Next Generation Beam Position Acquisition and Feedback Systems

ALBA Synchrotron, 12-14 November 2018

Suppression of the injection perturbations using feed-forward techniques

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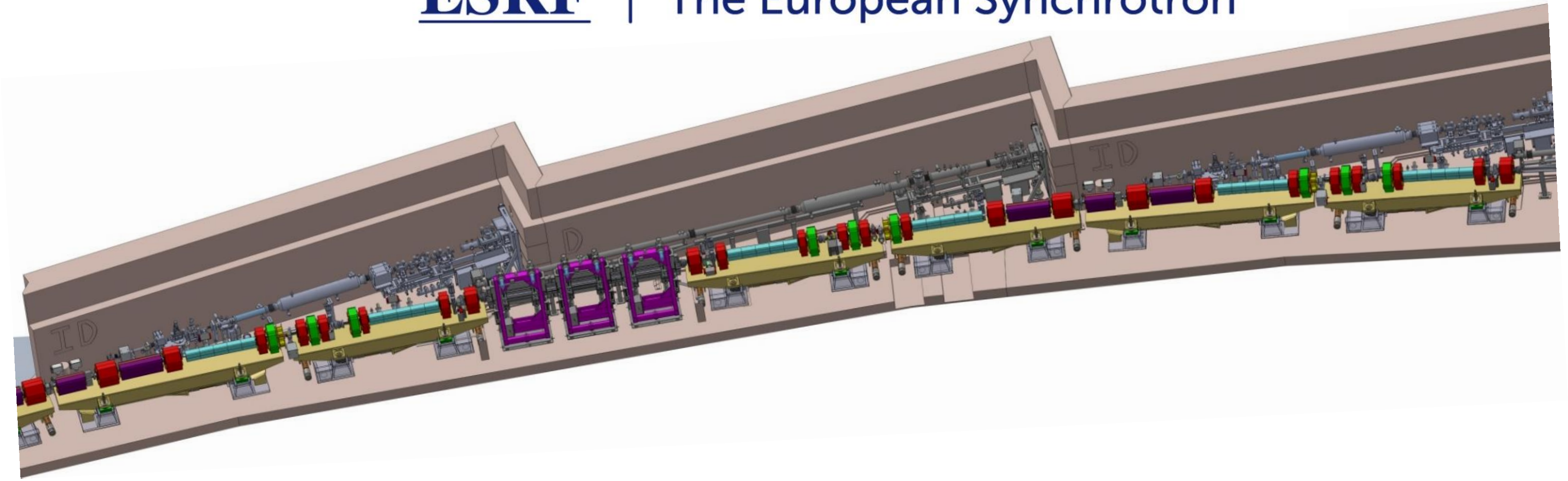
ESRF | The European Synchrotron



MOTIVATION OF OUR DEVELOPEMENTS

TOP UP OPERATION
(one refill every 20 minutes instead of twice a day)

⇒ we need to address a new kind of beam position perturbation;
The injection system (kickers and septum) causes
beam position oscillation which is perturbing our users experiments.

- Specificity:

Reproducible shape , triggered by the injection .

MOTIVATION OF THIS TALK

I DO NOT PRETEND THAT ANYTING IS REALLY
TECHNICALLY ORIGINAL IN OUR SYSTEMS

BUT I THINK IT IS INTERESTING TO PRESENT
THIS APPROACH IN THE FRAME OF THIS WORKSHOP
IN ORDER TO COMPARE IT TO WHAT COULD BE ACHIEVED
WITH PURE FEEDBACK SYSTEMS

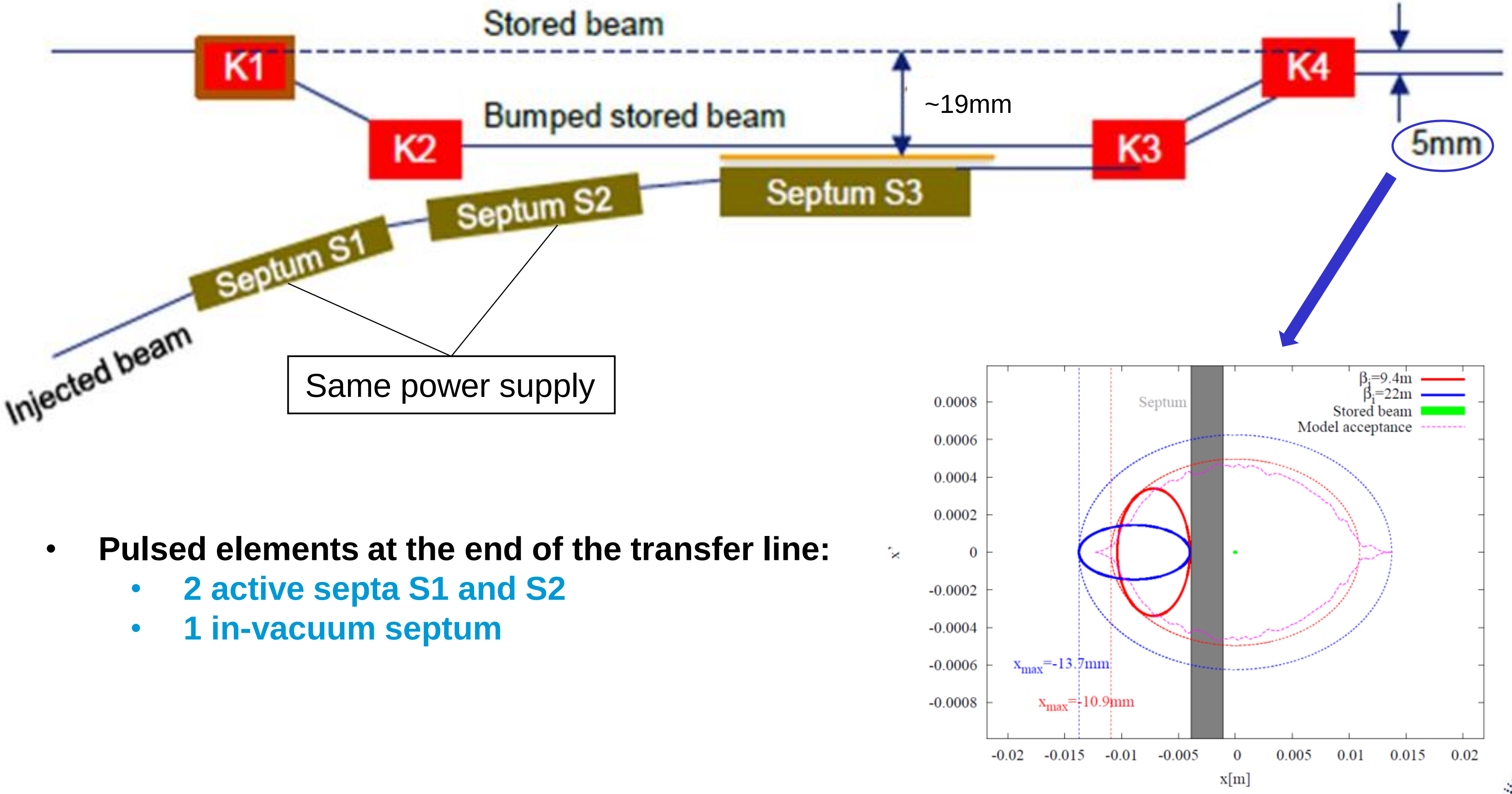
ESRF storage ring injection scheme

Classical four kickers bump scheme

Injection induced perturbation:

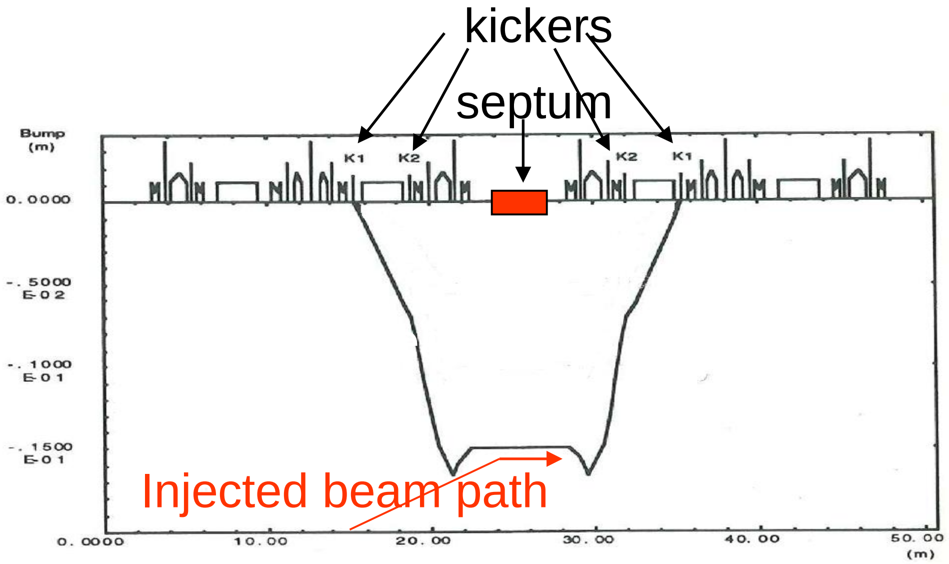
- Septum field leakage
- Non closure of the bump during the rise and fall of the bump due to the presence of sextupoles inside the bump

ESRF storage ring injection scheme



- **Pulsed elements at the end of the transfer line:**
  - **2 active septa S1 and S2**
  - **1 in-vacuum septum**

PARASITIC BEAM POSITION OSCILLATION DURING THE INJECTION IN THE SR

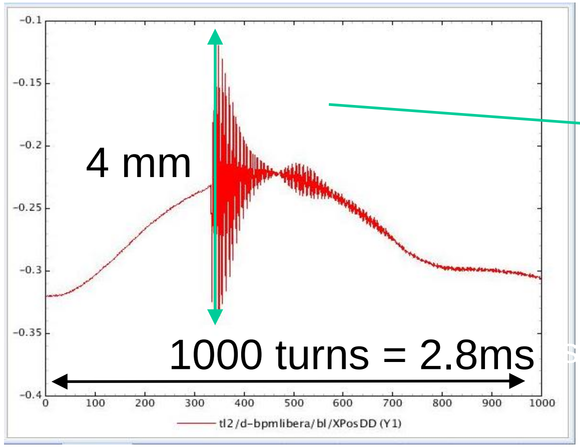


The injection kick path includes sextupoles =>

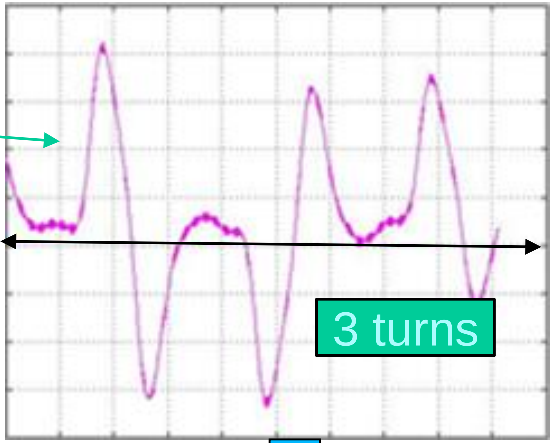
the kicker bump is not closed during the kick rise time and fall time

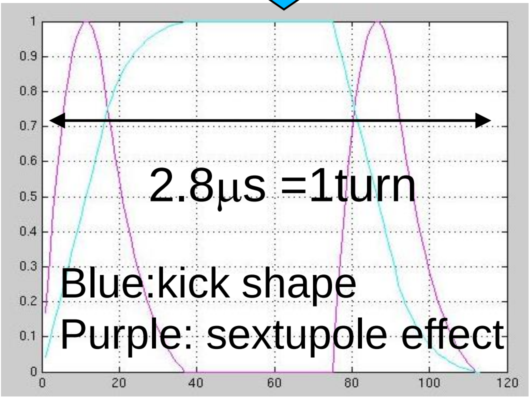
There is a small leakage of the septum field

PERTURBATION OBSERVED ON THE HORIZONTAL BEAM POSITION


4 mm

1000 turns = 2.8ms


3 turns


2.8μs =1turn

Blue:kick shape

Purple: sextupole effect

LIMITED FEEDBACK EFFECT

Orbit Correction Feedback :

- Limited bandwidth
  (compared to the available correctors bandwidth)
- Limited kicker strength.

Instability Feedback:

- Limited kicker strength
- Limited bandwidth
  (compared to the available correctors bandwidth)

EFFECT OF THE FAST ORBIT CORRECTION ON THE KICK DUE TO THE SEPTUM

Orbit Correction Feedback bandwidth: 150Hz
Corrector strength:
Parasitic kick strength:
The correction signal results in overshoot without real reduction of the perturbation peak amplitude.
Sometime the orbit correction stops due to an excessive demand on the corrector strength

The corrector bandwidth is 500Hz which is enough to generate a correction signal, so how can we use it more efficiently?

