Description of Experiment

I. Physics Justification

Fission barriers and their consequent fission probabilities reflect the balance between the long-range Coulomb force and the surface tension as the nucleus deforms. The surface symmetry energy influences how fission barriers evolve away from the valley of stability. Improved understanding of fission of exotic nuclei can lead to improved constraints on the effective interactions used to calculate the surface symmetry energy and vice-versa. The increased deformations of saddle point configurations mean that fission barriers can provide constraints on nuclear effective interactions that are independent of those provided by ground state masses.

Improved predictions for fission barriers of rare isotopes is also important for r-process nucleosynthesis predictions. Simple liquid drop model considerations predict fission to be a dominant decay mode for rare isotopes with fissility parameter $x = \frac{E_{Coul}}{2E_{Surf}} = \frac{Z^2}{47A(1-\eta I^2)}$ greater than unity. (Here $I = \frac{(N-Z)}{A}$, $\eta = -a_{ssym}/a_{surf}$ and a_{surf} and a_{ssym} are the surface and surface symmetry energy coefficients.) Figure 1 illustrates the connection between effective interactions and the LDM fission limit for the SkI3 and SkM* effective interactions as well as that for $\eta = 1.7826$ and $\eta = 0$ (no isospin dependence) [Niko2001].

Fission barriers for exotic nuclei and the role of fission on the r-process are intimately connected with the density dependence of the symmetry energy at the sub-saturation densities attained in nuclear surface and in the neck region at the maximum of the fission barrier [Niko2001]. For example, r-process pathway may where it crosses the x=1 contour. In this case, final r-process abundance pattern will be strongly affected by fission cycling, in which such highly fissile heavy nuclei fission and the resulting fragments provide fresh seed nuclei that initiate a new r-process cycle [Cowan1991, Rauch1994]. In addition, beta-delayed and neutrino-Induced fission may play a role in limiting the r-process yields of thorium and uranium isotopes that are interesting cosmological chronometers [Cowan1991, Rauch1994]. Furthermore, neutrino-induced fission during freeze-out has been proposed to partially correct the abundance trough observed around A = 110−120. To determine the role of these different fission aspects in the r-process, measurements of fission barriers and fission fragment distributions over a wide range of neutron-rich nuclei are crucial. However, most of these fissionable nuclei lie outside the domain of direct measurement and require an accurate extrapolation of measurements closer to the valley of stability.

NSCL PAC 37 – 1. Description of Experiment

Measurements of fission barriers with rare isotope beams can provide an empirical basis for improved extrapolations of ground state and fission saddle point binding energies away from the valley of stability and towards the r-process much more stringently [Kelic2006]. Figure 2 shows the large range of nuclei where the fission barriers are unknown and that can be experimentally studied at CCF and FRIB. Currently, the list of primary beams only allow measurements near Z=92 (Uranium), Z=82 (Pb) and Z=54 (Xe), but the development of new primary beams could enable exploration of the promising region $55 < Z < 82$. There measurements of the fission cross section as a function of incident energy can provide much needed information about the surface symmetry energy, deformation, pairing, and shell effects in highly deformed saddle point configurations

II. Goals of proposed experiment

We propose to extend our knowledge of the asymmetry dependence of fission barriers by measuring the fission branching ratios as a function of excitation energy for ^{196}Pb and ^{121}Cs compound nuclei. We propose to create these compound nuclei by fusing them with Hydrogen target nuclei that constitute the counter gas within the Prototype Active Target-Time Projection Chamber (PAT-TPC). This technique offers the advantage of inverse kinematics, which enables the identification of fission processes with very high efficiency. In addition, because thicker targets are feasible with fast beams, the desired intensities of $\sim 10^4$ s^{-1} are lower than those (10^6 s^{-1}) required for low energy reaccelerated beams.

The expected fission barrier heights for ^{196}Pb and ^{121}Cs are of the order of 20 and 34 MeV, respectively [Dahl1982]. Figure 3 shows the expected cross sections for ^{196}Pb as a function of energy. We don't have a prediction for ^{121}Cs for the full range of energies, as it is a completely unknown region for fission and it depends strongly on the unknown fission barrier. Thus, we estimated the upper limit of the cross-sections based on the trends in the data for A=180-189 [Jing2001] to A=209 [Prokofiev2002,Dahl1982]. The larger barrier for ^{121}Cs should leads to significantly small fission cross-sections for that system. At E/A=75, we estimate it to be about 0.4 mb. Even if is an order of magnitude lower (0.04 mb), we will be able to measure it and this information will be an important benchmark for future fission studies in this region.

