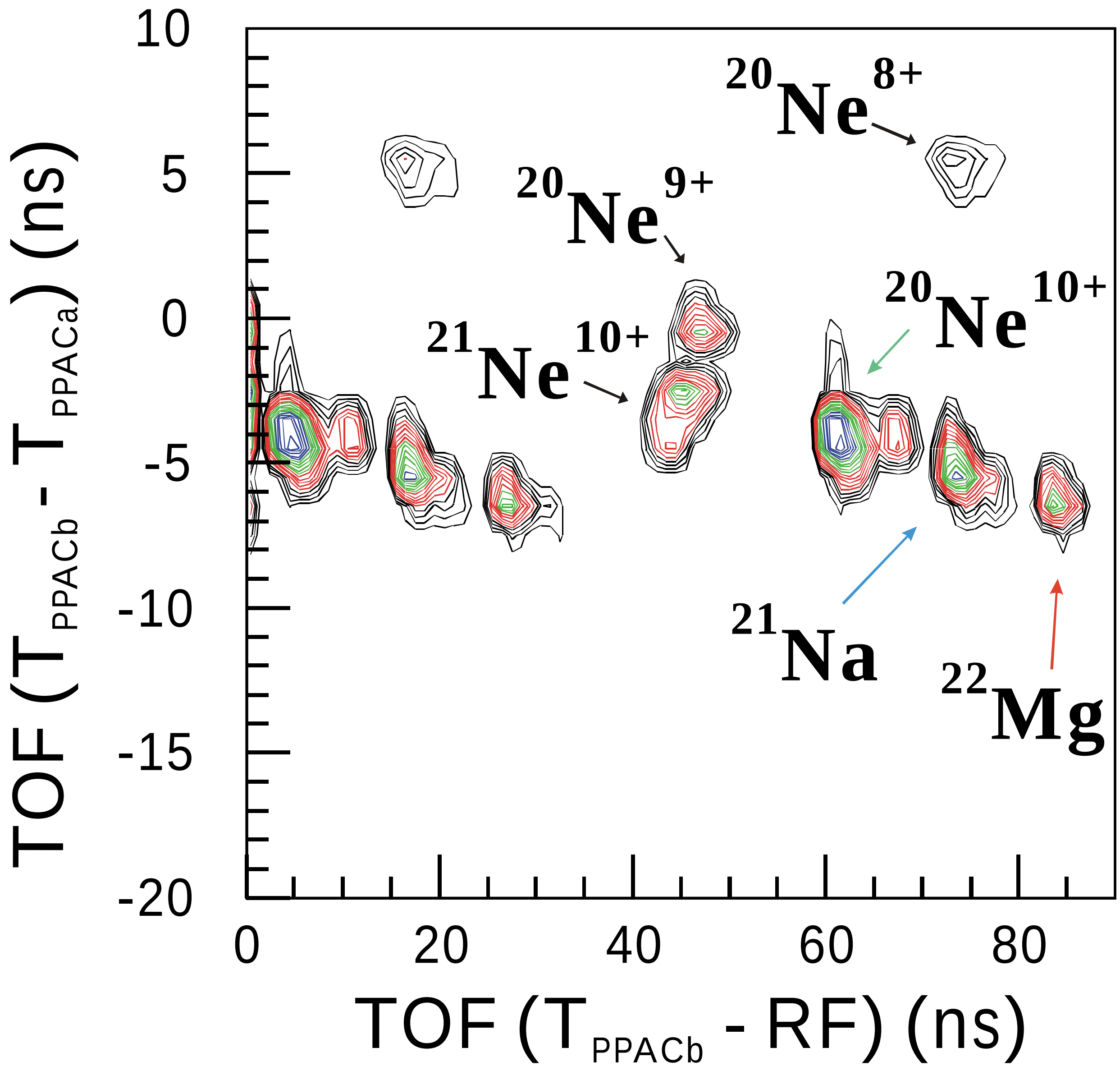
^{21}Na: 4.0 AMeV
24.3 kaps (12%)

