Longitudinal injection into low-emittance ring: A novel scheme for SOLEIL upgrade

Marie-Agnès Tordeux
and Accelerators & Engineering Division

Outline

I. Introduction
II. Longitudinal injection
III. New scheme
IV. Challenges
V. Summary

I. Introduction

Low-ε lattice investigation is under way @ SOLEIL, with a new step of increasing the symmetry (one type of straight section). 2 kinds of lattices are under study :

- ε_x > 100 pm.rad with a large dynamic aperture (off-axis injection)
- ε_x < 100 pm.rad with small dynamic aperture (on-axis injection).

This talk deals with the latter case.

On-axis injection

This presentation aims to propose an alternative solution to On-axis injection, **other than :**

- the swap out method.
- the use of a very fast transverse kicker.

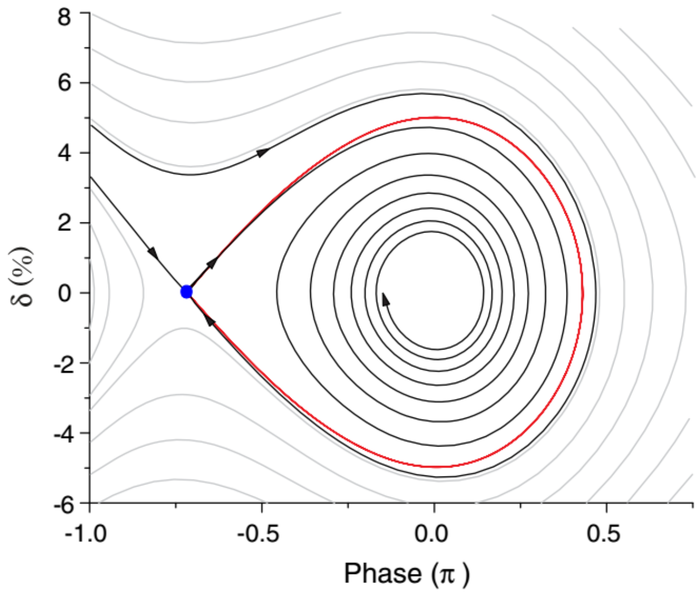
Longitudinal injection

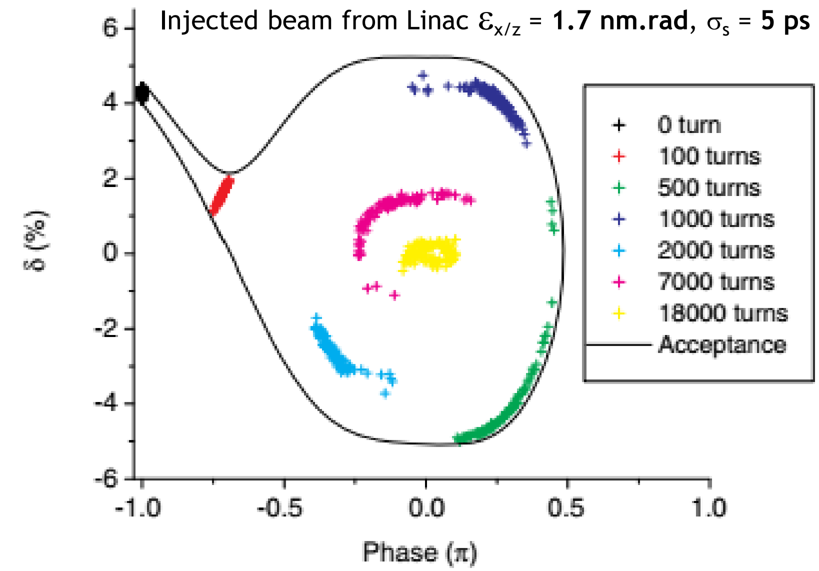
It starts with the longitudinal injection scheme developed by the SLS group.

II. Longitudinal injection: recall of SLS scheme

- applied to MAX IV

M. Aïba et al., PRST AB 18, 020701 (2015)





A transparent injection is presented where the injected beam is longitudinally separate from the stored beam by $\Delta\varphi = -\pi$.

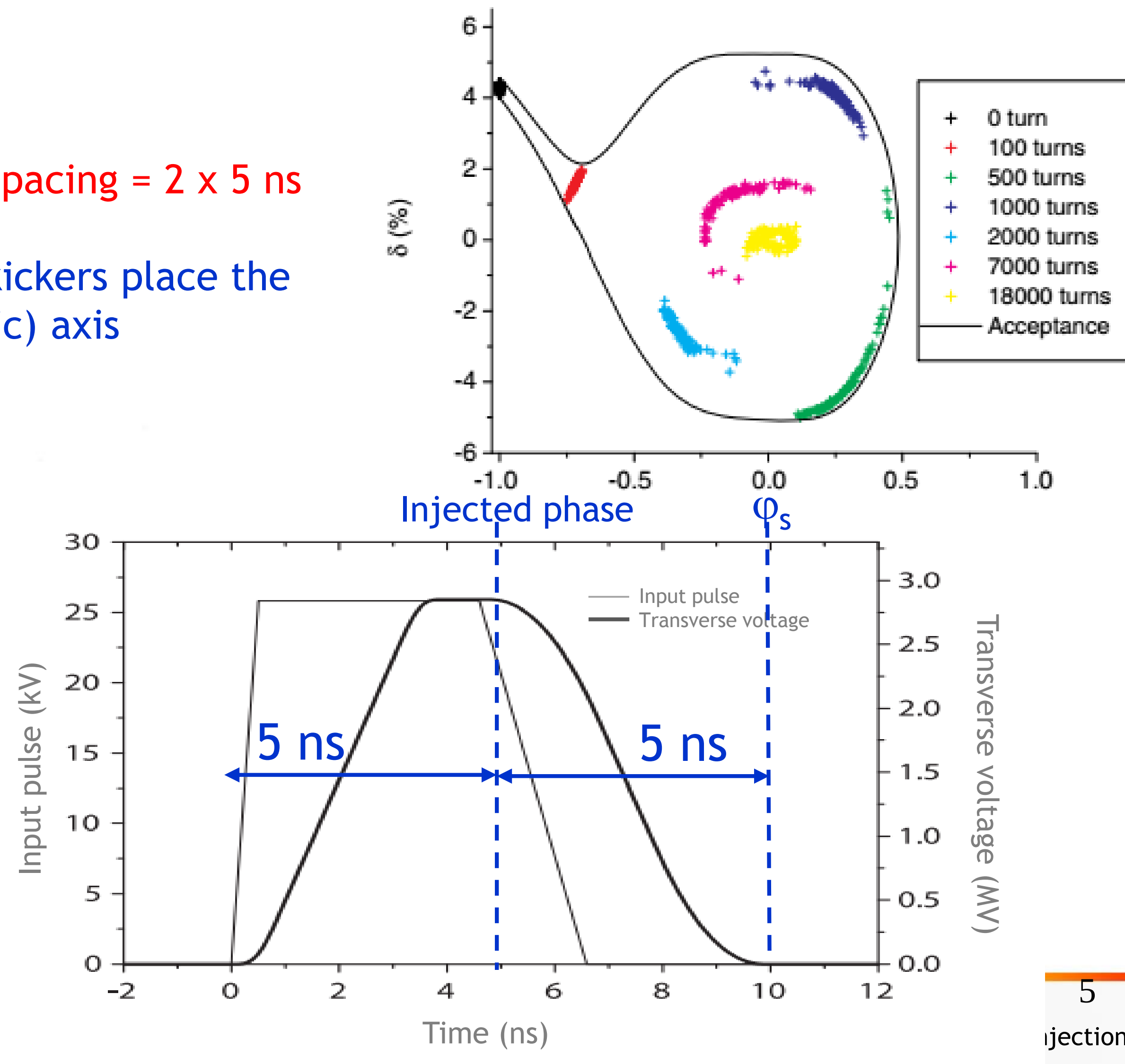
The longitudinal acceptance phase-space looks like a **"golf club"** and allows a specific off-momentum beam to be naturally trapped and merged into the circulating beam.

