Beamline Manual

Version 2.1

S. Stepanyan

July 16, 2021

1 Contacts

Beamline cell phone (757) 303-3996

Personnel listed in Table 1 should be called whenever there is a problem beyond the on-hand expertise. The beam line expert is the main source for help.

Who	Expertise	Cell Phone	Office
MCC	Beam tune, vacuum		x7048 & x7043
Expert on call	Beamline devices and applications	(757) 303-3996	
Stepan Stepanyan	Beamline devices and applications	(757) 303-0499	x7196
Engineering on call	General beamline (vacuum, magnets)	(757) 748-5048	

Table 1: The beamline on-call list.

2 What to Monitor along the Beamline

2.1 Beam conditions

There are automatic controls and alarms for the beam conditions. These systems will terminate beam delivery in the event of beam excursions to prevent beam damage to the equipment. Nevertheless, the shift personnel must continuously monitor the beam parameters (beam position at various BPMs, beam current, and halo rates) and act accordingly.

After the initial beam tune, reference numbers for the beam position of the beam on position monitors and the rates of halo counters will be posted in the logbook and on the run wiki page and must be used as a reference.

2.1.1 Beam Current

Consistency in the beam current readings between the Faraday Cup (see Section 3.3) and the "nA" BPMs is one way to check that the electron beam is cleanly transported to the beam dump (Faraday Cup). **Note:** for experiments, where requested beam current exceeds allowed power limit for the Faraday cup, $\sim$ 175 W (Power in W = Current in nA x Energy in GeV), a beam blocker, see Section 3.3.1, will be inserted in front of the Faraday cup. Even with blocker in-beam, Faraday cup reading is meaningful, it will be a scaled value of the beam current. The coefficient of the proportionality is beam energy-dependent [1] and will be calibrated at each given energy setting [2]. With blocker in-beam, the ratio of the currents read by Faraday cup and other current monitors (e.g. nA BPMs [3], Section 3.4, and SLM, Section 3.6) must be constant. In addition to inconsistencies in the beam current readings, the halo counters (see Section **??**) will show an increased activity if the beam scraps beam pipes. Also higher than normal rates in the detectors would be indicative of scraping.

In the event that there appears to be unacceptable beam losses the following course of action is recommended:

1. Stop the beam delivery and data taking, make a log entry flagging any data runs that may have been affected.

2. Call MCC and explain to the operator what has been observed and why beam is unacceptable.

3. Work with the MCC operator to come up with a solution to fix the problem.

4. Document the solution and start taking data again.

2.1.2 Beam Halo

The presence of the beam halo (long tails) is usually accompanied by increase count rates in the beam halo counters. Typically, when the beam is delivered to the Faraday cup, the upstream (2 counters), tagger (2-counters), midstream (4 counters), downstream (4 counters), and the HPS-L/R counters are very quiet. Any count rate above $\sim$ 100 Hz (after initial gain adjustments for a well-tuned beam) is indicative of a problem. Note that increase count rates on these counters can also indicate an obstacle on the beam path or just a bad beam tune.

If the beam halo is unacceptable, take the following steps:

1. Stop beam delivery and data taking, make a log entry.

2. Call MCC and explain to the operator what has been observed and why this tune is unacceptable.

3. Work with MCC to solve the problem.

4. Document the solution and start taking data again.

If needed to further investigate the source of the large halo counter rates, harp scans using relevant wire harps can be performed (see "Electron beam profile scan" procedure in Section 3.5).

2.1.3 Beam Position

The beam position before HPS is available from three "nA" cavities, 2C21, 2C24, and 2H01, and two stripline BPMs [4], 2H00 and 2H02. The latter two are the most important for HPS. At beam currents below 25 nA only "nA" cavities are reliable. The Feedback system (the Orbit Lock) uses (x,y) positions on 2H00 and 2H02 BPMs to keep the beam position stable at the target using VH correctors on 2C24 and 2H00 girders. Drifts more than 0.1 mm should be brought to the attention of MCC. The nA BPMs measure the beam position as well as the current. Before data taking, the shift worker must confirm that the feedback system is active (make sure the indicator on the main GUI is active).

Note, the (X,Y) positions on BPMs have the following convention: positive X is beam right, positive Y is up.

2.2 Beamline Vacuum

The beamline vacuum on Hall-B line (from upstream tunnel to the Faraday cup) can be monitored from the vacuum gauge readings available on the Main scaler GUI (see below). Usually, the vacuum upstream of the tagger magnet (upstream tunnel) is better than 10^{-6} torr , vacuum downstream of the tagger magnet and in the downstream beam line should be on order of or better than 10^{-5} torr. Vacuum is tightly monitored and interlocked to the beam delivery.

2.2.1 Catastrophic Loss of Vacuum

Three vacuum windows are components of the HPS beamline, a 30 μm aluminum window on the beam pipe going through the tagger magnet yoke, the photon beamline exit window at the downstream end of the last Frascati dipole magnet vacuum chamber, and a 100 μm aluminum window at the downstream end of the beamline, at Faraday cup. If any of these windows fail, there are fast valves interlocked to the pressure gauges that will close automatically. These valves will limit the loss of the vacuum to a small section of the beamline. Valves are interlocked to the beam Fast Shutdown System (FSD) and will terminate beam delivery in case of a vacuum loss. Note, although the Hall-B tagger vacuum chamber is pumped down, the failure of the window will not affect the beamline vacuum as it is isolated by the beam pipe through the yoke.

