A Study of $^{20,22}Ne(p,\gamma)^{21,23}Na$

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University of Notre Dame

OUTLINE

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  - Hydrogen Burning
  - NeNa Cycle
  - Astrophysical Importance
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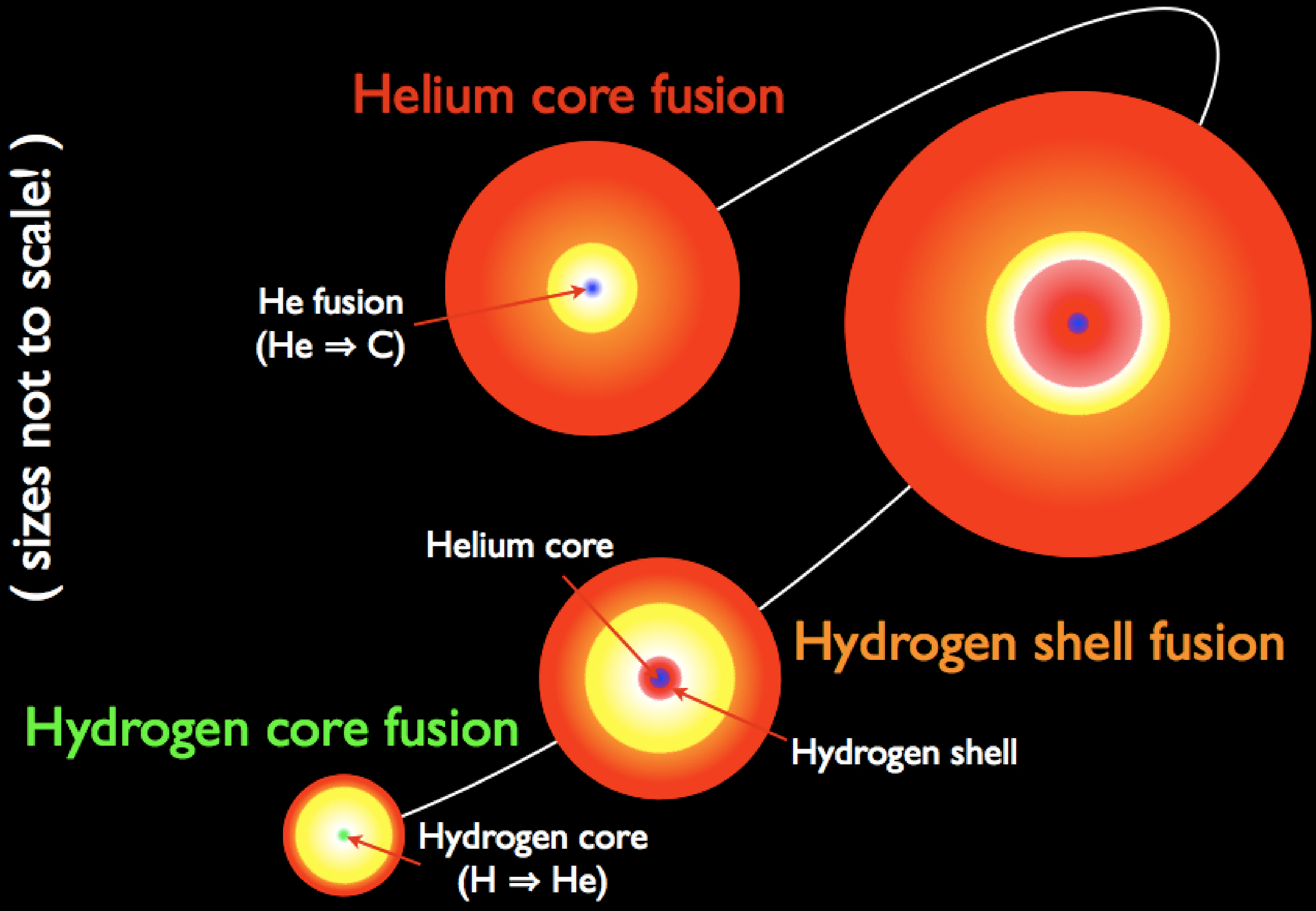
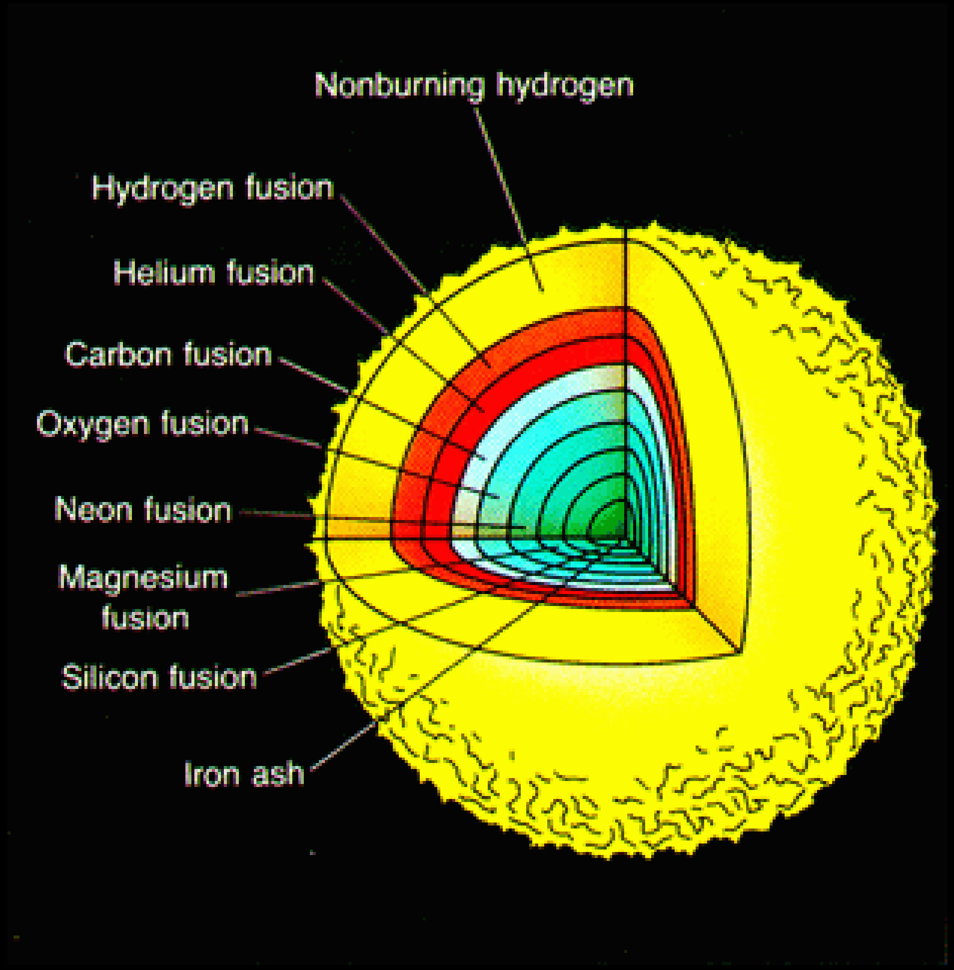
  - $^{22}Ne(p,\gamma)^{23}Na$ Results
  - $^{20}Ne(p,\gamma)^{21}Na$ Results
- Cross-Section Measurements
  - 5U-4 St. Ana Accelerator
  - Gas Target Set-up

