

FCC-ee optics and layout - update and plan

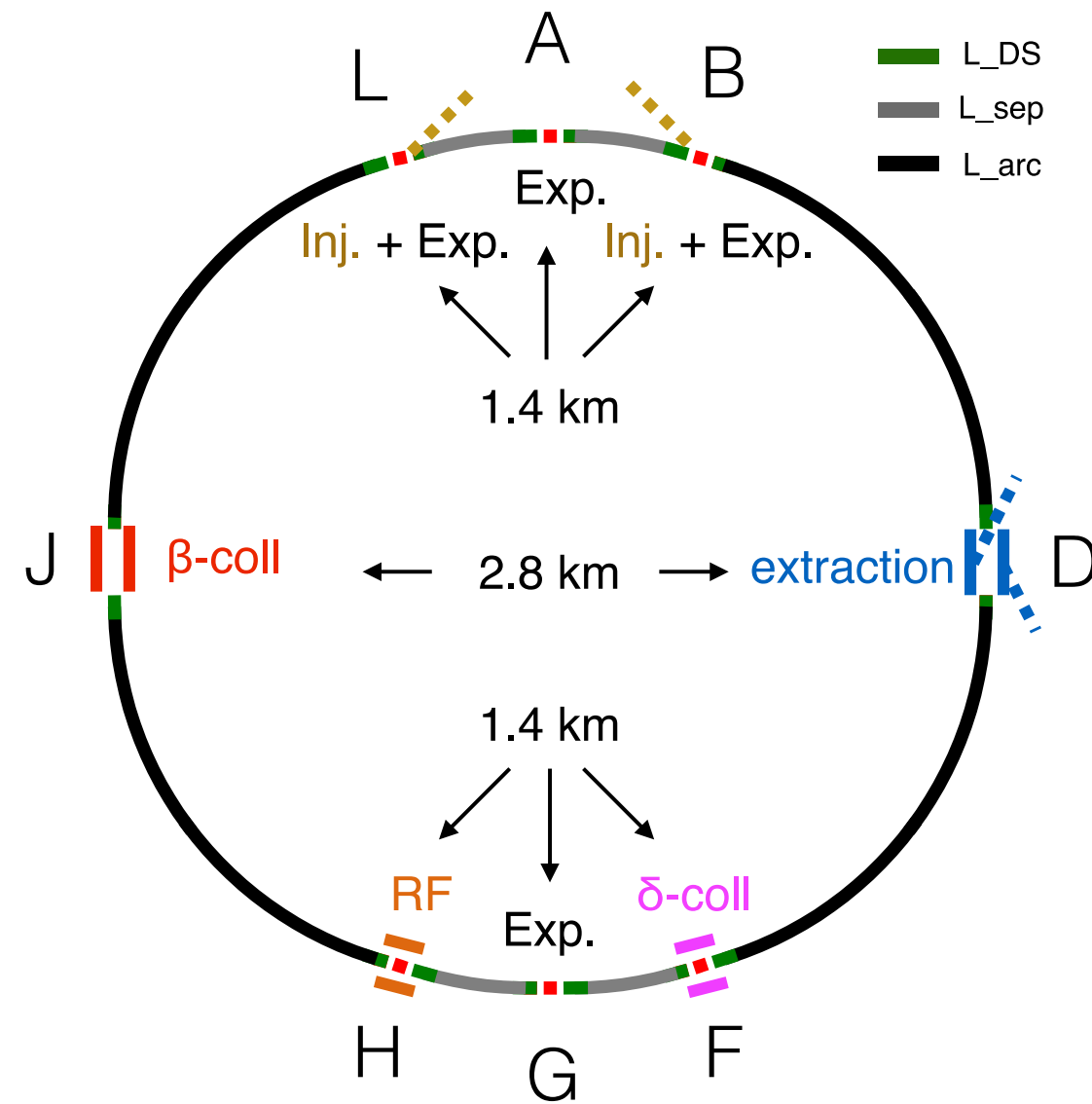
K. Oide

June 29, FCC Week 2021

Many thanks to M. Benedikt, J. Gutleber, V. Mertens, F. Zimmermann, and FCC-ee/FCCIS colleagues.

- Optics for several layouts
- 2 RF sections for 4 IP layout
- Importance of the periodicity in the layouts
- Modification of the interaction region to reduce the discrepancy between ee- and hh- rings
- Subjects for further refinements

Layouts for the optics study

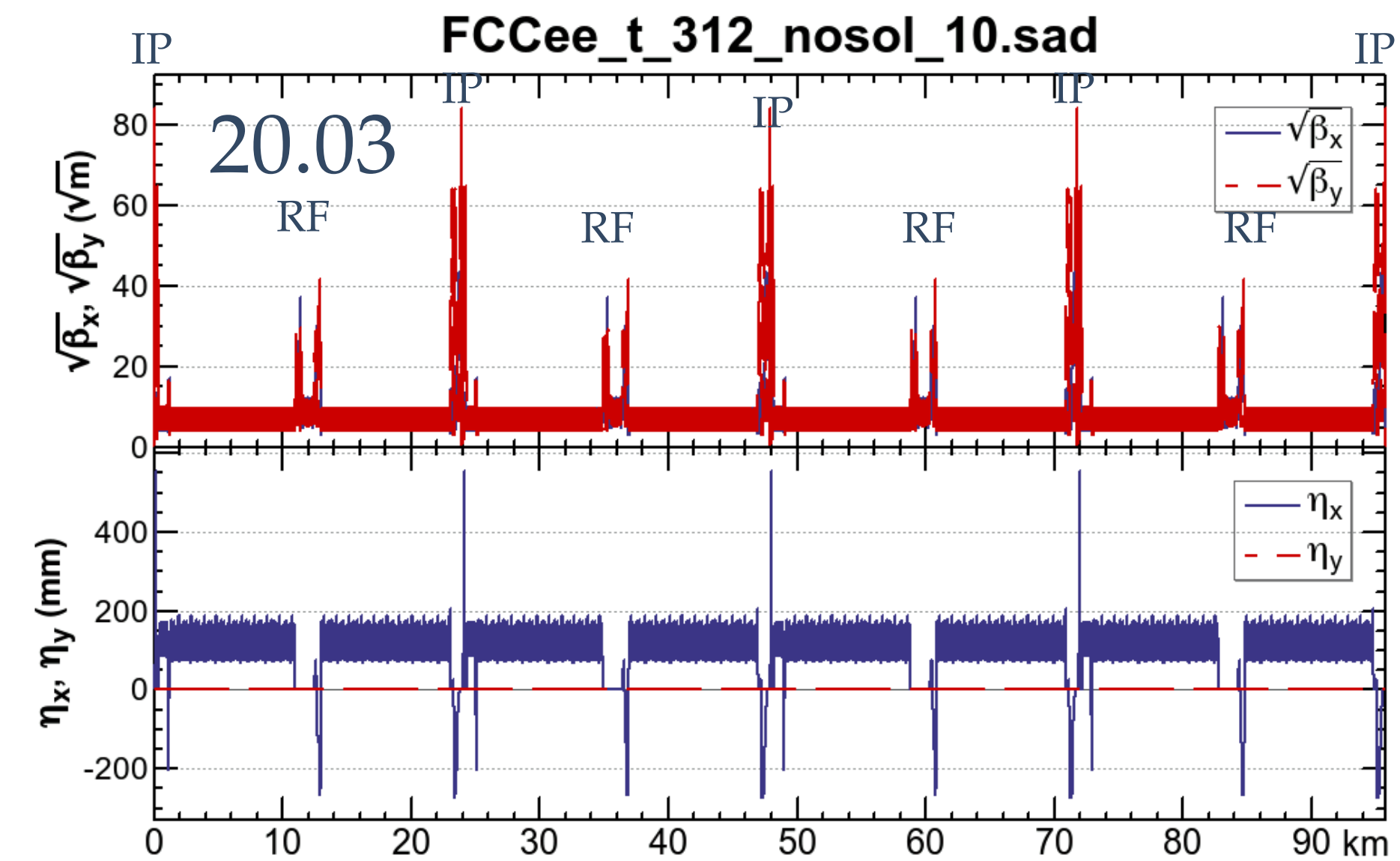
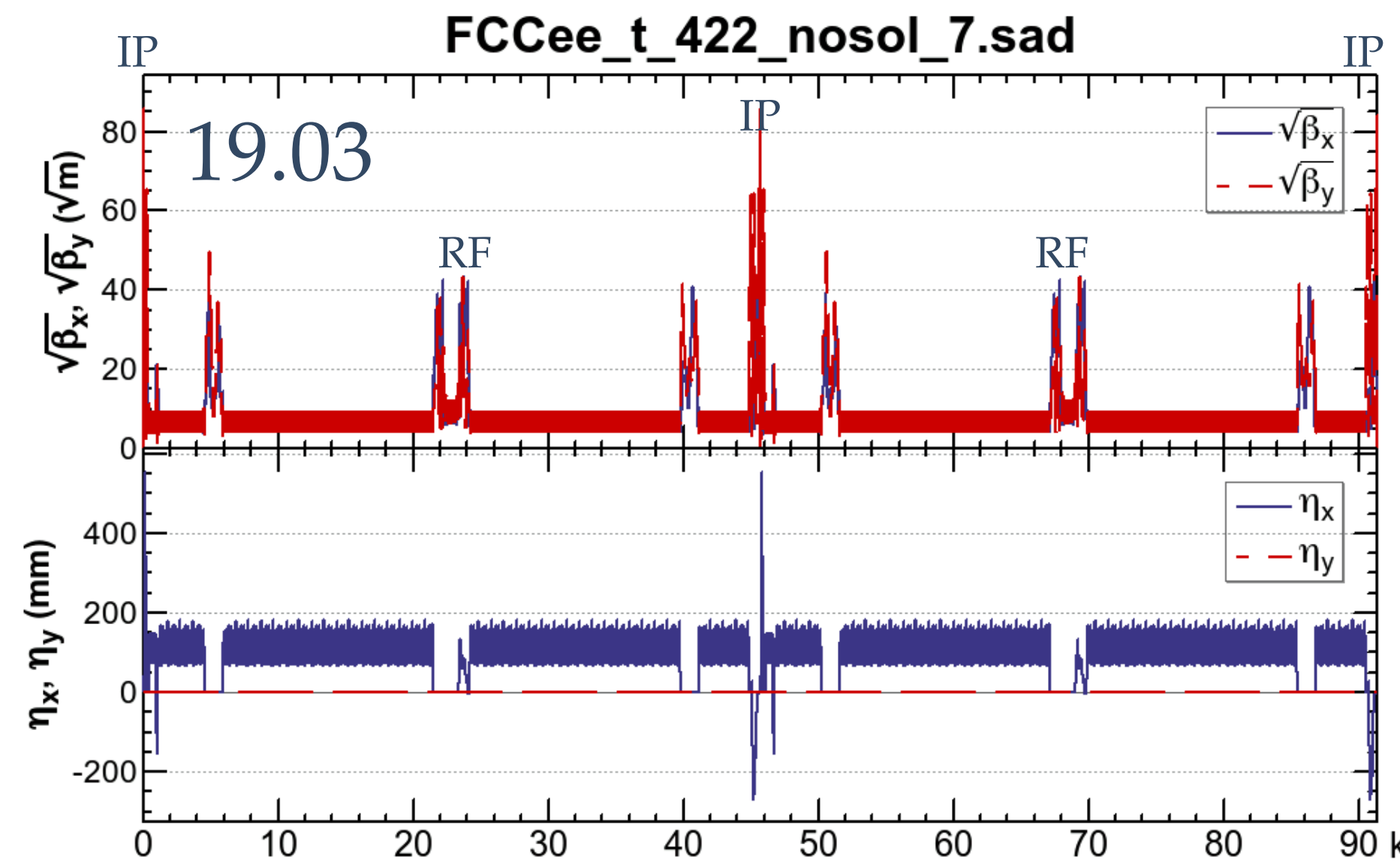
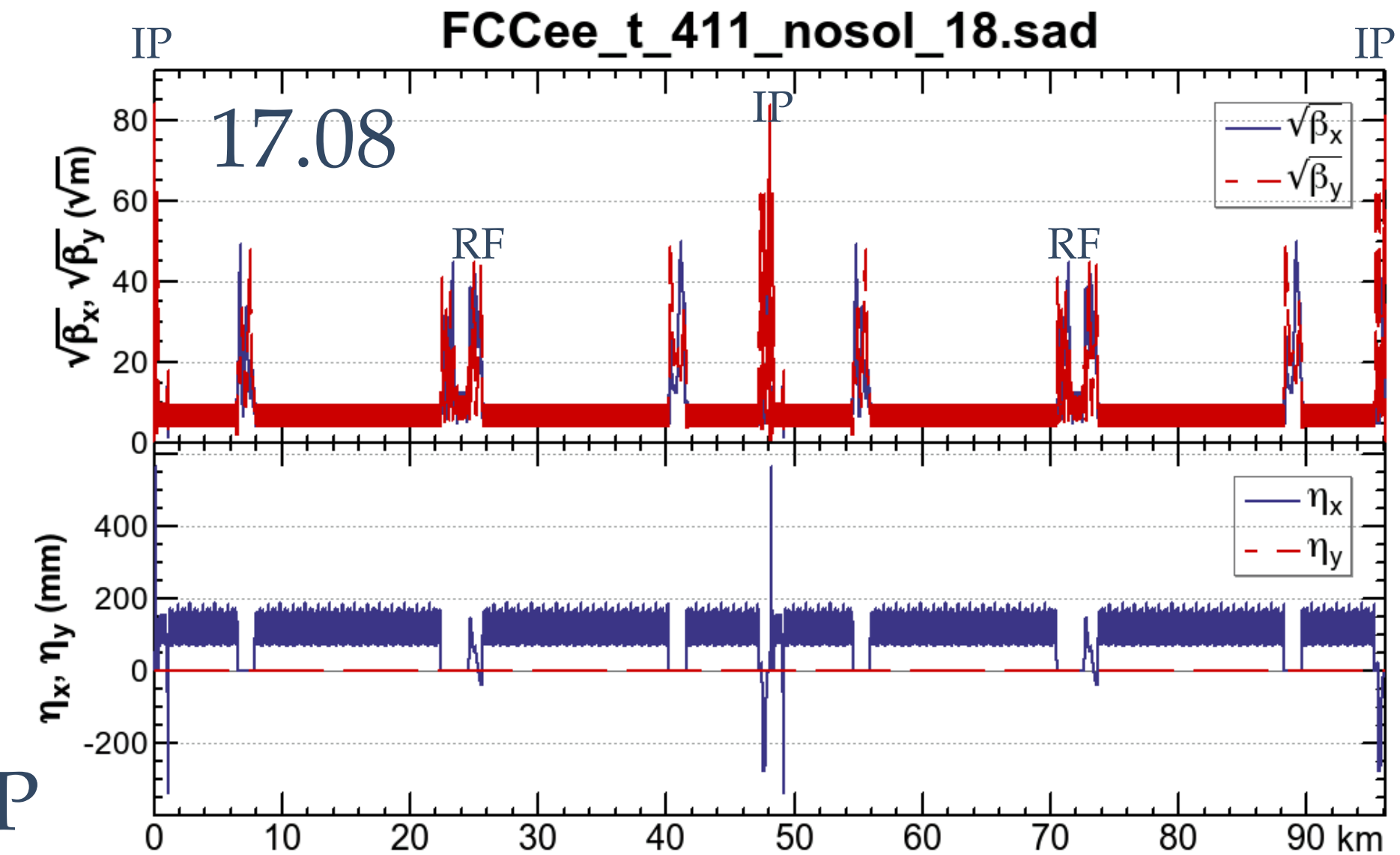
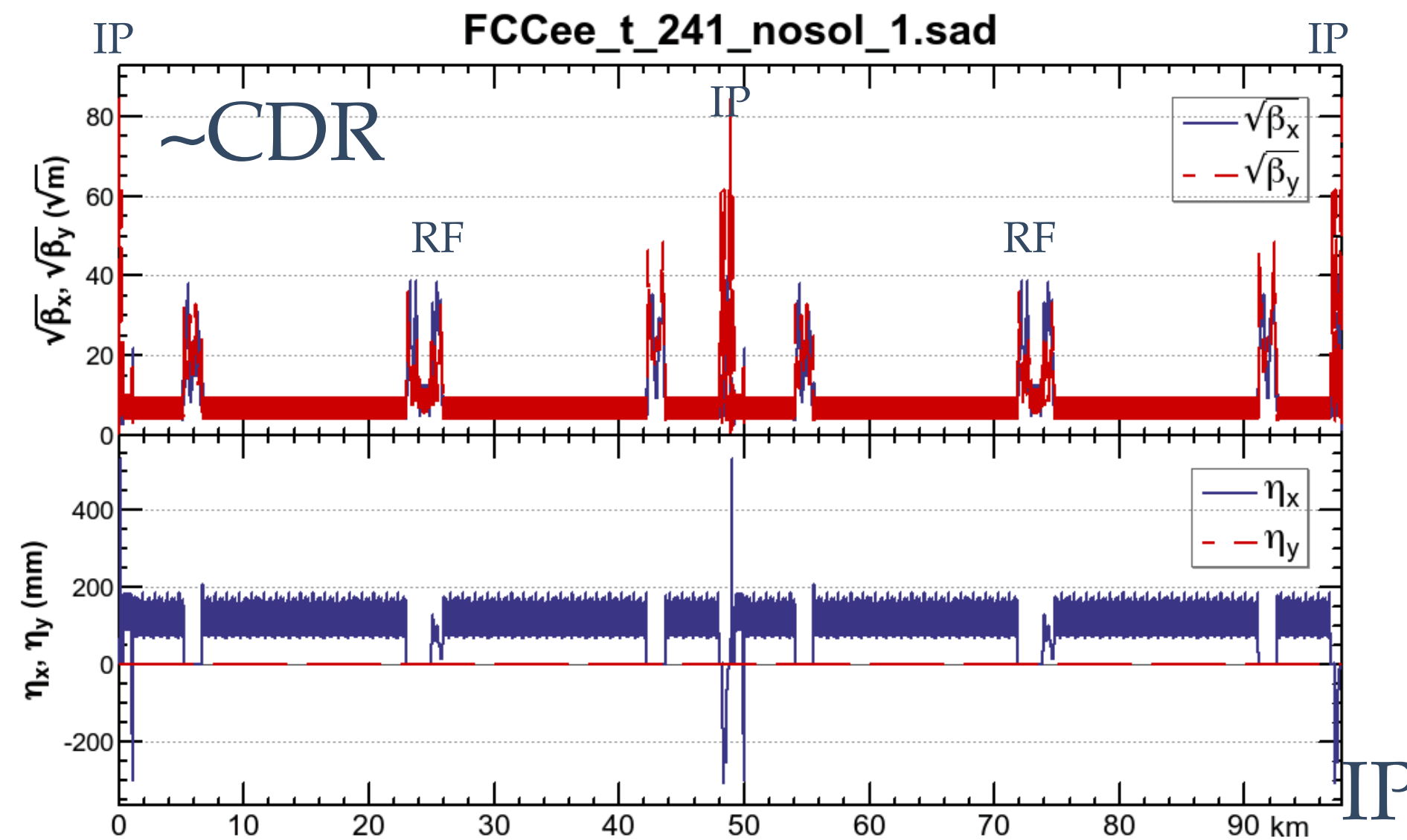


