Comparative momentum stability measurement at UITF and CEBAF

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We have performed high-time-resolution, long-term measurements of the beam position upstream and downstream of the spectrometer dipole behind the booster cryomodule at the UITF and at CEBAF, granting insight into the relative performance of the two cryomodules in their respective environments.

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Contents

1 BPM measurements at the UITF

The beam positions in the non-dispersive location M601 and the dispersive location M702 were measured by running the beam into the M703 spectrometer dump and continuously recording the data from the two BPMs. Both booster cavities were operated on crest to deliver a total momentum of $8\,\mathrm{MeV}/c$.

1.1 Frequency domain

The high-time-resolution measurement was performed in CW mode at a current of $9.5\,\mu\mathrm{A}$ but was limited to one hour of data taking. The BPM data were recorded quasi-continuously at a sampling rate of $25\,\mathrm{kHz}$.

The spectrum of all BPMs averaged over the whole run is shown in Fig. 1. With the exception of the strong mains hum on M601, which is mainly caused by the buncher heater [1], the beam upstream of the dipole is virtually free of audio-band motion. Everything seen on M702 but not on M601 is added by the booster. While many of the low-frequency peaks are attributed to microphonics, the strong peak at $692\,\mathrm{Hz}$ and its harmonics is unexplained.

Figures 2 and 3 show the spectra in a time-windowed fashion over the course of an hour. Apart from the spectral content, there are strong intermittent excursions of the momentum about every $5\,\mathrm{min}$, which are under investigation and may or may not be caused by an unknown microphonic source [2].

1.2 Long-term stability

Figure 4 shows the average BPM readings while delivering tune beam to the M703 spectrometer dump throughout a 4-hour period. A PID feedback loop was used to keep the average beam current constant at about $80\,\mathrm{nA}$. Neglecting any upstream orbit change, the horizontal displacement at M702 is proportional to momentum change ($\eta_x \approx 1\,\mathrm{m}$, so $1\,\mathrm{mm}$ of displacement means $\delta p/p \approx 1 \times 10^{-3}$). The short-term momentum changes have already been discussed; what can be seen on top of those is a 1×10^{-3}-level fluctuation on a time scale of hours. One has to assume the drift is even worse when observed over a longer time scale.

