An on-axis injection for CEPC

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For CEPC Group

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Outline:

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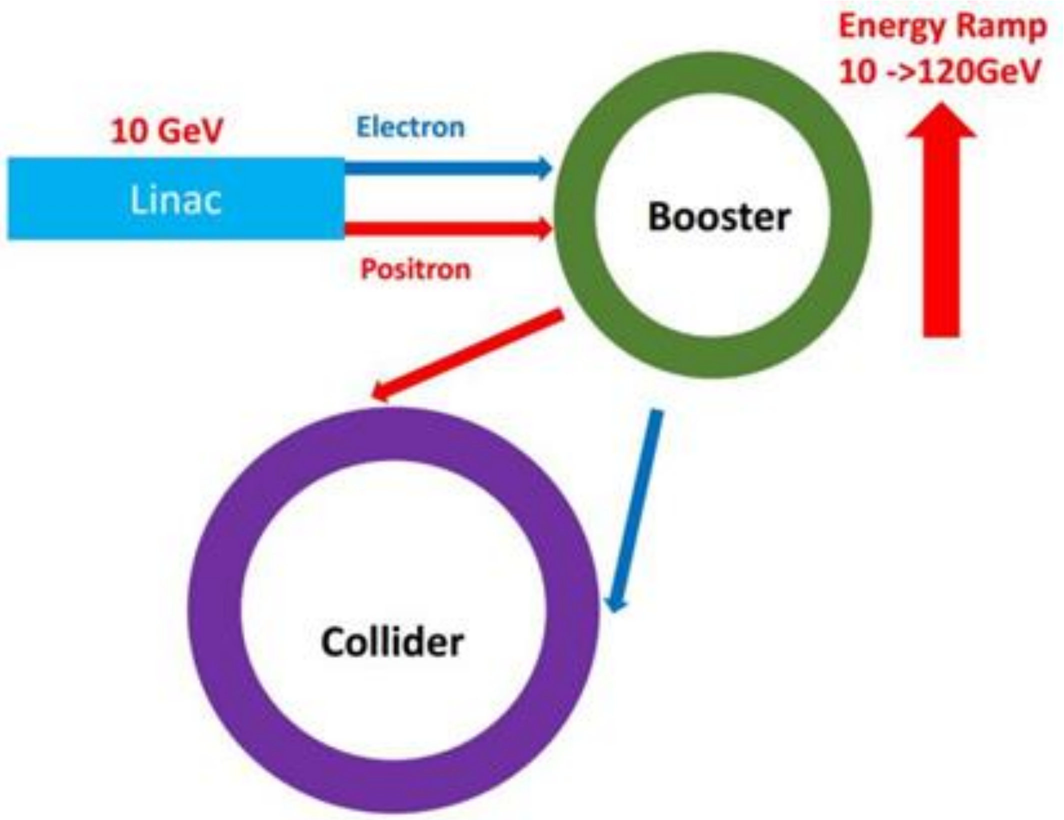
- 2. Why on-axis injection?
- 3. The idea of on-axis injection
- 4. Discussions
- 5. Injection efficiency
- 6. Summary

1. Introduction to CEPC:

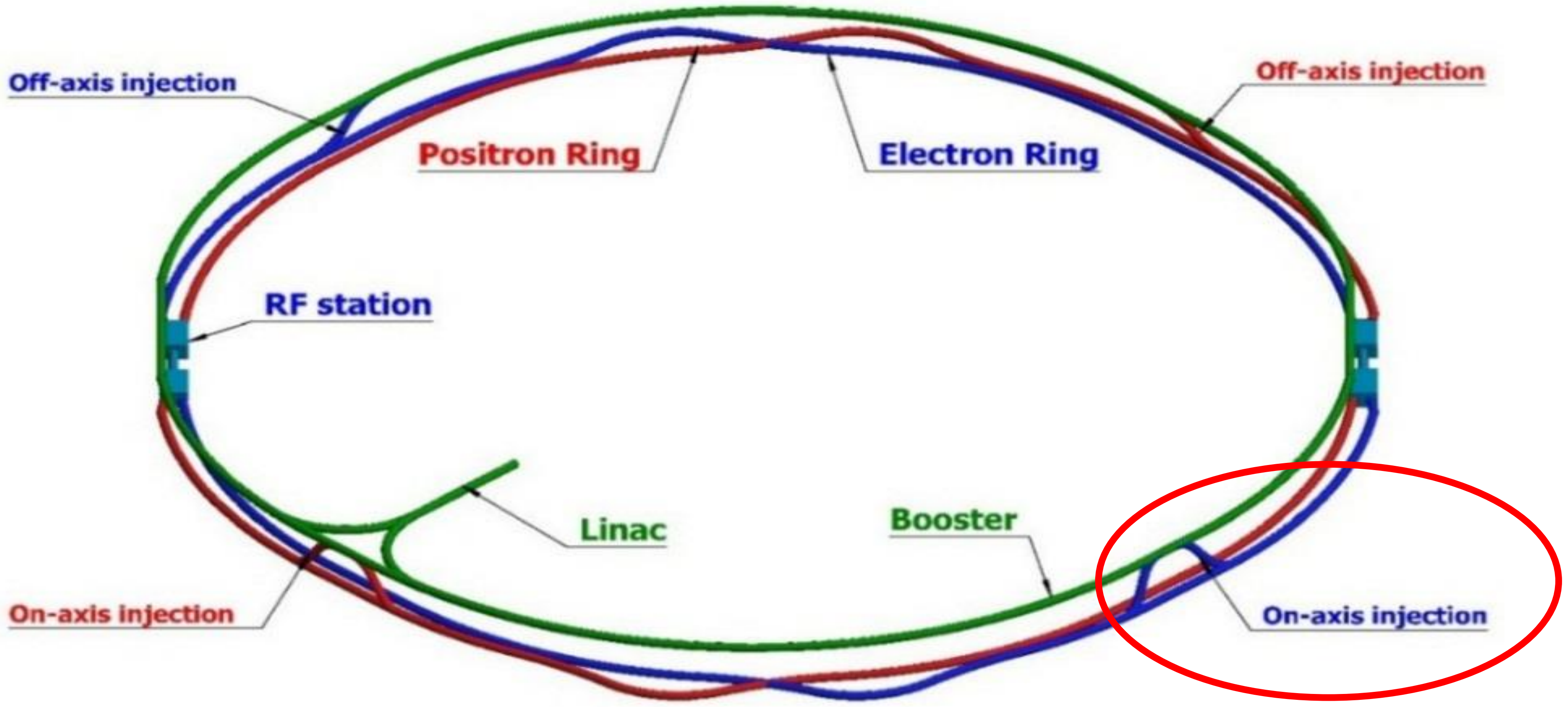
- The CEPC is a circular e+e- collider with a 100-km circumference.
- The collider will operate as a Higgs factor (240 GeV center-of-mass energy), and a W factory(160 GeV center-of-mass energy), and Z factory(91 GeV).
- It consists of a double-ring collider, a booster, and a linac.
- The Linac accelerate electrons and positrons to 10 GeV.
- The booster has the same circumference with the collider, and will be in the same tunnel.



Some Key parameters:

	Collider (Higgs energy)	Booster (Higgs energy)
Beam energy (GeV)	120	120
Circumference (km)	100	100
Bunch number	242	242
Bunch charge (nC)	24	0.72
Current (mA)	17.4	0.52
Emittance x/y (nm.rad)	1.21/0.0024	3.57/0.0178
Bunch length σ_z (mm)	4.4	2.8
Energy spread (%)	0.134	0.094
Damping time $\tau x/\tau y/\tau z$ (ms)	46.5/46.5/23.5	52/52/26
Lifetime (hour)	0.43	/

The geometry:

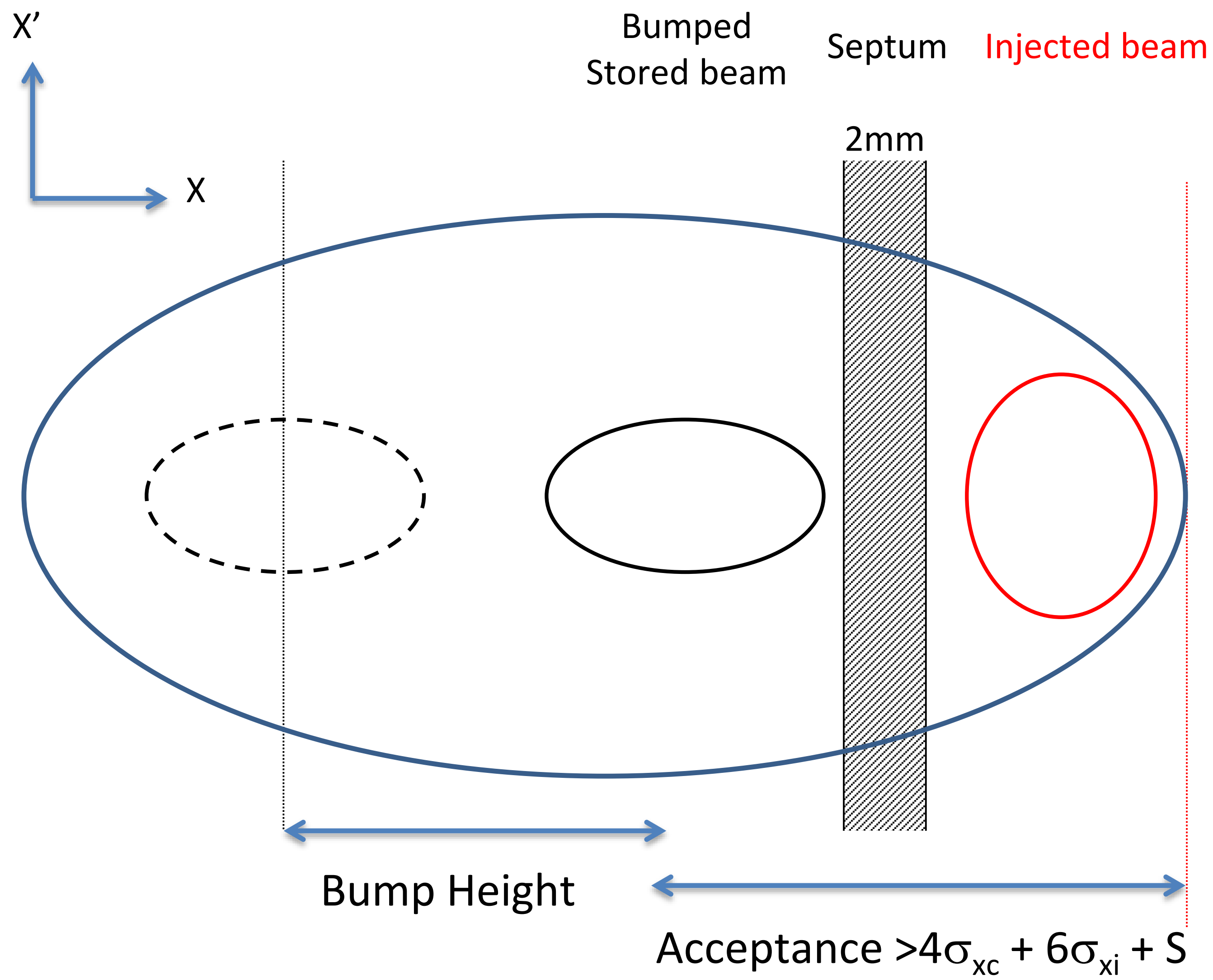


2. Why an on-axis injection ?

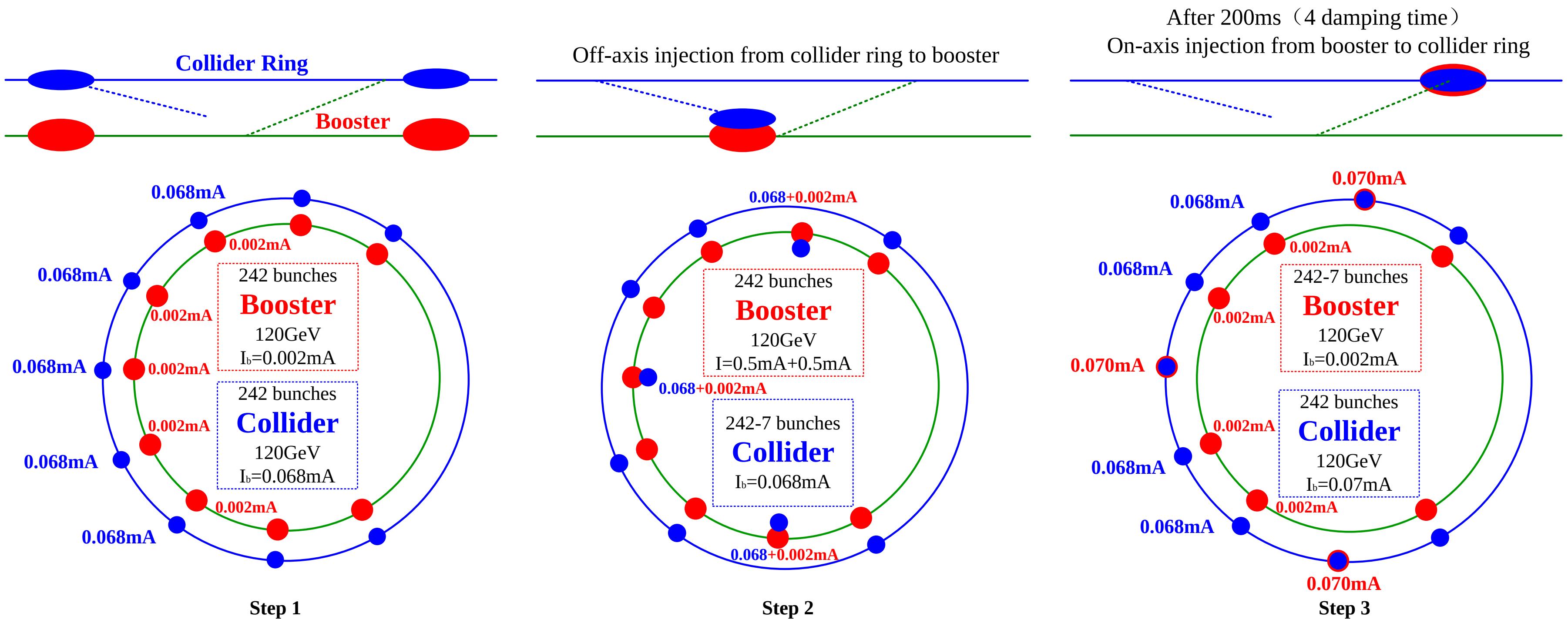
Not Enough DA for off-axis injection

- For the simplicity and robustness of the injection system, a conventional off-axis injection is chosen as our baseline design.
- But for Higgs energy, when we consider errors effects, maybe there's not sufficient DA for injection.

For Higgs:
ε_x = 1.21 nm.rad; ε_inject = 3.6 nm.rad
σx = 0.47 mm, σ_inject = 0.45 mm
Septum = 2 mm
DA > 13 σx

