Layout and Arcs lattice design

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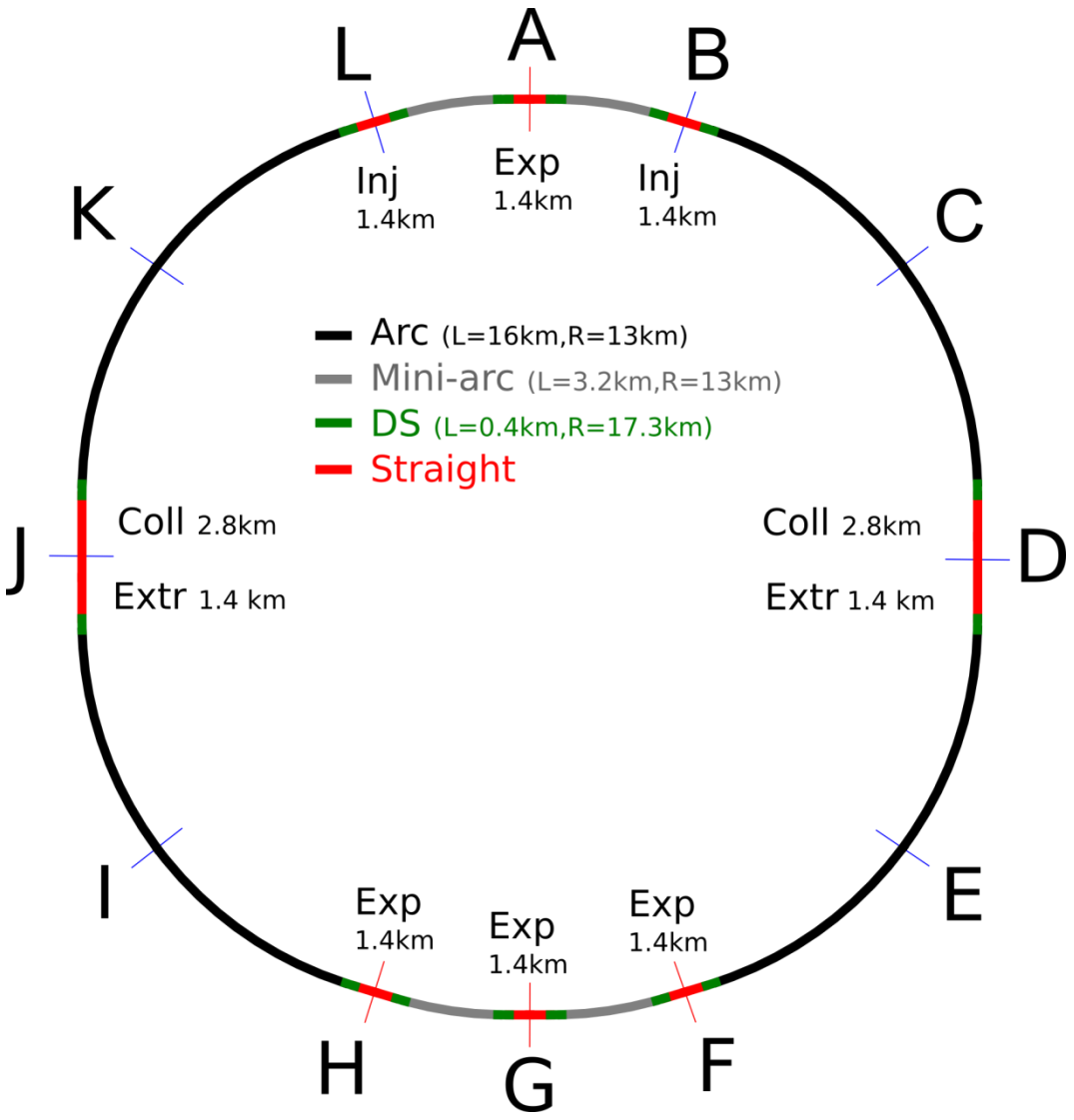
Outline

- General inputs
- Arc cell design
- Integration with insertions
- Sensitivity to layout and cell parameters
- Alternative layout
- Conclusion and Outlook

Layout and functional sections

First layout developed

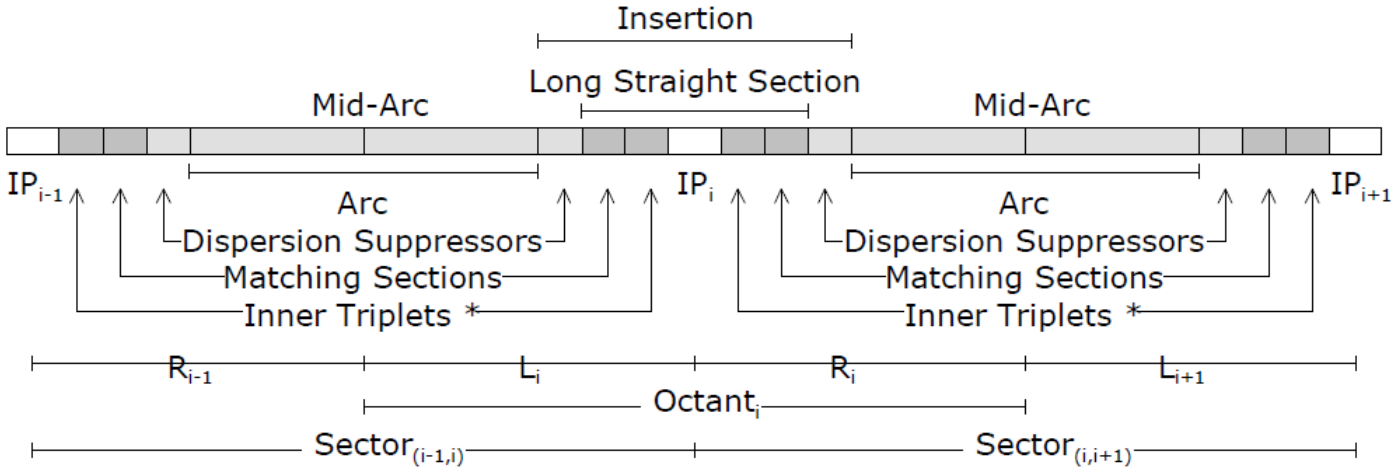
- Two high-luminosity experiments (A and G)
- Two other experiments (F and H)
- Two collimation lines
- Two injection and two extraction lines
- Insertion lengths are based on first order estimates, will be reviewed as optics designs are made



Sections and naming convention

Abbreviation	Generic name	Number	Length [km]
LSS	Long straight section	6	1.4
ESS	Extended straight section	2	4.2
TSS	Technical straight section	4	ε
DS	Dispersion suppressor	16	0.4
SARC	Short arc	4	3.2
LARC	Long arc	8	depends on total length

- A particular Functional Section has a name defined as:
  <generic abbreviation>-<Point or Sector identifier>(-<Order number>)
  Examples: LSS-A, ESS-D, DS-AB-1, DS-CD,…
- Numbering of the elements in the cells is the same of LHC:

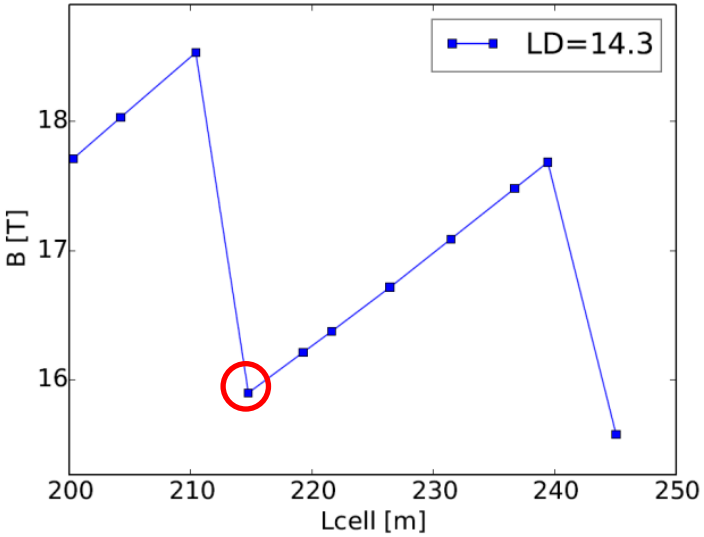


with i = A, i-1=L, i+1=B

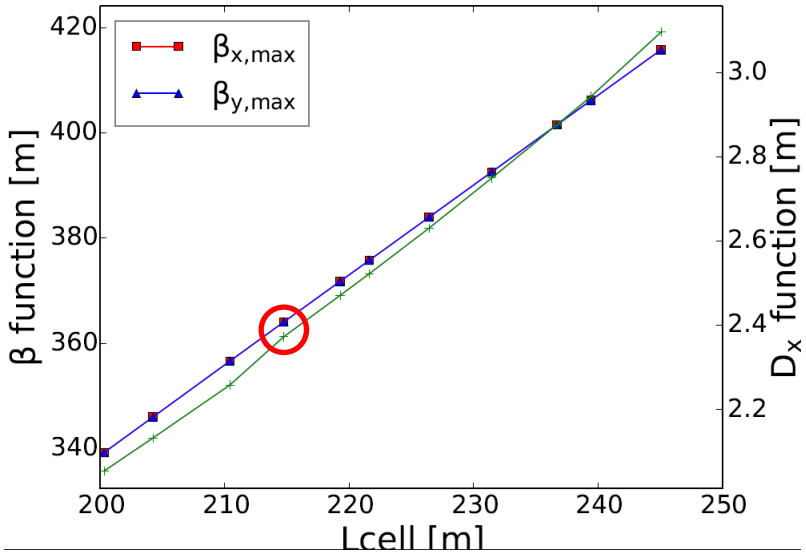
CELL PARAMETERS

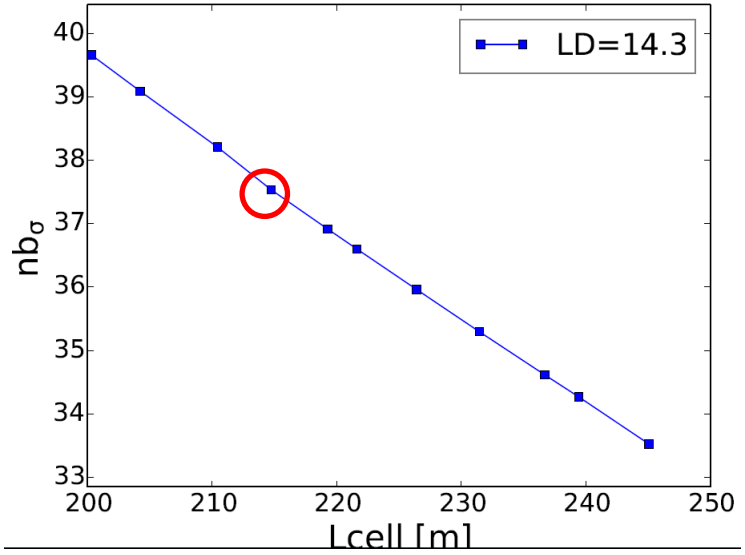
Input parameters:

- Minimum space between dipoles 1.36 m
- Dipole maximum field 16 T
- Dipole length 14.3 m
- Minimum space between quadrupole and dipoles 3.67 m
- Maximum gradient of the quadrupole 370 T/m
- ∅ = 50 mm, beam screen radius 20 mm
- Sextupole length 0.5 m
- Space between quadrupole and sextupole 1.0 m
- Phase advance per cell 90° x/y
- Circumference 3.75 × LHC ~ 100 km



# of sigma at E_{inj}=3. 3 TeV



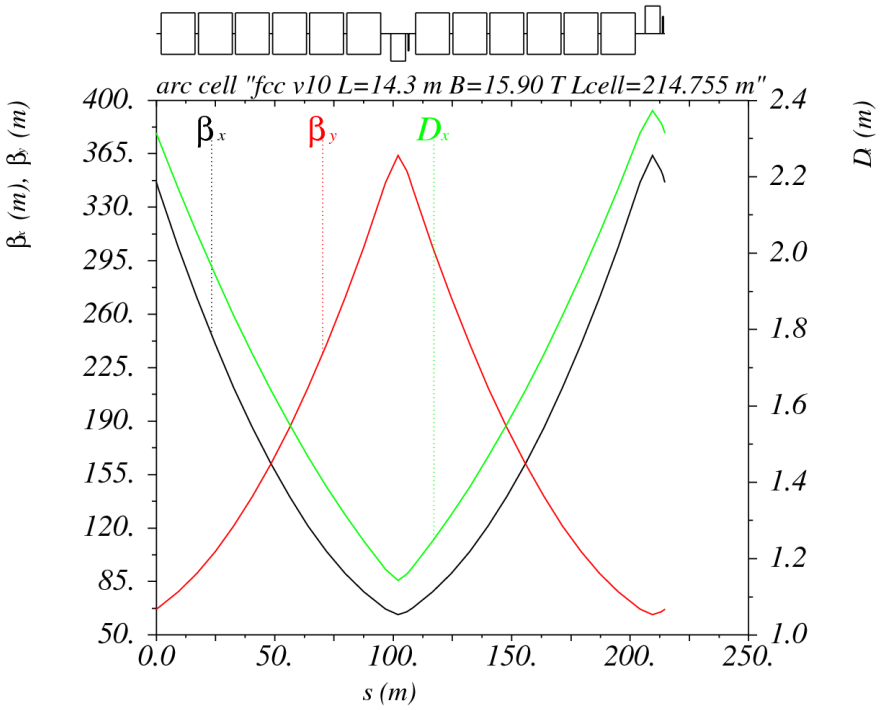


ARC CELL

# dipoles	B max [T]	Length [m]
4368	15.90	14.3

# quadrupoles	G max/min [T/m]	Length [m]
812*	356/-356.26	6.29

# sextupoles	G max/min [T/m^2]	Length [m]
700	-7144.37/ 3551.32	0.5 (fixed)



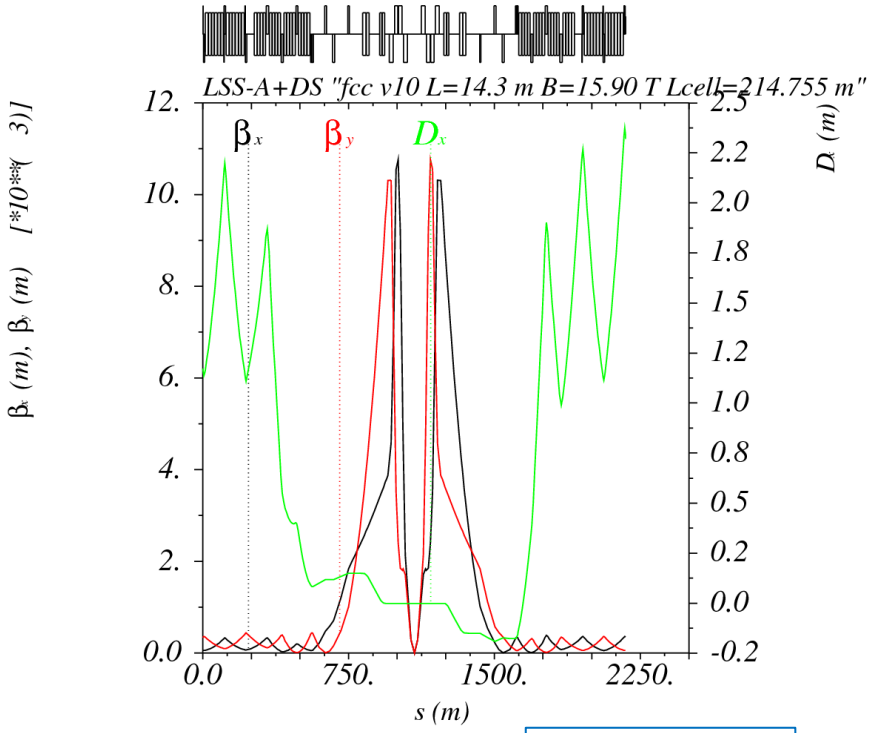
- quadrupole length results from the optimization

* the number of quadrupoles includes the quads in the dispersion suppressor

Integration of the Interaction Region and Dispersion Suppressor

# dipoles	B max [T]	Length [m]
16	15.90	13.50
4	12	12.5
4	10	15

# quad/ trim	G max/min [T/m]	Length [m]
4	355.40/-336.31	6.8
2	91.35/-58.29	9.6
16	-370/367.51	0.65
8	175.77/-46.87	2.64
4	220.30/-220.30	20.0
4	220.30/-220.30	17.5
2	95.58/-70.63	9.6
2	-91.77/70.58	6.8



