Status of Integrated Simulations Based on PLACET

Andrea Latina (CERN)

European LC Workshop

January 8-11, 2007 - Daresbury Laboratory, UK

- Introduction
- Simulations Results
- Conclusions and Outlook

Introduction

- Integrated Simulations have been carried out in order to evaluate the global performances of the ILC and CLIC
  - Bunch Compressor, Main Linac, Beam Delivery System and IP have been simulated

- We used the tracking code PLACET
  - is a tracking code for linear colliders which implements

    wake-fields, synchrotron radiation emission, multi-bunch effects, longitudinal motion,...

- We used also GUINEA-PIG
  - a beam-beam interaction code to simulate beam-beam collisions

Outline

- **Bunch Compressor** (BC)
  - Static alignment of the BC
  - Use of the Bunch Compressor for ML alignment
- **Main Linac** (ML)
  - Static alignment strategies for a laser-straight and a curved layout
    - impact of BPM calibration errors and quadrupole power supply ripples
  - Emittance preservation using *dispersion bumps* and *wakefields bumps* and their optimal design
  - Dynamic Effects
    - jitter during alignment
    - orbit feedback to cure ground motion

Outline

- **Beam Delivery System** (BDS)
  - Static alignment of the BDS
  - Dynamic effects of the ground motion and BDS feedback loops
    - pulse-to-pulse and intra-pulse feedbacks
  - Halo tracking and background
  - Impact of Collimator wakefields on the luminosity
  - Nonlinear Design and Optimisation (CLIC)
- **Bunch Compressor + Main Linac**
  - Using the bunch compressor to align the main linac
  - Use of the Bunch Compressor for ML alignment
- **Main Linac + Beam Delivery System + IP**
  - Main linac feedback loops
  - IP parameters optimisation

ILC Main Linac Simulations

- **Simulation Setup**
  - XSIF ILC2006e version of the lattice
  - Standard ILC misalignments:

quadrupole position	300 μm
quadrupole tilt	300 μrad
quadrupole roll	300 μrad
cavity position	300 μm
cavity tilt	300 μrad
bpm position	300 μm

  - BPM resolution $= 1\mu$m
  - Curved layout obtained introducing small angles between the cryo-modules (KICKs)
  - Undulators section represented via *EnergySpread* elements

- All results are the average of many seeds

Static Alignment

- **Alignment strategy:**

  1. 1-to-1 correction

  2. dispersion free steering
  (“*target dispersion steering*” for a curved machine)

  3. dispersion bumps and wakefields bumps

- Parameters Settings for **Dispersion Free Steering:**

  - it minimises the merit function

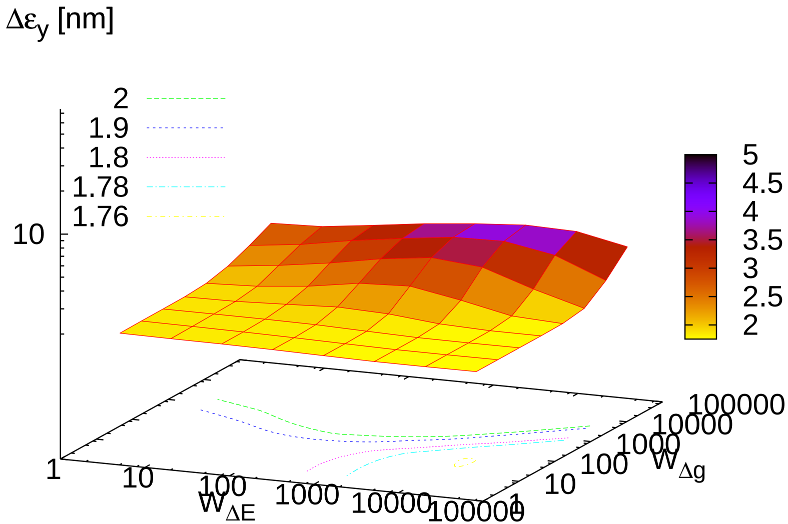
$$M = \sum_{i=1}^{n} \omega_0 \, y_{0,i}^2 + \sum_{j=1}^{m} \sum_{i=1}^{n} \omega_j \, \left(y_{j,i} - y_{0,i} - \Delta_i\right)^2$$

  n beam position monitors; m test beams; ω_j weights; Δ_i target dispersion
  ($\Delta_i = 0 \; \forall i$ in a laser-straight machine)

$\Rightarrow$ a detailed study of the **optimal parameters set** will be presented in the parallel session

Emittance Growth in a Straight Linac

Emittance growth as a function of the DFS weights after the alignment procedure:



- Here we used two test beams:

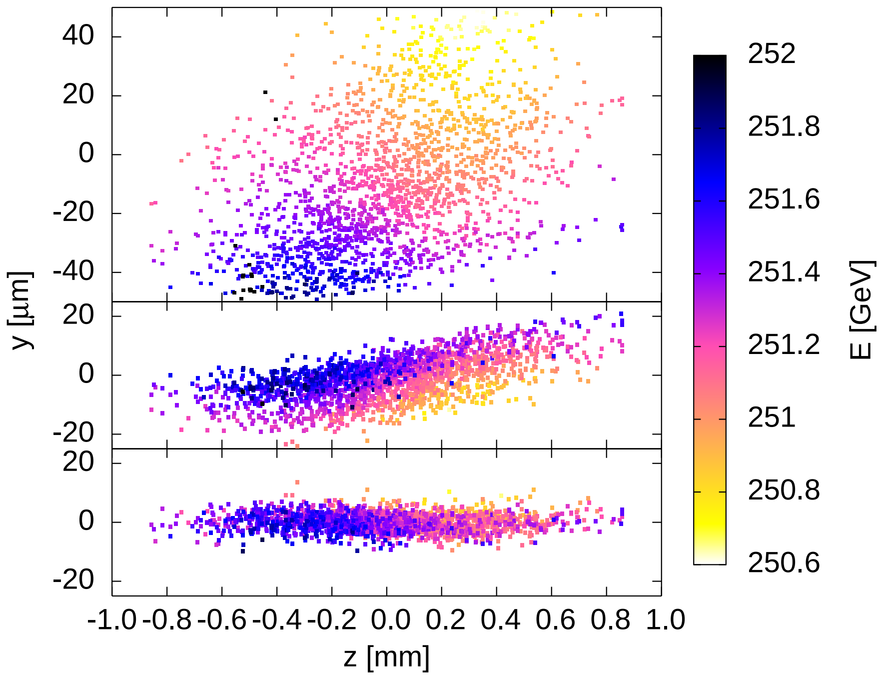
  1) ΔE=0.2 $\rightarrow$ $E_{\text{initial}} = 80\%\ E_{0,\text{initial}}$
  2) Δg=0.2 $\rightarrow$ $E_{\text{final}} = 80\%\ E_{0,\text{final}}$

$\Rightarrow$ Residual emittance growth after the correction procedure is $\boxed{\Delta\epsilon = 1.7 \text{ nm}}$
(quadrupole roll is not corrected)