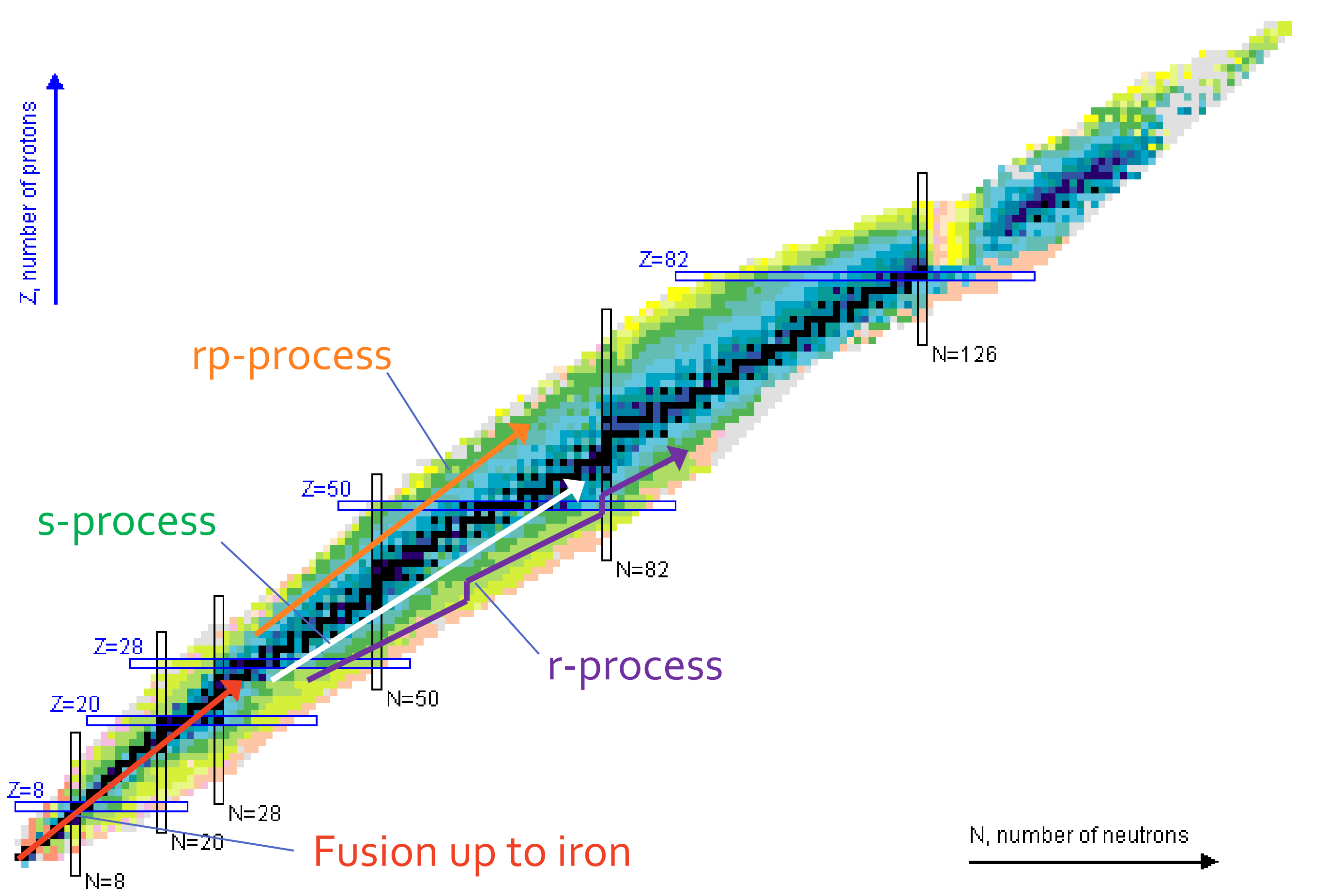
STELLAR BURNING



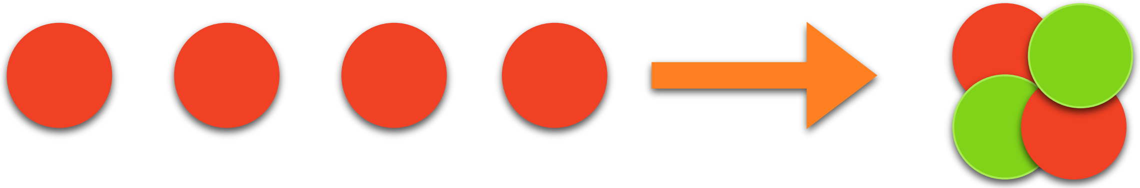


Thomas Kallinger, University of British Columbia and University of Vienna

THERMONUCLEAR REACTIONS generate energy through various processes and synthesize the elements we see in the universe today.



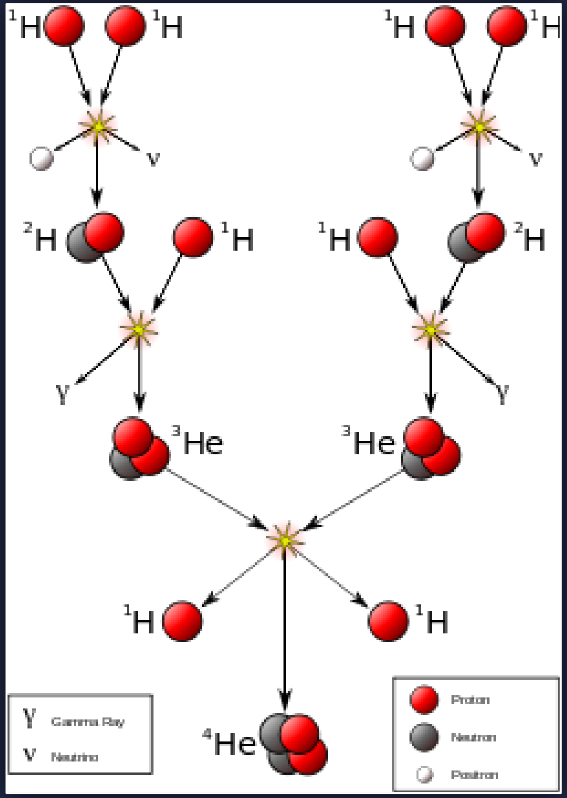
STELLAR HYDROGEN BURNING

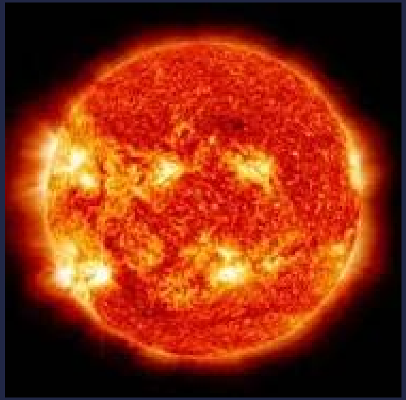


+ E

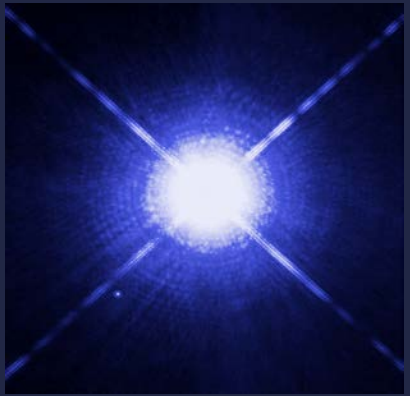
P-P chain

($M \leq 1.5\ M_{sun}$)





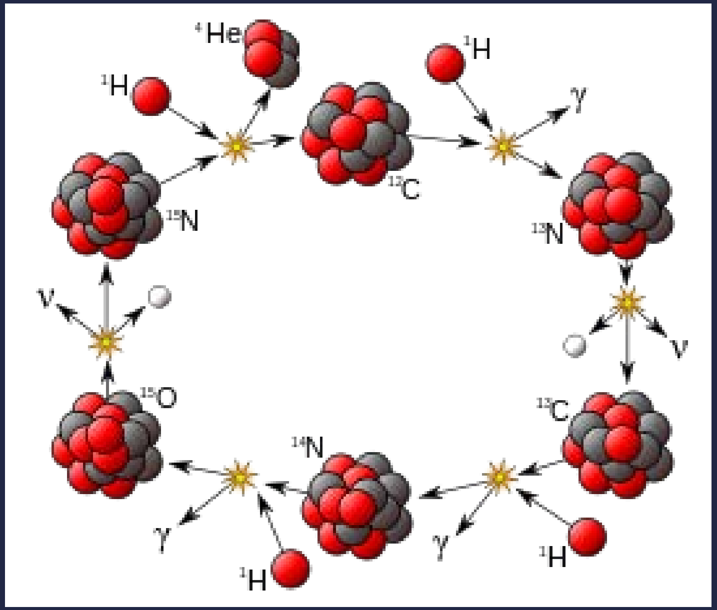
Our Sun



Sirius A

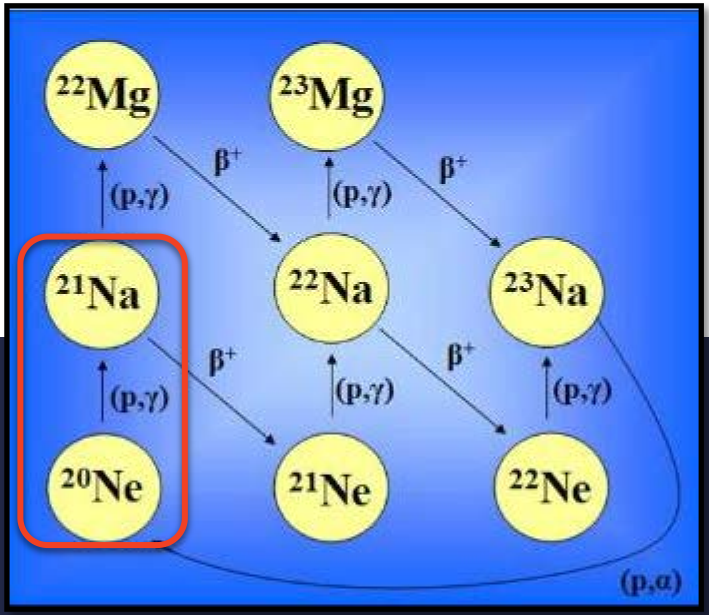
CNO cycle

($M \geq 1.5\ M_{sun}$)



NENA CYCLE

- Breakout from Hot-CNO
- Advances H-burning
- Creates isotopes of Ne, Na, and Mg



REACTION RATES AND HALF-LIVES OF THE NeNa CYCLE

Reaction	Recommended Reaction Rates $N_A \langle \sigma v \rangle_{gs} (cm^3 mol^{-1} s^{-1})$	β^+ Decay	Half-life
$^{20}Ne(p,\gamma)^{21}Na$	5.91E-06	^{21}Na	23 s
$^{21}Na(p,\gamma)^{22}Mg$	1.99E-02	^{22}Mg	3.9 s
$^{21}Ne(p,\gamma)^{22}Na$	1.08E-01	^{22}Na	2.6 y
$^{22}Na(p,\gamma)^{23}Mg$	2.76E-02	^{23}Mg	11 s
$^{22}Ne(p,\gamma)^{23}Na$	3.68E-05		
$^{23}Na(p,\alpha)^{20}Ne$	1.47E-02		

SOURCE: Reaction rates taken from Illiadis (2001) [11] and Beta decay half-lives taken from the Chart of the Nuclides, Temp = 2 x 10^8 K.

