



S800 Spectrograph Service Level Description

I. Standard Configuration

A. General

The S800 is a large acceptance, high-resolution spectrograph designed for experiments using radioactive beams produced by projectile fragmentation. It is composed of two main parts:

1. The Analysis Line

- This section of the S800 is used for different purposes: tuning the beam on the reaction target, implementing various optical modes as well as measure the characteristics of the incoming particles.
- It spans from the object to the target, and is semi-symmetric around the intermediate image.
- Its acceptances vary depending on the mode used, and its maximum rigidity is around 5 Tm, also depending on the tune of the quadrupole triplets.

2. The Spectrograph

- This is the large acceptance part of the S800, spanning from the target to the focal plane.
- The solid angle acceptance is 20 msr, defined roughly as an ellipsoid of $\pm 3.5^\circ$ in the dispersive plane by $\pm 5^\circ$ in the non-dispersive plane.
- The momentum acceptance is around $\pm 3\%$, although the solid angle acceptance is greatly reduced on the edges.
- The maximum rigidity is 4 Tm.
- The energy and scattering angle resolutions depend on the experimental conditions, such as the object size, target thickness and whether or not tracking is used prior to the target. Moreover, the resolution values depend on the optics mode used (see next section and the S800 technical article¹).

B. Optics

The analysis line allows several optics modes to be used, each having different characteristics. The modes currently supported are described in the following.

¹ D. Bazin *et al.*, Nuclear Instruments and Methods B 204, 629 (2003)
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1. Dispersion matched mode

- In this mode the whole S800 (analysis line + spectrograph) is achromatic, which means that the position distribution of the beam at the focal plane does not depend on its momentum spread at the object.
- To achieve this achromatism, the beam is momentum dispersed on the target. For this reason, the maximum momentum acceptance of the analysis line in this mode is only $\pm 0.5\%$.
- The dispersion at the target is about 11 cm/%; therefore a $\pm 0.5\%$ momentum bite implies a target 11 cm long in the dispersive direction.
- For practical means, the momentum acceptance is often reduced to $\pm 0.25\%$ to accommodate 2" wide targets.
- The main advantage of this mode is that no momentum tracking of the incoming particles is required, therefore the maximum energy resolution of the S800 can be reached only in this mode.
- Note however that tracking detectors are required in order to measure the angles of the incoming particles, if an angular resolution better than 10 mrad is needed by the experiment.
- This mode is used in experiments where the highest momentum resolution is required.

2. Focused mode

- In this mode the analysis line is achromatic, which means that the beam is focused on target and the momentum spread of the beam at the object is not cancelled at the focal plane.
- The momentum resolution is therefore set by the momentum acceptance in the A1900 fragment separator (image 2 slits).
- If a better momentum resolution is desired, the momentum of the incoming particles needs to be measured prior to the reaction using tracking detectors.
- This mode entails a larger momentum acceptance of roughly $\pm 2\%$ in the analysis line, and is used in experiments where the momentum resolution is not critical or small targets have to be used.

3. Monochromatic mode

- This mode requires the fabrication of a mono-energetic wedge to be placed at the intermediate image.
- Since the profile of this wedge is energy and particle dependent, it is not possible to design a fit-all version of it.
- This tune is used to produce a very low energy (5-10 MeV/u) radioactive beam from a high energy fragmentation beam, and is still in development stage.



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C. Target setup

1. Scattering chamber

- A large chamber has been built to accommodate bigger detector systems such as the HiRA array.
- The available volume inside the chamber is 200 ft³ or 5.67 m³.
- The pumping system allows vacuum at the level of 10⁻⁶ Torr with the chamber empty. The pump down time to reach this vacuum is about 1/2 day.
- This chamber has a target mechanism allowing vertical translation, and can be mounted at different positions along the beam axis.
- This feature is necessary for experiments requiring more space downstream of the target for detecting particles at forward angles.
- Note that moving the target upstream of the nominal position reduces the solid angle of the spectrograph and requires retuning of the last two quadrupole triplets of the analysis line.
- The adaptation of the chamber to various spectrograph angles can be realized using flanges with fixed angles.
- This chamber is not part of the supported S800 equipment. Its installation and use are all under the responsibility of the user.
- Note that experimenters intending to work in the target chamber need to obtain confined space training if the activity intended by the user is considered “confined space work”.
- Installation of the scattering chamber is a very demanding operation requiring a large amount of time (~1 week). It needs proper coordination with NSCL staff.

