Fourier Analysis of MI TBT data

E.Gianfelice

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

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

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

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

Twiss functions may be computed through a Fourier analysis:

$$Z_j(Q_z) \equiv \text{ Fourier component of } z_j$$

$$\beta_z^j = |Z_j(Q_z)|^2 / A_z^2 \qquad\qquad \mu_z^j = \arg\,(Z_j) - \delta_z$$

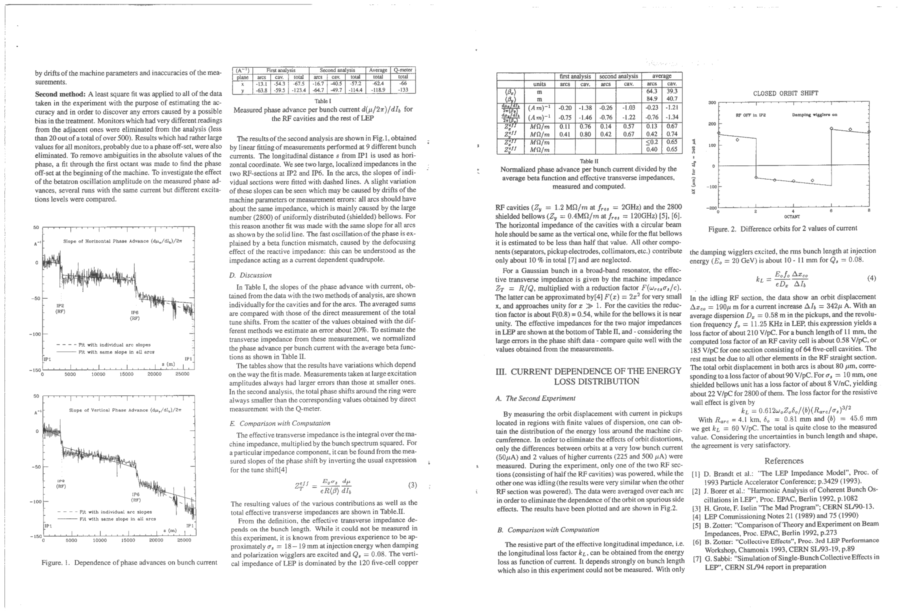
Amplitude fit:

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

TBT measurement goal for MI (besides optics measurement):

- measure dependence of tunes and phase advance upon bunch current
- measure dependence of closed orbit upon bunch current

D.Brandt et al.,
PAC95

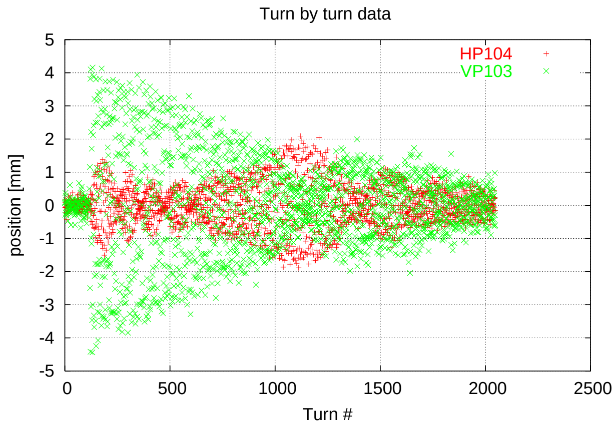


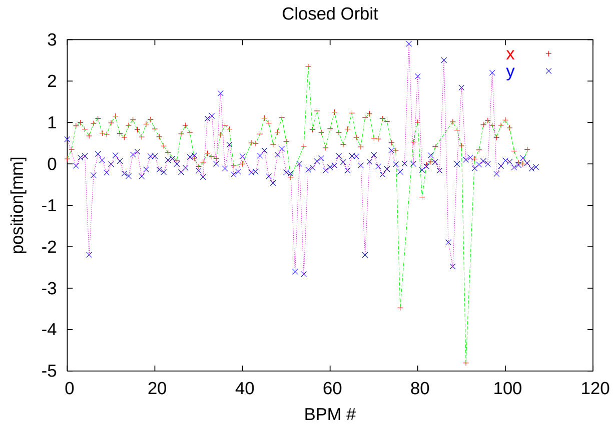
Two data sets are here analysed (30 bunches, machine status 15)