If any of the valves close due to poor vacuum:

1. notify MCC immediately, turn off the beam (if it is not already OFF)
2. call the engineering on call

2.3 Magnet Power Supplies

In Table 2 list of the magnets, their power supplies, and point of control (POC) are shown. The shift personal will manage items listed with B as the point of control. MCC controls the vertical and horizontal correctors and the tagger magnet. The shift personal should monitor their settings. The tagger magnet power supply is interlocked to the machine Fast Shutdown System (FSD). Interlocks are activated if run requires dumping the beam in the tagger beam dump, e.g. during the initial beam tuning. This interlock must be masked when the electron beam is delivered to the experiment. The HPS chicane dipoles, Frascati-1, HPS-dipole, and Frascati-2, are controlled by the shift personnel. The two "frascatis" share the same power supply, so-called the Hall-B mini-torus power supply. The HPS-dipole is on a separate power supply. Both power supplies are interlocked to the FSD system and will terminate beam delivery if any of the power supplies will trip.

If the tagger or any of the chicane magnets do trip or are set to incorrect value (**alarm will go OFF**) take the following action:

1. Call MCC immediately, tell them to shut off the beam (if it is not off already).
2. Make a log entry.
3. Restore magnets
   - have MCC restore the tagger dipole, if it was the tagger dipole
     or
   - use procedure for powering chicane magnets (HPS-dipole or frascati dipoles)
4. Restore beam, (if beam was going to Faraday cup, verify that the beam is incident on the downstream viewer on the same location as before the trip.)

If there is an issue with restoring the power supply call engineering on-call for support.

Magnet	Power Supply	POC	Function	Status
MB2C21V		MCC	Vertical kick	Active
MB2C21H		MCC	Horizontal kick	Active
Møller-Q A	Dyna-B	B	Møller polarimeter	Not used
Møller-Q B	Dyna-C	B	Møller polarimeter	Not used
MB2C22H		MCC	Horizontal kick	Active
MB2C23V		MCC	Vertical kick	Active
Raster_h1	Danfysik	B	First horizontal raster dipole	Not used
Raster_v1	Danfysik	B	First vertical raster dipole	Not used
Tagger	Danfysik	MCC	Bends beam to the tagger dump	Active
MBD2H00H		MCC	horizontal kick	Active
MBD2H00V		MCC	vertical kick	Active
MQA2H00		MCC	Quadrupole	Active
MQA2H00A		MCC	Quadrupole	Active
Frascati-1	Dyna-A	B	Bends beam by 30 mrad	Active
HPS-dipole	Danfysik	B	Spectrometer magnet	Active
Frascati-2	Dyna-A	B	Bend beam by 30 mrad	Active

Table 2: List of the magnets along the Hall B beamline and their functionality.

2.4 Magnet and Power Supply Beacons

Near every magnet in Hall B, there is a red flashing beacon that indicates the status of the magnets. If beacon is flashing then the magnet **is powered** or **can be powered** at any time. If you need to work near or on a magnet and the red light is flashing, you must turn the supply OFF. The dangers of working near a magnet are limited to those associated with stray magnetic fields. All the high current bus work is enclosed in protective shields so there is no shock hazard. Of course, the supply needs to be shut off, and locked, and tagged before any of the protective shields is removed.

After any work that required the power supply to be locked and tagged, a through a sweep of the magnet area for magnetic debris is required before the lock-and-tag can be removed.

3 Hall B Epics Screens for beamline monitoring and control

3.1 EPICS GUI Launcher

The *hps_epics* (see Fig.1) is a *medm* screen that serves as an icon manager of *medm* screens. The bulk of the epics applications for HPS are accessible from this GUI. It is recommended to terminate (**not iconized**) *medm* screens after the use. If needed, screens can be launched again from the *hps_epics*. In this manner searching through all the degenerate icons is eliminated. To start the *hps_epics*:

- log on one of **clon** PCs or **clonsl(1,2,3)** computers as *hpsrun*
- type: **hps_epics**

3.2 Main GUI

Main Scaler screen shown in Figure 2 can be opened from the pull down menu of the *hps_epics* under *Bemline*. The main GUI contains most of the beam line and detector parameters that needs to

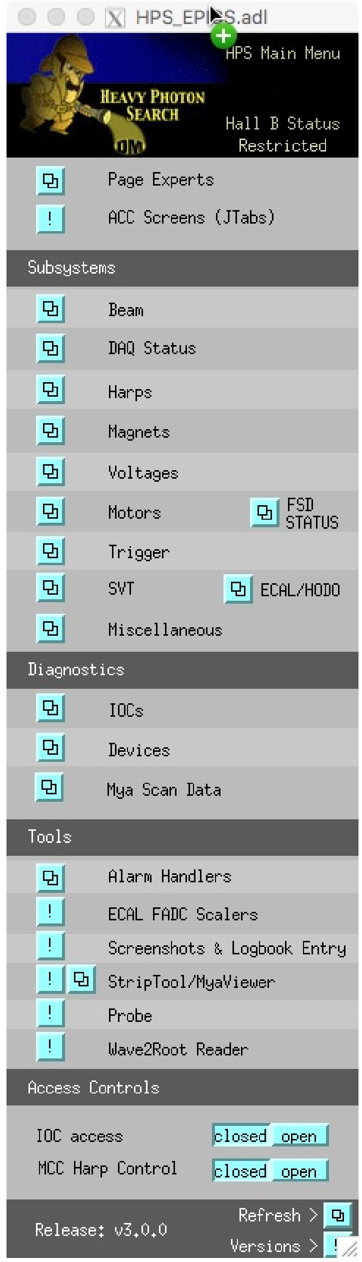

Figure 1: HPS EPICS GUI launcher.

be monitored; FSD settings, halo counter and detector rates, BPM readings, Faraday cup value, motor positions, vacuum gauges, magnet setting and etc.

