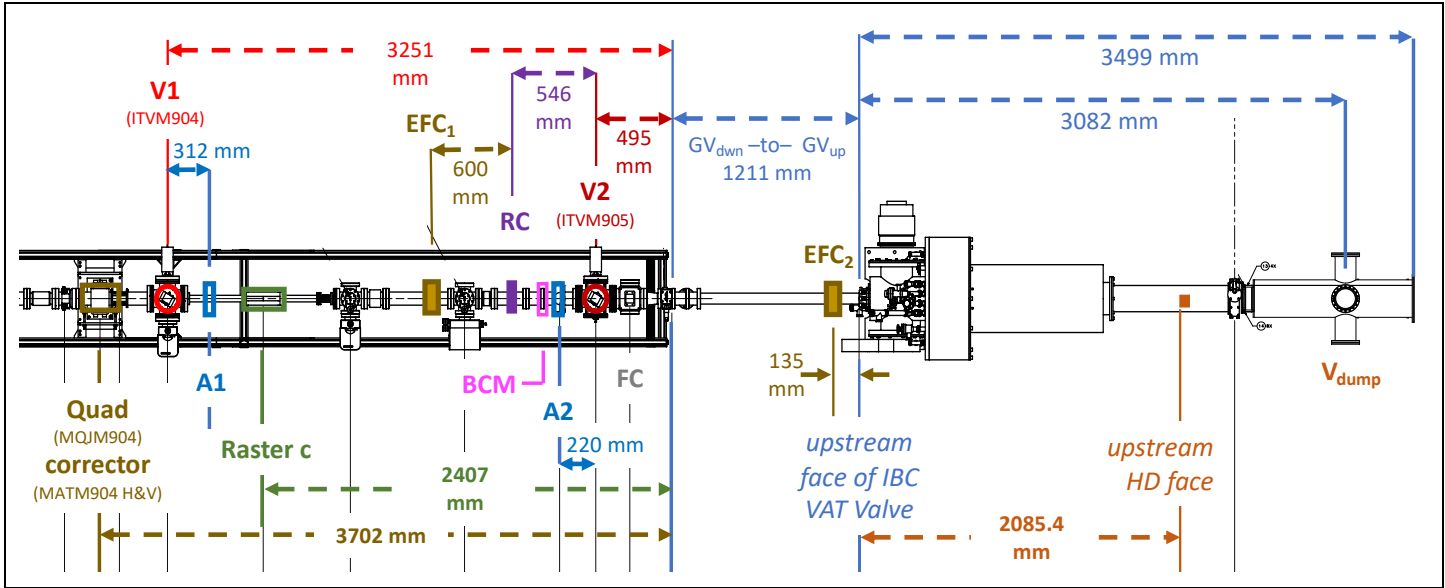


Plans for the execution of HDice Runs at the UITF

The plans for HDice Runs 1 through 3 were outlined by Sandorfi in his second ERR presentation. The Committee has requested more detail. We provide this below, together with approximate time requirements, *in blue*. These time estimates assume the following:

- In the absence of any historical experience for the UITF, we assume that useful beam will be available with a 50% efficiency.
- Due to a shortage of personnel with appropriate familiarity and training, we assume 2 shifts (16 hr) / day, at least for Runs 1 and 2. (If CEBAF operators are available, Run 3 could be executed with 3 shifts/day.)

The sequence of measurements detailed below refers to components of the beamline. For convenience, we repeat the schematic layout, including an expanded level of detail:



Run1 measurement plan:

Beam-line commissioning up to the IBC:

Run 0 will have brought ~10 MeV beam to the waist-high dumps at the entrance to cave-2. Run 1 will be the first time that beam of any energy will be taken up the vertical chicane and onto the elevated beam line.

I. With the pre-IBC Faraday cup blocking beam (FC in the beamline schematic above), the following sequence of operations is planned:

Set up beam for HDice: (5 shifts : 2.5 days) x 2 = 5 days

- Measure the energy from the Booster cryomodule using the waist-high 25° spectrometer and set the beam energy to 9.5 MeV.
- Bring the beam up the chicane to the elevated beamline. The vertical dipoles create dispersion, which will be managed with quadrupoles. The dispersion determines the tails on beam, and will limit how rapidly a rastered beam falls at its outer edge. This will in turn fix the maximum radius of the raster pattern that can fill the target while still avoiding the cell walls. Adjust the energy spread via the Booster, and the dispersion via the beam-line quads to create a circular beam spot with minimal tails on all viewers.

