Fermilab

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Future Circular Collider— 100 km Circumference at 50 TeV

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SIST
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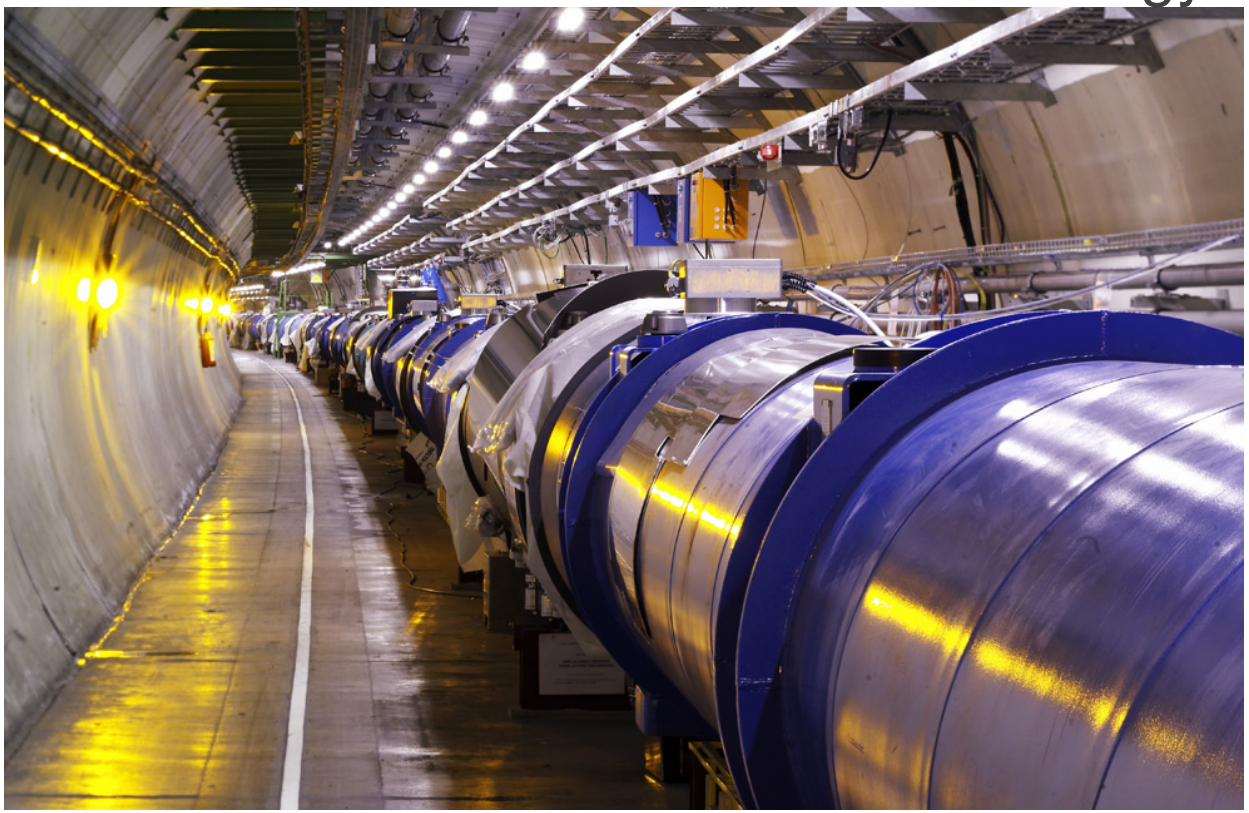
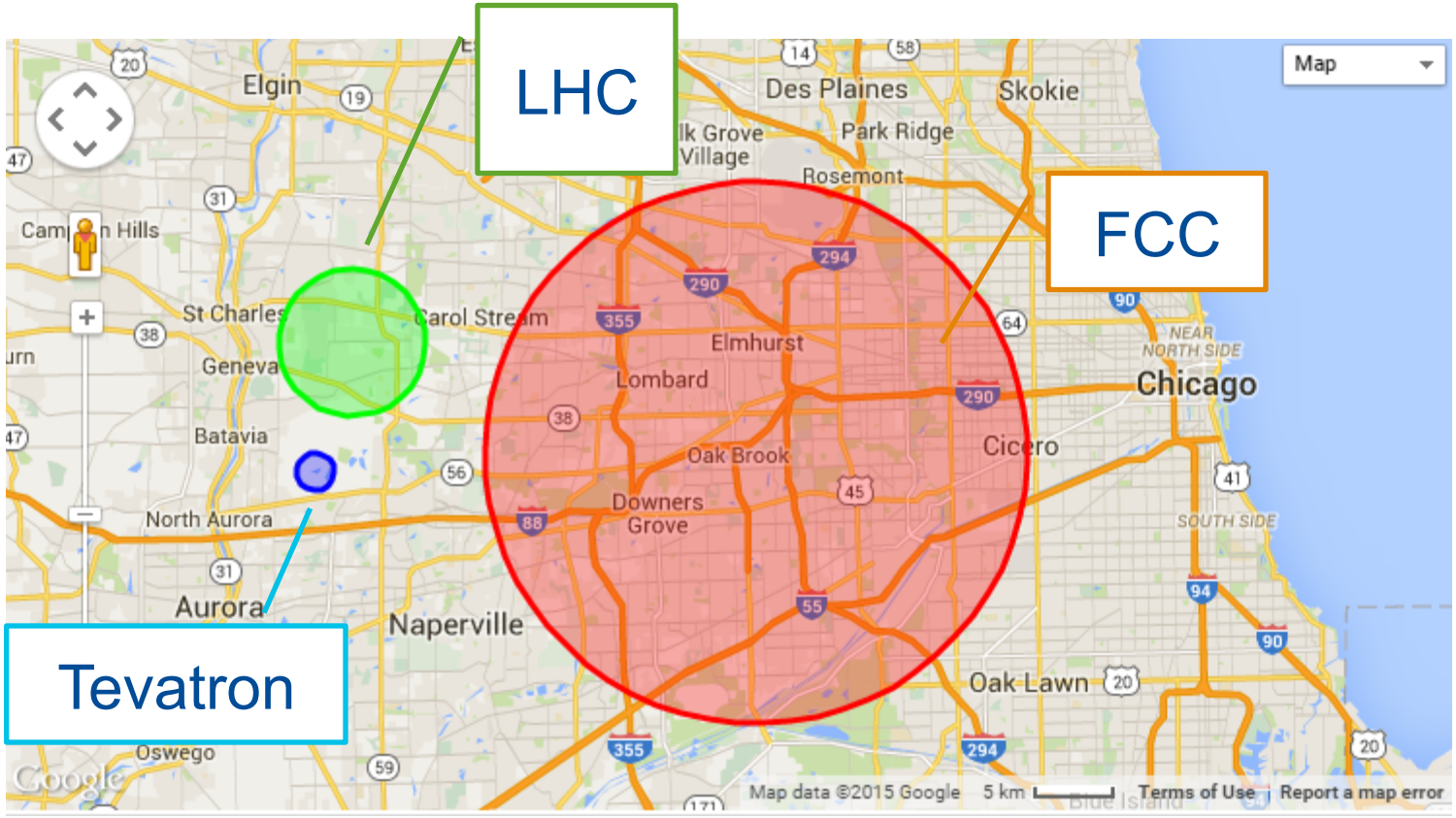
Motivation

- In 2012 the LHC discover the Higgs with 7 TeV collision energy
- Run 2 of the LHC will be at 13 Tev collision energy

