BL2C Split Ratio vs. Harmonic Coils

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1 Simulation Conditions

- The COMA runs were started at 5.5 MeV, well beyond the central region, to avoid failure in the simulation of electric focusing. An initial emittance of 1.0 πmm-mrad (normalized) was well matched with machine in $r-$ and $z-$ both planes; the initial phase band was 41°.
- A foil was sitting at R=183.588 inches and $\theta = 278.05°$. This location corresponds to an extraction of 110 MeV down to 2C. Radially, the foil was 0.25 inch wide; vertically, it was assumed to be fully intercepting the circulating beam.

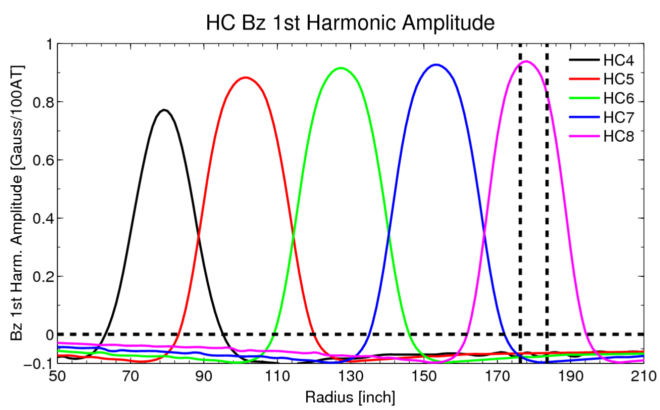

Figure 1: *The B_z 1st harmonic amplitude (per 100 Amp-Turns) vs. radius, produced from harmonic coils 4,5,6,7 and 8 respectively. Note that the 2 vertical dash lines mark the 2C extraction radii for the 100 MeV (Left) and 110 MeV (Right) beam.*

- The harmonic coils generate the B_z 1st harmonic component, represented as

$$B_z(r) = H_1(r)\cos\theta + G_1(r)\sin\theta = A_1(r)\cos(\theta - \phi_0), \tag{1}$$

where

$$H_1(r) = A_1(r)\cos\phi_0, \quad G_1(r) = A_1(r)\sin\phi_0. \tag{2}$$

Where the amplitude $A_1(r)$ vs. radius r was created with a legacy function HRCOIL and then as input was fed into CYCLOPS to generate transfer matrices, whereas ϕ_0 denotes the initial phase angle of the 1st harmonic component generated.

Fig. 1 shows the field amplitude as a function of radius for the harmonic coils 4,5,6,7 and 8.