2. Other setups

- Some detector arrays do not require a scattering chamber; in this case the chamber is removed using a rail system and the target is slid into a pipe surrounded by the detector.
- The GRETINA, CAESAR CsI(Na) and SeGA Germanium arrays, as well as the plunger devices have standard setups to be used with the S800.
- Other detector arrays would require the design and fabrication of new setup hardware.
- Note that in this configuration a change of target implies venting the target section and dismounting part of the hardware to gain access inside the pipe.
- This operation typically takes about 45 minutes.



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D. Trajectory reconstruction

1. Method

- The S800 spectrograph is equipped with only a few magnets to correct aberrations: a sextupole is embedded in the second focusing quadrupole, and each dipole has a trim coil to flatten the field on its edges.
- Rather, the aberrations introduced mostly by the fringe fields of the magnets are calculated based on measured field maps, and corrected for analytically.
- This method uses the ion optics code COSY Infinity to calculate the aberrations to any order, invert the obtained polynomial matrix, and then apply the corrections event by event in the analysis code.
- These so-called “inverse maps” are typically calculated up to order 5 for which the corrections are on the same order as the resolution of the position detectors in the focal plane.
- The main advantage of this method is to avoid tracking of each individual particle in the magnetic fields of the spectrograph, and therefore a much faster processing of the data.
- The standard S800 analysis code provides all the necessary functions and interface to perform these calculations.

2. Inverse map calculations

- The inverse map relates the positions and angles measured in the focal plane in both dispersive and non-dispersive planes to the energy, two projections of the scattering angle and non-dispersive position at the target location.
- Because the energy is one of the 4 quantities deduced from the map, the beam position in the dispersive plane at the target cannot be calculated, and is assumed to be zero.
- This assumption means that the final resolution is obtained by folding the finite size of the beam spot in that direction with the size obtained from the reconstruction, itself depending on the detector resolution and the order to which the calculation is performed (see previous paragraph).
- Note that this is still the case even when the S800 is operated in dispersion-matched mode, in which the incoming beam is momentum dispersed – and therefore rather large – on the



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target. In that case it is the size at the object location that matters since the whole S800 (analysis line + spectrograph) is achromatic.

- Since the shapes of the fringe fields vary significantly with the absolute strength of the magnets, inverse maps need to be calculated for each $B\rho$ setting of the spectrograph.
- Users can request these maps for which only the magnet strengths, $B\rho$ and type of particle are necessary. For more information, use the URL link <https://wikihost.nsl.mscl.msu.edu/S800Doc/doku.php?id=mapserver>. In case of problems, please contact the S800 device physicists.
- The magnet settings of the beam lines during the experiment can be saved (“Barney printouts”) and are a necessary requirement for the provision of an inverse map.

E. Detectors

1. Focal plane

The S800 focal plane is equipped with various detectors for trajectory reconstruction as well as particle identification.

a) Position detectors

- Two Cathode Readout Drift Chamber (CRDC) detectors about 1 meter apart are used to measure the positions and angles in the focal plane.
- Note that the nominal optical focal plane is located on the upstream detector.
- Each CRDC has a position resolution of 0.5 mm in both dispersive and non-dispersive directions.
- The active area covered by these detectors is approximately ± 28 cm by ± 13 cm in the dispersive and non-dispersive directions respectively.
- They are filled with a mixture of 80 % CF_4 – 20 % Isobutane at a pressure of 40 Torr.
- Due to their mode of detection (drift of electrons in gas), they are rather slow – typically up to 5 μs per event – and therefore cannot be run at high counting rates.
- The maximum rate until which they function properly is around 5,000 counts per second. Above this rate, efficiency losses and distortions due to ion back-flow are to be expected, in particular if it is concentrated on a small area of the detector.
- For this reason, it is recommended to run high rate experiments in focus mode, for which the focal plane is dispersive in momentum and the beam is spread due to its intrinsic momentum width.
- The nominal angle and energy resolutions have been realized experimentally at very low rates, 30 Hz for the example of a ^{209}Bi beam.



