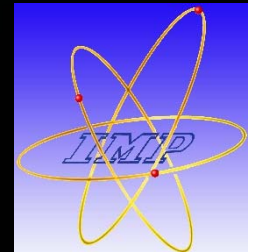


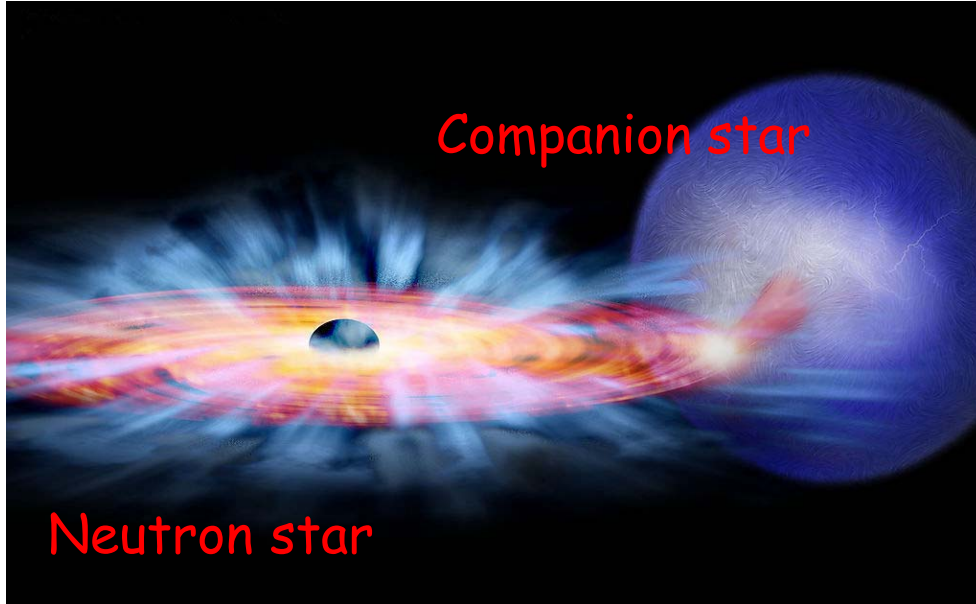
Indirect measurement of the $^{18}\text{Ne}(\alpha, p)^{21}\text{Na}$ reaction rate

Liyong Zhang

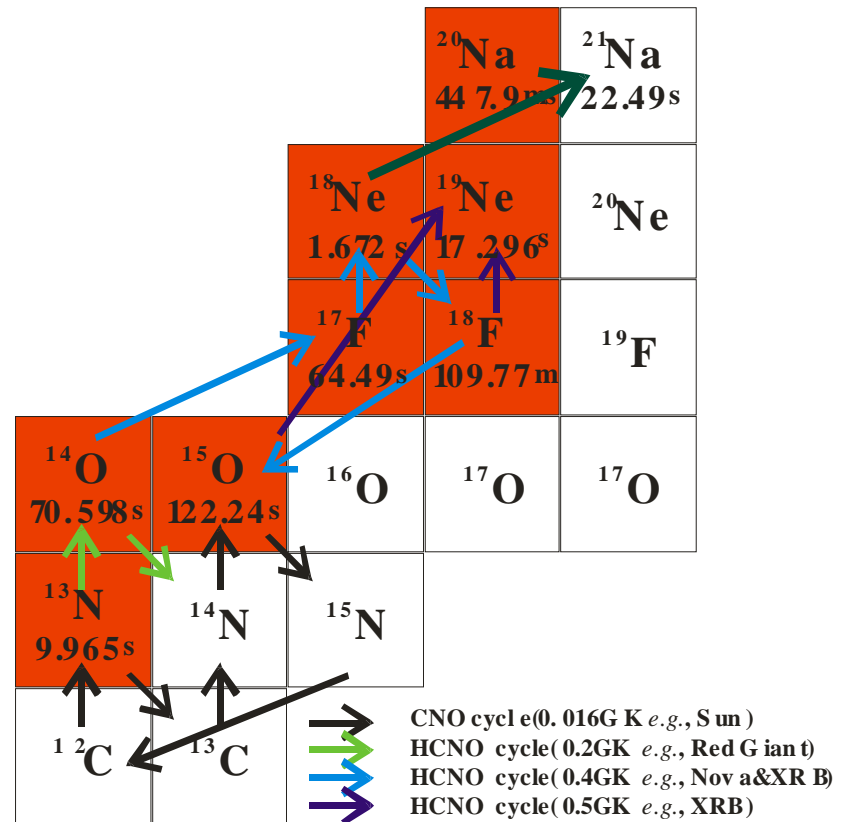
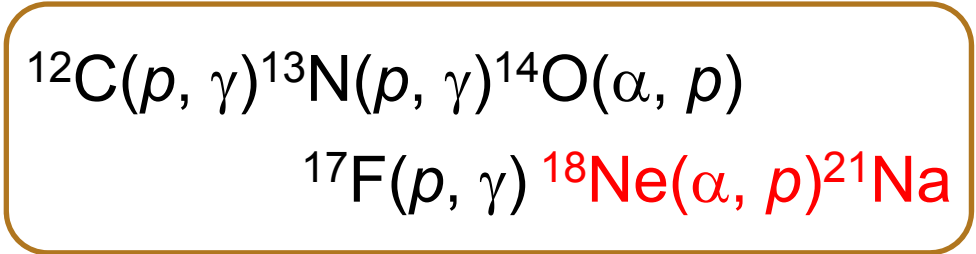
Nuclear Astrophysics Group
Institute of Modern Physics (Lanzhou)



Scientific Motivation



Explosive hydrogen and helium burning



Reaction Mechanism:

- Resonance reaction rate:**

$$N_A \langle \sigma v \rangle = 1.54 \times 10^{11} (\mu T_9)^{-3/2}$$

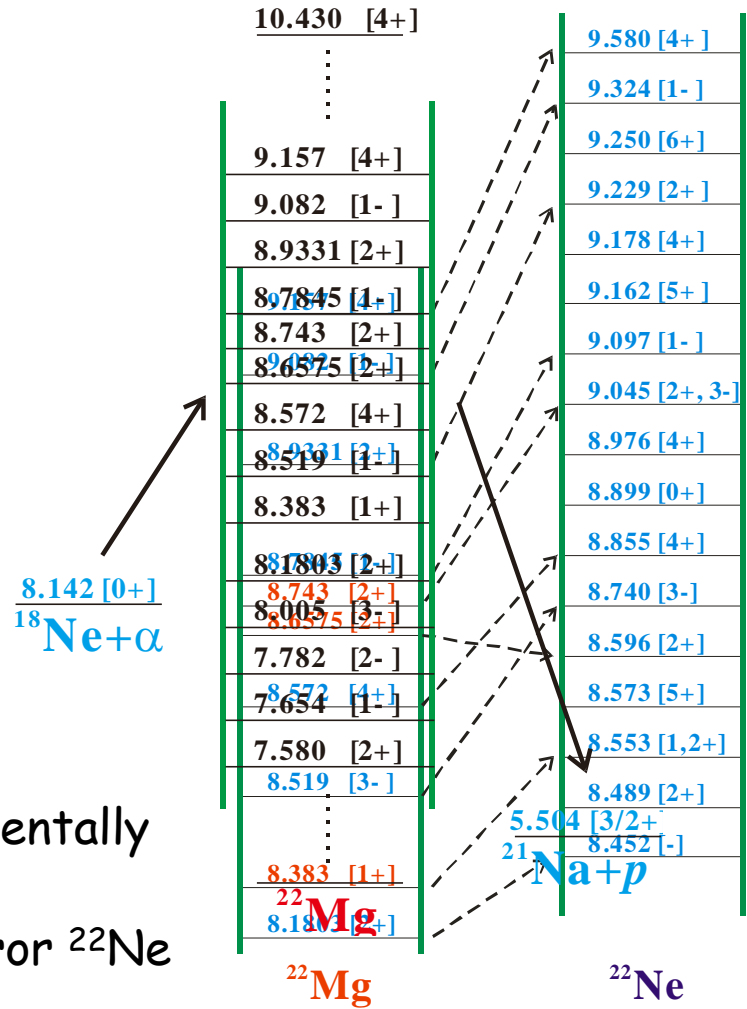
$$\sum_i (\omega\gamma)_i \times \exp(-11.605 E_i/T_9) [cm^3 s^{-1} mol^{-1}]$$

$$\omega\gamma \approx \frac{2J_{22Mg} + 1}{(2J_p + 1)(2J_{21Na} + 1)} \Gamma_\alpha$$

$$\Gamma_\alpha = \frac{3\hbar^2}{\mu R_n^2} C^2 S_\alpha \times P_l(E_i)$$

- Indirect measurement:**

- Determine E_i and J^π of ^{22}Mg levels experimentally
- The S_α factors were adopted from the mirror ^{22}Ne



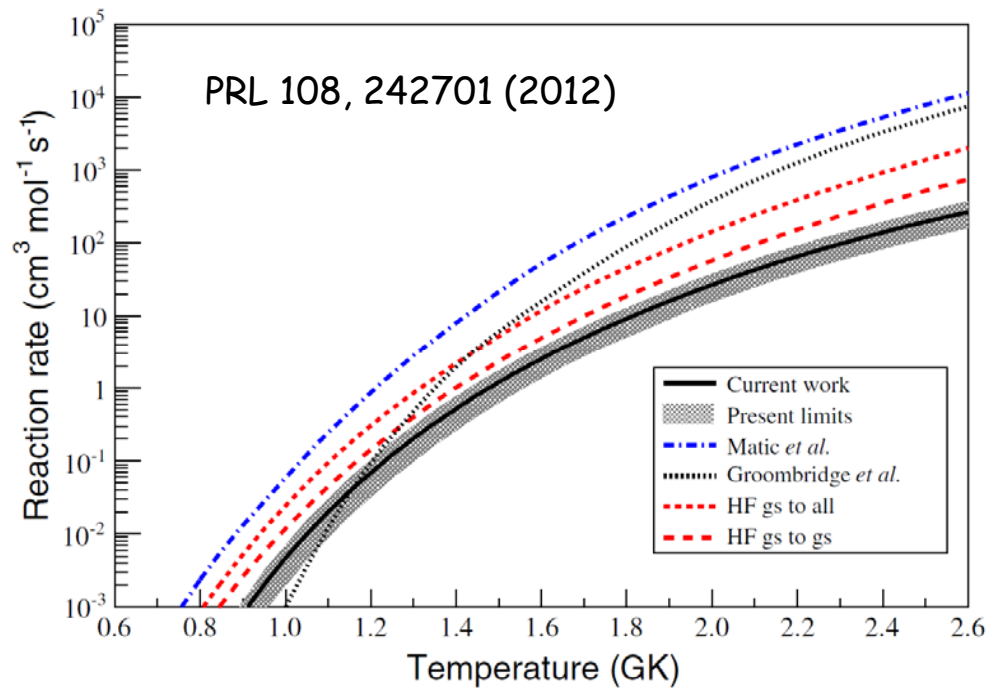
Present Status

PRC 80, 055804 (2009)

