BASELINE OPTICS AND LAYOUT FOR THE FCC-EE COLLIDER RING

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Many thanks to K. Oide, T. Raubenheimer, D. Shatilov, R. Tomás, F. Zimmermann, and all colleagues from the FCC-ee collaboration

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Introduction

- FCC-ee poses several challenges for the optics design
  - Delivering record luminosities at four different center of mass energies with minimal changes between operation modes
  - Beam line to follow the tunnel layout for the FCC-hh
  - Double ring collider, tapering, $E_{critical}$ below $100\ keV$ for the last dipoles upstream of IP, top-up injection, record stored beam energy for lepton collider, crab waist scheme, …

- The general feasibility of such a machine has been demonstrated in the CDR
  - Based on a tunnel with a circumference of 97 km and with two experiments

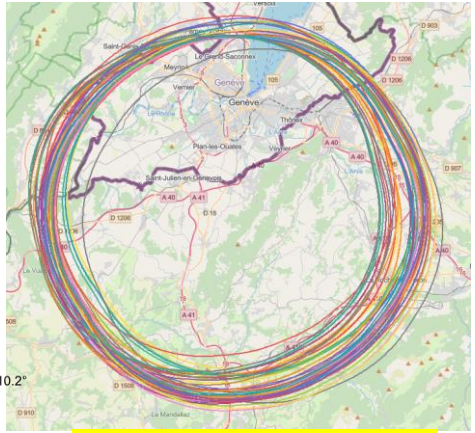
- Continued studies in many areas since the publications of the CDR
  - In this talk, summary of new baseline layout with changes to follow recent developments

Placement Studies & new tunnel baseline

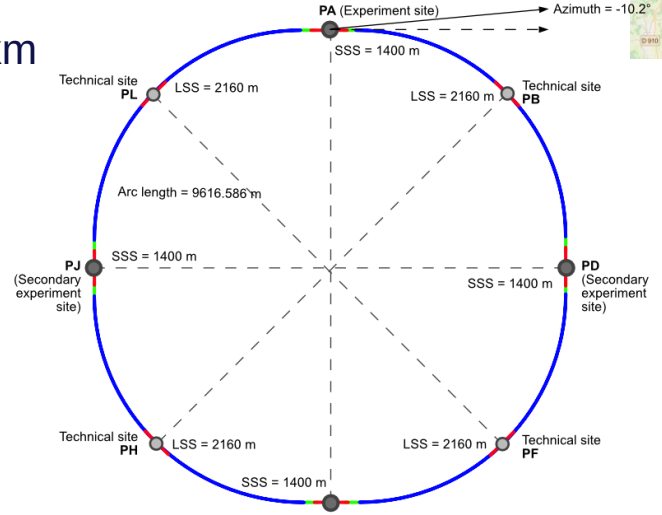
- Following the CDR, continued studies to optimize the placement of ring
  - Many factors to consider:
    Geology, Infrastructure, Access tunnels, Periodicity, …

- New baseline tunnel layout PA31-1.0
  - Decrease in circumference to 91 km
  - Four-fold periodicity

- Small adjustments foreseen to facilitate injection into FCC-hh



J. Gutleber, V. Mertens



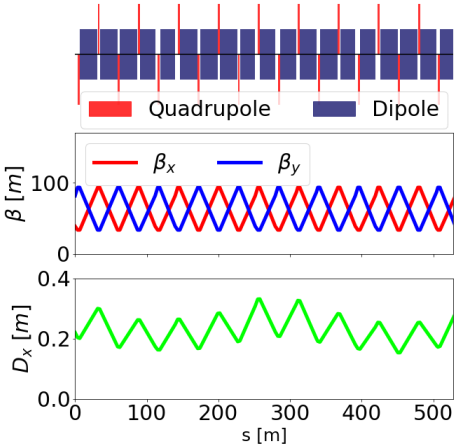
Arc cell considerations & CDR layout

- FODO cell is used in the arcs due to high packing factor

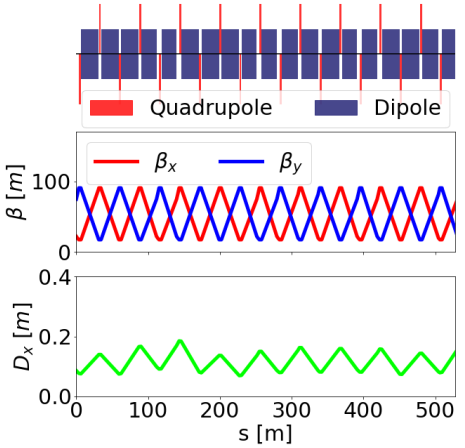
  - In CDR, cell length of ~50m and arc cell phase advance of $60^\circ/60^\circ$ for Z and W operation,
    and $90^\circ/90^\circ$ for H and $t\bar{t}$ operation