III. Experimental Details

We propose to perform measurements of these fission cross sections in the PAT-TPC, but placing it at the end station of the RF separator beam line within the S-2 vault. Figure 4 shows a schematic drawing of the experimental setup. In this drawing, the PAT-TPC is shown as a cylinder with the correct dimensions. About 30 cm upstream of the PAT-TPC, we have a MicroChannel Plate (MCP) tracking detector, and an Ion Chamber (IC) to verify the charge of the beam is situated between the MCP and the PAT-TPC.

Figure 5 shows a drawing of the interior of the PAT-TPC. It consists of a cylindrical pressure vessel with an entrance window for the beam to enter the field cage, a cylindrical internal cage that supplies the electric field, which transports the electrons to the anode, and spatially segmented anode that multiplies the primary ionization and allows it to be read out. The anode is a MICROMEGAS structure, consisting of a fine mesh grid that is situated about 120 microns from the segmented pad plane. The pad plane is 30 cm in diameter and segmented into annular rings of 2 mm width. Over most of the pad plane each ring is further segmented into 4 quadrants; however, at $r < 1.5$cm, each ring is more finely segmented into 8 octants. This design allows the radial coordinate where the ionization is sensed on the pad plane to be measured with higher accuracy than the azimuthal coordinate, as appropriate for measurements for which the polar angle contains the most relevant information.

The incident beam will enter the interior of the field cage of the PAT-TPC through a 2 cm window. The field cage will be filled with H_2 gas at a pressure of 1 atmosphere. The projectile, entering the H_2 gas, has a probability $2x10^{-6}$ of producing a fission within the volume of the field cage for a fission cross section of 1 mb. Fission events will display the characteristic signature of a two body final state, shown in Figure. 6, of a "v-shaped" arrangement of tracks. Detection of ionization away from the beam, in the rings at radii greater than 2 cm will serve as this event trigger. As the ionization of the fission fragments greatly exceeds that of alpha particles, there should be no problem distinguishing the fission events from other two body final states. The length the beam track before the fission event will allow one to correct for the energy loss of the beam prior to the fission event and select fission events by the excitation energy in the compound nuclear system.

We calculated the beam intensities and beam purities with Lise++ version 9.3.13. Beam purification for the ^{120}Xe beam was a straightforward exercise, which resulted in a ^{120}Xe of greater than 99% purity at E/A=60,75 MeV, and 90% purity at E/A= 100 MeV in the worst case. These contaminants have different velocities; we propose to use a TOF scintillator after the I2 wedge and a MCP before the PAT-TPC to remove them. Beam purification for the ^{195}Tl beam was more difficult. Even with time selection, the secondary beam contained 55% (30%) **^{195}Tl** , 20%(30%) **^{193}Hg** and 15% (25%) **^{197}Pb** at E/A= 35 (75) MeV in the best (worst) case. To tag the observed fission events by the incident ion, we propose to construct segmented longitudinal field Ion Chamber (IC). It will be 4 cm in diameter, and 15 cm long. The length of the ion chamber will be segmented into 5 separate ion chamber, each 3 cm long, with a central foil anode and two foil cathodes 1.5 cm upstream and on 1.5 cm downstream. As the drift times in the gas will be well below 1 μ sec, we anticipate that the IC can function well at intensities of 50 kHz, well in excess of our requirements. Figure 7 shows simulated energy losses for a cocktail beam of 30% ^{195}**Tl,** 25% ^{193}**Hg** and 30% ^{197}**Pb** at E/A= 35 MeV. (The remainder of beam contaminants were removed by a time gate.) It should be possible to tag each event by the beam particle. We do not expect to be event rate limited so that we will obtain additional fission cross sections for ^{193}**Hg+p** and ^{197}**Pb+p**, with lower statistical precision throughout this experiment. IN addition, there will be a cell mounted on a ladder with a gas volume and silicon detector. When inserted, the energies of beam ions traveling through hydrogen gas or without hydrogen gas can be compared to check the stopping power values for the incident beam in hydrogen.

The energy loss in the PAT-TPC is limited by the length of the field cage. Thus, several incident energies will be necessary to achieve the full fission excitation function. We therefore request incident energies of 110, 100, 90, 75, 60 MeV/u for the ^{120}Xe beam and 75, 65, 55, 50, 40, 35 MeV/u for the ^{195}Tl beam. We used measured cross sections for 197Au, 202Hg, 205Tl and 208Pb [Figure 8, Prokofiev2002] to estimate the cross sections for the ^{195}Tl beam. For the ^{120}Xe , we used the extrapolation based on the available data [Prokofiev2002,Jing2001]. The expected beam intensities, cross sections and count rates are given in Table 1. The time to measure the fission cross section at given energy is given in Table 2. In total, we request 94 hours for the measurement of the fission cross section for the p+^{195}Tl reaction and 118 hours for the measurement of the fission cross section for the p+^{120}Xe reaction. In addition, we request 24 hours with a degraded ^{208}Pb at 70 MeV to optimize the trigger and electronics for this experiment. During this time, we will be able to test our procedures, as the fission barrier for ^{209}Bi is known. We therefore request 236 hours of beam on target. In addition, we require 174 secondary beam tuning changes, so our total time request is 410 hours.

