Update on matching section layout vs. crab-cavity voltage

B. Dalena, R. De Maria, S. Fartoukh, J. Payet

Thanks to: M. Giovannozzi and B. Holzer

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.

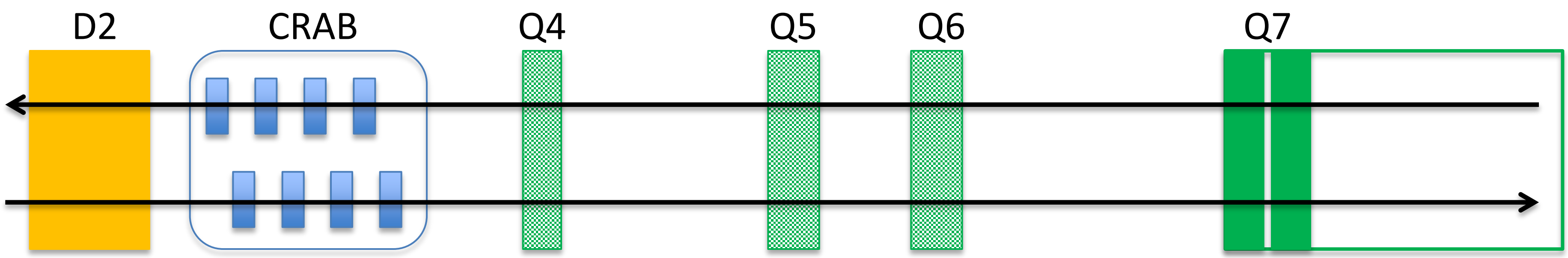
Contents

- introduction and motivation
  - reduction of crab voltage
- proposed IR1/5 Matching Section (MS) layouts
- properties of the new layouts
  - collision optics
  - chromatics properties
  - injection optics
  - considerations on optics transitions

INTRODUCTION

Crab cavity voltage

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



⇒ increasing the beta function at the CRAB

using

- MS quadrupole types
- MS quadrupole positions

	LHC	HL-LHC baseline
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

Optimization desiderata

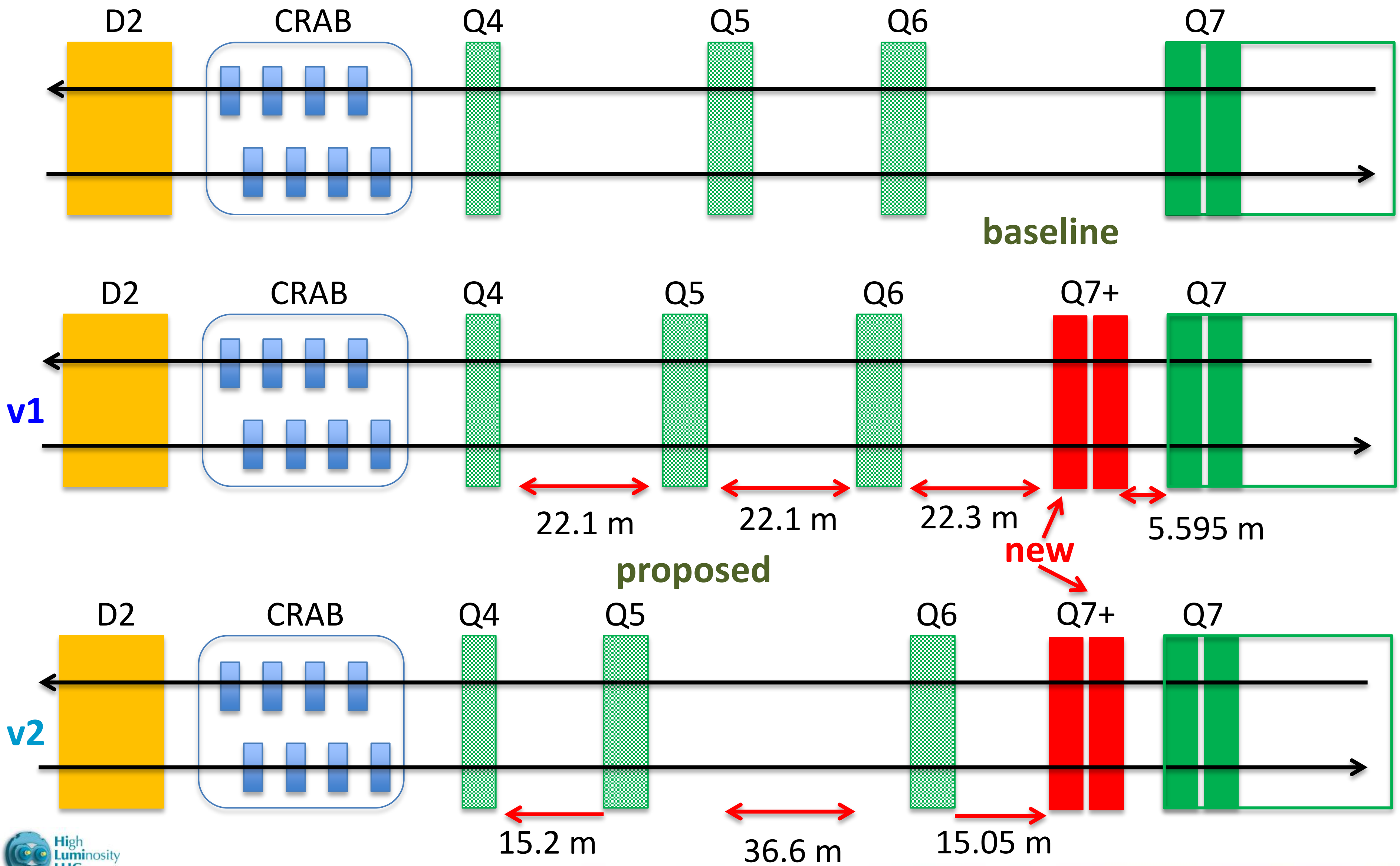
- Higher β function at crab cavity location

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

Results shown have the triplet gradient of 140 T/m, ∅ = 150 mm, latest HLLHCV1.0 version

