National Superconducting Cyclotron Laboratory
Proposal Form—PAC 28

TITLE: Investigation of in-medium cross sections, momentum and density dependence of the asymmetry term

By submitting this proposal, the spokesperson certifies that all collaborators listed have read the proposal and have agreed to participate in the experiment.

SPOKESPERSON: __Michael Famiano____

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BACKUP SPOKESPERSON: _William G. Lynch_______________________________________

Institution: __NSCL Michigan State University ___________________________________

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Is this a thesis experiment? (Yes) No If yes, for whom?_____New student_________________________

OTHER EXPERIMENTERS: (please spell out first name) Check, if applicable

Name	Organization	Grad	Sr. Grad
Lee Sobotka	Washington University		
Robert Charity	Washington University		
Demetrios Sarantites	Washington University		
Walter Reviol	Washington University		
Sergei Karmarov	Washington University		X
Konrad Gelbke	Michigan State University		
Man-Yee B. Tsang	Michigan State University		
Franck Delaunay	Michigan State University		
Andrew Rogers	Michigan State University		X
Sergei Lukanov	JINR Dubna		

REQUEST FOR PRIMARY BEAM SEQUENCE INCLUDING TUNING, TEST RUNS, AND IN-BEAM CALIBRATIONS:
(Summary of information provided on Beam Request Worksheet(s). Make separate entries for repeat occurrences of the same primary beam arising from user-requested interruptions to the experiment.)

	Isotope	Energy (MeV/nucl.)	Minimum Intensity (particle-nanoampere)	Sum of Beam Preparation Times (Hours)	Sum of Beam-On-Target Times (Hours)
Beam 1	^{48}Ca	140	0.5	22	56
Beam 2	^{48}Ca	90	0.5	22	56
Beam 3	^{48}Ca	50	0.5	22	56
Beam 4	^{40}Ca	140	0.5	22	56
Beam 5	^{40}Ca	90	0.5	22	56
Beam 6	^{40}Ca	50	0.5	22	56
Beam 7	^{48}Ca	80	0.5	22	56
Beam 8	^{40}Ca	80	0.5	22	56
Beam 9	^{18}O	25	0.5	22	8
Beam 10	^{18}O	25	0.5	22	8

ADDITITIONAL TIME REQUIREMENTS THAT REQUIRE USE OF THE CCF (e.g. modification of the A1900 standard configuration, development of optics, … Obtain estimates from the A1900 Device Contact.)

Additional CCF use time: ______

Total Hours: 220 | 464

TOTAL TIME REQUEST (HOURS): 684

(Calculated as per item 4. of the Notes for PAC 28 in the Call for Proposals)

HOURS APPROVED: ______________ HOURS RESERVED: ________________

Access to:		SET UP TIME (before start of beam)	TAKE DOWN TIME
	Experimental Vault	21 days	7 days
	Electronics Set-up Area	9 days	4 days
	Data Acquisition Computer	5 days	2 days

WHEN WILL YOUR EXPERIMENT BE READY TO RUN? 1 / 1 / 2006

DATES EXCLUDED: ______________________________

EXPERIMENTAL LOCATION:

___ Transfer Hall (in the A1900)
___ N2 vault
___ N3 vault (92" chamber removed)
___ N4 vault (Sweeper line)
___ S1 vault (RPMS line)
X S2 vault
___ Transfer Hall (downstream of the A1900)
___ N3 vault (with 92" chamber)
___ N4 vault (Gas stopping line)
___ N4 vault (User line)
___ S1 vault (Irradiation line)
___ S3 Vault

EXPERIMENTAL EQUIPMENT:

___ A1900
___ 4pi Array
X Neutron Walls
___ NaI Array
___ Segmented Ge Array [ ] classic [ ] mini [ ] beta [ ] delta [ ] other
___ S800 Spectrograph [ ] with [ ] without scattering chamber
X Other (give details)
WU MicroBall, Start Array (see text)
___ Beta Counting System
___ 92" Chamber
___ Modular Neutron Array
___ Neutron Emission Ratio Observer
___ Beta-NMR Apparatus
___ Sweeper Magnet
___ SuperBall
X High Resolution Array
___ APEX NaI Array

DETAIL ANY MODIFICATION TO THE STANDARD CONFIGURATION OF THE DEVICE USED, OR CHECK NONE:
[X] NONE

DETAIL ANY REQUIREMENTS THAT ARE OUTSIDE THE CURRENT NSCL OPERATING ENVELOPE, OR CHECK NONE (Examples: vault reconfiguration, new primary beam, primary beam intensities above what is presently offered, special optics, operation at unusually high or low rigidities): [] NONE

Downstream hemisphere of the SuperBall in S2 must be removed.

TARGETS:
^{48}Ca, ^{40}Ca, ^{112}Sn, ^{124}Sn, CH_2

LIST ALL RESOURCES THAT YOU REQUEST THE NSCL TO PROVIDE FOR YOUR EXPERIMENT BEYOND THE STANDARD RESOURCES OUTLINED IN ITEMS 6, 7, AND 11. OF THE NOTES FOR PAC 28 IN THE CALL FOR PROPOSALS.

LIST ANY INTERRUPTIONS REQUIRED IN RUNNING YOUR EXPERIMENT: (Examples of why an experiment might need an interruption: to change the experimental configuration; to complete the design of an experimental component based on an initial measurement.)

The proposed experimental program should accommodate an arbitrary break in time (minimum of two weeks) between beams 5 and 6 for preliminary data analysis and target reconfiguration before proceeding to the final experimental configuration.

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

SUMMARY (no more than 200 words):

An experimental program is proposed to investigate the density dependence of the nuclear asymmetry term of the equation-of-state as well as the in-medium nucleon-nucleon (NN) cross-sections. A two-stage program is described in which the experimental setups in each stage are nearly identical. Predicted observables sensitive to the density dependence of the in-medium NN cross-sections are the neutron-proton emission ratios at forward angles. Similarly, neutron-proton emission ratios at 90^0 in the center-of-mass are also sensitive to the stiffness and momentum dependence of the nuclear equation-of-state. These observables will help to constrain the density dependence of the asymmetry term in the EOS, which is currently largely unconstrained. As isotopically resolved light fragment yields are a useful observable in the characterization of the stiffness of the nuclear EOS, these will also be observed.

