HEPS

Charge Limit Simulations of the HEPS Accelerators

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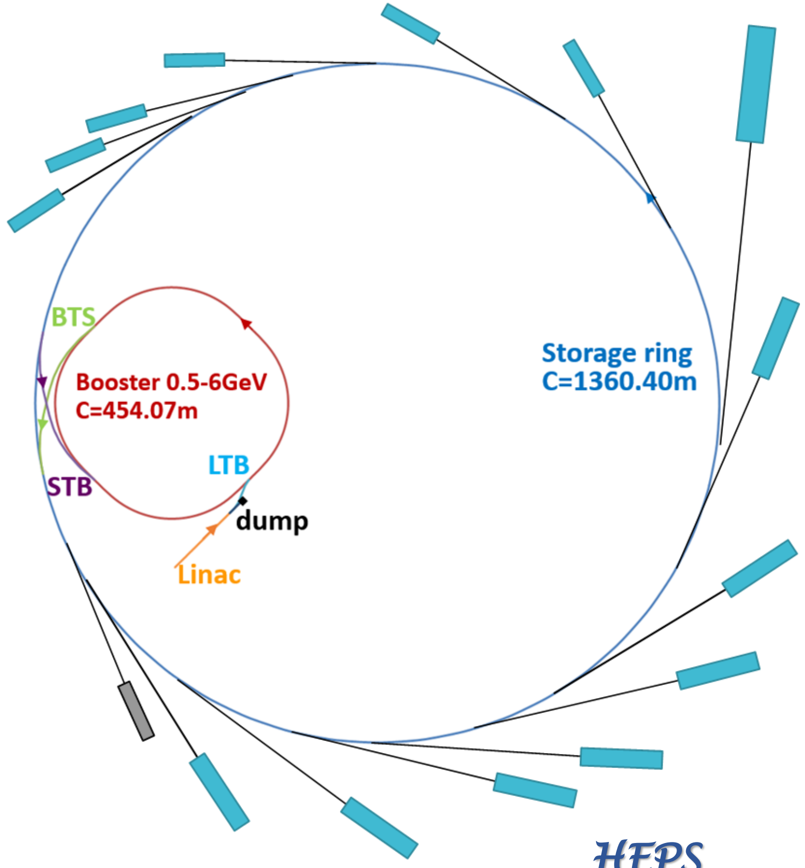
Outlines

1. Introduction
2. Charge Limit Simulations for HEPS Storage Ring
3. Charge Limit Simulations for HEPS Booster
4. Summary

Introduction

- High Energy Photon Source (HEPS) is designed as a 6-GeV storage-ring-based synchrotron light source.

Main parameters	Unit	Value
Beam energy	GeV	6
Circumference	m	1360.4
Emittance	pm·rad	< 60
Brightness	phs/s/mm²/mrad²/0.1%BW	$>10^{22}$
Beam current	mA	200



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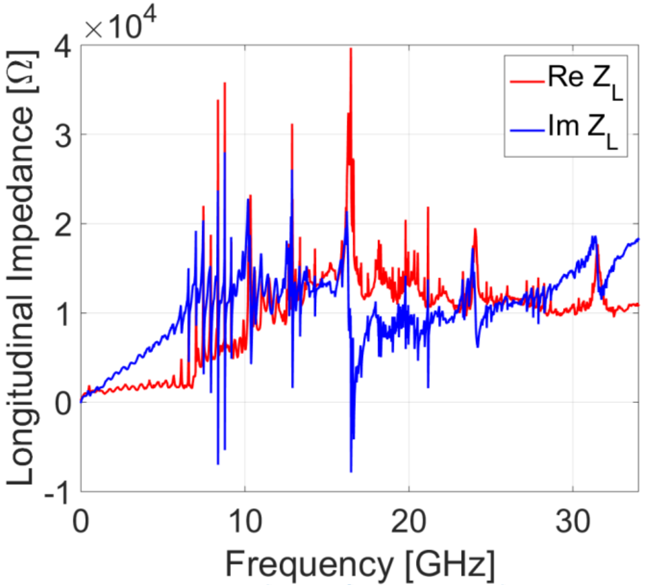
Charge Limit for the HEPS Storage Ring

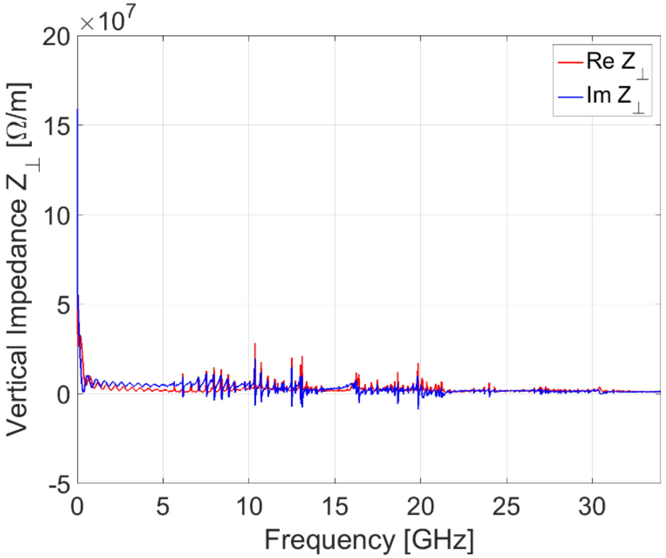
- Beam loss is the first thing to worry about, especially in the proposed high-charge operation scheme.
  - The effects due to high charge, which may cause beam loss, are what we focus on here.
- Transverse single-bunch instability may lead to serious particle loss
- Transient effect right after injection especially for high-charge swap-out injection is a newly coming problem in the proposed high-charge operation.
- Fast-beam ion instability may be a problem in the commissioning.

Impedance Modeling

- Total impedance spectrum has been used in the calculations of the charge limit.
- Update of the impedance model is still on-going since the more detailed engineering designs of components is on-going.



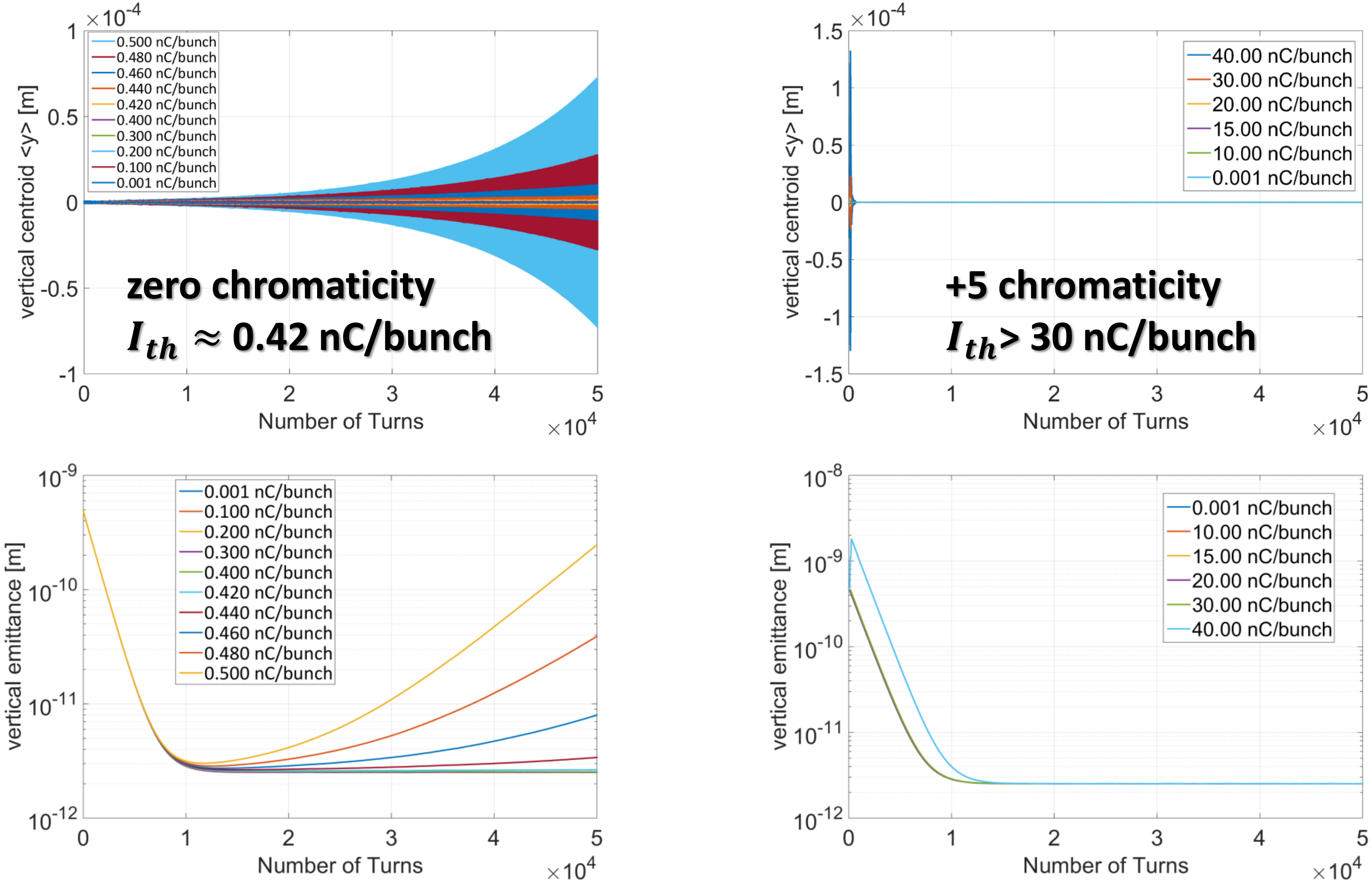
Longitudinal Impedance



Transverse Impedance

Elements	Number	Elements	Number
Resistive wall	-	In-vacuum IDs	7
Primary RF cavities	5	Tapers of Out-vacuum IDs	14
Harmonic cavities	2	BPMs	576
Vacuum transitions	240	Injection kickers	10
Bellows	1500	Extraction kickers	10
Flanges	2064	Longitudinal Feedback kicker	1
In-line absorbers	600	Transverse Feedback kicker	1
Vacuum pumping ports	288		