2 Simulation Results

2.1 HC4 Excitation of 60 A-T

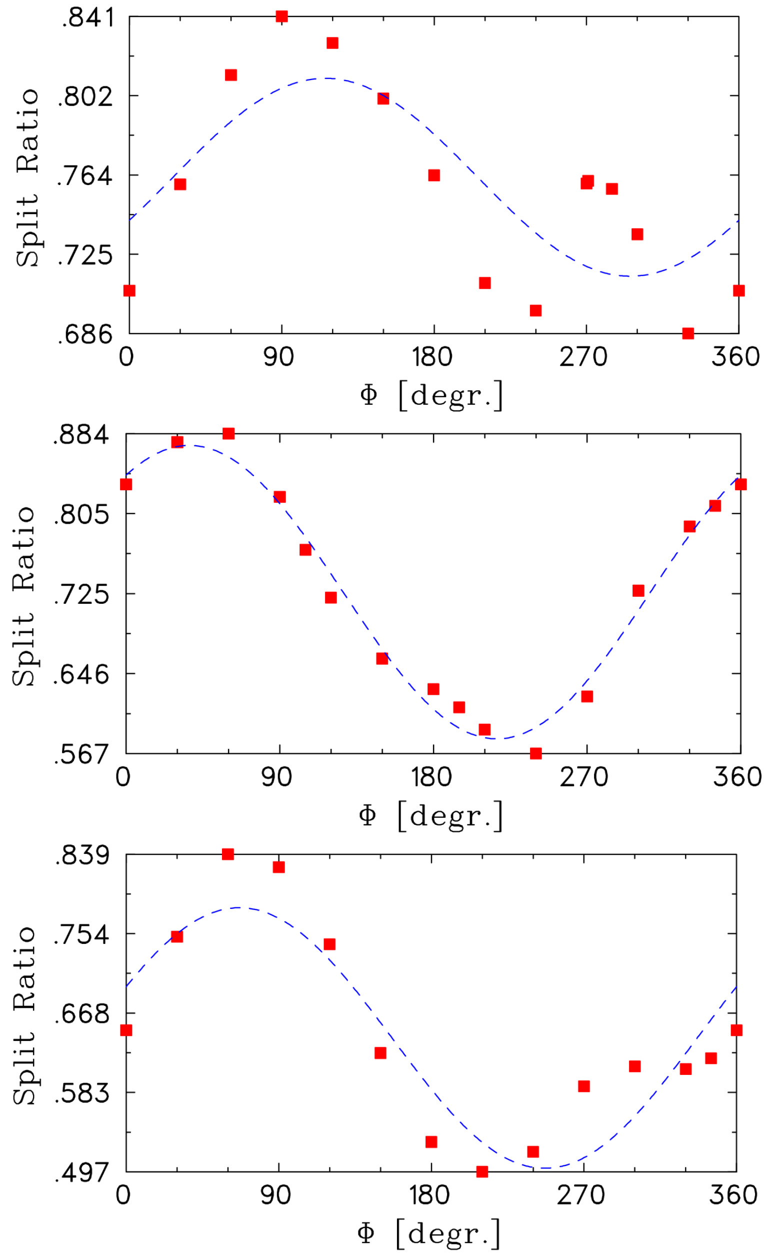

Figure 2: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC4 with an excitation of 60 A-T. Initially, the beam was well centered radially (Top), off-centered in r by 0.2 inch (Middle), and off-centered in both r and p_r by 0.2 inch (Bottom).* **The variation is NOT necessarily sinusoidal. It depends on the circulating beam centering condition.**

