DE LA RECHERCHE À L'INDUSTRIE

Lattice integration

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CEA/DRF/IRFU/DACM

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EuroCirCol
A key to New Physics

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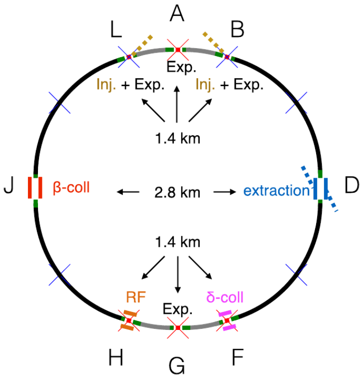
Irfu



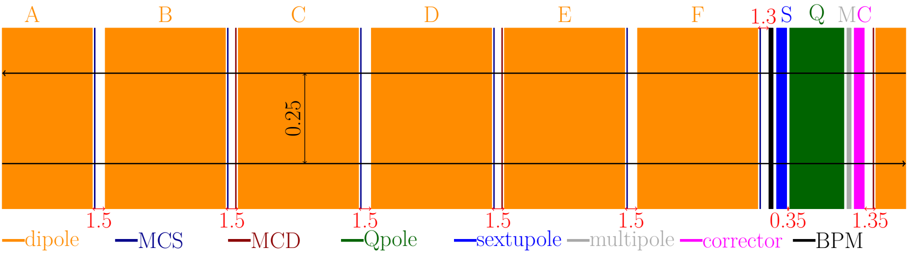
- New arc FODO cells:
  - FODO cells a bit longer.
  - b_2 up to 50 units in the main dipoles.
  - More realistic magnet fields.
    - Courtesy D. Schoerling's group
  - Longer inter-dipole distance.
    - 1.36 m → 1.5 m
    - $\Rightarrow B_{MB} \uparrow$
- New experimental insertion region:
  - $L = 1.5$ km → $L = 1.4$ km.
    - LAR a bit longer.
    - $\Rightarrow B_{MB} \downarrow$
  - Alternative inner triplet.
- $B_{MB} = 15.71$ T → $B_{MB} = 15.96$ T

Main changes

- **New intra-beam distance: 204 mm → 250 mm**
  - ⇒ **New b_2 value in the dipoles**: 0 at collision and 6 units at injection.
  - Reduced integrated gradient in the main quadrupoles MQs.
  - Shorter MQs and longer main dipoles: reduced peak dipole field.
- **Insertions have been updated**:
  - Updated interaction region with enlarged intra-beam distance.
  - Updated injection + low-luminosity region.
  - New extraction section.
  - Momentum collimation section with enlarged dispersion (increase by 25% at collision and by 60% at injection).
  - Updated RF insertions (new phase advance in the FODO cells).
- **Smaller optical functions in the dispersion suppressors**.
- **No more missing dipole at the middle of TSS** to get empty place (civil engineering has put a local cavern nearby).
- **New method to set the global tune and phase advances between IPs** by playing with FODO cells of long arcs.
- **Updated aperture model** (thanks to R. Martin and WP4).

Reminder: Integration strategy

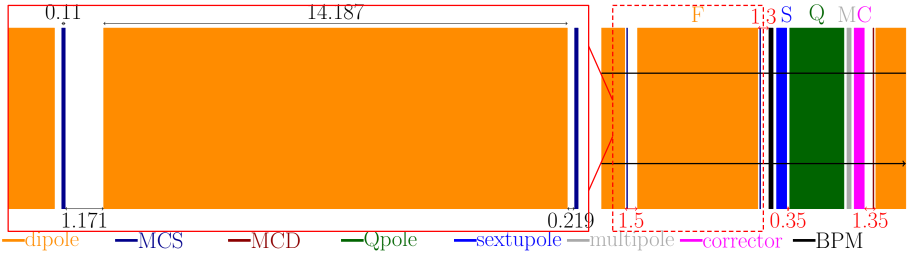
- MAD-X files automatically generated with python for the integration of the different lattices and of the insertions.
- The FODO cells of the arcs are generated according to some input parameters (e.g. range of the cell length).
- The dispersion suppressors are generated.
- The matching macros are generated.
- Some matching sections between the dispersion suppressors and insertions can be added.
- The insertions are optimized by different groups.
- The global tune is matched with the phase advance of the FODO cells in the long arcs.
  - Phase advances of the FODO cells in the SAR: 90°.
  - Phase advances of the FODO cells in the LAR: $90 + \epsilon_{x,y}{}^{\circ}$.
- The chromaticity is corrected by two sextupole families.