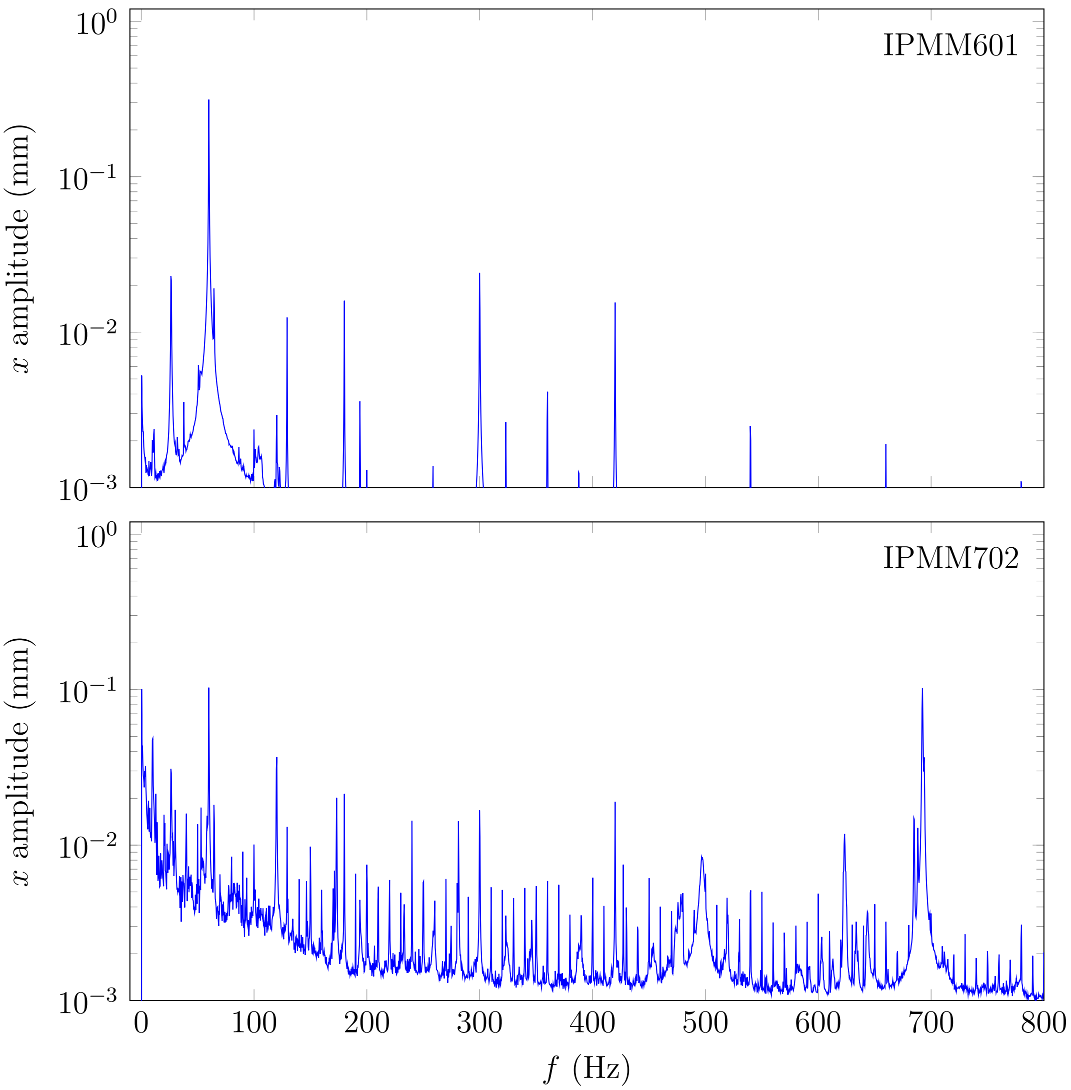

Figure 1: Average BPM spectra of non-dispersive and dispersive BPM in comparison.