- Beam optics for $t\bar{t}$ have been generated for a few candidates of the layouts, which are proposed by J. Gutleber & V. Mertens.
- All candidates have *perfect periodicity* depending on the number of IPs.
- Dynamic aperture (DA) has been optimized to ensure the momentum acceptance of the CDR.
- We may obtain a feeling how the layout affect the luminosity performance.

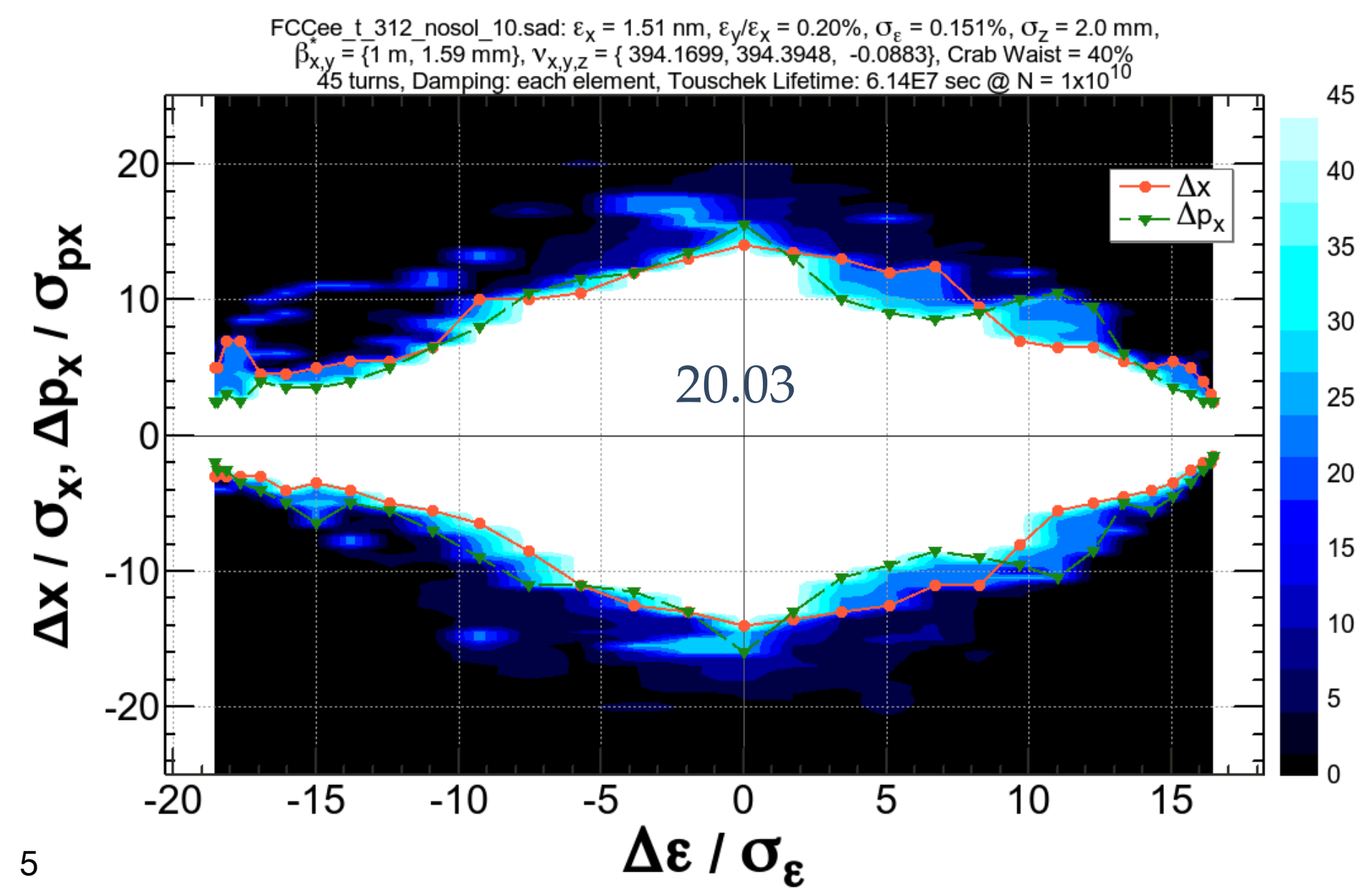
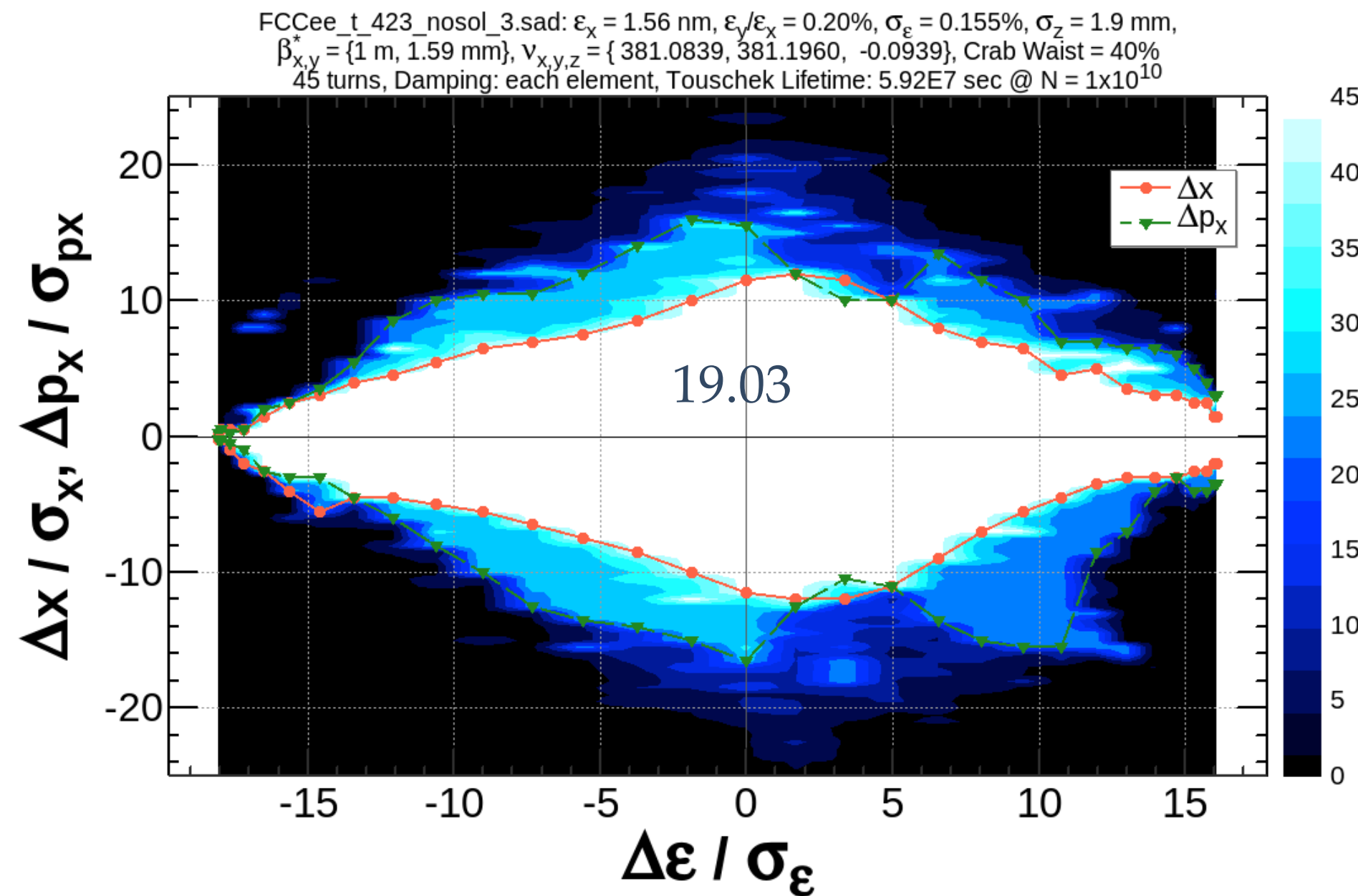
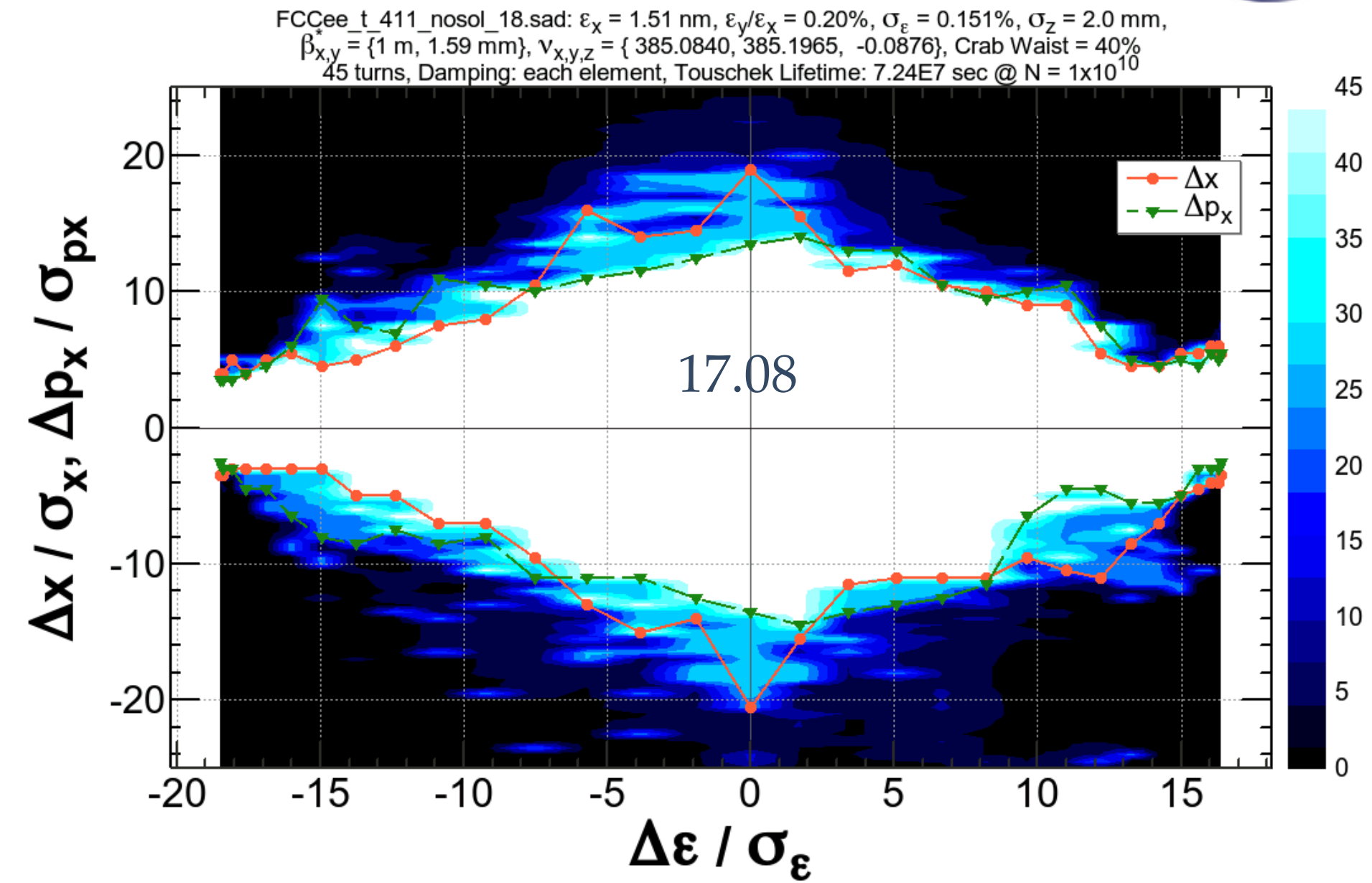
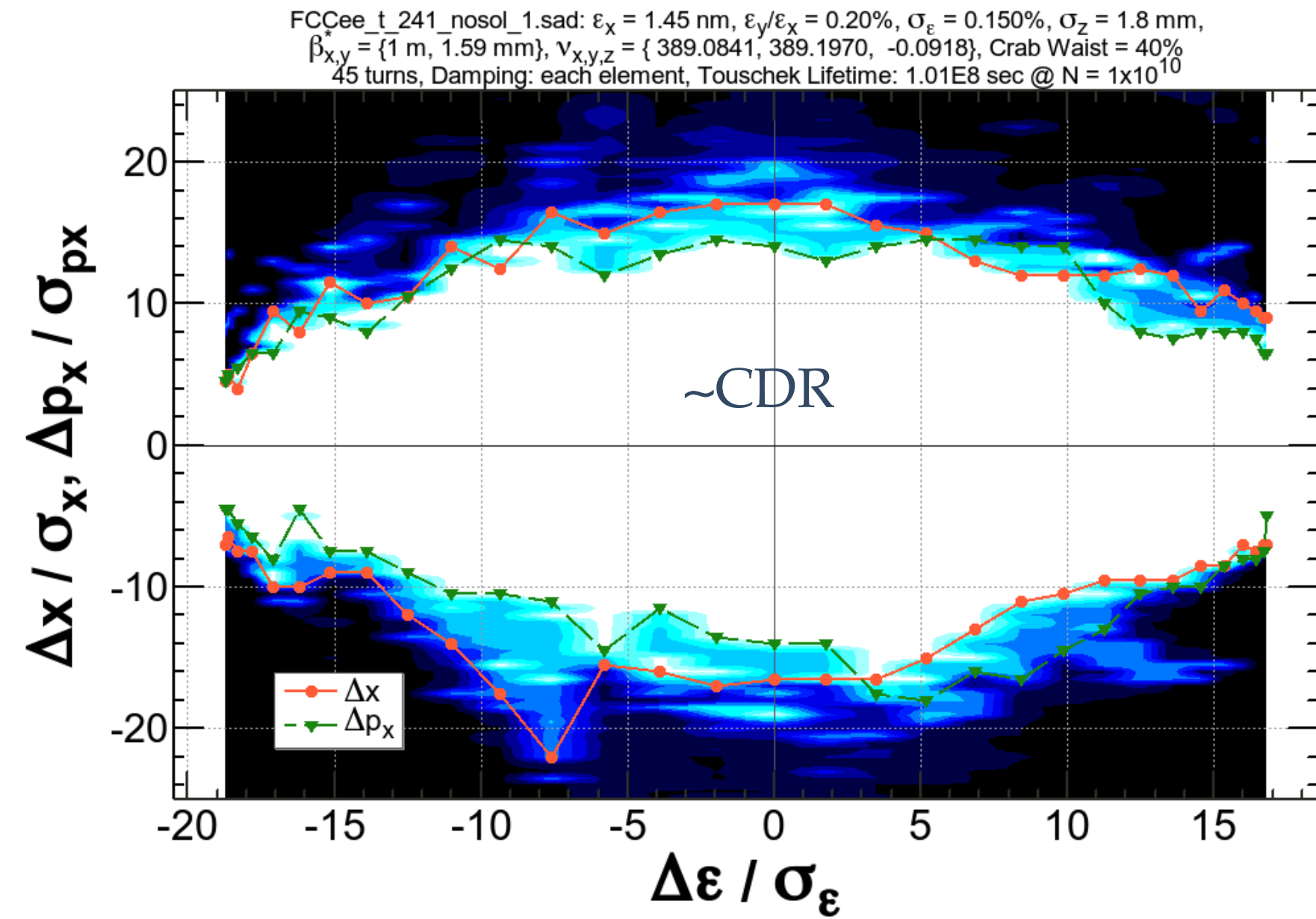
J. Gutleber, V. Mertens