⇒ The FODO cell is 213.04 m long.

- The distance inter-dipole is 1.5 m.
- The main dipole MB is 14.19 m long.
- The maximum dipole field is 15.81 T with an aperture of 50 mm.
- MCS has the same length as in LHC: 0.11 m.
- MCD has been added at every other dipole to correct b_5.
- MQ is shorter (6.4 m) with a quadrupole gradient of 358 T/m.
- The maximum corrector field is 4 T.

Arc cell: baseline



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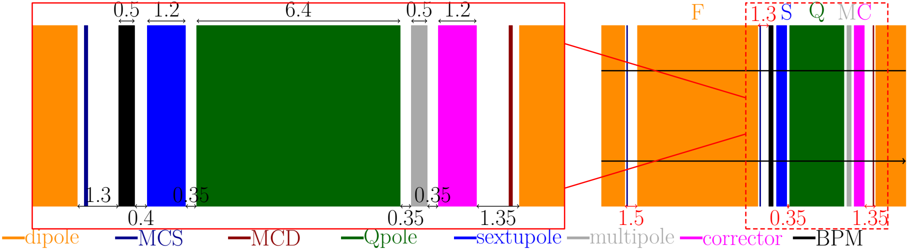

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- Courtesy: D. Schoerling

Magnet type	Distance (m)	Remarks
MB-MB	1.5	May be longer if stronger MCS required
MB-SSS	1.3	Does not include BPMs
MQ-Other	0.35	Other magnetic elements in SSS
Other-Other	0.35	

Magnet type	# per beam	Max. Strength	Length	SC material	LHC nominal strength (56 mm aperture)	LHC strength scaled to 50 mm aperture
Main Dipole (MB)	4672	16 T	14.2 m	Nb_3Sn	8.33 T	8.33 T
Main Quadrupole (MQ)	744	360 T/m	6.4 m	Nb_3Sn	223 T/m	250 T/m
Trim Quadrupole (MQT)	88	220 T/m	0.5 m	Nb-Ti	123 T/m	140 T/m
Skew Quadrupole (MQS)	96	220 T/m	0.5 m	Nb-Ti	123 T/m	140 T/m
Main Sextupole (MS)	696	7000 T/m^2	1.2 m	Nb-Ti	4430 T/m^2	5560 T/m^2
Main Octupole (MO)	480	200,000 T/m^3	0.5 m	Nb-Ti	63,000 T/m^3	90,000 T/m^3
Sextupole Corrector (MCS)	4672	3000 T/m^2	0.11 m	Nb-Ti	1630 T/m^2	2050 T/m^2
Decapole Corrector (MCD)	2336	2.8×10^6 T/m^4	0.07 m	Nb-Ti	4.3×10^6 T/m^4	
Dipole Corrector (MCB)	792	4 T	1.2 m	Nb-Ti	3 T	3 T
DIS Trim Quadrupole (MQTL)	48	220 T/m	2.2 m	Nb-Ti	129 T/m	145 T/m
DIS Quadrupole (MQDA)	48	360 T/m	9.1 m	Nb_3Sn	129 T/m	145 T/m

Insertions: main experiments

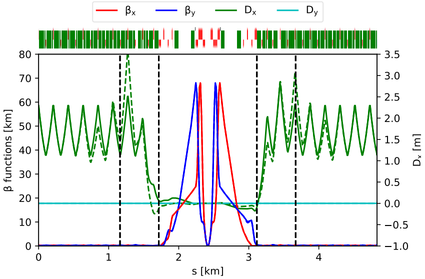
- Version 7b of the EIR.
- $L^* = 40$ m.
- BPMs and correctors have been integrated.