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 requested from the NSCL.
4. Results from, or status of analysis of, previous experiments at the CCF listed by experiment number (publications, presentations, Ph.D.s awarded, Master's degrees awarded).

Note: Graphics should be such that black-and-white copies will convey the intended information correctly; references to color should be avoided.

I. Physics Justification

Experimental studies have placed significant constraints upon the Equation of state (EOS) for isospin symmetric nuclear matter [1]. The dependence of the EOS on the isospin asymmetry $\delta=(\rho_n-\rho_p)/(\rho_n+\rho_p)$, however, remains largely unconstrained; theoretical estimates of the uncertainty due to this term suggest that it may be the dominant contribution to the uncertainty in the EOS of neutron matter [1]. Not surprisingly, the asymmetry term governs many macroscopic properties of neutron stars, such as their radii, their moments of inertia [2,3], their maximum masses [4], how they are formed and cool [5] and the possibility that exotic matter may occur in the neutron star core [2,6,7]. The radii and moments of inertia are particularly sensitive to the density dependence of the asymmetry term at normal and sub-normal density. There, the uncertainty in the pressure due to the nuclear asymmetry term can be larger than many estimates for the total pressure of the system [1].

Measurements at the NSCL have recently provided information about the density dependence of the asymmetry term [8,9]. Figure 1 shows a comparison between measured (cross-hatched region) and calculated values (points) for the isospin asymmetry ratio constructed from semi-peripheral ^{112}Sn+^{124}Sn, ^{112}Sn+^{124}Sn, ^{124}Sn+^{112}Sn and ^{124}Sn+^{124}Sn collisions. (Results for central collisions are also expected from the analysis of Exp. 01032, which is in progress.) The points labeled "BUU" in Figure 1 represent BUU calculations using momentum independent mean field potentials with different assumptions for the density dependence of the interaction part of the asymmetry term $S(\rho)_{\text{int}} \propto \rho^{\gamma}$. The open points labeled "BUU+m*" represent corresponding calculations using mean field potentials that include a momentum dependence consistent with the Lane potential. While a momentum dependent interaction term with a linear density dependence provides a better description of the data, past experience dictates that such conclusions should be taken with caution. Stringent constraints will only be obtained if measurements constrain the momentum dependence of the isovector mean field potentials and also the isospin dependence of the in-medium cross sections. This proposal aims to provide such constraints.

We take some guidance for our proposal from recent calculations for the emission of light particles in asymmetric collisions [12]. Figure 2 shows corresponding predictions for the ratio of the center of mass spectra for neutrons and protons in central ^{52}Ca+^{48}Ca collisions at E/A=80 MeV [12]. Somewhat smaller but quite measurable effects will be observable in ^{48}Ca+^{48}Ca system that we propose to study at the NSCL. The results for three different models with different momentum dependences for the isovector mean field potential are shown in the figure illustrating the potential sensitivity to the momentum dependence of the asymmetry term that we want to explore. To constrain Coulomb effects, we propose to also measure central ^{40}Ca+^{40}Ca collisions wherein the Coulomb term remains but the asymmetry term vanishes on average.

The isospin dependence of in-medium nucleon-nucleon (NN) cross sections in asymmetric matter has also received little attention, and the few studies that explore this dependence do not lead to the same conclusion. Fig. 3 shows calculations that predict the ratio σ_{np}/σ_{pp} of in-medium cross sections may decrease as a function of the density in symmetric nuclear matter [13]. Other calculations predict an opposite trend of increasing σ_{np}/σ_{pp} with density [14]. Recently, studies have revealed a strong sensitivity in the rapidity dependence of the asymmetry δ of light particles to the isospin dependence of the in-medium cross section.[11,12]. The left side of Figure 4 shows the predictions calculated for a ^{100}Zn beam from RIA and the right panel shows the corresponding predictions for the reverse reaction with a ^{40}Ca beam. A factor of two difference in the asymmetry δ=(Y(n)-Y(p))/(Y(n)+Y(z)) is predicted at beam rapidities, depending on assumptions about the in-medium cross section. While ^{100}Zn as a beam or a target is unfeasible at the NSCL, we can perform sensitive measurements using a ^{40}Ca beam on a ^{124}Sn target and contrast those measurements with additional measurements on a ^{112}Sn target. The number of p-n collisions, which governs the predicted effect, will be roughly the same with the ^{124}Sn target as for a ^{100}Zn target, but will be more than the number of collisions for a ^{112}Sn target. On the other hand, the number of protons will be the same for both Sn targets allowing a "subtraction" of the influence of collisions with the target protons. We propose to examine the influence of the corona effect in which projectile spectator neutrons avoid the target by measuring collisions between a ^{48}Ca beam and ^{112}Sn and ^{124}Sn targets during the same experiment.

We note that the asymmetry term strongly influences the asymmetry at backward rapidities. We may choose to propose measurements of this effect in a follow up measurement involving ^{112}Sn and ^{124}Sn beams and ^{40}Ca and ^{48}Ca targets, but we do not propose this measurement at the present time.

II. Goals of the Current Experiment

In order to deconvolve the dependence of the neutron and proton observables on the isospin asymmetry, incident energy, the density and momentum dependencies of the asymmetry term in the EOS, and the isospin dependence of the in-medium cross sections, several experiments are needed. We imagine the experiment running as one block at each incident energy. Each block would involve measurements with ^{40}Ca and ^{48}Ca beams on ^{112}Sn and ^{124}Sn targets to obtain constraints on the isospin dependence of in-medium nucleon-nucleon cross sections, as well as measurements with ^{40}Ca and ^{48}Ca beams on ^{40}Ca and ^{48}Ca targets to obtain constraints on the momentum and density dependence of the asymmetry term of the EOS.

Because the densities achieved, the Pauli blocking and the momentum dependence of the mean fields evolve with incident energy, we believe that three incident energies, E/A ≈ 50, 100, and 150 MeV, will be needed to map this behavior and to permit a more accurate extrapolation to the higher-densities.

The precise energy of the beam is not critical and these three energies can be changed somewhat to optimize the operation of the facility. The beam on target can be degraded primary beam, and it is not necessary to operate the cyclotron in stand-alone mode. To obtain precise comparisons with transport theory, we must know that the efficiency of the neutron detector is independent of the beam-target combination. For example, we should do a complete set of measurements, e.g. ^{40}Ca and ^{48}Ca beams on ^{112}Sn and ^{124}Sn targets or ^{40}Ca and ^{48}Ca beams on ^{40}Ca and ^{48}Ca targets before the experiment is stopped. We would like to start with the measurements at E/A = 100 MeV.

