National Superconducting Cyclotron Laboratory
Proposal Form—PAC 35

TITLE: _ **Continuum spectroscopy of: ^{9}C-^{8}B$_{IAS}$, ^{12}O-^{12}N$_{IAS}$, and ^{16}Ne- ^{16}F$_{IAS}$.**

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

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OTHER EXPERIMENTERS: (Please spell out first name and indicate Graduate Students (GS), Undergraduate students (UG) and Postdoctoral Associates (PD); include a separate sheet if necessary)

Last name, First name	Organization	Last name, First name	Organization
Shane, Rebecca	WU - GS	**Lynch, Bill**	MSU
Dirks, Rebecca	WU - UG	**Tsang, Betty**	MSU
Elson. Jon	WU- Engineer	**Chajecki, Zbigniew**	MSU-PD
Wuosmaa, Alan	WMU	**Youngs,Michael**	MSU-GS
Shore, Aimee	MSU-GS	**Coupland,Daniel**	MSU-GS
Baugher, Travis	MSU-GS	**Gade,Alaxander**	MSU
Stroberg, Ragnar	MSU-GS	**Weisshaar,Dirk**	MSU
Winkler, Rayan	MSU-PD	**Bedoor, Shadi**	WMU-GS
Winkelbauer, Jack	MSU-GS	**Hodges, Rachel**	MSU-GS

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	**^{16}O**	150	150	(12+5)+(12+5)+4(5)= 54	(72)+(48)+4(5)= 140
Beam 2	**^{20}Ne**	120	100	(12+5)=17	(48)
Beam 3					
Beam 4					

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: Dev. of 20Ne beam

Total Hours: 71 | 188

TOTAL TIME REQUEST (HOURS): _235_______
(Calculated as per item 5. of the Notes for PAC 35 in the Call for Proposals)

Access to:		SET UP TIME (before start of beam)	TAKE DOWN TIME
	Experimental Vault	___20_____ days	____10____ days

Electronics Set-up Area	___20_____ days	____10____ days
Data Acquisition Computer	___20_____ days	____10____ days

HOURS APPROVED: ________________ HOURS RESERVED: _____________________

WHEN WILL YOUR EXPERIMENT BE READY TO RUN? ___________ / ________ / _________

DATES EXCLUDED: ____

EXPERIMENTAL LOCATION:

___ Transfer Hall (in the A1900) ___ Transfer Hall (downstream of the A1900)
___ N2 vault ___ N2 vault (with Sweeper line)
___ S2 vault (Irradiation line) _x__ S2 vault
___ S3 vault (We could run in the s-800 line. This would only make sense, if HiRA was already set-up there.)

EXPERIMENTAL EQUIPMENT:

___ A1900 ___ Beta Counting System ___ Beta-NMR Apparatus
___ Sweeper Magnet ___ Neutron Walls ___ LENDA
___ Modular Neutron Array ___ Neutron Emission Ratio Observer
_X__ High Resolution Array ___ 53" Chamber _X_ CsI(Na) Scintillator Array
___ Segmented Ge Array: [ ] classic; [ ] mini; [ ] beta; [ ] delta; [ ] barrel; [ ] other
___ S800 Spectrograph: [ ] with; [ ] without scattering chamber
_X__ Radio Frequency Fragment Separator ___ DDAS ___ Other (give details)

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): [X] NONE

_______________Be____
REACTION TARGETS AT EXPERIMENTAL STATION:

LIST ALL RESOURCES THAT YOU REQUEST THE NSCL TO PROVIDE FOR YOUR EXPERIMENT BEYOND THE STANDARD RESOURCES OUTLINED IN ITEM 12 OF THE NOTES FOR PAC 35 IN THE CALL FOR PROPOSALS. [ ] NONE

LIST ANY BREAKS REQUIRED IN THE SCHEDULE YOUR EXPERIMENT, OR CHECK NONE: (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.) [ ] NONE
It might be reasonable to split the experiment into two segments, one using the ^{16}O primary and the other using the ^{20}Ne primary.

OTHER SPECIAL REQUIREMENTS: (Safety related items are listed separately on following pages.) [ ] NONE

SUMMARY (no more than 200 words):

1. **Detect the gamma ray from the decay of the residue (^{6}Li$_{IAS}$). from the ^{8}B$_{IAS}$ 2*p* decay.**
2. **Measure the 3-body correlations for ^{8}B$_{IAS}$ 2*p* decay so that a comparison to the ^{8}C 2*p* decay can be made.**
3. **Collect the data required to find two more cases of IAS-2*p* decay: ^{12}N$_{IAS}$ and ^{16}F$_{IAS}$.**

4. **Measure the 2-dim correlation data for 2*p* decay from the T_z=-2,T=2 ^{12}O and ^{16}Ne ground states and compared to 3-body calculations.**
5. **Obtain higher resolution measurements of the decay widths of the ^{8}C, ^{12}O and ^{16}Ne ground states.**

Description of Experiment

(no more than 4 pages of text for items 1through 3 - 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—what is to be measured; technical feasibility of measurement; count rate estimate; basis of time request; discussion of present state of readiness of the experiment and an estimated earliest date for inclusion in the run schedule; discussion of any technical assistance (design, fabrication, installation, etc.) that may be requested from NSCL; apparatus (including sketch).

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

Physics Justification

Overview

In our previous continuum-decay spectroscopy study (08001, done in January 2010) we found that: a) the ^{8}C ground state decays via two sequential steps of prompt 2*p* decay (through the $^{6}Be_{gs}$ intermediate state), b) the first 2*p* decay in this sequence has a enhanced “diproton” character, and c) that the analog of ^{8}C in ^{8}B ($^{8}Be_{IAS}$) also undergoes 2*p* decay [1]. The latter case, one of three cases we intend to study further here, is the first case of a 2*p* decay for which 1*p* decays are energetically allowed but isospin forbidden.

Figure 1 shows the level diagrams for the decay of ^{8}C (top) and $^{8}B_{IAS}$ (bottom). The previous experiment was designed to study the former, but we got a glimpse of the latter. We had set up our ranges in the Si ΔE detectors for the decay products of ^{8}C, only alphas and protons. However we just caught a sliver of the ^{6}Li locus in our ΔE-E maps, otherwise most of them over-ranged the amplifiers. This resulted in a substantial bias on the measured correlations between the decay fragments.

