Users' Manual for DRAGON Separator hardware

Revision history

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1.0	D.A. Hutcheon	Initial document	3 January 2003

Contents

1 Magnets

The DRAGON magnets include 2 dipoles (MD1, MD2), 10 quadrupoles (Q1–Q10), 4 sextupoles (SX1–SX4) and 5 double steerers (SM0–SM4). Regulated DC power supplies for the magnets are located on or under the (purple) DRAGON platform. The power supplies are interlocked to thermal switches (all magnets) and to flowmeters for cooling water (all except SM1 and SM2).

The flow of cooling water to each magnet is monitored by a meter connected to an "intelligent flow controller" box mounted at the east railing on the upper platform. Table 1 gives the channel assignments in the flowmeter controllers. Water flow and thermal switches attached to the magnet coils are interlock inputs to the magnet power supplies. If EPICS indicates no water flow, check first to see if the rotor of the flowmeter (located at the magnet) is turning. If the rotor is turning rapidly, go up to the flow controller, open the front cover and look for a flashing light, indicating good flow, on the channel in question. If the rotor is turning but the interlock condition cannot be reset (yellow text changing to black) by the RST button , consult Controls group. If the rotor is not turning, either the water has been turned off or the flowmeter has stopped working: call Beamlines group or consult with ISAC Operations.

1.1 Dipoles

Designed to bend particles with maximum rigidity of 0.5 Tesla-m (150 MeV/c), the dipoles have a maximum rated current of 500 A. (See G.S. Clark design notes TRI-DN-98-12 and -98-10.) The magnet power supplies are designed to give a DC current stable to 0.01%. The MD1 power supply is beneath the platform on the north side, and the MD2 supply to the south. The AC breakers for the Philtek power supplies are

Table 1: Channel assignments in DRAGON flow controllers.

Unit	Channel	Magnet
Upper	1	Q1
	2	Q2
	3	Q3
	4	Q4
	5	Q5
	6	Q6
	7	Q7
	8	Q8
Middle	1	Q9
	2	Q10
	3	MD1
	4	MD2
	5	SM0
	6	–
	7	SM3
Lower	1	SM4
	2	–
	3	SX1
	4	SX2
	5	SX3
	6	SX4
	7	–
	8	–

located in a panel under the platform at the foot of the stairway.

Control of the dipole power supplies is via interface cards on a Canbus circuit. The EPICS page for MD1 (or MD2) is called from DRAGON menu OPTICS|Optics(1) (Optics(3) for MD2) and clicking on the MD icon. The page has buttons to turn the magnet On ("1") or Off ("0") and to reset latched interlocks ("RST"). If the magnet refuses to turn On remotely, try going to EPICS page Diagnostics|Canbus diagnostics|DRA:MD1 and hit "RST P/S". A Setpoint slider and current readback are calibrated in Amperes.

The MD magnetic field is sensed by an NMR probe (#3 probe for MD1 and #4 probe for MD2) inserted through a hole in the "inside" return yoke at beam height. A jig holds the probe at a well-defined position and orientation, just outside the vacuum vessel, in a region where the field is still flat. Each probe is connected to a CERN-type controller located in the electronics rack under the platform. Controller output (field in Gauss) is displayed on a front-panel display and is sent also to EPICS where it is presented as part of the MD1 (or MD2) panel. The controller can search and lock on the resonance — when it locks, the field value displayed by EPICS changes from white to blue. The (rather narrow) search range is set by a 0–6.5V level fed in the back of the controller unit. The level comes from a supply which is controlled by slider/On/Off/status buttons on the bottom row of the MD1 entry of Optics(1) (Optics(3) for MD2). The search range is not quite a linear function of input voltage (slightly S-shaped): if the NMR is not locked, observe the search range of the displayed (white) field values and adjust the voltage to make the search range bracket the expected field. (The expected value for MD1 can be calculated from the Setpoint current: B = 11.7*I + 100. For MD2: B = 16.5*I.)

1.2 Quadrupoles

Quadrupoles 1–8 were built to TRIUMF design by Sunrise Engineering (Delta). Two (Q1, Q6) are "4-inch" quads (see G.M. Stinson design note TRI-DNA-98-4); five (Q3,Q4,Q5,Q7,Q8) are "6-inch" quads (see G.M. Stinson, TRI-DNA-98-5); one (Q2) is "6-inch" with a 6% sextupole component (G.M. Stinson, TRI-DNA-99-3). The 4-inch quads were designed to produce a field gradient of 0.5 kG/cm at maximum current 325 A, the 6-inch quads 0.36 kG/cm at 325 A.

