NATIONAL SUPERCONDUCTING CYCLOTRON LABORATORY
PROPOSAL FOR EXPERIMENT

Date Submitted: _______10/23/2003______________ Experiment # ____________________________________
(Assigned by NSCL)

TITLE: _____***Fragmentation of ^{68}Ni***____

SPOKESPERSON: _Betty Tsang____
Address: ________NSCL/MSU South Shaw Lane, East Lansing, MI_________________________________
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Phone: _____333-6386____________ Fax:______________________ E-Mal: tsang@nscl.msu.edu__

BACKUP SPOKESPERSON: ___Oleg Tarasov ____
Institution: __________ NSCL/MSU South Shaw Lane, East Lansing, MI _______________________________
Phone: _____333-6320__________ Fax:______________________ E-Mail: tarasov@nscl.msu.edu___

Is this a thesis experiment? **Yes** No If yes, for whom? ____incoming student_________

OTHER EXPERIMENTERS: (please spell out first name)

Name	Organization	Grad (Check, if applicable)	Sr. Grad
Betty Tsang	NSCL		
Bill Lynch	NSCL		
Michal Mocko	NSCL		X
Mike Famiano	NSCL		
Mark Wallace	NSCL		X
Daniel Bazin	NSCL		
Andrew Rogers	NSCL	X	
Sergei Lukyanov	Dubna		
Klaus Summerer	GSI		
Wolfgang Trautmann	GSI		

REQUEST FOR PRIMARY BEAM SEQUENCE INCLUDING TUNING, TEST RUNS, AND IN-BEAM CALIBRATIONS
(summary of the detailed beam delivery time calculation.)

	Isotope	Energy (MeV/nucleon)	Beam delivery time (Hours)	On-target time (Hours)
Primary beam 1	^{76}Ge	140	24	96
Primary beam 2	^{72}Ge	140	24	48

TOTAL REQUESTED HOURS: ____192_____ (Calculated as per item 4. of the Notes for PAC27 in the Call for Proposals)

HOURS APPROVED: ____________________

HOURS RESERVED: ____________________

		SET UP TIME (before start of beam)	TAKE DOWN TIME
Access to:	Experimental Vault	_____7___ days	_____2____ days
	Electronics Set-up Area	_____7____ days	_____2____ days
	Data Acquisition Computer	_____7____ days	_____2____ days

WHEN WILL YOUR EXPERIMENT BE READY TO RUN? _________06__ / ___01_____ / ___04______

DATES EXCLUDED: ____

EXPERIMENTAL LOCATION:

_X_	Transfer Hall	___	N2 vault	___	N3 vault (with 92" chamber)
___	N3 vault (92" chamber removed)	___	N4 vault User line	___	N4 vault (Gas stopping line)
___	N4 vault (Sweeper line)	___	S1 vault (RPMS line)	___	S1 vault (Irradiation line)
___	S2 vault (SuperBall line)	___	S2 vault (RPMS line)	_X_	S3 Vault

EXPERIMENTAL EQUIPMENT:

_X_	A1900	___	Beta Counting System	___	Beta-NMR Apparatus
___	4pi Array	___	92" Chamber	___	Sweeper Magnet
___	Neutron Walls	___	Modular Neutron Array	___	SuperBall Neutron Calorimeter
_X_	S800 Spectrograph	___	Segmented Ge Array	___	High Resolution Array
___	NaI Array	___	Neutron Emission Ratio Observer		
___	Other (give details)				

DETAIL ANY MODIFICATION TO THE STANDARD CONFIGURATION OF THE DEVICE USED, IF ANY:

TARGETS:
^{9}Be, ^{181}Ta

PLEASE LIST ITEMS THAT REQUIRE NSCL DEVELOPMENT:

OTHER SPECIAL REQUIREMENTS: (Safety related items are listed separately on following pages.)

SUMMARY (no more than 200 words):

We propose to measure projectile fragmentation at E/A=140 MeV of ^{68}Ni on two targets (^{9}Be, ^{181}Ta). ^{68}Ni is a radioactive beam. This data set will complement the fragmentation of stable Ni nuclei ^{58}Ni, ^{64}Ni, and will greatly assist the development of a theoretical understanding production of neutron rich isotopes.