References

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[Cowan1991] J.J. Cowan et al, Phys. Rep. 208 (1991) 267.

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[Phair 2005] Contribution to the Isotope Science Facility whitepaper.

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[Prokofiev2002] A. V. Prokofiev, S. G. Mashnik, W. B. Wilson, nucl-th/0210071, LANL Report LA-UR-02-5837 (2002)

Supplemental Information (Figures, Tables, References, etc., including one figure that depicts the layout of the experimental apparatus)

Figures:

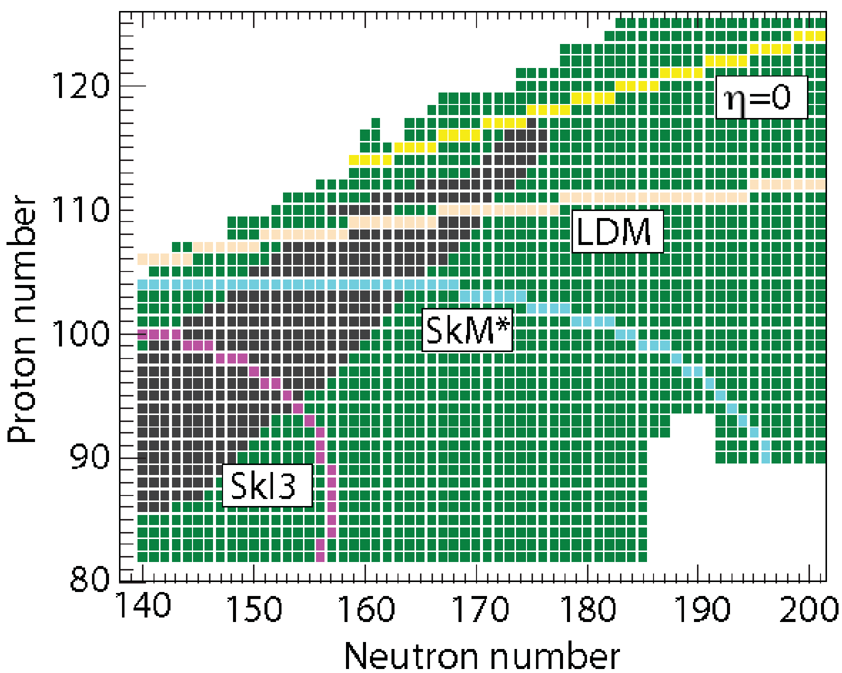

Figure 1: The upper part of the chart of the nuclides with the x = 1 limit indicated for SkI3 and SkM* energy density functionals, the value of η = 1.7826 used in Ref. [Stone2007] (LDM), and for no isospin dependence (η = 0). The region of known nuclides is marked by black squares. Expected particle bound, but beta unstable nuclei are denoted by the green squares. From ref. [Niko2001]

