Bunch Compressor for Main Linac Alignment

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- PLACET Simulation Package
- Dispersion Free Steering
- Main Linac alignment using the Bunch Compressor

The Tracking Code PLACET

- PLACET is a tracking code that simulates **beam transport** and **orbit correction** in linear colliders originally developed by Daniel Schulte
- it takes into account
  - long/short-range wakefields
    - in the accelerating structures
    - in the crab cavities
  - multi-bunch effects and beam loading,
  - geometric and resistive wall wakes in the collimators
- it can track the longitudinal phase space
- it implements **synchrotron radiation emission**: ISR, CSR
- it implements two beam models
  - **sliced beams**: macro-particles and second order moments
  - **single particles**: macro-particles

  it can switch between these models during tracking

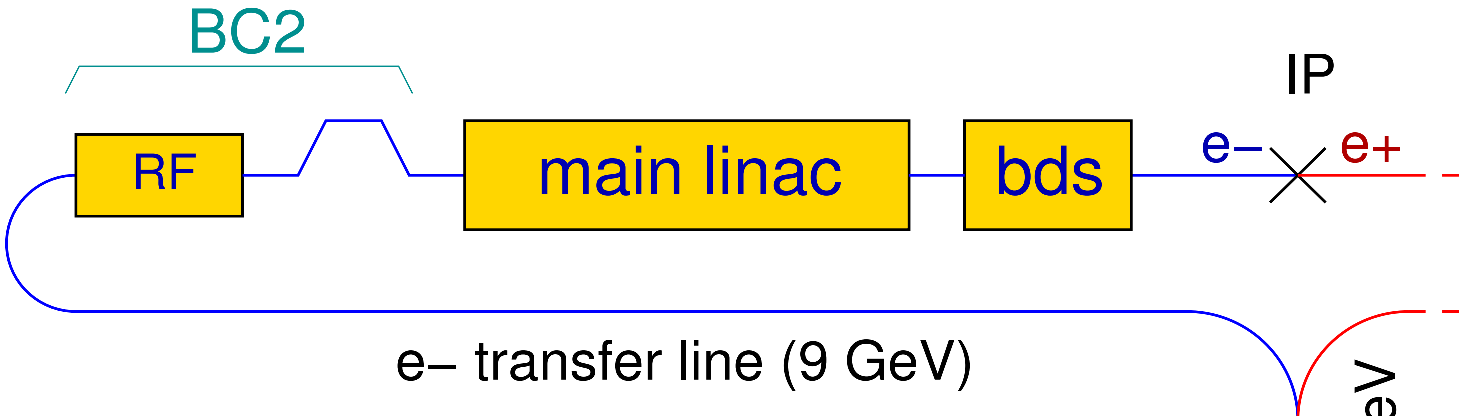
⇒ PLACET can simulate: bunch compressor, main linac, drive beam, beam delivery system (including crab cavities and instrumentation), interaction point (using **guinea-pig**) and soon : post collision line

