IR Optics for FCC-ee

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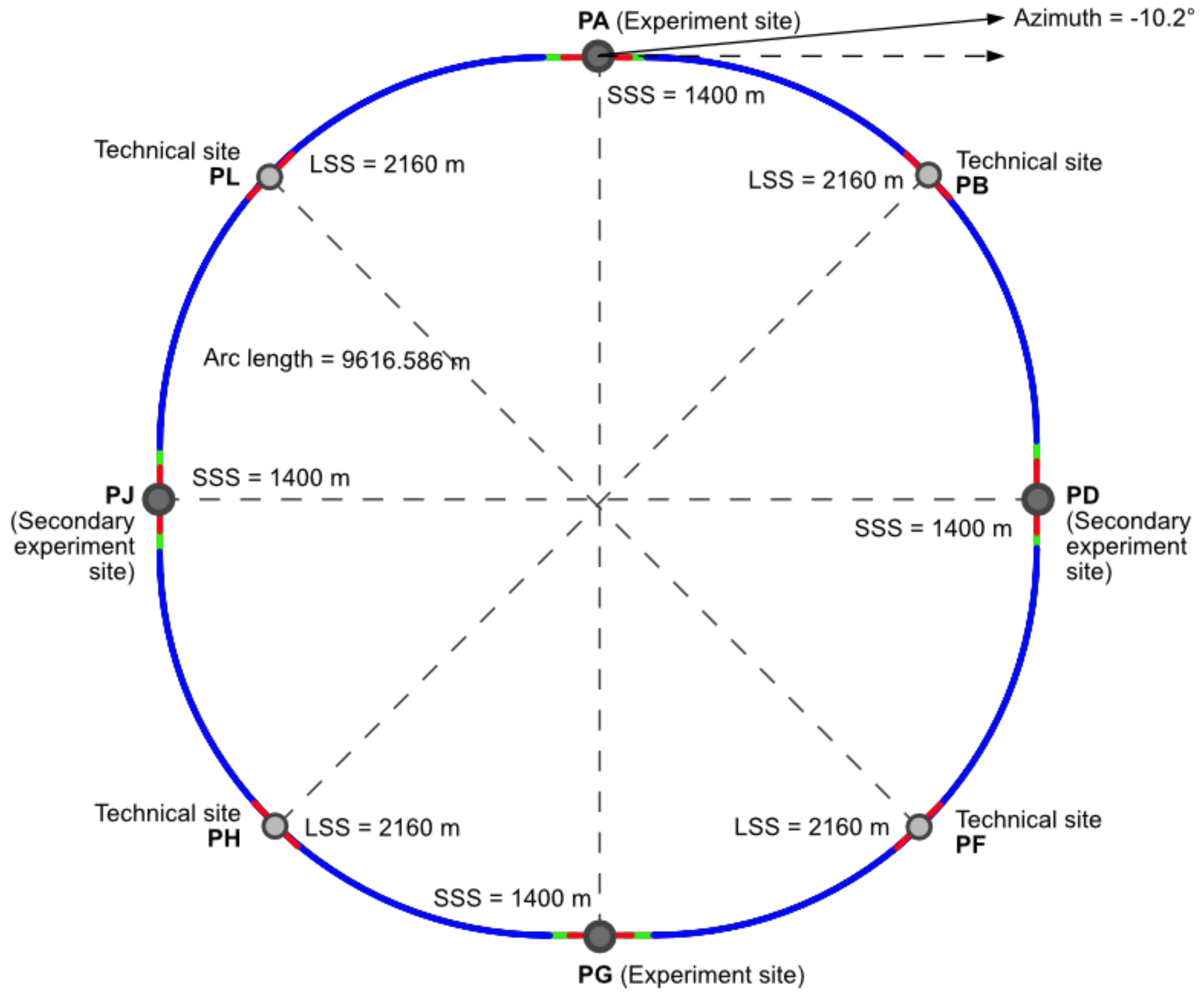
Many thanks to M. Benedikt, A. Blondel, M. Boscolo, M. Hofer, M. Koratzinos, T. Raubenheimer, D. Shatilov, F. Zimmermann, and all FCC-ee/FCCIS colleagues

The 4 IP layout

- The new layout "31" series has been presented by J. Gutleber in the last optics meeting.
  - 8 surface sites, 4 IP.
  - complete period-4 + mirror symmetries.
- Let us choose "PA31-1.0" for the baseline, for the time being.
  - The adaptation to other variants, if necessary, will be minor.
  - An update "PA31-2.0" has been proposed with a change in the length of IP straights. The optics will adapt it soon with several other changes.



PA31-1.1 & 1.6 fallback alternatives

J. Gutleber

Scenario	PA31-1.0	PA31-1.1	PA31-1.6
Number of surface sites	8 (potential additional small access shafts at CERN or for ventilation at sites with long access tunnels, e.g. PF)		
Number of arc cells	42		
Arc cell length	213.04636573 m		
SSS@IP (PA, PD, PG, PJ)	1400 m	1400 m	1410 m
LSS@TECH (PB, PF, PH, PL)	2160 m	2100 m	2110 m
Azimuth @ PA (0 = East)	-10.75°	-10.45°	-10.2°
Sum of arc lengths	76 932.686 m		
Total length	91 172.686 m	90 932.686 m	91 052.686 m

Layout in the interaction region

- Both IPs of FCC-ee and FCC-hh now completely overlap.
  - The IP transversely deviates from the layout line by about 10.5 m outward.
- Beams always enter the IP from inside of the ring.
  - Thus they must cross to each other in the RF straight sections.
- The placement of the booster has not been perfectly determined.
  - It must bypass the FCC-ee detector by more than 8 m separation from the IP.

