Update on Single-Stage Bunch Compressor for ILC-SB2009

A. Latina, N. Solyak (FNAL)

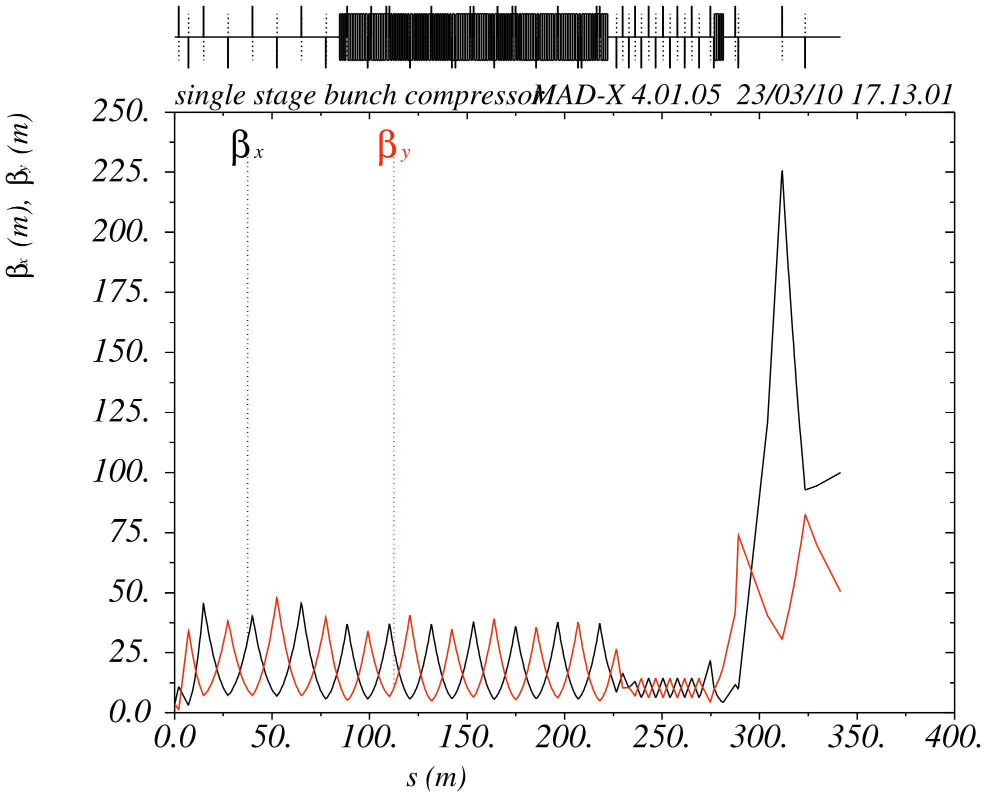
March 26-30, 2010

LCWS2010 - Beijing, China

- Bunch compressor description
- Bunch compressor performances
- Toward shorter bunches: non-linearities and possible cures
- Conclusions

BC1S Optics and General Description

- Single-Stage Bunch Compressor optics



- 6 type-4 cryomodules for RF acceleration
- 6-cells Tenenmbaum-Seletskiy Wiggler
- diagnostics, matching

Bunch Compressor Schematics

- Beam at injection

charge	2e10 (3.2 nC)
energy	5 GeV
energy spread	0.15% (0.13% at damping rings exit)
bunch length	6 mm

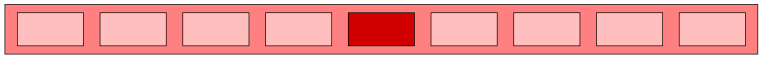
- RTML ahead : turnaround, spin rotator, emittance measurement station, beam diagnostics

- BC1S is composed by the following consecutive parts
  - **BC0** : entrance
  - **BC1 RF** : RF section, 6 CM, 48 accelerating structures, $\sim$ 75 meters
  - **BC1 RF2WIG** : matching section from RF to wiggler
  - **BC1 WIGGLER** : 6-cells, $\sim$ 24 meters long each
  - **BC1WIG2DIAG** : matching section to diagnostics
  - **BC1 DIAG** : 4 laserwires, phase monitor, bunch length monitor (LOLA cavity)
  - **BC1 ML_1** : kickers to the extraction line
  - **BC1_ML_2** : matching section to main linac FODO

$\Rightarrow$ Total length is now : 342 m

RF-System Description

- 6 Type-4 cryomodules (quadrupole in the middle) in a fodo lattice with 90 degrees phase advance per cell



- Characteristics of the rf-system are:

Integrated voltage	1,332 MV @ 1.3 GHz
Cavity gradient	≈26.8 MV/m
Accelerating Structures	48 (6 Type-4 cryomodules)
Phase	-127.7 degrees
Energy Loss	815.2 MeV

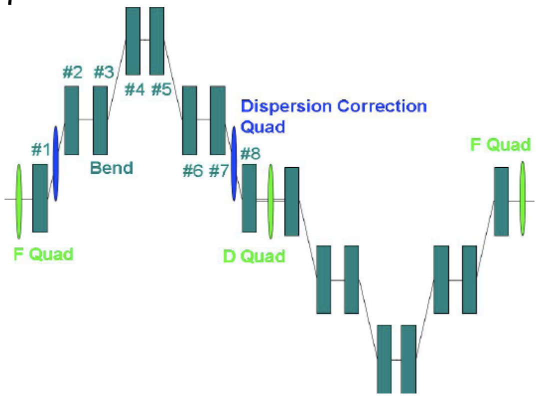
- Design is optimized (RF phase, acc gradient, R_{56}) to achieve:

  ⇒ final bunch length : 0.3 mm

  ⇒ energy spread at ML entrance (baseline): 1.07%

Wiggler Description

- Based on WEOAAB02 @ PAC07

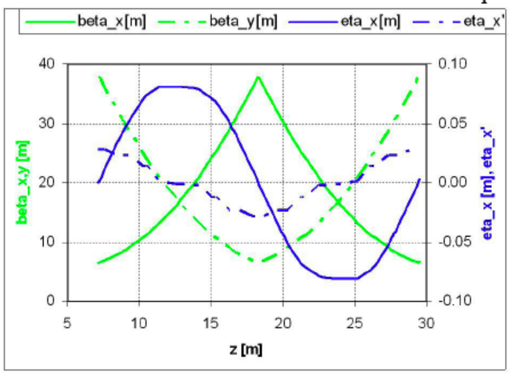


- Description
  - 6 cells (like in the figure) in a FODO lattice with 90^o phase advance per cell
  - focusing and defocusing quads are placed in the zero dispersion regions
  - 4 additional normal quads are inserted for dispersion cancellation and 4 skew quads (in cells 1,3,4 and 6) for dispersion correction and coupling cancellation
  - wiggler is preceeded and followed by a dispersion matching section composed by 3 bending mangnets each
- R_{56} : -145 mm (see later)

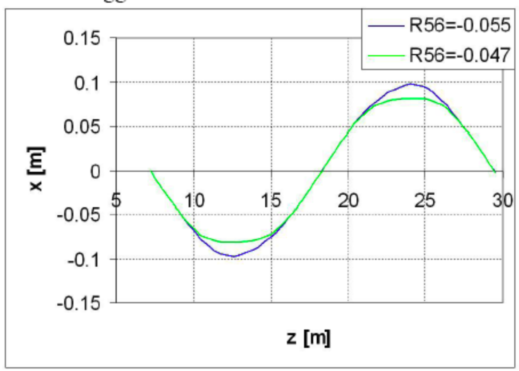
Wiggler Optimization

- Wiggler optimization was redone to meet the requirements
  - for a given R_{56} keep $\phi 1$, $\phi 8$ and η' constant, $\phi_{16-i} = -\phi_i$ with $i = 1, 2, \ldots 8$
    $\Rightarrow$ Beam is not moved in quads when wiggler is tuned
  - zeroth the horizontal trajectory displacement over the half of the cell
    $\Rightarrow$ Trajectory at wiggler's exit is fixed to the reference orbit
  - require the mirror symmetry of the first and second halves of the cell
  - require that $\sum_{i=1}^{8} = -2\eta'$
    $\Rightarrow$ Dispersion in FODO quads is zero; η' at the exit of each cell is equal to its entrance value
  - we explicitly constrain R_{56} to the required value
- We have 5 degrees of freedom

