Beam-Beam Effects at CEPC

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CEPC Workshop, Nanjing

Oct. 23, 2023

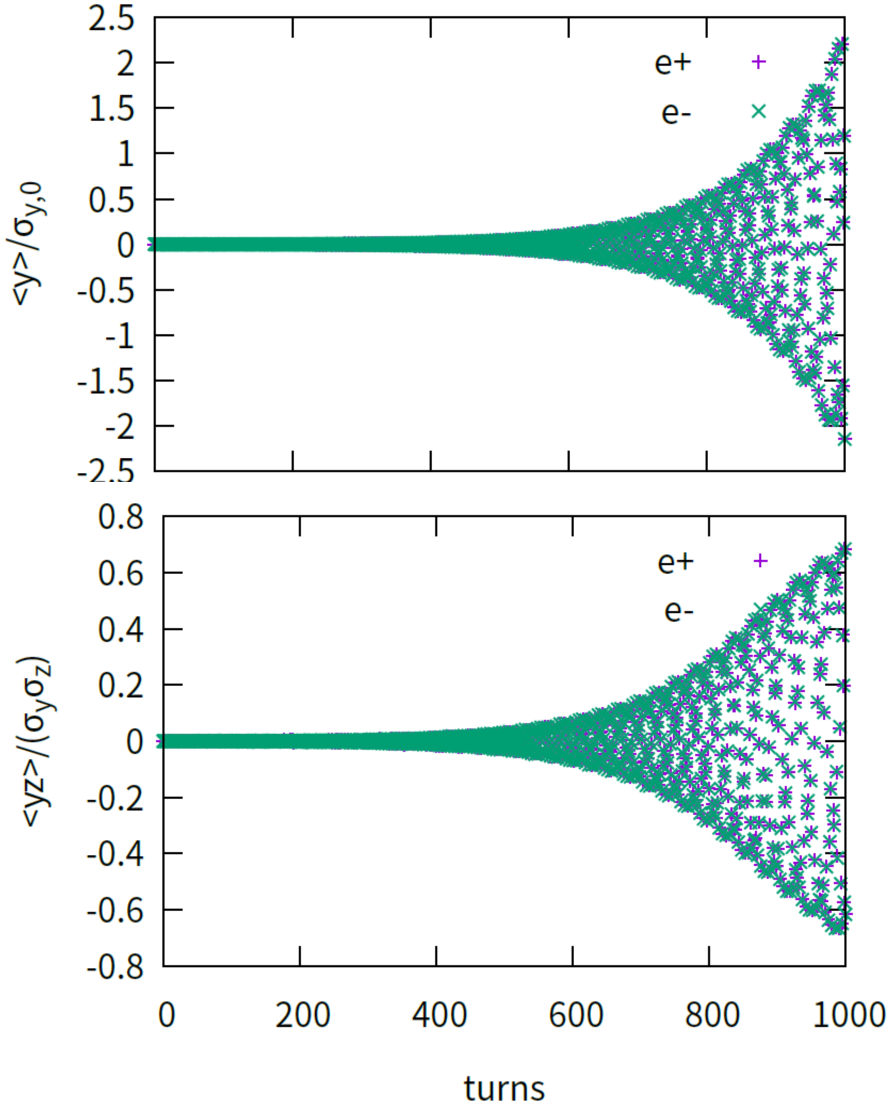
Thanks:
Na Wang, Zhiyuan Li, Kazuhito Ohmi(KEK), Chuntao Lin (IASF), Demin Zhou(KEK), M. Zobov(INFN/LNF)
M. Migliorati, D. Shatilov, K. Oide

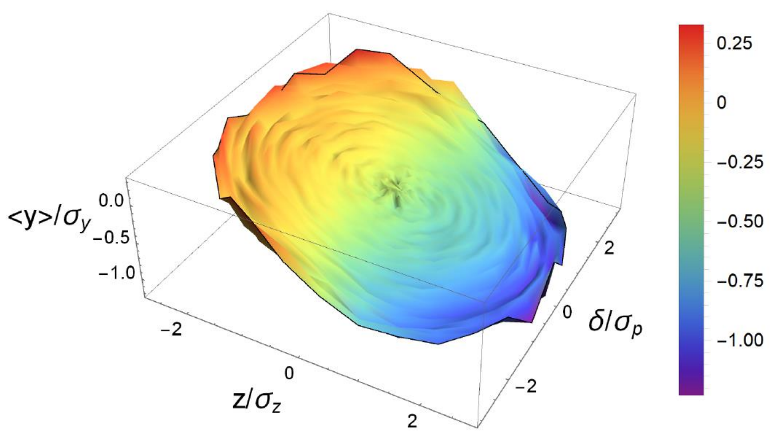
Outline

- Vertical Instability
  - TMCI
  - Resistive Feedback (chromaticity)
  - Hourglass Effect (chromaticity)
- Horizontal Instability
  - Chromaticity
  - Local ZT
  - Resistive Feedback
- Strong-Strong Simulation with Lattice
- Summary

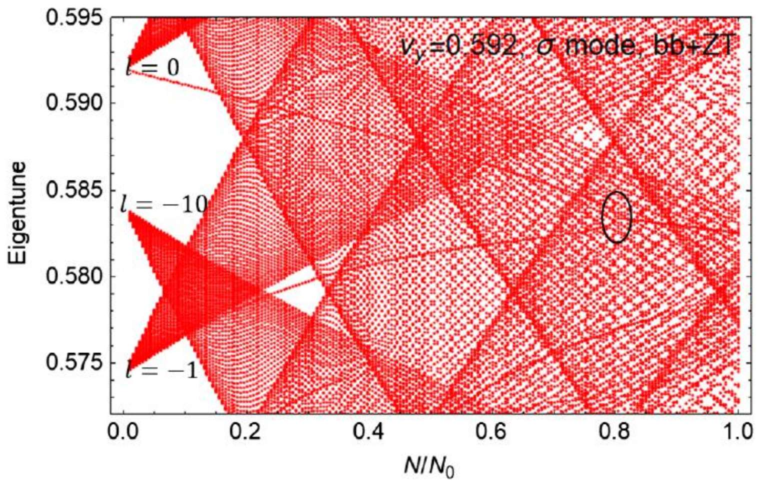
Y. Zhang et al., PRAB 26, 064401 (2023)

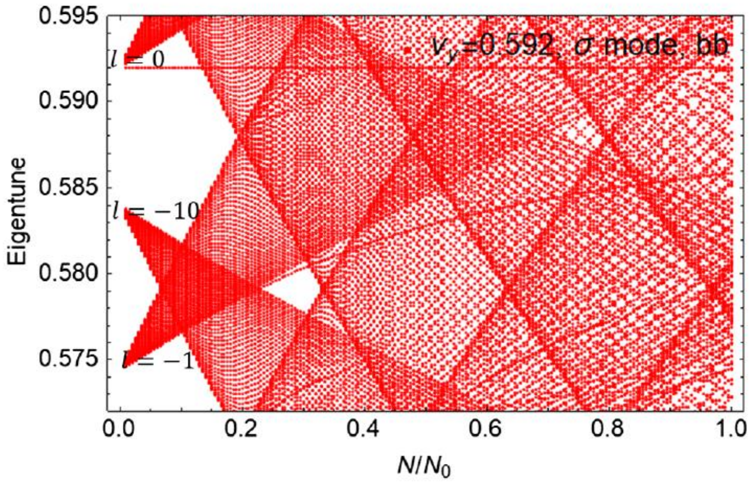
Vertical mode coupling with ZT($\boldsymbol{\sigma}$-mode)





TMCI threshold is reduced from about 21e10 to 11e10

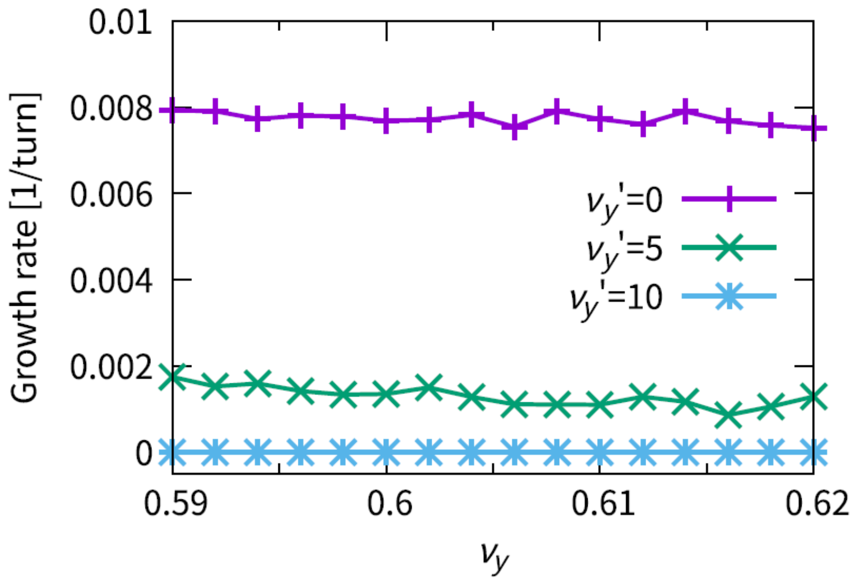




Y. Zhang et al, PRAB 26, 064401 (2023)

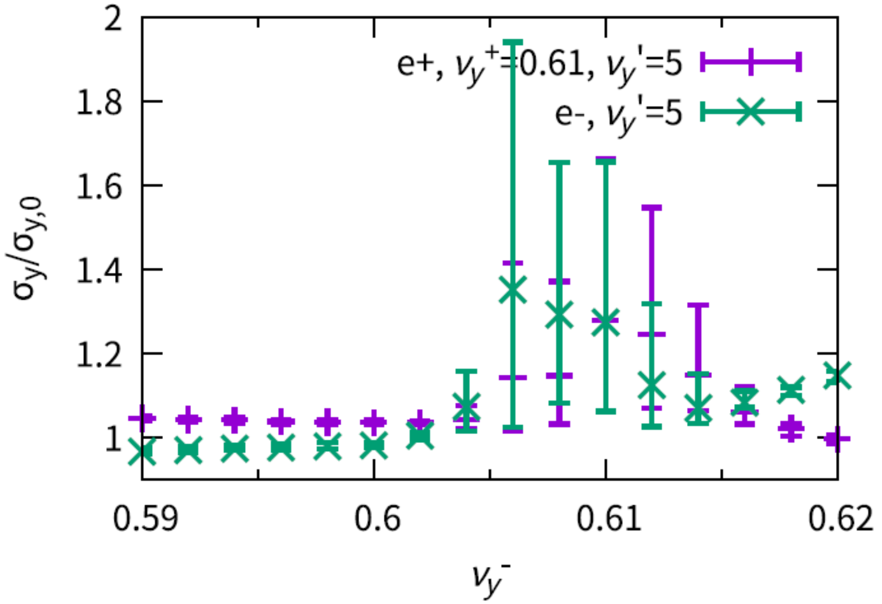
Mitigation of Vertical TMCI (BB+ZT)

Chromaticity



Growth rate of vertical centroid versus tune with different vertical chromaticity. Both transverse and longitudinal impedance are considered.

Asymmetrical Tunes + Chromaticity



vertical beam size versus asymmetric vertical tunes with different vertical chromaticity. Both transverse and longitudinal impedance are considered. One beam’s vertical working point is fixed at 0.610.

Could expected strong damper help? (Off-collision)

- Thanks: M. Zobov, M. Migliorati

Y. Zhang, HK-IAS, 2023

CEPC-EU-WORKSHOP

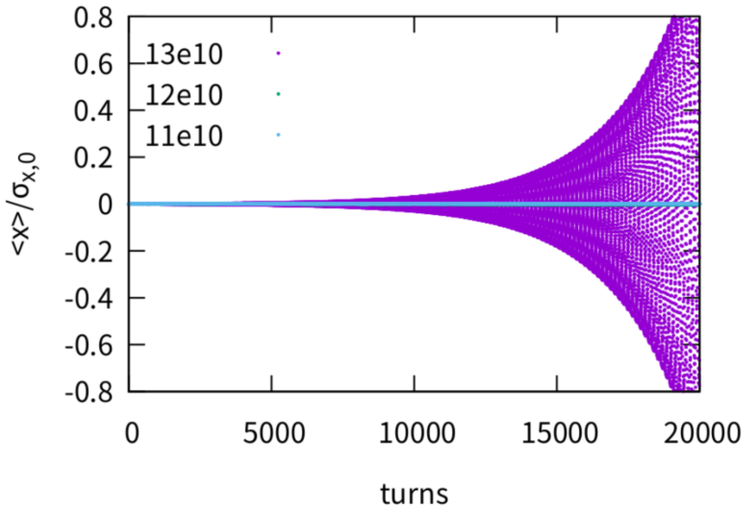
$\nu_s = 0.0176$

A simplified resistive damper is used:

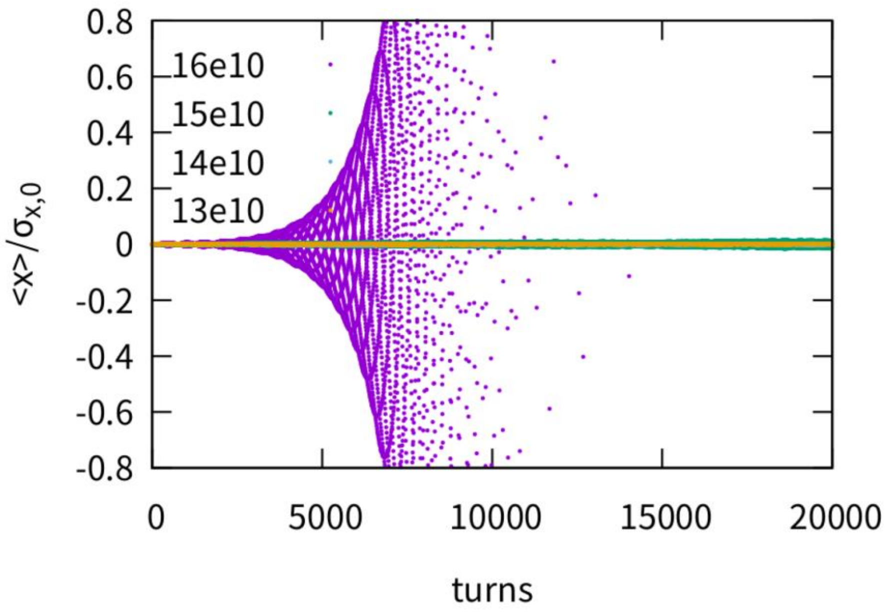
$$\Delta p_i = -2d_p p_i$$

It is found stronger damper reduce the TMCI threshold.

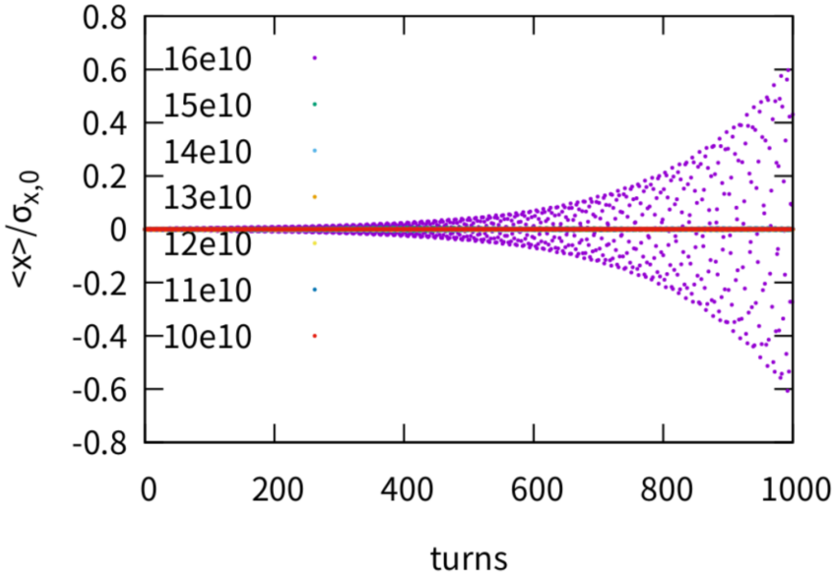
- **Dp=0.1**, threshold ~ 12e10.