In the Ca+Ca measurements, neutron and proton energy spectra will be measured for a symmetric system (^{40}Ca+^{40}Ca, δ=0), an asymmetric system (^{48}Ca+^{48}Ca, δ=0.17), and the mixed systems (^{48}Ca+^{40}Ca and ^{40}Ca+^{48}Ca, δ=0.09). For the Ca+sn measurements, measurements with four systems ^{40}Ca+^{112}Sn, ^{40}Ca+^{124}Sn, ^{48}Ca+^{112}Sn, and ^{48}Ca+^{124}Sn target will also be required. For each Ca+Ca and Ca+Sn system, simultaneous measurements of the spectra of isotopically resolved charged particles will allow us to track the average flow of all neutrons and protons during the collision, regardless of whether such the neutrons and protons are bound or free.

III. Experimental Details

Measurement of the relative neutron and proton flow observables in this energy regime will require three major components. These include neutron detectors with a large angular range, charged particle telescopes capable of a similar angular range and sufficient energy range to provide emission spectra extracted from the mid-rapidity region in the described reactions, and way of measuring the reaction impact parameter via charged particle multiplicity. These devices already exist in the form of the large liquid scintillator neutron walls at the NSCL, elements of the LASSA array (Alternatively, HiRA can also serve the same purpose for collisions at E/A≤100 MeV.), and the Washington University MicroBall array. Additionally, a simple position sensitive trigger detector array will also be constructed for timing and acquisition triggering.

The experimental setup is shown in Figure 5. Neutron walls will be placed a distance of about 4-6 m from the target with an angular coverage in the lab of 15^0 to 60^0, providing a center-of-mass coverage of 70^0 to 110^0 for the EOS experiment, as well as a large angular coverage at forward angles for the NN cross-section measurement. A similar coverage will be provided by six charged-particle telescopes. The S2 vault is large enough to accommodate the neutron walls north of the target area.

Impact parameter will be determined via charged-particle multiplicity in the MicroBall detector[16], which will be complimented by a granular plastic scintillator start detector. We envision using 55 CsI detectors from the five backward rings of the Microball. The Microball provides over 97% coverage over backward angles, as well as particle identification. The combined information from the charged-particle telescopes, the start detector information, and the microball will provide a good measure of the impact parameter and reaction plane needed for proper event characterization.

The start detector will be thin segmented plastic scintillator array placed at forward angles (see Fig. 5). This array provides signal with a resolution of less than 300ps, and will also serve as the time reference for the experiment. In addition to providing the time reference, the multiplicity in this detector will complement the microball multiplicity (explained below) in the impact parameter selection. Past experiments have used a four-segment version of this device. The proposed experiment will utilize a replica with higher granularity – 32 segments, in order to achieve better impact parameter identification.

The thin-walled Washington University scattering chamber at the target location will accommodate the charged-particle telescopes, the microball, and the start detector and is sufficient to perform the Ca+Sn experiments without modification. Hardware from a previous experiment (NSCL experiment #01032) already exists for mounting these detectors. For experiments with Ca targets, however, provision must be made for vacuum transfer of the targets. For this reason, it may be necessary to begin our measurements with the Ca+Sn system.

For central collisions of ^{48}Ca+^{48}Ca with a 5mg/cm^2 target, a collision rate of 7x10^4 s^{-1}pnA^{-1} is expected. The neutron detection efficiency is the limiting factor for useful events in this experiment. For both neutron walls with active areas of 4 m^2 placed 5m from the target, the geometric efficiency is 0.025. The neutron detection efficiency in the energy region of interest has been simulated to be about 10%. Given a target thickness of 5mg/cm^2, the total neutron detection rate is estimated at about 175 s^{-1}pnA^{-1}. Rate estimates, and requested time justifications for each stage of the experiment are given in Table 1. The requested time is to obtain $\geq 10^6$ useful events. Also shown are calculations for the $^{(48,40)}$Ca + $^{(112,124)}$Sn reaction for a target thickness of 5mg/cm^2.

While the NSCL is capable of intensities up to 15 pnA of Ca isotopes, an intensity of ~0.5pnA is requested to accommodate a low emittance and a small spot size. This large reduction in intensity is due to the fact that a small beam spot size – 2mm – is requested. In order to minimize background events, a beam purity of 99% is requested. A momentum acceptance of 1% or less is also desired, as well as an emittance less than about 20mrad so as to avoid background from scattering off of the downstream beamline.

In addition to the requested data-taking period, an additional 8 hours per beam/target combination is requested for background corrections using shadowbar measurements. Finally, an additional 8 hours of ^{18}O at 25 MeV/μ per run is requested for calibration of the HiRA array via proton recoils from a polyethelene target.

With the impact parameter selection criteria of the MicroBall, central collisions will be separated from the bulk data, and the two observables described previously will be studied. The relative neutron-to-proton ratios as a function of energy will be measured for angles near 90^0 in the C.M. Additionally, the prediction that the t/^{3}He ratio at intermediated energies as a measure of the asymmetry energy will be studied and constrained to predictions given by previous models [12].

The mean transverse momenta of light fragments will be measured using the methods of Tsang et al. [17]. The x-axis - corresponding to the reaction plane - will be determined by mean collective momenta of particles detected in the microball, LASSA, and the neutron wall. Particle momenta projections onto the reaction plane will be used as an independent flow measurement [17,19].

IV. Previous Measurements

Neutron and proton observables were observed for the first time in NSCL experiment 01032. Using the reactions ^{124}Sn+^{124}Sn (δ=0.19) and ^{112}Sn+^{112}Sn (δ=0.11), neutron-to-proton spectral ratios were measured at 90^0 in the center-of-mass. These results are compared to predictions from BUU calculations in Figure 6. Transverse momenta are currently being extracted from this experiment for A=1 and A=3 fragments. Results from this experiment are currently constrained to center-of-mass energies of $\lesssim$ 80 MeV. While these results appear consistent with an asy-soft EOS, higher statistics at higher center-of-mass energy will remove much of the ambiguity of this measurement. The range of asymmetry explored in this measurement is also higher than that of the previous measurement (δ(^{40}Ca+^{40}Ca)=0; δ(^{48}Ca+^{48}Ca)=0.17). The overlap between the previous experiment and the proposed experiment will allow for a more accurate extrapolation to very asymmetric matter, such as that of neutron stars.

