Emittance Growth in ML and BC with Couplers' RF-Kick and Wakefields

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LCWS 2008 Meeting, Chicago - November 19, 2008

RF-Kick Simulation (I)

- Asymmetries of couplers generate transverse RF field in the accelerating cavities

$$\vec{V} = a\vec{V}_z \times e^{i\varphi}$$

- Period:

upstream rf-kick - drift space1 – acc. structure - drift space1 - downstream rf-kick - drift space2

- Parameters (calculated using HFSS):

	Amplitude	Phase φ [deg]
Upstream , V_x/V_a	$68.9\ 10^{-6}$	-176.9
Upstream , V_y/V_a	$48.4\ 10^{-6}$	176.0
Downstream, V_x/V_a	$75.5\ 10^{-6}$	118.9
Downstream, V_y/V_a	$43.5\ 10^{-6}$	19.5

- Kick for an off-phase particle

$$\vec{V}(s) = aGLe^{i(\varphi+\psi+ks)}$$

RF-Kick Simulation (II)

RF-Kick Voltage is:

$$\vec{V}(s) = (\vec{V}_0 / V_a) GLe^{i(\varphi+\psi+ks)}$$

$$\mathrm{Re}\vec{V}(s) = aGL\cos(\varphi + ks) = aGL(\cos\varphi \cdot \cos ks - \sin\varphi \cdot \sin ks)$$

For a short bunch

$$\mathrm{Re}\vec{V}(s) \approx -aGL(\cos\varphi + \sin\varphi \cdot \sin ks)$$

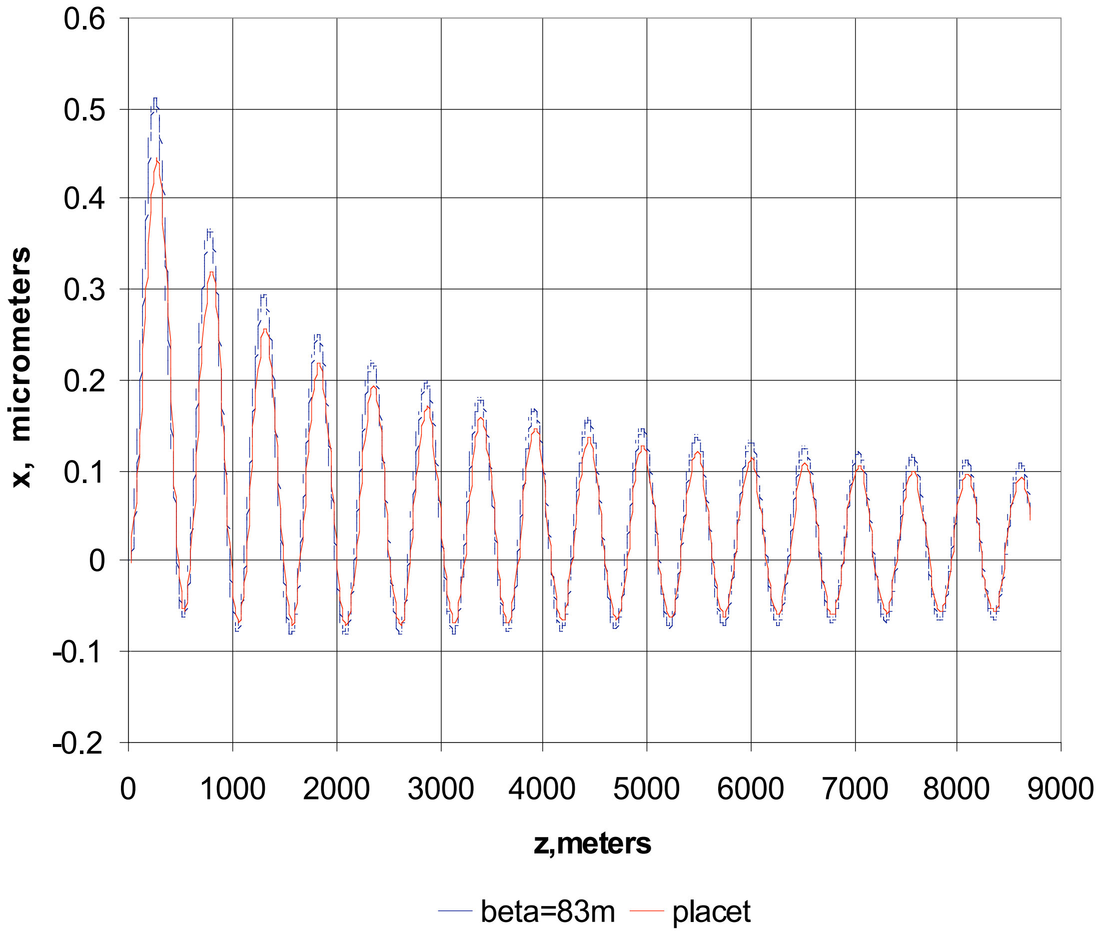
- The first term doesn’t depend on *s* and may be compensated by static alignment
- The second term is responsible for the emittance dilution
- The RF-Kick has been implemented using a Crab Cavity rotated by -90° around the beamline axis