Proposed layouts

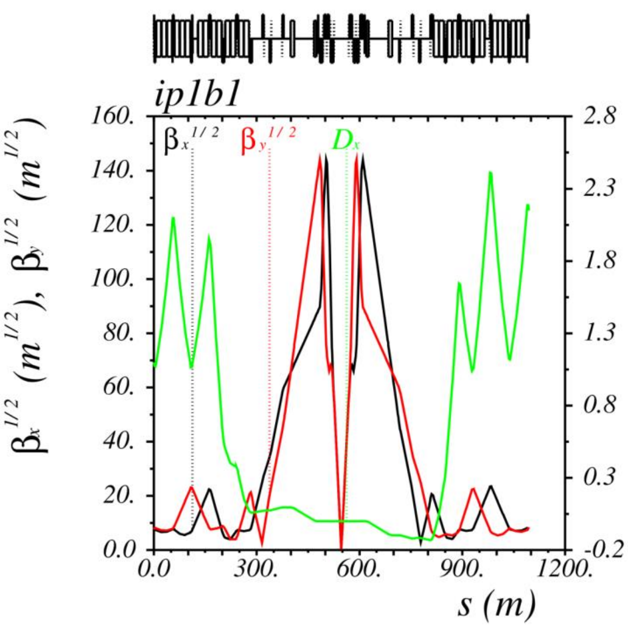


COLLISION

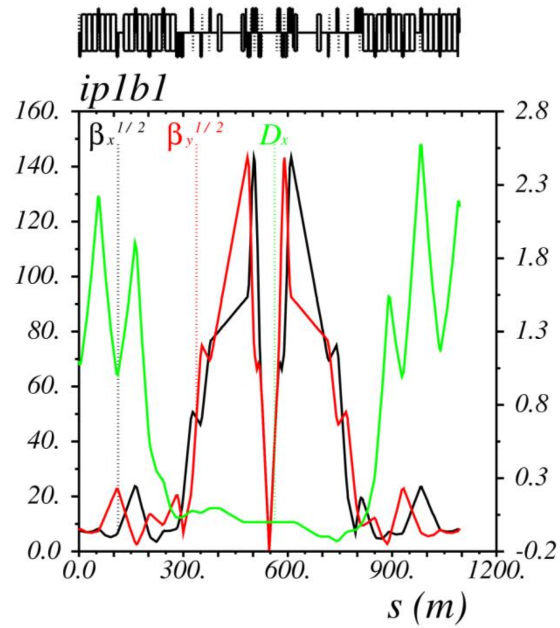
Round Optics

β* = 15 cm (ATS)

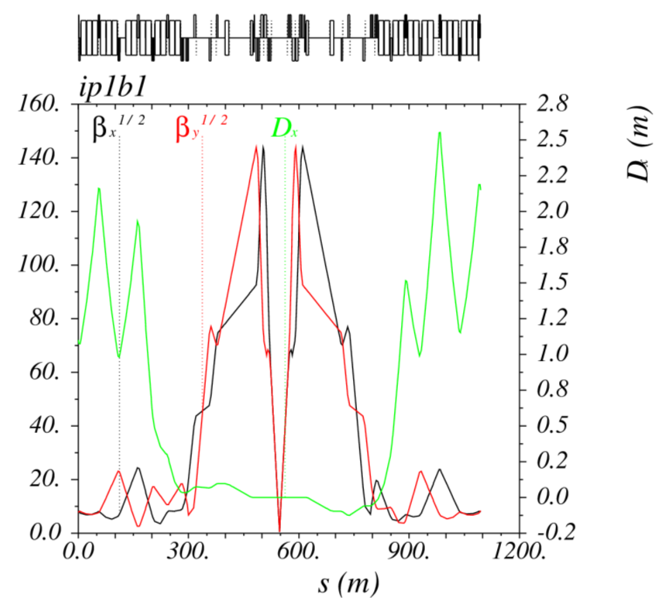
baseline



proposed v1



proposed v2

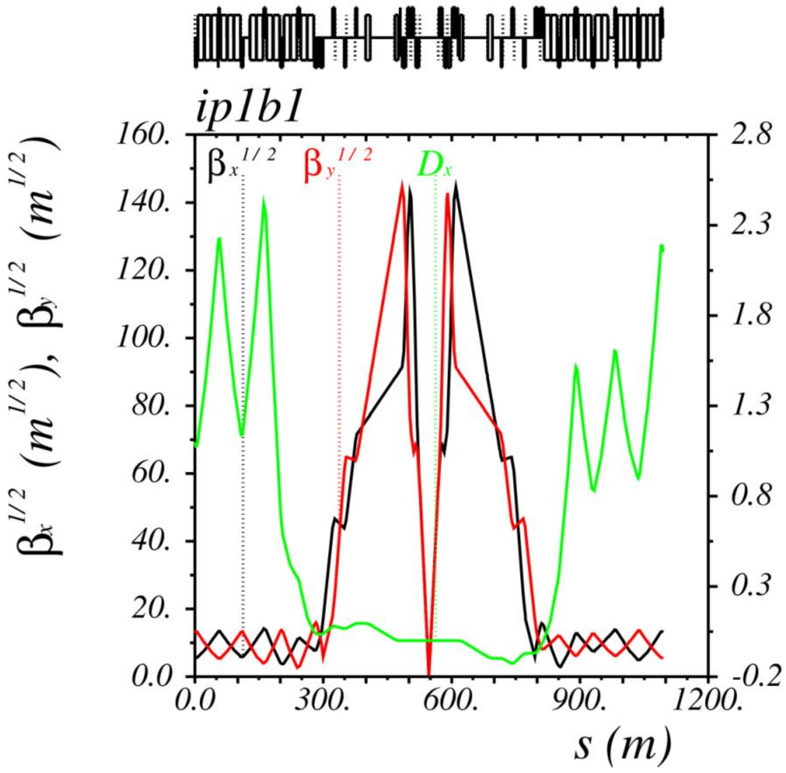


About same β functions increase with respect to the baseline optics at the crab location (s~400 m and s~700 m) in **v1** and **v2**

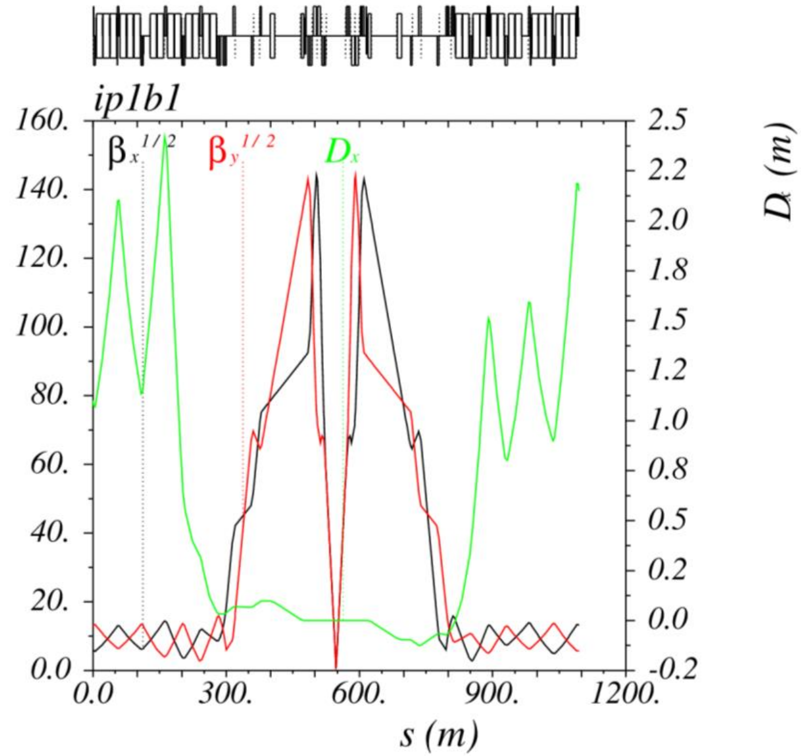
Non ATS optics

β* = 15 cm (ATS)