Results from NSCL experiment 01032 are currently being finalized for journal submission this year. Preliminary results were presented at the APS Division of Nuclear Physics at Chicago in October. Also, results will be presented at the 229th American Chemical Society Meeting as an invited talk for the Glenn T. Seaborg Award Symposium.

References

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[2] Lattimer, J.M. & Prakash, M., ApJ **550** (2001) 426.
[3] Carriere, J., Horowitz, C.J., & Piekarewicz, J., ApJ **593** (2003) 463.
[4] Prakash, M., Ainsworth, T.L., & Lattimer, J.M., Phys. Rev. Lett. **61** (1988) 2518.
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[9] Chen, L. –W., Ko, C.M., & Li, B.-A., Phys. Rev. Lett. **94** (2005) 032701.
[10] Li, B.-A., Ko, C.M., & Ren, Z., Phys. Rev. Lett. **78** (1997) 1644.
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[12] Chen, L. –W., Ko, C.M., & Li, B.-A., Phys. Rev. C **69** (2004) 054606.
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[14] Kohno, M., Higashi, M., Watanabe, Y., & Kawai, M., PRC **57** (1998) 3495.
[15] Li, G.Q. & Machleidt, R., PRC **48** (1993) 1702.
[16] Sarantites, D.G., Hua, P.-F., Devlin, M., Sobotka, L.G., Elson, J., Hood, J.T., LaFosse, D.R., Sarantites, J.E., Maier, M.R., NIM A **381** (1996) 418.
[17] Tsang, M.B. et al., Phys Rev C **53** (1996) 1959.
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Table 1. Count Rate Estimates for Each Beam/Target Configuration						
Beam (0.5 pnA)	**Target**	**Central Collision Rate (s^{-1})**	**Neutron Detection Rate (s^{-1})**	**Events/day**	**Number of days**	**Total Events**
^{48}Ca	^{48}Ca	35000	88	$7.6x10^6$	1	$7.6x10^6$
^{48}Ca	^{40}Ca	35000	88	$7.6x10^6$	0.5	$3.8x10^6$
^{40}Ca	^{48}Ca	35000	88	$7.6x10^6$	0.5	$3.8x10^6$
^{40}Ca	^{40}Ca	35000	88	$7.6x10^6$	1	$7.6x10^6$
^{48}Ca	^{112}Sn	11000	28	$2.4x10^6$	1	$2.4x10^6$
^{48}Ca	^{124}Sn	11000	28	$2.4x10^6$	1	$2.4x10^6$
^{40}Ca	^{112}Sn	11000	28	$2.4x10^6$	1	$2.4x10^6$
^{40}Ca	^{124}Sn	11000	28	$2.4x10^6$	1	$2.4x10^6$

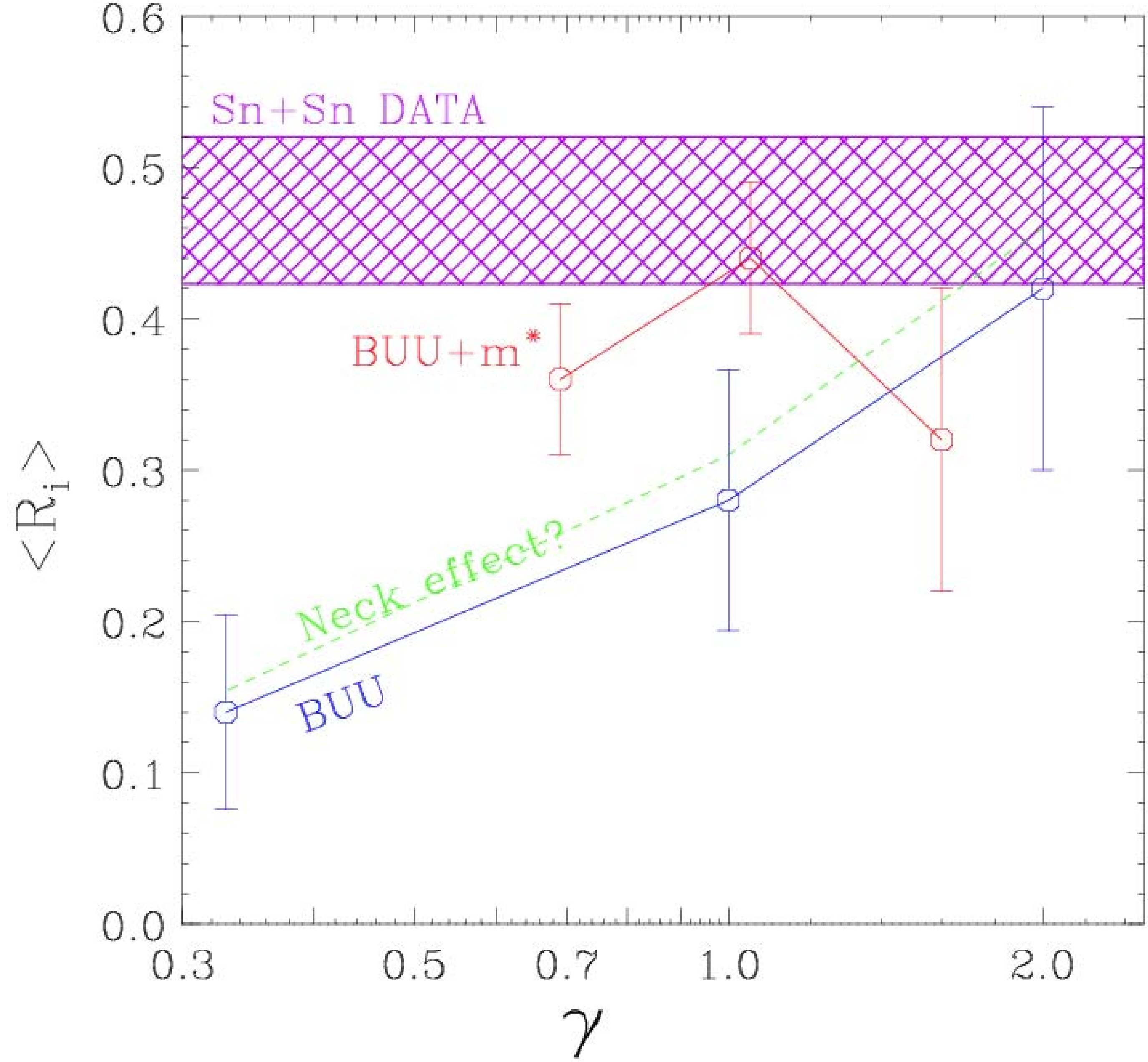

Figure 1 Comparison between measured (cross-hatched region) and calculated values (points) for the isospin asymmetry ratio constructed from semi-peripheral $^{112}Sn+^{124}Sn$, $^{112}Sn+^{124}Sn$, $^{124}Sn+^{112}Sn$ and $^{124}Sn+^{124}Sn$ collisions.[9]

