Can we simplify HL-LHC circuits?

R. De Maria

Thanks to G. Arduini, S. Fartoukh, P. Fessia, D. Gamba, M. Giovannozzi, F. Mateos, H. Prin.

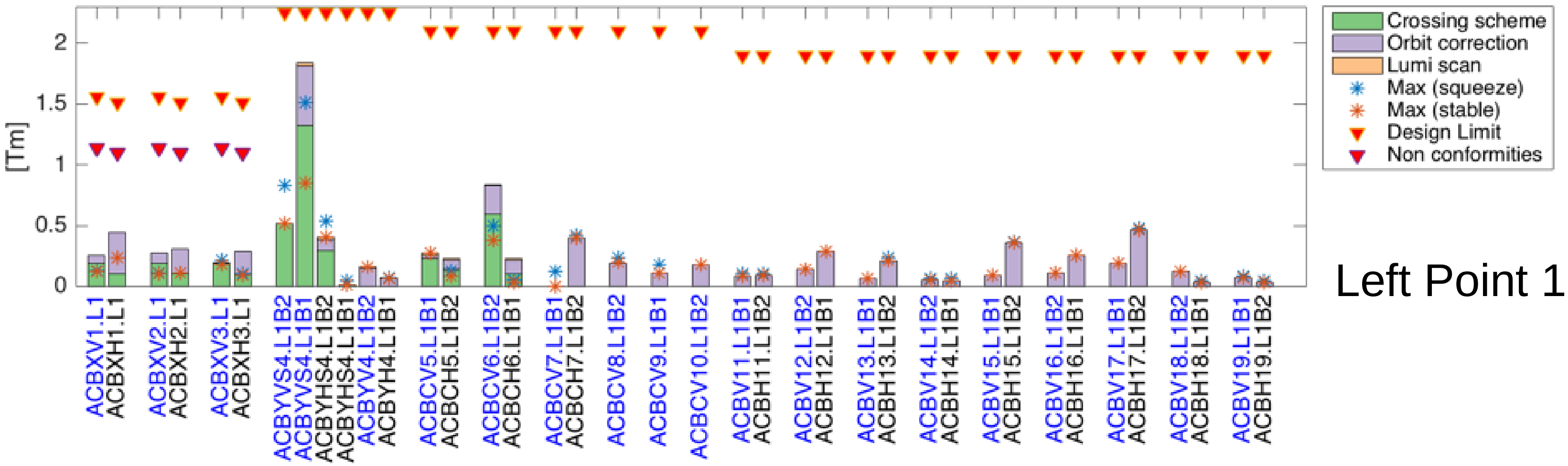
WP2, 17/01/2017

Content

- Requirements for orbit control and correction in IR1 and IR5
- Needs of additional sextupole in Q10
- Q5 current requirements in IR6

Orbit correctors

IR Orbit corrector LHC Experience



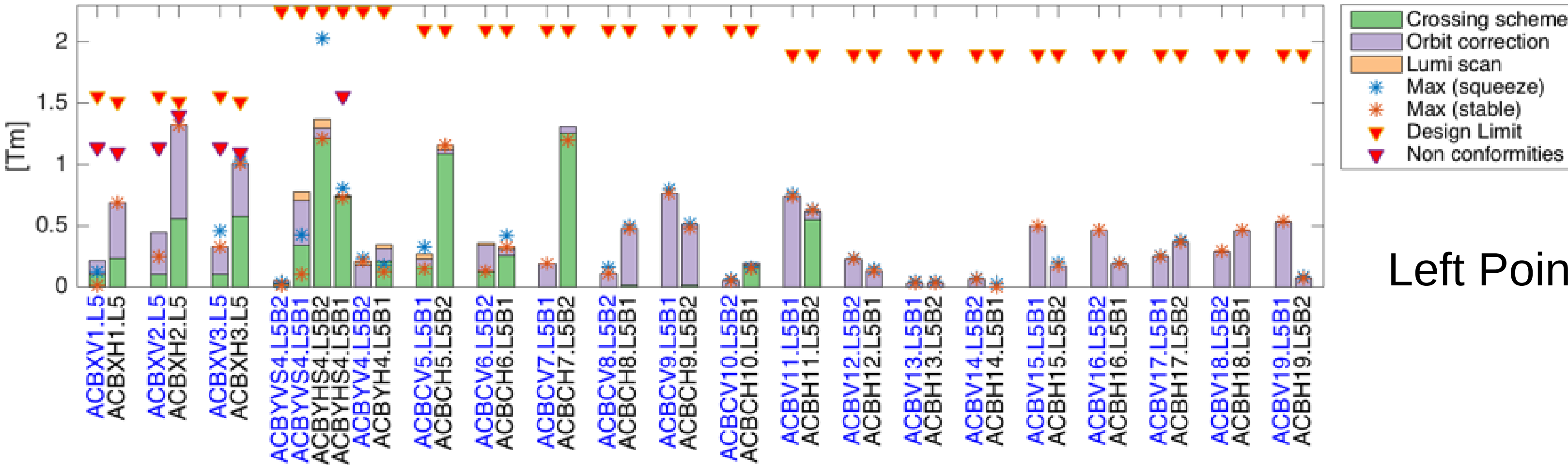
Left Point 1

Courtesy D. Gamba

Orbit correctors are needed to:

- Correct the orbit from quadrupole misalignment and transfer function errors
- Implement crossing angle and separation bumps
- Implement IP adjustment for luminosity optimization
- Implement non-standard orbit bumps

IR Orbit corrector LHC Experience



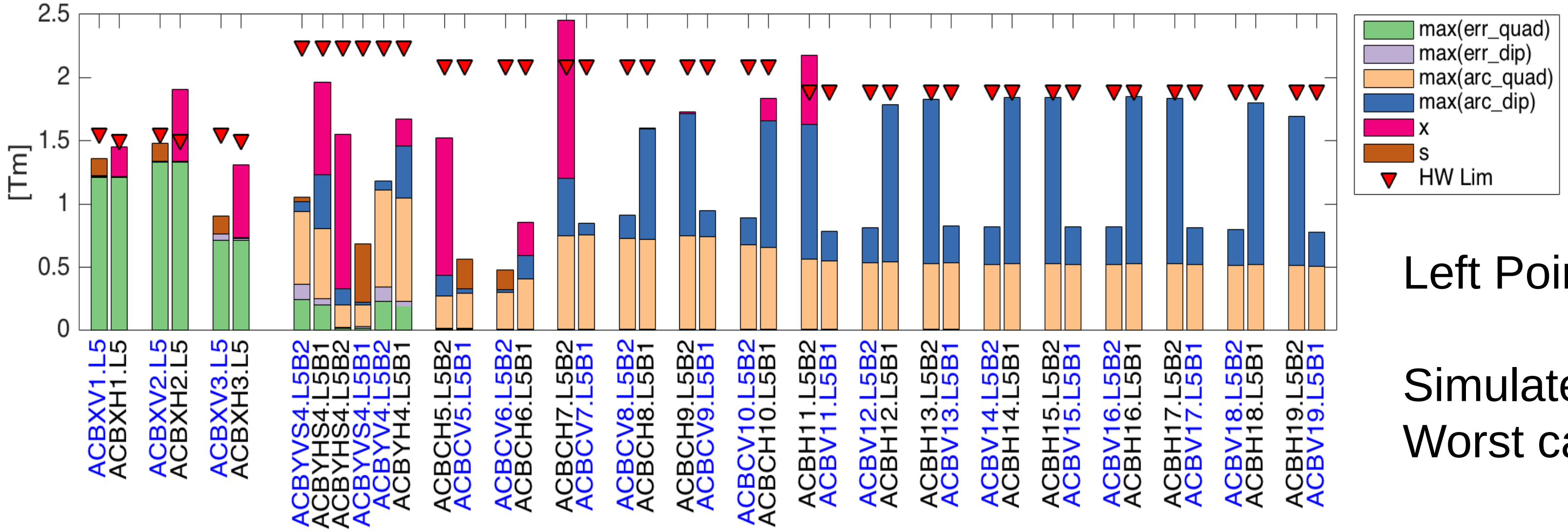
Left Point 5

Courtesy D. Gamba

Orbit correctors are needed to:

- Correct the orbit from quadrupole misalignment and transfer function errors
- Implement crossing angle and separation bumps
- Implement IP adjustment for luminosity optimization
- Implement non-standard orbit bumps