PLACET vs. Analytical Calculation

Vyacheslav Yakovlev

- Numerical simulation vs analytical calculation:
  1. Einitial=15 GeV;
  2. Efinal =223 Gev;
  3. Lacc = 8691 m;
  4. Vy=363.4 V;

  (first 100 FODO cells)

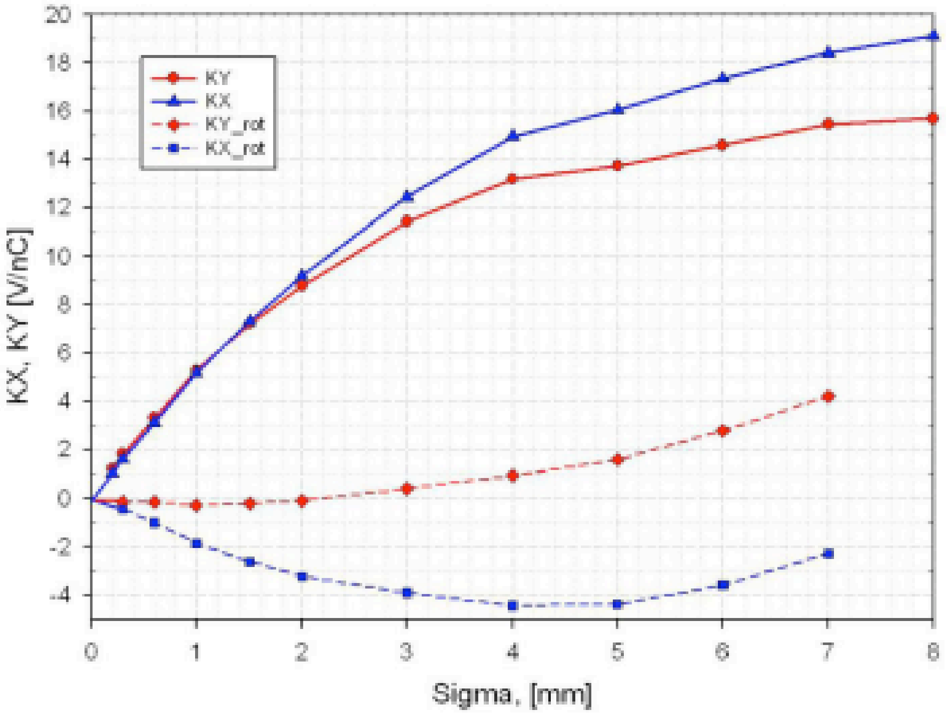


Coupler’s Wakefields (I)

- Originally people believed that couplers’ wakes were independent of the bunch length

- Afterwards we found that for:
  - Short bunches it depends linearly on the bunch length
  - For longer bunches it depends (about) on the square root of the bunch length

