FCC-pp - Collider

First Look at the Arc Lattice

cout J. Wenninger -> photo of the Jura
R. Alemany -> ζ (dipole fill factor)
LHC -> as a very nice example to follow

Where do we come from ??

LHC parameters:

energy	7000 GeV
dipole magnets	N = 1232
dipole length	*l* = 14.3 m

dipole field $\int B\,dl \approx N\,l\,B = 2\pi\; p/e$

$$B \approx \frac{2\pi \;\; 7000 \;\; 10^9 eV}{1232 \;\; 15\, m \;\; 3\; 10^8 \dfrac{m}{s} \;\; e} = 8.3\; Tesla$$

Basic Cell:

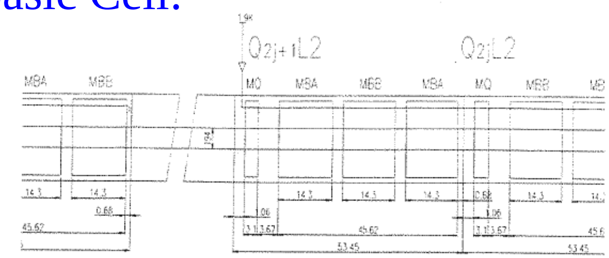
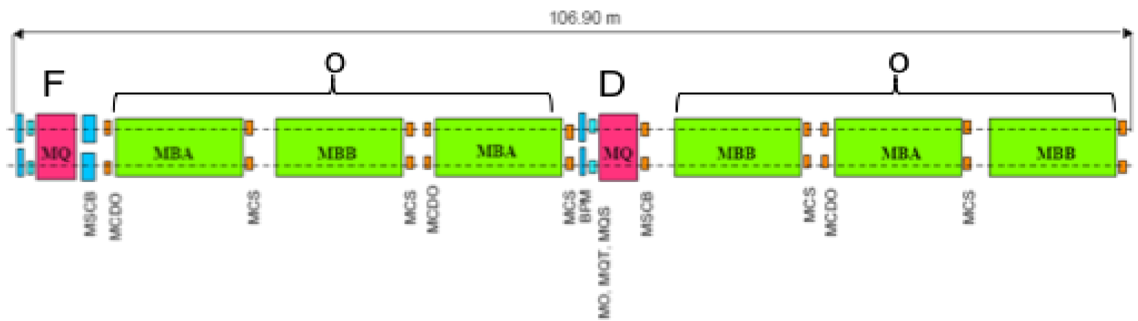


Figure 3.1: Schematic layout of an LHC half-cell



For the time being we keep the magnet distances as in the case of LHC.   tbcccc

How do we start ??

first scaling from LHC

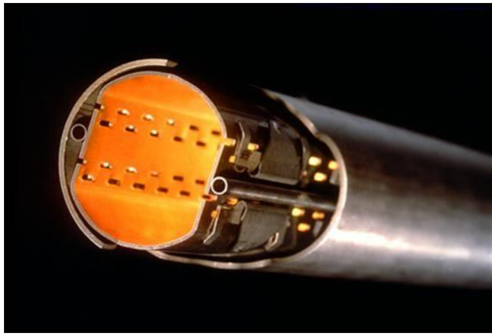
bare aperture considerations

LHC arc:

$$\varepsilon_n = 3.5 \cdot 10^{-6} \, m\, rad$$

$$\rightarrow \varepsilon_0 = 7.3 \cdot 10^{-9} \, m\, rad$$ ... at 450 GeV inj energy

$$\rightarrow \varepsilon_0 = 5 \cdot 10^{-10} \, m\, rad$$ ... at 7 TeV flat top energy



$$\hat{\beta}_x = \hat{\beta}_y \approx 180\, m \quad \rightarrow \quad 1\sigma(inj) = 1.1 mm$$

$$\hat{D} \approx 2m$$

Beam pipe:

$$\left.\begin{array}{l} a_0 = 56mm \\ \text{beam screen: } 34 * 44\, mm^2 \end{array}\right\} \rightarrow r_{\min} = 17mm \approx \; 15\sigma$$

