NEW BASELINE LAYOUT OF THE CERN FUTURE CIRCULAR HADRON-HADRON COLLIDER

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Overview

- **FCC and current design of FCC-hh**
- **16-dipole arc cell**
- **Overview of insertion optics**
- **Review of corrector systems**
- **Current and further work**

FCC-hh main machine parameters

parameter	FCC-hh	HL-LHC	LHC
collision energy cms [TeV]	84 - 120	14	
dipole field [T]	14 - 20	8.33	
circumference [km]	90.7	26.7	
arc length [km]	76.9	22.5	
beam current [A]	0.5	1.1	0.58
bunch intensity [10^{11}]	1	2.2	1.15
bunch spacing [ns]	25	25	
synchr. rad. power / ring [kW]	1100 - 4570	7.3	3.6
SR power / length [W/m/ap.]	14 - 58	0.33	0.17
long. emit. damping time [h]	0.77 – 0.26	12.9	
peak luminosity [10^{34} cm^{-2}s^{-1}]	~30	5 (lev.)	1
events/bunch crossing	~1000	132	27
stored energy/beam [GJ]	6.3 – 9.2	0.7	0.36
Integrated luminosity/main IP [fb^{-1}]	20000	3000	300

With FCC-hh after FCC-ee: significantly more time for high-field magnet R&D aiming at highest possible energies

Formidable challenges:

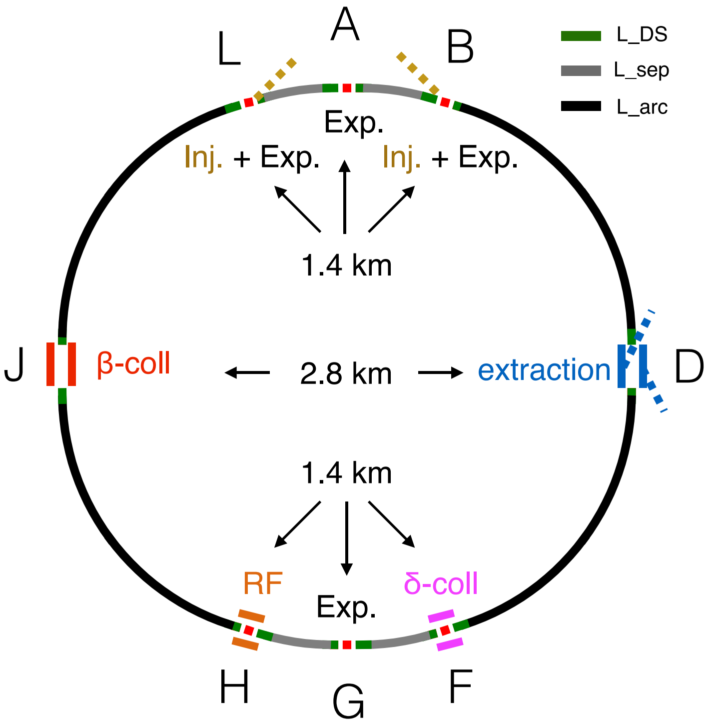
- high-field superconducting magnets: 14 - 20 T
- power load in arcs from synchrotron radiation: 4 MW → cryogenics, vacuum
- stored beam energy: ~ 9 GJ → machine protection
- pile-up in the detectors: ~1000 events/xing
- energy consumption: 4 TWh/year → R&D on cryo, HTS, beam current, …

Formidable physics reach, including:

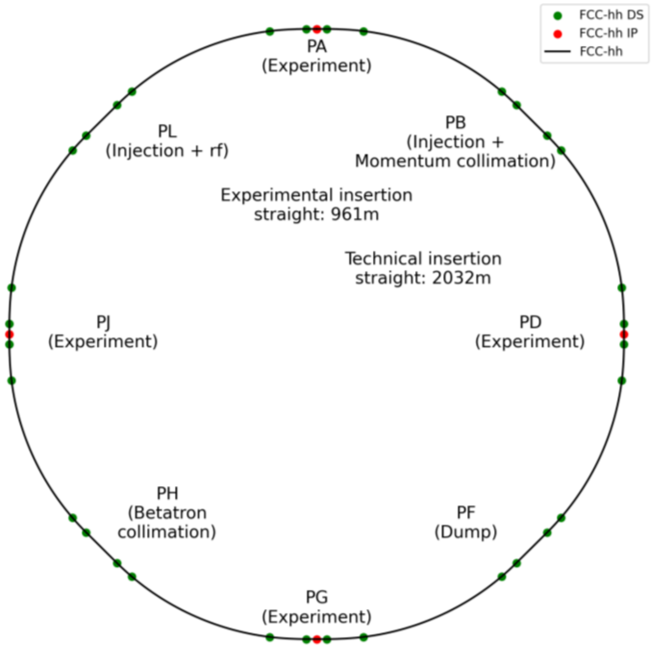
- Direct discovery potential up to ~ 40 TeV
- Measurement of Higgs self to ~ 5% and ttH to ~ 1%
- High-precision and model-indep (with FCC-ee input) measurements of rare Higgs decays ($\gamma\gamma$, Zγ, $\mu\mu$)
- Final word about WIMP dark matter

F. Gianotti

FCC-hh: Changes from CDR



Circumference: 97.75 km



Circumference: 90.66 km

FCC-hh: Changes from CDR

The main drivers

- Placement studies
- FCC-ee layout (the choice of having four symmetrical experimental IPs)
- RF harmonic number to optimize transfer from injector

