Parameter Choices in Reverse-Phase Operation and GHC Optics Updates

K. Oide (UNIGE/CERN/KEK)

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Reverse phase RF

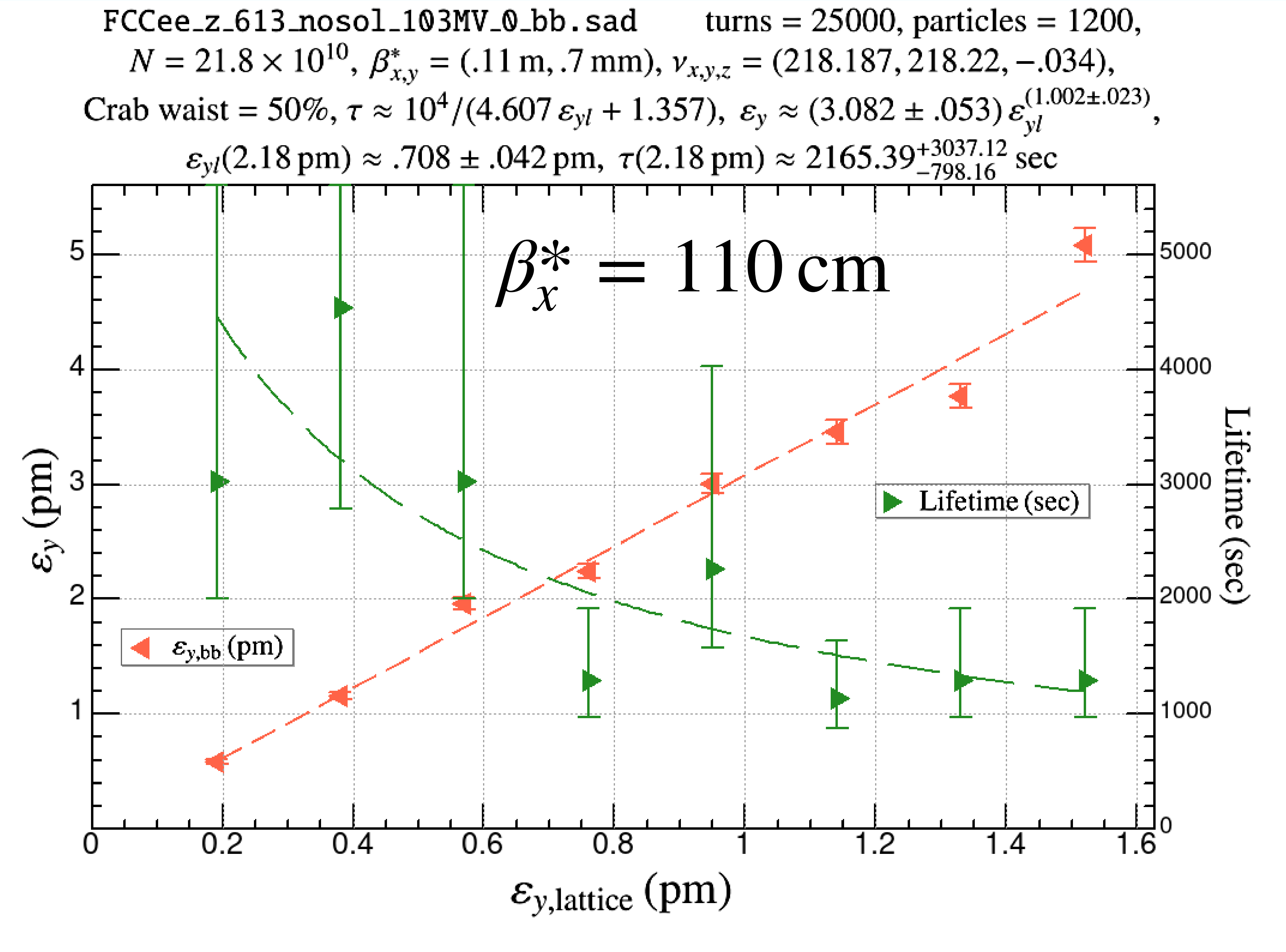
- As shown in the previous presentation, the reverse phase operation requires a higher RF voltage.
  - The associated shorter bunch length leads to stronger beamstrahlung, larger bunch energy spread.
  - Then smaller bunch population is favorable, if we can increase the number of bunches in the ring.
  - As a mitigation, we increase β_x^* from 110cm to 130 cm for better lifetime.

