Proposal: Two octupoles and QD0 for the ultra-low beta* optics

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Outline

Ultra-low β^* Optics

Project	Status	Energy [GeV]	$\gamma\epsilon_y$ [nm]	σ_y^* [nm]	β_y^* [mm]	L* [m]	ξ_y
FFTB	Designed	46.6	2000	52	0.1	0.4	4000
FFTB	Measured	46.6	2000	70	-	0.4	-
ATF2 Nominal	Designed	1.3	30	37	0.1	1.0	10000
ILC	Designed	250	35	5.9	0.48	3.5	7500
ATF2 Ultra-low β^*	Proposed	1.3	30	23	0.025	1.0	40000
CLIC L*= 3.5 m	Designed	1500	20	1	0.069	3.5	50000

Exploration of ultra-low β^* optics is of common interest for future e^+e^- LC.

ATF2 σ_y^* values are calculated assuming error-free lattices.

Impact of Magnetic errors

Negligible effect for the Nominal lattice.
35% $\Delta\sigma_y^*$ for the Ultra-low β^* lattice.

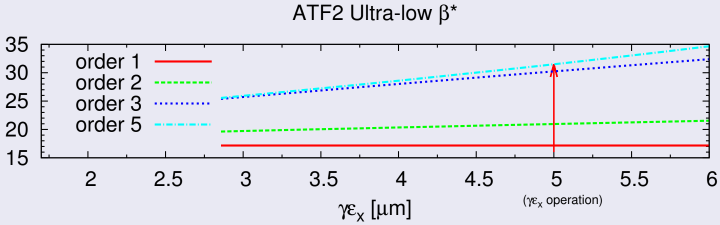
Project	Magnetic Errors	β_x^* [mm]	σ_x^* [μm]	β_y^* [μm]	σ_y^* [nm]
ATF2 Nominal	OFF	4	3.2	100	37
ATF2 Nominal	ON	4	3.2	100	38
ATF2 $10\beta_x^* 1\beta_y^*$	ON	40	9.0	100	37
ATF2 Ultra-low β^*	OFF	4	3.2	25	23
ATF2 Ultra-low β^*	ON	4	3.2	25	31
ATF2 $10\beta_x^* \frac{1}{4}\beta_y^*$	ON	40	9.0	25	22

Presently ATF2 is running with a modified optics in order to:

- lower the backgrounds at the IP
- minimise the potential impact of the magnetic errors

Beam size growth

The MAPCLASS analysis reveals which order is the most responsible of the evaluated $\Delta\sigma_y^*$.



If $\delta p/p$=0 $\rightarrow$ σ_y^*=19.5 nm

Chromatic Skew Octupole Aberration

CONSIDERED SOLUTIONS

QD0 Field quality

Relative tolerances at R = 0.01 cm for the multipole content of QD0FF. Each tolerance represents a $\Delta\sigma_y^*$=2%.

QD0FF		Normal [10^{-4}]			
		6-pole	8-pole	10-pole	12-pole
	Tol.	0.2	1.8	3.1	15.0
	Meas.	1.8	0.4	2.9	3.5
	PM	-1.8	-0.3	-0.5	1.2
		Skew [10^{-4}]			
QD0FF		4-pole	6-pole	10-pole	12-pole
	Tol.	0.2	0.8	0.6	9.0
	Meas.	1.8	0.3	0.3	0.2
	PM	0.2	0.1	-0.1	-0.2

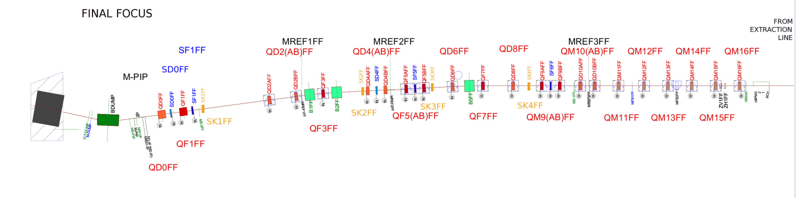
The obtained IP spot sizes are:

σ_x^* **= 3.3 μm** σ_y^* **= 27 nm**

QD0FF is a partial contributor to the observed $\Delta\sigma_y^*$.

Octupoles Insertion

We have inserted 2 octupoles of 10 cm (magnetic length) separated by a phase advanced of π.



Option A:

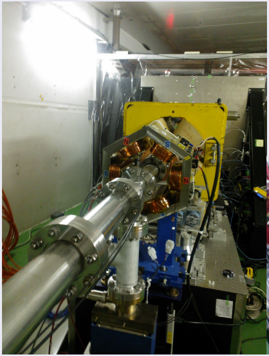
OCT2FF located in between of QD4BFF and QD4AFF (0.4 m).
OCT1FF located in between of SD0FF and QD0FF (0.3 m)

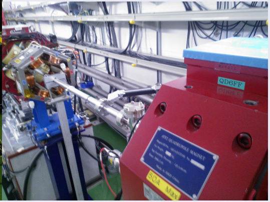
Option B:

OCT2FF located in between of QD6FF and SK3FF (1.0 m).
OCT1FF located right before SK1FF (3.8 m).

