Review of the lattice optimization applied on the CLIC 380 GeV BDS with an *L** of 6 m

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OUTLINE

1) The good and bad of longer L* for the BDS

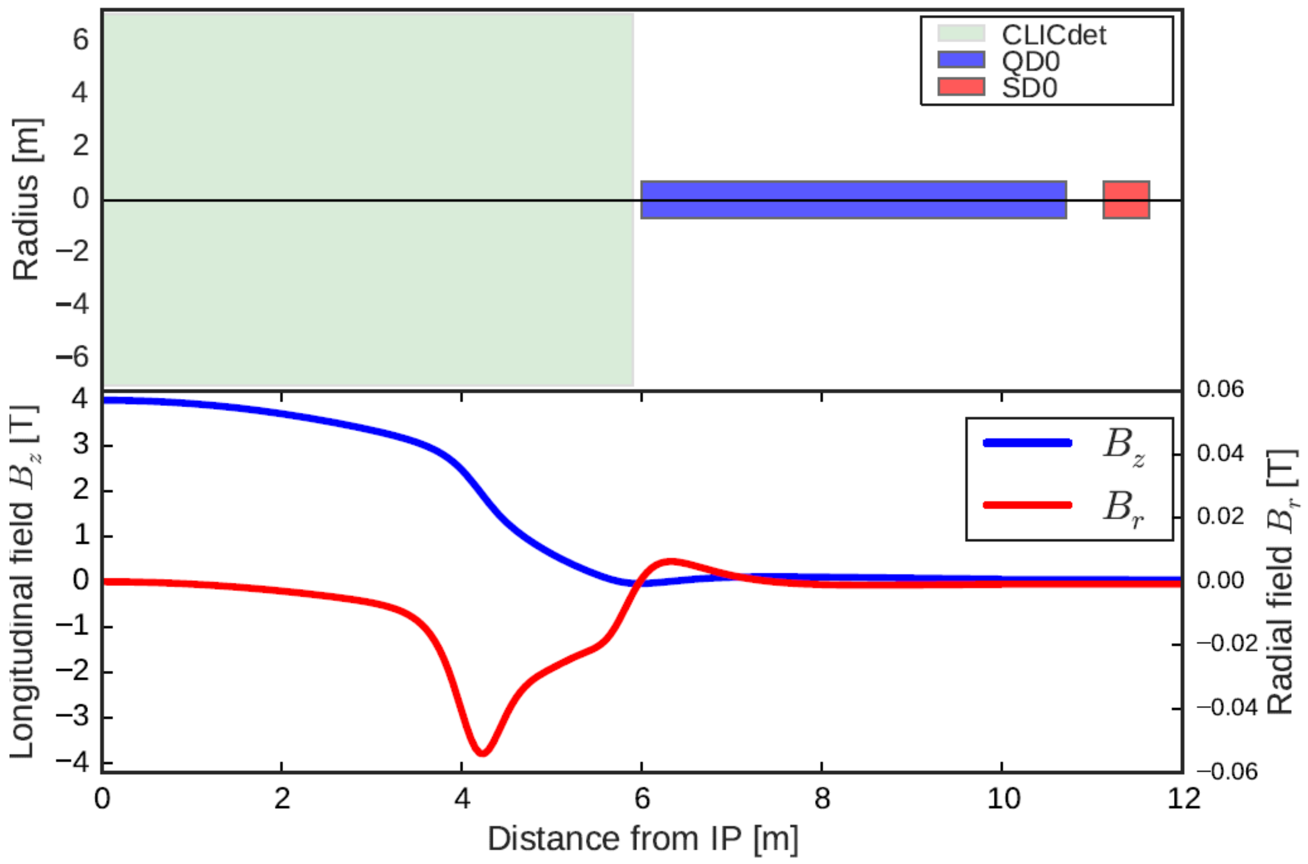
2) Optimization steps applied to improve the Luminosity and tuning performance:

   - FFS length scaling
   - Dispersion/ Sextupole strength optimization
   - Use of octupoles
   - Impact on the tunability
   - Limitation of the BDS geometry

3) Conclusions

The good of longer L* for the BDS

- A new CLIC detector allowing QD0 to be located outside the experiment with an L* of 6 m in order to alleviate engineering and stabilization issues of the CDR MDI
- QD0 sits outside the experiment on the stable tunnel ground ➔ No pre-insulator needed
- Easier detector opening and access for interventions in the QD0 region
- Solenoid field zeroed along QD0 → NO need to be protected by an anti-solenoid
- The detector forward region acceptance is extended with QD0 outside the experiment



