Results of the ALBA Booster commissioning

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on behalf of the ALBA Booster commissioning team

The ALBA Booster commissioning team:

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Summary

- Injector characteristics
- Sep-Oct 2010 run: results
- Beam from linac, LTB transmission, LTB matching
- Booster DC mode:
  - w.p., tunes, orbit, lifetime…
- Booster ramp to 3 GeV:
  - capture, w.p., tunes, waveforms, orbit, chromaticity…
- Modeling: LOCO, calibrations, betas, dispersion, tunes…

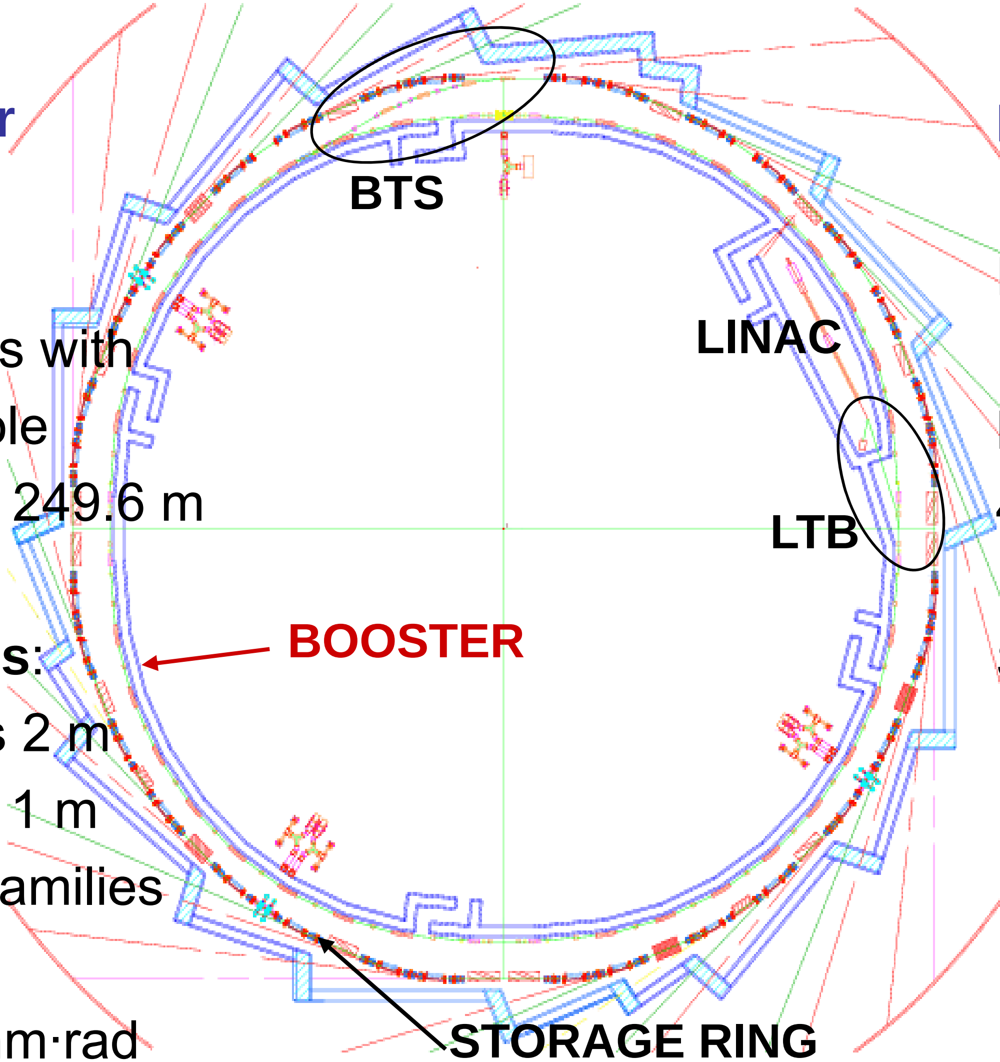
ALBA Injector

3 GeV Booster

SLS choice:
gradient dipoles with
built-in sextupole
circumference: 249.6 m

4 superperiods:
32 long dipoles 2 m
8 short dipoles 1 m
60 quads in 4 families

Emittance 10 nm·rad
Power supplies at 3 Hz



Linac 110 MeV

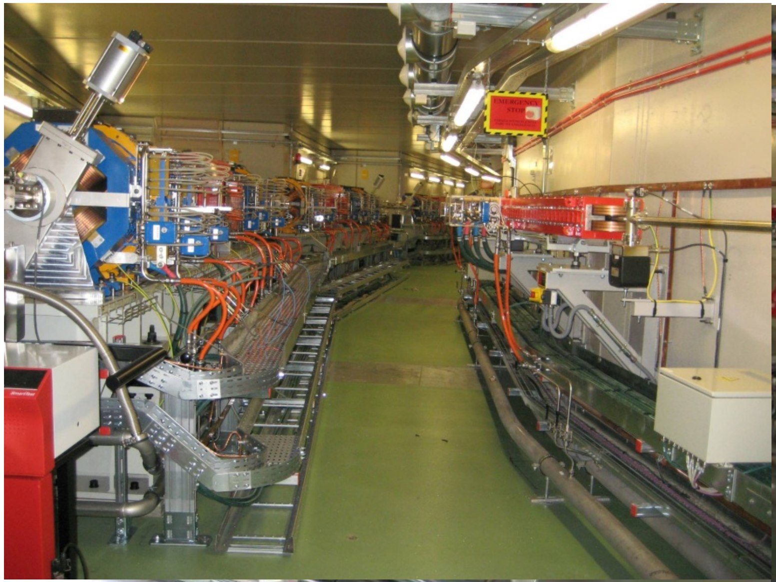
Repetition rate 3 Hz

Multi bunch mode:
4 nC in 112 ns

Single bunch mode:
1 nC in 4 pulses (2ns)

Same tunnel as the SR

Arcs

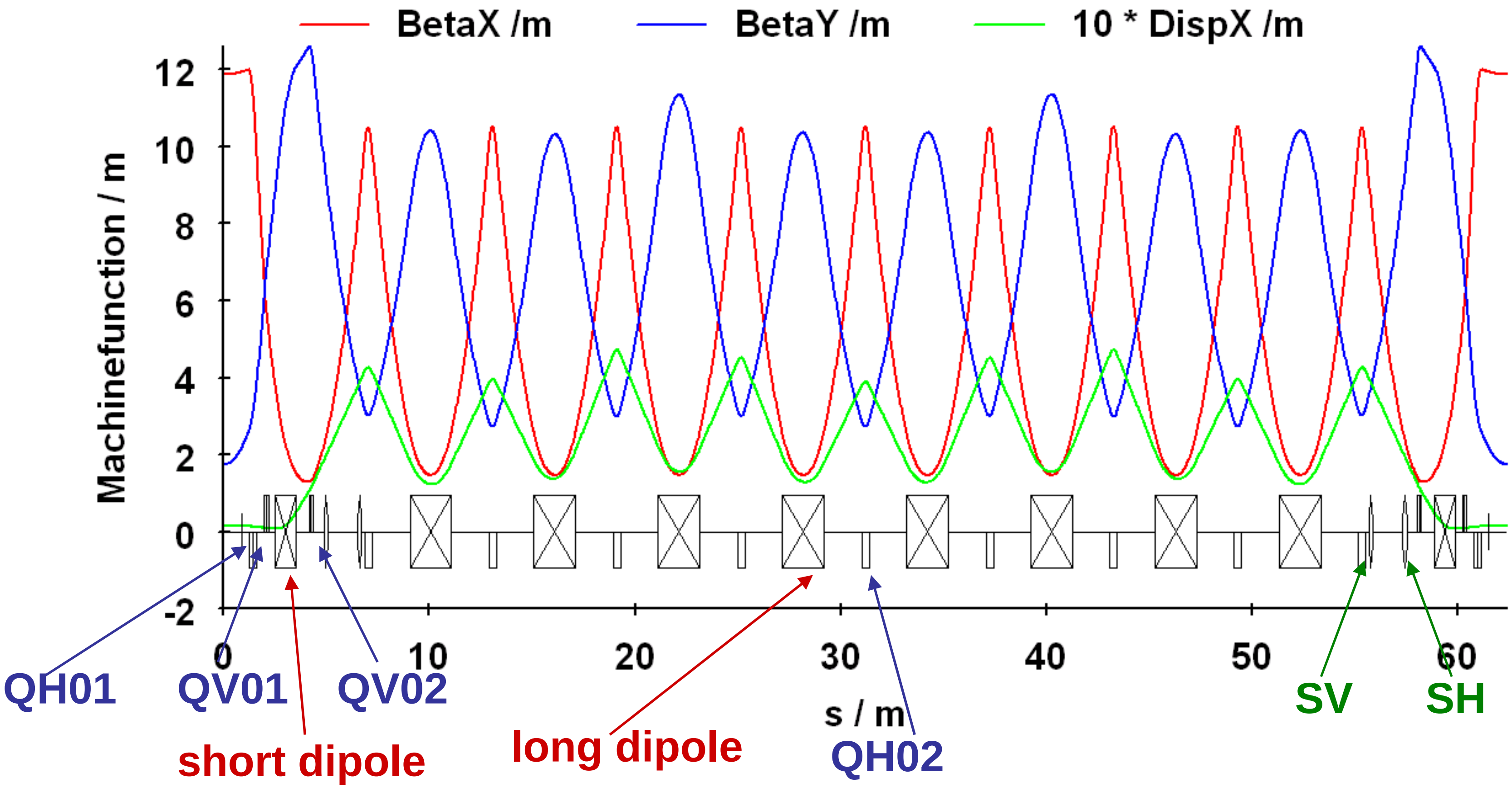


RF Cavity (PETRA)

Injection

Extraction

Booster: design optics



the design working point is Q_x = 12.42, Q_y = 7.38

Commissioning: run Sept-Oct 2010

In the 4 weeks of run (shifts from 14:00 to 22:00) the first beam at 3 GeV was achieved.

The best transmission efficiency:

- LTB transfer line: 75%
- Booster capture (first 1000 turns): 60%
- Booster ramp:
  - with correctors in DC: 70%
  - with correctors ramped: 100%
- Overall LTB-Booster (correctors ramped): 45%

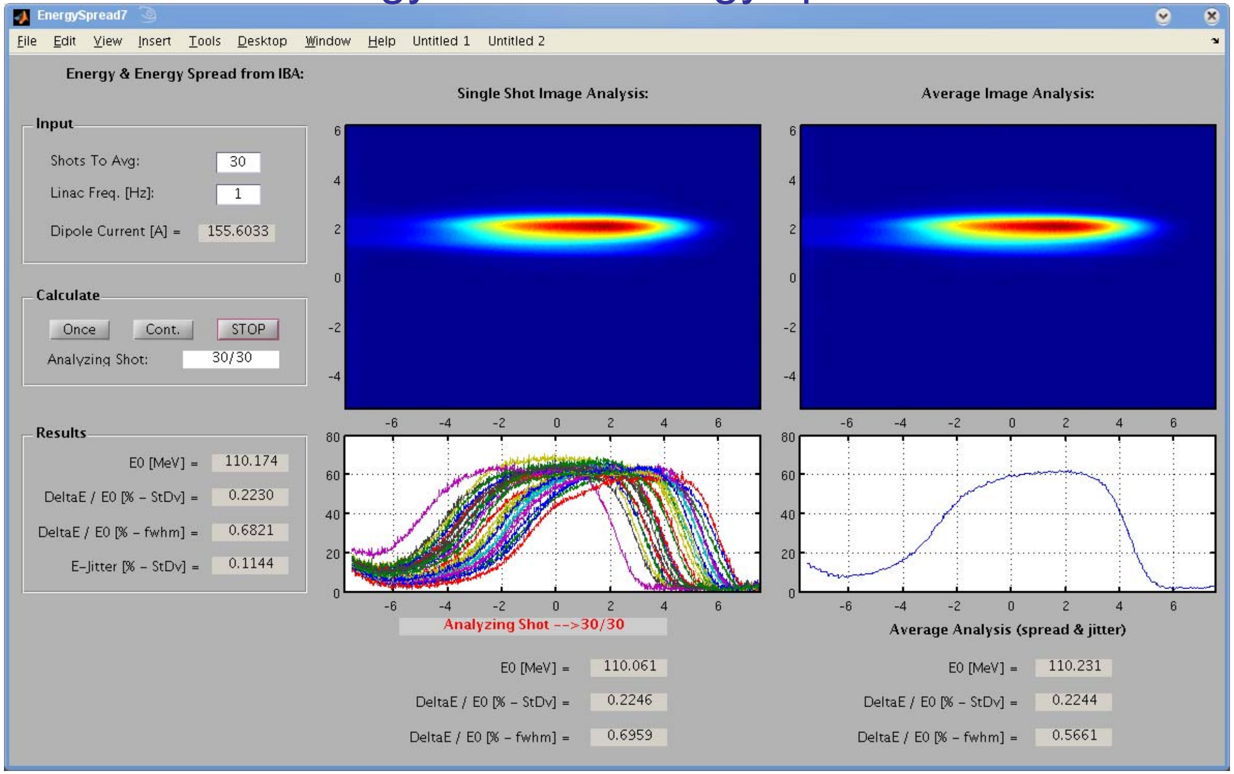
Matlab Middle Layer use

Extensive use of MML:

- turn-by-turn data treatment
- tune measurements in DC and ramp
- response matrix measurements
- orbit correction
- dispersion measurements
- many scripts written on the fly during shifts
- modelling (magnet calibrations along ramp)
- LOCO…

Beam from Linac: energy and energy spread

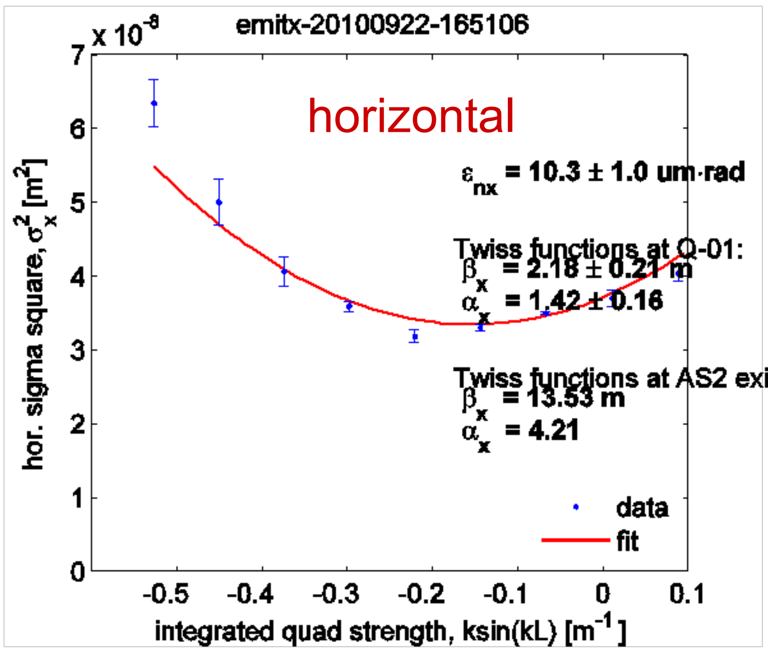
the calibration of a bending and the horizontal profile at a dispersive screen monitor are used to measure the energy and the energy spread:

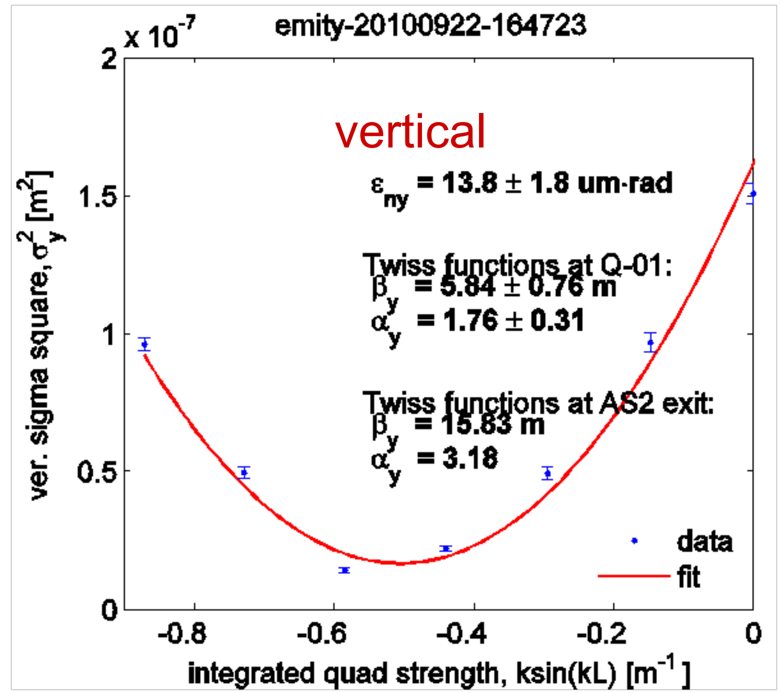


E = 110.0 MeV, σ_E/E = 0.25%

linac energy stability during the run ±0.3 MeV

Emittance and Twiss parameters measured with the quad scan techinque

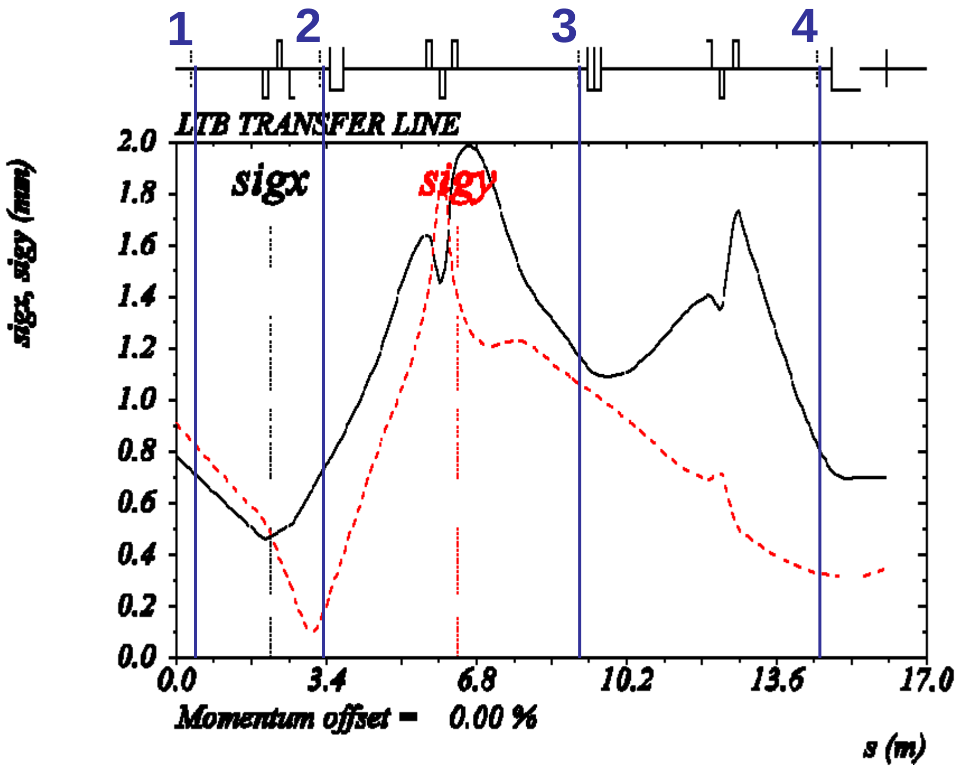


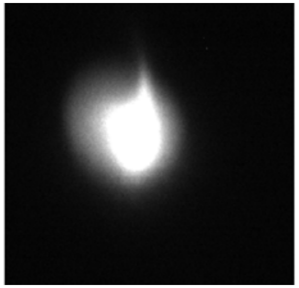


normalized emittance: ε_{xn} = 10 μm·rad, ε_{yn} = 14 μm·rad

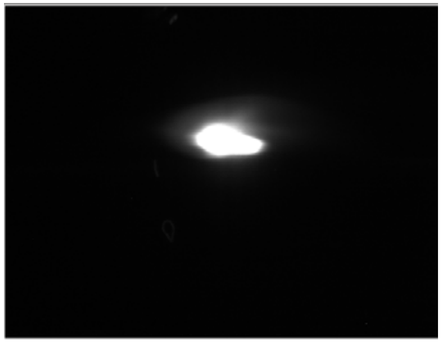
repeatability within 30%

LTB: optics matching at screen monitors

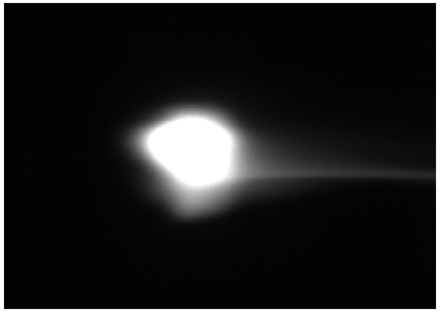




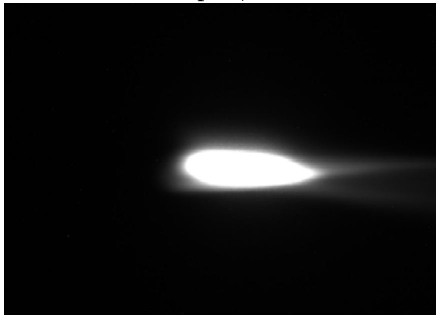
1) LI-FS03 (Linac exit)



2) LT01- FSOTR01 (after first quad triplet)



3) LT01- FSOTR02 (after BEND-01 and second quad triplet)



4) LT01-FSOTR03 (after BEND-02 and third quad triplet)

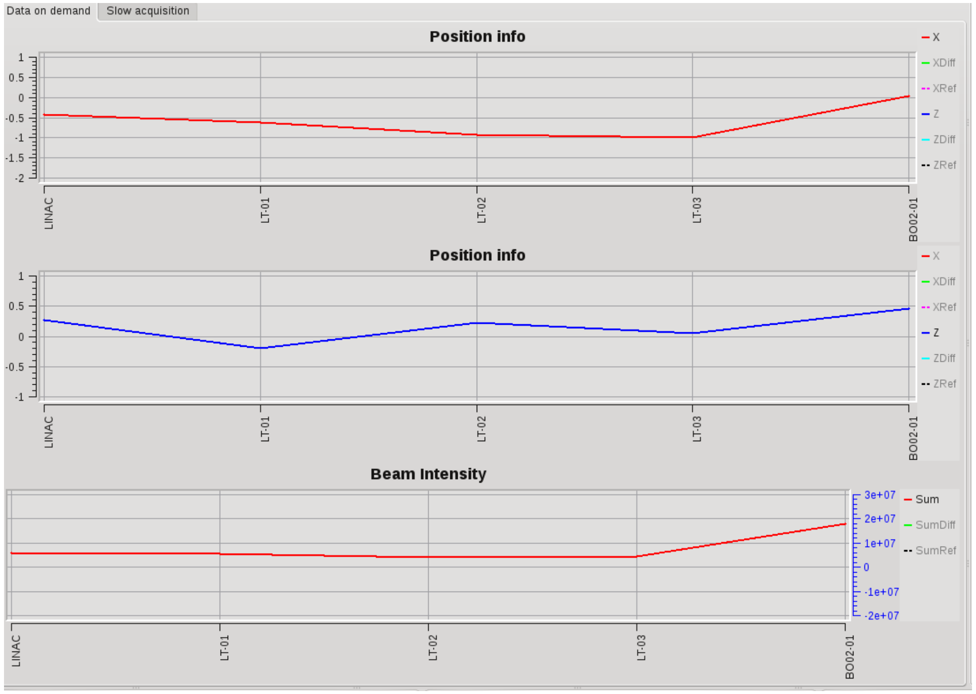
rms beam sizes measurements at FSOTR monitors along the line are in good agreement with the matched optics