DESCRIPTION OF EXPERIMENT

(no more than 4 pages of text - 1 1/2 spaced, 12pt; no limit on figures or tables)

Please organize material under the following headings or their equivalent:

1. Physics justification, including background and references.
2. Goals of proposed experiment
3. Experimental details—apparatus (enclose sketch); what is to be measured; feasibility of measurement; count rate estimate (including assumptions); basis of time request (include time for calibration beams, test runs and beam particle or energy changes); technical assistance or apparatus construction required from the NSCL.
4. Status of previous work done at the CCF.

Physics justification

Projectile fragmentation is one of the most efficient ways to produce very short-lived rare isotopes. Understanding the mechanism for producing these isotopes is important because it is needed for accurate planning and operation of rare isotope facilities and because it is the main nuclear reaction mechanism at high incident energies with important links to the study of hot nuclei and nuclear matter.

Currently, phenomenological parameterizations such as EPAX2 [1] are widely used to estimate rates at the Coupled Cyclotron Facility and at other labs such as GSI and Riken. EPAX2 appears to provide reasonably accurate rates for production of nuclei at the CCF not too far from the valley of stability, however, problems emerge when these predictions are extended to the neutron-rich extremes of the secondary beams. Whether these problems are related to the number of protons that are removed from the beam or are related to actual properties of the final fragments is not known. This issue becomes particularly important when one wants to predict how the produced yield of a given rare isotope depends on the choice of primary beam. This is important for designing experiments at the NSCL. It is also very important, for example, to rates calculated for high energies where thick targets are used. In such cases, calculations have shown that multiple interactions in the target may be the dominant contribution and may be essential to describe thick target data[2]. If one assume for the purposes of argument that EPAX2 predictions are the correct description for the contribution from single interactions, one can make the prediction for the two and multi-step contributions. The solid line in Figure 1 shows the RIA prediction of Sulphur isotopes from fragmentation of ^{82}Ge beams using a 10g/cm2 ^{9}Be target, which corresponds to 1.2 interaction lengths. The calculations use EPAX2. The dashed line shows the EPAX2 prediction for the contributions from one-step interactions and the solid line shows the yield for two-step interaction. Clearly the production of the extremely n-rich Sulfur isotopes with A>49 in such situations would be dominated by the 2-step processes; the dominance of 2-step processes is currently assumed in the official computations of the intensities of very heavy Sulfur isotope beams at RIA. Most of the 2-step processes arise from interaction of the unstable nuclei produced in the first step. Thus, it is important to understand and be able to predict the production yields from the fragmentation of unstable neutron-rich isotopic beams.

Phenomenological models such as EPAX2 derives its parameters from a careful empirical fit to a limited data set of production cross-sections measured under a wide variety of experimental conditions. It is better at interpolating between measured data points taken under similar conditions than predicting isotopes far away from the valley of stability. Recent measurements with fragmentation of proton-rich projectile ^{36}Ar [3] are in good agreement with EPAX2. However, there are indications that EPAX2 prediction of n-rich isotopes production does not agree well with measurements. For example, for isotopes produced by mainly removing protons from a projectile without removing neutrons, EPAX2 underestimates fragment cross-sections when only a couple protons are removed but overestimates fragment cross-sections when many protons are removed (>3). The disagreement worsens with increasing neutron excess of the produced isotopes. This discrepancy is shown in Figure 2 where the p-removal chain from the fragmentation of ^{58}Ni and ^{40}Ca are plotted as data points. In order to show the two data sets together, cross-sections from the p-removal chain of ^{40}Ca are displaced by 1000. The dashed lines are EPAX2 predictions, which over-predict the most n-rich nuclei in this region by orders of magnitudes. Similar observation is also obtained in the p-removal chain of ^{86}Kr.