Tuning Bumps in the ILC Linac

Beam portrait in the $z - y$ plane, the colour corresponds to the energy

- top: beam after 1-to-1 correction
- middle: beam after DFS
- bottom: beam after emittance tuning bumps



Emittance Growth in a Curved Linac

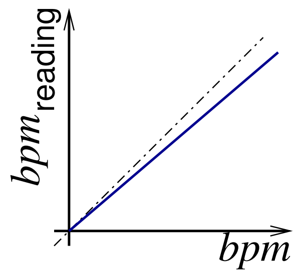
- Let's recall the DFS formula

$$M = \sum_{i=1}^{n} \omega_0 \, y_{0,i}^2 + \sum_{j=1}^{m} \sum_{i=1}^{n} \omega_j \, (y_{j,i} - y_{0,i} - \Delta_i)^2$$

$\Rightarrow$ Erroneous **BPM calibrations** can cause error in evaluating the dispersion, biasing the "target dispersion" steering

- In our model, the BPM readings are linear to the actual measurements but there is a *scale factor* a_i

$$x_{i,\text{reading}} = a_i \, x_i$$



- in the simulations scale factors have a Gaussian distribution with width σ_a around 1

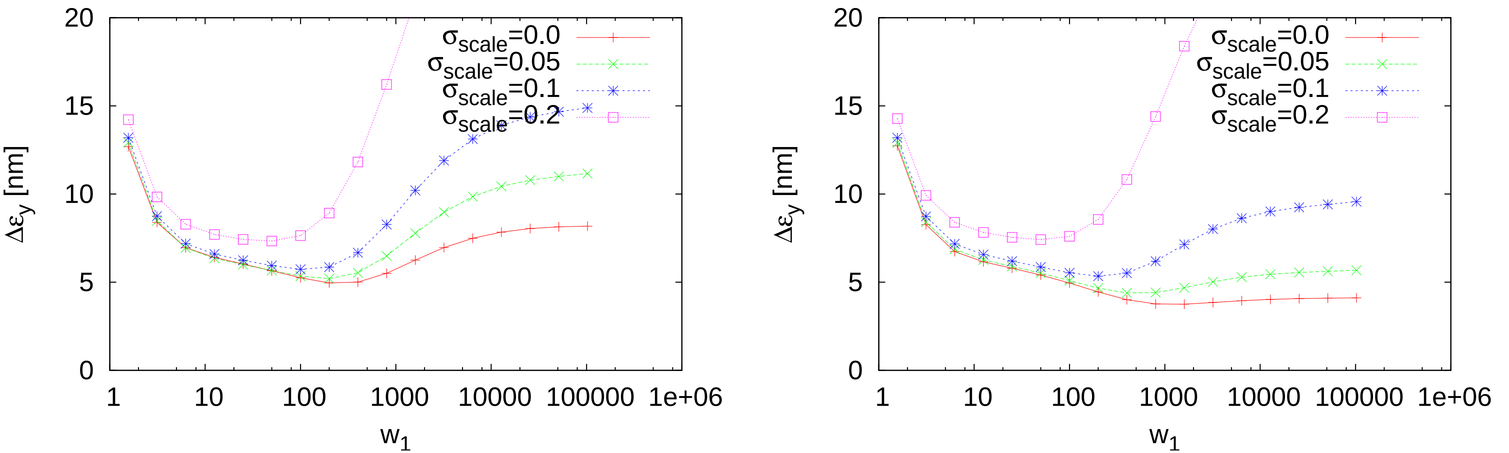
$\Rightarrow$ The estimated error in measuring the dispersion, compared to the BPM resolution, is

$$\sigma_D^2 = \sigma_a^2 \, D^2 + \sigma_{\text{res}}^2 \, (E/\Delta E)^2$$

at a given BPM

BPM Calibration Error

- Emittance growth as a function of the weight ω_1 $(\omega_0 = 1)$ for different calibration errors σ_a
- We used one test beam with an energy 20% below the nominal energy

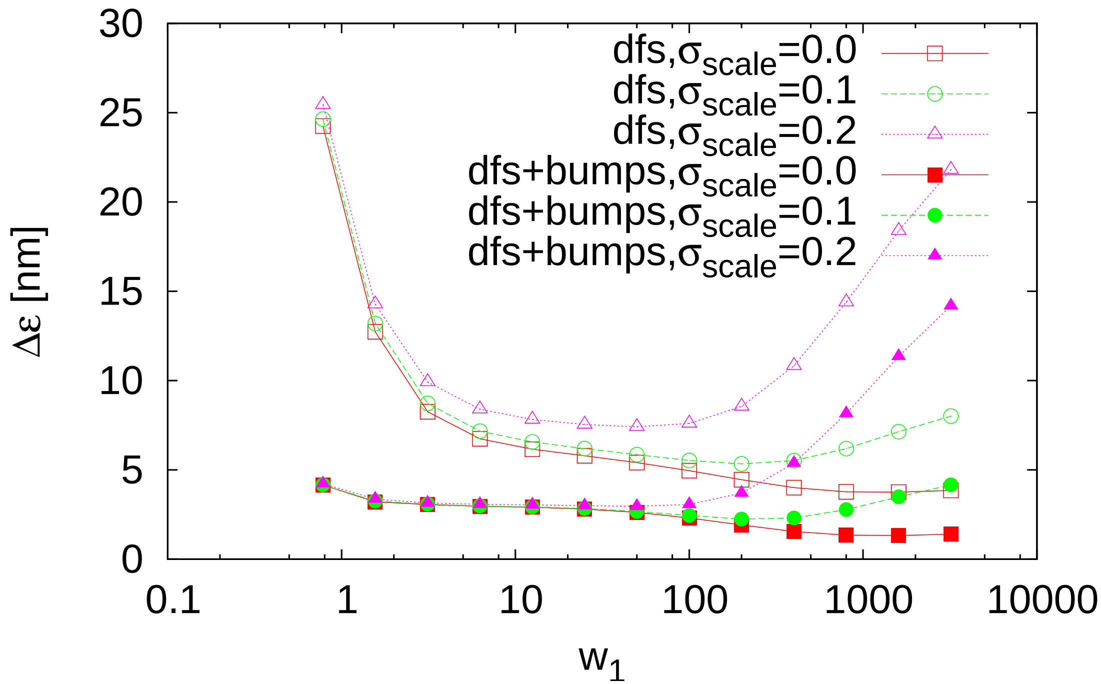


(BPM resolution 10 μm) (BPM resolution 1 μm)

$\Rightarrow$ For large scale errors, the curvature does not allow to use large values of ω_1 and thus one does not take full advantage of the good BPM resolution

BPM Calibration Error and Tuning Bumps

- Emittance tuning bumps can significantly reduce the emittance growth
- We investigated the impact of one dispersion bump before and one after the main linac

