Alternative design of the matching section for crab-cavity operation

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in collaboration with:
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Thanks to:
B. Holzer and M. Giovannozzi

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.

Contents

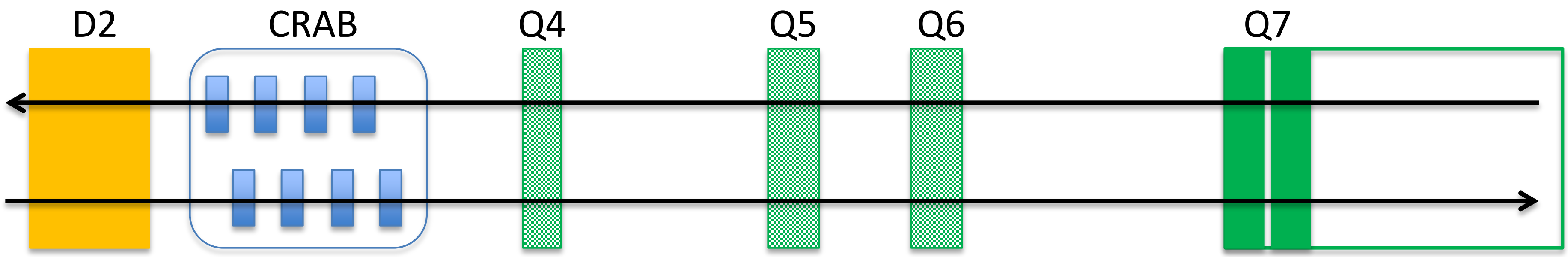
- **motivation & layouts**
  - reduction of crab voltage
  - alternative IR1/5 Matching Section (MS) layouts

- **properties of the latest alternative layout (**as compared to HL-LHC v1.0**)**
  - collision (ATS, non ATS, large β^* optics , apertures)
  - chromatics properties
  - crab voltage
  - injection and transition optics

ALTERNATIVE LAYOUT

Crab cavity voltage

Reduce the voltage of the crab cavity: $V_{crab} = \frac{cE\,\theta_c/2}{\omega_{crab}\sqrt{\beta^*\beta_{crab}}}$



$\Rightarrow$ increasing the beta function at the CRAB

using

- MS quadrupole types
- MS quadrupole positions

	LHC	HL-LHC v1.0
Q4	MQY, G=160 T/m @4.5 K ∅ = 70 mm, L = 3.4 m	MQYY, G=125 T/m @1.9 K ∅ = 90 mm, L = 3.5 m
Q5	MQML, G=160 T/m @4.5 K ∅ = 56 mm, L = 4.8 m	MQYL, G=160 T/m @4.5 K ∅ = 70 mm, L = 4.8 m
Q6	MQML, G=160 T/m @4.5 K ∅ = 56 mm, L = 4.8 m	MQML, G=160 T/m @4.5 K ∅ = 56 mm, L = 4.8 m
Q7	2×MQM, G=200 T/m @1.9 K ∅ = 56 mm, L = 3.4 m	2×MQM, G=200 T/m @1.9 K ∅= 56 mm, L = 3.4 m

HL-LHC v1.1
Q5 MQY G=200 T/m @1.9 K
∅ = 70 mm, L = 4.8 m

Optimization desiderata and optics versions

- Higher β function at crab cavity location

Compatible with

- injection optics (at β* 3, 5, ? m)
- pre-squeeze within and possibly beyond the chromatic limits
- squeezable to very low β* to back-up ATS

Optimization already performed for:

- Optics with the triplet gradient of 170 T/m, ∅ = 120 mm
- Optics with the triplet gradient 140 T/m, ∅ = 150 mm HLLHCV1.0 version (before IPAC'13)
- Optics with the triplet gradient 140 T/m, ∅ = 150 mm HLLHCV1.0 version (after IPAC'13)