The main choices

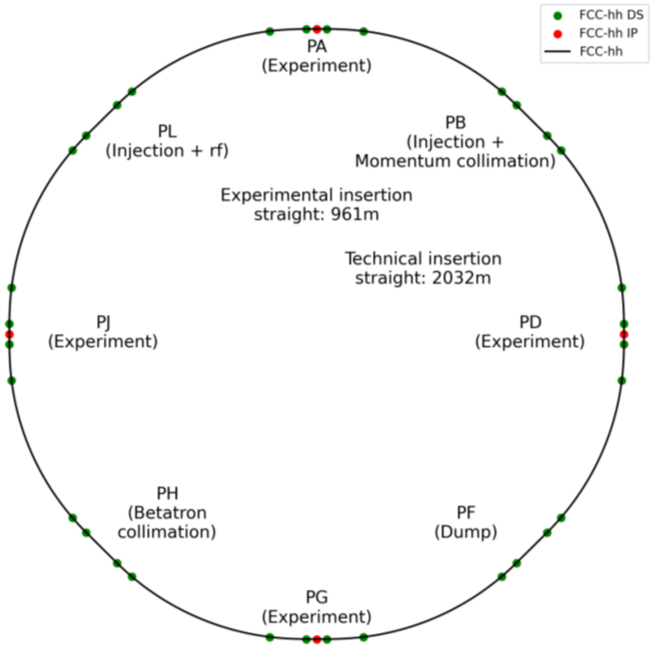
- Reduce the length of the ring circumference
- Reduce the length of technical insertions
- Displace radially the experimental IPs to match position of FCC-ee IPs
- Four-fold symmetry
- Re-organize functionalities of insertions
- Locate transfer lines in ring tunnel

FCC-hh: Layout & main parameters

Target: 90 TeV @ 14T

Parameter	Value
Collision energy cms [TeV]	84.6 - 120.8
Dipole field [T]	14(Nb_3Sn) - 20(HTS/Hybrid)
Circumference [km]	90.66

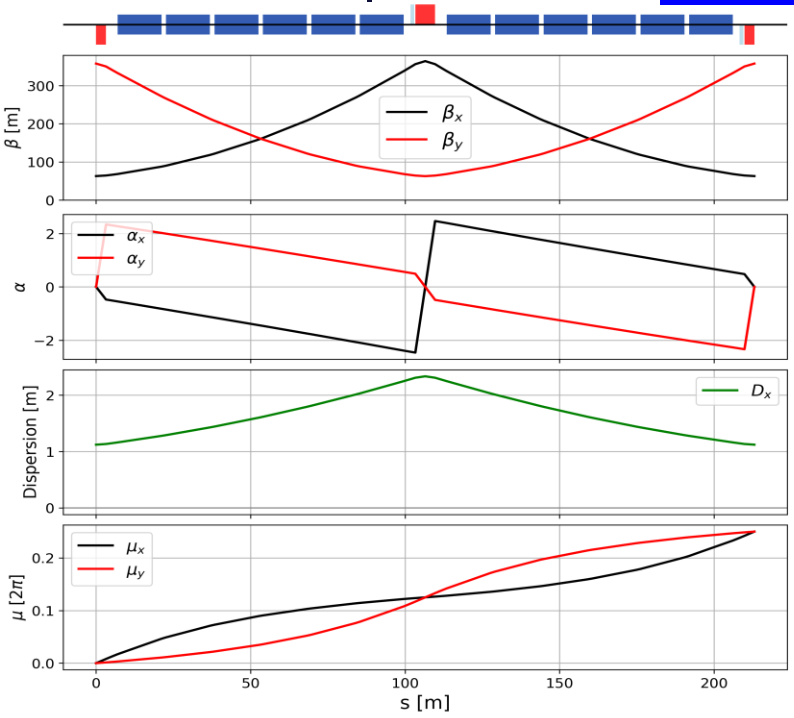
- Although some of the circumference reduction comes from technical insertion, lost ~6.5km of arcs.
- Maximize dipole filling factor to maximize collision energy.



