IFast Karlruhe 06-08 Marsh 2024

Modifications to the ESRF booster for ESRF-EBS

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On behalf of the Beam Dynamics Group

ESRF | The European Synchrotron

Outline

Top up related upgrades.

EBS or ESRFII related Upgrades:

- Off energy working point
- Stabilisation of Pulsed magnets
- New Lattice with increased H tune

Incremental Upgrades

- Emittance exchange
- RF Phase Ramping
- On line automatic injection tuning

Futur

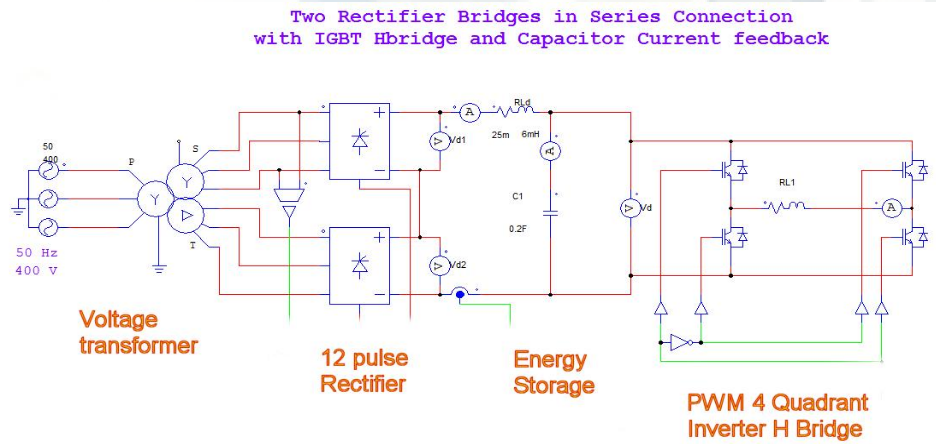
- NLK injection
- Fast SL developement

Top-Up Related Upgrades (~2010)

Injector switched on every Hour instead of every 12 hours.

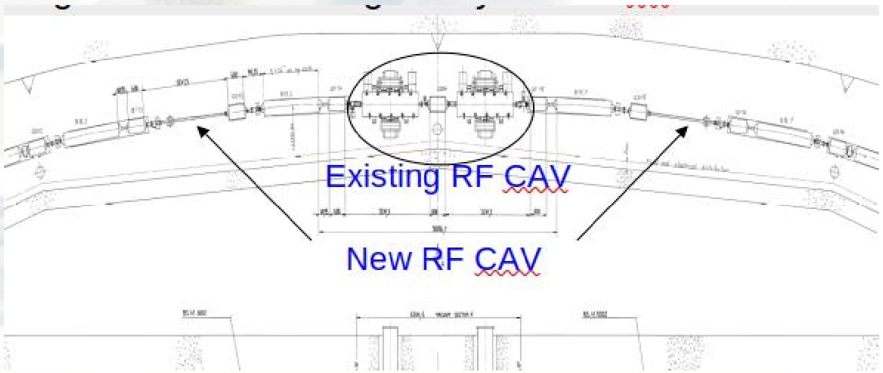
Reliability must be increased

Replace old magnet power supplies based on oscillating circuits with ramped power supplies



Dipoles PS architecture

Add 2 LEP type RF cavities to the 2 existing ones to deliver the 9MV needed.



RF section layout in the booster

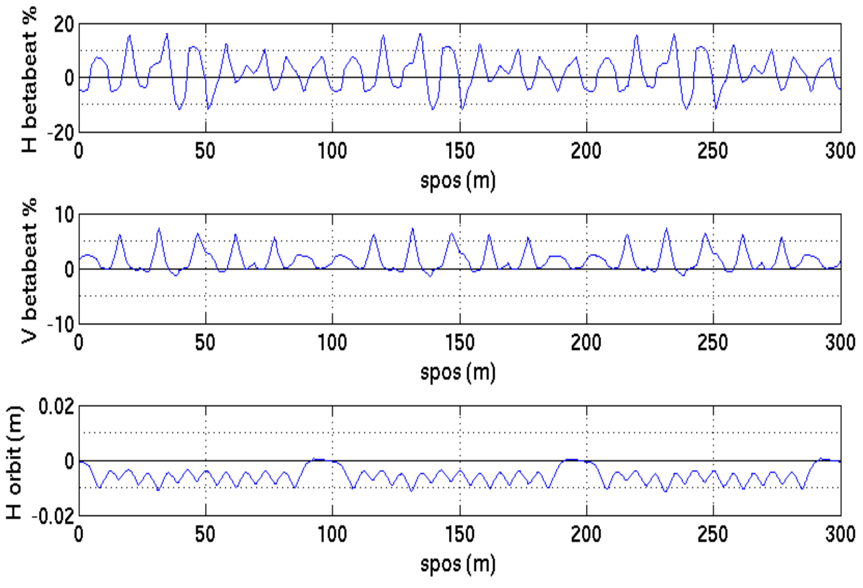
EBS Related Upgrades: Off Energy Working Point