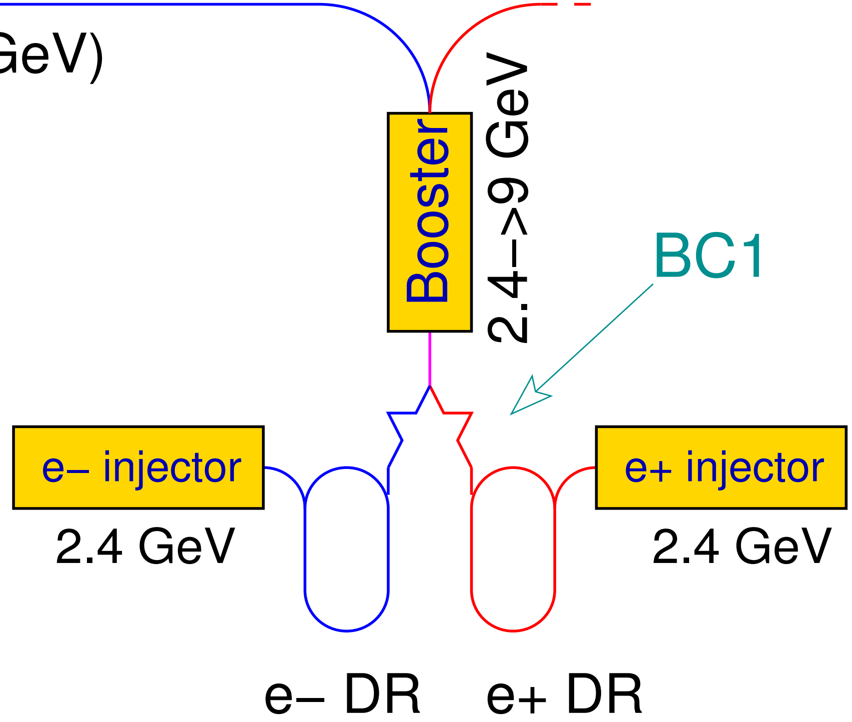
The Tracking Code PLACET

- it is -relatively- easy to use
- 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 is **open** to other codes:
  - it can read **MAD/MAD-X** deck files, as well as **XSIF** files
  - it uses the **Universal Parser Library** and **AML**
  - can be easily interfaced to Guinea-Pig
  - it can use other codes to perform beam transport
- it has a **graphical** interface (beam, beamline)
- it embeds **Octave** [1]
  - rich set of numerical tools
  - easy to use optimization / control system tool-boxes

[1] Octave is a mathematical toolbox similar to MatLab (but *open-source*)

Main Beam Sketch





- there is not yet a complete design
- beam at the exit of the damping ring:

energy	2.424 GeV
no. of particles per bunch	$2.56 \cdot 10^9$
bunch length	1550 μm
uncorrelated energy spread	0.13%

- beam at main linac injection:

energy	9 GeV
no. of particles per bunch	$2.56 \cdot 10^9$
bunch length	30 μm
uncorrelated energy spread	2%

- CLIC requires **two** bunch compressors

  $\Rightarrow$ I will focus on BC2, at the entrance of the ML

Main Linac Alignment Strategy

1) Surveyor Pre-Alignment, averaged misalignment amplitudes are estimated of the order of:

- 10 μm RMS for BPMs and cavities and
- 50 μm RMS for quadrupoles

2) Beam-Based Alignment (BBA), in four steps:

1. 1-to-1 correction : alignment of the quadrupoles
2. dispersion free steering : dispersion free correction (or ballistic alignment)
3. RF alignment : alignment of the accelerating cavities
4. emittance-tuning bumps : emittance minimization using wakefield bumps

$\Rightarrow$ **Dispersion Free Steering** (DFS)

A nominal beam + one or more *test beams* with different energies are used to determine the dispersion along the linac.

The nominal trajectory is steered and the differences between the nominal and the off-energy trajectories are minimized:

$$\chi^2 = \sum_{i=1}^{n} \omega_{1,i}\, y_{0,i}^2 + \sum_{j=1}^{m} \sum_{i=1}^{n} \omega_{2,j} \left(y_{j,i} - y_{0,i}\right)^2 + \sum_{k=1}^{p} \omega_{3,k}\, c_k^2$$

$i = 1..n$	BPMs	$y_{i,j}$	position of beam j in BPM i
$j = 0..m$	beams ($j = 0$ for nominal beam)	c_k	strength for the corrector k
$k = 1..p$	correctors	$\omega_{1,i}$, $\omega_{2,j}$, $\omega_{3,k}$	weights for orbit, difference and correction terms

Bunch Compression for Dispersion Free Steering (1/3)