Parameters:

- $\beta^* = 1.1$ m
- $L^* = 36$ m

R. Martin
R. Tomas
A. Seryi talk

Dispersion Suppressor (DS) LHC-like type

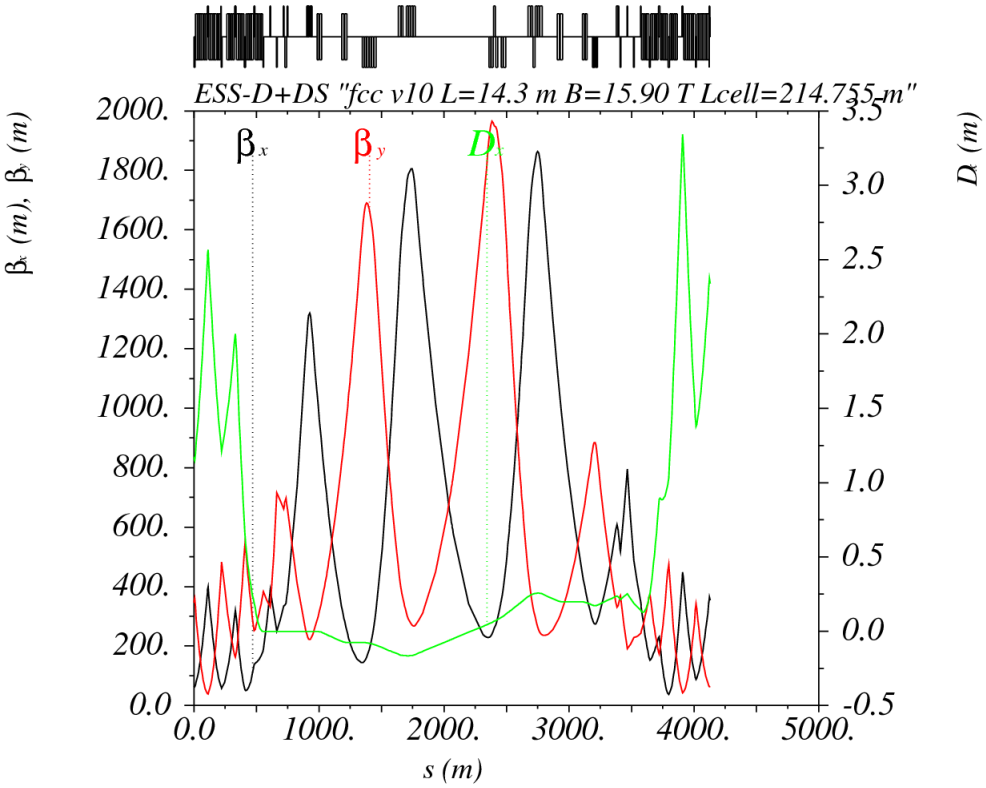
Integration of Betatron Collimation region

- additional matching section required

β_x/β_y=336.83/667.74

# dipoles	B max [T]	Length [m]
8	1.86	17.00

# quad	G max/min [T/m]	Length [m]
16	-369.11/ 354.79	9.74
8	-286.30/240.32	11.77
12	21.83/ -19.08	6.5
2	18.9/ -9.60	6.5
20	8.91/-8.91	15.54
4	2.21/-0.21	15.54

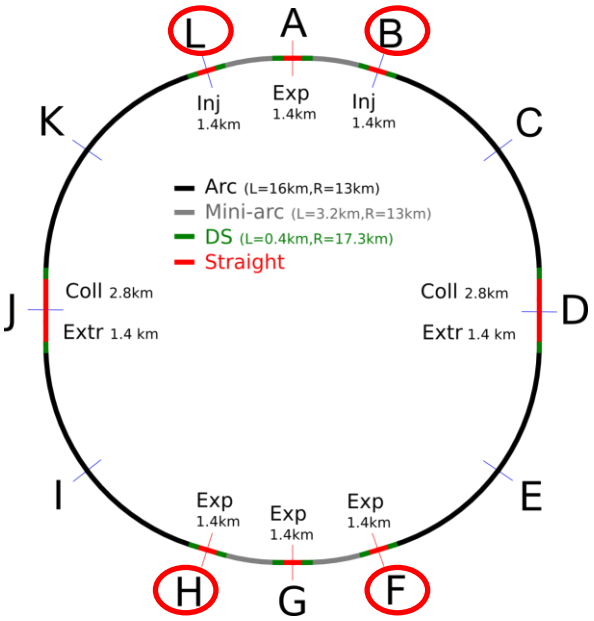


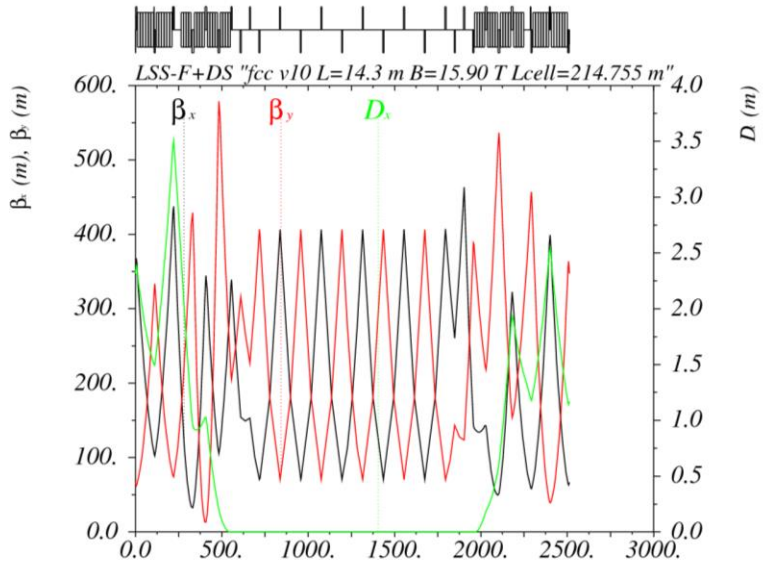
R. Tomas
M. Fiascaris talk

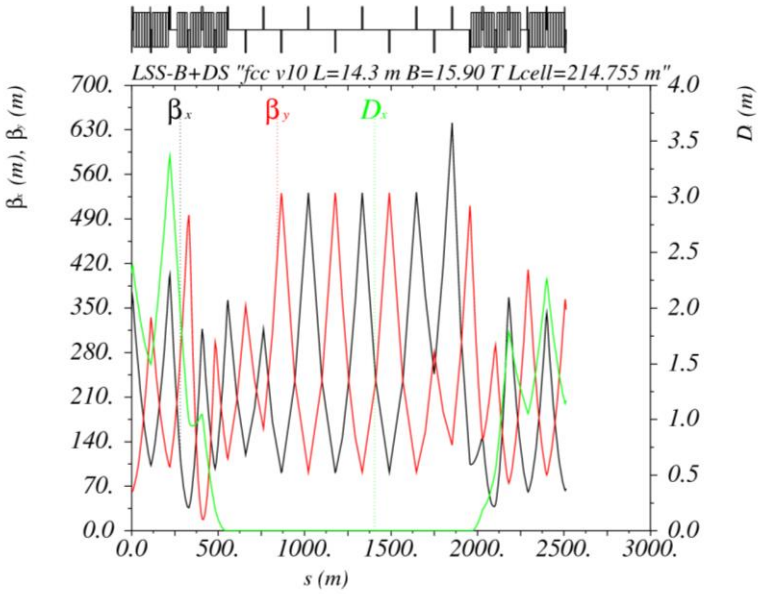
Other 2 Interaction and Injection Regions

No input for the moment:

- Simple FODO cells. The length of the FODO cells is adjusted to have a length of 1.4 km.
- In the injection section, the spacing between the quadrupoles has been enlarged to enable the injection (**W. Bartmann**).