Quantify Beam Position monitors: (2 shifts : 1 day) x 2 = 2 days

- Study the sensitivity of the YAG view screens, V1 and V2, to low currents:
The beamline viewers upstream of the raster and V1 will see tightly focused beams that can be up to 20 nA or higher in intensity during tuning. These view screens are typically 0.25 mm thick. To enhance the optical signal from low-density rastered beams we have increased the thickness of the viewers V1, V2 and V_{dump} by an order of magnitude (2 – 4 mm) to increase the light output by increasing the energy loss. Their sensitivity to current will be characterized at low currents by increasing the laser attenuation of the source.
- Measure the position sensitivity of the Rogowski coil (RC):
Using the last beamline corrector MATM904, correlate RC position measurements with beam positions determined from analysis of the CCD images at V2. Start at 20 nA, decreasing in ~2 nA steps to 0.2 nA .

Quantify Current monitors: (2 shifts : 1 day) x 2 = 2 days

- Study the sensitivity of the five potential current monitors:
 - (i) the current measured by a biased Keithley *PicoAmmeter* on the pre-IBC Faraday cup (FC);
 - (ii) the X-ray intensity of two fast scintillators positioned next to the pre-IBC Faraday cup
 - (iii) the BCM cavity (SBCM905) just upstream of V2;
 - (iv) the integrated intensity of the CCD signal at V2, the YAG view screen;
 - (v) the summed signal from the Rogowski coil.
- Correlate the five signals, starting at 20 nA and decrease in about 2 nA steps to 0.2 nA by increasing the laser attenuation of the source. (The *PicoAmmeter* and the BCM are expected to become unreliable below a couple of nA, but higher current measurements will define the slope for the other current monitors.)

II. Beam alignment through the IBC to the dump with pencil-beam, raster-off : (3 shifts : 1.5 days) x 2 = 3 days

- Set the *Earth Field* correctors to the *g4BL* design fields, using currents determined from field maps:

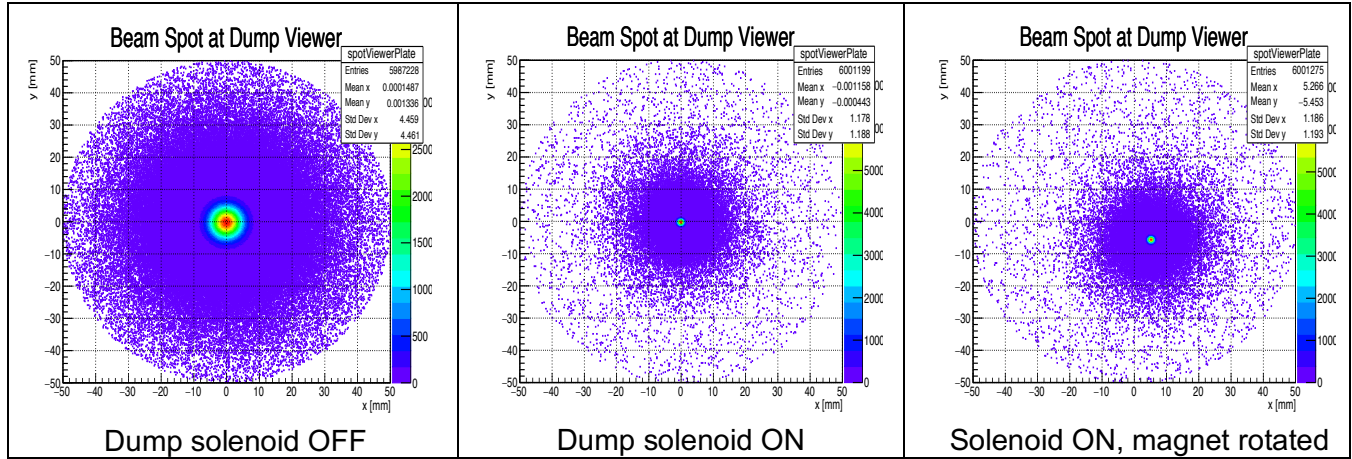
<i>corrector</i>	$EFC_1(x)$	$EFC_1(y)$	$EFC_2(x)$	$EFC_2(y)$
B•dL (gauss-cm)	27.0 (beam-left)	200.0 (up)	0.8 (beam-left)	21.5 (up)
I (Amps)	0.164 A	1.089 A	0.006 A	0.127 A

Directly verify the sign of the current, and hence the deflection direction, with a gauss meter.

