Optics for LHC phase 1 upgrade

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Introduction

The presentation will cover:

- a survey of the parameter space using a simplified model;
- results of studies for several upgrade optics implementation.

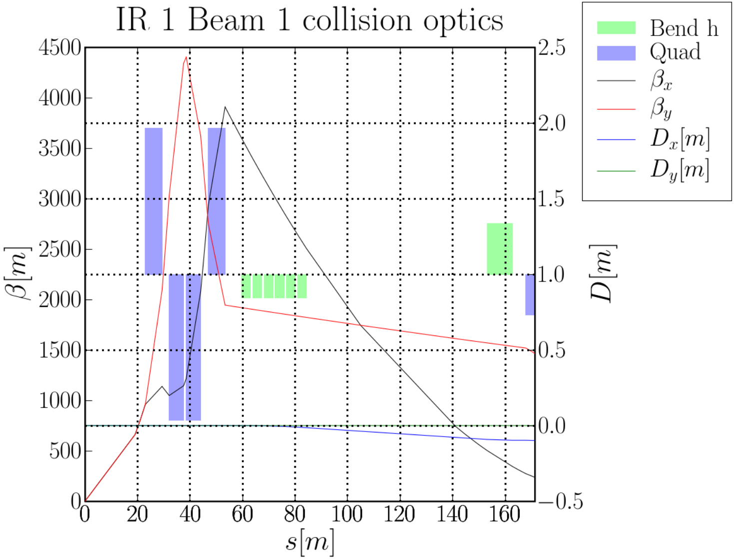
Phase 1 upgrade

Phase 1 upgrade aims at:

- $\beta^* = 25$cm, $L^* \geqslant 23$m;
- limiting the beam size in the focusing system (for reducing chromatic aberrations and errors sensitivities)
- maximizing the aperture margins in the focusing system (for reducing the heat load, radiation damage and increasing operational margin)
- making the final focusing system as short as possible (for reducing the number of long range beam beam interaction, reducing the field of D1/D2, reducing the cost)
- replacing less equipment as possible while maximizing the potential integrated luminosity gain.

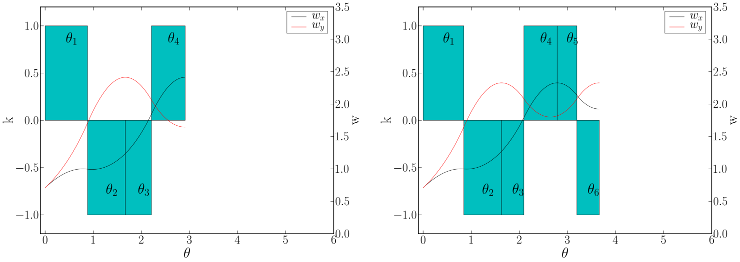
Nominal LHC triplet

The nominal LHC triplet cannot fulfill the Phase 1 targets because of aperture limitations.



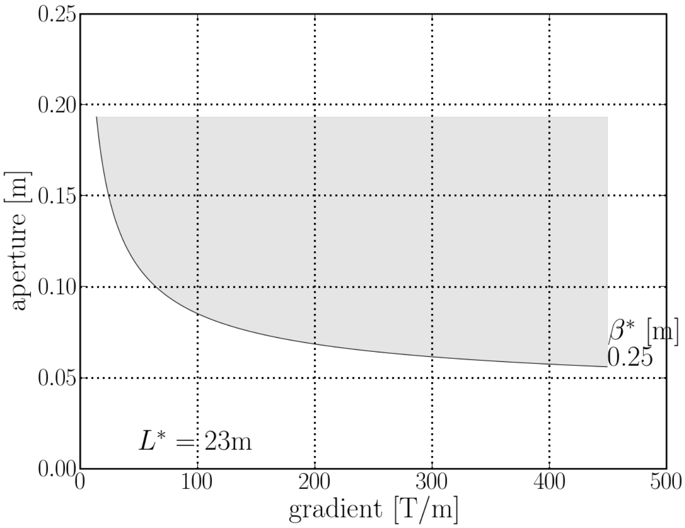
Parameter space via simplified triplet and quadruplet

I use a simplified triplet and quadruplet, in order to study the parameter space.
They are gap-less point to parallel focus system.



