High Luminosity LHC

HLLHCV1.0: HL-LHC layout and optics version for 150 mm Nb3Sn triplets and local crab-cavities

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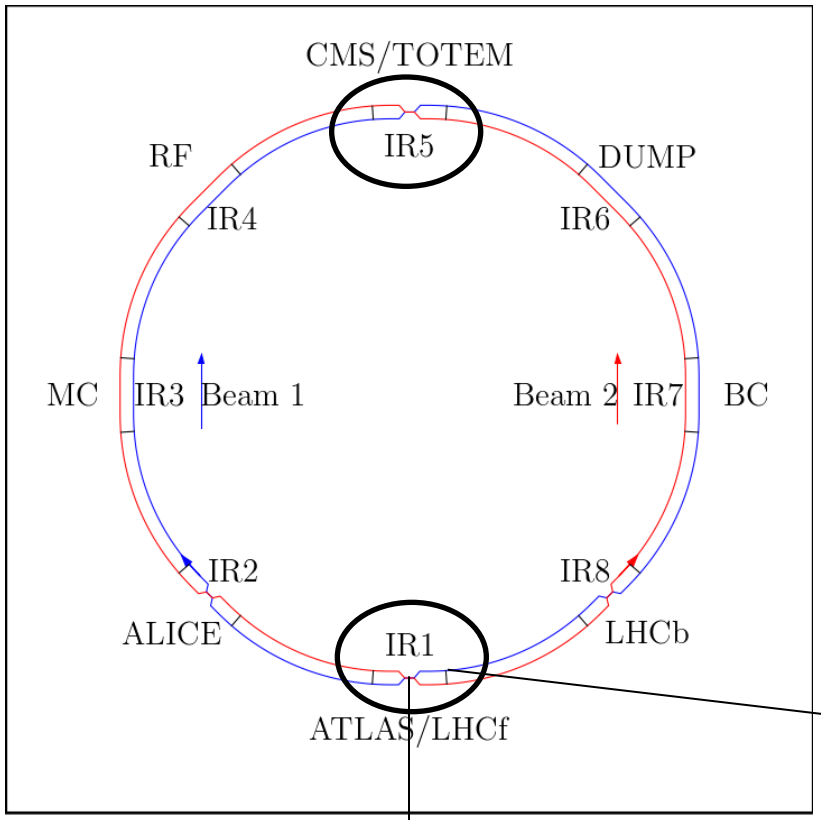
Introduction

- A new IR1-5 layouts and LHC optics solutions are needed to support low beta* values for the HL-LHC upgrade project.

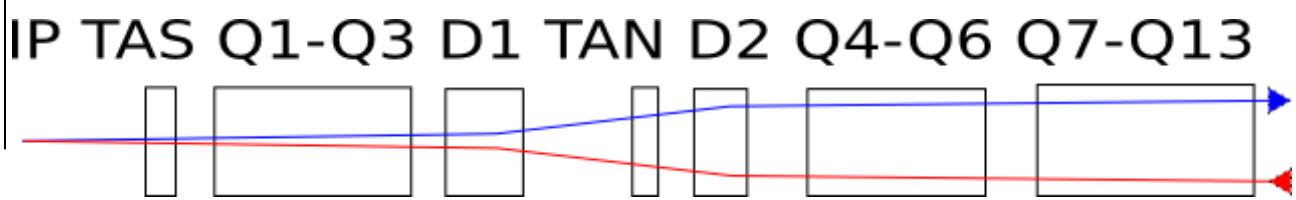
Short chronological development on LHC upgrade optics:

- 2002-2007 Care-HHH: exploratory effort focused on beta*=25cm. Solution converged on low gradient large aperture triplets, chromatic aberrations and optics limitations as outstanding issues.
- 2008-2010 Phase-I (SLHCV2.0) realistic layout and optics with NbTi technology (120mm, 123T/m) for beta*=30cm. Overcomes previous difficulties but further improvements limited by aperture limitations, optics flexibility and chromatic aberrations.
- 2010-2011 SLHCV3.0: Proof of principle of the Achromatic Telescopic Squeeze (ATS to overcome Phase-I limitations) with the Phase-I triplets, used as benchmark for chromatic effects and dynamic aperture.
- 2011-2012 SLHCV3.1b: Effort on a realistic layout with crab cavity integration and optimized optics for a 150T/m gradient, 140mm scenario. In parallel proof of principle for alternative layouts (NbTi 100T/m 140mm, Nb3Sn 170T/m 120mm). Each variation follows well established scaling laws.
- 2011-2012 ATS-V6.503: Redefining a full ATS optics version compatible with the existing LHC (200T/m IT) and demonstrate most of the ATS principle down to beta*=10 cm → The ATS is triplet invariant.
- 2012 HL-LHCV1.0: Follow up of 3.1b after decision on 150mm, 140T/m Nb3Sn triplets and 90mm Q4 plus further optics optimization for IR8(LHCb) and IR2(Alice). In parallel investigations for alternative layouts and optimization of the crab cavity voltage.

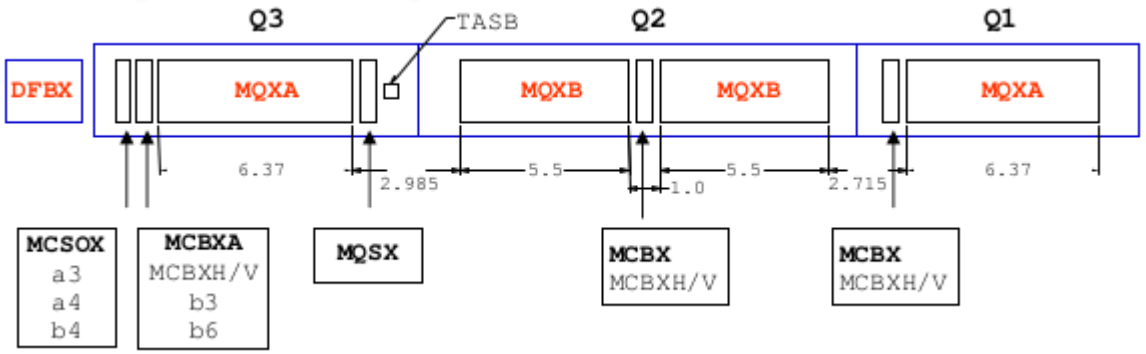
LHC Ring and Interaction Region (IR) layout



Most of the optics related layout upgrades are concentrated around IP 1 and 5.

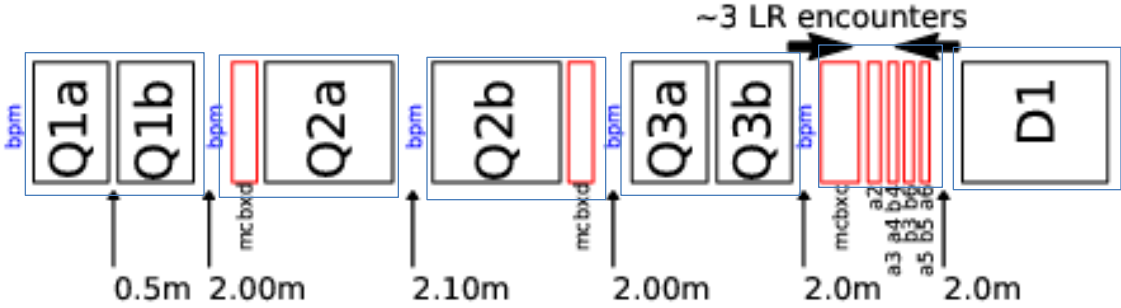


Triplet layout



Nominal layout:
NbTi:
(3 cryostats)

HLHC V.10 layout:
Nb3Sn
6 cryostats



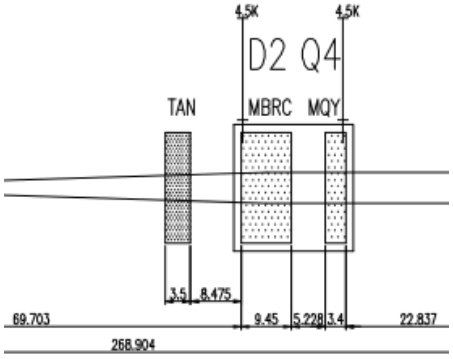
Q1/3 a/b: 3.99m, 140 T/m, 150mm
Q2 a/b: 6.76m, 140 T/m, 150mm
D1: 7.7m, 40 Tm, 160mm

MCBXD: 1.3m, 1.8Tm, h/v nested orbit corrector
MCBXC: 2.00m, 4.5Tm in xing plane(for crab) and 1.8Tm in the other plane
MQSX3: 0.67m, skew quadrupole corrector
MCSTX3: 0.50m, (b3,b6) nested correctors
MCOSSX3: 0.50m, (a3,a4,b4) nested correctors
MCDTSX3: 0.50m, (a5,b5,a6) nested correctors

HLLHC V1.0: Layout Features

- New Triplets with 140T/m 150mm aperture and split Q1, Q3;
- Extended corrector package with orbit correctors for Crab Cavities;
- Cold 7.7m D1;
- Large aperture TAS and TAN;
- Large aperture and shifted D2(105mm, +11m towards the IP) with orbit correctors for crab cavity operations without orbit shifts;
- Large aperture Q4(90mm, 3.5m), shifted and large aperture Q5(MQML → MQYL at +15m towards the arc);
- 4 2-in-1 new sextupoles in Q10 in IR1,5 (MCBC → MSCB) for better chromatic correction;
- new Q5 (MQY → MQYL) in IR6 for ATS squeeze range in IR5;

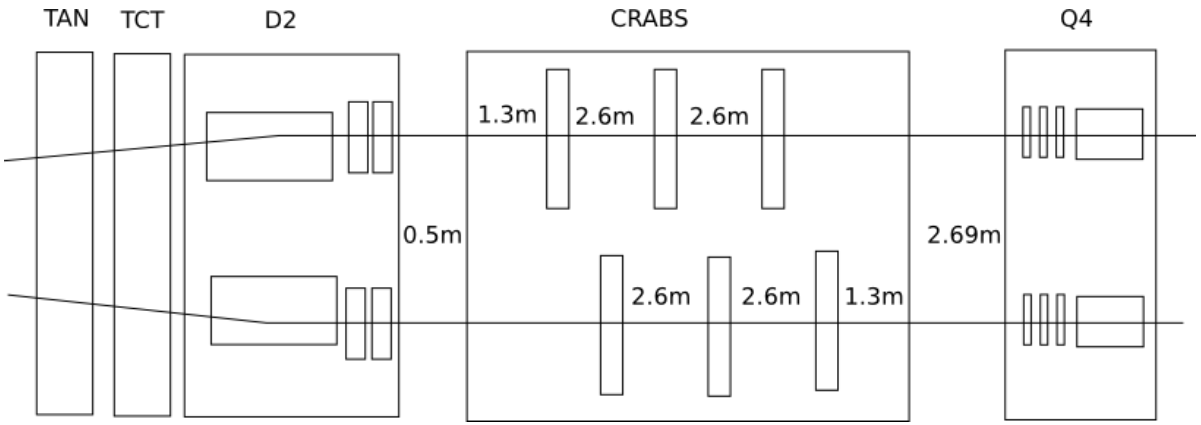
Crab cavity layout



Nominal layout:

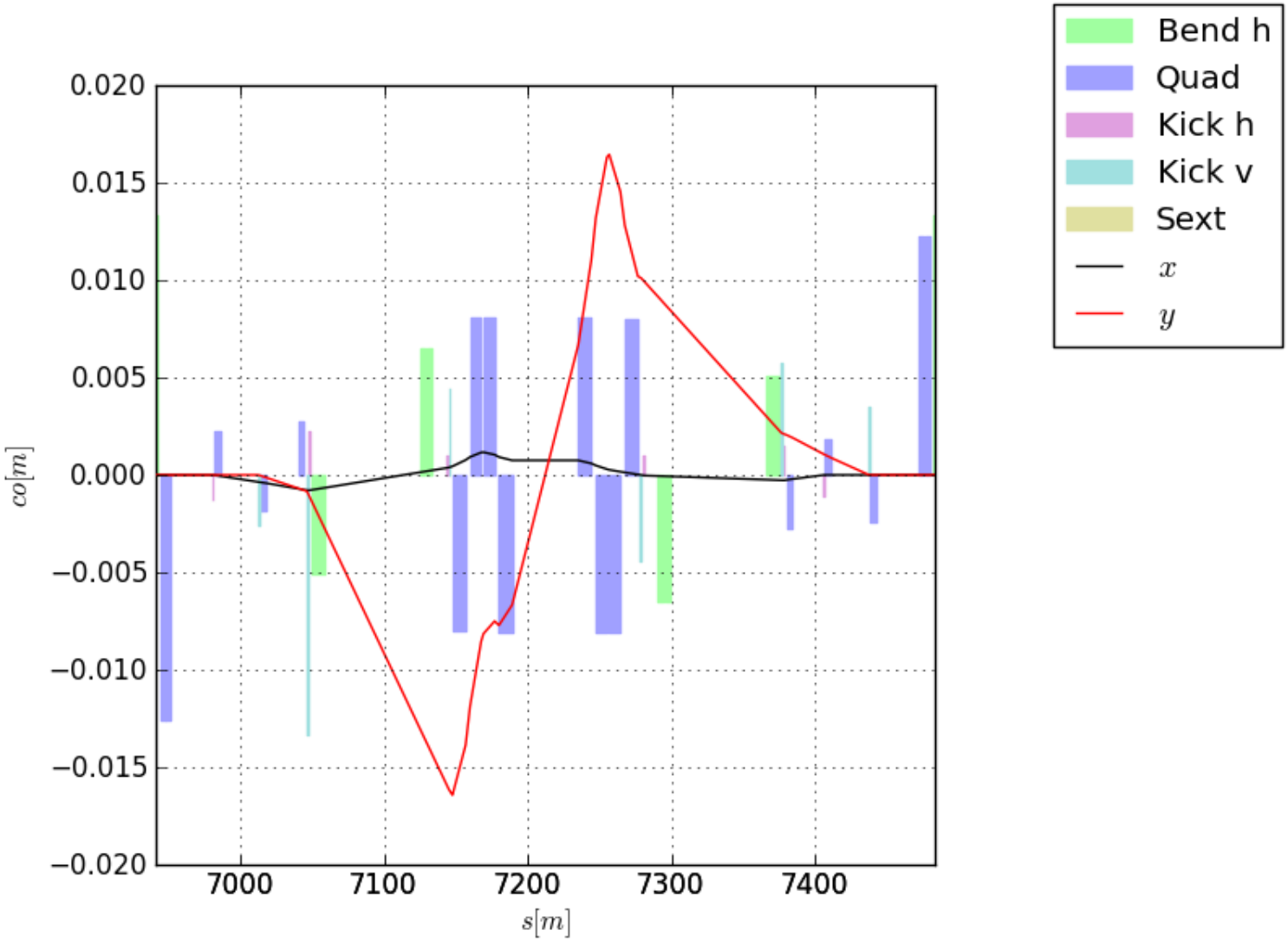
• one cryostat for D2 Q4 and corrector package

HLLHC V1.0 layout

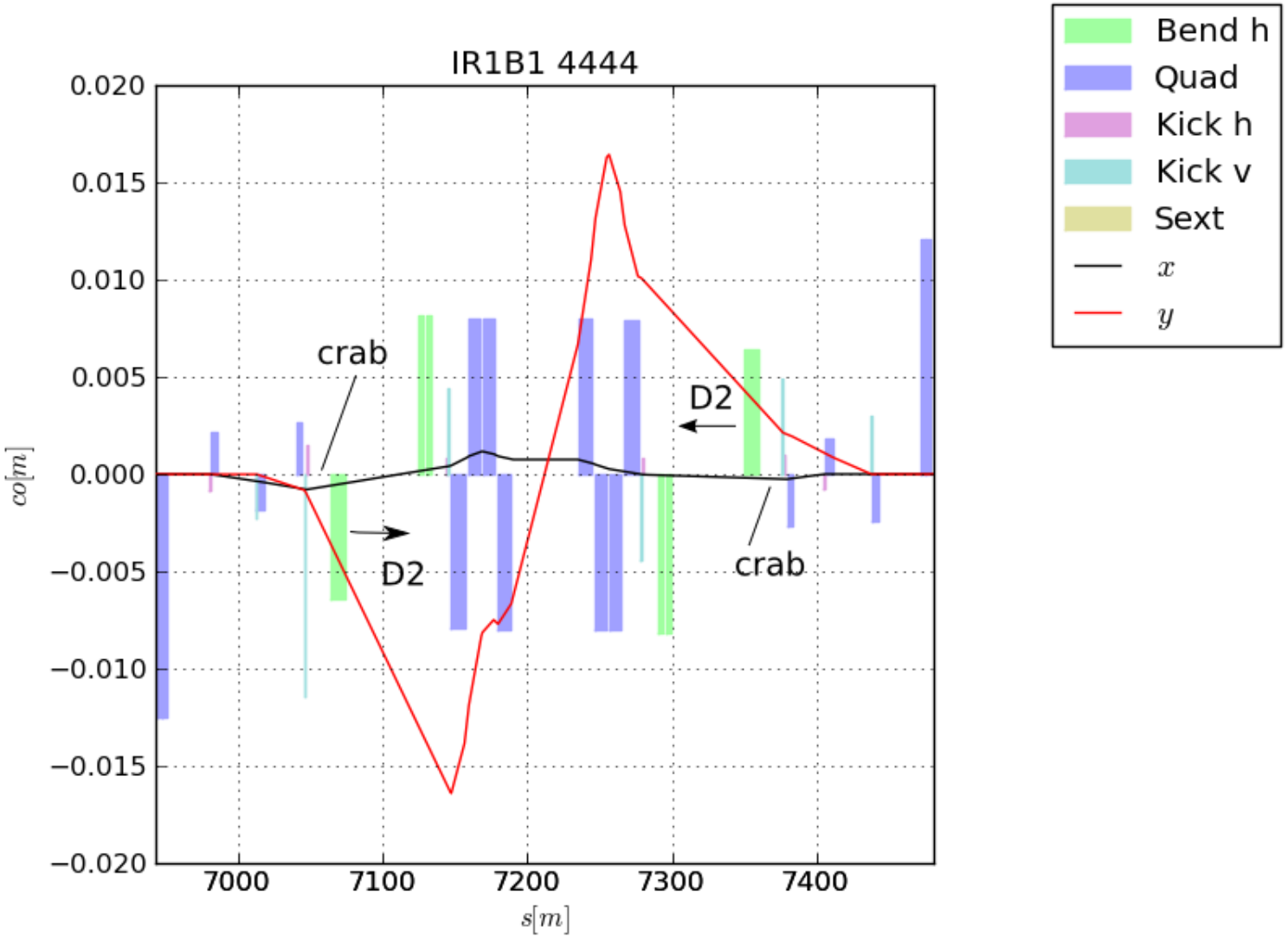


•Separate D2 and Q4 cryostat;
•Total cavity voltage for 590murad 12MV (for full crabbing);
•3 cavities allocated per side per beam;
•Alternated location for voltage equalization;
•Introduce stronger corrector for crossing scheme gymnastic.

