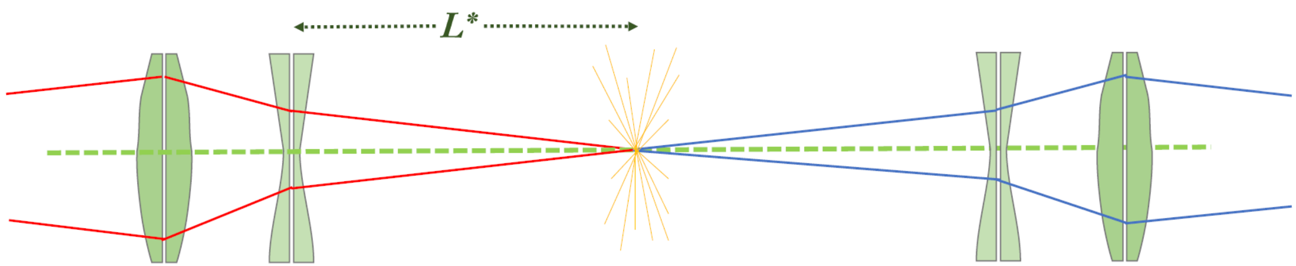
Long L* option for ILC Final Focus System

Design and **Tunability** of a short **Traditional** FFS scheme with $L^* = 8$ m



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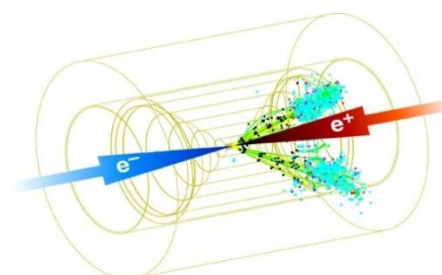
INTERNATIONAL WORKSHOP ON FUTURE LINEAR COLLIDERS

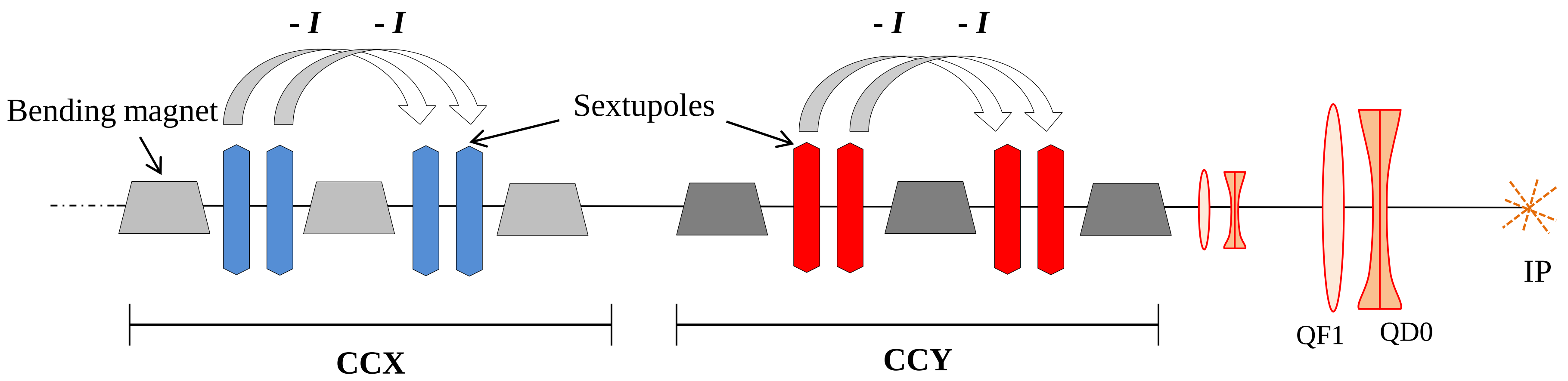


OUTLINE

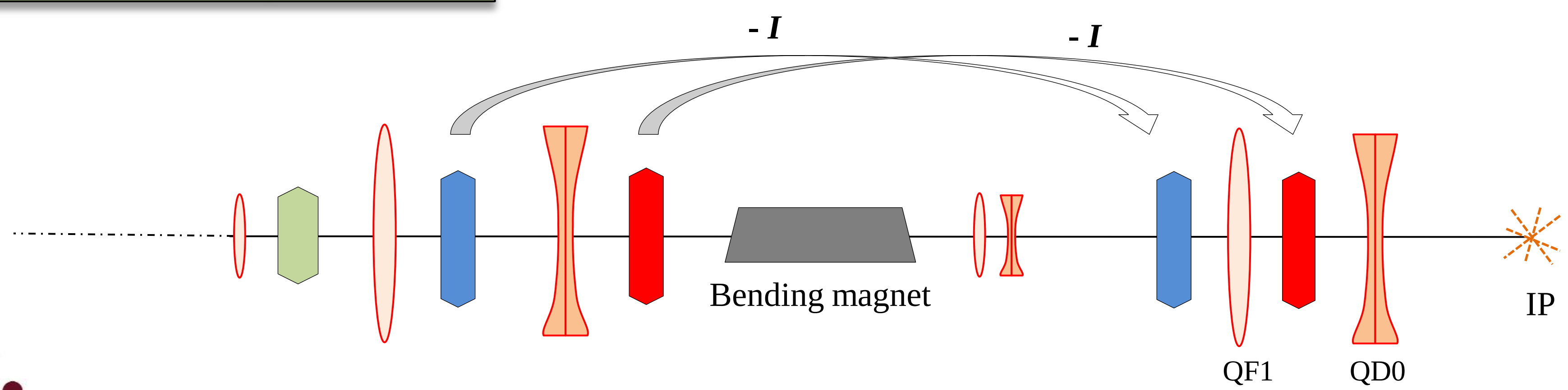
1. ILC Final Focus System
   - Review of the traditional design
   - Long L^* option for ILC Final Focus
2. Design optimization and results
   - Traditional lattice design and optimization for $L^* = 8$ m
   - Comparison for shorter L^* design
3. Tuning simulation using extra sextupoles
   - Tuning set up
   - Alignment procedure (A. Latina algorithm)
   - Steps before tuning the FFS
   - Tuning preliminary results
4. Summary and conclusions

1 Review of the FFS chromaticity correction

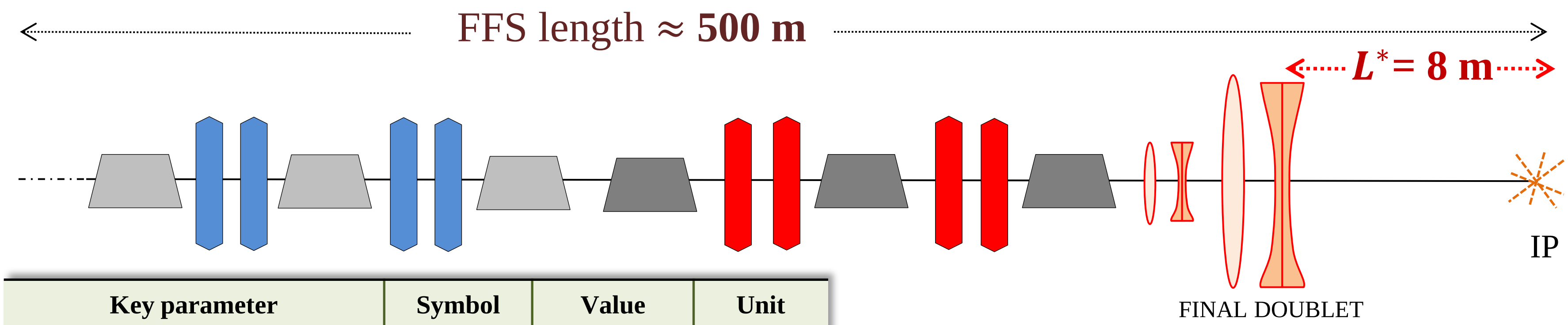
Traditional design → Chromaticity corrected in dedicated section but not in the Final Telescope



