Sweeper Service Level Description

I. Standard configuration

A. General

The Sweeper is a large gap, large rigidity open dipole magnet designed for experiments using radioactive beams produced by projectile fragmentation. Its main purpose is to sweep charged particles away from 0° while letting neutrons continue their path to a secondary detector. For this reason, it is primarily used in tandem with the MoNA neutron detector array. However, it could be used either in standalone mode or with other types of secondary detectors as well, such as light charged particle detectors.

The fragments deflected by the Sweeper enter a "focal plane" box similar to that of the S800, containing the same set of position, energy loss and timing detectors. The information gathered from these detectors can be used for particle identification and tracking.

The maximum nominal magnetic field of the Sweeper is 4 Tesla corresponding to the maximum rigidity of 4 Tm. (radius is 1 meter).

The solid angle and momentum acceptances of the Sweeper can vary depending on the longitudinal location of some of the focal plane detectors, which are mounted on a rail system. The first position detector always stays as close as possible to the focal plane box entrance, whereas the others are moveable at a distance ranging from 32 cm to 140 cm.

The optimum location of the detectors depends on the experimental goals, and is always a trade-off between resolution and acceptance.

At the location corresponding to the largest acceptance (32 cm), the solid angle and momentum acceptances are 36 msr and 30 % respectively, whereas they are reduced to 11 msr and 15 % at the location corresponding to the highest resolution (140 cm).

The beam line upstream of the Sweeper is equipped with tracking detectors aimed at the determination of the positions and angles of the incoming particles on the target. This determination is not straightforward though, as several quadrupole lenses are also located on the beam line and need to be taken into account in the calculations.

B. Optics

In its present standard configuration, the Sweeper is run with the target located just prior to the entrance of the dipole magnet. For that reason, there is no proper focal plane in the "focal plane" box, and the characteristics of the deflected ions (energy and scattering angle) can only be measured using inverse tracking based on magnetic field maps. This configuration gives the maximum acceptance for neutrons emitted in the reactions.

There is provision for another mode of operation in which the target would be located prior to the quadrupole triplet now used to focus the beam on the present target location. In this case proper focusing in the focal plane should be possible, however the neutron acceptance would be greatly reduced by the aperture of the quadrupole and the large distance to the exit flange of the Sweeper. This mode is not presently part of the standard configuration.

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C. Target setup

As previously mentioned, in the present standard configuration the target is located in a pot between the last quadrupole triplet and the dipole magnet. It is mounted on a drive that can be inserted remotely. Also located in this pot are a scintillating viewer used for beam tuning, as well as a plastic scintillator used for time-of-flight measurements.

D. Trajectory reconstruction

1. Method

The Sweeper dipole is a superconducting magnet with fields far above ferromagnetic saturation. For this reason, the magnetic field inside the gap is highly non-uniform, and fringe fields extend far outside the magnet, even though trim coils located on the outside iron help to reduce it.

The aberrations introduced by these non-uniformities are calculated on the basis 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.

This method is similar to what is used on the S800 spectrograph, on which 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.

At this time the details of this method are still being worked out for the Sweeper and are not yet available to users. In the future, the standard Sweeper analysis code will provide 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).

Since the shape of the magnetic field vary significantly with the absolute strength of the magnets, inverse maps need to be calculated for each $B\rho$ setting of the Sweeper dipole.

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So far, magnetic field maps have been taken at the following currents: 250, 300, 330, 350 and 365 Amps, corresponding to a Bρ ranging from 2.86 to 3.72 T.m.

Note that the 365 Amps measurement is at the present limit of the magnet. Going higher in rigidity would take a fair amount of development.

E. Detectors

1. Focal plane

The Sweeper 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 are used to measure the positions and angles in the focal plane. 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 ± 15 cm by ± 15 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. The angular resolution depends on the distance between the two detectors (32 to 140 cm).