Cell of the optimized BC2 wiggler



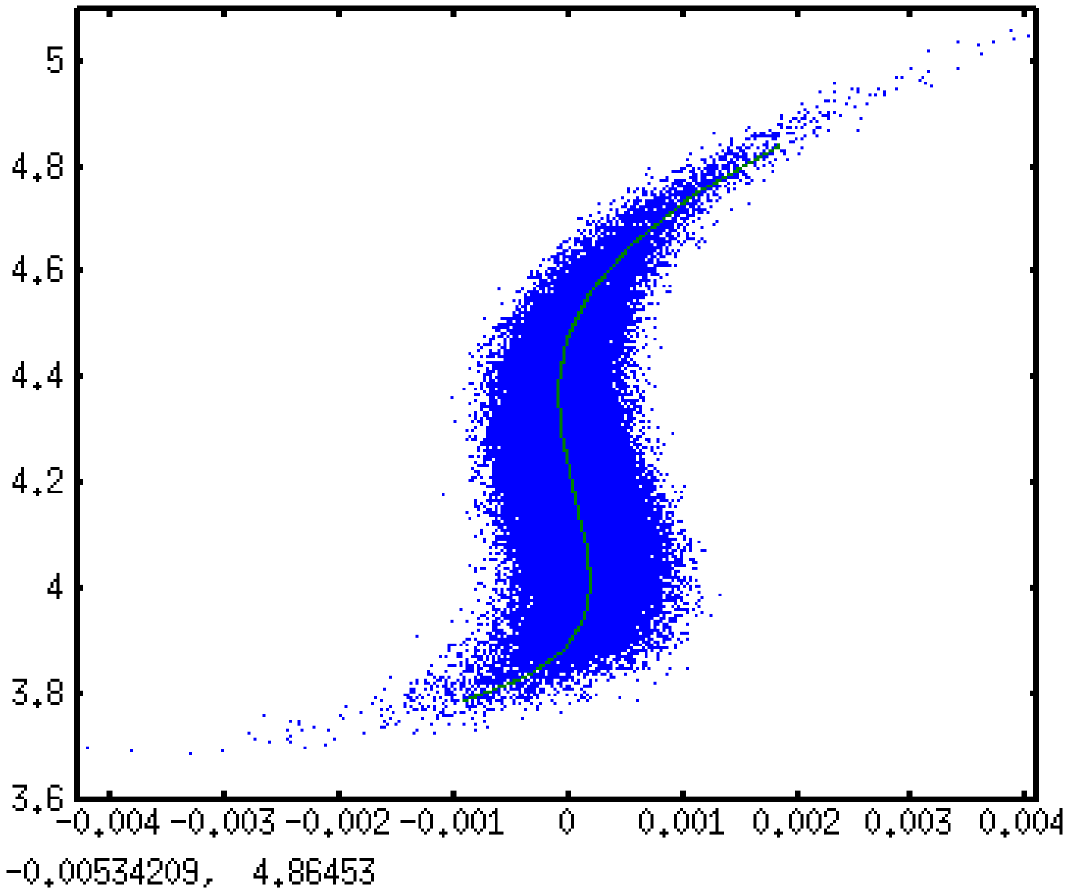
Twiss parameters in BC2 wiggler's cell



Beam trajectory in BC2 wiggler's cell

Particle Tracking

- Beam profile after phase space optimization



- Final bunch length 300 μm

Performances: Static Imperfections

- Effect of **element misalignments** and correction
  - "COLD" model

$$
\begin{array}{lcll}
\sigma_{\text{quad}} & = & 300\ \mu\text{m} & \text{quadrupole position error} \\
\sigma_{\text{quad roll}} & = & 300\ \mu\text{rad} & \text{quadrupole roll error} \\
\sigma_{\text{cav}} & = & 300\ \mu\text{m} & \text{cavity position error} \\
\sigma_{\text{cav pitch}} & = & 300\ \mu\text{rad} & \text{cavity pitch error} \\
\sigma_{\text{sbend angle}} & = & 300\ \mu\text{rad} & \text{sbend angle error} \\
\sigma_{\text{bpm}} & = & 300\ \mu\text{m} & \text{bpm position error}
\end{array}
$$

  - Bpm resolution error: $\sigma_{\text{bpmres}} = 1\ \mu\text{m}$

  $\Rightarrow$ impact and cure using beam-based alignment

- Effect of **couplers RF-Kick and Wakes**

$$
\begin{aligned}
k_{\text{rfkick, upstream}} &= (\,-45.3 + 4.7i\,) \times 10^{-6} \\
k_{\text{rfkick, downstream}} &= (\,38.5 + 13.7i\,) \times 10^{-6}
\end{aligned}
$$

- Effect of **element misalignments** and **couplers RF-Kick and Wakes**

Beam-Based Alignment

- **Alignment Procedure**

  1) 1-to-1 Correction

  2) Dispersion Free Steering

     - a phase offset, ± 5 degrees, is applied to the RF cavities of the BC1S in order to generate the energy difference for the DFS's test beams

       (then test beams are synchronized to the Linac's RF phase for ML alignment)

  3) Dispersion bumps optimization

     - using the skew quadrupoles that are in the wiggler

     - two *knobs*: tune dispersion to minimize the final vertical emittance

  4) *new* Girder pitch optimization

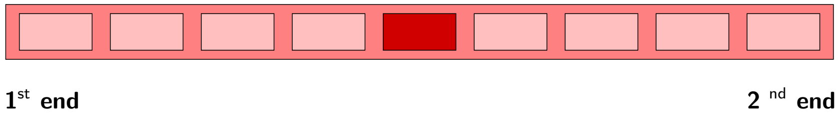
⇒ **Dispersion Free Steering**

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

⇒ we **scan** the weight $\omega_{1,j}$ to find the optimum

Girder Pitch Optimization

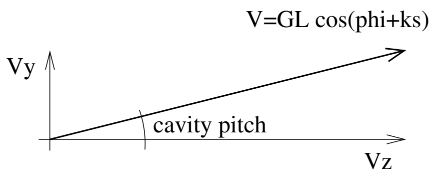
- GPO is meant to counteract intrabunch effects such as couplers rf- and wake- kicks:

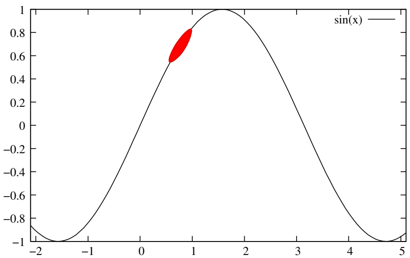


For instance, $\Delta\vec{V}_{RF} = \underbrace{\vec{k}\,GL\,e^{-i(\phi_{RF}+ks)}}_{\text{RF}-\text{Kick}}$ results in

$$\Delta\vec{V}_{RF} = V_{\text{real}}\cos(ks) \;-\; \underbrace{V_{\text{imag}}\sin(ks)}_{\sim\, GL\cos(\phi_{RF})\,\sigma_{\text{PITCH}}\,ks}$$

⇒ Like RF-kick, cavity pitch gives two contributions:



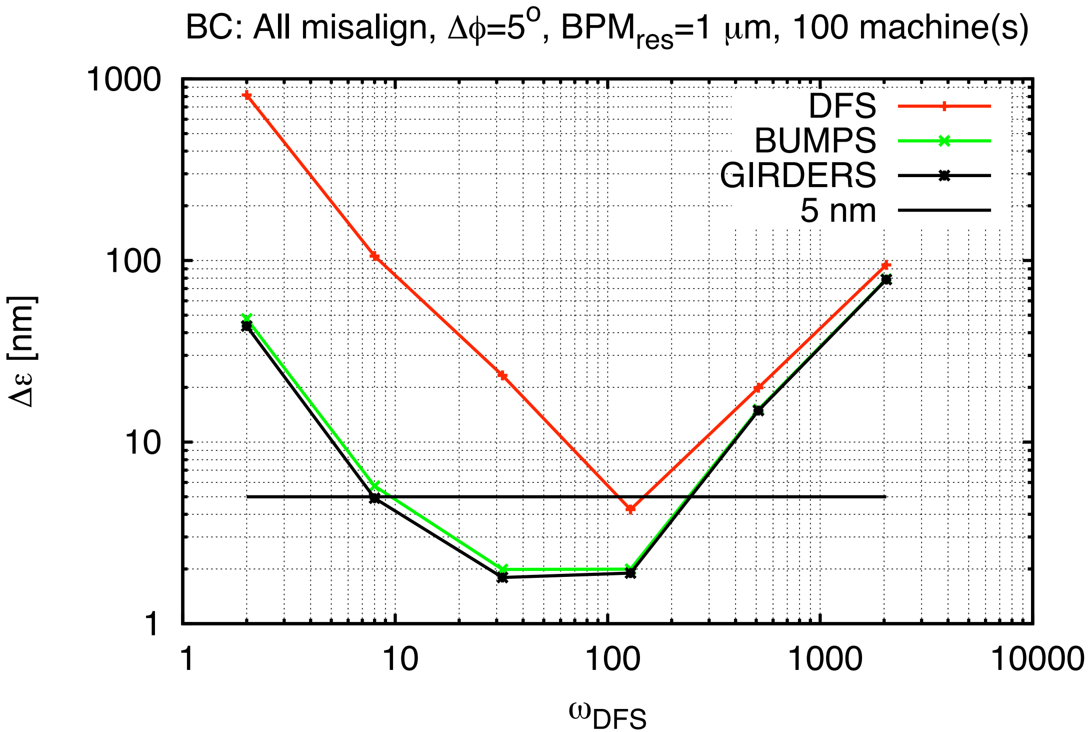


- an average kick to all the entire bunch and

- a slope along the bunch, proportional to the phase

Particle Tracking

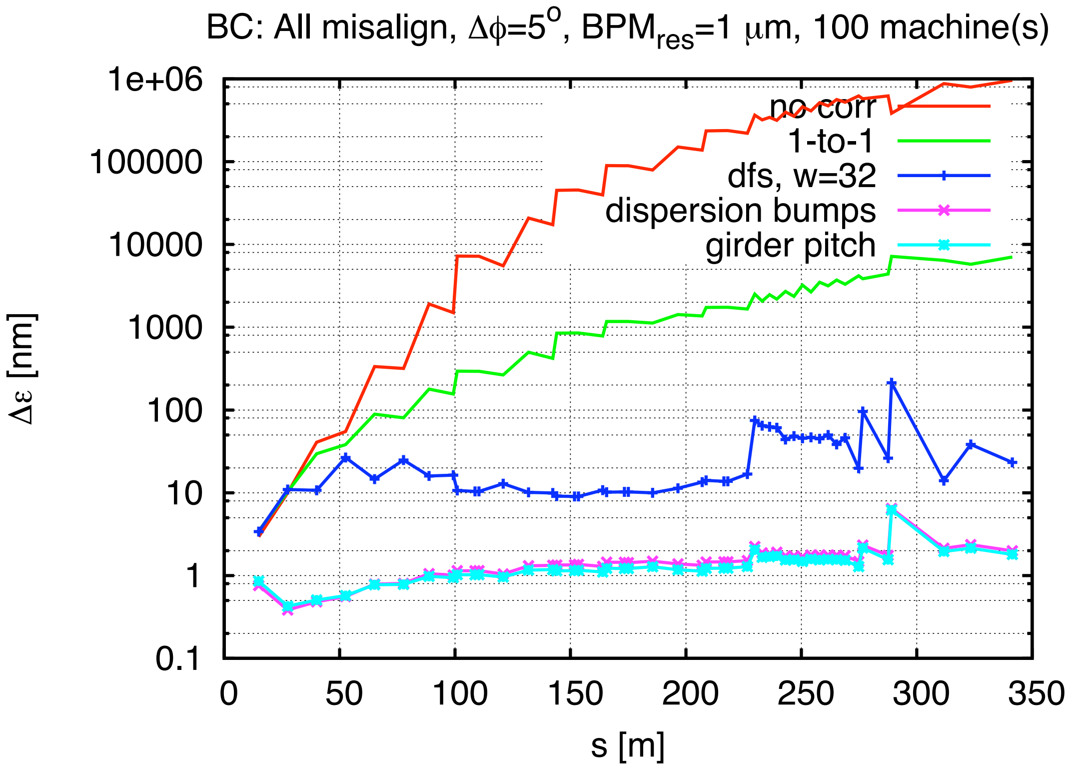
- Vertical emittance along BC1S in case of misalignments
- Couplers kick is not considered



⇒ final emittance growth is 1.8 nm

Particle Tracking

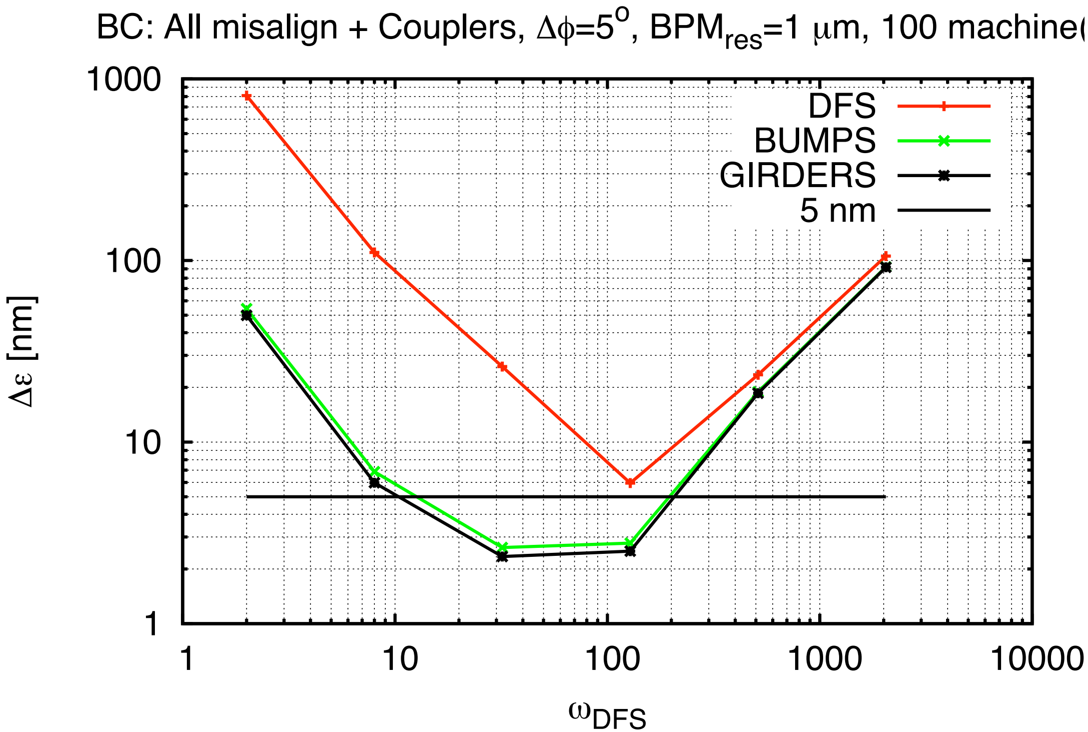
- Vertical emittance along BC1S in case of misalignments
- Couplers kick is not considered



