TRIUMF Beam Physics Note
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Correction of Coupling Resonance $\nu_r - \nu_z = 1$

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Abstract: In this note we summarize the results of measurements that we took with HE probes about the correction made to the coupling resonance $\nu_r - \nu_z = 1$ in TRIUMF cyclotron.

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1 Introduction

In TRIUMF cyclotron, small changes in the circulating beam orbit can induce large oscillations to the vertical centre-of-gravity and the size of beam due to passage through the coupling resonance $\nu_r - \nu_z = 1$. In particular, for the particles of extreme positive phases, they are less well centred radially and can possess a combined coherent and incoherent amplitude of >0.5". The resonance converts the large radial amplitudes into large vertical motions, causing spills in the cyclotron and even in the beam-lines.

The coupling resonance is driven by an asymmetry in the median plane of the cyclotron due to presence of the first harmonic in the magnetic field B_r component. It occurs at 166 MeV and then again at around 291 MeV, as is shown in the tune diagram Fig. 1.

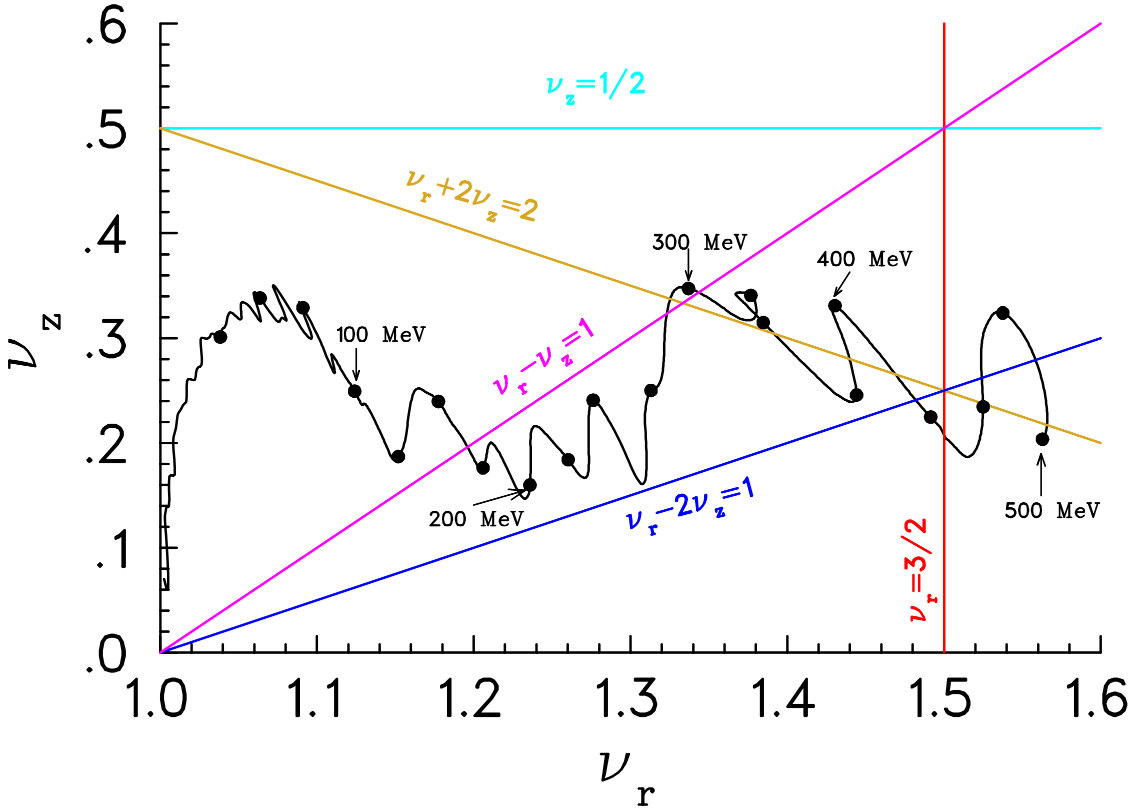


Figure 1: The TRIUMF cyclotron tune diagram, showing three passages through the coupling resonance $\nu_r - \nu_z = 1$.

If there were no radial-vertical coupling, then the vertical flag, serving as a jaw in the centre region to restrict the beam height from bottom, would be able to reduce vertical beam spill all the way to the extraction. But we observe that it has hardly any such effect. This motivated us to look into this resonance with a view to correcting it.

2 Measurements

We took meassurements on the Beam Dev. shift of 2019-Jun-17 with high energy probes HE1 and HE2 both. During the measurements, a coherent radial centring error (roughly $0.3''$) of the beam orbit was introduced intentionally by either detuning the centre region electrostatic deflector's high voltage, or by detuning the amplitude or phase of HC2 B_z first harmonic from the production settings.

For correction of the resonance, the optimized settings that we worked out for the 3 harmonic coils HC8, HC10 and HC12 in the B_r 1st harmonic mode were

HC8 $= 0^\circ$ **& 307 AT,**
HC10$= 336^\circ$ **& 387 AT,**
HC12$= 132^\circ$ **& 26 AT.**

The figures that follow show results of the measurements.

One can see that the HE1 and HE2 probes give exactly the same results, although they are 180° **apart in azimuth.**

2.1 Detune Deflector By +45 DAC

Fig. 2 and Fig. 3 show the HE1 and HE2 measured vertical centre-of-gravity and beam transmission vs. the radial position, when the centre region electrostatic deflector was intentionally detuned by +45 DAC from ±2665 DAC to ±2710 DAC.