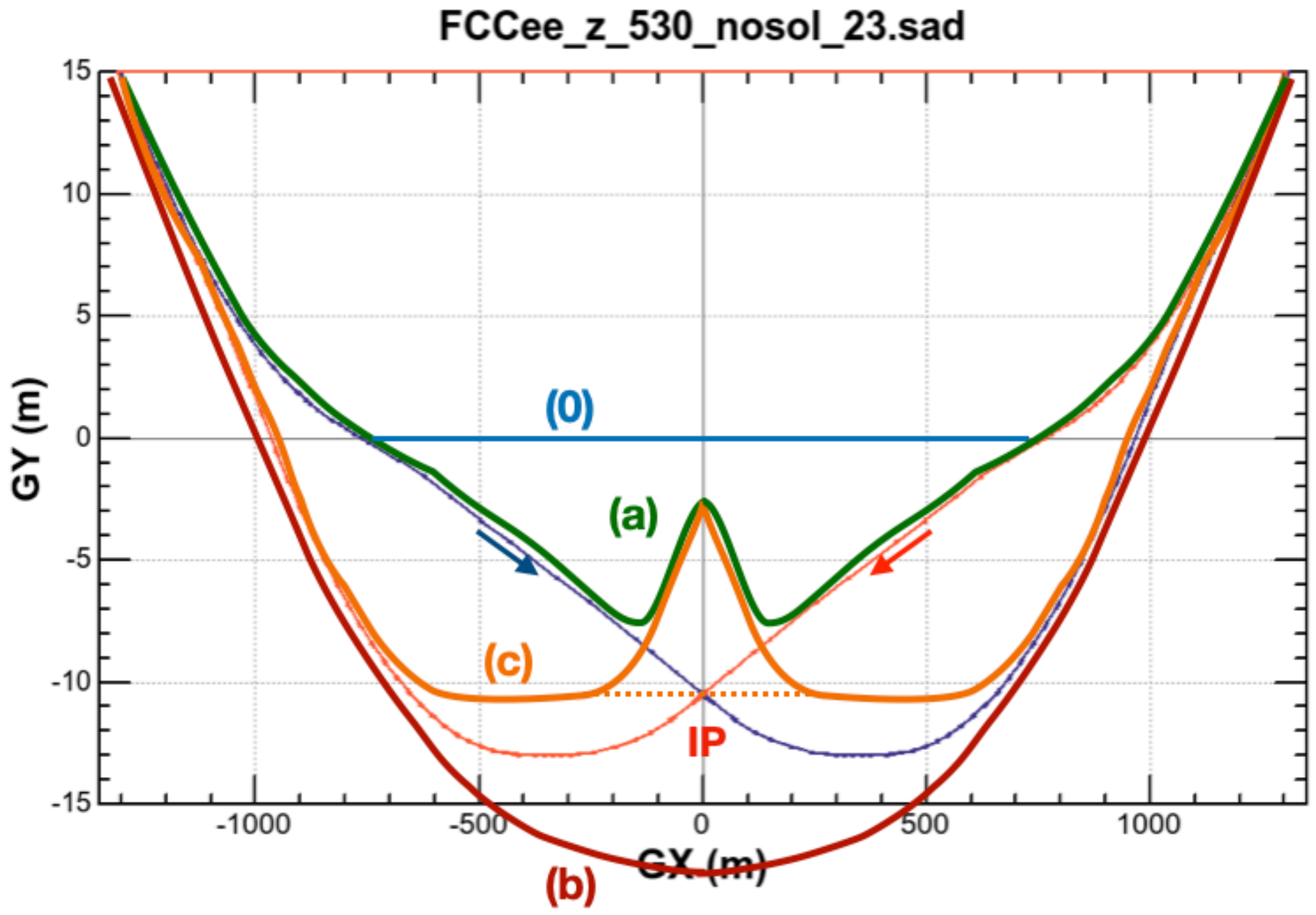
    Several choices (and more) are conceivable:

    (0) Layout line

    (a) stay inside of the inner collider ring with a bypass chicane within about ±200 m of the IP.

    (b) going outside of the detector

    (c) follow the FCC-hh beam line with a bypass chicane.
  - If the booster is placed on the same plane as the colliders, (c) has to cross the colliders at several locations.
  - To avoid the crossing, (a) and (b) have to stay inside or outside of the colliders, respectively.
- The choice will be made considering the size of the associated tunnel, synchrotron radiation towards the detector, etc.



Size of the IR tunnel (CDR)