The bad of longer L* for the BDS

- The FD is the main responsible for the FFS chromaticity ➔ Longer L* implies larger chromaticity to be corrected

$$\frac{\Delta_y^*}{\sigma_y^*} \approx \frac{L^*}{\beta_y^*}\delta_p \sim \xi_y \delta_p$$

- Stronger sextupole may be required ➔ increase of nonlinear aberration contribution to the beam size

- Large increase of the β-functions at the FD ➔ larger aperture required, stronger field, increase of nonlinear aberration contribution, increase of sensitivity to magnet imperfections

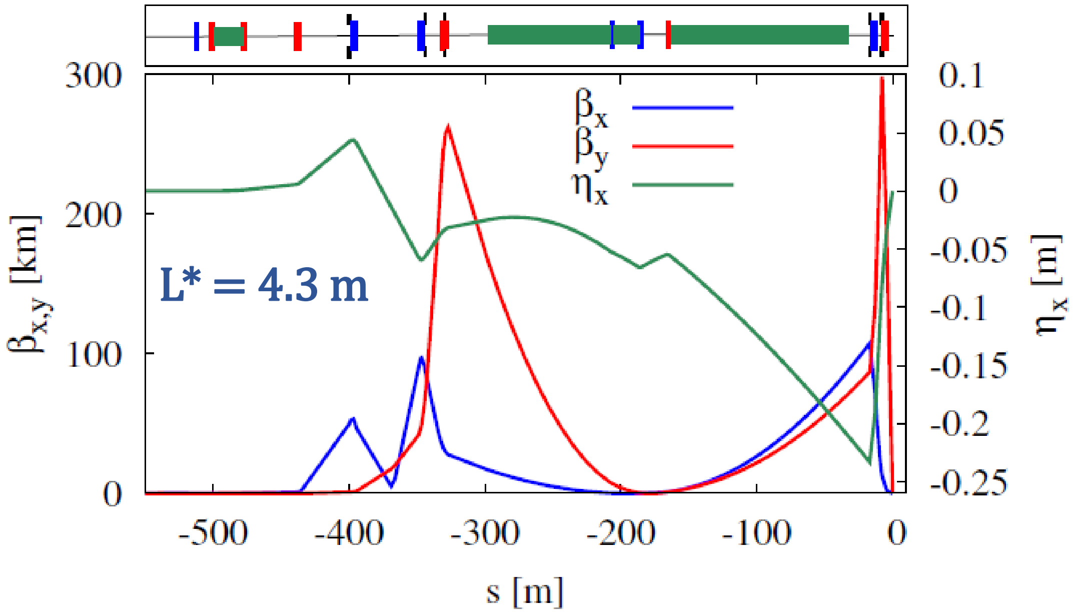
$$L^*\sqrt{\frac{\varepsilon_y^*}{\beta_y^*}} = \sqrt{\varepsilon_y \beta_y^{QD0}} \Rightarrow \beta_y^{QD0} = \frac{L^{*2}}{\beta_y^*}$$

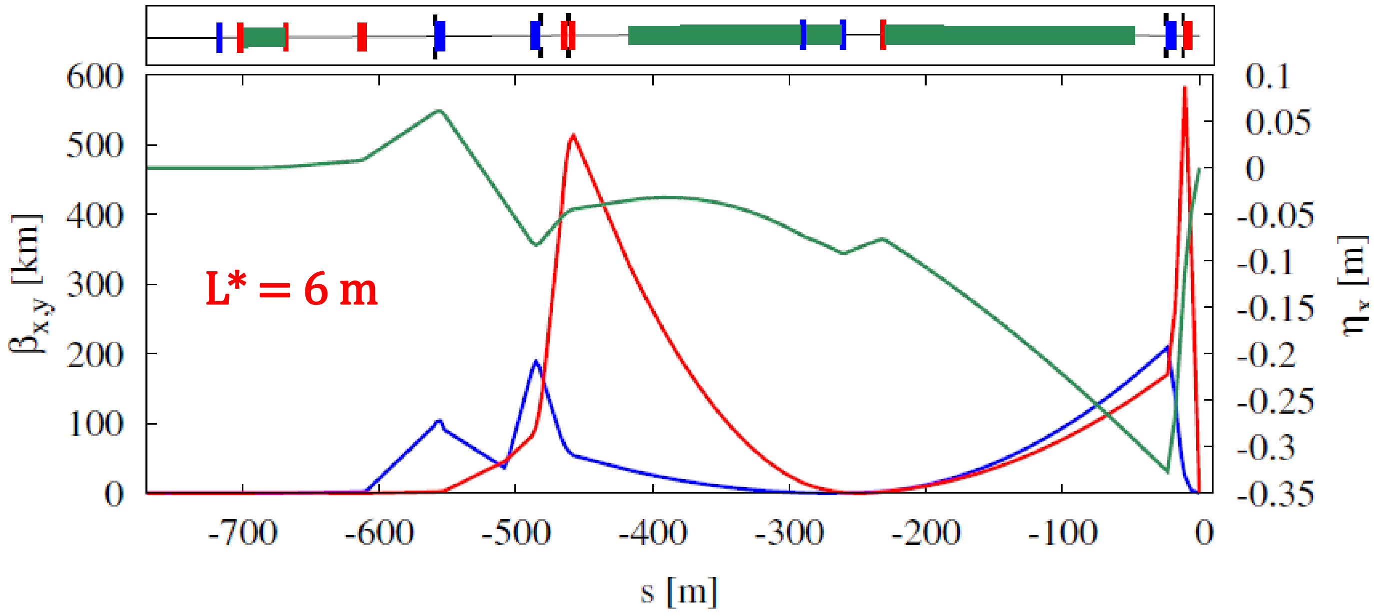
- Other consideration such as collimation