⇒ final emittance growth is 1.8 nm

Particle Tracking

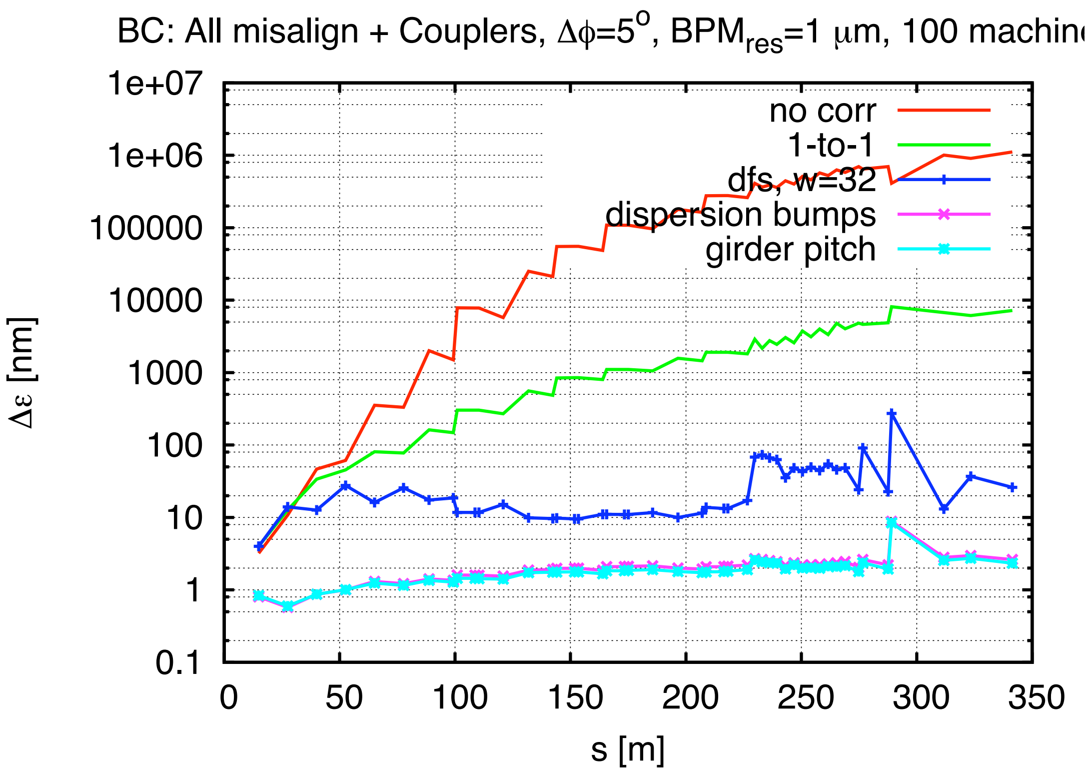
- Vertical emittance along BC1S in case of misalignments
- Couplers kicks are considered



⇒ final emittance growth is 2.3 nm

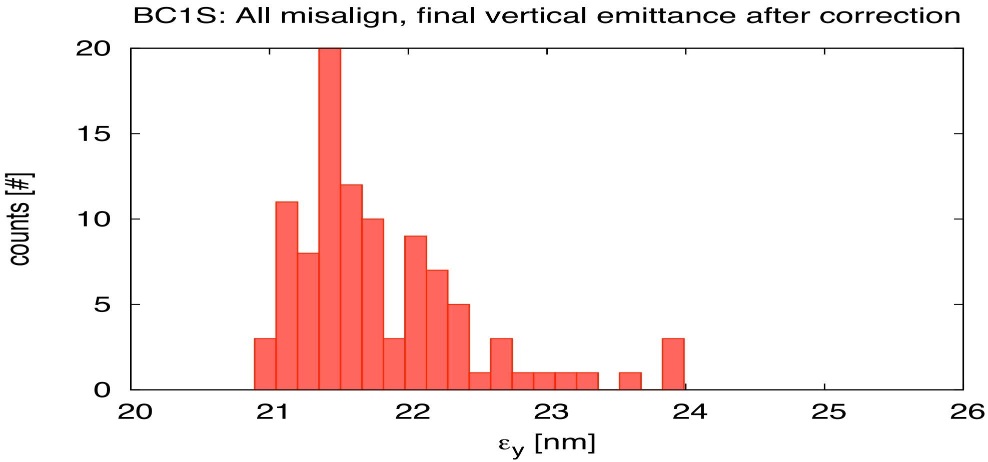
Particle Tracking

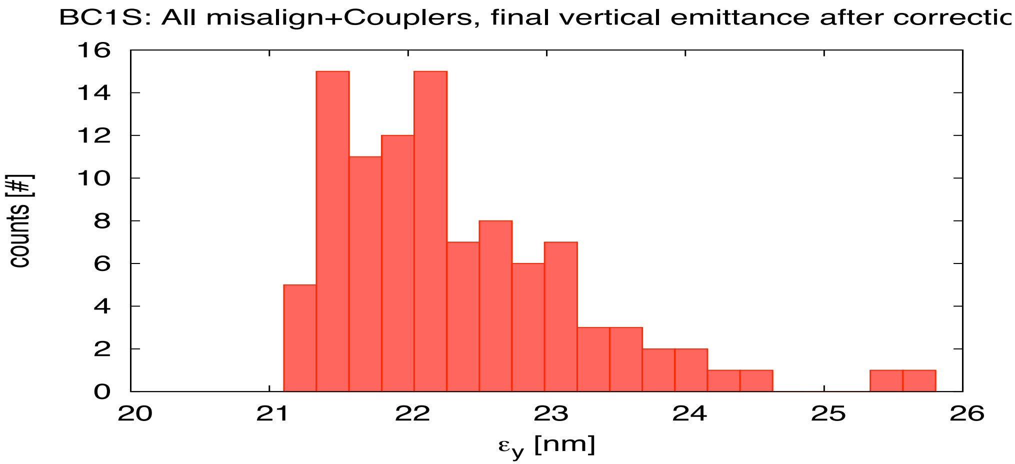
- Vertical emittance along BC1S in case of misalignments
- Couplers kicks are considered



⇒ final emittance growth is 2.3 nm

Particle Tracking





Bunch Compressor + Main Linac Simulation

- Integrated simulations, Single-Stage Bunch Compressor + Main Linac, have been performed

- all misalignments have been applied to the whole system

- beam-based alignment

  1) 1-to-1 correction, the whole machine

  2) dispersion free steering, using two test beams:
  - $\pm$5 deg off-phase bunches in BC1S
  - 1.05$\times$ and 0.8$\times$ the gradient of the ML's cavities, respecitvely

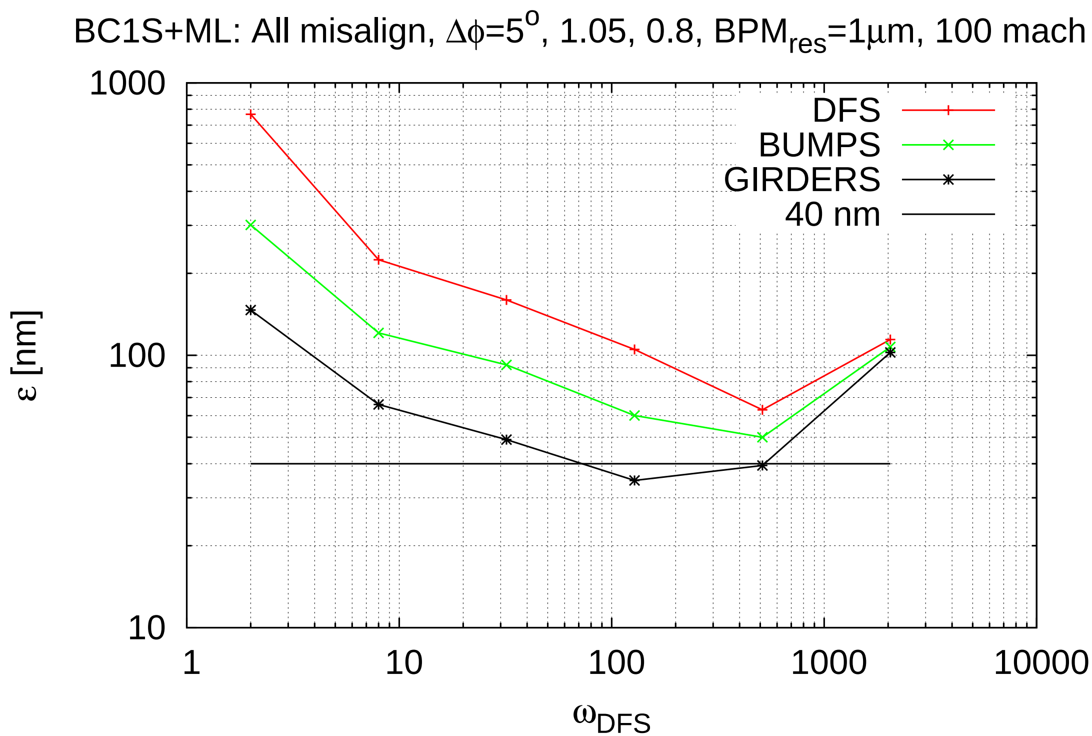
  3) bumps
  - dispersion bumps in BC1S
  - dispersion removal at the end of ML