10.430(19)	10.429 [4+]	10.423 (3+)	10.325 3+ T
		10.384 (6+)	10.270 6+ T
10.2717(17)	10.272 [2+]	10.297 (0.1,2)	b
(10.168(9))	10.170 [3+]	10.282 (0.1,2)	b
		10.208 1+	b
10.087(15)	10.085 [2+]	10.137 2+	
	9.948 [1+]	10.066 (0+)	
9.861(6)	9.860 [0+]	9.842 (2+)	
9.7516(27)	9.752 [2+]	9.725 (3-)	
(9.70(5))	9.709 [0+]	9.652 (6+)	9.793 6+ T
	9.640 [6+]	9.625 (2+)	9.662 2+ T
9.546(15)	9.542 [2+]	9.541 2+	
9.492(13)	9.482 [3-]	9.508 (4+)	9.422 4+ T
	9.315(14)	9.324 (1-)	
	9.248 [6+]	9.250 (6+)	9.219 6+ T
9.157(4)	9.157 [4+]	9.229 2+	
9.082(7)	9.080 [1-]	9.178 (4+)	9.143 5+ T
		9.162 (5+)	
		9.097 1-	
		9.045 (2+,3-)	
8.9331(29)	8.932 [2+]	8.976 (4+) a	
		8.899 (0+)	8.794 0+ T
8.7845(23)	8.783 [1-]	8.855 4+	
8.743(14)	8.743 [4+]	8.740 (3-)	
8.6575(17)	8.657 [0+]	8.596 2+	
8.572(6)	8.574 [4+]	8.573 (5+)	
8.5193(21)	8.519 [3-]	8.553 (1,2+)	
		8.489 2+	
8.383(13)	8.385 [2+]	8.452 (-)	
		8.376 (3-)	
8.1803(17)	8.181 [2+]		
	8.062 [3+]	8.162 (3+)	8.435 3+ T
8.0070(13)	8.005 [3-]		

^{22}Mg

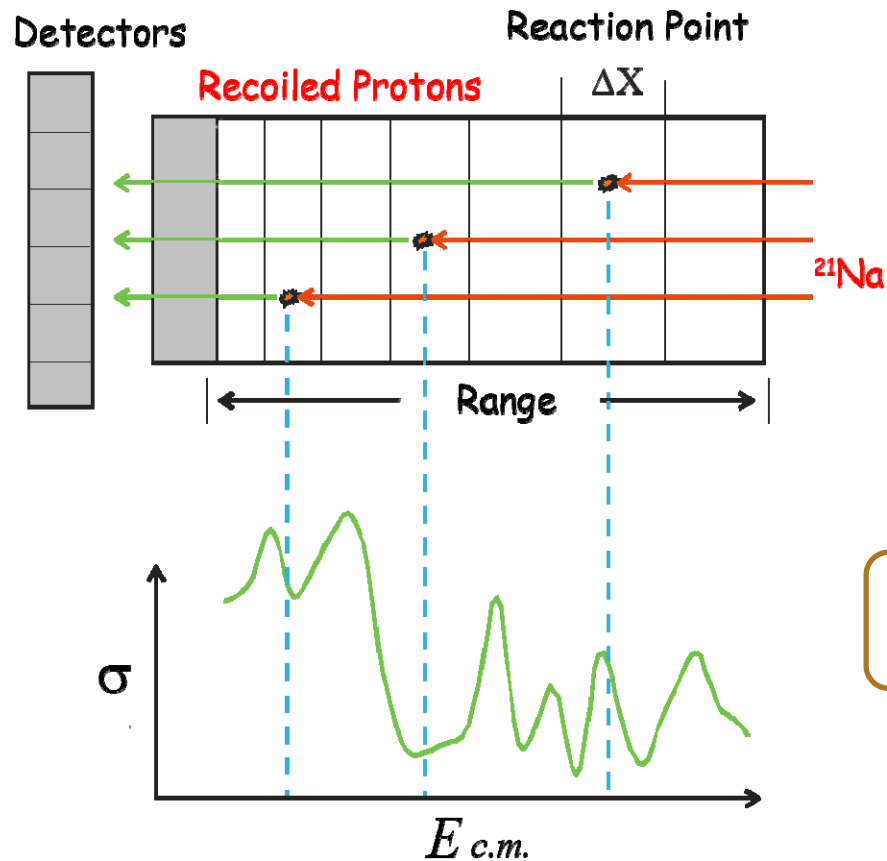
^{22}Ne



Indirect Measurement
 $^{24}\text{Mg}(p, t)^{22}\text{Mg}$

Direct Measurement
 $^{21}\text{Na}(p, \alpha)^{18}\text{Ne}$

Thick Target Method:



^{21}Na beam + CH_2 Target

$^{21}\text{Na}(p,p)^{21}\text{Na}$ cross section



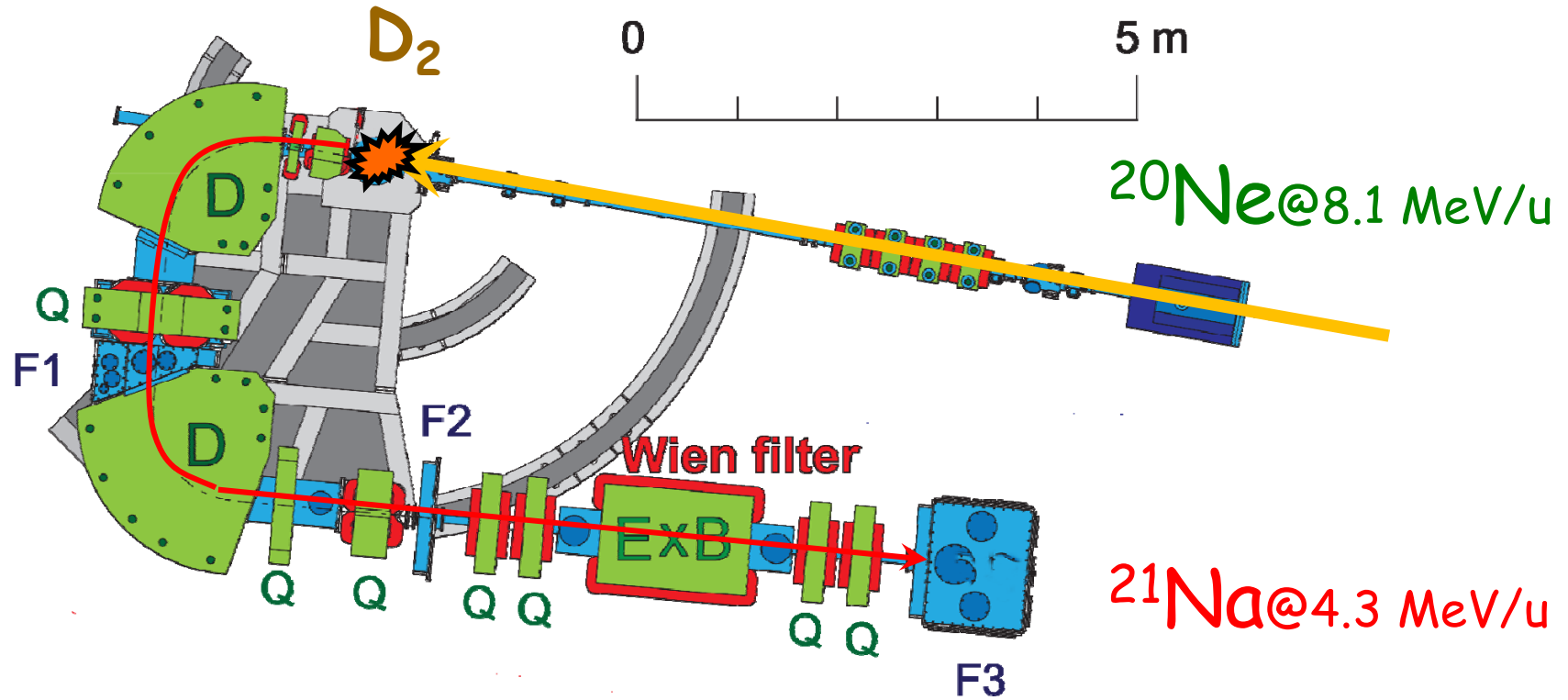
R-Matrix Analysis



E_i and J^π

Beam Production

CRIB(CNS low-energy Radioactive-Ion Beam) separator

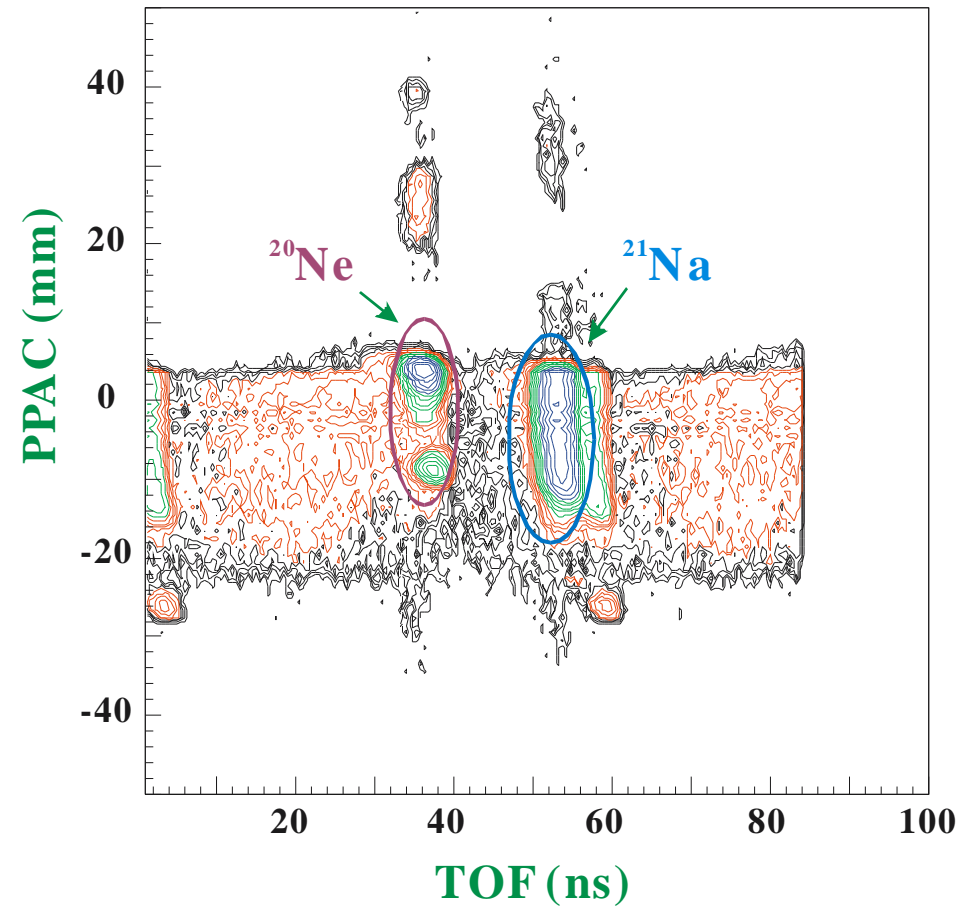
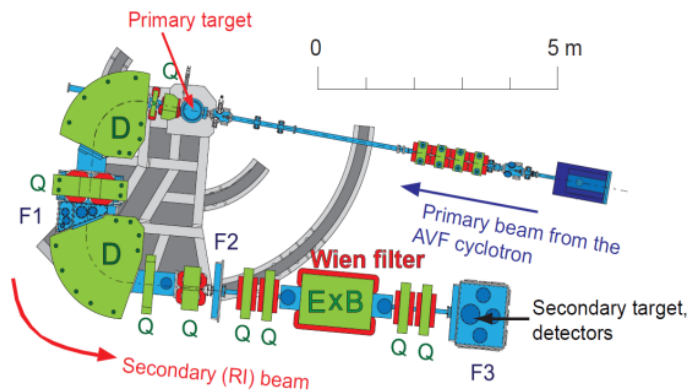