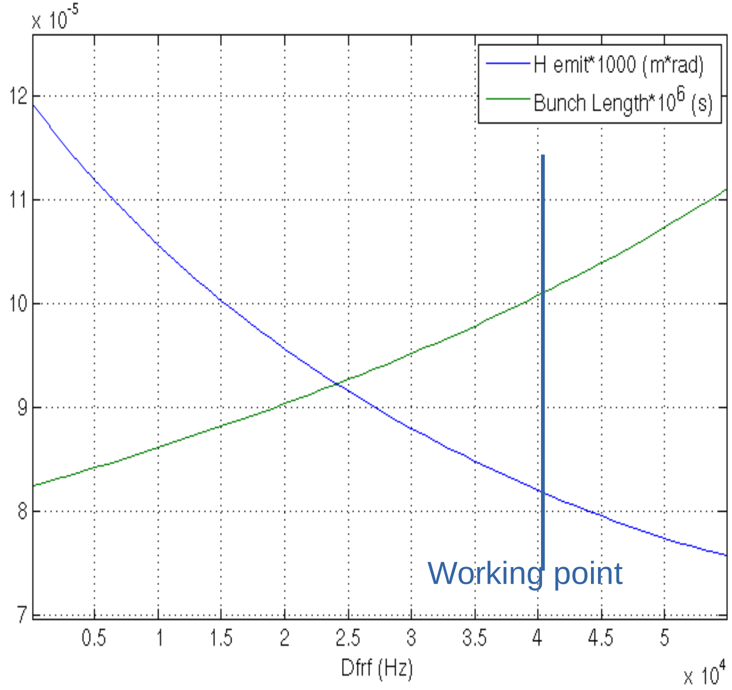
RF frequency of the new machine is higher by 170kHz . We had to adapt the booster circumference to this new frequency.
Girder adjustments where limited and a mismatched RF was beneficial to reduce the H emittance. The circumference change includes the mismatch of 40kHz between Rf frequency and machine length.

	RF frequency	Matched booster length
ESRF I	352.200 MHz	299.6141 m
EBS	352.372 MHz	299.4757 m
EBS-40kHz	352.332 Mhz	299.5099 m

- 105mm

EBS Related Upgrades: Off Energy Working Point





RF offset of 40kHz: H emittance reduced from 120 to 83 nm.rad

Blength increased from 82 to 100ps

Mean H orbit from 0 to 6mm

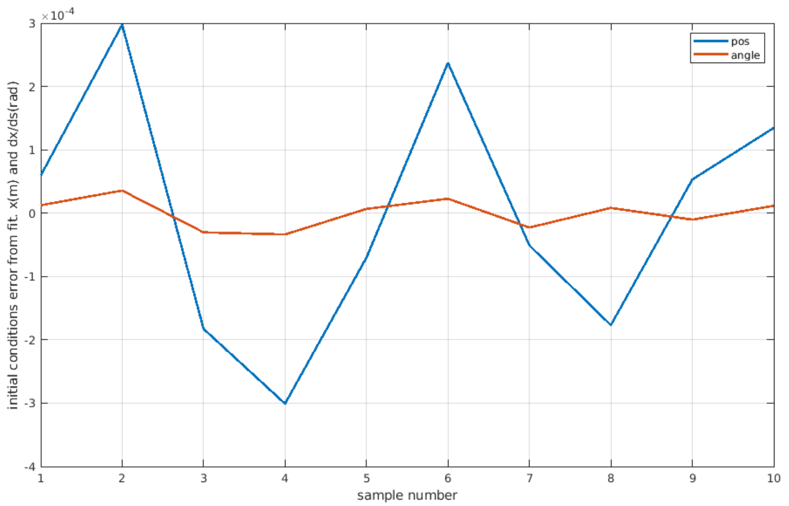
Septum/Kicker Stability

Shot to shot variation of pulsed ellements induces orbit jitter. It increases the apparent beam size as would do an emittance growth.

To mitigate as much as possible the Jitter:

- Permanent magnets septums where used for 55% of the integrated deflection.
- When the PM solution was not possible, upgrade of the PS.

Position jitter divided by a factor ~2.5



Jitter of injected beam H position and angle at injection point.

rms pos=0.182mm

rms angle=0.022mm

~ 38 µrad in the extraction septum.

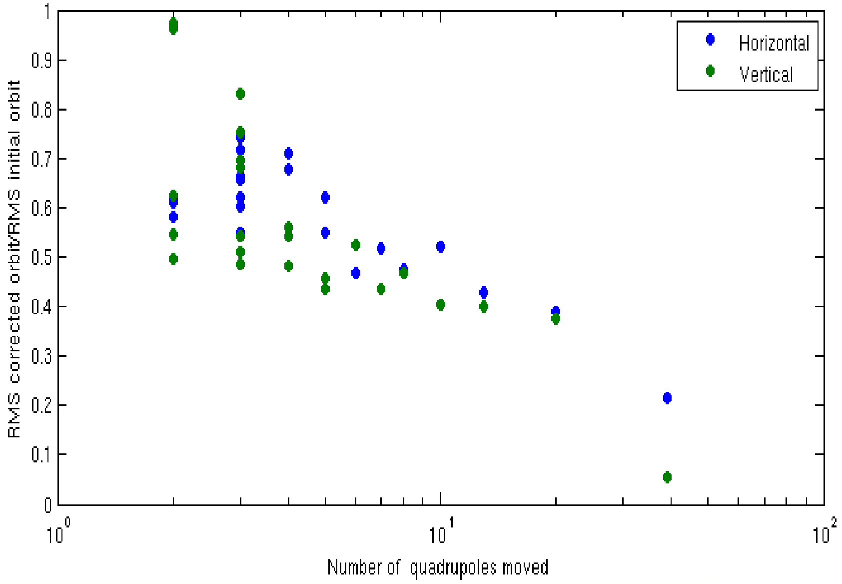
Integrated deflection of pulsed magnets used for injection: ~400 mrad.

Motorised Tables for Orbit Control in the Booster

ESRF I had only DC correctors in the booster allowing orbit correction only at low energy.

Quadrupoles missalignement can be used as ramped correctors as they provide constant deflection during energy ramping: $\theta = K_{normalised} * offset$.

Motorised tables allowing translation in a single direction have been installed.
8 focusing quadrupoles and 4 defocussing Quads are equiped.

