Single Stage Bunch Compressor Studies

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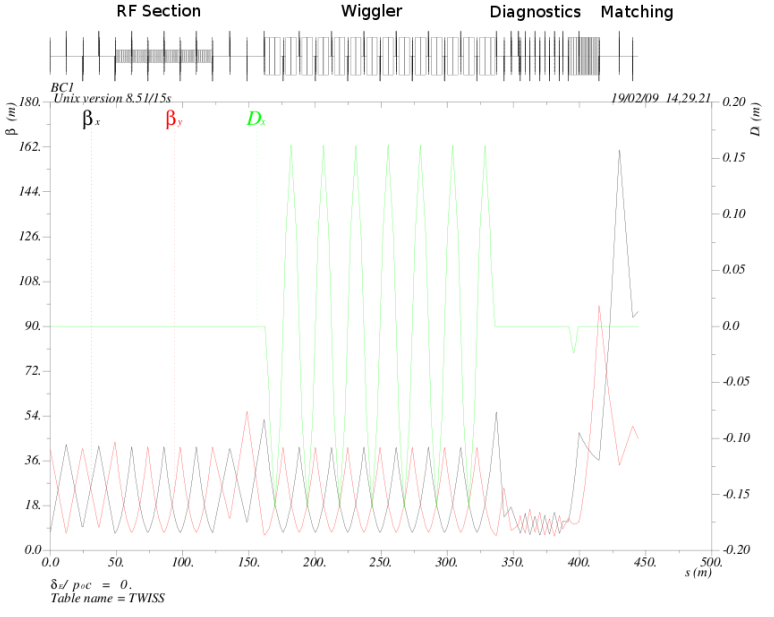
GDE Main Linac & Beam Dynamics

- Description of BC1S and Update
- Beam Dynamics Simulations
- Conclusions and Work Plan

BC1S Optics and General Description

- Based on the original design at 5 GeV by PT in April 2005:

`http://www-project.slac.stanford.edu/ilc/acceldev/LET/BC/OneStageBC.html`



- six cryomodules for RF acceleration
- 6-cells *Raubenheimer-type* wiggler: a *single bend magnet* between quads in a *6-cells FODO lattice*

⇒ NEW sections added:

(1) beam **diagnostics** and **extraction** adapted from BC2 (extraction line to be taken from BC1 ⇒ shorter)

(2) **pre-linac** to rise the energy from 5 to 15 GeV

BC1S Single Stage Schematics

- 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
  - **BC2 DIAG** : 4 laserwires, phase monitor, bunch length monitor (LOLA cavity)
  - **BC2 ML_1** : kickers to the extraction line
  - **BC2_ML_2** : matching section to main linac FODO

  - **BC1PRELINAC** : accelerating section from 5 to 15 GeV, adapted from ML ILC2007b

$\Rightarrow$ Total length is now : 896.34 m

Design Characteristics

- The beam properties at injection are:

Charge	2e10 (3.2 nC)
Energy	5 GeV
Energy spread	0.15% (actually 0.13% from Damping Ring)
Bunch Length	6 mm

- Properties of the bunch compressor are:

Integrated voltage	1275.2 MV @ 1.3 GHz
Cavity gradient	≈25.6 MV/m
Accelerating Structures	48 (6 cryomodules; old-type : quadrupole is at the END)
Phase	-119.5 degrees
Energy Loss	627.9 MeV
R_{56}	-147.5 mm
Total length	∼433 m (∼423)

- Pre-Linac Acceleration: 36 CM, same structures used in the ML

⇒ Desired final bunch length : 0.3 mm

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

BC1S vs BC1+BC2

BC1S: total length = 896.34 m (∼886 m with 10 m shorter EXT-LINE)

BC1STAGE	number	unit	total
units	2	-	2
gradient	25.6 MV/m	-	-
cryo-modules	2×(CMQ-CMQ-CMQ)	-	6
quadrupoles	45	-	45
bpms	45	-	45
acc structures	2×(8+8+8)	-	48
length	433.37	m	433.37 (∼423)

