Exploring the αp process path

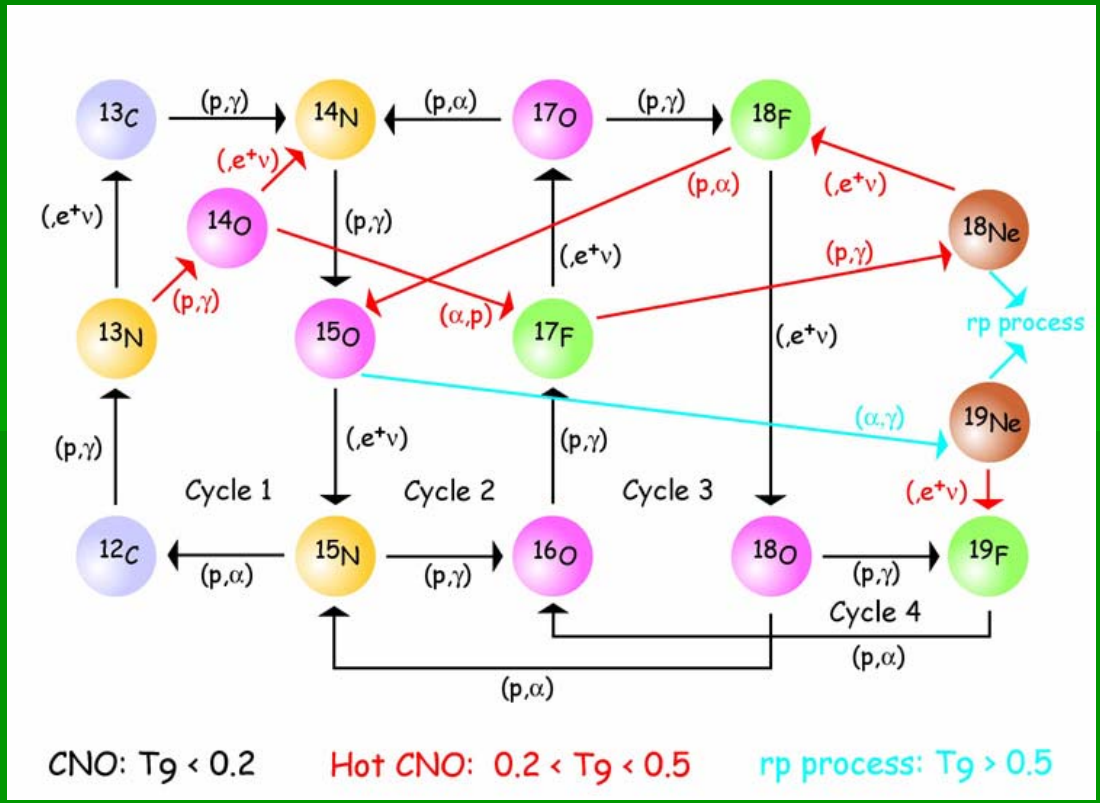
Shawn O'Brien
University of Notre Dame

Introduction

- What is the αp-process?
  - Series of (α,p) and (p,γ) reactions
  - Dominant branch begins with $^{14}O \rightarrow$ even Z, $T_z = -1$ nuclei undergo (α,p)
  - Ends in A ≈ 42-46 region (where rp-process continues)
- Where does this occur?
  - Explosive scenarios (time 1-1000 seconds)
  - Accretion layers on white dwarfs and neutron stars