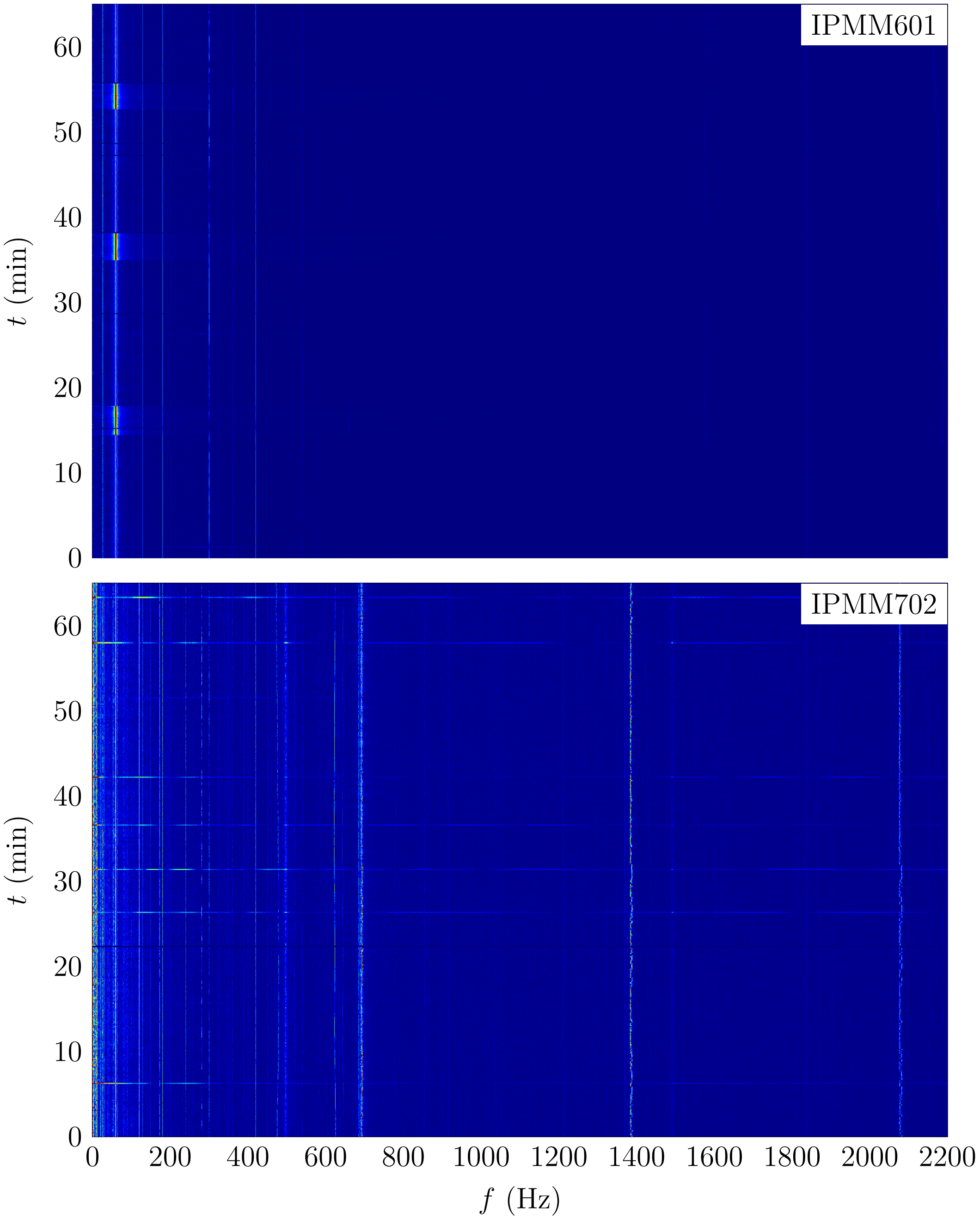

Figure 2: Spectrogram of non-dispersive and dispersive beam position, respectively. Linear color scale in arbitrary units.

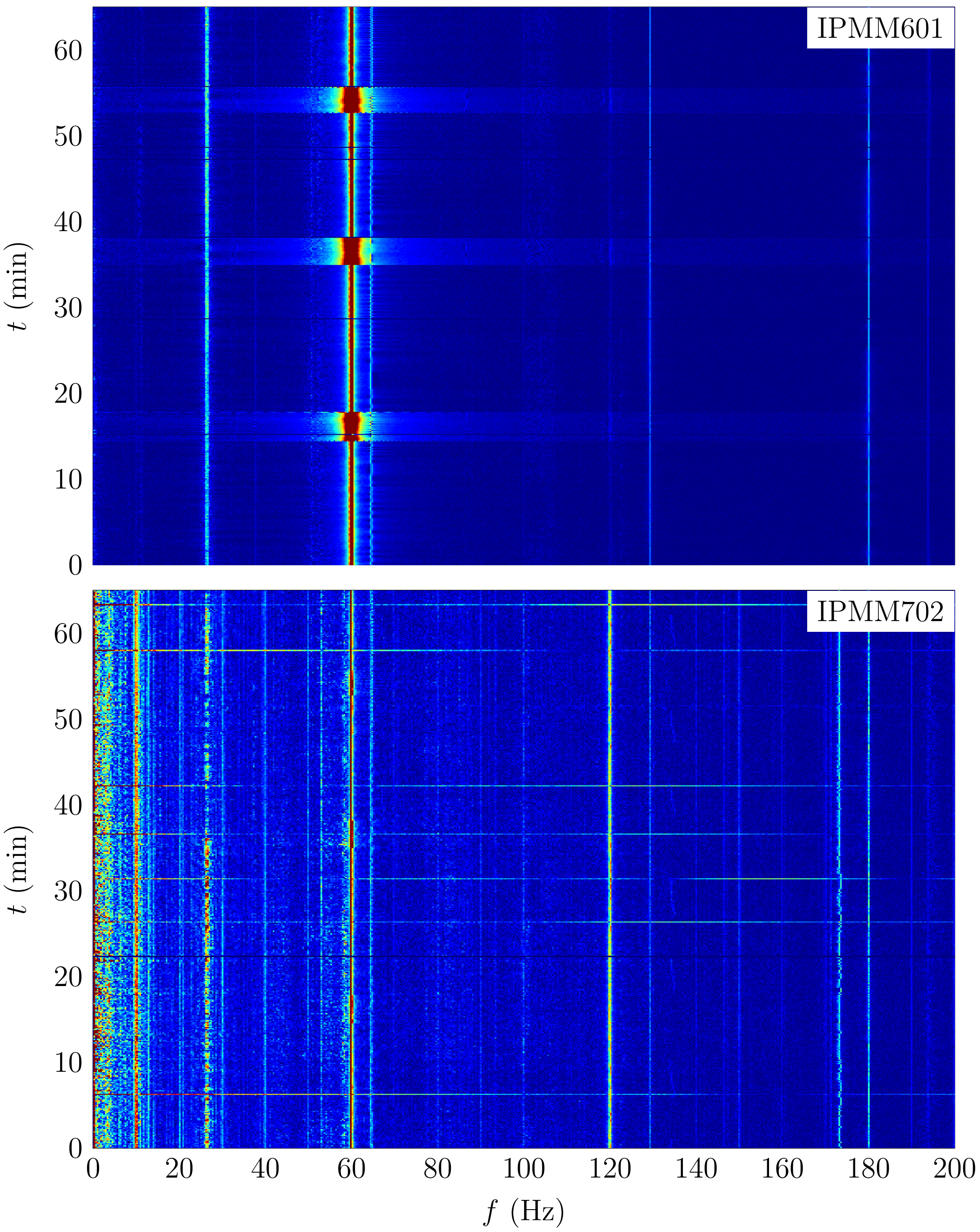

Figure 3: Spectrogram of non-dispersive and dispersive beam position, respectively. Linear color scale in arbitrary units. Narrower frequency scale than Fig. 2.

