High Resolution/Rigidity Spectrometers @ FRIB

S800 high-resolution spectrometer is key to fast beam program at NSCL and will be at FRIB.

motivations	**tools**	**secondary devices**
shell structure	knockout	SeGA
limits of stability	transfer	CAESAR
mass surface	charge-exchange	HiRA
symmetries	inelastic scattering	LENDA
pairing	Coulomb Excitation	GRETINA
weak interaction rates	TOF mass measurements	....
rp-process	excited state lifetime measurements	LH_2 target
neutron skins	....	
....		

S800 spectrometer

Capability	
energy resolution	1/10000 primary/tracked beams 1/2000-3000 secondary beam, dispersion matched
angular resolution	0.5x1.7 mrad primary/tracked beams 5-10 mrad secondary beams
bending capability	4 Tm (beam line to S800: 4.8-5 Tm)
momentum acceptance	5%
angular acceptance	20 msr [120 (disp) x170 (non-disp)] mrad
rate capability	limited to 5kHz – less for localized high-Z events
particle ID	ion-chamber/plastic scintillators/TOF (up to Z=30)
beam tracking	PPAC/channelplates rate<1 MHz

- improvements needed & possible for running at FRIB
- cannot be changed

Recent/Ongoing/Planned Improvements important for FRIB physics

- improved PID capability
  - high-pressure ion-chamber (1 atm): improved S/N ratio:soon
  - segmented CsI hodoscope: heavy nuclei/charge-states: soon

- focal plane detector rates
  - gated CRDCs: under development
  - DAQ?

- tracking
  - ideal solution: segmented diamond detectors
    - high rates (10^7 pps)
    - 1mm pitch: high resolutions with secondary beams
    - fast
  - development needed

Sweeper magnet

- currently used in combination with MoNA for study of neutron unbound states

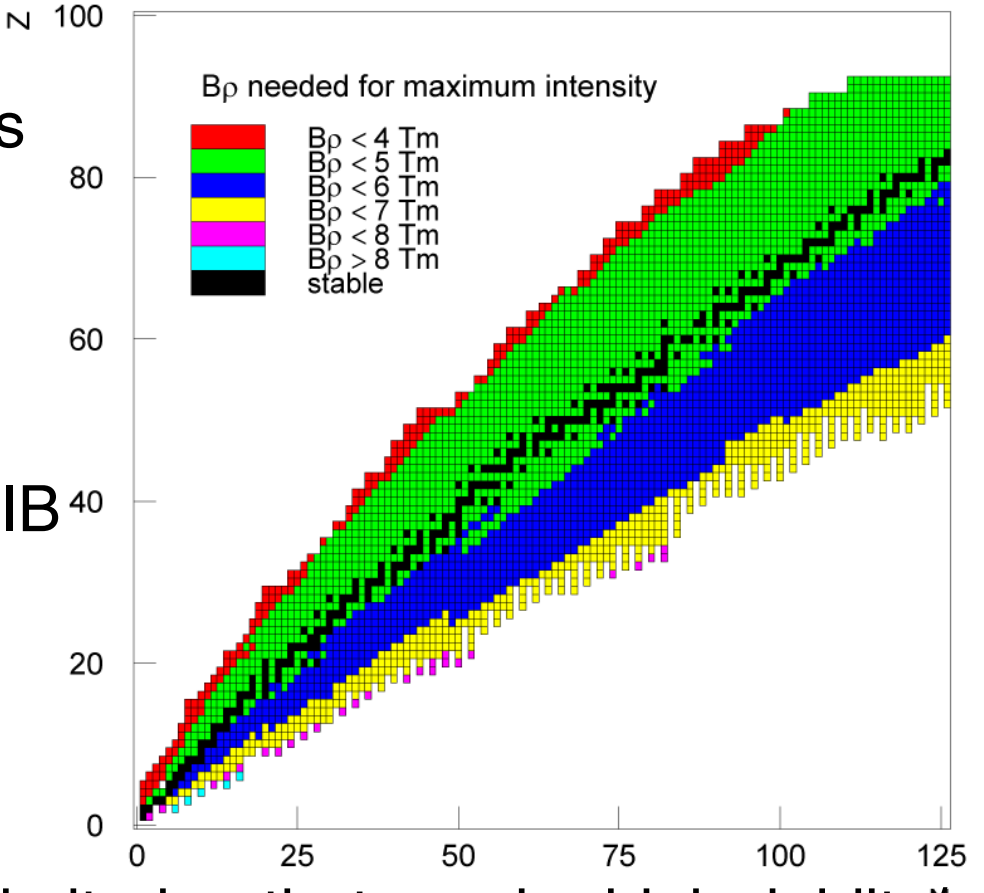
Capability	
energy resolution	**<1/1000**
magnet gap	**14 cm**
FP angle acceptance	**11-32 msr acceptance**
FP momentum acceptance	**15-30%**
bending capability	**4 Tm, 43^{o} 1-m bending radius**
angular acceptance	**20 msr [120 (disp) x170 (non-disp)] mrad**