LTB trajectory GUI

horizontal position

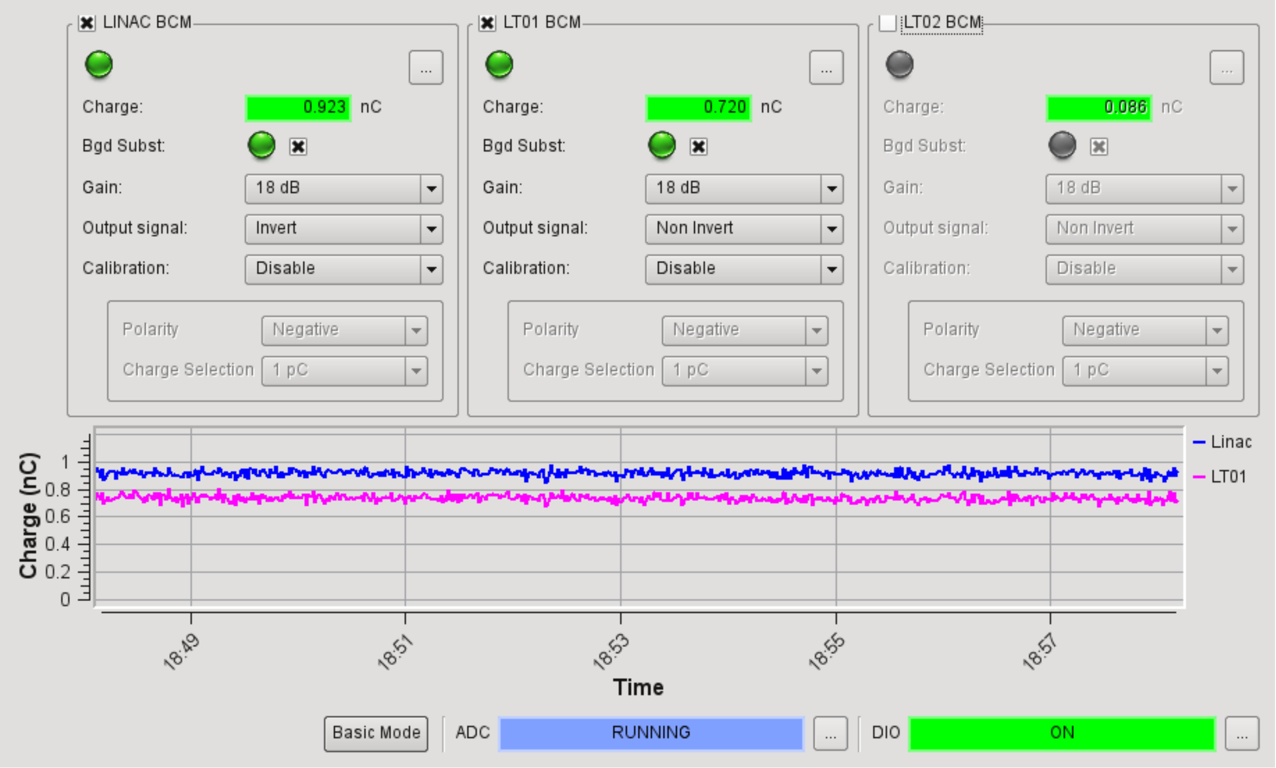
vertical position

intensity



trajectory kept within ±0.5 mm in both planes with a pair of H/V correctors upstream of each quad triplet and a BPM downstream

BCM GUI



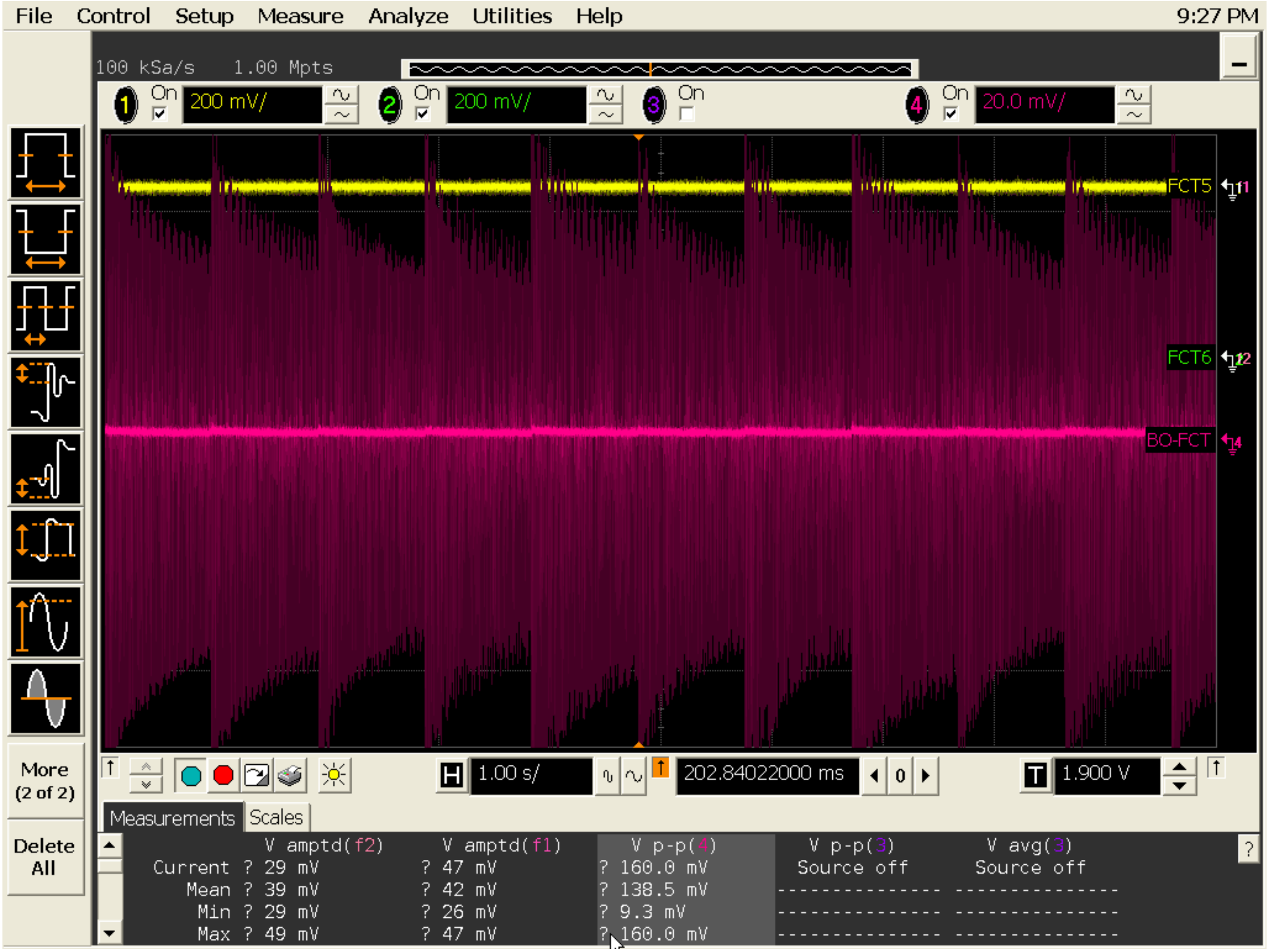
beam transmission measured at 2 BCMs: 75%

(does not agree with the measured beam losses at detectors: BCM calibration…)

Booster: DC mode

- DC operation at 110 MeV to set the injection pulsed magnets and correct the orbit.
- Capture of the beam at the design w.p. (12.42, 7.38) was impossible because of the large horizontal orbit distortion.
- First w.p. was set empirically at (12.63, 7.23) and the orbit corrected using a measured response matrix.
- Next, succeed to move to the design w.p. (12.42, 7.23).
- Beam capture efficiency of 60%
- Performed measurements of tunes, dispersion, lifetime. (chromaticity in DC was impossible).
- Modeling with LOCO

