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Automatic Luminosity Optimisation of the ILC Head-On BDS

J. Payet, A. Chancé, O. Napoly, D. Uriot
CEA/DSM/DAPNIA/SACM
S. Auclair, EFREI

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    - 250 GeV BDS
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Introduction

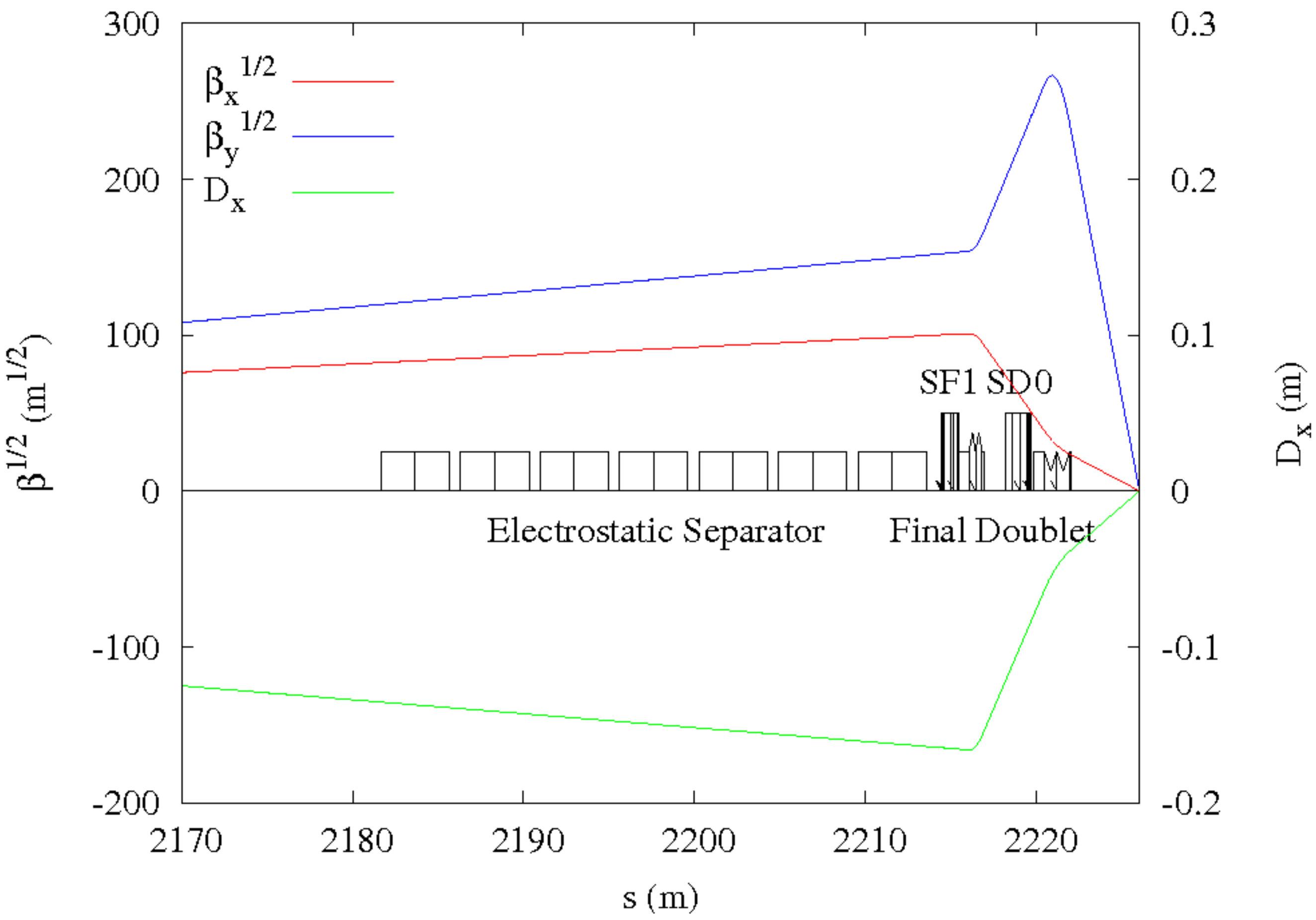
- With the local chromaticity correction scheme, the luminosity optimisation of the $e+e-$ International Linear Collider (ILC) Beam Delivery System (BDS) is challenging.
- It is a long and complex process and its automation becomes a necessity.
- It was recently shown that it is possible to employ a minimization method of the beam sizes at the Interaction Point (IP), without adding any other constraint on the beam line parameters.
- To achieve this goal, we have developed a minimization code which uses analytical computations of the IP beam sizes based on the high order transport coefficients calculated by the code TRANSPORT.
- We also use the code TRACEWIN which tracks a particle cloud and minimise the rms beam sizes at the IP to optimise the luminosity, and we compare with the previous results.