rigidity limitations

Options for slowing down beams

- thick production target/wedges
- degraders
- lower injection energy
- best solution: case-by-case
- intensity loss factor 1.5-5

A large class of experiments at FRIB are preferably ran at 50-150 MeV/nucleon and require good resolution: use S800



For experiments that are intensity limited or that require high rigidity/ momentum acceptance, but not superior resolution: high-rigidity large-acceptance spectrometer is needed

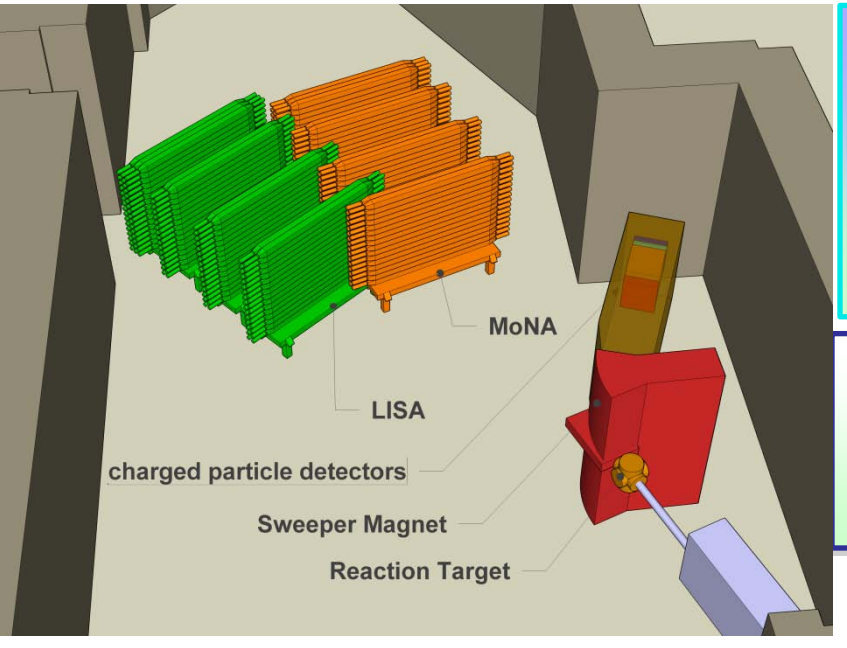
MoNA-LISA @ FRIB

Physics motivation

Structure of exotic neutron-rich nuclei along the neutron drip line.