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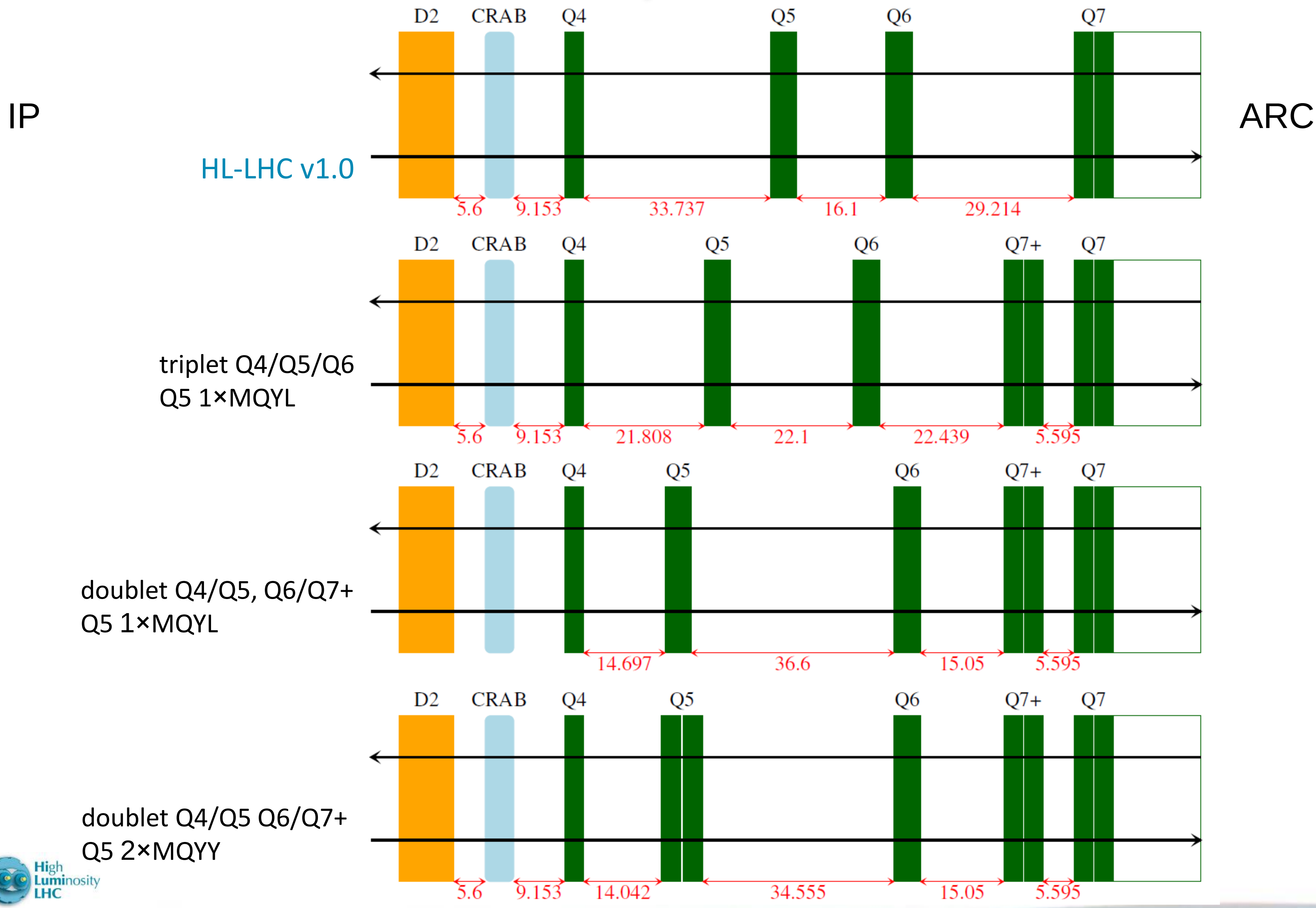
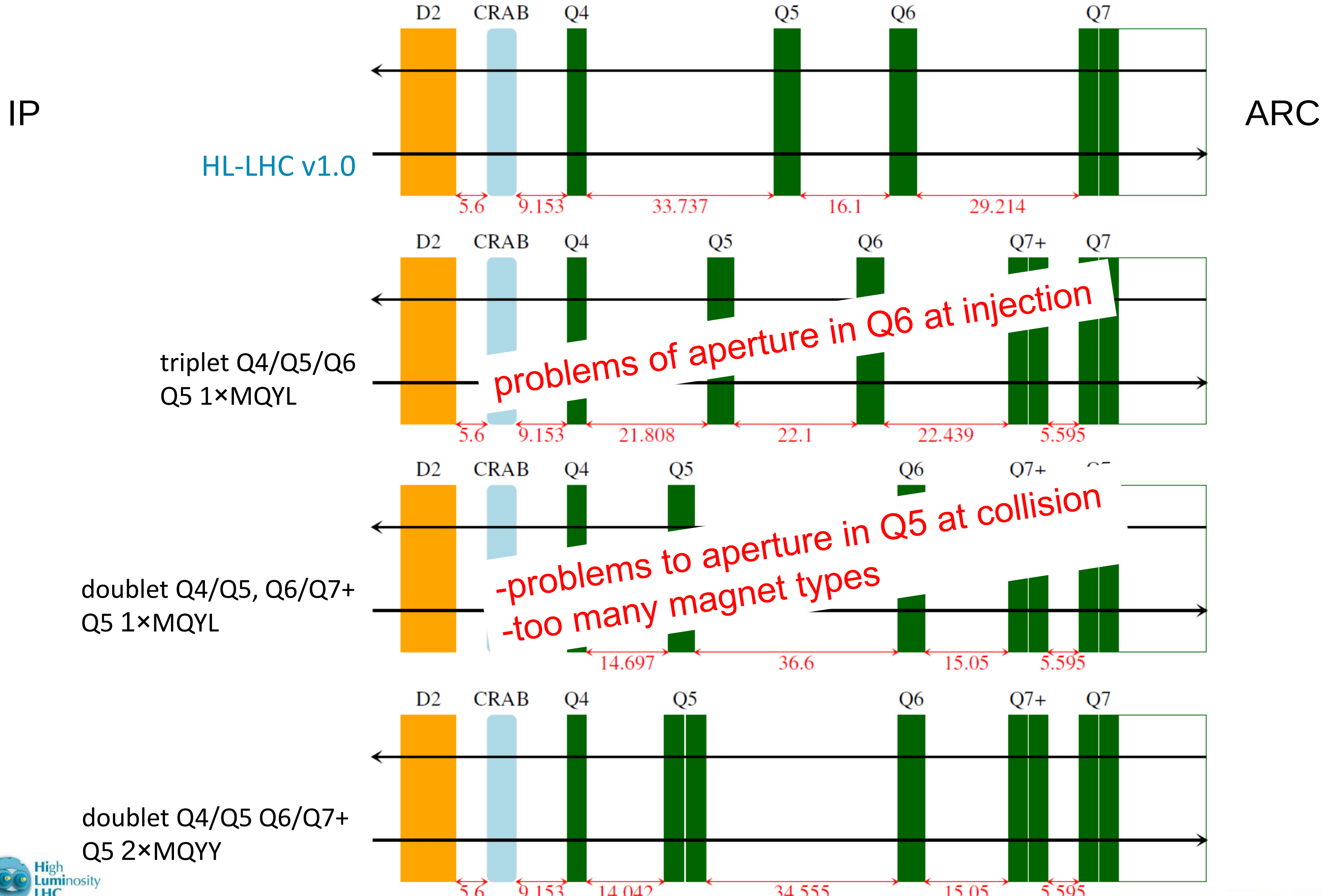
Main MadX scripts and main optics variants available at dalena@lxplus.cern.ch:~/public/lhc/optics

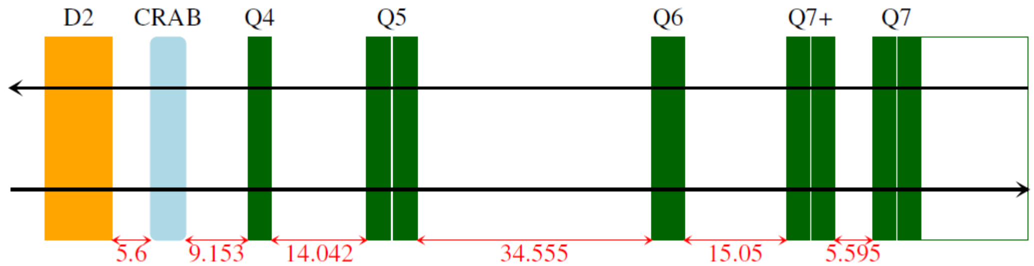
Alternative layouts HLLHCV1.0



Alternative layouts HLLHCV1.0



Alternative layout HLLHCV1.0



	LHC	HL-LHC v1.0	Alternative layout
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Q7+			2×MQM, G=200 T/m @1.9 K ∅= 56 mm, L = 3.4 m

presented at IPAC'14 (TUPRO001)

technical note to be finalized

HL-LHC v1.1
Q5 MQY G=200 T/m @1.9 K
∅ = 70 mm, L = 4.8 m

CERN-ATS-Note-2014-xxx

February 2014

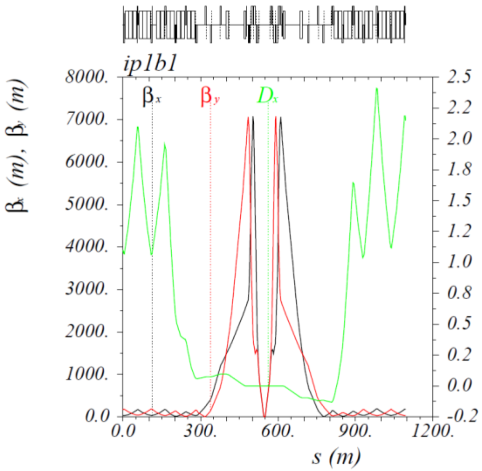
Layout and optics scenario for an enhanced crab kick in the HL-LHC high-luminosity insertion.