❑ applied to MAX IV

M. Aïba et al., PRST AB 18, 020701 (2015)

100 MHz RF system: bunch spacing = 2 x 5 ns

As a first step, short pulse kickers place the injected beam on-(chromatic) axis



II. Longitudinal injection: recall of SLS scheme

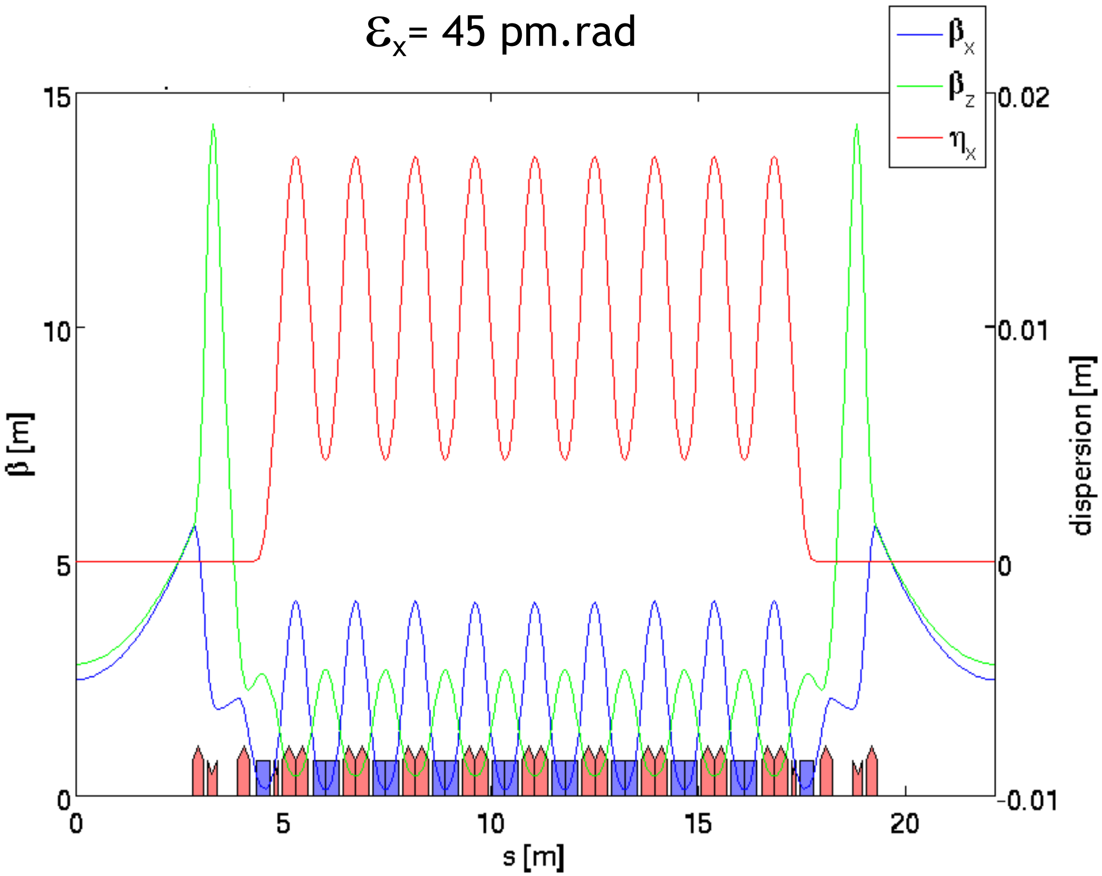
- applied to SOLEIL Upgrade:

SOLEIL synchrotron
- Linac injector: *100 MeV*
- Booster: 157 m outside SR tunnel
- Storage Ring: 354 m, *2.75 GeV*
- RF system: cryogenic, 352.2 MHz

II. Longitudinal injection: recall of SLS scheme

❑ applied to SOLEIL Upgrade:

Example of prospect lattice with very low H. emittance.



SOLEIL synchrotron

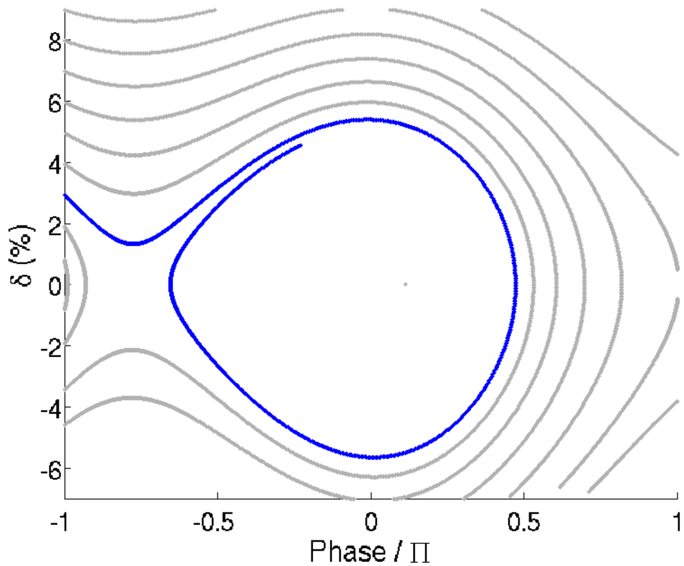
- Linac injector: *100 MeV*
- Booster: 157 m outside SR tunnel
- Storage Ring: 354 m, *2.75 GeV*
- RF system: cryogenic, 352.2 MHz

- 16 periods, 354 m, 2.75 GeV
- Working point = (73.43, 42.11)
- $(\beta x, \beta z)_{sp}$ = (2.5,2.8) m with straight = 5.655 m
- Max K1 = 10 [m-2] => 92 T/m @2.75 GeV
- Combine sextupole into quad and bends
- Bends: (0.65 T, 49 T/m, 7183 T/m2) @2.75 GeV

Hung Chun Chao, IPAC 2017

- applied to SOLEIL Upgrade

Motion in the longitudinal phase space (Accelerator Toolbox tracking)



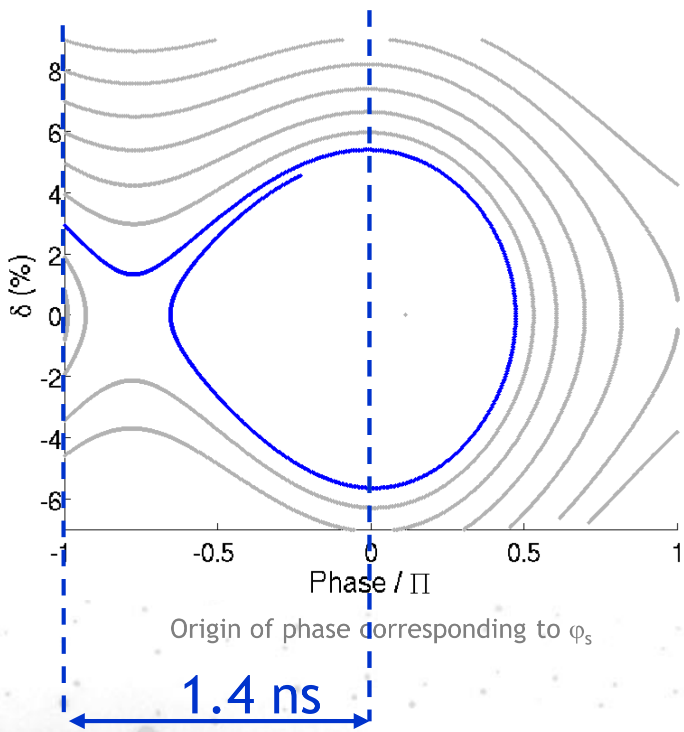
Origin of phase corresponding to φ_s

Taking into account radiation and damping.