Transverse Single-Bunch Instability w/ 3^{rd} Harmonic Cavity



zero chromaticity

$I_{th} \approx$ **0.42 nC/bunch**

+5 chromaticity

$I_{th} >$ **30 nC/bunch**

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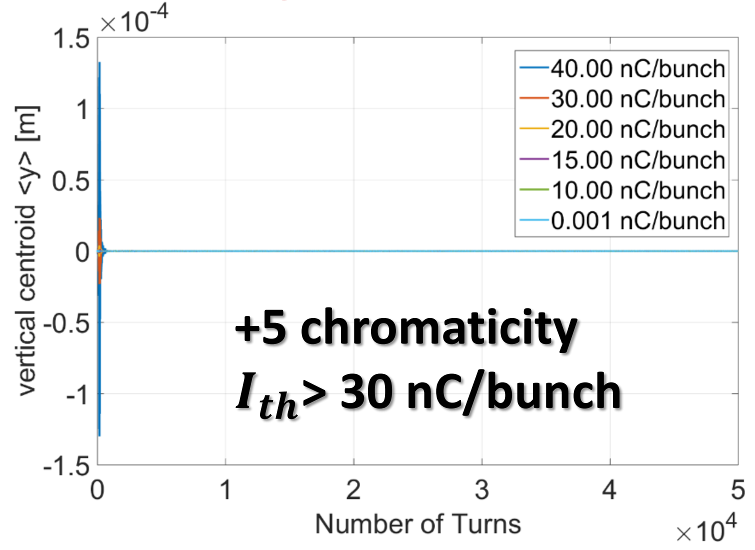
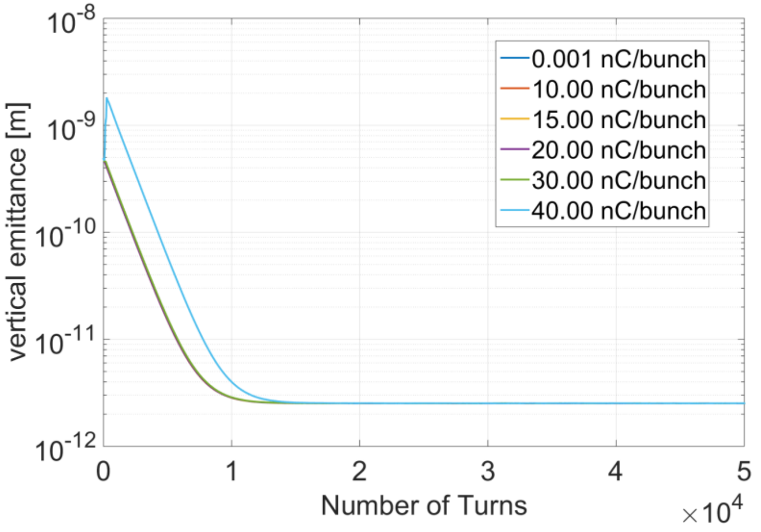
Transverse Single-Bunch Instability w/ 3rd Harmonic Cavity



+5 chromaticity

I_{th}> 30 nC/bunch



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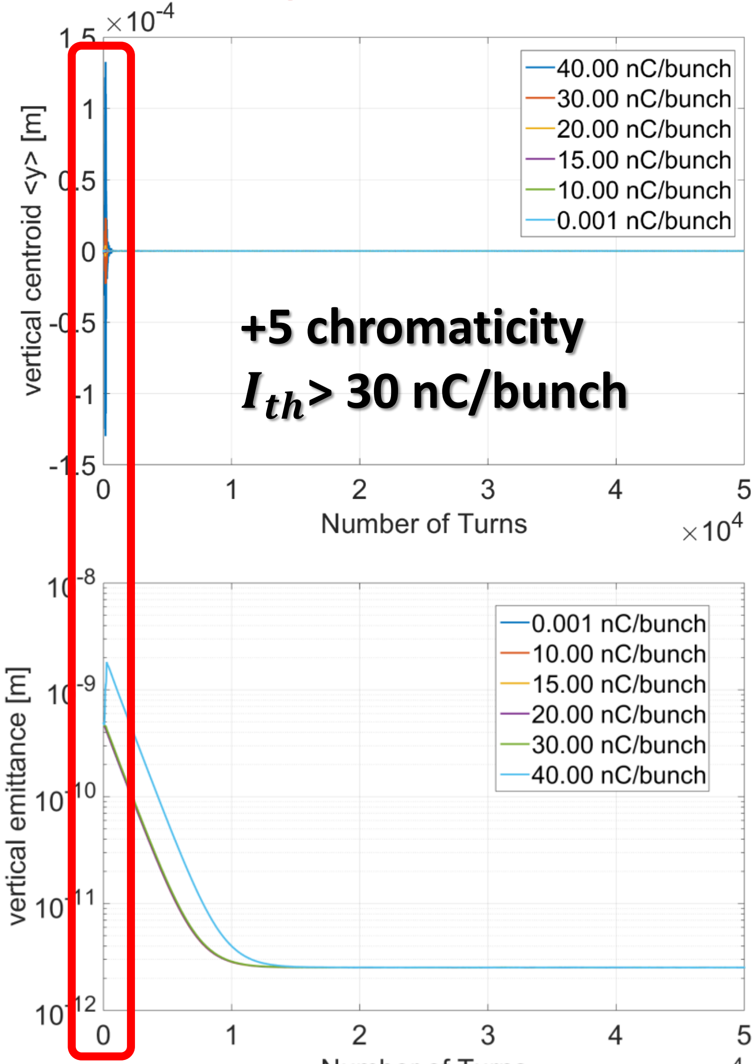
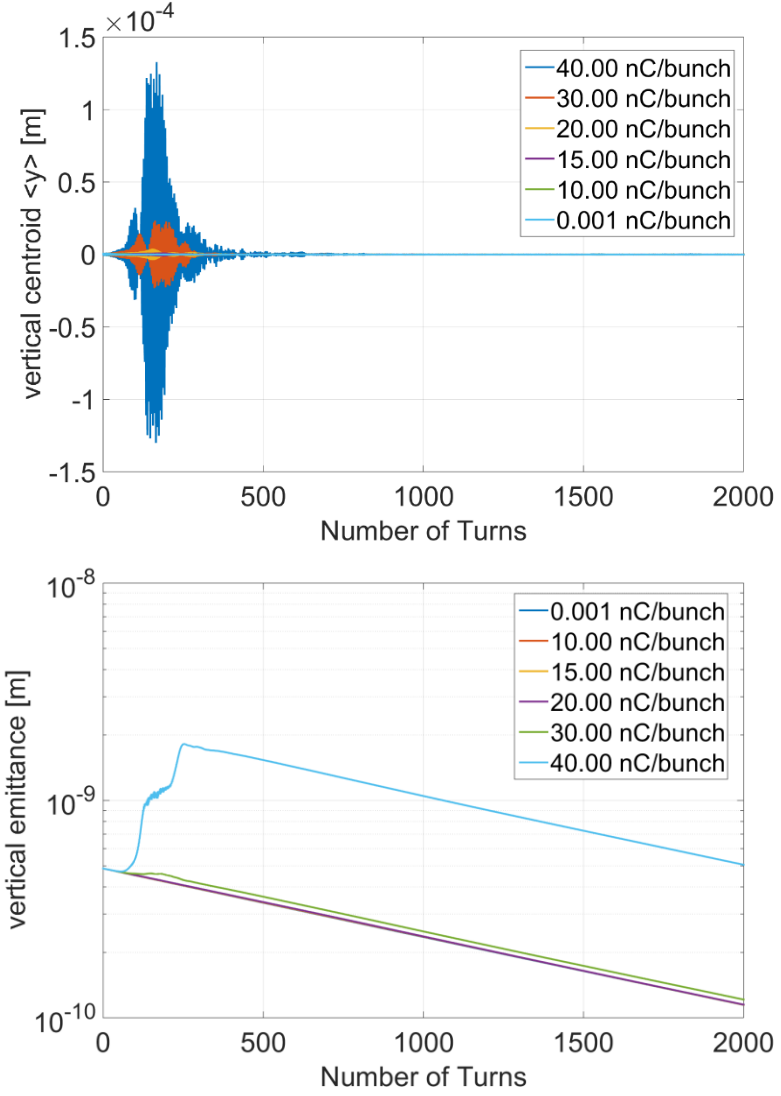


+5 chromaticity

I_{th}**> 30 nC/bunch**

Zoom in



- SR damping time ≈ 3000 turns.
- **High-charge effects in the transient process after injection needs careful study[*].**

[*], R. Lindberg, M. Borland, and A. Blednykh, Collective Effects at Injection for the APS-U MBA Lattice, in Proceedings of NAPAC2016, Chicago, IL, USA.

