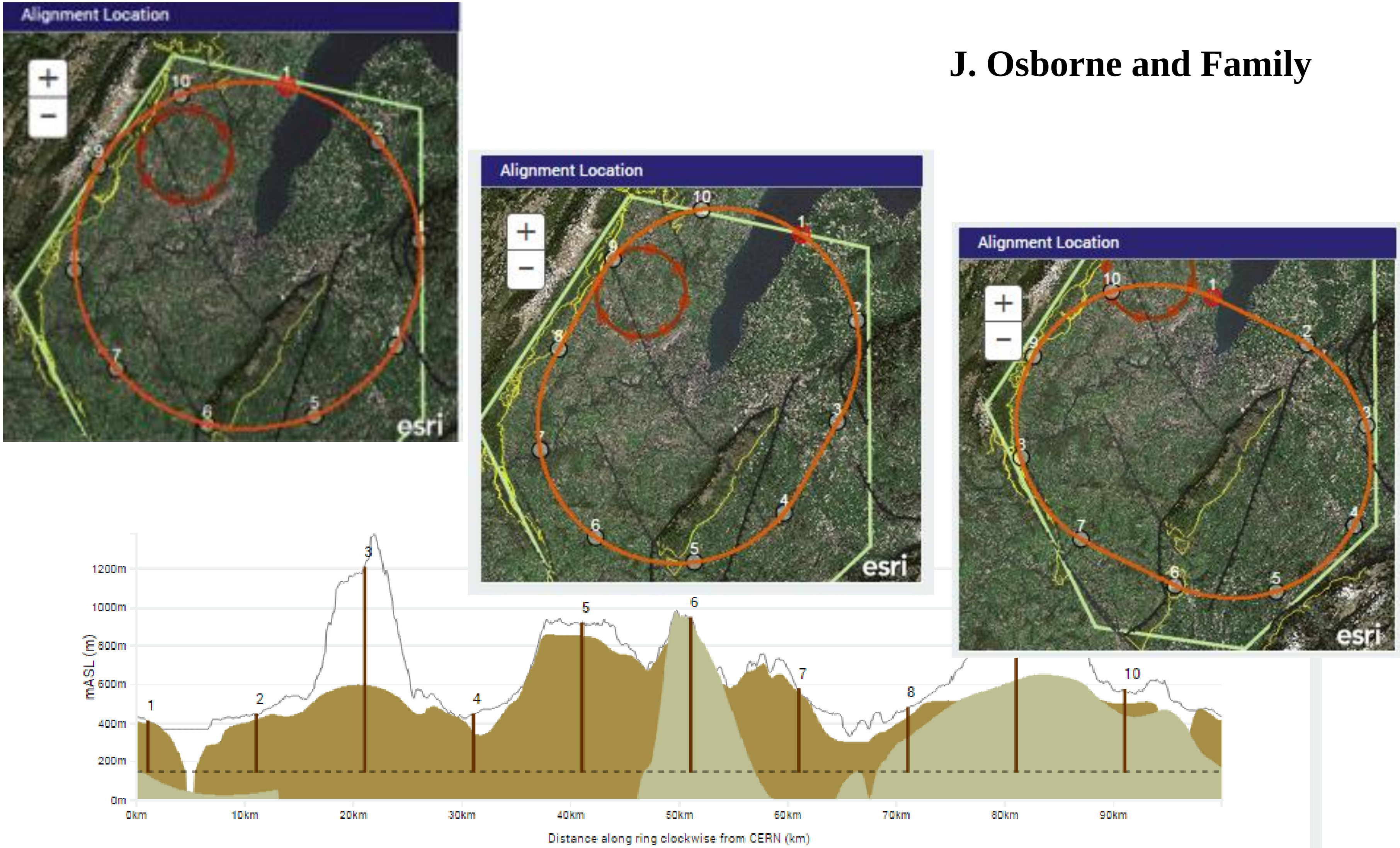
FCC-pp - Collider

First Look at the Arc Lattice

R. Alemany & B. Holzer

Latest News: Geographical / Geological Considerations

J. Osborne and Family



Build the Lattice Design on a modular basis using building blocks that are matched / or "matchable" to each other to follow a large variety of geometries

Where do we come from ??

LHC parameters:

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

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

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

Basic Cell:

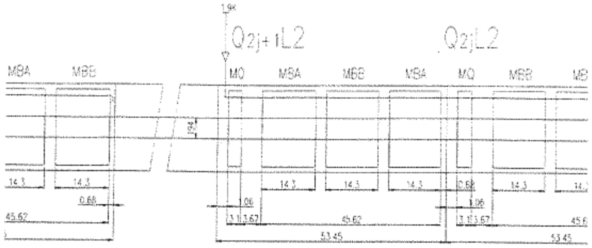
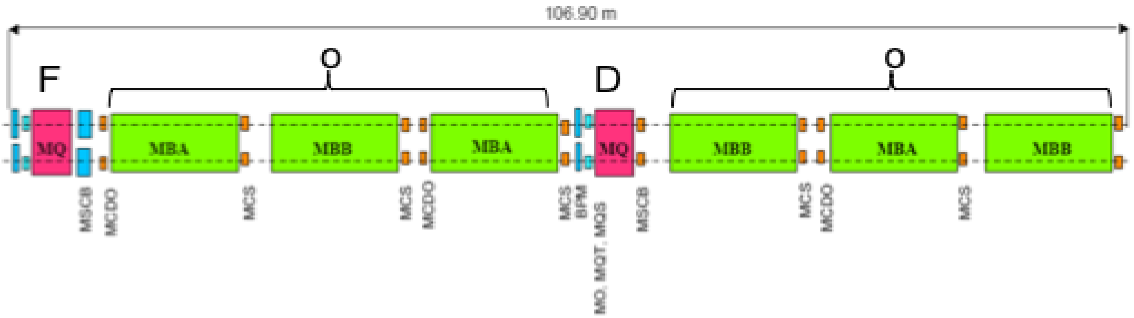


Figure 3.1: Schematic layout of an LHC half-cell



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

Scaling for FCCpp

Magnet aperture scaled down 56mm -> 40mm

1.) assumption: LHC rule holds for the future beam screen $\rightarrow r_{min} = 12mm$

2.) normalised emittance a la LHC ... ??