II. Longitudinal injection: recall of SLS scheme

- applied to SOLEIL Upgrade

Motion in the longitudinal phase space (Accelerator Toolbox tracking)



In the case of SOLEIL, rise/fall time requirement for the fast transverse kicker = 1.4 ns for a few mrad strength.

It is far beyond the today state of the art.

352 MHz RF system: bunch spacing = 2 x 1.4 ns

III. Longitudinal injection: new scheme

Instead, we propose to use 2 kinds of "Non-Linear Kicker" (NLK):

- A Transverse Non-Linear Kicker (or Multipole Injection Kicker MIK) with no constraint in duration, to place the injected beam on a chromatic orbit and then perform an on- (chromatic) axis injection. It assumes:
  - The injected beam is off-momentum (δ_{inj})
  - It exists a H. dispersion bump in the lattice
    - This bump may be especially created @ MIK position → breaks the symmetry of the ring → the lower bump the better
    - Or use of the natural "low" dispersion

  In both cases, high δ_{inj} is needed to get a reasonable chromatic orbit @ MIK (*chromatic Closed Orbit* > *4 mm*).

- A Longitudinal Non-Linear Kicker to improve the capture of this high momentum beam.

III. Longitudinal injection: new scheme

❑ Create a “longitudinal NLK”

= Additional RF pulse that will:

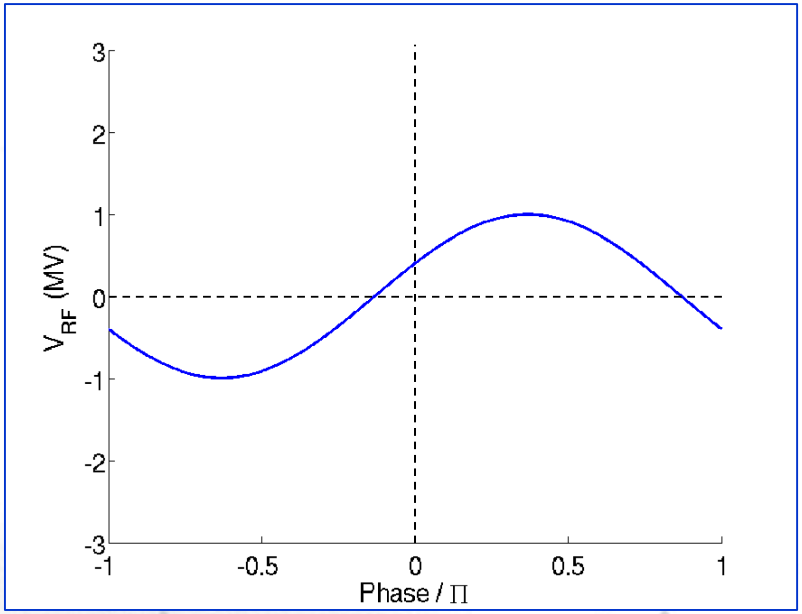
- Reduce the injected off-momentum deviation as quickly as possible and let enter the particles into the longitudinal bucket
- Keep the stored beam unaffected, in terms of centroid position and bunch length.

III. Longitudinal injection: new scheme

❑ Create a “longitudinal NLK”

= Additional RF pulse that will:

- Reduce the injected off-momentum deviation as quickly as possible and let enter the particles into the longitudinal bucket
- Keep the stored beam unaffected, in terms of centroid position and bunch length.



Origin of phase corresponding to φ_s

Main 352 MHz RF pulse

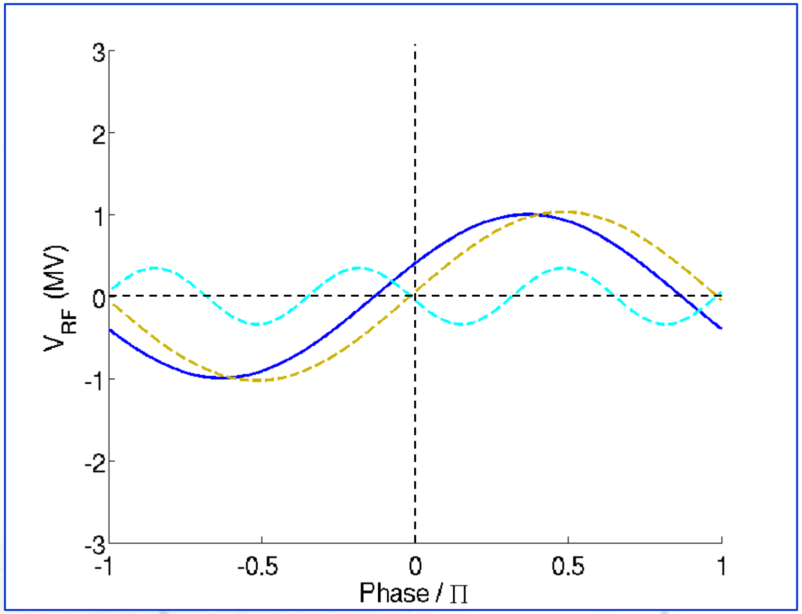
V_{main} = 1 MV

U_0 = 360 keV/turn

III. Longitudinal injection: new scheme

❑ Create a "longitudinal NLK"

= Additional RF pulse that will:
- Reduce the injected off-momentum deviation as quickly as possible and let enter the particles into the longitudinal bucket
- Keep the stored beam unaffected, in terms of centroid position and bunch length.



Origin of phase corresponding to φ_s

Main 352 MHz RF pulse
V_{main} = 1 MV
U_0 = 360 keV/turn

\+ additional 352 MHz pulse
Shifted by φ_s
V_{add} ~ 1 MV

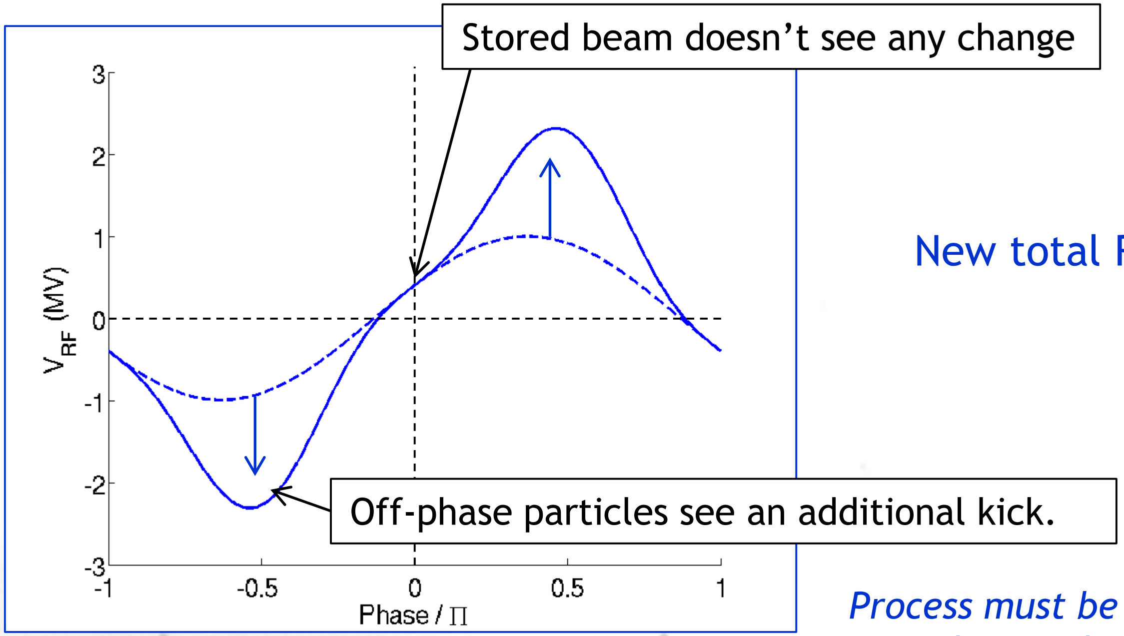
\+ correction by 3rd harmonic
$V_{3rd} = V_{add} / 3$

III. Longitudinal injection: new scheme

❑ Create a “longitudinal NLK”

= Additional RF pulse that will:

- Reduce the injected off-momentum deviation as quickly as possible and let enter the particles into the longitudinal bucket
- Keep the stored beam unaffected, in terms of centroid position and bunch length.