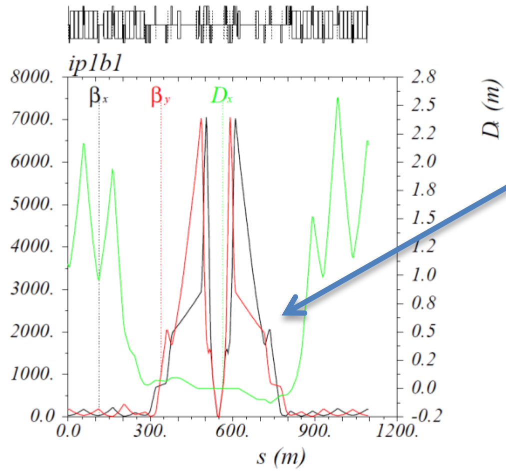
B. Dalena, J. Payet, A. Chancé (CEA), R. De Maria, S. Fartoukh (CERN)

COLLISION

Collision Optics (round)

pre-squeeze (β^* = 44 cm)



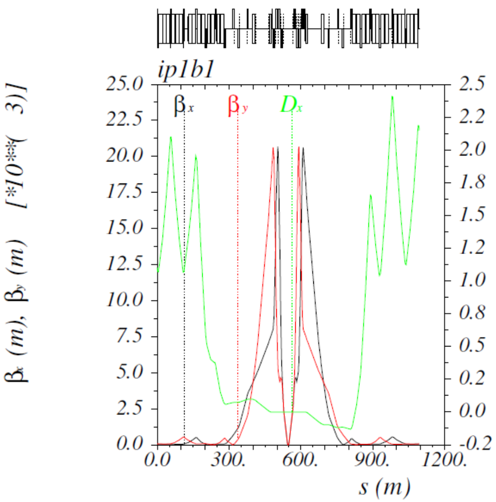


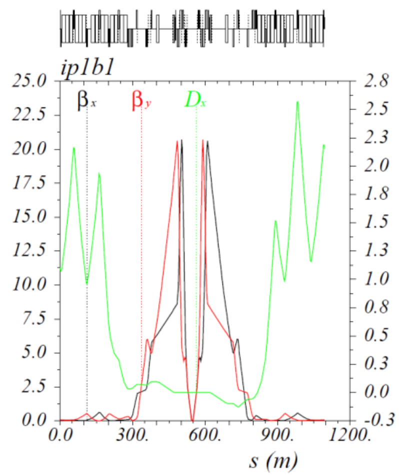
Higher β between D2 and Q5

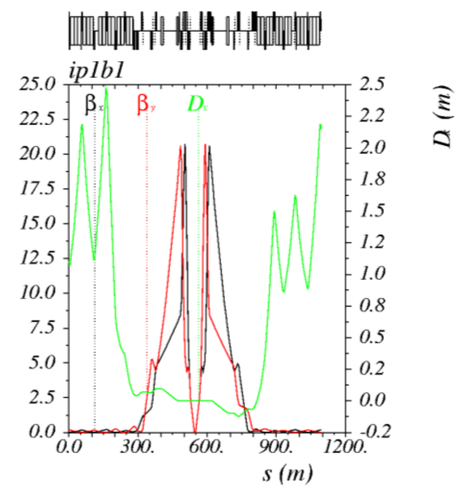
HL-LHC v1.0

Alternative ATS

Alternative non ATS



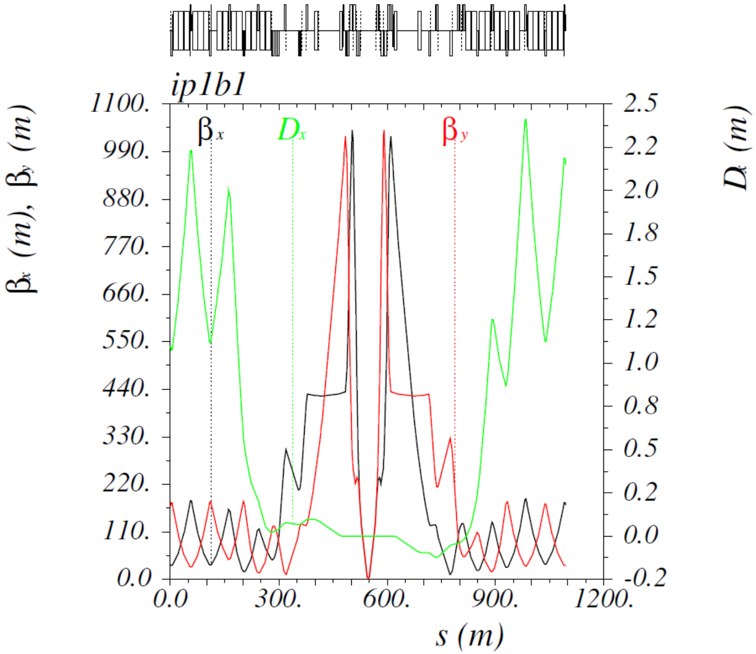




β^* = 15 cm

Large β^* optics

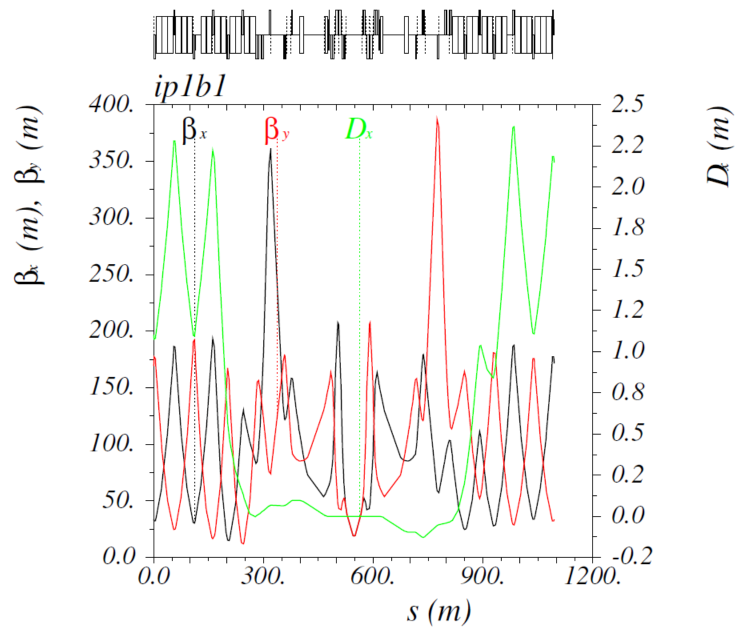
- β^* = 3 m is the maximum value for pre-squeeze (ATS L/R phases)



- β^* = 19 m Van der Meer optics (vdm), non ATS L/R phases

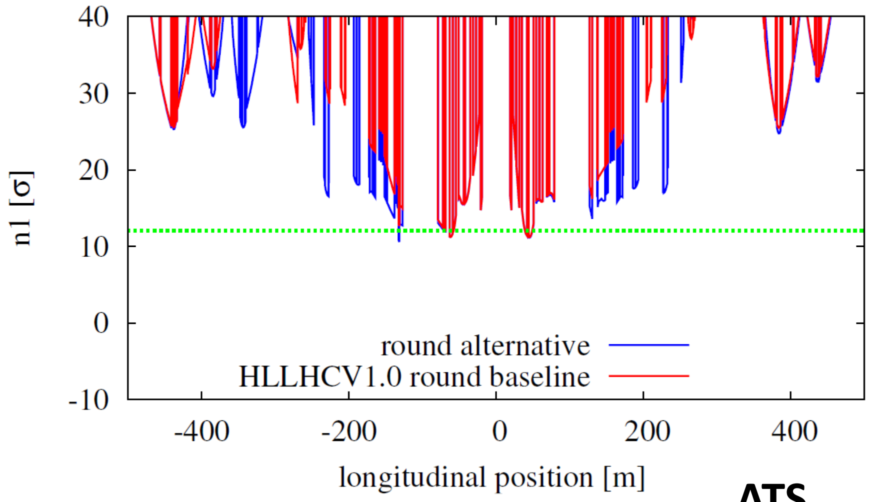
  It is possible to reduce the β peaks in Q6 but:

  - Q4 exceeds the strength limit



Collision apertures

- apertures of Q5 modeled as Q4 (MQYY)
- apertures of Q7+ modeled as Q7
- apertures in the triplet use an octagon model with ISO tolerances (bs_type = 4)

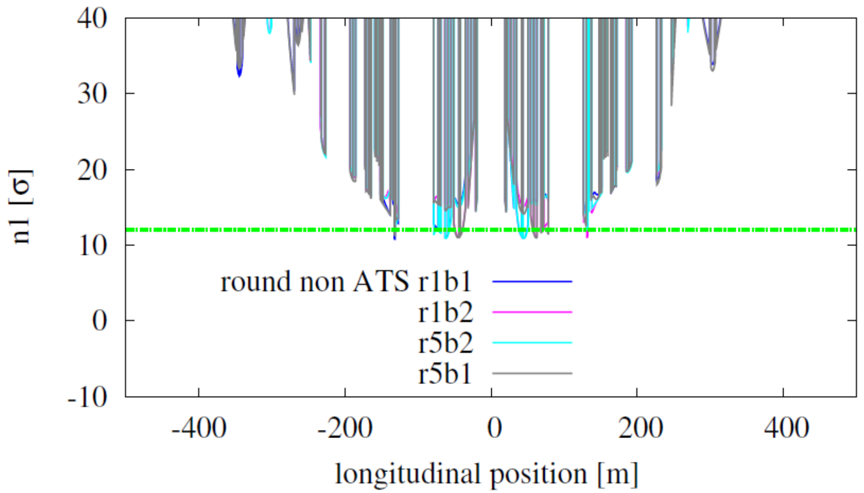


ATS

-nominal normalized emittance: $\gamma\varepsilon$=3.5 μm rad
total crossing angle: 590 μrad

-latest aperture model for the new HL-LHC magnets described in R. De Maria, S. Fartoukh, TUPFI014, IPAC13

-beam tolerance budget (closed orbit, beta-beating, spurious dispersion and beam halo geometry) as the one described in R. Bruce et al., CERN-ACC-2014-0044.



non ATS

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Computed apertures & magnet types

Minimum value of b1, b2 in IR1 and IR5

HL-LHC v1.0	collision [σ]	alternative (type)	collision [σ]	non ats [σ]
TAS	14.63		14.65	14.25
Triplet	10.96		10.96	10.89
CRAB	24.56		20.55	20.03
TAN	14.52		12.16	12.31
D2	16.80		13.61	13.59
Q4(MQYY)	22.66	Q4(MQYY)	16.26	16.45
Q5(2 MQYL)	27.73	Q5(2 MQYY)	17.06	17.86
Q6(MQML)	28.09	Q6(MQML)	24.56	18.00
Q7+(-)	(-)	Q7+(2 MQM)	30.34	28.35

-nominal normalized emittance: $\gamma\varepsilon$=3.5 µm rad; total crossing angle: 590 µrad

-latest aperture model for the new HL-LHC magnets described in R. De Maria, S. Fartoukh, TUPFI014, IPAC13

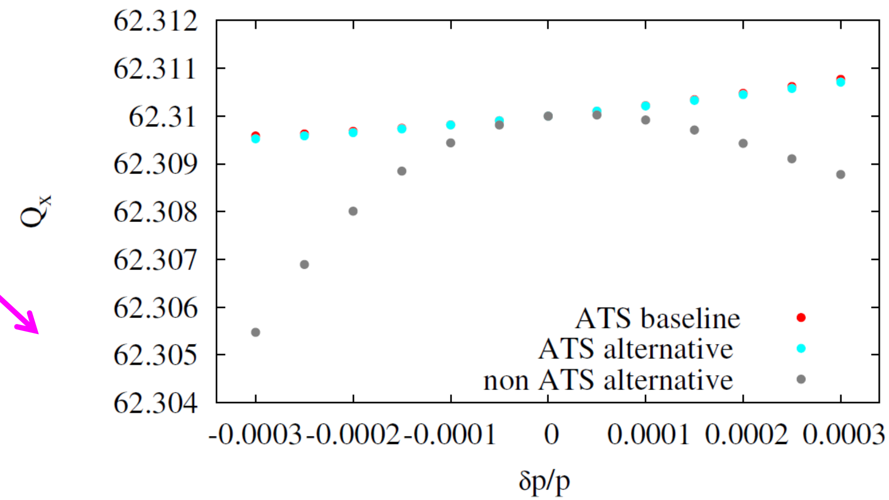
-beam tolerance budget (closed orbit, beta-beating, spurious dispersion and beam halo geometry) as the one described in R. Bruce et al., CERN-ACC-2014-0044.

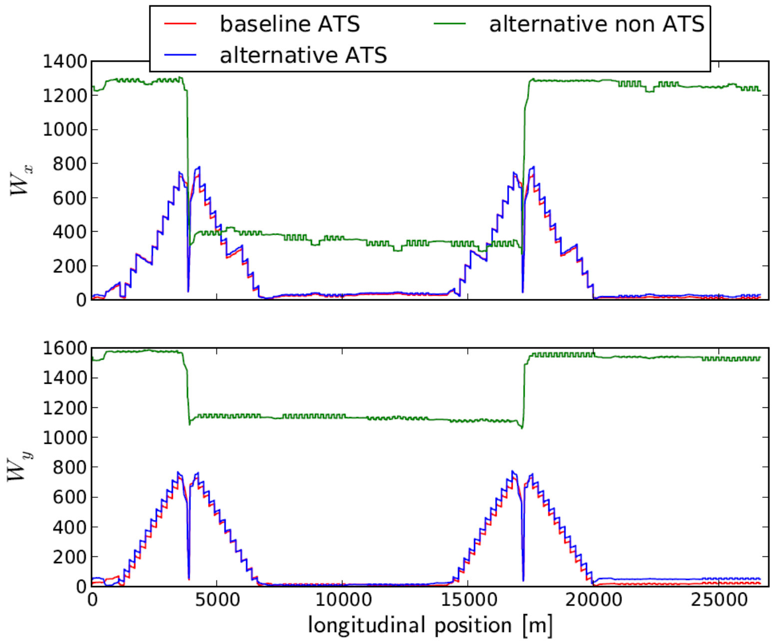
- crab cavity aperture: rectellipse r=42 mm

Chromatic properties

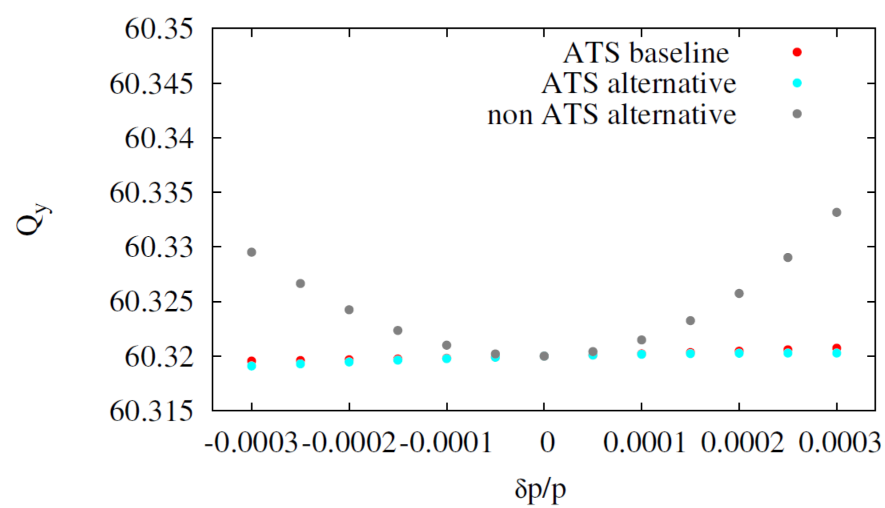
HL-LHC v1.0 vs Alternative:

- tunes vs $\delta p/p$
- Montague functions:
    - squeeze ATS very similar
    - non ATS similar to nominal-like LHC





IP1 **IP5**



Crab-cavity voltage

Equivalent kick calculated using 3 crab cavities

Side, IR and beam	HL-LHC v1.0 [MV]	Alternative round [MV]
H L/R 5 b 1	10.8/12.0	8.7/8.8
H L/R 5 b 2	12.0/10.8	8.8/8.7
V L/R 1 b 1	11.8/10.8	8.7/8.7
V L/R 1 b 2	10.8/11.8	8.7/8.7

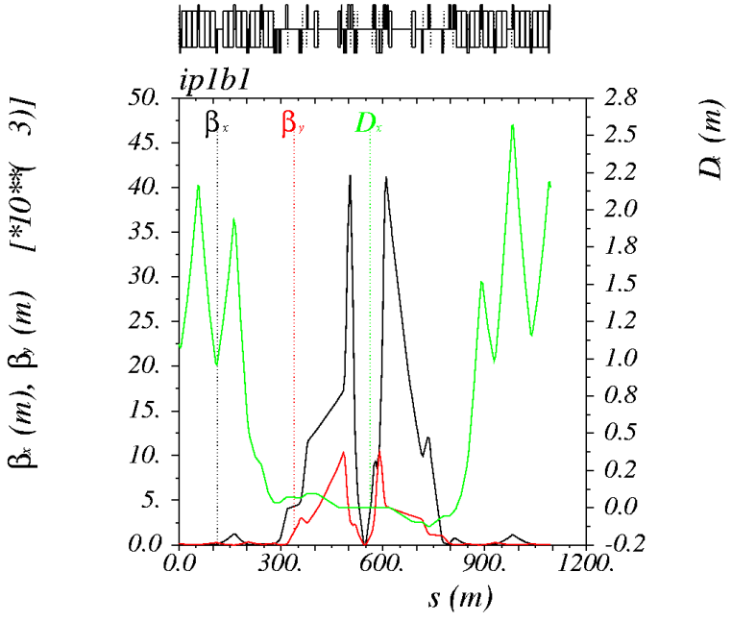
possibility to reduce the crab voltage of about 20%

Side, IR and beam	Alternative non ATS [MV]
H L/R 5 b 1	9.3/9.3
H L/R 5 b 2	9.3/9.1
V L/R 1 b 1	9.2/9.3
V L/R 1 b 2	9.3/9.2

in non ATS: problem to match the residual dispersion with the present correctors

Flat optics

- relative gain in the crab voltage same as round
- smaller apertures in all matching section (compared to round optics)



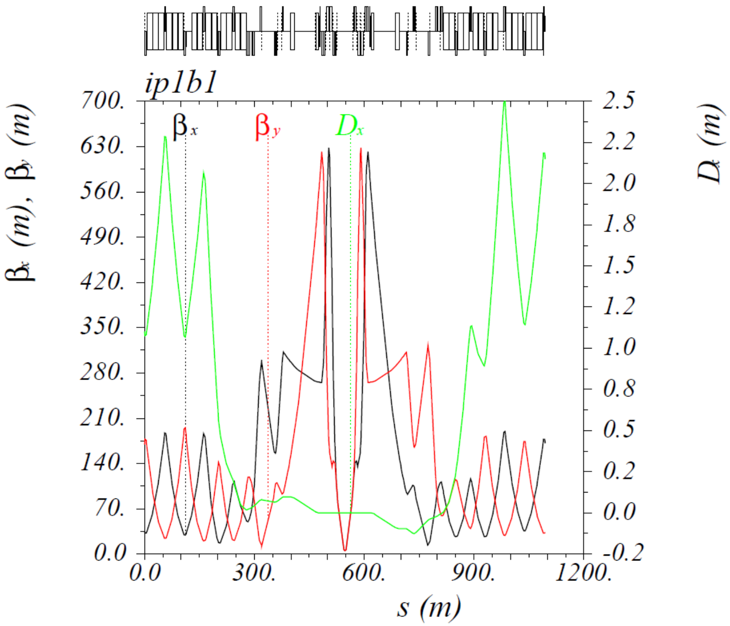
alternative (type)	collision flat [σ]	collision round [σ]
TAS	12.74	14.65
Triplet	11.07	10.96
CRAB	14.64	20.55
TAN	9.65	12.16
D2	10.35	13.61
Q4(MQYY)	11.48	16.26
Q5(2 MQYY)	12.10	17.06
Q6(MQML)	11.99	24.56
Q7+(2 MQM)	18.39	30.34

Side, IR and beam	HL-LHC v1.0 flat [MV]	Alternative flat [MV]
H L/R 5 b 1	10.1/11.4	8.2/8.2
H L/R 5 b 2	11.4/10.1	8.2/8.2
V L/R 1 b 1	11.2/10.1	8.1/8.2
V L/R 1 b 2	10.1/11.2	8.2/8.1

INJECTION & TRANSITIONS

Optics injection

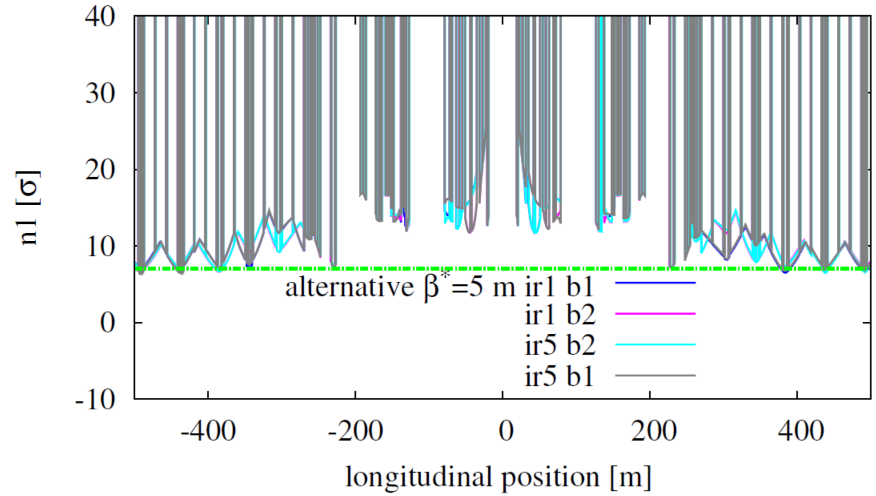
- Total phase advance IR5/1 same as ATS optics
  (μxIP5/1=2.6427, μyIP5/1=2.6420)
- L/R phases at β^* = 5 m
  (μxIP1b1_L=1.1836; μxIP1b1_R=1.4591;)
  (μyIP1b1_L=1.5896; μyIP1b1_R=1.0524;)
- Possibility to easily switch to the injection phase
- No symmetry condition for Q4 and Q5