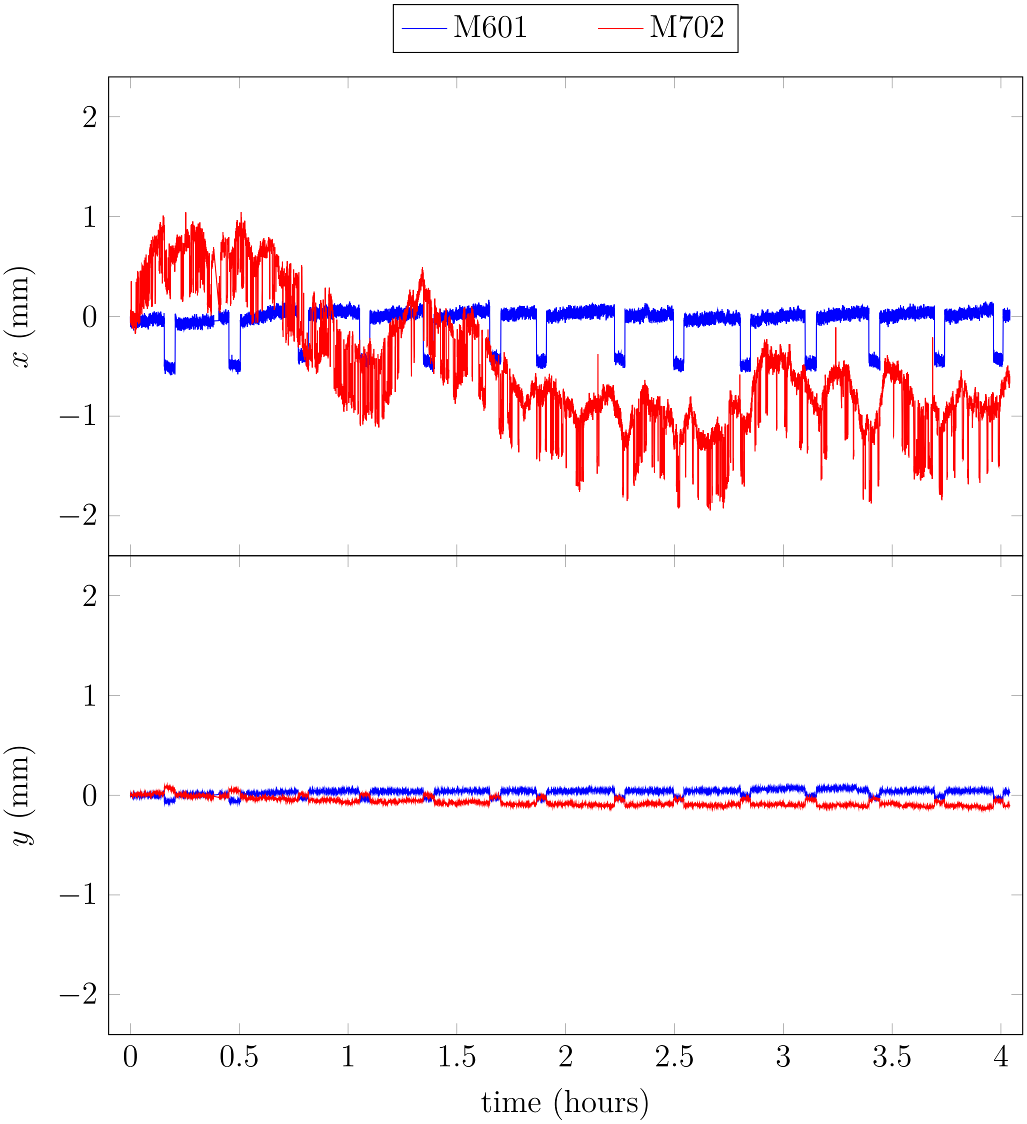

Figure 4: Average beam position over time (offset-subtracted to start at zero). With $\eta_x \approx 1\,\mathrm{m}$ at IPMM702, the 4-hour drift of the momentum (neglecting AC components) is about 2×10^{-3} peak to peak. While the jumps in the M601 orbit are caused by the buncher heater, the frequent short-term excursions in the M702 orbit are an unresolved issue with the booster.

2 BPM measurements at the CEBAF injector

For comparison, we performed the same study at the CEBAF injector by running 10 µA of CW beam into the 2D spectrometer dump and continuously recording the time-domain data from the 0L02 and 2D00 BPMs at a sampling rate of 10 kHz. The booster was configured for nominal injector operation.