2.2 HC6 Excitation of 60 A-T

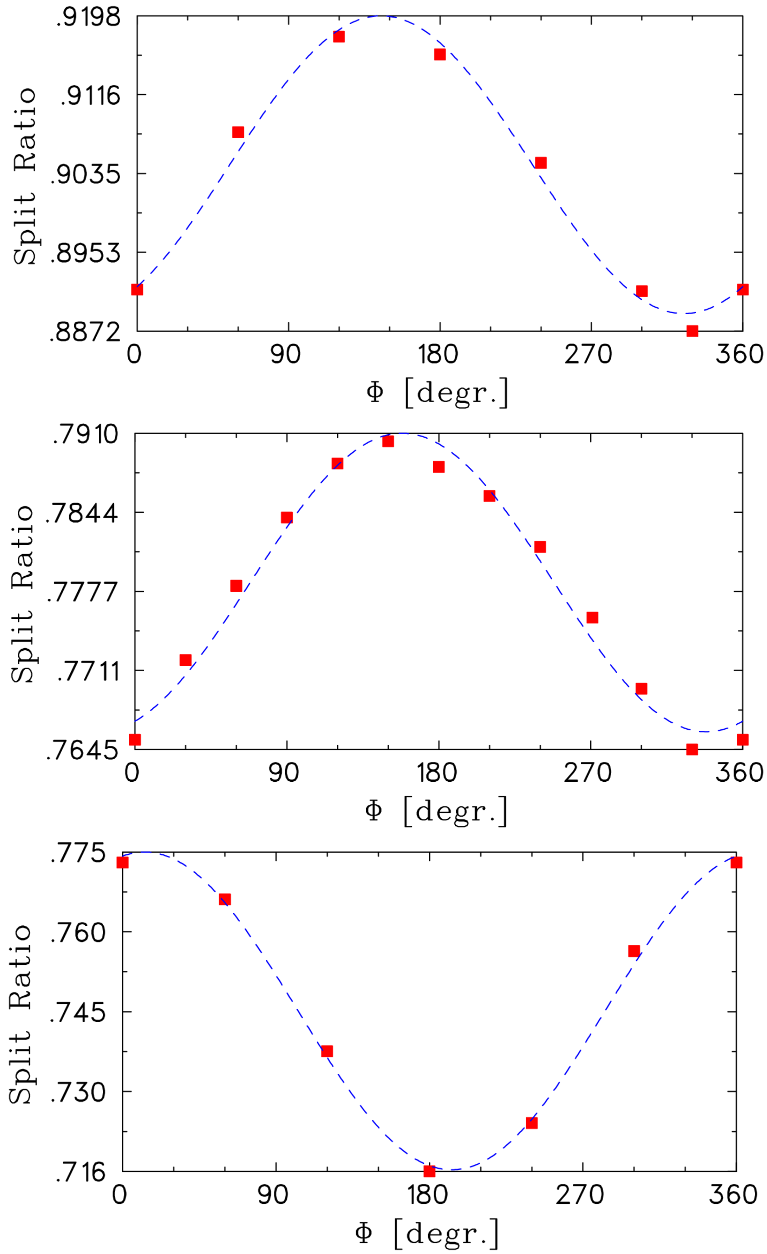

Figure 3: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC6 with an excitation of 60 A-T. Initially, the beam was well centered radially (Top), off-centered in r by 0.2 inch (Middle), and off-centered in both r and p_r by 0.2 inch (Bottom).* **In a limit of variation less than ±5%, the dependence can be very well approximated with a sinusoid.**

