CLIC Final Focus System (FFS) Multipoles Requirements

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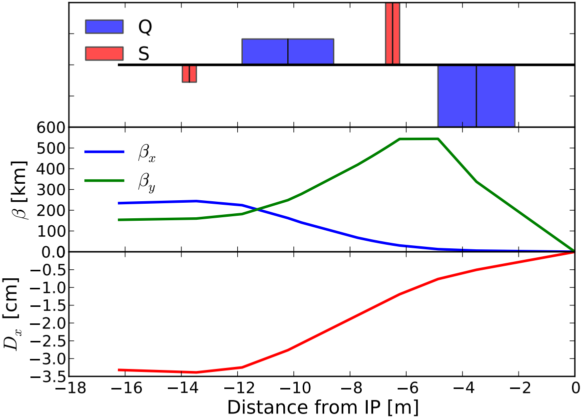
- CLIC Beam Delivery System (BDS) imposes challenging optics in order to create the smallest beam spot possible.
- A QD0 prototype was recently constructed, more prototypes are in the planning.
- Giving accurate specifications is challenging.
- CLIC CDR specified 5 units of **octupolar** tolerance for QD0 and L* of 3.5 m.
- Imperfections may cause bigger problems, in particular skew components.

Outline

- QD0 Prototype
- Simulations
- QD0 Error Margins
- QF1 Error Margins
- SD0/QD2 Error Margins
- ILC QF1 Error Margins and comparison to Mapclass

FFS Overview



Error Units

Error units in this presentation given as **relative** to the base multipole, multiplied by 10^4, for a radius of 1 mm.

Strength k_j is related to the relative error err_j as

$$k_j = r^{n-j} \frac{j!}{n!} \cdot err_j \cdot k_n \tag{1}$$

where r is the radius, n is the base order (2 for QD0), and j is the order of the multipole component (e.g. 4 for octupole). k_n is the strength of the reference multipole.

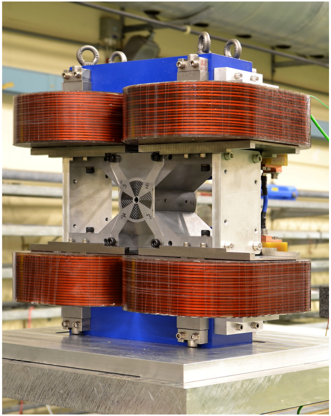


Image courtesy M. Modena

QD0 Prototype

NI [A]	Current [A]	b3	b4	b5	b6	b7	b8	b9	b10		a3	a4	a5	a6	a7	a8
0.0	0.0	8.86	6.21	-0.50	5.12	0.03	0.03	0.00	-0.02		9.19	0.42	-1.36	-0.25	0.02	-0.01
1004.4	3.1	6.61	5.16	-0.44	3.80	0.02	0.02	0.00	-0.02		0.97	0.53	-0.91	-0.11	0.03	0.00
2008.8	6.2	2.38	3.66	-0.29	0.93	0.01	0.01	0.00	-0.02		0.02	0.02	-0.56	0.09	0.00	0.00
2462.4	7.6	2.24	3.66	-0.22	0.02	0.02	0.01	0.00	-0.02		-0.90	0.26	-0.54	0.12	0.01	0.00
5022.0	15.5	0.71	3.36	-0.31	-0.72	0.02	0.00	0.00	-0.01		4.00	-0.40	-0.41	0.16	-0.01	0.00
6026.4	18.6	1.00	3.48	-0.27	-0.70	0.02	0.00	0.00	-0.01		3.20	-0.35	-0.48	0.16	0.00	0.00
5022.0	15.5	0.99	3.46	-0.29	-0.71	0.02	0.00	0.00	-0.01		4.15	-0.30	-0.44	0.15	0.00	0.00
2268.0	7.0	3.34	3.54	-0.26	0.34	0.02	0.01	0.00	-0.02		0.49	0.32	-0.56	0.10	0.00	-0.01
2008.8	6.2	3.18	3.57	-0.21	0.86	0.02	0.01	0.00	-0.02		-0.25	0.24	-0.44	0.08	0.01	0.00
1004.4	3.1	7.06	5.11	-0.45	3.73	0.04	0.02	0.00	-0.02		1.96	0.27	-0.94	-0.18	0.02	-0.01
0.0	0.0	8.35	6.33	-0.57	5.10	0.03	0.03	0.00	-0.02		9.13	0.37	-1.13	-0.24	0.02	-0.01

Table from M. Modena et Al.

- $6000\ \mathrm{A}$ corresponds to normal running conditions.
- Well below the 5 units specified for octupolar components.
- Skew components are obviously machining imperfections, R&D ongoing to know what tolerances can be expected.

Introduced these measurements in PLACET/GUINEA-PIG and simulated the luminosity loss.