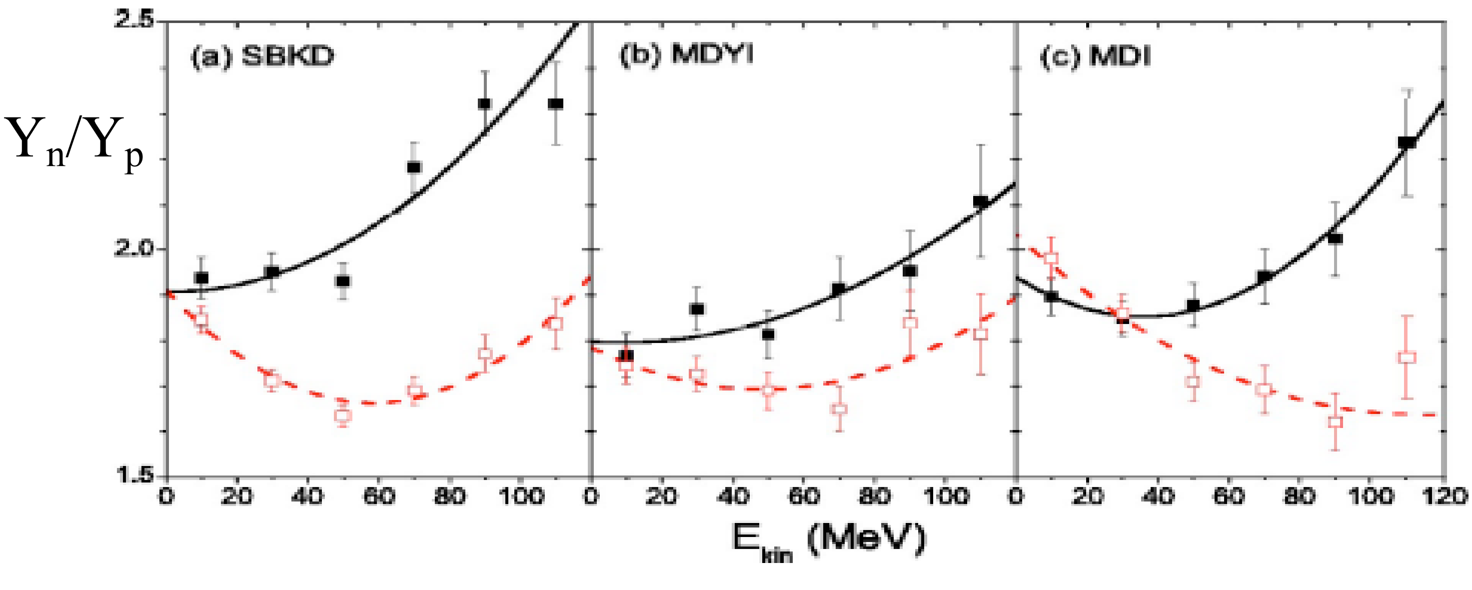

Fig. 2: Calculated pre-equilibrium yield ratios of tritium and ^3He for the $^{52}Ca+^{48}Ca$ reaction at 80 MeV/μ. Each plot corresponds to a different model. In each plot, the solid squares correspond to ratios predicted using an "asy-soft" potential, while the empty squares correspond to an "asy-stiff" potential [10].