- The target that will be used for the Run 1 commissioning is a 0.5 mm thick copper disk. As discussed in our response to the comment in ERR charge item 5, this aperture target has been modified to have the pattern shown in the photo to the right, with a central 2 mm ID hole and open arcs at a radius of 7.75 mm.
- With IBC magnets at their design fields, the dump solenoid OFF, and the *Earth Field* correctors EFC_1 and EFC_2 set at their calculated fields, center a few nA beam (20 nA max) through the 2 mm hole of the aperture target in the IBC. Use the last beamline corrector MATM904 for steering. (The rates in the Halo detectors will define the edges of the 2 mm aperture.) Measure beam positions at V1, V2, and at the Rogowski coil. These become the future reference points for defining the electron momentum vector that is centered through the IBC. We will refer to this as the **IBC axis line**.
- With the beam at the nominal center of V1, the EFC_1 corrector is set to cancel the integral of the earth's field from MATM905 to V2. (There is some freedom in that changes in the position at V1 will require different settings of EFC_1 .) Turn the EFC_1 corrector off and verify the beam positions at V1, RC and V2. The beam at V2 should shift to *beam-right*, and *Up*.



- Dump solenoid alignment: with the dump magnet off, measure the position of the beam at V_{dump} . The expected distribution is shown below in the left panel. Next, charge the dump solenoid to its full current of 320 A (0.25 tesla central field) and observe the position of the beam spot at V_{dump} (center panel) – the distribution is collapsed by the field. The mechanical axis of the dump solenoid has been aligned on the beam line by the Survey Group. However, the magnetic axis may be somewhat different due to manufacturing limitations, and that could steer the beam. The right panel below shows the example of the

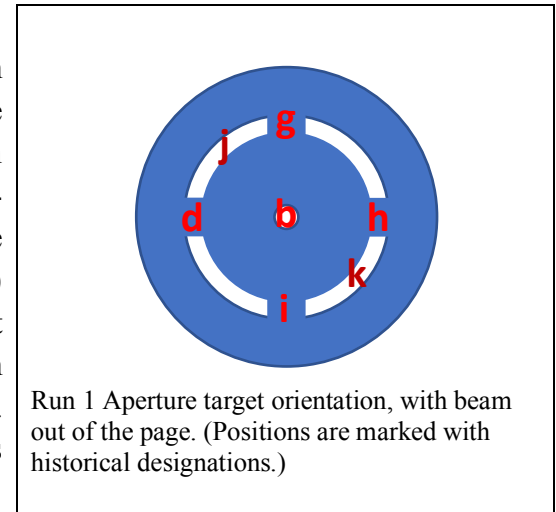


beam spot, off-center due a hypothetical shift in the upstream face of the magnet by 5 mm in the horizontal plane, a 0.6° rotation of the magnetic axis. The resulting spot on the dump viewer appears shifted +5.27 mm to beam-left and -5.45 mm down. The pedestal stand that supports the dump solenoid incorporates sufficient degrees of freedom to adjust offsets, pitch and yaw (although as it turned out, vertical adjustments are quite time consuming). These will be adjusted iteratively to bring the Magnet-ON spot back to the Magnet-OFF central position.

