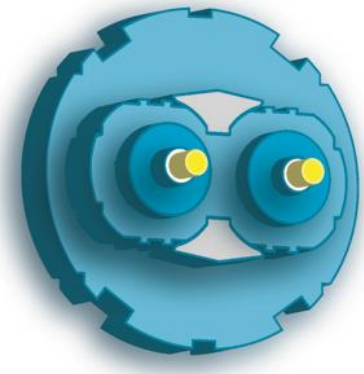


High Luminosity LHC

Review of Q5 in IR6 and MS10 in IR1-IR5

R. De Maria, S. Fartoukh, M. Giovannozzi with input from
R. Bruce, M. Korostelev, Y. Uythoven.

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Introduction

- ATS scheme has been adopted as the baseline optics for HL-LHC.
- The ATS can be fully exploited in the LHC by an additional lattice sextupole in Q10 (MS10) of IR1-IR5 and a stronger Q5 in IR6 in order to keep a balanced β* reach in ATLAS and CMS.

"In practice, the scheme proposed requires rather limited hardware modifications in 95% of the LHC ring (new Q5 at least 20% longer in IR6, additional lattice sextupoles equipping Q10 in IR1 and IR5, see Sections 4.1 and 4.2) but of course more deeper interventions in LSS1 and LSS5 in order to replace the existing magnets with other ones of larger aperture (see Section 4.3)" S. Fartoukh, sLHC PR. 49 2010.

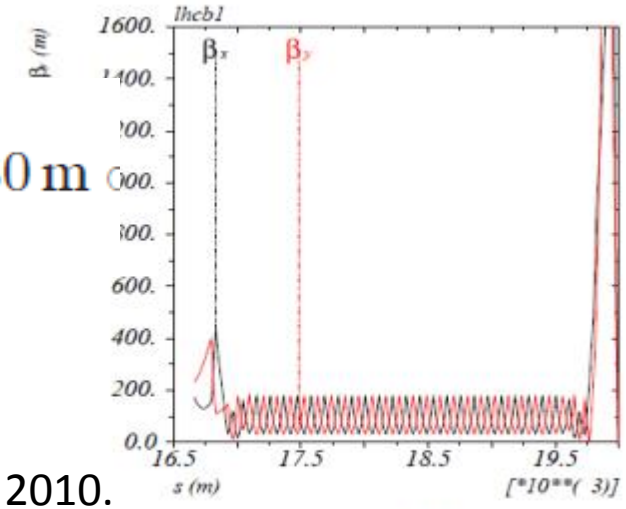
ATS scheme principles

- Blow-up β in the arc to reduce β* done by perturbing optics of IR8,2 for ATLAS and IR4,6 for CMS. IR6 optics not flexible enough with Q5 going out of strengths.
- Specific phase advances are enforced to compensate chromatic aberrations of the triplet, however geometric aberrations are enhanced by the increase arc β.

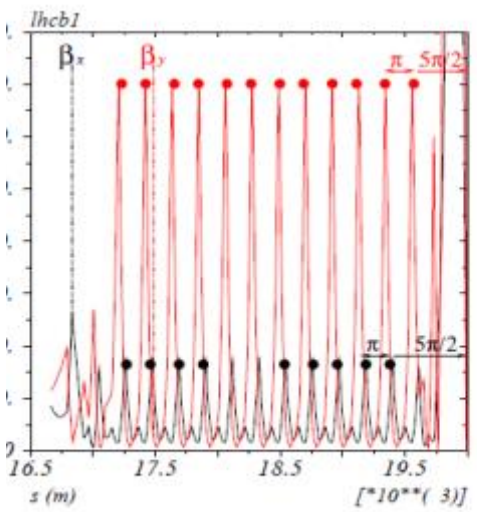
$$\hat{\beta}_{\mathrm{arc}} \approx \frac{\beta^*_{\mathrm{pre-squeeze}}}{\beta^*_{\mathrm{col}}} \times 180\,\mathrm{m}$$