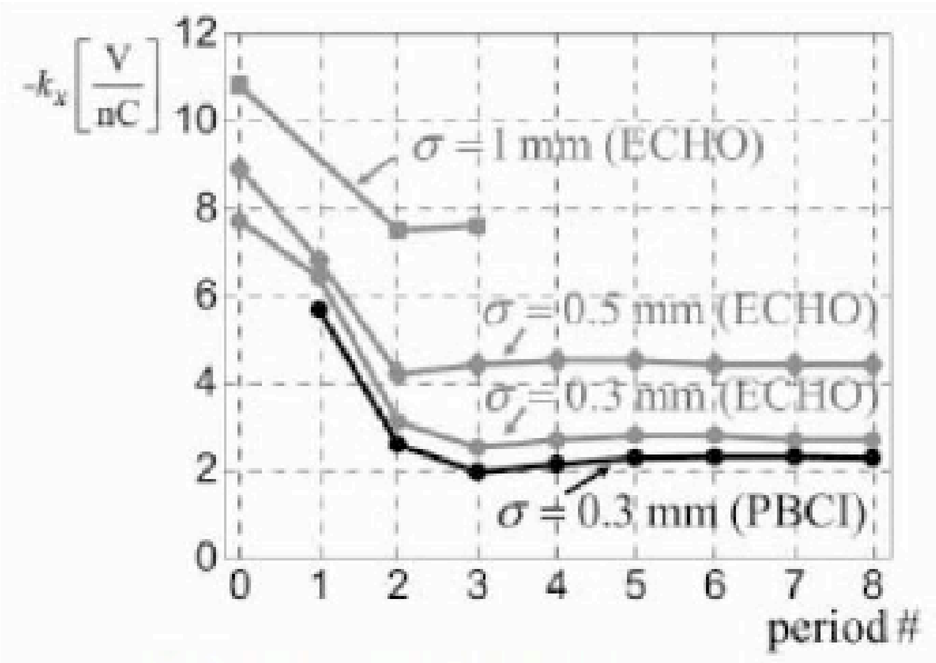
  - for 0.3 mm is about 3 times smaller than for 1 mm bunch length (that was used for earlier calculations)



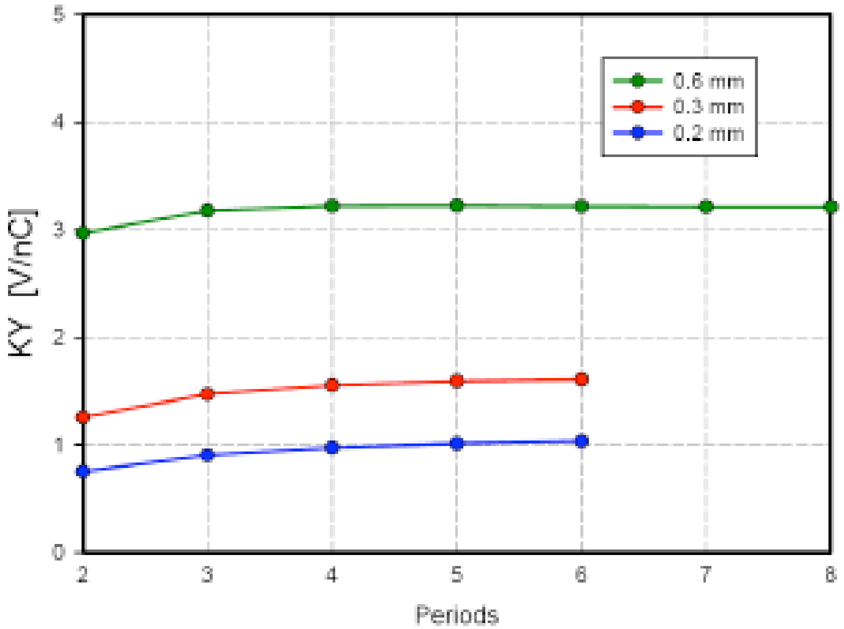
Coupler's Wakefields (II)

- Karl Bane found a simple explanation for this (EPAC2008)

- Then two calculation were performed:
    - By Igor, using ECHO 3D and PBCI : indirect integration and considering the beamline wakes
    - By us, using GdFidL : no indirect integration (i.e. no beamline wakes) <= Warner Bruns' suggestion to save computational time
        - Asymptotic behavior is the **same**



M. Dohlus et al., MOPP013



by Vyacheslav Yakovlev (Slava)