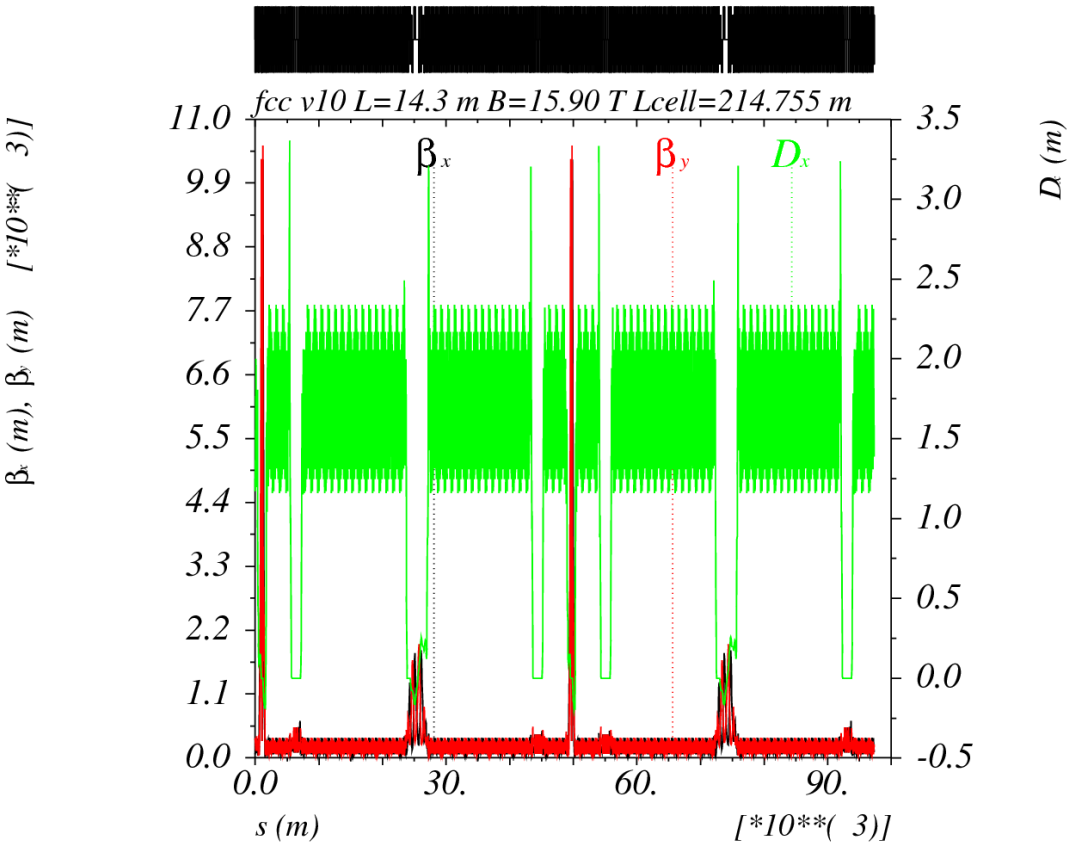






Some Lattice parameters

Parameter	value
Bρ [T m]	166667
γ	53289
$\gamma_{transition}$	97
α	0.0001
β* [m]	1.1
Natural chromaticity x/y	-196./-197.
Equilibrium emittance* [m rad]	1e-12
$\varepsilon_{norm}/\beta\gamma$ [m rad]	4.1e-11
Transverse/Longitudinal Damping time** [h]	2/1



* $\varepsilon_{eq} = \frac{C_q \gamma^2 I_5}{\left(I_2\left(1-\frac{I_4}{I_2}\right)\right)}$

** $\tau_t = \frac{2E_0T_0}{U_0} \quad \tau_l = \frac{2E_0T_0}{U_0\left(2+\frac{I_4}{I_2}\right)}$

Sensitivity to the parameters and layout choices

The present baseline layout and optics is based on:

- scaling lows from LHC
- possibility to re-use the know how and R&D developed for the LHC to handle the construction and maintenance of the different elements

What we can gain or lose by changing some parameters ?

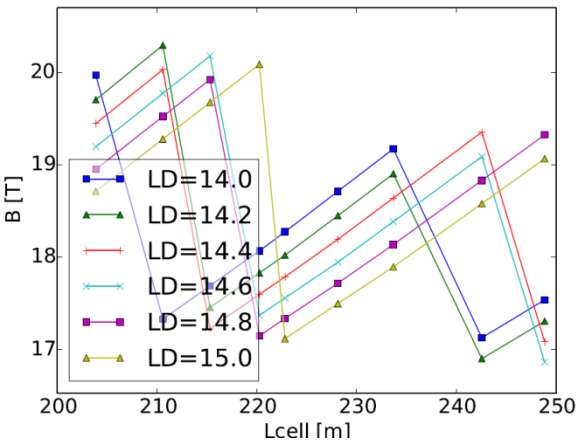
- circumference of the “roundracetrack” : 3.5 , 3.75 and 4.0 times LHC
- dispersion suppressor types
- cell parameters

In the following:

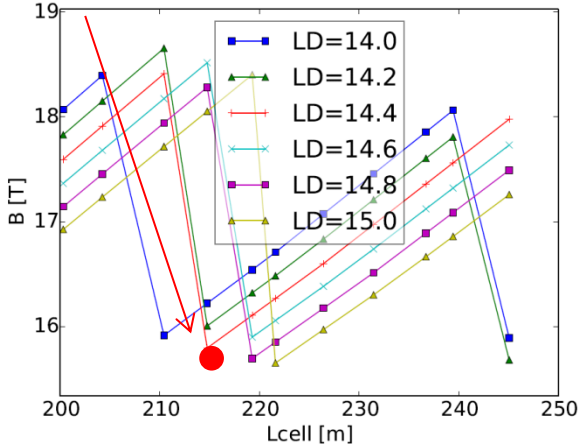
- The reference energy for the protons is 50 TeV
- LD = dipole length
- Lcell = cell length
- nb_σ = number of RMS beam sizes (aperture) at injection energy

