ALEGRO

Crystal focusing-based Final Focus for a Collider

Vera Cilento and Rogelio Tomás

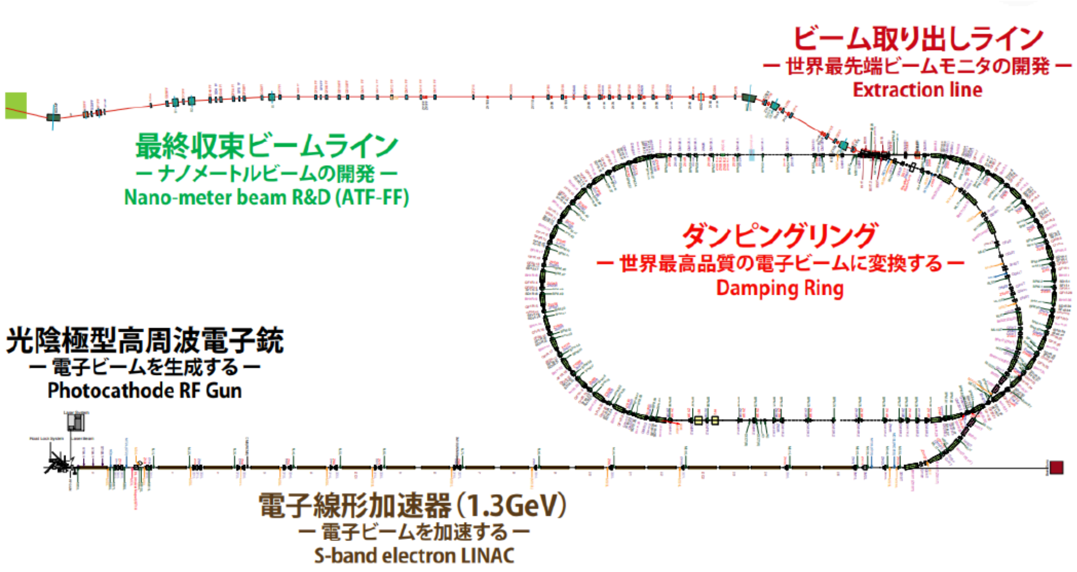
Advanced LinEar collider study GROup

Outline

- ➢ Introduction
- ➢ Principle of Crystal Focusing
- ➢ Implementation of the Crystal in MAD-X
- ➢ Simulation studies
  - Impact on the beta function and on the horizontal dispersion
  - Impact on the natural chromaticity
  - Impact on the beam size
  - Impact on the luminosity for CLIC 1.5 TeV
- ➢ Conclusions

Introduction

- The main goal of ATF2 is to achieve a 37 nm vertical beam size at the IP



Introduction

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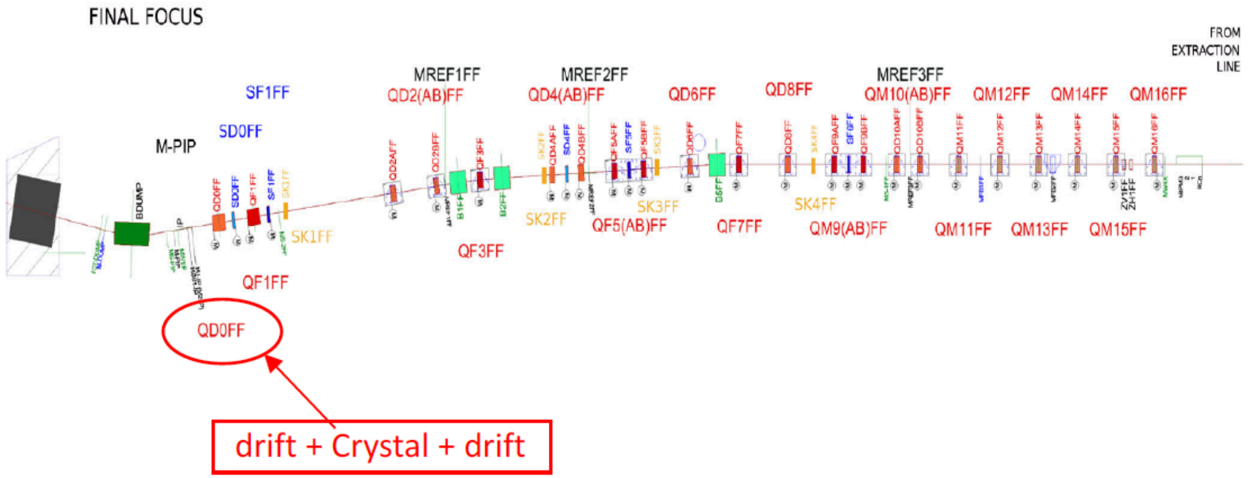
- Two different cases have been studied in simulation:
  1. Lattice with QD0 from MAD-X of ATF2 → ultra-low β_y^* optics
  2. Development of a new lattice which includes the Si crystal → QD0 has been replaced by the crystal and 2 drifts