Simulation Setup

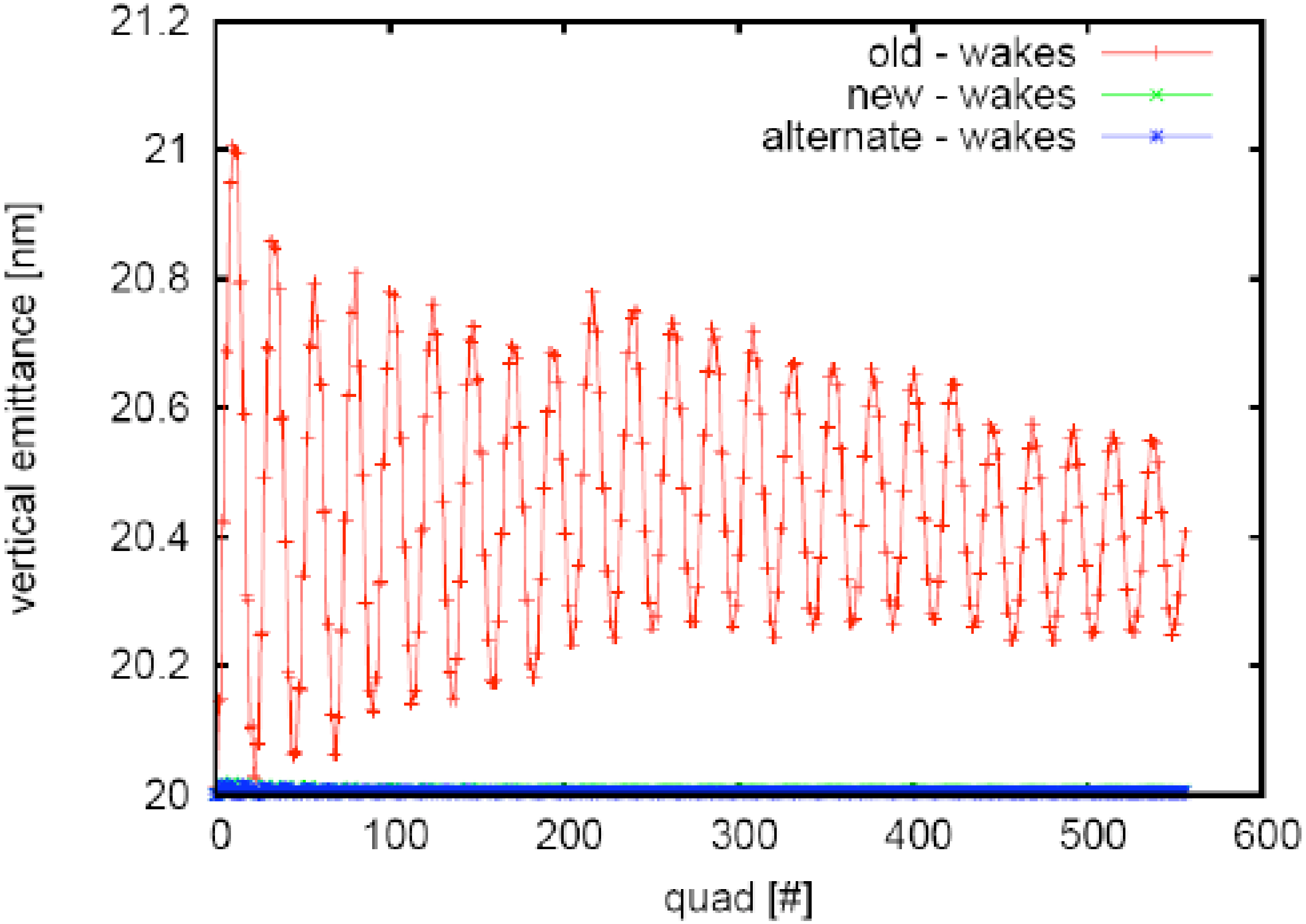
- All simulations performed using PLACET
- ILC2007b lattice (latest version?)
- ML: positron line
- BC: 2 stages, from 9 mm to 300 um

	BC1	BC2	ML
charge	$2 \cdot 10^{10}$ e	$2 \cdot 10^{10}$ e	$2 \cdot 10^{10}$ e
b.length	9 mm	1 mm	300 μm
e.spread	0.15 %	2.5 %	1.07 %
initial energy	5 GeV	4.88 GeV	15 GeV
Emittance x/y	8 μm / 20 nm	8 μm / 20 nm	8 μm / 20 nm