IR Orbit corrector LHC Experience



Left Point 5

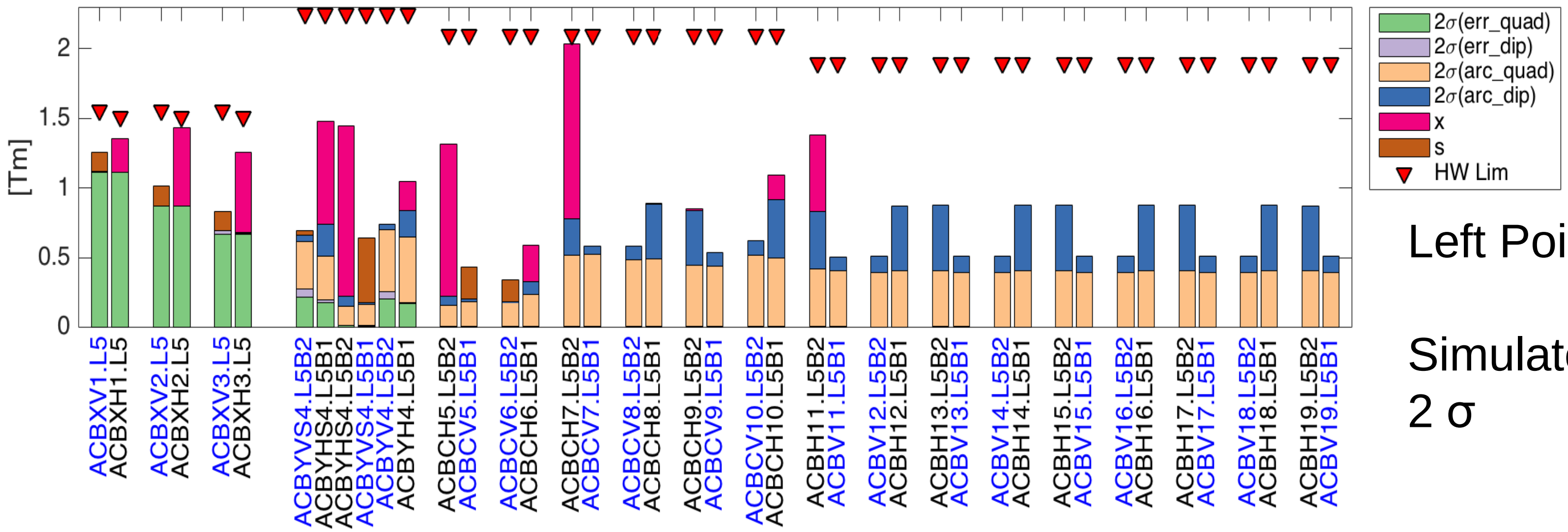
Simulated:
Worst case

Courtesy D. Gamba

Orbit correctors were designed:

- To correct for the worst case scenario
- Use margins for non-conformities

IR Orbit corrector LHC Experience



Left Point 5

Simulated:
2 σ

Courtesy D. Gamba

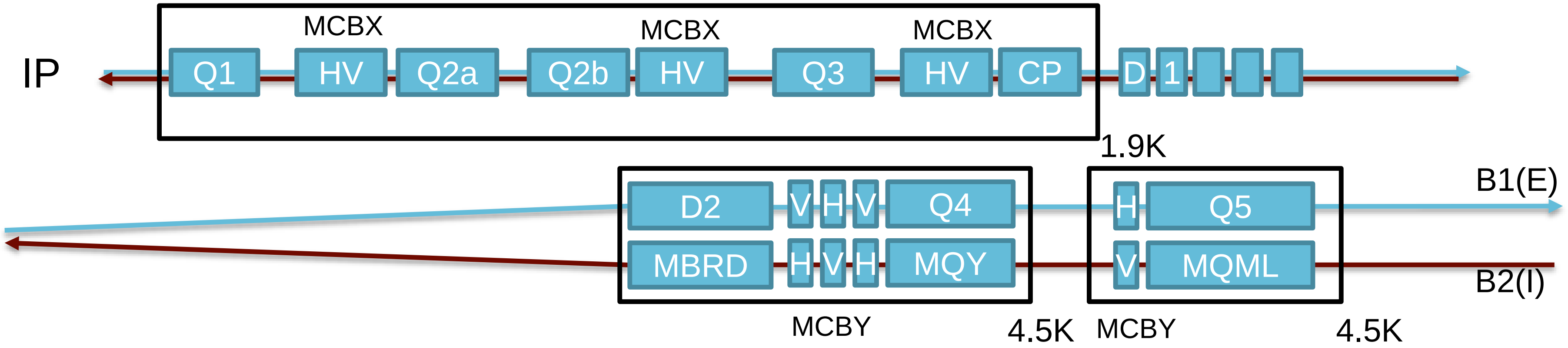
Orbit correctors were designed to:

- to correct for the worst case scenario
- use margins for non-conformities

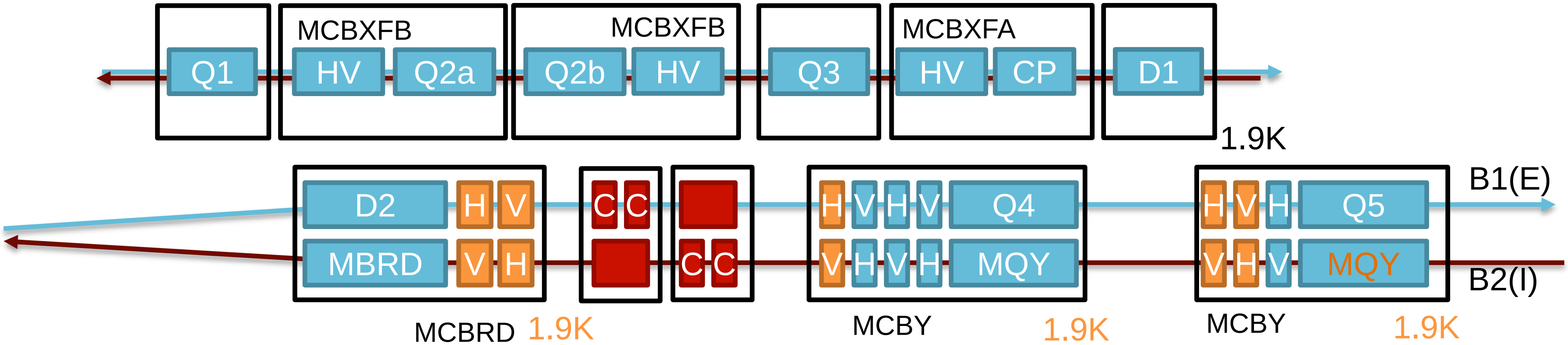
Present LHC experience:

- 2 σ of a uniform distribution of expected imperfections reproduces better the average usage of the correctors (e.g. measured MCB : μ~0.2 Tm, σ~0.5 Tm)
- Few outliers at the strength limit are anyway present

Orbit corrector layout



Orbit corrector layout

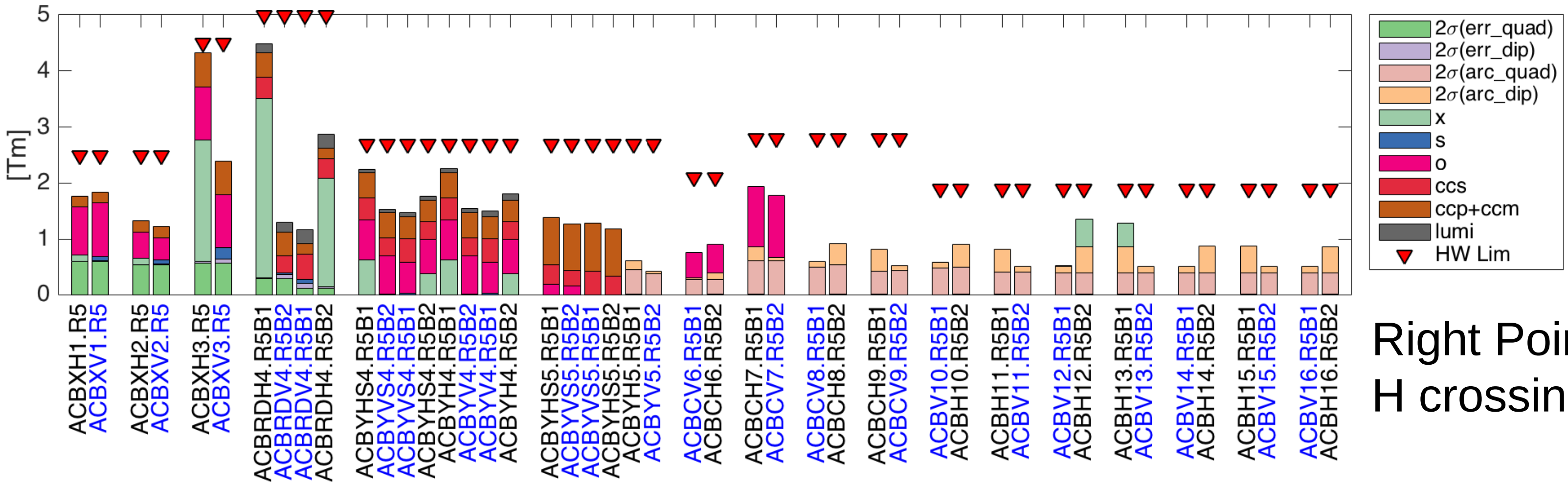


HL-LHC baseline designed to
- Provide HV crossing plane in both Point 1,5
- Correct quadrupole misalignments and dipole tilt and transfer function errors
- Avoid large orbit offsets at the crab cavities
- Provide knobs for adjusting orbit at the crab cavities independently from the IP