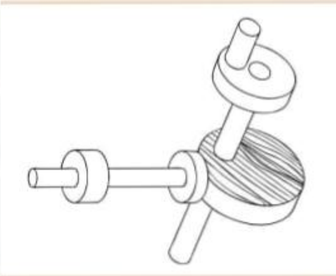


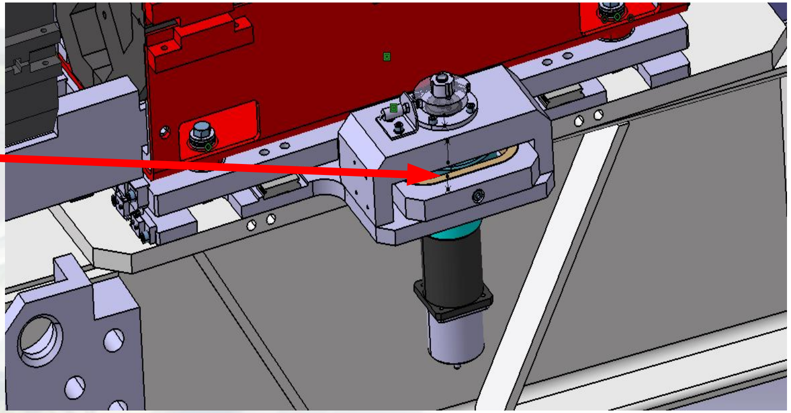
Expected orbit correction for different configuration of correctors VS number of quads equiped.

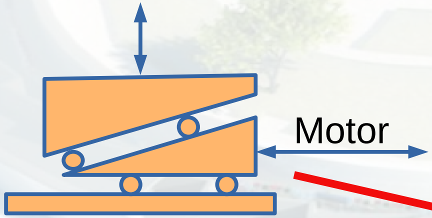
Motorised Tables for Orbit Control in the Booster

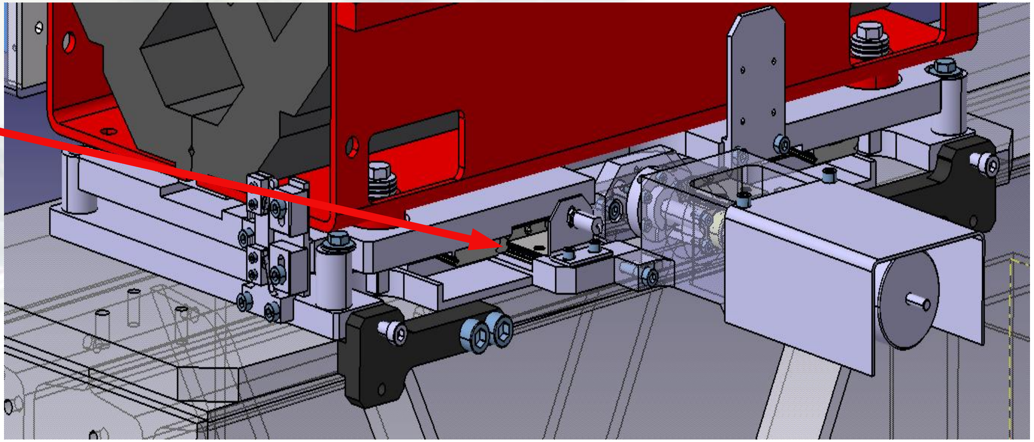
Horizontal:

Excentric cam drives horizontal motion of uper table.









Vertical:

A third beveled tabled is inserted between the two plates and moves vertically the quad when pushed in/out by motorisation.

Courtesy B. Ogier, N. Benoist, F. Taoutaou

Motorised Tables for Orbit Control in the Booster

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Positioning reproducibility = 20 µm.

Not a single failure in 10 years of operation.

RMS orbit at extraction reduced by a factor 2 and is today at 0.4-0.5mm in both planes

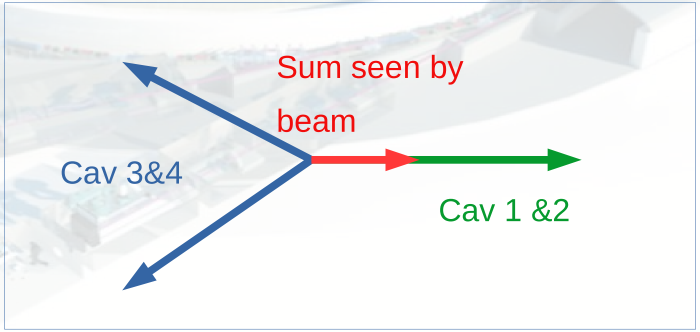
Rf at injection in the booster

To minimise beam loading disturbance and proper operation of the feed-back loops in RF cavities we want Vrf>0.3MV in each cavity.

$\neq$

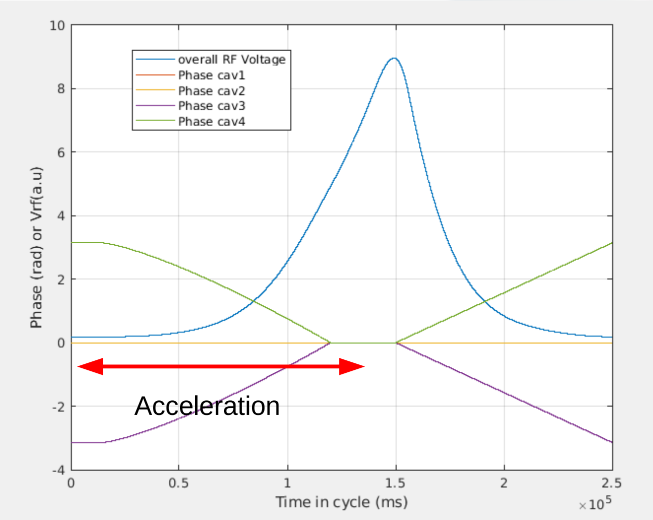
To optimise longitudinal matching and beam capture in the booster we need to have the sum of the voltage of the 4 cavities to be as low as possible.

