Cryogenic Collimator Optics for LHC IR7

John Jowett

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Preliminary studies (see presentations by T. Weiler (protons), G. Bellodi (ions) at ABP-LCU meeting 15 July 2008) have shown that the installation of cryogenic collimators in IR7 significantly improves the loss maps from collimation inefficiency for both types of beams.

Making space for these elements requires moving dipoles and hence a change of geometry of the LHC rings.

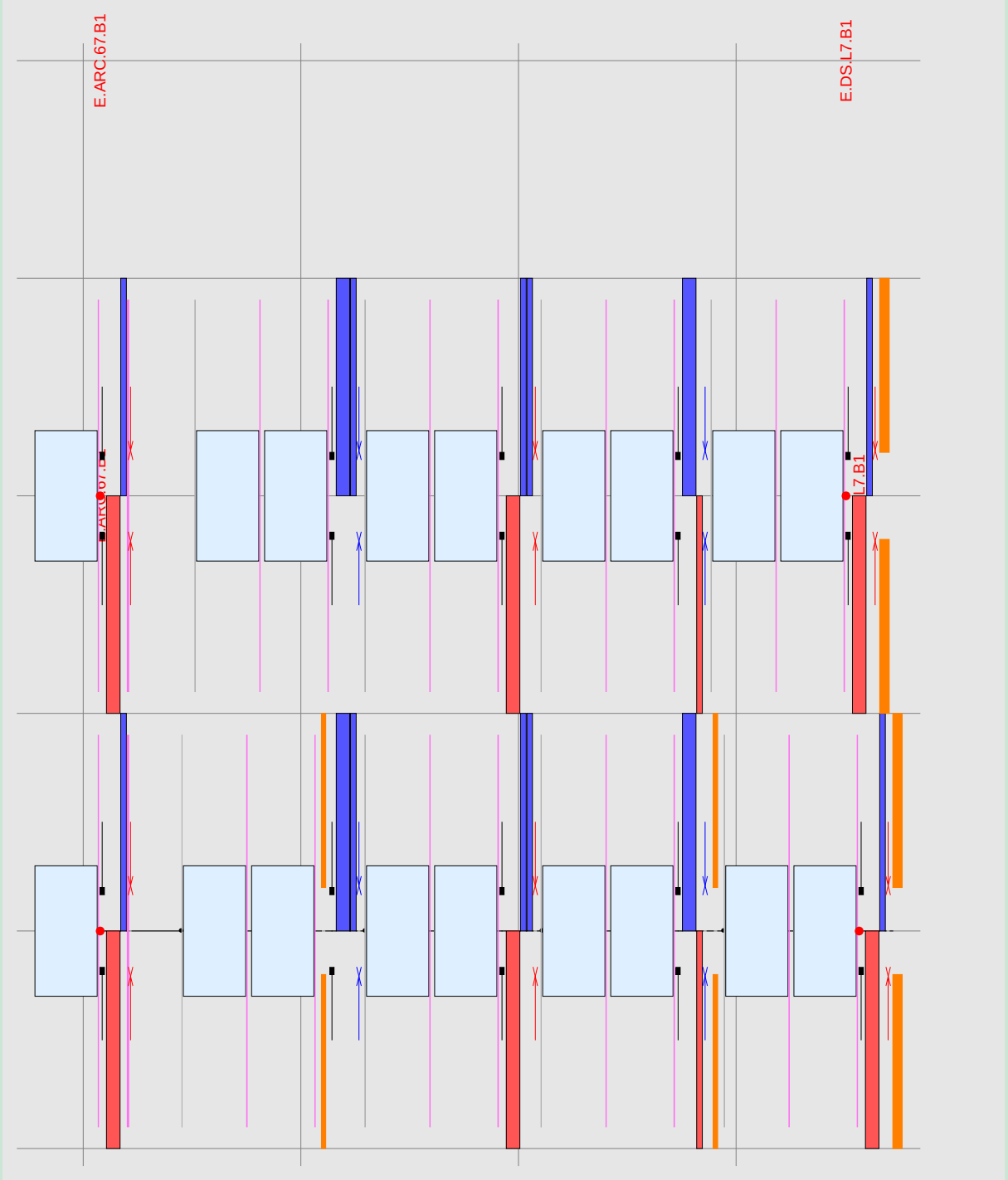
No discussion here of the hardware changes.

However the preliminary studies were done either with an unchanged V6.500 thin-lens optics (protons) or a mismatched thick-lens V6.500 optics (Pb ions) with beta-beating.

Since then the geometry perturbations have been correctly accommodated and the optics of IR7 has been properly rematched.