The preface

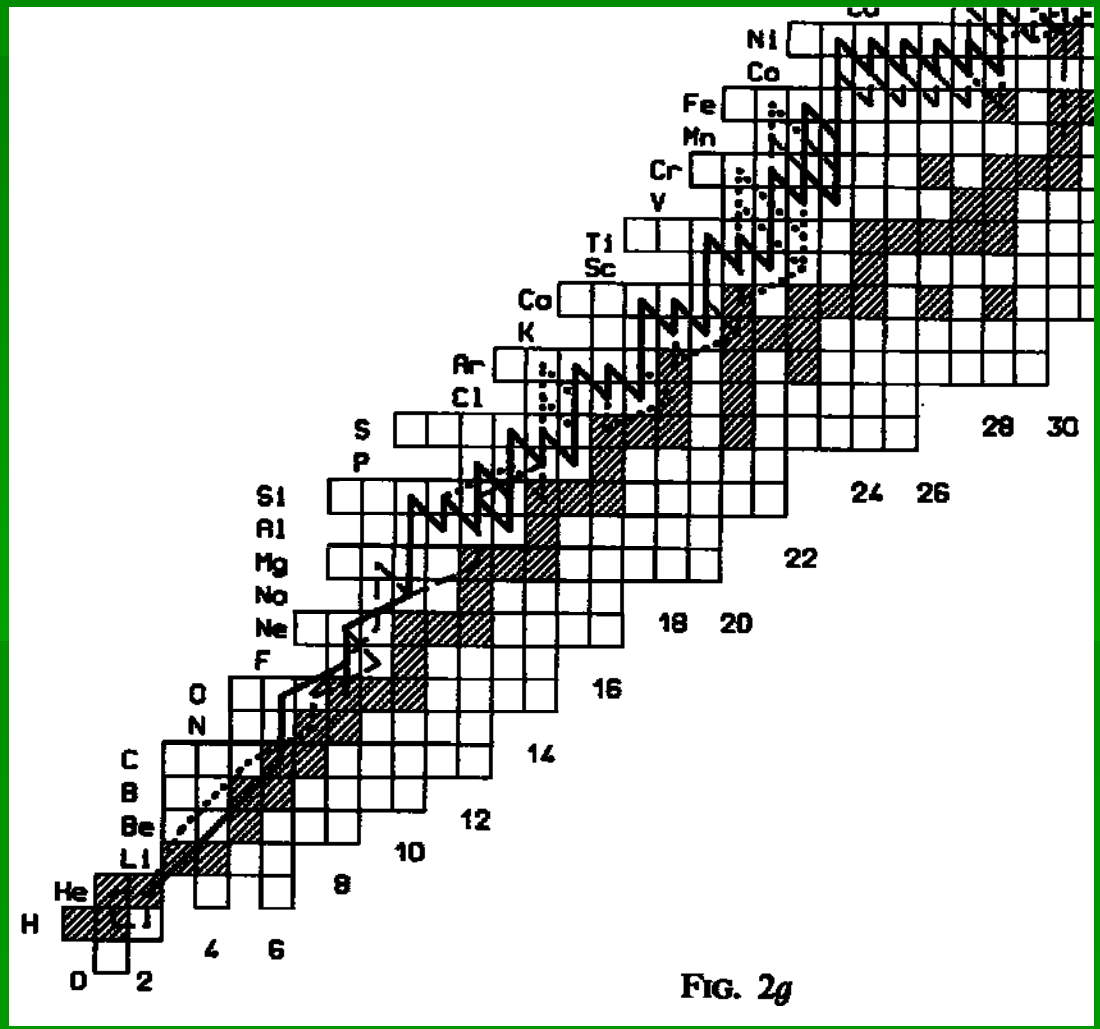
- αp-process begins with the breakout of the hot CNO cycle