Quads Q9 and Q10 (CERN "Smit-Elma") have a 15-cm aperture (see G.S. Clark design note TRI-DN-98-17). Pole tip fields were surveyed to be 19 Gauss/Amp.

The quadrupole power supplies, designed for 0.1% current stability, are rack-mounted units (Xantrex and Power Ten) located on the power-supply platform. Their AC breakers are in panel P456 at the east railing of the platform.

Quadrupole fields are measured by Hall probes, jig-mounted in the middle (longitudinally) of each quad. The probes for Q1–Q8 are located in the gap between poles, at the radius where the field is a maximum. On Q9 and Q10 this location was not accessible. The Hall probe control boxes, located close to the quads, are on a Canbus daisy-chain. When viewing quadrupole field values on the EPICS Optics pages, make certain that the page is wide enough so that the high-order digits are displayed. Expected B/I readings for Q1 and Q6 are 11.6 Gauss/Amp; for Q3,4,5,7,8 it is 12.5 Gauss/Amp; for Q2, 12.9 Gauss/Amp; for Q9 and Q10, nnn Gauss/Amp.

1.3 Sextupoles

SX1 and SX2, 6-inch sextupoles originally installed in meson channel M13, were surveyed to have pole-tip fields 18.5 Gauss/Amp. SX3 and SX4 came from channel M15; they give 18.1 Gauss/Amp.

The sextupole power supplies are rack-mounted units (Xantrex) located on the power-supply platform. Their AC breakers are in panel P456 at the east railing of the platform.

They are not equipped with Hall probes.

1.4 Steerers

The double-steerers can deflect ions of maximum rigidity (0.5 T-m) by up to 25 mrad in x and/or y. Steering magnets SM1 and SM2, obtained from Chalk River, are air-cooled and have maximum rated current of 5 A. (If they are to be used above 3 A, a fan or other forced-air cooling should be installed.) SM3 and SM4 are water-cooled, with maximum current 100 A and have 6-inch apertures (see G.M. Stinson design note TRI-DNA-99-1); they have 3.88 Gauss/Amp. SM0 (a.k.a. "the Wobbler") is used for separator optics studies, for which it is mounted at the target position. It is a 4-inch design (G.M. Stinson, TRI-DNA-98-7), water cooled, maximum current 100 A, having 3.24 Gauss/Amp.

The sextupole power supplies are rack-mounted units (Xantrex and zzz) located on the power-supply platform. Their AC breakers are in panel P456 at the east railing of the platform. When SM0 is not in use (most of the time), its power supply will be locked out; thus, most of the time the EPICS icons for SM0X and SM0Y are red.

2 Electrostatic dipoles

Dipoles ED1 and ED2 consist of polished cylindrical titanium electrodes having a gap of 100 mm and radii of curvature 2 m for ED1, 2.5 m for ED2. Design bending power is 8 MV (energy/charge 4 MeV/q) which requires electrode voltages of $\pm$200 kV on ED1, $\pm$160 kV on ED2. They are housed in large cylindrical tanks. The HV units are stacks powered by Glassman r.f. supplies; the stacks are immersed in SF_6 gas at 2 atm, enclosed in re-entrant insulating cylinders (nylon in ED1, ceramic in ED2).

The tank is encased in 6 mm of lead, to absorb x-rays given off during voltage conditioning. X-ray production is monitored by thick plastic scintillators connected to photo-multiplier tubes, mounted above a viewing port on the lid of each vacuum tank. The PMT high-voltage supply is a LeCroy unit, manually controlled, in the 19” rack below the platform. Customary HV setting is -2000 V. A discriminator in the same rack provides logic signals which are counted in a scaler in the VME crate on the platform.

The Glassman supplies are close to their respective electrodes, in a 19” rack for the anodes and slung from the vacuum tank for the cathodes. They are controlled via a Canbus link. The AC to the Glassman supplies is interlocked: cages around the feed-throughs to the stacks must both be closed; there must be less than 0.5 atm in the tank as measured by a mechanical gauge; there must be less than 10^{-5} Torr in the tank as measured by an ion gauge; at least one of the tank pumps (turbo, cryo or ion) must be on. The interlock boxes are located in the racks that hold the anode power supplies.