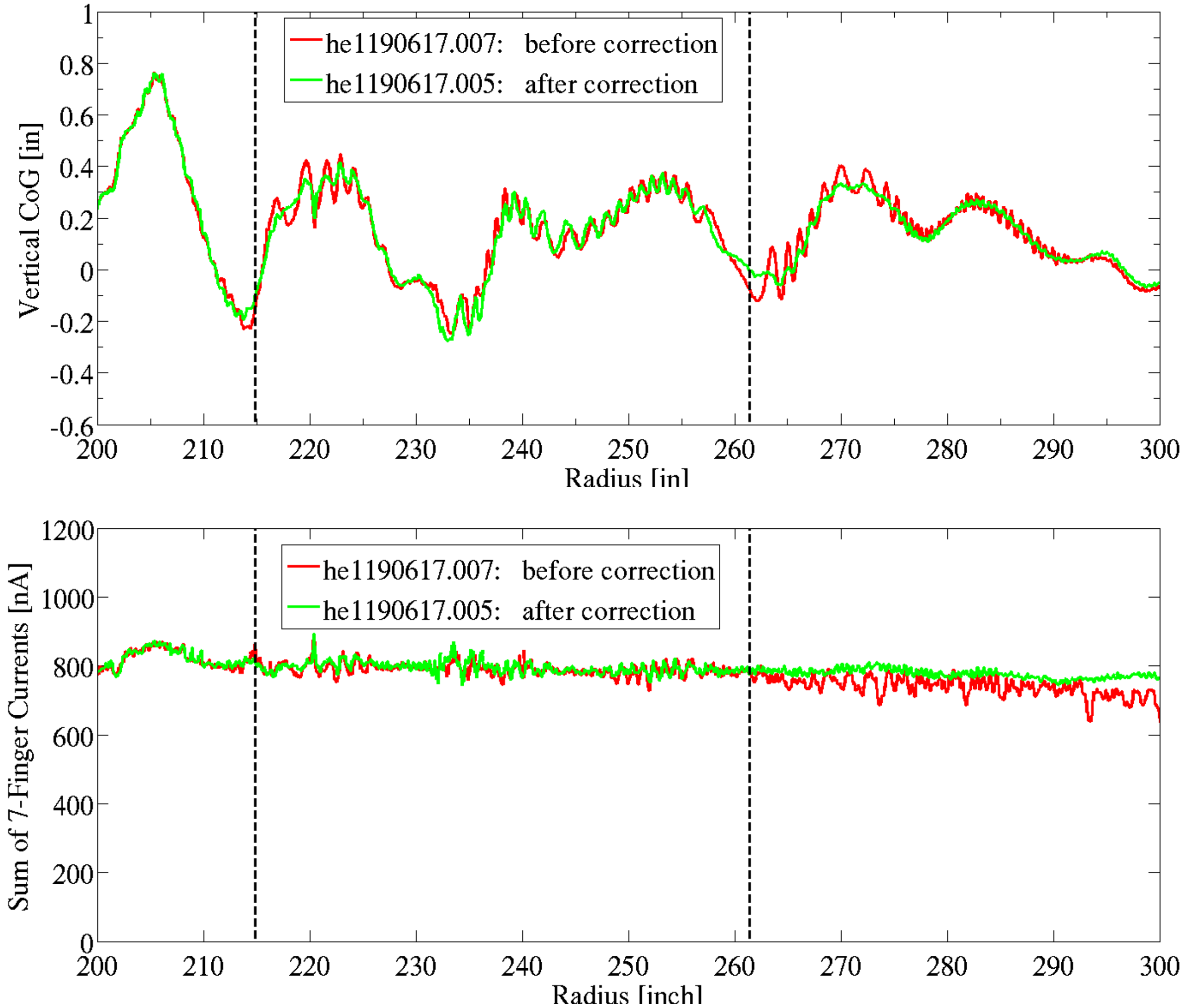
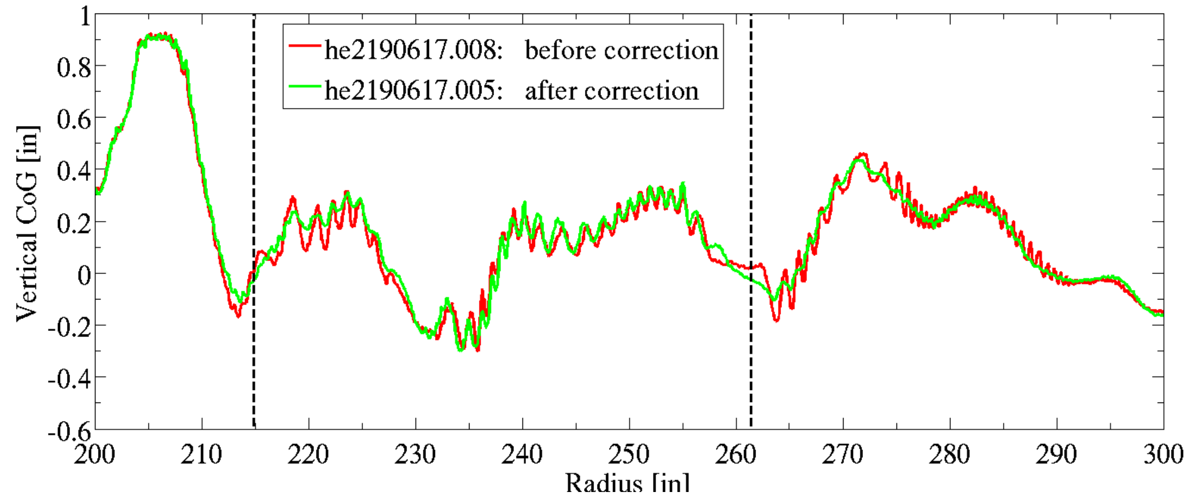


Figure 2: *(Upper) HE1 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction. The 2 vertical dash lines mark where the coupling resonance* $\nu_r - \nu_z = 1$ *occurrs.*

Notice that the oscillations reappear from $\sim 230''$ to $\sim 255''$, suggesting a passage through some other resonance occuring at $\sim 230''$. But this resonance is unknown for the moment. We shall need further investigation.