III. Correlate beam positions at V2 and on target – check simulations: *(1/2 shift : 1/4 day) x 2 = 1/2 day*

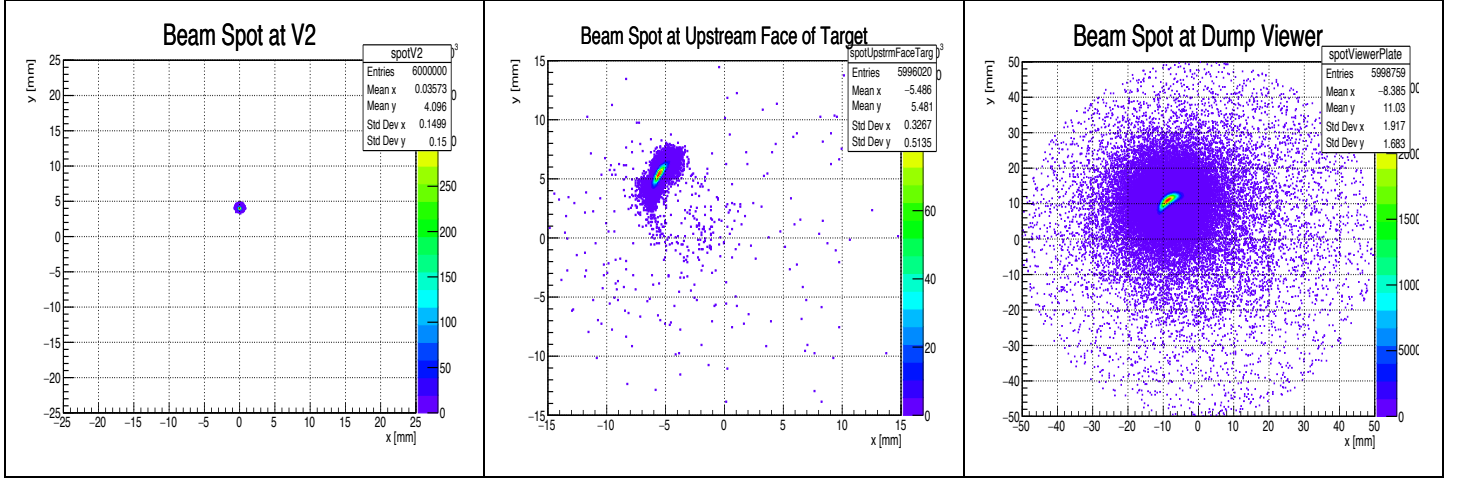
With a *pencil* beam on the *IBC axis line* at V1, the position at V2 determines the location of the spot on target, provided that the IBC solenoids are correctly modelled in the simulations. The Run1 aperture target is installed with the orientation pictured below.

- Steer the beam with corrector MATM904 to the location on YAG screen V2 that is expected by simulation to put the beam through the upper-left open arc, position *j* in the figure. The solenoids within the IBC generate a helical motion of the beam that results in a rotation of very nearly 2 and 1/8 turns (counter-clockwise in this view). Thus, a vertical displacement of the beam at V2 of +4.10 mm up (and -0.04 mm to beam-right) should center the beam on the 7.75 mm radius open arc at position *j*. The predicted positions of the beam spot at V2, on the aperture target, and at V_{dump} are shown in the figure below. The smattering of events outside the central spot on target is due to scattering from the radiation baffle within the IBC, upstream of the target. At the dump viewer, the spray outside the central spot is due to scattering from the IBC radiation foils after the target.

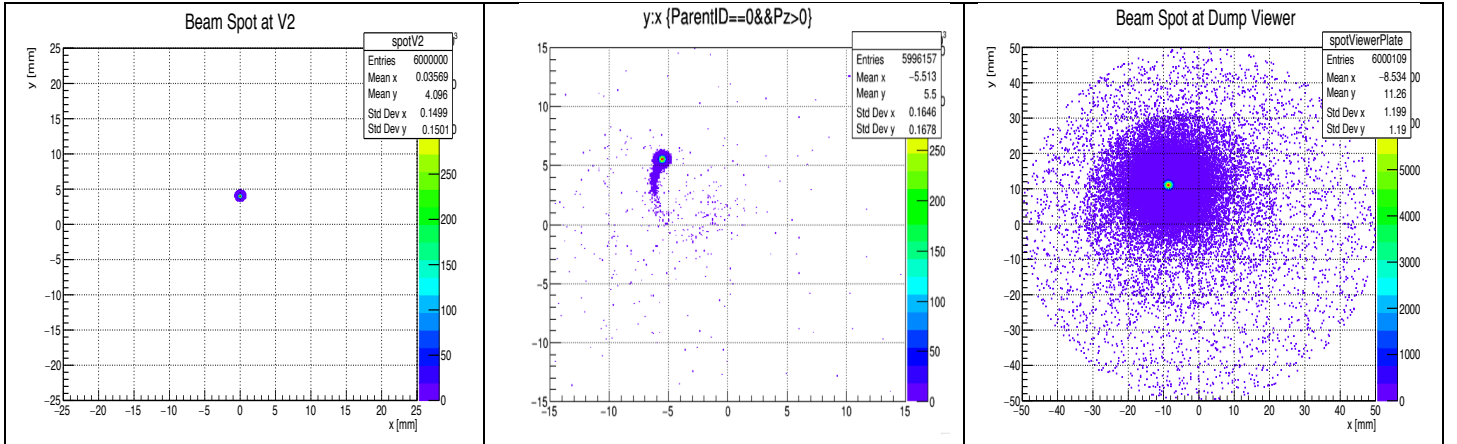


- With the beam centered on the open arc, the halo rates should be negligible. Steer the beam radially on

