HL-LHC layout and optics with implication for forward physics

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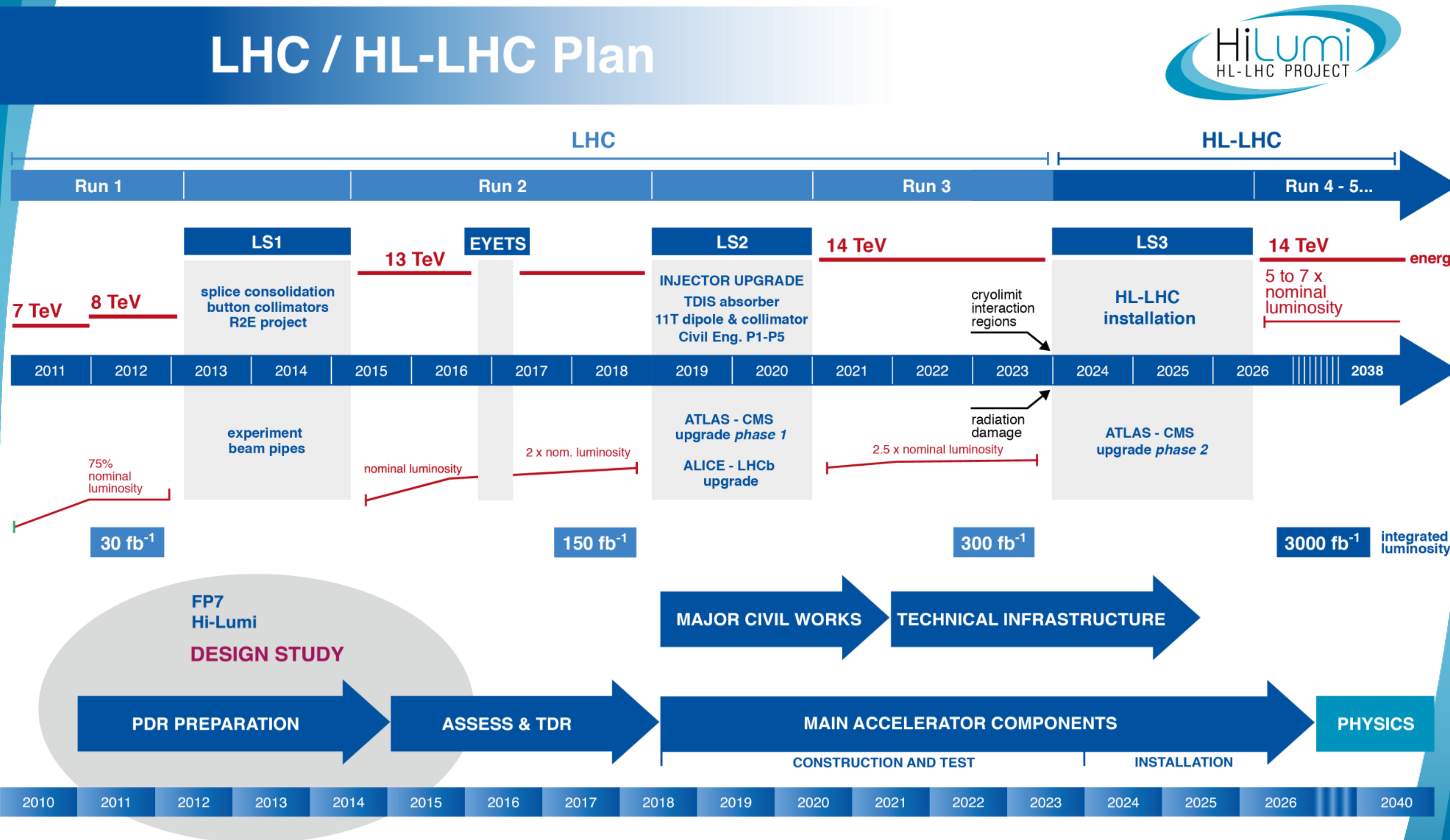
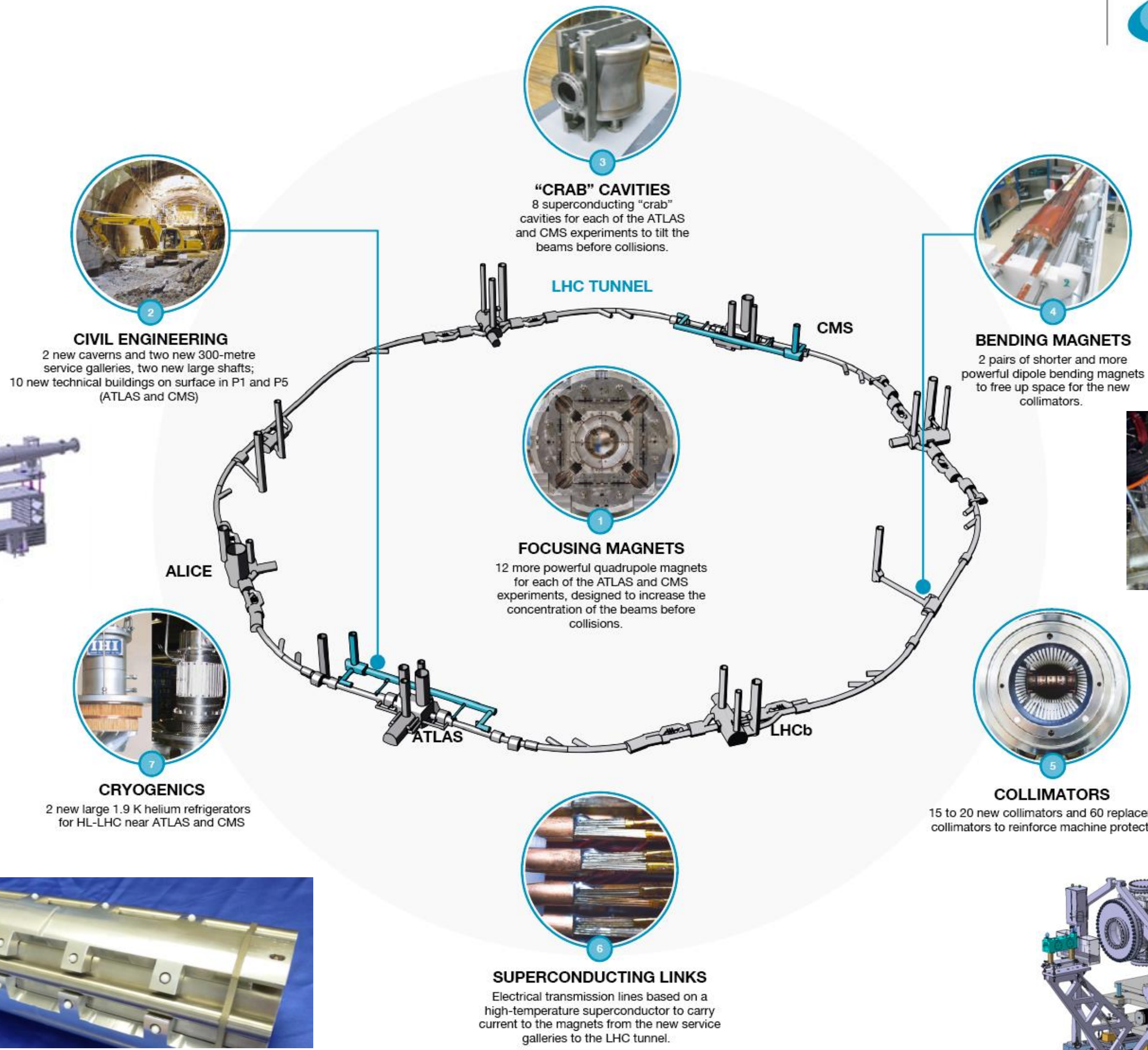
Thanks to M. Deile, P. Fessia