Circumference

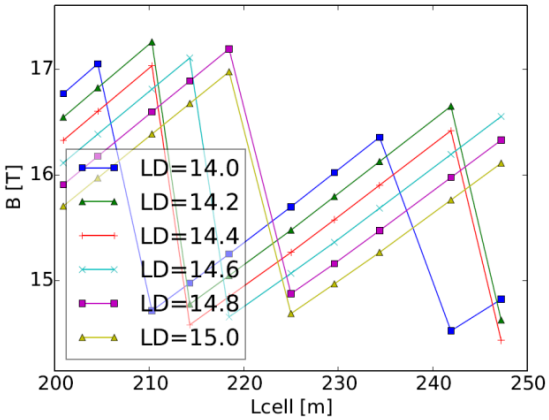
Baseline



93.45 km

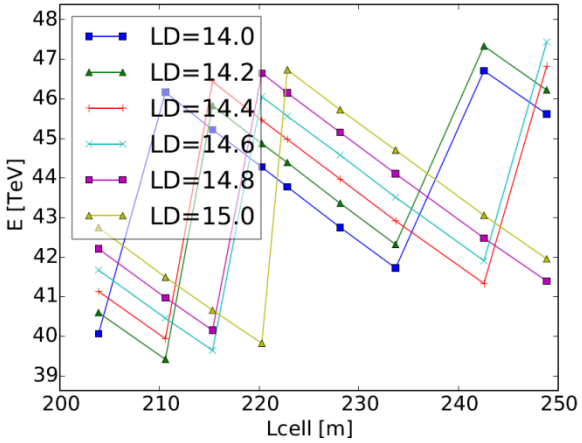


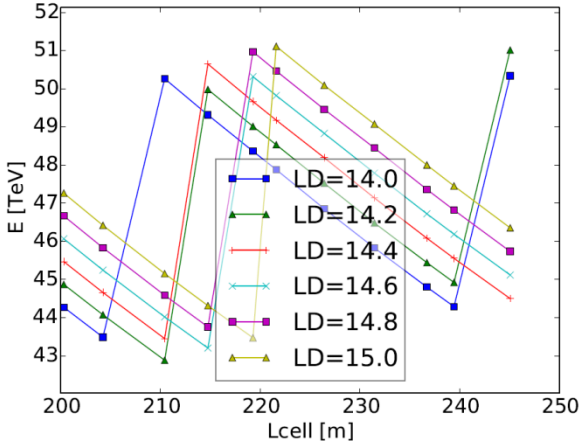
100.12 km

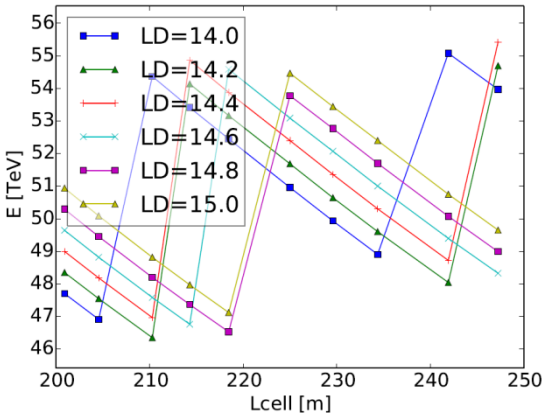


106.80 km

Proton energy reachable for a maximum field of 16 T



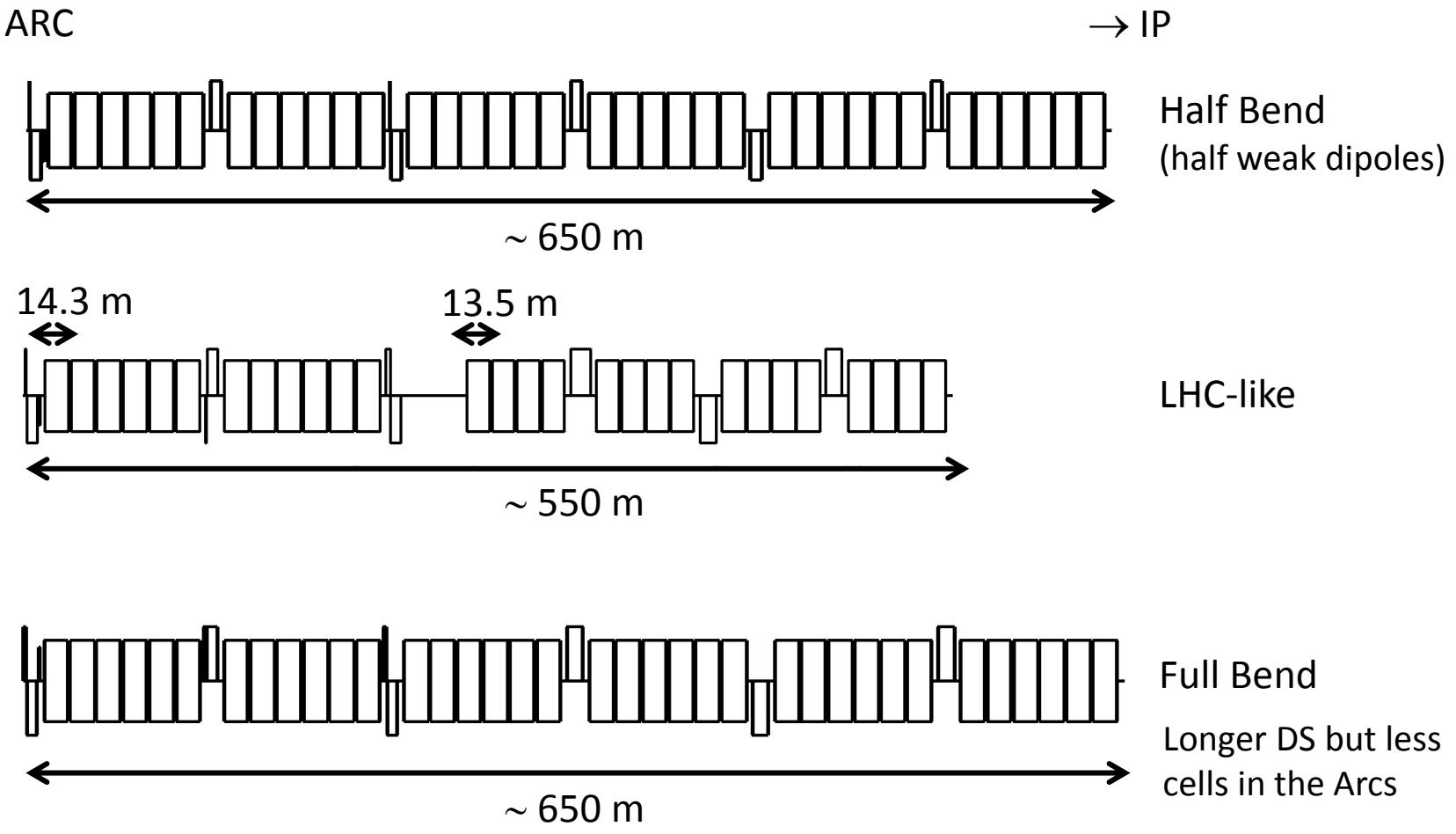




$\Rightarrow$ 3.5 $\times$ LHC: no solution found with a dipole field of 16T for 100 TeV c.m. energy

$\Rightarrow$ 4.0 $\times$ LHC: 9% lower dipole field but 6% longer machine with respect to 3.75 $\times$ LHC

Dispersion Suppressor (DS) types



Half Bend
(half weak dipoles)

LHC-like

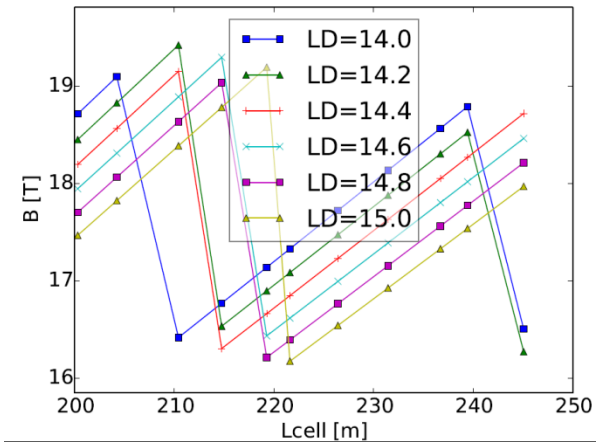
Full Bend

Longer DS but less cells in the Arcs

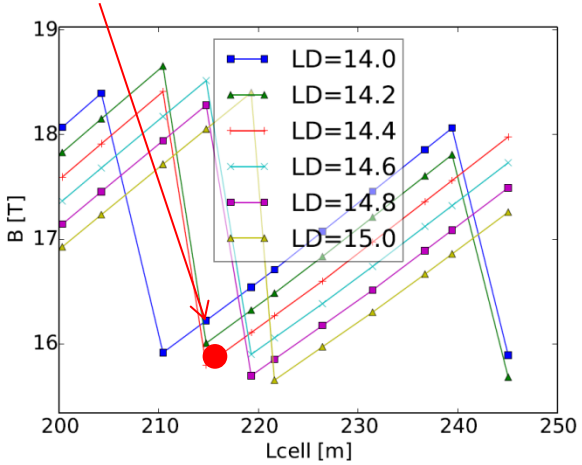
Dispersion Suppressor and dipole Field

Circumference = 100.12 km

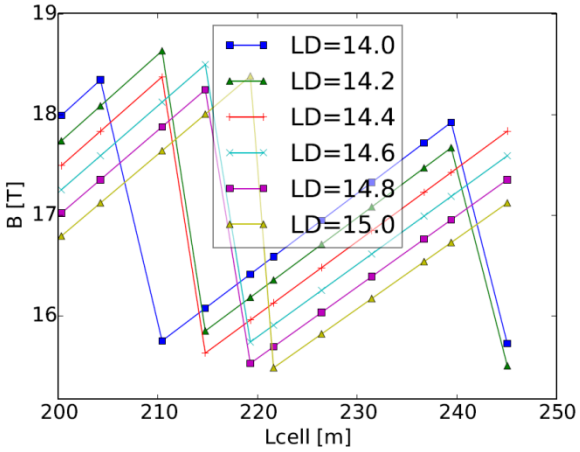
Half Bend



baseline LHC-like



Full Bend



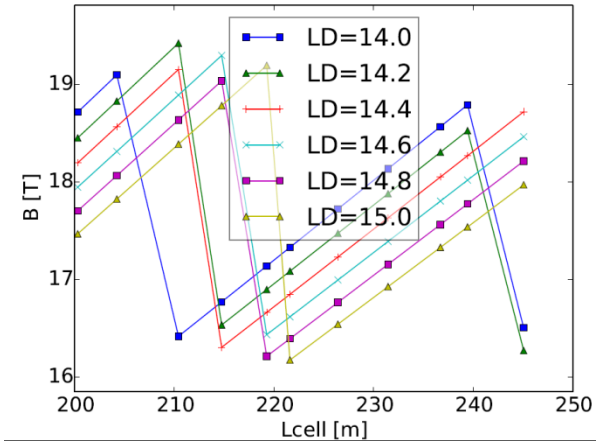
⇒ Full Bend DS: ~1% lower dipole field with respect to LHC-like DS