- **In general the longer L* may makes the machine tuning more challenging and implies a loss of luminosity** ➔ Should be minimized with linear/nonlinear lattice optimization

Optimization: FFS length scaling

- When increasing L* one has to preserve the chromaticity correction properties along the FFS of the Local scheme
- The solution chosen was to scale the drifts, dipoles and quadrupoles w.r.t the increase of L* → FFS lengthened by a factor 6/4.3
- It allows to fully correct chromaticity and 2nd order dispersion terms at the IP
- The length of the FFS does not necessarily need to be scaled, one can also re-optimize the FD configuration to restore the chromatic correction properties



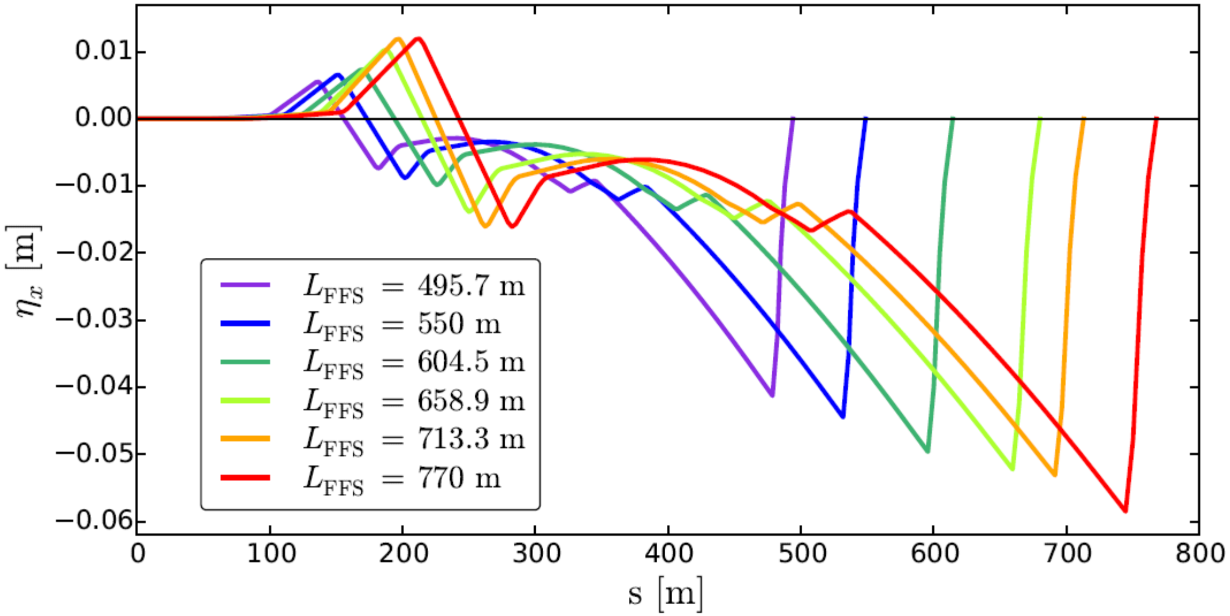


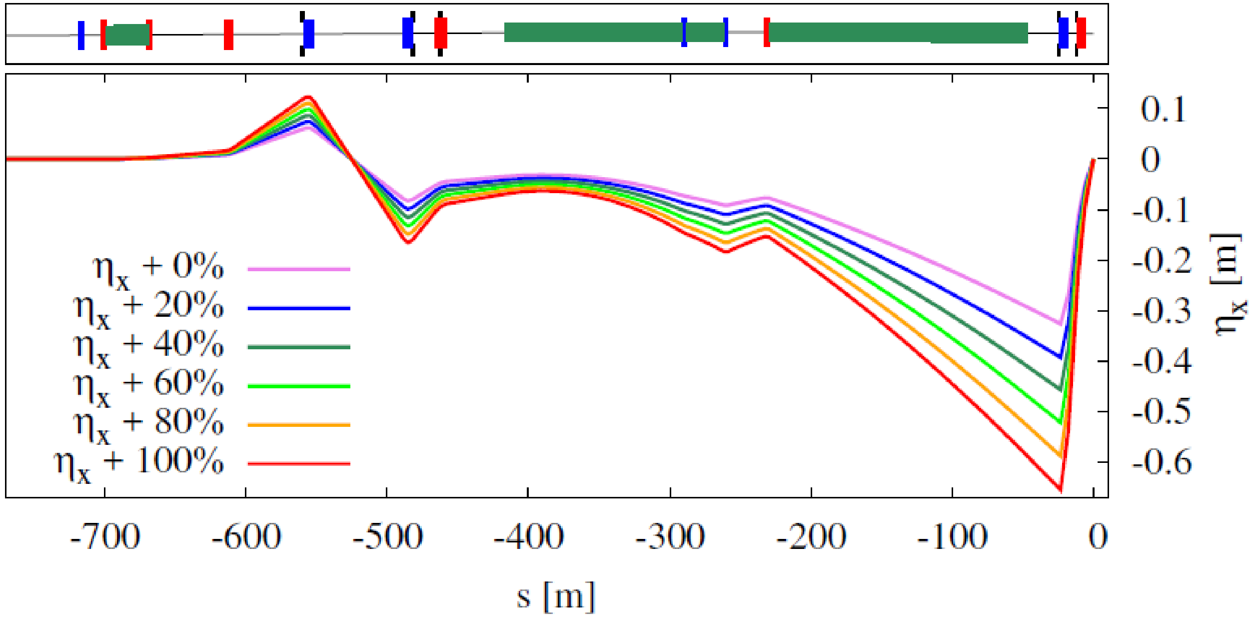
Optimization: Dispersion / Sext. Strength optimization

- Simulations have shown the importance of optimizing the dispersion function along the FFS to improve the performance

- Impacts the sextupole strength and therefore the nonlinear correction performance but also the sensitivity to imperfections

- Dispersion can be changed by FFS length scaling or by increasing the dipole strength
- Need to find the right balance between nonlinear correction/tunability and synchrotron radiation generated by the bending magnets