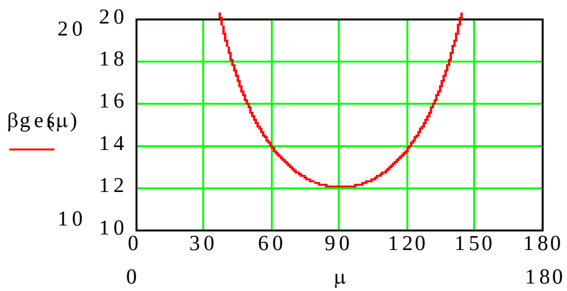
$$\varepsilon_n = 3.75 \cdot 10^{-6} m\, rad$$

injection energy = 3 TeV ... to be discussed ... $\varepsilon_n = 2.2 \cdot 10^{-6} m\, rad$

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

3.) we keep the required free aperture

$$n_\sigma = 15 = \frac{r_{min}}{\sqrt{\varepsilon\beta}} \rightarrow \hat{\beta} < 680m \qquad \beta_\pm = \frac{(1 \pm \sin\frac{\psi_{cell}}{2})L}{\sin\psi_{cell}}$$



Magnets

4.) assumption: dipole B-field increased by factor **2 (Nb_3Sn) -> B_0=16T** $\qquad B = \frac{\mu_0\, n\, I}{h}$

5.) Quadrupole Magnets:

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

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

Just as Example and for completeness:

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

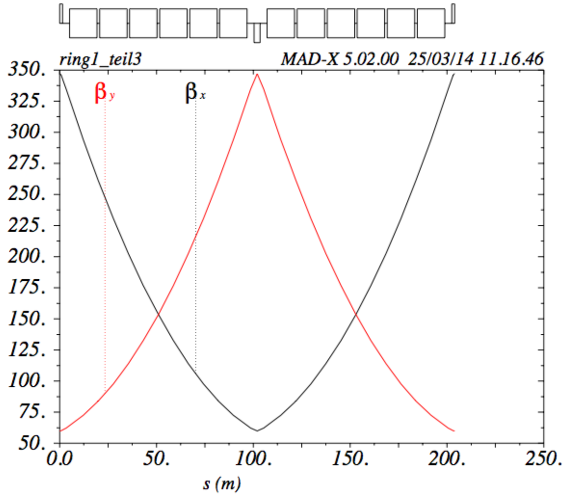
The storage Ring:

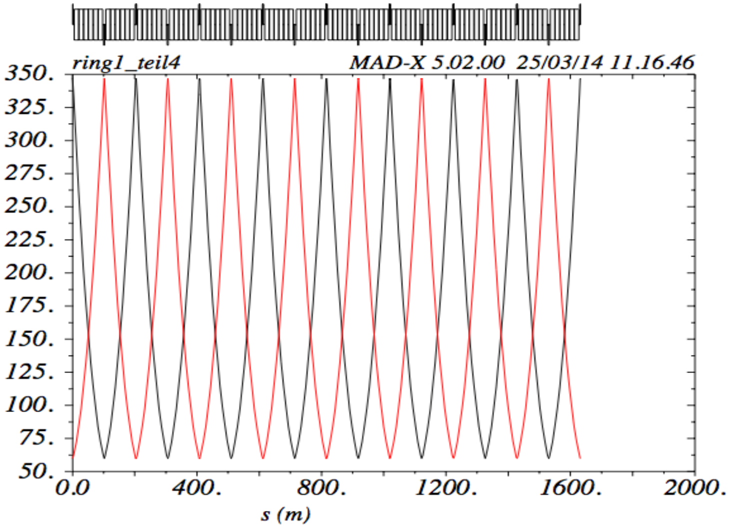
12 Arcs, 12 Straights ... yes yes the racetrack will come soon.

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

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

$=105\ km$





Scaling for FCCpp: Dipole Fill Factor for present Version V3:

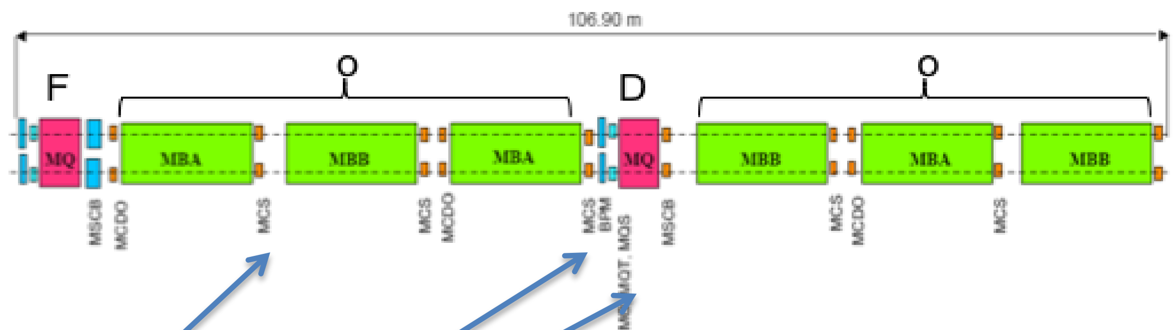
Pushing the limit (Dipole Fill Factor):

- 12 dipoles per cell, l_{dipole}=14.2m
- 34 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

$$\zeta = \frac{L(\Sigma_{dipoles})}{L_{cell}} = 82\%$$

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 per cell to optimise the fill factor for E=50TeV



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 Optimisation:

for the fun of it ...

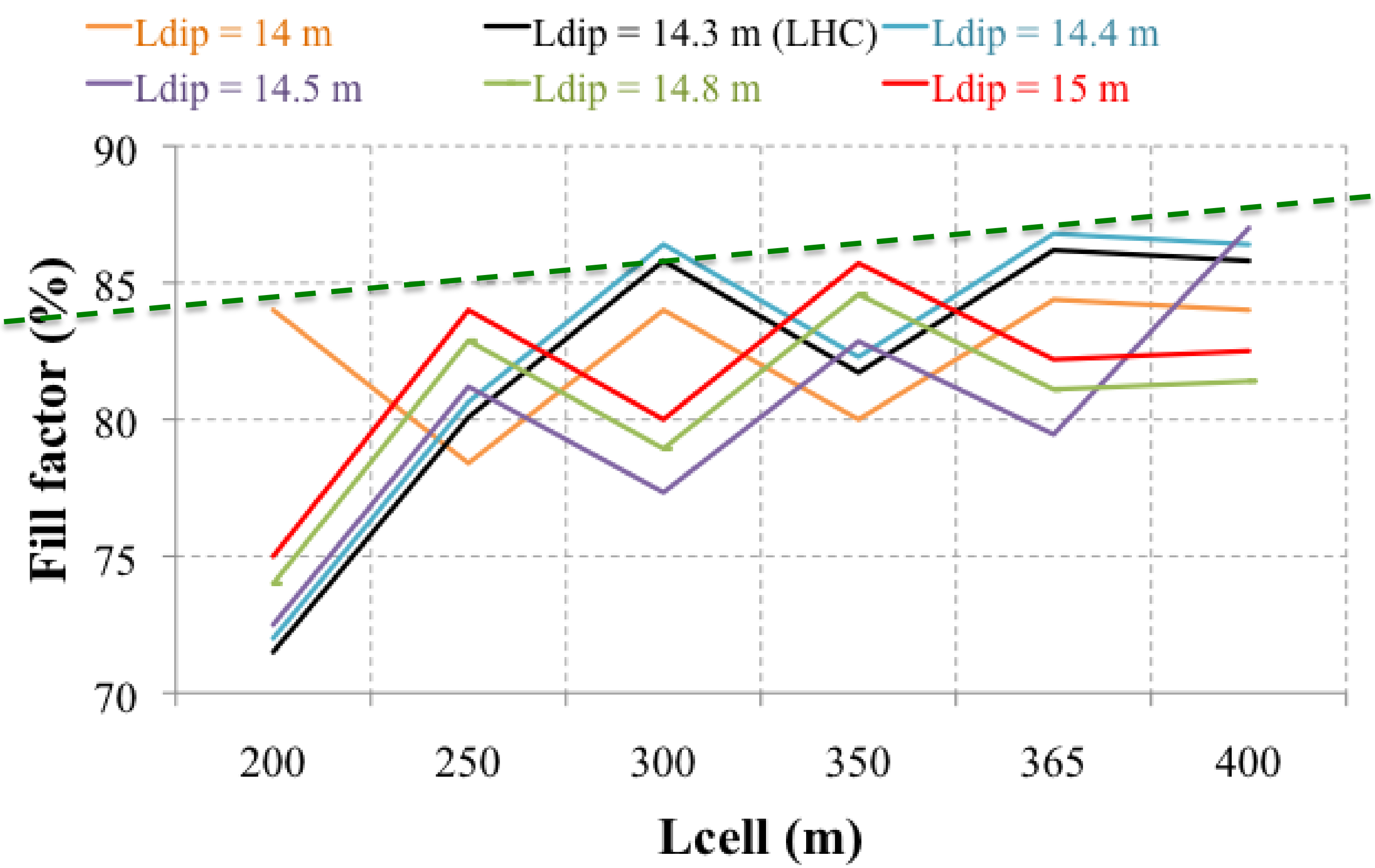
scaling dipole lengths
cell lengths
β-functions
fill factors

