DE LA RECHERCHE À L'INDUSTRIE

New lattice design

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CEA/DRF/IRFU/DACM

4th EuroCirCol meeting @ KIT
17th October 2018

The European Circular Energy-Frontier Collider Study (EuroCirCol) project has received funding from the European Union's Horizon 2020 research and innovation programme under grant No 654305. The information herein only reflects the views of its authors and the European Commission is not responsible for any use that may be made of the information.

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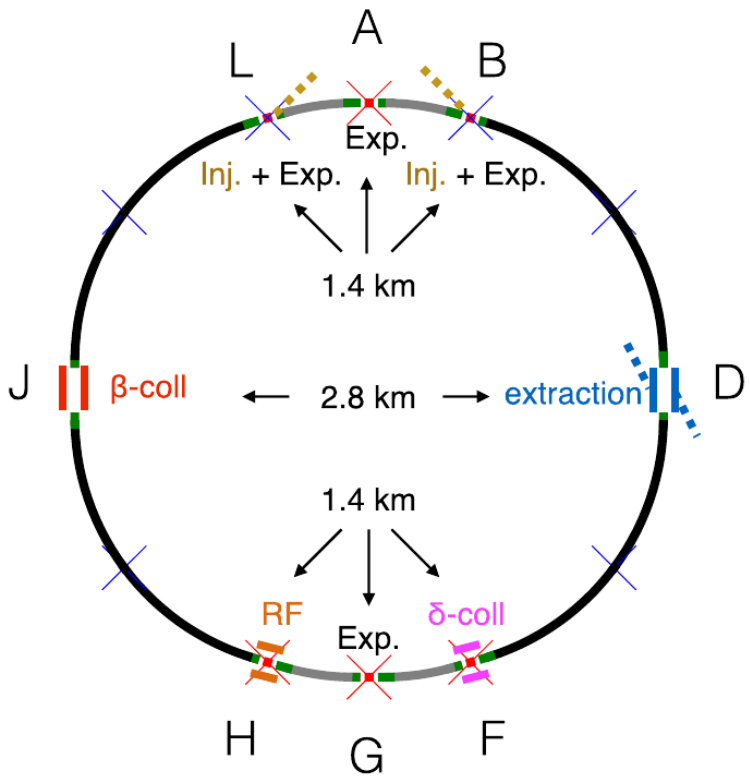


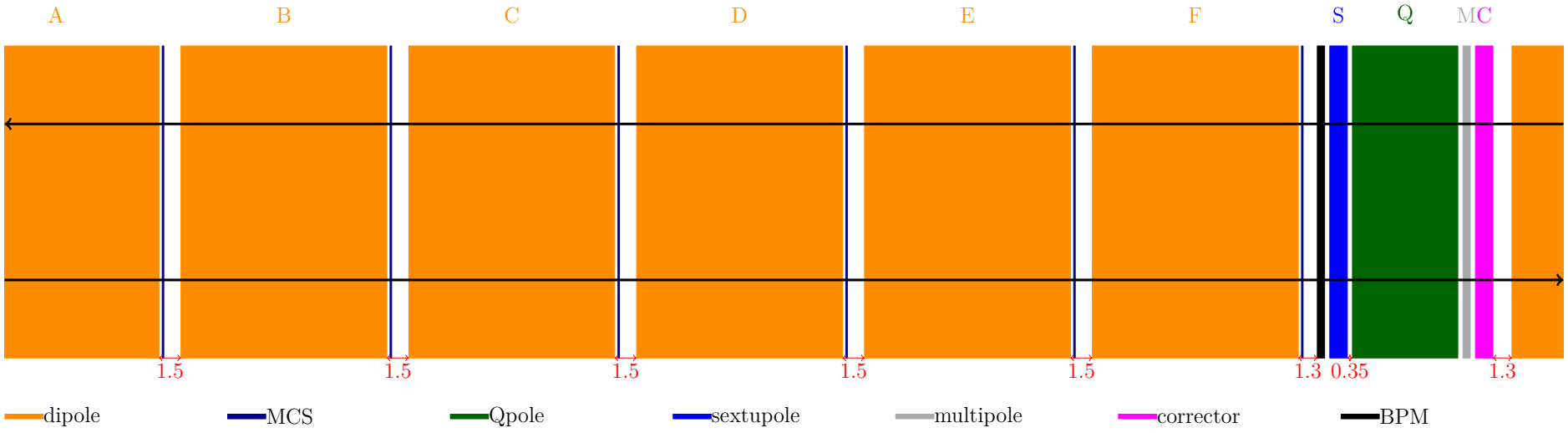
- New arc FODO cells:
  - FODO cells a bit longer.
  - b_2 up to 50 units in the main dipoles.
  - More realistic magnet fields.
    - Courtesy D. Schoerling's group
  - Longer inter-dipole distance.
    - 1.36 m → 1.5 m
    - ⇒ $B_{MB} \uparrow$
- New experimental insertion region:
  - $L = 1.5$ km → $L = 1.4$ km.
    - LAR a bit longer.
    - ⇒ $B_{MB} \downarrow$
  - 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 20 units at injection.
  - b_2 may decrease even more with new magnet design.
- **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).
- Reduction of the optical functions in the dispersion suppressors to enlarge the physical aperture.
- 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.
- Bug correction on the aperture calculation (thanks to Roman Martin).

Arc cell: baseline



⇒ The FODO cell is 213.03 m long.

- The distance inter-dipole is 1.5 m.
- The main dipole MD is 14.069 m long.
- The maximum dipole field is 15.94 T with an aperture of 50 mm.
- MCS has the same length as in LHC: 0.11 m.
- The maximum quadrupole gradient is 318 T/m in the arcs (against 360 T/m before thanks to b_2 reduction). MQs could be shortened.
- The maximum corrector field is 4 T.

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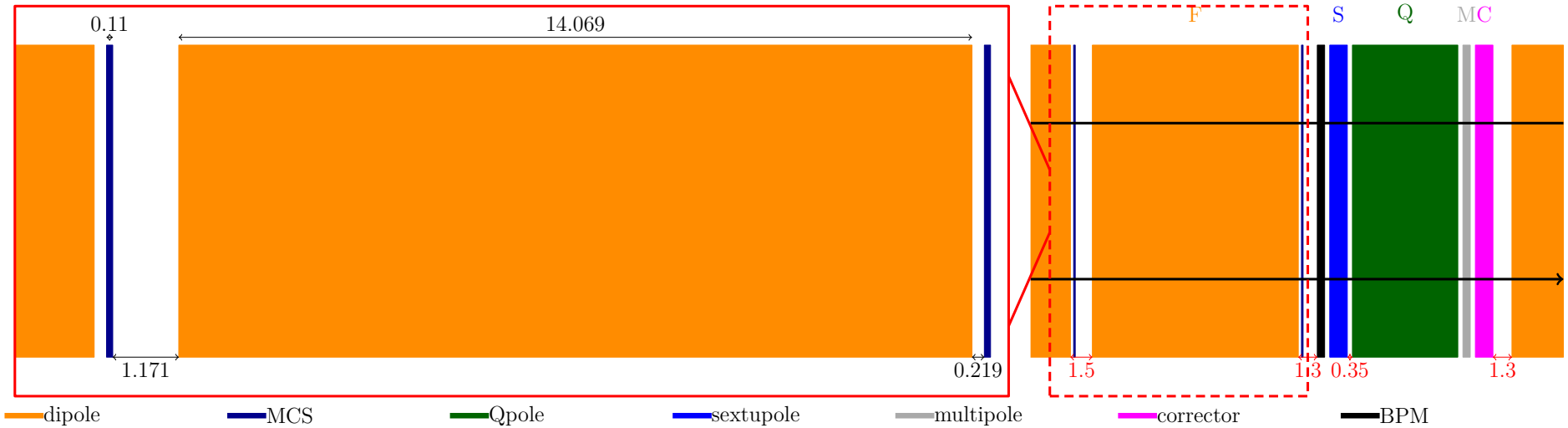