→ **see Martin: “EIR Optics”**

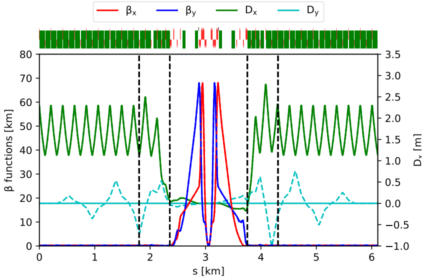
→ **see Van Riesen-Haupt: “EIR Alternative optics”**

- Considered β^*:
  - 6.0 m (injection)
  - 4.6 m (baseline injection)
  - 1.1 m (baseline)
  - 0.3 m (ultimate)
  - 0.2 m (more ultimate)
  - 0.15 m (most ultimate)
  - 1.2 m/0.15 m (flat beam)

PA $\beta^* = 0.3$ m baseline



PG $\beta^* = 0.3$ m baseline



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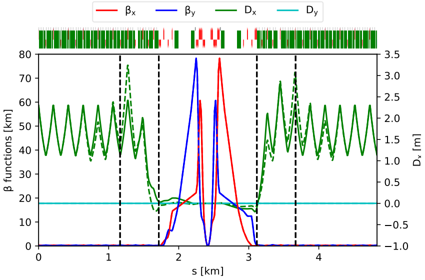
PA $\beta^* = 0.3$ m alternative



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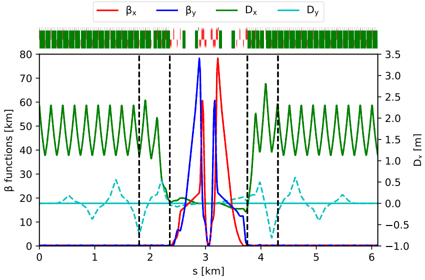
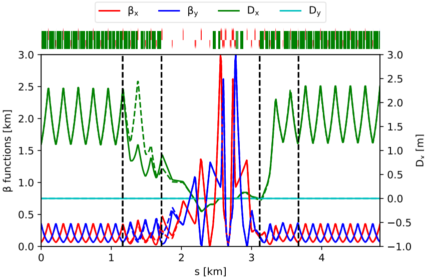


- Injection in the same section as the additional experiments.
- $L^* = 25$ m
- New version of the insertion implemented.

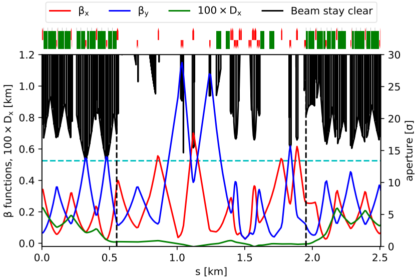
→ **see Hofer: "Low luminosity interaction regions"**

- Considered β^*:
  - 27 m (injection)
  - 3 m (collision)

Inj.+Exp. section: LSS B (@ collision)



Inj.+Exp. section: LSS B (@ injection)



Insertions: injection + low-$\mathscr{L}$ experiment

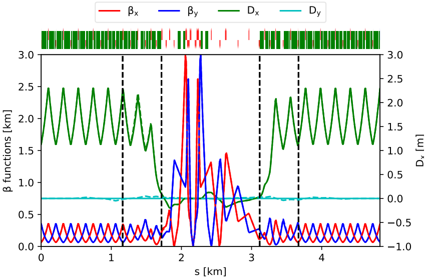
- Injection in the same section as the additional experiments.
- $L^* = 25$ m

- New version of the insertion implemented.