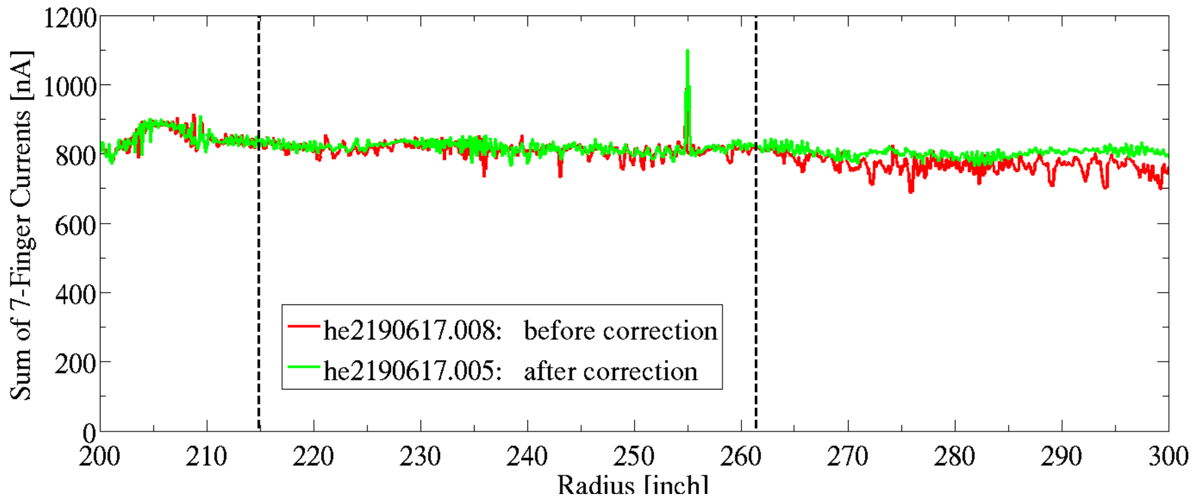


Figure 3: *(Upper) HE2 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

2.2 Detune Deflector By -125 DAC

Fig. 4 and Fig. 5 show the HE1 and HE2 measured vertical centre-of-gravity and beam transmission vs. the radial position, when the centre region electrostatic deflector was intentionally detuned by -125 DAC from ±2665 DAC to ±2540 DAC.