- **Dp=0.01**, threshold ~ 15e10.



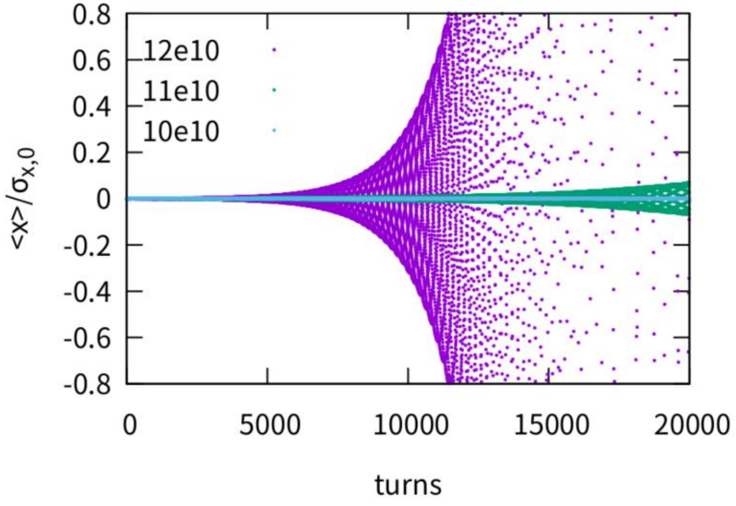
- **Dp=0**, threshold ~ 15e10.



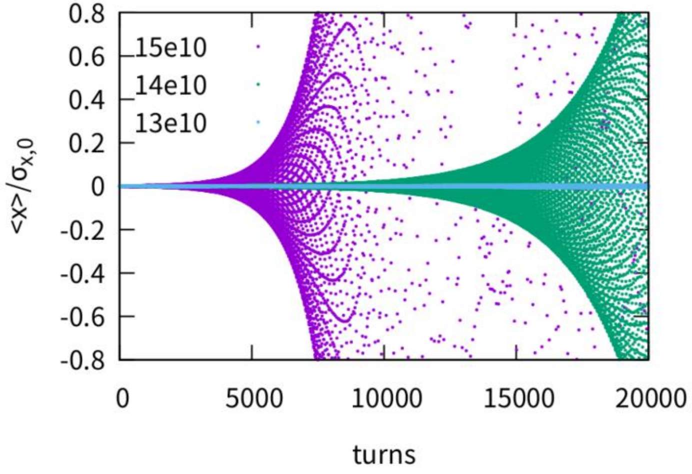
Resistive damper + Qx’=5 (w/o collision)

Qx’=5: instability threshold increase with the damper strength

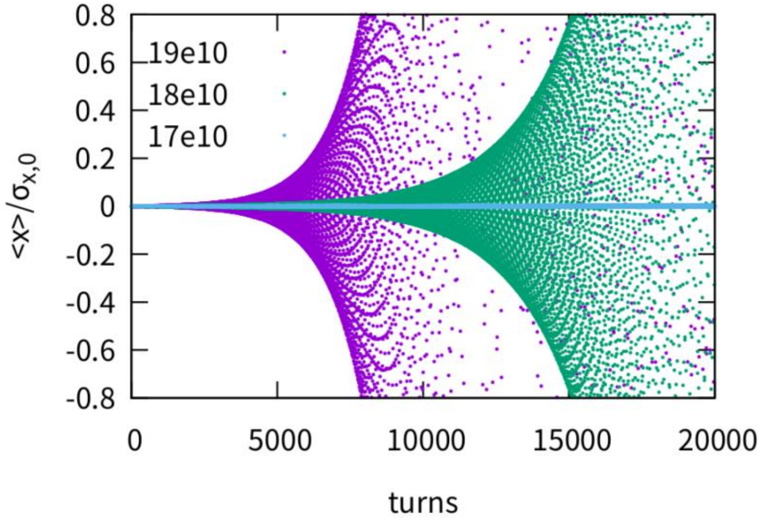
Dp=0.01, threshold~10e10



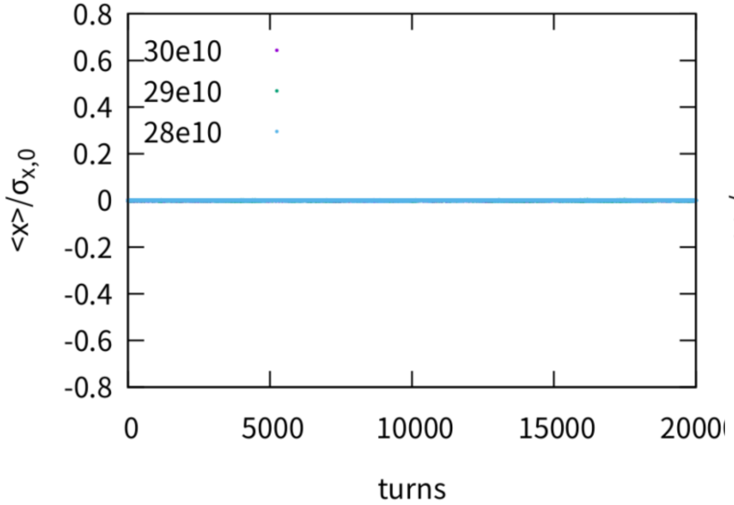
Dp=0.02, threshold~13e10

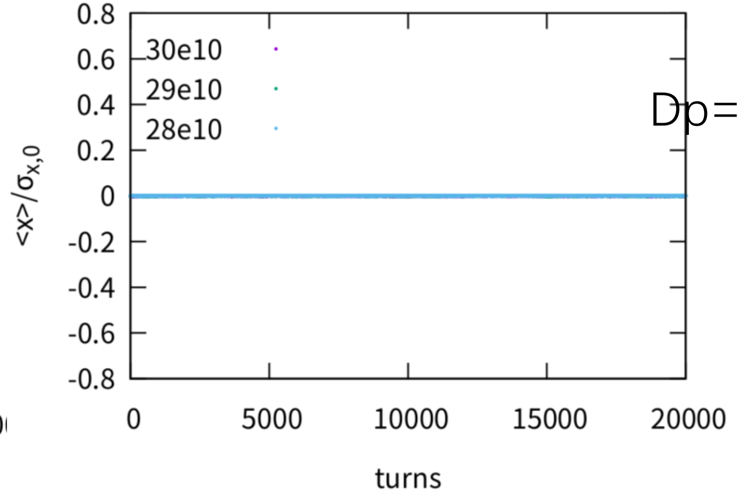


Dp=0.03, threshold~17e10



Dp=0.04, threshold~30e10



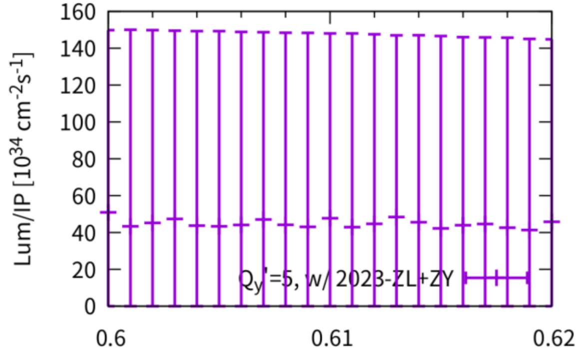


Dp=0.05, threshold~30e10

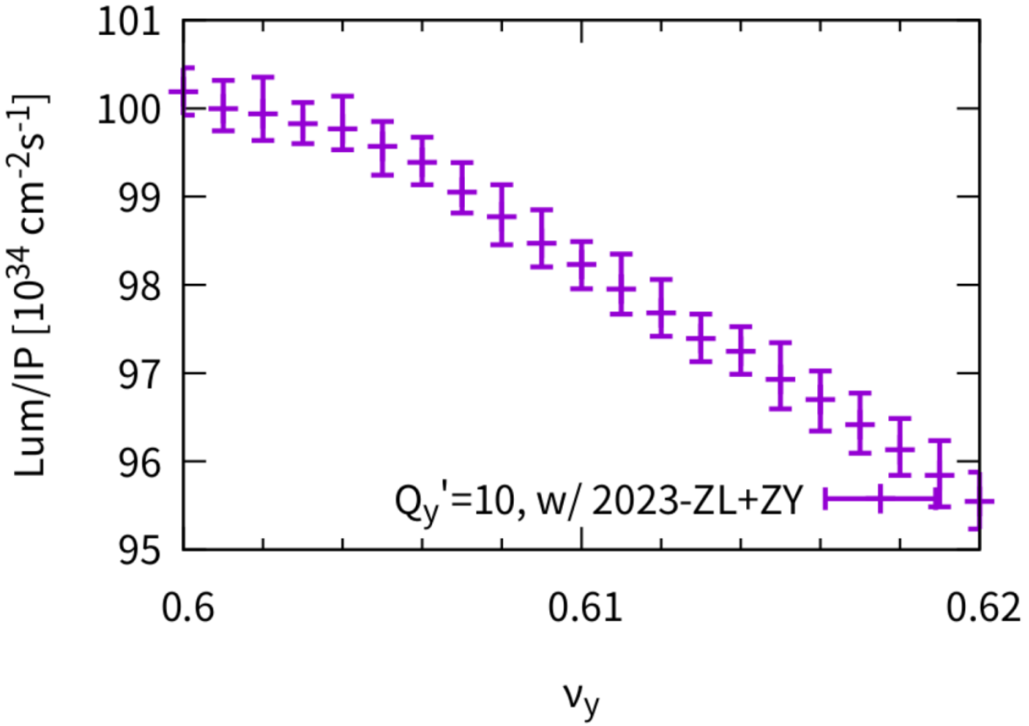
2023-impedance

ZY+ZL, resistive damper dp=0.05

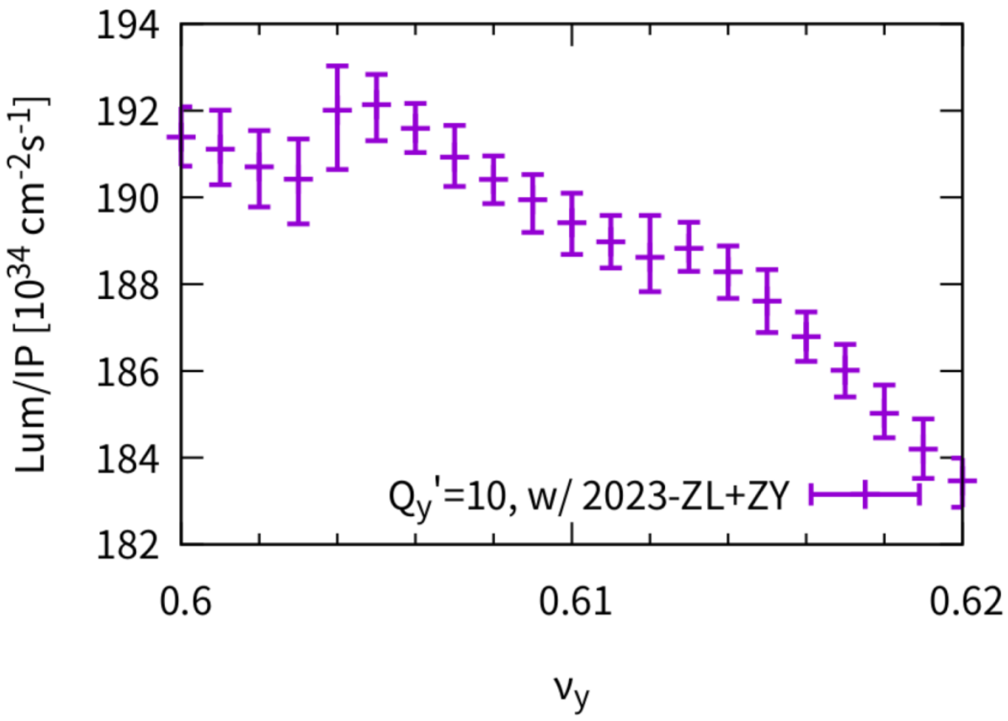
Np=14e10, **Qy'=5 unstable**



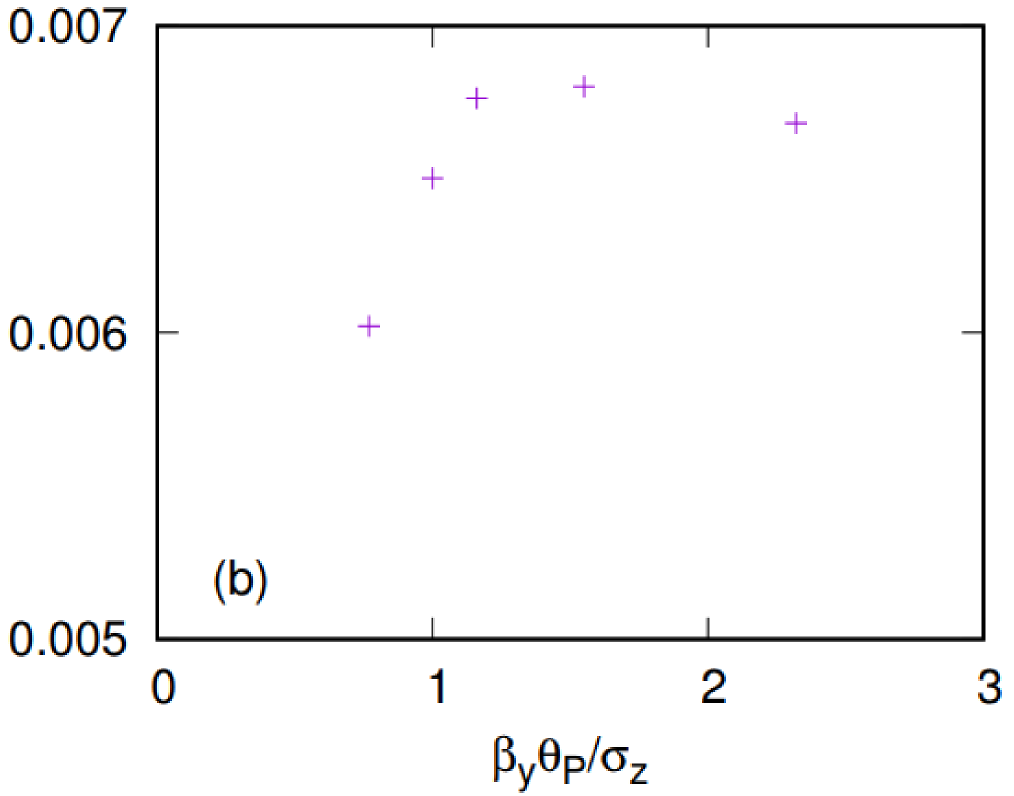
- Np=14e10, Qy'=10 is stable



- Np=21e10, Qy'=10,50MW (stable)



