Non-linear optimization of the BDS

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Thanks to H. Braun, D. Schulte & F. Zimmermann

(This talk summarizes the contents of the CLIC Note 659)

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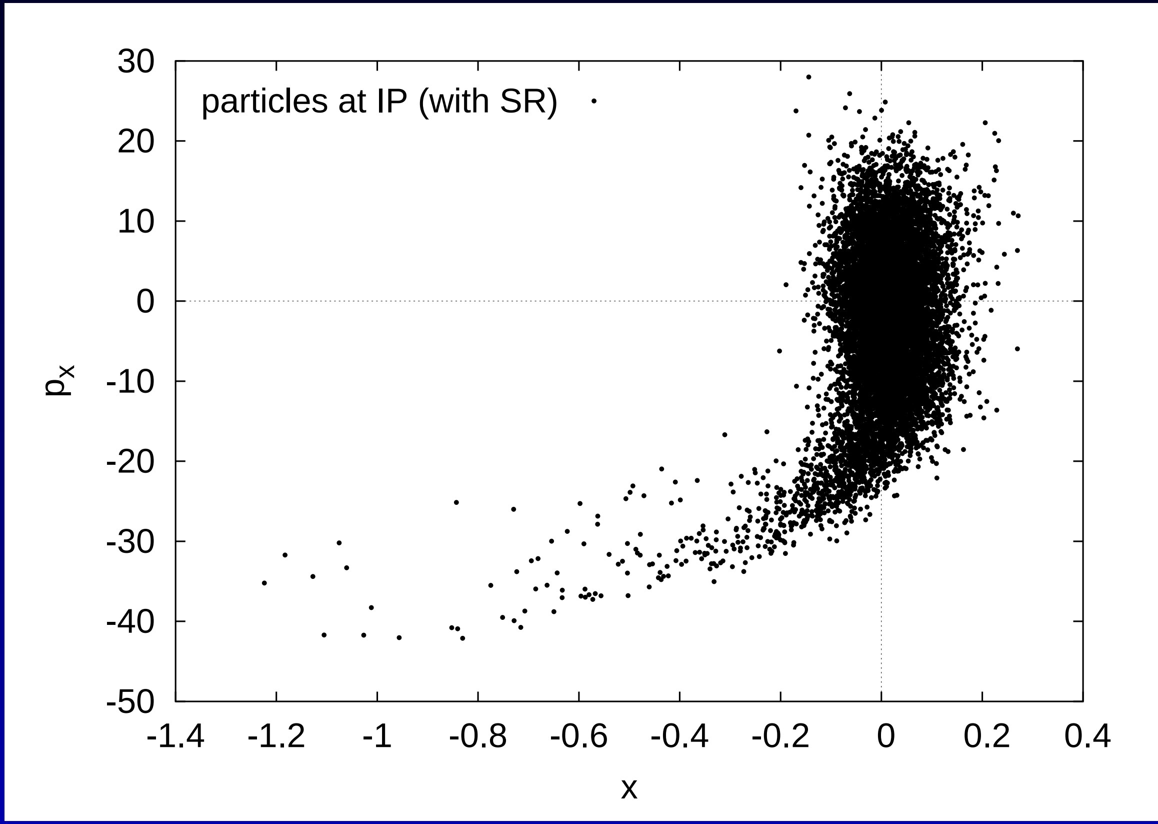
Motivation



$\rightarrow$ Deformation reveals non-linear aberrations

$\rightarrow$ Can we correct them?

$\rightarrow$ Can we focus more?

$\rightarrow$ Can we reduce the SR effect?

Correction: Beam size as observable

We need an observable that quantifies aberrations:
$\rightarrow$ The most natural is the beam size at the IP
Given the transfer map between one location of the accelerator and the IP in the form:

$$\vec{x}_{IP} = \sum \vec{X}_{jklmn}\, x^j\, p_x^k\, y^l\, p_y^m\, \delta^n$$

and given the particle density at the initial location, the rms beam size at the IP is given by:

$$\sigma_{IP}^2 = \sum X_{jklmn} X_{j'k'l'm'n'} \int x^{j+j'} p_x^{k+k'} y^{l+l'} p_y^{m+m'} \delta^{n+n'} \rho dv$$

X_{jklmn} are obtained from MADX-PTC to any order.