Lcell (m)	200	250	300	350	365	400
β (m)	341	427	512	598	623	683
Ldip (m)	14					
Ndip opt/cell	12	14	18	20	22	24
Ndip tot	4992	4662	4986	4760	5016	4992
η (%)	84	78.4	84	80	84.38	84
p (TeV/c)	53.42	49.87	53.42	50.87	53.66	53.42
Ldip (m)	14.3					
Ndip opt/cell	10	14	18	20	22	24
Ndip tot	4160	4662	4986	4760	5016	4992
η (%)	71.5	80.08	85.8	81.71	86.19	85.8
p (TeV/c)	45.47	50.93	54.56	51.96	54.81	54.56
Ldip (m)	14.4					
Ndip opt/cell	10	14	16	20	20	24
Ndip tot	4160	4662	4986	4760	5016	4992
η (%)	72	80.64	86.4	82.29	86.8	86.4
p (TeV/c)	45.79	51.31	54.88	52.39	55.21	54.94
Ldip (m)	14.5					
Ndip opt/cell	10	14	16	20	20	24
Ndip tot	4160	4662	4432	4760	4560	4992
η (%)	72.5	81.2	77.33	82.85	79.45	87
p (TeV/c)	46.11	51.67	49.12	52.75	50.54	55.33
Ldip (m)	14.8					
Ndip opt/cell	10	14	18	20	20	24
Ndip tot	4160	4662	4432	4760	4560	4576
η (%)	74	82.88	78.93	84.57	81.1	81.4
p (TeV/c)	47.06	52.74	50.13	53.85	51.58	51.76
Ldip (m)	15					
Ndip opt/cell	10	14	16	20	20	22
Ndip tot	4160	4662	4432	4760	4560	4576
η (%)	75	84	80	85.71	82.19	82.5
p (TeV/c)	47.69	53.45	50.81	54.57	52.28	52.46

LHC

Dipole Fill Factor: ζ

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

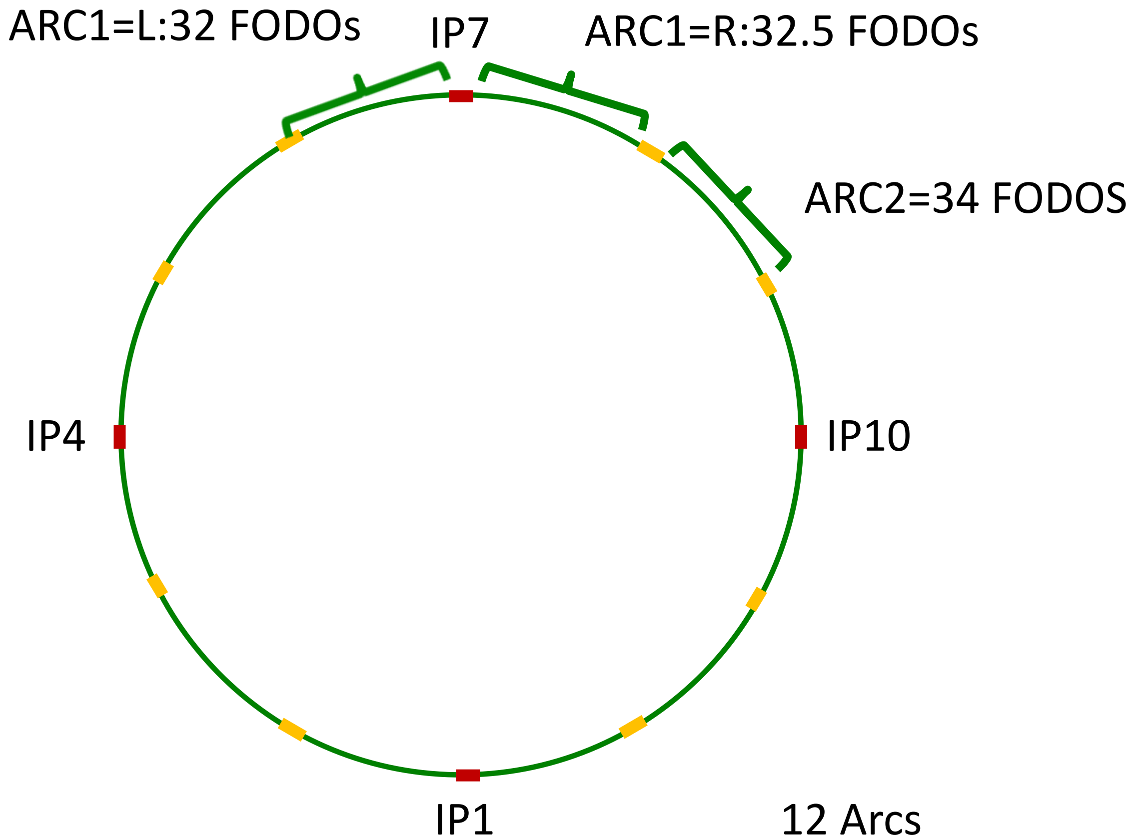


The quadrupole length is small compared to overall dipole length per cell

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

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

THE RING VERSION “V3”



Ctot= 99130 m

Lminbeta = 1783.106 m
(from DS to DS)
Linsertions = 1248.84 m
(from DS to DS)

