Low Luminosity Experimental Insertions

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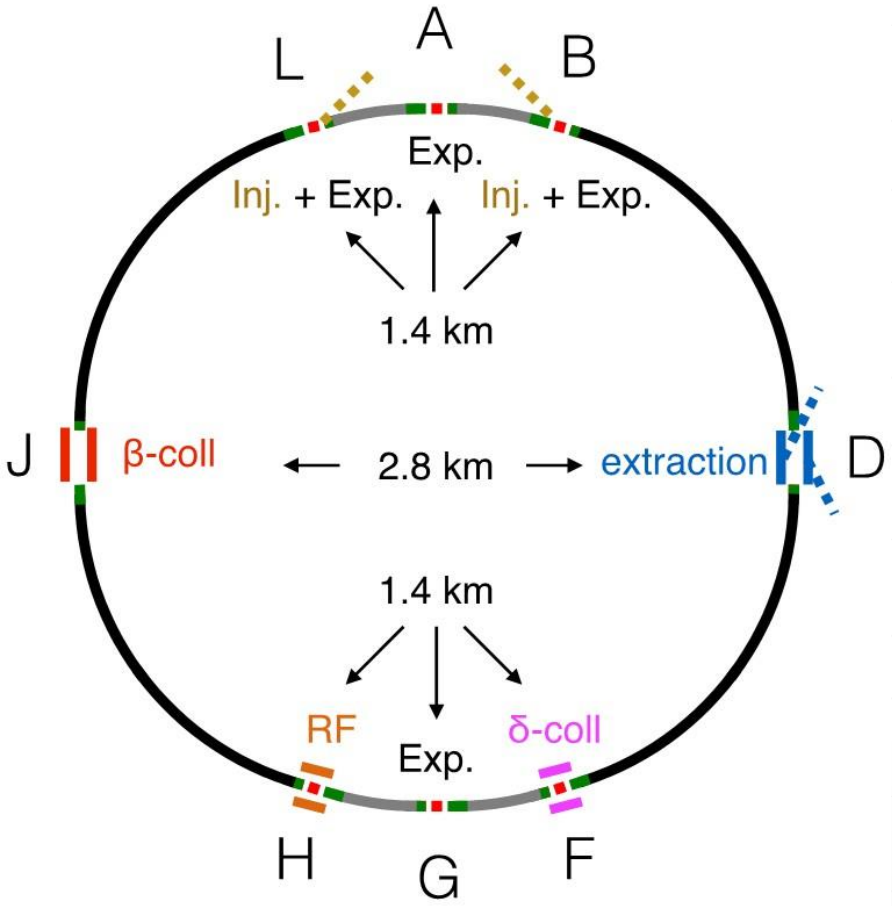
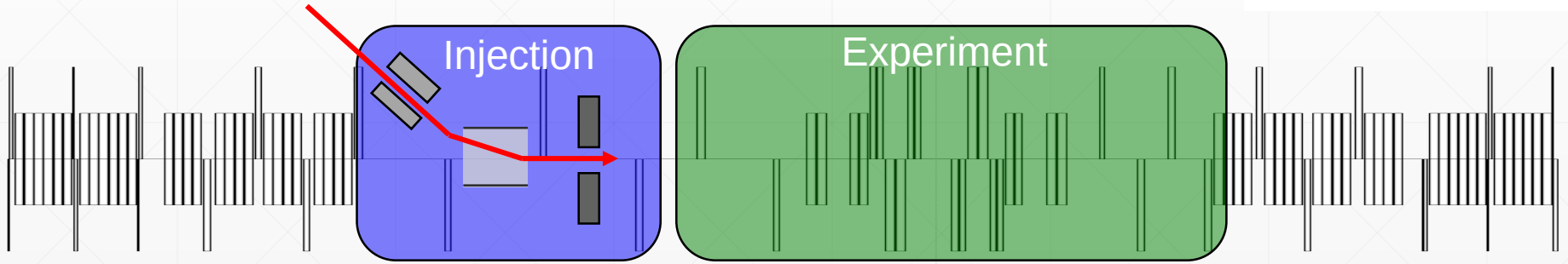
Status after FCC-Week 2017

