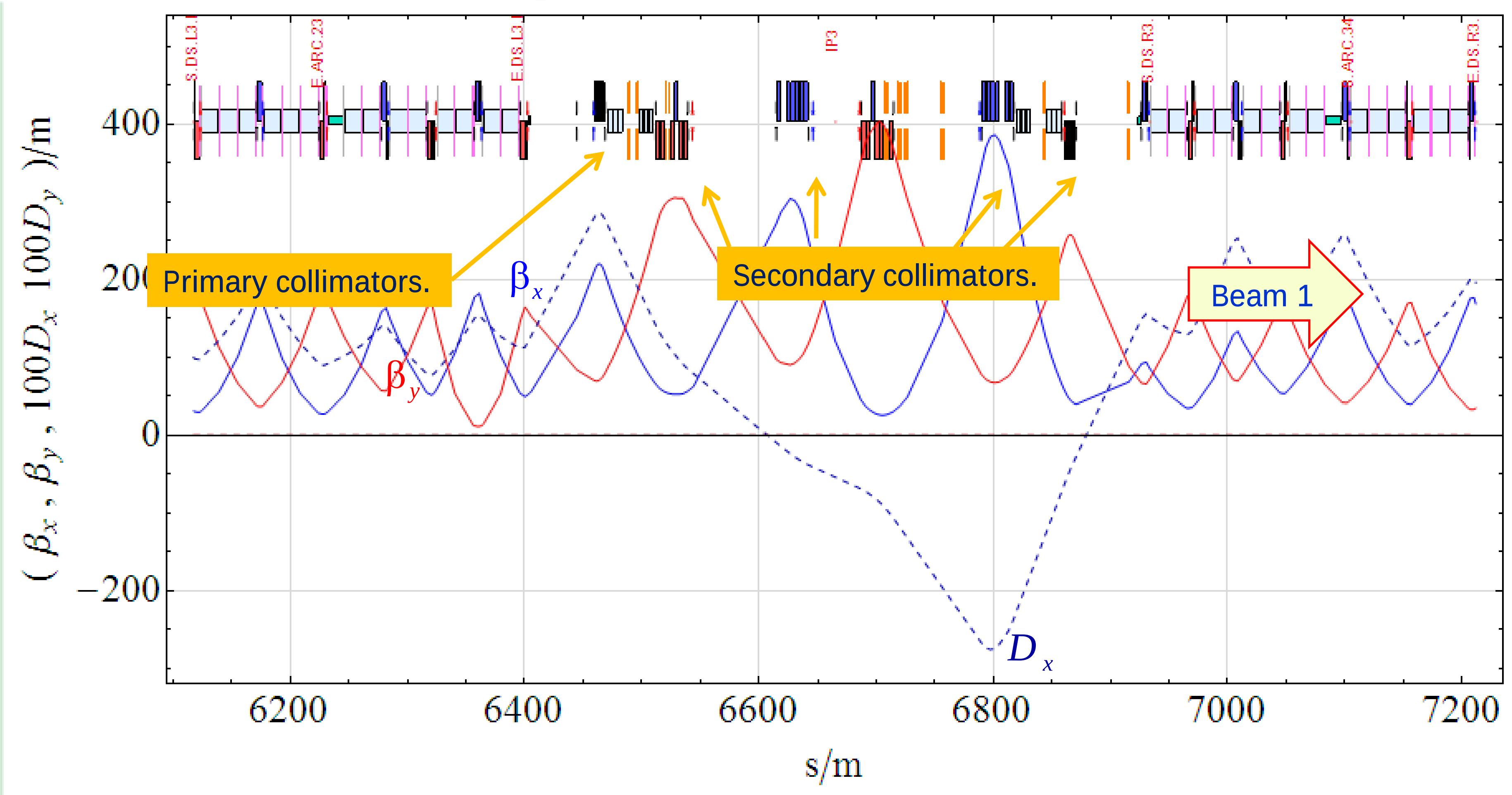
Modified Collimation Layout & Optics (for cryogenic collimators in IR3 with maximum 4.5 m displacement of elements)

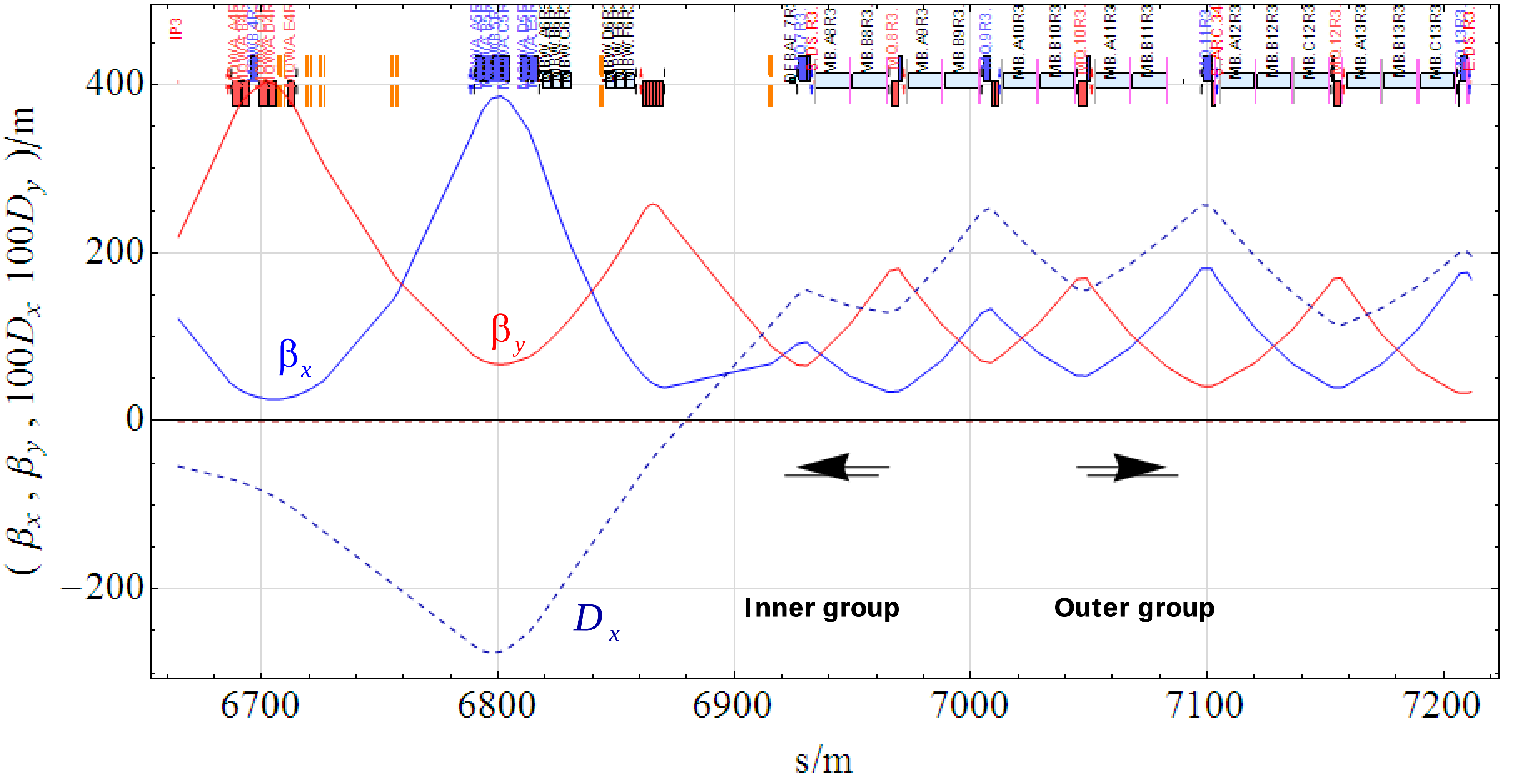
IR3 Optics overview, Beam 1



Beam 2 has F and D quads inverted, but imperfect (left-right, *x-y*) asymmetry, so has to be treated separately.

IR3 optics is **constant** – no change with energy, β-squeeze, etc.

