High-precision (p,t) reactions to determine $^{18}Ne(\alpha,p)^{21}Na$ reaction rates

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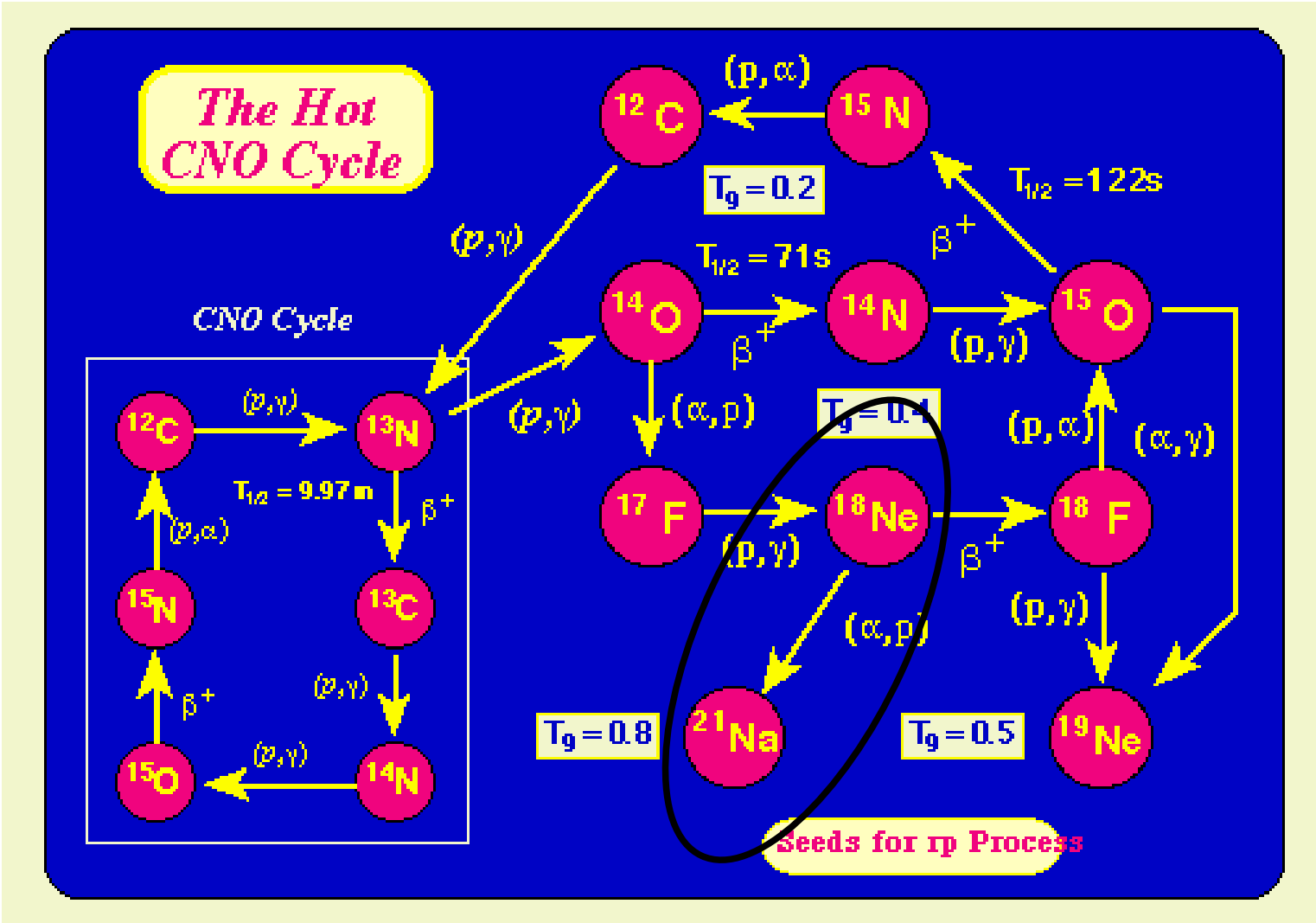
Outline

