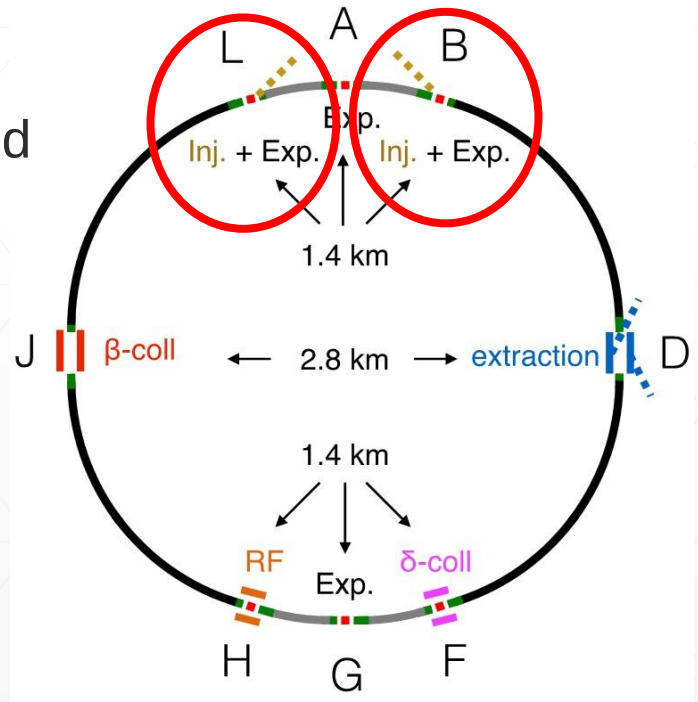
Low Luminosity experimental insertions

M. Hofer, W. Bartmann, M.I. Besana, F. Burkart, F. Cerutti, R. Martin, E. Renner, D. Schulte, R. Tomas

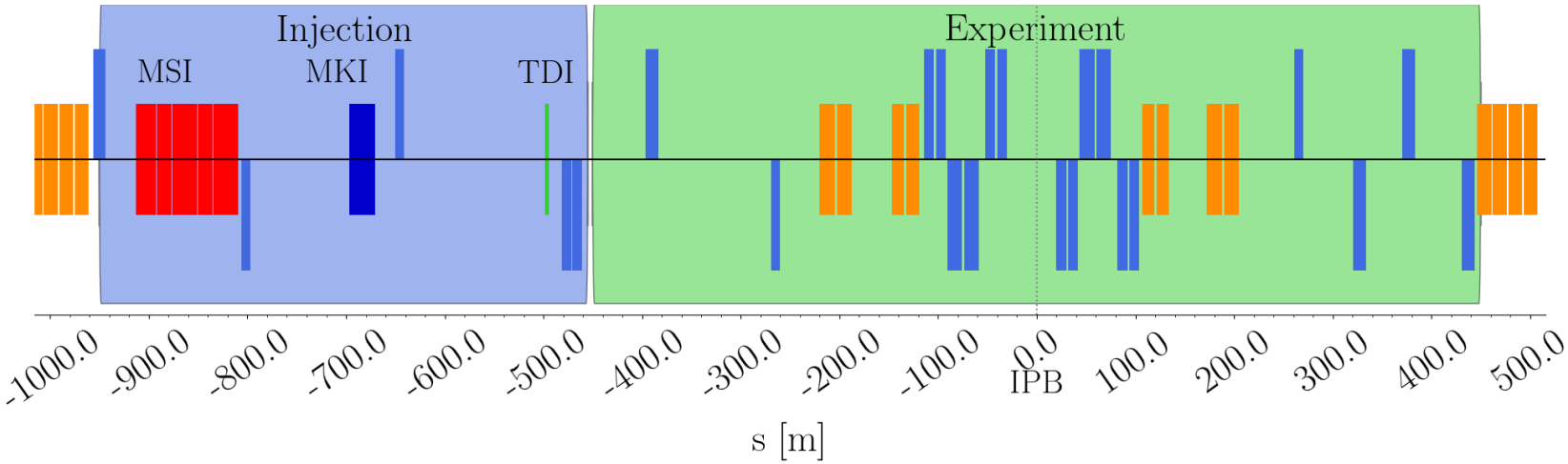
Introduction

- As in the LHC, in the FCC-hh the low luminosity experiments are combined with the injection
- Overall insertion length is limited to 1.4 km, same as high luminosity insertions
- Currently, no luminosity requirements for these experiments have been specified
  - No experimental scenario
  - No design for detector
- In the following focus on Point B
  - Same layout also used for Point L
  - Point L also candidate for the FCC-eh collision point