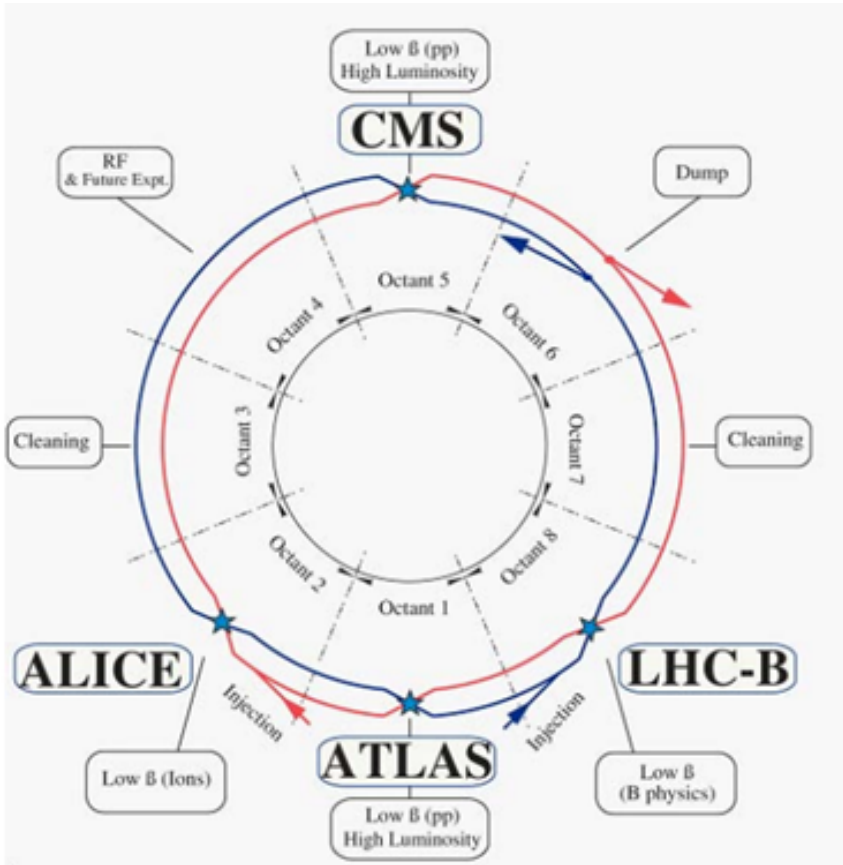


http://www.extremetech.com/extreme/176969-searching-for-supersymmetry-work-begins-on-large-hadron-colliders-60-mile-long-successor

Basic LHC Design



Basic LHC Design

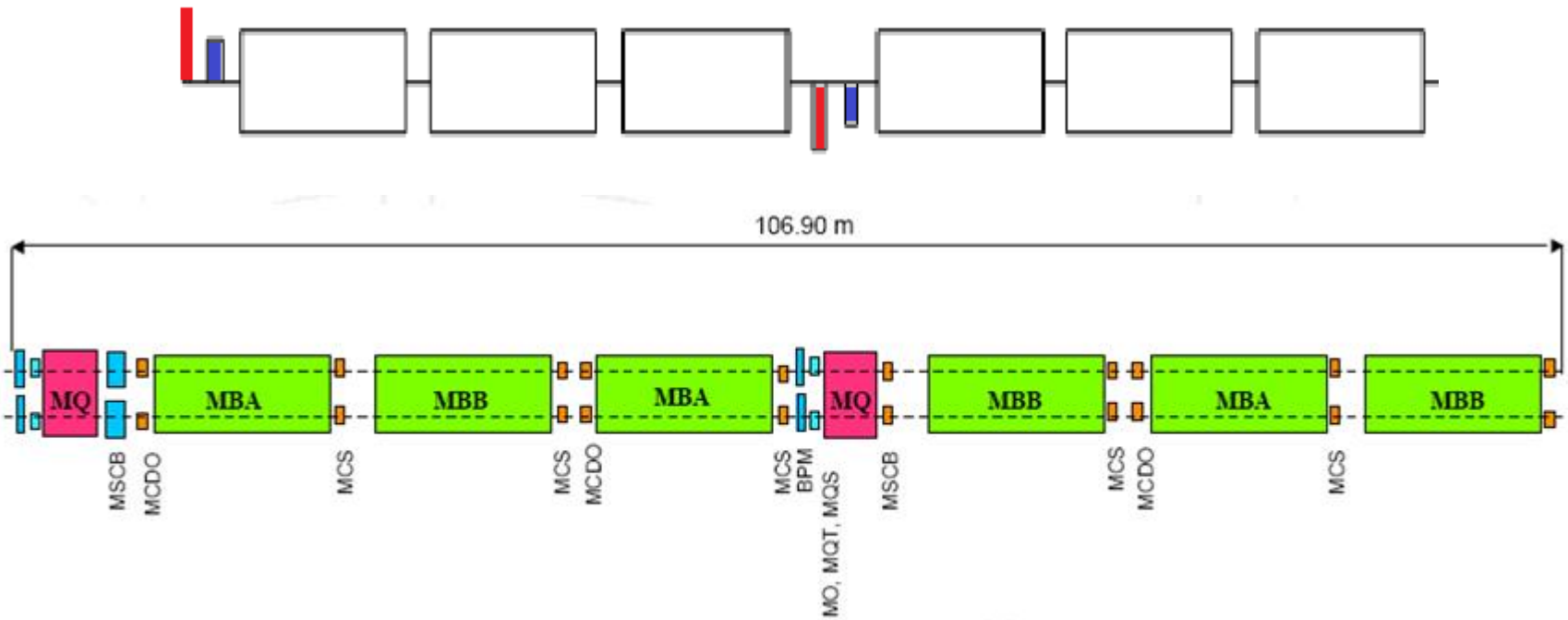


http://www.symmetrymagazine.org/breaking/2008/08/25/free-online-full-documentation-for-the-large-hadron-collider

- Circumference=27km
- 8 straight sections
- Each straight section = 528m
- Arc fill factor = 0.84

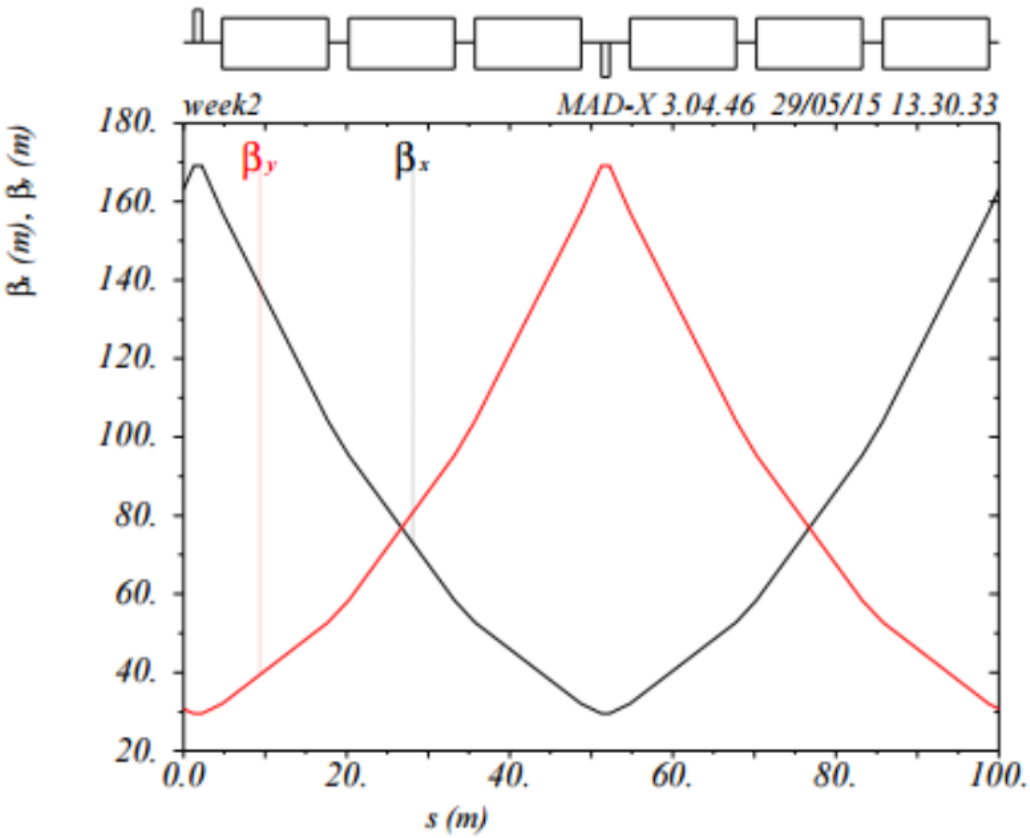
FODO Cell

- Dipoles bend the beam
- Quadrupoles focus the beam
- Sextupoles give the chromaticity of the machine
- Packing Fraction=length of magnets/length of cell



