ESLS 2018

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Injection perturbation mitigation at ESRF

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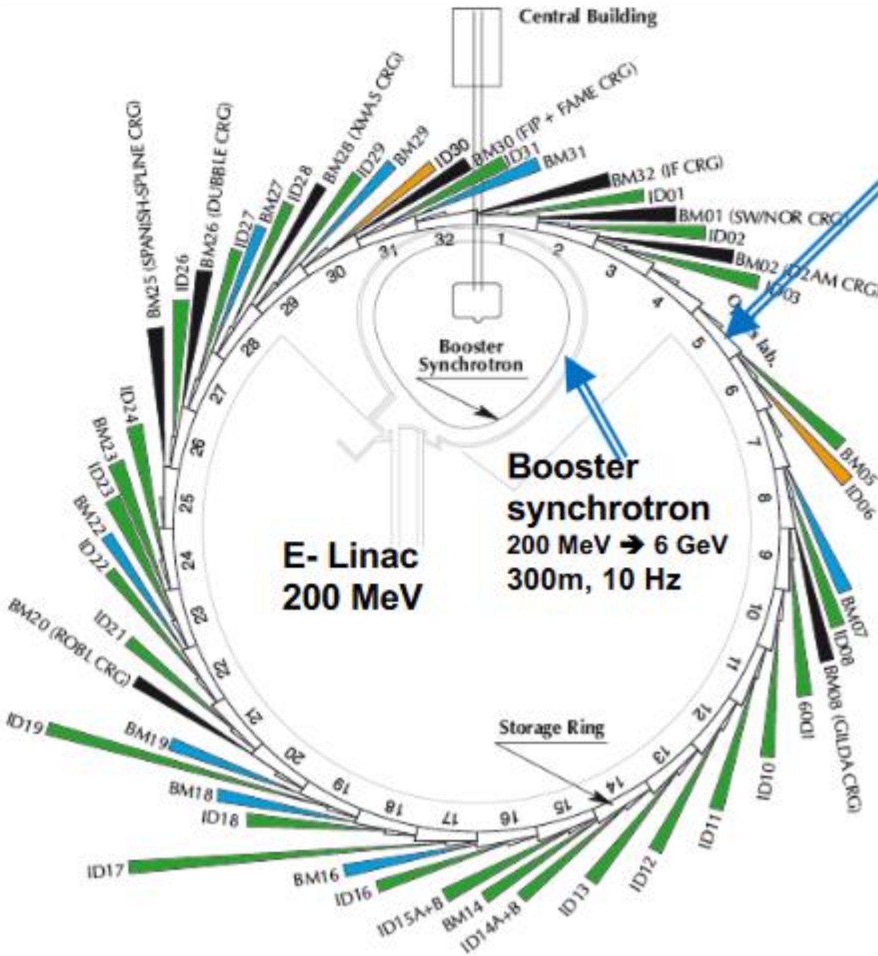
ESRF | The European Synchrotron

ESRF TODAY



Energy	GeV	6.04
Multibunch Current	mA	200
Horizontal emittance	nm	4
Vertical emittance	pm	3.5

32 straight sections

DBA lattice

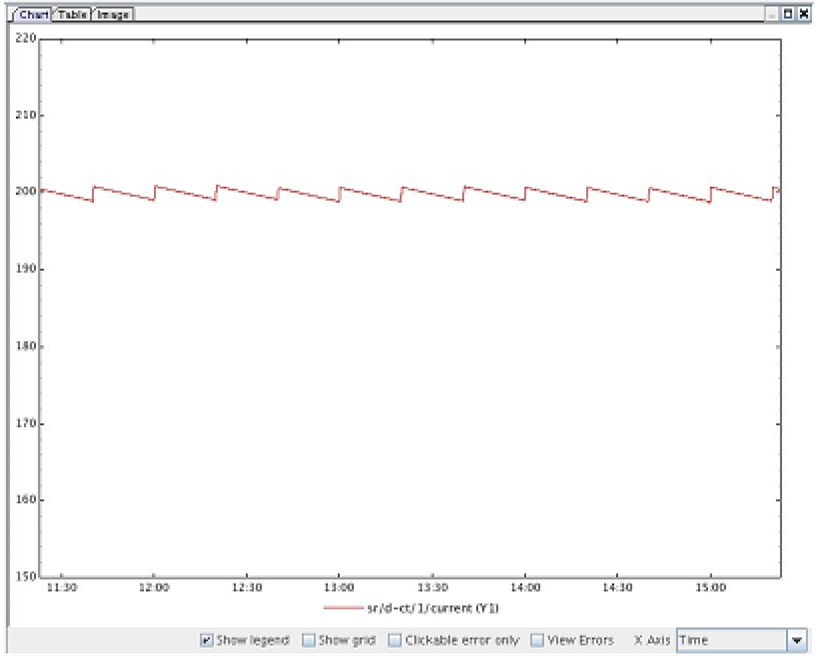
42 Beamlines

12 on dipoles

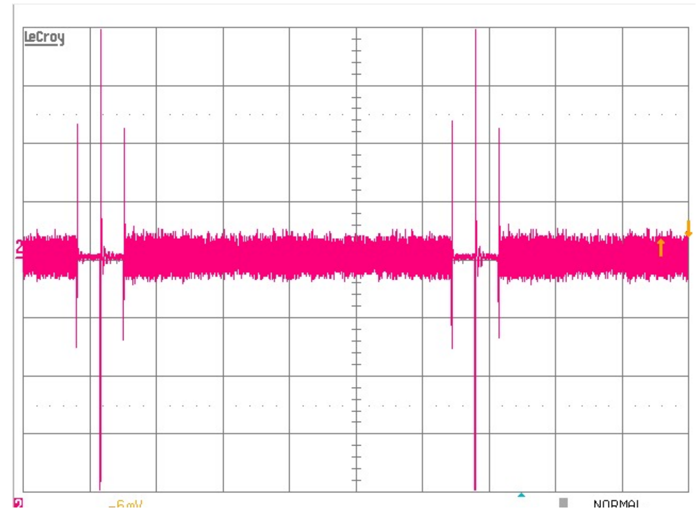
30 on insertion devices

72 insertion devices:
55 in-air undulators, 6 wigglers,
11 in-vacuum undulators, including
2 cryogenic

TOP UP OPERATION



Example of a storage ring filling mode



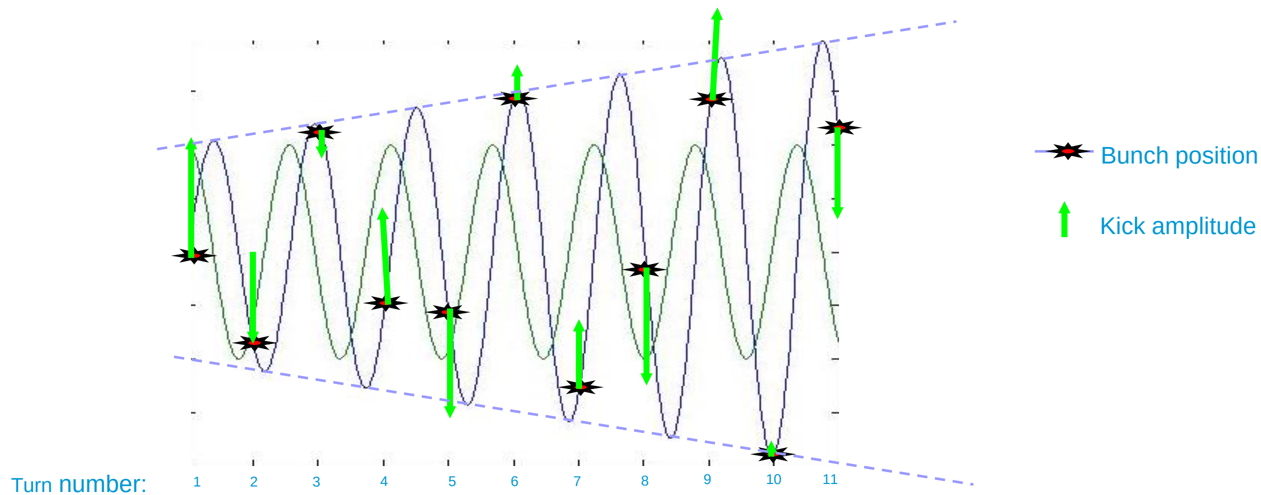
ESRF top up operation scheme:

one refill every 20 minutes

at each refill we want to have the buckets of the gaps in the filling pattern perfectly clean of parasitic electron

Cleaning method: parasitic bunches elimination

RESONNANT CLEANING PRINCIPLE



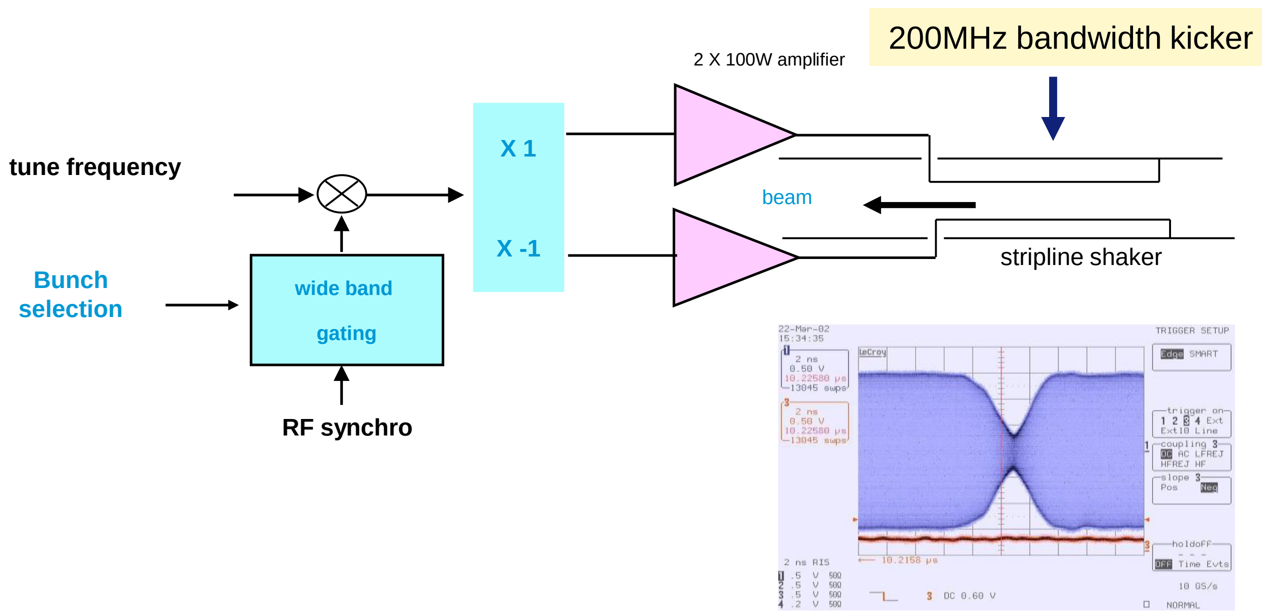
Beam position at turn n: $z_n = z_0 \sin(2\pi\upsilon_z * n)$

