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 T.m., 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 ±3.5° in the dispersive plane by ±5° in the non-dispersive plane.

The momentum acceptance is around ±3%, although the solid angle acceptance is greatly reduced on the edges.

The maximum rigidity is 4 Tm.

The spectrograph can rotate from 0° to 90°, however the present and future target chambers only allow fixed angle settings from 0° to 15° typically.

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.

For radioactive beams best resolutions of 1 part in 2,000 in energy and 10 mrad in scattering angle are customary.

Reaching the nominal resolutions of 1 part in 10,000 in energy and 2 mrad in scattering angle would require additional effort and an object beam spot of 0.5 mm or less in diameter.

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. Dispersion matched mode

In this mode the whole S800 (analysis line + spectrograph) is achromatic, which means that the momentum spread of the beam at the object is cancelled at the focal plane.

This means however that the beam is momentum dispersed on the target. For this reason, the maximum momentum acceptance of the analysis line in this mode is only ±0.5%.

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The dispersion at the target is about 11 cm/%; therefore a ±0.5% momentum bite implies a target 11 cm long in the dispersive direction.

For practical means the momentum acceptance is reduced to ±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.

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.

This implies that 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 ±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.

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 ft^3 or 5.67 m^3.

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 the possibility of varying the target position 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.

A minimum of two additional drives will also be provided in the future for additional diagnostic and/or tracking detectors. These drives will also be adjustable along the beam axis.

The adaptation of the chamber to various spectrograph angles will be realized using flanges with fixed angles.

The installation of this chamber has been completed and drives are being implemented and finalized as of December 2004.

There is no support for equipment put in the chamber. It is 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”.

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 APEX NaI and SeGA Germanium arrays 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.

D. Trajectory reconstruction

1. Method

The S800 spectrograph is equipped with very little 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 of 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 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 Bρ setting of the spectrograph.

Users can request these maps for which only the magnet strengths, Bρ and type of particle are necessary. The inverse map calculation is now automated and provided by a server. The URL link to access the input form is available from the S800 page on the NSCL web site www.nscl.msu.edu/tech/devices/s800/tech.html.

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 50 torr.

Due to their mode of detection (drift of electrons in gas), they are rather slow – typically up to 20 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 are to be expected, in particular if it is concentrated on a small area of the detector.

The exact reasons behind the efficiency losses at high rate are still under investigation, but it is clear from past experience that spreading the high rate over a large portion of the active area is highly desirable in order to minimize charge-screening effects.

In addition, premature aging of the anode wire has been observed after a long exposure to a tightly localized high rate. Replacing the wire on both detectors takes a minimum of one to two days.

For these reasons, it is highly 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.

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 set of 4 plastic scintillators of thicknesses 3 mm, 5 cm, 10 cm and 20 cm, each equipped with two phototubes on each side.

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 140 torr and is able to separate elements up to Z=30. For a better Z separation, a thicker window is necessary before the pressure can be increased.

The back of the chamber is covered and sealed by the first scintillator, hence eliminating the need for a second window.

The timing resolution for a point-like beam spot in the focal plane is around 100 ps.

However, this resolution worsens significantly (up to 1 ns) when the whole focal plane is illuminated, because of path length differences in such large scintillators.

Mapping of the time response is planned in the near future, and should restore the resolution in the range of the point-like value.

2. Tracking in analysis line

The S800 analysis line is equipped with a number of tracking detectors for measuring the characteristics of the particles prior to their interaction with the target.

a) 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.

This detector is usually left in the beam during experiments and can withstand rates of up to 1 MHz.

A large surface (5 cm x 5 cm) PIN 300 µm silicon detector is also installed in this box for energy loss measurement.

This detector is used for checking the radioactive beam composition and is not meant to stay in the beam during data accumulation. It can only withstand rates of up to 1 kHz.

b) Intermediate image

The intermediate image box is equipped with two tracking Parallel Plate Avalanche Counters (PPAC) with individual strip readout for tracking the trajectories of the incoming particles.

The individual strip digital readout allows them to function at rates of up to 1 MHz independently of the trigger rate, and with no latency.

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.

Please note that the tracking PPAC efficiency drops significantly below Z=10, and becomes extremely dependent on the intrinsic disruptive limit of the individual detectors, as well as on the count rate.

Tracking detectors for Z>10 are available, with performce degredation for rtes above 200kHz. For lighter particles, attempts to use small CRDC detectors have been made, but they have proven unreliable due to fast aging problems. A viable solution is still under development.

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.

c) Target

As mentioned before in section III, the scattering chambers are 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.