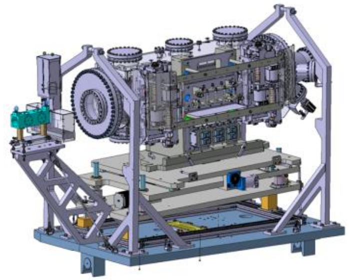
Forward physics 11/6/2019

High Luminosity LHC Project



HL-LHC: Hardware Highlights

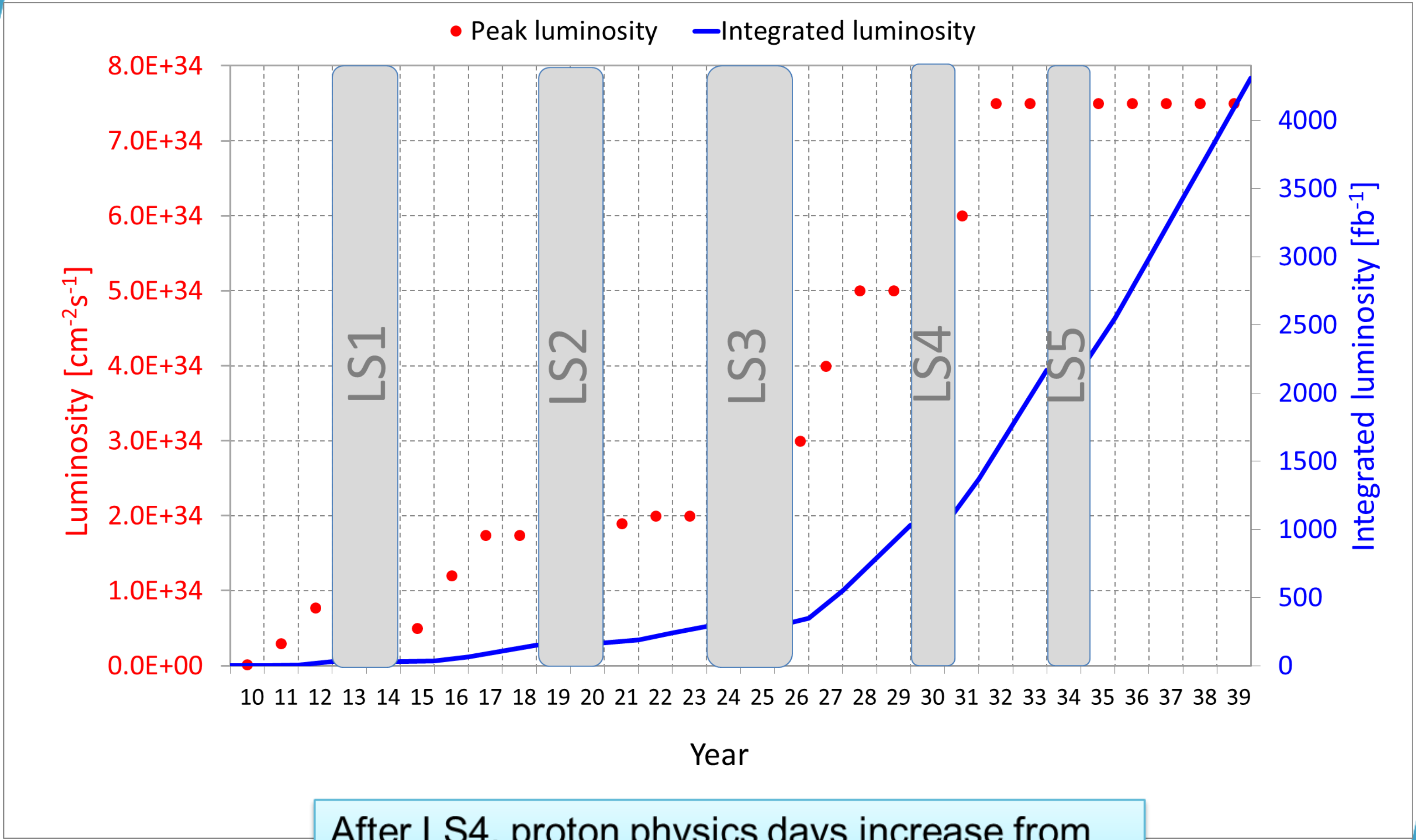




Updated table of parameters

Parameters	Nominal LHC (Design report)	LHC 2018 max values	HL-LHC (standard)	HL-LHC 8b+4e[12]	HL-LHC (Ultimate)
Beam energy in collision [TeV]	7	6.5	7	7	7
N_b	1.15E+11	1.15E+11	2.2E+11	2.2E+11	2.2E+11
n_b	2808	2556	2760	1972	2760
Number of collisions in IP1 and IP5 [1]	2808	2544	2748	1967	2748
N_{tot}	3.2E+14	2.9E+14	6.1E+14	4.3E+14	6.1E+14
beam current [A]	0.58	0.52	1.1	0.79	1.1
x-ing angle [μrad]	285	320 ==> 260	500	470[10]	500
beam separation [σ] [11]	9.4	10.3 ==> 6.8	10.5	10.5[10]	10.5
β^* [m]	0.55	0.30 ==> 0.25	0.15	0.15	0.15
ε_n [μm]	3.75	2 ==> 2.5	2.50	2.20	2.50
r.m.s. bunch length [m]	7.55E-02	8.25E-02	7.61E-02	7.61E-02	7.61E-02
Total loss factor R0 without crab-cavity			0.342	0.342	0.342
Total loss factor R1 with crab-cavity [13]			0.716	0.749	0.716
Virtual Luminosity with crab-cavity: Lpeak*R1/R0 [cm^{-2} s^{-1}] [13]			1.70E+35	1.44E+35	1.70E+35