Layout	IP	Shafts	circumference	Arc radius of curvature	short arc	long arc	straight sections		
					A-B, F-G, G-H,	B-D, D-F,	A, G	B, F, H, L	D, J
~CDR			97750	13329	4448	16489	1.4	1.4	2.8
17.08	2	12	96109	12922	5782	14517	1.4	1.4	3.25
19.03			91350	12380	3864	15582	1.36	1.36	2.69
20.03	4	8	95713	13058	10256	10256	1.45	2.0	1.45 (km)

Optics fitted to the layouts ($t\bar{t}$)



Dynamic apertures ($t\bar{t}$)



Parameters ($t\bar{t}$)

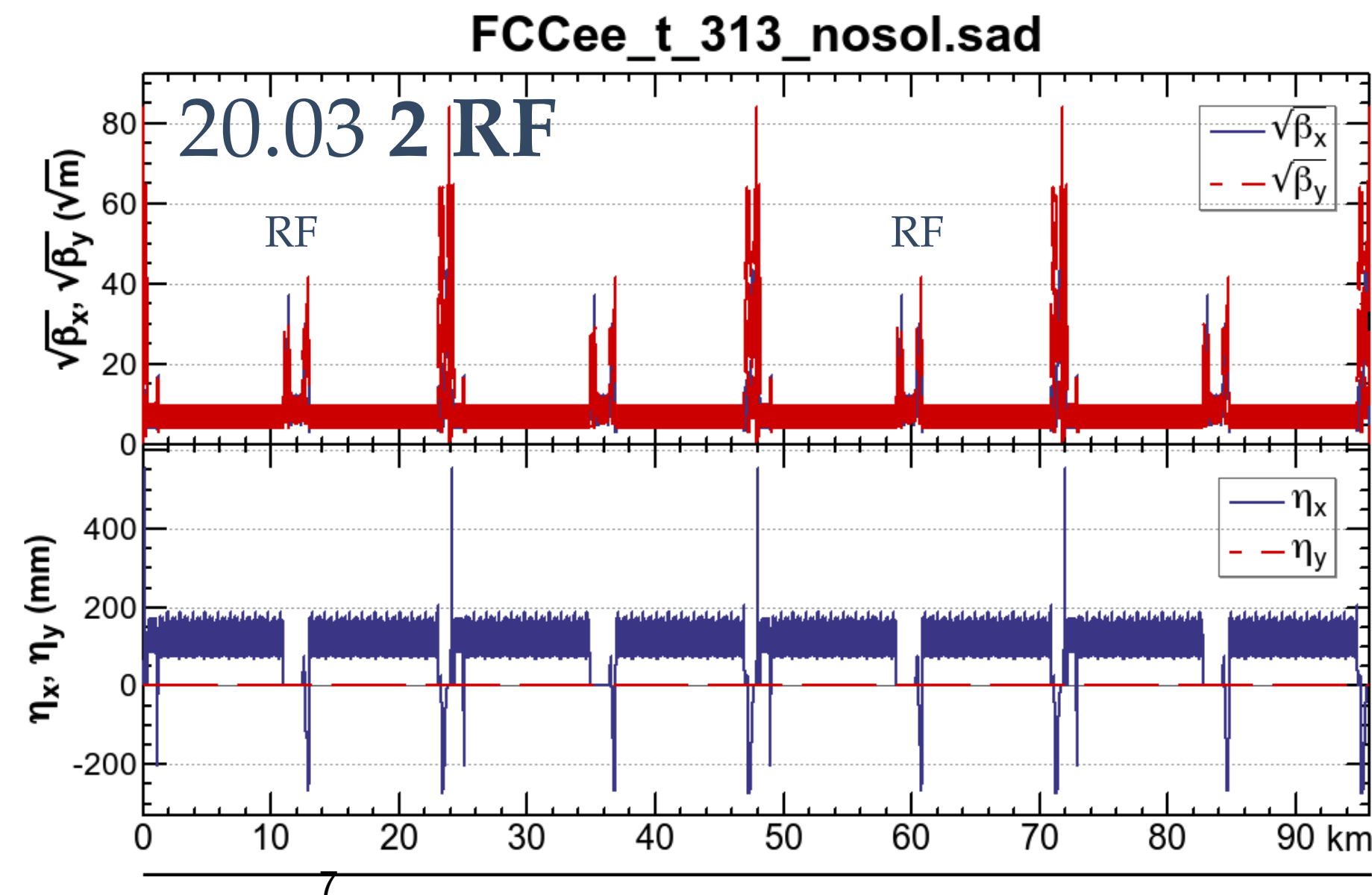
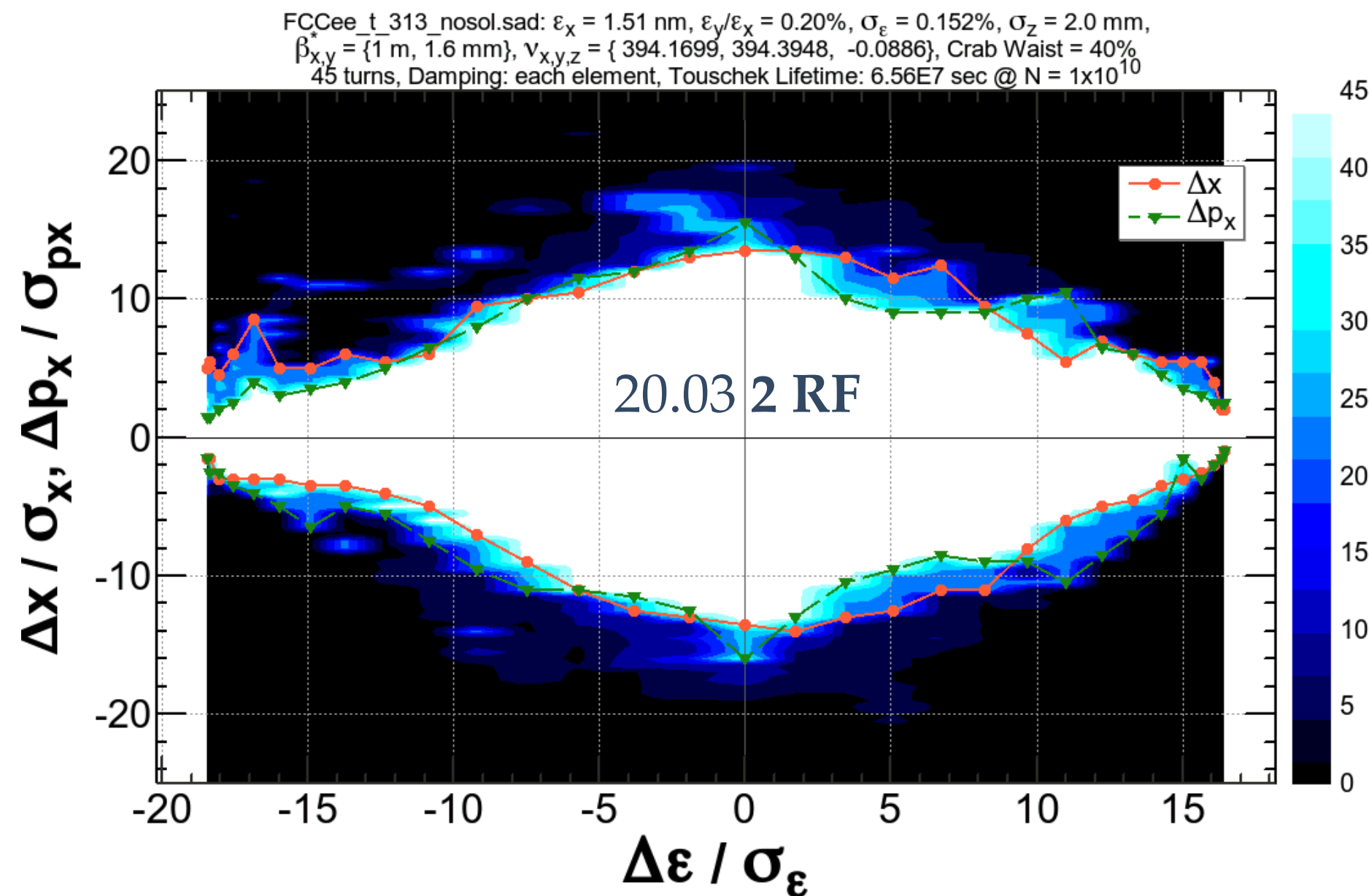
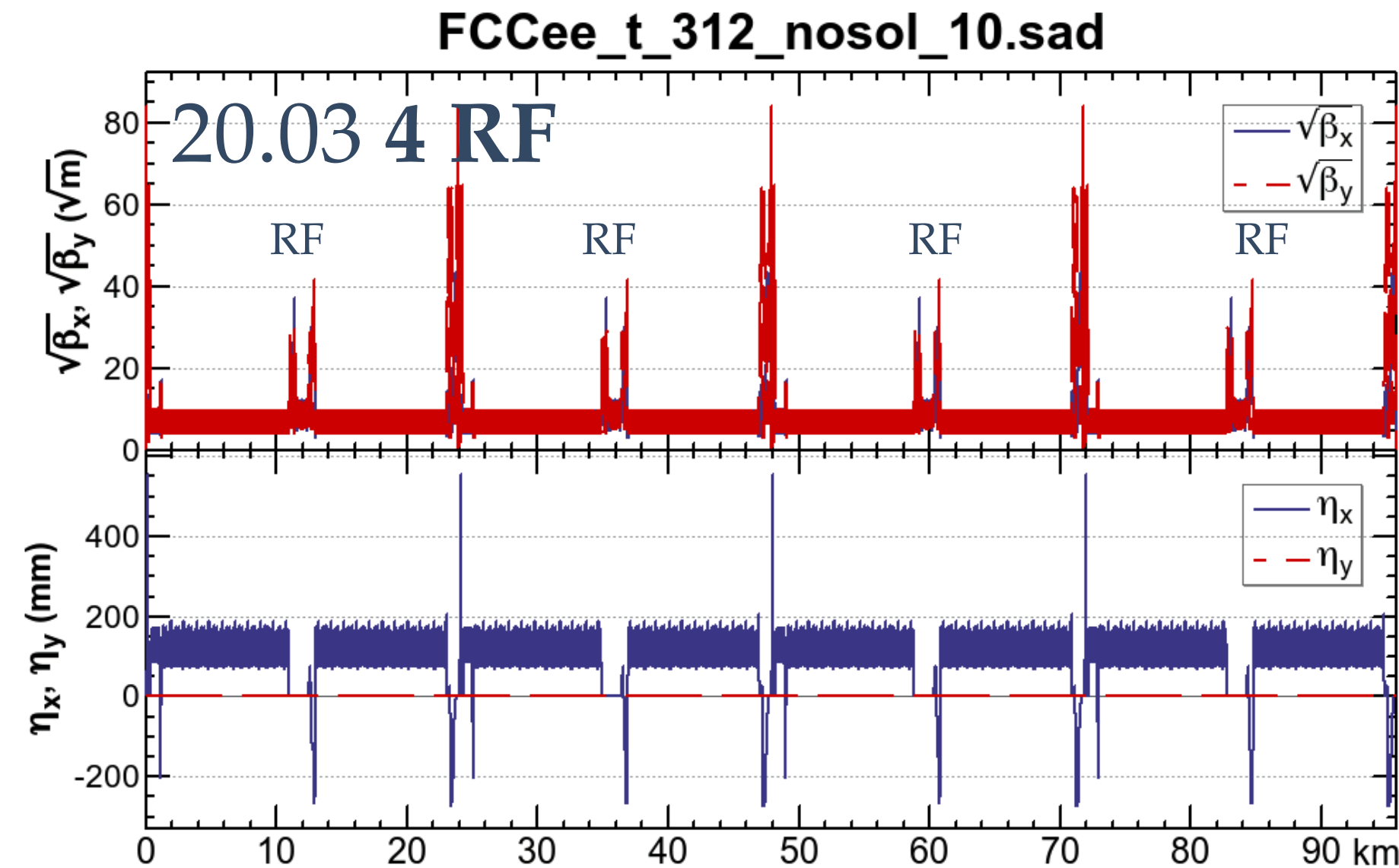
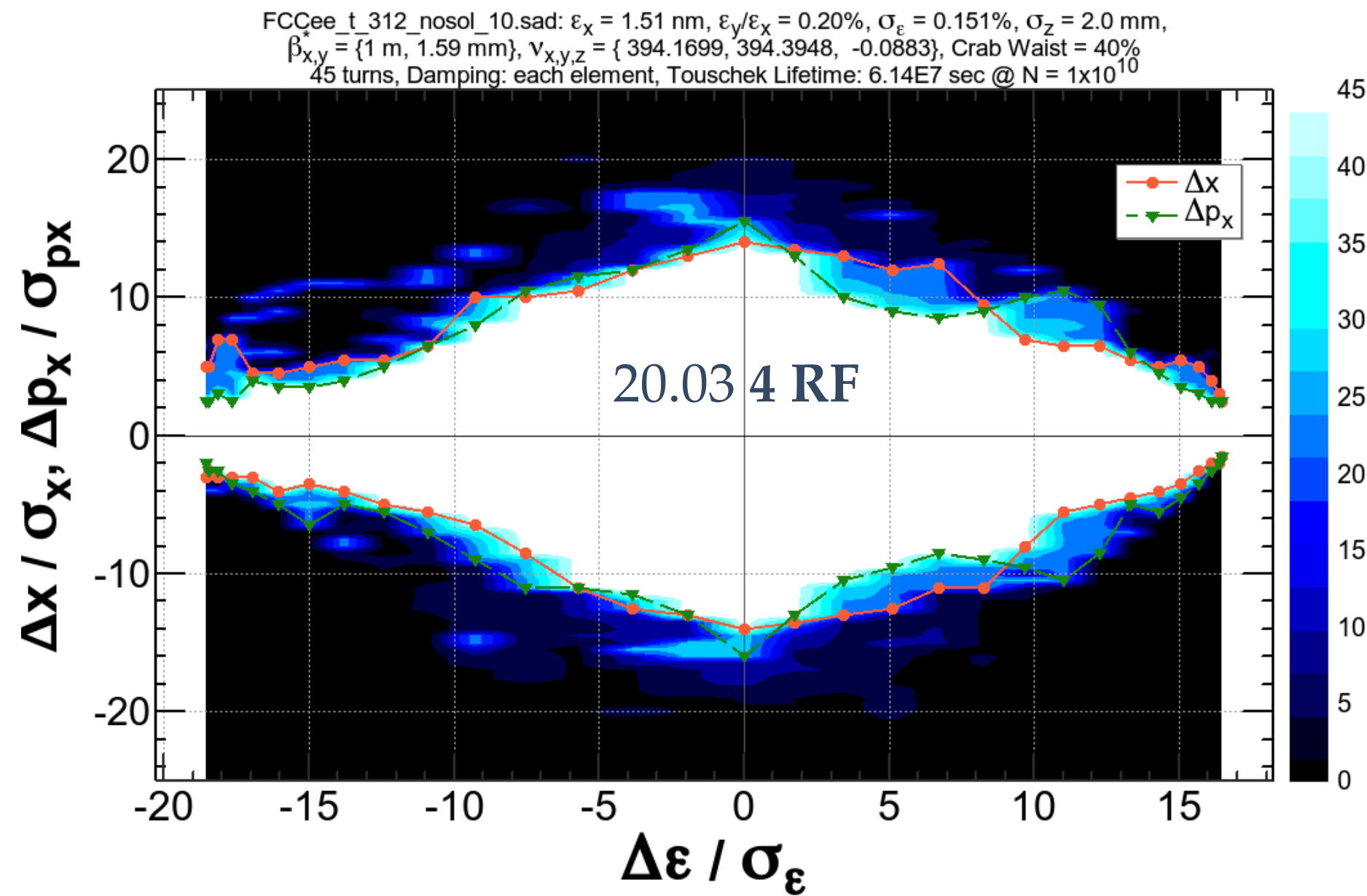
Layout # of IPs		~CDR	17.08 2	19.03	20.03 4
Circumference	[km]	97.750	96.109	91.350	95.713
Beam energy	[GeV]	182.5			
Bending radius	[km]	10.760	10.522	9.991	10.642
Energy loss / turn	[GeV]	9.19	9.39	9.87	9.28
SR power / beam	[MW]	50			
Beam current	[mA]	5.44	5.32	5.07	5.39
Bunches / beam		48			
Bunch population	[10^{11}]	2.30	2.22	2.01	2.24
Horizontal emittance ε_x	[nm]	1.45	1.51	1.53	1.51
Vertical emittance ε_y	[pm]	2.90	3.02	3.06	3.02
Momentum compaction α_p	[10^{-6}]	7.31	7.43	7.52	7.51
Arc sextupole families		294	290	288	144
Horizontal β_x^*	[m]	1.0			
Vertical β_y^*	[mm]	1.6			
Energy spread (SR/BS) σ_δ	[%]	0.150/0.196	0.151/0.192	0.155/0.189	0.151/0.193
Bunch length (SR/BS) σ_z	[mm]	1.93/2.52	1.93/2.46	1.93/2.35	1.93/2.46
RF voltage 400/800 MHz	[GV]	4.0 / 6.94	4.0 / 7.03	4.0 / 7.59	4.0 / 6.81
Synchrotron tune Q_s		0.0888	0.0898	0.0887	0.0880
Long. damping time	[turns]	20.4	19.9	19.0	19.9
RF acceptance	[%]	3.4	3.6	3.6	3.4
Energy acceptance (DA)	[%]	-2.8 +2.5		-2.6 +2.5	-2.8 +2.5
Beam-beam ξ_x/ξ_y^a		0.100/0.144	0.097/0.136	0.091/0.123	0.097/0.137
Luminosity / IP	[$10^{34}/\text{cm}^2\text{s}$]	1.43	1.32	1.16	1.35 ^b
Lifetime (q + BS)	[sec]	3500	5300	4700	2450
Lifetime (lum)	[sec]	1500	1600	1590	780

^aincl. hourglass, different from Shatilov/Ohmi's definition

^bshould be multiplied by 0.85 due to the reduction for 4 IP.

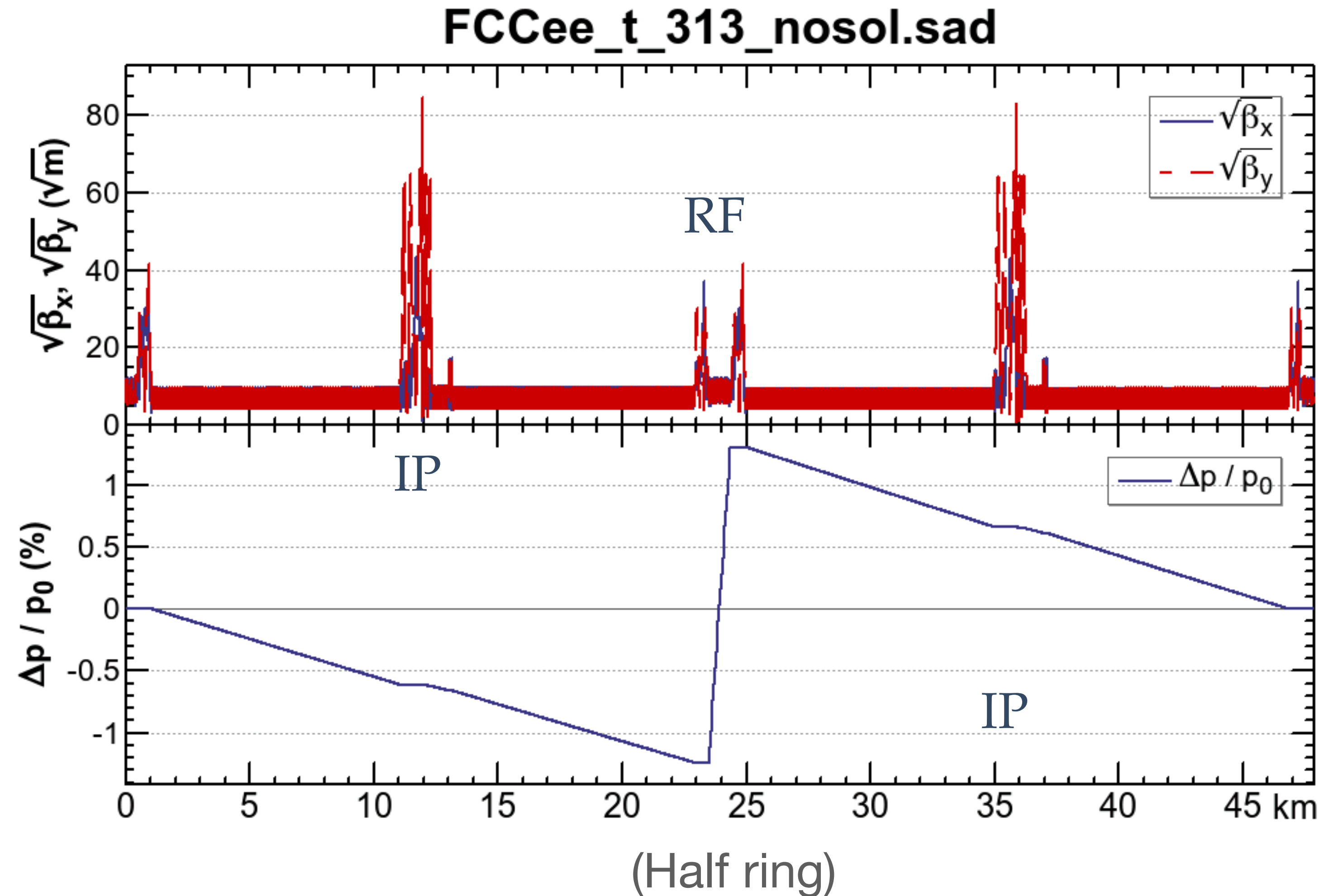
The luminosities and beam-beam related numbers above are based on a simple model w/o beam-beam simulations.

Dynamic apertures with 2 RF sections ($t\bar{t}$)



- The dynamic aperture for the 2RF/4IP configuration looks very similar to 4RF/4IP.
- Although the DA is the same, the beam-beam performance can be different. it is to be studied.