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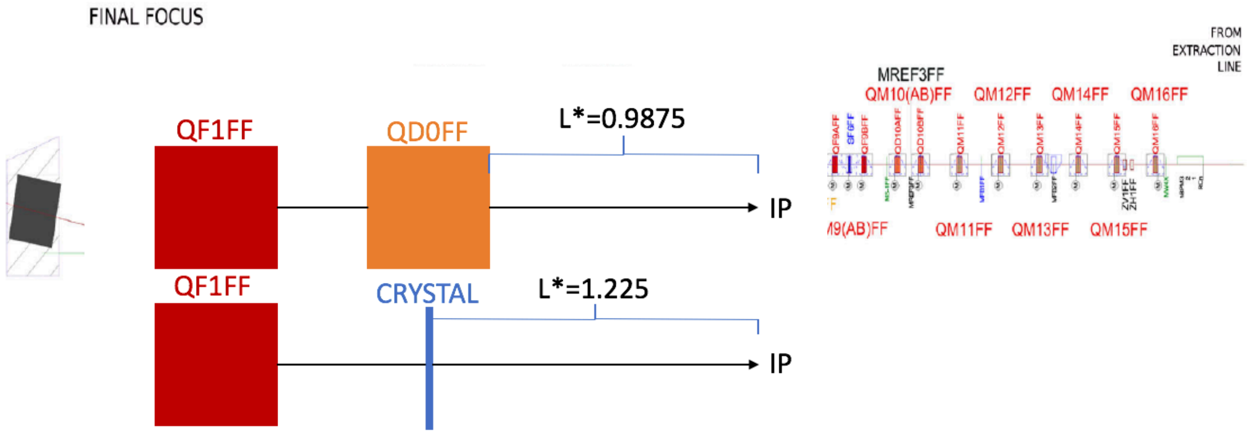
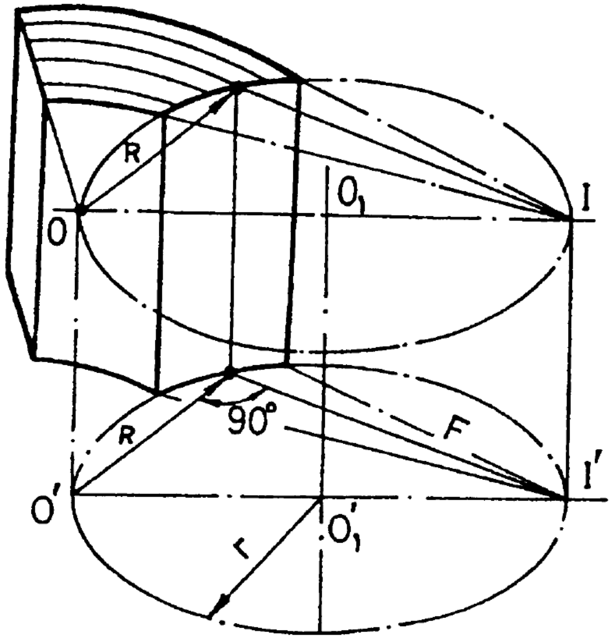


Principle of Crystal Focusing

- The focal length f is then $f = (4r^2 - R^2)^{1/2}$
- The critical angle is quite small → θ_c = 0.02–0.002 mrad for particles of energies from 100 GeV to 10 TeV for planar channelling in silicon
- This technology makes possible to achieve a focal length of the order of several centimeters
- The dimensions of the beam are ≈10µm for the GeV energies and ≈ 1µm for the TeV range.



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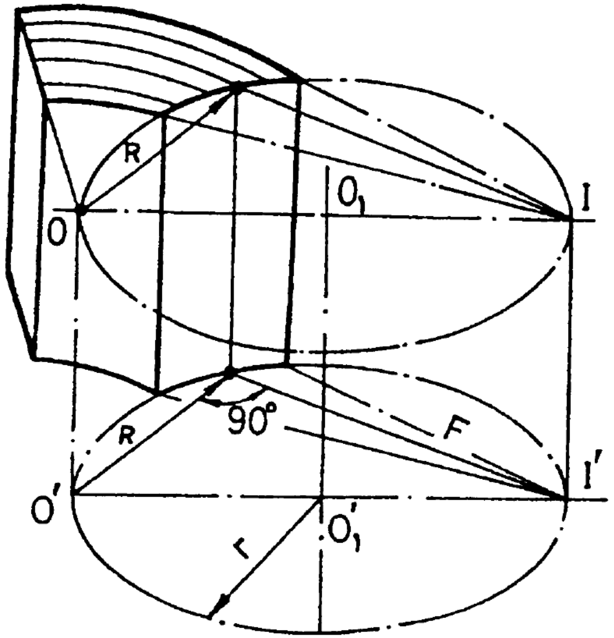


Some references:

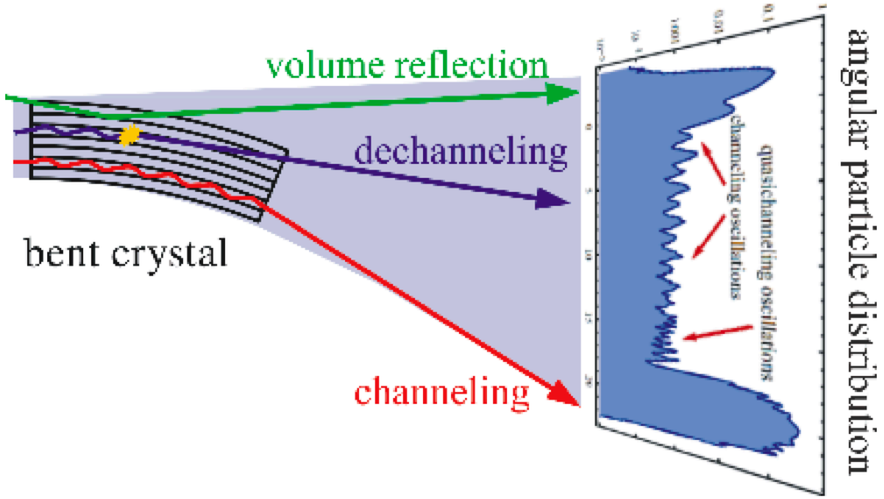
→ Biryukov V. M., Vladilen Ivanovich Kotov, and Yu A. Chesnokov. "Steering of high-energy charged-particle beams by bent single crystals." *Physics-Uspekhi* 37.10 (1994): 937.

→ Denisov A. S., et al. "First results from a study of a 70 GeV proton beam being focused by a bent crystal." *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms* 69.2-3 (1992): 382-384.