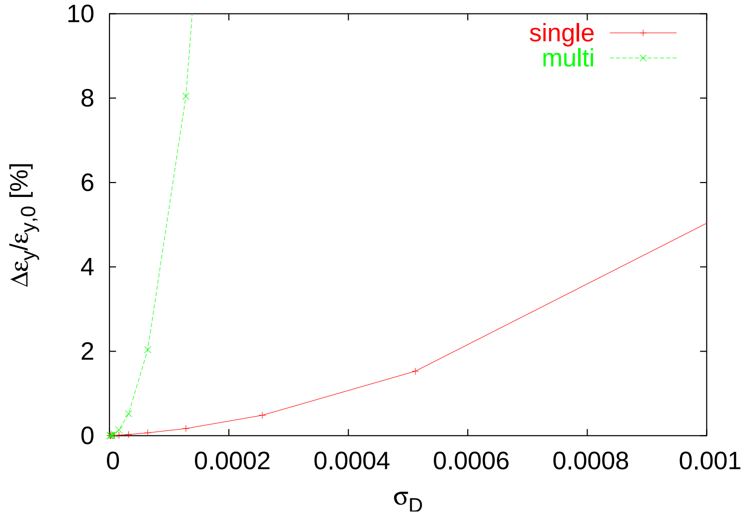


⇒ With zero BPM calibration error the performances are almost identical to those for the laser-straight machine.

Dynamic Effects

In a linac which follows the Earth's curvature, the beam will be guided around the curvature by using the corrector coils in the quadrupoles

- small ripples in the power supply of these correctors may lead to unwanted deflections of the beam
- we focused on studying this effect for a perfectly aligned linac



⇒ in green the emittance integrated over a few pulses and assuming that no feedback is used

⇒ the main contribution is due to trajectory jitter: a jitter of 0.5σ leads to 12% growth

Static Alignment of the ILC Main Linac

Conclusions

⇒ The curved and laser-straight layouts give comparable performances

- In case of a curved linac, beware of BPM calibration errors:
  - they can significantly impact the performance of beam-based alignment
    - ⇒ with a BPM resolution, σ_{res}, of 10 μm a scale error up to 10% is acceptable
    - ⇒ better resolutions magnify the impact of this error but, on the other hand, allow to reduce the energy difference between test and nominal beam

- Dynamic Effects:
  - ⇒ the stability of a few times 10^{-4} is well within the state of the art
  - ⇒ the required power supply stability for the corrector coils seem to be not critical

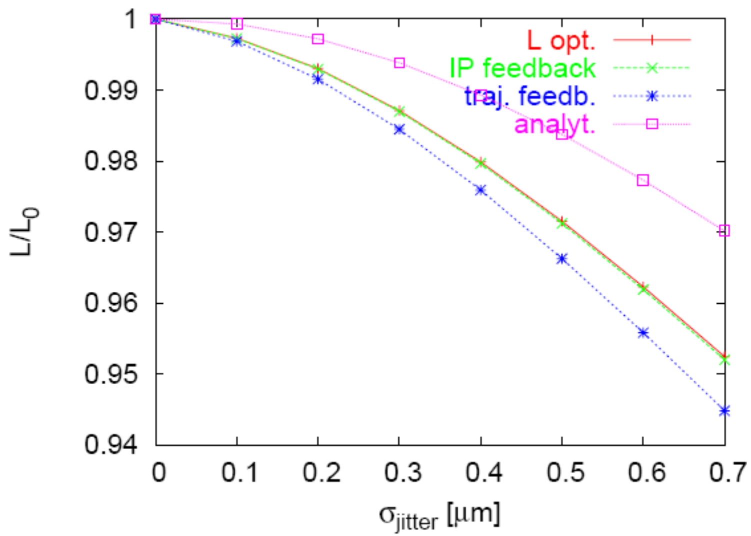
Luminosity Loss Due to Quadrupole Jitter

Simulation parameters:

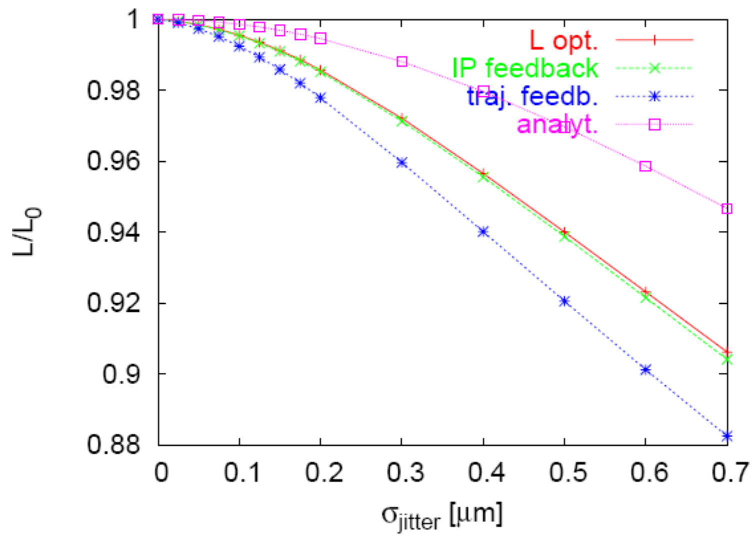
- we used GUINEA-PIG to calculate the luminosity
- at the linac entrance, the transverse emittances have been increased to the values at the IP
- a perfect machine has been used in the simulation
- and the end of the linac an **intra-pulse feedback** has been used to remove incoming beam position and angle errors at a single point
- quadrupoles in the electron linac have been scattered, while the ones in the positron linac are kept fixed
- the beam delivery system is represented by a **transfer matrix**: the end-of-linac Twiss parameters are transformed into the ones at the IP

Luminosity Loss Due to Quadrupole Jitter

- The luminosity as a function of the quadrupole jitter in the main linac:



(IP vertical emittance 40 nm)



(IP vertical emittance 20 nm)

Luminosity Loss Due to Quadrupole Jitter

Conclusions

- $\Rightarrow$ BPM based beam-beam feedback and luminosity optimisation feedback give very similar performance
- $\Rightarrow$ the emittance is a reasonable measure for the luminosity performance
  - a bit optimistic for small jitters
  - a bit pessimistic for large jitters
- $\Rightarrow$ beam-beam orbit feedback improves the luminosity performance compared to the case with no feedback
- $\Rightarrow$ a quadrupole jitter of 100 nm should be acceptable from the point of view of the luminosity loss at the entrance point.