Local Chromaticity correction → Chromaticity corrected at the Final Doublet



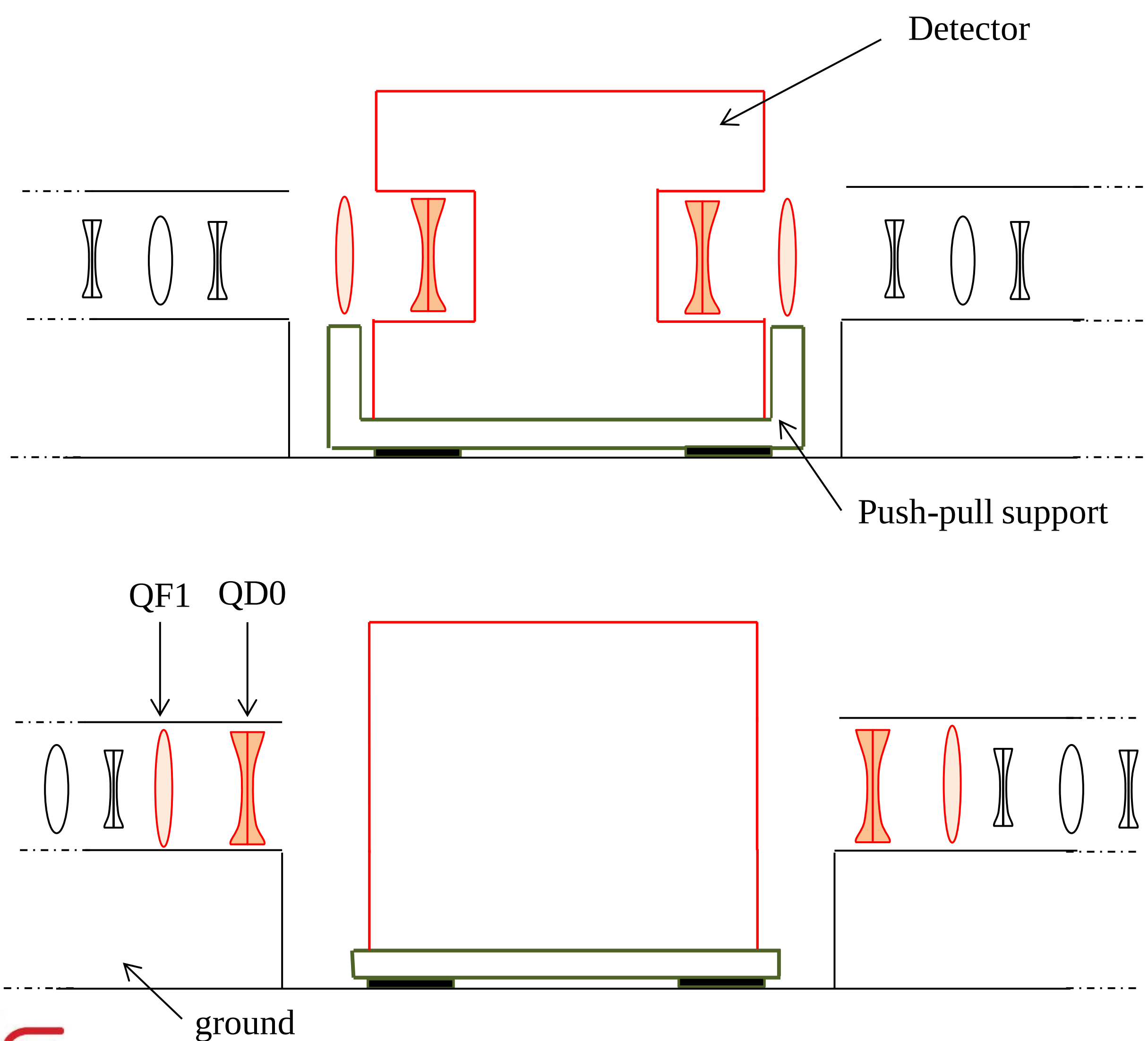
1 Review of the FFS chromaticity correction



Key parameter	Symbol	Value	Unit
Beam energy	E_{beam}	250	GeV
FFS length	l	**500**	m
Last Drift	L^*	**8**	m
Normalized emittances	$\epsilon_{Nx}/\epsilon_{Ny}$	10 / 0.035	µm
IP β-functions	β_x^* / β_y^*	**11 / 0.48**	mm
Nominal beam sizes	σ_x^* / σ_y^*	**474 / 5.87**	nm
RMS bunch length	σ_z	300	µm
RMS energy spread	σ_δ	0.125	%
Bunch population	$N^{+/-}$	2×10^{10}	
Numbers of bunches	n_b	1312	
Collision rate	f_{rep}	5	Hz
Nominal total luminosity	L_T	$\mathbf{1.5 \times 10^{34}}$	$cm^{-2}s^{-1}$
Fraction of luminosity in top 1%	$L_{1\%}$ / L_T	58.3	%

- FFS design is driven by **correcting chromatic and geometric** aberrations
- Traditional scheme offers **separated functions** and straightforward cancellation of geometrical aberrations.
- Chromaticity $\xi \sim \frac{L^*+L_Q/2}{\beta^*}$ ⟹ **small β^*** and **long L^*** causes high chromatic aberrations
- **Not locally corrected** ⟹ unavoidable lack of cancellation of high order chromatic aberration.

1 Long L^* option for ILC Final Focus



ILC Baseline Design

- Small L^* using SC magnet
- Less chromaticity generated at the IP
- Large magnet vibration

Long L^* option

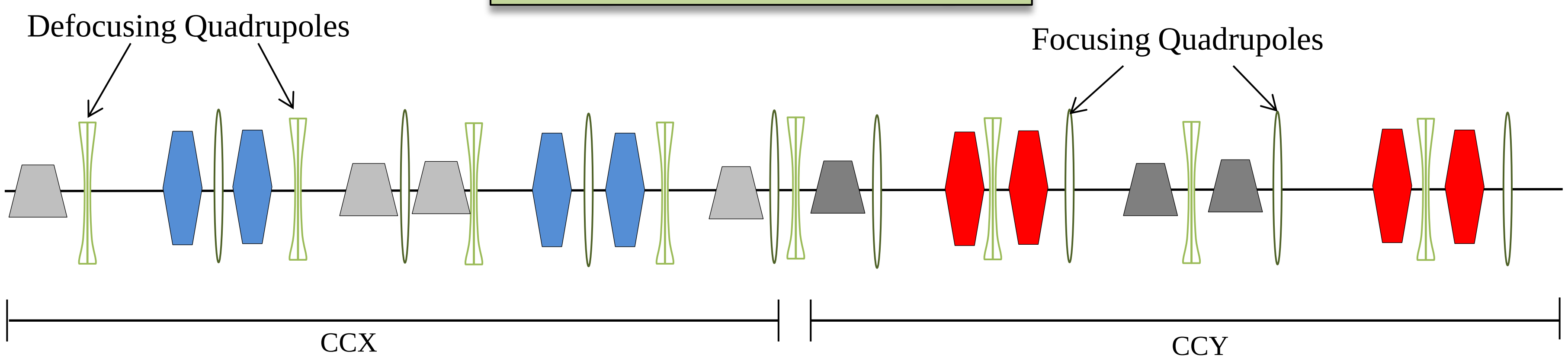
- Magnets outside of the detector on a stable ground ⇒ **small magnet vibration**
- Same magnet for all detectors

Problem :