Main Background: ^{20}Ne

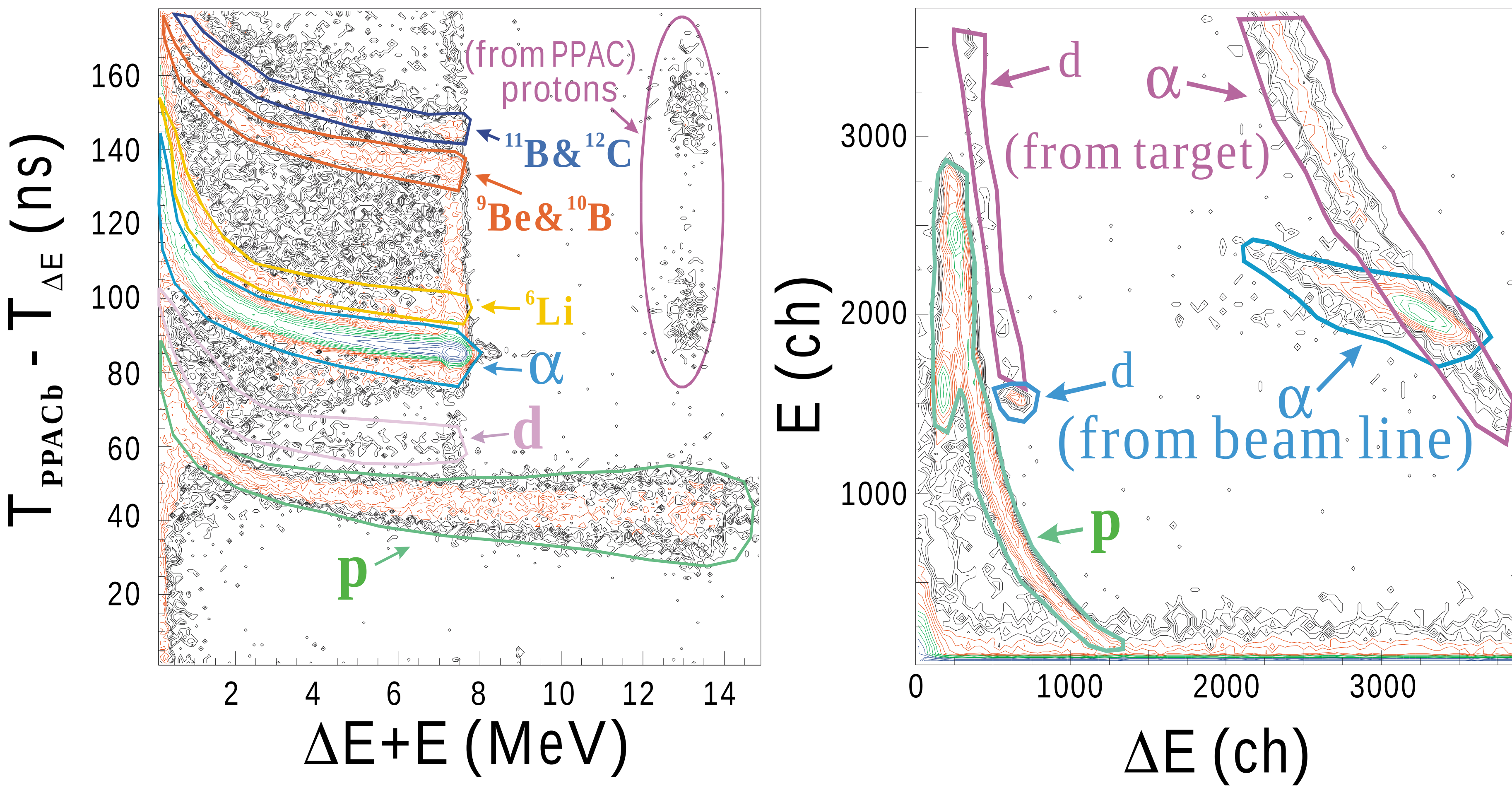
Target $(CH_2)_n$
φ3 cm, 90 μm
(C target)

5×5 cm^2
- - ΔE(75 μm, PSD)
- - E(1.5 cm, SSD)
- - E_{Rej}(1.5 cm, SSD)