  - For mitigation of collective instabilities,
    large momentum compaction at Z and W required
    - For luminosity, preference is to have
      arc cell phase advance of $45^\circ/45^\circ$ for Z,
      $60^\circ/60^\circ$ for W, and $90^\circ/90^\circ$ for H and $t\bar{t}$
    - Optics for Z with $45^\circ/45^\circ$ phase advance is problematic for sextupole

Z



$t\bar{t}$

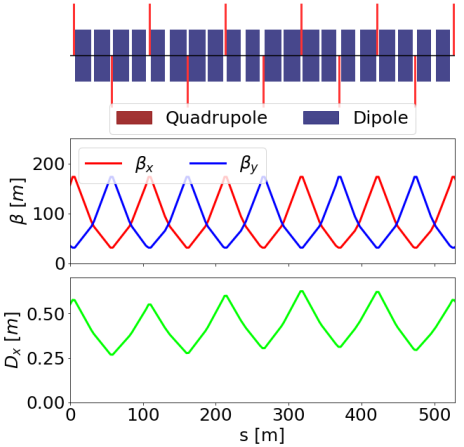


Arc optics in new layout

- New baseline layout now implements variable arc cell length
  - For Z and W, cell length of ~100m and phase advance of $90^\circ/90^\circ$ used
  - By installing quadrupoles in the gaps between dipoles, the cell length for H and $t\bar{t}$ is reduced back to 50m, using again $90^\circ/90^\circ$ phase advance to achieve small ϵ_x

  - Modification of arc cell to include correctors, BPMs, gaps between elements are investigated (see talk by L. van Riesen-Haupt)

Z



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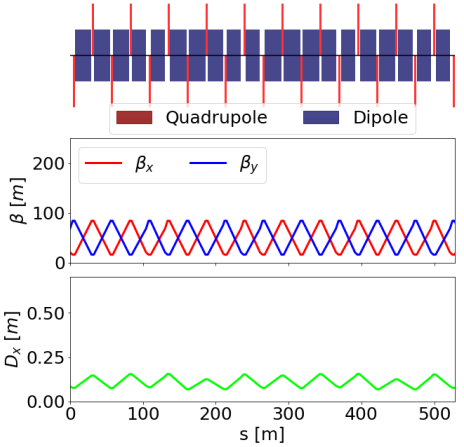
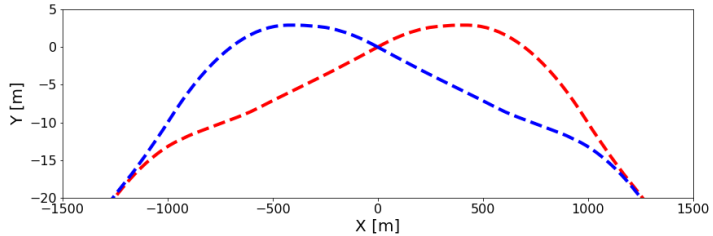
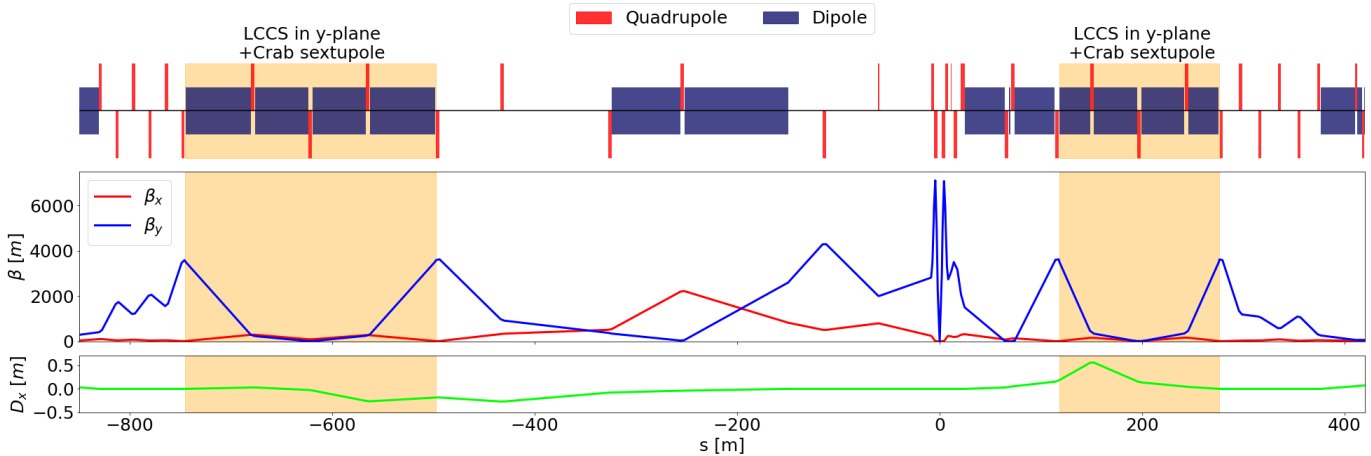