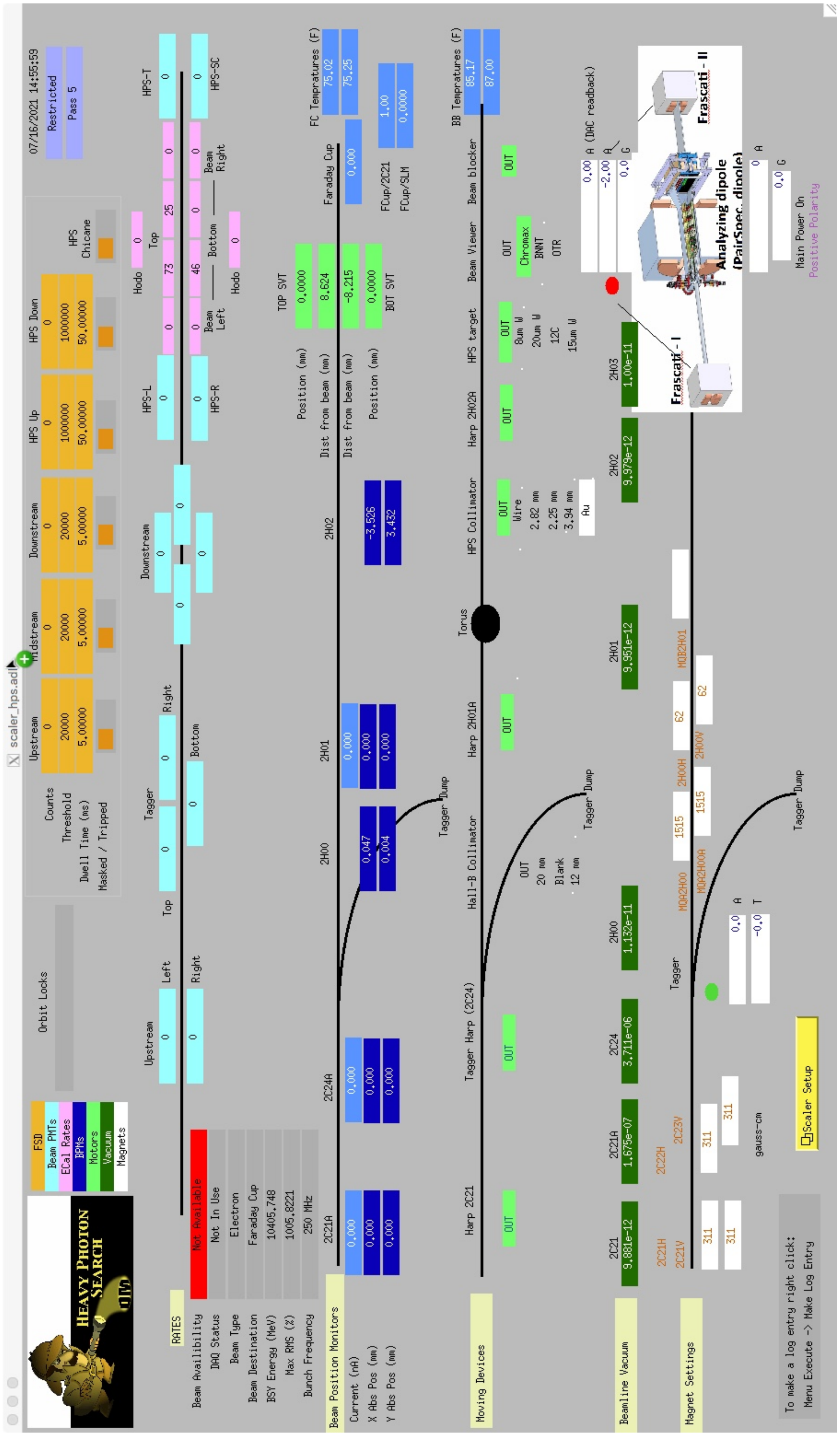

Figure 2: The main scaler GUI.

3.3 Faraday Cup (classc4)

The instantaneous beam current reading from the Faraday cup is available on the **Main Scaler** screen as shown in Figure 2. The update rate of the beam current reading is the same as for scalers for the beam halo counters. The scaler update rate is accessible from the pull-down menu at the bottom of the main scaler GUI. An important consideration is that the Faraday Cup current integrator rate is 10 counts/sec for 1 nA beam current. Expect large statistical fluctuations if the scaler update rate is less than a second.

3.3.1 Beam blocker

The Hall-B Faraday cup is not cooled and cannot operate at high currents. The power limit on the Faraday cup is 175 W, it can operate for half an hour with a beam of up 1000 W. If run requires beam currents above the limit (for example more than 35 nA at 3.7 GeV), the beam blocker, cooled copper absorber, must be position in front of the Faraday cup. The beam blocker control GUI is shown in Figure 3 and is accessible from the main EPICS GUI under *Motors*. Push the "Go beam" button to put the blocker on the beam and "Go Home" to retract it from the beamline.

Figure 3: The beam blocker GUI.

3.4 nA BPM Displays

The readout of the nA BPMs are displayed on the main scaler GUI as well as on BPM GUI, Fig. 4. The BPM screen can be launched from the *hps_ epics* by selecting the *Beam* pull down menu. The BMP readings are also available on the **Main Scaler** screen.

Note, the (X,Y) positions on BPMs have the following convention: positive X is beam right, positive Y is up. The X-direction is reverse of the detector (CLAS12 and HPS) coordinate system where positive X means beam left.

