BEAM BASED DIAGNOSTIC TESTS THAT INDICATE A POSSIBLE CHOPPING APERTURE MISALIGNMENT

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During the Summer, 2001 physics program evidence of a possible misalignment of the Hall C chopping aperture was observed. This was again affirmed at the beginning of the Fall, 2001 physics program when the effect was enhanced because of different beam intensity conditions. A temporary solution was to reverse through which apertures the Hall A & C electron bunches pass the chopper. This is possible because the Hall A experiment does not presently use their chopping aperture. Removing the chopping chamber for inspection is not an easy task so it is preferable to identify the problem in a noninvasive manner. To diagnose the problem, a beam based measurement of the master slit and chopping apertures alignment is outlined.

1 Beam Chopping System

The RF portion of the injector beam chopping system employs two rectangular RF cavities positioned around a chopping aperture chamber. Each of the two cavities operates in a TE mode at 499 MHz. The incoming beam bunches are deflected by the first cavity radially outward, transported through the chopping chamber where various apertures are located, and then finally recombined by the second cavity to a common axis again, as shown in Figure 1.

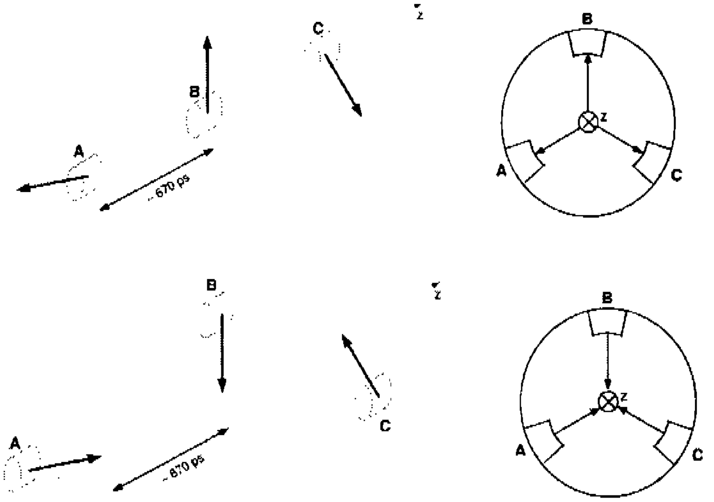

Figure 1. The upper cartoon shows the net effect of the first RF cavity on the electron bunches. The circle depicts their location at the center of the chopping chamber. The lower cartoon shows the reverse effect; the bunches, after passing apertures, are deflected back to a single axis again [1].

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The central chopping chamber, which supports the chopping apertures, limit the phase acceptance and ultimately defines the beam intensity for each hall. An image of the chopping chamber looking downstream is shown in Figure 2.

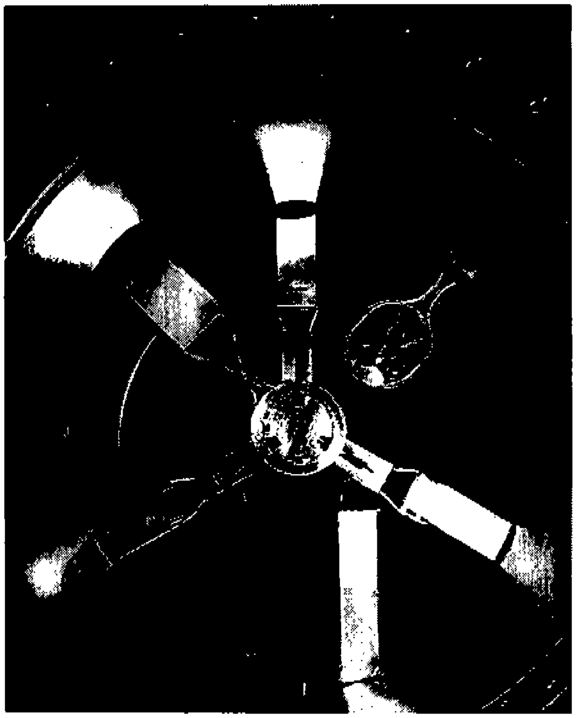

Figure 2. Looking downstream, the inside of the chopping chamber is shown. From foreground, the *master slit* (held at 10 o'clock) defines the maximum possible transmission. The Hall A, B and C master slit apertures are located at 8, 12, and 4 o'clock, respectively. Each defines a phase acceptance of 60° at 1497 MHz. The two smaller apertures are used for testing and do not pass beam during normal operation. The master slit has a small aperture (not easily seen) at the disk center for beam centering measurements. The Hall A, B, and C *chopping apertures* are next, held at the same respective orientations. Each chopping aperture can be fully inserted (entirely masking the master slit aperture), be fully retracted (entirely revealing the master slit aperture), or be partially inserted (to limit the beam intensity passed). At one location, each chopping aperture has a well defined slit equal to 10 at 1497 MHz, used for specific tests. Finally, the central plug is shown (held at 2 o'clock, which is always inserted as a safety precaution if the chopper RF were to inadvertently turn off.