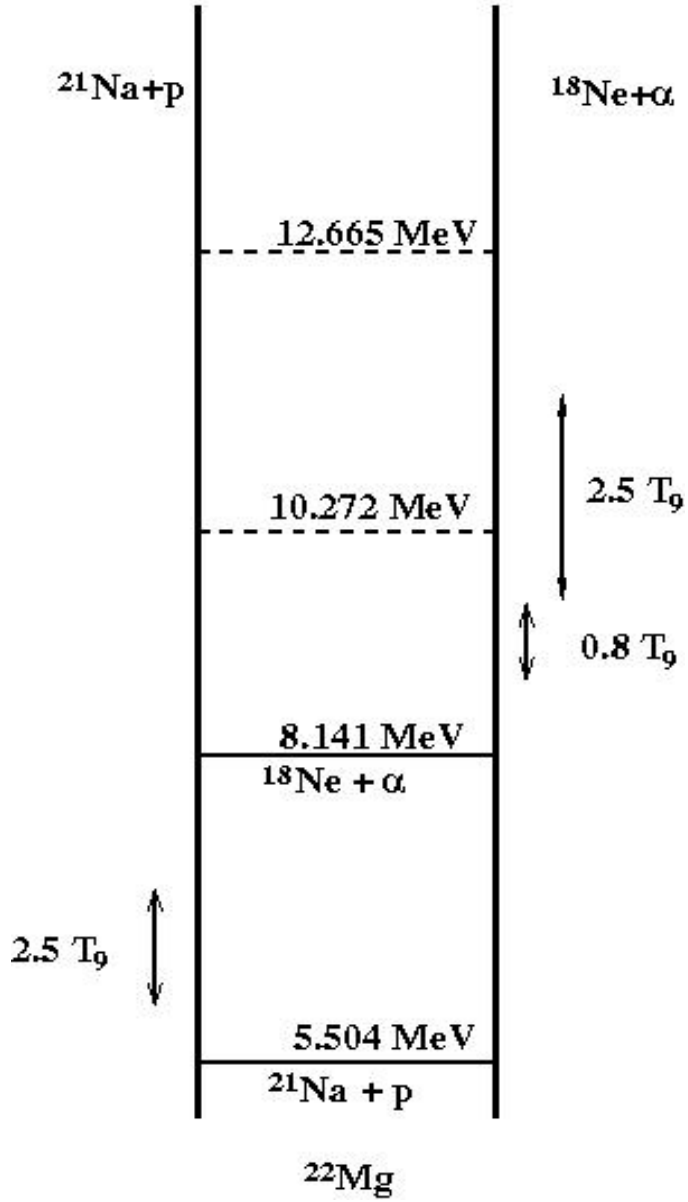
- **Motivation for $^{24}Mg(p,t)^{22}Mg$**
- **Experimental setup.**
- **^{22}Mg nuclear structure and its astrophysical impact.**
- **Conclusion.**

CNO cycle and connection to r-p processes via $^{18}Ne(\alpha,p)^{21}Na$ reaction



Astrophysical interesting excitation-energy regions in ^{22}Mg

2.5 T_9 – X-ray burst peak tempetature



0.8 T_9 possible breakout from CNO cycle

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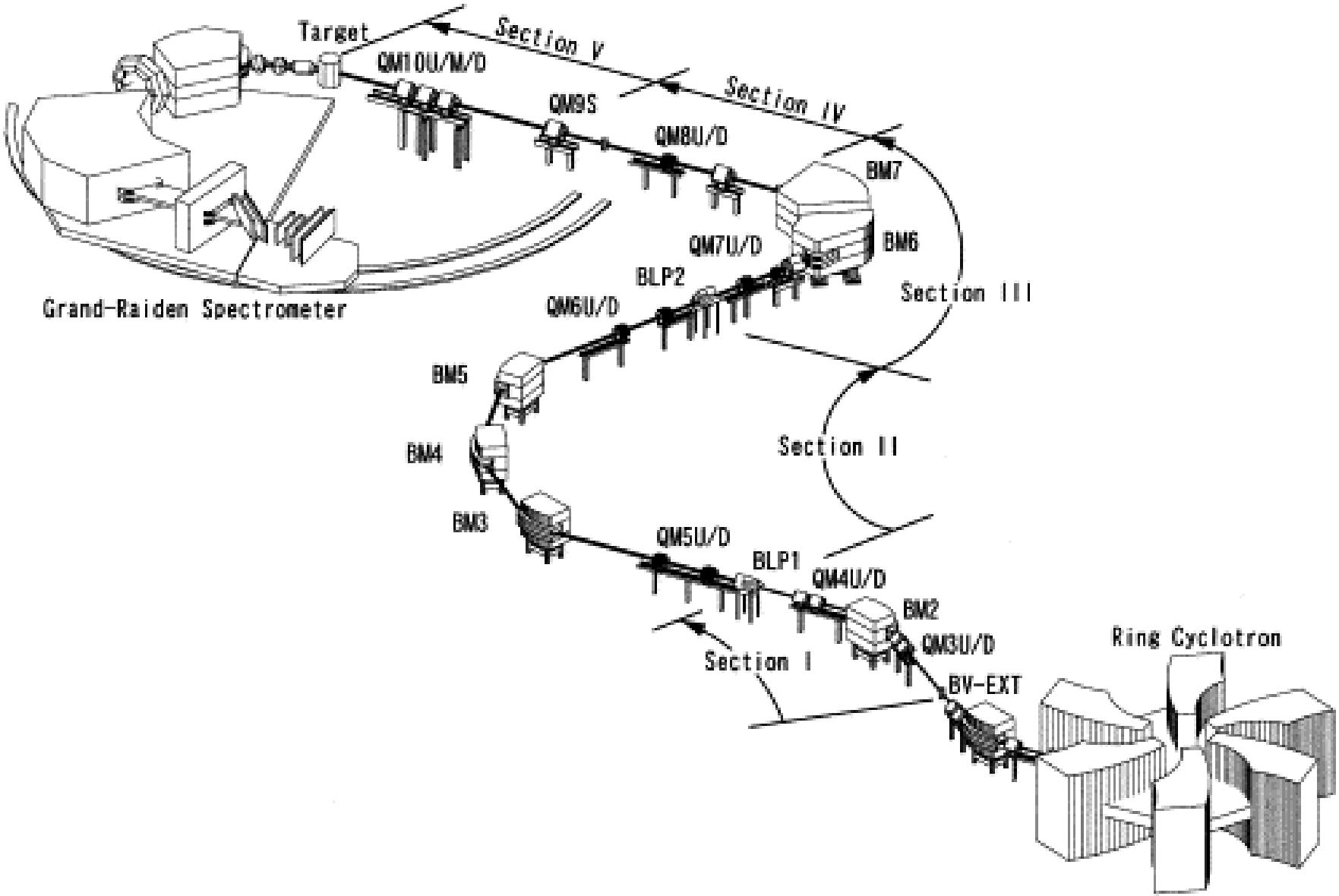
Experimental area at RCNP Osaka