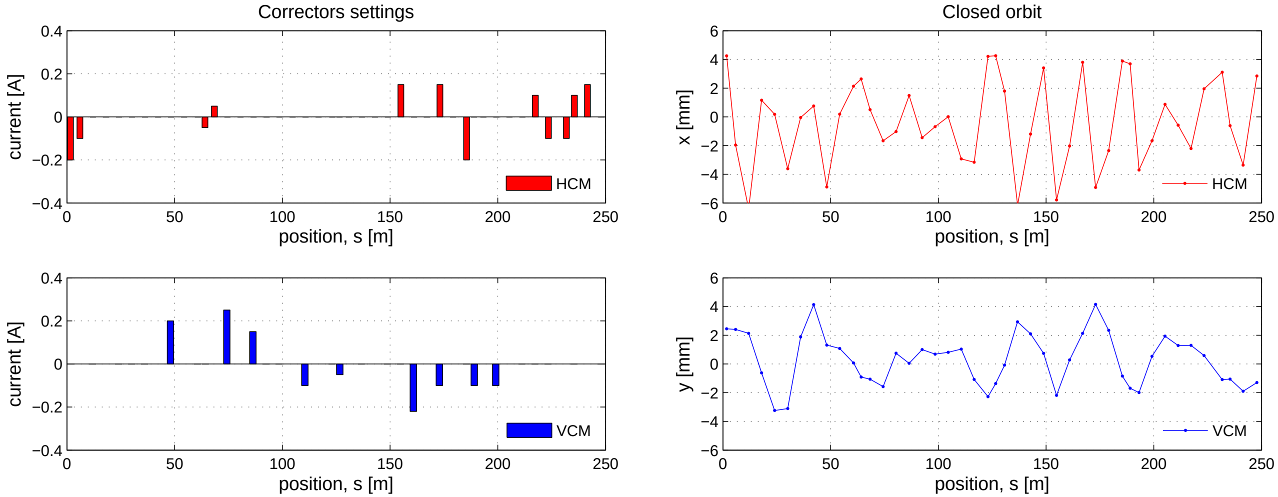
Beam stored in DC 110 MeV



FCT signal: 1 Hz injection

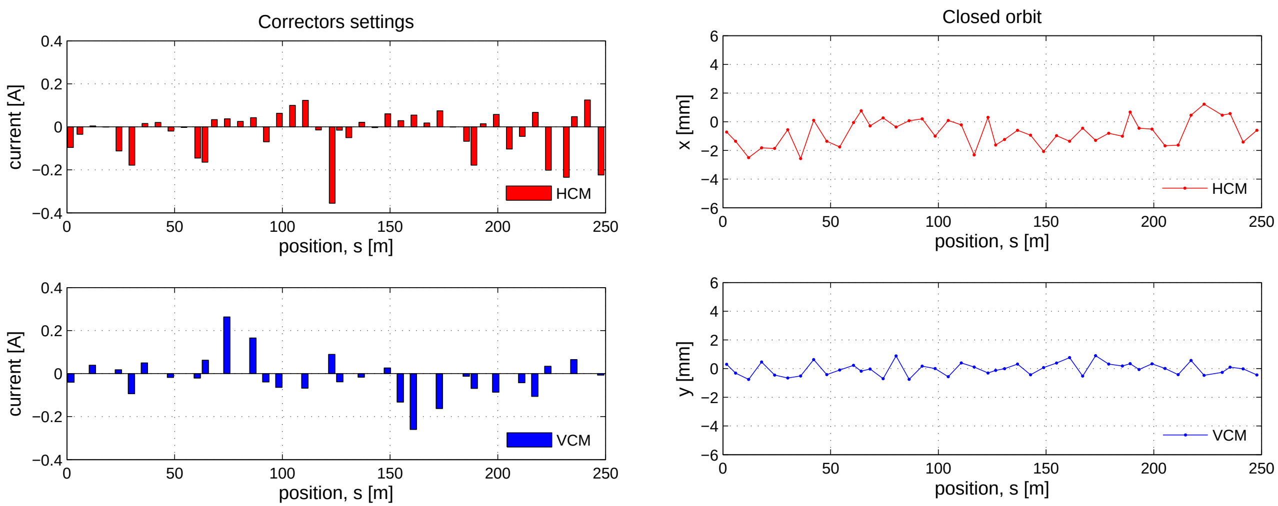
DC mode: orbit correction

first orbit before global correction



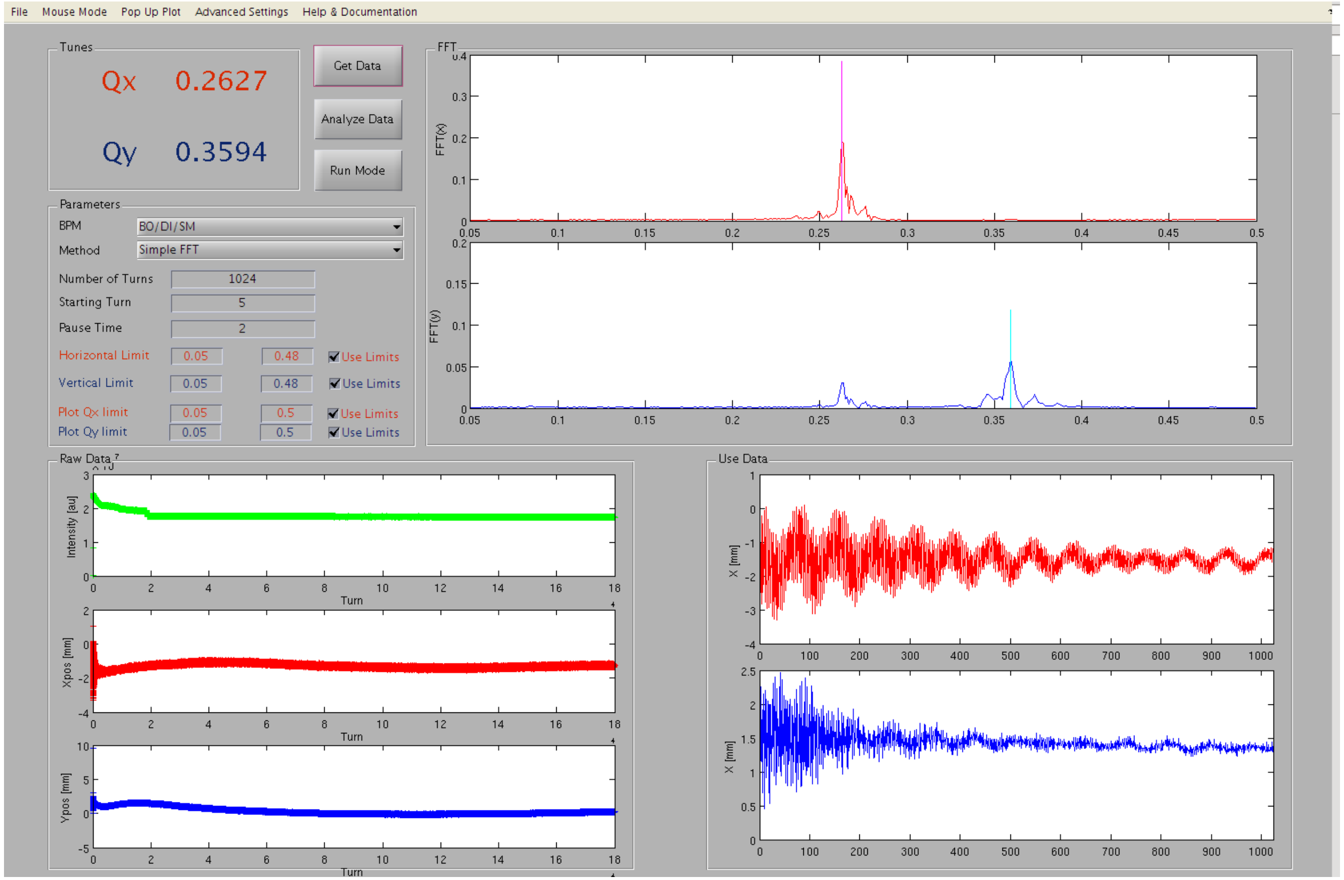
injecting w/o any horizontal corrector was impossible

after global correction



horiz. correctors in the 4 straight sections and in the 4th sector are stronger

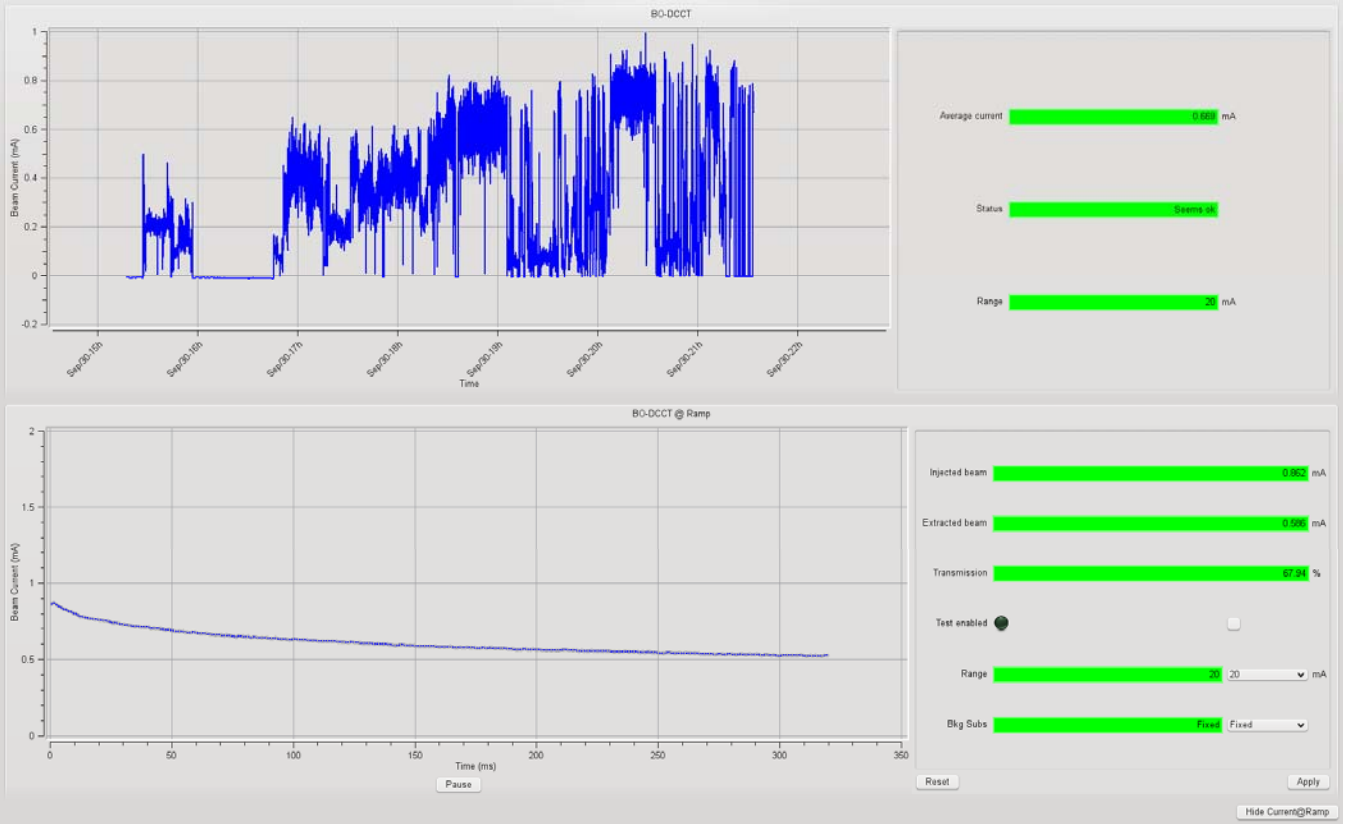
Tune measurement application (Matlab)



turn-by-turn data analysis from stripline or BPMs

Efficiency and lifetime at 110 MeV

DCCT monitor

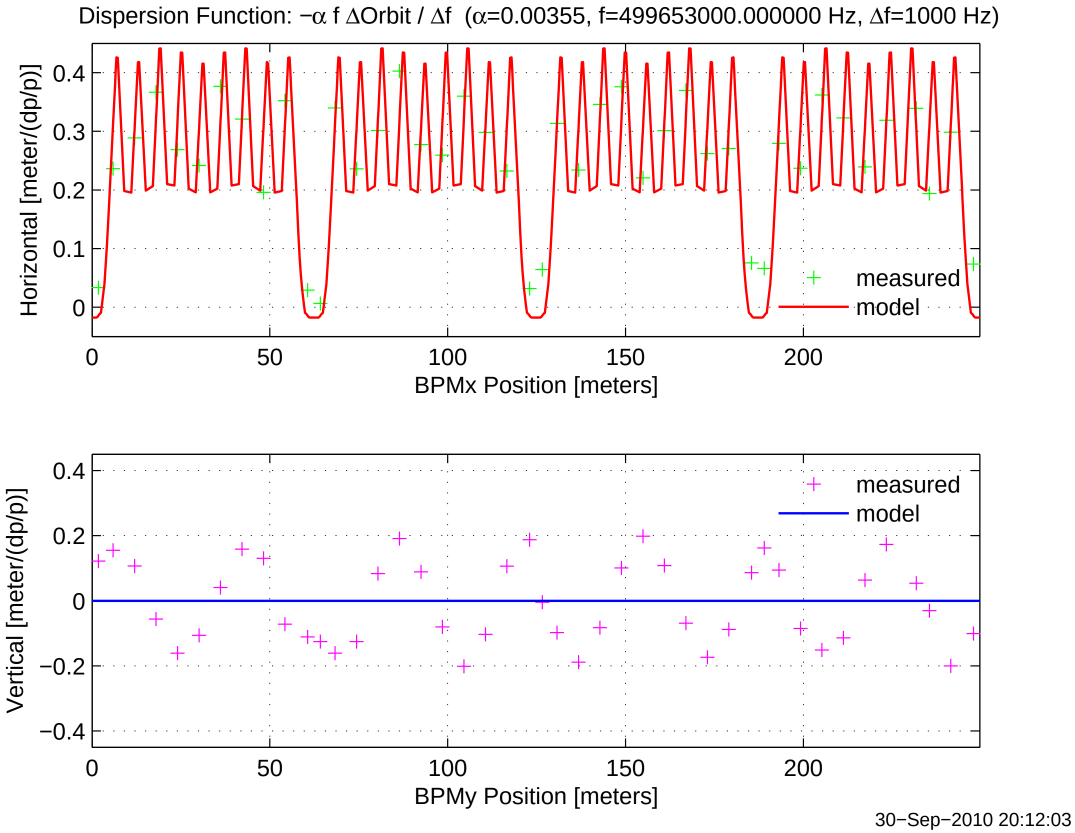


capture efficiency of 60%

lifetime better than 1 s in agreement with what was expected

Dispersion measurement

dispersion measured varying the RF



horizontal dispersion agrees with the model

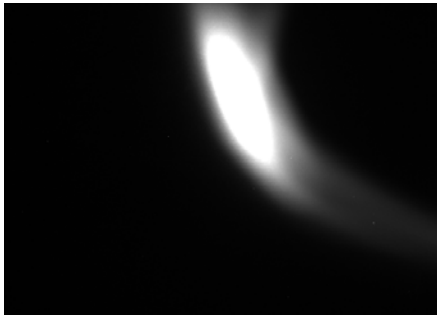
large vertical dispersion due to coupling