ATS factor

S. Fartoukh, sLHC PR. 49 2010.



(b): Pre-squeeze, $\beta^{*IP1,IP5}_{x,y} = 60$ cm



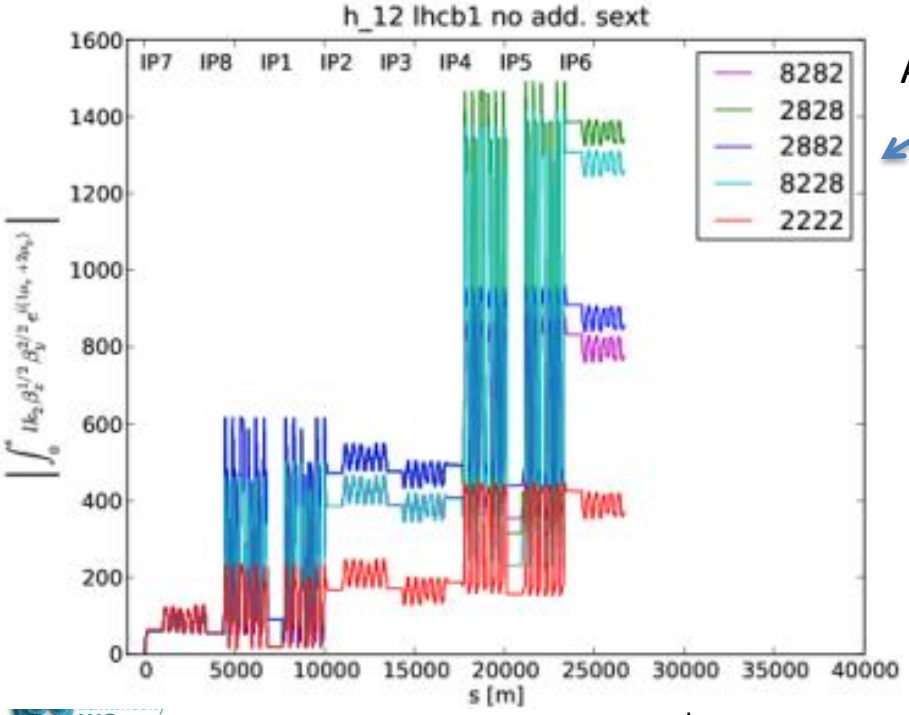
n, $\beta^{*IP1}_{x/y} = 7.5/30$ cm and $\beta^{*IP5}_{x/y} = 30/7.5$ cm

Additional MS10 Option

The additional MS in Q10 is needed:

- To bring the β* reach at 7 TeV of the pre-squeeze optics to 44 cm at 7 TeV instead of 48 cm already taking counting on the lattice sextupoles at 600A.
- To compensate the geometric aberrations of the MS14 that are enhanced by the blow-up in the arc.

It has been part of the baseline since the beginning.



ATS factors

Sextupole Families in ATS arcs: no change

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

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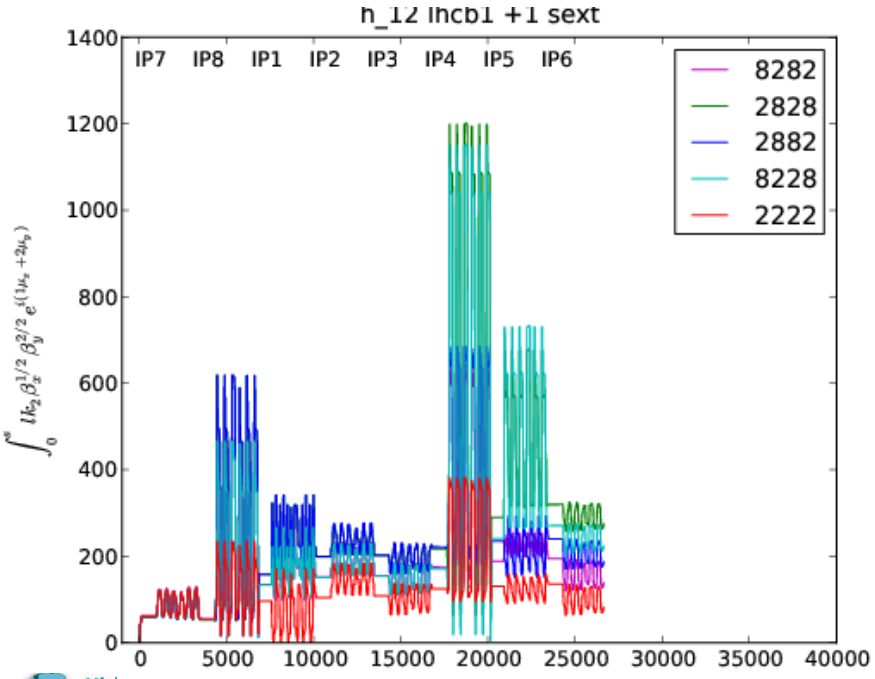