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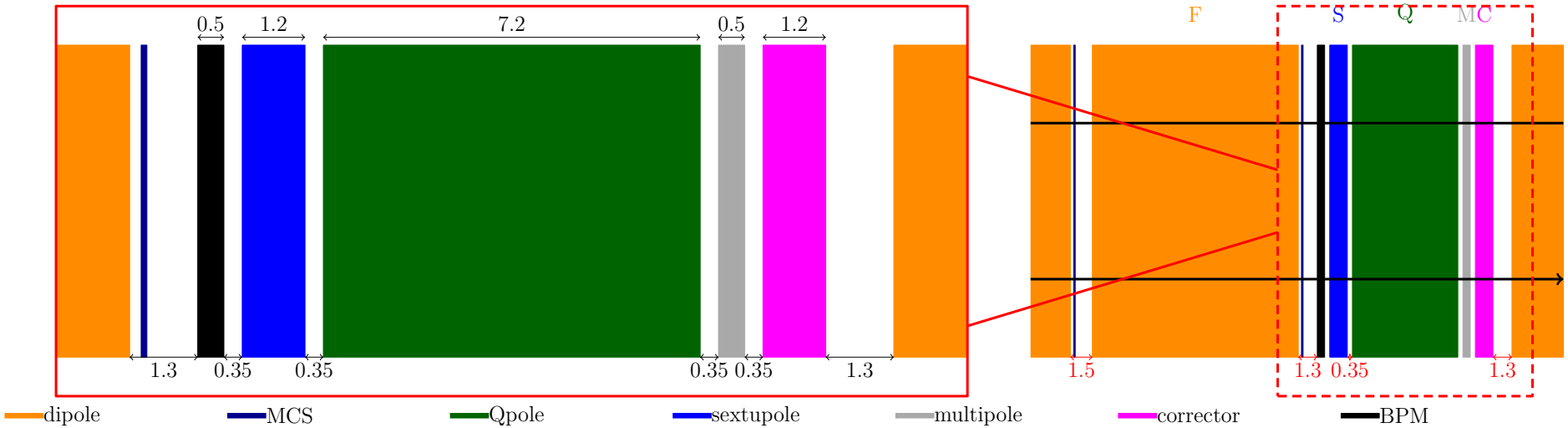

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Arc lattice: magnets

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	Number	Max. Strength	Length	SC material	LHC nominal strength (56 mm aperture)	LHC nominal strength scaled to 50 mm aperture
Main Dipole (MB)	4672	16 T	14.1 m	Nb_3Sn	8.33 T	8.33 T
Main Quadrupole (MQ)	744	360 T/m	7.2 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)	9344	3000 T/m^2	0.11 m	Nb-Ti	1630 T/m^2	2050 T/m^2
Dipole Corrector (MCB)	792	4 T	1.2 m	Nb-Ti	3 T	3 T
DIS Trim Quadrupole (MQTL)	48	220 T/m	2.0 m	Nb-Ti	129 T/m	145 T/m
DIS Quadrupole (MQDA)	48	360 T/m	9.7 m	Nb_3Sn	129 T/m	145 T/m

Insertions: main experiments

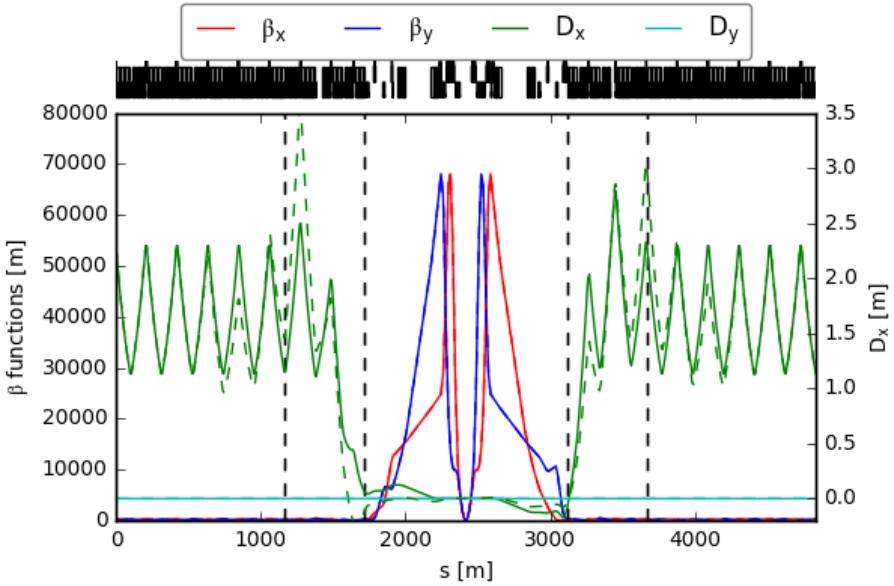
- Version 7 of the EIR.
- $L^* = 40$ m.
- BPMs and correctors have been integrated.
- Courtesy: R. Martin *et al.*.

→ **see Martin: "Overview of IR"**

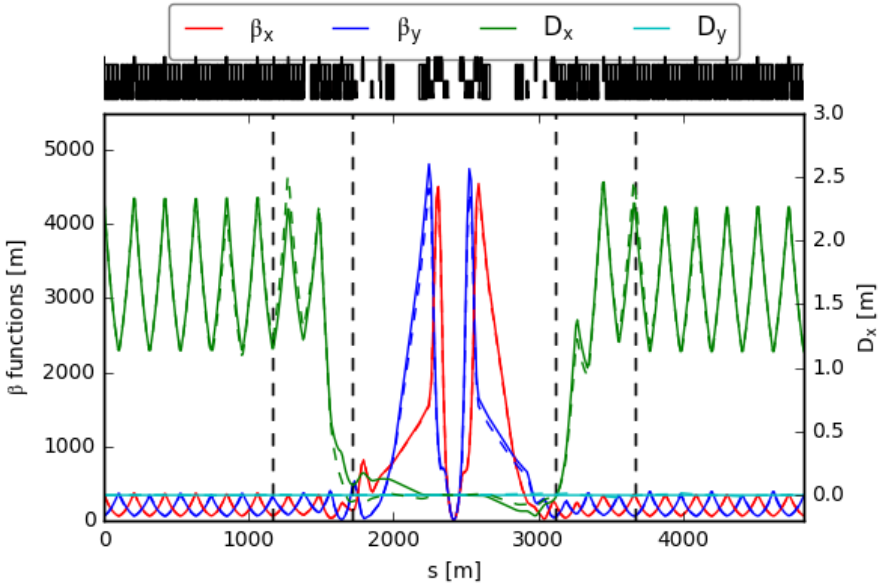
→ **see Van Riesen-Haupt: "Alternative IR for FCC-hh and HE-LHC IR"**

- 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 (ultimate ultimate)
  - 1.2 m/0.15 m (alternative flat beam)