- 4 TBT data with 0.3 e12 particles
- 4 TBT data with 1.2 e12 particles

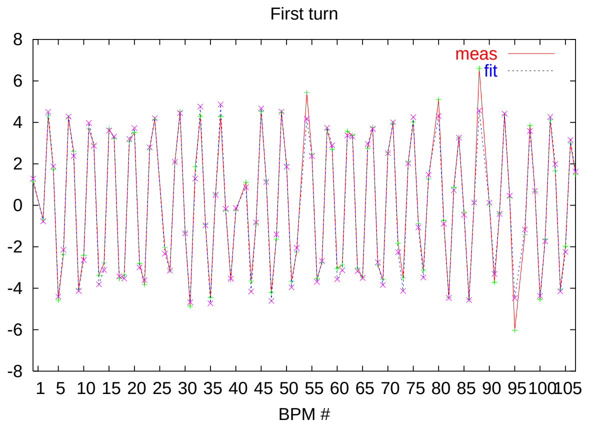
The large aperture quadrupole BPMs have been excluded from the analysis.

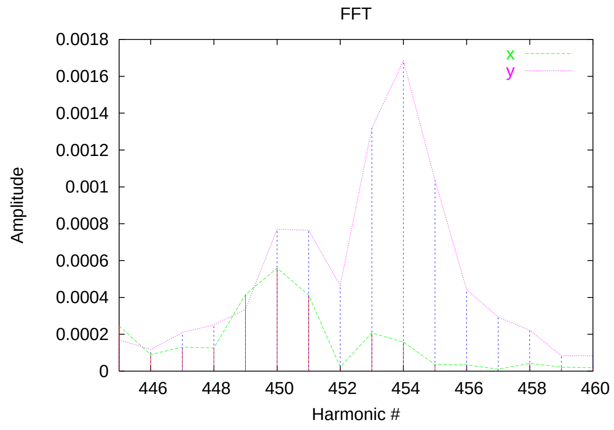
MI data (October 26)



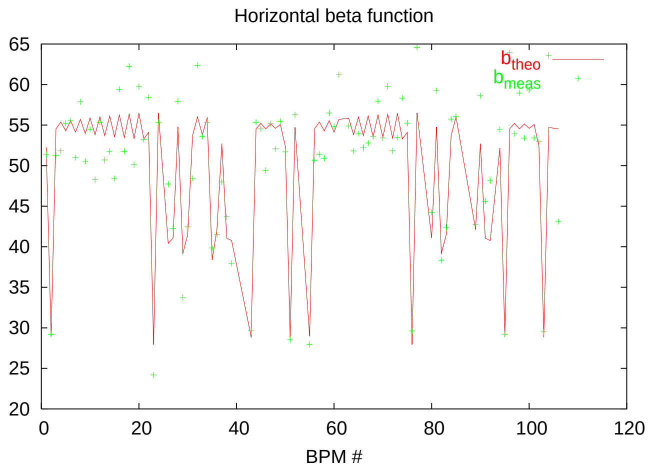


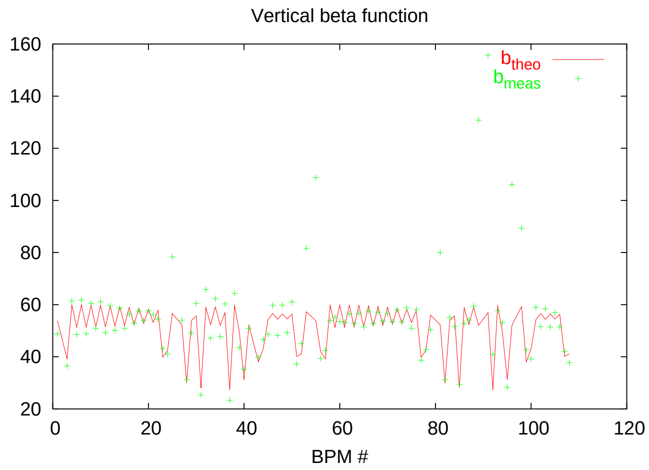
The BPMs measuring a closed orbit larger than 5 mm have been excluded.