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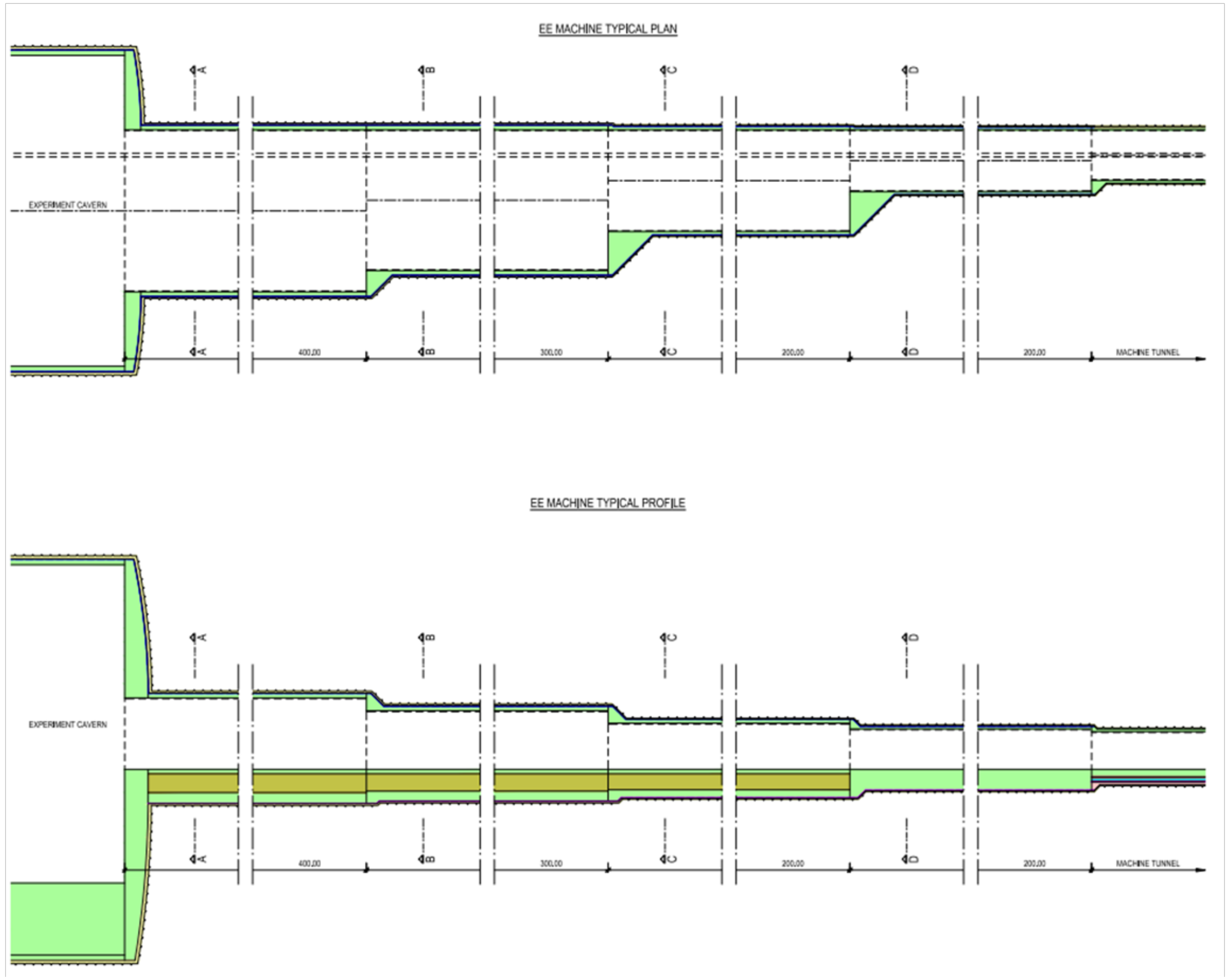
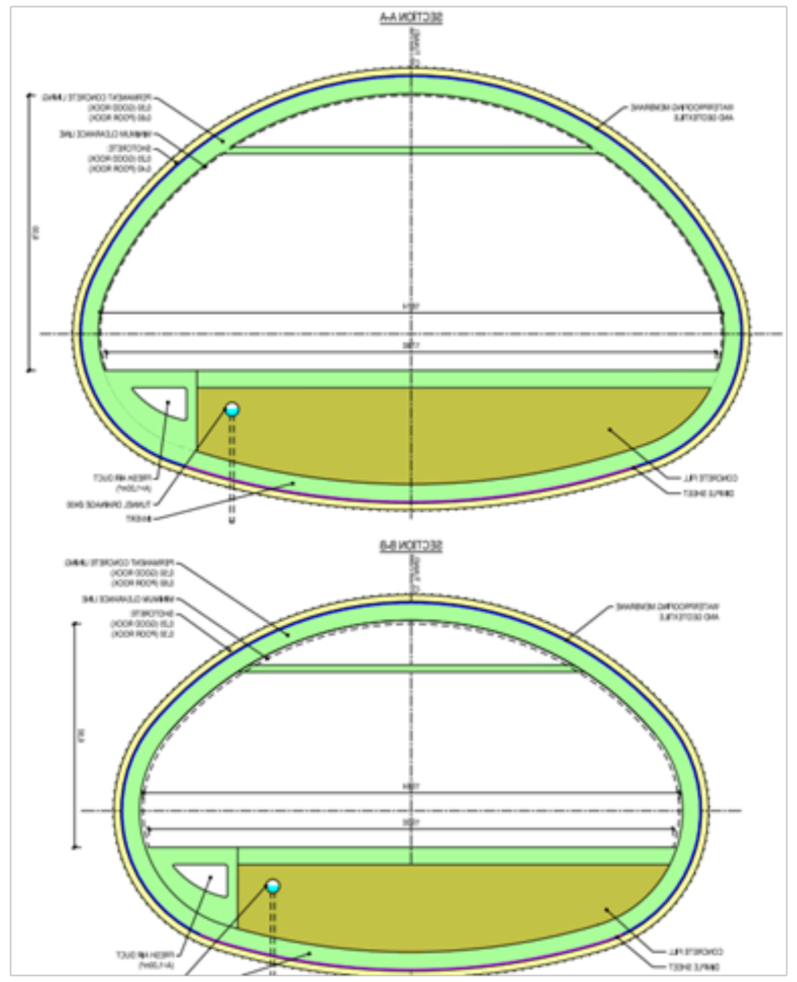
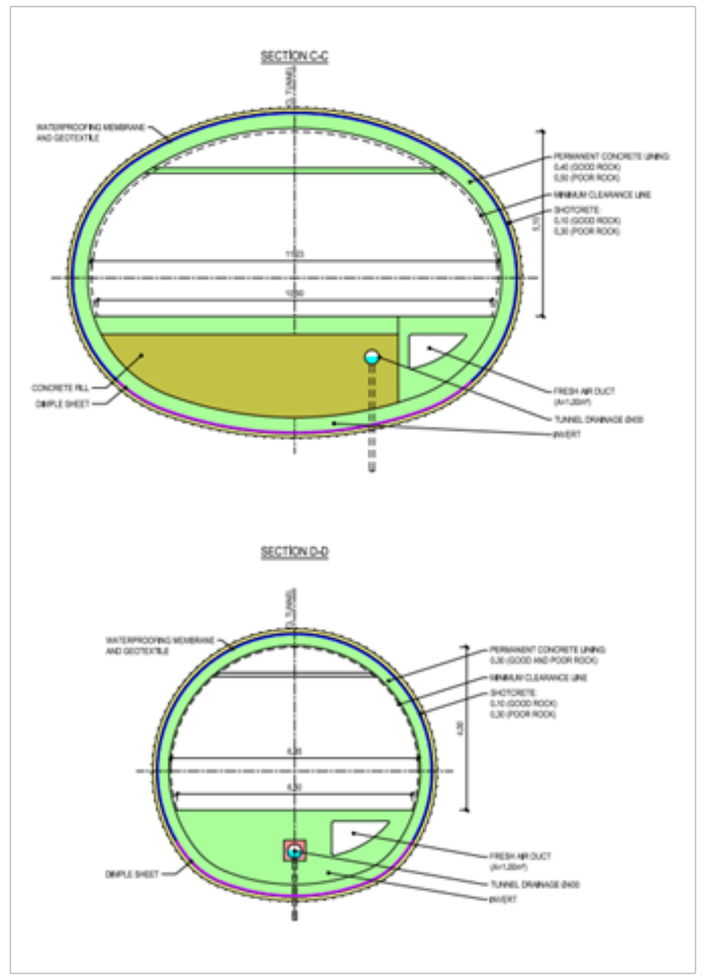
CDR Tunnel Widening (ee) – Experiment Sites
Original CDR Widening