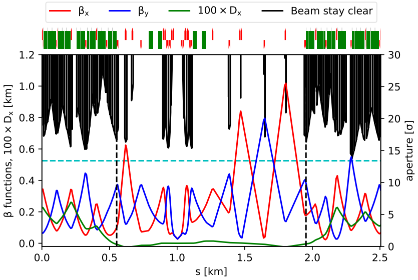
→ **see Hofer: "Low luminosity interaction regions"**

- Considered β^*:
  - 27 m (injection)
  - 3 m (collision)

Inj.+Exp. section: LSS L (@ collision)



Inj.+Exp. section: LSS L (@ injection)



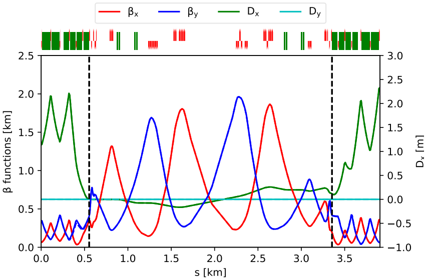
- Dedicated section to β-cleaning
- The DIS is optimized to enhance the losses coming from β and δ collimation.

→ **see Bruce:"Status of FCC-hh collimation studies"**

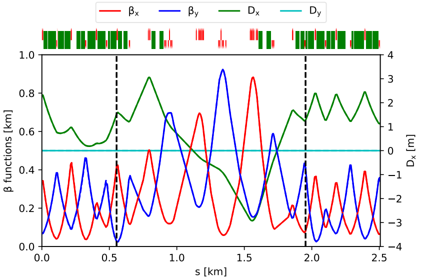
→ **see Molson:"Collimation inefficiency"**

- LHC-scaled δ-cleaning insertion
- Enlarged beam separation: 250 mm → 420 mm.
- Enlarged dispersion (max: 3 m at collision, 4 m at injection).

β-cleaning section: ESS J



δ-cleaning section: LSS F collision



Insertions: collimation sections

- Dedicated section to β-cleaning
- The DIS is optimized to enhance the losses coming from β and δ collimation.

→ **see Bruce:“Status of FCC-hh collimation studies”**

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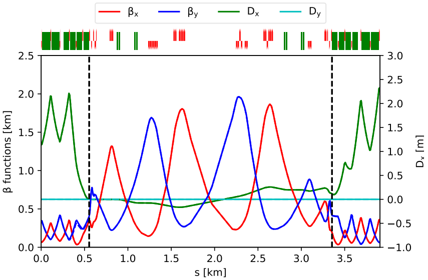
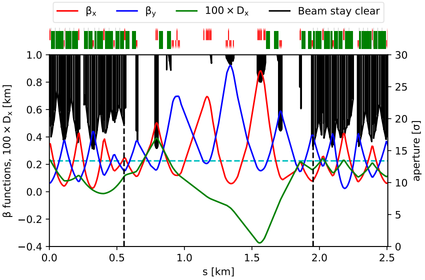
β-cleaning section: ESS J



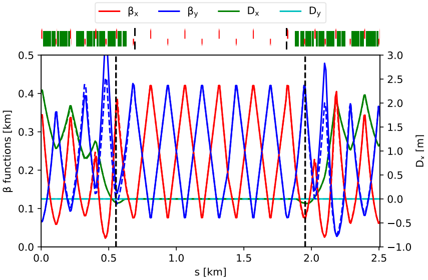
δ-cleaning section: LSS F injection



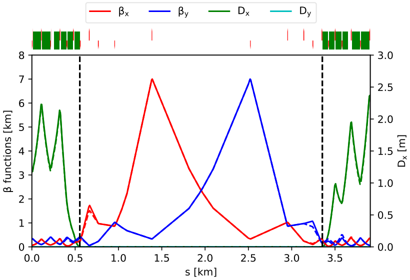
- RF section is made of FODO cells: phase advances of 72° (to reduce dispersion peak in the DIS).
- Enlarged beam separation: 250 mm → 420 mm.
- Dedicated section for the extraction (2.8 km).
- New version of this insertion has been integrated.