2.1 Frequency domain

The spectrum of both BPMs averaged over the whole run is shown in Fig. 5. In contrast to the UITF measurement shown in Fig. 1, the dispersive spectrum is virtually the same as the non-dispersive one. While the beam position is humming loudly with a broad spectrum of mains harmonics, there is no significant spectrum on the momentum. Note, however, that the dispersion is only 0.4 m in this case: less than half of what it is in Fig. 1. The only difference that stands out in the dispersive spectrum is the two peaks between 670 and 690 Hz. Whether or not these have anything to do with the 692 Hz peak at the UITF is unknown.

Figures 6 and 7 show the spectra in a time-windowed fashion over the course of four hours. Apart from the non-dispersive BPM showing an unexplained spectral line at 2.9 kHz, which disappears after two hours, the motion on both BPMs is constant over time.

2.2 Long-term stability

In parallel to the high-resolution study, we recorded the average beam position on both BPMs over the course of 12 h. The result is shown in Fig. 8. Significant drift is observed in both coordinates on both BPMs. With $\eta_x \approx 0.4\,\mathrm{m}$ at IPM2D00, the 12-hour drift of the momentum (neglecting AC components) would be about 3×10^{-3} peak to peak assuming a stable beam upstream of the dipole, but the motion upstream and downstream is clearly correlated. The source of the upstream beam motion would need to be removed for the momentum drift to be measurable in isolation.