Origin of phase corresponding to φ_s

New total RF pulse

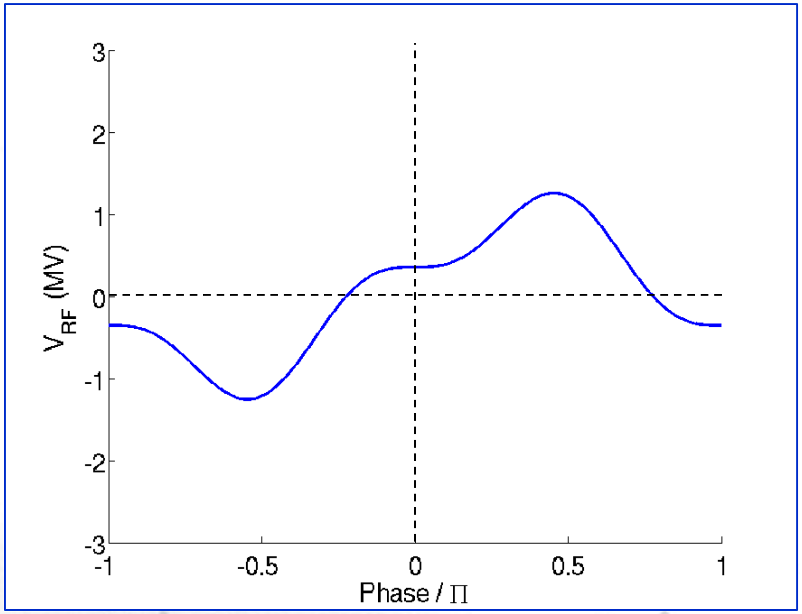
Process must be stopped as soon as injected particles reach the synchronous phase

III. Longitudinal injection: new scheme

❑ Create a “longitudinal NLK”

= Additional RF pulse that will:

- Reduce the injected off-momentum deviation as quickly as possible and let enter the particles into the longitudinal bucket
- Keep the stored beam unaffected, in terms of centroid position and bunch length.



In practice, stored beam will be lengthened with the 3rd harmonic , which suggests that 3 HC already exists and can be also used for NLK scheme.

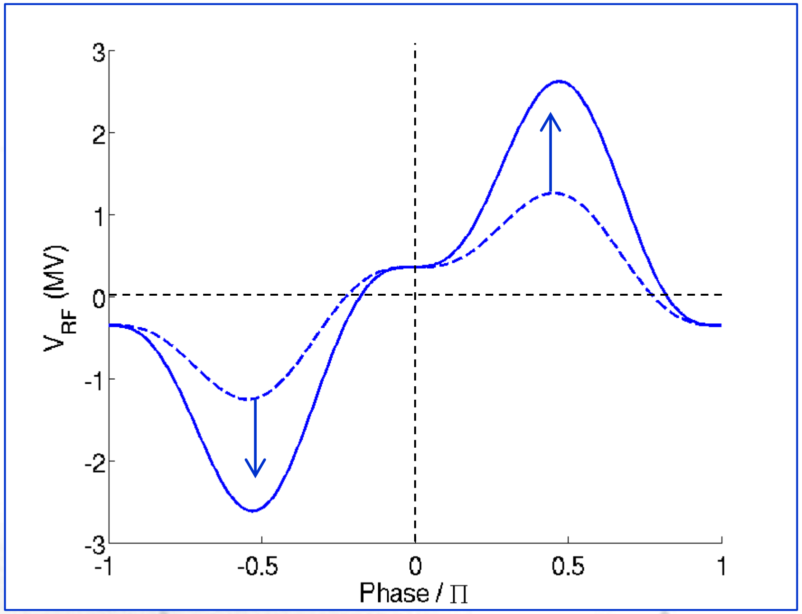
Main RF pulse

III. Longitudinal injection: new scheme

❑ Create a “longitudinal NLK”

= Additional RF pulse that will:

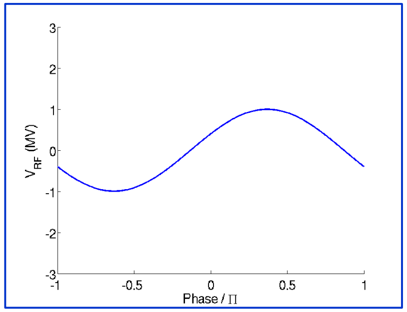
- Reduce the injected off-momentum deviation as quickly as possible and let enter the particles into the longitudinal bucket
- Keep the stored beam unaffected, in terms of centroid position and bunch length.



In practice, stored beam will be lengthened with the 3rd harmonic , which suggests that 3 HC already exists and can be also used for NLK scheme.

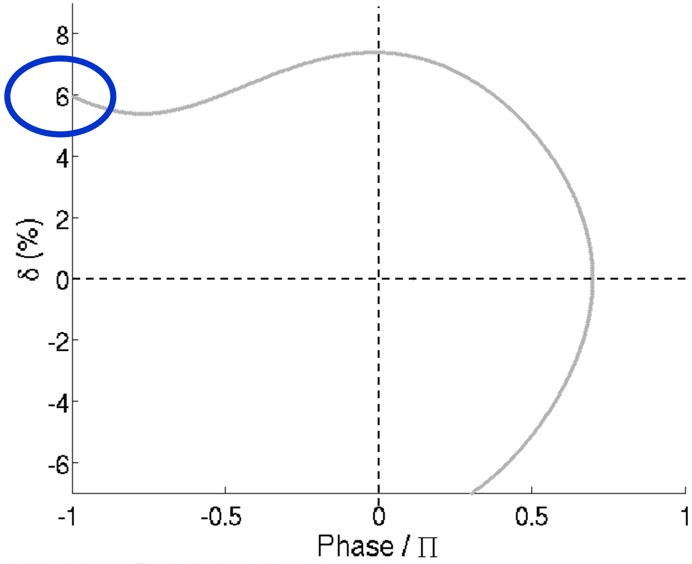
New total RF pulse

Effect of the "longitudinal NLK"