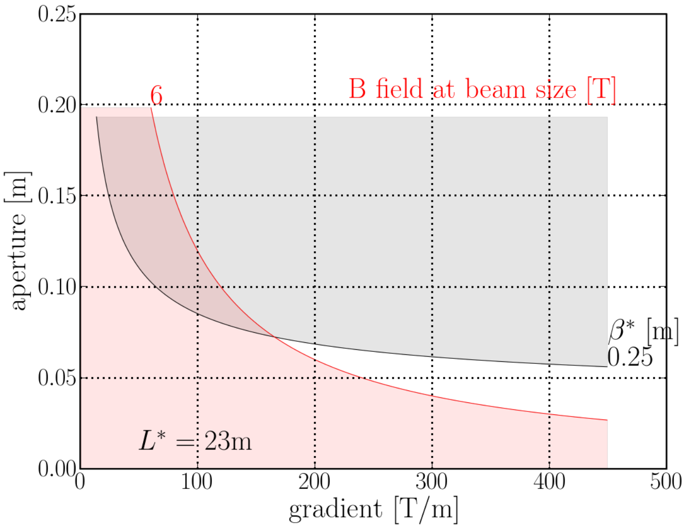
If we fix the gradient, L* and β* we can find the smaller possible beam size (beta peak) in the triplet or quadruplet.
References are in reviewing stage.

Beam size vs gradient



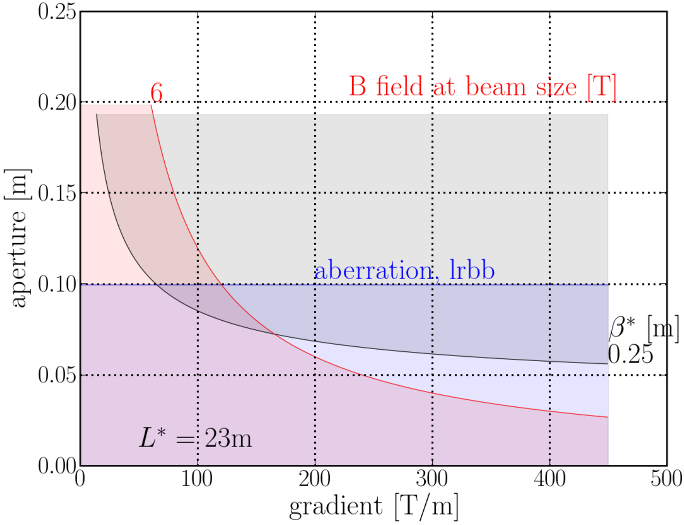
Beam size vs gradient

Beam size: $33\sigma + 22$mm. Cannot be too precise.



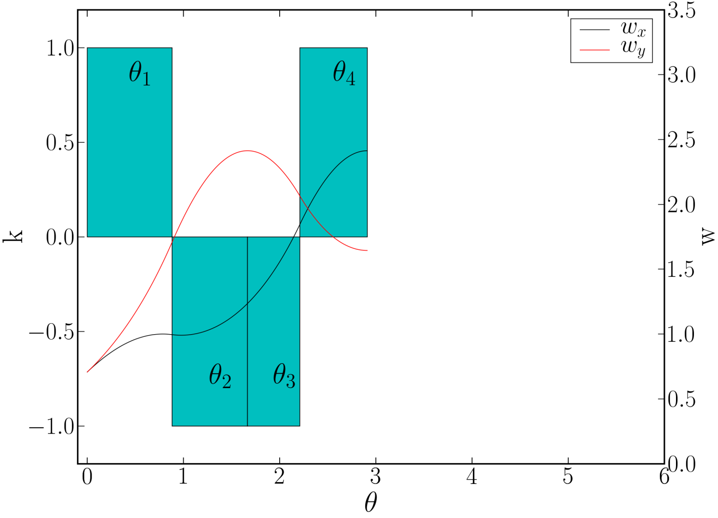
Beam size vs gradient

Beam size: $33\sigma + 22\text{mm}$. Cannot be too precise.