Luminosity [cm^{-2} s^{-1}] or Leveling luminosity for HL-LHC	1.00E+34	2.00E+34	5.0E+34[5]	3.82E+34	7.5E+34[5]
Events / crossing (with leveling and crab-cavities for HL-LHC) [8]	27	55	131	140	197
Peak line density of events [event/mm] (max over stable beams)	0.21	0.38	1.3	1.3	1.9
Leveling time [h] (assuming no emittance growth) [8, 13]	-		7.2	7.2	3.5

Luminosity profile: ULTIMATE



After LS4, proton physics days increase from standard 160 days to 200 and after LS5 to 220

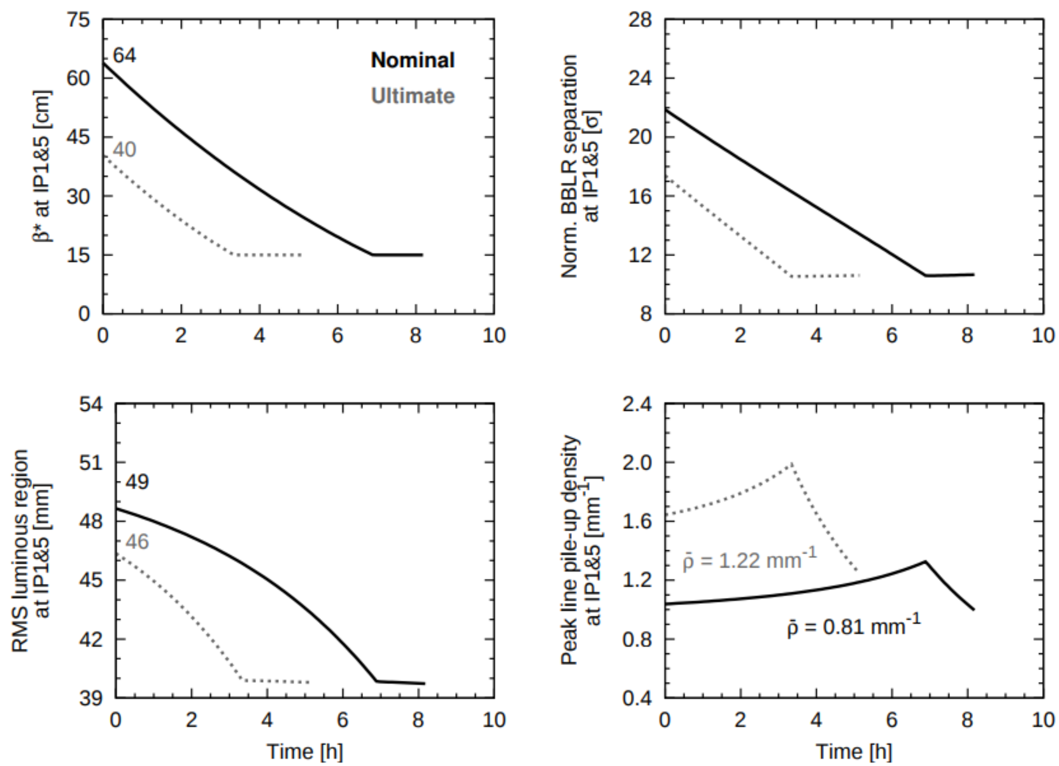
Operational scenario

Baseline levelling	Begin	End
Bunch population	$2.2\ 10^{11}$	$1.1\ 10^{11}$
β*	64 cm	15 cm
Crossing angle	500 µrad (21.8 σ)	500 µrad (10.5 σ)

Main scenario: β* levelling, 250 fb^{-1}/year, 7h levelling time, round β*.

Scenarios Option:

- Ultimate luminosity -> shorter levelling time
- Flat optics -> smaller crossing angle

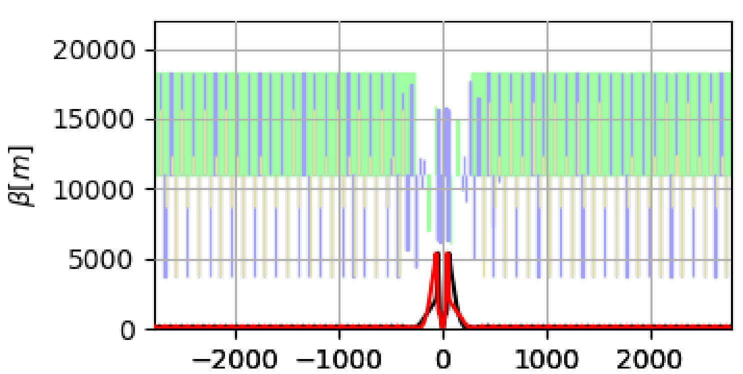


[Update of the HL-LHC operational scenarios for proton operation](), CERN-ACC-NOTE-2018-0002