Goals of proposed experiment

There is no substitute for confronting theory with good quality data. To test the fragmentation of neutron-rich nuclei, we propose to measure the fragmentation of ^{68}Ni on two targets (^{9}Be, ^{181}Ta). This nucleus is chosen because we have a good fragmentation cross-section measurement data set for ^{58}Ni and the fragmentation measurement for ^{64}Ni is scheduled to run early next year. The addition of the ^{68}Ni beam will provide a clear indication whether one can expect significant improvements in neutron-rich secondary beam yields by fragmenting a neutron-rich radioactive projectile. It may be that the cross-sections on the neutron rich side are strongly limited by the weak binding of the produced nuclei and little increase in cross-section is actually obtained.

We plan to use the S800 as a fragment separator for the identification of the fragments produced in the fragmentation of ^{68}Ni. In order to develop the method of measuring absolute fragmentation cross-sections and to ensure that we understand the transmissions and characteristics of the S800, we propose to measure the fragmentation of ^{64}Ni at the S800 spectrometer. The ^{64}Ni beam will be produced as secondary beam from the primary beam of ^{72}Ge. The result can be compared directly with the ^{64}Ni fragmentation cross-sections measured at the A1900. The latter measurement is scheduled to run early part of 2004.

Experimental Details & Beam Time Request:

The experiment will be performed with the A1900 and S800 spectrometer. ^{68}Ni ions will be produced as a secondary beam from the fragmentation of ^{76}Ge primary beam and transmitted to the S800 vault. With the target placed in the S800 scattering chamber, the fragment products will be identified by the S800 spectrometer in the focal plane. The S800 magnet setting will be optimized so that isotopes of the same N/Z ratios are measured. To optimize the counting rates and to improve the data acquisition rates with minimal dead time, we will avoid the N/Z=1.43 of the beam, i.e. we will focus on the n-rich region and the p-rich region compared to the beam. Counting rates are lower for the n-rich region so we provide the count rate for the production of ^{65}Mn (N/Z=1.6) as shown in Figure 3. From the LISE calculation, assuming 6000 pps of ^{65}Mn and 150 mg/cm2 Be, the count rate estimate of ^{65}Mn is 0.002 per sec.

A ^{68}Ni beam was developed and used in an experiment at the S800 vault in January 2003. Thus we are more certain about the beam intensity (2500 cts per pnA of ^{76}Ge beam). If 10 pnA is produced based on past experience, the count rate estimates above should be increased by a factor of 4. Thus obtaining 100 ^{65}Mn nuclei will require 3.3 hours or 3.5 hours including time for setting magnets. Each of the settings will give measurements of 3-4 isotopes with similar N/Z. We expect to do about 10 settings for the Be target, a total of 35 hours. For the Ta target, due to the much smaller event rate for the same energy loss of the beam in the target, we cannot complete the measurements of most neutron-rich isotopes within the same allotment of time. Thus we request 16 extra hours for the Ta target and we will use a much thicker Ta target to produce the n-rich fragments. Based on our experience on A1900 fragmentation cross-section measurements, we need an extra 8-hour overhead to calibrate beam intensity monitors, charge state distributions measurements and check the data coming from the detector setup of the S800. Thus we are requesting a total of 4 days (36(Be)+52(Ta)+8(setup)=96 hr) for the ^{68}Ni beam on target. For the calibration secondary beam of ^{64}Ni, we will skip the measurement with Ta target and the beam time request is 48 hr. (36(Be)+12(setup)=48 hr.)

Status of previous work done at the CCF.

Of the four beams requested in experiment #01036, we have completed the fragmentation cross-section measurements of ^{40}Ca 2003. Due to technical problems, we did not pursue the Kr beams, instead we ran ^{58}Ni beam in October 2002. Both of these experiments are in the final stage of data analysis. Some of the results was discussed in the NSCL 2003 user workshop [4].

Comparison of the cross-sections with neutron-rich beams will start with the fragmentation experiment of ^{48}Ca scheduled to run in November or December this year, and the fragmentation experiment of ^{64}Ni beam will run early next year.