Type	Number	Strength
MCBXFB	2	2.5 Tm
MCBXFA	1	4.5 Tm
MCBRD	2	5 Tm
MCBY.4	4 (1.9K)	2.8 Tm
MCBY.5	3 (1.9K)	2.8 Tm

- Adjust the IP position without mechanical realignment of the triplets-D1 (although cavities do need to be realigned)
- Compatible with additional 4 cavities per side (not in the plot)
- Provide margins from Q5 onwards to absorb or degrade orbit gracefully in case of some non-conformities in the arc and the matching section.

Orbit corrector budget



Right Point 5
H crossing

Knobs:

- IP crossing, separation, offset (**x:** ±295 μrad, **, s:** ±0.75 mm, **o:** ±2.0 mm)
- **Lumi** scan (IP shift of ±100 μm)
- beam based alignment of crab cavities: **ccp** + **ccm** (shift): ±0.5 mm, **ccs** (slope): ±0.25 mm

Machine errors (**uniformly distributed**, **uncorrelated**):

- **0.5 mm max** transverse displacement of quadrupoles at the IT (**err_quad**) and in the arc (**arc_quad**).
- **10 mm max** longitudinal displacement, **0.5 mrad max** roll, **0.2% max** field error for D1 and D2 (**err_dip**) and in the arcs (**arc_dip**).

HL-LHC PROJECT

Courtesy D. Gamba

Possible simplifications

- Connect in series RCBY.5 with RCBY.S5 to reduce currently leads in Q5 provided:
  - a solution to handle large voltage, protection and bandwidth is found (A. Verweij, S. Yammine)
  - suspend or delay the run to replace critical non-conform RCBY
- Similarly use RCBY.5 as hot spare to be connected in case of need provided
  - To accept the down time for a re-connection
- Reduce MCBY correctors in the non-crossing plane in Point 1 and Point 5 mainly to build Q4 with 3 instead of 4 correctors (suggested by Stephane), provided:
  - crab cavity can operate with large displacement in the non crossing plane (R. Calaga: not desirable but can be studied)
  - no crab kissing with 4 cavities per beam/plane
  - hardware modifications when flipping the crossing plane foreseen to reduce the radiation damage in the triplet
  - two new MCBY types introduced (HH) or (VV) in addition to the existing HV, VH
- Reduce budget for misalignments to save 1 or 2 orbit (specific) correctors in Q4 and Q5 provided:
  - to foresee fast, remote and frequent realignment campaigns from Q1 to Q4: e.g. every yearly shutdown and during the run for fine tuning. Not demonstrated in LHC, e.g. the unsatisfied triplet alignment requested by CMS in 2017.
  - to accept risk of delaying or interrupting a run in case of non-conformities

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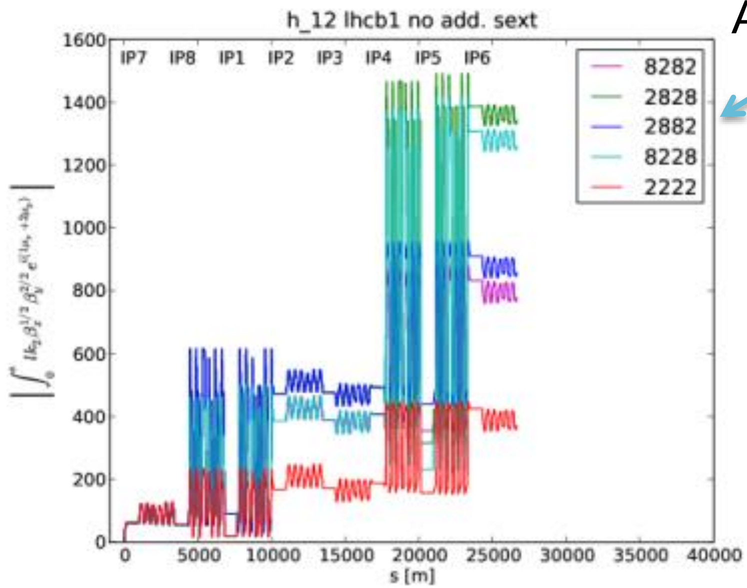
Additional sextupole in Q10

Additional Sextupole in Q10

The additional MS in Q10 in Point 1, 5is needed:

- to compensate the geometric aberrations of the MS in Q14 that are enhanced by the blow-up in the arc.
- 10% smaller β in the arc for the same β* reach in IP1/5.

It has been part of the baseline since the beginning.



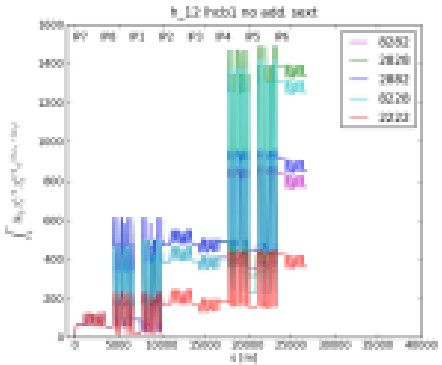
ATS factors

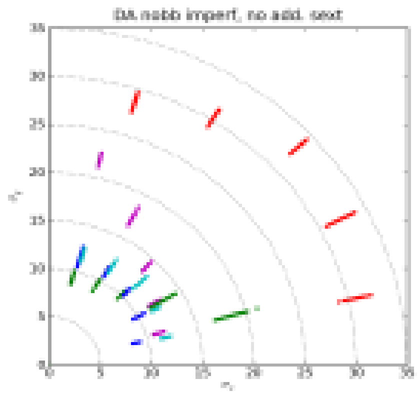
Number of sextupoles per family

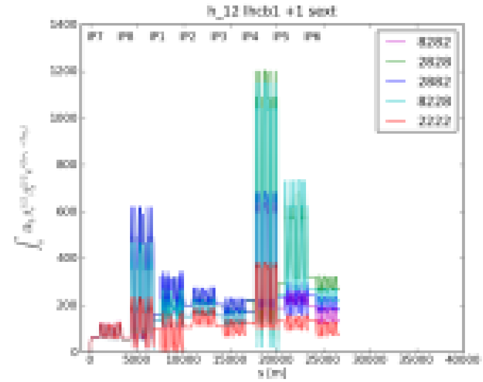
Arc	MS14	MS13	MS12	MS11
B1: 81,45	F1(9)	D1(12)	F2(10)	D2(12)
B2: 81,45	D1(11)	F1(10)	D2(12)	F2(10)
B1: 12,56	D2(11)	F2(10)	D1(12)	F1(10)
B2: 12,56	F2(9)	D2(12)	F1(10)	D1(12)

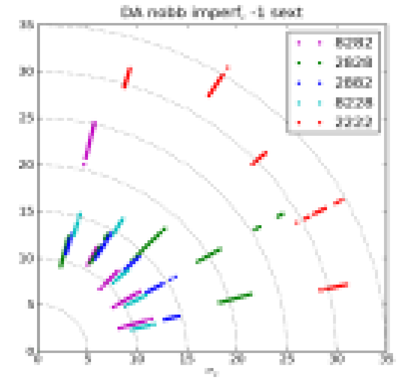
R. De Maria, S. Fartoukh, 64th LMC 2010, sLHC PR.50, sLHC PR.55