Reconstruction of neutron unbound states from decay products:

fast neutron + fragment (+ γ)



MoNA-LISA

- MoNA : 144 individual plastic scintillator modules; 10 cm×10 cm×200 cm; stack to match experimental needs
- LISA: additional 144 modules (MRI – funded)

- FRIB requirements for MoNA: Flight path of at least 10 m to maintain the same energy resolution

New HRS requirements – 7 Tm

Acceptances similar to Sweeper

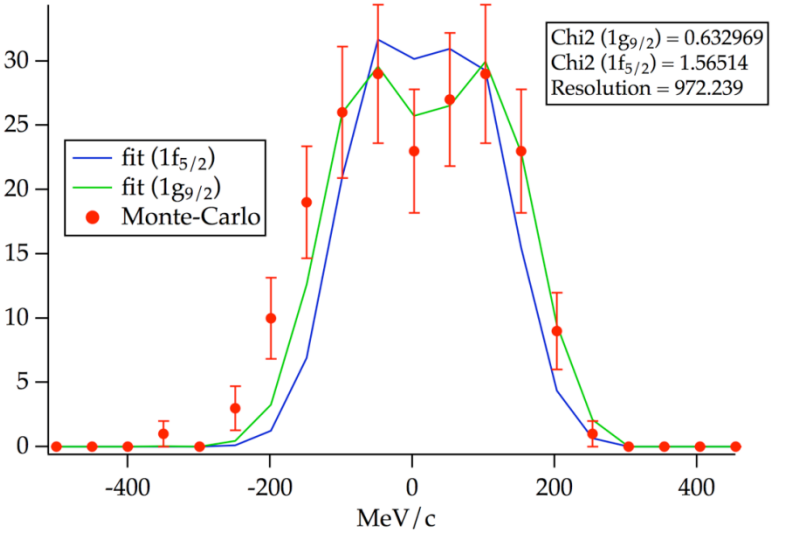
Larger flight path

Larger neutron window that extends to the side

A. Spyrou

Knockout reactions of FRIB neutron-rich RIBs

- Motivation
  - Slowing down FRIB neutron-rich at 4 Tm costs a factor between 1.5 and 5 in intensity
  - Moderate resolution needed for angular momentum identification (see figure)
- Requirements
  - Large acceptances (similar to S800)
  - Maximum rigidity: 7 T. m.
  - Needs to accommodate γ-ray arrays around target