If some cavities work in opposition of phase with respect to the reference one, it is possible to have a low sum but a relevant voltage in each cavity.



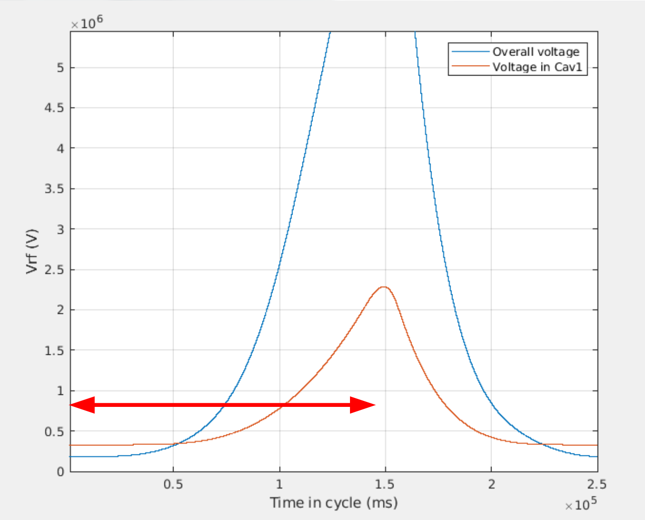
Rf requirements at extraction from the booster

At extraction from the booster the cavities need to be in phase to ensure maximum sum voltage.



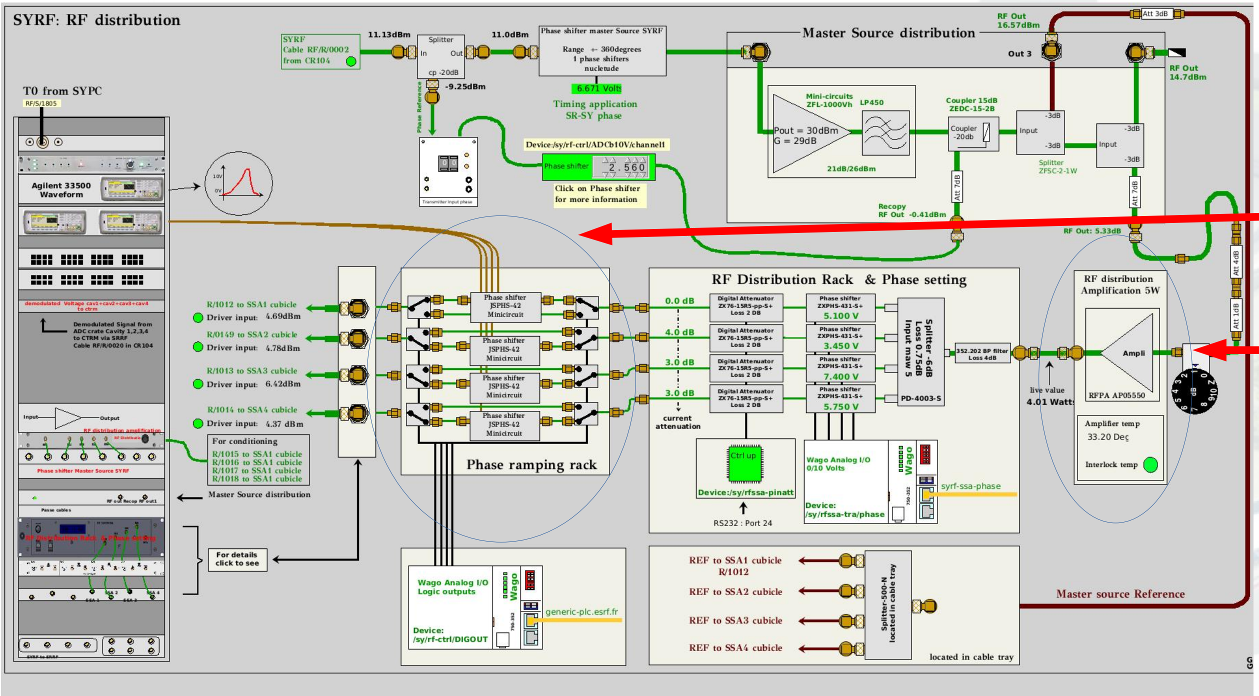
Phase

Voltage



Hardware has been developed to enable phase ramping. It is now possible to have two cavities out of phase at injection and phased at extraction.

RF Phase Ramping



Courtesy G. Gautier

New Hardware developed.

For each transmitter, the phase of the low level RF can be ramped using a waveform generator.

Transmission between linac and booster increased from 65 to 80%.

Higher charge can most provably be captured in a single bunch.

Idea initially presented By P. Kuske and F. Kamer: Exchange horizontal and vertical emittance right before injection in the storage ring.

At ESRF the magnets PS can provide a sufficiently fast tune crossing to optimise emittance exchange during the tune crossing.