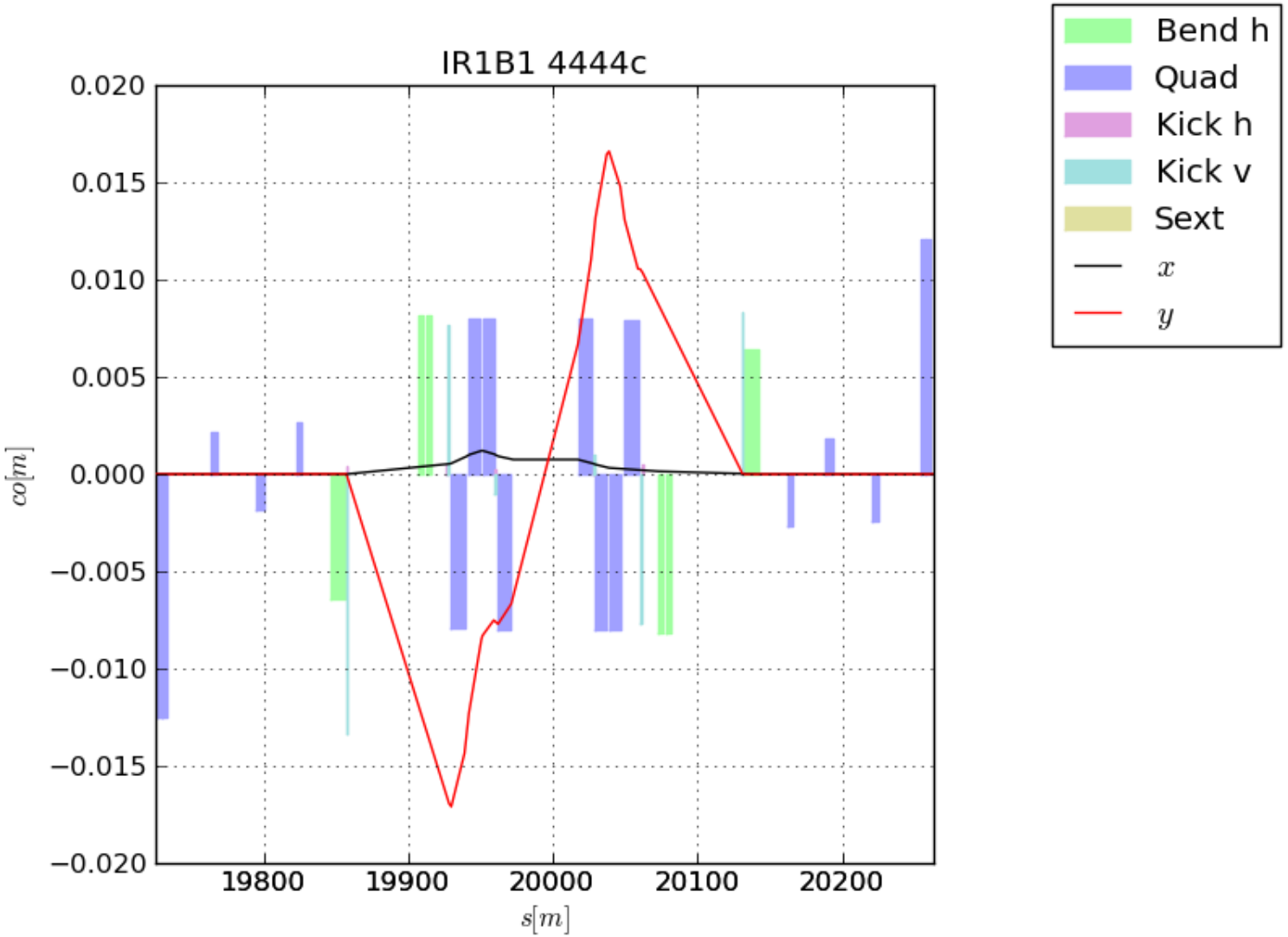
New crossing angle



New crossing angle



New crossing angle



HLLHC V1.0: Optics Features

- Pre-squeeze at 44cm and 3.45m in IR1 and 5;
- Squeeze at 15→10cm (round) or 30/7.5cm→20/5cm (flat);
- New phase advance for IR2 and IR8 for optimal squeeze-ability in non-ATS-mode (50 cm in IP2 and 8 for ions) or ATS-mode for protons (10 m in IP2, 3 m in IP8) keeping the same injection optics for both modes.
- Pre-squeeze at high-beta and transition to injection at 6m for IR1 and 5 is under study. Injection at 11m, 18m also available;
- Q4 length is optimized for the combined limitations of the operating current at injection and collision.

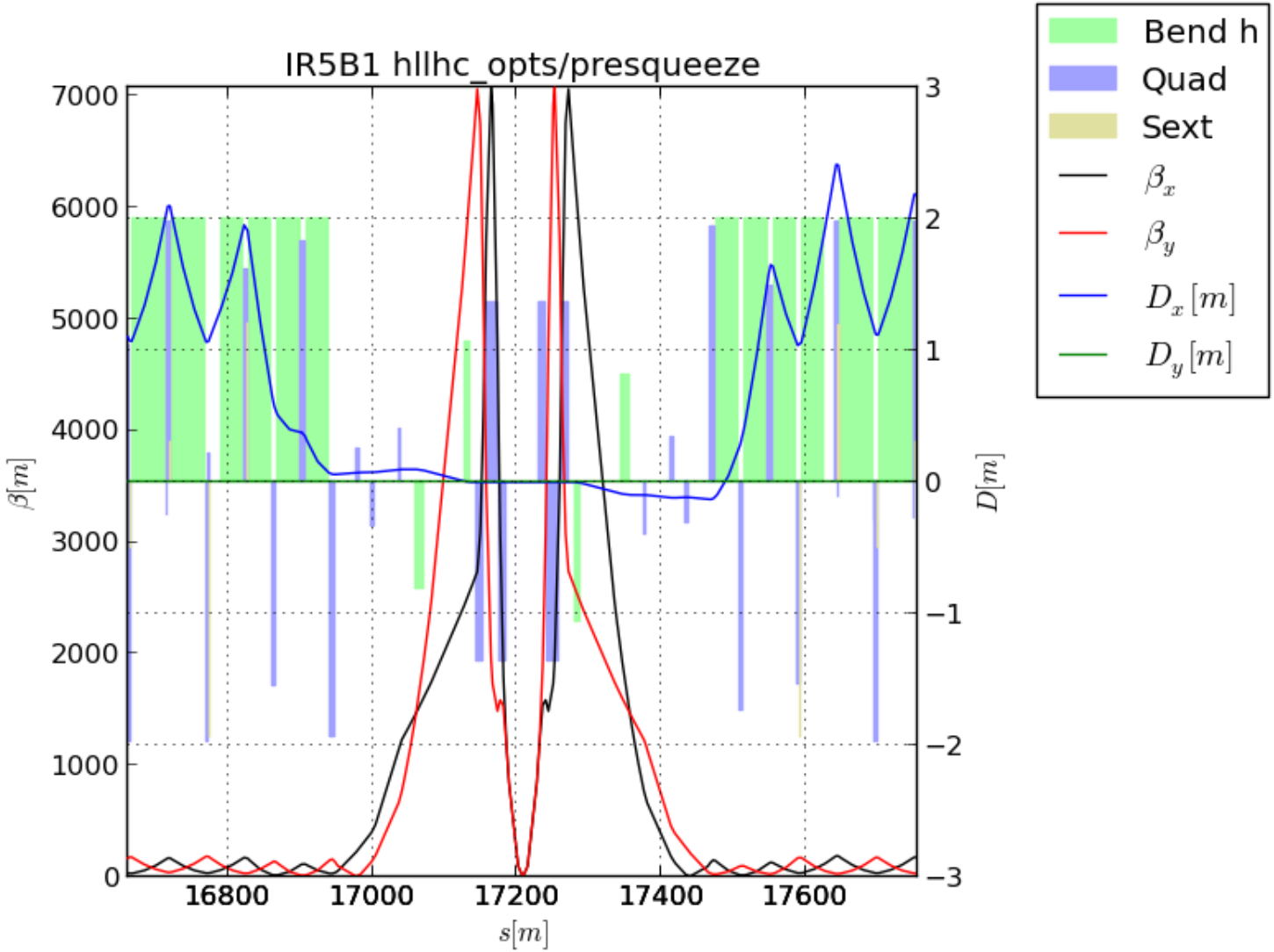
IP optics parameters (1)

Name	IP1-5			IP2			IP8		
	Beta* [cm]	Angle [murad]	sep [mm]	Beta * [m]	Angle [murad]	sep [mm]	Beta* [m]	Angle [murad]	sep [mm]
presqueeze	44	360	0.75	10	340	2	3	340	2
round	15	590	0.75	10	340	2	3	340	2
sround	10	720	0.75	10	340	2	3	340	2
flat	7.5, 30	550	0.75	10	340	2	3	340	2
sflat	5, 20	670	0.75	10	340	2	3	340	2
ions	44	350	0.75	0.5	340	2	0.5	340	2

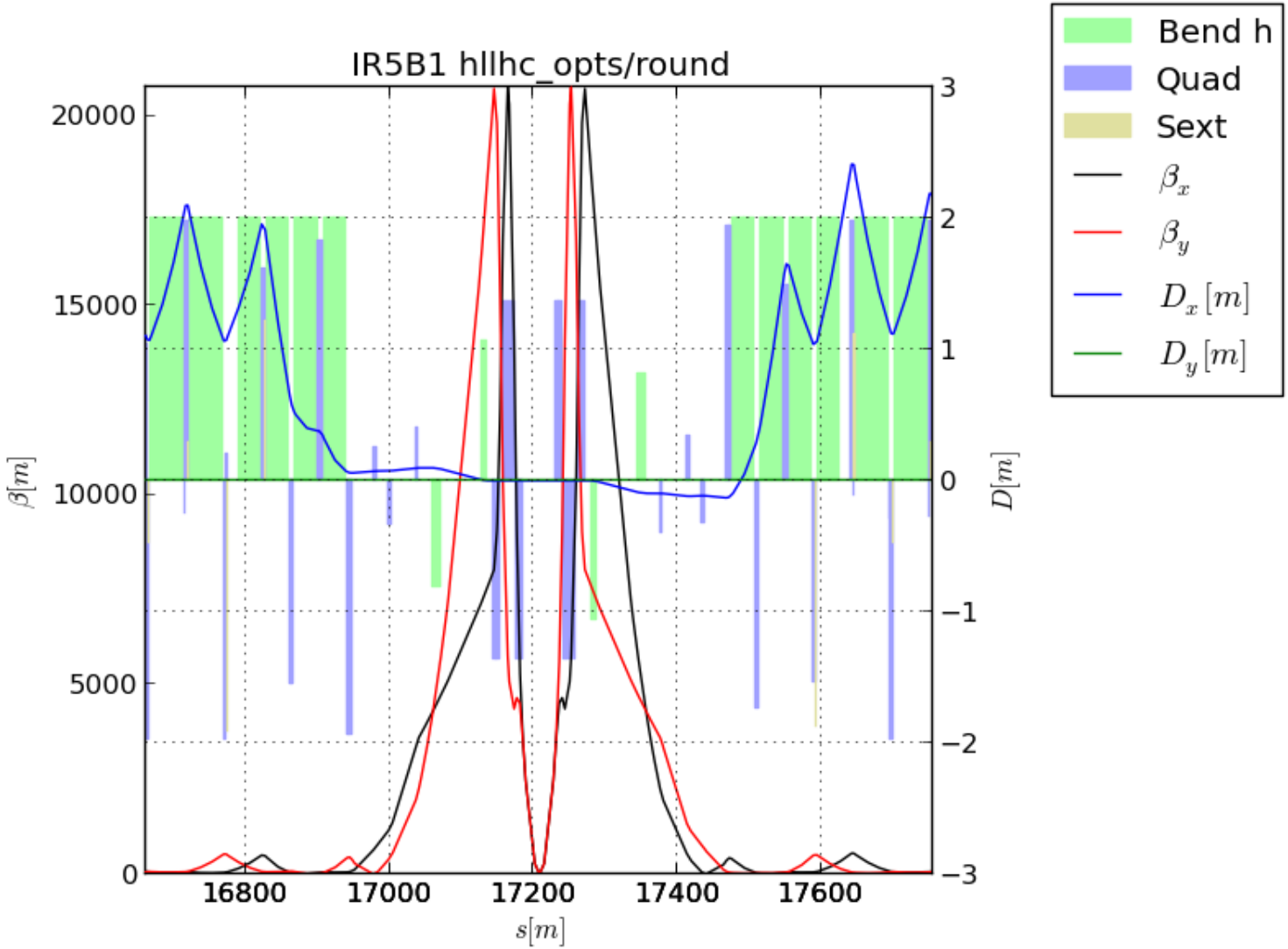
IP optics parameters (2)

Name	IP1-5			IP2			IP8		
	Beta* [m]	Angle [murad]	sep [mm]	Beta* [m]	Angle [murad]	sep [mm]	Beta* [m]	Angle [murad]	sep [mm]
Presqueeze_3450	3.45	360	0.75	10	340	2	3	340	2
endoframp	6	360	2	10	340	2	10	340	2
inj	6	490	2	10	340	2	10	340	2
Inj_11m	11	340	2	10	340	2	10	340	2
Inj_17m	17	340	2	10	340	2	10	340	2