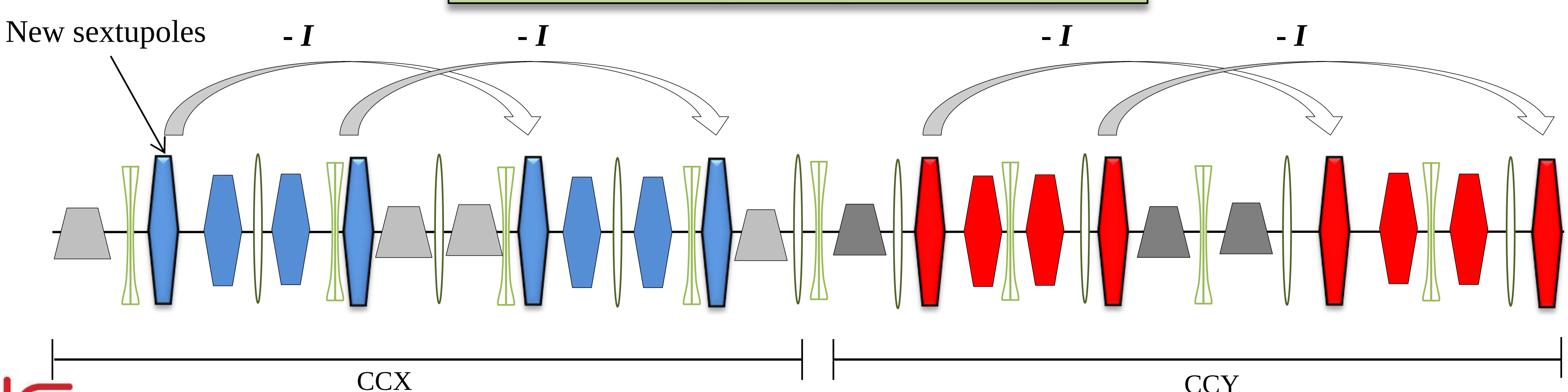
Luminosity and tuning of the FFS for the long L^* option

2 Traditional lattice design and optimization for $L^* = 8$ m

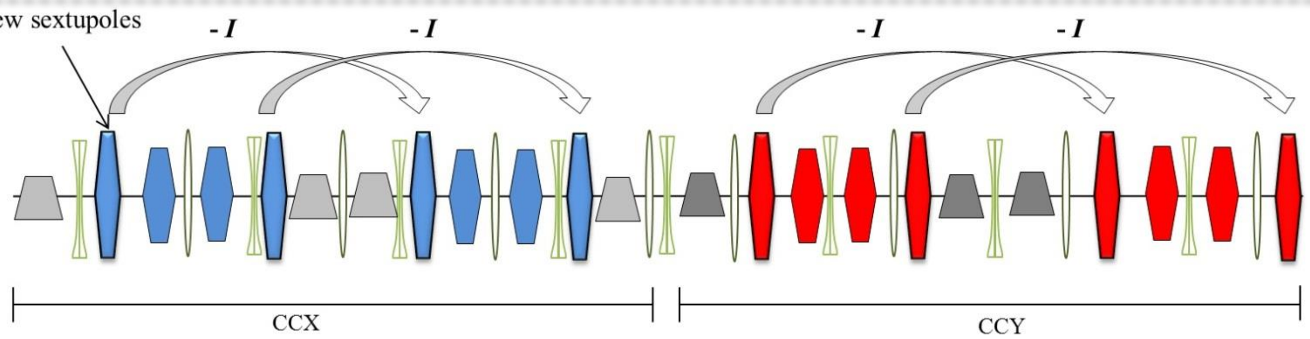
Original traditional design



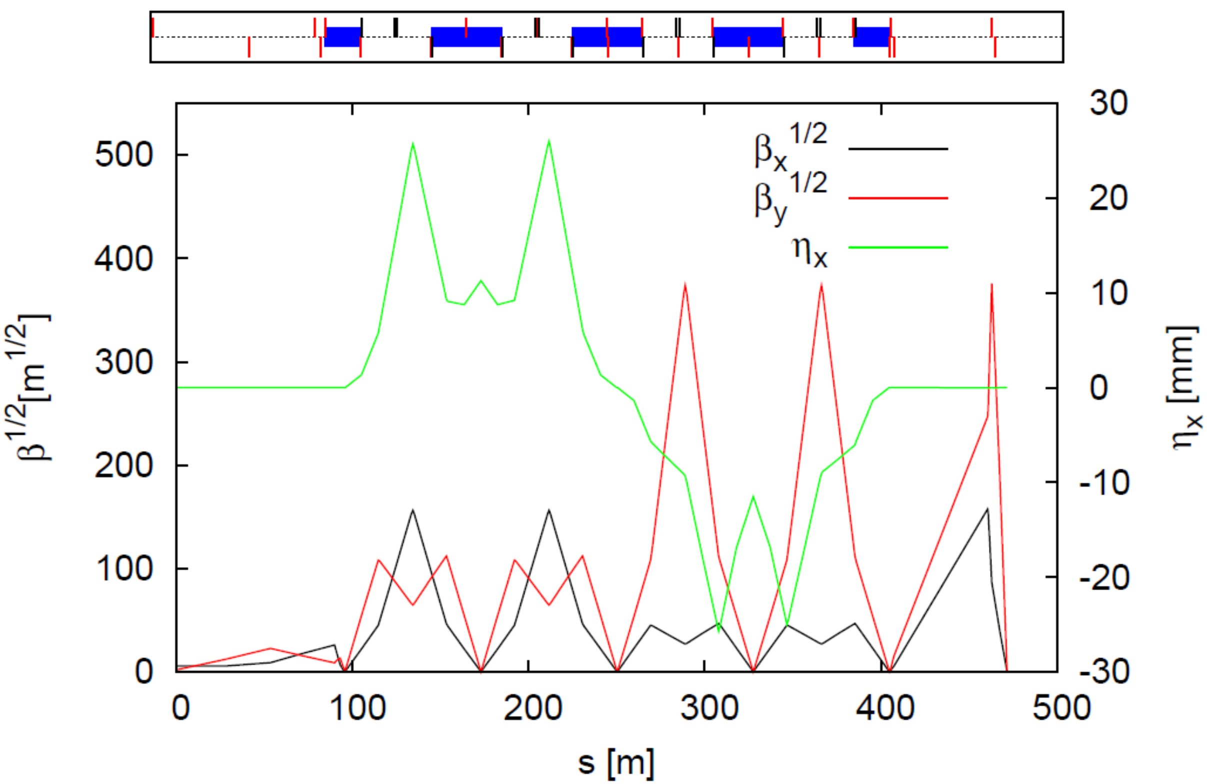
Traditional design using extra sextupoles



2 Traditional lattice design and optimization for $L^* = 8$ m



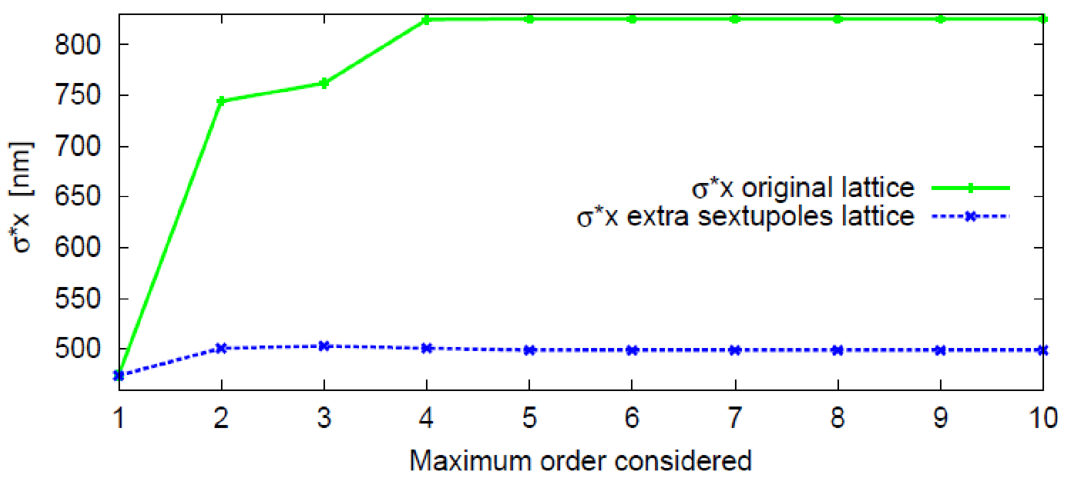
- **2 additional pairs** of sextupoles located in each chromatic correction section CCX and CCY
- high **β-function** and high **dispersion** D_x region
- ***-I* transformation** between pairs of sextupoles