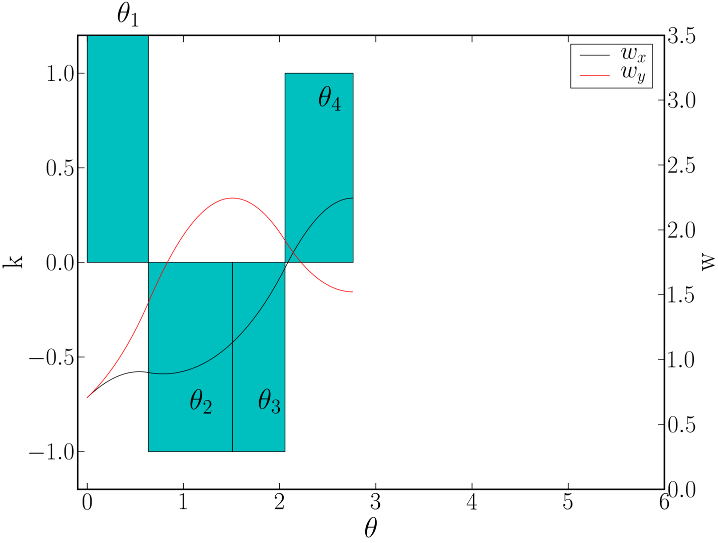
Realistic implementation

Starting from the ideal case



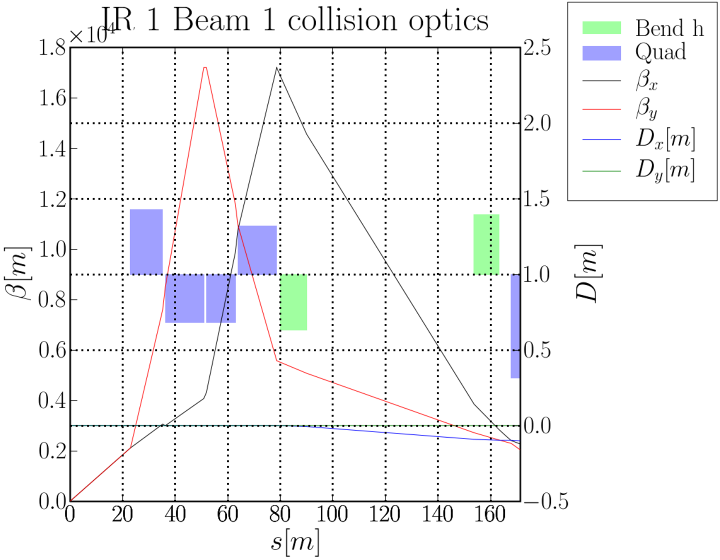
Realistic implementation

Optimize Q1



Then split and focus to match to the arc.

Compact



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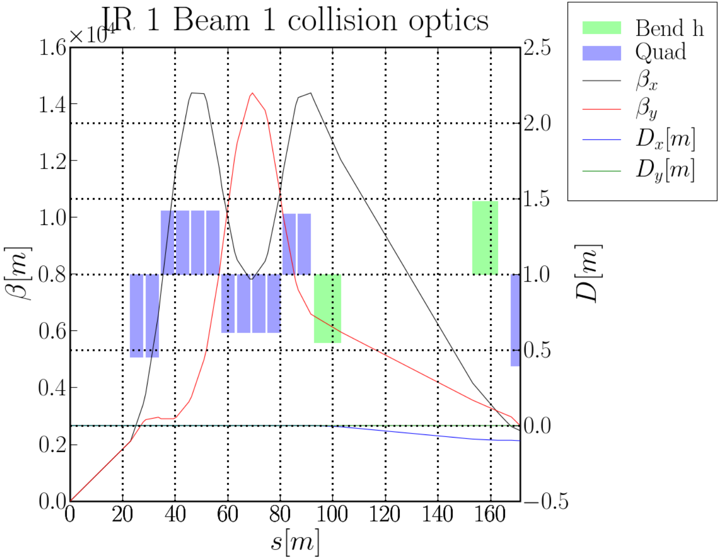
Modular