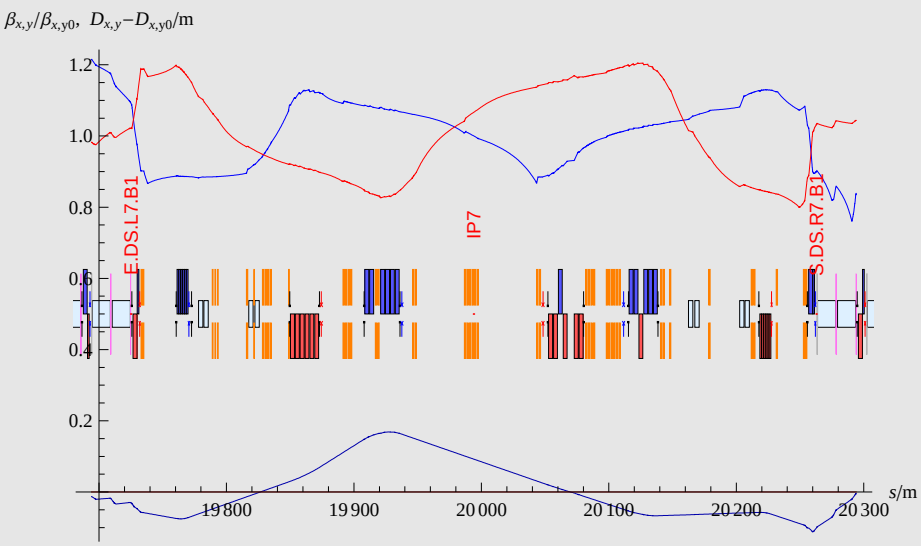
Optics is based on LHC Version 6.503, both sequences LHCB1 and LHCB2 are treated.

Layout changes in LHCB1, IR7



Optics perturbations in LHCB1, IR7

Beating of periodic solutions with no corrections



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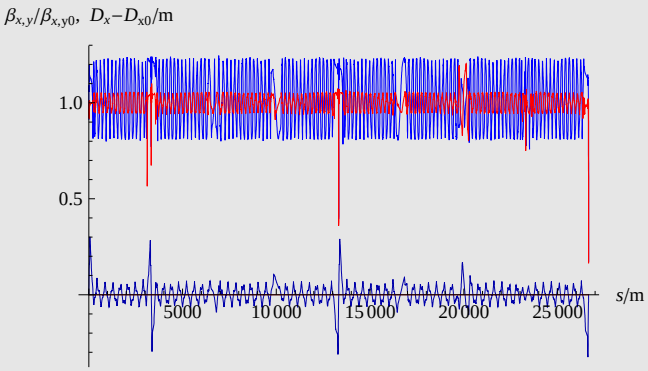
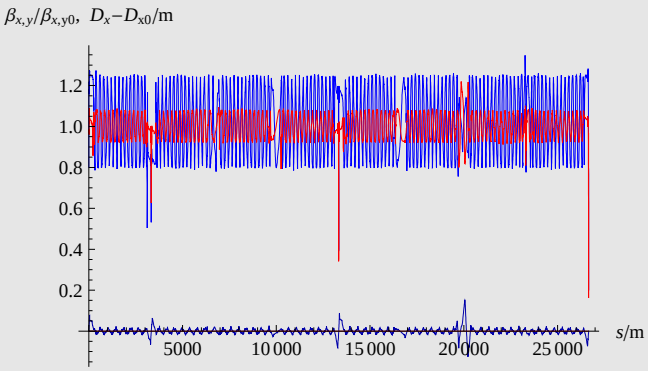
Global beating

Beating in LHCB1 and LHCB2





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Geometry perturbations

The movement of bends has moved IP7

tabulateIPmovement["IP7"]

	S	X	Y	Z
LHCB1	19994.16239999976100	−4204.725962242862800	0.	−4204.838115131831
LHCB1CryocollUncorrected	19994.16239999976100	−4204.72502612265270	0.	−4204.838134231296
LHCB2	19994.162399999670000	−4204.72596166135830	0.	−4204.614115273854
LHCB2CryocollUncorrected	19994.162399999670000	−4204.72502554114820	0.	−4204.614134373314

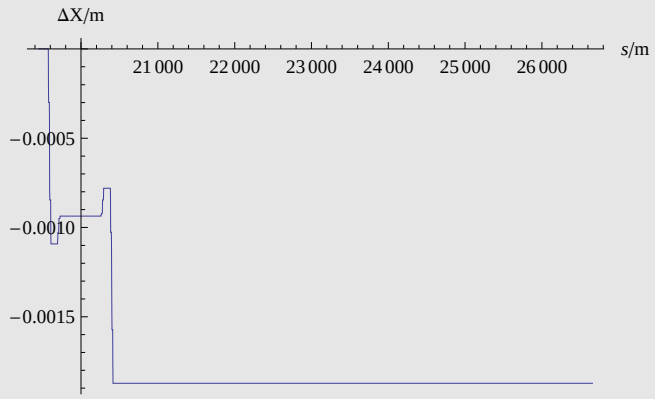
The ring no longer closes

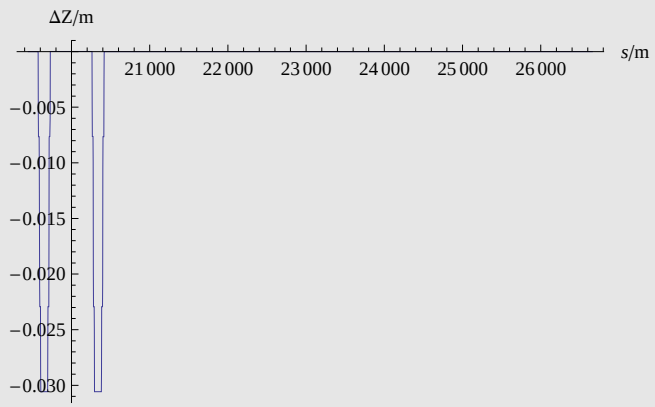
tabulateIPmovement["IP1.L1"]