target, by adjusting MATM904-vertical, to find the edges of the open arc by observing the increase in Halo rates. Record the motion at V2. Since the arcs are 1.5 mm across (radially), the motion at V2 calibrates the magnification of the motion on target.



While we have requested UITF beams with an energy spread better than $\Delta P/P = 0.001$, in these simulations we have conservatively assumed a beam energy spread of $\Delta P/P = 0.01$. This leads to the banana shaped spots in the above plots. For comparison, we include below the predicted beam spots when 0.001 is assumed for $\Delta P/P$.



- Next, steer the beam with corrector MATM904 to the location on YAG screen V2 that is expected to put the beam through the lower-right open arc, position *k* in the above schematic. This should require a vertical displacement of the beam at V2 of -4.10 mm down (and -0.04 mm to beam-right). The resulting Halo rates should be negligible. Now steer the beam radially on target by moving the beam vertically at V2 to find the edges of the open arc, based on increases in the Halo rates. Verify the same magnification in the transport between V2 and the target as observed above with the beam at position *j*.

IV. Calibrate Halo asymmetries with *pencil* beam positions on target: (1 shift : 1/2 day) x 2 = 1 day

We next compare simulated Halo asymmetries with beam offsets by moving the beam onto the ribs that separate the open arcs in the aperture target.

- For each of the positions indicated in the previous schematic, move the beam with corrector MATM904 to the positions on V2 that bring the beam to the desired locations on target. These predicted beam offsets at V2 are listed in the Table below. Correct these, if necessary, with the measured magnification determined from the above beam studies at locations **j** and **k**.
- Record and compare the positions at the Rogowski Coil (RC) and the dump YAG, V_{dump} with the predictions in the table below.
- Record and compare the asymmetries in the Halo detector count rates with the predictions in the table. (The tabulated errors are from simulations whose statistics are always limited. The actual rates with beam will be in the range of 100s KHz/nA, where statistical uncertainties will be insignificant.) Here we define the Halo asymmetries as:

$$A^H(x) = \frac{Y(\text{beam left}) - Y(\text{beam right})}{Y(\text{beam left}) + Y(\text{beam right})} \quad \text{and} \quad A^H(y) = \frac{Y(\text{beam up}) - Y(\text{beam down})}{Y(\text{beam up}) + Y(\text{beam down})}.$$

Position label	RC(x) (mm)	RC(y) (mm)	V2(x) (mm)	V2(y) (mm)	tgt (x) (mm)	tgt (y) (mm)	$A^H(x)$	$A^H(y)$	$V_{\text{dump}}(x)$ (mm)	$V_{\text{dump}}(y)$ (mm)
a (dump off)	-1.208	+0.1556	-0.0209	-0.0087	+0.0214	-0.0089			-1.053	-1.459
b (dump on)	-1.208	+0.1501	-0.0214	-0.0142	+0.0154	-0.0184			+0.0330	-0.1961
j	-1.180	+3.543	+0.0127	+4.075	-5.500	+5.457	—	—	-8.552	+11.05
k	-1.238	-3.235	-0.0571	-4.095	+5.505	-5.501	—	—	+8.522	-11.42
d	-3.586	+2.570	-2.887	+2.901	-7.761	-0.0391	+0.57 (±0.02)	+0.01 (±0.03)	-5.373	-0.5754
g	+1.207	+2.530	+2.890	+2.853	-0.0150	+7.741	-0.07 (±0.03)	+0.53 (±0.02)	-1.081	+5.078
h	+1.166	-2.263	+2.841	-2.923	+7.762	-0.0056	-0.50 (±0.02)	-0.08 (±0.03)	+5.322	+0.7405
i	-3.628	-2.224	-2.937	-2.876	+0.0139	-7.787	-0.08 (±0.03)	-0.53 (±0.02)	+0.9113	-5.157

- For each of the azimuthal cases **d**, **g**, **h**, and **i**, adjust the corrector MATM904 so that the beam positions V2(x) and V2(y) have half the values of those above and complete a similar table with the corresponding RC and V_{dump} positions, and the resulting Halo asymmetries A^H .