Longer arc cells

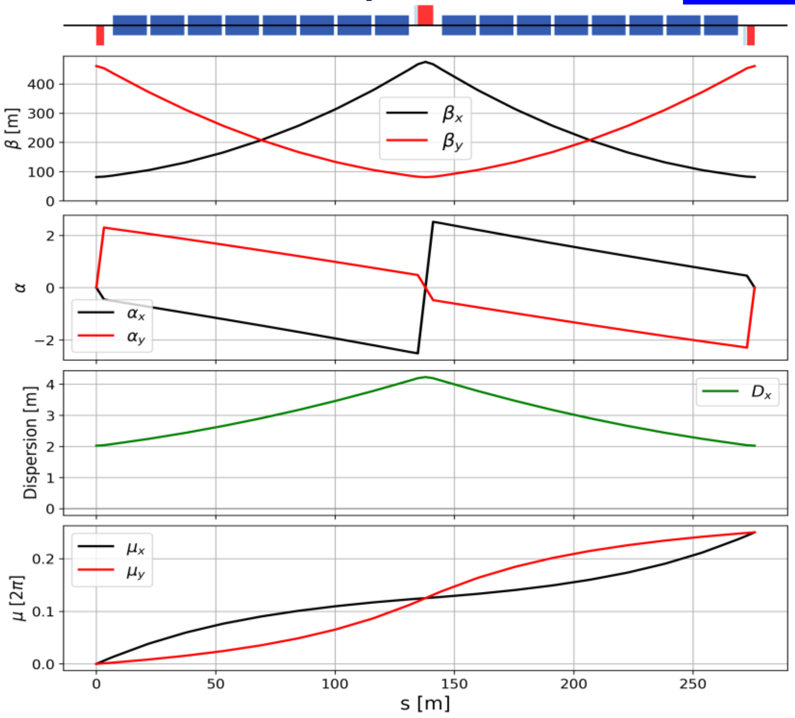
12-dipole cell

~213m



16-dipole cell

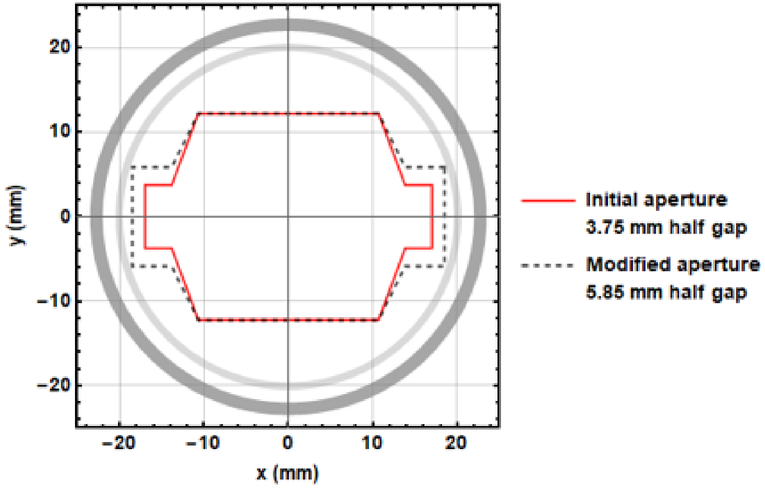
~275m



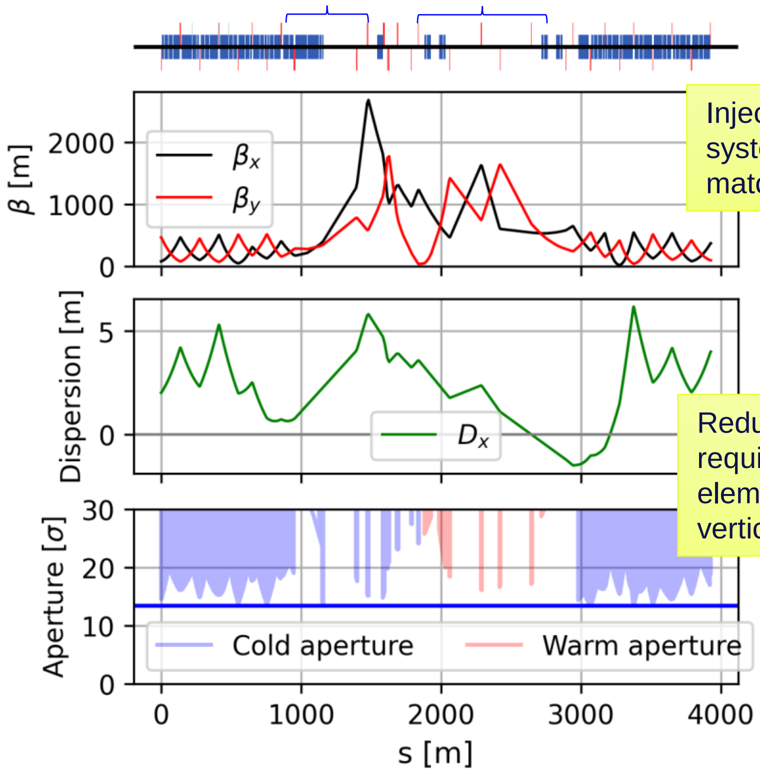
Longer arc cells

- Increase dipole filling factor
- Although reduction in the number of dipoles w.r.t. CDR, ~4% increase compared to a 12-dipole configuration for the current placement (4288 dipoles).
- Larger beam sizes can be accommodated by a minor review of the beam screen geometry

	CDR cell 12-dipole	12-dipole	16-dipole
# dipoles	4668	4288	4464
Cell length (m)	213.03	213.03	**275.79**
Circumference (km)	97.75	**90.66**	**90.66**



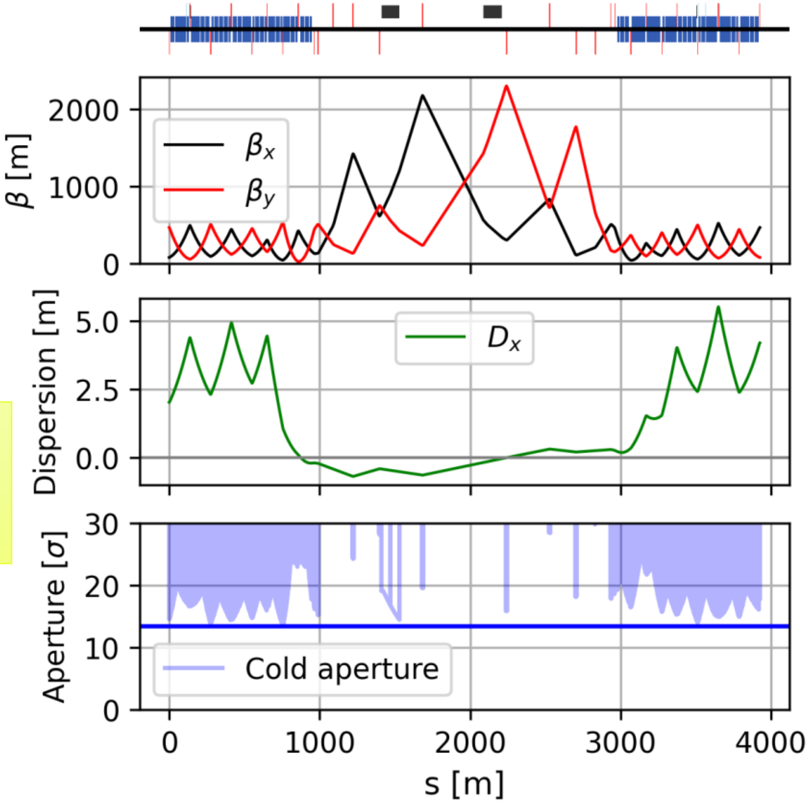
Injection clockwise beam & momentum collimation – PB