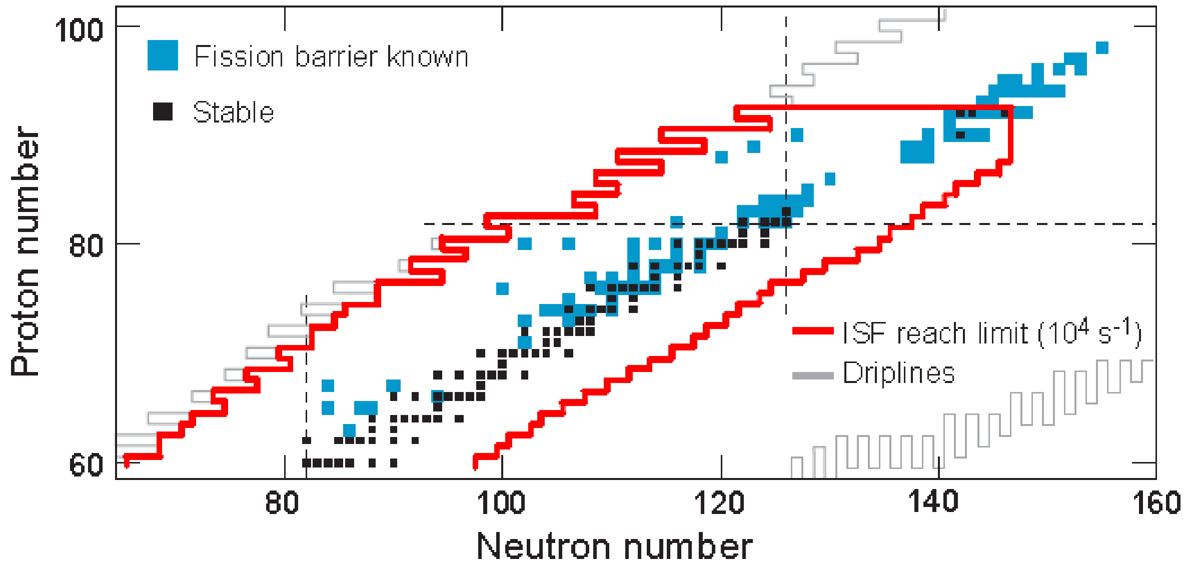

Figure 2: The red boundary indicates the region where fast beams intensities greater than 10^4 s^{-1} were predicted for the proposed ISF. The comparable region of intensities for FRIB are comparable. The black points correspond to stable nuclei. The blue points indicate nuclei with measured fission barriers [From ISF whitepaper, Phair 2005].

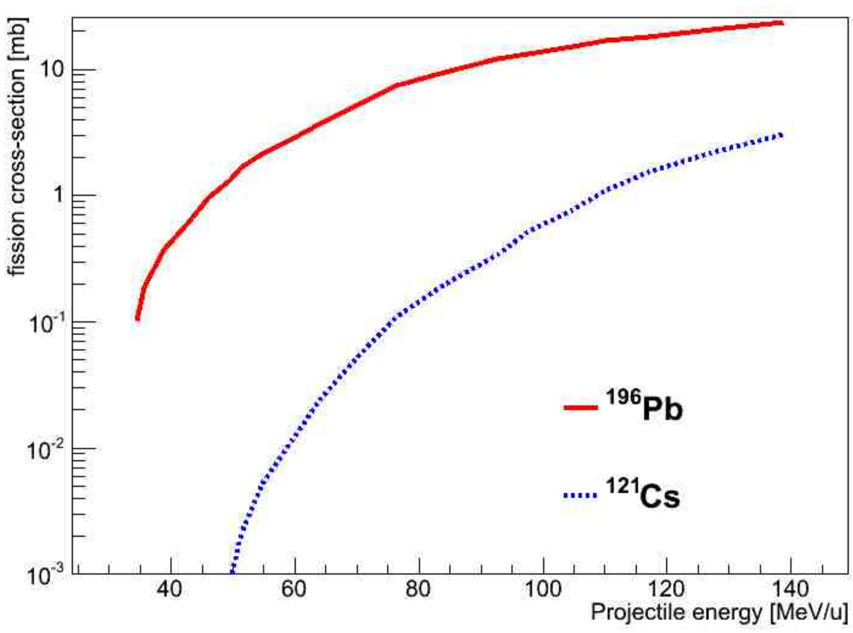

Figure 3: Expected fission cross section for 196Pb. Estimation is based on the available experimental data [Jing2001,Prokofiev2002,Dahl1982]