Correction: Beam size order-by-order

By truncating the map at different orders σ_q ($q = j+k+l+m$) we obtain different sigmas related to:

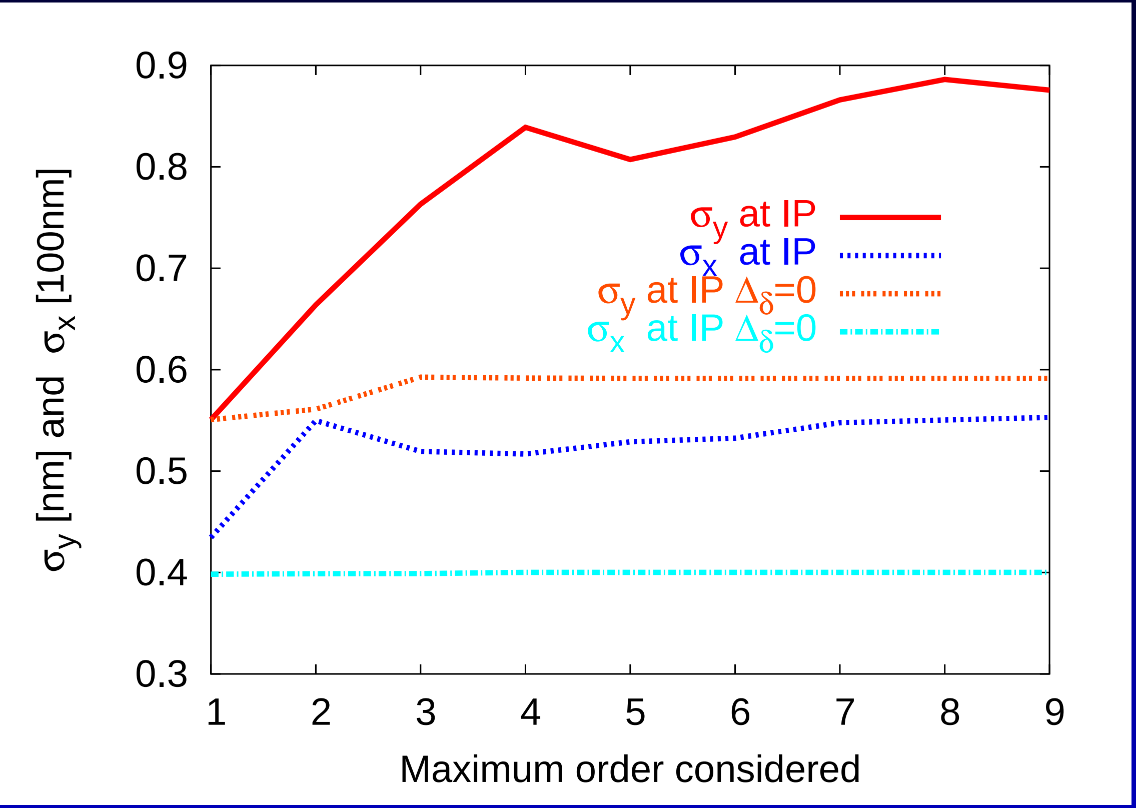
σ_1	Quadrupoles and dipoles
σ_2	chromaticity & sextupoles
σ_3	chromaticity & octupoles
σ_4	...

$\rightarrow$ From σ_q the leading orders of the aberrations are inferred and therefore the most suitable correctors.

$\rightarrow$ By evaluating $\sigma_{q,\delta=0}$ for a monochromatic beam the chromatic part of the aberrations is also inferred.