Booster: ramp mode

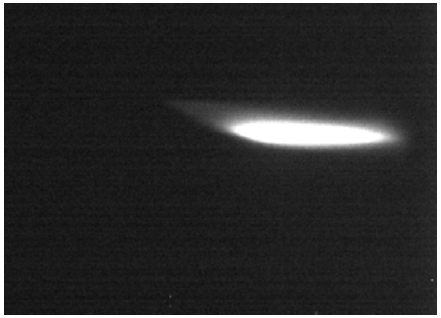
- Injecting in the design w.p. (12.42, 7.32). Sinusoidal waveforms in the power supplies. Resonances crossing and horiz. orbit blow-up leaded to ramp efficiency of 60%.
- Moved to (12.26, 7.38). Sinusoidal quad waveforms corrected at two points to keep the tunes constant. Correctors in DC. Resonances avoided → stable beam, BUT still large horiz. orbit blow-up (±8 mm). Ramp efficiency 70%.
- Correctors ramped → orbit reduced to ±2 mm. Ramp efficiency 100%.
- Open points:
  - Ramping horizontal correctors is needed
  - Capture efficiency stays around 60% under any condition

Optics matching

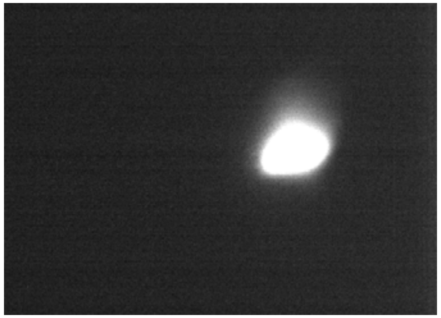
first turn beam at booster screen monitors



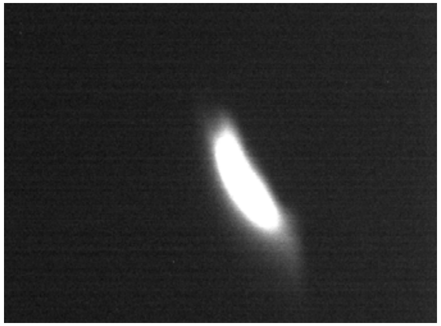
1) FSOTR-BO0201 (downstream of the injection point and the short bend)



2) FSOTR-BO0301 (in the free dispersion straight section between quadrant 2 and 3)



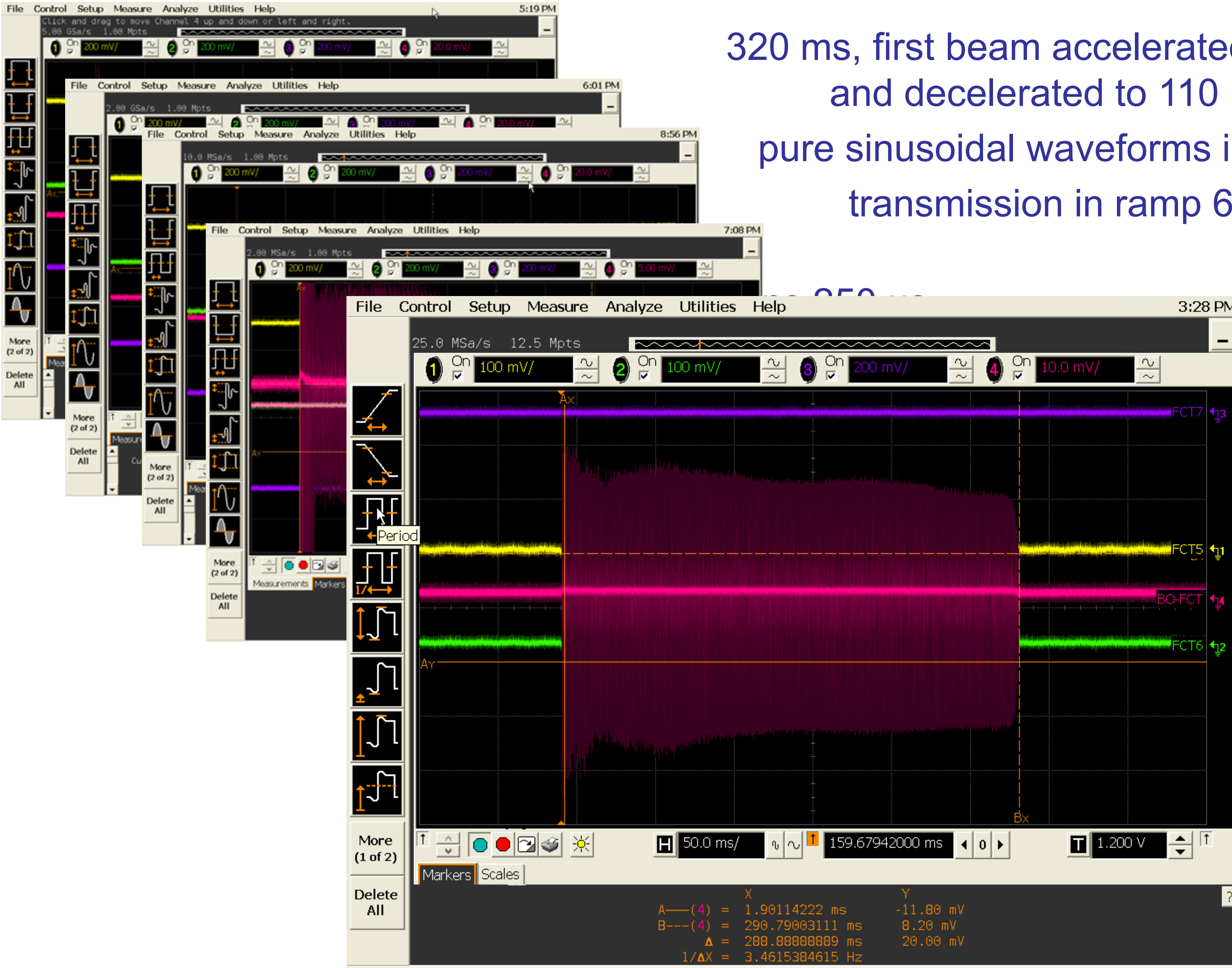
3) FSOTR-BO0401 (after the extraction kicker)



4) FSOTR-BO0101 (upstream of the injection point and the short bend)

agreement with optics model is not good, but it seems we have a closed optics in the first turn

Energy ramp: first beam at 3 GeV

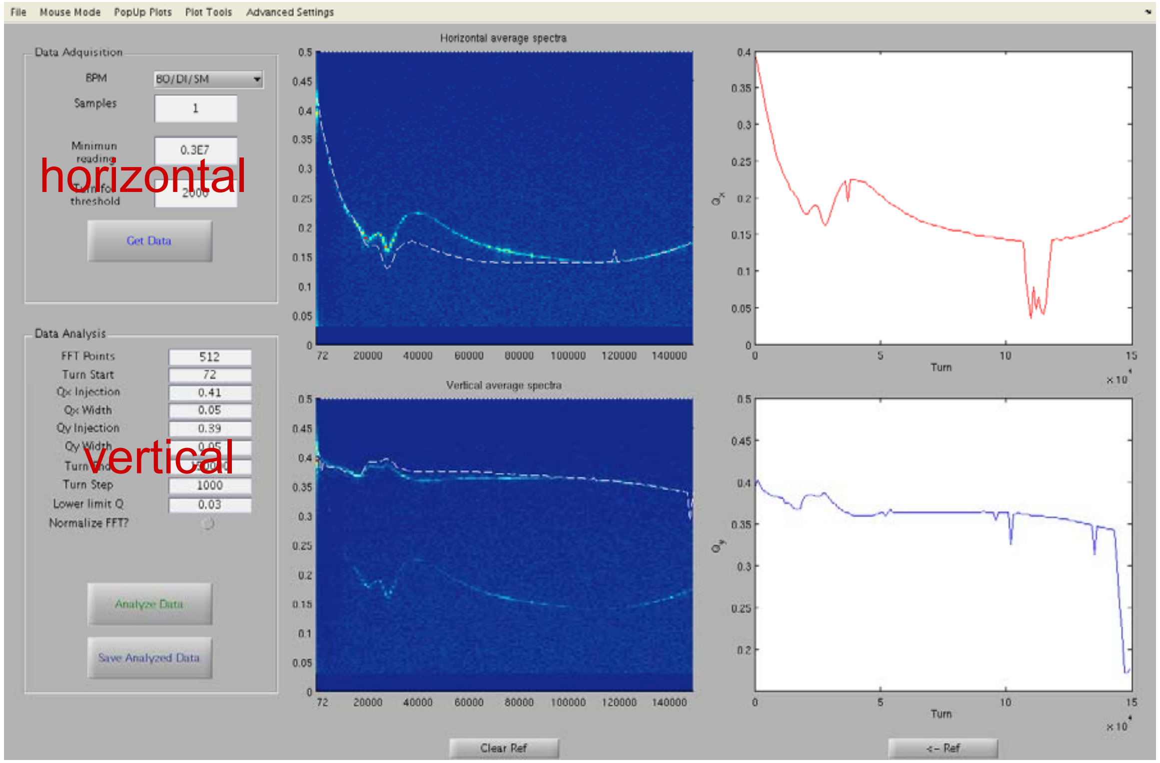


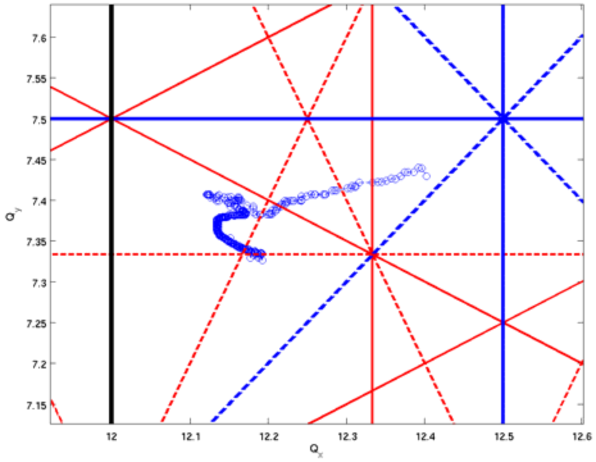
320 ms, first beam accelerated to 3 GeV and decelerated to 110 MeV