ATF2 FFS Beam line

Upstream of SK1FF Downstream of QD6FF





High Order Multipoles Optimisation

The Simplex algorithm has been used to optimise

- Octupole magnets
- Octupole Tilts
- Normal sextupole magnets
- Skew sextupole magnets

Obtained normalised strength for the OCTs are:

Option-A:	$K_{(OCT1FF)}$ = 1238 m^{-4}	$K_{(OCT2FF)}$ = -359 m^{-4}
	$Tilt_{(OCT1FF)}$ = -1.6 deg	$Tilt_{(OCT2FF)}$ = -0.9 deg
Option-B:	$K_{(OCT1FF)}$ = 1526 m^{-4}	$K_{(OCT2FF)}$ = -567 m^{-4}
	$Tilt_{(OCT1FF)}$ = -2.0 deg	$Tilt_{(OCT2FF)}$ = -1.5 deg

The obtained IP spot sizes are:

Option-A:	**σ_x^* = 3.3 μm**	**σ_y^* = 22 nm**
Option-B:	**σ_x^* = 3.4 μm**	**σ_y^* = 21 nm**

MAGNET DESIGNS

QD0FF Magnet

Adopted QD0FF design: **HYBRID solution**[a]
PM blocks + electromagnetic coils

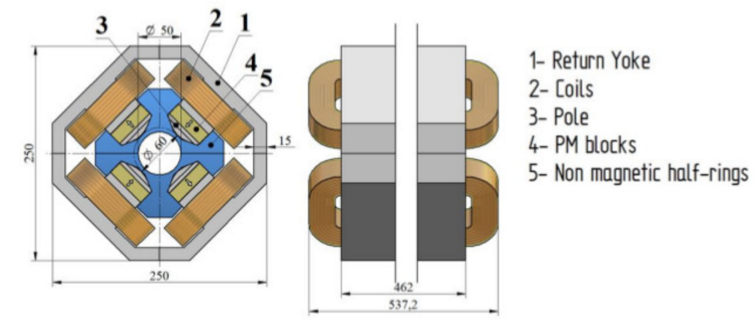


Figure 1: Preliminary layout of the quadrupole magnet, arrows indicate the direction of magnetization of the permanent magnet blocks.

[a] for further details: M. Modena, *Magnet Studies*, CLIC Workshop 2014.

Octupole Specifications

Adopted OCTFF design: **Electromagnetic** [a].

Parameter	Unit	Value
Nominal Gradient	Tm-3	8565
Required tunability	%	-75, +20
Integrated gradient	T/m-2	560
Aperture radius	mm	50
Iron length	m	0.100
Magnetic length	m	0.106
Coil number of turns		61
Conductor size	mm x mm	5 x 5
Ampere-turns	A	1200
Current	A	19.7
Resistance (per coil)	mÎ©	14
Conductor length (per coil)	m	19.9
Conductor mass (per coil)	kg	4.5
Yoke mass	kg	56
Total mass	kg	92

[a] for further details: M. Modena, *Magnet Studies*

Octupole Field Quality (Option-A)

Relative tolerances at R = 0.02 cm for the multipole content of the octupole magnets. Each tolerance represents a $\Delta\sigma_y^*$=2%.

OCT1FF	Normal [10^0]			
	4-pole 0.001	6-pole 0.013	10-pole 0.4	12-pole 1.7
OCT1FF	Skew [10^0]			
	4-pole 0.001	6-pole 0.007	10-pole 0.2	12-pole 0.7
OCT2FF	Normal [10^0]			
	4-pole 0.002	6-pole 0.01	10-pole 1.5	12-pole 2.4
OCT2FF	Skew [10^0]			
	4-pole 0.0006	6-pole 0.008	10-pole 0.9	12-pole 4.8

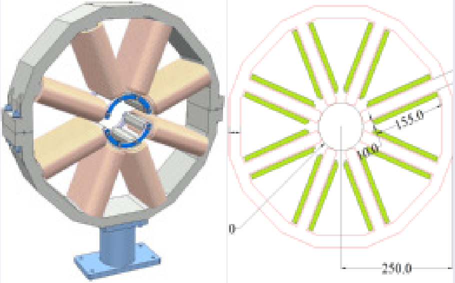
4-pole and 6-pole errors could be compensated by re-matching quads and optimising sexts.

10-pole and 12-pole tolerances should be easily achievable.

