

# Novel injection schemes (II)

## Summary

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# Outline

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**Top-UP for FCC (M. Aiba - PSI)**

**n/a (P. Kuske - BESSY)**

**Injection in crabbed cavities (X. Huang – SLAC)**

**Longitudinal off-energy injection (M. Aiba – PSI)**

**Novel schemes for longitudinal injection (M Tordeux – SOLEIL)**

**Longitudinal injection with triple RF system (G. Xu - HEPS)**

# Top-UP in FCC (Aiba)

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- **Challenges in FCC-ee top-up injection**
  - Collider ring optics is designed/optimised for achieving high luminosity
  - Luminosity lifetime of ~1 hour at 175 GeV
  - **Top-up injection is essential and should be robust**
  - **Very squeezed  $\beta^*$  to maximise the luminosity → Strong nonlinear elements required → Limited dynamic aperture**

Dynamic aperture:  $\sim 15\sigma$  for on-energy,  $5\sigma$  up to  $\pm 2\%$  off-energy  
cf. **SLS:  $\sim 15$  mm dynamic aperture corresponds to  $\sim 100\sigma$**

Septum thickness

5 mm (3 mm + mechanical margin) or

Wire septum  $\sim 0.2$  mm ( $\sim 20$   $\mu$ m + mechanical margin)

Widely used in hadron machine but never used for lepton beams

(?)

# Top-UP in FCC (Aiba)

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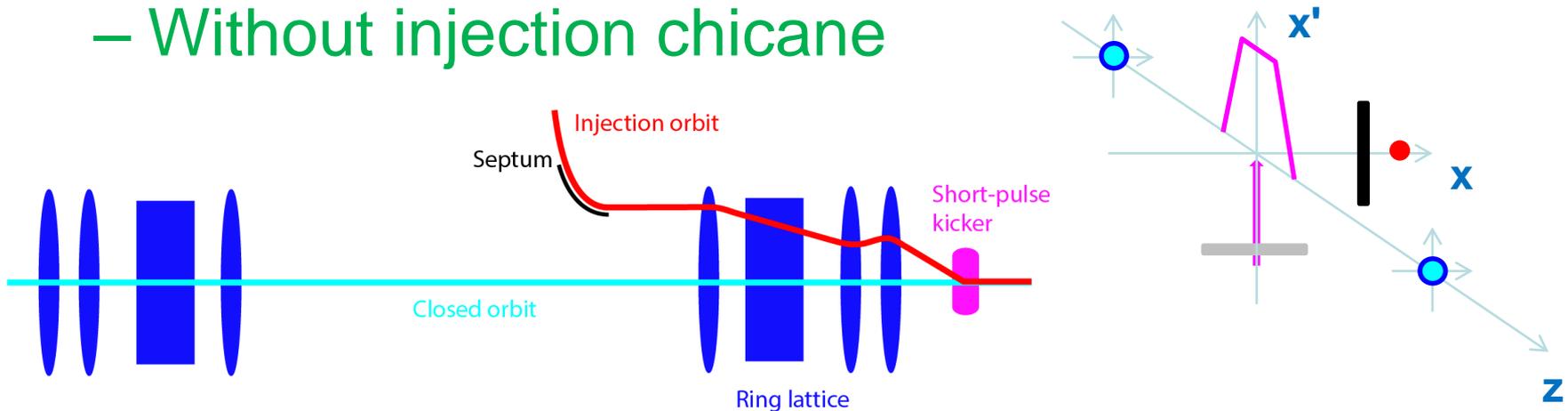
**Review of many injection scheme with a systematic assessment of their pros/cons**

**• Conventional scheme and Multipole kicker injection are applicable to FCC-ee top-up injection**

- **On-axis injection is preferable in colliders**
  - **Applicable to higher beam energy operation modes**
  - **Off-energy dynamic aperture is not enough for lower beam energy operation modes**
- **In spite of very high beam energy, injection kicker specifications are modest thanks to the large beta function available**

# Longitudinal injection (Aiba)

- Septum + Short-pulse dipole-kicker
  - On-axis injection
  - Transparent to circulating bunches
  - Without injection chicane



The injected bunch will be accepted?