Additional MS10 Sextupole







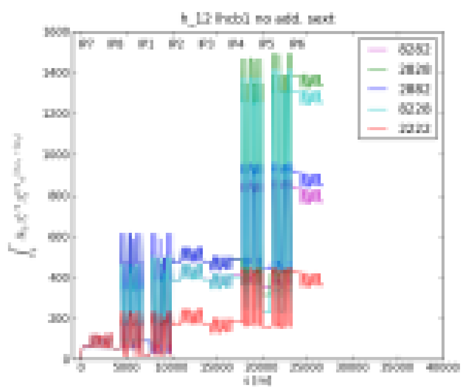


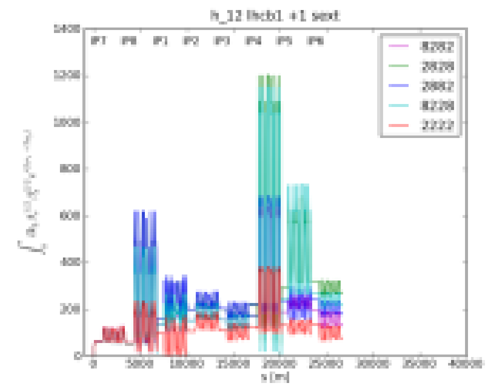
Optics v3.01 (valid for any layout)	Min DA with only arc errors and no bb (relative loss matters)	
ATS factors 1,5	With MS10	No MS10
(2x,8x) (8x,2x)	11.0 σ	8.3 (-2.7) σ
(8x,2x) (2x,8x)	11.3 σ	9.9 (-1.4) σ
(4x,4x) (4x,4x)	15.0 σ	13.4 (-1.8) σ

- Due to sextupole-induced resonances, the absence of MS10 results in an expected reduction of DA of about 2 sigma for low β*.
- The number of sextupoles is also relevant for the minimum pre-queeze β*

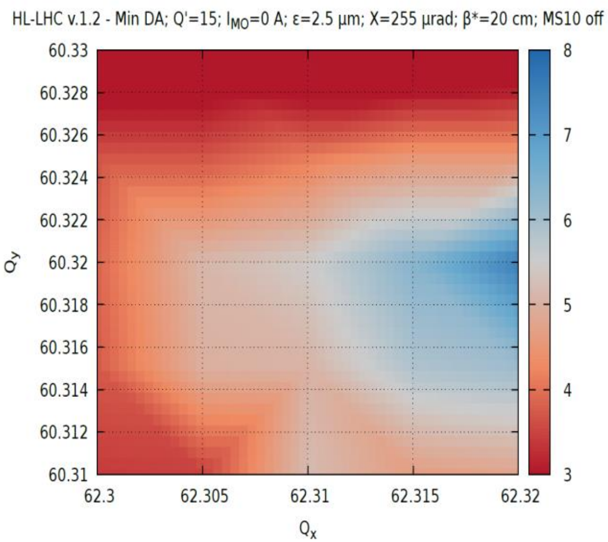
Beam-beam simulations confirm the losses in DA (work in progress)

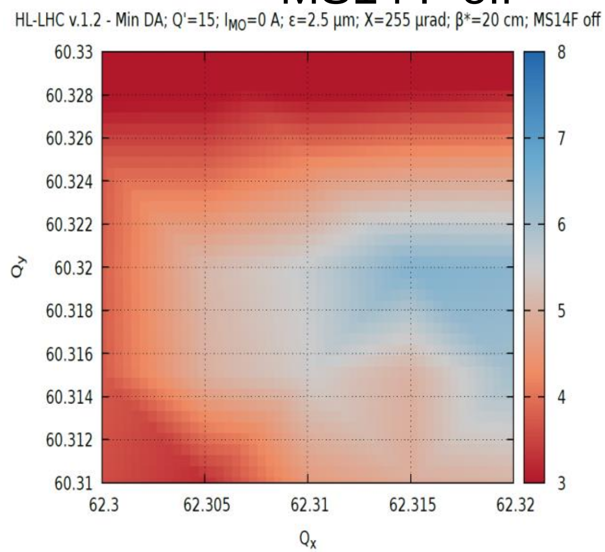
Additional MS10 Sextupole

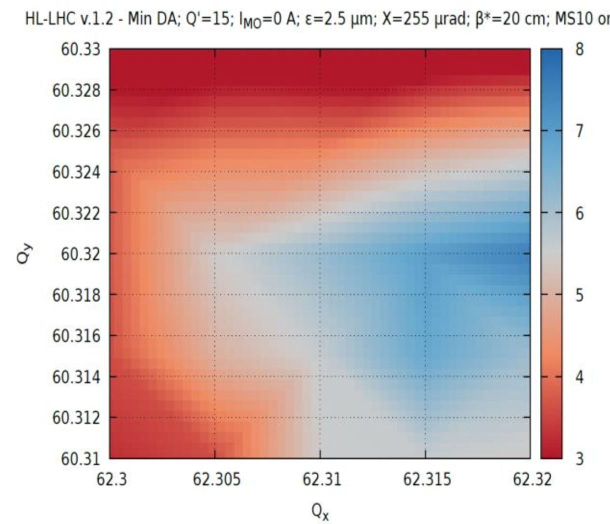




MS14 F off







Beam-beam simulations confirm the losses in DA even for β*=20 cm. Worse DA reduction expected for smaller β* and flat beams.

D. Pellegrini,
N. Karastathis

First Results

Alternative to MS 10 installation

- Accept DA reductions and larger β (+5%) in the arc for the same β* (or larger β* for the same β in arc)
- Disconnect only focusing sextupoles in Q14 (B1: 81,45 B2: 12,56) contributing to 3,0 resonances and accept DA reduction.
- As before and change optics (only vertical phase advance suggested by Stephane). Promising at the moment: (Point 1/5 optics found, Point 4/6/2/8 to study).
- Disconnect all sextupoles in Q14 and accept larger β (+10%) in arcs (or larger β* for the same β in arc).

Remarks: ATS squeeze range may be limited by aperture (machine experience needed) and the strengths of Q5 in IR6 in particular if Q5 is not upgraded to 1.9 K.

Q5 strength in IR6

IR6 squeeze range

- ATS optics needs optics manipulations in IR6 (and IR4) to squeeze β* in IP5.
- IR6 is an optically difficult insertion because of less quadrupoles than typical LHC insertions and strict constraints for the dump system.
- Q5.L and Q5.R are the quadrupoles closer to strength limits for the nominal optics (3% margin at 7 TeV) and exceed the limit for ATS optics with low values of β*.
- The baseline foreseen to reduce the operating temperature to 1.9K of Q5 (similarly done for Q5 in Point 5) to increase the strength margins.
- Q5 right is less demanding and it has less priority.

βx [cm]	βy [cm]	Q5 L6B1	Q5 L6B2	Q5 R6B1	Q5 R6B2
15	15	164.2	162.9	155.4	150.7
10	40	172.2	159.2	158.3	151.1
40	10	150.6	158.4	154.9	145.5
18	18	161.8	160.0	155.0	150.0

Strength at 7 TeV

Preliminary results with many compromises in dispersion, β in Q5, MKD-TCT phase for flat optics, total IR6 phase advance, no margin on Q8.L6.B2
Study for Beam 1 to be refined.
Study for alternative phase advance to be completed.

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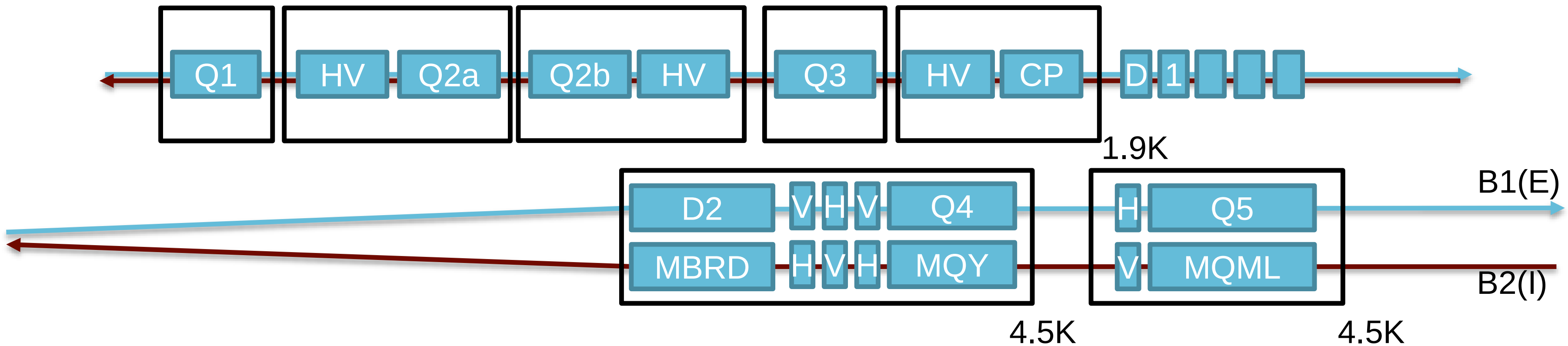
Back-up