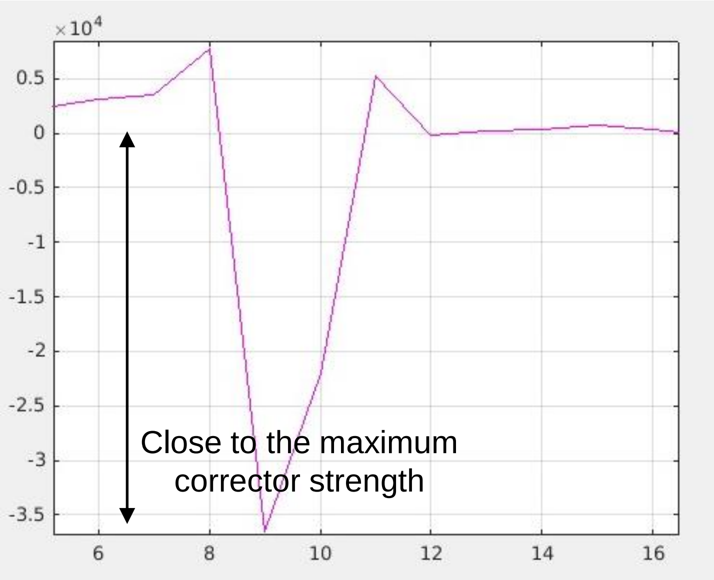
Normal Fast Orbit Correction effect:

Correction calculated with the normal orbit correction matrix :

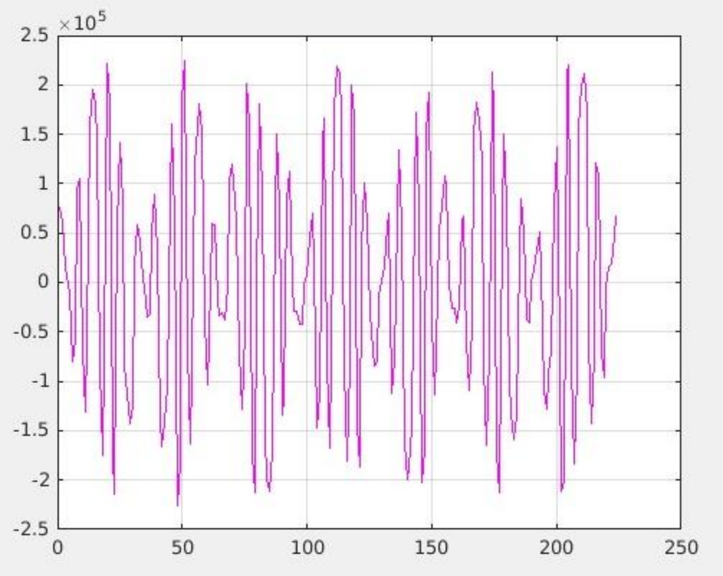
- Will use mostly two correctors

The feedback bandwidth is 150Hz:

- The correction will be produced with a delay of about 2ms => no effect!



Close to the maximum corrector strength



FEEDFORWARD APPROACH FOR THE FAST ORBIT CORRECTION:

Correction signal stored in a look up table :

- Efficient use of the corrector bandwidth:
  - No loop stability problem
  - Allows some bandwidth extension by pre emphasis of the signal

- Better use of the available correction strength:
  - Correction spread over 6 correctors instead of 2 when the correction is calculated by the feedback loop using the standard SVD derived correction matrix

Orbit correction: feedforward correction

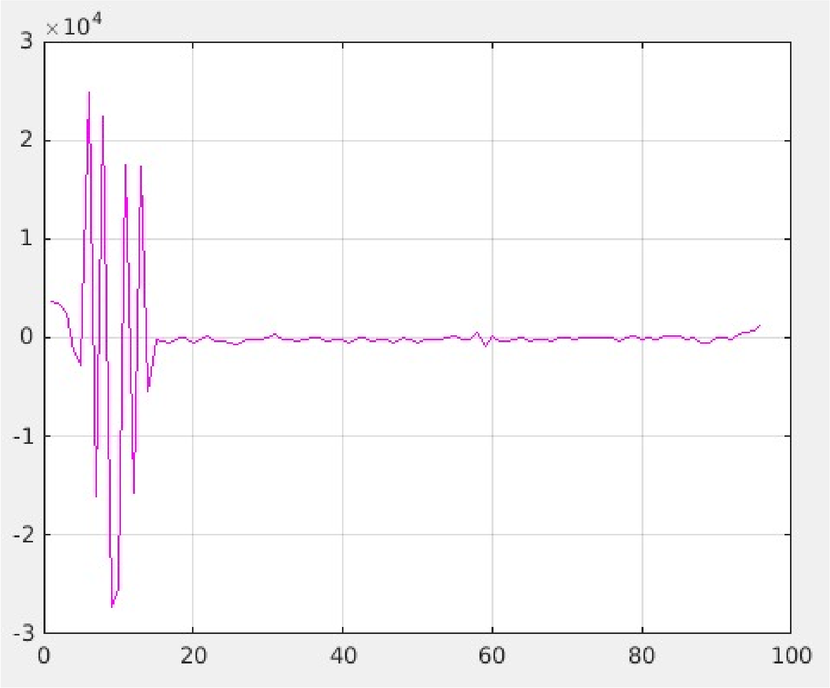
We can use more correctors :

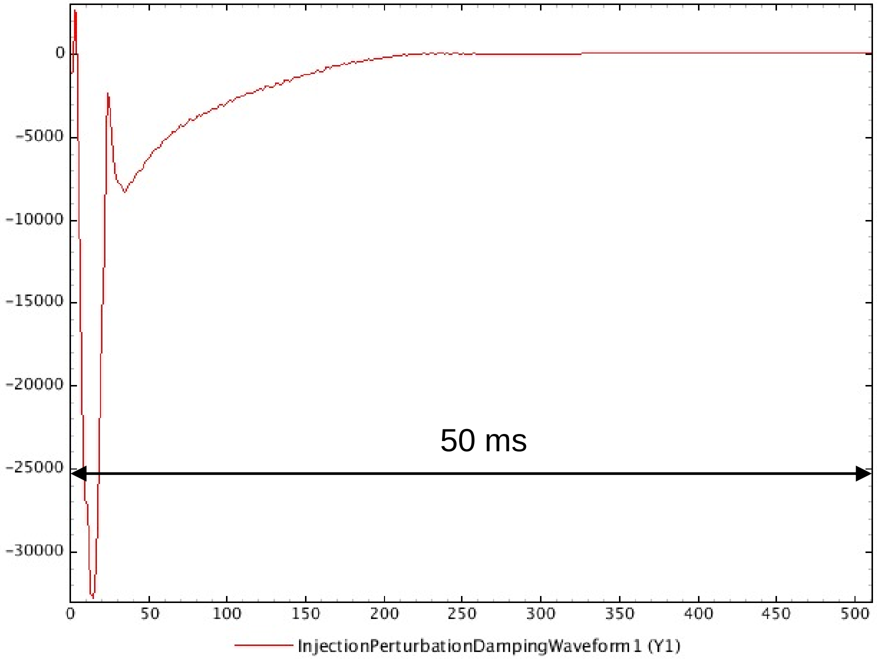
- 6 correctors are available between the two ID straight sections surrounding the injection straight section