3.5 Hall-B Harps (classc3/classc4)

There are four wire harps on the Hall B beamline; 2C21, "tagger" (2C24), 2H01A, and 2H02A. Harps are devices with a "fork" like aluminum frame with 25 μm tungsten wires strung between fingers of the "fork" arms. The frame is connected to a stepper motor and can move in and out of the beam. All four harps have "forks" crossing the beam at 45° from above as shown in Figure5. Due to space constraints, the direction of the motion for different harps is different. In Table 3, the location, orientation, and the wire arrangement of four harps used by HPS are shown. The Y-direction on all four harps is the same, oriented downwards with the increase of the wire position value (motor position value).

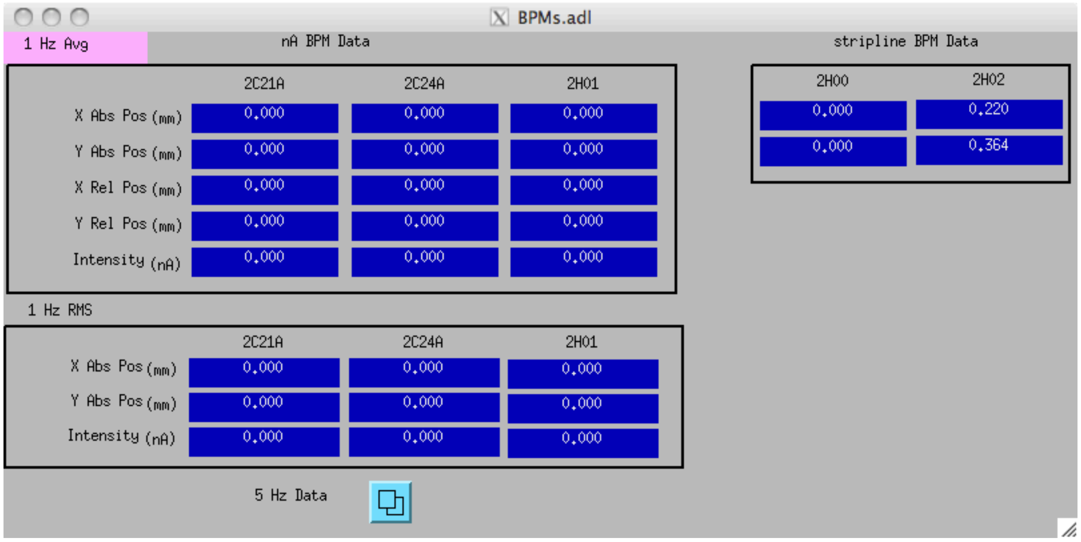

Figure 4: The Hall B current screen. The current reading, in nAmps. The Faraday Cup current reading is updated at the same rate as the beam halo scalers.

The 2C21 harp has two 25 μm tungsten wires that cross the beam in horizontal (X) and vertical (Y)directions. The "tagger", 2H01A, and 2H02A harps have three thin 25 μm tungsten wires, which cross the beam in X, Y, and 45° axis.

Table 3: Location, orientation and wire arrangement of four harps used by HPS.

Harp	Orientation of the X-direction	Number of wires	Order of wires as they cross beam	Location
2C21	From Beam left-to-right	2	X, Y	Upstream tunnel
2C24	From Beam right-to-left	3	45°, Y, X	Upstream tunnel
2H01	From Beam left-to-right	3	X, Y, 45°	Space frame
2H02A	From Beam right-to-left	3	Y, X, 45°	Space frame

The harp launch GUI, Figure 6, enables the operator to open control GUI for the desired harp. For beam profile measurements, the stepper motor positions and the rates in the beam halo counter are recorded. The harp operation is controlled from the Harp GUI, see Figure 7. During a scan the beam halo scaler GUI is controlled by the scan application (see Section **??**).

To perform a harp scan one should push the "SCAN" button. After the scan is finished (motor position has been restored at 0.0 position) use "Analyze Scan Data" to see beam profile and fit results to the scaler distributions. Make sure the beam is stable during the scan. If the beam has been lost during the scan, the scan must be repeated.

3.5.1 Wire Scan

Setup

- MCC is not moving the beam or changing the beam conditions, orbit lock is on
- Ask MCC to mask HPS Halo Counters in FSD as we are doing Collimator Wire Scan.
- SVT is fully retracted and the power is off.