Experimental conditions

Grand Raiden magnetic spectrometer

momentum resolution $p/\Delta p$ 37000

momentum range 5%

Three different magnetic field settings, in order to collect partly overlapping spectra up to excitation energy 13 MeV

Targets:

^{24}Mg 0.815 mg/cm^2 {self supporting}

mylar 1mg/cm^2

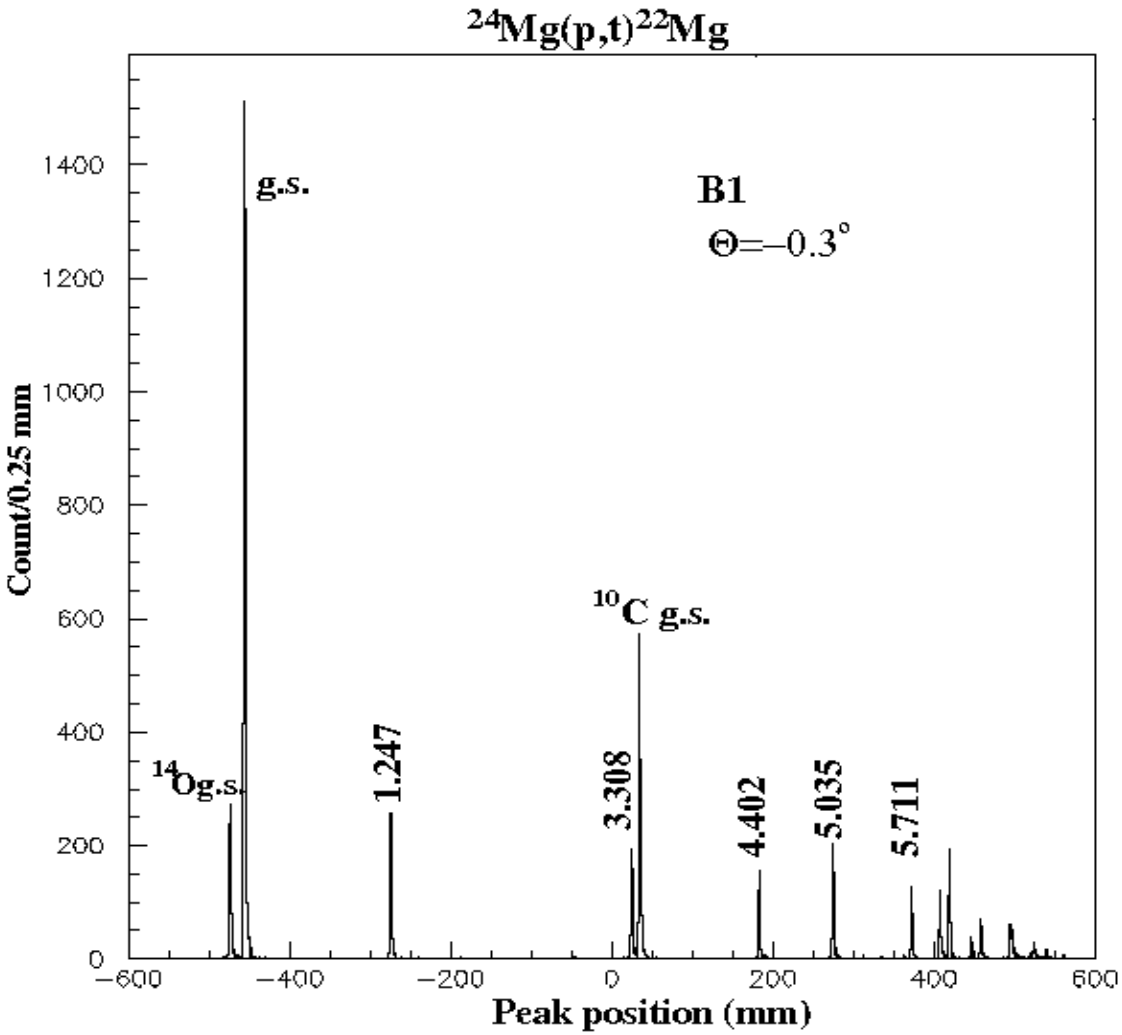
CH_2 1mg/cm^2

Measurements:

beam energy 98.7 MeV

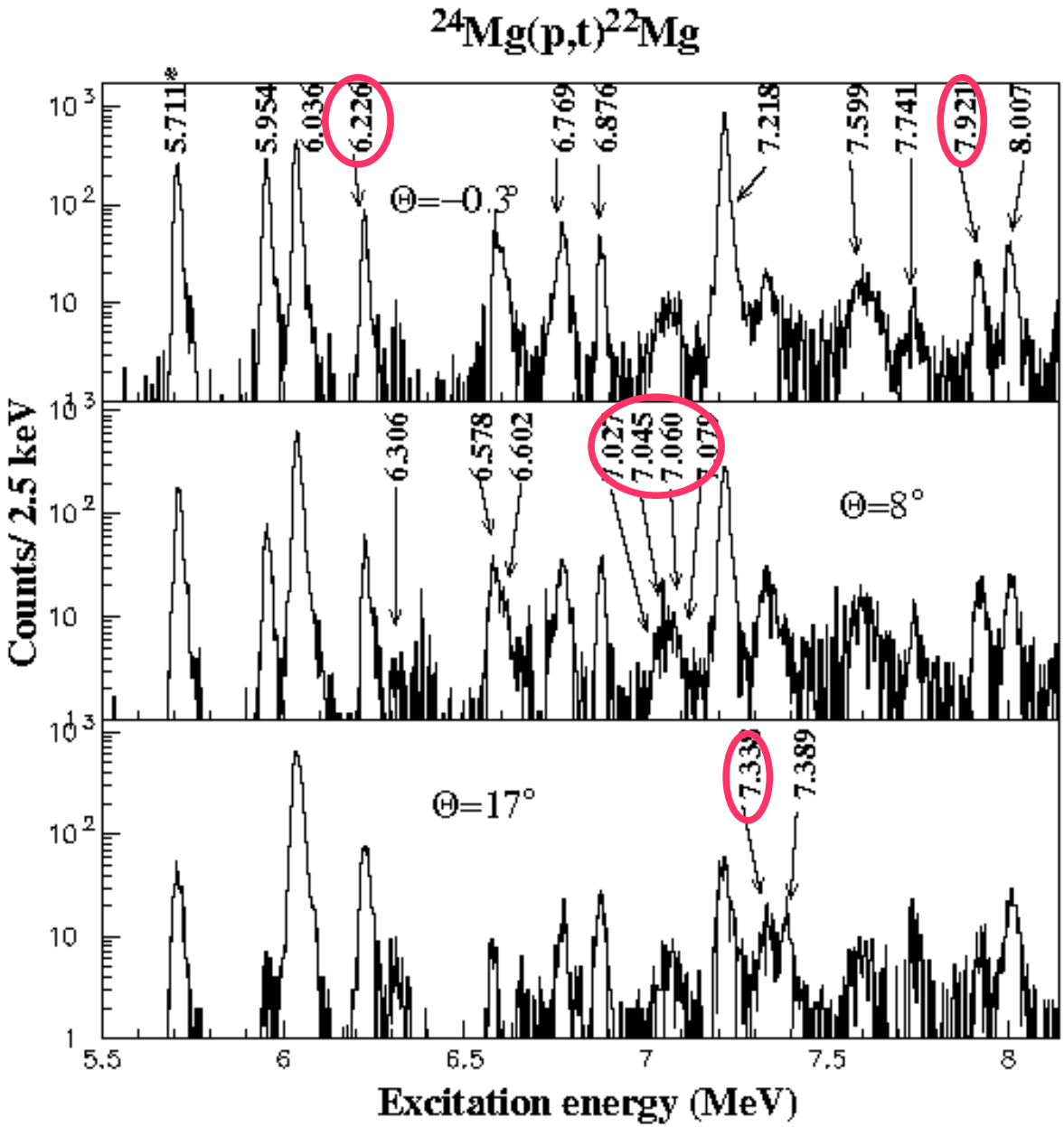
angles -0.3°, 8° ,17°

Calibration done by using new high precision ^{22}Mg γ-spectrometry data, Seweryniak *et al. (2005)*

