FCC-hh overview, main parameters & hh lattice

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Overview

- **FCC and current design of FCC-hh**
- **Overview of insertion optics**
- **Dispersion suppressors and arc cell**
- **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 (γγ, Zγ, μμ)
- Final word about WIMP dark matter

F. Gianotti

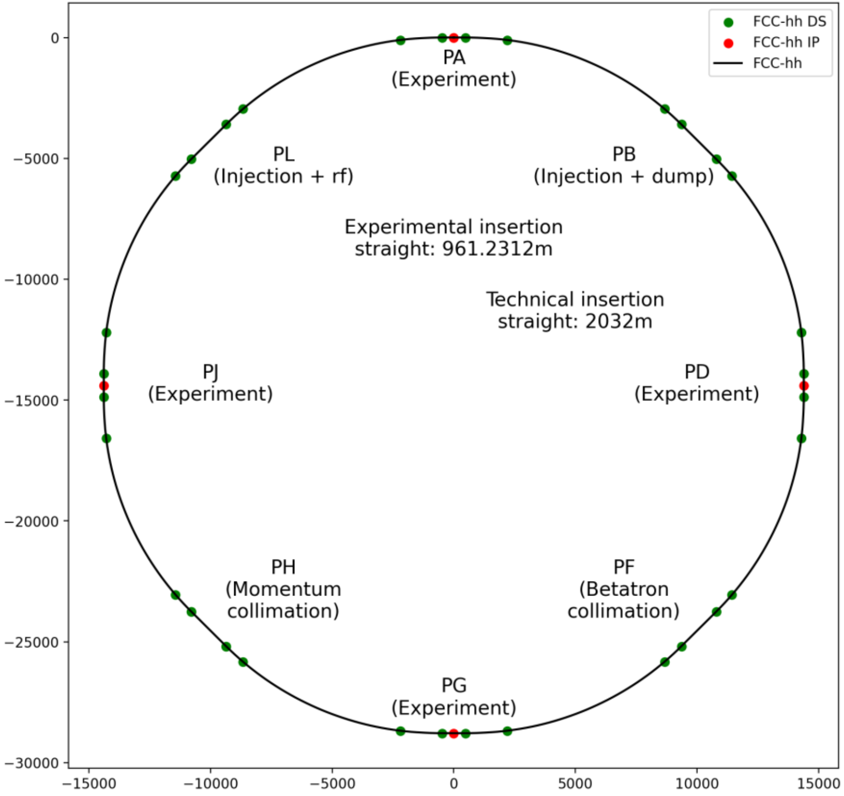
FCC-hh: Layout & main parameters

Status at last year's FCCWeek

Parameter	Value
Collision energy cms [TeV]	84.6 – 120.8
Dipole field [T]	14(Nb_3Sn) - 20(HTS/Hybrid)
Circumference [km]	90.657

- Adapted layout and lattice following placement studies.
- Maximize dipole filling factor to maximize collision energy.

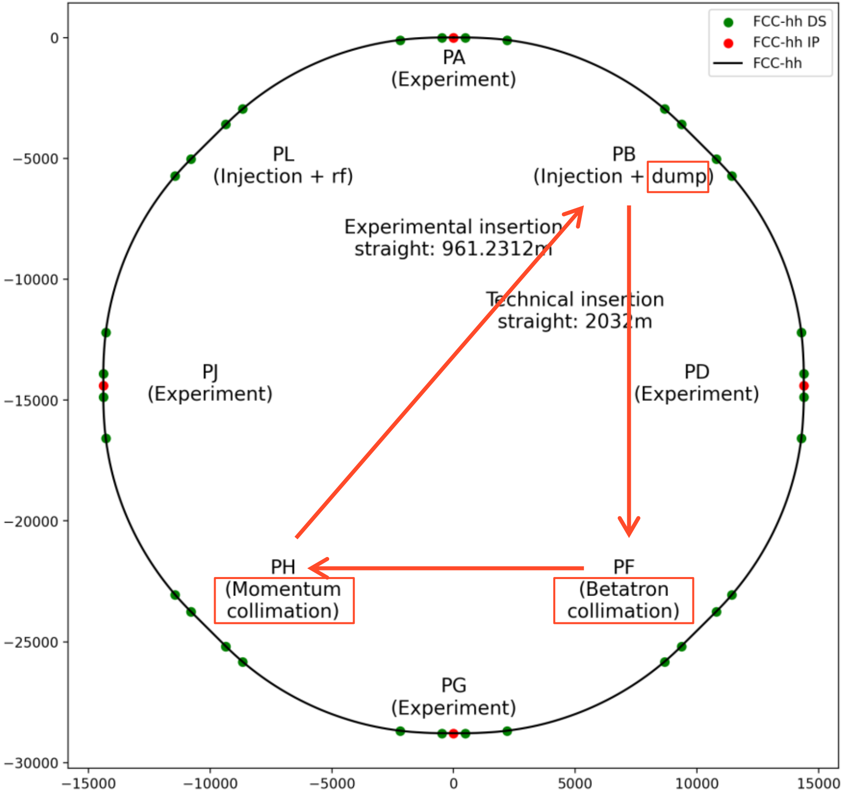
- Follow up conclusions from FCCWeek2023 and feasibility study midterm review.

