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Fourier Analysis of Booster TBT data

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Beam position at the j-th BPM after a *single* kick:

$$z_n^j = \sqrt{\beta_z^j} e^{i\Phi_z^j} A_z e^{iQ_z(\theta_j + 2\pi n)} + c.c. \quad (z = x, y)$$

$$n \equiv \text{ turn number} \quad A_z = |A_z| e^{i\delta_z} \equiv \text{ constant of motion}$$

$$\Phi_z \equiv \int_0^\theta d\theta' \frac{R}{\beta_z} - Q_z \theta \quad \text{(periodic phase function)}$$

Twiss functions:

$$\beta_z^j = |Z_j(Q_z)|^2 / A_z^2 \qquad \mu_z^j = \arg\,(Z_j) - \delta_z \quad Z_j(Q_z) \equiv \text{ Fourier component of } z$$

Amplitude fit:

$$|A_z|^2 = \frac{\sum_j 1/\beta_{0z}}{\sum_j 1/|Z_j(Q_z))|^2}$$

In the presence of *coupling*, the excitation of one mode will excite the other too at the *same* frequency. Following for instance a horizontal kick (first order approximation):

$$y_n^j = \left[\sqrt{\beta_y^j}\left(\mathrm{e}^{-i\Phi_y^j} w_+^j - \mathrm{e}^{i\Phi_y^j} w_-^j\right) - \sqrt{\beta_x^j}\mathrm{e}^{i\Phi_x^j}\sin\chi_j\right] A_x \mathrm{e}^{iQ_x(\theta_j+2\pi n)} + c.c.$$

$$\chi_j \equiv \text{tilt of } j\text{-th BPM}$$

Coupling functions:

$$w_\pm(\theta) = -\int_0^{2\pi} d\theta' \frac{C_\pm(\theta')}{4\sin\pi Q_\pm}\mathrm{e}^{-iQ_\pm[\theta-\theta'-\pi\,\mathrm{sign}(\theta-\theta')]}$$

$$Q_\pm \equiv Q_x \pm Q_y$$

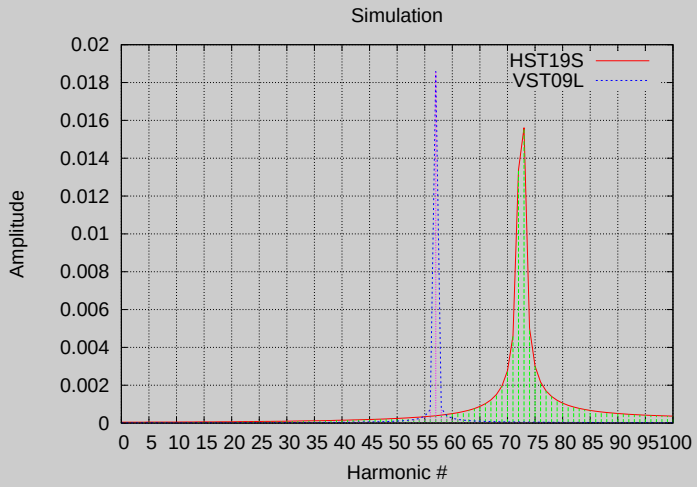
$$C_\pm(\theta) \equiv \frac{R\sqrt{\beta_x\beta_y}}{2B\rho}\left\{\left(\frac{\partial B_x}{\partial x} - \frac{\partial B_y}{\partial y}\right) + B_\theta\left[\left(\frac{\alpha_x}{\beta_x} - \frac{\alpha_y}{\beta_y}\right) - i\left(\frac{1}{\beta_x} \mp \frac{1}{\beta_y}\right)\right]\right\}\mathrm{e}^{i(\Phi_x \pm \Phi_y)}$$

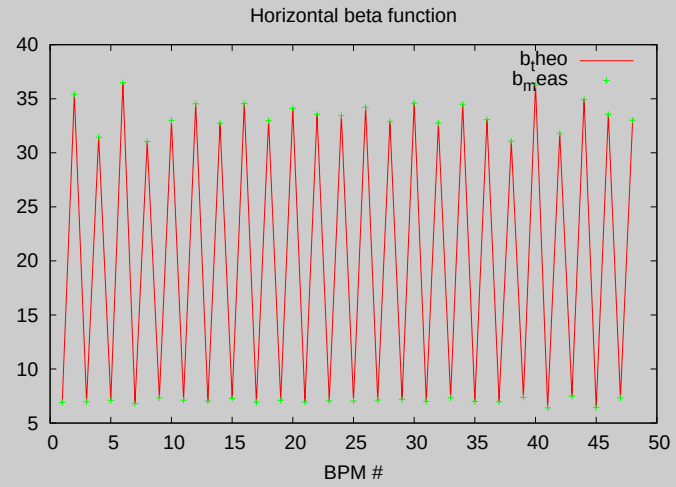
Minimum tune split:

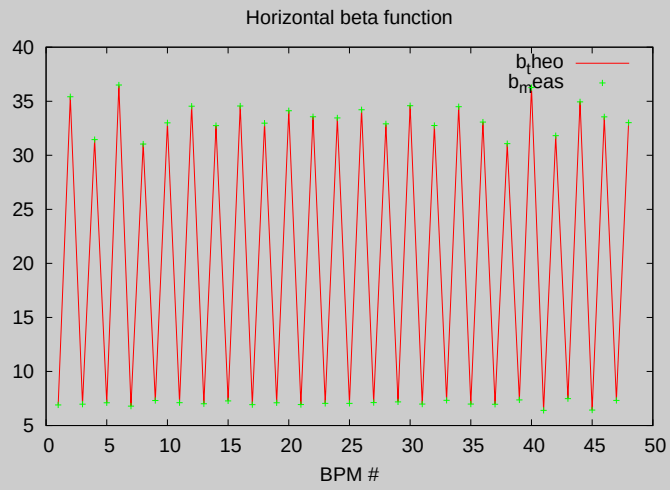
$$\Delta \equiv |\bar{C}_-| \quad \bar{C}_\pm = \frac{n_\pm - Q_\pm}{\pi}\int_0^{2\pi} d\theta\, w_\pm \mathrm{e}^{in_\pm\theta} \quad n_\pm \equiv \mathrm{Round}(Q_x \pm Q_y)$$

This analysis is *routinely* used for correcting the coupling at Tevatron during shot set up.

Test with simulated Booster data





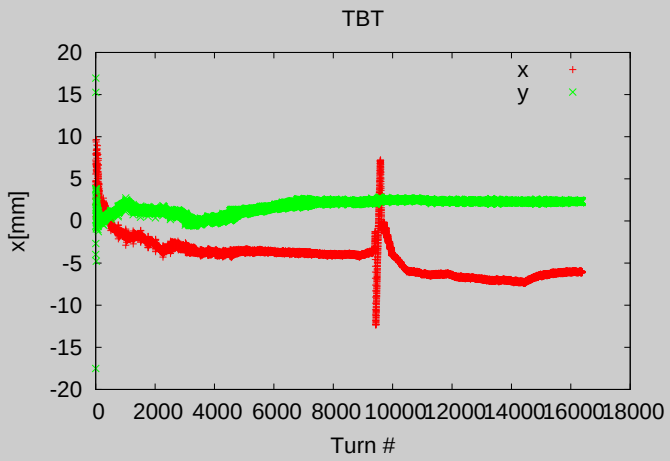


Actual Booster data - AC mode (January 08)

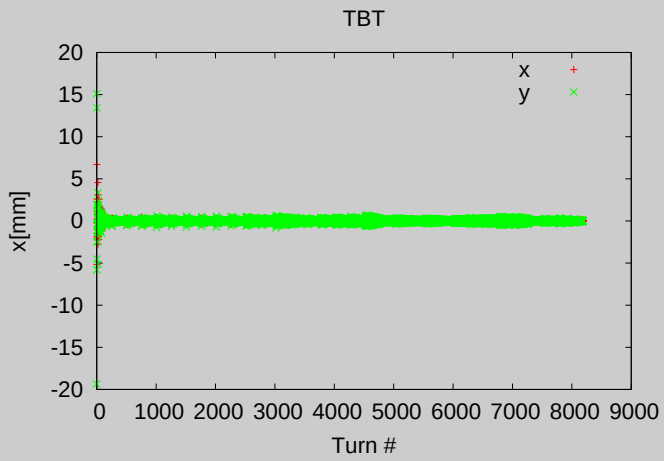
Data sets:

File	kick	periodicity	comments
TBT_1201208926_00	h	50	
TBT_1201207388_00	h	150	no kick visible
TBT_1201207388_00	h	250	no kick visible
TBT_1201210976_00	h	50	
TBT_1201206987_00	-	-	no kick visible
TBT_1201210976_00	v	50	
TBT_1201209649_00	v	150	
TBT_1201210712_00	v	250	analysed

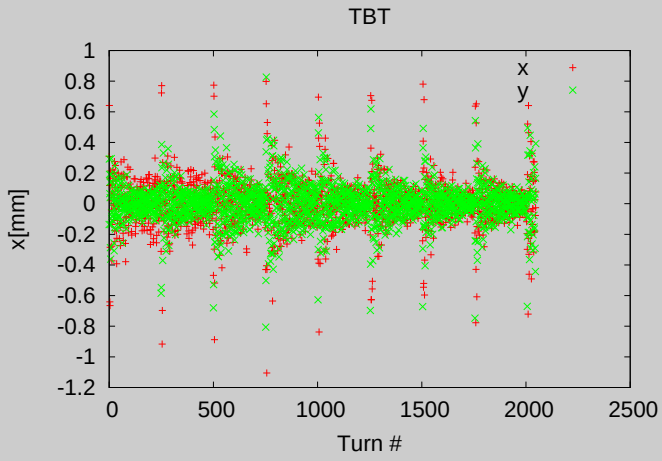
TBT_1201210712_00



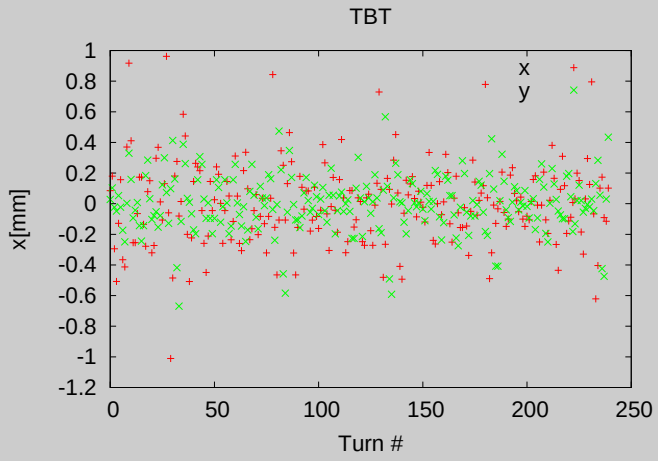
TBT_1201210712_00 smoothed



TBT_1201210712_00



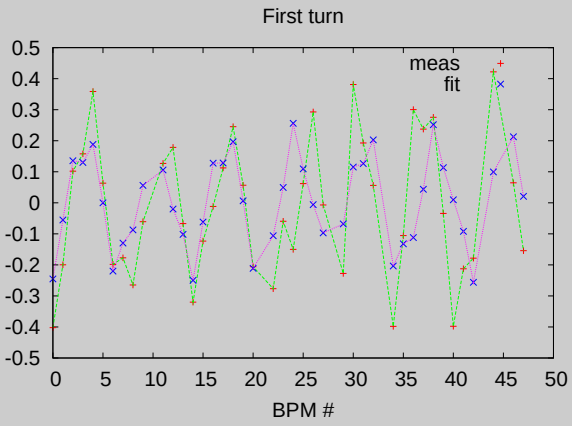
TBT_1201208926_00



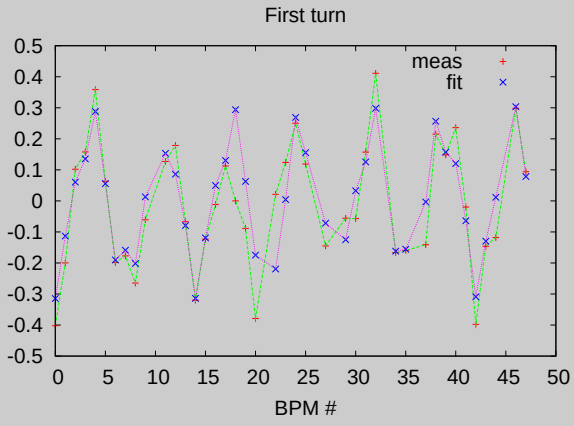
Useful data are contained in the first 8.7 msec.

