Status of ILC Beam Dynamics Studies Using PLACET

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- Introduction
- Simulations Results
- Conclusions and Outlook

PLACET Physics Highlights

- PLACET is a tracking code that simulates **beam transport** and **orbit correction** in linear colliders
- it takes into account **collective effects** such as:
  - synchrotron radiation emission,
  - short/long range wakefields in the accelerating structures / in the crab cavities,
  - multi-bunch effects and beam loading,
  - geometric and resistive wall wakes in collimators
- it can track the longitudinal phase space
- it can track **sliced beams** as well as **single particles** beams, and can switch between them during the tracking

⇒ It can simulate: bunch compressor, main linac, drive beam, beam delivery system (including crab cavities and instrumentation), interaction point (using Guinea-Pig) and soon : post collision line

PLACET Technical Highlights

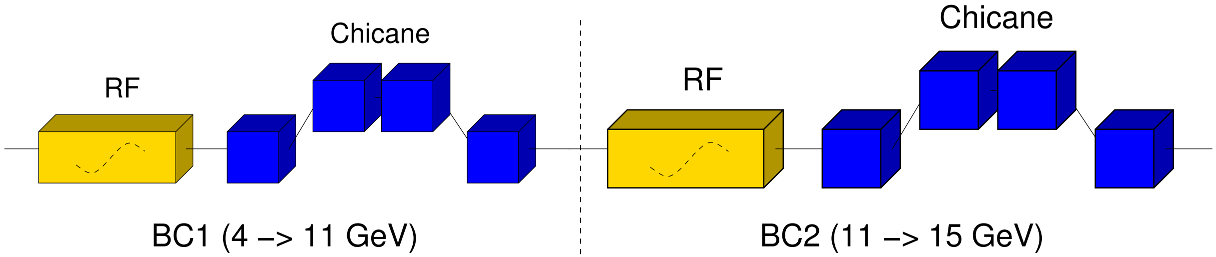
- It is -relatively- easy to use
- It is **open** to other codes:
  - it can read **MAD/MAD-X** deck files, as well as **XSIF** files
  - can be easily interfaced to Guinea-Pig
  - it can use other codes to perform beam transport
- It is fully **programmable** and **modular**, thanks to its **Tcl/Tk** interface and its external modules:
  - it allows the simulation of feedback loops
  - ground motion effects are easy to include
  - external MPI parallel tracking module (limited tracking)
- It has a **graphical** interface
- [NEW] it embeds **Octave**, a mathematical toolbox like MatLab (but *free*)
  - rich set of numerical tools
  - easy to use optimization / control system tool-boxes

Recent Simulation Results

- **Bunch Compressor** (BC)
  - Alignment
- **Main Linac** (ML)
  - Static alignment strategies for a laser-straight and a curved layout
    - use of BC to align the ML
    - impact of BPM calibration errors and quadrupole power supply ripples
  - Dynamic Effects
    - jitter during alignment
    - orbit feedback to cure ground motion
- **Beam Delivery System** (BDS)
  - Feedback Studies
  - Crab Cavity Simulation
  - Collimator Wakefields and Halo Particles

Bunch Compressor

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



- Simulation Setup:

  - Misalignments : "COLD" model

σ_{quad}	=	300 μm	quadrupole position error
$\sigma_{\mathrm{quad\ roll}}$	=	300 μrad	quadrupole roll error
σ_{cav}	=	300 μm	cavity position error
$\sigma_{\mathrm{cav\ angle}}$	=	300 μrad	cavity angle error
$\sigma_{\mathrm{sbend\ angle}}$	=	300 μrad	sbend angle error
σ_{bpm}	=	300 μm	bpm position error