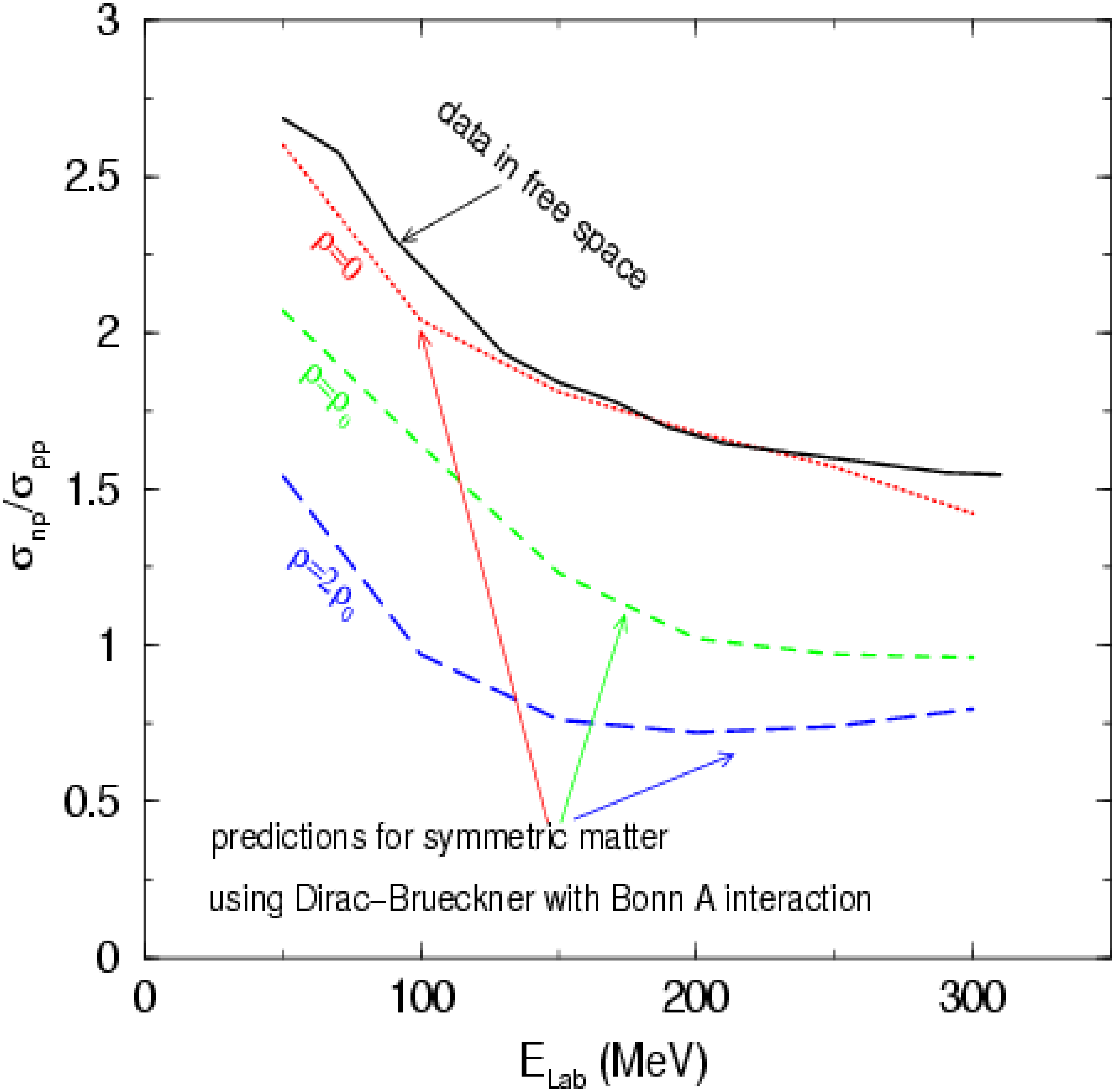

Fig. 3 Predicted in-medium nucleon cross section ratios as a function of density and lab energy [11].

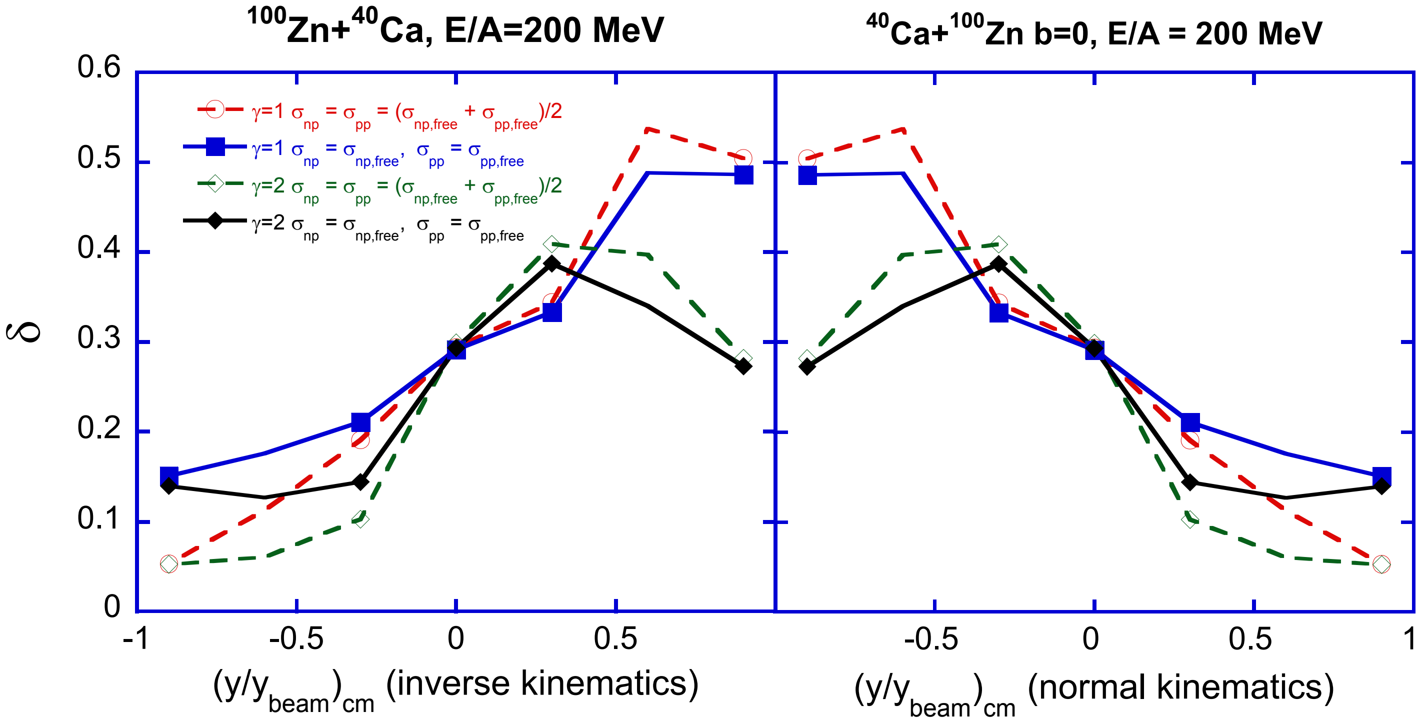

Fig. 4: Predicted isospin asymmetries as a function of relative rapidity for an asy-soft (γ=1) and asy-stiff (γ=2) EOS for two different extremes in the NN in-medium cross-sections.