Stech (thesis), 2004

PREVIOUS MEASUREMENTS

HYDROGEN BURNING OF ^{20}Ne AND ^{22}Ne IN STARS†

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and

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and

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California State University, Los Angeles, California

and

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Received 11 December 1974

Absolute resonance strengths in the ^{20,21,22}Ne$(p,\gamma)^{21,22,23}$Na and ^{21}Ne$(p,p_1\gamma)^{21}$Ne reactions

J. Keinonen, M. Riihonen, and A. Anttila

Department of Physics, University of Helsinki, Helsinki, Finland

(Received 1 June 1976)

The ^{21}Ne$(p,\gamma)^{22}$Na and ^{21}Ne$(p,p_1\gamma)^{21}$Ne reactions have been studied in the energy range $E_p = 0.5$–2.0 MeV. The absolute resonance strengths $S = 13 \pm 2$ eV and 0.20 ± 0.03 keV have been obtained for the first time in the ^{21}Ne$(p,\gamma)^{22}$Na and ^{21}Ne$(p,p_1\gamma)^{21}$Ne reactions at $E_p = 1205$ and 1090 keV, respectively. The absolute resonance strengths of 25 (p,γ) and 27 $(p,p_1\gamma)$ resonances in ^{22}Na have been determined relative to these values. The strengths $S = 1.6 \pm 0.3$ and 21 ± 2 eV for the (p,γ) resonances at $E_p = 1169$ and 1278 keV in ^{21}Na and ^{23}Na, respectively, have been remeasured. The total widths have been determined for 24 resonances in ^{22}Na using a thin ^{21}Ne target. The γ-ray decay properties of resonances in ^{22}Na and the astrophysical importance of the (p,γ) resonance strengths in ^{21,22,23}Na are discussed.

[NUCLEAR REACTIONS ^{21}Ne(p,γ), $(p,p_1\gamma)$, $E = 0.5-2.0$ MeV, ^{20}Ne(p,γ), $E = 1.2$ MeV, ^{22}Ne(p,γ), $E = 1.3$ MeV; measured $\sigma(E)$; deduced resonance strengths. Enriched targets.]

Source	Strength Value [eV]
Rolfs (1975)	1.125 ± 0.075
Keinonen (1977)	0.80 ± 0.15
Stech, thesis (2004)	1.17 ± 0.06

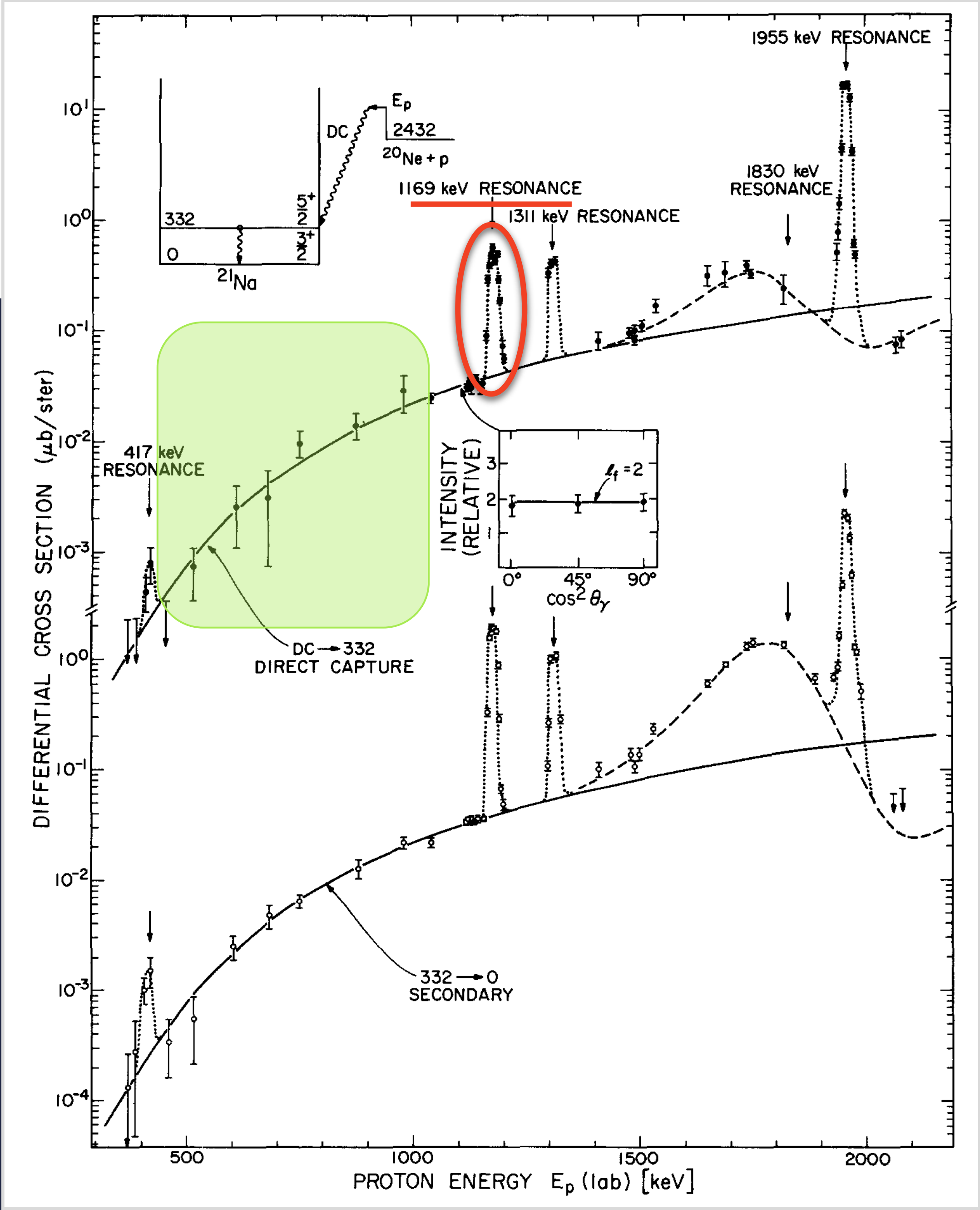
EXPERIMENTAL MOTIVATION

Understand direct-capture cross-section at low energies.

→Measure cross-section relative to the 1169 keV resonance

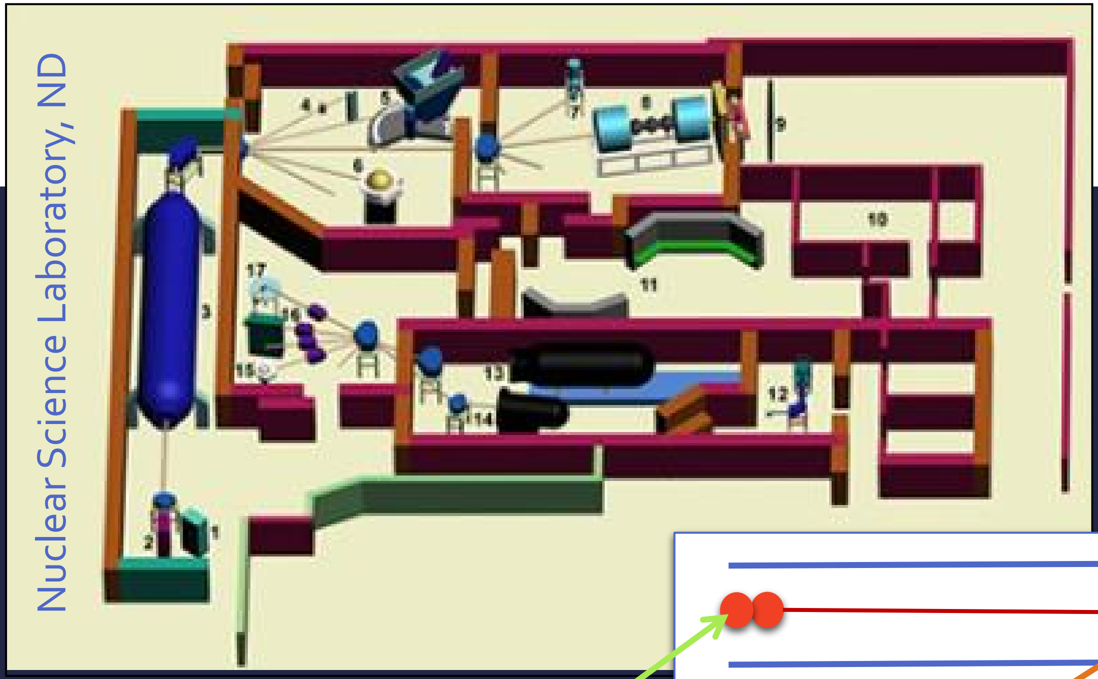
$$\int_0^\infty \sigma_{BW}(E)dE = 2\pi^2 \lambda_R^2 \omega\gamma$$