Reference:

[1] K. Summerer and B. Blank, Phys. Rev. C 61, 034607 (2000).
[2] W. Friedman, Proceedings of the Yukawa International Seminar 2001, November 5-10, 2001, Kyoto, Japan.
[3] K. Summerer, private communication.
[4] M.B. Tsang, NSCL user-workshop, September 27-28, 2003, E. Lansing, USA http://meetings.nscl.msu.edu/userworkshop2003/Presentation%20files/tsang.pdf

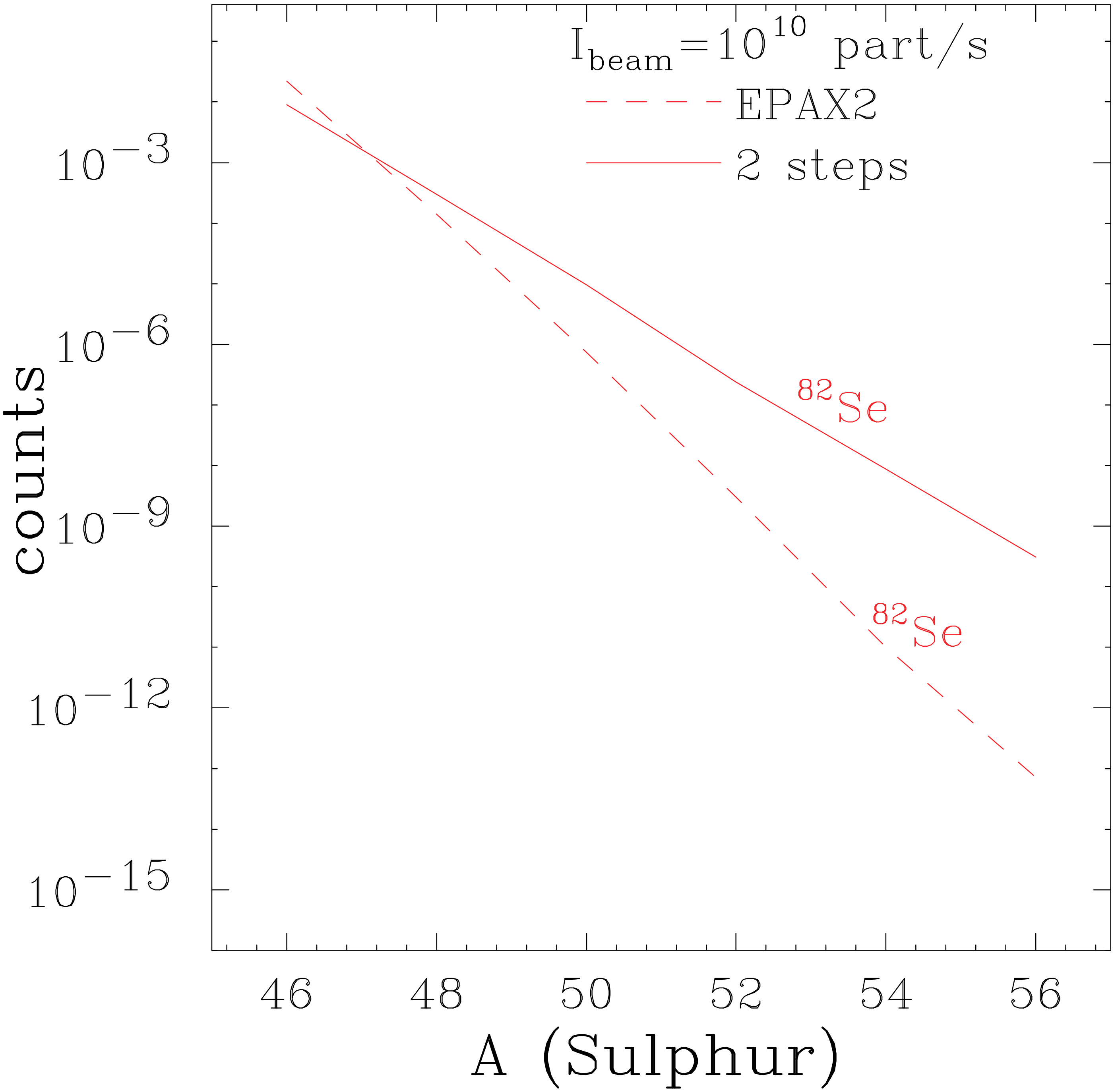

Figure 1: Production of Sulfur isotopes in RIA.