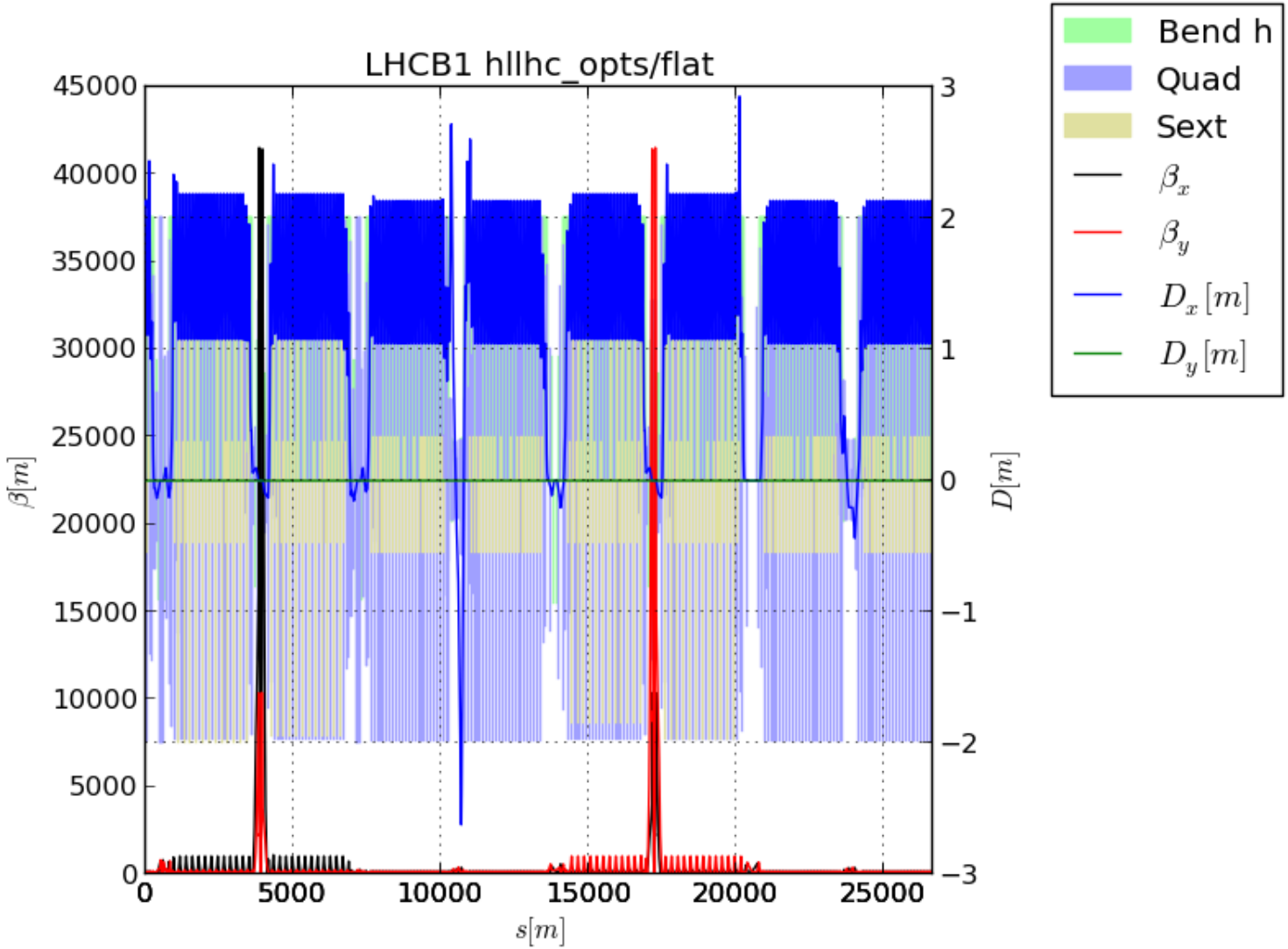
Presqueeze (44 cm)



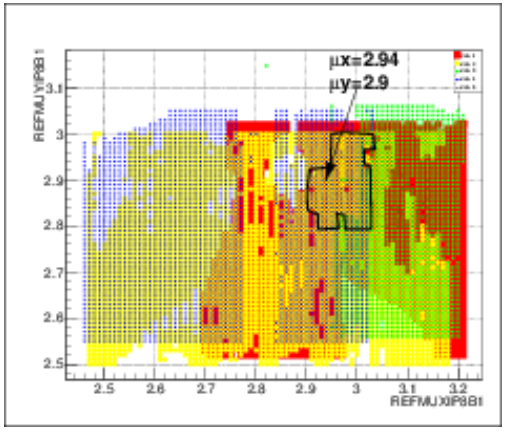
Round Squeeze (15 cm)

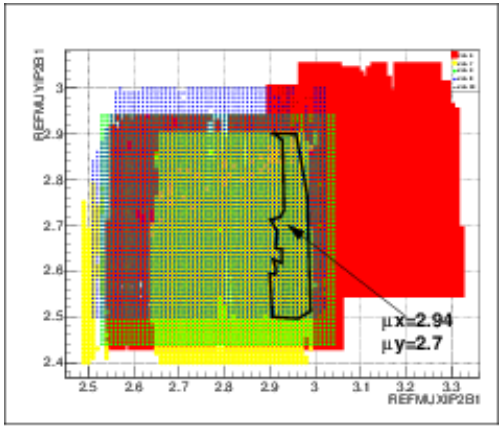


Flat Squeeze (7.5/30 cm)



IR2 – IR8 new phase



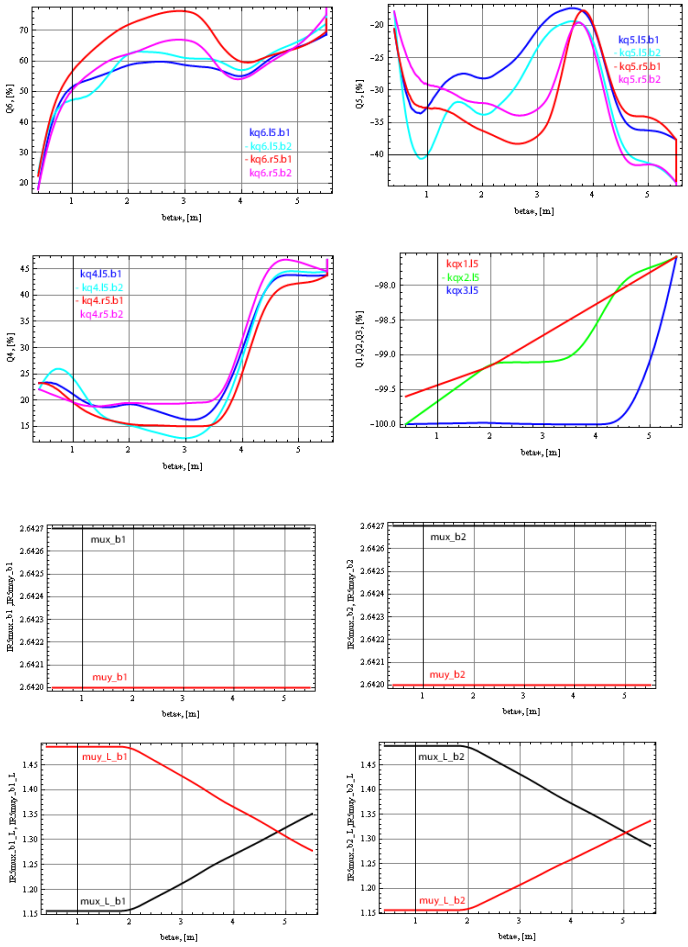


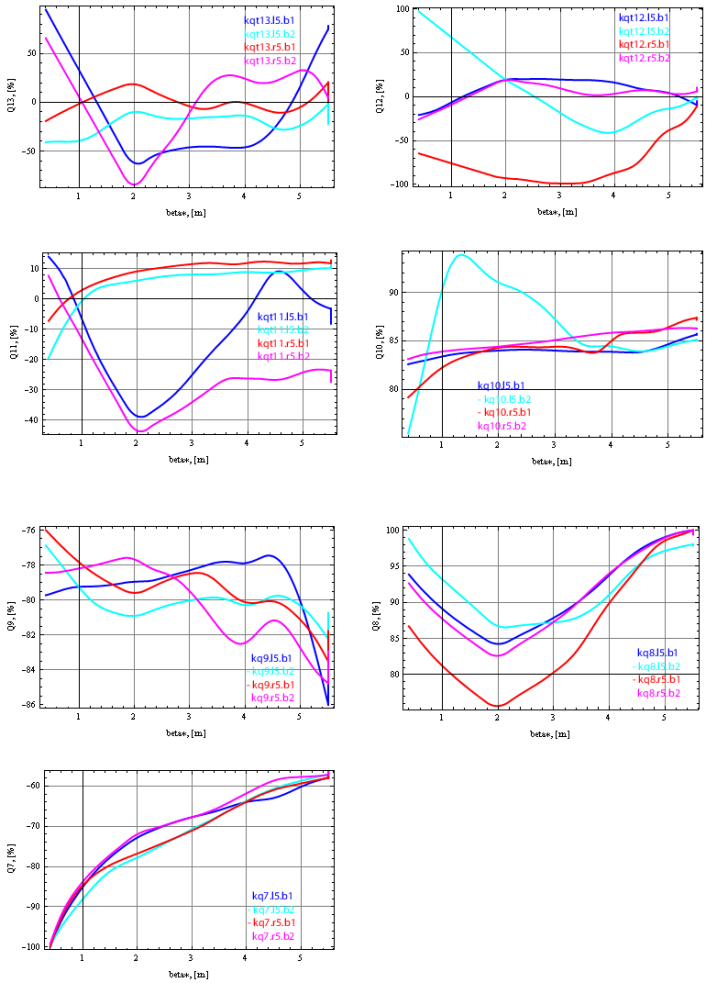
Combined optimization for:
- Injection aperture
- Low beta (50cm beta*)
- ATS squeeze at 3m,and10m beta* for:
  - 4x round
  - (8x,2x), (2x,8x) flat

A. Bogomyagkov

	Nominal		SLHC2.0-3.1b		HLLHC1.0	
	mux	muy	mux	muy	mux	muy
IP2	2.986,2.991	2.8086, 2.884	3.02	2.9	2.95	2.67
IP8	3.183, 3.059	2.974, 2.782	3.02	2.9	3.02	2.8

Transition for SLHC3.1b



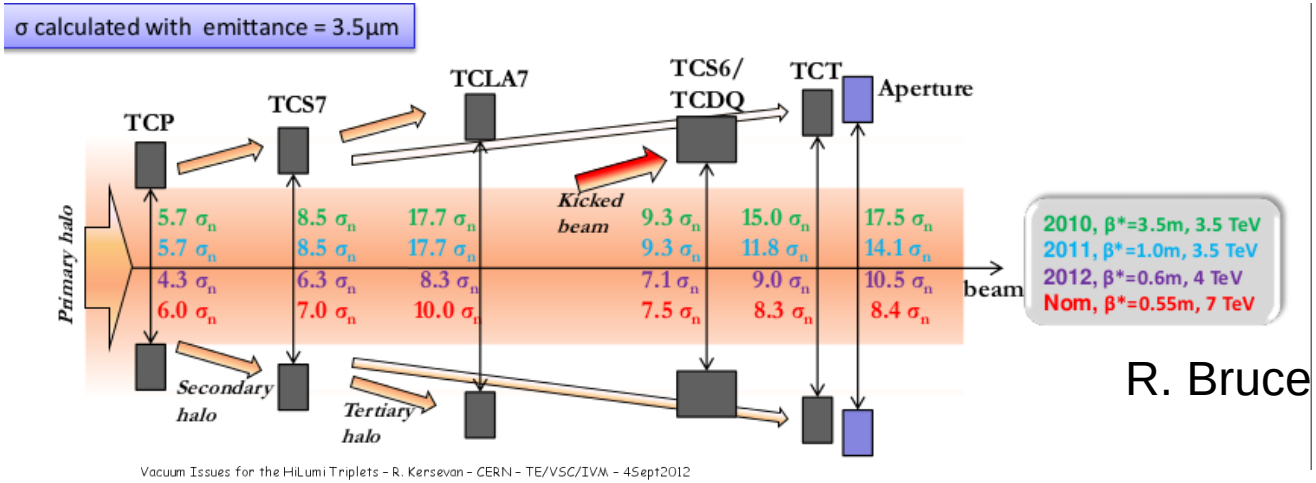


M. Korostolev

HLLHCV1.0: Performance Figures

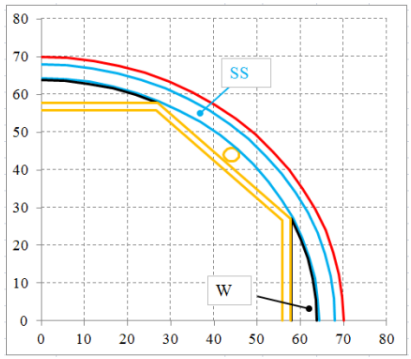
- Aperture margins and beta* reach.
- Chromatic correction.
- Aperture margins at injections.