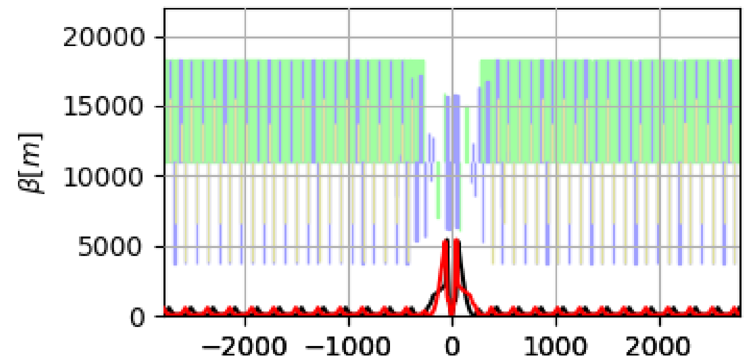
High Luminosity optics scenario

Two possible scenarios for β* levelling

IR1/IR5 squeeze during ramp

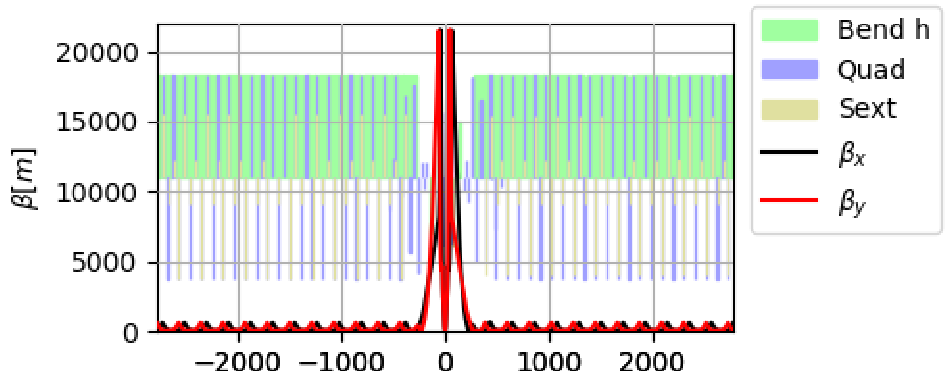


IR1/IR5 partially squeezed and ATS fully deployed during the ramp.



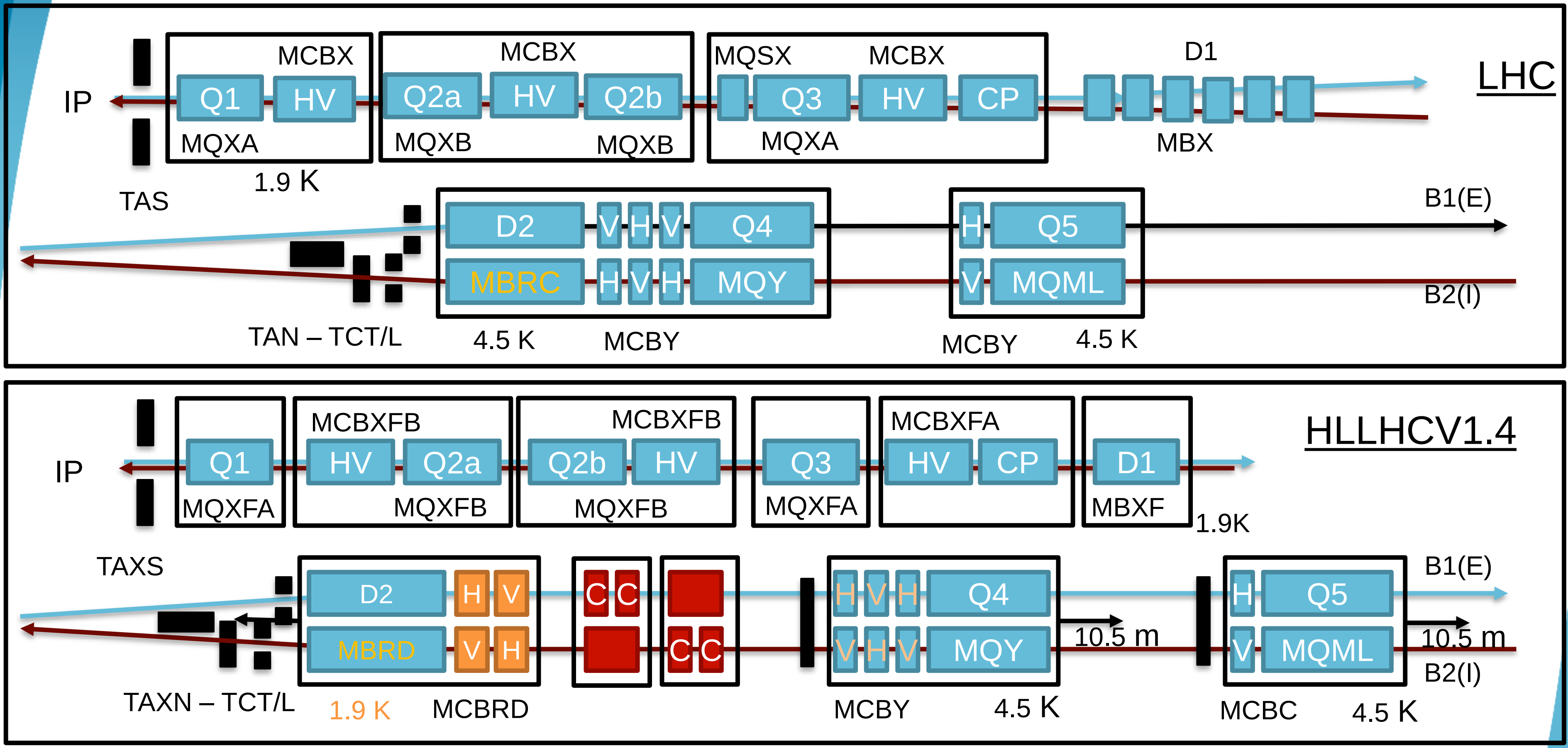
Final squeeze with ATS

Final squeeze with IR1/IR5



Choice has an impact on normalized dispersion (e.g. at 233 m)

Main changes in Point 1 and 5



Main changes:
New triplets, cold D1, D2-Q4 separated, orbit correctors and crab cavities inserted, Q4-Q5 displaced, mask inserted.

Beam stay clear

Effective model of the beam stay clear region.