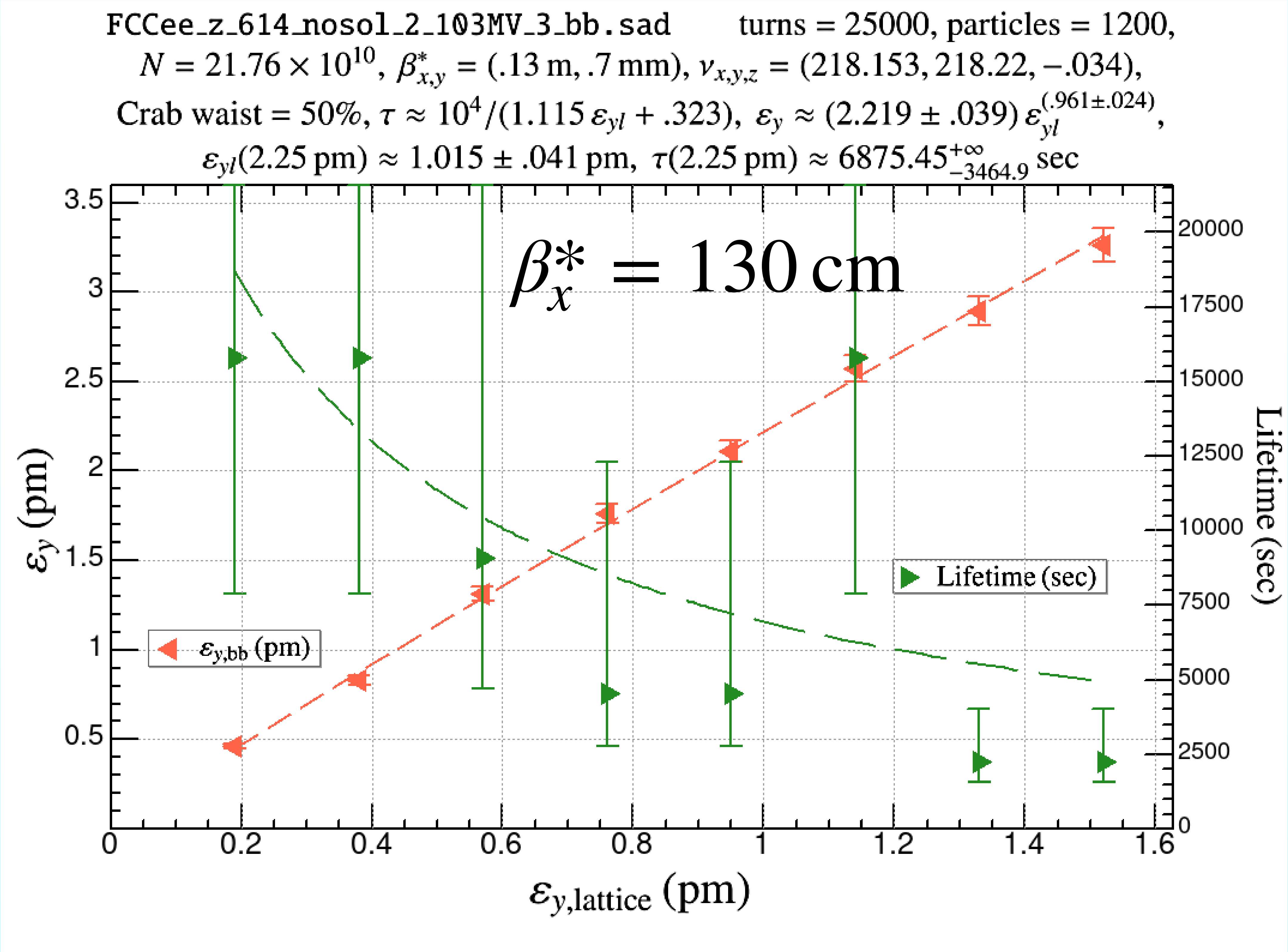
Option #	V_{nom} (MV)	V_{min} (MV)	V_{max} (MV)	$Q_{s,nom}$	$Q_{s,min}$	$Q_{s,max}$
Baseline	88.48	78.86	92.47	0.0311	0.0289	0.0319
1	103	94.83	106.43	0.0341	0.0324	0.0347
2	117.86	110.77	120.86	0.0368	0.0355	0.0373
3	132.96	126.71	135.61	0.0394	0.0383	0.0398