	S	X	Y	Z
LHCB1	26658.883199998883000	0.000121704	0.	−0.0000796906
LHCB1CryocollUncorrected	26658.883199998883000	0.00199394	0.	−0.0000796906
LHCB2	26658.88319999879600	0.000122265	0.	−0.0000796906
LHCB2CryocollUncorrected	26658.88319999879600	0.00199451	0.	−0.0000796906

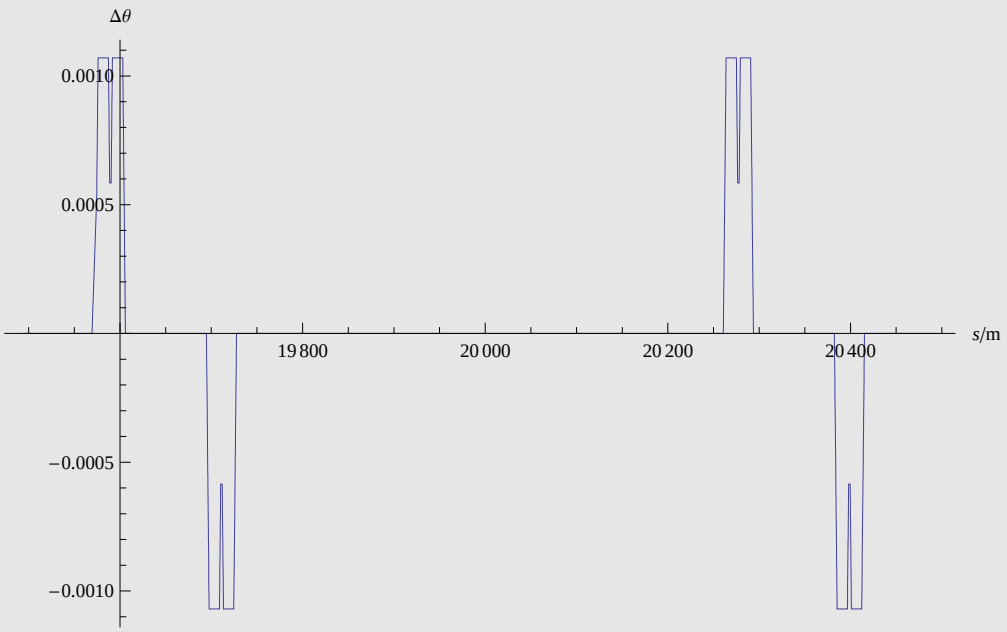
Displacements in global coordinates of reference orbits

Show the difference between global coordinates for LHCB1, starting on left of IR7, through to IP1.L1 (which normally coincides with IP1):





The only difference in the CS triad orientation occurs in the moved sections for the angle θ:


Δθ
0.0010
0.0005
−0.0005
−0.0010
19 800
20 000
20 200
20 400
s/m

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Geometry correction

Although we have only moved elements in IR7, MAD's present mechanism for building a sequence (placing elements at given *s* values, like beads on a necklace) means that all elements in the two octants from IP7 back to IP1.L1 will move. The geometry correction involves a shift of the installed *s* coordinate for all of them (by different amount inside the moved section). This closes the ring again.

To avoid confusion, we have given the new sequences new names, **LHCB1CC, LHCB2CC**.