2 Nonlinear optimization (w/o SR)

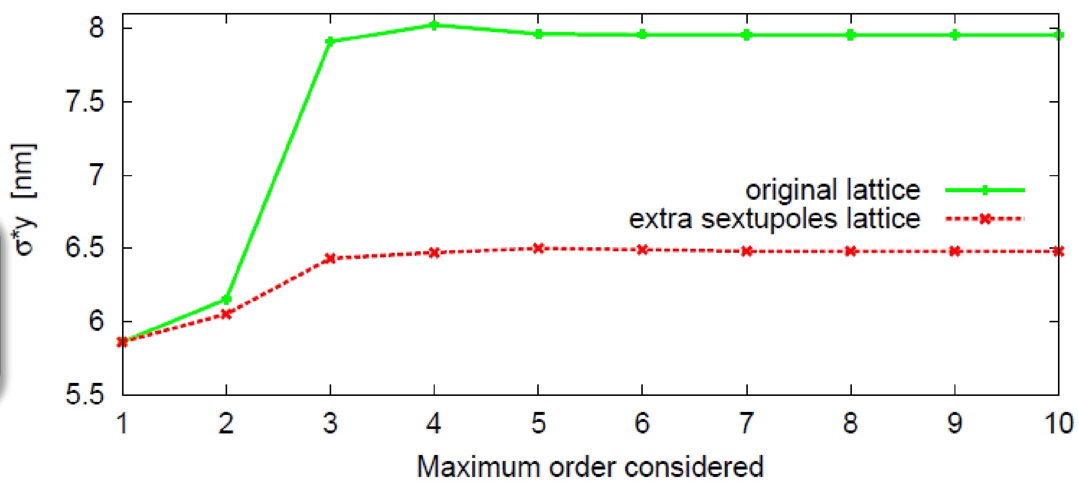
Original lattice:
σ_x (10) = 825.35 nm
74% of deviation from ILC design σ_x

Extra sextupoles lattice:
σ_x (10) = **498.1 nm**
5% of deviation from ILC design σ_x



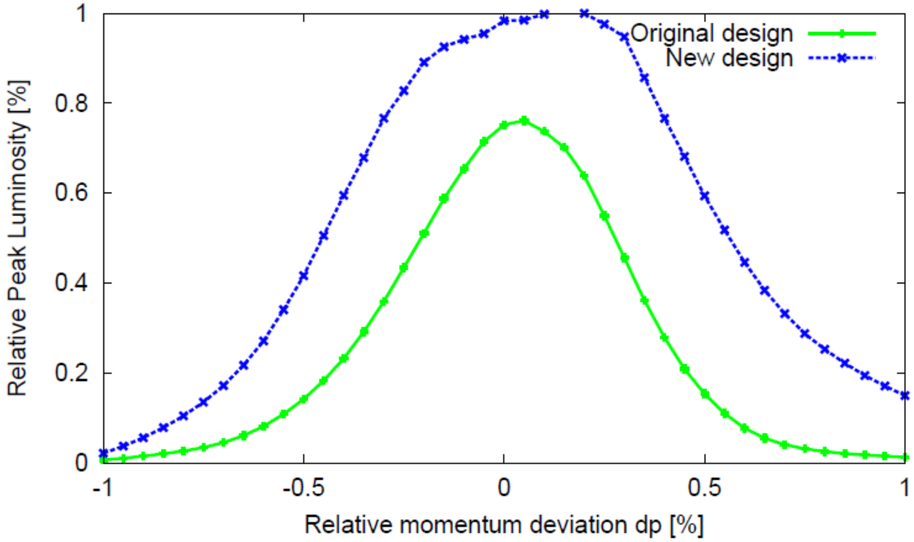
Original lattice:
σ_y (10) = 7.96 nm
36% of deviation from ILC design σ_y

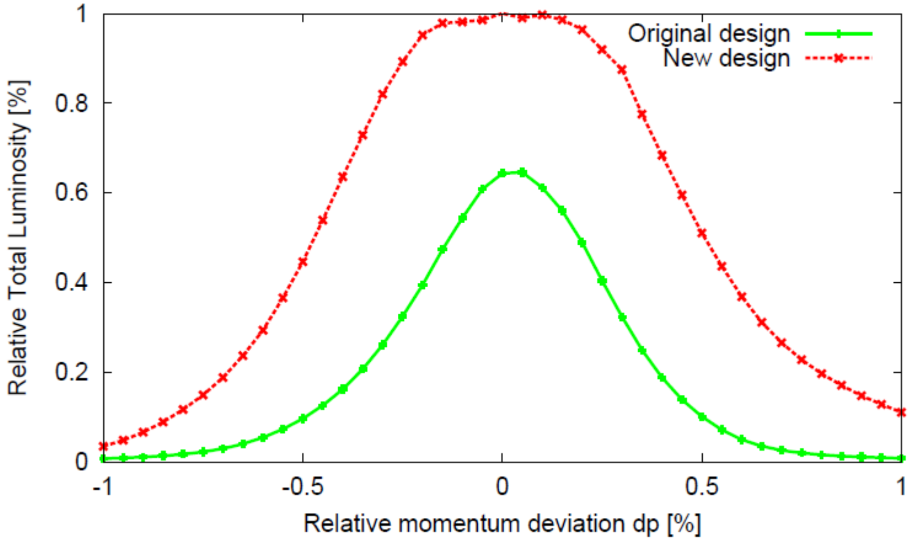
Extra sextupoles lattice:
σ_y (10) = **6.46 nm**
10% of deviation from ILC design σ_y



Calculations made using MAPCLASS code

2 Luminosity and momentum bandwidth (with SR)





Original lattice:
L_{peak} = $0.652\times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
Influence of synchrotron radiation : 1.2%

Extra sextupoles lattice:
L_{peak} = **0.84×10^{34}**$\text{cm}^{-2}\text{s}^{-1}$
Influence of synchrotron radiation : **5%**
Larger momentum bandwidth

Original lattice:
L_T = $0.874 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
42% of luminosity loss from $1.5 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
Influence of synchrotron radiation : 1.8%

Extra sextupoles lattice:
L_T = **1.36×10^{34}**$\text{cm}^{-2}\text{s}^{-1}$
10% of luminosity loss from $1.5\times 10^{34}\text{cm}^{-2}\text{s}^{-1}$
Influence of synchrotron radiation : **5.5%**
Larger momentum bandwidth

Calculations made using PLACET and Guinea-Pig

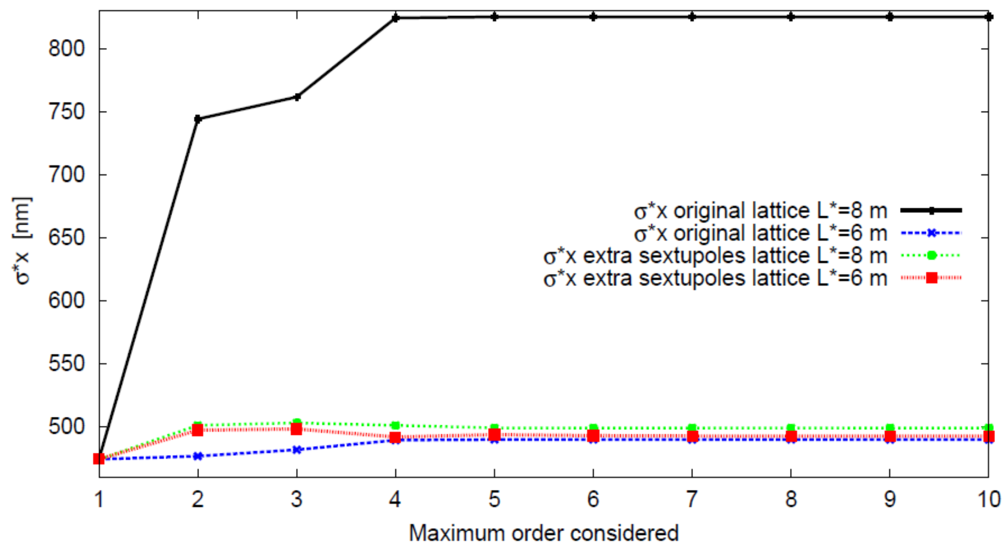
2 Comparison for shorter L^* design

What is the impact of the L^* on the traditional design performances?