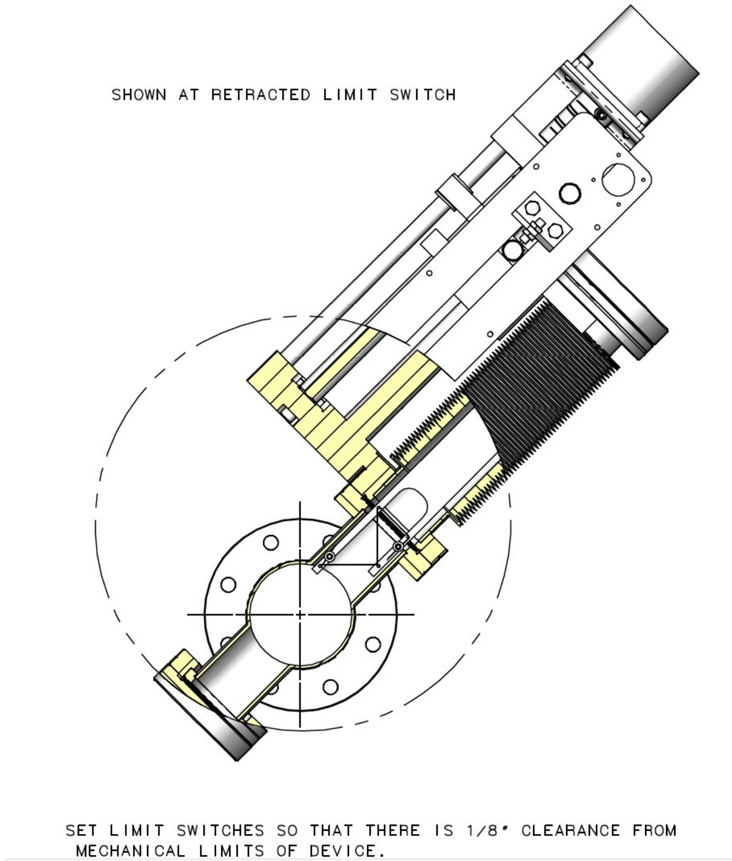

Figure 5: 2H02A Harp mounting diagram. The other harps have similar mounting arrangement, and differ by orientation, beam left or beam right (as in the case of 2H02A).

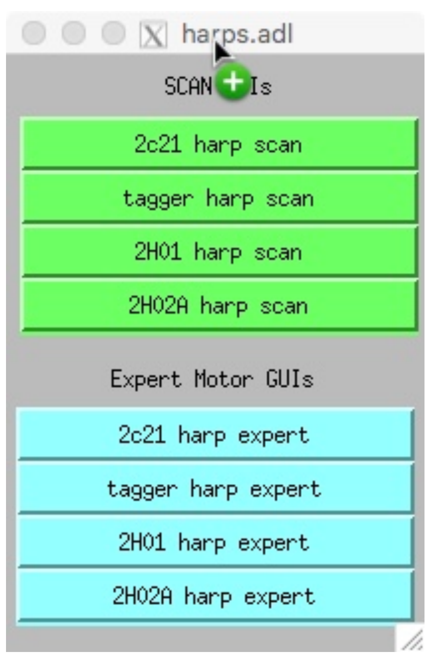

Figure 6: The main Harp medm screen. The green buttons on the top are for opening individual harp control. Cyan buttons below for expert GUIs.

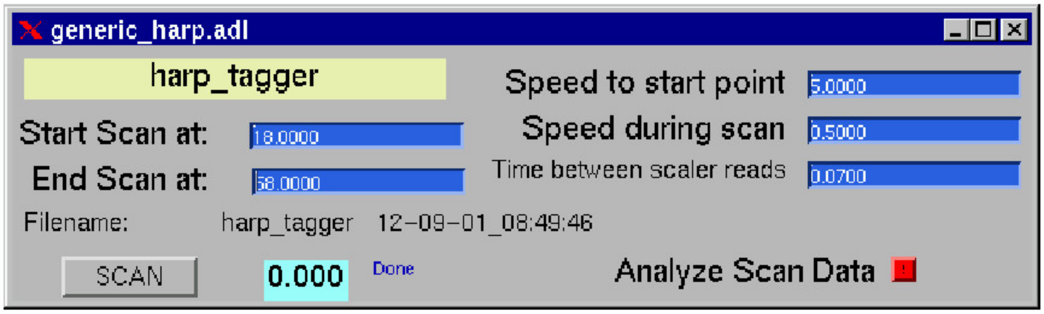

Figure 7: The tagger harp medm screen. This GUI controls a stepper motor and the halo counter scaler settings.

- ECal is operational.
- Downstream Halo Counters are operational.

Scan

A wire scan can be performed from the wire scan GUI (Figure 7) which is launchable from *clas epics*. Once the scan is completed, the collimator will move to "out" position.

- Click "scan" using default values.
- When the motor is "Done", click the red button to the right of "Analyze Scan Data".
- Choose either ECal or Halo Counter as the detector.
- Find the beam offset (Δy) from the nominal beam position

3.6 Synchrotron Light Monitor

Synchrotron light monitor (SLM) is a PMT device that measures amount of synchrotron light generated by electron beam in the magnetic field of the last dipole right before the Hall-B upstream tunnel (when beam gets to the hall beamline elevation level). The synchrotron light device, nomenclature name 2C20, is composed of a mirror and a prism that splits the synchrotron light image in two. One is used by accelerator operations as beam viewer, another is directed to a 2" PMT and read out on current integrator. The PMT signal is used by Hall-B as beam current monitor.

The main use of this current monitor is to measure helicity related beam intensity (charge) asymmetry. While PMT signal strength depends on the beam position, for fast (>Hz) asymmetry measurements it works well without any corrections for position drifts, since position drifts are usually very slow process. Position dependence can be corrected using the 2C21 BPM position readout and in principal this device can be used for beam charge accounting if needed.

3.7 Beam halo counters

The beam halo counters consist of photomultiplier tubes strapped to the beampipe along the beamline. There are two halo counters upstream of the Hall-B tagger magnet, three counters are installed on top of the tagger magnet vacuum box, four counters located in the apex of the forward carriage, two counters downstream of the Frascati-1, and two counters downstream of the HPS target behind the ECal. The beam halo counter scalers are displayed on the main scaler GUI.

3.8 Hall-B Collimator

To prevent direct beam exposure of the SVT in an event of beam excursions upstream of the Hall-B, a collimator is installed ∼ 40 meters upstream of the detectors. This is the same collimator box and a 20 cm long Nickel collimator that has been used in the past for the tagged photon beams in Hall B. One of the collimators has been resized to have a 20 mm diameter hole. The collimator control GUI will have sizes and motor positions for each collimator in the box, see Figure 8. To position the required collimator open the *Motors* GUI, select *Hall-B Collimator* tab and click on the collimator button you want to move.