Kick at turn n: $z_n = z_0 \cos(2\pi\upsilon_z * n)$

We neglect the decoherency due to ξ

PARASITIC BUNCHES SELECTION : TIME DOMAIN SELECTION

stripline gated shaker setup



MAIN ISSUES

***Stored beam vertical perturbation and temporary gap pollution*:**

Parasitic bunches cleaning when performed in the SR =>

temporary gap buckets pollution, parasitic main bunches transverse excitation…

***Stored beam horizontal and vertical perturbation*:**

Parasitic kick and transient beta perturbation due to the injection

MAIN ISSUES

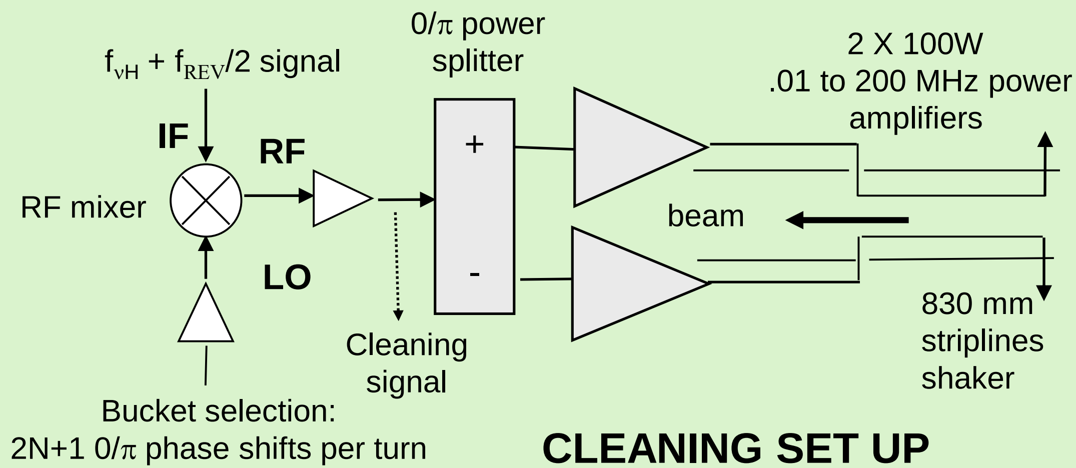
***Stored beam vertical perturbation and temporary gap pollution*:**

Parasitic bunches cleaning when performed in the SR

***Solution* :**

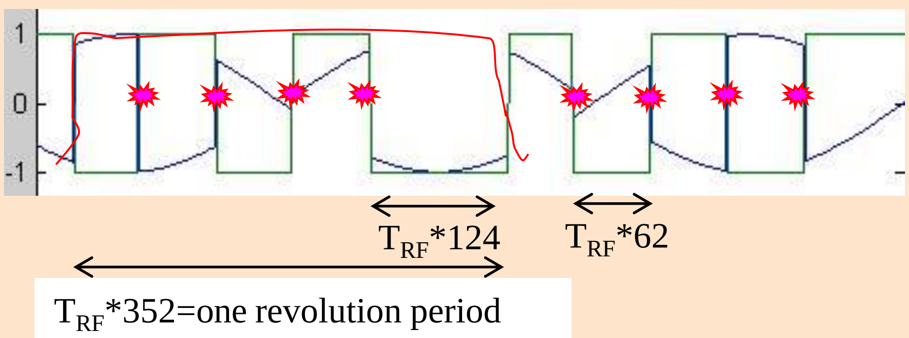
Cleaning performed in the booster

BOOSTER BUNCH CLEANING PRINCIPLE AND SET UP

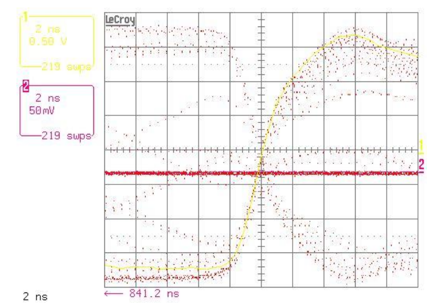


CLEANING SET UP

- Injection energy: 200meV
- Cleaning performed at 600meV
- Scrapper opening +/-16mm

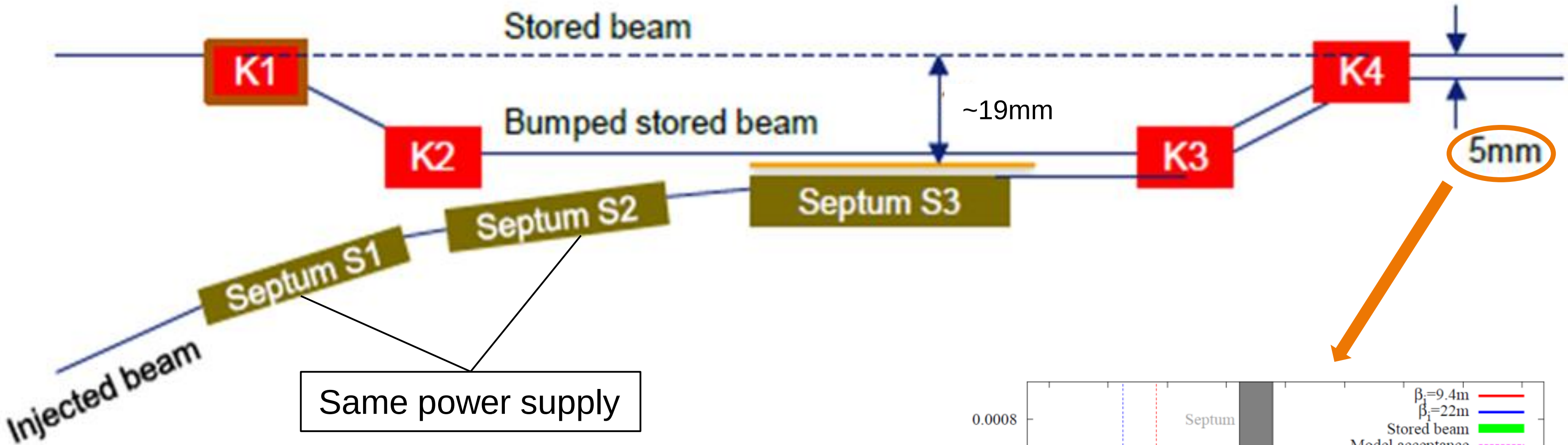


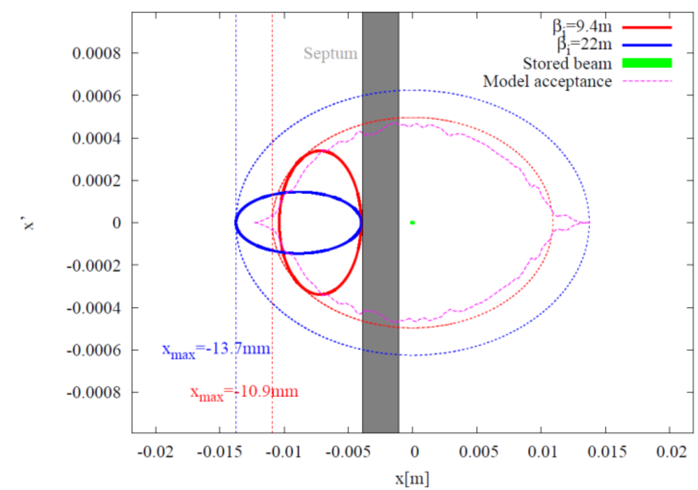
example of a cleaning signal (blue) with no DC component over 2 revolutions, for ν_H=.2 and four bunches(red: injection kicker signal, pink: bunches)



high power amplifier signal (phase transition)

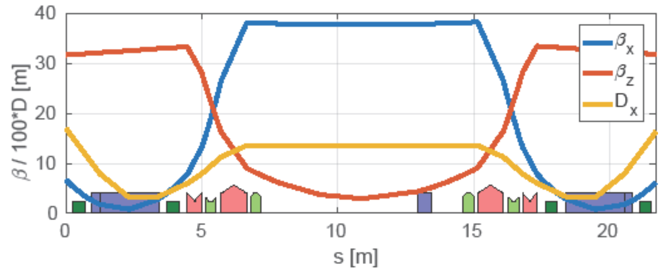
INJECTION INTO THE STORAGE RING

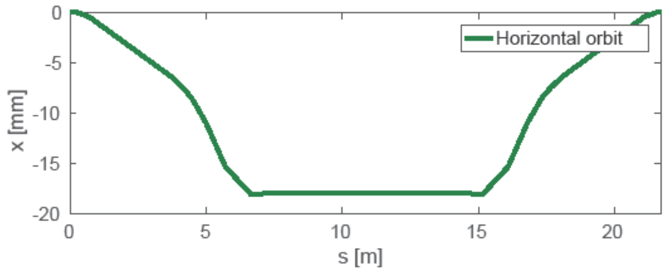


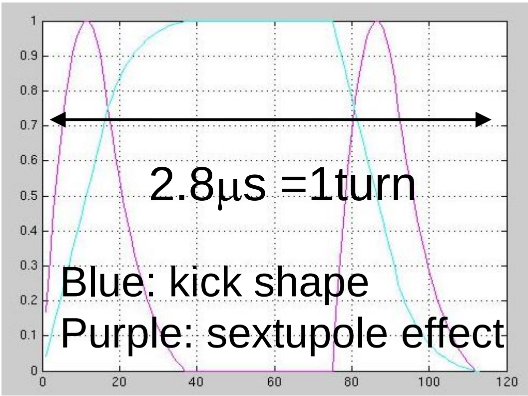


- **Pulsed elements at the end of TL2:**
  - **2 septa S1 and S2 – 2ms**
  - **1 in-vacuum septum S3 – 66µs**

INJECTION INTO THE STORAGE RING





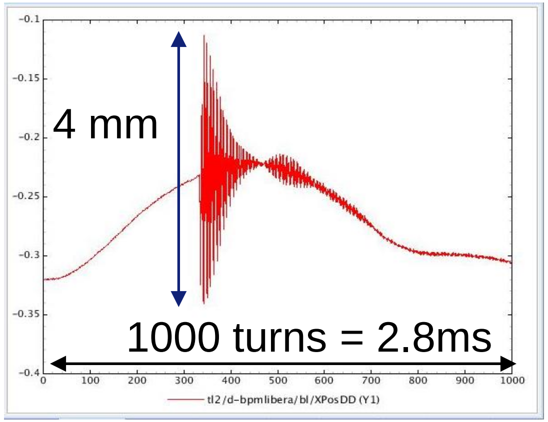


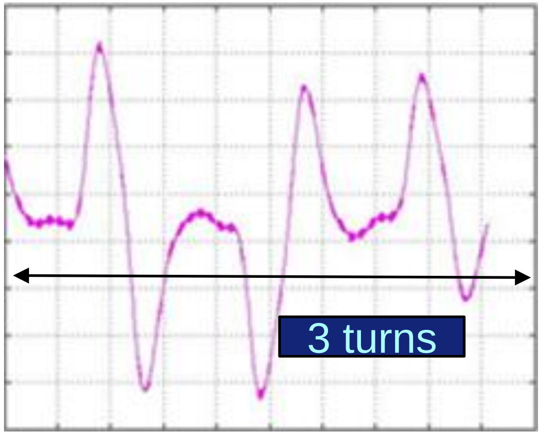
- **Injection pulsed magnets:**
  - **Septa:** fringe fields, depends on field strength and distance to the stored beam dominated by S1/2. Un-shielded current leads
  - **Kickers:** bump non-closure, 4 identical kickers pulse shape (timing, pulse shape,…)
- **Storage ring:**
  - **Sextupoles inside the bump:** non closure, envelop oscillations
- **Vertical perturbations also observed:**
  - Coupling, misaligned elements,…
- **Now running in top-up mode: significant effort ongoing to reduce these perturbations**
- **Goal: allow for continuous beam line data acquisition over injection**

Injection pulsed magnets:

- **Septa:** fringe fields, will cause a 2ms bell shape orbit perturbation
- **Kickers: the** bump non closure causes a position oscillation at the betatron frequency with the intra turn pattern showing the rise time- flat top- fall time related pattern.