The BDS

- We adapt the ILC 2006e (2 mrad FFS) beam transfer line to the Head-on case.
- The main modifications concern the Final Doublet (FD) region.
  - ➢ The FD quadrupoles are replaced by superconducting quadrupoles.
  - ➢ The distance l^* between the IP and the FD is set to 4.1 m, to keep the final quadrupole away the solenoid field.
  - ➢ A 28 m long electrostatic separator is located as close to the IP as possible in order to extract the spent beam.
- To improve our chromatic correction, a sextupole is added at the middle of the energy collimation section.
- We use the ILC nominal parameter set.

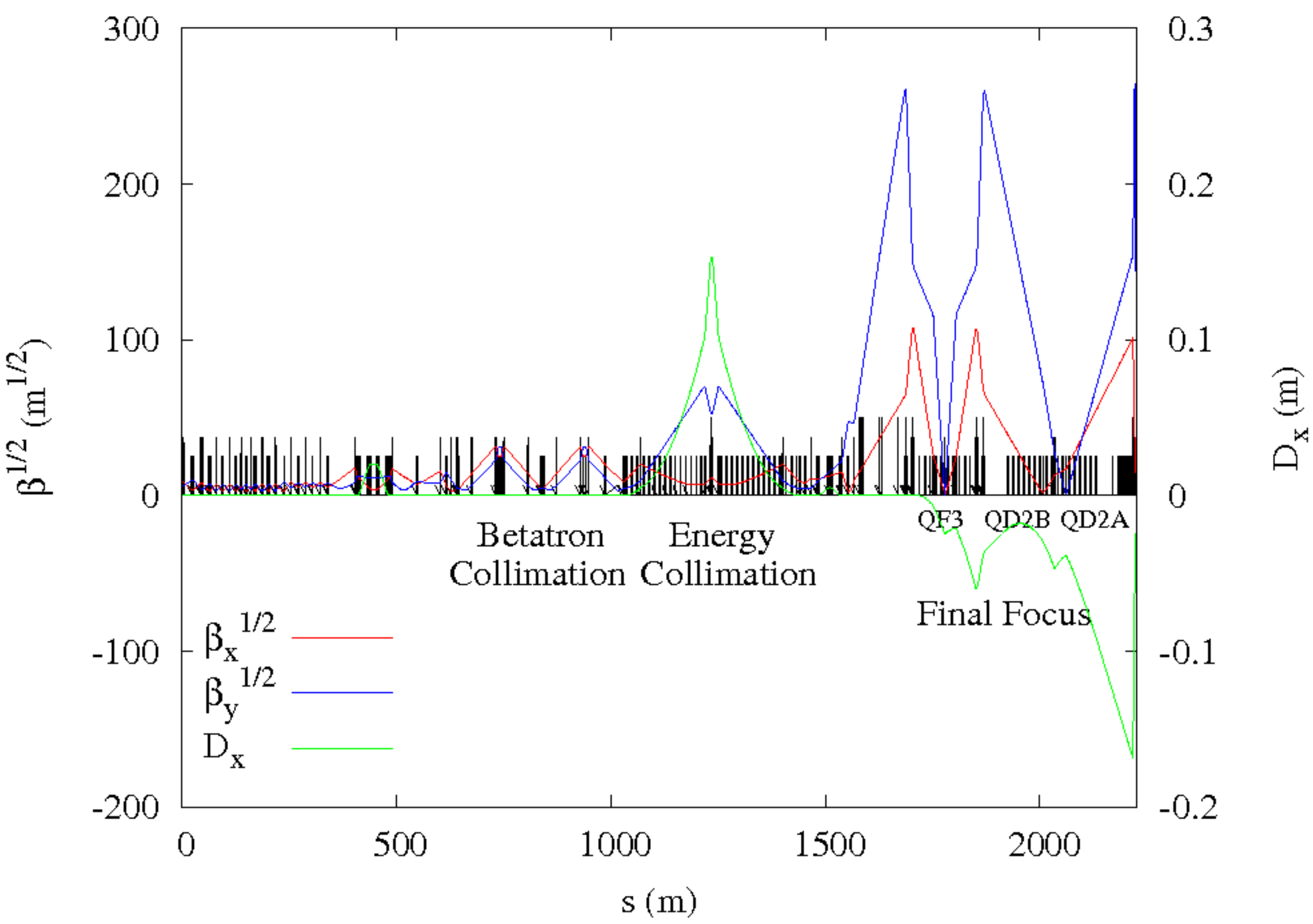
Beam energy (GeV)	250	500
Repetition rate f *$N_{bunches}$ (Hz)	5*2625	4*2625
Number of particles/bunch	2.05 10^{10}	2.05 10^{10}
IP Beta functions β_x/β_y (mm)	20/0.4	30/0.3
IP Beam sizes σ_x/σ_y (nm)	639.4/5.7	553.7/3.5
Geometric Luminosity L_0 ($cm^{-2}.s^{-1}$)	1.20 10^{34}	1.81 10^{34}

500 GeV BDS with *l**=4m: Final Focus



Optical functions in the FD region at 500 GeV.

500 GeV BDS with *l**=4m: Optical Functions



Optical functions of the 500 GeV BDS.