$\beta^* = 0.3$ m baseline



$\beta^* = 4.6$ m baseline



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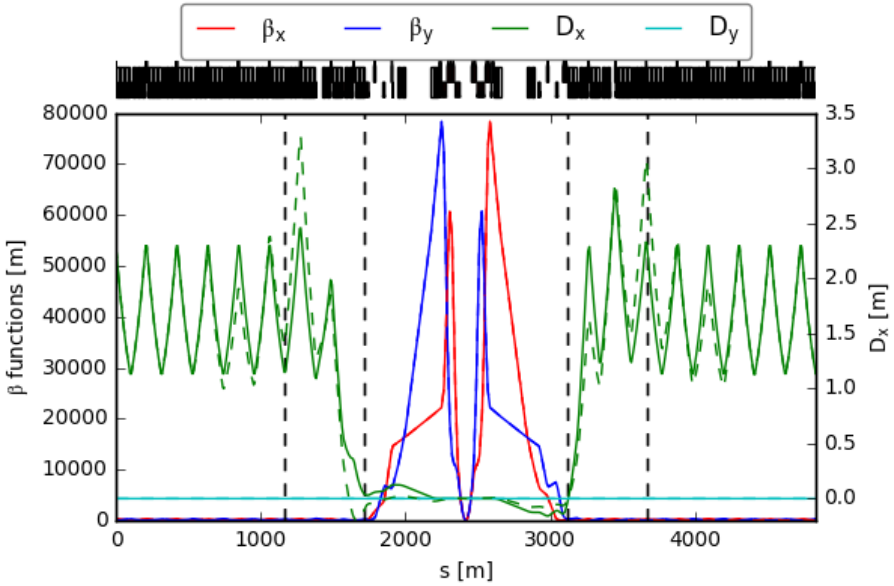
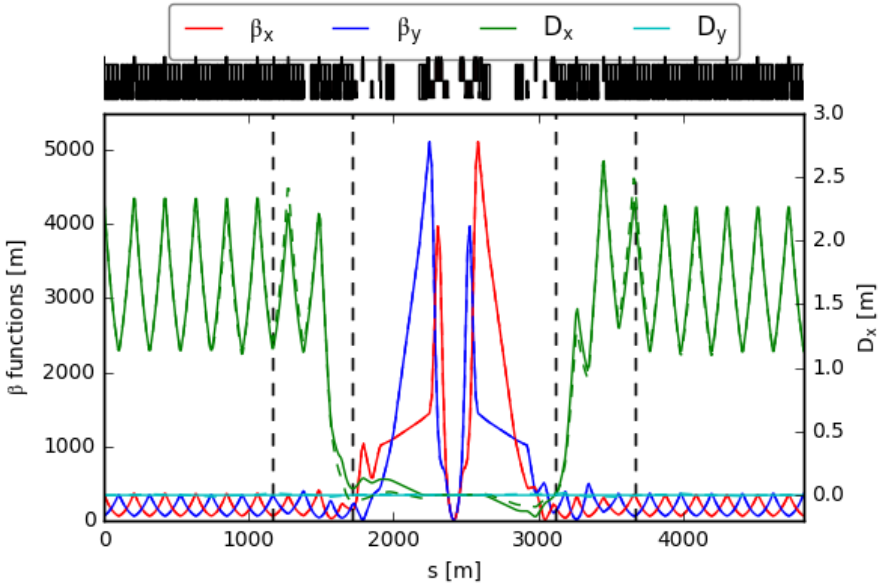
$\beta^* = 0.3$ m alternative



$\beta^* = 4.6$ m alternative

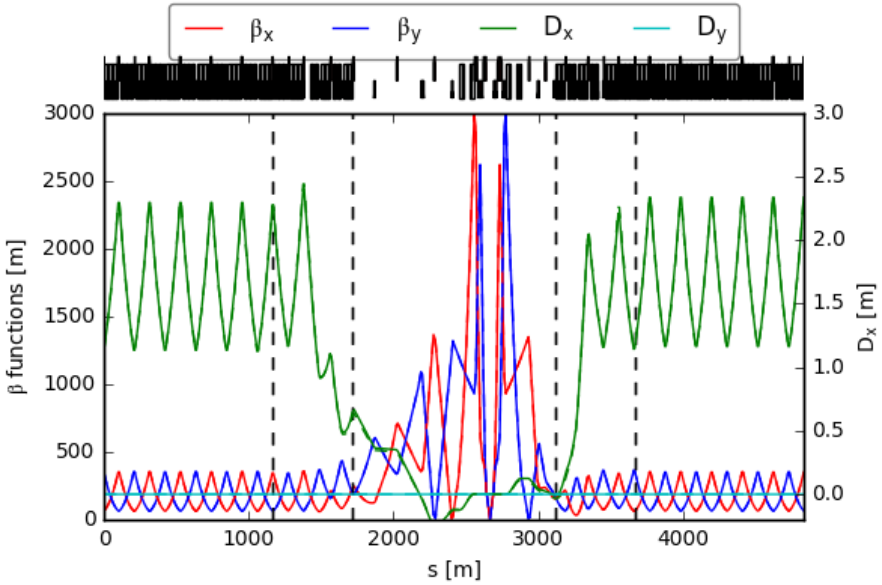


Insertions: injection + low-$\mathscr{L}$ experiment

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

- New version of the insertion implemented.
- Courtesy: M. Hofer *et al.*
- Considered β^*:
  - 27 m (injection)
  - 3 m (collision)

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



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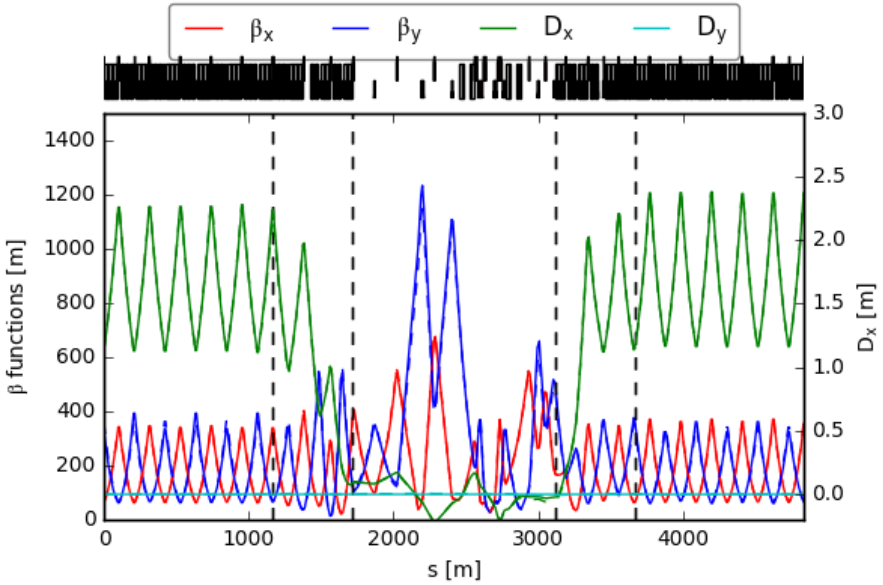