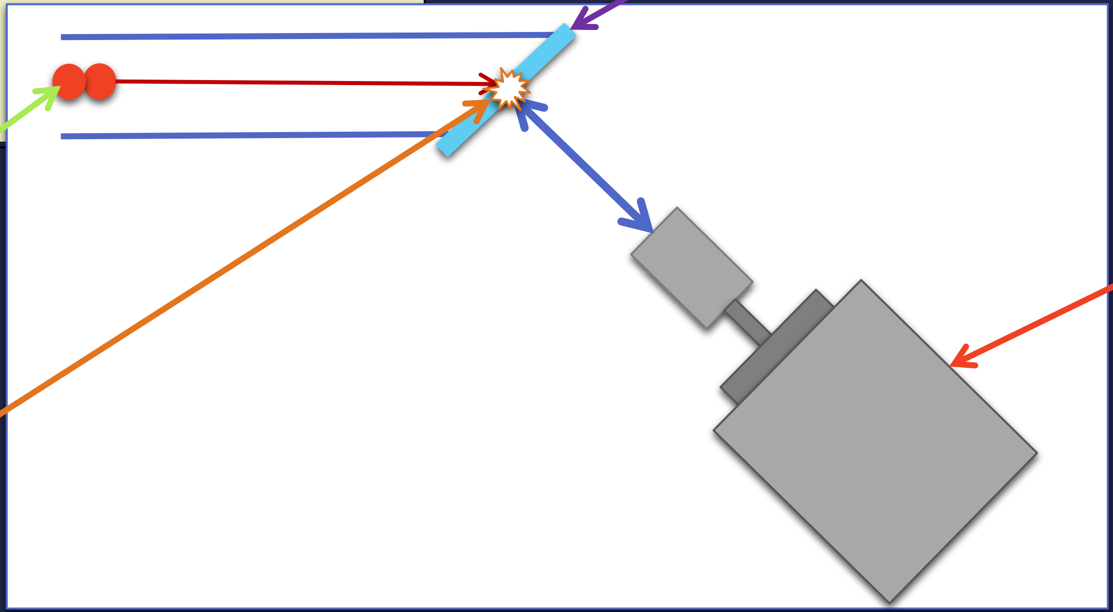
Resonance strength value unknown!



(Rolfs, 1975)

EXPERIMENTAL SETUP





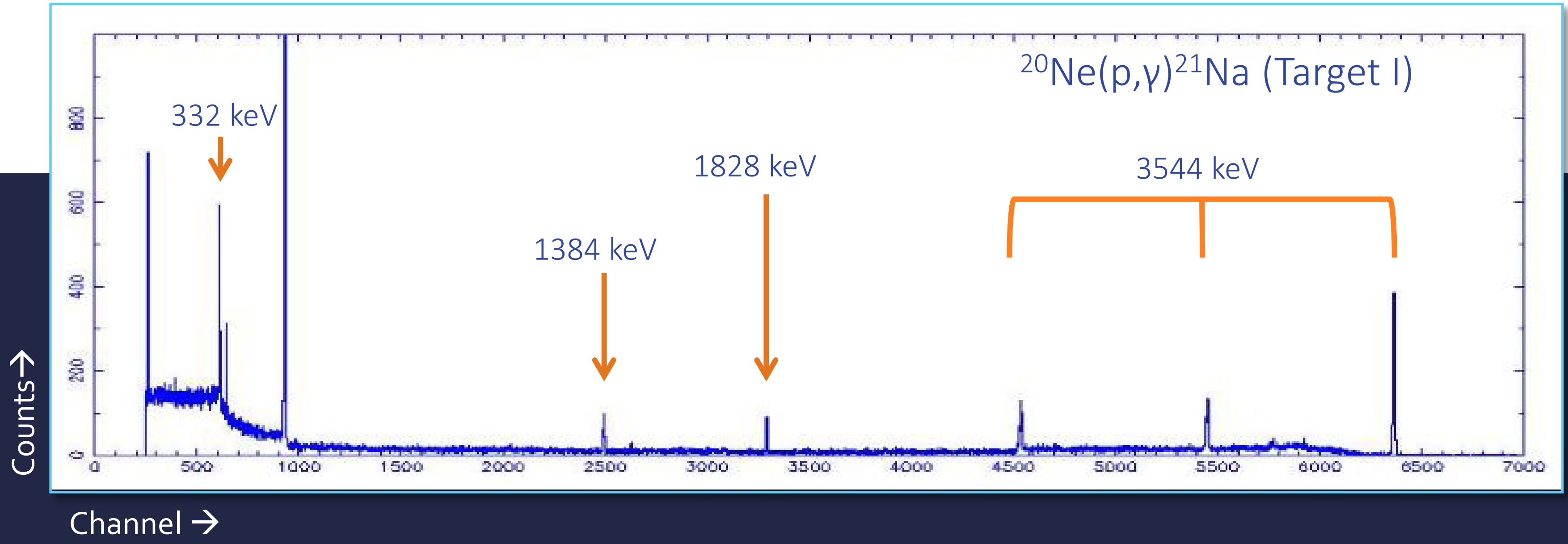
Detector placed at 45° to beam, on variable distance table