(4) Identification of RI Beam



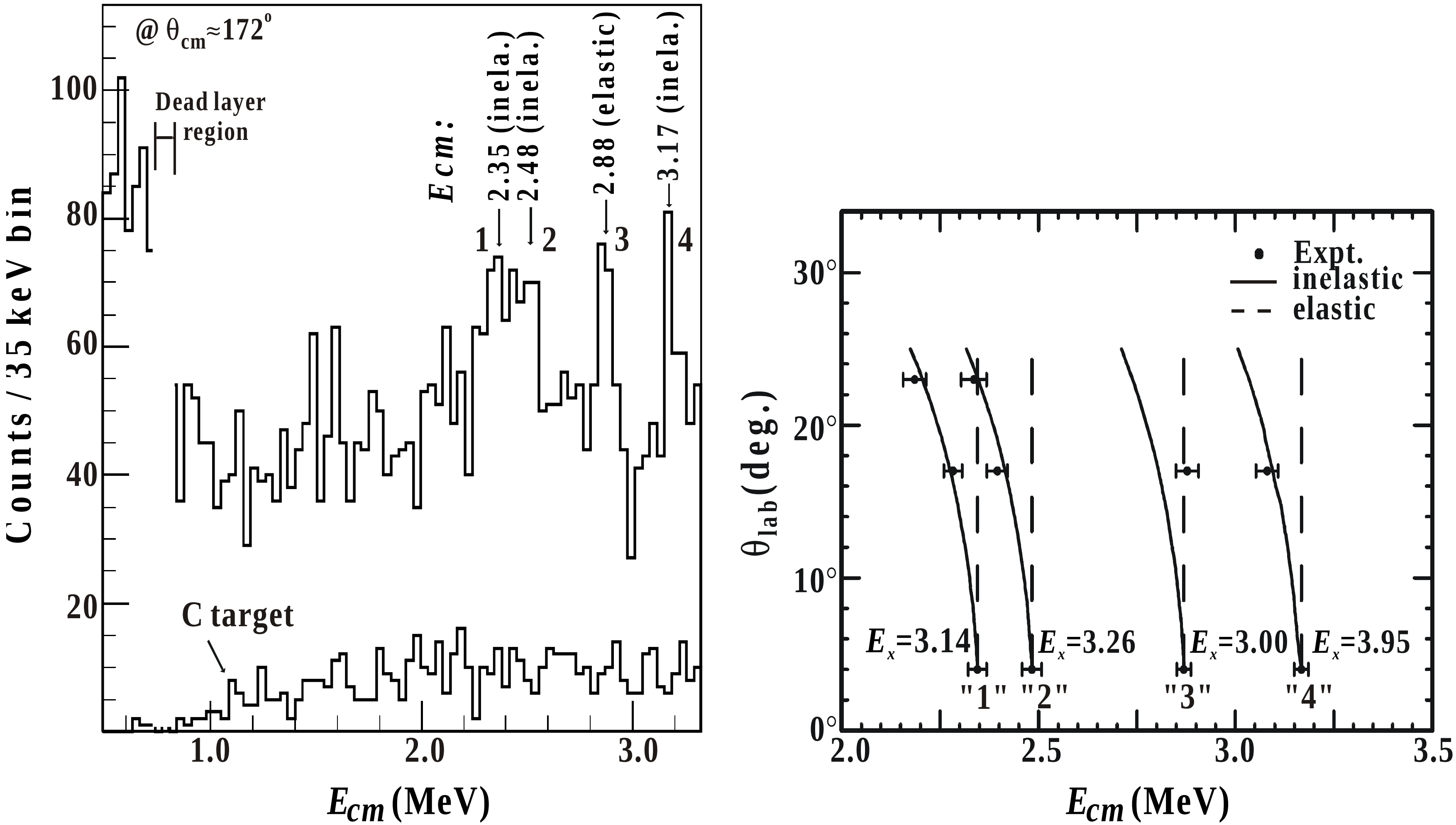
(5) Identification of Particles



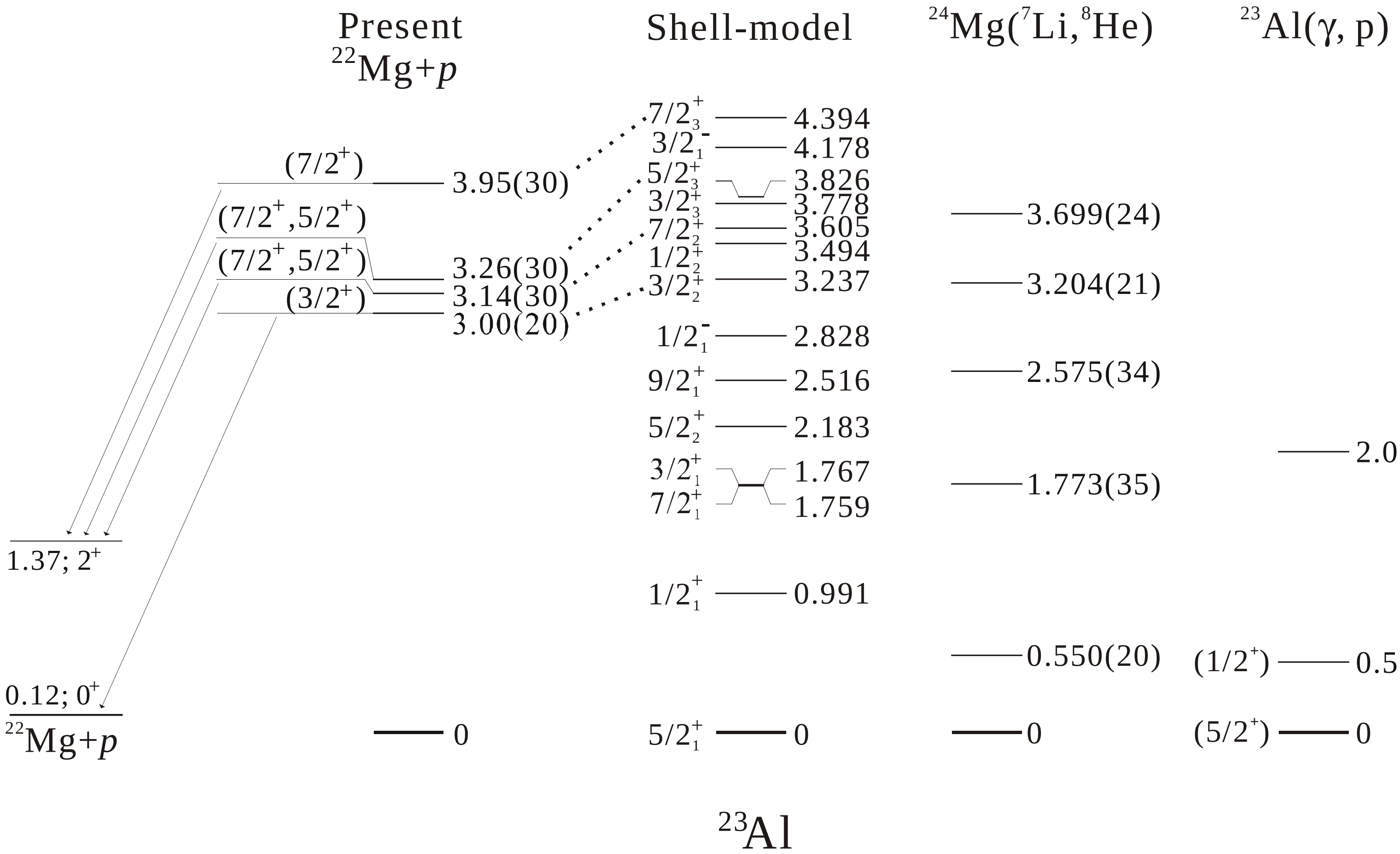
(Max energy for ΔE is 7.5 MeV)