Scaling for FCCpp

magnet aperture scaled down 56mm -> 40mm

1.) assumption: same rule holds for the future beam screen $\rightarrow r_{\min} = 12mm$
2.) normalised emittance a la LHC

$$\varepsilon_n = 3.75 \cdot 10^{-6}\, m\, rad$$

injection energy = 3 TeV ... to be discussed

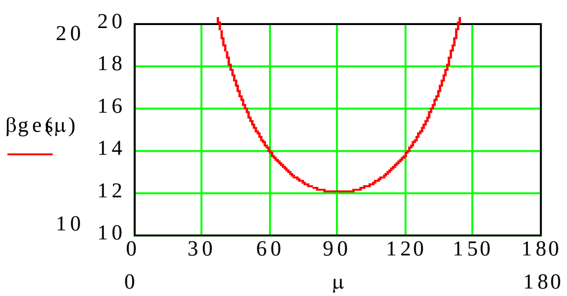
$$\rightarrow \varepsilon_0 = 9.4 \cdot 10^{-10}\, m\, rad$$

3.) we keep the required free aperture

$$n_\sigma = 15 = \frac{r_{\min}}{\sqrt{\varepsilon\beta}} \quad \rightarrow \quad \hat{\beta} < 680\, m$$

Very first Attempt:
FoDo design for β = 600m

$$\hat{\beta} = \frac{(1+\sin\frac{\psi_{cell}}{2})L}{\sin\psi_{cell}} \qquad \check{\beta} = \frac{(1-\sin\frac{\psi_{cell}}{2})L}{\sin\psi_{cell}}$$



phase advance: optimum for ψ_{cell} =90°

=> L_{cell} = 350m

Scaling for FCCpp

Magnets

4.) assumption: dipole B-field increased by factor 2 ($Nb_3 Sn$) -> B_0=16T

$$B = \frac{\mu_0 \, n \, I}{h}$$

5.) Quadrupole Magnets:

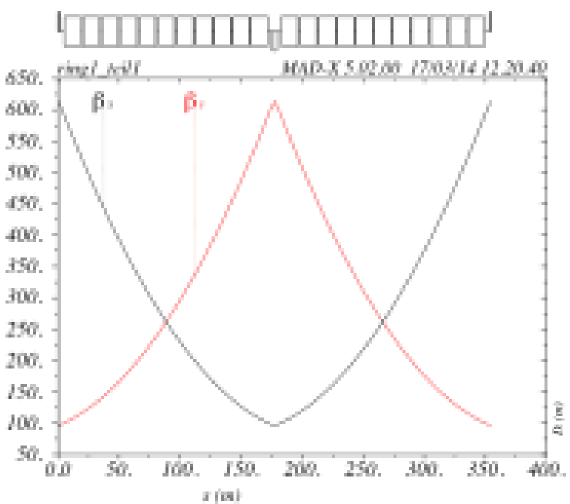
$$k = \frac{g}{B\rho} = \frac{B_0}{r_a} \quad \rightarrow \quad \frac{k_{Fcc}}{K_{LHC}} \approx 0.4$$

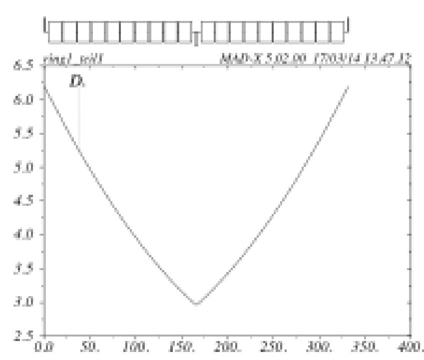
... to be discussed / to be checked / to be re-iterated