18.1m

15.6m



11.2m

6.9m

via F. Zimmermann

“latest” parameters

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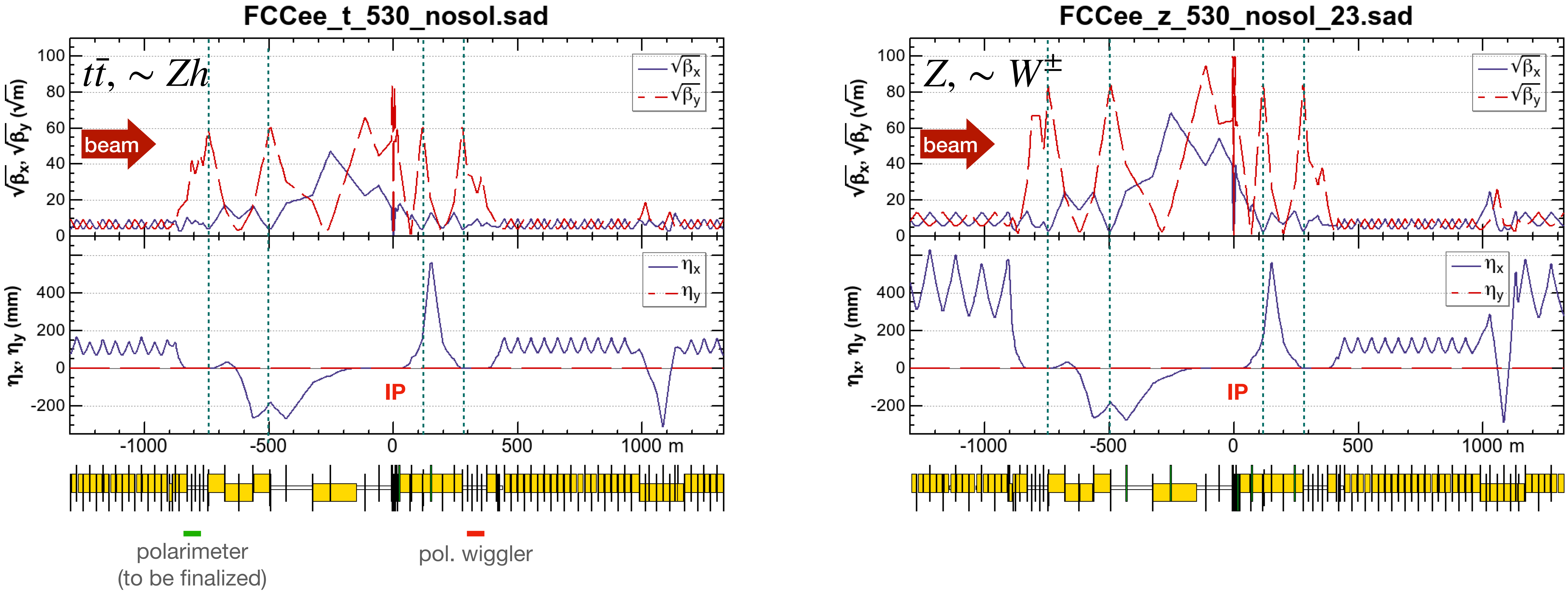
Beam energy	[GeV]	45.6	80	120	182.5
Layout		PA31-1.0			
# of IPs		4			
Circumference	[km]	91.174117		91.174107	
Bending radius of arc dipole	[km]	9.937			
Energy loss / turn	[GeV]	0.0391	0.370	1.869	10.0
SR power / beam	[MW]	50			
Beam current	[mA]	1280	135	26.7	5.00
Bunches / beam		10000	880	248	40
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 / 0.221
Bunch length (SR/BS) σ_z	[mm]	4.38 / 15.4	3.55 / 8.01	3.34 / 6.00	1.95 / 2.75
RF voltage 400/800 MHz	[GV]	0.120 / 0	1.0 / 0	2.08 / 0	2.5 / 8.8
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	3.0
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	0.093 / 0.140
Luminosity / IP	[10^{34}/cm^{2}s]	182	19.4	7.26	1.25
Lifetime (q + BS + lattice)	[sec]	840	–	< 1065	< 4062
Lifetime (lum)	[sec]	1129	1070	596	744

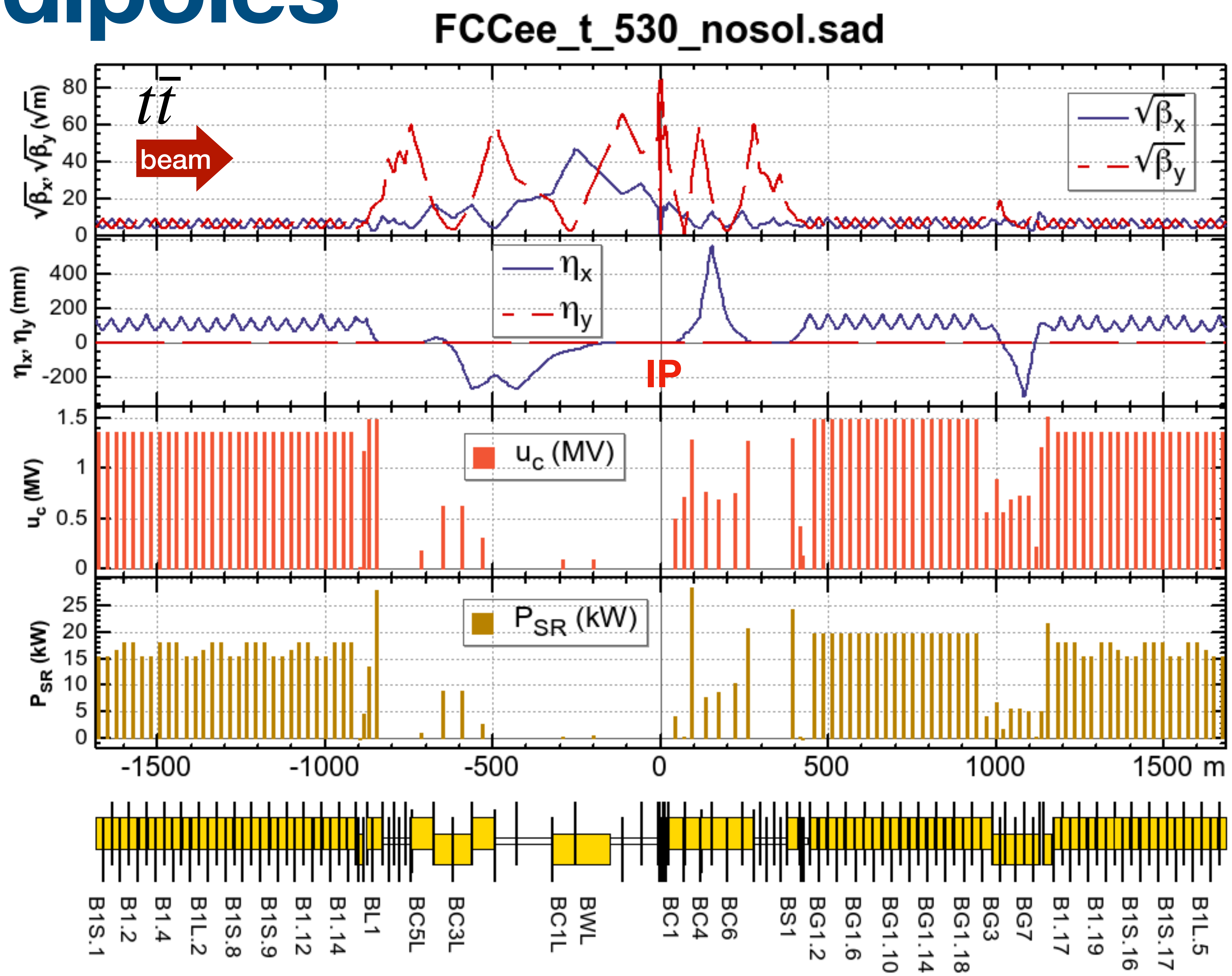
[a]incl. hourglass.