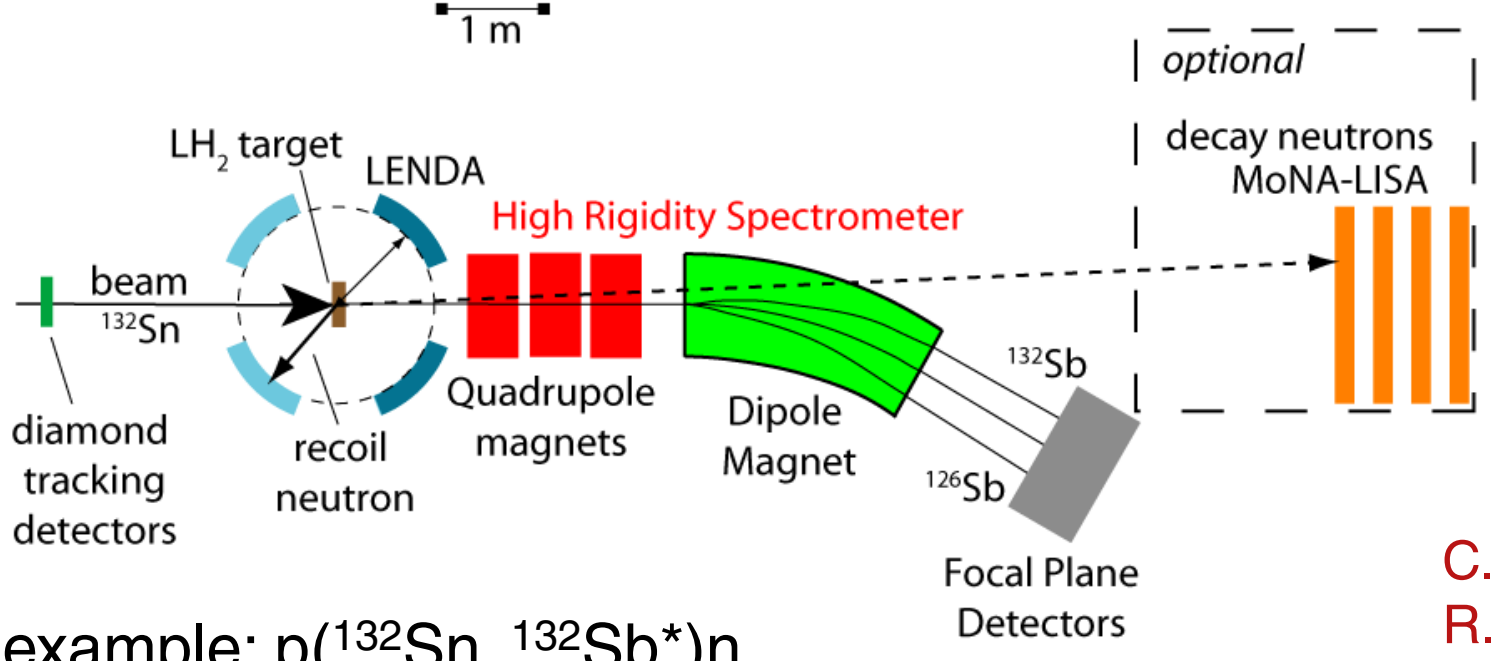


Simulation of the longitudinal momentum distribution of ^{89}Zr from the neutron knockout of ^{90}Zr, assuming the valence neutron is either in the $1f_{5/2}$ or $1g_{9/2}$ orbital. A resolution of 1/1000 in momentum is sufficient to identify the angular momentum from the shape of the simulated $1g_{9/2}$ momentum distribution.

D. Bazin

(p,n) charge-exchange reactions and isovector giant resonances

- isovector giant resonances: symmetry energy/EOS, isovector component of NN interaction, neutron-skin thickness, weak interactions for astrophysics.
- slow recoil neutron measured in LENDA: kinematics reconstruction
- high excitation energies in neutron-rich nuclei: multiple n-decays
- large momentum acceptance is needed to tag all decay products
- similar setup can be used for (p,p'), (α,α') etc. Replace LENDA with detectors for charged particles (silicon strip/active gas target)