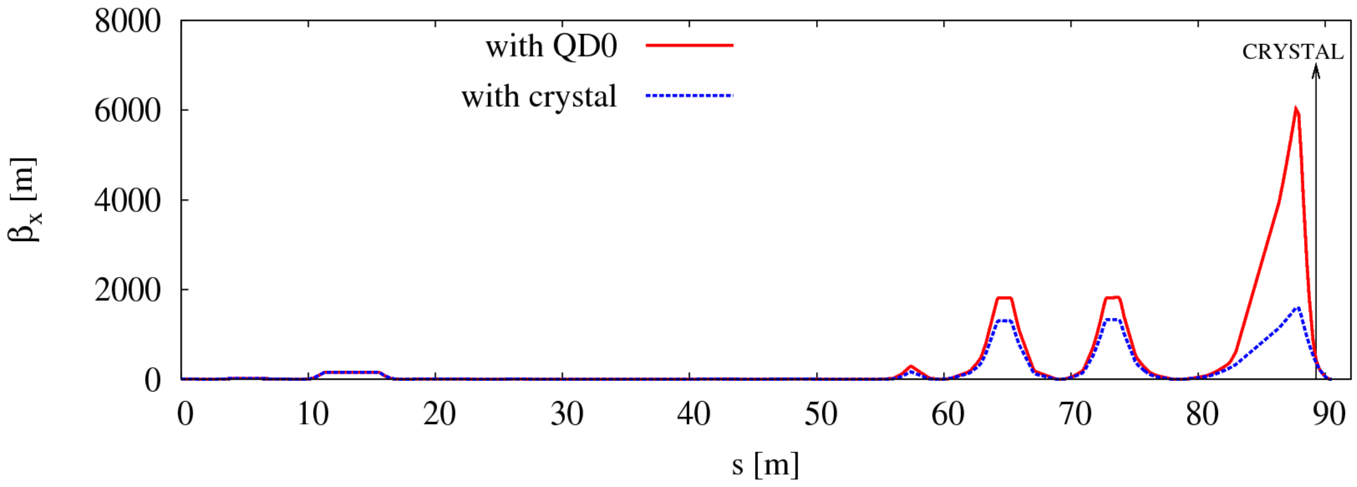
→ Scandale W., et al. "Observation of focusing of 400 GeV/c proton beam with the help of bent crystals." *Physics letters B* 733 (2014): 366-372.

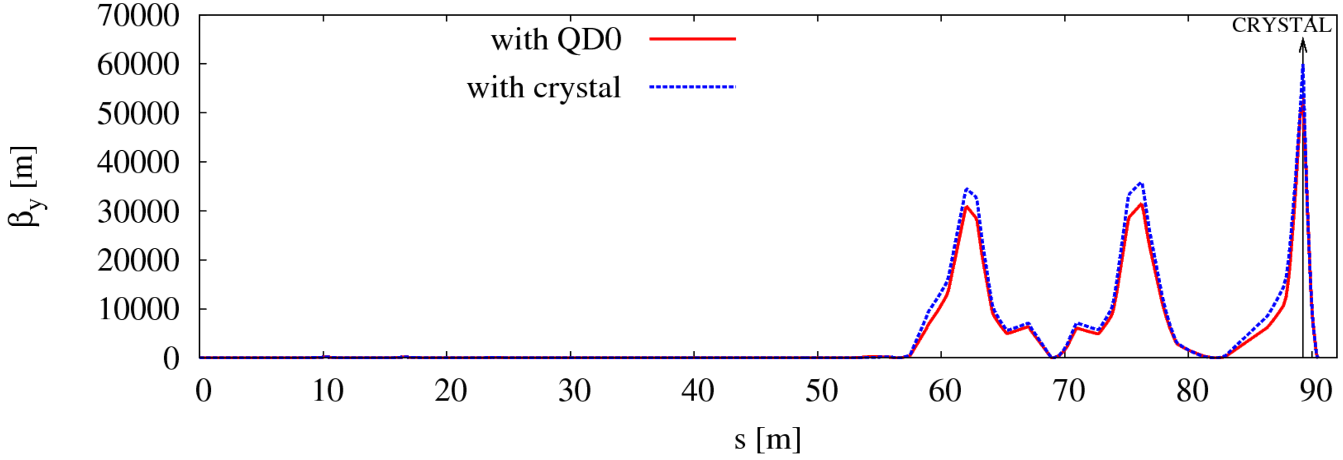
Implementation of the crystal in MAD-X

- Approximation of the crystal with a thin matrix element that only focuses in the vertical plane
- The crystal does not act in the horizontal plane
- Neglect of the bending of the beam by the crystal in the vertical direction
- Neglect of the volume reflection
- The chromatic aberration can be neglected due to the achromatic property of the crystal
- Neglect the fact that the particles inside a channel are not focused and the channel beam size grows with the divergence of the beam