12 Arcs
12 straight sections
distributed equidistantly
dispersion free
LSS ≈1.5 km

FODO CELL CHARACTERISTICS OF THE ARC

V3

N_{tot} dipoles = 5016 ➔ **16 T** ➔ **99130.304 km**

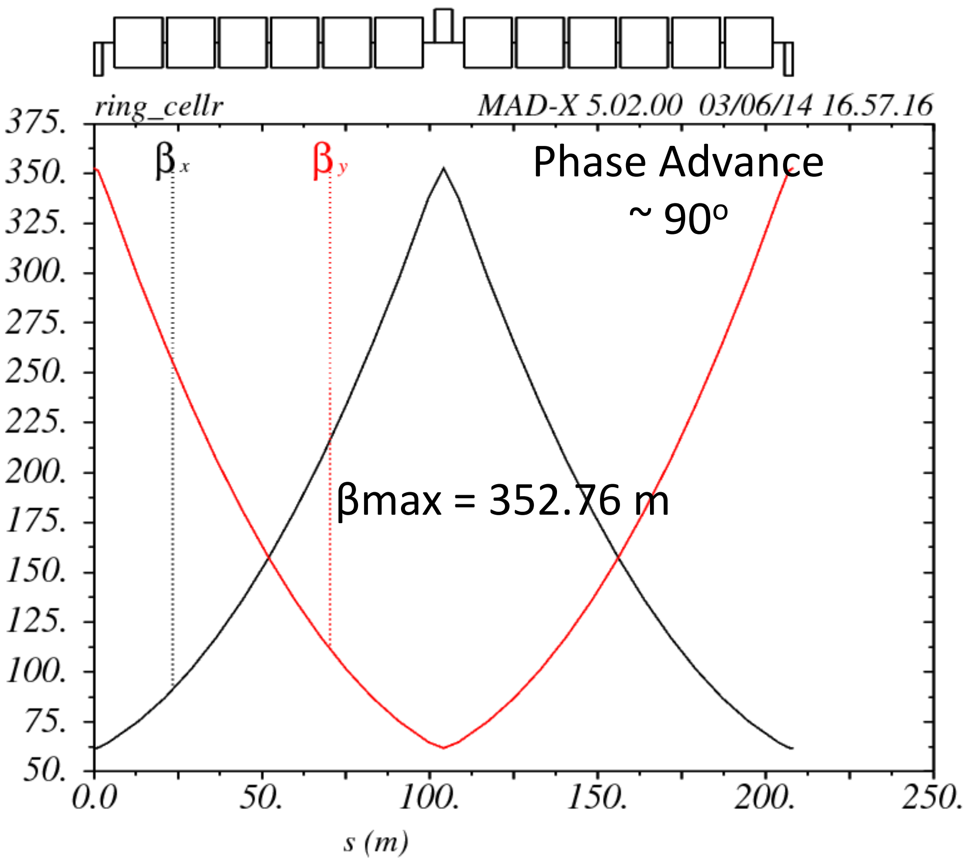
L_{cell} = **208.14 m**, **12 dipoles/cell**,

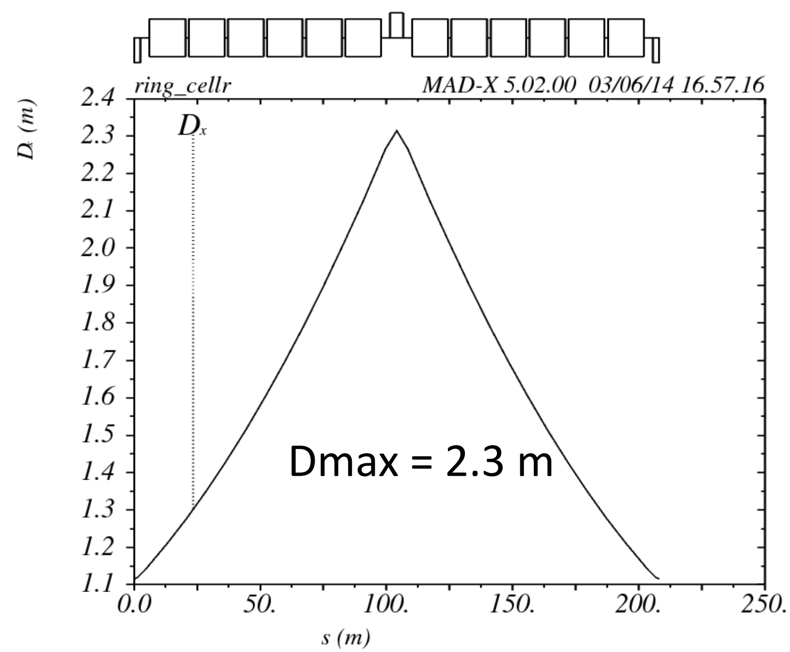
L_{dip}=14.2 m

Lquad = **5.17 m** ➔ based on a second estimation of the attainable gradient for Nb3Sn

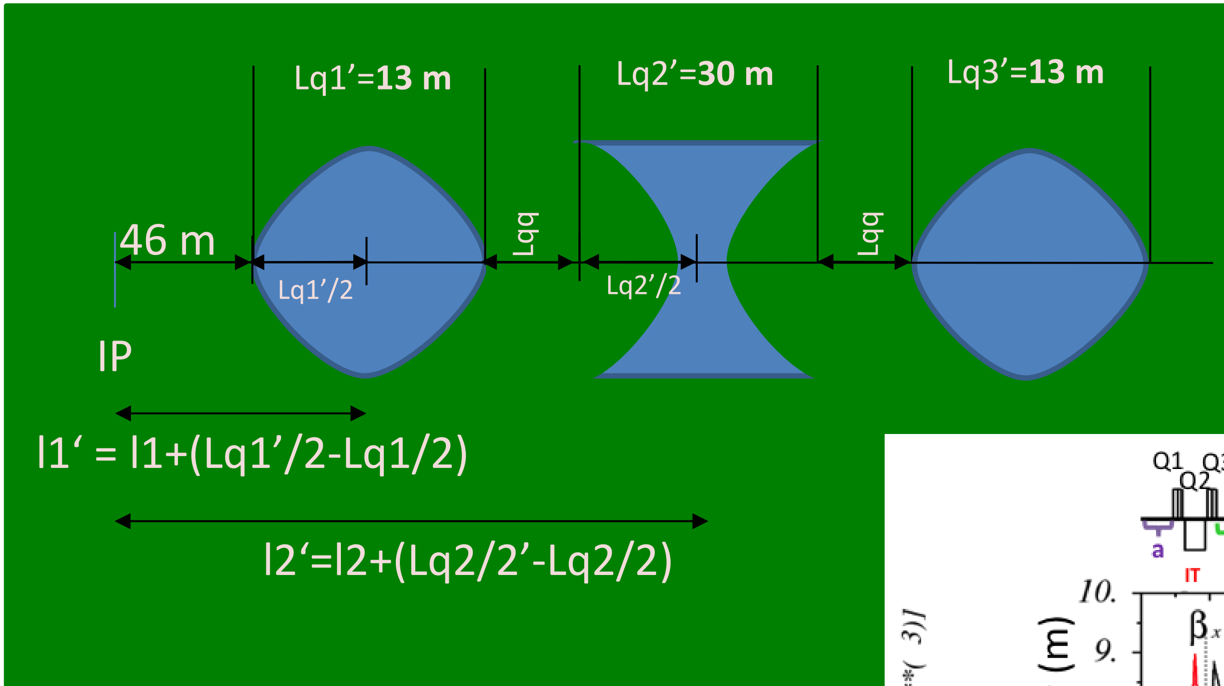
➔ R =**20 mm** g = **450 T/m** ➔ k = 2.67 10^{-3} m^{-2}