More measures to suppress vertical TMCI



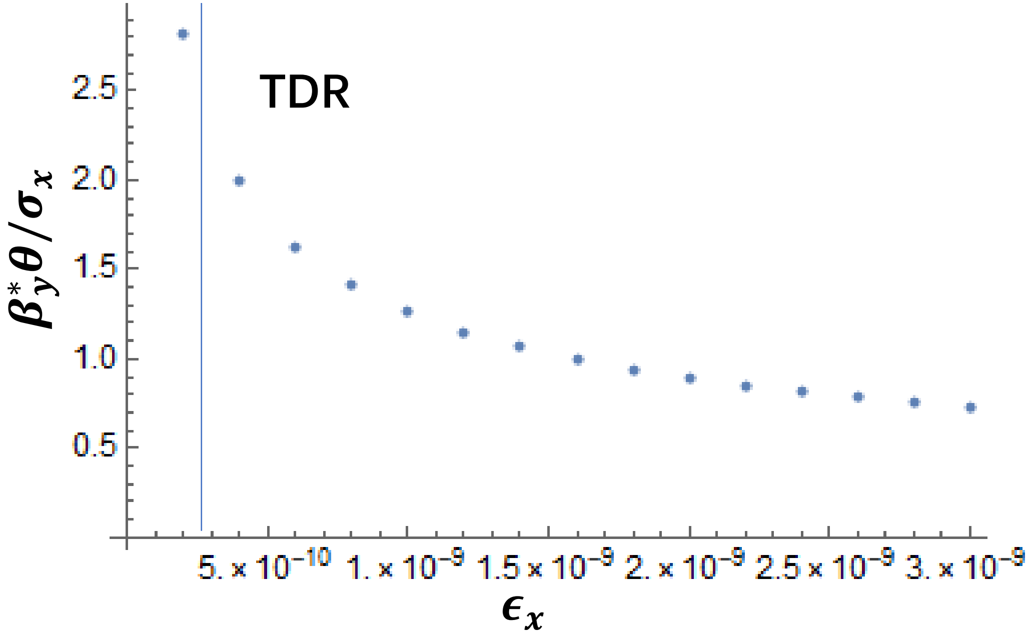
$$\theta_\beta \equiv \beta_y^* \theta_P / \sigma_z$$

Hourglass effect

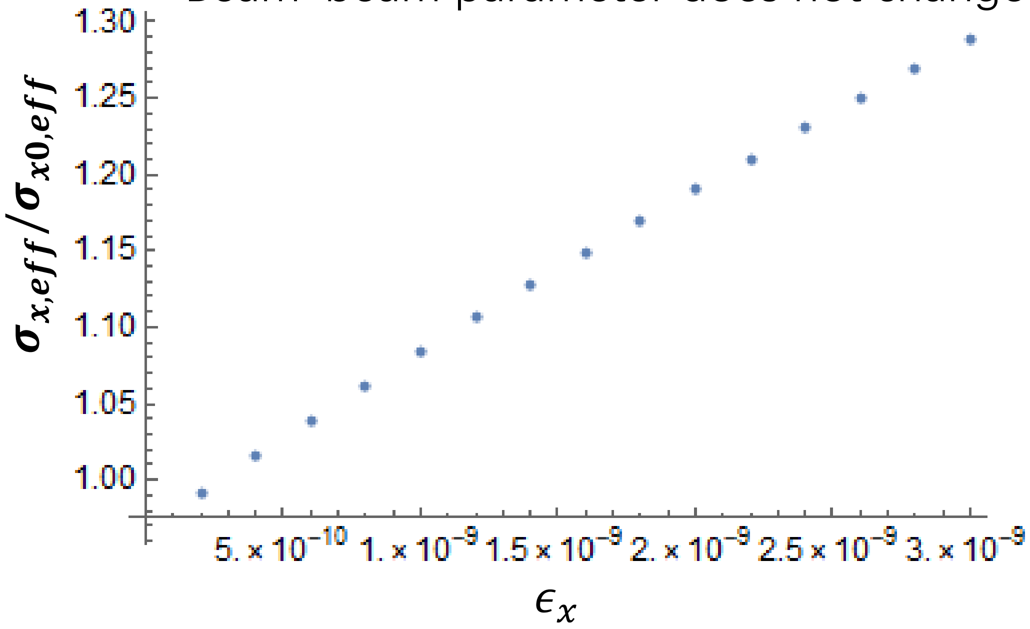
- $\beta_y^* < \sigma_x/\theta$ (K. Ohmi)

Simulation study of Hourglass effect

- Beamstrahlung off (sigmaz = 9.6mm, sigmap= 1.36e-3)
- Only tuning the horizontal emitx (**TDR: emitX = 0.27 nmrad**)
  - Effective sigmax nearly constant ($\beta_x^* = 0.13$ m)
  - $\sigma_{x,eff} = \sqrt{\sigma_x^2 + \sigma_z^2\theta^2}$



Beam-beam parameter does not change clearly

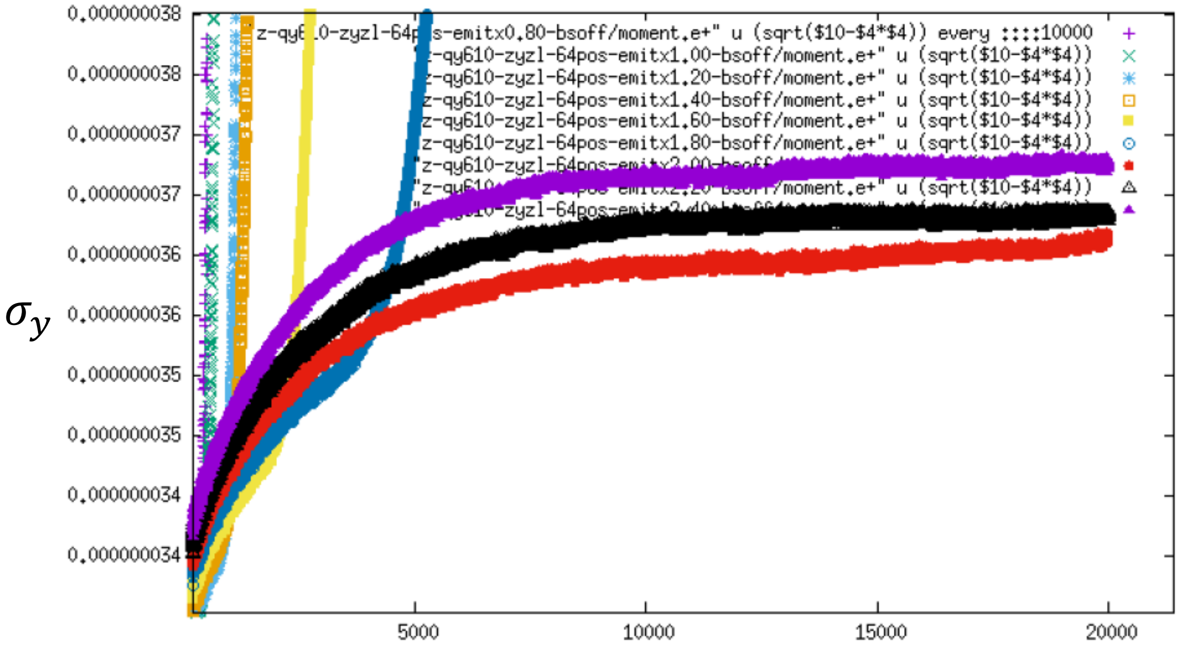


2023-impedance

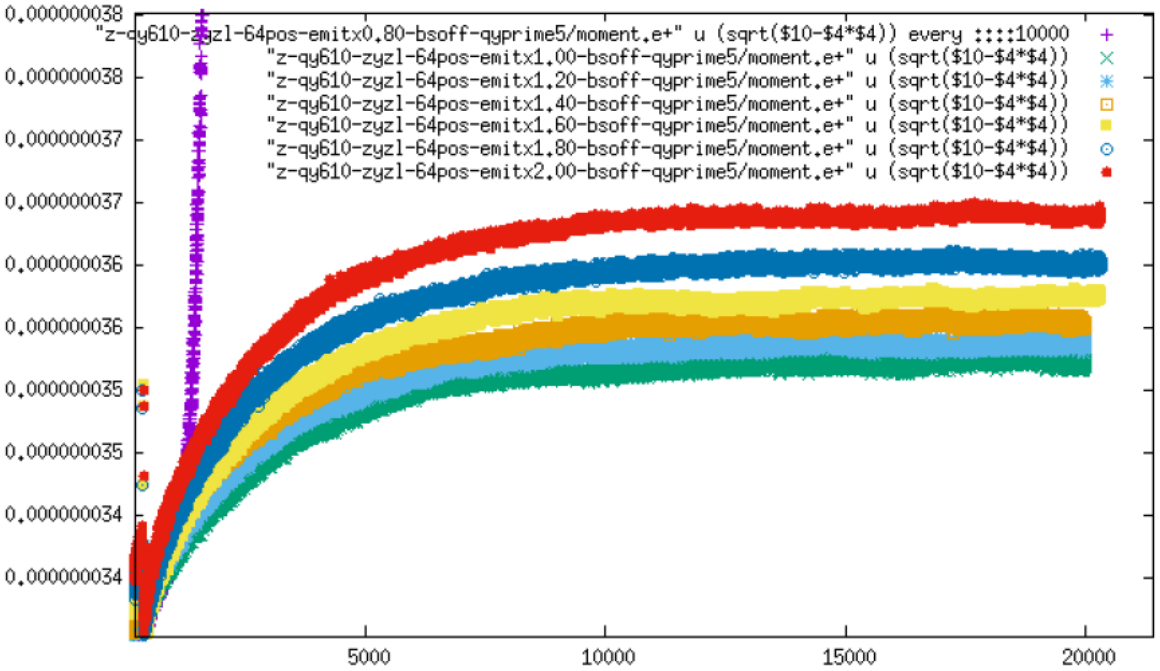
Chromaticity + Hourglass effect

REMINDER:
higgs, emitx = 0.64 nmrad
W, emitx = 0.87 nmrad
ttbar, emitx = 1.4 nmrad

Qy'=0,
Threshold: emitx = **2.0** nmrad, stable,
where $\frac{\beta_y^*\theta}{\sigma_x} = 0.89$



Qy'=5,
Threshold: **emitx = 1 nmrad** stable,
where $\boldsymbol{\beta_y^*\theta/\sigma_x} \approx \mathbf{1.26}$



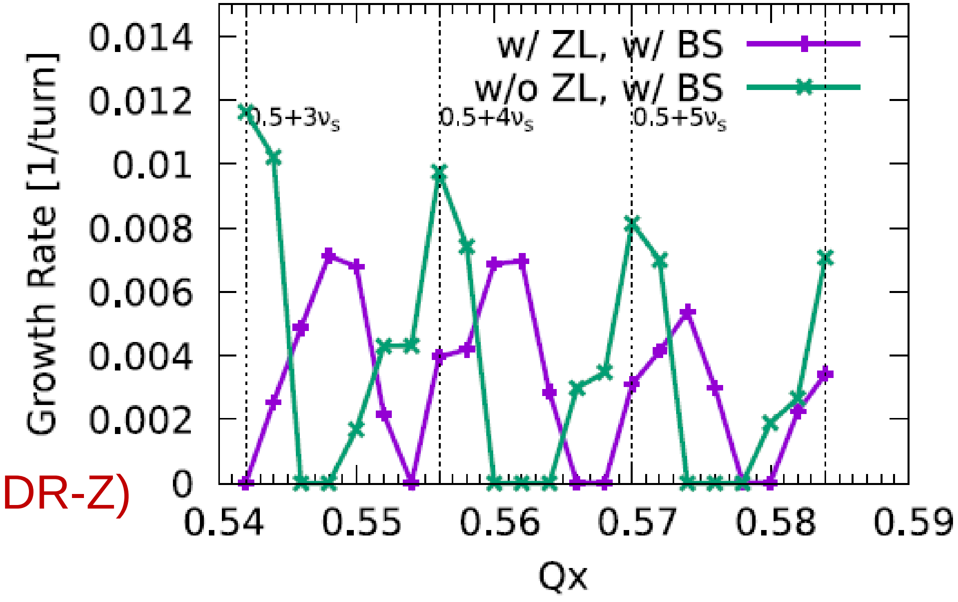
- X-Z instability

K. Ohmi and et al., PRL 119, 134801 (2017)
N. Kuroo et al, PHYS. REV. ACCEL. BEAMS 21, 031002 (2018)
Y. Zhang etal., PRAB 23, 104402, (2020)
C. Lin etal.,, PRAB 25, 011001 (2022)

X-Z instability with and without beam coup… e

By including the impedance stable areas become narrower and are shifted

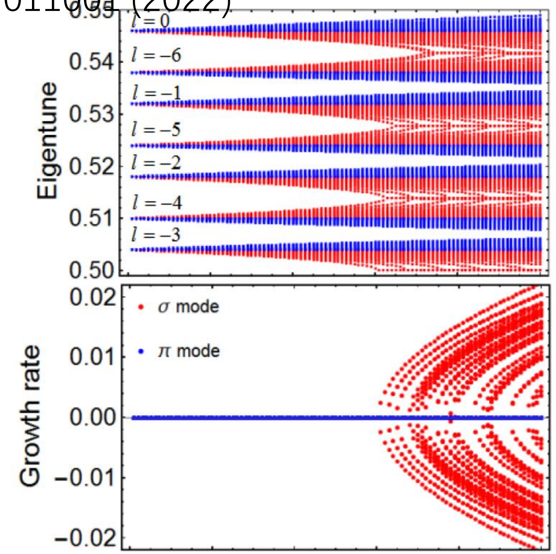
(CEPC-CDR-Z)



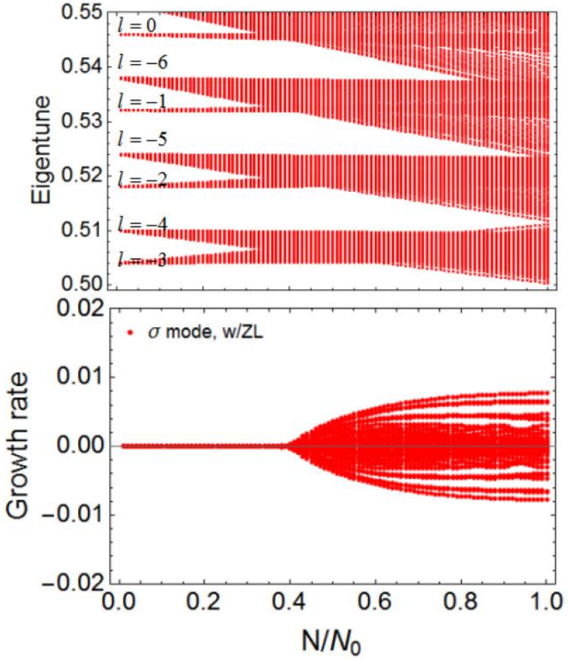
After the horizontal beta function reduction from 0.2 m down to 0.15 m

FIG. 3. The horizontal beam size growth rate versus horizontal tune with and without longitudinal coupling impedance (ZL). Beamstrahlung (BS) effect is turned on.

