High Luminosity LHC

Progress on HL-LHC Optics and Layout Validation

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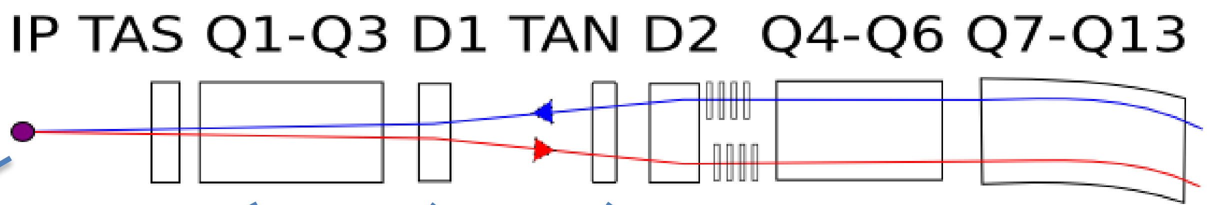
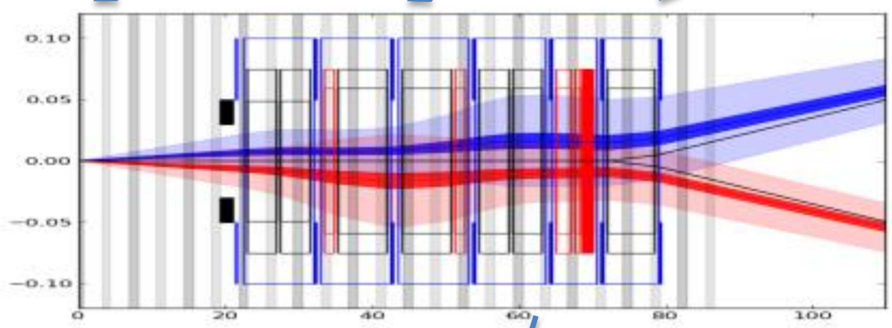
Status

- HLLHCV1.0 is the present baseline model for layout and optics: files available in/afs/cern.ch/eng/lhc/optics/HLLHCV1.0.
- Layout and optics frozen and under validation for:
  - energy deposition;
  - magnetic elements specifications;
  - mechanical integration;
  - collimation performance;
  - powering needs;
  - heat loads

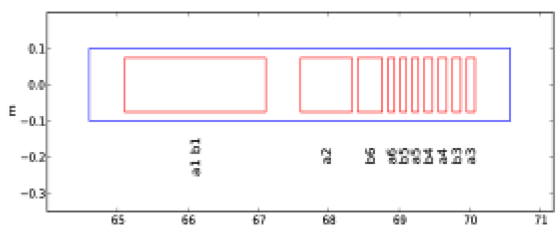
The status of the update is reported (action PLC 2/7/2013).

IR1 and IR5 HL-LHC layout

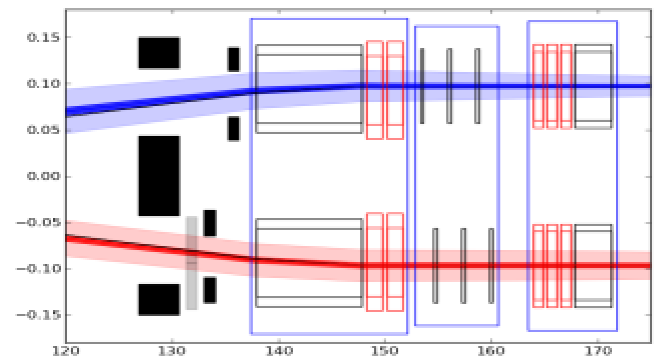




Triplet area



Corrector package



TAN, TCT, TCL, D2, Crabs, Orbit Correctors, Q4 and Q5 (not shown)

D1 in IR1 and IR5

- Shorter D1 (6.7m to 6.25 m for 35 Tm) to be compatible with test stations [1]. Implies:
  - short sample margins from 30% to 25%;
  - marginal improvement of apertures;

Approval requested by WP3 and recommended by WP2.

[1] E. Todesco, 3rd Joint HiLumi/Larp meeting.

