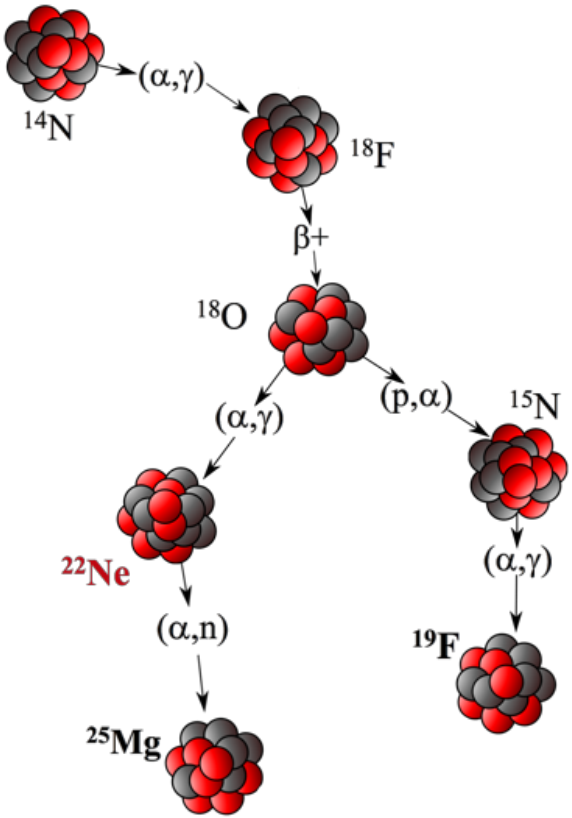
Investigation of High-Lying (α, γ) Resonances in ^{22}Ne via High-Resolution Gamma Ray Spectroscopy in Inverse Kinematics

Beau Greaves
CAP Congress 2019
SFU

UNIVERSITY of GUELPH

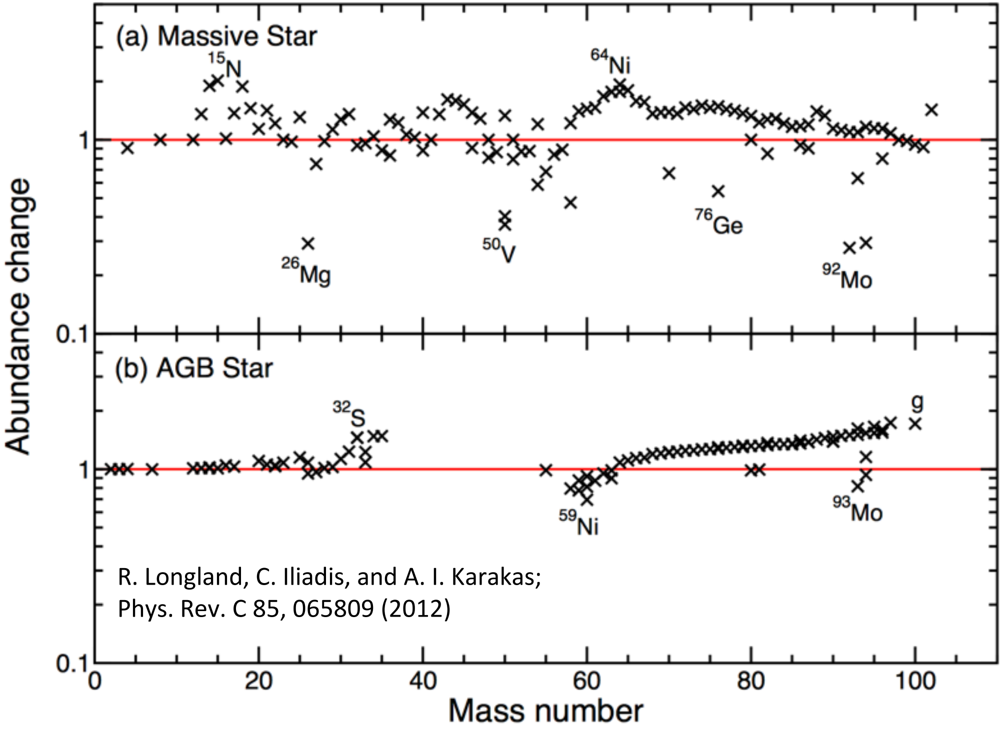
Stellar Nucleosynthesis of ^{22}Ne



^{22}Ne produced in AGB stars from $^{18}O(\alpha, \gamma)$ out of CNO cycle

$^{18}O(\alpha, \gamma)^{22}Ne$ competes with production of ^{19}F, the abundance of which is poorly characterized in AGB stars

Reaction rates for the s-process neutron source ^{22}Ne+α



^{22}Ne produced in AGB stars from $^{18}O(\alpha, \gamma)$ out of CNO cycle

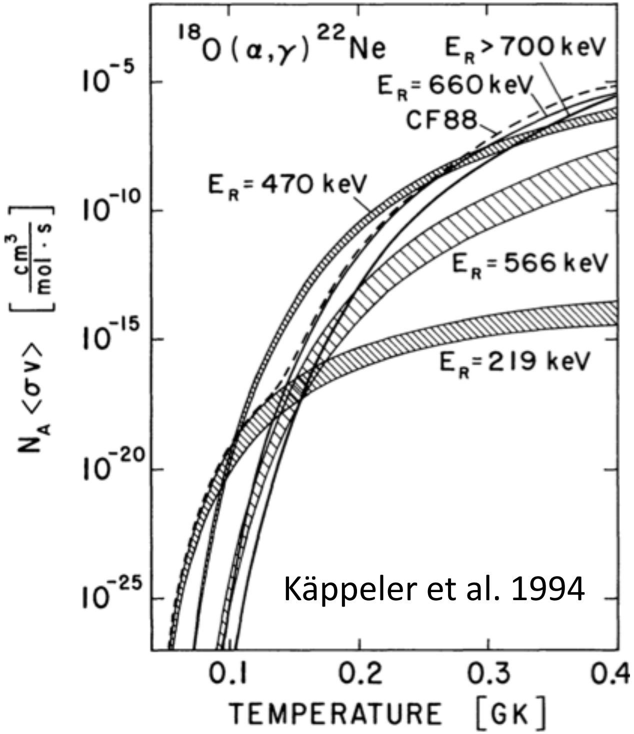
Following ^{22}Ne(α,n)^{25}Mg is main neutron source for heavy element s-process

Recent rate adjustments show drastic impact on abundances

- ^{22}Ne(α,γ)^{26}Mg
- ^{22}Ne(α,n)^{25}Mg

Spectroscopy of ^{22}Ne resonances at ISAC-II

E_r (MeV)	E_x (MeV)	J^{π} [a]	$\omega\gamma_{(\alpha,\gamma)}$ (μeV) [b]	$\omega\gamma_{(\alpha,n)}$ (μeV) [b]
		$^{18}O + \alpha$		
0.058……	9.72	3^-	4.1×10^{-40}	
		(2^+)	1.5×10^{-39}	
0.218……	9.85	2^+	7.1×10^{-12}	
		(1^-)	5.8×10^{-11}	
0.470……	10.05	0^+	0.55	
		(1^-)	0.23	
0.566……	10.13	4^+	7.9×10^{-3}	
		(2^+)	1.95	
		(3^-)	0.15	
0.662……	10.21	1^-	230 ± 25 [c]	



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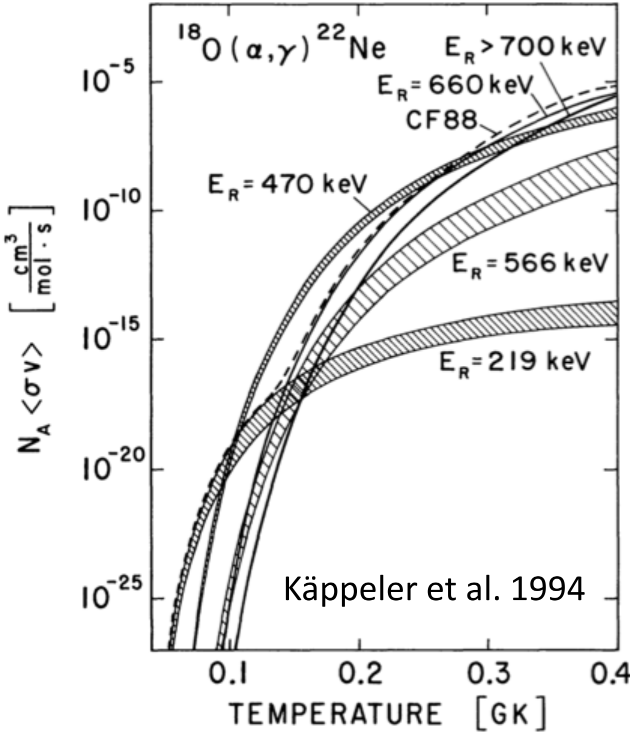
} indirect: TUDA, TACTIC, **TIGRESS**, IRIS, EMMA