Experimental IR

- Experimental IR straight section layout remains as presented in the CDR
  - Focus lies on a 4-IP configuration
  - Minor changes:
    - Reduction of β_x^* to 10cm to suppress coherent beam-beam instability (D. Shatilov, Y. Zhang, M. Zobov)
    - Modifications of length of drift spaces to install polarisation wigglers





Operation mode	β_x^* [mm]	β_y^* [mm]
Z	100	0.8
W	200	1
H	300	1
$t\bar{t}$	1000	1.6

Parameters

- New optics and parameter on the FCC-ee optics repo in the V22 branch

- Parameters adjusted for lower circumference and new arc optics
  - Results in a slight decrease of luminosity per IP
  - Luminosity numbers based on simple model, to be refined with simulations

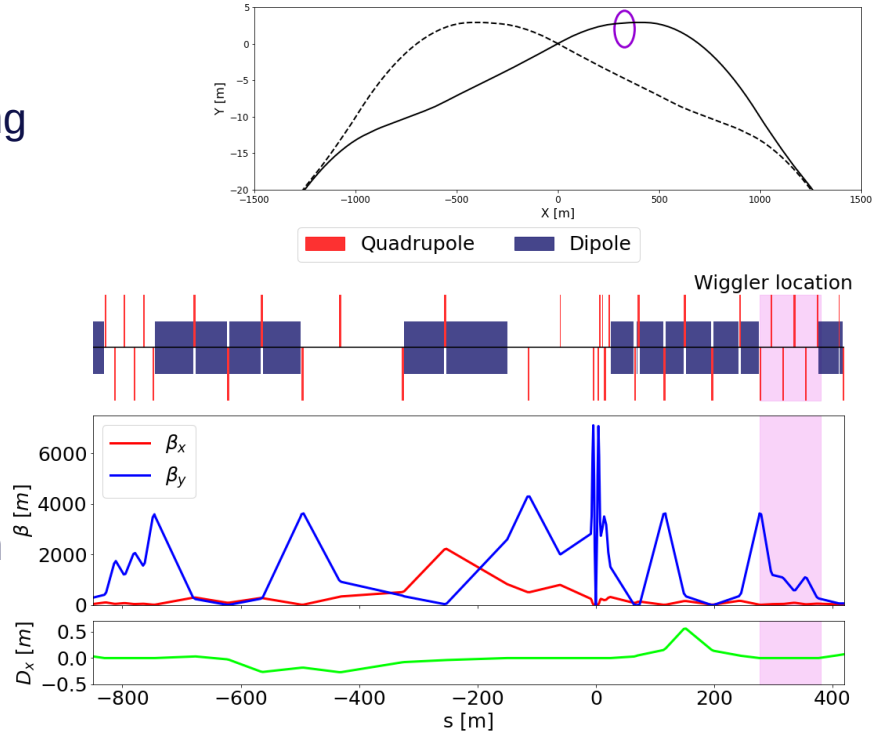
Operation mode	Z (45.6 GeV)		$t\bar{t}$ (182.5 GeV)	
	V22.2	CDR	V22.2	CDR
Circumference [km]	91.17	97.75	91.17	97.75
Bending radius of main dipoles [km]	9.937	10.76	9.937	10.76
Energy loss/turn [GeV]	0.0391	0.036	10.0	9.2
Bunches/beam	10000	16640	40	48
Bunch population [10^{11}]	2.43	1.7	2.37	2.3
Hor. Emittance [nm]	0.71	0.27	1.49	1.46
Ver. Emittance [pm]	1.42	1.0	2.98	2.9
β_x^*/β_y^*[mm]	100/0.8	150/0.8	1000/1.6	1000/1.6
Luminosity/IP [$10^{34} cm^{-2} s^{-1}$]	182	230	1.24	1.5