Tip Field = 9 T





V3: Combining the arcs with a – first sketch of a – mini-β

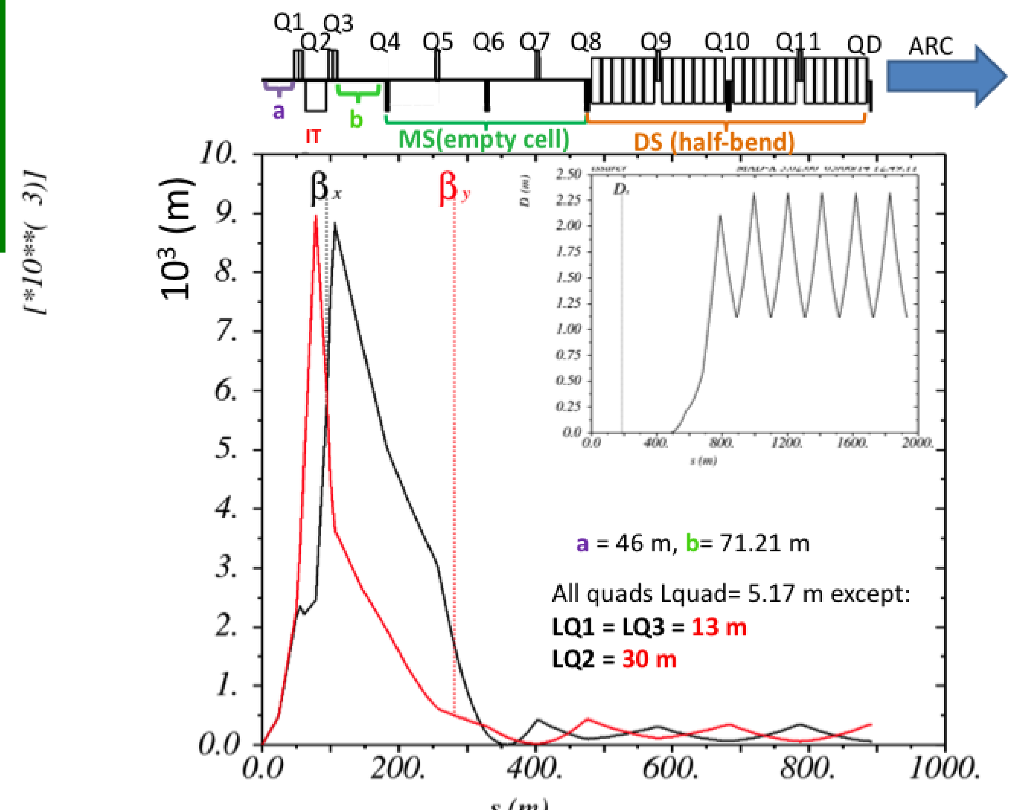


β* = 1.1 m

$L_{q1/q2}$=13 m & 30 m

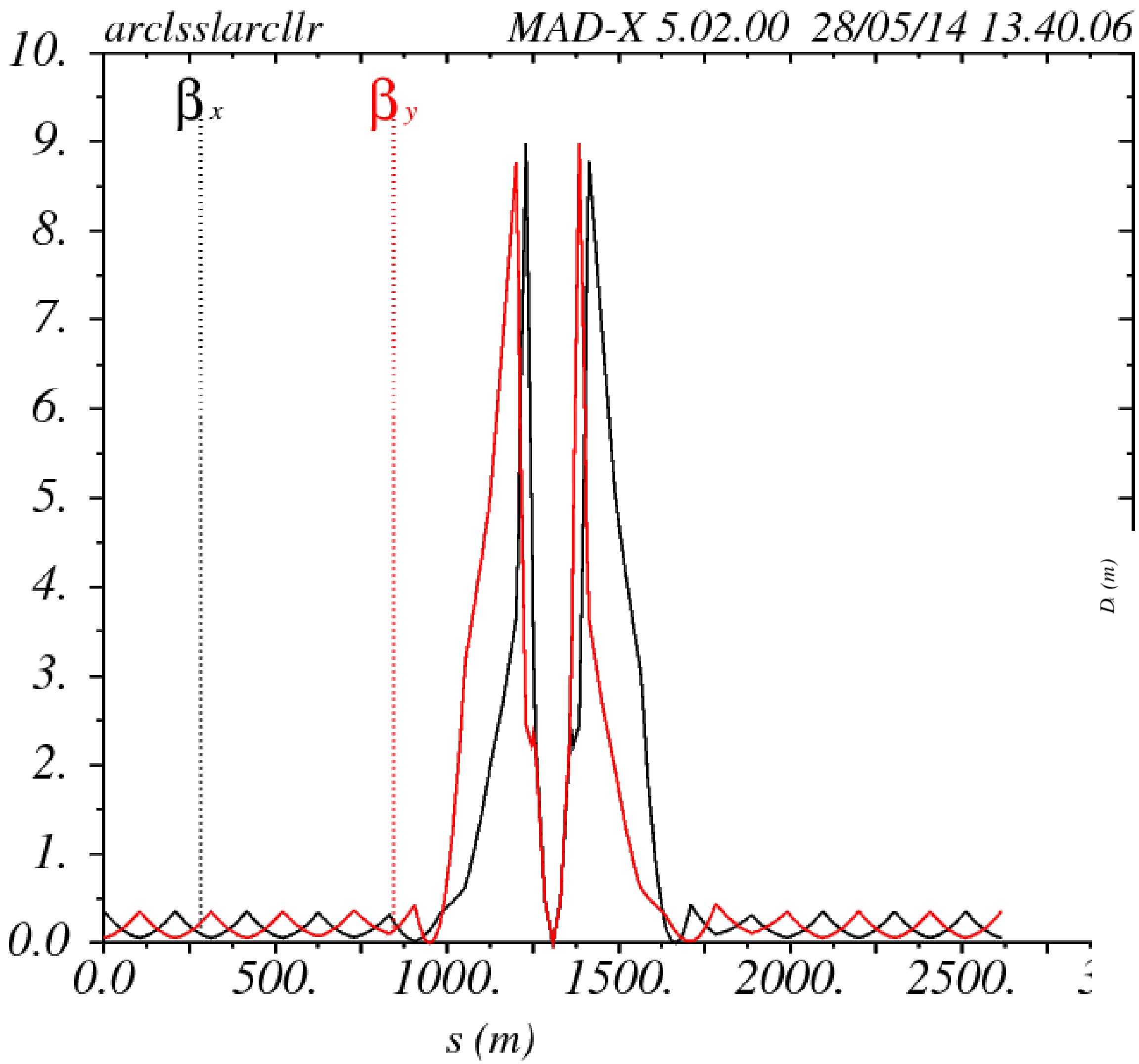
➔ β(@IT) ~ 9 km

$$\beta(s) = \left(1 + \frac{l_2'}{f_1'}\right)^2 * \beta^* + \frac{1}{\beta^*}\left(l_1' + l_2' + \frac{l_1' l_2'}{f_1'}\right)^2$$