2.3 HC6 Excitations of 60, 160 and 260 A-T

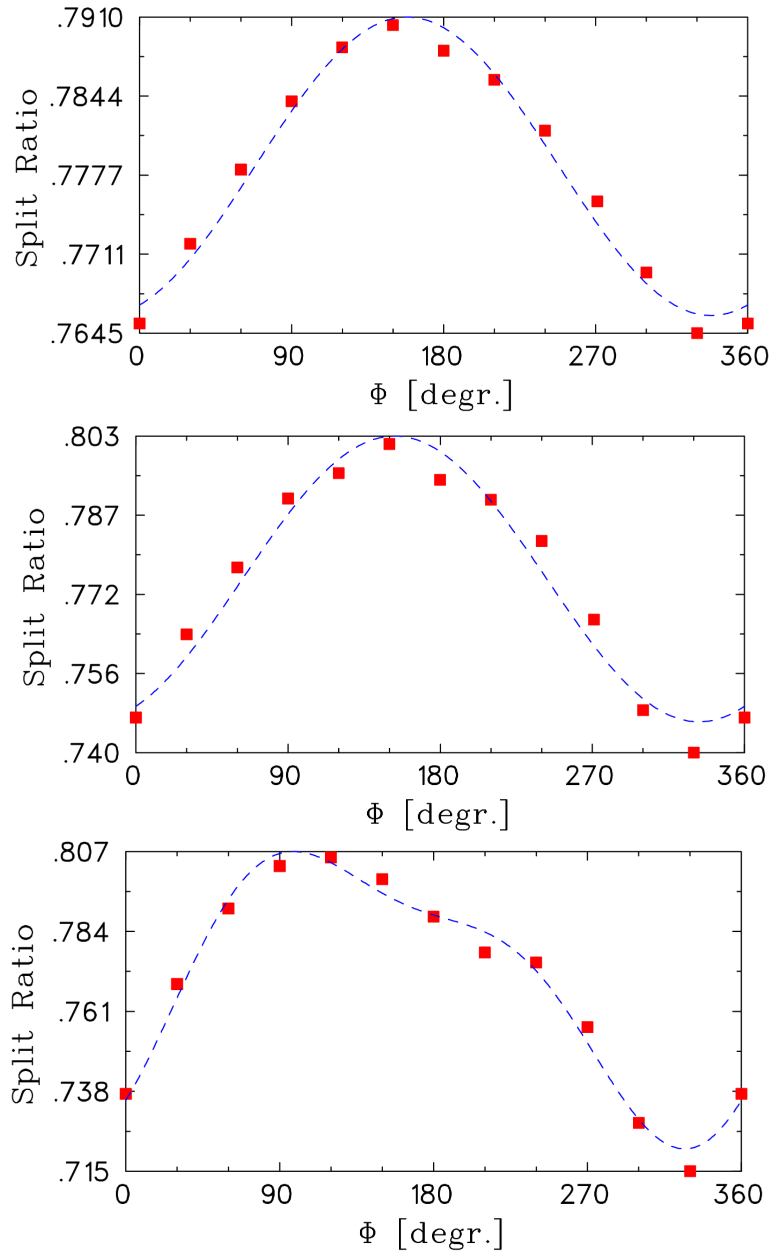

Figure 4: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC6 with Excitations of 60 A-T (Top), 160 A-T (Middle) and 260 A-T (Bottom). In all the 3 cases, the initial beam was off-centered in r by 0.2 inch.* **Clearly, with the increase of coil excitation strength, the split ratio vs. the phase angle is gradually deviating from sinusoid.**

2.4 HC6 Excitation of 260 A-T

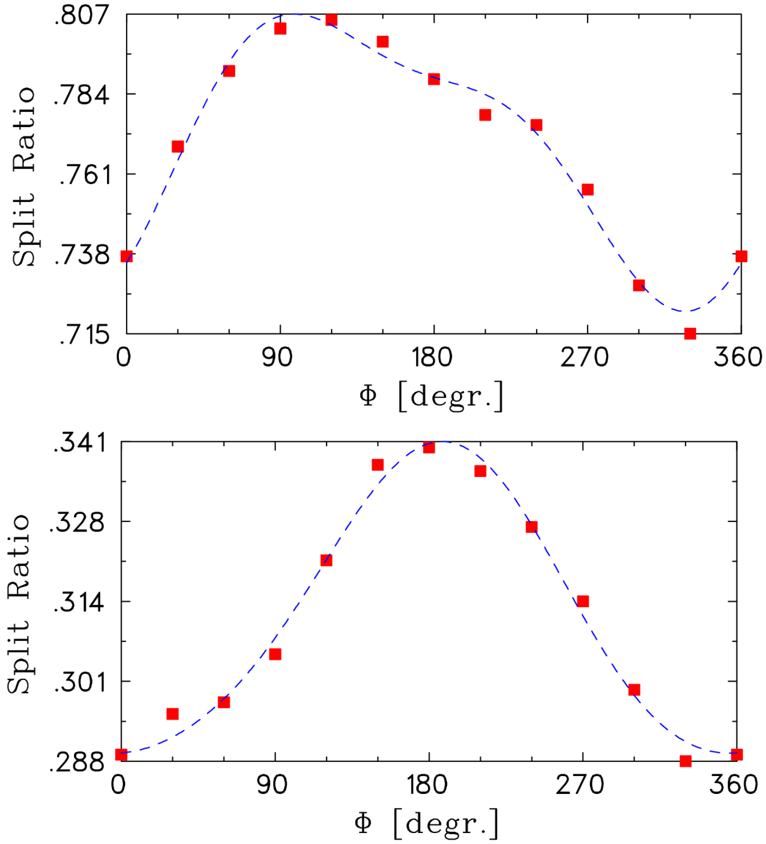

Figure 5: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC6 with excitation of 260 A-T when the 2C foil was fully (Upper) and partially (Lower) intercepting the beam vertically. In both cases, the initial beam was off-centered in r by 0.2 inch.* **A partial dip foil gives rise to a less amount of split, thus creating a more sinusoidal-like variation.**