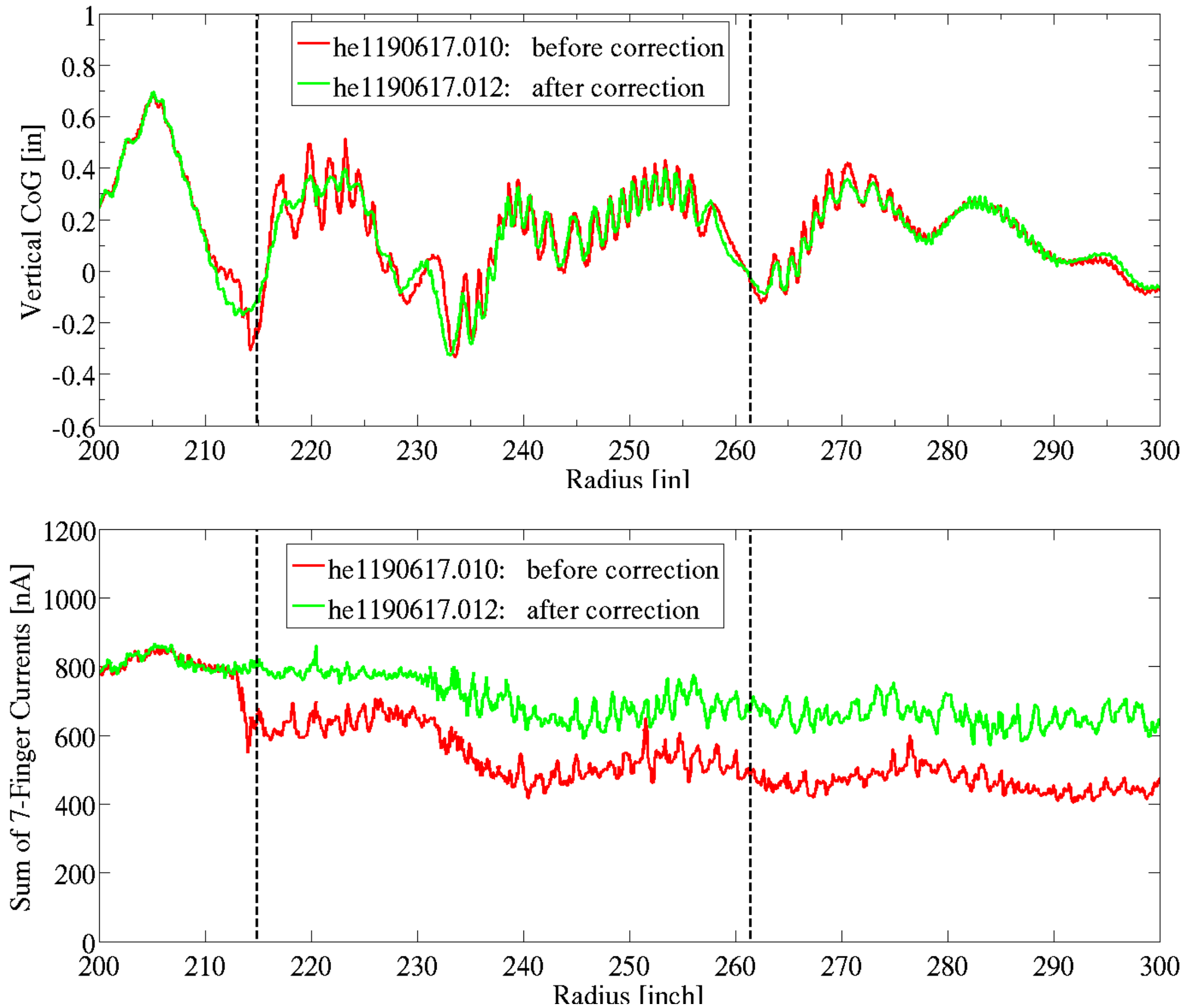


Figure 4: *(Upper) HE1 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

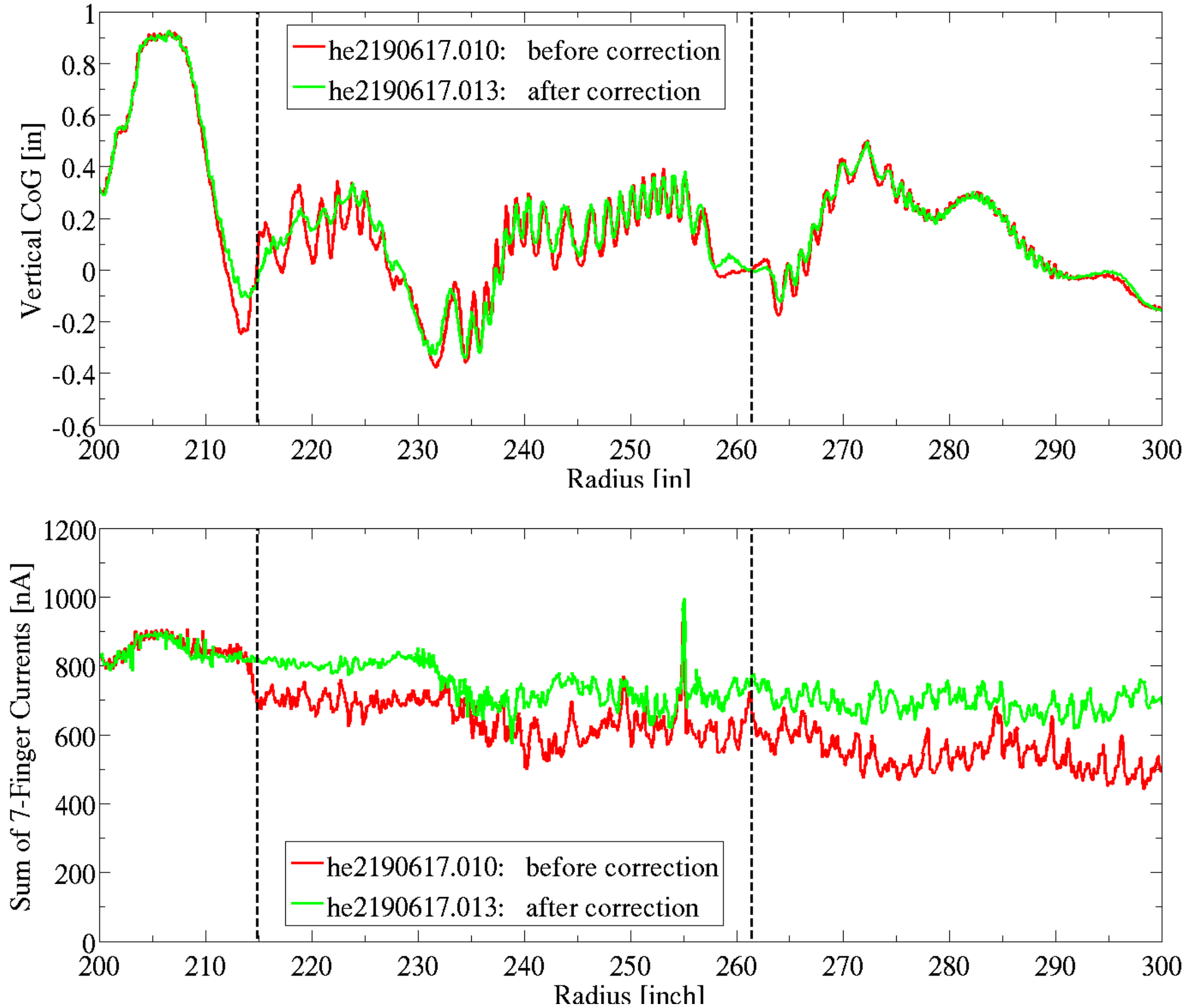


Figure 5: *(Upper) HE2 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

2.3 Detune HC2 B_z Amplitude By 200 AT

Fig. 6 and Fig. 7 show the HE1 and HE2 measured vertical centre-of-gravity and beam transmission vs. the radial position, when the HC2 B_z 1st harmonic amplitude was intentionally detuned by 200 AT from 398 AT to 200 AT, while its phase angle was kept unchanged.