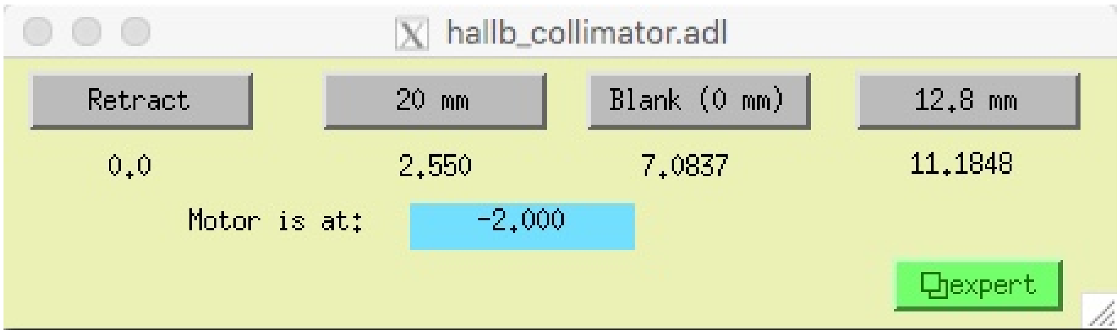

Figure 8: Hall-B collimator.

3.9 Target

Figure 9 shows the HPS target. The 4μm-thick tungsten is used for 1.1 GeV and 2.2 GeV data taking, and the 8μm-thick tungsten is for 4.4 GeV and 6.6 GeV. The graphite and CH_2 targets are for calibration.

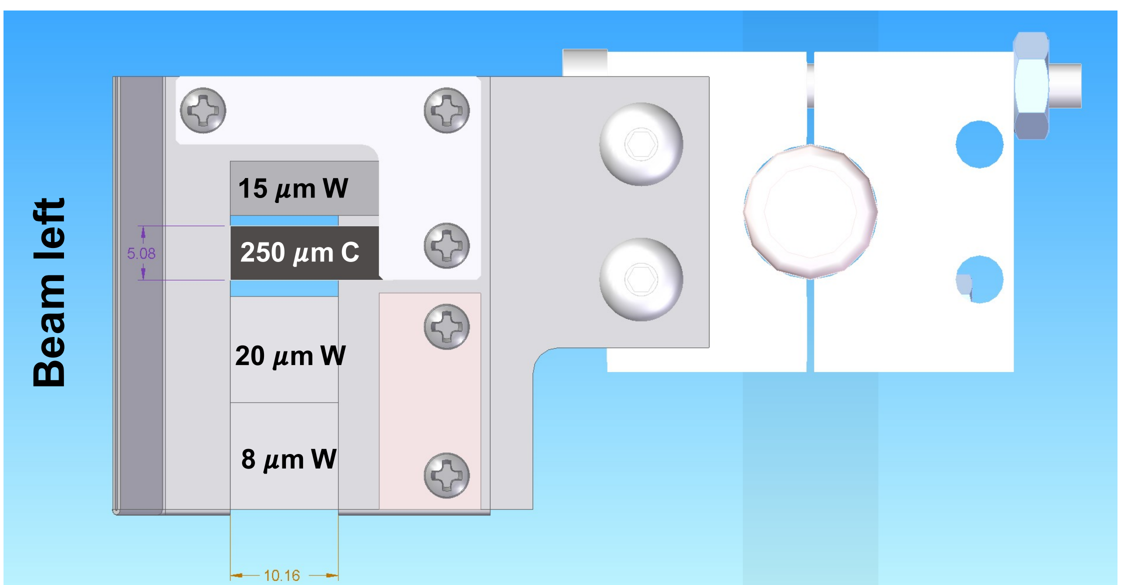

Figure 9: HPS target.

3.9.1 Setting the target

Target can be set by running the target GUI (Figure 10).

- Call MCC to turn off the beam
- hit appropriate target button.
- use "Retract" button to remove the target from the beam

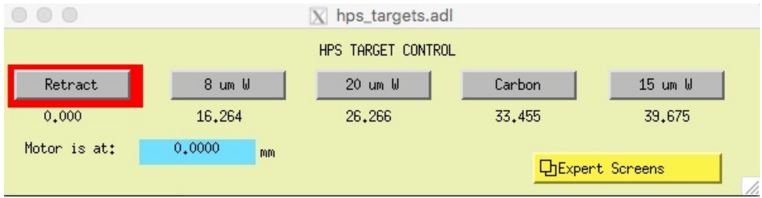

Figure 10: Target GUI

3.10 SVT Protection Collimator

Figure 11 shows the SVT protection collimator. This is a 1cm-thick Tungsten with three different size rectangular holes. In addition to the tungsten block, there is a 25 μm wire mounted on the same ladder. The sizes of the rectangular holes are (from closest to the beam); 8×10 mm^2, $2.82x10$ mm^2, and 2.25 mm^2. For beam tuning when SVT is retracted, the 8 mm collimator must be on the beam. Depending on the beam conditions, either of the small collimators will be used for data taking.