ATS factors

Sextupole Families in ATS arcs adding MS10

Arc	MS10	MS13	MS12	MS11
B1: 81,45	F1(10)	D1(12)	F2(10)	D2(12)
B2: 81,45	D1(12)	F1(10)	D2(12)	F2(10)
B1: 12,56	D2(12)	F2(10)	D1(12)	F1(10)
B2: 12,56	F2(10)	D2(12)	F1(10)	D1(12)

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

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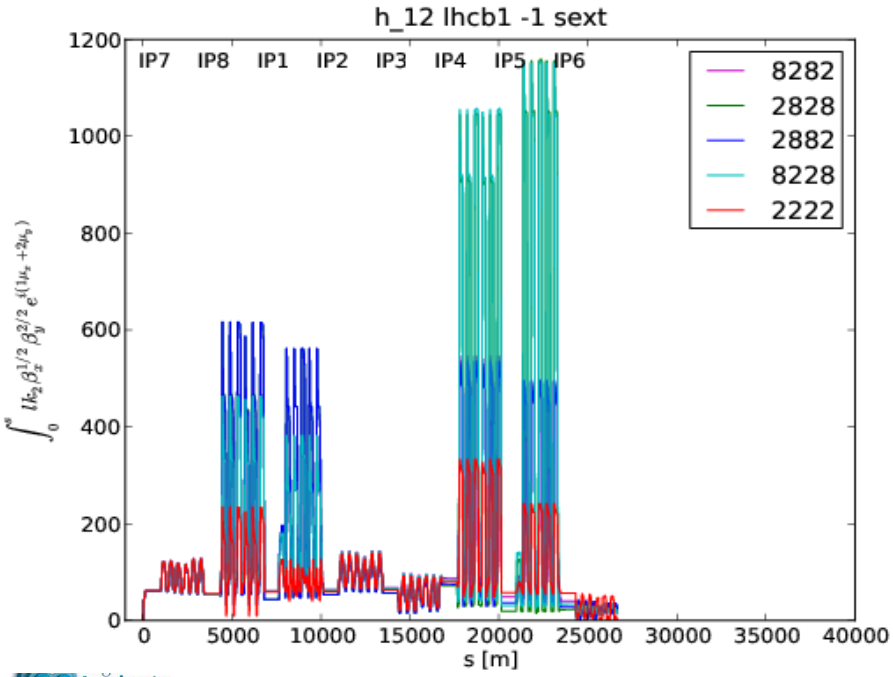
It has been part of the baseline since the beginning.



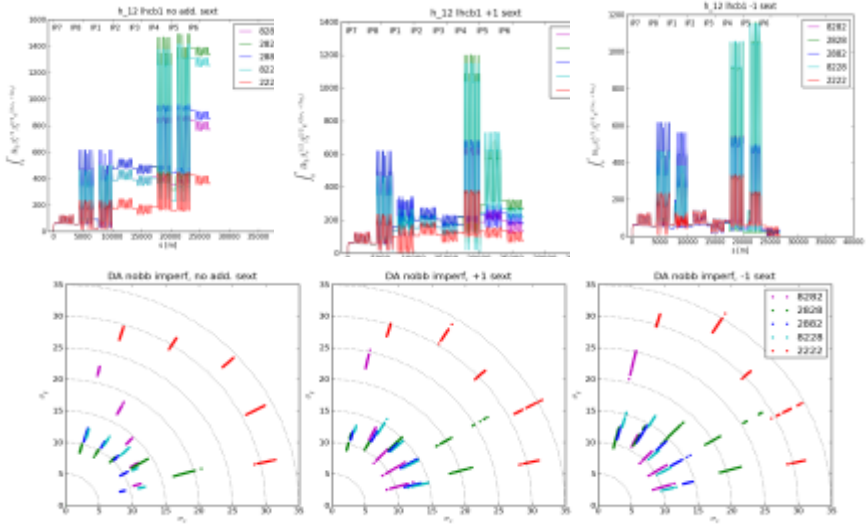
ATS factors

Sextupole Families in ATS arcs by passing MS14

Arc	MS18	MS13	MS12	MS11
B1: 81,45	F1(8)	D1(12)	F2(10)	D2(12)
B2: 81,45	D1(10)	F1(10)	D2(12)	F2(10)
B1: 12,56	D2(10)	F2(10)	D1(12)	F1(10)
B2: 12,56	F2(8)	D2(12)	F1(10)	D1(12)

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

Sextupole options



Sextupole Families

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)

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*

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

Mitigation strategies for MS10

Different phase advances for IR1-IR5 could have avoided the MS in Q10, but no optics solution has been found or presented yet.