2 First Indication of Chopping Problem and Beam Based Measurement

During late Summer, 2001 the Hall C GeN experiment inquired about unexpected variation in the electron beam polarization. Subsequent investigation revealed the possibility that improper beam chopping may have resulted in inadvertently sampling, at different times, the beam polarization at either the head or tail of the Hall C electron bunch.

During this period a single 1497 MHz diode laser system was used to produce the polarized electron beam. The chopping problem was investigated on September 6.

With the master slit inserted we scanned the laser phase to move the electron beam bunches across the chopping apertures for 2 cases; each aperture fully retracted (-1 mm) and then partially inserted (15.8 mm). In each we determined the optimum laser phase to transmit maximum current through the one particular chopping aperture with the other two inserted (8 mm) using a downstream Faraday cup. A typical scan for the retracted and partially inserted chopping apertures is shown in Figure 3.

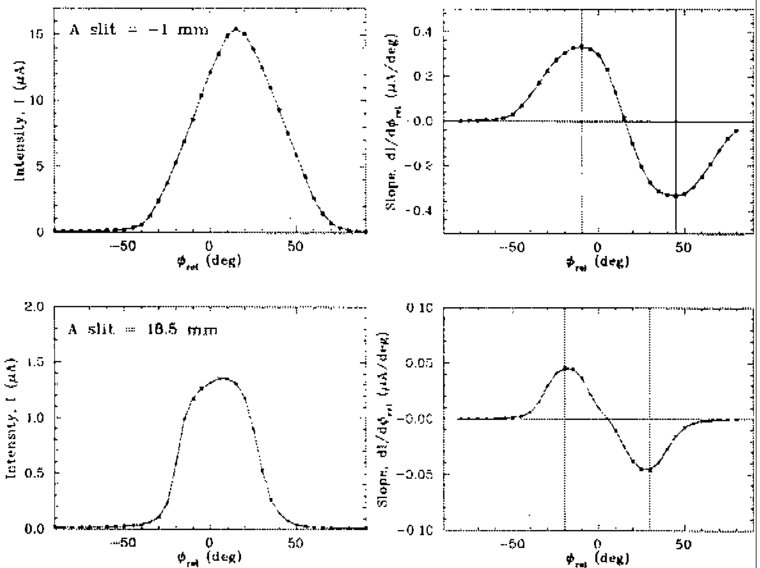

Figure 3. The leftmost plots show the beam intensity versus laser phase for the case where the chopping aperture is retracted (-1 mm) and the case where the chopping aperture is partially inserted (18.5 mm). The rightmost plots show the numerical derivative of the respective intensity scans; the vertical bars indicate the position of the aperture edges in terms of phase. This plot only shows the Hall A results. Note that this length of the electron bunch (~60) is not particularly suited for such measurements.

A summary of the cases for each chopping aperture is shown in Table 1.

Aperture & Location	-1 mm		18.5 mm	
	ϕ_0	Δ	ϕ_0	Δ
A slit	17.5°	55°	5.0°	50°
B slit	0.0°	50°	0.0°	50°
C slit	22.5°	55°	40.0°	50°

Table 1. The central location of each aperture (ϕ_0) and the width of the aperture (Δ) are reported for two cases; with the slit retracted (-1 mm) and with the slit partially inserted (18.5 mm). In each case the other two slits were fully closed (8 mm). Note that all phases are at 1497 MHz.

Unfortunately, a conclusion was not particularly clear, partially due the technique of using the electron bunch as the probe with a relatively comparable pulse length (~60°). Statistically, the master slit central location is 13 ° ± 12°. With the chopping apertures inserted the central phase is 15° ± 22°; the disparity being the Hall C chopping aperture. At that point it was clear a problem existed and it was noted that we may have been delivering the head or tail of the bunch since restoring the machine in June, 2000, since the laser phase is adjusted for transmission purposes.

Two explanations were considered:

- the Hall C chopper slit is improperly aligned, moving along a radial line that is "out of phase" with the Hall A & C slits.
- the chopper is improperly setup; either cavity #1 is set poorly creating an ellipse instead of a circle at the chopping chamber mid -plane or the beam is not centered in the chopper properly.