  4) girder pitch optimization, using:
  - 2 girders in BC1S
  - 2 girders in ML

- Initial vertical emittance is 20 nm

Particle Tracking

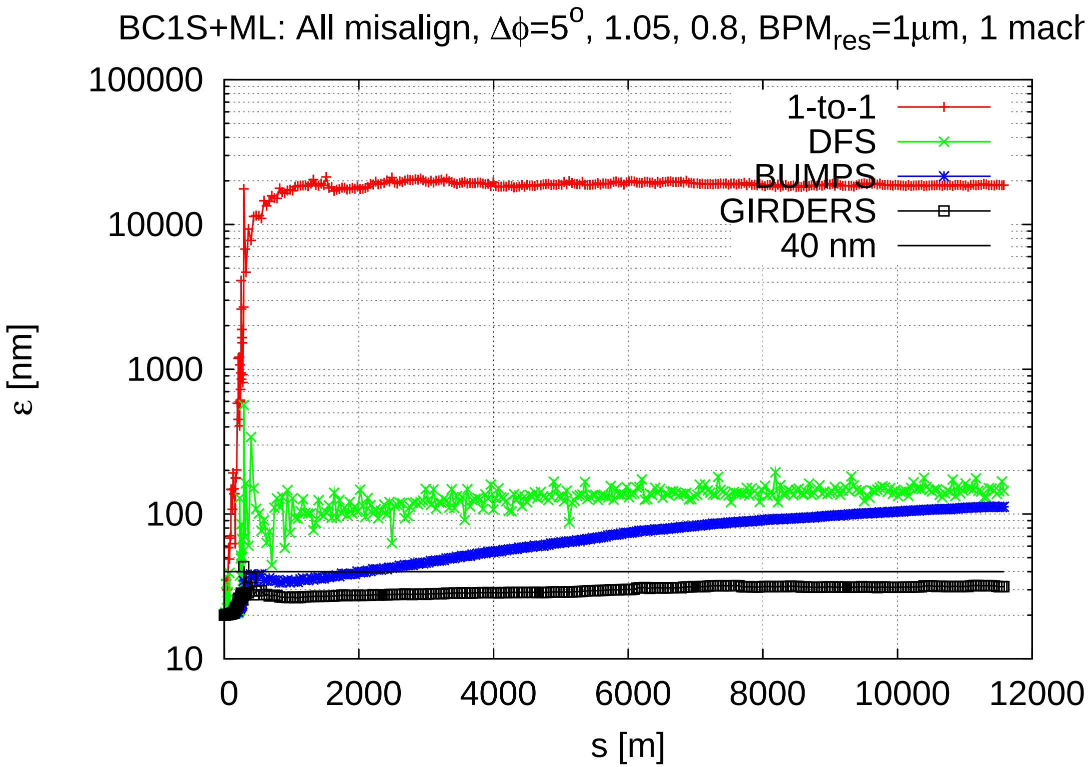
- Vertical emittance along BC1S+ML in case of misalignments
- Couplers kicks are not considered, wakefields are not considered



⇒ average final emittance is 34.7 nm

Particle Tracking

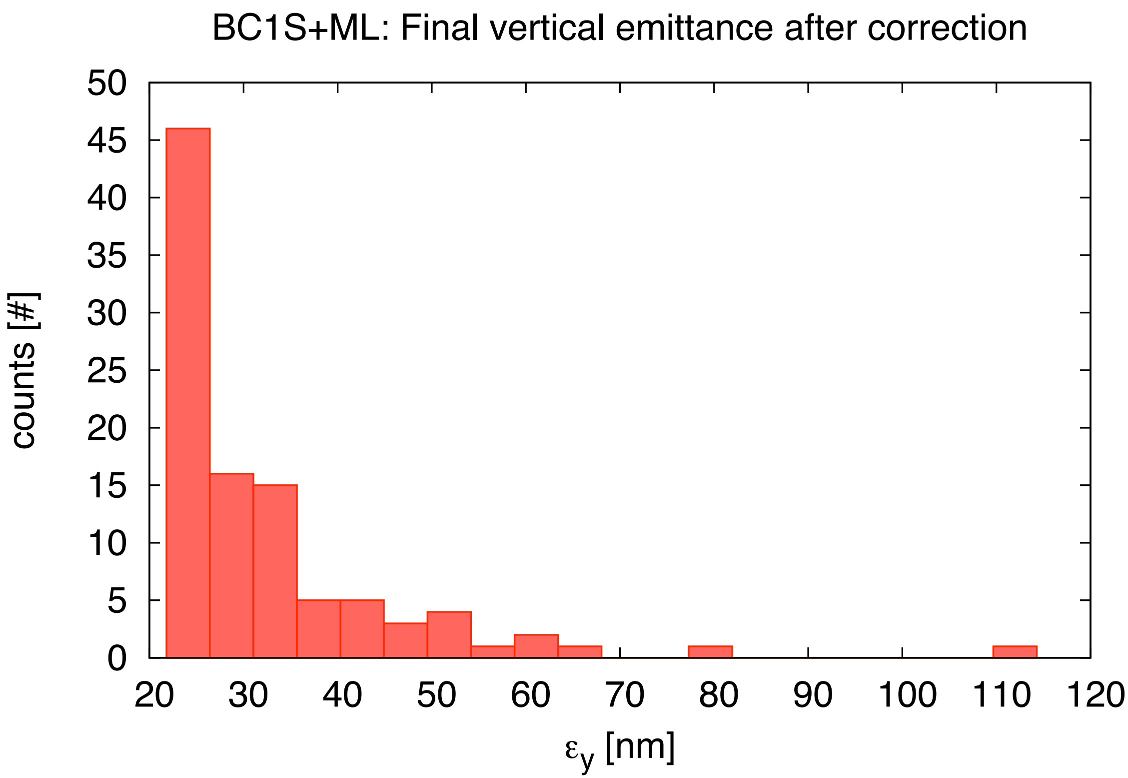
- Vertical emittance along BC1S+ML in case of misalignments
- Couplers kicks are not considered, wakefields are not considered



⇒ final emittance is 31.5 nm

Particle Tracking

- Vertical emittance along BC1S+ML in case of misalignments
- Couplers kicks are not considered, wakefields are not considered

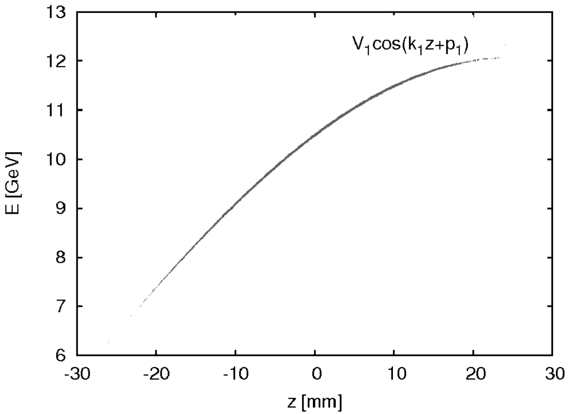


⇒ average final emittance is 34.7 nm ($> 80\%$ of the seeds are below 20 nm emittance growth)

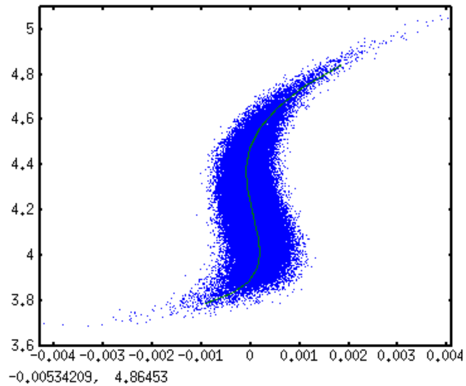
Compression from 6 mm to 200 μm

- Many efforts have been done to compress the bunches down to 200 μm with a single-stage bunch compressor.