BC1S_PRELINAC	number	unit	total
units	12	-	12
gradient	31.5 MV/m	-	-
cryo-modules	12×(CM-CMQ-CM)	-	36
quadrupoles	12	-	12
bpms	12	-	12
acc structures	12×(9+8+9)	-	312
length	462.97	m	462.97

BC1+BC2: total length = 1093.5 m

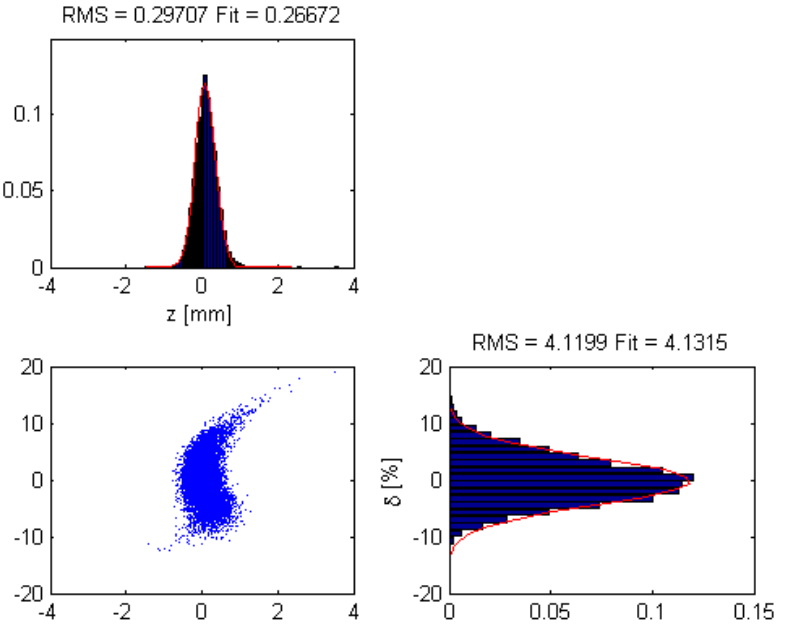
BC1	number	unit	total
units	1	-	1
gradient	18.0 MV/m	-	-
cryo-modules	(CMQ-CMQ-CMQ)	-	3
quadrupoles	29	-	29
bpms	27	-	27
acc structures	$(8+8+8)$	-	24
length	221.8	m	221.8

BC2	number	unit	total
units	15	-	15
gradient	30.2 MV/m	-	-
cryo-modules	15×(CM-CMQ-CM)	-	45
quadrupoles	29	-	29
bpms	27	-	27
acc structures	$15 \times (9+8+9)$	-	390
length	871.66	m	871.66

Design Beam Profile

- Nominal beam parameters at exit
  - blength = 266 μm
  - energy = 4.3797 GeV
  - espread = 4.13 %

$\Rightarrow$ espread @ 15 GeV $\simeq$ 1.2%



$\Rightarrow$ Notice that the nominal value of the energy spread at the entrance of the ML is 1.07%

Beam Profile Optimization

- Nominal beam parameters at exit
  - blength = 266 μm $\Rightarrow$ we would like 300 μm
  - energy = 4.3797 GeV
  - espread = 4.13 %
  - espread @ 15 GeV = 1.2 % $\Rightarrow$ we would like 1.07 %

  $\Rightarrow$ 300 μm and 1.07 % correspond to the beam parameters for the baseline design

- Cavities' *phase* and *gradient* as well as *wiggler's* R_{56} were scanned to optimize the beam profile at the entrance of the main linac
- Optimization was run to match the following characteristics:
  1. 300 μm bunch length
  2. 1.07% energy spread
  3. minimal correlation coefficient in the longitudinal phase space $E - z$

