$\beta_x^* = 10$ cm optics for Z

(+ an update on polarization)

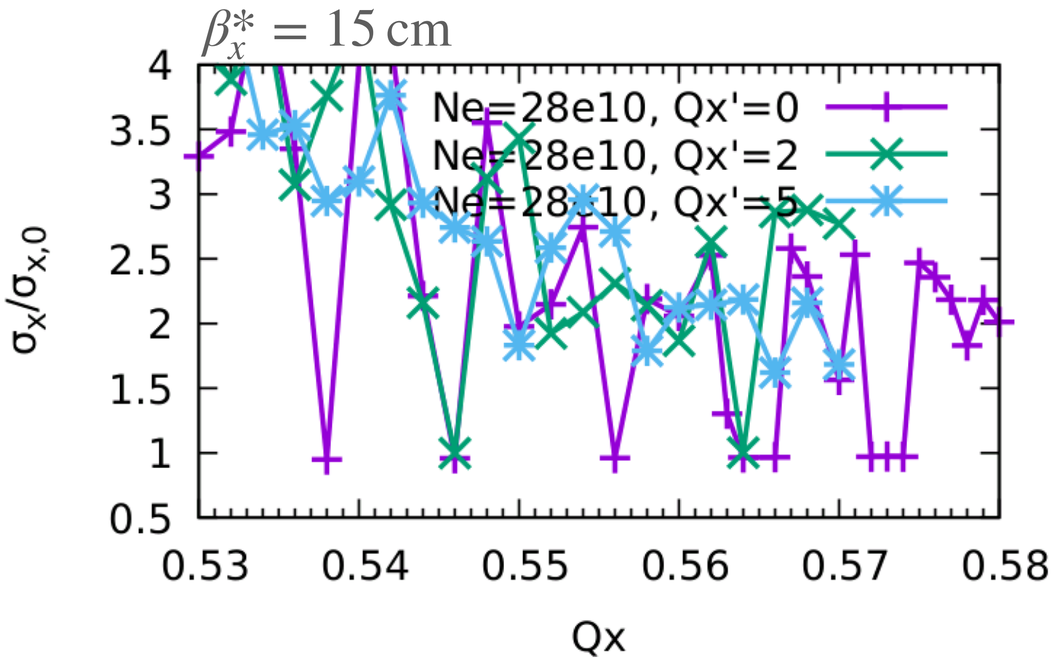
K. Oide

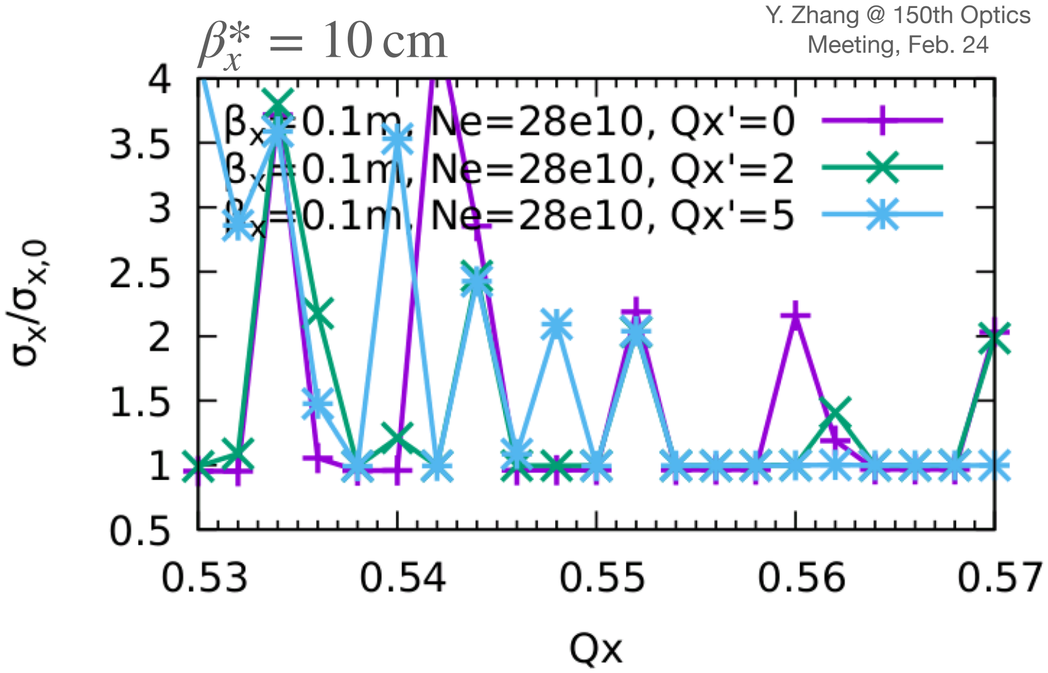
Mar. 17, 2022 @151st FCC-ee Optics Design Meeting & 22nd FCCIS WP2.2 Meeting