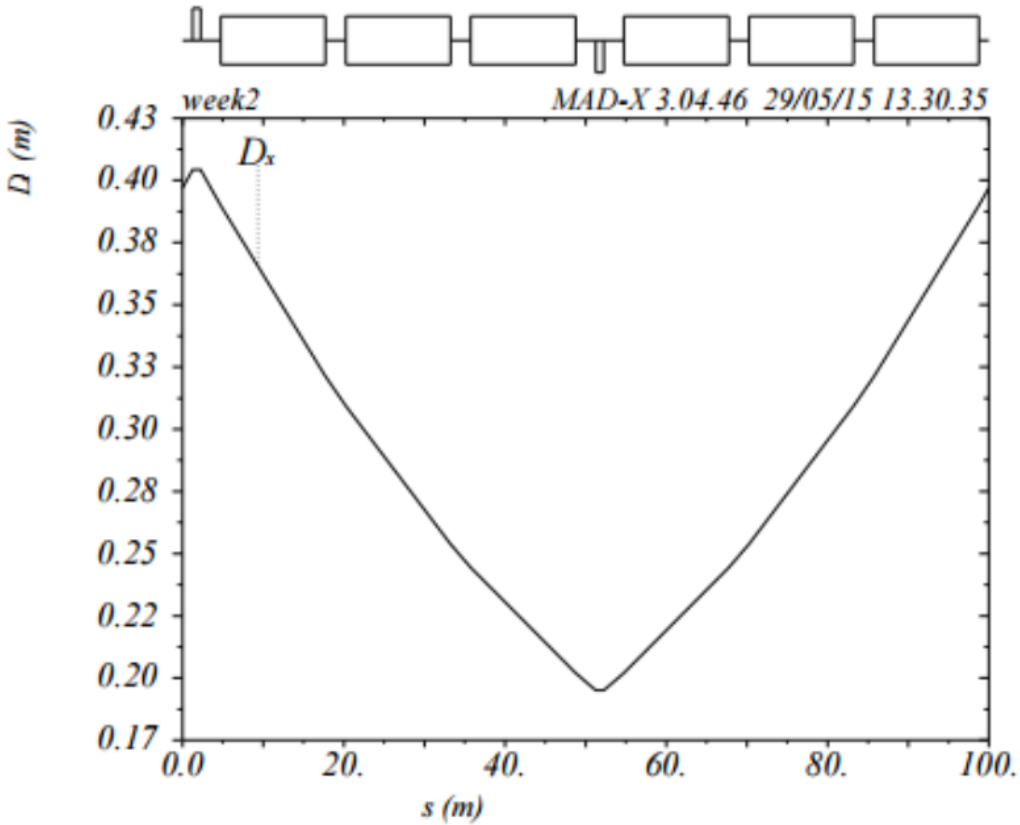
http://lhc-closer.es/taking_a_closer_look_at_lhc/0.lhc_layout

Optics Functions - Beta



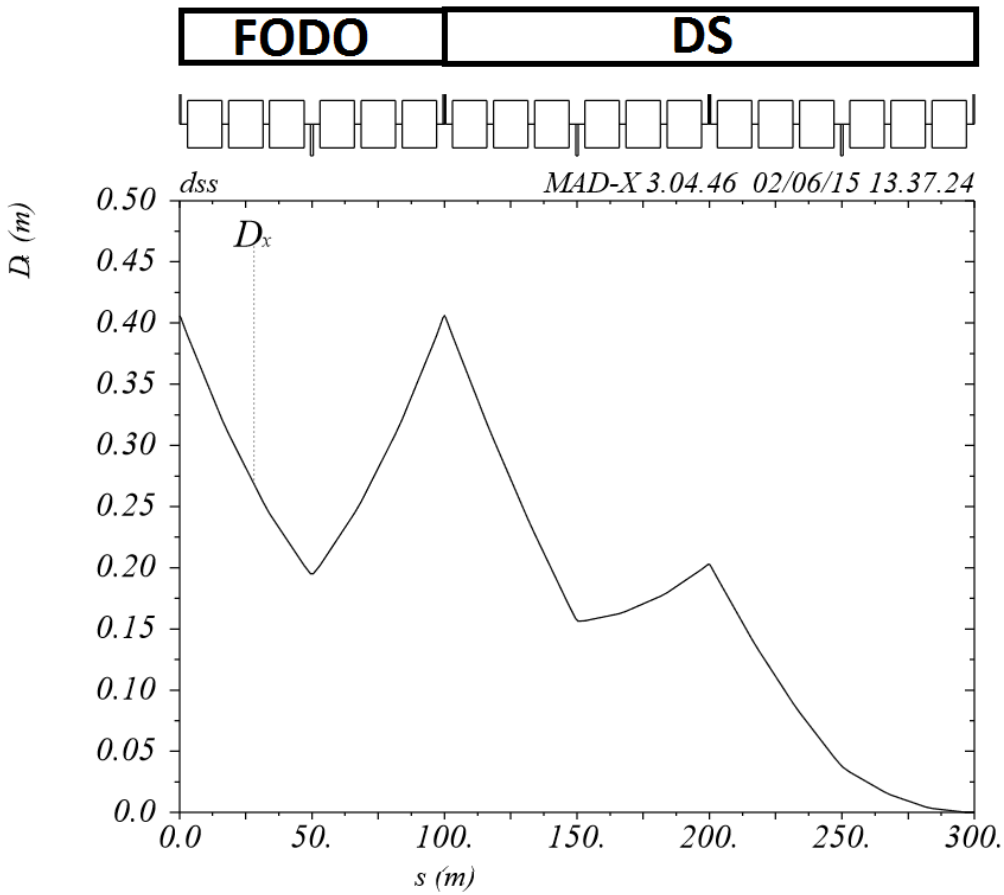
- $\beta_{Max} = L(1+\sin(\Delta\varphi_c/2)/\sin(\Delta\varphi_c))$
- $\Delta\varphi_c = \pi/2 = \int ds/\beta(s)$
- $\Delta\varphi_c$ is determined by the strength of the Quad