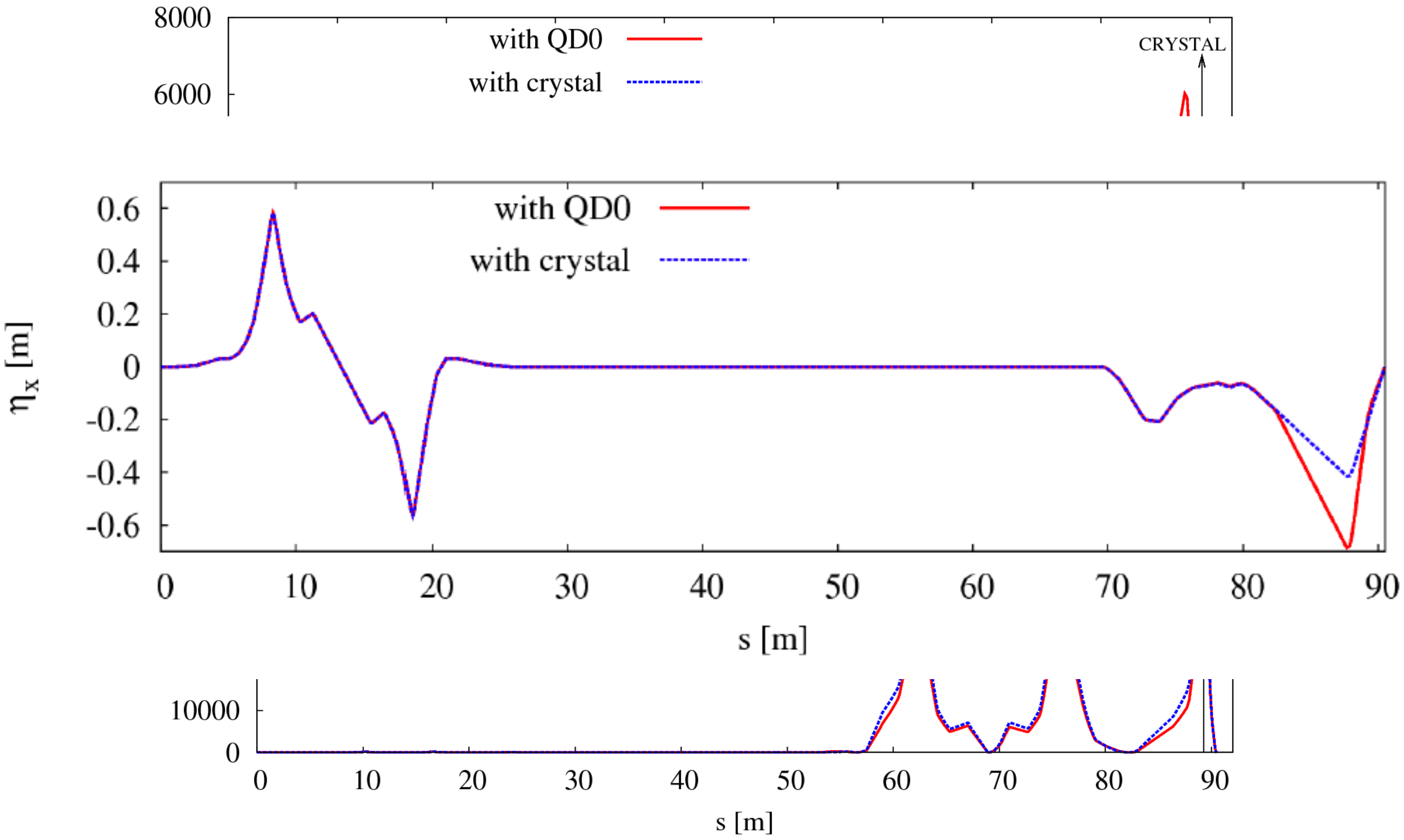


Impact on the beta functions





Impact on the beta functions and on horizontal dispersion



Impact on the natural chromaticity

- Sextupoles are switched off in order to get the natural chromaticity of quadrupoles that is expressed as:

  - $\xi_x^2 = X_{x,10001} X_{x,10001} \frac{\beta_{yo}}{\beta_y^*} + X_{x,01001} X_{x,01001} \frac{1}{\beta_{y0}\beta_y^*}$
  - $\xi_y^2 = X_{y,00101} X_{y,00101} \frac{\beta_{yo}}{\beta_y^*} + X_{y,00011} X_{y,00011} \frac{1}{\beta_{y0}\beta_y^*}$

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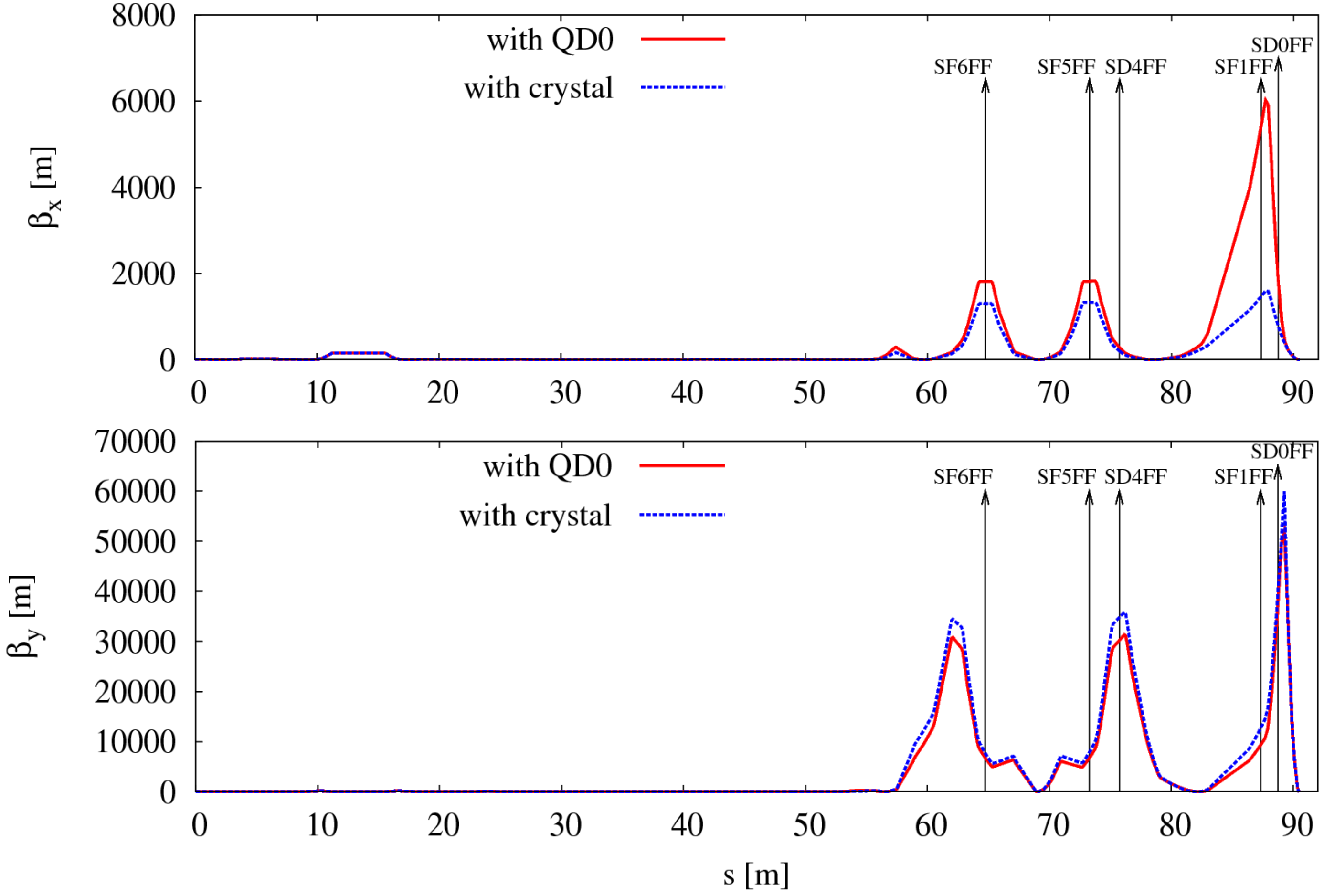
- Visible impact on the chromaticity in both planes