See J. Kallestrup Talk

TRANSVERSE EMITTANCE EXCHANGE FOR IMPROVED INJECTION EFFICIENCY *

P. Kuske[†] and F. Kramer, Helmholtz-Zentrum Berlin, Berlin, Germany

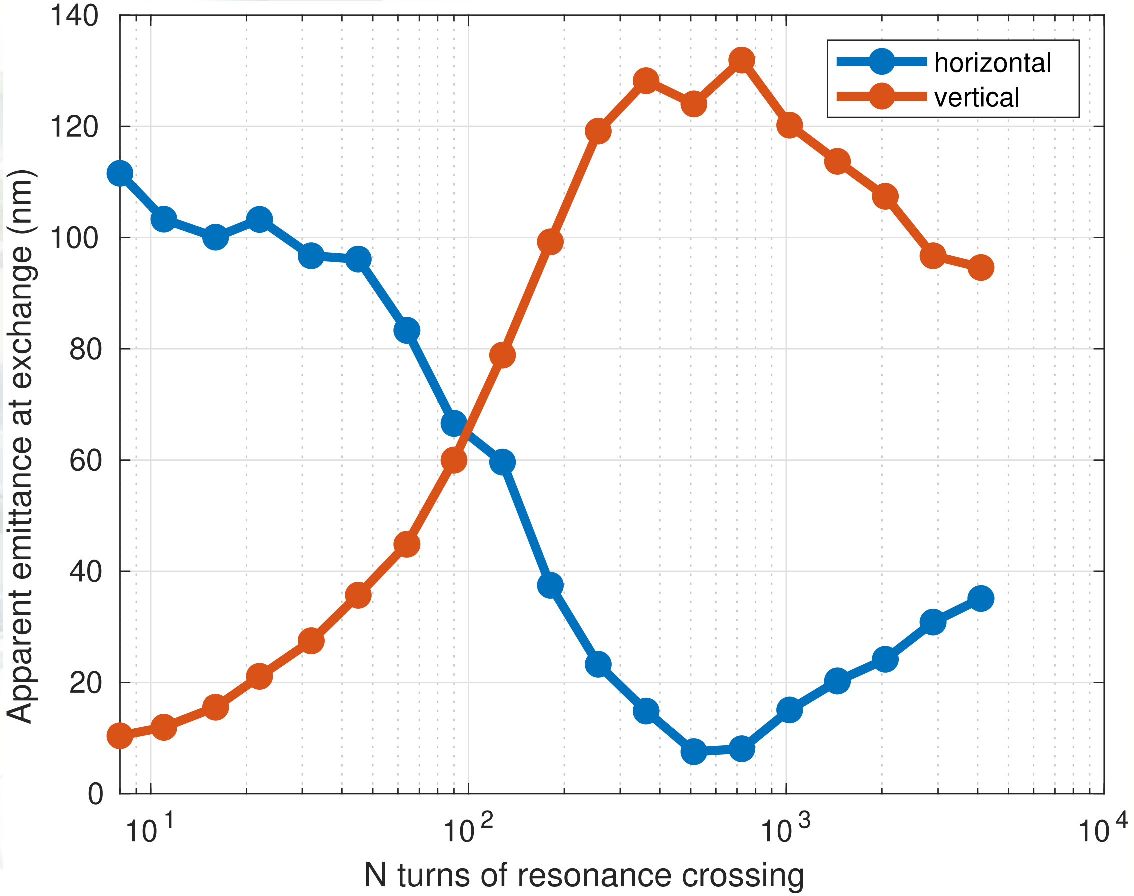
Emittance Exchange in The Booster

Optimum emittance exchange is with tune crossing in 700 turns (0.7 ms), which is feasible with ESRF booster power supply.

Even a not optimal crossing time of 4000 turns would give a horizontal emittance of less than 40 nm, much better than the 60 nm of the full coupling case.

Courtesy N. Carmignani

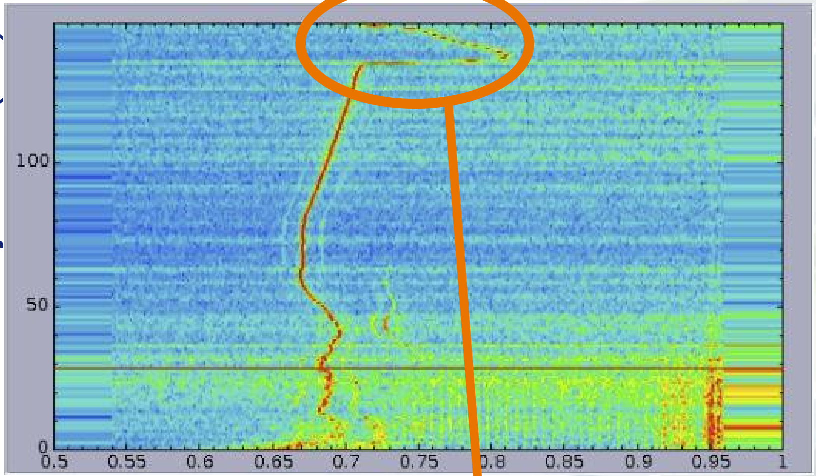
Maximum exchange vs tune crossing time



Emittance Exchange in the Booster

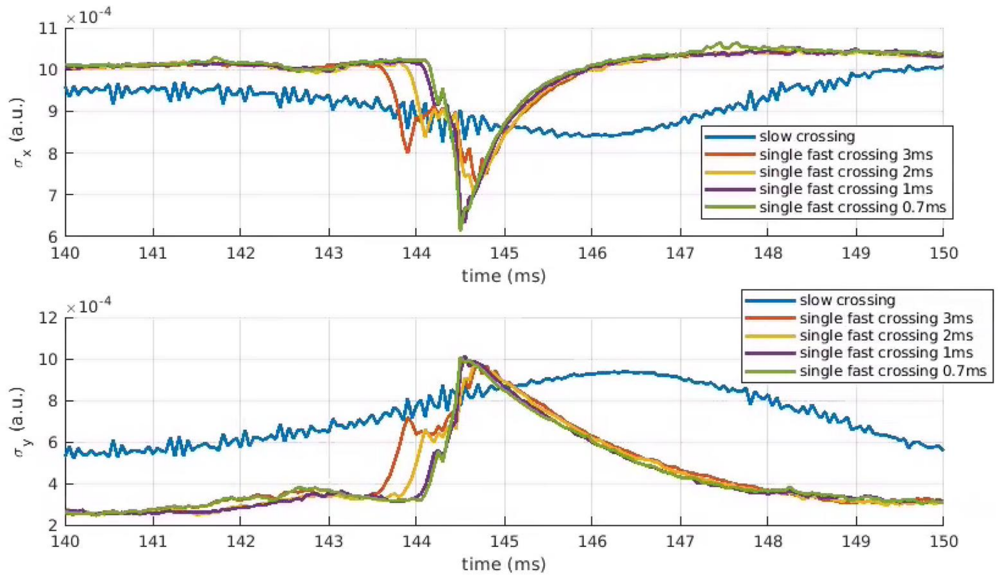
Emittance exchange in the booster done by crossing the tunes changing the vertical quickly

