High-Resolution (S800) and High-Rigidity Spectrometers at FRIB

HRS working group - February 2011

https://groups.frib.msu.edu/group/working-group-high-resolution-spectrometer-s800-frib

Overview & Science Program

Spectrometers are indispensable for a strong physics program with fast rare isotope beams at FRIB. At present, the S800 spectrometer is the most heavily-used experimental device at NSCL. A wide variety of experiments are conducted with the S800, addressing all of the 5 overarching nuclear science questions posed in the 2007 NSAC long-range plan. These experiments employ nucleon knockout, transfer, charge-exchange reactions, inelastic scattering, intermediate-energy Coulomb excitation, time-of-flight (TOF) mass measurements and excited-state life-time measurements. Scientific topics addressed include, but are not limited to, the investigation of the limits of stability and the evolution of shell-structure in the exotic regime, the origin of simple patterns in complex nuclei and the effects of pairing, the nature of nuclear halos and skins, the study of electro-weak reaction rates of importance for late stellar evolution and the mapping of nuclear structure information key to understanding the rp-process. Sophisticated secondary detection systems are used in combination with the S800, such as the Segmented Germanium Array (SeGA) and the Caesium Iodide Array (CAESAR) for gamma-ray detection, the Low-Energy Neutron Detector Array (LENDA) for neutrons from 0.1-10 MeV, the High Resolution Array (HiRA) for charge-particle detection and in 2012 the first campaign with GRETINA is scheduled to take place at the spectrograph. In addition, advanced target systems are available, such as a plunger device for life-time measurements and a liquid Hydrogen/Deuterium target for reaction studies. The S800 focal plane detection system undergoes continuous developments (i) to improve particle-identification capabilities (recent additions are a high-pressure ionization chamber and a segmented CsI hodoscope) and (ii) to increase the capability to deal with high event rates (e.g. gated tracking detectors). Work is ongoing to facilitate high-rate and high-resolution beam tracking prior to the reaction target with diamond and Xenon detectors to improve the accuracy of kinematic reconstructions.

In a complementary physics program, NSCL's Sweeper magnet is used in combination with the Modular Neutron Array (MoNA) and its soon-to-be-finished upgrade, the Large multi-Institution Scintillator Array (LISA), to conduct studies of neutron-unbound states near or beyond the neutron dripline. This research addresses the role of nuclei as open quantum systems in the regime of weak binding and the proximity of the continuum. The MoNA-LISA-Sweeper setup is also used together with auxiliary detection systems, such as CAESAR.

In combination with the secondary detection systems, users of the S800 and sweeper magnet will be uniquely positioned to conduct world-leading science at the very beginning of FRIB operation. The rigidity of both spectrometers is limited to about 4 Tm. This is sufficient for most experiments involving rare-isotope beams with energies of 100 AMeV or less. However, at FRIB, maximum intensities for secondary rare-isotope beams produced from fast-fragmentation will be achieved at beam energies roughly double of those currently available at NSCL and reaction products, in particular from the most neutron-rich secondary beams will exceed the bending limits of the S800 and Sweeper by a factor of 1.5-2. Schemes to slow down the beams are possible but would result in intensity and purity losses, ultimately limiting the reach of experiment. Therefore, in the FRIB equipment workshop of January 2010 the HRS working group proposed the construction of a high-rigidity (7 Tm), large momentum acceptance (10%) spectrometer that complements the capabilities of the S800 spectrometer and will replace the sweeper magnet. The S800 will be used for experiments that are preferably run at 50-150 AMeV and/or that require high resolution. Experiments that are intensity limited and/or require high rigidities and momentum acceptance would be pursued at the HRS.

The High-Ridigity Spectrometer (HRS) at FRIB

The capabilities of the S800 spectrometer and HRS are put side-to-side in table 1. The HRS nearly doubles the bending capability and has double the momentum acceptance of the S800. Table 2 provides the tentative design parameters of the HRS. The HRS is envisioned to have 3 quadrupole magnets and a single C-type dipole magnet (QQQD) compared to the QQDD layout of the S800. The location of the quadrupoles would be variable to allow for maximum flexibility to tune the optics for different types of experiments and for the placement of the target. A C-type dipole magnet is required to allow for an unperturbed flight path for neutrons to the MoNA-LISA array. Like the S800, the HRS will be able to run with all major secondary detection systems for gamma, neutron and charge-particle detection.

Table 1 Overview of Specifications and Capabilities of the S800 spectrometer and the HRS at FRIB

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

Table 2 Tentative design parameters for the HRS

		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

The tentative design parameters of the HRS are based on existing technologies, thereby reducing the risks for the implementation of the device in terms of design, construction and operational costs. For example, the QQQD layout was selected based on the need to keep the pole-tip fields of the quadupole magnets at 2.5 T or less, when the spectrometer is operated at the highest rigidities. Based on these design parameters, a very tentative cost estimate was made, shown in table 3. The design and construction of the focal plane detector system would be based on that in place for the S800, thereby reducing the cost and effort involved.

Table 3 Tentative cost (in 2011 S) of the HRS based on the design parameters in tables 1 and 2. The costs are for the HRS only and do not include the beam line from the fragment separator to the HRS.