6.) V0 Optics L_{cell}= 350m

$$\sin(\psi_{cell}/2) = \frac{L_{cell}}{4f} \quad \rightarrow \quad k_{Fcc} = 2.6\cdot 10^{-3} \leftrightarrow k_{LHC} = 8.9\cdot 10^{-3}$$

$$l_q \approx 3m$$





Pushing the limit (Dipole Fill Factor):

22 dipoles per cell, l_{dipole}=14.0m
19 cells per arc
12 arcs
dipole field =15T <--> 50TeV
or 16T <--> 53.33TeV
5016 dipoles
drifts a la LHC: dipole-quad=3.6m
dipole-dipole=1.3m

$$\zeta = \frac{L(\Sigma_{dipoles})}{L_{cell}} = 87\%$$

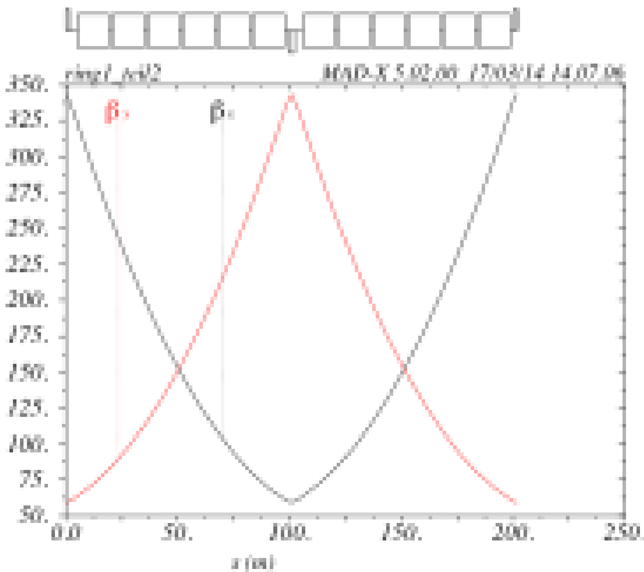
Scaling for smaller Cell Length: FCCpp

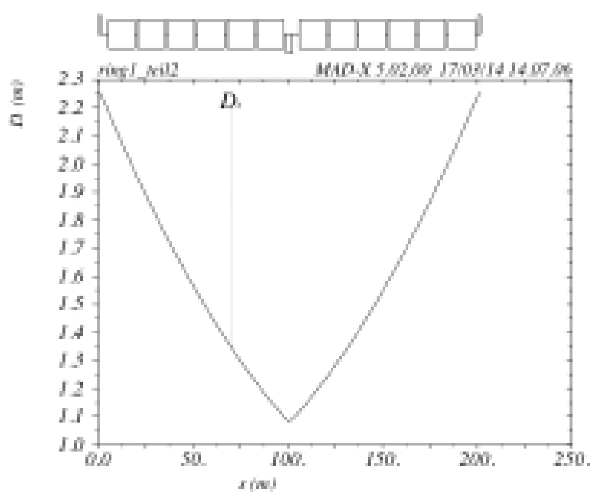
*Cell Length ≈ 2 * LHC-Cell*

„ ... the other extreme“

Realistic compromise:

$L_{cell} \approx 2^* L_{cell}(LHC)$
12 dipoles per cell
19 cells per arc
12 arcs
4608 dipoles
dipole length=14.2m
drifts a la LHC: dipole-quad=3.6m
dipole-dipole=1.3m
dipole field =16T <--> 50TeV
cell length=202m