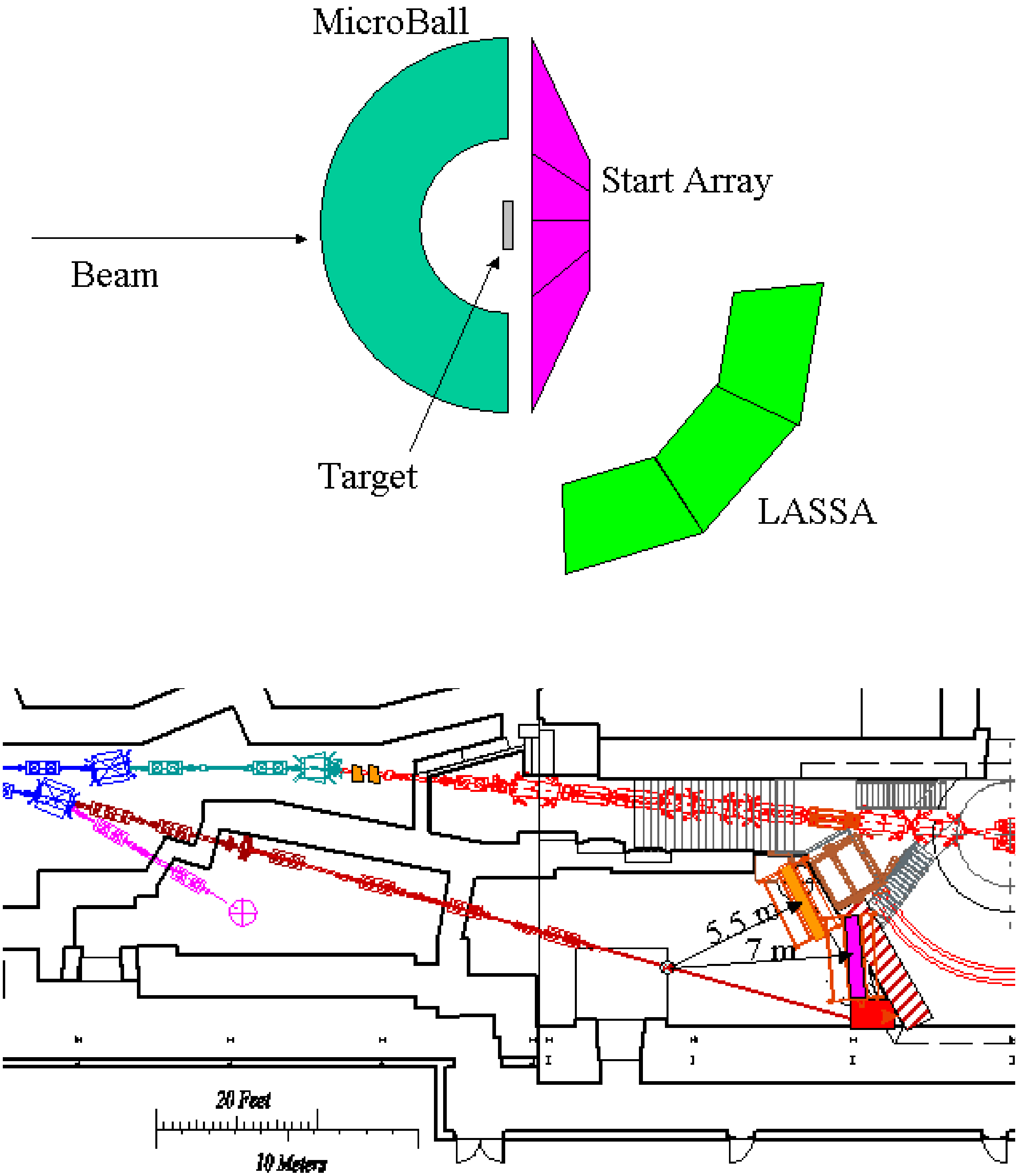

Fig. 5: Diagram of proposed experimental setup with the target location installed on the RPMS line in the S2 vault (top). The neutron walls are located at roughly 5.5m and 7m. The bottom figure shows a schematic of the proposed setup of the scattering chamber.