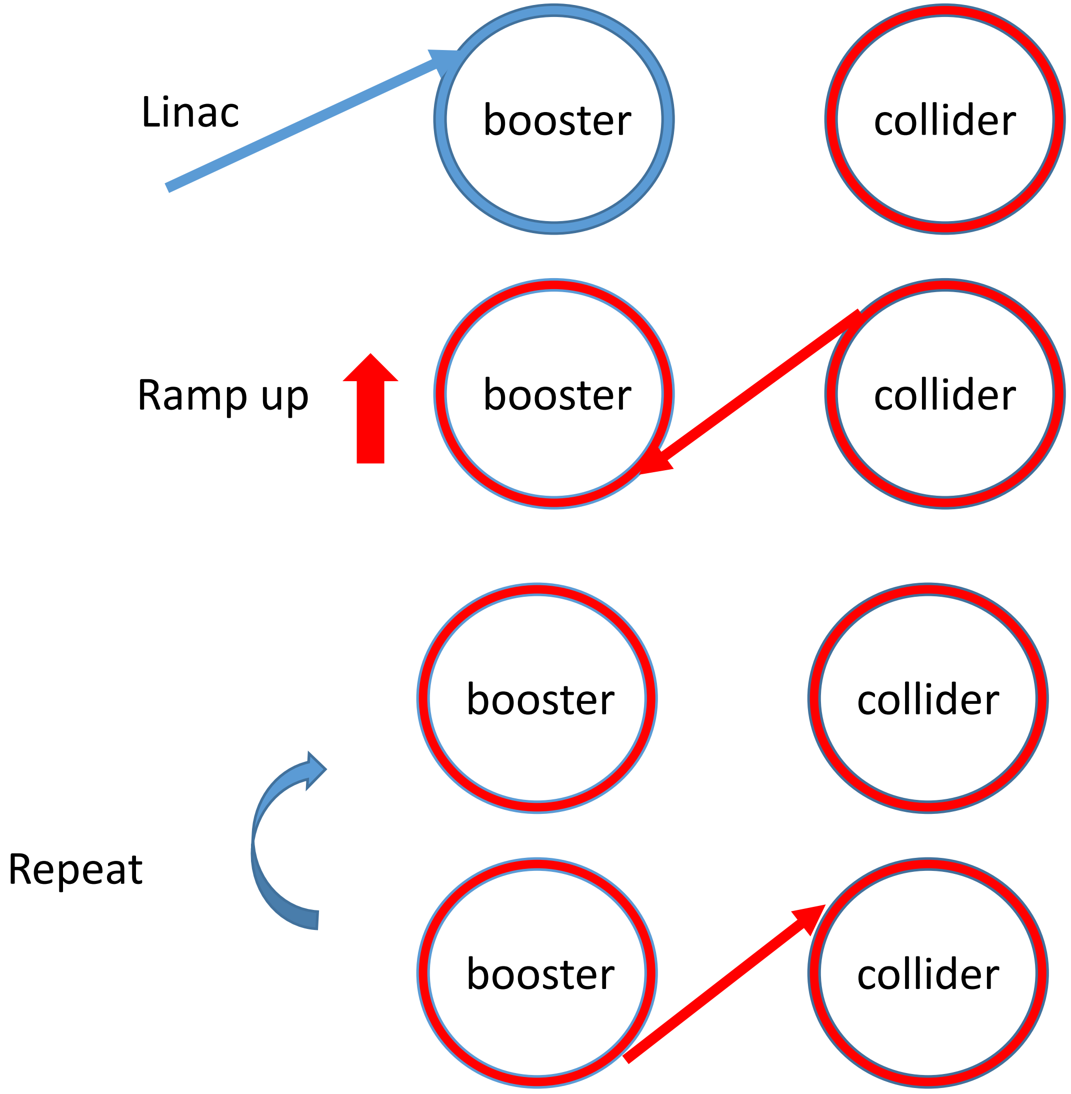


3. The idea of on-axis injection



Merge bunches in the booster

- 1. The booster is used as an accumulator ring.
- 2. Inject the large bunch in the collider into the booster, not the other way around.
- 3. off-axis injection and bunch mergence are performed in the booster, whose dynamic aperture is large enough.
- 4. With this on-axis injection, the required dynamic aperture in the collider is only 8 σx.
- 5. For W, Z mode, the dynamic aperture in the collider is large enough, and we don’t need this on-axis injection.



1. Inject 242 small bunches into the booster.

2. Ramp the booster to high energy and inject several (7 for example) bunches from the collider into the booster.

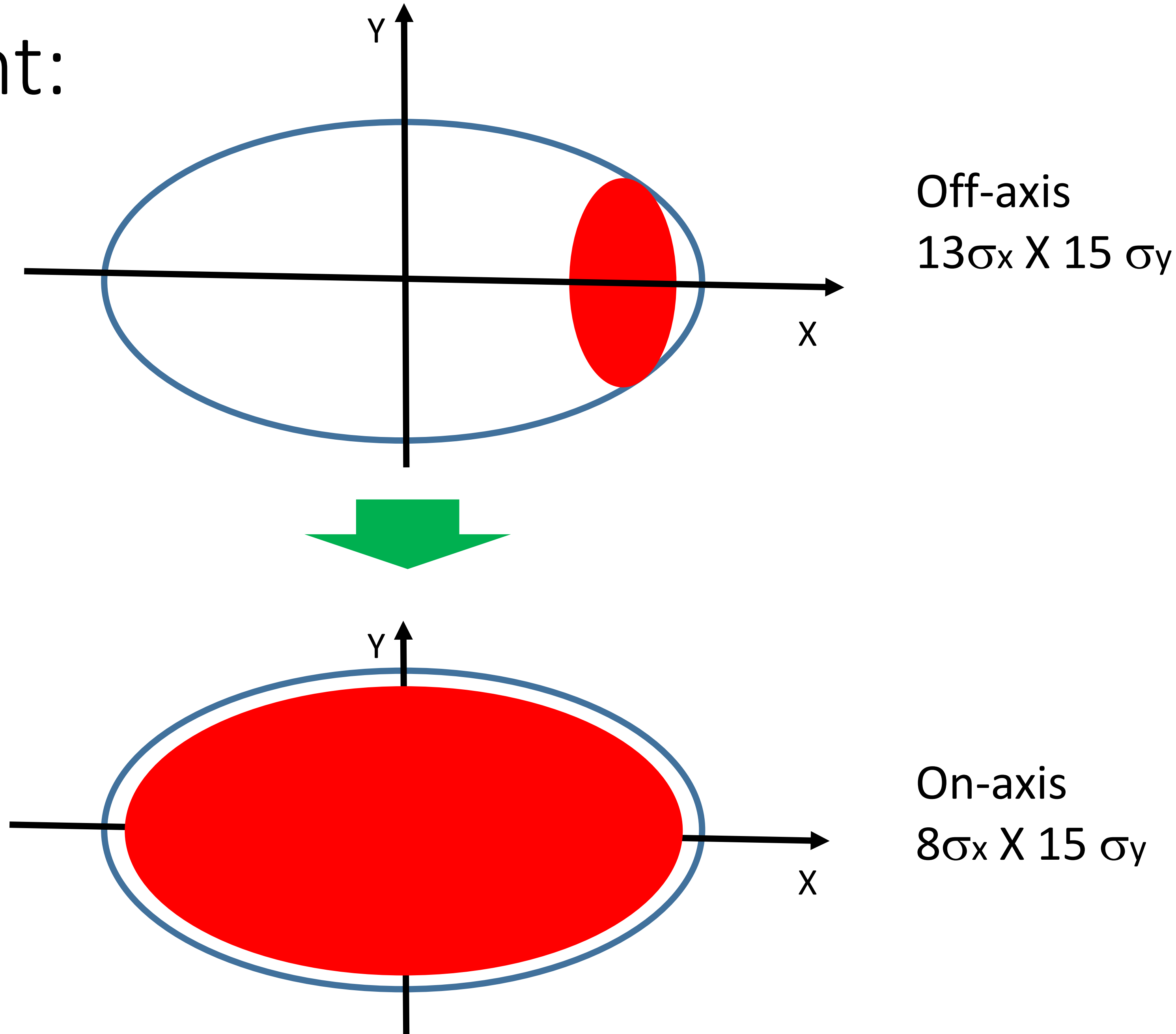
3. Large bunches stay in the booster for 4 damping time(200ms), so that the injected bunches merge with booster bunches.

4. Inject the merged large bunches back to the same empty buckets left by the last step.

5. Repeat the last steps.

DA requirement:

- The required horizontal DA in the booster reduce from 13σx to 8σx.
- The required vertical DA also decrease a little.