Correction: Evaluation of BDS aberrations

Optical rms beam sizes using MAPCLASS (no SR)



→ Almost pure chromatic aberrations

→ Sextupolar, octupolar and decapolar correctors are needed

Correction: Algorithm

Variables to minimize:

$\sigma_{x,q}$, $\sigma_{y,q}$ at the IP, from MAPCLASS without SR

Variables to vary:

Strengths of all sexts, otcs and decapoles (octs and decapoles need to be placed in the FFS. We first assume that the existing sextupoles are combined magnets with oct and decapolar fields)

Variables not to vary:

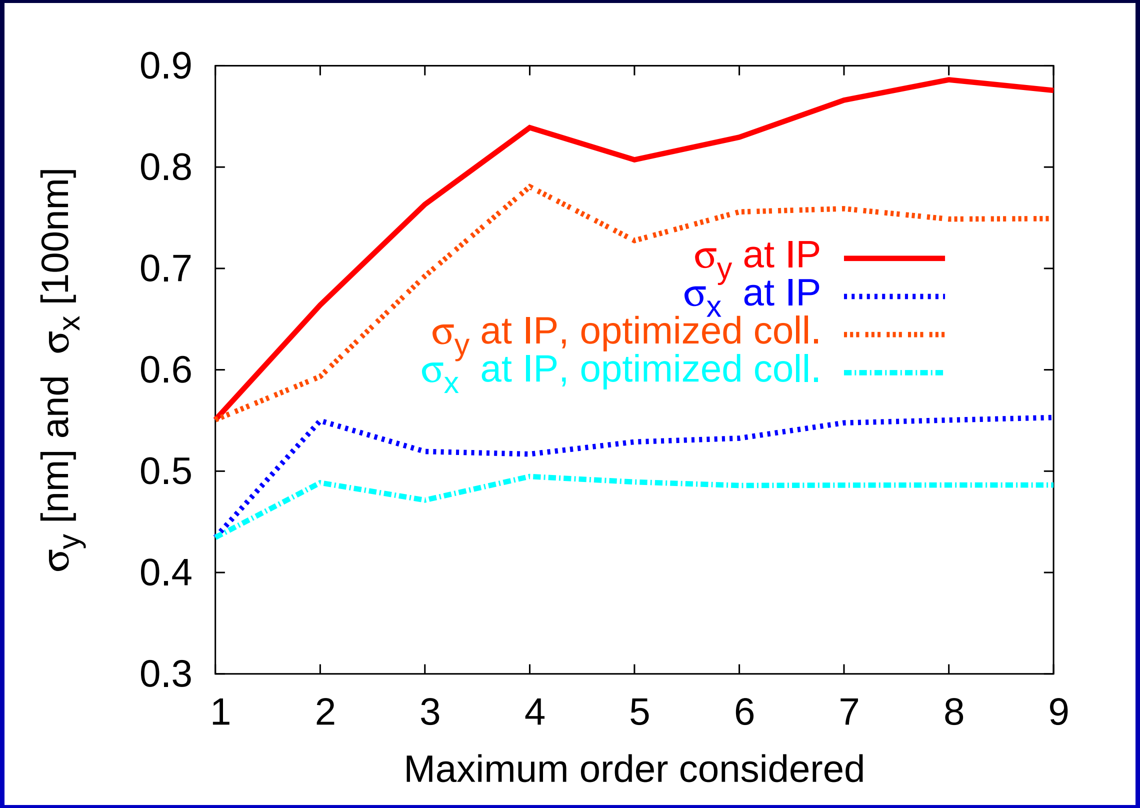
Strengths of dipoles since this will impact SR, which is not considered yet.

Optimization algorithm:

Simplex

Correction: Collimation section

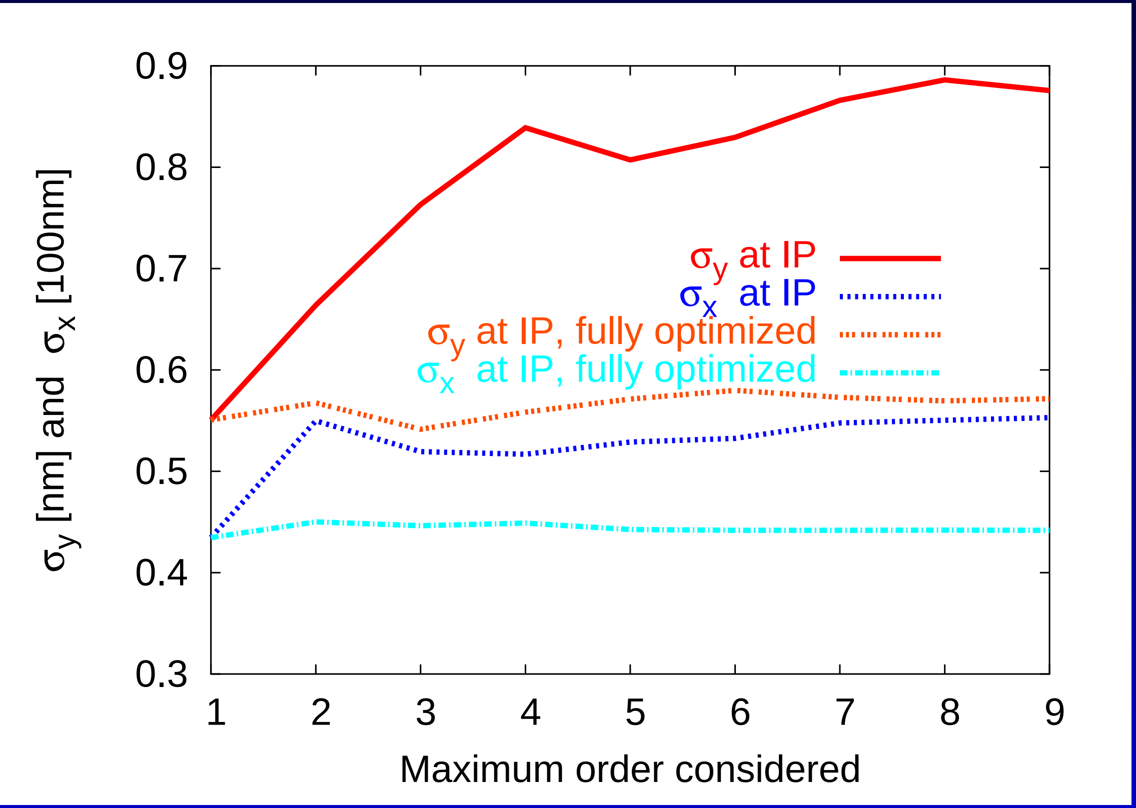
First, only the sextupoles at the collimation section are varied



Sextupoles of the collimation section were overpowered!

Correction: FFS

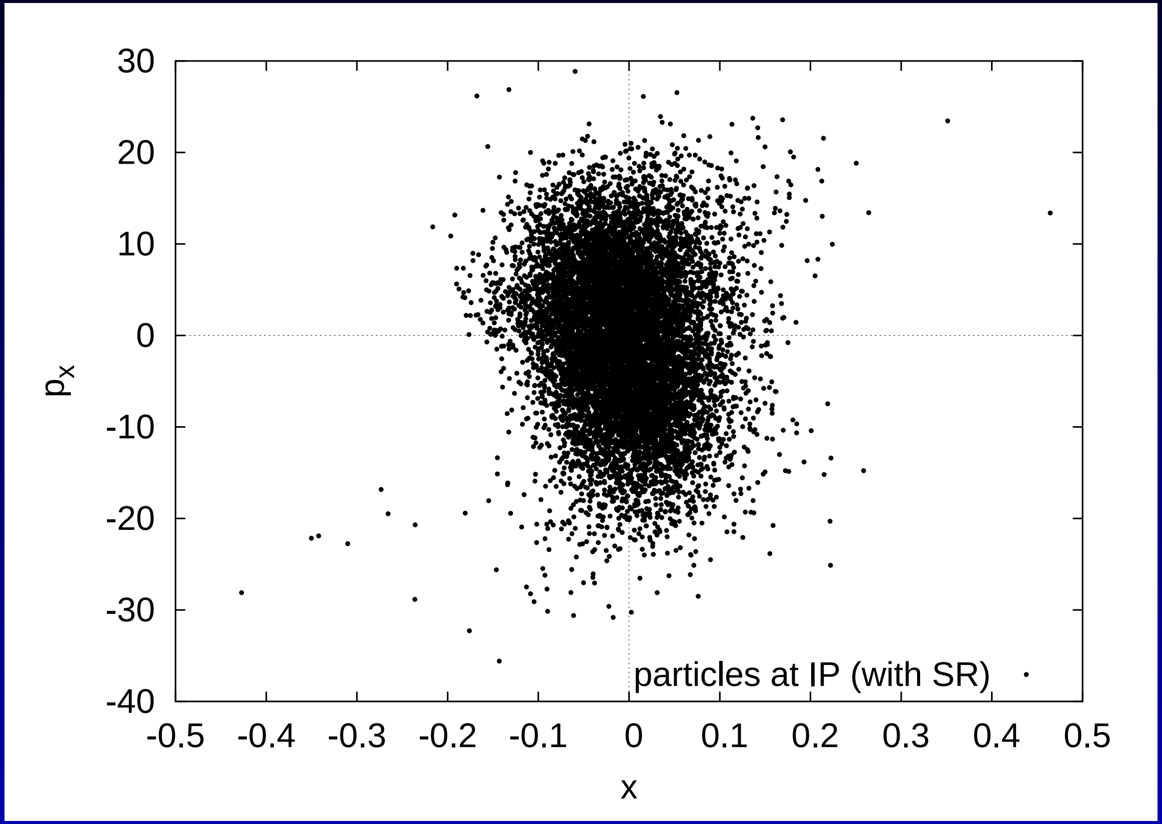
The FFS sextupoles are combined magnets with oct and decapolar fields