Trim Q2a Q2b

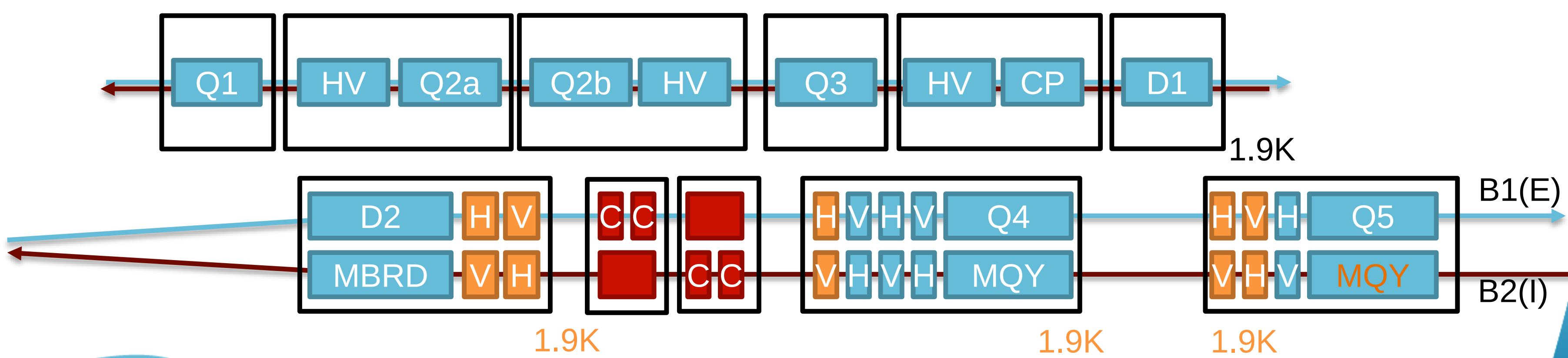
- Up to 15 units, matched optics can found but after many iterations (e.g. could not keep unperturbed beta in Q4) .
- Transfer functions errors should be well measured, otherwise are difficult to correct with beam measurements only.