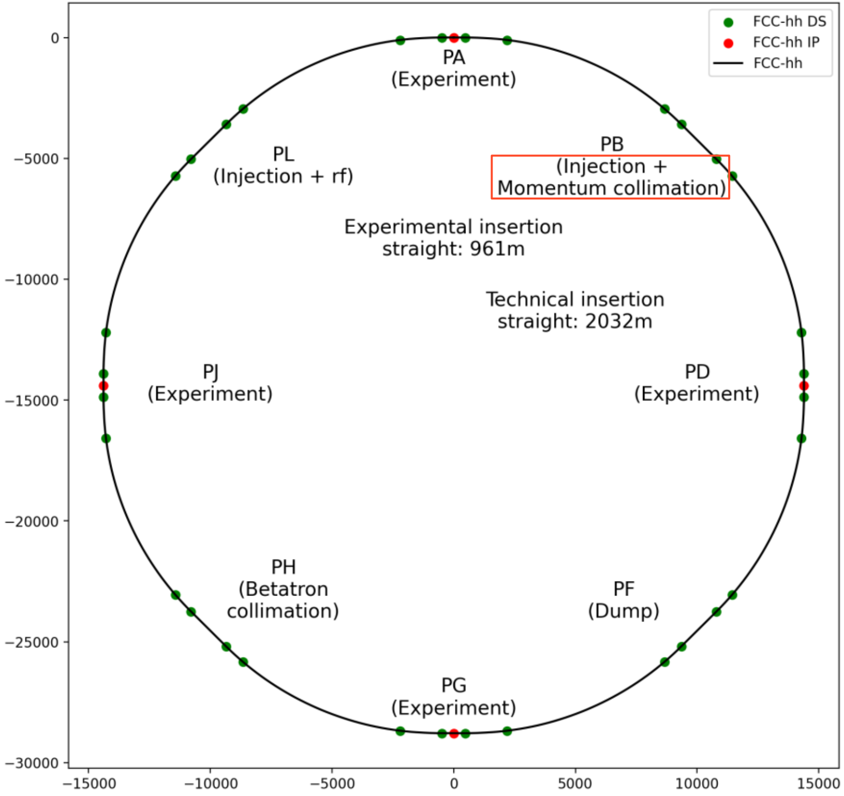


Reshuffle of technical insertion placements

Brand new design of PB

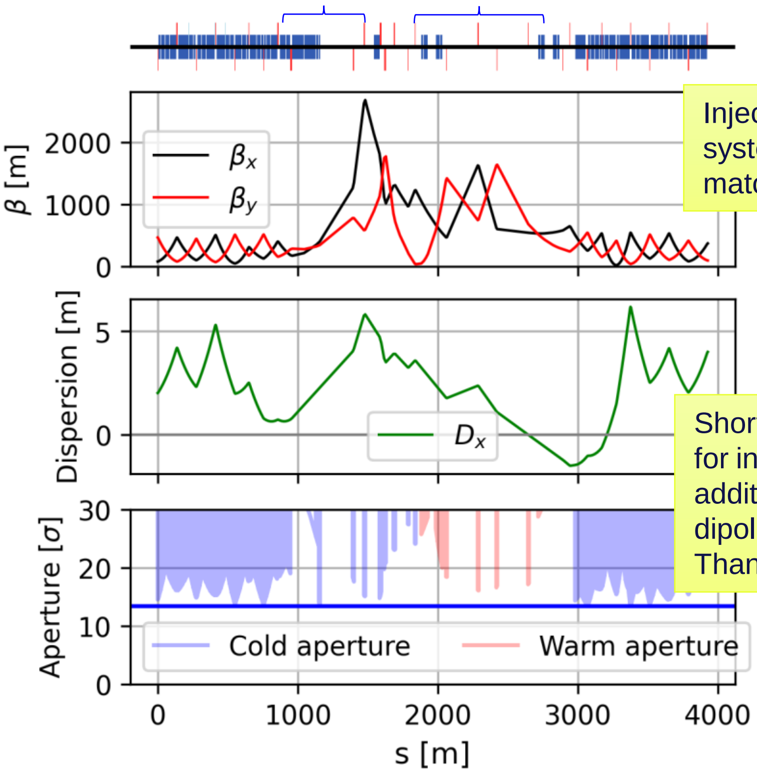
FCC-hh: Layout changes





Brand new design of PB

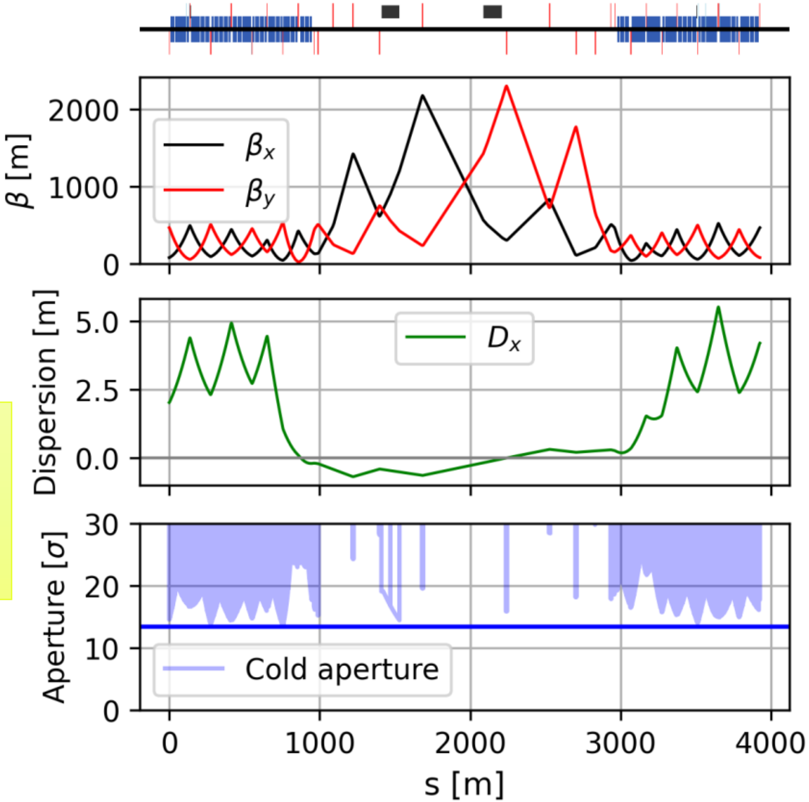
Injection beam 1 & momentum collimation – PB