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.

b) Particle identification

Downstream of the two CRDC detectors are the ion chamber for energy loss measurement, followed by two plastic scintillators of thicknesses 0.5 cm and 15 cm, each equipped with four phototubes. 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 larger pressure may be necessary. The back of the chamber is covered and sealed by the first scintillator, hence eliminating the need for a second window.

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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 beam line

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

a) Target

The target pot of the Sweeper contains a thin plastic scintillator (250 µm) for time-of-flight measurements. This detector can be left in the beam during experiments and can withstand rates of up to 1 MHz. Other thicknesses might be available upon request.

b) Beam line

The beam line 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 in both the dispersive and non-dispersive planes. The characteristics of the incoming particles at the target location can be calculated using an optics calculation that takes into account the magnetic lenses used between the detectors and the target.

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 performance degradation for rates 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.

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

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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. The 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.

This digital electronics system is directly compatible with the S800 spectrograph system, of which a more detailed description will be available at groups.nscl.msu.edu/s800/Technical/Electronics/Electronics_frameset.htm

2. Trigger module

The standalone Sweeper trigger logic is implemented in an FPGA module (LeCroy ULM2367) and driven from a Graphical User Interface (GUI).

When used in combination with the MoNA array, it is set in “slave” mode and simply routes the MoNA provided master trigger to the various gate generators.

This module provides 4 inspect channels routed to the Data-U to visually check the timing of the signals throughout the trigger module.

Again, as this module is also being used on the S800 spectrograph, a detailed description is available at groups.nscl.msu.edu/s800/Technical/Electronics/Electronics_frameset.htm

G. Data acquisition

1. Sweeper dedicated computer

All Sweeper monitoring and setting are now run from a dedicated computer located in Data-U4. Since the Sweeper 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:

- High Voltage control of the gas detectors
- Trigger and other modules remote control via a GUI
- Sweeper scalers

- Sweeper standalone SpecTcl

2. Configuration files

The configuration of the Sweeper data acquisition is stored in configuration files located in the Sweeper account (/user/sweeper/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 Sweeper electronics and data acquisition setup times.

3. Secondary detector(s)

In the present standard configuration, the Sweeper is run in tandem with the MoNA array as secondary detector.

Because of timing constraints in the MoNA array, it is preferable to generate the master trigger in MoNA and use the Sweeper trigger in slave mode.

For other secondary detectors, this situation could be reversed and the master trigger would be generated in the Sweeper trigger module.

In both cases, the combined readout and SpecTcl codes are under the responsibility of the users, and should be built using provided Sweeper packages.

4. Sweeper 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 Sweeper is hexadecimal 0x5900, therefore the Sweeper event packet always starts with:

- Packet Length (including itself)
- Tag: 0x5900
- Version Number

The version number is used to keep track of changes occurring in the Sweeper readout as it evolves. The standard Sweeper SpecTcl package checks the version number and rejects events that are not compatible.

H. Alarms and interlocks

The Sweeper 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-U4 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 Sweeper 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.

II. Support level

A. General

The NSCL support level of the Sweeper for PAC28 approved future experiments 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 Sweeper 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 Sweeper 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 Sweeper 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 other tasks after proper training. They include the following:

- Insert or retract detectors or hardware located in the N4 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 Sweeper
- Restart the data acquisition, analysis and monitoring systems after a failure
- Change trigger configuration
- Perform calibrations of the gas-filled detectors

B. Details

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

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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.

2. Training time estimates

These trainings are offered once per experiment, at a pre-arranged time that suits the experimenters' convenience.

- Target change: 1/2 hour
- CRDC calibrations (masks, alpha source): 1/2 hour
- SpecTcl and Readout: 2 hours
- Diagnostics and monitoring using Sweeper SpecTcl: 1 hour
- Securing the N4 vault: 1/2 hour
- Restarting the data acquisition, analysis and monitoring systems: 1 hour
- Alarms and interlocks: 15 min

III. 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 Sweeper 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 Sweeper.

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 Sweeper.

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