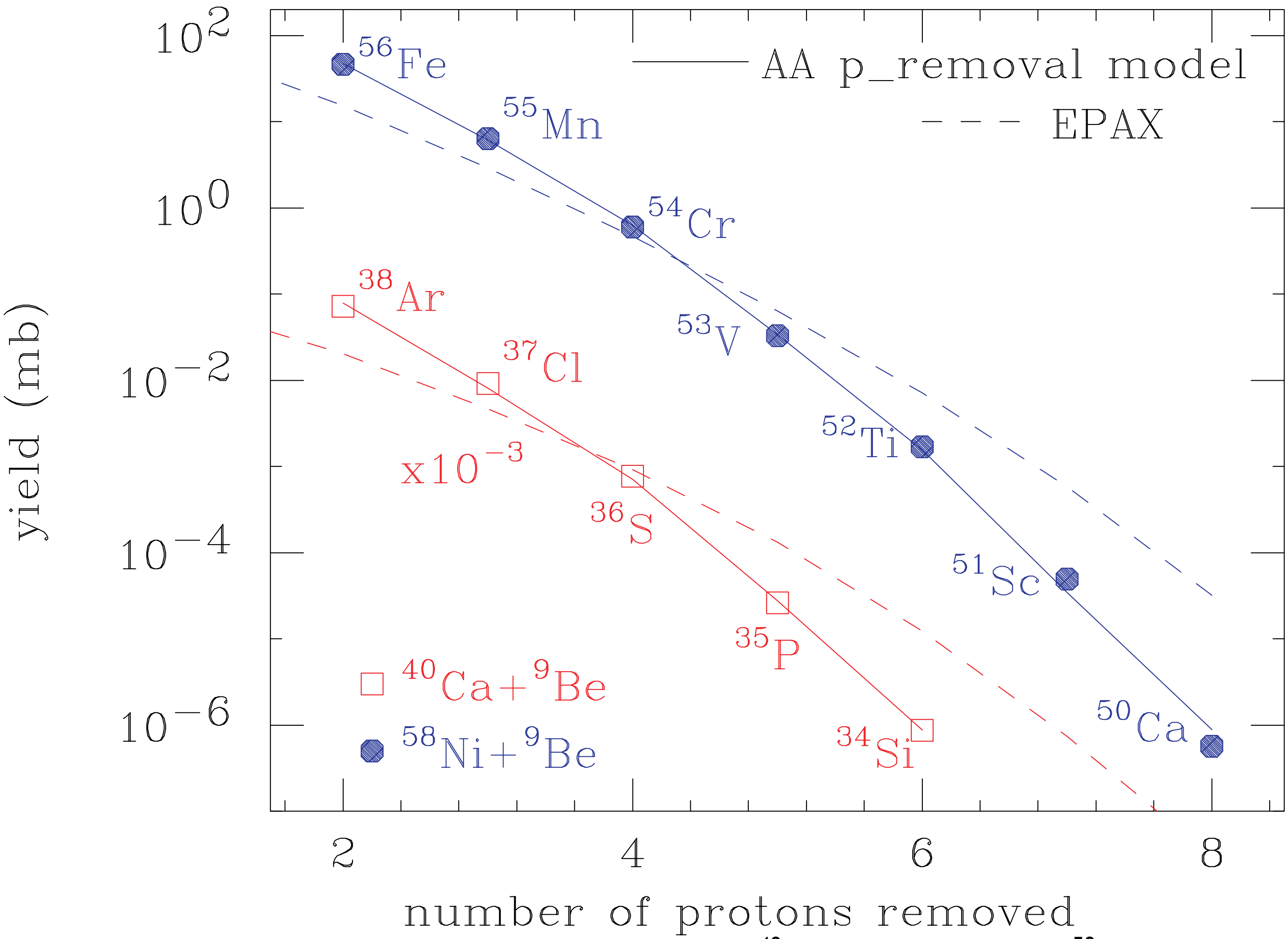

Figure 2: p-removal cross-section for fragmentation of ^{40}Ca (red squares) and ^{58}Ni (solid circles).