Energy sawtooth with 4 IP 2 RF sections ($t\bar{t}$)

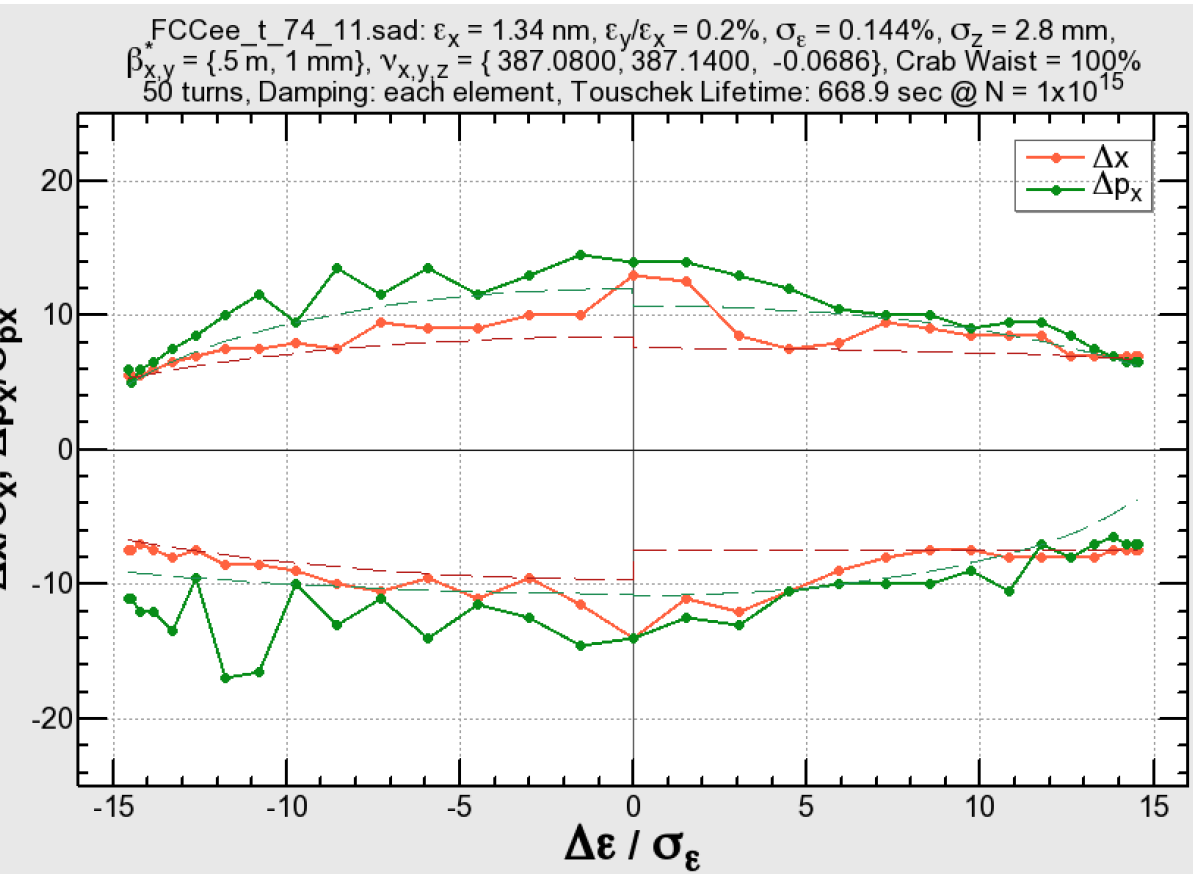


- The beam energies at each IP will be different due to the 4IP2RF placement.
- Electrons and positrons deviate in opposite, but the CM energies stay nearly unchanged.

