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CEA - Saclay

Update on dipoles field quality and DA at injection

B. Dalena

in collaboration with: D. Boutin, A. Chancé, E. Cruz Alaniz, S. Izquierdo Bermudez, D. Schoerling, D. Schulte, C. Tambasco, R. Tomas

thanks to: J. Barranco, J. Coello de Portugal, R. De Maria, S. Fartoukh, R. Martin, A. Mereghetti, T. Pieloni, E. Todesco

FCC week 2017 Berlin 2017

DA presented for:

-table v0 and v1
-different collider layouts/optics
-injection and collision
-impact of Landau Damping octupoles at injection is important!

v0

normal	Sys inj	Sys coll	Uncert	Ran
2	0	0	0.484	0.484
3	-5	20	0.781	0.781
4	0	0	0.065	0.065
5	-1	-1.5	0.074	0.074
6	0	0	0.009	0.009
7	-0.5	1.3	0.016	0.016
8	0	0	0.001	0.001
9	-0.100	0.05	0.002	0.002
10	0	0	0	0
skew				
2	0	0	1.108	1.108
3	0	0	0.256	0.256
4	0	0	0.252	0.252
5	0	0	0.05	0.05
6	0	0	0.04	0.04
7	0	0	0.007	0.007
8	0	0	0.007	0.007
9	0	0	0.002	0.002
10	0	0	0.001	0.001

v1

normal	Sys inj	Sys coll	Uncert	Ran
2	0	50	1.000	1.000
3	7	-1	1.600	1.600
4	0	0.5	0.100	0.100
5	1	0.5	0.100	0.100
6	0	0	0.020	0.020
7	-1.5	0.3	0.030	0.030
8	0	0	0.002	0.002
9	-0.1	0.1	0.005	0.005
10	0	0	0.001	0.001
skew				
2	0	0	2.200	2.200
3	0	0	0.500	0.500
4	0	0	0.500	0.500
5	0	0	0.100	0.100
6	0	0	0.080	0.080
7	0	0	0.010	0.010
8	0	0	0.010	0.010
9	0	0	0.003	0.003
10	0	0	0.002	0.002

Outline

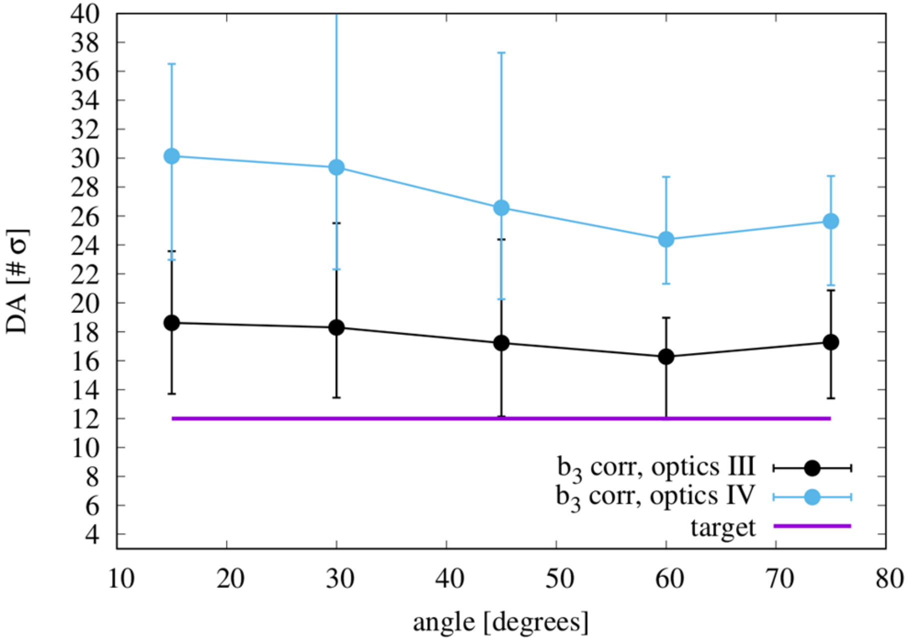
- DA at injection of new lattice (integer part of the tunes, number of cells, new IRs (see **A. Chancé** talk):
  - Table v1 (multipoles ≥3)
  - Impact of triplet errors at injection
  - Impact of Landau Damping octupoles (same polarity)