- Major problems arise from the intrinsic non-linearities of the system:
  - off-crest RF-phase



$\Rightarrow$



  - $T_{566} \neq 0$:

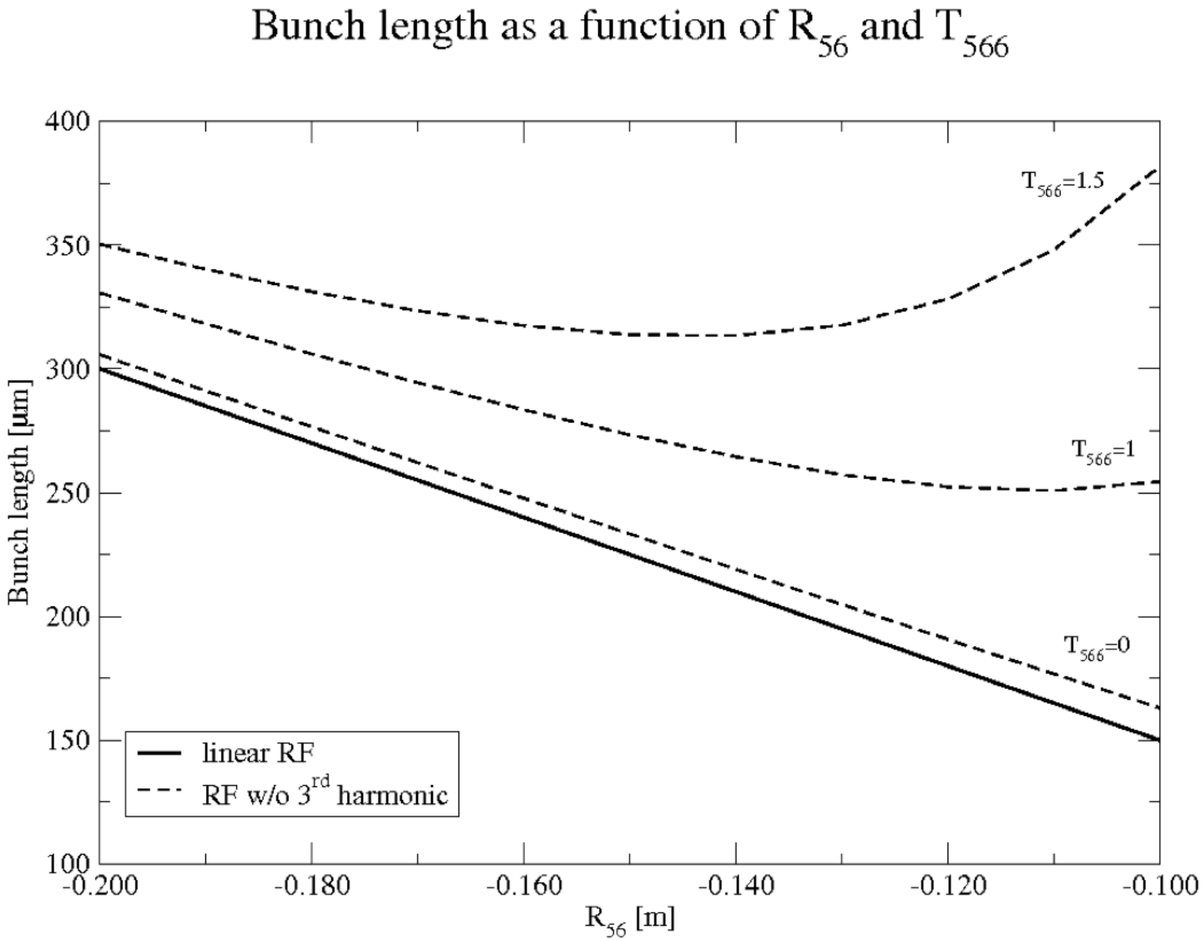
$$z_f = z_i + R_{56}\,\delta + T_{566}\,\delta^2$$