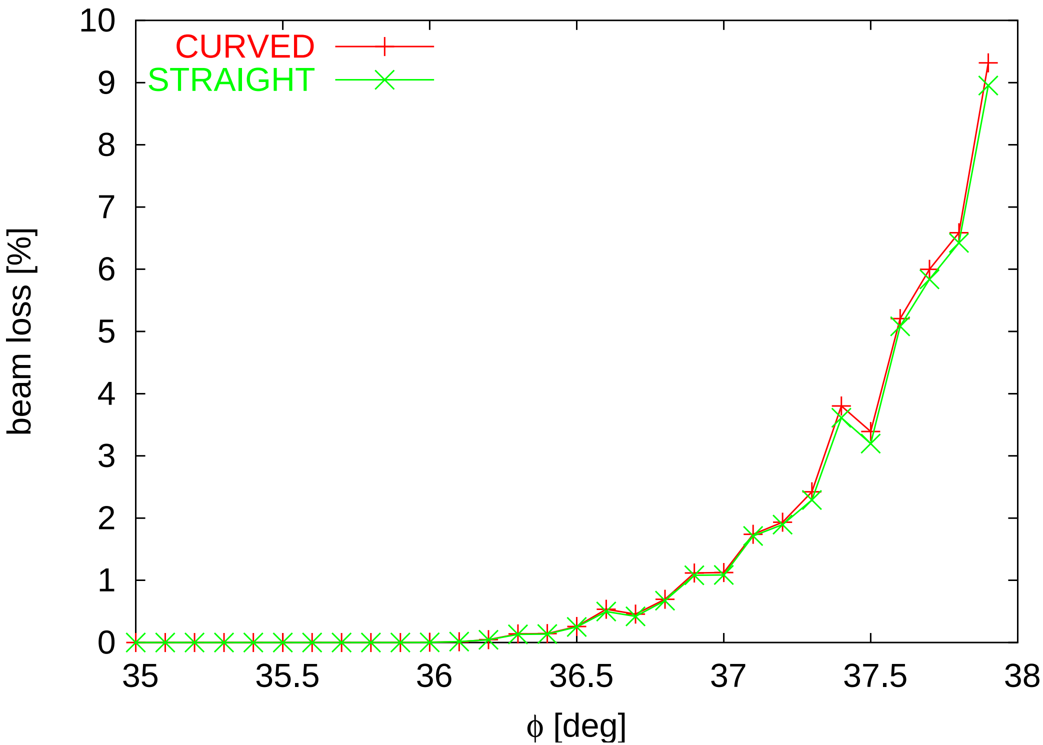
Failure Modes

- Failures in the ILC can lead to beam loss or damage the machine
- The main linac is the most expensive subsystem of the ILC, therefore even a seldom failure scenario may be worth considering

- We considered the failure of the klystron phase
  - a change in the klystron phase will modify the acceleration
  - the deviation from the design orbit can become too large and the beam becomes instable
  - here we consider the case that the phase for all klystrons is changed by a common offset

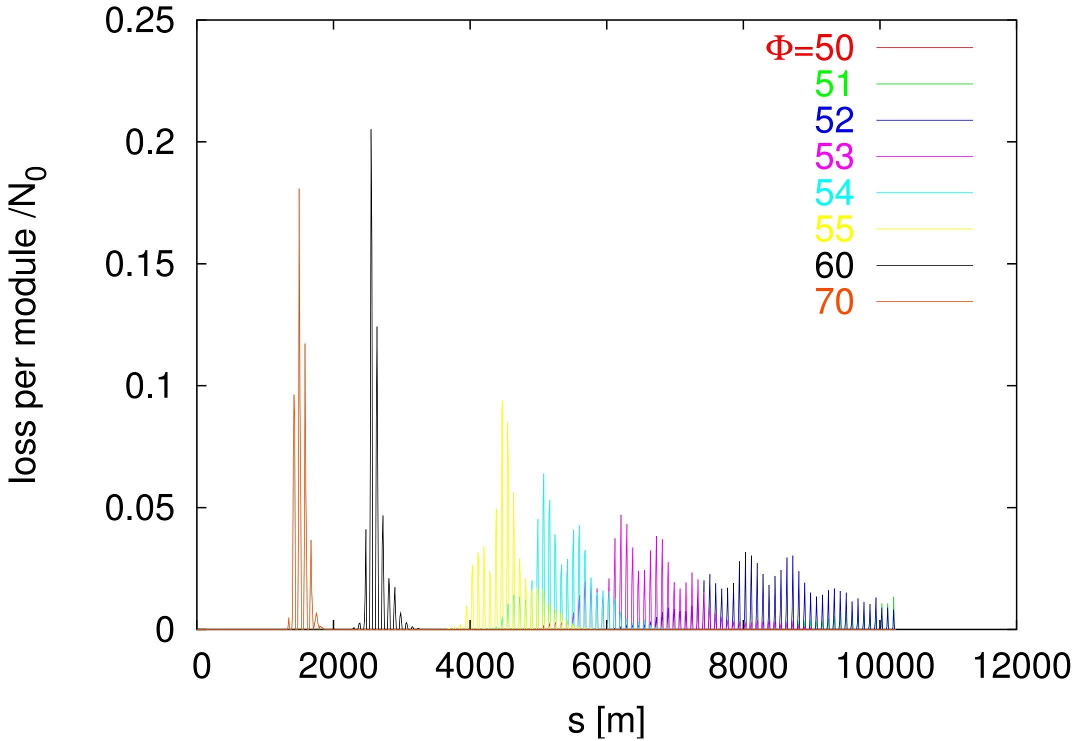
Failure Modes in the Main Linac

Beam loss due to klystrons phase shifts



Failure Modes in the Main Linac

Spatial distribution of lost particles for different klystrons phase shifts



Beam Delivery System Simulations

- Ground motion and feedback loops
- Collimator wakefields and their impact on the luminosity
  - collimator wakefields have been implemented in PLACET
  - the model for the wakefields does not include nonlinear and near-wall effects
- Halo tracking
  - identify and study critical issues (halo sources, transfer lines,...)
  - provide a generic tool for beam halo studies:
    - beam-gas generator, halo tracking, photon tracking, multiple scattering in spoilers are already available in PLACET

Collimators in the CLIC BDS

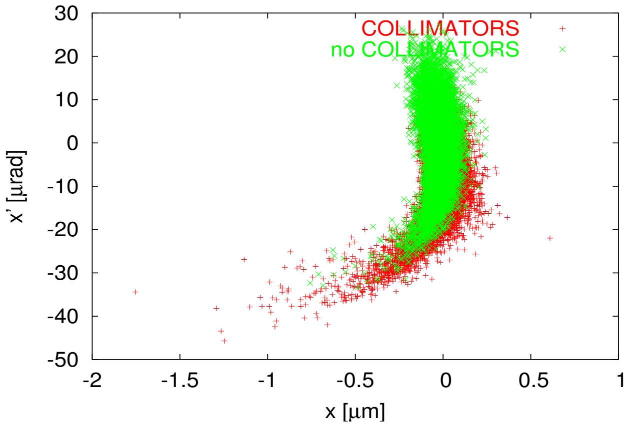
- Collimation system has to collimate in the two transverse planes (betatron collimation)