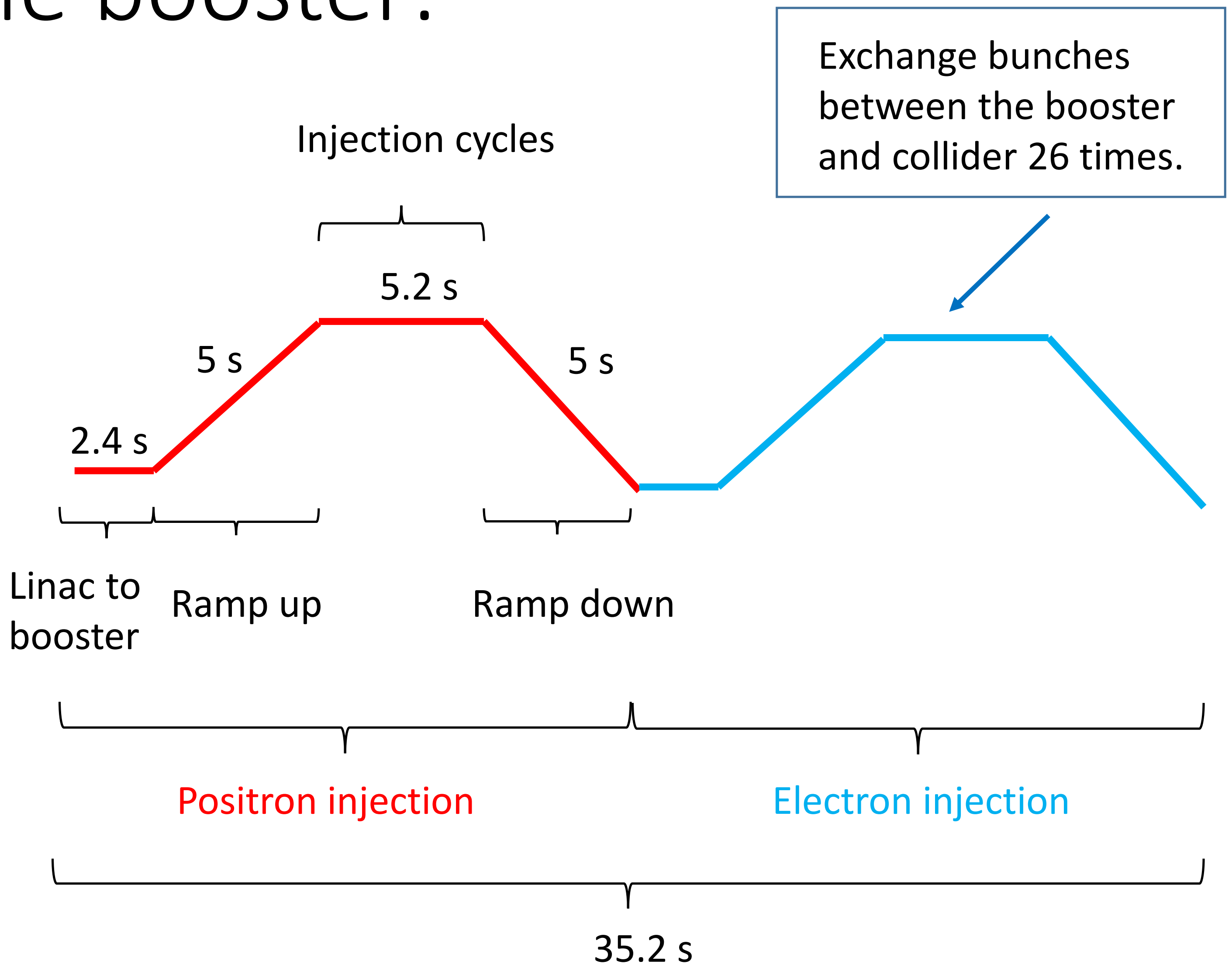
Time structure of the booster:

3% current decay in the collider

- The small bunch charge in booster is 3% of the charge of the colliding bunch in the collider.
- With a 3% current decay, the injection period of CEPC should be less than 47s.

Current limit in the booster

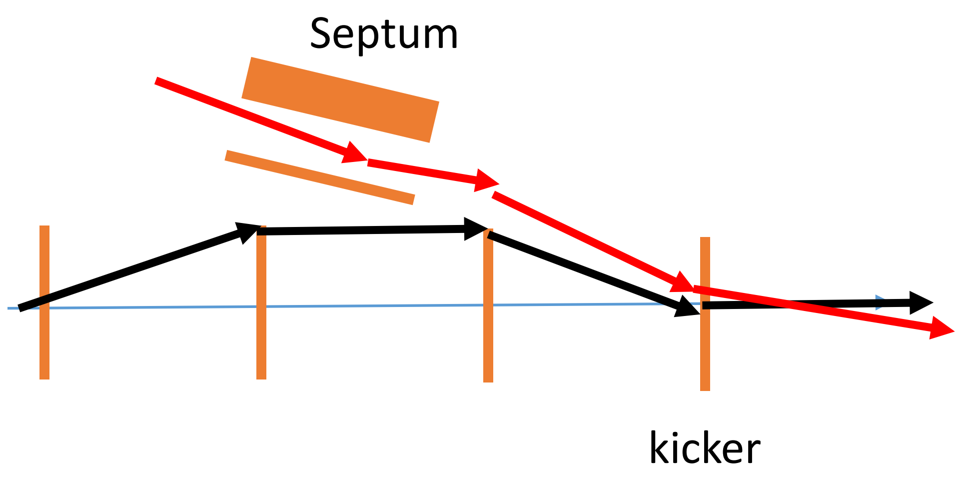
- The bunch charge in the collider is 24nC, which is less than the booster's single bunch charge limit of 100 nC.
- At the beginning, only 7 bunches are injected into the booster, so that the current in the booster does not exceed the 1mA threshold limited by the RF power.

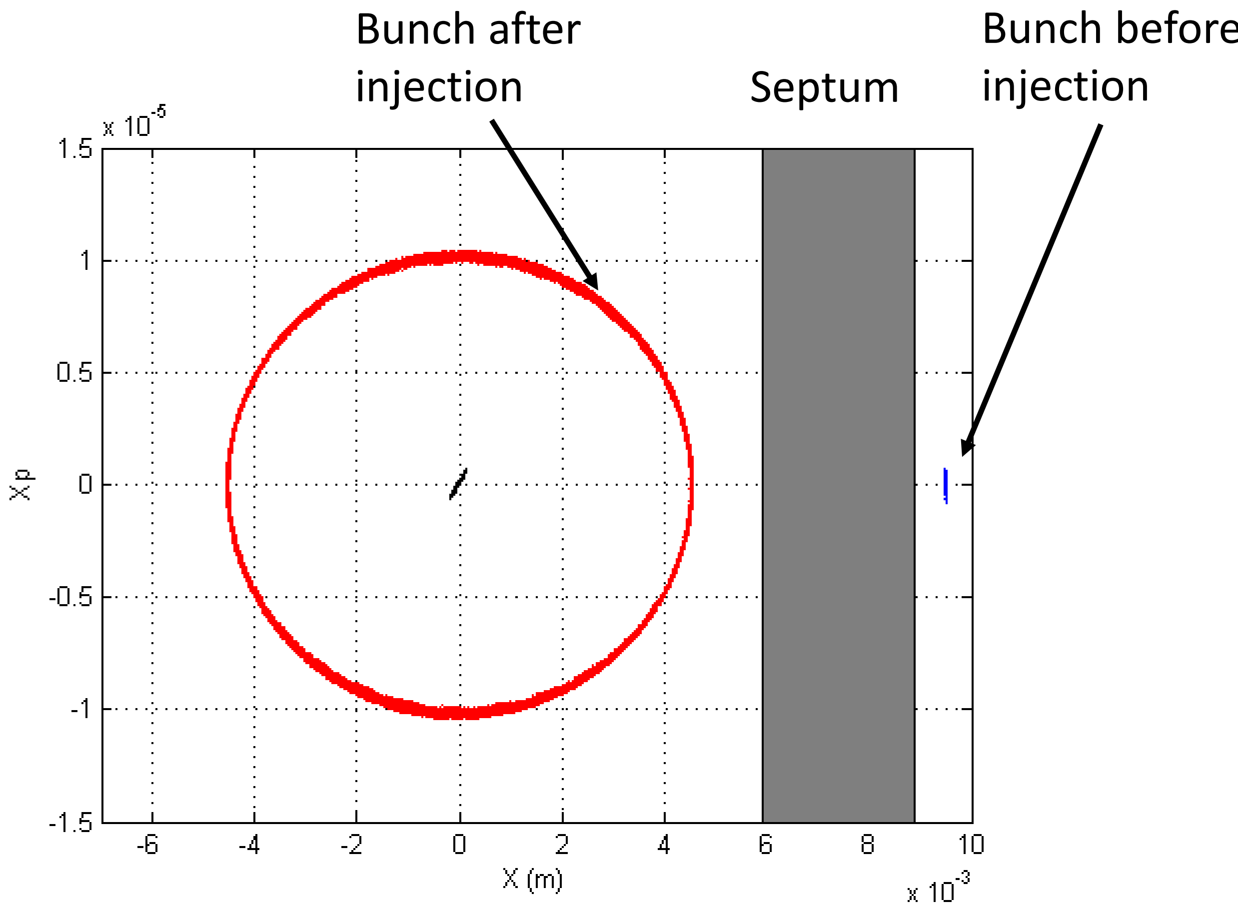


Injection from the collider to booster

A vertical off-axis injection

- Transfer beam from the collider to booster vertically.
- 4-kicker bump in the booster.