Beta* reach inputs

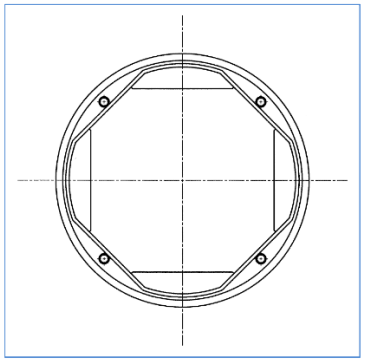


R. Bruce

2. Triplet Region Lay-out, Lattice and Vacuum Model



1/4th of 2D model showing the cross-section of the 140 mm ID cold-bore
(E. Todesco, private comm. 10/7/12)



Starting point: drawing LHCVSSX_0004
6/10/2009, "Phase 1 Upgrade"
(re-scaled to 140 mm cold-bore ID, and 6mm W shielding)

Conceptual 3D Model of 140 mm ID (cold bore, CD) Beam Screen (BS):

- W radiation shield is placed EXTERNALLY to the BS (see next slide)
- 4x4 Pumping Slots, racetrack-shaped like in the LHC arcs' BS have been added (see below), with a longitudinal spacing of 16 mm.

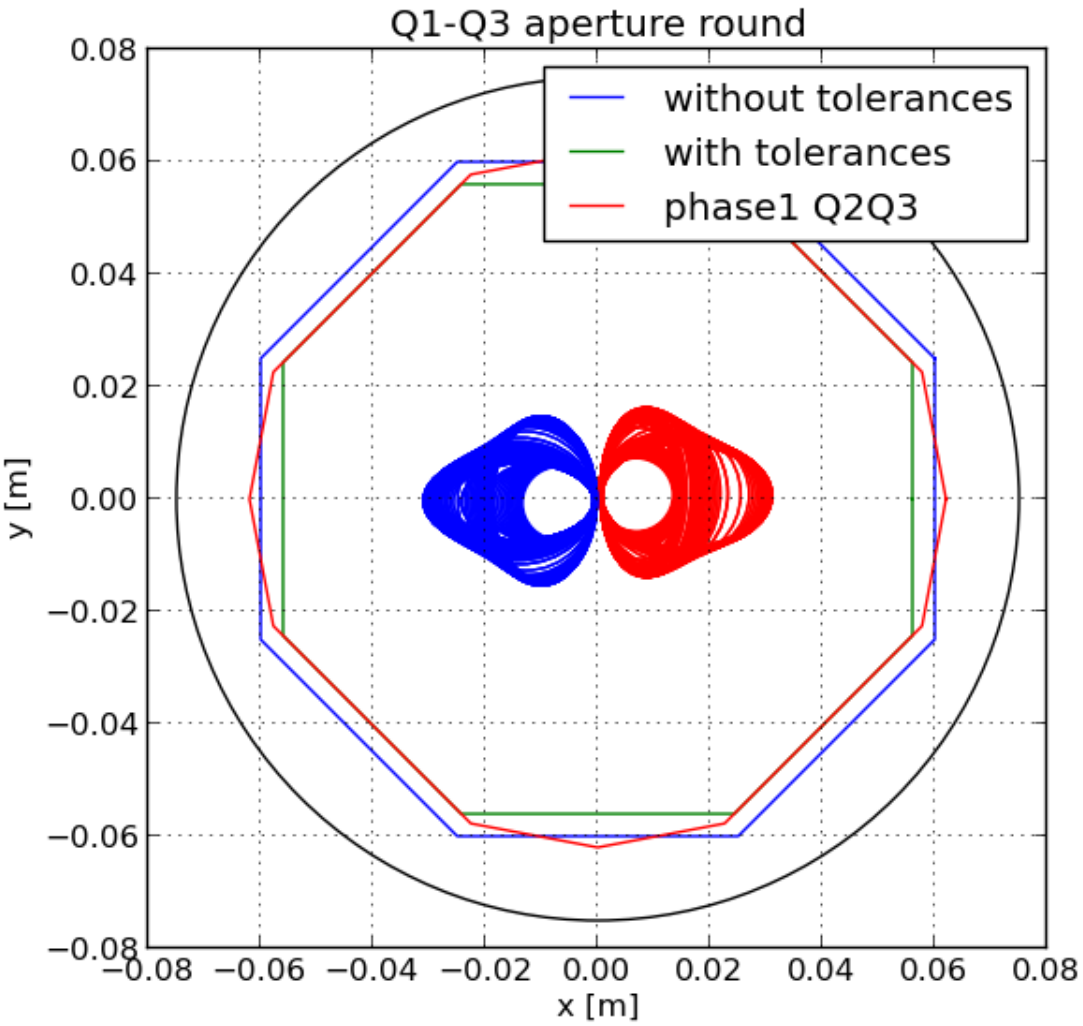
R. Kersevan

Tentative target of triplet aperture at 12 sigma of the without beam related tolerances.

Octagonal beam screen shape to host:

- 4 cooling tubes
- Tungsten inserts for debies protection

Triplet Aperture (6 sigma beam)

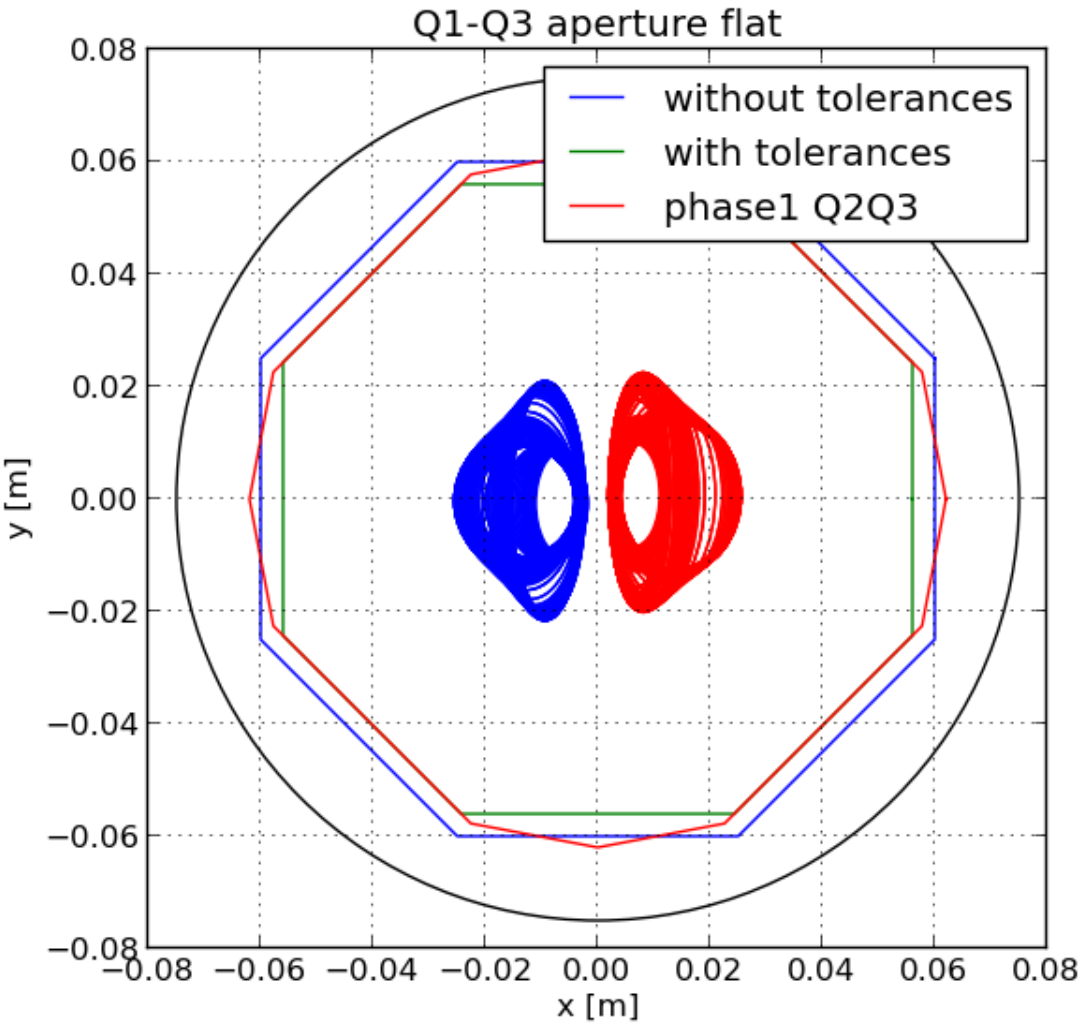


•150mm coil aperture
• Octagonal beam screen inner geometry
•Room for 6mm shielding and cooling tubes

•Optimistic case includes:
- •Helium 2 mm
- •Cold bore 3.7 mm
- •Beam screen 2 mm
- •BS clearance 0.5mm