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- Nominal resolutions are not guaranteed at moderate or high rates with the limit on the rate to be determined during the experiment.

b) Particle identification

- Downstream of the two CRDC detectors are the ion chamber for energy loss measurement, followed by a thin plastic scintillator of either 1 mm or 5 mm thickness (default is 1 mm), itself followed by a 32-fold segmented CsI(Na) hodoscope.
- They provide time as well as energy loss and/or total energy measurements.
- Note that the CRDC detectors cannot function without at least one scintillator to provide a time reference to measure the drift time of the electrons.
- In standard configuration, the ion chamber is filled with P10 gas at a maximum pressure of 600 Torr and is able to separate elements up to $Z=50$, after momentum and position corrections are applied.
- The ion chamber now consists of 16 pairs of alternating anode and cathode aluminum evaporated mylar foils. With this geometry electrons and ions are collected on a much shorter distance than in the previous empty gas volume configuration (about 1.5 cm compared to 30 cm). Both pile-up and position dependence effects are reduced by using this configuration (typical drift times $\sim 3 \mu\text{s}$).
- The timing resolution for a point-like beam spot in the focal plane is around 400 ps.
- However, this resolution worsens significantly (up to 4 ns) when the whole focal plane is illuminated, because of path length differences in such large scintillators. It can be recovered by tracking the position of each event on the scintillator from the position and angle information provided by the CRDC detectors.
- The 32 CsI(Na) hodoscope crystals are 2" thick and cover the whole active area of the focal plane. They provides a measurement of the total kinetic energy of the particles that stop within the crystals. The purpose of the hodoscope is to provide charge state identification orthogonal to the traditional A/Q identification provided by time-of-flight measurement. Commissioning tests have shown good separation for isotopes up to $Z=30$.
- The hodoscope can also be used as a gamma-ray detector when biased at around 800 V. An aluminum plate can be installed in front where the particles are stopped and their subsequent decay is detected. This technique is useful to measure isomeric populations for lifetimes longer than the typical time-of-flight in the spectrograph (about 150 ns). Maximum measurable decay lifetimes are limited to few μs .

2. Object

- The object box of the S800 analysis line contains a thin plastic scintillator (125 μm) for time-of-flight measurements. For lighter projectiles, a thickness of 1 mm is also available.



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- This detector is usually left in the beam during experiments and can withstand rates of up to 1 MHz.
- It is also possible to install other types of detectors in the object box, such as diamond timing detectors or Silicon detectors for energy loss measurement. These optional detectors are under the responsibility of the user.

3. Intermediate image

- The intermediate image box is equipped with two tracking delay Parallel Plate Avalanche Counters (D-PPAC).
- They cover a surface area of 10 cm x 10 cm and provide measurements of positions and angles in both the dispersive and non-dispersive planes.
- The tracking of light particles (Z below 10) is affected by a significant reduction in the detection efficiency.
- Maximum rates of up to few hundreds of KHz are possible.
- The characteristics of the incoming particles at the target location can be calculated in much the same way as for the spectrograph, using an optics calculation that relates the coordinates at the target to the coordinates at the intermediate image.
- The principal advantage of this method is to use the final bend of the analysis line to eliminate the contamination due to reactions in the tracking detectors.
- The transfer map between the target and the intermediate image depends on the optics mode used in the S800.

4. Target

- As mentioned before in section I.C.1, the scattering chamber is equipped with drives that can accommodate any kind of tracking detector (with a small adaptation).
- Standard PPAC detectors (maximum rate 1 kHz) can be installed at those locations. However, one has to keep in mind that reaction products from these detectors contaminate those produced from the target, and require background runs to subtract their contribution when running with thin targets.
- They should therefore not be left in the beam during data accumulation, and only serve for checking the tracking deduced from the intermediate image.
- Detector systems beyond the standard configuration outlined in this document and their readout are entirely within the responsibility of the experimenters. None of the detectors installed the scattering chamber are part of the standard configuration.