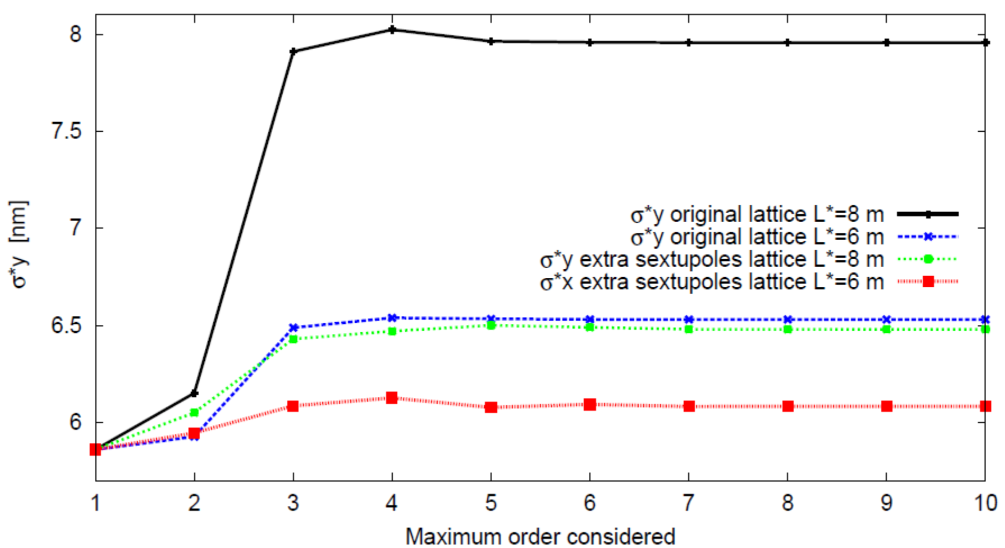
(Optimization for $L^* = 6$ m)

2 Shorter L^* design : nonlinear optimization (w/o SR)

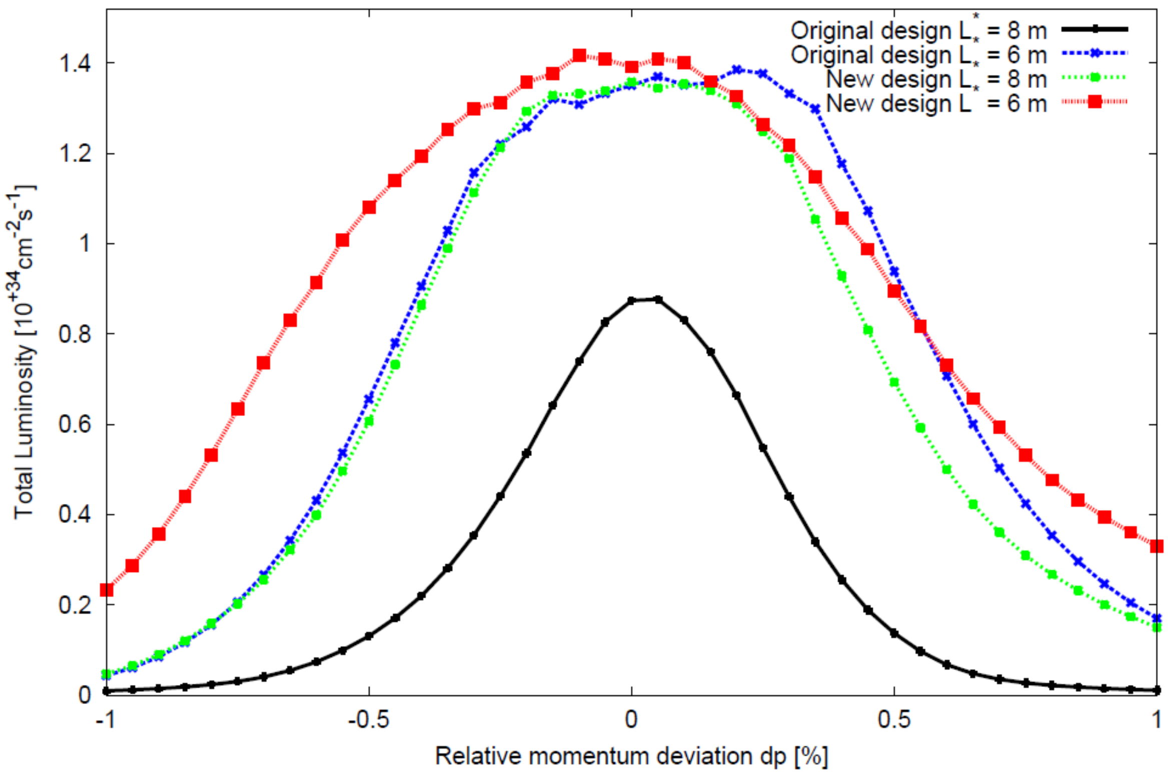
lattice	σ_x [nm]	σ_y [nm]
Original design L^*=8m	825.35	7.96
New design L*=8m	498.1	6.46
Original design L*=6m	**489.67**	**6.54**
New design L*=6m	**492.48**	**6.08**



- The original design for L^*= 6 m provides better horizontal beam size than the extra sextupole design for L^*= 8 m
- The extra sextupoles design for L^*= 6 m reduces only the vertical beam size σ_y
- The shorter L^* generates less chromatic aberrations at the FD



2 Shorter L^* design : momentum bandwidth (with SR)



- Original design L^*= 6 m : $\boldsymbol{L_T = 1.38 \times 10^{34}}\mathrm{cm^{-2}s^{-1}}$
- Extra sextupoles design L^*= 6 m : $\boldsymbol{L_T = 1.42 \times 10^{34}}\mathrm{cm^{-2}s^{-1}}$
- **Larger momentum acceptance** for both design with L^*= 6 m
- **Large impact of** L^* on the traditional scheme performance

3 Tuning simulation

- The performance of a linear collider drops when we consider **magnet misalignments**
- Under realistic conditions the luminosity is reduced and an **alignment procedure** is mandatory
- Tuning process brings the system to its design performance using **beam-based alignment** techniques and **beam parameters optimization** algorithm

Tuning set up (≠ ILC errors parameters)

- Short **Traditional** lattice using **extra sextupoles** and $\boldsymbol{L^*}$ **= 8 m**
- Take into account nonlinearities and synchrotron radiation
- 110 randomly misaligned machines (seeds)
- Initial misalignment : **10 µm** RMS in transverse plane (x, y)
- Elements misaligned : Quadrupoles, Sextupoles , BPMs
- Dipole correctors : Corrector + Quad + BPM
- BPM resolution : **10 nm**
- Tracking and luminosity measurement provided by PLACET and Guinea-Pig
- Luminosity goal : $\boldsymbol{L_T = 1.5 \times 10^{34}}\,\mathrm{cm^{-2}s^{-1}}$

3 Alignment procedure (A. Latina algorithm)

Beam Based Alignment (orbit correction) : Sextupoles switched OFF

1 **1-1 correction** $\begin{pmatrix} b_x \\ b_y \end{pmatrix} = \begin{pmatrix} R_{xx} & 0 \\ 0 & R_{yy} \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$

⇨ Minimize BPMs reading

2 **DFS** $\begin{pmatrix} b \\ \omega_1(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega_1 D \\ \beta I \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$

⇨ correct orbit and dispersion simultaneously

3 **Multipole-shunting (1)**
Sextupoles Powered individually

4 **Multipole Knobs 1**

Beam parameters optimization using orthogonal knobs

Beam Based Alignment Sextupoles switched ON

5 **DFS** $\begin{pmatrix} b \\ \omega_2(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega_2 D \\ \beta I \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$

