Measurement of $^{22}Na(p,\gamma)^{23}Mg$ Reaction Rate

University of Washington REU

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Sky Sjue
Anne Sallaska
Prof. A. Garcia

Stephanie Stattel
Department of Applied Physics and Mathematics
Columbia University

Outline: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

- Background
  - ^{22}Na as cosmic gamma ray emitter
  - ^{22}Na(p,♑)^{23}Mg reaction and ^{22}Na cosmic abundance
  - Measuring (p,♑) resonances

- Experiment
  - Beam line (modeling/construction)
  - Strain and Yield calculations

- Conclusions
  - Future work
  - Design issues

Background: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

- Explosive hydrogen burning and nucleosynthesis occur in novae, x-ray bursts and type II supernovae.
- Within the hot, dense H-rich environment, a complex series of proton capture and beta-decay reactions occur, through which heavier elements are created and ejected into space.
- The proton captures that affect the abundances of cosmic gamma ray emitters are of particular interest. These gamma rays are observed using gamma-ray telescopes.
- Understanding the rates of various reactions allows resulting isotopic abundances to be predicted and provides insight into the processes themselves.

A gamma-ray burst and a supernova occur essentially simultaneously

March 29, 2003 "Rosetta Stone"

Background: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

The central regions of our galaxy, as seen by INTEGRAL in gamma rays

Credit: ESA, F. Lebrun (CEA-Saclay)

- To be a candidate for observation by gamma-ray telescopes, the nuclei produced in novae must live long enough for the ejected debris to become transparent, and they must emit characteristic gamma rays of >1 MeV at some point in their decay.
- Over the past 5 years, γ-rays from 2 nuclei have been identified: ^{22}Na and ^{26}Al.
- Of these, only ^{26}Al has been identified in known burning sites.

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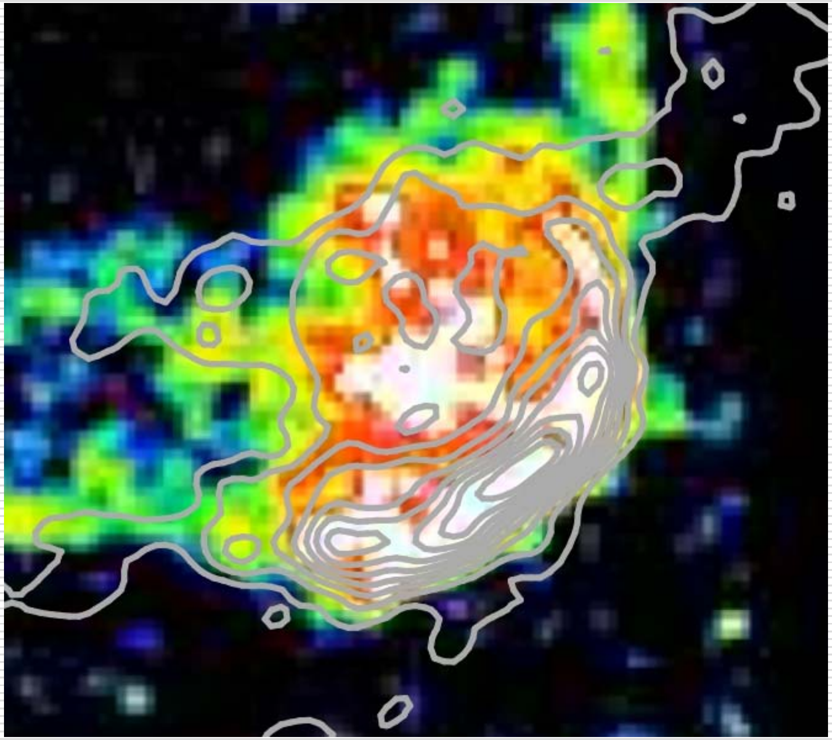

Chandra image of a **classical nova**

Credit: X-ray: S¸ölen Balman (METU, Turkey) and NASA; Radio: E. Seaquist (U Toronto)

- The nucleus ^{22}Na could be especially important in the diagnosis of classical nova outbursts, which are violent events that take place on the white dwarf component of a close stellar binary system.
- A radioactive isotope, ^{22}Na decays with a 2.602 year half-life, into a short-lived excited state of ^{22}Ne, which emits a 1.275 MeV gamma ray.
- Explosions within a few kiloparsecs of the Sun may provide detectable γ-ray fluxes associated with ^{22}Na decay.