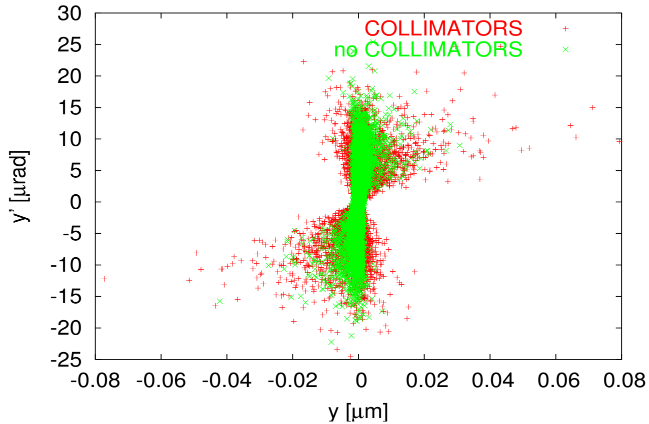
- The collimation depths for betatron collimation determined from the condition that beam particle and SR photons emitted in the final quadrupoles should not hit ant magnetic apertures on the incoming side of the IP. For CLIC: collimation depths should be less than **14** σ_x and **83** σ_y

- For energy collimation depth is determined by the failure modes in the linac. For CLIC: protection against mis-steered or errant beam with energy errors $\geq 1.3\%$

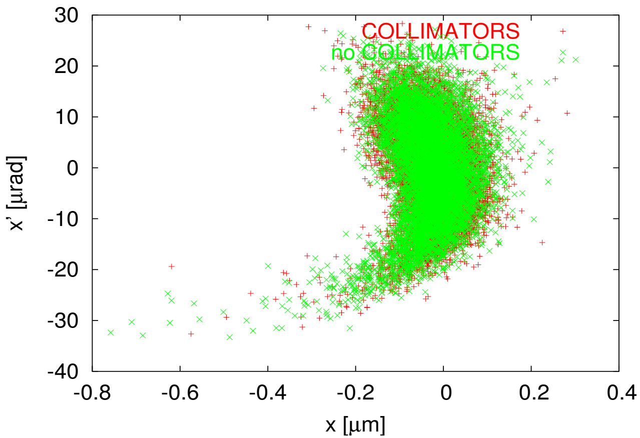
Phase Space Portraits at the end of the BDS

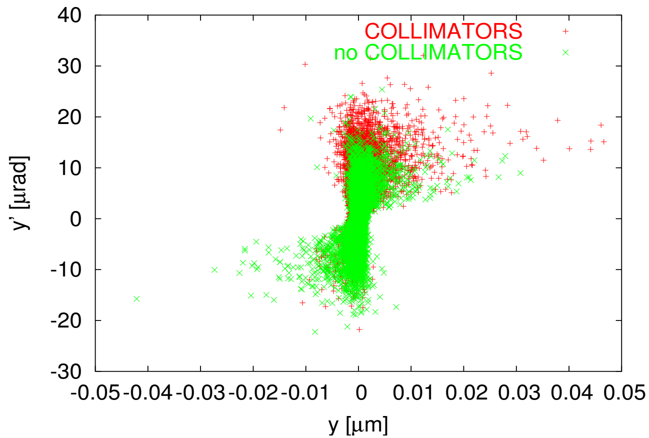
1) with horizontal beam jitter $1\,\sigma_x \sim 4\mu$





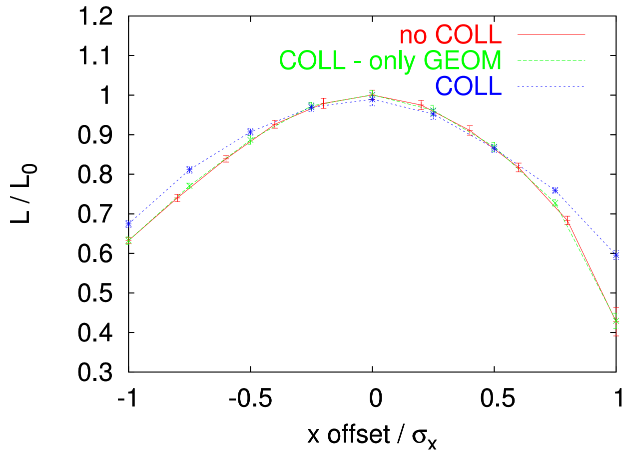
2) with vertical beam jitter $1\,\sigma_y \sim 0.25\mu$



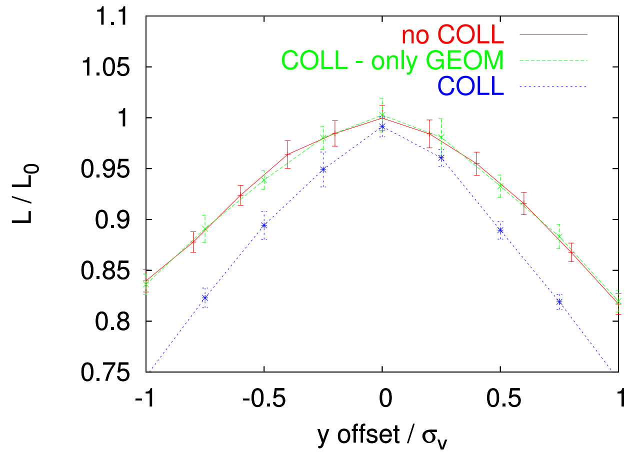


Luminosity Reduction Curves

- due to beam jitter in x and y at the entrance of the BDS



$(\sigma_x \sim 4\mu\text{m})$

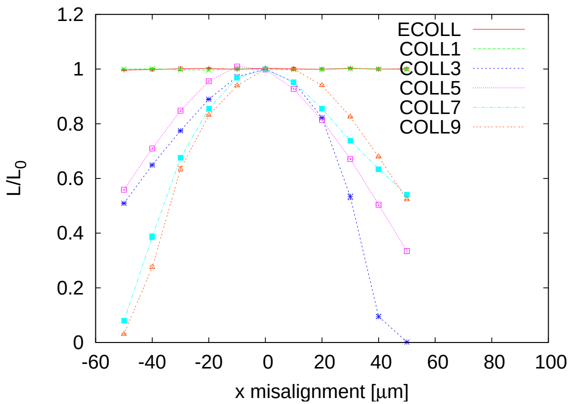


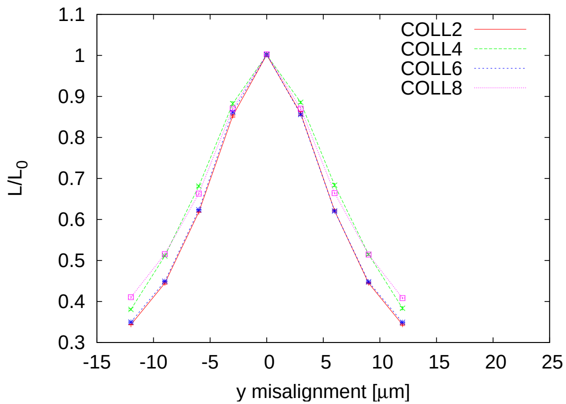
$(\sigma_y \sim 0.25\mu\text{m})$

Luminosity Reduction Curves

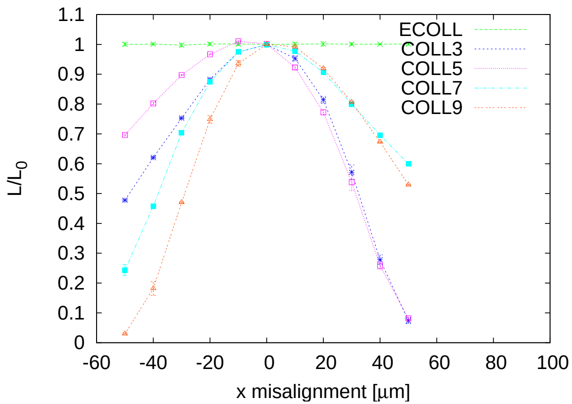
Each collimator is offset horizontally and vertically