2.5 HC6 Excitations of 60 and 420 A-T

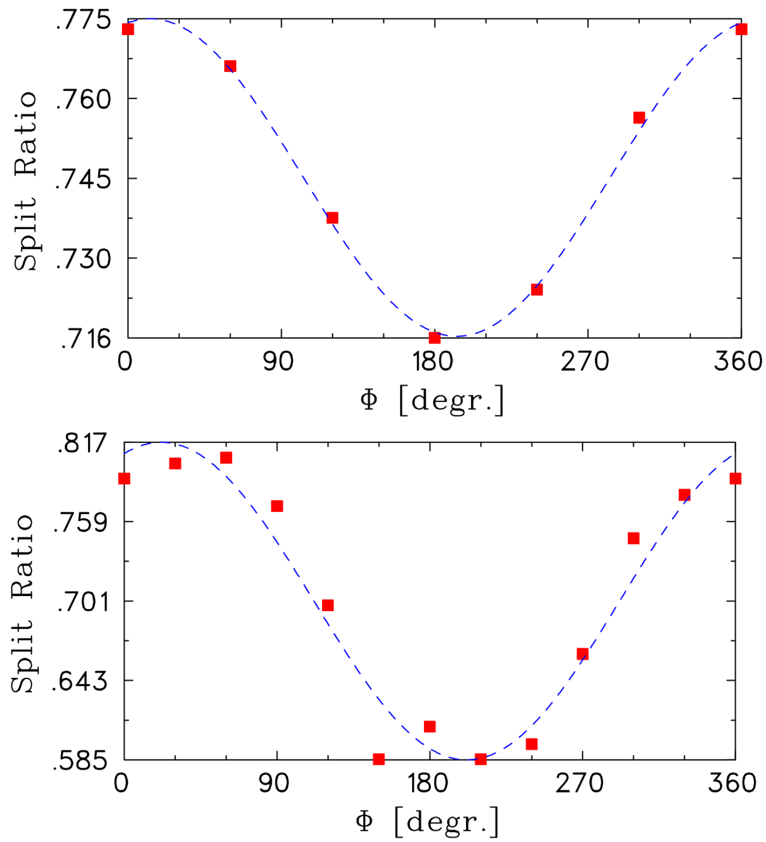

Figure 6: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC6 with excitations of 60 A-T (Upper) and 420 A-T (Lower). In both cases, the initial beam was off-centered in r and p_r by 0.2 inch.* **Again, it's seen that the split ratio vs. the phase angle is deviating from a sinusoid with the increase of coil excitation strength.**