Results

(1) Spectrum of $^{22}Mg+p$ Scattering



(2) Level Scheme in ^{23}Al



Model Calculations

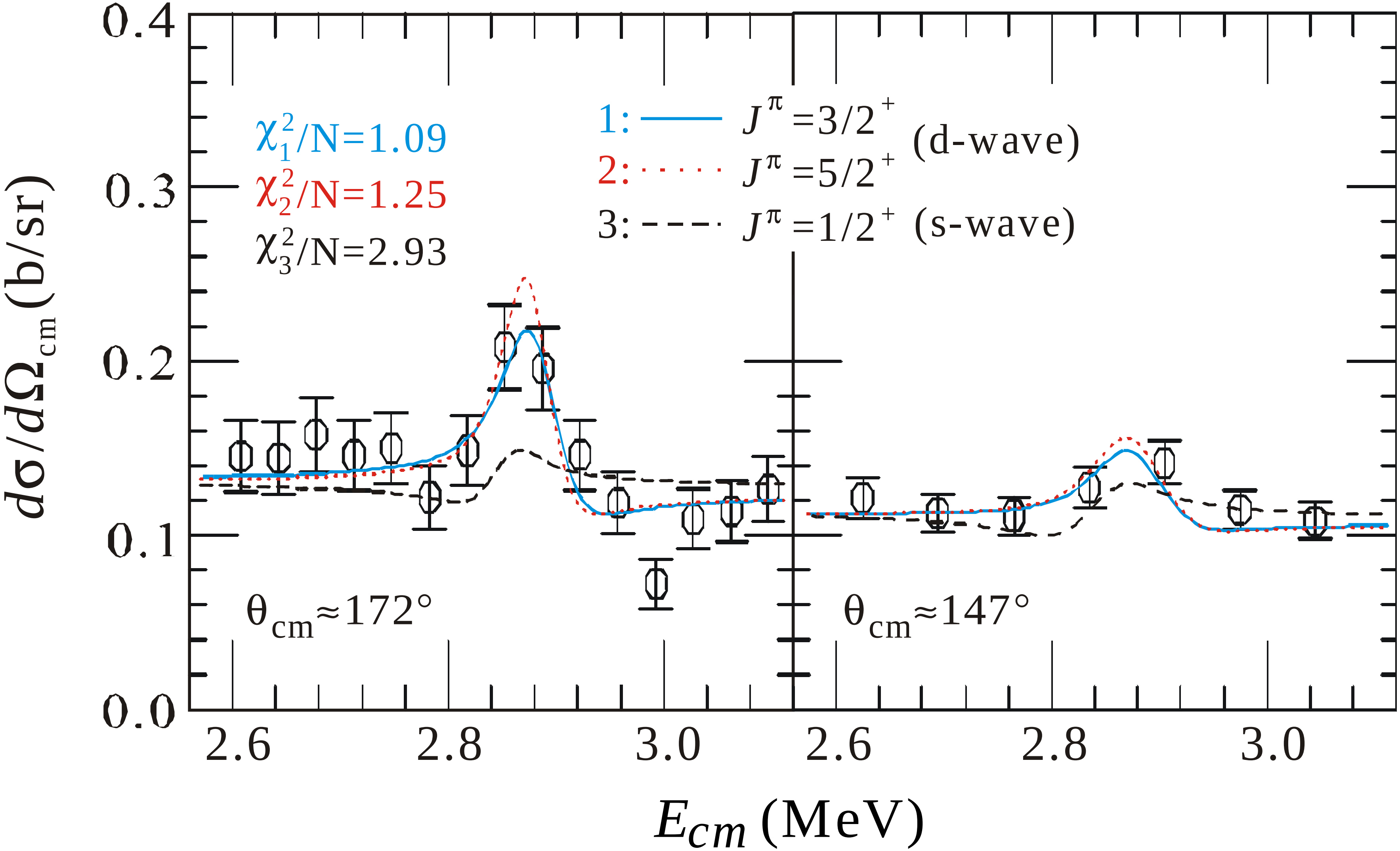
(I) R-matrix code: SAMMY-M6-BETA

A Code System for Multilevel R-Matrix Fits to Neutron and Charged-Particle Cross-Section Data Using Bayes' Equations (By Nancy M. Larson @ORNL**)**