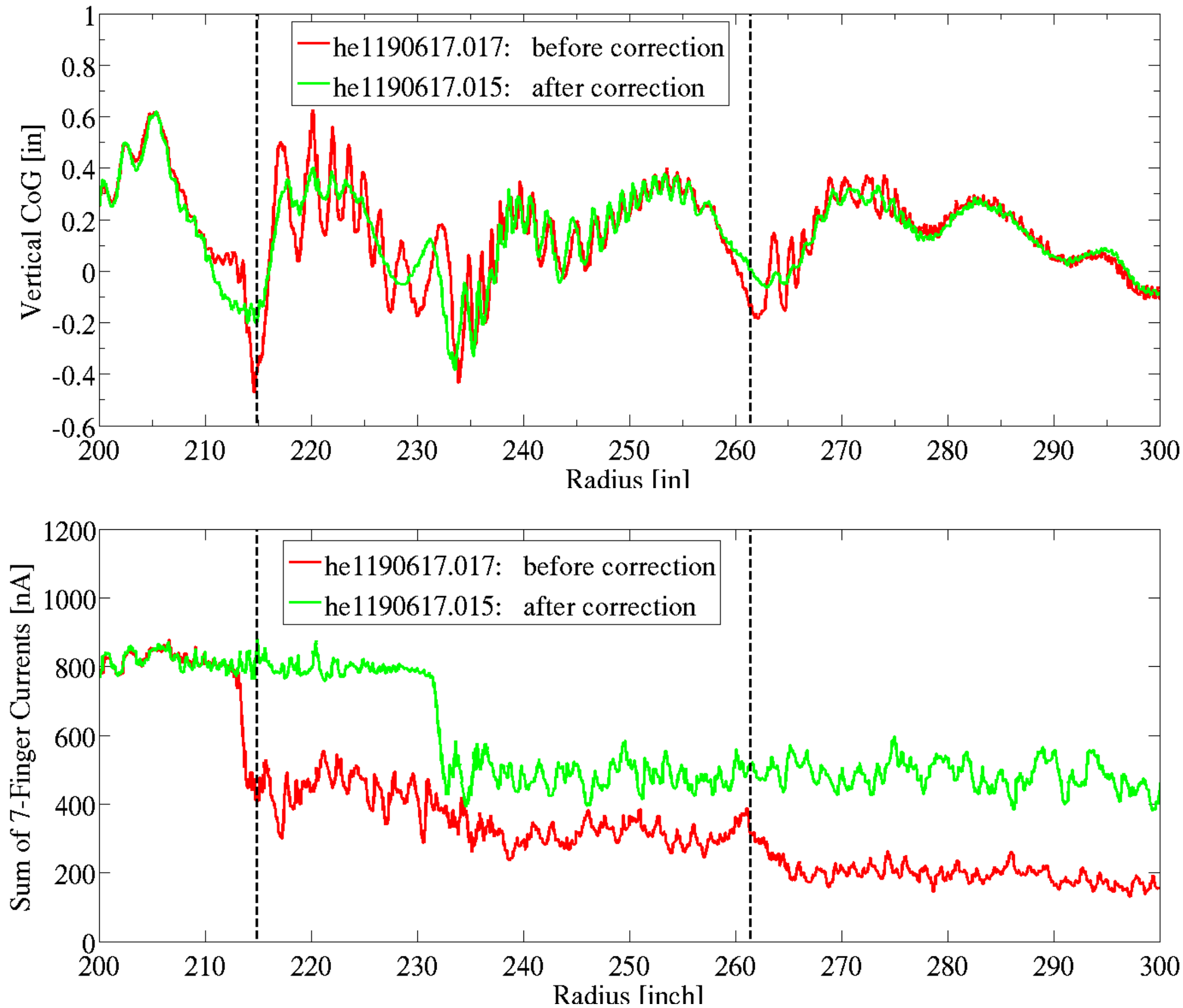


Figure 6: *(Upper) HE1 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

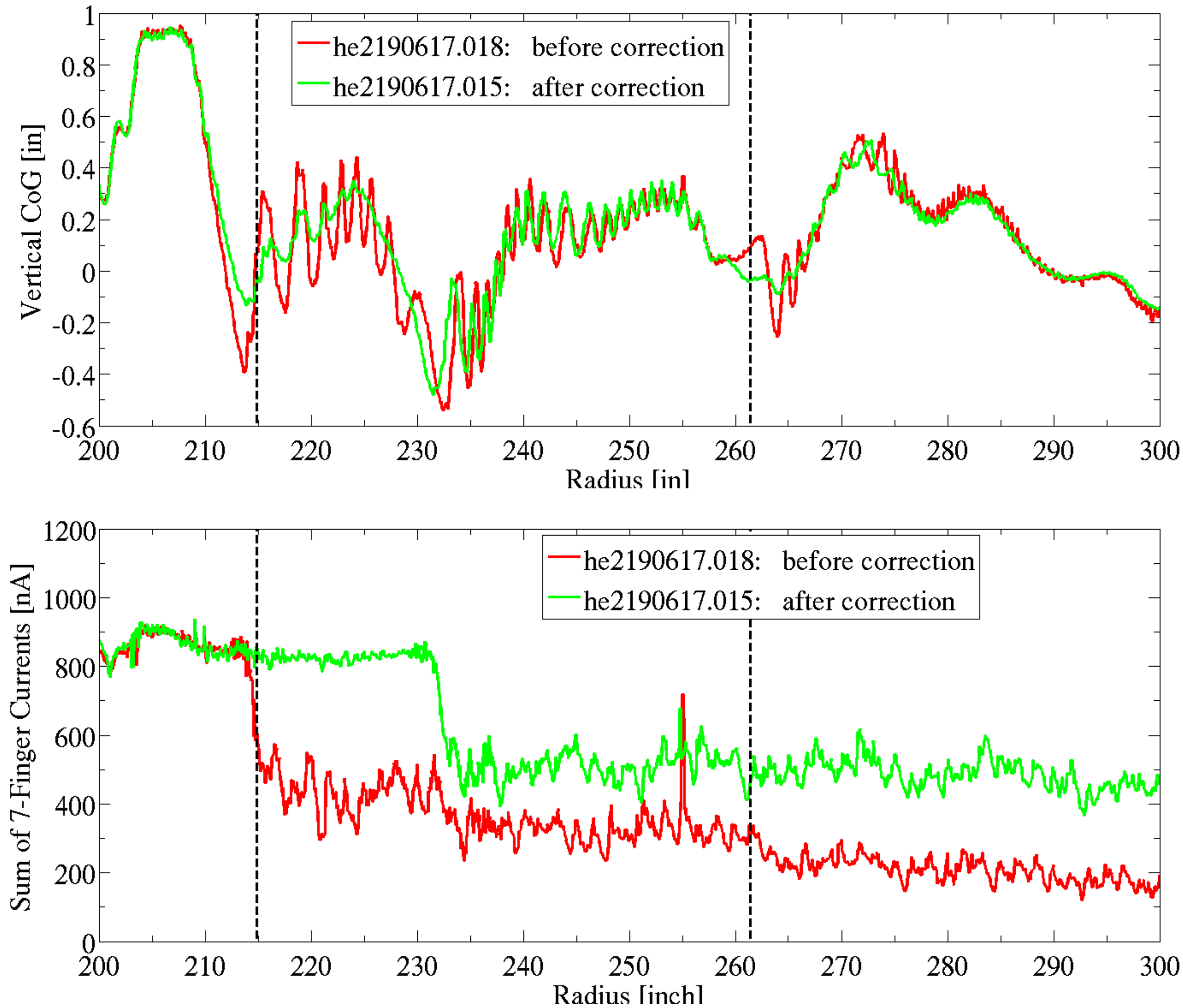


Figure 7: *(Upper) HE2 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

2.4 Detune HC2 B_z Phase By 46°

Fig. 8 and Fig. 9 show the HE1 and HE2 measured vertical centre-of-gravity and beam transmission vs. the radial position, when the HC2 B_z 1st harmonic phase angle was intentionally detuned by 46° from 196° to 150°, while its amplitude remained unchanged at 398 AT.