} direct: DRAGON



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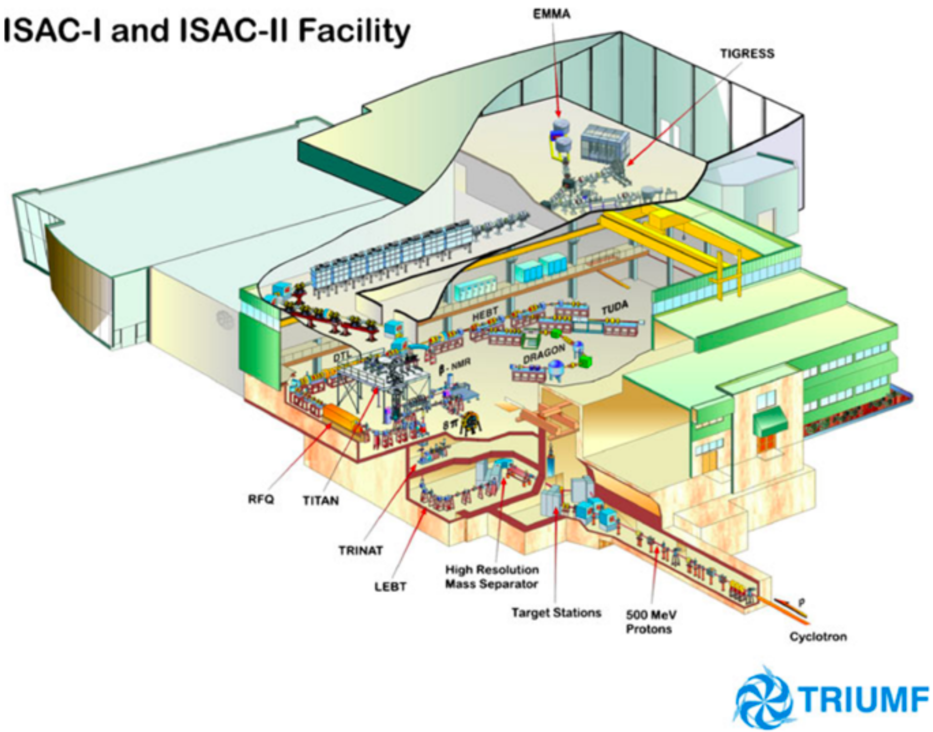
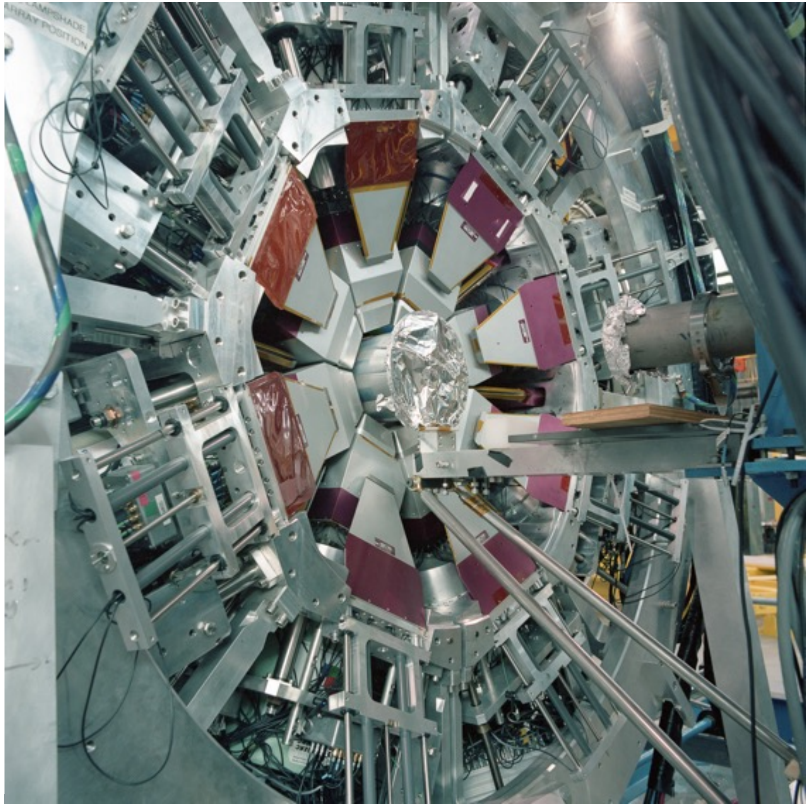
ISAC-II at TRIUMF



TIGRESS



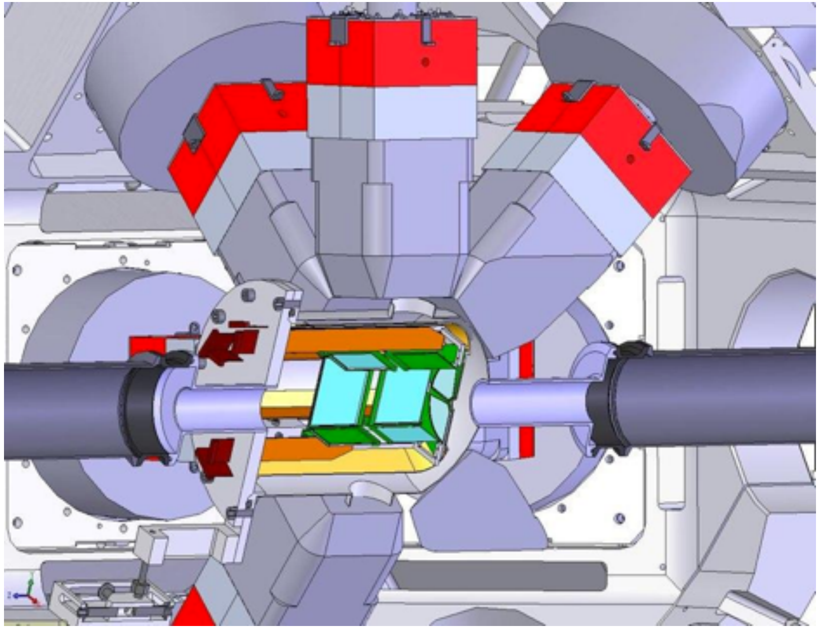
Experimental Setup

- **Experiment S1855 – $^{21}Ne(d,p)^{22}Ne$**
  - Beam energy: 165 MeV (7.89 MeV/u)

- **Thin Target**
  - 120 $\mu g/cm^2$ self-supporting CD_2

- **SHARC**
  - Reduced noise to allow for measurement of high-lying excitation energies
  - Able to gate on excitation energies

- **TIGRESS**
  - Eight 90° detectors and four 135° detectors



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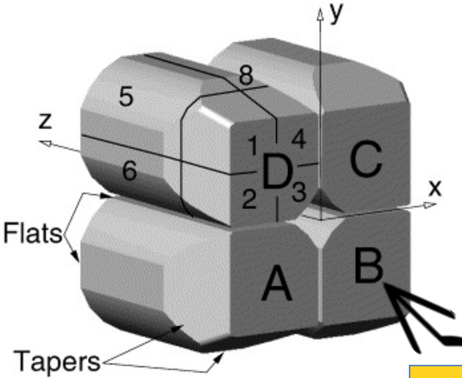
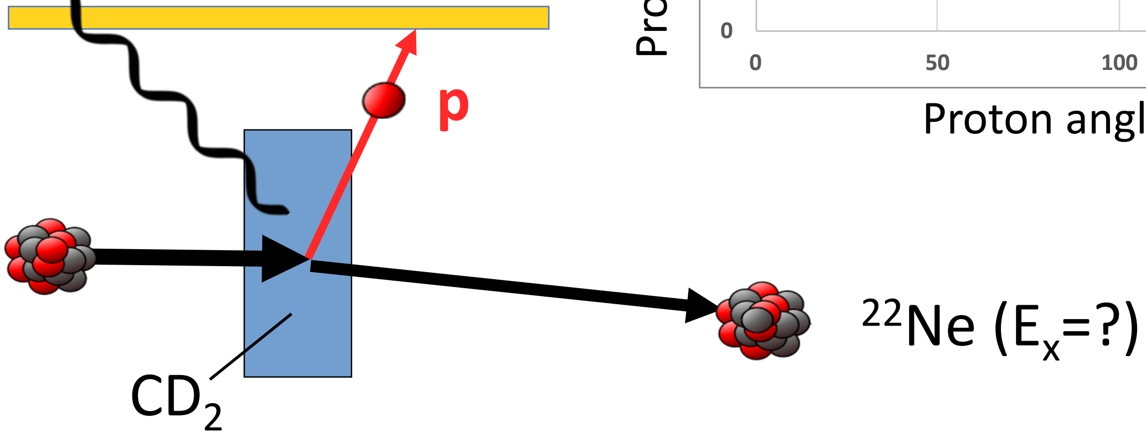
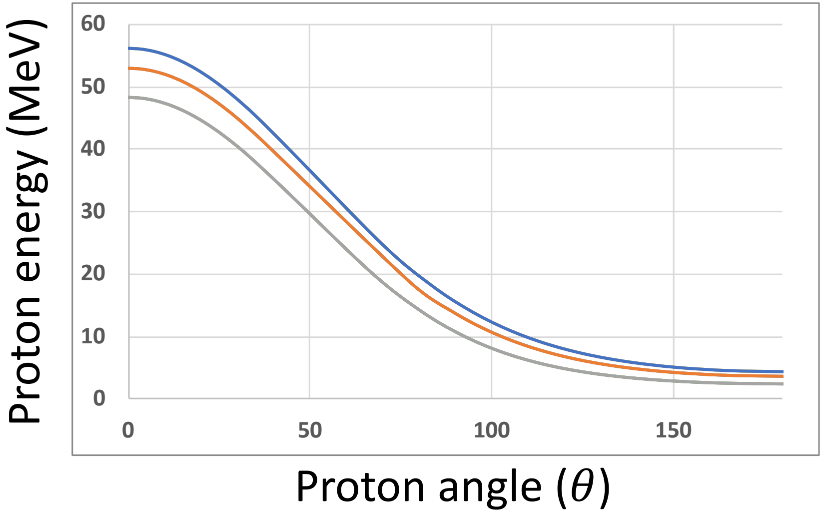
Experiments in Inverse Kinematics