http://www.cococubed.com/images/net_hotcno/cno_cycles_rp_web.jpg

Basic reaction flow

- $t=10^3$ s
- $T=10^9$ K
- $\rho=10^4$ g/cm^3



Van Wormer et al, 1994

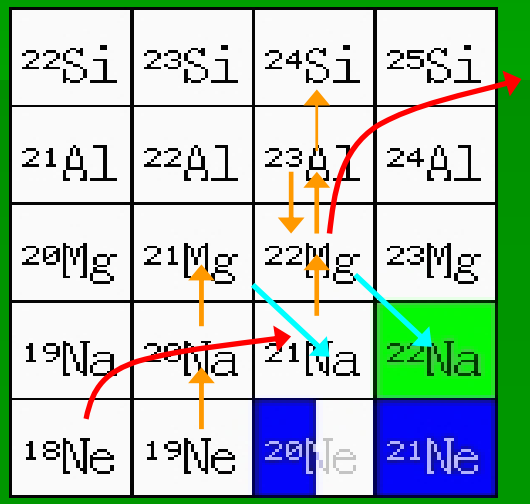
Relevant information

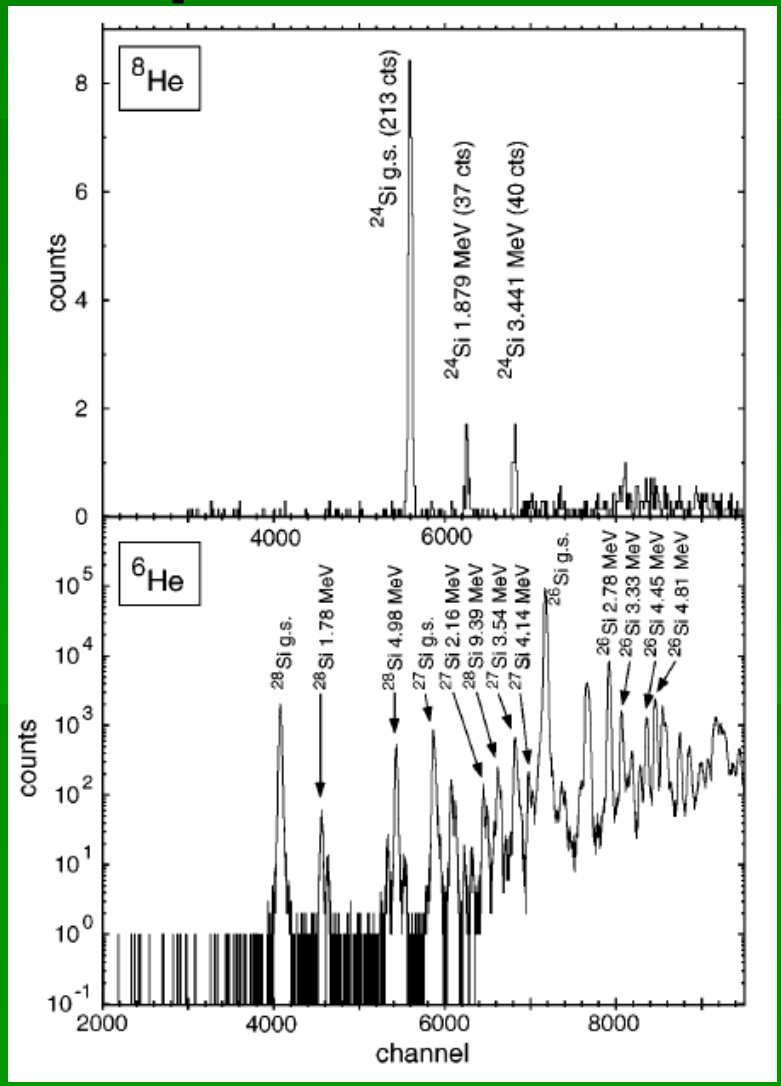
$$N_A \langle \sigma v \rangle = 1.540 \times 10^{11} (\mu T_9)^{-\frac{3}{2}} \omega\gamma \times e^{-\frac{E_{res}}{kT}}$$

- The resonance energy is the most important factor in calculating the reaction rate
- Shell models calculations give errors of the order 100 keV
  - This results in reactions rates with errors of 3 orders of magnitude

Previous (α,^{8}He) experiments

- ^{28}Si(α,^{8}He)^{24}Si done at IUCF
- Excitation energies in ^{24}Si measured for 80 hours





Current efforts

$(\alpha,{}^{8}He)$ at RCNP

$^{50}Cr(\alpha,{}^{8}He)^{46}Cr$

- ^{44}Ti production depends on $^{45}V(p,\gamma)$ rate
- No experimental information about states above p threshold in ^{46}Cr

$^{46}Ti(\alpha,{}^{8}He)^{42}Ti$

- $^{38}Ca(\alpha,p)^{41}Sc$ is thought to be the **end** of the αp-process
- Comparison of levels of ^{42}Ti with shell model predictions

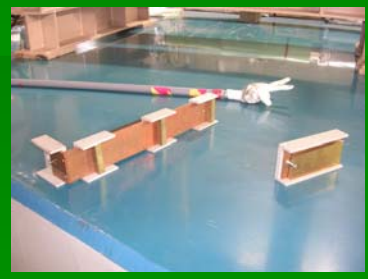
Why RCNP?

- Grand Raiden plus the WS beam line

Beam spread ~ 100 keV or better

Dispersion matched beam can have resolution of 10 keV!!!