Injection β^* = 5 m

Injection apertures

- apertures of Q5 modeled as Q4 (MQYY)
- apertures of Q7+ modeled as Q7
- apertures in the triplet use an octagon model with ISO tolerances (bs_type = 4)



-nominal normalized emittance: γε=3.75 μm rad; total crossing angle: 590 μrad

-latest aperture model for the new HL-LHC magnets described in R. De Maria, S. Fartoukh, TUPFI014, IPAC13

-beam tolerance budget (closed orbit, beta-beating, spurious dispersion and beam halo geometry) as the one described in J.B. Jeanneret, R. Ostojic, CERN-LHC-Project-Note 111 (1997)

alternative (type)	Injection [σ]
TAS	12.58
Triplet	12.21
CRAB	16.40
TAN	11.79
D2	12.98
Q4(MQYY)	13.16
Q5(2 MQYY)	15.92
Q6(MQML)	7.15
Q7+(2 MQM)	8.07

Minimum value of b1, b2 in IR1 and IR5

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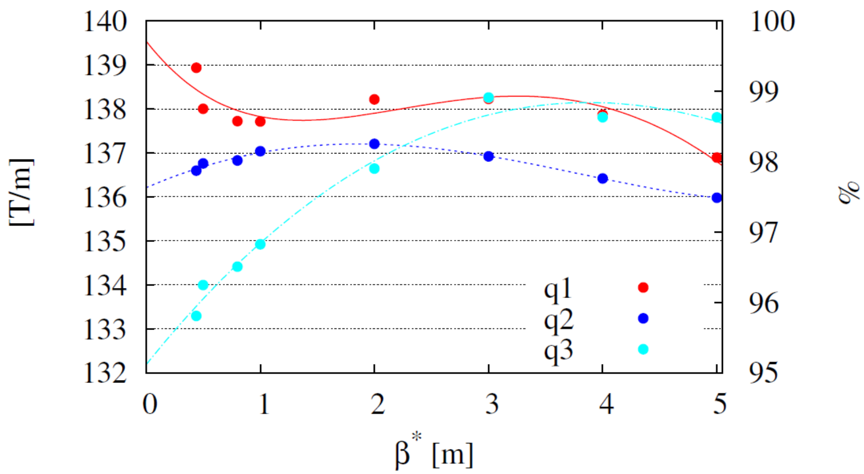
Q1/Q2/Q3 strengths vs β^* (transitions)

Optics at different β* found with same tool developed for crab voltage optimization.

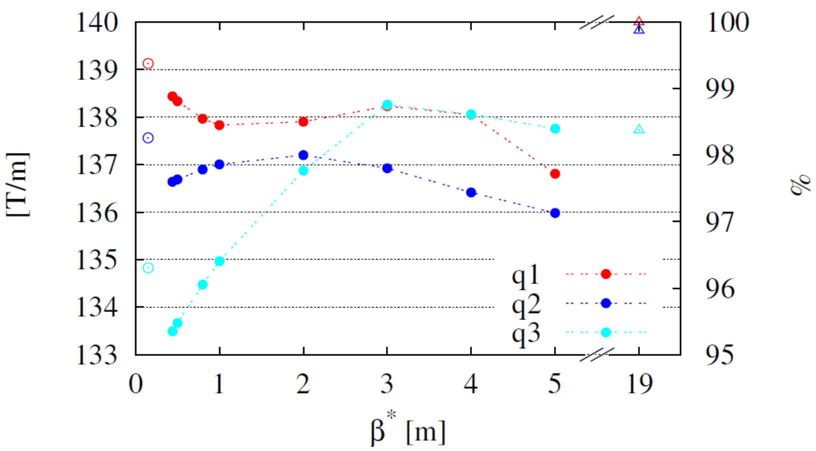
Smoothing function:

$$f(x) = (a + bx + cx^2 + dx^3)e^{(hx)}$$

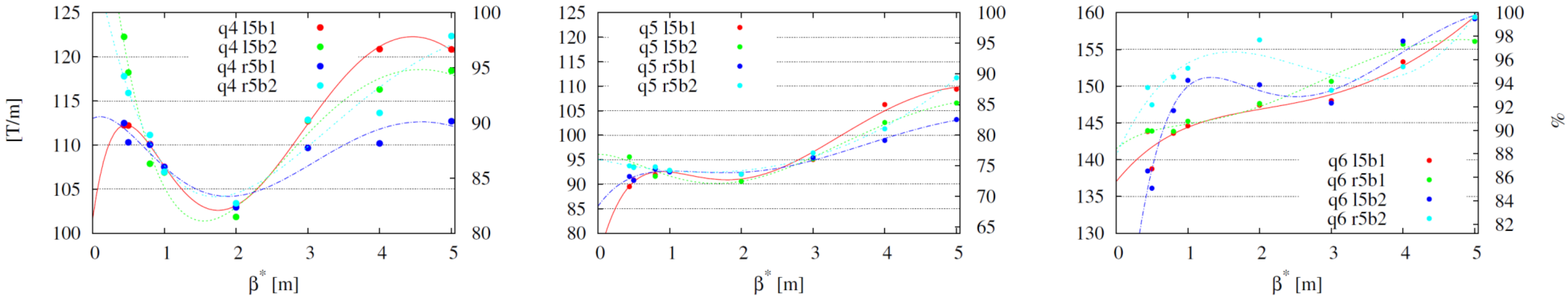
with *a,b,c,d,h* free parameters for each quadrupole.

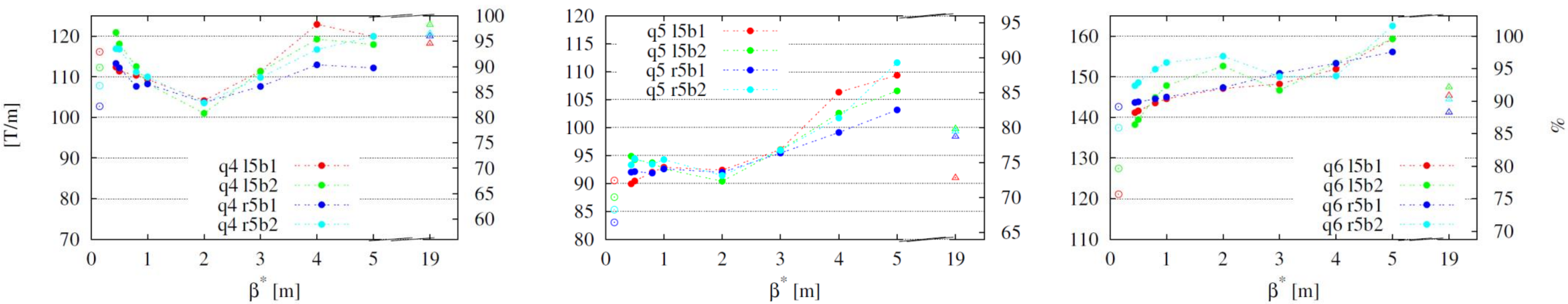


- filled circle: transitions optics after smoothing
- unfilled circle: non ATS
- unfilled triangle: vdm optics
- strengths variation between collision and injection ~ 5%
- maximum strength variation in transition ~ 5% (< 11% given by the Trim)