Automatic Optimisation

The optimization procedure has to minimize, at the IP, the product:

$$\Sigma_{IP} = \overline{\left(x-\overline{x}\right)^2} \cdot \overline{\left(y-\overline{y}\right)^2}$$

Two approaches are used:

- We develop the code LUMOPT which computes analytically the beam sizes and minimizes their product.
  - We use analytical expressions of the rms beam sizes based on the beam distribution parameters and the high order transfer matrix terms.

- We use the code TRACEWIN which tracks a particle cloud to the IP, computes the rms dimensions and search for a minimum of the rms dimensions product.

Analytical Expressions

We want to minimise at IP the product $\Sigma_{IP} = \overline{\left(x-\overline{x}\right)^2} \cdot \overline{\left(y-\overline{y}\right)^2}$

The particle coordinates at IP are expressed with the high order matrix terms:

$$x_i = \sum_j R_{ij} x_j^{(0)} + \sum_{jk} T_{ijk} x_j^{(0)} x_k^{(0)} + \sum_{jkl} U_{jkl} x_j^{(0)} x_k^{(0)} x_l^{(0)} + o(3)$$

We assume that the initial beam distribution is a centred Gaussian. So the odd moments are null and one can write:

$$\overline{x_i} = \sum_{jk} T_{ijk} \overline{x_j^{(0)} x_k^{(0)}}$$

One can write the standard deviations at IP as:

$$\overline{\left(x_i - \overline{x_i}\right)^2} = \sum_{jj'} R_{ij} R_{ij'} \overline{x_j^{(0)} x_{j'}^{(0)}} + \sum_{jk} \sum_{j'k'} T_{ijk} T_{ij'k'} \left(\overline{x_j^{(0)} x_k^{(0)} x_{j'}^{(0)} x_{k'}^{(0)}} - \overline{x_j^{(0)} x_k^{(0)}} \cdot \overline{x_{j'}^{(0)} x_{k'}^{(0)}} \right)$$
$$+ 2 \sum_j \sum_{j'k'l'} R_{ij} U_{ij'k'l'} \overline{x_j^{(0)} x_{j'}^{(0)} x_{k'}^{(0)} x_{l'}^{(0)}} + \sum_{jkl} \sum_{j'k'l'} U_{ijkl} U_{ij'k'l'} \overline{x_j^{(0)} x_k^{(0)} x_l^{(0)} x_{j'}^{(0)} x_{k'}^{(0)} x_{l'}^{(0)}}$$

The high order terms of the transfer matrix are given by TRANSPORT.

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Analytical Expressions

- The initial beam distribution is Gaussian
  - One can write the 4th order moment as a function of the 2nd order moments:

$$\overline{x_j^{(0)}x_k^{(0)}x_l^{(0)}x_m^{(0)}} = \overline{x_j^{(0)}x_k^{(0)}}\cdot\overline{x_l^{(0)}x_m^{(0)}} + \overline{x_j^{(0)}x_l^{(0)}}\cdot\overline{x_k^{(0)}x_m^{(0)}} + \overline{x_j^{(0)}x_m^{(0)}}\cdot\overline{x_k^{(0)}x_l^{(0)}}$$

  - The 6th order beam moments can be expressed by the same way.

$\Rightarrow$ The rms beam sizes at the IP are functions of the 2nd order moments.

- REMARK: To keep the $U_{ijkl}\ U_{i'j'k'l'}$ terms we should have to develop the coordinate up to the 5th order, not possible with TRANSPORT.
  - But, without these terms the optimisation is less efficient.