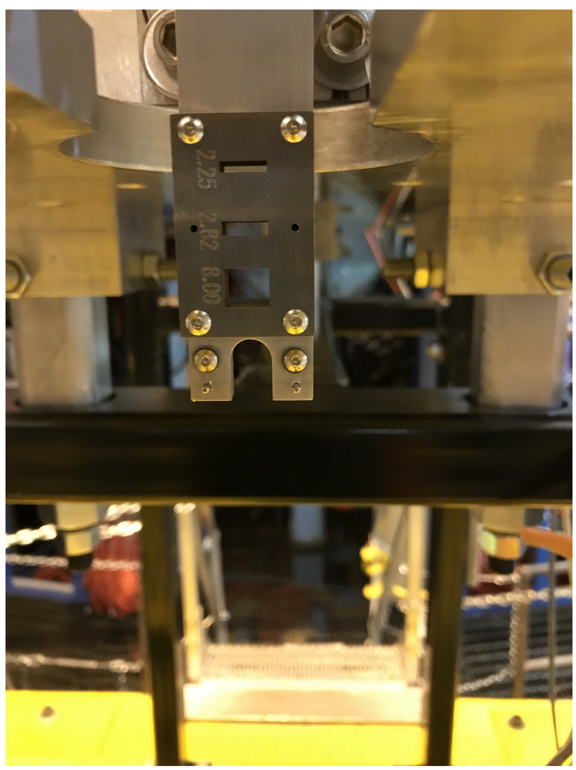

Figure 11: SVT Protection Collimator

3.10.1 Changing the collimator setting

Note: Collimator should be on the beam all the time, for beam tuning the 8 mm height hole is used. Once the beam is tuned, the proper hole for data taking can be set by running the collimator GUI shown in Figure 12.

- Call MCC to turn off the beam
- Push appropriate button on the GUI
- If position on the GUI is not what the new beam tune requires call the EPICS (slow control) expert and ask to fix the DB. In the meantime, use the expert GUI to move the motor on the right position

The “Retract" button moves the collimator out of beam.

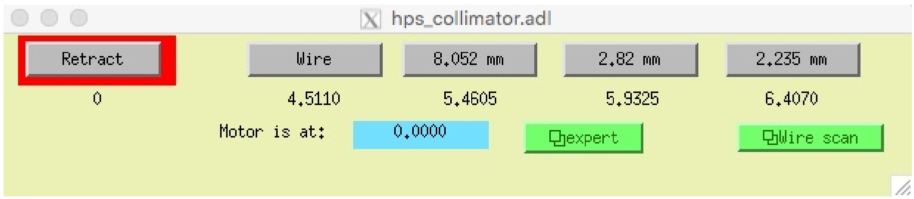

Figure 12: SVT protection collimator control GUI.

3.11 Magnets

Monitoring of all three power supplies (tagger, pair spectrometer and mini-torus for Frascati's) and the control of power supplies for the pair spectrometer and the mini-torus, can be done through GUIs available for each power supply. The power supply GUIs can be opened from the main HPS EPICS GUI from "Magnets" button. Clicking it will show a pull down menu with GUIs for magnet power supplies. The first item in the pull down menu is the *Chicane* that can setup the chicane magnets to the proper currents based on the beam energy

A detail instructions how to setup the chicane, how to use the GUI (Figure13) are provided in a separate document on the run wiki documentation page.

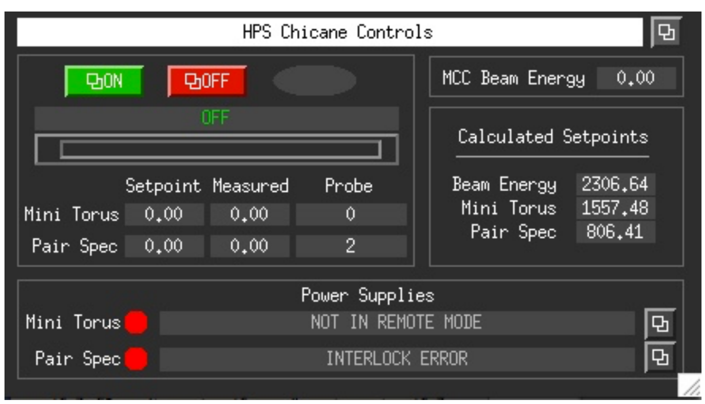

Figure 13: The mini torus power supply control GUI.

3.11.1 Mini-Torus Magnet(classc3)

The "Frascati-1 and Frascati-2 dipoles are controlled by the Hall-B mini-torus magnet GUI (see Figure 14) launchable from "Magnets" of the *"hps_epics"*. The magnet current settings vary depending on the run conditions, check with the shift leader, Run Coordinator or PDL if you are unsure of the appropriate current setting. The power supply is 10000 A/30 V supply. In EPICS control system of this power supply the max current to the magnets will be limited to 1200 A.