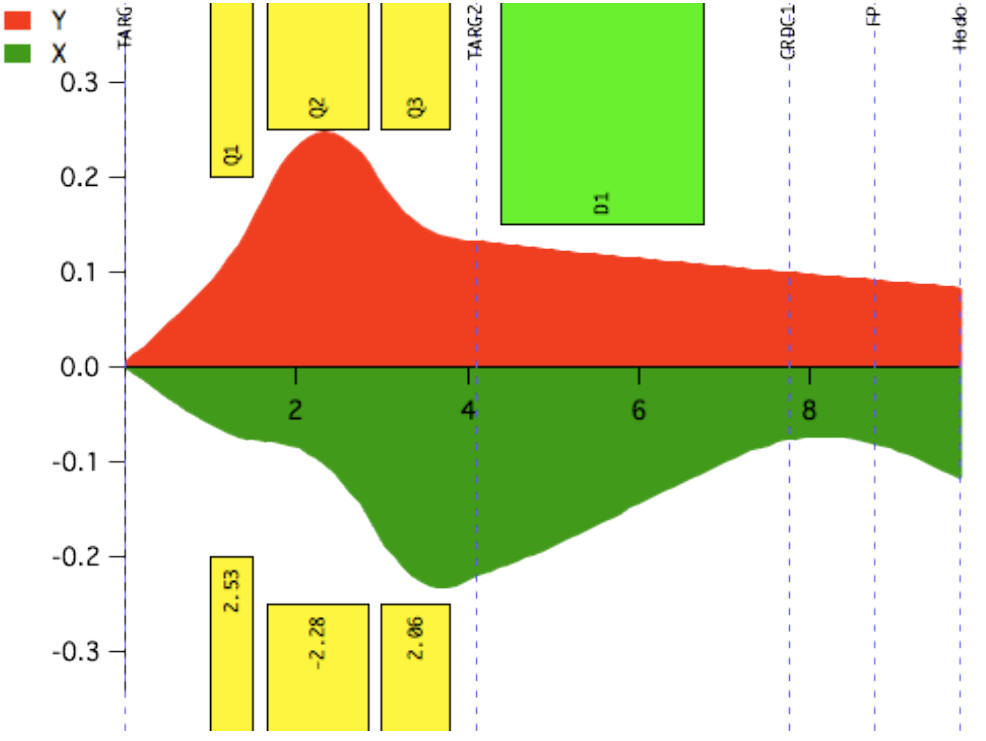


example: p(^{132}Sn, ^{132}Sb*)n

C. Guess
R. Zegers

High Rigidity Spectrometer: simple design

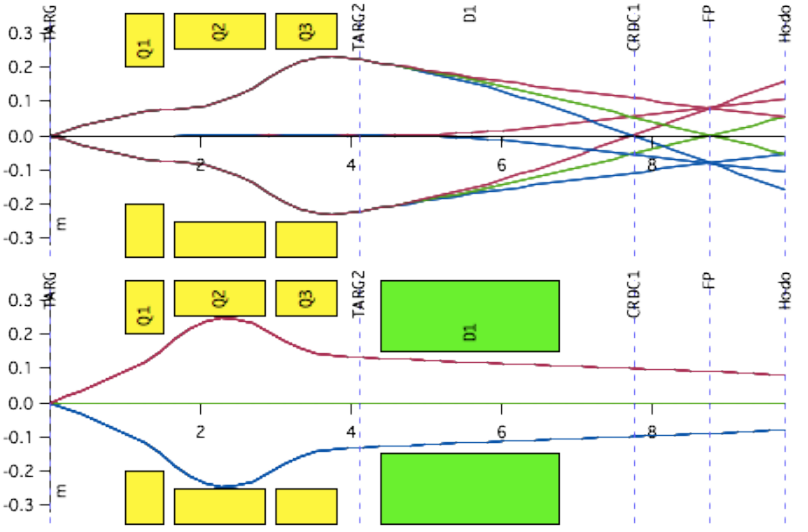
- QQQD configuration
  - Quadrupole triplet needed to reduce pole tip fields at 7 Tm.
  - Adds flexibility for optics
- Single C-type dipole
  - 4.5 m radius, 30 degrees bend, 30 cm gap
- Target locations
  - Upstream or downstream of triplet
  - Moveable triplet?