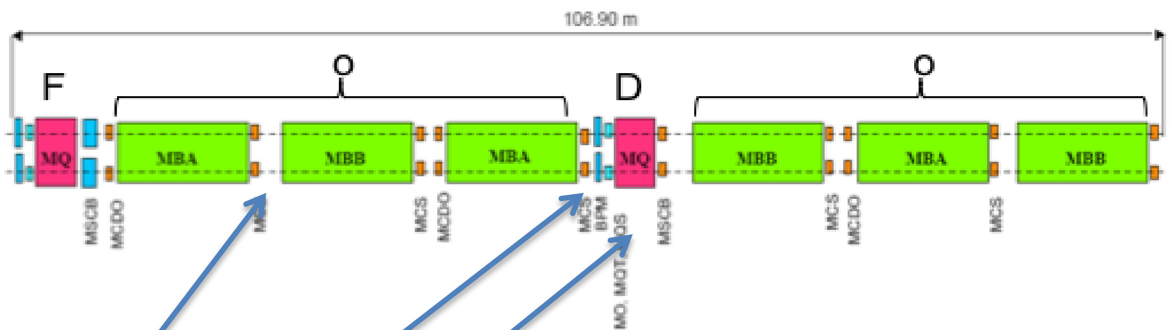


$$\zeta = \frac{L(\Sigma_{dipoles})}{L_{cell}} = 84\%$$

Dipole Fill Factor: ζ

For each cell length there is an optimum β_{max}

and there is an optimum dipole length to fit in a integer number of magnets and to optimise for E=50TeV the fill factor



Ingredients:

Variables:

dipole length
dipole number
cell length

Constants (??):

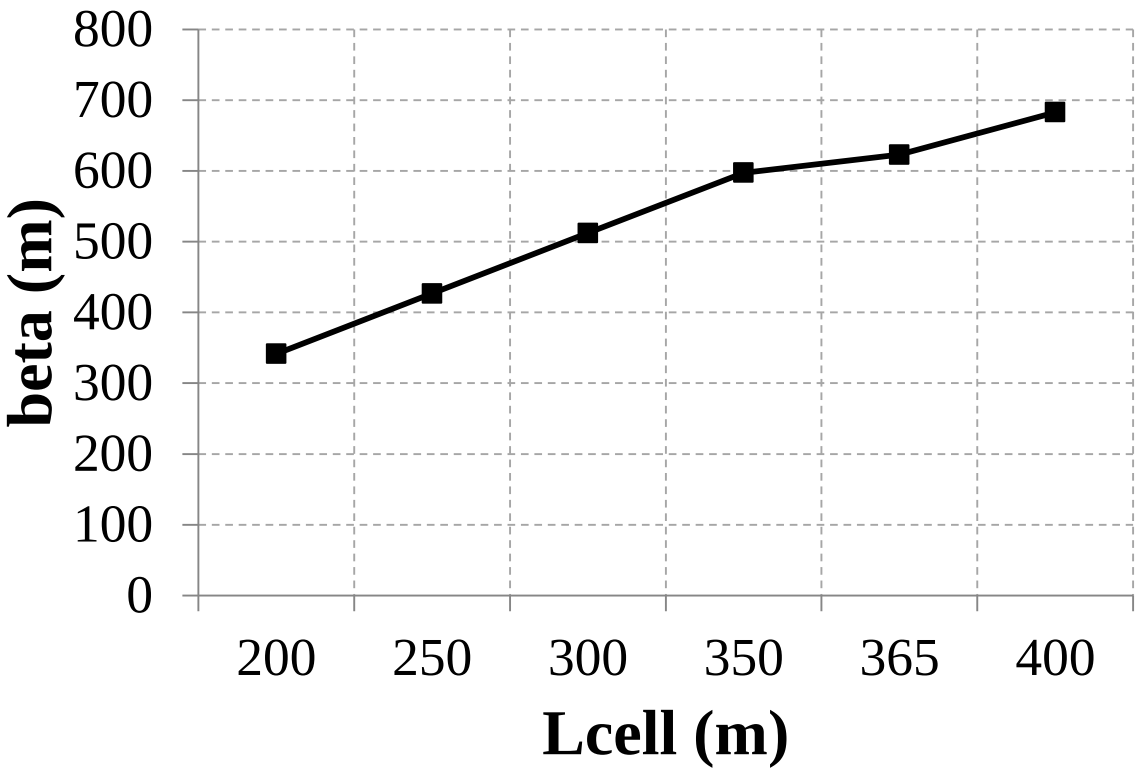
drift (dipole-dipole)	*=1.3m*
drift (dipole-quadrupole)	*=3.6m*
quadrupole length	*=3.1m*

to be discussed !!!