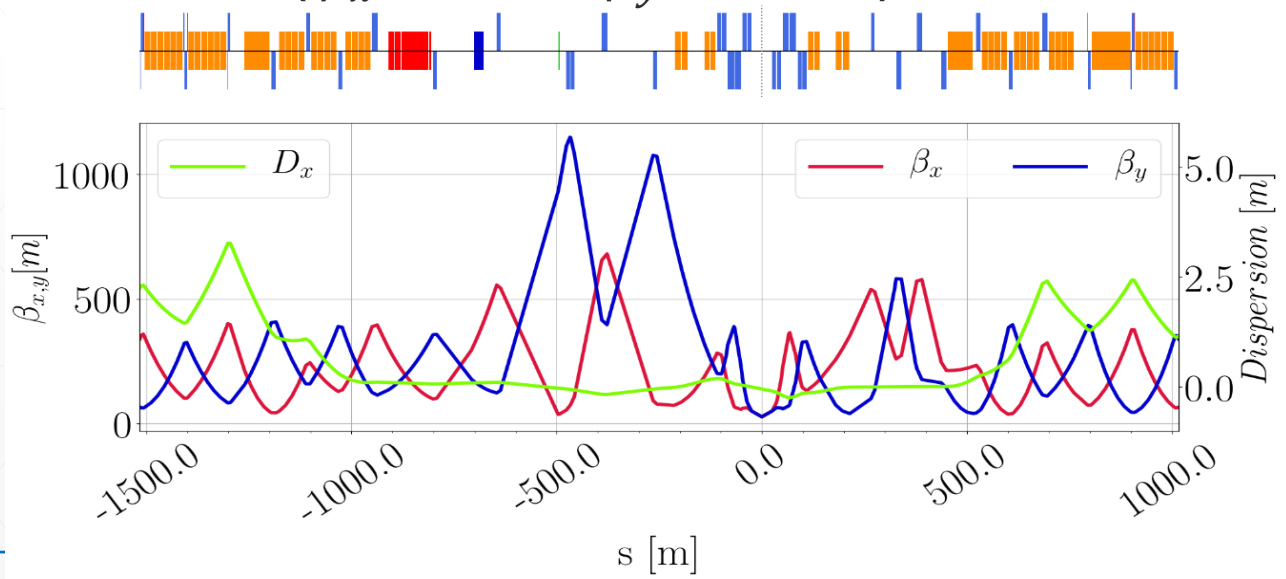
Insertion Layout

- Contrary to the LHC low luminosity insertions, the design for the FCC-hh is asymmetric
  - Separates injection and experiments, which is favourable from machine protection point of view
  - Injection dump (TDI) is not located in between the superconducting dipoles as in LHC
- Due to early hardware considerations, the length of cells containing injection hardware has been set to 150 m
- To provide space for experiment, superconducting separation and recombination dipoles are required



Injection optics

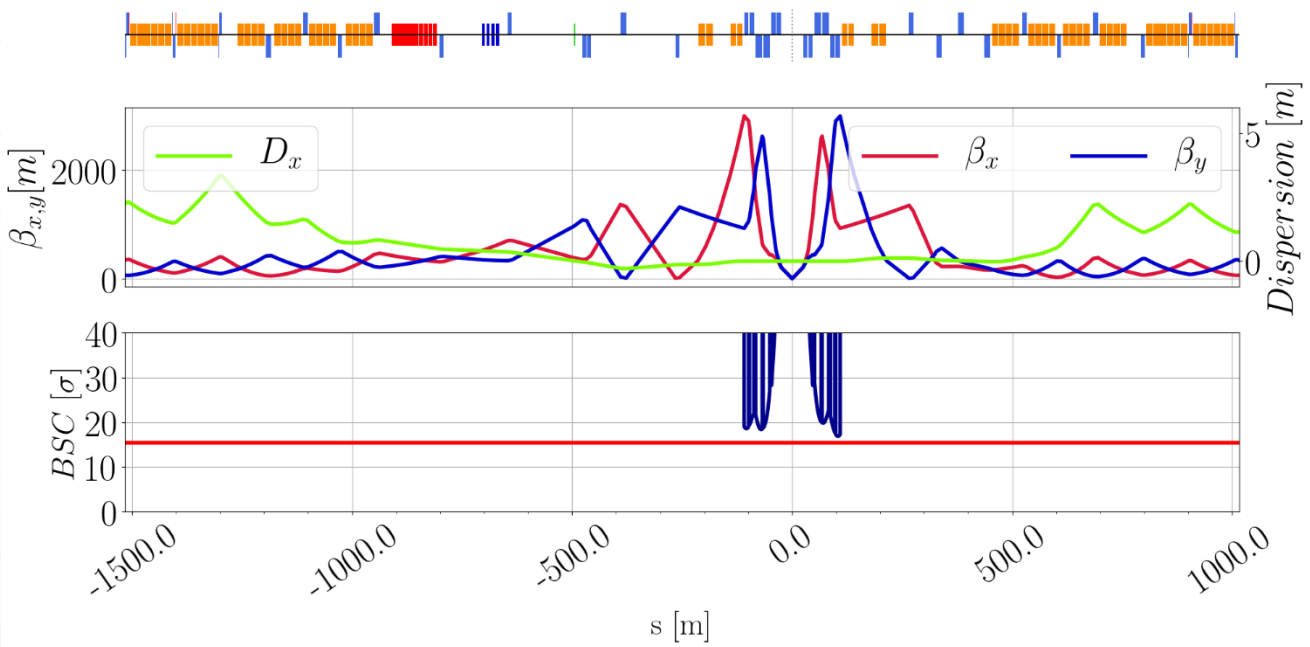
- For optimal machine protection, some constraints on injection optics apply
  - Phase advance between kicker and TDI close to 90 degree, such that miskick translates into additional orbit offset at TDI
  - Small dispersion to reduce kicker aperture and ease of protection device setup
  - Large beam size at the TDI to limit peak energy density on the absorber [1]
- Currently very flat beam at TDI ($\beta_x = 37\ m$, $\beta_y = 932\ m$)
  - Possible issues with collimator alignment [2]
  - Alternative concepts to be looked into in the future



