Beam-Beam Effects at CEPC

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CEPC IARC Meeting

2022-Jun

Outline

- Update with New Longitudinal Impedance (ZL)
- Simulation with Transverse Impedance (ZT)
- Mitigation Scheme
- Summary

Longitudinal impedance has been updated in last Review Meeting, but not considered in Beam-Beam Simulation

- Na Wang, CEPC DAY (2022-Feb-23)
- Y. Zhang, IAS workshop, 2022

Motivation

- The updated impedance has higher value and may induce microwave unstable ⇒ influence on the luminosity needs to be further checked.

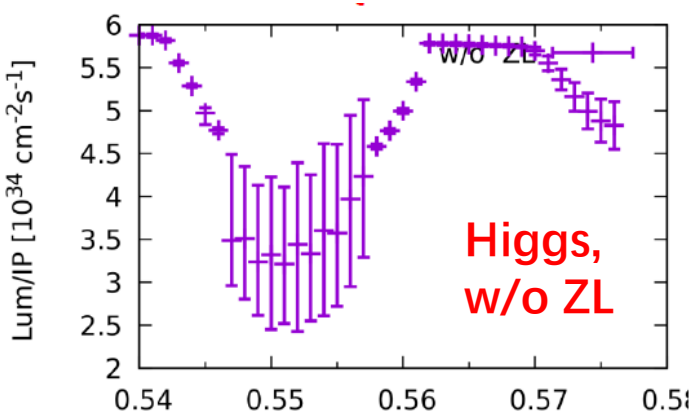
w/o Collision:

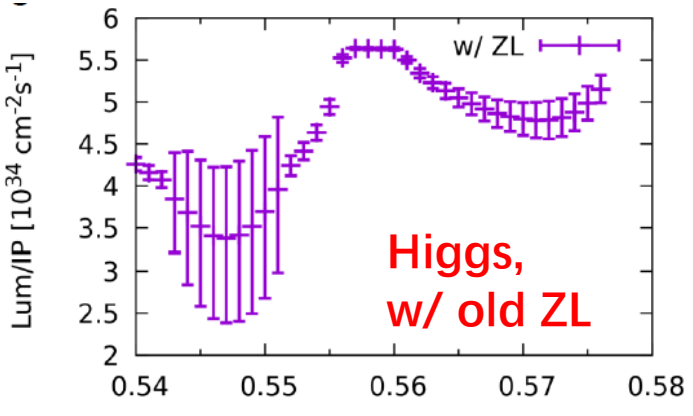
	Higgs	W
Threshold $Z_{\|\|}/n$ [mΩ]	6.0	4.1
Evaluated $Z_{\|\|}/n$ [mΩ]	11.4	
Evaluated k_{loss} [V/pC]	786.8	

50MW	Higgs	W
Threshold $Z_{\|\|}/n$ [mΩ]	6.0	4.1
Evaluated $Z_{\|\|}/n$ [mΩ]	15.3	
Evaluated k_{loss} [V/pC]	664.9	

- Stable tune area for Higgs is limited with old impedance model

Higgs, Collision:

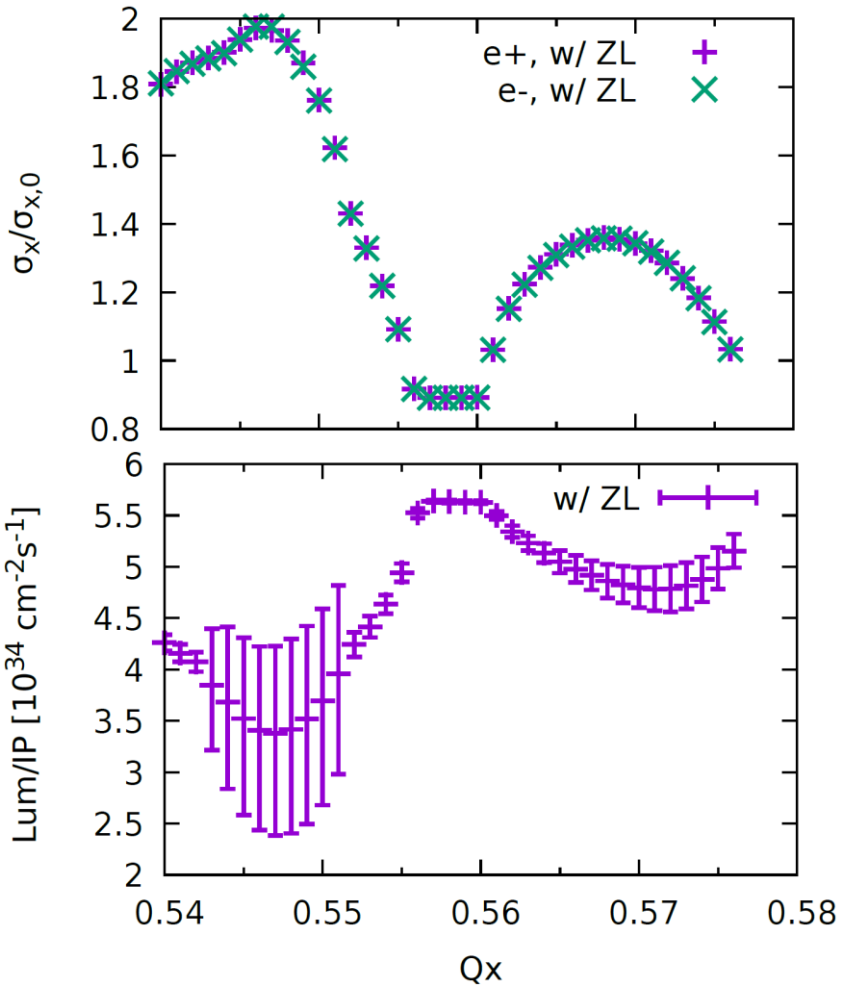




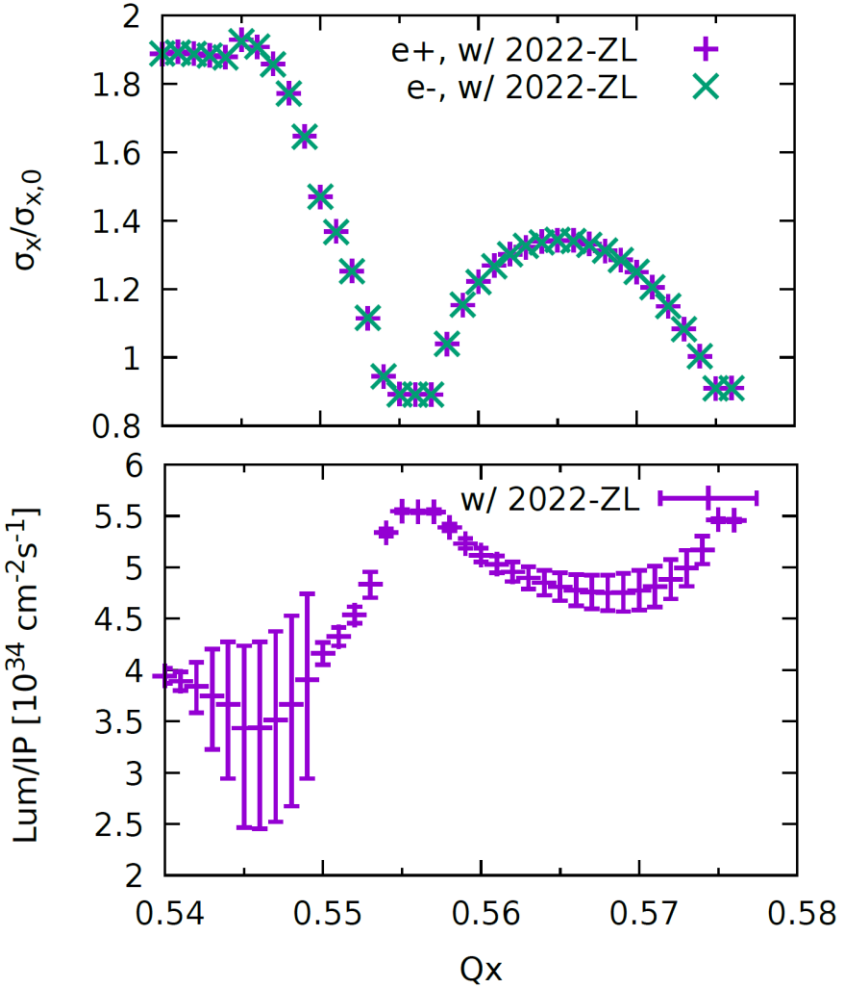
Stable tune area is too limited

Higgs: σ_x & L versus Horizontal tune

Old Impedance

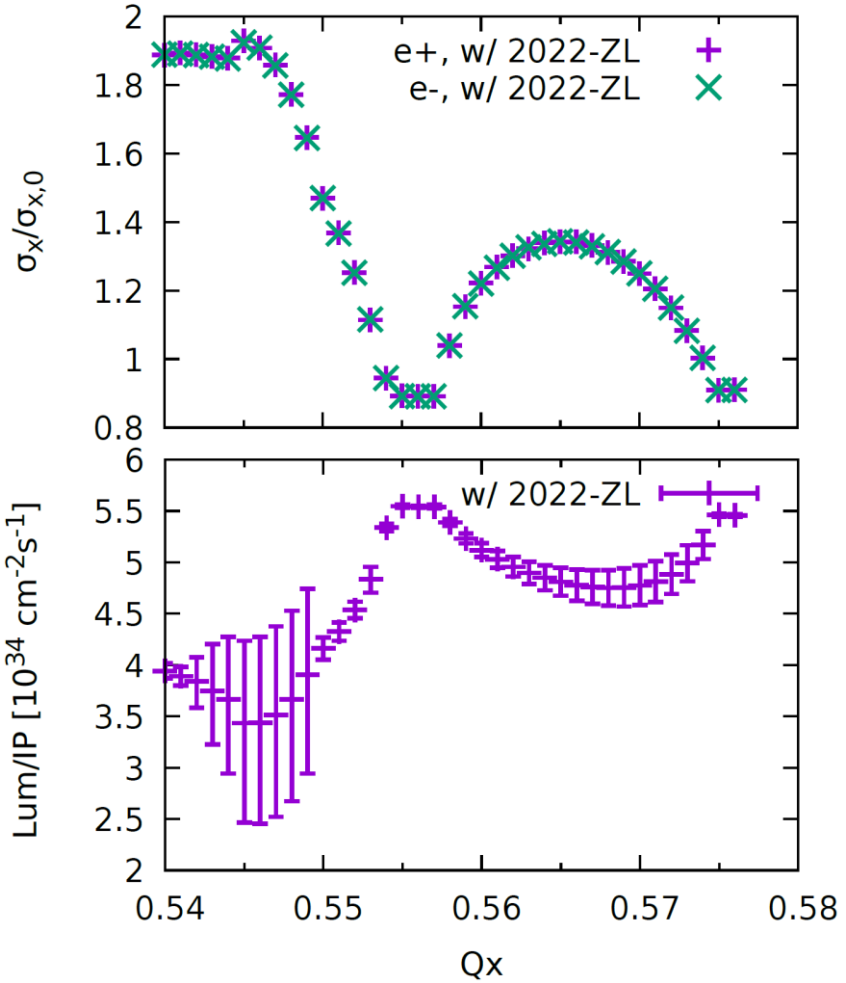


New Impedance

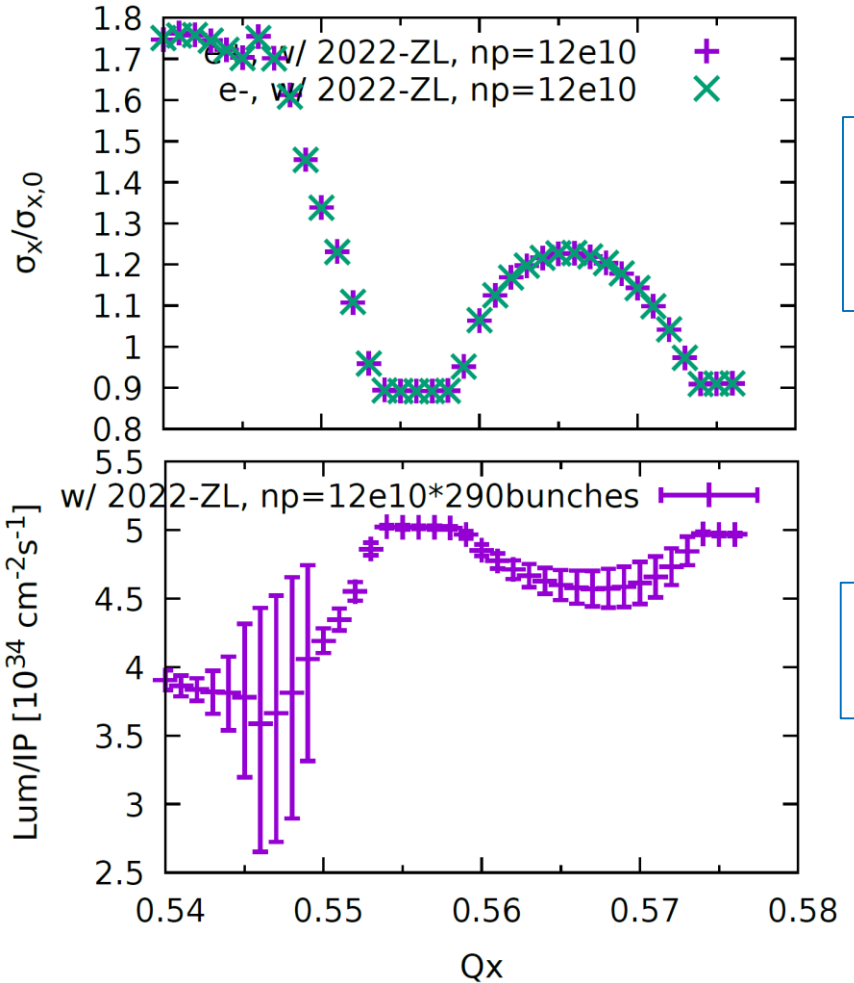


Optimization of Higgs Parameters: Lower bunch population (14e10->12e10)

14e10



12e10

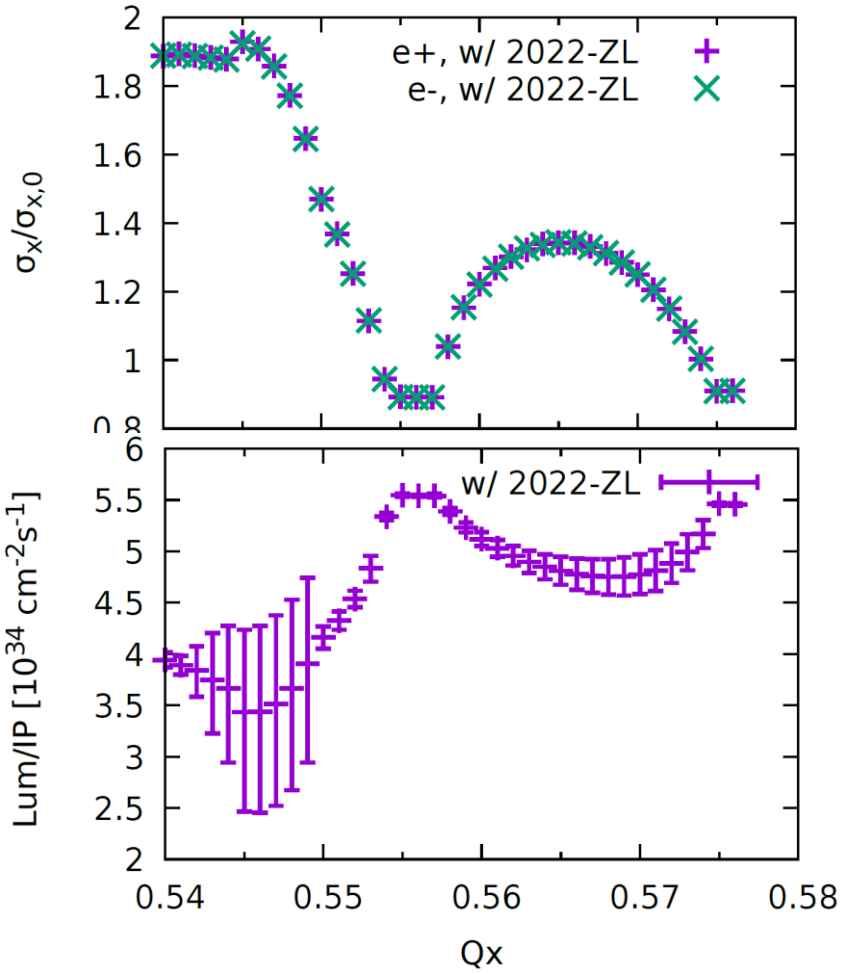


Width of stable region: 0.002 -> 0.004

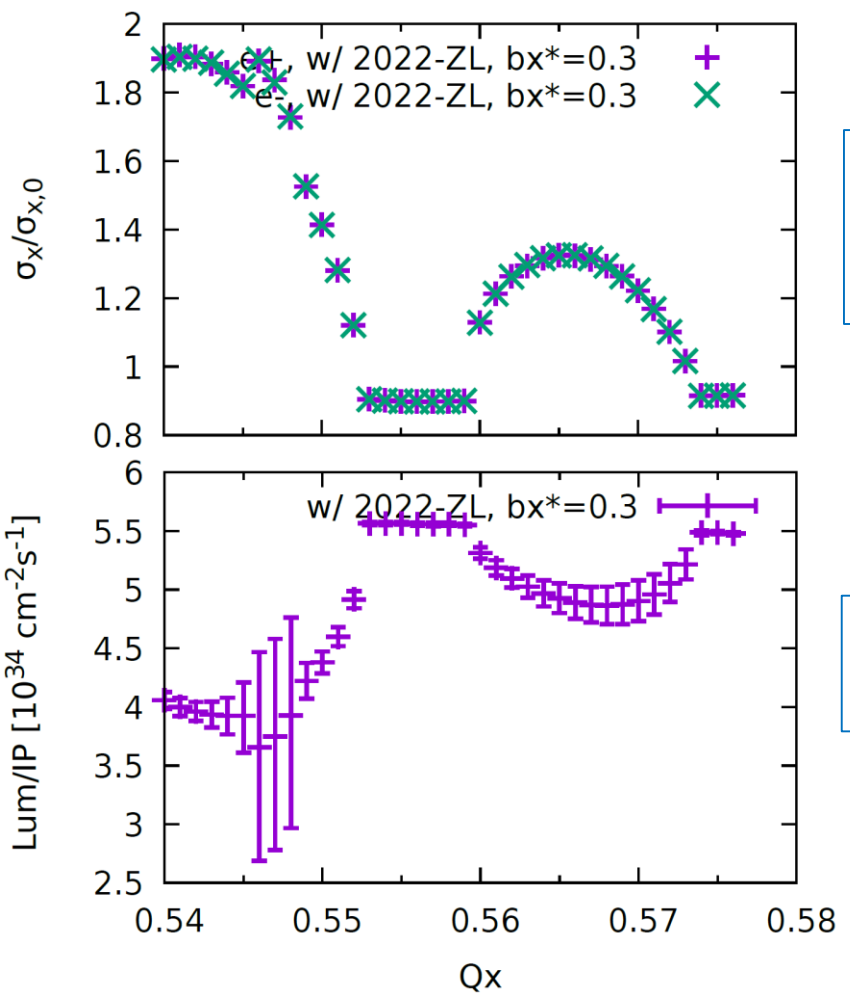
Luminosity: 5.5e34 -> 5e34

Higgs: σ_x versus Horizontal tune
Squeeze β_x^* (0.33 m-> 0.30 m)