→ **see Chmielinska: "Injection and extraction insertions"**

RF section: LSS H



Extraction section: ESS D

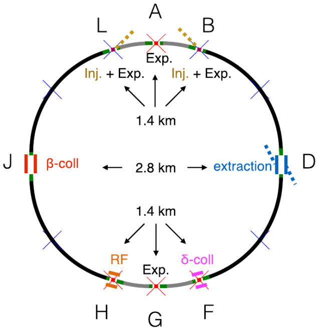


- 3 schemes are currently implemented to tune the ring:
  - FODO cells of long are slightly detuned ($90°+\epsilon$). DIS are rematched.
  - Use of phase trombones in insertions.
  - **Use of different phase advances in the long arcs** to tune the machine and phase advances between IPs (baseline).
- Correction schemes have been implemented.
  - BPMs and dipole correctors are integrated in the lattice to correct the orbit. Additional BPMs in the insertions have been added.
  - Trim quadrupoles are integrated to correct the horizontal spurious dispersion, the β-beating and the dispersion-beating
  - Skew quadrupoles are used to correct the coupling (sets of 4 separated by 90° each) and the vertical spurious dispersion.

  → **see Boutin: "Correction schemes"**.
- The dynamic aperture studies have shown that:
  - b_3 (coll + injection) and b_5 (injection) correctors are mandatory.
  - Phase advances between PA end PG have a big impact at collision.

  → **see Dalena: "Field Quality at injection for FCC-hh"**

  → **see Cruz-Alaniz: "Dynamic aperture studies"**
- Octupoles integrated for Landau damping and beam-beam correction.

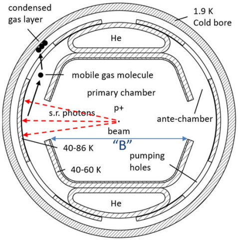


Parameters

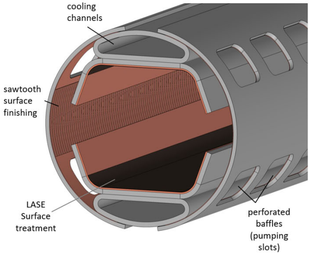
Parameter		Value
Energy	TeV	50
Circumference	km	97.75
β^*	m	0.3
L^*	m	40
α	10^{-4}	1.032
γ_{tr}	-	98.41
Q_x coll	-	109.31
Q_y coll	-	107.32
Q_x inj	-	109.28
Q_y inj	-	107.31
Q'_x	-	2
Q'_y	-	2
MB field	T	**15.81**
MQ gradient	T/m	**358**
MS gradient	T/m^2	6974

- Contrary to LHC, the dipoles are assumed to be straight.
- A margin of 1.2 mm is added to the horizontal tolerance to handle the sagitta.
- Reduction of the beam-stay clear by 1.5σ because of the sagitta.

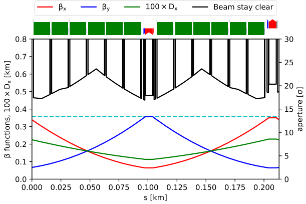
Courtesy: I. Bellafont *et al.*



Courtesy: R. Martin



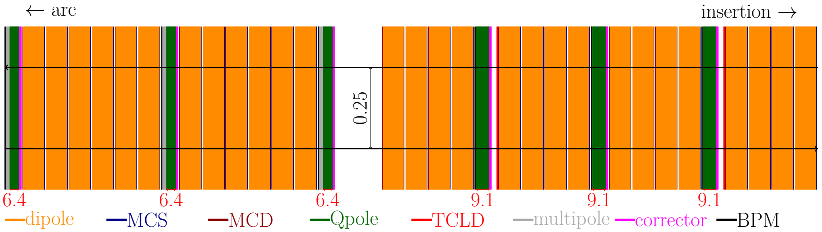
Arc AB: $b_2 = +6$



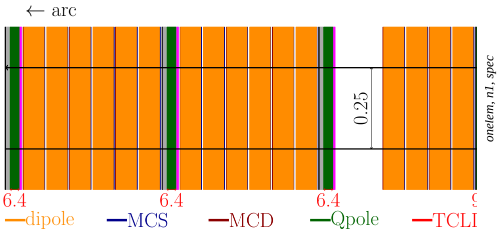
$n_{1,\text{min}} = 16.9$

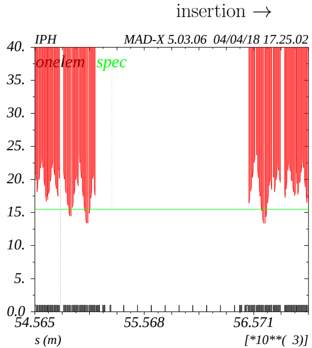
- **Target: 13.4σ at injection and 15.5σ at collision.**