Reference

Lattice modifications

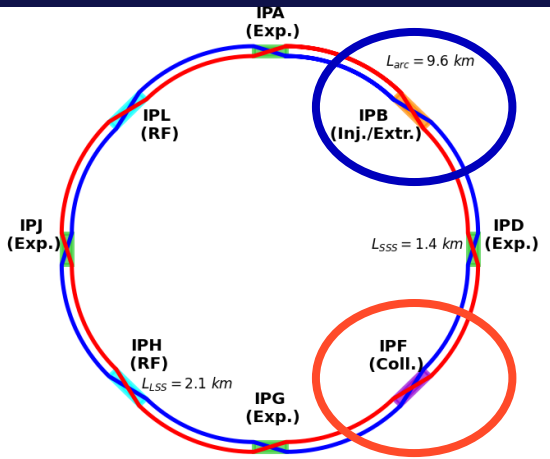
- For energy calibration runs at Z and W, two critical systems:
  - Wiggler to reduce the polarization time
  - Polarimeter to measure polarization
    based on spin-dependent Compton scattering

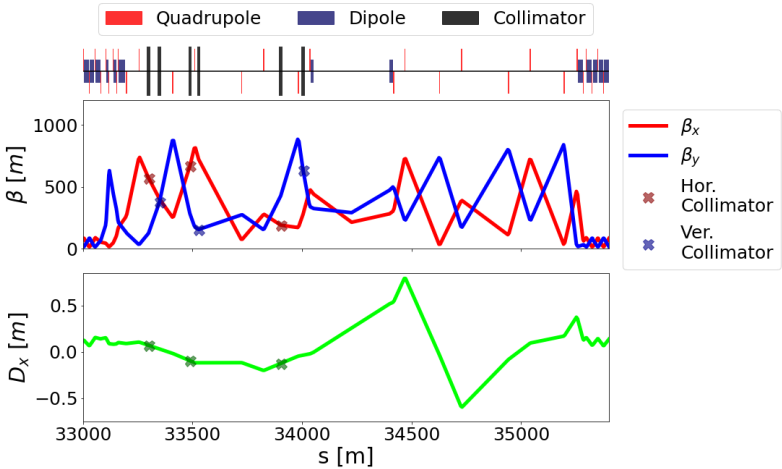
- Integration into new baseline layout ongoing
  (see talk by K. Oide)
  - Wiggler installed downstream
    of the experimental straight
  - Two locations for polarimeter under study:
    - Upstream of either
      an RF insertion or experimental insertion



Integration of auxiliary insertions

- In 4-IP layout, beam crossing in every straight section required
- First design of a collimation insertion under study (see talk by A. Abramov)
  - Betatron and momentum collimation in point F
- Top-up injection and extraction potentially located in point B
  - Studies on top-up injection currently ongoing, using CDR type lattice for now (see talk by P. Hunchak)
  - Layout to be adapted to 4-IP



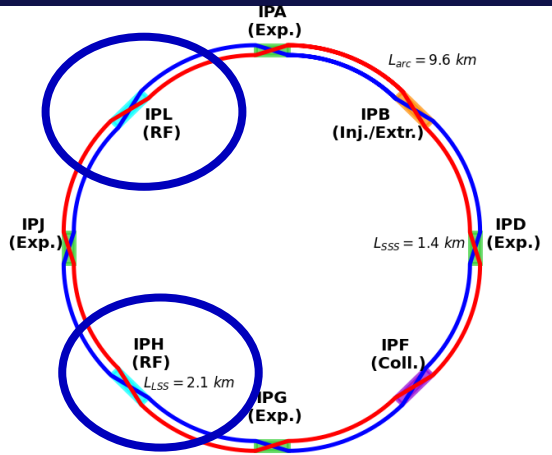


RF insertions

- After preliminary survey of surface sites, recommendation is to place RF in points H and L (see presentation by K. Hanke)
  - In case of 2-IP, straight sections D and J also feasible