QD0FF Magnet

Preliminary design

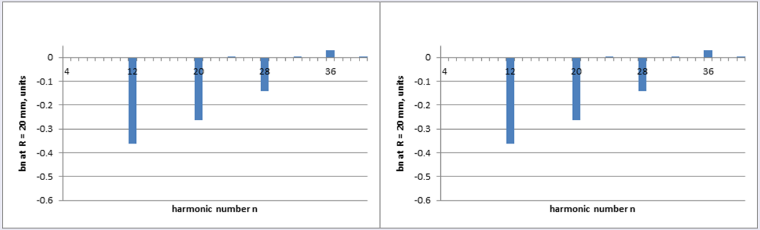
- two halves of yokes
- big aperture
  - avoid low saturation
  - ease the assembling
  - field quality
- coils optimised for low current density



QD0FF Magnet

Field Quality

Obtained field quality in units of 10^{-4} at a radius of 20 mm for the permitted harmonics (12-pole, 20-pole, 28-pole and 36-pole).



The field quality is less than 10^{-4} at a radius of 20 mm.

ADDITIONAL ADVANTAGES

Tuning Study (Option-A)

Error Conditions

The tuning study considers 100 machines with different initial error conditions.
Errors are randomly assigned following a Gaussian distribution.

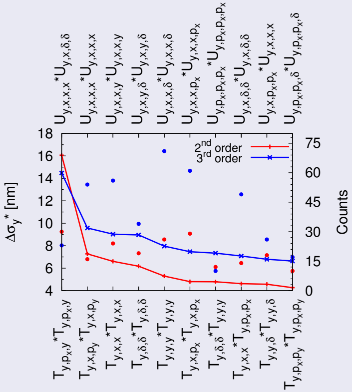
Error	Unit	σ_{error}
Horizontal misalignment	[μm]	100
Vertical misalignment	[μm]	100
Tilt along *s*-coordinate	[μm]	300
Strength	[%]	0.1
IP measurement	[%]	10
Magnetic errors		ON

Tuning Results II

Knobs

With linear knobs only 33% of machines reach a $\sigma_y^* \leq 1.2\sigma_{y,0}^*$.

Residual IP aberrations:



2 order knobs:
$T_{y,p_x,y}$, T_{y,x,p_y},
$T_{y,\delta,\delta}$, $T_{y,x,x}$

3 order knobs:

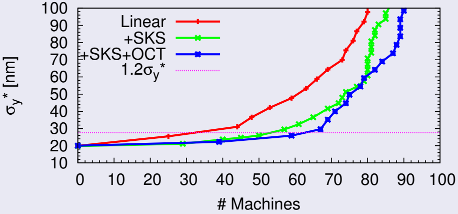
$U_{y,x,x,x}$, $U_{y,x,\delta,\delta}$.

Potential benefits for tuning the $10\beta_x^*$ and Nominal lattice!

Tuning Results II

High Order Knobs

Taking advantage of the skew sextupole and octupole magnets new knobs are obtained.

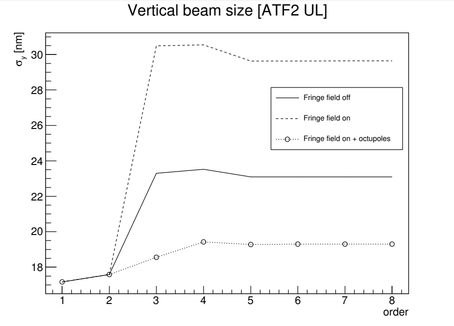


Linear knobs: 33% of machines reach a $\sigma_y^* \leq 1.2\sigma_{y,0}^*$.
Linear + *T-knobs: 54% of machines reach a* $\sigma_y^* \leq 1.2\sigma_{y,0}^*$.
Linear + T+U-knobs: 63% of machines reach a $\sigma_y^* \leq 1.2\sigma_{y,0}^*$. [a]

[a] more details: *TUPBA25, Proceedings of PAC2013, Pasadena, (USA)*

Fringe Fields Compensation

Recent studies on the effect of fringe fields of the FD[a] have shown $\Delta\sigma_y^*$ for the ATF2 ultra-low β^* lattice.
Assuming an error-free lattice:



Partially compensation thanks to the OCTs.

[a] more details: M. Patecki, *Effects of quadrupolar fringe fields in Final Focus System*, CLIC Workshop 2014.

Summary and Outlook

Summary

- The insertion of 2 octupole magnets permits to achieve smaller σ_y^* than by replacing QD0FF
  - Permit the exploration of higher chromaticity lattices at ATF2.
  - Better tuning results
  - Fringe fields effects are mitigated
- ATF2 provides the possibility to assess the effect of field errors in FFS.
- Preliminary design of the octupole meet the requirements.

Outlook

- Continue on the design of the octupole magnet
- Design of the supports and movers.

Thank you for your attention!!