Q4/Q5/Q6 strengths vs β*





- filled circle: transitions optics after smoothing
- unfilled circle: non ATS
- unfilled triangle: vdm optics
- strengths variation in transition optics ~ 20%
- Q6 at limit (high) at injection

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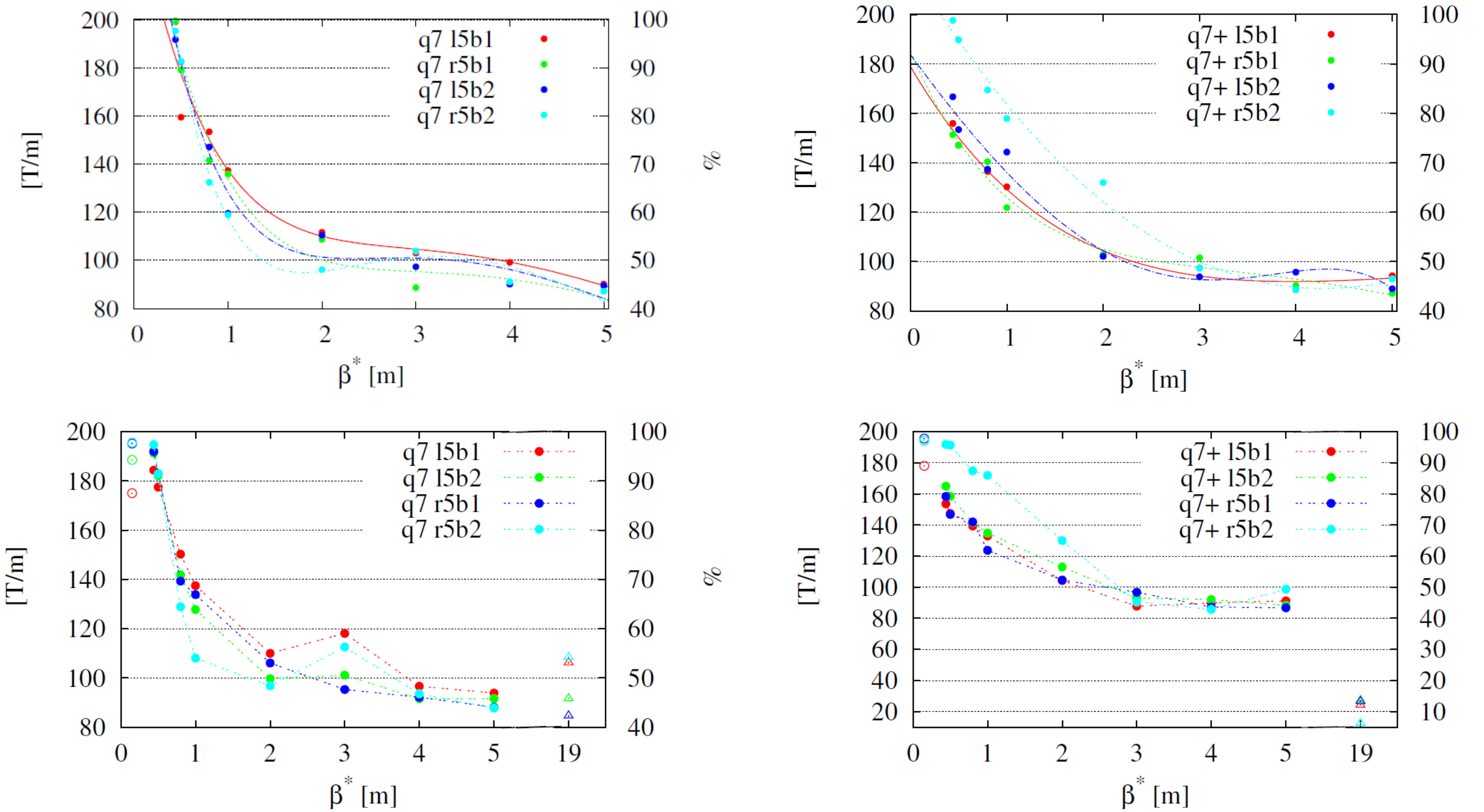
Q7/Q7+ strengths vs β^*



- filled circle: transitions optics after smoothing
- unfilled circle: non ATS
- unfilled triangle: vdm optics
- both Q7 strengths are at limit (low) for injection ($\beta^* = 5$ m)

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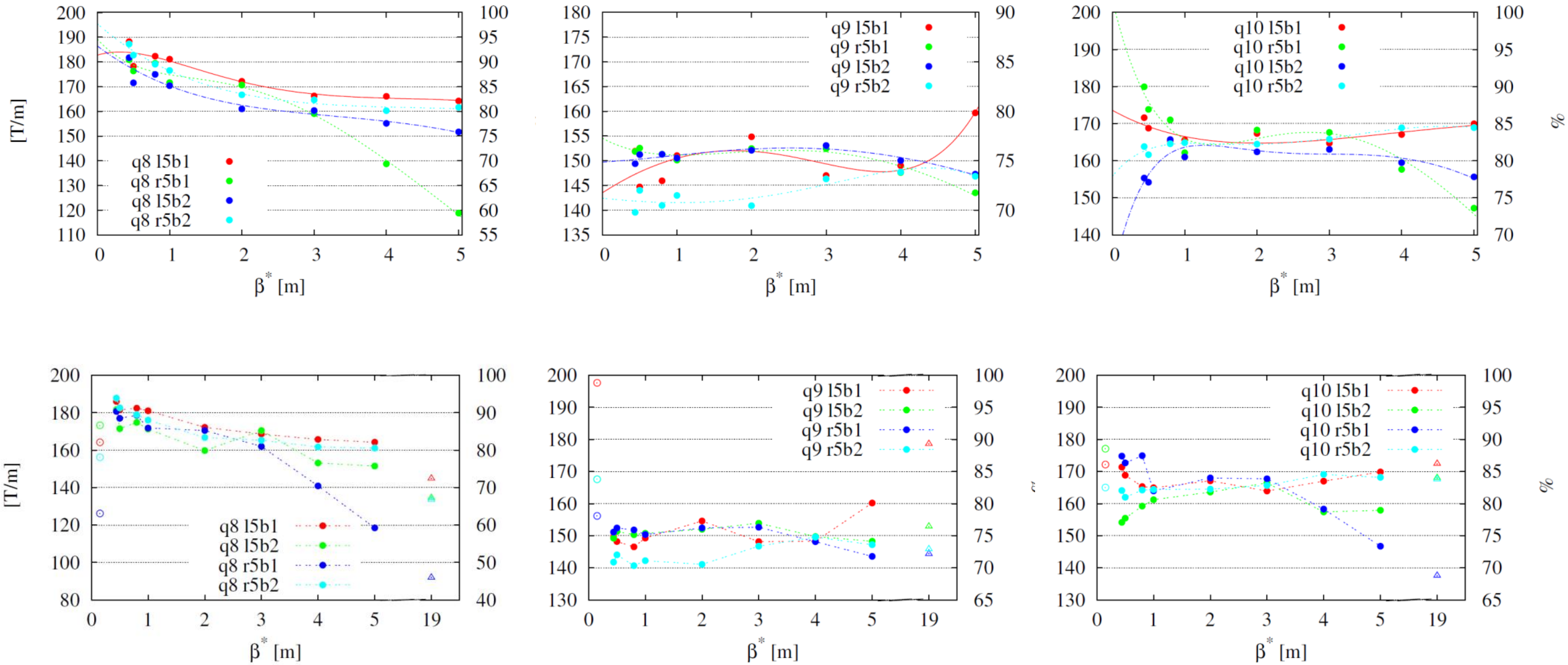
Q8/Q9/Q10 strengths vs β^*