proposed v1



proposed v2



Q7+ gives more flexibility at collision towards small β functions

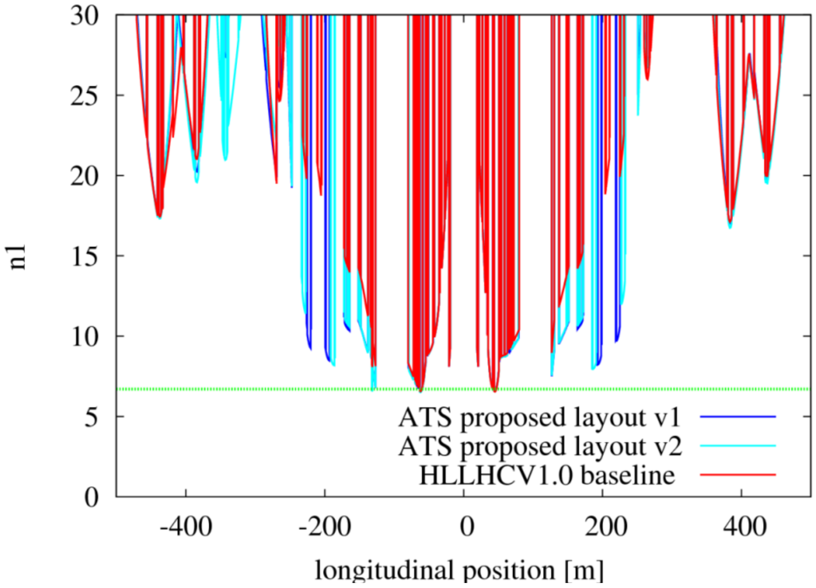
Collision apertures

Round beams ATS

• Q5 beam screen re-oriented in the plane with higher β

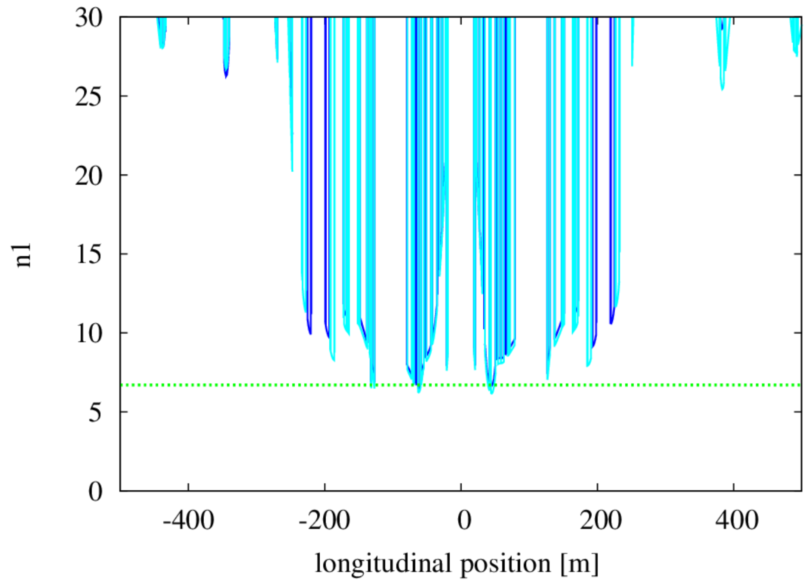
• apertures of Q7+ magnet modeled as Q7

• apertures in the triplet use an octagon model with ISO tolerances (bs_type = 5)



Round beams non ATS

• similar to ATS optics in the matching section quadrupoles



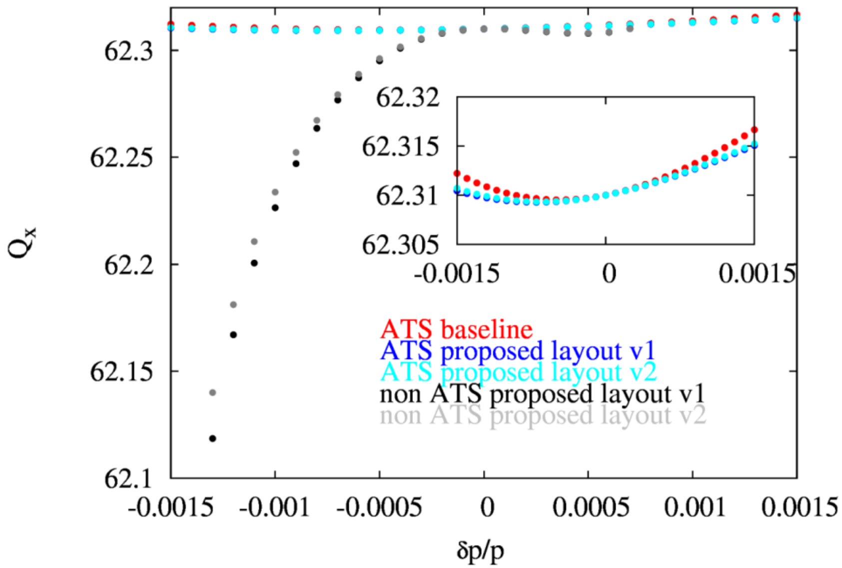
-nominal normalized emittance: $\gamma\varepsilon$=3.75 μm rad
total crossing angle: 590 μrad