The EPICS display shows set voltage and stack current for anode and cathode. Normally the current reading is about 1 μA per 6 kV. (Due to a calibration problem in the r.f. supply for ED1 cathode, it reads back a voltage which is ≈13% lower than indicated by direct measurement.)

Following a power glitch or a re-boot of EPICS it is not uncommon for the HV to refuse to come on. If it is not due to a genuine interlock fault, go to the EPICS ED page and bring up the Expert panel. Change the “I+” setpoint to 0 then to 40, and do the same for the “I-” setpoint. (“40” is the current limit in μA.) If HV still doesn’t come on, call a high-voltage expert.

The electrodes must be “conditioned” for stable operation at high voltage. As the voltage is increased, at some point the current will jump up to the current limit of the supply, vacuum will get worse by an order of magnitude, and the x-ray counts will jump from from tens or hundreds per second to many tens of thousands per second. If the voltage is set just above the onset of these effects, the system should return to good vacuum, low x-ray counts and 1 μA per kV within a minute or so. Then the voltage can be raised slightly and the cycle repeated. If signs of conditioning persist for more than $\approx$1 minute after a small increase in voltage (say 10 V), this may indicate a problem such as carbon tracking along the nylon insulator; reduce the voltage and consult an HV expert.

3 Diagnostics

3.1 Faraday cups

DRAGON has 4 Faraday cups: FC1 is between Q2 and MD1; FCCH is after the slits at the Charge Selection focus following MD1; FCM is after the slits at the Mass Selection focus following ED1; FCF is after the Final slits at the end of the separator. They can be inserted or retracted by a pneumatic actuator, controlled via EPICS. The EPICS control panel for each cup allows selection of a full-scale current range for the current integration. The readout noise is approximately 10 pA, setting a lower limit on the beam currents which can be read reliably. An integration time of 1-2 seconds has been built into the ADC readout routine, so several seconds are needed for the readings to reach a stable value.

Each Faraday cup is equipped with a bias ring at the front, to suppress the escape of secondary electrons. If the "good bias" indicator is not green, click on "Bias" and set the bias to greater than 100 V on Reverse polarity.

The bias power supplies and the charge-integrating ADCs are located in a Controls VME crate in rack 23A on the platform.

3.1.1 FCF and the MCP

The In/Out control of the Final cup FCF is complicated by the fact that FCF and the multi-channel plate detector (MCP) plus its target foil go “In” to the same volume immediately behind the Final slits. Care must be taken to prevent FCF from crunching into the MCP when the MCP and Foil are in their In position. This is controlled by the EPICS page summoned by clicking on “MCP/Foil/FCF Interlocks” on Optics(4). This page shows the status of the “flip-flop” logic which grants permission to move to *either* FCF *or* MCP/Foil. In order to insert FCF, both MCP and Foil must be Out and their Request status be Off, and the Request status of FCF must be On. Conversely, to insert either MCP or Foil, FCF must be Out and its Request status be Off, and the Request status of MCP or Foil be On.

3.2 Slits

Two pairs of motor-driven slits are located at each of 3 focus points: XSLITC and YSLITC are the horizontally-moving and vertically-moving slit pair at the Charge selection focus; XSLITM and YSLITM are at the Mass selection focus; XSLITF and YSLITF are at the Final focus.

Each member of a pair (e.g. the Left and Right parts of an XSLIT pair) is driven by a stepping motor. However, the user specifies the Width and Position of the slit opening and EPICS control takes care of computing the Left and Right (or Top and Bottom) positions. The sign convention is that of GIOS or TRANSPORT ion optics codes: positive x is to the left, looking downstream in the direction of particle motion; positive y is up.

The stepping motor controllers are located in rack 23A on the platform, below the

VME crate. Calibration of slit positions is done by means of a microswitch at the "Out" position of each drive. Following a power failure or an EPICS re-boot, it is necessary to do a "Calibrate" operation for each slit drive. This causes the slit member to be driven out to the outer (microswitch) limit, then in to the position required by the Position and Width settings.

A 3rd microswitch protects against an attempt to close the slit pair beyond the point of contact ("negative Widths"). This means that care must be taken if very small Widths are called for: a Calibrate operation may never complete when Width=0 if the collision microswitch engages before the motor has stepped to the computed 0 width; a change in Position when Width is <2mm may produce the "collision" condition during the movement of the slit members. In the latter case, the EPICS driver will stop the "pursuing" member but allow the "leader" to continue to its proper destination — the indication that this has happened is that the read-back position (blue number) doesn't end up at the Setpoint number for Width and Position and the "Closed limit" light is green for the "leader".