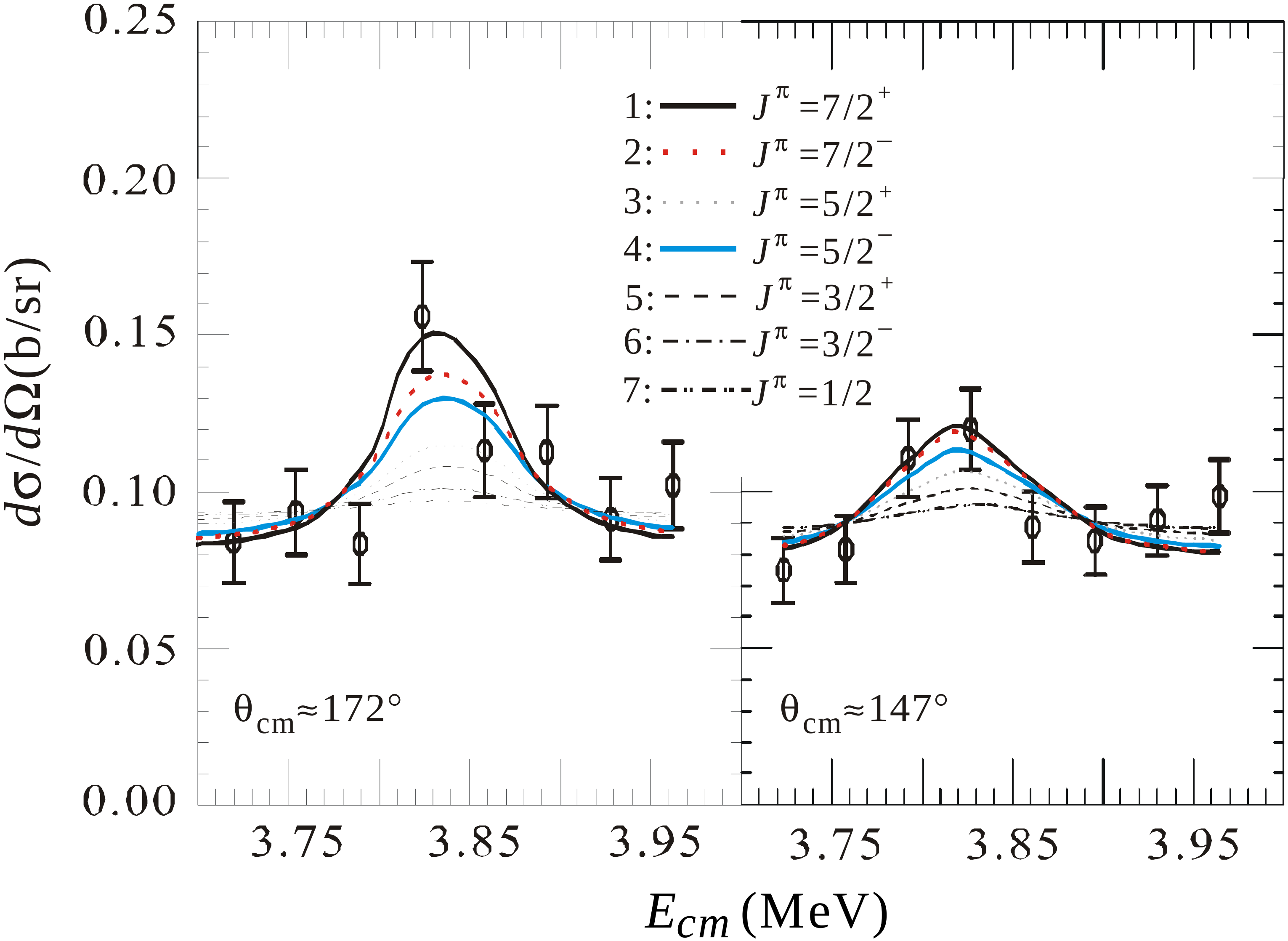
Data Type of Cross Sections

1. Elastic (both Angle-Integrated and Differential);
2. Inelastic scattering;
3. Angle-Differential Reaction Cross Sections;
Total; Transmission; Fission (or Reaction); Capture; Absorption, etc.

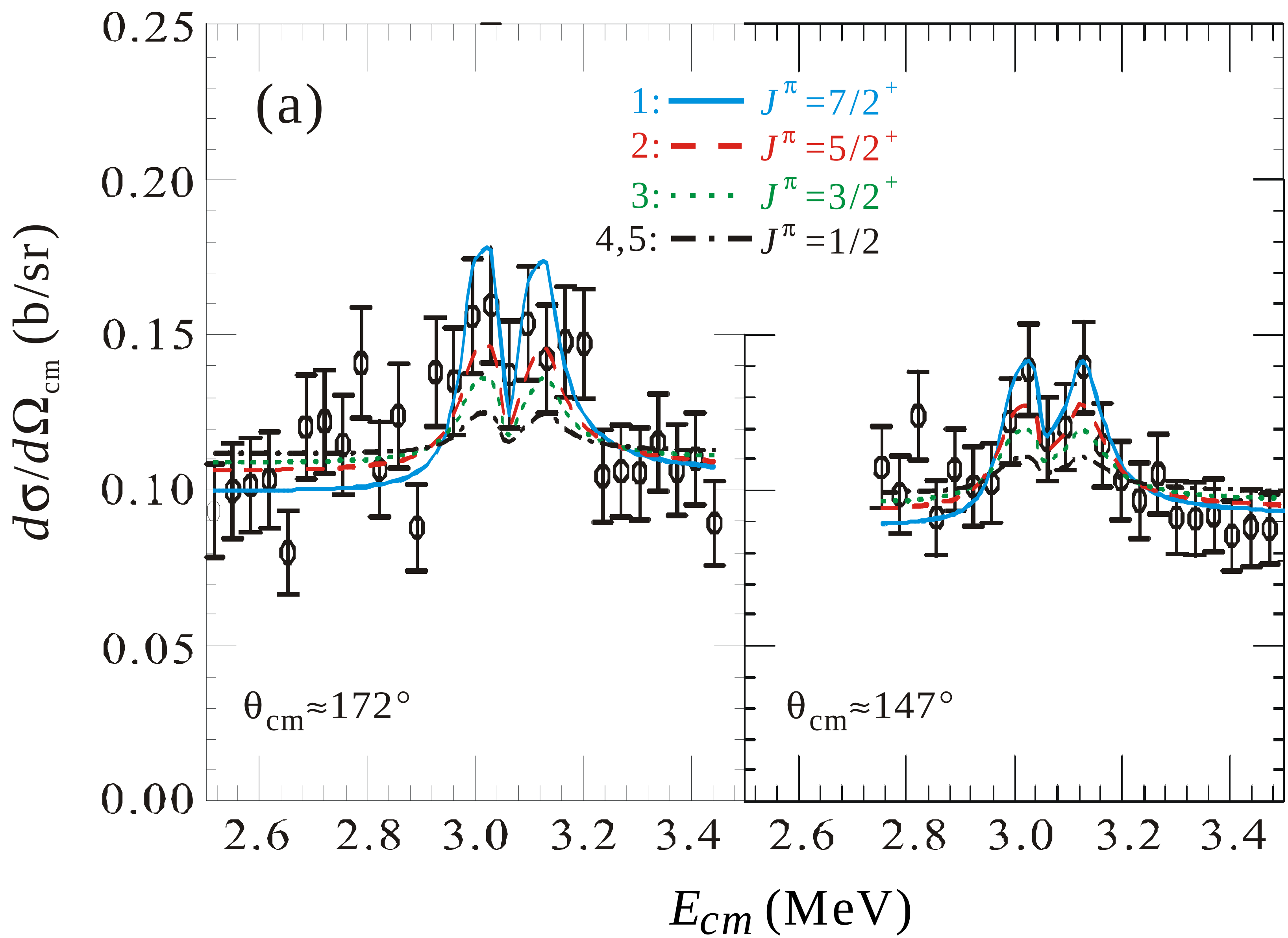
(I-1) *R*-matrix fits for 3.00-MeV state