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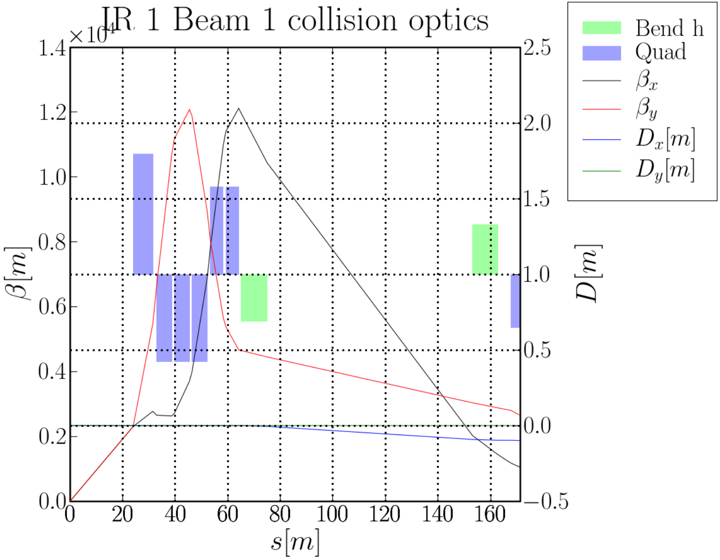
Lowbetamax



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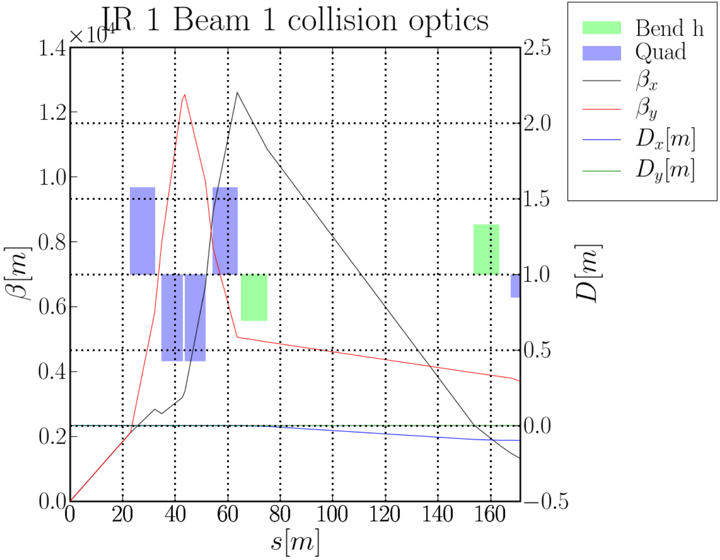
Symmetric