Optics Functions - Dispersion



- Comes from off energy particles being bent a different amount by the dipoles

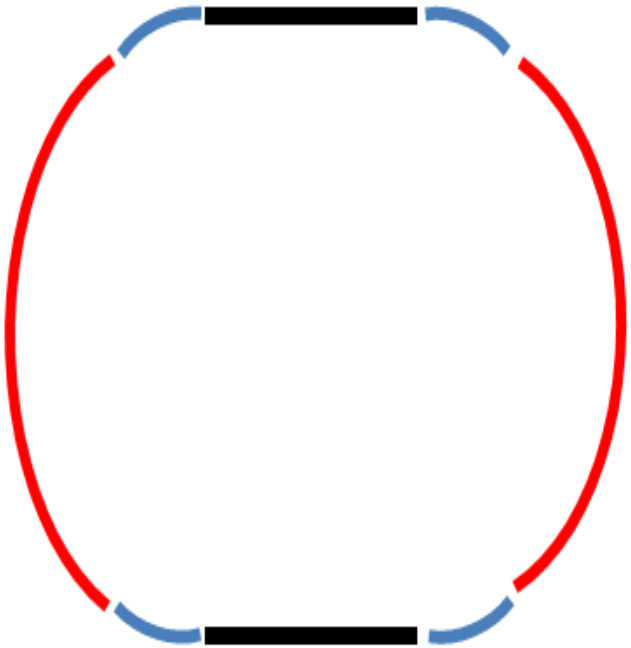
Dispersion Suppressor



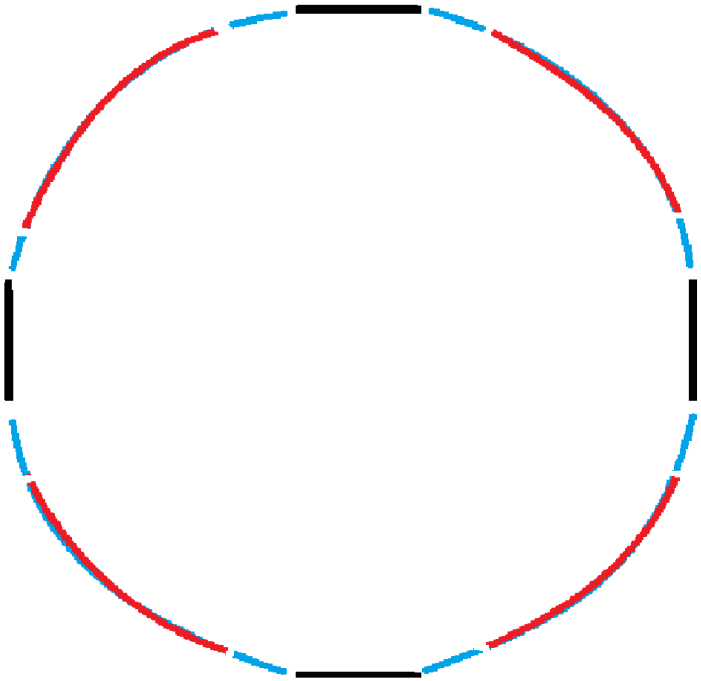
- Made of 2 FODO cells with dipoles that are ½ strength

Ring Designs

- Racetrack



- 4 straight sections



Ring Parameters

- arc fill factor = 0.84 (DS are considered part of straights)
- Packing fraction = 0.86
- Half aperture = 0.02 m (same as SSC)
- Phase advance per cell = $\pi/2$
- Chromaticity = 1
- RF frequency = 400MHz , Voltage = 100MV

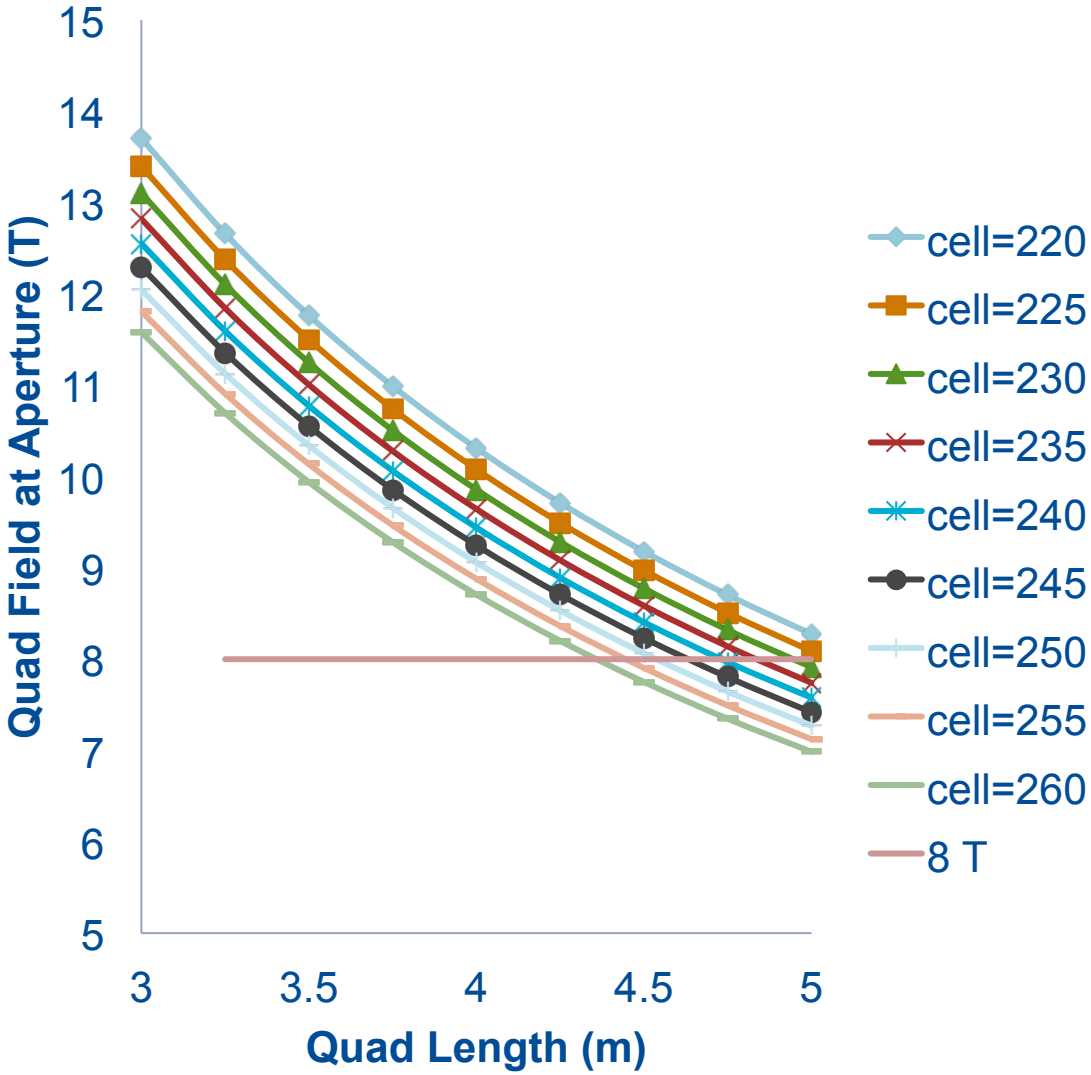
Ring Parameters

- Variables
  - Cell length (200-260 m)
  - Quad length (≤ 5 m)
  - Dipole length (5-15 m)
- Goal
  - Keep dipole field under 15 T
  - Keep quad field at aperture under 8 T

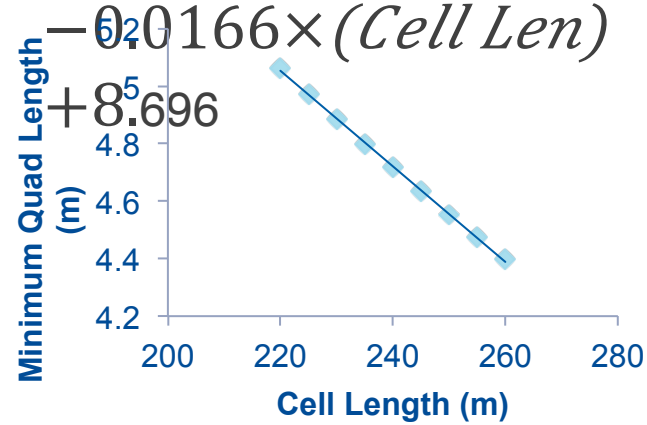
MADX

- Build a FODO cell, DS, or ring
  - Define a beam
  - Calculates and plots optics functions
  - MATCH command finds the strengths of the magnets to get $\Delta \varphi\downarrow c = \pi/2$ and dq1=1
    - Quad coefficient is reduced by 5% to avoid integer tunes
  - TRACK particles around the ring

Reducing the Number of Variables – Quad Length



- Quad length ≤ 5 m
- Quad field at aperture ≤ 8 T
- $Quad\ Field = Const./Quad\ Len$
- Set Quad field= 8T, and solved for Quad Len
- $Min\ Quad\ Len = -0.0166 \times (Cell\ Len) + 8.696$



Dipole Field

- Number of dipoles / cell
  - numbdip $=2*floor(lencell*maxpack-2*quad/2*\mathrm{dip})$
- Number of cells/ arc
  - $\mathrm{numbcell}=\mathrm{floor}(1/\mathrm{numb\ str}\ (100000*\mathrm{arcfill}/\mathrm{lencell}-4*\mathrm{numb\ str}))$
- Bend angle / dipole
  - $bend=2\pi/numb\ dip*numb\ str\ (numb\ cell+2)$
- Dipole Field
  - $dip\ field=(B\rho)*bend/dip$