The first turn fit indicates that the "turn order uncertainty" has been correctly removed.

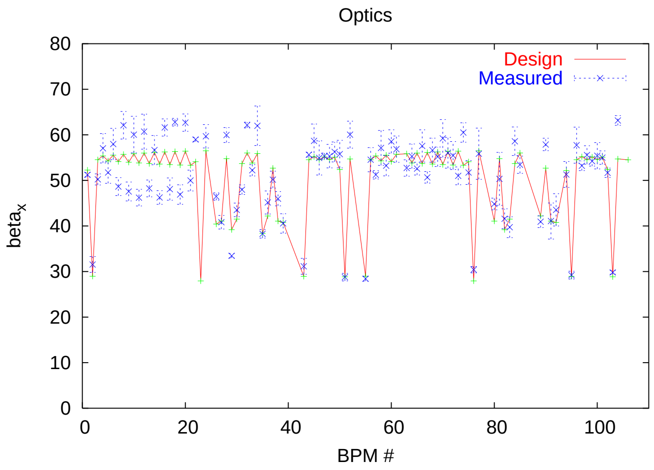


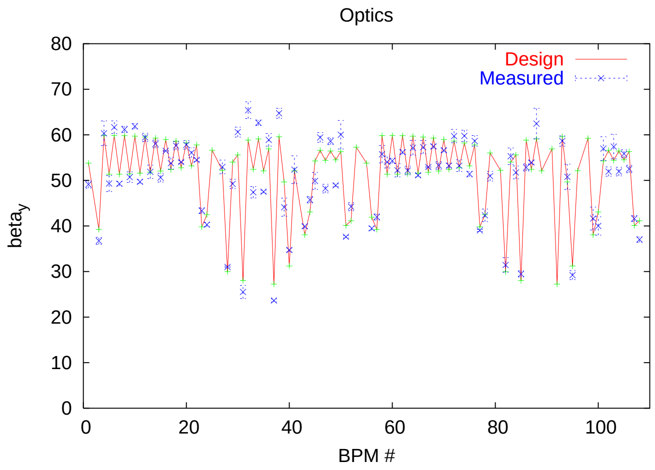


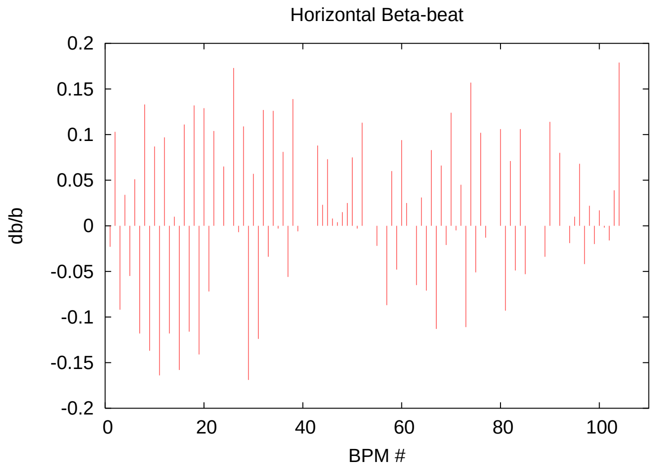
Some vertical BPMs show a “systematic” (understood!) calibration error in the TBT mode:

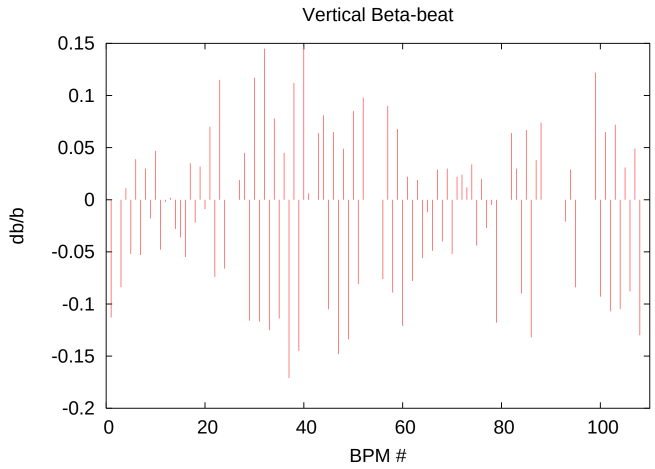
name	db/b	closed orbit(mm)
I:VP401	0.5	-2.6
I:VP403	1.0	-2.7
I:VP523	0.5	2.1
I:VP607	1.5	-2.5
I:VP609	1.9	1.9
I:VP611	0.5	0.1
I:VP619	1.0	0.0
I:VP621	0.6	2.2

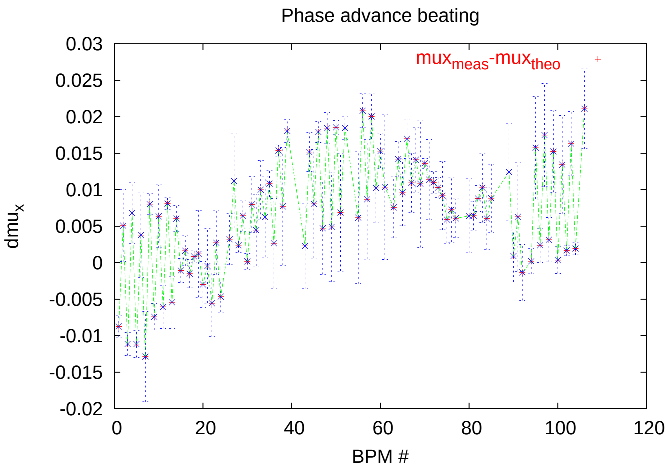
Averaging over all low current measurements and excluding “bad” BPMs:

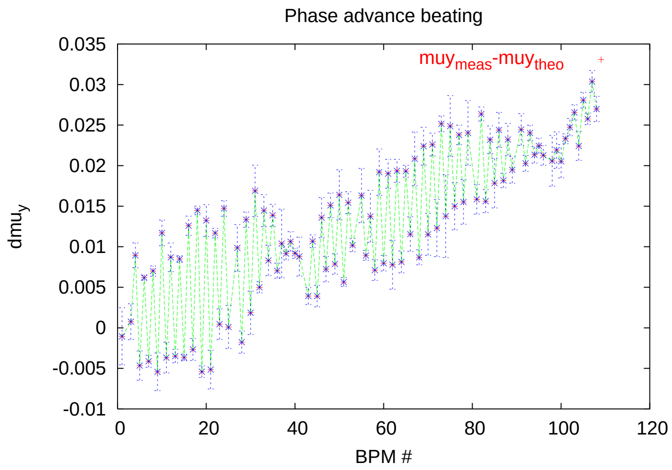




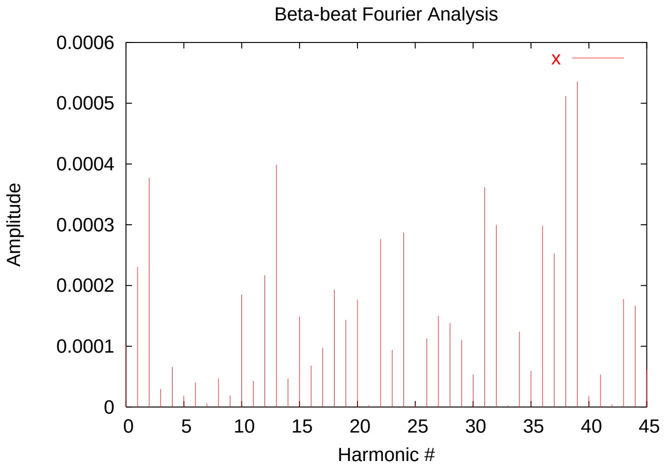


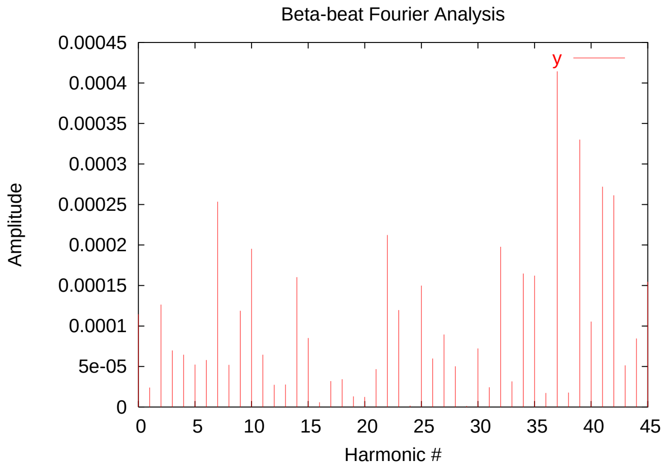






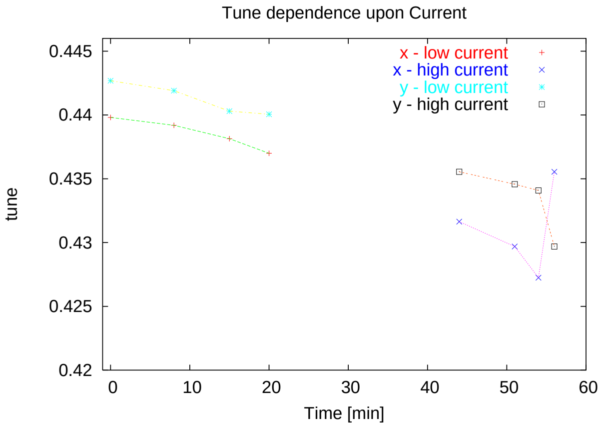
Fourier Analysis of beta-beat (BPMs with db/b $<$ 0.3 retained)