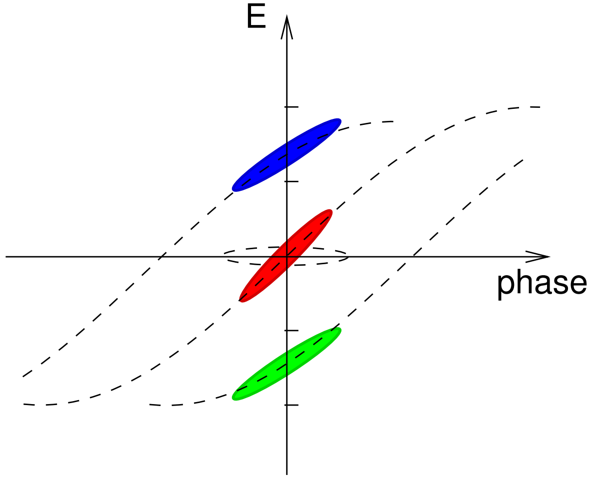
- in order to generate the energy difference for the DFS test beams, we introduce a *phase delay* in the BC's RF structure

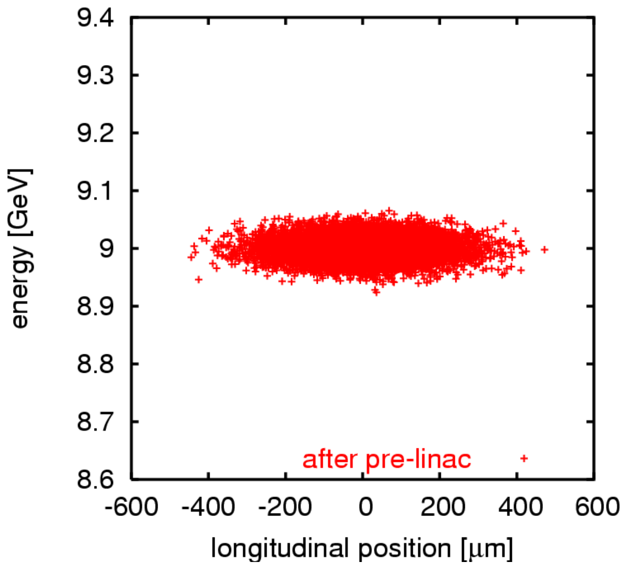
- we want to have:

  - one nominal beam : i.e. the *in phase beam*, which is fully compressed, nominal energy

  - two test beams : obtained offsetting the *phase* :
    $\phi_1 = \phi_0 + \Delta\phi_1$ and
    $\phi_2 = \phi_0 - \Delta\phi_2$

  we chose $\Delta\phi_1 = \Delta\phi_2$.





- the nominal beam is not accelerated. whereas the test beams, whose relative phase is $\pm\Delta\phi$, get an acceleration

Bunch Compression for Dispersion Free Steering (2/3)

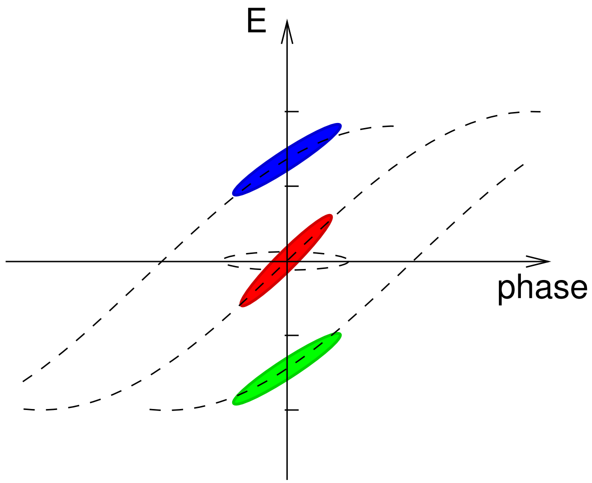
- in order to generate the energy difference for the DFS test beams, we introduce a *phase delay* in the BC's RF structure