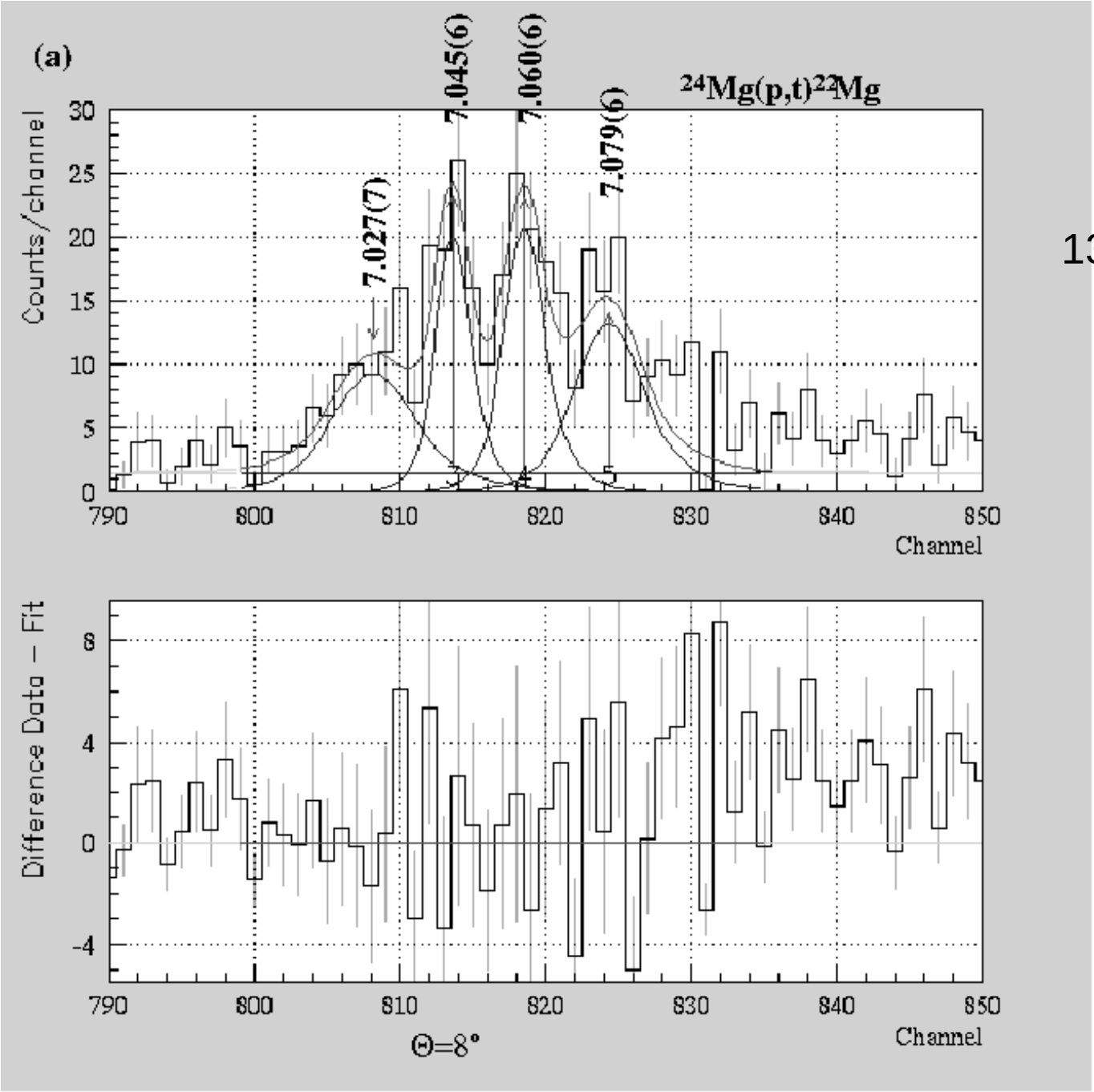


Jπ	Seweryniak	Bateman	Caggiano
	(p,γ)	(p,t)	(3He,6He)
0^+	g.s.	-	g.s.
2^+	1.24718(3)	-	1.2463 *
4^+	3.30821(6)	-	3.3082 *
2^+	4.4020(3)	4.3998(42)	4.4009 *
2^+	5.0354(5)	5.0370(14) *	5.033(7)
(1^+)	5.0893(8)	5.0897(17)	-
4+	5.2931(14)	5.2957(16)	5.301(4)
2^-	5.2960(4)		-
3^+	5.4524(4)	5.4543(16)	5.451(5)
2^+	5.7110(10)	5.7139(12) *	5.7139 *

The ^{22}Mg spectra above the proton-emission threshold (5.5042 MeV – 8.142 MeV)