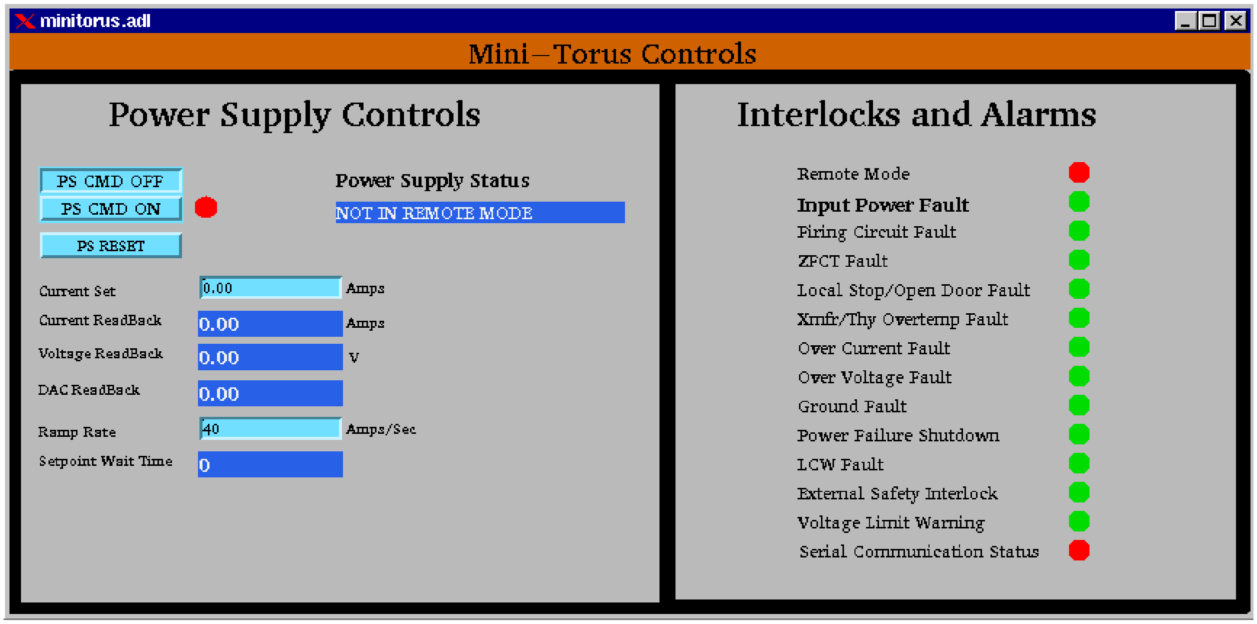

Figure 14: The mini torus power supply control GUI.

3.11.2 HPS-dipole Magnet(classc3)

The HPS-dipole magnet is fed from the Hall-B pair spectrometer magnet power supply. The power supply is controlled by a GUI (see Figure 15) launchable from "Magnet" of the *"hps_epics"*. The magnet current settings vary depending on the primary electron beam energy, check with the shift leader, Run Coordinator or PDL if you are unsure of the appropriate current setting. The magnet and power supply can operate up to 3600 Amps.

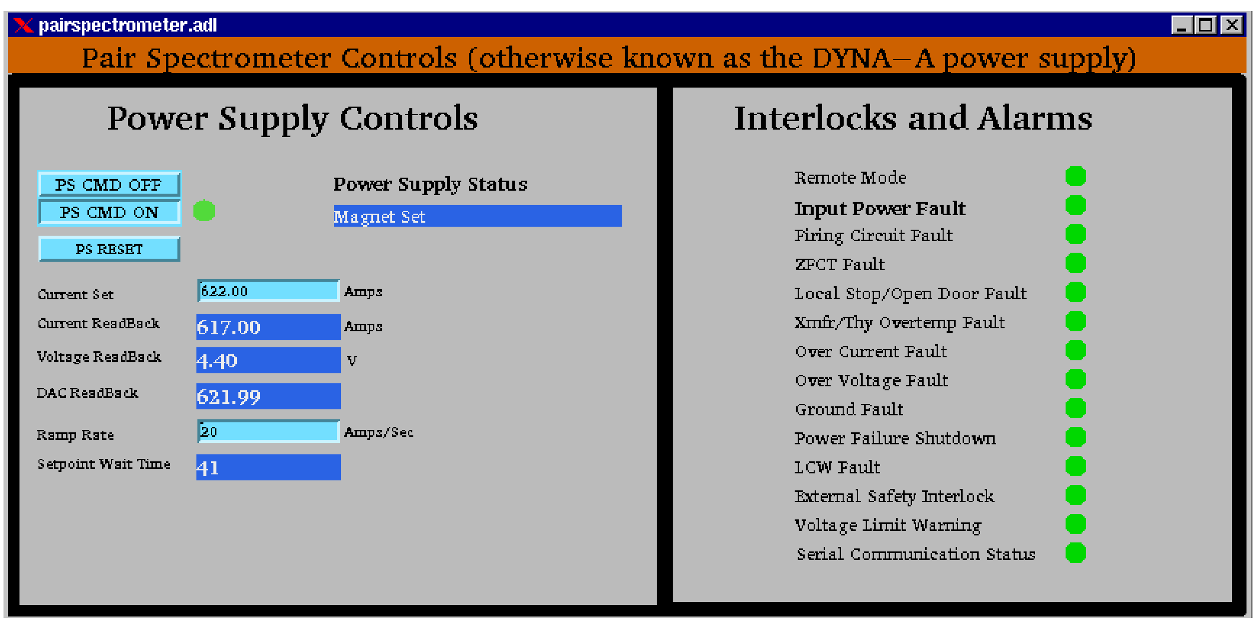

Figure 15: The mini torus power supply control GUI.

References

[1] R. Paremuzyan and S. Stepanyan, CLAS12 Note 2018-004 (2018)

N. Dashyan and S. Stepanyan, CLAS12 Note 2016-004 (2016)

[2] R. Paremuzyan and S. Stepanyan, CLAS12 Note 2018-003 (2018)

[3] R. Ursic, M. Piller, R. Flood, E. Strong, and L. Turlington, Conf.Proc. C970512 (1997) 2131, JLAB-ACE-97-02 (1997)

[4] P. Evtushenko, A. Buchner, H. Buttig, P. Michael, B. Wustmann, K. Jordan, Stripline BPM Monitors for ELBE, Proc. DIPAC 2001, ESRF, Grenoble, France.

[5] A. Freyberger, Proceedings of the DIPAC 2005, Lyon France, pp 12-16. JLAB-ACC-05-318 (2005).

[6] HPS update to PAC39, `https://www.jlab.org/exp_prog/proposals/12/C12-11-006.pdf`

[7] N. Baltzell et al., Nucl. Instr. Meth. **A859**, 69 (2017)

[8] D. Sober et al., Nucl. Inst. and Meth. A 440, 263 (2000).