LHC phase 1 upgrade

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LHC phase 1 upgrade

In 2012 LHC should have reached its maximum performance.
An upgrade of the interaction region called "phase 1" should provide a reliable improvement to help the LHC reach and possibly exceed the nominal performance.
The upgrade aims to a $\beta^* = 25cm$ and $L^* = 23m$. The upgrade should leave untouched the experimental area.

Limits for a final focus for the LHC

The boundaries used as a guideline for designing a new interaction region are:

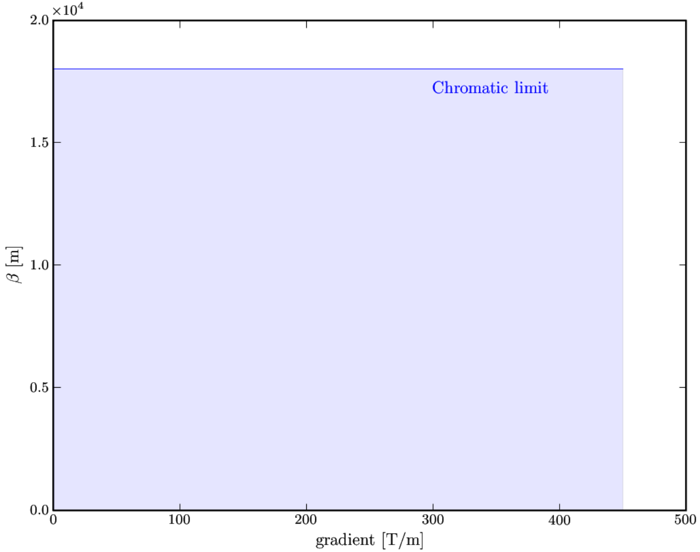
- chromaticity;
- peak field in the quadrupole coils;
- lowest maximum beta function.

There are many other conditions to be checked but they are left for the next iterations.

Aberration limit

Past experience shows that linear chromaticity can be corrected for optics where β max is smaller than 18km. Because it is not wise to go further in beta max for other aberrations as well, it seems reasonable to set this limit.

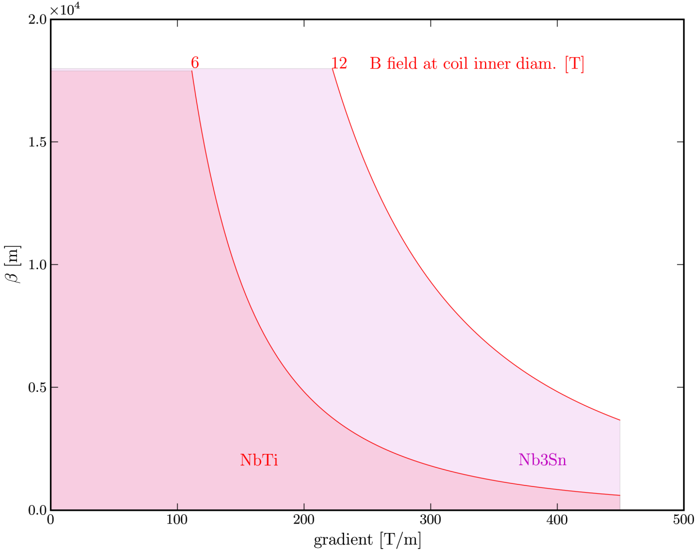
Aberation limit



Peak field limit

Coil inner diameter can be estimated using:
beam envelope $(33\sigma + 7\text{mm})+$
beam screen and beam pipe (10mm).
Peak field in the coils is approximately 10% greater than the peak at the coil inner diameter.

Peak field limit



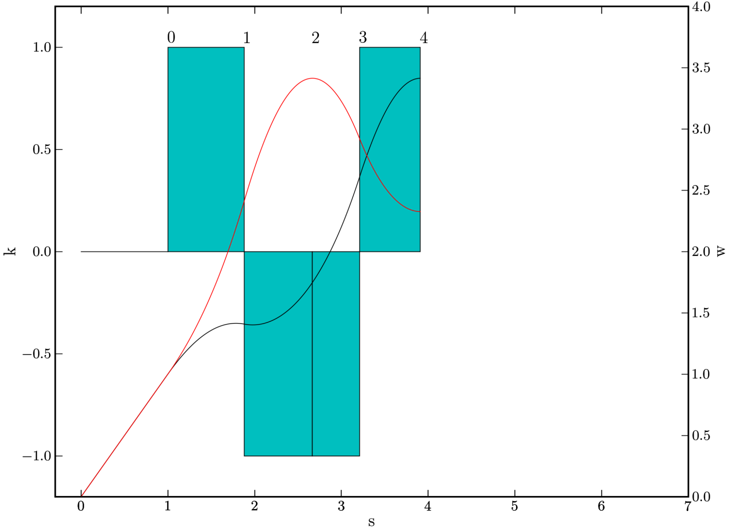
Focus system

For a round beam it is possible to design an optimized focusing system using:

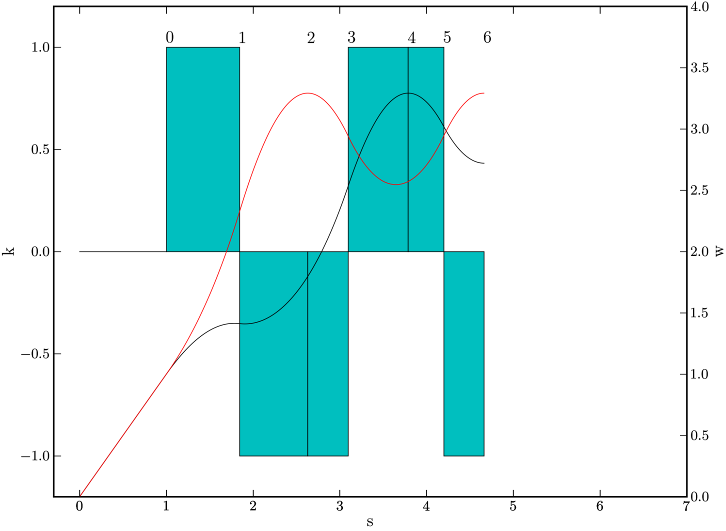
- a triplet
- a quadruplet
- a quintuplet and so on.

Experience shows that while there is a gain beta max passing from triplet to quadruplet, this gain is limited to a quintuplet.