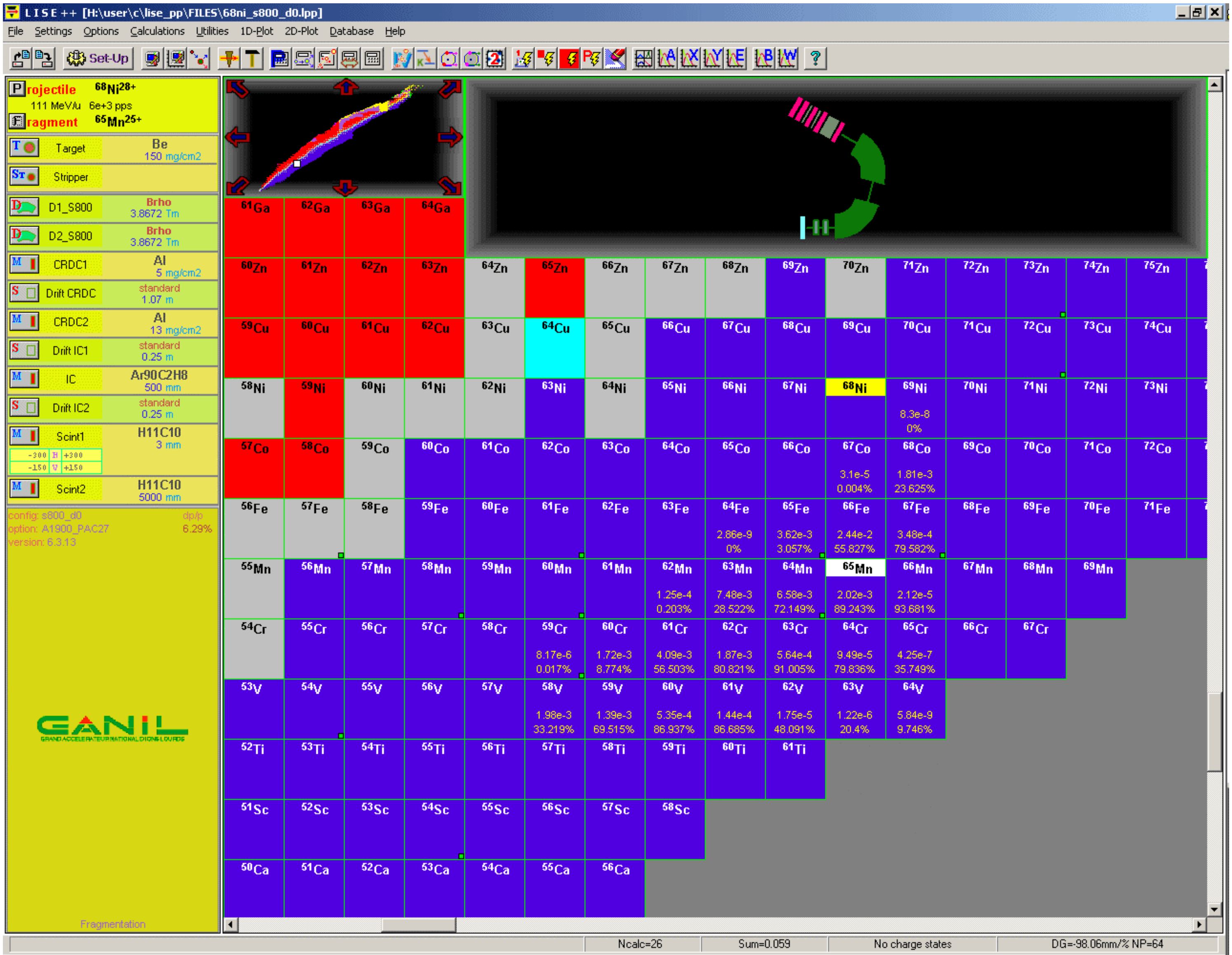

Figure 3: Count rate estimates using LISE++. The magnet setting is optimized to produce ^{55}Mn.