pure sinusoidal waveforms in the PC

transmission in ramp 60%

Tune ramp application: turn-by-turn data analysed with Matlab



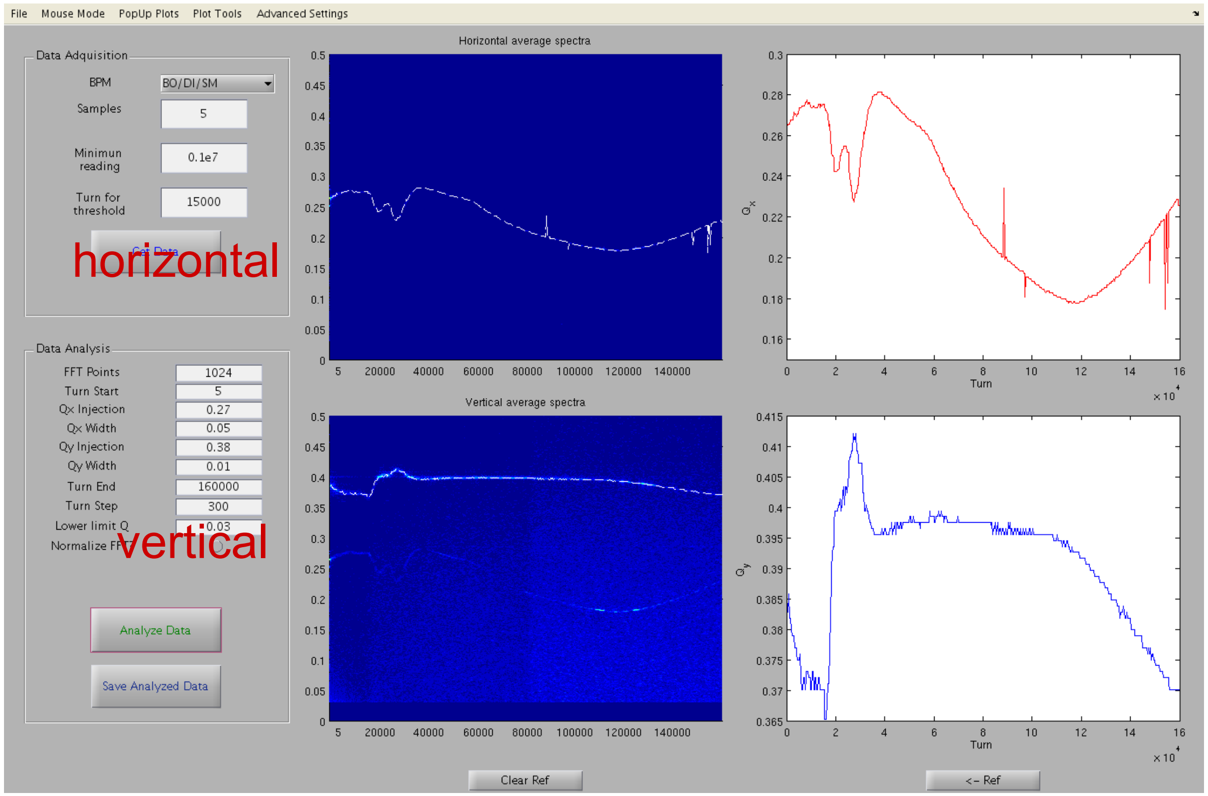


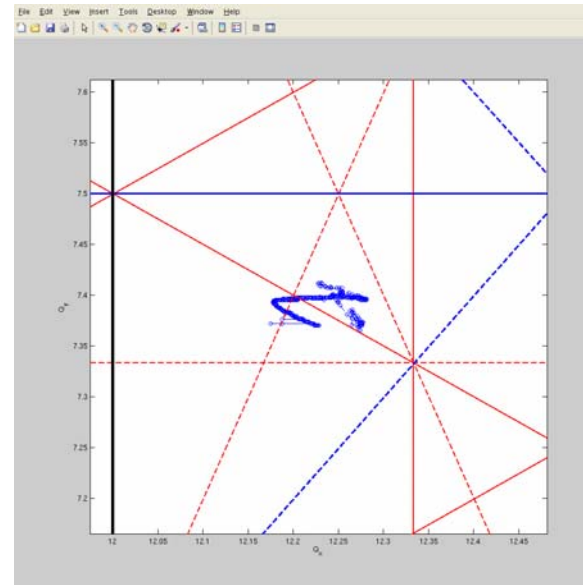
first beam to 3 GeV: injection on w.p. (12.42, 7.38)

large drop of horiz tune at the start due to PS tracking and nonlinear quad calibration

vertical tune is flat: most of the vertical focusing is provided by the gradient bending moved to (12.26, 7.38) to avoid resonances

sinusoidal waveforms of 2 quads corrected at 2 points to make tunes flat



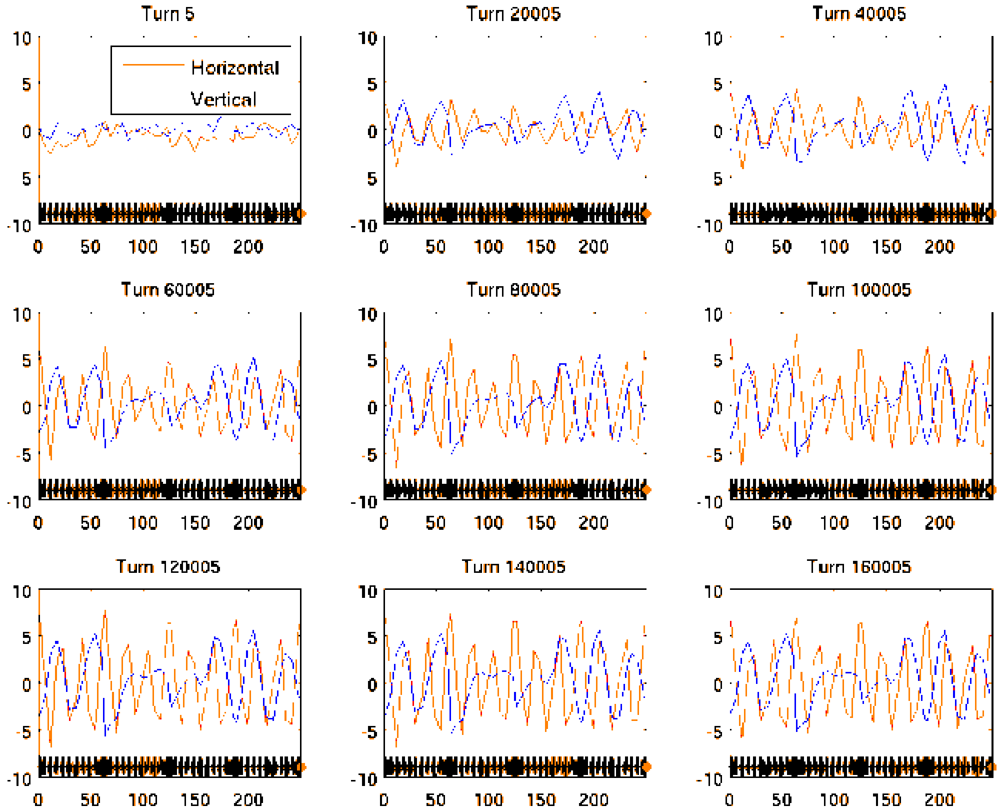


ramp transmission improved only to 65%:

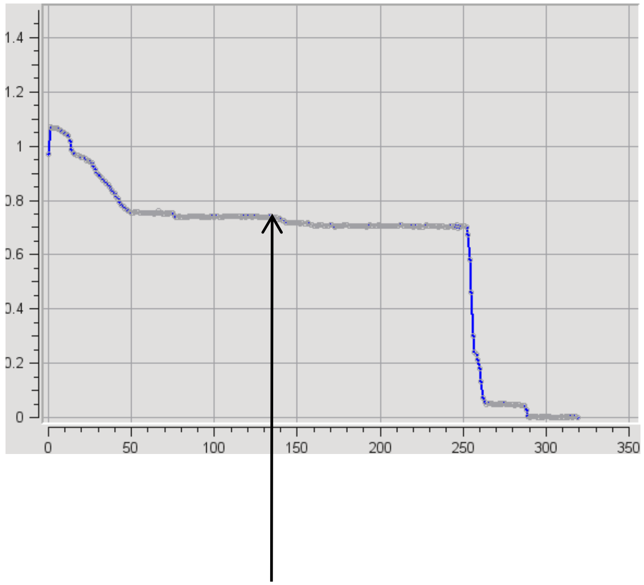
the problem was not due the resonance crossing

Transmission with correctors in DC

orbit blow up in ramp, especially horizontal ±8 mm



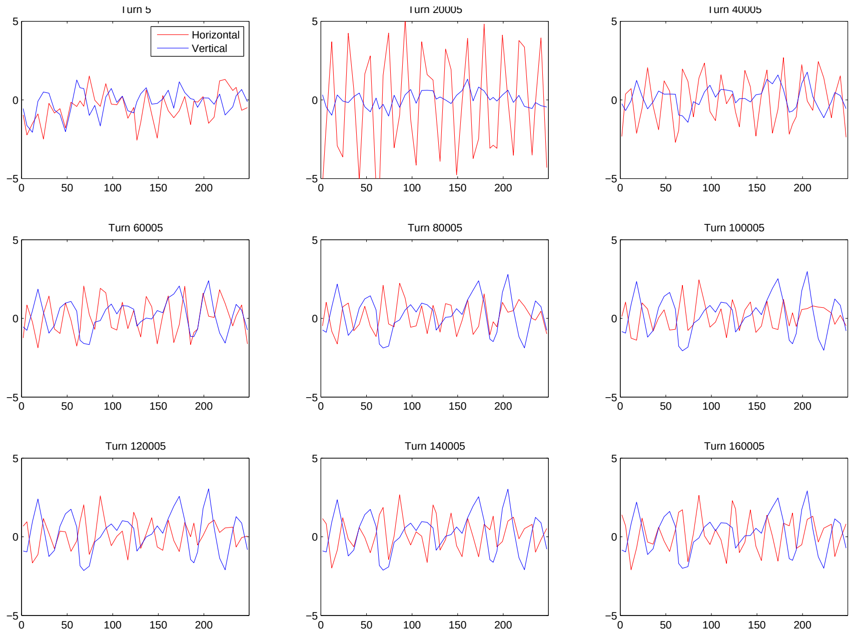
DCCT transmission



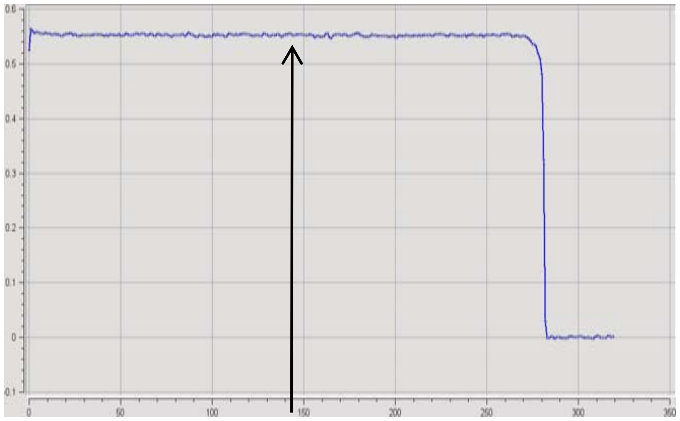
35% of the captured beam is lost in the first 50 ms (60000 turns)

Transmission with ramped correctors

orbit corrected to ±2 mm along the ramp



DCCT transmission



3 GeV

ramping the correctors, beam transmission during ramp 100%

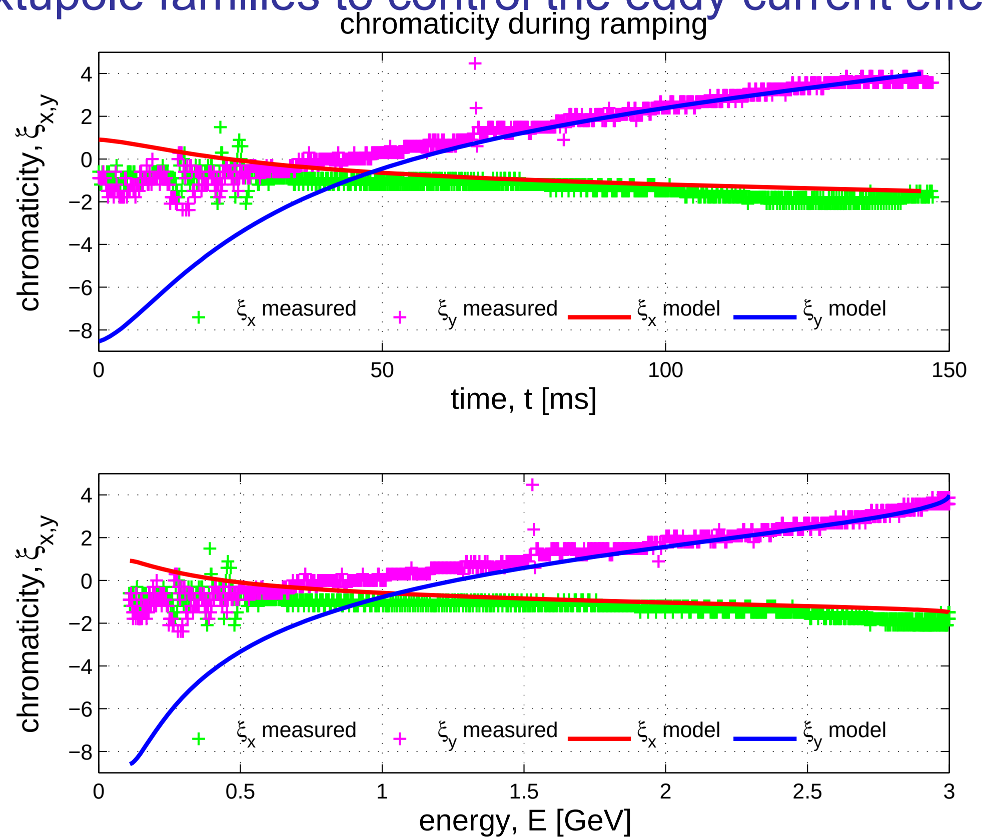
→ the problem came from the orbit

Chromaticity and sextupoles

Chromaticity was measured during ramp by varying the RF

Integrated sextupole component into combined bendings corrects natural chromaticity