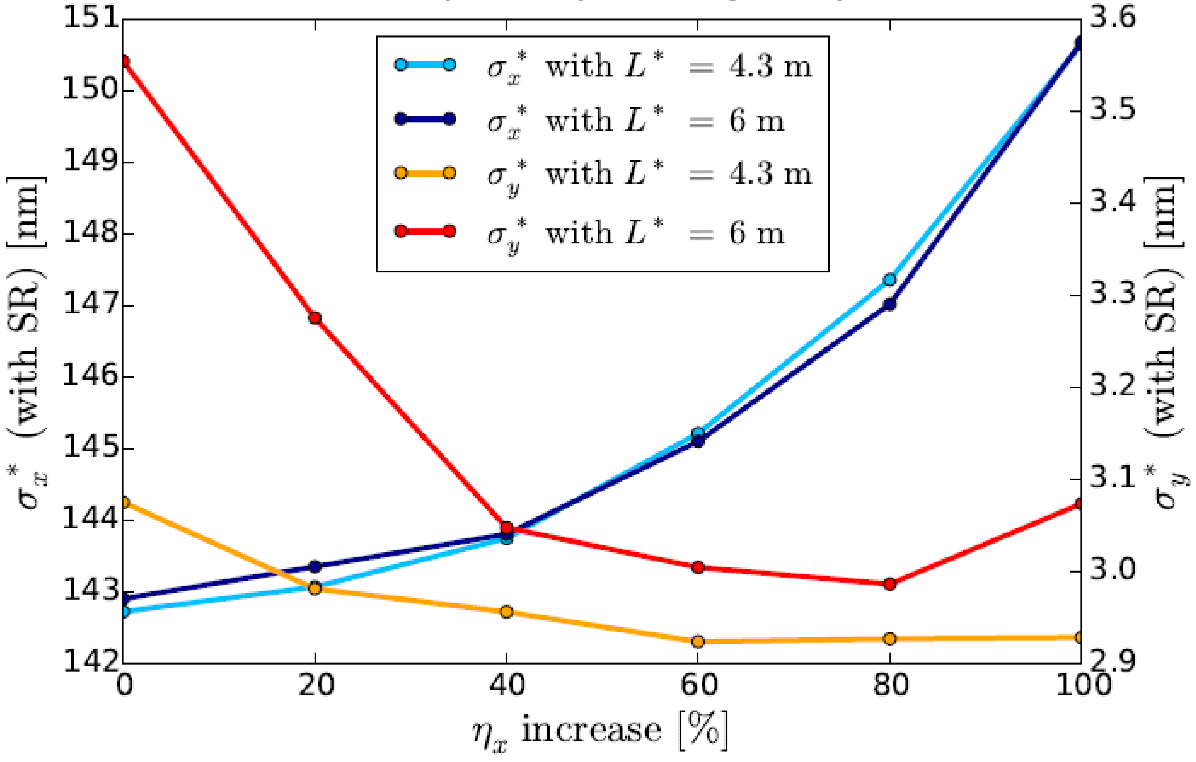




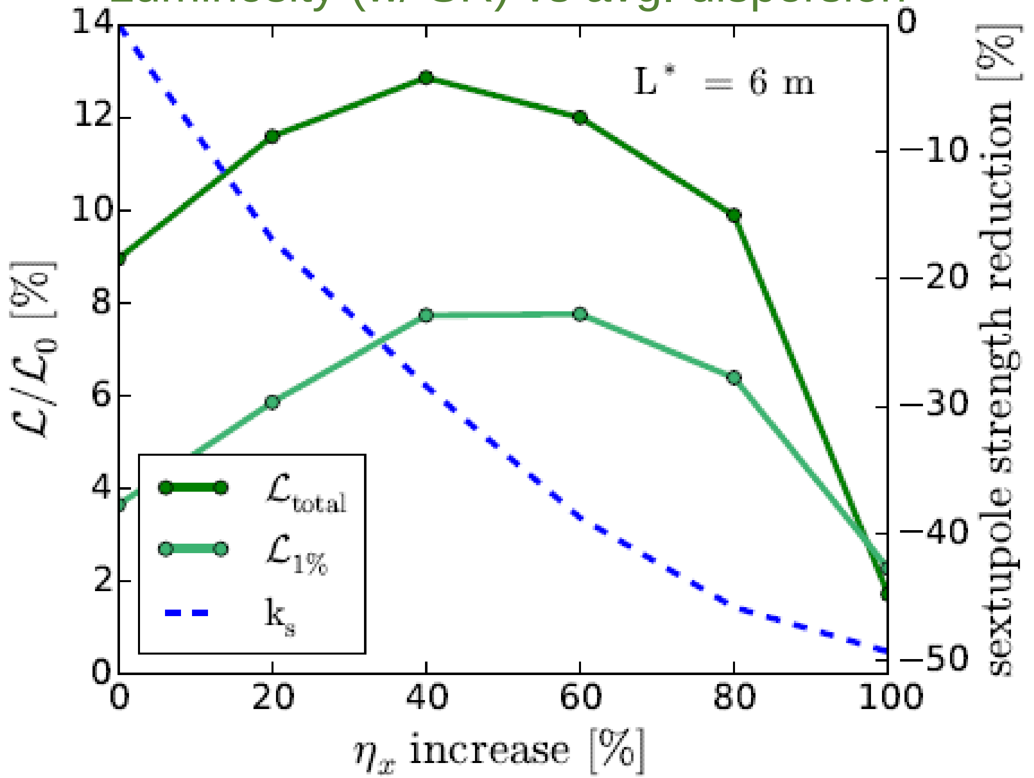
Optimization: Dispersion / Sext. Strength optimization

- The dispersion level impacts a lot the nonlinear dynamic and needs to be optimized
- Even at 380 GeV the synchrotron radiation can contribute to the beam size increase for large bending angle ➔ limit the increase of dispersion in the FFS