Making space, IR3 right, Beam 1

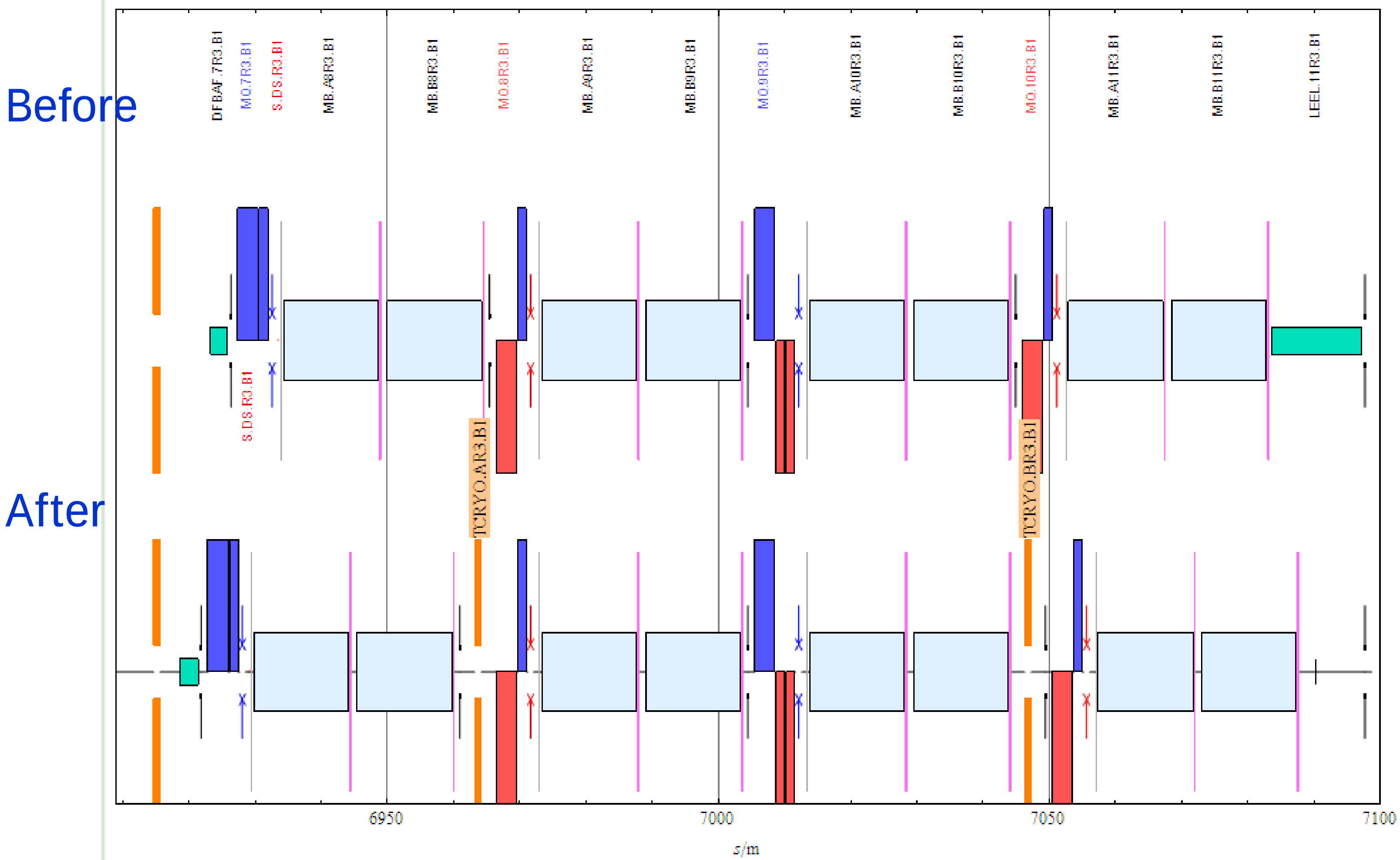


Move outer group of elements 4.5 m away from IP into missing dipole space.

Move inner group of elements 4.5 m towards IP to (roughly) compensate change in geometry.

Similarly on left of IP3.

Zoom on displacements along reference orbit



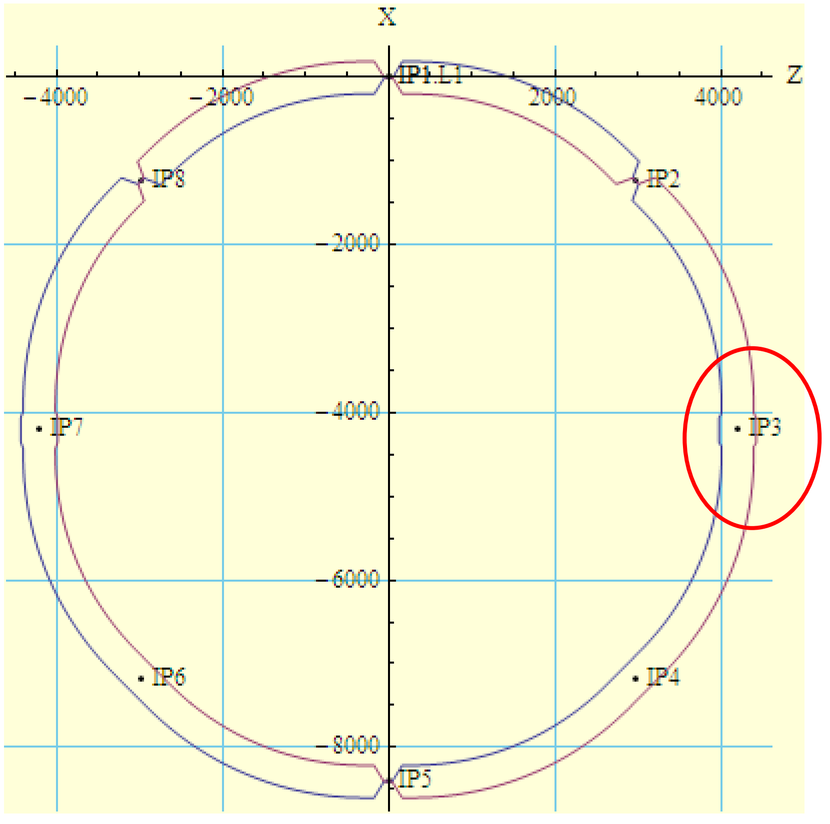
This vacates enough space in the right places to install the cryogenic collimators.

N.B. this is in Courant-Snyder coordinate *s*, so we do not see the change in geometry of the LHC.