- In the current 97.75 km long baseline layout, injection and low luminosity experiments are combined, similar as in the LHC
- Different to the LHC insertion, an asymmetric design was chosen, as it seems more favorable from a machine protection point of view
- This way, the injection protection elements are further away from the experiments





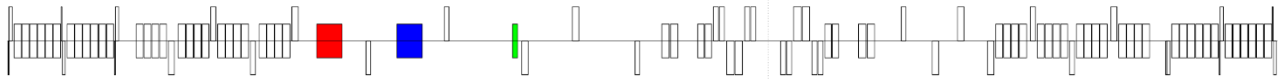
Optics

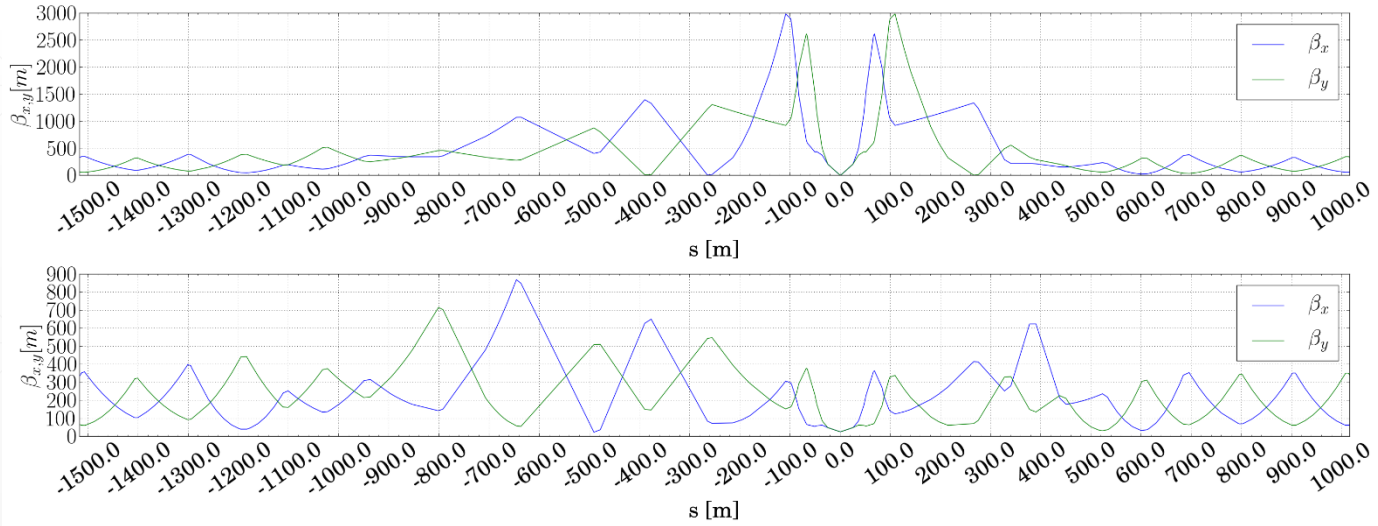
- For collision energy, optics is matched to a $\beta^* = 3\,m$,
  Injection to $\beta^* = 27\,m$ taking into account constraints to provide optimum efficiency of the protection elements

- Since FCC-Week 2017, only minor changes:
  β in kickers was increased and intra-beam spacing decreased to 204 mm

- Aperture model now includes tolerances (Courtesy A. Langner)

- Crossing angle during collision was kept at 39 μrad,
  but with the current triplet aperture it could be increased to 90 μrad while keeping the current β^*