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Triplet: heat load

Heat load for the triplet evaluated and transmitted to cryogenics

- Beam-screen impedance [1]

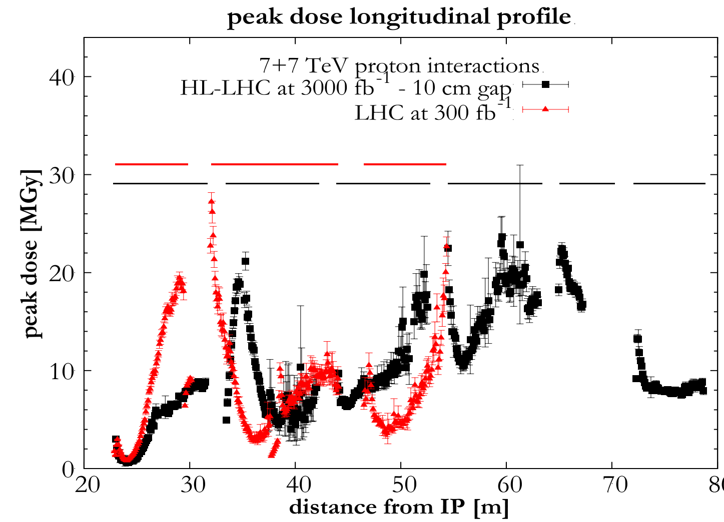
Power loss for 2 beams in mW/m Nominal bunch length	Nominal (25 ns)	ultimate (25 ns)	HL-LHC (25 ns)	HL-LHC (50 ns)
# bunches N_b [10^{11} p]	2808 1.15	2808 1.8	2808 2.2	1404 3.5
Q2/Q3 BS (HL-LHC)	189	332	693	877
Q1 BS (HL-LHC)	157	276	575	728

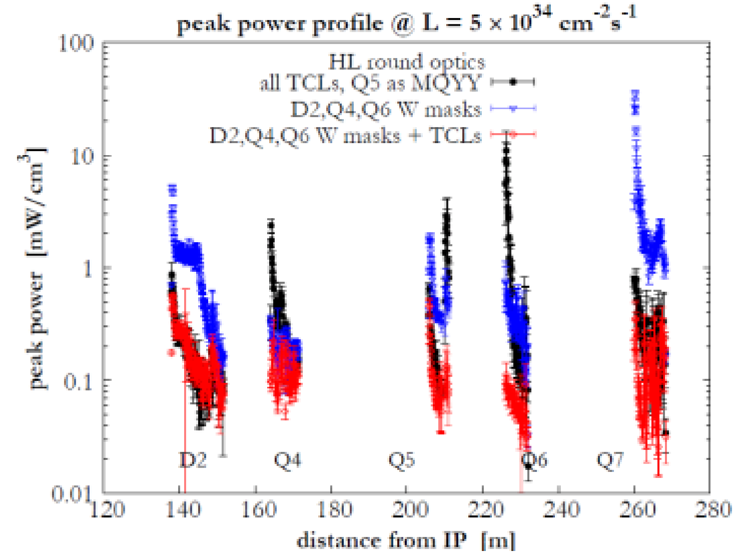
- E-cloud estimate from simulation [2]:
  - 200W assuming SEY 1.1 (but expect even lower SEY with nanographite – to be tested)
- Energy deposition [3]: 600W from colliding debris .

[1] B. Salvant [2] G. Iadarola [3] F. Cerutti

Debris protection in IR1 and IR5

- Below 2 mW/cm3 at 5 x10^{34} $cm^{-2}s^{-1}$.
- Below 25 MGy after 3000 fb^{-1}.
- Assuming shielded BPM in the triplet.
- Additional masks (on both beams) and TCLs on (outgoing beam) in front of D2, Q4, Q5, Q6 [2].
- TAN apertures to be redesigned and optimized (non parallel axis, circular apertures considered [2]) Movable TAN to be considered ➔ WP8
- Integration and validation on going
- Removal TCT in between TAN and D2 by relying on TCTs (for the incoming beam) in front of Q4 and Q5 will be studied.