It is possible to bypass MS14 at the cost of increasing β* of the pre-squeeze to 52 cm, thus increasing the ATS factor to reach the same β* and about the same DA as the baseline. The increase of the ATS factor has implications on IR6 optics, collimation performance and machine protection that are yet to be quantified.

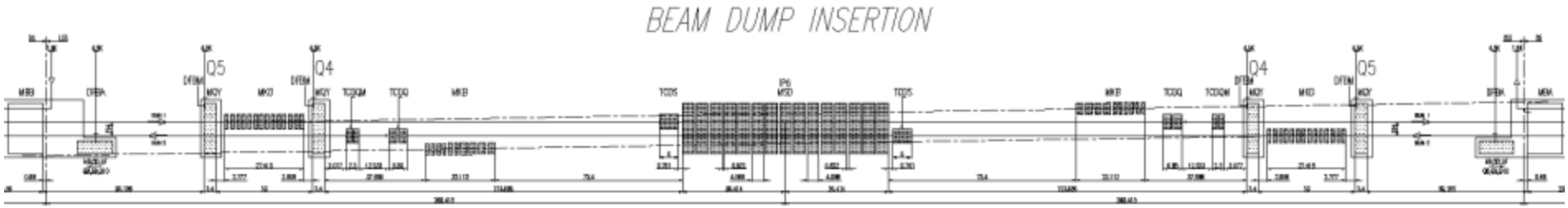
Other ideas of mitigation strategies are under consideration with semi-local compensation, requiring a smaller increase of the ATS factor but they could be evaluate when more information and experiments on lifetimes will be available.

We recommend installing the additional MS in Q10 as it is the best option based on the current knowledge of the machine models.

IR6 Layout

Different squeeze sequences are needed depending on the final β* for CMS.

IR6 optics is very rigid due to position of the quadrupoles and internal phase advances.



Since the beginning the ATS optics had stronger Q5:

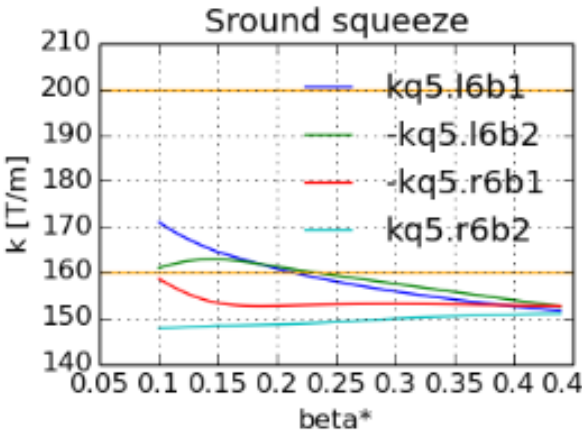
- SLHCV3.0, SLHCV3.01: double MQY
- SLHC3.1b, HLLHCV1.0: MQYL
- HLLHCV1.1: Double MQY

Basic needs taken into account: MKD – Septum phase advance , beam size at dumps. However optics are not validated for collimator settings and failure scenarios (WP5 - WP14):

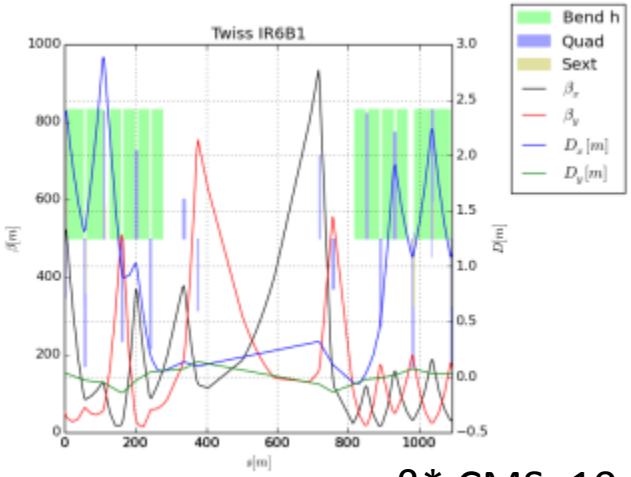
- beta functions at collimators do vary during the squeeze
- phase advance between MKD TCT are not optimal optimized.