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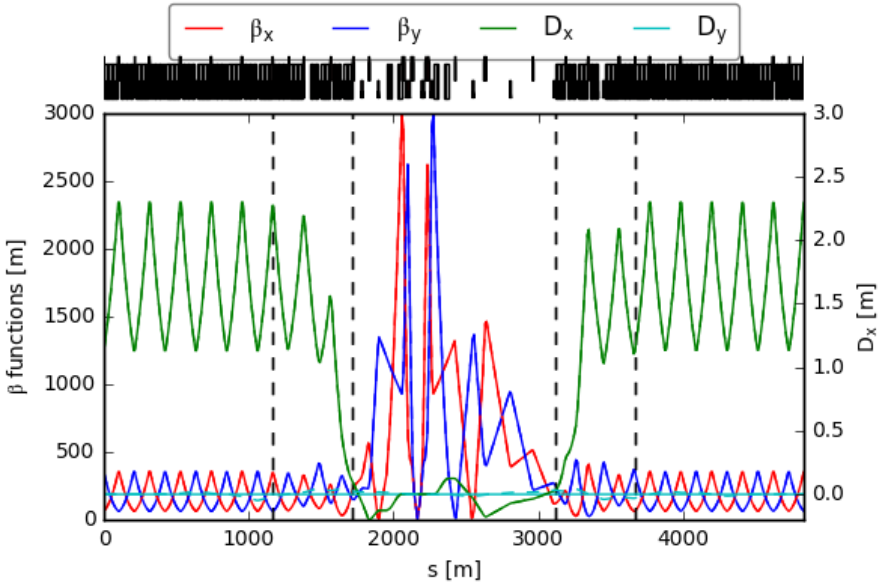
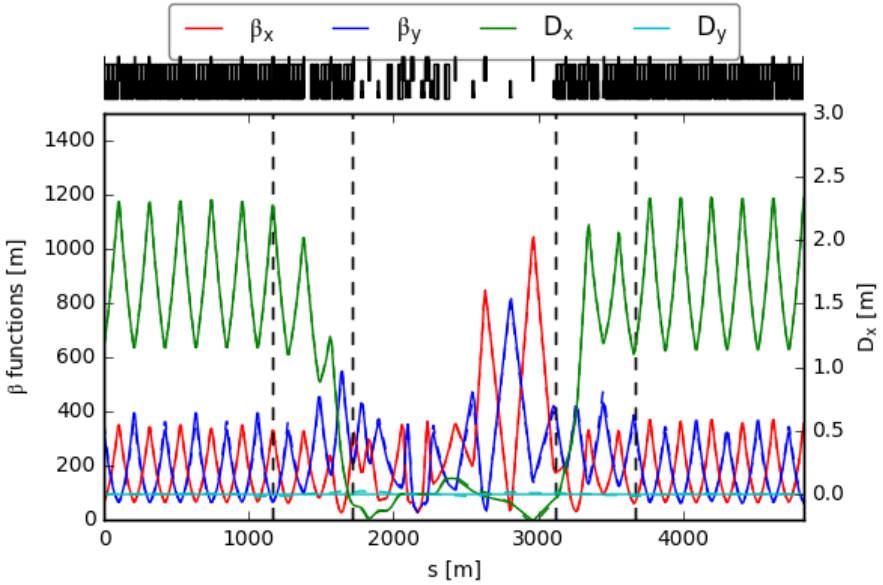
Inj.+Exp. section: LSS L (@ collision)



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



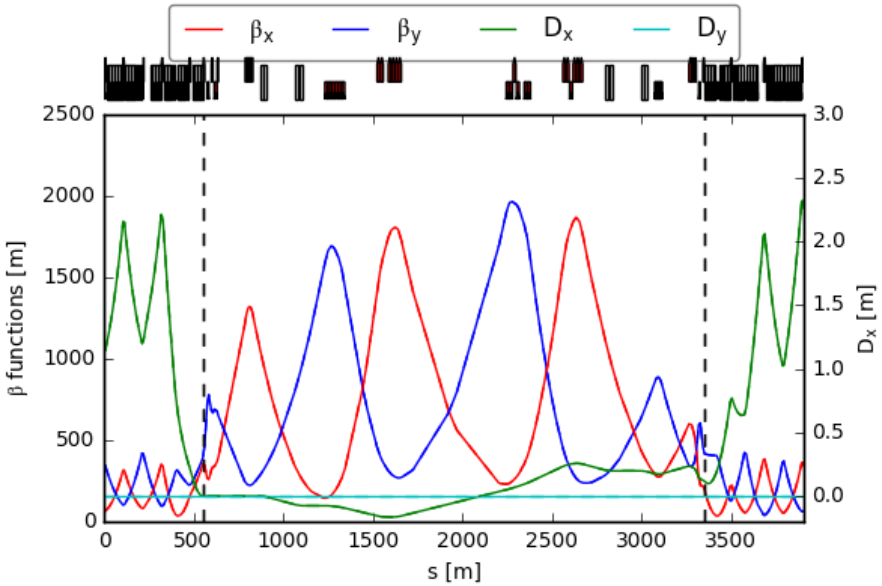
Insertions: collimation sections

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

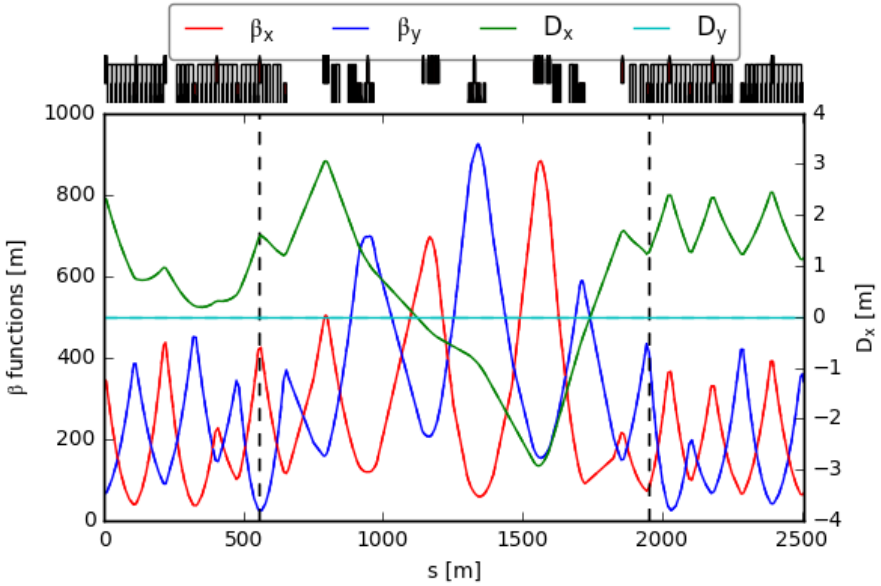
→ **see Molson:"FCC-hh collimation"**

- LHC-scaled δ-cleaning insertion
- Courtesy: J. Molson
- Enlarged dispersion (max: 3 m at collision, 4 m at injection).

β-cleaning section: ESS J



δ-cleaning section: LSS F collision



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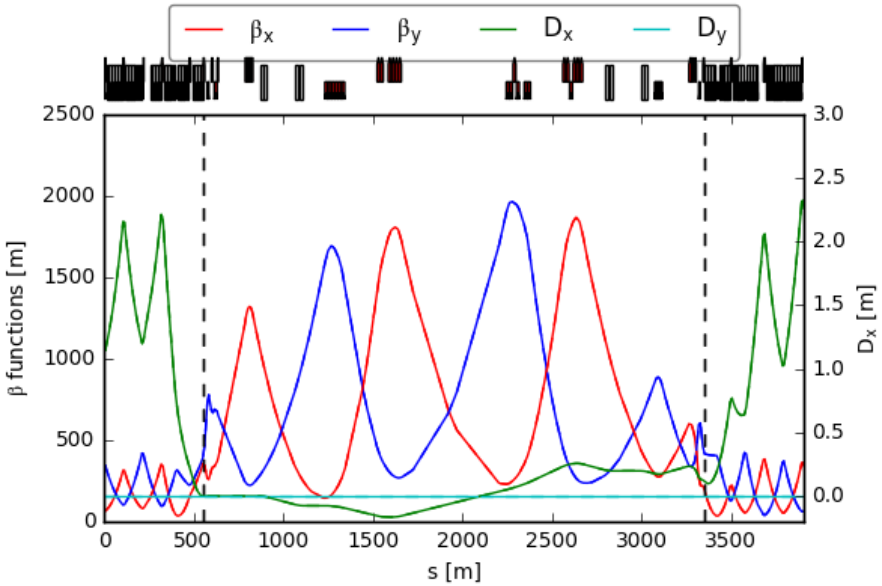
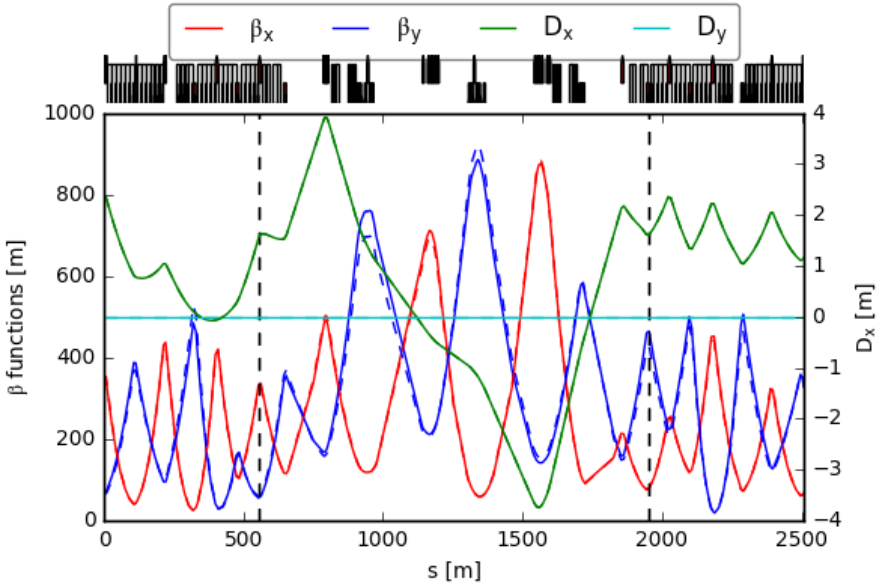