Experimental Setup



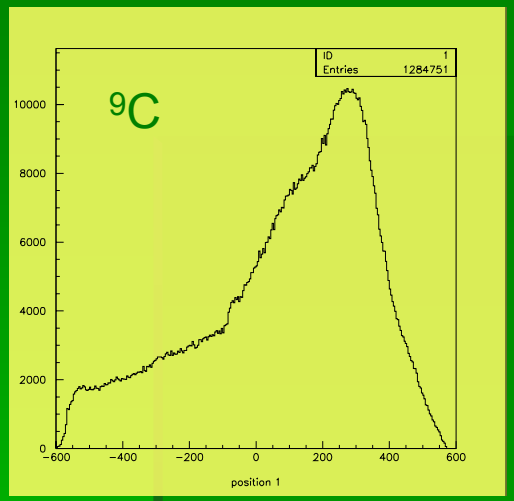
Experimental Technique

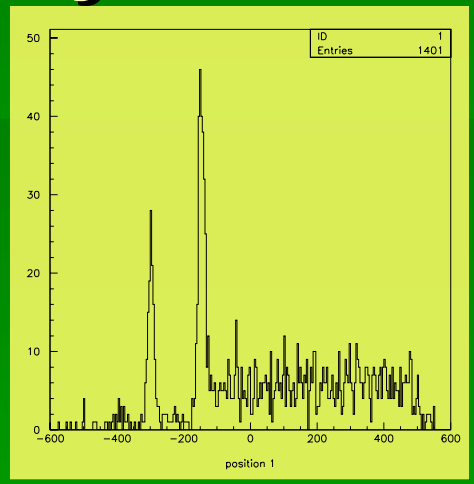
- 200 MeV α particles onto targets ~ 1 mg/cm^2 thick
- Beam in full dispersion matched mode
- Selection of ^{8}He particles with Grand Raiden near 0º
- Energy of the excited states of the recoil determined by Bρ of excited ^{8}He particles and kinematics

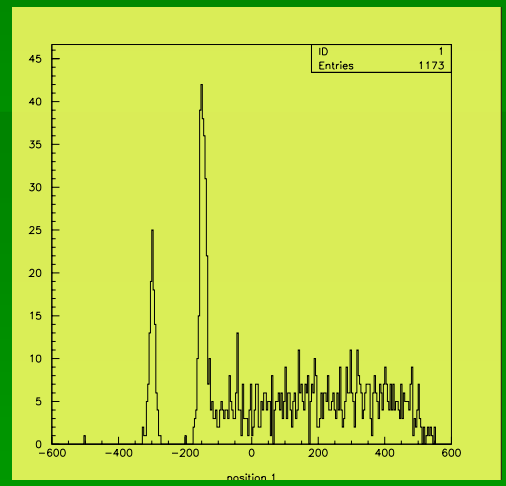
Experimental Difficulties

- Decreasing cross section with increasing mass
  - σ~ 60 bn/str for ^{13}C, ~ 15 bn/str for ^{28}Si
- Dispersion matching is not simple
  - Tuning is time intensive
- Target effects
  - Differences in energy loss