Baseline orbit corrector layout

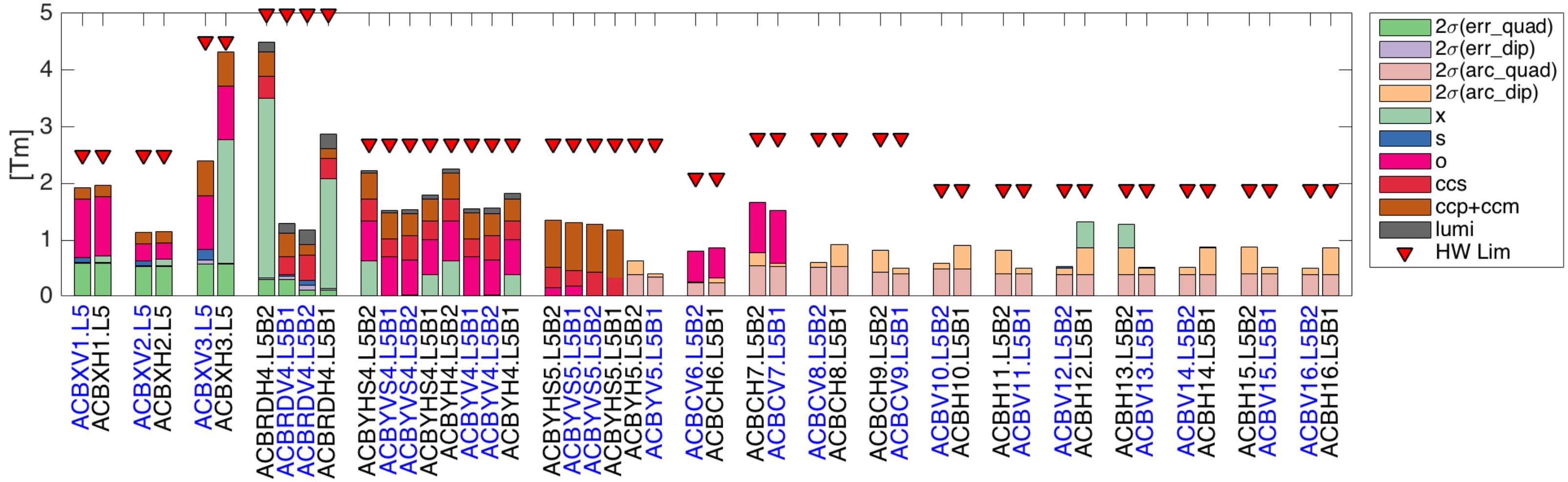
LHC: Right side

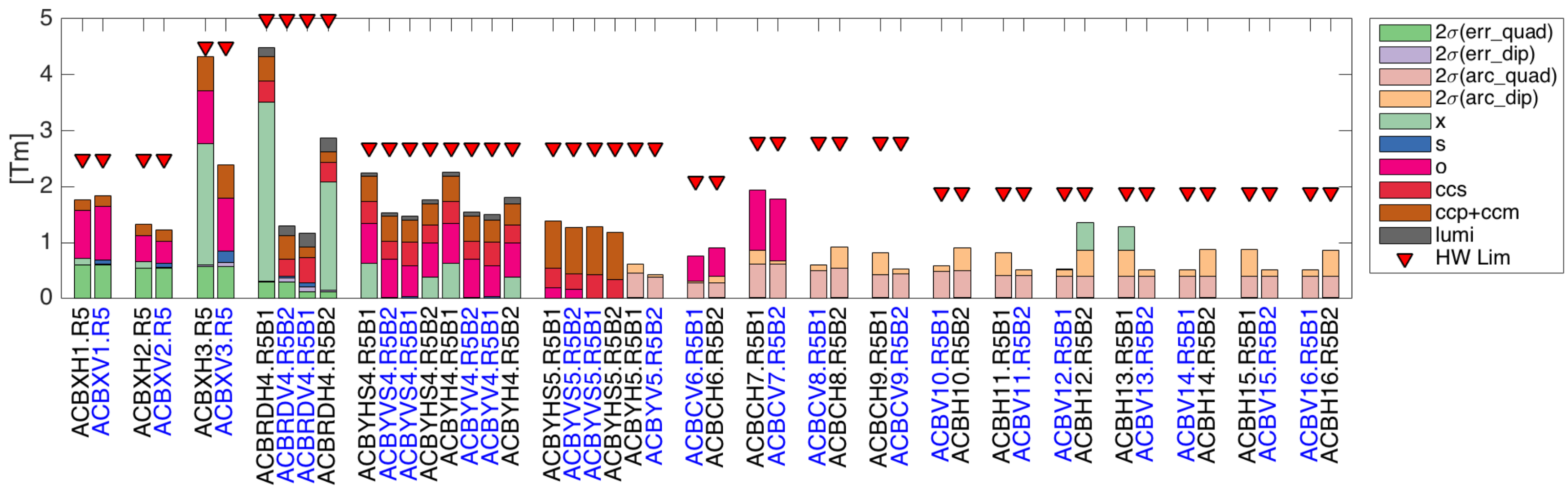


Baseline HL-LHC: Right side

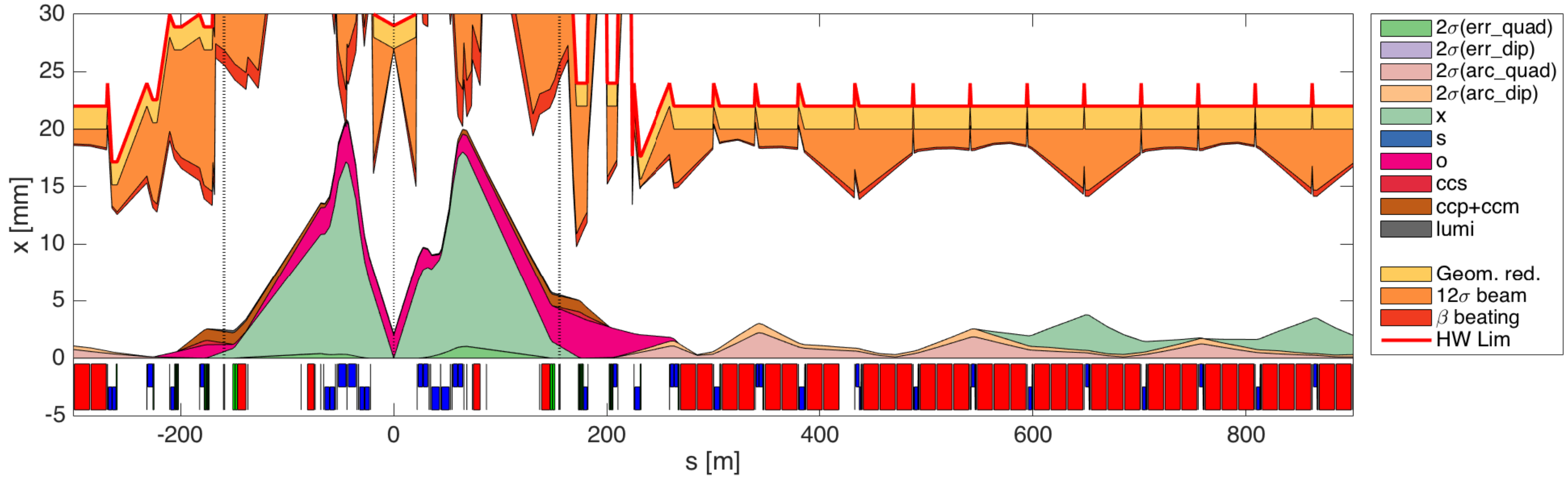


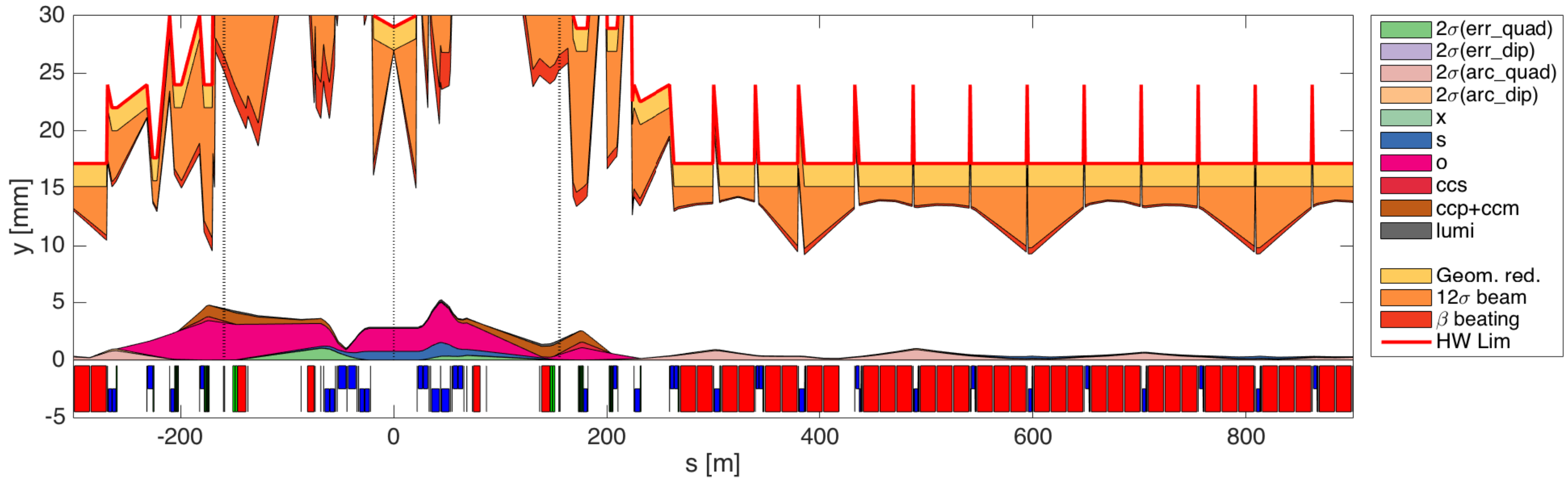
HL-LHC_V1.3 Round: corr. strengths @IP5





HL-LHC_V1.3 Round: B1 orbit @IP5

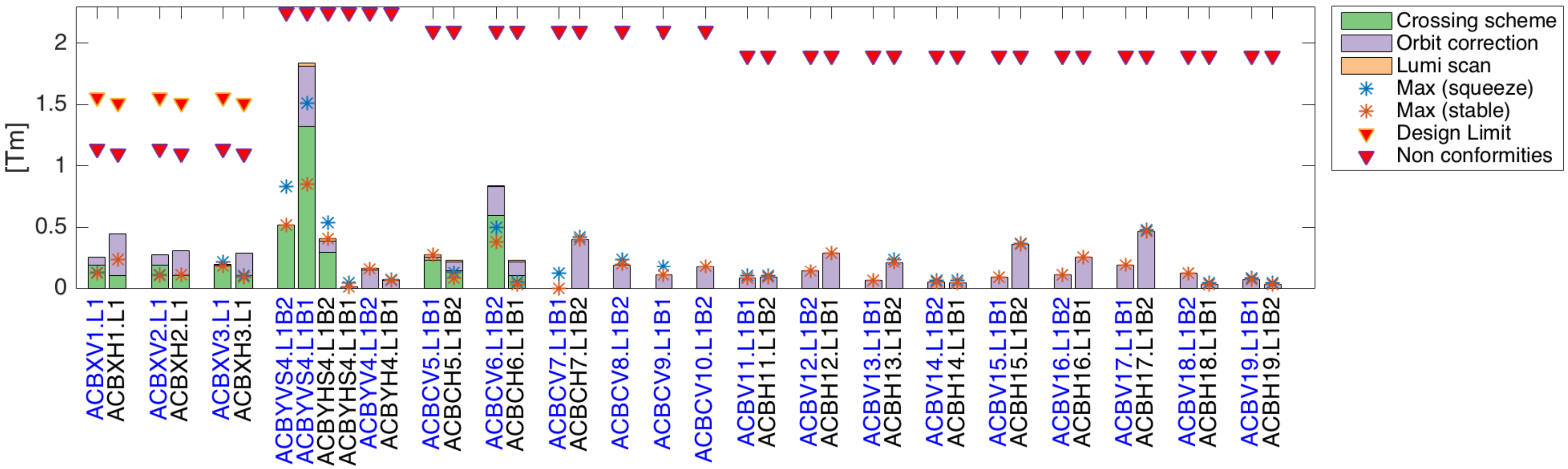


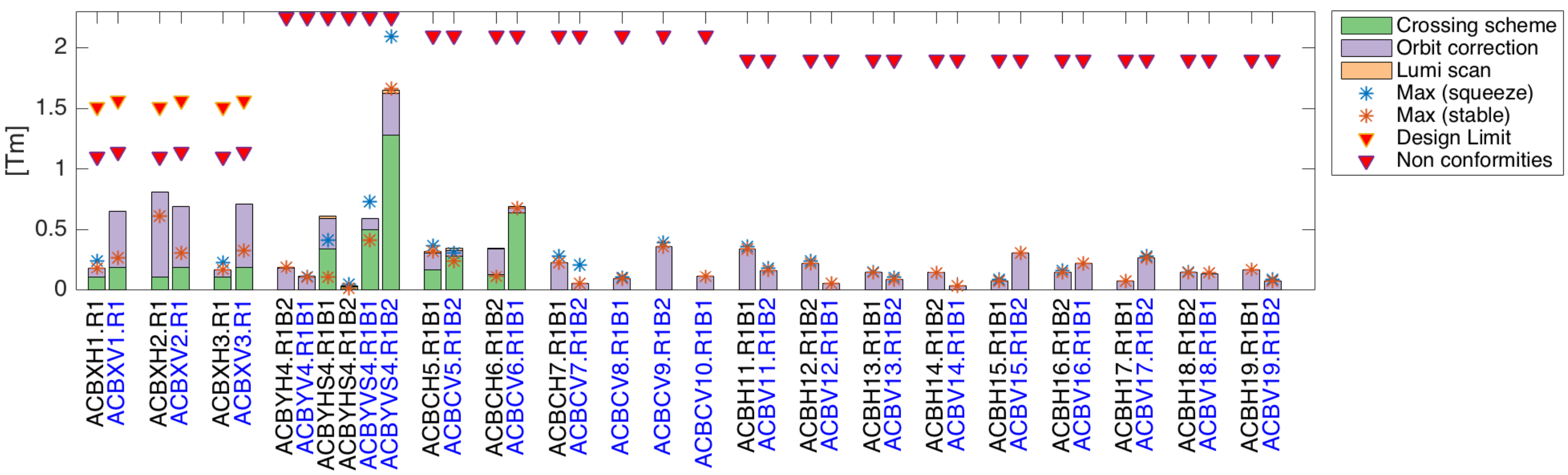


HL-LHC_V1.3 Round: data

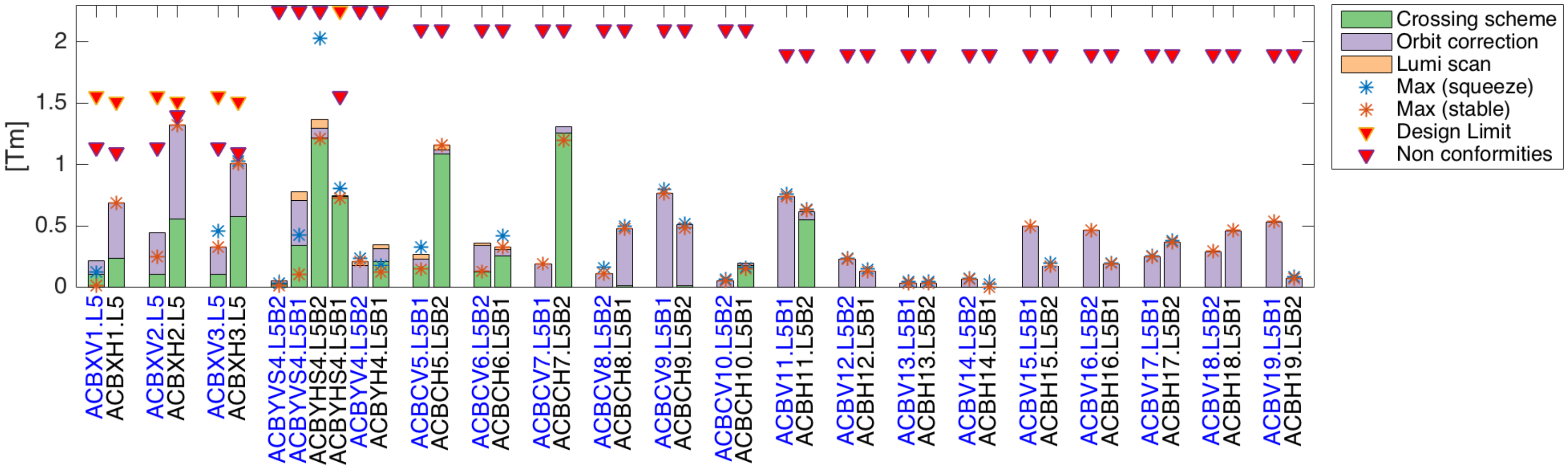
[Tm]	Err_Q 2σ	Err_Q max	Err_D 2σ	Err_D max	Arc_Q 2σ	Arc_Q max	Arc_D 2σ	Arc_D max	x	s	o	ccs	ccp +ccm	lumi
MCBX1	0.598	0.888	0.013	0.022	0	0	0	0	0.121	0.082	1.05	0	0.198	0
MCBX2	0.539	0.813	0.011	0.021	0	0	0	0	0.121	0.082	0.468	0	0.198	0