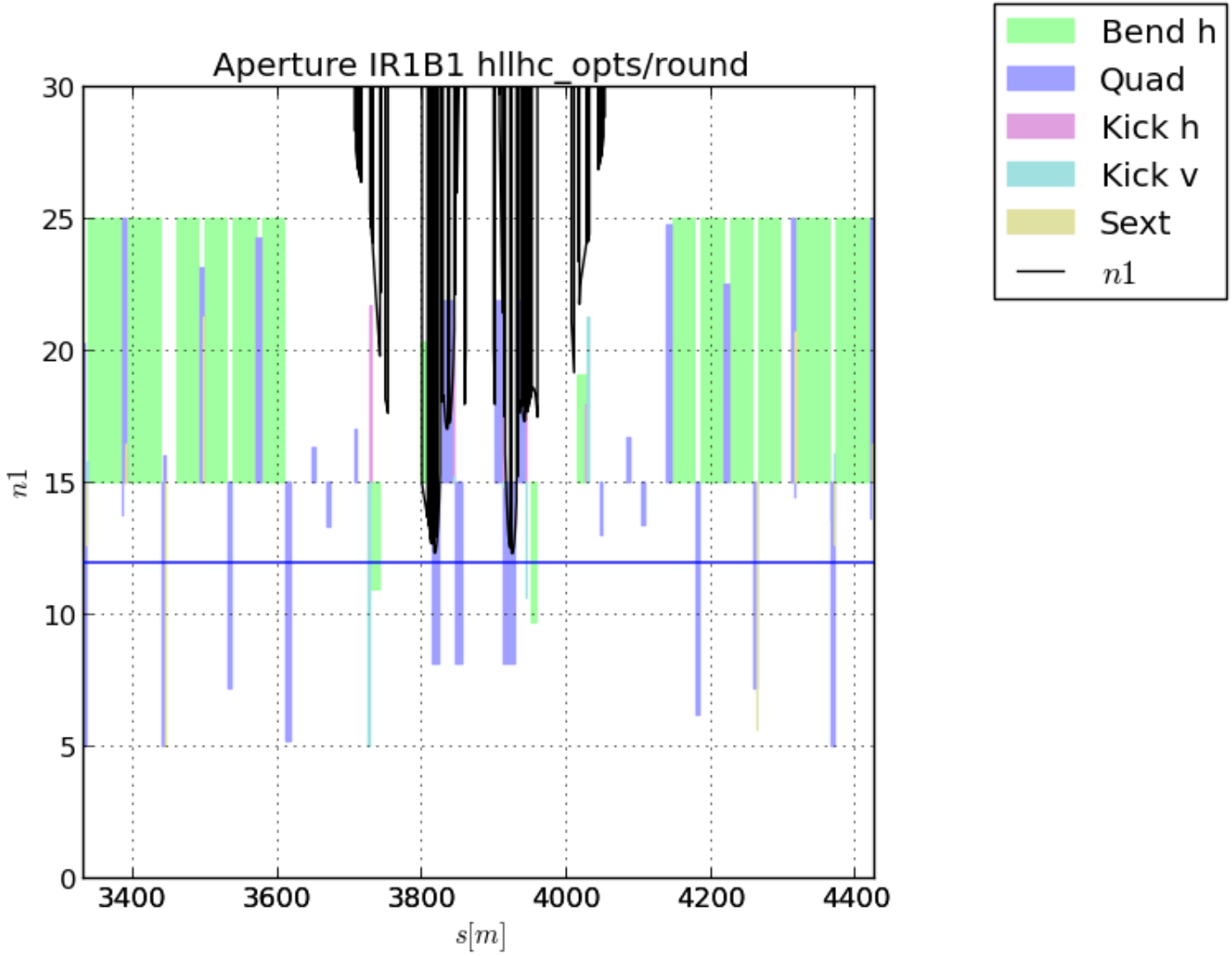
•Phase I case (N. Kos) adds:
- •BS support rings
- •ISO tolerances
- •Thermal contraction

Triplet Aperture flat case

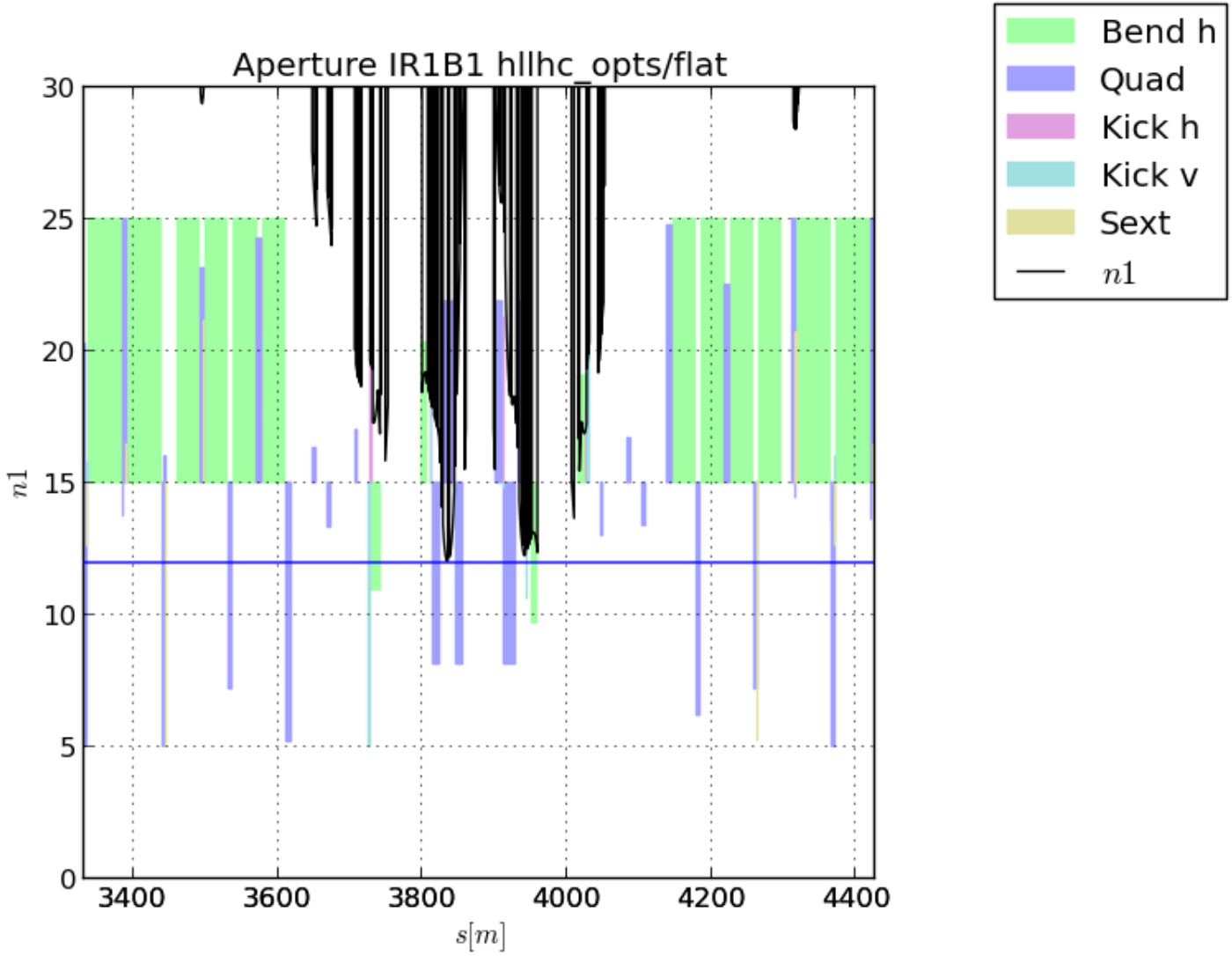


- Same geometric average but ¼ aspect ratio
- Larger crossing angle to recover bb footprint of a round case
- Still well fitted in round like aperture

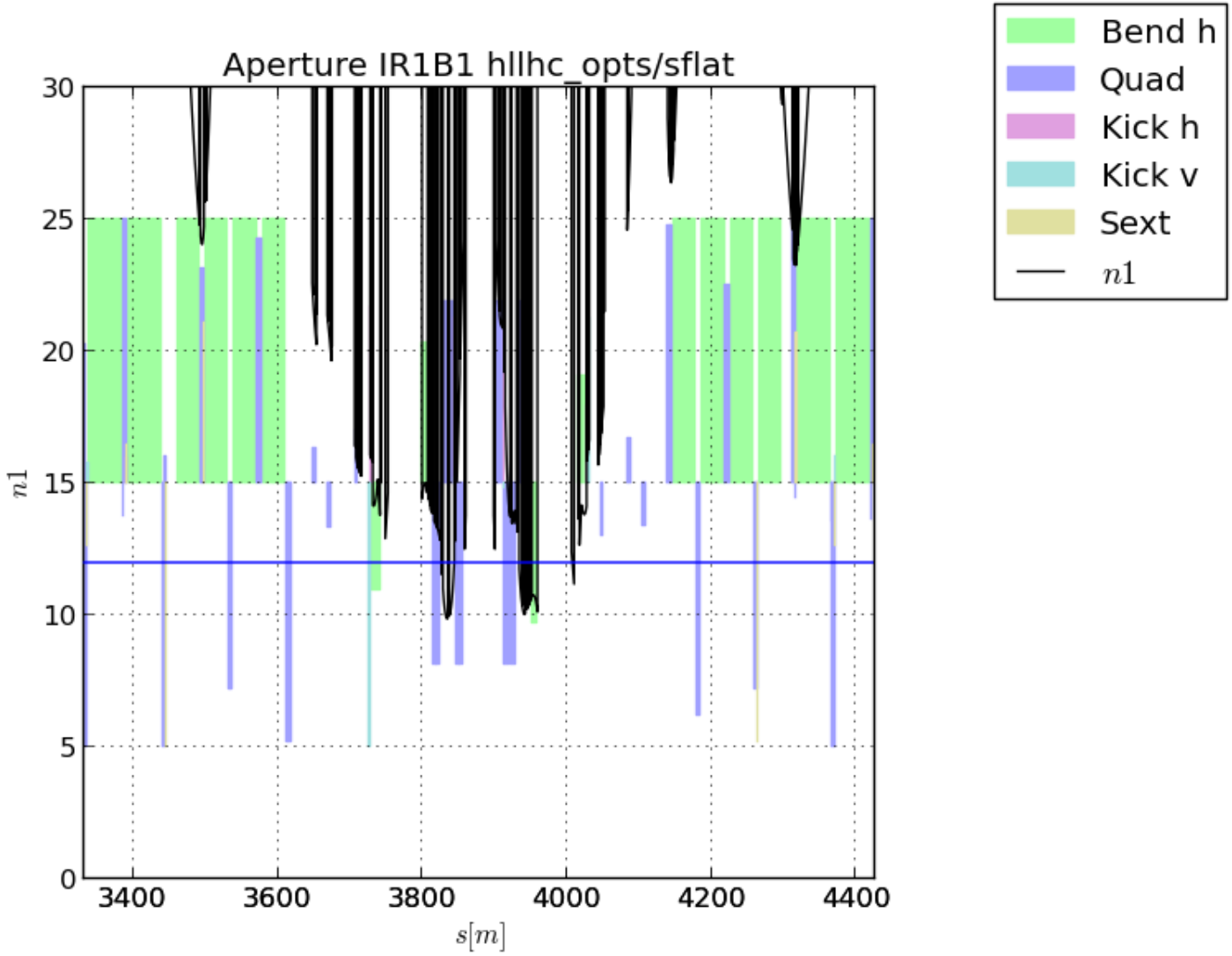
Aperture margins at 15 cm with tolerances