I. Karpov, Oct. 28

Vc (MV)	σ_z (SR/BS) (mm)	σ_δ (SR/BS) (%)
79	5.53 / 15.7	0.039 / 0.110
103	4.70 / 14.6	0.039 / 0.121
120	4.31 / 13.7	0.039 / 0.123
130	4.11 / 13.4	0.039 / 0.127

Choice of β_x^*





β_x^* (cm)	lifetime (s)	ε_y (pm)	$\varepsilon_{y,\mathrm{lattice}}$ (pm)
110	2200	2.18	0.71
130	6900	2.25	1.02

Choice of Q_x: X-Z coherent beam-beam instability

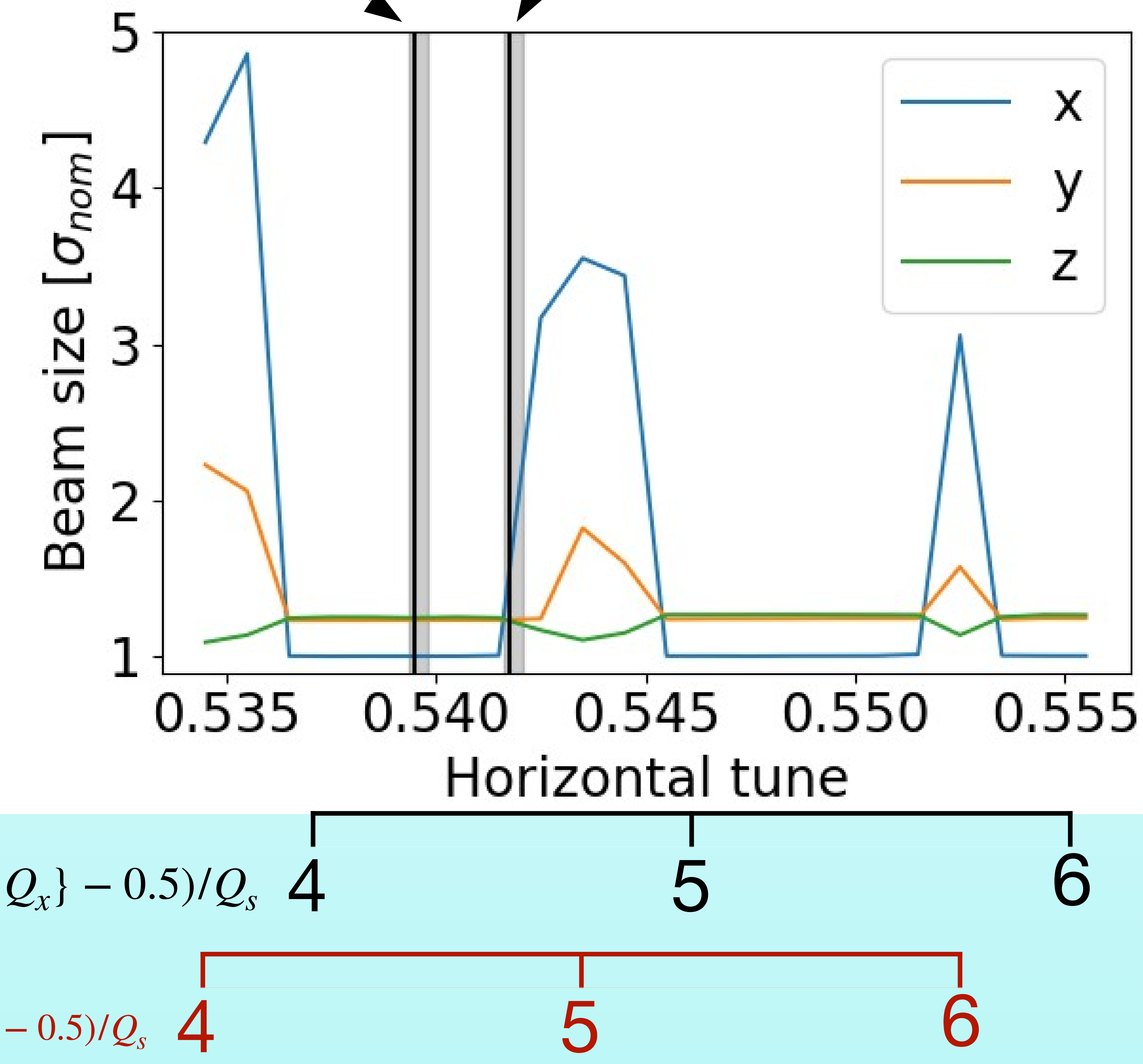
X. Buffet, Nov.4

Strong-strong simulations (XSuite) simulations for ¼ machine using **K. Oide's "120MV"** parameter table and including longitudinal impedance show a large enough stable tune space in the horizontal plane

https://cernbox.cern.ch/pdf-viewer/public/BGDbaAueV6Ao8VF/2024-11-06_2cellRF_120MV.pdf?contextRouteName=files-public-link&contextRouteParams.driveAliasAndItem=public%2FBGDbaAueV6Ao8VF&items-per-page=100

Present horizontal tune (218.158/4) + Expected synchrotron tune spread (based on I. Karpov's estimations)

New horizontal tune (218.167/4) is at the edge of stable area → should be shifted down



- According to the recent strong-strong beam-beam simulation with impedance by X. Buffet (left), the X-Z instability seems manageable by choosing Q_x between the sidebands.