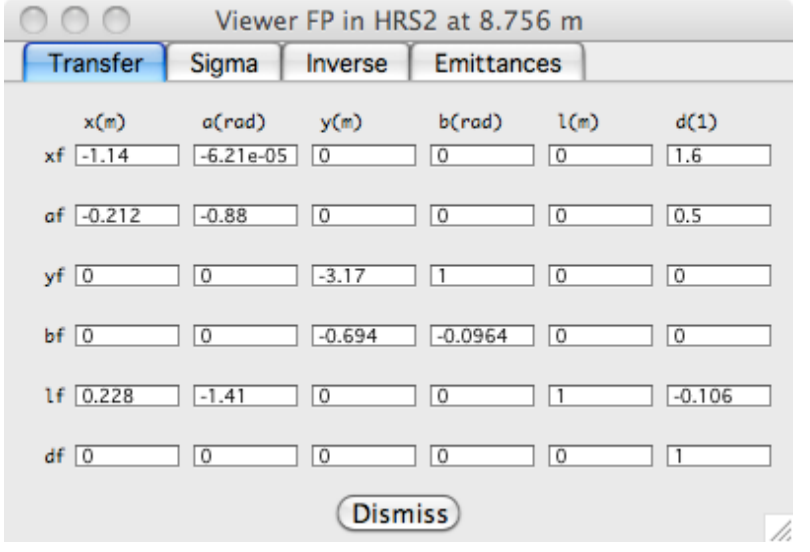


D. Bazin

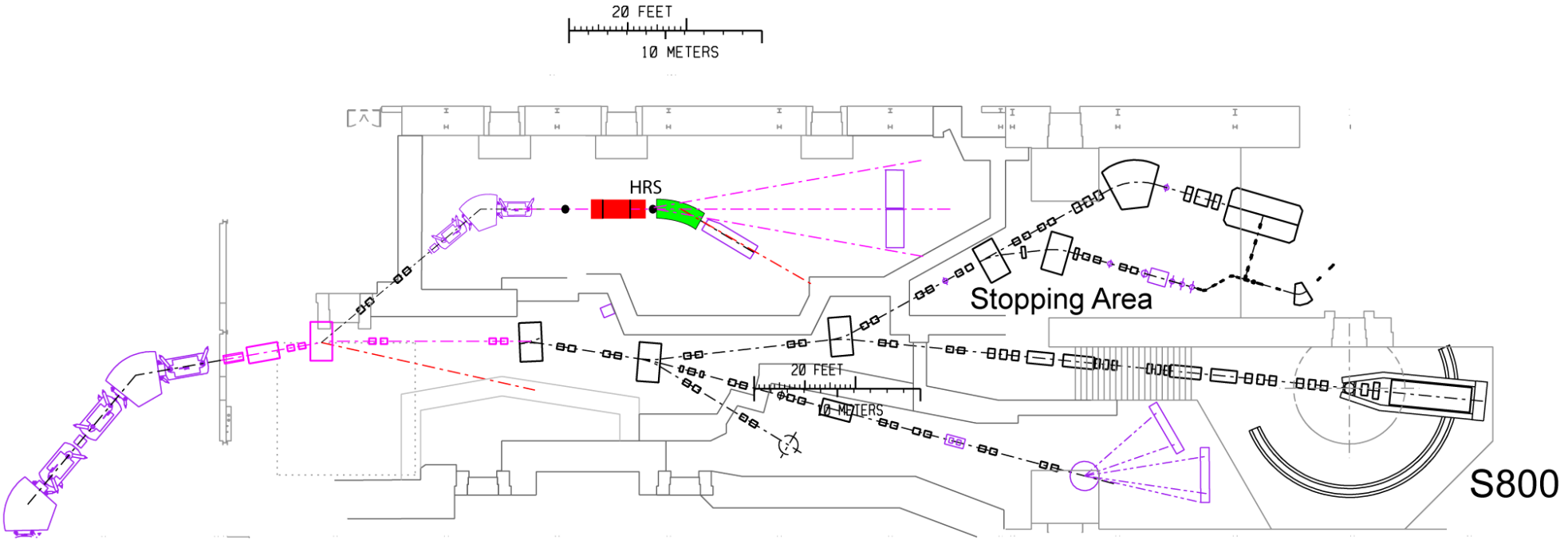
High Rigidity Spectrometer: optics properties

- Resolution
  - 1/1400 in momentum
- Acceptances
  - 20 msr (same as S800: ± 60 mrad dispersive, ± 85 mrad non-dispersive)
  - ± 5 % momentum, easy to increase
- Neutron vertical acceptances
  - Upstream target: ± 1.3°
  - Downstream target: ± 3.2°





possible location



- short beam line from fragment separator to HRS
- space for MoNA-LISA
- space for other detectors (SeGA/GRETINA/CAESAR/LENDA)

preliminary cost estimate

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 (other than magnet design)	$0.5M
Total	$6.9M

A. Zeller

working group

Currently 38 members

- Concordia
- FSU
- Hope College
- LBL
- U. Tennessee
- Ursinus
- Westmont College
- NSCL/MSU

- RIKEN
- U. Tokyo
- GSI
- Niigata U.

conveners: Remco Zegers Daniel Bazin, Alexandra Gade, Paul Fallon, Ingo Wiedenhoever, Michael Thoennessen

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

comparison S800 and FRIB

Parameter	S800@FRIB	HRS
Energy resolution	1/2000 (1/10000 with tracking)	1/1400 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