IR optics



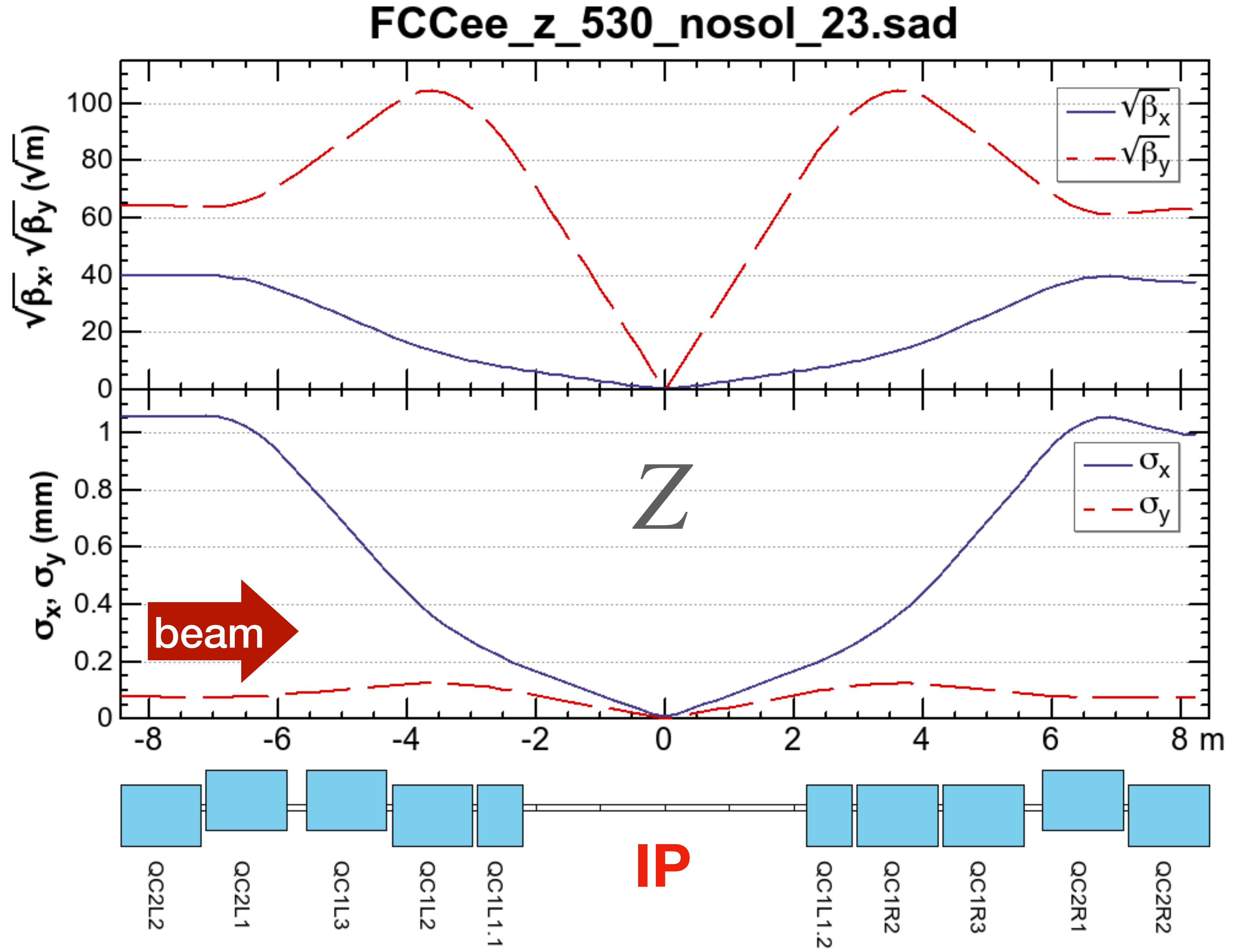
- The beam optics are highly asymmetric between upstream/downstream due to crossing angle & suppression of the SR from upstream to the IP.
- Crab waist/vertical chromaticity correction sextupoles are located at the dashed lines.
- The matching sections may be used for polarimeters (upstream) and polarization wigglers (downstream) (A. Blondel, M. Hofer).

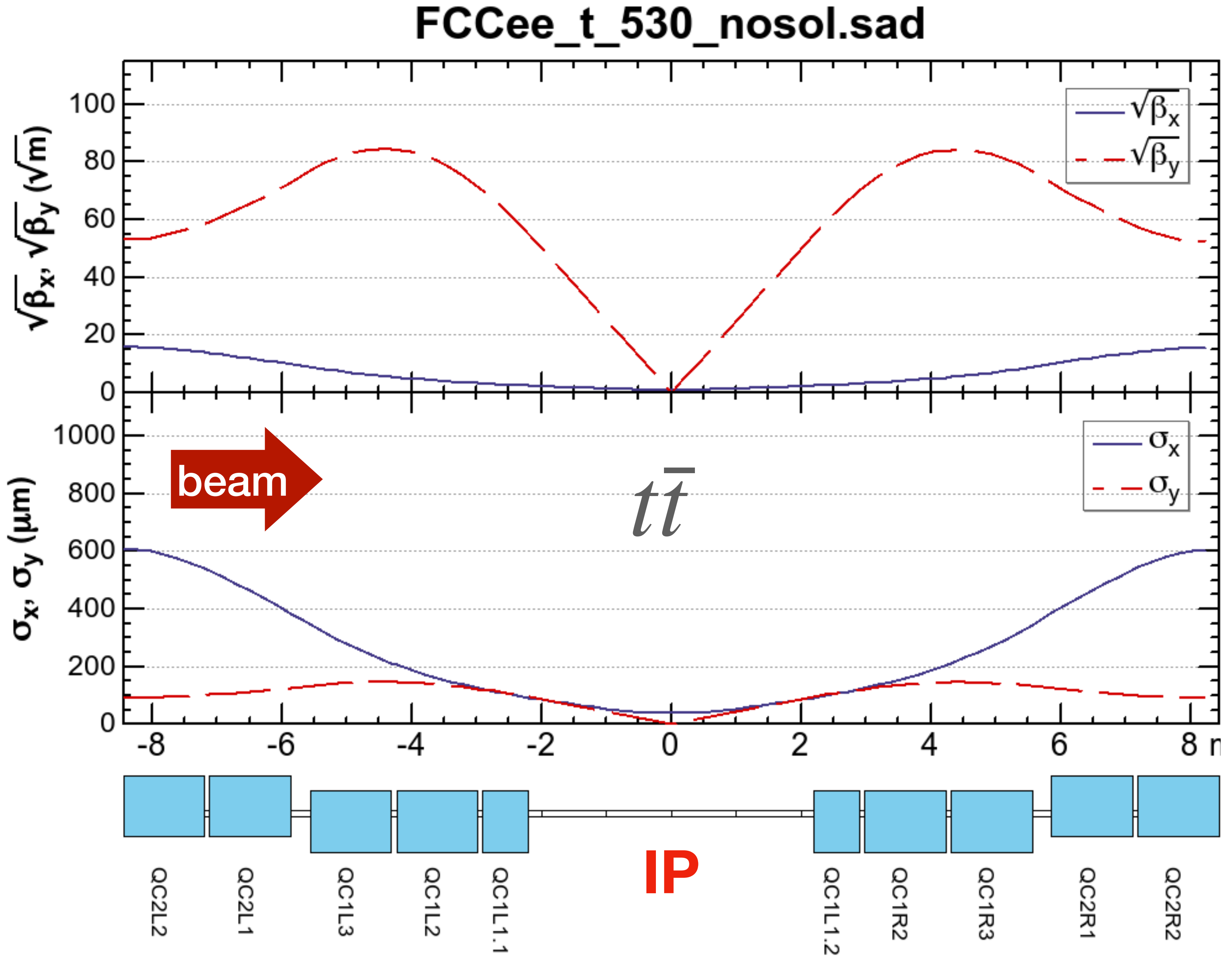
SR from dipoles



- The critical energy of the SR from dipoles upstream the IP is suppressed below 100 keV up to $\sim 500\,\mathrm{m}$ from IP at $t\bar{t}$.