[1] A. Lechner, “FCC-hh protection absorbers and dumps”, FCC-Week 2018
[2] E. Renner, “FCC–hh: Transferlines and Injection Insertion”, FCC-Week 2018

Collision Optics

- For the low luminosity experiments an L^* of 25 m was suggested by the detector design group
- With this layout a minimum β* of 3 m was matched
  - At this β* a crossing angle of up to $45\ \mu rad$ is possible
  - All triplet quadrupoles have the same aperture of 64 mm
  - Aperture of the triplet quadrupoles is reduced by a 10 mm tungsten shielding

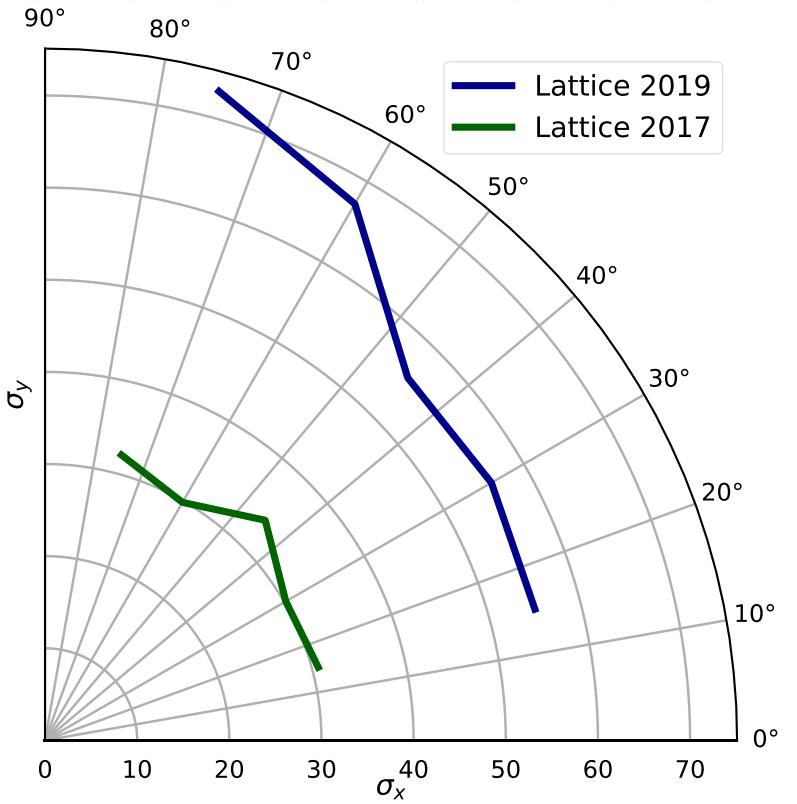


Dynamic Aperture

- Impact of FQ of triplet quadrupoles and superconducting separation and recombination dipoles studied
  - For the triplet quadrupoles, the errors from the HL-LHC triplet were scaled to the reduced aperture and increased length
  - For the dipoles, the error tables from the HL-LHC D1 and D2 were used, scaled to the aperture
- DA is evaluated using SixTrack