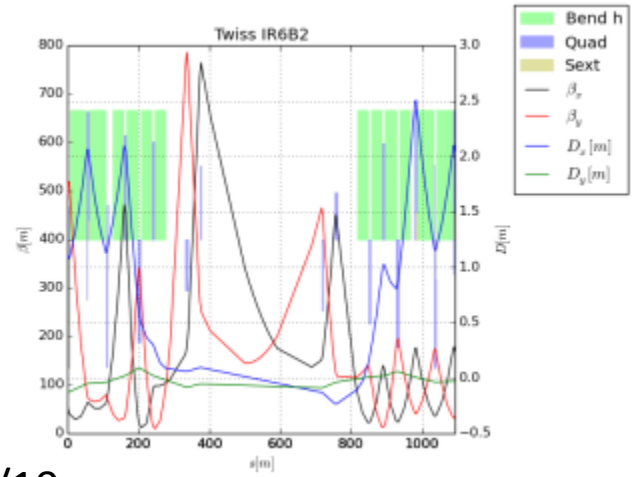
IR6 Optics and Q5 Squeeze assuming the exiting MQY

Squeeze of Q5 to reach final optics.

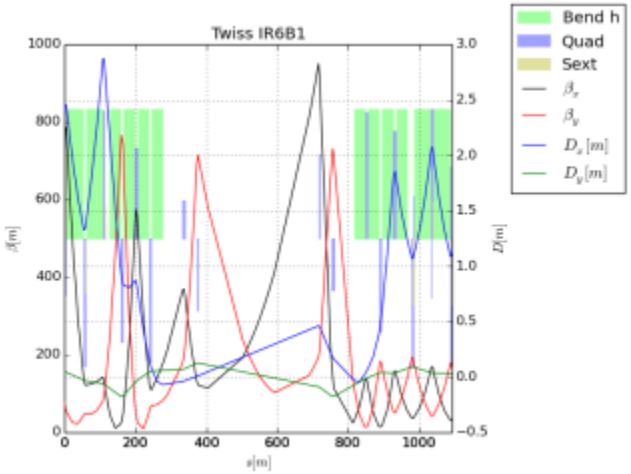


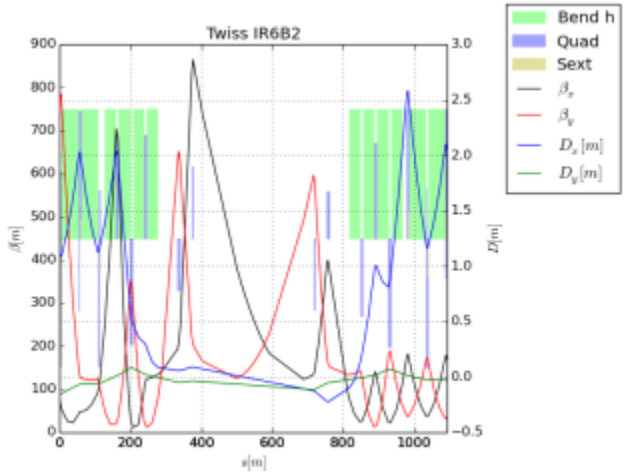
β* CMS: 15cm/15cm





β* CMS: 10cm/10cm