0.33 m



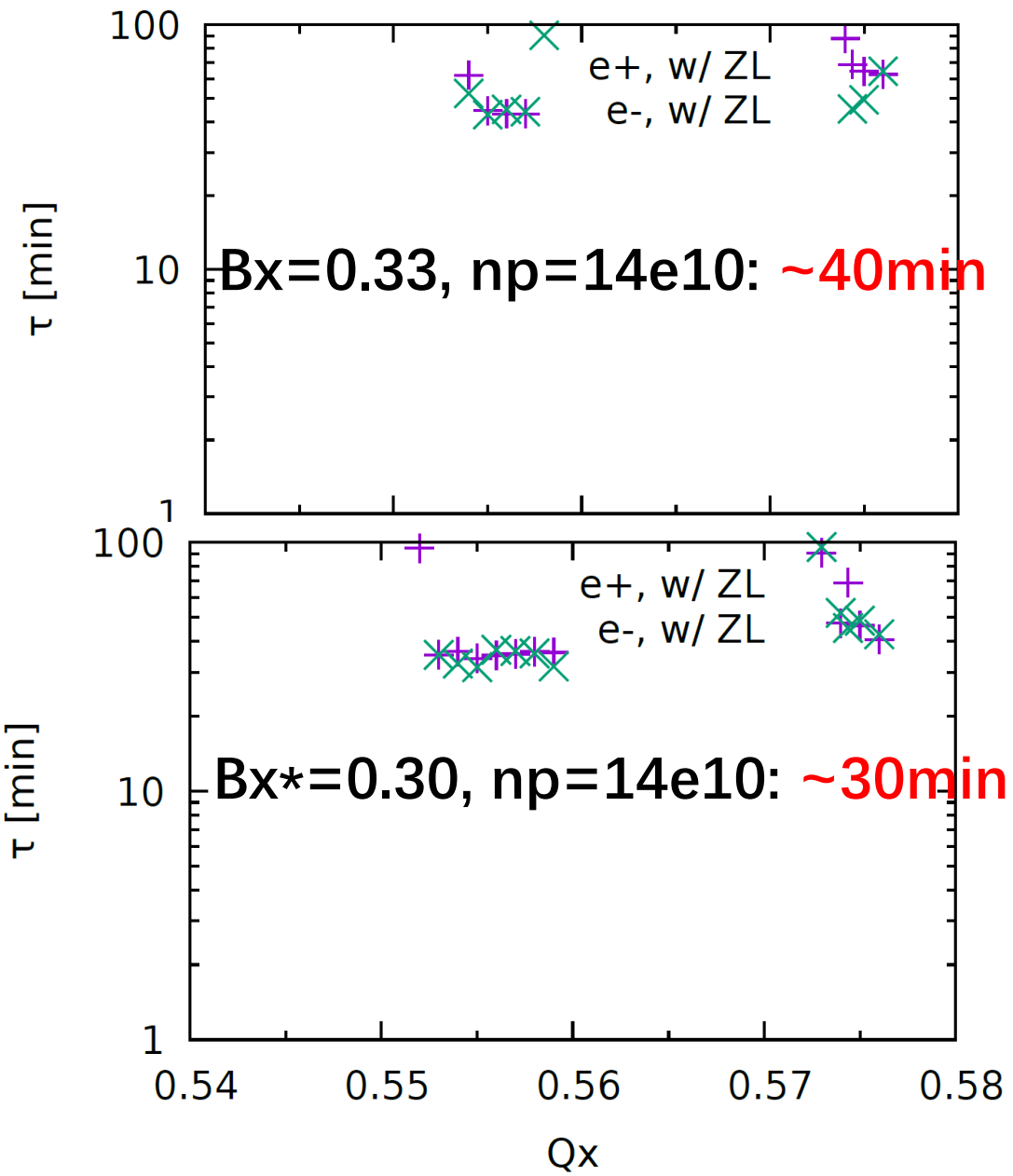
0.30 m

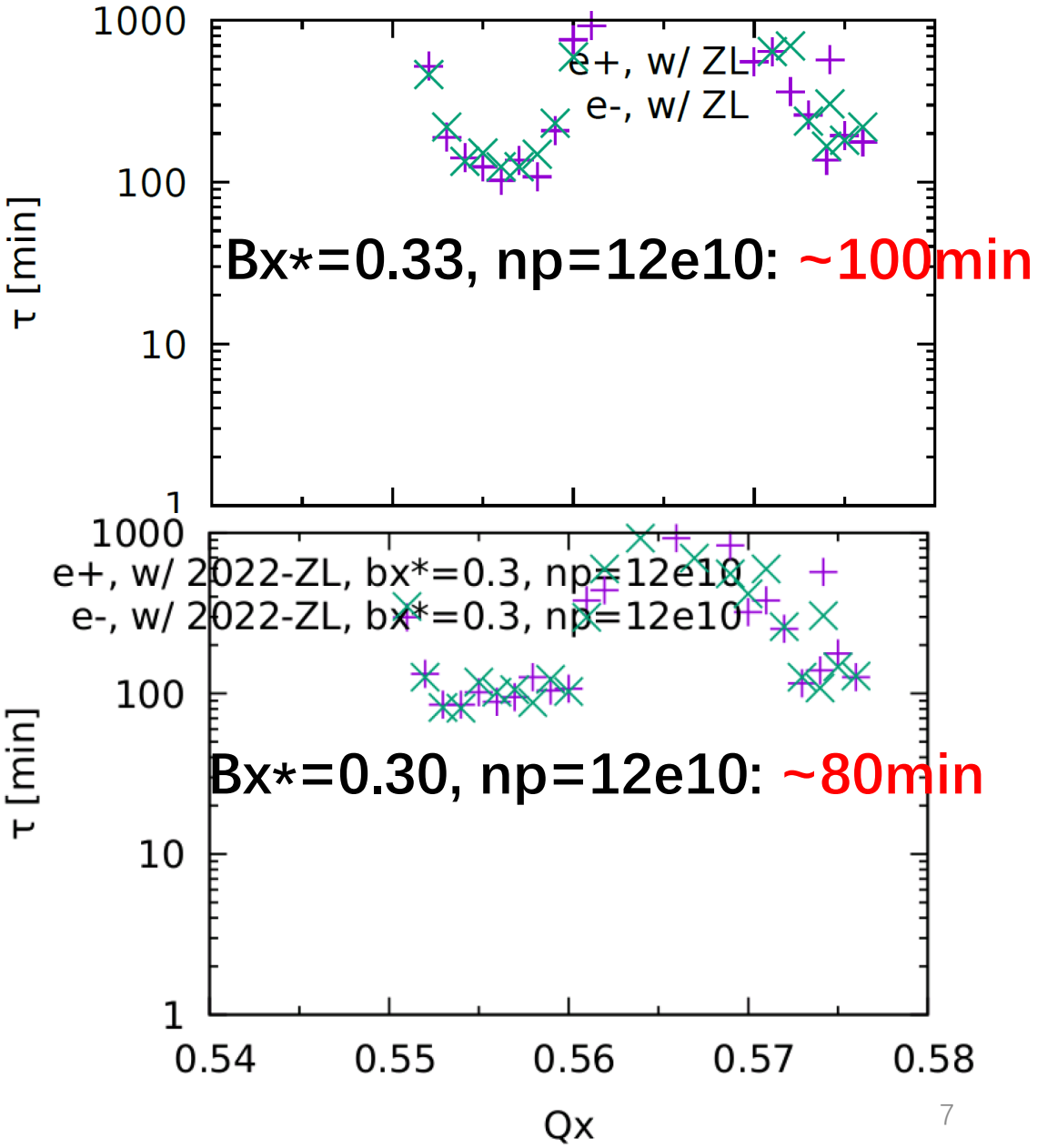


Width of stable region: 0.002 -> 0.006

Luminosity: 5.5e34

Higgs: Beamstrahlung Lifetime

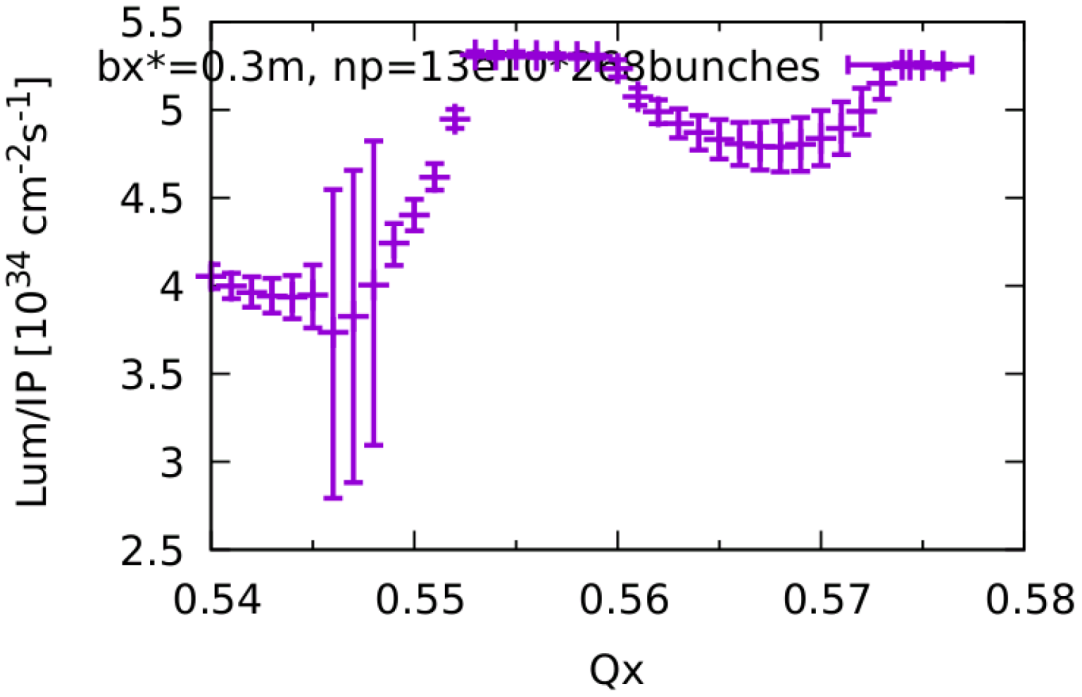




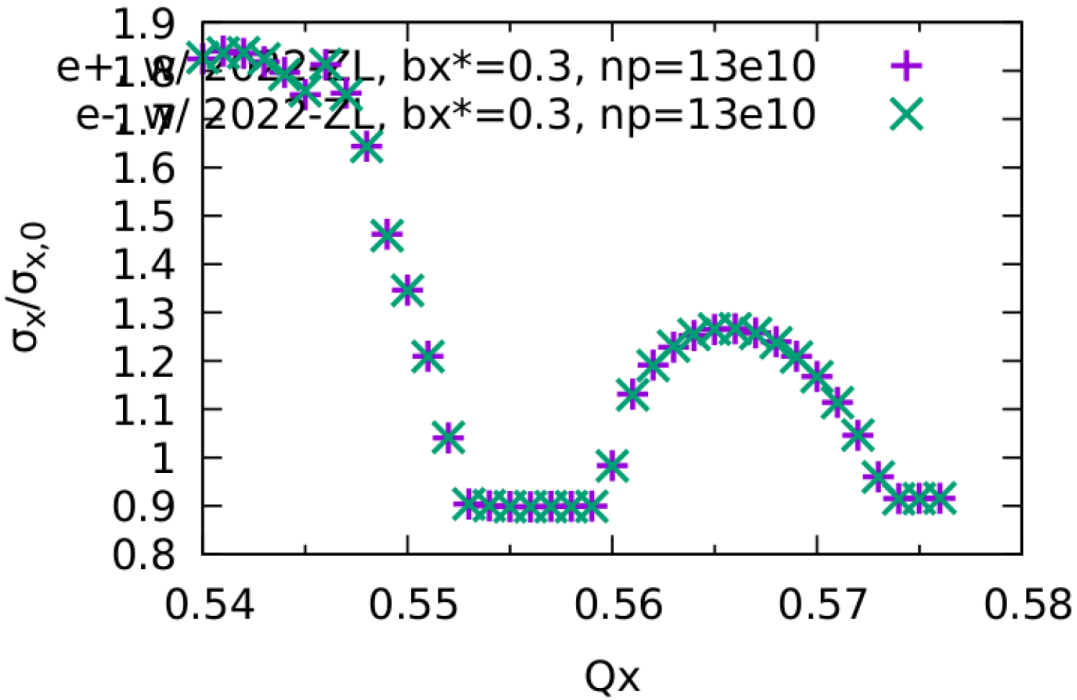
Higgs: Bx*=0.3m, ne=13e10

- Width of stable tune area: 0.006
- Lum ~ 5e34

Luminosity



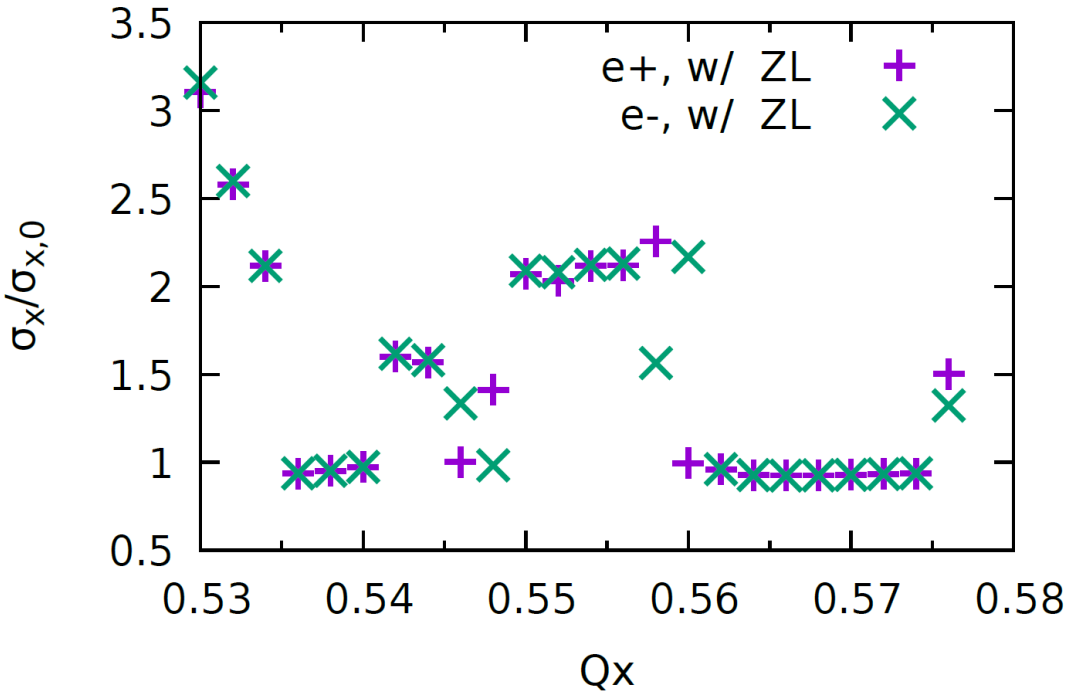
σ_x versus Horizontal tune



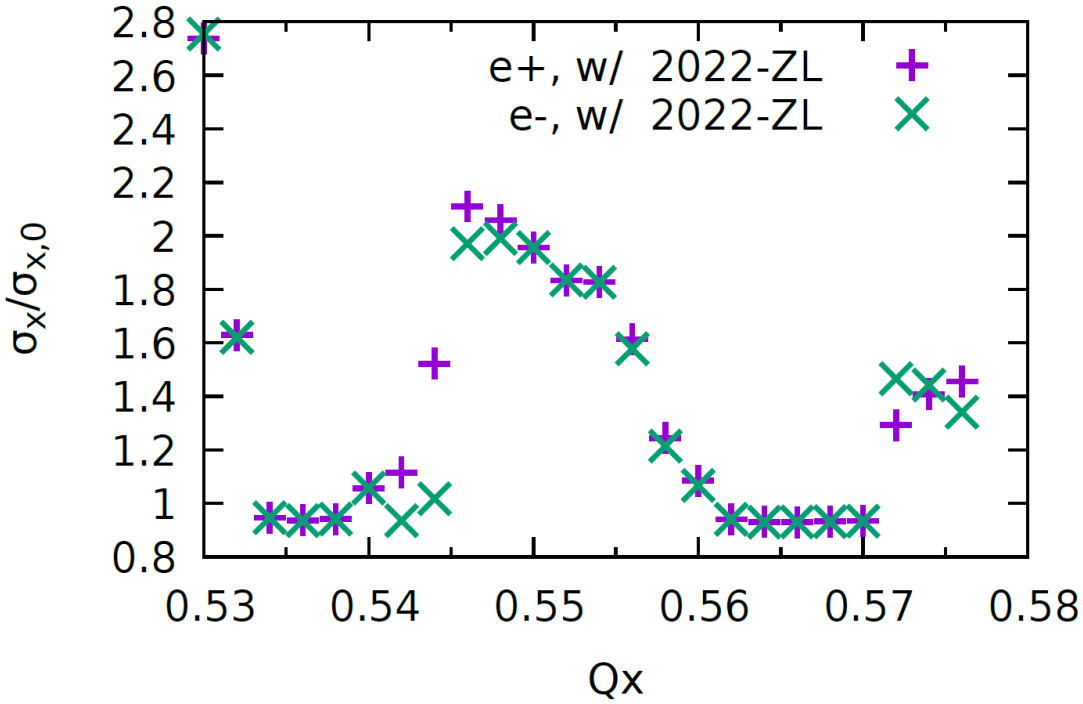
W: σ_x versus Horizontal tune

Stable tune area is still large enough, even squeezed.

Old Impedance

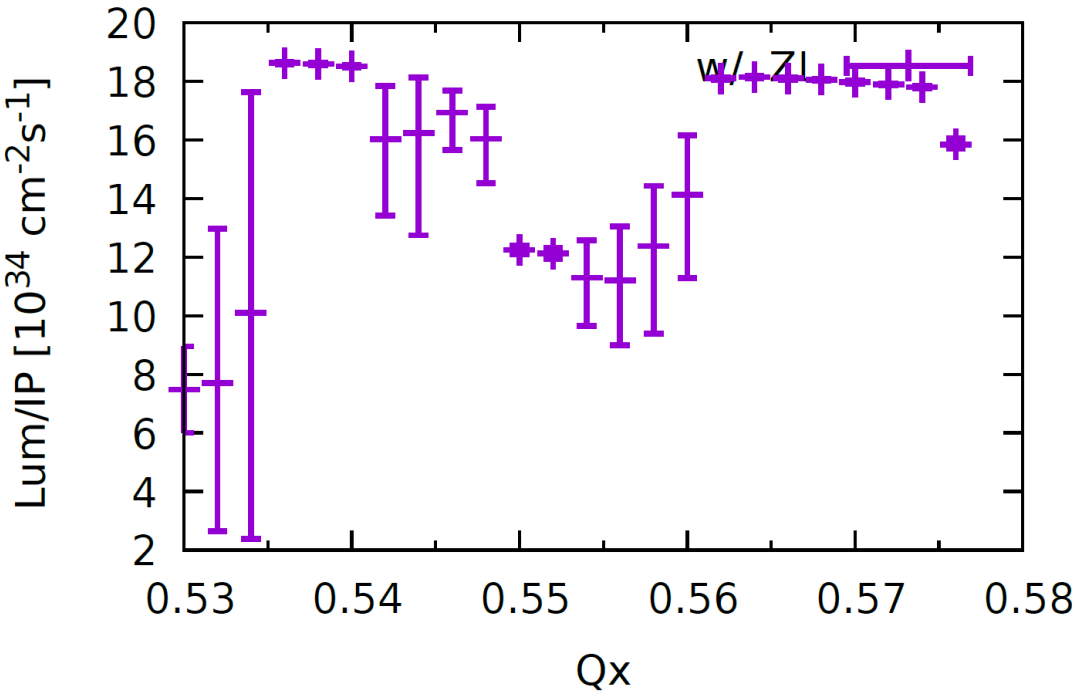


New Impedance

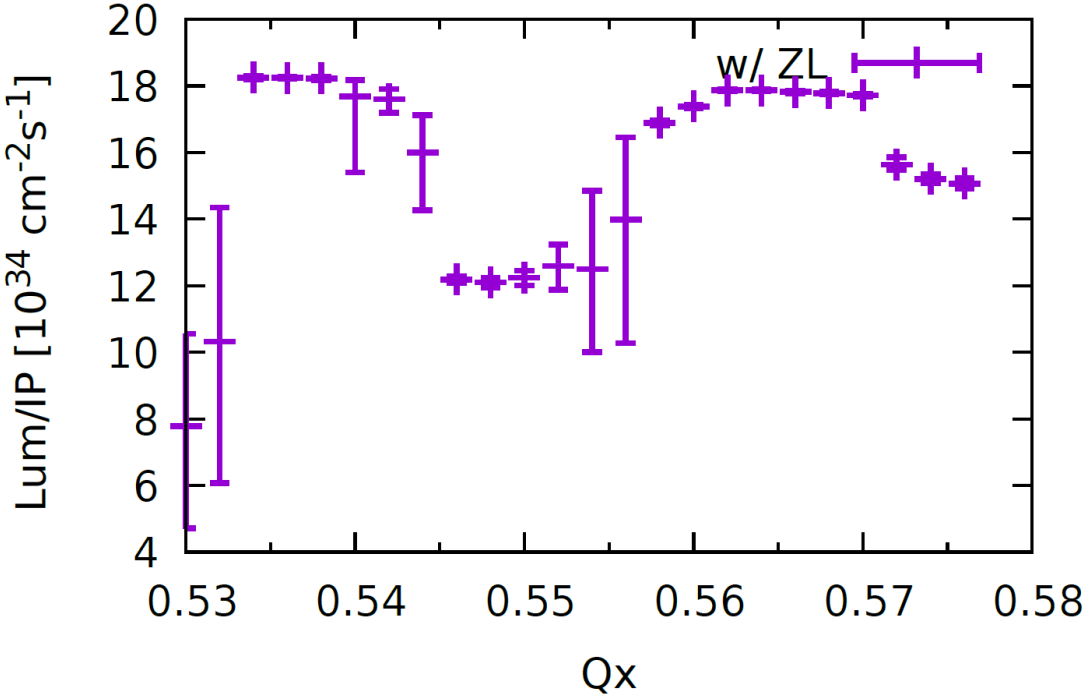


W: Luminosity versus Horizontal tune

Old Impedance



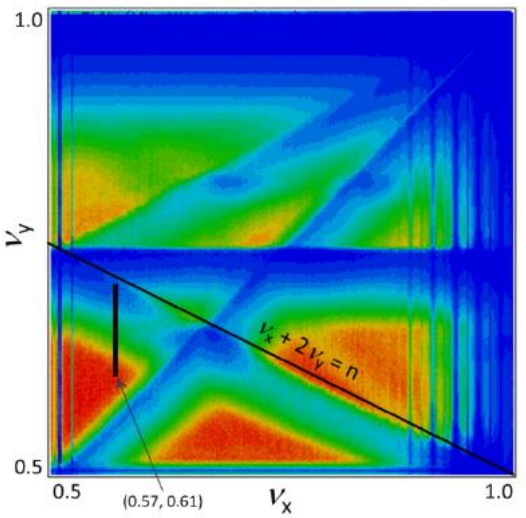
New Impedance



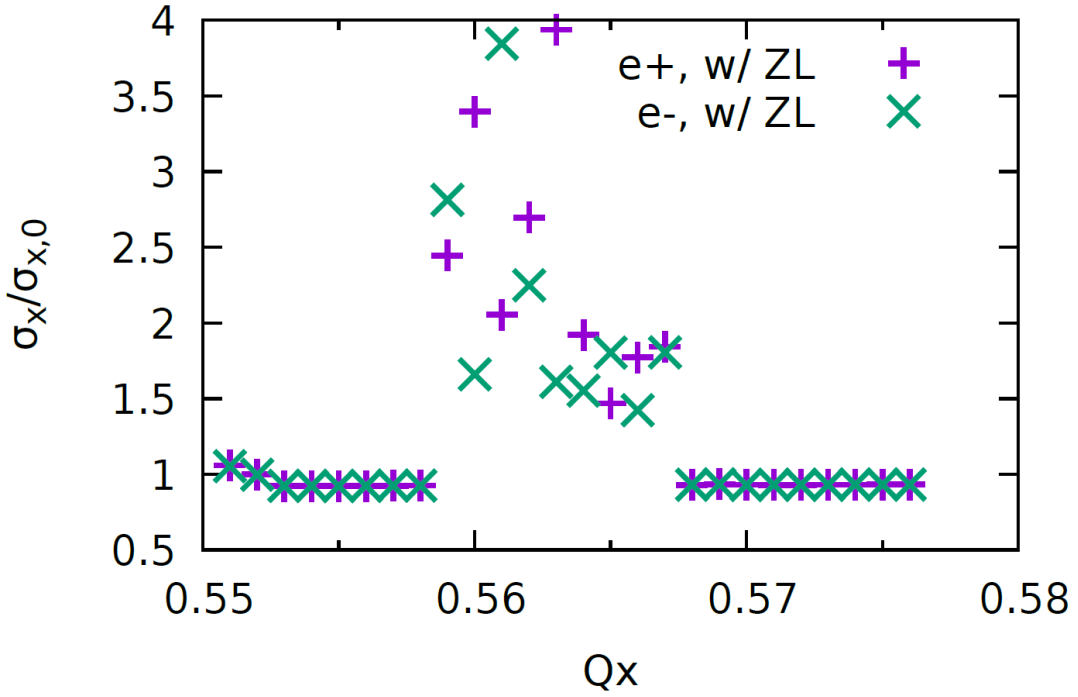
D. Shatilov, *ICFA Beam Dyn.Newslett.* 72 (2017) 30-41