Injection and collimation systems separated by matching section

Reduction of the space requirement for injection elements with additional vertical dipoles

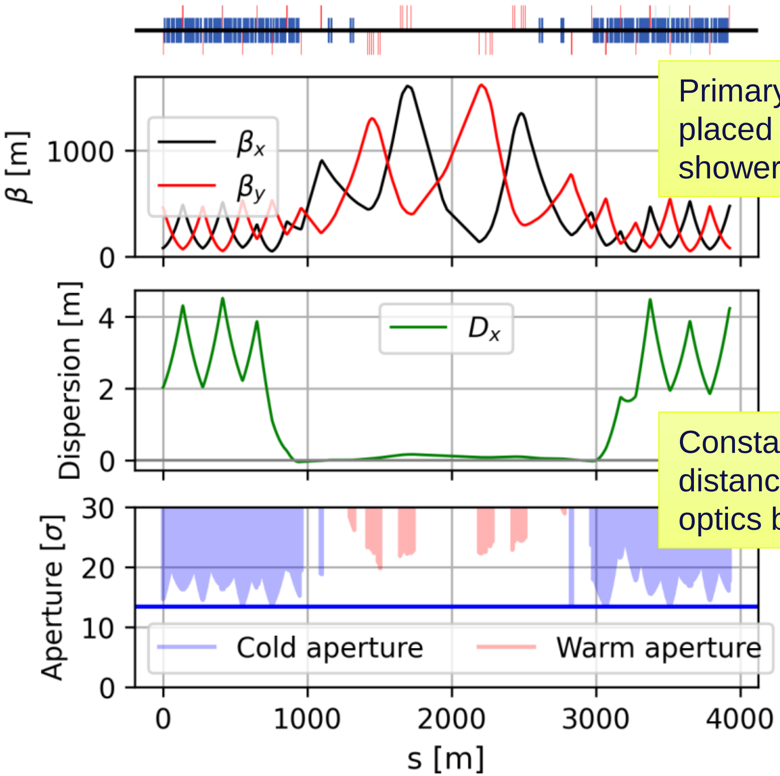
Beam dump – PF



Betatron collimation – PH

High beta collimation optics following HL-LHC studies

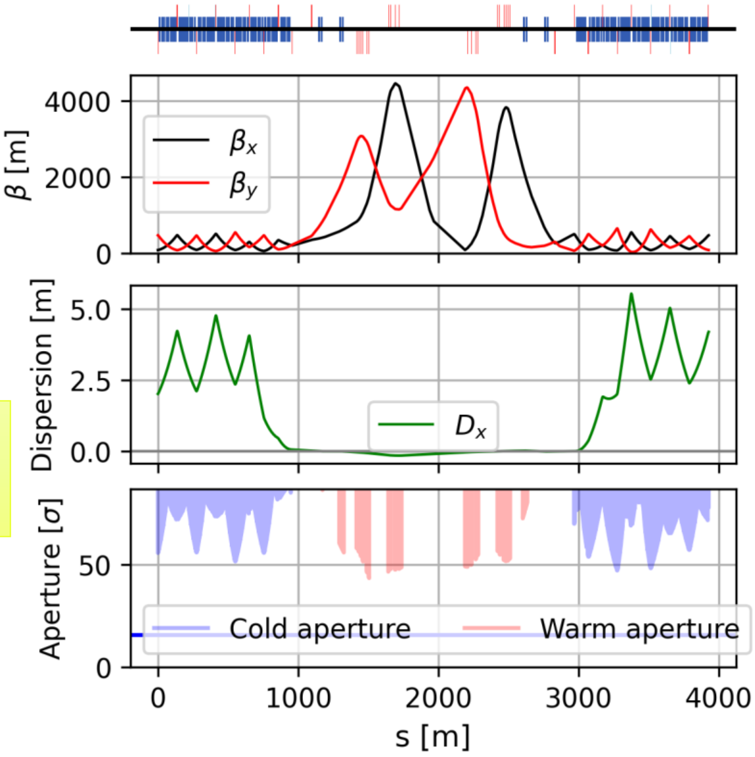
Low beta



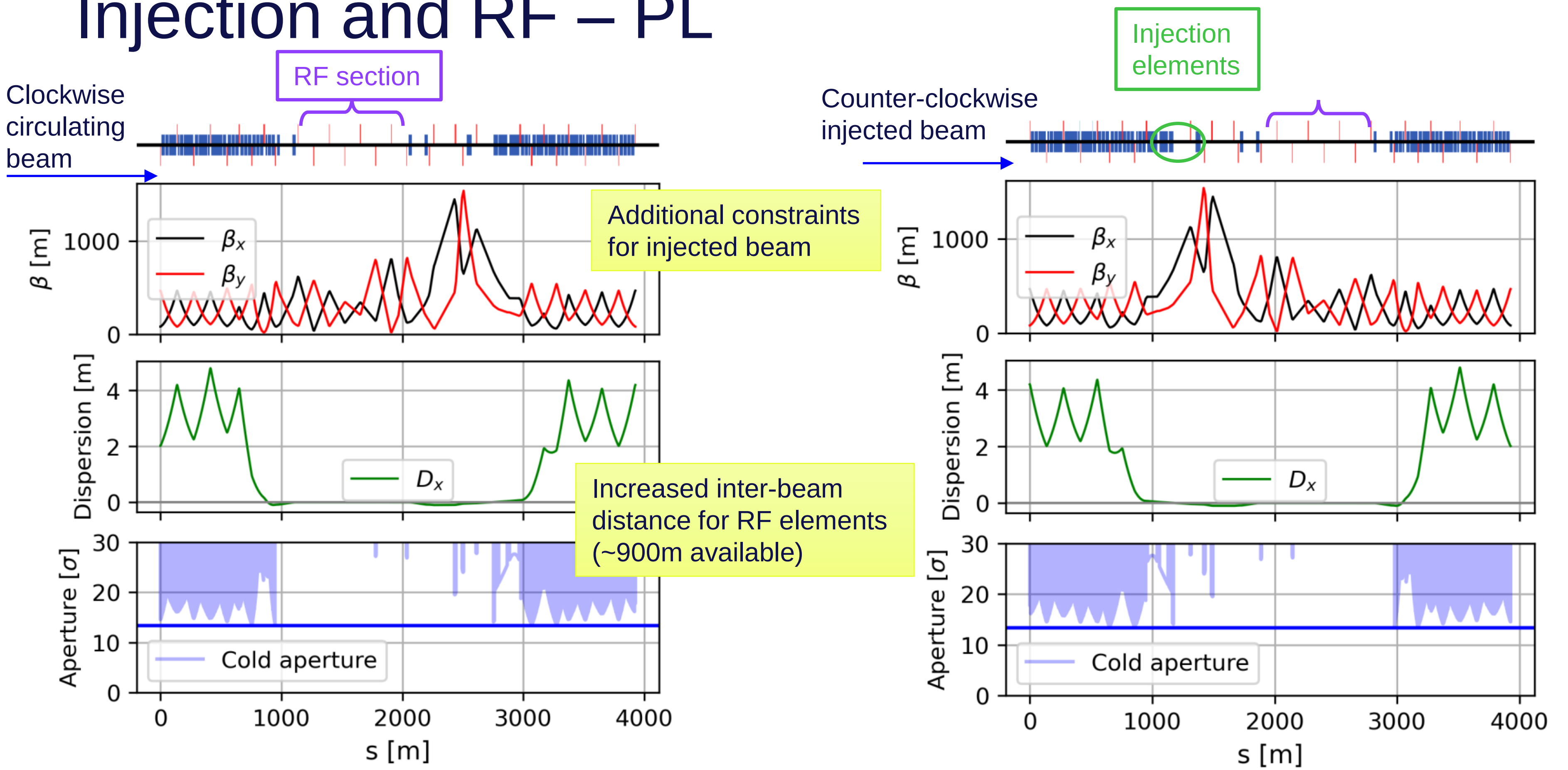
Primary collimators placed in doglegs to avoid showers of neutrals