- Three cases have been cosidered:
  - Original configuration, AKA ***old***
  - ***new*** configuration, optimized to reduce the wakefields
  - ***alternate*** configuration, flipping *up* and *down* each three cryomodules

Main Linac: Couplers' Wakefields

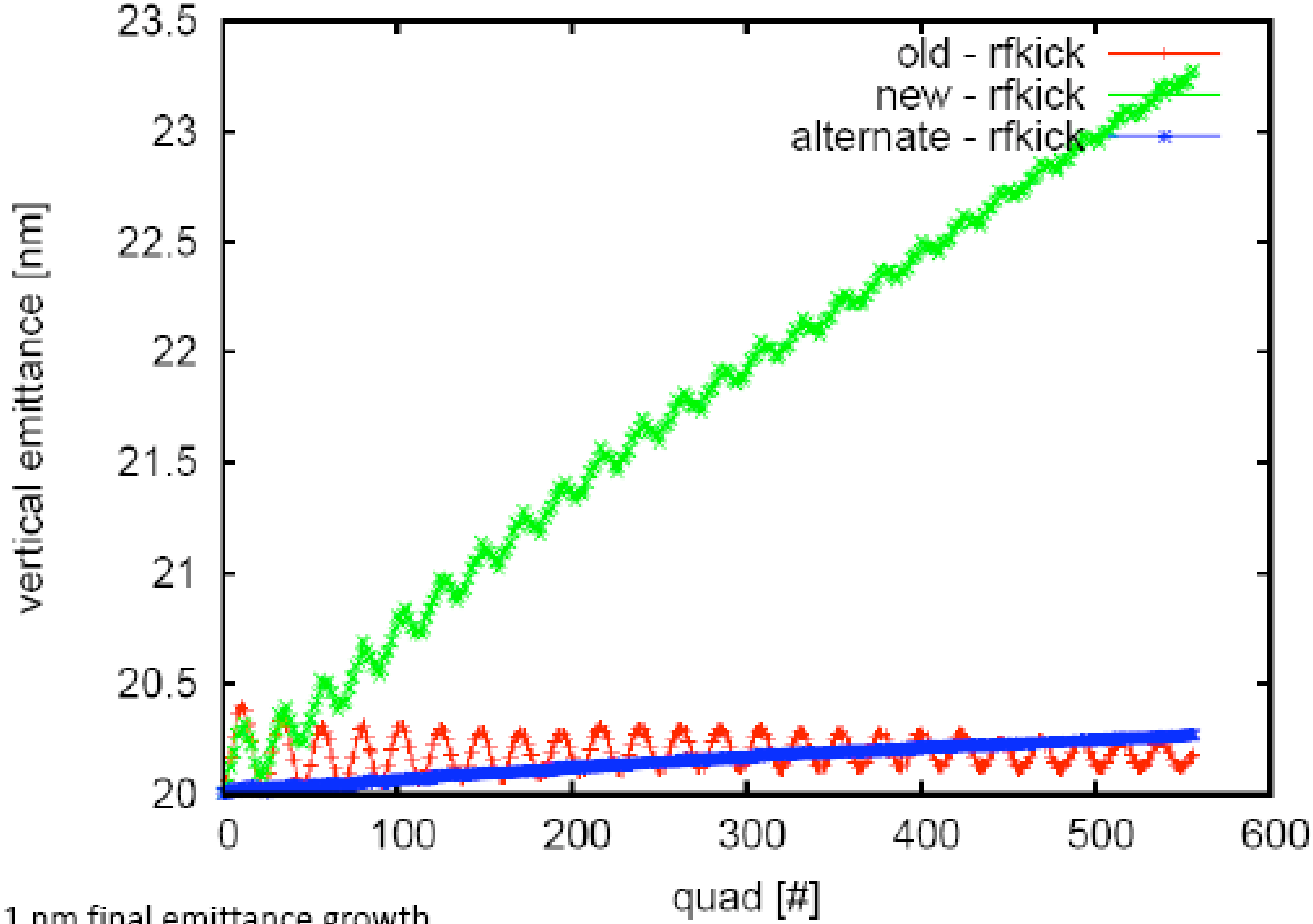
•ILC 2007b lattice
• Wakefields only
• Comparison "old", "new", "alternate": notice that "new" was expressly introduced to set at zero the wakes' kick