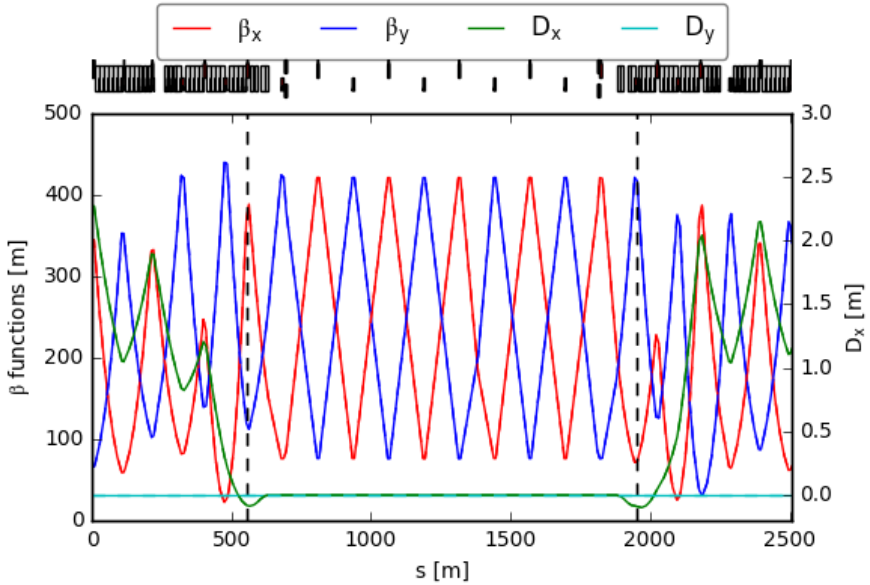
δ-cleaning section: LSS F injection



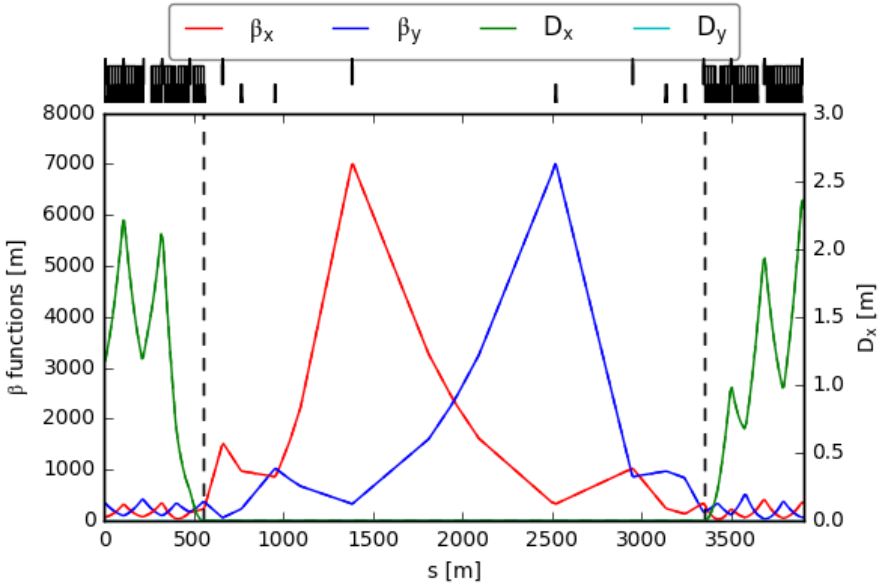
Insertions: RF+extraction

- RF section is made of FODO cells: it can be used to adjust phase advances between insertions.
- The lattice of this section has been implemented.
- Dedicated section for the extraction (2.8 km).
- New version of this insertion has been integrated.
- Courtesy: F. Burkart, W. Bartmann *et al.*

RF section: LSS H



Extraction section: ESS D



Tuning and correction

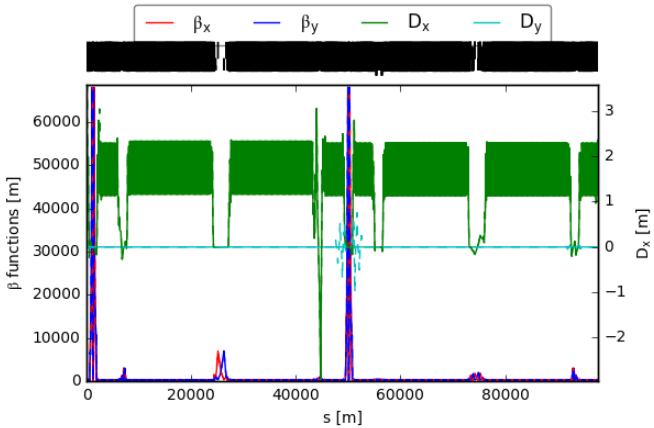
- 3 schemes are currently implemented to tune the ring:
  - FODO cells of long are slightly detuned ($90°+\epsilon$). DIS are rematched.
  - Use of phase trombones in insertions.
  - **Use of different phase advances in the long arcs** to tune the machine and phase advances between IPs (baseline).
- BPMs and dipole correctors are integrated in the lattice to correct the orbit. Additional BPMs in the IR 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.

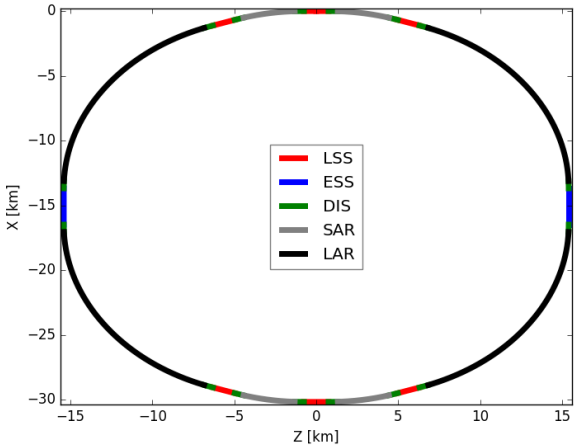
  → **see Boutin: "Correction scheme"**.
- The dynamic aperture studies have shown that:
  - b_3 (coll + injection) and b_5 (injection) correctors are mandatory.
  - b_4 does not need corrections