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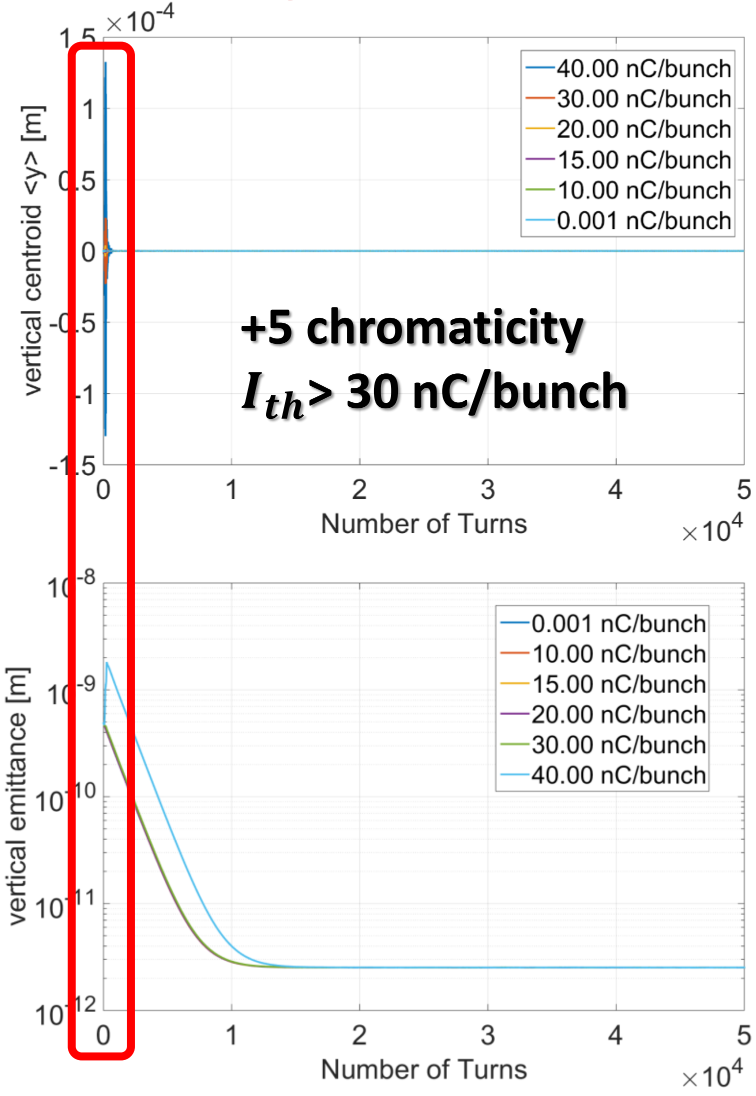

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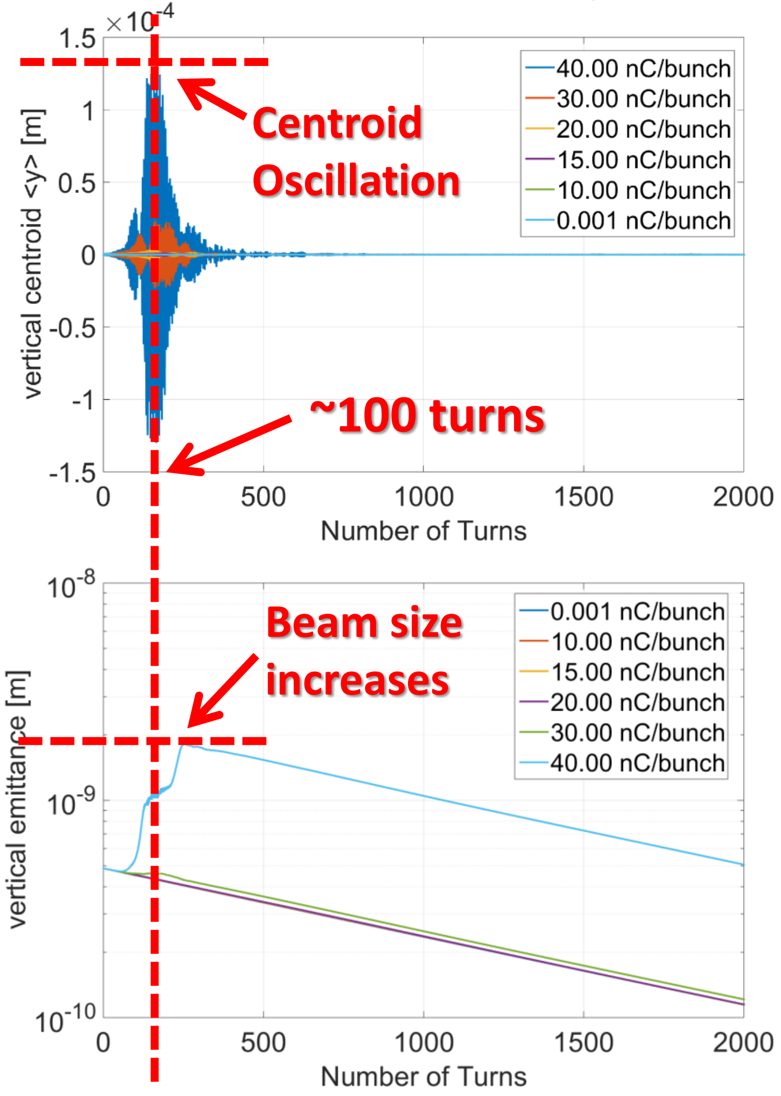

Centroid Oscillation

~100 turns

Beam size increases

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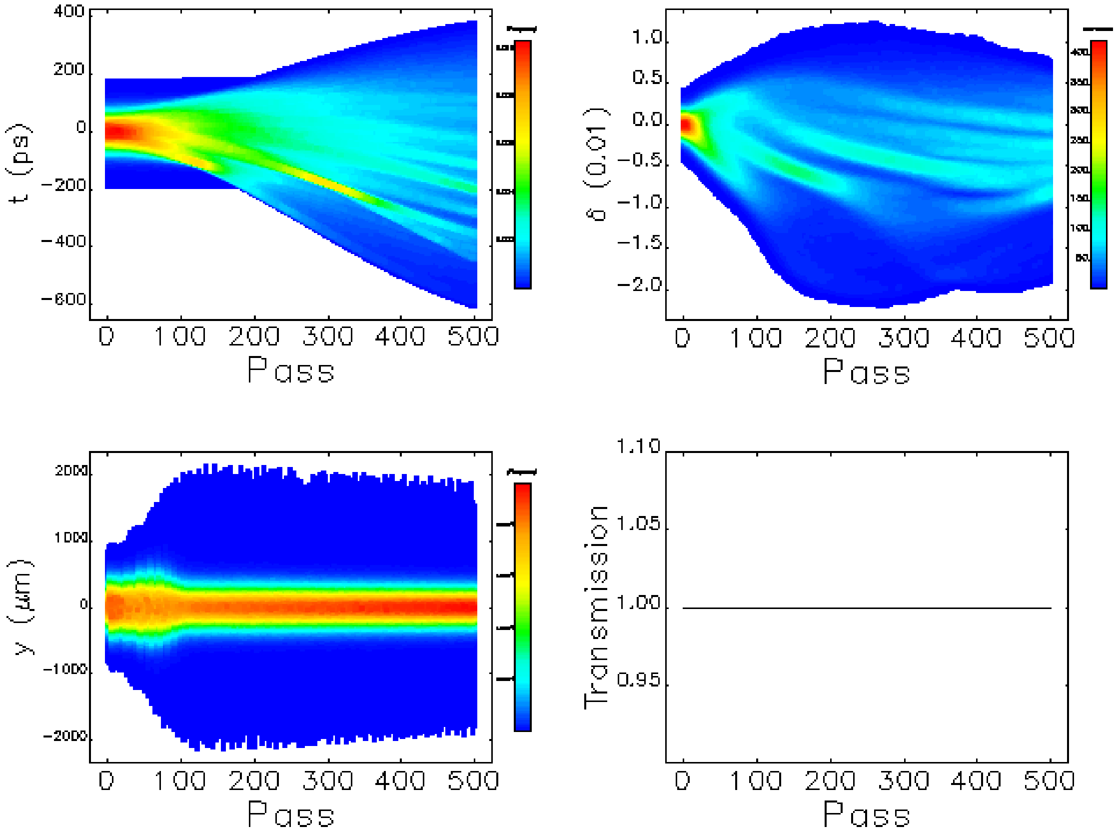
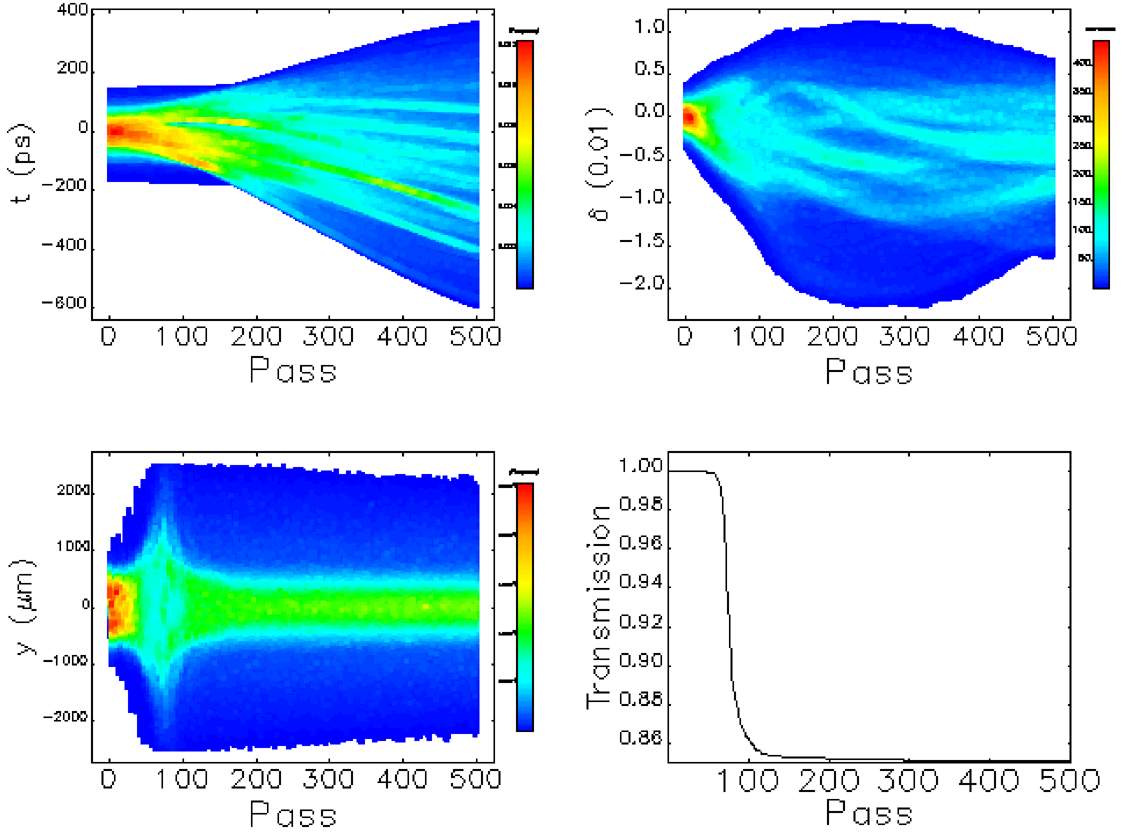
High-Charge Limit in the transient process after injection