  In addition: focusing change during the kickers pulse => enveloppe oscillation due to the sextupoles.

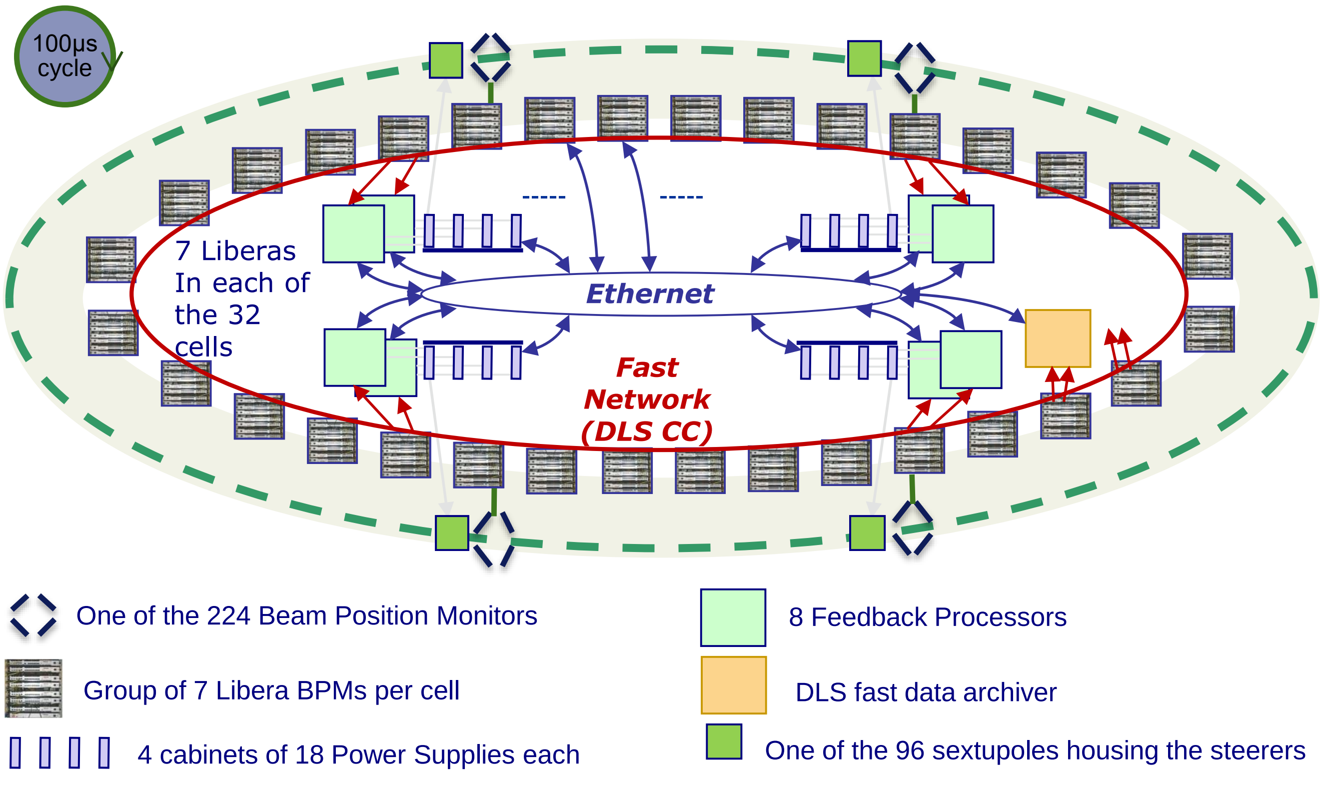




- **Vanishing with same time constant as radiation damping time**

SEPTUM PERTURBATION CANCELLATION:

using the fast orbit feedback in feedforward mode…



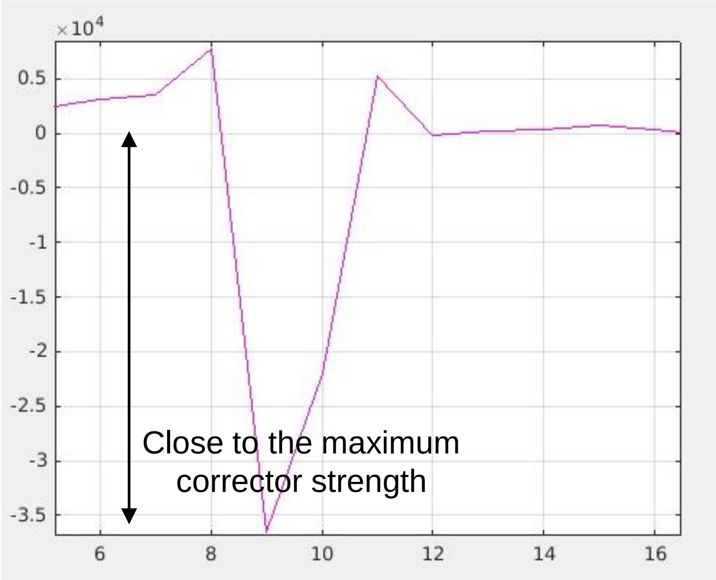
Normal Fast Orbit Correction effect:

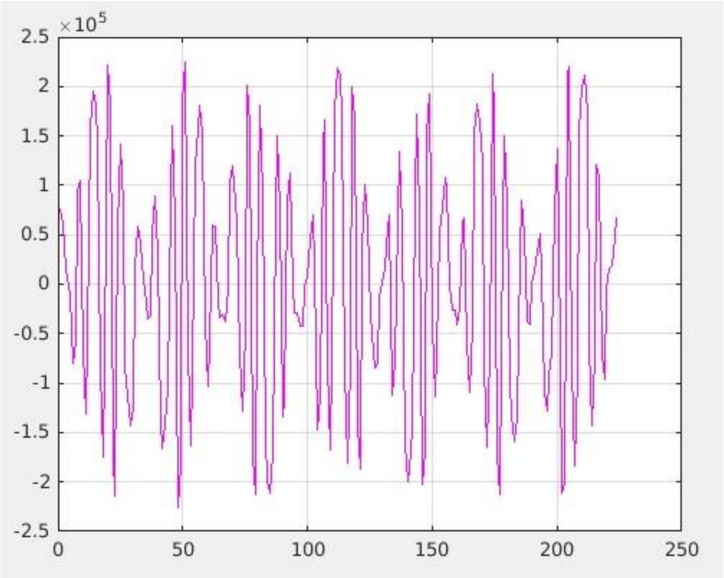
Correction calculated with the normal orbit correction matrix :

- Will use mostly two correctors

The correctors bandwidth is 500Hz but he feedback bandwidth is 150Hz:

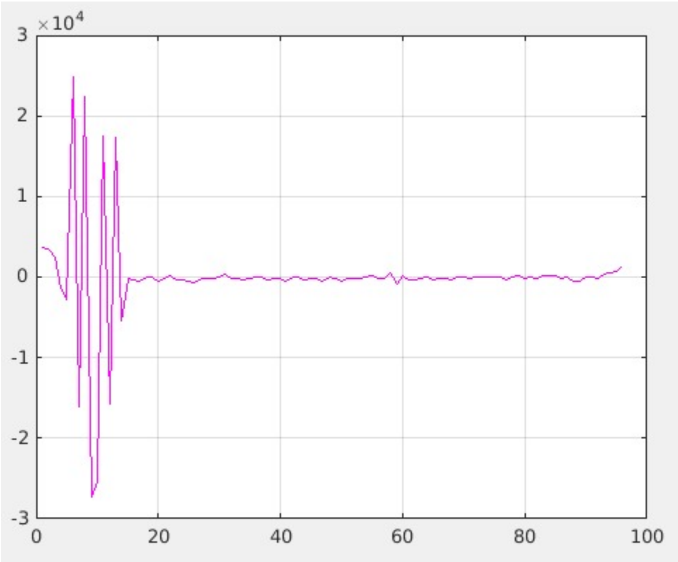
- The correction will be produced with a delay of about 2ms => no effect!