Constant inter-beam distance allows shared optics between both beams

High beta

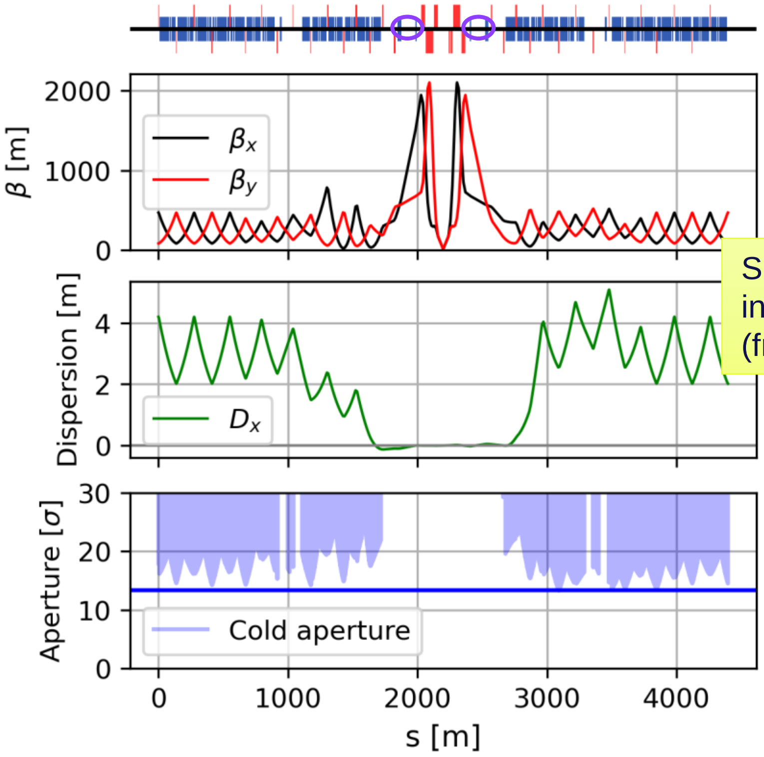


Injection and RF – PL



Experimental straight sections

Injection $\beta^* = 10\text{m}$

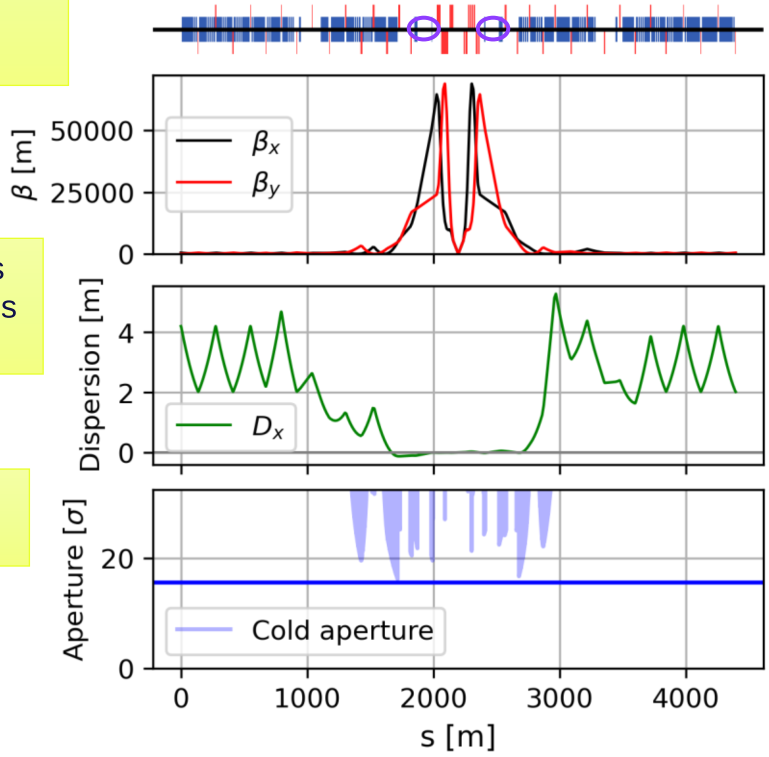


Four identical experimental insertions except for crossing scheme

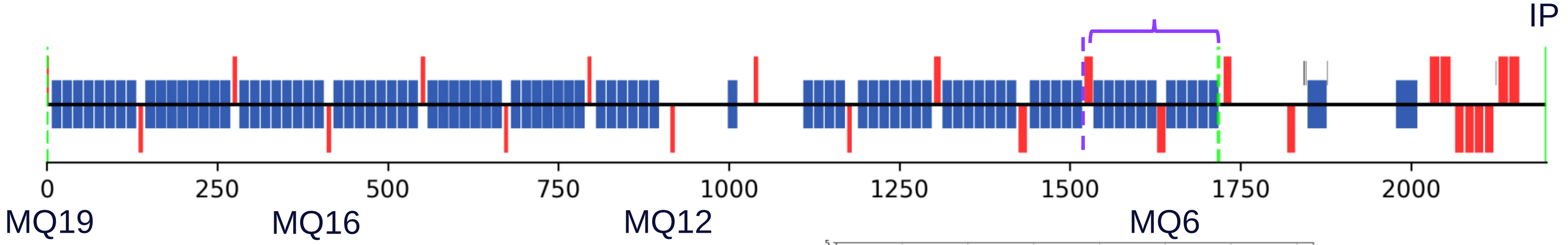
Superconducting dipoles in experimental insertions (from HL-LHC)