6 **Multipole-shunting (2)**

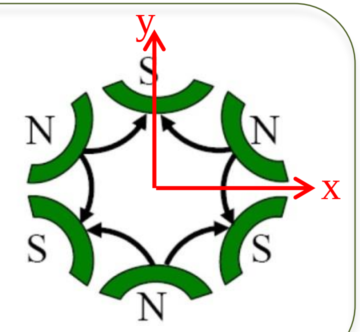
7 **Multipole Knobs 2**

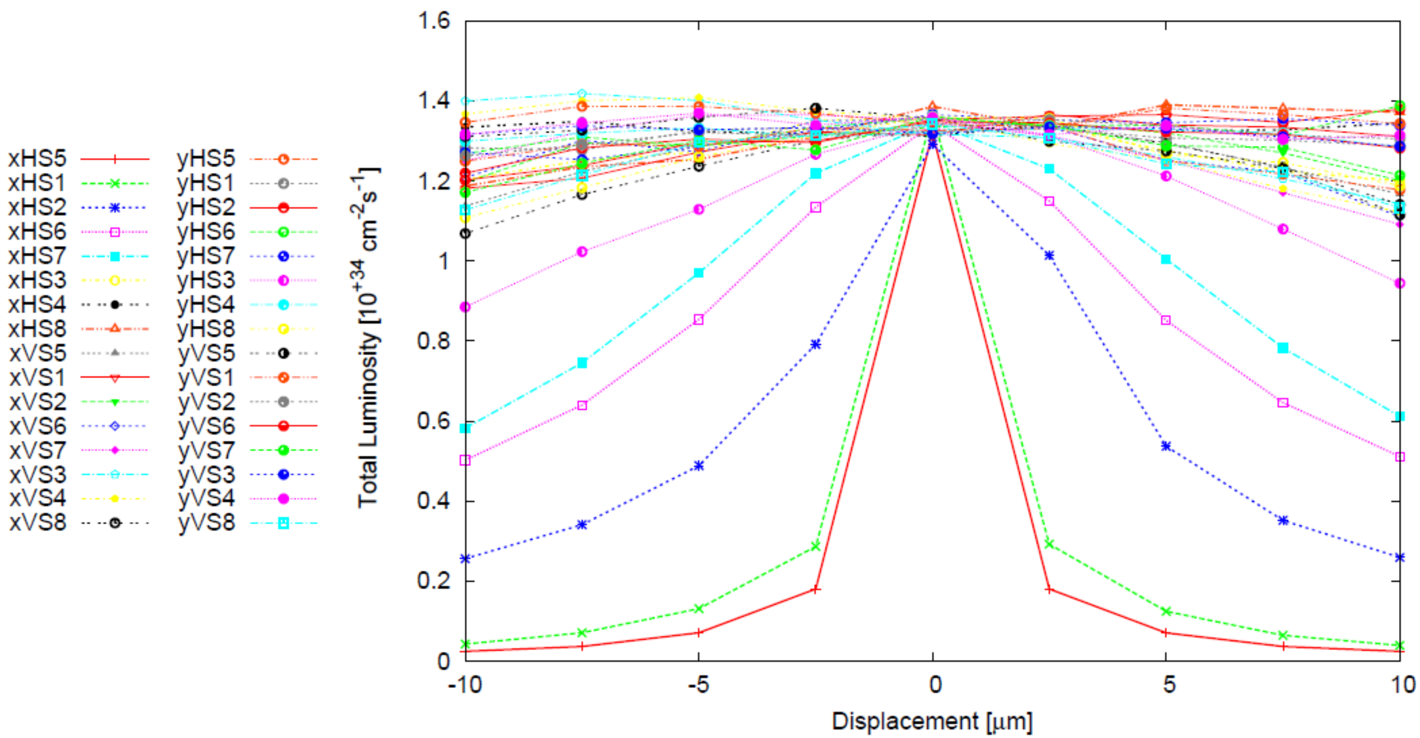
Beam parameters optimization using orthogonal knobs

3 Steps before tuning

- Response matrices calculation : R, D
- Weigthing factors $\beta, \omega_1, \omega_2$
- Knobs computation

- 16 sextupoles in the lattice
- **32 sextupole position** in x and y for the beam corrections
- The tuning simulation **time increases** with the number of knobs



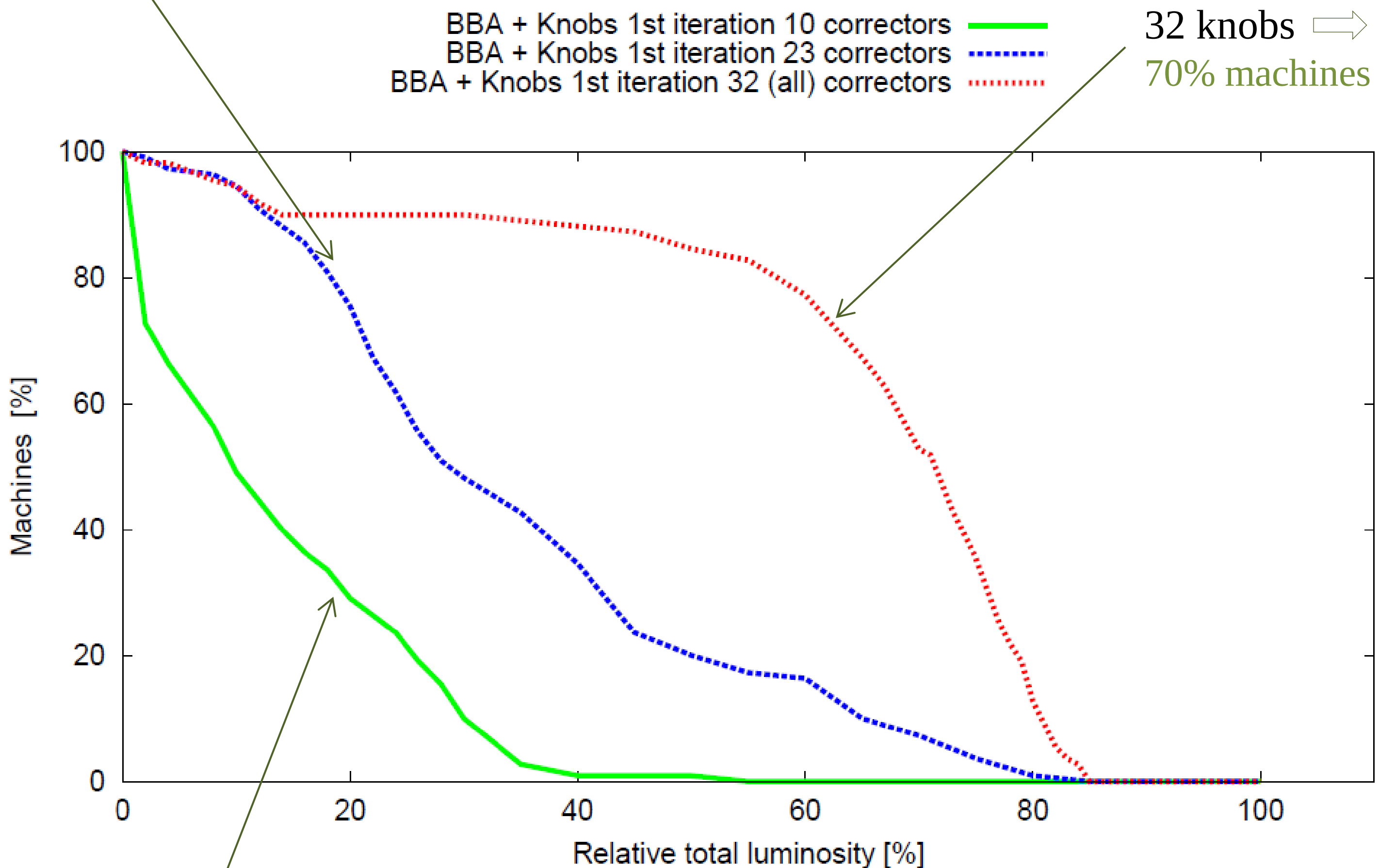


- 1 iteration using **10 knobs**
- 1 iteration using **23 knobs**
- 1 iteration using **32 knobs**