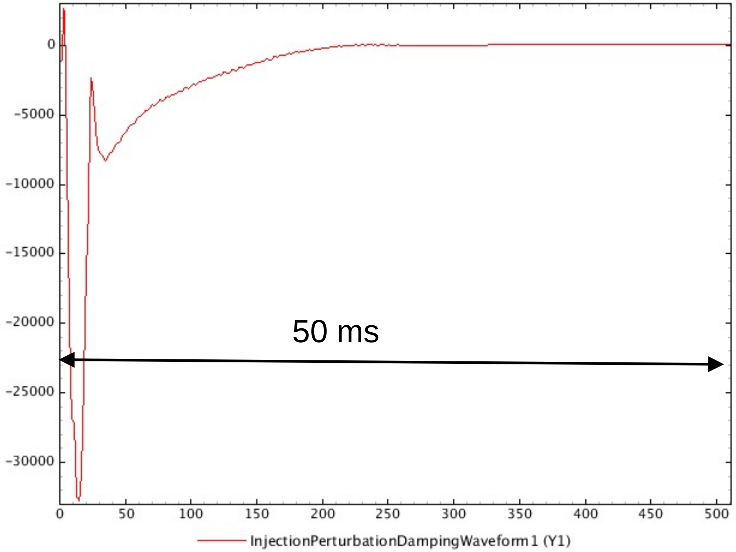




feedforward correction principle:

Correction signal from a lookup table triggered a each injection

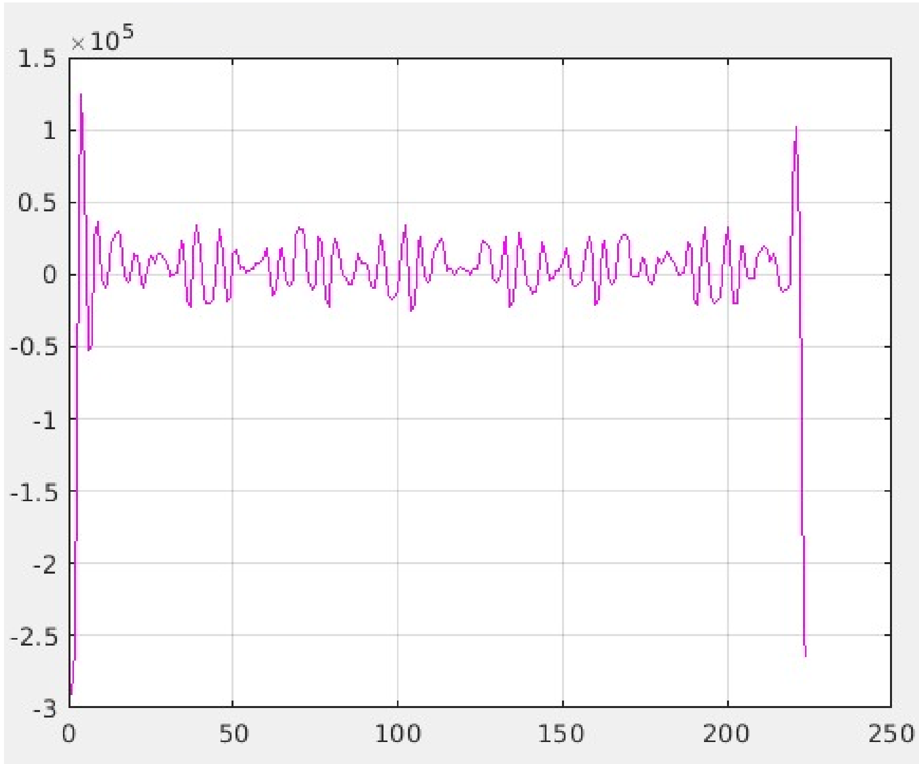




6 CORRECTORS BUMP CANCELLING THE SEPTUM LEAK

TIME DOMAIN WAVEFORM USED TO MODULATE THE CORRECTION KICKS

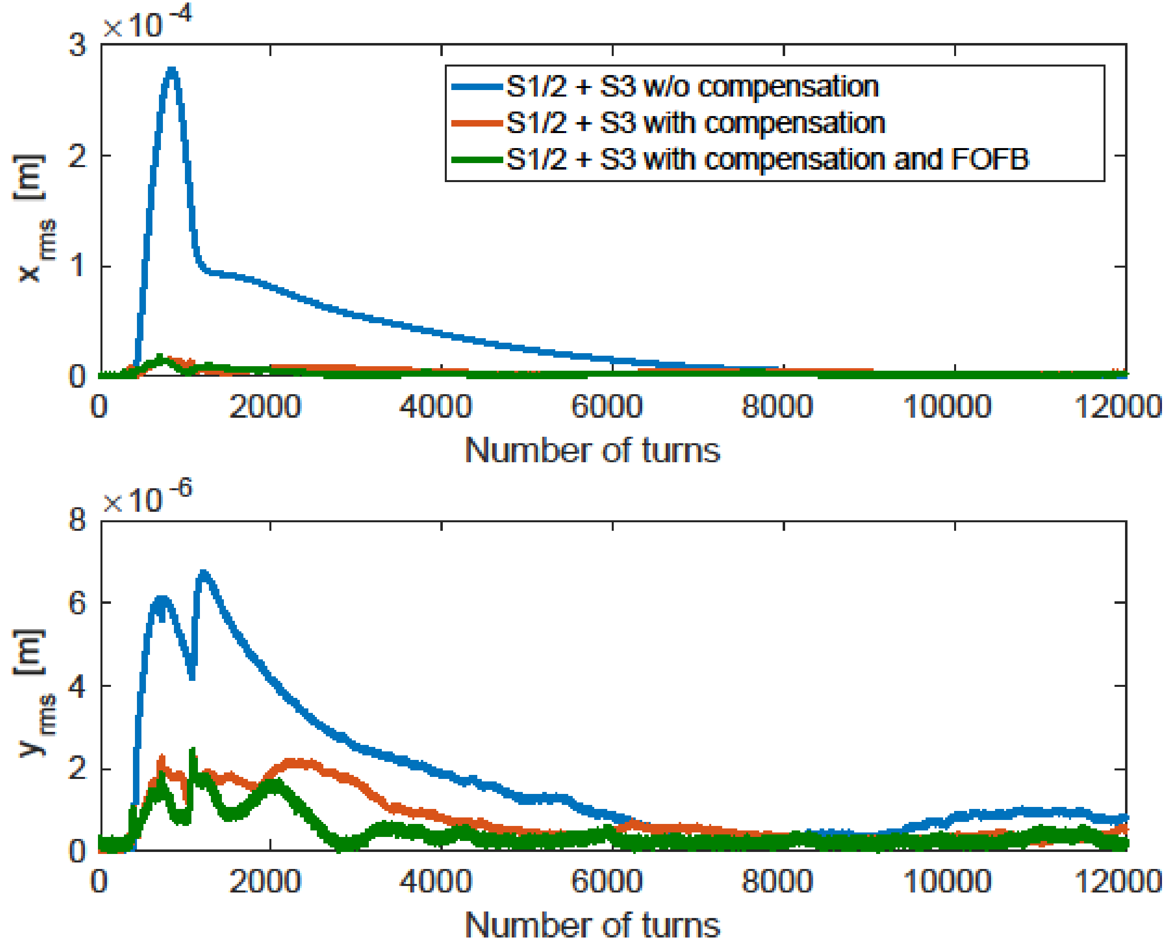
Orbit correction: feedforward correction



MAXIMUM ORBIT PERTURBATION DURING THE SEPTUM PULSE

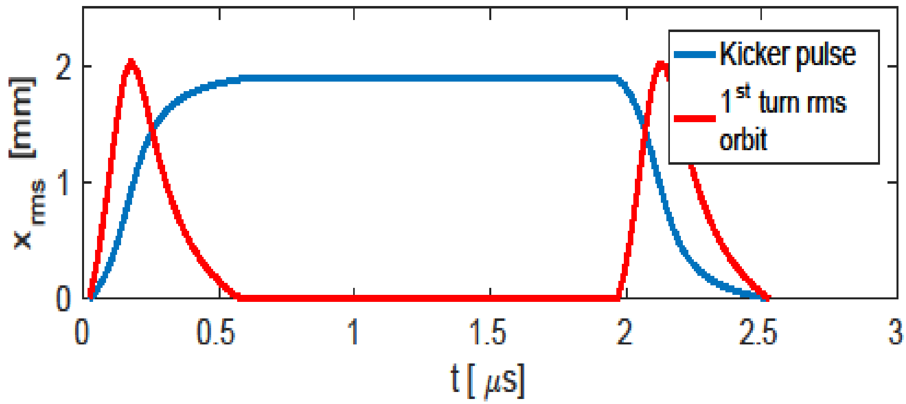
SEPTUM COMPENSATION

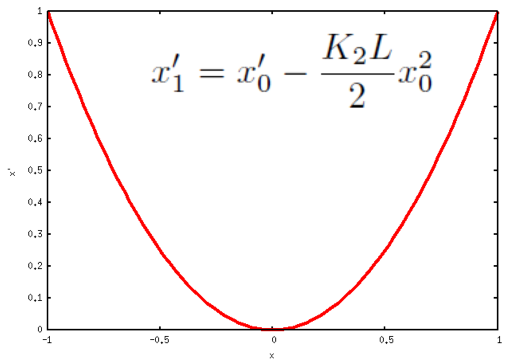
- **Fully operational since last year**
- Uses FOFB system
- Correction slightly improved to reduce the residual excitation after few 1000 turns
- **Peak residual oscillation (rms orbit):**
    - **~10-15µm in horizontal**
    - **~2-5µm in vertical**

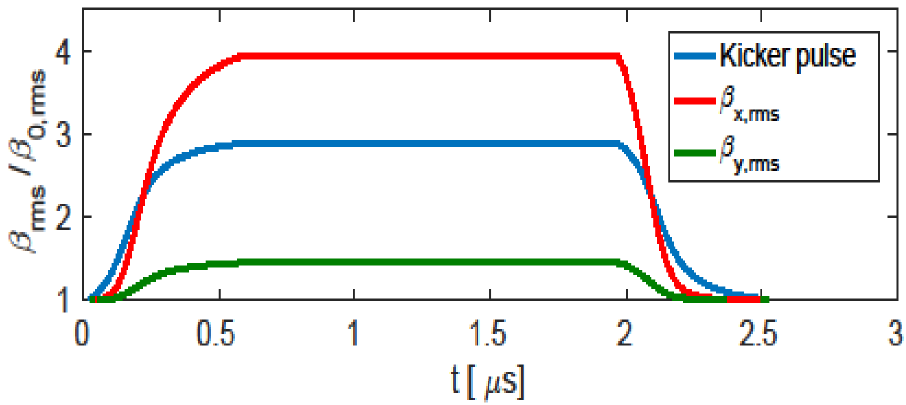


- **Sextupoles are located inside the injection bump:**
  - $B_y(x)$ evolves quadratically
  - Amplitude (time) dependent orbit distortion
  - Amplitude (time) dependent β-beat