Injection and collimation systems separated by matching section.

Shortening length required for injection systems with additional vertical bending dipoles.
Thanks to P. Thonet

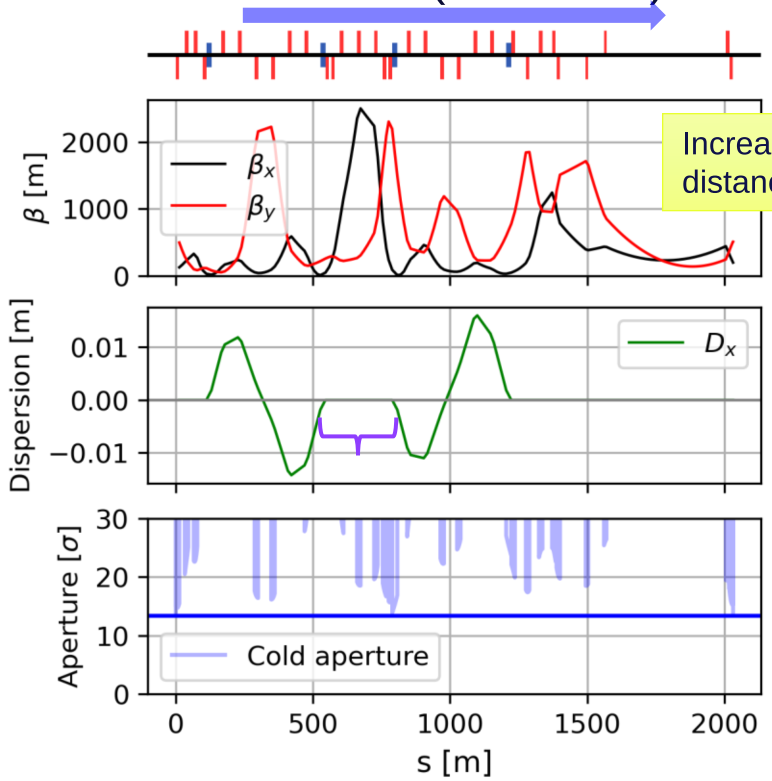
Beam dump – PF



Injection beam 2 and RF – PL

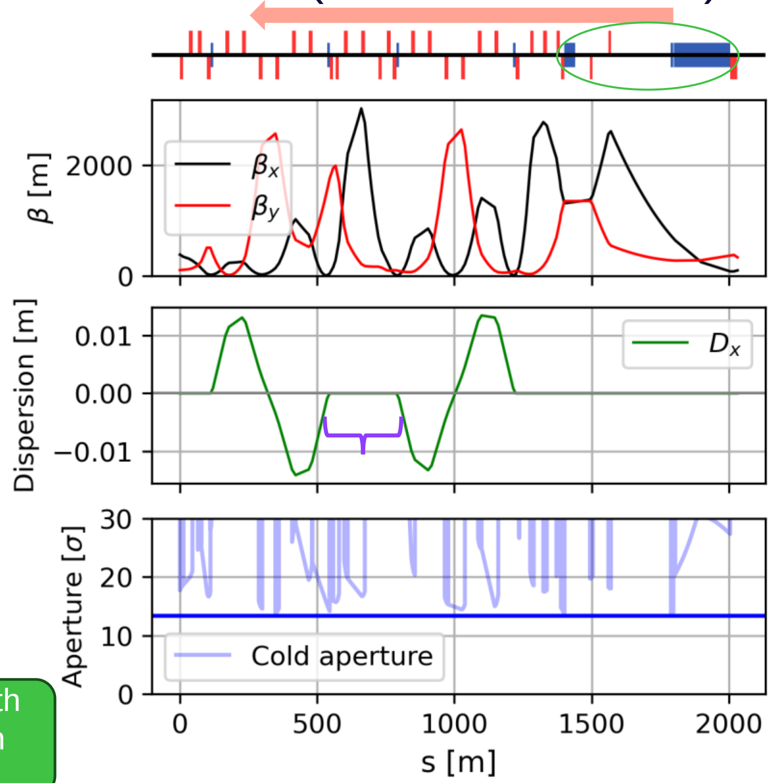
Additional constraints for injected beam

