Plans for lattice design and integration work

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Preliminary thoughs for a lattice design

- Type of lattice for the arcs?
  - FODO lattice with phase advance of 90°
    - Compact lattice.
    - Number of elements minimized.
    - Good ratio β_{max}/L_{cell}.
    - Sextupole compensation every 2 cells.
  - Cell length to be optimized.
- Quadrupole in Nb_3Sn or NbTi?
  - Nb_3Sn: More compact.
  - NbTi: Less development and less risky but longer quadrupoles.
- Racetrack or sector ring?.
- Dispersion-free insertions ($\approx$ 600 m w/o a dispersion suppressor).
  - Length for the low beta insertion (interface with WP3).
  - Length for the other insertions (collimation, RF, extraction, ...).
- Dispersion suppressor.
  - 2 FODO cells with half dipoles.
  - At the interface with WP3 (matching of the quadrupoles).

Optimization of the cell length

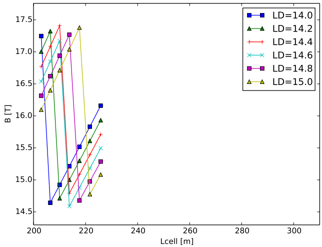
- We had a very similar (although a bit different) approach (see Bernhard's presentation and note).
- We have varied the cell length and compared the performances of the lattice (fill factor, dipole field, Twiss functions, ...)
- A python script was written to generate and run MADX input files for different configurations.
  - Easy to generate the lattice (thanks to a dedicated class).
  - Easy to access to lattice properties.
- Constraints put in the python script:
  - The **total circumference is fixed**.
  - The length of the dispersion suppressor and of the insertions (except low beta) is a multiple of the cell length.
  - The spacing quadrupole/dipole is adjusted (above a given value) to get the cell length.
  - When the quadrupole gradient is greater than a limit value, the quadrupole length is changed to reduce the gradient.

Input values

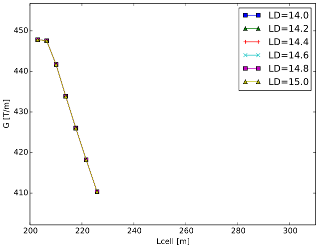
We used the same values as in Bernhard's note.

Injection energy	3.3 TeV
Energy spread	10^{-4} (?)
Total Circumference	100 km
Range for cell length	200-300 m
Maximum gradient	450/200 (Nb_3Sn/NbTi) T/m
Minimum QPole length	5.17 Tm
Dipole length	14-15 m
Aperture radius	20 mm
Low beta length (w/o disp. supp.)	950.5 m
Insertion length (w/o disp. supp.)	416/950.5 (ring/racetrack) m
Allowed variation insertion length	±10 %
Dipole spacing	1.36 m
Spacing between dipole/QPole	3.45 m

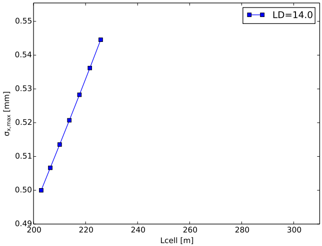
Dipole field vs cell length



QPole gradient vs cell length

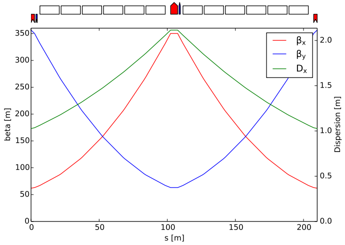


Beam size vs cell length

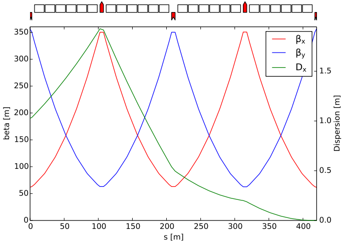


- The bump in dipole fields corresponds to a change of the dipole number per cell.
- Quadrupole gradient too high for cell length below 200 m.
- Few solutions to have an integer number of cells in the insertions.