The experiment we propose now will get an unbiased data set on this first case of IAS 2*p* decay and search for two more likely cases (see Table I and Fig. 2.). The major difference between the *A*=8 case as compared to the *A*=12 and A=16 cases is that *the energies of the* $^{12}N_{IAS}$ *and* $^{16}F_{IAS}$ *are not known*. In fact, the correlation measurement proposed here is likely the best way to find these states and to determine their energies to high accuracy (to within 15 keV.) Doing so will allow for a study of the Coulomb shifts for *A*=8, 12, and 16 nuclei for cases pressed into the continuum. As is the case ^{11}Li-$^{11}Be_{IAS}$ [2] one expects that the 2nd s state will have come down so that it plays a role in the structure of nuclei generally considered to be p-shell.

There are no data on IAS 2*p* decay other than ours on $^{8}B_{IAS}$. There are exiting data on ^{12}O ground-state decay [3] (on which a subset of the collaboration participated) and on ^{16}Ne [4]. The latter data are of marginal statistical significance and the ground-state decay was not well isolated.

TABLE I

Primary	Secondary	pps/pna	purity	T_z=2		IAS	IAS 2p Final state
^{16}O➔	^{9}C	1.6*10^{3}	>90%	$^{8}C_{gs}$ ➔	^{6}Be+2p	$^{8}B_{IAS}$➔	$^{6}Li_{IAS}$ (3.56 MeV)+2p
^{16}O➔	^{13}O	4.7*10^{3}	40% ^{12}N,^{11}C,^{10}B	$^{12}O_{gs}$➔	^{10}C+2p	$^{12}N_{IAS}$ ➔	$^{10}B_{IAS}$(1.740 MeV)+2p
^{20}Ne➔	^{17}Ne	2.2*10^{3}	20% ^{16}F,^{15}O,^{14}N	$^{16}Ne_{gs}$ ➔	^{14}O+2p	$^{16}F_{IAS}$➔	$^{14}N_{IAS}$ (2.313 MeV)+2p

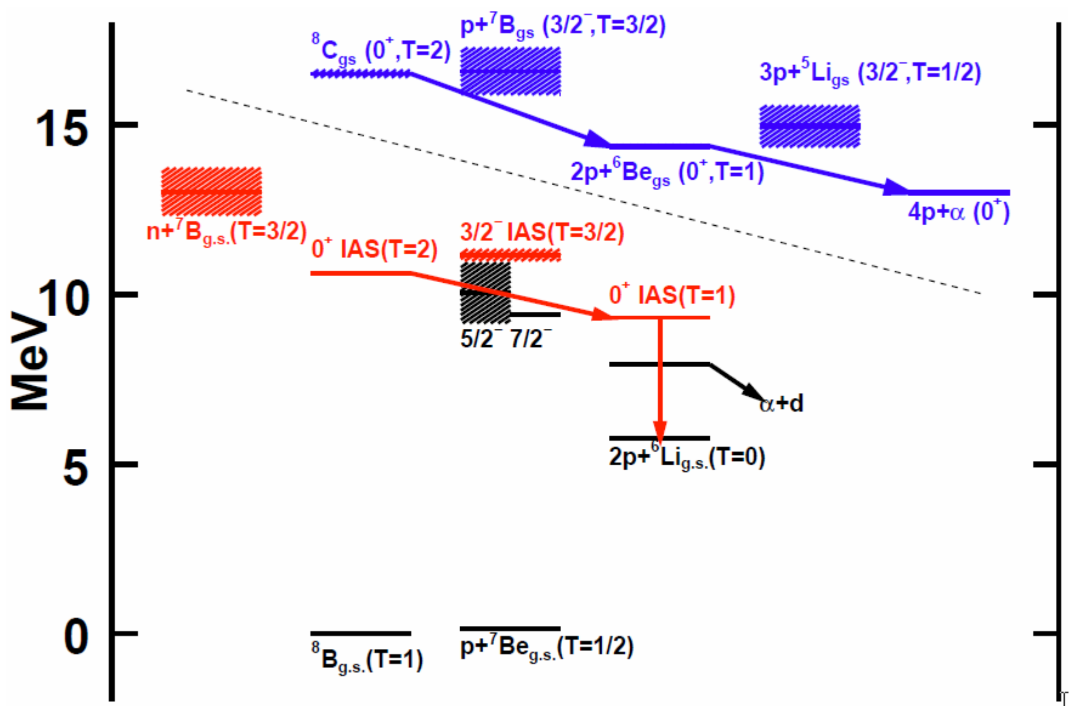

Fig. 1: Decay schemes for A=*8* 2*p* decay cases. Decay of ^{8}C has been shifted up the ordinate. The decays in color are isospin allowed. The decay indicated by the red arrows are those we intend to study here.