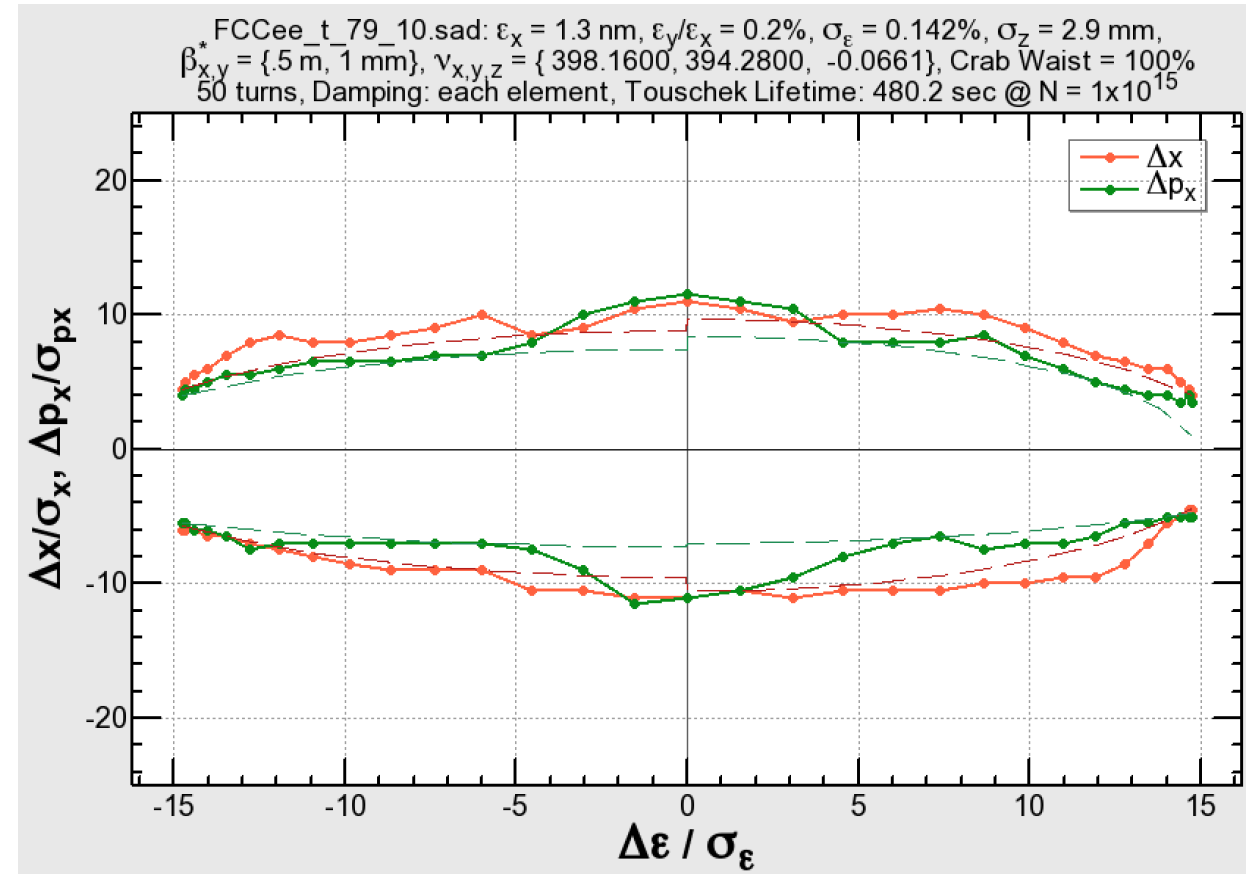
Periodicity in the lattice and RF

175 GeV, $\beta_{x,y}^* = (0.5 \text{ m}, 1 \text{ mm})$

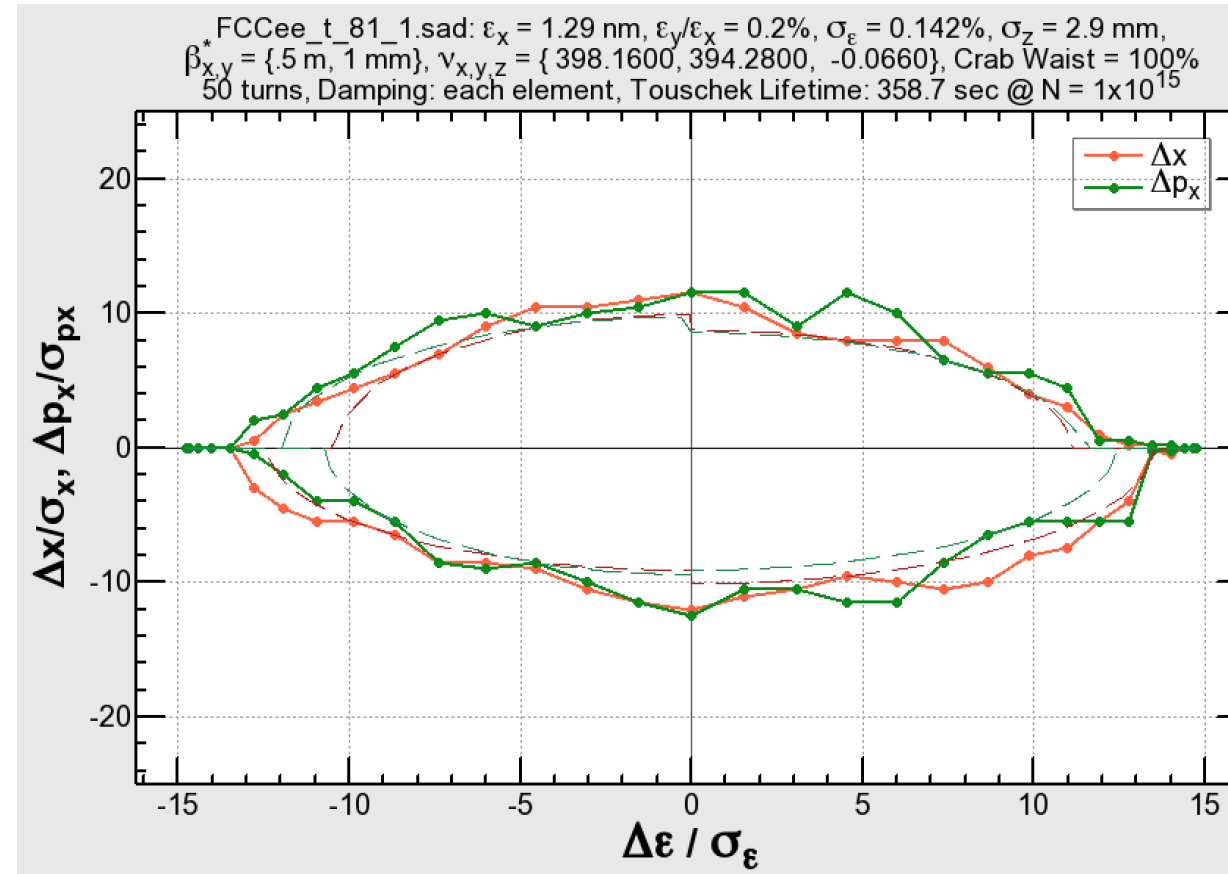
2 IP



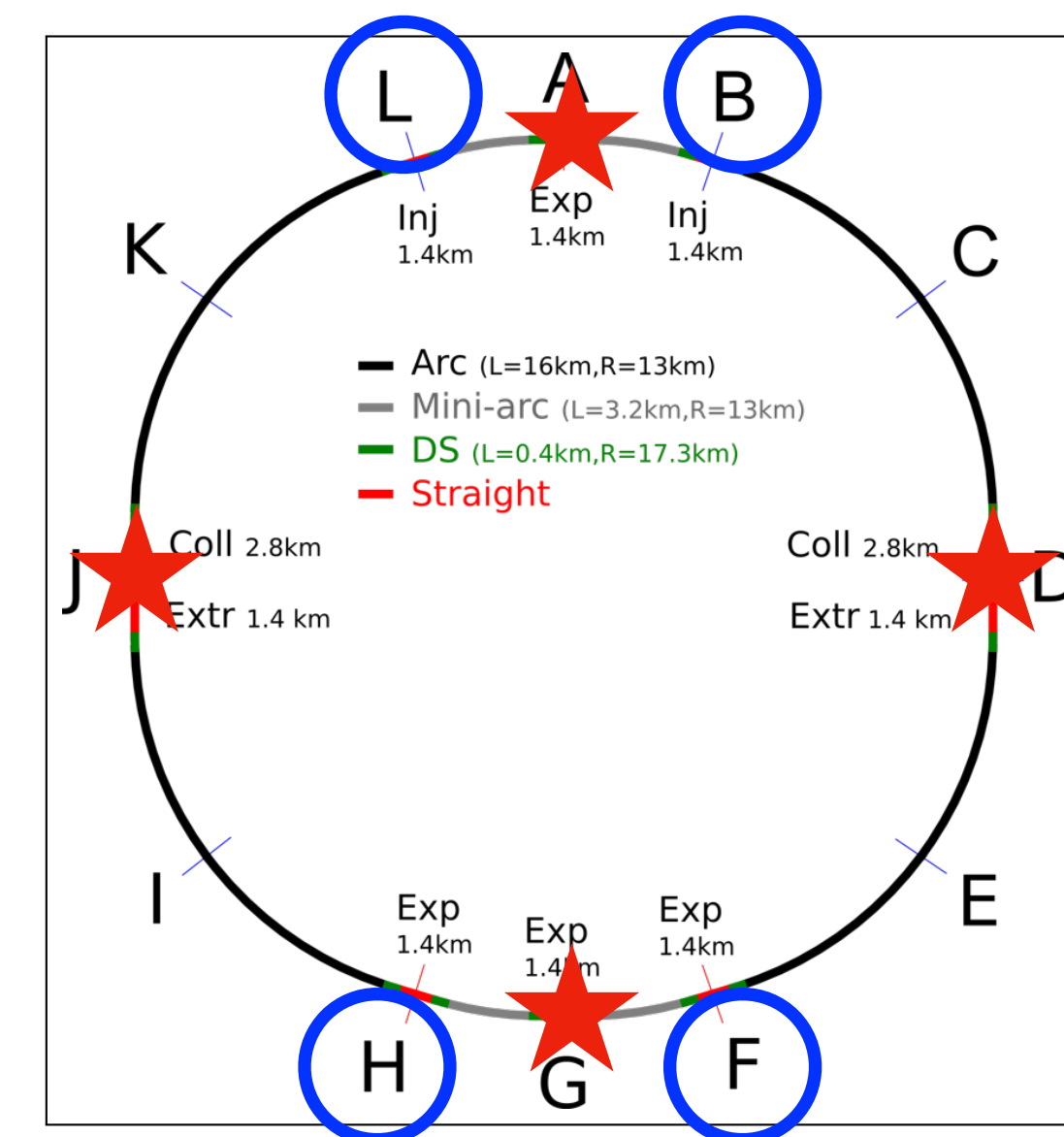