  - BPM resolution : $\sigma_{\mathrm{bpm\ res}} = 1\ \mu$m

$\Rightarrow$ Wakefields of the cavities are taken into account

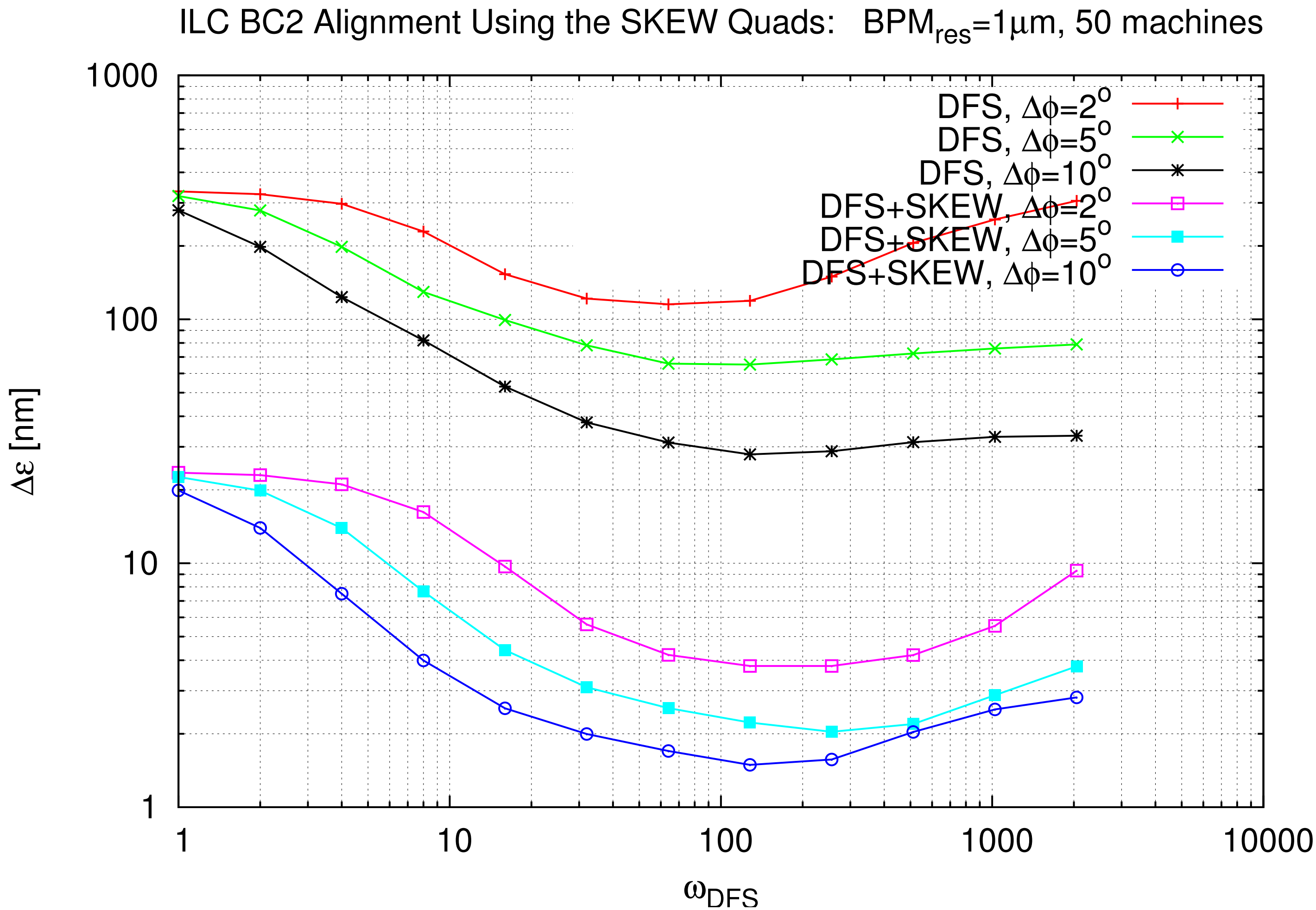
Case 1: BC1 used to align BC2

- Alignment Strategy
  - 1-to-1 correction
  - dispersion free steering using two test beams, $\pm\Delta\phi$
  - dispersion bumps optimization using the skew quadrupoles in BC2
- A perfectly aligned BC1 is used to generate the test beams for DFS in BC2
  - an offset of few degrees in the RF phase of the BC1 accelerating structures, leads to an energy difference at the entrance of BC2
  - bunch energy as a function of the RF phase offset

$$
\begin{array}{llll}
\Delta\phi = +2^o & \Rightarrow \quad 99.59\%\ E_0; & \Delta\phi = -2^o & \Rightarrow \quad 100.41\%\ E_0 \\
\Delta\phi = +5^o & \Rightarrow \quad 98.98\%\ E_0; & \Delta\phi = -5^o & \Rightarrow \quad 101.04\%\ E_0 \\
\Delta\phi = +10^o & \Rightarrow \quad 98.01\%\ E_0; & \Delta\phi = -10^o & \Rightarrow \quad 102.11\%\ E_0
\end{array}
$$

$\Rightarrow \phi_0 \ = \ 110$ deg

$\Rightarrow \mathrm{E}_0 \ \simeq \ 4.79$ GeV



⇒ Final emittance growth after DFS and SKEW quad optimization

- $\Delta\phi = \pm 2^o \Rightarrow$ 3.7 nm
- $\Delta\phi = \pm 5^o \Rightarrow$ 2.0 nm
- $\Delta\phi = \pm 10^o \Rightarrow$ 1.5 nm

Case 2: alignment of BC1 and BC2 at once

- the BC is aligned at once : the phase offset is applied to **all** cavities

  ...using DFS and SKEW quad optimization

  - the RF phase of all accelerating structures is offset by few degrees

    $\Rightarrow$ thus the bunches gain different acceleration $\Rightarrow$ this can be exploited by DFS

    $\Rightarrow$ the energy difference grows along the BC (efficacy of DFS grows along the lattice)