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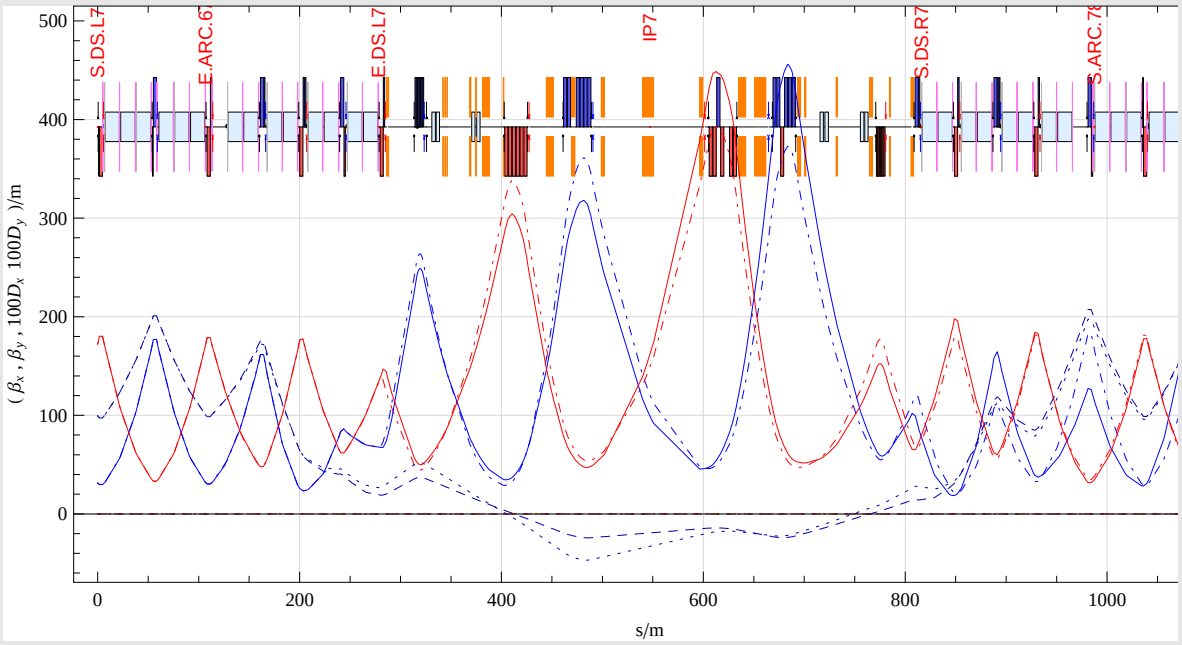
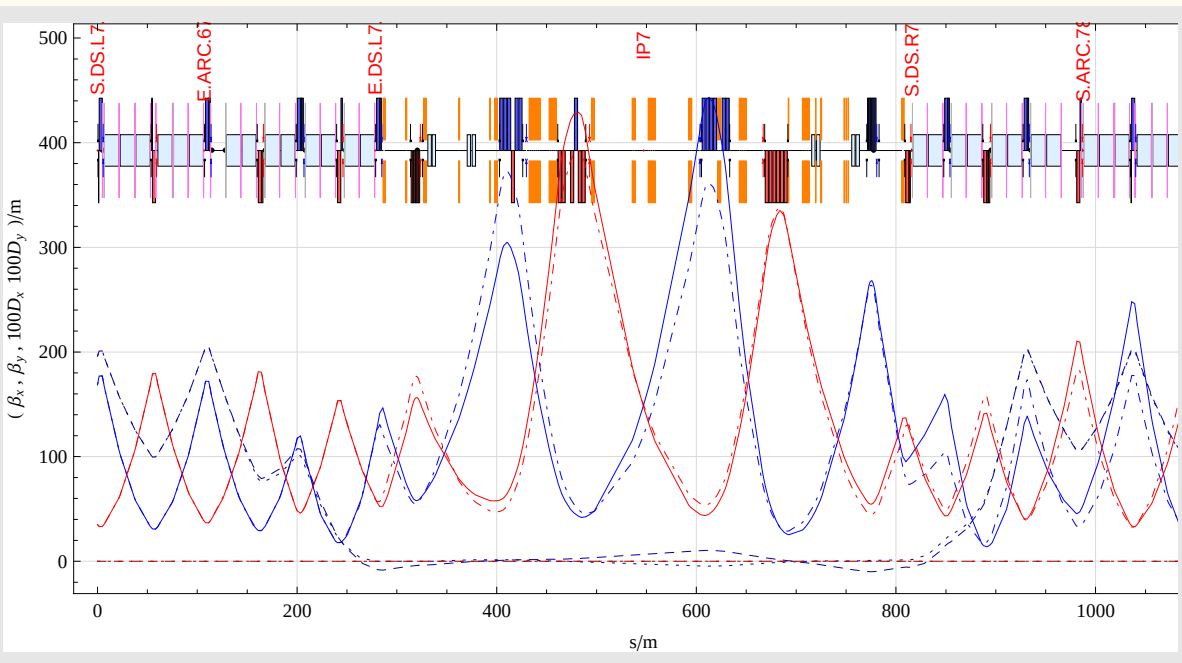
Perturbation of optics from layout changes