SAFETY INFORMATION

It is an important goal of the NSCL that users perform their experiments safely, as emphasized in the Director's Safety Statement. Your proposal will be reviewed for safety issues by committees at the NSCL and MSU who will provide reviews to the PAC and to you. If your experiment is approved, a more detailed review will be required prior to scheduling and a Safety Representative needs to be designated.

SAFETY CONTACT FOR THIS EXPERIMENT: ____

HAZARD ASSESSMENTS (CHECK ALL ITEMS THAT MAY APPLY TO YOUR EXPERIMENT):

__________	Radioactive sources required for checks or calibrations.
__________	Transport or send radioactive materials to or from the NSCL.
__________	Transport or send— to or from the NSCL—chemicals or materials that may be considered hazardous or toxic.
__________	Generate or dispose of chemicals or materials that may be considered hazardous or toxic.
__________	Mixed Waste (RCRA) will be generated and/or will need disposal.
__________	Flammable compressed gases needed.
__________	High-Voltage equipment (Non-standard equipment with > 30 Volts).
__________	User-supplied pressure or vacuum vessels, gas detectors.
__________	Non-ionizing radiation sources (microwave, class III or IV lasers, etc.).
__________	Biohazardous materials.

PLEASE PROVIDE BRIEF DETAIL ABOUT EACH CHECKED ITEM.

DETAILED BEAM REQUIREMENTS

The information supplied in this section will serve as the basis for the total beam time requested from the PAC. In addition to Beam-on-target time[1] entered below, an estimate of the beam delivery time[2] calculated according to the guidelines under the section entitled "Beam Delivery Time Calculation" in the PAC 27 Call for Proposals will also be presented to the PAC.

For each primary beam requested, please fill in the table below. Not all items will apply to all experiments. Please add additional primary and secondary beams as needed. Please list the total time requested for each primary beam on the first page of this proposal.

Primary Beam 1 (from beam list, to be included in **Beam Delivery Time**) Primary beam tune 24 hrs

Isotope ____
Energy[3] ____ MeV/nucleon
Minimum intensity ____ (particle nA)

Modification of A1900 standard configuration — Addt'l time per Tom Ginter ____ hrs

Development of special optics — Addt'l time per Tom Ginter ____ hrs

Secondary beam A from primary beam 1 — Delivery time per table ____ hrs

Isotope ____
Energy ____ MeV/nucleon
Rate[4] ____ $(\text{particle nA}\bullet\text{sec})^{-1}$
A1900 Momentum acceptance ± ____ %
Acceptable purity ____ %
Additional requirements[5] ____ Event-by-event momentum correction from position in A1900 Image 2 measured with ___ PPAC ___ Scintillator
____ Timing start signal from A1900 extended focal plane

Secondary beam B from primary beam 1 — Delivery time per table ____ hrs

Isotope ____
Energy ____ MeV/nucleon
Rate ____ $(\text{particle nA}\bullet\text{sec})^{-1}$
A1900 Momentum acceptance ± ____ %
Acceptable purity ____ %
Additional requirements ____ Event-by-event momentum correction from position in A1900 Image 2 measured with ___ PPAC ___ Scintillator
____ Timing start signal from A1900 extended focal plane

If experiment is not in A1900 — Tune to vault (4 hrs) ____ hrs

Beam-on-target time for primary beam 1 ____ **hrs**
On-target time for primary beam 1 ____ hrs
On-target time for secondary beam A ____ hrs
On-target time for secondary beam B ____ hrs

Beam delivery time for primary beam 1 ____ **hrs**

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[1] Beam-on-target time is the time that the beam is needed for the purpose of the experiment, including activities such as testing, debugging the experimental setup, and calibrations.
[2] Beam delivery time is the time required by the NSCL for beam development and beam delivery; this time is not part of the time available for performing the experiment.
[3] A primary beam can be delivered with reduced energy by passing it through a degrader of appropriate thickness; this process necessarily impacts the beam properties.
[4] The rate for secondary fragment should be reported in units of particles per second per particle-nanoampere of primary beam.
[5] These capabilities are described in detail in the A1900 standard configuration.