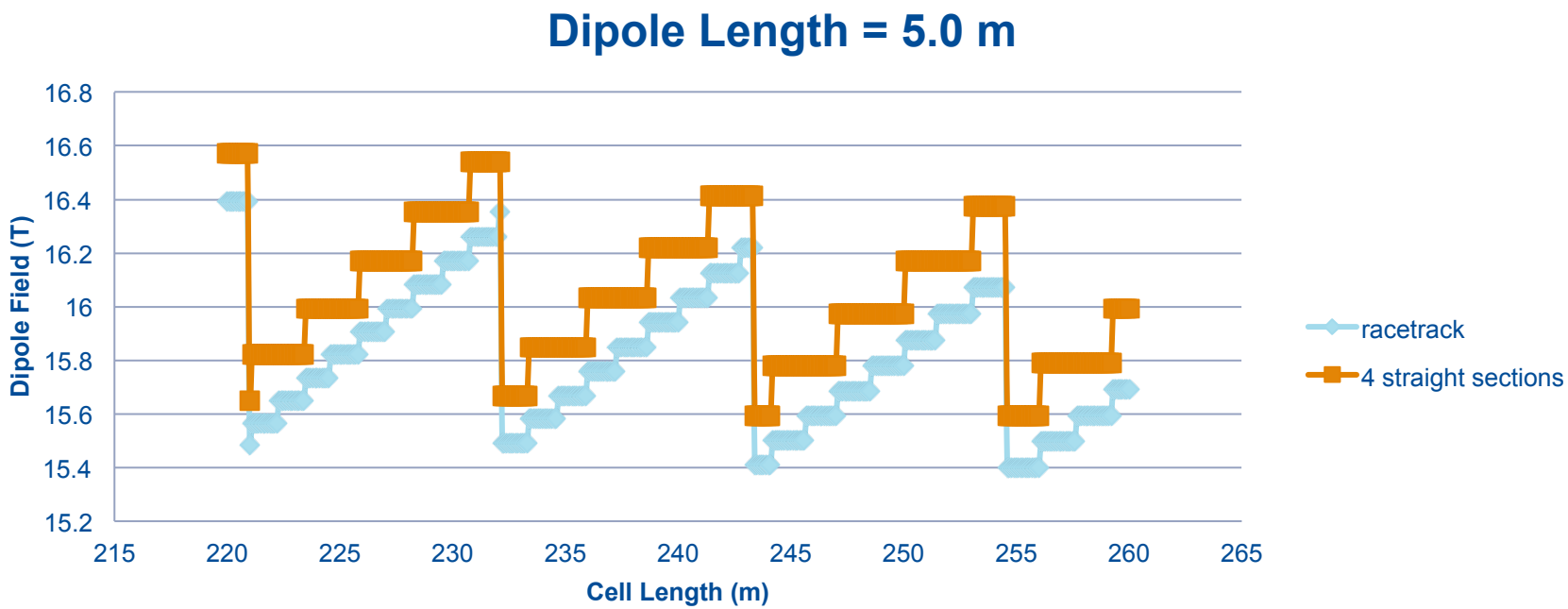
Minimizing Dipole Field

- Using a C++ program to scan over cell length and dipole length
  - It writes the matching cells to an output file
  - Does this for both rings

Number of Solutions		
Max Field (T)	4 straights	racetrack
15.2	0	0
15.3	0	4
15.4	0	4453
15.5	12	22991
15.6	3108	50244

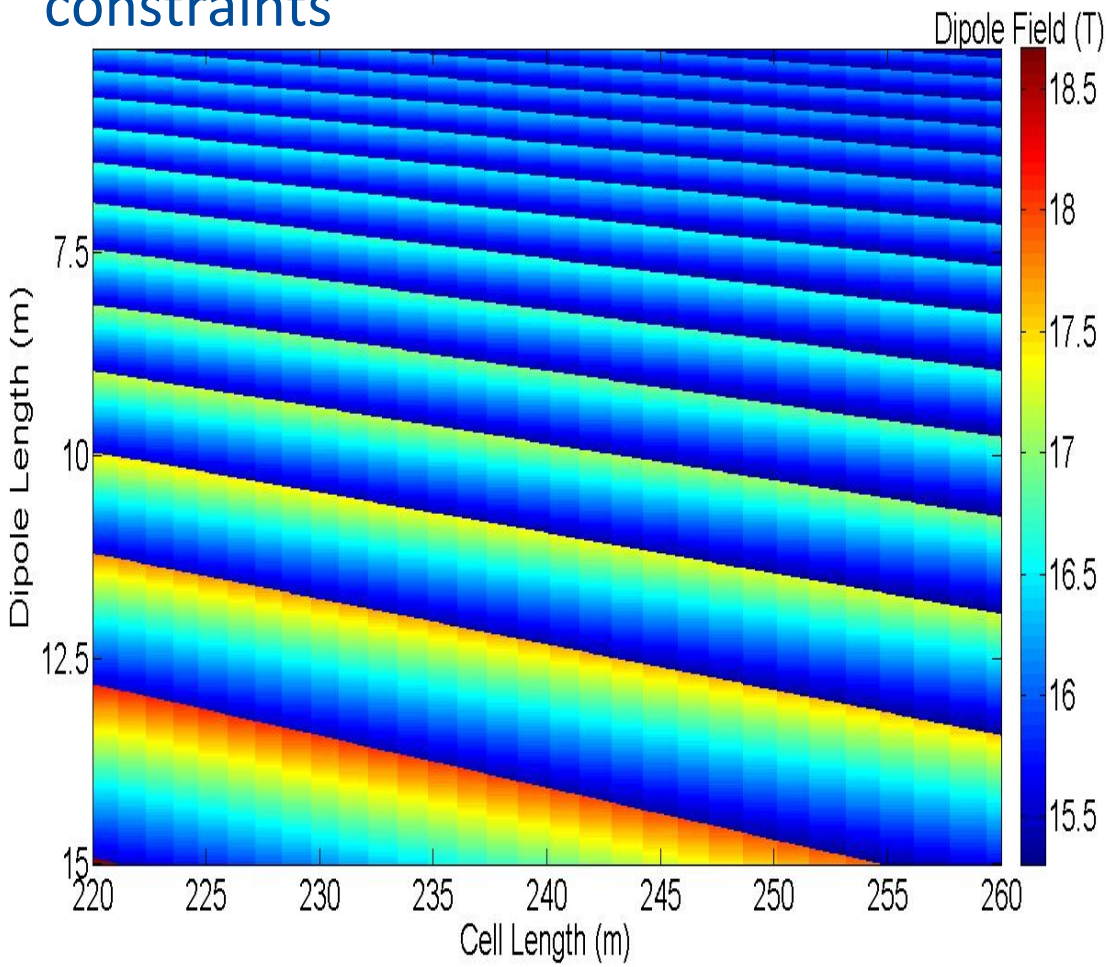
Number of solutions

- Why is there more solutions for the racetrack?
  - Combine Equations for bend, numb cell, numb dip, and dipole field
  - $Dipole\ Field = 2\pi * (B\rho)/dip * numb\ dip\ (K - 2 * numb\ str)$
    - $K = 100000 * arc\ fill/len\ cell$