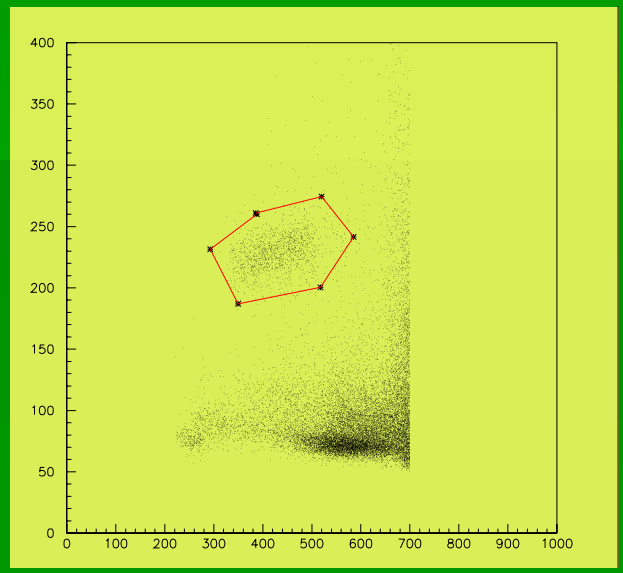
Data Analysis







ΔE



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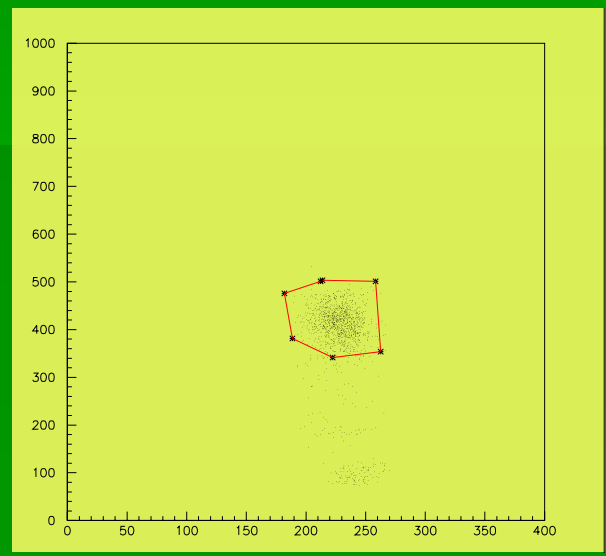
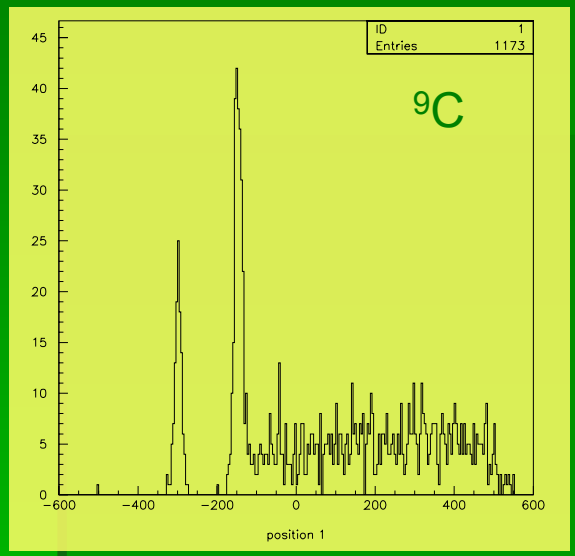
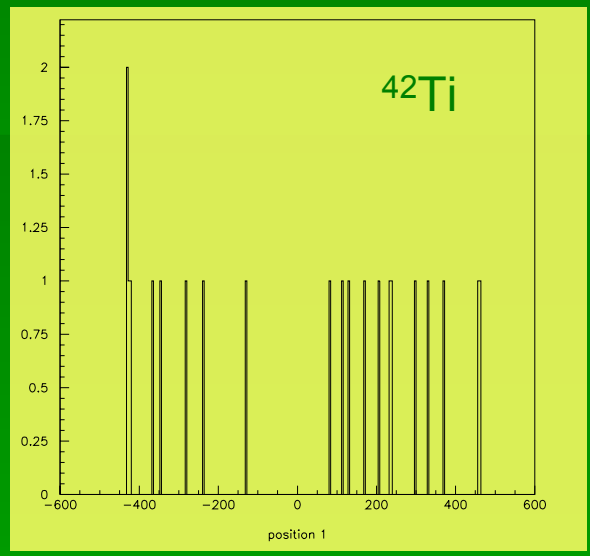
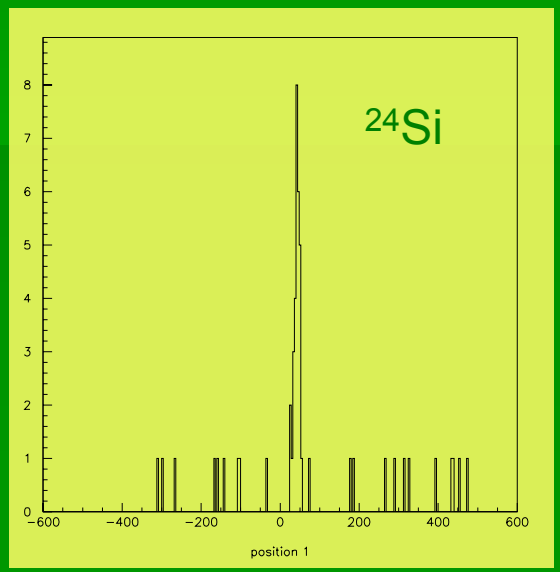
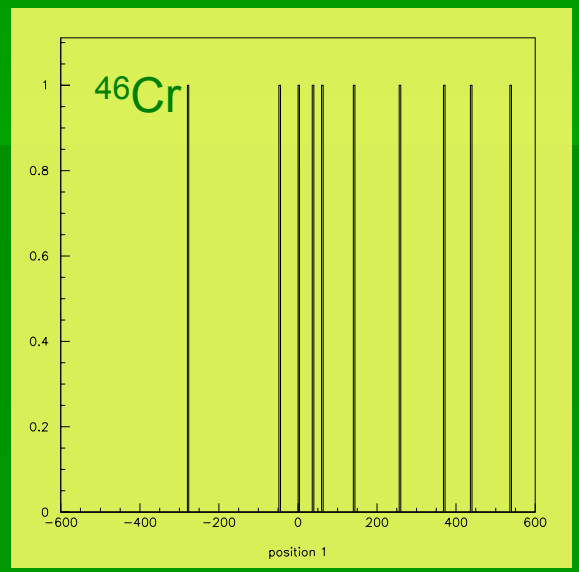