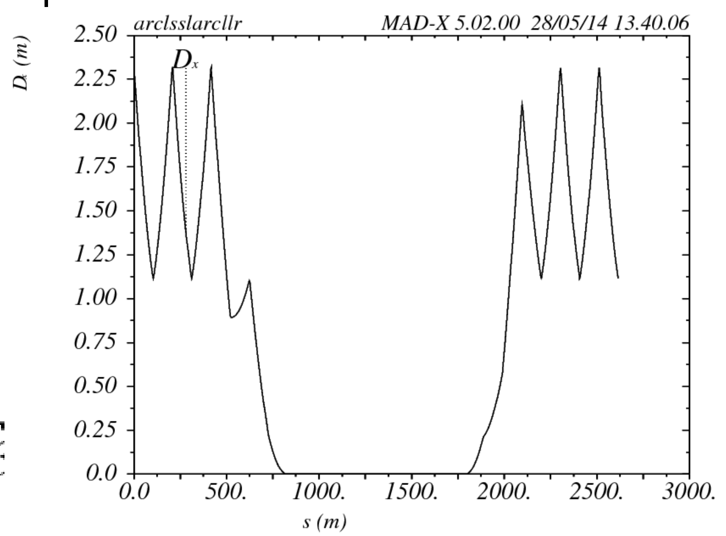
V3 first Layout of an IR optics

more sophisticated work by Roman & Rogelio

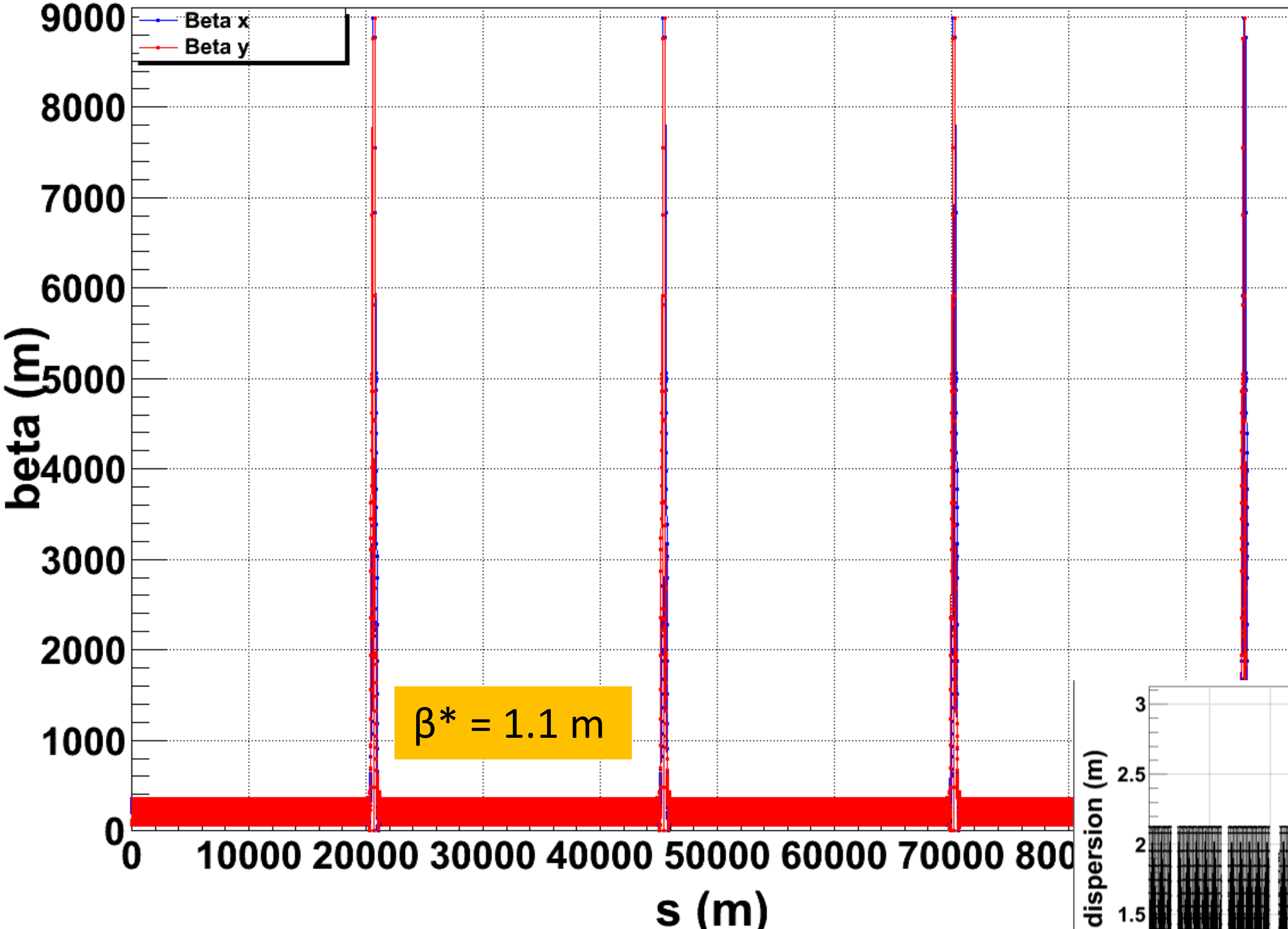


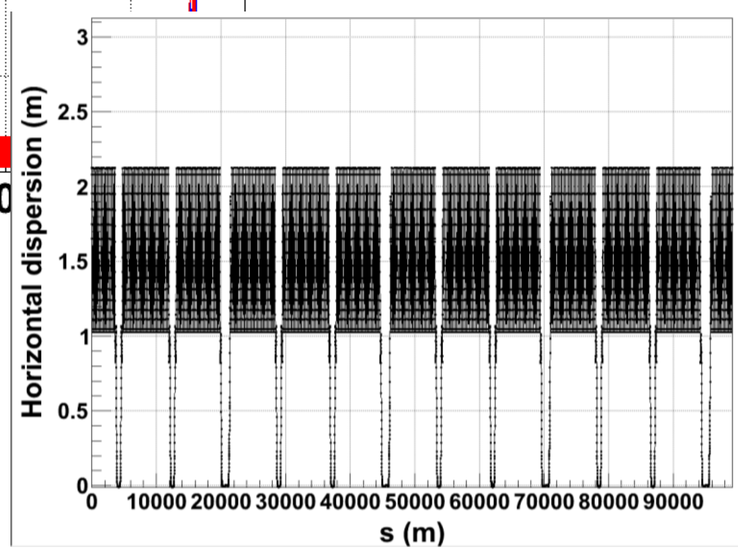
LQ1 = LQ3 = 13 m
LQ2 = 30 m
kQ1 = 2.23 10-3 m-2
kQ2 = 1.69 10-3 m-2
kQ3 = 2.07 10-3 m-2