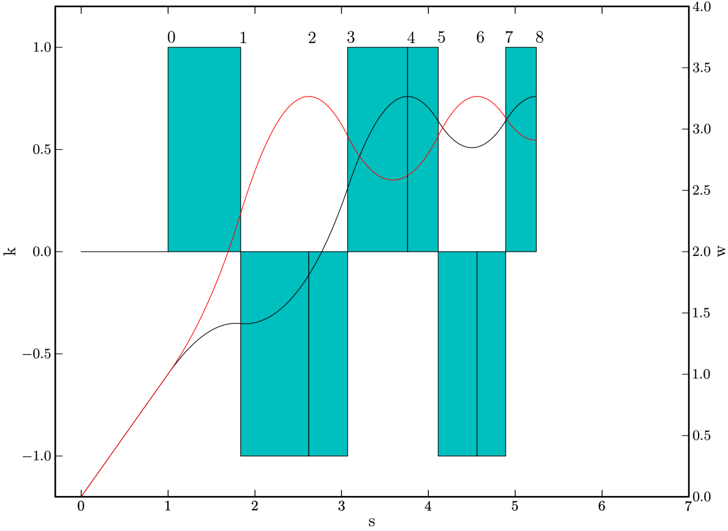
Triplet



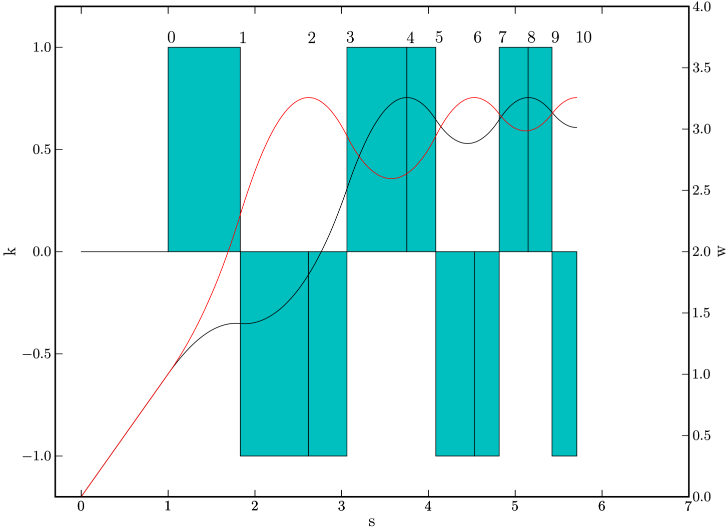
Quadruplet



Quintuplet



Sextuplet



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k
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2.0
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1.0
0.5
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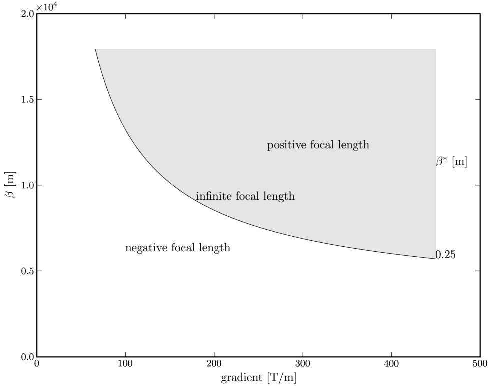
6
7
s

Focus limit

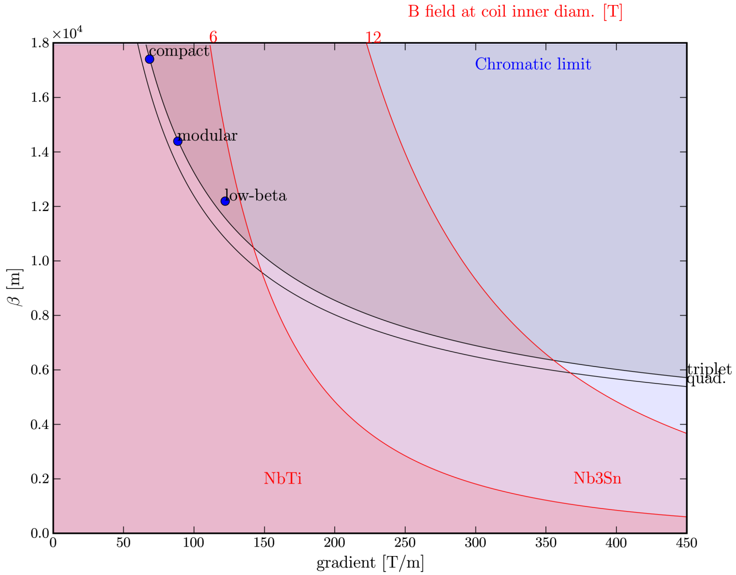
It has been observed, but not rigorously demonstrated (yet), that:

- for a given peak field, there is a lower bound for the maximum beta function in the quadrupoles of a focusing system.
- the lower bound is equal to the maximum beta for a the system which has an infinite focal length and the gradients of all but the first quadrupole are equal.