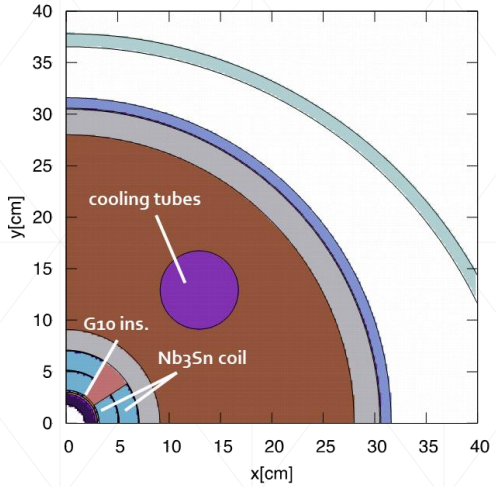
Tracking parameters	
n_{turns}	10^5
n_{angles}	5
n_{seeds}	60
ϵ_n	$2.2\ \mu m$

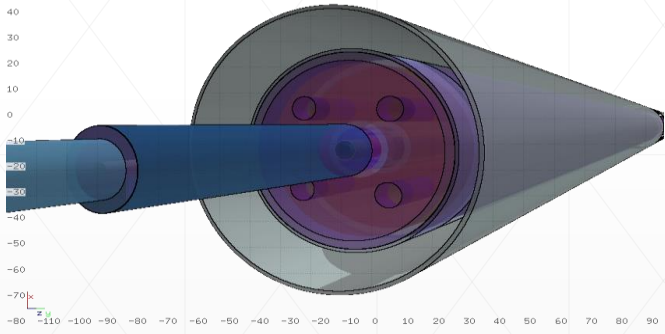
- For the current lattice, DA with errors in the low lumi insertions and with crossing angle is not a concern

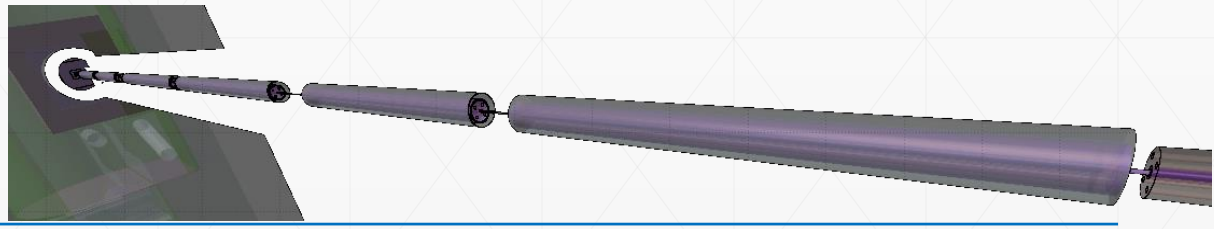


Energy deposition

- Energy depositions studies conducted to determine luminosity reach
  - Max. instantaneous luminosity determined by quench limit of magnets
  - Cumulated dose sets the achievable integrated luminosity
- Triplet quadrupole model from High Lumi exp scaled to smaller aperture of Low Lumi exp.
  - 10 mm tungsten (INERMET180) shielding in quadrupole aperture
  - 76 cm long mask in front of Q1A
- Shielding gaps of 70 cm between quadrupoles