The BPMs are now triggered at the same time: oscillation starts at the same data index. The number of data per BPM is the same ($\pm$ 1). Empirical shift of data:

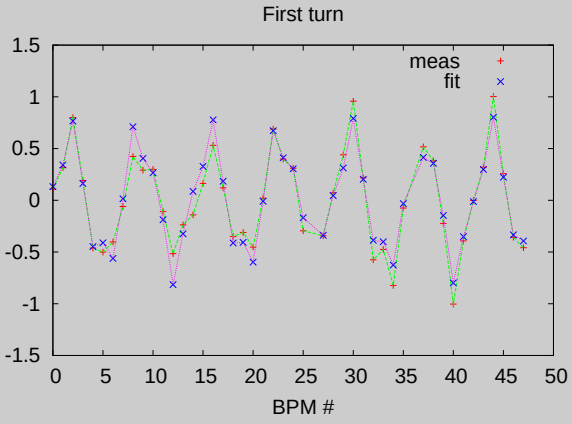
BPM	calibration	shift	BPM	calibration	shift
B:H(V)ST09L	1.0604	0	B:H(V)ST09S	1.0217	0
B:H(V)ST10L	1.0050	0	B:H(V)ST10S	1.0791	0
B:H(V)ST11L	1.1194	0	B:H(V)ST11S	1.0534	0
B:H(V)ST12L	1.0000	-1	B:H(V)ST12S	0.9873	-1
B:H(V)ST13L	1.1794	-1	B:H(V)ST13S	1.0845	-1
B:H(V)ST14L	1.0440	-1	B:H(V)ST14S	1.0231	-1
B:H(V)ST15L	1.1214	-1	B:H(V)ST15S	1.0837	-1
B:H(V)ST16L	1.0859	-1	B:H(V)ST15S	0.9331	-1
B:H(V)ST17L	1.0371	-1	B:H(V)ST17S	0.9788	-1
B:H(V)ST18L	1.0917	-1	B:H(V)ST18S	1.0726	-1
B:H(V)ST19L	1.0748	-1	B:H(V)ST19S	1.0075	-1
B:H(V)ST20L	1.0499	-1	B:H(V)ST20S	1.0174	-1
B:H(V)ST21L	1.0990	-1	B:H(V)ST21S	1.0187	-1
B:H(V)ST22L	1.0876	-1	B:H(V)ST22S	1.0772	-1
B:H(V)ST23L	1.0680	-1	B:H(V)ST23S	0.9731	-1
B:H(V)ST24L	1.0138	1	B:H(V)ST24S	1.0047	1
B:H(V)ST01L	1. 0000	1	B:H(V)ST01S	1. 0144	1
B:H(V)ST02L	1. 0000	1	B:H(V)ST02S	1. 1302	1
B:H(V)ST03L	1. 0000	1	B:H(V)ST03S	1. 0691	1
B:H(V)ST04L	1. 0496	1	B:H(V)ST04S	1. 0829	1
B:H(V)ST05L	1. 0925	1	B:H(V)ST05S	1. 0907	1
B:H(V)ST06L	1. 0261	1	B:H(V)ST06S	0.9859	1
B:H(V)ST07L	1. 0705	1	B:H(V)ST07S	1. 0380	1
B:H(V)ST08L	1. 0746	1	B:H(V)ST08S	1. 0641	1