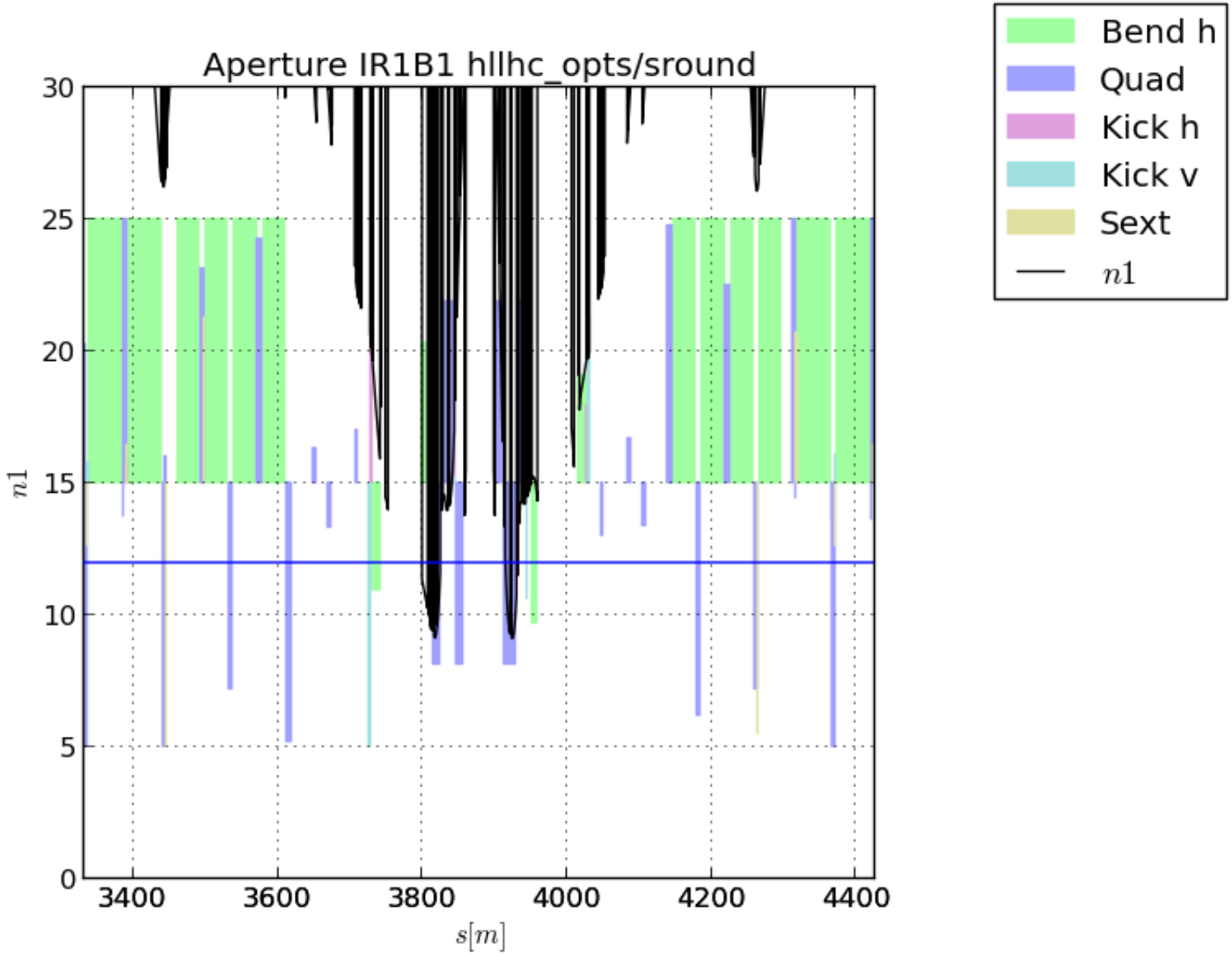
Aperture margins at 7.5/30 cm (flat)



Aperture margins 5/20 cm flat

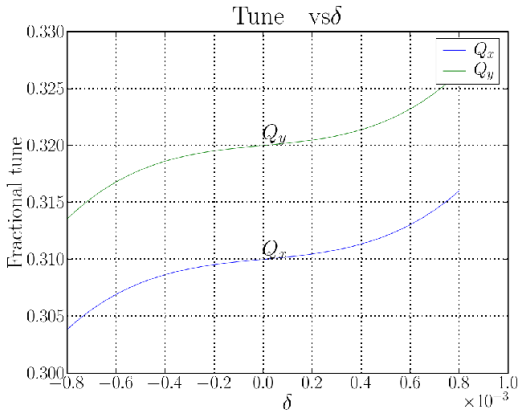


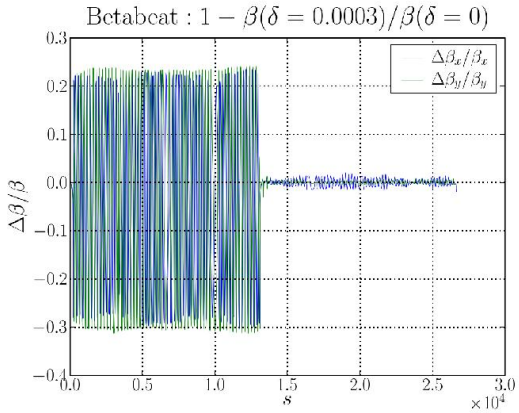
Aperture margins 10cm round



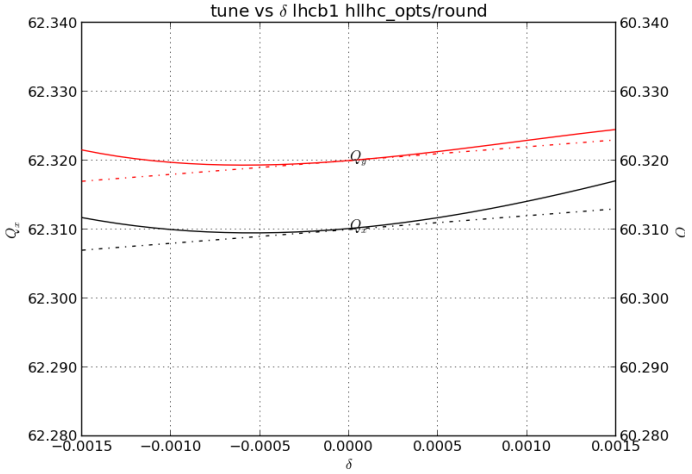
Chromatic Correction

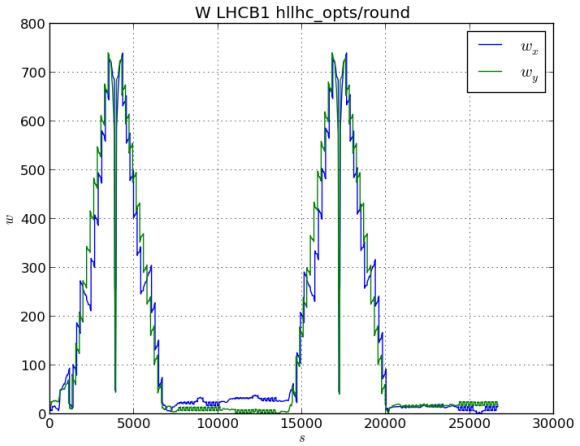
25cm with no IR, arc phase advance optimization.