The correction generation is triggered by the injection timing

- no delay
- Correction signal generation is fully using the 500Hz correctors bandwidth

Orbit correction: feedforward correction

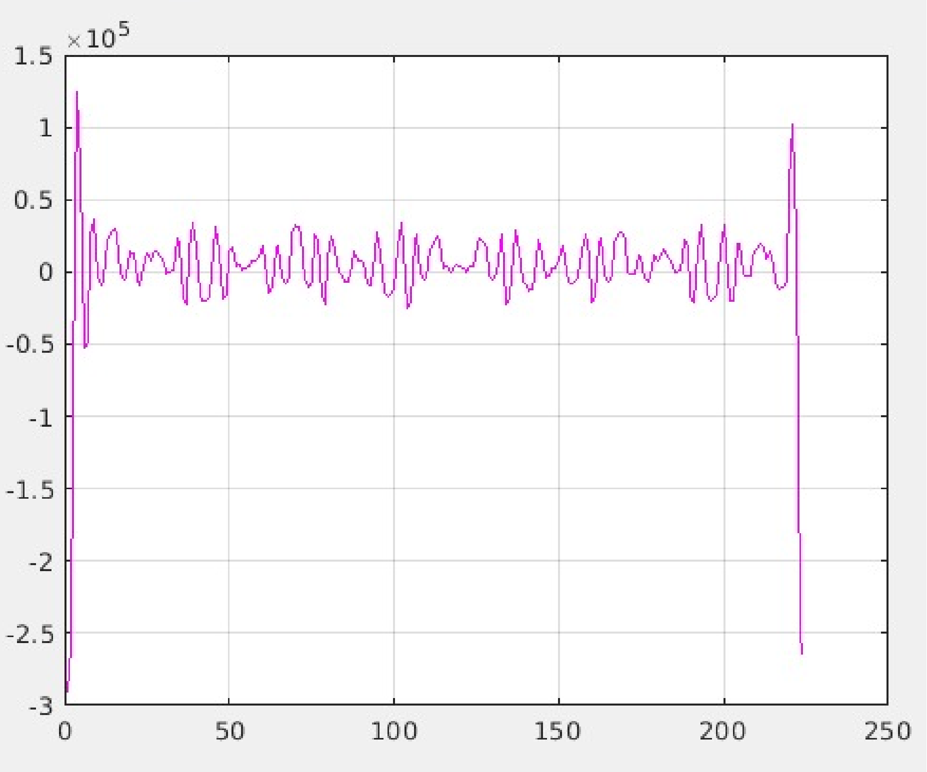




CORRECTION KICKS
CANCELLING THE SEPTUM LEAK

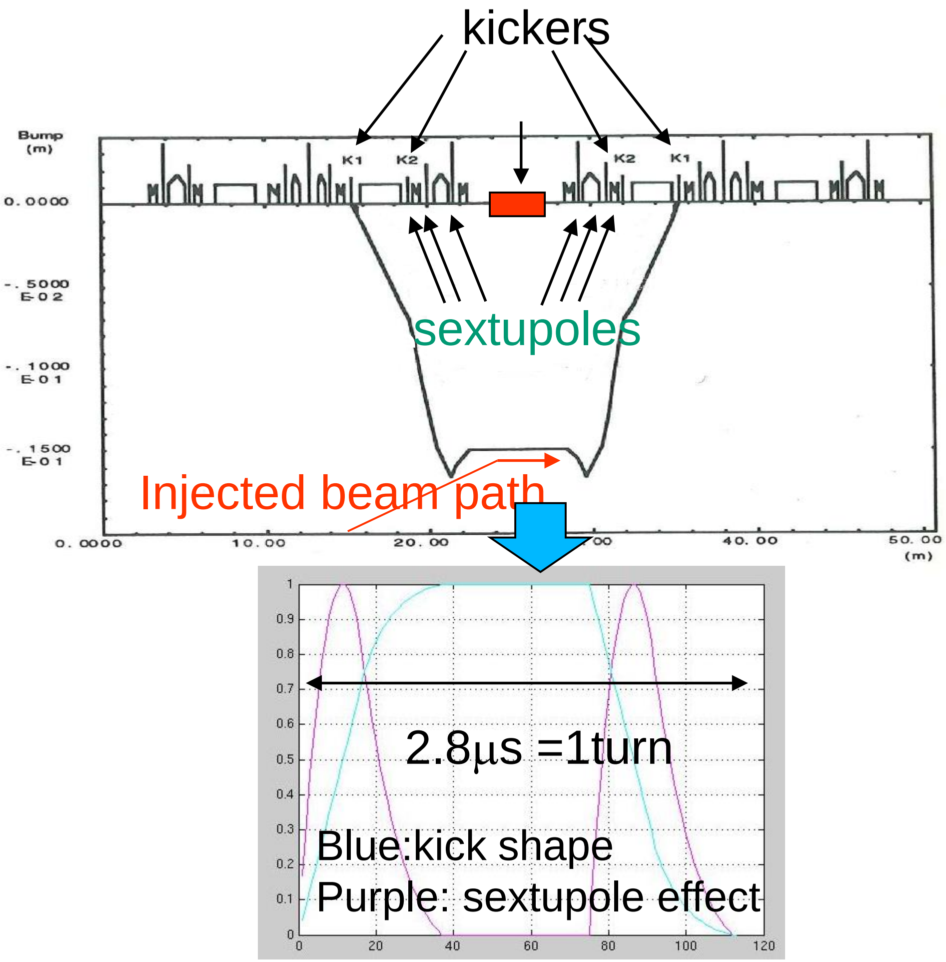
TIME DOMAIN WAVEFORM USED TO
MODULATE THE CORRECTION KICKS

Orbit correction: feedforward correction



MAXIMUM ORBIT PERTURBATION DURING THE SEPTUM PULSE

PERTURBATION DUE TO THE INJECTION KICKERS



kickers

sextupoles

Injected beam path

2.8μs =1turn

Blue:kick shape

Purple: sextupole effect

PERTURBATIONS CAUSED BY THE INJECTION KICKERS

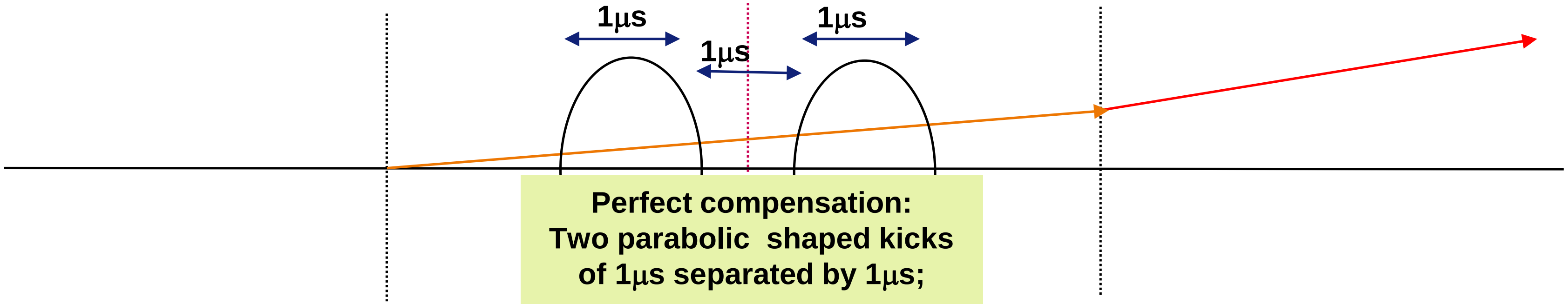
KICKERS STRENGTH: .5 mrad
SPURIOUS KICKS DUE TO THE SEXTUPOLES: .05 mrad

PURELY ACTIVE CANCELLATION WOULD
REQUIRE VERY STRONG CORRECTORS