[2] L. Esposito et a., 3rd Joint HiLumi/Larp meeting.

Matching section: D2

- D2:
  - Significant improvement in expected field quality (thanks to WP3!) but improvement is still necessary in particular for b2 and b3 → WP3.
  - Need to agree on another version of the table. Interest to shorten D2 (higher field) compatibly with field quality (SLAC contribution [1]).

normal	mean	uncertainty	random
b2	**±65→±25**	**3.0→2.5**	**3.0→2.5**
b3	**-30→3.0→1.5**	**5.0→1.5**	**5.0→1.5**
b4	**±25→±2.0**	**1.0→0.2**	**1.0→0.2**
b5	**-4.0→-1.0**	**1.0→0.5**	**1.0→0.5**

  - Length – field optimization ongoing.

[1] Y. Nosochcov 3rd HiLumi Joint Meeting

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Matching section: Q5

- Q5 (alternatives to MQYL):
  - Two alternative options being considered for IR1 and IR5:
    - MQY at 200 T/m if operated at 1.9K (but this might be at the limit),
    - 2 or longer MQYY (90mm 2-in-1 foreseen for Q4).
  - Energy deposition with MQY with 70 mm aperture and masks to be done.
  - Optics constraints to be fully evaluated.
  - For Q5 IR6 adding an MQY at 4.5K to double the strength of the present one (option studied in SLHCV3.0).

Studies on going on optimization:

- Tracking tools for HL-LHCv1.0 to be updated (split Q1/Q3, 11T dipoles) ➔ high priority
- β*>6m optics solutions (injection and VDM for Q5 limits)
- Orbit corrector strength and length to comply with hardware and functional requirements.
- Possible reduction D1-D2 distance for crab voltage optimization.
- Phase advance optimization to avoid additional MS in Q10.
- Optics transitions during leveling (interplay IR8/IR1 and IR5 optics).
- Impact of power converter ripple.
- Specification on longitudinal alignment errors.

Backup

Collision low-β optics parameters

Name	IP1-5			IP2			IP8		
	β* [cm]	Angle [murad]	sep [mm]	β* [m]	Angle [murad]	sep [mm]	β* [m]	Angle [murad]	sep [mm]
Round	**15**	**590**	**0.75**	**10**	**340**	**2**	**3**	**340**	**2**
flat	**7.5, 30**	**550**	**0.75**	**10**	**340**	**2**	**3**	**340**	**2**
flathv	**30, 7.5**	**550**	**0.75**	**10**	**340**	**2**	**3**	**340**	**2**
sround	10	720	0.75	10	340	2	3	340	2
sflat	5, 20	670	0.75	10	340	2	3	340	2
sflathv	20, 5	670	0.75	10	340	2	3	340	2
ions	**44**	**350**	**0.75**	**0.5**	**340**	**2**	**0.5**	**340**	**2**

- Optics available under /afs/cern.ch/eng/lhc/optics/HLLHCV1.0 [1)]
- Baseline round and flat optics at 15 cm or 7.5/30 cm.
- Ultimate squeeze for improved performance provided tight collimation settings.
- Optics for ion operations with low β* in all Ips.

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Supporting optics parameters

Name	IP1-5			IP2			IP8		
	Beta* [m]	Angle [μrad]	sep [mm]	Beta* [m]	Angle [μrad]	sep [mm]	Beta* [m]	Angle [μrad]	sep [mm]
inj_18m (in prep.)	18	340	2	10	340	2	10	340	2
inj_11m (in prep.)	11	340	2	10	340	2	10	340	2
inj	6	490	2	10	340	2	10	340	2
endoframp	6	360	2	10	340	2	10	340	2
Presqueeze_3000	3	360	0.75	10	340	2	3	340	2
presqueeze	44	360	0.75	10	340	2	3	340	2

- Optics available under /afs/cern.ch/eng/lhc/optics/HLLHCV1.0[1].
- Injection optics optimized for aperture.
- End of ramp optics for tune jump and IR2-8 triplet relaxation.
- Pre-squeeze optics to enable ATS mechanism.
- Van-der-Mer scan optics requested 15 to 20 m at collision energy under study.