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Optimisation

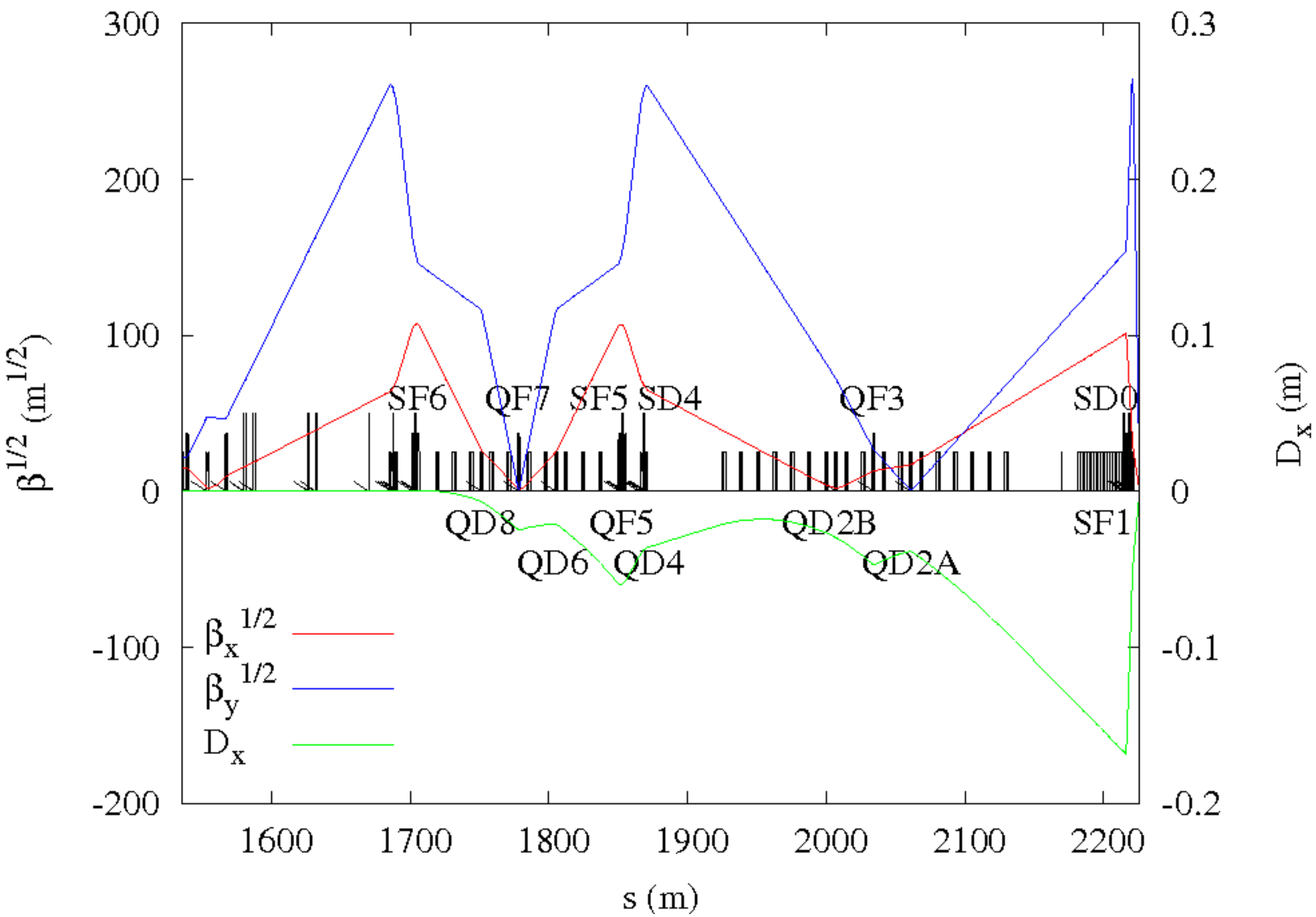
- The 2nd order terms are minimised with the sextupoles.

- The variables are the Final Focus quadrupoles and sextupoles:
  - 6 sextupoles : SD0 to SF6 + Energy Collimation sextupole
  - 8 quadrupoles : QD2A to QD8 (efficient QD2A, QD2B, QF3 located at waists)

- The beam momentum spread is an optimisation parameter:
  - ➢ for large $\sigma_{dp/p}$ => more weight on chromatic terms
    => flat curve
  - ➢ for small $\sigma_{dp/p}$ => more weight on geometric terms
    => peaked curve around the origin

- After each optimisation we match, if needed, the beta functions at IP to the nominal values:
  - ➢ for each tuning $\Sigma_{IP} = \sqrt{\overline{(x-\bar{x})^2}} \cdot \sqrt{\overline{(y-\bar{y})^2}}$ is the same.

BDS optimisation variables



Final Focus optics and optimisation variables.

Luminosity computation (w/o beam-beam)