Dispersion suppressors (FCC week 2018)



- The selected dispersion suppressor is similar to LHC: best compromise between filling factor and flexibility.
- Two collimators (TCLD) of 1 meter are inserted to clean the beam at the arc entrance (the needed space is 5 meters for each TCLD).
- Bottleneck for the machine aperture (location of betatron and dispersion peaks).
- **New constraints in the DIS** to reduce betatron and dispersion peaks there. Shorter MQDA: 9.1 m. Longer MQTL: 2.2 m.





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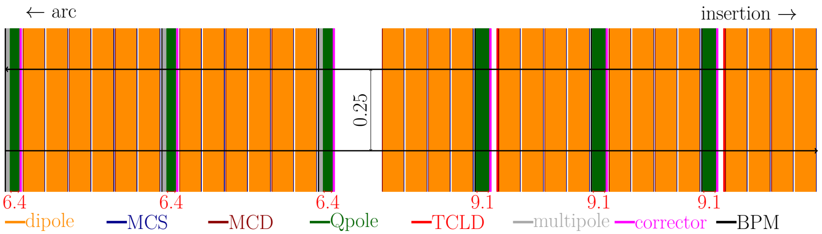

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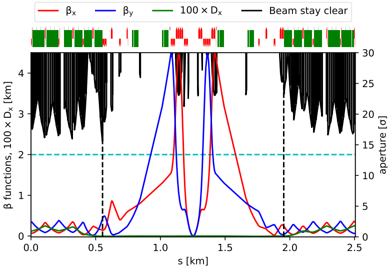
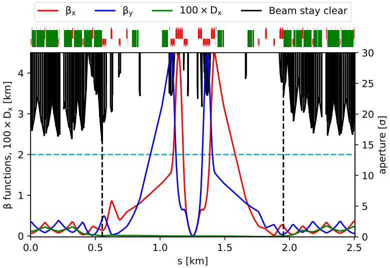
Interaction region aperture @ injection