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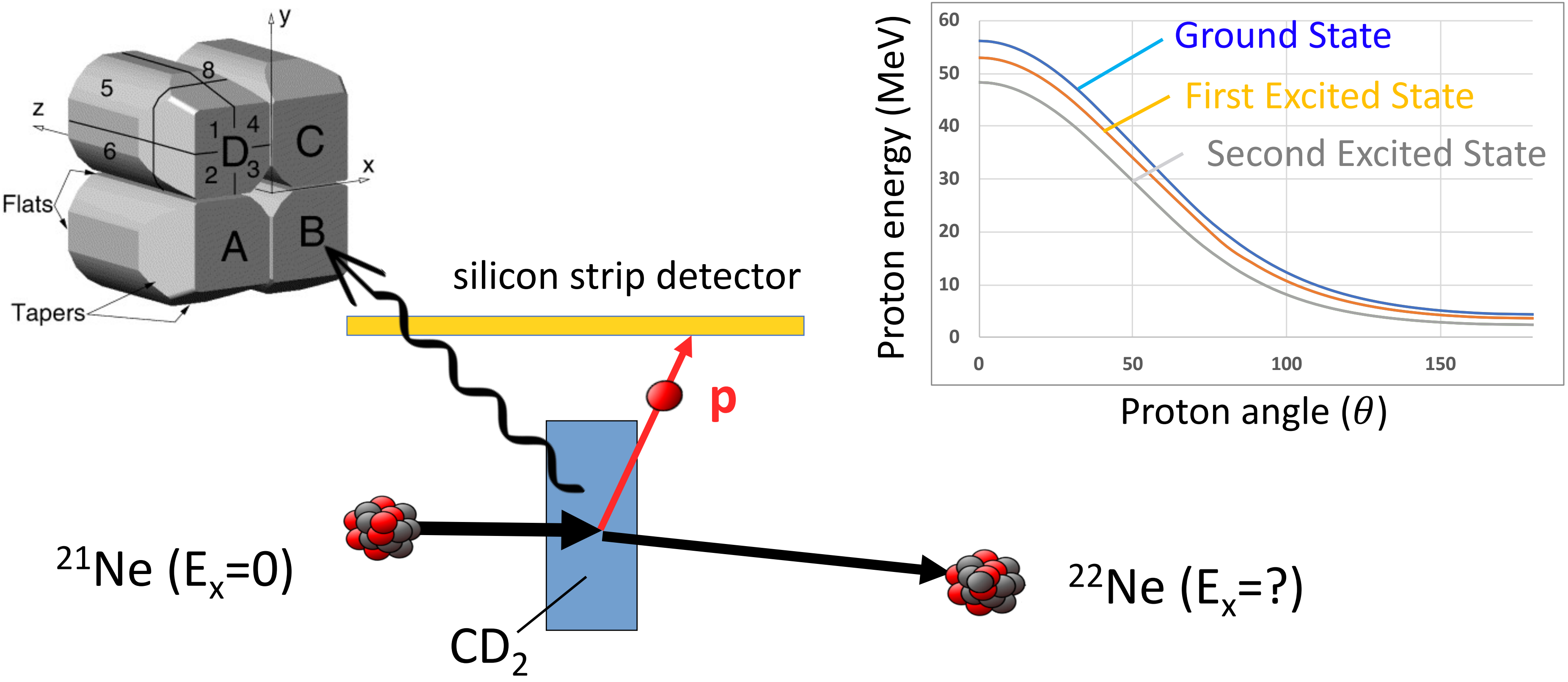

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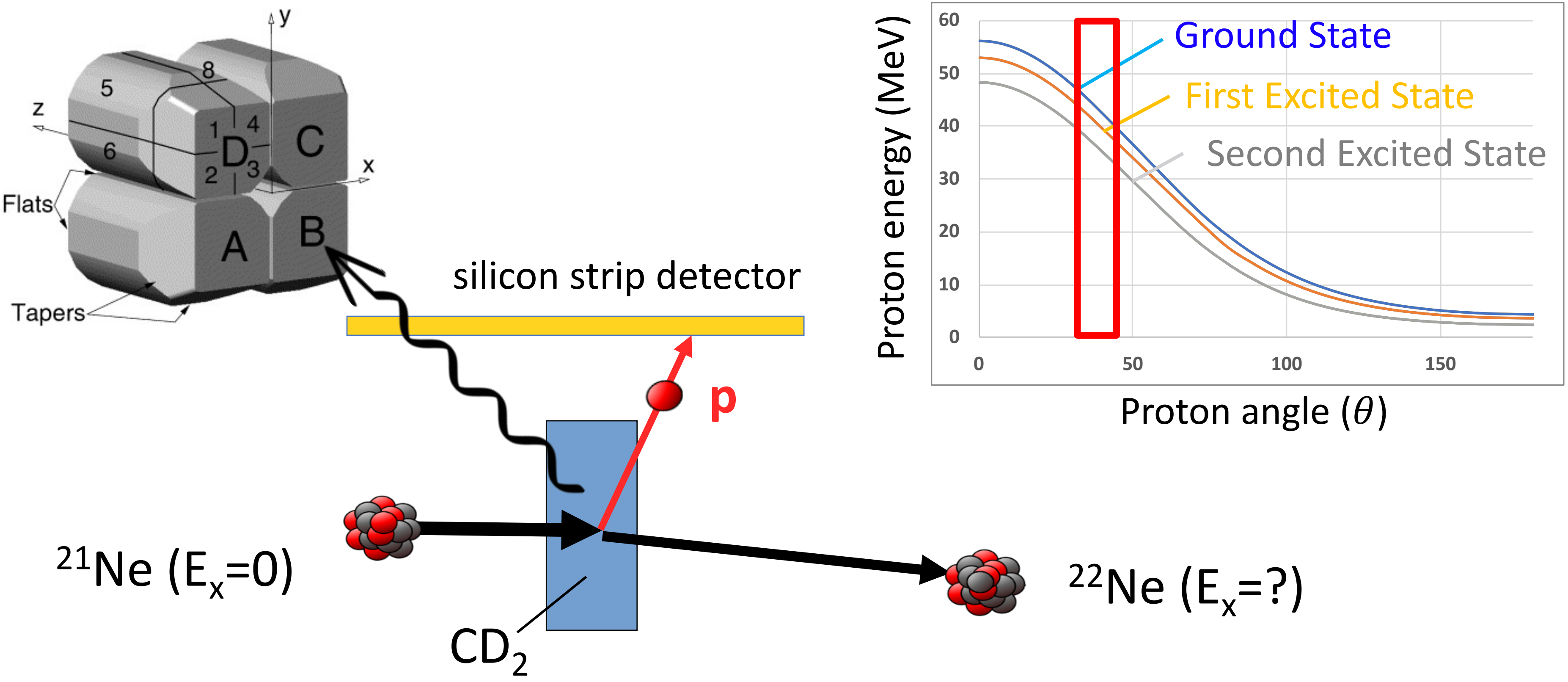