Non-linear correctors from HL-LHC

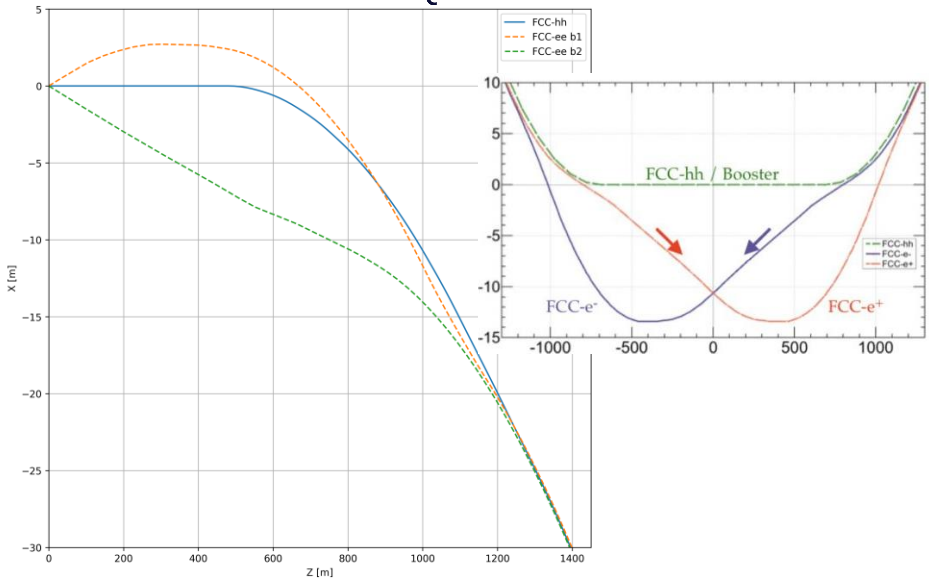
Collision $\beta^* = 30\text{cm}$



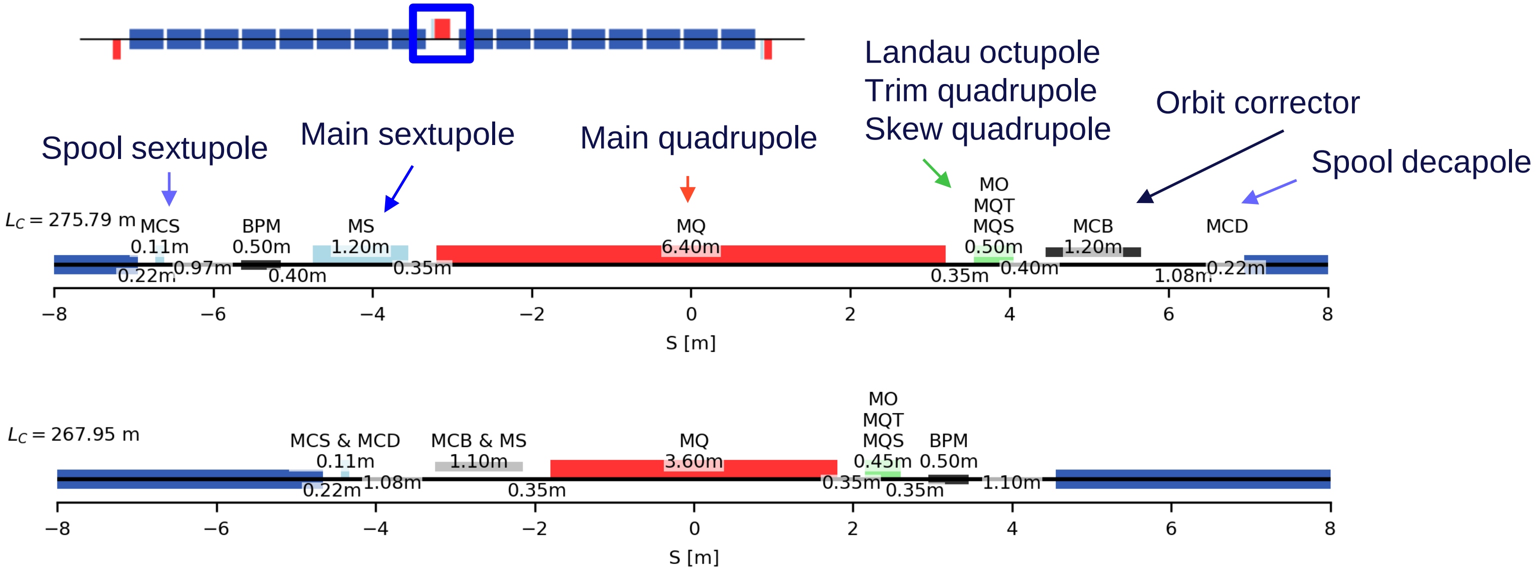
Dispersion suppressor – experimental insertion



- Displacing dipoles towards the IP moves the position of the IP outwards.
- Maintaining upstream dipole distribution makes FCC-ee and FCC-hh arcs overlap.
- Keep regular positioning of quadrupoles to ensure transverse focusing.
- Shortening of the straight section to keep circumference constant.



Review of short straight sections



These **16 dipole arc cells** result in less cells and therefore fewer short straight sections and **fewer correctors**.
However, **higher β-functions** and **dispersion** make correctors more **efficient**!

Review of short straight sections