  - Strong reduction of the chromaticity when including the Crystal → we replace a quadrupole with an achromatic element

	QD0	CRYSTAL
ξ_x	5868.55	2639.82
ξ_y	87888.89	56734.92

Sextupoles position in the FFS

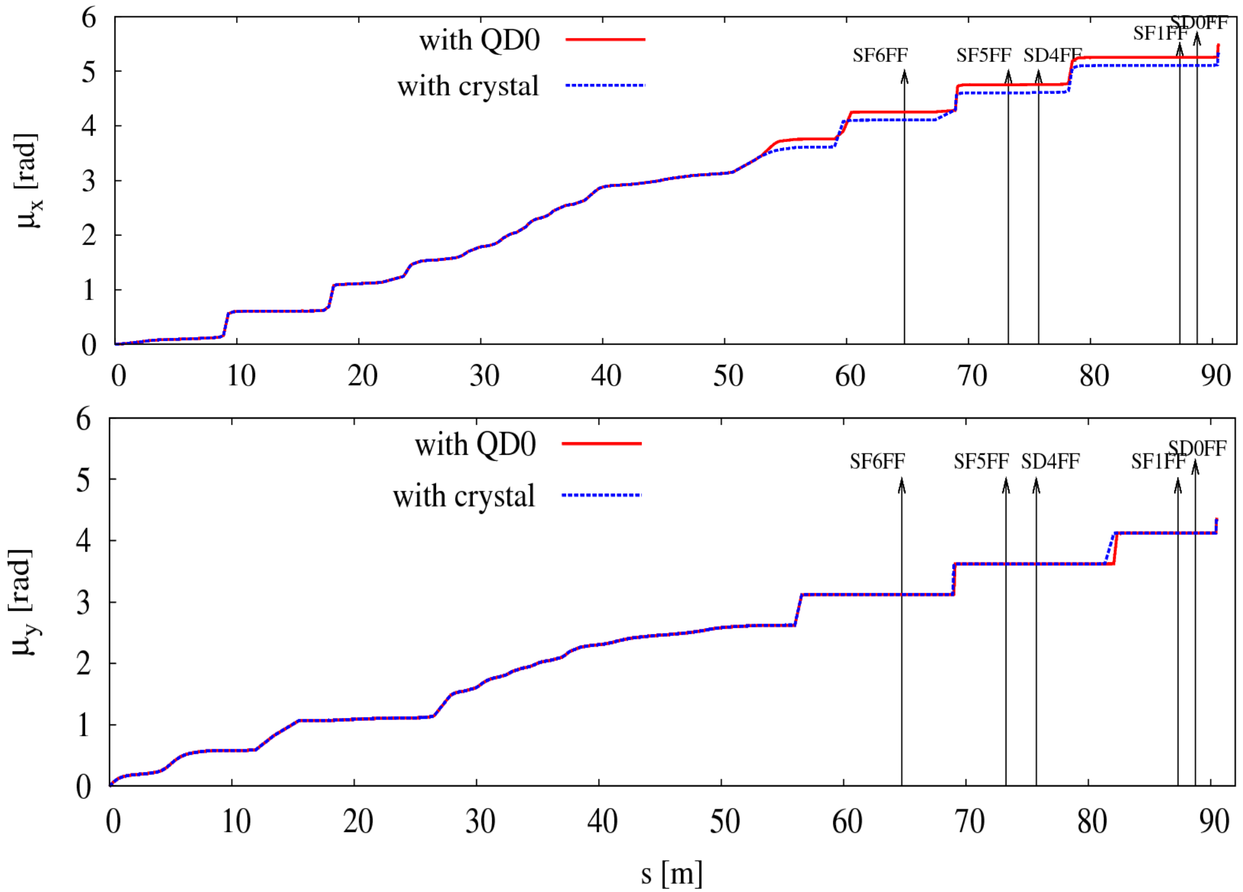
- In order to compute the beam size we switched on the sexupoles:



Sextupoles phases

- An important feature of the FFS is that the phase advance between the sextupoles and the IP satisfies the condition:

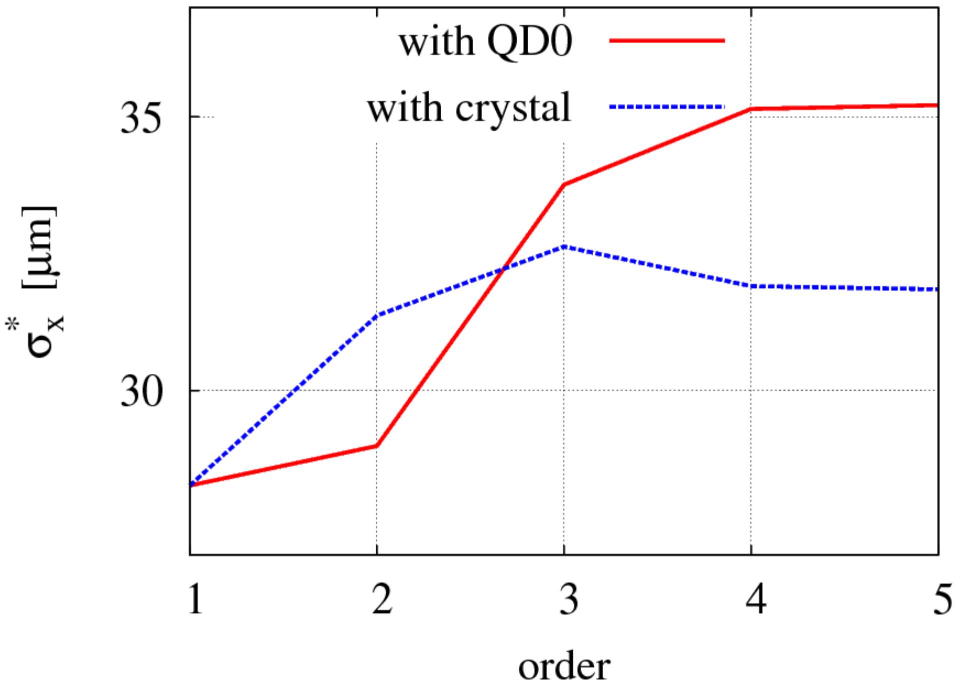
$$\Delta\mu_{x,y} = \frac{\pi}{2} + n\pi$$