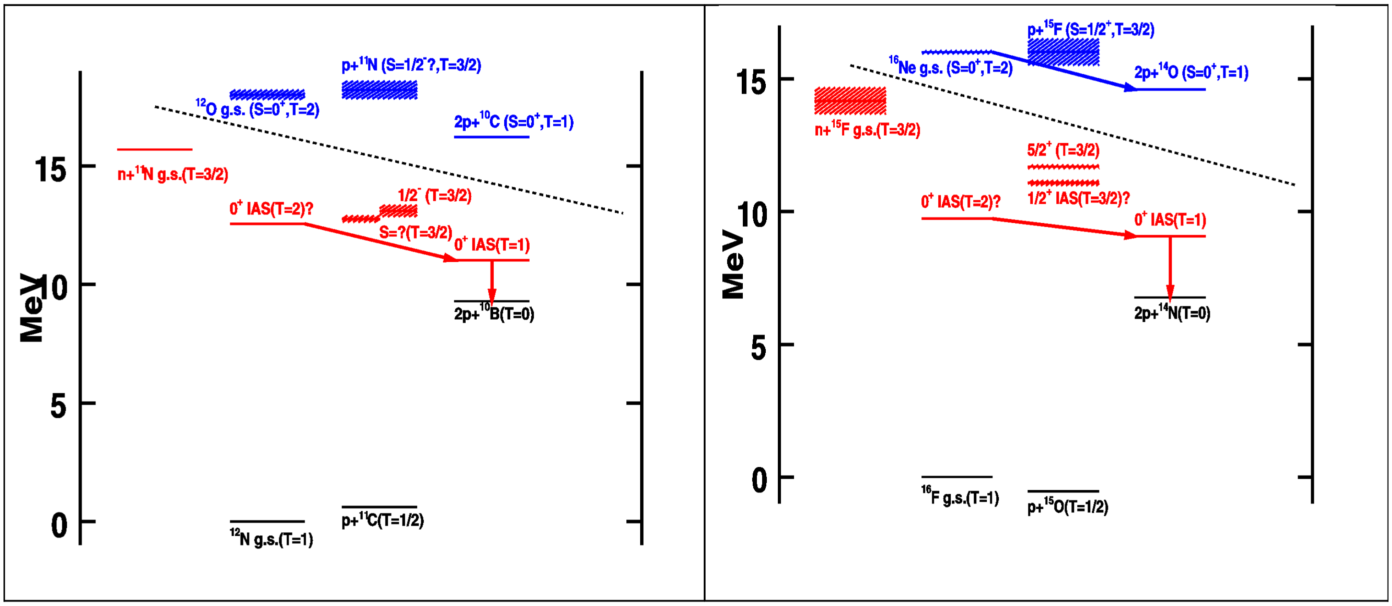

Fig. 2: Decay schemes for A=12 (left) and A=16 (right) suspected 2p decay cases. Decay of schemes of the $T=2,T_z=-2$ cases has been shifted up the ordinate. The decays in color are isospin allowed. Note the energies of $^{12}N_{IAS}$ and $^{16}F_{IAS}$ are unknown, in these figures they are taken from the energy of the mirror level minus 200 keV which gives the correct value for $^{8}B_{IAS}$.

Background

We summarize the results from our prior experiment in this section [1]. This experiment had two parts, one using a secondary beam of ^{7}Be and the other with a secondary beam of ^{9}C. Figure 3 shows the reconstructed excitation spectra for a) ^{8}C and b) ^{6}Be from the ^{9}C and ^{7}Be secondary beams, respectively. The ground states of ^{8}C and ^{6}Be are clearly seen (in parts a and b, respectively), as is the first excited state of ^{6}Be (in part b). The spectrum resulting from all 6 combinations of α-p-p grouping from each α-p-p-p-p events (consistent with $^{8}C_{g.s.}$ formation) leads to the ^{6}Be spectrum shown in c). If ^{6}Be is the intermediate in all ^{8}C decays, one expects to see the $^{6}Be_{gs}$ signature from the correct combination along with a background from the 5 miscorrelated combinations. The peak at Ex(^{6}Be) = 0 in Fig. 3c is almost exactly 1/6th of the total area, indicating that the decay sequence of ^{8}C leads through $^{6}Be_{gs}$ all, or almost all, of the time. (For details see [1], available on request.)

The projected correlations in the two 3-body decay steps of ^{8}C decay, as well as those seen directly from ^{6}Be decay, are shown in Fig. 4. The correlations shown here are the projections of the Jacobi "T" system. In this system the energy coordinate is the fraction of the total decay energy in the p-p relative motion. The decay of ^{6}Be, either directly (e and f) or as the second step in ^{8}C decay (c and d) are similar to each other and to the 3-body quantum model of Grigorenko [5]. The first 2p decay step of ^{8}C shows an enhancement at small relative proton energy (see Fig. 4 b). This region is sometimes called the "diproton" region.

Figure 5 shows the reconstructed decay of ^{8}B from the 3-particle exit channel ^{6}Li-p-p. (These data were generated with the sliver of ^{6}Li events on scale.) The peak could correspond to either a

7.05 MeV in ^{8}B, if the ^{6}Li ground state was directly populated, or a 10.61 MeV state, if the 3.5-MeV T=1 ^{6}Li state was populated (this is the only gamma-decaying state in ^{6}Li). Based on the mirror nucleus, we do not expect any narrow state at 7.05 MeV, but the alternative, 10.61 MeV, is exactly the energy of the IAS in ^{8}B. Thus is the first case of 2*p* decay where 1-nucleon decay is either energetically allowed and isospin forbidden or, the reverse, isospin allowed but energy forbidden. It thus opens a widow for a new class of 2*p* emitters where isospin plays a major role. We proposed to detect the 3.5-MeV gamma ray to confirm, without any doubt, that the IAS state in ^{8}B is responsible for these 2*p* decays. Adding a modest array of gamma detectors around the target is the most significant change to the apparatus. The decay of the IAS (i.e. $^{8}B_{IAS}$) should show, in the absence of isospin breaking effects, the same "diproton" enhancement seen in the first step of ^{8}C decay. One of the principle goals is to obtain these correlations.

The ^{8}C and $^{8}B_{IAS}$ fragments were obtained from neutron and proton knockout from a ^{9}C beam. With ^{13}O and ^{17}Ne beam we can obtain two other pairs of ground-state (T_z =-2, T = 2) and IAS (T_z=-1,T=2) two-proton decays. Namely a) ^{12}O:$^{12}N_{IAS}$, and b) ^{16}O:$^{16}F_{IAS}$. See Table I and Fig.2 for details. The energies of the $^{12}N_{IAS}$ and $^{16}F_{IAS}$ states are unknown and by measuring them we will complete the T=2 isobaric quintets for A=12 and 16. These can then be fit with the isobaric-multiplet mass equation. Deviations from this equation give information on isospin mixing [6].

The decay of ^{8}C is the only case where the residue of the 2*p* decay is particle unbound. In all other cases, the decays from the T_z =-2, T = 2 ground states produce the particle-bound ground states (^{10}C and ^{14}O) while the 2p decays from their IAS should populate the T=1 particle-bound excited states of the T_z=0 residue ($^{6}Li_{IAS}$, $^{10}B_{IAS}$,$^{14}N_{IAS}$). The latter have excitation energies of 3.56, 1.74, and 2.31 MeV and all gamma decay. Our former experiment was a 5-particle correlation experiment (for ^{8}C decay). Here we are proposing to obtain the 3-particle correlations on the new pairs ^{12}O:$^{12}N_{IAS}$ and ^{16}O:$^{16}F_{IAS}$. The T_z =-2,T = 2 cases are produced in low cross section (~ 5 mb) via neutron removal, the IAS versions are produced with almost a factor of 10 higher cross section via proton removal.

The $^{16}F_{IAS}$ 2*p* case is particularly nice in that the 1p isospin allowed decays are expected to have significant positive Q values (Fig 2) like the $^{8}B_{IAS}$ case. On the other hand, the $^{12}N_{IAS}$ might (depending on the precise energy of this state) be able to decay via sequential 1*p*-1*p* emission through the moderately narrow 270-keV-wide $^{11}C_{IAS}$. (Fig. 2). The phase space of the first decay would however be very small. The 2-dim correlation plots will provide information on the decay process.