Beam 1 (clockwise)



Increased inter-beam distance for RF elements

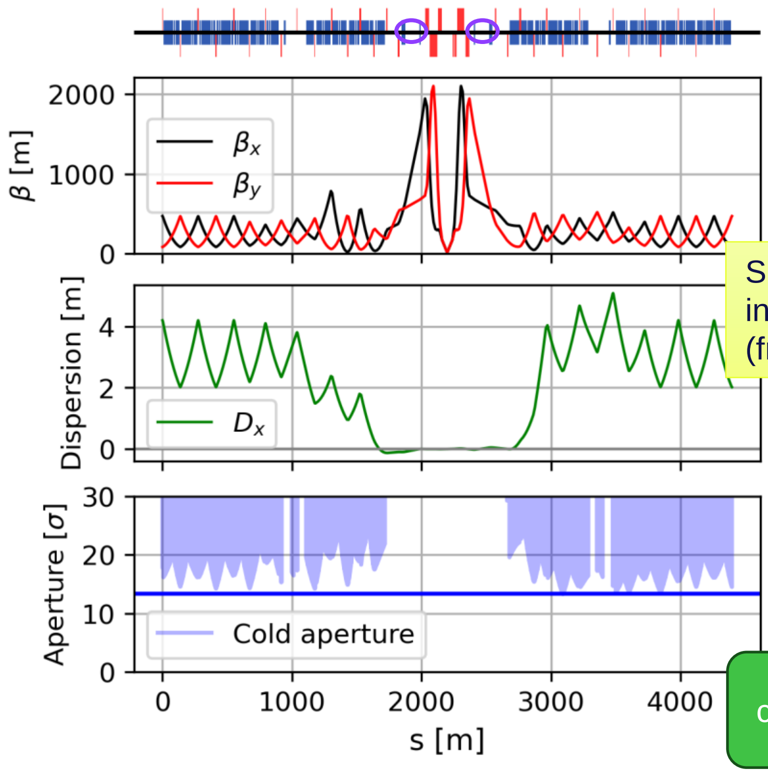
Beam 2 (counter-clockwise)



Updated design with improved injection layout

Experimental straight sections

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



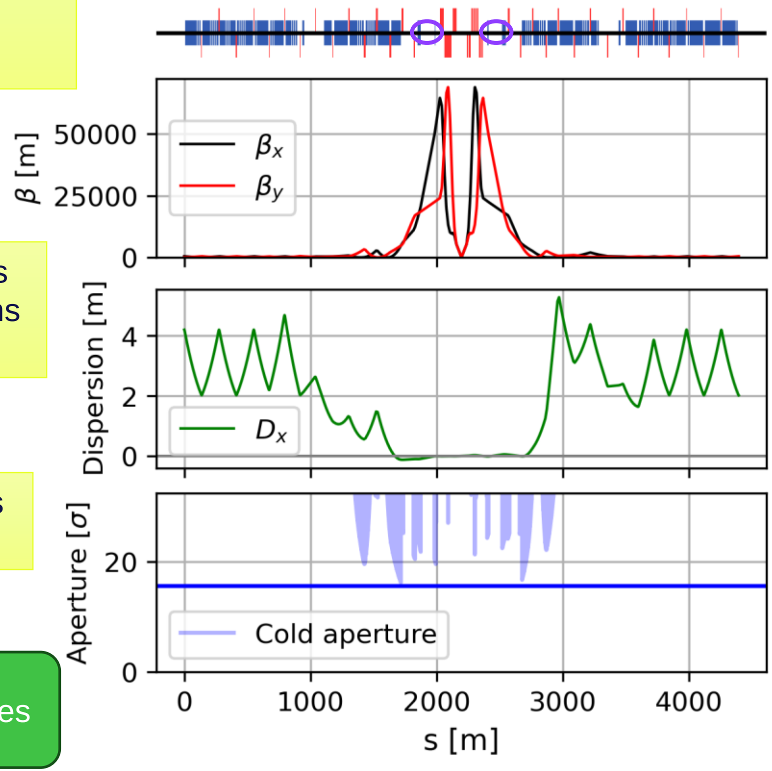
Four identical experimental insertions except for crossing scheme

Superconducting dipoles in experimental insertions (from HL-LHC)