Beam Particle Identification

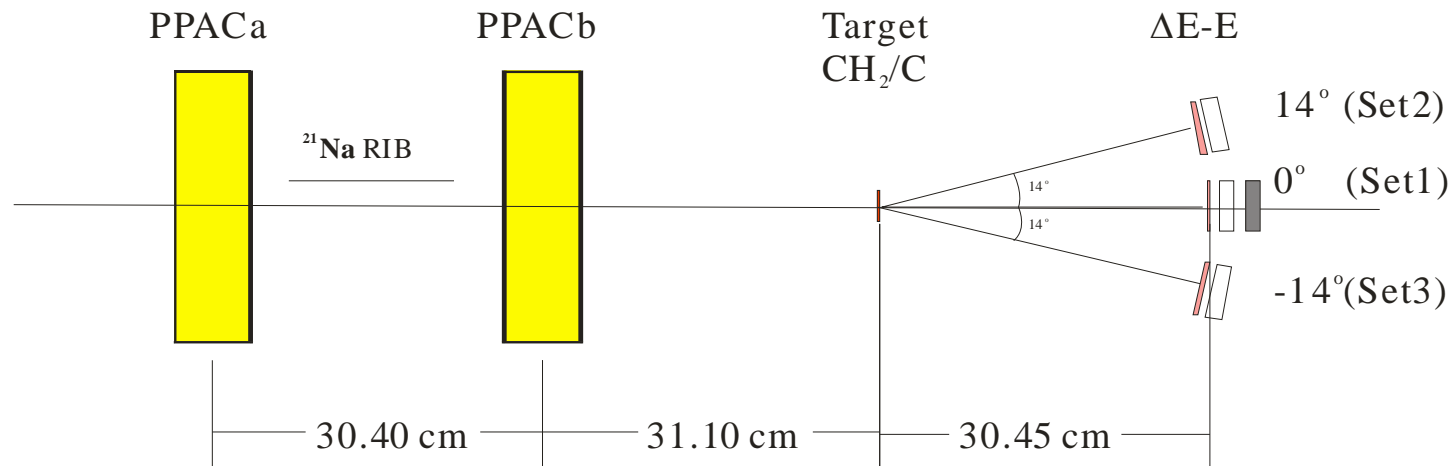
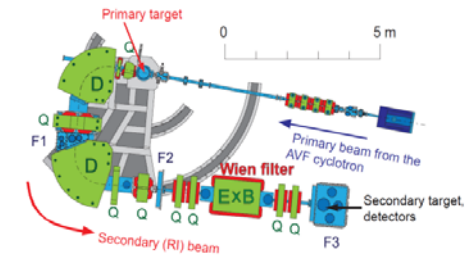
Beam intensity: 2×10^5 pps

Purity: 70%

Spot size : 9.5×4.8 mm (FWHM)



Experimental Setup



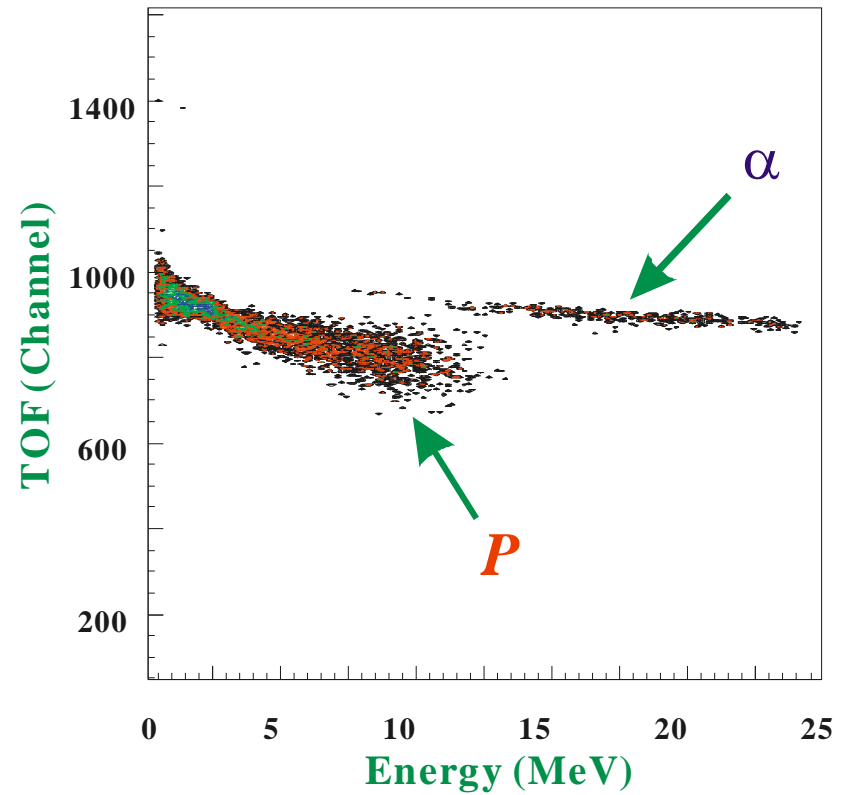
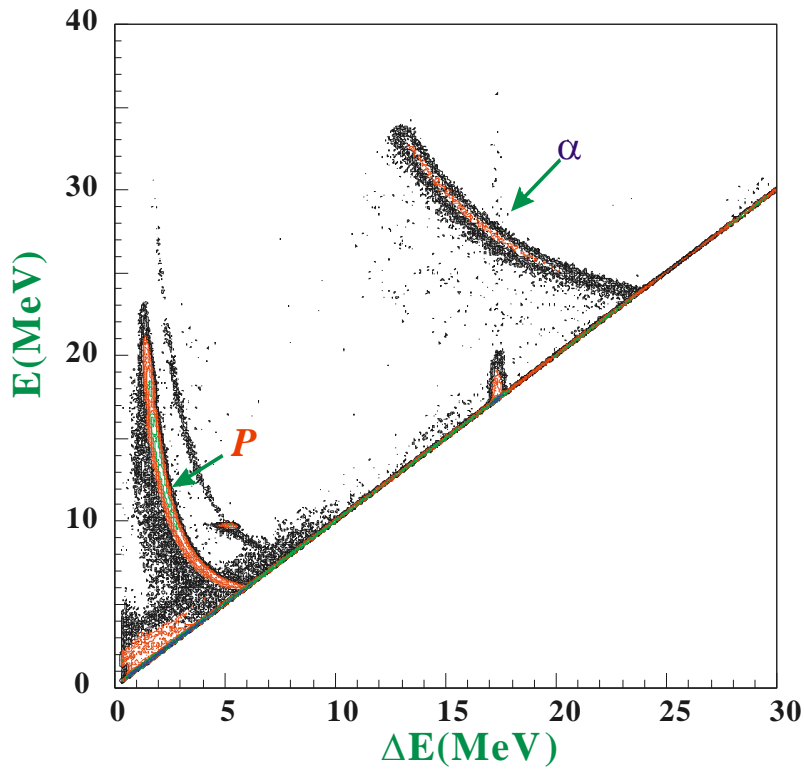
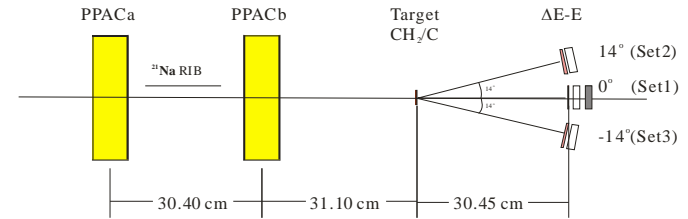
PPACs
 Position Resolution: 1 mm
 Count Rate: 10^6 pps