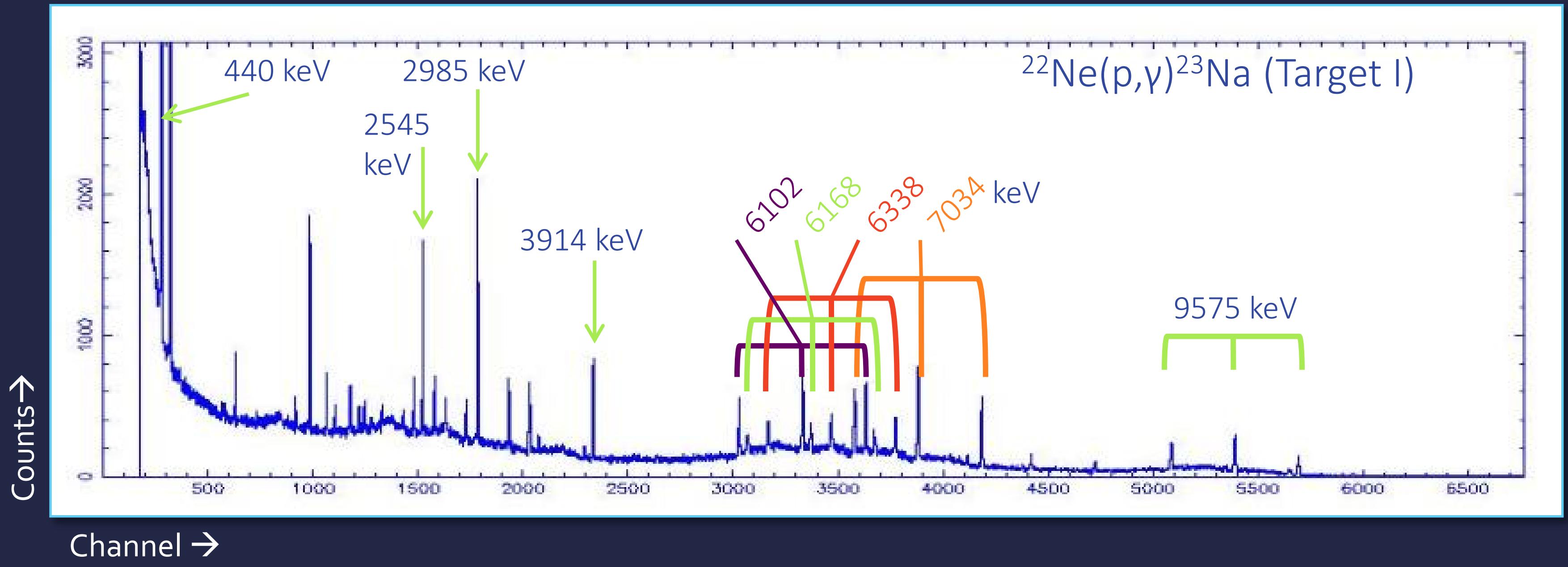
ORTEC Ge Detector

10 μA Proton beam

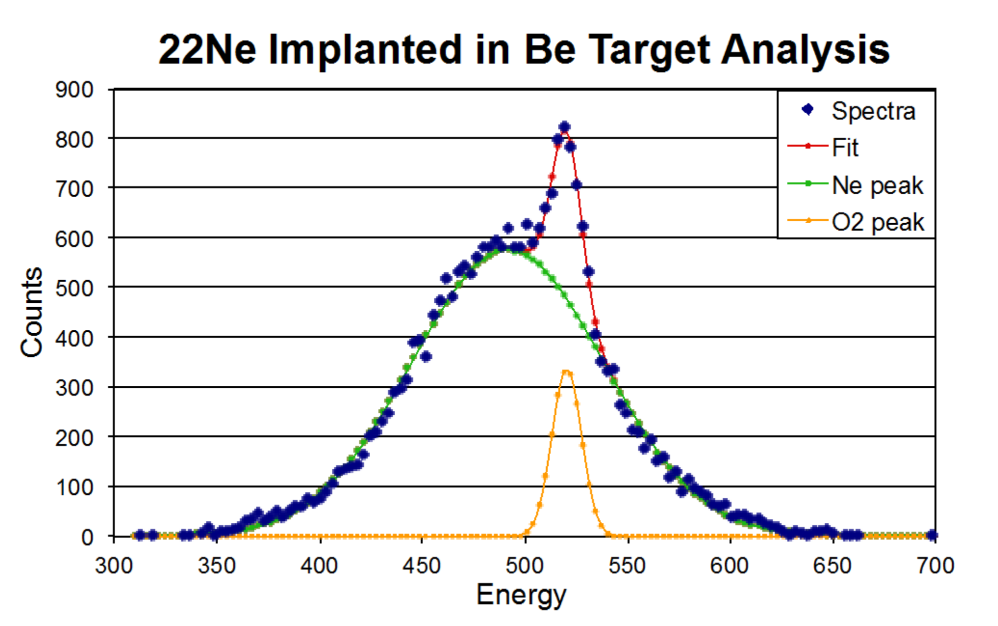
Implanted targets

^{20}Ne AND ^{22}Ne REACTION SPECTRA





IMPLANTED TARGET CHARACTERIZATION



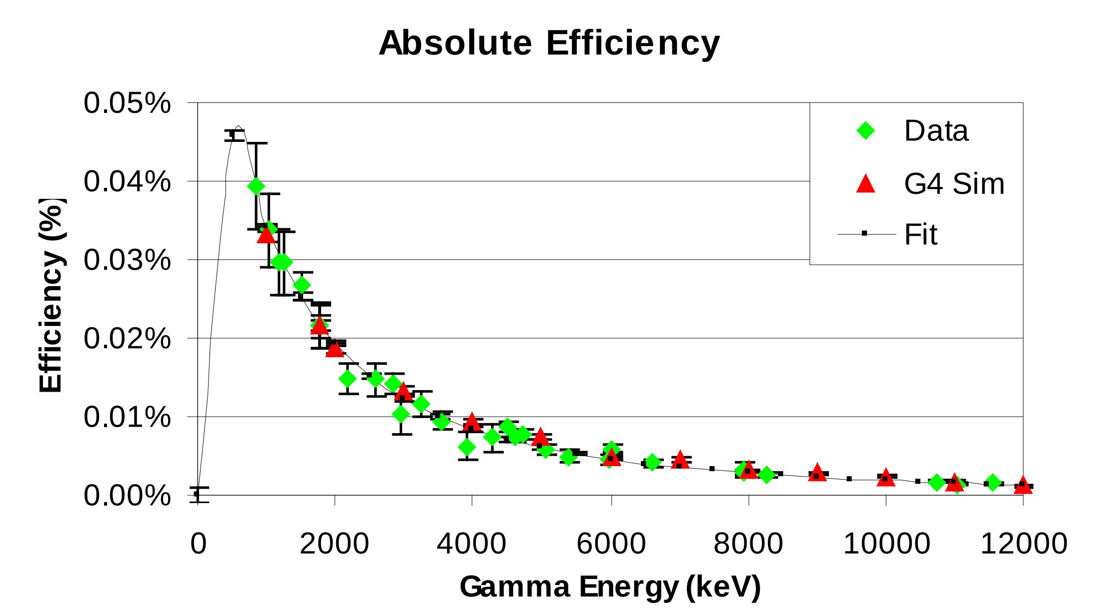
Target	n_{atoms} (at/cm^2)
22Ne/Be	$3.28 \pm 0.16 \times 10^{17}$
20Ne/Ta I	$5.42 \pm 0.29 \times 10^{17}$
22Ne/Ta I	$1.91 \pm 0.04 \times 10^{17}$
Natural Ne	$5.93 \pm 0.24 \times 10^{16}$

$$\omega\gamma = \frac{2}{\lambda_R^2}\frac{1}{n_{atoms}}\int Y\,dE$$

$$Y = \frac{C \times N_{counts}}{N_{Beam}\,\eta(E_\gamma)W(\theta)B(E_\gamma)}$$

GE DETECTOR CHARACTERIZATION

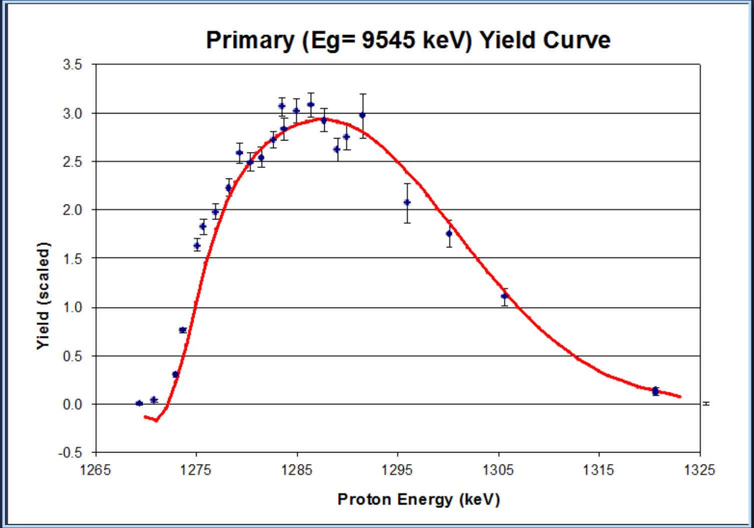
Efficiency sources: ^{137}Cs, ^{56,60}Co, ^{27}Al(p,γ)^{28}Si



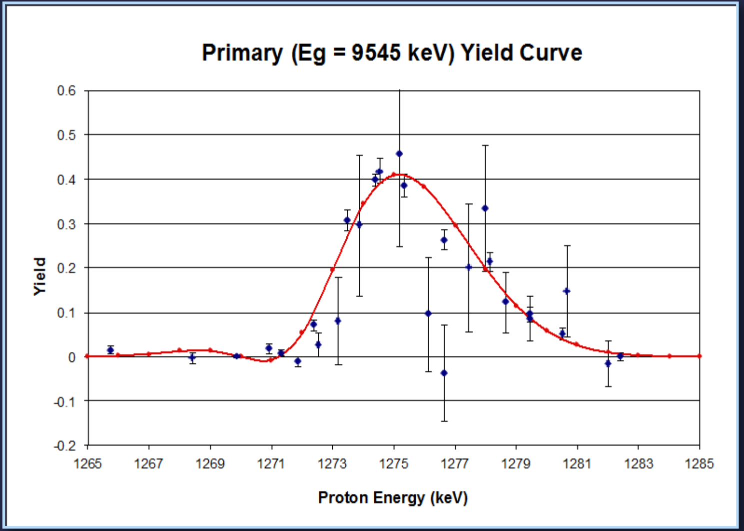
$^{22}Ne(p,\gamma)^{23}Na$ Strength Values

Target	ωγ (eV)
^{22}Ne/Be backing	11.64 ± 0.16
^{22}Ne/Ta backing	11.99 ± 0.22
Natural Abundance	12.14 ± 0.58
Keinonen (1977)	*12.50 ± 0.95*
Smit (1979)	*10.98 ± 1.05*

^{22}Ne/Ta Target



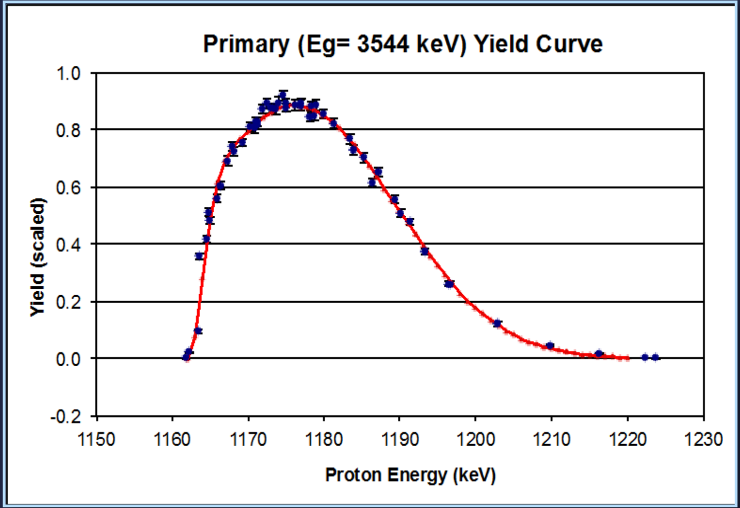
Natural Abundance Target



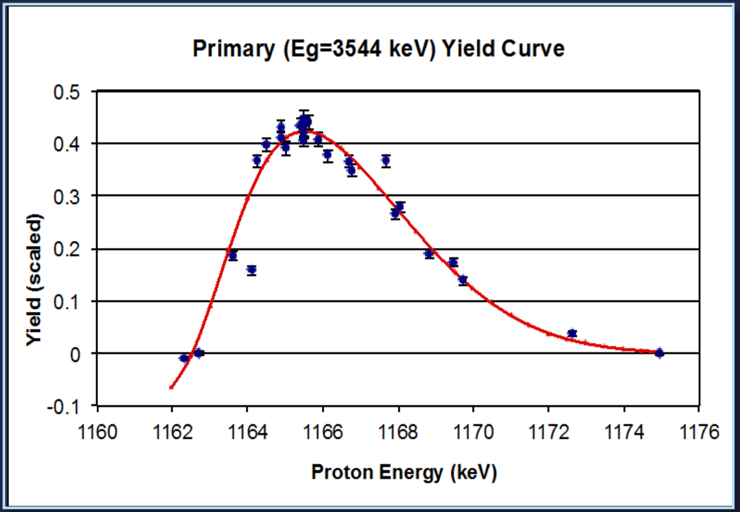
$^{20}Ne(p,\gamma)^{21}Na$ Strength Values