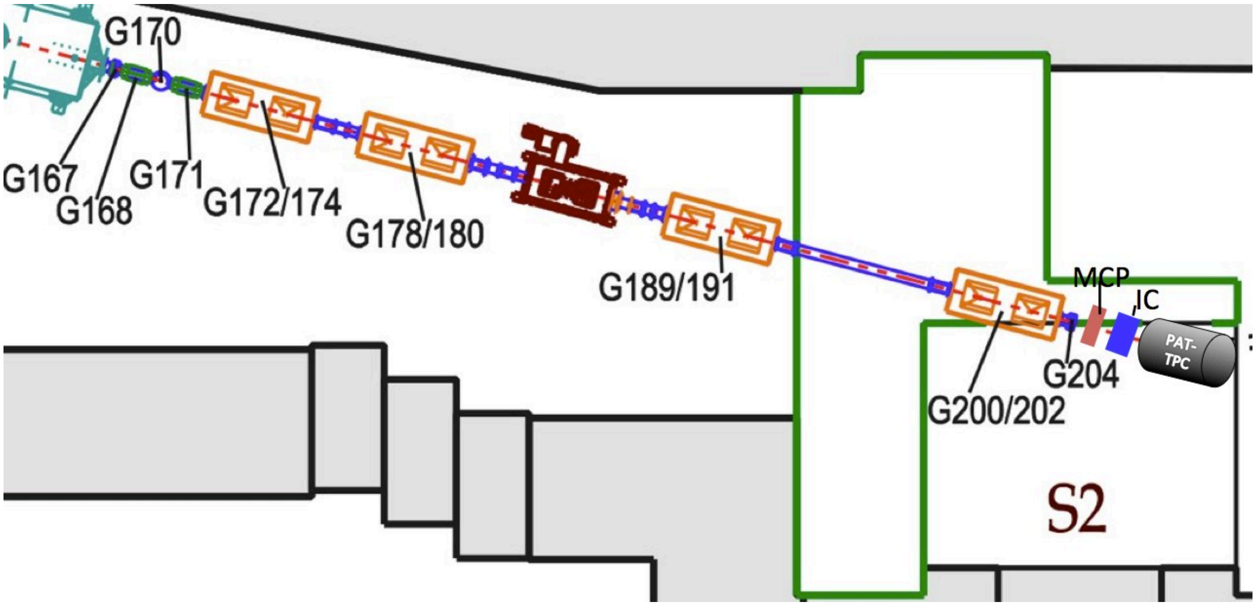

Figure 4: The schematic view of the experimental vault with PAT-TPC detector.

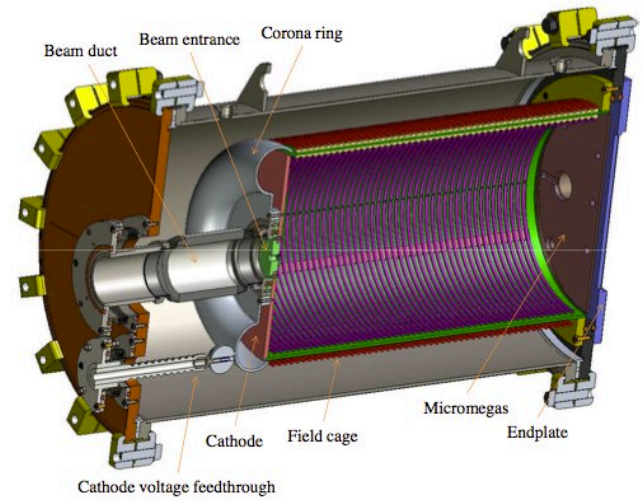

Figure 5: The cross section of Prototype Active Target Time Projection Chamber detector [Ref]

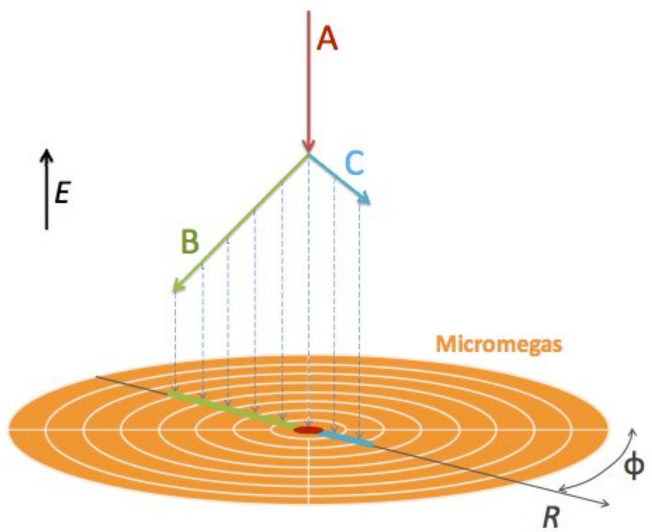

Figure 6: Example of the tracks coming from the reaction in the PAT-TPC and their signal in the micromegas. [Ref]

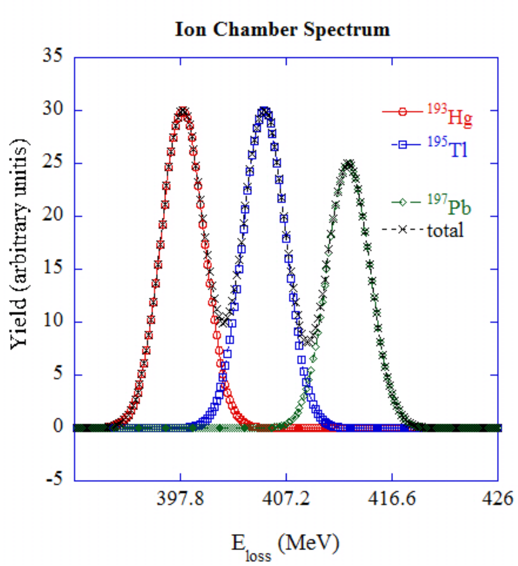

Figure 7: simulated energy losses for a cocktail beam of 30% ^{195}**Tl,** 25% ^{193}**Hg** and 30% ^{197}**Pb** at E/A= 35 MeV