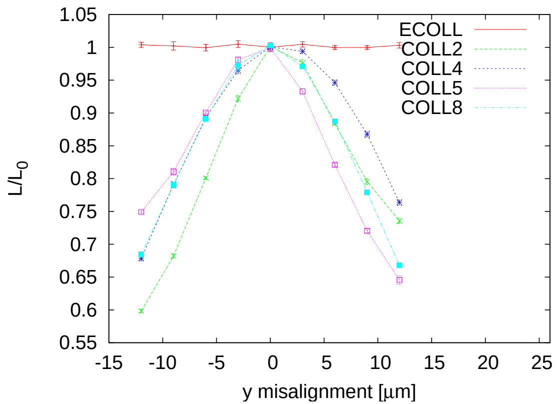
LINEAR BDS:





NON-LINEAR BDS:





Beam Delivery System Simulations

- **Conclusions**

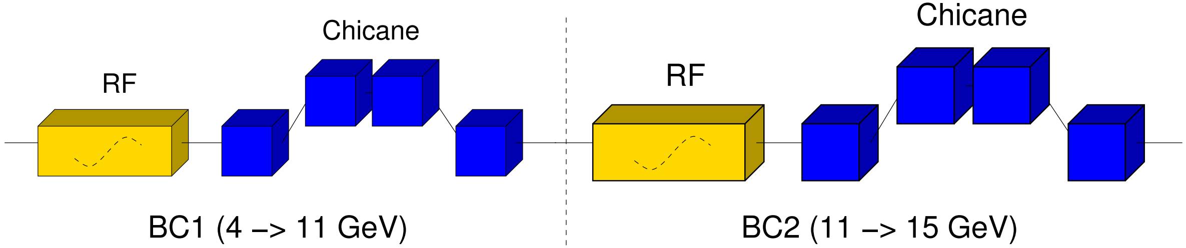
⇒ Collimator wakefields (both geometric and resistive wall, different regimes) have been implemented in PLACET to allow full tracking

⇒ Luminosity reduction curves due to wakefields have been obtained for initial jitters and different collimator misalignments

⇒ The performances of the nonlinear collimation system, including wakefields, have started being investigated

Bunch Compressor Simulations

- ILC BC is composed by two accelerating stages and two magnetic chicanes



- Idea: off-phase beams gain different energy with respect to the nominal one

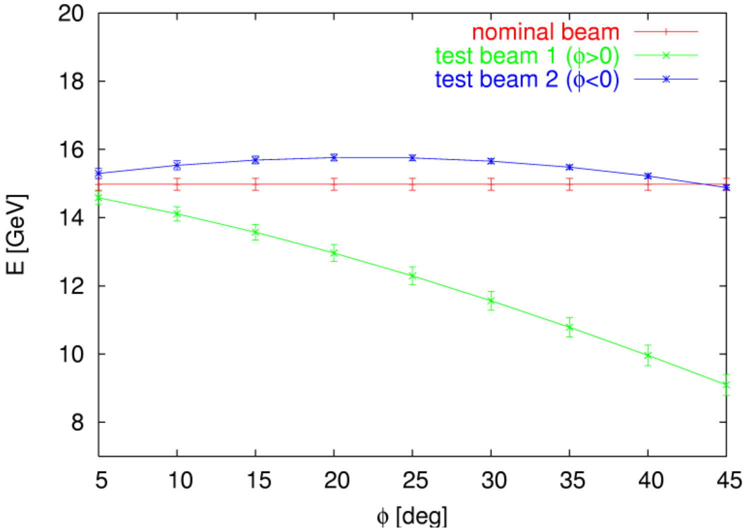
  $\Rightarrow$ off-phase beams can be used as test-beams for the DFS in the Main Linac