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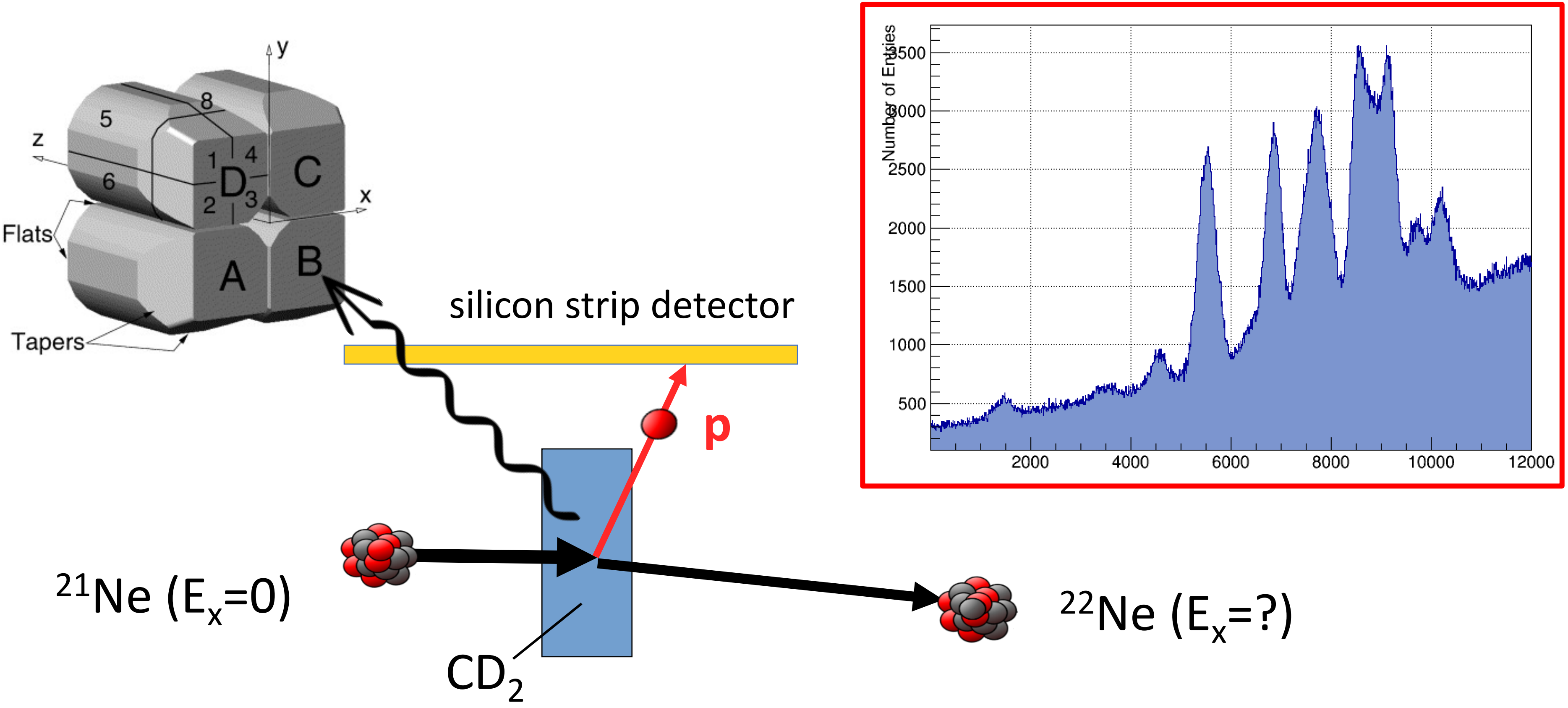

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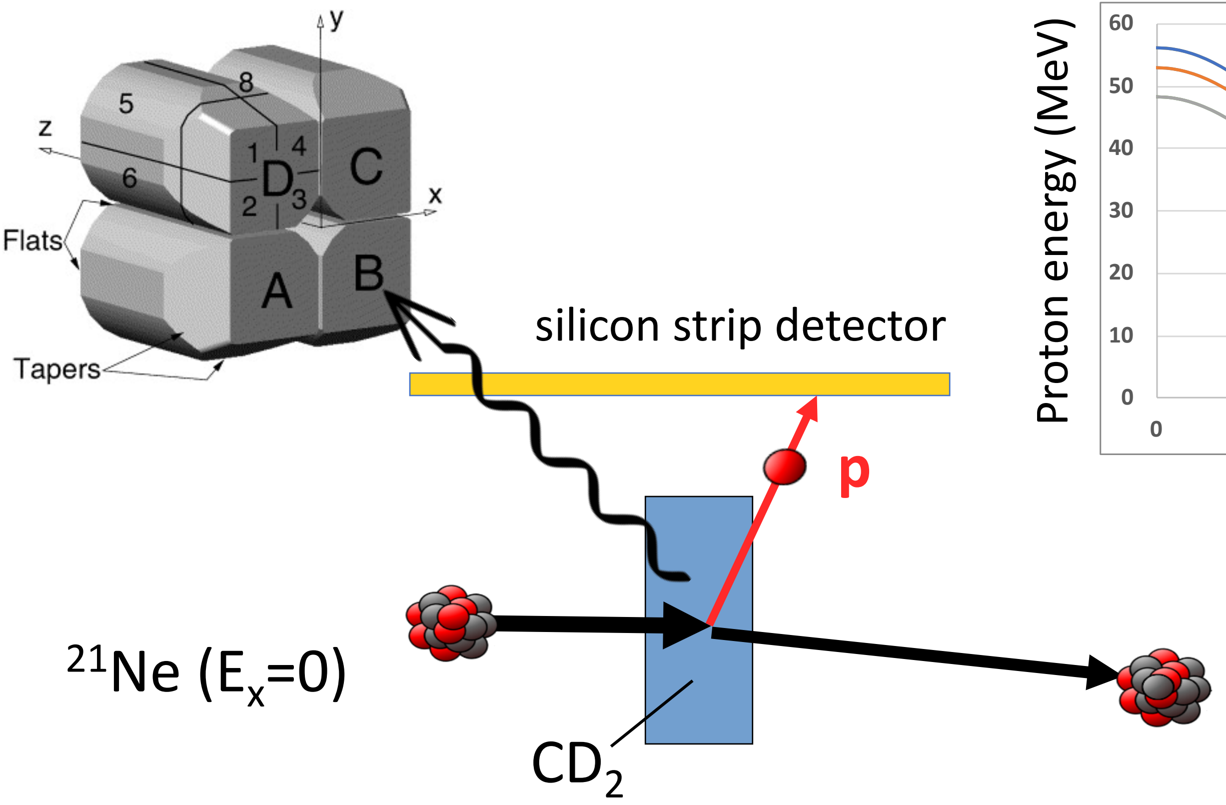

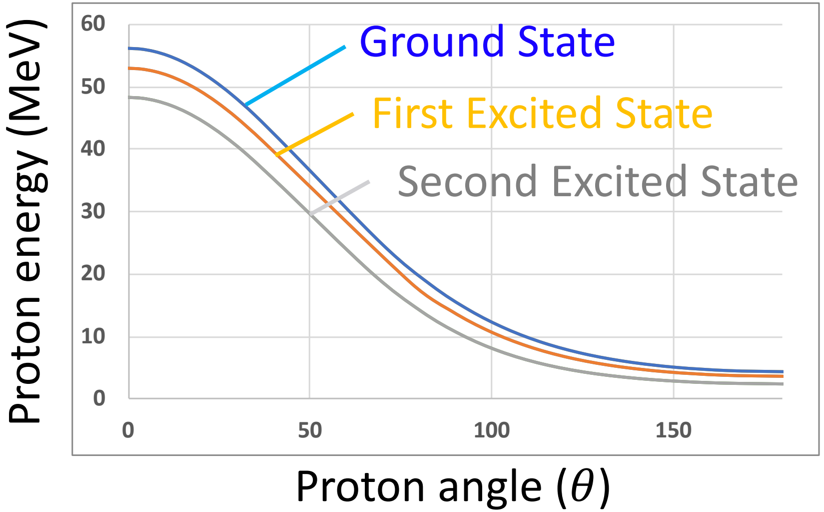

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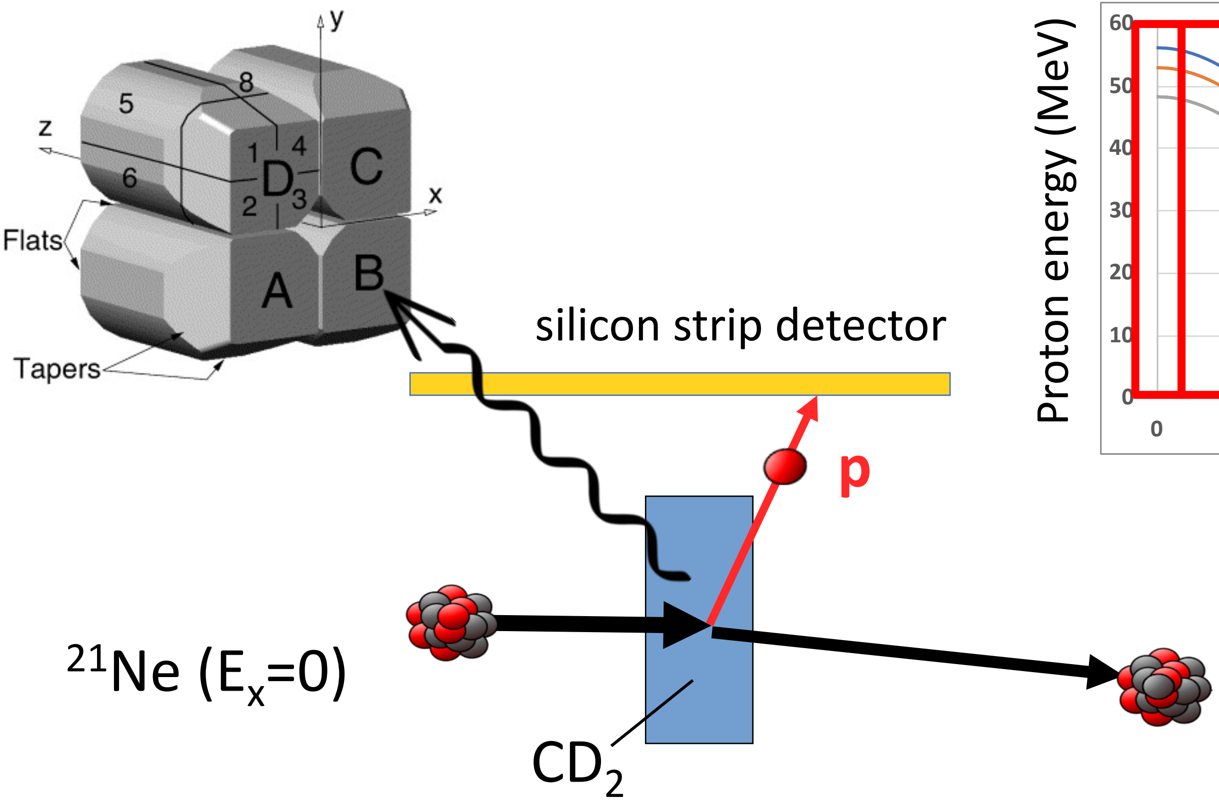