F. Electronics



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1. Digital electronics

- Both focal plane CRDCs are equipped with digital electronics.
- They consist of a number of front-end electronics boards as designed for the STAR TPC detector at RHIC, followed by interface boards feeding and receiving data to and from a programmable FPGA VME module called XLM72 built by JTEC instruments.
- Each chain of these 3 components forms an independent data acquisition system of its own, driven by state machines programmed into the FGPA.
- The signals occurring on the detectors are sampled by the electronics and locally stored into the internal memory of the XLM72 modules.
- The sampling frequencies are adjustable, and have typical values of 25 MHz.
- The number of samples read out is also adjustable, with typical values 4.
- The dead time of the digital electronics readout and the amount of data to transfer through the VME crate are directly proportional to the number of samples. A typical “event” generates a dead time of about 150 μ s. Note that this is the main “source” of dead-time in the S800 DAQ (~20% at trigger rates ~2000 pps).
- The amount of data also depends on how many channels have fired. As there is no data reduction performed in the FPGA other than zero suppression below thresholds, the relatively large amount of data is read from the XLM72 in block mode.
- A more detailed description of the digital electronics system is available at <https://wikihost.nsl.mscl.edu/S800Doc/doku.php?id=electronics>

2. Trigger module

- The S800 trigger logic is implemented in an FPGA module (LeCroy ULM2367) and driven from a Graphical User Interface (GUI).
- Its main purposes are to implement coincidences between the S800 focal plane and a secondary detector, provide means to adjust the timing easily and remotely, reduce the number of modules necessary to implement the trigger logic, and allow users to keep a record of the trigger configuration for each run.
- In addition, the module provides 4 inspect channels routed to the Data-U to visually check the timing of the signals throughout the trigger module.
- A detailed description is available at <https://wikihost.nsl.mscl.edu/S800Doc/doku.php?id=trigger>

G. Data acquisition

In the standard S800 detector configuration, the performance of the S800 data acquisition is characterized by a dead-time of ~20% for trigger rates ~2000 pps (mostly defined by the dead



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time of the CRDC digital readout), and a maximum data volume of ~0.4 KB/event. These are just approximated values observed in typical experiments.

1. Data acquisition computer and software

- The data acquisition computer is maintained by the Computer Department. This computer is located in the S3 vault as an integral part of the S800 electronics setup. Software changes will follow the process outlined in the NSCL DAQ Service Level Description.
- The software used to acquire data from the S800 detectors is the standard NSCL DAQ which is maintained and supported by the Scientific Software Team in the Experimental Nuclear Science Department.
- More information on this software is available in the documentation pointed to in the NSCL DAQ SLD.
- The formatted events from the S800 event stream can be immediately processed by the supported S800 back end software package (scalers, SpecTcl, event dump...).
- Software failures will be addressed on a best effort response time basis consistent with a negotiation with the experimenter about how and when diagnosis can be performed with a minimum impact on the running experiment.
- At the end of every experiment, the data acquisition software and scaler files are recorded in a remote git repository

2. S800 dedicated computers

- All S800 software is run from a dedicated computers (Linux box u6pc5 and Windows desktop u6pc6) located in Data-U6.
- The use of these computers is restricted to device and beam physicists, as well as trained users for some of the functionality.
- In standard configuration, this computer provides access to the following:
 - Full CSStudio tuning page, needed to tune the S800 and change rigidities
 - Knob-control box software
 - NCS applications (PanelMate, ChannelLog, etc.)
 - NMR magnetic field readings of the S800 dipoles
 - High Voltage control GUI
 - Labview Gas Handling system
 - Trigger control via a GUI
 - Constant Fraction Discriminator GUI
 - S800 scalers
 - S800 standalone SpecTcl
 - NSCL DAQ GUI for S800 data acquisition (implemented as ReadoutGUI)