  - all 4 pairs of SKEW quadrupoles are used for dispersion reduction

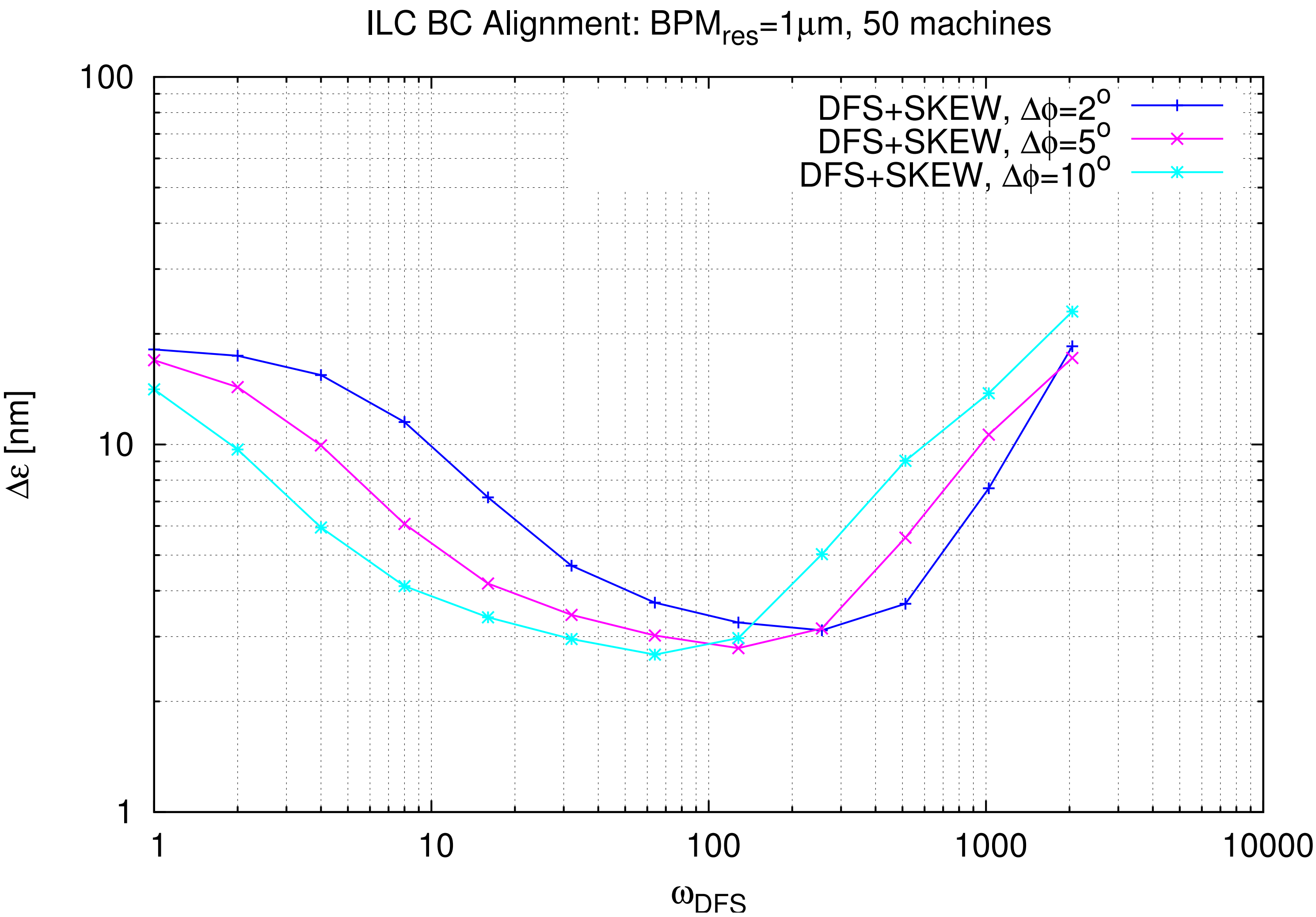
- Results:

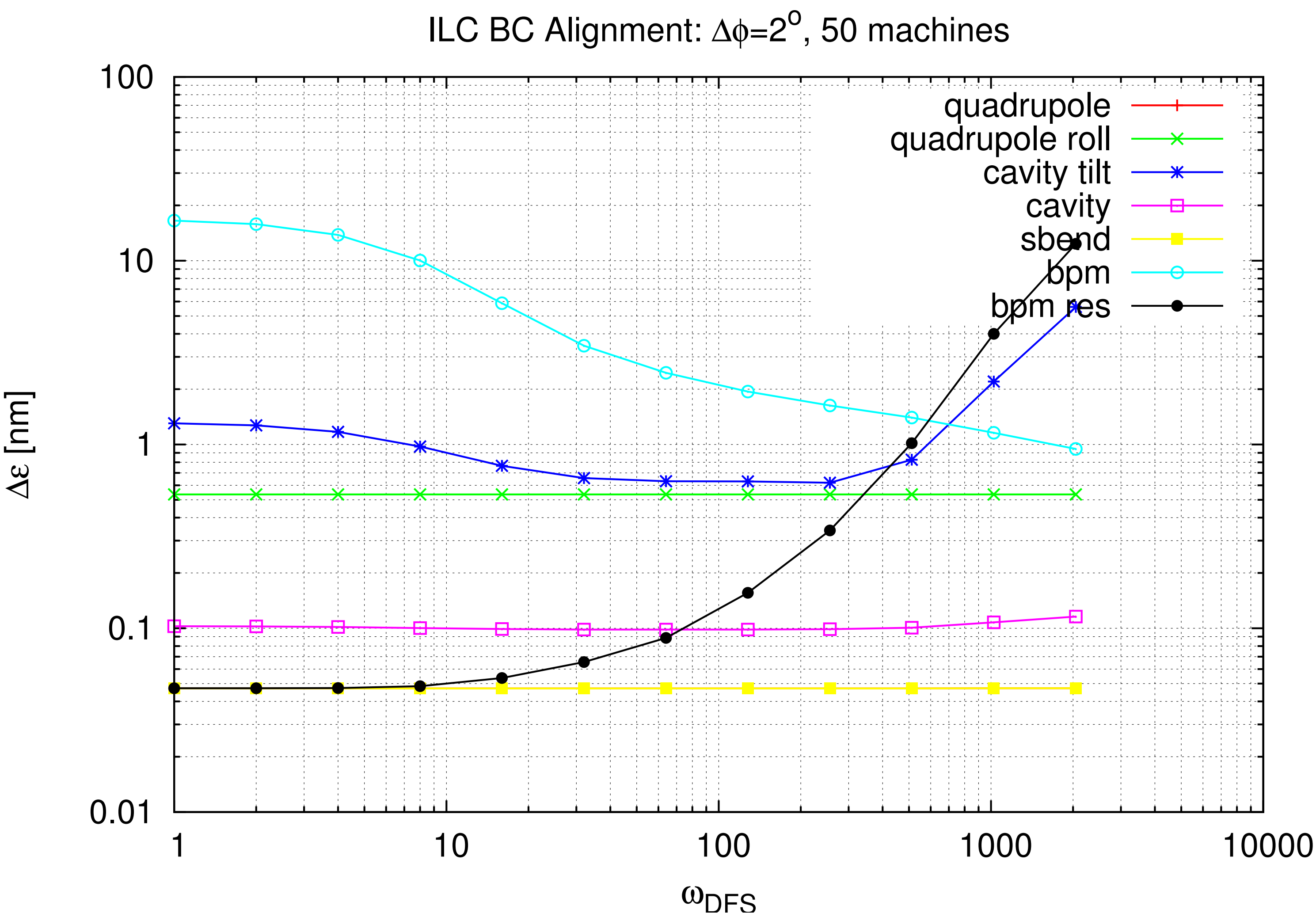
  $\Rightarrow$ Final emittance growth after DFS and SKEW quad optimization