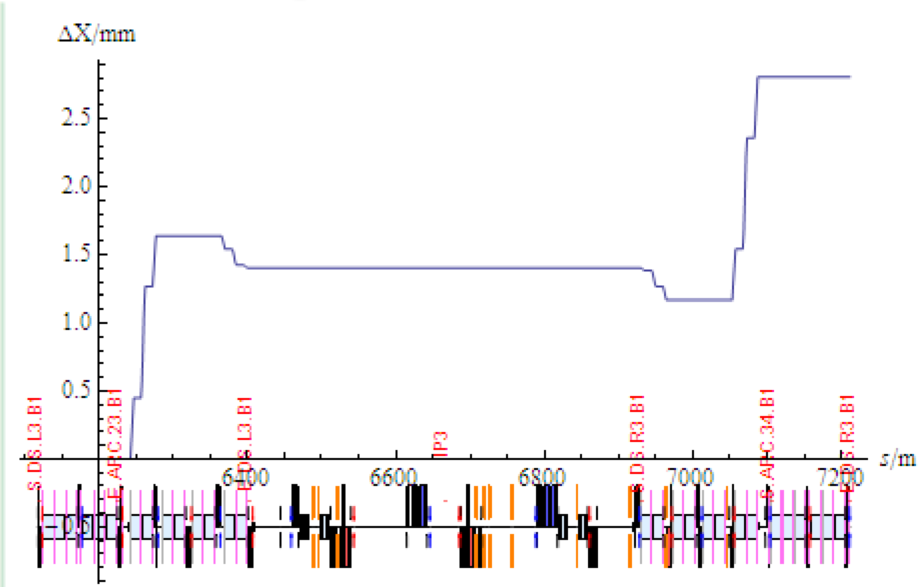
Global Cartesian Coordinate System

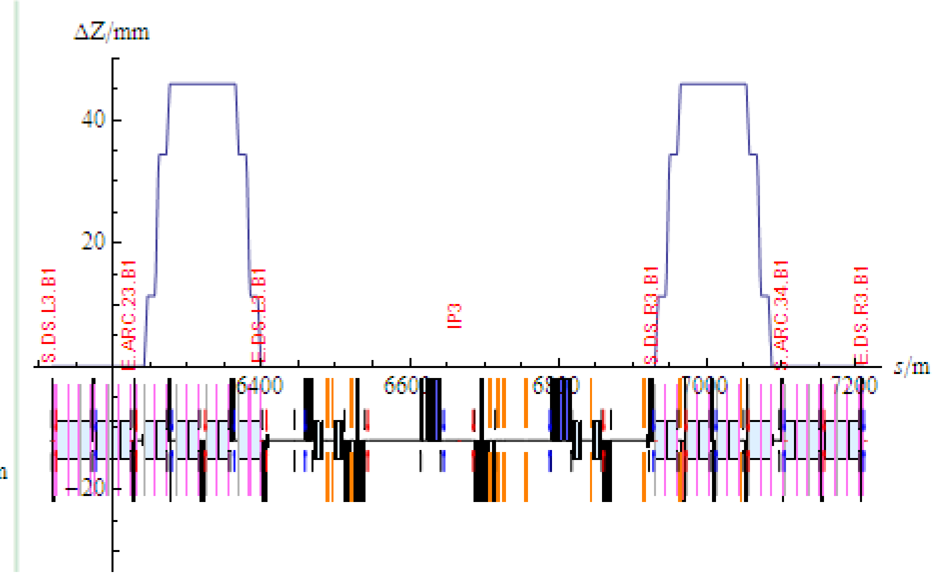
- Global coordinates with origin at IP1
  In the *straight section including* IP3, it happens that:
  - *X* is longitudinal
  - *Y* is vertical
  - *Z* is “radial”

  w.r.t. Courant-Snyder coordinates.
- Use (*Z*,*X*) as coordinates in the machine plane

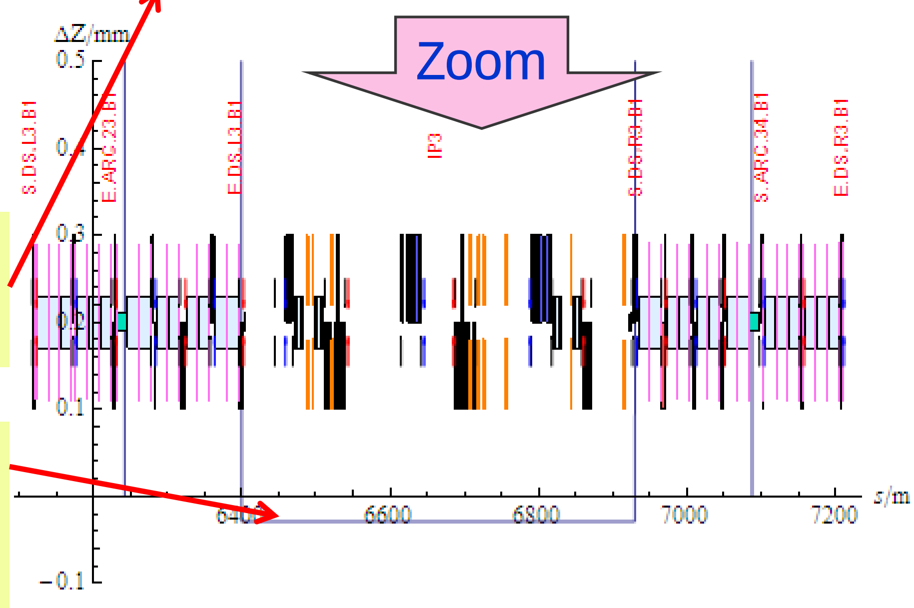


Displacements of reference orbit, Beam 1





Longitudinal displacement mainly reflects change in length of reference orbit – can be fixed.



Radial displacement of reference orbit between shifted sections by 46 mm. N.B. Not the displacement of elements!

Radial displacement of IP3 and straight section due to non-commutativity of rotations and translations is small enough (-0.026 mm) to neglect.

Displacements of moved elements, Beam 1, left of IP3

In the global cartesian frame, the displacements of the outer and inner groups of elements include a component from the angle ("curvature") of the initial reference orbit.

Outer group

	ΔZ/m	ΔX/m
MCO.11L3.B1	-0.1835	4.496
MCD.11L3.B1	-0.1835	4.496
MB.B11L3.B1	-0.1835	4.496
MCS.B11L3.B1	-0.1835	4.496
MB.A11L3.B1	-0.1835	4.496
MCS.A11L3.B1	-0.1835	4.496
BPM.10L3.B1	-0.1835	4.496
MQ.10L3.B1	-0.1835	4.496
MQTLI.10L3.B1	-0.1835	4.496
MCBCH.10L3.B1	-0.1835	4.496

Inner group

	ΔZ/m	ΔX/m
MCO.8L3.B1	0.00002865	-4.501
MCD.8L3.B1	0.00002865	-4.501
MB.B8L3.B1	0.00002865	-4.501
MCS.B8L3.B1	0.00002865	-4.501
MB.A8L3.B1	0.00002865	-4.501
MCS.A8L3.B1	0.00002865	-4.501
E.DS.L3.B1	0.00002865	-4.501
BPM.7L3.B1	0.00002865	-4.501
MQ.7L3.B1	0.00002865	-4.501
MQTLI.7L3.B1	0.00002865	-4.501
MCBCV.7L3.B1	0.00002865	-4.501
DFBAE.7L3.B1	0.00002865	-4.501

MAD - and the LHC Layout Database - use the "beads on a necklace" method of laying out the machine so everything downstream of IR3 moves and the ring does not close … this is not real of course but has to be corrected in our description.

	ΔZ/m	ΔX/m
IP1	0	0
IP2	0	0
IP3	0.00002865	-0.001404
IP4	0	-0.002808
IP5	0	-0.002808
IP6	0	-0.002808
IP7	0	-0.002808
IP8	0	-0.002808
IP1.L1	0	-0.002808

Corrected layout

Small negative displacements of all elements downstream of IR3 along the reference orbit restores them to their original position in the global cartesian system and closes the ring.

	ΔZ/m	ΔX/m
IP1	0	0
IP2	0	0
IP3	0.00002865	0
IP4	0	-6.294×10^{-10}
IP5	0	-6.294×10^{-10}
IP6	0	-6.303×10^{-10}
IP7	0	-6.330×10^{-10}
IP8	0	-6.330×10^{-10}
IP1.L1	0	-6.331×10^{-10}

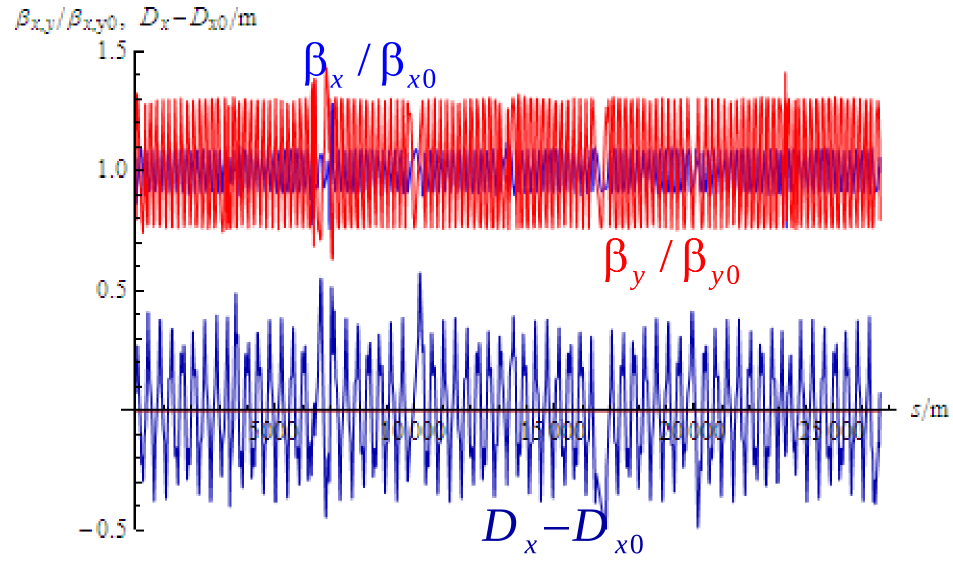
New sequence descriptions created for both rings.