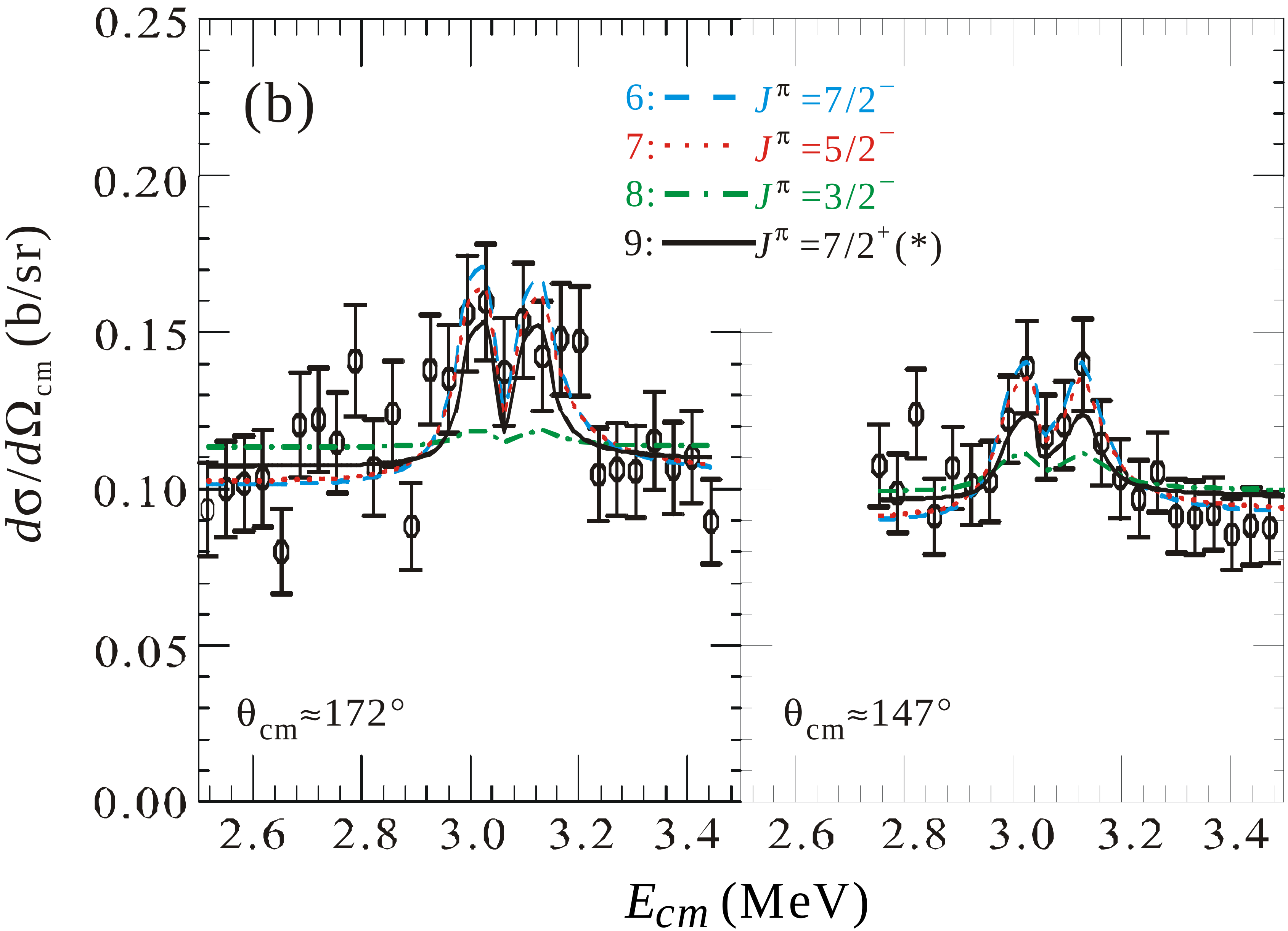
(I-2) *R*-matrix fits for 3.95-MeV state