- filled circle: transitions optics after smoothing
- unfilled circle: non ATS
- unfilled triangle: vdm optics
- 10% strength variation: except for Q8 right b2

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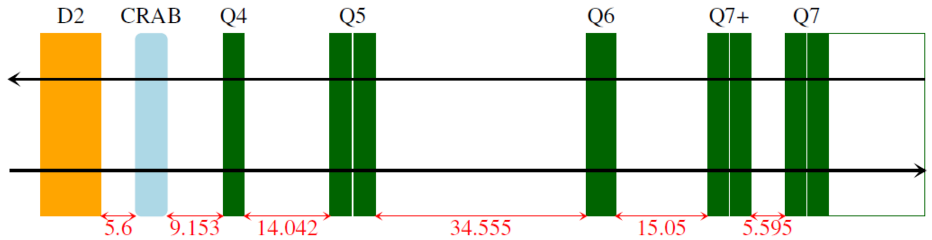
Conclusions



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Q7+			2×MQM, G=200 T/m @1.9 K ∅= 56 mm, L = 3.4 m

HL-LHC v1.1
Q5, MQY, G=200 T/m @1.9 K
∅ = 70 mm, L = 4.8 m

- possibility to reduce crab cavity voltage by 20%
- possibility to gain lattice flexibility in collision

Drawbacks

- additional quadrupoles required (2 MQM and MQYL→2 MQYY)
- integration with the DFB not easy
- apertures closer to beam stay clear limit

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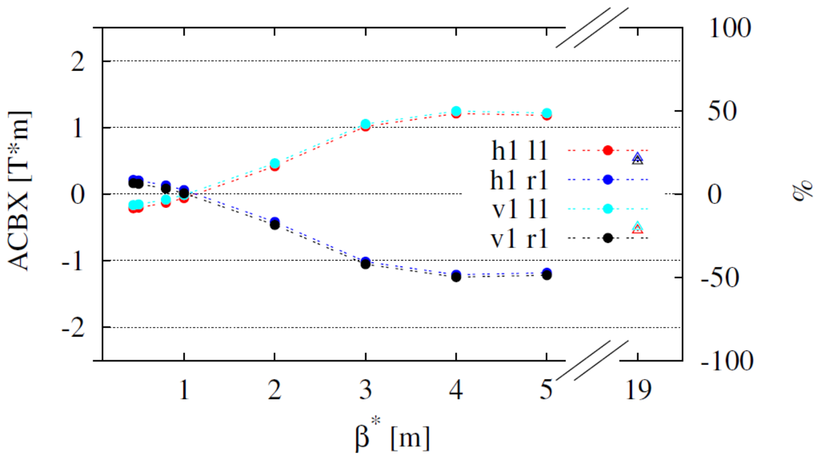
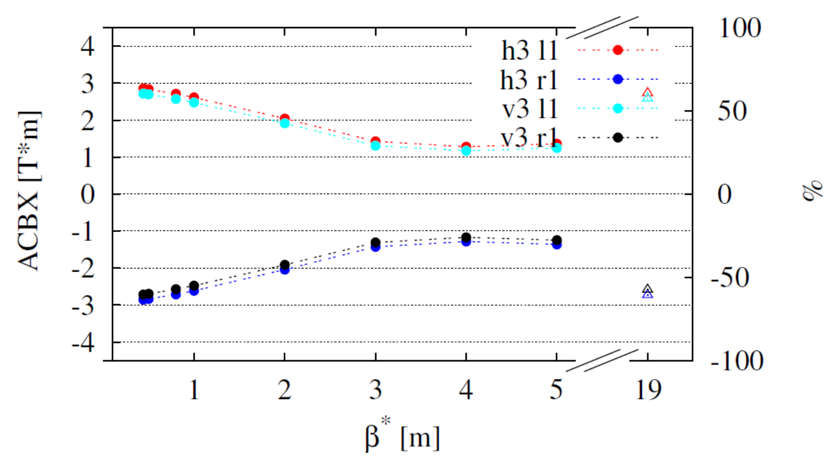
Transitions summary

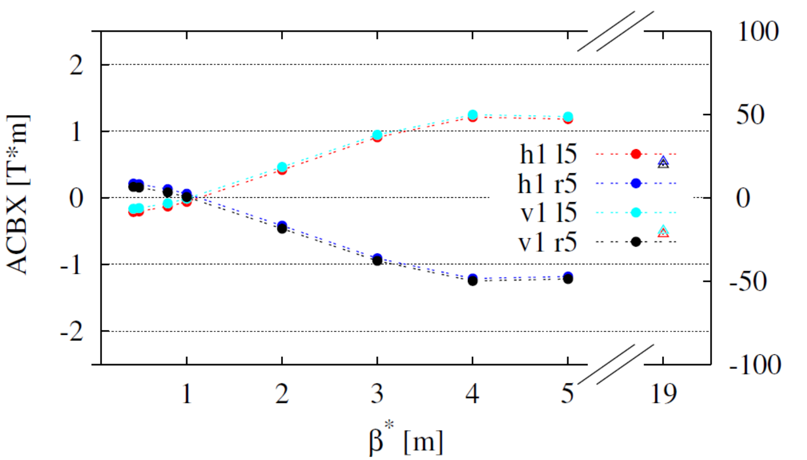
	[T/m]	[m]
Q1/Q2/Q3	133-140	8.004-6.792
Q4	100-125	3.5
Q5	80-110	2×3.5
Q6	120-162	4.88
Q7	80-200	2×3.4
Q7+	6-200	2×3.4
Q8	90-190	4.8
Q9	140-200	3.4
Q10	135-180	4.8

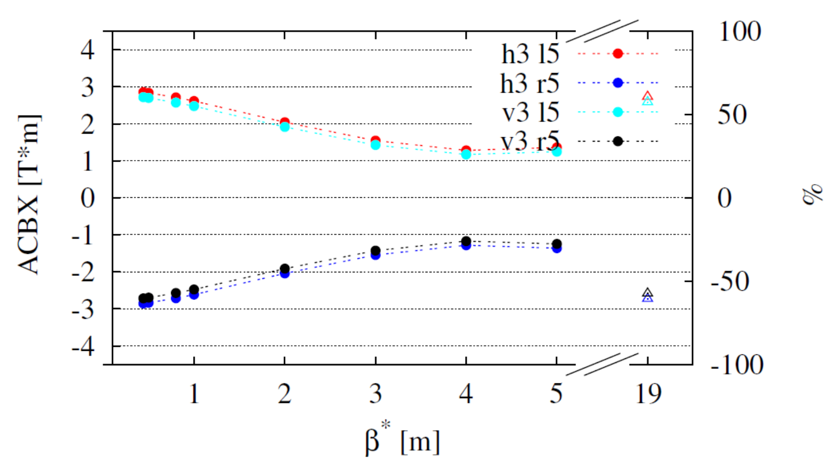
Including non-ATS and vdm optics.

Crossing scheme (ACBX)









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