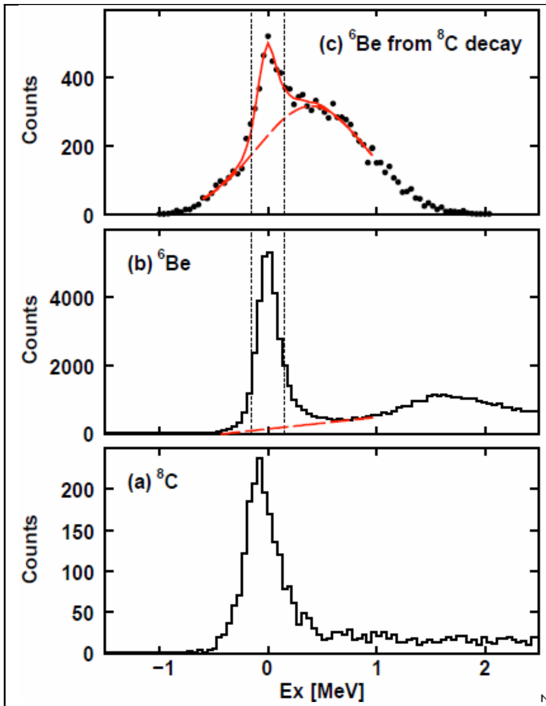

Fig. 3: Reconstructed excitation energies of: a) ^{8}C from α-p-p-p-p events (^{9}C beam), b) ^{6}Be from α -p-p events (^{7}Be beam), and c) ^{6}Be from α -p-p-p-p events (consistent with $^{8}C_{g.s.}$ formation) using all 6 combinations,

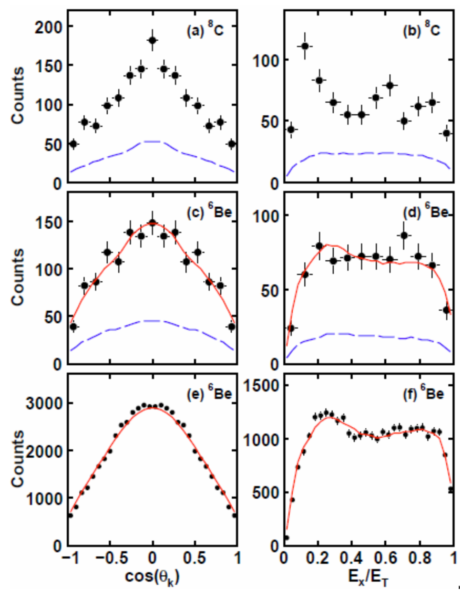

Fig. 4: Projections on the Jacobi "T' coordinates for: a,b) First step of ^{8}C decay, C,d) the second step of ^{8}C decay (i.e. ^{6}Be decay) and e,f) ^{6}Be decay. The 3-body quantum calculations [5] are shown, after passing a detector filter, in red. The dashed lines are the background from wrongly chosen combinations.

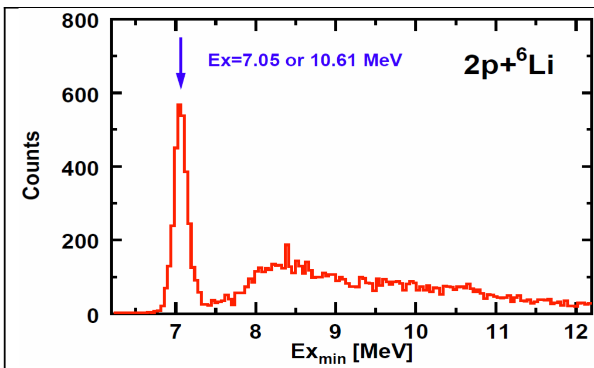

Fig. 5: Reconstructed excitation of ^{8}B from ^{6}Li-p-p events. With no missing energy, the sharp peak corresponds to an excitation energy of 7.06 MeV. There is no known state at this energy. If the decay goes to the T=1 state in ^{6}Li, there is a missing energy of 3.56 MeV. Adding this energy gives the excitation energy of the T=2 state in ^{8}B, see Fig. 5.

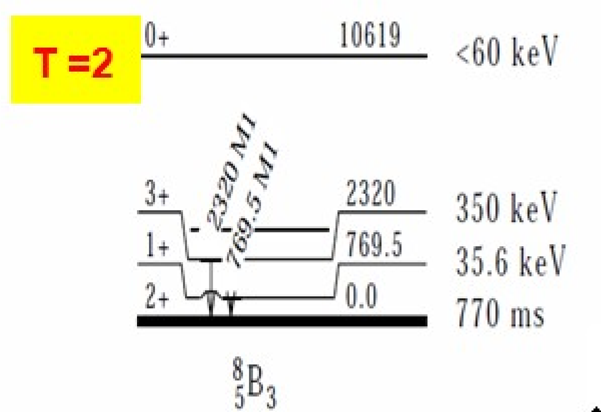

Fig. 6: Known levels in 8B.

The nature of the 2*p* decay of the ^{12}O and ^{16}Ne ground states (sequential through the ^{11}N or ^{15}F ground states or 3-body) is also connected to the width of these states. In the original ^{12}O decay measurement of Kryger[3], diproton emission of the two-protons was inconsistent with the measured correlations, and, although sequential emission through the ^{11}N ground state was consistent with the correlations, is was not consistent with the large ^{12}O decay width of ~400 keV determined in this work and from [7]. In a later paper [8], it was suggested that if the ^{11}N ground state, which is not well determined experimentally, was lower in energy, a sequential scenario would be consistent. Subsequently, Barker stated that this paper was inconsistent and that the ground-state width of ^{12}O is much narrower than the reported experimental values [9]. This was reiterated by Gregorenko et al. [10] who also suggested that the width should be < 100 keV. Gregorenko et al also suggested that the experimental width tabulated for ^{16}Ne (~122 keV) is also too large.

In addition to the above uncertainties, the possible intermediate states (^{11}N and ^{15}F ground states) have a proton in the $s_{1/2}$ orbital and their widths are expected to be quite large. Thus the concept of a sequential decay may not make sense as, during the lifetime of the intermediate state, the first proton will not have traveled any distance and thus the two protons come out at essentially the same time. The ^{6}Be ground-state 2p decay has a similar situation and it requires a three-body calculation to reproduce the correlations [8,11]. The full correlations in two-proton decay are completely described in 2 dimensions and unfortunately Kryger et al. presented only a one-dim distribution which are less stringent in defining the decay mechanism. Theoretical two-dimensional correlations from 3-body calculations already exist for ^{12}O and ^{16}Ne [10]. The only other cases where experimental and theoretical two-dim correlations have been compared are ^{6}Be and ^{45}Fe [12].