- Single-bunch 15 nC, initial vertical offset $y_{ini} = 300\mu m$, initial bunch length $\sigma_{t-ini} = 40\ ps$, initial energy spread $\sigma_{\delta-ini} = 0.001$



Linear One-Turn Map



Element-By-Element

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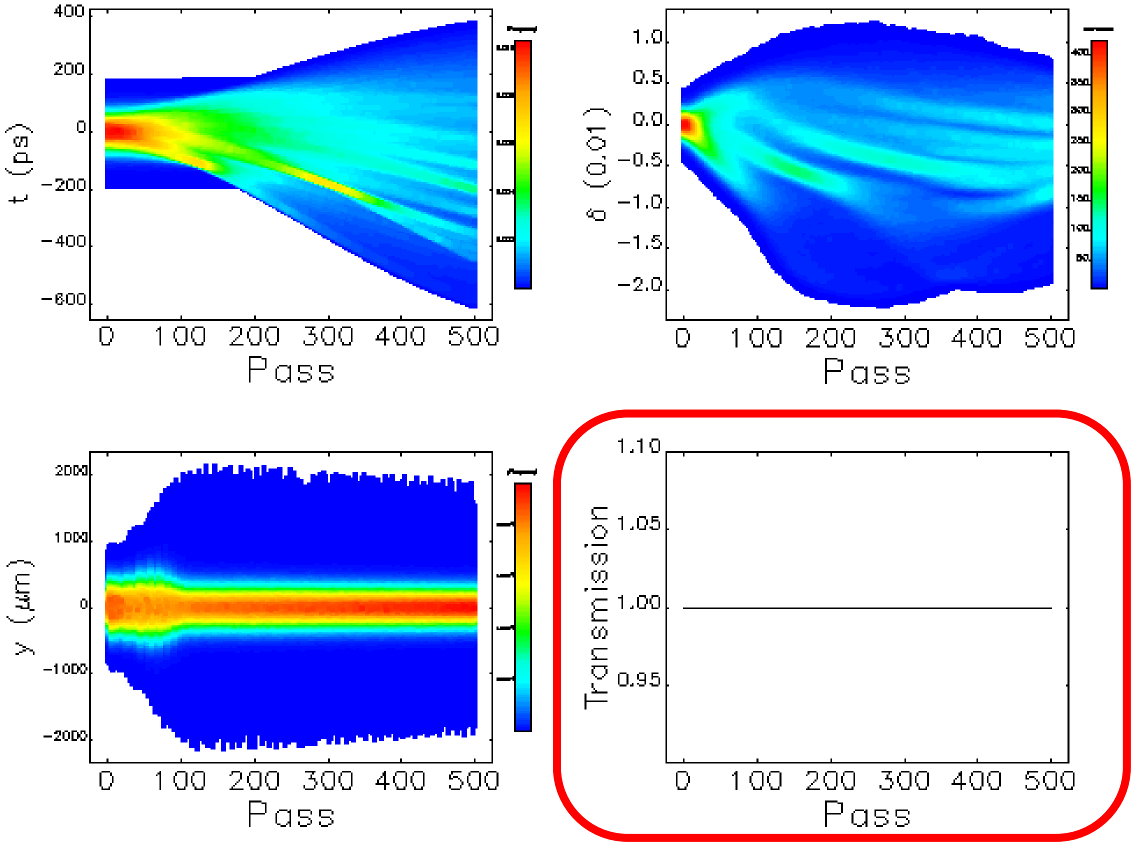

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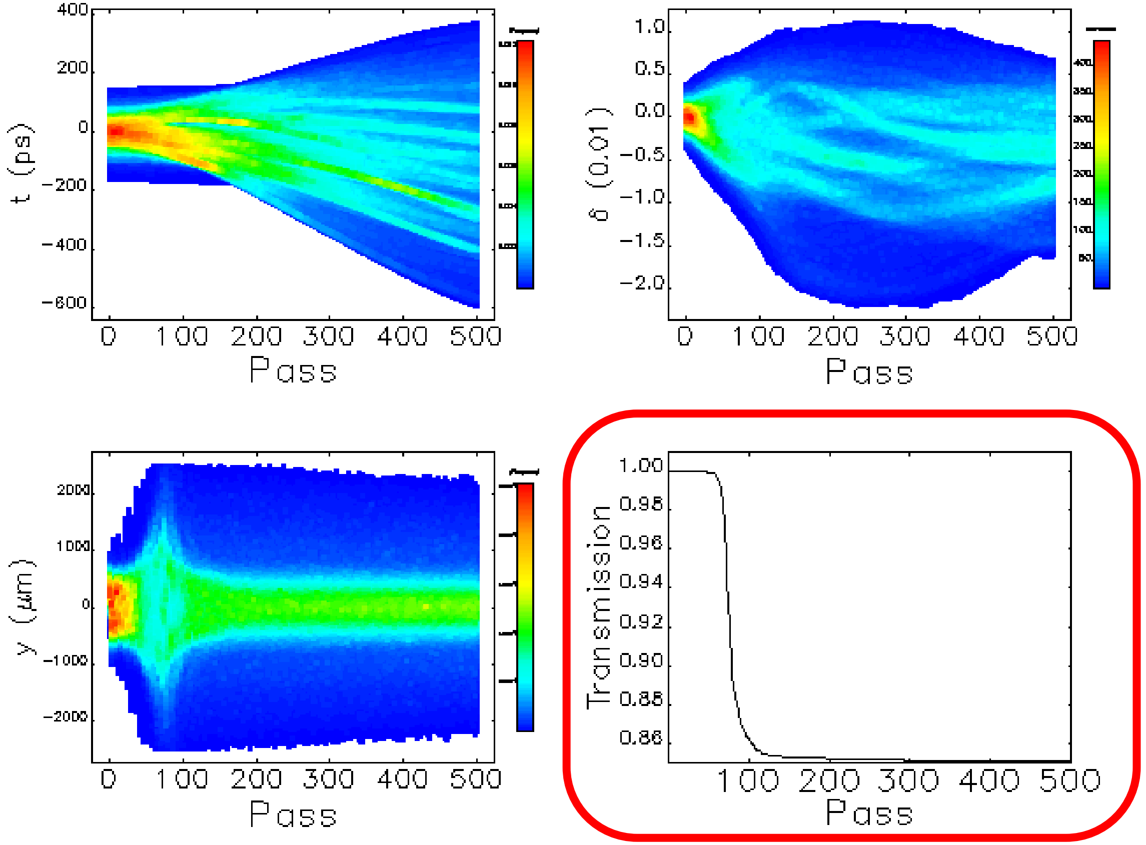
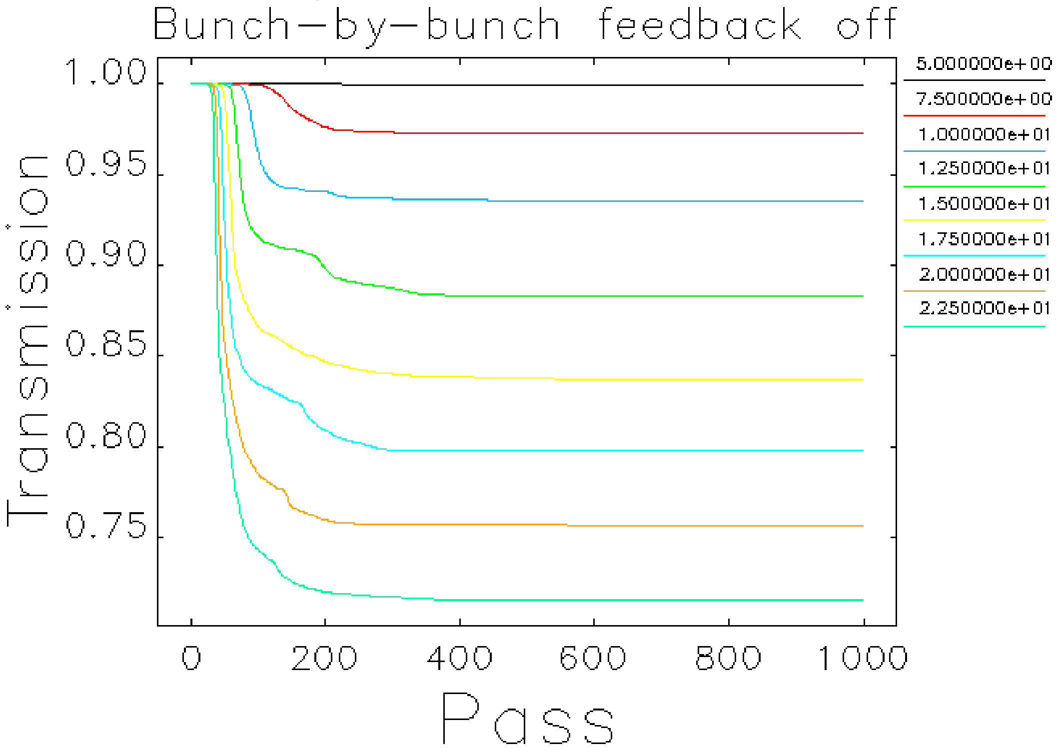
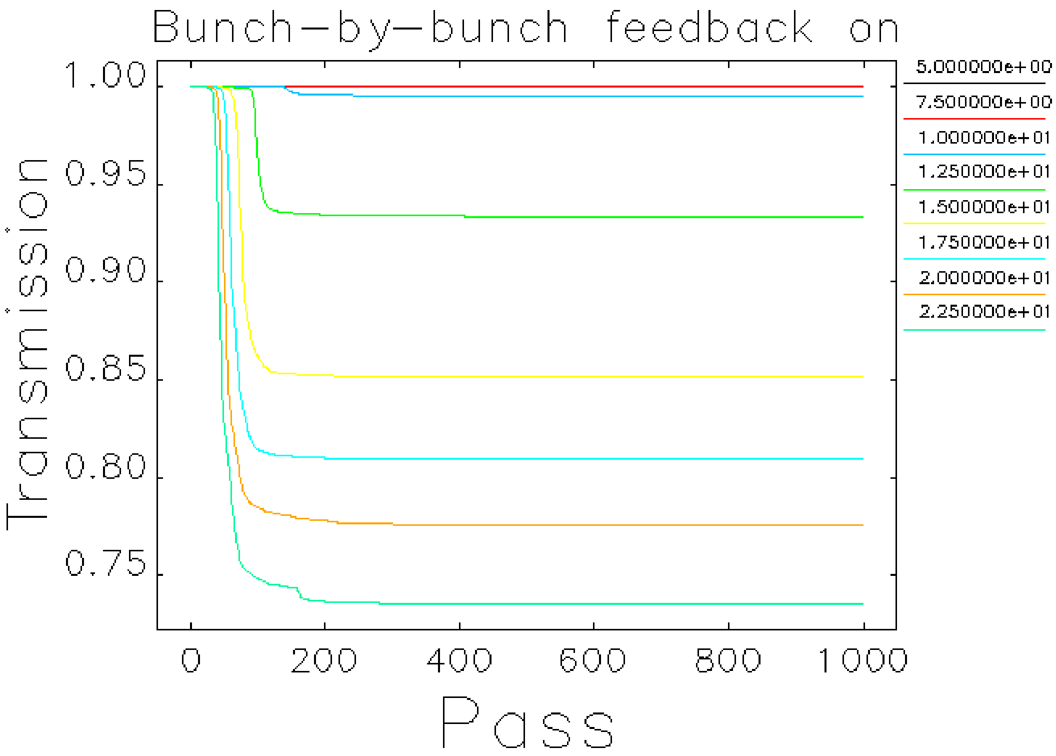