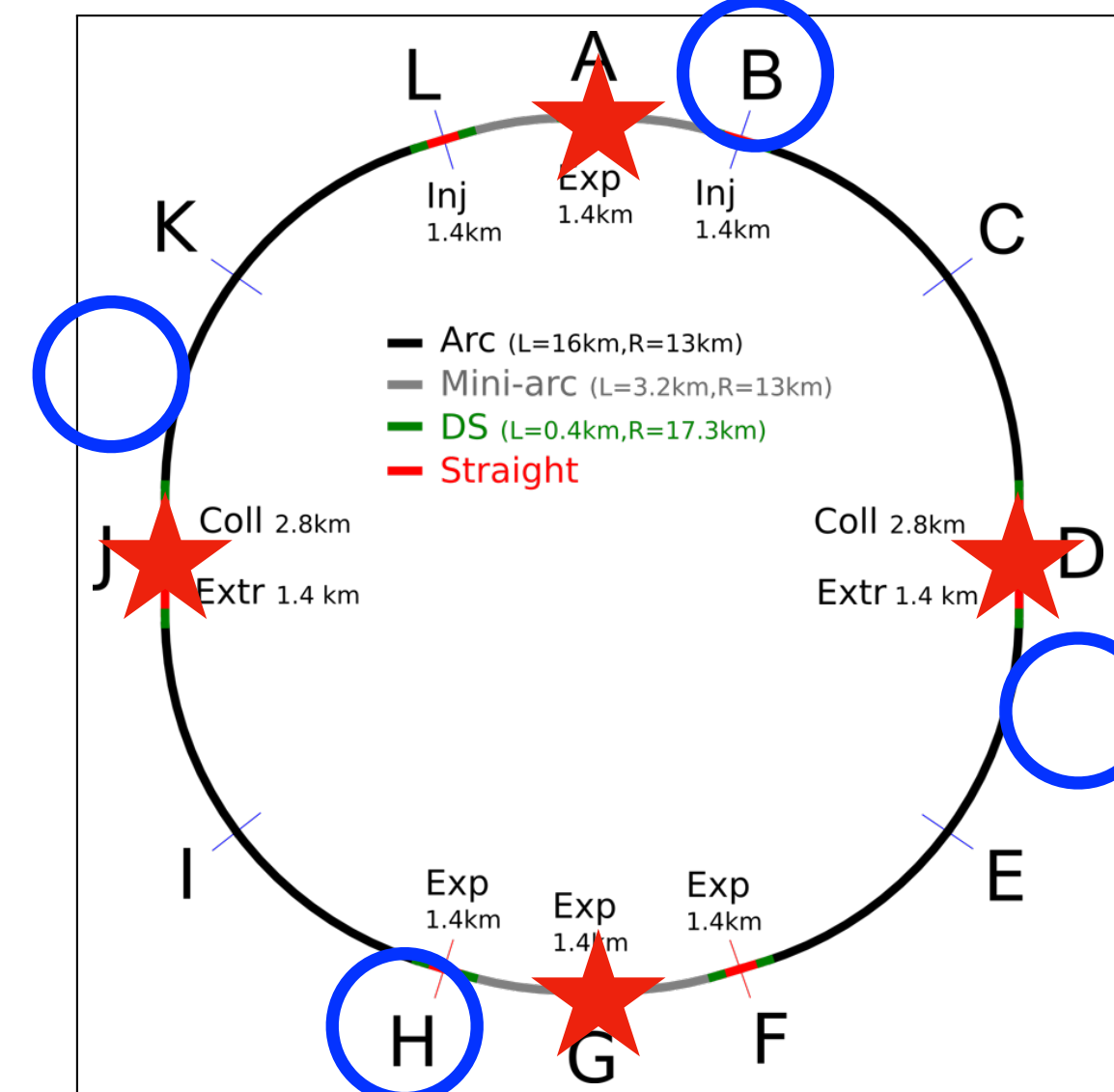
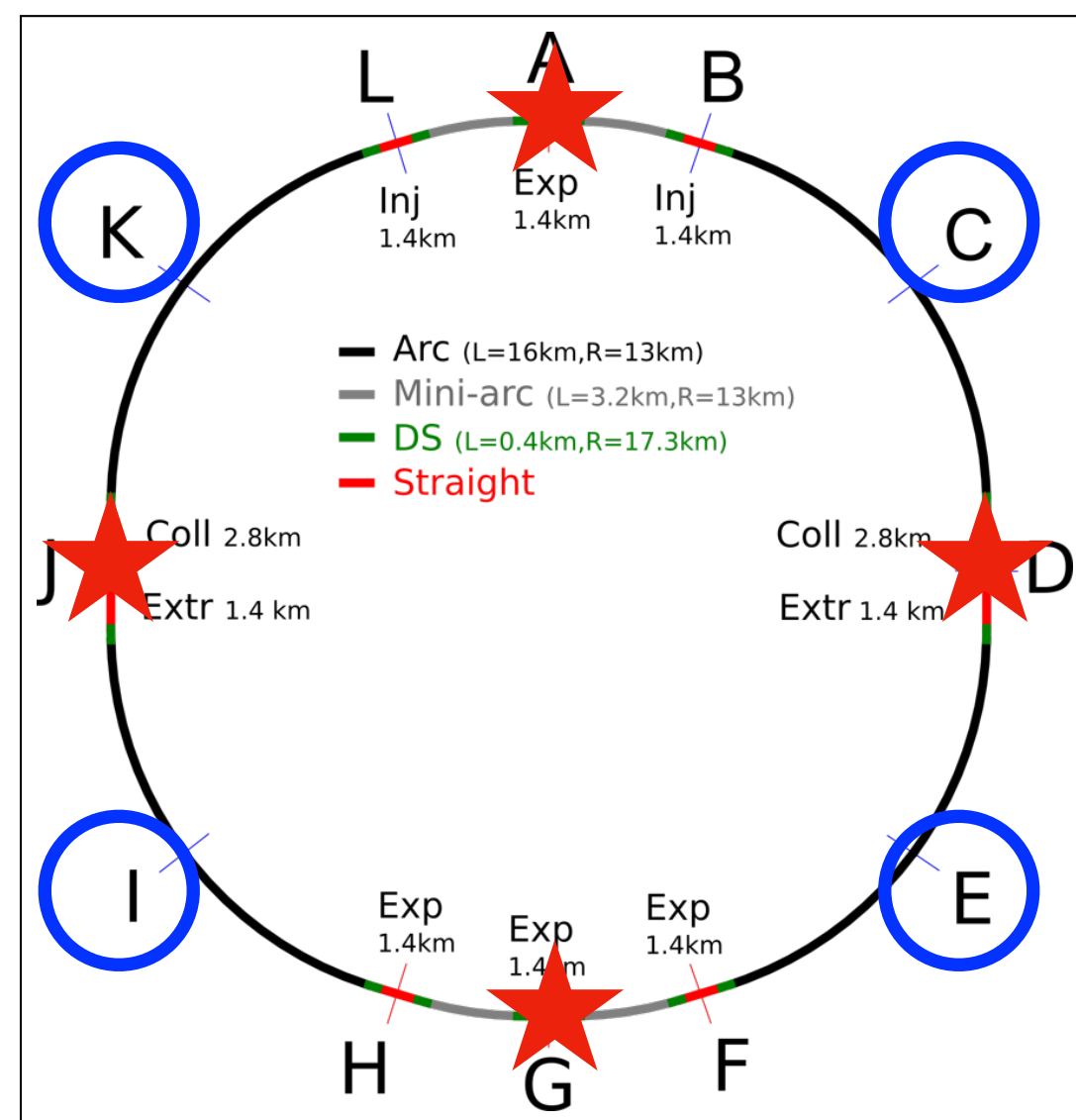
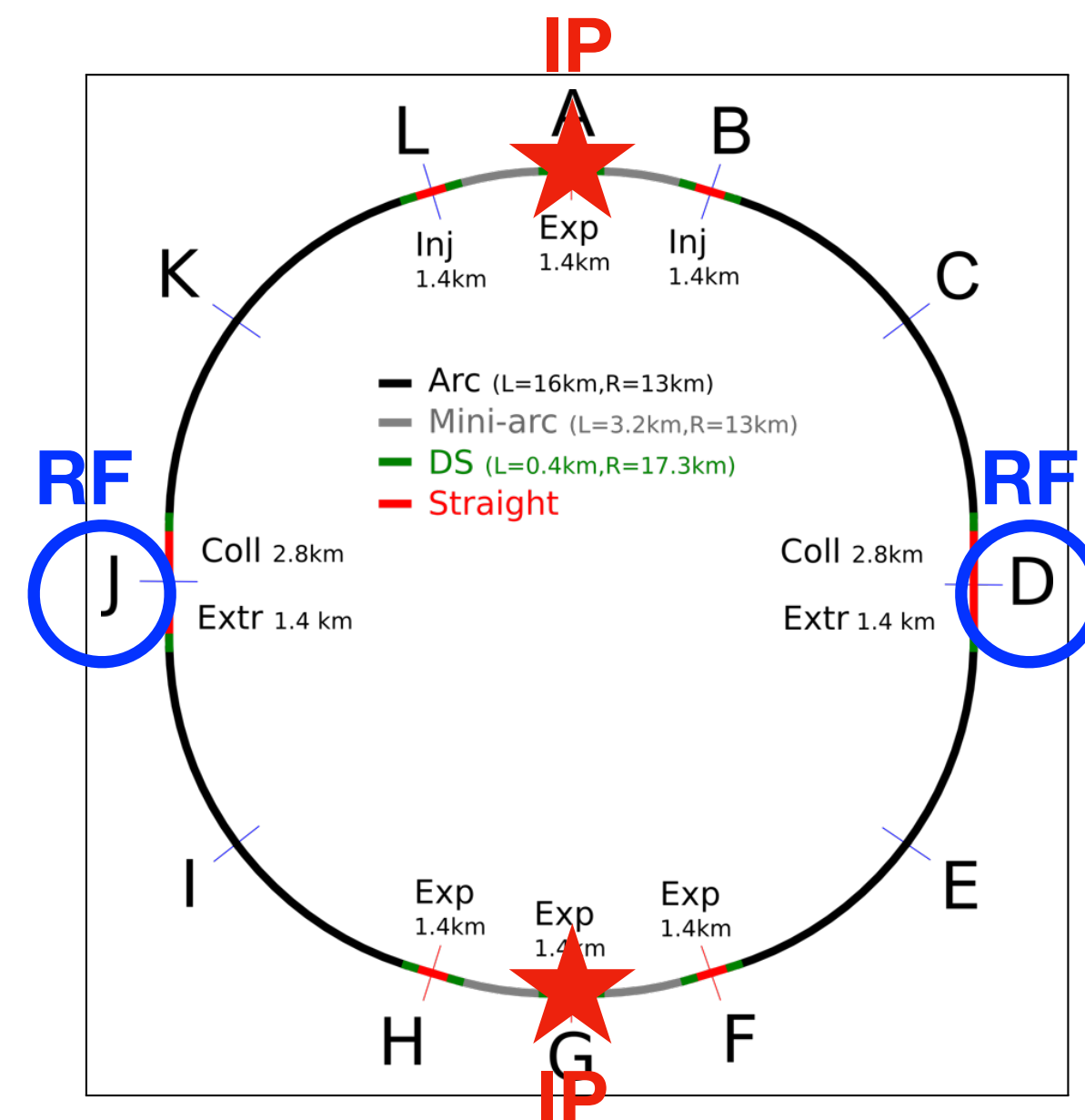
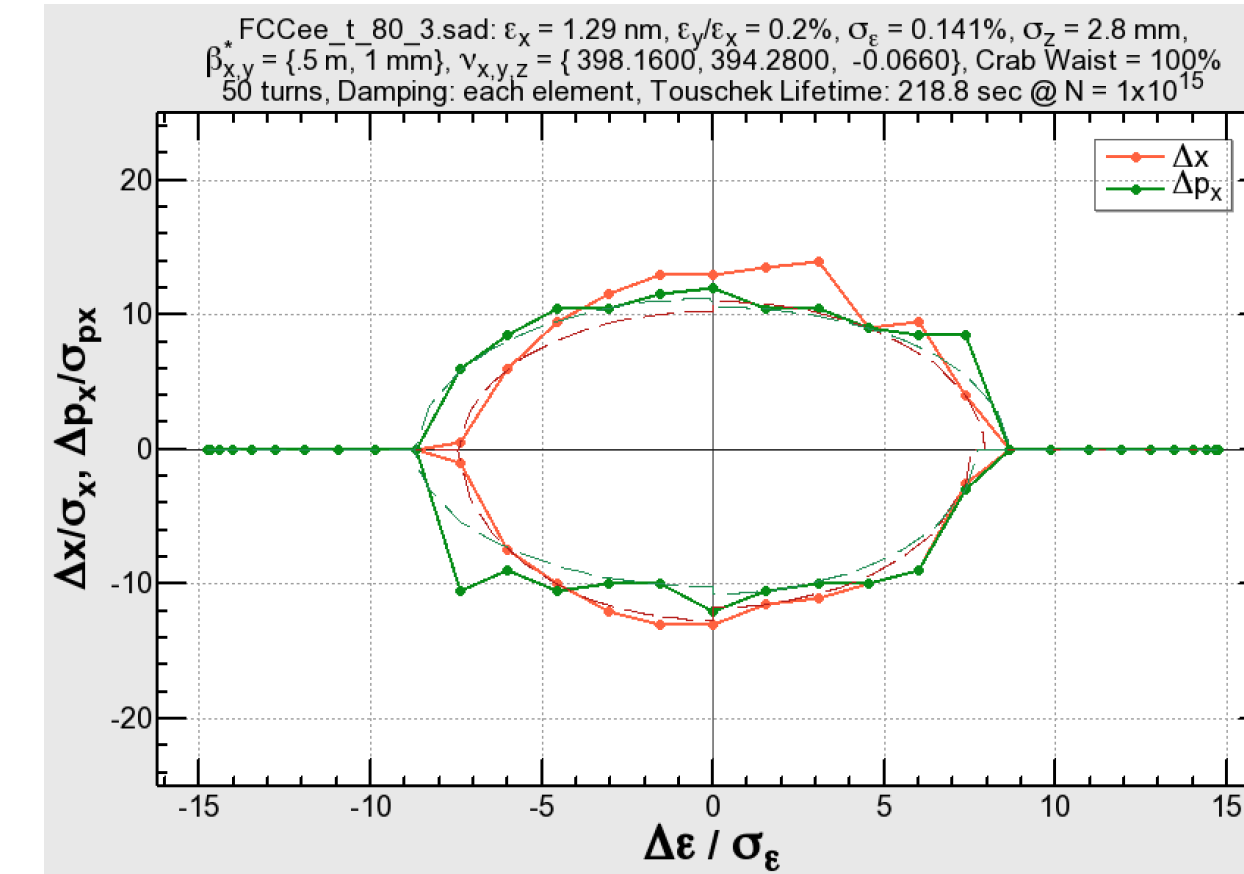
4 IP
(period 4, 45 RF)