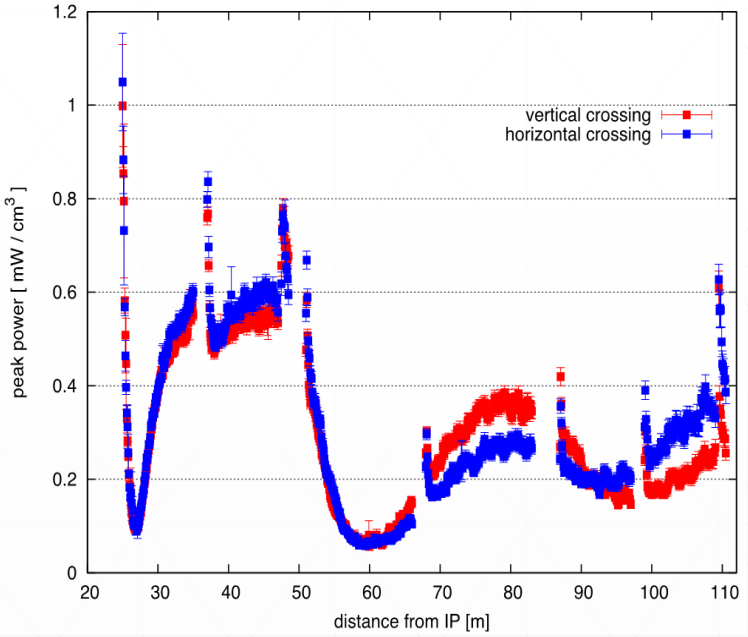




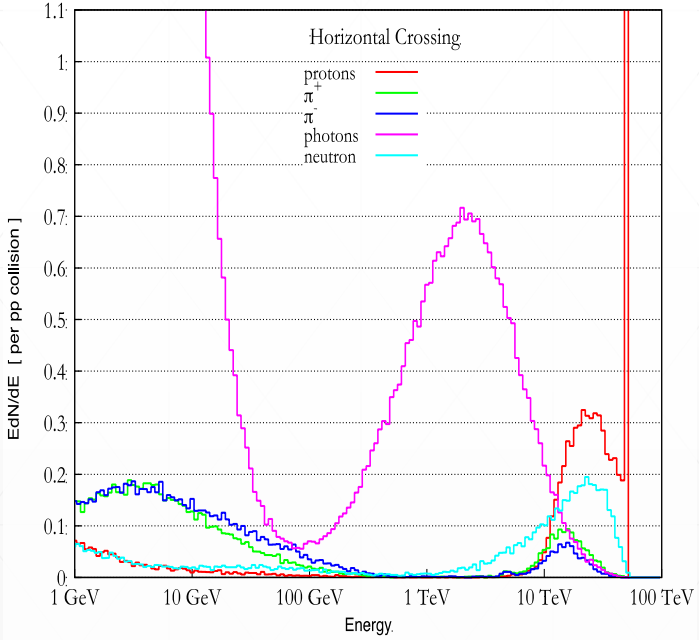


Peak power density

- For an instantaneous luminosity of $5 \cdot 10^{33} cm^{-2} s^{-1}$, peak power density is around $1\ mW cm^{-3}$
  - Effect of shielding gaps clearly visible
- 63 % of the total power (2.6 kW) is escaping the triplet
  - Further simulations needed to see where escaping particles impact



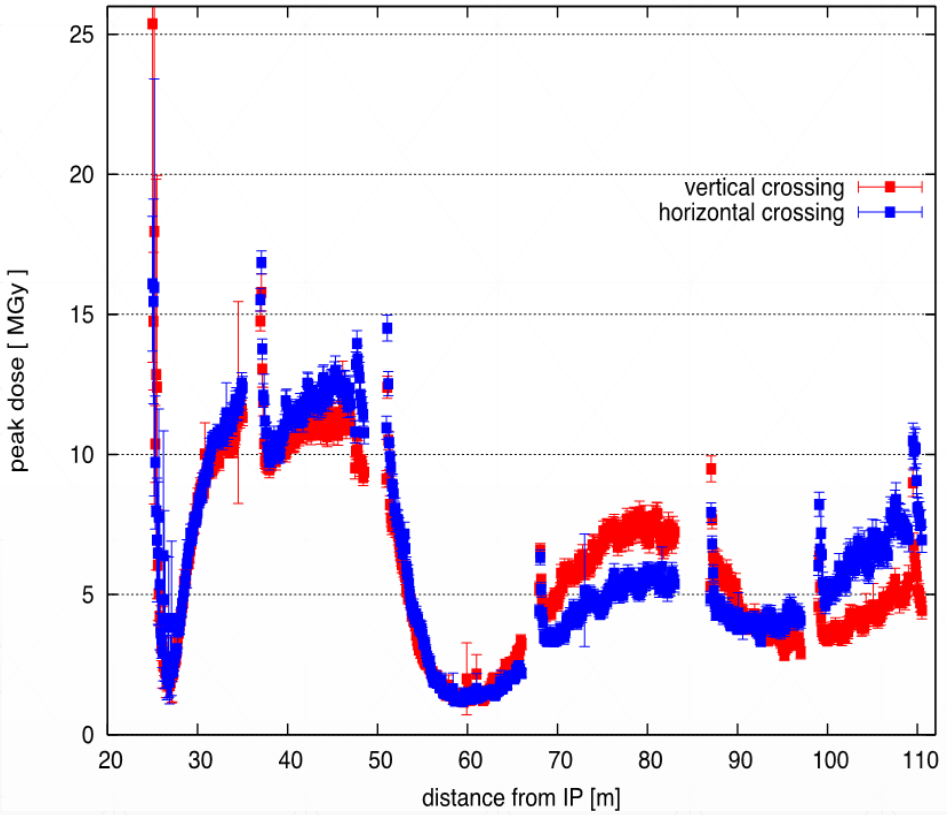
Peak power density for $5 \cdot 10^{33}\ cm^{-2} s^{-1}$