Cell Length and β function:

$$\hat{\beta} = \frac{(1+\sin\frac{\psi_{cell}}{2})L_{cell}}{\sin\psi_{cell}}, \quad \sin(\psi_{cell}/2) = \frac{L_{cell}}{4f}$$

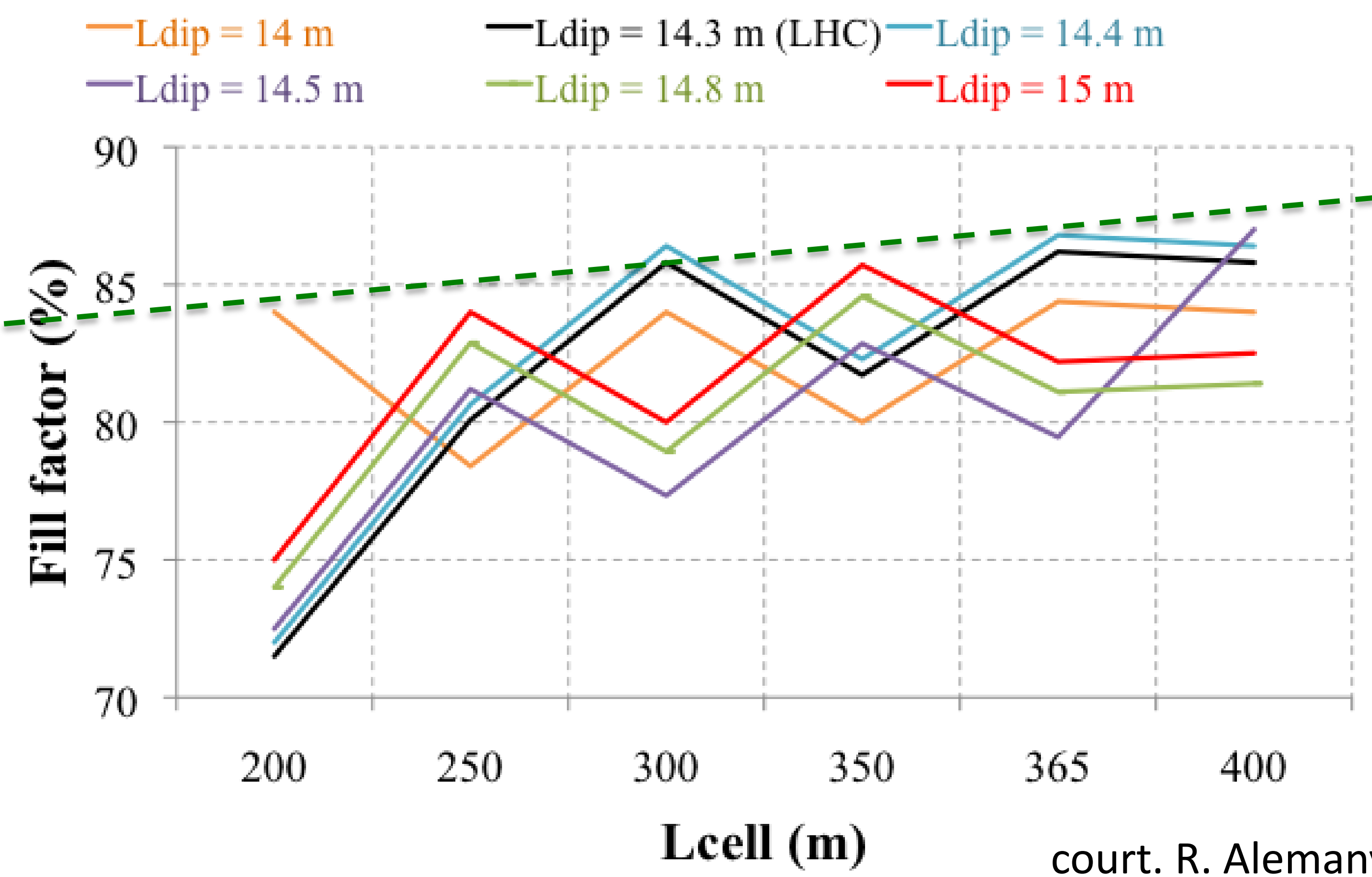
For each case the dipole length has been re-optimised to obtain an integer number of magnets per cell