Preliminary Results

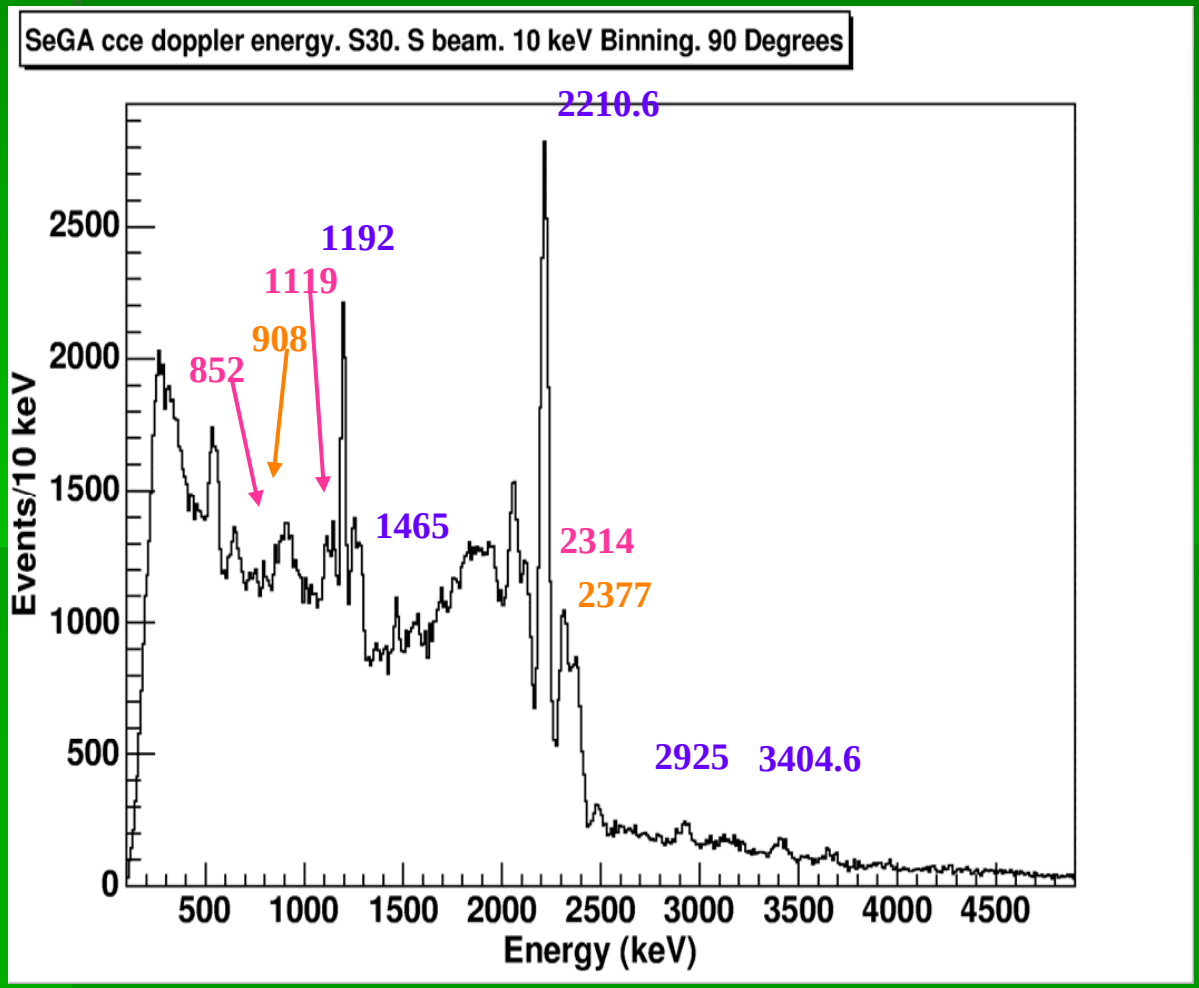


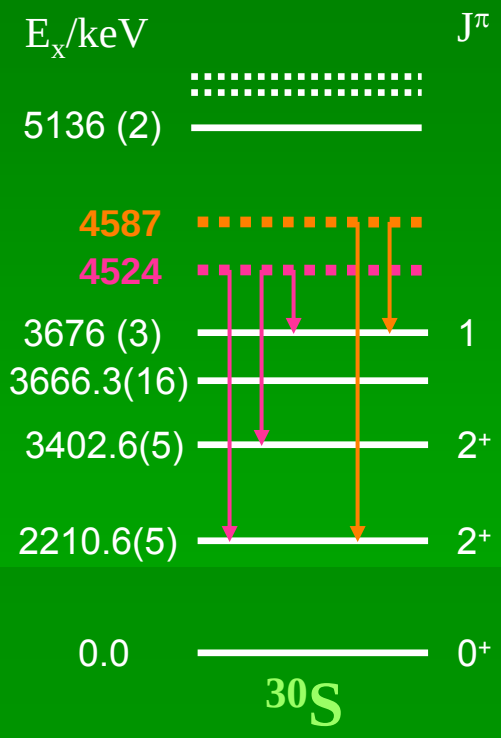