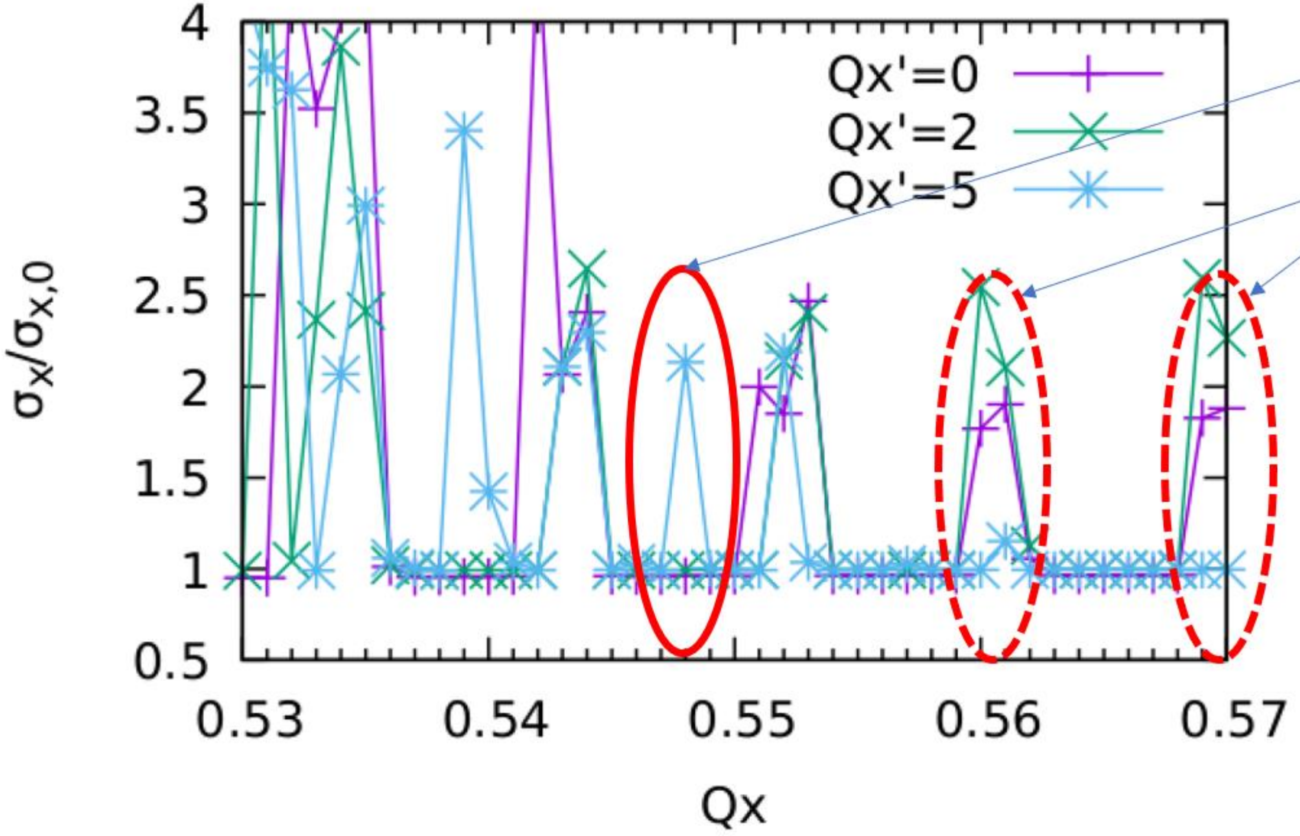
w/o ZL



w/ ZL, σ mode



Chromaticity on X-Z instability at FCCee



- Non-zero tune chromaticity bring new resonance
- In the high order resonance region (0.5+n*nus), some resonance may be suppressed or weakened

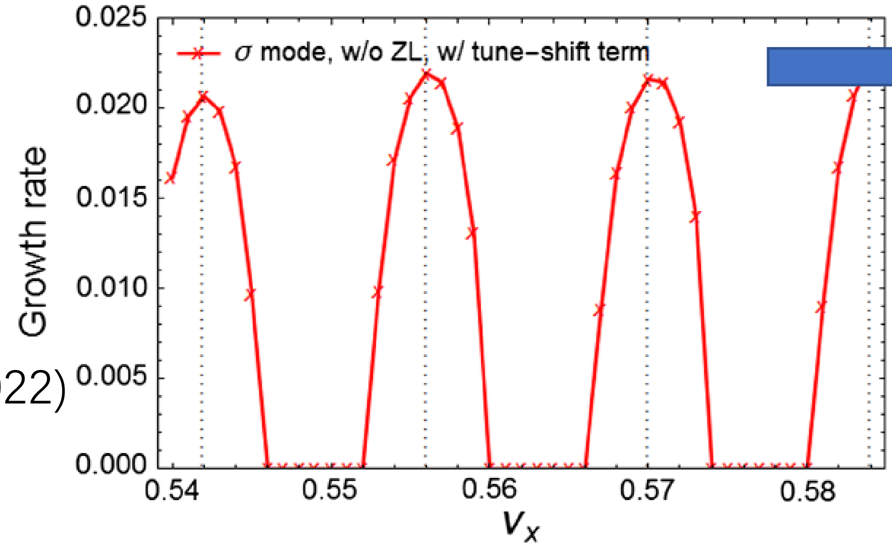
Future work:
- Analysis work considering linear tune chromaticity
- Simulation work considering realistic chromaticity (from lattice model)

FCCee

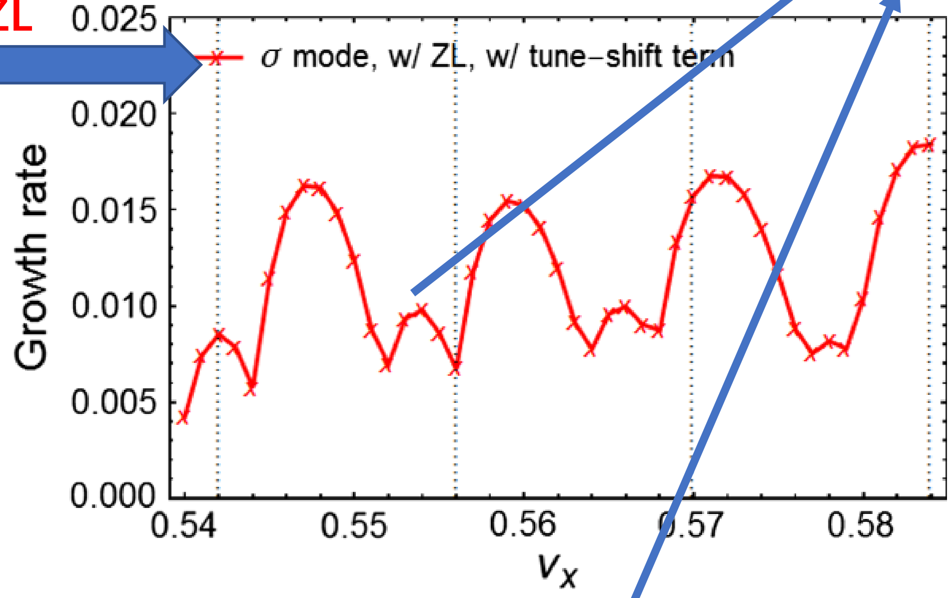
Chromaticity: X-Z instability (w/o ZL)

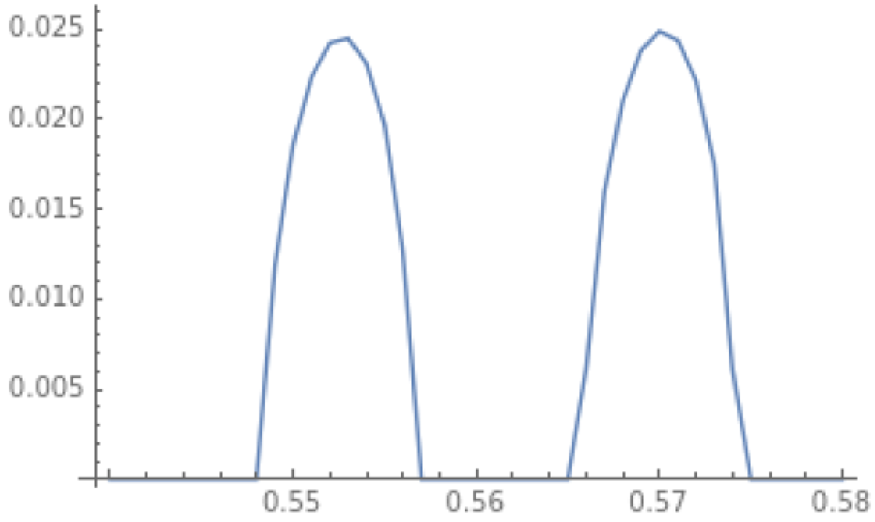
Similar?

C. Lin etal, PRAB 25, 011001 (2022)



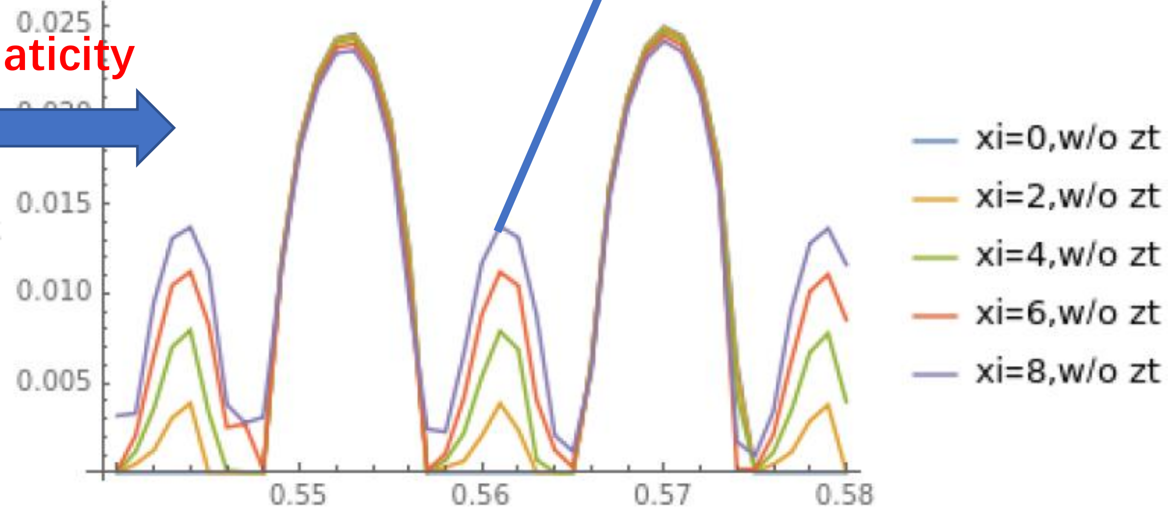
ZL



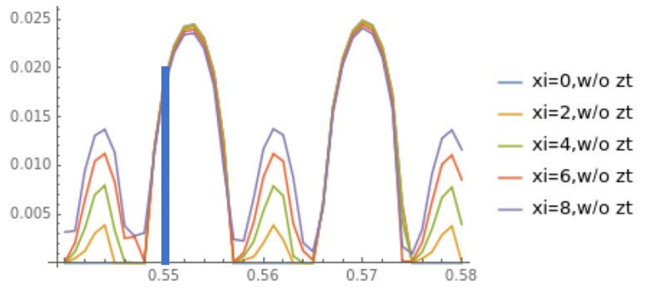


Chromaticity

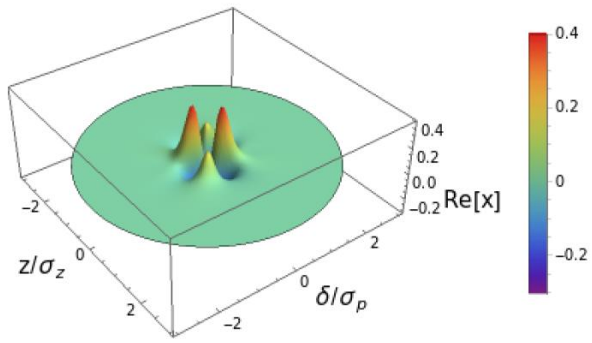
xi=0,w/o

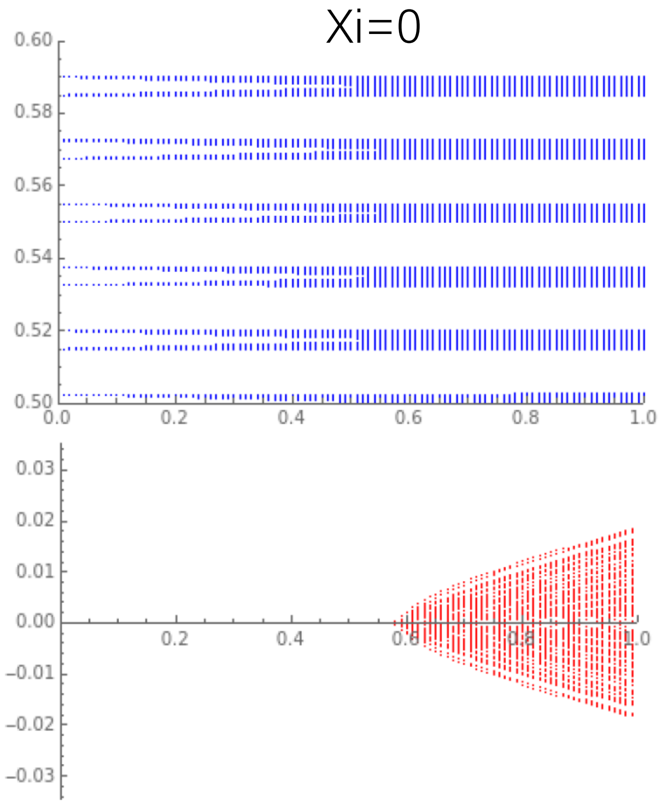


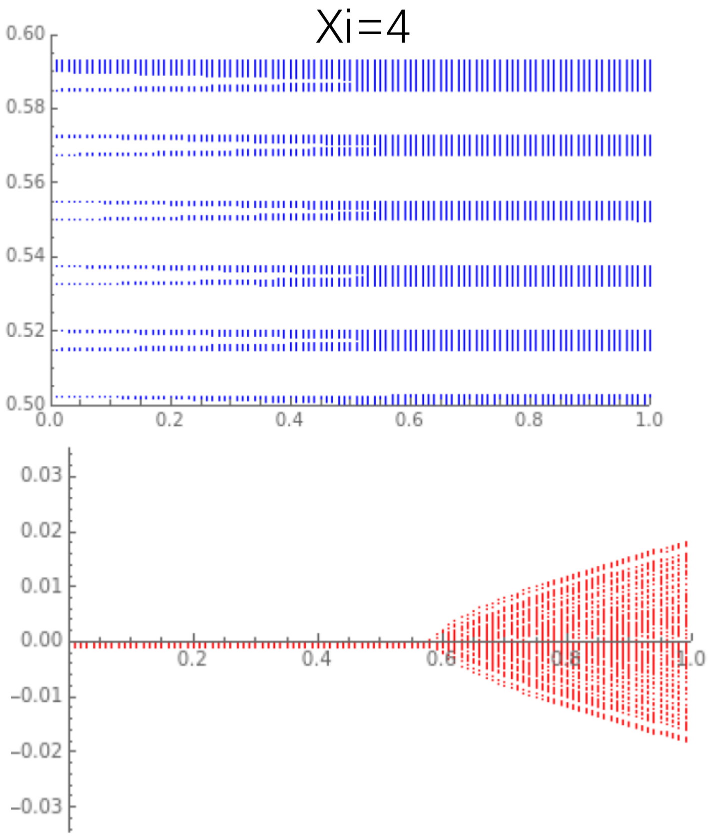
Chromaticity: X-Z instability – w/o ZL Qx=0.55



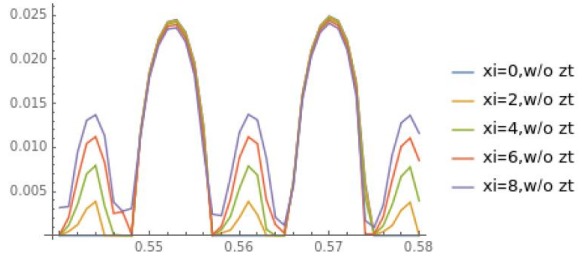
- No clear difference:
  - NP=NP0, Most unstable mode tune: 0.5175 (coupling between l=-2 and l=-4)