Beam stay clear =

$1.1\, n_\sigma\, \sigma_{nominal} + 2$ mm

where:

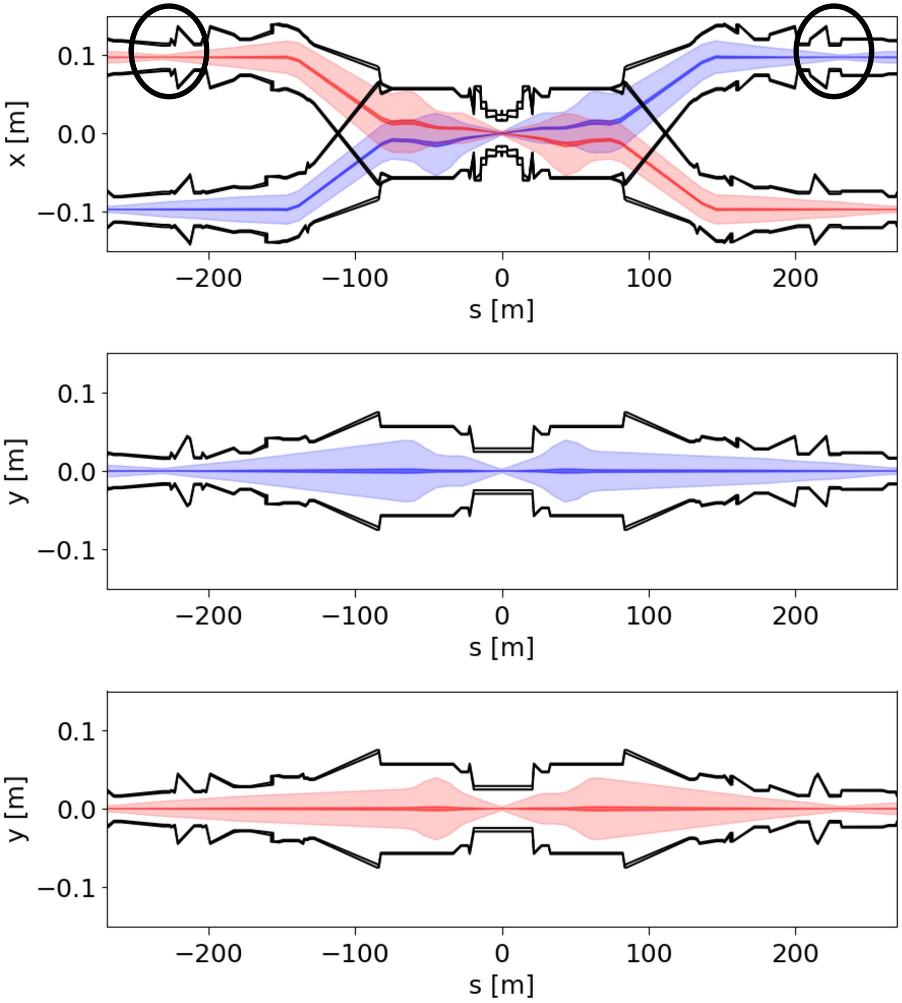
n_σ = 13.25 up to D1

n_σ = 15 TAXN-Q5

n_σ = 20 sigma Q6 to Q7.

Table available here.

Horizontal crossing

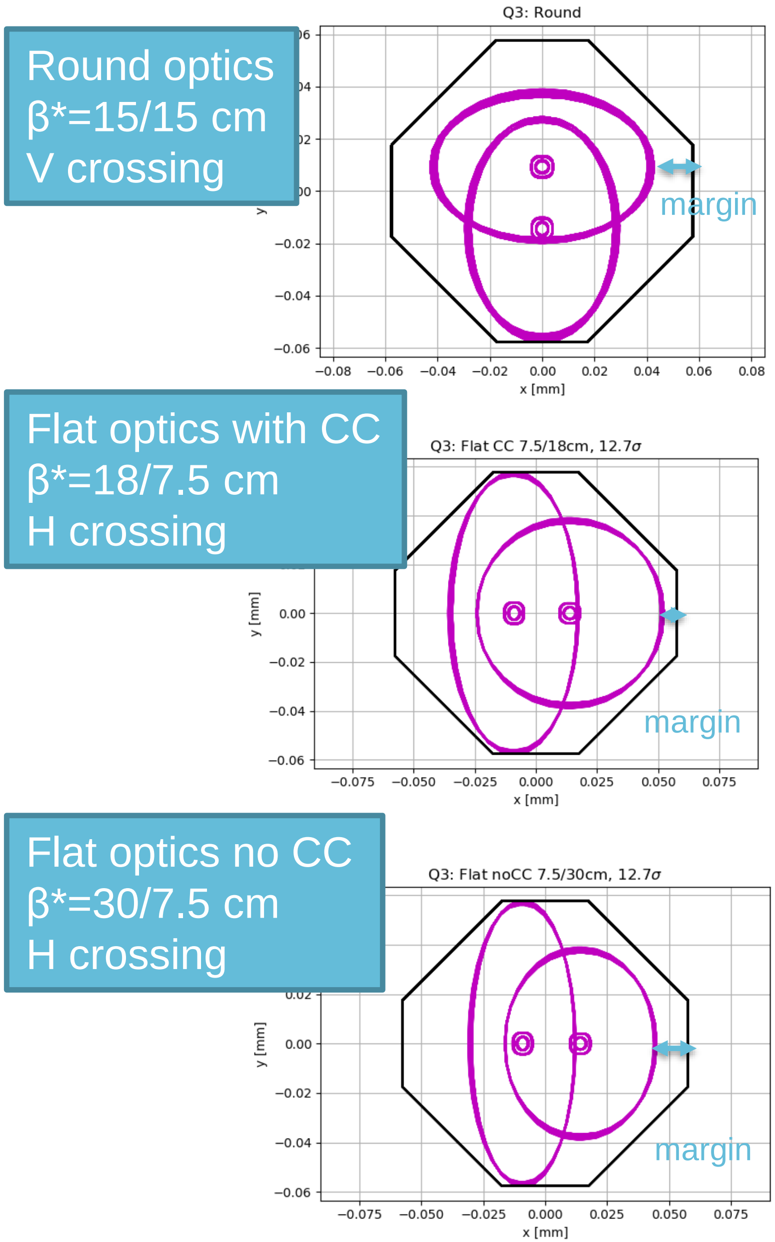


Crossing plane choices

- Crab cavities act on either H or V plane and cannot easily exchanged. Decision 2019.
- MKD failure scenario and TCT damage threshold reduce the horizontal aperture margins in Point 5.