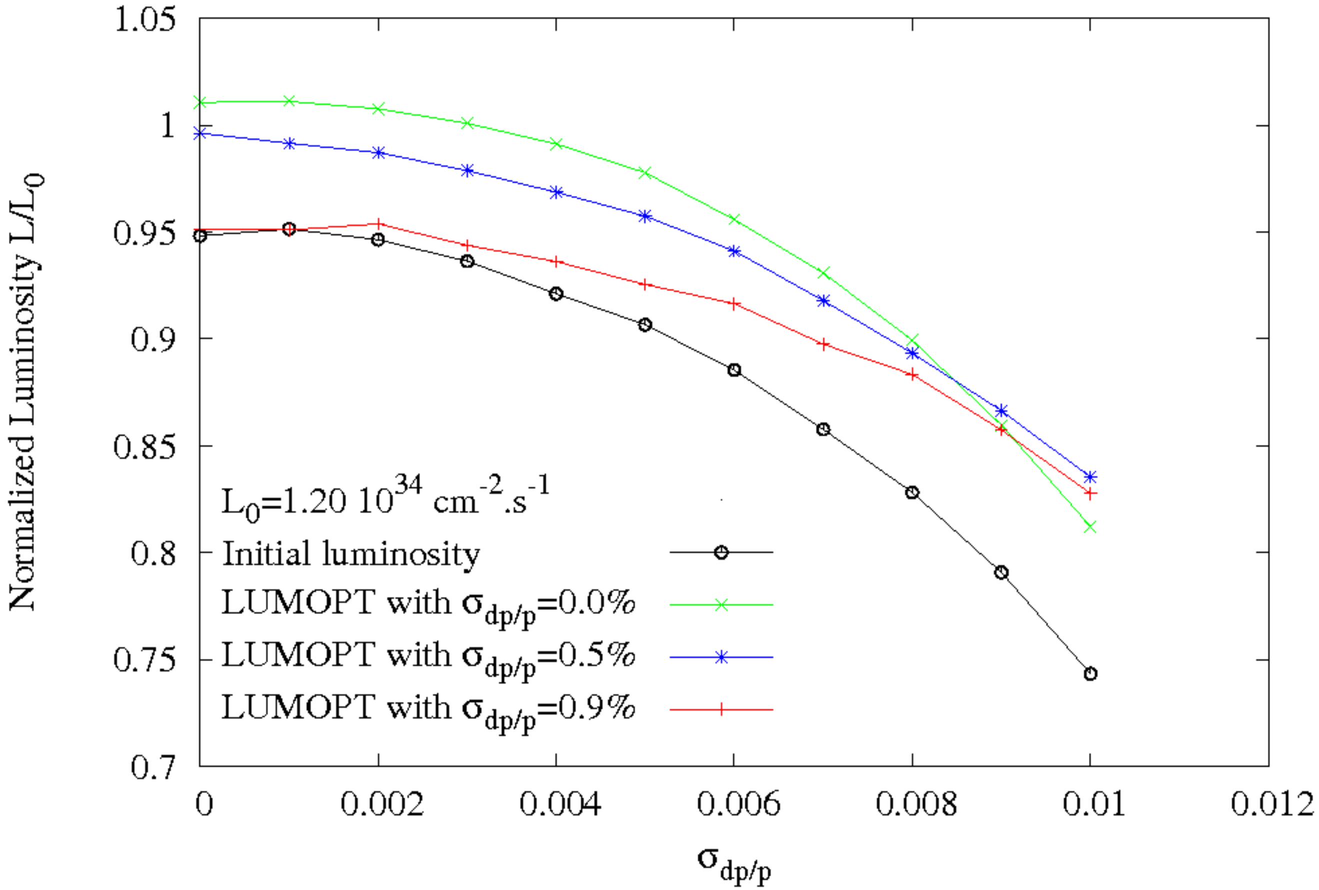
- We always use the same procedure to compare the luminosity optimisation resulting from different tuning processes.

  – We track 6D Gaussian distribution particle clouds, truncated to 3 rms in x,x',y,y',z and to 2 rms in momentum with DIMAD by varying the beam rms momentum spread.

  – For each momentum spread, we count at the IP the particles which are in an elementary cell, n_i, of a rectangular surface, centred on the machine axis and divided by a 240×480 $x \times y$ grid.

  – The luminosity is computed by integrating the overlap of the transverse beam distribution on itself.