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)	$1.0M (includes overhead/fringes)
Total	$7.4M

Location of the HRS

Operation of the HRS requires a beam line from the fragment separator that can operate at equally high rigidities. To reduce the costs of building such a beam line, it is preferable to keep the distance between the HRS and the exit of the fragment separator as short as possible. One suitable solution would be to place the HRS in the N1/N2/N3 vaults that currently house the sweeper magnet and the MoNA-LISA array. A schematic floor plan is shown in Figure 1.

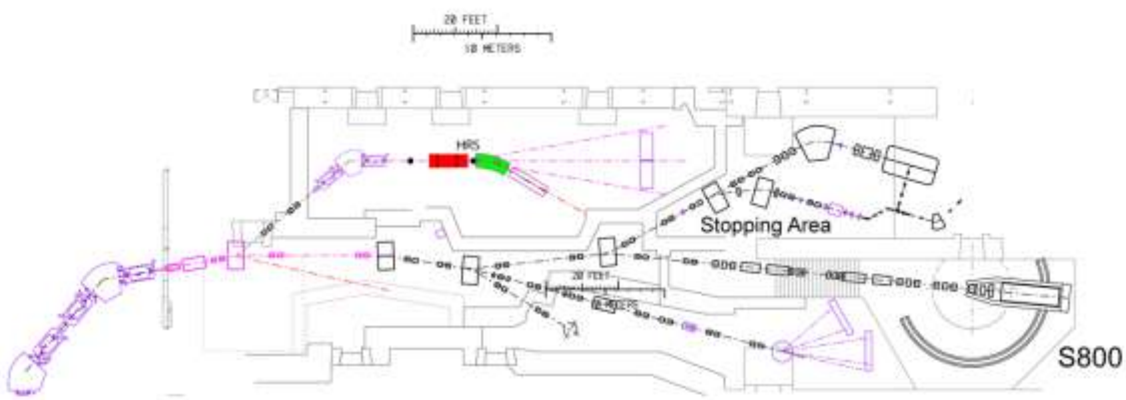

Figure 1 Schematic floor plan of the HRS in the current NSCL N1/N2/N3 vaults. The quadrupole triplet is shown in red with the possible target locations in front (allowing for the placement of auxiliary devices) and after (for experiment with MoNA-LISA) the triplet indicated by a black dots. Downstream of the dipole magnet (in green) is the focal plane detection system. The proposed floor plan allows for placement of the MoNA-LISA array with a sufficiently-long flight path between the the target and the detectors to achieve neutron-energy resolutions comparable to those achieved in current experiments with MoNA and the sweeper magnet.

Time line and funding profile for the design and construction of the HRS.

Since the HRS is designated for experiments with high-rigidity beams currently not available at the NSCL, it is not envisioned to complete the construction of the HRS a long time before FRIB comes online. Starting the design of the HRS in 2015 would allow for the start of the construction in 2018 and completion in 2020. This has the further advantage that both the design and construction efforts of the HRS would not interfere with the design and construction of other magnets needed for FRIB and can benefit from infrastructure and expertise available from the development of those other magnets. We note that the beam switchyard at the end of the fragment separator should allow for guiding the high rigidity beams to the vault where the HRS will be placed and thus be taken into account when designing the fragment separator. A very tentative spending profile for the construction of the HRS is shown in Table 4. Since the design effort would start in the next 1-5 year period, it is further specified in table 5. Both are for the the spectrometer and associated equipment only and do not include additional costs for the beam line from the fragment separator to HRS.

Table 4 Tentative spending profile for the design and construction of the HRS. Units are 2011 k$ and do not include the costs of the beam line from the fragment separator to the HRS.

	2015	2016	2017	2018	2019	2020	total
design	200	300	100				600
procurement			1800	4000	500		6300
installation				200	200	100	500
yearly totals	200	300	1900	4200	700	100	7400

Table 5 Estimated design costs for the HRS and associated detector systems Units are 2011 k$ and do not include the costs of the design of the beam line from the fragment separator to the HRS.

	Estimated effort (FTEs)	Fully-loaded rate per FTE	Estimated cost
Magneto-static design	0.5	200	100
Mechanical design	2	150	300
Magnetic engineering	0.25	200	50
Layout design	0.25	200	50
Detector design	0.5	200	100
Total	3.5		600

The HRS user community and the path towards the HRS spectrometer.

The working group currently has 52 members from the following institutions:

US:
Concordia College
Florida State U.
Hope College
Indiana U. South Bend
LBNL
NSCL/Michigan State U.
Rhodes College
U. Tennessee
U. Massachusetts Lowell
Ursinus College
Westmont College

Non-US:
GSI (Germany)
Niigata U. (Japan)
Osaka U. (Japan)
INFN (Italy)
RIKEN (Japan)
U. Tokyo (Japan)
Kyoto U. (Japan)
Khalifa U. (UAE)

Within about a year, the working group is planning a **workshop aimed at further detailing the required specifications for the HRS and laying the ground work for a proposal/whitepaper.** Since it is ensured that a large community of people would be interested in performing experiments with the device at FRIB, this would also provide a great opportunity to expand the working group and connect with new members.