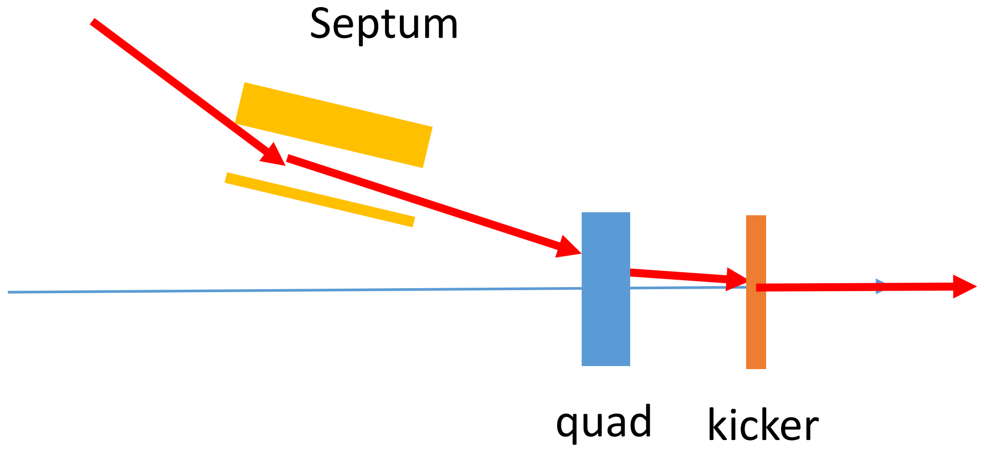


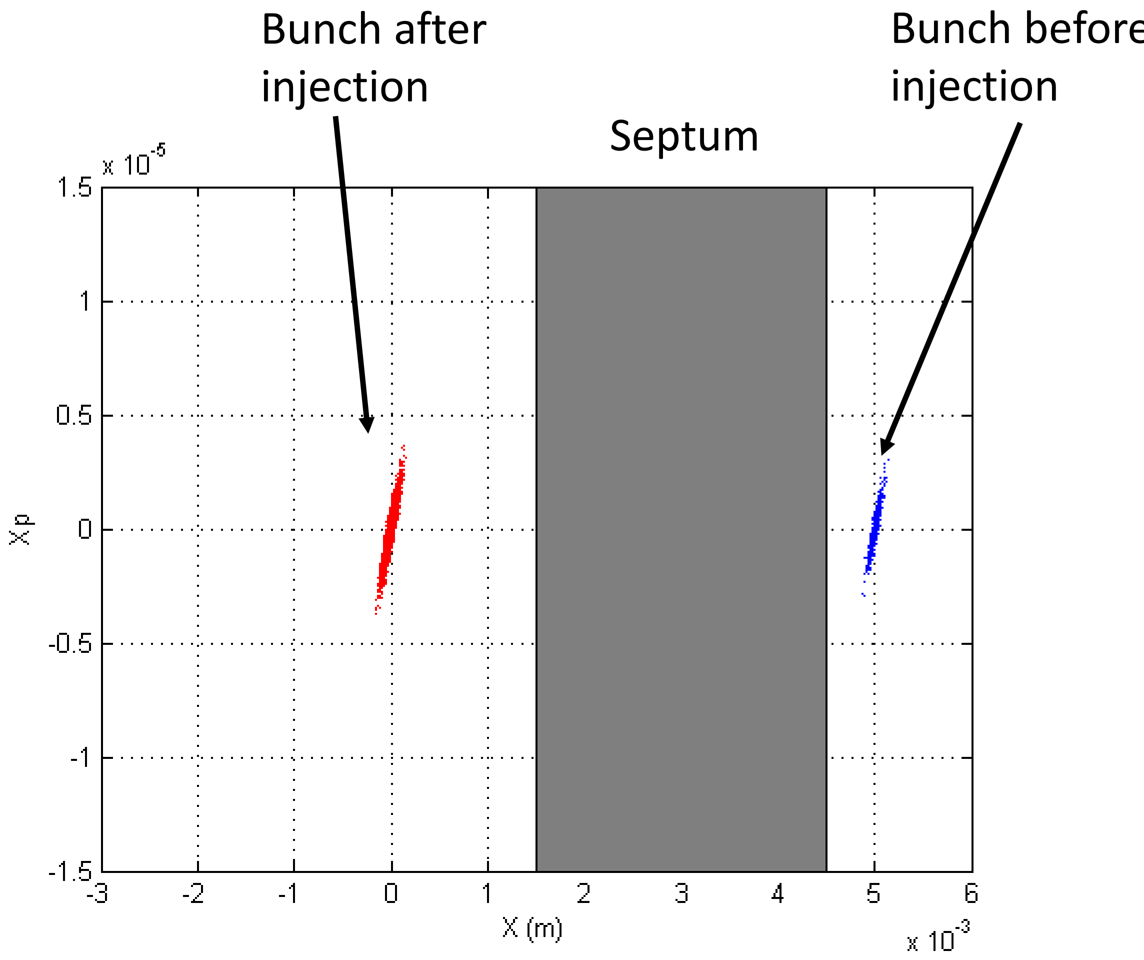
Phase space of the first 100 turns

Injection from booster to the collider

A vertical on-axis injection

- Transfer beam back to the collider vertically.



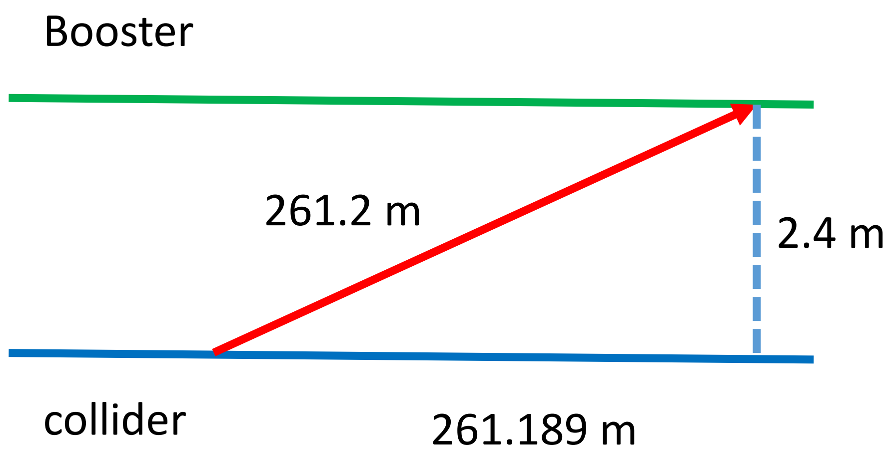


Phase space of the first 100 turns

4. Discussions:

1. Longitudinal matching

- We need to inject the bunch back into the same bucket after damping in the booster.
- The booster and collider has the same circumference, which makes this easier.
- Due to the different paths traveled by the injection beam and the circulating beam, a longitudinal deviation is introduced.



Longitudinal phase shift

- The length of the transport line is 261.2 meters, and the path difference between the injected beam and the circulating beam is only 0.011 meters, or 0.037 ns in time.
- This is equivalent to a 17 degree phase shift in the booster, and is in the stable region. This phase shift can be damped by synchrotron radiation.