Main quadrupole

- Longer cells require lower gradient.
- Increase the maximum gradient from 367 T/m to 450 T/m.

6.4 m to 3.6 m

Trim quadrupoles, skew quadrupoles and octupoles

- Able to correct tune and linear coupling.
- Maintain the same amplitude detuning considered in previous studies.

0.5 m to 0.45 m

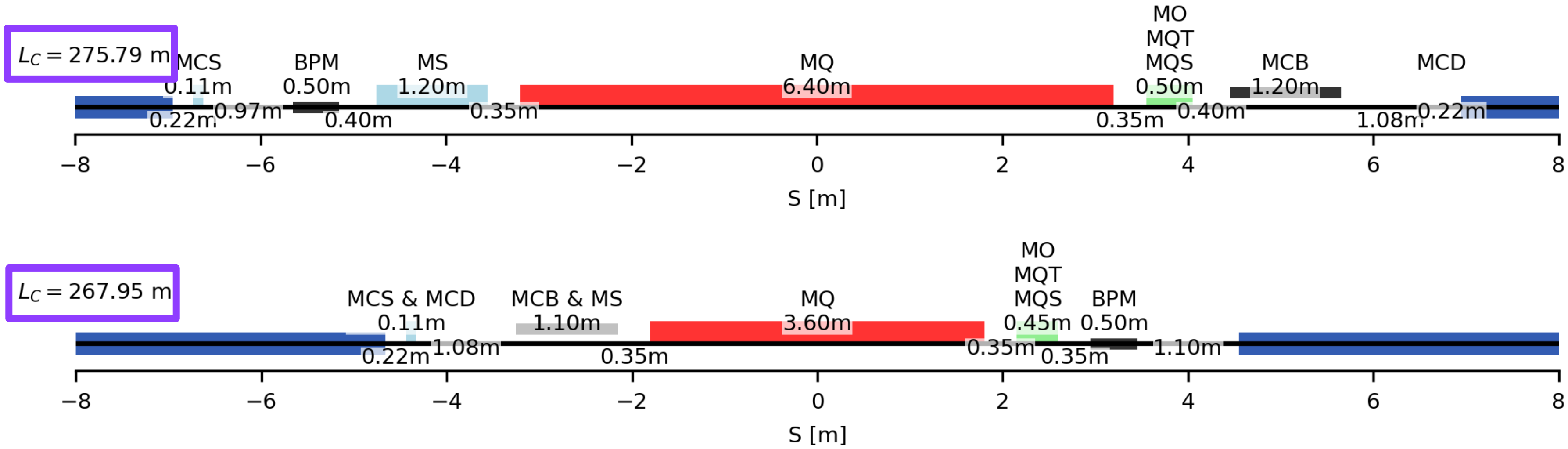
Orbit correctors & main sextupoles

- Modest increase of dipole corrector strength allows shortening while keeping the same integrated strength.
- Sextupoles still able to correct chromaticity

1.2 m to 1.1 m

Nest orbit corrector with main sextupole

Review of short straight sections



Gains in filling factor by either fitting more regular cells in the arcs or increasing the number of dipoles in the dispersion suppressors.