PASSIVE CANCELLATION BY:

1. SHAPING THE KICKERS FIELDS (DIPOLE +QUADRUPOLE)
2. ADDING AN OCTUPOLE IN THE BUMP

PASSIVE COMPENSATION



Perfect compensation:
Two parabolic shaped kicks
of 1µs separated by 1µs;

First sextupole

Second sextupole

Parasitic kick: $d*K(t)^2$

How can we generate: $K(t) - d*K(t)^2$ instead of $K(t)$?

$$K(t) - d*K(t)^2 = K(t) *(1- d*K(t))$$

we can get the $*(1- d*K(t))$ factor from the B field variation with dx inside the kicker magnet:

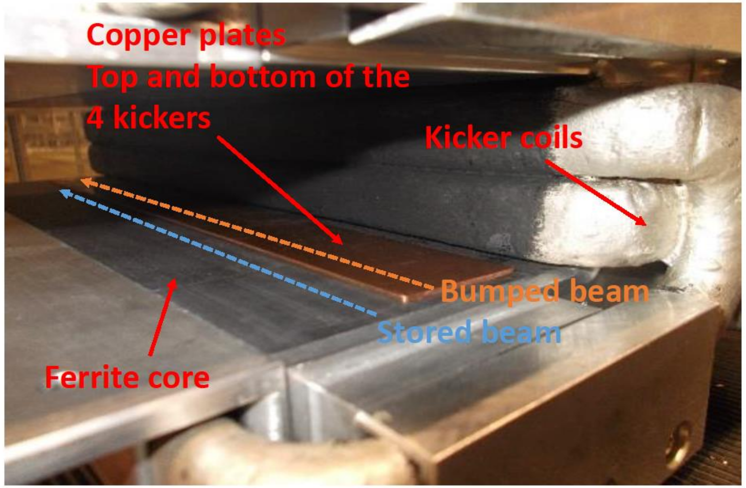
$$B= B_0 - (b*dx)$$

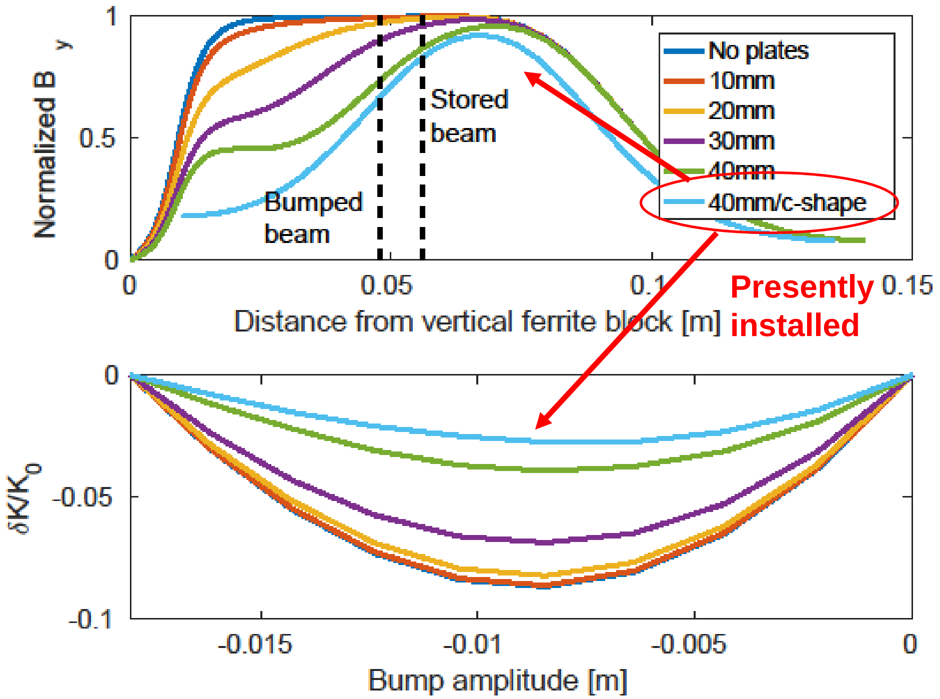
Kicker passive compensation

- **Idea: add copper shims inside the kickers ferrite gap to generate a non-linear field**

- Shape this field with the shims dimension in order to cancel the sextupole field: **reduction of both beta-beat and orbit distortions**