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3. Configuration files

- The configuration of the S800 data acquisition is stored in configuration files located in the S800 account (/user/s800/s800daq/Configs).
- It is possible to automatically copy these configuration files alongside the “raw” and “formatted” data files for each run of a running experiment. This requires coordination between users and device physicists

4. Secondary detector(s)

- Secondary detectors such as the GRETINA, SeGA array or the HiRA array can be combined with the S800 but are under the responsibility of the users or specific device physicists (for supported devices)
- As mentioned earlier, a trigger input is provided for a secondary detector and the trigger module provides means to take S800 or secondary single events, coincidences, and any combinations of the above.
- The combined readout and SpecTel codes are under the responsibility of the users, and should be built using provided S800 packages.

5. S800 event packets

- The NSCL data acquisition system provides means to combine various devices together in event driven streams of data.
- Each device is assigned a tag used to recognize the source of the data, and each device should encapsulate its data in a packet labeled with this tag.
- The tag for the S800 is hexadecimal 0x5800, therefore the S800 event packet always starts with:
 - Packet Length (including itself)
 - Tag: 0x5800
 - Version Number
- The version number is used to keep track of changes occurring in the S800 readout as it evolves.
- The standard S800 SpecTel package checks the version number and rejects event that are not compatible.
- More details are available at https://wikihost.nsl.mscl.edu/S800Doc/doku.php?id=data_acquisition_daq



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H. Alarms and interlocks

- The S800 focal-plane detectors are protected from excessive rate by an interlock system that de-phases the cyclotron's RF whenever the count rate limit set by the device or beam physicists is exceeded.
- The limit will be experiment specific since, as outlined above, rate damage especially in the CRDCs has been observed to correlate with Z and intensity/area.
- The shutoff of the beam is accompanied by a voice alarm in the cyclotron control room.
- The bottle gas level for all gas detectors used in the S800 are tracked remotely. In the event a low level is detected, a voice alarm will sound in the control room. Beam and/or S800 device physicist on call will be notified and then take the appropriate action.
- The high voltage of the above-mentioned detectors is controlled by a Tcl/Tk application on the S800 dedicated computer. In case of a trip, the GUI indicates the fault and allows to reset the condition to normal after the cause of the trip has been corrected.

II. Support level

A. General

- The NSCL support level of the S800 spectrograph involves the 3 standard phases of an experiment: preparation, running and analysis.
- The support provided by laboratory staff during these phases covers only the standard configuration (described above). Any modifications or additions are under the sole responsibility of the users.
- The device and beam physicists responsible for the S800 provide the following support:
 - Answer technical questions for users during the preparation of experiment proposals
 - Train users in operating the device prior to the experiment
 - Provide software packages necessary for using the S800 data acquisition and analysis.
 - Ensure the proper functioning of the device as specified in the standard configuration
 - Perform device setting changes as required by the experiment
 - Provide emergency support during the experiment to ensure proper functioning of the device
 - Assist users in inspecting and understanding the on-line data
 - Assist users during the off-line analysis phase
- Some tasks, such as venting or pumping the focal plane, are always the responsibility of the device or beam physicists.



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- Users are expected to become proficient in and perform other tasks after proper training. They include the following:
 - Insert or retract detectors or hardware located in the S3 vault
 - Operate the security systems used to secure and deliver beam in the vault
 - Vent/pump target area
 - Change targets/viewers
 - Install camera in the target area
 - Applying or removing high voltage to the detectors
 - Changing the magnetic rigidity of the spectrograph (Section 8) and matching its dipoles
 - Follow user-level troubleshooting documentation as a first response to a failure of the data acquisition, analysis and monitoring systems.
 - Change trigger configuration
 - Perform calibrations of the gas-filled detectors

B. Details

1. Contacts and support documentation

- The S800 has three support device physicists:
 - Jorge Pereira (primary contact): pereira@nscl.msu.edu
 - Shumpei Noji: noji@nscl.msu.edu
 - Daniel Bazin: bazin@nscl.msu.edu
- Most extended documentation about the S800 can be found in the S800 wiki: <https://wikihost.nsl.msu.edu/S800Doc/doku.php>

2. Device support coverage (Experimental Device Tuning or XDT)

- Device support for working days is limited and runs only during normal hours (from 8:00AM to 5:00PM).
- Due to limited personnel resources, evening support (5:00PM to 12:00AM) can be planned in advance provided the users schedule it and inform the device or beam physicists at least one day in advance.
- Emergency support (on call duty) is provided from 12:00AM to 8:00AM and during non-working days. For all emergency support, users are required to first inform the Operator in Charge, who will then decide to call the device or beam physicist for help
- In case a device or beam physicist is also one of the experimenters, his/her research time can also be allocated to device support.