Time from injection (ms)



Vertical tune

The vertical tune is changed by 0.15 at extraction time



With emittance exchange in the booster, the injection efficiency improved by 5-10%.
H emittance of extracted beam estimated at 40-50nm.

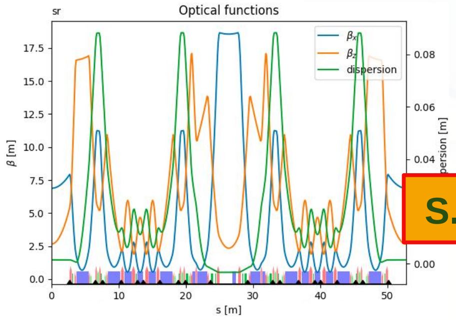
The “non linear kicker” (NLK) scheme, by removing the need of a solid blade, allows to reduce the perturbations to almost 0. Initially proposed by K. Harada (KEK, Japan)

New injection scheme using a pulsed quadrupole magnet in electron storage rings

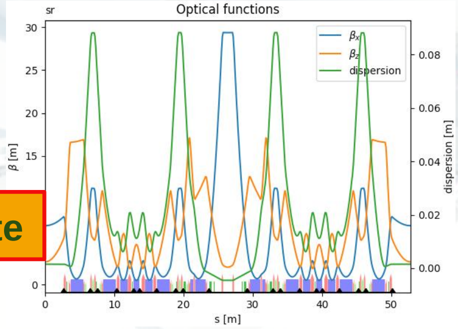
Kentaro Harada, Yukinori Kobayashi, Tsukasa Miyajima, and Shinya Nagahashi
Phys. Rev. ST Accel. Beams **10**, 123501 – Published 21 December 2007

This option is under study at ESRF since a couple of years, and is provably the best candidate to reach minimum perturbation.

Design a new injection cell to increase β_h at injection and find space space for the NLK.



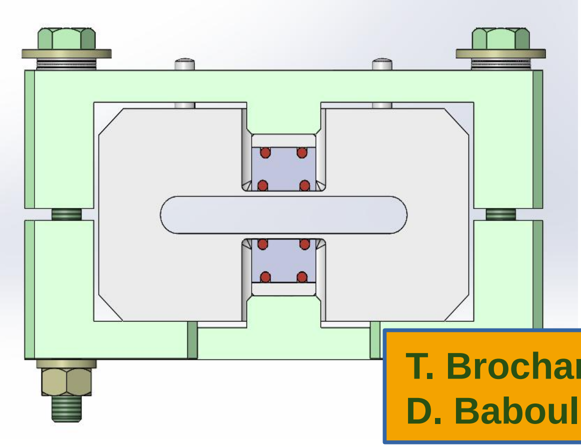
β_h=18m



β_h=30m

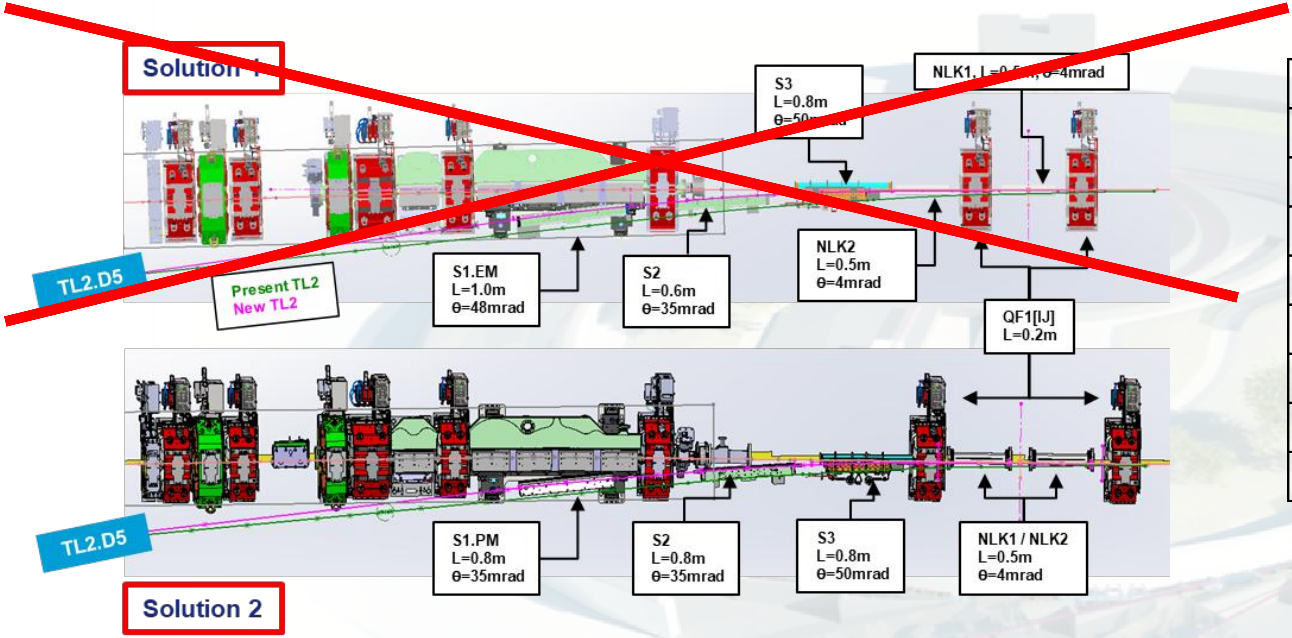
S.White

Design a non linear kicker magnet.