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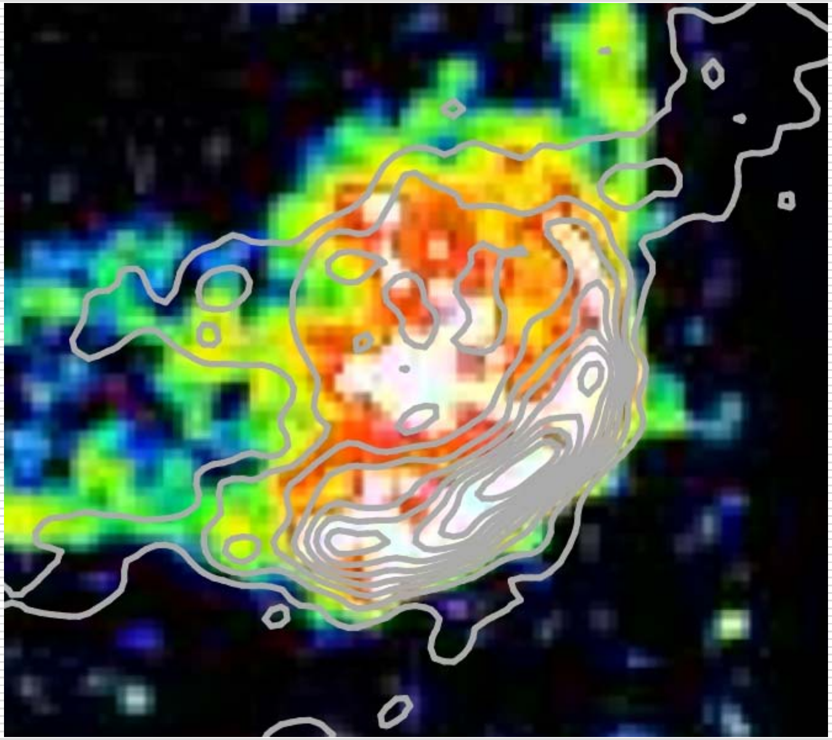


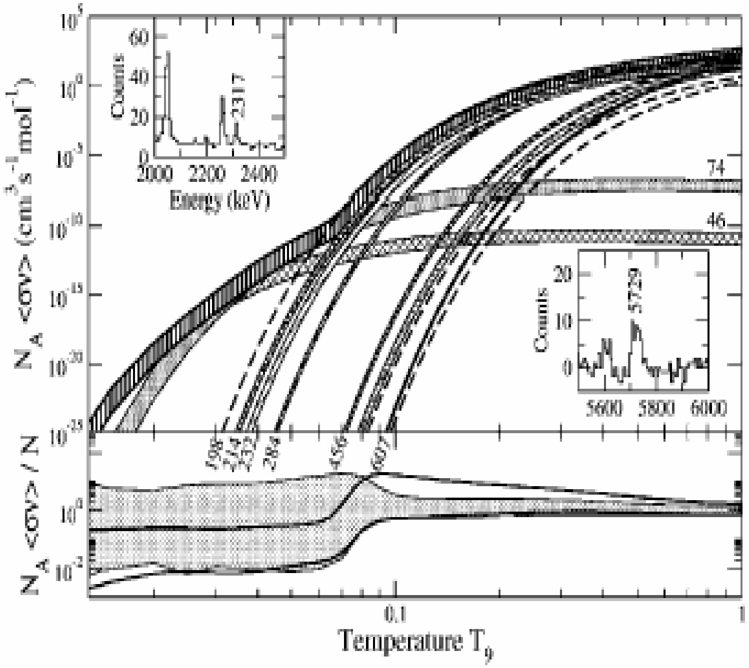
Chandra image of a **classical nova**

Credit: X-ray: S¸ölen Balman (METU, Turkey) and NASA; Radio: E. Seaquist (U Toronto)