  → **see Dalena: "Dynamic aperture studies of FCC-hh at injection"**

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

Collision optics integration





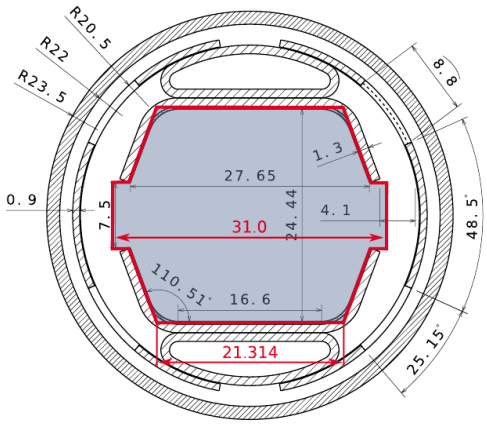
Parameters

Parameter		Value
Energy	TeV	50
Circumference	km	97.75
β^*	m	0.3
L^*	m	40
α	10^{-4}	1.035
γ_{tr}	-	98.31
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	**15.94**
MQ gradient	T/m	**319**
MS gradient	T/m^2	6997

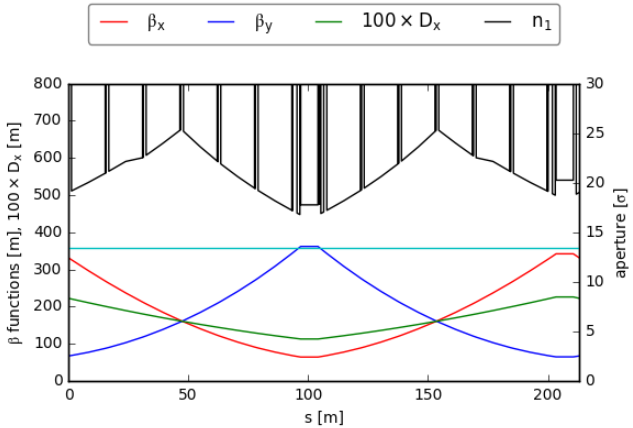
Arc aperture @ injection

- 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.

Courtesy: I. Bellafont *et al.*
Courtesy: R. Martin

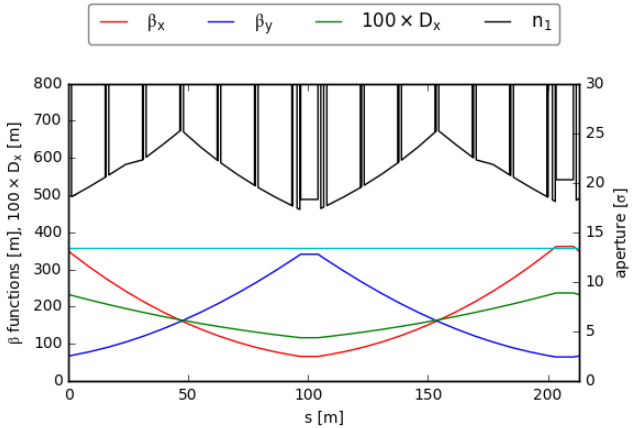


Arc AB: $b_2 = +20$



$n_{1,\min} = 16.8$

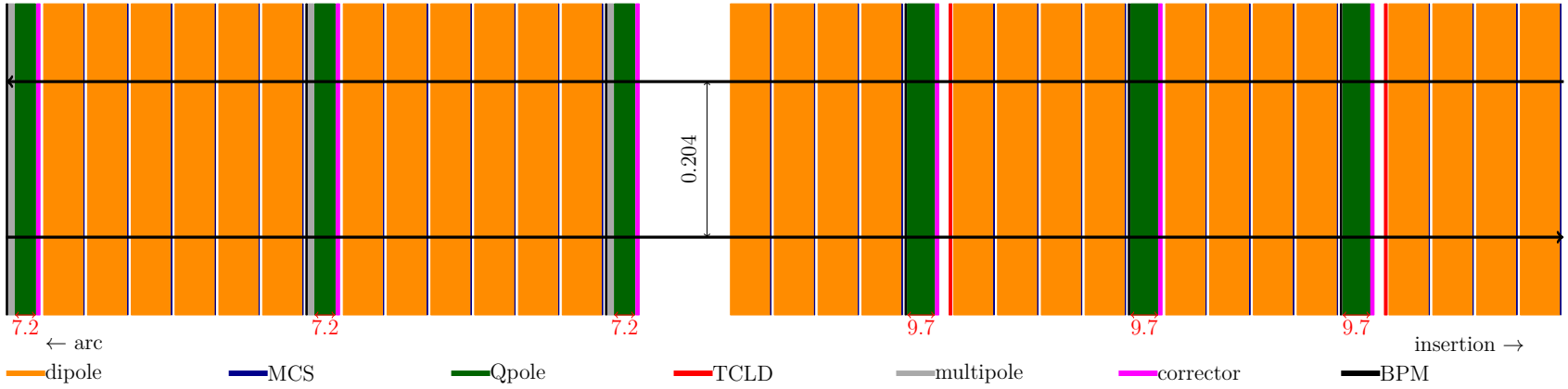
Arc BC: $b_2 = -20$



$n_{1,\min} = 17.3$

- Reduction of the beam-stay clear by 1.5σ because of the sagitta.
- **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.

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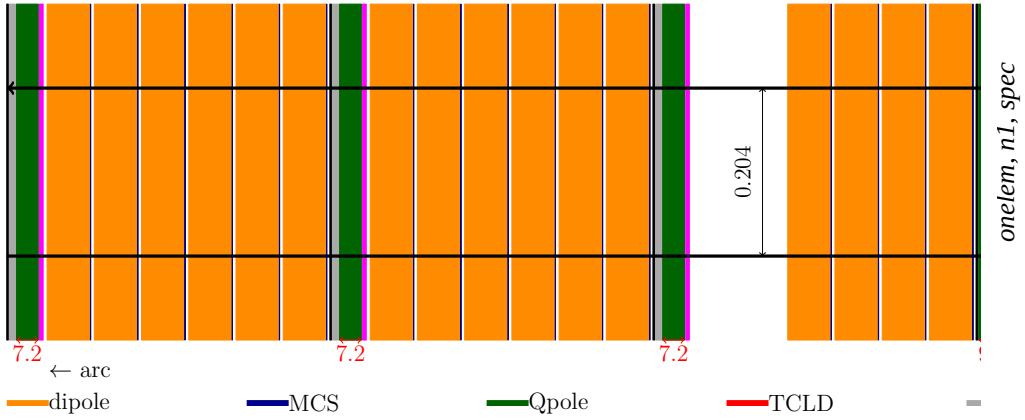