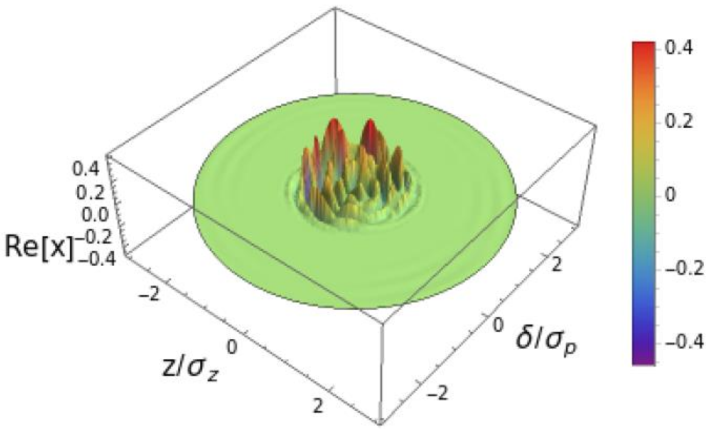


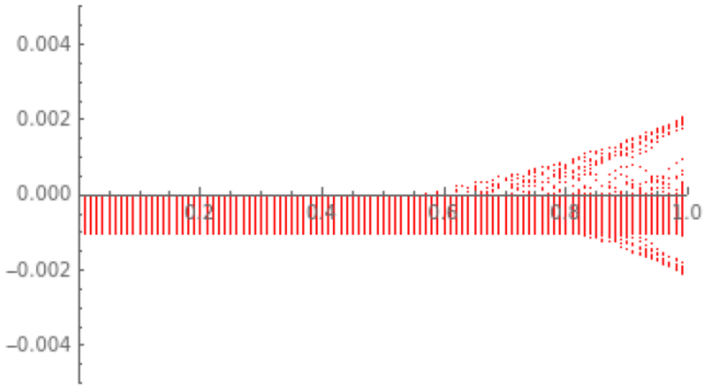


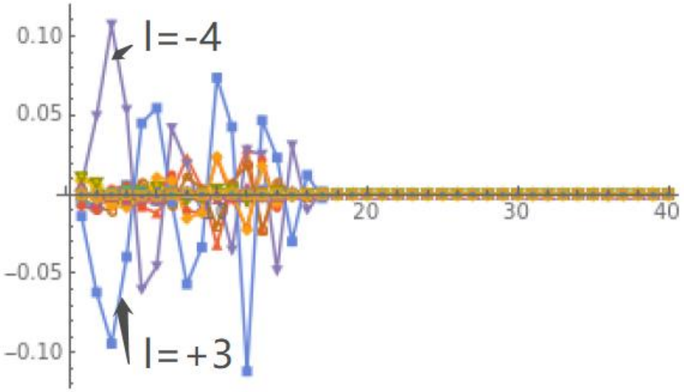
Chromaticity: X-Z instability – w/o ZL Qx=0.559/0.561

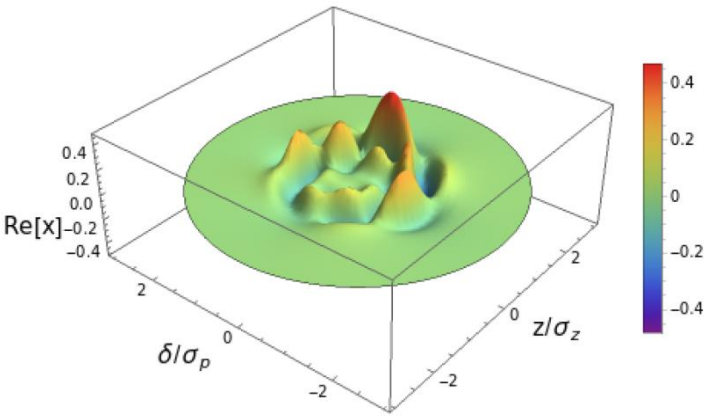


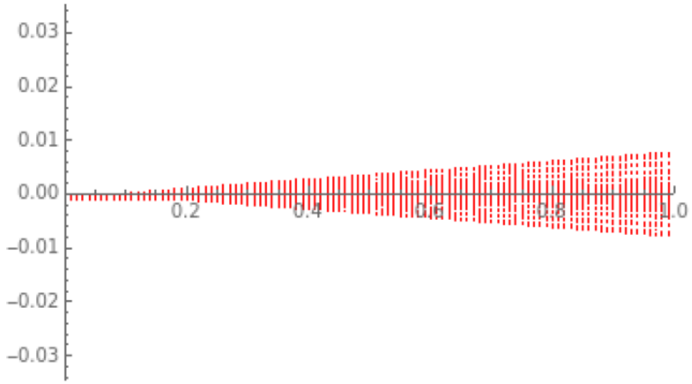
- Does the singular mode would appear in reality?

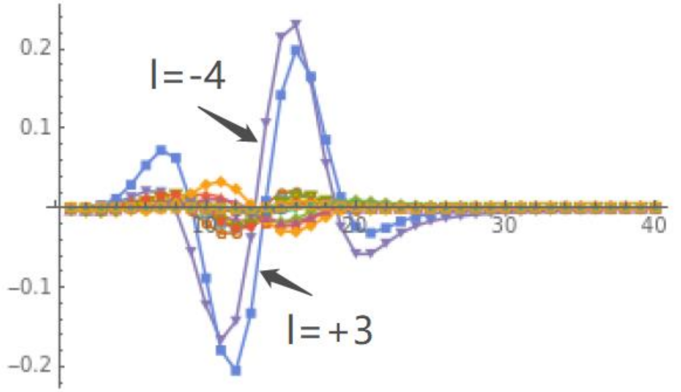










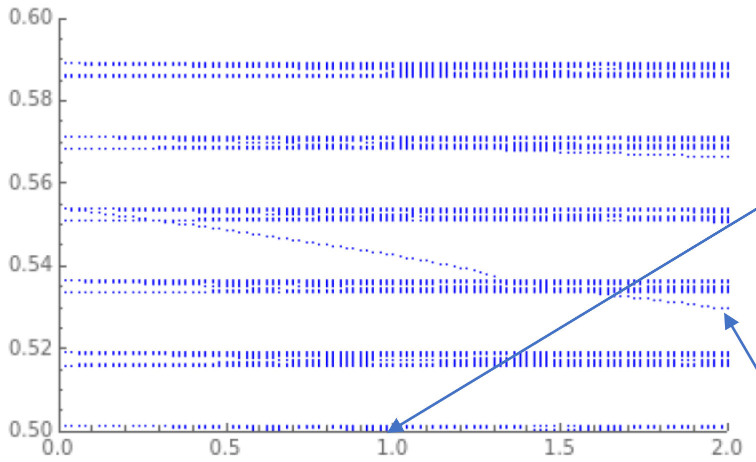


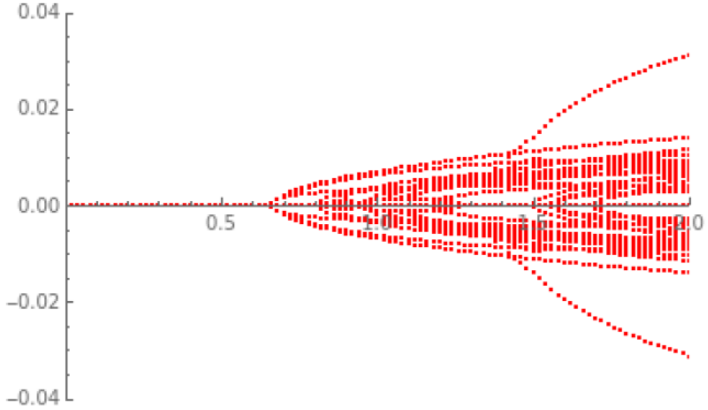
Short Discussion: Chromaticity on X-Z instability

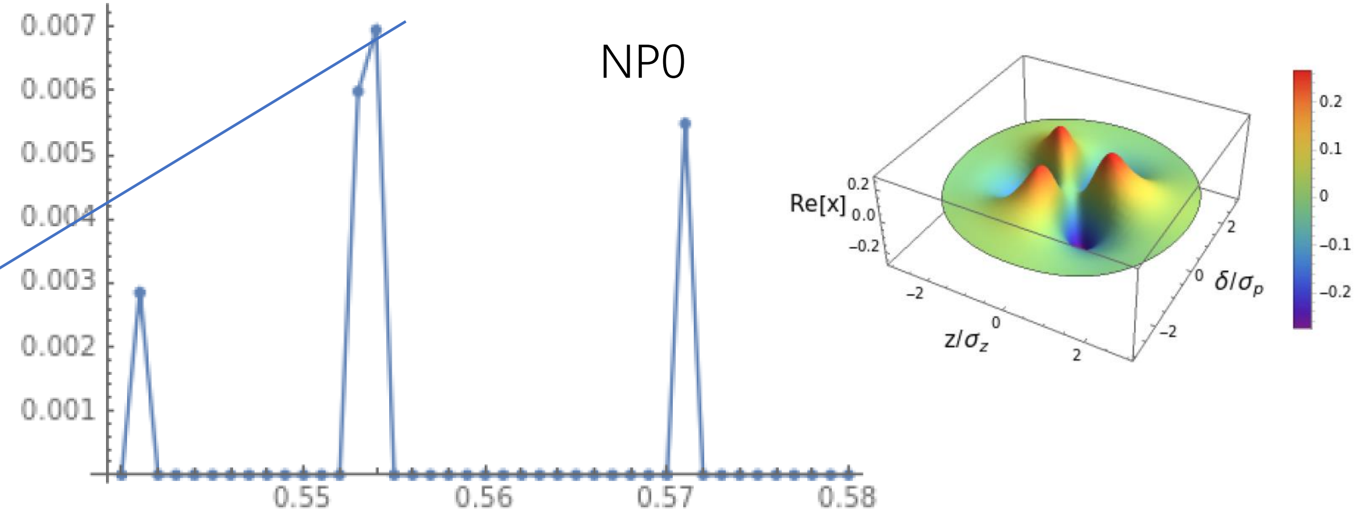
- Chromaticity and ZL both induce coupling between different parity mode
- It is supposed chromaticity could help only if PWD is included
- More simulation and analysis work will be done

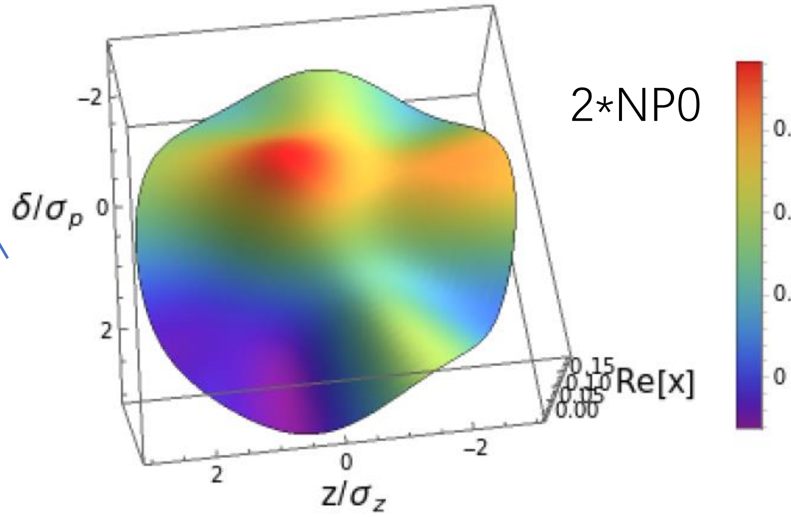
Local wake (ZT), w/o beam-beam

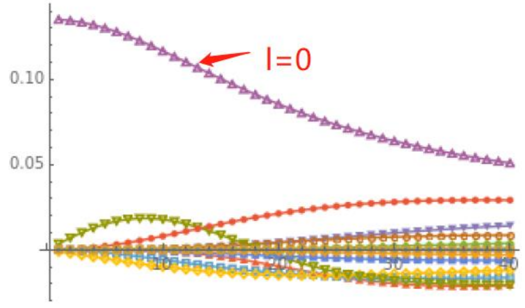
- Qx=0.554







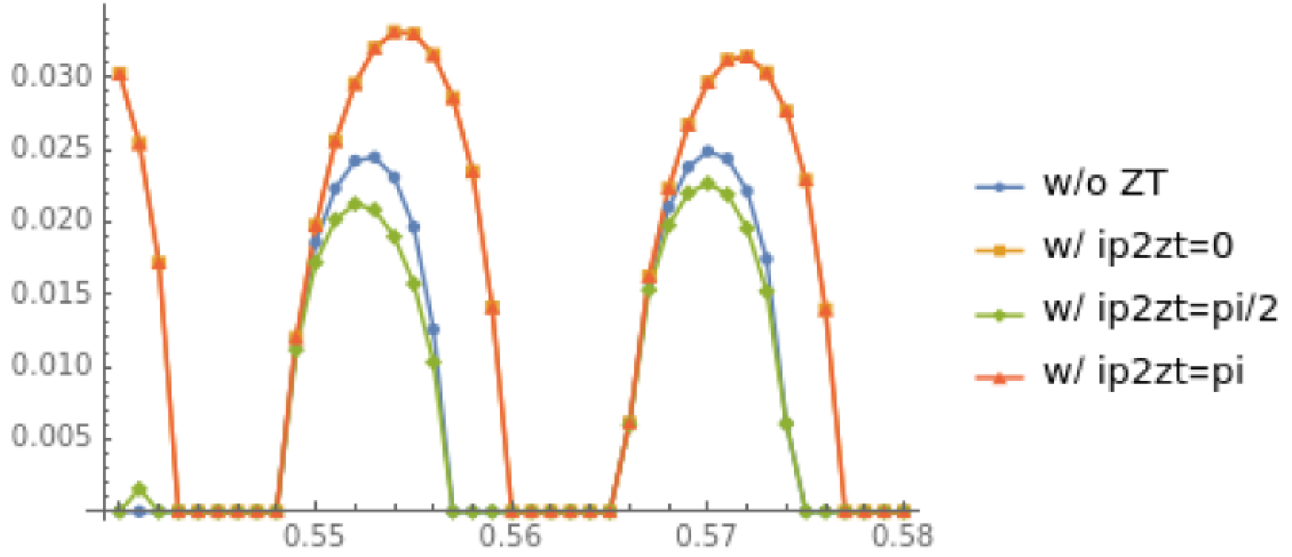




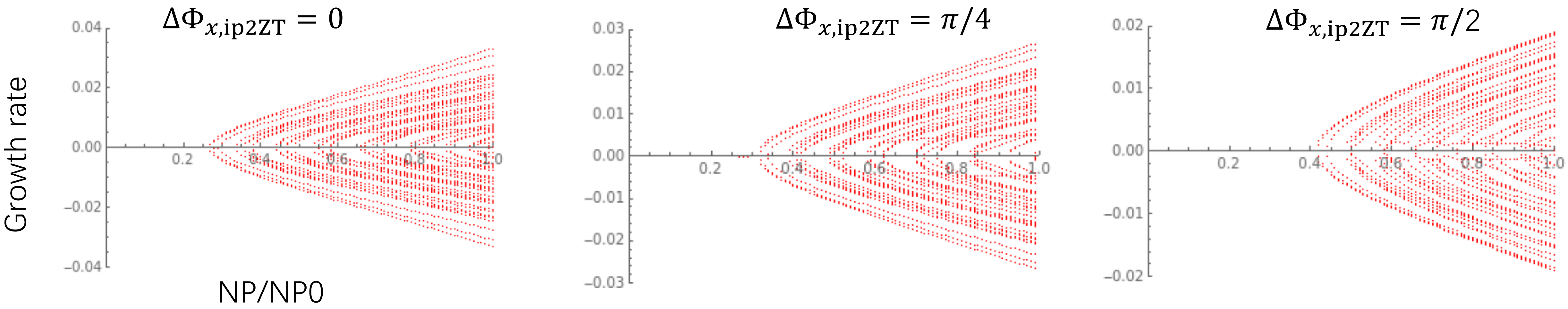
X-Z instability, w/ local ZT – different deltaPhi_IP2ZT