3 Second Indication of Problem and Improved Beam Measurement

During the restoration period following the September -October shutdown the chopping problem re-surfaced, but in a more pronounced way. During the summer operation the relatively low intensity beam (all halls <15 μA) precluded use of the injector prebunching cavity. After the shutdown, however, Hall A was ope rating at >110 μA (prebunching required) and the consequence was that any "corrective" laser phasing which had been useful earlier was no longer compatible with operation of the prebuncher. Essentially, use of the prebuncher requires proper laser phasing.

To verify the problem a second beam based test was made on October 24. At this time the 3-laser system (499 MHz) was being used and an alternative beam based measurement approach, using the prebuncher cavity, was found. To do this, the 780 nm wavelength laser (high QE) was used without RF, thus producing a DC beam of a few microamps. By turning on the prebuncher strongly (26 dBm) a beam pattern with intensity modulation at 1497 MHz was produced at the chopping apertures, depicted in Figure 5.

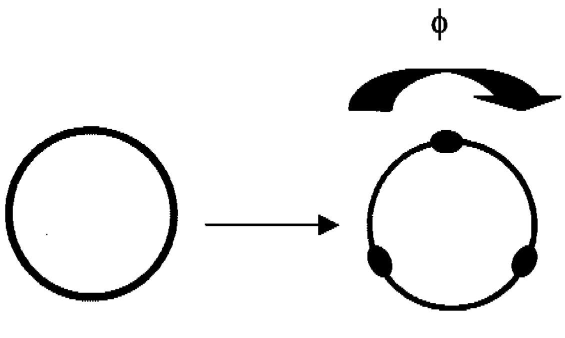

Figure 5. Operation of the laser in DC mode simply produces a uniform circle of beam at the chopping chamber mid-plane. By energizing the prebuncher cavity the resultant pattern has a 1497 MHz intensity modulation which can be rolled in phase using the prebucher phase setpoint.

Four cases were measured. First, all chopping apertures (except the master slit) were retracted (-1 mm) and the intensity profile versus prebuncher phase was measured. For the remaining three one chopping aperture at a time was partially inserted to a 10° calibration slit (60 mm). The resulting plots and aperture information are shown and summarized in Figure 6 and Table 2, respectively.