$\Rightarrow$ Simplex on rf gradient (1), rf phase (2), wiggler angle (R_{56}) (3) to minimize:

$$M = \left(1 - \frac{\Delta E/E}{1.07\%}\right)^2 + \left(1 - \frac{\sigma_z}{300\mu\mathrm{m}}\right)^2 + 10 \cdot \mathrm{corrcoeff}(\{\mathrm{E}\}, \{\mathrm{z}\})^2$$

Beam Profile Optimization Results

- Initial Parameters
  - gradient = 25.6 MV/m
  - espread = 0.15 %
  - blength = 6 mm
  - wiggler angle = 0.03935 rad

- Nominal exit parameters
  - blength = 268.88 μm
  - energy = 4.3797 GeV
  - espread = 4.13 %
  - espread @ 5 GeV = 3.6 %

$\Rightarrow$ Optimization 1

- wiggler not changed
- blength = 301.18 μm
- energy = 4.2897 GeV
- rf gradient = 25.517 MV/m
- rf phase = -124.45
- espread = 3.88789 %
- espread @ 5 GeV = 3.33559 %
- espread @ 15 GeV = 1.11 %

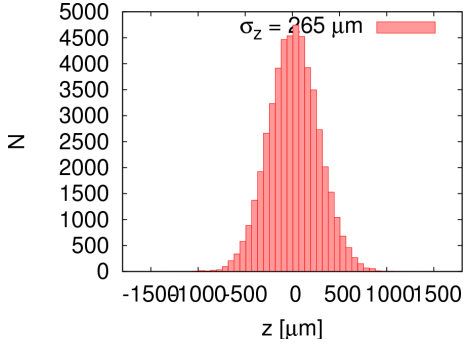
$\Rightarrow$ Optimization 2

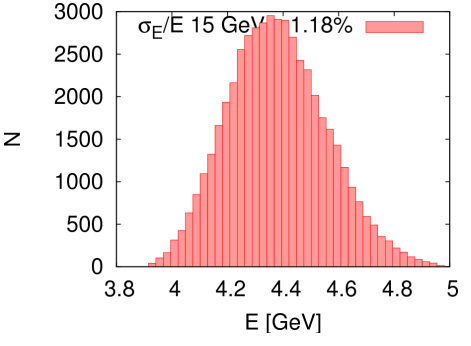
- blength = 301.20 μm
- energy = 4.4143 GeV
- rf gradient = 23.580 MV/m
- rf phase = -122.38
- wiggler angle = 0.042207 rad
- espread = 3.5452 %
- espread @ 5 GeV = 3.12989 %
- espread @ 15 GeV = 1.07 %

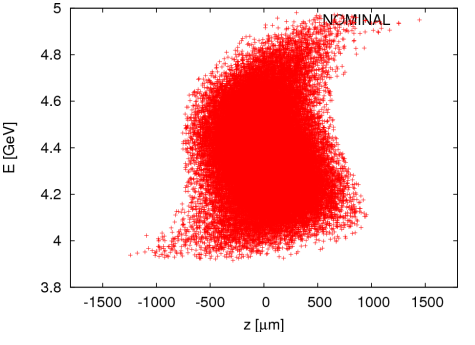
Longitudinal Phase Space Before and After Optimization

- Before optimization
  - Bunch length = 265 μm
  - energy spread = 4.13 %
  - energy spread @ 15 GeV = 1.18 %
- After optimization
  - Bunch length = 300 μm
  - energy spread = 3.54 %
  - energy spread @ 15 GeV = 1.07 %