court. R. Alemany

Dipole Fill Factor: ζ

$$\zeta = \frac{L(\Sigma_{dipoles})}{L_{cell}}$$



court. R. AlemanyA

The quadrupole length is small compared to overall dipole length per cell

-> increasing the cell length is always helpful to optimise ζ.

-> however the effect is not dramatic and smaller cell lengths might have optical advantages

Arc Cell V1:

First Arc Layout:

$L_{cell} \approx 206.4m$
$L_{dipole}=14.2m$
12 dipoles per cell
32 cells per arc
12 arcs

4608 dipoles
drifts a la LHC: dipole-quad=3.6m
dipole-dipole=1.3m
dipole field =16T <--> 50TeV

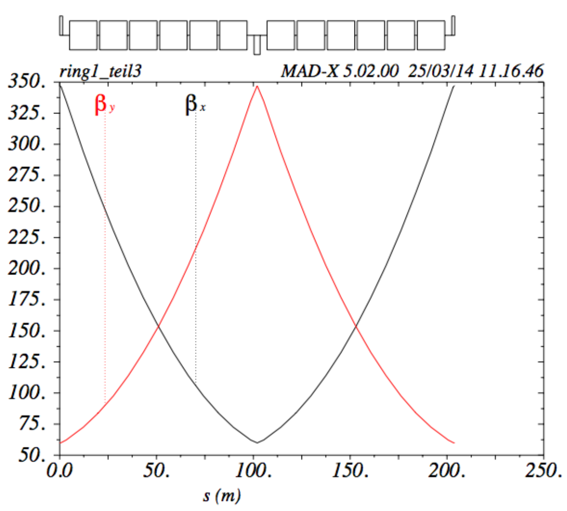
The storage Ring:

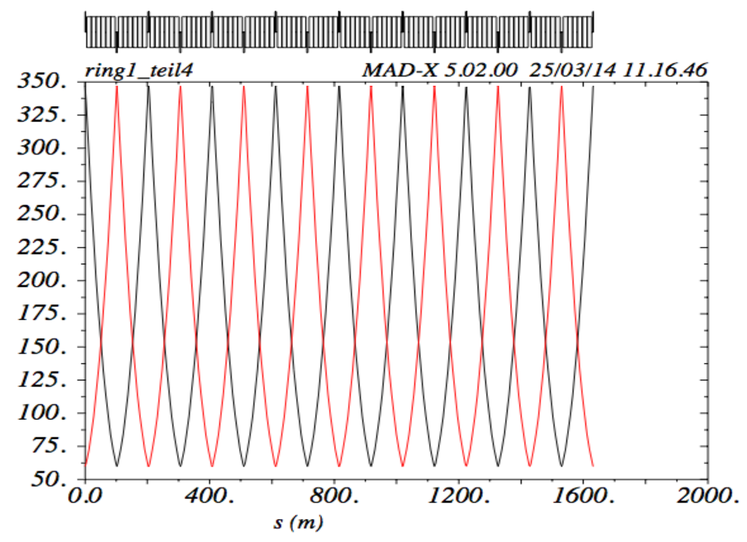
12 Arcs, 12 Straights ... yes yes the racetrack will come soon.