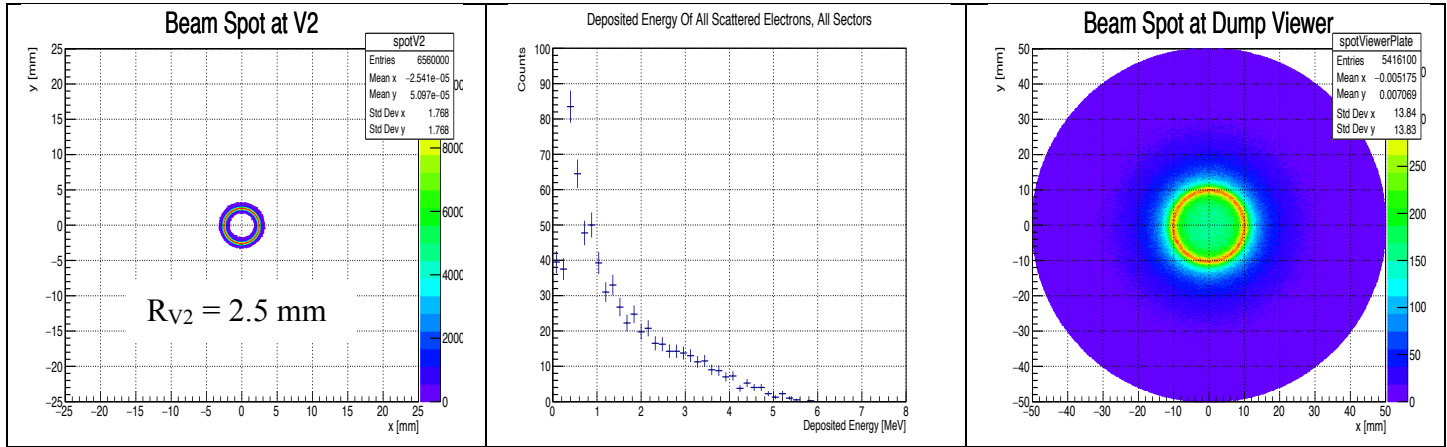
V. Calibrate the amplitude gain of the raster: (1/2 shift : 1/4 day) x 2 = 1/2 day

The UITF raster is designed to frequency modulate the currents to the raster dipole fields (at ~20 KHz) to create a circular beam pattern. This circle is filled in by modulating the amplitude of the currents (at ~1 KHz). The maximum amplitude of this oscillation determines the outer dimensions of the beam spot on target.

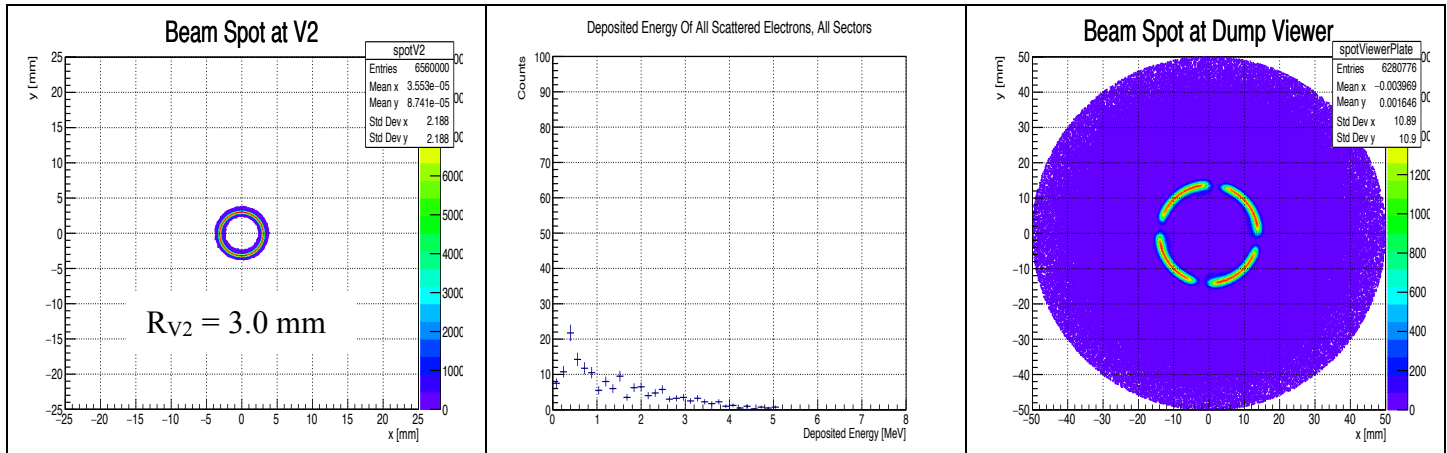
- Calibrate the amplitude gain of the raster control circuit by turning off its modulation and operating the raster at a fixed amplitude.
 - (1) The center of the raster is 5.7 m from the target position. However, the Horizontal (H) and Vertical (V) raster coils are separated along the beamline (in z). Each is driven by a separate audio amplifier. Setting their amplitude gains to the same value would create an elliptical pattern on target. The YAG viewer V2 is inserted from the top at a 45° to the beam, and is viewed from the side. As such, its CCD readout gives directly the vertical beam dimension. Adjust the raster amplitude so that the ring pattern