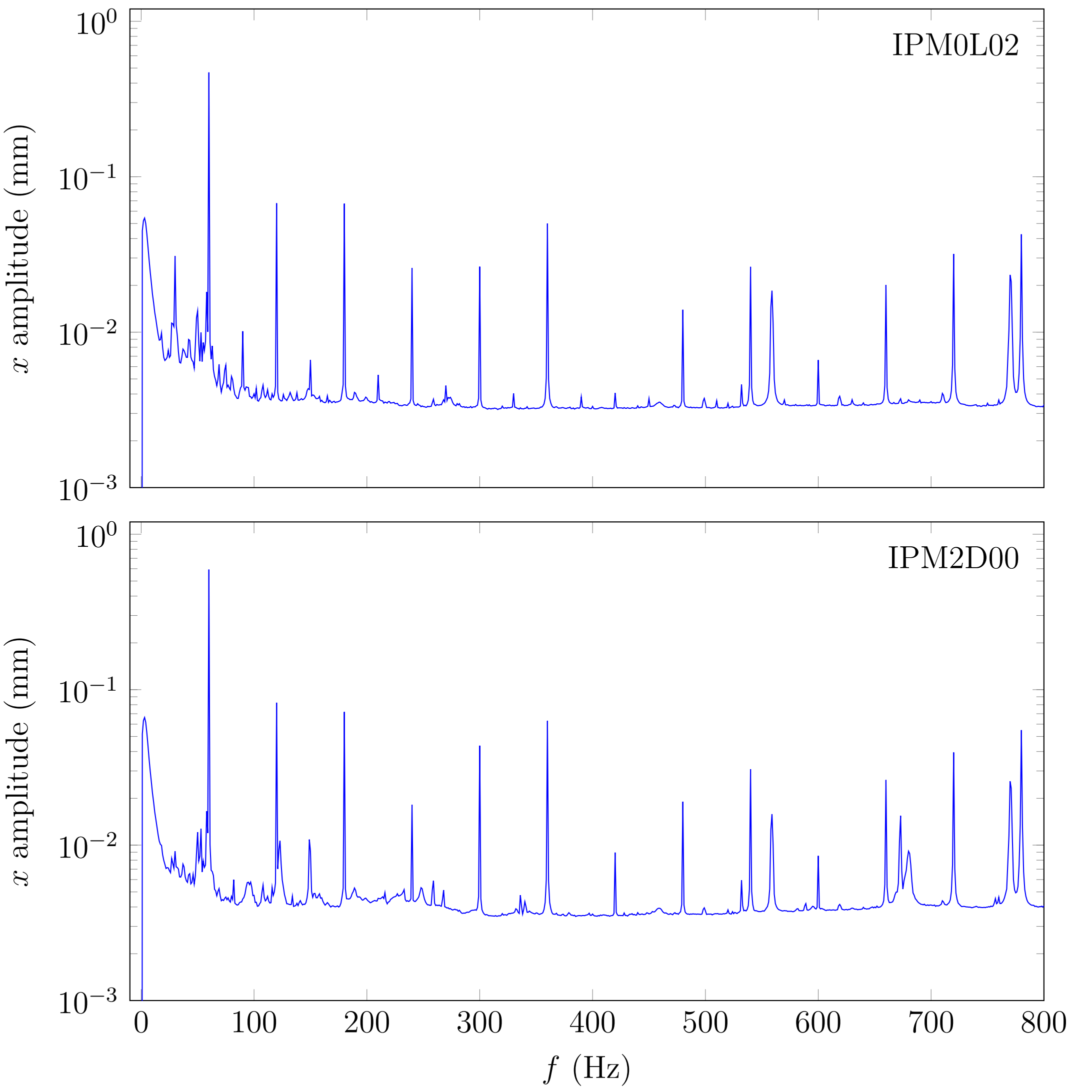

Figure 5: Average BPM spectra of non-dispersive and dispersive BPM in comparison.

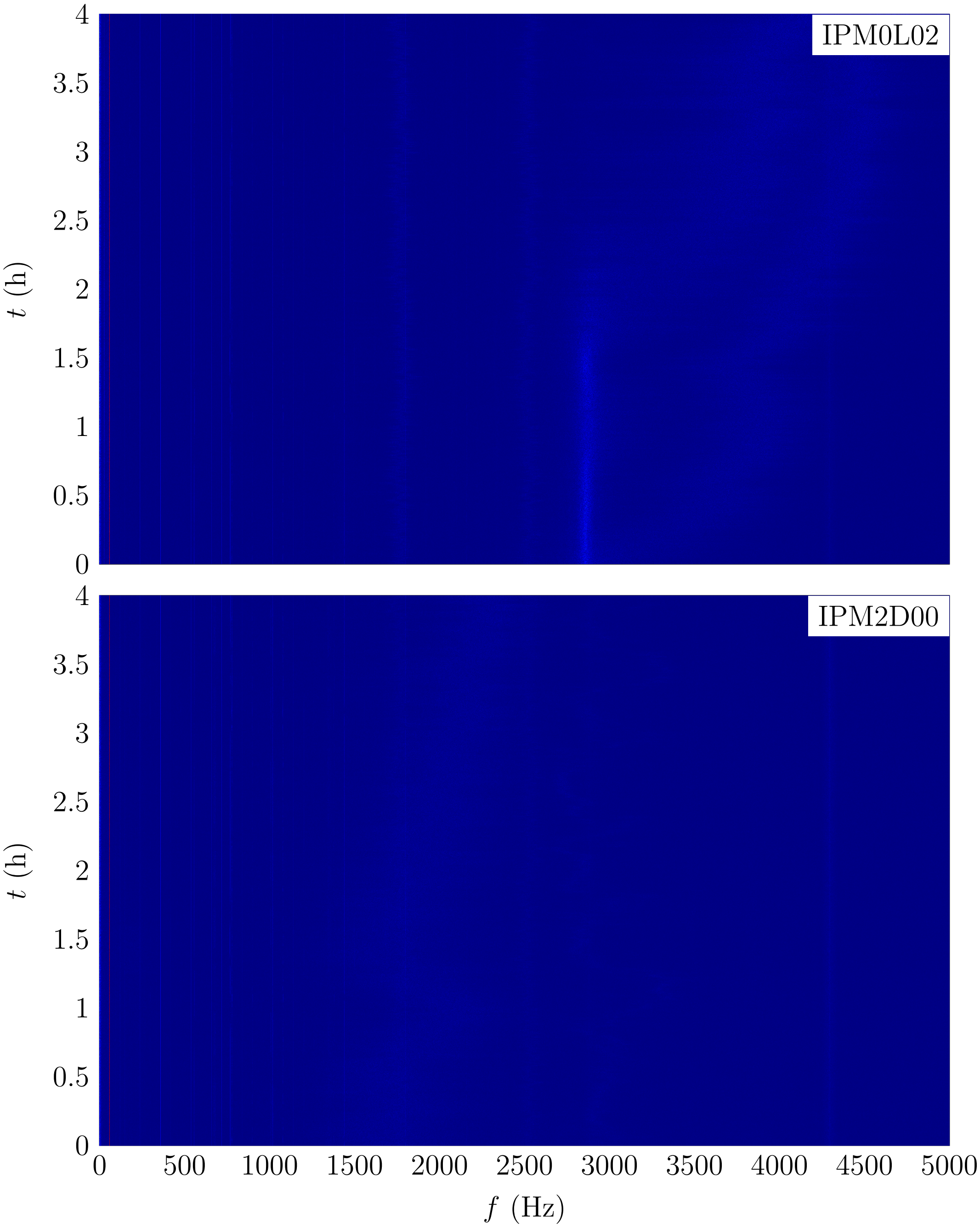

Figure 6: Spectrogram of non-dispersive and dispersive beam position, respectively. Linear color scale in arbitrary units.