250 GeV BDS with *l**=4 m, LUMOPT optimisation

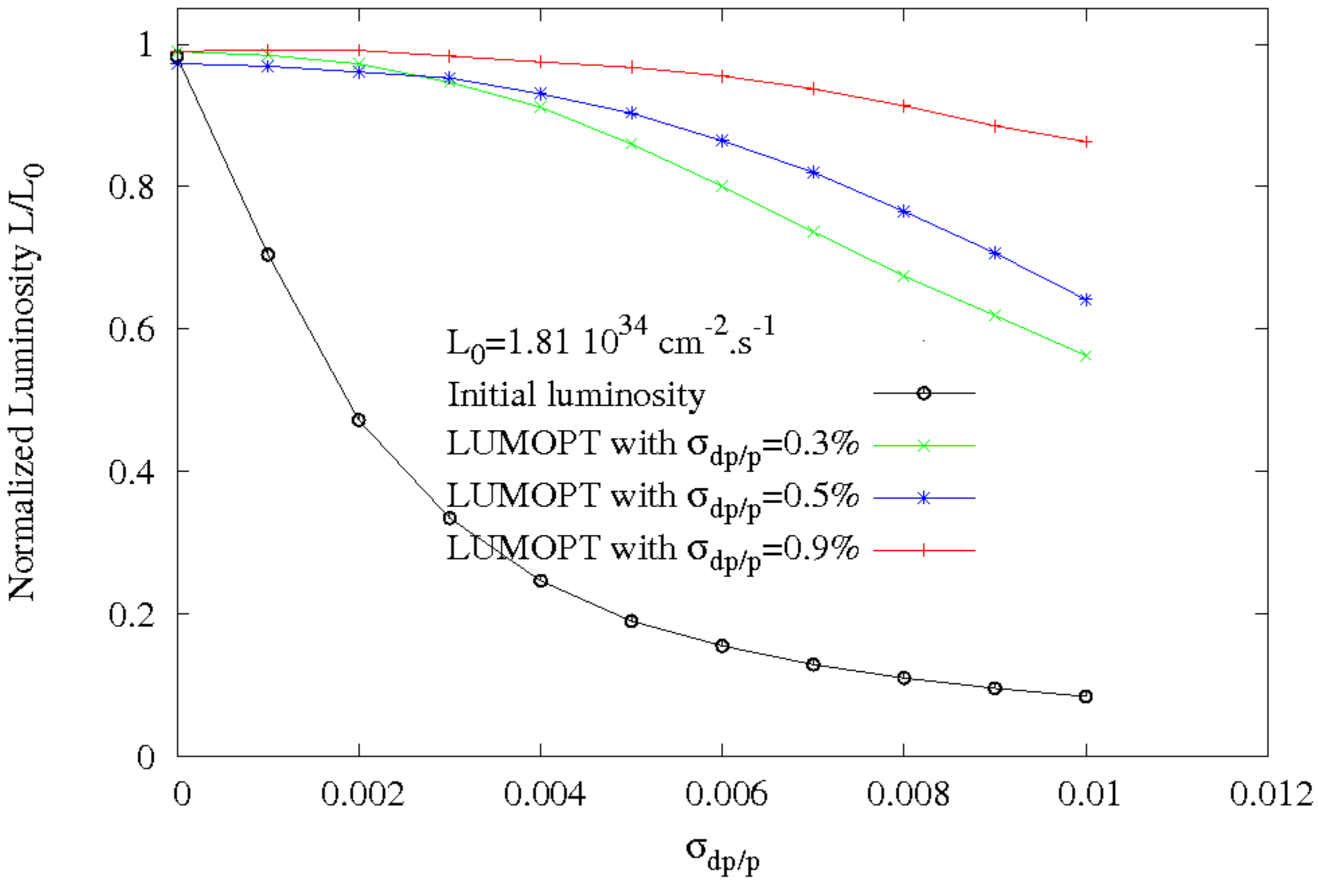


LUMOPT reaches its objective, the luminosity is greater than L_0 up to 0.4%.

When the $\sigma_{dp/p}$ parameter increases:

- The curve is flatter.
- The results are better for large momentum spread.