LHC circumference is changed by -2.808 mm.

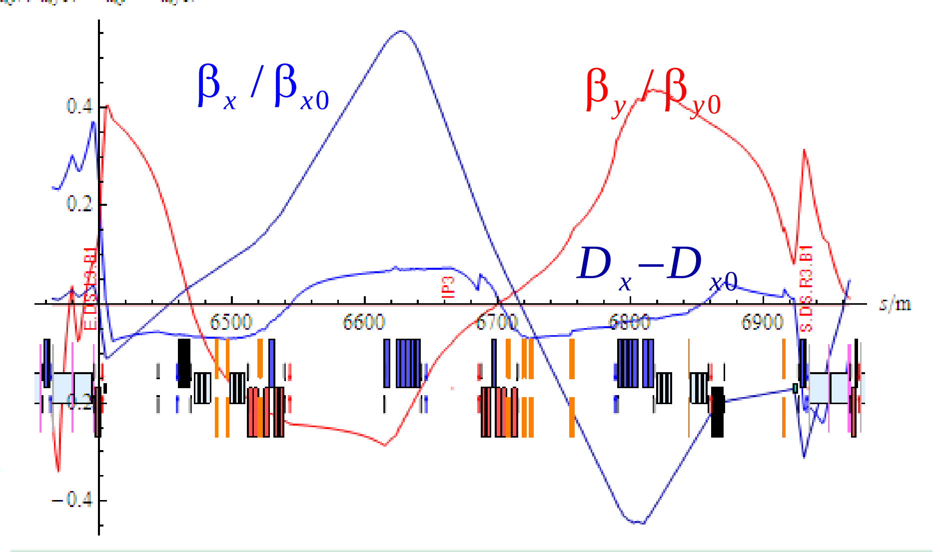
/afs/cern.ch/eng/sl/ilhc/JMJ/CryoCollimatorOptics/IR3/LHCCC.seq

Use new sequence names LHCB1CC, LHCB2CC.

Optical perturbations



β-beating in whole Ring 1



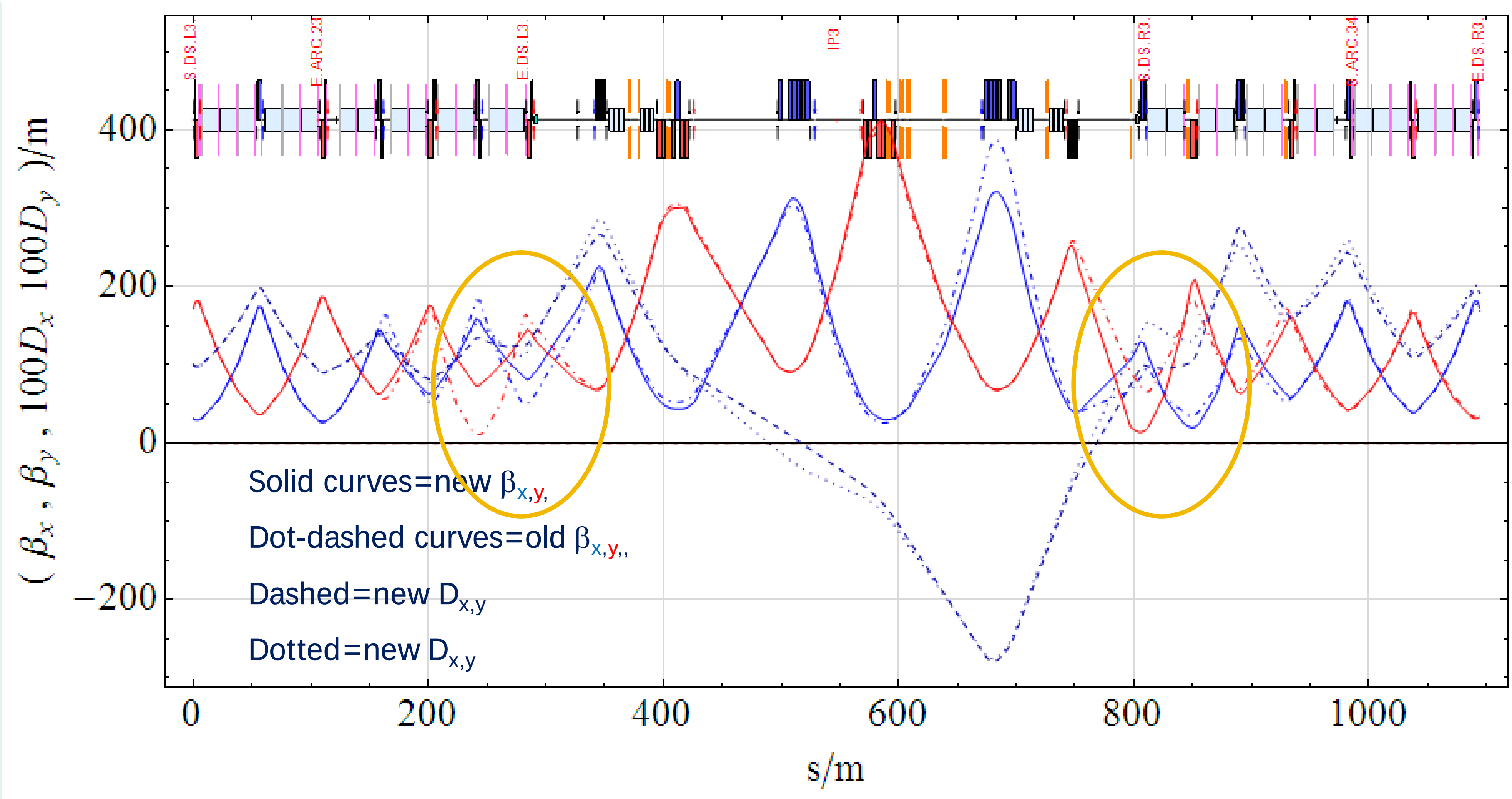
β-beating in IR3, Ring 1

Change in layout perturbs the optical functions, giving about 20% β-beating which must be corrected everywhere outside IR.

Optics perturbation in IR3 would cause severe aperture loss.

Rematch IR3 for each ring without using the common quadrupoles that affect both.