F. Electronics

1. Digital electronics

Both focal plane CRDCs and intermediate image tracking PPACs 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 50ns for the CRDCs and 100ns for the PPACs.

The number of samples read out is also adjustable, with typical values between 8 to 12.

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.

This dead time is around 16µs per sample, therefore the readout code reading sequence starts with other modules first (such as Camac), and finishes with the XLM72 modules.

The amount of data also depends on how many channels have fired. As there is no data reduction performed in the FPGA so far, 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 groups.nscl.msu.edu/s800/Technical/Electronics/Electronics_frameset.htm

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 groups.nscl.msu.edu/s800/Technical/Electronics/Electronics_frameset.htm

G. Data acquisition

1. S800 dedicated computer

All S800 monitoring and setting are now run from a dedicated computer located in Data-U6.

Since the S800 electronics and data acquisition are a permanent setup, it makes sense to dedicate a computer as a permanent interface.

The use of this computer is restricted to Device Physicists and trained users.

In standard configuration, this computer provides access to the following:

- Full Barney access, needed to tune the S800 and change rigidities
- NMR magnetic field readings of the S800 dipoles
- High Voltage control of the gas detectors
- Trigger and other modules remote control via a GUI
- S800 scalers
- S800 standalone SpecTcl

2. Configuration files

The configuration of the S800 data acquisition is stored in configuration files located in the S800 account (/user/s800/experiment/current).

Each experiment account should establish symbolic links to those files in their own experiment/current folder, which is automatically copied to a separate folder bearing the name of the current run being recorded.

This system greatly reduces the S800 electronics and data acquisition setup times.

3. Secondary detector(s)

Secondary detectors such as the SeGA array or the HiRA array can be combined with the S800 but are under the responsibility of the users.

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 SpecTcl codes are under the responsibility of the users, and should be built using provided S800 packages.

4. S800 event packets

The NSCL data acquisition system provides means to combine various devices together in the event driven stream 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 SpecTcl package checks the version number and rejects event that are not compatible.

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 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.

A Tcl-based alarm server is used to monitor the gas handling system of the focal-plane detectors and the HV power supply of the CRDCs, the ion chamber, and the tracking PPACs.

For the gas handling system, a voice alarm in Data-U6 is triggered whenever the reading of one of the three mass flow controllers (isobutane and CF_4 for the CRDCs and P10 for the ion chamber) reads outside of the accepted range.

The high voltage of the above-mentioned detectors is controlled by a Tcl/Tk application on the S800 dedicated computer and a voice alarm is triggered when the read back value of the power supply does not match the set value.

With this, a tripped detector is being brought to the attention of the on-shift person immediately.

The device physicists provide instructions on the expected response to the possible alarms.

Support level

I. General

The NSCL support level of the S800 spectrograph involves the 3 standard phases of an experiment: preparation, running and analysis.

The support provided during these phases covers only the standard configuration (described above). Any modifications or additions are under the sole responsibility of the users.

The device physicists responsible for the S800 spectrograph 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. This software enables the user to read out and analyze data taken in standard configuration with the supported detectors and can be used by the experimenter to setup a combined readout and analysis software when detection systems beyond the supported S800 standards are used.
- 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 physicists.

Users are expected to become proficient in and perform others 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
- Change targets
- Applying or removing high voltage to the detectors
- Changing the magnetic rigidity of the spectrograph (Section 8) and matching its dipoles
- Restart the data acquisition, analysis and monitoring systems after a failure
- Change trigger configuration
- Perform calibrations of the gas-filled detectors

J. Details

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

Due to limited personnel resources (2 device physicists at 50%), device support during normal hours is limited and runs from 9:00AM to 5:00PM for working days.

Evening support (5:00PM to 12:00AM) can be arranged in advance provided the users schedule it and inform the device physicists at least one day in advance.

Emergency support (on call duty) is provided from 12:00AM to 9:00AM 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 physicist for help

In case a device physicist is also one of the experimenters, his/her research time can also be allocated to device support.

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2. Training time estimates

These trainings are 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

II. User responsibilities

A. Expectations

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 physicists are outlined in the “support level” section.

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.

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.

The experimenter in charge is expected to:

- Document changes in running conditions and actions taken by experimenters
- Inform the device 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 physicist’s and spokesperson’s instructions

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 physicists in a timely manner
- Schedule changes in the device setting in advance and in coordination with the device physicist
- Check the integrity and quality of the incoming data and instruct the experimenters in charge how to do so
- Make tape copies of the data immediately after the end of the experiment

B. Recommendations

We recommend that the device 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 such as the S800 spectrograph.

We recommend Barney printouts on a regular basis during shifts. Without Barney printout the provision of an "inverse map" cannot be taken for granted.