Crab cavities

To comply with total voltage requirement (12.5 MV [S. Fartoukh] and be consistent with the present cavity module specification:

- 3 ➔ 4 modules per IR, side, beam with 3.5 MV each [E. Jensen, R. Calaga].
- precise location of crab cavities defined by ongoing integration studies [R. Calaga, P. Fessia].

WP joint meetings for validation

References:

13/8, 27/9, 25/10, L. Esposito et al., Energy Deposition Simulations, talk and minutes, WP2 Task leader meeting and Collimation meetings.

1/11, M. Zerlauth et al., Crab cavity voltage and quantity, Minutes of Discussion in PLC action list.

11-15/11, Daresbury Workshop: talks cover all aspects (see agenda).

25/11, M. Giovannozzi et al., Brainstorming on layout optimization, Minutes to be posted.

29/11, P. Fessia et al. Meeting Energy deposition mechanical models, Minutes to be posted.

Triplet beam screens (impedance)

B. Salvant

- Expected from theory, accounting for the weld on the side and magnetoresistance, accounting for factor 2 in addition (could be worst case for 2 beams in same aperture, pessimistic). Not yet accounting for the change of impedance linked to the transverse position inside the triplets

Power loss for 2 beams in mW/m Nominal bunch length	Nominal (25 ns)	ultimate (25 ns)	HL-LHC (25 ns)	HL-LHC (50 ns)
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- Large aperture pays off

G. Iadarola

Total heat load on the triplet beam screen

Bunch intensity is larger but also chamber is wider. For the **same SEY**:

→ energy of multipacting electrons is quite similar

→ number of impacting electrons about x2 larger

→ Total **heat load about x2 larger**

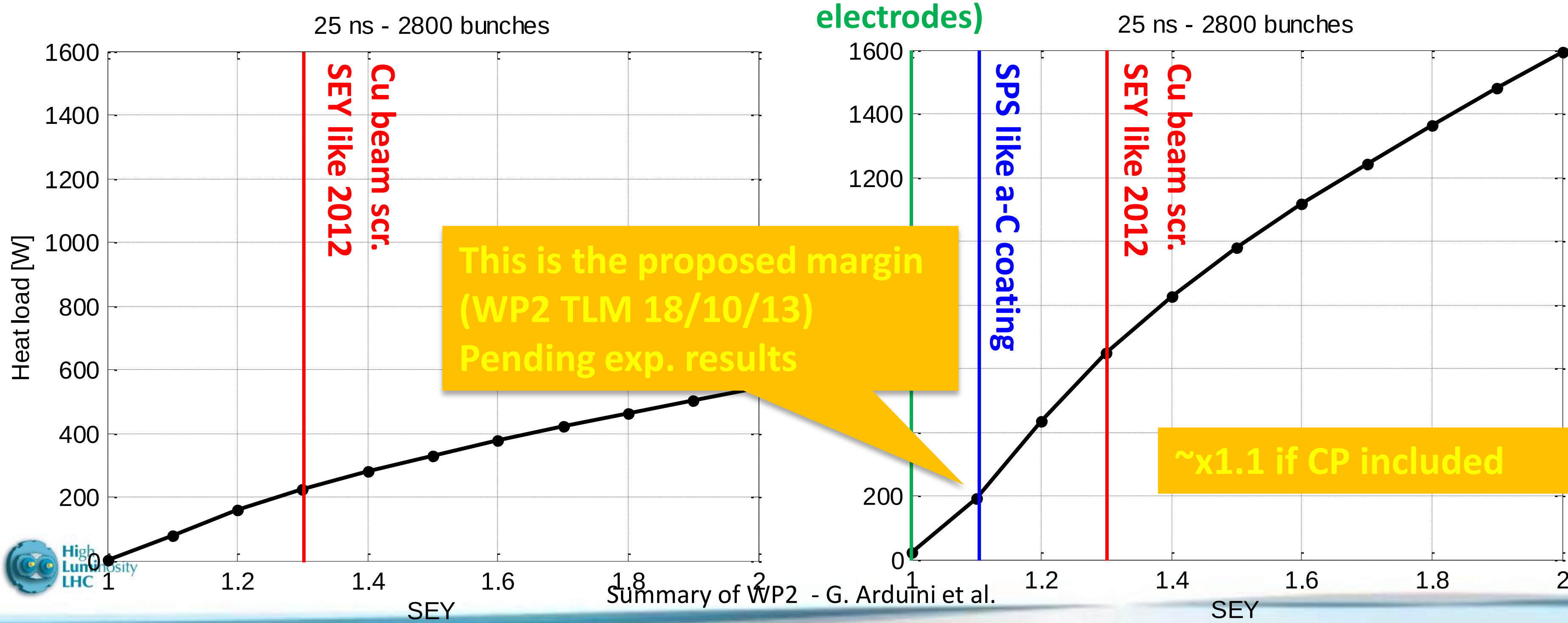
e-cloud suppression can be obtained using **low SEY coatings** and/or **clearing electrodes**