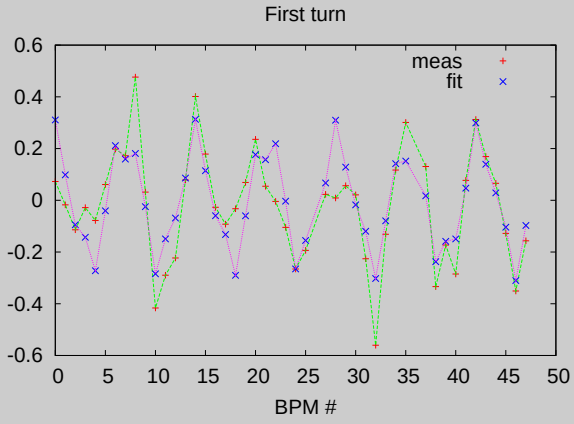
t=7.4 msec, raw data



t=7.4 msec, empirical shifts



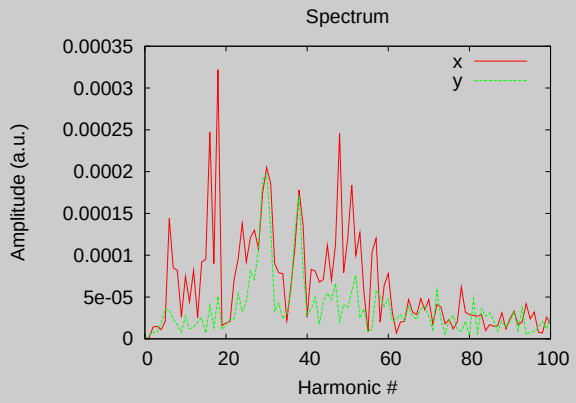
t=2.2 msec, empirical shifts



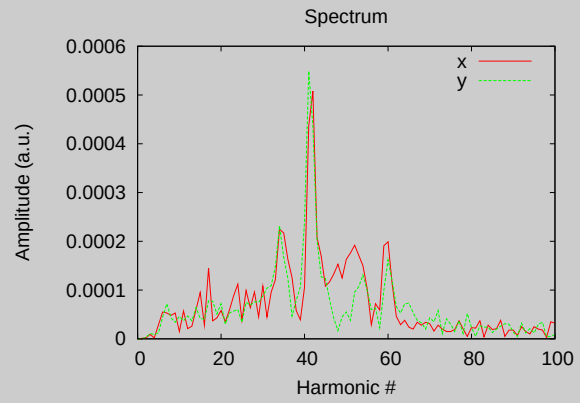
t=8.3 msec, empirical shifts

Spectrum is quite confused in the beginning of the ramp, it is difficult to understand which are the tunes. Criterion: minimize beta-beating (?)