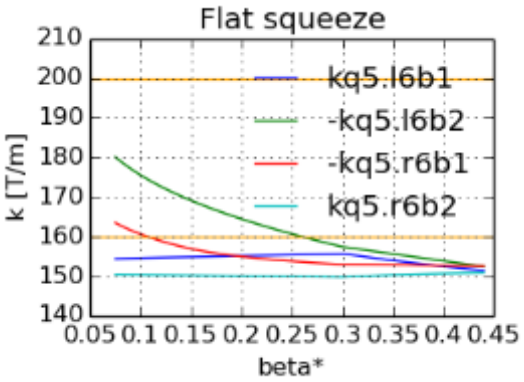


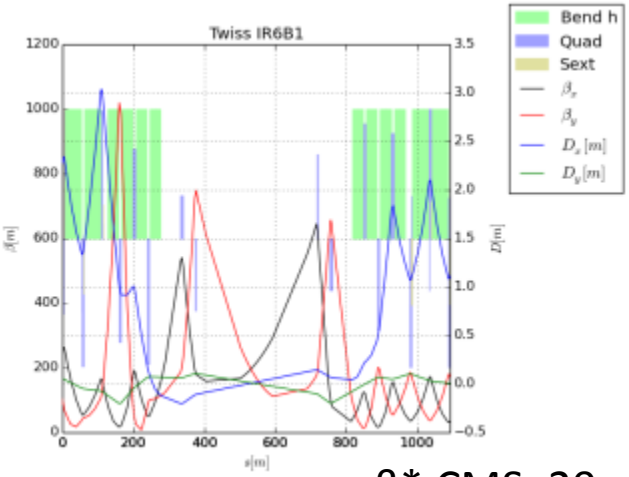
A similar squeeze has been develop and tested with pilot beam in the LHC. S. Fartoukh et al. ATS MD notes I-II-III.

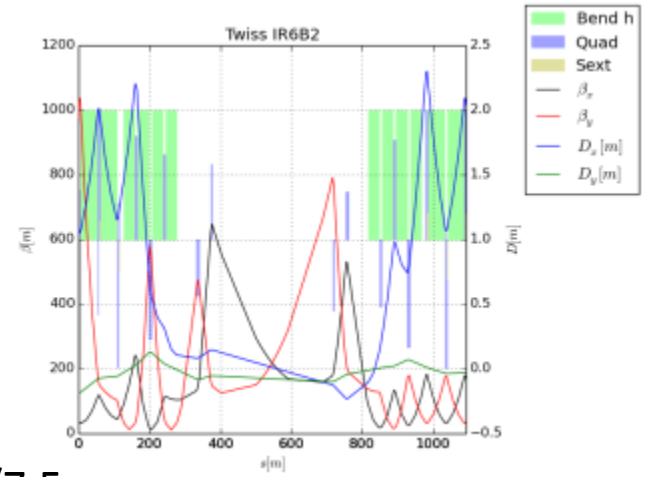
R. De Maria, M. Korestelev, Task2.2 Meeting March '14