4 IP
(period 4, odd location)



4 IP
(period 2, odd location)



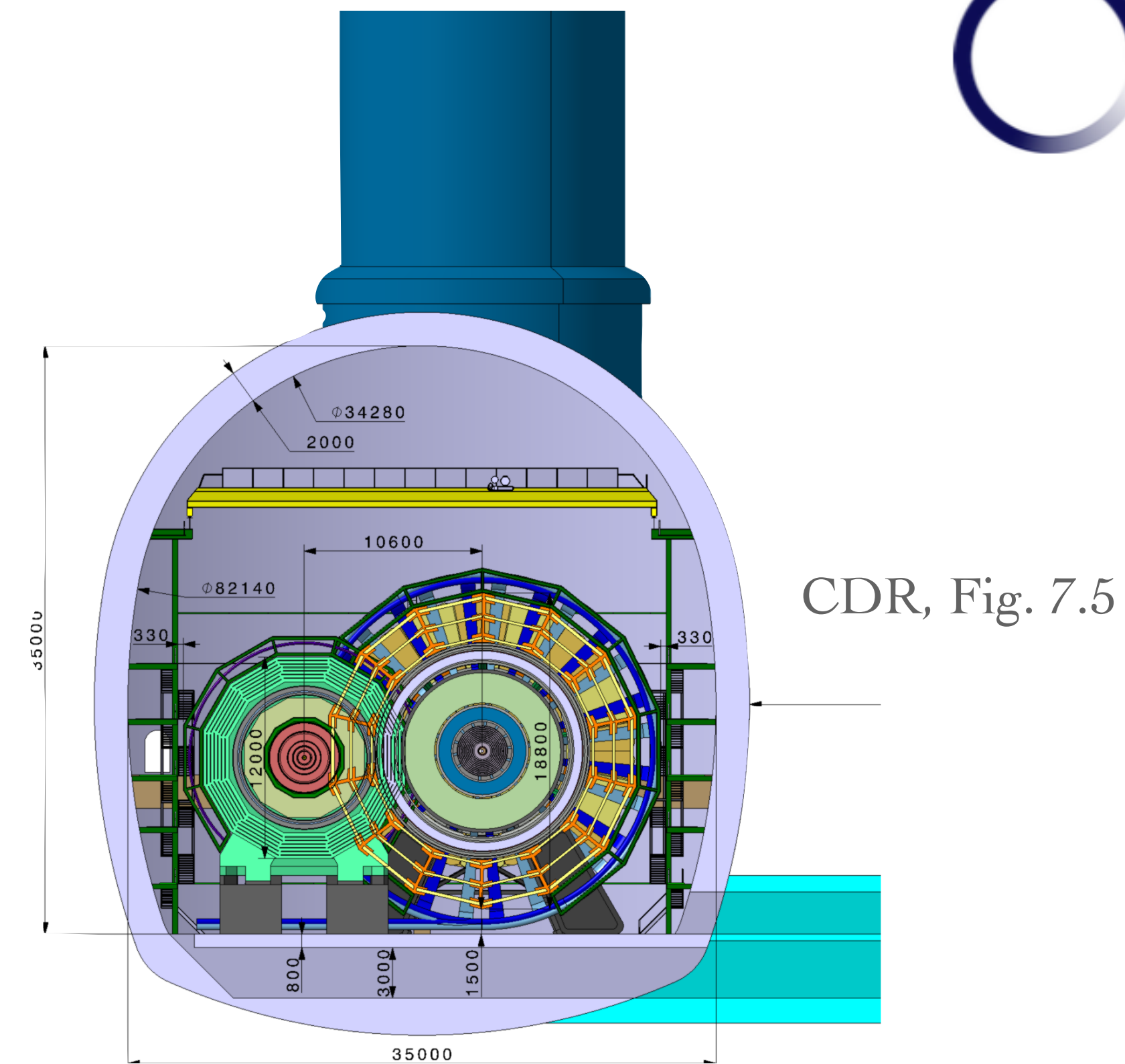
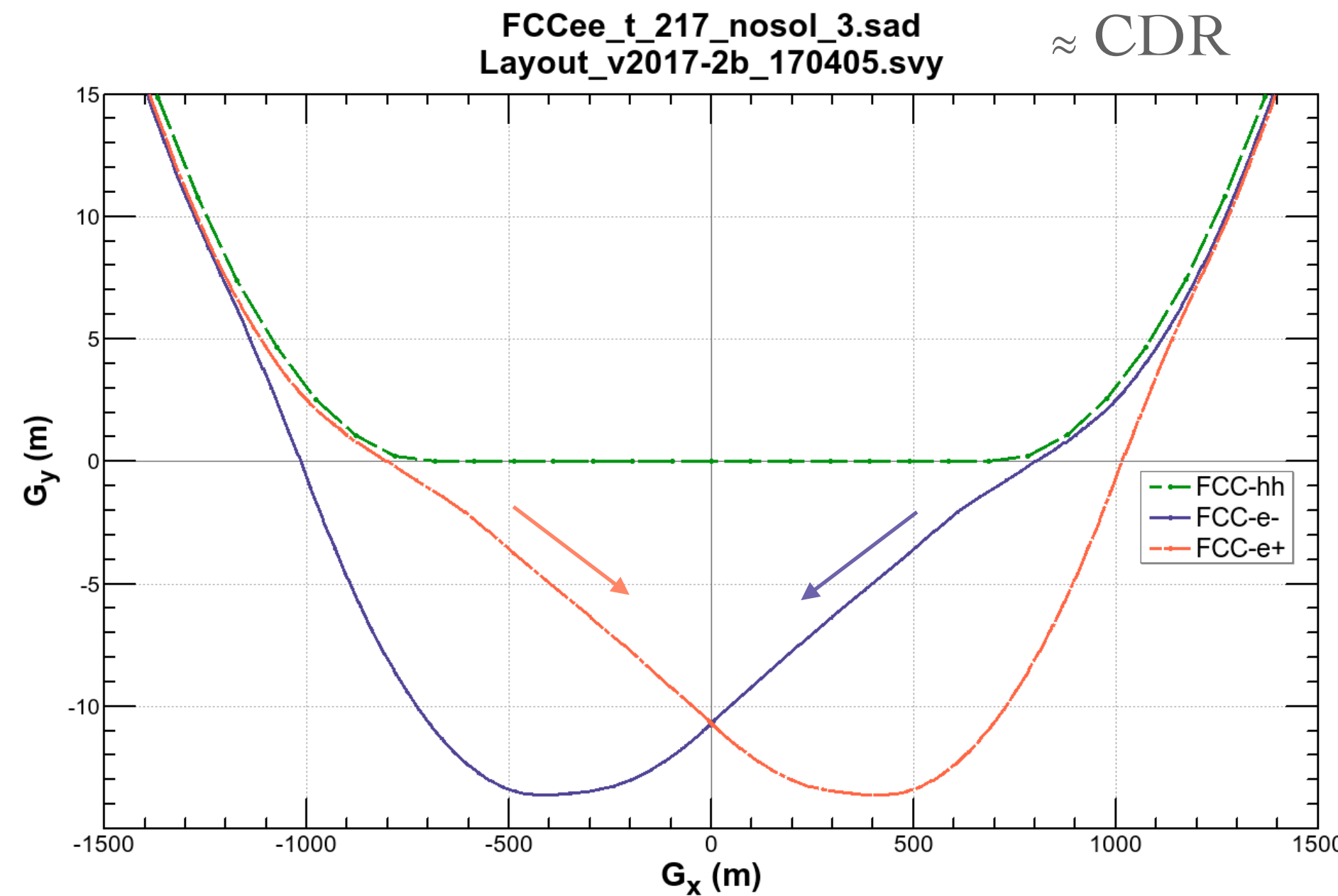
Importance of periodicity in 4 IP beam optics (summary)

lattice periodicity	RF (stations, location)	momentum acceptance (%)
4	4, symmetric	-2.8, +2.5
4	4, odd	± 1.7
2	4, odd	± 1.0
4	4, symmetric	-2.8, +2.5
4	2, symmetric	-2.8, +2.5

- The momentum acceptance is highly degraded by reducing the periodicity of the lattice including the RF.

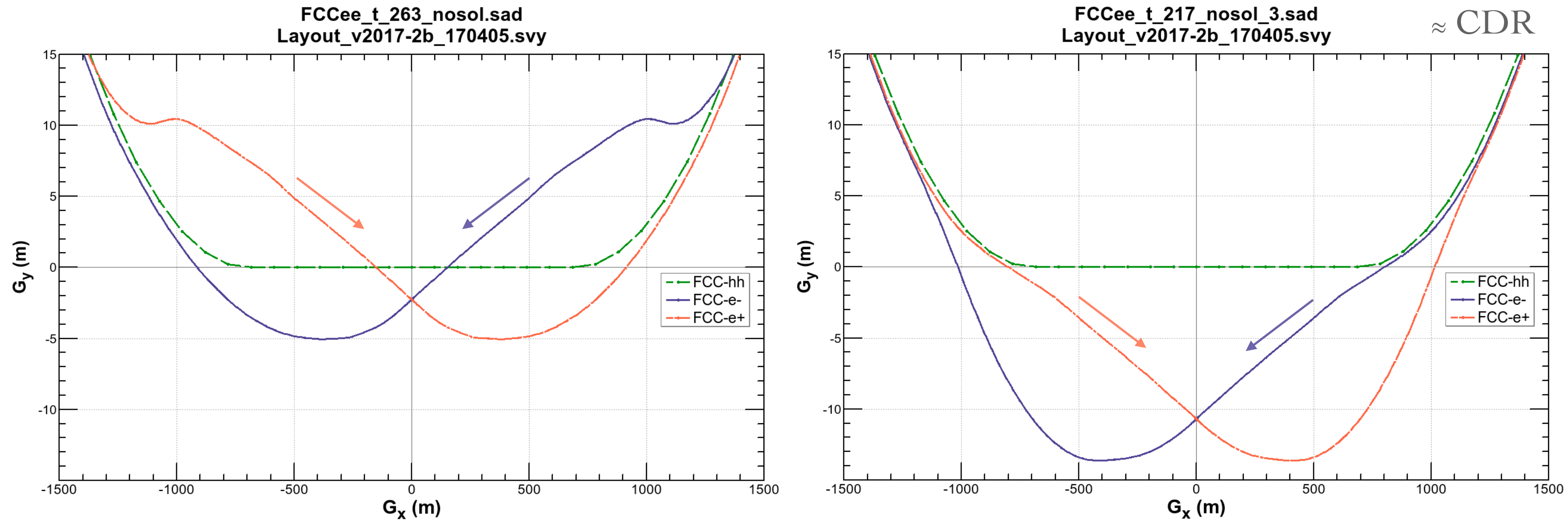
Making IPs closer for ee and hh

(motivated by M. Benedikt)