Element-By-Element

High-Charge Limit in the transient process after injection

- Initial vertical offset $y_{ini} = 300\mu m$, initial bunch length $\sigma_{t-ini} = 40\ ps$, initial energy spread $\sigma_{\delta-ini} = 0.001$, element-by-element tracking.
- Two different situations w/ and w/o bunch-by-bunch feedback system.
- Further systematic calculations are needed to optimize the injection efficiency at high bunch charge.





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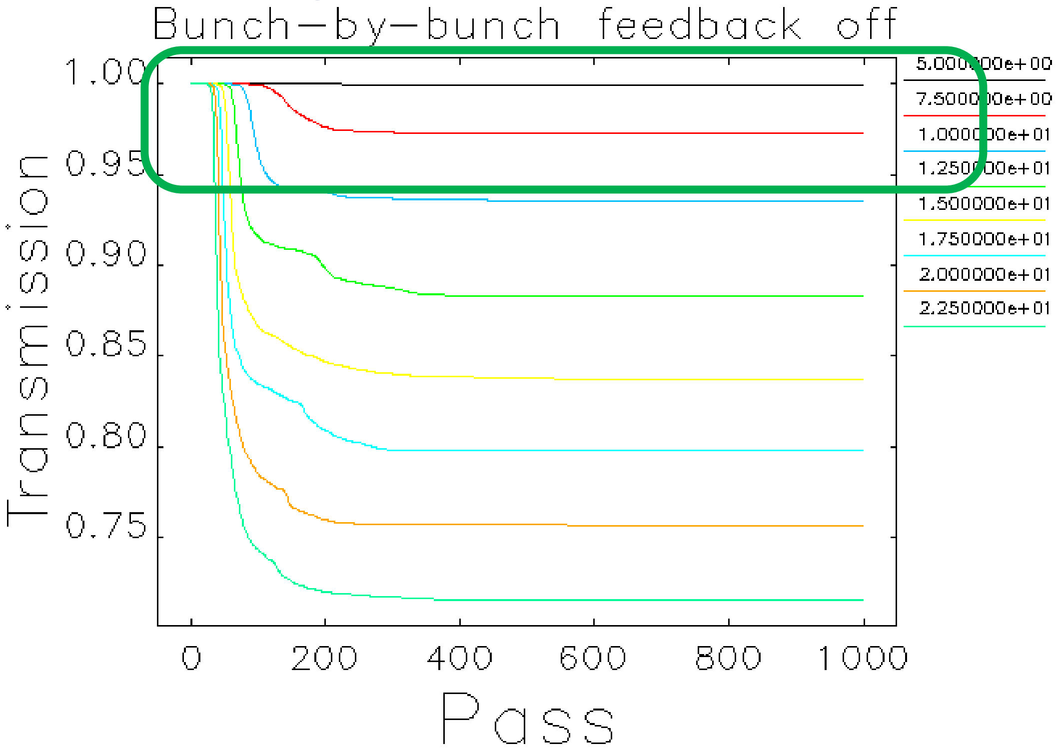