  $$\begin{array}{lcl} \Delta\phi = \pm 2^o & \Rightarrow & 3.12 \text{ nm} \\ \Delta\phi = \pm 5^o & \Rightarrow & 2.79 \text{ nm} \\ \Delta\phi = \pm 10^o & \Rightarrow & 2.68 \text{ nm} \end{array}$$

  $\Rightarrow$ A study of each single source of misalignment was performed

  All results are the average of 50 machines


ILC BC Alignment: BPM$_{res}$=1μm, 50 machines
DFS+SKEW, Δϕ=2°
DFS+SKEW, Δϕ=5°
DFS+SKEW, Δϕ=10°
Δε [nm]
ω$_{DFS}$
100
10
1
1
10
100
1000
10000



ILC BC Alignment: Δφ=2°, 50 machines
100
10
1
0.1
0.01
Δε [nm]
1
10
100
1000
10000
ω_DFS
quadrupole
quadrupole roll
cavity tilt
cavity
sbend
bpm
bpm res

Main Linac Simulations

- Main Linac Alignment Technique
  - 1-to-1 correction
  - dispersion free steering
  - dispersion bumps optimization

- **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

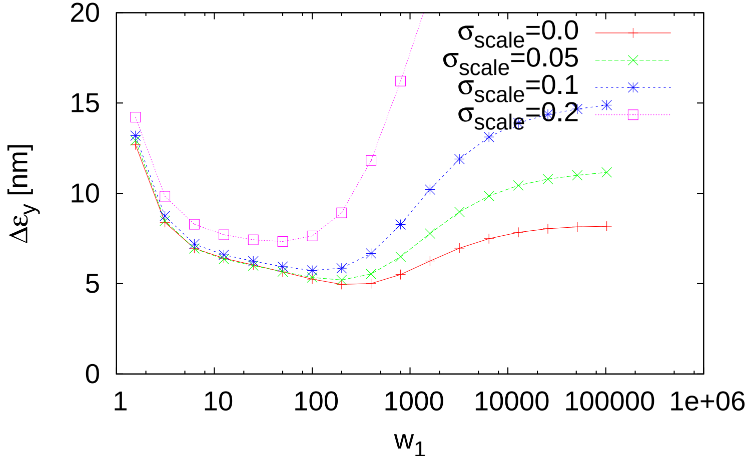
  - BPM resolution $= 1\mu$m
  - Curved layout obtained introducing small angles between the cryo-modules (KICKs)
  - Undulators section represented using *EnergySpread* elements

All results are the average of 100 seeds

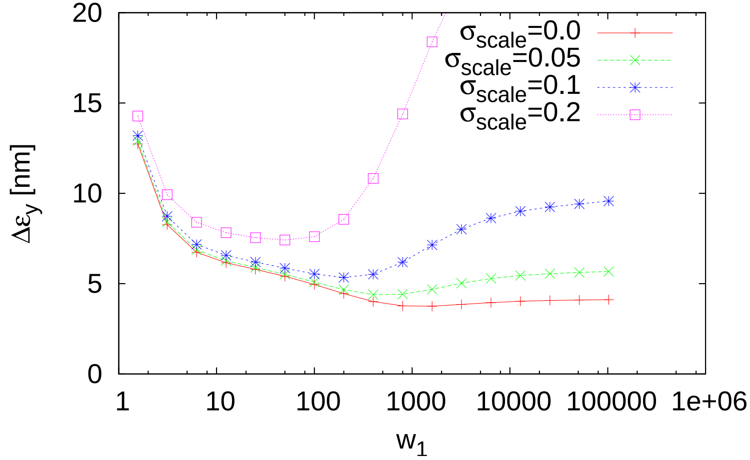
Main Linac

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)