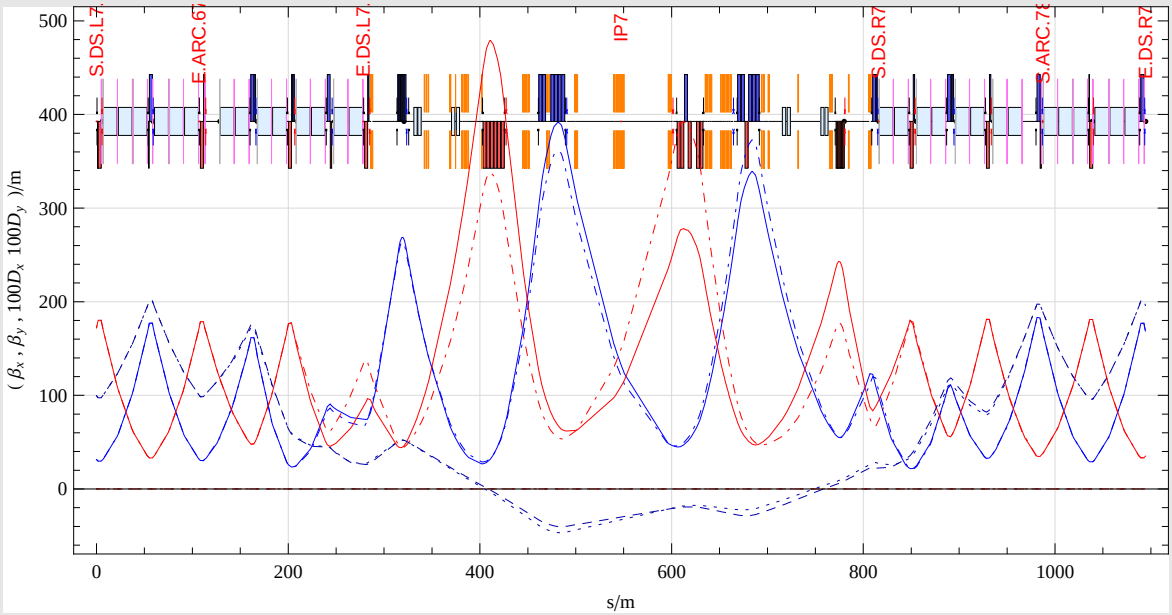
This shows us how the differences arise between the two optics, starting from the usual initial conditions on the left. It plots everything as a function of s only showing the first layout (i.e. the CC one) so does not compare optical functions exactly at the ends of elements. LHCB1, then LHCB2:





Rematching, first look

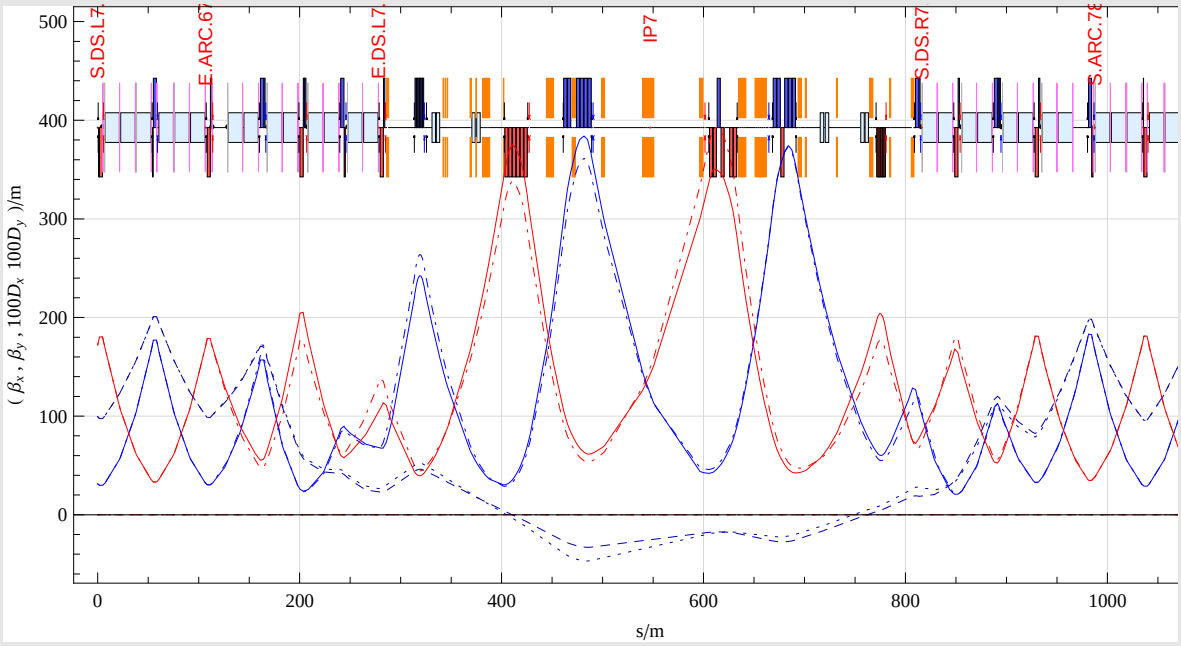
The optics can be rematched for both beams, imposing exactly the same optical functions over the whole IR7 insertion.