L_{quad} (except IT) =**5.17 m**
k_Q < 2.66 10-3 m-2 to get
g = 450 T/m, d=40 mm apert

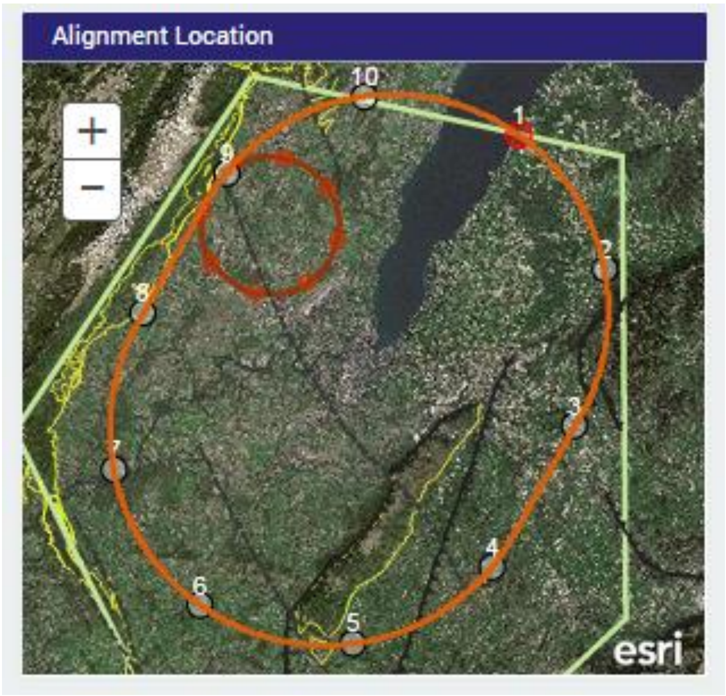


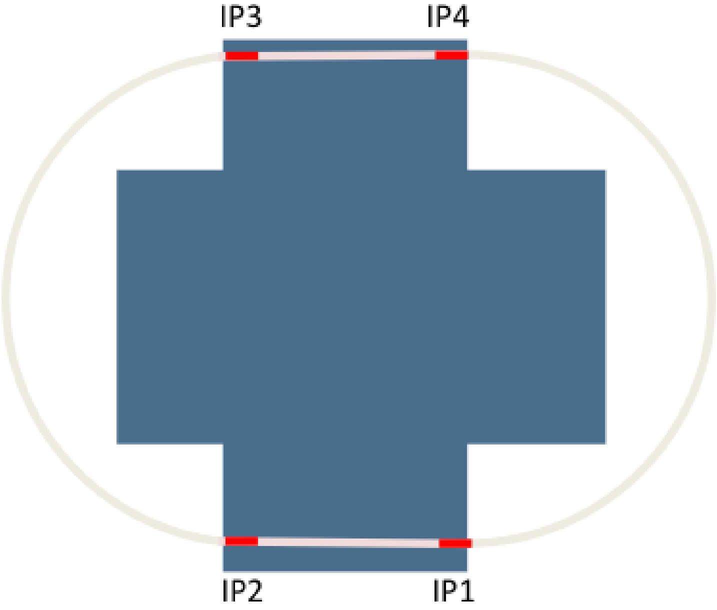
Optics for complete Ring: Version V3:





RACE TRACK VERSION V3



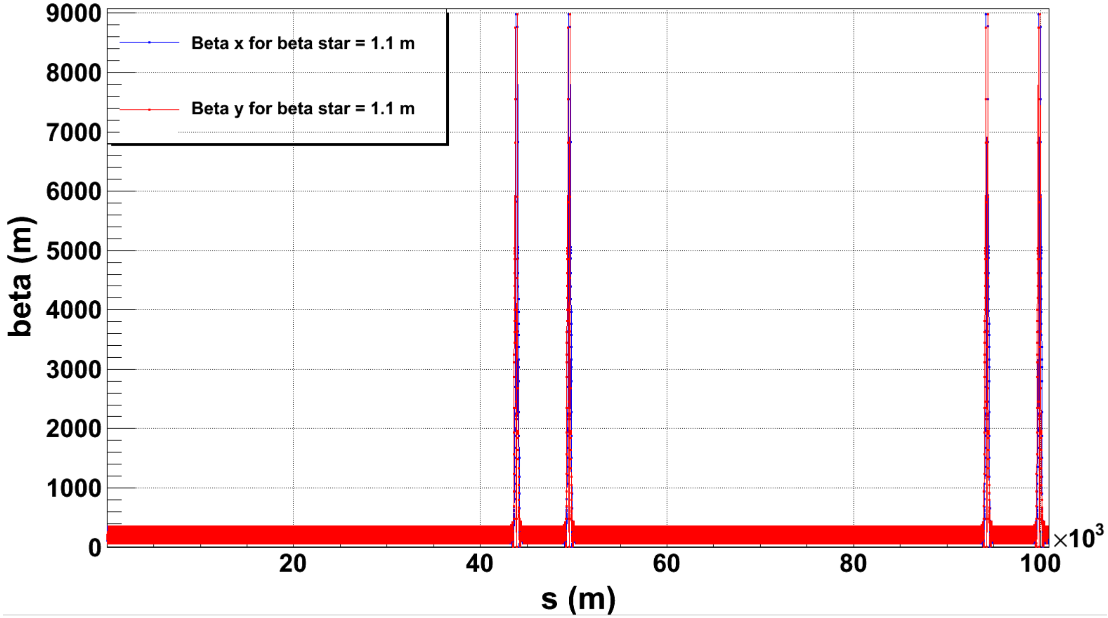


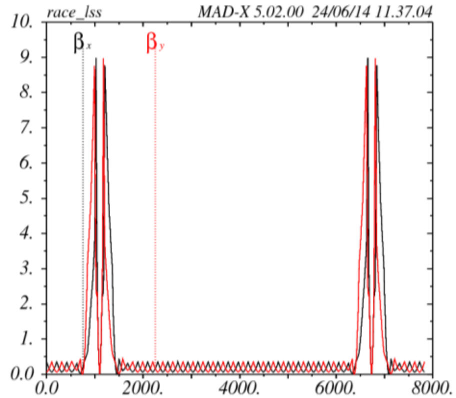
Questions to be answered:

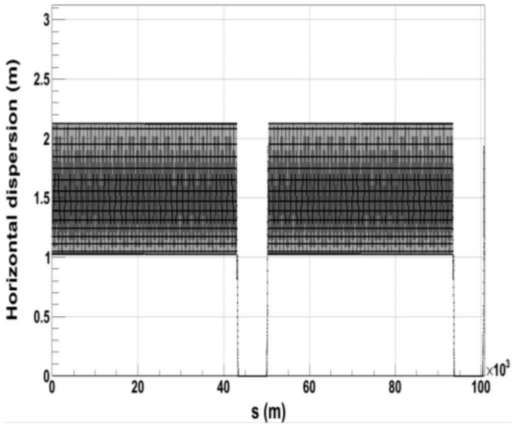
even / odd number of IPs per LSS ??
Length of LSS ??
Distance between IPs in the LSS