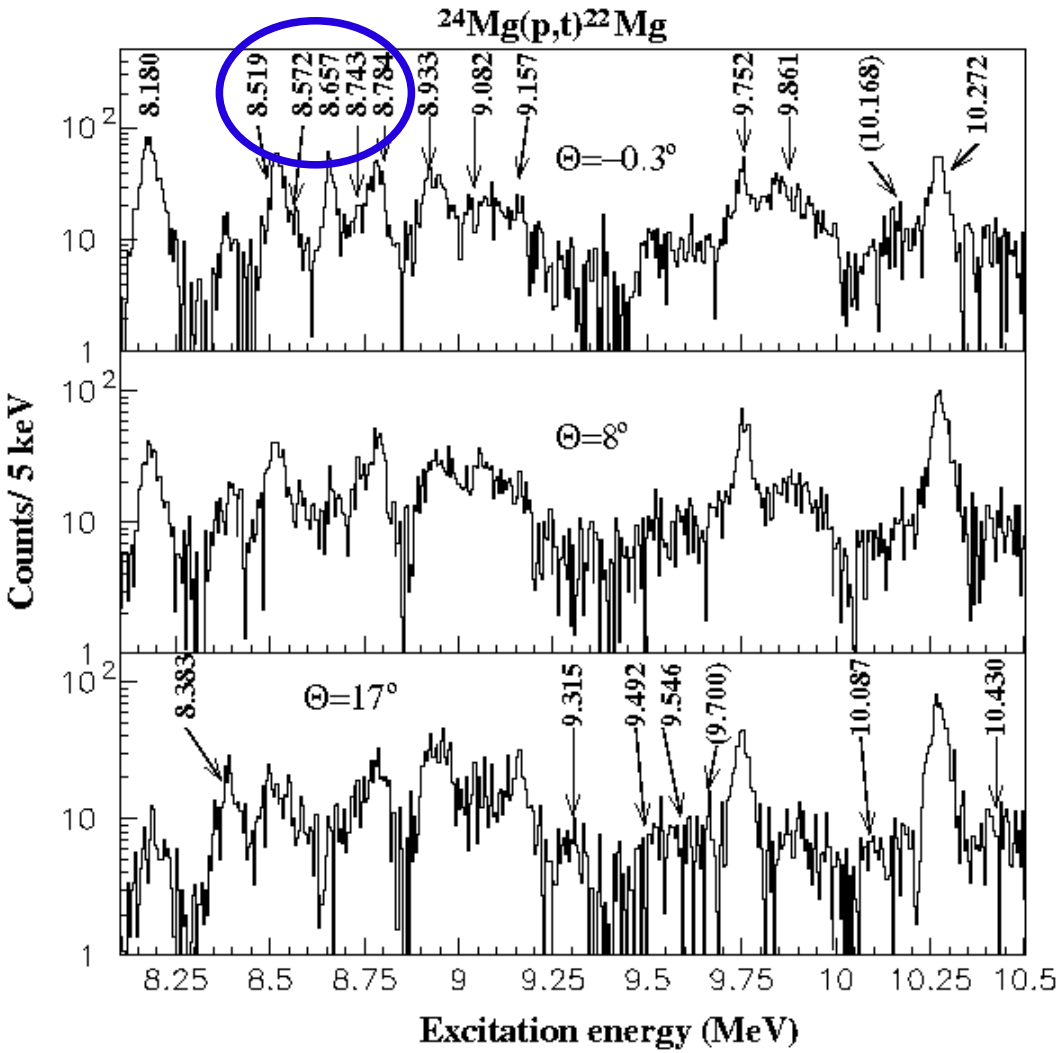


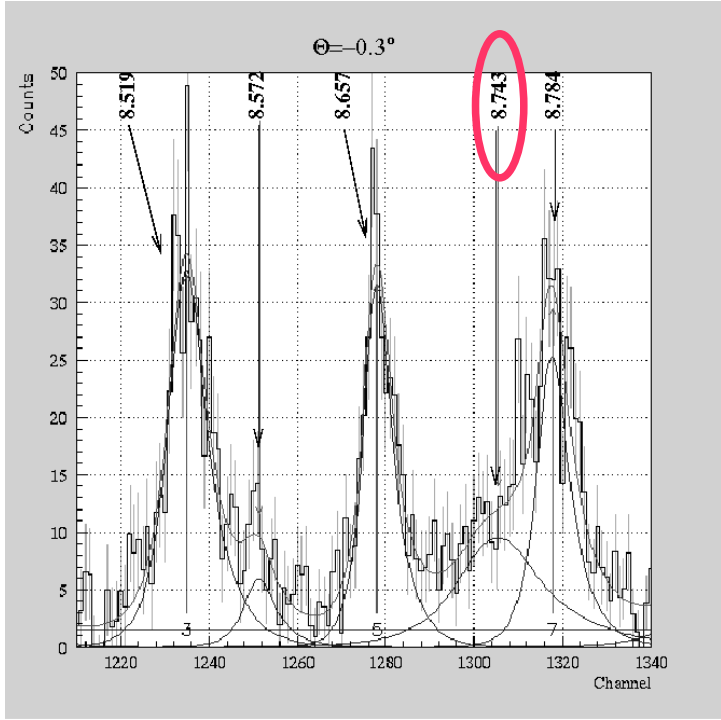
13 keV FWHM

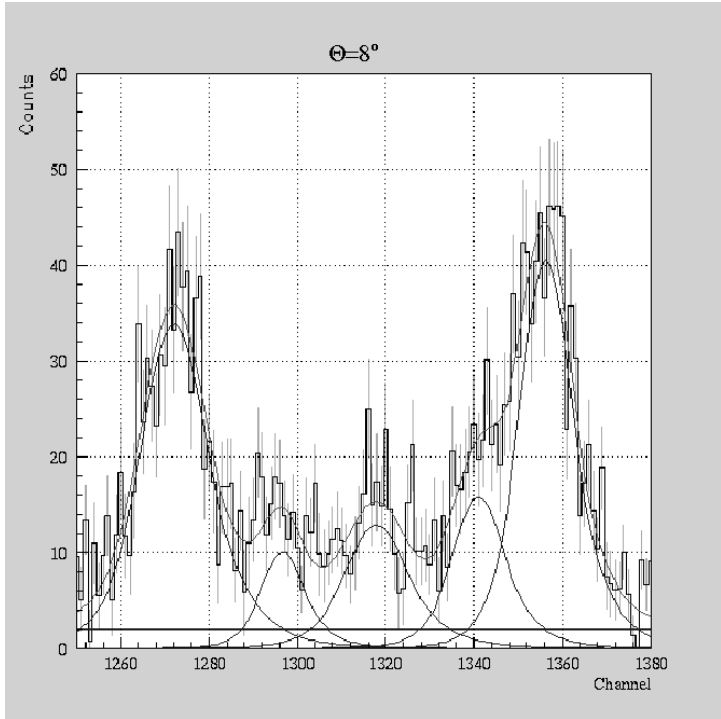

(a)
^{24}Mg(p,t)^{22}Mg
7.027(7)
7.045(6)
7.060(6)
7.079(6)
Counts/channel
Channel
Difference Data – Fit
Θ=8°