→ Almost total correction of aberrations

→ Phase space plot?

Correction: Phase space illustration

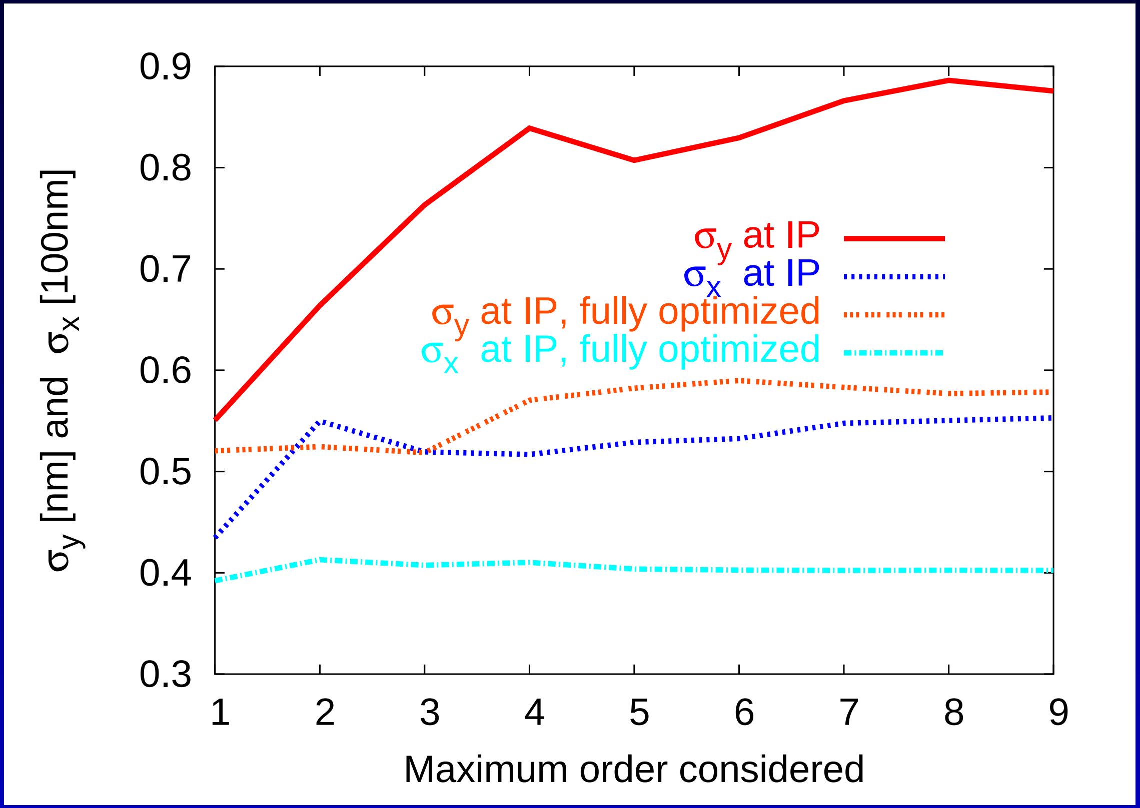


→ No comma shape!

→ Now, is it possible to focus more using the same algorithm but including quad strenghts?