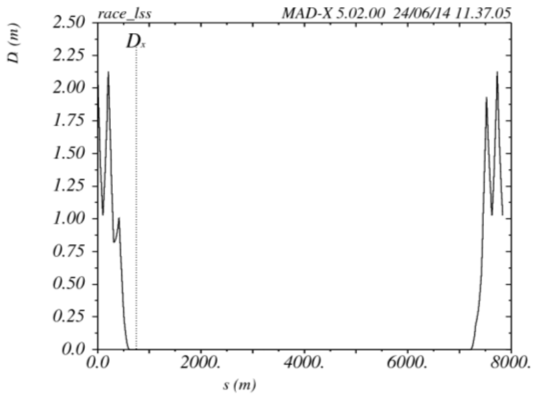
Ctot= 100.795 m
Lss = 2* 7416.802 m (from DS to DS)
Arc = 2* 46689.311 m

Racetrack-Latticee: Use the Ring Modules & Recombine them in an adequate manner   et c'est ca.





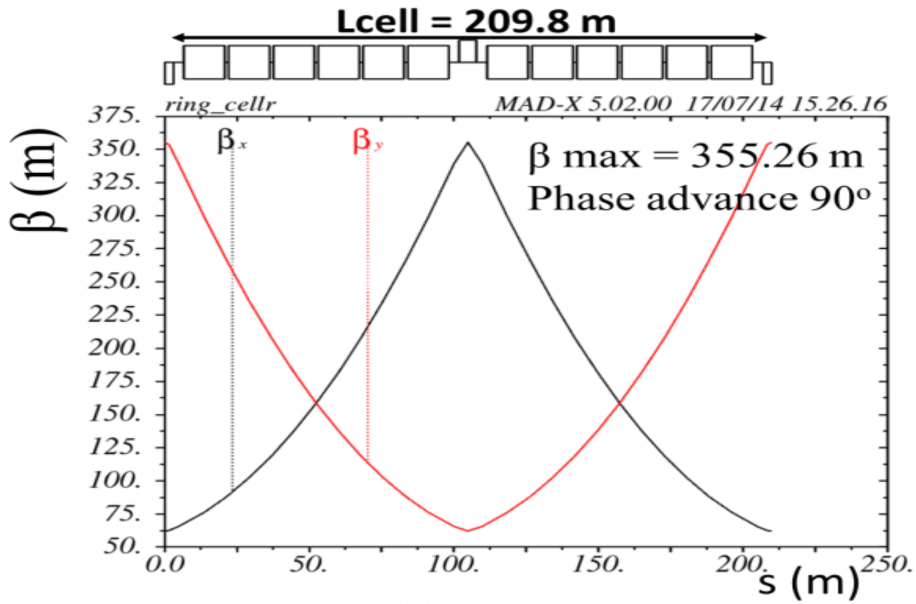




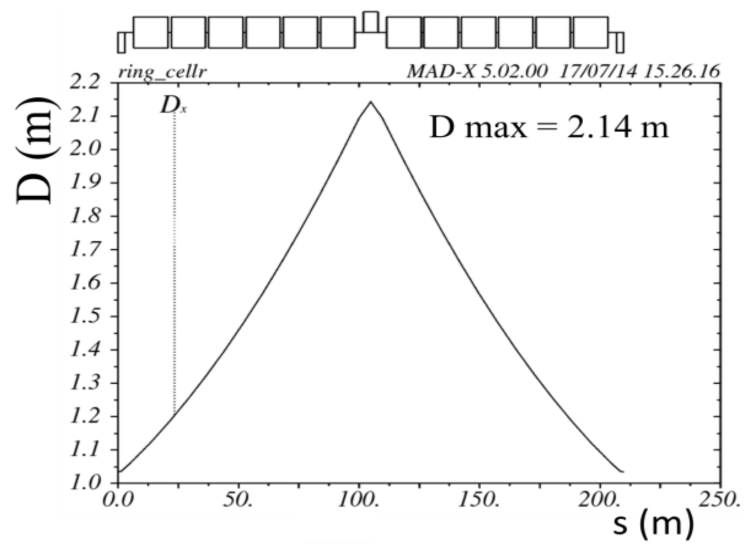
two mini-betas in the LSS   arcs combined by disp suppr module   disp free region in LSS

Small Remark from Impedance Police: 40mm coil diameter might be tough

Version V4: Rescaling magnet strengths
magnet lengths → Cell Lengths for 48mm



Gradient (T/m)	Diameter (mm)	Pole tip field (T)
450	40	9
370	50	9.25
320	60	9.6



FCC Project Note 0002

2014-09-16

Lattice Design of the Future Hadron-Hadron Collider with 48 mm Aperture Magnets

Author(s) / Department-Group: Reyes Alemany Fernandez/ BE-OP, Bernhard Holzer/ BE-ABP

Next Steps:

Complete the Storage Ring: ✓

12 Arcs, 12 Straights

Discuss the magnet parameters !

Ezio Todesco second iteration:

g = 450 T/m, d=40 mm aperture

g = 370 T/m, d=50 mm aperture

g = 320 T/m, d=60 mm aperture

(Re -) Optimise Cell Length

add matching quadrupoles in Dispersion Suppressor Region,

add empty cells to **design the straights according to the MDI needs** !

include a first mini-beta

Finalise in first version the "Modules" ✓

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

?? Arrangement and number of IPs per LSS ??

... mid term planning:

magnet parameters / multipoles / inter magnet drifts ?? / Combine with IR Design

Resume':

V3 lattice presented here is summarised in a FCC Project Note (waiting for publication)
A summary of the scaling to 48mm is in preparation "V4"

Where you find all that:

/afs/cern.ch/eng/fcc/hh ....

Arc Design → LATTICE_V3
* for Ring
* for Racetrack

IR design → upscaled_HL-LHC_V0.1
upscaled_LHC_V0.1

FCC Project Note xxxx

2014-06-23

First Considerations on Beam Optics and Lattice Design for the Future Hadron-Hadron Collider FCC

Author(s) / Department-Group: Reyes Alemany Fernandez/ BE-OP, Bernhard Holzer/ BE-ABP

Keywords: FCChh design study, lattice design

Summary

The present document explains the steps carried out in order to make the first design of the Future Hadron-Hadron Collider (FCC-hh) following the base line parameters that can be found in [1]. Two lattice layouts are presented, a ring collider with 12 arcs and 12 straight sections, four of them designed as interaction points, and a racetrack like collider with two arcs and two straight sections, each of them equipped with two interaction points. The lattice design presented in the paper is modular allowing the same modules be used for both layouts. The present document addresses as well the beta star reach at the interaction points.

1. Introduction

Following the recommendations of the European Strategy Group, several next generation large collider projects are studied at present to carry on the investigations of the fundamental