2.6 HC7 Excitation of 60 A-T

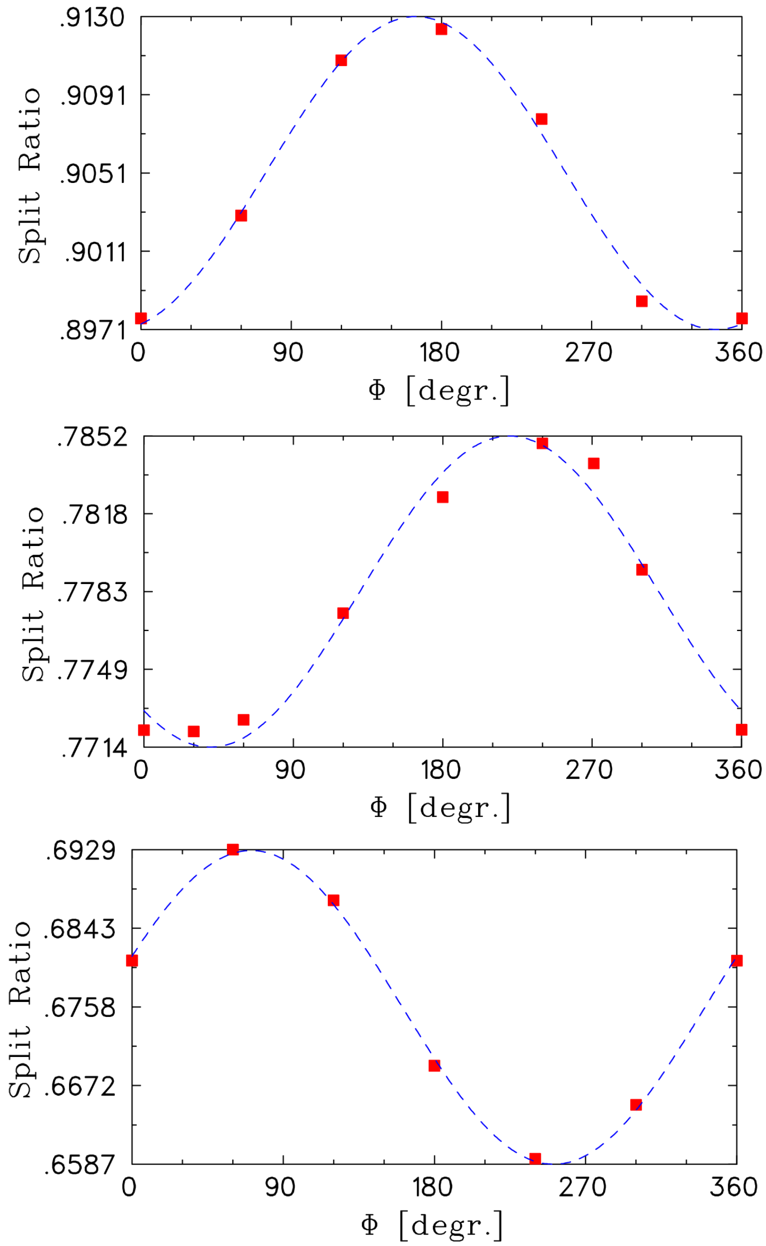

Figure 7: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC7 with an excitation of 60 A-T. Initially, the beam was well centered radially (Top), off-centered in r by 0.2 inch (Middle), and off-centered in both r and p_r by 0.2 inch (Bottom).* **As well, in the limit of variation less than ±5%, the dependence is approximately a sinusoid.**