- Creates vertical field gradient: **alignment is now critical**





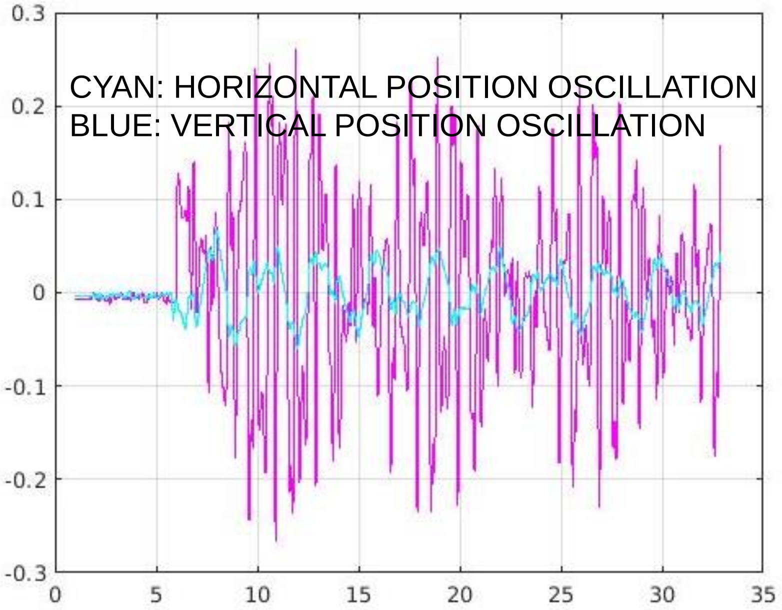
- **Ideal conditions and 18mm bump amplitude, simulations indicate a factor 3 improvement**

Courtesy Simon White

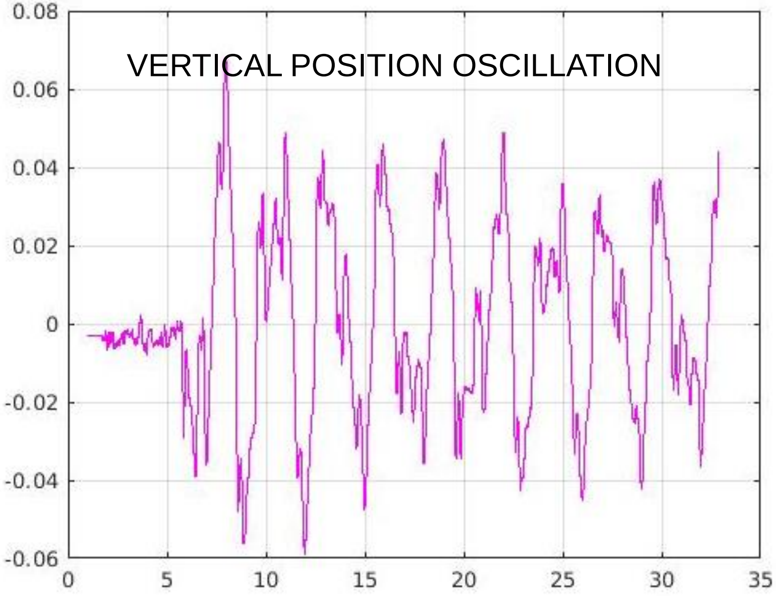
ADDITION OF AN OCTUPOLE

ACTUALLY THE FULL PASSIVE COMPENSATION OF THE SEXTUPOLES EFFECT REQUIRED ALSO THE IMPLEMENTATION OF AN OCTUPOLE IN ORDER TO FULLY CANCEL THE TRANSIENT QUADRUPOLE FIELD EFFECT WICH RESULTED IN A BEAM BLOW UP DURING THE BUMP CREATION

SITUATION AFTER THE SHIMS AND OCTUPOLE IMPLEMENTATION



CYAN: HORIZONTAL POSITION OSCILLATION
BLUE: VERTICAL POSITION OSCILLATION



VERTICAL POSITION OSCILLATION

1. HUGE REDUCTION OF THE HORIZONTAL PERTURBATION
2. STILL A VERTICAL PERTURBATION DUE TO A MORE DIFFICULT ALIGNEMENT OF THE KICKERS (NOW DIPOLE/QUADRUPOLE)

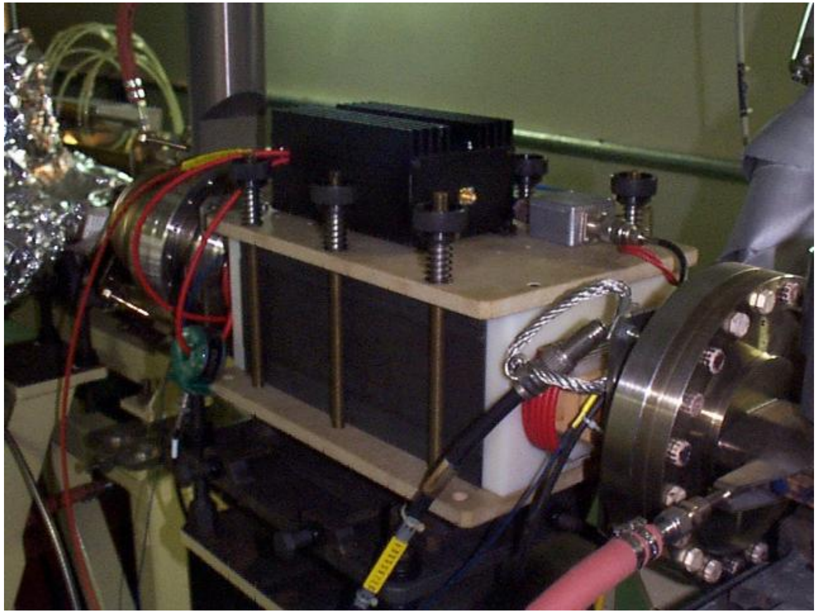
ADDITIONAL ACTIVE CORRECTION

REQUESTED BANDWITH: around 1 MHz
REQUESTED KICKER STRENGTH: 6μrad (H) and 2μrad (V)

STRIPLINE KICKERS: .5μrad
MAGNETIC KICKERS: 4μrad

BUT ONLY ONE STRIPLINE OR MAGNETIC KICKER AVAILABLE
=> no closed bump correction possible

TRANSVERSE DAMPING TIME : 6ms =>
a perturbation suppression obtained over
a several 2.8μs revolutions will still be very beneficial.
And it reduces also the necessary kicker strength



SR magnetic shaker

- 400W amplifier => 4 A peak current
- 6 coils
- Set up bandwidth: 1 MHz
- 6 Gev beam, B field effect => 4 μrad peak /turn

ACTIVE CORRECTION SCHEME

The chromaticity on the ESRF storage ring is high, especially in the vertical plane => Due to the decoherency the correction cannot be done over a too large number of turns

Other constraint: no DC component in the correction waveform (the amplifier bandwidth does not goes down to DC)

1. HORIZONTAL CORRECTION OVER 9 TURNS (H tune= .44)
2. VERTICAL CORRECTION OVER 5 TURNS (V tune = .39)
3. CORRECTION SIGNAL GENERATED USING A LOOK UP TABLE.