Target	ωγ (eV)
^{20}Ne/Ta backing	1.13 ± 0.02
Natural Abundance	1.26 ± 0.17
Rolfs (1975)	*1.125 ± 0.075*
Keinonen (1977)	*0.80 ± 0.15*
Stech, thesis (2004)	*1.17 ± 0.06*

^{20}Ne/Ta Target

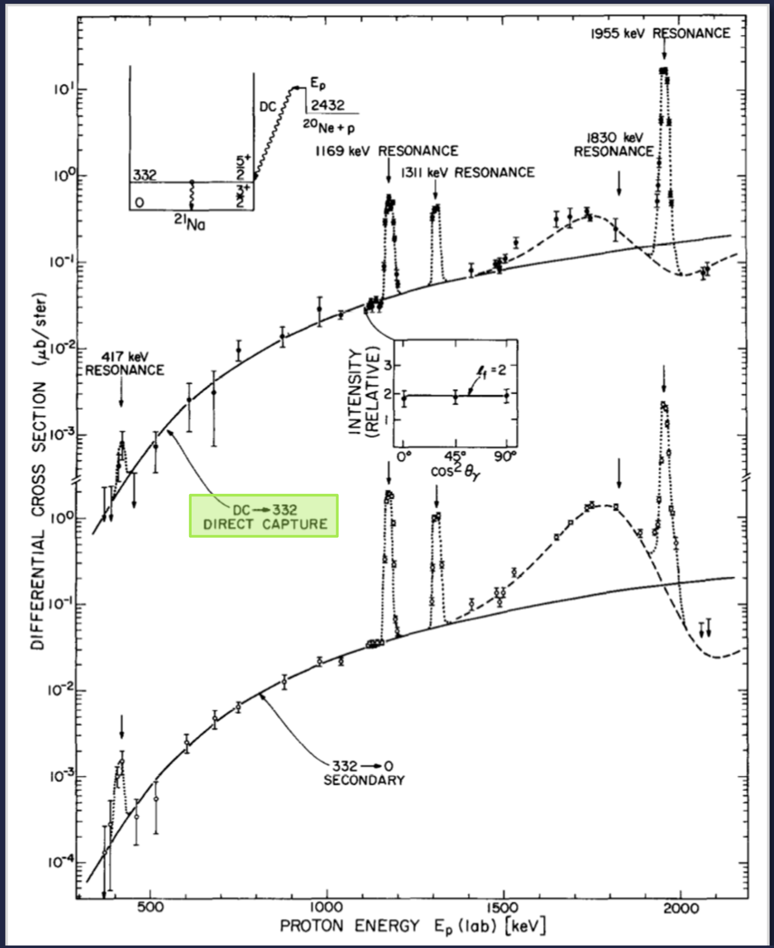


Natural Abundance Target



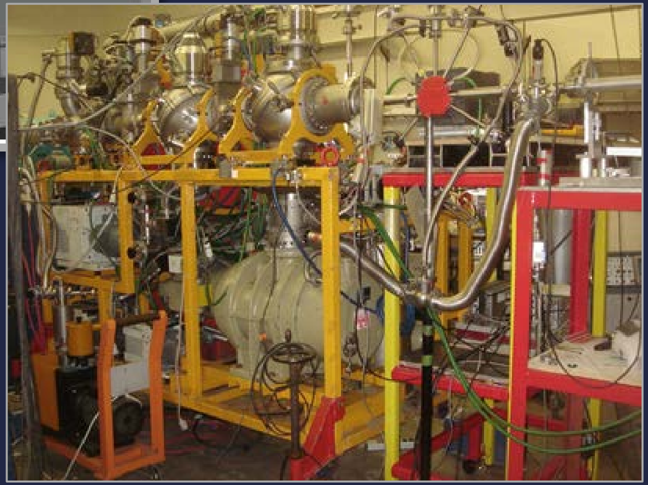
Measuring the Cross-section

This is the second phase of our experimental goal to measure the direct-capture cross-section of $^{20}Ne(p,\gamma)^{21}Na$.



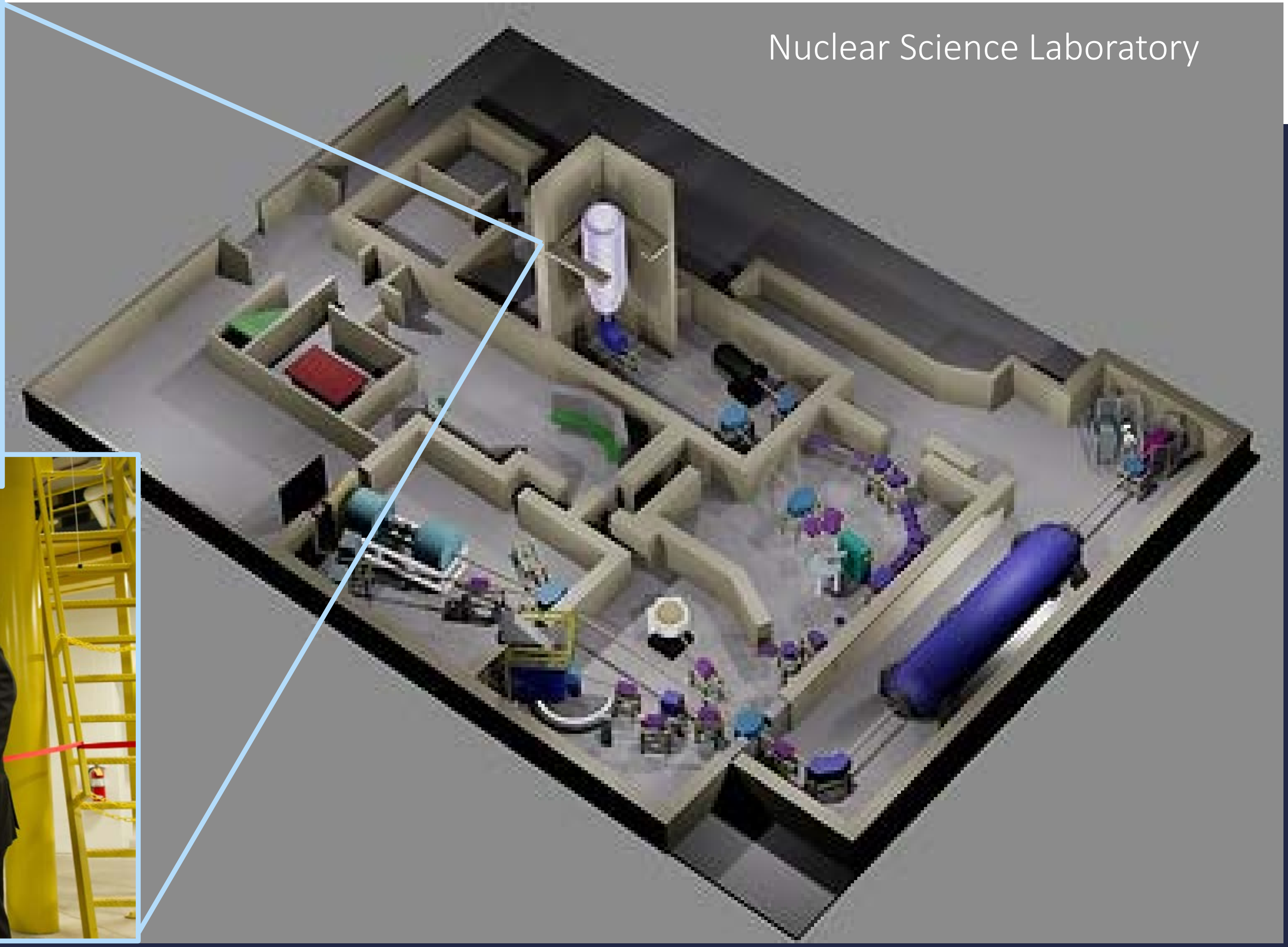
(Rolfs, 1975)