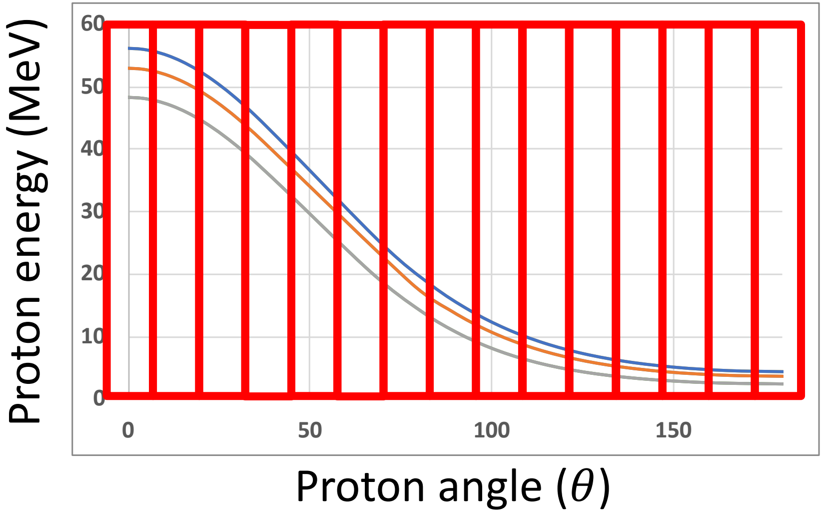

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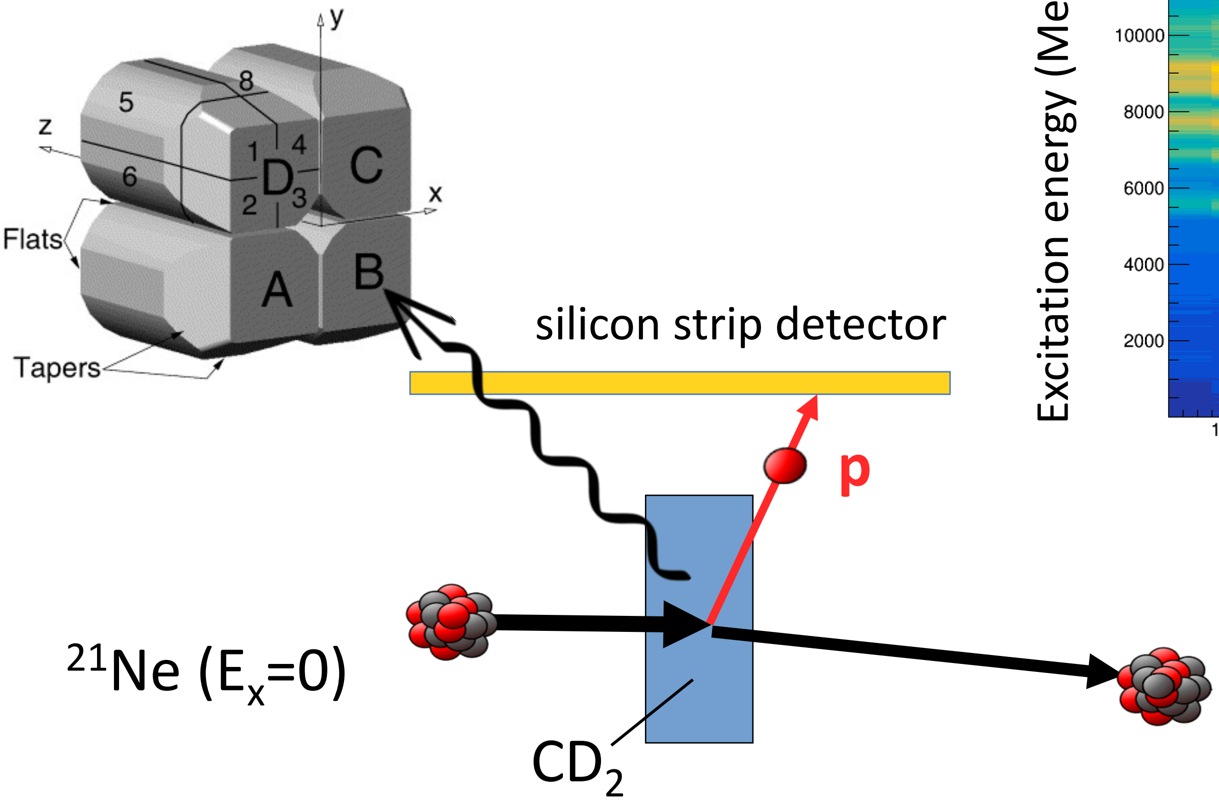

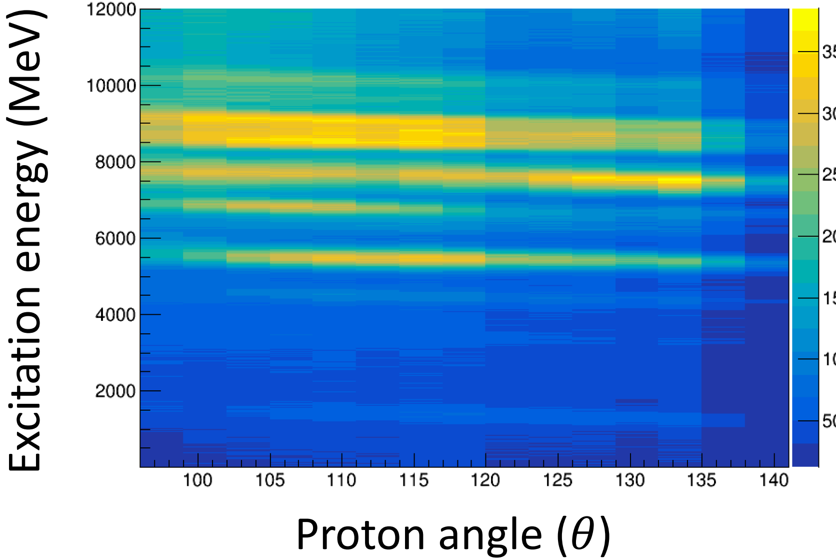

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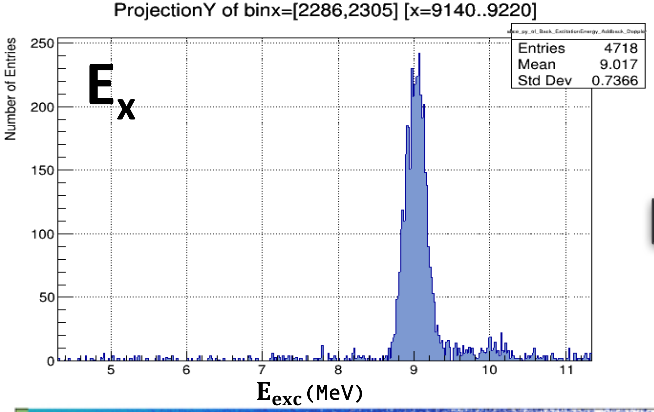