Z: σ_x versus Horizontal tune

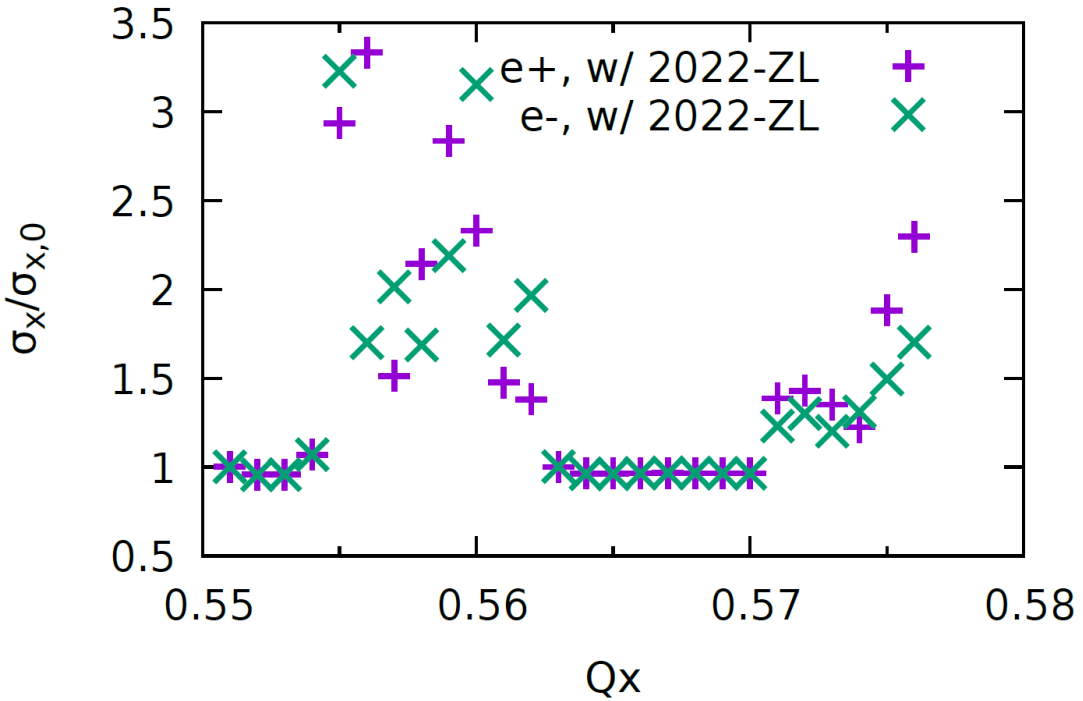
1) Stable tune area is still large enough, even squeezed.
2) The stable region is even better. (with lattice nonlinearity)



Old Impedance

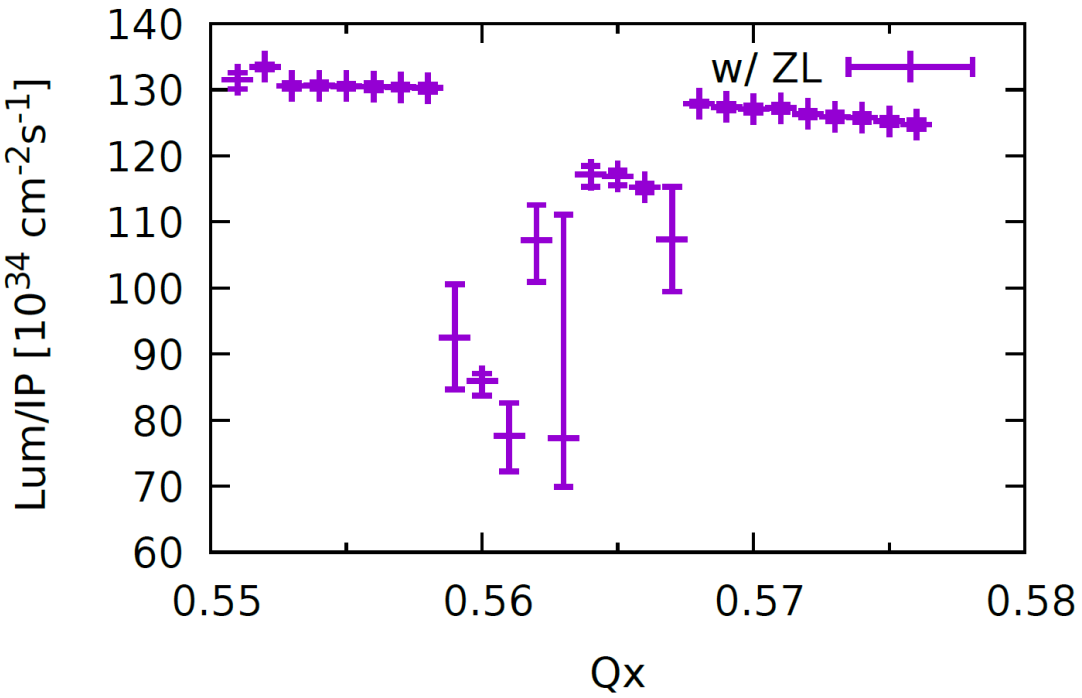


New Impedance

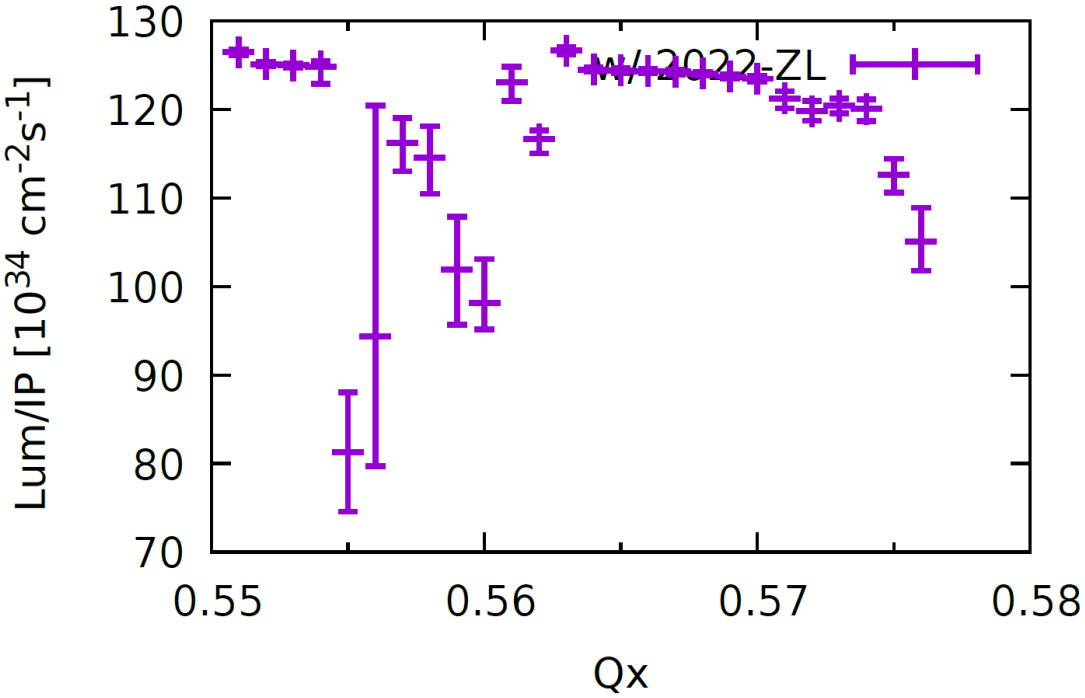


Z: Luminosity versus Horizontal tune

Old Impedance

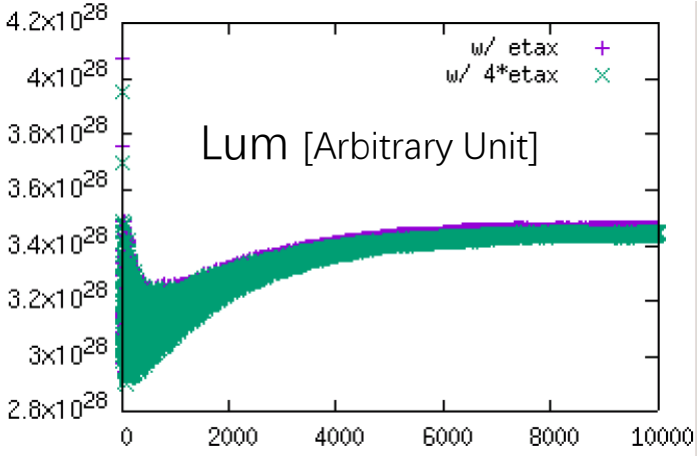


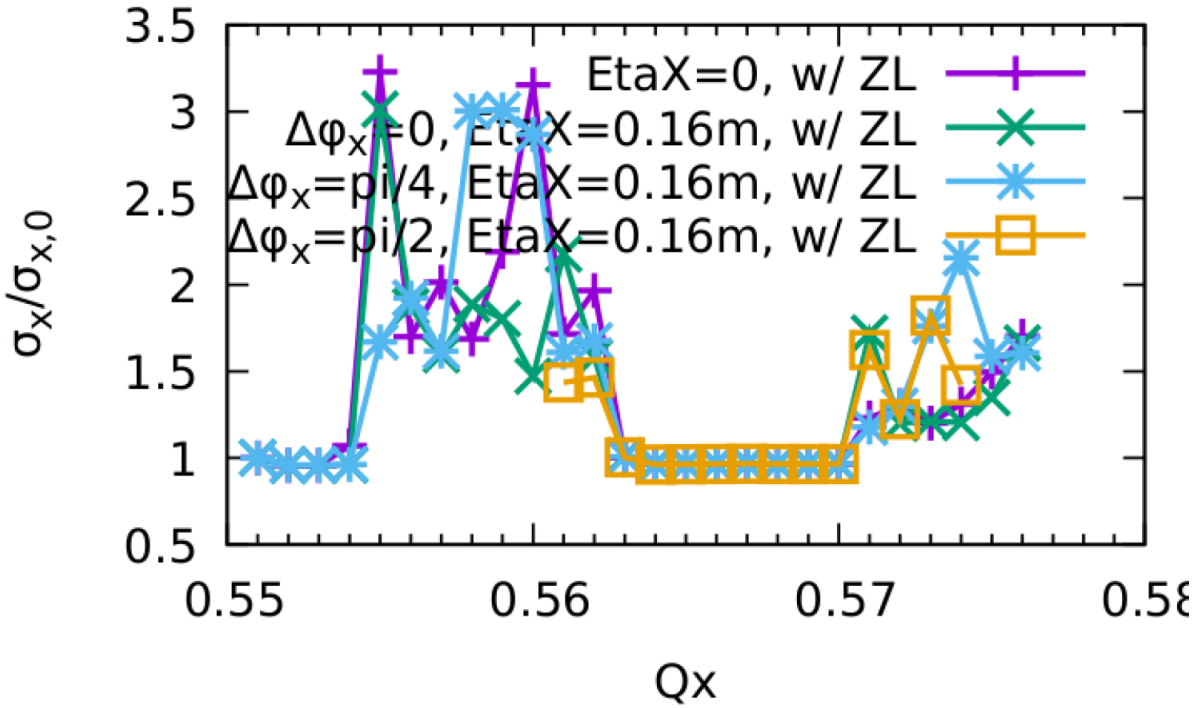
New Impedance

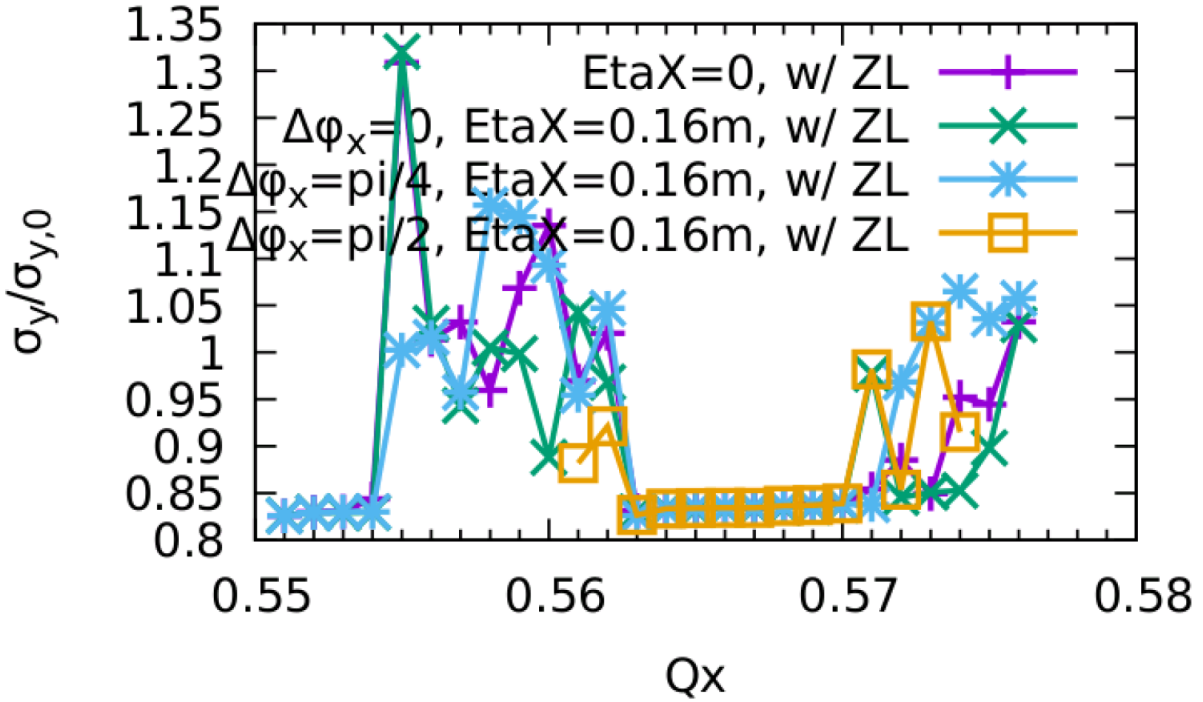


Finite dispersion @ ZL

- It is not found any clear effect from finite dispersion



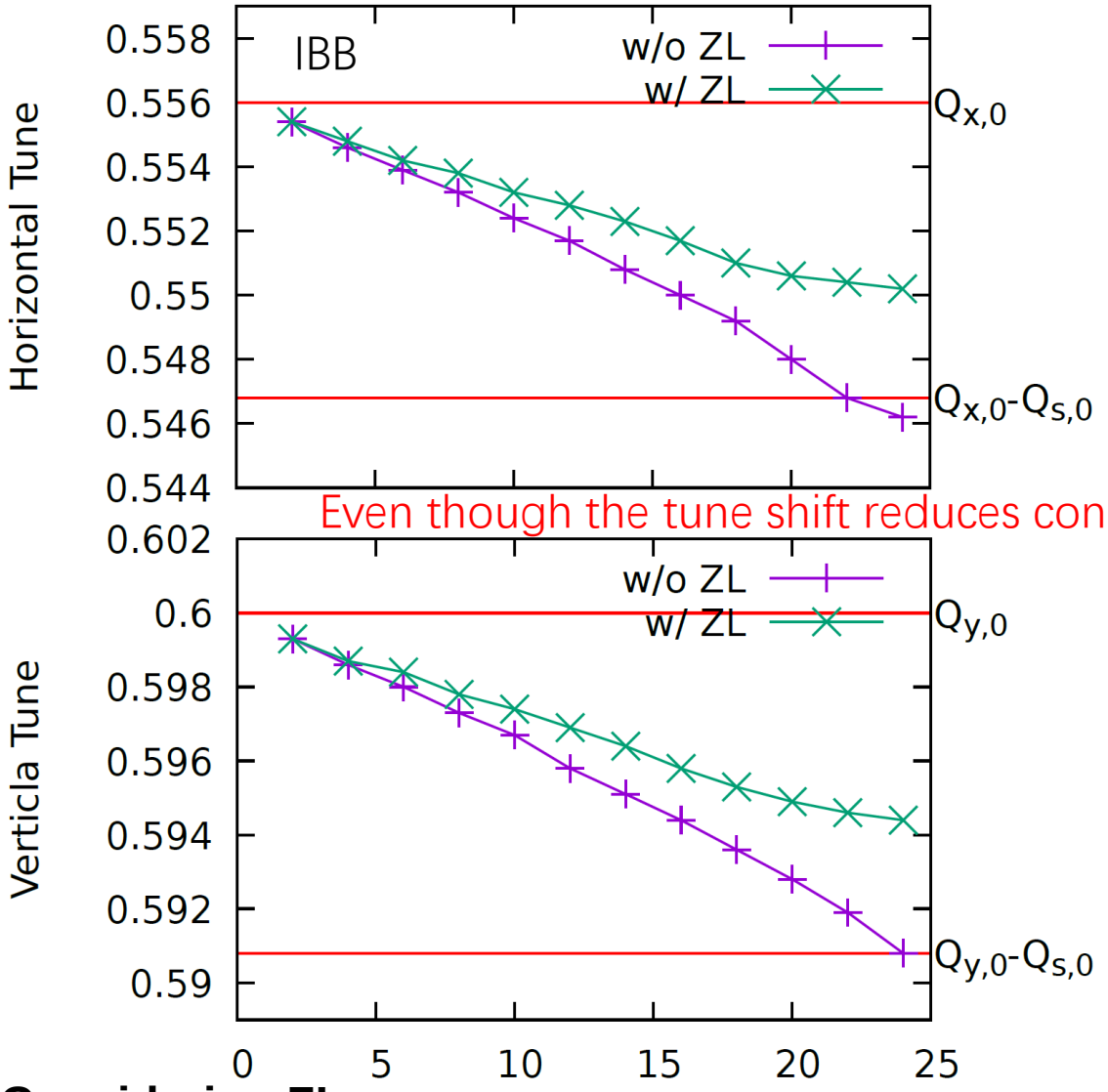




Frequency Analysis of Single Beam with Transverse Impedance (ZT)

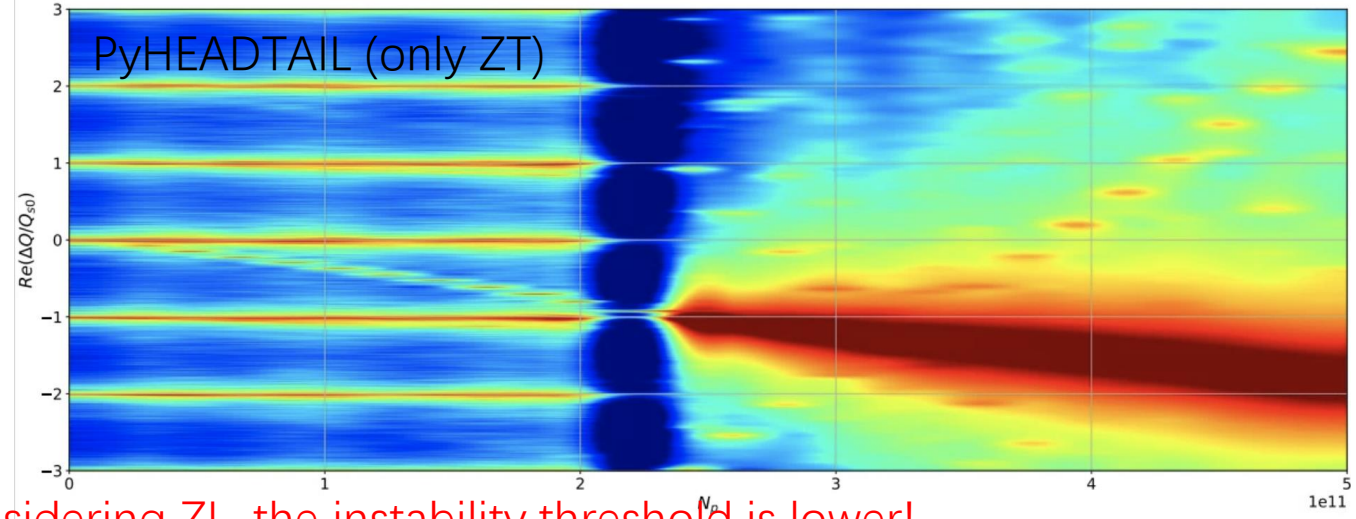
Courtesy of Mauro Migliorati

Considering ZL,
the X threshold reduces from 22e10 to 18e10.