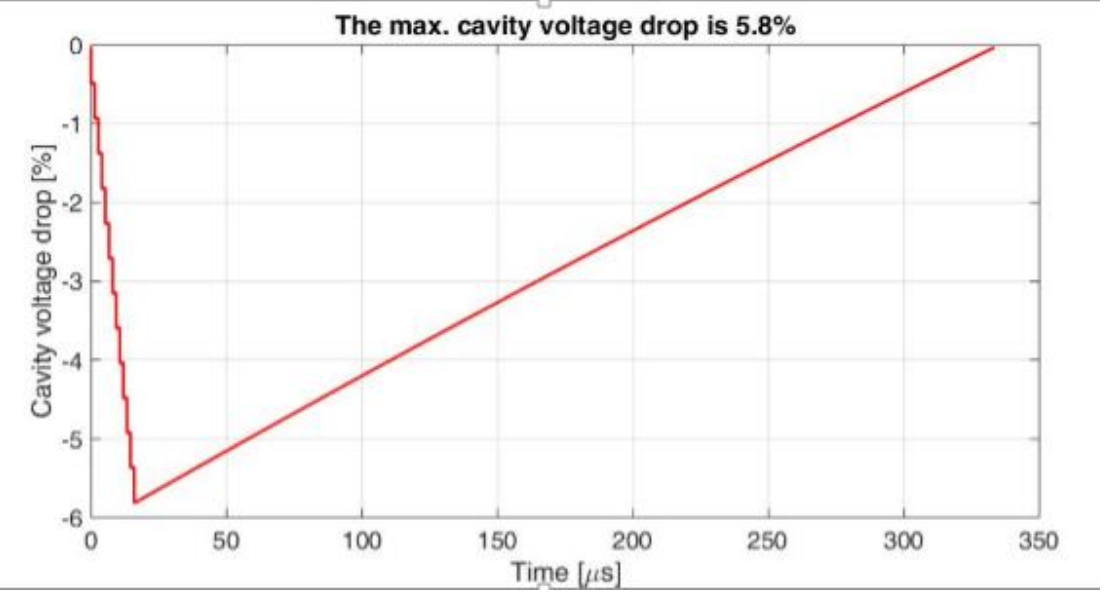
Or move the RF phase of the booster

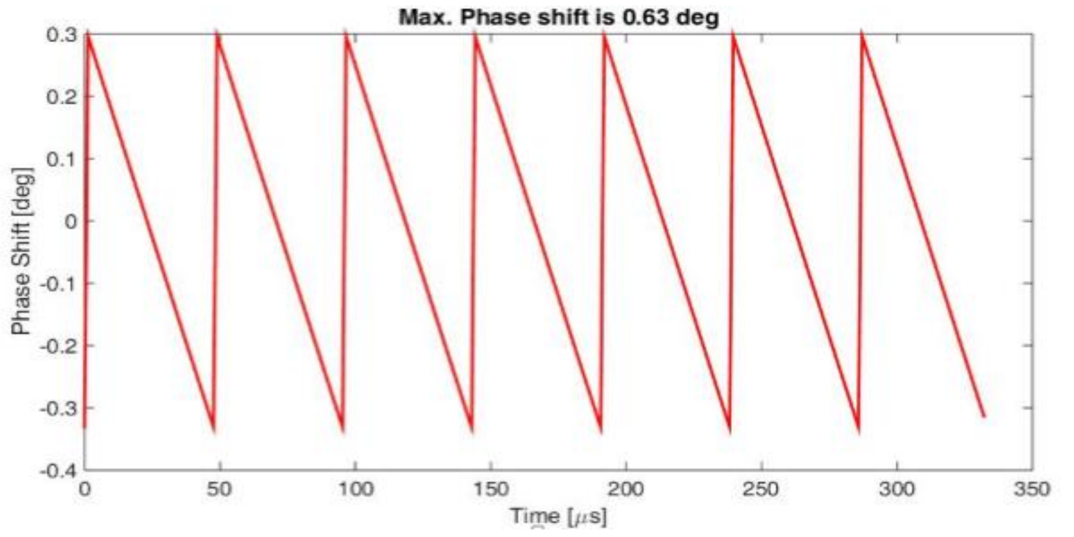
Did experiment at BEPC II, we found that 200 ms is enough to move a 17 degree.

2. Beam loading

Beam loading effect is weak

- Transient beam loading in the booster by the injection of large bunch and larger total beam current
- With 7 large bunches (0.07mA) evenly distributed among the other small bunches. Max cavity voltage drop is 0.48 %. Max phase shift is 0.63 deg.
- For 13 large bunches. Assume they are in a very short bunch train. Max cavity voltage drop is 5.8% . The maximum phase shift is 7.7 deg.



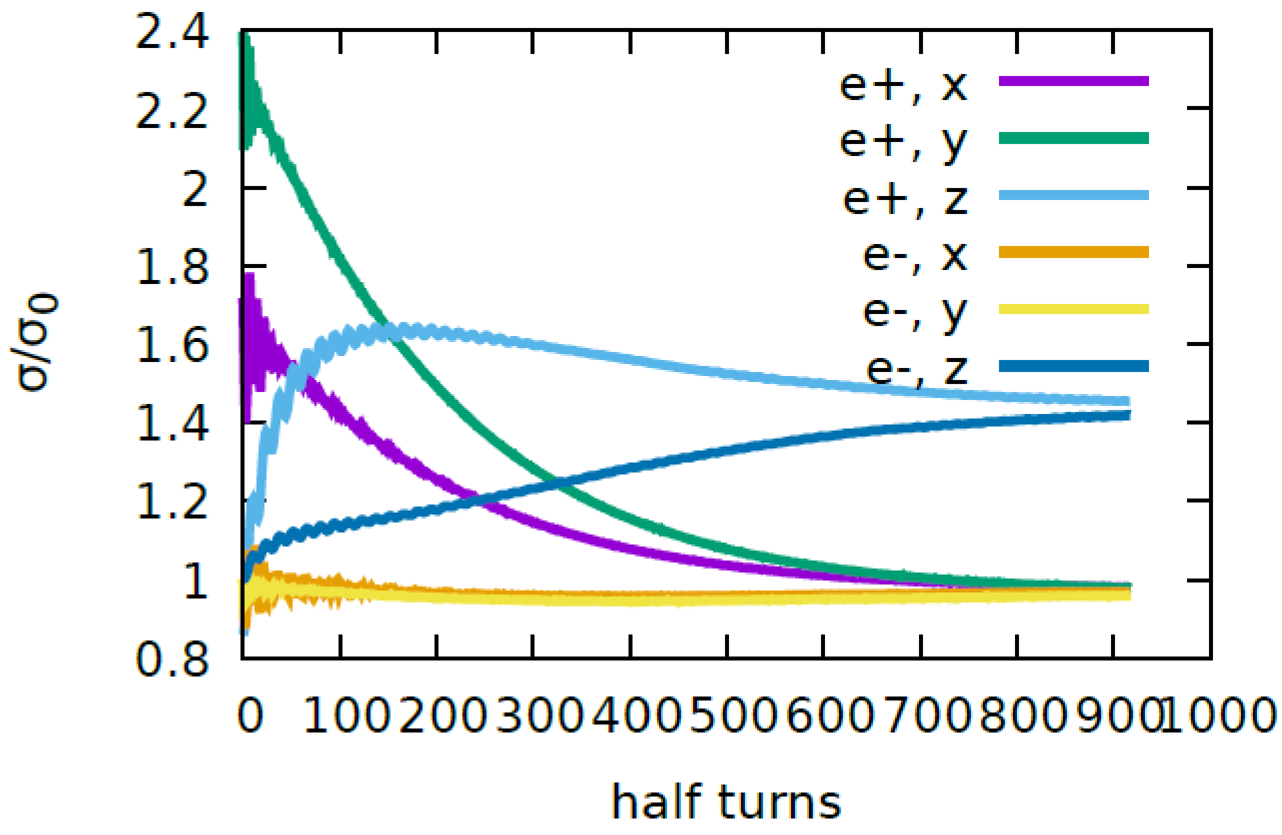


3. flip-flop instability

Beam is stable

- We considered bunch instability due to the absence of several bunches in the collider.

- A beam-beam simulation shows that there is no flip-flop instability.