IR6 Optics and Q5 Squeeze assuming the exiting MQY

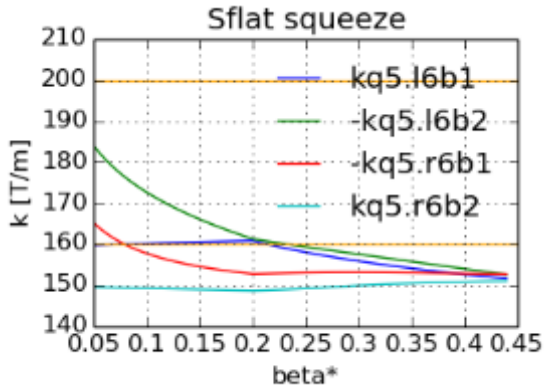
β* CMS: 30cm/7.5cm

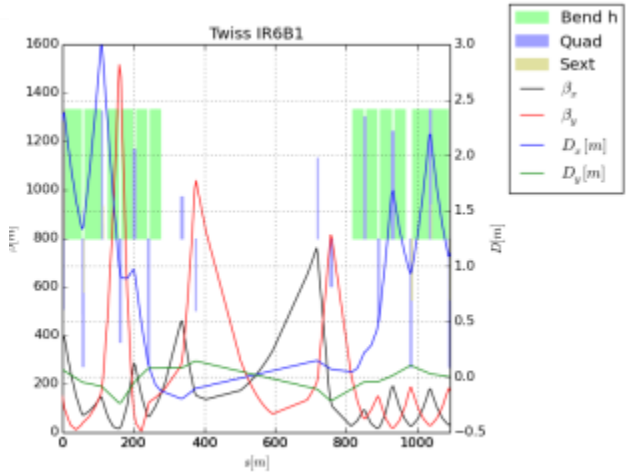


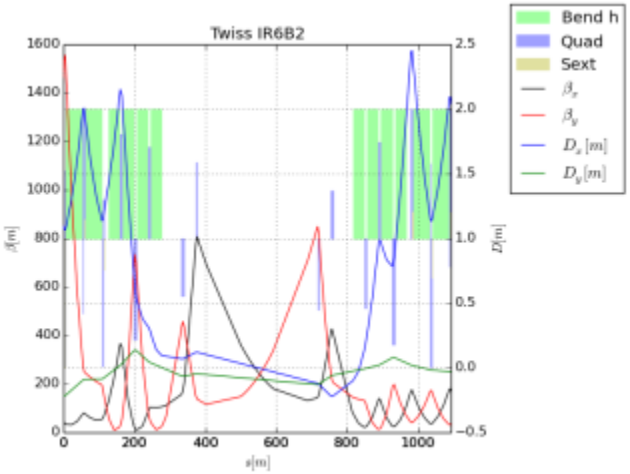




β* CMS: 20cm/7.5cm



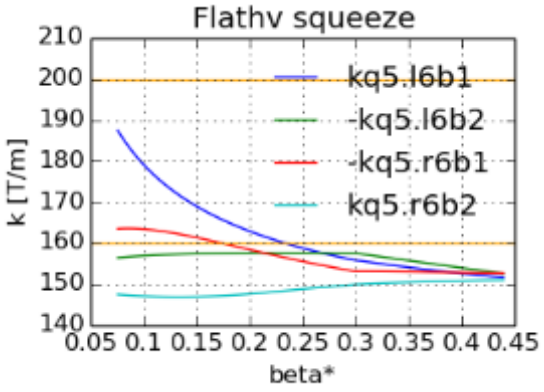


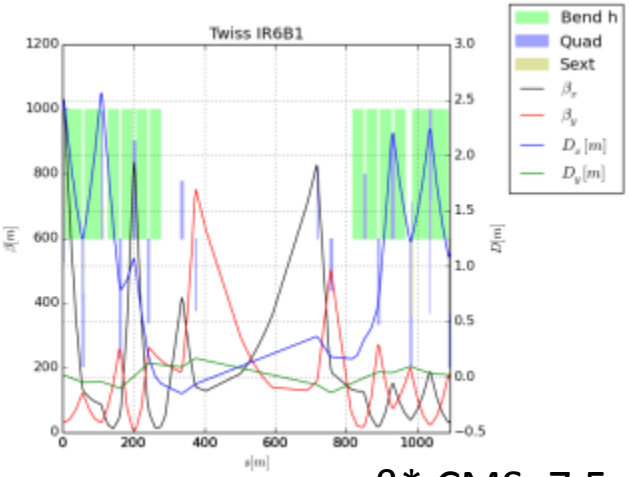


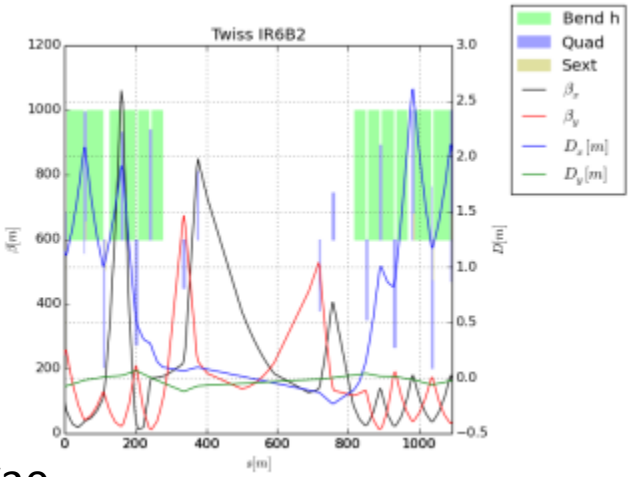
R. De Maria, M. Korestelev, Task2.2 Meeting March '14