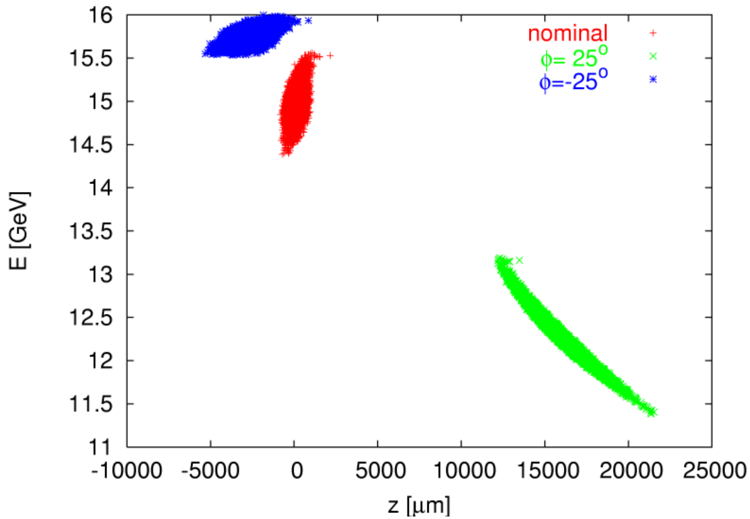
- **Simulation Procedure**

  - 1 nominal beam and

  - 2 off-phase beams to align the ILC Main Linac with DFS

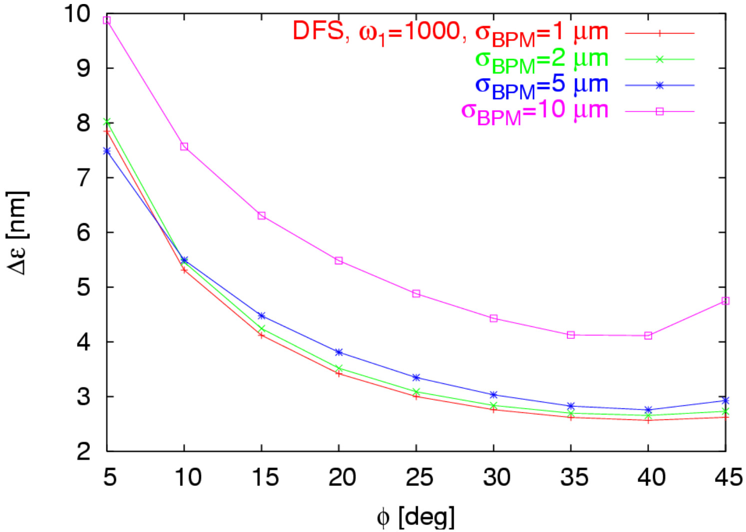
Compression of off-phase bunches

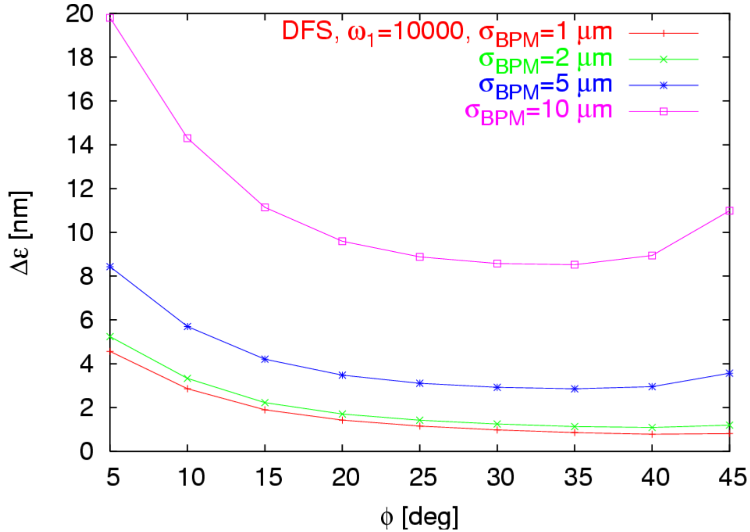




- with respect to the nominal beam, off-phase beams have:
  - different energy spread
  - greater bunch length
  - phase out of sync
- their phase must be synchronised with the ML accelerating phase

Final Emittance Growth after DFS as a function of Φ



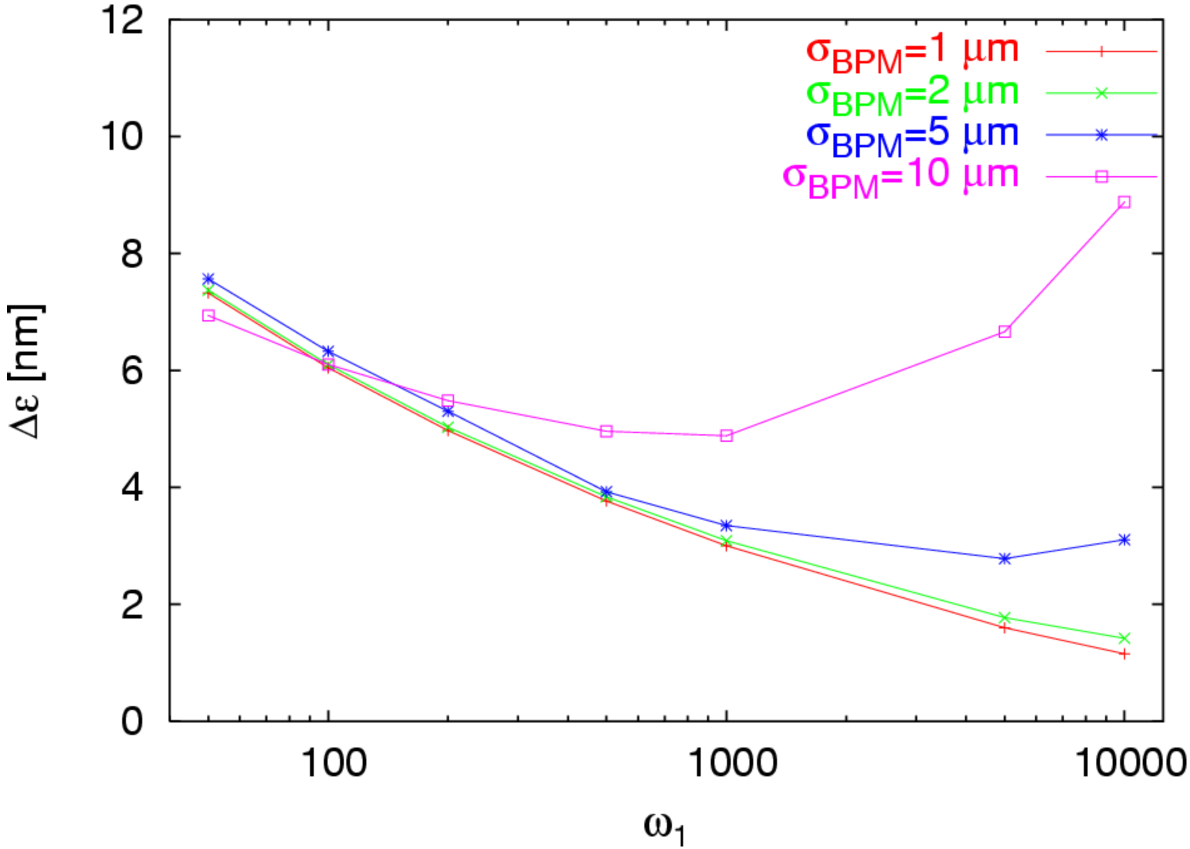


- two cases are shown: ω_1 =1000 and ω_1 =10000 (second gives better results)
- each point is the average of 100 machines

$\Rightarrow$ there is an optimum (which seems to vary with the weight)

- We focused on Φ=25^o

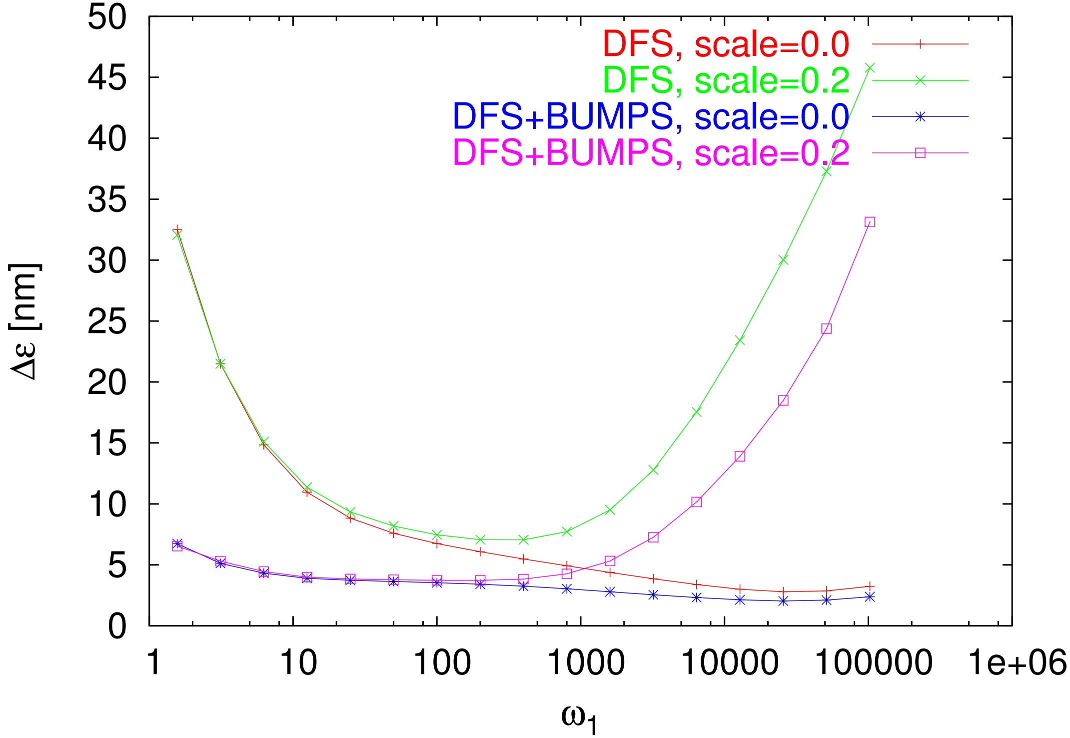
Final Emittance Growth after DFS as a function of Φ



for a laser-straight linac, DFS (with ω "big", BPM resolution of 1 μm) leads to excellent results but...