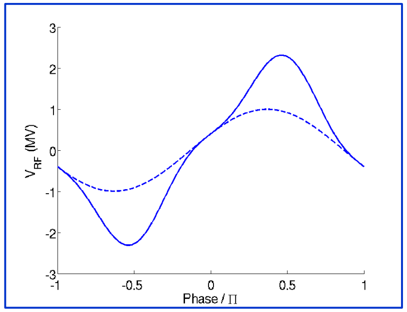
- Standard V_{RF}

Particle with zero betatron amplitude



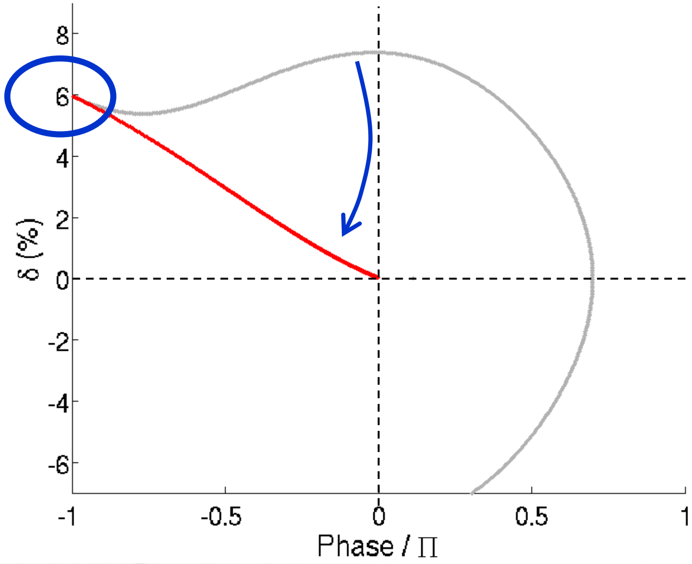
III. Longitudinal injection: new scheme

❑ Effect of the "longitudinal NLK"



- Switch on $V_{RF\ add}$ = 1 MV,
- Switch off when particle passes φ_s

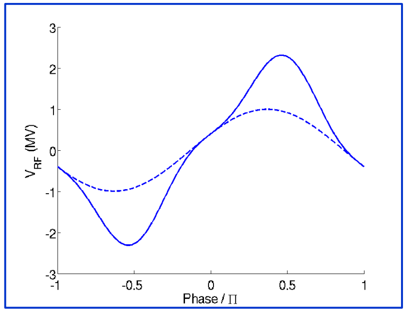
Particle with zero betatron amplitude



Effect of the "longitudinal NLK"

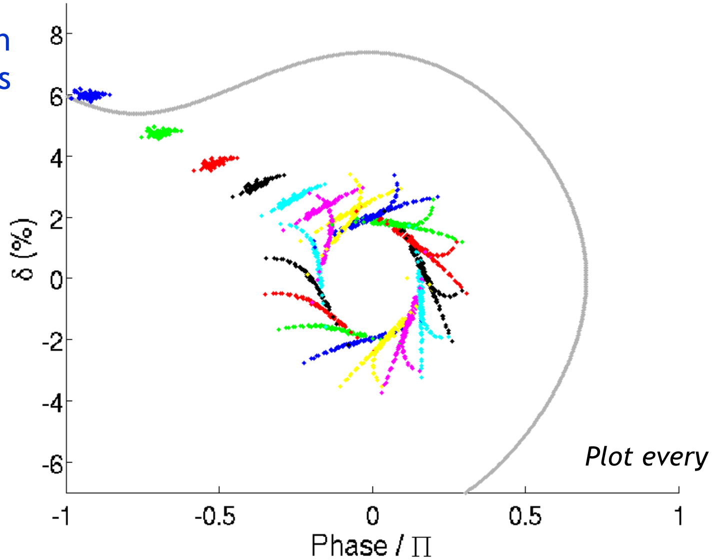
Simulate realistic injected beam from Booster:

Considering a basic MBA lattice for Booster with $\varepsilon_x = \varepsilon_z =$ **10 nm.rad**, $\sigma_s =$ **35 ps**



- Switch on $V_{RF\ add}$ = 1 MV,
- Switch off when "mean phase" = φ_s

Injected beam with adapted β functions

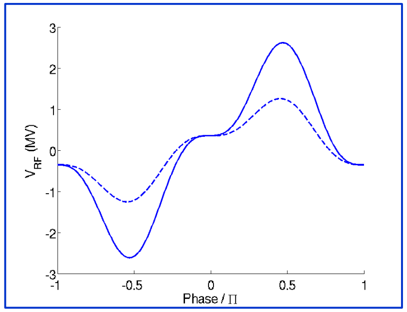


III. Longitudinal injection: new scheme

❑ Effect of the "longitudinal NLK"

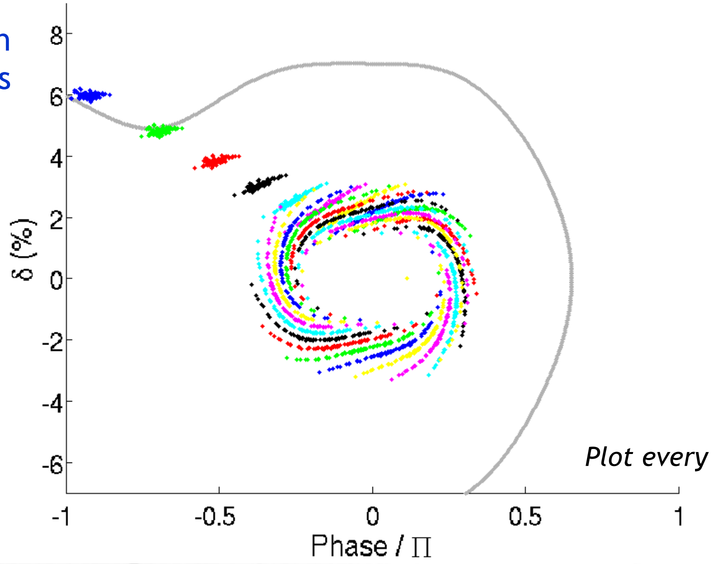
Simulate realistic injected beam from Booster:

Considering a basic MBA lattice for Booster with $\varepsilon_x = \varepsilon_z =$ **10 nm.rad**, $\sigma_s =$ **35 ps**



- Considering the stored beam lengthening with the 3rd HC.

Injected beam with adapted β functions



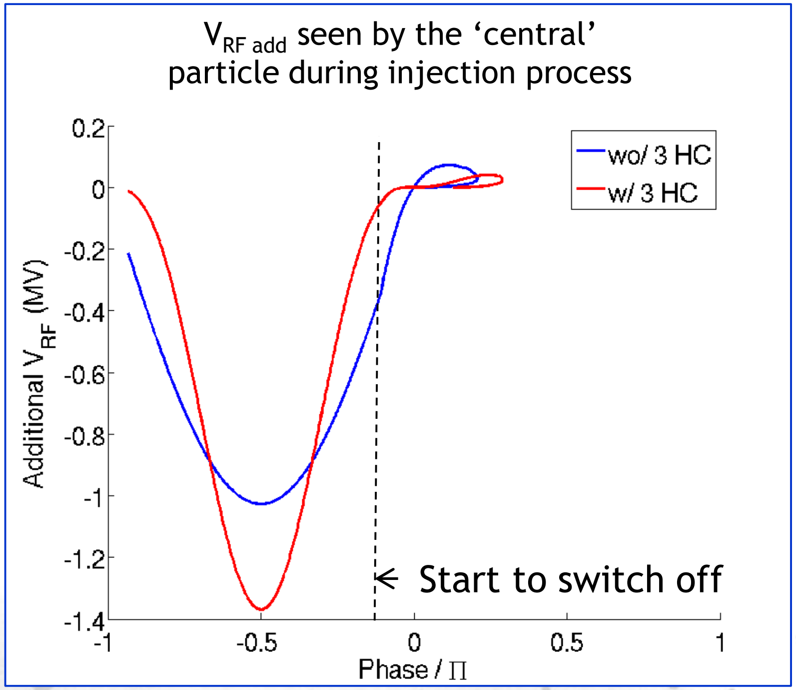
Plot every 50 turns

Modeling realistic rise and fall time of the additional RF pulses

Switch on / off takes into account the loaded quality factor Q_L of cavities:
One must consider:

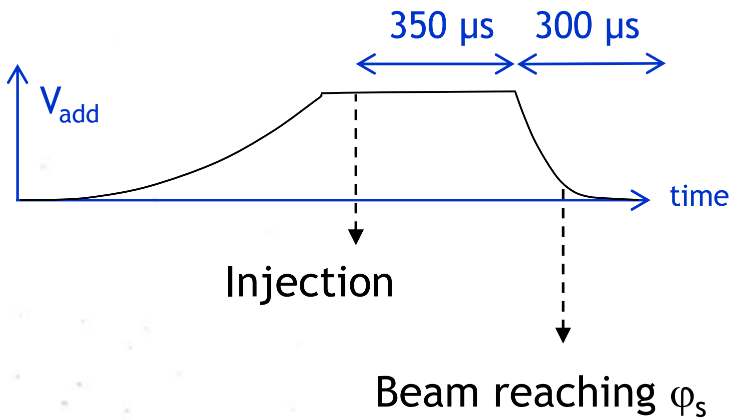
$$\tau_L = \frac{2\, Q_L}{2\, \pi\, f_{RF}}$$

- How to get similar τ_L for 3rd HC compared to main RF
- The phase control of main RF during voltage change



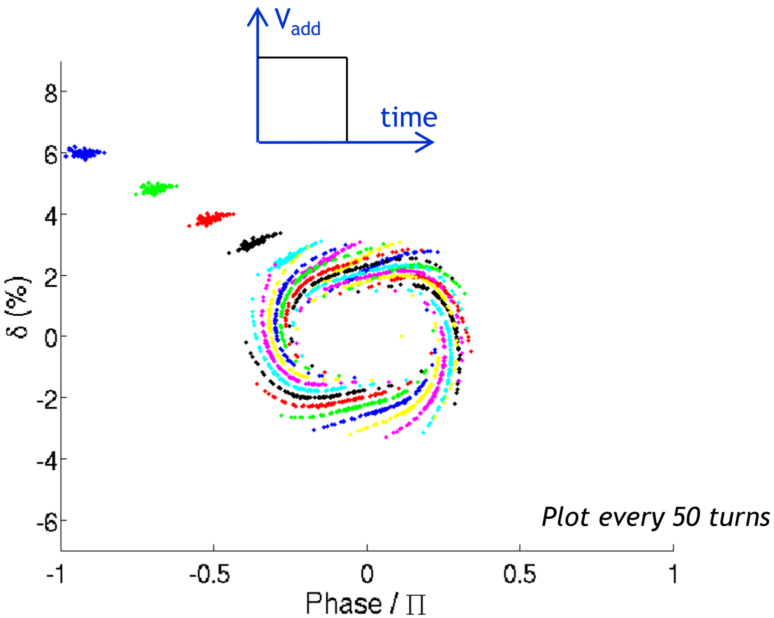
SOLEIL Upgrade, same cryogenic 352 MHz cavities as now

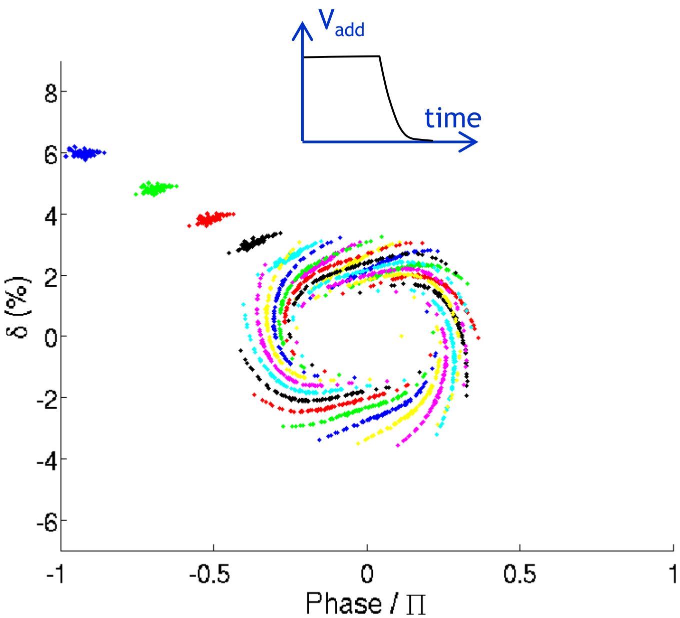
$Q_L < 10^5$, $\tau_L < 100$ μs ~ 80 turns

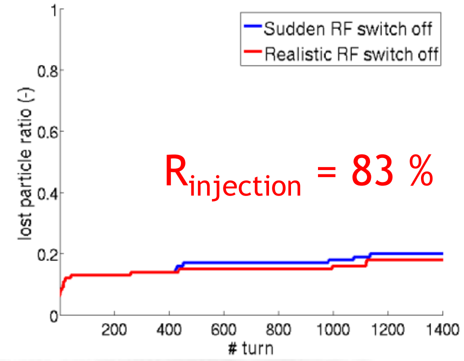


III. Longitudinal injection: new scheme

- Modeling realistic rise and fall time of the additional RF pulses







→ No significant impact on the injection efficiency

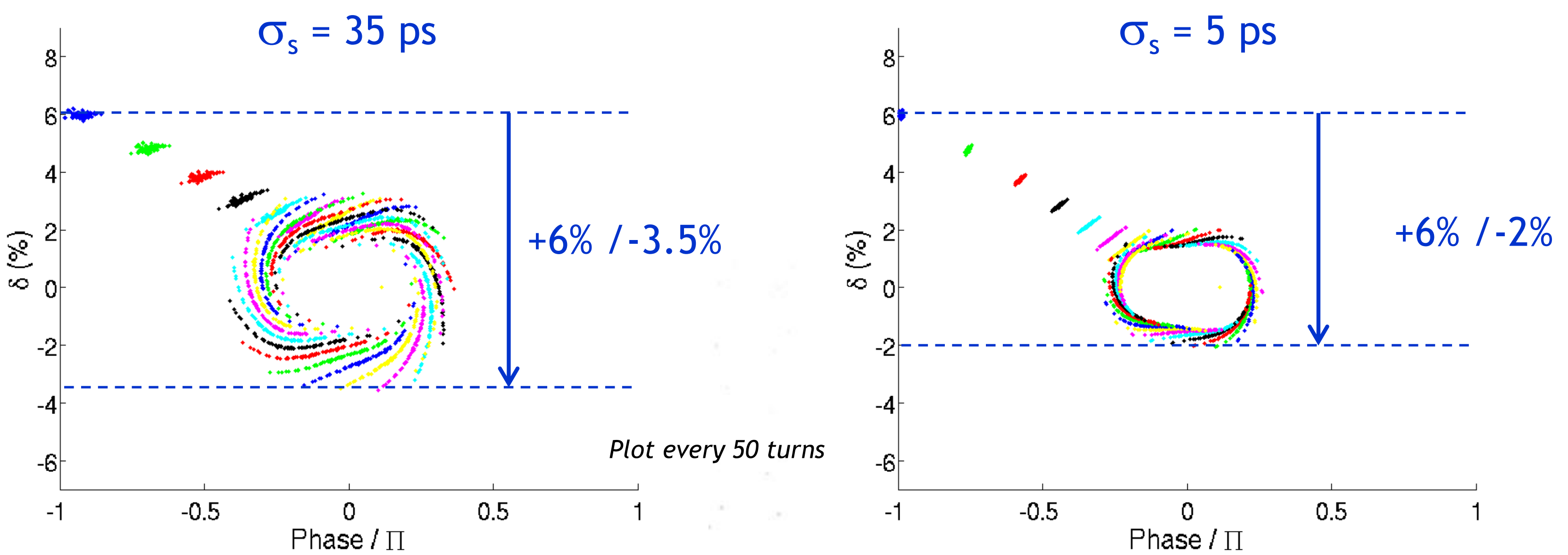
III. Longitudinal injection: new scheme

- Performance of the scheme:

  1) Dependency on injected beam bunch length:

The shorter bunch length, the smaller the oscillation amplitude in δ during injection process.