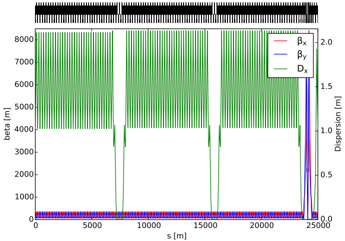
Arc FODO lattice



Dispersion suppressor



Quarter of the FCC ring (25 km)



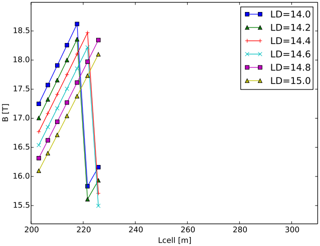
- 5016 dipoles of 14.2 m and 14.7 T.
- The cell length is 210 m.
- $\beta_{x,\max} = 350.2$ m,
  $\beta_{y,\max} = 356.5$ m
- $D_{x,\max} = 2.11$ m

Quid of NbTi quadripoles ?

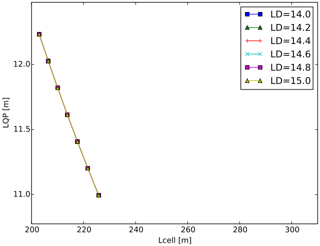
- The needed length for NbTi QPoles is about twice the one for Nb_3Sn QPoles.
- The total QPole length is increased by 10 m per cell.
- The total dipole length is decreased by 10 m per cell.
- For a cell of 200 m, the total dipole length is decreased by 5%.
- The dipole field is increased by 5%.
- For 16 T dipoles, the field dipole should increase by +0.8 T.
- The shorter the cell length is, the more interesting it is to use Nb_3Sn QPoles.

Results for a ring with 12 sectors (NbTi)

Dipole field vs cell length



QPole length vs cell length



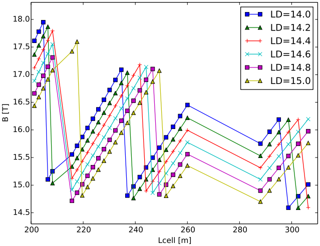
- The quadrupole length must be more than 10 m.

⇒ Must they be splitted in two?

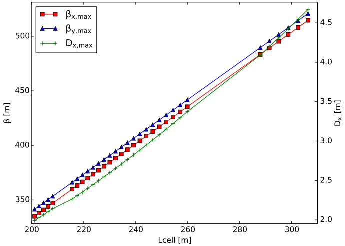
- As expected, the dipole field is increased by about 0.8 T compared to the Nb_3Sn case.

Results for a racetrack (Nb_3Sn)

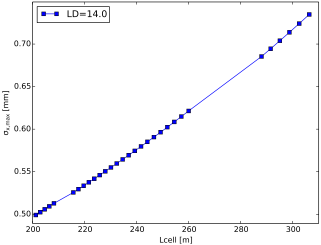
Dipole field vs cell length



Optical functions vs cell length

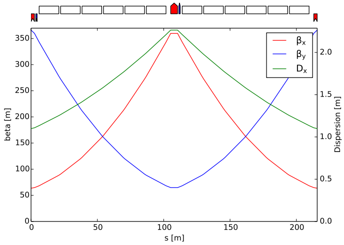


Beam size vs cell length

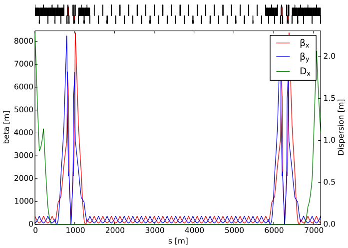


- More solutions for the cell length.
- The beam size is more than 20 σ for an aperture radius of 20 mm.
- No real gain on the dipole field for cells longer than 250 m.
- Shorter cells are better to reduce the beam size (lower β).