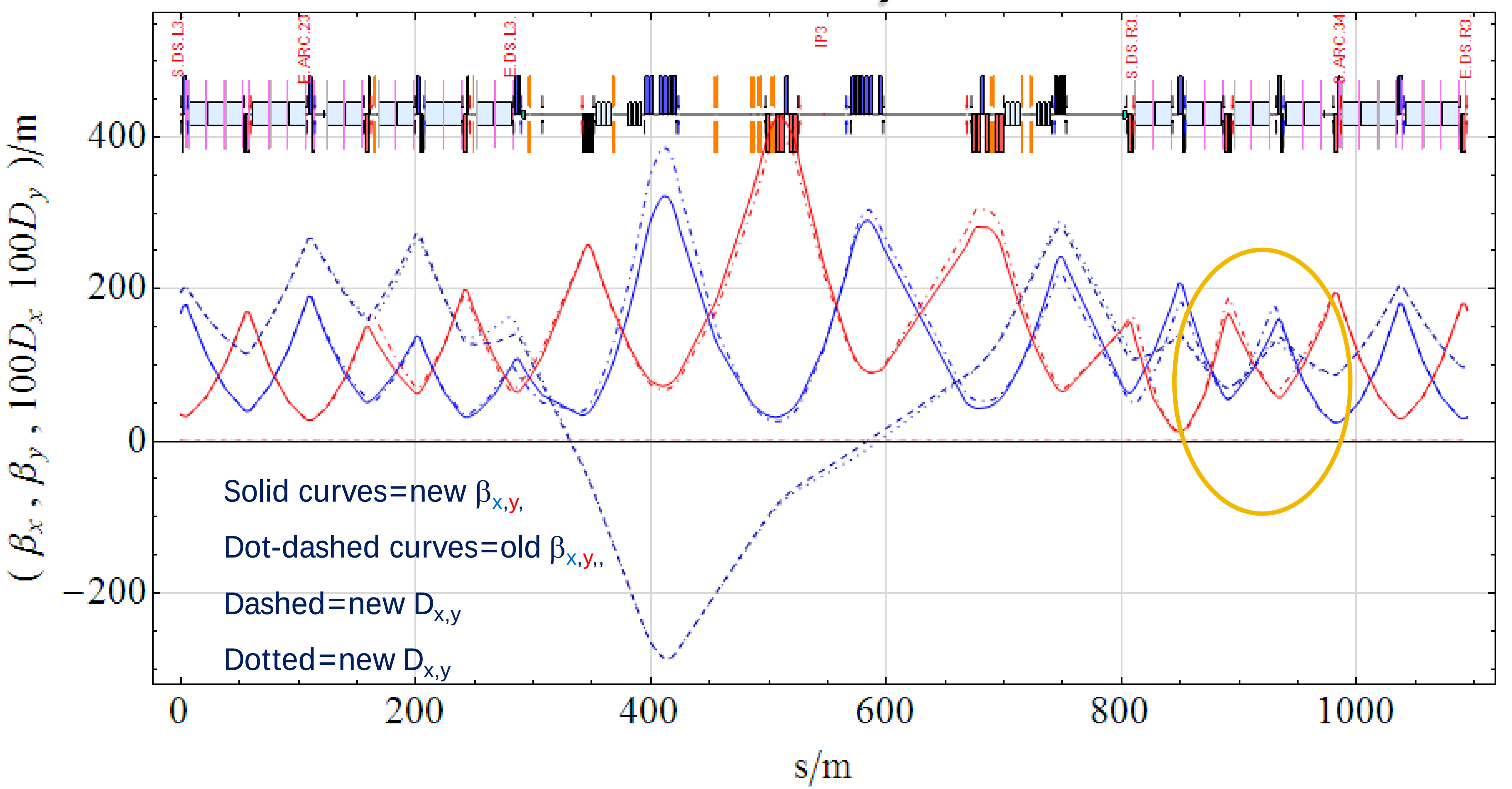
Rematch of IR3, Beam 1



Perfect match – same transfer matrix over IR3 - (also for Ring 2) so can be used in modular way with all existing LHC optics configurations.

Adjusted β-function peaks so available aperture is not changed significantly.

Rematch of IR3, Beam 2



Perfect match – same transfer matrix over IR3, so can be used in modular way with all existing LHC optics configurations.

Adjusted β-function peaks so available aperture is not changed significantly.

Had to use more quadrupoles than for Beam 1.

Quadrupole strengths after rematch, Beam 1

	K1NAMES	K1MIN	K1	K1MAX	K1CHECK
MQTLI.10L3.B1	KQTL10.L3B1	-0.083276	-0.0019737	0.083276	True
MQTLI.B9L3.B1	KQTL9.L3B1	-0.083276	0.002172	0.083276	True
MQTLI.A9L3.B1	KQTL9.L3B1	-0.083276	0.002172	0.083276	True
MQTLI.8L3.B1	KQTL8.L3B1	-0.083276	-0.0071218	0.083276	True
MQTLI.7L3.B1	KQTL7.L3B1	-0.083276	0.00838	0.083276	True
MQTLH.F6L3.B1	KQ6.L3B1	-0.059959	0.0025123	0.059959	True
MQTLH.E6L3.B1	KQ6.L3B1	-0.059959	0.0025123	0.059959	True
MQTLH.D6L3.B1	KQ6.L3B1	-0.059959	0.0025123	0.059959	True
MQTLH.C6L3.B1	KQ6.L3B1	-0.059959	0.0025123	0.059959	True
MQTLH.B6L3.B1	KQ6.L3B1	-0.059959	0.0025123	0.059959	True
MQTLH.A6L3.B1	KQ6.L3B1	-0.059959	0.0025123	0.059959	True
MQTLH.A6R3.B1	KQ6.R3B1	-0.059959	-0.0034277	0.059959	True
MQTLH.B6R3.B1	KQ6.R3B1	-0.059959	-0.0034277	0.059959	True
MQTLH.C6R3.B1	KQ6.R3B1	-0.059959	-0.0034277	0.059959	True
MQTLH.D6R3.B1	KQ6.R3B1	-0.059959	-0.0034277	0.059959	True
MQTLH.E6R3.B1	KQ6.R3B1	-0.059959	-0.0034277	0.059959	True
MQTLH.F6R3.B1	KQ6.R3B1	-0.059959	-0.0034277	0.059959	True
MQTLI.7R3.B1	KQTL7.R3B1	-0.083276	0.0022552	0.083276	True
MQTLI.8R3.B1	KQTL8.R3B1	-0.083276	-0.0049622	0.083276	True
MQTLI.A9R3.B1	KQTL9.R3B1	-0.083276	0.0010513	0.083276	True
MQTLI.B9R3.B1	KQTL9.R3B1	-0.083276	0.0010513	0.083276	True
MQTLI.10R3.B1	KQTL10.R3B1	-0.083276	0.0029929	0.083276	True

All quads are comfortably within bounds at 7 TeV.

/afs/cern.ch/eng/sl/ilhc/JMJ/CryoCollimatorOptics/IR3/LHCCryoCollimatorOpticsIR3.str

To be used on top of any other set of strengths for LHC optics V6.503, with the new sequences LHCB1CC, LHCB2CC.

