High Resolution (S800) and High Rigidity Spectrometers

1) *What is the primary physics motivation and experimental capability of the proposed instrument and why is this important for FRIB science?*

The **S800 high resolution spectrometer** is at present used for a wide variety of experiments (knockout, transfer, charge-exchange reactions, inelastic scattering, intermediate-energy Coulomb excitations, TOF mass measurements and excited-state life-time measurements). All these techniques will remain key tools for the study of rare isotopes, their structure and the implications for astrophysics also at FRIB. Upgrades of the S800 are proposed, for example, related to high-rate beam tracking using segmented diamond detectors. The rigidity of the S800 is limited to 4 Tm, which is sufficient for typical experiments that require beam energies of <100 MeV/u. However, at FRIB the magnetic rigidity of some reaction products, in particular induced by neutron-rich secondary beams produced at their intensity maximum, would exceed the bending power of the S800 by a factor of 1.5-2. While various schemes exist that slow the secondary beams down to energies suitable for experiments at the S800, they all would presumably result in intensity losses. The same rigidity considerations also impact experiments that aim at the spectroscopy of neutron-unbound states as currently performed at NSCL with the Sweeper Magnet setup (maximum rigidity also 4 Tm). To complement the opportunities at the S800 spectrograph and to make maximum use of the MoNA-LISA neutron detection facility, it is proposed to construct a new **High-Rigidity (7 Tm) Spectrometer (HRS) with large momentum acceptance** for experiments where high rigidity/momentum acceptance capability is critical. The new HRS spectrometer under consideration is proposed to replace the present Sweeper Magnet setup and thus would allow coincidence spectroscopy with the MoNA-LISA neutron detector array and/or gamma/particle detector arrays placed around the target. Such a HRS would also open up new opportunities, such as the study of giant resonances in rare isotopes. Experiments that require only moderate resolution but large momentum acceptance – the momentum acceptance of the S800 is limited to 5% - would benefit from the HRS. A staged implementation is possible.

2) *What are the unique capabilities of this device that are not available in existing equipment? Is this instrument stand alone or is it to be used (solely or partially) in conjunction with other instrument?.*

Table 1Overview of S800 and HRS. For more details on the HRS, see table 2.

Parameter	**S800@FRIB**	**HRS**
Energy resolution	1/2000 (1/10000 with tracking)	1/1300 with tracking
Bending Capability	4 Tm (beam line 5 Tm)	7 Tm
Momentum Acceptance	5%	10%
Angular acceptance	20 msr (120 mrad x 170 mrad)	20 msr (120 mrad x 170 mrad)
Bending angle/radius	150^o/2.8 m	30^o/4.5 m
Layout	QQDD	QQQD
Focal plane detectors	Ion Chamber/CRDCs/plastic scintillators/ Segmented CsI Hodoscope	Ion Chamber/CRDCs/plastic scintillators/ Segmented CsI Hodoscope
Tracking Detectors	Tracking PPACs/Channel Plates/ Segmented Diamond Detectors	Segmented Diamond Detectors
Other devices	SeGA/CAESAR/LENDA/ HiRA/Gretina/Greta	SeGA/CAESAR/LENDA/ Gretina/Greta/MoNA-LISA

3) *Describe the instrument in some detail – how does it meet the scientific requirements and what are the (estimated) performance specifications? Be brief but as detailed as you can. Is the design fixed or are multiple options still being discussed and encouraged?*

The S800 and HRS spectrometers combined will allow for a broad physics program with fast RI beams as discussed in 1). The magneto-optical design of the S800 is fixed, except for details gained with improved beam tracking. Various options to produce RI beams with suitable energies for experiments with the S800

must be investigated (thicker production targets, degraders or lower initial beam energy) to optimize quality and intensity.
The design of the HRS presented here is very preliminary and could change depending on a variety of factors, such as location, other equipment that might be used in coincidence (beyond what is mentioned in 2) and exact operation conditions of the FRIB fragment separator. A possible location for the HRS is in the N1/N2/N3 vaults (see Fig. 1).

4) *What is the current stage of development of your project ?*
Several upgrades to the S800 are already underway (e.g. a CsI hodoscope will complement the focal plane detection system) and will be finished in the next years. The main new development concerns high-rate diamond tracking detectors. Prototypes are being worked on and will have a staged implementation at NSCL. The HRS spectrometer has been discussed within the working group and a preliminary design is proposed. Further development requires the input from the larger user community and specification of external factors (location of the spectrometer/layout of fragment separator). This is a longer-term project. The goal would be to have the HRS available for experiments when FRIB comes online, a staged implementation is also thinkable.