- Over the last 25 years, several experimental searches for the γ-ray signature associated with ^{22}Na have been conducted.
- The production of ^{22}Na in novae is very sensitive to the explosive conditions. With a short half-life, ^{22}Na is spatially and temporally localized near its production place and time, forming an interesting tracer
- ^{22}Na is an elusive γ-ray emitter, however, and it has not been observed with orbiting telescopes anywhere except in the central galactic bulge.

Background: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

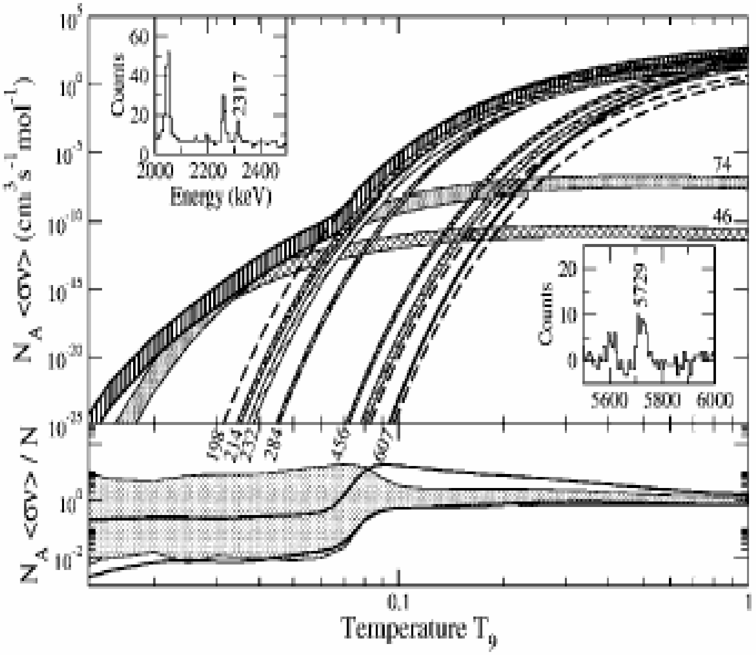
- Many scientists believe that ^{22}Na should be made prolifically in novae, with some models predicting ^{22}Na production equal to that of ^{26}Al.
- To resolve this discrepancy, knowledge of the science behind these production sequences must be advanced.
- Proton-capture reactions on the “seed” nuclei are responsible for the synthesis of significant amounts of the unstable nucleus ^{21}Na, which through β decay or additional proton captures eventually leads to ^{22}Na.
- The ^{22}Na(p, γ) reaction rate has the largest effect on ^{22}Na production, and at nova temperatures this reaction rate may be dominated by a single new resonance.
- No direct measurement of the resonance strength has been performed, however, and other key resonances have only been measured to 50 % accuracy.



The contribution of individual resonances to the total reaction rate for the 22Na(p,γ) reaction