CORRECTION SIGNAL CALCULATION

PERTURBATION SHAPE MEASUREMENT:

- BPM pick up:

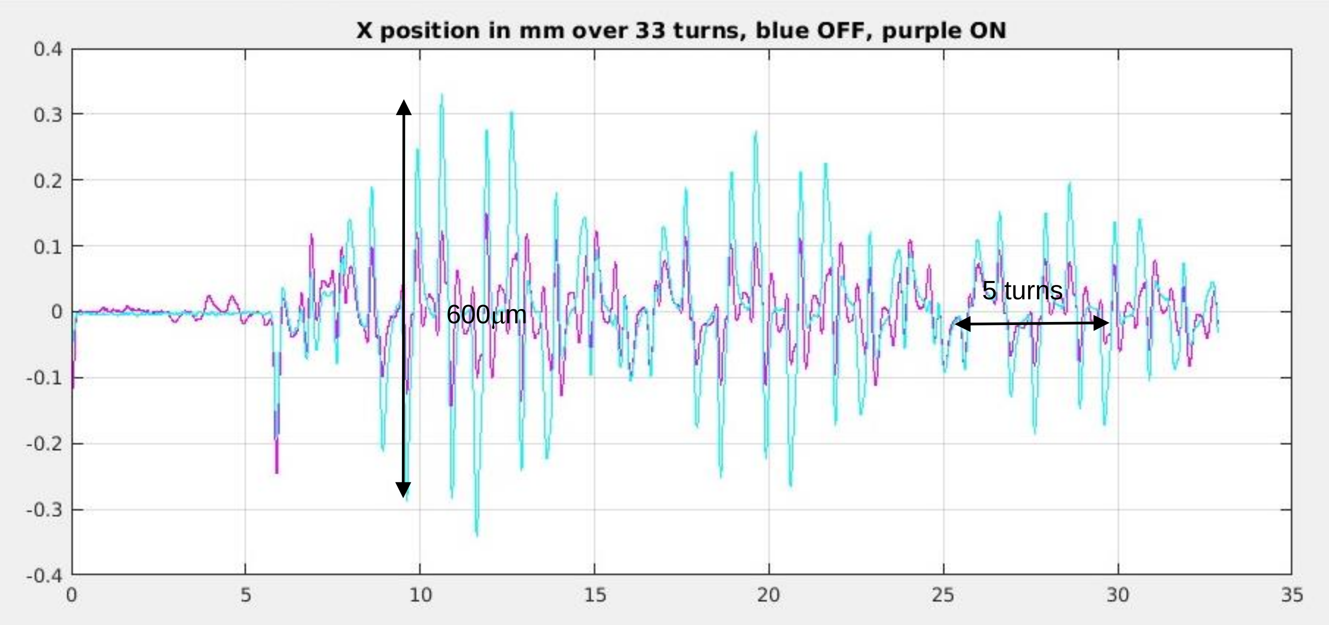
4 buttons with RF matching transformers

- Signal processor:

ADC data from an Itech Spark => 304 samples per turn,1014 samples

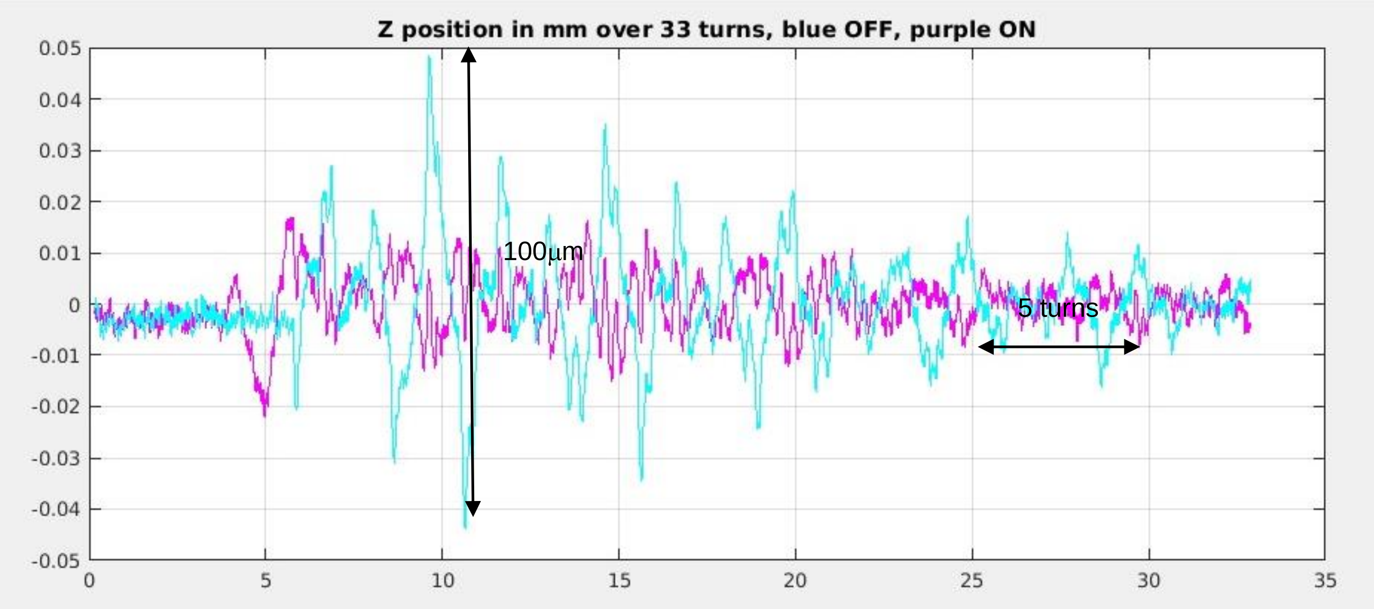
For each of the 304 samples we get the amplitude and phase of the perturbation over 9 turns (horizontal) or 5 turns (vertical) , assuming it is an oscillation at the betatron frequency , and we use these data and the phase shift between the BPM pick up and the corrector to calculate a correction signal ….