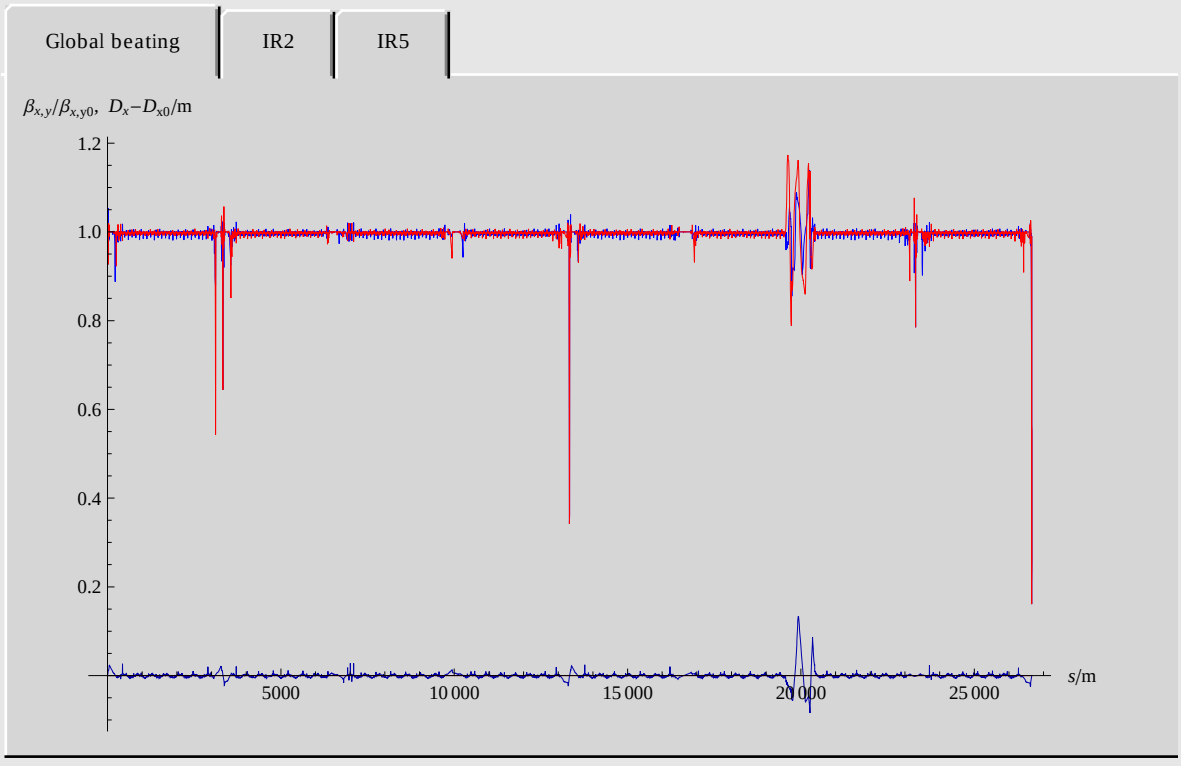


However this solution is not good enough because of large peaks in β-functions.

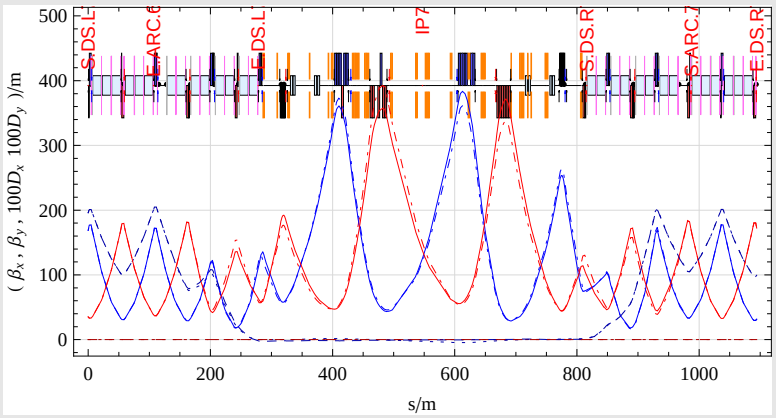
Rematching with β-functions controlled

LHCB1:

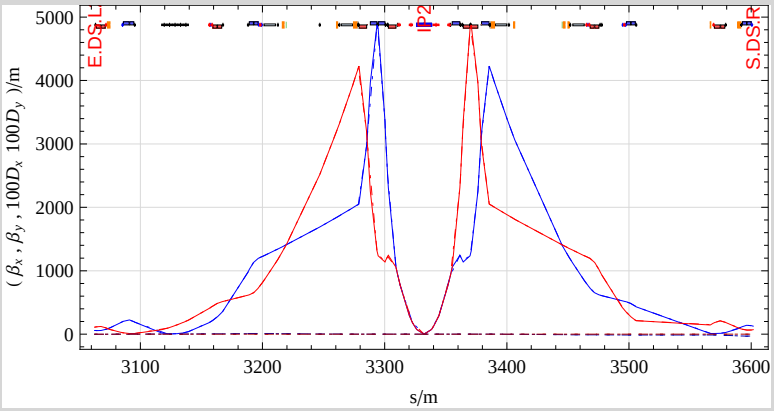




LHCB2



Global beating | IR2 | IR5



This looks generally acceptable. Compare global tunes:

	V6.503	CryoColl3
Q1	64.31	64.3029
Q2	59.32	59.3201
DQ1	-26.9533	-26.9081
DQ2	-27.0242	-27.0194

The expected differences in circumference

```
mfsKeyValue[LHCtwiss["LHCB1CC"], "LENGTH"] -
 LHCCircumference["LHCB1"]
```

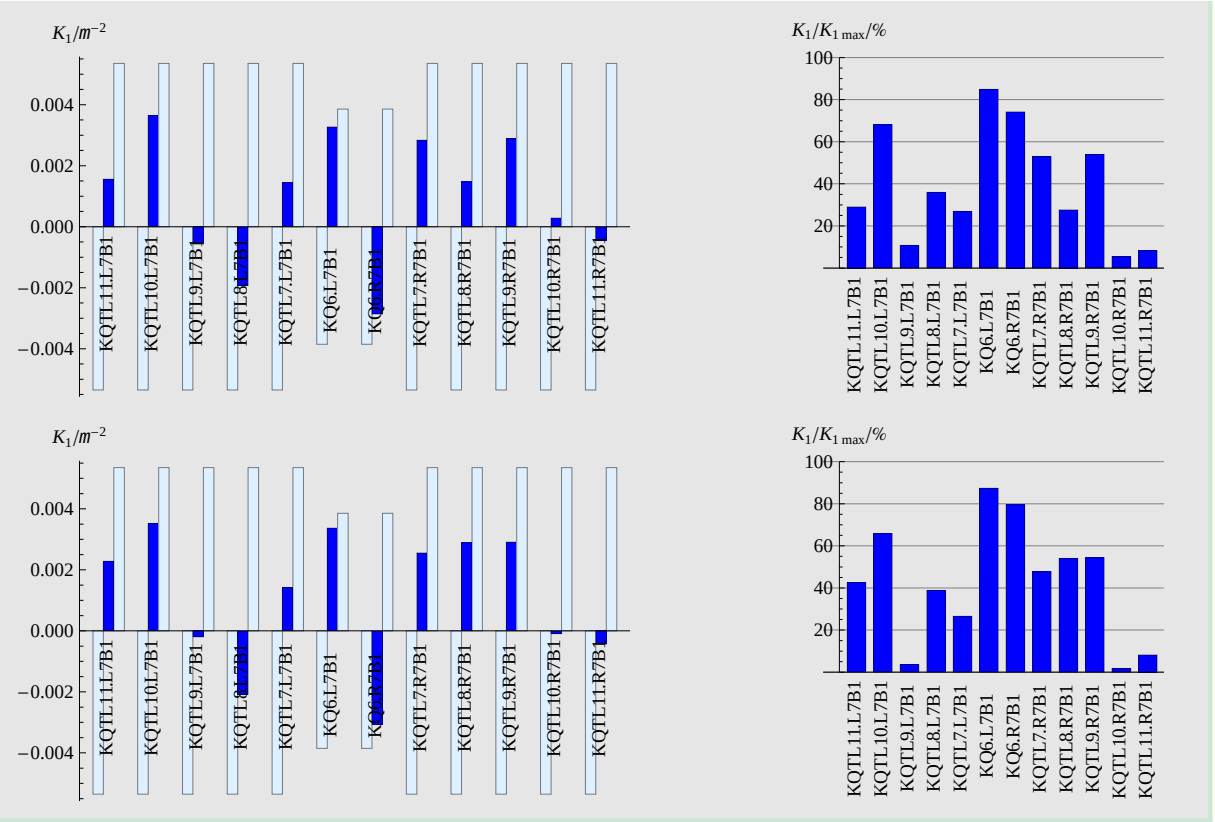
```
-0.00187223999800
```

```
mfsKeyValue[LHCtwiss["LHCB2CC"], "LENGTH"] -
 LHCCircumference["LHCB2"]
```