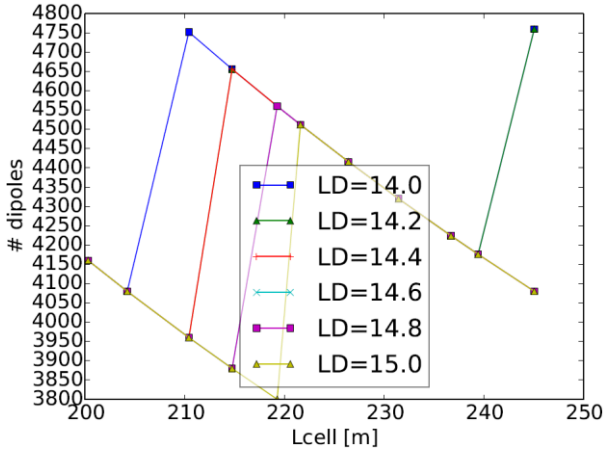
⇒ Half Bend DS: no solution below 16 T

Dispersion Suppressor types & dipoles

Circumference = 100.12 km

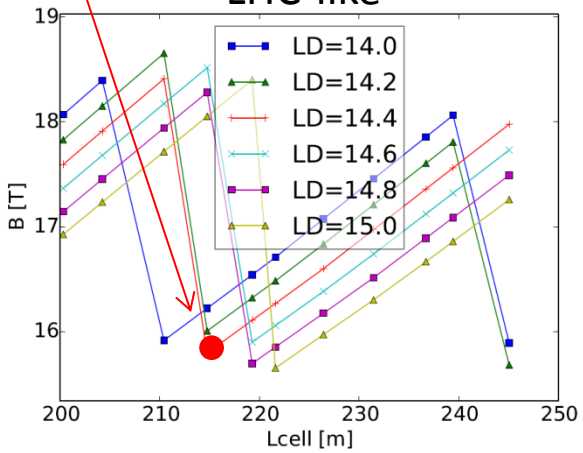
Half Bend

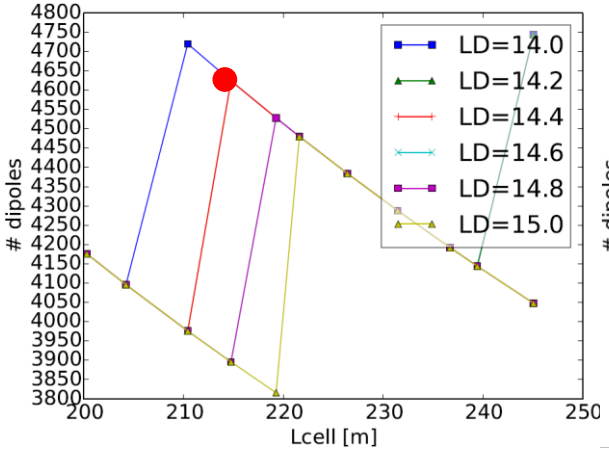




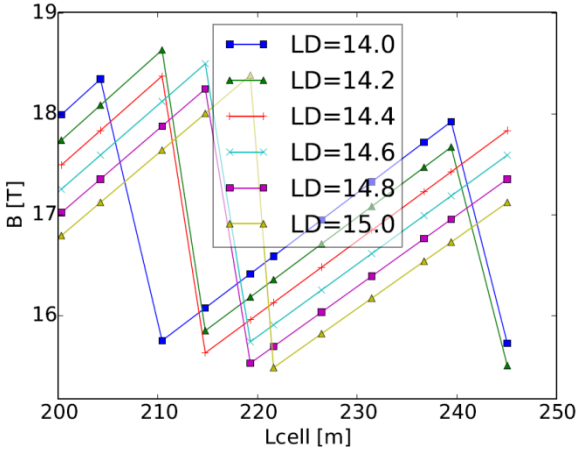
Baseline

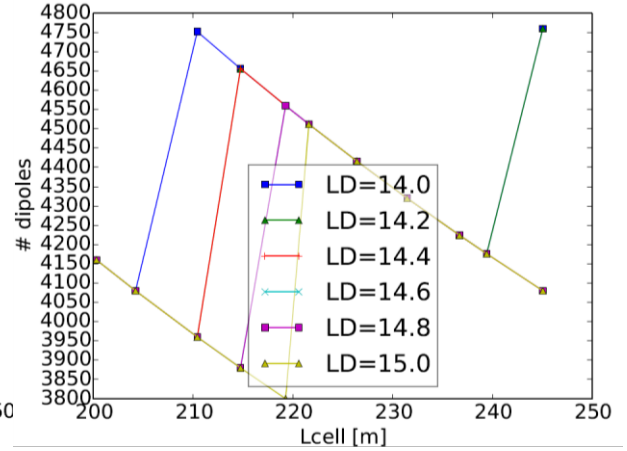
LHC-like





Full Bend



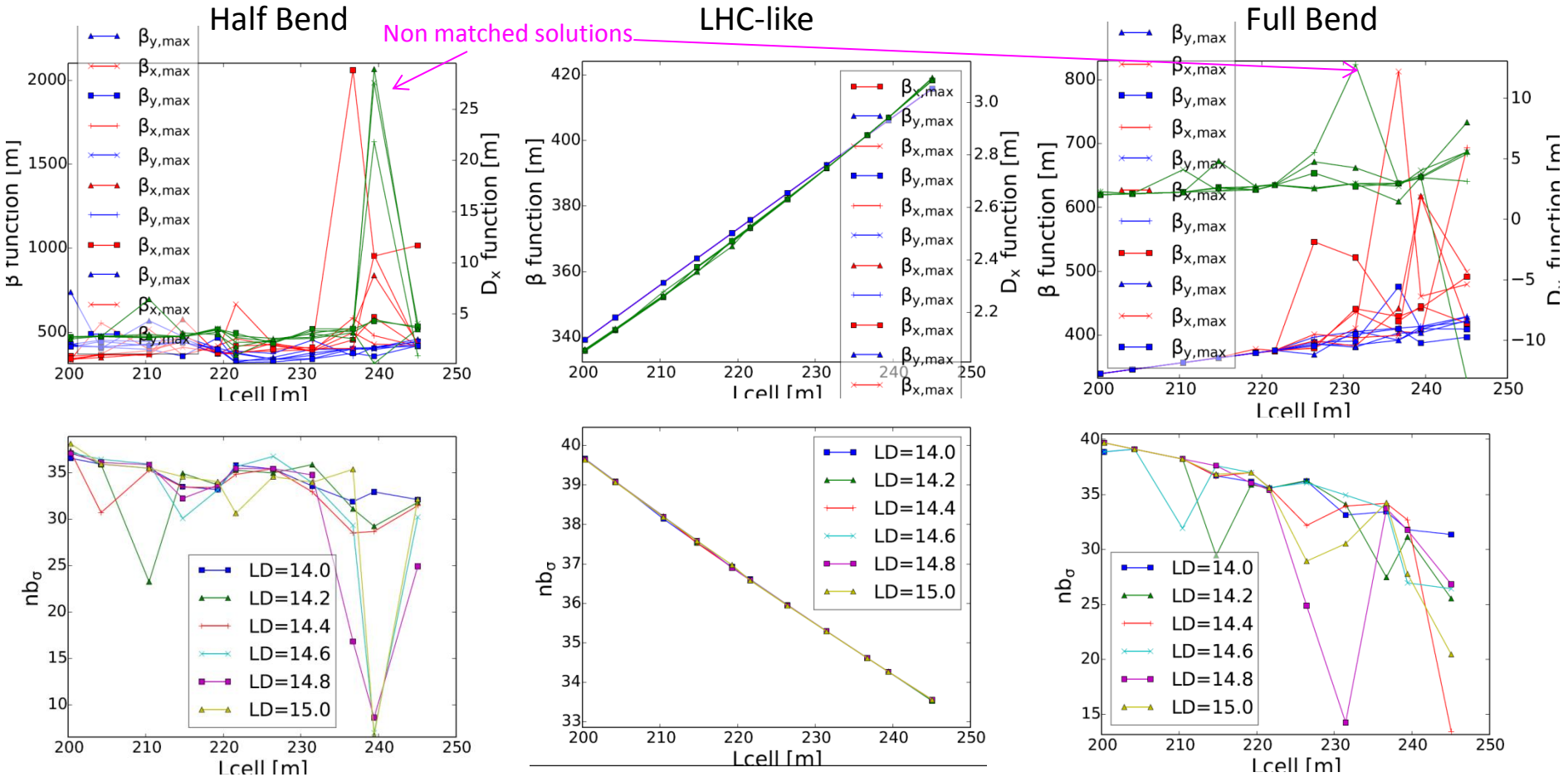


⇒ LHC-like DS has 32 less dipoles (and two different lengths) with respect to Full Bend DS