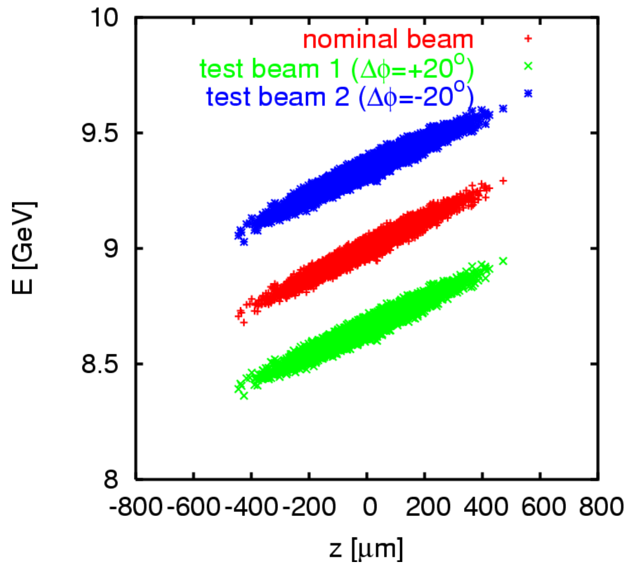
- we want to have:

  - one nominal beam : i.e. the *in phase beam*, which is fully compressed, nominal energy

  - two test beams : obtained offsetting the *phase* :
    $\phi_1 = \phi_0 + \Delta\phi_1$ and
    $\phi_2 = \phi_0 - \Delta\phi_2$

  we chose $\Delta\phi_1 = \Delta\phi_2$.





- the nominal beam is not accelerated. whereas the test beams, whose relative phase is $\pm\Delta\phi$, get an acceleration

Bunch Compression for Dispersion Free Steering (3/3)

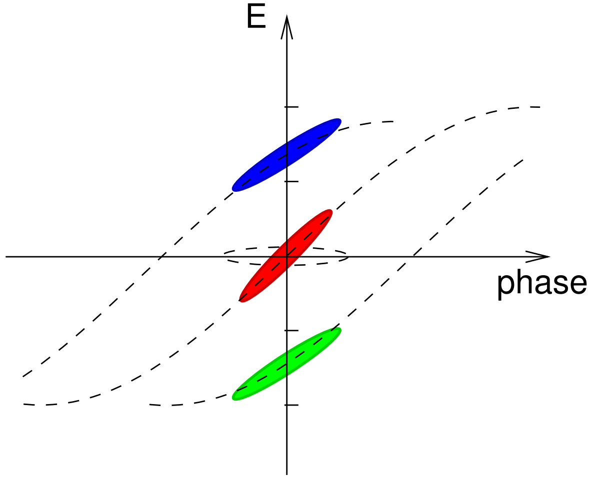
- in order to generate the energy difference for the DFS test beams, we introduce a *phase delay* in the BC's RF structure

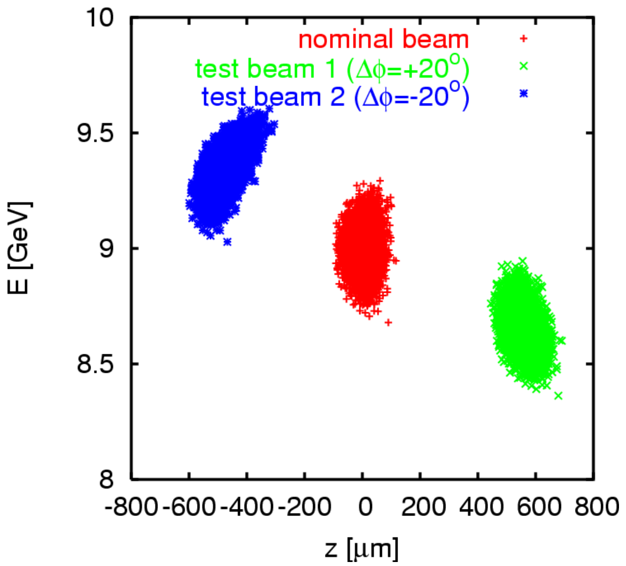
- we want to have:

  - one nominal beam : i.e. the *in phase beam*, which is fully compressed, nominal energy

  - two test beams : obtained offsetting the *phase* :
    $\phi_1 = \phi_0 + \Delta\phi_1$ and
    $\phi_2 = \phi_0 - \Delta\phi_2$

  we chose $\Delta\phi_1 = \Delta\phi_2$.