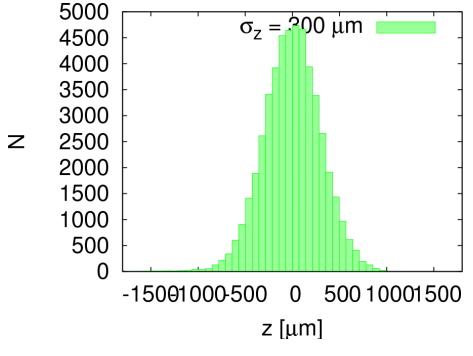
$\Rightarrow$ Before

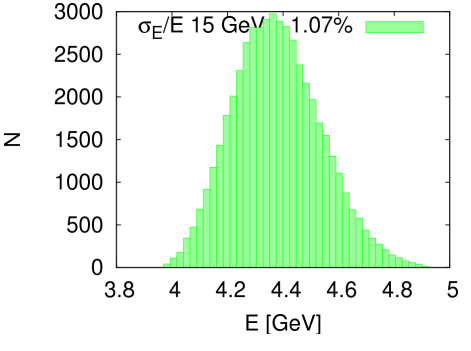


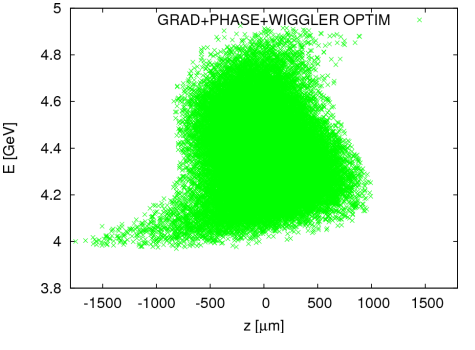




$\Rightarrow$ After

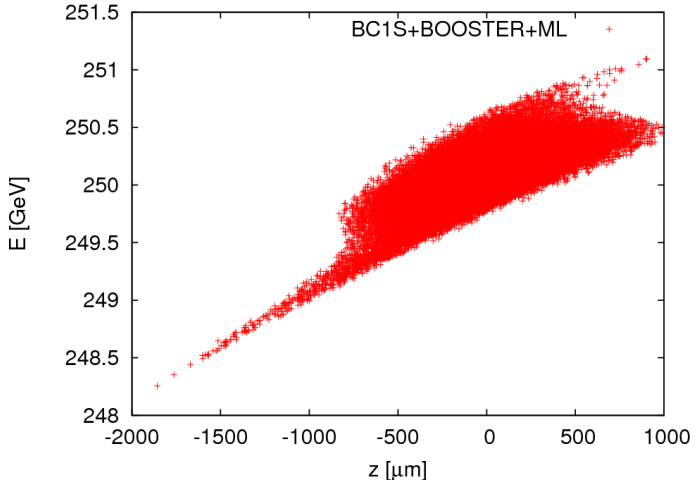


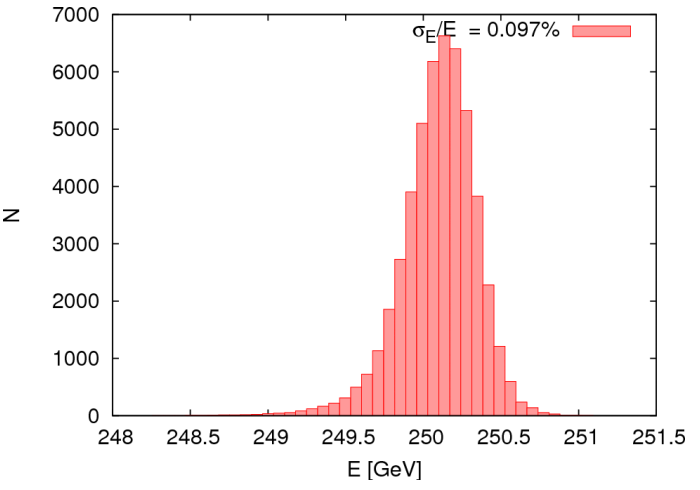


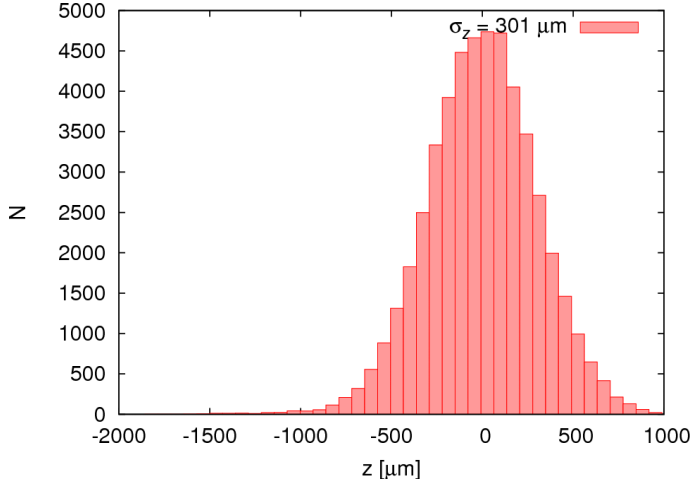


Particle Tracking with Placet

- Beam profile at the end of the Main Linac