→ Both resulting in apparent emittance increase





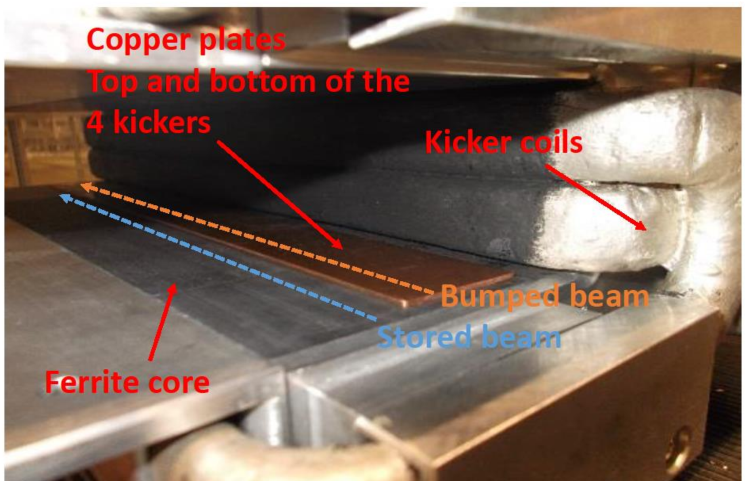


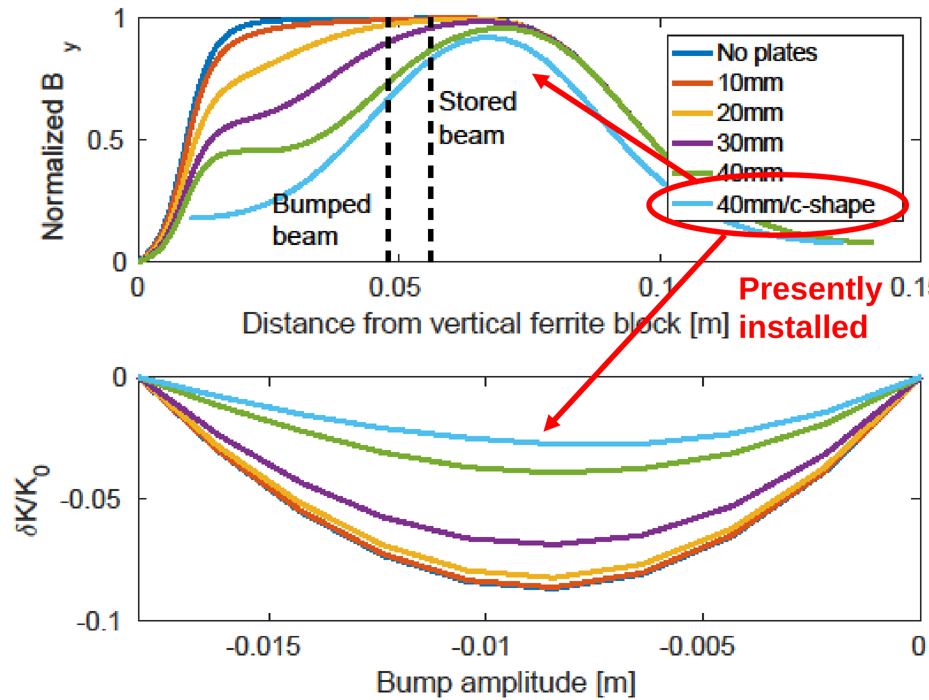
THE POOR MANS ALTERNATIVE TO A MULTIPOLE INJECTOR KICKER

PASSIVE AND ACTIVE COMPENSATION OF THE SEXTUPOLES EFFECT

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**

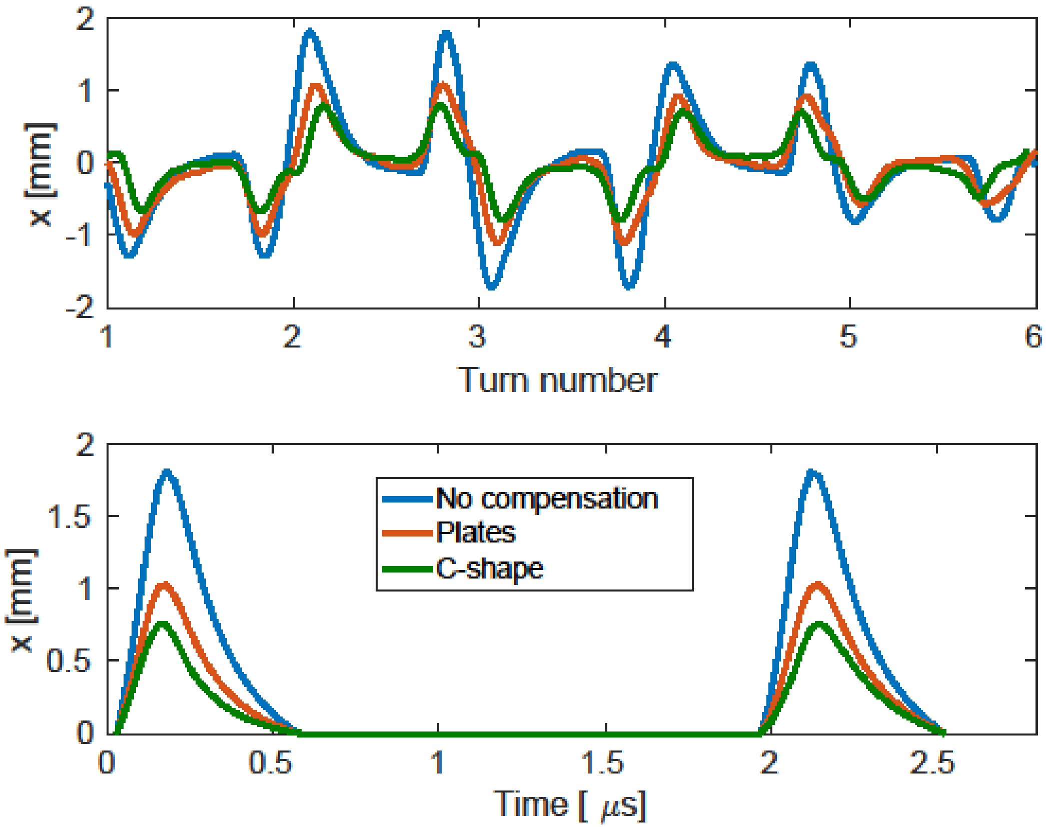




- **Ideal conditions and 18mm bump amplitude, simulations indicate a factor 3 improvement**

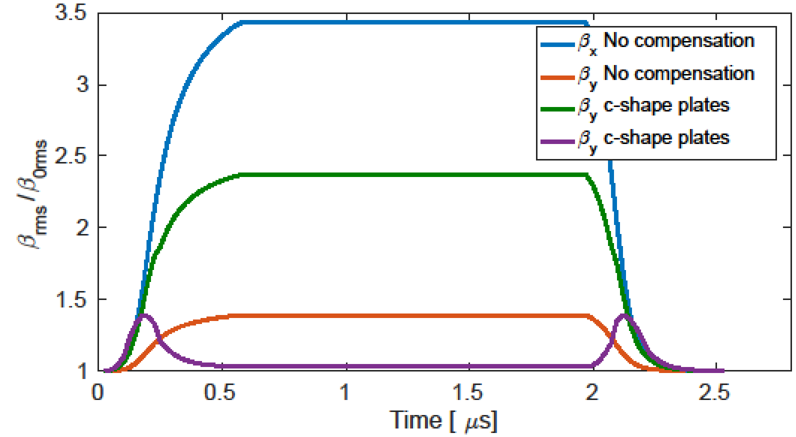
EXPERIMENTAL RESULTS

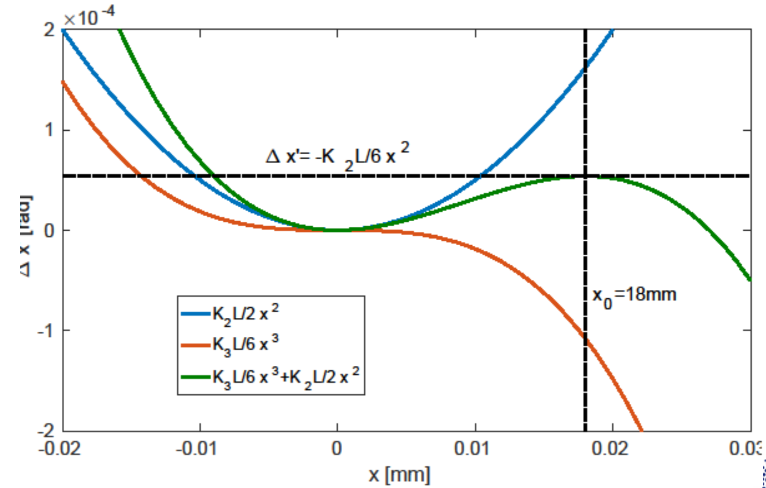
- **In reality the bump is approximately 16mm or less to allow single bump injection:**
  - **Compensation efficiency (field derivative) reduced**
- **Data renormalized for 16mm bump amplitude in all case:**
  - **Peak perturbation reduced by a factor ~2**
  - **Very consistent with simulations giving ~2.5**
- **Further improvement with shims very difficult:**
  - **No space for thicker plates**
  - **Reaching maximum kicker current**
- **Look into other solution…**



BEAM SIZE OSCILLATIONS

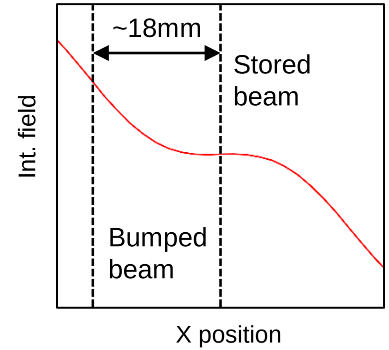
- The stored (bumped) beam sees an additional quadrupole during injection driving beam size oscillations all around the ring:
  - apparent emittance blow-up
  - Copper shims already reduce it by a factor 2
- It is however possible to cancel the field derivative at a given amplitude using a combination of multipoles:
  - Reduces both dipole and quadrupole perturbation
  - Example: octupole + sextupole
- Decision was taken to investigate the possibility of using an octupole for ESRF

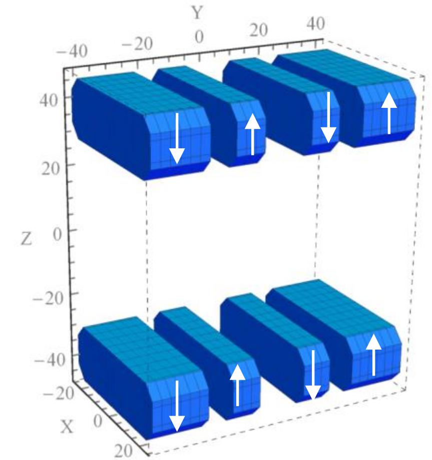


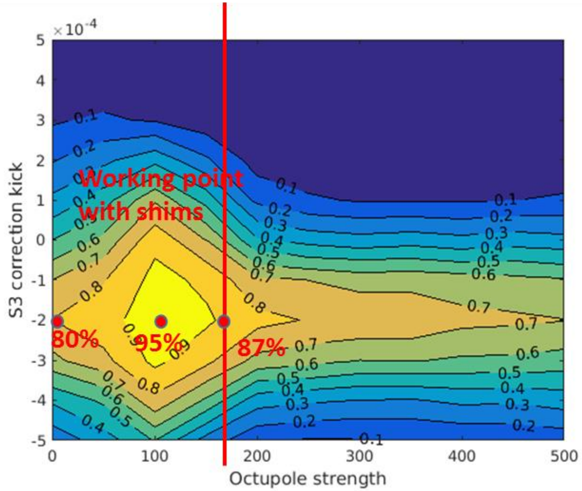


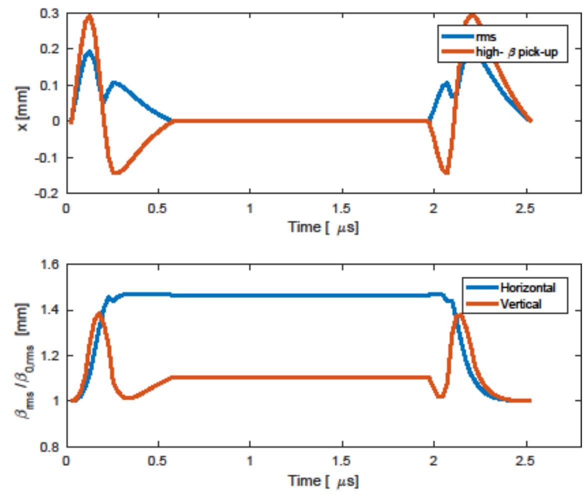
OCTUPOLE DESIGN

- The octupole was made in-house using insertions devices permanent magnets
- Strength chosen based on simulation, **no tuning possible**
- **Gain of a factor 2 both in dipole and quadrupole perturbation**