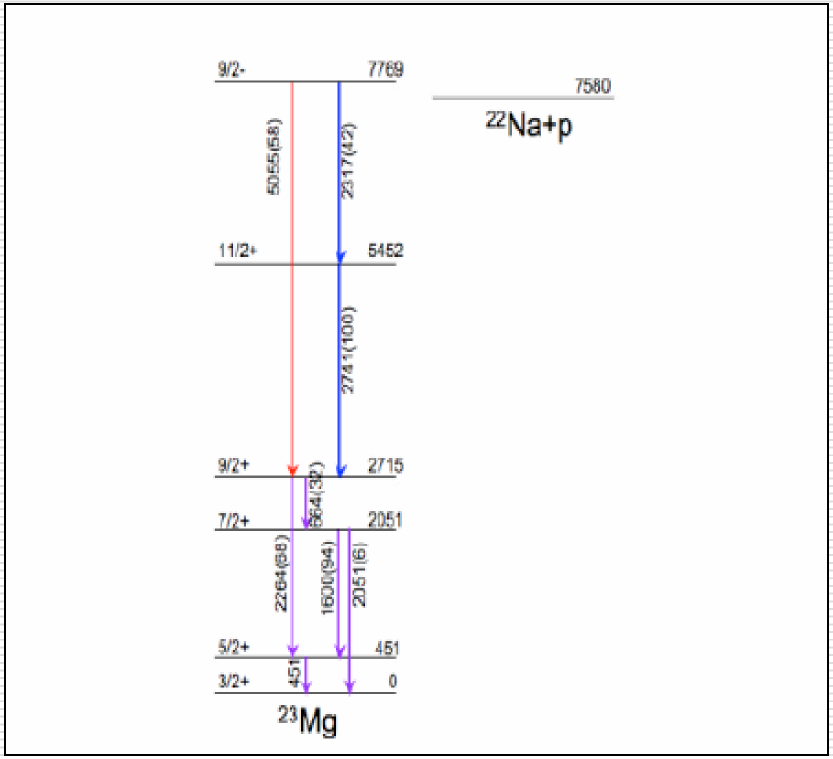
Background: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

- The key to an analysis of the astrophysical reaction rate for the ^{22}Na(p,γ) reaction is a detailed knowledge of properties such as excitation energy, spin , and parity.
- Conventionally, by bombarding a specially prepared radioactive ^{22}Na target with protons, one can detect the γ rays that follow proton capture.
- Using this direct approach, one can then find resonances in the reaction for different energies.
- The problem of high background rates as well as the difficulty of producing such a radioactive target makes these measurements extremely difficult.



The contribution of individual resonances to the total reaction rate for the 22Na(p,γ) reaction

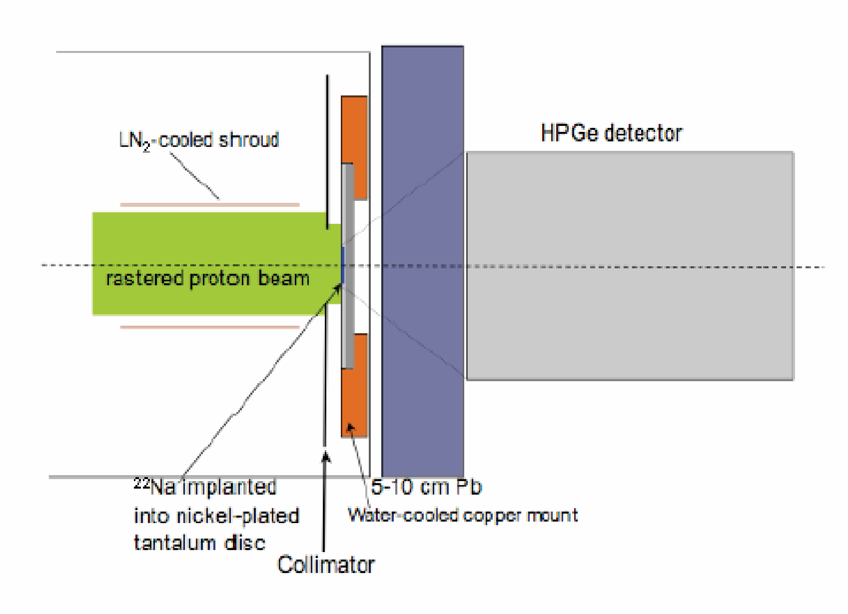
Background: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate



A proton interacts with Na to produce an excited state of Mg, which then de-excites and emits a γ ray

- A recent measure of ^{23}Mg structure discovered an state that could have huge implications on the rate of ^{22}Na destruction via the ^{22}Na(p,γ)^{23}Mg reaction.
- This new resonance was discovered in a gamma-ray spectroscopic measurement using the ^{12}C(^{12}C,n)^{23}Mg reaction with Gammasphere.
- Using mirror symmetry arguments, it was estimated that a new ^{23}Mg energy level at 7.769 MeV (with E_p=198keV) could have a resonance strength of up to 4MeV.
- With a strength of 4MeV, this resonance would dominate the reaction rate at nova temperatures.
- A direct measurement of the resonance strength of E_p=198keV is desired, along with re-measurements of other resonances to reduce the 50% uncertainty in their rates.