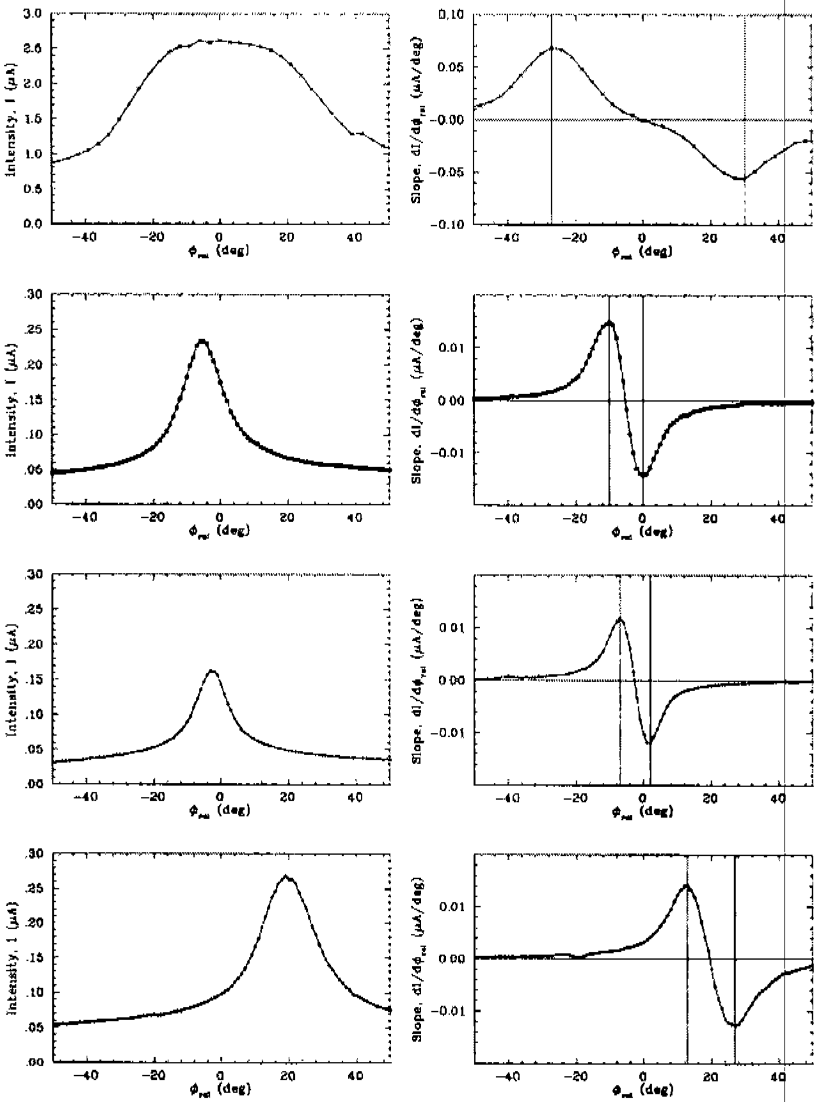

Figure 6. Intensity scans versus prebuncher phase, and their derivative plots, are shown respectively for four cases - a) A/B/C slits removed, b) A slit at 60 mm, c) B slit at 60 mm, and d) C slit at 60 mm. In the latter three cases the other two slits were fully closed.

The results indicate a misalignment of the Hall C chopping aperture with respect to the other apertures. A indication of confidence of this method is the agreement of the measured aperture width Δ of the master slit and of the Hall A & B chopping aperture calibration positions (60 mm), as shown in Table 2.

Aperture	ϕ_0	Δ	Δ (expected)
A/B/C (-1 mm)	1.5°	57°	60°
A (60 mm)	-5.0°	10°	10°
B (60 mm)	-2.5°	9°	10°
C (60 mm)	20.0°	14°	10°

Table 2. The central location of an aperture ϕ_0) and the width of the aperture (Δ) are reported for four cases; with all slits retracted (-1 mm) and then only with each slit individually inserted to the 10 reference (60 mm). Note that the phase is at 1497 MHz.

Since the Hall A physics program does not presently require use of their chopping aperture a temporary solution was to interchange through which chopping apertures the Hall A & C bunches pass. In this way, the previous Hall A chopping aperture is now used to maintain the Hall C beam intensity. There are two ways to do this; interchange the laser phase or reverse the sense of choppe r cavity rotation. The latter was chosen. The software controls for the two slits were also swapped to leave the interchange transparent. Still, most of the injector warm -rf phases also required changes afterwards as well. This is how we have operated from late October through Thanksgiving.

4 Beam Based Proposal to Diagnose Chopper Non -invasively

Although evidence exists to support that the Hall C chopping aperture is misaligned, it does not appear likely [2]. So, doubt persists over whether an improper chopper setup is to blame. Two tests are outlined below which should help map the chopping aperture alignment.

4.1 Master Slit Alignment

The master slit is used to setup the RF chopping and de -chopping. To verify that the master slit is well aligned with the chopping apertures attempt to test whether the axis of the master slit coincides with where each chopping aperture extends radially.

1) Retract the central plug.
2) Perform a Home/Reset of the chopping apertures.
3) Retract the three chopping apertures.
4) Turn off the chopper RF.
5) Deliver beam through the master slit central hole to a downstream Faraday cup.
6) Remove the master slit.
7) Insert each chopping aperture incrementally until beam is intercepted.
8) Record the position of the chopping aperture.

4.2 *Chopping Aperture Alignment versus Inserted Position*

A more comprehensive phase scan of the chopping apertures, particularly versus insertion set point (radial information), may provide a 2 -dimensional picture of the chopping aperture geometry.

1) Verify the chopper is in its normal state for physics operation.
2) Perform a Home/Reset of the chopping apertures.
3) Verify the central plug and master slit are inserted.
4) Retract the three chopping apertures.
5) Turn the laser RF off and use a 780 nm diode laser to generate a few microamps at a Faraday cup downstream of the chopper.
6) Turn on the prebuncher and verify increased transmission (or use a viewer).
7) Perform a prebuncher phase scan of the master slit.
8) In turn (do for each chopping aperture), insert two of chopping apertures, and perform prebuncher phase scans for the third chopping aperture at a variety of inserted positions.
9) Suggested are regions just at the very start of transmission (15 mm), at a couple intermediate location (30 & 50 mm), and then a series around the 10° slit (60 mm) to determine the set points which describe the radial length of the 10° slit.

5 Acknowledgements

The collaborators of the GeN experiment provided useful information which lead to an investigation and observation of the chopper misalignment symptoms.

References

1. Both plots extracted from M. Baylac's *PhD* thesis.
2. C. Sinclair, public communication.