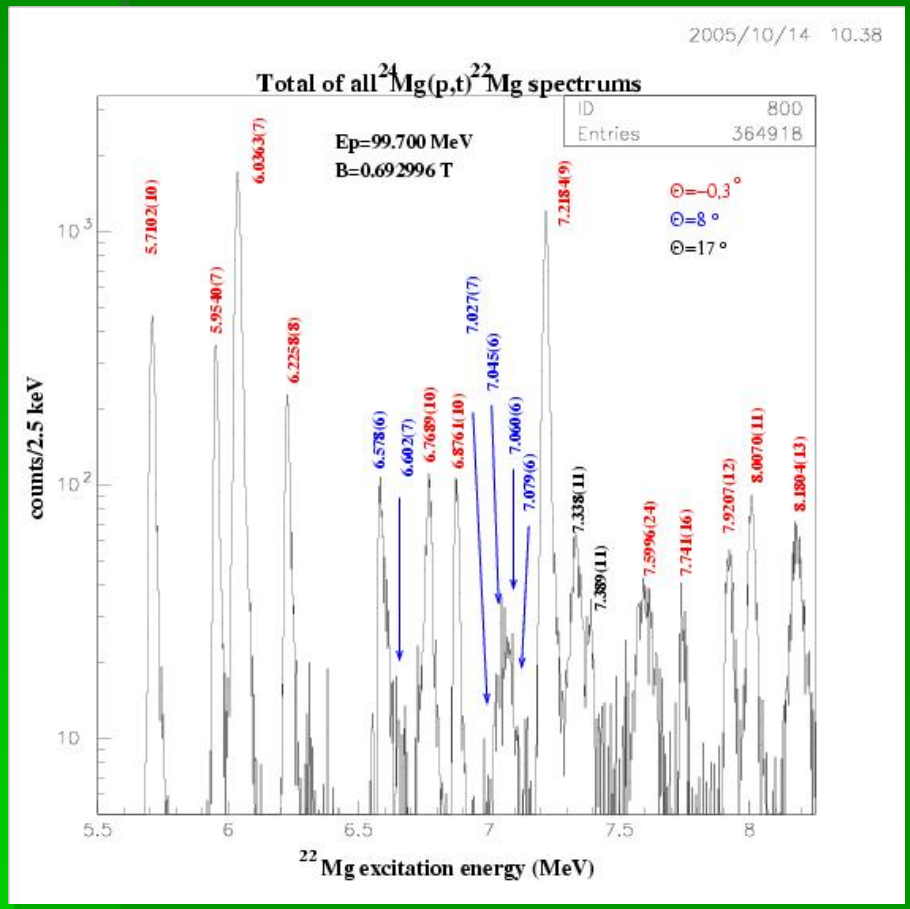
Other Current Experiments
^{30}S at NSCL