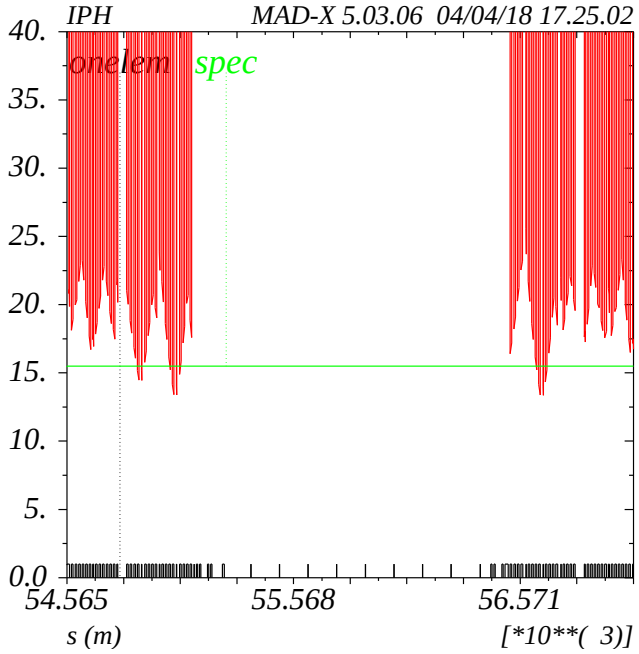

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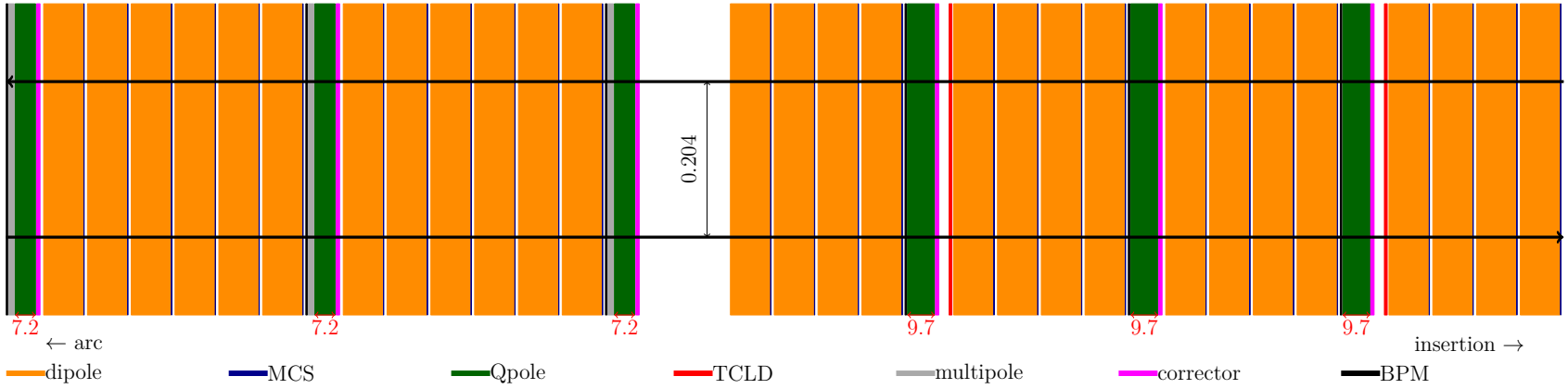

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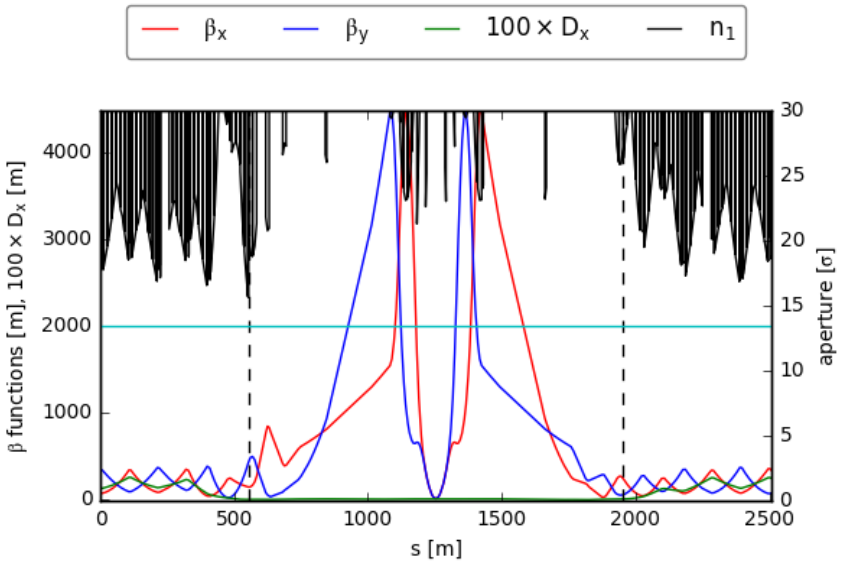
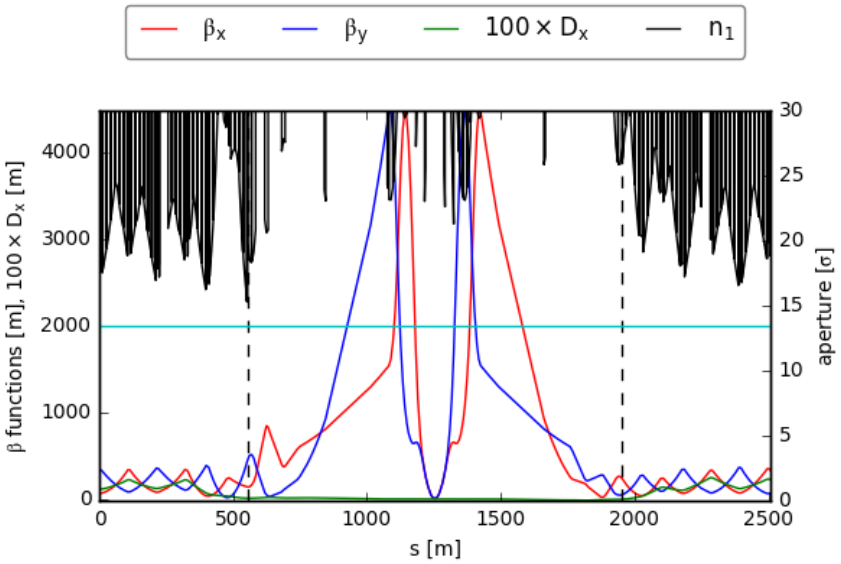
Interaction region aperture @ injection