2.7 HC7 Excitations of 60 and 420 A-T

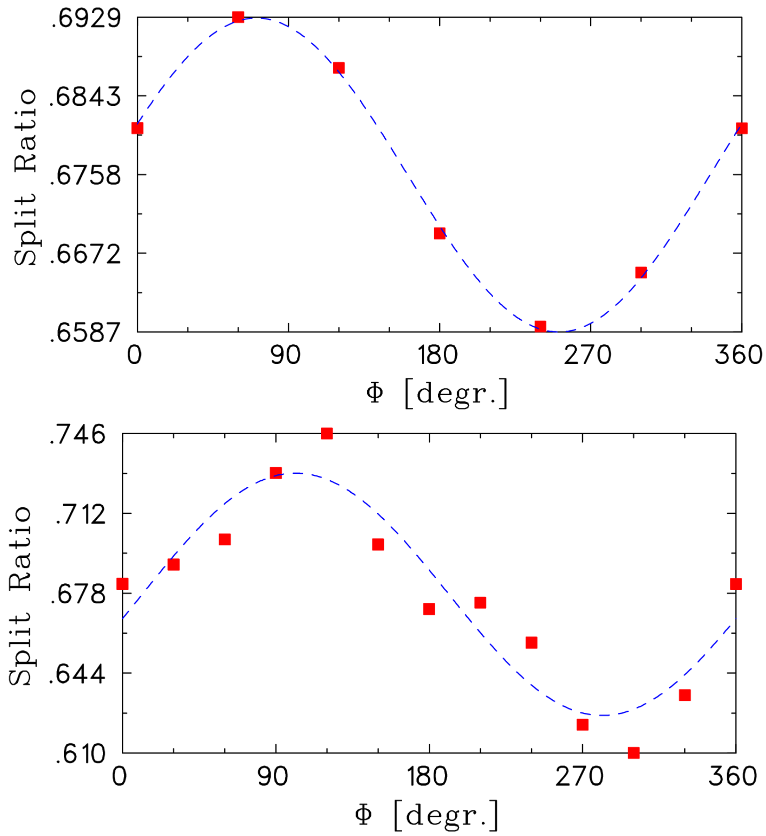

Figure 8: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC7 with excitations of 60 A-T (Upper) and 420 A-T (Lower). In both cases, the initial beam was off-centered in r and p_r by 0.2 inch.* **Likewise, the split ratio vs. the phase angle is deviating from a sinusoidal curve with the increase of coil excitation strength.**

2.8 HC8 Excitation of 420 A-T

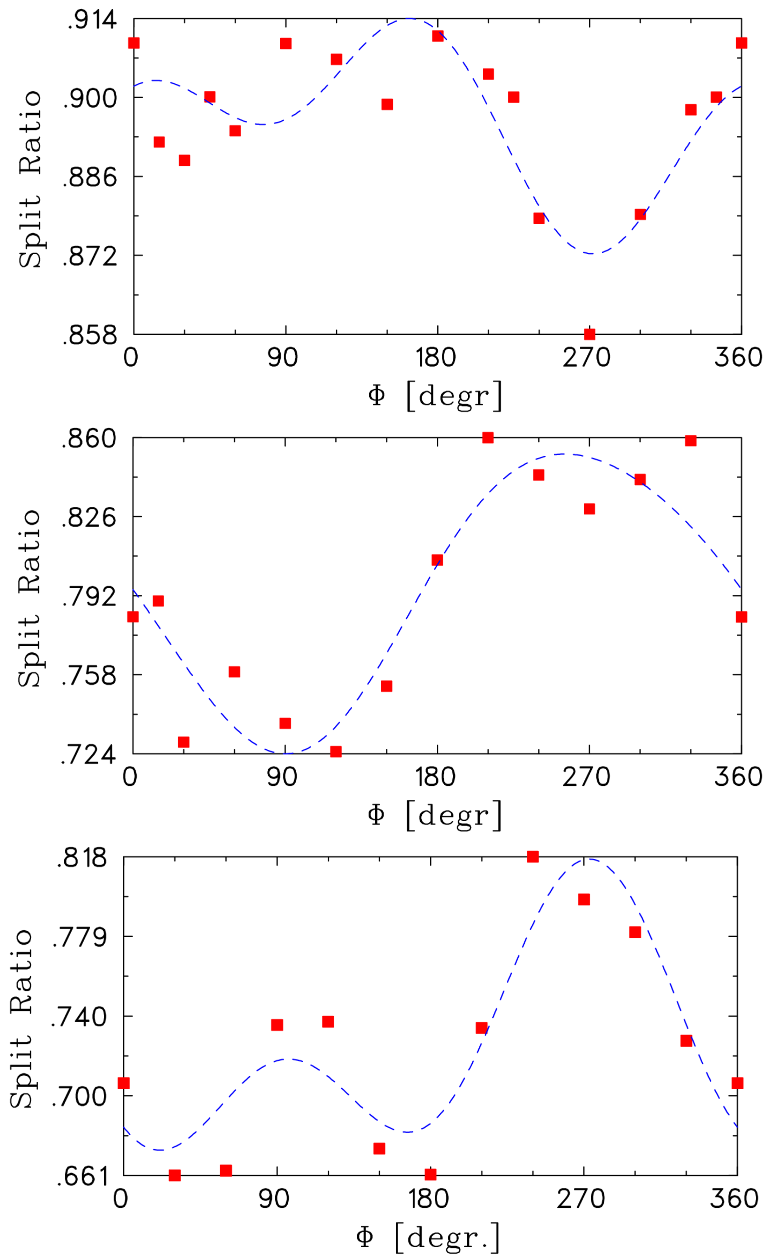

Figure 9: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC8 with an excitation of 420 A-T. Initially, the beam was well centered radially (Top), off-centered in r by 0.2 inch (Middle), and off-centered in both r and p_r by 0.2 inch (Bottom).* **The split ratio does not change sinusoidally at all, instead, it's random. This suggests that it's not a right choice to use HC8 to stabilize the 2C split.**