Non-linear correctors from HL-LHC

New matches with constant phase advances during squeeze

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

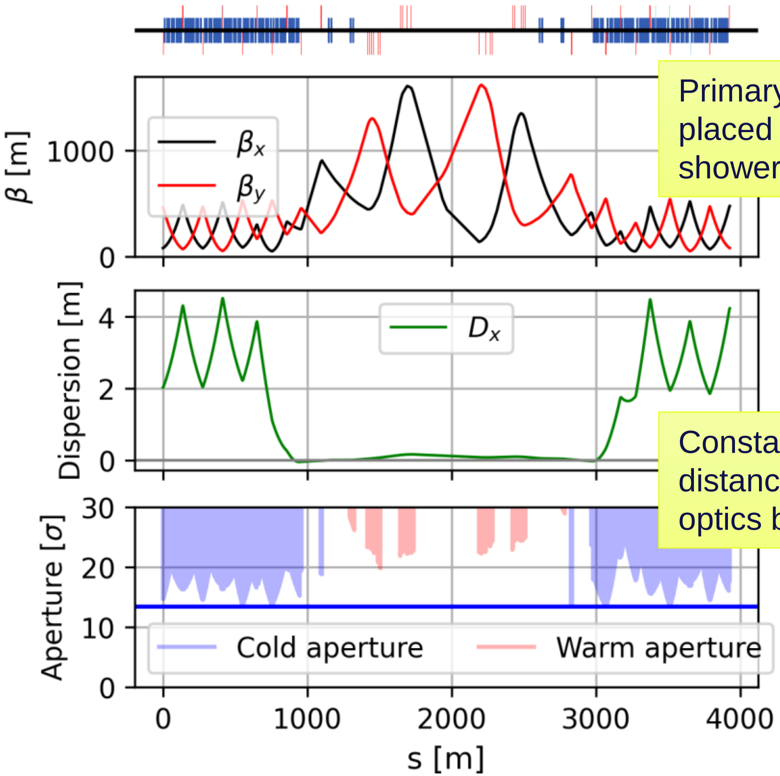


Betatron collimation – PH

Dedicated talk on collimation later by R. Bruce

High beta collimation optics following HL-LHC studies

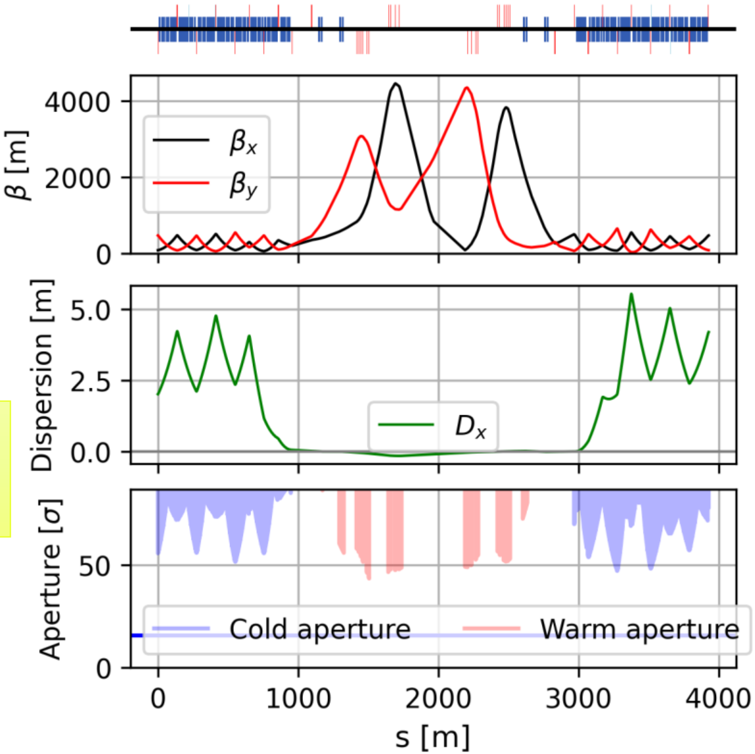
Low beta



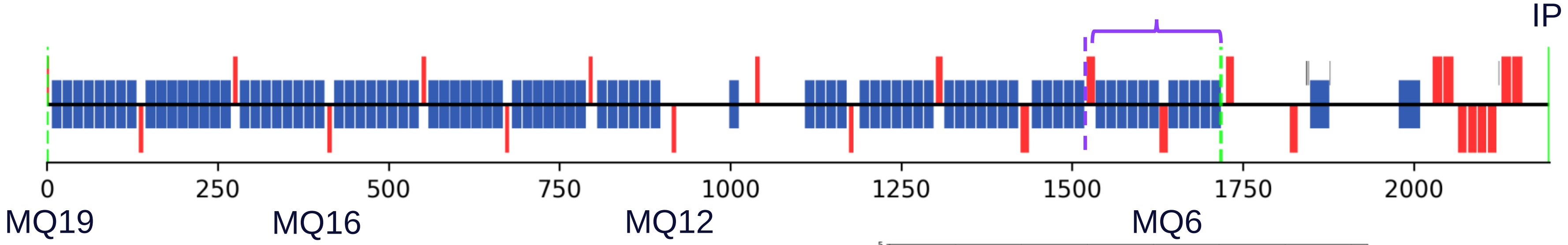
Primary collimators placed in doglegs to avoid showers of neutrals