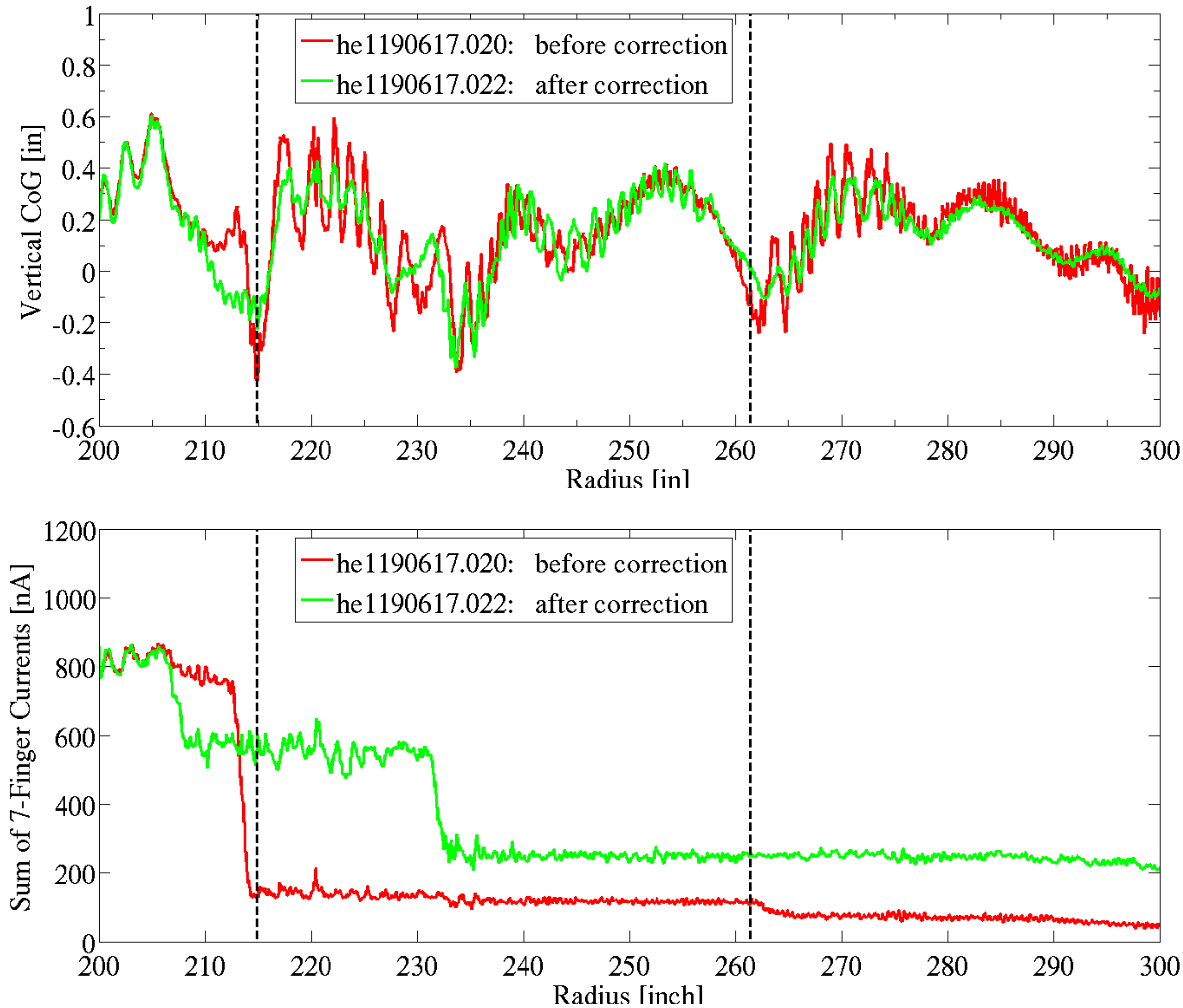


Figure 8: *(Upper) HE1 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

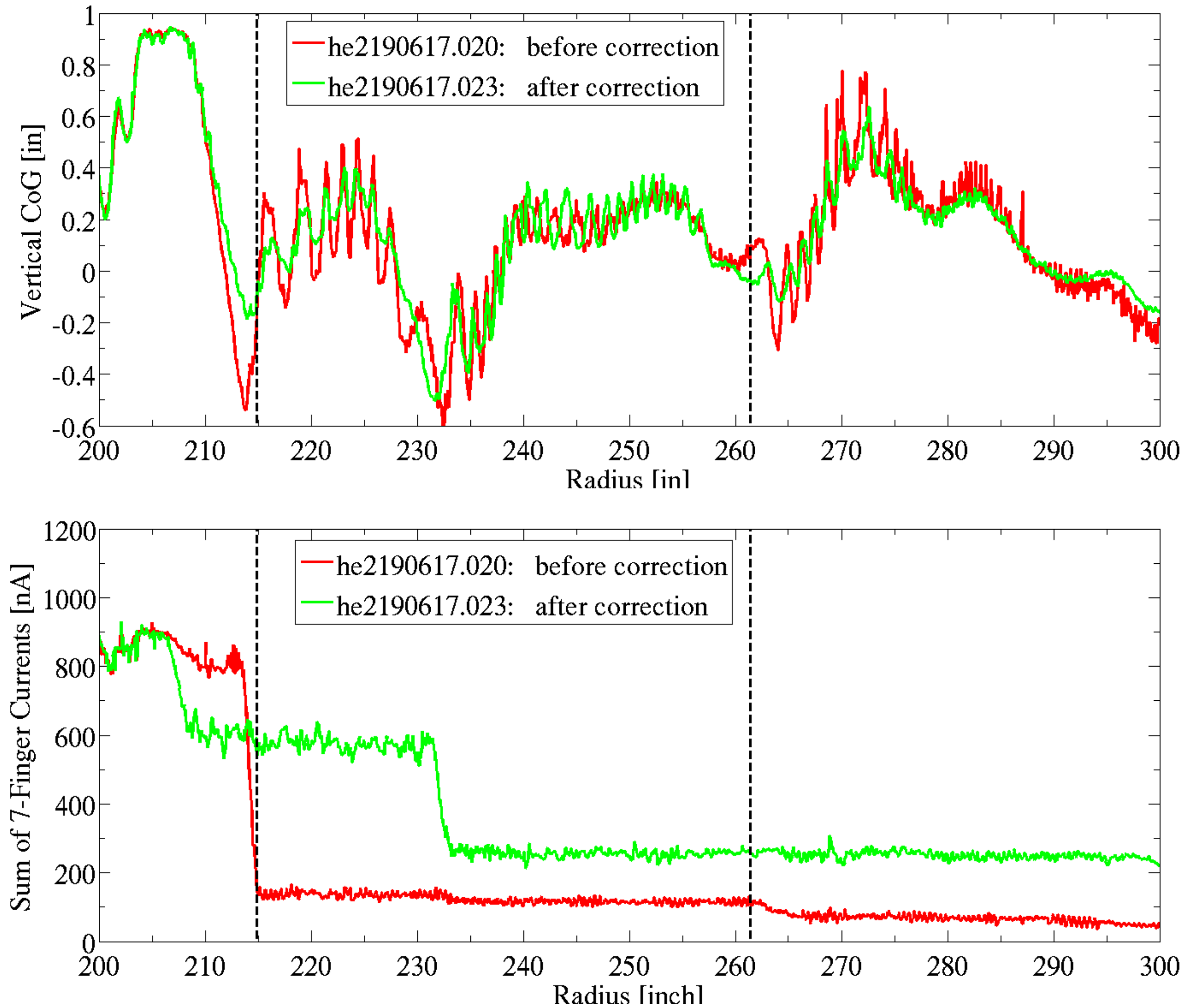


Figure 9: *(Upper) HE2 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

2.5 Flip the Correction Phases

Fig. 10 and Fig. 11 show the HE1 and HE2 measured vertical centre-of-gravity and beam transmission vs. the radial position, when the correction was, respectively, off, on with flipped phases, and on with right phases. Here the electrostatic deflector was intentionally detuned by −125 DAC from ±2665 DAC to ±2540 DAC.