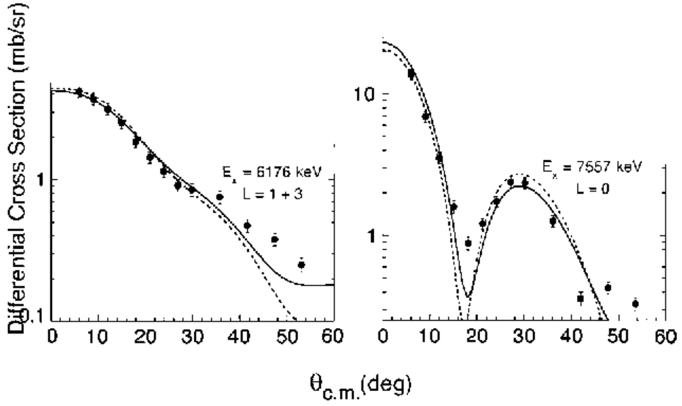

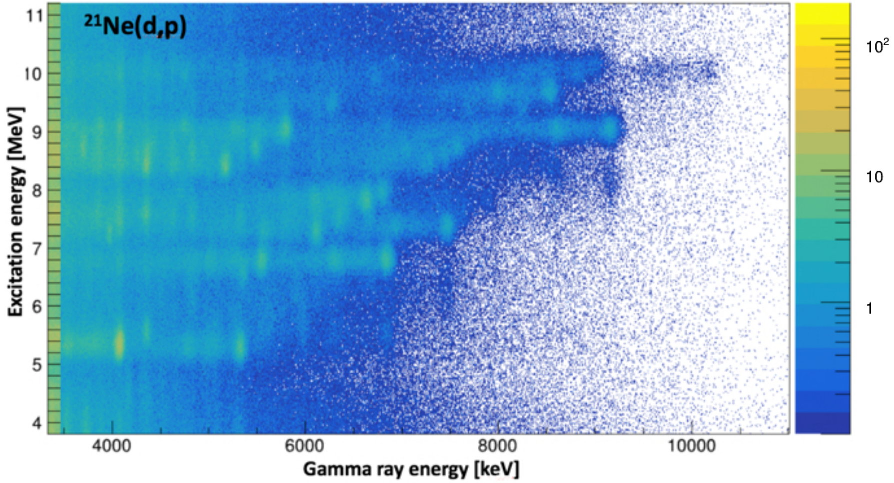

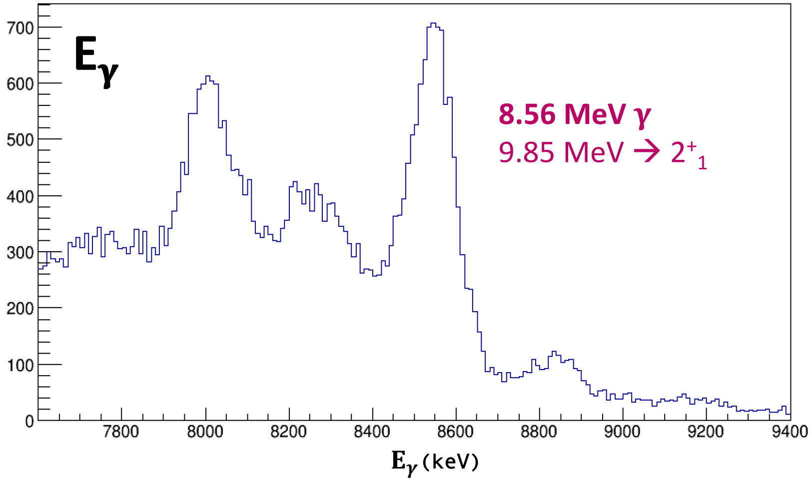

Analysis Status

- 20 states observed so far
- 28 corresponding γ rays have been found
  - **4 new, 3 of which correspond to resonances**
- Angular distributions for key γ rays found, but detector efficiencies require refinement

Ei	Si	Ef	Sf	Eg
1.274	2+	0	0+	1.274
3.357	4+	1.274	2+	2.083
4.456	2+	1.274	2+	3.182
5.329	1+	0	0+	5.329
5.363	2+	1.274	2+	4.089
5.523	(4)+	3.357	4+	2.166
5.641	2+	1.274	2+	4.367
6.345	4+	3.357	4+	2.988
6.345	4+	5.523	(4)+	0.822
6.636	(3,4)+	1.274	2+	5.362
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6.819	2+	1.274	2+	5.545
6.819	2+	4.456	2+	2.363
6.819	2+	5.363	2+	1.456
6.854	(1+)	0	0+	6.854
6.853	(1)+	1.274	2+	5.579
7.341	(4)+	3.357	4+	3.984
7.405	(3)-	1.274	2+	6.131
7.489	1-	0	0+	7.489
7.921	(2)+	1.274	2+	6.647
9.178	1+	0	0+	9.178
9.841	(2+,1-)	5.363	2+	4.478
9.841	(2+,1-)	1.274	2+	8.567
10.137	2+	1.274	2+	8.863
10.208	1-	0	0+	10.208
10.294	2+	1.274	2+	9.02
10.294	2+	4.456	2+	5.838
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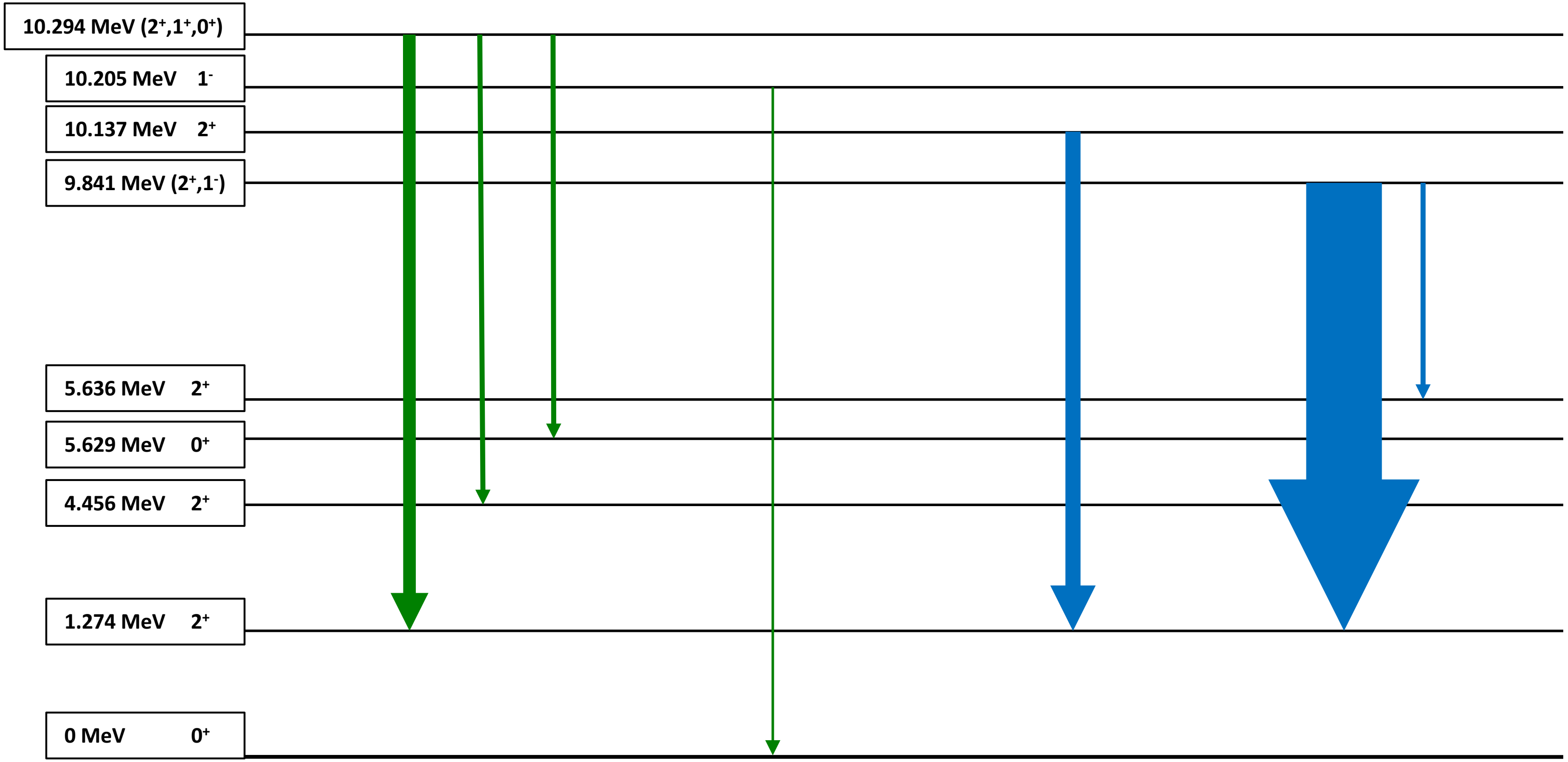
Spin Investigation of 9.85 MeV Resonance