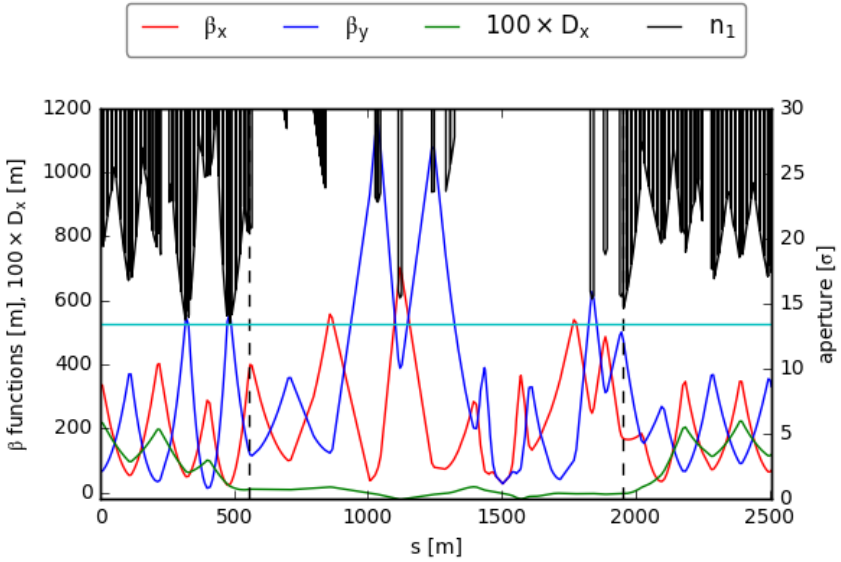
EIR: LSS A



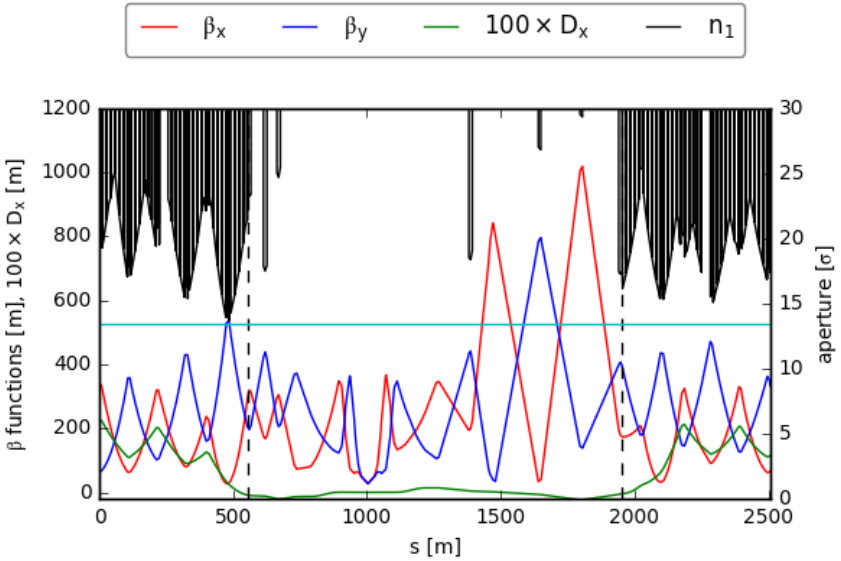
EIR: LSS G



Low-lumi + injection section: LSS B

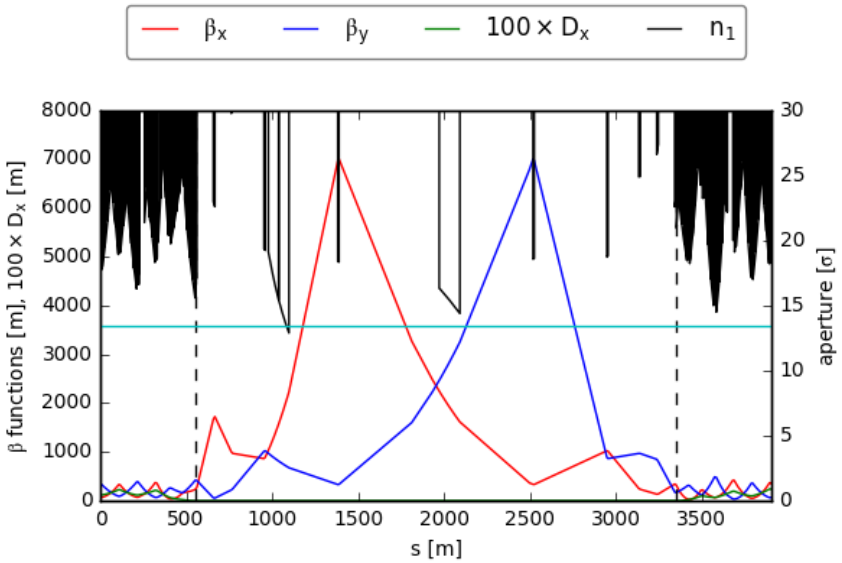


Low-lumi section: LSS L

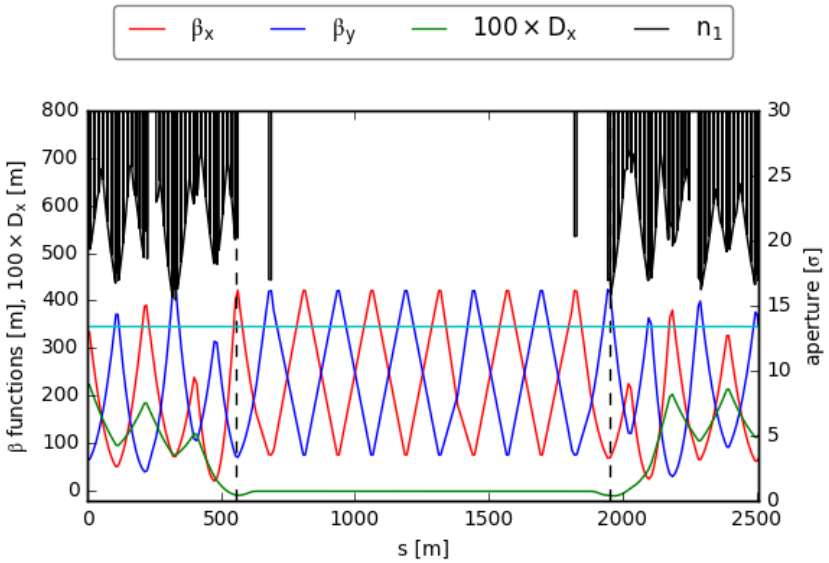


Insertions aperture @ injection

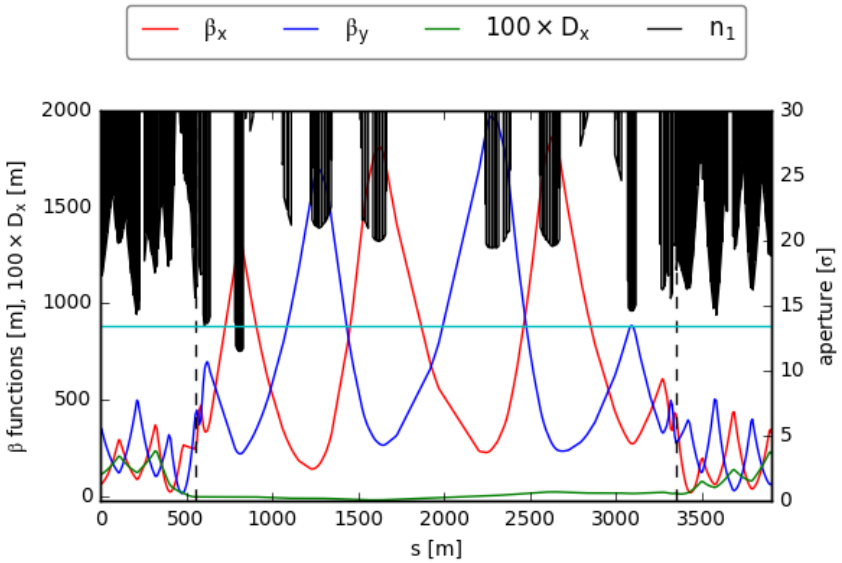
Extraction: ESS D



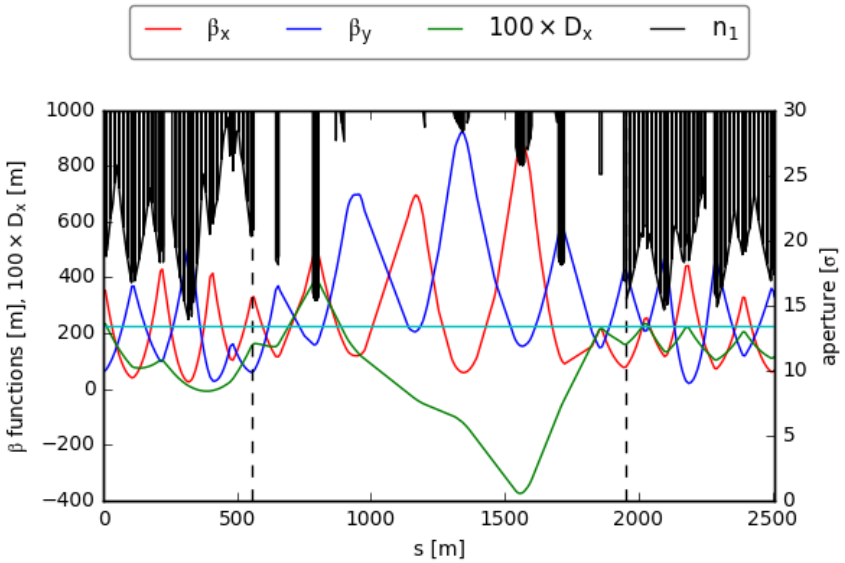
RF section: LSS H



β collimation: ESS J



δ collimation: LSS F



Summary

- New lattice has been presented:
  - b_2 is smaller in dipoles: 20 units at injection and 0 unit at collision.
  - Updated insertions: larger intra-beam separation in the insertions, larger dispersion in the δ collimation 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.

Next steps

- To check with collimation team that the new δ collimation insertion fits the expectations.
- To release on gitlab a new lattice (the last release is already obsolete).
- To finalize the magnet list: effort was focused on arcs. Collimation, extraction and RF insertions were not investigated as much.
- To integrate b_5 correctors.
- To consolidate the lattice files.
- CDR writing.
- CDR debugging.
- CDR checking.