For a wiggler $\Rightarrow$ $\boxed{T_{566} \approx -\frac{3}{2} R_{56}}$

$\Rightarrow$ Minimum bunch length achieved 250: μm

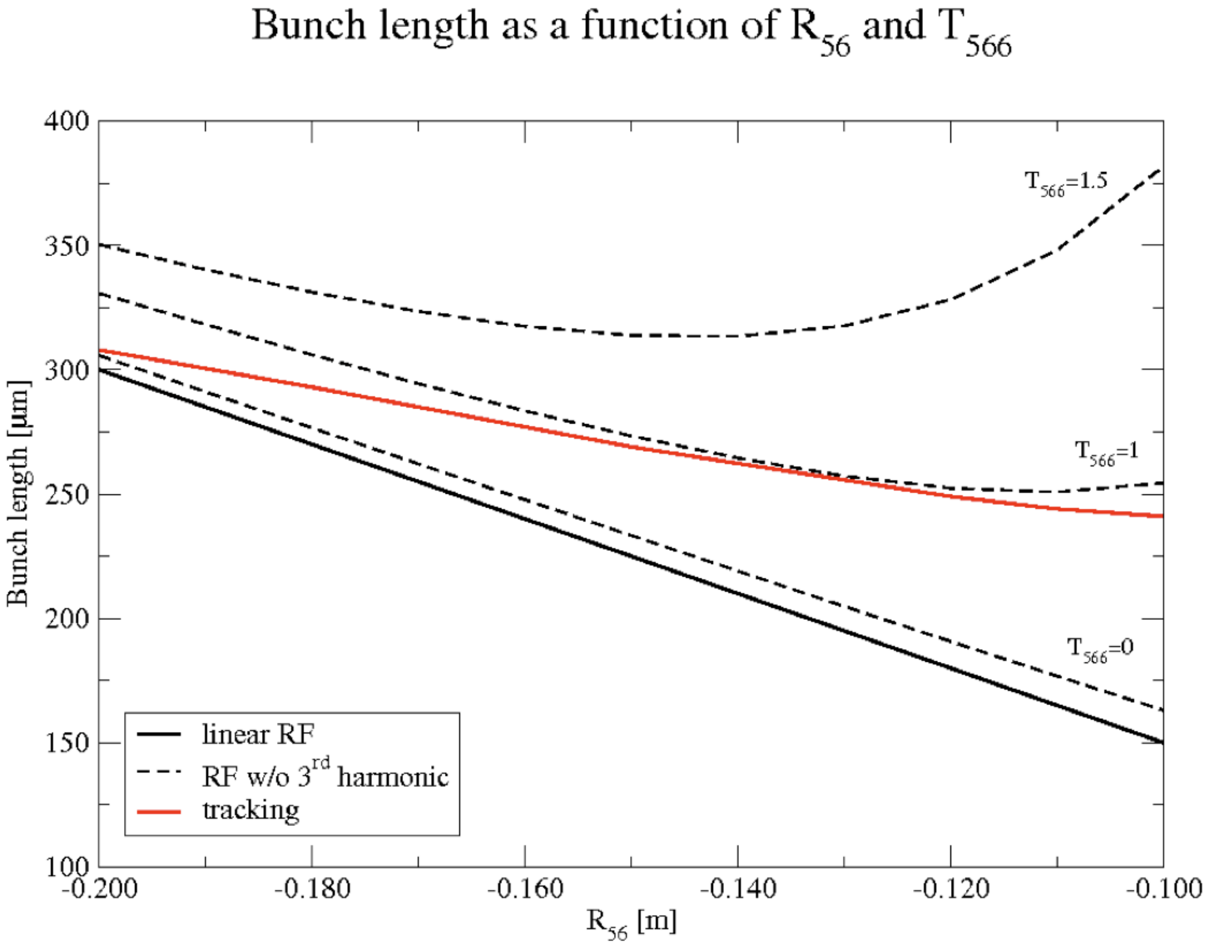
Parameters' Space Scan

Free parameters: V_1, ϕ_1, T_{566}



Parameters' Space Scan

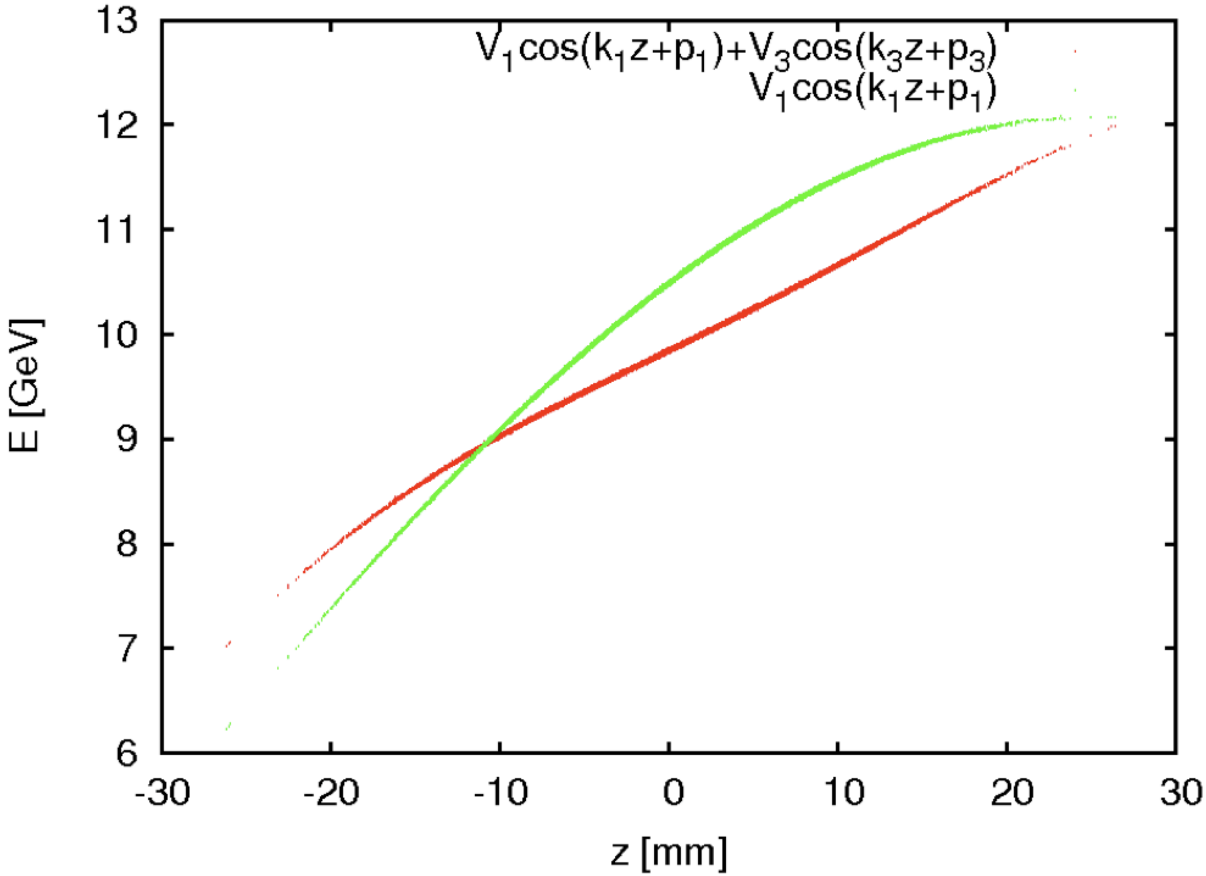
Free parameters: V_1, ϕ_1, T_{566}



3^{rd} harmonic cavity to linearize the RF-section

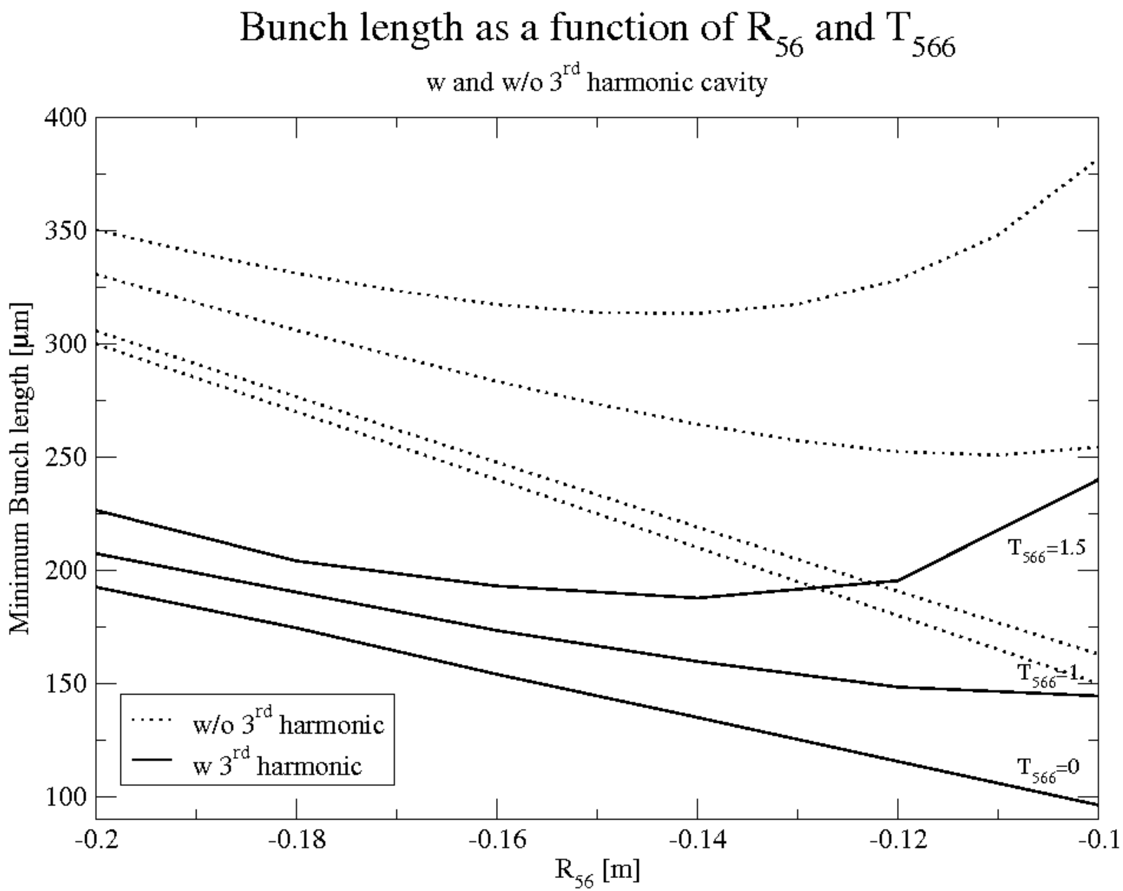
A 3^{rd} harmonic cavity has been added to the lattice to linearize the phase space