500 GeV BDS with *l**=4 m, LUMOPT optimisation

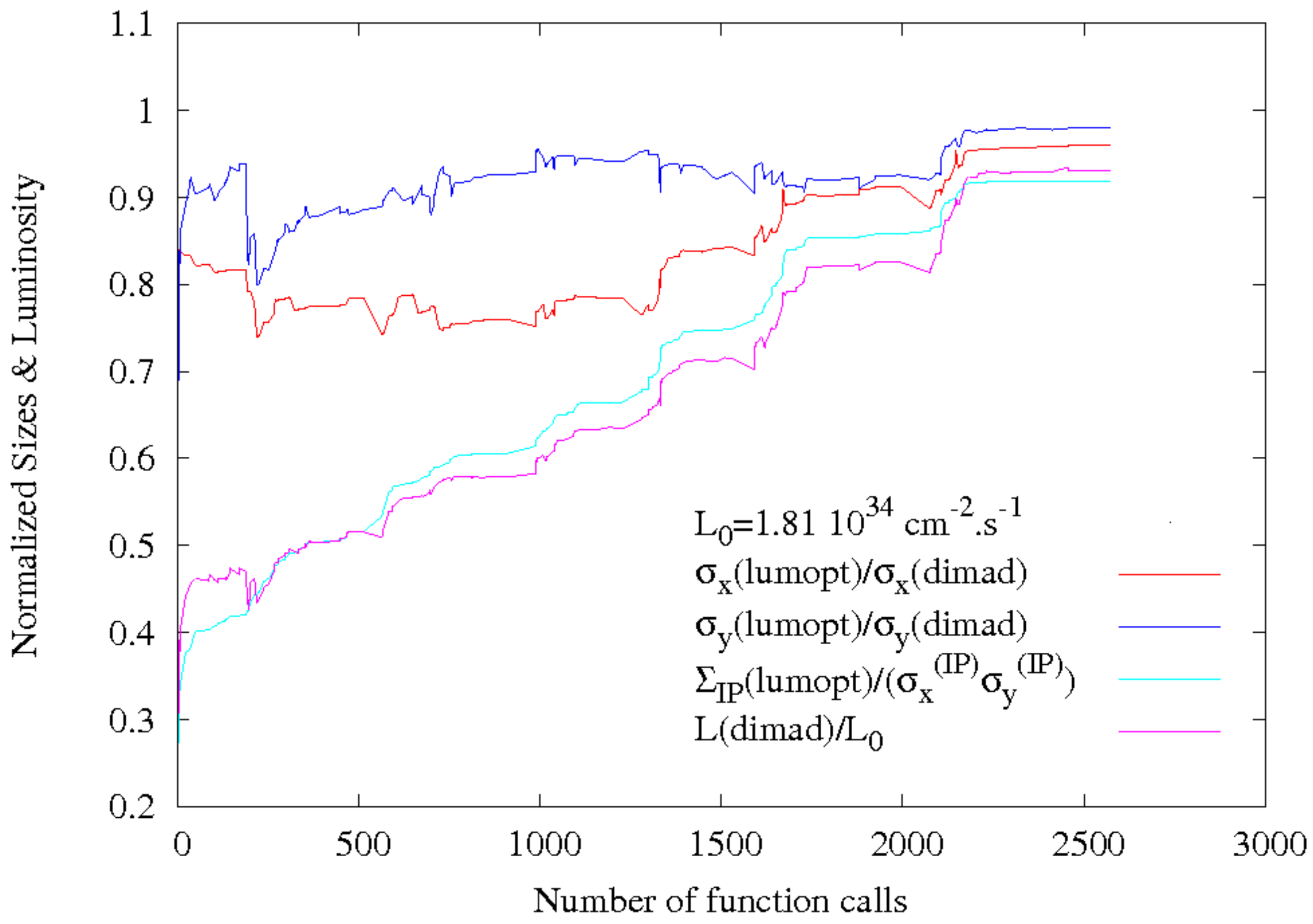


Even if the initial state is far away the solution, LUMOPT obtain good results.

As previously:

- With large $\sigma_{dp/p}$ parameter : better results for large momentum spread.
- With small $\sigma_{dp/p}$ parameter : better results for low momentum spread.

500 GeV BDS with *l**=4 m, optimisation evolution

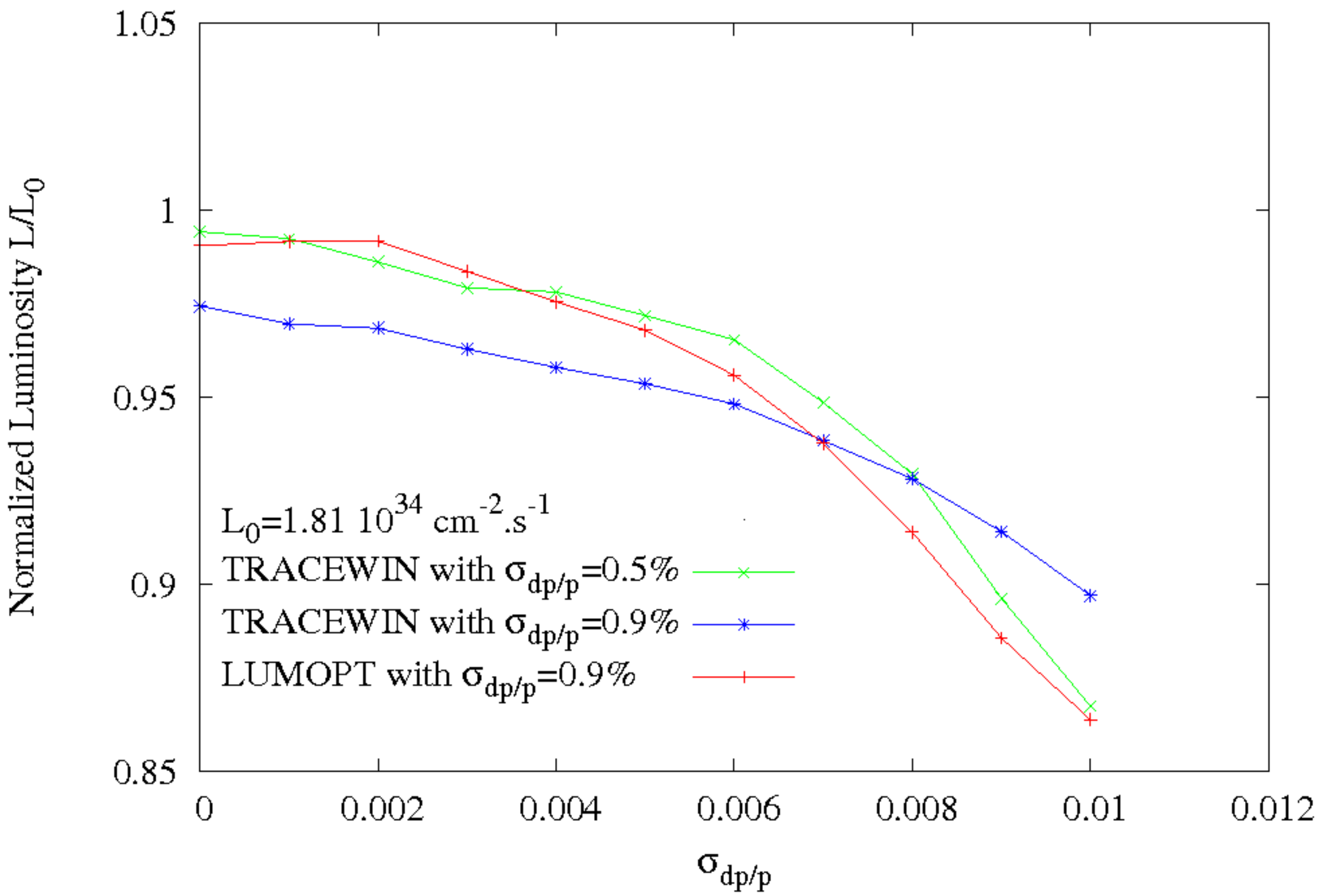


The agreement with tracking becomes better along the optimisation.