- Round optics have larger aperture margins in the parallel separation plane. Vertical crossing is best in Point 5.
- Flat optics have larger aperture margins in the crossing angle plane. Horizontal crossing is best in Point 5 (also because this improves TCDQ gaps).
- Wire compensator (not baseline) needs to be close to beam in the crossing plane. Vertical crossing is overall best in Point 5 [S. Fartoukh].

Baseline assumes vertical crossing in Point 5 based on the round optics scenario.



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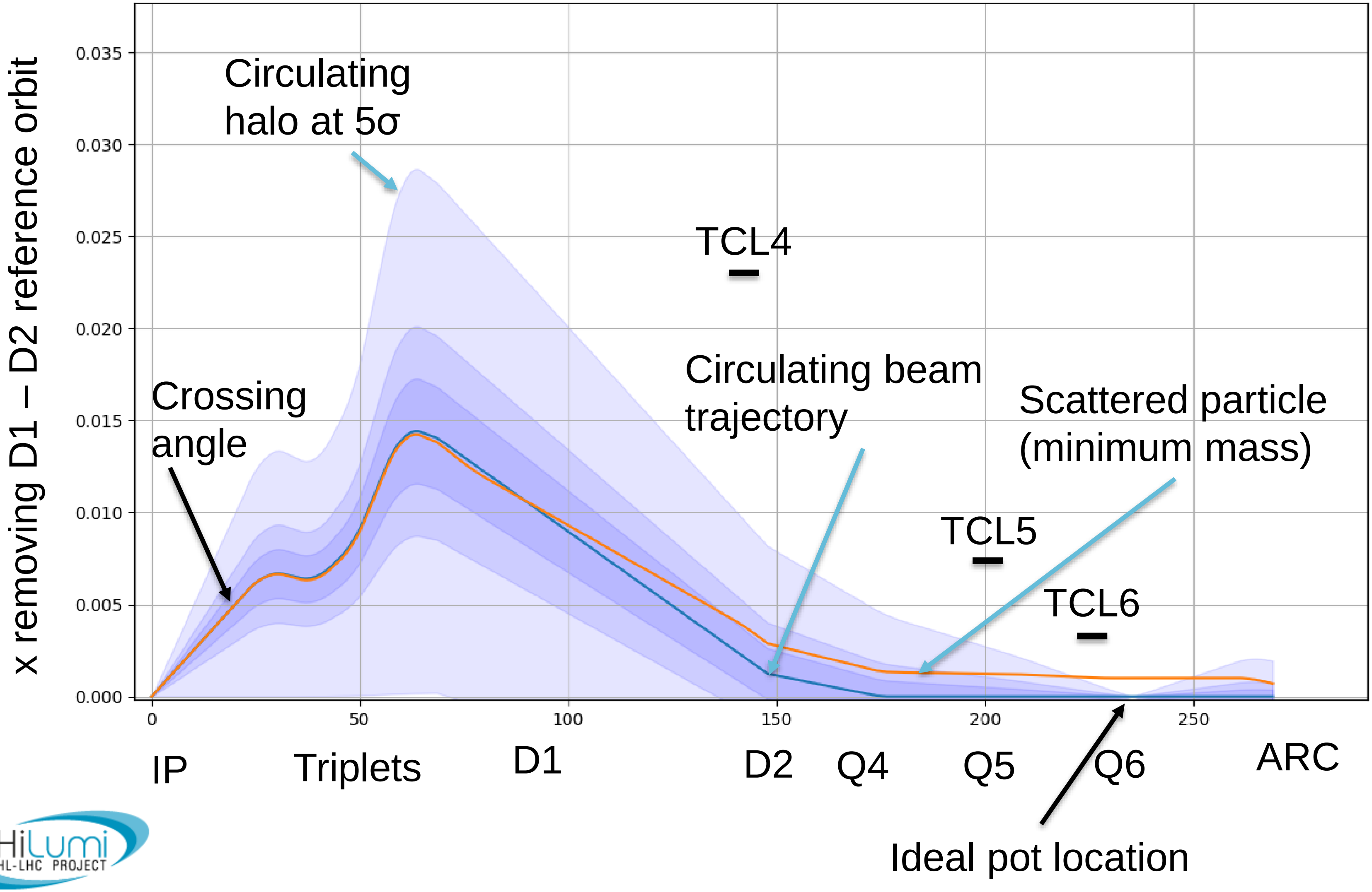
Off-momentum orbits



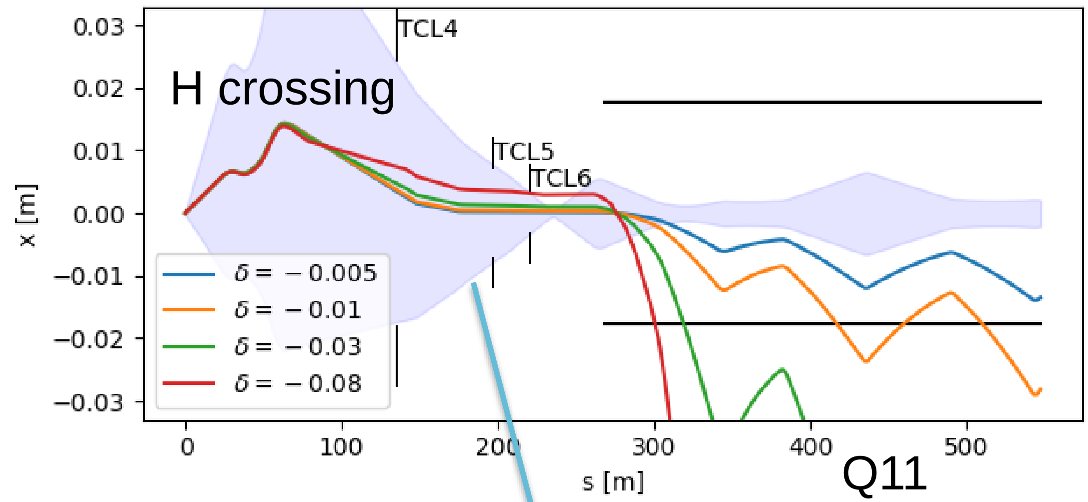
Crossing plane off momentum trajectories

Crossing plane change off momentum trajectories.