- the nominal beam is not accelerated. whereas the test beams, whose relative phase is $\pm\Delta\phi$, get an acceleration

Energy Difference for Dispersion Free Steering

- There are (at least) two ways to generate the test beams' energy offset:
  1. creating an initial energy difference before the man linac (using the BC)
  2. reducing the gradient of the main linac accelerating structures

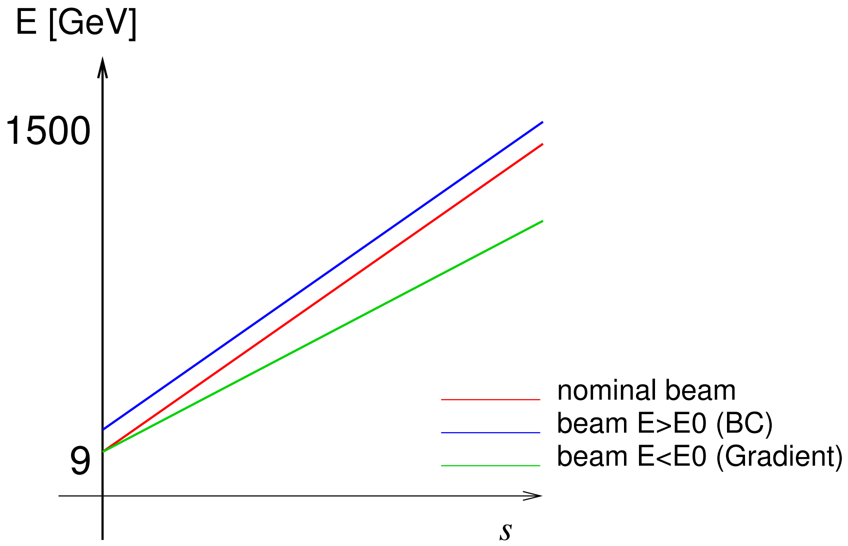
  ⇒ **we need both.**

- Let's consider the DFS formula:

$$\chi^2 = \sum_{i=1}^{n} \omega_{1,i}\, y_{0,i}^2 + \sum_{j=1}^{m} \sum_{i=1}^{n} \omega_{2,j}\, \left(y_{j,i} - y_{0,i}\right)^2 + \sum_{k=1}^{p} \omega_{3,k}\, c_k^2$$

  we have three contributions:

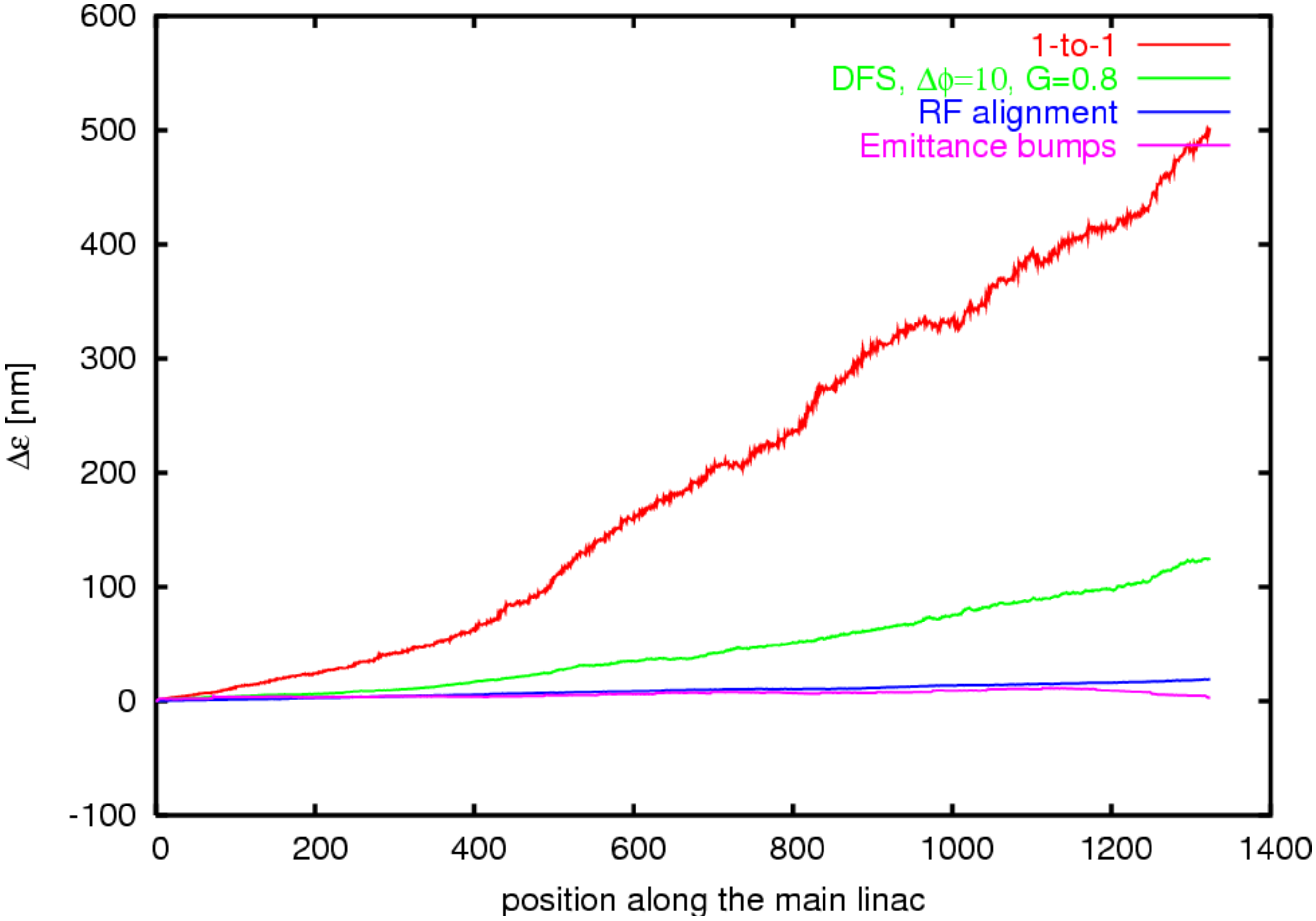
  1. nominal beam steered to the nominal trajectory
  2. test beams steered to the nominal beams
  3. balancing term