In the proposed experiment, we will also be able to measure the ^{12}O and ^{16}Ne ground-states widths with improved resolution. Our simulated experimental resolution (FWHM) is 200 keV with a 1-mm-thick Be target. This is a significant improvement to the ~500-keV resolution obtained in the Kryger experiment [3]. The 2^+ first excited states of ^{12}O and ^{16}Ne should have excitation energies greater than 1.5 MeV and so, with our simulated resolution, these should be clearly separated from the ground states. The ^{12}O first excited state is interesting in itself, Suzuki et al. [13] report an excitation energy of 1.8 MeV, this is a striking 1 MeV lower than the corresponding mirror level in ^{12}Be. This is yet to be explained. The Suzuki data suffers from a large background contribution and the proposed experiment should be able to check this value of the excitation energy.

Goals of the proposed experiment

Our goals are to:

a) Obtain high statistics data for the 2*p* decay of the ^{12}O and ^{16}Ne ground states, construct the 2-dim correlations and compare them to the 3-body calculations of Gregorenko et al.
b) To measure the ground-state widths of ^{12}O and ^{16}Ne with improved resolution compared to past experimental studies.
c) To measure the correlations in the two-proton decay of the T=2 isobaric analog of ^{8}C in ^{8}B and compared them to the ground-state correlations.
d) Use 2*p* decay to locate the IAS in ^{12}N and ^{16}F and measure the correlations.
d) To measure the gamma rays emitted from the residue T=1 states formed in these decays to confirm the decay scenario.

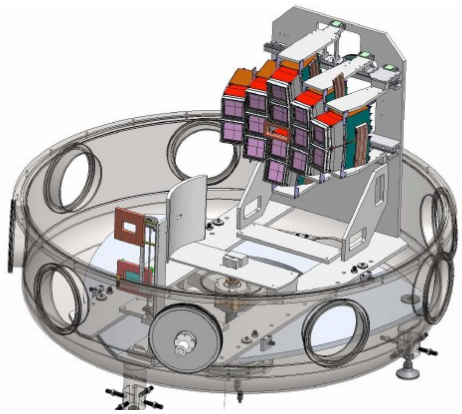

Fig: 7 Apparatus for 8001. The vault is S2 and the target and HiRA are shown in the chamber.

Experimental Details

We will make three changes to the apparatus used in our previous experiment displayed in Fig. 7. None of these changes are major. As the last experiment was focused on detecting protons and alphas in HiRA, the lithium fragments were almost pushed entirely off scale. A small change to the electronics will allow all Li fragments to be detected. (This is a truly trivial modification; only 28 resistors need to be changed.) This is adequate for detecting the $^{6}Li_{IAS}$, the residue of $^{8}B_{IAS}$ decay. However, the chip's internal charge-sensitive amplifier (CSA) on our ASIC will saturate for the residues of the other two cases.

While coverage for protons needs to be extended to rather large angles, almost all of the residues for the ^{13}O and ^{17}Ne beams hit the two detectors closest to the beam. Figure 8 shows simulations of the hit patterns for protons (left) and residues (right) for the selected cases (see caption.) Fortunately our ASIC has the unusual feature that we can use external CSAs. (We generally employ this feature for thinner Si detectors due to their large capacitance.) We intend to use this feature with lower-gain external CSAs (5 mV/MeV - the internal one is 12 mV/MeV) on just the two detectors above and below the beam. These 128 preamplifiers all exist as does all the hardware to use them. (We will use external CSA system built at WU and which were used several times including for our experiments on ^{10}C at TAMU).

Finally, we intend to move the target into an upstream beam box and slide HiRA closer to the center of the scattering chamber. The target to HiRA distance will be slightly longer than used in 08001, this will improve the efficiency for residue detection in the proposed reactions. However the main reason for doing this is to allow us to assemble a modest array of gamma detectors around the secondary target. We plan on using the upstream half of the CAESAR array.

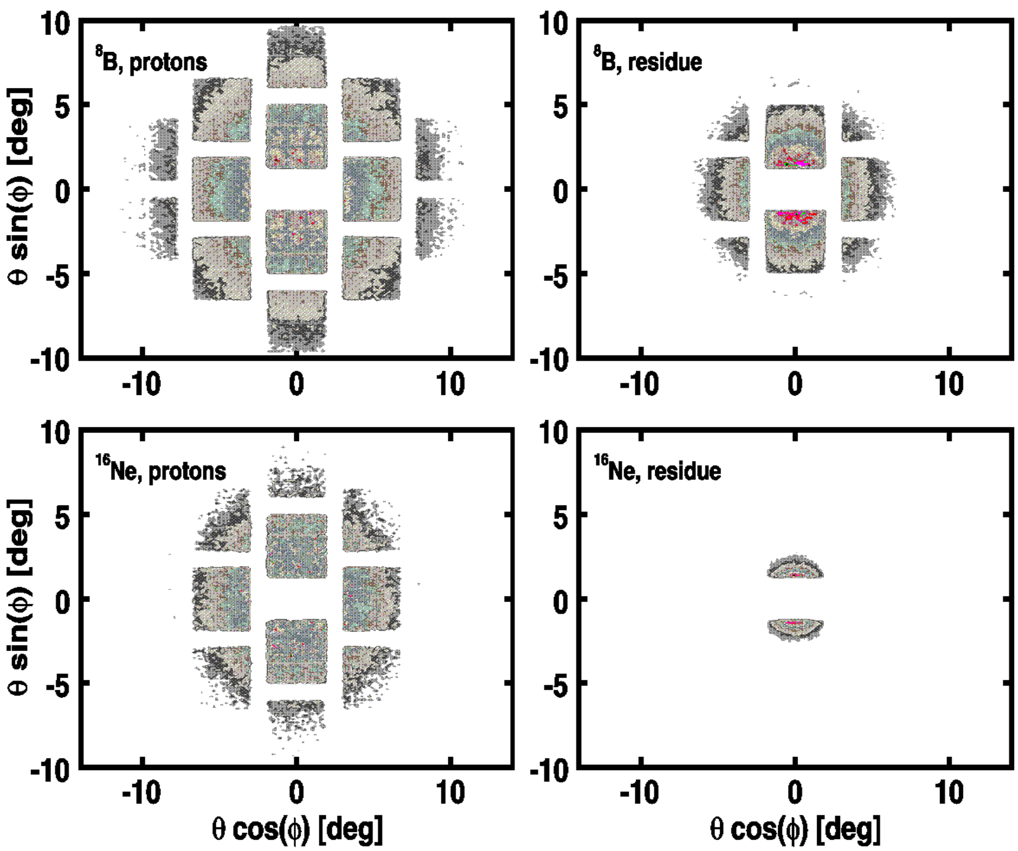

Fig: 8 Simulated hit pattern on the HiRA detectors for protons and the residues in the ^{16}Ne ground state and $^{8}B_{IAS}$ decays.