Many thanks to D. Shatilov, Y. Zhang, F. Zimmermann, M. Zobov, and all FCC-ee/FCCIS colleagues

Motivations

- It has been pointed out by D. Shatilov, Y. Zhang, M. Zobov that the $\beta_x^* = 15$ cm optics in Nov. 2021 for Z does not have stable tune space against the coherent beam-beam instability including long. impedances.
  - The CDR has a $\beta_x^* = 10$ cm optics for Z.
- Then let us make a $\beta_x^* = 10$ cm optics and examine its performance.





Y. Zhang @ 150th Optics Meeting, Feb. 24

Parameters

$\beta_x^* = 10\,\mathrm{cm}$ @Z

Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	91.174117		91.174107	
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		10000	880	248	40
Bunch population	[10^{11}]	2.43	2.91	2.04	2.37
Horizontal emittance ε_x	[nm]	0.71	2.16	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.32	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	100 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.563 / 53.600		100.565 / 98.595	
Energy spread (SR/BS) σ_δ	[%]	0.038 / 0.132	0.069 / 0.154	0.103 / 0.185	0.157 / 0.219
Bunch length (SR/BS) σ_z	[mm]	4.38 / 15.4	3.55 / 8.01	3.34 / 6.00	2.00 / 2.80
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	4.0 / 7.25
Harmonic number for 400 MHz		121648			
RF freuqeuncy (400 MHz)	MHz	399.994581		399.994627	
Synchrotron tune Q_s		0.0370	0.0801	0.0328	0.0826
Long. damping time	[turns]	1168	217	64.5	18.5
RF acceptance	[%]	1.6	3.4	1.9	3.1
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y [a]		0.0023 / 0.135	0.011 / 0.125	0.014 / 0.131	0.091 / 0.139
Luminosity / IP	[10^{34}/cm^{2}s]	182	19.4	7.26	1.24
Lifetime (q + BS)	[sec]	–		1065	5090
Lifetime (lum)	[sec]	1129	1070	596	752

[a] incl. hourglass.