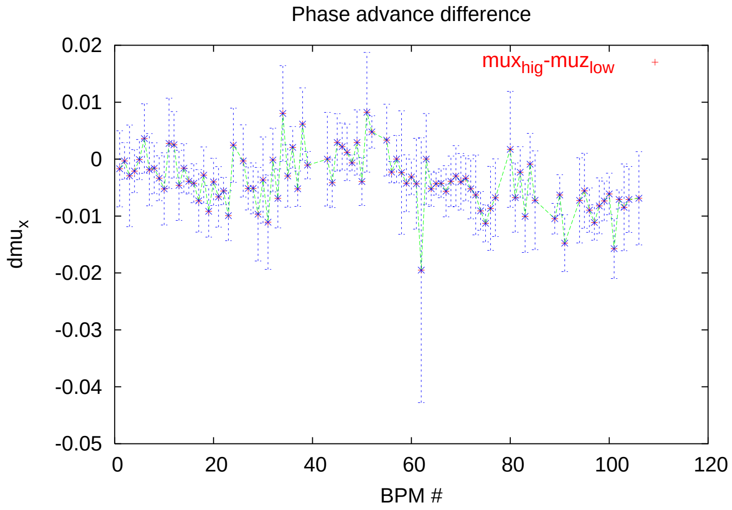


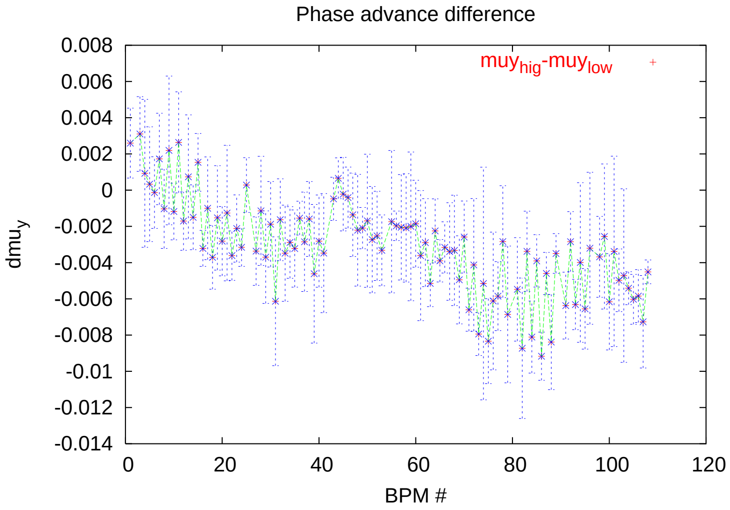
Peaks expected at 39 and 41.

Dependence of phase advance upon beam current



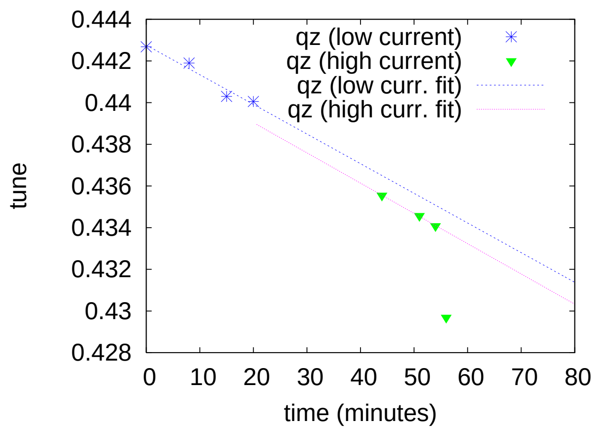
← Tunes drifting with time?





Last TBT data set has been excluded. Phases have been *rescaled* with total averaged tune corresponding to the same beam current. No large evidence of a localised reactive impedance.

Making for instance a *linear* fit of the low current vertical tune values vs. time and extrapolating, it looks as *there is* a dependence upon bunch current:



Effective transverse impedance:

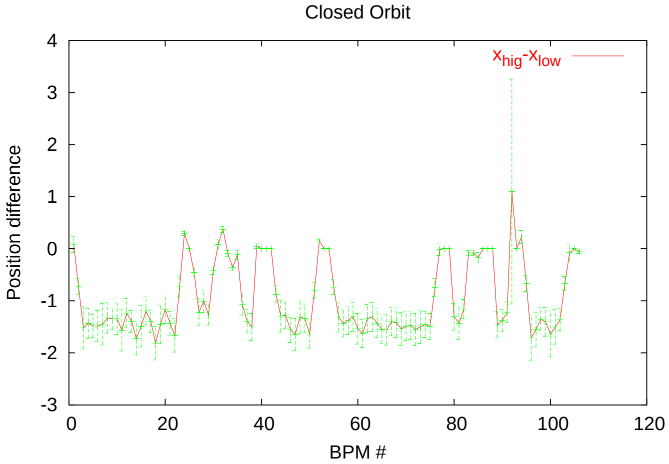
$$Z^T = \frac{E\sigma_\ell}{eR < \beta >} \frac{d\mu}{dI_b}$$