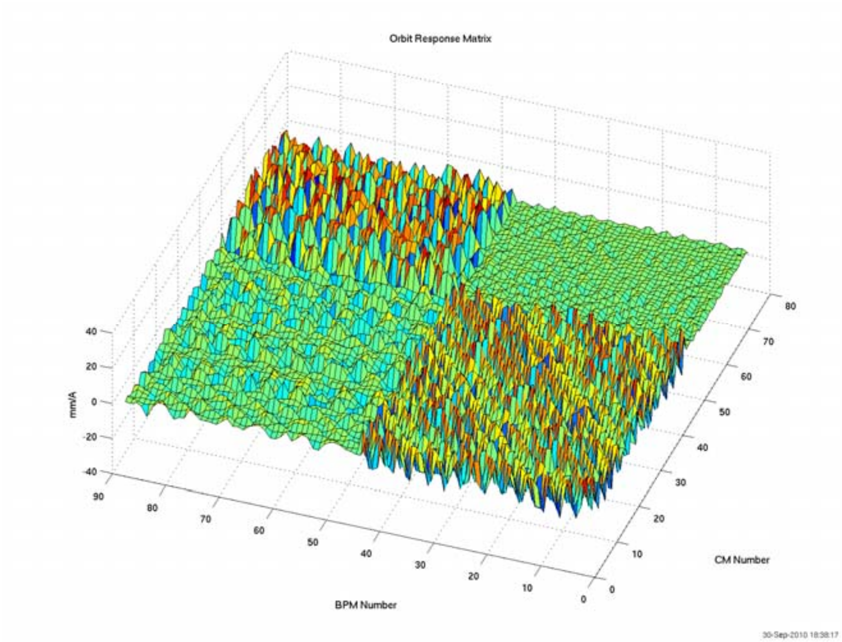
The two additional sextupole families to control the eddy current effects no needed so far

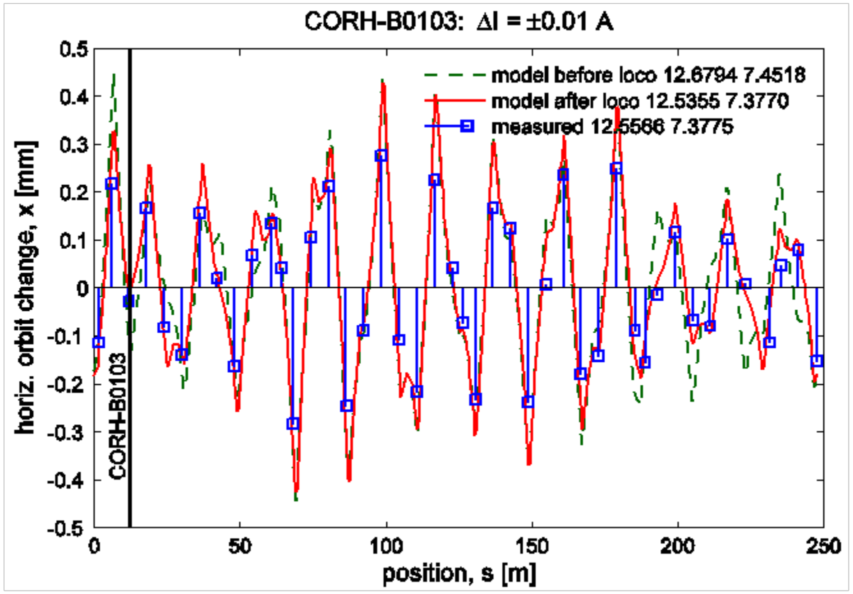


the measurements agree very well with the model at energy higher than 1 GeV while at low energy chromaticity is hard to be measured (still investigating)

Modelling with LOCO

several orbit response matrix were acquired in DC mode



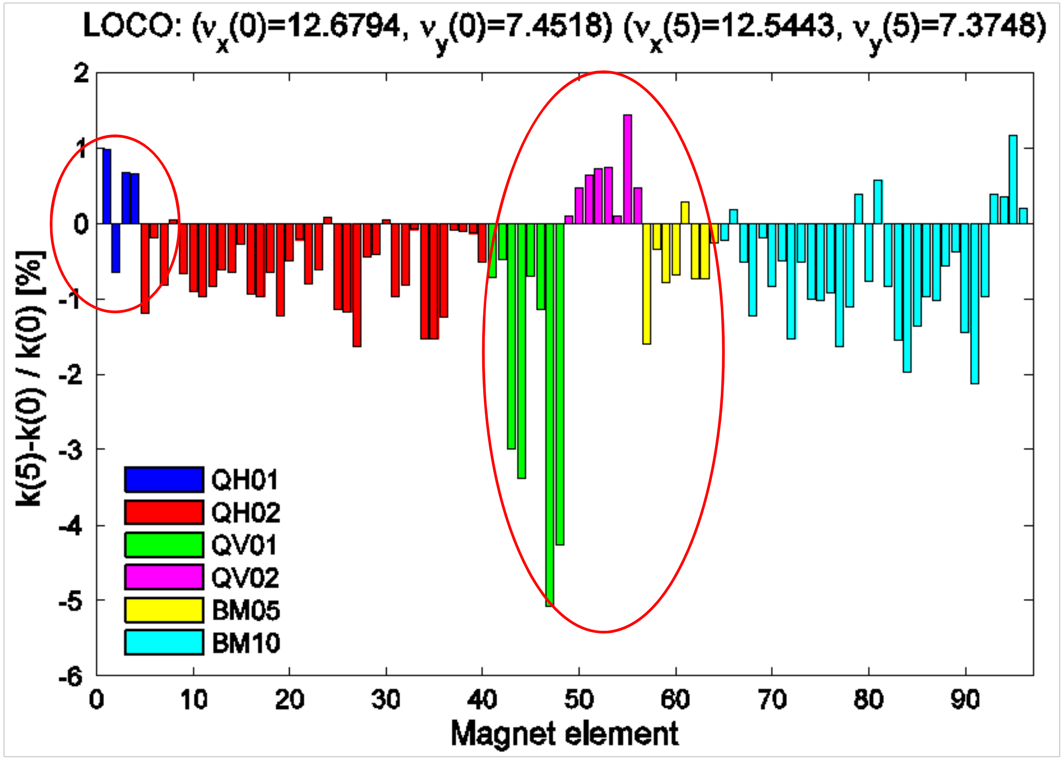


LOCO was used to correct the gradient calibrations (very useful with 4 quad families and especially for combined function magnets).

- confirm the integer tunes that were not clear at the beginning
- change the working point relaying on the model
- calculate quad waveforms that gives the expected tunes

LOCO fit by single magnets

gradient calibrations of quadrupoles and combined bendings

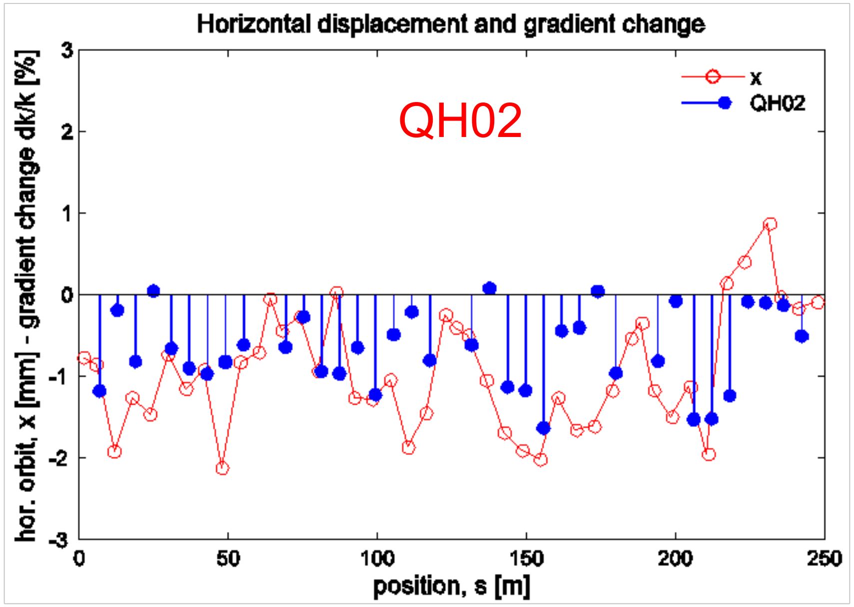


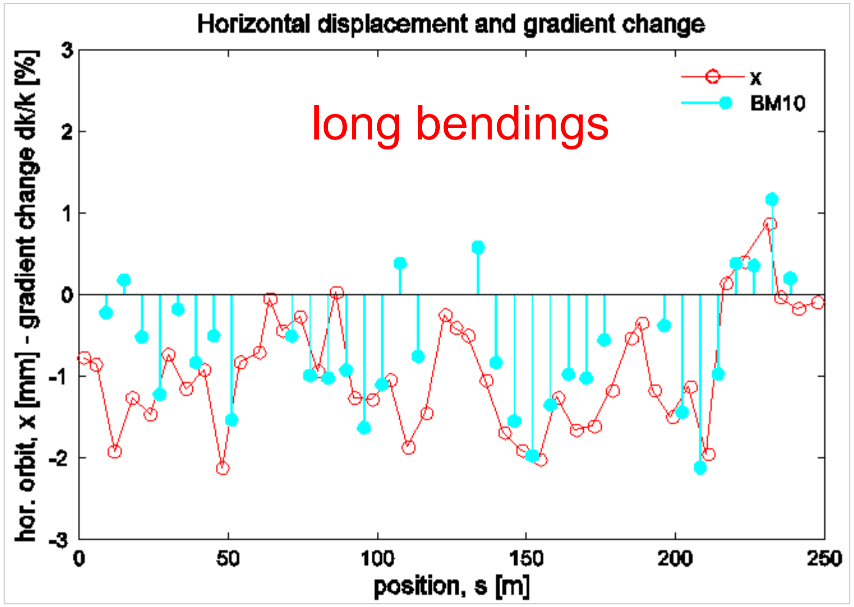
BPMs are close to QH02 and long bendings and loco corrections make sense because of they have a built-in sextupole component.

QH01, QV01, QV02 and short bendings are very close w/o BPMs in between, Loco corrections compensate each other and are an artifact of the fit.