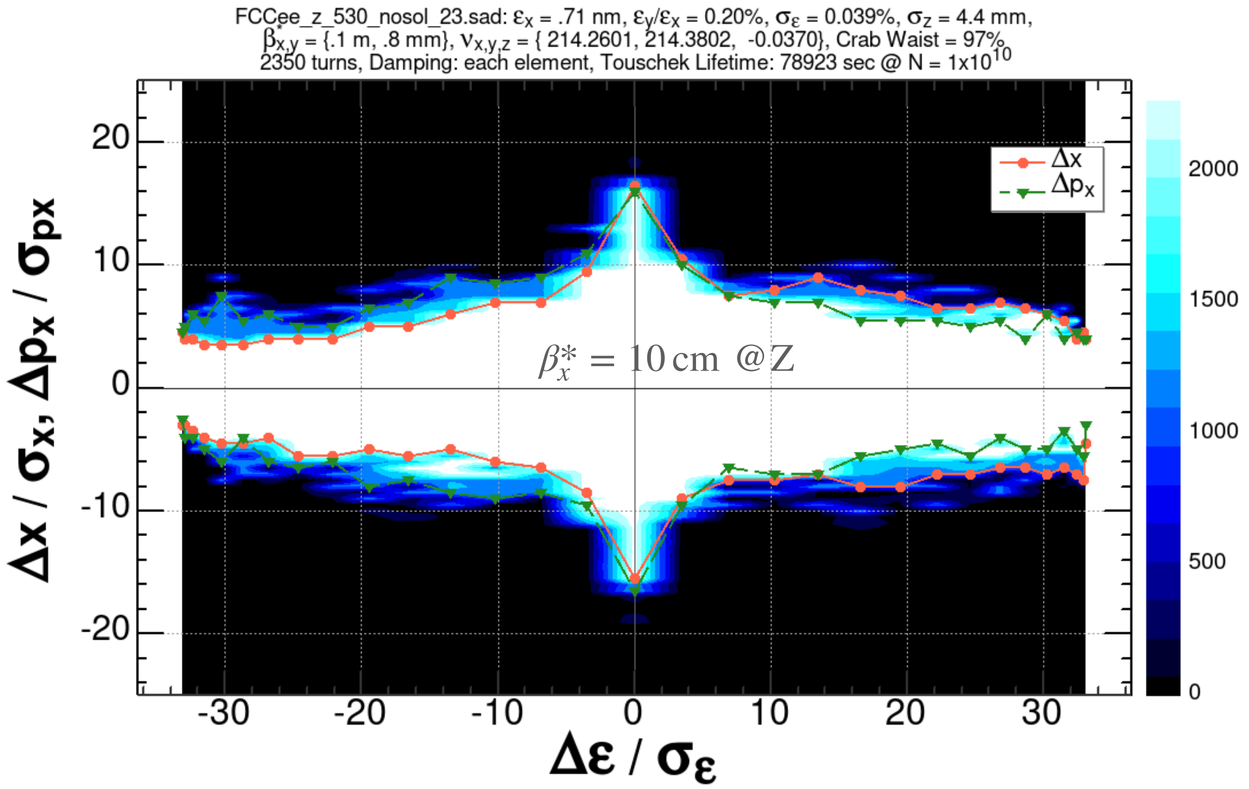
$\beta_x^* = 15\,\mathrm{cm}$ (Nov. 29)