More focusing

The FFS quadrupoles are used to focus more



$\rightarrow$ Need to stop focusing when aberrations arise

$\rightarrow \Delta\beta_x^{QF}/\beta_x^{QF} = +42\%$, $\Delta\beta_x^{IP}/\beta_x^{IP} = -19\%$

$\rightarrow$ Good, but what about luminosity?

Luminosity

Nominal Total Luminsoty=6.15 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Luminosity in energy peak (1%)=2.65 10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$

σ_x^{rms}=88 nm

$Case$	$\frac{-\Delta\sigma_x}{\sigma_x^{rms}}$ (no rad)	$\frac{-\Delta\sigma_x}{\sigma_x^{rms}}$ (rad)	$\frac{-\Delta\sigma_y}{\sigma_y^{rms}}$ (no rad)	$\frac{-\Delta\sigma_y}{\sigma_y^{rms}}$ (rad)	$\frac{\Delta L_{tot}}{L_{tot}}$	$\frac{\Delta L_{1\%}}{L_{1\%}}$	$\frac{L_{1\%}}{L_{tot}}$
Nominal	0	0	0	0	0	0	43
Coll corrected	12	30	14	58	9	6	42
Non-linearities	20	35	35	69	31	19	39
More focusing	27	37	34	64	45	29	38

(All numbers are percent)(Tracking with PLACET including SR)

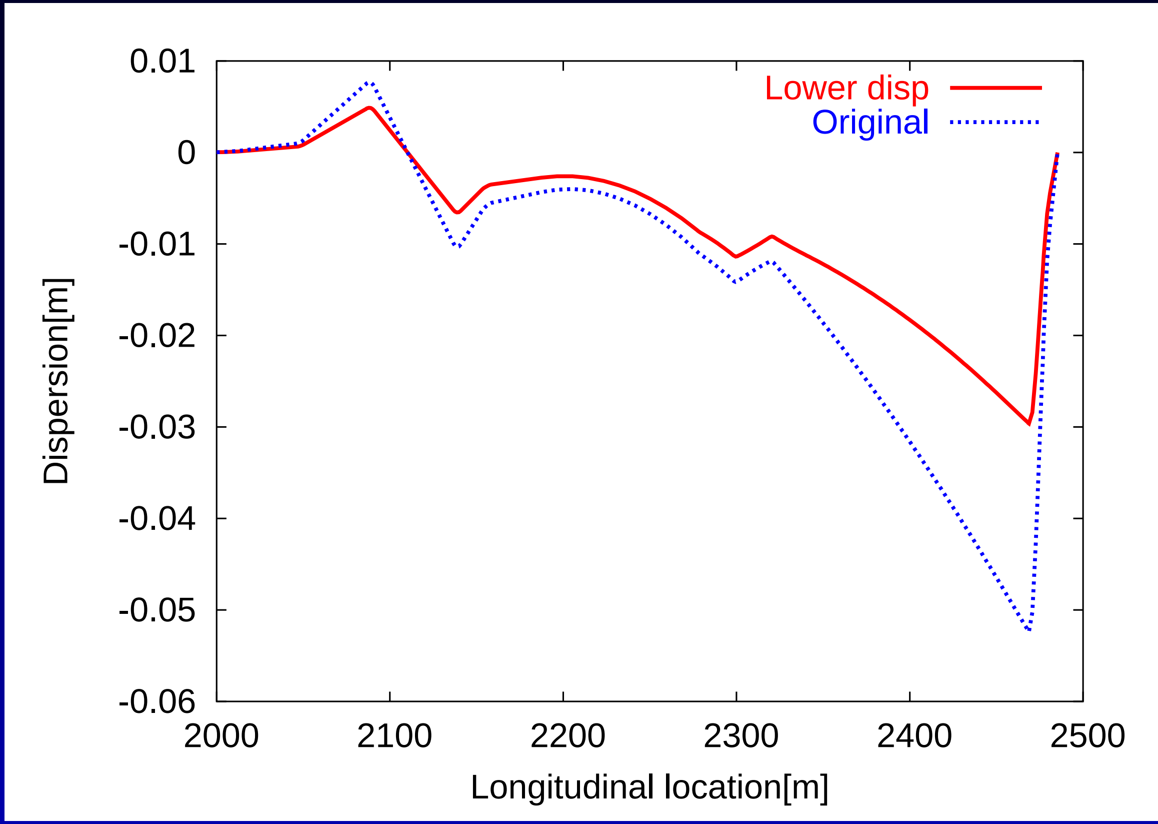
Can we reduce the SR effect?