In case there is concern that the slit drive has not stepped to the desired position, the X slit pairs are equipped with pointers and millimeter scales to allow independent verification of the actuator position. The scales are marked also with the readings that correspond to the out-limit microswitches; these numbers should appear in the EPICS table used in Calibration.

As for the Faraday cups, slit currents are sent to an ADC. The slits have no bias for secondary electron suppression.

3.3 Beam centring monitors

Six beam centring monitors (BCMs), together with the 3 sets of slits and the target aperture, allow beam position to be defined at two locations in each of the 5 straight-line segments of the separator. Each BCM consists of 4 plates arranged in a 2x2 array, mounted on insulators and separated from each other by a small gap. The current from each plate is read by an ADC and EPICS combines the 4 readings to show total current plus asymmetry of current in each of left-right and top-bottom directions.

Insertion and retraction is by pneumatic actuator. If the device fails to reach its In limit (defined by a microswitch) in time (e.g. low compressed air pressure), a Timeout is indicated. Timeout flag may be cleared with the RST button.

The current range scale must be chosen so that none of the quadrants is shown with full-scale current, or else the asymmetry calculations will not be valid. There have been occasional problems with a quadrant of a BCM reading a substantial current, even with no beam on it. This may be due to a flexible lead shorting out, for example, which requires venting a section of the separator in order to investigate further. A temporary work-around is to steer the beam so that none of it falls on the "bad" quadrant and adjust the horizontal or vertical steering for equal currents on each of the two pairs of adjacent plates, in turn.

3.4 Beta monitor

The Beta monitor is a pair of plastic scintillators which detect beta particles emitted by radioactive beam atoms which stop in the Mass slit. Located in air in a well in the Mass focus diagnostics box, the Beta monitor subtends about 1/1500 of 4π solid angle at XSLITM. The rate for coincidence detection of a particle in the two scintillators is presented to the VME EPICS scaler ("Scaler 7" in menu item Diagnostics|DRAGON scaler) and the MIDAS DAQ (10th scaler channel). The coincidence response depends upon the energy distribution of the decay betas: a detected beta must have eneough energy to pass through the entrance window, through the first scintillator (6mm) and far enough into the second scintillator to be above discriminator threshold. As well as the coincidence rate, the front-counter singles rate is sent to the MIDAS scaler (12th channel).

The HV for the plastic scintillator photo-multiplier tubes is from channels 2 and 3 of the same LeCroy HV unit which supplies the ED x-ray monitors. The discriminators, coincidence unit, and level adapter modules are in the same NIM bin as the NMR controllers (rack under the platform).

3.5 CCD camera

A CCD (Starlight Xpress MX7-C) and lens doublet of 500mm focal length view upstream through an alignment port of dipole MD1, to the target position. When beam is passing through a gas target, it emits light which can be imaged on the CCD. The position of the beam can be determined relative to the apertures of the gas cell with sub-millimeter accuracy. The width of the beamspot can be seen also (but it is a measure of beam width only if the light comes from beam ions, not target gas which may have diffused before recombination).

The MX7-C is controlled from the gas target PC via the Starlight Xpress driver. 2-d density plots may be made (generally need to start with a Linear Stretch of the intensity scale in order to see the beamspot). A Photometry option gives counts for individual pixels. The counts from the entire pixel array may be stored in a .FITS file for later analysis.

The location of the gas cell aperture may be determined by closing isolation valve HEBT2:IV8 and turning on ion gauge IGU3 (and opening valve IV11 !). The outline of the 6mm cell entrance aperture appears backlit by light scattered off IV8.

4 Vacuum

The separator vacuum system has 5 sections, each with independent high-vacuum pumps, which are connected in a common system when ions pass through. These sections are: the ED1 tank; the ED2 tank; the Charge slit box, MD1 vacuum box and pipe between the Charge box and ED1 tank; the Mass slit box, MD2 box and other pipe between ED1 and ED2 tanks; the Final slit box and pipe between it and ED2.

A single roughing pump connects to one (at a time) of these volumes. It is a Leybold Dri-pump — oil-free, pumping down to about 50 mTorr. Similarly, all the turbo pump backing is done by a second Dri-pump. Interlock conditions on opening roughing valves (RV) or backing valves (BV) protect against gross Operator errors, such as trying to rough down a volume when its vent valve is open. (However, this is true only if the interlocks have not been Bypassed — if a valve has "Interlocks bypassed" and you don't know why, find out why before opening it.)