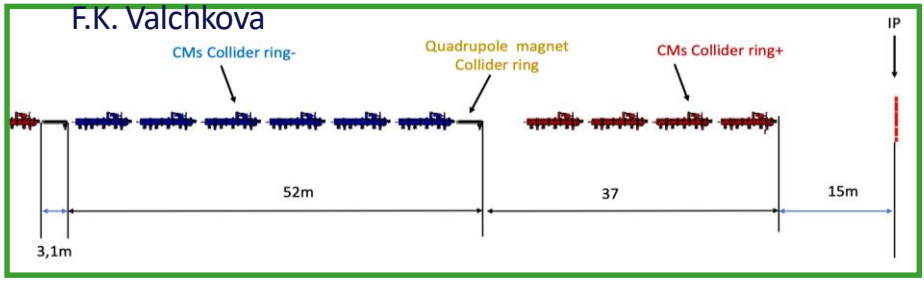
- To reduce the uncertainty on center-of-mass energy, RF located in a single place for Z and W operation

- In $t\bar{t}$ operation, RF cavities distributed between points H and L
  - Different RF settings and their impact on center-of-mass energies under study (see talk by J. Keintzel)

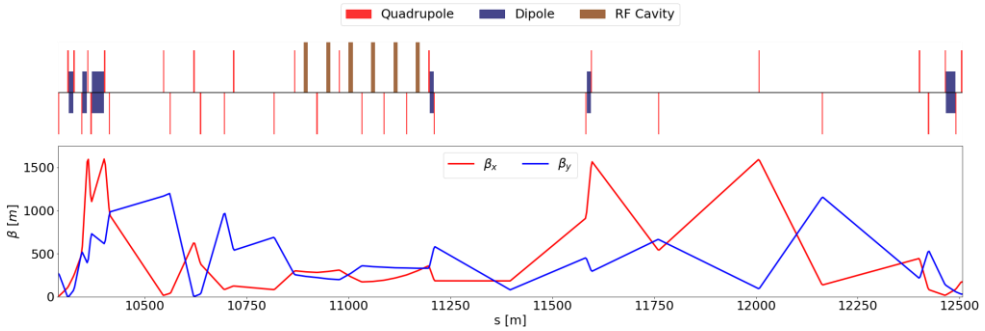


RF insertions II

- RF insertion layout similar to CDR
  - Drift Space for cavities extended to 52 m
  - At Z and W, separate RF for each beam
    - Beam crossing in the middle of the insertion
  - Common RF for H and $t\bar{t}$ operation modes



Z



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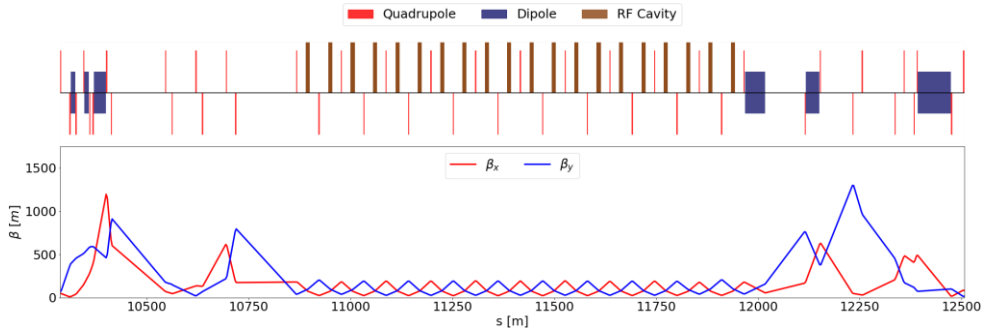
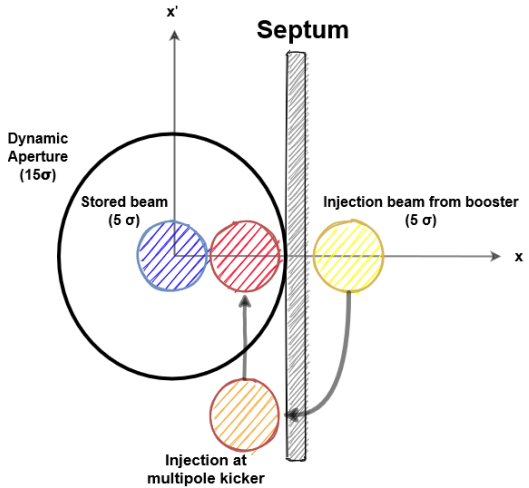