# Longitudinal injection (Aiba)

- Equations of motion & RF bucket:

$$\frac{dz}{dt} = -c\alpha\delta + \dots$$

$$\frac{d\delta}{dt} = \frac{eV(t) - U_0 (1 + 3\delta + 3\delta^2 + \delta^3)}{E_0 T_0}$$

$z$ : Longitudinal position

$c$ : Speed of light

$\alpha$ : Momentum compaction

$\delta$ : Relative momentum deviation,  $\frac{dP}{P} \sim \frac{dE}{E}$

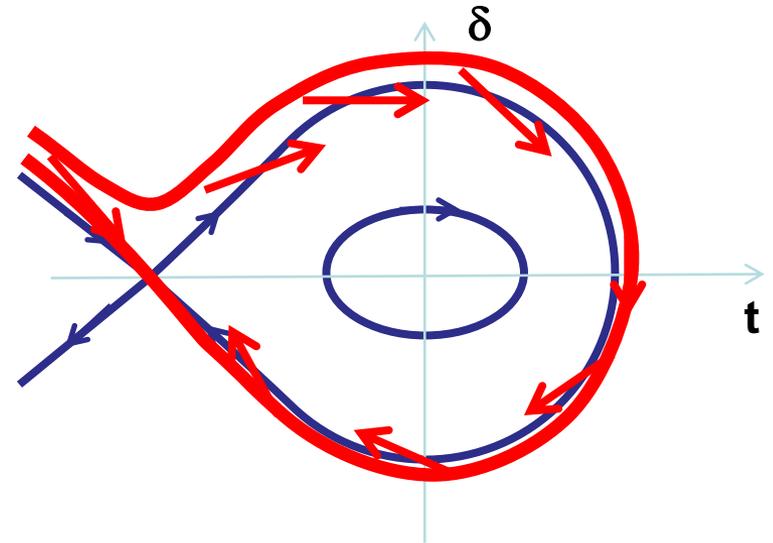
$e$ : Electron charge

$V$ : RF voltage

$U_0$ : Radiation loss per turn for the nominal energy

$E_0$ : Nominal beam energy

$T_0$ : Revolution period



RF bucket is modified  
by the energy dependent  
terms

Golf club created by emission of synchrotron radiation not by RF acceleration/deceleration

# Longitudinal injection (Aiba)

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Applications to MAX IV OK – 100 MHz – 10 ns RF bucket separation

## Comments

- Longitudinal injection requires injection beams with rather short bunch and small energy spread...
- There is “new trend” in science labs, which fulfils the injector requirement: Light source + FEL
  - PSI: SLS + SwissFEL
  - DESY: PETTRA + European X-FEL
  - Elettra: Elettra + Fermi
  - RIKEN: SPRing-8 + SACLA (New injection line is built)
  - Lund: MAX IV + Short pulse facility (Used as injector by design)
  - And more!

# Novel Schemes at SOLEIL (Tordeux)

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- Low- $\varepsilon$  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 :
- $\varepsilon_x > 100$  pm.rad with a large dynamic aperture (off-axis injection)
- $\varepsilon_x < 100$  pm.rad with small dynamic aperture (on-axis injection).