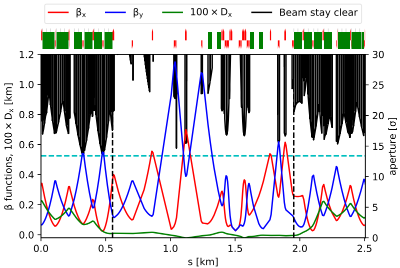
EIR: LSS A



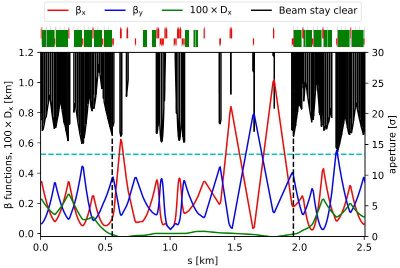
EIR: LSS G



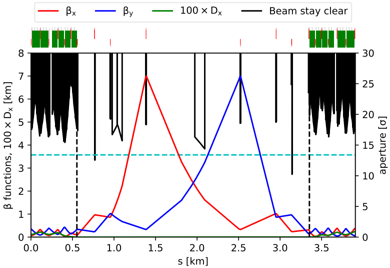
Low-lumi + injection section: LSS B



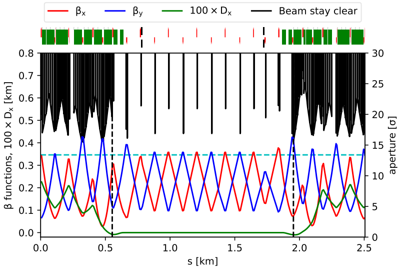
Low-lumi section: LSS L



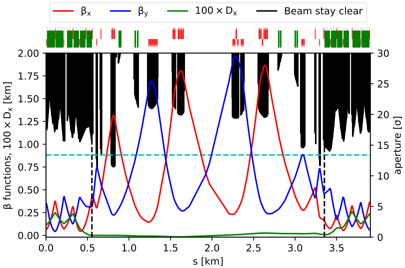
Extraction: ESS D



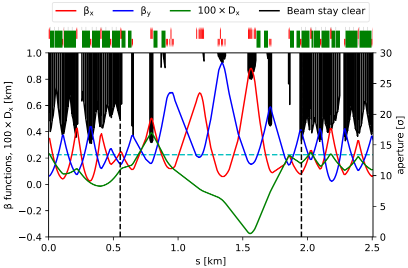
RF section: LSS H



β collimation: ESS J



δ collimation: LSS F



Alternatives for the FCC-hh ring

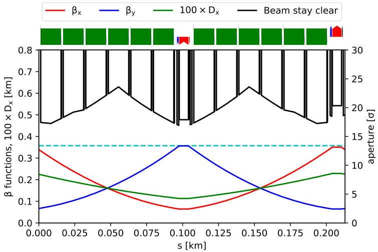
- Alternative triplet for the experiment insertion has been integrated (and flat optics)

→ **see Van Riesen-Haupt: "EIR Alternative optics"**

- Phase advance of 60 degrees against 90 degrees (idea: E. Todesco).
  - The integrated quadrupole gradient is multiplied by $\frac{\sin 30°}{\sin 45°} \approx 0.7$.
  - ☺ With the same FODO cell length, the maximum quadrupole gradient is decreased from 360 T/m to 220 T/m.
  - With the same maximum gradient, the quadrupole can be shortened from 6.4 m to 4.5 m.
  - The dipoles are lengthened (by 0.33 m).
  - ☺ The reached dipole field we can get is 15.44 T (against 15.81 T before).
  - ☹ The correction schemes must be modified.
    - ☺ With a system of 6 trim quadrupoles with 60 degrees in between, possibility to correct beta-beating, dispersion beating, coupling (if skew),or tune as the system of 4 quadrupoles in the case of 90° by phase advance.
  - ☹ The dispersion is enlarged: reduction of the beam stay clear.

Phase advance of 60 degrees

Apertures @3.3 TeV (90°)



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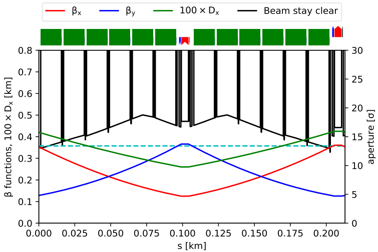

$n_1 = 16.9 \rightarrow n_1 = 12.9$ below the target!

Parameters

Parameter		Value
Energy	TeV	50
Circumference	km	97.75
β^*	m	0.3
L^*	m	40
α	10^{-4}	2.068
γ_{tr}	-	69.54
Q_x coll	-	78.31
Q_y coll	-	75.32
Q_x inj	-	78.28
Q_y inj	-	75.31
Q'_x	-	2
Q'_y	-	2
MB field	T	15.44
MQ gradient	T/m	360
MS gradient	T/m^2	3215

- Lattice has been updated:
  - b_2 is smaller in dipoles: 6 units at injection and 0 unit at collision.
  - MQs are shorer and dipoles are longer with a reduced peak field (15.81 T).
  - Additional correctors in the lattice: an MCD has been inserted every other dipole to correct b_5.
  - Updated insertions: larger intra-beam separation in the insertions, larger dispersion in the δ collimation section, new extraction section.
  - Machine is now tuned with phase advances in the FODO cells of the long arcs.
  - No missing dipole in the long arcs.
  - Optical functions reduced in the DIS.
- Physical aperture is now within the specifications at injection.
- Magnet list has been updated.
- Alternative optics exists.