Experiment: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate



- We would like to perform a direct (p,γ) measurement of this new resonance, while also improving the accuracy of other resonance measurements.
- The ^{22}Na targets will be made at TRIUMF-ISAC at a range of thicknesses and activities.
- To measure the reaction, we will bombard a ^{22}Na target, implanted in a Ni substrate, with protons of energies 0.2-0.6 MeV. We will use a 100% Ge detector to measure the resulting gamma rays.
- To reduce the high rate of 511keV and 1.275 MeV gamma rays, a 5 cm-thick lead shield will be placed between the target and detector
- Using more target material and Ge detectors, we hope to improve upon the past measurements of other resonances.

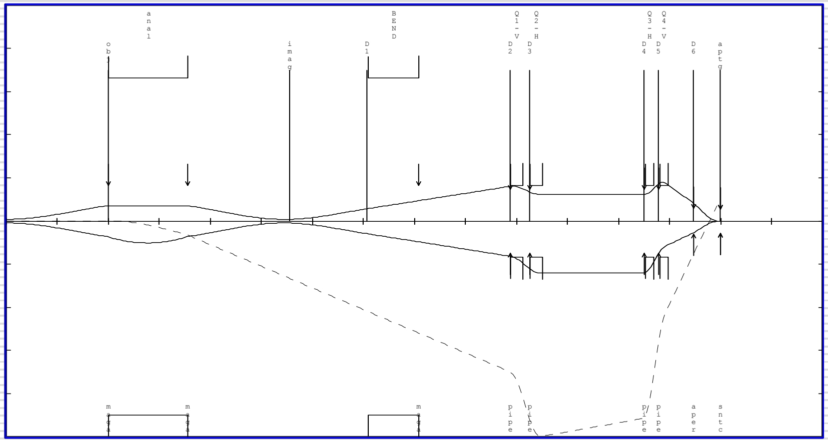
Experiment: Measurement of $^{22}Na(p,\gamma)^{23}Mg$ Reaction Rate

- We are currently in the beginning stages of setting up this experiment at CENPA, which entails dismantling the previous beam-line experiment and assembling all of the parts needed for the current project.
- To optimize the new set-up, we are performing yield and strain calculations.
- In addition, using a program called Transport, we are simulating the beam profile and tuning parameters to minimize the beam spot.
- We would like to identify features of our experiment that limit precision and efficiency, as well as ways in which our set-up can be improved over previous experiments.