DAMPING OF THE HORIZONTAL PERTURBATION OVER 9 TURNS



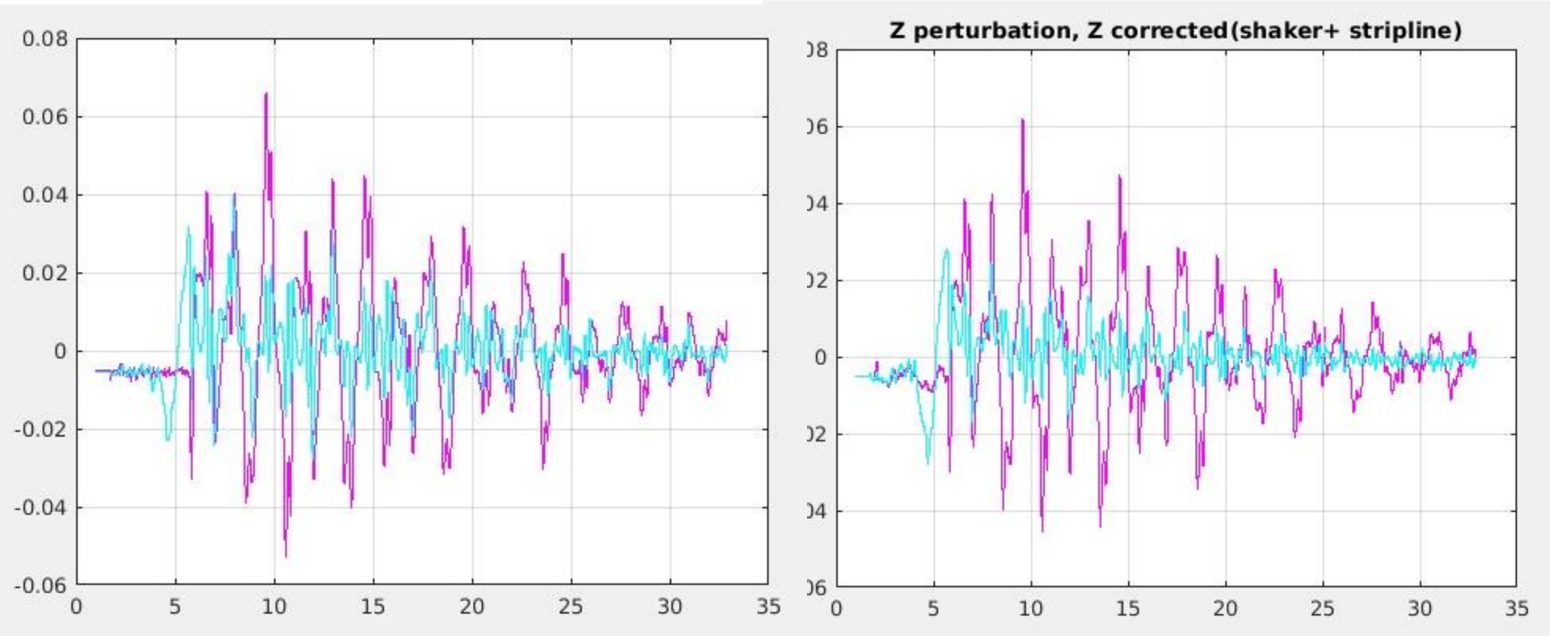
rms oscillation:
Without active damping: 100µm
with damping: 50µm
normal beam size: 350µm

DAMPING OF THE VERTICAL PERTURBATION OVER 5 TURNS

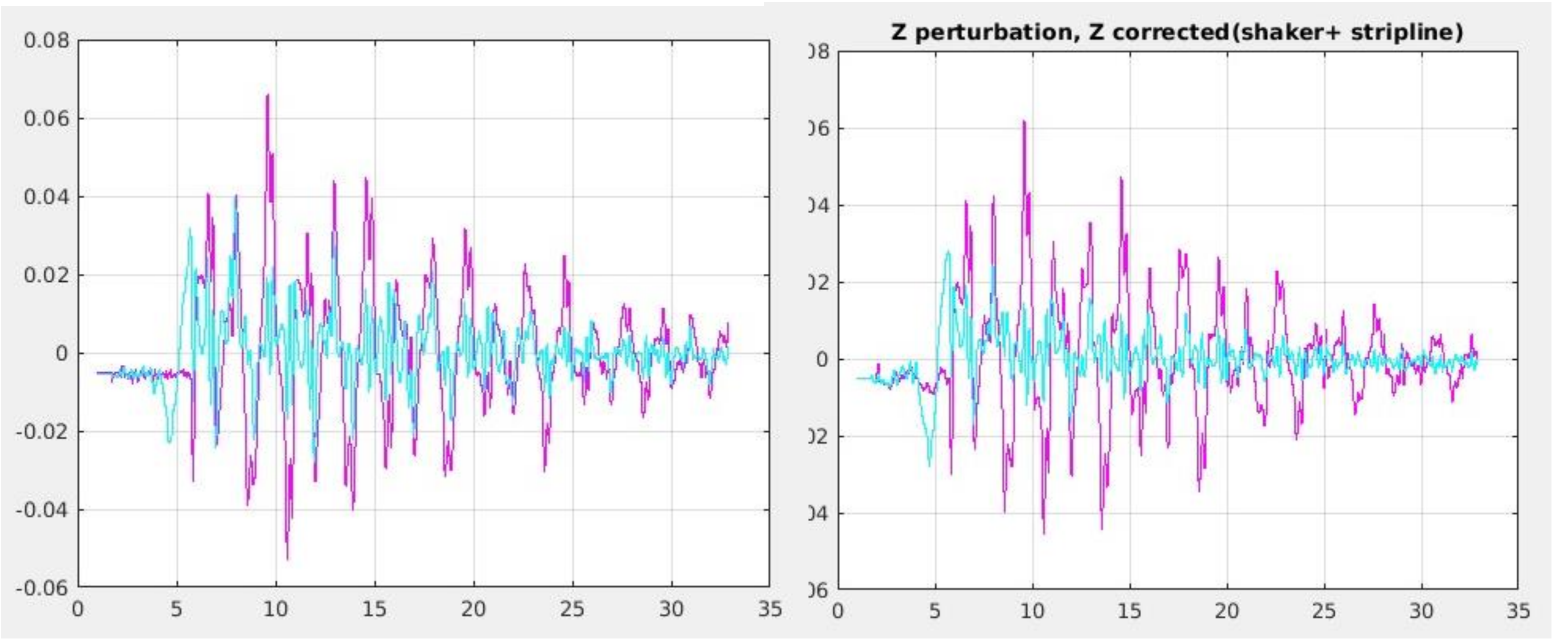


rms oscillation:
without active damping: 25µm
with damping:10µm
normal beam size: 15µm

IMPROVED DAMPING OF THE VERTICAL PERTURBATION BY ADDING A STRIPLINE



Left : damping with the shaker Right: damping using the shaker and the stripline



Left : damping with the shaker Right: damping using the shaker and the stripline

OPEN ISSUES

RANDOM PERTURBATION PATTERN

1. PERTURBATION MEASUREMENT OVER ONE TURN
2. CORRECTION CALCULATION AND GENERATION OVER A FEW EXTRA TURNS

THANKS FOR YOUR ATTENTION