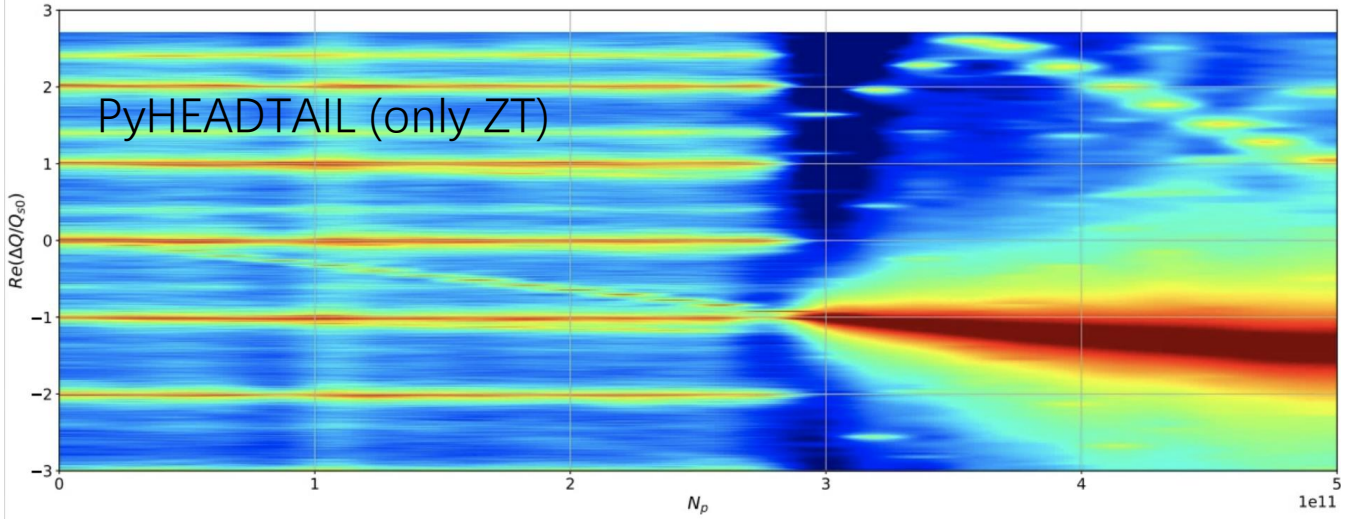


Considering ZL,
the Y threshold reduces from 24e10 to 18e10.

Considering ZL,
the X threshold reduces from 22e10 to 18e10.



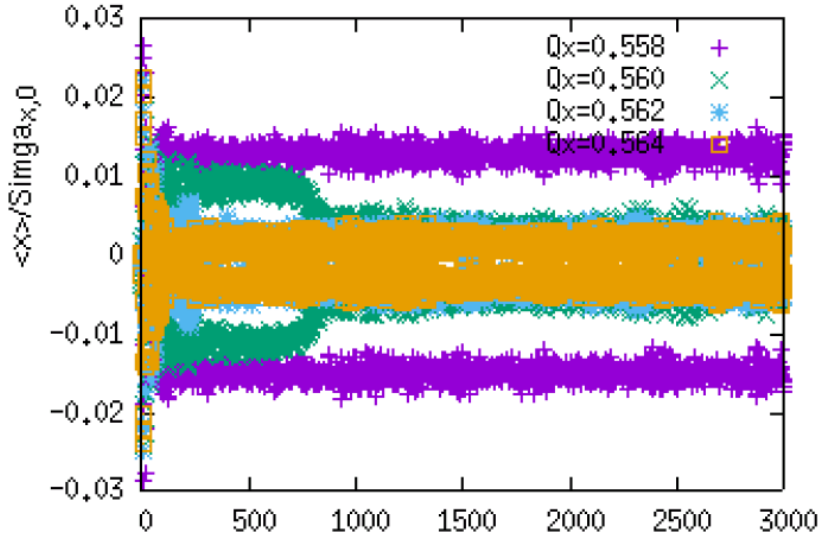
Even though the tune shift reduces considering ZL, the instability threshold is lower!

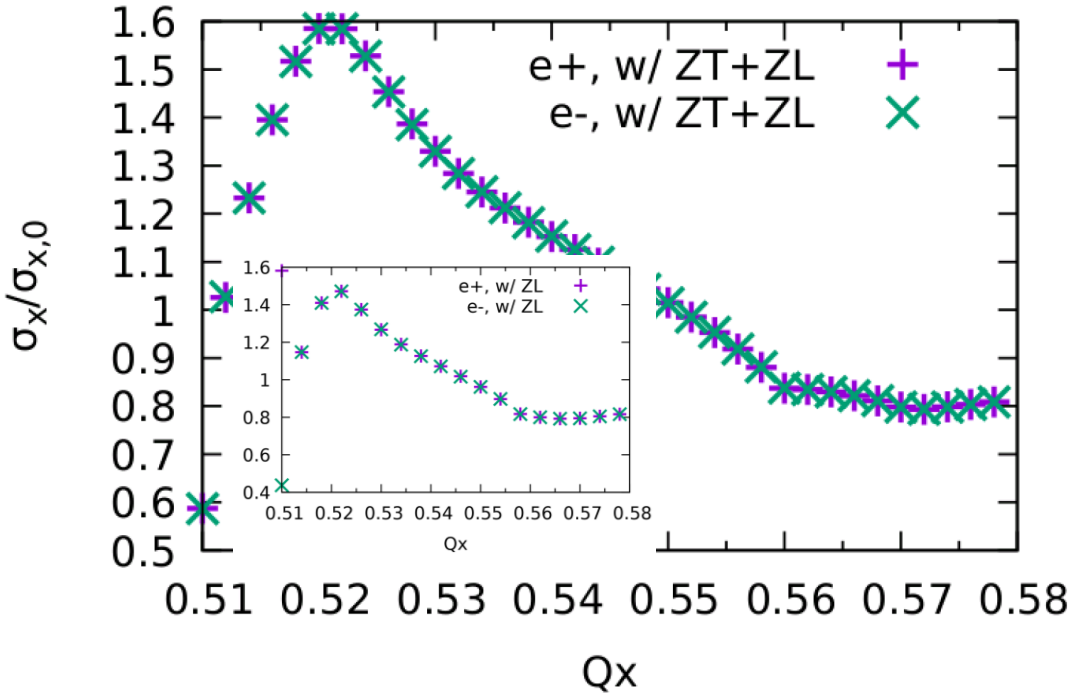


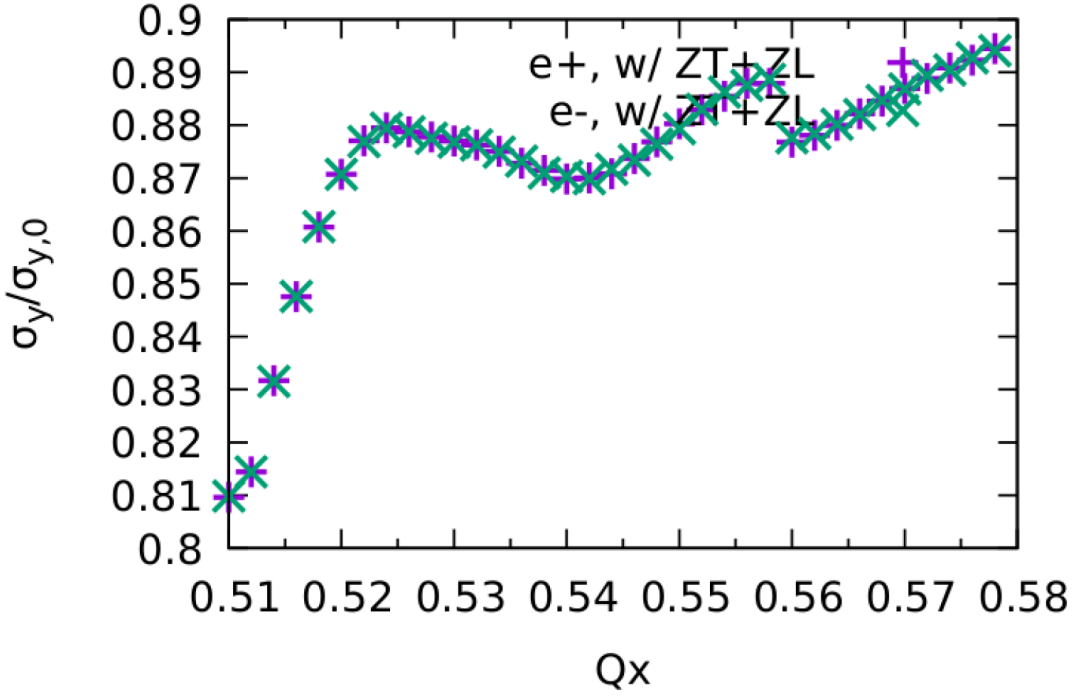
Considering ZL,
the Y threshold reduces from 30e10 to 20e10.

ttbar, w/ZT

No clear effect from transverse impedance.

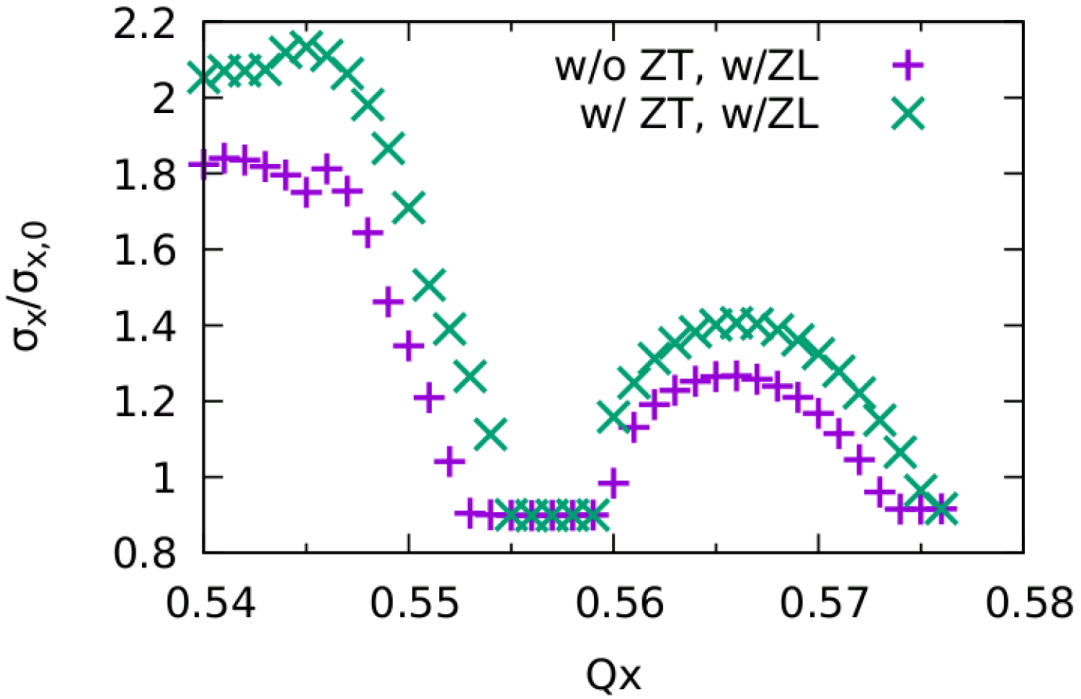


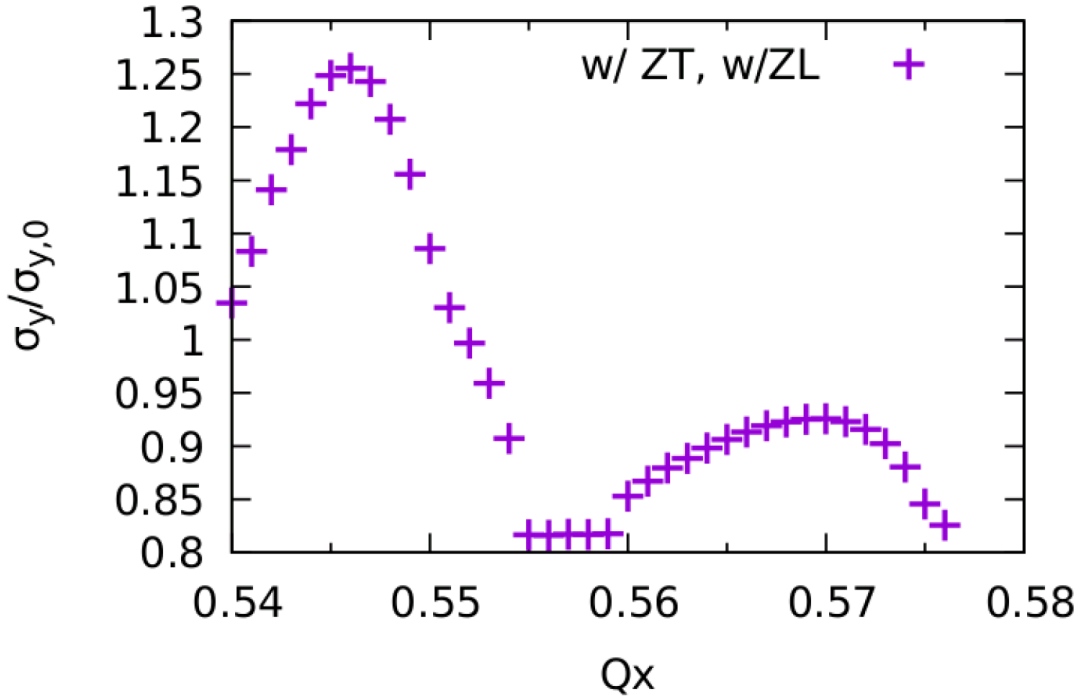




Higgs, w/ ZT

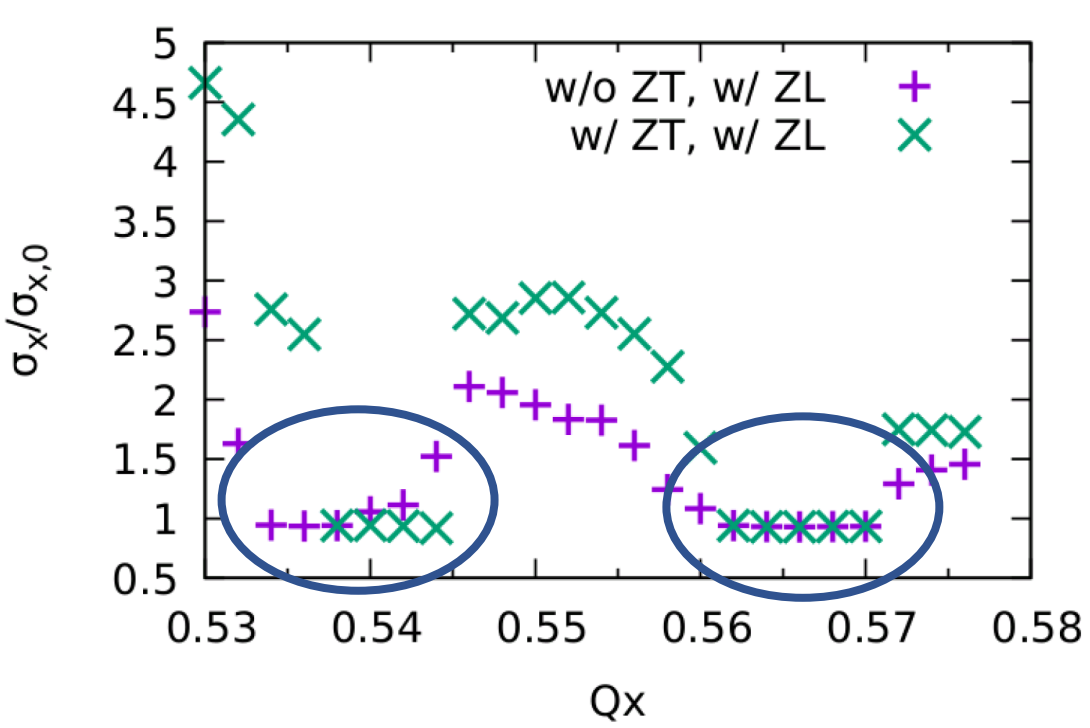
- Only X-Z instability
- Stable width seems to be reduced a little

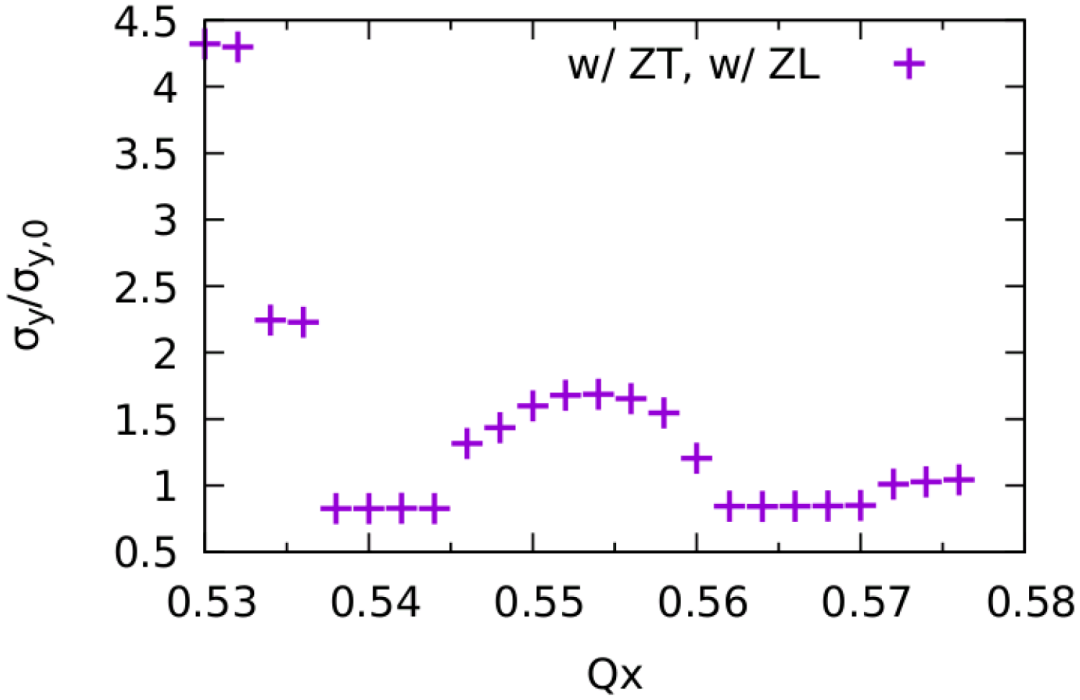




W, w/ ZT

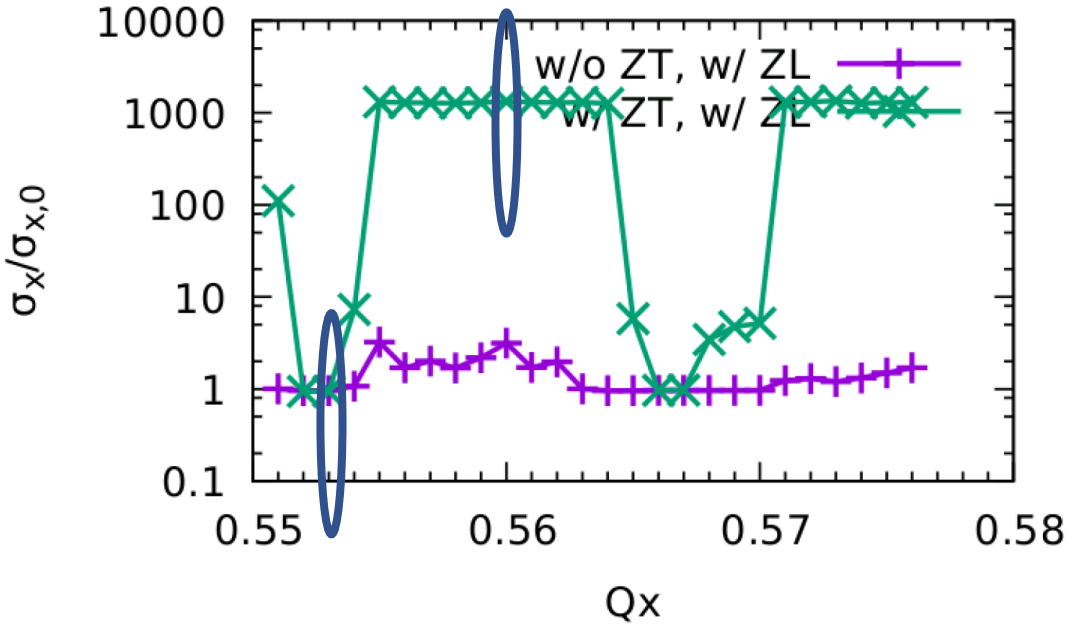
- Only X-Z instability
- Shift of stable region to be understood