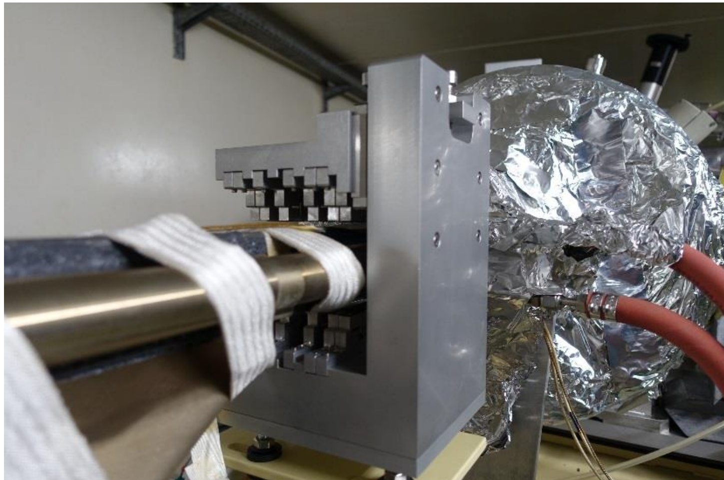


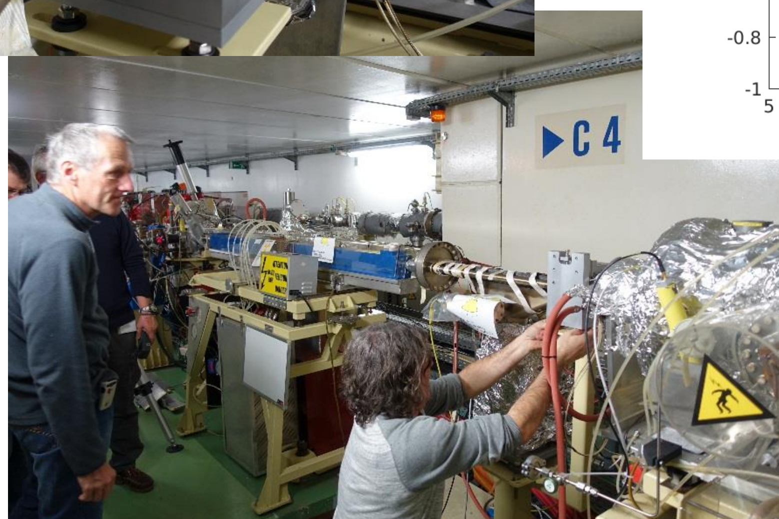


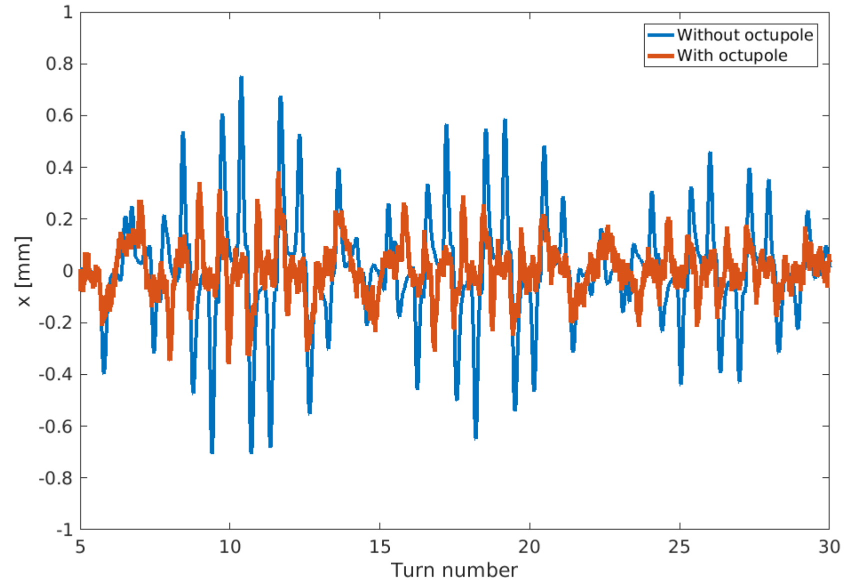




RESULTS



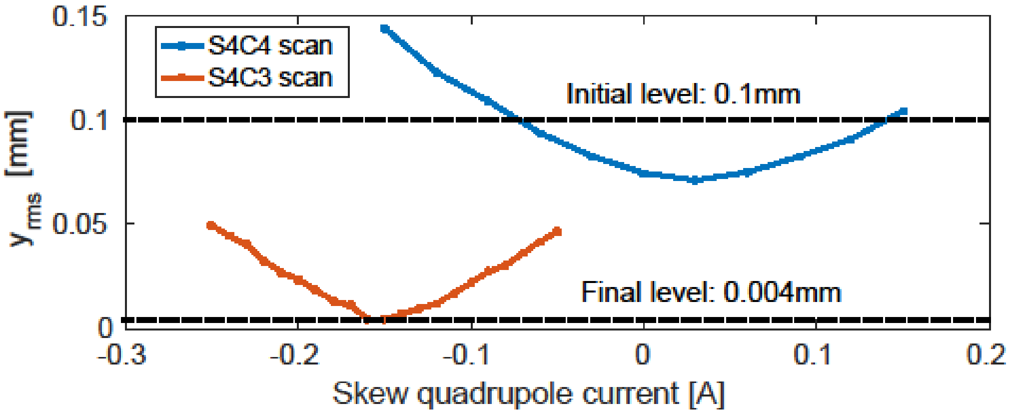


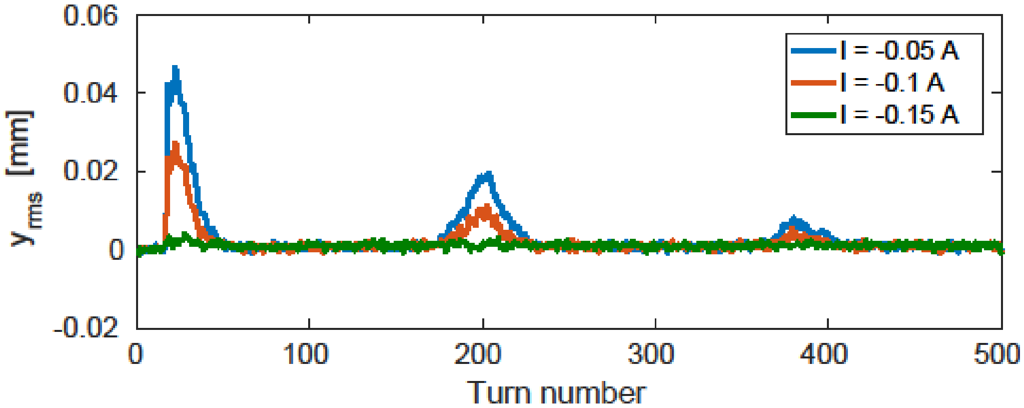


- **Factor 2 improvement**

VERTICAL COMPENSATION

- **Introduction of non-linear kicker field degraded the vertical stability:**
  - **The stronger the shims the more sensitive we are to misalignment**
- **Several alignment iterations:**
  - **Perturbation reduced but not stable over time**
- **Use skew quadrupoles (from correctors) inside to correct these errors:**
  - **Successful implementation, adjustable**
  - **Very efficient on flat-top, much less on the ramps**
- **Need additional active compensation**





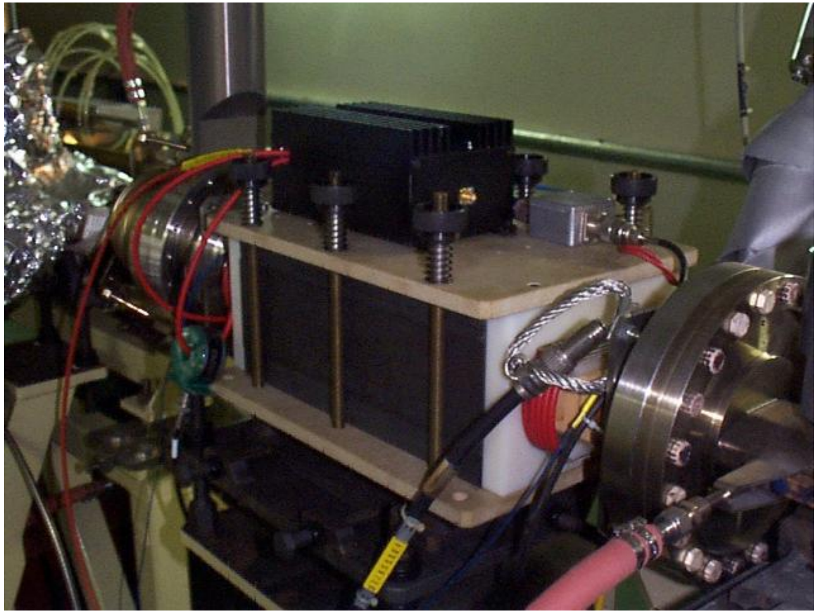
ADDITIONAL ACTIVE CORRECTION

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 few 2.8μs revolutions would 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

FEEDFORWARD SCHEME

***THE BUNCH BY BUNCH FEEDBACKS ARE INEFFECTIVE*:**

The Damping time is too long (30 turns) =>

The high vertical and horizontal chromaticity results in a fast decoherence

FEEDFORWARD SOLUTION:

Correction applied over a small number of turn at the maximum kicker power

Extra constraint:

No DC component in the correction signal (due to the amplifier bandwidth):

- **Correction duration equal to an integer number of betatron periods**

=> Vertical correction signal: 5 turns (ν_V=.39)

=> Horizontal correction signal: 9 turns (ν_H=.44)

CORRECTION SIGNAL CALCULATION

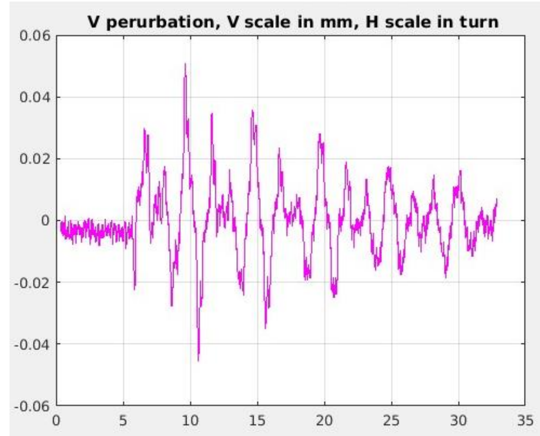
PERTURBATION SHAPE MEASUREMENT:

- BPM pick up:

4 buttons with RF matching transformers

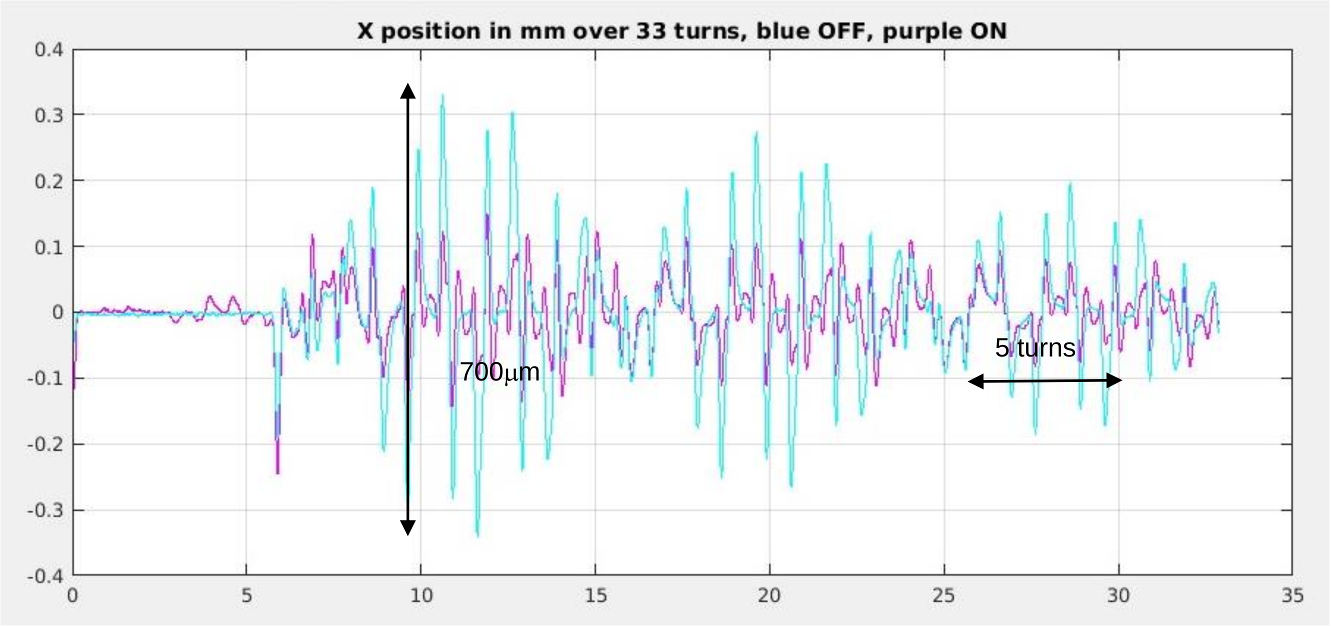
- Signal processor:

ADC data from an Itech Spark =>
304 samples per turn,10000 samples



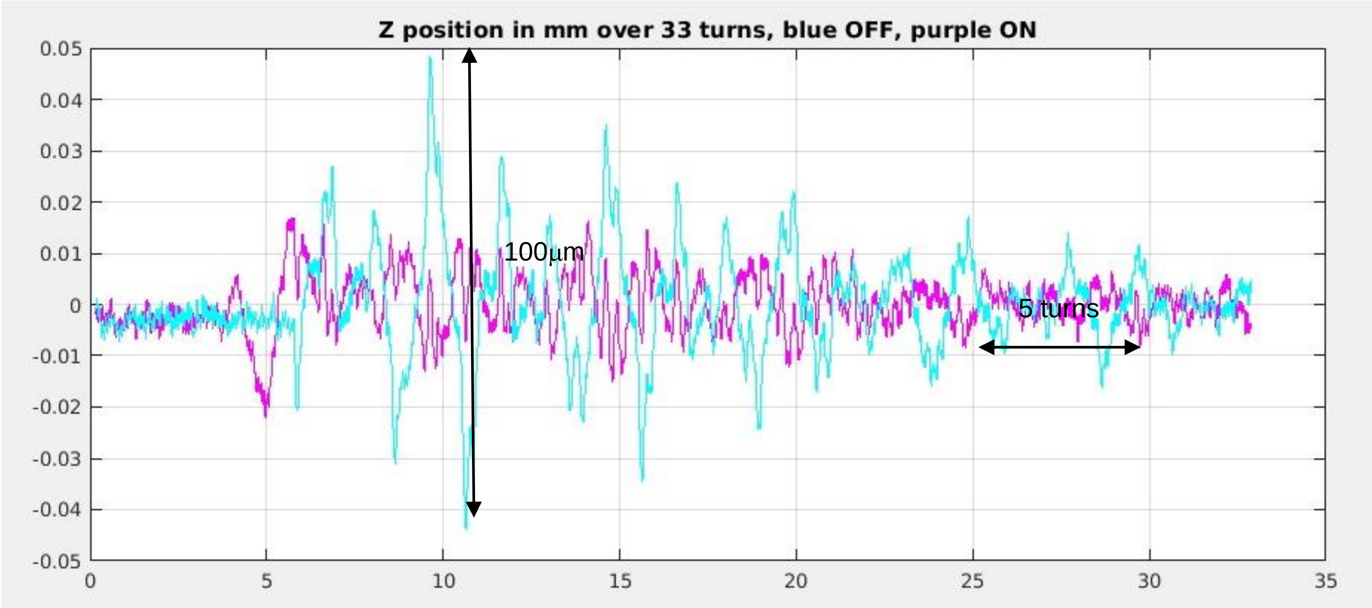
For each of the 304 samples we get the amplitude and phase of the perturbation over 9 turns (horizontal) or 5 turns (vertical) , assuming it is an oscillation at the betatron frequency , and we use these data and the phase shift between the BPM pick up and the corrector to calculate a correction signal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

DAMPING OF THE HORIZONTAL PERTURBATION OVER 9 TURNS



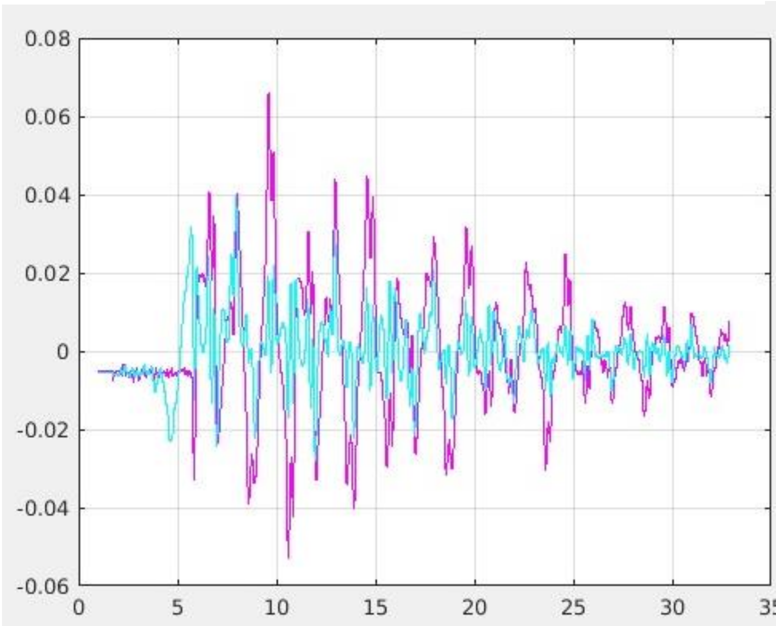
rms oscillation:
Without active damping: 100µm
with damping: 50µm
normal beam size: 350µm

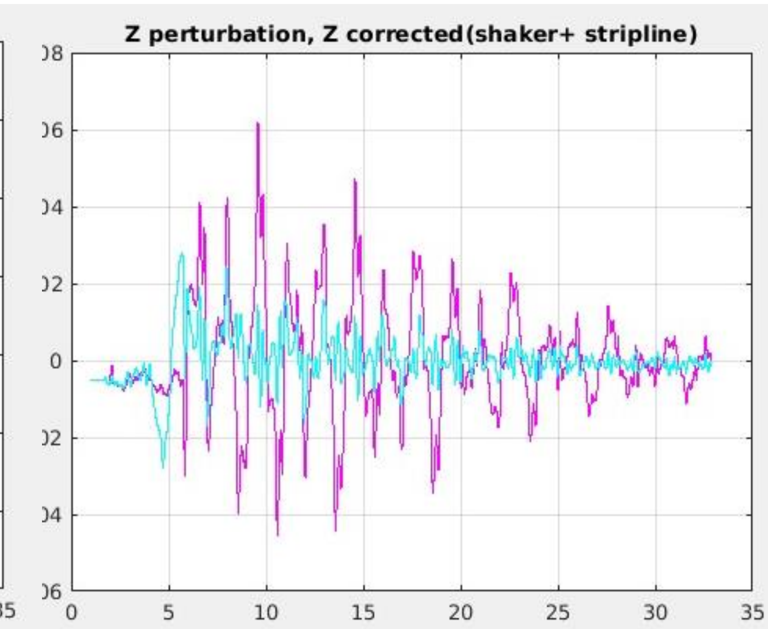
DAMPING OF THE VERTICAL PERTURBATION OVER 5 TURNS



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

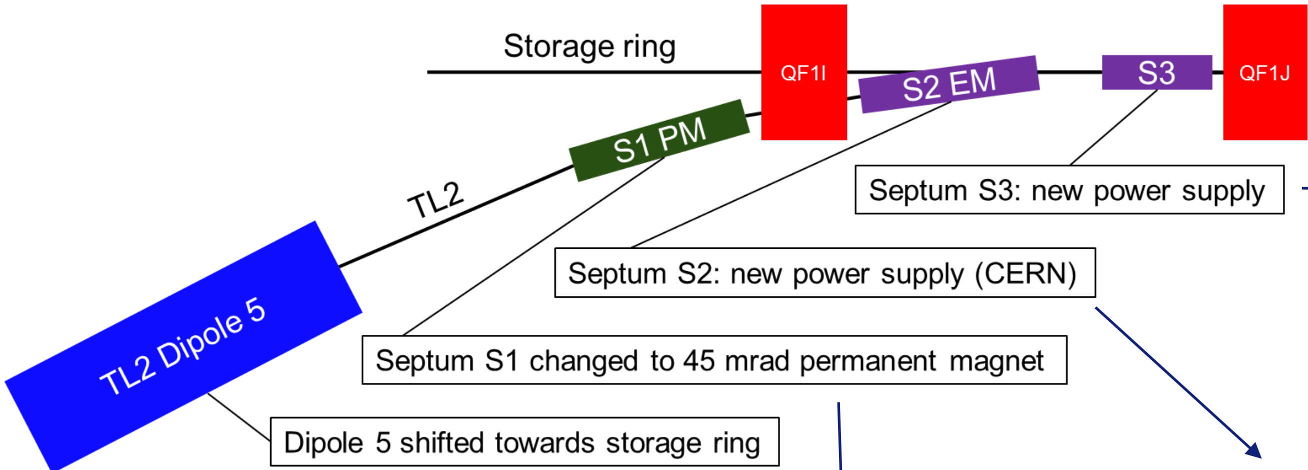
SITUATION AT THE END OF OUR STORAGE RING LIFE

THE REFILLS IN TOP UP OPERATION ARE NOW TRANSPARENT ACCORDING TO MOST OF OUR USERS

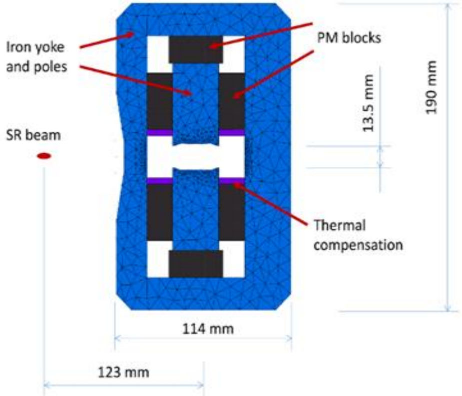
WE GAINED EXPERIENCE FOR THE EBS FUTURE OPERATION (TOP UP WILL BE MANDATORY)