Included components	Luminosity $[L/L_0]$
Octupolar and higher	0.98
Normal sext.	0.95
Skew sext.	0.79
All	0.73

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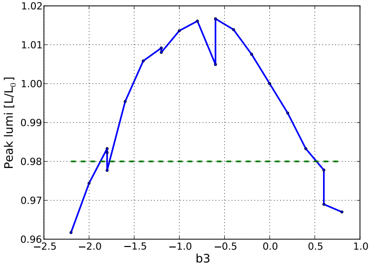
- But our tuning simulations show we can get back to at least 94-95%

In the following we evaluate the effect of **one** multipolar component for **one** magnet at the time.

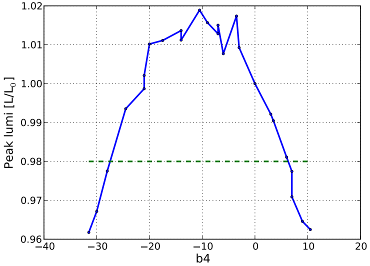
- We loosely define the requirement as keeping luminosity loss below 2% loss per component.
- Please note, 2% per multipole component per magnet equals ... Quite a lot.

Normal Components



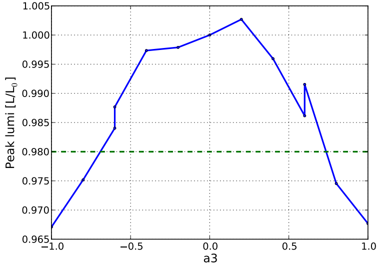
- The *b*3 should be less than 0.5 units, compared to about 1 units measured in the prototype.
- There is a larger tolerance if *b*3 is negative.

Normal Components



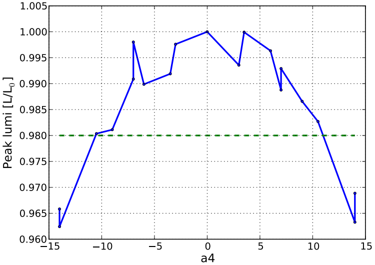
- Losses from *b4* corresponds well to the requirement specified in the CDR.
- Again, tolerances are higher if the *b4* is negative.

Skew Components



- The *a*3 should be less than 0.7 units, compared to more than 3 units measured in the prototype.

Skew Components



- Up to about 8-10 units of a4 can be accepted.
- Slightly more than the b4 we can accept since the curve is symmetric.

QD0 Table

The units are given at the limit of 2% luminosity loss. Since the normal components are asymmetric, we give both the positive and negative margin.

Tolerances increase rapidly for higher orders.

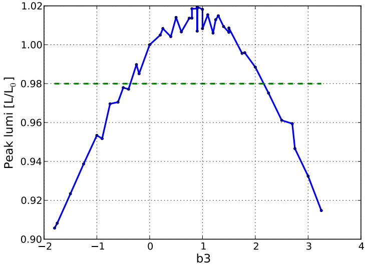
	min	max
b3	-1.8	0.5
b4	-27	6
b5	-220	80
a3	$\pm$0.7	
a4	$\pm$8	
a5	$\pm$130	

QF1 Multipolar Components

The horizontal beam size is much larger in QF1
-> more fragile to imperfections.

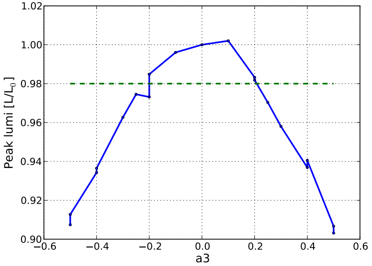
QF1 have smaller alignment tolerances than QD0 [1]

QF1 Sextupolar Errors



- For QD0 we could accept 0.5 units of b3, here 0.4.
- Again asymmetric, but opposite direction.

QF1 Sextupolar Errors



- Skew components cause more trouble in the QF1 compared to QD0.

QF1 Table

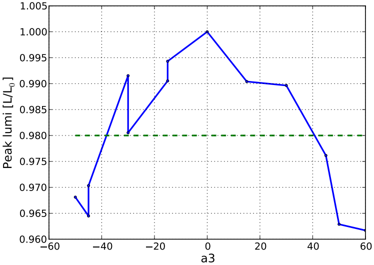
	min	max
b3	-0.4	2.2
b4	-2.5	3.3
b5	-4	18
b6	-15	32
a3	$\pm$0.2	
a4	$\pm$0.5	
a5	$\pm$1.7	
a6	$\pm$4.8	

- Skew components have tighter tolerances.
- Generally tolerances do not drop off as rapidly for higher orders.