## On -axis injection

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

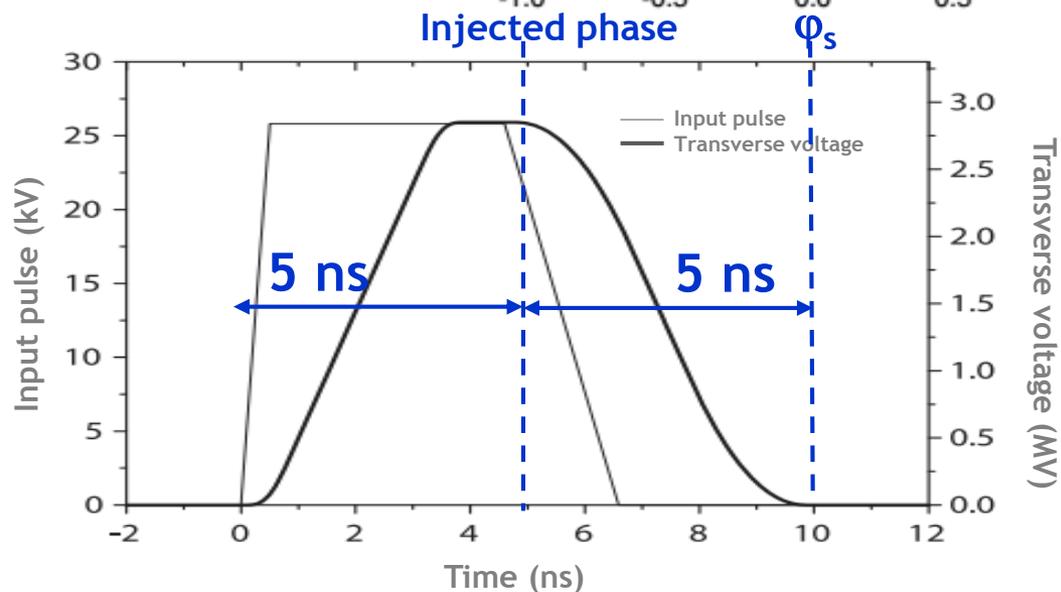
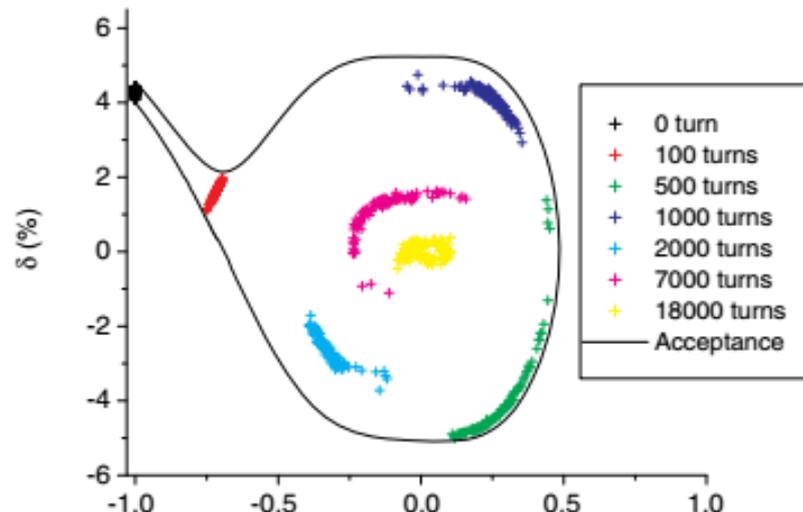
## II. Longitudinal injection: recall of SLS scheme