MCBX3	0.577	1.188	0.052	0.075	0	0	0	0	2.172	0.197	0.945	0	0.604	0
MCBRD4	0.227	0.521	0.054	0.076	0	0	0	0	3.187	0.096	0	0.456	0.425	0.252
MCBY4	0	0	0	0	0	0	0	0	0.637	0.019	0.7	0.427	0.457	0.106
MCBYYS4	0	0	0	0	0	0	0	0	0.637	0.019	0.7	0.427	0.457	0.074
MCBY5	0	0	0	0	0.395	0.811	0.156	0.527	0	0	0	0	0	0
MCBY5S	0	0	0	0	0	0	0	0	0	0	0.177	0.434	0.856	0
MCBC6	0	0	0	0	0.26	0.502	0.074	0.213	0	0	0.562	0	0	0
MCBC7	0	0	0	0	0.584	0.919	0.169	0.386	0	0	1.101	0	0	0
MCBC8	0	0	0	0	0.528	0.75	0.279	0.864	0	0	0	0	0	0
MCBC9	0	0	0	0	0.427	0.744	0.289	0.969	0	0	0	0	0	0
MCB10	0	0	0	0	0.492	0.698	0.301	1.002	0	0	0	0	0	0
MCB11	0	0	0	0	0.412	0.667	0.296	1.108	0	0	0	0	0	0
MCB12	0	0	0	0	0.397	0.541	0.34	1.253	0.496	0.025	0	0	0	0
MCB13	0	0	0	0	0.399	0.578	0.343	1.336	0.416	0.002	0	0	0	0