13 keV FWHM

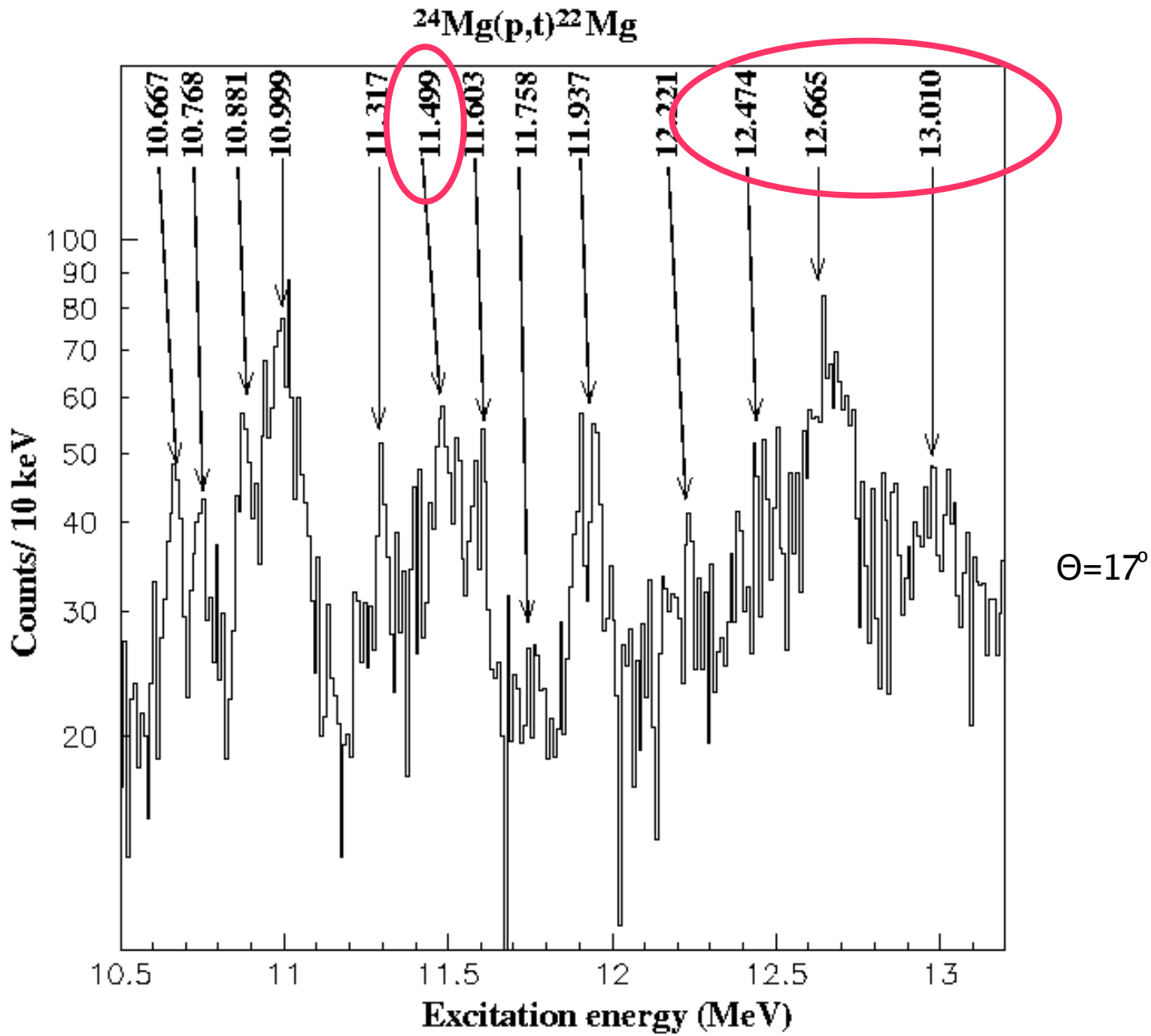
^{22}Mg spectra above the proton emission threshold 8.142 MeV







^{22}Mg spectra above 10.5 MeV



Region above proton-emission threshold 8.142 MeV

Jπ	present	Caggiano	Chen	Berg
	(p,t)	(^{3}He,^{6}He)	(^{16}O,^{6}He)	(^{4}He,^{6}He)
(2+)	8.1803(17)	8.229(20)	8.203(23)	8.197(10)
(2+)	8.383(13)	8.394(21)	8.396(15)	8.380(10)
(3-)	8.5193(21)	8.487(36)	8.547(18)	8.512(10)
(4+)	8.572(6)	8.598(20)	-	-
(0+)	8.6575(17)	-	8.613(20)	(8.644(18))
(4+)	8.743(14)	-	-	-
(1-)	8.7845(23)	8.789(20)	8.754(15)	8.771(9)
(2+)	8.9331(29)	-	8.925(19)	8.921(9)
(1-)	9.082(7)	-	9.066(18)	(9.029(20))
(4+)	9.157(4)	-	(9.172(23))	9.154(10)
(6+)	-	-	(9.248(20))	-
(2+)	9.315(14)	-	9.329(26)	(9.378(22))
(3-)	9.492(13)	-	(9.452(21))	-
(2+)	9.546(15)	-	9.533(24)	9.542(12)
(6+)	-	-	9.638	9.640(10)
(0+)	(9.70(5))	-	9.712(21)	-
(2+)	9.7516(27)	-	-	9.746(10)
(0+)	9.861(6)	-	9.827(44)	9.853(11)
(1+)	-	-	9.924(28)	9.953(13)
(2+)	10.087(15)	-	10.078(24)	(10.128(20))
(3+)	(10.168(9))	-	10.190(29)	-
(2+)	10.2717(17)	-	10.297(25)	10.260(10)
(4+)	10.430(19)	-	10.429(16)	(10.389(20))

Error in excitation energy from 1.7 keV - 20 keV.