Time estimates

Proton knock-out (leading to the IAS), from these proton rich nuclei, proceed with cross sections several times larger than the neutron removal. On the other hand, we want to detect the coincident gamma rays in the IAS decays. These effects largely cancel, and the two objects of study from each pair require about the same time. Our goal is to collect 2000 *p*-*p*-residue events for the T_z=-2, T=2 ground-state cases and 10,000 for the IAS T_z=-1 cases. Simulations predict a 4% photopeak efficiency for the upstream half of CAESAR. See Fig. 9 the simulated response. (We only need to show the gamma ray is in coincidence with the sharp reconstructed peak. If it is, it must be so 100% of the time.) Of course, the pairs (e.g. ^{16}Ne-$^{16}F_{IAS}$) come in at the same time so three secondary beams (from two primary beams) must be requested. Our simulations indicate that 50 hours of data collection is required for each pair. With time to verify that the data are sound, we have requested 3 days per secondary beam plus an additional day for shake-down at the beginning of the run.

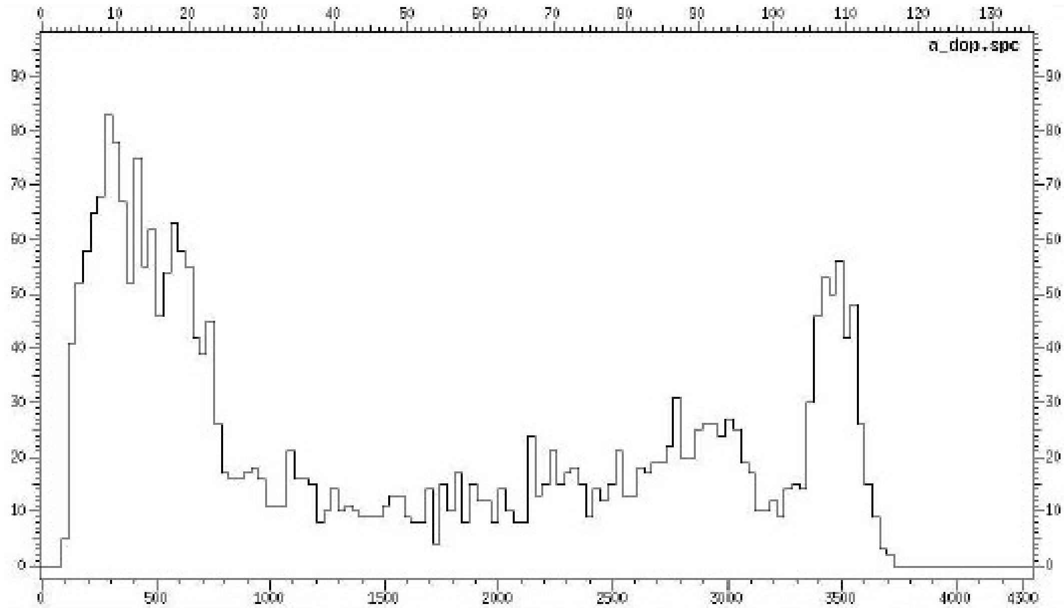

Fig.9 Simulated response of the the upstream half of CAESAR to 10,000 3.5-MeV gamma rays. The x axis is labeled in keV.

The largest uncertainly in the simulations is the transverse momentum distributions of the knockout product and ultimately in the 2p residue that determines the 3-particle efficiency. For these distributions we have used MOMDIS [13].

Precision measurements of the ^{12}O and ^{16}Ne ground-state widths and the $^{12}N_{IAS}$ and $^{16}F_{IAS}$ energies will require accurate energy calibrations of the CsI(Tl) detectors in each HiRA module. These are specific for each particle type. We require two beams (60 and 80 MeV/A) for protons, two with N=Z cocktail beams (^{6}Li, ^{10}B, ^{14}N) and another two with ^{10}C and ^{14}O beams.

In addition, the ^{9}C, ^{13}O and ^{17}Ne secondary beams come with useful contaminates for calibration. In each case, the product of the IAS decay is a weak contaminate (^{6}Li, ^{10}B and ^{14}N, in the first, second the third cases respectively.) This will provide an energy calibration that will not interfere with the data. When the fragments are from the beam they will not be in coincidence with anything (let alone 2 protons.) We also record the TOF from the scintillator after the A1900 to distinguish beam particles. However we will require the RF-kicker for the ^{17}Ne case as, without it, the rate of $^{16}F_{gs}$ and $^{15}O_{gs}$ is likely to limit our acquisition rate.

Other considerations

As we would use the same HiRA mount as in the ^{8}C experiment (08001), no hardware for HiRA would need to be constructed. A mount for the subset of the CAESAR detectors would have to be built. All hardware that needs to be purchased or fabricated would be done so by WU. However, we do request a few days of design time assistance from Craig Snow who designed the HiRA mount and a few other hardware components from the previous experiment. (We estimate 3 days of this time is required.)

As beam development is required for the ^{20}Ne primary (needed for the ^{17}Ne secondary) it would be reasonable to split this experiment into two parts, one for ^{9}C and ^{13}O and the other for ^{17}Ne. So that we do not occupy the vault for long, the parts should not be separated by more than a month.

We will be ready to run in the summer of 2011. All the analysis software is written and well exercised.

Although the beam time asked for is large, breaking this proposal up into smaller experiments distributed over a long time period and where the detectors are removed will be counterproductive as the calibrations beams (which occupy a significant fraction of the beam time) will have to be repeated each experiment. All energy calibration of the residues is complicated by the non-linear nature of the CsI(Tl). While the secondary beams of ^{6}Li (40.3 MeV/u) ^{10}B (46.6 MeV/u), and ^{14}N (50.7 MeV/u), more points are needed to establish the required isotope specific calibrations. Therefore 4 calibration secondary beams are required. Two are for the proton calibration and two (rich cocktails) for the HI calibrations. The species and energies of the fragments in the two cocktails are given in Table II.