μ_x	QD0	CRYSTAL
SF1FF- SF5FF	0.50033	0.50083
SD0FF- SD4FF	0.49987	0.50024

μ_Y	QD0	CRYSTAL
SF1FF-SF5FF	0.50001	0.49994
SD0FF-SD4FF	0.50003	0.49999

Impact on the beam size

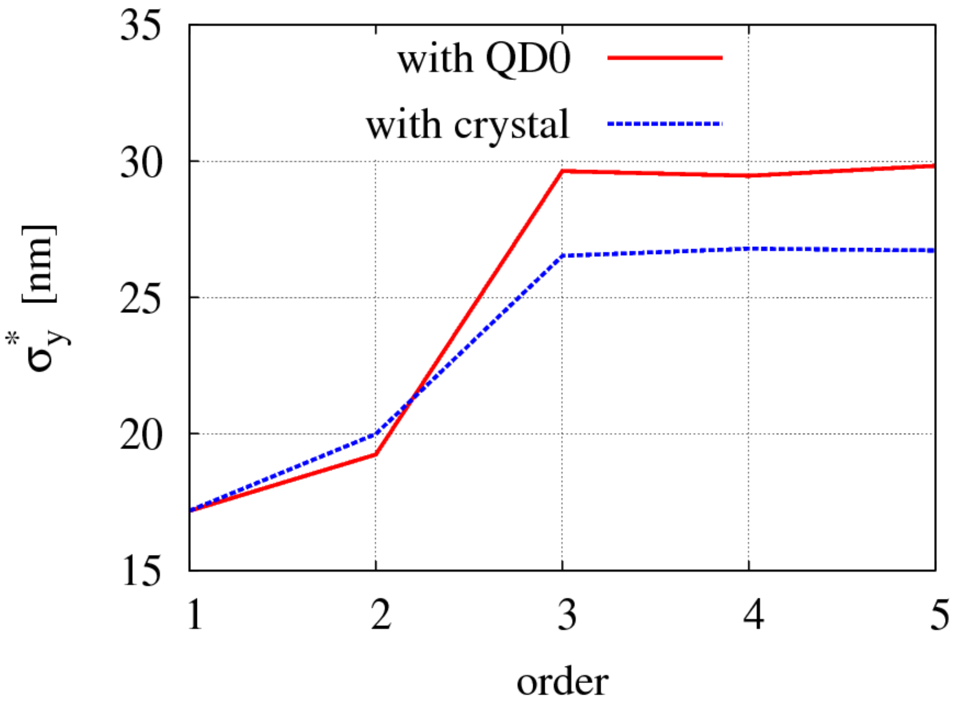


➢ With Crystal beam size reached:

- σ_x^*= 3.18 μm
- σ_y^*= 26.7 nm

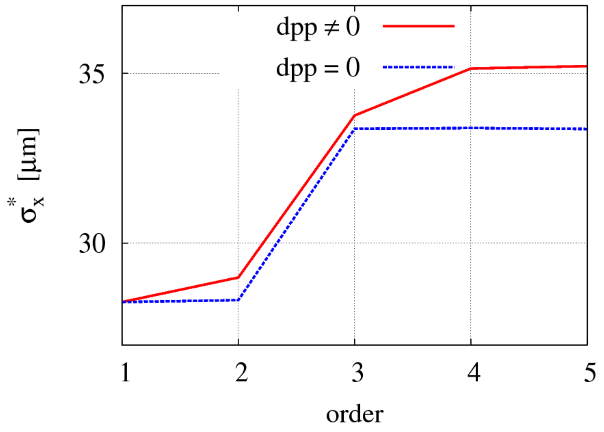
➢ With QDO beam size reached:

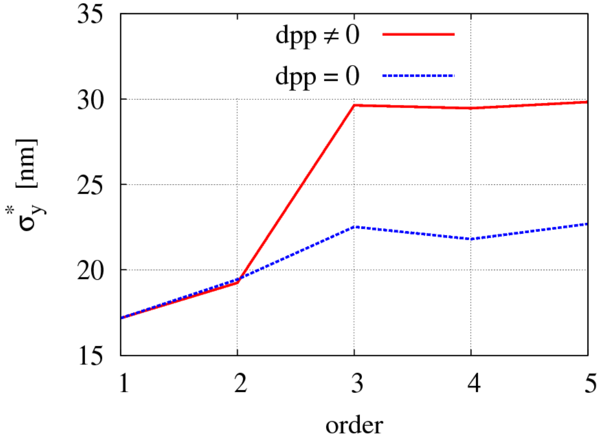
- σ_x^*= 3.52 μm
- σ_y^*= 29.8 nm



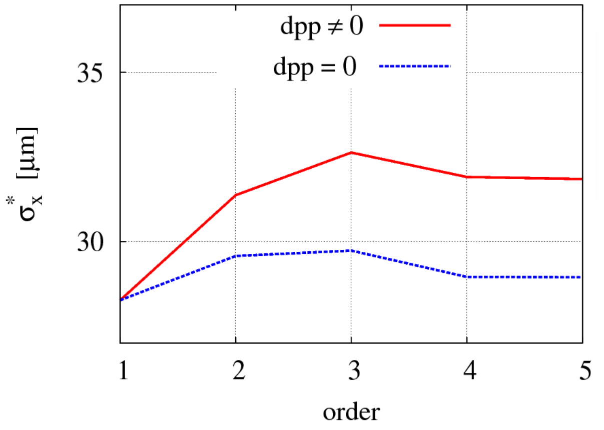
Impact on the beam size (without energy spread)