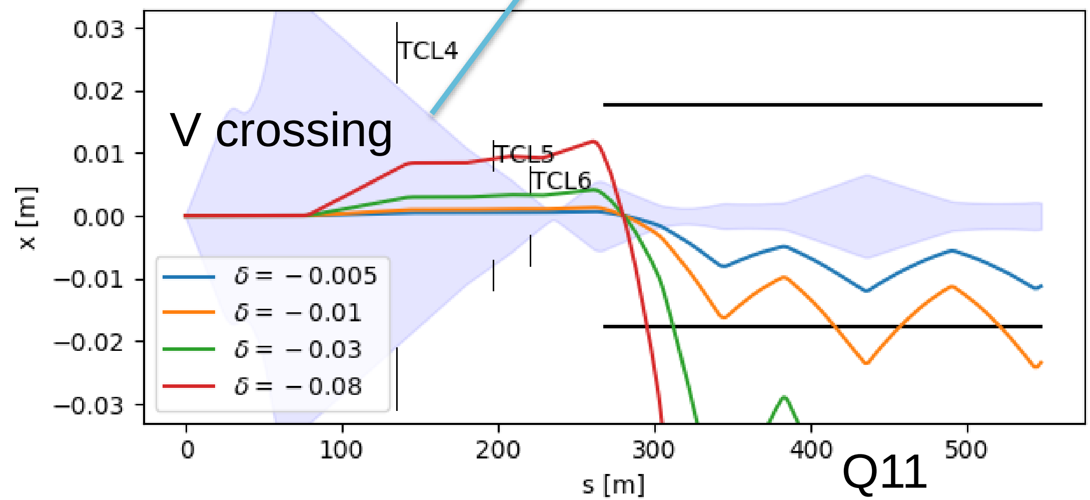
Crossing plane choice is under study:

- Baseline: H (Point 1) and V (Point 5) better for round optics.
- Option: V (Point 1) and H (Point 5) better for flat optics.

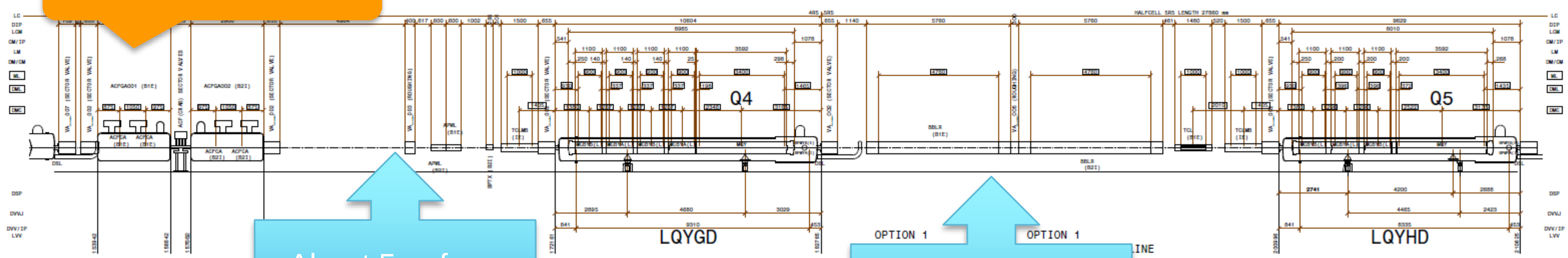
Choice cannot be (easily) changed after crab cavities installation.

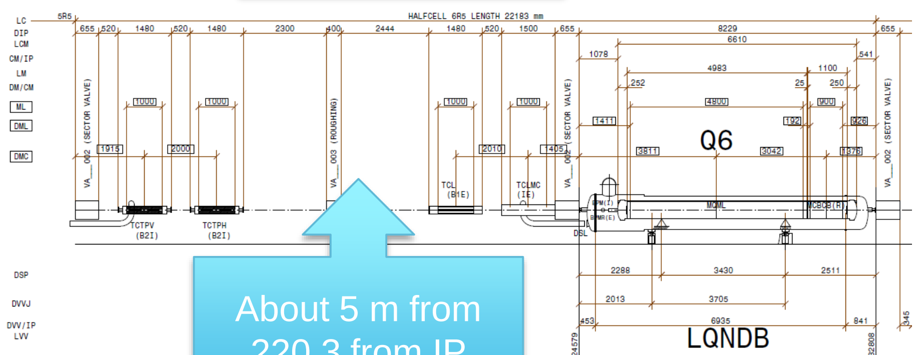


Halo: (nTCT+3) σ + 0.3 mm



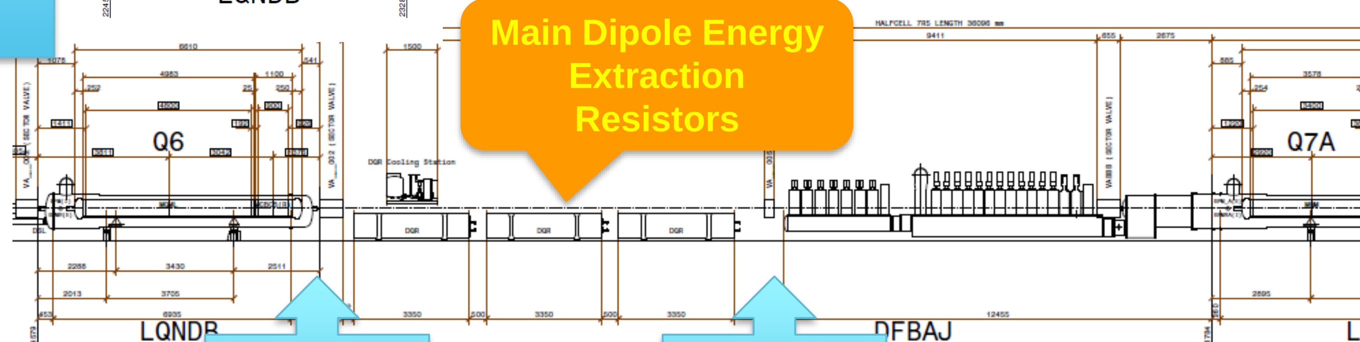
Possible layout location





Layout being reviewed:

- Possible displacement of the CC
- Q4 – Q5 slightly displaced

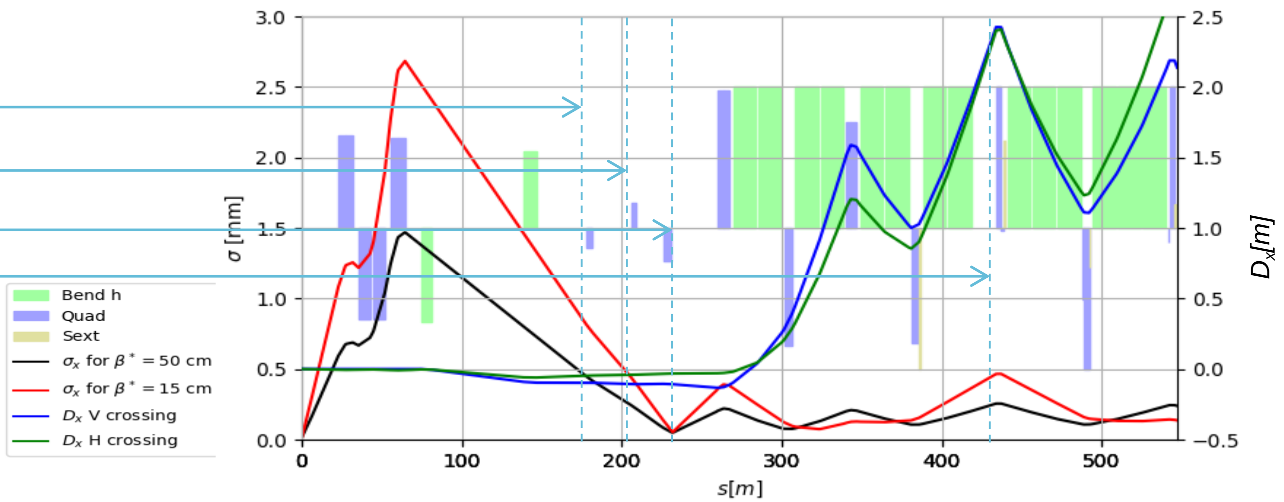


Forward Physics in HL-LHC

Proposed pot location:

- in between Crab-Q4,
- in between Q4-Q5,
- in between Q6-Q7,
- Q11 empty-cryostat.

P. Fessia, coordination meeting, 5/6/2018



Comments:

- Matching section optics and layout under review.
- Beam size and dispersion in Q6 are subject to changes and cannot be easily optimized.
- TCL settings: can reduce acceptance, TCL4 (TCLX) critical for D2 protection (assumed 13.5 σ F. Cerutti annual meeting 14/7/2017, 14.2 σ for collimation studies (D. Mirarchi, colUSM, 24/2/2017)
- No request of high-beta optics (VDM optics β*=30 m).

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Conclusion

Parasitic forward physics will be more difficult in the HL-LHC due to many constraints:

- Layout is has less available space.
- Optics is more constrained.
- Crossing plane constrained by crab cavities.
- TCL settings (in particular TCLX) cannot be easily relaxed.

Location around Q6 seems the most promising.

Specific optics optimization can be further attempted but probably at the expenses of crab cavity efficiency.

New effort to reduce radiation in Cell 9 to protect MCBC may lead result in layout changes around Q6.

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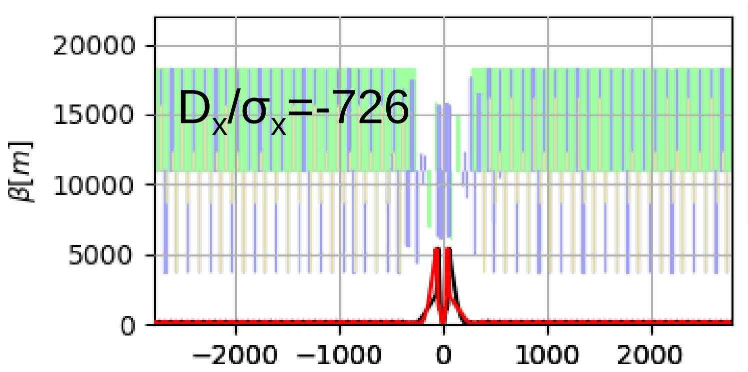
Optics scenario

Two possible scenarios for β* levelling

IR1/IR5 squeeze during ramp



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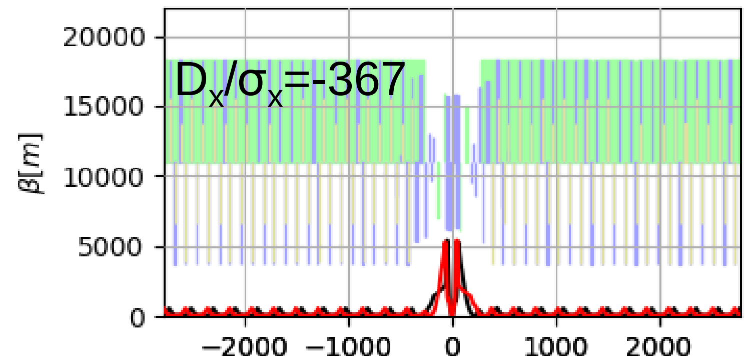
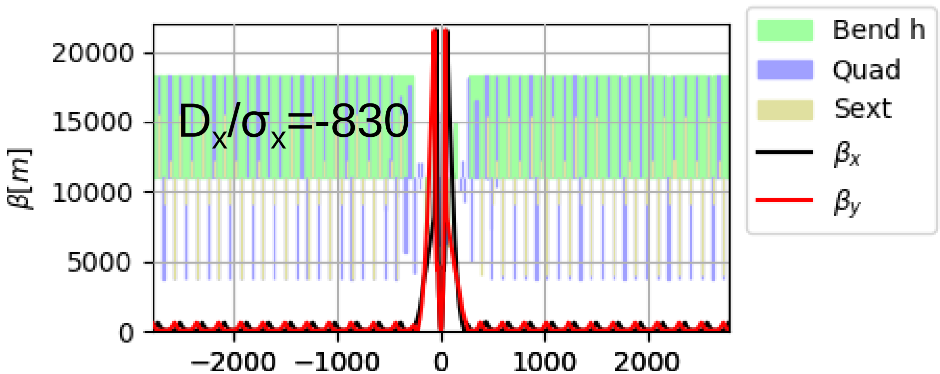


Final squeeze with ATS

Final squeeze with IR1/IR5



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