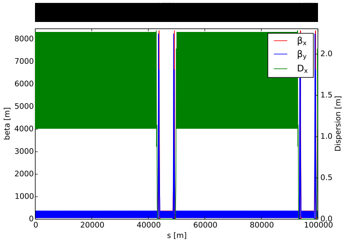
Arc FODO lattice



Straight section

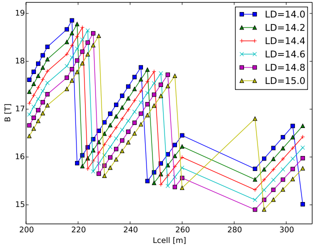


FCC racetrack (100 km)

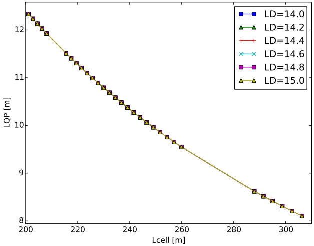


- 4812 dipoles of 14.8 m and 14.7 T.
- Straight section: 7185.5 m.
- The cell length is 215.7 m.
- $\beta_{x,\text{max}} = 359.8$ m,
  $\beta_{y,\text{max}} = 366.1$ m.
- $D_{x,\text{max}} = 2.26$ m.

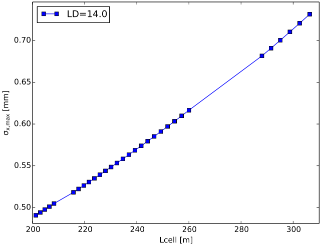
Dipole field vs cell length



QPole length vs cell length



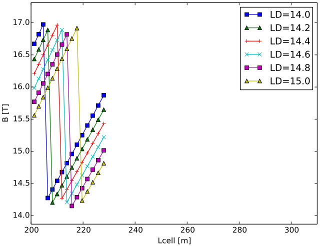
Beam size vs cell length



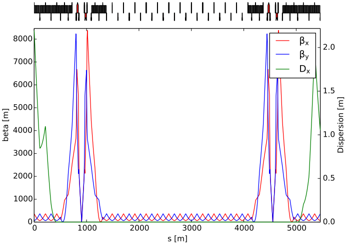
- The dipole field is above 15 T.
- Long quadrupoles (or quadrupoles splitted in 2?).

- The length of the straight sections is shortened (5400 m) to have the same total length of the dispersion-free as in the ring with 12 sectors.
- The arcs are a bit longer.
- The dipole field decreases (-0.5 T).

Dipole field vs cell length



Straight section



- We can expect a dipole field near 14 T.

Conclusion about present work

- A tool was written to quickly generate a lattice for FCC after inputting a few parameters.
  - We can explore the parameter set for the arcs with a fixed circumference.
  - The dipole field in the arcs is near 15 T if we use Nb_3Sn quadrupoles.
  - The racetrack is a promising option and should be investigated further.
- Some questions remain to go further and to refine the optimization of the first order lattice.
  - Minimum length for dispersion-free insertion?
  - Cost optimization criteria for dipoles.
- A mirror-symmetry between the different IPs should be explored:
  - Integer number of cells in the arcs (the arcs can be π or 2π insertions).
  - We naturally kill some high order terms: better for stability.
  - Is it trouble for beam-beam effects?

Plans for future (1)

- Plans for WP2:
  - Tune exploration to optimize the working point.
  - To look at the needed space for the collimation insertion.
  - To study a mirror-symmetry lattice.
  - To integrate the different versions of low beta insertion made by WP3.
  - **Discussion with other WPs** to refine the optimization criteria.
- Open questions:
  - Injection energy (3.3 TeV now against 7 TeV). A higher injection energy will enable to reduce the aperture and the field range in FCC.
  - Minimum length for the straight section in the racetrack configuration.
    - Do we fix the arc length? We have then more space for the insertions.
    - Do we fix the length of the dispersion-free sections?

Plans for future (2)

- Questions to WP3:
  - Range for the length of the low beta insertion (w/o dispersion suppressor).
- Questions to WP4:
  - There is some margin with an aperture of 20 mm (in the arcs).
  - Which realistic minimum for the beam screen radius (13 mm?)?
- Questions to WP5:
  - We have to clarify the costing rules.
  - **Scaling rule** for dipoles and QPoles with length, field, aperture?