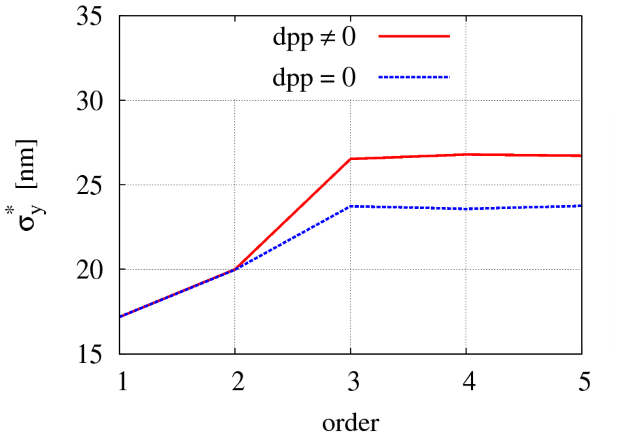
- To compute the beam size at the IP considering only the geometric aberrations → dpp =0
  - For QD0:



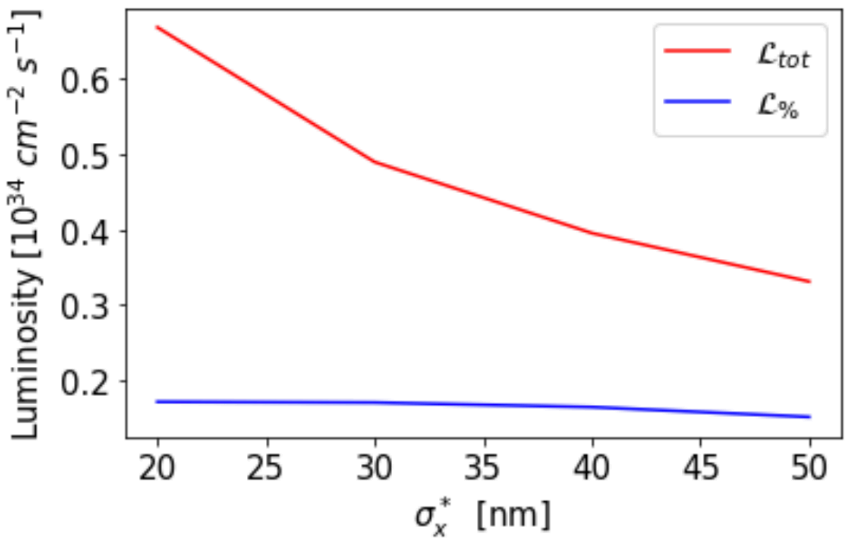


  - For Crystal:

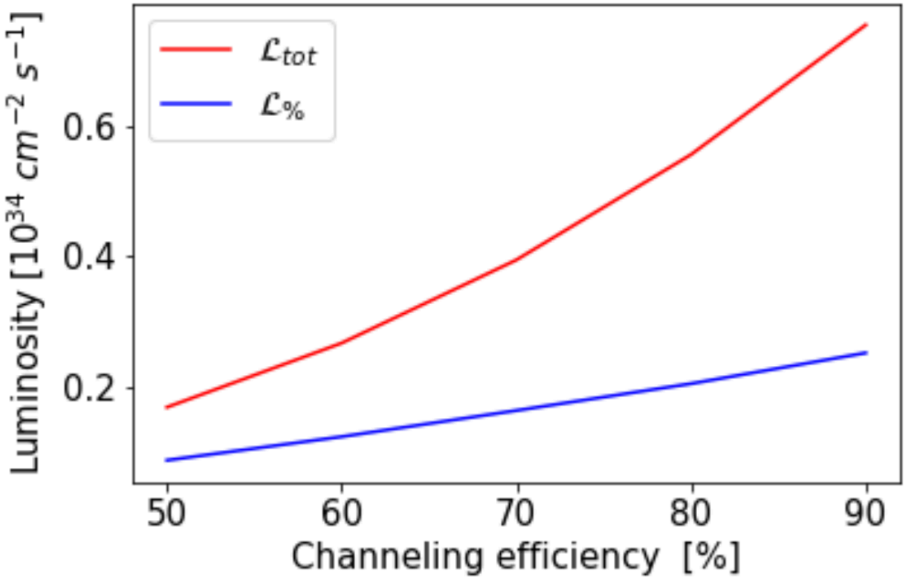




Impact on the Luminosity for CLIC 1.5 TeV



	1 TeV e^-	1 TeV e^+
σ_x^* [nm]	50	20-50
σ_y^* [nm]	15	1
channeling efficiency [%]	50-70	70-90



These results on the luminosity reached for CLIC 1.5 TeV show a significant lower luminosity performance when using crystals to focus e- & e+ beams.
Lumonisity design values for CLIC 1.5 TeV:
$\mathcal{L}_{tot}$= 3.7 and $\mathcal{L}_{\%}$ = 1.4 $[10^{34}\ cm^{-2}\ s^{-1}]$

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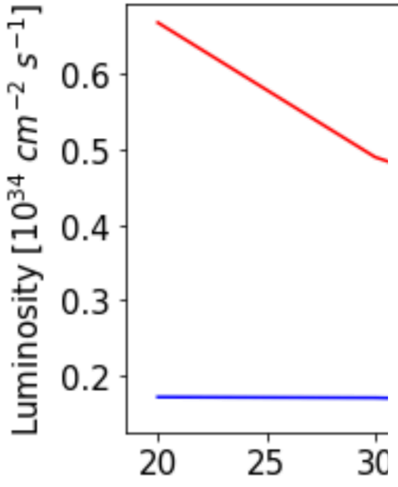

1 TeV e^-	1 TeV e^+
50	20-50
15	1
0-70	70-90

Can electron beams be really focused by bent crystals?