$\varepsilon_{x\ inj} = \varepsilon_{z\ inj} = 10$ nm.rad



Same injection rate, but dissymmetry in momentum oscillation becomes larger when bunch length decreases

III. Longitudinal injection: new scheme

- Performance of the scheme:

  2) Dependency on injected beam emittances:

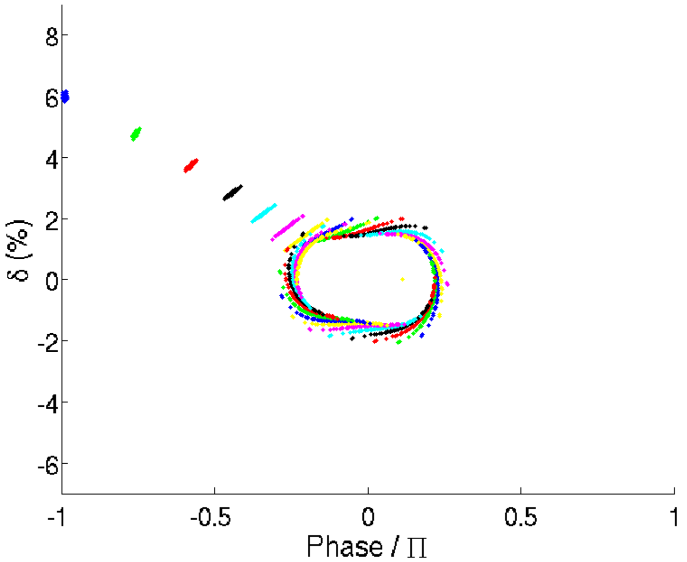
  Limitation comes from transverse acceptance at high momentum.

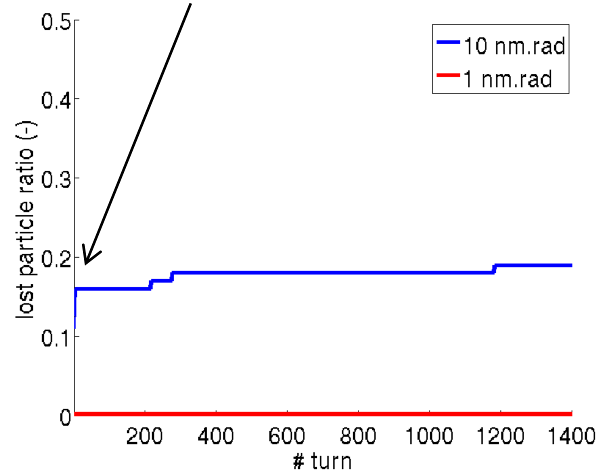
$\varepsilon_{x\ inj} = \varepsilon_{z\ inj} = 10$ nm.rad

$\varepsilon_{x\ inj} = \varepsilon_{z\ inj} = 1$ nm.rad

= same behaviour in longitudinal plane

But losses at high momentum disappear.





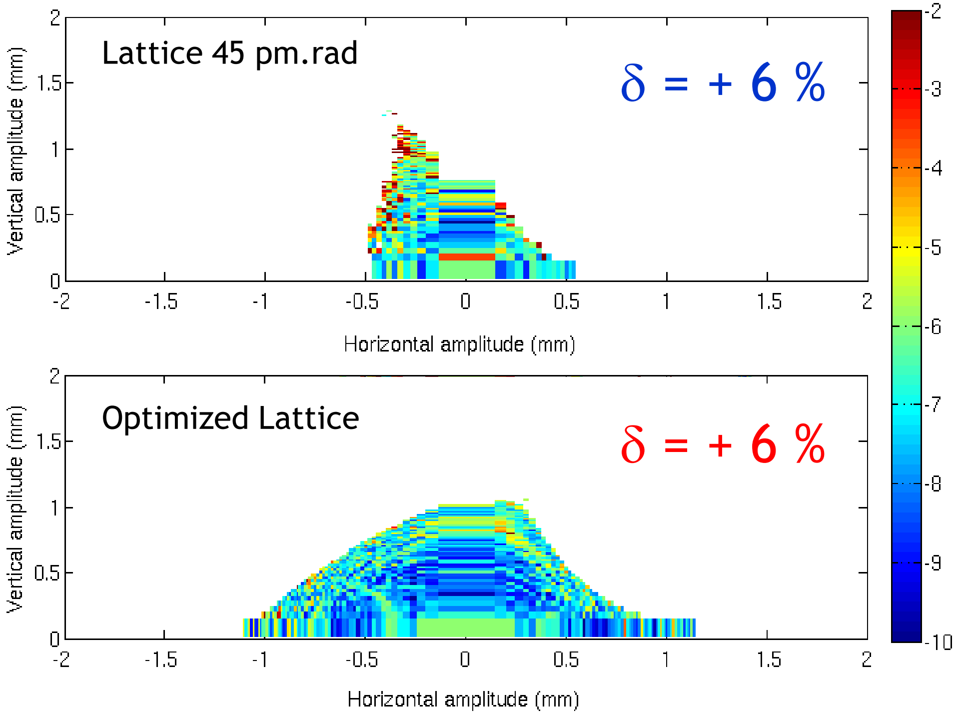
$\sigma_s = 5$ ps

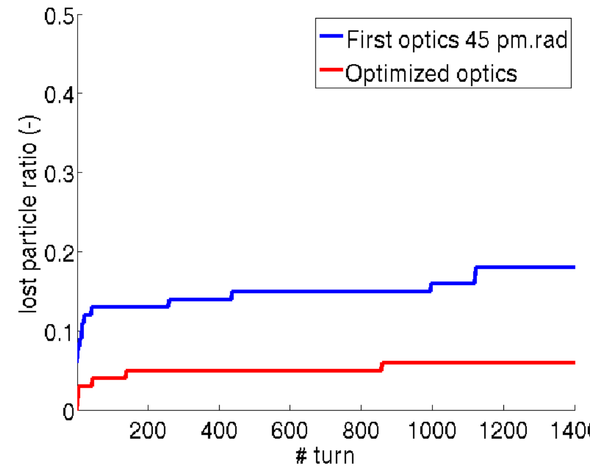
IV. Longitudinal injection: challenges

- Increase dynamic aperture for large positive energy deviation.

New lattice optimized in terms of off-momentum transverse dynamic acceptance
→ confirms origin of losses at high momentum.

TRACY III code (10³ turns)

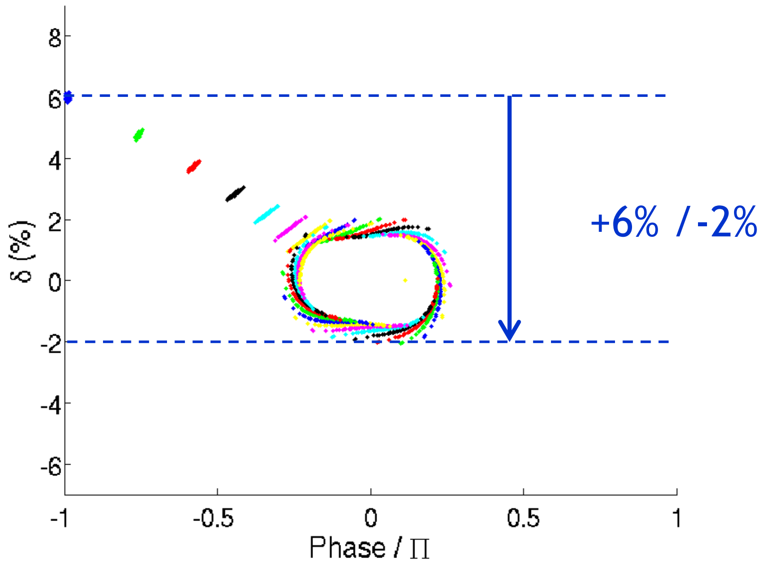




IV. Longitudinal injection: challenges

- Take advantage of the dissymmetric energy oscillation to relax constraints on the DA for negative momentum.