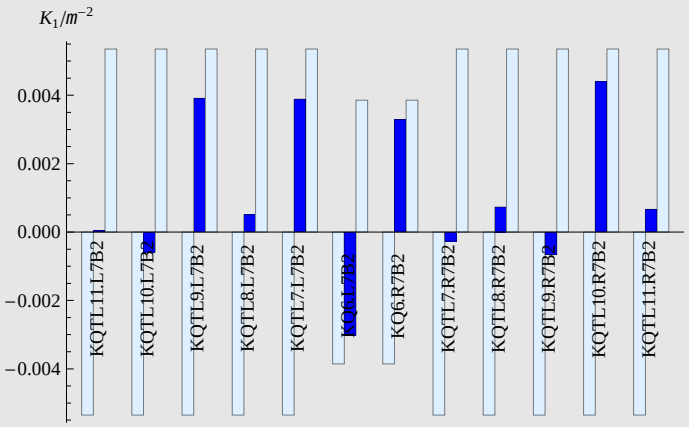
```
-0.00187223995800
```

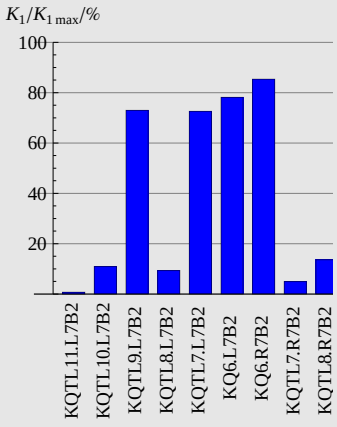
Final quadrupole strengths

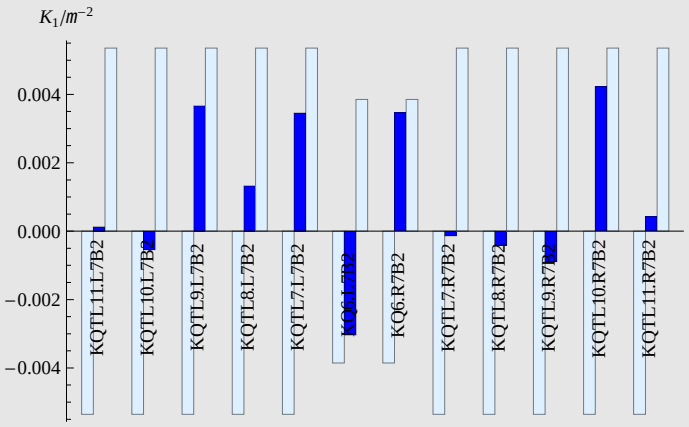
Before and after matching the strengths used for LHCB1CC. Light blue bars on left hand side plots are the maximum strengths.

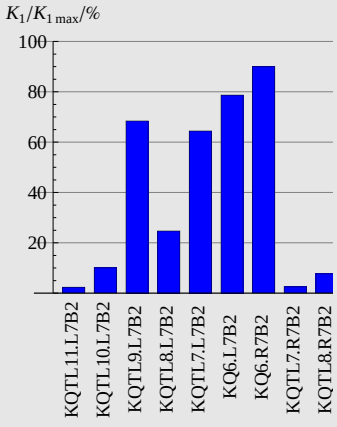


Before and after matching the strengths used for LHCB2CC


K_1/m^{-2}
0.004
0.002
0.000
−0.002
−0.004
KQTL11.L7B2
KQTL10.L7B2
KQTL9.L7B2
KQTL8.L7B2
KQTL7.L7B2
KQ6.L7B2
KQ6.R7B2
KQTL7.R7B2
KQTL8.R7B2
KQTL9.R7B2
KQTL10.R7B2
KQTL11.R7B2


$K_1/K_{1\,max}/\%$
100
80
60
40
20
KQTL11.L7B2
KQTL10.L7B2
KQTL9.L7B2
KQTL8.L7B2
KQTL7.L7B2
KQ6.L7B2
KQ6.R7B2
KQTL7.R7B2
KQTL8.R7B2


K_1/m^{-2}
0.004
0.002
0.000
−0.002
−0.004
KQTL11.L7B2
KQTL10.L7B2
KQTL9.L7B2
KQTL8.L7B2
KQTL7.L7B2
KQ6.L7B2
KQ6.R7B2
KQTL7.R7B2
KQTL8.R7B2
KQTL9.R7B2
KQTL10.R7B2
KQTL11.R7B2


$K_1/K_{1\,max}/\%$
100
80
60
40
20
KQTL11.L7B2
KQTL10.L7B2
KQTL9.L7B2
KQTL8.L7B2
KQTL7.L7B2
KQ6.L7B2
KQ6.R7B2
KQTL7.R7B2
KQTL8.R7B2

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Summary

The new optics including all Phase 2 collimators and cryogenic collimators is available for both beams at

```
/afs/cern.ch/eng/sl/ilhc/JMJ/CryoCollimatorOptics/
```

It now has the geometry corrections so the machine closes again (with a slightly shorter circumference) and all elements outside IR7 are back where they should be.
The changes are defined as a patch to the standard V6.503 layout and optics, creating two new sequences LHCB1CC and LHCB2CC that are new versions of LHCB1 and LHCB2.
Besides the cryogenic collimators these new sequences also include the other Phase 2 collimators.

There are 3 files:

- **CryoCollimatorLayoutOpticsIR7.m** - contains everything in two expressions for use within Madtomma:
  `madLHCCryoCollimatorLayout["IR7"]`
  `madLHCCryoCollimatorOptics["IR7"]`
- **LHCCryoCollimatorLayoutIR7.madx** - the layout changes and installation of all Phase 2 collimators, making the new sequences, in MADX format
- **LHCCryoCollimatorOpticsIR7.str** - the rematched quadrupole strengths, in MADX format

Cryogenic collimators may also be installed in IR3 (momentum collimation), IR1 and IR5 (collision debris) and IR2 (possible cure for BFPP losses in Pb-Pb collisions). This will require further optics changes.

Finally, initial results (ICOSIM simulations run by GB) indicate that the installation of cryogenic collimators dramatically improves the collimation efficiency for Pb ions in the LHC.