⇒ Full Bend DS has 1% lower dipole field with respect to LHC-like

Dispersion suppressor types & optics

Circumference = 100.12 km, beam screen radius = 20 mm



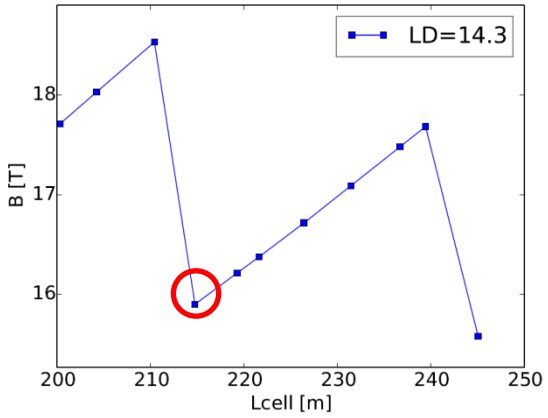
⇒ Lcell ~215 m good for optics functions and number of sigma of the beam

⇒ LHC-like DS easiest to match to the insertions

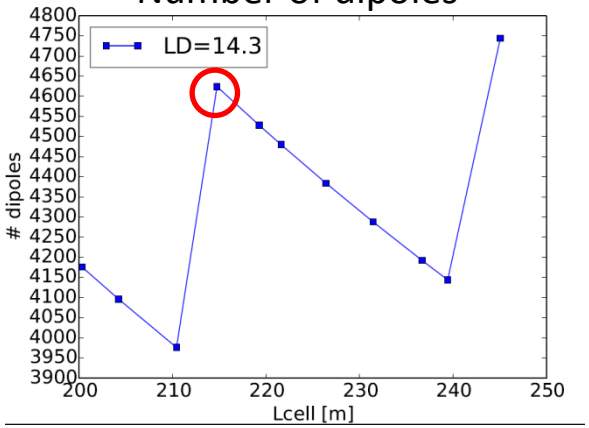
Closer look to dipoles and cells length

Circumference = 100.12 km, beam screen radius = 20 mm, LHC-like dispersion suppressor

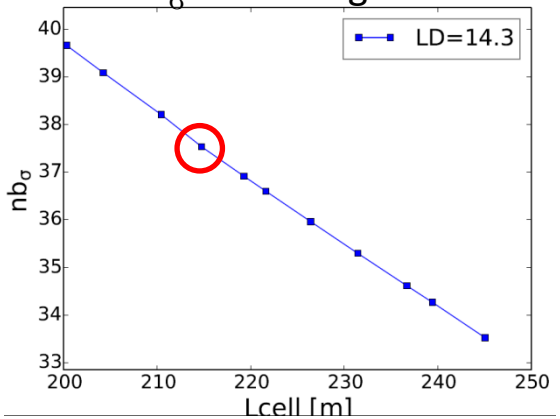
B field [T]

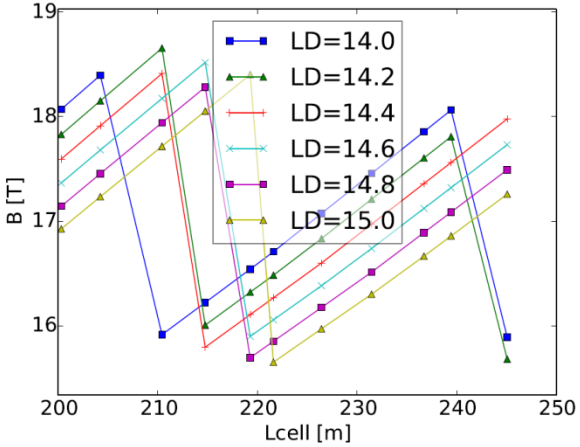


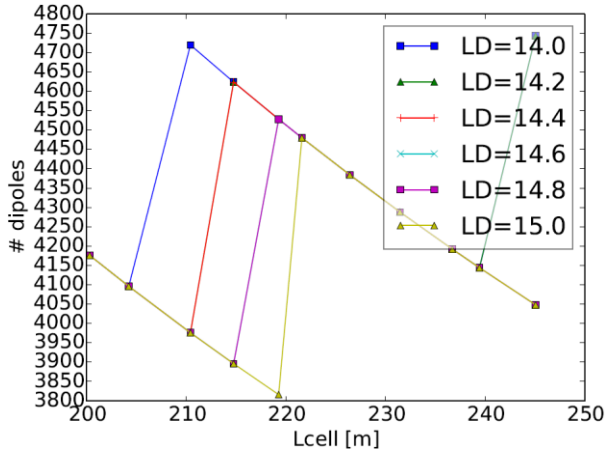
Number of dipoles

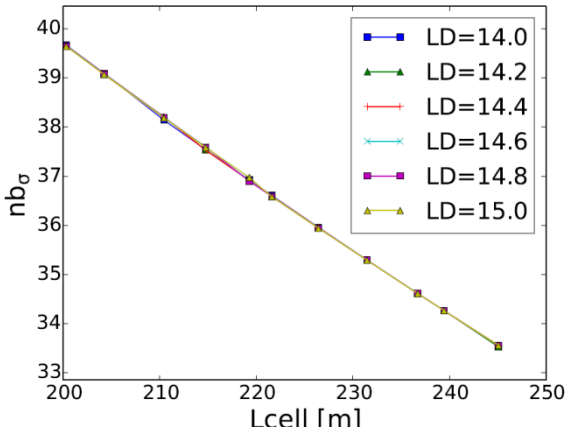


nb_σ = cell length







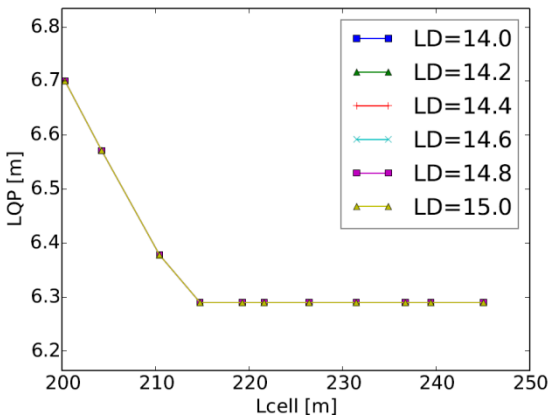


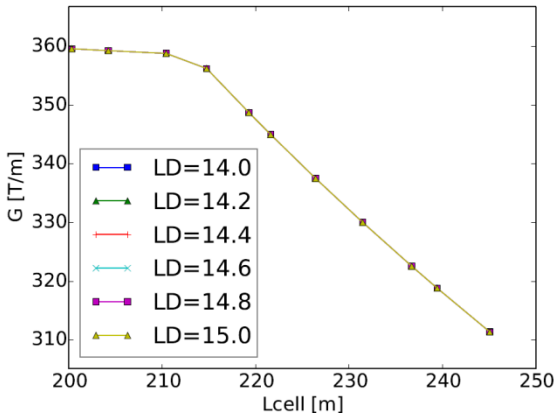
⇒ LD =[14.0 : 14.3] m and Lcell=245 m ~2% of dipole field is saved, losing ~15% of beam sigma and having 2.5-4% more dipoles

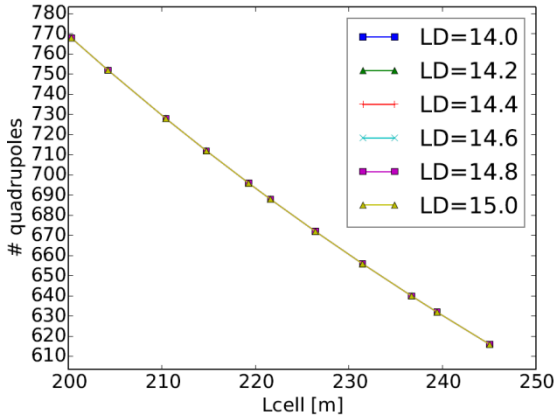
⇒ LD =14.8 m and Lcell=219 m ~3% of dipoles and 1% of dipole field can be saved, losing ~3% of beam sigma