Particle Spectra at the exit of Q3B per collision

Integrated Dose

- With current baseline radiation limits of 30 MGy, $500\ fb^{-1}$ seem feasible
- Options could be explored to increase triplet lifetime
  - Switch in crossing plane
  - Swap of triplet magnet in a long shutdown



Peak dose for $500\ fb^{-1}$

Conclusions

- Similar to the LHC layout, the FCC-hh layout features combined experimental and injection insertions
- In the absence of specific luminosity goals, a generic insertion was designed
  - A β* of 3 m could be achieved at collision energy
  - From energy deposition studies the currently attainable integrated luminosity for this design is about $500\ fb^{-1}$
    - Impact of particles escaping the triplet to be studied
- From injection protection view show sufficient local protection efficiency
  - Further optimisation of optics to lighten alignment tolerances

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Thank you for your attention!

Reserve

Magnet parameter

Type	Gradient [T/m]	Field [T]	Aperture [mm]	Length [m]	Units per IP
Triplet Q1	270	-	64	10	4
Triplet Q2	270	-	64	15	4
Triplet Q3	270	-	64	10	4
Separation Dipole D1	-	12	100	12.5	4
Recombination Dipole D2	-	10	60	15	4
Matching Quadrupole Short Type MQM	200	-	70	9.1	4
Matching Quadrupole Long Type MQML	300	-	50	12.8	6

Triplet Field Quality in HL-LHC

HL-LHC TDR V0.1

	Triplet field quality version 4 - May 20 2015 - R_{ref}=50 mm															
	Straight part										Ends		Integral			
	Systematic						Uncertainty		Random				Q1/Q3		Q2a/b	
Normal	Geometric	Ass. & cool	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field	Conn. Side	Non conn. Side	Injection	High Field	Injection	High Field
2									10	10						
3	0.000	0.000	0.000	0.000	0.000	0.000	0.820	0.820	0.820	0.820			0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.570	0.570	0.570	0.570			0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.420	0.420	0.420	0.420			0.000	0.000	0.000	0.000
6	-2.200	0.900	0.660	-20.000	-21.300	-0.640	1.100	1.100	1.100	1.100	8.943	-0.025	-16.692	0.323	-18.593	-0.075
7	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.190	0.190	0.190			0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.130	0.130	0.130	0.130			0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.070	0.070	0.070	0.070			0.000	0.000	0.000	0.000
10	-0.110	0.000	0.000	4.000	3.890	-0.110	0.200	0.200	0.200	0.200	-0.189	-0.821	3.119	-0.175	3.437	-0.148
11	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.026	0.026	0.026			0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.018	0.018	0.018	0.018			0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.009	0.009	0.009			0.000	0.000	0.000	0.000
14	-0.790	0.000	-0.080	1.000	0.210	-0.870	0.023	0.023	0.023	0.023	-0.545	-1.083	0.033	-0.856	0.106	-0.862
Skew																
2									10.000	10.000	-31.342		-2.985	-2.985	-1.753	-1.753
3	0.000	0.000	0.000	0.000	0.000	0.000	0.650	0.650	0.650	0.650			0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000	0.000	0.000	0.650	0.650	0.650	0.650			0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000	0.000	0.000	0.430	0.430	0.430	0.430			0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000	0.000	0.000	0.310	0.310	0.310	0.310	2.209		0.210	0.210	0.124	0.124
7	0.000	0.000	0.000	0.000	0.000	0.000	0.190	0.190	0.190	0.190			0.000	0.000	0.000	0.000
8	0.000	0.000	0.000	0.000	0.000	0.000	0.110	0.110	0.110	0.110			0.000	0.000	0.000	0.000
9	0.000	0.000	0.000	0.000	0.000	0.000	0.080	0.080	0.080	0.080			0.000	0.000	0.000	0.000
10	0.000	0.000	0.000	0.000	0.000	0.000	0.040	0.040	0.040	0.040	0.065		0.006	0.006	0.004	0.004
11	0.000	0.000	0.000	0.000	0.000	0.000	0.026	0.026	0.026	0.026			0.000	0.000	0.000	0.000
12	0.000	0.000	0.000	0.000	0.000	0.000	0.014	0.014	0.014	0.014			0.000	0.000	0.000	0.000
13	0.000	0.000	0.000	0.000	0.000	0.000	0.010	0.010	0.010	0.010			0.000	0.000	0.000	0.000
14	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005	0.005	0.005	-0.222		-0.021	-0.021	-0.012	-0.012
	Magnetic length straight part				Q1/Q3	3.459	Q2a/b	6.409	Mag. Len. Ends		0.400	0.341				