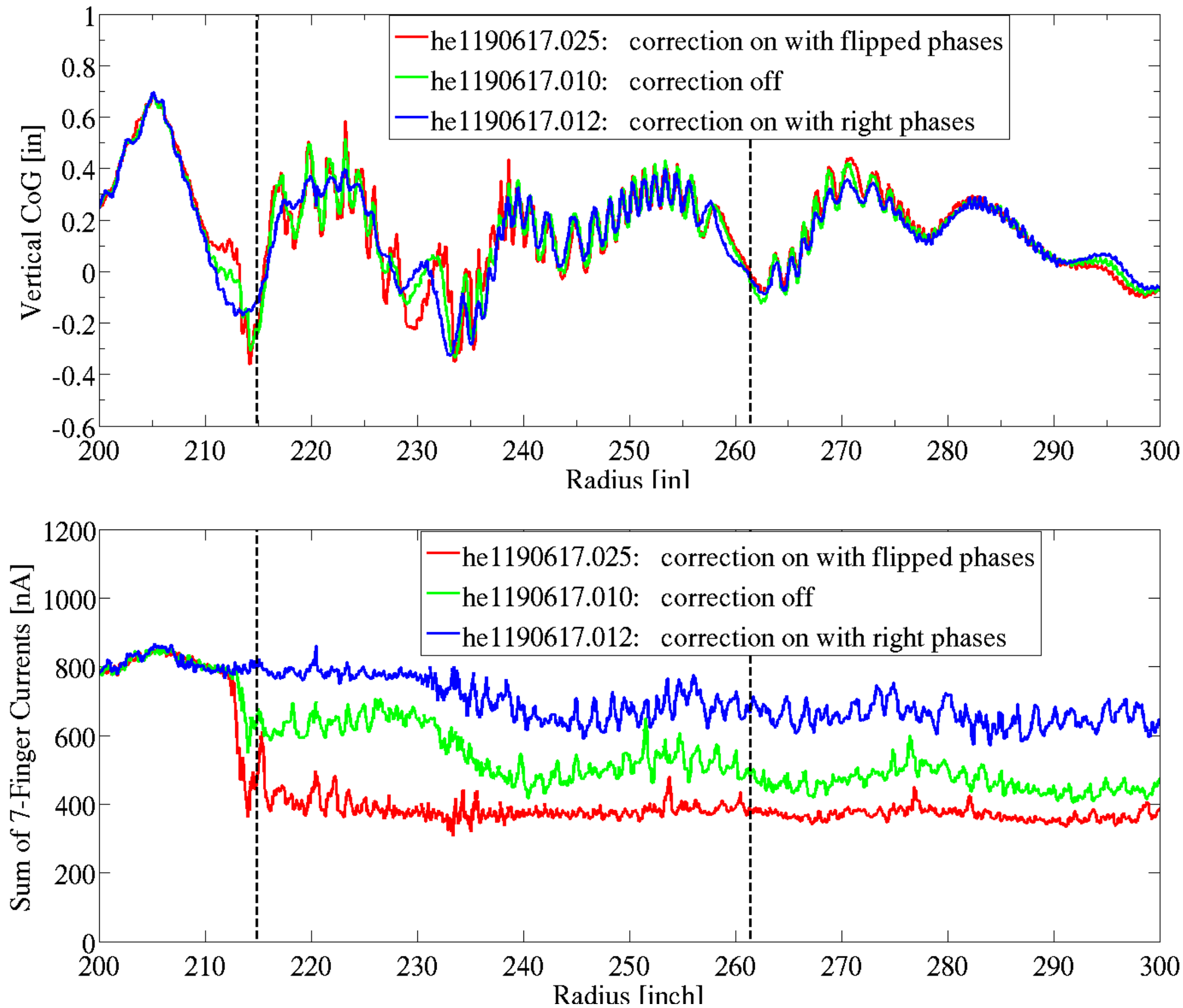


Figure 10: *(Upper) HE1 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*

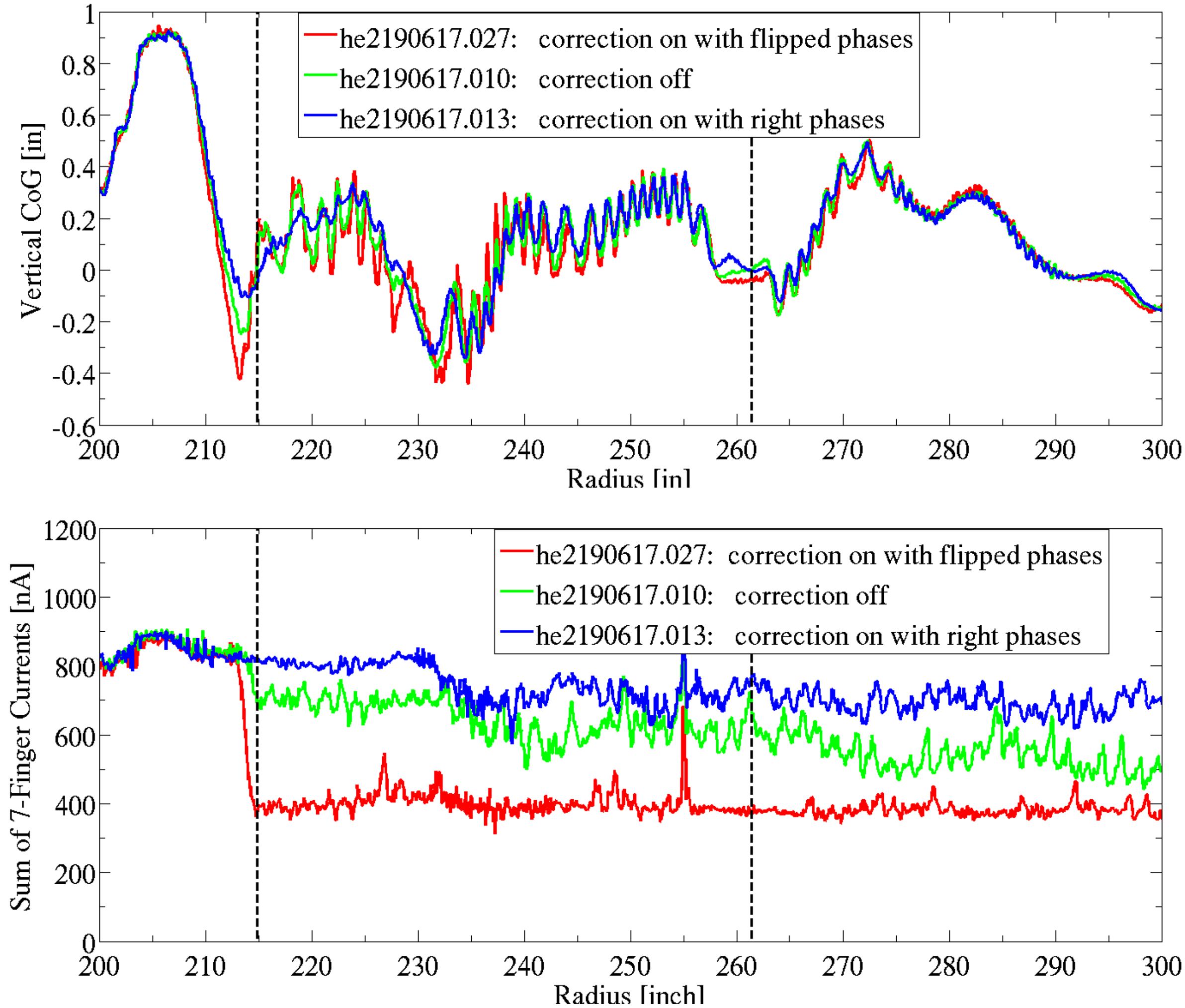


Figure 11: *(Upper) HE2 probe measured vertical centre-of-gravity vs. radial position, before and after correction of the resonance. (Lower) The probe measured beam transmission vs. radial position, before and after the correction.*