Table II – Energies (MeV/u) of two HI calibration beam cocktails. Done without a wedge.

Bρ	^{13}O	^{14}O	^{15}O	^{12}N	^{13}N	^{14}N	^{9}C	^{10}C	^{11}C	^{12}C	^{8}B	^{9}B	^{10}B	^{7}Be	^{6}Li
2.3347	94.4	82.1	72.0	85.3	73.3	63.5	109.6	90.0	75.0	63.6	97.0	77.7	63.4	81.9	63.2
1.8916	63.0	54.7	47.8	56.8	48.7	42.18	73.3	60.0	49.9	42.2	64.7	51.7	42.1	54.5	42.0

The group at Washington University has no approved unperformed experiments at the NSCL nor do they plan to submit any other proposals until the objectives outlined in this proposal are met.

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2. Teranishi, et al., Phys. Lett. **407**, 110 (1997).
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Status of Previous Experiments

Results from, or status of analysis of, previous experiments at the CCF listed by experiment number. Please indicate publications, invited talks, Ph.D.s awarded, Master's degrees awarded, undergraduate theses completed.

02019
"Particle decay of ^{12}Be excited states," R. J. Charity, S. Komarov, L. G. Sobotka, J. Clifford, D. Bazin, A. Gade, Jenny. Lee, S. M. Lukyanov, W. G. Lynch, M. Mocko, S. P. Lobastov, A. M. Rogers, A. Sanetullaeu, M. B. Tsang, M. S. Wallace, R. G. T. Zegers, S. Hudan, C. Metelko, M. A. Famiano, A. Wuosmaa, M. J. van Goethem, Phys. Rev. C **76**, 064313 (2007).

"Investigation of particle-unbound excited states in light nuclei with resonance-decay spectroscopy using a ^{12}Be beam," R. J. Charity, S. Komarov, L. G. Sobotka, J. Clifford, D. Bazin, A. Gade, Jenny. Lee, S. M. Lukyanov, W. G. Lynch, M. Mocko, S. P. Lobastov, A. M. Rogers, A. Sanetullaeu, M. B. Tsang, M. S. Wallace, R. G. T. Zegers, S. Hudan, C. Metelko, M. A. Famiano, A. Wuosmaa, M. J. van Goethem, Phys. Rev. C **78**, 054307 (2008).

07009 - Neutron and Proton Knockout Cross Sections for ^{36}Ca (Charity) . Thesis project for Rebecca Shane. Manuscript (and thesis) in preparation.

08001
"2p-2p decay of ^{8}C and 2p decay of the isobaric analog state in ^{8}B," R.J. Charity, J.M. Elson, J. Manfredi, R. Shane, L.G. Sobotka, Z. Chajecki, D. Coupland, T. Ghosh, H. Iwasaki, M. Kilburn, J. Lee, W.G. Lynch, A. Sanetullaev, M.B. Tsang, J. Winkelbauer, M. Youngs, S. Marley, D.V. Shetty, A.H. Wuosmaa, M. Howard, submitted for publication.

Other relevant publications for continuum decay spectroscopy.

"Decay of ^{10}C excited states above the 2p+2a threshold and the contribution from "democratic" two-proton emission," R. J. Charity, K. Mercurio, L. G. Sobotka, J. M. Elson, M. Famiano, A. Banu, C. Fu, L. Trache, and R. E. Tribble, Phys. Rev. C **75**, 051304(R) (2007).

"Correlated two-proton decay from ^{10}C," K. Mercurio , R. J. Charity, R. Shane, L. G. Sobotka, J. M. Elson, M. Famiano, A. H. Wuosmaa, A. Banu, C. Fu, L. Trache, R. E. Tribble, and A. M. Mukhamedzhanov, Phys. Rev. C **78**, 031602(R) (2008).

"Complete correlation studies of two-proton decays: ^{6}Be and ^{45}Fe," L.V. Grigorenko, T. D. Wiser, K. Miernik, R. J. Charity, M. Pfutzner, A. Banu, C. R. Bingham, M. Cwoik, I. G. Darby, W. Dominik, J. M. Elson, T. Ginter, R. Grzywacz, Z. Janas, M. Karny, A. Korgul, S. N. Liddick, K. Mercurio, M. Rajabali, K. Rykaczewski, R. Shane, L. G. Sobotka, A. Stolz, L. Trache, R. E. Tribble, A. Wuosmaa, and M. V. Zhukov, Phys. Lett. B **677**, 30 (2009).

"Three-body decay of ^{6}Be," L.V. Grigorenko, M. V. Zhukov, T. D. Wiser, K. Mercurio, R. J. Charity, R. Shane, L. G. Sobotka, J. M. Elson, A. Wuosmaa, A. Banu, M. McCleskey, L. Trache, and R. E. Tribble, Phys. Rev. C **80**, 034602 (2009).

"Continuum spectroscopy with a ^{10}C beam; Cluster structure and three-body decay," R. J. Charity, T. D. Wiser, K. Mercurio, R. Shane, L. G. Sobotka, A. H. Wuosmaa, A. Banu, L. Trache, and R. E. Tribble, Phys. Rev. C **80**, 024306 (2009).

Educational Impact of Proposed Experiment

If the experiment will be part of a thesis project, please include how many years the student has been in school, what other experiments the student has participated in at the NSCL and elsewhere (explicitly identify the experiments done as part of thesis work), and whether the proposed measurement will complete the thesis work.

This experiment will not be part of the PhD thesis. It will be used for an undergraduate thesis for Juan Manfredi. Juan will be between his jr. and sr. years in the summer of 2011. Note that all the analysis software is written and very well exercised in past projects.

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 safety 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.
__________ Lifting or manipulating heavy equipment (>500 lbs)

PLEASE PROVIDE BRIEF DETAIL ABOUT EACH CHECKED ITEM.

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 5. of the Notes for PAC 35 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 6. of the Notes for PAC 35 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, an electronic copy of the LISE++ files used to estimate the rare-isotope beam intensity must be e-mailed to the A1900 Device Contact.