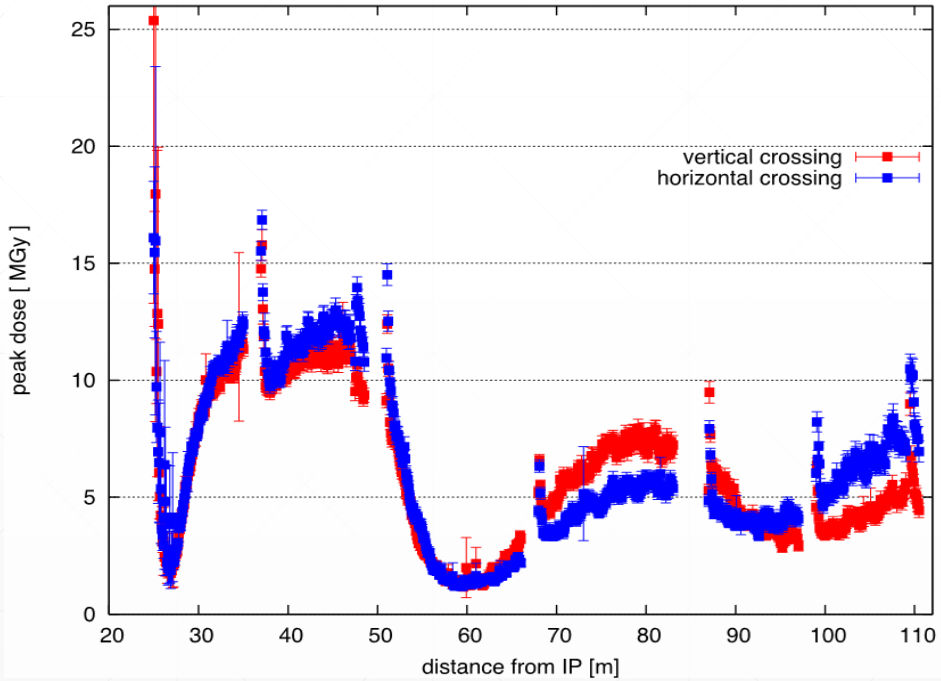




Energy deposition

- All triplet quadrupoles have the same aperture and use a 10 mm thick tungsten shielding
- Sufficient to bring the peak power density in the triplet below the design limit of Nb_3Sn of $5\ mW cm^{-3}$
- Concerning the integrated luminosity, $500\ fb^{-1}$ seem feasible with the current baseline radiation limits

Current FCC-hh target radiation limits	
Baseline	30 MGy
Ultimate (R&D Goal)	250 MGy



Peak dose for $500\ fb^{-1}$
Courtesy of M.I. Besana and F.Cerutti

Dynamic Aperture Studies

- Initial Dynamic Aperture Studies with magnetic errors in the triplet and a previous lattice version (L*=45m) showed high dynamic aperture both with and without crossing angle
- With crossing angle the DA was only slightly reduced
- Now checking the DA with the updated lattice, which includes the latest layout of the low luminosity insertions and the L*=40m EIR and magnetic errors in the separation and recombination dipoles

Dynamic Aperture

- For Dynamic aperture studies at collision energy, the systematic errors from the HL-LHC triplet quadrupole error table were adapted for the LLIR triplet quadrupoles
- Reference radius set to one third of the aperture (same as in HL-LHC)
- b_1, b_2, a_1 and a_2 harmonics turned off

	Normal		Skew	
	Q1a/b Q3a/b	Q2a/Q2b	Q1a/b Q3a/b	Q2a/Q2b
2	0	0	-1.254	-0.836
6	-0.236	-0.370	0.088	0.059
10	-0.137	-0.128	0.003	0.002
14	-0.864	-0.866	-0.009	-0.006