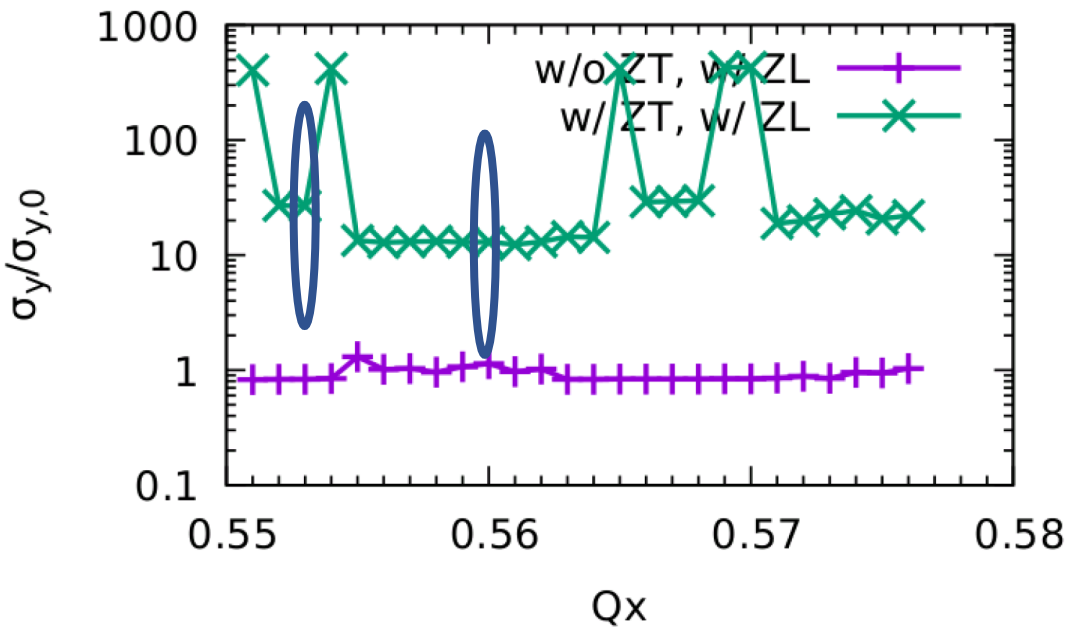




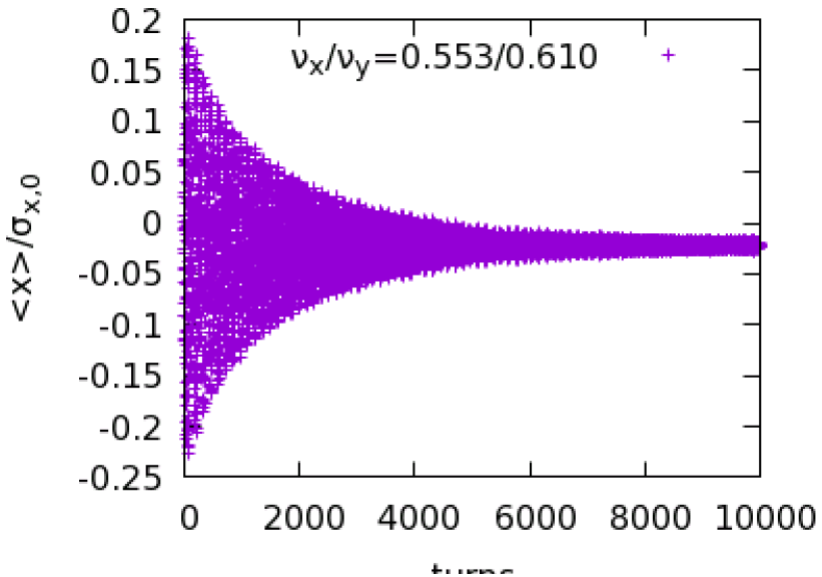
Z, w/ ZT

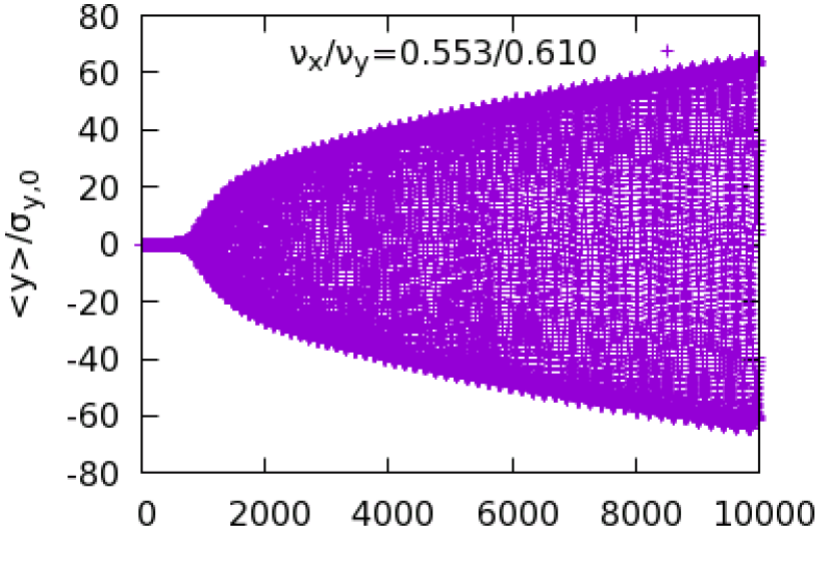
- Nearly no stable working points
- There exist very strong blowup in both X/Y direction

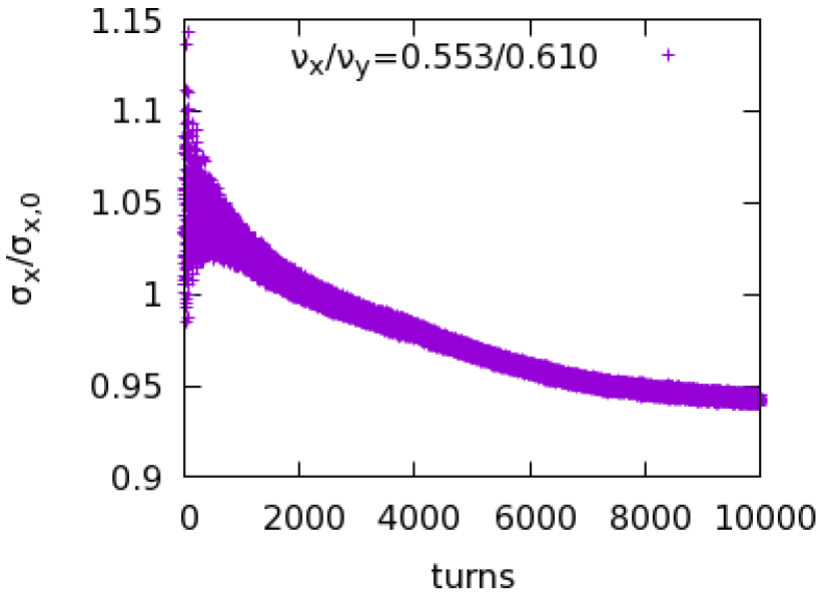


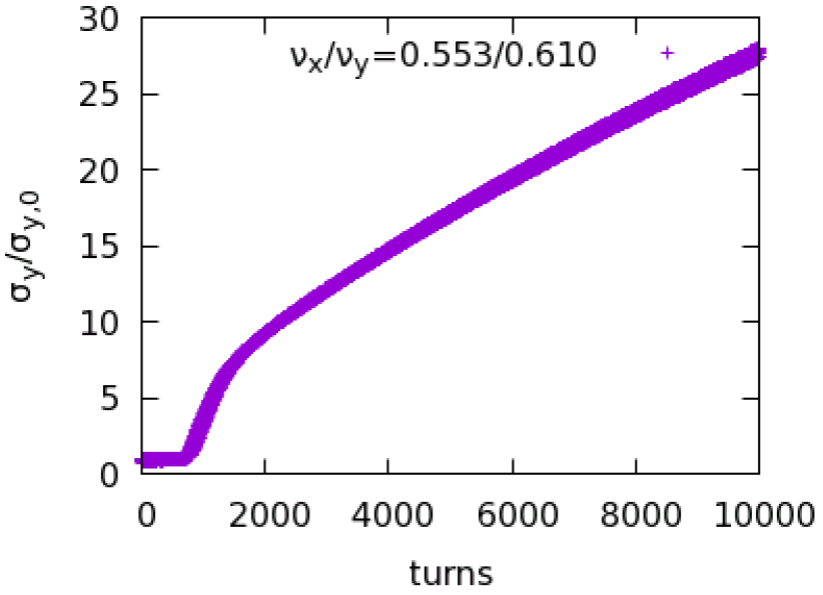


Evolution @(0.553,0.610), w/ZT



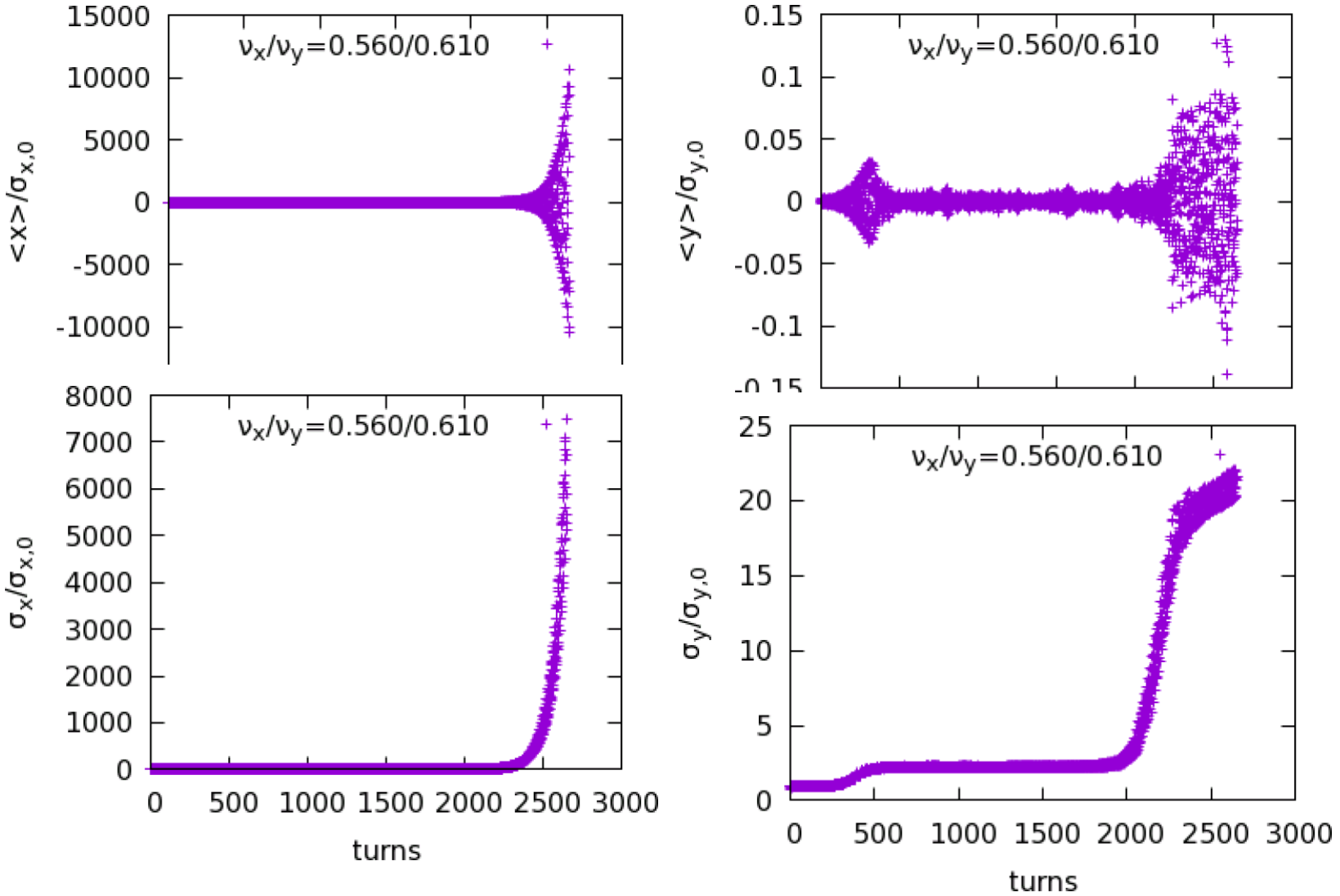






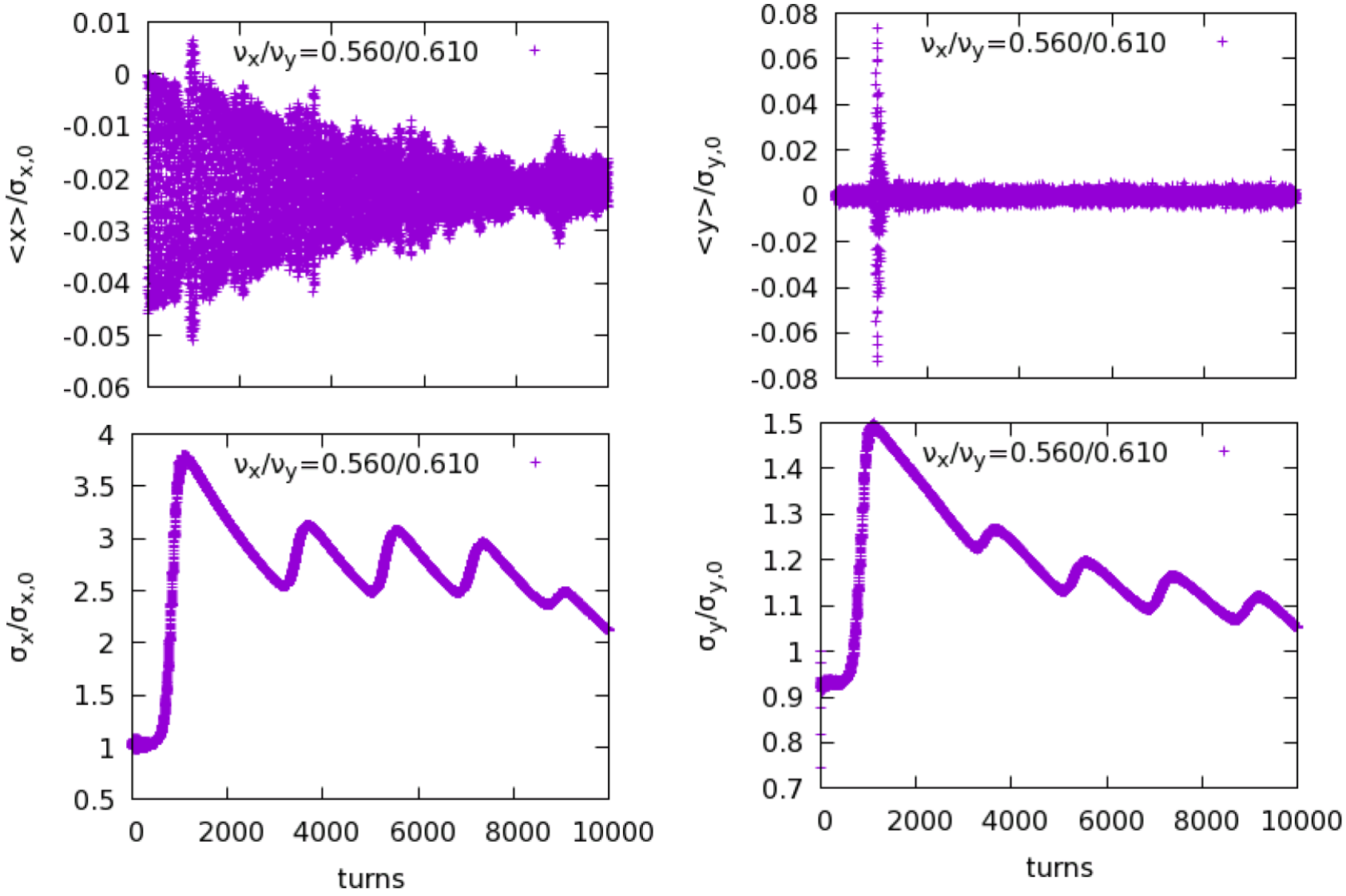
- Both dipole and quadrupole oscillation is unstable in Y direction
- TMCI like instability

Evolution @(0.560,0.610), w/ZT



- There exist exponential growth in both dipole and quadrupole oscillation in X direction, which is different from X-Z instability
- The vertical instability is damped more or less when there exist strong instability in X direction