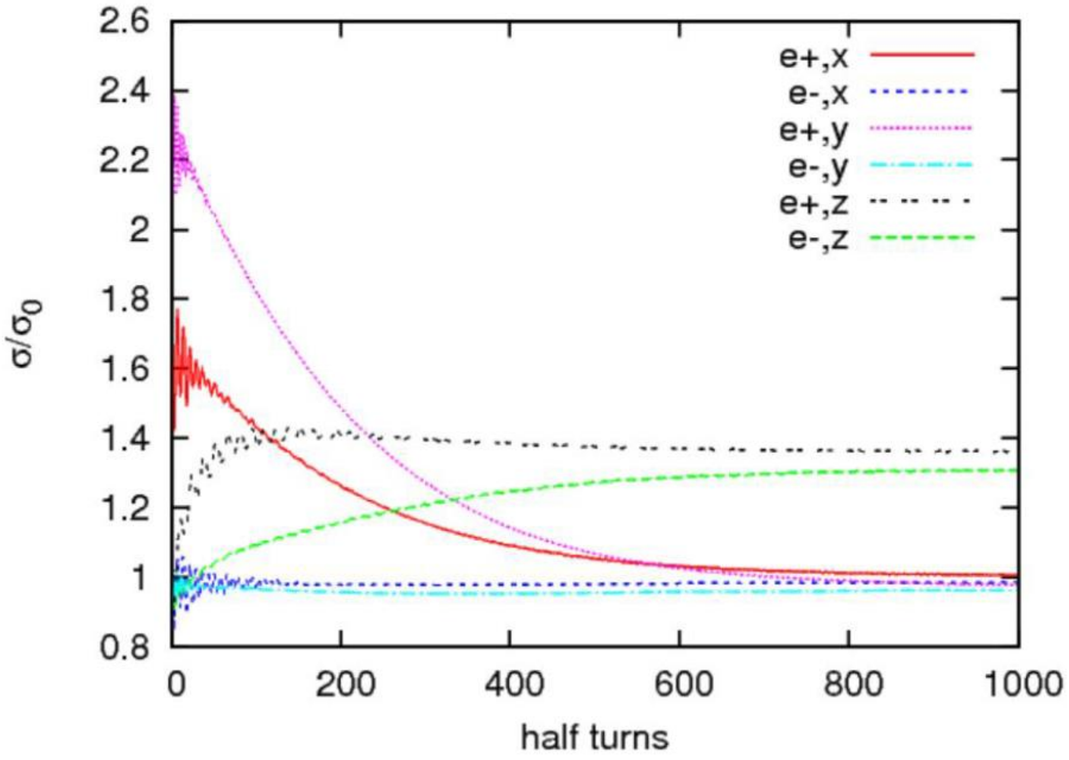


Simulation result of Zhang Yuan

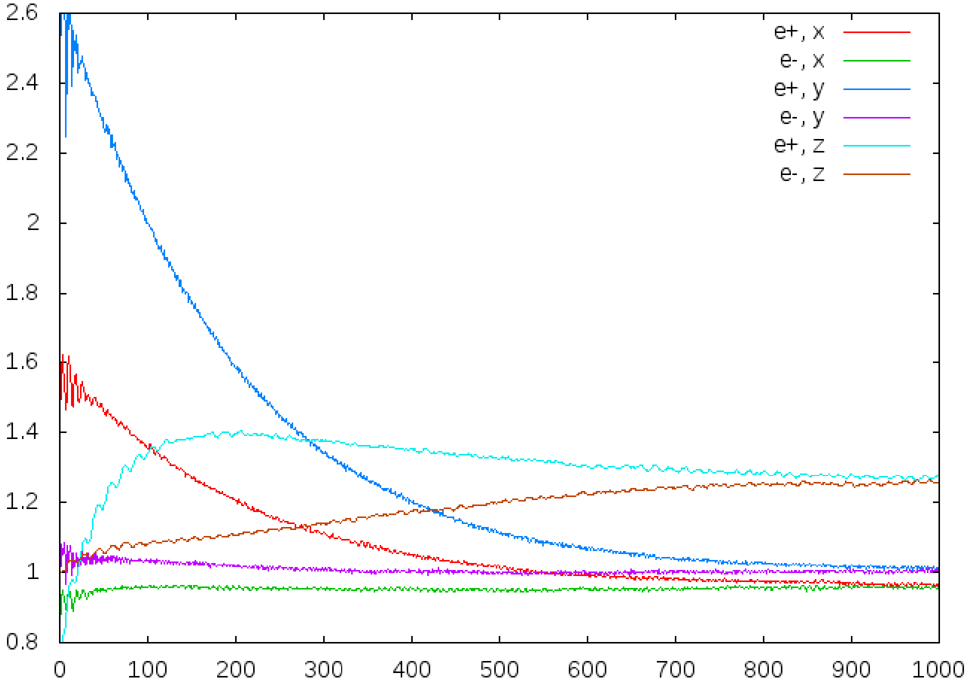
Code cross check

K.Ohmi and D.shatilov did the same simulation with their codes.

Different codes agree well



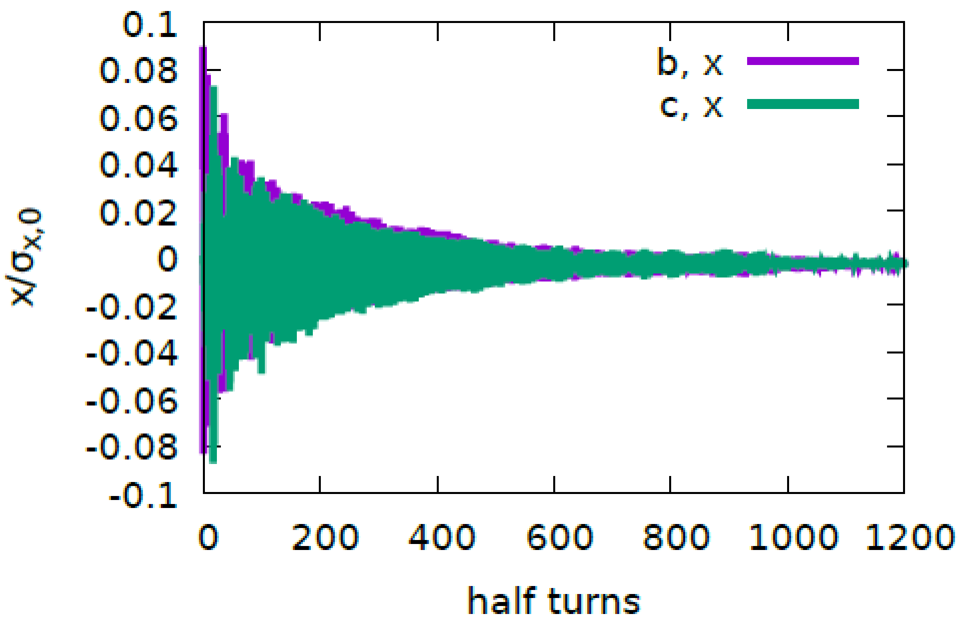
K. Ohmi

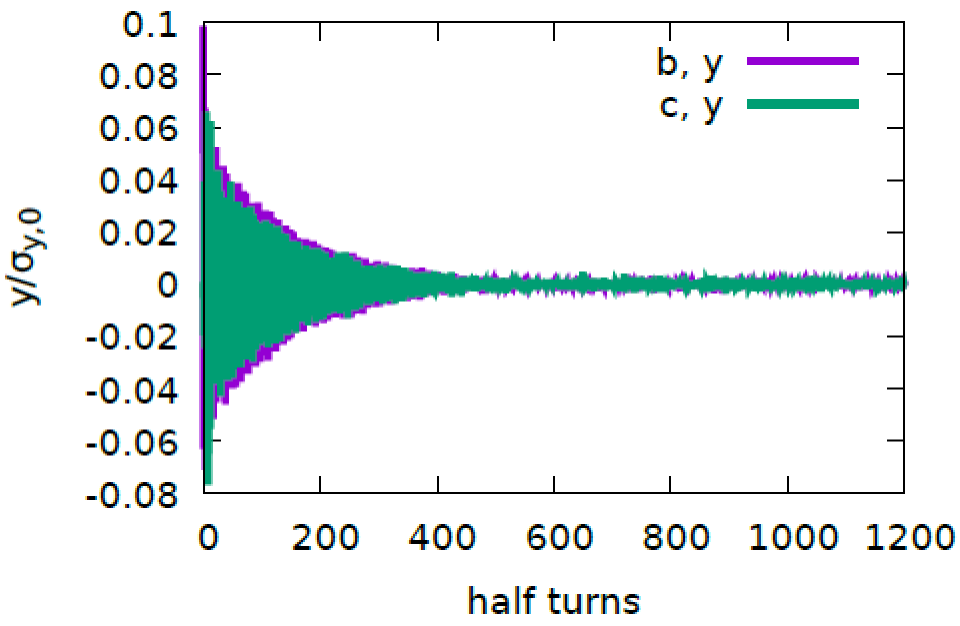


D. Shatilov

Simulation with initial conditions

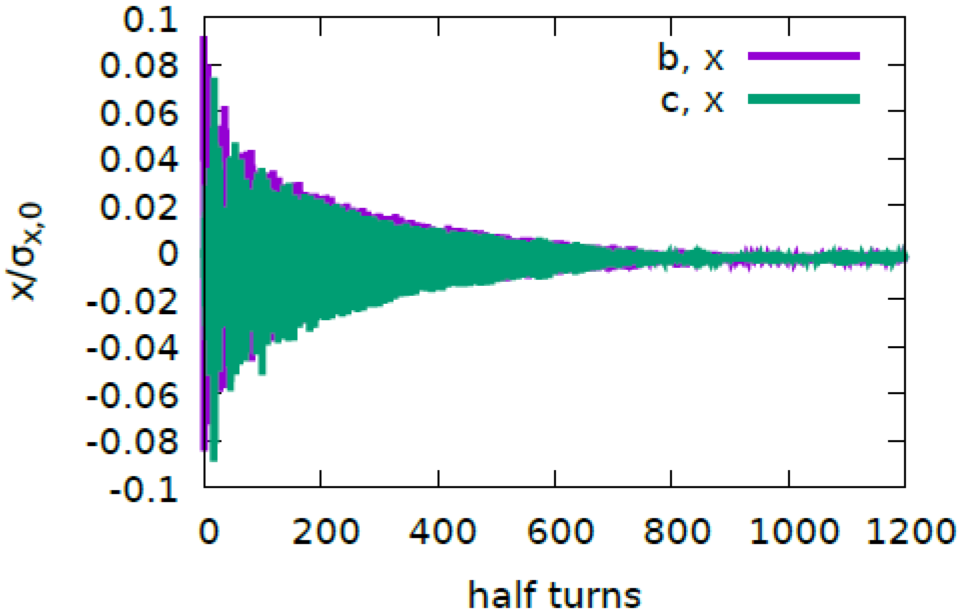
Horizontal offset： 9% σx.
vertical offset : 10 % σy.
Intensity difference： 3%.