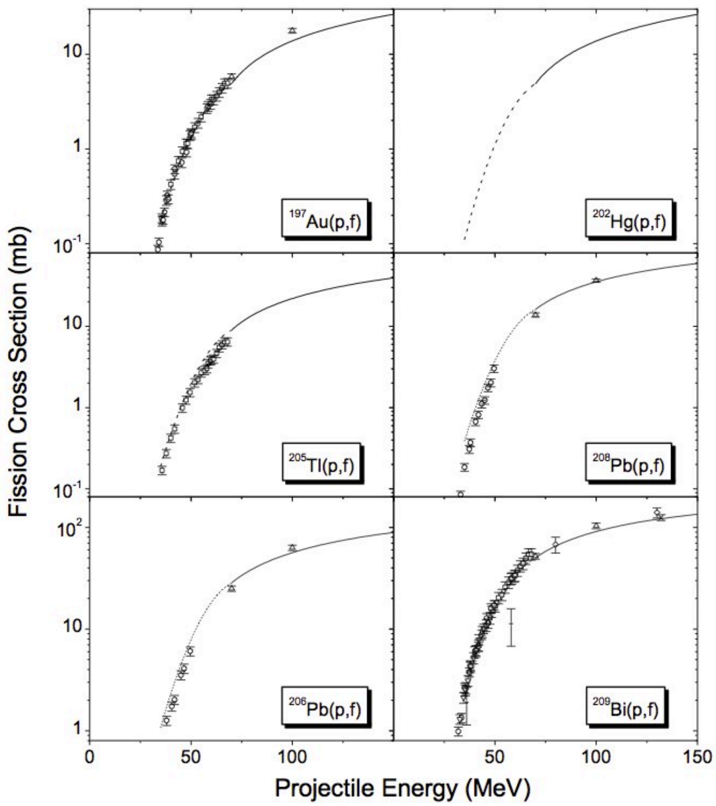

Figure 8: Fission cross sections. Those cross sections were interpolated to estimate the expected cross section for 196Pb [Ref]

RI beam	Primary beam	Energy of RIB [MeV/u]	Production target	A1900 Wedge [Al]	$\Delta p/p$ [%]	Purity	RIB rate (pps)
^{195}Tl	208Pb (1.5pnA) 85 MeV/u	75	Be 18 mg/cm^2	56 micron	0.51	30%	2600
		65	Be 55 mg/cm^2	175 micron	0.51	40%	3000
		55	Be 84 mg/cm^2	255 micron	0.51	45%	2400
		50	Be 104 mg/cm^2	255 micron	0.51	45%	1400
		40	Be 101 mg/cm^2	420 micron	0.51	45%	1800
		35	Be 89 mg/cm^2	502 micron	0.85	55%	1400
^{120}Xe	^{124}Xe (10pnA) 140 MeV/u	110	Be 37 mg/cm^2	870 micron	0.34	90%*	3400
		100	Be 37 mg/cm^2	1070 micron	0.34	93%*	12000
		90	Be 111 mg/cm^2	1070 micron	0.85	94%*	30000
		75	Be 111 mg/cm^2	1460 micron	0.85	100%	50000
		60	Be 111 mg/cm^2	1800 micron	0.85	100%	17000

Table 1: Beam settings.
* Contaminants can be separated with TOF technique

RIB beam	Fissle nucleus	RIB beam energy [MeV/u]	estimated cross-section [mb]	RIB intensity [1/s]	Fission rate in AT-TPC [1/s]	time [h] (10% error)
^{195}Tl	^{196}Pb	75	5	2600	0.028	2
		65	4	3000	0.026	2
		55	2	2400	0.011	4
		50	1.5	1400	0.005	10
		40	0.5	1800	0.002	24
		35	0.2	1400	0.0006	52
^{120}Xe	^{121}Cs	110	1	3400	0.008	5
		100	0.9	12000	0.024	3
		90	0.1	20000*	0.004	8
		75	0.03	20000*	0.0013	24
		60	0.01	17000	0.0004	78

Table 2: Beam on target time required to achieve a 10% error in the cross section based on the estimated rates of RIB beams, estimated fission rates.

*The maximum rate at PAC-TPC is 20000/s so we have to lower the rate of the secondary beam

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.