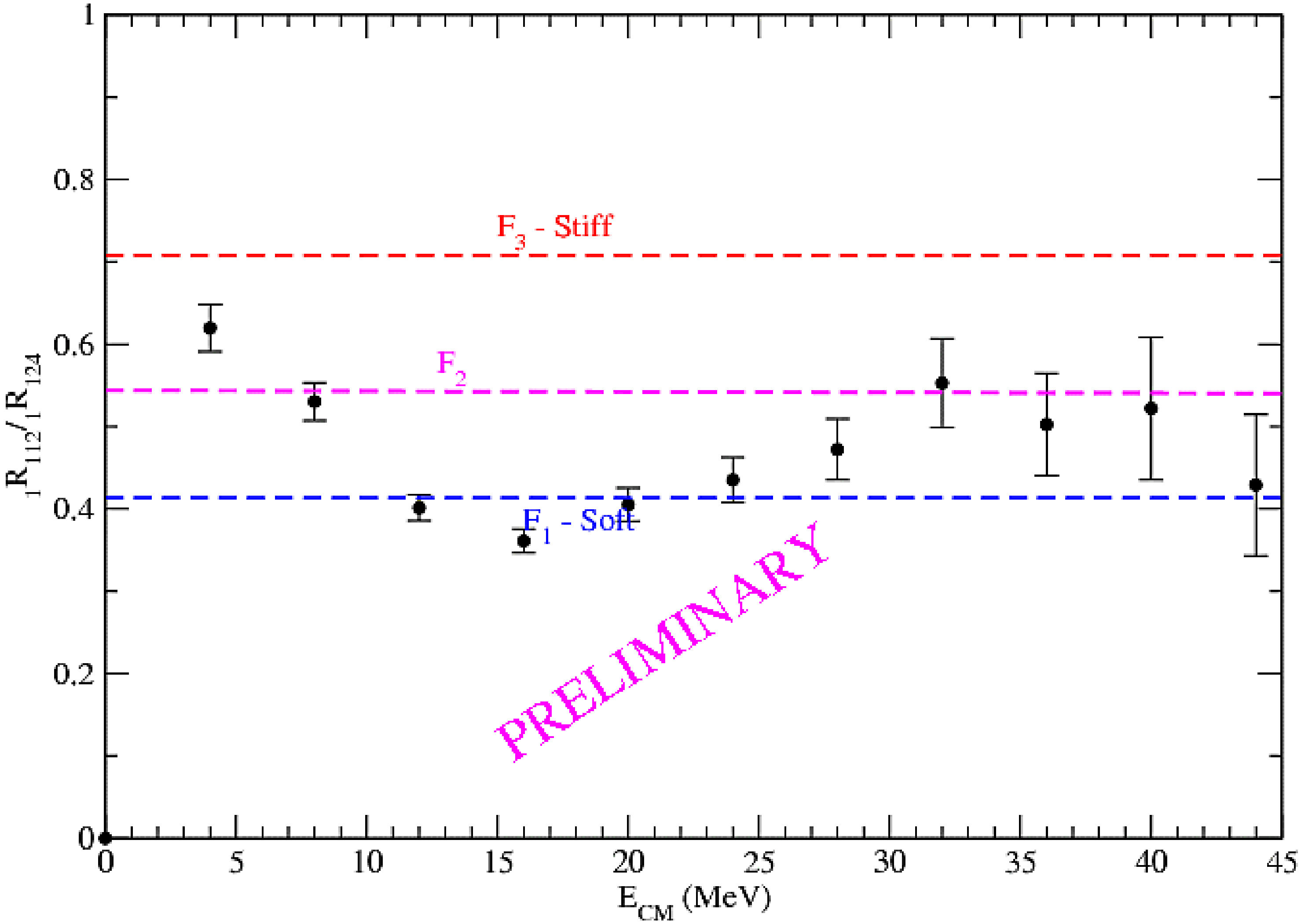

Fig. 6: Experimental pre-equilibrium yield ratios of neutrons to protons for the two systems compared in Figure 3 compared to theoretical predictions[8]. Shown are the double ratios for each measurement, i.e, $(Y_n/Y_p)_{112}/(Y_n/Y_p)_{124}$ is plotted. The results are from NSCL experiment #01032.

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 you will need to designate a Safety Representative for your experiment.

SAFETY CONTACT FOR THIS PROPOSAL: ______________________________

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

X	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.

Sealed gamma ray sources (~1μCi) will be required for liquid scintillator calibrations.
Neutron sources will also be required (e.g., PuBe) for n-γ discrimination tests of the neutron walls.
Alpha sources (e.g., ^{241}Am) will be required for silicon detector calibration.

BEAM REQUEST WORKSHEET INSTRUCTIONS

Please use a separate worksheet for each distinct beam-on-target requested for the experiment. Do not forget to include any beams needed for calibration or testing. This form does not apply for experiments based in the A1900. Note the following:

(a) **Beam Preparation Time** is the time required by the NSCL for beam development and beam delivery. This time is calculated as per item 4. of the Notes for PAC 28 in the Call for Proposals. This time is not part of the time available for performing the experiment.

(b) **Beam-On-Target Time** is the time that the beam is needed by experimenters for the purpose of performing the experiment, including such activities as experimental device tuning (for both supported and non-supported devices), debugging the experimental setup, calibrations, and test runs.

(c) The experimental device tuning time (XDT) for a supported device is calculated as per item 5. of the Notes for PAC 28 in the Call for Proposals. For a non-supported device, the contact person for the device can help in making the estimate. In general, XDT is needed only once per experiment but there are exceptions, e.g. a change of optics for the S800 will require a new XDT. When in doubt, please consult the appropriate contact person.

(d) A **primary beam** can be delivered as an on-target beam for the experiment either at the full beam energy or at a reduced energy by passing it through a degrader of appropriate thickness. The process of reducing the beam energy using a degrader necessarily reduces the quality of the beam. Please use a separate worksheet for each energy request from a single primary beam.

(e) Report the Beam-On-Target **rate** in units of particles per second per particle-nanoampere (pps/pnA) for secondary beams or in units of particle-nanoampere (pnA) for primary or degraded primary beams.

(f) More information about **momentum correction** and **timing start signal** rate limits are given in the A1900 service level description.

(g) For rare-isotope beam experiments, please remember to send an electronic copy of the LISE++ files used to obtain intensity estimates.

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{40}Ca	
Energy	140	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{40}Ca	
Energy	140	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22** **hrs**

Experimental device tuning time [see note (c) above]: 0 hrs

S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]

On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: **56** **hrs**

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{40}Ca	
Energy	90	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{40}Ca	
Energy	90	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22 hrs**

Experimental device tuning time [see note (c) above]: 0 hrs

S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]

On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: **56 hrs**

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{40}Ca	
Energy	50	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{40}Ca	
Energy	50	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%

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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22 hrs**

Experimental device tuning time [see note (c) above]: 0 hrs
S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]
On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: **56 hrs**

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

		Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{48}Ca	
Energy	140	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{48}Ca	
Energy	140	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22 hrs**

Experimental device tuning time [see note (c) above]: 0 hrs

S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]

On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: **56 hrs**

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{48}Ca	
Energy	90	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{48}Ca	
Energy	90	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22 hrs**

Experimental device tuning time [see note (c) above]: 0 hrs

S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]

On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: **56 hrs**

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{48}Ca	
Energy	50	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{48}Ca	
Energy	50	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22** **hrs**

Experimental device tuning time [see note (c) above]: 0 hrs

S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]

On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: **56** **hrs**

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

		Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{40}Ca	
Energy	140	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{40}Ca	
Energy	80	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: 22 hrs

Experimental device tuning time [see note (c) above]: 0 hrs
S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]
On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: 56 hrs

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{48}Ca	
Energy	140	MeV/nucleon
Minimum intensity	0.5	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{48}Ca	
Energy	80	MeV/nucleon
Rate	0.5pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	99	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22** **hrs**

Experimental device tuning time [see note (c) above]: 0 hrs

S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]

On-target time excluding device tuning: 56 hrs

Total on-target time for this beam: **56** **hrs**

BEAM REQUEST WORKSHEET

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{18}O	
Energy	25	MeV/nucleon
Minimum intensity	2	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{18}O	
Energy	25	MeV/nucleon
Rate	2pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	95	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22 hrs**

Experimental device tuning time [see note (c) above]: 0 hrs

S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]

On-target time excluding device tuning: 8 hrs

Total on-target time for this beam: **8 hrs**

Please use a separate sheet for each distinct beam-on-target requested

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope	^{18}O	
Energy	25	MeV/nucleon
Minimum intensity	2	particle-nanoampere

Tuning time (18 hrs; 0 hrs if the beam is already listed in an earlier worksheet): 18 hrs

Beam-On-Target

Isotope	^{18}O	
Energy	25	MeV/nucleon
Rate	2pnA	pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance	1	% (e.g. 1%, not ±0.5%)
Minimum Acceptable purity	95	%
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

Delivery time per table (or 0 hrs for primary/degraded primary beam): 0 hrs

Tuning time to vault: 4 hrs

Total beam preparation time for this beam: **22 hrs**

Experimental device tuning time [see note (c) above]: 0 hrs
S800 [ ] SeGA [ ] Sweeper [ ] Other [ ]
On-target time excluding device tuning: 8 hrs

Total on-target time for this beam: **8 hrs**