Final quadupoles QC{12}

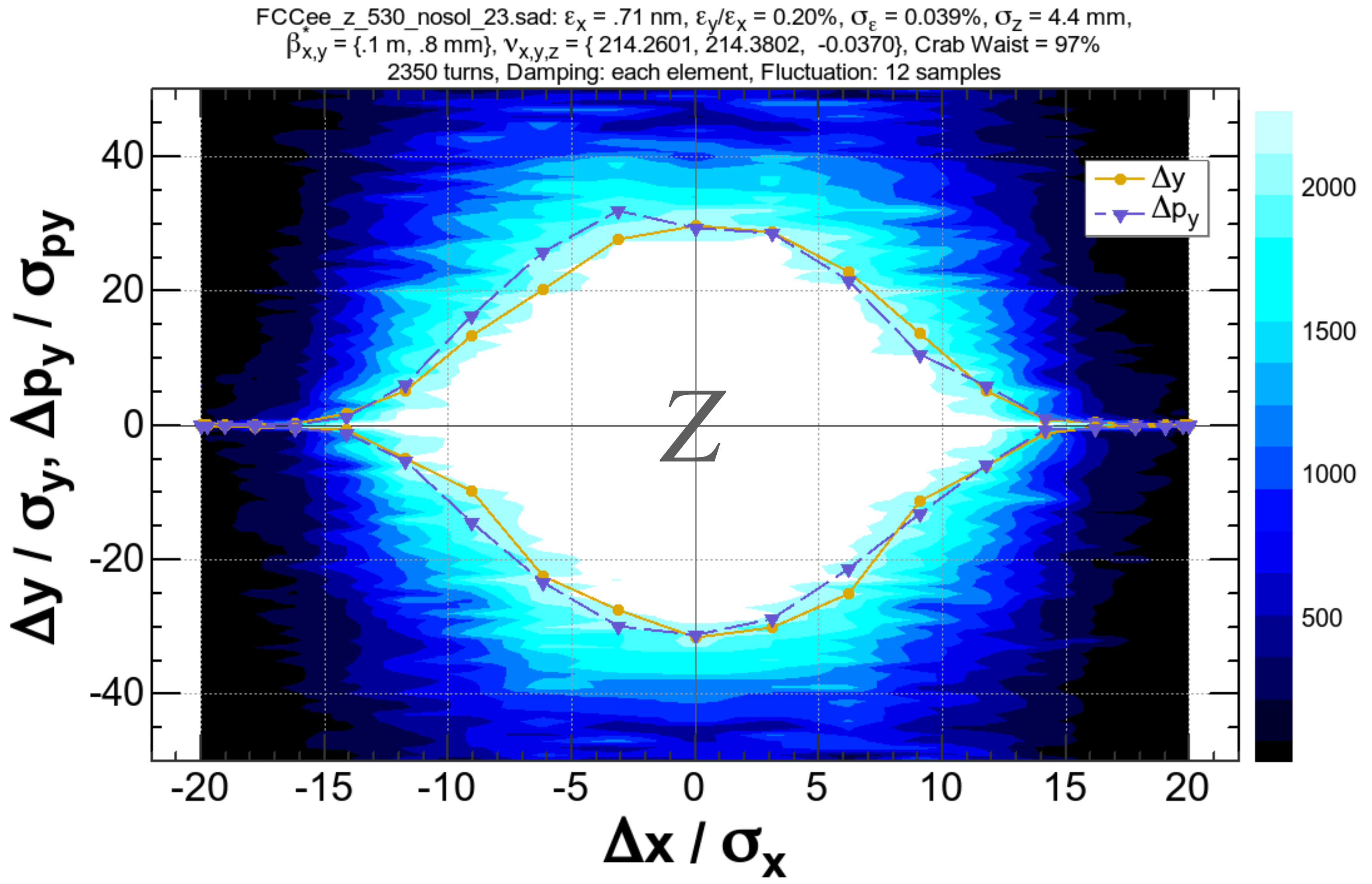


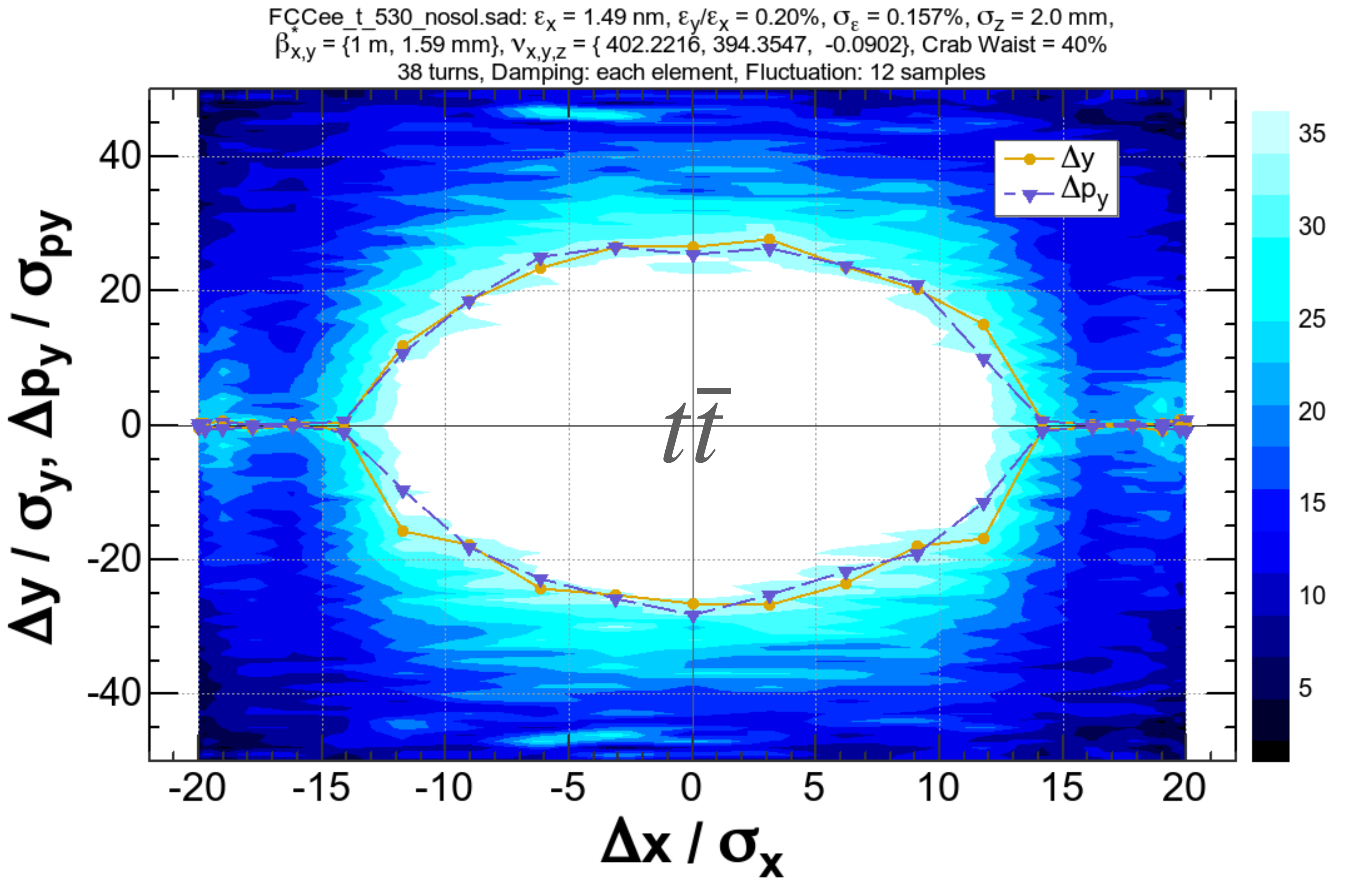


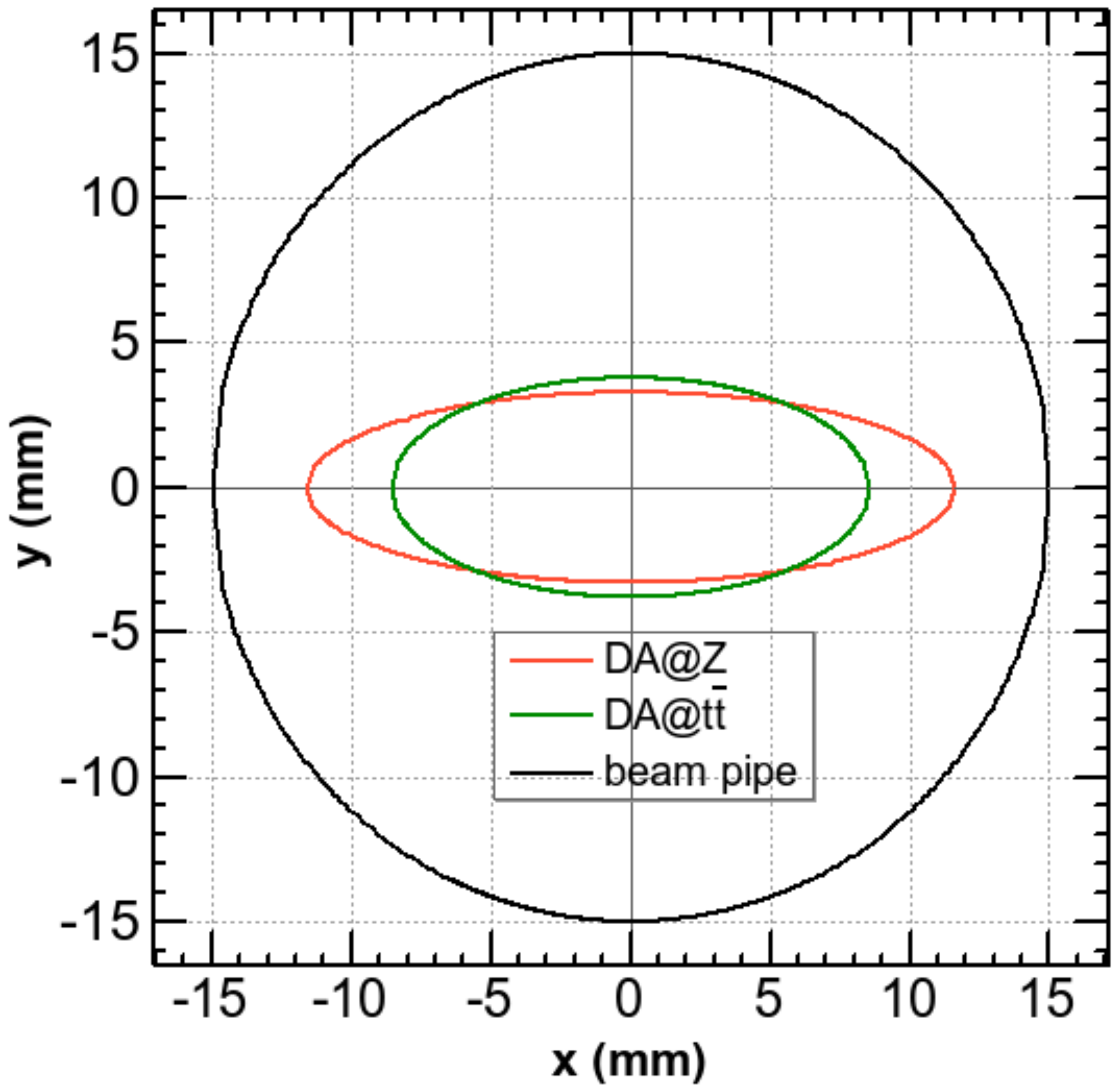
			z_530	t_530
	L (m)	s (m)	B' (T/m)	
QC2L2	1.25	-8.440	-1.654	76.954
QC2L1	1.25	-7.110	30.848	32.886
QC1L3	1.25	-5.560	0.567	-89.722
QC1L2	1.25	-4.230	-41.472	-98.144
QC1L1.1	0.7	-2.900	-41.500	-97.996
QC1L1.2	0.7	2.200	-41.500	-97.996
QC1R2	1.25	2.980	-41.500	-99.892
QC1R3	1.25	4.310	-2.489	-88.582
QC2R1	1.25	5.860	39.756	27.356
QC2R2	1.25	7.190	-5.071	96.462

- The final quadrupoles are split into slices.
- Each slice may change the gradient/polarity depending on the beam energy.
- The maximum gradient is 100 T/m (x tapering).
- At Z, too high gradient degrades the DA.

Dynamic aperture @ QC1







- The dynamic apertures above are evaluated with SR & tapering for 2x long. damping time at Z&$t\bar{t}$.
- The strength of QC1 affects the vertical DA via SR fluctuation @Z.
- The dynamic aperture in the final quad QC1* is much smaller than the beam pipe radius in both x&y (left plot).
  - This may imply that the necessary collimation depth can be larger than the DA, somewhere between the DA and the pipe radius.
    - This may mean that the collimators will not affect the beam lifetime.