- New Dipole field quality (Tables v2)

- b_2(S), a_2(U) correction

DA new lattice

- big impact of first order optics on DA
- min DA 12.1σ (table v1, old optics)
  20.2σ (table v1, new optics)

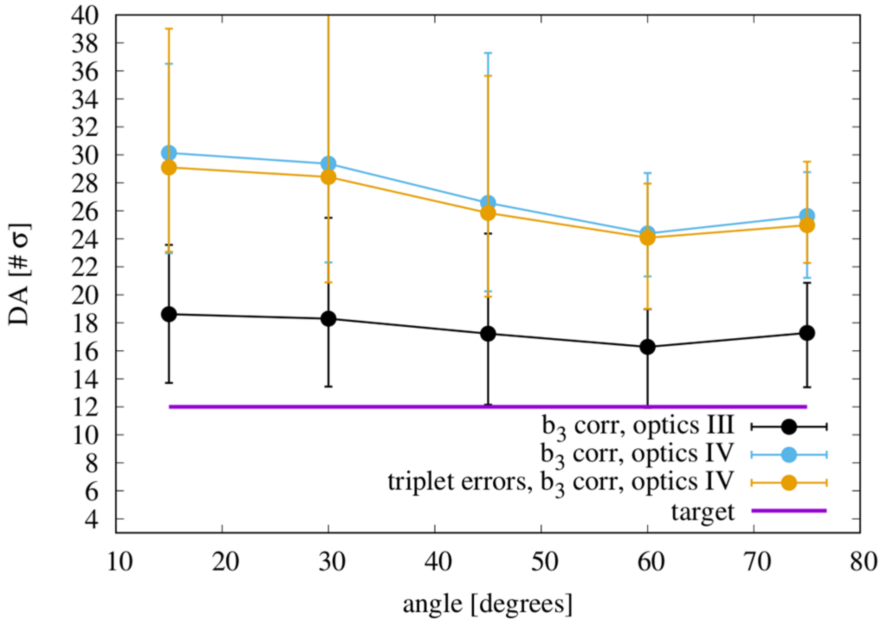


Optics III: 97.75 km layout, L*=45 m, Qx=111.28, Qy=109.31
Optics IV: 97.75 km layout, L*=40 m, Qx=110.28, Qy=108.31

Impact of inner triplet IPA&IPG

- minor impact of triplet errors (**E. Cruz**) on DA

- min DA 20.2 σ (table v1, MB errors only)
  19. σ (table v1, MB and MQX errors)



Optics III: 97.75 km layout, L*=45 m, Qx=111.28, Qy=109.31
Optics IV: 97.75 km layout, L*=40 m, Qx=110.28, Qy=108.31

Impact of Landau Damping Octupoles

- 452 octupoles installed in the long arcs new lattice (+~64 possible if trims not installed at all)
- G_max = 220000 T/m^3, Length = 0.32 m, I_max =720 A (D. Schoerling)
- K_MO = (G_max/Br) (I_oct/I_max)(50/energy [TeV])
- F and D Octupoles with same polarity
- I_oct = 4.5 A at injection (**C. Tambasco**)

	I_oct [A]	Min DA [σ]
inj	0	19.0
	-1	18.
	-4.5	<1

Main dipoles (table v1) and triplet errors included

⇒ important reduction of DA!