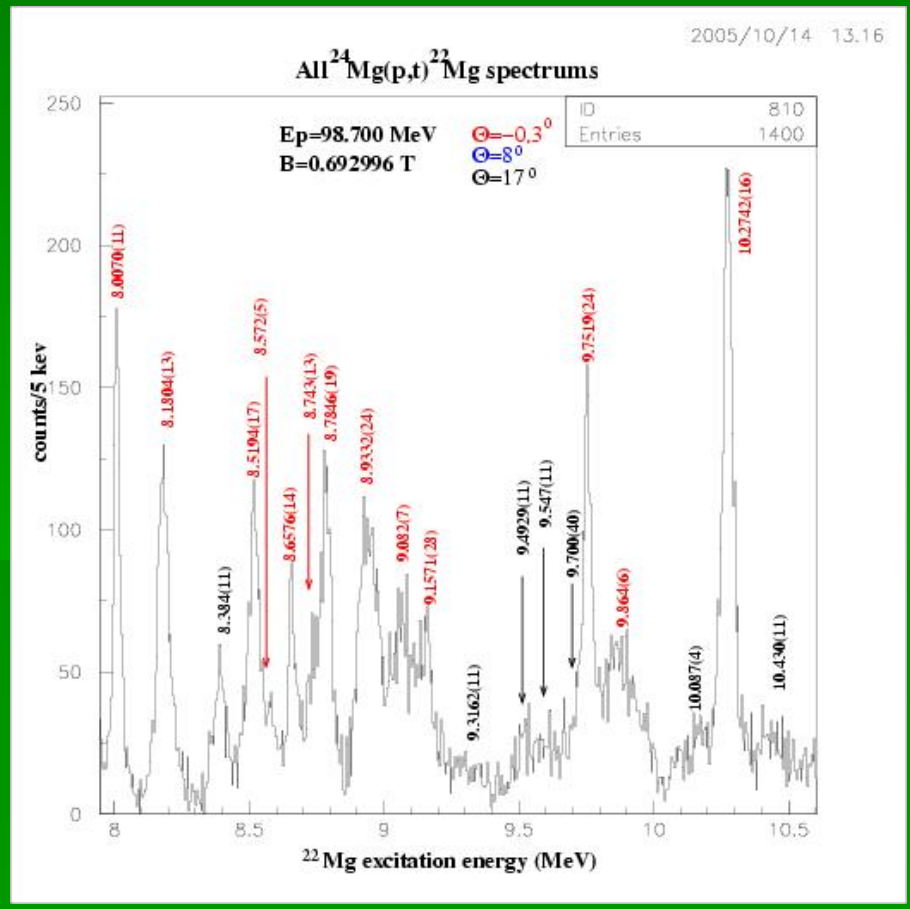




Daniel Galaviz NSCL / MSU

Other Current Experiments
^{22}Mg at RCNP





Andrija Matic KVI

Other Current Experiments
^{22}Mg at RCNP

J^π	Present	Seweryniak *et al* [1]	Bateman corrected	Caggiano *et al* [3]	A.B. McDONALD *et al et al* [7]	Chen *et al* [4]	Berg *et al* [5]
2^+	5.7110[a]	5.7110(10)	5.7106(12)	5.7139*	5.699(20)	5.711*	-
0^+	5.9540(7)	-	5.9577(25)	-	5.945(20)	-	-
-	6.0363(7)	-	6.0413(30)	6.051(4)	-	6.041(11)	6.059(9)
6^+	6.2258(8)	6.254(4)	6.2411(51)	6.246(4)	6.263(20)	6.255(10)	6.244(9)
-	-	-	6.3170(60)	6.329(6)	-	-	-
-	6.578(6)	-	-	-	6.573(20)	-	-
-	6.602(7)	-	6.606(7)	6.616(4)	-	6.606(11)	6.606(9)
3^-	6.7689(10)	-	6.780(14)	6.771(5)	6.770(20)	6.767(20)	6766(12)
3^-	6.8761(10)	-	-	6.878(9)	-	6.889(10)	-
-	7.027(7)	-	-	-	-	-	-
-	7.045(6)	-	-	-	-	-	-
-	7.060(6)	-	-	-	-	-	-
-	7.079(6)	-	-	-	-	-	-
0^+	7.2184(9)	-	-	7.206(6)	7.201(20)	7.169(11)	7.216(9)
-	7.338(11)	-	-	-	-	-	-
-	7.389(11)	-	-	7.373(9)	-	7.402(13)	-
-	-	-	-	-	-	-	-
-	7.5996(24)	-	-	7.606(11)	-	-	7.614(9)
-	-	-	-	-	-	7.674(18)	-
-	7.7411(16)	-	-	7.757(11)	-	7.784(18)	-
-	7.9207(12)	-	-	-	-		7.938(9)
-	8.0070(11)	-	-	7.986(16)	-	7.964(16)	-
-	-	-	-	-	-	8.062(16)	-

Table 1: Region above of p threshold (5.512 - 8.14 MeV)

J^π	Present	Caggiano *et al* [3]	Chen *et al* [4]	Berg *et al* [5]
	8.1804(13)	8.229(20)	8.203(23)	8.197(10)
	8.384(11)	8.394(21)	8.396(15)	8.380(10)
	8.5194(17)	8.487(36)	-	8.512(10)
	8.572(5)	8.598(20)	-	-
	8.6576(14)	-	-	(8.644(18))
	8.743(13)	-	-	-
	8.7846(19)	8.789(20)	8.754(15)	8.771(9)
	8.9332(24)	-	8.925(19)	8.921(9)
	9.082(7)	-	9.066(18)	(9.029(20))
	9.1571(28)	-	(9.172(23))[d]	9.154(10)
	-	-	(9.248(20))[d]	-
	9.316(11)	-	9.329(26)	(9.378(22))
	9.493(11)	-	(9.452(21))[d]	
	9.547(11)	-	9.533(24)	9.542(12)
	-	-	9.638	9.640(10)
	(9.695(34))	-	9.712(21)	-
	9.7519(24)	-	-	9.746(10)
	9.864(6)	-	9.827(44)	9.853(11)
	-	-	9.924(28)	9.953(13)
	10.088(11)	-	10.078(24)	(10.128(20))
	-	-	10.190(29)	-
	10.2742(16)	-	10.297(25)	10.260(10)
	10.430(14)	-	10.429(16)	(10.389(20))

Table 2: Region above of α threshold (8.14 - 10.5 MeV)

Outlook

- Approach αp-process from all experimental sides to measure energy of the relevant states
  - The future is with radio active beams
  - First measure the energy levels, then investigate the resonance strengths
- Several (p,t) experiments have been proposed to study ^{30}S, ^{34}Ar and ^{38}Ca