3 Tuning preliminary results : Number of knobs

23 knobs ⇨ **18h 24min** (simulation time)
15% machines reach 60% of L_{T0}

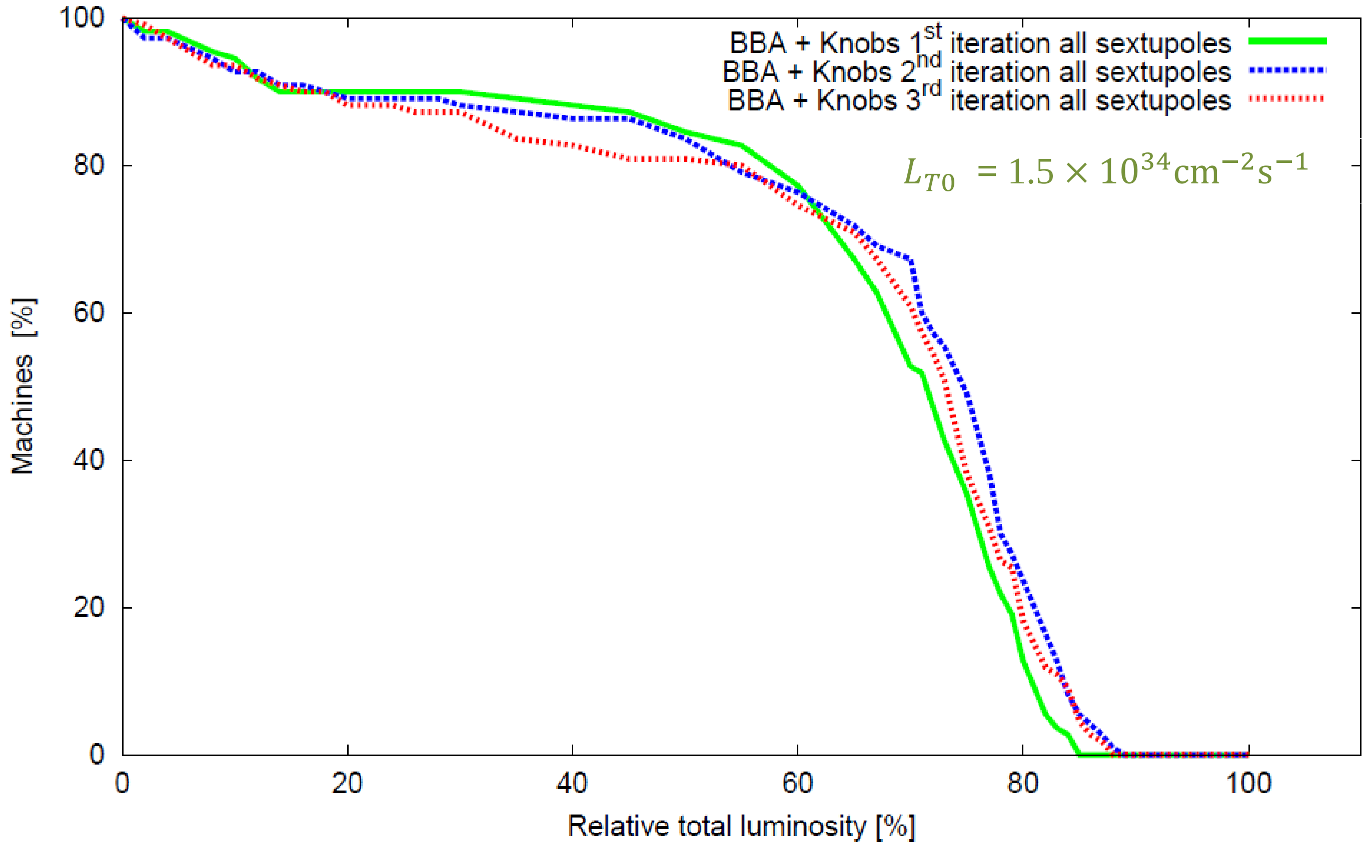
32 knobs ⇨ **25h 36min**
70% machines reach 65% of L_{T0}



10 knobs ⇨ **8h**
10% machines reach 30% of L_{T0}

$$L_{T0} = 1.5 \times 10^{34} \mathrm{cm}^{-2} \mathrm{s}^{-1}$$

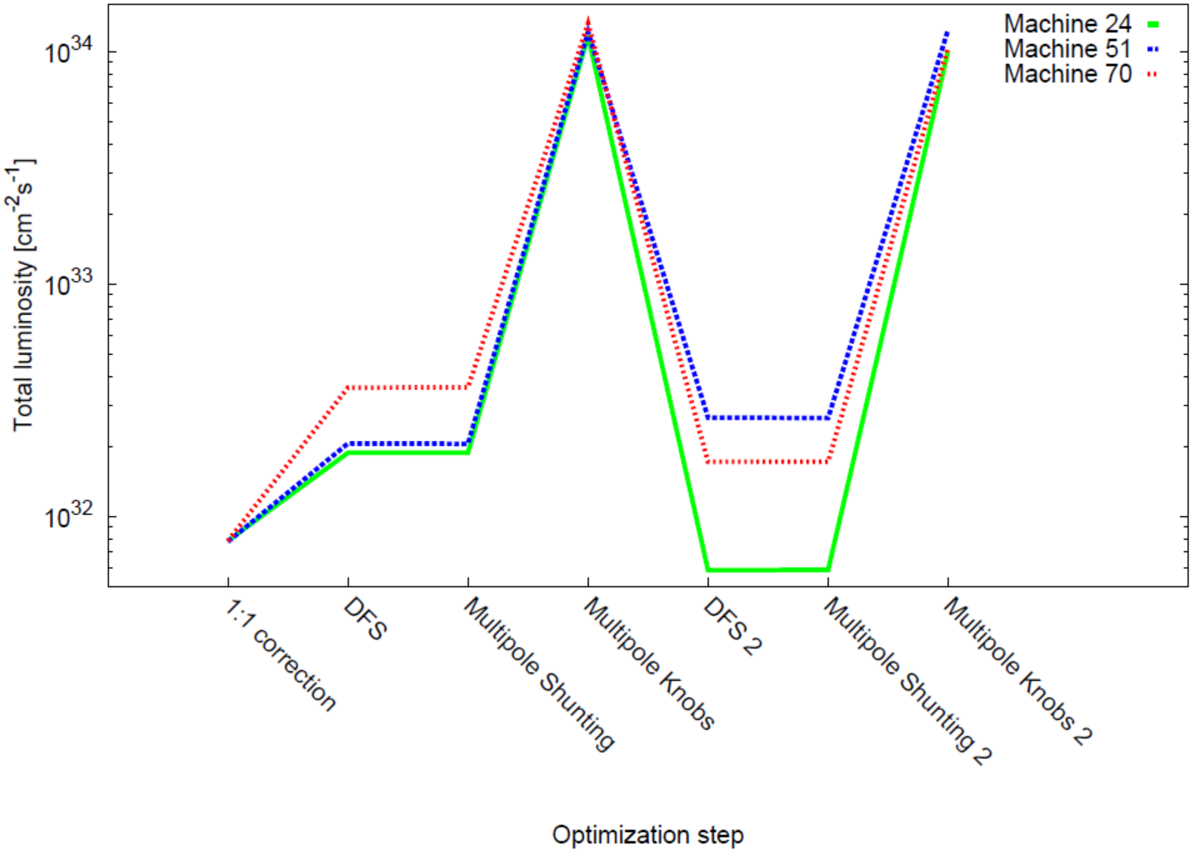
3 Tuning preliminary results : all knobs



- BBA + Knobs iterations do not improve the luminosity
- Need to optimize the weights $\beta, \omega_1, \omega_2$
- 70% machines reach more than 70% of L_{T0} and 25% machines reach more than 80% of L_{T0}