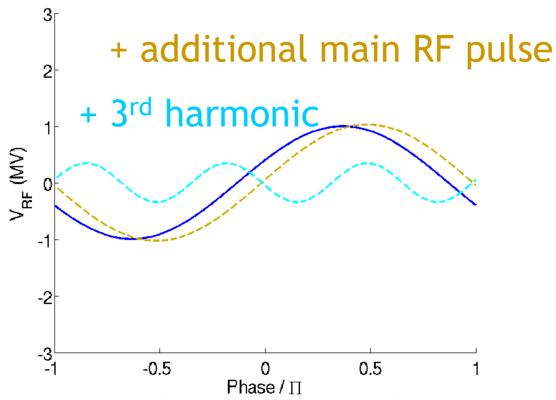
→ Investigations are foreseen, using MOGA with specific objectives.

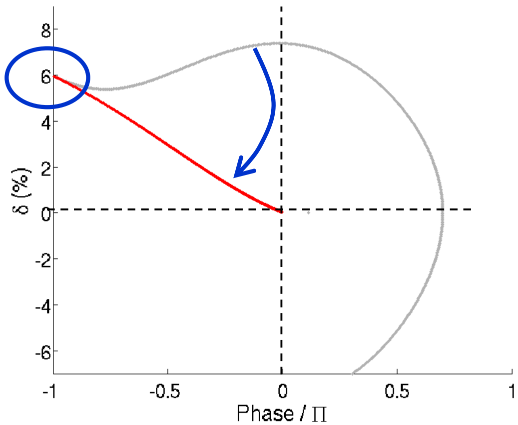


$\varepsilon_{x\ inj} = \varepsilon_{z\ inj}$ = 10 nm.rad, σ_s = 5 ps

VI. Summary

Starting from the longitudinal injection described by SLS group, a novel scheme is proposed for an on-axis injection.





- It does not involve any fast transverse kicker, but a MIK with no time constraint.
- It uses cavities already installed: main RF and its 3rd harmonic with manipulation of phase and power during injection process.
- It doesn't affect the stored beam, in terms of phase and bunch length.
- It aims at enhancing capturing of off-momentum particles by kicking them into the longitudinal bucket

VI. Summary

Challenges:

- In SOLEIL case, adapt the present 'high emittance' Booster in order to reduce injected emittance and pulse length.
- Optimize the off-momentum dynamic aperture of the low-emittance lattice for (only) high positive momentum. Use of MOGA for this dissymmetric optimization.
- Ensure the appropriate horizontal dispersion @ MIK position to get the 'few mm' chromatic orbit, without reducing off-momentum DA.
- RF issues

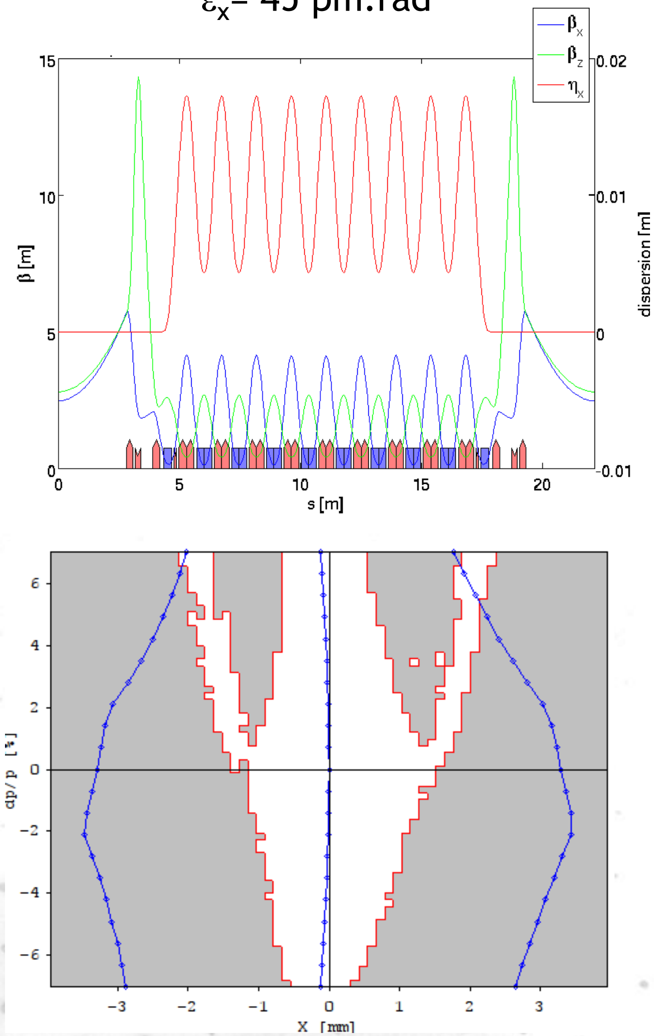
Acknowledgments

Many thanks to Dr Alex Chao for very fruitful discussions, P. Marchand and F. Ribeiro (SOLEIL) for first analysis of RF manipulation feasibility, and the rest of the Accelerator Group for support ..

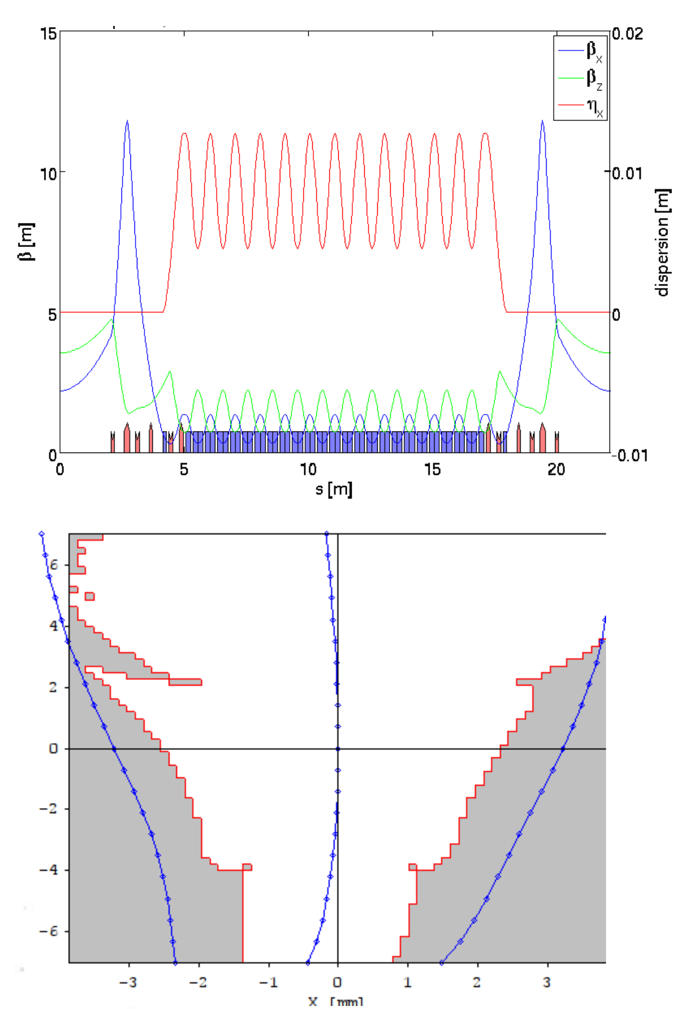
Thank you for your attention !

Backup slide

ε_x= 45 pm.rad



ε_x= 39 pm.rad



OPA code