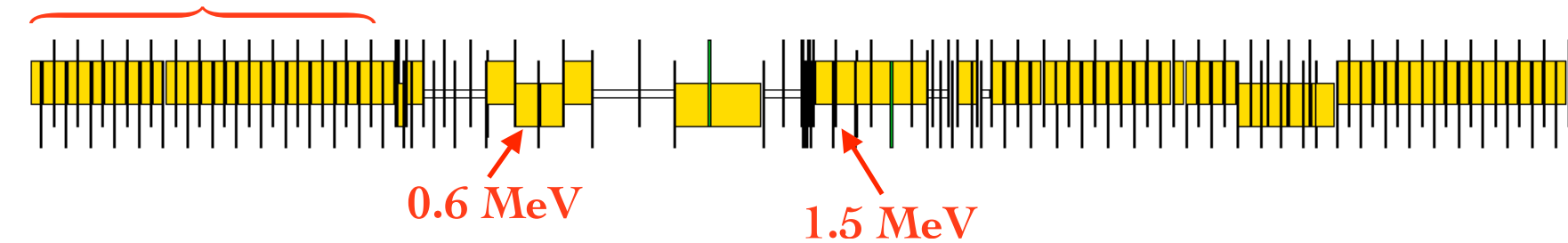
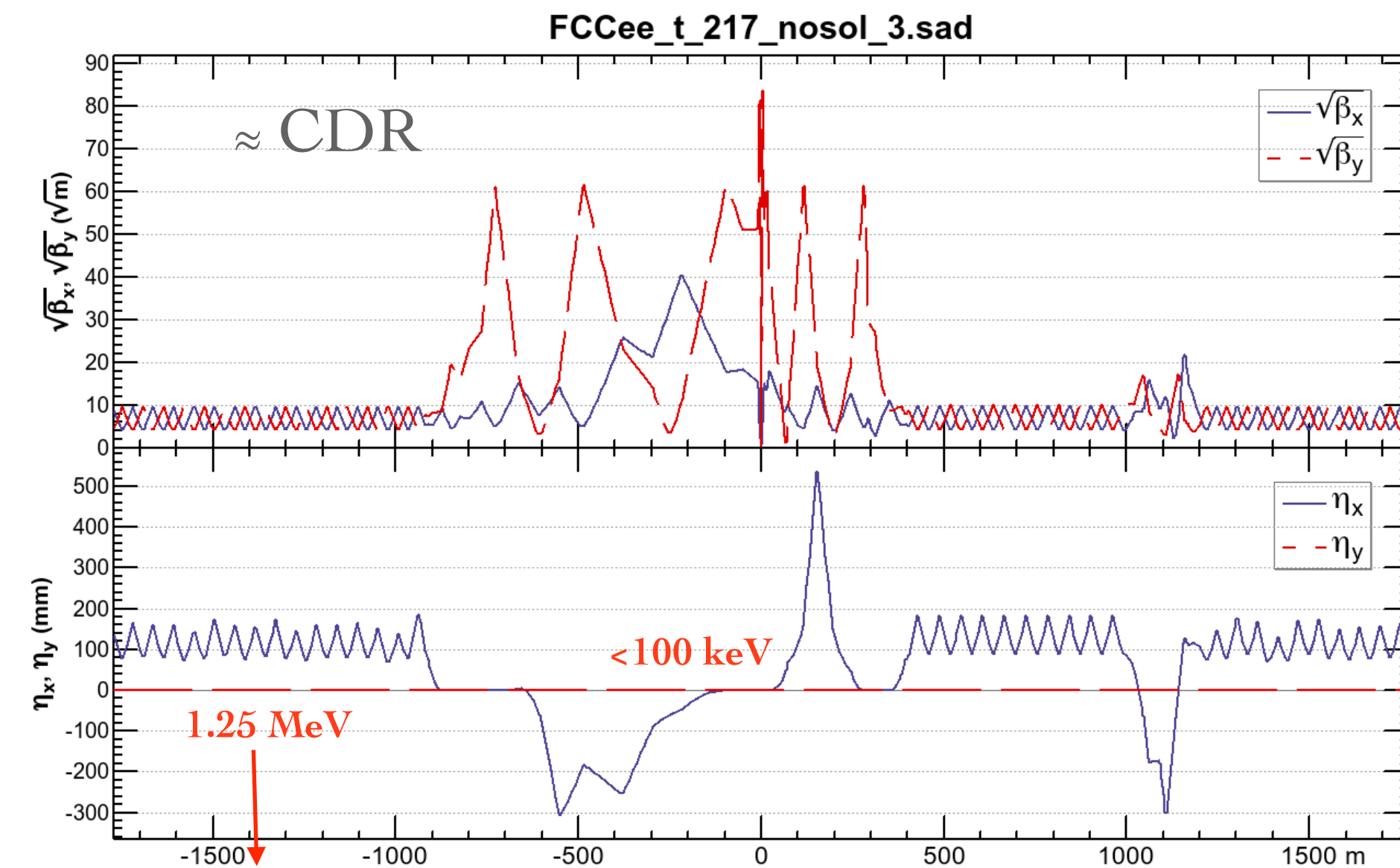
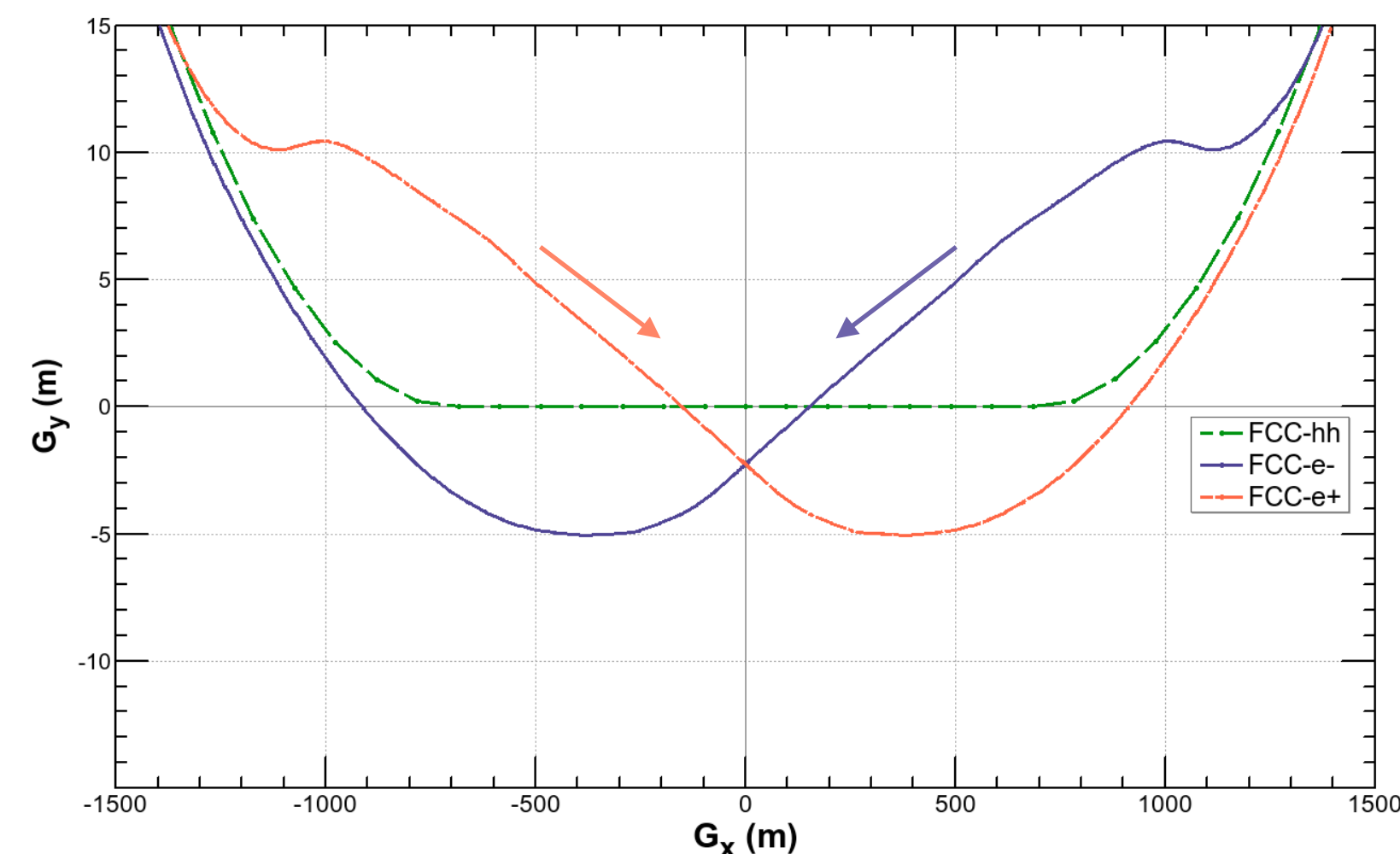
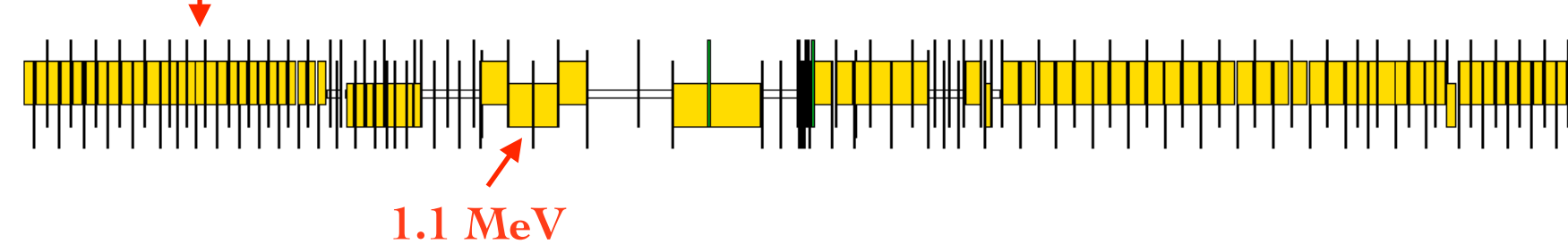
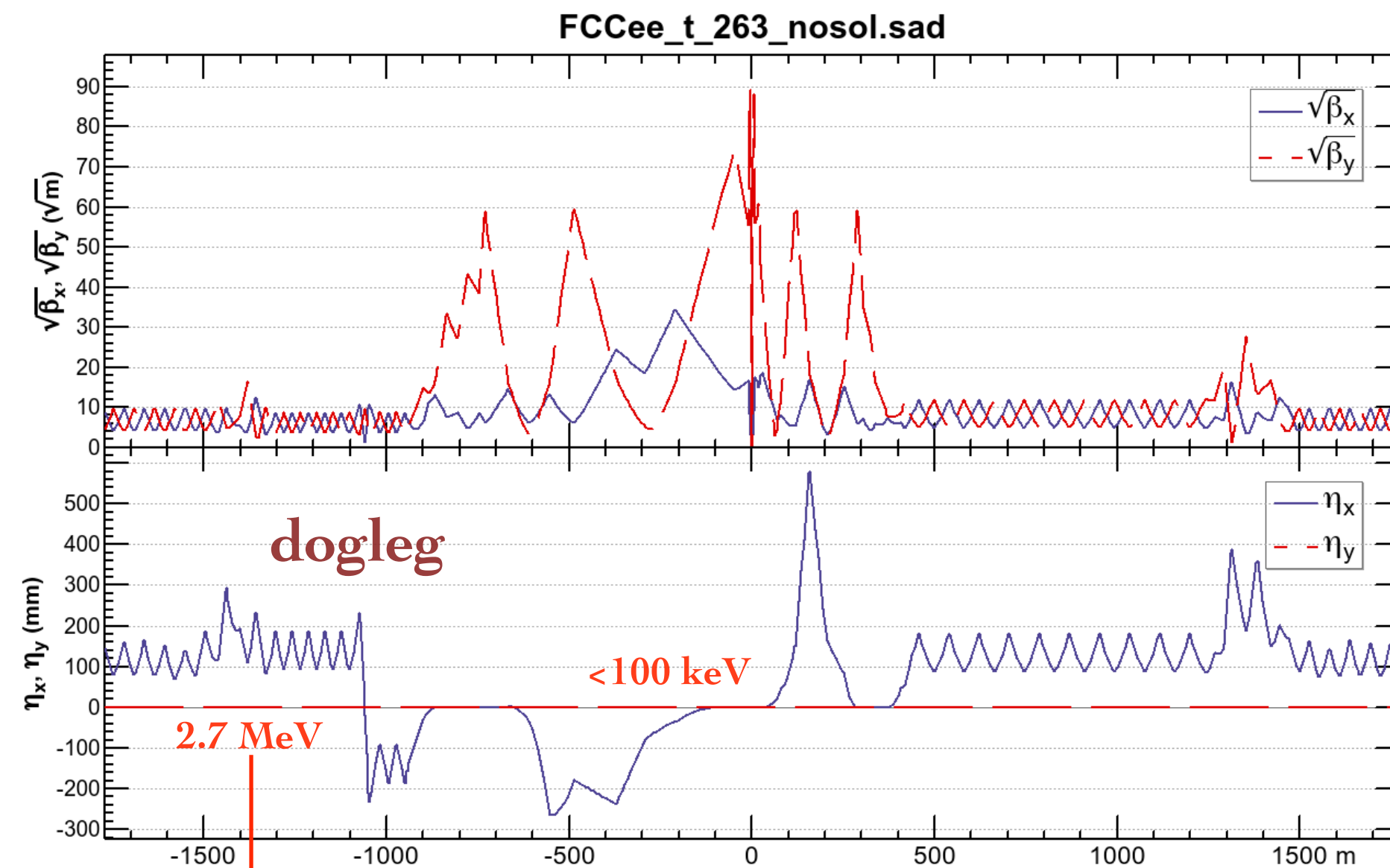
- The layout of the beam lines in the IR is designed to minimize the synchrotron radiation for the incoming beams. The resulting shift of the ee's IP from hh's is 10.7m.
- The cavern to accommodate two detectors (HH: ≈ 22.8 m ϕ , ee: ≈ 16 m ϕ) will be as wide as 35 m, with margins (3.3 m on the both sides), as shown in the figure.
- If we can reduce the separation below $(HH - ee)/2 = 3.4$ m, the entire width will shrink to $HH + 6.6$ m = 29.4 m. The reduction of the cost $\approx (29.4/35)^2 = -30\%$??
- A complete adjustment further may benefit to reconstruct the HH detector on recycling some parts of the ee detector.
- The numbers are read from Fig. 7.5 in the CDR.

An example beam layout for smaller separation



- An example of the IR optics has been constructed: now the shift of the IP from HH's is 2.26 m.
- The critical energy of the incoming beam is still suppressed below 100 keV up to 470 m from the IP @ $t\bar{t}$.
- There are at least three issues:
 - Emittance generated by the extra bending (dogleg): 1.50 nm vs. 1.45 nm @ $t\bar{t}$.
 - The critical energy of the further upstream dipoles and the dogleg reaches reach 1.1 MeV and 2.6 MeV (Arc dipoles: 1.25 MeV).
 - The separation of three beams starts at ± 1.3 km, reaches ≈ 9 m at ± 1 km from the IP. The CDR optics: starting at ± 1.2 km, reaches ≈ 1.3 m at ± 0.5 km from the IP.
- The booster needs a horizontal bump to bypass¹² the ee detector.

IR beam optics with dogleg



- An extra dogleg is necessary in the incoming beam to shift the IP toward hh's.
- The dogleg can be used for chromaticity correction, by installing 3 families of sexts.
- A complete adjustment of both IPs will be very difficult.
- Dynamic aperture, etc. are not yet done.

Moving ee's IP towards hh's

... more difficulties than merits

- An example of alternative IR optics is presented to reduce the separation between hh and ee IPs.
- The distance between two IPs is reduced from 10.7 m to 2.26 m. Then the ee detector will completely reside within the HH detector.
- An upstream dogleg makes the shift of the IP. Stronger SR up to $u_c \lesssim 2.7$ MeV is expected.
 - The horizontal emittance increase is acceptable (by $\approx 3\%$).
 - Further reduction of the separation towards the complete overlap needs earlier deviation from HH in the arc.
- Even wider tunnels are needed before the end of the arc for the dogleg.

moving hh's beam line and the IP may be possible (Thys Risselada).

Remaining issues for further study

- Decision on the placement must be done first: many details depend on this.
- Beam dynamics with beam-beam + lattice under machine errors, tuning schemes (☞ D. Shatilov, T. Charles) + impedance (☞ M. Migliorati, Y.Zhang)
- Optics with IP solenoids at each energy.
- 45 degree lattice for Z (☞ D. Shatilov).
 - Compatibility for 45, 60, 90 phase advances in the arc will be much easier by overlapping quads and sexts with HTS (M. Koratzinos).
- Missing insertion optics: RF for all energies, injection, abort, collimators, polarization wigglers, polarimeter (esp. for 4 IP) (☞ M. Aiba, J. Bauche, A. Krainer, F. Peauger, A. Abramov, M. Hofer).
 - The common RF scheme for tt needs an adjustment of path length between RF and the IP.
- The tapering scheme (☞ J. Bauche, D. Aguglia).
- Filed profiles (esp. longitudinal) of magnets.
- Spaces between components.
- More missing components: correctors, BPMs, feedback systems, electrostatic separators...

Summary

- Beam optics for layouts (“17.08”, “19.03”, “20.03”) have been generated.
- The dynamic apertures are optimized up to some extent. The results look OK for all layouts.
 - The resulting momentum acceptance for “19.03” is slightly worse ($-2.6\%+2.5\%$) than others ($-2.8\%+2.5\%$). A possible reason is that slightly stronger sextupoles are needed in the arc.
- The luminosity performances basically follow the changes in the ring circumferences or the bending radii, due to the SR loss.
- Maintaining the lattice periodicity is important for a good DA.
- Shifting ee’s IP toward hh’s *by tweaking the ee beam line* will have more demerits than the merits. Hope better handled by the hh side.
- (Too) many details in the optics design remain after the choice of the layout...