Radiation is not directly considered in the presented algorithm, however:

- Lower dispersion in the FFS implies lower SR effect
- But also implies stronger sextupoles for chromaticity and therefore stronger aberrations
- There must be an optimum value of dispersion that maximizes luminosity

$\longrightarrow$ A scan in the FFS dispersion doing a full optimization (quads, sexts, octs...) at every step should reveal the optimum value for the dispersion.

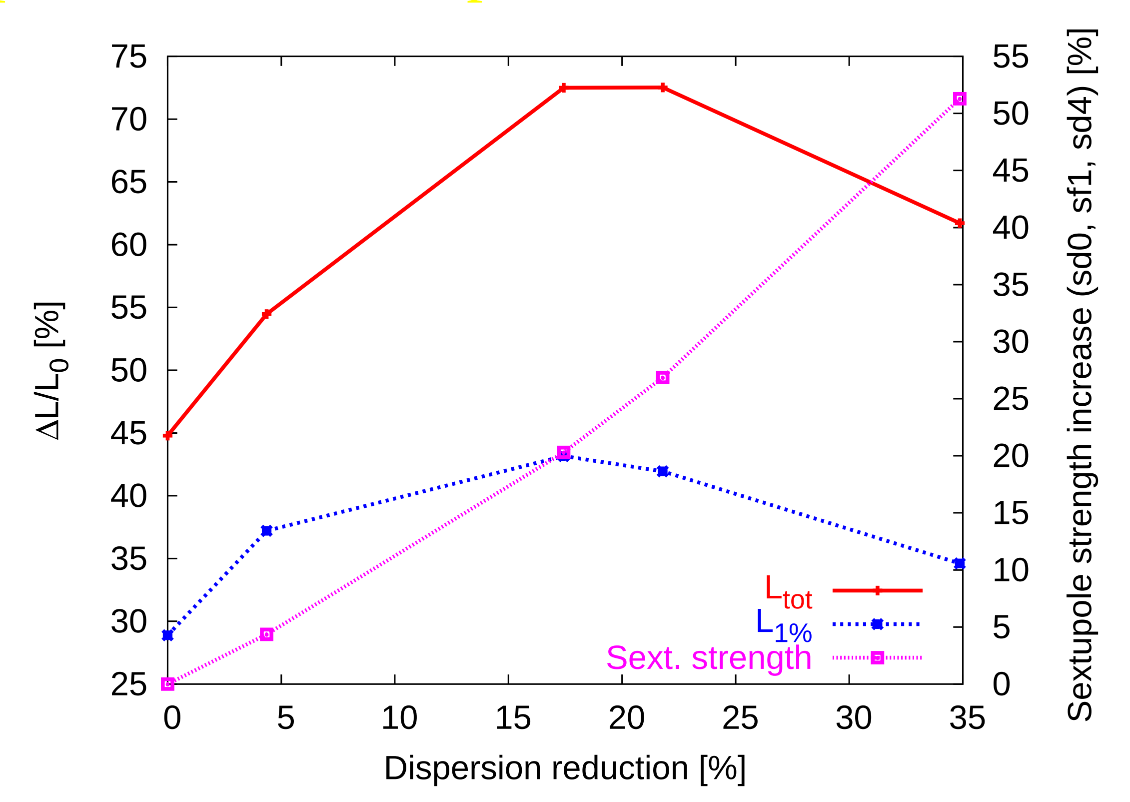
FFS Dispersion reduction: example



$\rightarrow$ An example on dispersion reduction on the FFS by about a 40%

FFS Dispersion scan

0 disp reduction corresponds to the best former case



→ Peak of L_{tot} and $L_{1\%}$ at about 17% dispersion reduction

FFS Dispersion scan: table

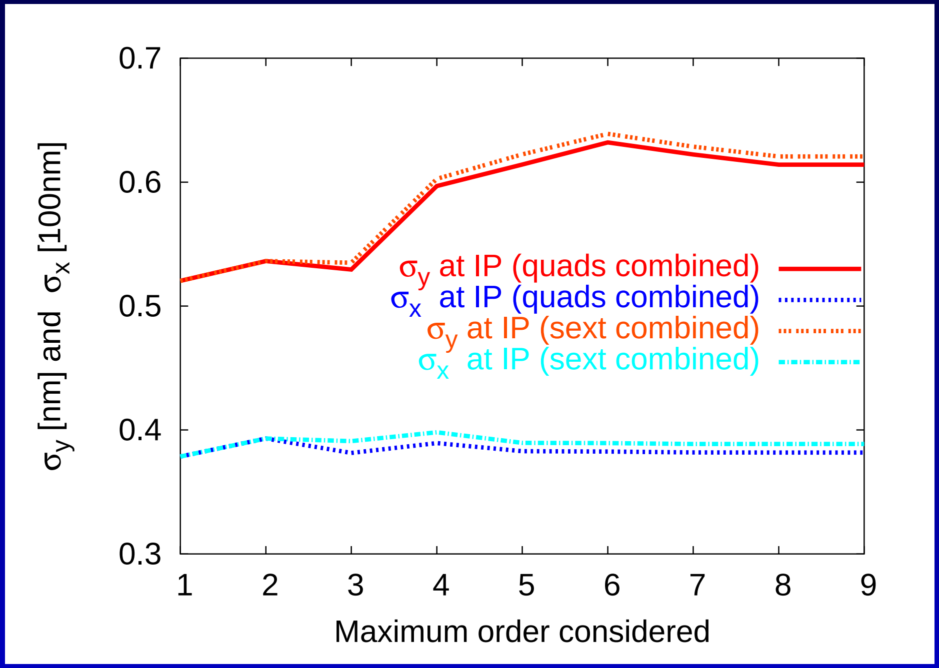
Disp. reduct.	$-\frac{\Delta\sigma_x}{\sigma_x^{rms}}$ (no rad)	$-\frac{\Delta\sigma_x}{\sigma_x^{rms}}$ (rad)	$-\frac{\Delta\sigma_y}{\sigma_y^{rms}}$ (no rad)	$-\frac{\Delta\sigma_y}{\sigma_y^{rms}}$ (rad)	$\frac{\Delta L_{tot}}{L_{tot}}$	$\frac{\Delta L_{1\%}}{L_{1\%}}$	$\frac{L_{1\%}}{L_{tot}}$
0	27	37	34	64	45	29	38
4.3	27	39	34	65	54	37	38
17.4	30	40	29	69	72	43	36
21.8	30	40	27	67	72	42	35
34.9	32	26	18	68	62	35	36

(All numbers are percent)(Tracking with PLACET including SR)