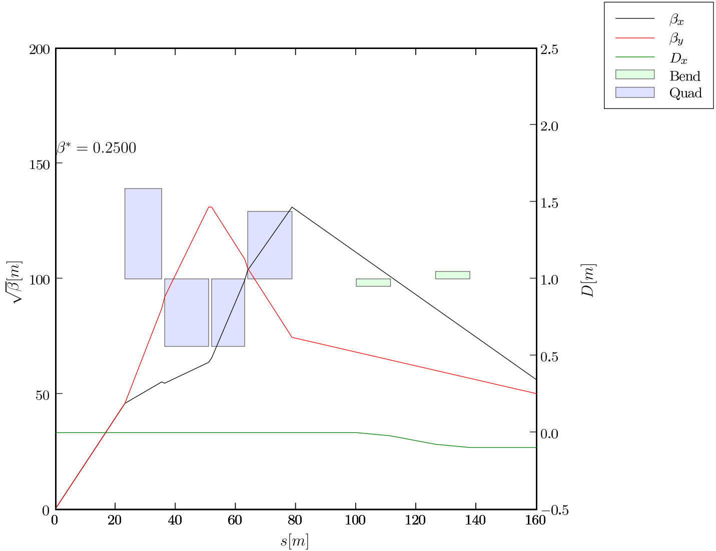
Focus limit for the LHC upgrade



All together for $\beta^* = 25$cm and $L^* = 23$m



Compact low gradient



Compact low gradient

Type Triplet like solution

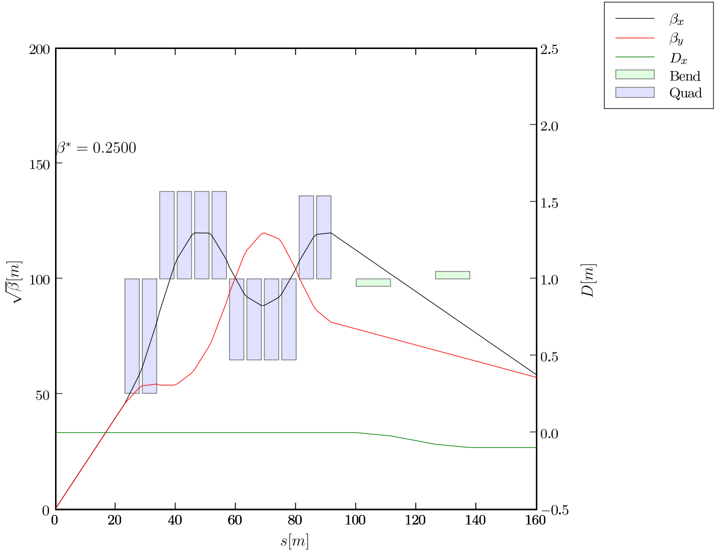
Purpose Provide the largest additional aperture margin requirements

Requirements 2(1) apertures, 2 gradients, 3 lengths

Name	Length	Start p.	Gradient
	[m]	[m]	[T/m]
MQXN1.R5.B1	12.2444	23	91.4487
MQXN2.R5.B1	14.6249	36.2444	-68.3344
MQXN3.R5.B1	10.9992	51.8693	-68.3344
MQXN4.R5.B1	14.7506	63.8684	68.3344

Name	Beta max	Sigma	Beam size	Coil diam.
	[m]	[mm]	[mm]	[mm]
MQXN1.R5.B1	7593.09	1.95362	81.4695	164.026
MQXN2.R5.B1	17193.9	2.9398	114.013	219.509
MQXN3.R5.B1	17193.9	2.9398	114.013	219.509
MQXN4.R5.B1	17193.3	2.93975	114.012	219.509

Modular low gradient



Modular low gradient

Type Quadruplet like solution

Purpose Provide additional aperture margin and optimize magnet requirements

Requirements 2(1) apertures, 2 gradients, 1 lengths

Name	Length	Start p.	Gradient
	[m]	[m]	[T/m]
MQXN1.R5.B1	4.8	23	-115.854
MQXN2.R5.B1	4.8	28.8	-115.854
MQXN3.R5.B1	4.8	34.6	88.5221
MQXN4.R5.B1	4.8	40.4	88.5221
MQXN5.R5.B1	4.8	46.2	88.5221
MQXN6.R5.B1	4.8	52	88.5221
MQXN7.R5.B1	4.8	57.8	-82.0402
MQXN8.R5.B1	4.8	63.6	-82.0402
MQXN9.R5.B1	4.8	69.4	-82.0402
MQXN10.R5.B1	4.8	75.2	-82.0402
MQXN11.R5.B1	4.8	81	84.059
MQXN12.R5.B1	4.8	86.8	84.059