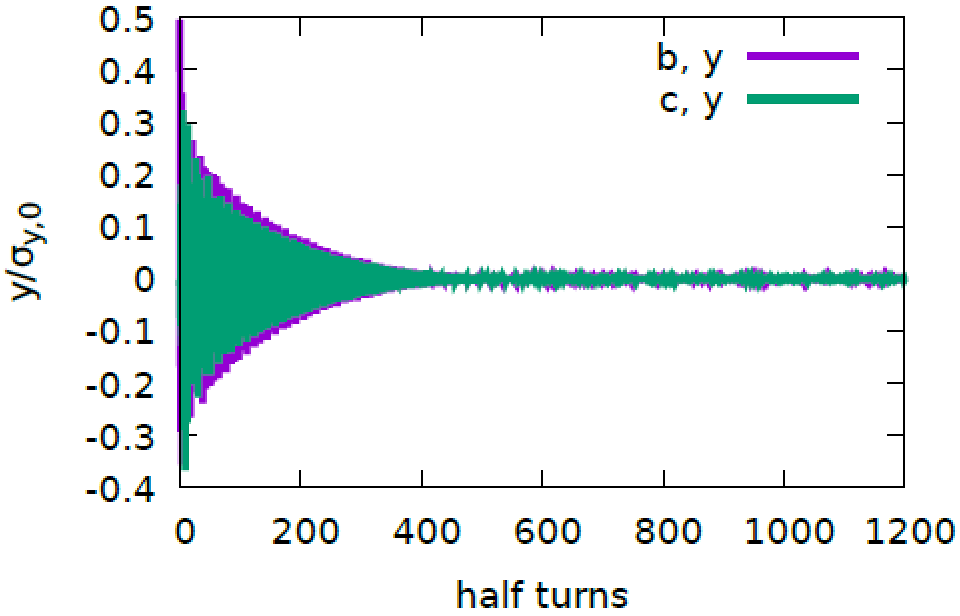




Beam is stable even with a 50% σy offset.

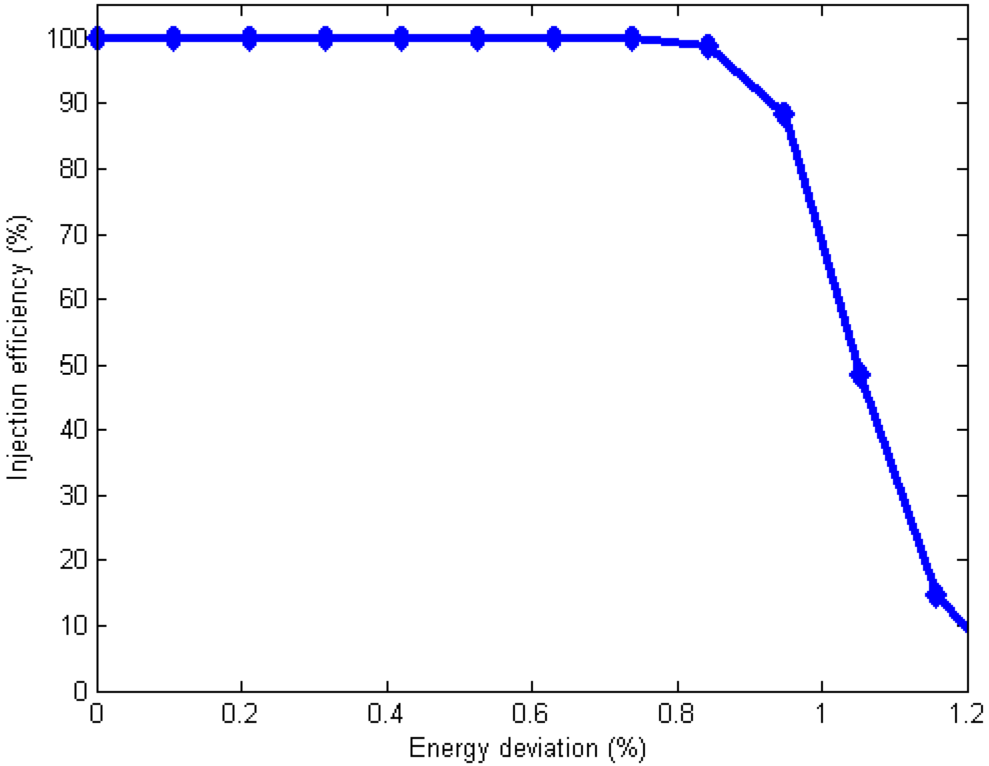
Horizontal offset： 9% σx.
vertical offset : 50 % σy.
Intensity difference： 3%.



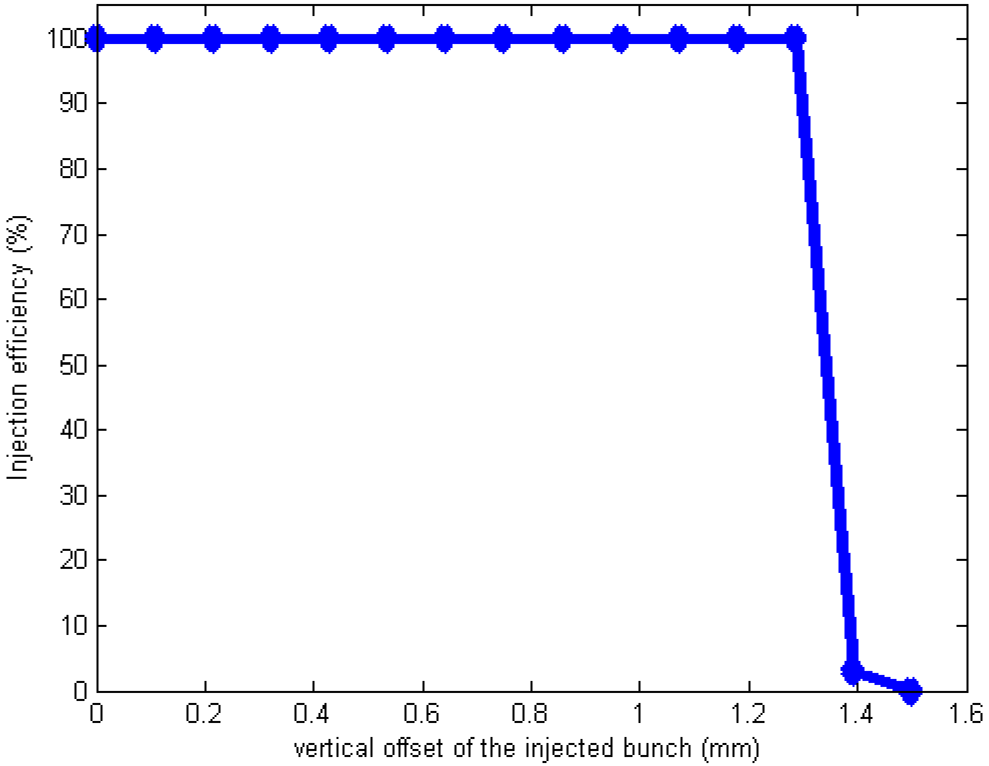


5. Injection efficiency

Very preliminary



A small Energy Deviation



A small offset

5. Injection efficiency

It’s needed and challenging to have a very high injection efficiency

To do list:

- Design optimization
- Magnet errors.
- Beam stability
- Feed back

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6. Summary:

- An on-axis injection design for CEPC is given.
- With this injection scheme, the required horizontal dynamic aperture of the collider reduce to 8 σ_x.
- The booster energy should have a long flattop at 120 GeV, the magnet power will increase.
- Many work to do to improve the injection efficiency to make this on-axis injection a real design.

Thank You for your attention!