..for a Curved Machine Things Go Differently

In a curved linac BPM calibration errors, $x_{\text{reading}} = a\,x_{\text{real}}$, have an impact on the BC+DFS performances:



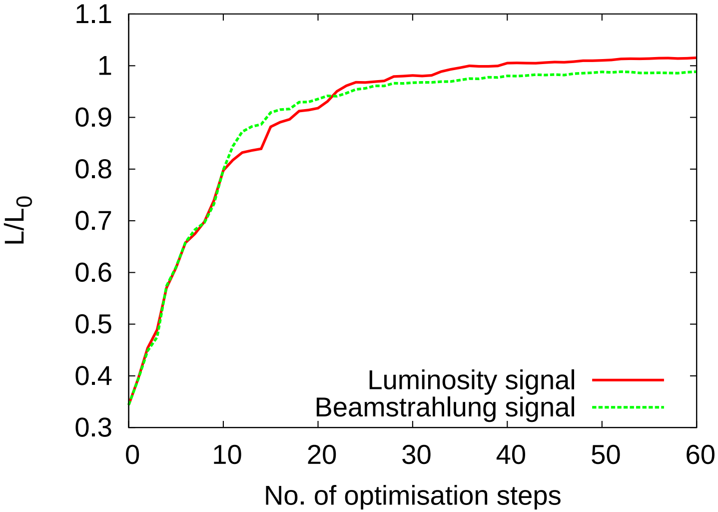
- Calibration errors prevent from using "big" weights

$\Rightarrow$ We need to use Dispersion Bumps to reduce the emittance growth

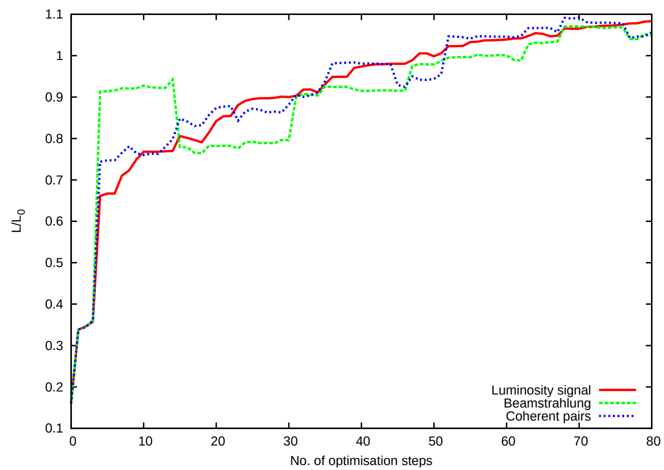
IP Luminosity Optimisation

- In case of imperfections/misalignments in the BDS, tuning bumps can be used to achieve optimal luminosity
- Luminosity is optimised by tuning IP parameters such as angle, offset, waist and dispersion
- The observable used for the tuning can be for example beamstrahlung or coherent pairs
- In these studies IP parameters were randomly changed and then tuned with the knobs
  - in our simulation the parameters were tuned by directly modifying the particle coordinates

CLIC

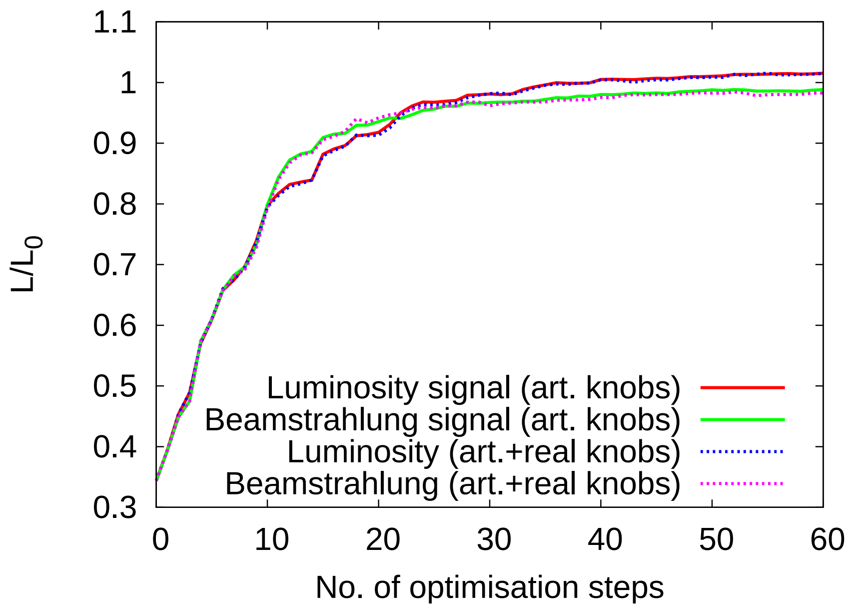


ILC



IP Luminosity Optimisation

- Here, the tuning of vertical dispersion and waist is performed in a more realistic way using transversal displacements of the FFS sextupoles



- In a similar way it should be possible to tune the horizontal dispersion and waist

⇒ More realistic studies (for CLIC) show good results

Conclusions

- Critical subsystems of both ILC and CLIC have been successfully simulated

  $\Rightarrow$ Several results have been benchmarked against other tracking code/simulation packages

- Each subsystem, studied under different conditions, has not manifested critical problems

  $\Rightarrow$ dynamic effects

  $\Rightarrow$ ground motion

  $\Rightarrow$ failures

  have been considered

- The way toward integrated simulations is almost completed

  $\Rightarrow$ Simulating the machine from the BC up to the IP is virtually possible

- **Acknowledgements**

  - Besides myself, this work has been carried out by: Daniel Schulte, Peder Eliasson, Lionel Neukermans, Giovanni Rumolo, Javier Resta-Lopez, Rogelio Tomas, Helmut Burkhardt

Test Beams for Dispersion Free Steering

- Why we do need two test beams:
  1. ΔE=0.2 $\rightarrow E_{\text{initial}} = 80\% \, E_{0,\text{initial}}$
  2. Δg=0.2 $\rightarrow E_{\text{final}} = 80\% \, E_{0,\text{final}}$