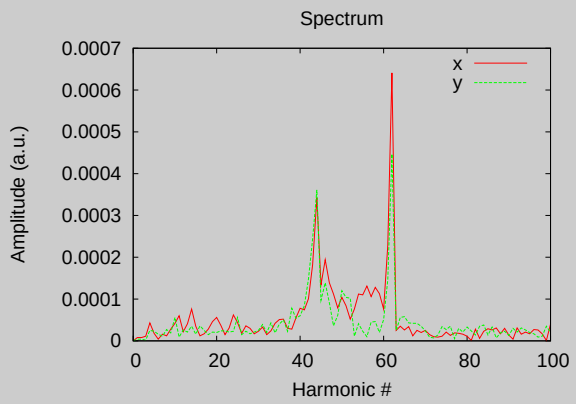
t=0.57 msec



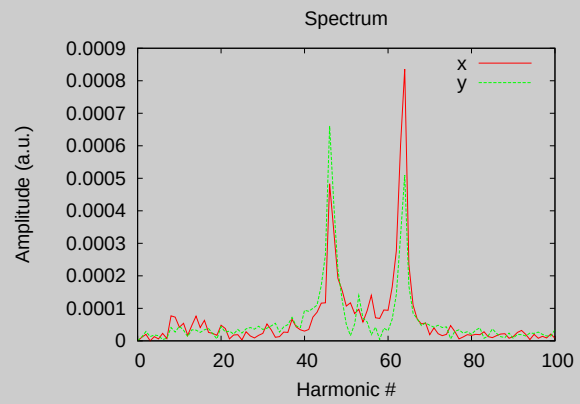
t=2.2 msec

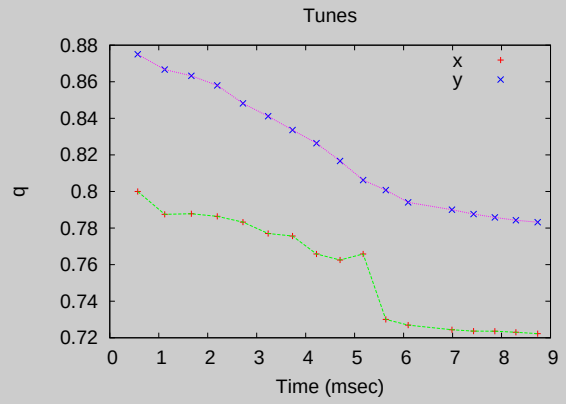


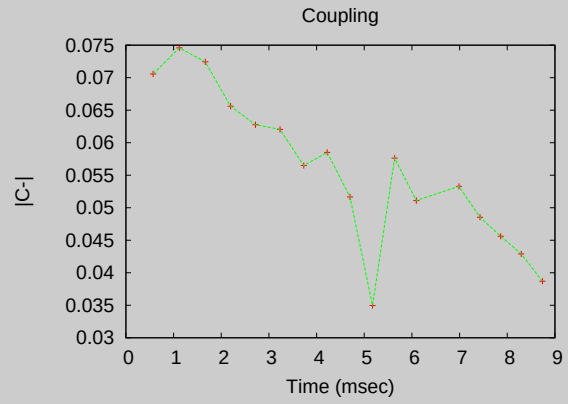
t=4.7 msec

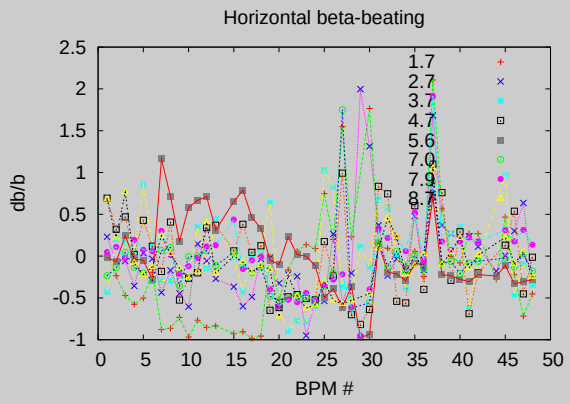


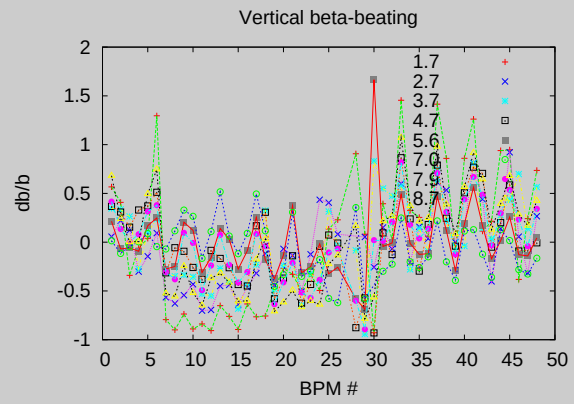
t=5.2 msec



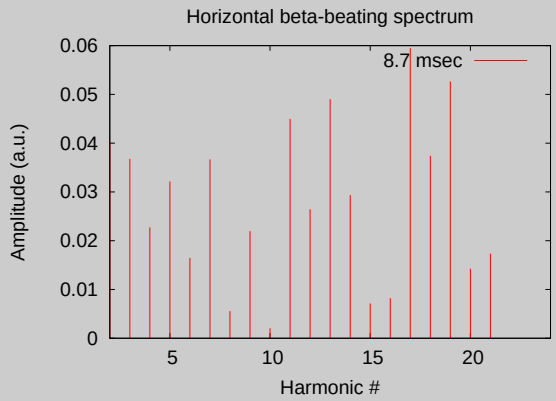

Tunes
q
Time (msec)
x
y

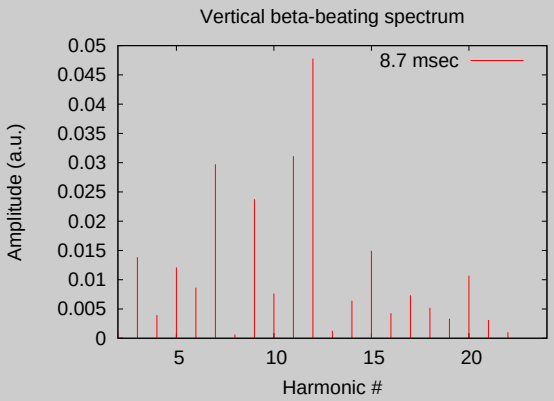

Coupling
|C-|
Time (msec)


Horizontal beta-beating
db/b
BPM #
1.7
2.7
3.7
4.7
5.6
7.0
7.9
8.7


Vertical beta-beating
db/b
BPM #
1.7
2.7
3.7
4.7
5.6
7.0
7.9
8.7

Horizontal beta-beating is too noisy, the vertical one could contain something true.:





Conclusions

- The HST15S (no peak in spectrum) and VST03L ($\simeq$50% calibration error) were bad in all time slots.
- Data are not good enough for an optics reconstruction.
- Would a smaller kick (avoid quick decoherence) helps?
- Would a longer period between kicks helps?