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3. Training time estimates for users

- This training is offered once per experiment, at a pre-arranged time that suits the experimenters' convenience.
 - Target change not involving the scattering chamber: 1/2 hour
 - Target change involving the scattering chamber: 1/2 day
 - CRDC calibrations (masks, alpha source): 1/2 hour
 - SpecTcl and Readout: 2 hours
 - Diagnostics and monitoring using S800 SpecTcl: 1 hour
 - Securing the S3 vault: 1/2 hour
 - Restarting the data acquisition, analysis and monitoring systems: 1 hour
 - Alarms and interlocks: 15 min

4. Training time estimates for users

- The data acquisition software used to acquire data from the S800 detectors is supported by the Scientific Software Team in the Experimental Nuclear Science Department.
- Documentation will be provided, in a publicly accessible format, which describes troubleshooting procedures executable by the Experimenters in Charge as a first response to problems leading to a loss of data acquisition from the S800 system
- Call-in support is provided on a best effort response time basis to resolve issues that are not resolved using the documentation.

III. Users responsibilities

- We expect an active involvement of the experimenters during the setup and preparation of the experiment to become familiar with the device and the data acquisition system.
- For each experiment, a student, postdoc or faculty member is expected to be at the NSCL 3 days in advance of the experiment (or the first run of the “campaign” the experiment is scheduled in) to actively participate in the setup and shake down.
- This is intended to give the experimenters the opportunity to gain the necessary experience with the experimental setup, the NSCL DAQ, the online analysis software, and the detector system of the spectrograph prior to the experiment.
- Time estimates for training offered by the device and beam physicists are outlined in the “support level” section (II.B.3).
- We stress that this training is a necessary requirement for users to be able to run shifts and actively and safely participate in experiments using the S800 spectrograph.
- Detector systems beyond the standard configuration and their readout are the responsibility of the experimenter.



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- A request for help with incorporating additional detectors in the Readout code must be addressed in a timely manner and should be accounted for as additional setup time.
- While running an experiment in the S800, the *experimenter in charge* is expected to:
 - Document changes in running conditions and actions taken by experimenters
 - Inform the device or beam physicists immediately in case of abnormal occurrences observed in the operation of the device
 - Check the quality of the incoming data according to the device or beam physicist's and spokesperson's instructions
 - Perform changes as instructed during training
- The *spokesperson* of the experiment is expected to:
 - Communicate the points outlined above to their experimenters in charge
 - Take the leading role in decision making during the running phase of the experiment
 - Discuss necessary changes to the experiment with the device or beam physicists in a timely manner
 - Schedule changes in the device setting in advance and in coordination with the device or beam physicist
 - Check the integrity and quality of the incoming data and instruct the experimenters in charge how to do so
 - Collect the tape copies of the data made by the IT personnel of the Computer Department
 - Fill out the "end of experiment" form provided by the User Liaison Representative
- We recommend that the device or beam physicist be consulted for technical questions during the preparation of the proposal and during the planning of the experiment several weeks in advance of the run.
- If the experiment requires the detector systems to run at their specification limits, we encourage to request test beam time (to be scheduled before the experiment) and recommend involvement of the detector specialist in the proposal as well as in the experiment.
- An immediate offline analysis of the data taken is strongly recommended to check whether or not the results meet expectations and to diagnose subtle problems, which can never be entirely excluded when running a complex device like the S800.
- We recommend setting printouts on a regular basis during shifts (they can be done from CSSstudio). Without these printouts, the provision of an "inverse map" cannot be taken for granted.