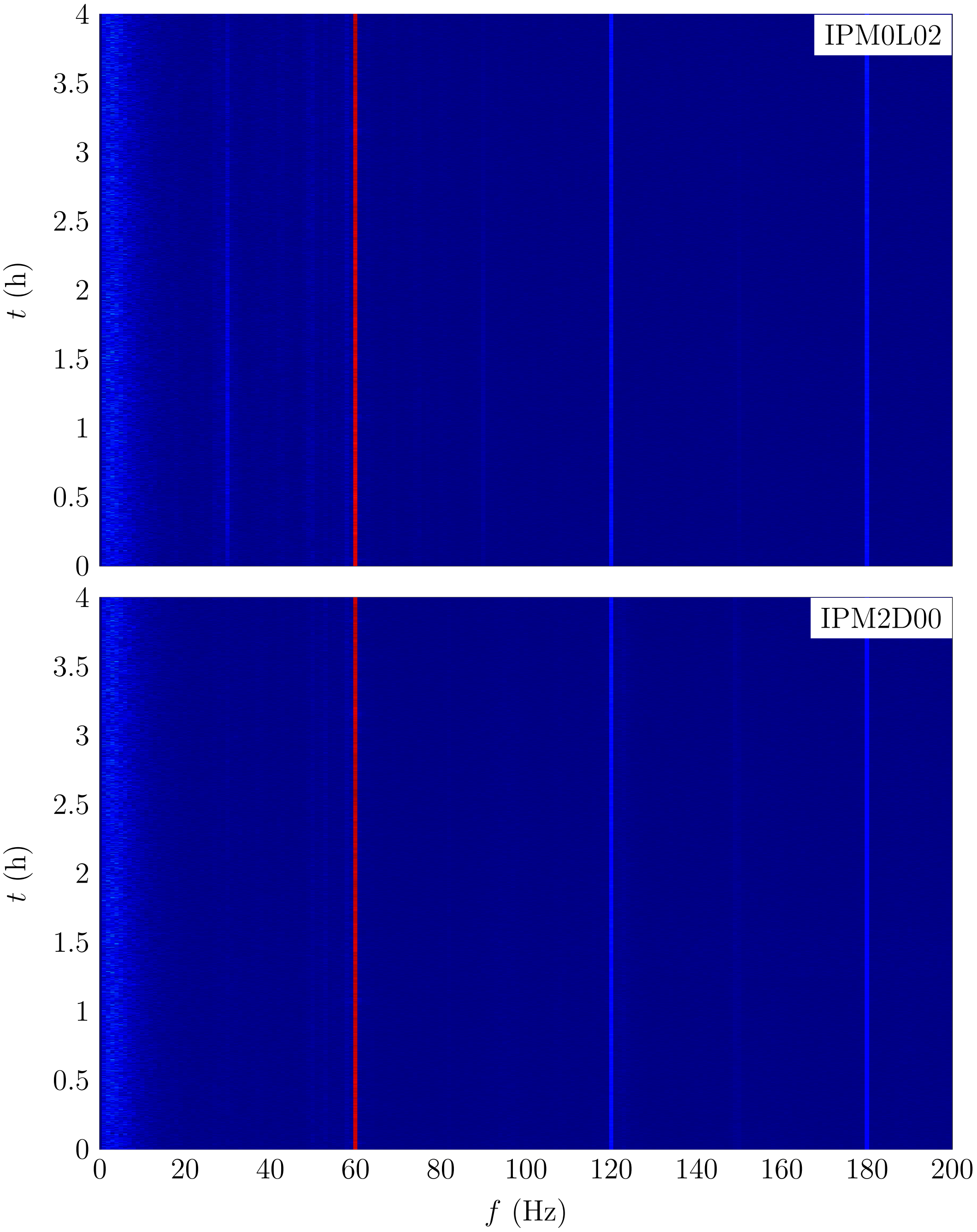

Figure 7: Spectrogram of non-dispersive and dispersive beam position, respectively. Linear color scale in arbitrary units. Narrower frequency scale than Fig. 6.