Target
 $\phi=30$ mm, $90 \mu\text{m}$ CH_2
 $\phi=30$ mm, $50 \mu\text{m}$ C

Si Telescopes
 Size: 5×5 cm
 ΔE : 300/65 μm
 E: 1.5 mm

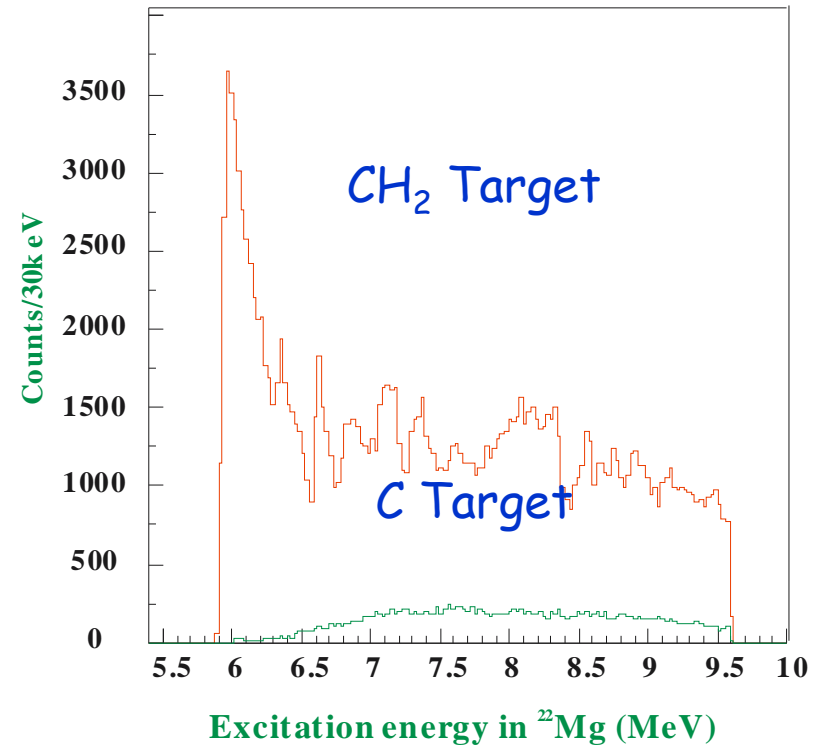
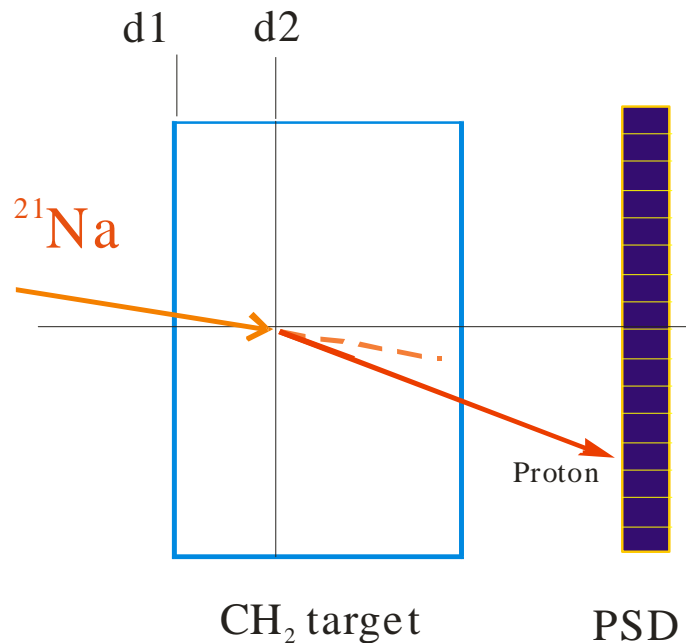
Reaction Product PID