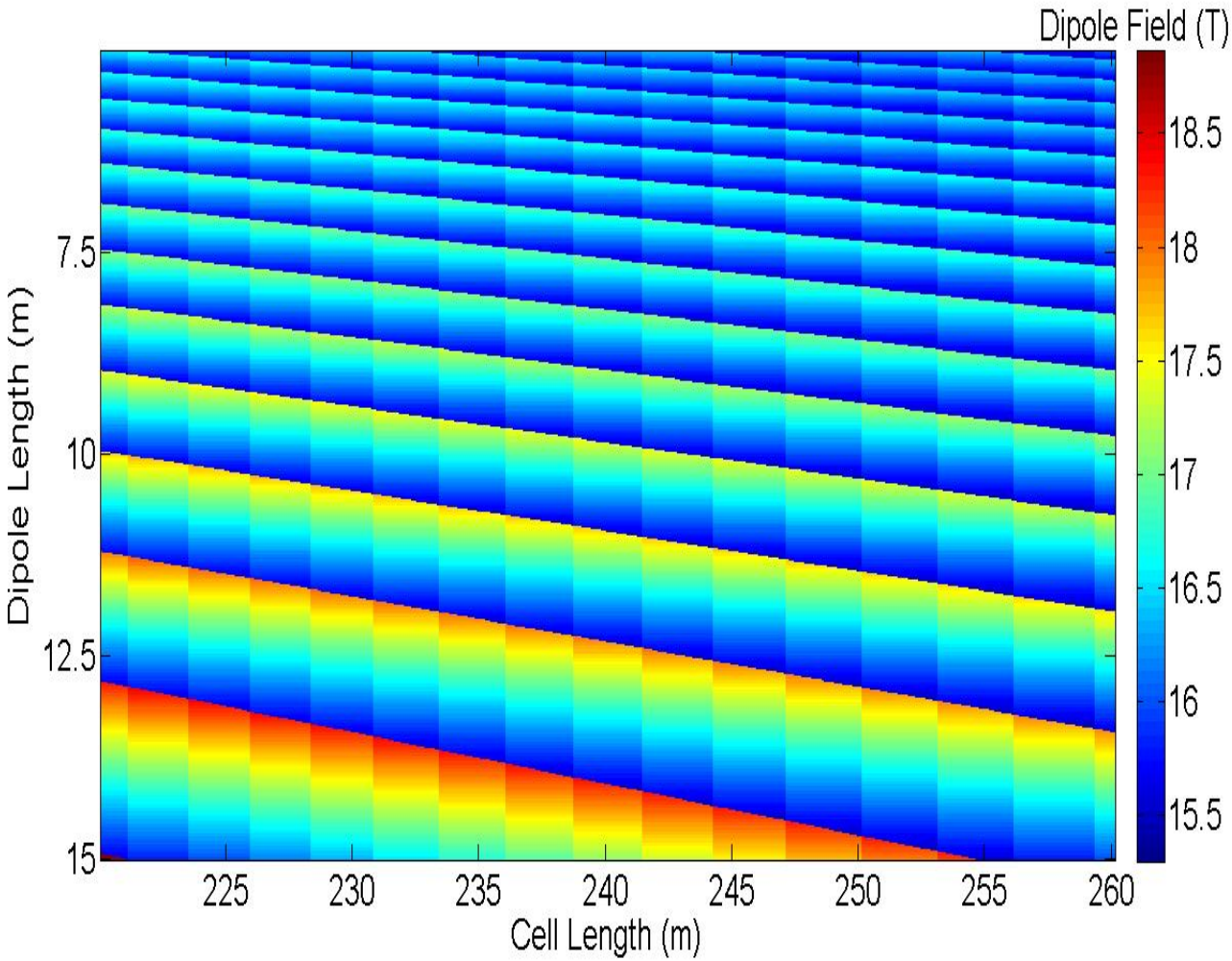
Dipole Field – Racetrack

- Combining the 5 equations and keeping the integer constraints



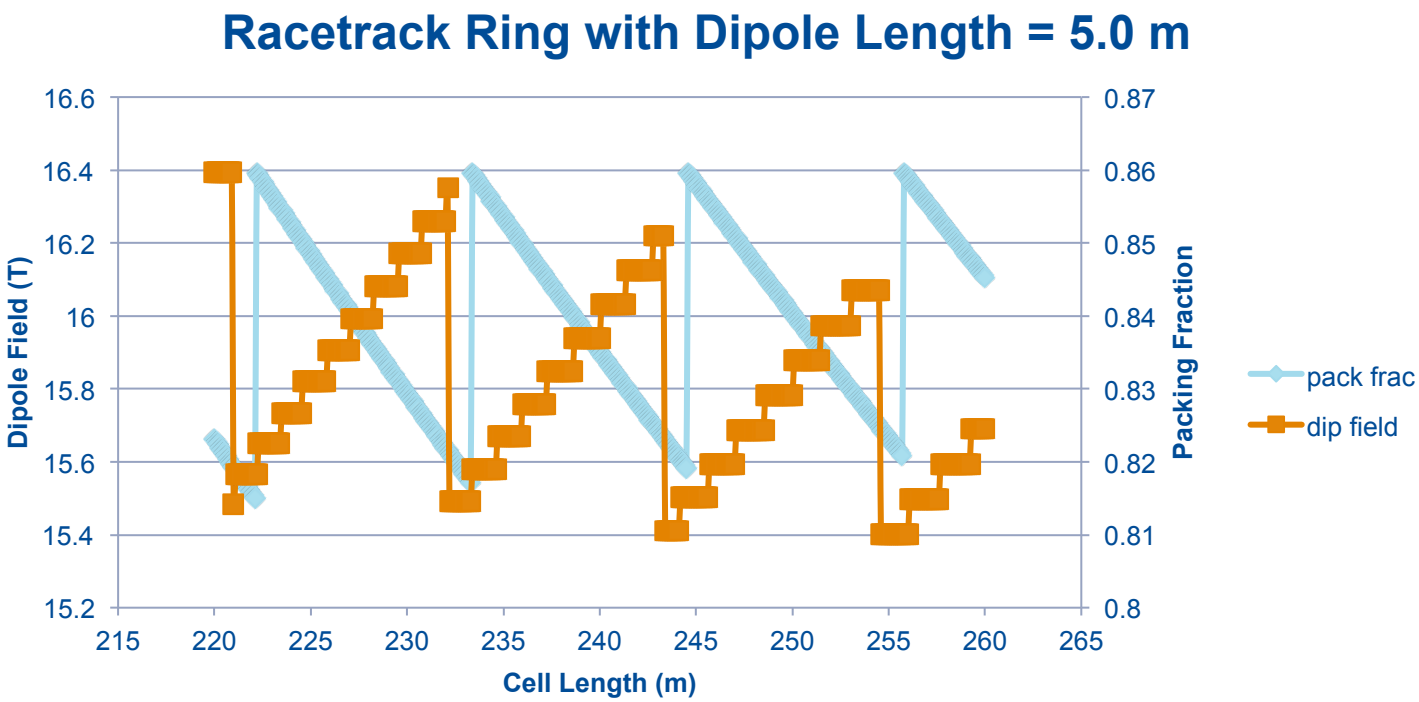
- Pixels are to small to see a trend

Dipole Field – 4 Straight Sections



Dipole Length = 5.0 Cross Section

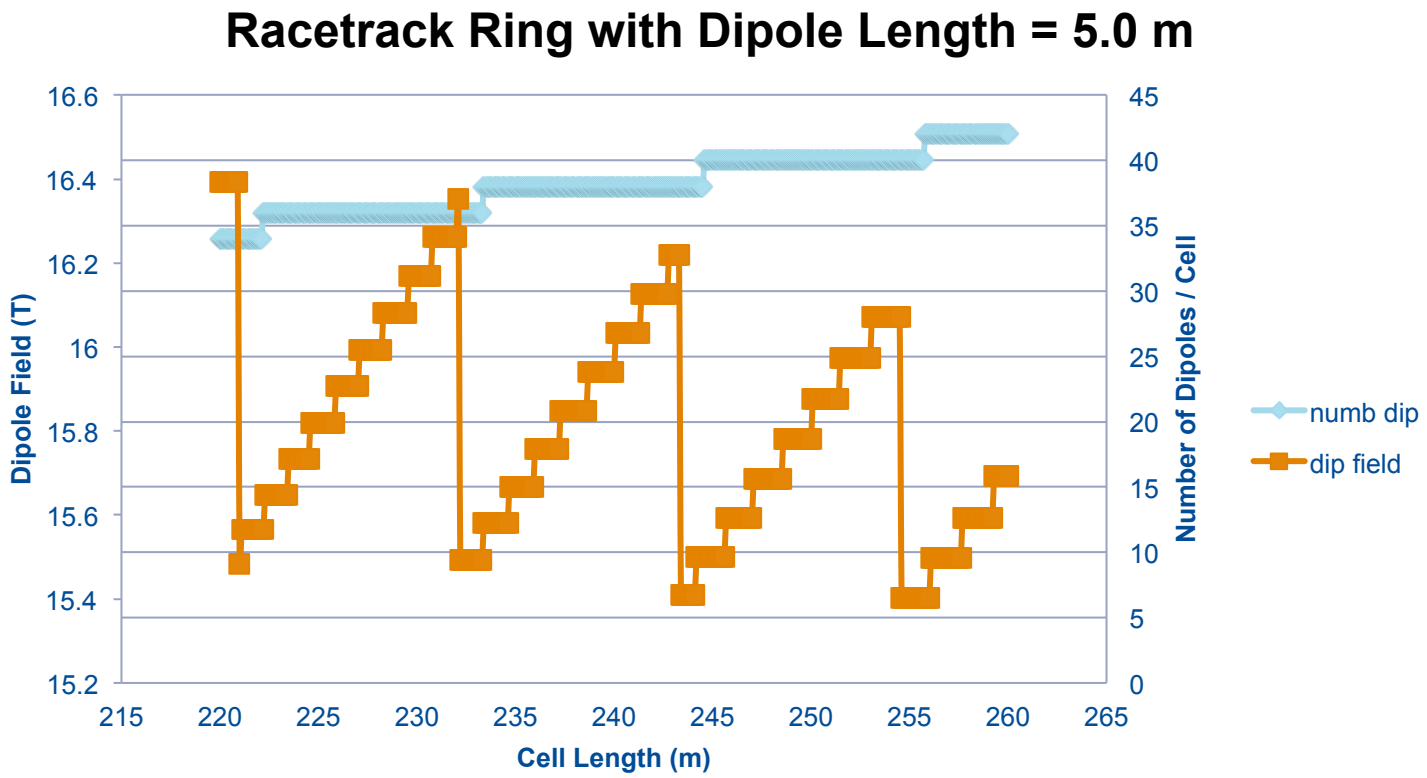
- Consider the racetrack



- Field is inversely proportional to packing fraction