The experiment commissioning the PAT-TPC detector was performed at Notre Dame University in April 2011 using radioactive beams to study the fusion and scattering in $^{6}He+^{4}He$ reactions. It was successful effort and proved that the detector is fully operational.
Further, two more experiments were performed at the same facility studying $^{10}Be+^{4}He$ reactions to measure the elastic scattering in 2011 and $Ar+^{6}He$ fusion in 2012.

Educational Impact of Proposed Experiment

If the experiment will be part of a thesis project, please include the total number of years the student has been in graduate 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 what part the proposed measurement plays in the complete thesis project.

6 NSCL graduate students will be involved in the experiment.

Safety Information Worksheet

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: [Zbigniew Chajecki]

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).
___x______	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.

Redioactive sources: 228Th source (alpha particle source) will be used to calibrate micromegas and PAT-TPC detector.

Vacuum vessels, gas detectors: PAT-TPC detector will be filed with H2 gas with pressure at atmospheric pressure and Ion Chamber will be filled with P10 gas at pressure around 1/3 atm. The vacuum pumps are used to keep the stable pressure of the gasses in the detector.

We acknowledge that there is not a safety authorization to run the proposed experiment using AT-TPC prototype in the S2 vault and we will have to obtain the proper authorization before the experiment is scheduled if it is approved.

Spectrograph Worksheet for S800 Spectrograph or Sweeper Magnet

The NSCL web site contains detailed technical information and service level descriptions about the S800 Spectrograph (Service Level Description) and the Sweeper Magnet (Service Level Description).

1. Timing detectors

a) Is a plastic timing scintillator required (at the object of the S800 or in front of the sweeper magnet)?

[x] No
[ ] Yes

i. What is the desired thickness? [ ] 125 μm [ ] 1 mm [ ] other _____
ii. What maximum rate is expected on this scintillator? _______ Hz

b) Do you plan to use a different type of timing detector (at the object of the S800 or in front of the sweeper magnet)?

[x] No
[ ] Yes

If "Yes," please give details.

2. Tracking detectors

Tracking detectors for incoming beam are available for Z>10. Performance limitations are to be expected at rates exceeding 200 kHz.

Are tracking detectors needed?

[x] No
[ ] Yes

3. Focal-plane rates

a) What detectors are planned to be used?
b) What is the maximum rate expected in the focal-plane detection system? __10^5 Hz

4. For S800 experiments only: Optics mode and rigidities:

a) Which optics mode is needed?

[ ] Dispersion matched [ ] focused [ ] Other _________________________

b) What are the maximum and minimum rigidities planned to be used for the analysis beam line?

_____ Tm minimum, _____ Tm maximum

c) What are the maximum and minimum rigidity planned to be used for the spectrograph?

_____ Tm minimum, _____ Tm maximum

d) The maximum particle rate in the focal plane is 6 kHz when the CRDC detectors are being used. What is the maximum total particle rate expected in the S800 focal plane?

_____ Hz

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 37 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 37 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 _1_ of _12_.

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time
Primary Beam (from beam list)		
Isotope: 208Pb		
Energy: 85 MeV/nucleon		
Minimum intensity: 1.5 particle-nanoampere (pnA)		
Tuning time (12 hrs; 0 hrs if the beam is already listed in an earlier worksheet):	12 hrs	

Beam-On-Target

Isotope: 208Pb
Energy: 69 MeV/nucleon
Rate at A1900 focal plane: 1.27×10^{9} pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance: 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane: 100 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[ ] No
[ ] 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)

	Beam Preparation Time	Beam-On-Target Time
Delivery time per table (or 0 hrs for primary/degraded primary beam):	0 hrs	
Tuning time to vault:	3 hrs	
Total beam preparation time for this beam:	**15 hrs**	
Experimental device tuning time [see note (c) above]: S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]		hrs
On-target time excluding device tuning:		24 hrs
Total on-target time for this beam:		**24 hrs**

Beam Request Worksheet 2 of 12 .

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 208Pb
Energy 85 MeV/nucleon
Minimum intensity 1.5 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 195Tl
Energy 75 MeV/nucleon
Rate at A1900 focal plane 4.12×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 9 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 0 hrs

Total beam preparation time for this beam: **12** **hrs**

Experimental device tuning time [see note (c) above]: hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 2 hrs

Total on-target time for this beam: **2** **hrs**

Beam Request Worksheet 3 of 12.

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 208Pb
Energy 85 MeV/nucleon
Minimum intensity 1.5 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 195Tl
Energy 65 MeV/nucleon
Rate at A1900 focal plane 3.82×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 11 %

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

[x] No
[ ] 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?