IR6 Optics and Q5 Squeeze assuming the exiting MQY

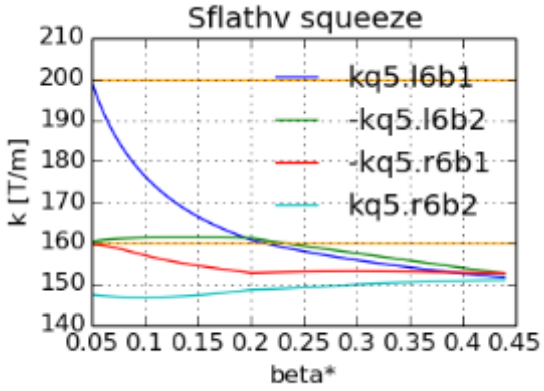
β* CMS: 7.5cm/30cm

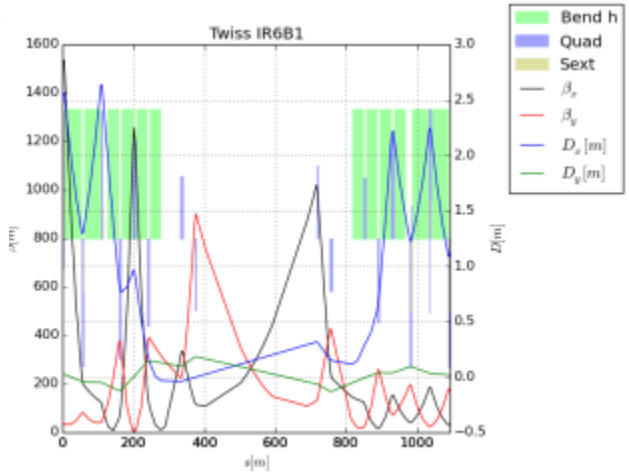


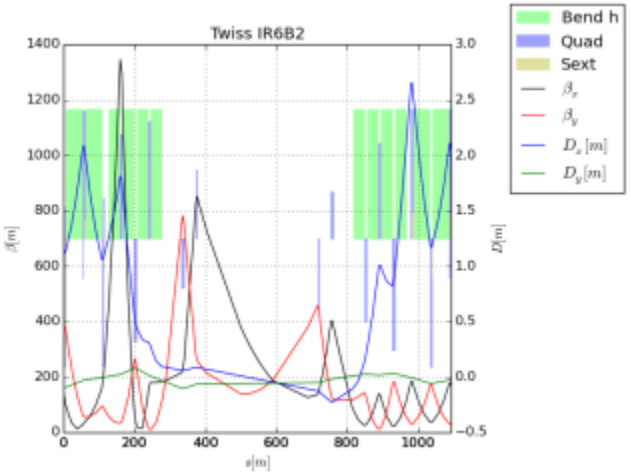




β* CMS: 7.5cm/30cm







R. De Maria, M. Korestelev, Task2.2 Meeting March '14

IR6 Optics and Squeeze

Basic needs taken into account:

- MKD – Septum phase advance
- Beam size at dumps.

However optics and squeeze are not fully validated (WP5, WP14):

- phase advance between MKD and TCT are neither optimal nor optimized and impact TCDQ – TCT retraction.
- Failure scenarios with ATS in the arc

optics	β_x IP6	β_y IP6	μ_x tcsg → mkd_h5l6b1	β_x dump	β_y dump
inj b1	187.3	168.1	94.8	5012	3955
inj b2	187.7	178.4	94.8	5052	3698
round b1	324.3	188.2	90	8172	4463
round b2	248.8	176.7	90	6123	3698
flat b1	212.2	156.3	90	5067	4643
flat b1	217.6	238.5	90	5238	4286
flathv b1	298.1	236.3	90	7466	4446
flathv b2	272.8	205.9	90	6784	3717
sround b1	241.2	185	90	5900	3955
sround b2	252.5	167.2	90	6224	3725
sflat b1	236.9	190.6	90	5778	6771
sflat b2	248.7	237.1	90	6120	3728
sflathv b1	314	176.8	90	7895	3956
sflathv b2	277.7	216.9	90	6918	3722

KQ4.L6B1 and KQ4.R6B2 have nominal strength.

- β-functions at TCDQ, TCDS, TDE do vary during the squeeze.
- Warnings issued for low β_y TCDQAR6.B1- TCDQAL6.B2 in sflathv and flat resp. large and large β_y in flathv, sflathv (Y. Uythoven 10/4/2014).

Mitigation strategies for Q5 in IR6

- Adding an MQY in Q5 solves all issues.
- No changes in the present Q5 is not an option unless downgrading β*.
- Powering the existing Q5 at 200T/m at 1.9K like in IR1-5 fulfills the β* reach for CMS for the present optics (without margins for most push flat).

  However this solution:
  - still limits the β* reach in CMS with respect to ATLAS
  - does not leave much margins in case new optics in IR6 are required after all validations are conclusive.

200 T/m at 1.9 K is a viable option if the optics is frozen as is.

Otherwise doubling MQY is the best solution in terms of potential.

(R. De Maria, 26th WP2 TLM meeting)

Outlook

- Scenarios without MS10 and no stronger Q5 in IR6 have been explored for the RLIUP workshop [1], implying a β* reach of 16cm/36cm or 20 cm for CMS compared to 10 cm, or 5/20 cm for ATLAS.
- Limits are not hard, but additional risks are put on performance reach of the HL-LHC if today's best solutions are not used.
- Some of the risks could be mitigated by further studies and experiments with ATS optics in the present LHC.

[1] M. Fitterer et al, CERN-ACC-NOTE-2014-031