• "old" configuration gives 0.4 nm final emittance growth

Main Linac: RF-Kick

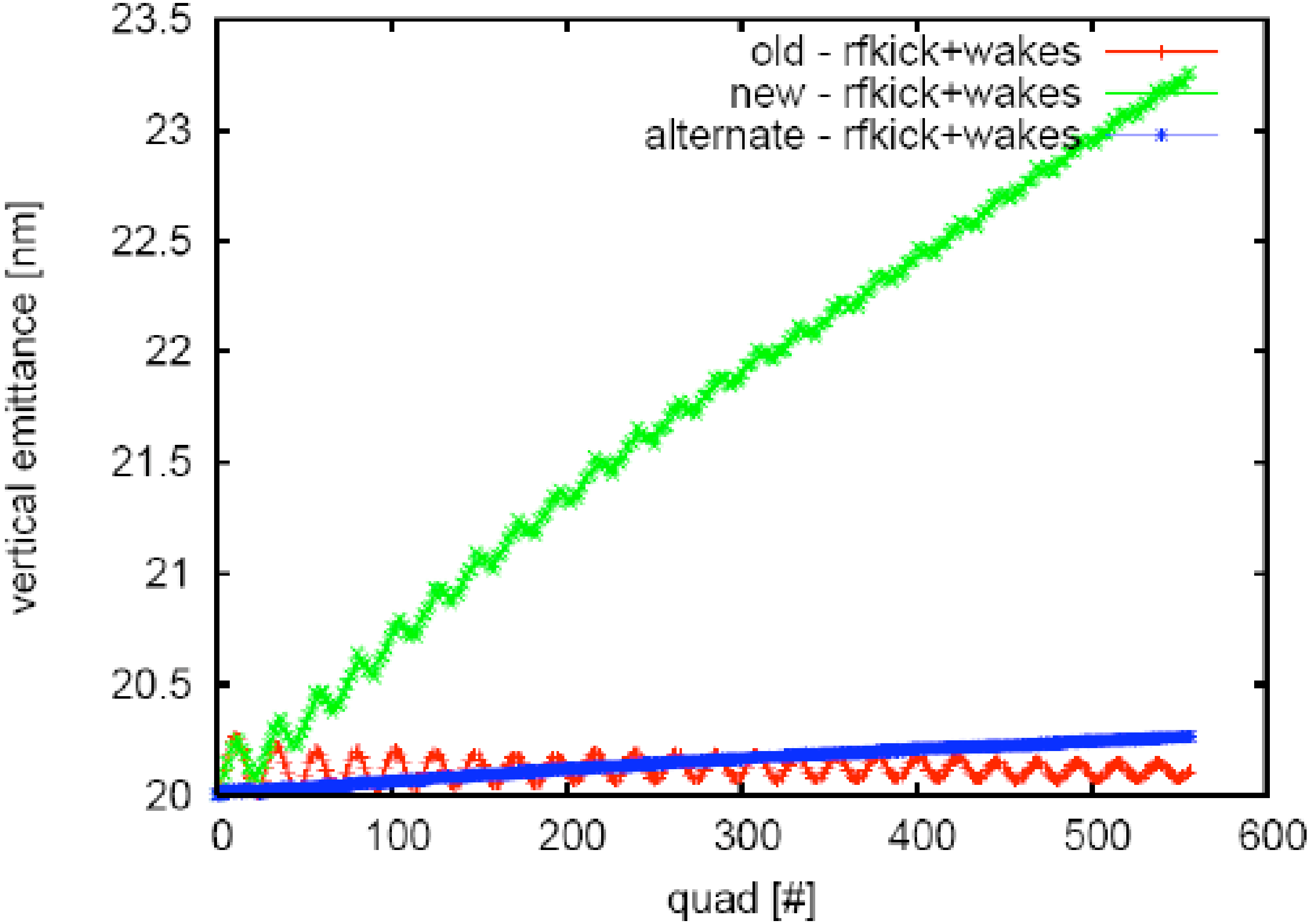
- ILC2007b, positron linac
- The opposite of the wakes: *old* is better, *new* is much worse
- Comparison: “new”, “old”, “alternate”: “alternate” is introduced to reduce the RF-Kick in the “new” confiuration