Beam size (w/ SR) vs avg. dispersion



Luminosity (w/ SR) vs avg. dispersion



Optimization: Impact on tunablity

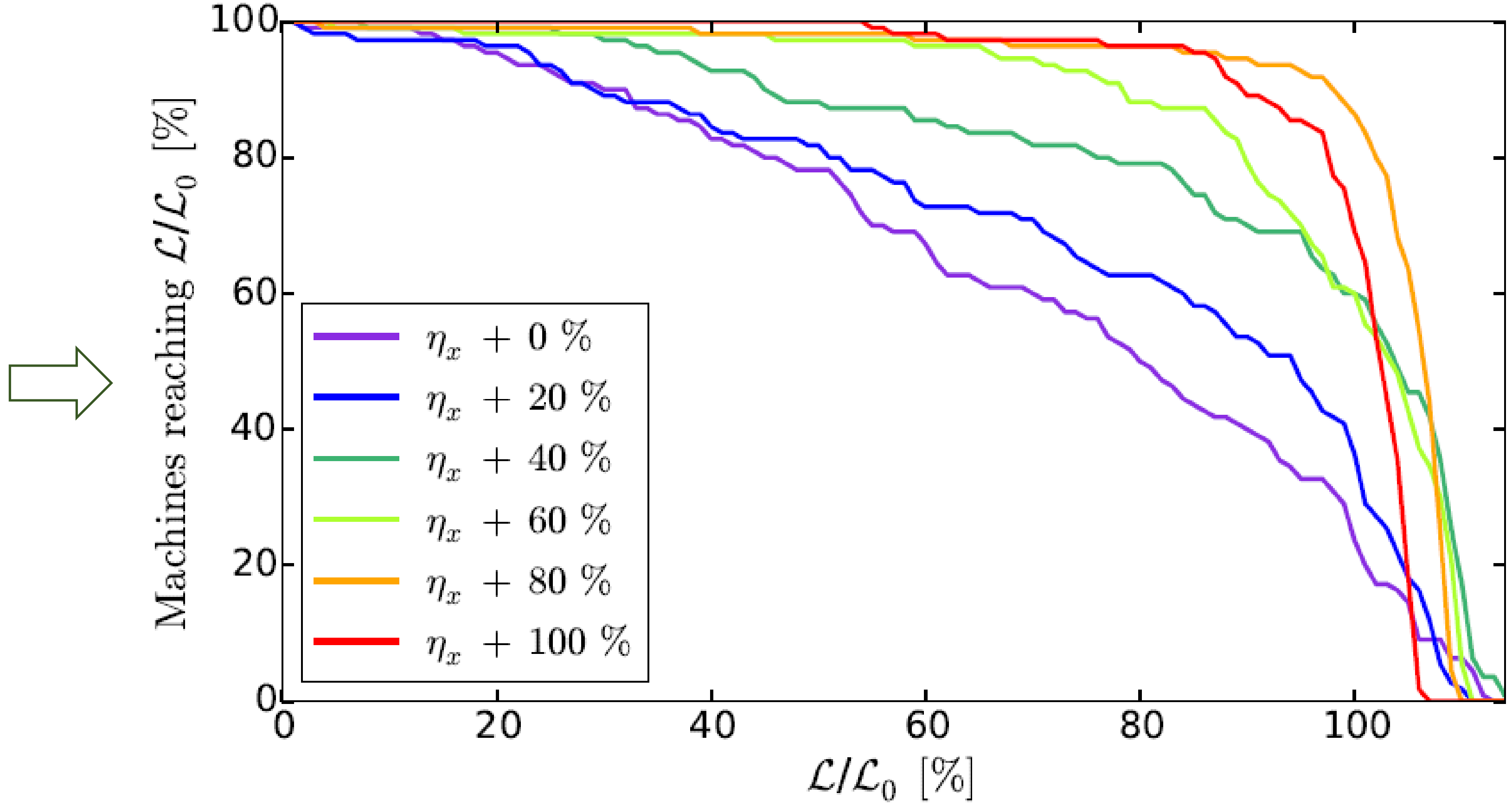
- Larger L* also impacts the system sensitivity to magnet imperfections and how well the machine can recover the design luminosity (tuning)
- It has been shown that the tunability can also be improved by optimizing the dispersion function along the FFS