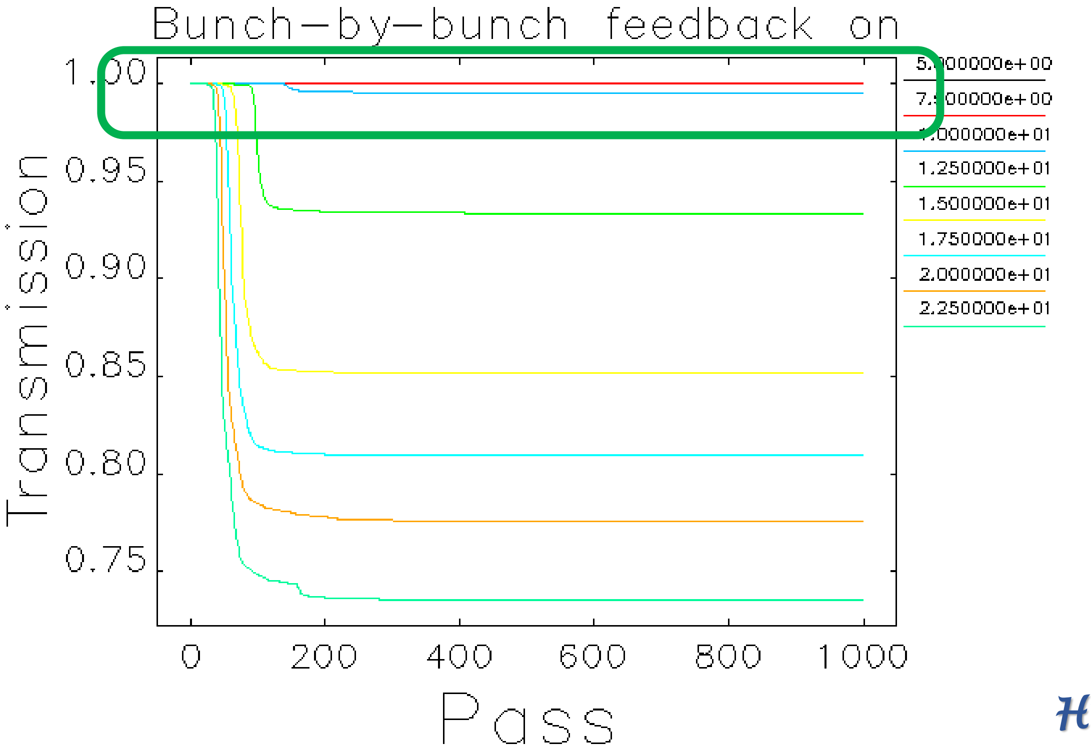

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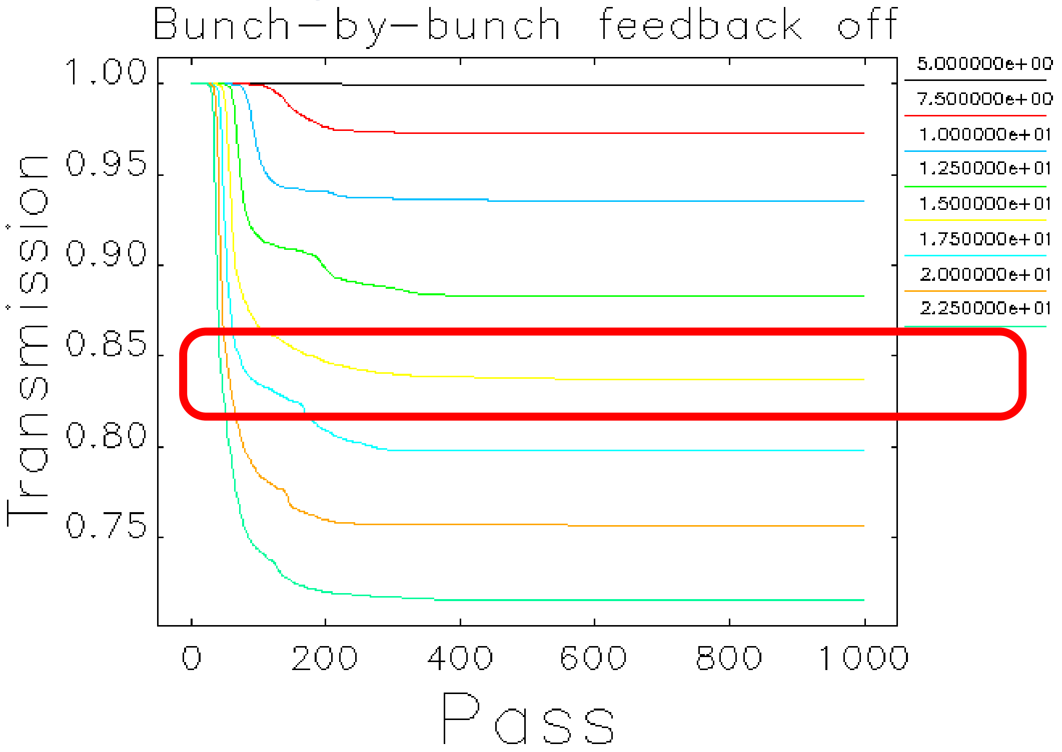

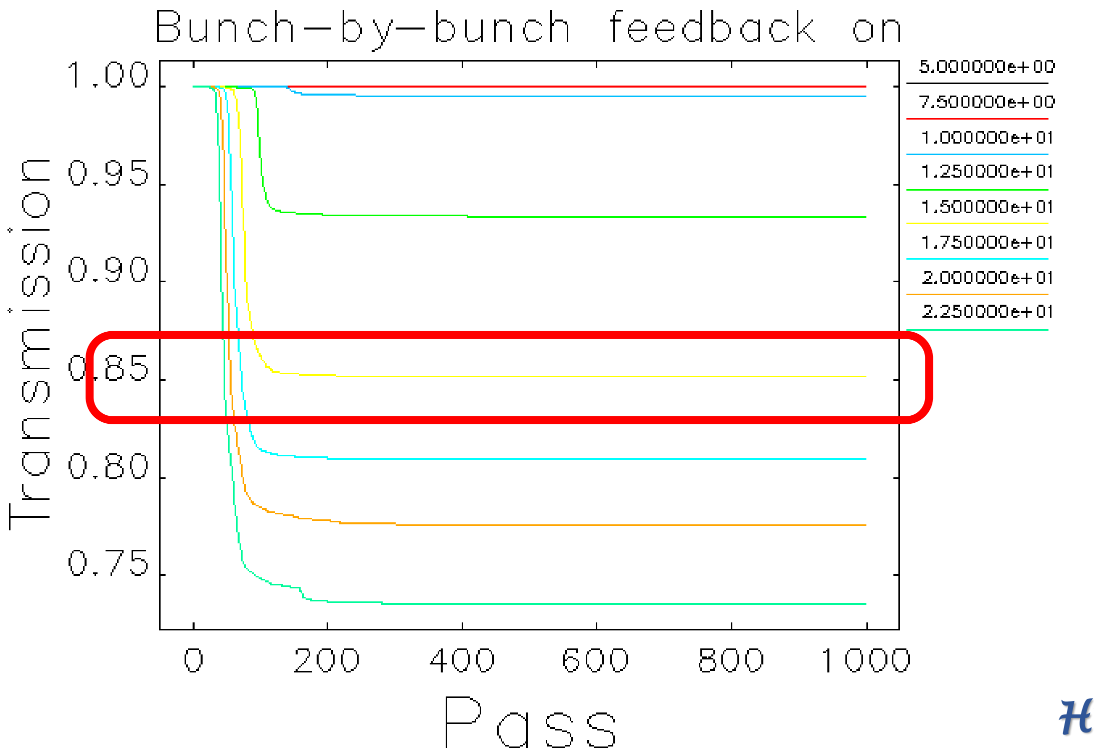

Fast-Beam Ion Instability

- Analytic estimations have been carried out by assuming different beam currents and different vacuum pressures:
  - $\tau_y \approx 18$ ms

$y \ll \sigma_y$

$$\frac{1}{\tau_e} \approx \frac{1}{\tau_c}\frac{c}{4\sqrt{2}\pi L_{sep} n_b a_{bt} f_i}$$

$y \gg \sigma_y$

$$\frac{1}{\tau_H} \approx \frac{1}{\tau_c}\frac{c}{2\pi f_i L_{sep} n_b^{3/2}}$$

$$\frac{1}{\tau_c} = \frac{4 d_{gas}\sigma_{ion}\beta N_e^{3/2} n_b^2 r_e r_p^{1/2} L_{sep}^{1/2} c}{3\sqrt{3}\gamma\sigma_y^{3/2}\left(\sigma_y+\sigma_x\right)^{3/2} A^{1/2}}$$

T.O. Raubenheimer and F. Zimmermann, Fast Beam-Ion Instability I: Linear Theory and Simulations, SLAC-PUB-6740, Phys. Rev. E, Vol. 52, 5, pp. 5487–5498 (1995).
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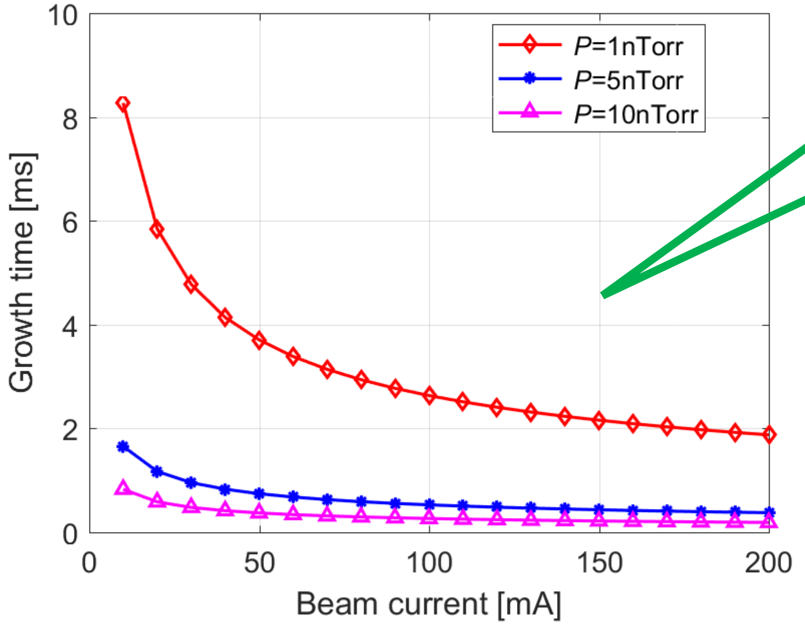

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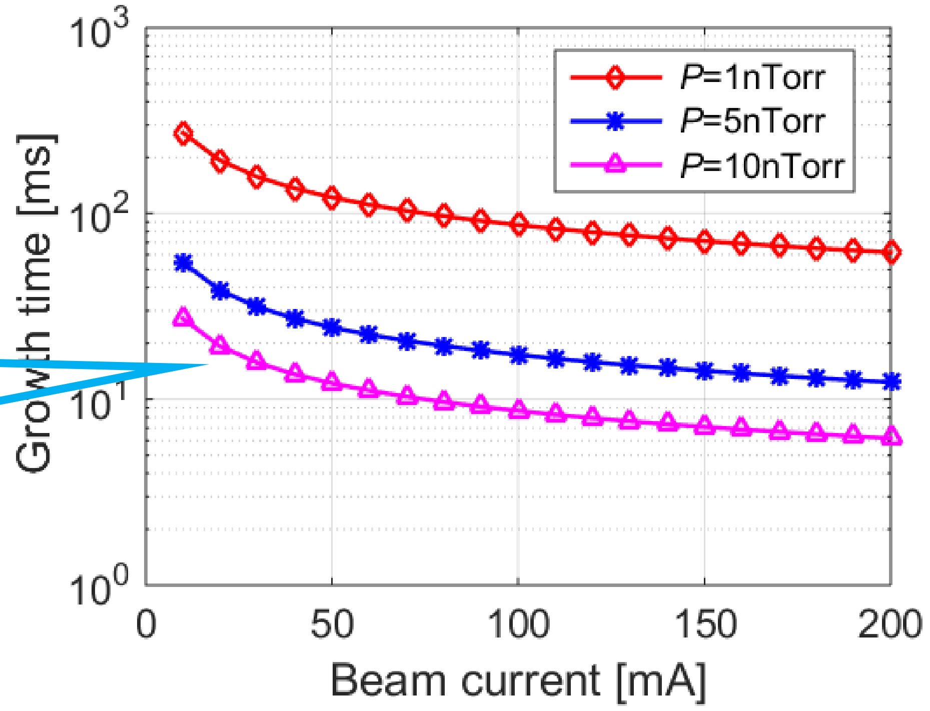