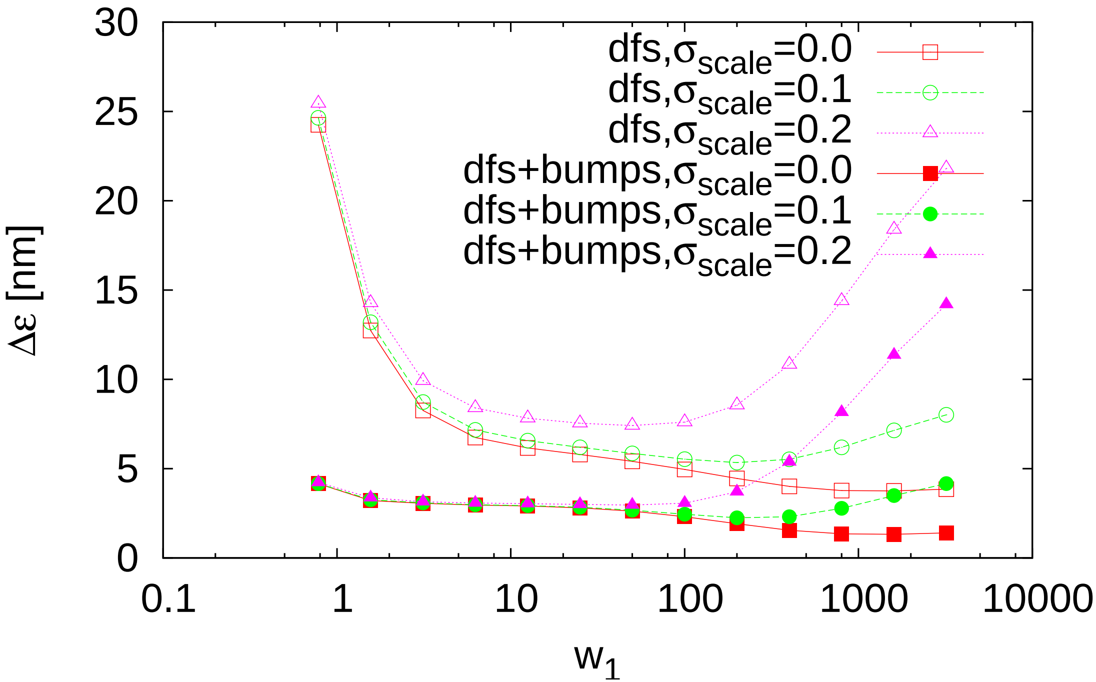


(BPM resolution 1 μm)

$\Rightarrow$ 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 growthhey are likely required already in the laser-straight linac
- We investigated the impact of one dispersion bump before and one after the main linac

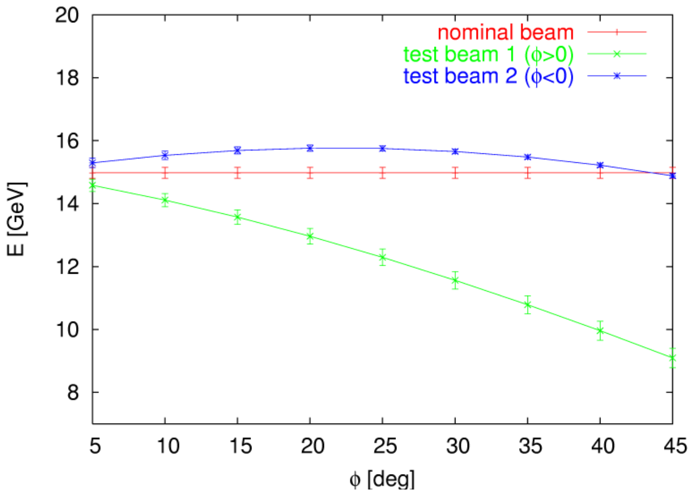


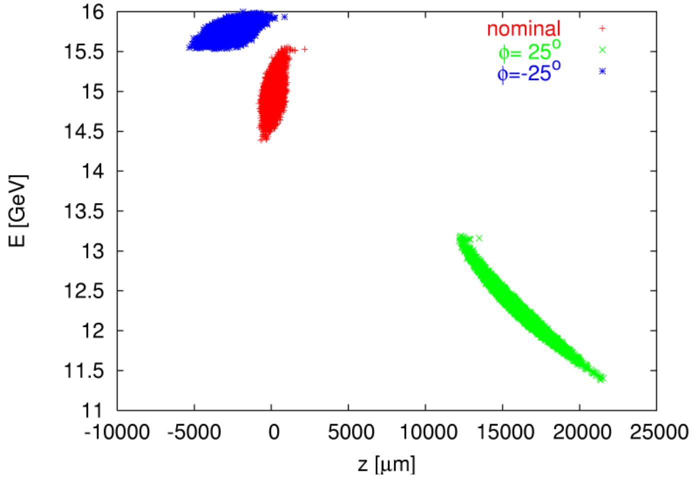
⇒ With zero BPM calibration error the performances are almost identical to those for the laser-straight machine.

Bunch Compressor for Main Linac Alignment

- Compression of off-phase beams

  ⇒ they get different energy with respect to the nominal one and can be used for DFS in the Main Linac