The luminosity obtained by tracking does not always grow.

But, it follows the merit function evolution.

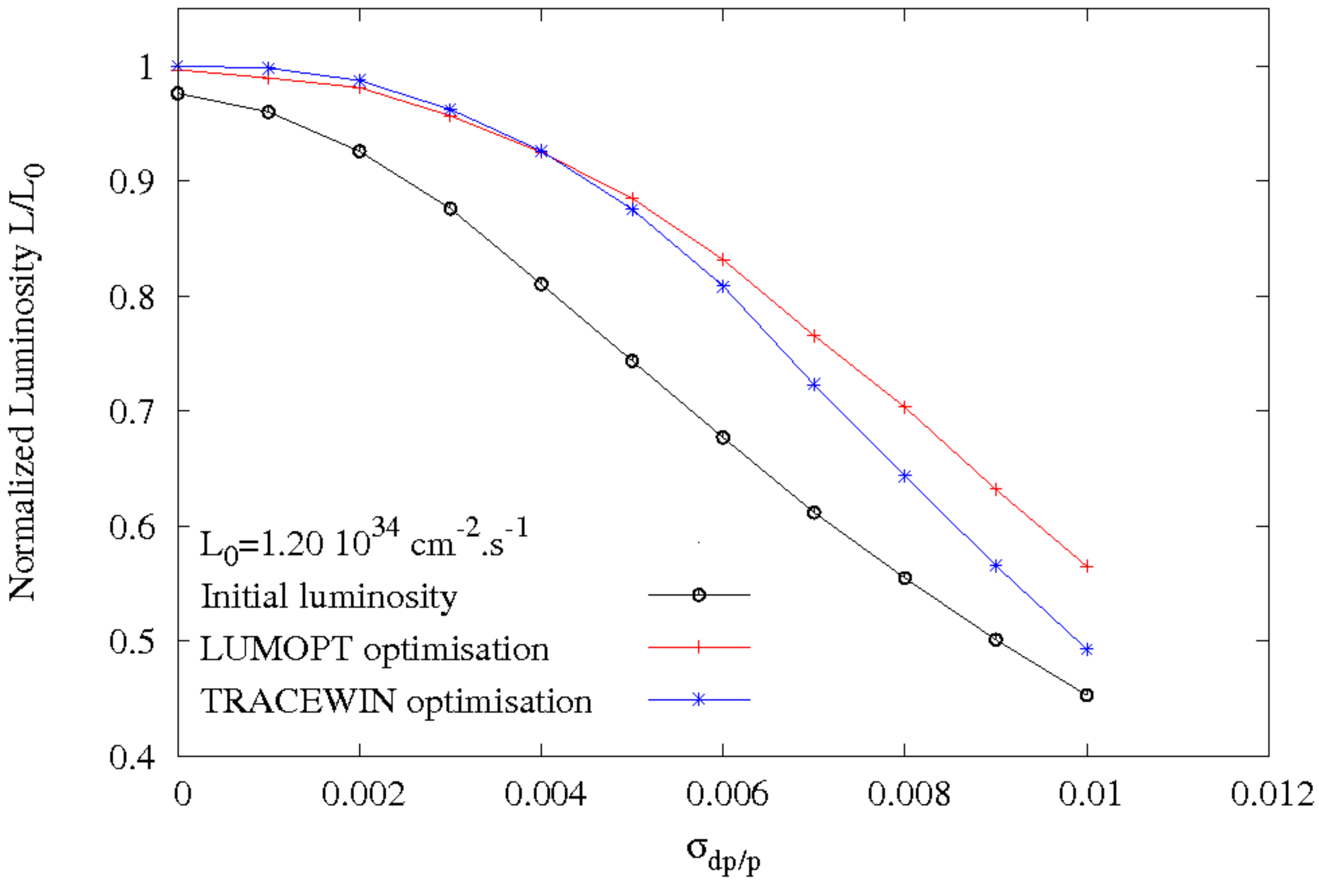
500 GeV BDS with *l**=4 m, TRACEWIN optimisation



The tracking code TRACEWIN gives similar results as LUMOPT.

Optimisation with a tracking code has the same behaviours toward the momentum spread parameter.

250 GeV BDS with *l**=6.1 m, optimisation



TRACEWIN and LUMOPT give comparable results.

The luminosity curves decrease more quickly than for the *l**=4 m BDS.

But, the luminosity remains greater than 0.88 L_0 up to 0.5%.

Conclusions

- The two codes LUMOPT and TRACEWIN allow the automatic optimisation of the BDS luminosity.

- The obtained luminosity curve are comparable to the 14 mrad and 2 mrad BDS one.

- The code LUMOPT reaches its goal in a relatively short time in comparison with the tracking code TRACEWIN.

- The results depend on the starting point, so we are studying improvements on :
  - the optimisation algorithm,
  - the merit function,
  - the initial lattice tuning.