Orbit offsets and sextupole component

correlation between horizontal orbit and gradient change found by LOCO in QH02 and bendings with integrated sextupole component

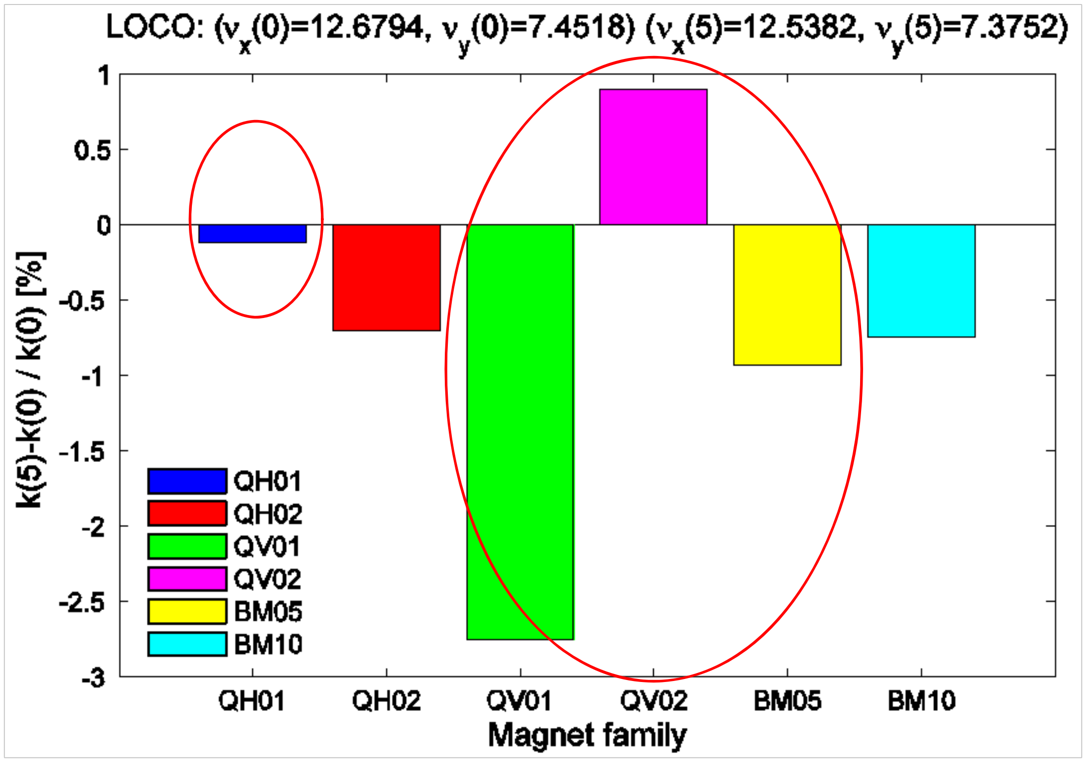




(the horizontal corrected orbit displaced towards negative values has to be understood)

LOCO fit by family magnets

gradient calibrations of quadrupoles and combined bendings



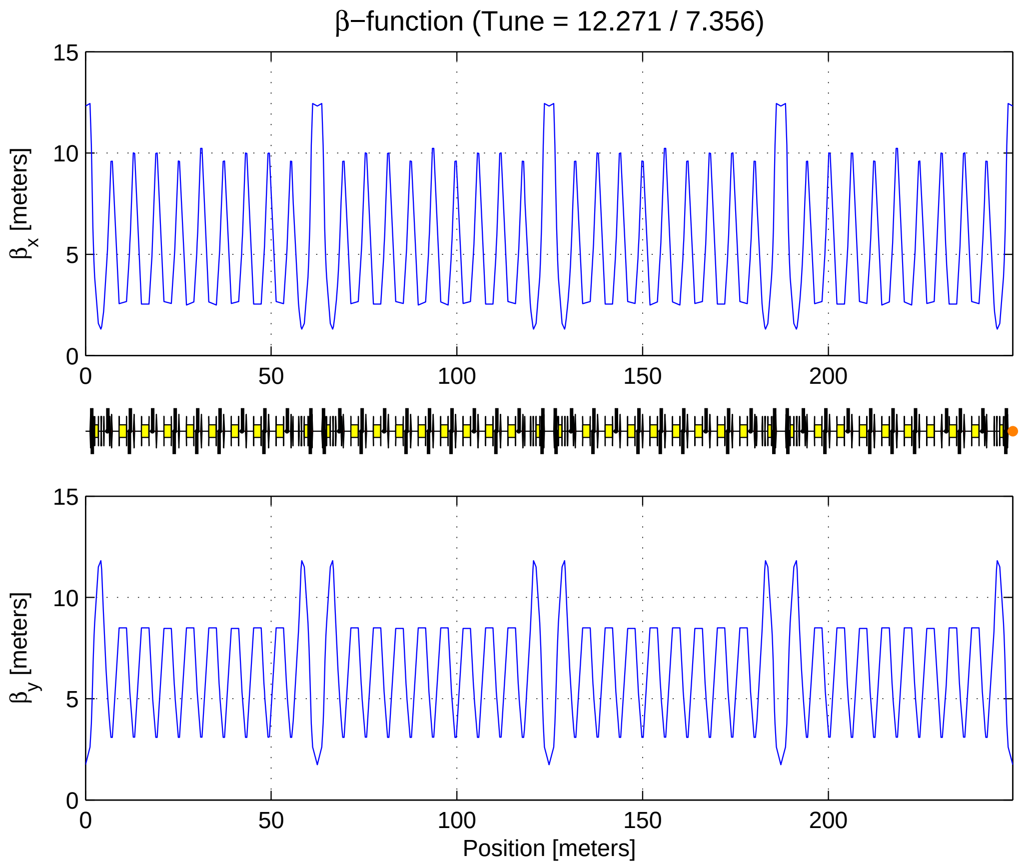
Results in agreement with the single analysis.

QH02 and long bending corrections were introduced in the model.

QH01, QV01, QV02 and short bendings were not.

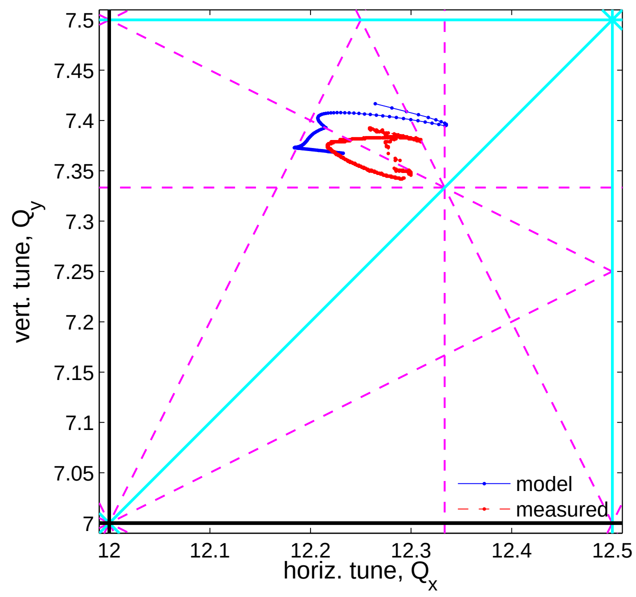
LOCO: beta functions

Beta functions reproduced by the model calibrated with LOCO are very close to the design values

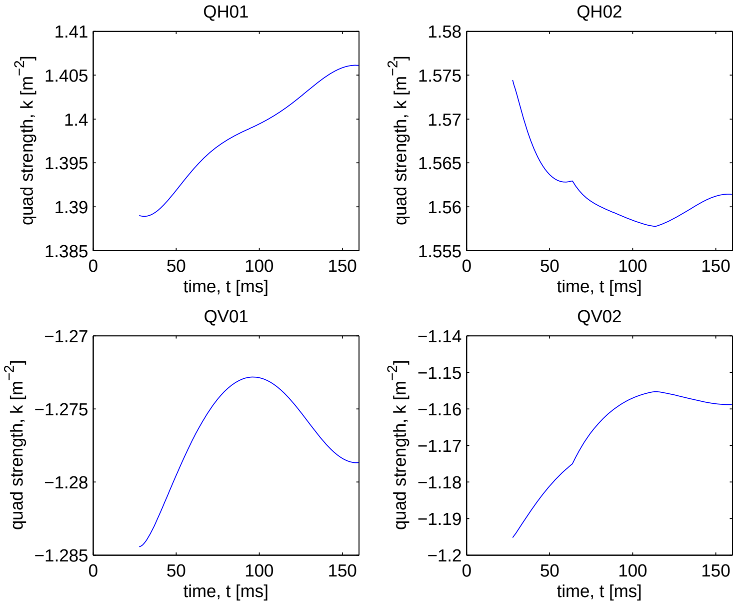


Tunes and quad strengths along the ramping

mesasured-model tunes comparison



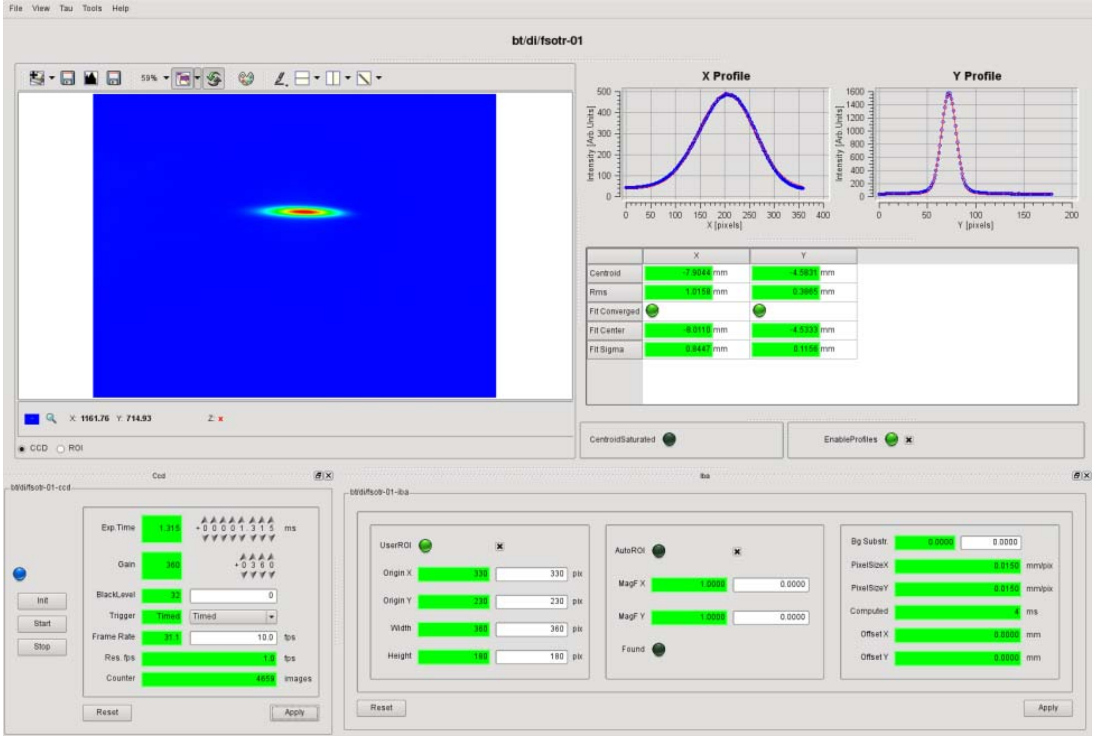
model quad k-values along the ramping according to the calibrations



the model of the booster optics in the ramping has a good agreement both at low and high energy, this is very useful to set the power supplies waveforms

Extraction: emittance

Extraction at full energy was texted with success and the emittance at 3 GeV measured at the first Booster to Storage Ring transfer line screen monitor.



a natural emittance of 13.8 nm·rad and coupling of 14% were measured (theoretical emittance was 11.0 nm·rad)

Conclusions

- The full energy of 3 GeV was achieved
- Capture efficiency has to be improved
- Horizontal orbit problem (large distorsion and ramped corrector) must be solved
- Tracking of the power supplies must be understan better
- Many machine studies were carried out and the model is very accurate
- The ALBA injector is ready for the Storage Ring commissioning

Test in progress to study the horizontal orbit…

The large horizontal orbit distorsion can due to the two families of dipoles (short bending 5° and long bending 10°) sharing the same power supply.

In the short dipole an integrated field of -0.5% wrt to the design was measured (only one magnet).

Last Tuesday we was able to inject with all the horiz correctors off but the 8 correctors next to the short dipoles set at the same value (-0.6% of the short intgrated field).

If this is the reason of the low capture efficiency, optimizing the phase advance between the short bendings (moving the w.p.), the horizontal orbit distorsion could be reduced to only the randon alignment contribution. Now we are performing tests and working on this problem.

“Bare” orbit

Horizontal orbit obtained with only the 8 CORH in the straight sections at -1.7 mrad