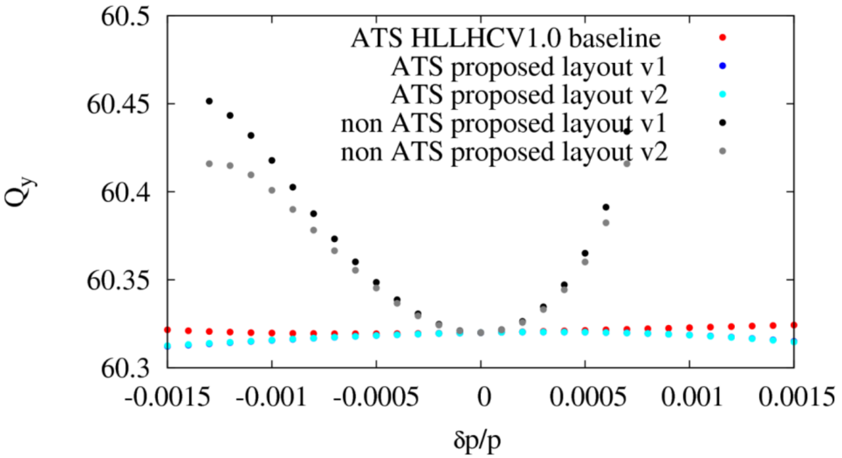
Chromaticity correction

- both proposed versions give about same quality of chromaticity correction with respect to the baseline (in both x,y planes)

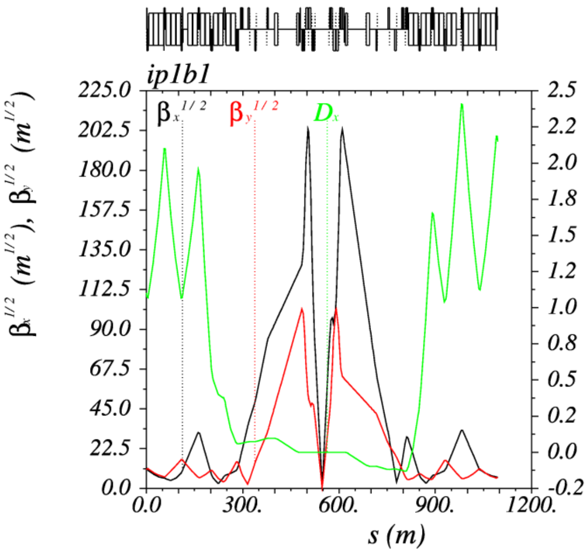
- in non ATS optics first order chromaticity corrected using all the sextupoles of the LHC arcs

- no correction of second and third order chromaticity in non ATS optics

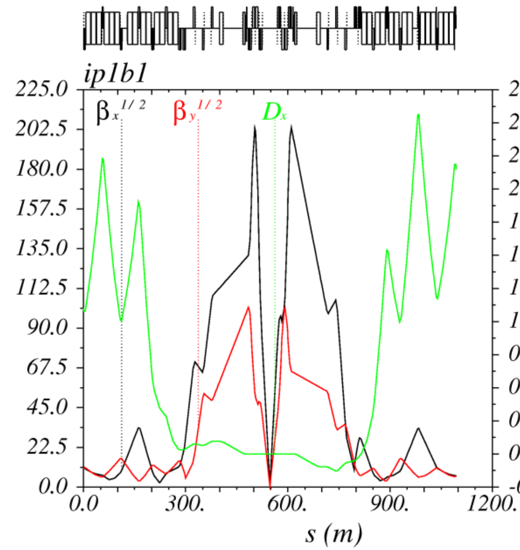




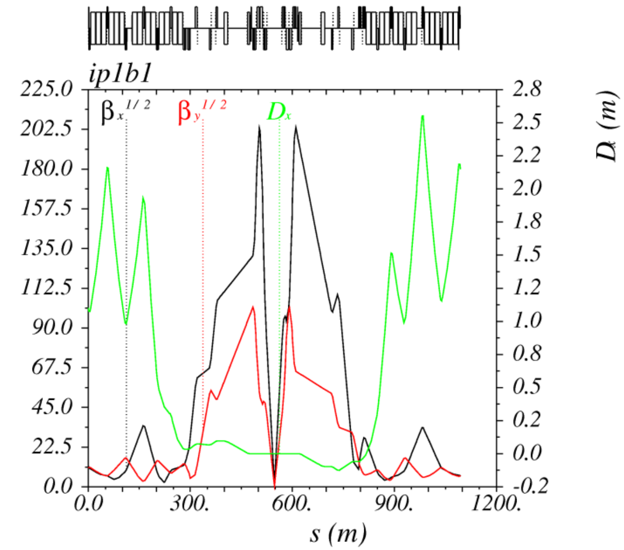
Flat beam optics



baseline



proposed v1



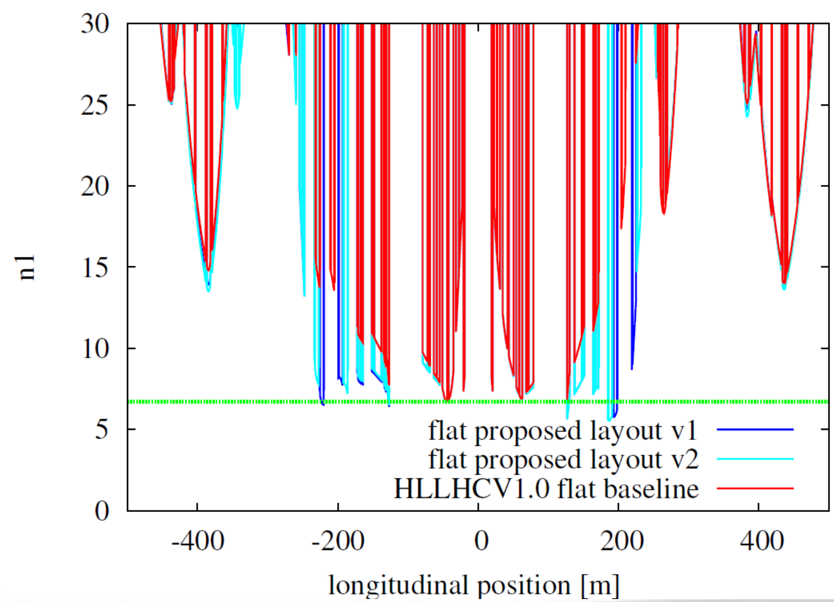
proposed v2

β_x = 0.075 m
β_y = 0.300 m

- Q5 beam screen re-oriented in the proposed layout

- total crossing angle 550 µrad

Q5 apertures below the n1 value



Crab-cavity voltage gain

Round beams

Side, IR and beam	Baseline [MV]	Proposed [MV] v1	Proposed [MV] v2	Proposed non ATS [MV] v1	Proposed non ATS [MV] v2
H L/R 5 b 1	**10.8/12.0**	**8.7/8.8**	**8.9/8.8**	**9.2/9.4**	**8.8/9.4**
H L/R 5 b 2	**12.0/10.8**	**8.8/8.7**	**8.8/8.9**	**9.4/9.2**	**9.4/8.8**
V L/R 1 b 1	**11.8/10.8**	**8.7/8.7**	**8.7/8.9**	**9.3/9.3**	**9.3/8.6**
V L/R 1 b 2	**10.8/11.8**	**8.7/8.7**	**8.9/8.7**	**9.3/9.3**	**8.6/9.3**