Quadrupole strengths after rematch, Beam 2

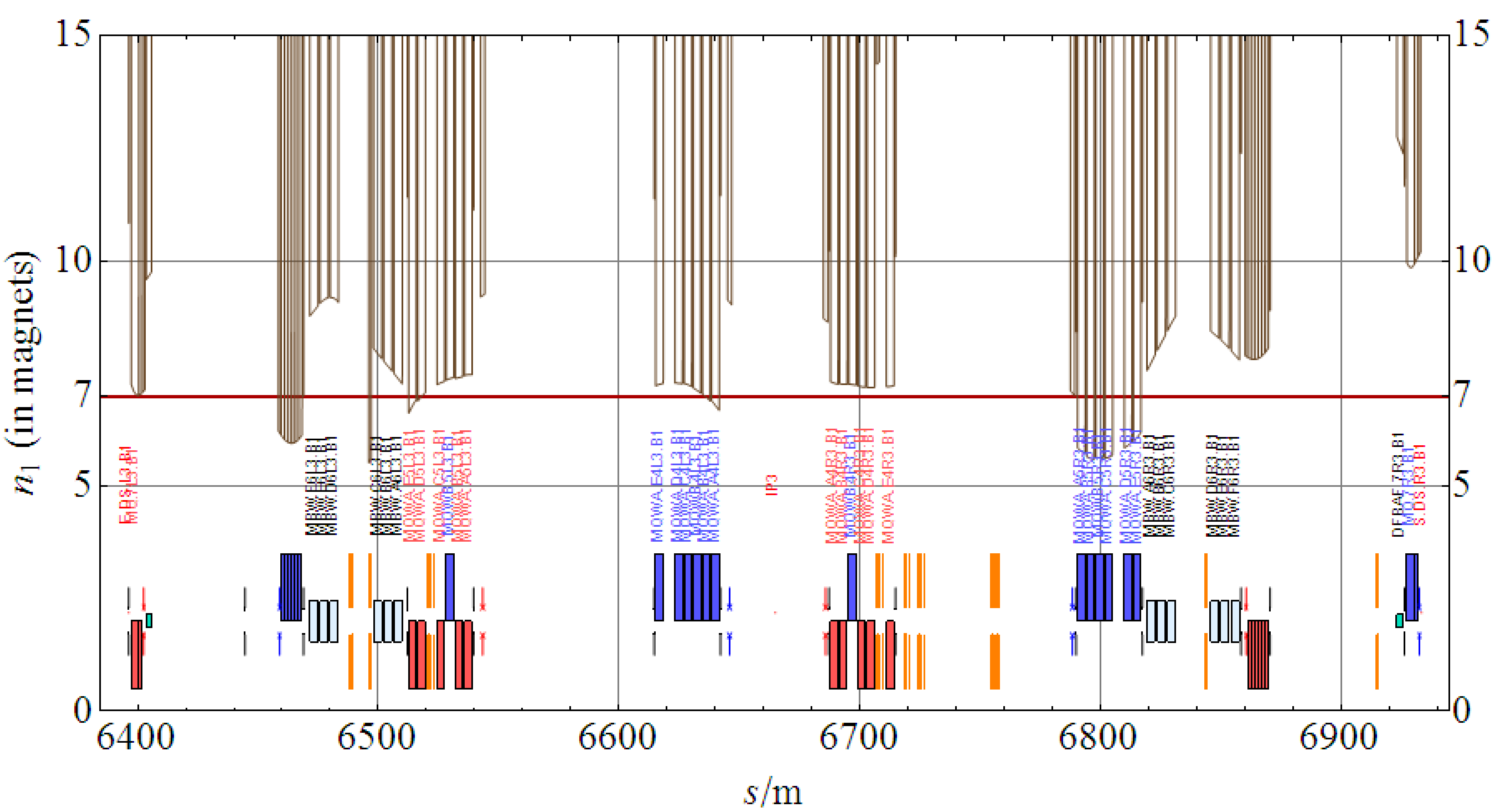
	K1NAMES	K1MIN	K1	K1MAX	K1CHECK
MQTLI.11L3.B2	KQTL11.L3B2	~ 0.083276	~ 0.0029077	0.083276	True
MQTLI.10L3.B2	KQTL10.L3B2	~ 0.083276	0.00093013	0.083276	True
MQTLI.B9L3.B2	KQTL9.L3B2	~ 0.083276	~ 0.00013174	0.083276	True
MQTLI.A9L3.B2	KQTL9.L3B2	~ 0.083276	~ 0.00013174	0.083276	True
MQTLI.8L3.B2	KQTL8.L3B2	~ 0.083276	0.0022066	0.083276	True
MQTLI.7L3.B2	KQTL7.L3B2	~ 0.083276	0.00084624	0.083276	True
MQTLH.F6L3.B2	KQ6.L3B2	~ 0.059959	~ 0.0025024	0.059959	True
MQTLH.E6L3.B2	KQ6.L3B2	~ 0.059959	~ 0.0025024	0.059959	True
MQTLH.D6L3.B2	KQ6.L3B2	~ 0.059959	~ 0.0025024	0.059959	True
MQTLH.C6L3.B2	KQ6.L3B2	~ 0.059959	~ 0.0025024	0.059959	True
MQTLH.B6L3.B2	KQ6.L3B2	~ 0.059959	~ 0.0025024	0.059959	True
MQTLH.A6L3.B2	KQ6.L3B2	~ 0.059959	~ 0.0025024	0.059959	True
MQTLH.A6R3.B2	KQ6.R3B2	~ 0.059959	0.0027831	0.059959	True
MQTLH.B6R3.B2	KQ6.R3B2	~ 0.059959	0.0027831	0.059959	True
MQTLH.C6R3.B2	KQ6.R3B2	~ 0.059959	0.0027831	0.059959	True
MQTLH.D6R3.B2	KQ6.R3B2	~ 0.059959	0.0027831	0.059959	True
MQTLH.E6R3.B2	KQ6.R3B2	~ 0.059959	0.0027831	0.059959	True
MQTLH.F6R3.B2	KQ6.R3B2	~ 0.059959	0.0027831	0.059959	True
MQTLI.7R3.B2	KQTL7.R3B2	~ 0.083276	~ 0.0027615	0.083276	True
MQTLI.8R3.B2	KQTL8.R3B2	~ 0.083276	~ 0.0016878	0.083276	True
MQTLI.A9R3.B2	KQTL9.R3B2	~ 0.083276	~ 0.0027554	0.083276	True
MQTLI.B9R3.B2	KQTL9.R3B2	~ 0.083276	~ 0.0027554	0.083276	True
MQTLI.10R3.B2	KQTL10.R3B2	~ 0.083276	~ 0.00020587	0.083276	True
MQTLI.11R3.B2	KQTL11.R3B2	~ 0.083276	0.0013974	0.083276	True

All quads are comfortably within bounds at 7 TeV.

/afs/cern.ch/eng/sl/ilhc/JMJ/CryoCollimatorOptics/IR3/LHCCryoCollimatorOpticsIR3.str

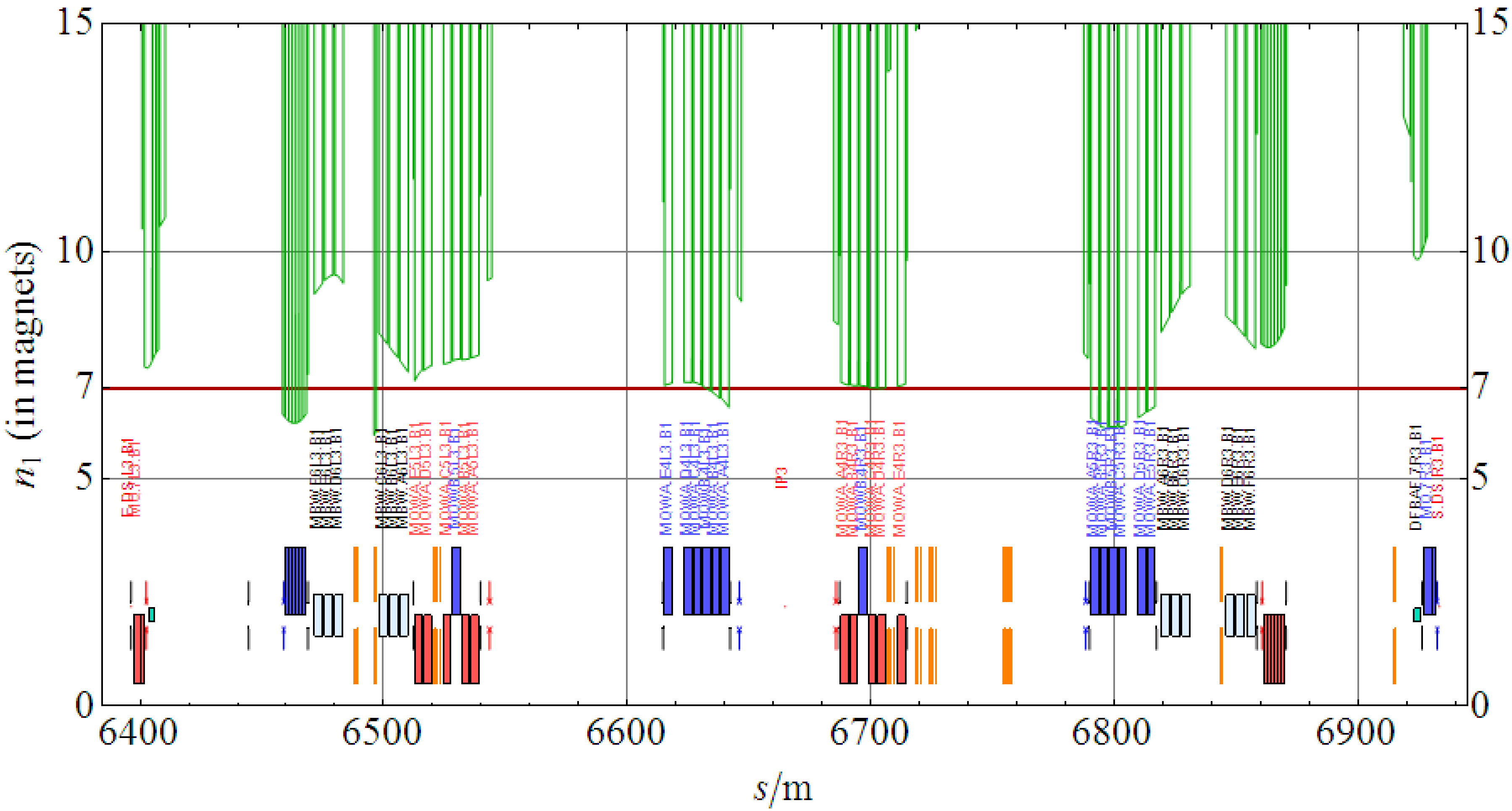
To be used on top of any other set of strengths for LHC optics V6.503, with the new sequences LHCB1CC, LHCB2CC.