Constant inter-beam distance allows shared optics between both beams

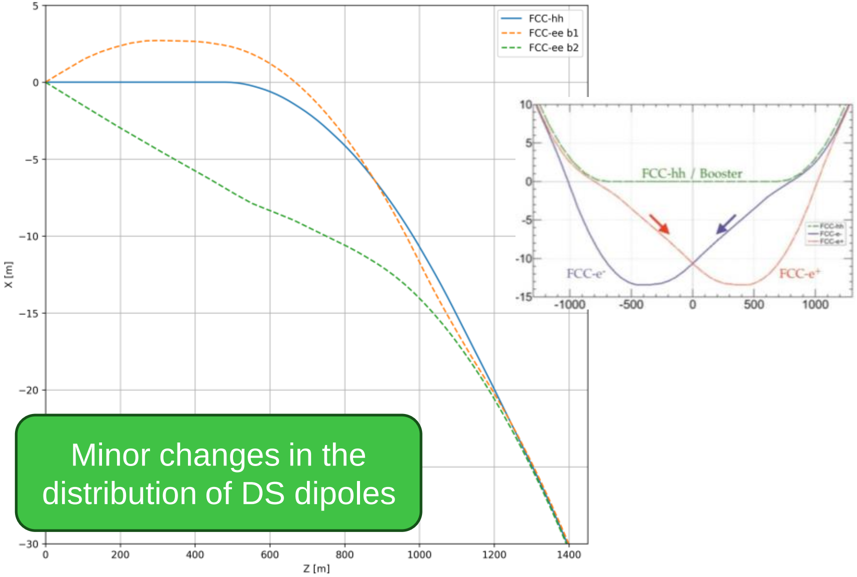
High beta



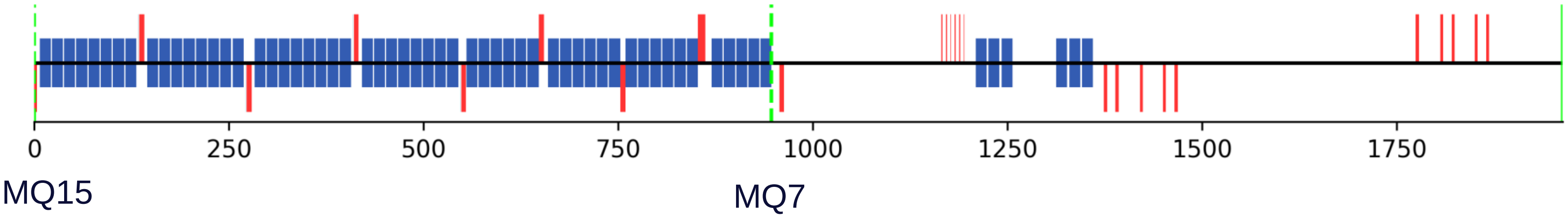
Dispersion suppressor – experimental insertion



- 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.



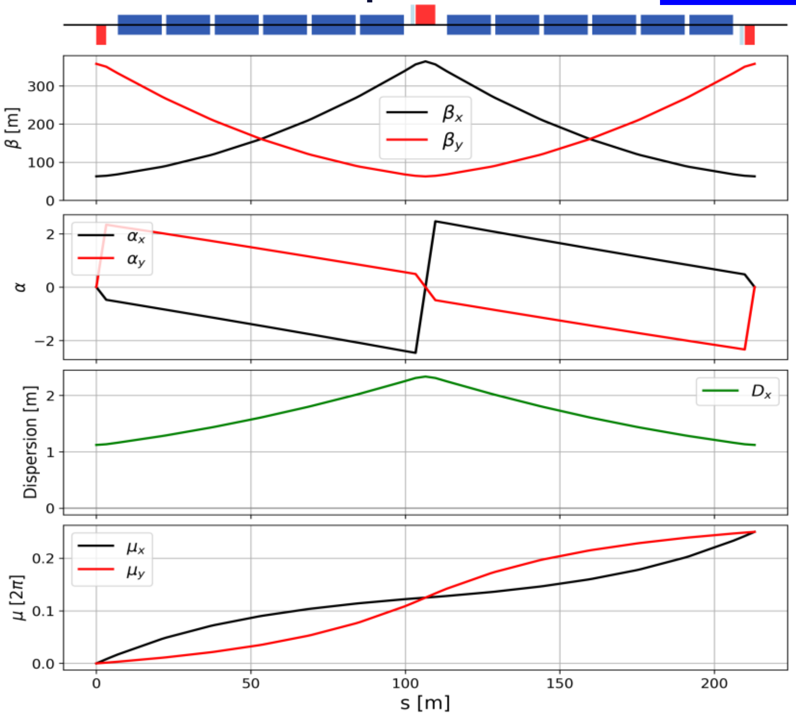
Dispersion suppressor – technical insertion