of the beam at V2 has a vertical spread of 2.50 mm. Now adjust the gain of the H raster dipole until the apparent horizontal spread at V2 is $\sim 2.50/\sqrt{2} = 1.77$ mm. Use the 1cm x 1cm etched grid on the YAG screens to accurately match the H and V sizes. This ratio of H/V raster gains will create a circular pattern on target.

- (2) Adjust the raster amplitude so that the ring pattern of the beam strikes the copper foil of the target, outside the central hole but inside the open arcs. A raster amplitude that produces a 2.50 mm radius circle at V2 is predicted to create a 6.25 mm radius ring on target, and a ring peaked at 10.0 mm radius at the dump viewer (as below). The expected average rate in each of the Halo counters is 720 KHz/nA.



- (3) Next adjust the raster amplitude so that the ring pattern of the beam is centered on the open arcs of the aperture target. From the G4BL simulation, the radius of the ring at V2 should be 3.00 mm, as seen below.



The rate in the Halo counters is expected to drop by about a factor of four (reflecting the fact that the copper tabs which support the central disk account for about a quarter of the circumference of the arcs). The center panels in the above figures show predicted energy deposition spectra (in KHz/nA/MeV) for a set of three Halo detectors at any of the four azimuthal positions surrounding the target. Small adjustments of the raster amplitudes (keeping the H/V ratio fixed to what was determined in the first step) can be used to find the copper edges of the arcs, based on the Halo count rates. The centroid of the minimum in rate will correspond to a radius on target of 7.75 mm.

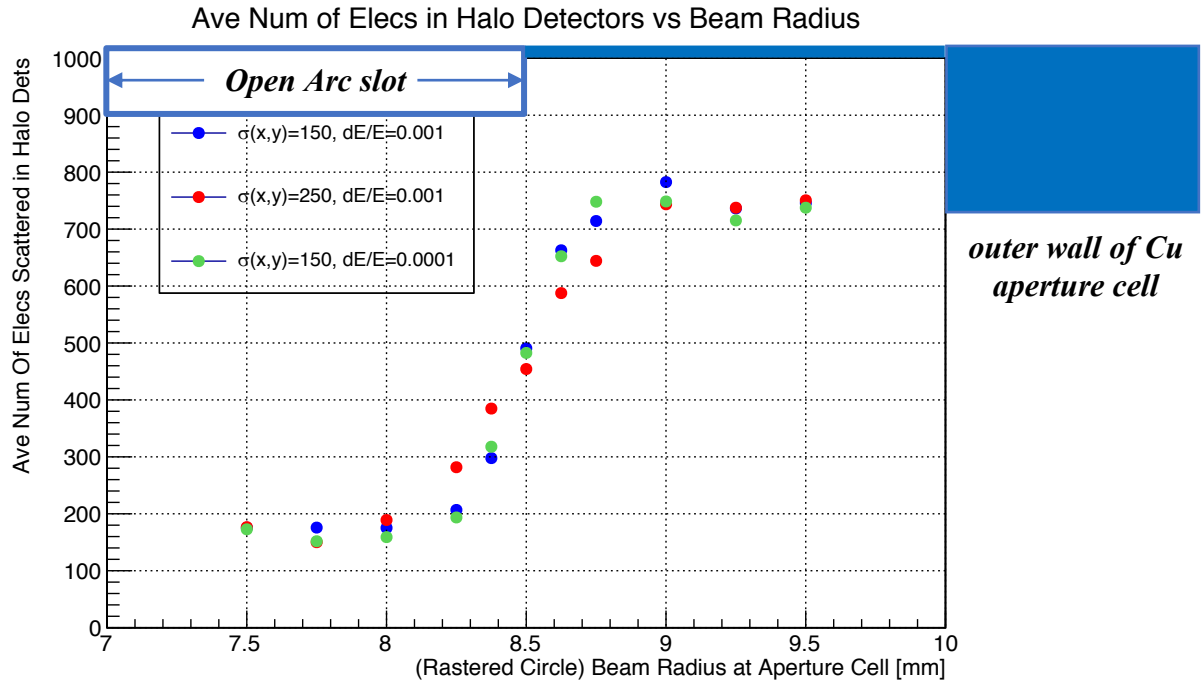
⇔ This calibrates the amplitude gain of the raster, and allows any desired radius on target to be dialed in.