Quadrupoles and cell length

Circumference = 100.12 km, beam screen radius = 20 mm, LHC-like dispersion suppressor

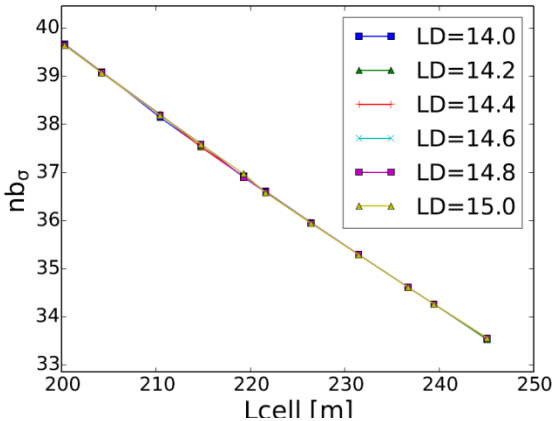




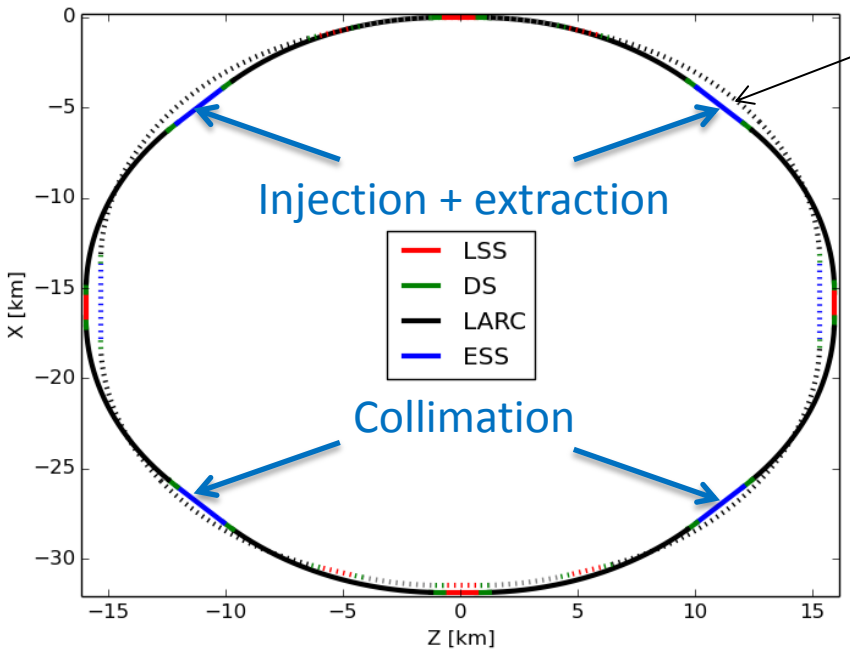


⇒ Lcell = 245 m: quads have same length as Lcell=215 m

⇒ Lcell = 245 m: 14% quadrupole gradient and 20% of quadrupoles can be saved, losing ~15% of beam sigma



Alternative to the baseline



- We have now 4 extended straight sections of 2.8 km (against 2 of 4.2 km in the baseline) and 4 long straight sections of 1.4 km (against 6 in the baseline)
- The extraction section is moved from the section where the collimation occurs to the section where the injection is located

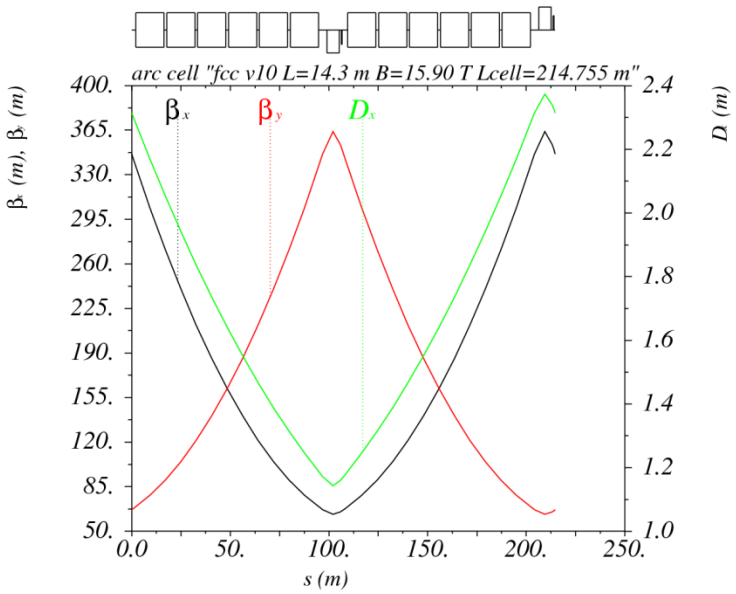
Pros	Cons
More regular layout.	Light modification of the layout.
The 2 additional IPs are separated by a diameter: good for synchronism.	Injection transfer lines might be longer.
Same number of DS as in the baseline.	More arcs but shorter (a pro if the TSS are not needed)

Optics of the Alternative

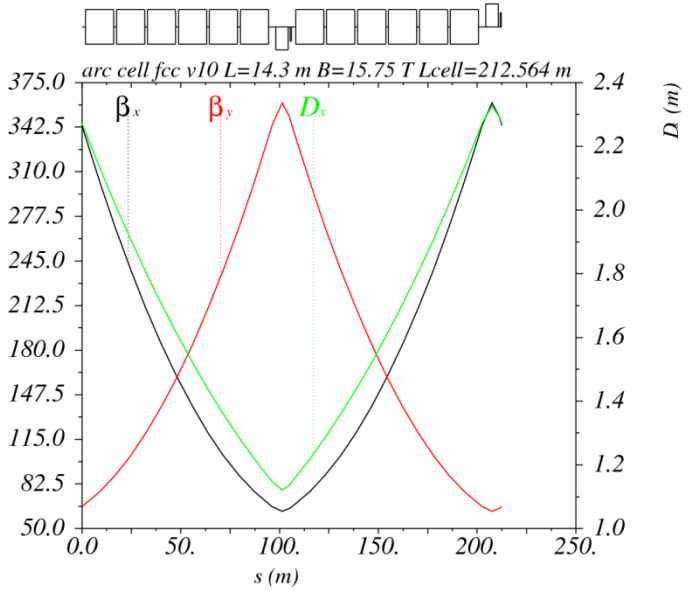
– The optical functions for this alternative are similar to the baseline optical functions.

Example in the case of a 100.12k-km-long ring:

Baseline



Alternative



– The first order optics can be computed for the baseline and directly applied to this alternative thanks to the modularity of MAD-X.

Conclusion

- A **first order** baseline **optics** for the FCC-hh arcs is computed taking into account general layout considerations and cell parameters constraints, for 100.12 km ring
- The **integration of the insertions** (IRs, Collimation, Injection, Extraction) started

$\Rightarrow$ madx files are in: http://fccr.web.cern.ch/FCCr/hh/LATTICE_V4/Baseline

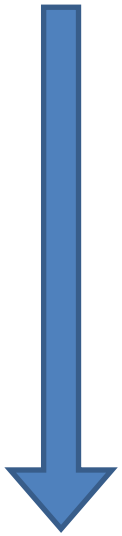
- There is a bit of **margin in** the **cell parameters choices** (cell and dipole lengths)
- Type of **dispersion suppressor** ? (Half Bend is not an option)

- In the case of 93.45 km ring and for 16T dipole field the center-of-mass energy is likely to decrease

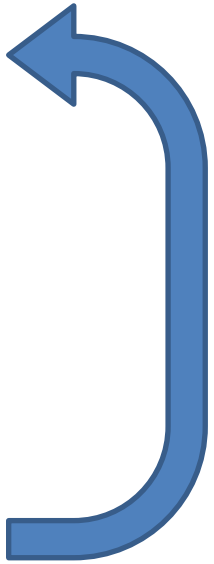
- An alternative layout is also investigated

$\Rightarrow$ madx files are in: http://fccr.web.cern.ch/FCCr/hh/LATTICE_V4/Alternative

Outlook



- Integration of the other insertions and other systems
- Integration of quadrupole trims for tune scanning
- Chromaticity
- Dynamic aperture and magnet tolerance study
- Eventually re-optimize the arc design



- Alternative layout

SPARES