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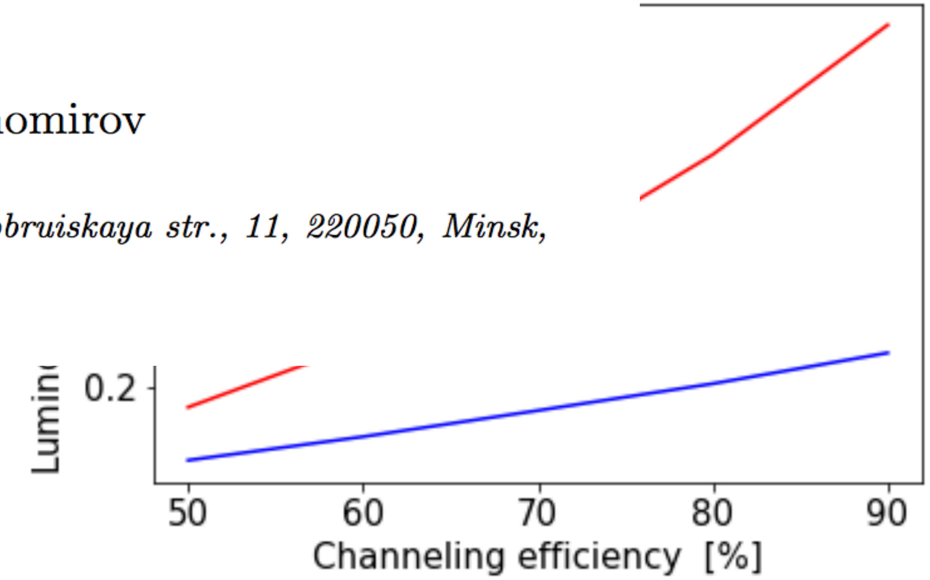

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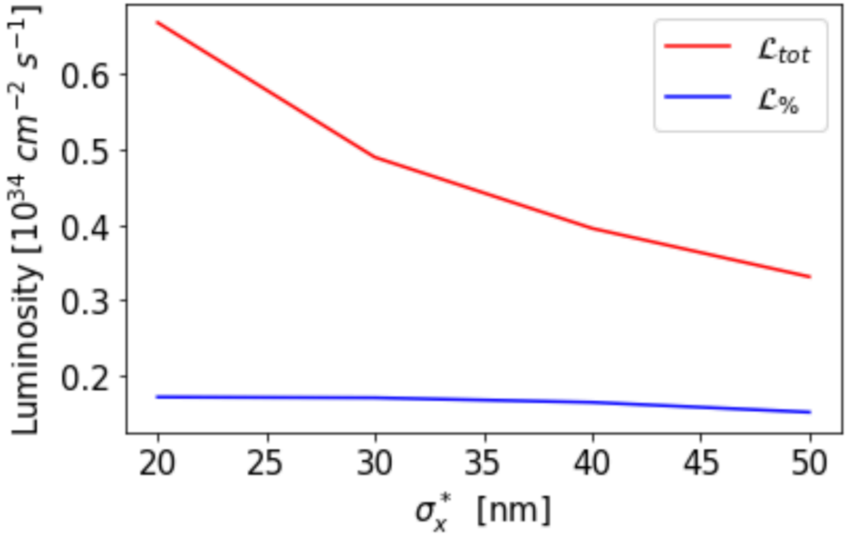

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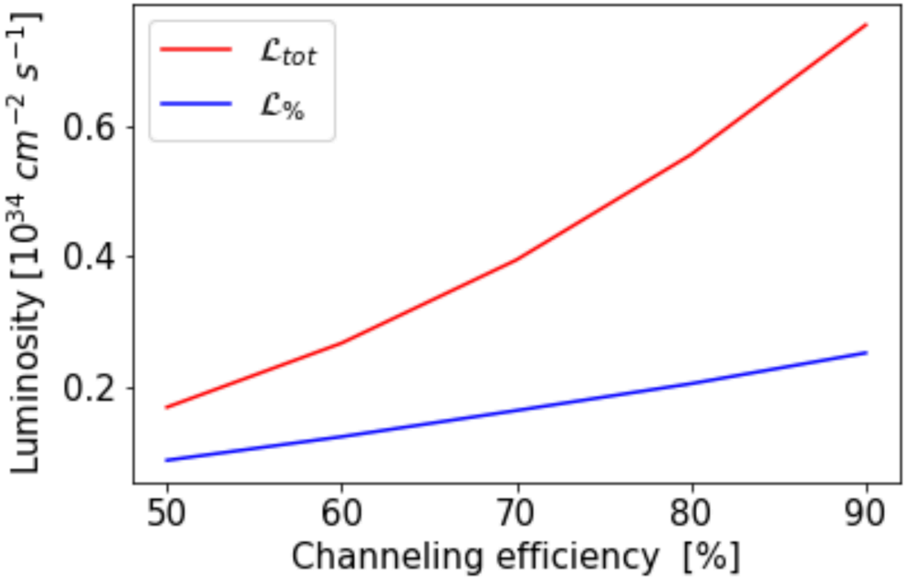

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Conclusions

- The optics simulations done initially showed a good potential for crystal focusing:
  - Good results in terms of beta functions and natural chromaticity
  - Good decrease of the beam size at the IP both in horizontal and vertical planes
  - Aberrations that contribute the most for a σ_x^*, σ_y^* increase are the 2nd and 3rd order

- The results on CLIC 1.5 TeV showed a very significant decrease of luminosity for all the possible cases → significant limitations in using crystals for focusing e- beams

Thanks for your attention!

Backup Slides

Sextupoles strengths

- Comparison between the sextupoles strengths for QD0 and Crystal:

k_s [m^{-2}]	QD0	CRYSTAL
SF6FF	9.08	8.77
SF5FF	-0.43	1.44
SD4FF	15.02	8.82
SF1FF	-2.62	-7.84
SD0FF	4.33	5.72
SK1FF	0.0029	-0.011
SK2FF	-0.12	-0.062
SK3FF	-0.059	-0.022
SK4FF	-0.092	-0.025