[x] 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): 12 hrs

Tuning time to vault: 0 hrs

Total beam preparation time for this beam: 12 hrs

Experimental device tuning time [see note (c) above]: hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 2 hrs

Total on-target time for this beam: 2 hrs

Beam Request Worksheet 4 of 12 .

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 208Pb
Energy 85 MeV/nucleon
Minimum intensity 1.5 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 195Tl
Energy 55 MeV/nucleon
Rate at A1900 focal plane 1.2×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 15 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 3 hrs

Total beam preparation time for this beam: 15 hrs

Experimental device tuning time [see note (c) above]: hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 4 hrs

Total on-target time for this beam: 4 hrs

Beam Request Worksheet 5 of 12.

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 208Pb
Energy 85 MeV/nucleon
Minimum intensity 1.5 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 195Tl
Energy 50 MeV/nucleon
Rate at A1900 focal plane 2.26×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 9 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 0 hrs

Total beam preparation time for this beam: 12 hrs

Experimental device tuning time [see note (c) above]: hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 10 hrs

Total on-target time for this beam: 10 hrs

Beam Request Worksheet 6 of 12.

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 208Pb
Energy 85 MeV/nucleon
Minimum intensity 1.5 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 195Tl
Energy 40 MeV/nucleon
Rate at A1900 focal plane 2.73×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 11 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 3 hrs

Total beam preparation time for this beam: 15 hrs

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

Total on-target time for this beam: 24 hrs

Beam Request Worksheet 7 of 12 .

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 208Pb
Energy 85 MeV/nucleon
Minimum intensity 1.5 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 195Tl
Energy 35 MeV/nucleon
Rate at A1900 focal plane 1.69×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 10 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 0 hrs

Total beam preparation time for this beam: 12 hrs

Experimental device tuning time [see note (c) above]: hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 52 hrs

Total on-target time for this beam: 52 hrs

Beam Request Worksheet 8 of 12.

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 124Xe
Energy 140 MeV/nucleon
Minimum intensity 10 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 120Xe
Energy 60 MeV/nucleon
Rate at A1900 focal plane 8.1 x10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 50 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 3 hrs

Total beam preparation time for this beam: 27 hrs

Experimental device tuning time [see note (c) above]: hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 78 hrs

Total on-target time for this beam: 78 hrs

Beam Request Worksheet 9 of 12.

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope: 124Xe
Energy: 140 MeV/nucleon
Minimum intensity: 10 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope: 120Xe
Energy: 75 MeV/nucleon
Rate at A1900 focal plane: 1.3×10^4 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance: 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane: 33 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 3 hrs

Total beam preparation time for this beam: 15 hrs

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

Total on-target time for this beam: 24 hrs

Beam Request Worksheet 10 of 12 .

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 124Xe
Energy 140 MeV/nucleon
Minimum intensity 10 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 120Xe
Energy 90 MeV/nucleon
Rate at A1900 focal plane 7.9×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 60 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 0 hrs

Total beam preparation time for this beam: 12 hrs

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

Total on-target time for this beam: 8 hrs

Beam Request Worksheet 11 of 12 .

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope: 124Xe
Energy: 140 MeV/nucleon
Minimum intensity: 10 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope: 120Xe
Energy: 100 MeV/nucleon
Rate at A1900 focal plane: 7.2×10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance: 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane: 40 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 3 hrs

Total beam preparation time for this beam: 15 hrs

Experimental device tuning time [see note (c) above]: hrs
S800 [ ]; SeGA [ ]; Sweeper [ ]; Other [ ]
On-target time excluding device tuning: 3 hrs

Total on-target time for this beam: 3 hrs

Beam Request Worksheet 12 of 12.

(Please number the sheets and use a separate sheet for each distinct beam-on-target requested.)

	Beam Preparation Time	Beam-On-Target Time

Primary Beam (from beam list)

Isotope 124Xe
Energy 140 MeV/nucleon
Minimum intensity 10 particle-nanoampere (pnA)

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

Beam-On-Target

Isotope 120Xe
Energy 110 MeV/nucleon
Rate at A1900 focal plane 1.7 x10^3 pps/pnA (secondary beam) or pnA (primary beam)
Total A1900 momentum acceptance 1 % (e.g. 1%, not ±0.5%)
Purity at A1900 focal plane 25 %

Is a plastic timing scintillator required at the A1900 focal plane for providing a timing start signal?
[x] No
[ ] 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?
[x] 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): 12 hrs

Tuning time to vault: 0 hrs

Total beam preparation time for this beam: 12 hrs

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

Total on-target time for this beam: 5 hrs