(I-3a) Fits for 3.14, 3.26 MeV states



(I-3b) Fits for 3.14, 3.26 MeV states



(I-4) *R*-matrix fitting results

E_x (MeV)	J^π	Γ_p (keV)	$\Gamma_{p'}$ (keV)
3.00 (0.02)	$(5/2^+, 3/2^+)$	17 (3), 32 (5)	
3.14 (0.03)	(7/2, 5/2)	$2 \le \Gamma_p \le 5$	30 (20)
3.26 (0.03)	(7/2, 5/2)	$2 \le \Gamma_p \le 5$	30 (20)
3.95 (0.03)	$(7/2, 5/2^-)$	20 (10)	30 (20)

(II) Shell model code: OXBASH (B. A. Brown, MSU)

MODEL SPACE: full (0 + 1) $\hbar\omega$ (named as *spsdpf*)

INTERACTION: Isospin-conserving *WBT* interaction of Warburton and Brown

ADVANTAGE: Positive ($0\hbar\omega$) and negative ($1\hbar\omega$) states can be treated within the same procedure.

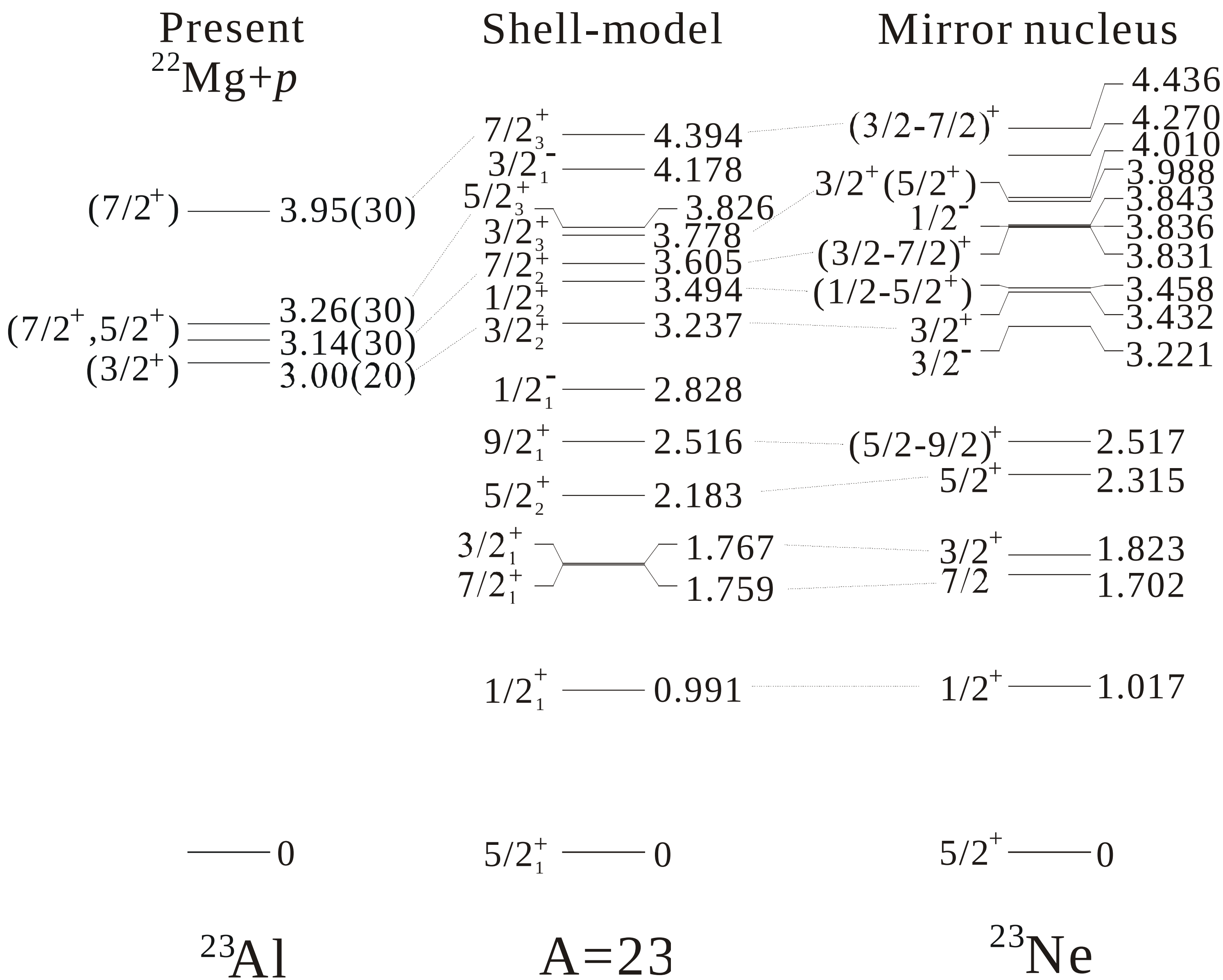
(II-1) Spectroscopic factor C^2S

E_x ^{23}Ne	E_x (cal.)	ΔE_x	J^π (expt.)	J^π (calc.)	ℓ	C^2S	
						(d, p)	calc.
0	0	0	$5/2^+$	$5/2_1^+$	2	0.22	0.34
1.017	0.991	0.03	$1/2^+$	$1/2_1^+$	0	0.70	0.66
1.823	1.767	0.06	$3/2^+$	$3/2_1^+$	2	0.02	0.08
2.315	2.183	0.13	$5/2^+$	$5/2_2^+$	2	0.06	0.09
3.221	4.178	-0.96	$3/2^-$	$3/2_1^-$	1	0.30	0.28
3.432	3.237	0.20	$3/2^+$	$3/2_2^+$	2	0.30	0.28
3.836	2.828	1.01	$1/2^-$	$1/2_1^-$	1	0.11	0.01
3.988	3.778	0.21	$3/2^+$ ($5/2^+$)	$3/2_3^+$	2	0.30	0.22