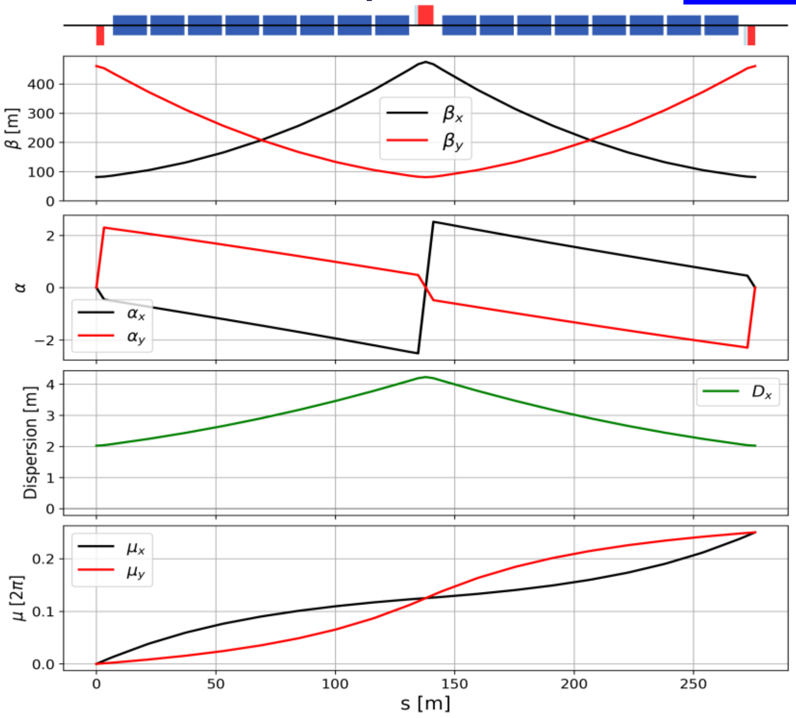
- Simpler than the experimental insertion, although also irregular.
- Space reserved too for collimators around Q8 and Q10.
- Possible to redistribute these drifts following results from collimation studies.

Longer arc cells

12-dipole cell ~213m



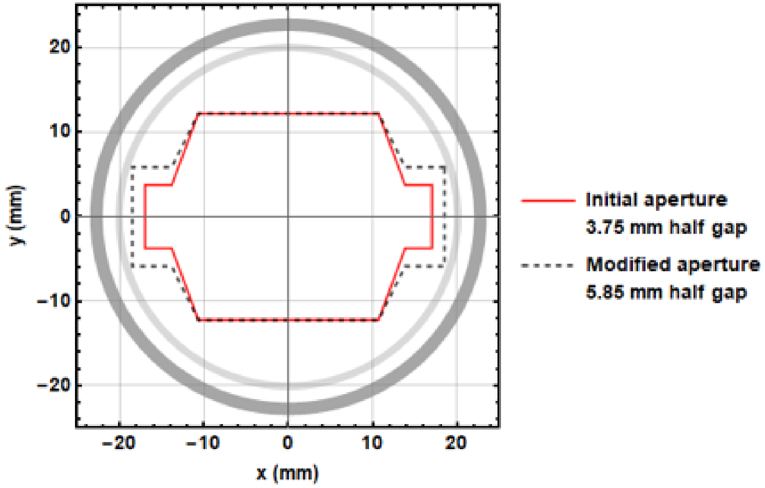
16-dipole cell ~275m



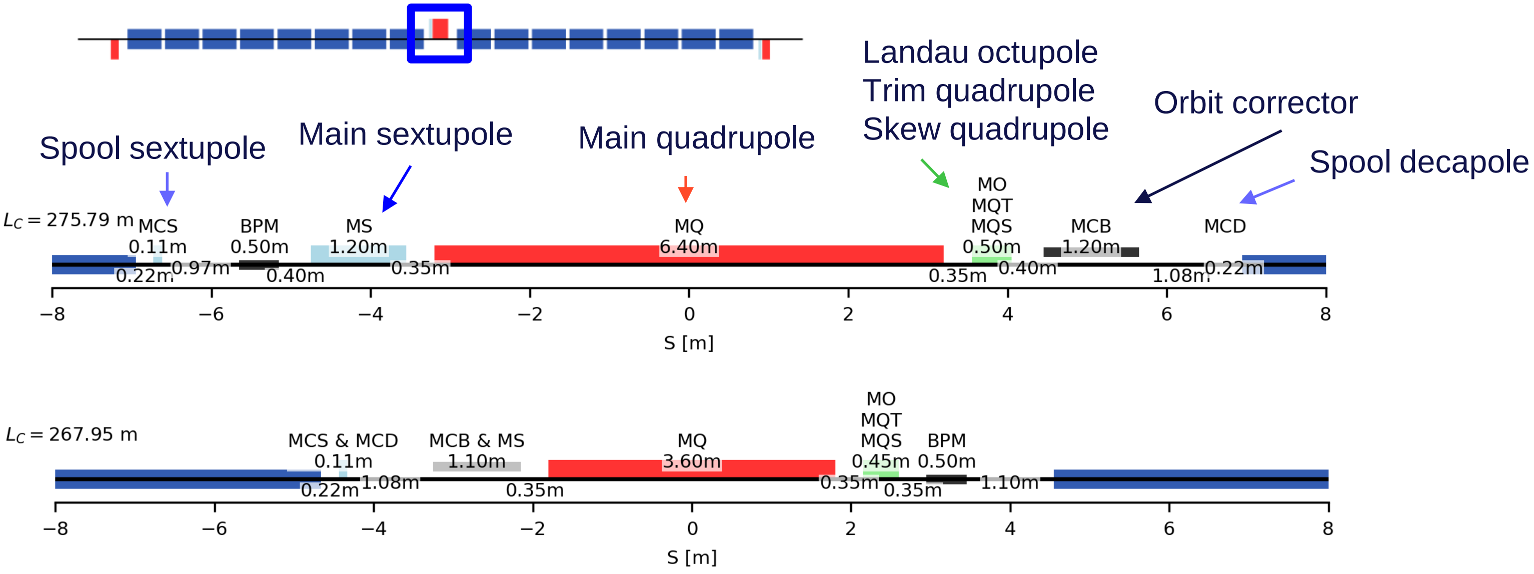
Longer arc cells

- 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)	213.030	213.030	**275.792**
Circumference (km)	97.75	**90.657**	**90.657**