Segment of previous beam-line

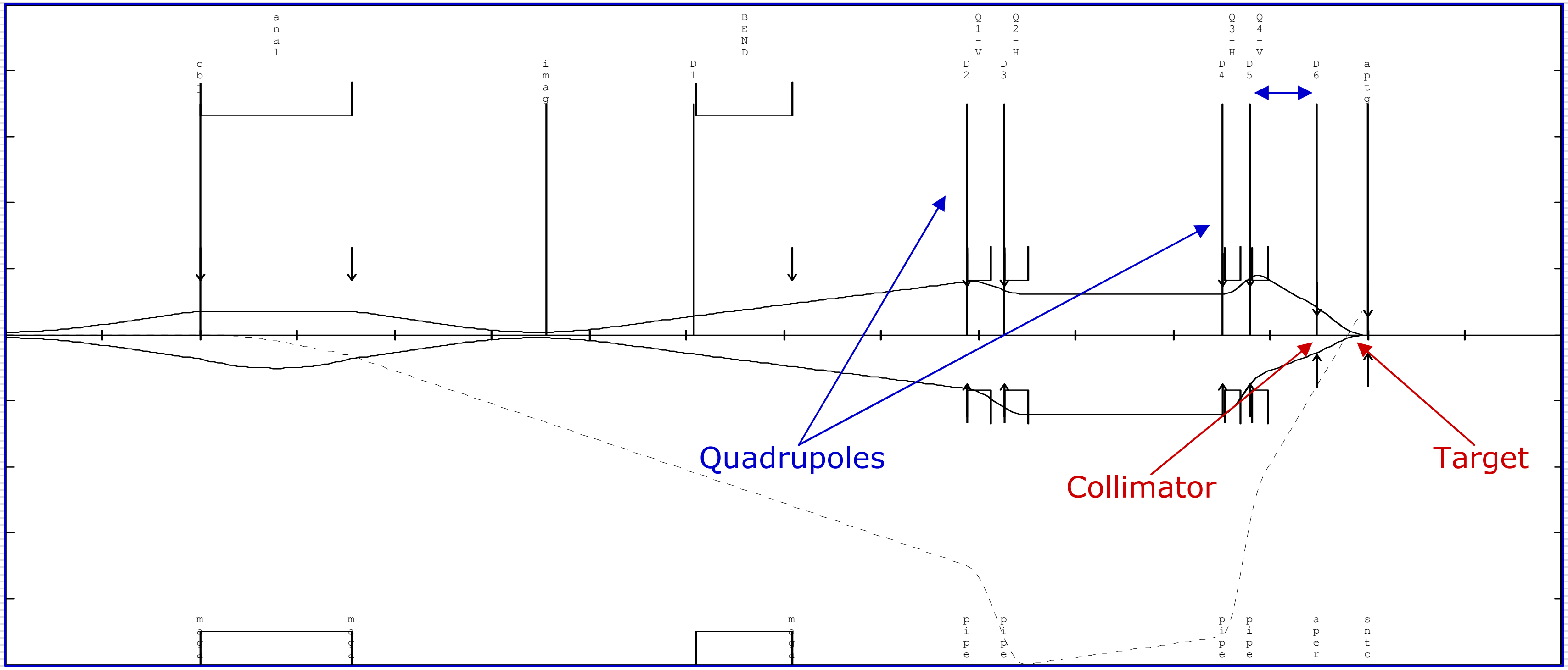
Experiment: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

Transport



- Transport is a first and second-order matrix multiplication computer program intended for the design of static-magnetic beam transport systems.
- In Transport, a beam line is defined as a sequence of elements, which may consist of magnets and the intervals between them, as well as specification of the input beam and special configurations of the magnet.
- Transport steps through the beam line, element by element, calculating the properties of the beam or other quantities where requested.
- In principle transport can search and find the first or second-order solution to any physically realizable problem.
- By adjusting the distances between quadrupoles and utilizing Transport's fitting capabilities, we attempted to minimize the beam spot size at the target.