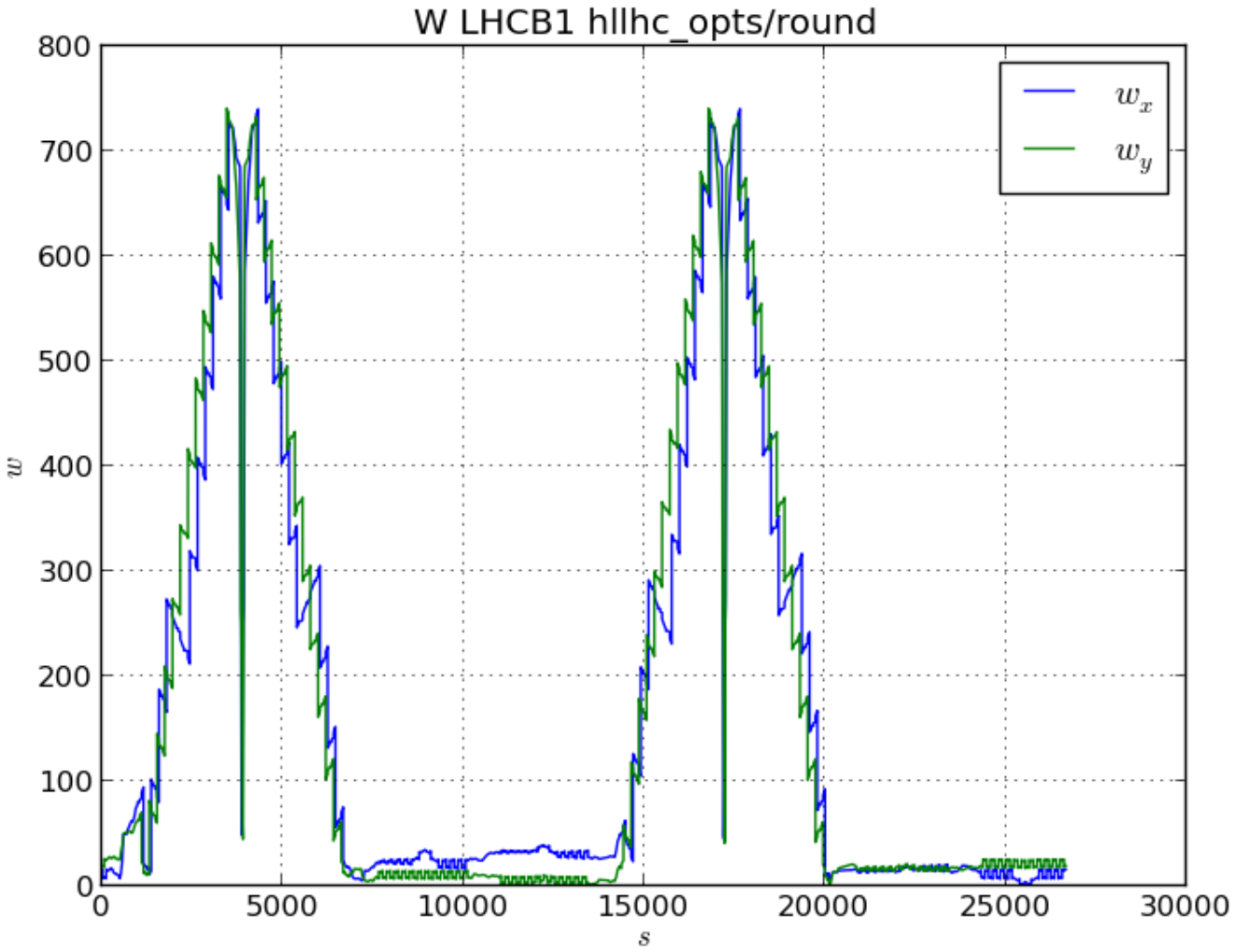


15cm with ATS

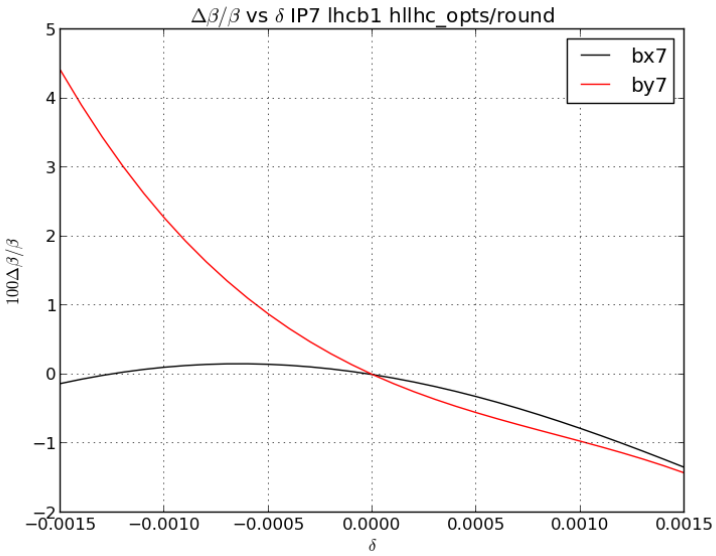


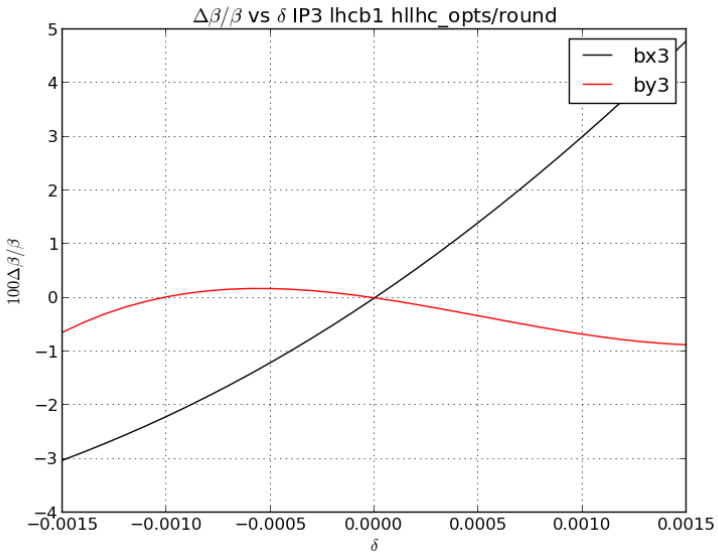


Chromatic Correction at 15 cm



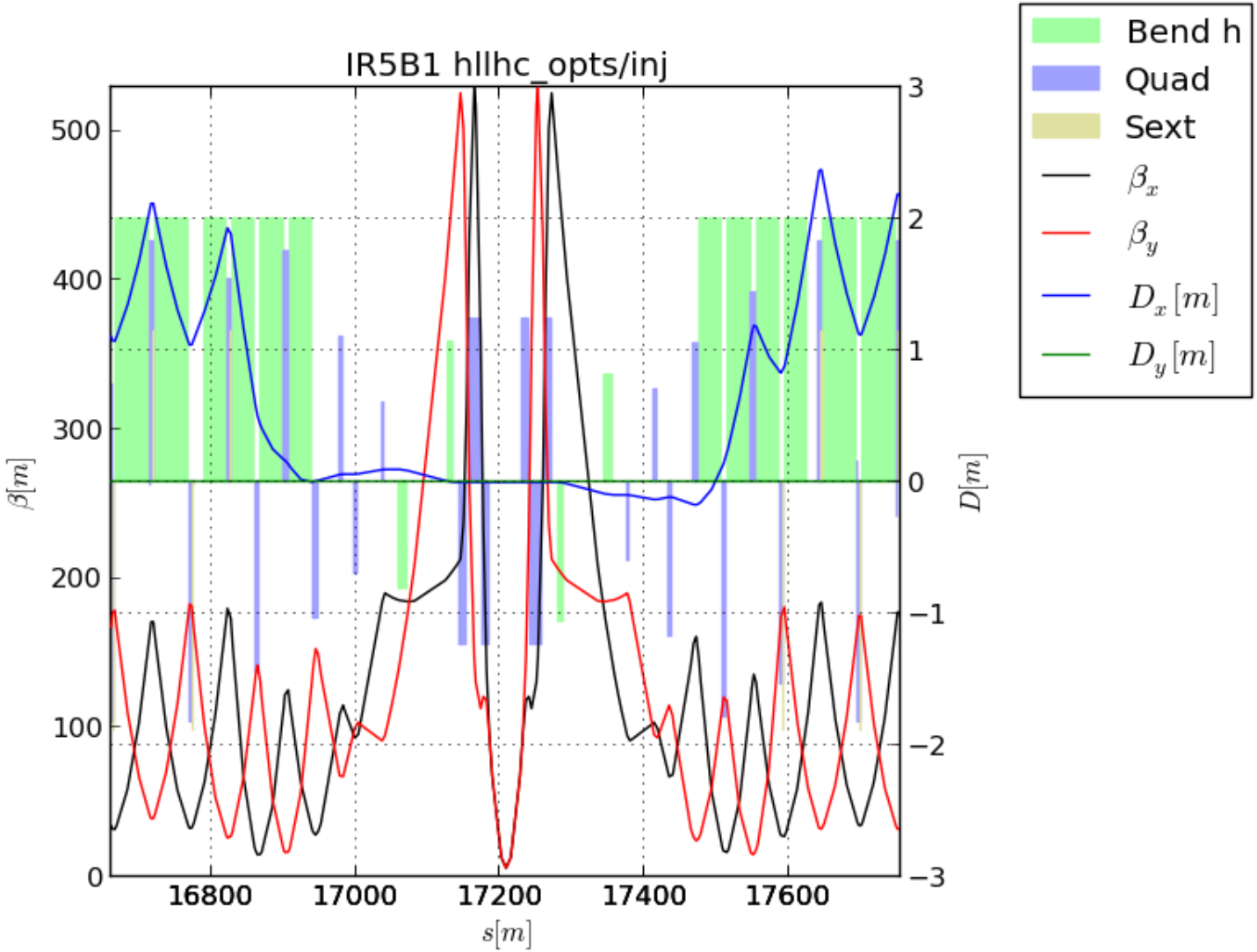
Chromatic Correction at 15 cm (2/2)



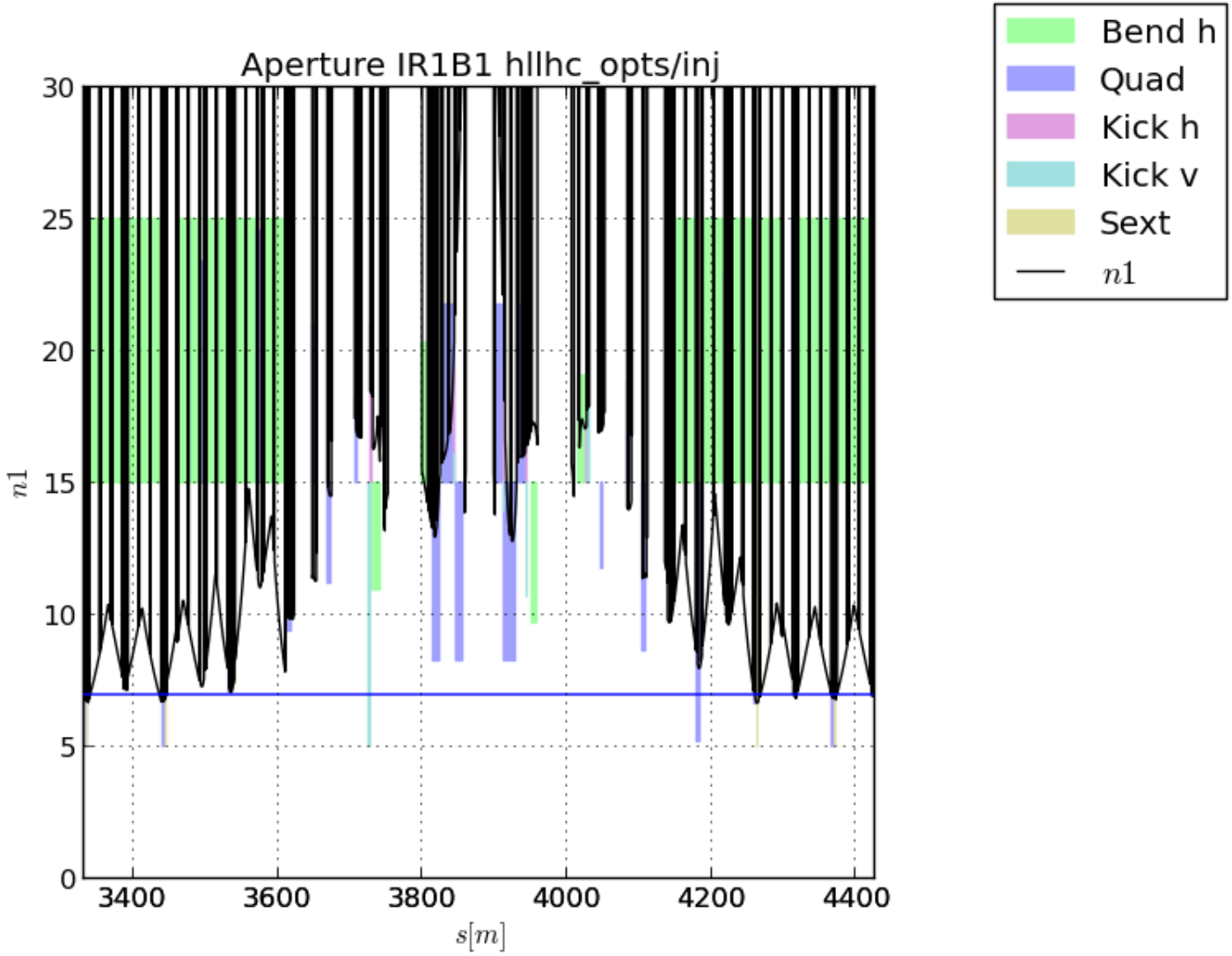


Negligible off momentum beta beating in the cleaning insertions through very large momentum window

Aperture at injection (6m)



Aperture at injection (6m)



HLLHC V1.0: Conclusions

- Complete layout and optics models for testing (thin, beam4, error routines will shortly be available);
- Evolution from 3.1b layout. Still possible iteration with an additional Q7 to reduce by 30-40% the crab-cavity voltage (see Barbara's Talk);
- Pre-squeeze and Squeeze transition (all experimental IRs) to be done as soon as the layout is frozen .

Further improvements for a realistic design:

- Area from Q3 to D1: DFB location and lengths, linear and non linear correctors length specifications;
- Area from TAN to D2: not validated for collimation and energy deposition;
- Beam screen: complete design with geometry and tolerances;
- D2 aperture assessment;
- Assessment on availability of new MQYL types (for Q5 in IR156) and MSCB in Q10;
- Realistic fringe field inclusion in the models