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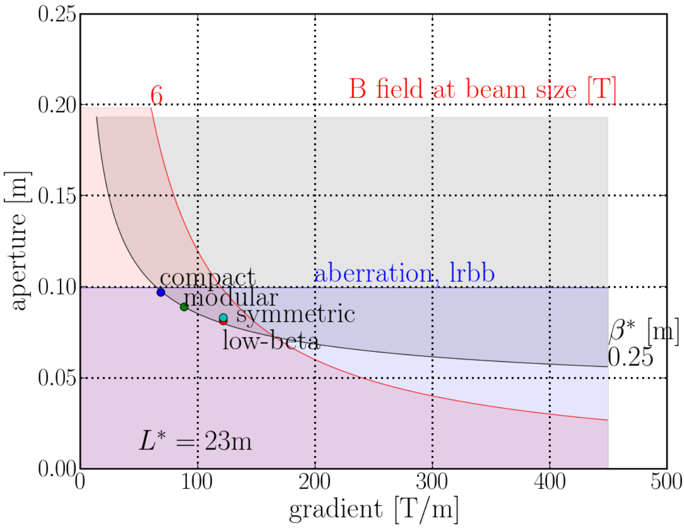
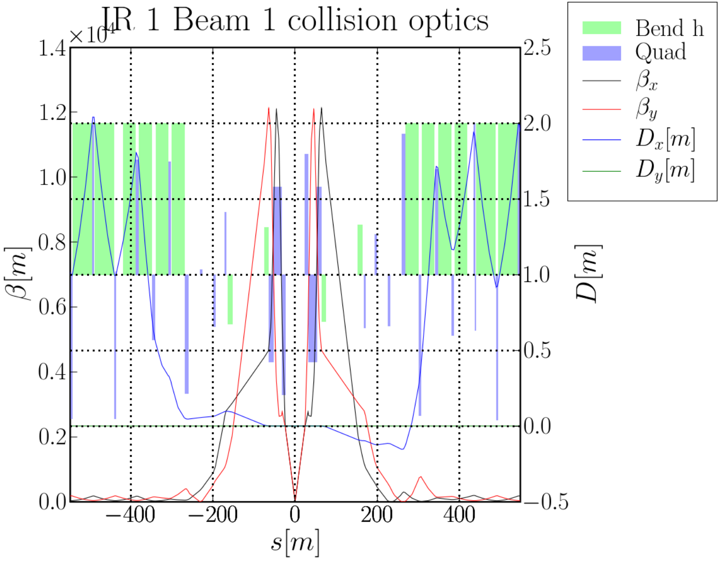
Choice of the gradient



Fine tuning and match

The last choice to be made is the slope at the end of the triplet. For this kind of tuning the first three layouts present more flexibility due a larger number of parameter used.
The last layout can use the gaps between quadrupole as additional parameters, but the solution may drift away from the optimum (larger overall length, bigger beam size).
I have chosen the one which simplifies joining the optics functions to the matching section. I did not use all the flexibility to optimize apertures in D2, Q4 and Q5.
The resulting layouts are extensively developed and studied. I'm not going to show all the results in detail. For reference see: http://cern.ch/rdemaria/layouts/html

Example of optics: lowbetamax IR 1 Beam 1



Layout

	Compact	Modular	Lowbeta	Symmetric
L* [m]	23	23	24	23
Gradient [T/m]	91,68	115,88,82,84	168,122	122
Module L [m]	12.2,14.6,11	4.8	7.4,5.7,4.9	9.2,7.8
Total L [m]	55	68	40	41
LRBB	23	26	19	19
Aper. MQX [mm]	170,220	130,170	90,130	130
B.S. MQX [mm]	74,79;99,104	54,59;99,104	34,39;54,59	54,59
B.S. D1 [mm]	50,64;45,64	50,64;45,64	50,64;45,64	50,64;45,64

Triplet apertures proposed by Franck Borgnolutti, Ezio Todesco.
D1 apertures proposed by Stephane Fartoukh.

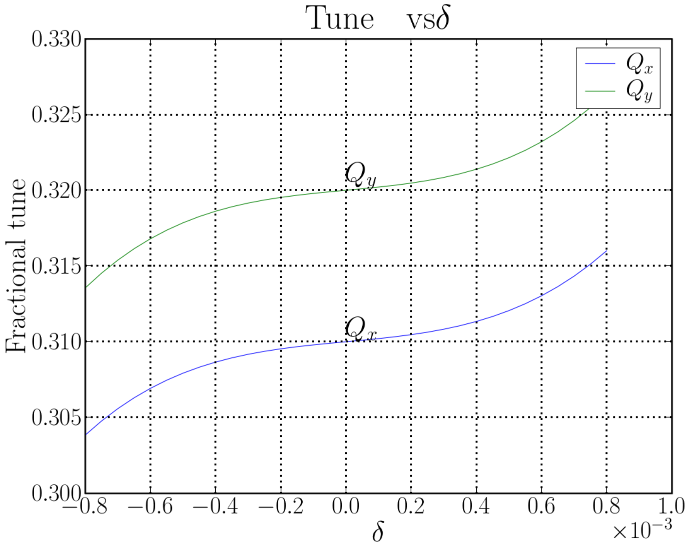
The beam screen apertures are given in term of half gap and radius. For the MQX the two couple refers to the twos aperture, while for D1 refer to IP1 and IP5.