VI. Measure the beam dispersion-limited outer definition of the raster: $(1/2 \text{ shift} : 1/4 \text{ day}) \times 2 = 1/2 \text{ day}$

The beam dispersion will determine the tails and will limit how rapidly a rastered beam falls at its outer edge.

This will in turn fix the maximum radius of the raster pattern that can be used to fill a target while still avoiding the cell walls. This can be determined with the aperture target by tracking the Halo counter rates as a function of raster radius (using the raster amplitude calibration determined above).

- Use a circular raster pattern, without amplitude modulation, with radius chosen from the previous study to center the circle radially in the open arcs of the aperture target. From this starting point, increase the radius in steps, recording the rates in the Halo counters, as well as the radius at V2. The outer radius of the open arcs is 8.5 mm, so that should be the point where the Halo rate reaches half of its maximum. The change in radius for a 90% change in Halo rate determines the required clearance between the full raster radius and the 9.5 mm radius of the inner target cell wall. For example, predictions for intrinsic beam widths of $\sigma = 150 \mu\text{m}$ with $dP/P = 10^{-3}$ and 10^{-4} , as well as $\sigma = 250 \mu\text{m}$ (for $dP/P = 10^{-3}$) are shown below. If data followed the profile given by the blue points, a 90% change in baseline-subtracted rate would occur over 0.5 mm. The maximum raster radius should then be taken as 9.0 mm.
- This rate profile mainly reflects the intrinsic beam width. If the profile compared to these simulations suggests an intrinsic beam size larger than $\sigma = 250 \mu\text{m}$, request a tuning adjustment from the accelerator group.



VII. Verify the uniformity of the raster pattern:

- REMOVE THE APERTURE TARGET FROM THE IBC. *1½ days*
 - Interrupt Run 1
 - remove roof tiles
 - set TC stabilizing chains
 - cold-transfer out aperture target
 - replace roof tiles
 - reestablish 9.5 MeV beam on *IBC beam axis* – ie. on reference positions at V1, RC and V2

- Measure the profiles of a fully rastered beam.

(1/2 shift : 1/4 day) x 2 = 1/2 day

At 9.5 MeV, any scattering source distorts the downstream image of the beam. Raster the beam, now with amplitude modulation. The expected profiles at V2, at the nominal Z location of the upstream face of a target, and at V_{dump} are shown in the plots below, first for a maximum raster radius of 6.25, and then for 9.25 mm. (These simulations assume an intrinsic beam width of $\sigma = 150 \mu\text{m}$.)

- Compare measurements of the widths at V2 and V_{dump} with these simulations.
- The YAG viewers at V_{dump} are at 45° to the beamline, and are inserted horizontally and viewed from above; as such, their CCD readouts give a direct measure of the horizontal profile. Verify that the vertical width is $\sim 1/\sqrt{2}$ of the horizontal width, as expected for a circular beam profile. Use the 1cm x 1cm etched pattern on the YAG screens to accurately calibrate the V width.