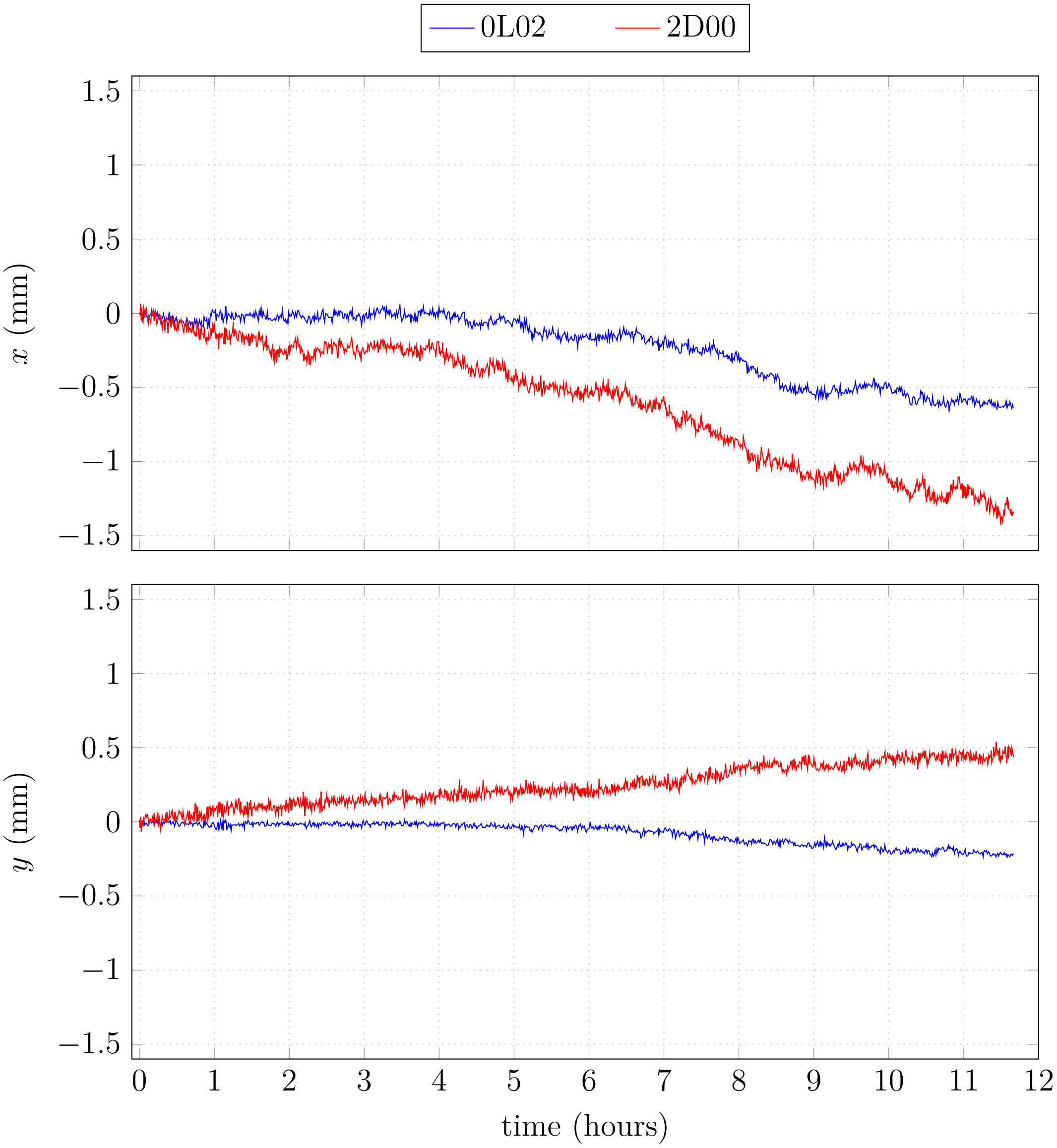

Figure 8: Average beam position over time (offset-subtracted to start at zero).

3 Conclusion

It is evident that the booster at the UITF causes substantial audio-band fluctuations of the beam momentum in addition to frequent unexplained transients. These issues are not visible in the CEBAF injector, which is to be expected given the quieter microphonic environment; however, we assume that not all issues with the UITF booster are due to microphonics, leaving room for investigation if surprises are to be avoided. The factor by which the CEBAF injector performs better is hard to measure because the spectrum is swamped by mains hum with wideband harmonic content for unknown reasons that most likely have nothing to do with the cryomodule. The same is true for the drift performance, the measurement of which is dominated by beam motion upstream of the dipole.

References

[1] Max Bruker. *Momentum spread and optics at the UITF—Preliminary results and mysteries*. Tech. rep. draft. Jefferson Lab, Dec. 2021. URL: `https://wiki.jlab.org/ciswiki/images/f/f6/UITF_Mysteries_20220112b.pdf`.

[2] Tom Powers and Peter Owen. *Booster Cryomodule Microphonics in the UITF*. Tech. rep. draft. Jefferson Lab, 2022.