□ applied to MAX IV

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

100 MHz RF system: bunch spacing =  $2 \times 5$  ns

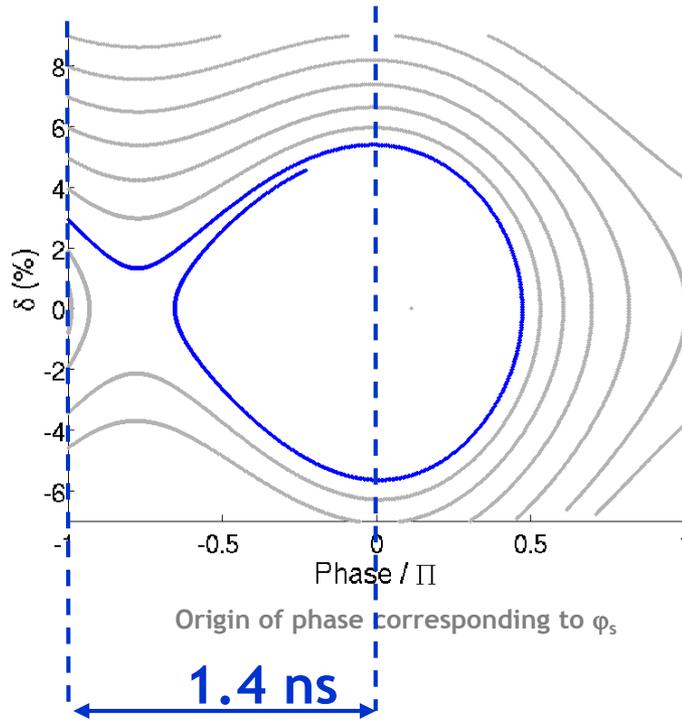
As a first step, short pulse kickers place the injected beam on-(chromatic) axis



## II. Longitudinal injection: recall of SLS scheme

### □ applied to SOLEIL Upgrade

*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**

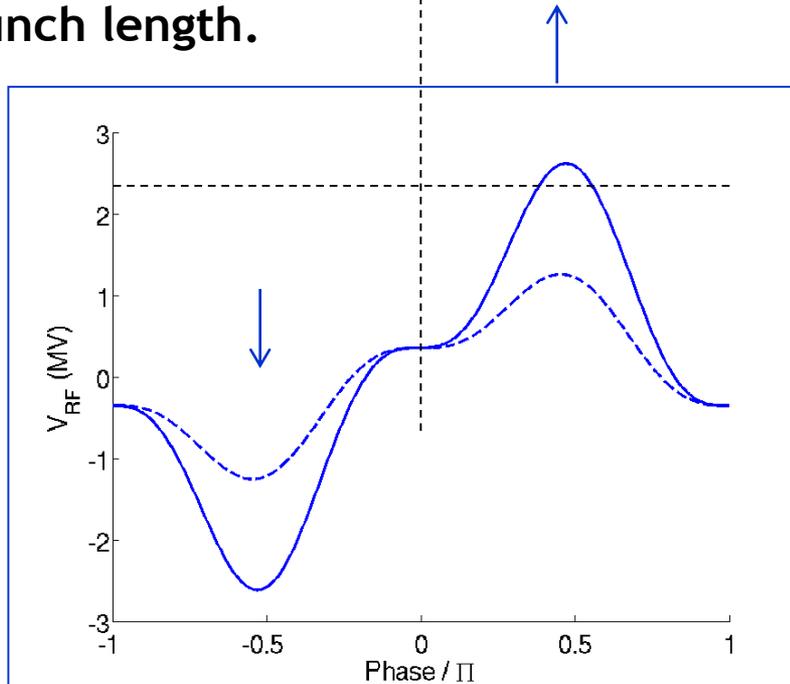
# III. Longitudinal injection: new scheme