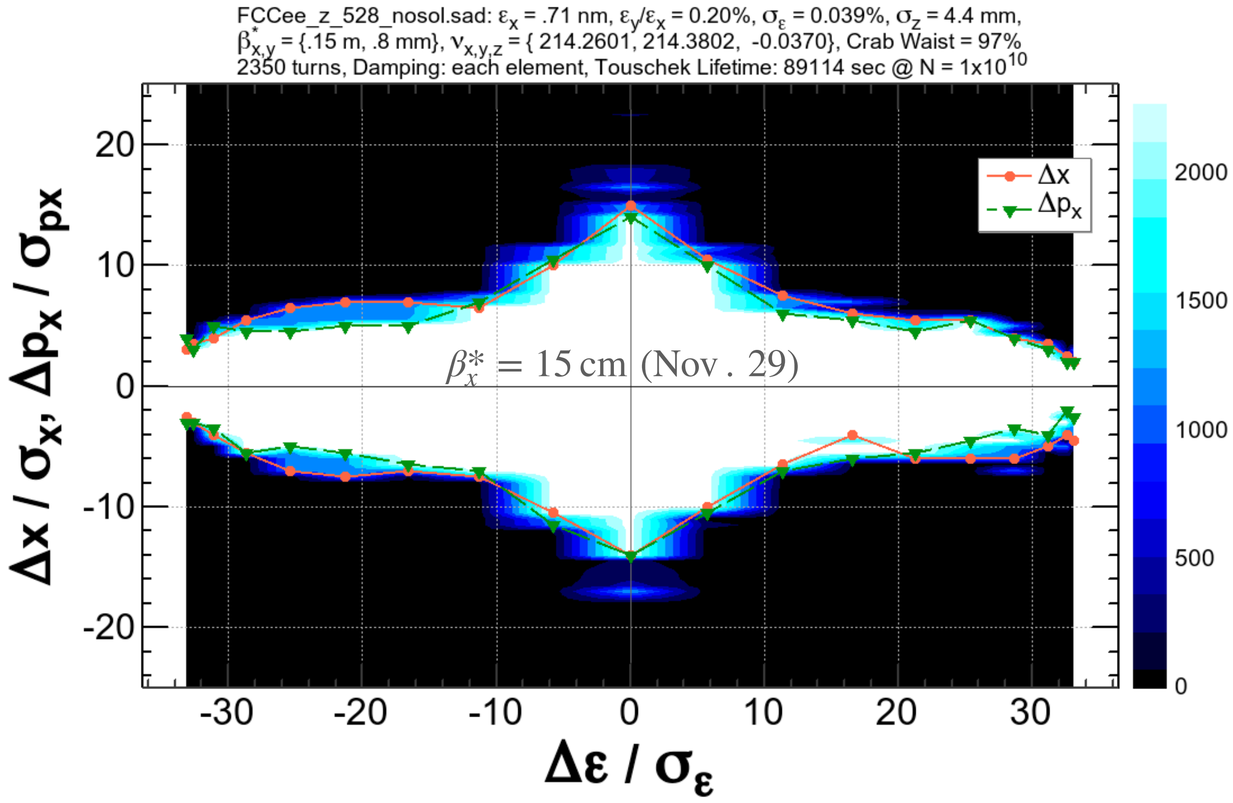
Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	91.174117		91.174107	
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		9600	880	248	36
Bunch population	[10^{11}]	2.53	2.91	2.04	2.64
Horizontal emittance ε_x	[nm]	0.71	2.16	0.64	1.49
Vertical emittance ε_y	[pm]	1.42	4.32	1.29	2.98
Arc cell		Long 90/90		90/90	
Momentum compaction α_p	[10^{-6}]	28.5		7.33	
Arc sextupole families		75		146	
$\beta^*_{x/y}$	[mm]	150 / 0.8	200 / 1.0	300 / 1.0	1000 / 1.6
Transverse tunes/IP $Q_{x/y}$		53.563 / 53.600		100.565 / 98.595	
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.130	0.069 / 0.154	0.103 / 0.185	0.157 / 0.229
Bunch length (SR/BS) σ_z	[mm]	4.37 / 14.5	3.55 / 8.01	3.34 / 6.00	2.02 / 2.95
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	4.0 / 7.25
Harmonic number for 400 MHz		121648			
RF freuqeuncy (400 MHz)	MHz	399.994581		399.994627	
Synchrotron tune Q_s		0.0370	0.0801	0.0328	0.0826
Long. damping time	[turns]	1168	217	64.5	18.5
RF acceptance	[%]	1.6	3.4	1.9	3.1
Energy acceptance (DA)	[%]	±1.3	±1.3	±1.7	-2.8 +2.5
Beam-beam ξ_x/ξ_y [a]		0.0040 / 0.152	0.011 / 0.125	0.014 / 0.131	0.096 / 0.151
Luminosity / IP	[10^{34}/cm^{2}s]	189	19.4	7.26	1.33
Lifetime (q + BS)	[sec]	–		1065	2405
Lifetime (lum)	[sec]	1089	1070	596	701

[a] incl. hourglass.

- By squeezing β_x^*, bunches/ring (bunch population), bunch length, energy spread also change. All affect the luminosity.
- $\xi_y \lesssim 0.14$ is set as a criterion (also set at $t\bar{t}$ this time).
- The betatron tunes are not yet chosen perfectly considering the instability.