Compare best and worst cases in a movie

Changing the combined function magnets

Octupolar field in the sextupole is not very natural.
What if we use the quads to place the octupolar field?
Decapolar field still in the sextupoles. $\Delta D = -17.4\%$



$\rightarrow$ A more natural field distribution gives equivalent results (also concerning luminosity).

Conclussions and outlook

- Non-linear correction, focusing and dispersion reduction led to a 72% total luminosity increase.
- Could other dispersion patterns increase luminosity?
- What happens to alignment tolerances?
- Feasibility of the new combined magnets sextupole-decapole, quadrupole-octupole needs to be addressed.

σ_x^* limitations from the BDS

Further focusing in the FFS faces:

- Quadrupole aperture
- Chromatic aberrations
- Synchrotron Radiation

Possible solutions:

- Emittance reduction, dispersion reduction or larger aperture quadrupoles.
- Multipolar correctors to compensate aberrations.
- Dispersion reduction.

Quadrupole aperture

- Present design, permanent magnet, aperture=3.8mm
- Superconducting option is difficult due to small size (CLIC note 506)
- $10\sigma_x = 10\sqrt{\epsilon_x\beta_x + D^2\delta^2}$=3.1mm
- More focusing needs larger β_x.
- Doubling β_x implies $10\sigma_x$ =3.5mm
- Doubling β_x and reducing D by 25% implies $10\sigma_x$ =3.1mm