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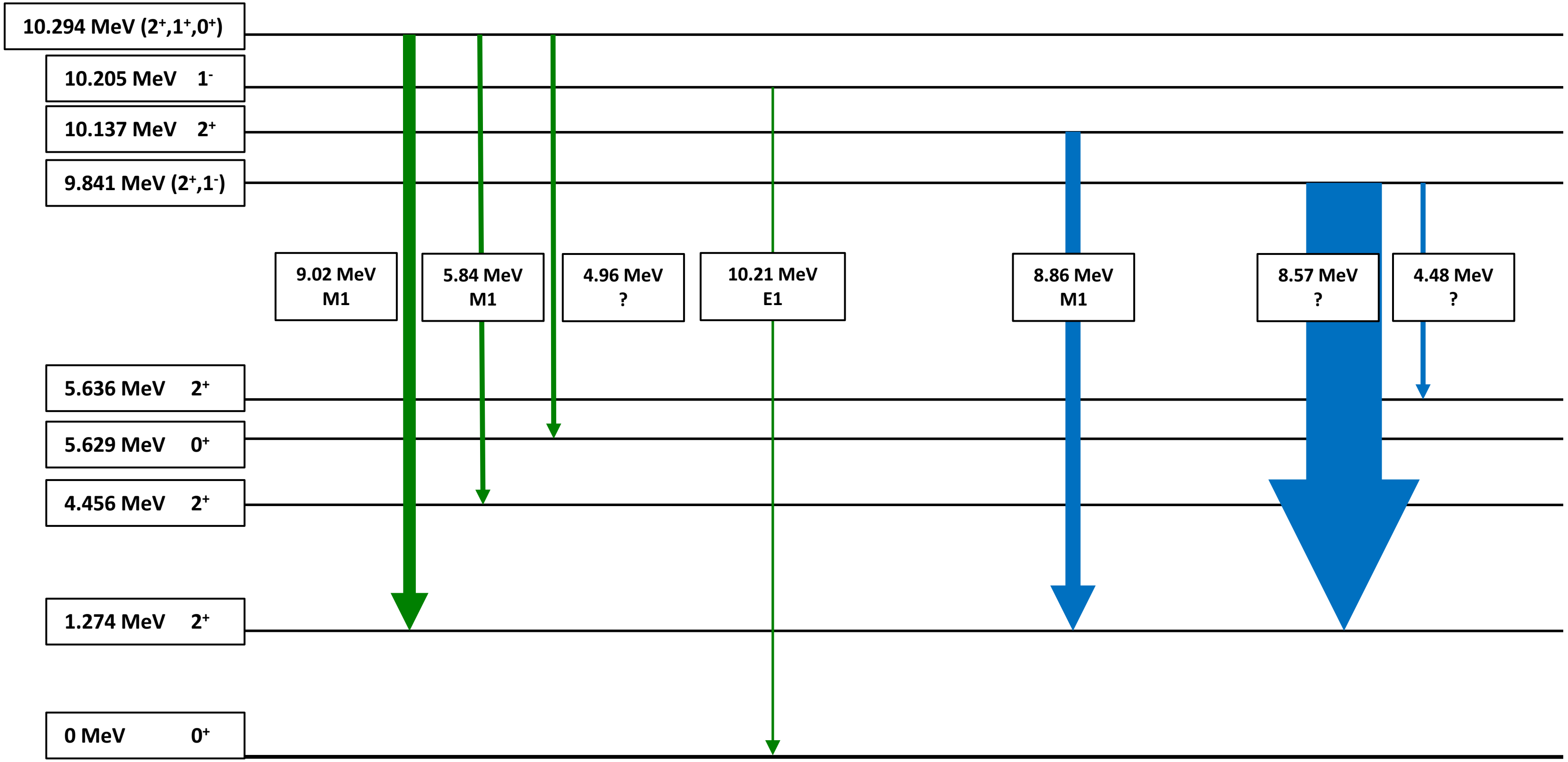
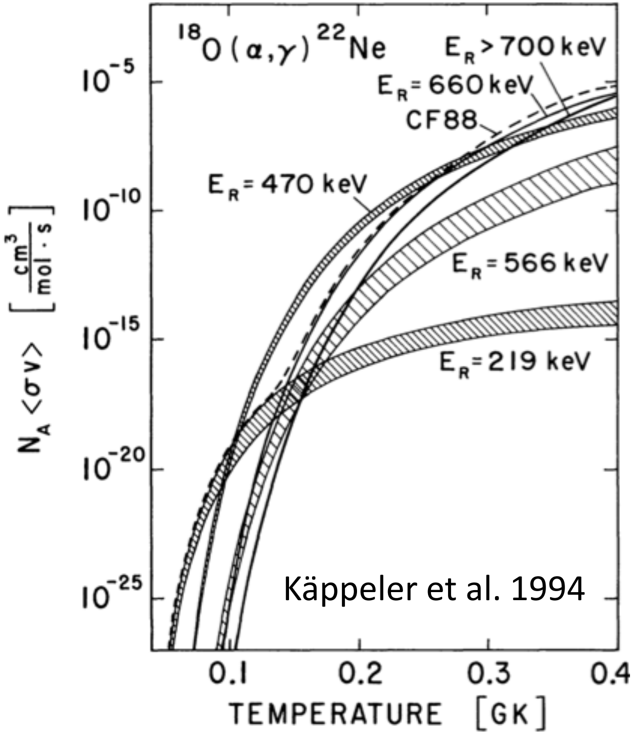


Spin Investigation of 9.85 MeV Resonance

- 9.85 MeV resonance decays to 2_1^+ and 2_3^+
  - Neutron transfer preferentially populates low J, positive parity states
  - Of states determined so far, eight are 2^+, compared to two 1^-
  - 2^+ decay primarily via M1 to 2^+
  - 1^- decay primarily via E1 to 0^+

Propose 9.85 MeV as 2^+, but currently investigating further



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Next Steps

- Determining origin of unclassified states with $\gamma - \gamma$ coincidence
- Investigate particle angular distributions for spin confirmation on 9.85 MeV and several other unconfirmed spin levels via DWBA simulations
- Refine segment efficiencies to for gamma angular distributions

Acknowledgements

- **University of Guelph** –D. Mücher, L. Atar, V. Bildstein, E. Kasanda, T. Rockman, C. Svensson
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- **NSCL** – A. Spyrou
- **Surrey** – W. N. Catford, P. Siuryte
- **University of Toronto** – T. Drake

Thank you for listening!

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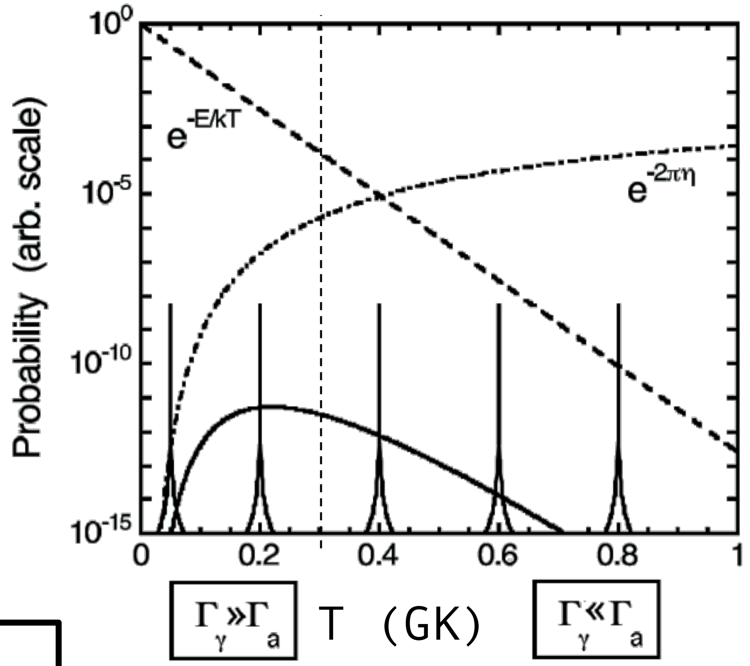
Breit-Wigner Expression

$$\langle\sigma v\rangle = \left(\frac{2\pi}{\mu k_B T}\right)^{\frac{3}{2}} \hbar^2 \sum_i \omega\gamma_i e^{\frac{-E_i}{kT}}$$

$$\omega\gamma_i = \frac{2J_i + 1}{(2J_p + 1)(2J_x + 1)} \frac{\Gamma_\alpha \Gamma_\gamma}{\Gamma_\alpha + \Gamma_\gamma}$$

$$= g(1 - B_\alpha)B_\alpha \frac{\hbar}{\tau}$$



$\langle\sigma v\rangle$ - reaction rate
E_i - resonance energy
$J_{i/p/x}$ - spins of resonance state/projectile/target
$\Gamma_{\alpha/\gamma}$ - Partial width of α/γ decay
τ - lifetime