ΔE _E and TOF_E method



Reconstruction of the $E_{c.m.}$ Spectrum

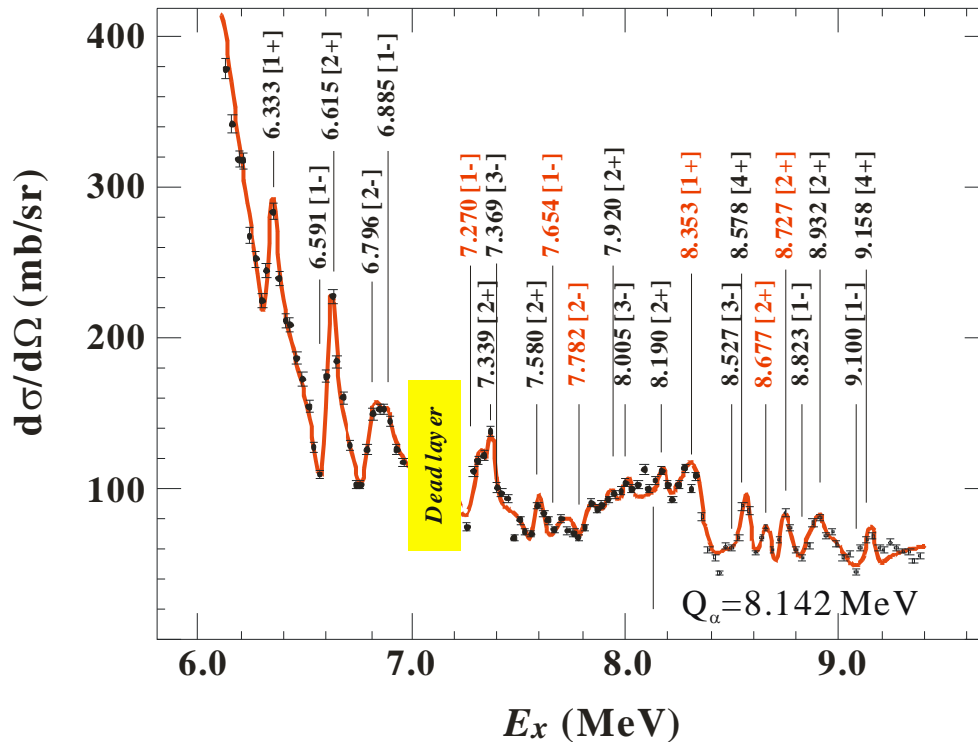
The reaction point is reconstructed



The Carbon background is subtracted

R-Matrix Fitting

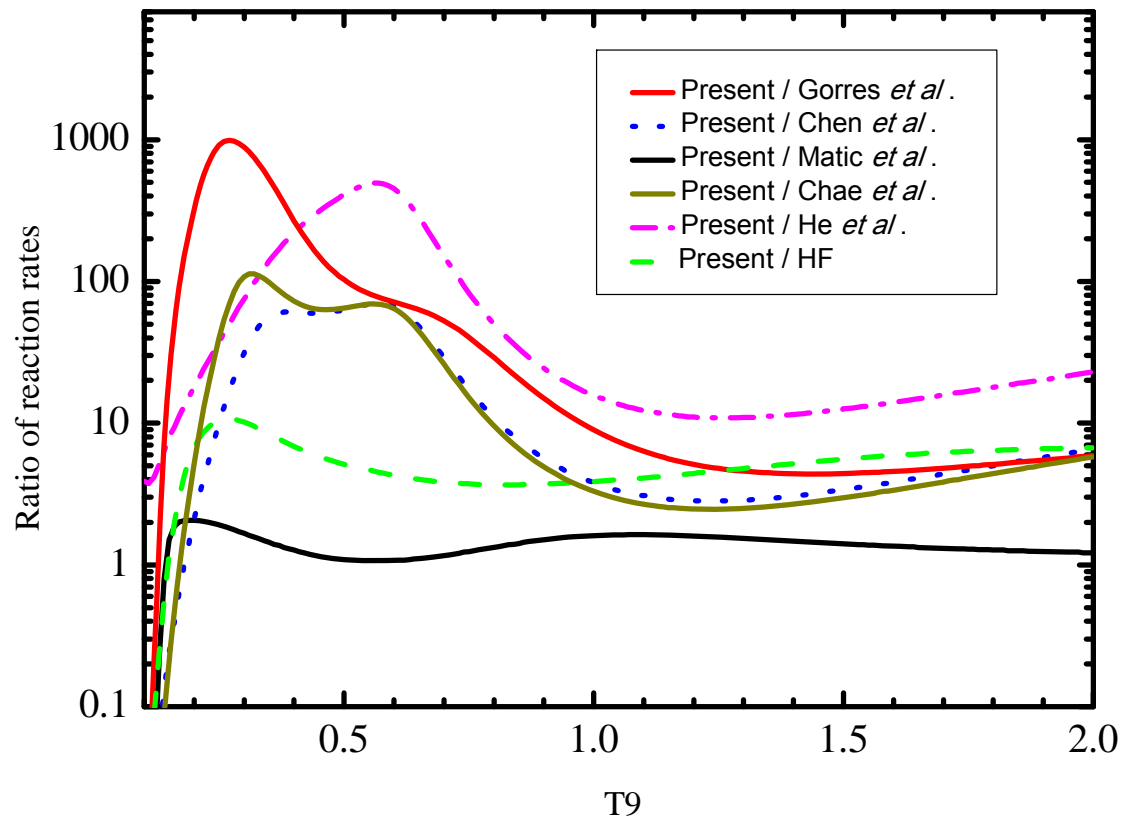
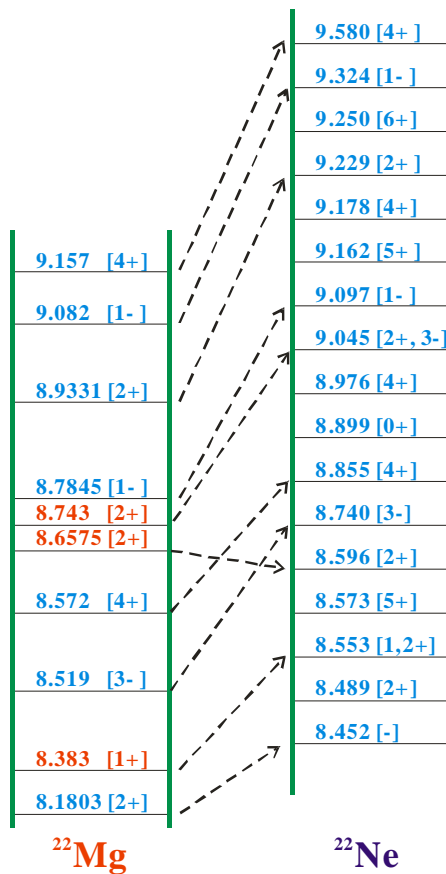
The Visual edition of the MULTI Program