⇒ See **C. Tambasco** and **J. Barranco** talk for details of calculation and alternatives

New Dipole errors table v2

- Even normal error components change sign between inner and outer chamber of the dipole*
- Odd skew error components change sign between inner and outer chamber of the dipole*
- Injection errors are for an **energy** of **1.3 TeV**

FCC Dipole field quality version 2 - 3 Oct 2017 - R_{ref}=16.7 mm. 1.3 TeV Injection										
	Systematic					Uncertainty		Random		
Normal	Geometric	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field
2	-2.230	-44.610	0.000	-2.230	-46.840	0.922	0.922	0.922	0.922
3	-18.140	17.000	222.990	204.850	-1.140	57.000	1.351	57.000	1.351
4	-0.100	-0.930	0.100	0.000	-1.030	0.449	0.449	0.449	0.449
5	-0.690	-0.340	-40.190	-40.880	-1.030	12.000	0.541	12.000	0.541
6	0.000	-0.010	0.000	0.000	-0.010	0.176	0.176	0.176	0.176
7	1.610	0.140	4.260	5.870	1.750	1.500	0.211	1.500	0.211
8	0.000	0.000	0.000	0.000	0.000	0.071	0.071	0.071	0.071
9	1.310	0.120	-14.160	-12.850	1.430	4.000	0.092	4.000	0.092
10	0.000	0.000	0.000	0.000	0.000	0.027	0.027	0.027	0.027
11	0.960	0.090	-0.210	0.750	1.050	1.000	0.028	1.000	0.028
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009
13	-0.170	-0.020	0.170	0.000	-0.190	0.000	0.000	0.000	0.011
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003
15	0.010	0.000	-0.010	0.000	0.010	0.000	0.000	0.000	0.004
Skew									
2	0.000	0.000	0.000	0.000	0.000	1.040	1.040	1.040	1.040
3	0.000	0.000	0.000	0.000	0.000	0.678	0.678	0.678	0.678
4	0.000	0.000	0.000	0.000	0.000	0.450	0.450	0.450	0.450
5	0.000	0.000	0.000	0.000	0.000	0.317	0.317	0.317	0.317
6	0.000	0.000	0.000	0.000	0.000	0.205	0.205	0.205	0.205
7	0.000	0.000	0.000	0.000	0.000	0.116	0.116	0.116	0.116
8	0.000	0.000	0.000	0.000	0.000	0.071	0.071	0.071	0.071
9	0.000	0.000	0.000	0.000	0.000	0.041	0.041	0.041	0.041
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	0.016	0.016	0.016	0.016
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.009
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002

Susana Izquierdo Bermudez et al. 3/10/2017

*NB. this is not true for one of the three design of the main dipoles…

New Dipole errors table v2

- Even normal error components change sign between inner and outer chamber of the dipole*
- Odd skew error components change sign between inner and outer chamber of the dipole*
- Injection errors are for an **energy** of **3.3 TeV**

FCC Dipole field quality version 2 - 3 Oct 2017 - R_{ref}=16.7 mm. 3.3 TeV Injection									
	Systematic					Uncertainty		Random	
Normal	Geometric	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field
2	-2.230	-44.610	0.000	-2.230	-46.840	0.922	0.922	0.922	0.922
3	-18.140	17.000	-38.560	-56.700	-1.140	3.000	1.351	3.000	1.351
4	-0.100	-0.930	0.100	0.000	-1.030	0.449	0.449	0.449	0.449
5	-0.690	-0.340	13.660	12.970	-1.030	2.000	0.541	2.000	0.541
6	0.000	-0.010	0.000	0.000	-0.010	0.176	0.176	0.176	0.176
7	1.610	0.140	-1.920	-0.310	1.750	0.250	0.211	0.250	0.211
8	0.000	0.000	0.000	0.000	0.000	0.071	0.071	0.071	0.071
9	1.310	0.120	3.970	5.280	1.430	1.000	0.092	1.000	0.092
10	0.000	0.000	0.000	0.000	0.000	0.027	0.027	0.027	0.027
11	0.960	0.090	-0.100	0.860	1.050	0.200	0.028	0.200	0.028
12	0.000	0.000	0.000	0.000	0.000	0.009	0.000	0.009	0.009
13	-0.170	-0.020	0.170	0.000	-0.190	0.011	0.000	0.011	0.011
14	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.003	0.003
15	0.010	0.000	-0.010	0.000	0.010	0.004	0.000	0.004	0.004
Skew									
2	0.000	0.000	0.000	0.000	0.000	1.040	1.040	1.040	1.040
3	0.000	0.000	0.000	0.000	0.000	0.678	0.678	0.678	0.678
4	0.000	0.000	0.000	0.000	0.000	0.450	0.450	0.450	0.450
5	0.000	0.000	0.000	0.000	0.000	0.317	0.317	0.317	0.317
6	0.000	0.000	0.000	0.000	0.000	0.205	0.205	0.205	0.205
7	0.000	0.000	0.000	0.000	0.000	0.116	0.116	0.116	0.116
8	0.000	0.000	0.000	0.000	0.000	0.071	0.071	0.071	0.071
9	0.000	0.000	0.000	0.000	0.000	0.041	0.041	0.041	0.041
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	0.016	0.016	0.016	0.016
12	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009	0.009
13	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.005
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.003
15	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002	0.002