BDS tuning for L=6m with different bending strength:*

1) Realisitic static machine imperfections applied

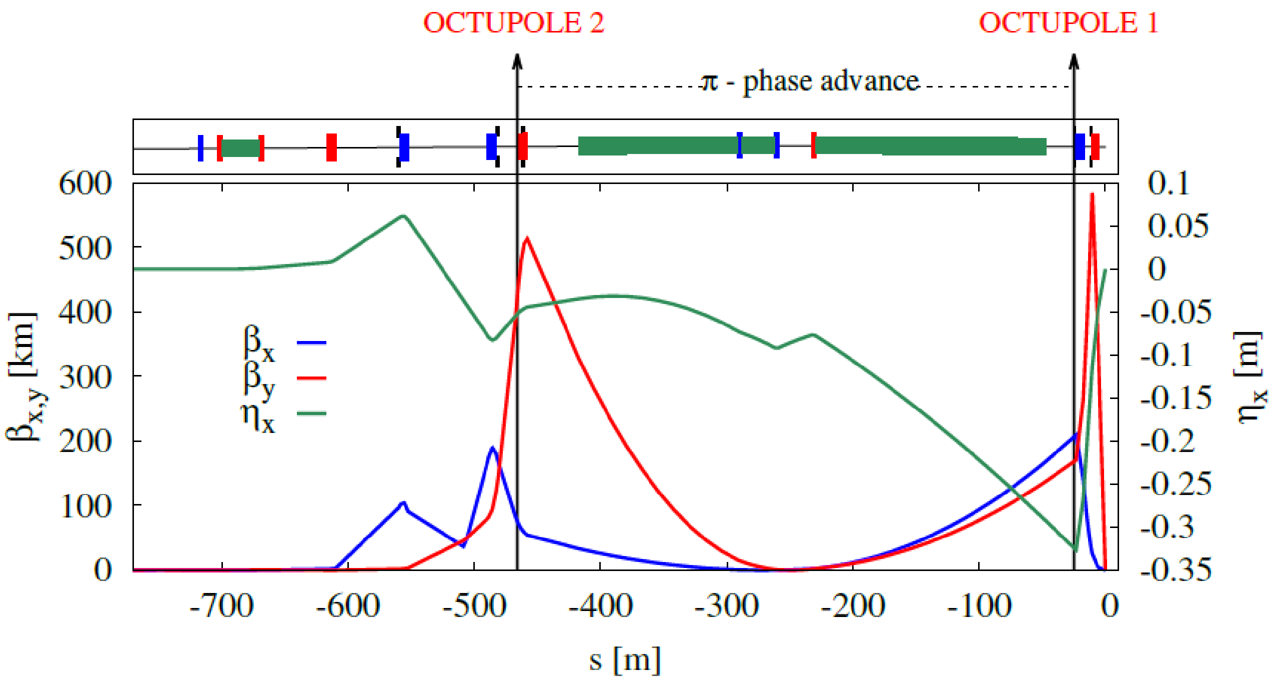
2) One iteration of orbit/dispersion correction

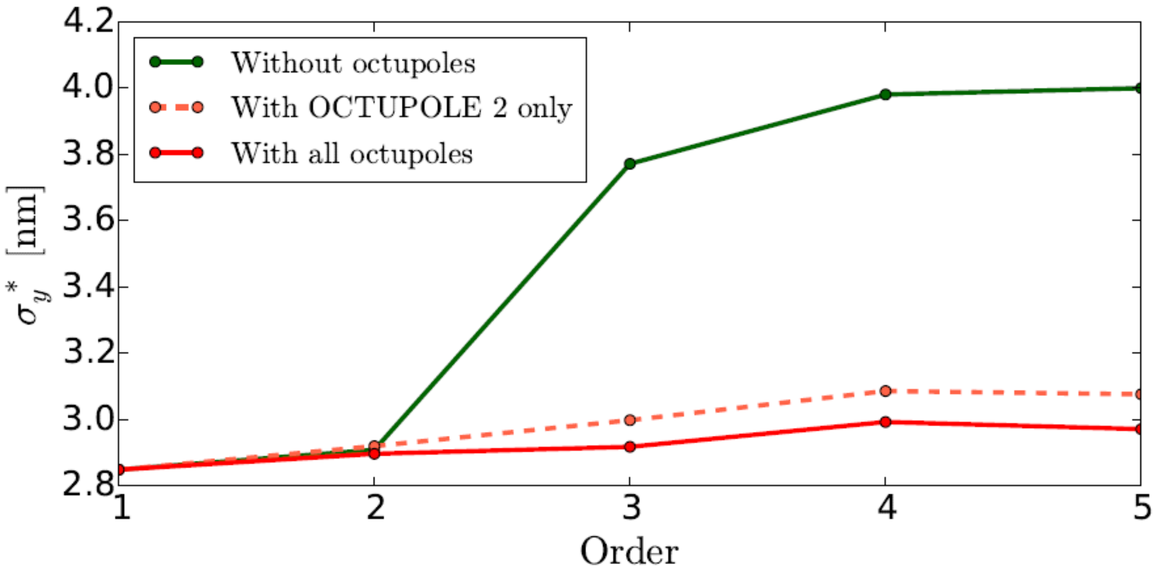
3) One iteration of sextupole knob tuning



Optimization: Use of octupoles

- This lattice shows large 3rd order contribution (mostly geometric) to the vertical beam size
- For L*=6m the use of octupoles is required to bring down the vertical beam size to a similar size as of the shorter L*