MANY THANKS FOR YOUR ATTENTION

ESRF-EBS INJECTION



- New, more stable septum power supplies: better efficiency, shorter injection
- Permanent magnet septum: reduction of perturbations



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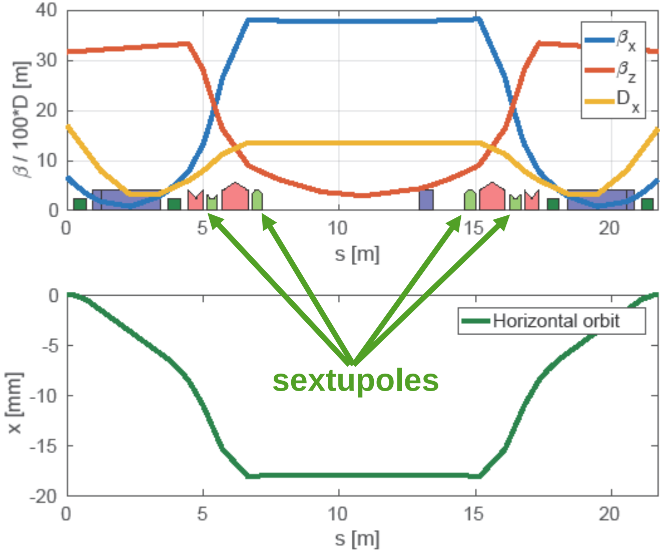
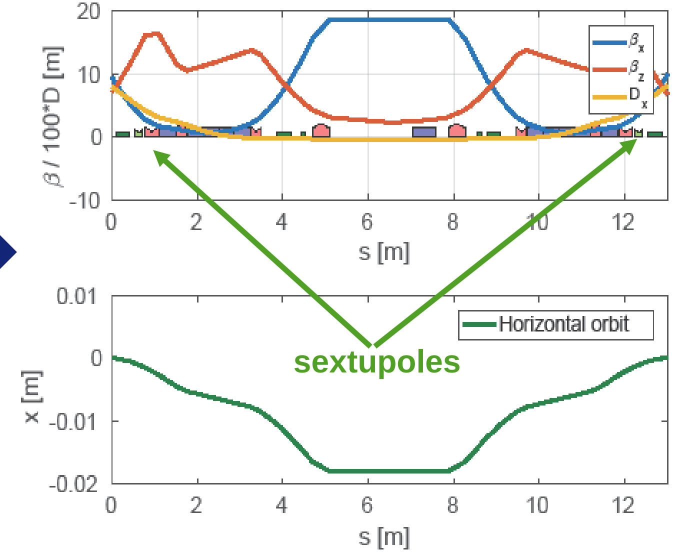
KICKER BUMP



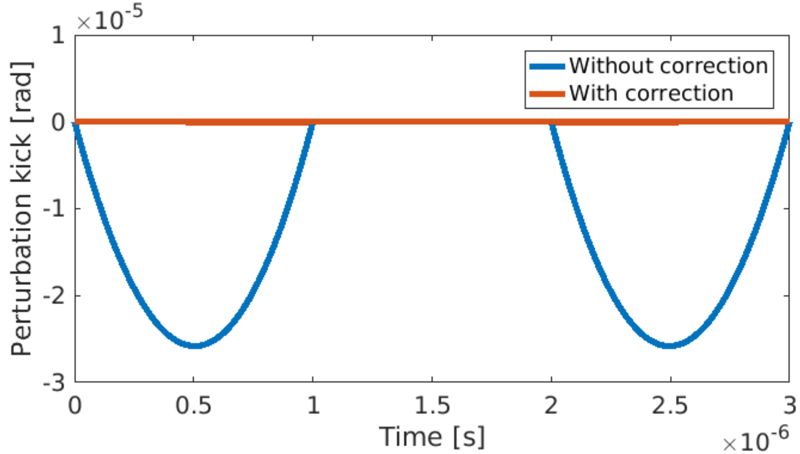


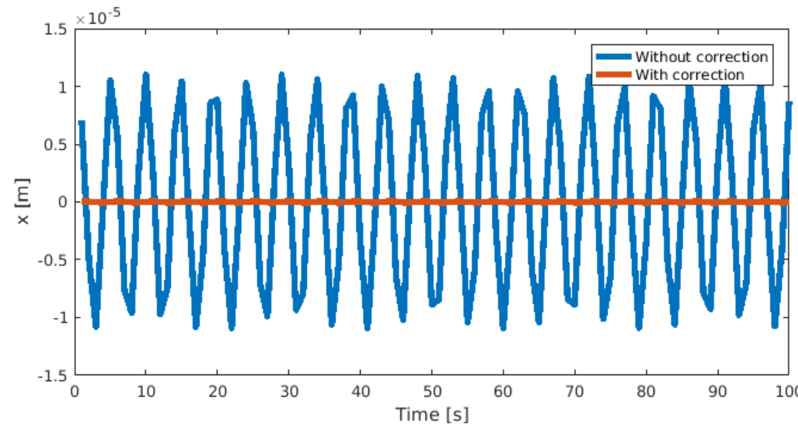
- The ESRF-EBS ring features a new injection cell and bump layout
- The principle and kickers power supplies are the same: 4 independent kickers bump + in-vacuum septum, no stability improvement to be expected
- **Main difference: no sextupoles at large bump amplitude, present limiting factor strongly reduced**

PERTURBATIONS

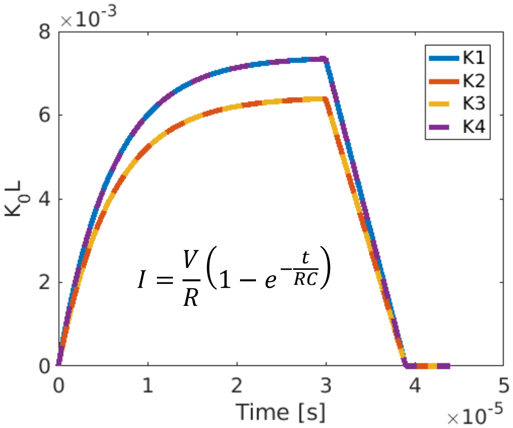
- **Sextupoles in the bump introduce an average perturbation of ~10-15μm in the IDs (0.3-0.5σ)**

- **2 correctors in the injection cell see the full bump amplitude:**
  - **They can be powered as sextupoles without removing any functionalities**
  - **The 2 phases provide almost perfect cancellation of the perturbation**
  - **Purchase of additional power supplies and cables approved, integration in the control system to be discussed**

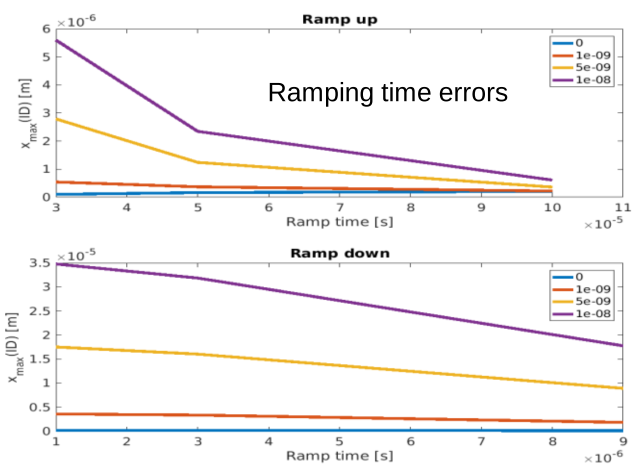


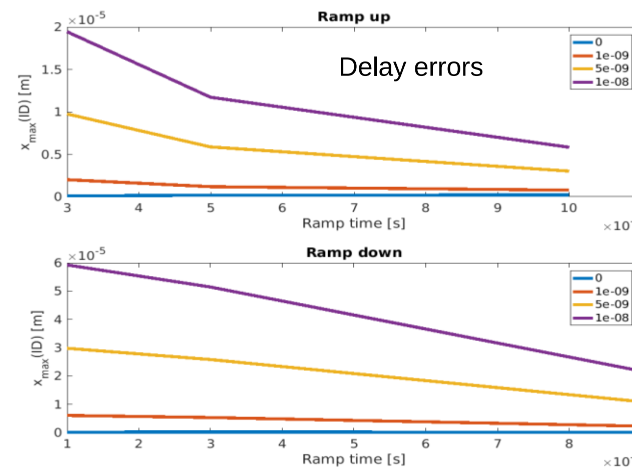


KICKERS POWER SUPPLIES



- **Kickers power supplies random fluctuations will be the most critical source of perturbation**
- Slowing down the ramps, reduces the sensitivity to such errors
- **Tolerance required to remain well below 1σ very tight (~1.0ns)**
- **Prototyping launched** to understand feasibility of such tolerances





WHAT CAN BE EXPECTED FOR ESRF-EBS?

- The absence of sextupoles at large bump amplitude will strongly reduce the perturbations by design:
  - The remaining can be compensated passively using a pair of sextupole correctors in the injection zone
- The septa perturbation is mitigated by replacing an EM by a permanent magnet:
  - The active compensation will still be operational
- Perturbations will be dominated by kickers power supplies random fluctuations:
  - Conceptual design for new power supplies ongoing
  - Prototyping should start this year
- Overall the absolute perturbation will be smaller, however the horizontal beam size will also be smaller (different ratios for high/low-β insertions):
  - The vertical plane should similar or better
  - In the horizontal plane, including all foreseen improvements 1σ level perturbation seems to be within reach
- The remaining residual oscillations will be of the order of few 10μm:
  - Random fluctuations
  - We need to devise a feedback system: can it be tested on this machine?