QD2/SD0 Multipolar Components

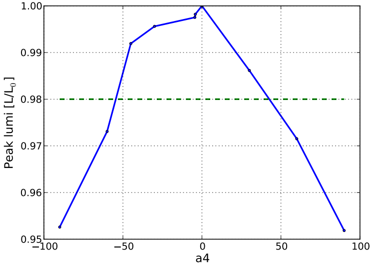
SD0 and QD2 are expected to be less problematic since their integrated strengths are lower, however we checked them for completeness.
SD0 prototype design specifications are under development, so these results aid in selecting the optimal specifications.

Skew Errors in QD2/SD0



- QD2 multipolar errors are not problematic.
- About 40 units of a3 can be tolerated.

Skew Errors in QD2/SD0



- SD0 multipolar errors are again not problematic.
- About 50 units of a3 can be tolerated.

Summary QD2/SD0

- For any multipole, the tolerance is well above 10 units for both QD2 and SD0.
- The skew components generally have somewhat tighter tolerances compared to normal components.

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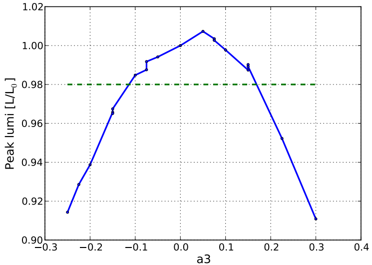
- For any multipole, the tolerance is well above 10 units for both QD2 and SD0.
- The skew components generally have somewhat tighter tolerances compared to normal components.
- The tolerances for QD2 and SD0 do not look alarming, and are more relaxed than QD0/QF1.

The QF1 is expected to be the most sensitive magnet for ILC in terms of multipolar errors.

For ILC we use 3 mm radius instead of 1 mm, to scale with the lower beam energy.

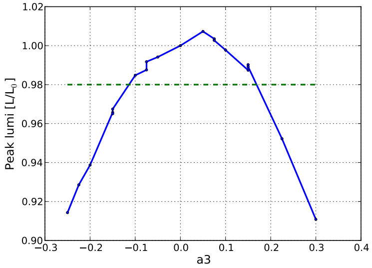
We have checked these errors in two independent studies, using PLACET as for CLIC, and using Mapclass to simulate the beam size growth.

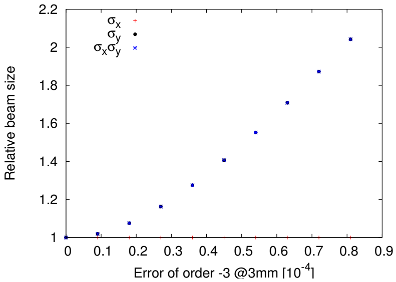
Comparison Mapclass/PLACET



- PLACET gives a luminosity loss of ∼2% at around 0.1 units of a3.

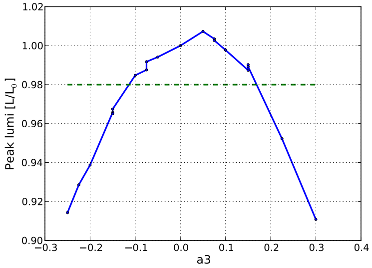
Comparison Mapclass/PLACET

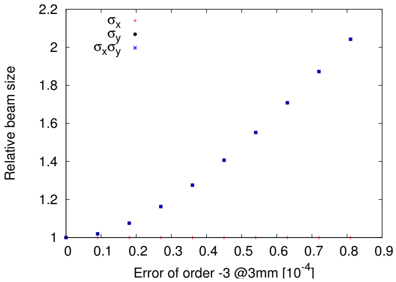




- PLACET gives a luminosity loss of ∼2% at around 0.1 units of a3.
- For the same value of a3, a few percent increase in vertical beam size is reported from Mapclass.

Comparison Mapclass/PLACET





- PLACET gives a luminosity loss of ∼2% at around 0.1 units of a3.
- For the same value of a3, a few percent increase in vertical beam size is reported from Mapclass.
- Generally PLACET show asymmetric margins for skew components (??)

Table of ILC QF1

	min	max
b3	-1.2	2.3
b4	-4.2	1.7
b5	-3	5
b6	-12	4
a3	-0.1	0.15
a4	-0.15	0.3
a5	-0.2	0.4
a6	-0.4	0.75

- Margins for b3/a3 are comparable to CLIC QF1.
- Higher orders seem to have a bit tighter tolerances.

Summary

- Luminosity loss due to multipolar components has been evaluated for all significant FFS magnets in CLIC@3TeV, and for ILC QF1.
- Good agreement between Mapclass and PLACET evaluations. Mapclass slightly more conservative.
- QF1 is the most fragile magnet in terms of multipolar errors in CLIC.
- For ILC, note that the higher orders seem to make a greater impact wrt. CLIC.
- CLIC@500GeV lattice should be checked as well...

References

Jochem Snuverink, Javier Barranco Garcia, Hector Garcia Morales, Yngve Inntjore Levinsen, Rogelio Tomás Garcia, and Daniel Schulte.
CLIC Final Focus System Alignment and Magnet Tolerances.