- Ip2zt=pi/2

mitigate the instability

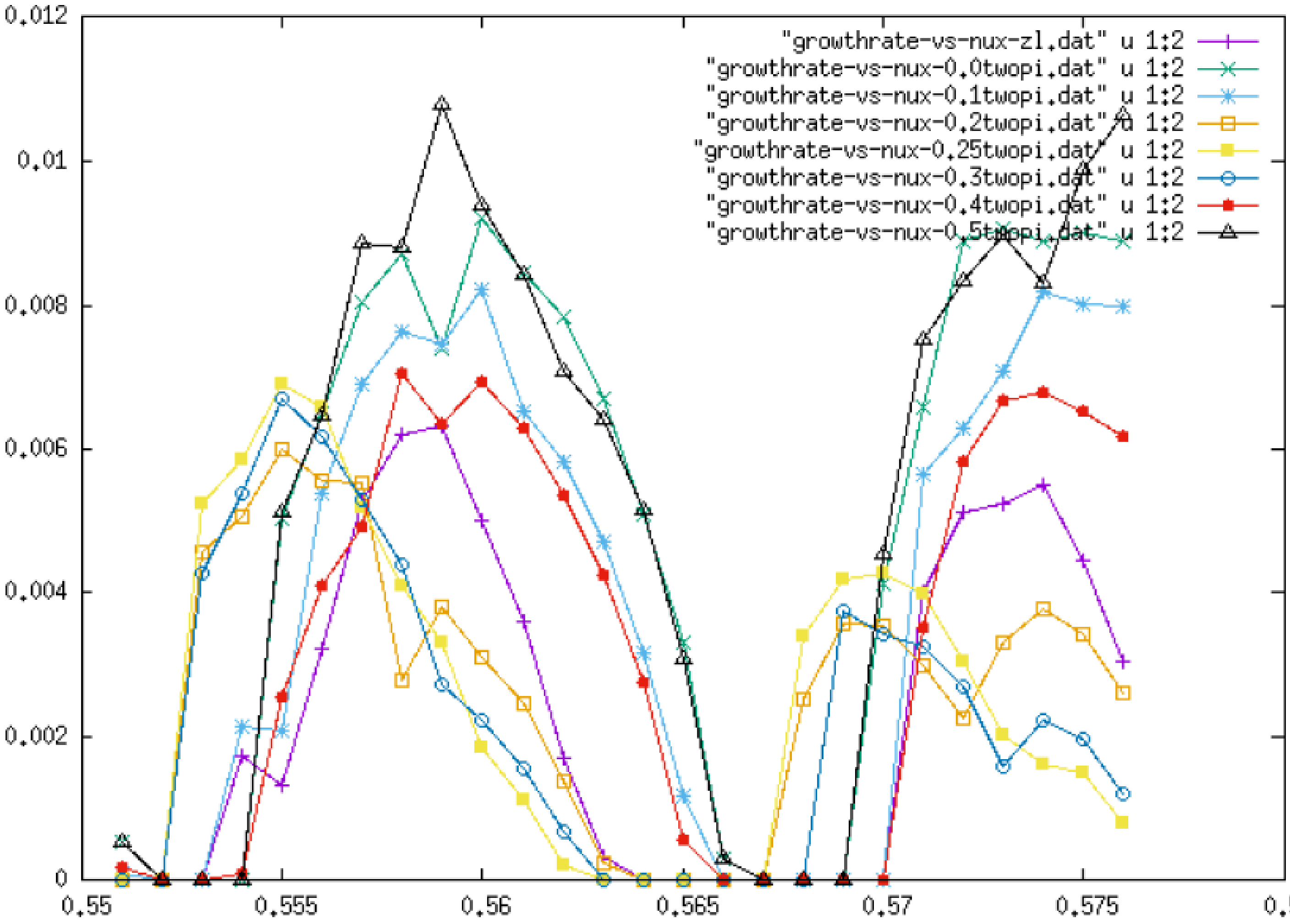


Qx=0.554



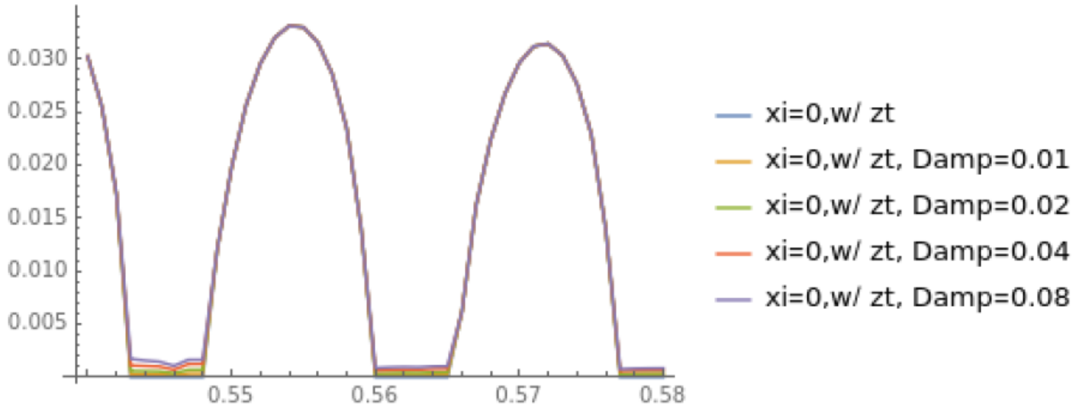
Simulation: X-Z instability, local ZT

- Depend on tune
- Pi/2 help mitigate instability

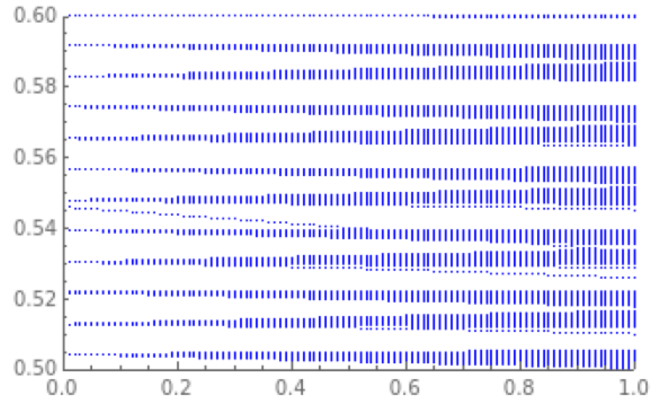


X-Z instability, w/ local ZT(phi=0) and **resistive feedback**

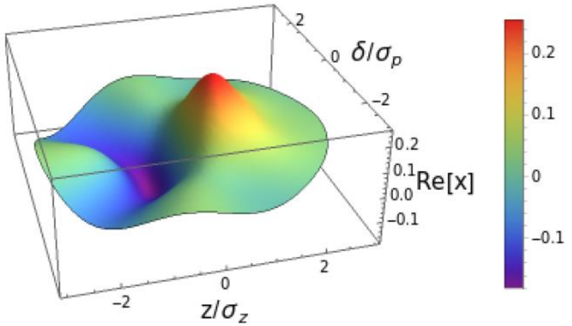
- feedback does not show mitigation ef

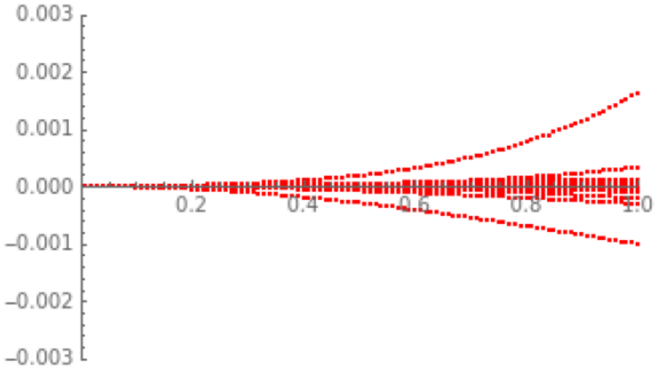


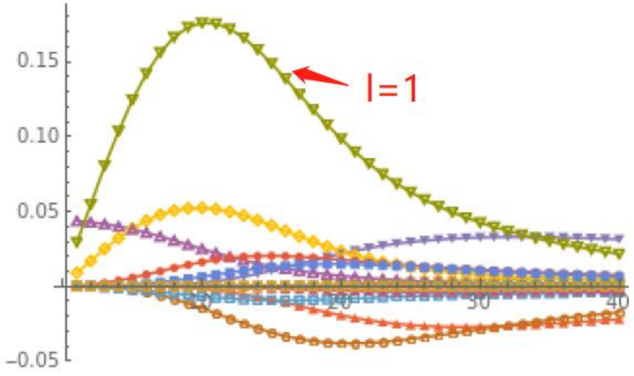
Qx=0.548
Damprate=0.08



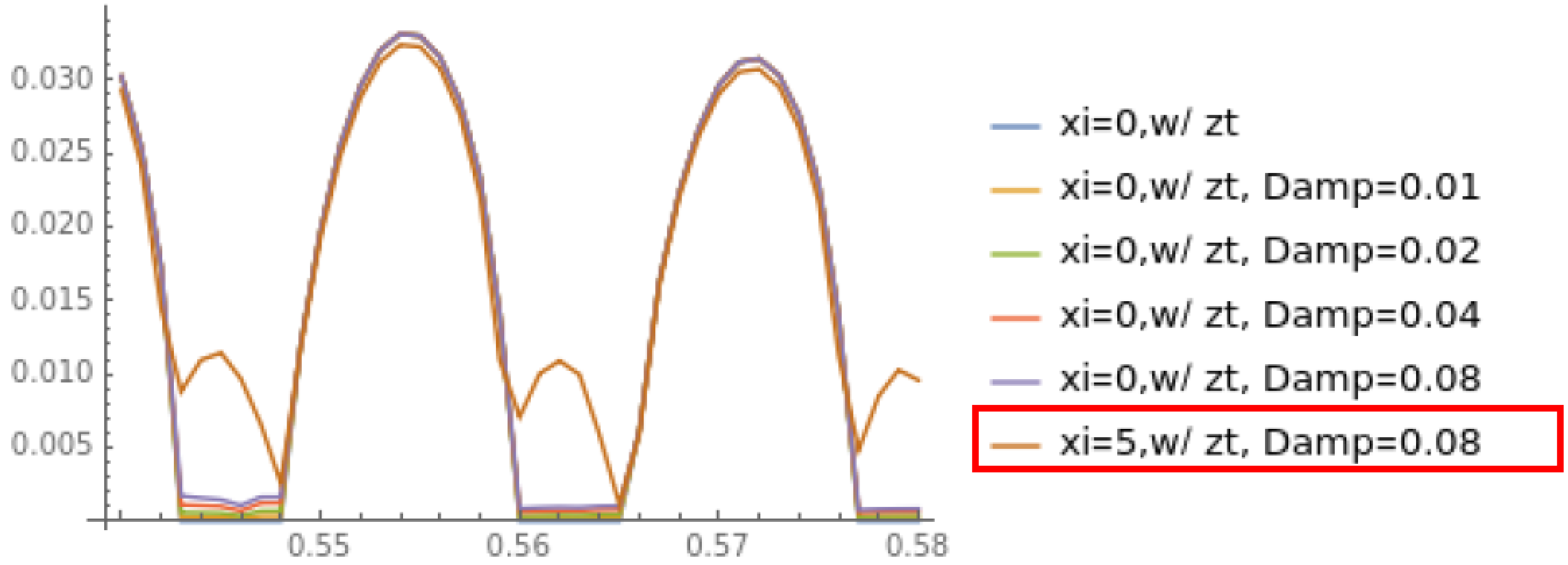
Eigen tune=0.526





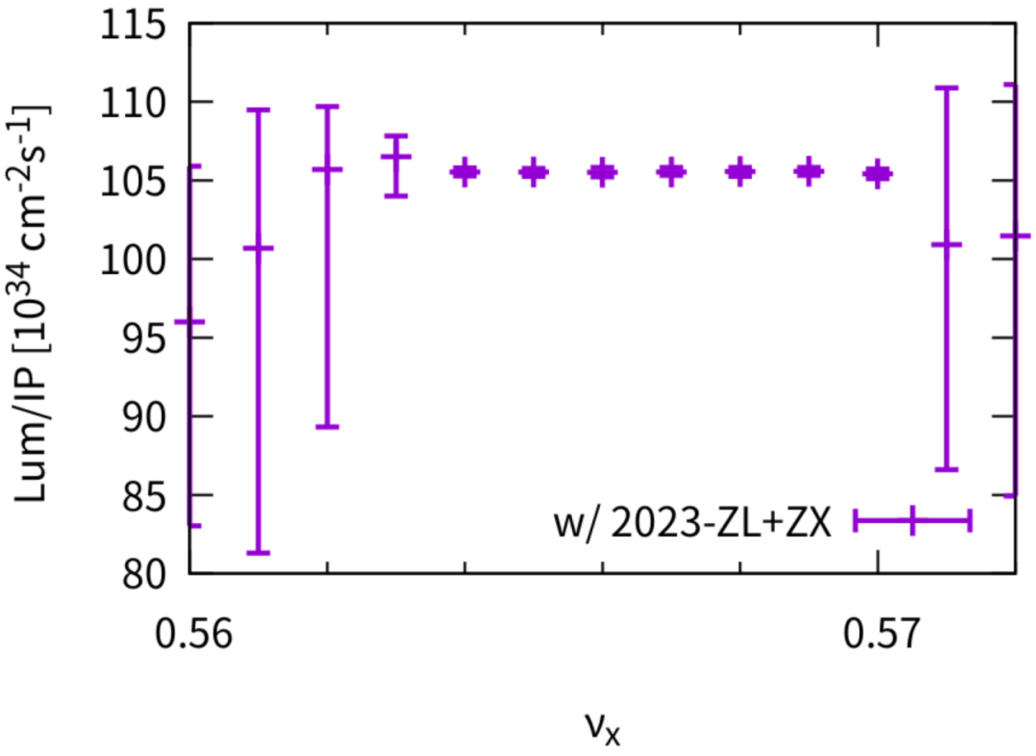


X-Z instability, w/ local ZT(phi=0) and **resistive feedback+chromaticity**

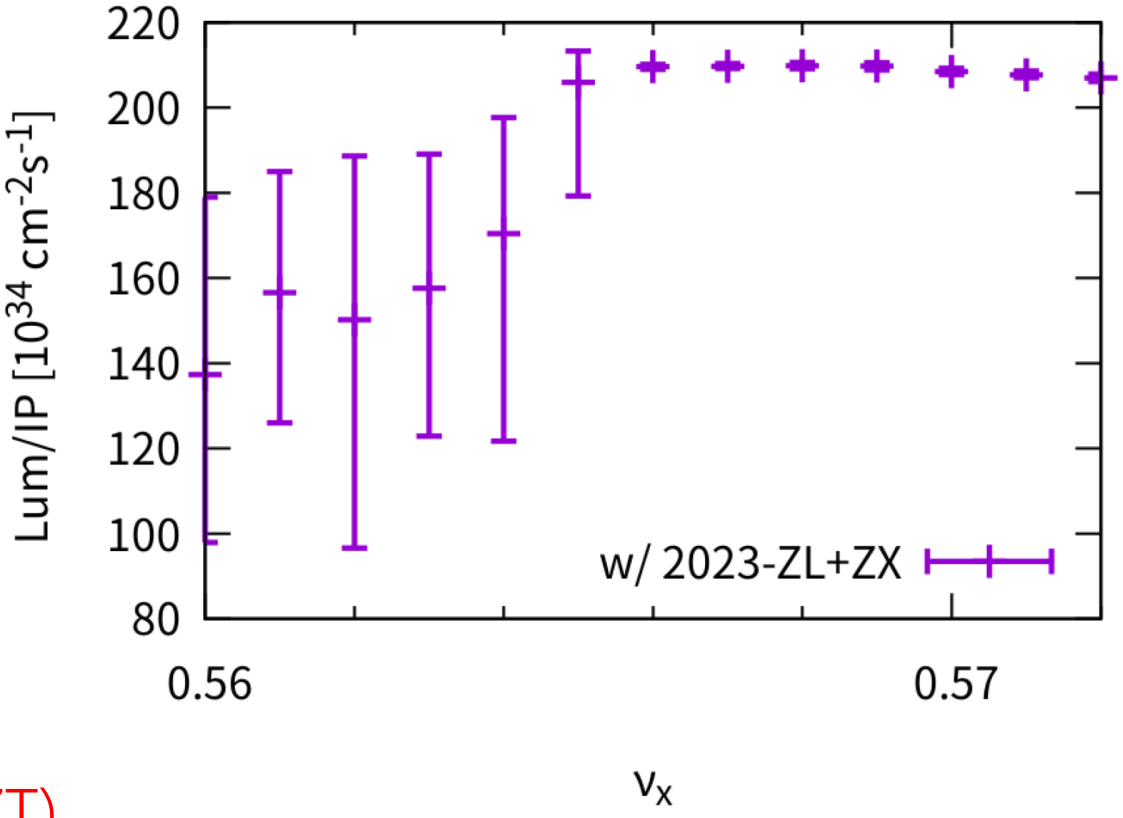


ZX+ZL, resistive damper, dp=0.05 (Qx'=5)