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 ^{16}O
Energy 150
Minimum intensity 175 particle-nanoampere

Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet): **12** hrs

Beam-On-Target

Isotope **^{9}C**
Energy 70 MeV/nucleon
Rate at A1900 focal plane $1.5*10^3$ pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Minimum Acceptable purity 90 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[ ] No
[X] Yes
What is the desired thickness? [ ] 125 μm; [x] 1000 μm
What is the maximum rate expected for this setting? ___10^4______Hz (1 MHz max)

Is event-by-event momentum correction from position measured at the A1900 Image 2 position required?
[ ] No
[ ] Yes
Which detector should be used? [ ] Scintillator; [ ] PPACs
What is the maximum rate expected for this setting? __________Hz (1 MHz max)

Delivery time per table (or 0 hrs for primary/degraded primary beam): **2** hrs

Tuning time to vault: **3** hrs

Total beam preparation time for this beam: **5** **hrs**

Experimental device tuning time [see note (c) above]: **24** hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: **48** hrs

Total on-target time for this beam: **72** **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 ^{16}O
Energy 150
Minimum intensity 175 particle-nanoampere

Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet): **12** hrs

Beam-On-Target

Isotope **^{13}O**
Energy 70 MeV/nucleon
Rate at A1900 focal plane $5*10^3$ pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Minimum Acceptable purity 40 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[ ] No
[X] Yes
What is the desired thickness? [ ] 125 μm; [x] 1000 μm
What is the maximum rate expected for this setting? ____10^4_____Hz (1 MHz max)

Is event-by-event momentum correction from position measured at the A1900 Image 2 position required?
[ ] No
[ ] Yes
Which detector should be used? [ ] Scintillator; [ ] PPACs
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Delivery time per table (or 0 hrs for primary/degraded primary beam): **2** hrs

Tuning time to vault: **3** hrs

Total beam preparation time for this beam: **5** **hrs**

Experimental device tuning time [see note (c) above]: **0** hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: **48** hrs

Total on-target time for this beam: **48** **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 ^{20}Ne
Energy 120
Minimum intensity 100 particle-nanoampere

Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet): **12** hrs

Beam-On-Target

Isotope **^{17}Ne**
Energy 70 MeV/nucleon
Rate at A1900 focal plane $2*10^3$ pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Minimum Acceptable purity 20 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?

[ ] No
[X] Yes
What is the desired thickness? [ ] 125 μm; [x] 1000 μm
What is the maximum rate expected for this setting? ___10^5______Hz (1 MHz max)

Is event-by-event momentum correction from position measured at the A1900 Image 2 position required?

[ ] No
[ ] Yes
Which detector should be used? [ ] Scintillator; [ ] PPACs
What is the maximum rate expected for this setting? __________Hz (1 MHz max)

Delivery time per table (or 0 hrs for primary/degraded primary beam): **2** hrs

Tuning time to vault: **3** hrs

Total beam preparation time for this beam: **5 hrs**

Experimental device tuning time [see note (c) above]: **0** hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: **48** hrs

Total on-target time for this beam: **48 hrs**

Beam Request Worksheet

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

proton Calibration

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope ^{16}O
Energy 150
Minimum intensity 175 particle-nanoampere

Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet): [ ] hrs

Beam-On-Target

Isotope **p**
Energy 60 MeV/nucleon
Rate at A1900 focal plane 10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Minimum Acceptable purity 50 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[ ] No
[X] Yes
What is the desired thickness? [ ] 125 μm; [ ] 1000 μm
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Is event-by-event momentum correction from position measured at the A1900 Image 2 position required?
[ ] No
[ ] Yes
Which detector should be used? [ ] Scintillator; [ ] PPACs
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Delivery time per table (or 0 hrs for primary/degraded primary beam): **2** hrs

Tuning time to vault: **3** hrs

Total beam preparation time for this beam: **5** **hrs**

Experimental device tuning time [see note (c) above]: **0** hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: **5** hrs

Total on-target time for this beam: **5** **hrs**

Beam Request Worksheet

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

proton Calibration

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope ^{16}O
Energy 150
Minimum intensity 175 particle-nanoampere

Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet): [ ] hrs

Beam-On-Target

Isotope p
Energy 80 MeV/nucleon
Rate at A1900 focal plane 10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Minimum Acceptable purity 50 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[ ] No
[X] Yes
What is the desired thickness? [ ] 125 μm; [ ] 1000 μm
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Is event-by-event momentum correction from position measured at the A1900 Image 2 position required?
[ ] No
[ ] Yes
Which detector should be used? [ ] Scintillator; [ ] PPACs
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Delivery time per table (or 0 hrs for primary/degraded primary beam): 2 hrs

Tuning time to vault: 3 hrs

Total beam preparation time for this beam: 5 **hrs**

Experimental device tuning time [see note (c) above]: 0 hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 5 hrs

Total on-target time for this beam: 5 **hrs**

Beam Request Worksheet

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

Alpha Calibration

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope ^{16}O
Energy 150
Minimum intensity 175 particle-nanoampere

Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet): [ ] hrs

Beam-On-Target

Isotope **^{10}C cocktail**
Energy 60 MeV/nucleon
Rate at A1900 focal plane 10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Minimum Acceptable purity 50 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[ ] No
[X] Yes
What is the desired thickness? [ ] 125 μm; [ ] 1000 μm
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Is event-by-event momentum correction from position measured at the A1900 Image 2 position required?
[ ] No
[ ] Yes
Which detector should be used? [ ] Scintillator; [ ] PPACs
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Delivery time per table (or 0 hrs for primary/degraded primary beam): **2** hrs

Tuning time to vault: **3** hrs

Total beam preparation time for this beam: **5** **hrs**

Experimental device tuning time [see note (c) above]: **0** hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: **5** hrs

Total on-target time for this beam: **5** **hrs**

Beam Request Worksheet

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

Alpha Calibration

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope ^{16}O
Energy 150
Minimum intensity 175 particle-nanoampere

Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet): [ ] hrs

Beam-On-Target

Isotope 10C cocktail
Energy 90 MeV/nucleon
Rate at A1900 focal plane 10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Minimum Acceptable purity 50 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[ ] No
[X] Yes
What is the desired thickness? [ ] 125 µm; [ ] 1000 µm
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Is event-by-event momentum correction from position measured at the A1900 Image 2 position required?
[ ] No
[ ] Yes
Which detector should be used? [ ] Scintillator; [ ] PPACs
What is the maximum rate expected for this setting? _________Hz (1 MHz max)

Delivery time per table (or 0 hrs for primary/degraded primary beam): 2 hrs

Tuning time to vault: 3 hrs

Total beam preparation time for this beam: 5 **hrs**

Experimental device tuning time [see note (c) above]: 0 hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 5 hrs

Total on-target time for this beam: 5 **hrs**