- The location of the sidebands seems slightly shifted from $\{Q_x\} - nQs = 1/2$ by $\xi_x Y_x/2$, where $Y_x = 4/3$ is the horizontal Yokoya factor for a flat beam.
- Then here we choose $n = 4.5$ for the time being.

Choice of bunch population

FUTURE CIRCULAR COLLIDER

I. Karpov on Oct. 30:

- The baseline filling scheme assumes 11200 bunches distributed in 20 trains of 560 bunches.
- Since bunch spacing is 25 ns, the total available number of bunch slots is h/10 = 121200/10 = 12120.
- This leaves 12120-11200 = 920 25-ns slots for gaps between trains.
- The new scheme with a reduced kicker rise-time would be 40 trains of 280 bunches.
- Each gap has 23 slots for possible accommodation of pilot bunches.
- ***If 25 ns spacing for pilots is possible***, one can fill half of the gap with electrons and another half with positrons.
- In this case the number of gaps can be reduced to 10-16, so more slots can be filled with nominal bunches. Theoretically, ***the maximum increase is up to 552 bunches.***

V_c (MV)	bunches /beam	particles /bunch (10^{11})	lifetime (s)	ε_y (pm)	$\varepsilon_{y,\mathrm{lattice}}$ (pm)
103	11200	2.18	3100	2.25	1.05
	12160	2.08	6700	2.11	1.05
120	11200	2.18	2600	2.40	1.09
	12160	2.08	8900	2.25	1.11

↑

(12160 is too large for 25 ns spacing)