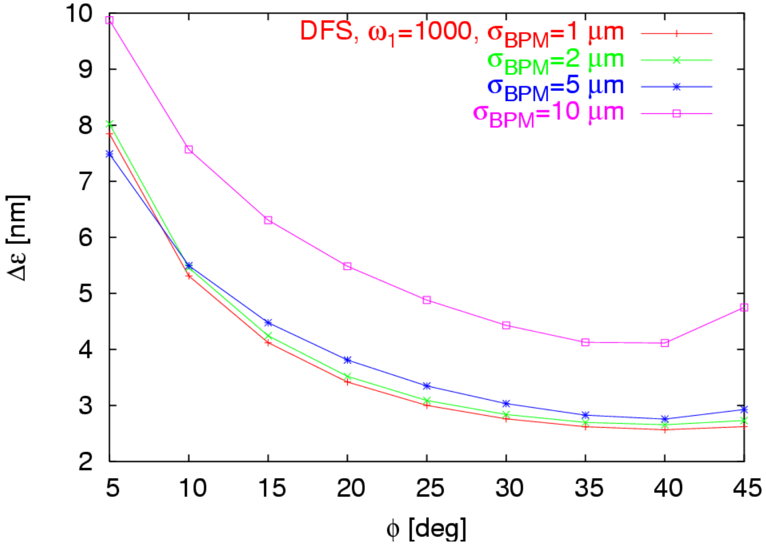


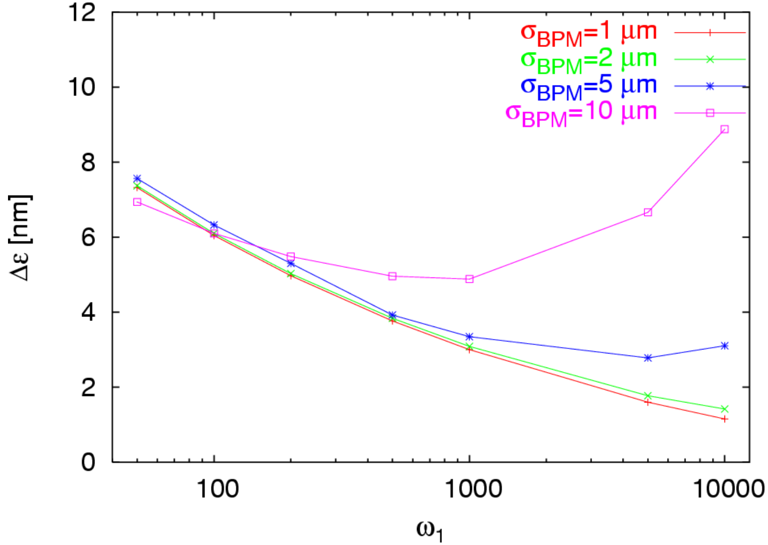


- the longitudinal phase space changes

⇒ their phase must be synchronized with the ML accelerating phase

Final Emittance Growth as a function of Φ and ω





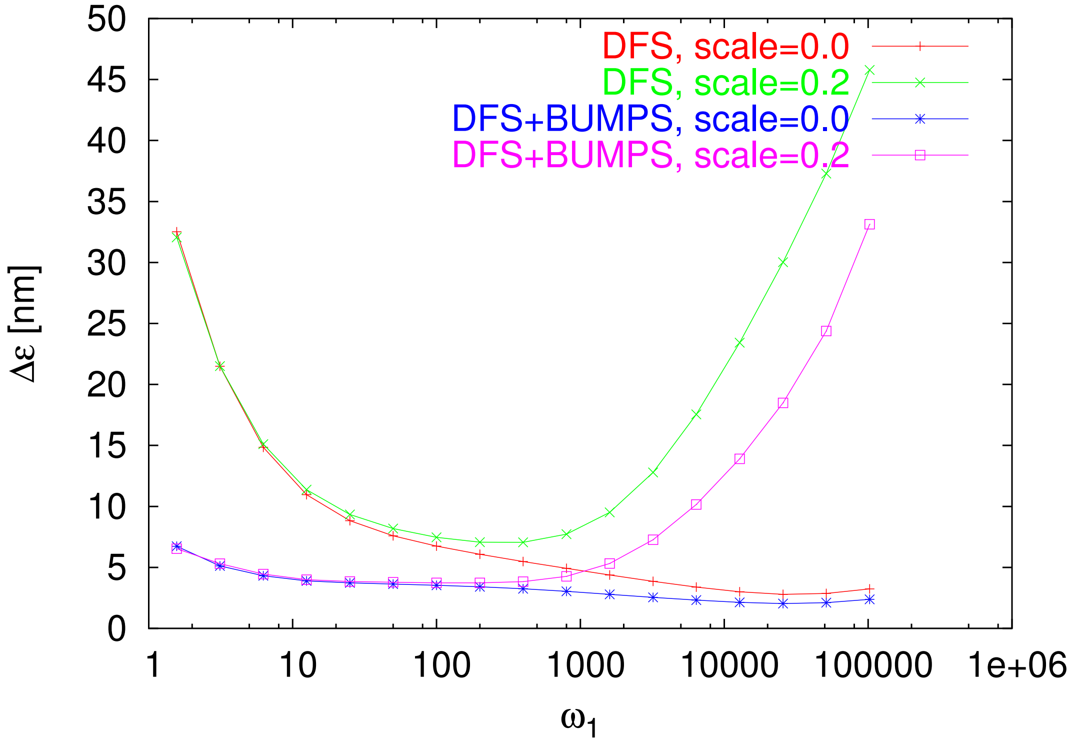
- left hand plot : ω_1 =1000, scan of the phase offset
- right hand plot : Φ=25^o, scan of the weight

\- each point is the average of 100 machines

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

BC for BBA in a Curved Linac

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

⇒ We need to use Dispersion Bumps to reduce the emittance growth

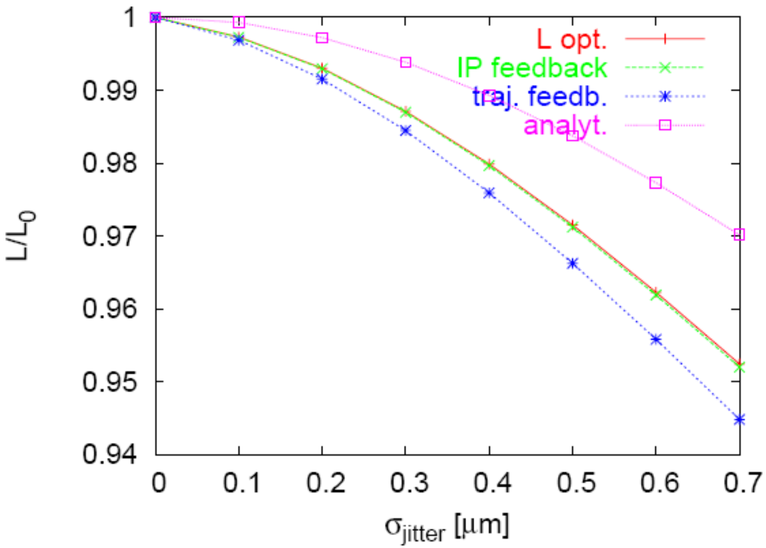
Luminosity Loss Due to Quadrupole Jitter