- “old” is better: 0.1 nm final emittance growth

Main Linac: RF-Kick + Wakes

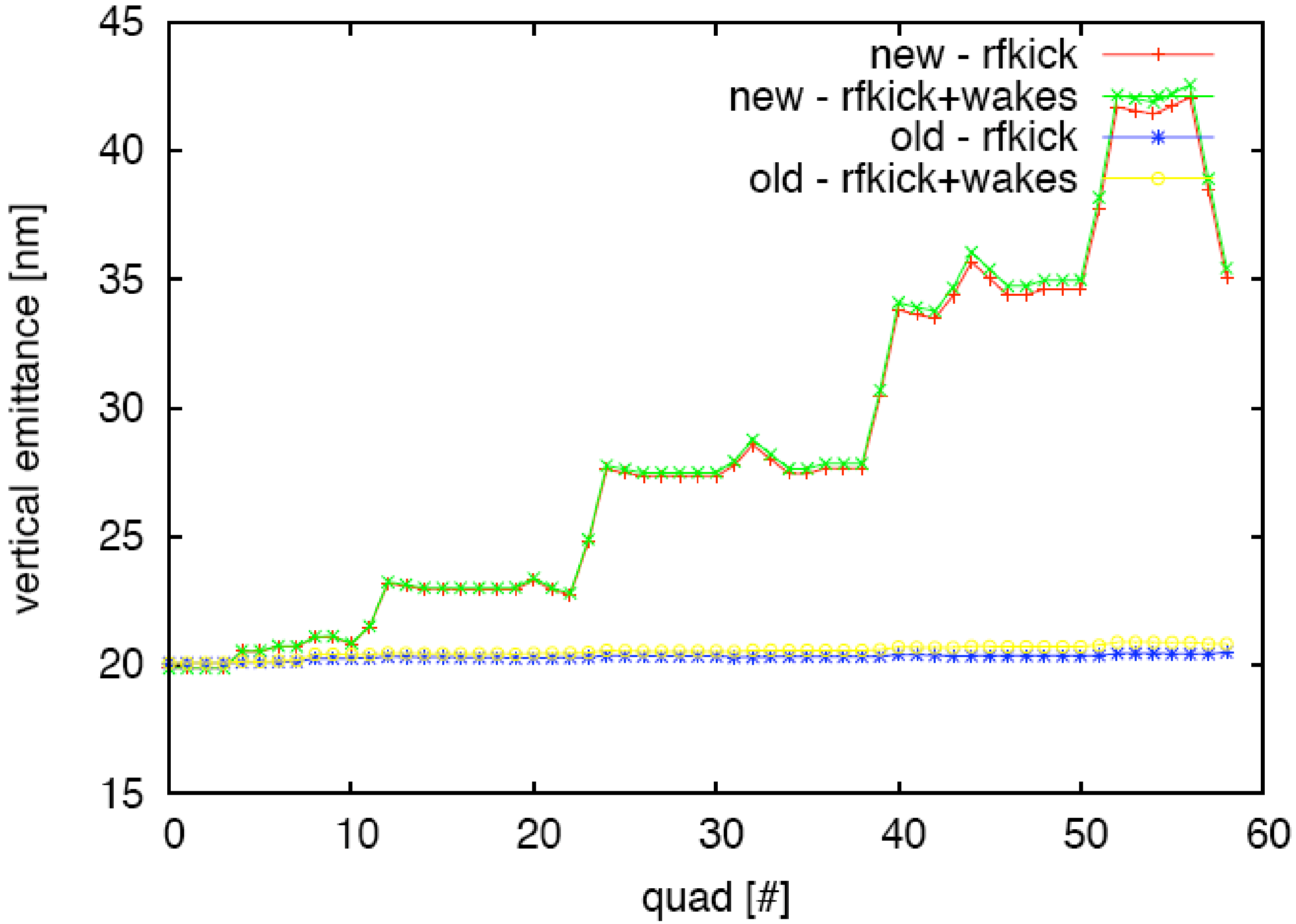
- ILC2007b, positron linac
- Comparison: “new”, “old”, “alternate”