- Np=14e10, 30MW (stable)



- Np=21e10, 50MW (stable)

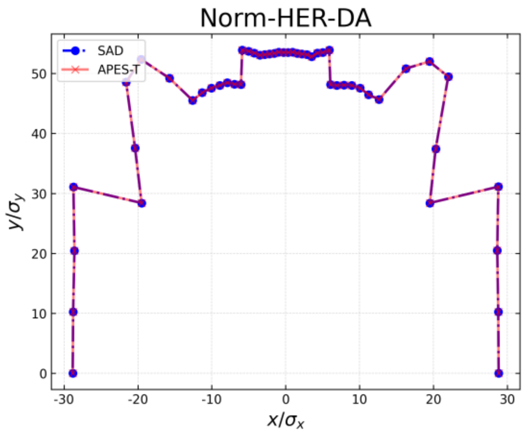


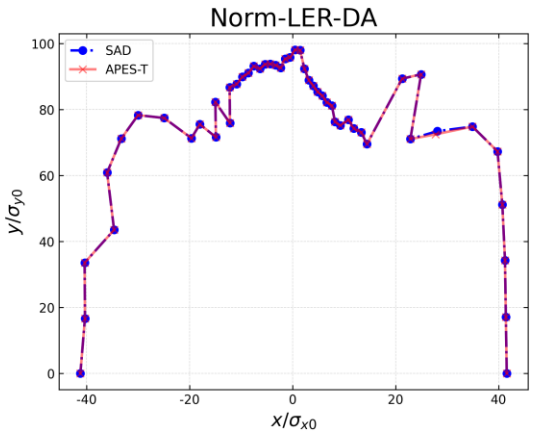
Disagree with analysis (w/o ZL, local ZT)

- lattice

APES-T: Benchmark with SAD

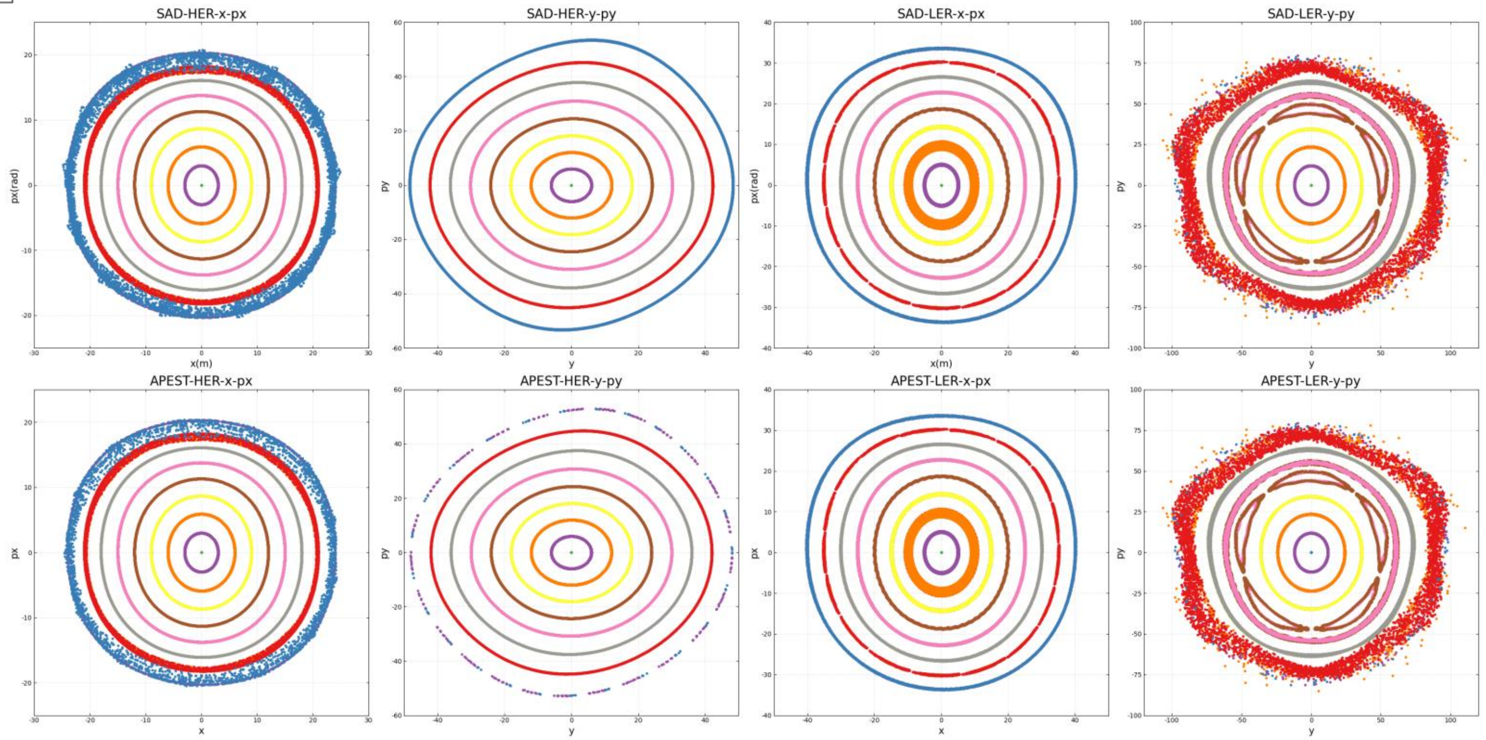
Zhiyuan, Li





Select SKEKB's ring for benchmarking

- Comparison of DA found by the two codes (SAD and APES-T) without radiation.
- The DA found by the two codes is essentially the same.



- Comparison of Hamiltonian contours in horizontal phase space
- The island-like structures show that the two codes have very similar results in horizontal tune values.

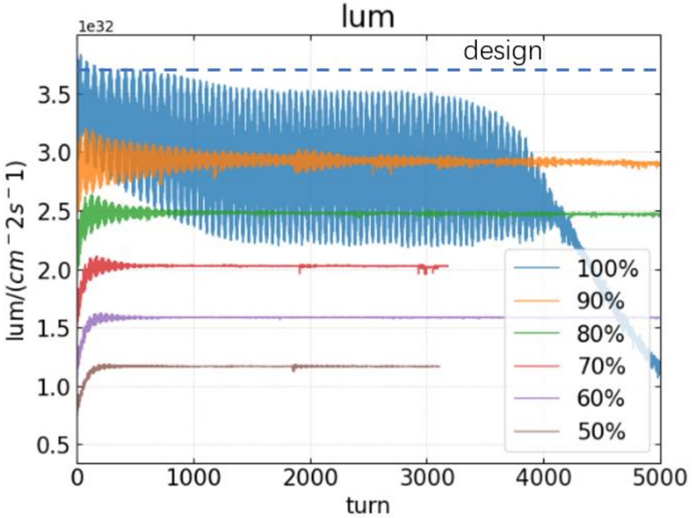
RAD in element is under development

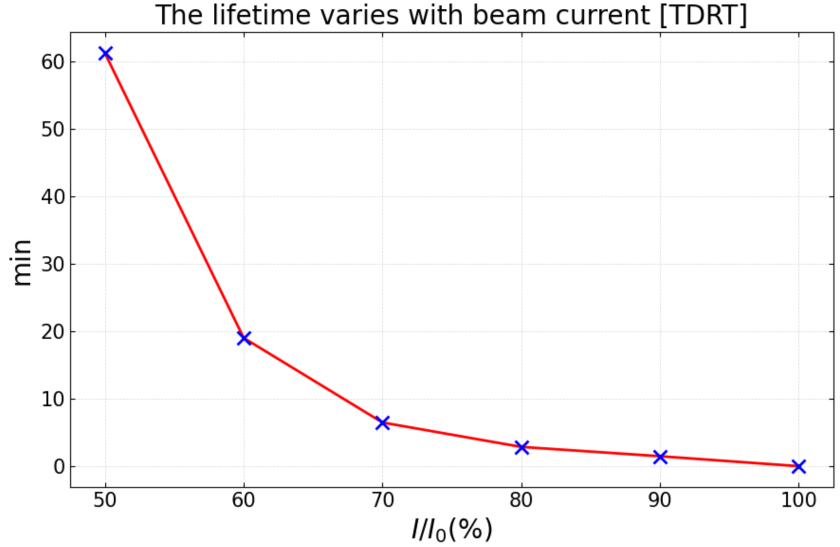
Zhiyuan, Li

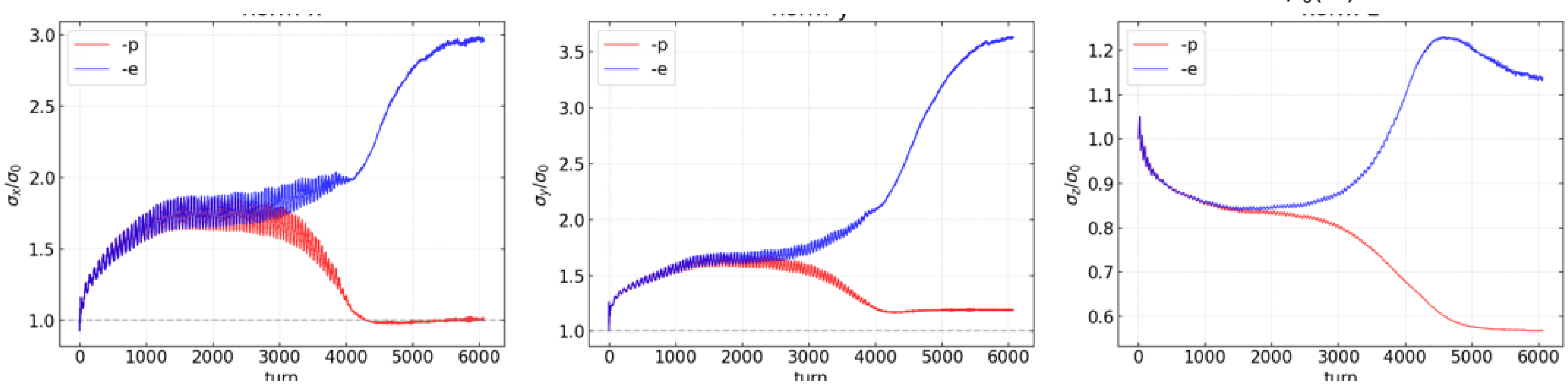
Initial Strong-Strong beam-beam simulation with lattice (higgs)

Beam lifetime (Bhabha/beamstrahlung) (min)	39/40
Beam lifetime (min)	20

- Initial: Collision Equlibrium Paramters







Initial Strong-Strong beam-beam simulation with lattice (higgs)

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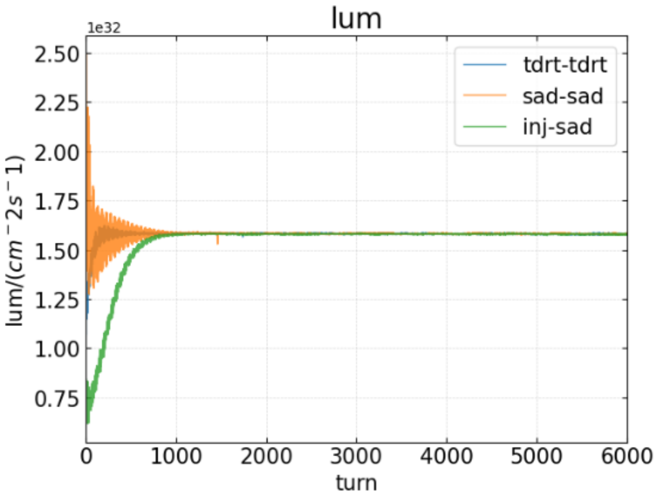
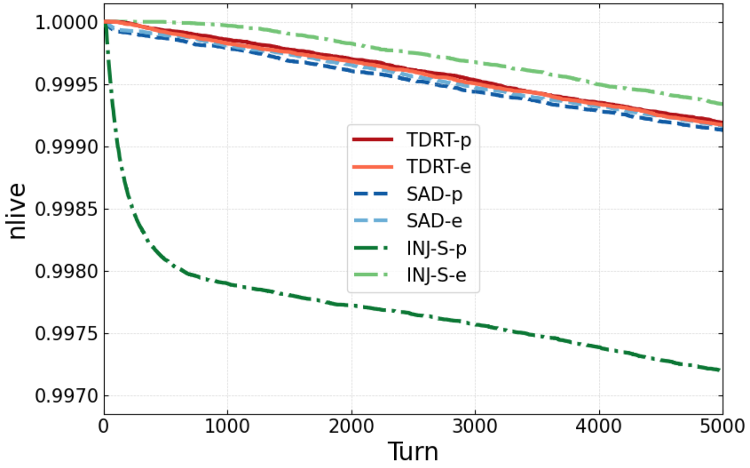
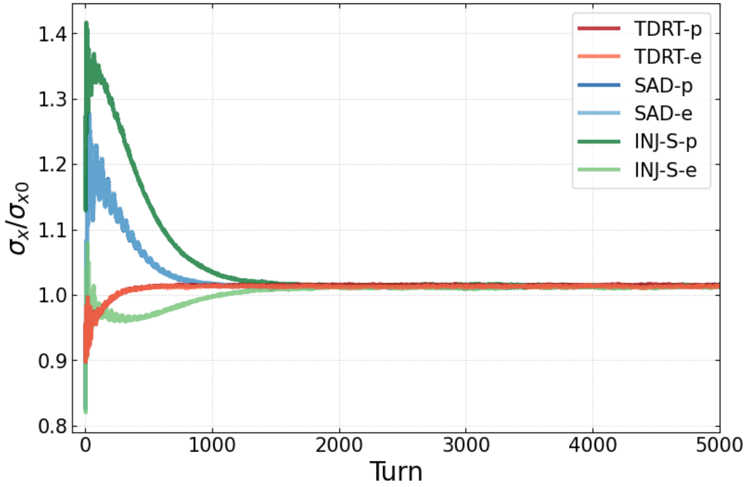
60% bunch population

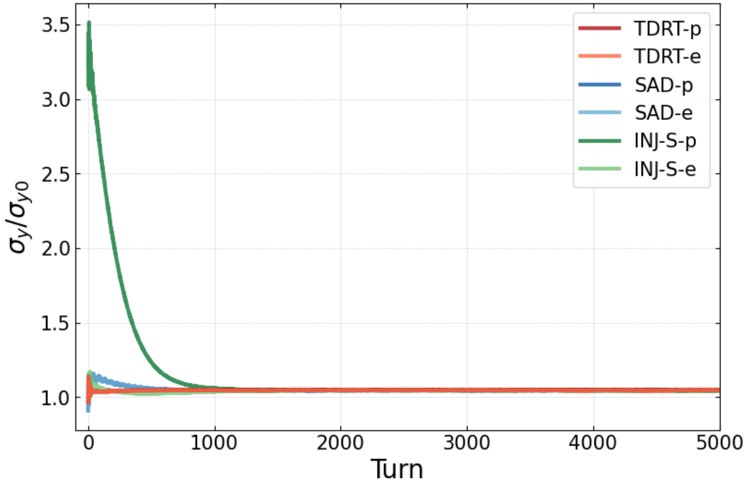


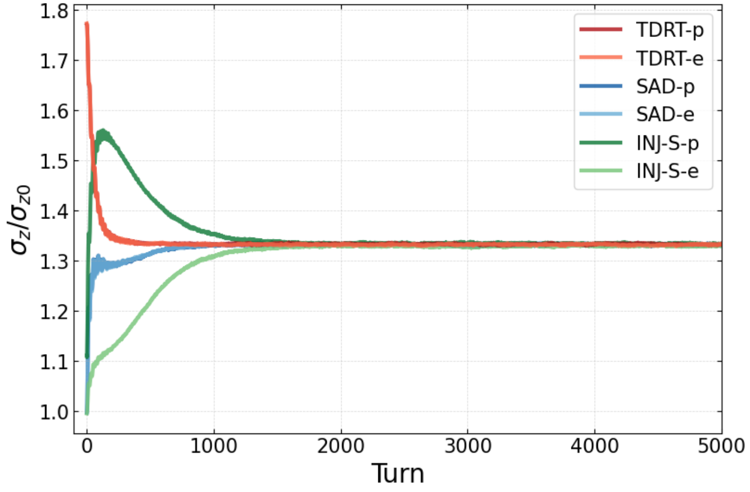


Different initial beam paratmers:

- TDRT: collision equilibrium
- SAD: collider lattice (except ϵ_y)
- INJ:
  - p: booster
  - e: collider lattice (except ϵ_y)







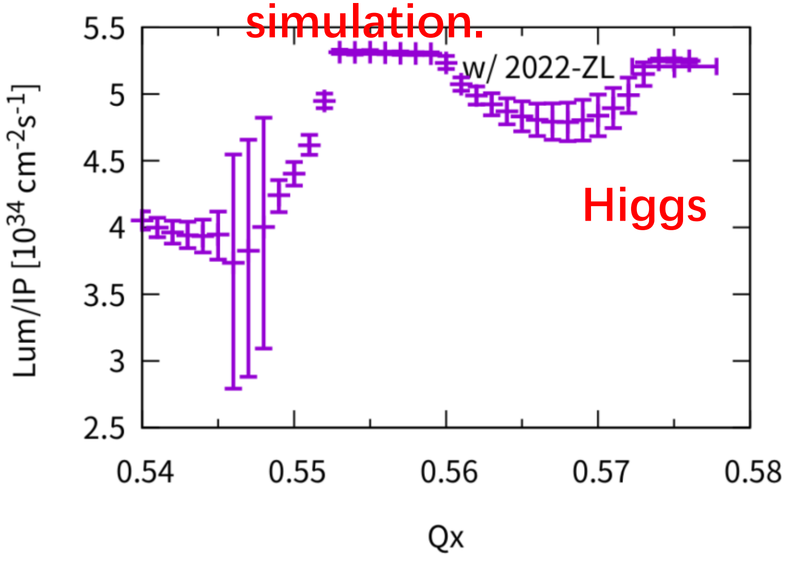
Summary

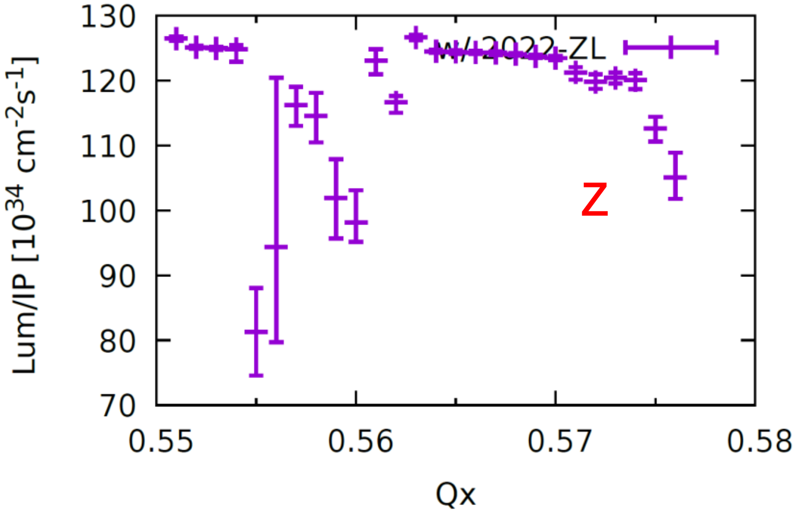
- More analysis/simulation on Coherent beam-beam instability
  - Chromaticity
  - Feedback
  - Local ZT
- Very first initial strong-strong beam-beam simulation considering lattice

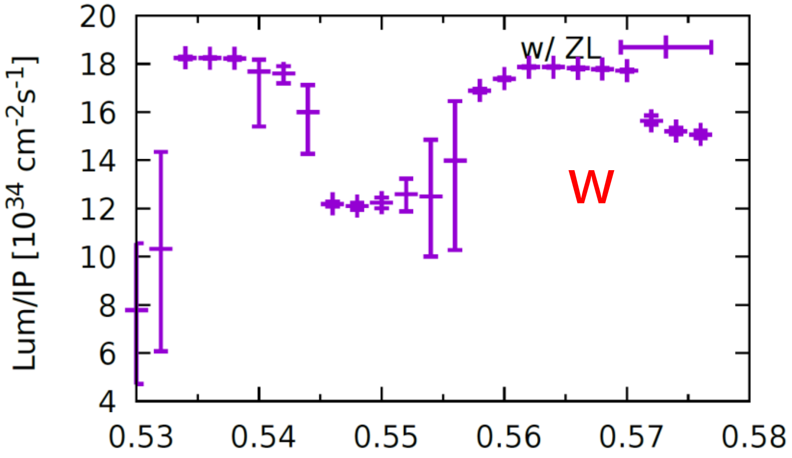
- backup

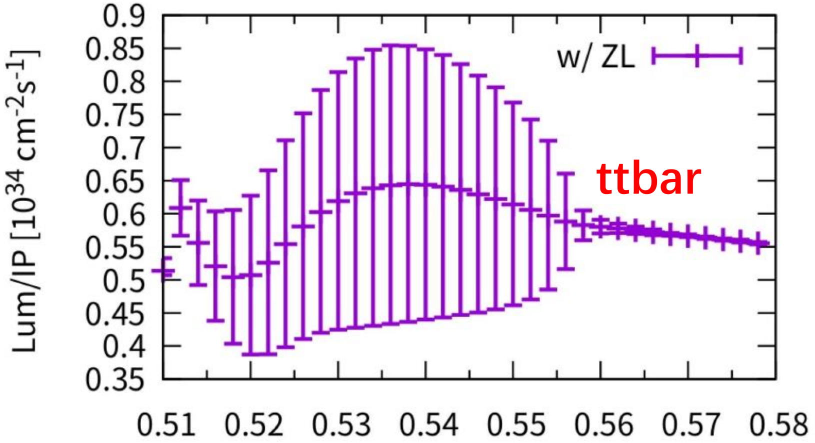
Luminosity versus horizontal tune

The design luminosity could be achieved in the pure beam-beam simulation.









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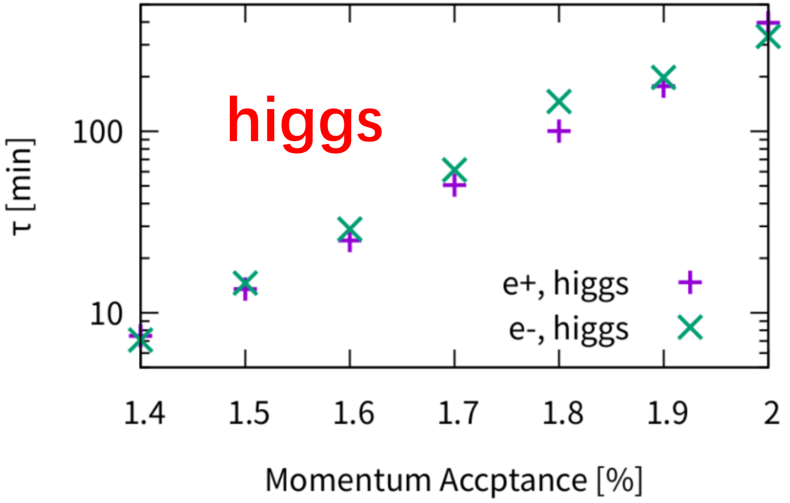
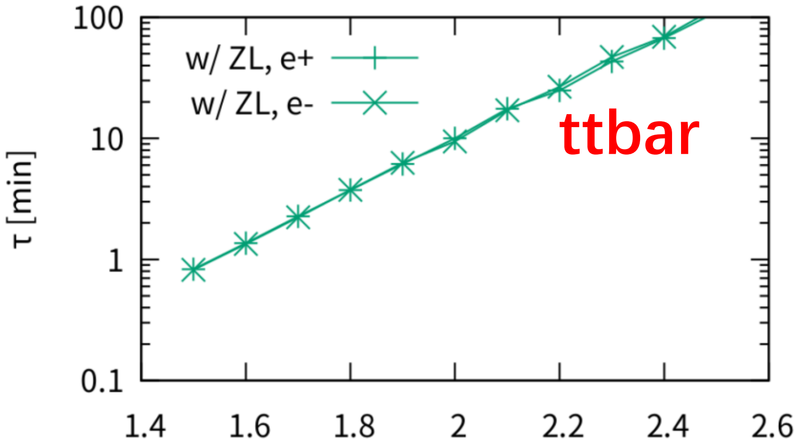
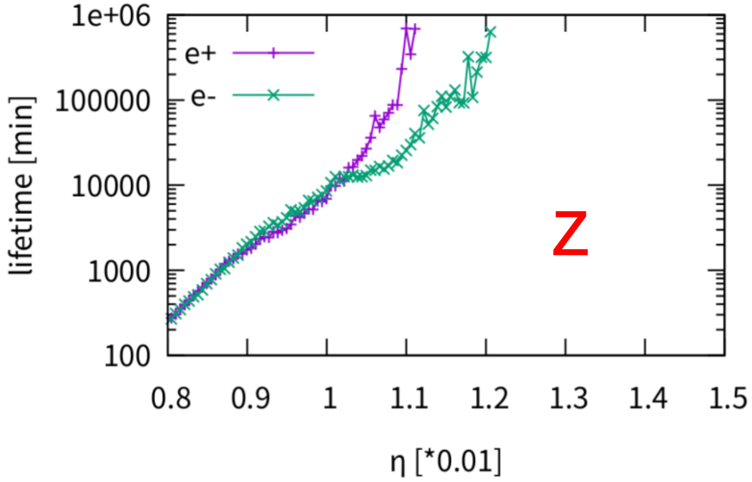
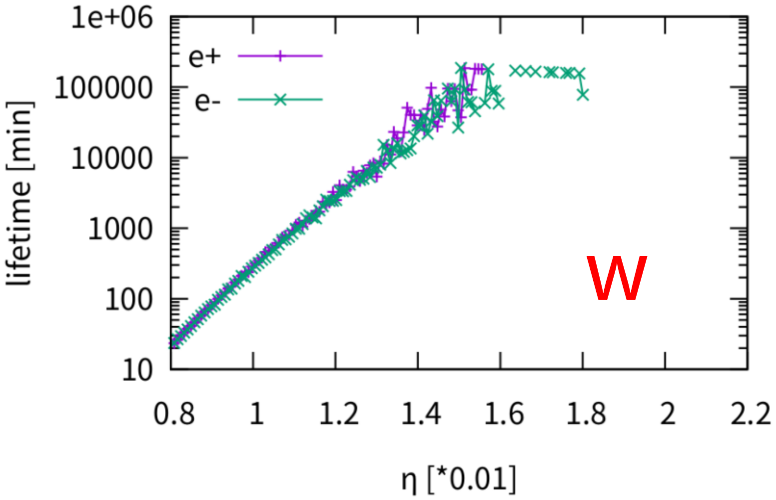
Beamstrahlung Lifetime vs Momentum Acceptance

The pure beam-beam simulation presents a goal value for Lattice optimization.







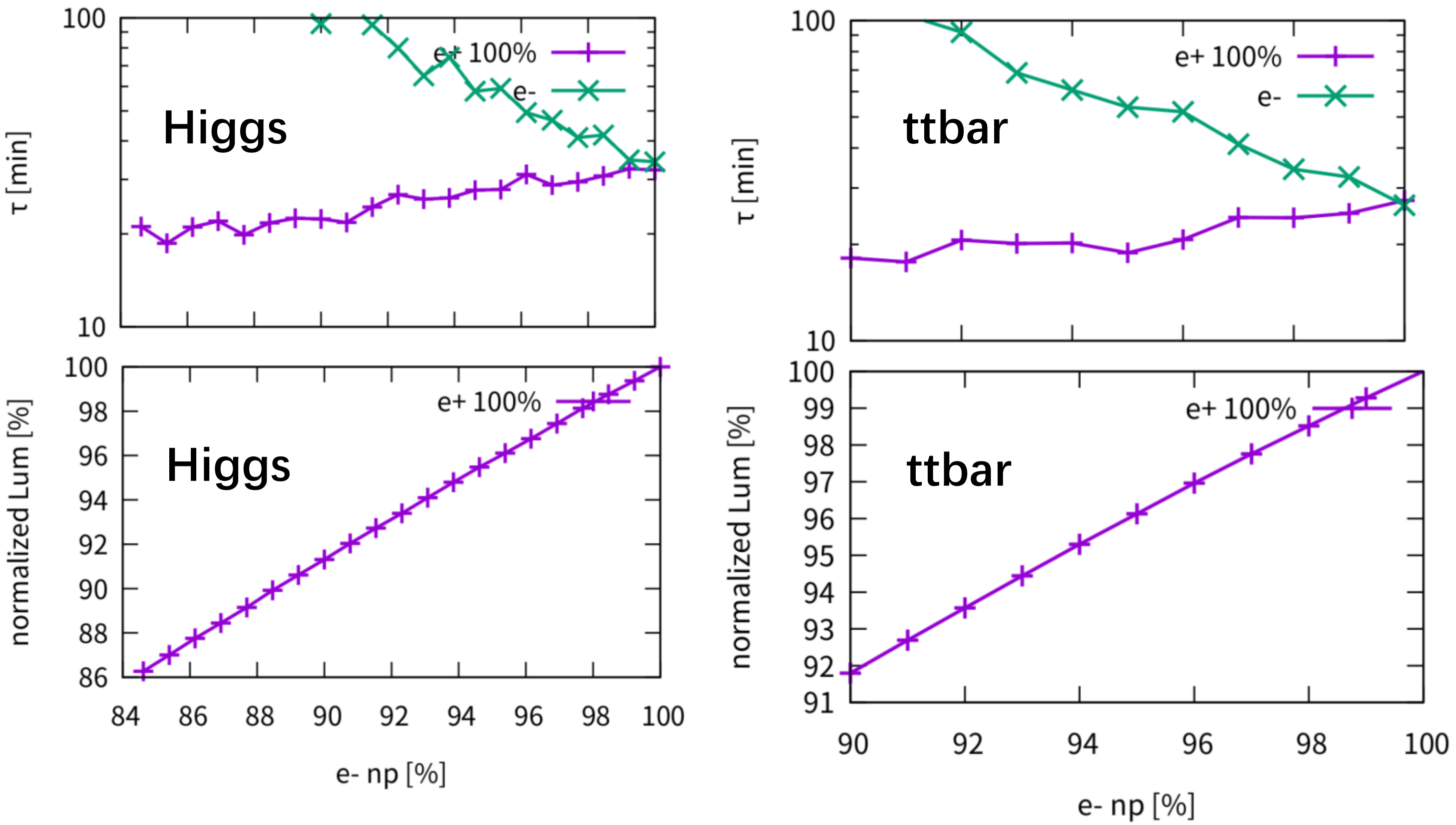


* If particles exceed the momentum acceptance are checked just after collision.

Asymmetric Collision: Higgs/ttbar

Lifetime

Luminosity



- The weak beam's lifetime would be about only half with collision between 100% vs 90% bunch population. (design 100% vs 97%: ~20% lifetime reduction)
- The luminosity scale linearly with the weak beam's bunch population

* If particles exceed the momentum acceptance are checked just after collision.