Layout

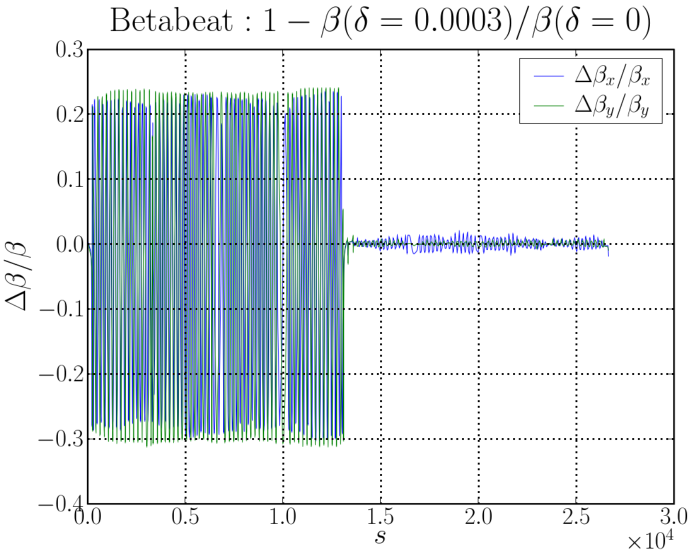
	LHC
L* [m]	22.965
Gradient [T/m]	205
Module L [m]	6.37,5.5
Total L [m]	30
LRBB	17
Aper. MQX [mm]	70
B.S. MQX [mm]	24,28.9
B.S. D1 [mm]	26.5,64

The beam screen apertures are given in term of half gap and radius.

Chromaticity: lowbetamax Beam 1



Off momentum beta beat: lowbetmax Beam 1 $\delta = 3 \cdot 10^{-4}$



Chromatic aberrations

	Compact	Modular	Lowbeta	Symmetric	LHC
Sextupoles [%]	88,56	87,58	74,46	75,46	48,28
Beat. $\delta = 3 \cdot 10^{-4}$ [%]	40	40	30	30	10
Beat. $\delta = 8 \cdot 10^{-4}$ [%]	150	150	100	105	30

The off momentum beta beat may reduce the collimation efficiency.

Dynamic aperture

	Compact	Modular	Lowbeta	Symmetric	LHC
Full	16	11	14	12	12
Triplet only	22	17	14	12	
Triplet escluded	16	11	20	16	

Results confirm the trend: more aperture margin more DA. The aperture bottlenecks in the LSS affect the DA. The difference between symmetric and lowbeta, which should have similar performance, may be explained within the error bars of this kind of studies (the average DA looks more similar indeed).

Field quality estimates and scalings provided by Ezio Todesco (see LHC Project Report 1010).

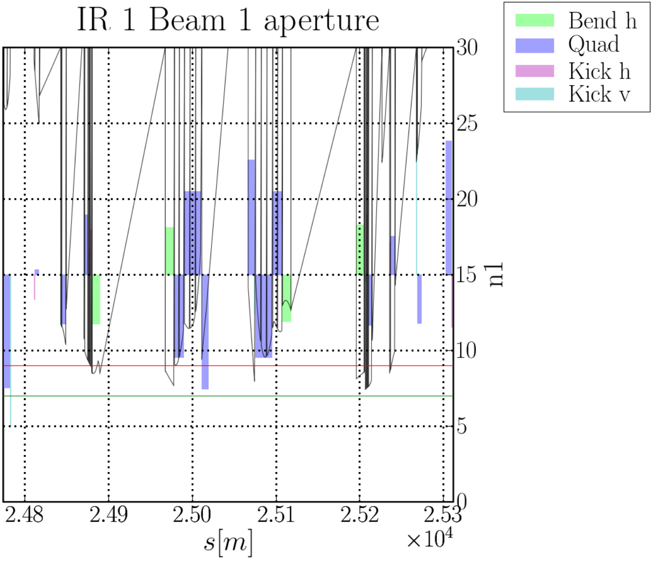
DA computed without multipole and coupling correction, with measured errors for the rest of machine. Field quality of D1, D2 is not included. The values are the minimum DA over 60 seeds.