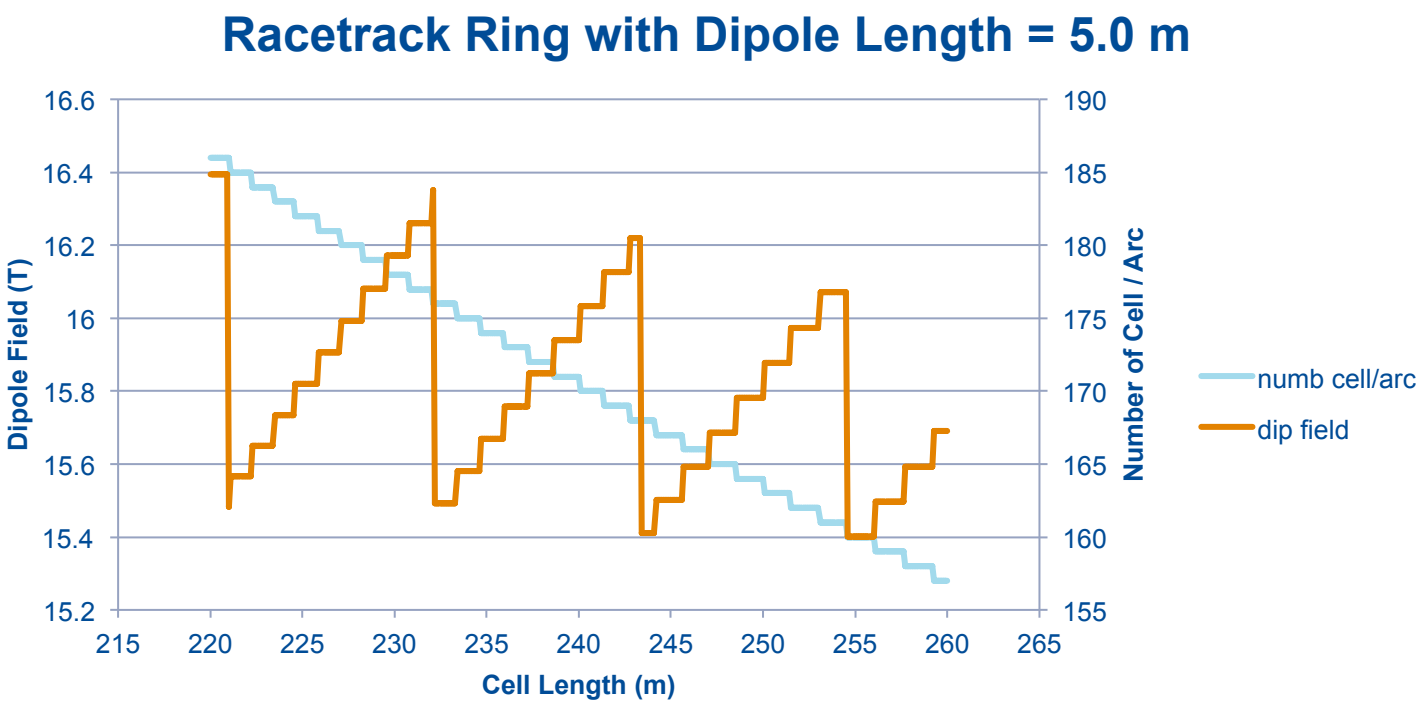
Dipole Length = 5.0 Cross Section

- Long periodicity comes from packing fraction and number of dipoles / cell



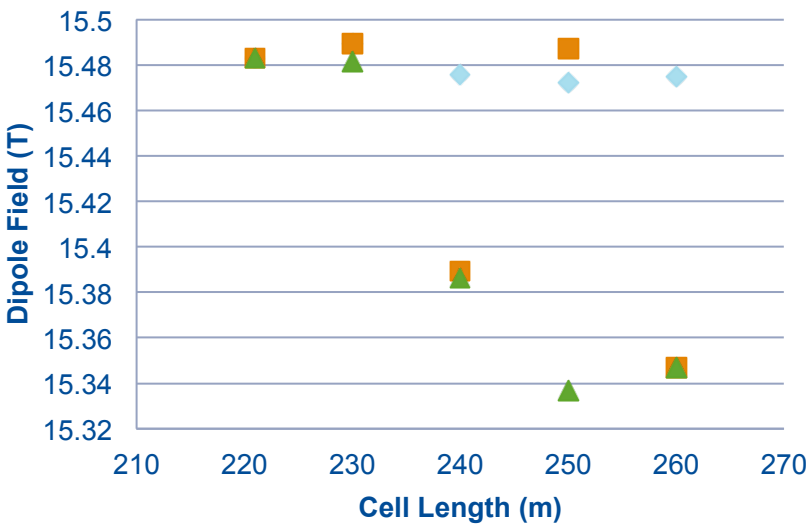
Dipole Length = 5.0 Cross Section

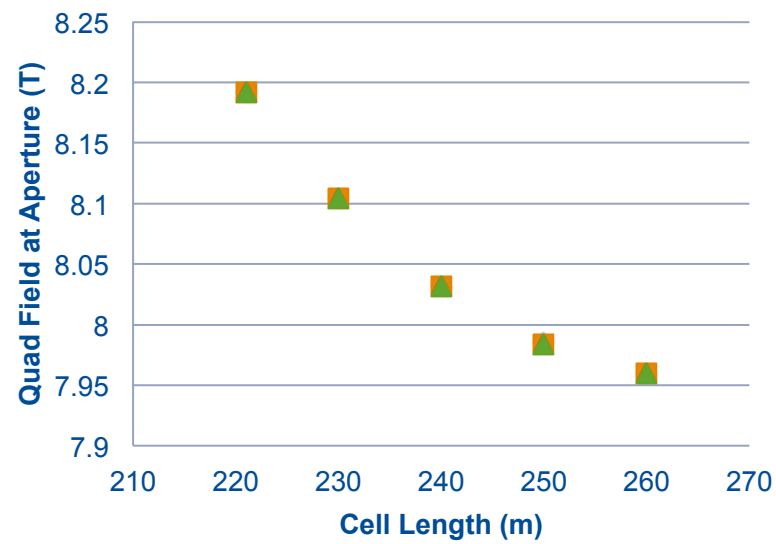
- Long periodicity comes from packing fraction and number of dipoles / cell
- Short periodicity comes from the number of cell/arc