$L_{Fccpp} = L_{cell} * N_{cell/arc} * N_{arc} + 12 * L_{straights} + 12 * 2 * 2 * L_{celldispcuppr}$

$= 206.4m * 32 * 12 + 12 * 1400m + 12 * 2_{li\text{-}re} * 2_{cells} * 206.4m$

$= 105\ km$





Arc Cell V1:

The storage Ring:

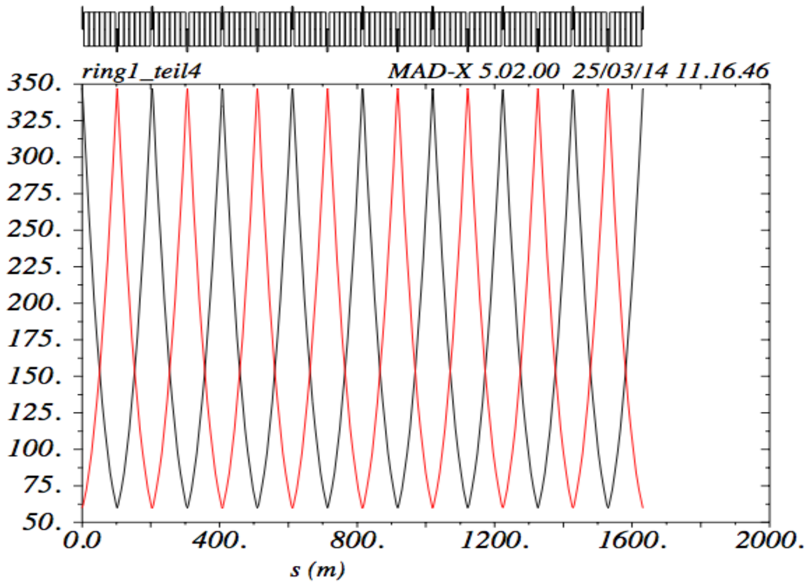
12 Arcs, 12 Straights

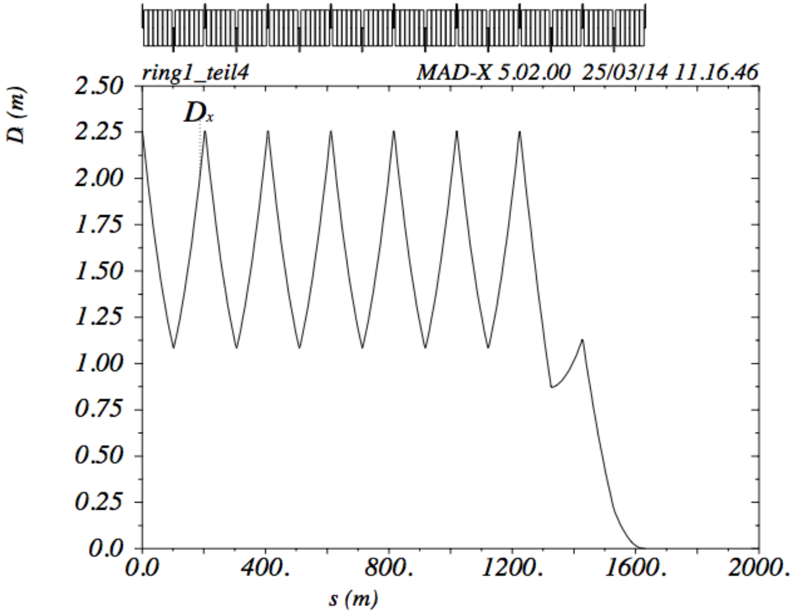
Dispersion Suppressor Arc - Straight:

unlike LHC ... text book like approach

$\Psi_{cell} = 90^o$ → two half bend cells will do the job

$$2*\delta_{supr}*\sin^2\left(\frac{n\Phi_c}{2}\right)=\delta_{arc}$$





Next Steps:

Complete the Storage Ring:

12 Arcs, 12 Straights

Discuss the magnet parameters

(Re -) Optimise Cell Length

add matching quadrupoles in Dispersion Suppressor Region,
add empty cells to design the straights
include a first mini-beta

Finalise in first version the "Modules"

Re-Define the Module arrangement to get a first layout of the Racetrack

... mid term planning:

magnet parameters / multipoles / inter magnet drifts ??