Susana Izquierdo Bermudez et al. 3/10/2017

*NB. this is not true for one of the three design of the main dipoles…

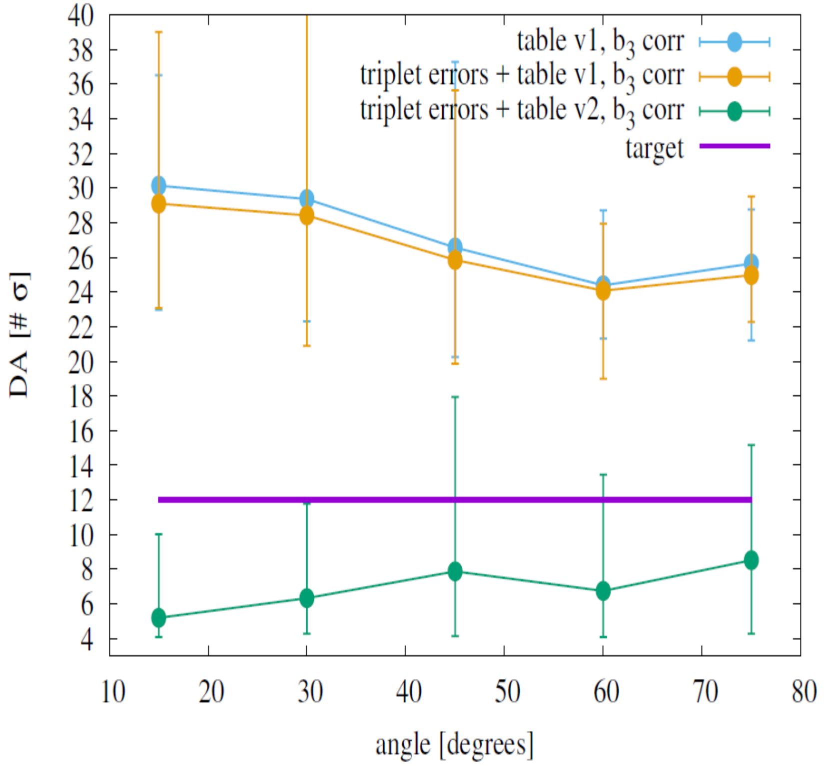
DA new lattice & table v2

- Preliminary DA at 3.3 TeV energy

- DA below the target!

⇒ Just looking at the values in the table v2 the 1.3 TeV seems to be excluded from DA point of view

⇒ Further iterations with magnets people needed



Optics IV: 97.75 km layout, L*=40 m, Qx=110.28, Qy=108.31

Normal and skew quadrupole errors in main dipoles

In all DA simulations shown b2 and a2 dipole errors are not taken into account (as well as mis-alignment).

Need dedicated correction before to be considered in DA simulations.