Kick beam on axis with a NLK and

## □ 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.

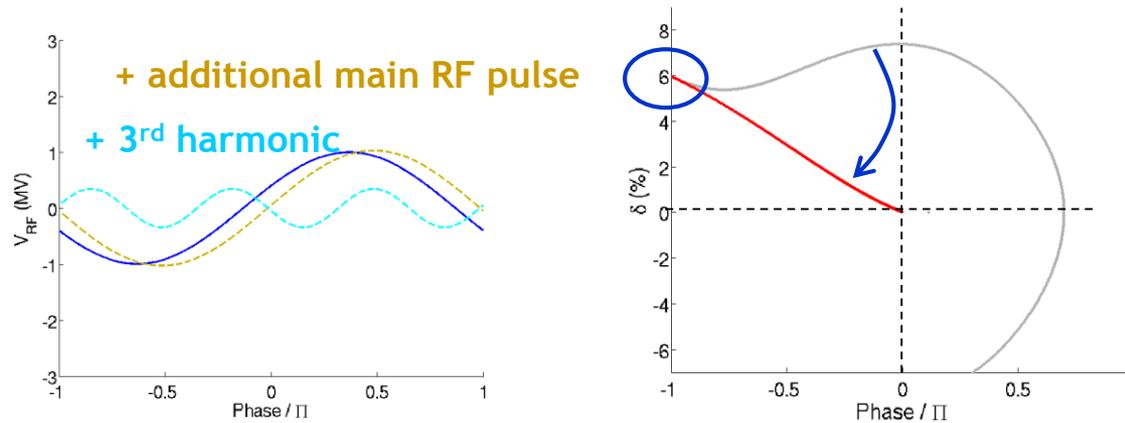


In practice, stored beam will be lengthened with the 3<sup>rd</sup> harmonic, which suggests that 3 HC already exists and can be also used for NLK scheme.

New total RF pulse

# 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 3<sup>rd</sup> 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

# Triple RF system (Xu)

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Starting from the longitudinal off-axis injection with 2 RF system

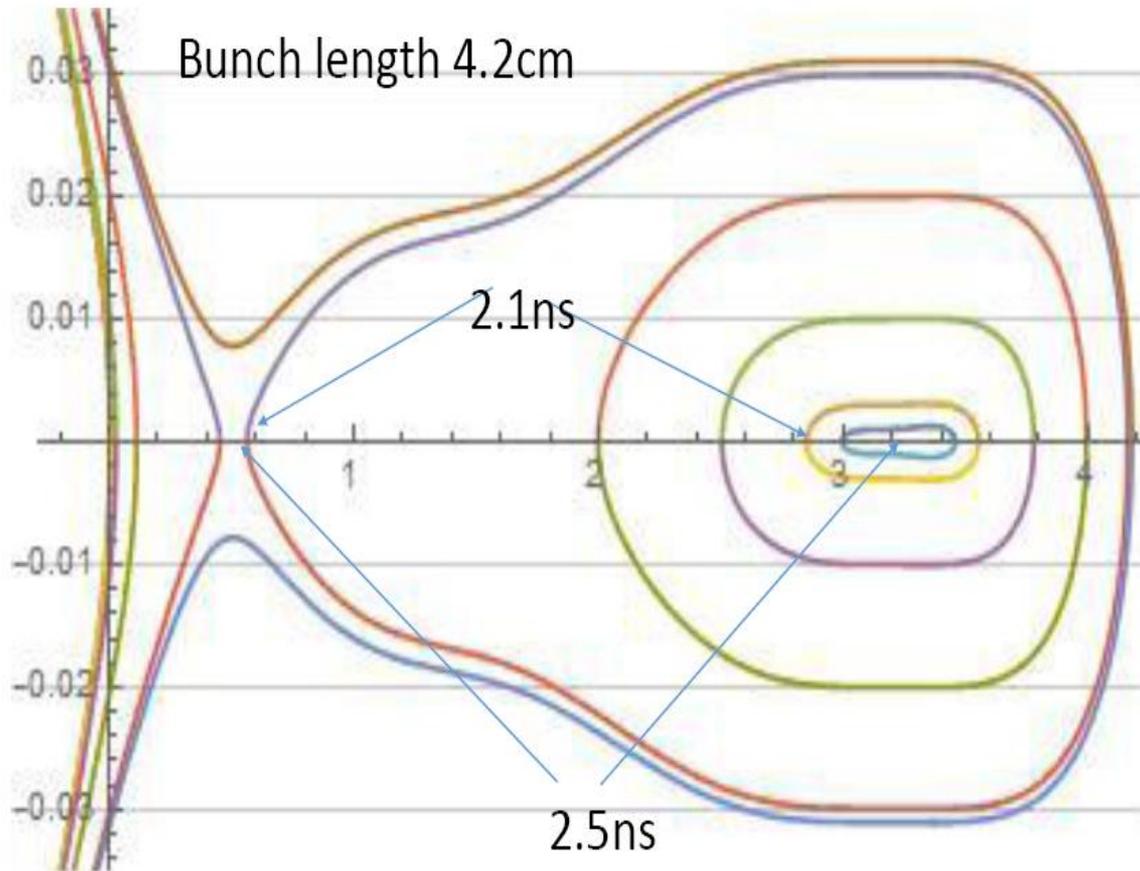
1<sup>st</sup> and 3<sup>rd</sup> RF combination