Simulation Parameters

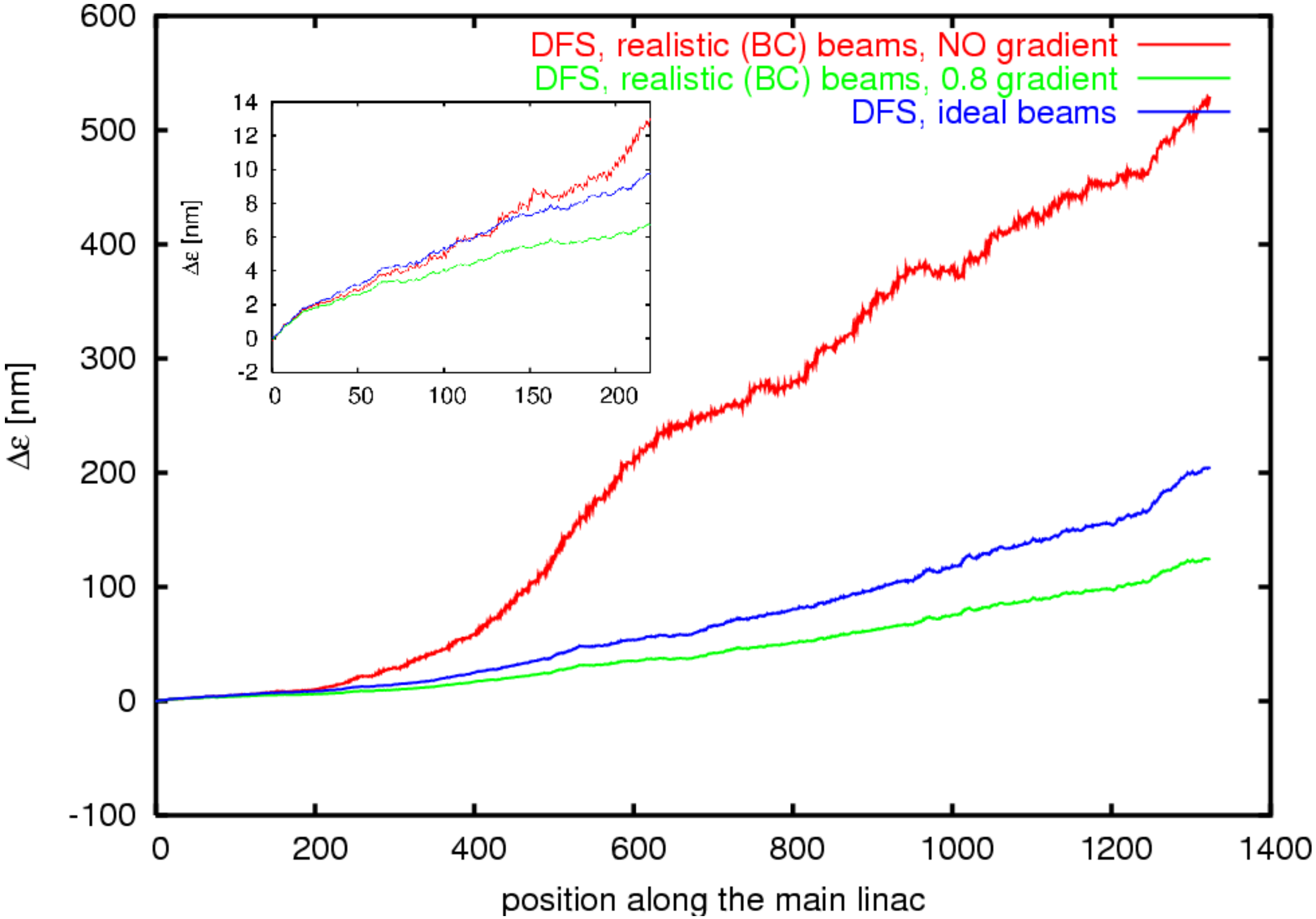
- bunch compressor:
  - incoherent synchrotron radiation emission considered
  - no wakefields in the BC cavities
  - perfectly aligned BC
- main linac misalignments:
  - $\sigma_{quad} = 50\,\mu\mathrm{m}$ Quadrupole position error
  - $\sigma_{cav} = 10\,\mu\mathrm{m}$ Cavity position error
  - $\sigma'_{cav} = 10\,\mu\mathrm{rad}$ Cavity angle error
  - $\sigma_{BPM} = 10\,\mu\mathrm{m}$ BPM position error
  - $\sigma_{res} = 0.1\,\mu\mathrm{m}$ BPM resolution
- DFS:
  - $\Phi_0 = 0$, nominal beam
  - $\Phi_{1,2} = \pm\Delta\Phi$, help beams
  - $\omega_{2,i}/\omega_{1,i} = 100$, orbit correction / 1-to-1 steering

Emittance Growth after Beam-Based Alignment



standard average misalignments, 2 test beams, $\Delta\Phi = \pm 10$, $\omega = 100$, $G = 0.8$, average of 50 machines, final emittance growth 2.8 nm

One vs Two Test Beams



standard average misalignments, 2 test beams, $\Delta\Phi = \pm 10$, $G = 1.0, 0.8$, $\omega = 100$, average of 50 machines

Conclusions

- main linac emittance growth is kept within the budget using bunch compressor and dispersion free steering
- it shows better performances than ideal beams -probably- because of the different longitudinal phase space
- two test beams are still necessary to correct both the two ends of the linac
- some studies have still to be done:
  - impact of the bunch compressor misalignments (wakefields)
  - how to align the BC2 itself (and BC1 as well)
  - does the big energy spread in the BC create problems? (apertures, . . .)

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