Simulation parameters:

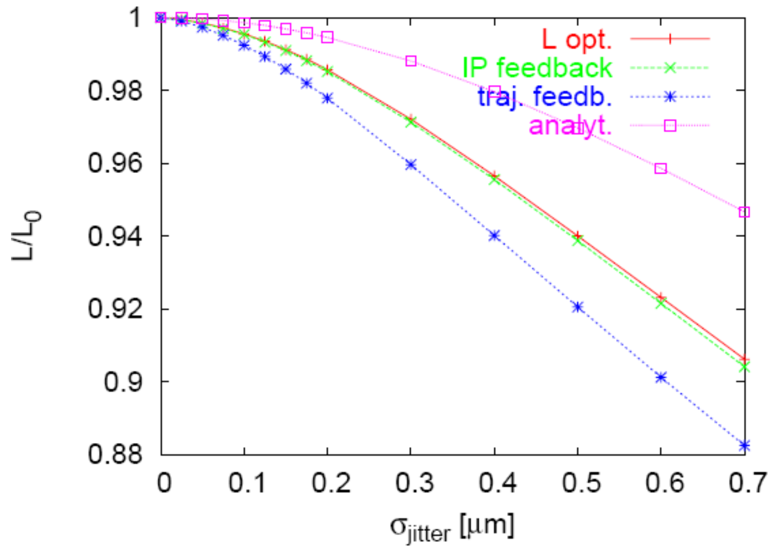
- we used GUINEA-PIG to calculate the luminosity
- a perfect machine has been used in the simulation
- and the end of the linac an **intra-pulse feedback** has been used to remove incoming beam position and angle errors at a single point
- quadrupoles in the electron linac have been scattered, while 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:



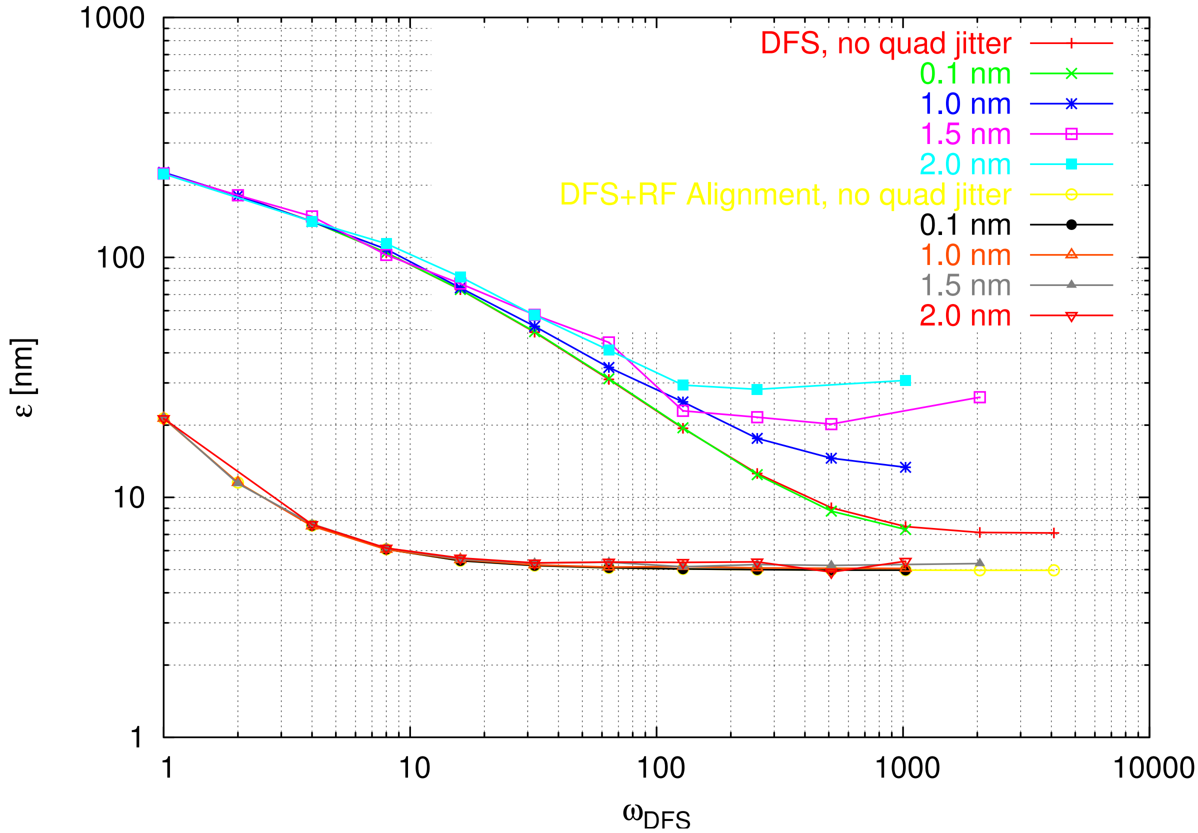
(IP vertical emittance 40 nm)