4.1 Pumping down a slit box volume

The following describes the steps in pumping down the Charge slit box volume, but it applies to the Mass slit box or Final slit box with suitable change in label of valves, pumps or gauges.

- close vent valve VV21
- turn on roughing pump RP21 and when convention gauge CG21B goes below

100 mTorr, open pump valve PV21.

- open RV21 and observe box pressure on CG21. Pressure should decrease steadily until CG21 reaches 100 mTorr, when RV21 will close.

- if backing pump BP31 is not already running and PV31 open, turn on BP31 and open PV31.

- open BV21 and turn on turbo pump TP21 (it may be necessary to RST latched interlock conditions). TP21 icon should turn dark green and CG21 drop to a near-zero reading. After 10–15 minutes the turbo should get up to speed and its icon change from dark green to light green.

- turn on ion gauge IG21. If the volume has been at atmosphere, initial IG21 readings may be in the 10^{-5} Torr range and will only slowly (over hours) decrease to 1–2×10^{-6} Torr as water is desorbed from inside surfaces.

The Final slit box has the complication that it may contain fragile MCP target foils. Roughing down begins through RV54, which is in series with a manual throttle valve which has been adjusted to limit initial pumpdown to a foil-friendly rate. If it is known for certain that no foils are mounted (e.g. by looking in the window of the MCP Foil mounting plate), fast pumpdown may be done through RV52 (with Bypassed interelocks).

4.2 Venting a slit box section to 1 atm

This procedure for the Charge slit box applies also to the Mass and Final slit boxes, with suitable change of labels on gauges, pumps and valves.

- close isolation valves IV11 and IV21

- turn off ion gauge IG21 and turbo TP21, and close backing valve BV21
- toggle vent valve VV21 open and closed as quickly as possible, to start the turbo braking process. CG21C may climb to ≈10 Torr, and then gradually decrease as TP21 spins down. When CG21C reaches 1–2 Torr, allow another quick gulp through VV21.
- when CG21C and CG21 become nearly equal, start the main venting: at the compressed Nitrogen cylinder beside MD2, verify that the manual valve "LN2 dewar pressure" is closed and "Separator vent" is open. Locate the vent line pressure relief valve (downstream of MD2, knee height, by valve VV21A. Adjust the pressure regulator (clockwise increases pressure!) until gas can be felt escaping the pressure relief valve.
- open VV21 and watch pressure rise on CG21. When it reaches 760 Torr, valve off the nitrogen cylinder.

4.3 The ED tanks

Only rarely will the ED tanks be vented to atmosphere. The general user is strongly discouraged from doing this, because of the lengthy time it takes to recover high vacuum (10^{-7} Torr level) after a venting. More likely will be a requirement to resume pumping if all the pumps are off following a power outage. Each tank is equipped with:

- a turbo pump (Varian 1000 l/s) used to pump down from "intermediate" vacuum (too high for the ion gauge, too low for a convection gauge) to the 10^{-6} Torr range. Otherwise, usually turned off and valved off to reduce wear & tear.
- a cryo pump used for its high pumping speed, during DRAGON operation with

beam. A single compressor runs 2 cold-heads, one at each ED tank. It is located near the Mass slit box, next to the Roughing and Backing pumps.

- an ion pump used to maintain vacuum when DRAGON is not in use for extended periods. It must be turned on or off manually — only the pressure readout is sent to EPICS, to indicate when the ion pump is on.

At least one of the 3 pumps must be on in order to turn on the tank ion gauge and (because they are interlocked to the IG) the electrode high voltage supplies.

4.3.1 Recovery after a power outage

The interlocks on the roughing valves (RV33, RV53) are such that they allow only the pump-out of a warm (>250 K) head, and the cryos (CP33, CP53) can be turned on only if they have been pumped down below 150 mTorr. If a power outage occurs during a run, it may be necessary to pump on the cryo head(s) if they have warmed up enough to release the gunk that they have pumped out of the tank.

- If the outage was brief and the pressure in both CG33C and CG53C is below 100 mTorr, restart the cryos CP33 and CP53. The temperatures of the CPs and the pressure at the associated CGs should drop. There should be a "rrr ... rrr ... rrr ..." sound from the cold-heads at the ED tanks; if there isn't, try turning the power off and on at the compressor (inside the fence, by the roughing and backing pumps) and re-starting CP33, CP53. If this doesn't work, consult an expert.