5U-4 St. Ana Accelerator



Rhinoceros Gas Target

NEW 5U-4 ACCELERATOR AT ND



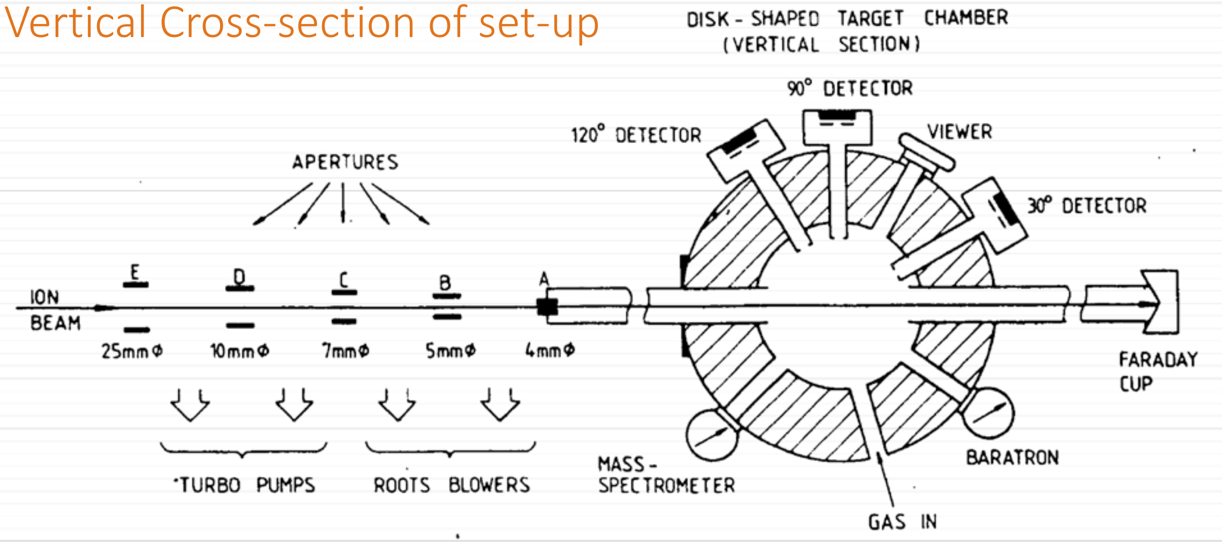
RHINOCEROS GAS TARGET

Use Rhino's window-less gas target set-up with an "Octopus" chamber.

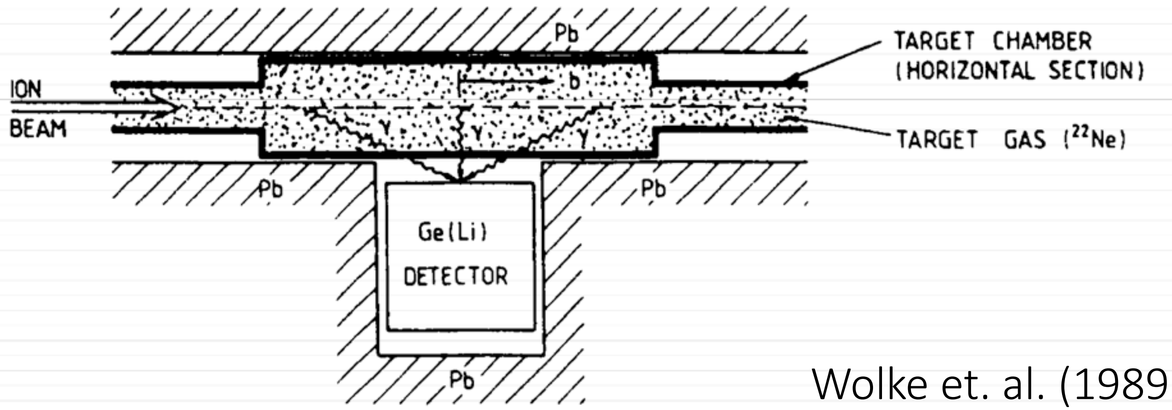
Advantages:

- Target is indestructible
- No background from a target backing
- Easily vary the thickness by adjusting the gas pressure
- Can make relative measurements easily by mixing gases in the target region
- Reduce straggling and background effects by stopping the beam far away from target region

Vertical Cross-section of set-up



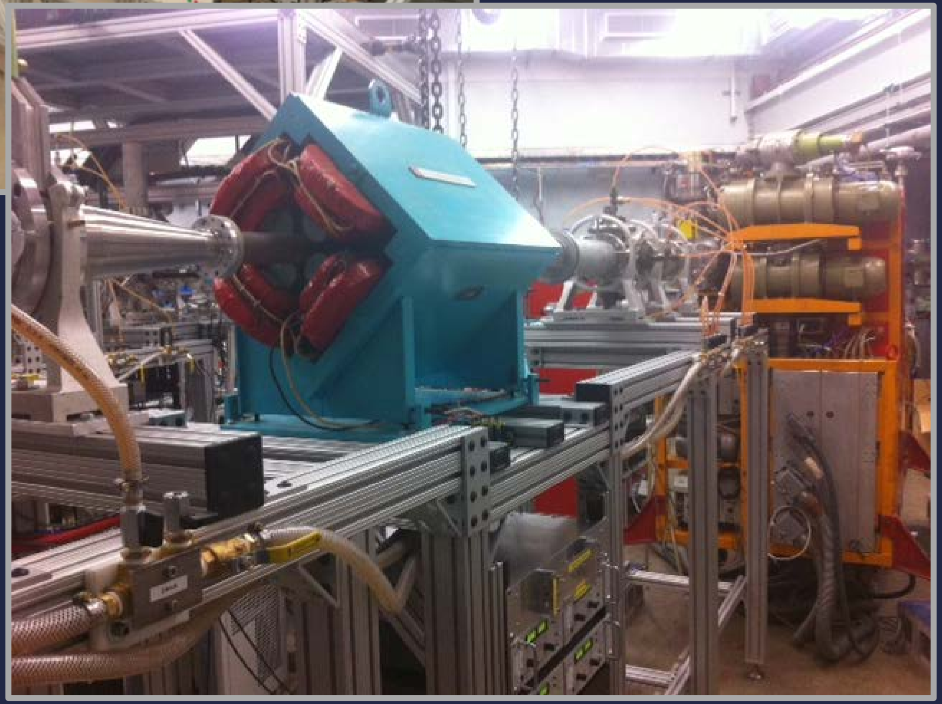
Horizontal Cross-section of set-up



Wolke et. al. (1989)

CURRENT STATUS

- ✓ Beamline from 5U to target room complete
- ✓ Rhino Gas Target beamline complete
- Rhino is currently under refurbishment
    - →Testing vacuum pumps
    - →Reprogramming controls for efficiency
- Beam development



IN THE NEXT YEAR

- Rhino beamline optimization
- Characterization of target region
- Repeat target tests with 5U and Georgina (Ge detector array)
- Perform in beam testing of gas target
- Perform and analyze cross-section measurement

THESIS WRITING!!!

ACKNOWLEDGEMENTS

All those that helped with experiment

Nuclear Science Laboratory Support Staff

Krell Institute

NSF

STEWARDSHIP SCIENCE GRADUATE FELLOWSHIP

JINA

UNIVERSITY OF NOTRE DAME
College of Science

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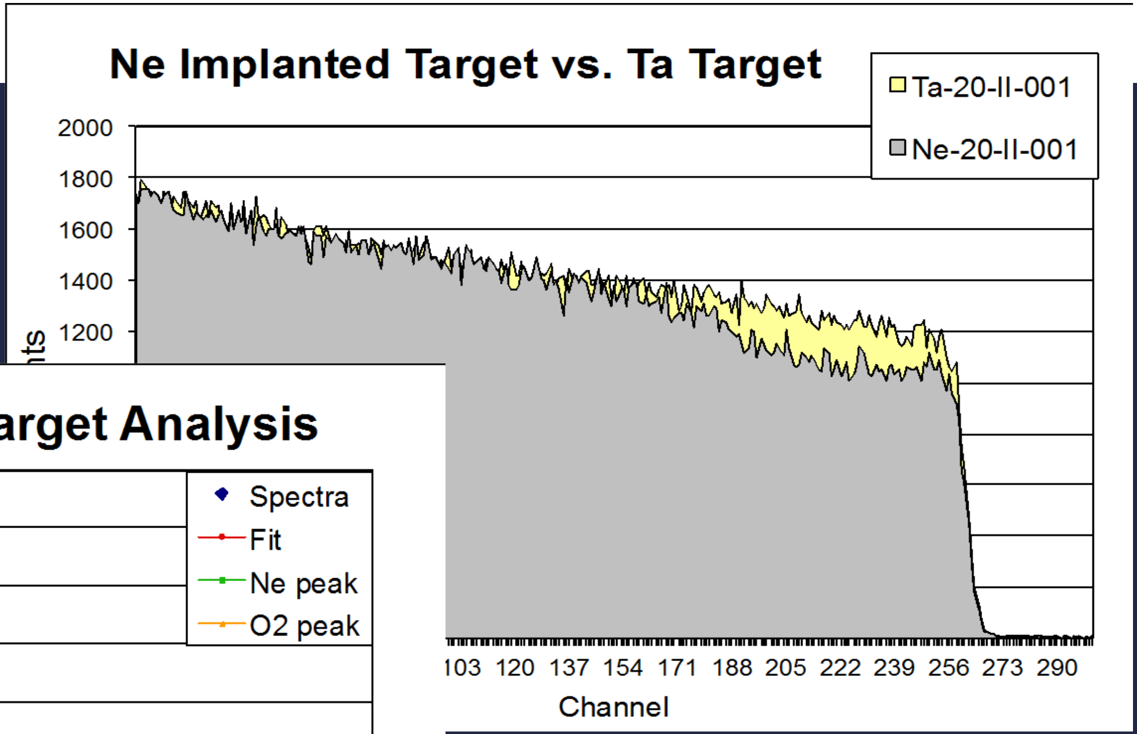
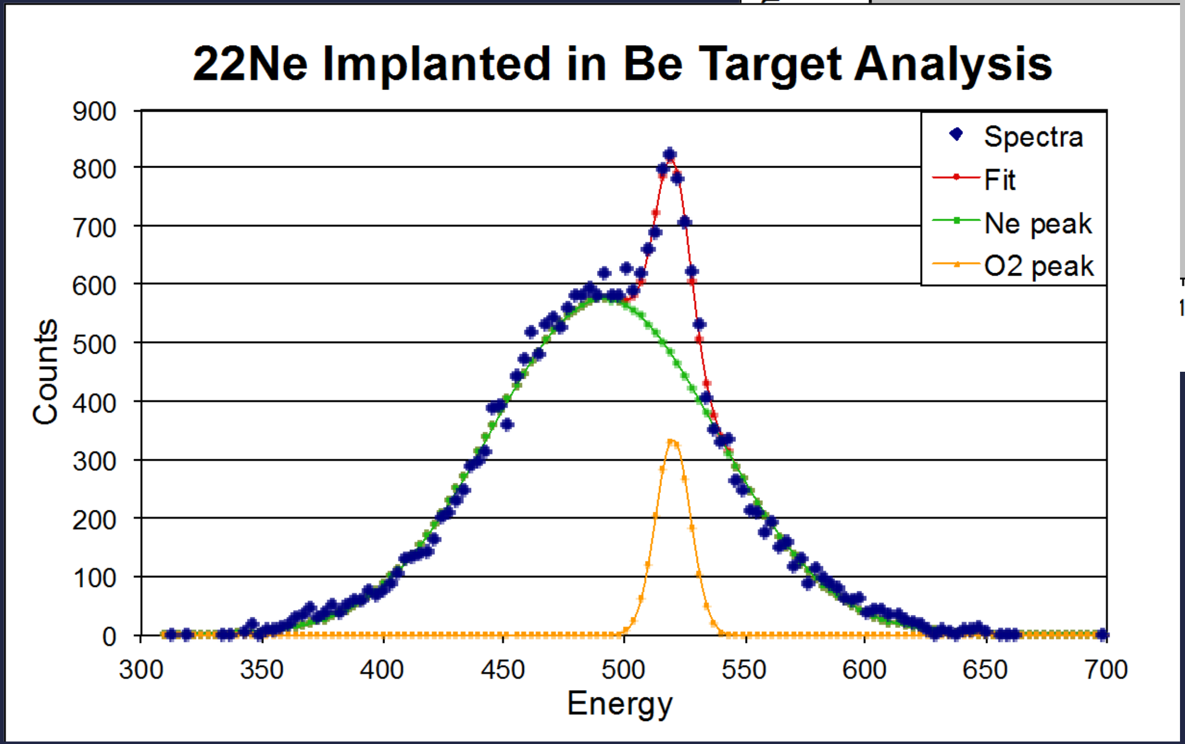
Implanted Target RBS Measurement