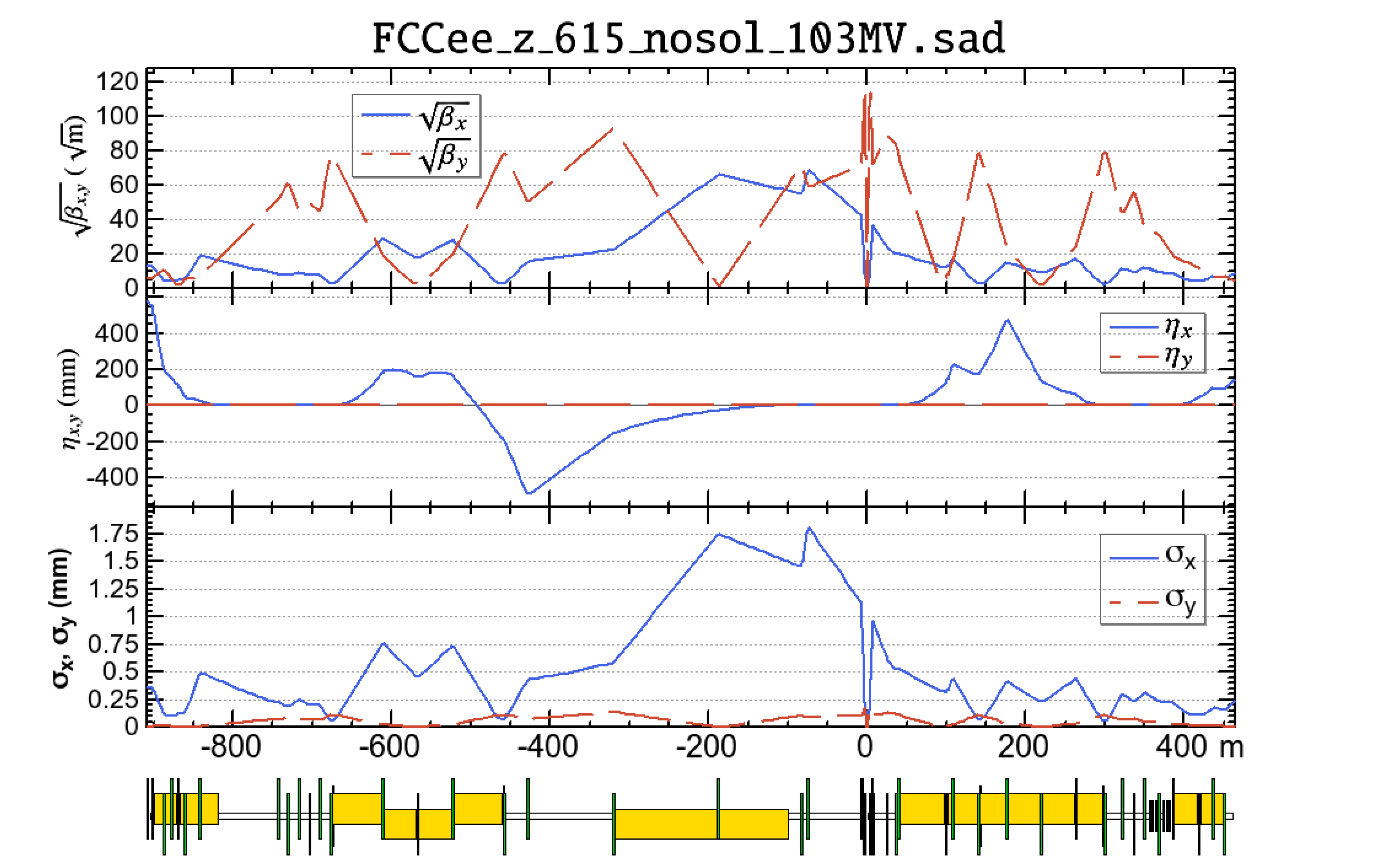
Parameters @Z

FCC-ee collider parameters for the GHC lattice at Z, Nov. 6, 2024.