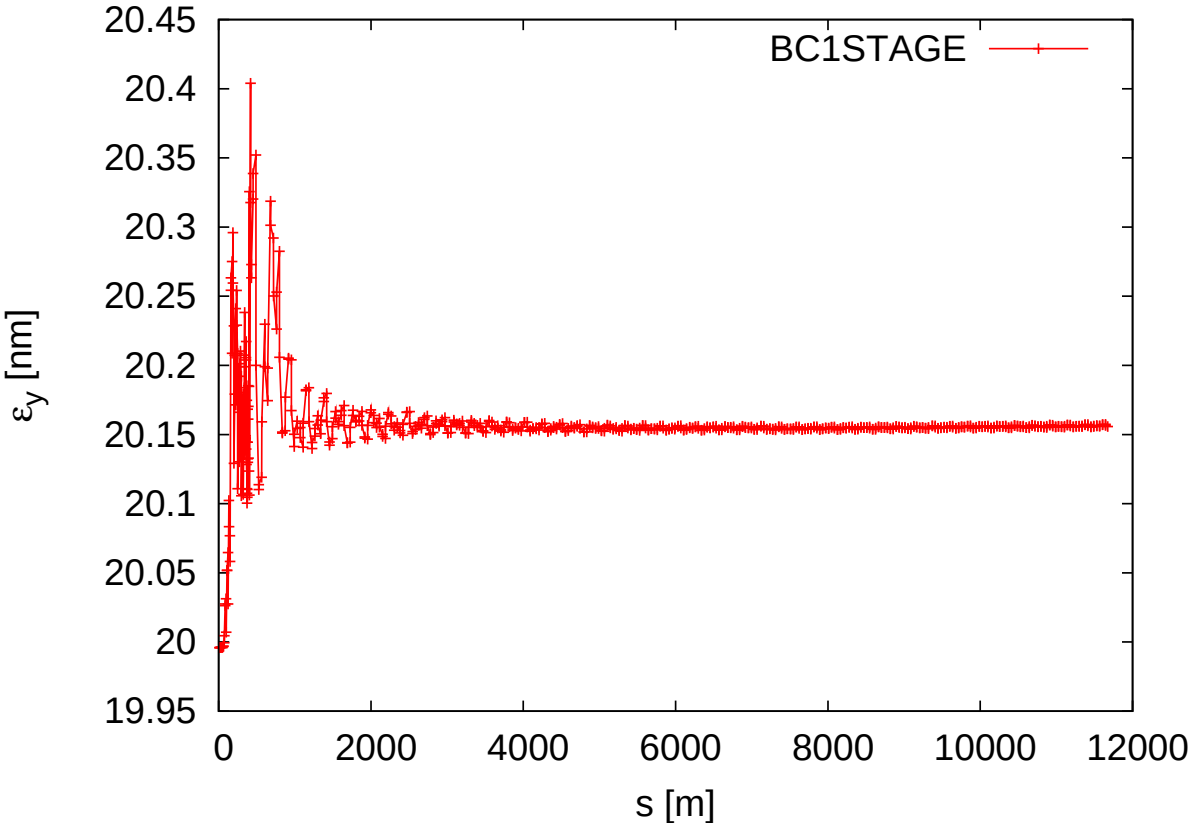






Particle Tracking Using Placet

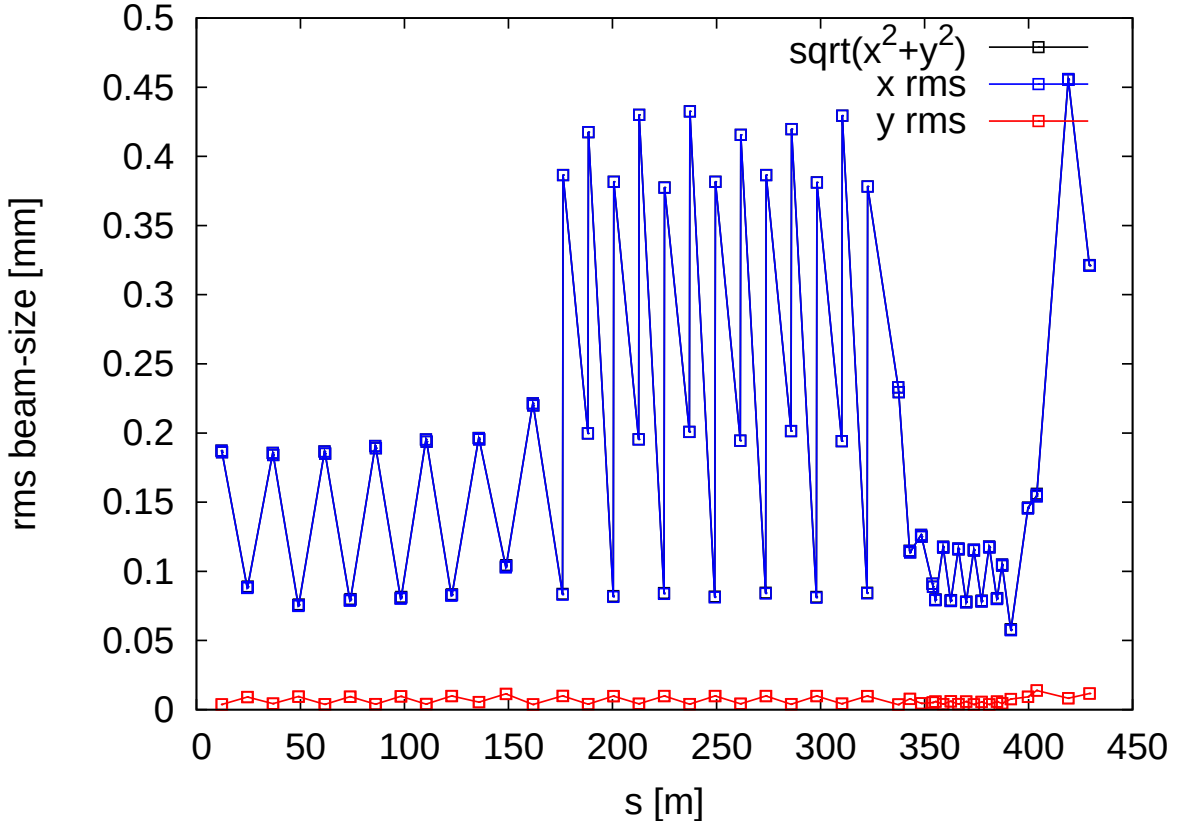
- Emittance along BC1S + PRE-LINAC + LINAC



$\Rightarrow$ Practically no emittance growth $\Rightarrow$ good matching between all sections

Particle Tracking Using Placet

- Beam sizes along BC1S



Conclusions and Work Plan

- Replace the current Wiggler with the schema presented by *Seletskiy, Tenenbaum* at PAC 2007
  - they have equivalent cell length ($\sim$ 24 meters) but,
  - at cost of more elements, the new schema allows more flexibility:
  - skew quadrupoles, coupling correction, ...

- Replace the crymodules with new design

- See my following talk for more beam dynamics in BC1S... (alignment and couplers)