Aperture of nominal IR3, Beam 1 at injection



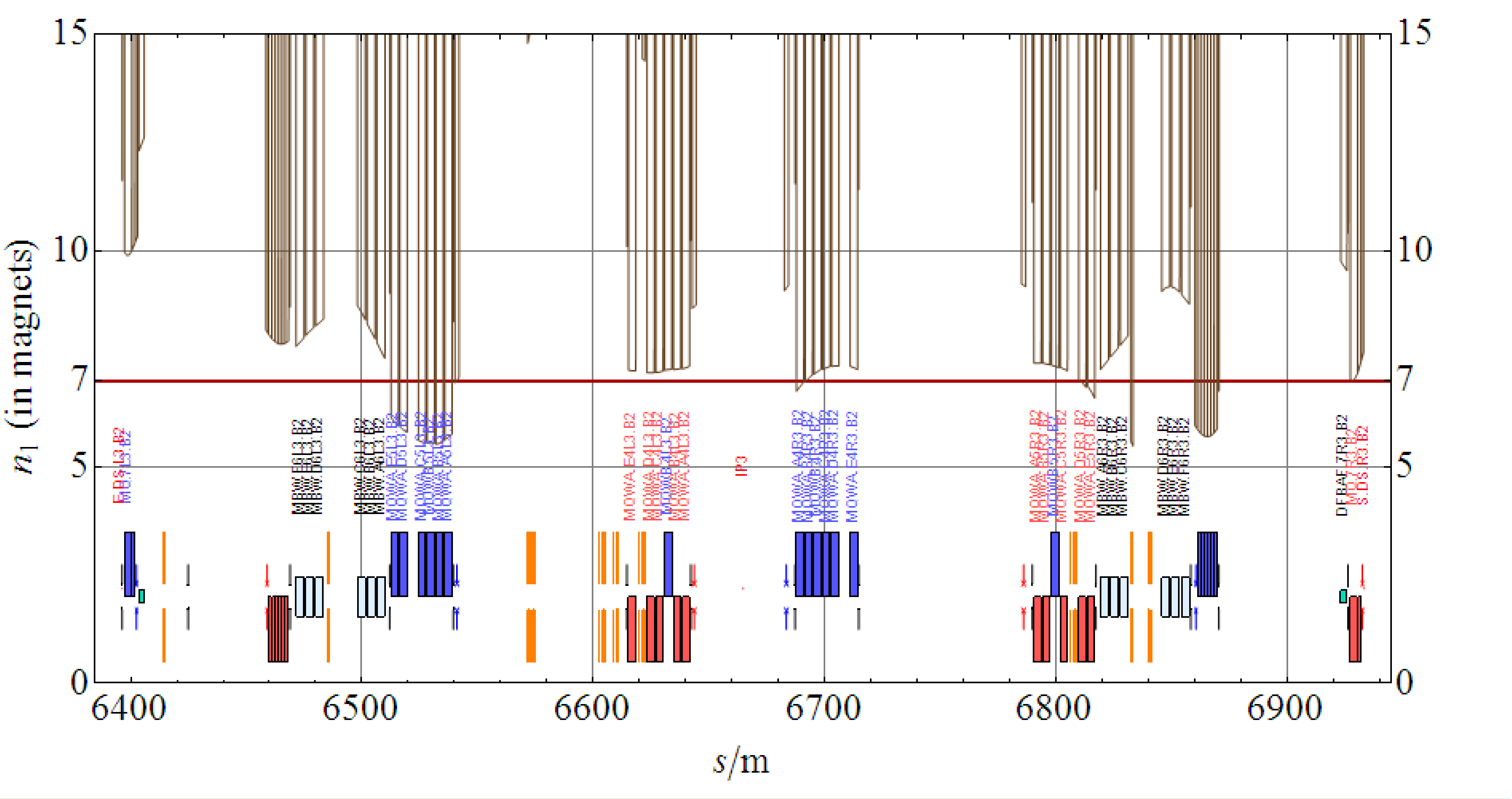
(n_1 is a quantity conventionally used to assess aperture available to beams in the LHC. It includes *x* and *y* planes and various “tolerances” in a single number according to a recipe coded in MAD.
Normally require n_1 > 7.) *N.B. usual optics has low n1 in IR3.*

Cryo-collimator optics IR3, Beam 1 at injection



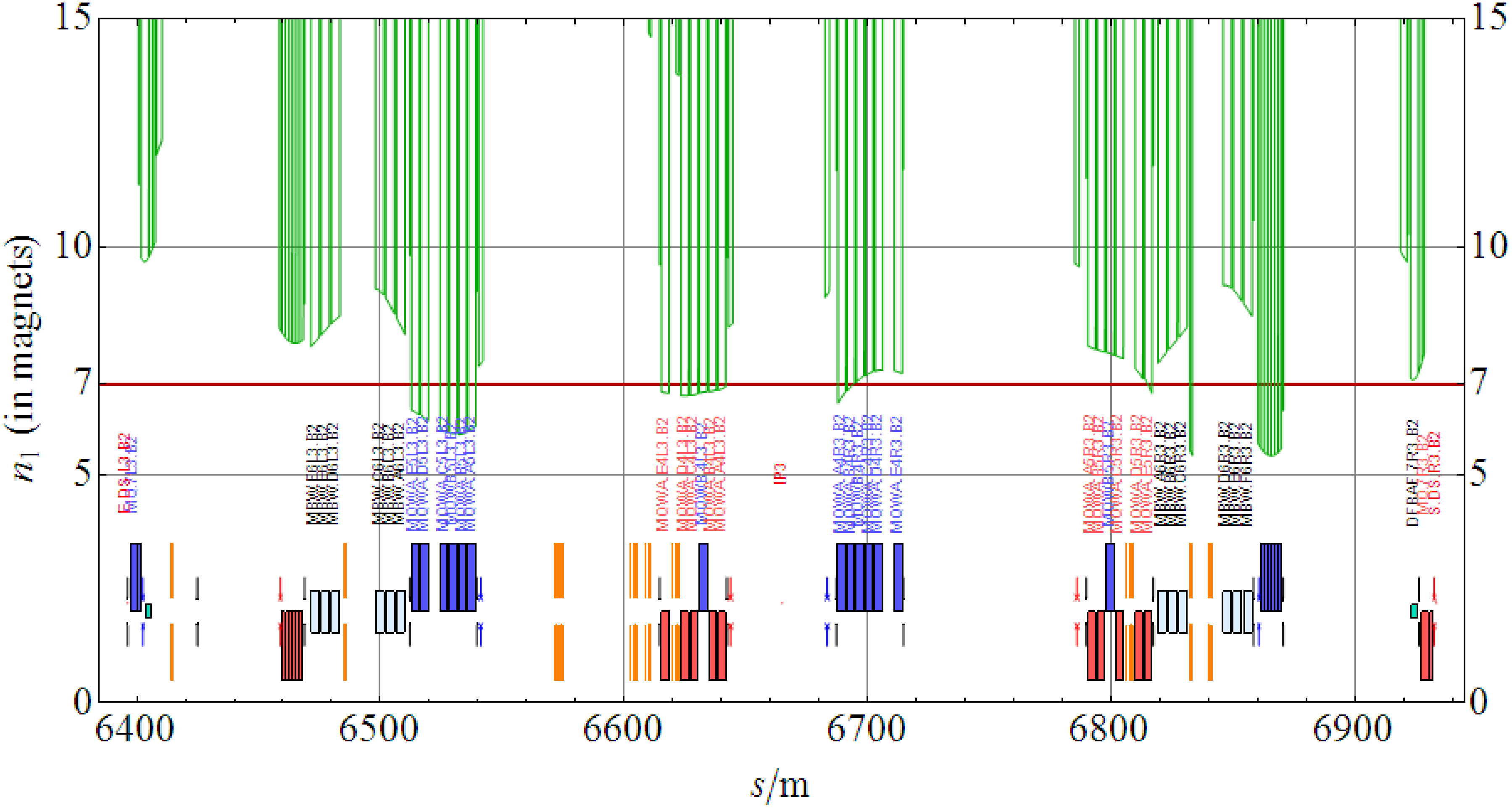
n_1 of the cryo-collimator optics is different