Iliadis 2007
Nuclear Physics of Stars

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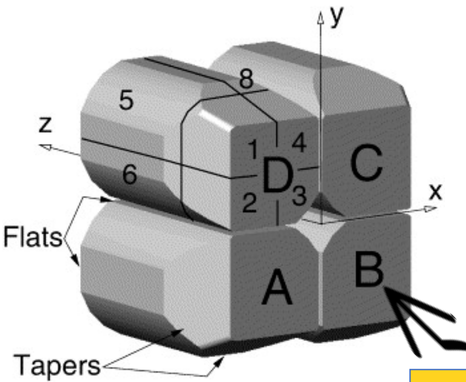
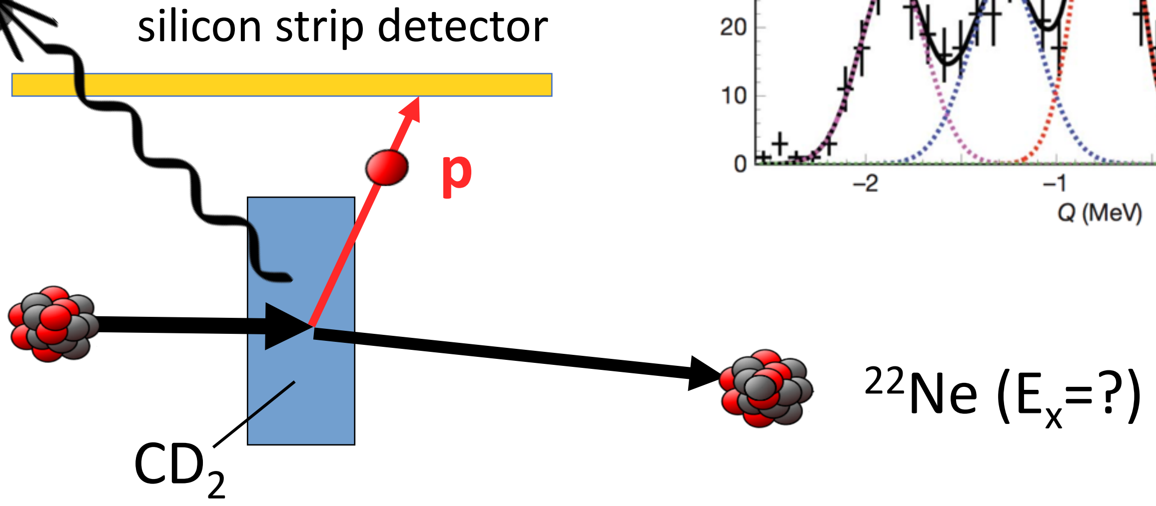
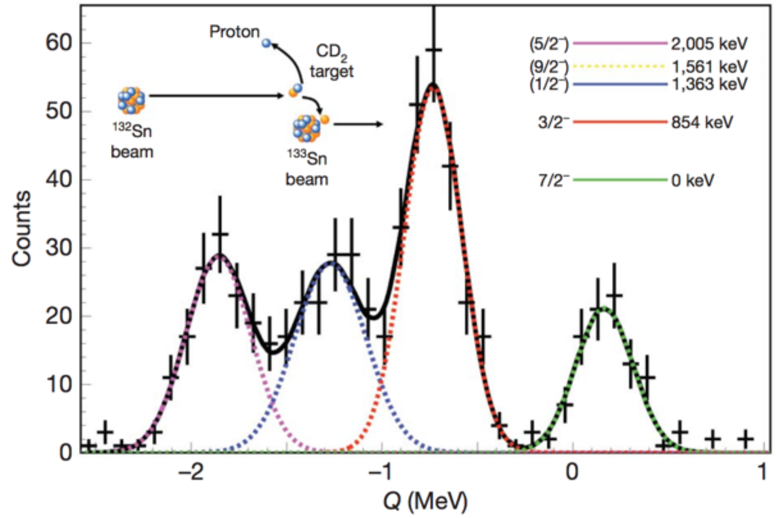
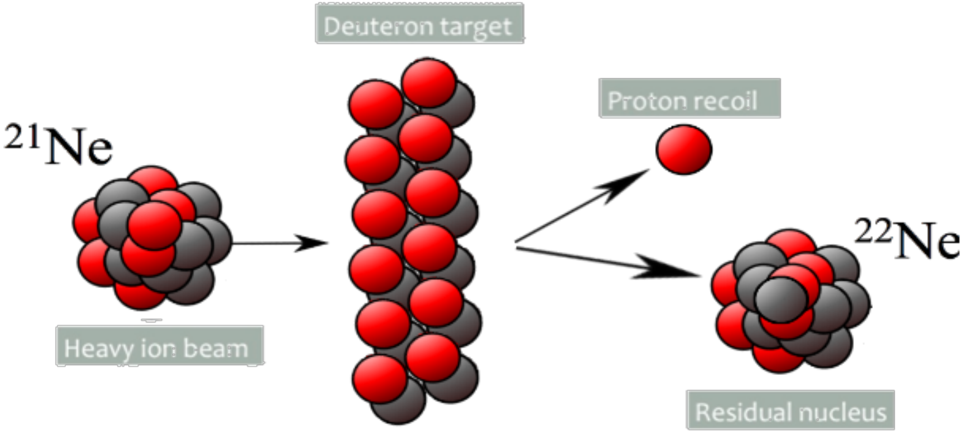
Experiments in Inverse Kinematics







Intro: indirect approaches to nucleosynthesis studies



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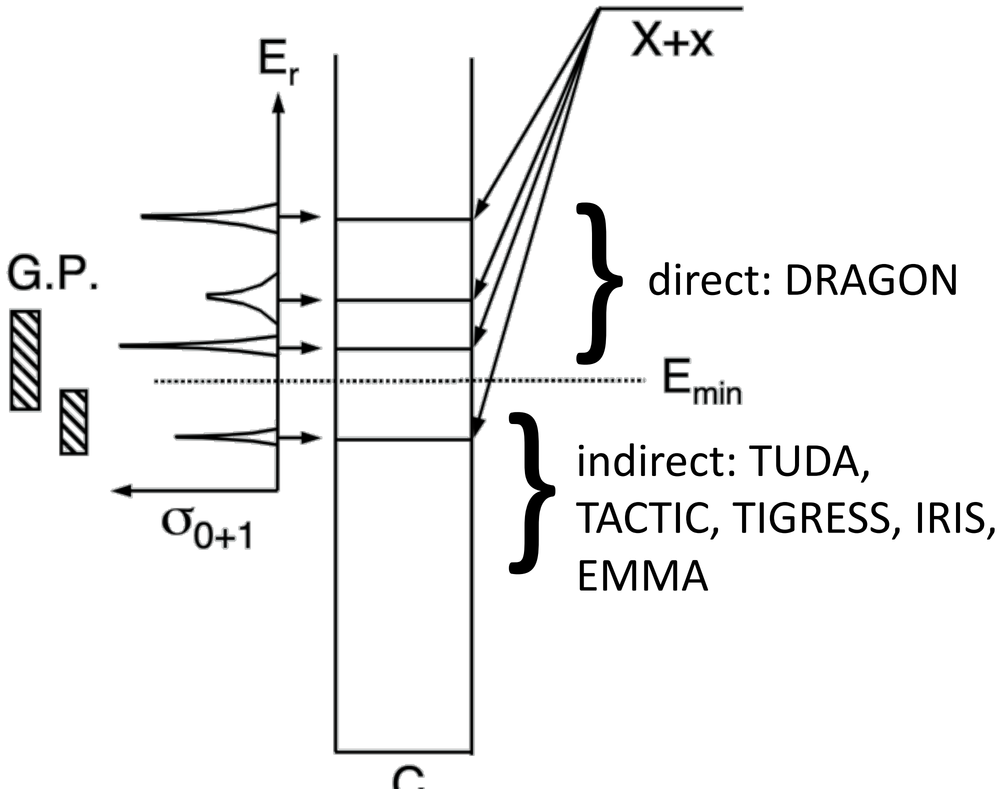
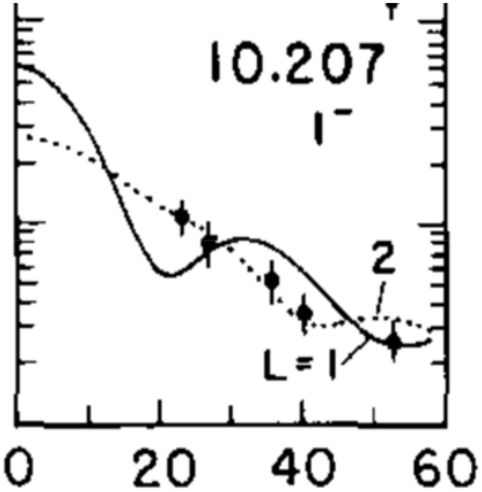
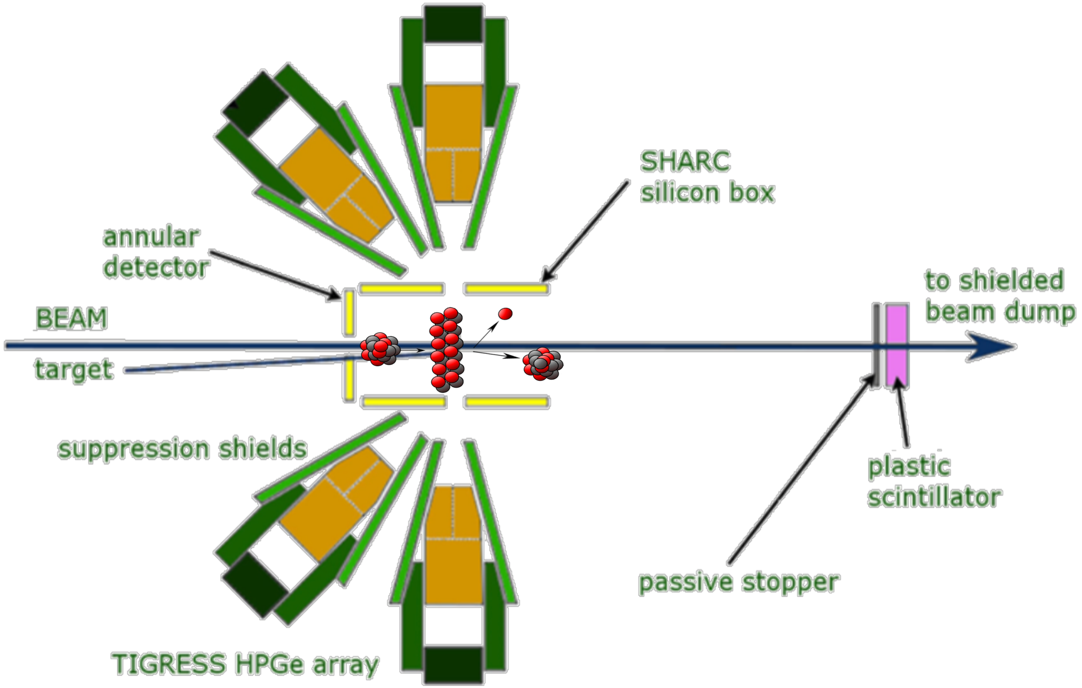


Example of particle angular distribution



theta(p)

Particle-gamma spectroscopy with TIGRESS



^{21}Ne(d,p), 7.9 MeV/u
August 2017