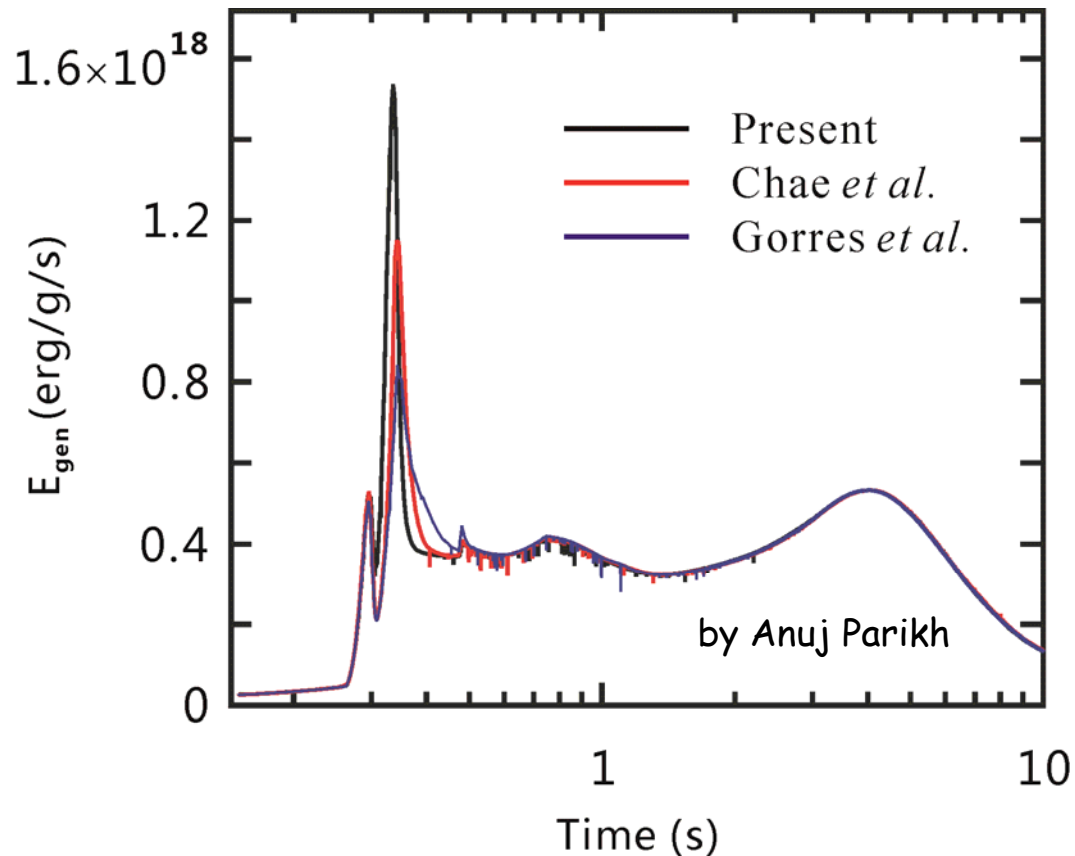
These spin-parity values were used to calculate the $^{18}\text{Ne}(\alpha, p)^{21}\text{Na}$ rate

Results: Calculated reaction rate

$$N_A \langle \sigma v \rangle = 1.54 \times 10^{11} (\mu T_9)^{-3/2} \sum_i (\omega \gamma)_i \times \exp(-11.605 E_i/T_9) [cm^3 s^{-1} mol^{-1}]$$



Results: Astrophysical impacts



One-zone postprocessing x-ray burst calculations

The peak energy generation rate increase by a factor of 1.4-1.8

PRC RC and Regular

Summary

- The $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ reaction rate was indirectly measured via a $^{21}\text{Na}(p,p)^{21}\text{Na}$ experiment
- The resonance properties were determined via an R-Matrix analysis
- The $^{18}\text{Ne}(\alpha,p)^{21}\text{Na}$ reaction rate is recalculated, which is 10 to 100 times larger than previous ones
- The peak energy generation rate increased by a factor of 1.4-1.8

Thank you

- typical temperature = 0.4 – 2.0 GK
- Corresponding Energy Region
 - $E_{cm}^{\alpha} = 0.7 - 2.1$ MeV
 - $E_x(^{22}\text{Mg}) = 8.8 - 10.2$ MeV
- LLN, Belgium (Edinburgh Group, PRC)
 - $E_{cm}^{\alpha} = 1.7 - 3.01$ MeV
 - ^{18}Ne beam + ^4He gas target
- ANL, USA (S. Sinha et al., ANL Annu. Report)
 - $E_{cm}^{\alpha} = 1.2 - 2.5$ MeV,
 - ^{21}Na beam + CH_2 target
- CNS (J.J. He et al., PRC)
 - $E_{cm}^{\alpha} \sim 0.76$ MeV,
 - ^{21}Na beam + CH_2 target
- Our results: $E_{cm}^{\alpha} = 0 - 1.6$ MeV

Experimental Setup

- + 1 primary beam $^{20}\text{Ne}^{8+}$
 - Energy: 8.1 AMeV
 - Intensity: 300 pnA

- + 2 Production Target: D_2
 - Length: 80 mm
 - Temperature: 80 K (液氮冷却)
 - Pressure: 500 Torr
 - Thickness: 2.4 mg/cm²