Beam energy	[GeV]	45.6		
Layout		PA31-3.0		
# of IPs		4		
Circumference	[km]	90.658728		
Bend. radius of arc dipole	[km]	10.021		
Arc cell		Long 90/90		
Momentum compaction α_p	$[10^{-6}]$	28.67		
Arc sext families		75		
Energy loss / turn	[GeV]	0.0390		
SR power / beam	[MW]	50		
Beam current	[mA]	1283		
Harm. number for 400 MHz		121200		
RF frequency (400 MHz)	MHz	400.787129		
Long. damping time	[turns]	1171		
Beam crossing angle at IP θ_x	[mrad]	±15		
Crab waist ratio	[%]	50		
RF voltage 400/800 MHz	[GV]	0.079 / 0	0.103 / 0	0.120 / 0
RF acceptance	[%]	1.06	1.41	1.62
Synchrotron tune Q_s		0.0289	0.0340	0.0371
Colliding bunches / beam		11200	11220	
Colliding bunch population	$[10^{11}]$	2.180	2.176	
Hor. emittance at collision ε_x	[nm]	0.70		
Ver. emittance at collision ε_y	[pm]	1.90	2.25	2.40
Lattice ver. emittance $\varepsilon_{y,\mathrm{lattice}}$	[pm]	0.76	1.06	1.09
$\beta^*_{x/y}$	[mm]	110 / 0.7	130 / 0.7	
Transverse tunes $Q_{x/y}$		218.158 / 222.200	218.144 / 222.220	218.158 / 222.220
Chromaticities $Q'_{x/y}$		+5 / +5		
Energy spread (SR/BS) σ_δ	[%]	0.039 / 0.110	0.039 / 0.121	0.039 / 0.123
Bunch length (SR/BS) σ_z	[mm]	5.53 / 15.7	4.70 / 14.6	4.31 / 13.7
Energy acceptance (DA)	[%]	±1.0		
Beam-beam ξ_x/ξ_y [a]		0.0022 / 0.0985	0.0025 / 0.0981	0.0034 / 0.1008
X-Z threshold param. Q_s/ξ_x		13.1	13.6	10.9
Piwinski angle $(\theta_x\sigma_{z,\mathrm{BS}})/\sigma^*_x$		26.9	25.0	21.4
Lifetime (q + BS + lattice)	[sec]	13000	3100	2600
Lifetime (lum) [b]	[sec]	1320	1320	1320
Luminosity / IP	$[10^{34}/\mathrm{cm}^2\mathrm{s}]$	145.2	145.0	145.1