Experiment: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate



Quadrupoles

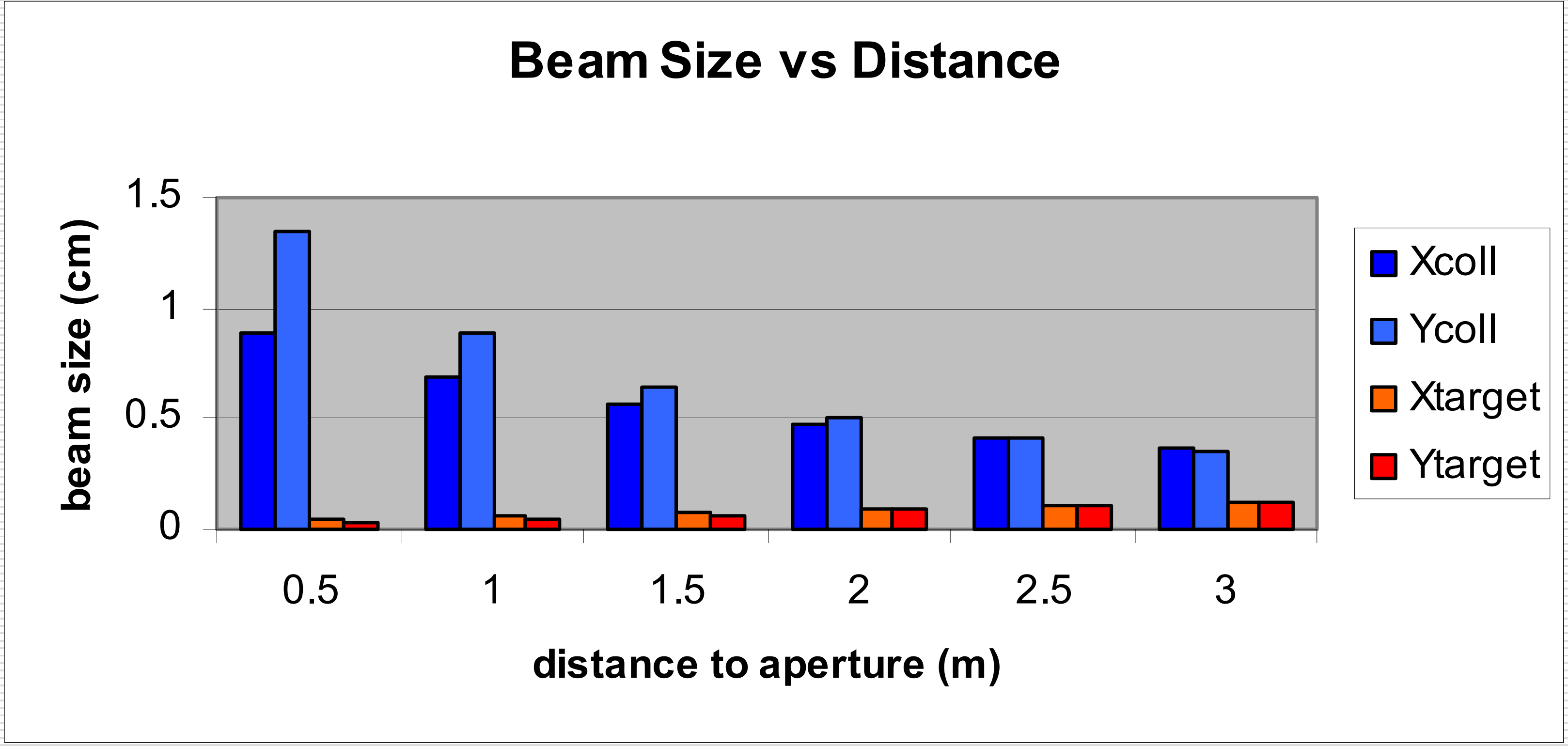
Collimator

Target

- Graphic Transport output, showing beam divergence in x and y direction as beam travels along the beam line

Experiment: Measurement of $^{22}Na(p,\gamma)^{23}Mg$ Reaction Rate

- Graph of beam size versus the distance from the second quadrupole to the collimator. Values were obtained using transport, optimizing the focus at the target for each distance



Experiment: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

- We do not understand the implantation process well enough to predict the density of ^{22}Na atoms on the target, and migration of ^{22}Na atoms can cause densities to change.
- By measuring yields at different beam energies, in what is called a "depth scan" we obtain:

$$\int Y(E)dE \sim \omega\gamma \text{ X } N(^{22}\text{Na})$$

which is proportional to the resonance strength and the number of ^{22}Na atoms.

- Rastering the beam to provide a uniform and known current density across the whole target simplifies the connection between N(^{22}Na) and the total ^{22}Na target activity.

Conclusions: Measurement of ^{22}Na(p,γ)^{23}Mg Reaction Rate

Future Work:

- In the coming months, we hope to construct a chamber to house the target.
- We will also begin collaborating with TRIUMF on the production of targets in a range of thicknesses and activities. To study the implantation process, we will work with stable ^{23}Na and proton beams at a range of energies.

Design issues:

- Cool target to prevent ^{22}Na migration (cold water);
- Contain possible migration of ^{22}Na (LN2 trap) ;
- Allow monitoring potential ^{22}Na migration;
- Allow beam position and focus on target (collimation);
- Good vacuum (10^{-7} Torr); LN2 trap to prevent C buildup;
- Provide easy maneuvering with radioactive target;