Systematic components at collision energy for the triplet quadrupoles

Dipole Field Quality

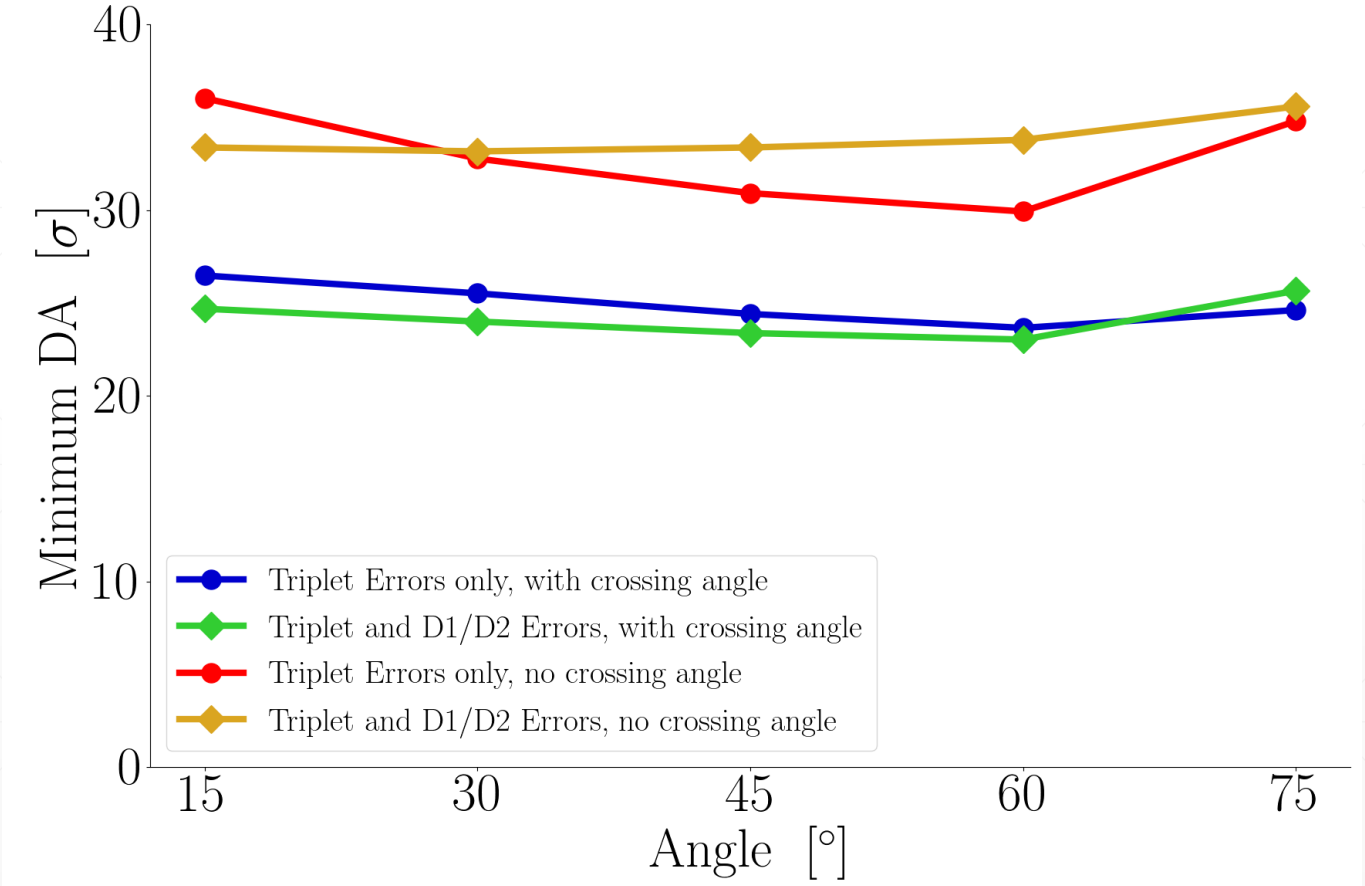
- To study the impact of magnetic errors on the DA in the superconducting separation- and recombination dipoles, the error tables from HL-LHC D1 and D2 were used
- Reference radius again set to one third of the aperture

	Normal		Skew	
	D1	D2	D1	D2
3	-0.900	3.00	0	0
4	0	2.00	0	0
5	0	-1.00	0	0
7	0.400	-0.200	0	0
9	-0.590	0.090	0	0
11	0.470	0.030	0	0
15	-0.040	0	0	0

Systematic components at collision energy for the separation and recombination dipoles

Dynamic Aperture

- Sixtrack studies carried out at collision energy with
  - 60 seeds
  - 5 angles
  - Amplitude step size 2 σ
  - With and without crossing angle



Conclusions and Outlook

- Layout is unchanged since FCC-week and integrated in the FCC-hh lattice
- With currently used triplet shielding, the integrated luminosity for these experiments will be $500\ fb^{-1}$
- Tracking studies with magnetic errors in the triplet quadrupoles and the superconducting separation- and recombination dipole show Dynamic Aperture above 23σ
- Orbit correction and coupling correction for these insertion should be refined
- Following up with Dynamic aperture studies including also magnetic errors in the main experiments

Thank you for your attention!

Triplet Field Quality in HL-LHC

CERN-ACC-2014-103

	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 HL-LHC

- For these error tables, the weighted average of straights and end parts
- Magnetic lengths of the ends is assumed to be the same as in HL-LHC

	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

Dipole Field Quality

CERN-ACC-2014-103

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