Dynamic aperture



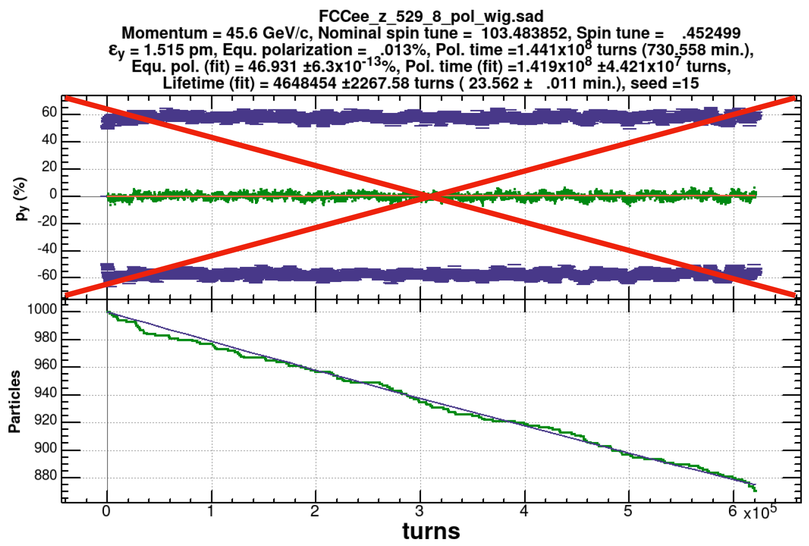


- Changes are in quads of the IR section and arc sextupoles.
- The dynamic aperture without machine errors seems still OK for $\beta_x^* = 10$ cm.
- Touschek lifetime may reduce by 12%.
- More optimization should be possible.

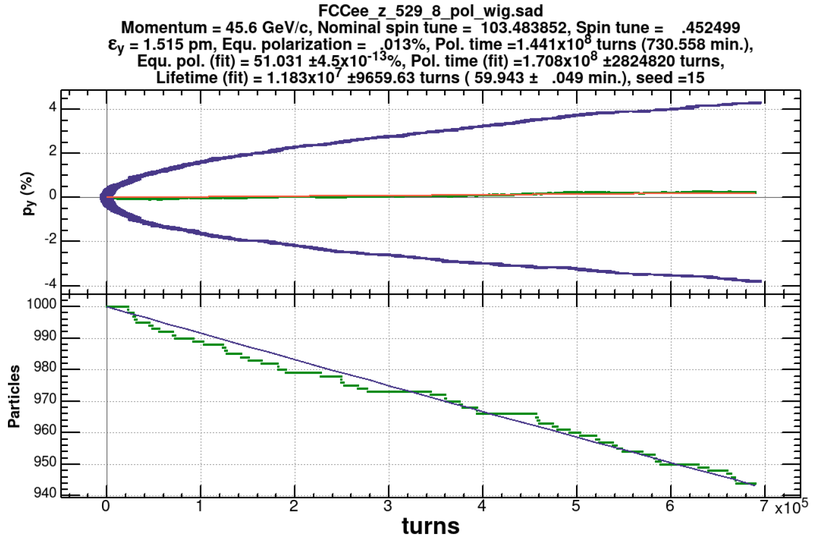
Summary

- $\beta_x^* = 10\,\mathrm{cm}$ optics for Z has been produced.
- The dynamic aperture looks comparable to the previous $\beta_x^* = 15\,\mathrm{cm}$ optics.
- A new parameter set is presented.
- Studies are needed for refinements on beam-beam, machine errors, etc., etc…..

An update on polarization



Fixed the bug



- The huge spread appeared in the polarization in the previous simulations (149th Optics Meeting, Jan. 20) was wrong, due to a confusion of B_z and $\int B_z ds$ in the spin tracking.
- After correcting the bug, the spread looks more or less reasonable.
- However, the spread after 1 hour may reach $\sim \pm 15\,\%$, and will grow afterwards. How does it affect the pol. measurement?