(II-2) Spectroscopic factor C^2S

E_x exp.	E_x calc.	J^{π} calc.	to Ground State of ^{22}Mg (0^+)			to Excited State of ^{22}Mg (2^+)		
			$1d_{5/2}$	$1d_{3/2}$	$2s_{1/2}$	$1d_{5/2}$	$1d_{3/2}$	$2s_{1/2}$
	0.0	$5/2_1^+$	0.335			0.82	0.005	0.002
0.55	0.991	$1/2_1^+$			0.66	0.40	0.026	
1.77	1.767	$3/2_1^+$		0.076		0.07	0.05	0.40
	2.183	$5/2_2^+$	0.086			0.15	0.01	0.62
3.00	3.237	$3/2_2^+$		**0.284**		0.005	0.06	0.02
3.14	3.605	$7/2_2^+$				0.024	**0.323**	
	3.778	$3/2_3^+$		0.22		0.005	0.11	0.17
3.26	3.826	$5/2_3^+$	0.007			0.01	**0.033**	**0.023**
3.95	4.394	$7/2_3^+$				0.002	**0.18**	

(II-3) States in ^{23}Al & ^{23}Ne

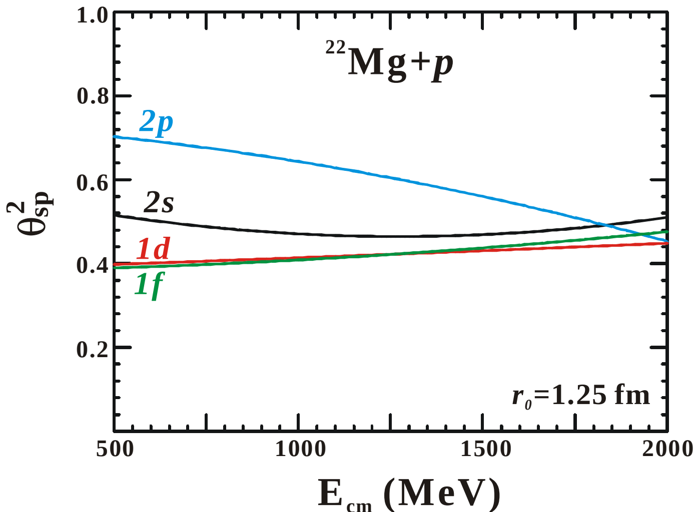


(II-3) Calc. of Partial Width Γ_p

By *C. Iliadis* [Nucl. Phys. **A618**, (1997) 166]

$$\Gamma_p = \frac{2\hbar^2}{\mu R^2} P_\ell C^2 S \theta_{sp}^2$$

μ is the reduced mass in *amu*.
P_ℓ the Coulomb penetrability calculated with standard program.
C^2 is the isospin Clebsch-Gordan coefficient, ***S*** is the single-particle Spectroscopic factor. C^2S can be calculated within shell model.
θ_{sp}^2 dimensionless single-particle reduced width.
R = $r_0(A_t^{1/3} + A_p^{1/3})$ is the channel (or interaction) radius in *fm*.



For radius range of r_0 =1.2 ~ 1.5 fm
Uncertainty of θ_{sp}^2 : 15 ~ 25 %
Uncertainty of P_ℓ : 40 ~ 60 %
Uncertainty of Γ_p : 2 ~ 8 %

Overall uncertainty of Γ_p : ≤ 15 %

Comparisons

E_x	J^{π}_{expt}	J^{π}_{calc}	ℓ	$\Gamma_{p,(p')}^{exp}$	$\Gamma_{p,(p')}^{cal}$
0.55	$(1/2^+)$	$1/2_1^+$	0		0.074
1.77	$(3/2^+)$	$3/2_1^+$	2		1.0
3.00	$(3/2^+, 5/2^+)$	$3/2_2^+$	2	32(5), 17(3)	44(7)
3.14*	$(7/2^+, 5/2^+)$	$7/2_2^+$	2	30(20)	6(1)
3.26*	$(7/2^+, 5/2^+)$	$5/2_3^+$	0	30(20)	10(2)
3.95*	$(7/2^+)$	$7/2_3^+$	2	30(20)	18(3)

* Their widths are for the decay branches to the 1st states in ^{22}Mg.

(Energy in MeV and width in keV)

Conclusion

(1) New observations:

E_x=3.00 MeV, J^π =(3/2$^+$) with Γ_p = 28(5) keV (elastic)

E_x=3.95 MeV, J^π =(7/2$^+$) with Γ_p = 30(15) keV (inelastic)

[2] E_x =3.14 & 3.26 MeV states:

inelastic p-decay to the first excited state in ^{22}Mg

Both most likely with J^π =(7/2$^+$, 5/2$^+$).

[3] Weak-coupling picture

E_x	3.00	3.14	3.26	3.95
Coupling	$0_1^+ \otimes d_{3/2}$	$2_1^+ \otimes d_{3/2}$	$2_1^+ \otimes s_{1/2}$&$2_1^+ \otimes d_{3/2}$	$2_1^+ \otimes d_{3/2}$