Flat beams

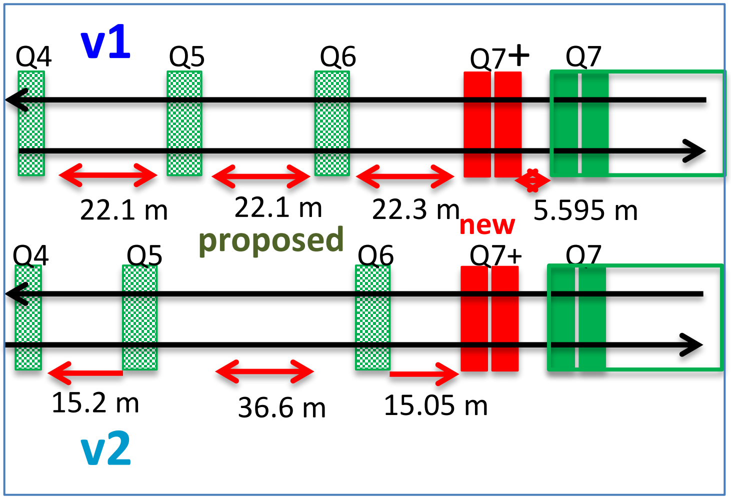
Side, IR and beam	Baseline [MV]	Proposed [MV] V1	Proposed [MV] v2
H L/R 5 b 1	**10.1/11.4**	**8.1/8.3**	**8.3/8.3**
H L/R 5 b 2	**11.4/10.1**	**8.3/8.1**	**8.3/8.3**
V L/R 1 b 1	**11.2/10.1**	**8.2/8.1**	**8.2/8.3**
V L/R 1 b 2	**10.1/11.2**	**8.1/8.2**	**8.3/8.2**

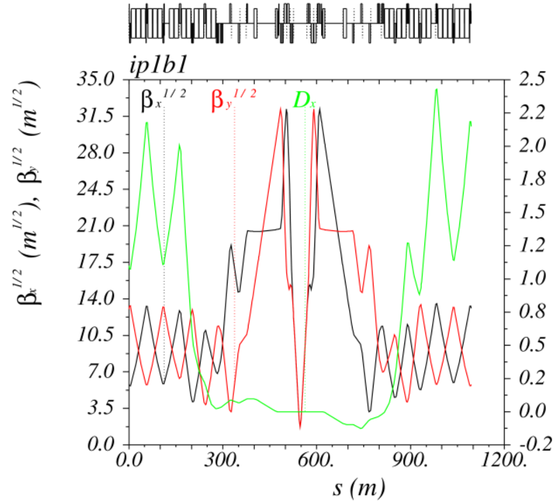
possibility to reduce the crab voltage of about 20%

INJECTION

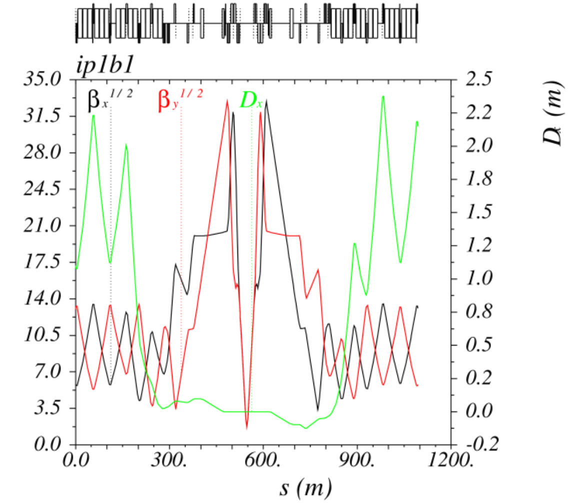
Optics injection

Injection β^* = 3 m



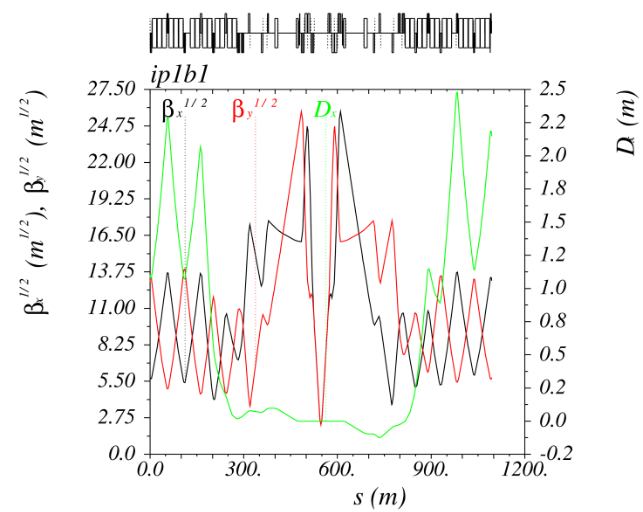


proposed **v1**



proposed **v2**

- Total phase advance IR5/1 fixed to ATS one
- L/R phases of ATS at β^* = 3 m
- No symmetry condition for Q4 and Q5 in **v2** for both β^* = 3 and 5 m



Injection β^* = 5 m

High Luminosity LHC

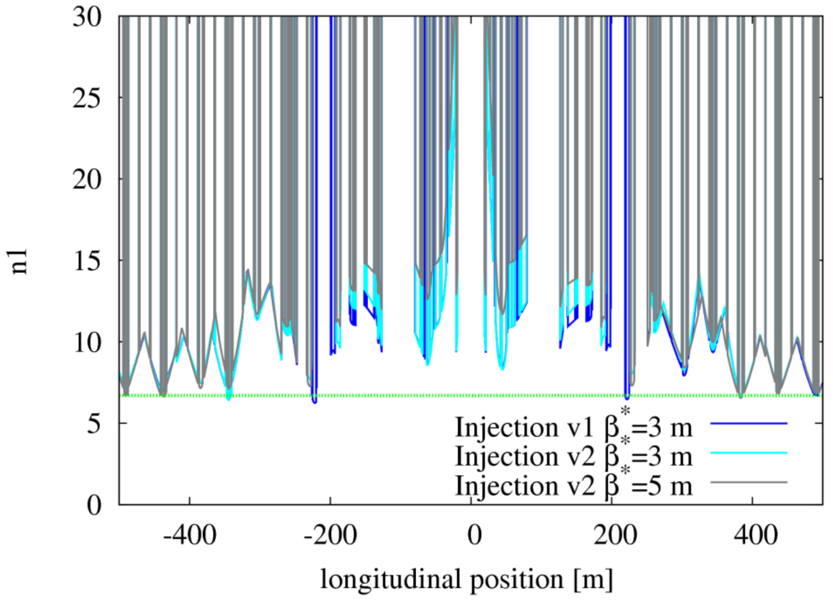
Injection apertures

• in v2 no aperture problem in Q6
⇒ in v1 it is cured by changing the MQML in MQYL type