Modular low gradient

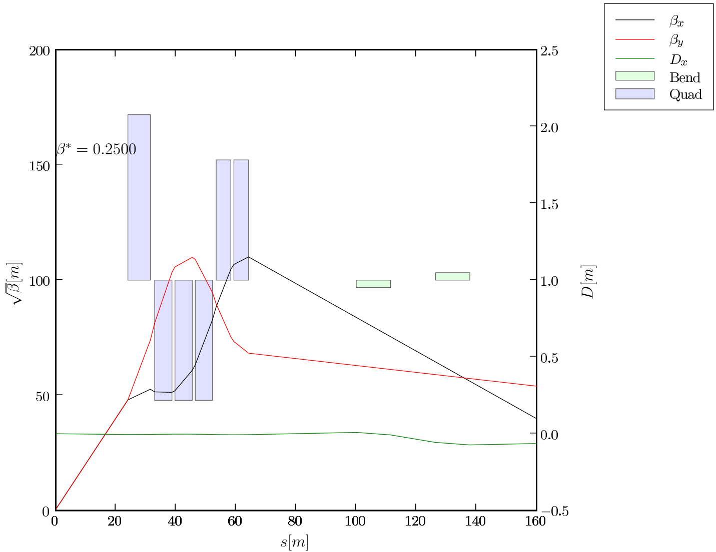
Type Quadruplet like solution

Purpose Provide additional aperture margin and optimize magnet requirements

Requirements 2(1) apertures, 2 gradients, 1 lengths

Name	Beta max	Sigma	Beam size	Coil diam.
	[m]	[mm]	[mm]	[mm]
MQXN1.R5.B1	3415.33	1.31023	60.2376	129.473
MQXN2.R5.B1	6567.85	1.81695	76.9593	129.473
MQXN3.R5.B1	11126.6	2.3649	95.0417	169.449
MQXN4.R5.B1	14133.6	2.66537	104.957	169.449
MQXN5.R5.B1	14390.4	2.68948	105.753	169.449
MQXN6.R5.B1	14095.1	2.66174	104.837	169.449
MQXN7.R5.B1	12097.4	2.46591	98.3749	182.837
MQXN8.R5.B1	14276.2	2.67878	105.4	182.837
MQXN9.R5.B1	14389.8	2.68942	105.751	182.837
MQXN10.R5.B1	13419.4	2.59715	102.706	182.837
MQXN11.R5.B1	13946.8	2.64769	104.374	178.446
MQXN12.R5.B1	14389.9	2.68942	105.751	178.446

Small beta low gradient



Small beta low gradient

Type Triplet like solution with $L^* = 24\mathrm{m}$.

Purpose Provide the lowest beta max

Requirements 2 apertures, 2 gradients, 3 lengths

Name	Length	Start p.	Gradient
	[m]	[m]	[T/m]
MQXN1.R5.B1	7.48577	24	167.677
MQXN2.R5.B1	5.75345	32.9131	-121.796
MQXN3.R5.B1	5.75345	39.6665	-121.796
MQXN4.R5.B1	5.75345	46.4201	-121.796
MQXN5.R5.B1	4.89064	53.373	121.796
MQXN6.R5.B1	4.89064	59.2741	121.796

Name	Beta max	Sigma	Beam size	Coil diam.
	[m]	[mm]	[mm]	[mm]
MQXN1.R5.B1	5473.73	1.65872	71.7377	89.4575
MQXN2.R5.B1	10682.8	2.31725	93.4693	123.157
MQXN3.R5.B1	12081.5	2.46428	98.3214	123.157
MQXN4.R5.B1	11879.5	2.4436	97.6388	123.157
MQXN5.R5.B1	10963.6	2.34751	94.4677	123.157
MQXN6.R5.B1	12117.5	2.46796	98.4425	123.157

Summary

The layouts presented represent extreme cases in terms of margins and implementations that can be further optimized.
Before such optimization it needs to be clarified:

- the requirements for the multipole correction scheme together with an estimate for the field quality of the magnets which can already exclude some of the options presented.
- the requirements for the radiation protection and estimates for heat deposition which will set the operational margin for the quadrupole.
- an estimate of the required beam-beam separation which should give the optimal $beta^*$ and therefore the potential luminosity gain of the upgrade.

Available studies

The studies and scripts are world readable starting from:

```
/afs/cern.ch/user/r/rdemaria/dott/layouts
```

The directory tree is organized like:

```
/compact
/compact/seq.lhc.madx
/compact/seq.lhc_coll.madx
/...
/compact/collision_optics/...
/compact/chromaticity_correction/...
/...
/modular/
/...
/lowbeta/
/...
```

Available studies

Studies	Compact	Modular	Low-beta
Beam 1	yes	yes	yes
Beam 2	old	old	yes
Chromaticity B1	yes	yes	yes
Chromaticity B2	setup	setup	setup
Tunability	setup	setup	setup
Squeeze	setup	setup	yes
Injection optics	setup	setup	yes
Crossing scheme	setup	setup	yes
Thin model	setup	setup	setup
Mask file	setup	setup	setup
Tracking	setup	setup	setup
Multipole corr.	no	no	no
Energy depos.	no	no	no

Implementation notes:
the optics are based on V6.500
the phase advances are not optimized and therefore IR4 and IR6 require stronger quadrupoles. Shouldn't be and issue, but it needs to be checked
D1 and D2 are currently implemented as two single cold magnets.

Acknowledgment

I would to thanks the members of the section for the continuous support, discussions, ideas, debugging, during the last two years who made my work proceed faster and easier.