(IP vertical emittance 20 nm)

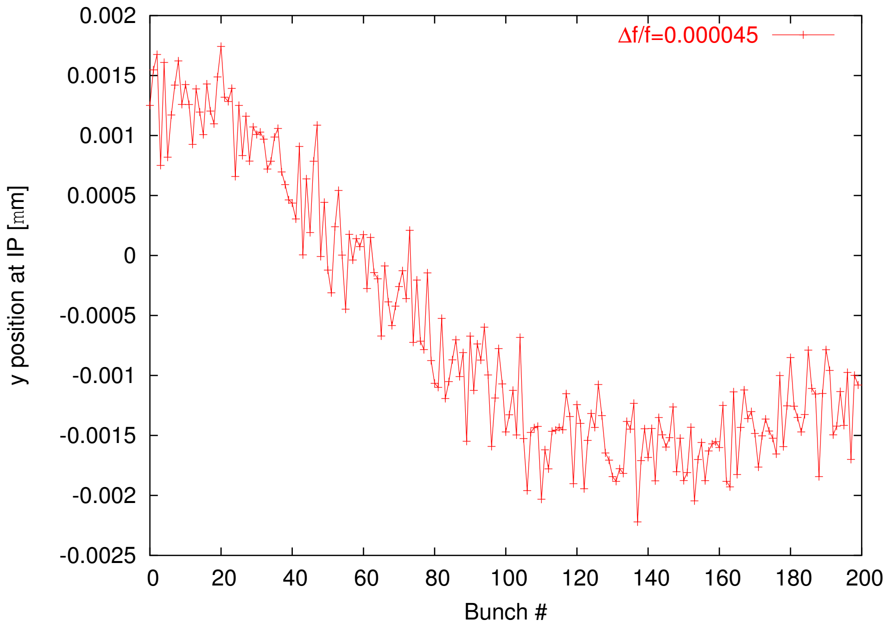
Dynamic Effects: Quadrupole Jitter during Alignment

Alignment of the CLIC Main Linac, with quadrupoles jittering during DFS



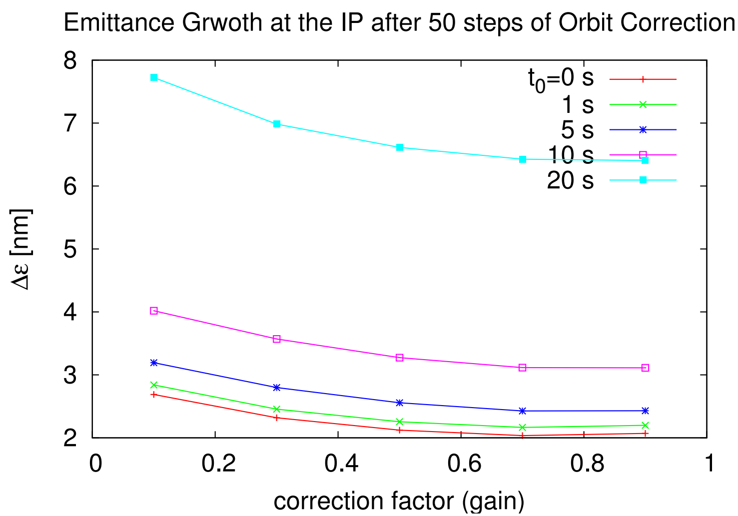
Wakefields in the Crab Cavities

- Wakefields dipole and monopole modes have been calculated at the Cockcroft Institute (Lancaster University) by A.Dexter and G.Burt, using MAFIA
- These values have been put into PLACET to evaluate the vertical offset at the IP due to long-range wakes in case of a frequency dilution of 1.000045



Intra-Pulse Orbit Correction

- In ILC the long pulse duration allows the use of intra-pulse orbit feedback
- Simulation Parameters
  - ground motion model "B" (medium noise)
  - intra-pulse one-to-one steering
- It gives an upper limit to the performances of the orbit correction



1-to-1 Correction Using PLACET-Octave

```
#!/home/andrea/bin/placet

source beamline.tcl
source beamdef.tcl
BeamlineSet -name "beamline"

SurveyErrorSet -quadrupole_y 300.0 \
               -quadrupole_roll 300.0 \
               -cavity_y 300.0 \
               -cavity_yp 300.0 \
               -bpm_y 300.0

Octave {
  B = placet_get_number_list("beamline", "bpm");
  C = placet_get_number_list("beamline", "quadrupole");
  R = placet_get_response_matrix("beamline", "beam0", B, C);

  placet_test_no_correction("beamline", "beam0", "Scatter");
  b = placet_get_bpm_readings("beamline", B);
  c = -pinv(R) * b;
  placet_vary_corrector("beamline", C, c);

  placet_test_no_correction("beamline", "beam0", "None");
  [b,S] = placet_get_bpm_readings("beamline", B);
  plot(S, b);
}
```

PLACET Graphical Output

- Longitudinal Beam Profile under the effects of transverse wakefield

Overview and Future Plans...

- PLACET has an extensive set of instructions
- Its Tcl/Tk interface allows to make complex simulations and to invoke easily external tools
- Its modularity and flexibility allow to interact and control the simulation program in several ways
- It has a Graphical Interface
- It can simulate a big fraction of the whole machine

  (Soon also damping rings and post collision line)
- It can be interfaced to external codes : MAD, BDSIM (in progress), Guinea-Pig, ...
- Inclusion of realistic wakepotentials calculated from GdfidL
- You are welcome to use it and contribute to it

http://savannah.cern.ch/projects/placet