Aperture of nominal IR3, Beam 2 at injection



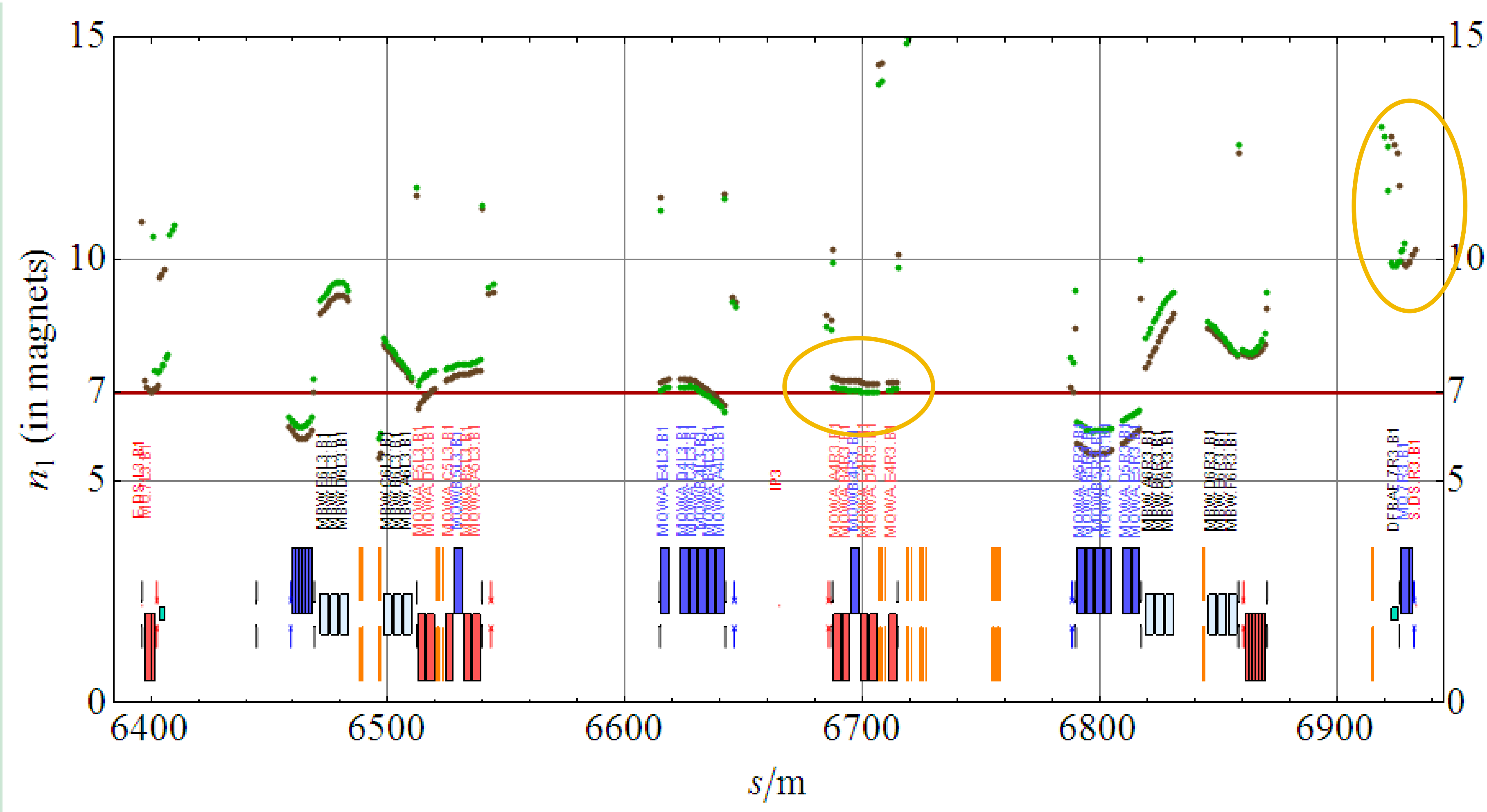
Somewhat different from reflected Beam 1

Cryo-collimator optics IR3, Beam 2 at injection



n_1 of the cryo-collimator optics is different

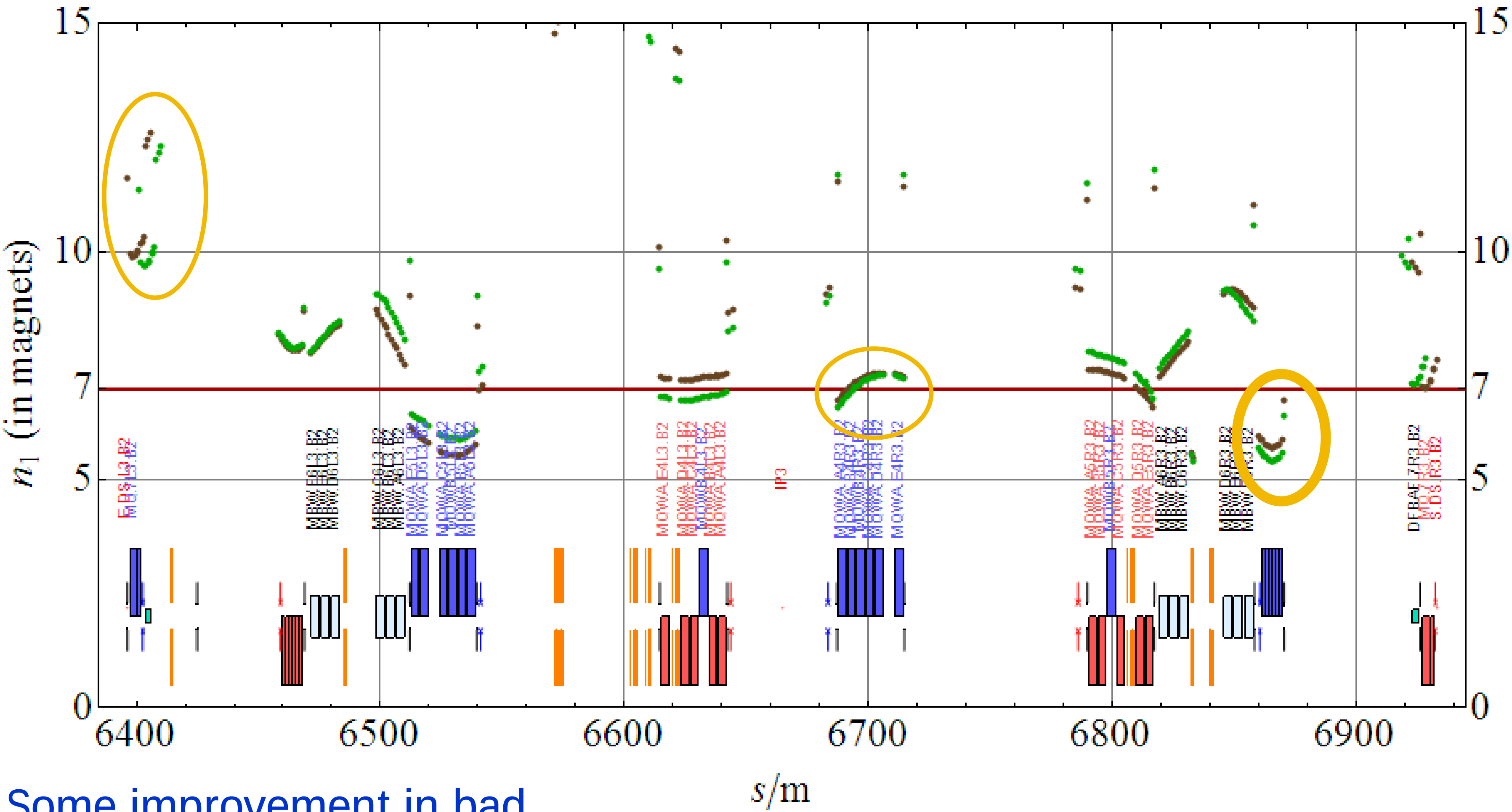
n_1 before and after, Ring 1, IR3



Some improvement in all worst places

Slight degradation in one other places

n_1 before and after, Ring 2, IR3



Some improvement in bad places again.

Reduced at worst place.

min n_1 in IR3	Ring 1	Ring 2
Optics V6.503	5.52	5.49
Cryo-collimator optics	5.96	5.42

Conclusions

- A new “cryo-collimator” layout for maximum 4.5 m shift of the dipoles and Q10 has been worked out
- Optics for both beams rematched with general improvement in aperture over standard IR3 optics
  - Reduced in one place for Beam 2