Already planned (nanographite) and possibly clearing electrodes

Present triplets (1.15x10^{11} p/b)

Full suppression (SEY≈1 or clearing electrodes)

HiLumi triplets – 2.2x10^{11} p/b



Latest D2 field estimate at r_0 = 35 mm ("D2_errortable_v4")

The recent optimization of iron geometry and coil in D2 (E. Todesco) resulted in significant reduction of b2, b3, b4, b5 terms at collision energy (D2_errortable_v4). It also significantly reduced the mean values of b3 (95.8→3.8) and b5 (15→3.0) at injection energy.
However, for most of this study, the D2_errortable_v3 was used as a reference table.

skew	mean	uncertainty	random		normal	mean	uncertainty	random
a2	0	0.679	0.6790		b2	**±65→±25**	**3.0→2.5**	**3.0→2.5**
a3	0	0.282	0.2820		b3	**-30→3.0**	**5.0→1.5**	**5.0→1.5**
a4	0	0.444	0.4440		b4	**±25→±2.0**	**1.0→0.2**	**1.0→0.2**
a5	0	0.152	0.152		b5	**-4.0→-1.0**	**1.0→0.5**	**1.0→0.5**
a6	0	0.176	0.176		b6	0	0.060	0.060
a7	0	0.057	0.057		b7	-0.2	0.165	0.165
a8	0	0.061	0.061		b8	0	0.027	0.027
a9	0	0.020	0.020		b9	0.09	0.065	0.065
a10	0	0.025	0.025		b10	0	0.008	0.008
a11	0	0.007	0.007		b11	0.03	0.019	0.019
a12	0	0.008	0.008		b12	0	0.003	0.003
a13	0	0.002	0.002		b13	0	0.006	0.006
a14	0	0.003	0.003		b14	0	0.001	0.001
a15	0	0.001	0.001		b15	0	0.002	0.002

Recommended target for D2 field quality

1) Use D2_errortable_v4 and further reduce b3m a factor of 2.
2) Minimize the b2 term or compensate its impact on beta function. Correction options are not yet decided, but may include adjustment of Q4 gradient or D2 spool-piece correctors.

skew	mean	uncertainty	random		normal	mean	uncertainty	random
a2	0	0.679	0.6790		b2	±25	2.5	2.5
a3	0	0.282	0.2820		b3	**3.0→1.5**	1.5	1.5
a4	0	0.444	0.4440		b4	±2.0	0.2	0.2
a5	0	0.152	0.152		b5	-1.0	0.5	0.5
a6	0	0.176	0.176		b6	0	0.060	0.060
a7	0	0.057	0.057		b7	-0.2	0.165	0.165
a8	0	0.061	0.061		b8	0	0.027	0.027
a9	0	0.020	0.020		b9	0.09	0.065	0.065
a10	0	0.025	0.025		b10	0	0.008	0.008
a11	0	0.007	0.007		b11	0.03	0.019	0.019
a12	0	0.008	0.008		b12	0	0.003	0.003
a13	0	0.002	0.002		b13	0	0.006	0.006
a14	0	0.003	0.003		b14	0	0.001	0.001
a15	0	0.001	0.001		b15	0	0.002	0.002