(Rolfs, 1975)

RESONANCE STRENGTH

Uncertainties in the resonance strength contribute to the errors in our knowledge of the cross-section

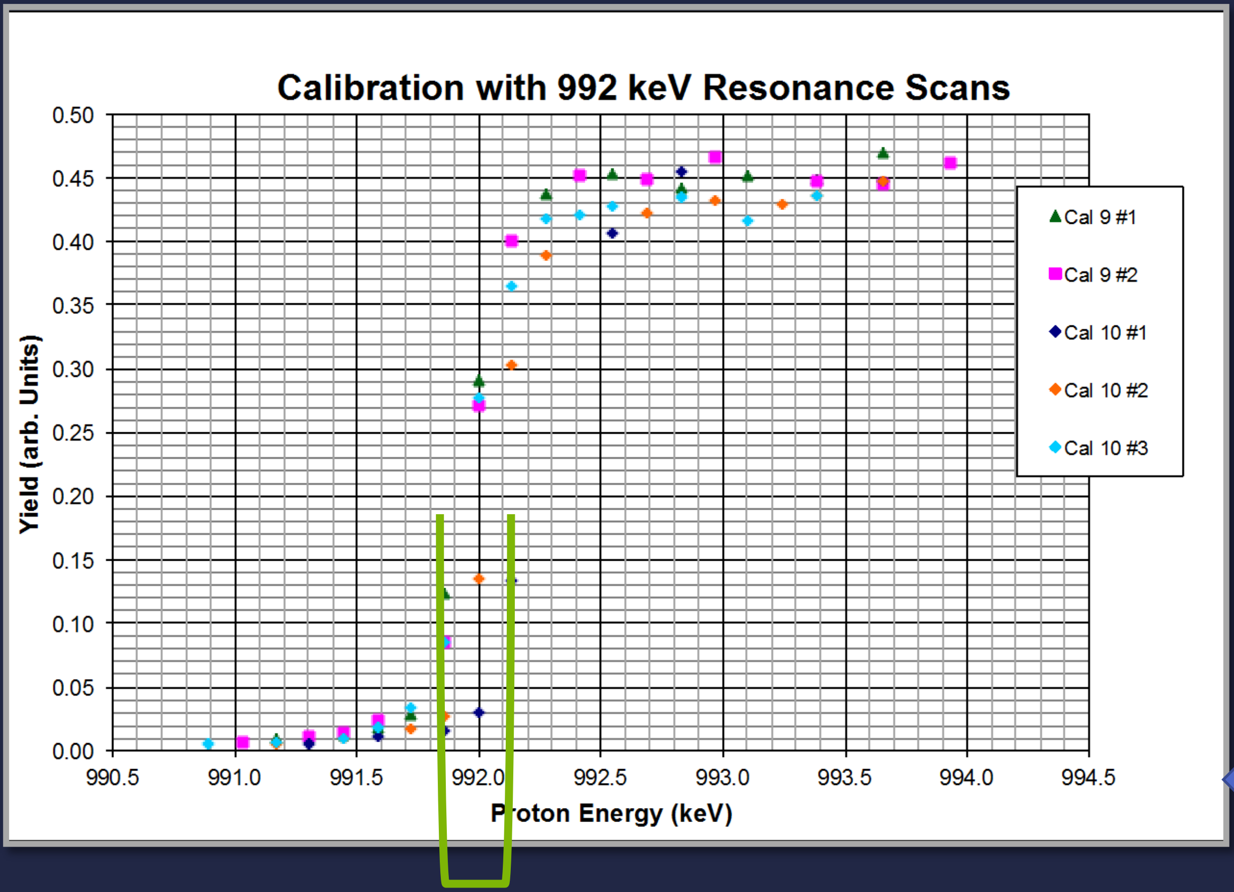
$$\sigma_{BW} = \frac{\lambda_R^2}{\pi} \frac{\omega\gamma}{\Gamma}$$

$$\omega\gamma = \frac{2}{\lambda_P^2} \frac{1}{n_{atoms}} \int Y \, d\mathrm{E}$$

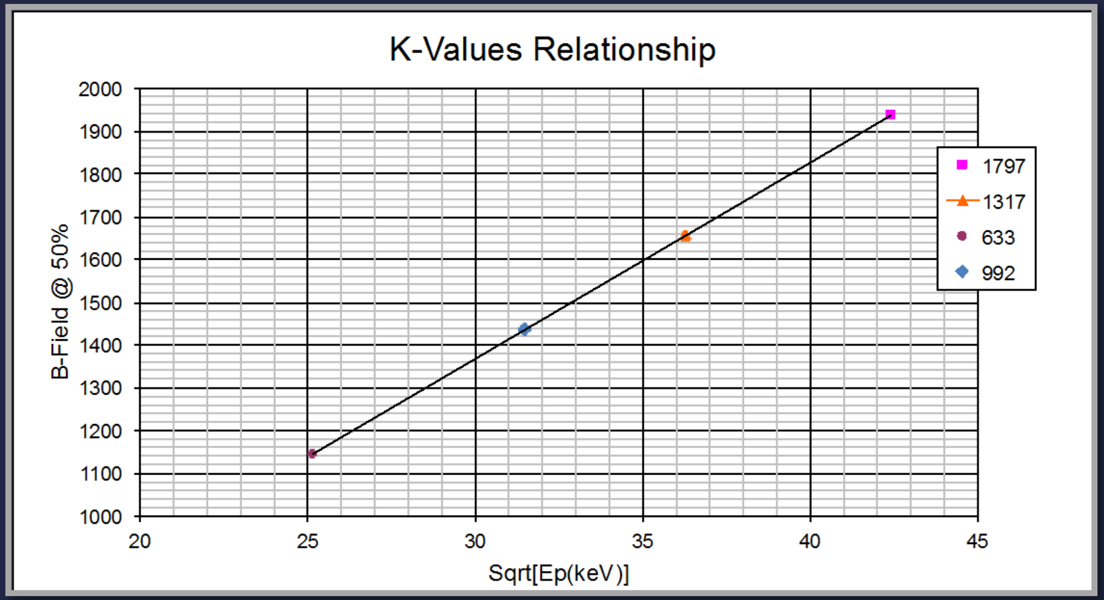
$$Y = \frac{C \times N_{counts}}{N_{Beam} \eta(E_\gamma) W(\theta) B(E_\gamma)}$$

Calibration Of The 5U-4 St. Ana Accelerator

$$B = 45.867\sqrt{E_P} - 8.7687$$



ΔB= 0.2 Gauss



Resonance scans were repeatable to within the precision of the hall probe.