- if the outage was long enough that CG33C or CG53C pressure rose above 100 mTorr but the temperature at CP33 or CP53 stayed well below 250K, it will be necessary to pump away some of the gas that was released by the warm-up of the cryo.

- on the DRAGON EPICS menu go to Bypass/force|Bypass vacuum and click On RV33 (or RV53). The text should change from black to yellow, indicating the interlock has been bypassed.
- turn on RV21 and open PV21. When CG21A $<$ CG33C (or $<$ CG53C), open RV33 (or RV53).
- if the pressure at CG33C (or CG53C) drops very slowly and rises rapidly when the RV is closed, a lot of gunk has been released and pumpdown may take a considerable time. If the tank turbo pump TP31 (or TP51) is not already running, turn it on (following the instructions as given above for TP21 in the Charge slit box volume). When TP31 (or TP51) gets up to speed and provided CG31 (or CG51) is $<$ 100 mTorr, open gate valve GV31 (or GV51). It should then be possible to turn on the tank ion gauge and HV, if time is of the essence and you want to resume use of the separator.
- continue pumping on the cryo-pump until pressure drops to 100 mTorr and when RV33 (or RV53) is closed the pressure rise is slow enough that CP33 (or CP53) can be turned on before pressure goes above the 150 mTorr interlock limit. The temperatures of the CPs and the pressure at the associated CGs should drop. There should be a "rrr ... rrr ... rrr ..." sound from the cold-heads at the ED tanks; if there isn't, try turning the power off and on at the compressor (inside the fence, by the roughing and backing pumps) and re-starting CP33, CP53. If this doesn't work, consult an expert.
- go to the interlock Bypass page and turn Off the bypasses on RV33 and RV53 (yellow text should turn to black).

- After pumping gunk from a cryopump, it often is seen that the roughing pump RP21 can pump down only to ≈150 mTorr instead of the usual ≈50 mTorr. (This may be due to release of large amounts of water from the cryos.) Purge the roughing line and roughing pump: close PV21 and vent the roughing line to nitrogen via VV21A (following the instructions given above for venting a slit box volume); close VV21A and pump out the roughing line through RV21. If this improves the vacuum at CG21B, a second purge may be useful. If purging did not reduce the pressure at CG21B, consult an expert.

5 Safety fence

Significant levels of radiation may be present when positron-emitting radio-active beam is in use. Approximately 60% of the beam stops at or near the Charge slits following MD1 and 40% on the Mass slits. Lead shielding around the Charge and Mass slit boxes reduces the radiation to acceptable levels at 1 m from the ion-optical axis of the separator. A gated mesh fence prevents people from getting closer than 1 m to the separator when radio-active beam is (or might be) delivered.

A number of gates allow access during maintenance periods or when stable beam is being delivered from OLIS. Each gate has a lock and key. The key can be removed only when the gate is locked; the key must be taken from the gate and inserted in a "transfer panel" in order to release a key which in turn is needed to get authorization for radio-active beam delivery. The transfer panel is located on a post to the north of the DRAGON end detectors.

6 Where is that controller?

The controller/power supplies for turbo pumps, ion gauges, motors, etc. are mostly in 19-inch racks "near" the pump, gauge or motor being controlled. The important racks are:

- Rack 7A — under the platform
  - MD1, MD2 NMR
  - HV4032A supply: XRAY1, XRAY2, BETA1, BETA2 PMT's
  - IG32 (south end)
  - TP32 (south end)
- Rack 18A — East of ED1 tank
  - ED1 HV interlock box
  - ED1 Anode HV supply
  - IG21, IG31
  - TP21, TP31
  - ED1 ion pump
- Rack 26A — Southwest of ED2 tank
  - ED2 HV interlock box
  - ED2 Anode HV supply
  - IG51, IG52
  - TP51, TP52

  - ED2 ion pump

- Rack 23A — on platform, North side
  - EPICS VME crate
  - stepping motor drivers
- Rack 23C — on platform, North side
  - power supplies for SX1, SX2, SM1X, SM1Y, SM2X, SM2Y
  - MD1, MD2 NMR ref. voltage DACs
- Rack 23D — on platform, North side
  - power supplies for Q1, Q2, Q3, Q4, Q5, SM0X, SM0Y
- Rack 24A — on platform, South side
  - power supplies for Q6, Q7, Q8, SM3X, SM3Y, SM4X, SM4Y
- Rack 24B(?) — on platform, South side
  - power supplies for SX3, SX4, Q9, Q10