T. Brochard, D. Baboulin

NLK Implementation



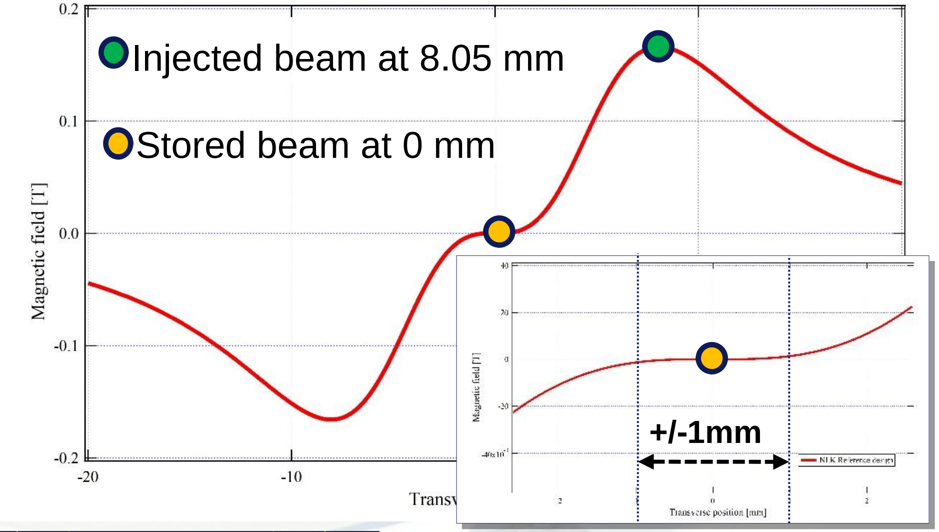
	Solution 1	Solution2
	Magnets	
S3	L=0.8, θ=50mrad	L=0.8, θ=50mrad
S2	L=0.6, θ=35mrad	L=0.8, θ=35mrad
S1	L=1.0, θ=48mrad	L=0.8, θ=35mrad
	Power supplies	
S3	I=11200A	I=11200A
S2	I=12800A	I=9600A
S1	I=10500A	N.A.

The solution 2 was adopted as the baseline solution:

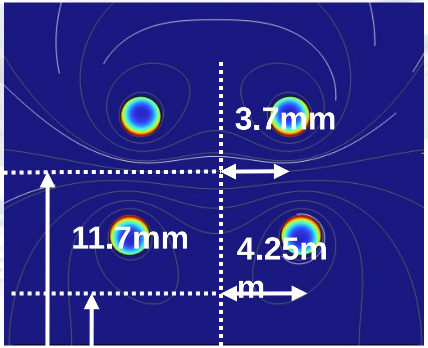
- **All NLK located between QF1, flat β-function**
- **All magnets compatible with present specification (Δθ/L ~constant)**
- **Distance between QF1 increased: smaller β at injection**

T. Brochard

Conductor	
Conductor Nº	8
Section	3.14 mm²
diameter	2 mm
Current I	5.5 KA
Frequency	90 kHz
Inductance	1.83 µH
Positioning Tolerance	30 µm



Magnetic field	
B at stored beam	0 T
B at injected beam	0.17 T
B at 0.3 mm	$7\ 10^{-5}$ T
Horizontal kick	4 mrad



All parameters within specifications

C. Benabderrahmane
M. Morati

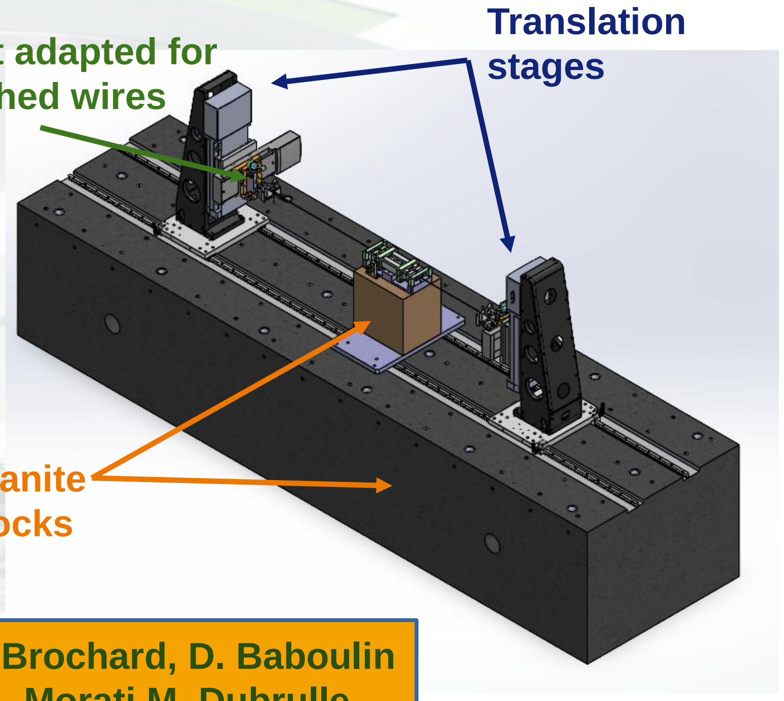
Prototyping is ongoing

Master student theses starting in April

The NLK design, production and assembly needs to be validated with precise magnetic measurements