$$\Delta E = V_1 \cos(k_1\, z + \phi_1) + V_3 \cos(k_3 + \phi_3)$$



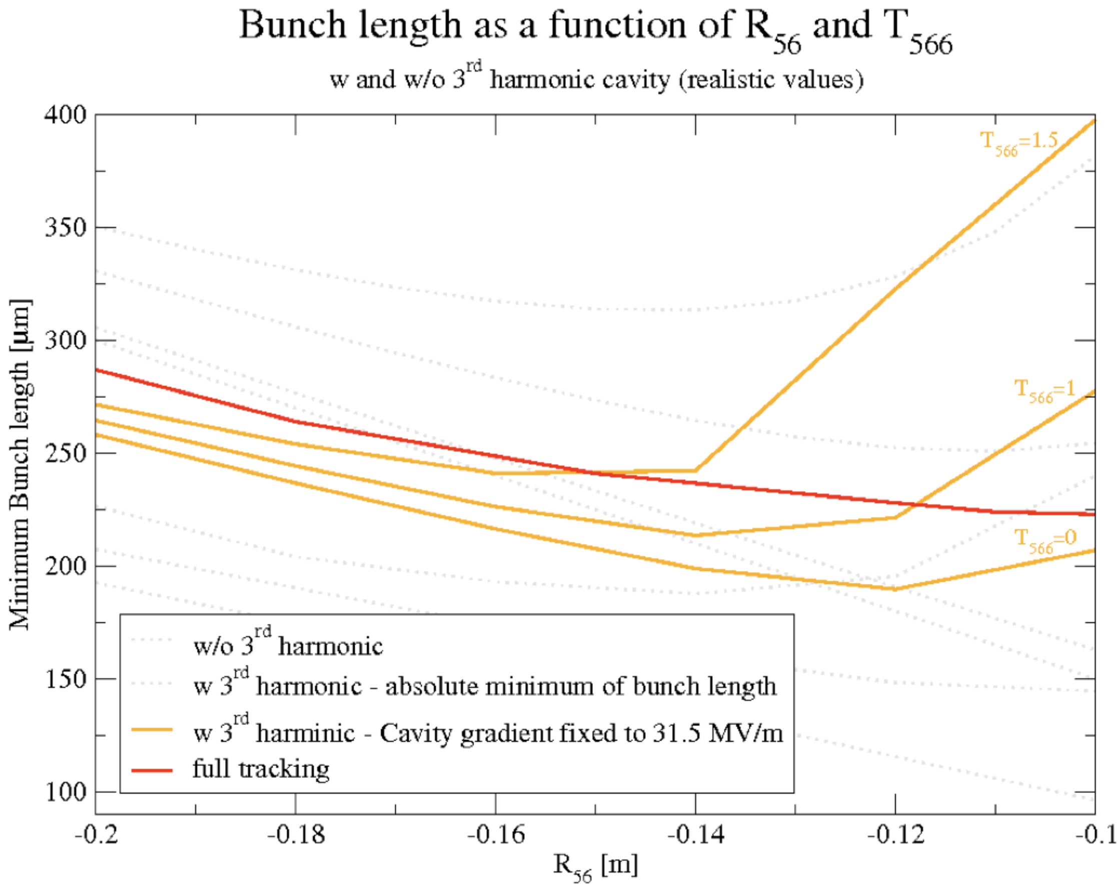
Parameters' Space Scan

- Free parameters: $V_1, \phi_1, V_3, \phi_3, T_{566}$
- No constraints: only constraint is on the bunch length $\rightarrow$ that has to be minimum



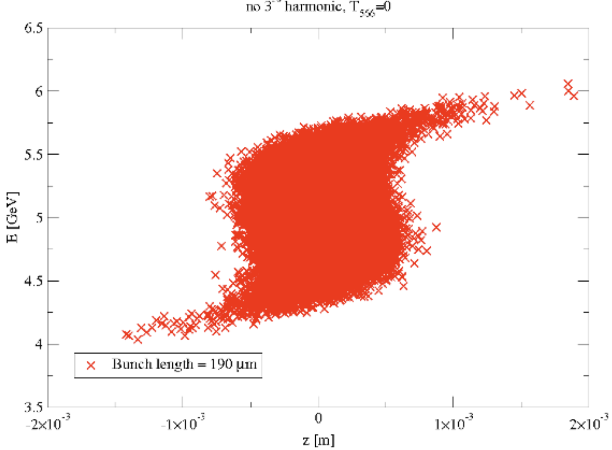
Parameters' Space Scan

- Free parameters: $V_1, \phi_1, V_3, \phi_3, T_{566}$
- Parameters are contraint to reasonable values

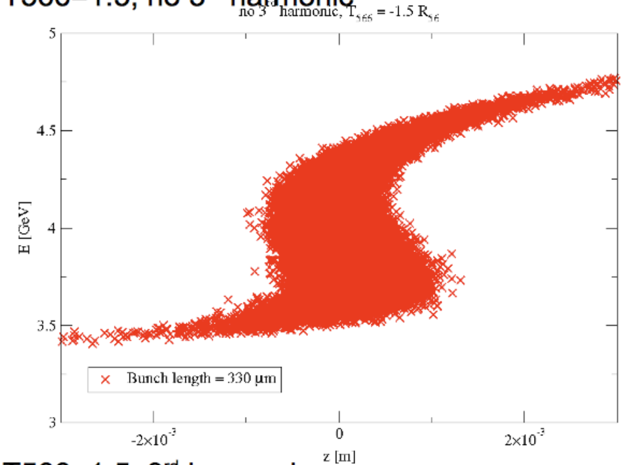


Beam Profiles

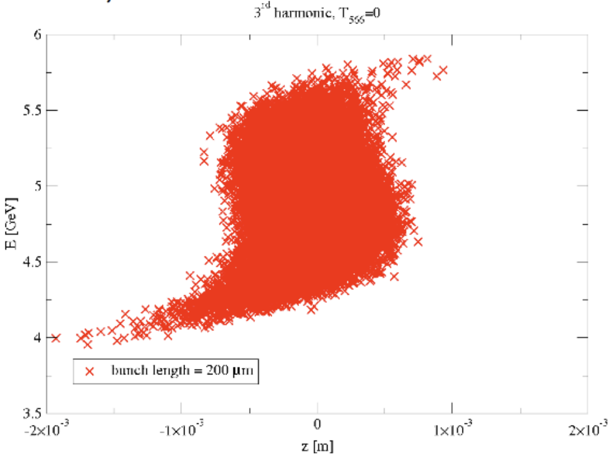
T566=0, no 3^{rd} harmonic



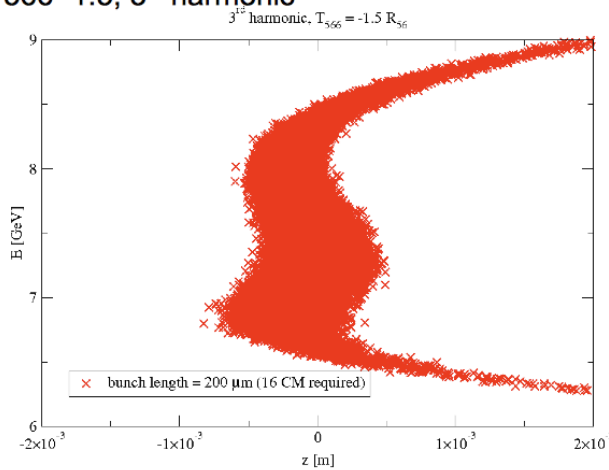
T566=1.5, no 3^{rd} harmonic



T566=0, 3^{rd} harmonic



T566=1.5, 3^{rd} harmonic



Conclusions

⇒ To obtain bunches shorter than 250 μm, T_{566} must be reduced

- This can be achieved:

  - by introducing sextupoles in the lattice for instance

- Sextupoles have been added to the lattice where the skew quadrupoles are (this can probably be optimized)

- Full 6d tracking results

R56	STD	STD+3rd	STD+Sextupoles	STD+3rd + Sextupoles
-0.120	249	226	234	220
-0.100	241	223	237	236

(STD = standard BC1S)

⇒ modest improvement

⇒ For bunches 300 μm long there are no problems and the performances are good also in terms of emittance preservation