5) *What is the approximate cost of the project: discuss possible sources of funding.*
Ongoing development of the S800 is performed with the operating budget of the NSCL (NSF). The HRS spectrometer is not yet funded. The very preliminary estimated costs are:

Item	**Costs (2010 $)**
Quadrupole Triplet (magnets/stands/power supplies)	$2.1M (30% contingency)
Dipole (magnets/stands/power supplies)	$3.4M (40% contingency)
Vacuum/beam chambers/NMRs	$0.4M (30% contingency)
Focal-plane & other detection systems	$0.5M (30% contingency)
Personnel costs (magnet engineering/other design & development/installation)	$0.5M (includes overhead/fringes)
Total	$6.9M

6) *Please provide a brief list of collaborators and institutions.*
The working group has members (34) from NSCL/MSU, GSI, Concordia, FSU, LBL, U. Tennessee, RIKEN, Ursinus, U. Tokyo, Hope College, Niigata U. and Westmont College. Working group conveners are: Remco Zegers (zegers@nscl.msu.edu), Daniel Bazin, Alexandra Gade (gade@nscl.msu.edu) (bazin@nscl.msu.edu), Paul Fallon (pfallon@lbl.gov), Ingo Wiedenhoever (iwiedenhoever@physics.fsu.edu), Michael Thoennessen (Thoennessen@nscl.msu.edu).

7) *Please can you outline how your collaboration has been developing your project and how you are growing your collaboration (How many meetings? Participants?, Circular mailings? Have you a web-site?)*
The main communication tool is the group's website:
https://groups.frib.msu.edu/group/working-group-high-resolution-spectrometer-s800-frib
where documents are placed and which allows for comments etc. Circular mailings are sent out when needed.

8) *Did you consider alternative designs? What alternatives were considered? How did you arrive at a final design?*
The design of the S800 is more or less fixed by the existing infrastructure. For beam tracking purposes, the diamond detectors are at present the best option for high-intensity RI beams but require still significant development. Other alternatives (which are currently employed at the NSCL) or could be considered (channel plates/ PPACs/wirechambers) suffer from count-rate limitations.
The design of HRS spectrometer is in its initial stages. The preliminary design (see Tables 1 and 2) is based on experiences with the A1900, S800 and the Sweeper magnet and several types of experiments that could be carried out with the device. Further development of the design will require continued investigation of the

needs for several classes of experiments, but also depends on external factors, such as the layout of the fragment separator and the location of the device.

9) *What existing equipment exists in the US Community that has similar goals and characteristics, even if inferior in performance?*

The S800 spectrometer already exists and there is no device with similar capabilities in the US. There is no alternative device for the proposed HRS spectrometer.

Table 2 Tentative design parameters for the HRS, used to estimate the cost and the floorplan.

		Quadrupole Triplet		
	Dipole	Quadrupole 1	Quadrupole 2	Quadrupole 3
Bending angle	30^0			
Bending Radius	4.5 m			
Vertical gap	30 cm			
Half Hor. gap	25 cm (C-type)			
Length	2.35 m	50 cm	120 cm	80 cm
Max. B-field	1.6 T	2.5 T (pole tip)	-2.3 T (pole tip)	2.1 T (pole tip)
Type	Iron Saturated	Superconducting	Superconducting	Superconducting
Warm bore radius		20 cm	25 cm	25 cm
Pole tip radius		23 cm	28 cm	28 cm

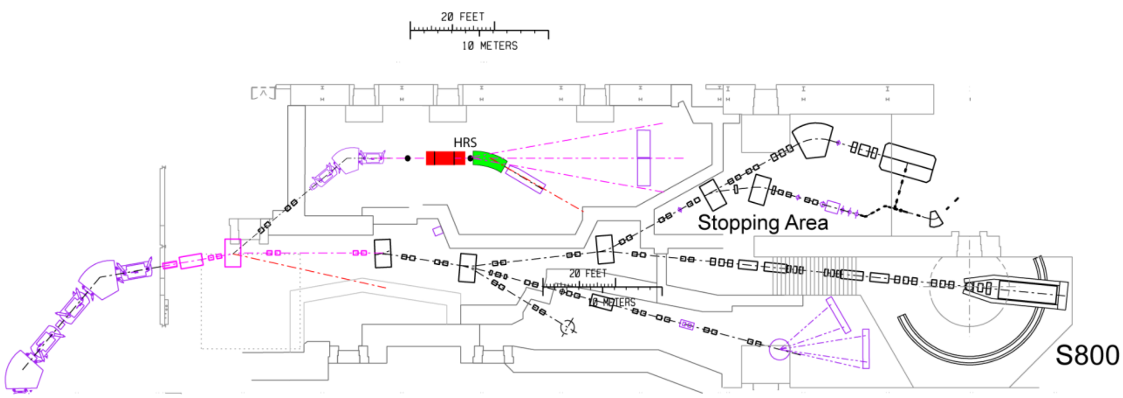

Figure 1 Floorplan showing a possible location for the HRS in the combined N1/N2/N3 vaults.