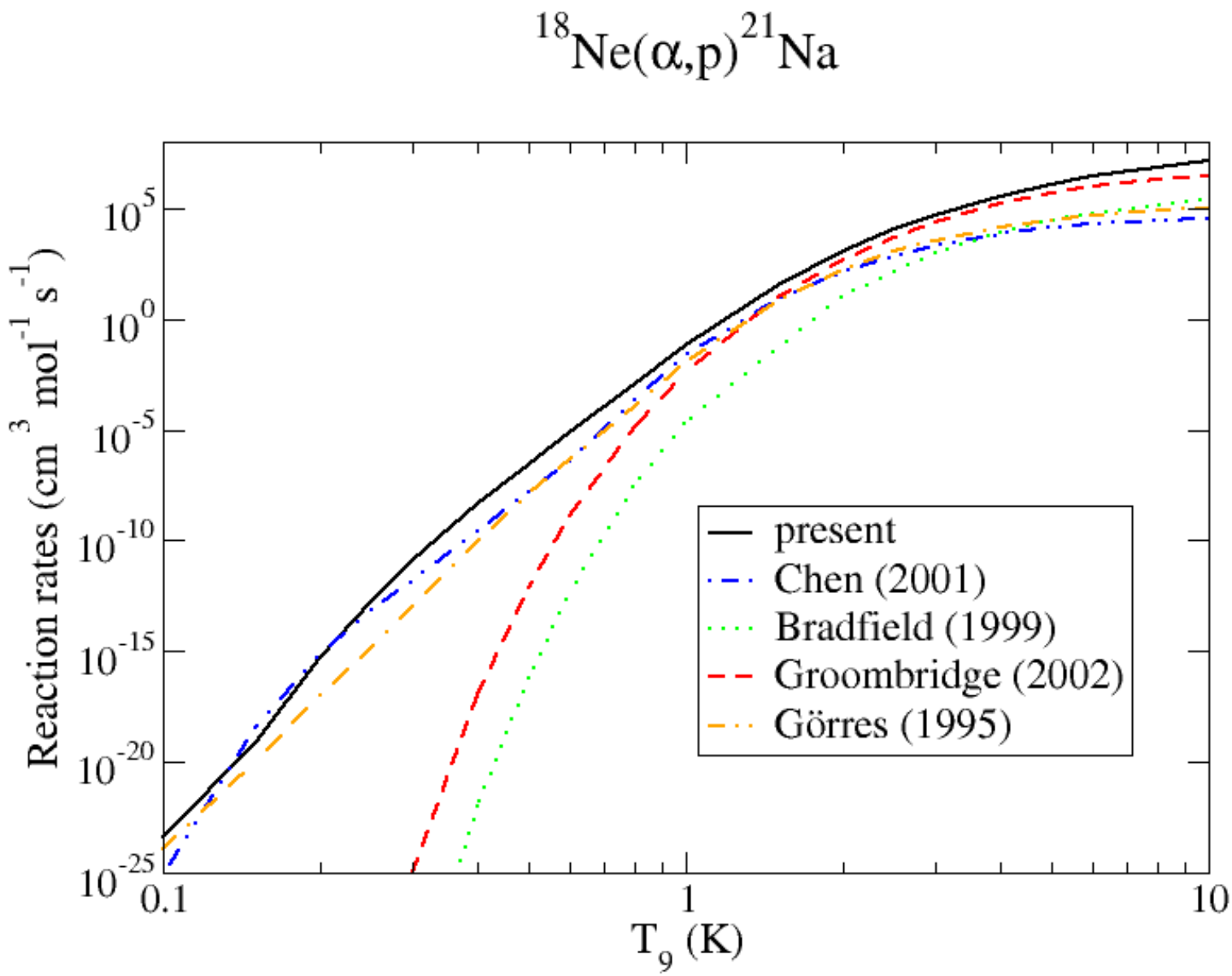
Region above 10.5 MeV

Jπ	present	Chen	Bradfield	Groombridge	Berg
	(p,t)	(^{3}He,^{6}He)	(^{18}Ne,p)	(^{18}Ne,p)	(^{4}He,^{6}He)
(3+)	-	10.570(25)	(10.580(50))	10.55(14)	-
(3-)	10.667(19)	10.660(28)	-	10.66(14)	10.627(20)
(2+)	10.768(21)	10.750(31)	-	-	10.776(20)
(4+)	10.881(15)	10.844(38)	(10.820(60))	10.86(14)	-
(8+)	-	-	10.910(50)	10.92(14)	(10.915(20))
(0+)	10.999(15)	10.980(31)	10.990(50)	11.01(14)	(11.015(20))
(6,7)	-	-	(11.050(50))	-	-
(7-)	-	11.135(40)	11.130(50)	-	(11.118(20))
(6+)	-	-	-	-	(11.231(20))
(4+)	11.317(27)	-	-	-	11.313(20)
(2+)	11.499(17)	-	-	-	-
(1-)	11.603(16)	-	-	-	11.581(20)
(0+)	11.76(3)	-	-	-	(11.742(20))
(0+)	11.937(17)	-	-	-	11.881(20)
(1-)	-	-	-	-	(12.003(20))
(3-)	12.220(30)	-	-	-	(12.169(20))
(2+)	12.474(26)	-	-	-	-
(3-)	12.665(17)	-	-	-	-
(0+)	(13.010(50))	-	-	-	-

Experimentally measured resonance strengths Groombridge et al. (2002)
Taken from previous works J. Görres *et al.* (1995)
Taken from mirror nuclei Goldberg *et al.* (2004)

Error in excitation energy from 15 keV- 30 keV

The $^{18}Ne(\alpha,p)^{21}Na$ reaction rates as function of temperature



^{22}Mg Summary

1) resolution of 13 keV FWHM.
2) resolved 62 of ^{22}Mg levels.
3) 12 levels were observed for the first time.
4) doublet at 6.2411 MeV resolved by measuring 6.2261(10) (4^+) level.
5) on base of measured excitation energies of ^{22}Mg we calculated ^{18}Ne(α,p)^{21}Na reaction rate.
6) ^{18}Ne(α,p)^{21}Na reaction rates are five times larger than previously calculated
7) it is necessary to obtain spin-parity data, and resonance strengths for more precise calculations.
8) Our experiment gives guidance for further experiments (energy calibration).

Collaboration

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