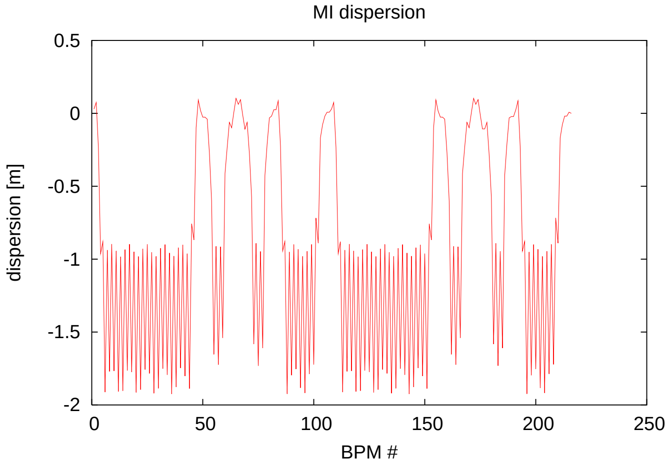
For MI at injection:

$$Z^T = \frac{8.9 \text{ GeV} \times 2.5 \text{ ns} \times 3 \times 10^8 \text{ m s}^{-1}}{528 \text{ m} \times 28 \text{ m}} \frac{d\mu}{dI_b} = 0.45 \times 10^6 \text{ V m}^{-1} \frac{d\mu}{dI_b}$$

Due to the longer bunches, the factor relating phase advance slope to the impedance is much larger when compared to lepton machines: the same impedance produces a much smaller slope. With $dQ = 2\pi \times 0.00081$ and $dI = 0.434$ mA is $Z^T = 5.3 \text{ M}\Omega \text{ m}^{-1}$ (!).

Dependence of closed orbit upon beam current



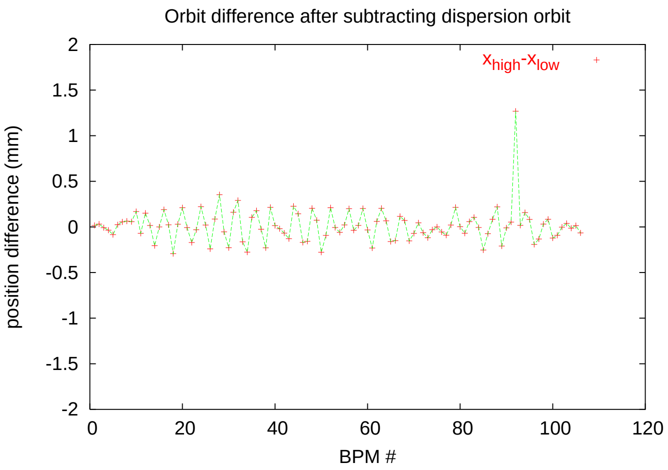


This is the horizontal dispersion: the energy of the high current beam was smaller ($\simeq 0.1\ \%$) than the energy of the low current beam?!

Fit to the theoretical dispersion:

Δt (min)	dp/p (%)	$[x_{meas} - x_{fit}]_{rms}$
8	-0.002	0.02
15	0.001	0.02
20	0.001	0.01
44	0.065	0.14
51	0.065	0.14
54	0.091	0.14
56	0.095	0.22

A *step* rather than a drift. Subtracting the contribution of the dispersion orbit:



Loss factor: $K_L = \frac{E f_{rev}}{e D_x} \frac{\Delta x_{co}}{\Delta I_b}$

For MI: $K_L < 383$ V pC^{-1}

Not a very tight upper limit...

Can the step observed in the vertical tune be explained by this energy step rather than by the beam current change? It can well be:

$$\Delta Q = \xi \frac{\Delta p}{p} \quad \rightarrow \quad \xi = \frac{2\pi \times 0.00081}{0.1\%} \simeq +5$$

A sensible number.

Conclusions

- A possible current dependence of the total tunes has been washed out by a tune drift with time. The tune drift is not related to the energy change observed in the closed orbit.
- The step observed in the tunes can be explained by the machine energy change, but as the chromaticity has been not measured, it is not known up to which amount.
- A possible closed orbit dependence upon current has been overwhelmed by a relatively large beam energy change.

What can we do better?

- For this measurement, the bunchlenght should be kept constant by increasing the RF voltage when injecting larger currents.
- Increase current range decreasing the low current.
- Lower chromaticity to get longer lasting oscillations and minimise tune dependence upon energy.
- Can we have better control of tunes and machine energy? If not, we must improve the measurement strategy: take more data, alternating low and high current.
- Suggestions?