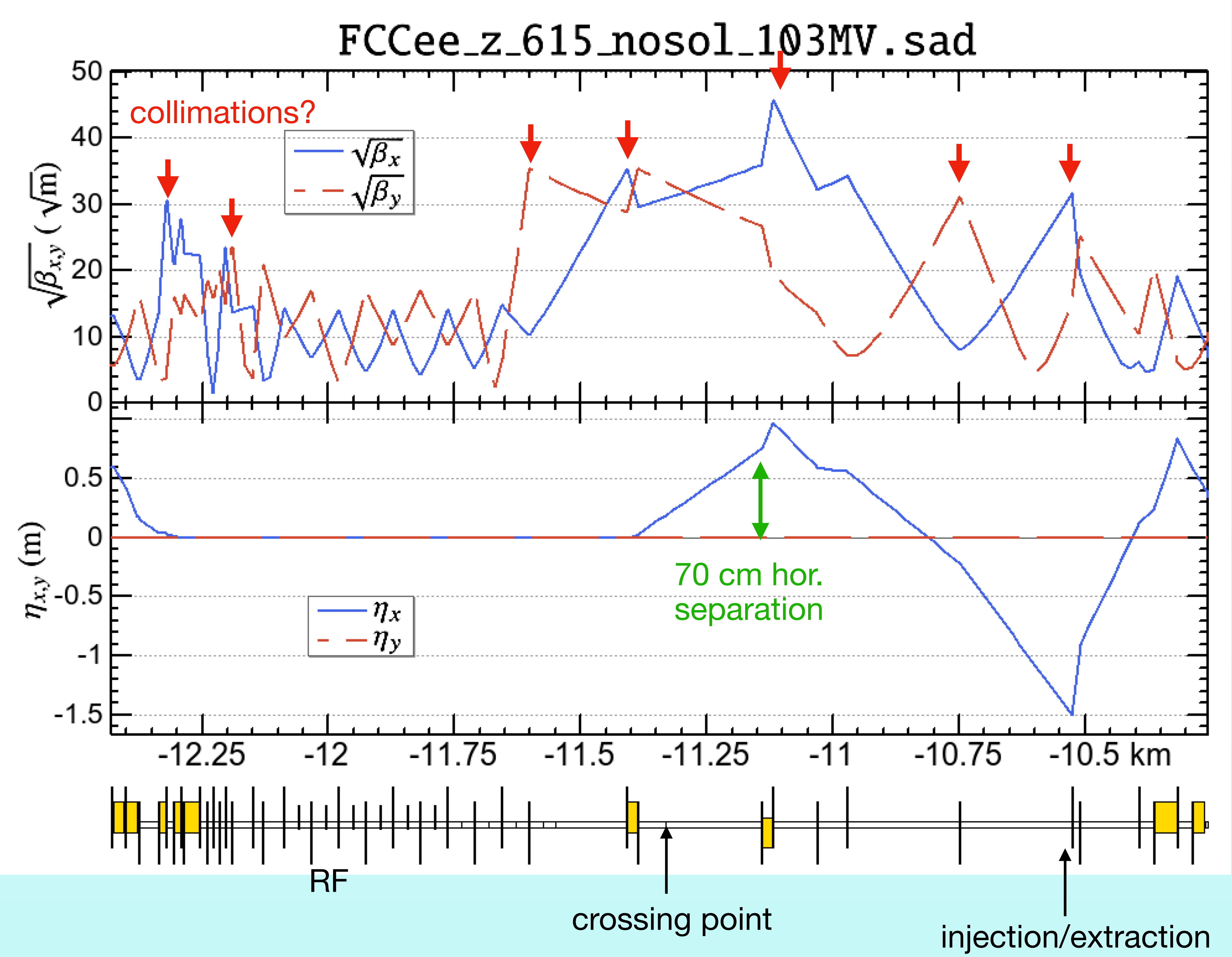
[a] incl. hourglass.
[b] only the energy acceptance is taken into account for the cross section, no beam-size effect.

IR optics



- As pointed out by G. Broggi, the horizontal beam size at iron quads at IP upstream can be have the smallest aperture. It has been reduced this time.

Common LLSS (Z/W)



- A common LLSS optics for RF, injection/extraction, collimation?
  - The superperiodicity / sextupole setting are preserved.
  - $\beta_{x,\mathrm{inj}} = 1000\,\mathrm{m}, D_{x,\mathrm{inj}} = -1.5\,\mathrm{m}.$
- The horizontal separation of two beams are increased from 35 cm to 70 cm after the crossing.

Summary

FUTURE CIRCULAR COLLIDER

- Parameters for the reverse-phase RF operation have been examined:
  - $V_c \approx 103, 120, 130\,\mathrm{MV}$.
  - Increased β_x^* from 110 cm to 130 cm for a better lifetime.
  - The horizontal tune should be chosen at $\{Q_x\} + \xi_x Y_x/2 - nQ_s = 1/2$.
  - More bunches/beam is in favor, if possible.
- (Tentative) optics files are attached in this INDICO with
  - Chromaticities $(\xi_x, \xi_y) = (+5, +5)$ have been set at Z.
  - Common LLSS optics for RF, injection/extraction, and hopefully collimation
  - Spaces for the non-local solenoid compensation.
  - Shorter quadrupoles except the LLSS.