Sextupoles and DA optimization

- Chromaticity correction by families of non-interleaved sextupole pairs, with –I transform between sextupoles
  - All 75(Z) / 146 ($t\bar{t}$) sextupole pair used in dynamic aperture optimization
    Impact of reducing number of sextupole families under study

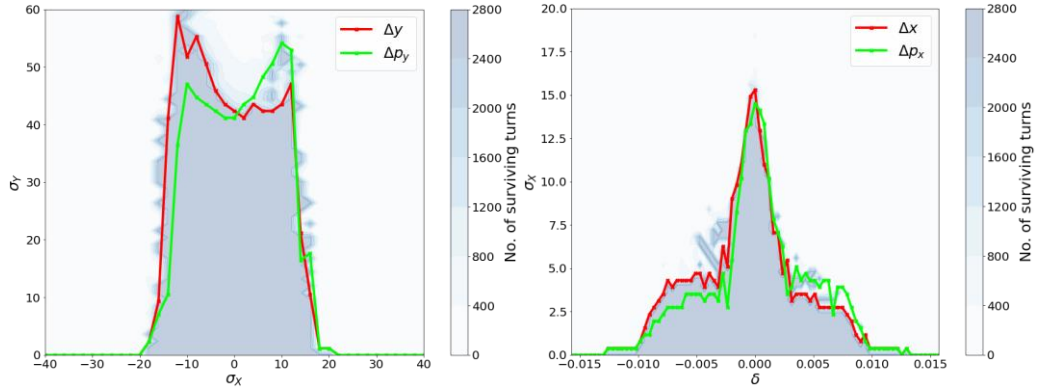
- For on-momentum top-up injection, a dynamic aperture of more than 15σ is required
  - For off-momentum injection, DA > 5σ for chosen setting of $\Delta p/p$
- Target for momentum acceptance based on beam lifetime in the presence of large energy spread due to beamstrahlung
  - For $t\bar{t}$, requirement is $\delta_{acceptance} > 2.8\%$, while for Z, threshold $\delta_{acceptance} > 1.3\%$



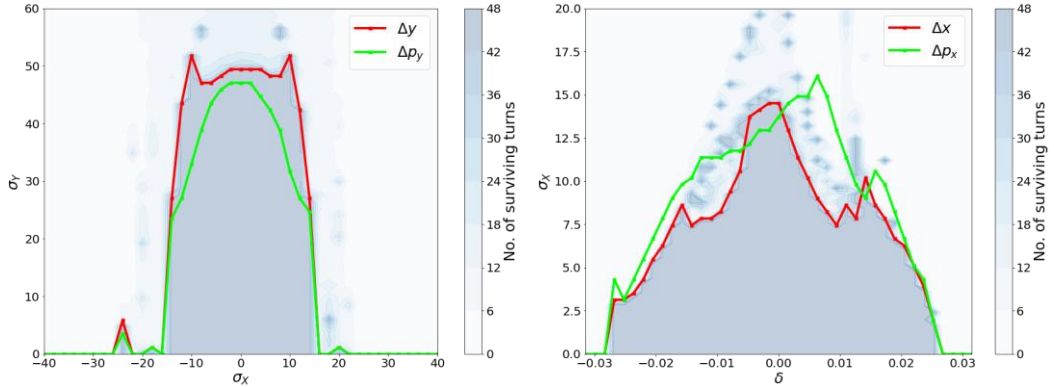
Sextupoles and DA optimization

- Sufficient dynamic aperture and momentum acceptance is found
  - Impact of reduction to $\beta_x^* = 10\ cm$ at Z and asymmetric placement of RF on DA small
- Achievable performance in presence of misalignments to be studied

Z



$t\bar{t}$



Conclusions and next steps

- New tunnel layout since the last FCC-week
  - Reduced circumference leads to a slight decrease in luminosity performance
  - Following 4-fold periodicity, most studies focus on 4-IP lattice

- Numerous changes in beam optics for new layout
  - Different arc cell length between Z/W and H/$t\bar{t}$, wiggler and polarimeter space, redesign of RF sections, …

- Next steps include integration of auxiliary system such as collimation and injection insertions into lattice

Thanks for your attention!