- Form two separate RF stable buckets for the injection bunch and storage bunch
- To merge two bunches RF parameters must be changed(ramp)
- There is a potential barrier between the two Separate RF stable buckets
- Making bunch lengthening to increase beam lifetime

1<sup>st</sup>, 2<sup>nd</sup> and 3<sup>rd</sup> RF combination

- In order to remove the potential barrier, the 2<sup>nd</sup> harmonic can be introduced
- There will increase two parameters(voltage and phase) , the solution will be not sole as for only 1<sup>st</sup> and 3<sup>rd</sup> combination
- Using simple program to find the solutions

# Triple RF system (Xu)



# Triple RF system (Xu)

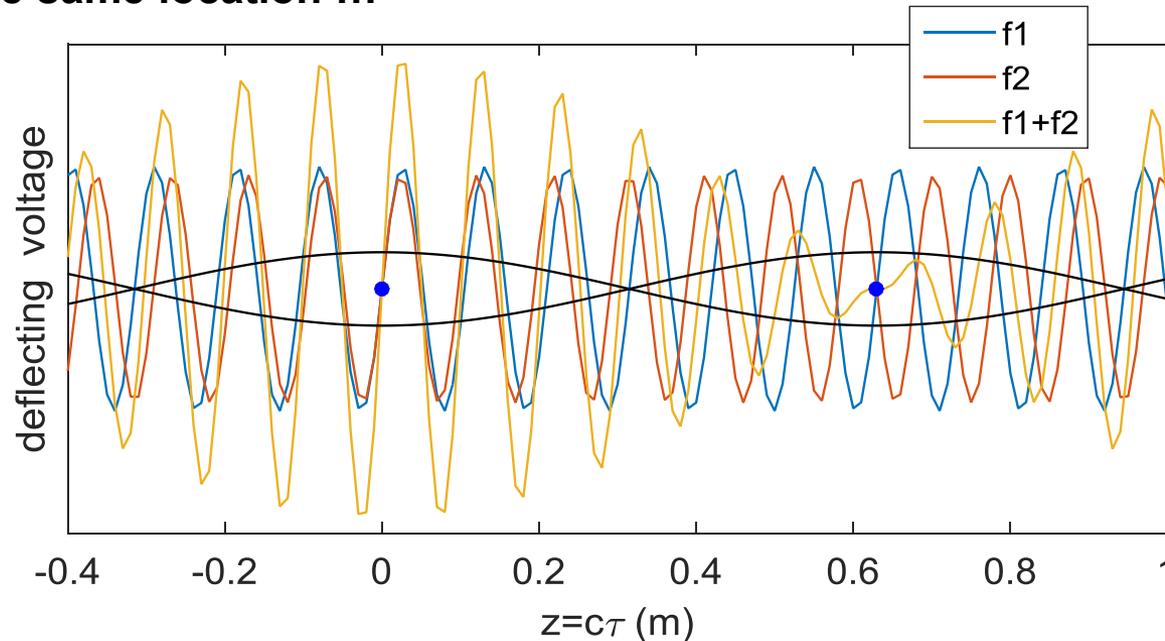
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## Summary

- With 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> harmonic RF systems combination (fundamental frequency 166.6MHz), one can get a stable RF buckets with far enough distance between injecting and circulating bunches
- The distance (about 3.06rad/2.9ns) is matched with our kicker system (6ns bottom width)
- RF system does not need ramping as the 1<sup>st</sup> and 3<sup>rd</sup> harmonic combination to avoid RF aging and bunch length changing
- The solution still need optimization.
- More simulation including to errors of KICKERs system, beam collective effects, etc.