3 Tuning optimization steps

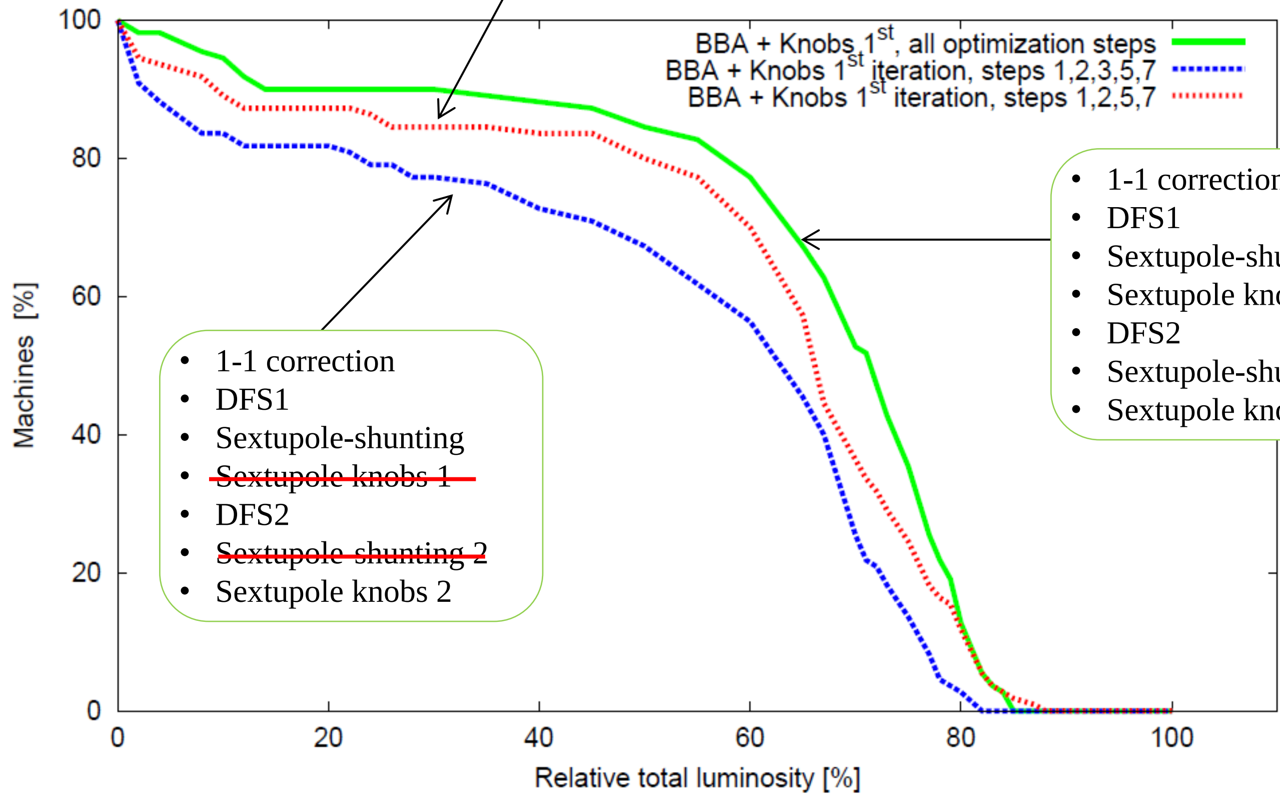
- Luminosity evolution after each optimization step for 3 random machines
- The **2nd BBA cancels** the luminosity gain by the 1st sextupole knobs tuning but the luminosity is recovered after the 2nd sextupole knobs
- Need to optimize the tuning algortihm?



3 Tuning optimization steps

- The **full algorithm** is still the **best option** for the BBA + Knobs tuning
- Other simulations are progressing for different optimization steps
- Need to **optimize the weigths** β , ω_1 and ω_2

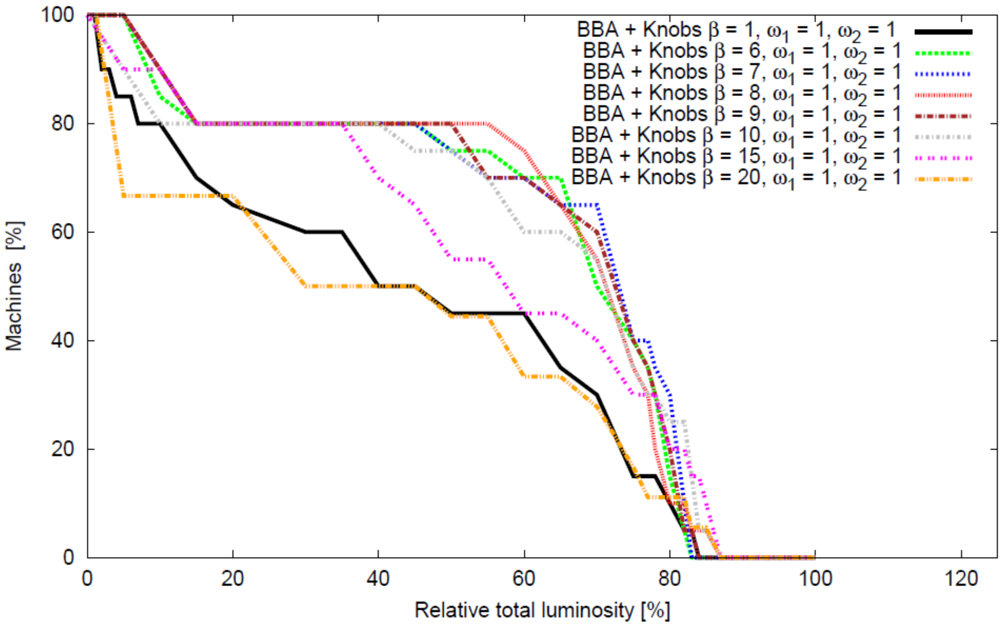
- 1-1 correction
- DFS1
- Sextupole-shunting
- ~~Sextupole knobs 1~~
- ~~DFS2~~
- ~~Sextupole-shunting 2~~
- Sextupole knobs 2



- 1-1 correction
- DFS1
- Sextupole-shunting
- ~~Sextupole knobs 1~~
- DFS2
- ~~Sextupole-shunting 2~~
- Sextupole knobs 2

- 1-1 correction
- DFS1
- Sextupole-shunting
- Sextupole knobs 1
- DFS2
- Sextupole-shunting 2
- Sextupole knobs 2

3 Weights optimization : β , ω_1 and ω_2



DFS1

$$\begin{pmatrix} b \\ \omega_1(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega_1 D \\ \beta I \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$$

DFS2

$$\begin{pmatrix} b \\ \omega_2(\eta - \eta_0) \\ 0 \end{pmatrix} = \begin{pmatrix} R \\ \omega_2 D \\ \beta I \end{pmatrix} \begin{pmatrix} \theta_x \\ \theta_y \end{pmatrix}$$

Theoretical value of ω:

$$\omega = \sqrt{\frac{\sigma_{\mathrm{BPM\ res}}^{2} + \sigma_{\mathrm{BPM\ misalign.}}^{2}}{2\sigma_{\mathrm{BPM\ res}}^{2}}}$$

- DFS equation must be weighted in order to have **the same impact on the vector of observables** on the left hand-side of the system
- The weights ω_1 and ω_2 are used for the dispersion terms while β for the SVD to limit the amplitude of the correctors θ
- Weight optimization is underway by simulating **several combinations of weights** on 40 seeds and by using as initial parameter the theoretical value of ω

4 Summary and conclusions

- The new traditional design using **extra sextupoles for L^*= 8 m** provides a good correction of high order aberrations with **10% of total luminosity loss** (**1.36× 10^{34}**$\mathrm{cm}^{-2}\mathrm{s}^{-1}$)

- The long last drift L^* **limits the FFS performance** especially for the non-local chromaticity correction scheme ⟹ **L^*= 6 m provides better performances**

- The tuning turns out to be **long due to the number of sextupoles** in the lattice

- With optimistic set up and errors parameters, the tuning of the system seems feasible but must be improved (70% machines reach more than 70% of ILC design luminosity)

- Several simulations are mandatory for the **optimization of the weights** β , ω_1 and ω_2 and the **alignment procedure** in order to conclude on the tunability of this design