• Q5 beam screen re-oriented in the plane with higher β

• apertures of Q7+ magnet modeled as Q7

• apertures in the triplet use an octagon model with ISO tolerances (bs_type = 5)



-nominal normalized emittance: $\gamma\varepsilon$=3.75 μm rad
total crossing angle: 590 μrad @ 3 m, 490 μrad @ 5 m

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

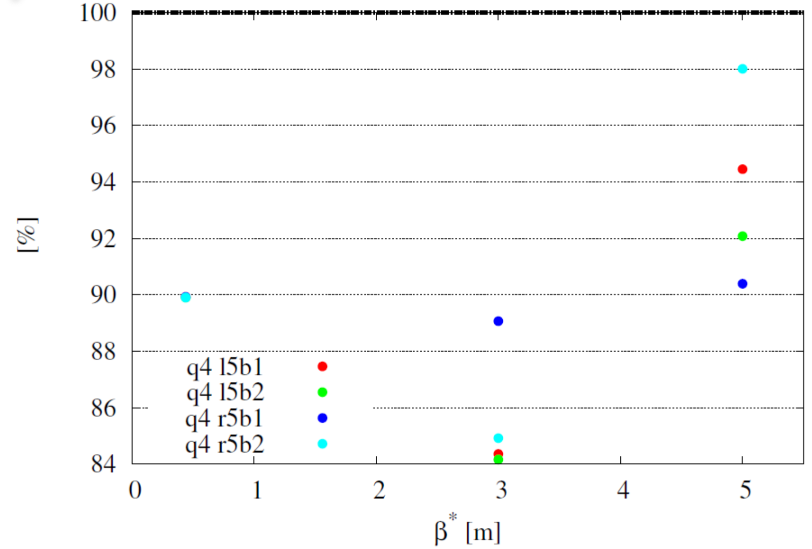
-beam tolerance budget (closed orbit, beta-beating, spurious dispersion) and beam halo geometry as the one described in J.B. Jeanneret, R. Ostojic, CERN-LHC-Project-Note 111 (1997)

CONSIDERATIONS ON OPTICS TRANSITIONS

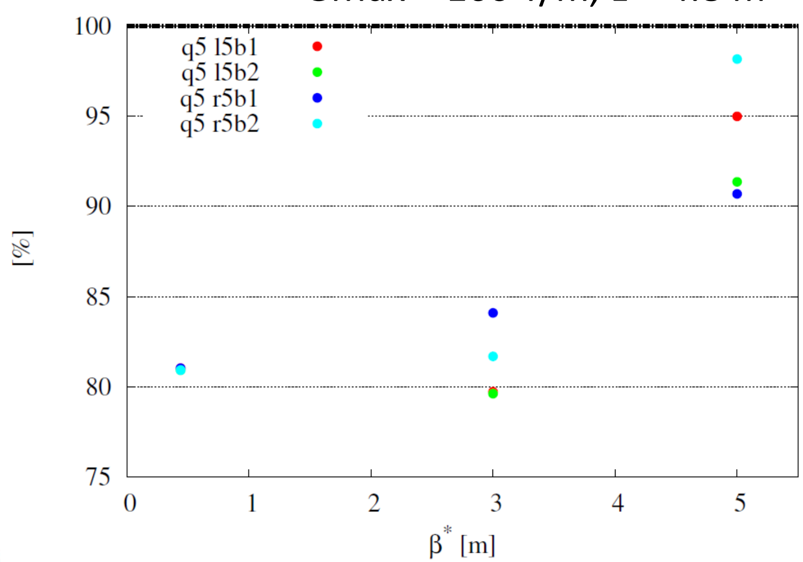
Q4/Q5/Q6 strengths vs β*

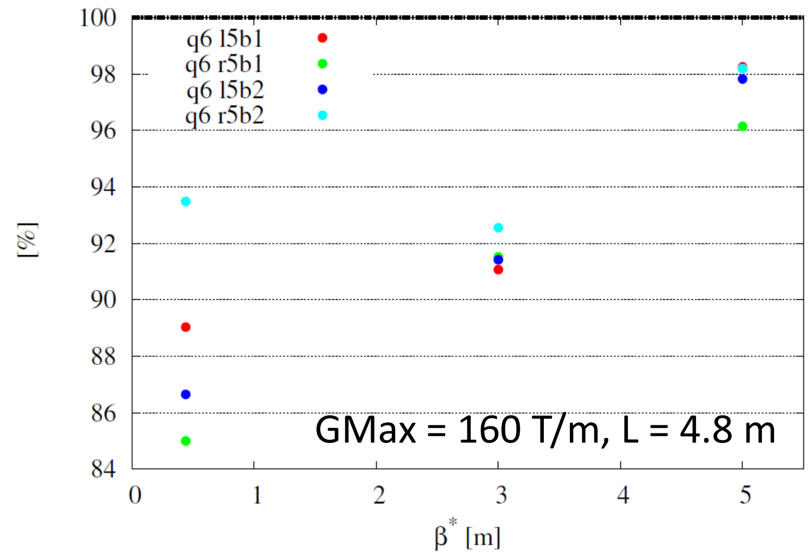
- Max strengths variation between collision and injection ~ 20%
- In transition optics they tend to exceed the maximum gradient
- Difficult to keep low beta in Q6 and catch the correct ATS R/L phase at β* = 3 m