2.9 HC8 Excitations of 60 and 420 A-T

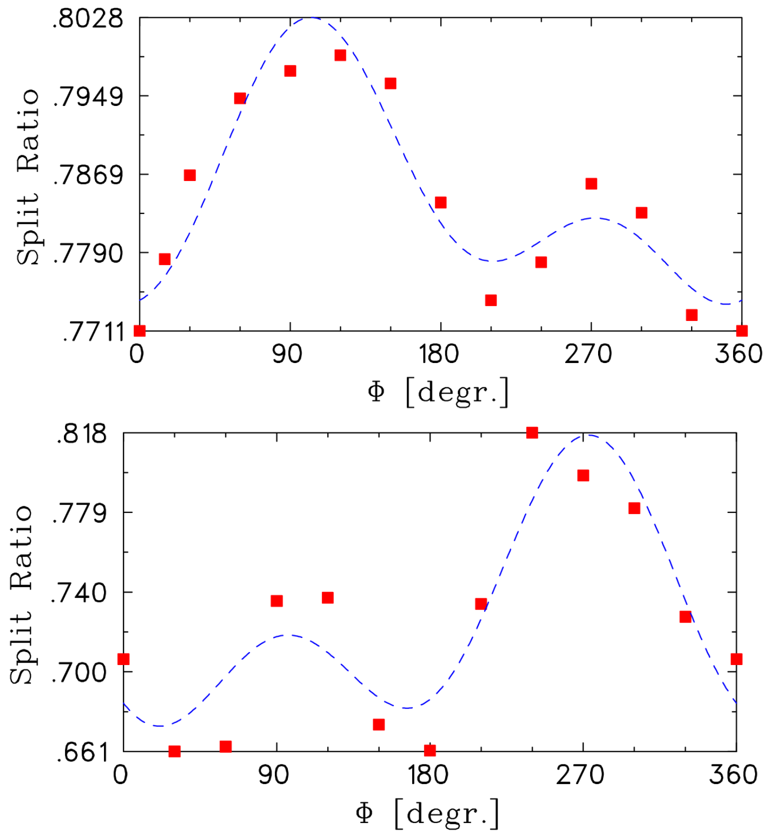

Figure 10: *BL2C split ratio vs. phase angle of the 1st harmonic generated from HC8 with excitations of 60 A-T (Upper) and 420 A-T (Lower). In both cases, the initial beam was off-centered in r and p_r by 0.2 inch.* **Even with a small excitation of 60 A-T resulting in a small variation in the split ($< \pm 2\%$), the variation significantly deviates from sinusoid. Again, this suggests that using HC8 is not a right choice.**

3 Conclusions

- The 2C split ratio vs. the phase angle of the 1st harmonic B_z as generated with the harmonic coils 4,6,7 respectively is NOT necessarily sinusoidal; it depends on the coil's excitation strength and the circulating beam radial centering condition. But, in a limit of split ratio variation less than $\pm 5\%$, sinusoid is a good approximation.
- In any case, it is not a right choice to use the HC8 to stabilize the 2C split, because the split ratio shows a random variation. This is because the HC8's field region covers the extraction radius of 2C from 100 MeV (at 176.29 inch) to 110 MeV (at 183.59 inch).
- To check out the above simulation results, we should consider to take actual measurements by using HC4, as HC4 is currently powered in the B_z 1st harmonic mode.