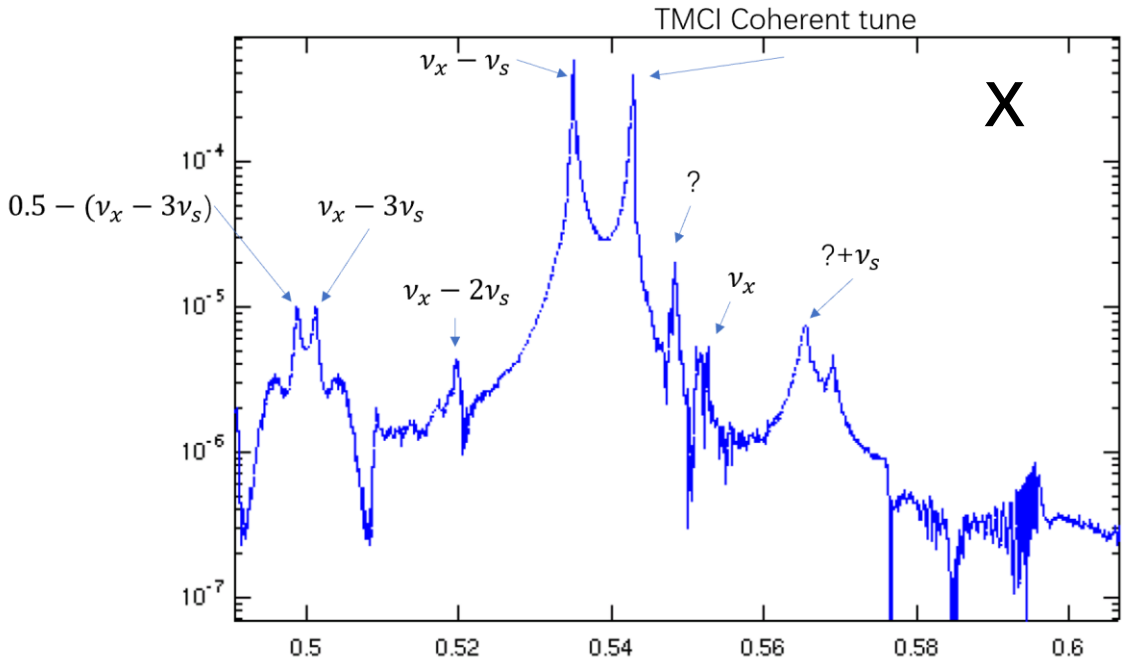
Evolution @(0.560,0.610), w/o ZT

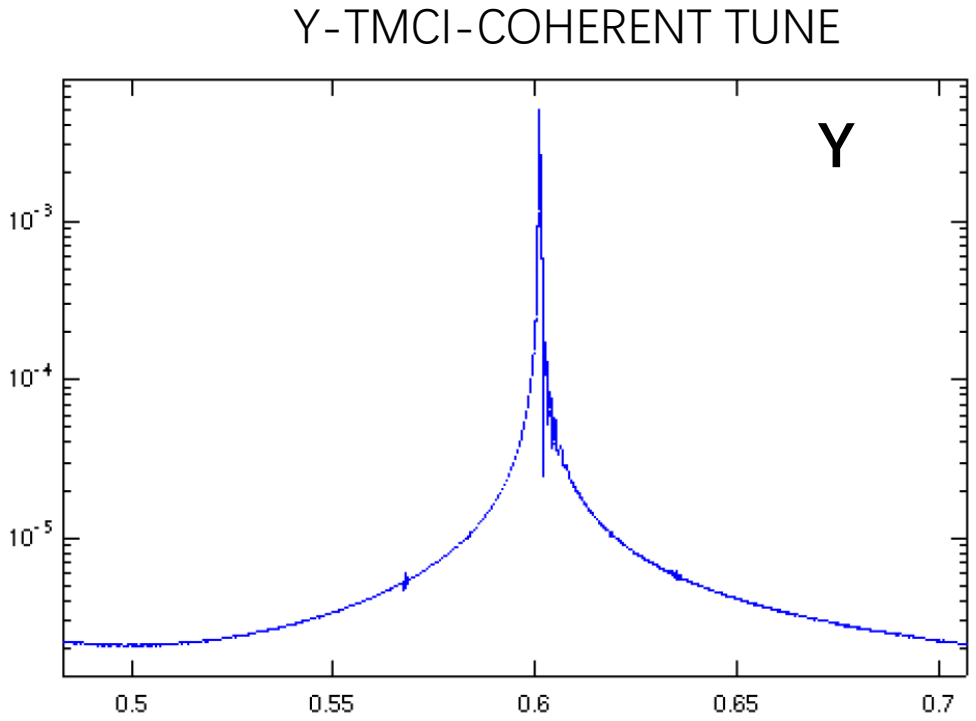


- Typical X-Z instability

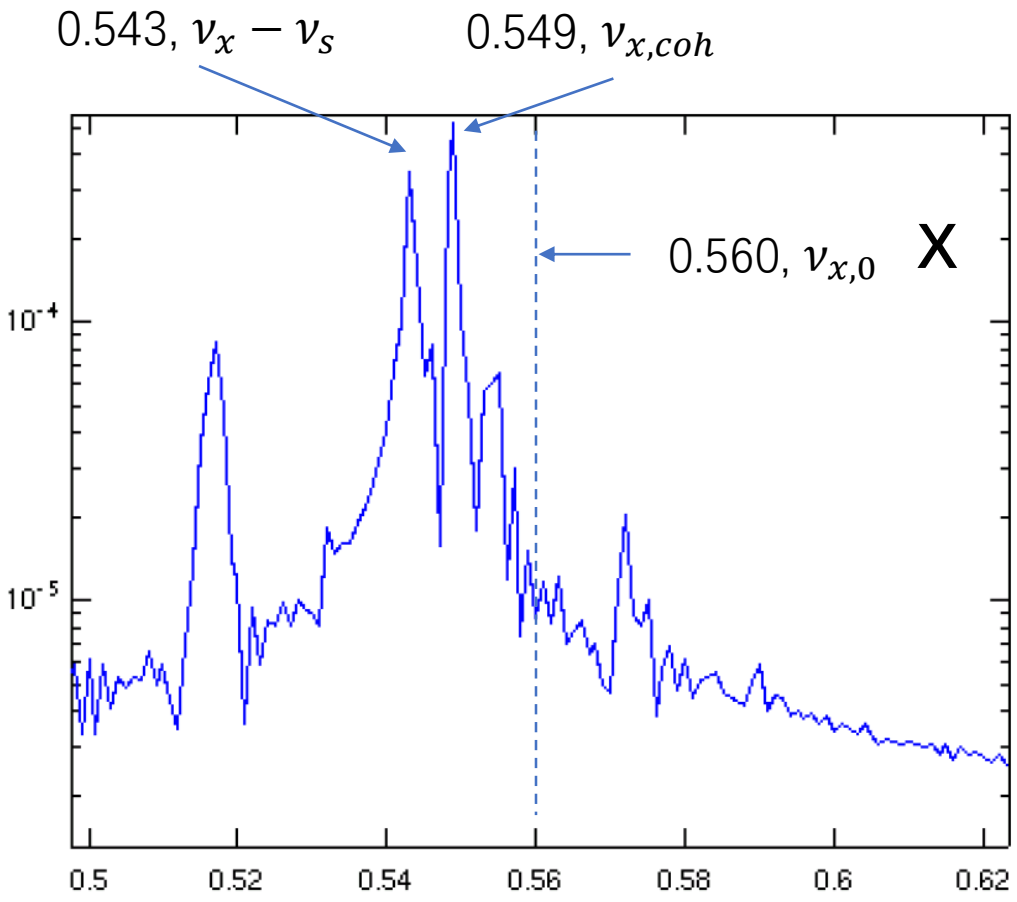
Spectrum @(0.553,0.610) , w/ ZT

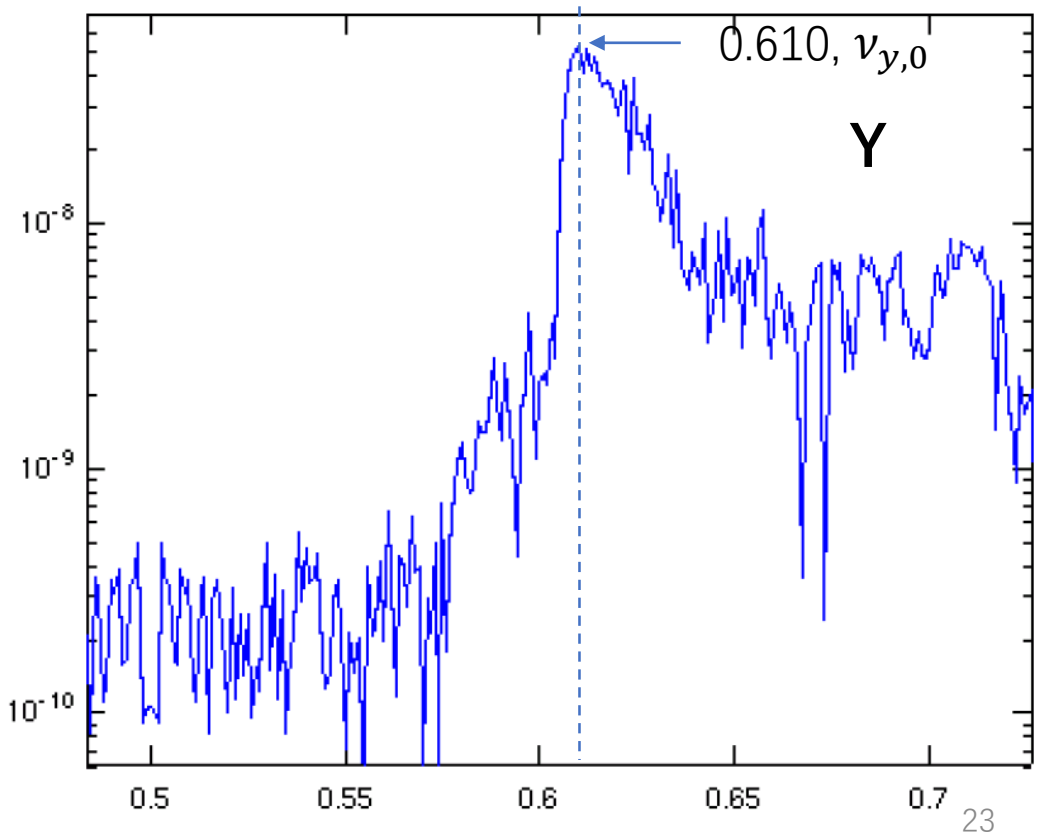
- Only Y unstable





Spectrum @ (0.56,0.610), w/ZT (1000turns)

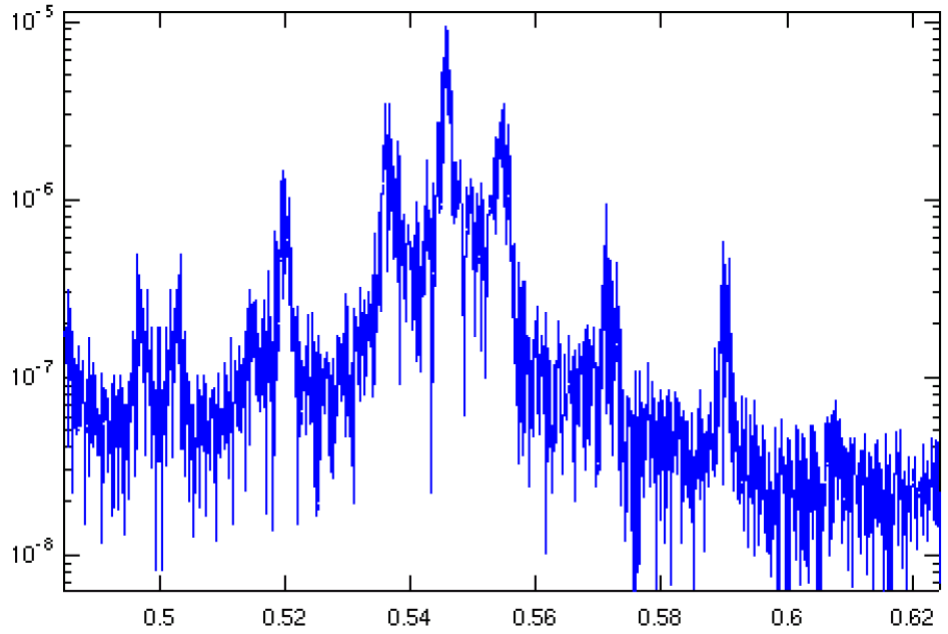


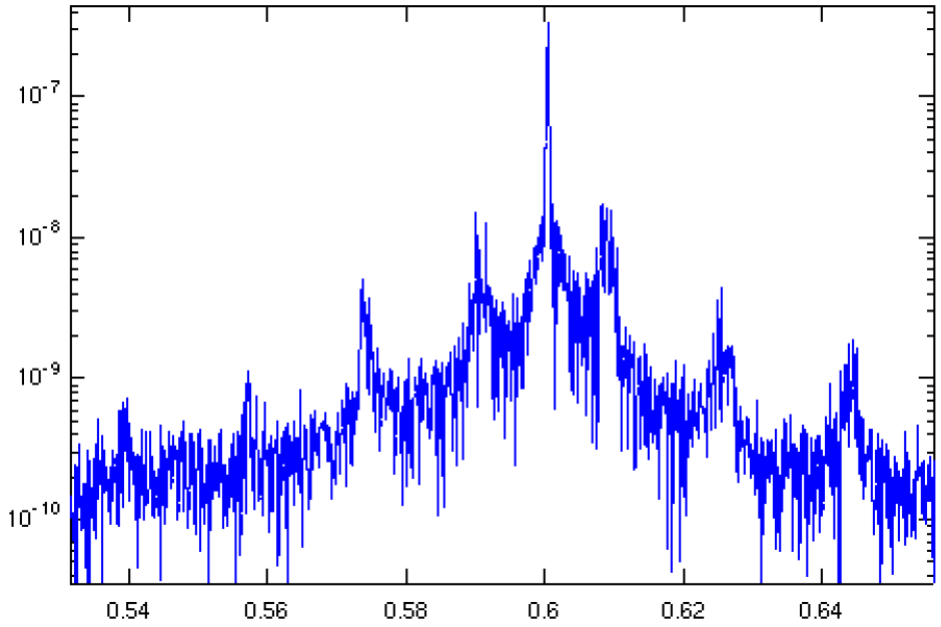


Keep same bunch length and energy spread as that with collision

Spectrum, off-col, w/ ZT

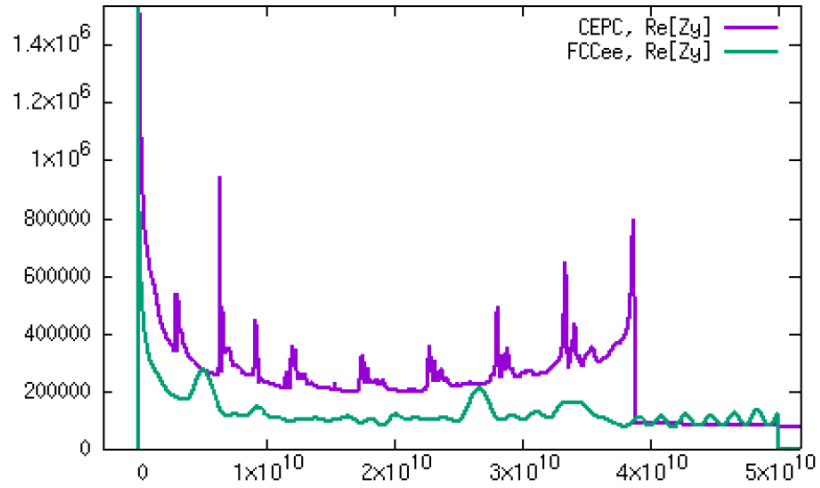
There does not exist mode coupling instability only considering ZT.