Strengths limitations

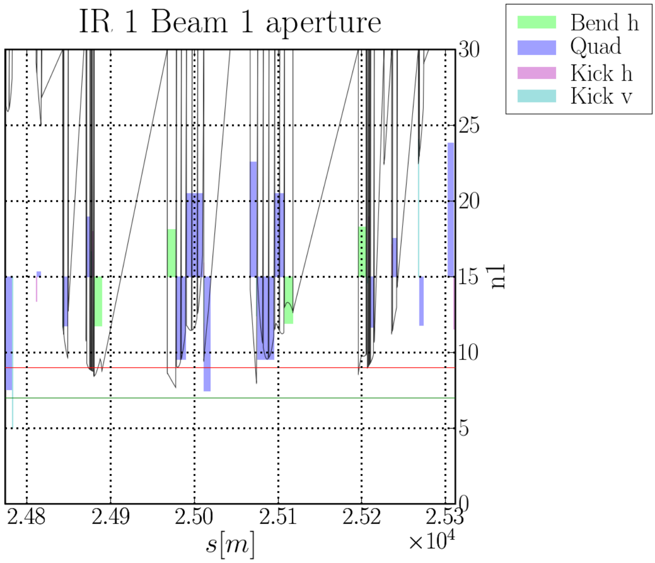
	Compact	Modular	Lowbeta	Symmetric
Q6	yes	yes	no	no

The limitation can be solved doubling Q6.

Aperture plot without b.s. rotation



Aperture plot with b.s. rotation



Aperture bottlenecks

	Compact	Modular	Lowbeta	Symmetric	LHC
MQX, ap 1	20.026	14.141	7.821	15.466	7.215
MQX, ap 2	16.953	12.633	8.830	8.438	6.845
D1	5.303	6.379	7.607	7.323	7.431
D2	5.372	4.271	7.959	6.518	15.152
Q4	7.387	6.432	8.685	7.184	15.615
Q5	4.701	3.859	10.425	7.028	16.871

Data in terms on n1. Lowbetamax and symmetric provide a better balance between apertures in triplets and LSS than compact and modular.

Crossing scheme and antisymmetry

Two crossing schemes are implemented.
The first optimizes strength and aperture, and it is used for aperture and DA calculations. No antisymmetry imposed (the optics is not).
The second keeps the left-right antisymmetry up to Q3, but it shows strength limitation of the orbit correctors for compact and modular layout.
It is opportune to check whether the experiments or operation rely on this symmetry for high luminosity operations.

Conclusions 1

The exercise was useful for understanding the actual limitations for the implementation of a new focusing system compatible with the targets of Phase 1 upgrade.
At this stage of the studies, the outstanding issues are:

- Apertures in D2-Q4-Q5. Serious bottleneck for compact and modular. The bottleneck of D2 for the symmetric may be solved by a redesign of the focus system.
- Vertical aperture in a 100-110 mm gap D1. It is a bottleneck for all options (more severe for compact and modular and for vertical crossing). It makes the aperture gain in the triplet useless.
- Off momentum beta beat. It is unavoidable, it must be studied carefully.
- The compact and modular requires additional Q6.

Conclusions 2

Many refinements are still needed for a final solution:

- check whether the larger off momentum beta beat affects the operation or the protection of the machine.
- check whether the heat load and radiation damage levels are compatible with the new elements.
- redesign the final focus system to reduce the beam size at Q4
- make sure that an injection optics exists
- determine whether the gaps between quadrupoles are in the right location for the BPM (far from the LRBB interactions), if not move the whole assembly or find a different splitting.