Furthermore, length reduction of the short straight section may allow to jump to **18-dipole** cells.

Conclusions and next steps

- Adapted FCC-hh lattice following the outcome of **placement studies**.
- Checked the performance of the **corrector systems** and concluded viable **shortening the arc cell by almost 8m** enabled by the change to 16-dipole cells.
- The reduction **in short straight section length** will be used to probe future cell configurations with **18** instead of **16 dipoles**.
- Revalidate performance of collimation system with the new momentum collimation design.

Thank you
for your attention.

Review of short straight sections

Main quadrupole

- Longer cells require lower gradient.
- Plan to increase the maximum gradient from 367 T/m to 450 T/m.

  (13 T, still below target for main dipole)
- Reduce magnetic length.

  6.4 m to 3.6 m

Orbit corrector

- Considered one of the arcs with alignment and field errors in all main dipoles and main quadrupoles.
- Kept residual orbit below 1 mm and residual angle below 8 $\mu\mathrm{rad}$.
- Modest increase of strength allows shortening while keeping the same integrated strength.

  4 T to 4.5 T & **1.2 m to 1.1 m**

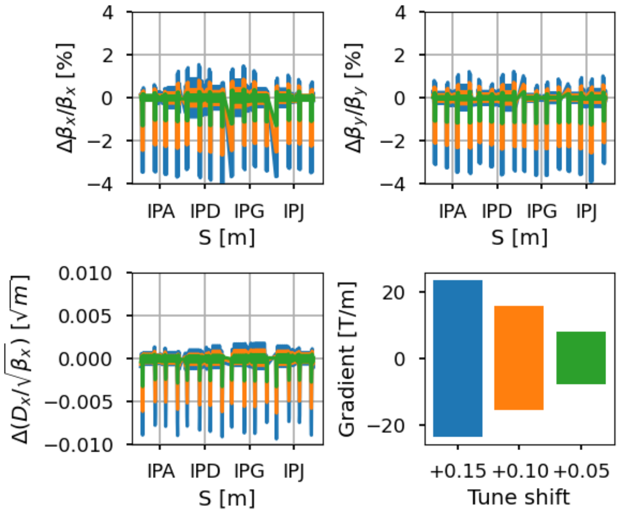
  Propose to **nest with main sextupole**

Review of short straight sections

Trim quadrupoles

- Used to correct the tune.
- Two families of four trim quadrupoles at each arc extremity.

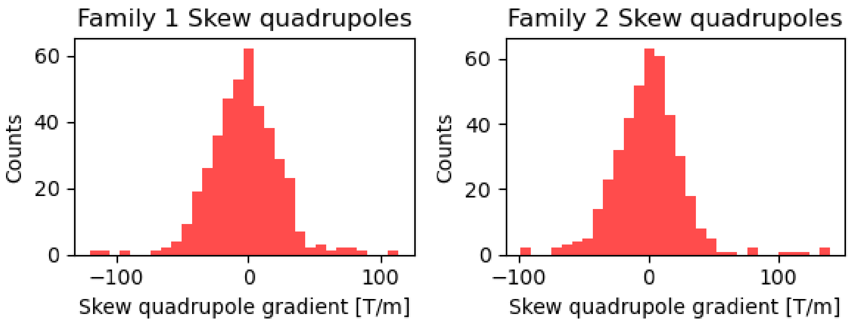
0.5 m to 0.45 m



Skew quadrupoles

- Used to correct the linear coupling between horizontal and vertical planes.
- Placed near the centre of the arcs and are divided into two families, separated by a phase advance of 90°.

0.5 m to 0.45 m



Review of short straight sections

Chromatic sextupoles

- Correct linear chromaticity.
- Two families following quadrupole polarities.
- In the most challenging configuration, 4IPs squeezed to $\beta^* = 30\text{cm}$, integral strength required are 2291 T/m and 4273 T/m for focusing and defocusing sextupoles respectively (7700T/m max.).

Combine with orbit correctors

1.2 m to 1.1 m

Landau octupoles

- Placed in every SSS that does not contain a trim quadrupole or a skew quadrupole.
- 296 available slots down from 480 in the CDR.
- Aim to maintain the same amplitude detuning considered in previous studies.

$$\frac{\Delta\nu_{x,y}^{\mathrm{F,D}}(J_x, J_y)}{\Delta\tilde{\nu}_{x,y}^{\mathrm{F,D}}(J_x, J_y)} = \frac{N_{\mathrm{oct}}^{\mathrm{F,D}}}{\tilde{N}_{\mathrm{oct}}^{\mathrm{F,D}}} \frac{K_4^{\mathrm{F,D}}}{\tilde{K}_4^{\mathrm{F,D}}} \left(\frac{L_{\mathrm{c}}}{\tilde{L}_{\mathrm{c}}}\right)^2$$

0.5 m to 0.45 m