For status of orbit correction see **D. Boutin** talk

FCC table v2

[redacted]

	Systematic					Uncertainty		Random	
Normal	Geometric	Saturation	Persistent	Injection	High Field	Injection	High Field	Injection	High Field
2	-2.230	-44.610	0.000	-2.230	-46.840	0.922	0.922	0.922	0.922
Skew									
2	0.000	0.000	0.000	0.000	0.000	1.040	1.040	1.040	1.040

LHC project report 501

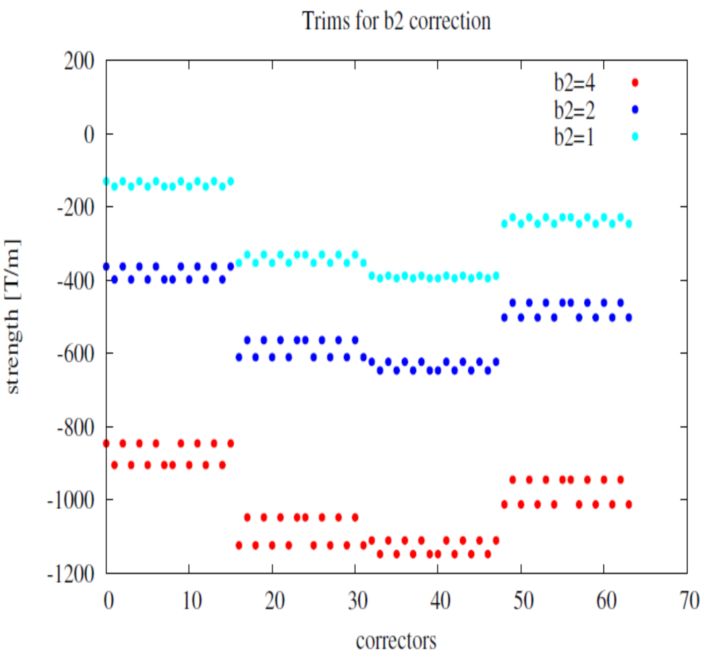
a_n & b_n	Main dipole MB (Sum of Persistent & Geometric)			
	Average		Uncertainty	Random
	Outer	Inner	(max. value)	(r.m.s.)
b_1	−8.630	−8.630	10.037	5.024
b_2	−1.405	1.399	.850	.746
a_2	−.002	−.002	.510	1.864

Systematic b2 correction (1/2)

8+8 normal trims installed at the entrance and exit of long arcs (same scheme as LHC)

Max 4 unit of systematic b2 matched so far

Too strong trims required (even rescaling for the length)



Systematic b2 correction (2/2)

b_{2S} =10 10^{-4} units	SAR AB KQF/KQD [T/m]	LAR BC KQF/KQD [T/m]	β change
nominal	376.8/-376.8	376./-377.4	
Arc by arc	379.8/-373.6	373.4/-380.3	30%
global	377.1/-377.1	376.3/-377.7	60%

- Few % of main quadrupole gradient give a big change in β

$\Rightarrow$ need to re-match all insertions

$\Rightarrow$ need to check the impact on apertures calculation

- Match more than 10 unit of systematic b2 needs even more work/thinking

a_{2U} tolerance

Analytic calculation for one arc*

$$|\Delta c_{-}^{mqs}| = |\Delta c_{-}^{arc}|$$

$$\frac{L_{mqs}}{2\pi}\sqrt{\beta_{x,mqs}\beta_{y,mqs}}\sum_{j=1}^{N_{mqs}}|cos(\mu_{x,j}-\mu_{y,i})|K_{max}(\%)|$$

$$\frac{N_{mb}^{cell}}{2\pi}\sqrt{\beta_F\beta_D}\frac{sin(N_{cell}(\mu_x-\mu_y)_{cell}/2.)}{sin((\mu_x-\mu_y)_{cell}/2.)}|\frac{\alpha_{mb}a_{2U}}{R_{ref}}|$$

$$K_{max} = 0.3\frac{B_{max}[T/m]}{Energy[GeV]}$$

A factor 1/7 with respect to LHC

A factor 3 or 4 bigger than LHC

to efficiently correct the coupling of the short arc in the long arc: $\Delta\mu_x \approx \Delta\mu_y$ in the insertions