Triplet Field Quality in the Low Lumi Triplet

	Low Luminosity Triplet Q1a/b Q3a/b Field Quality					
	Systematic		Uncertainty		Random	
Normal	Injection	High Field	Injection	High Field	Injection	High Field
2	0.000	0.000	0.000	0.000	10.000	10.000
3	0.000	0.000	0.820	0.820	0.820	0.820
4	0.000	0.000	0.570	0.570	0.570	0.570
5	0.000	0.000	0.420	0.420	0.420	0.420
6	-19.365	-0.236	1.100	1.100	1.100	1.100
7	0.000	0.000	0.190	0.190	0.190	0.190
8	0.000	0.000	0.130	0.130	0.130	0.130
9	0.000	0.000	0.070	0.070	0.070	0.070
10	3.566	-0.137	0.200	0.200	0.200	0.200
11	0.000	0.000	0.026	0.026	0.026	0.026
12	0.000	0.000	0.018	0.018	0.018	0.018
13	0.000	0.000	0.009	0.009	0.009	0.009
14	0.136	-0.864	0.023	0.023	0.023	0.023
Skew						
2	-1.254	-1.254	0.000	0.000	10.000	10.000
3	0.000	0.000	0.650	0.650	0.650	0.650
4	0.000	0.000	0.650	0.650	0.650	0.650
5	0.000	0.000	0.430	0.430	0.430	0.430
6	0.088	0.088	0.310	0.310	0.310	0.310
7	0.000	0.000	0.190	0.190	0.190	0.190
8	0.000	0.000	0.110	0.110	0.110	0.110
9	0.000	0.000	0.080	0.080	0.080	0.080
10	0.003	0.003	0.040	0.040	0.040	0.040
11	0.000	0.000	0.026	0.026	0.026	0.026
12	0.000	0.000	0.014	0.014	0.014	0.014
13	0.000	0.000	0.010	0.010	0.010	0.010
14	-0.009	-0.009	0.005	0.005	0.005	0.005

	Low Luminosity Triplet Q2a/b Field Quality					
	Systematic		Uncertainty		Random	
Normal	Injection	High Field	Injection	High Field	Injection	High Field
2	0.000	0.000	0.000	0.000	10.000	10.000
3	0.000	0.000	0.820	0.820	0.820	0.820
4	0.000	0.000	0.570	0.570	0.570	0.570
5	0.000	0.000	0.420	0.420	0.420	0.420
6	-20.010	-0.370	1.100	1.100	1.100	1.100
7	0.000	0.000	0.190	0.190	0.190	0.190
8	0.000	0.000	0.130	0.130	0.130	0.130
9	0.000	0.000	0.070	0.070	0.070	0.070
10	3.674	-0.128	0.200	0.200	0.200	0.200
11	0.000	0.000	0.026	0.026	0.026	0.026
12	0.000	0.000	0.018	0.018	0.018	0.018
13	0.000	0.000	0.009	0.009	0.009	0.009
14	0.160	-0.866	0.023	0.023	0.023	0.023
Skew						
2	-0.836	-0.836	0.000	0.000	10.000	10.000
3	0.000	0.000	0.650	0.650	0.650	0.650
4	0.000	0.000	0.650	0.650	0.650	0.650
5	0.000	0.000	0.430	0.430	0.430	0.430
6	0.059	0.059	0.310	0.310	0.310	0.310
7	0.000	0.000	0.190	0.190	0.190	0.190
8	0.000	0.000	0.110	0.110	0.110	0.110
9	0.000	0.000	0.080	0.080	0.080	0.080
10	0.002	0.002	0.040	0.040	0.040	0.040
11	0.000	0.000	0.026	0.026	0.026	0.026
12	0.000	0.000	0.014	0.014	0.014	0.014
13	0.000	0.000	0.010	0.010	0.010	0.010
14	-0.006	-0.006	0.005	0.005	0.005	0.005