Magnetic Fields – Racetrack

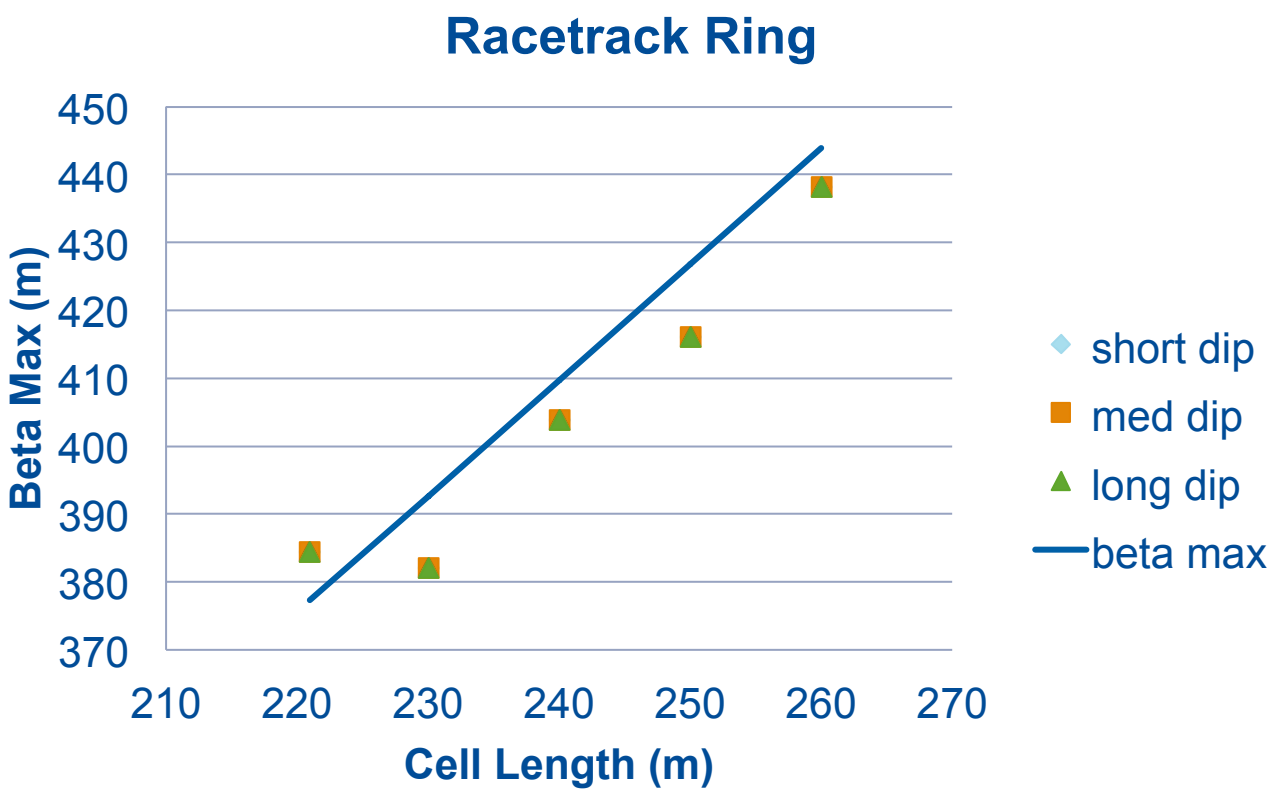
- Compare both extremes and middle of dipole lengths
- Chose the shortest, the closest to 10m, and the longest dipole length with Dipole Field ≤ 15.5T





Other Variables – Racetrack

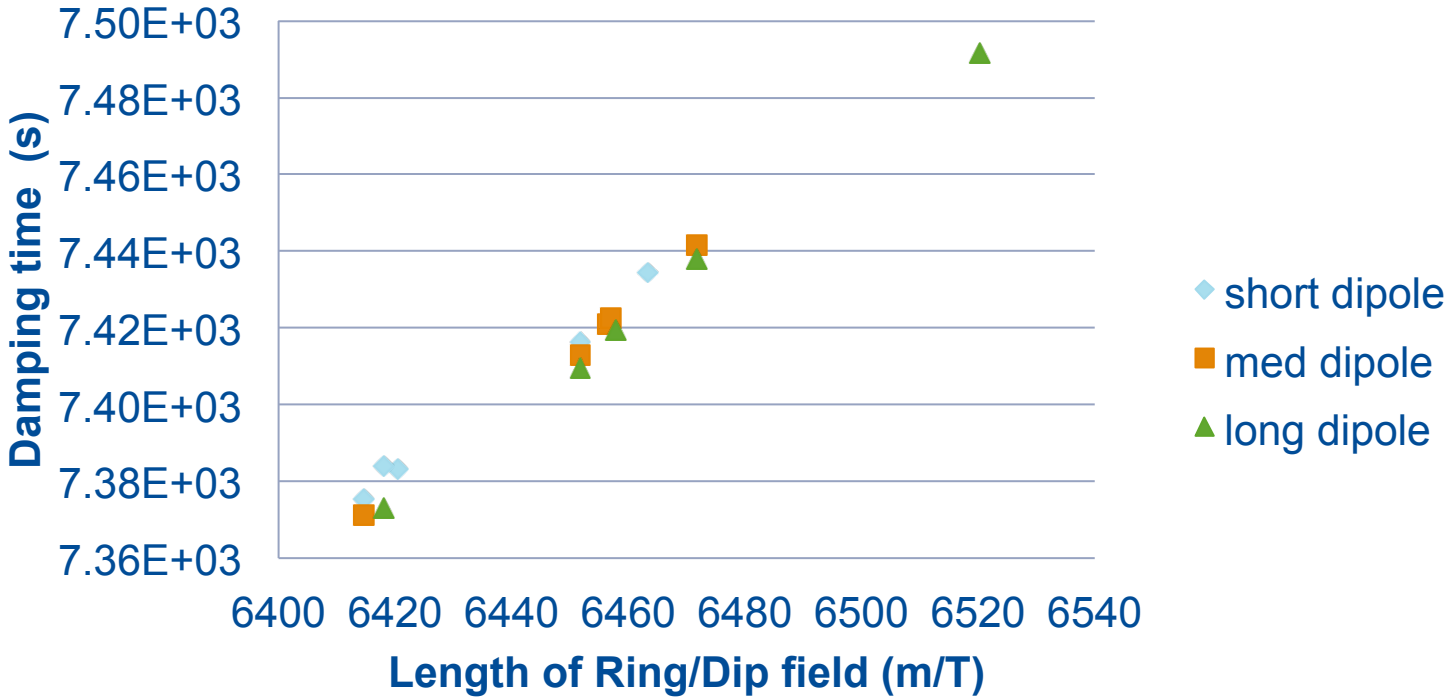
- $\beta_{max} = L(1+\sin(\Delta\varphi_c/2)/\sin(\Delta\varphi_c))$



Other Variables – Damping Time (mode 1)

- $\tau = 2\ E_0\ T_0\ /U_0$
- Time per revolution= $T_0 \propto Length\ of\ Ring$
- Energy lost per turn= $U_0 \propto I_2 \propto Dipole\ Field$

- $\tau \propto Lenght\ of\ Ring/field$



Picking a FODO Cell Design

Racetrack	
Dipole Field ≤15.3T	Dipole (length)
Cell Length= 259.2 m	6.69
	8.92
	9.72
	13.38

4 Straight Section	
Dipole Field ≤15.5T	Dipole (length)
Cell Length= 259.1 m	5.53
	8.23
	10.7
	11.89
Cell Length = 259.2 m	5.35
	6.69
	8.23
	8.92
	9.73
	10.7
	11.89
	13.38

Conclusions

- A cell Length of 259.2m minimizes the dipole field for both rings
  - Multiple dipole lengths work as long as packing fraction is maximized
- Points to consider
  - Beam dynamics: instabilities, beam-beam effects, …
  - Complete straight section design with Interaction Regions
  - Different dispersion suppressors