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.
- 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**

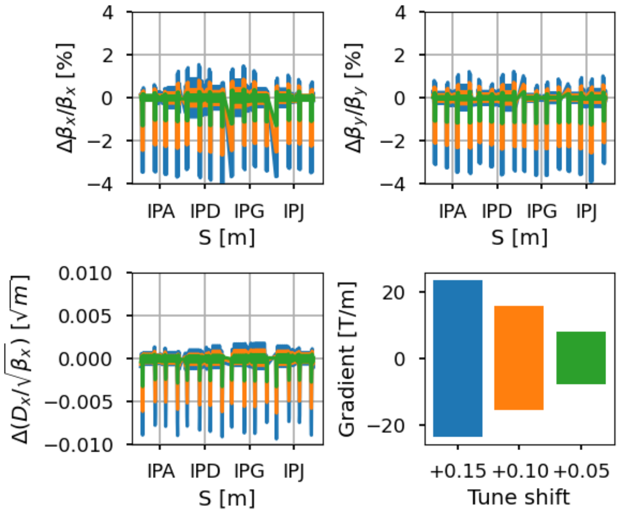
  Propose to **nest with main sextupole**

Review of short straight sections

Trim quadrupoles

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

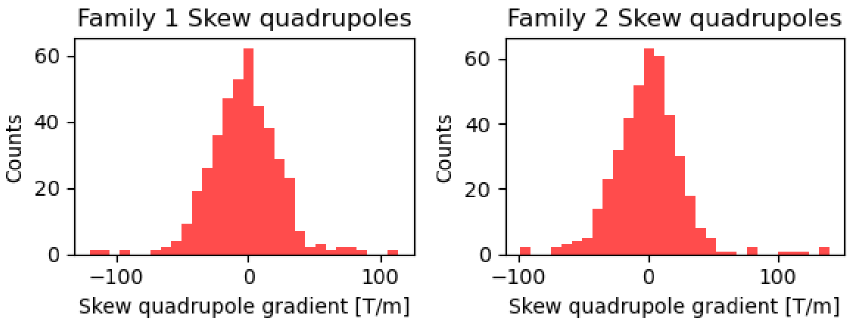
0.5 m to 0.45 m



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

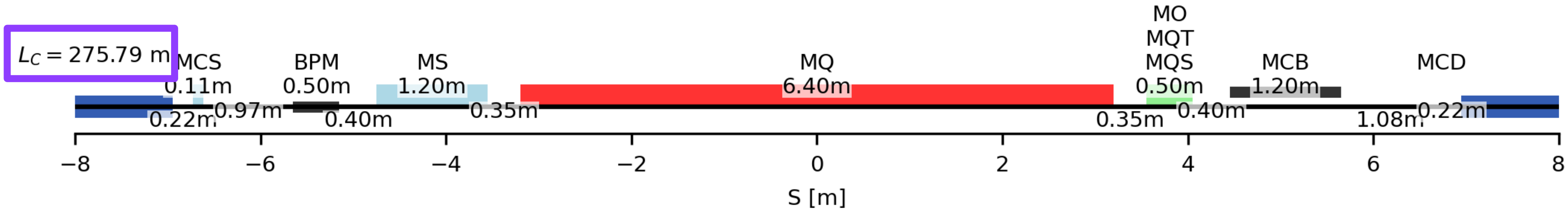
Landau octupoles

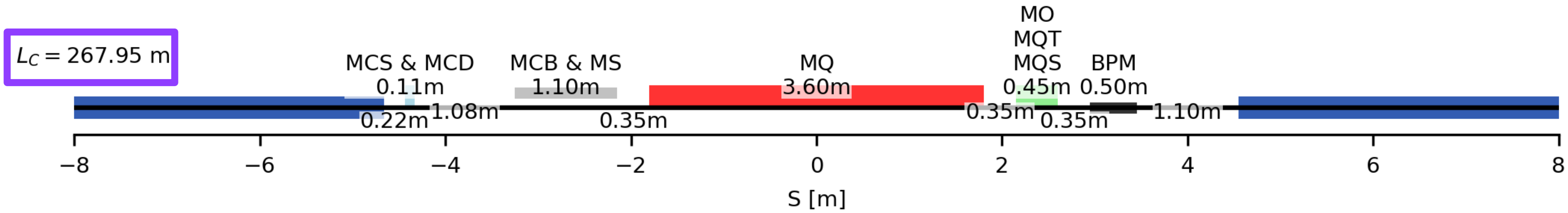
- Placed in every SSS that does not contain a trim quadrupole or a skew quadrupole.
- 296 available slots down from 480 in the CDR.
- Aim to maintain the same amplitude detuning considered in previous studies.

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

0.5 m to 0.45 m

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**.
- Decoupled **beam 1 injection** and **beam dump** (moved beam dump to **PF**) as conclusion of last year's FCCWeek and mid-term review.
- 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 cell 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.