GMax = 125 T/m, L = 3.5 m



GMax = 160 T/m, L = 4.8 m



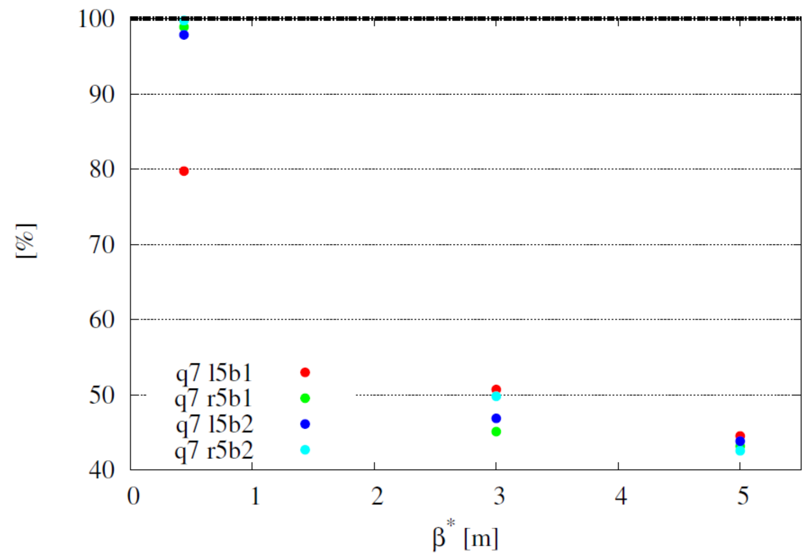


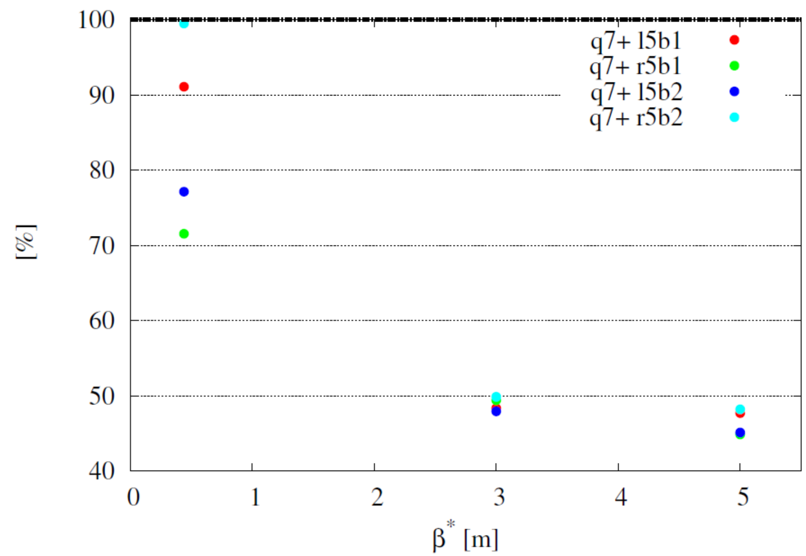
Q7/Q7+ strengths vs β^*

- Both Q7 strengths are at lower limit for injection (they limit the high β^* reach at injection)
- Monotone functions of strength as function of β^* in transitions optics can be find easly for these quadrupoles
- In order to overcome this lower limit at injection (and be able to rise the β^*), can we use:
  - Q7+ $\Rightarrow$ 1 MQ M + 2 MQTL
  - Q7+ $\Rightarrow$ 1 MQ + 2 MQTL

?

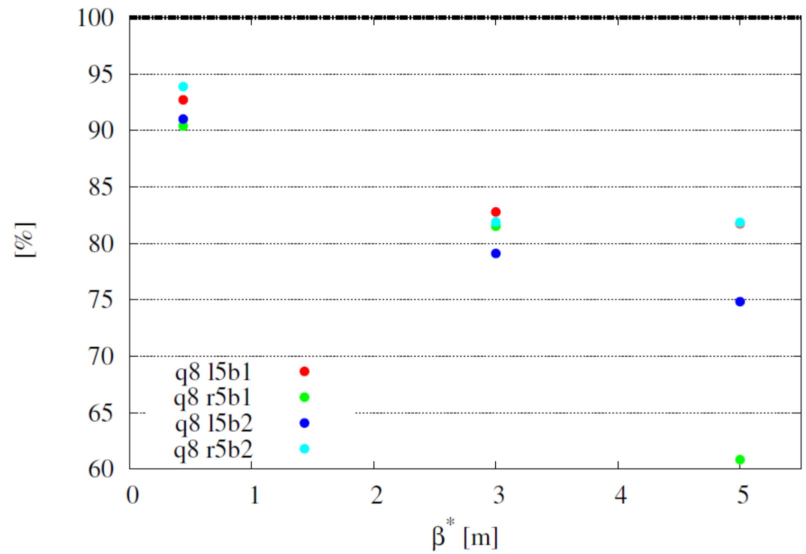
2×MQM, G=200 T/m, L = 3.4 m

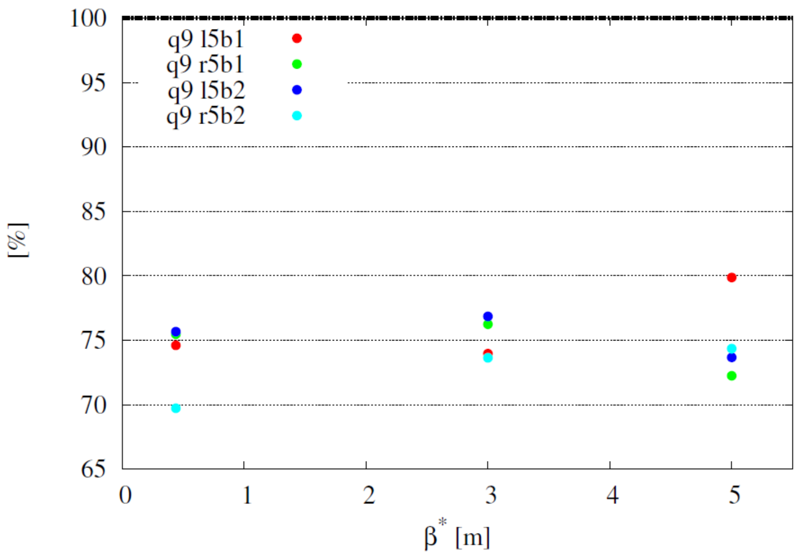


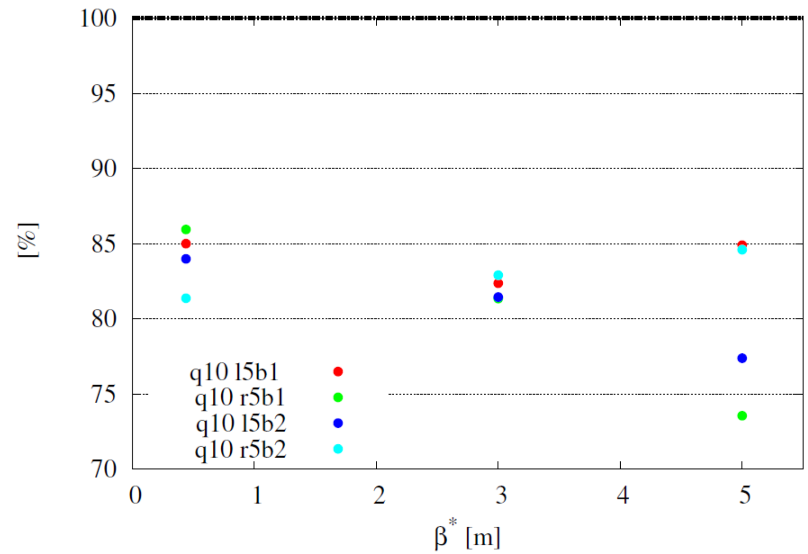


Q8/Q9/Q10 strengths vs β^*

- Almost constants (10% variation): except for Q8 beam 2, R side
- Relatively easy to get a monotonic behavior in the strength of most of these quadrupoles