L mqs [m]	B max [T/m]	# mqs in one LAR	a_{2U} 10^{-4} (50% kmax)	comment
0.32	120	4	~0.06	LHC correctors
1**	140**	16	~0.9	FCC equivalent tolerance of LHC
1.4	140	16	~1.2	To correct a_{2U} of table v0/v2

*LHC project report 501

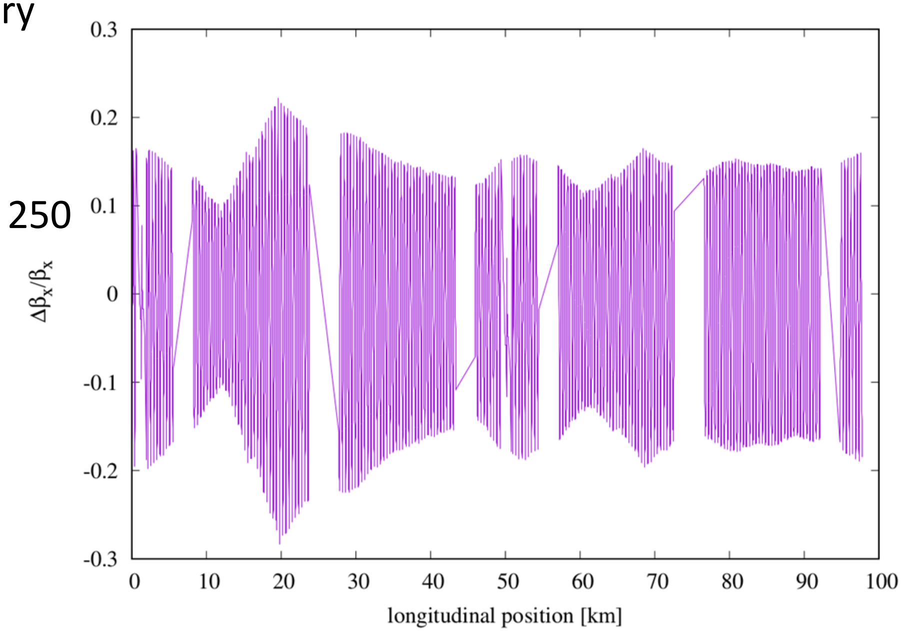
** **D. Schoerling**

a_{2U} correction

16 correctors in long arc only with mid arc symmetry and
180° phase advance

for a_{2U} = 1.1 unit : max correctors strength so far is 250 T/m with L=0.32 m $\Rightarrow$ i.e. ~80 T/m for L=1 m

$\Delta\beta/\beta$ =30%



if $\Delta\beta/\beta$ =10% at injection for aperture requirements $\Rightarrow$ dedicated beta-beating correction is required

$\Rightarrow$ **Rogelio** and **Jaime** shown interest in applying the LHC coupling and beta-beating correction to FCC

Conclusion

- First and second order optics details can have still a significant impact on DA

- Landau Damping Octupoles gives big reduction of DA even if octupoles with same sign

- Preliminary results with new dipole field quality table v2 gives DA below the target of 12 σ at 3.3 TeV injection energy $\Rightarrow$ 1.3 TeV seems to be excluded from DA point of view

- Systematic b_2 correction cannot be corrected with trims, few % of main quadrupole strength can correct 10 unit with 30% change in the arc's beta functions $\Rightarrow$ apertures computation still to be checked… more than 10 unit systematic b_2 is challenging

- Correction of a_{2U} = 1.1 unit seems to be feasible with 16 skew correctors per long arc (gradient=140 T/m, and length=1.4 m) but residual beta-beating need dedicated correction

Outlook

- Follow up of present studies
- Study a3 correction
- Tune scan at injection
- Impact of Main Quadrupole field quality