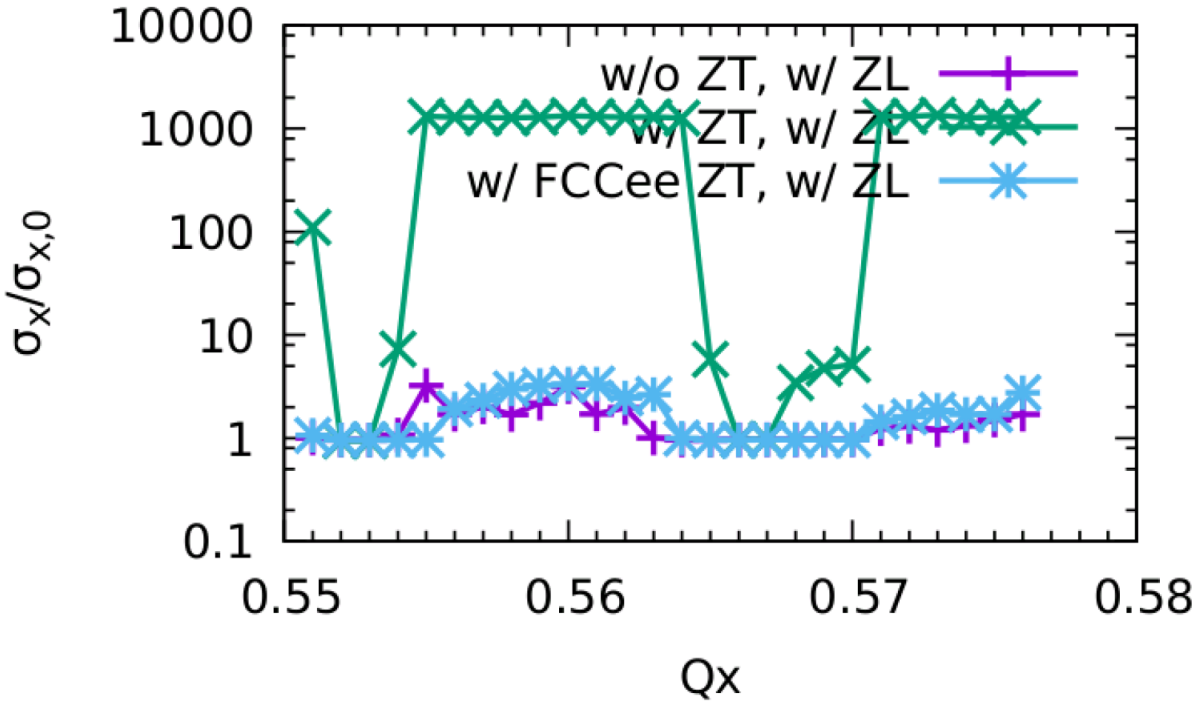


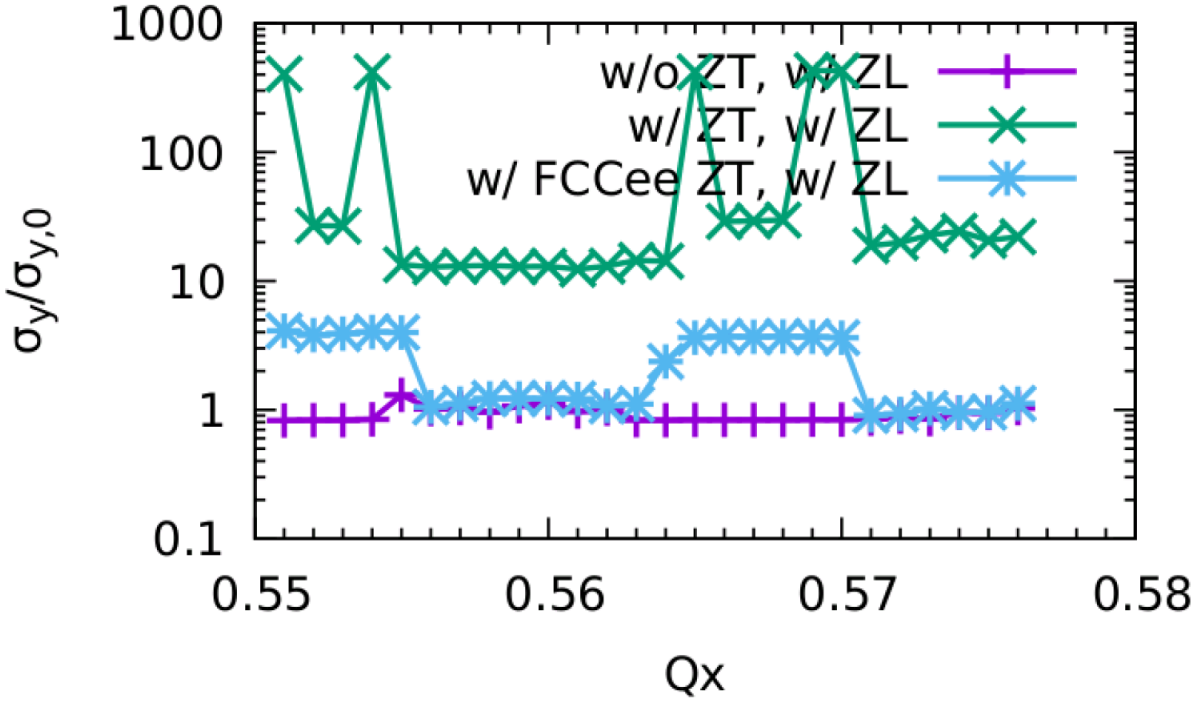


w/ ZT of FCCee

- Horizontal is stable
- Vertical is still unstable, but much weaker

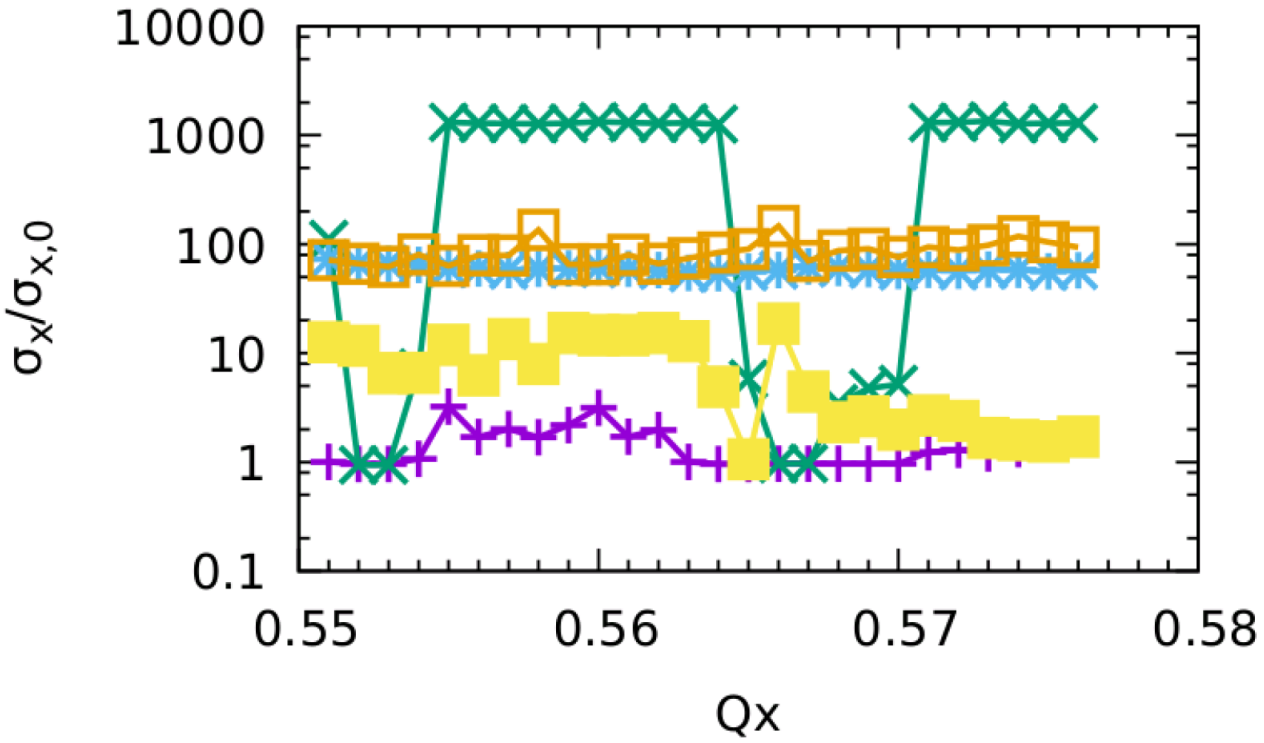


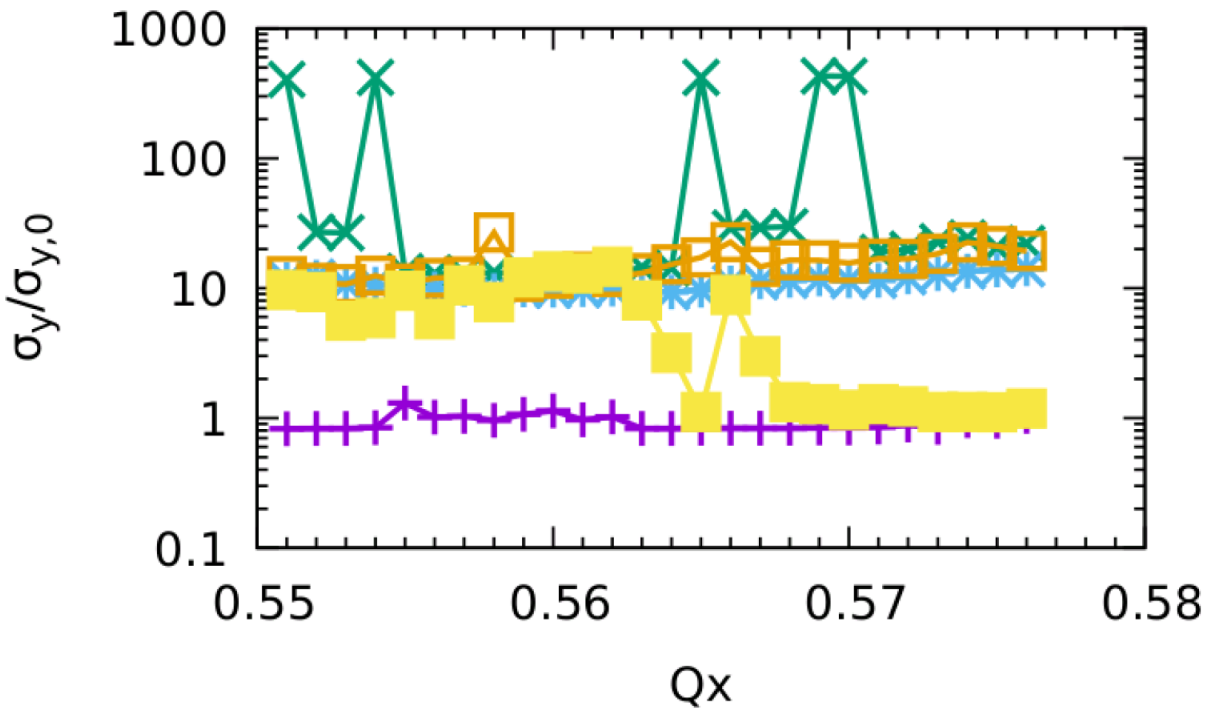




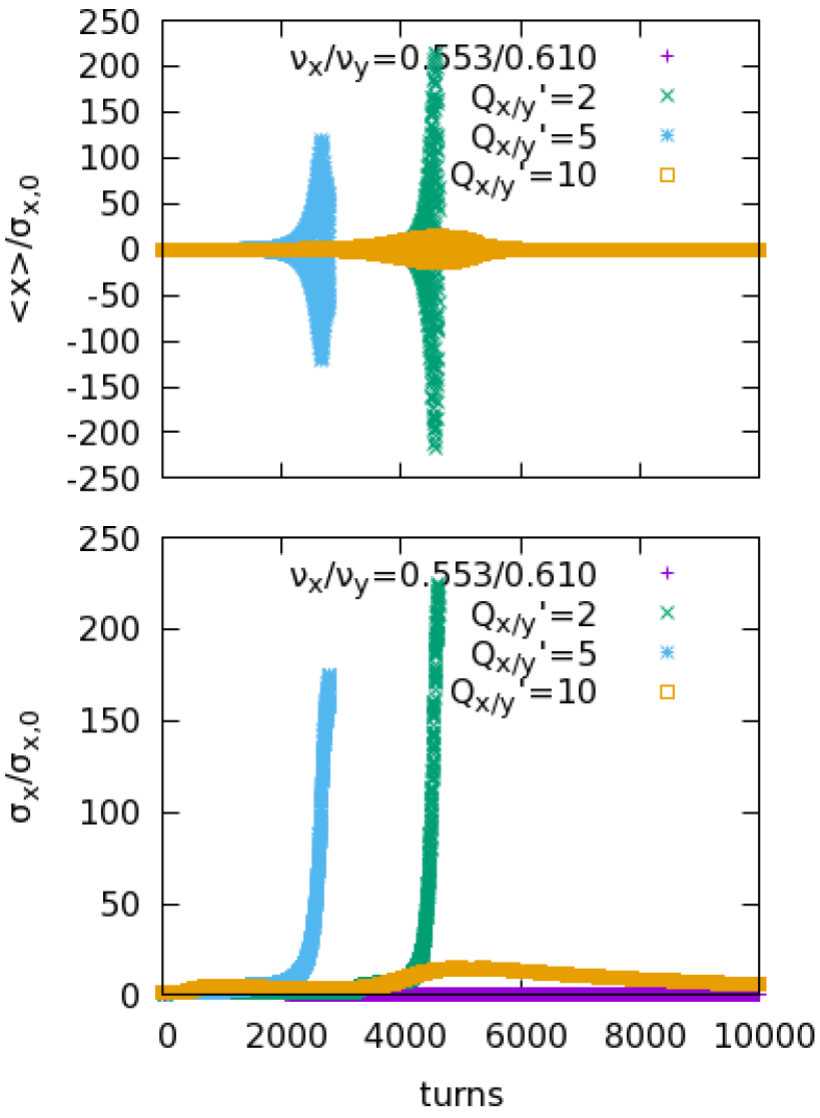
Tune Chromaticity

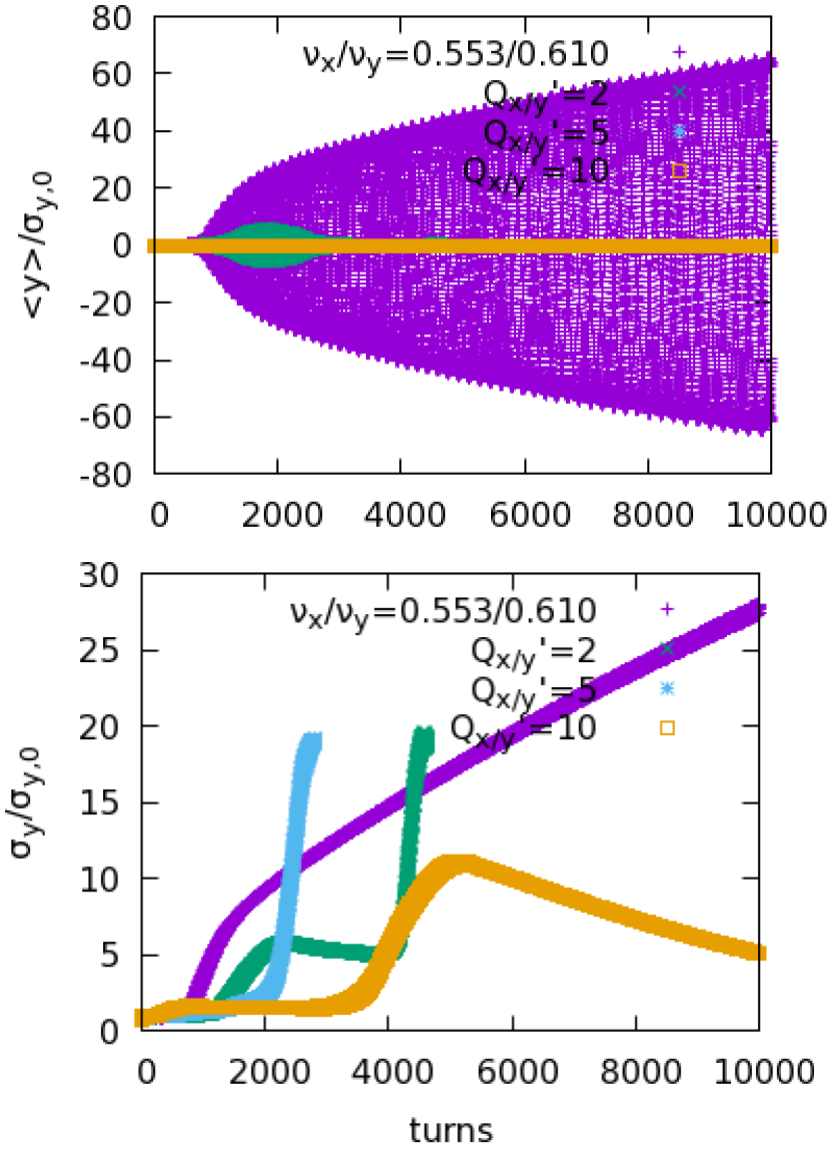
- Even the tune chromaticity could suppress the instability, there still exist clear beam size blowup.





Evolution with finite chromaticity (w/ ZT)

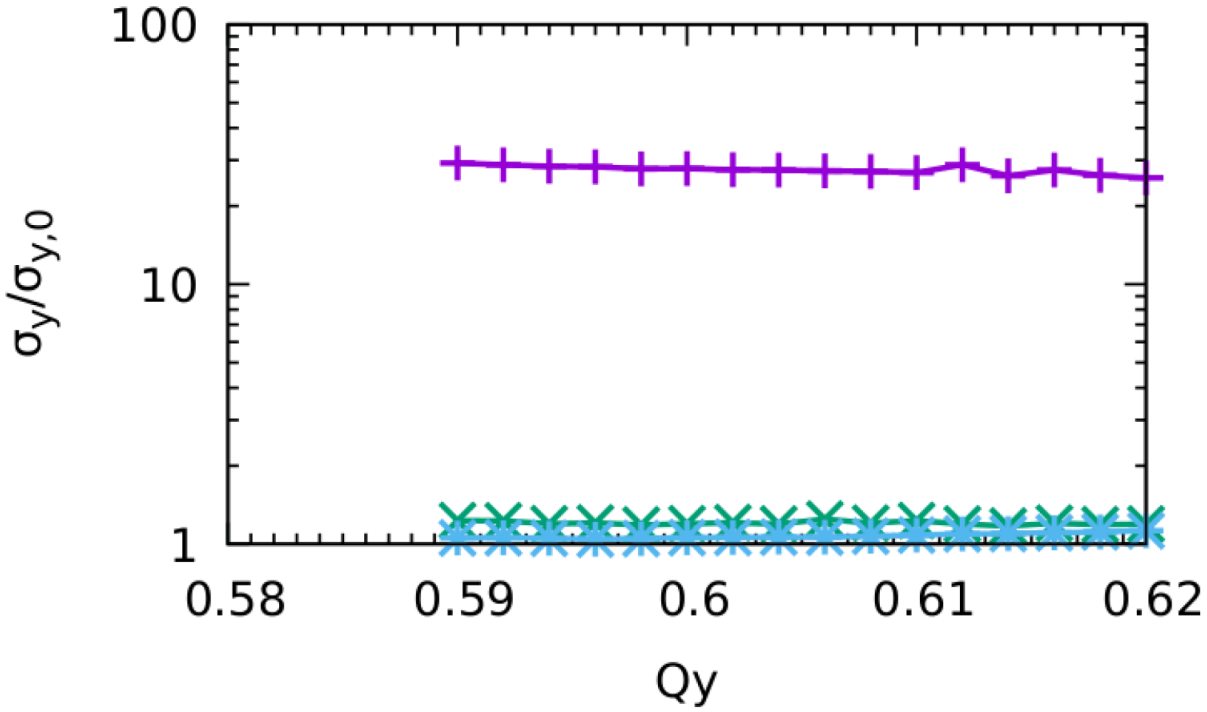


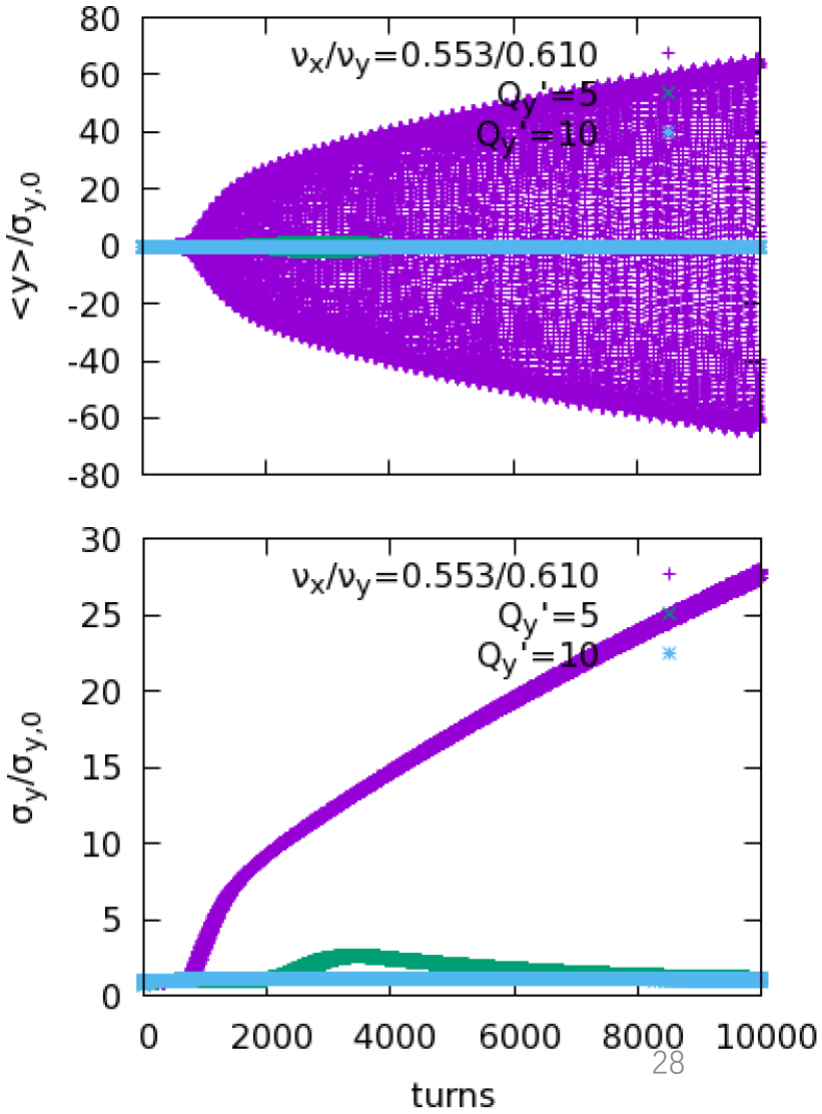


- Non-zero chromaticity could help mitigate the dipole instability (TMCI)
- For Q'=10/10, it seems more like a X-Z instability

Only with Vertical tune chromaticity (Qy')

- Qy'=10 could help mitigate the vertical instability

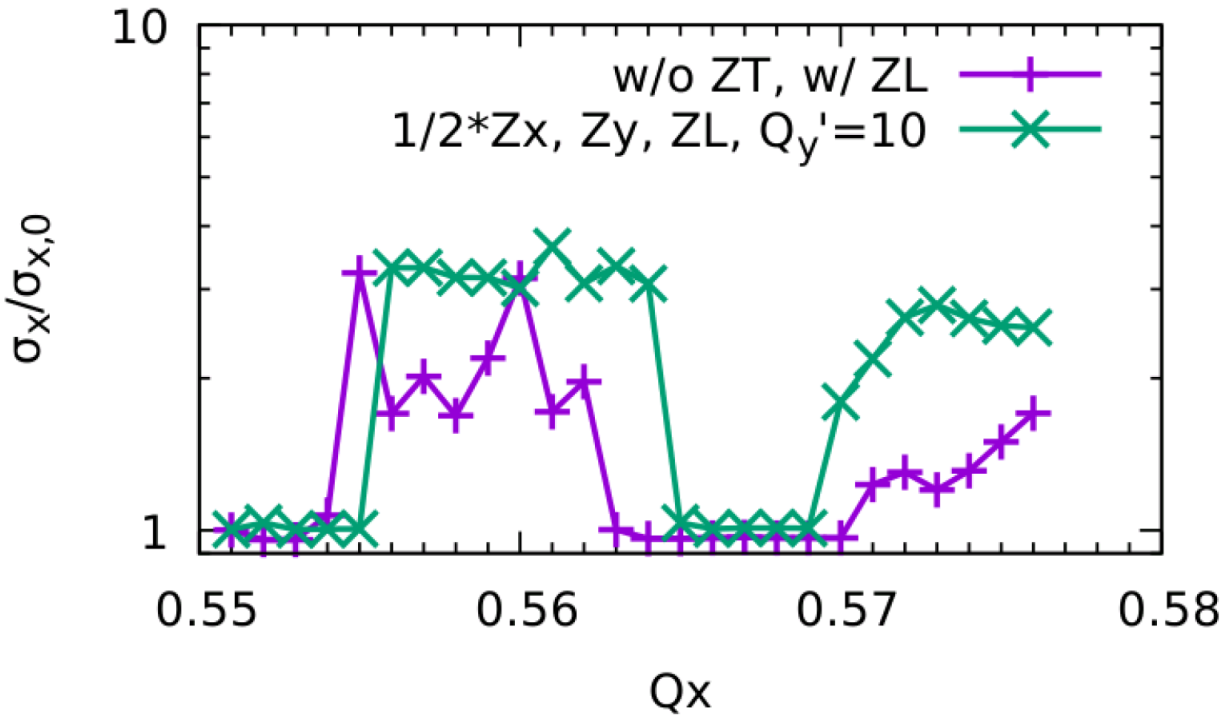


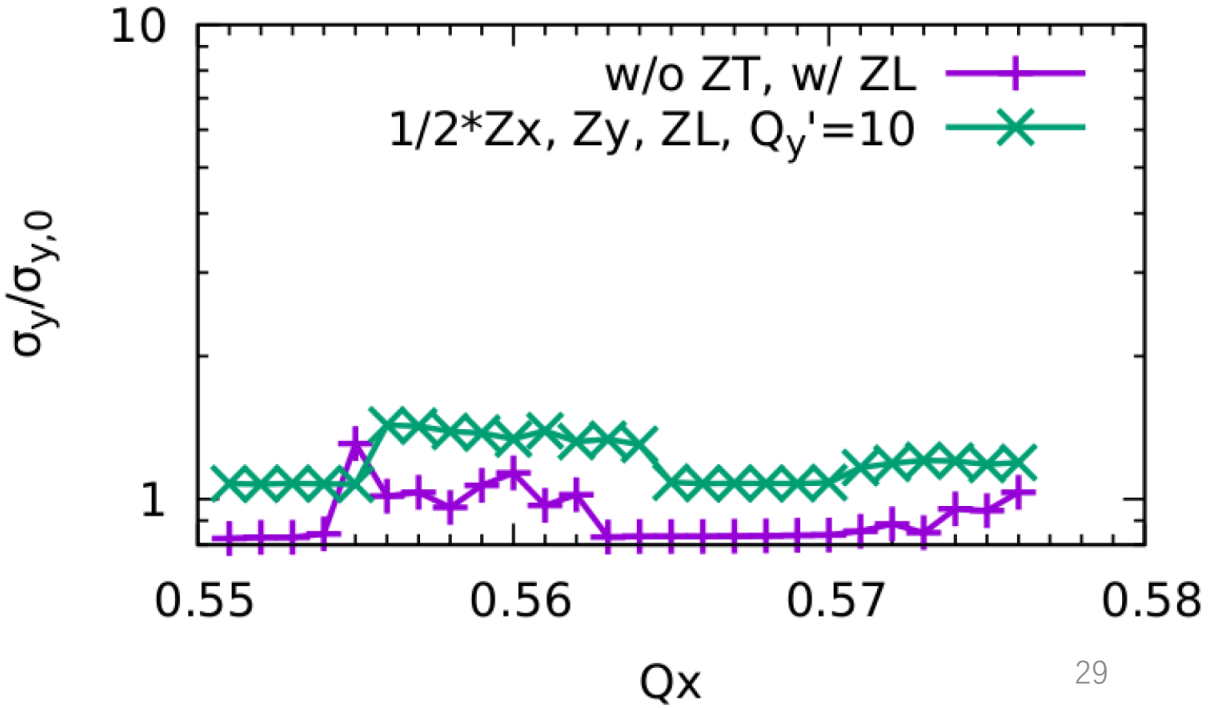


? Vacuum Chamber: Circular -> Elliptical

Zx*1/2 + Qy'=10

- There does not exist dipole exponential growth in both X and Y direction
- However the stable horizontal tune area is too limited (0.003)



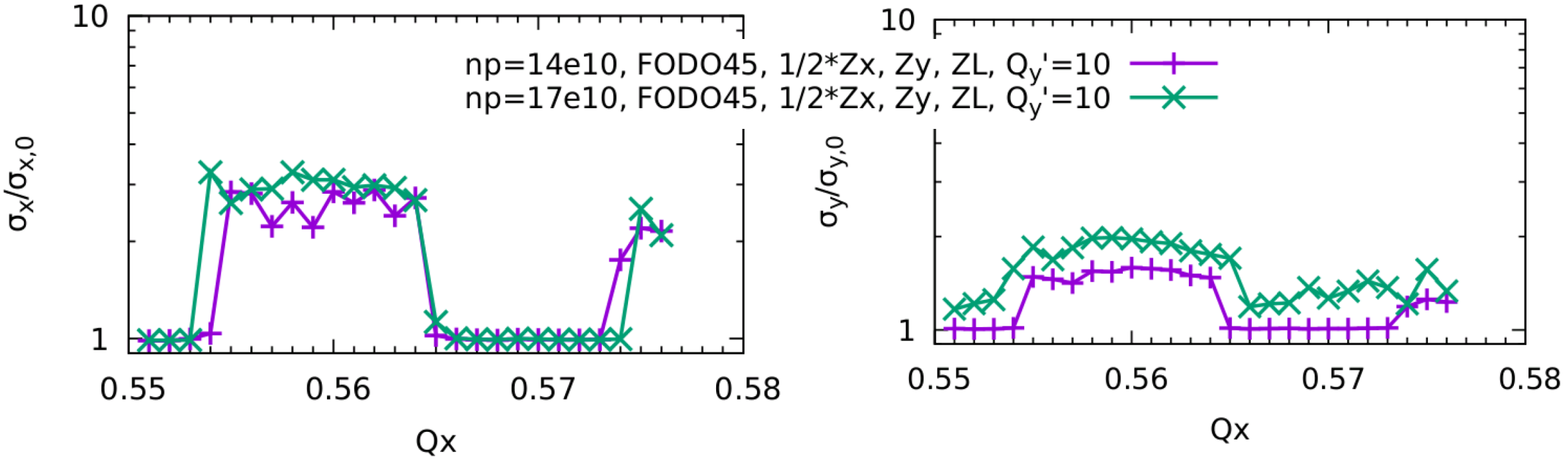


```
emitx = 0.64e-9 emity = 1.92e-12
```

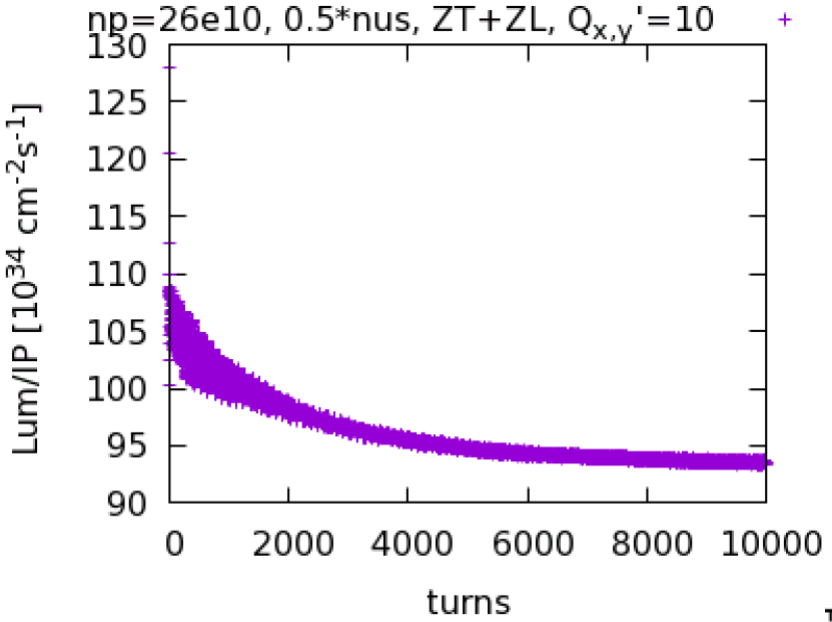
Fodo45, ½*Zx, Qy'=10

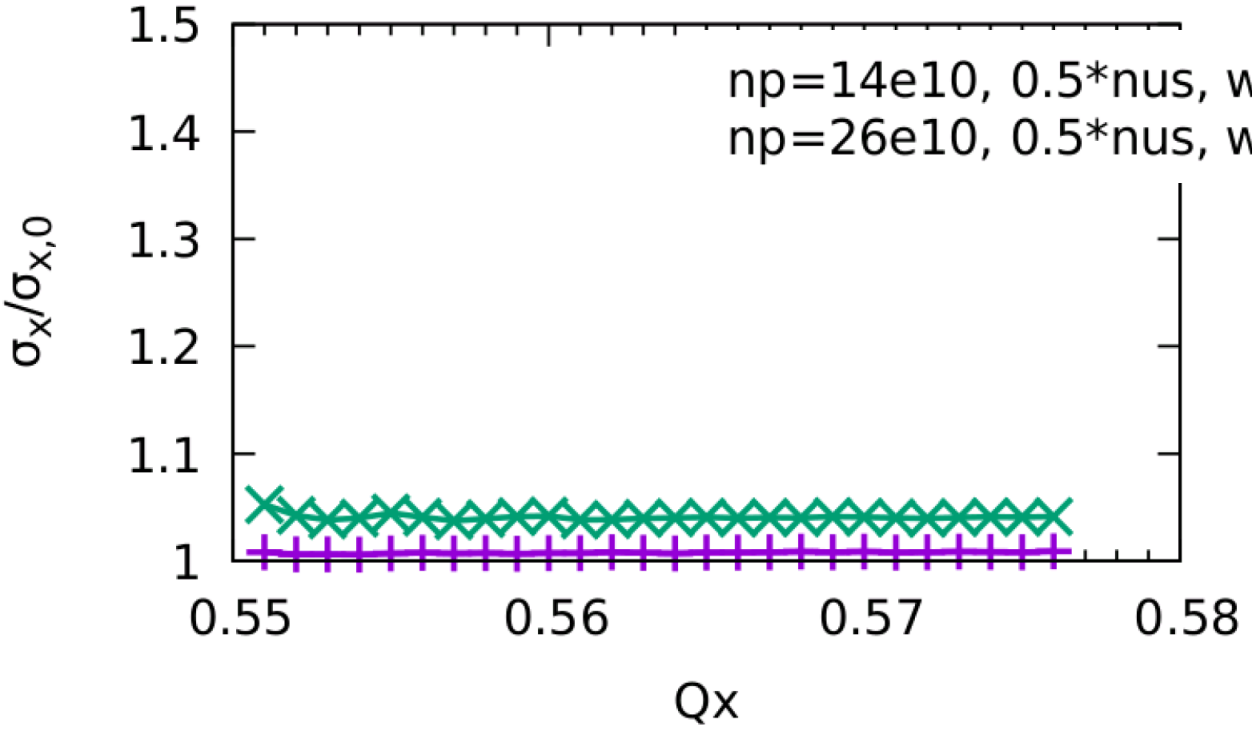
Nus=0.0235(half ring)