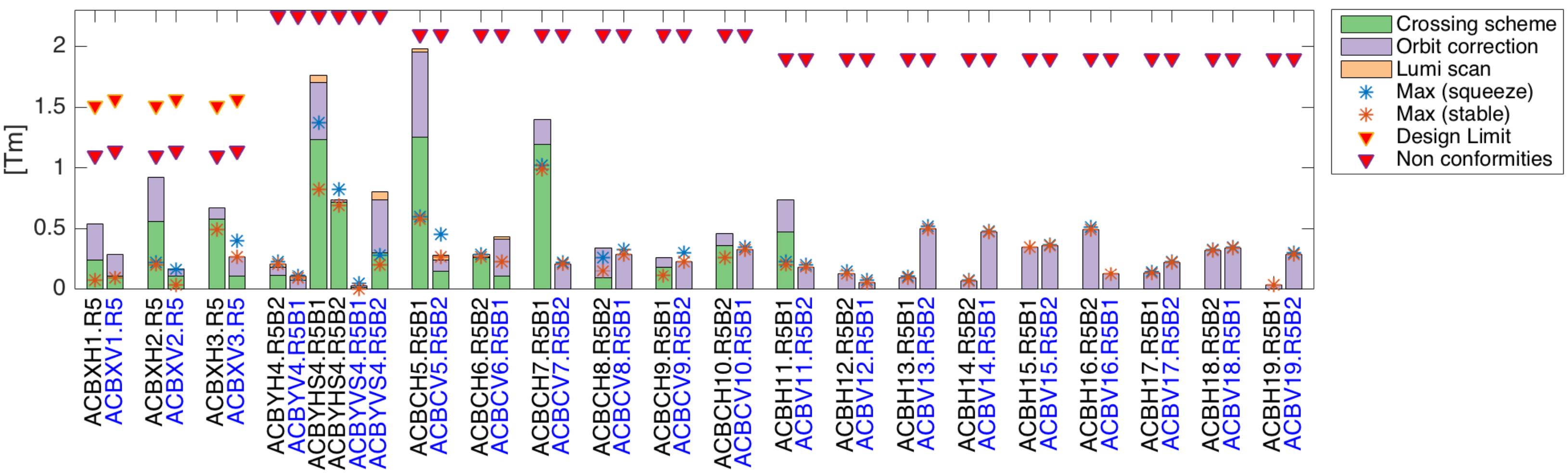
LHC: in use strengths @ IP1



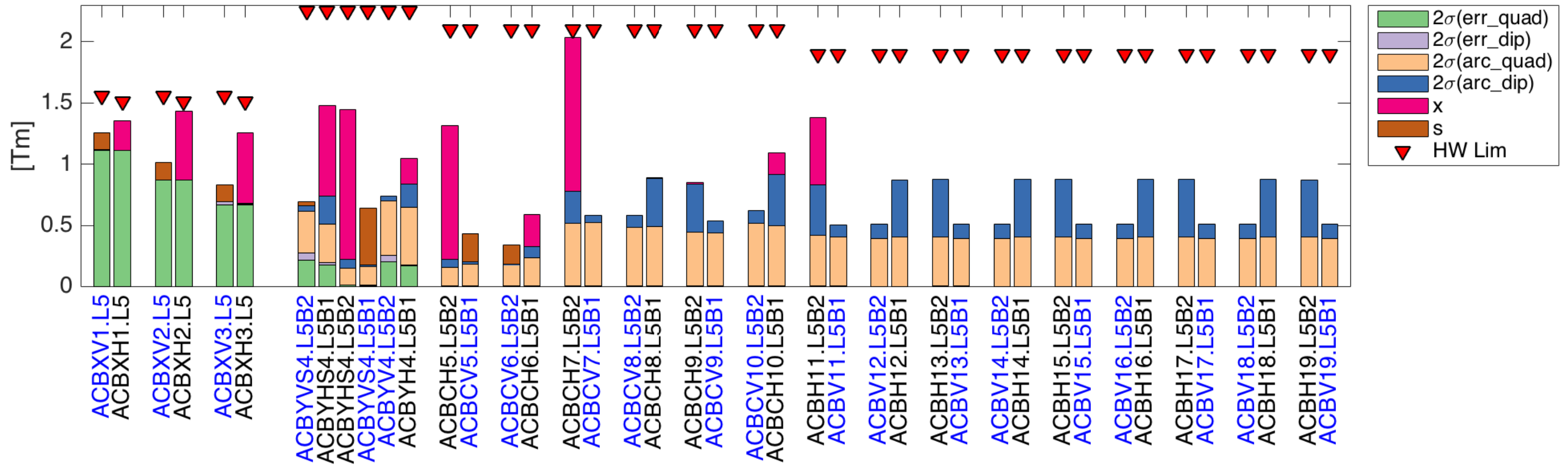


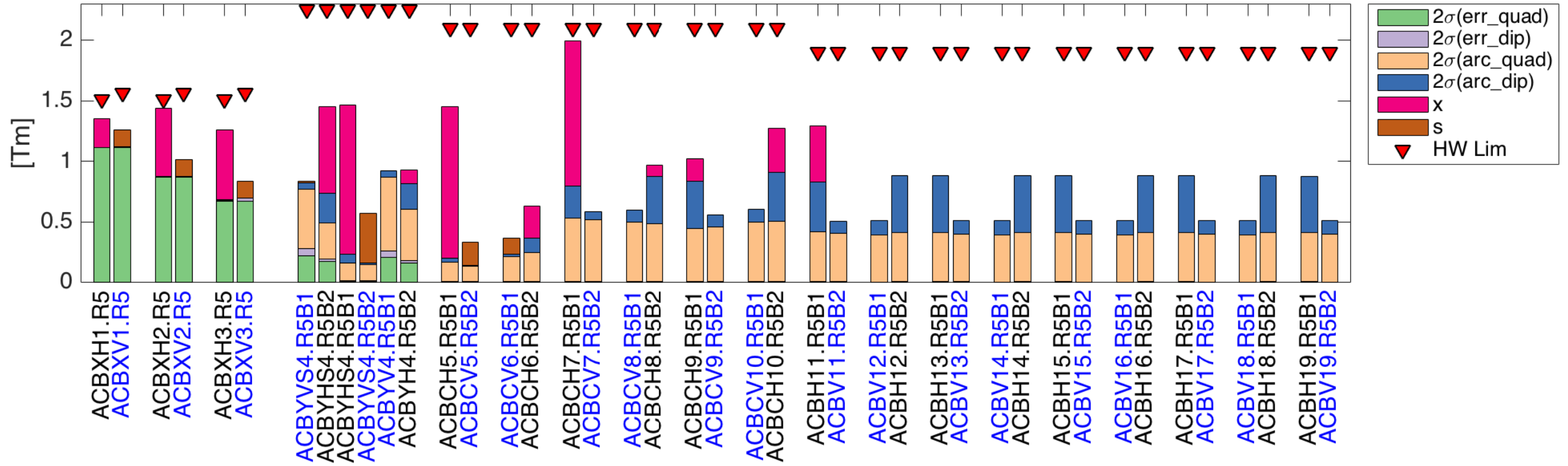
LHC: in use strengths @ IP5



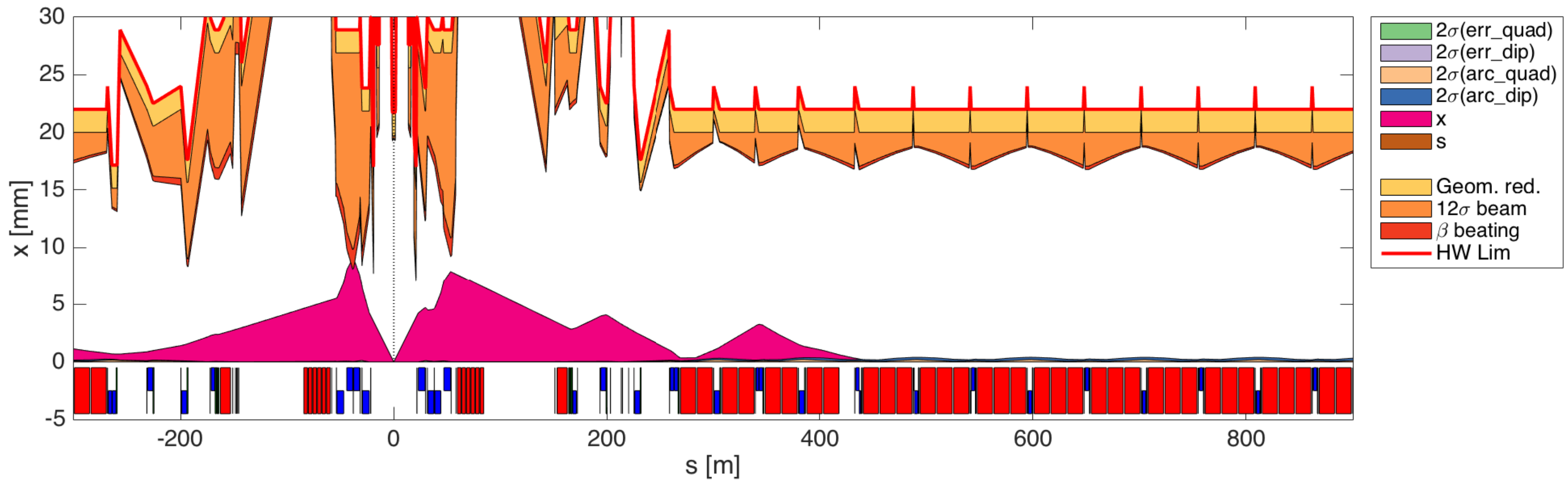


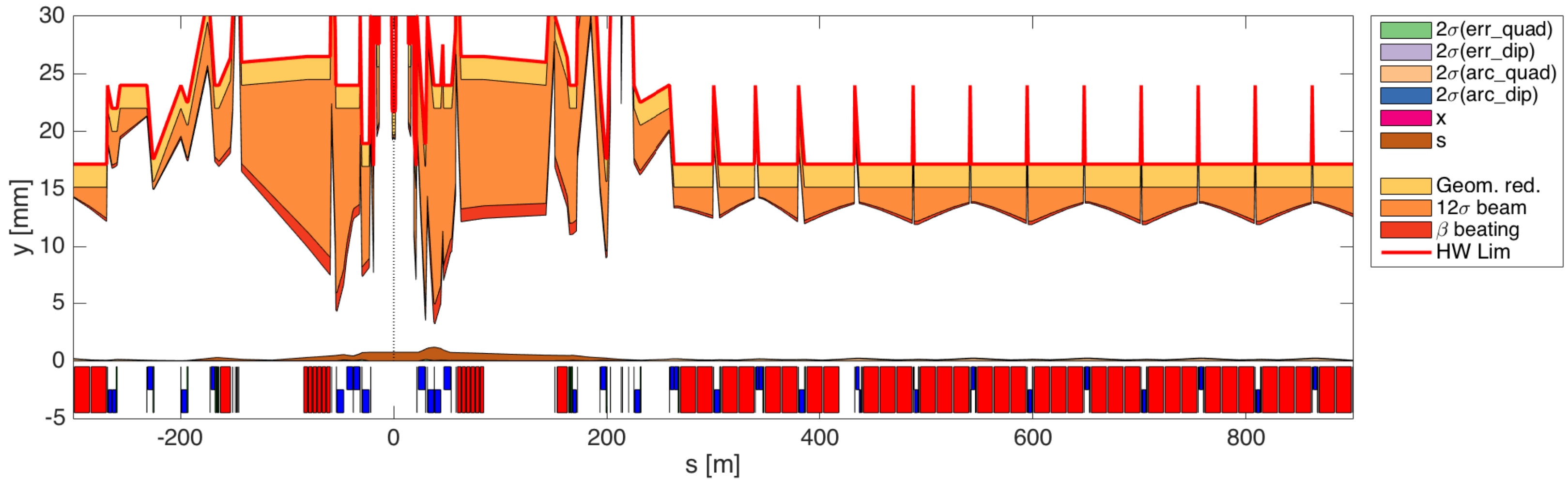
LHC simulation: corr. strengths @ IP5





LHC simulation: B1 orbit @ IP5





Ramp rates specifications

- Energy ramp
- Pre-cycle and ramp down
- Orbit and optics transitions
  - Parallel separation collapse
  - Squeeze times
- Orbit feedback
- Optics measurements
  - K modulation needs (speed and Q2A/B trim)