HL-LHC D1 and D2 Field quality tables

HL-LHC TDR V0.1

	Separation dipole D1 field quality version 1 - November 6 2012 - R_{ref}=50 mm								
	Systematic					Uncertainty		Random	
Normal	Geometric	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field
2	0.000	0.000	0.000	0.000	0.000	0.200	0.200	0.200	0.200
3	-1.800	0.900	-14.200	-16.000	-0.900	0.727	0.727	0.727	0.727
4	0.000	0.000	0.000	0.000	0.000	0.126	0.126	0.126	0.126
5	0.500	-0.500	-1.000	-0.500	0.000	0.365	0.365	0.365	0.365
6	0.000	0.000	0.000	0.000	0.000	0.060	0.060	0.060	0.060
7	1.600	-1.200	-0.700	0.900	0.400	0.165	0.165	0.165	0.165
8	0.000	0.000	0.000	0.000	0.000	0.027	0.027	0.027	0.027
9	-0.680	0.090	0.020	-0.660	-0.590	0.065	0.065	0.065	0.065
10	0.000	0.000	0.000	0.000	0.000	0.008	0.008	0.008	0.008
11	0.440	0.030	0.000	0.440	0.470	0.019	0.019	0.019	0.019
12	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.003	0.003
13	0.000	0.000	0.000	0.000	0.000	0.006	0.006	0.006	0.006
14	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
15	-0.040	0.000	0.000	-0.040	-0.040	0.002	0.002	0.002	0.002
Skew									
2	0.000	0.000	0.000	0.000	0.000	0.679	0.679	0.679	0.679
3	0.000	0.000	0.000	0.000	0.000	0.282	0.282	0.282	0.282
4	0.000	0.000	0.000	0.000	0.000	0.444	0.444	0.444	0.444
5	0.000	0.000	0.000	0.000	0.000	0.152	0.152	0.152	0.152
6	0.000	0.000	0.000	0.000	0.000	0.176	0.176	0.176	0.176
7	0.000	0.000	0.000	0.000	0.000	0.057	0.057	0.057	0.057
8	0.000	0.000	0.000	0.000	0.000	0.061	0.061	0.061	0.061
9	0.000	0.000	0.000	0.000	0.000	0.020	0.020	0.020	0.020
10	0.000	0.000	0.000	0.000	0.000	0.025	0.025	0.025	0.025
11	0.000	0.000	0.000	0.000	0.000	0.007	0.007	0.007	0.007
12	0.000	0.000	0.000	0.000	0.000	0.008	0.008	0.008	0.008
13	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.002	0.002
14	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.003	0.003
15	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001

	Recombination dipole D2 field quality version 1.4 - October 1 2013 - R_{ref}=35 mm								
	Systematic					Uncertainty		Random	
Normal	Geometric	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field
2	0.000	25.000	0.000	0.000	25.000	0.200	2.500	0.200	2.500
3	18.000	-15.000	-14.200	3.800	3.000	0.727	-1.500	0.727	-1.500
4	-8.000	10.000	0.000	-8.000	2.000	0.126	0.200	0.126	0.200
5	4.000	-5.000	-1.000	3.000	-1.000	0.365	-0.500	0.365	-0.500
6	0.000	0.000	0.000	0.000	0.000	0.060	0.060	0.060	0.060
7	0.800	-1.000	-0.700	0.100	-0.200	0.165	0.165	0.165	0.165
8	0.000	0.000	0.000	0.000	0.000	0.027	0.027	0.027	0.027
9	0.000	0.090	0.020	0.020	0.090	0.065	0.065	0.065	0.065
10	0.000	0.000	0.000	0.000	0.000	0.008	0.008	0.008	0.008
11	0.000	0.030	0.000	0.000	0.030	0.019	0.019	0.019	0.019
12	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.003	0.003
13	0.000	0.000	0.000	0.000	0.000	0.006	0.006	0.006	0.006
14	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001
15	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.002	0.002
Skew									
2	0.000	0.000	0.000	0.000	0.000	0.679	0.679	0.679	0.679
3	0.000	0.000	0.000	0.000	0.000	0.282	0.282	0.282	0.282
4	0.000	0.000	0.000	0.000	0.000	0.444	0.444	0.444	0.444
5	0.000	0.000	0.000	0.000	0.000	0.152	0.152	0.152	0.152
6	0.000	0.000	0.000	0.000	0.000	0.176	0.176	0.176	0.176
7	0.000	0.000	0.000	0.000	0.000	0.057	0.057	0.057	0.057
8	0.000	0.000	0.000	0.000	0.000	0.061	0.061	0.061	0.061
9	0.000	0.000	0.000	0.000	0.000	0.020	0.020	0.020	0.020
10	0.000	0.000	0.000	0.000	0.000	0.025	0.025	0.025	0.025
11	0.000	0.000	0.000	0.000	0.000	0.007	0.007	0.007	0.007
12	0.000	0.000	0.000	0.000	0.000	0.008	0.008	0.008	0.008
13	0.000	0.000	0.000	0.000	0.000	0.002	0.002	0.002	0.002
14	0.000	0.000	0.000	0.000	0.000	0.003	0.003	0.003	0.003
15	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.001	0.001