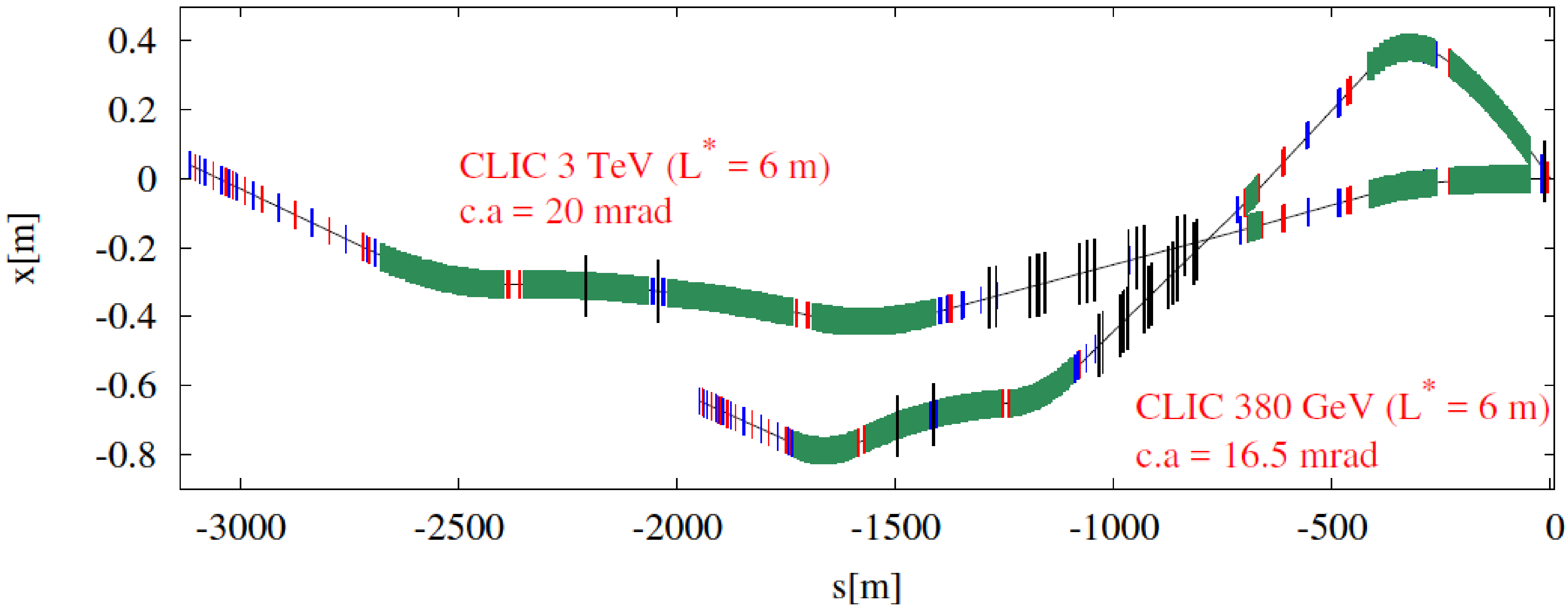


Design	ξ_y^*	σ_x^* [nm]	σ_y^* [nm]	$\mathcal{L}_{total}$ $[10^{34}cm^{-2}s^{-1}]$	$\mathcal{L}_{1\%}$ $[10^{34}cm^{-2}s^{-1}]$	$\frac{\mathcal{L}_{1\%}}{\mathcal{L}_{1\%}^{noSR}}$	$\sigma_{y,Oide}$ [nm]
L* = 4.3 m	63365	143	3.07	1.7	0.96	0.03	0.135
L* = 6 m	95388	145.1	3.00	1.64	0.94	1	0.133

Optimization: Limitation of the BDS geometry

- The change of FFS length and/or bending magnet strength has to take into account also the geometry of the BDS
- These changes needs to take into account the energy upgrade within the same tunnel and the IP crossing angle of the different energy stages

- For the CLIC BDS at 380 GeV and 3 TeV the designs were optimized taking into account the performance and the geometry/CA angle constraints



Conclusions

- Increasing the L* to 6m has required to re-optimize the **FFS length**, **dispersion level** by changing the dipole angles and to introduce **octupoles** to correct for the larger geometrical 3rd order contributions

- Finally these changes have allowed to obtain a competitive design that meet the requirements and with performance in terms of luminosity and tuning, equivalent to the shorter L* option at 380 GeV:

FFS design	σ_x^* / σ_y^* [nm]	$\mathcal{L}_{total} / \mathcal{L}_{1\%}$ $[10^{34}\text{cm}^{-2}\text{s}^{-1}]$	$\mathcal{L}_{total}$ achieved by 90% of the machines	Nbr. of $\mathcal{L}$ measurements
$L^* = 6$ m	152.0 / 4.25	1.36 / 0.82	-	-
$L^* = 6$ m*	151.2 / 3.20	1.52 / 0.91	96% $\mathcal{L}_0$	~6300
$L^* = 4.3$ m	148.2 / 3.22	1.55 / 0.93	92% $\mathcal{L}_0$	~7000

*with octupoles

- The gain for the MDI compared to the small difference in performance between short and long L* <u>after optimization</u> makes the L*=6m version a preferable option for CLIC (380GeV and 3TeV)

Reference : CERN-THESIS-2018-223