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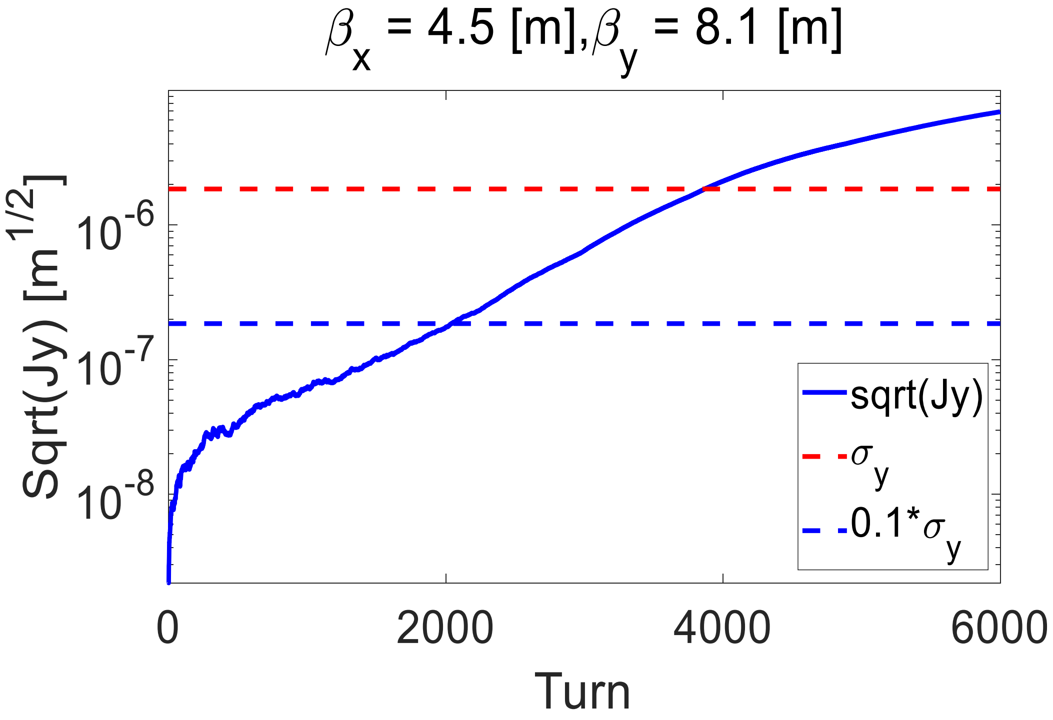
Fast-Beam Ion Instability

- Simulation by implementing weak-strong model:
  - 200 mA, 680 continuous bunches;
  - 'weak' : each electron bunch is represented as 1 macroparticle;
  - 1 nTorr;
- Bunch-by-Bunch feedback system is foreseen to cure the FBII.



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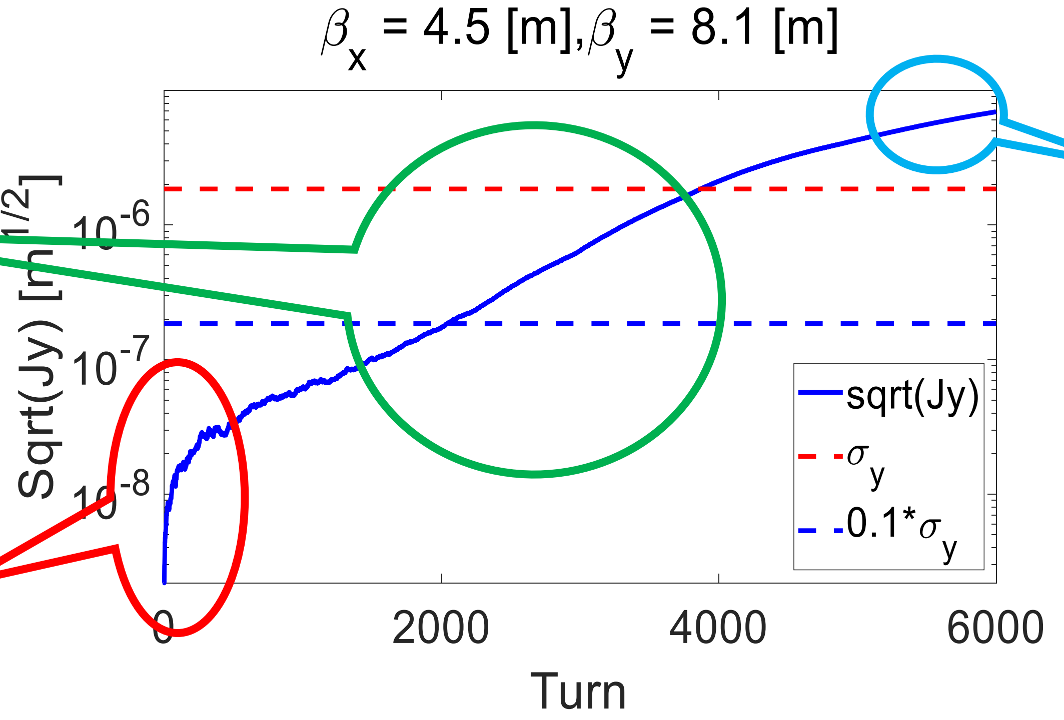


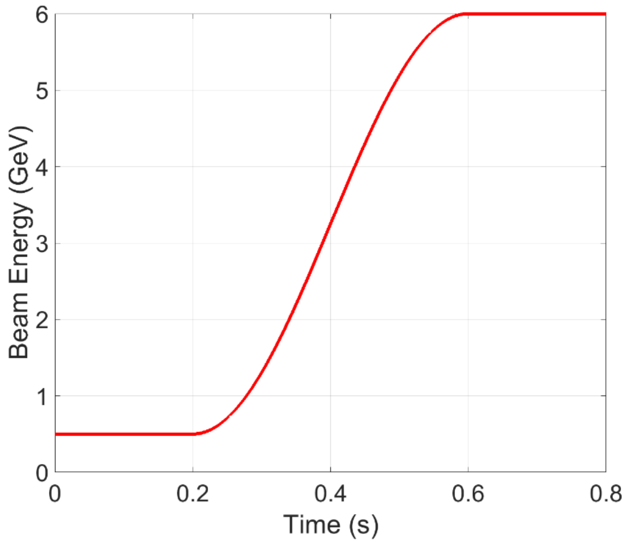
Exponential growth
$\tau \approx 4$ ms

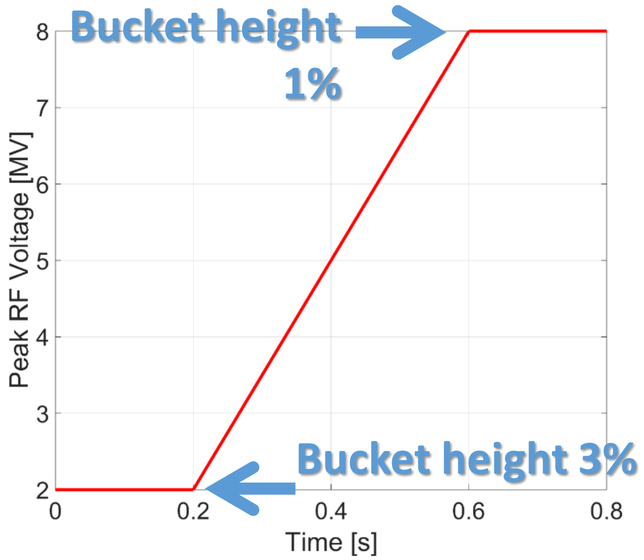
Growing slower than exponential growth

Growing faster than exponential growth

Charge Limit for the HEPS Booster

- The requirement of high single-bunch charge increases the risk of particle loss in the booster.
- Transverse single-bunch instability is what we pay much attention here.
- The proposed ramping process is based on the the idea of multi-bunch operation in the booster.
  - 499.8 MHz RF cavity
    - V_{peak}= 2MV @ 500 MeV
    - V_{peak}=8 MV @ 6 GeV
  - Ramping curve:
    - 200ms @ 500MeV for injecting the LINAC beam to the booster
    - 400ms for energy ramping up to 6GeV
    - 200ms@6GeV for beam re-injection and extraction
    - 200ms for energy ramping down to 500 MeV

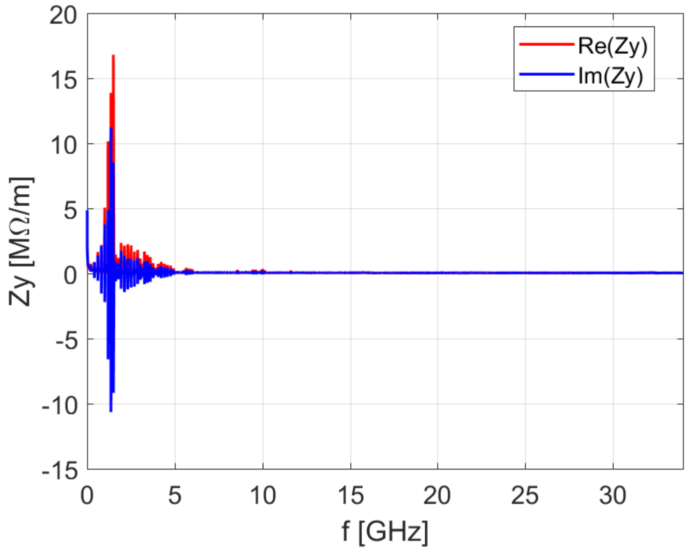




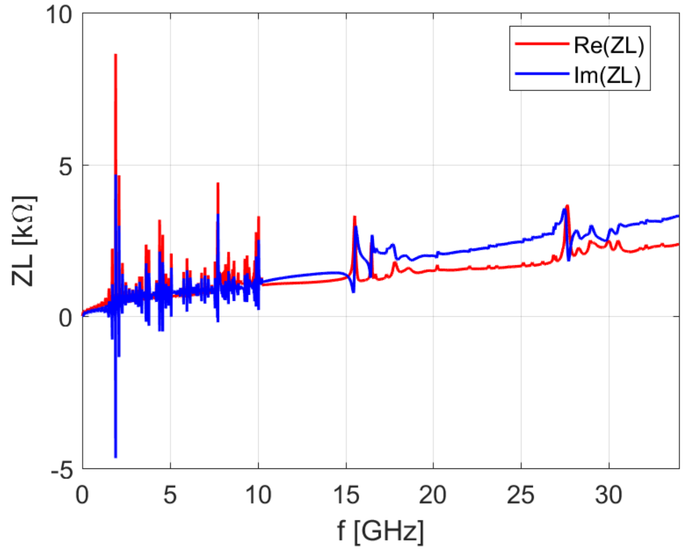
Impedance Modeling

- A preliminary impedance budget including many key components, has been created for the HEPS booster.
- Update of the impedance model is still on-going since the more detailed engineering designs of components is on-going.