Optics including a realistic solenoid (M. Koratzinos)

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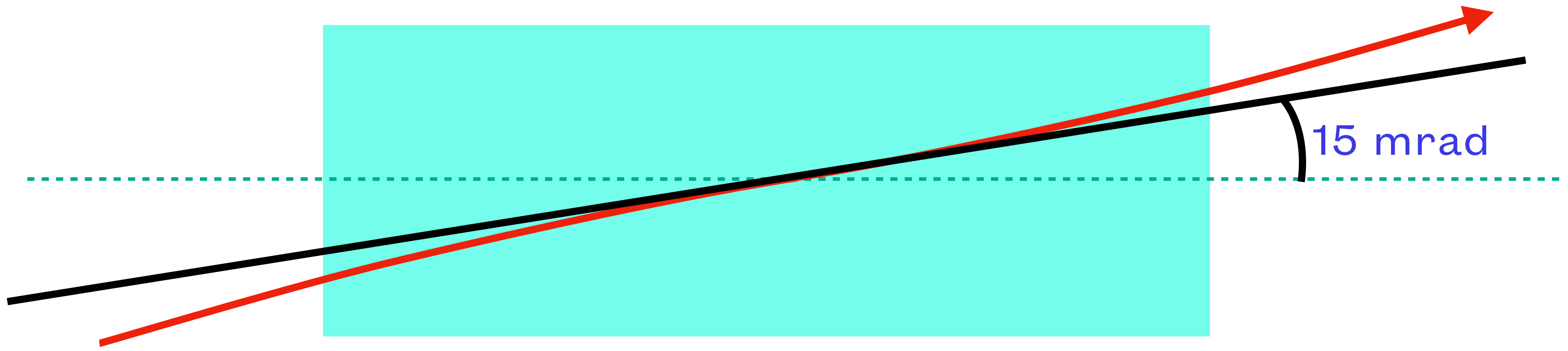
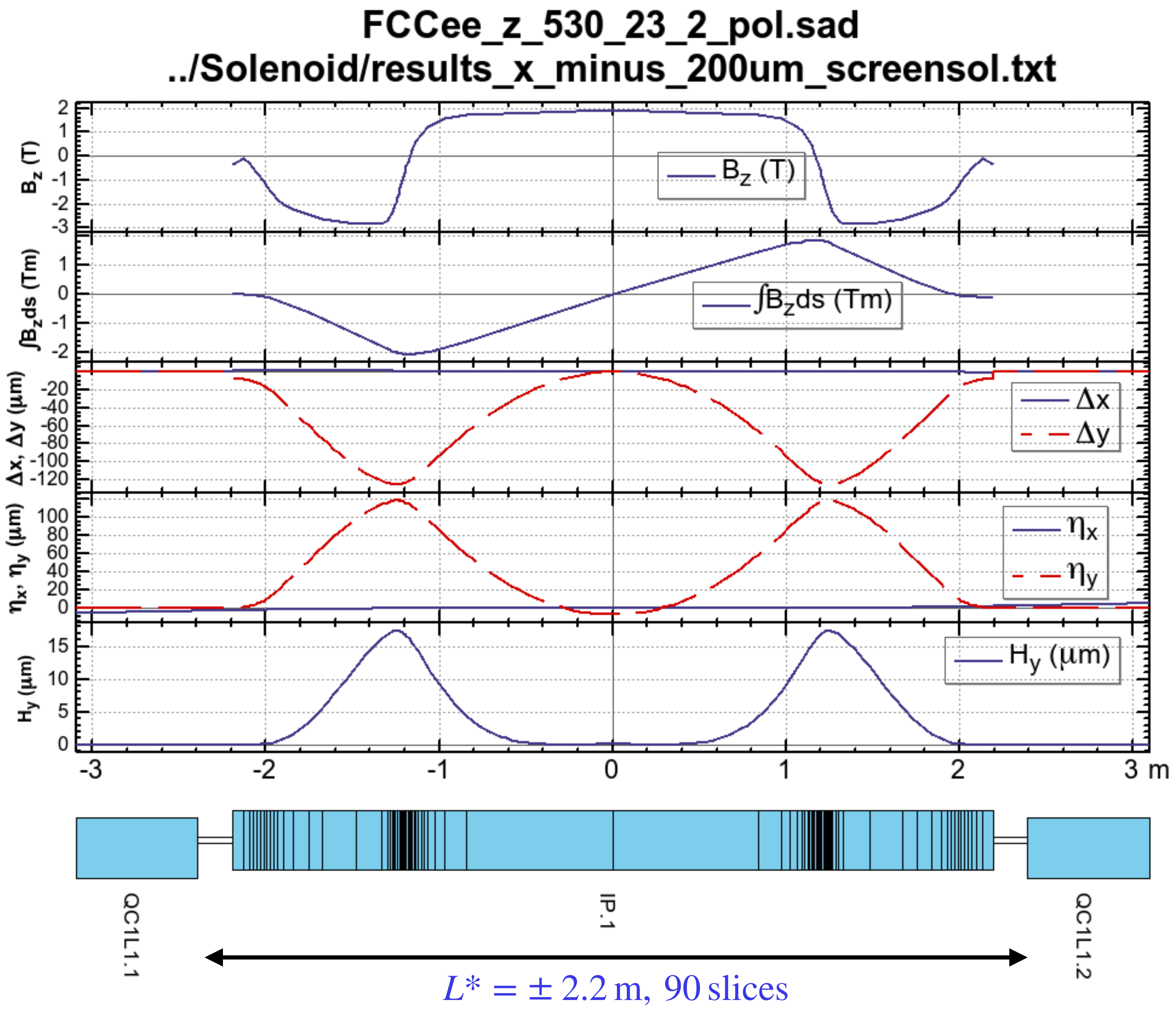
- A realistic solenoid + multipole field given by M. Koratzinos has been included into the latest 4 IP lattice.
  - Both MAD-X and SAD can include the same solenoid field map, *independently* (H. Burkhardt, L.V. Riesen-Haupt).
- The L* region (IP±2.2 m) is divided into 90 slices with *unequal thicknesses* ≧5 mm, *along the tilted straight line (±15 mrad),* not along the solenoid axis.
- No leak of vertical dispersion and x-y coupling to the outside region.
  - $\alpha, \beta,$ and hor. dispersion leak outside.
  - The leaked optics and hor. dispersion are adjusted to the no-solenoid case by tweaking several outer quads.
- The associated vertical emittance is 0.43 pm at Z.
- The highest contribution to the vertical emittance comes from the middle transition ($s \sim \pm 1.2$ m) of B_z.





Summary

- IR beam optics for $t\bar{t}$ & Z with the new layout "31.10" are designed taking into account:
  - 4 IP
  - $\pm 15\,\mathrm{mrad}$ crossing angle
  - Upstream SR below 100 keV @ $t\bar{t}$
  - crab waist + local vertical chromaticity correctionoid
  - realistic field map of detector + compensation solenoids
  - candidates of spaces for polarimeter & polarization wiggler
  - segmented final quads QC{12}
  - dynamic aperture with SR