We are adapting an existing bench

- Equipped with 4 stretched wires to measure varying fields
- Mechanical design and infrastructure work (fences) started
- Control, data acquisition and analysis to be done

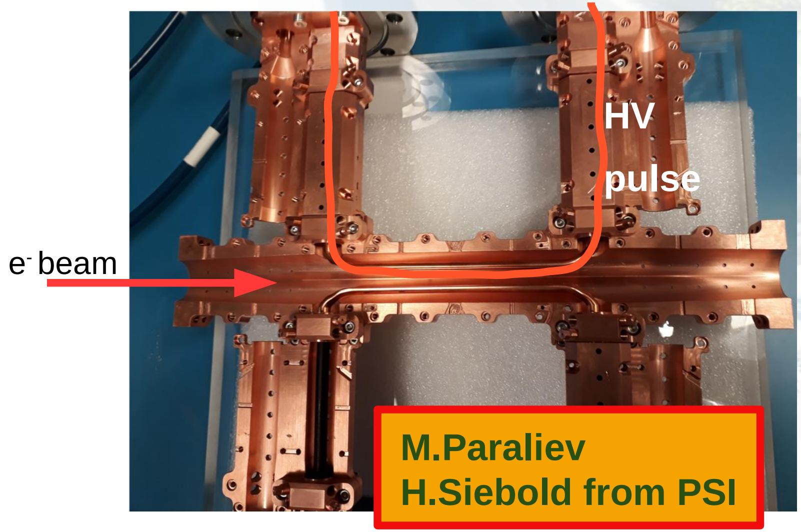


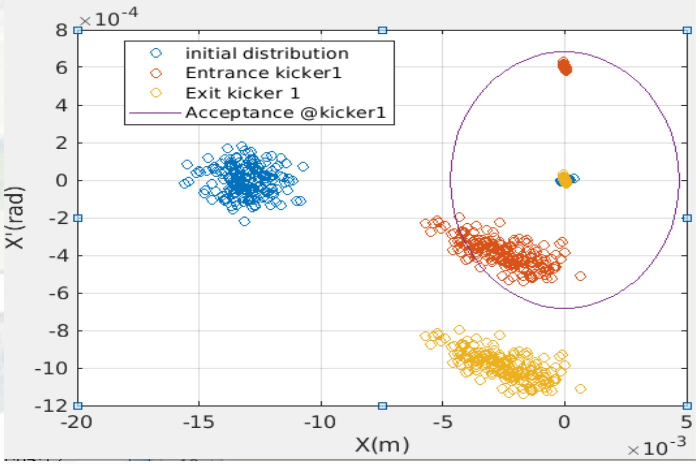
This is a long term investment for future pulsed magnets developments

T. Brochard, D. Baboulin M . Morati M. Dubrulle, G. Le Bec

Fast Strip-Line Kicker Tests

- The **SL kickers combined with ultra fast pulsers** are able to provide fast kicks of the order of ~2-10ns for a kick of 0.03-0.3mrad @6GeV.
- The injection perturbations can be reduced by interacting only with a few bunches at each injection shot instead of interacting with the full beam.
- Fourth generation SR light sources include this type of kicker in their design but for now no machine has succeeded in using them as reliable injection kicker (?).





Shared oscillation scheme: the kicker kicks both stored and injected beam.

In this case, a kick of 0.6 mrad drives both beams inside the acceptance.

Simulated injection efficiency is of 85%.

Mean first turn trajectory (10 samples)

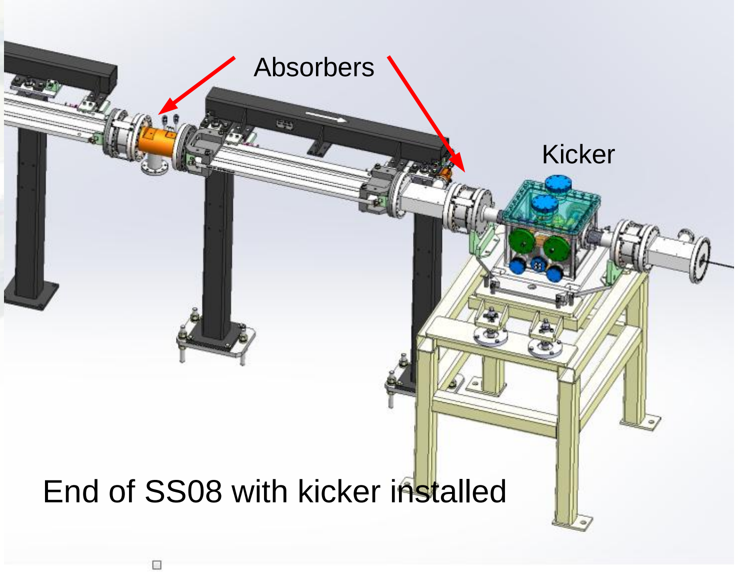
In the framework of a PSI-ESRF colaboration, we will test the SLSII kicker on our machine. Beam induced heating is to be qualified.

Schedule:

- ~~Test in TL2 October 2023~~ → Installation canceled due to pollution in the chamber observed once received at ESRF.
- Storage ring MDTs March 2024 (next week): **maintained.** SD specifically adapted to include three days of tests with beam.

These devices can increase performance of other injection schemes, and be implemented in parallel as they do not necessarily have to be placed in the injection section.

B. Ogier
C. Maccaronne
H. Pedroso-Marques



End of SS08 with kicker installed

Many Thanks for your Attention