Contribution	**$Z_{\parallel}/n$ [mΩ]**	**k_l [V/pC]**	**k_y [V/pC/m]**
Resistive Wall	101.1	1.9	736
RF cavities	-12.8	10.1	80.0
Flanges	17.0	5E-5	60.5
Bellows	11.8	7E-4	42.0
BPMs	9.5	0.03	33.5
Kickers (Inj & Ext)	-2.4	0.6	186.2
Total	**124.2**	**12.6**	**1138.2**

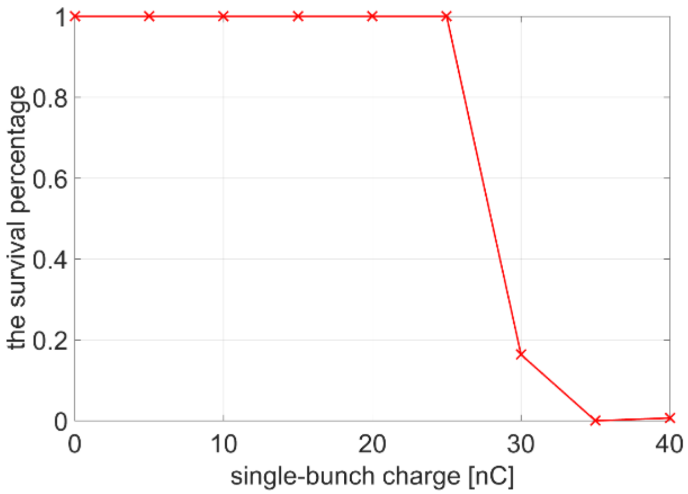


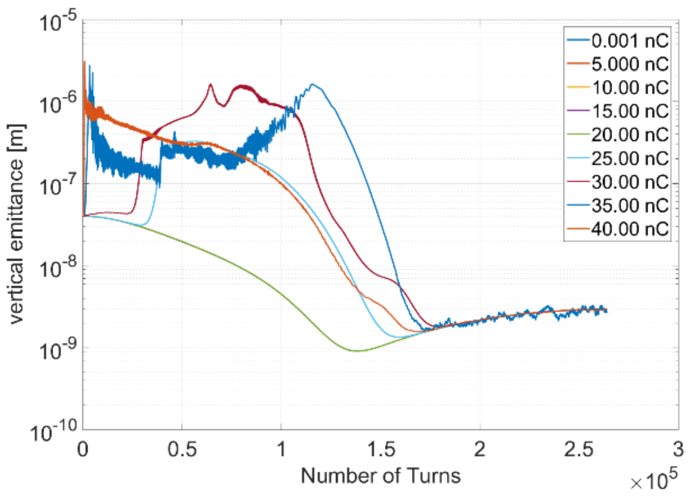
Transverse Impedance

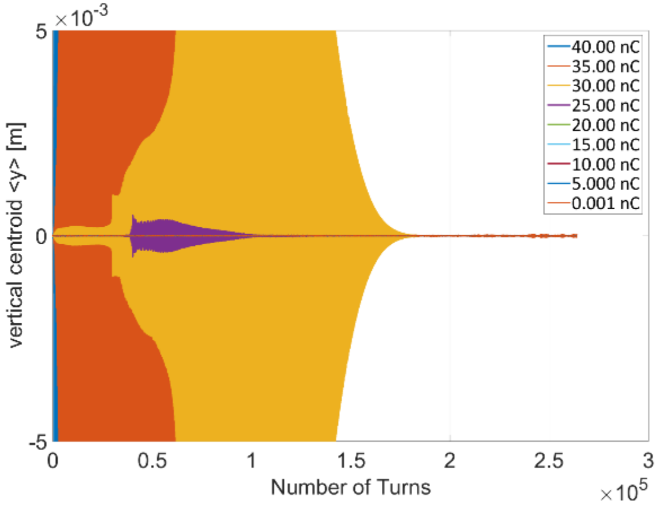


Longitudinal Impedance

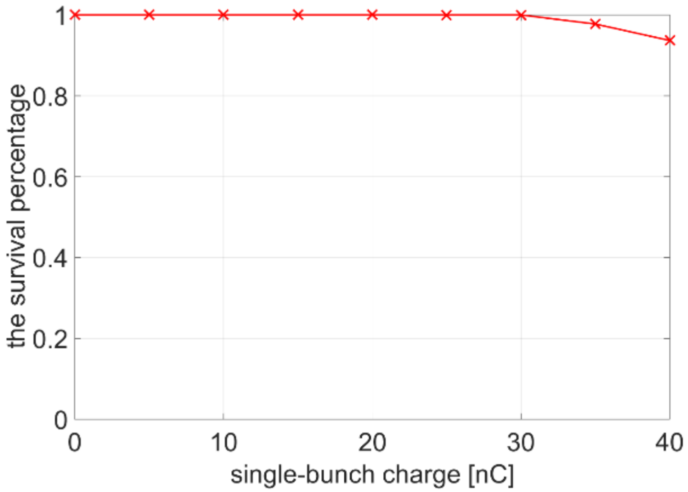
Transverse Single-Bunch: Ramping, Chromaticity

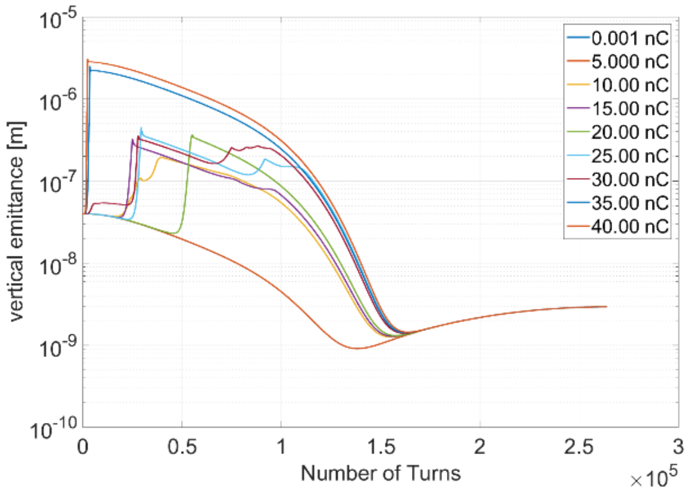


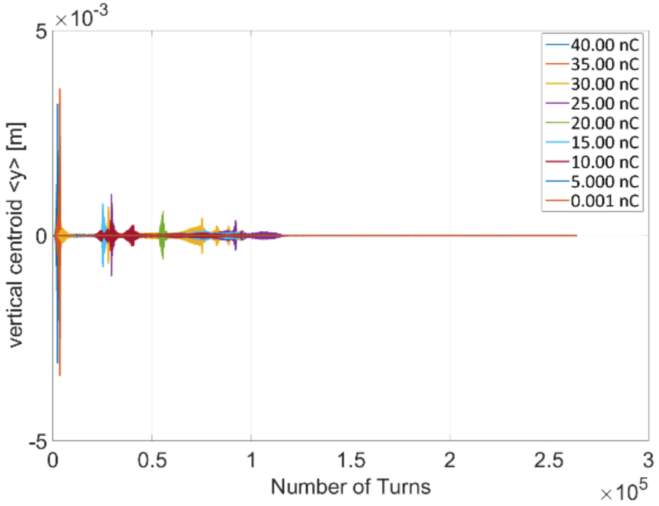




$\xi_y = 0$







$\xi_y = +1$

Transverse Single-Bunch: Ramping, Chromaticity

- The one-turn map is now used in the tracking of the booster.
- The blow-up of beam size happens at about the injection energy.
- The beam is getting more stable as the energy ramps.
- Landau damping introduced by the nonlinearities of the booster lattice help significantly stabilize the beam, especially at low energy.
- In the next step, more detailed element-by-element tracking is planed.

Summary & Outlook

- Most of the work is still on-going.
- Transverse single-bunch instability in the HEPS storage ring has been studied under the condition w/ (+5,+5) chromaticity and w/ 3rd harmonic cavity. The threshold current is high enough. However, the beam blow-up right after injection needs careful study.
- Preliminary study of the transient effect after injection shows that this effect strongly limits the single-bunch charge. Further systematic studies are needed.
- The proposal of high-charge operation in the storage ring and the idea of implementing swap-out injection scheme introduces difficulty to the charge limit in the booster.
- Systematic studies of the transient effects after injection are needed.

Thank you for your attention!