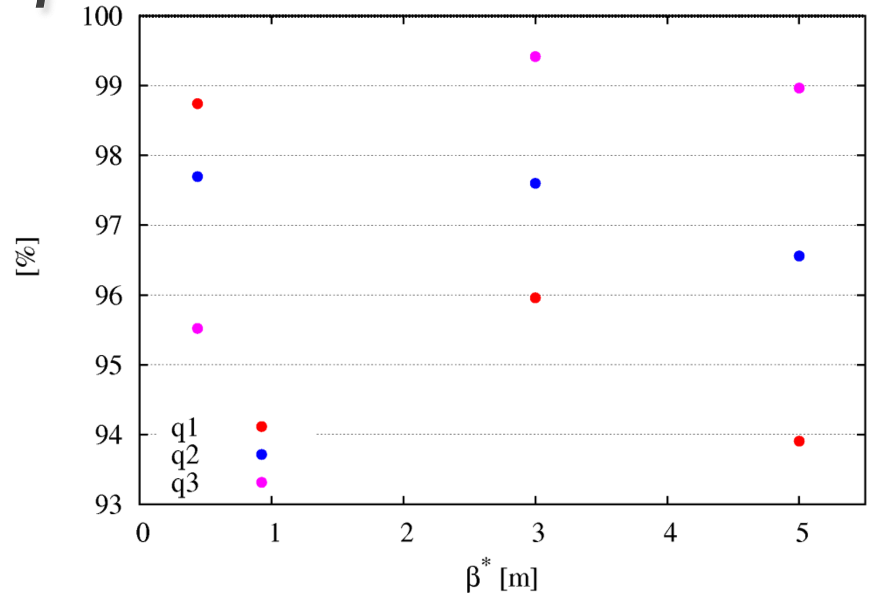


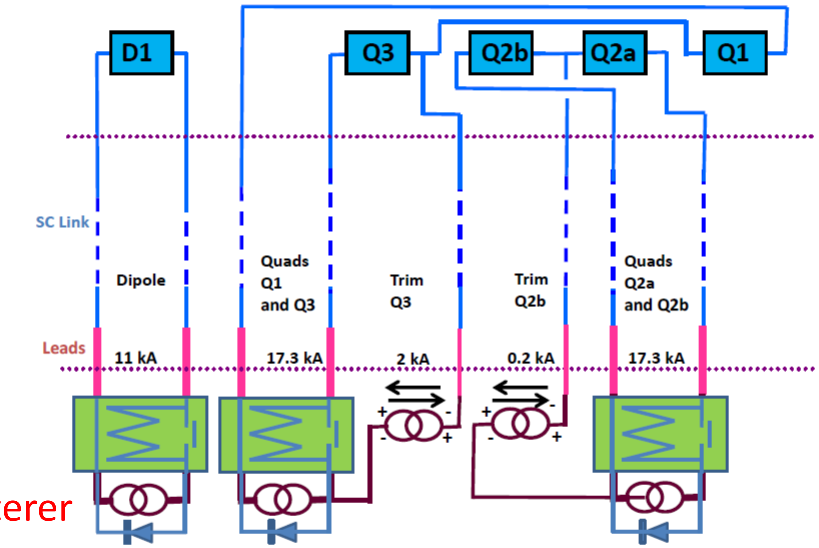




Q1/Q2/Q3 strengths vs β*

- Same geometry and maximum gradient of the baseline (140 T/m)
- Q1, Q2 decreasing ↓
- Q3 increasing ↑
- Max strengths variation between collision and injection ~ 5%
- Max strength variation between Q1, Q2 and Q3 ~ 5% (< 11% given by the Trim)





Courtesy of M. Fitterer

Conclusion & Outlook

	HiLumi baseline	Proposed layouts v1	Proposed layouts v2
Q4	MQYY, G=125 T/m @1.9K ∅ = 90 mm, L = 4.5 m	MQYY, G=125 T/m @1.9K ∅ = 90 mm, L = 3.5 m	MQYY, G=125 T/m @1.9K ∅ = 90 mm, L = 3.5 m
Q5	MQYL, G=160 T/m @4.5K ∅ = 70 mm, L = 4.8 m	MQYL, G=160 T/m @4.5K ∅ = 70 mm, L = 4.8 m	MQYL, G=160 T/m @4.5K ∅ = 70 mm, L = 4.8 m
Q6	MQML, G=160 T/m @4.5K ∅ = 56 mm, L = 4.8 m	MQYL, G=160 T/m @4.5K ∅ = 70 mm, L = 4.8 m	MQML, G=160 T/m @4.5K ∅ = 70 mm, L = 4.8 m
Q7	2×MQM, G=200 T/m @1.9K ∅= 56 mm, L = 3.4 m	2×MQM, G=200 T/m @1.9K ∅= 56 mm, L = 3.4 m	2×MQM, G=200 T/m @1.9K ∅= 56 mm, L = 3.4 m
Q7+		2×MQM, G=200 T/m @1.9K ∅= 56 mm, L = 3.4 m	2×MQM, G=200 T/m @1.9K ∅= 56 mm, L = 3.4 m

- possibility to reduce crab cavity voltage by 20% (rounds optics)
- possibility to gain lattice flexibility in collision
- Q5 apertures below the n1 limit for flat beams

Look more at:

⇒ Transition optics

⇒ High β^* > 5 m optics (**inj, vdm**)
with 1×MQ(M) + 2×MQTL instead of 2×MQM for Q7+

High Luminosity LHC

CERN

cern.ch

Chromaticity correction

- both proposed versions give about same quality of chromaticity correction with respect to the baseline (in both x,y planes)

- in non ATS optics first order chromaticity corrected using all the sextupoles of the LHC arcs

- no correction of second and third order chromaticity in non ATS optics