# The two-frequency crab cavity (2FCC) scheme (Huang)

If crab cavities of two frequencies are located at the same location ...



Two frequencies:

$$f_1 = n f_0,$$

$$f_2 = \left( n + \frac{1}{2} \right) f_0$$

Half of the buckets are tilted in  $y - z$  plane, the other half are un-affected.

To store regular, un-tilted beam, cancellation of crabbing kicks is needed.

For the 2FCC scheme, cancellation occurs in time, not in space as the tilt-and-cancel scheme does.

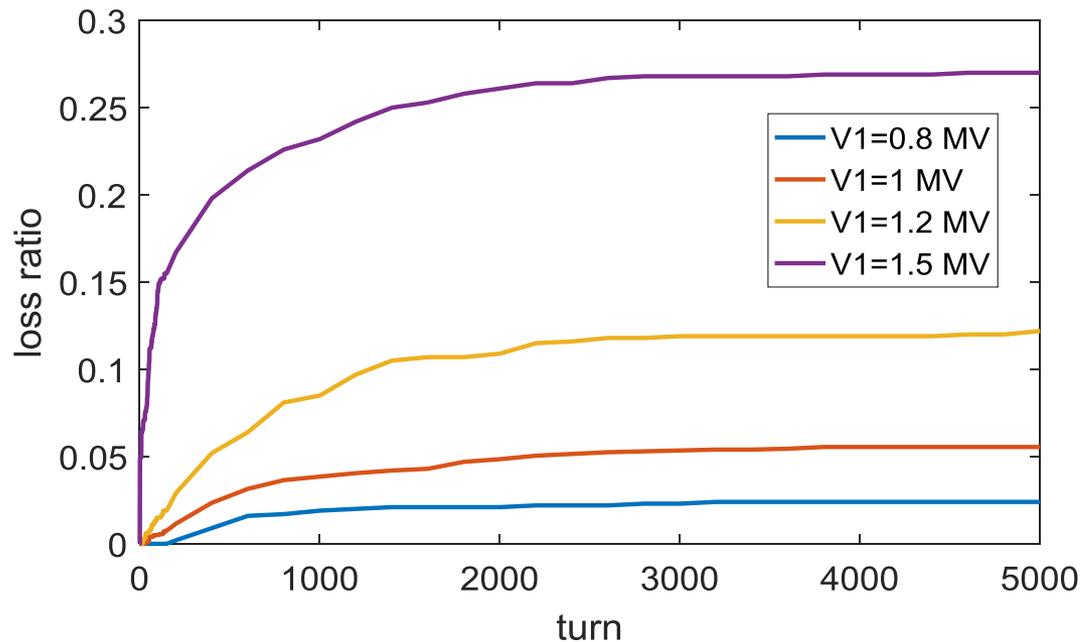
# Injection simulation in tilted bunches

- Launch 10,000 particles, spanned over 6 dimensions.
- Track for 20,000 turns.

## Injected beam initial parameters

$\epsilon_x$ (nm)	$\epsilon_y$ (nm)	$\sigma_t$ (ps)	$\sigma_\delta$	$\beta_x$ (m)	$\beta_y$ (m)	$D_{x,y}$	$D'_{x,y}$	Initial $x$ offset (mm)*
170	17	140	0.001	5	5	0	0	-7.5

$$*6 \times \sqrt{7.5\text{nm} \times 10\text{m}} + 3 \times \sqrt{170\text{nm} \times 5\text{m}} + 2.5 = 6.9\text{mm}$$



**For the  $V_1 = 1\text{MV}$  case, the loss ratio is 6%.**

# General comment

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Colliders like light sources are all planning Top-Up

A lot of new schemes for injection (small DA is the issue)

It is becoming overwhelming to keep track of all of them

See table by Masamitsu

.... ALL OF THEM UNPROVEN !!!

NEED R&D