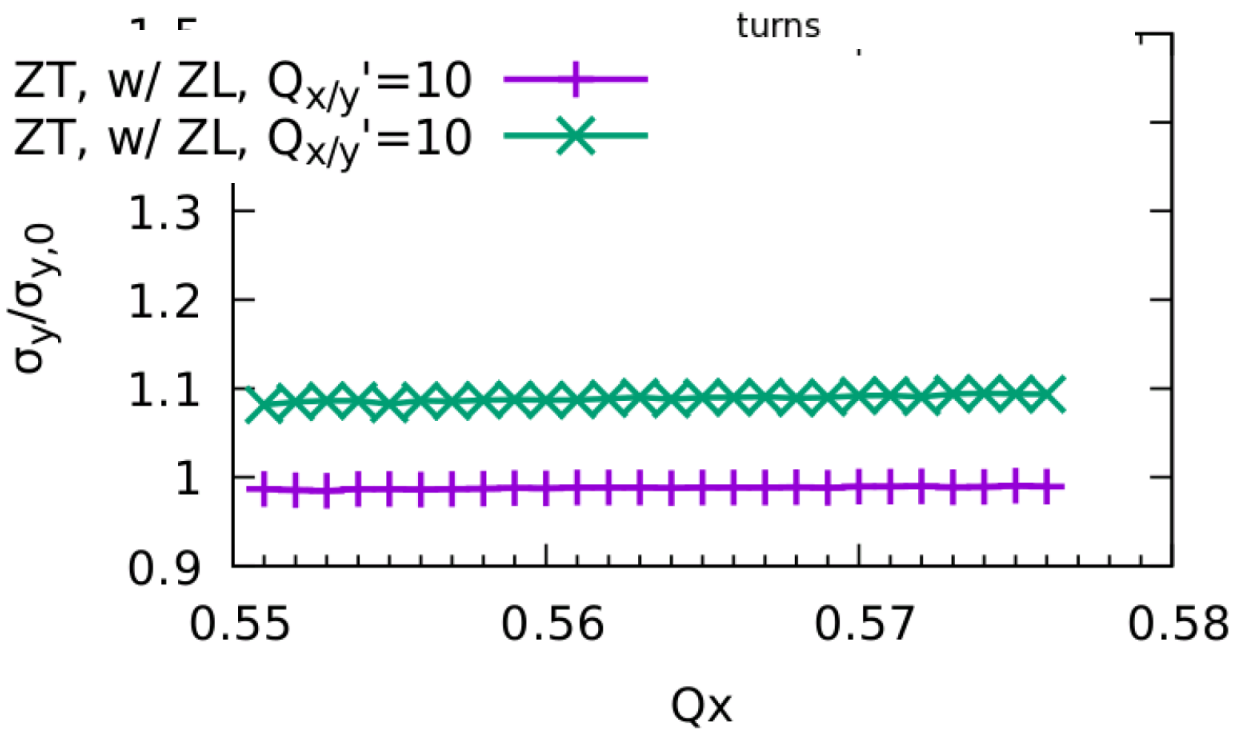
- Even design bunch population (14e10) is fine, it is unstable for 17e10.



½ ν_s (2*$\sigma_{z,0}$), Q'=10/10

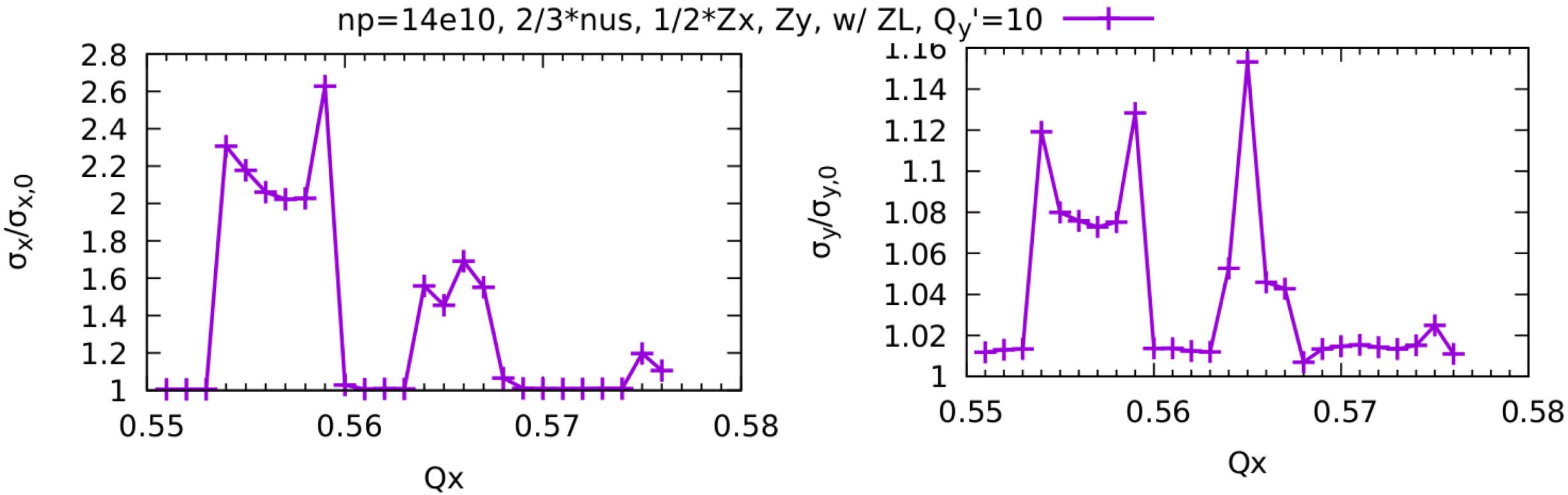






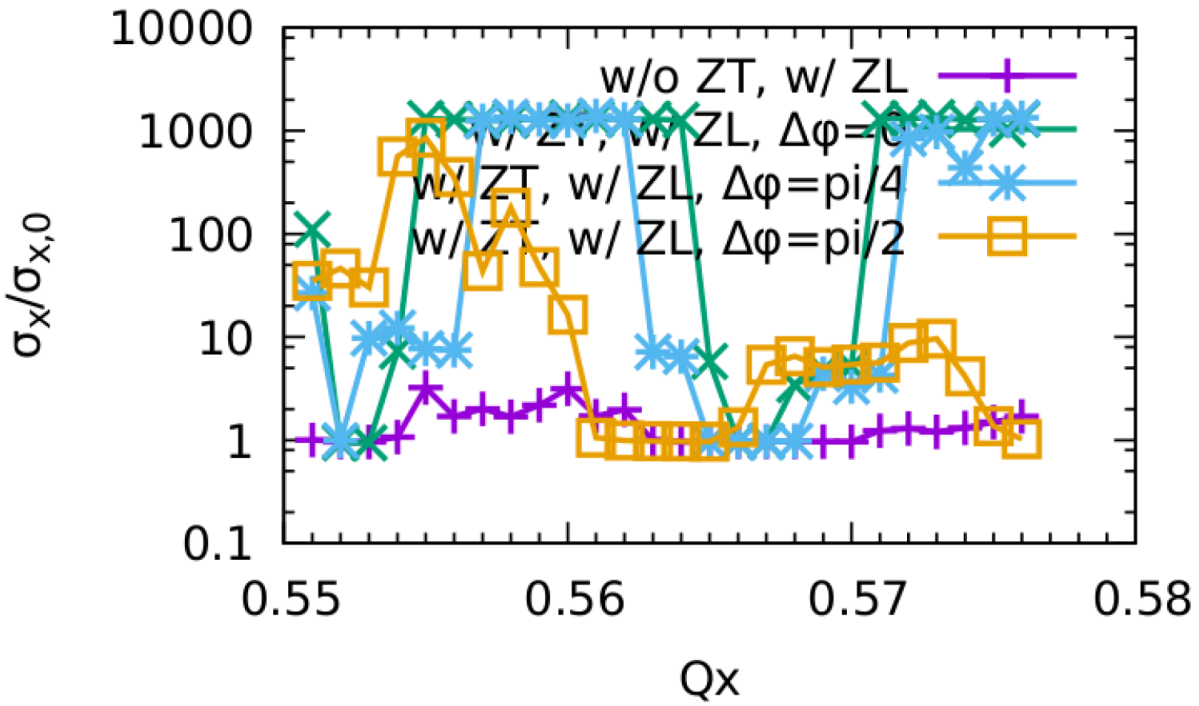
2/3*ν_s(1.5*$\sigma_{z,0}$); ½*Zx; Qy'=10

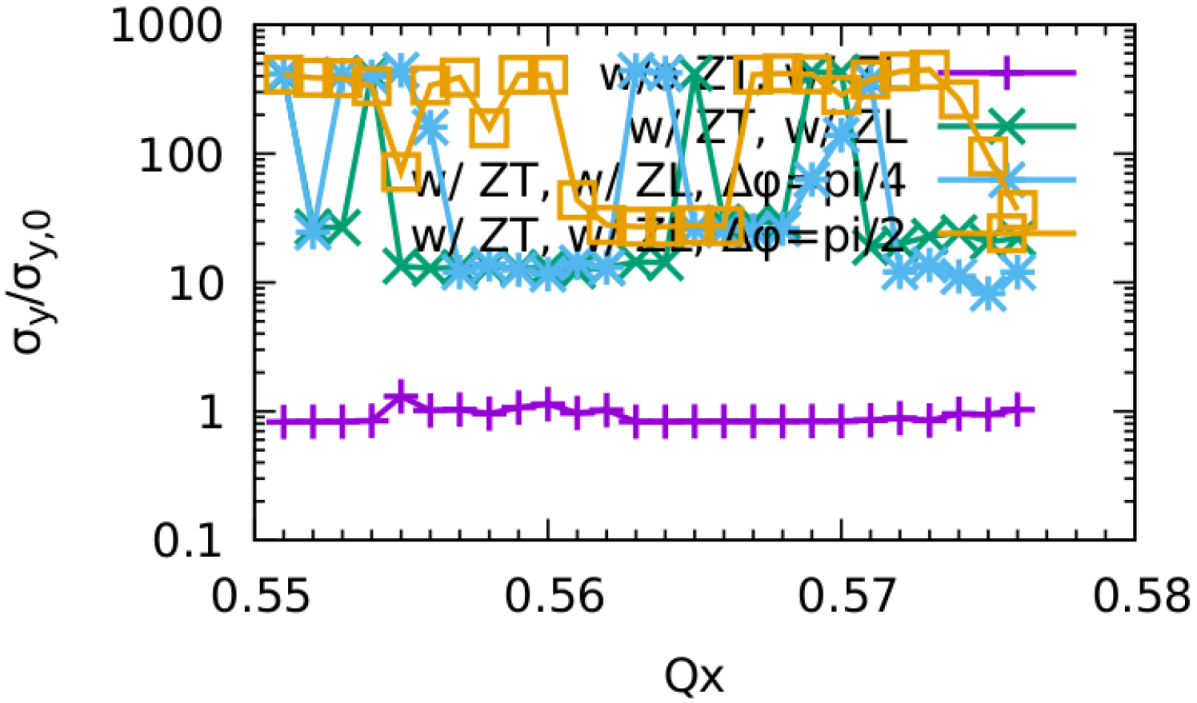
- Only X-Z instaiblity



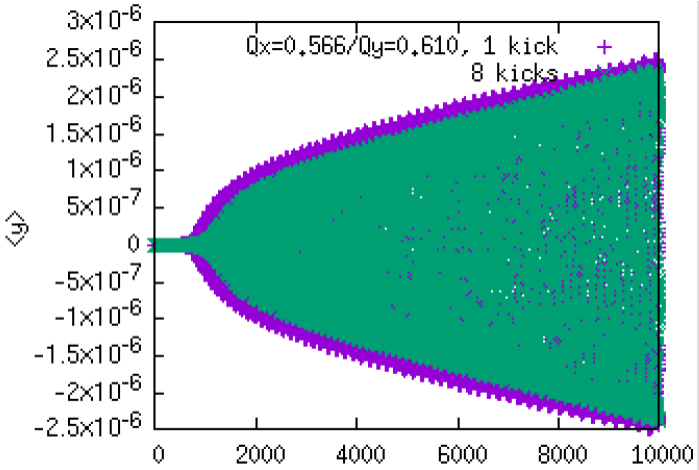
ZT @different position (only 1 kick of ZT)

- It seems there exist clear effect especially in X direction



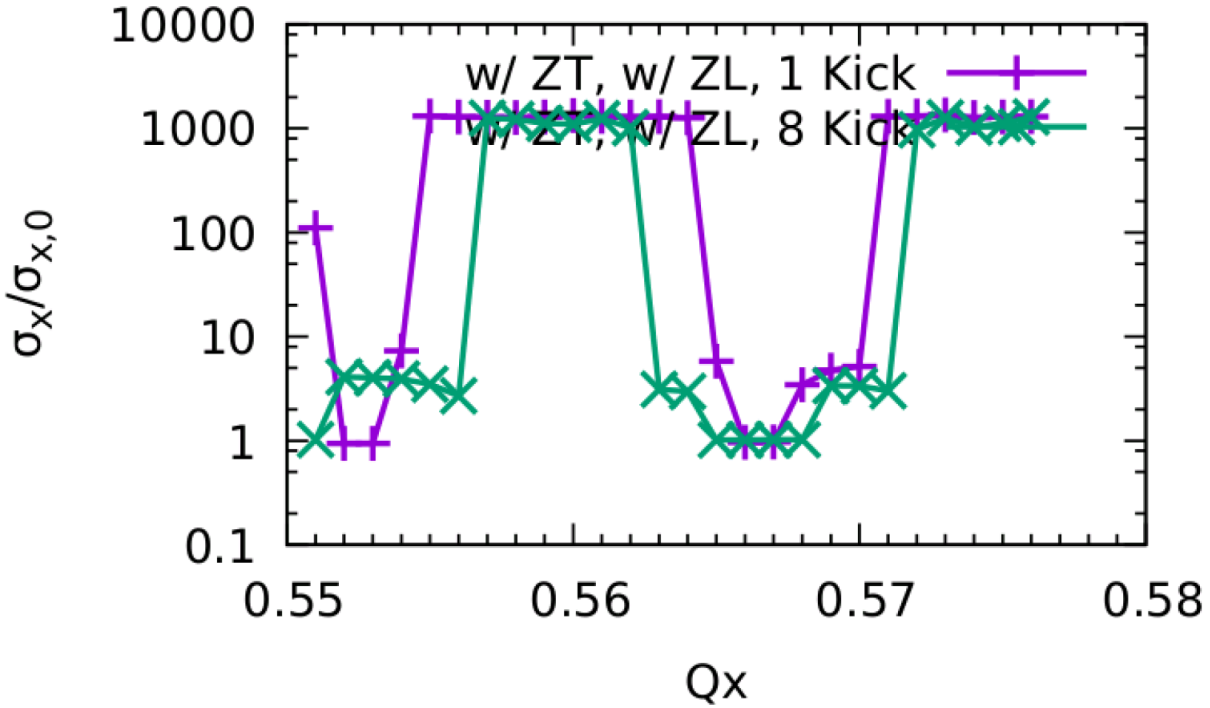


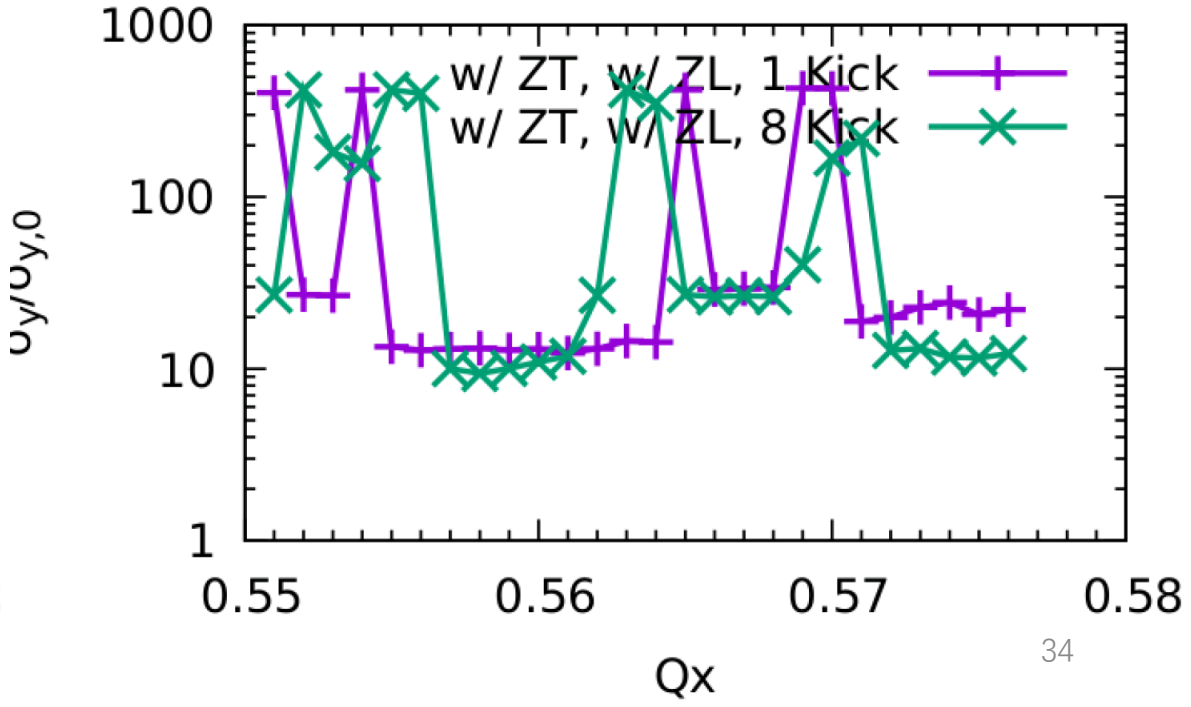
Distributed ZT on 8 positions



- The instability in Horizontal direction is weakened, comparing to only 1 kick
- There does not exist very clear effect in Y

? Azimuthal mode number





Summary

- Updated longitudinal impedance is considered, machine parameter is optimized further
- Finite dispersion where ZL is located does not take clear effect
- The transverse impedance does not take clear effect for ttbar/Higgs/W
- It seems there exist strong instability when ZT is considered for Z mode
  - Combined X-Z instability and TMCI in X direction
  - TMCI like instability in Y direction
  - Large vertical tune chromaticity could help
- The work considering ZT is still in progress

- backup

Machine parameters of CEPC

by CEPC AP group, 2 June 2022

	Higgs	Z	W	ttbar
Number of IPs	2			
Circumference [km]	100.0			
SR power per beam [MW]	30			
Half crossing angle at IP [mrad]	16.5			
Bending radius [km]	10.7			
Energy [GeV]	120	45.5	80	180
Energy loss per turn [GeV]	1.8	0.037	0.357	9.1
Piwinski angle	5.94	24.68	6.08	1.21
Bunch number	268	11934	1297	35
Bunch spacing [ns]	591 (53% gap)	23 (18% gap)	257	4524 (53% gap)
Bunch population [10^10]	13	14	13.5	20
Beam current [mA]	16.7	803.5	84.1	3.3
Momentum compaction [10^-5]	0.71	1.43	1.43	0.71
Beta functions at IP (bx/by) [m/mm]	0.3/1	0.13/0.9	0.21/1	1.04/2.7
Emittance (ex/ey) [nm/pm]	0.64/1.3	0.27/1.4	0.87/1.7	1.4/4.7
Beam size at IP (sigx/sigy) [um/nm]	14/36	6/35	13/42	39/113
Bunch length (natural/total) [mm]	2.3/4.1	2.5/8.7	2.5/4.9	2.2/2.9
Energy spread (natural/total) [%]	0.10/0.17	0.04/0.13	0.07/0.14	0.15/0.20
Energy acceptance (DA/RF) [%]	1.6/2.2	1.3/1.7	1.2/2.5	2.3/2.6
Beam-beam parameters (ksix/ksiy)	0.015/0.11	0.004/0.127	0.012/0.113	0.071/0.1
RF voltage [GV]	2.2	0.12	0.7	10
RF frequency [MHz]	650	650	650	650
Longitudinal tune Qs	0.049	0.035	0.062	0.078
Beam lifetime (bhabha/beamstrahlung)[min]	39/40	80/18000	60/700	81/23
Beam lifetime [min]	20	80	55	18
Hour glass Factor	0.9	0.97	0.9	0.89
Luminosity per IP[1e34/cm^2/s]	5.0	115	16	0.5