- “alternate” reduces the RF-Kick and allows to use the “new” configuration, that compensates the wakes…
- nevertheless the “old” configuration is better: 0.1 nm final emittance growth

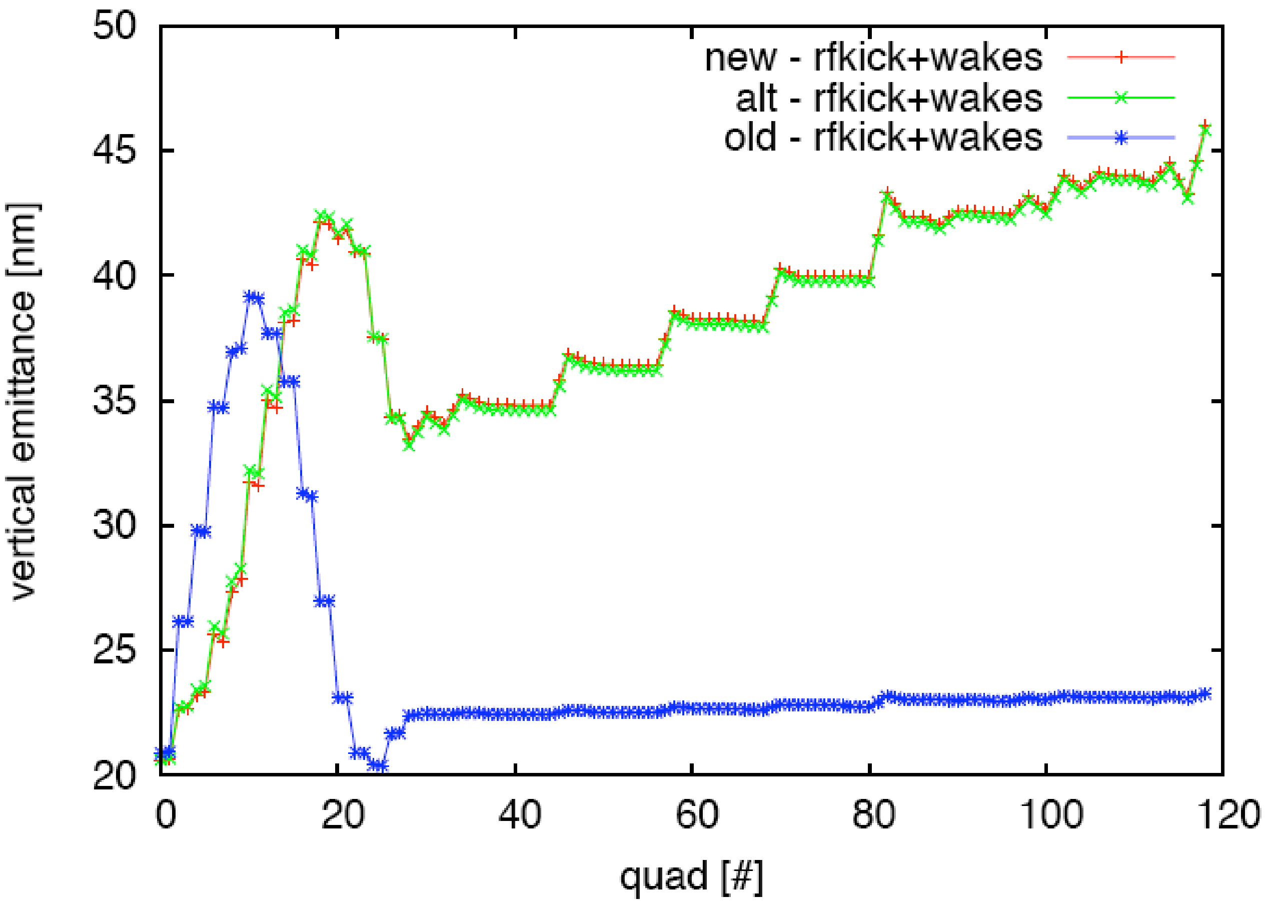
Bunch Compressor: Stage 1

- RF-Kick and Wakes are simulated
- dispersion-free emittance growth after 1-to-1 correction
- “old” configuration performs better : final vertical emittance growth 0.4 nm



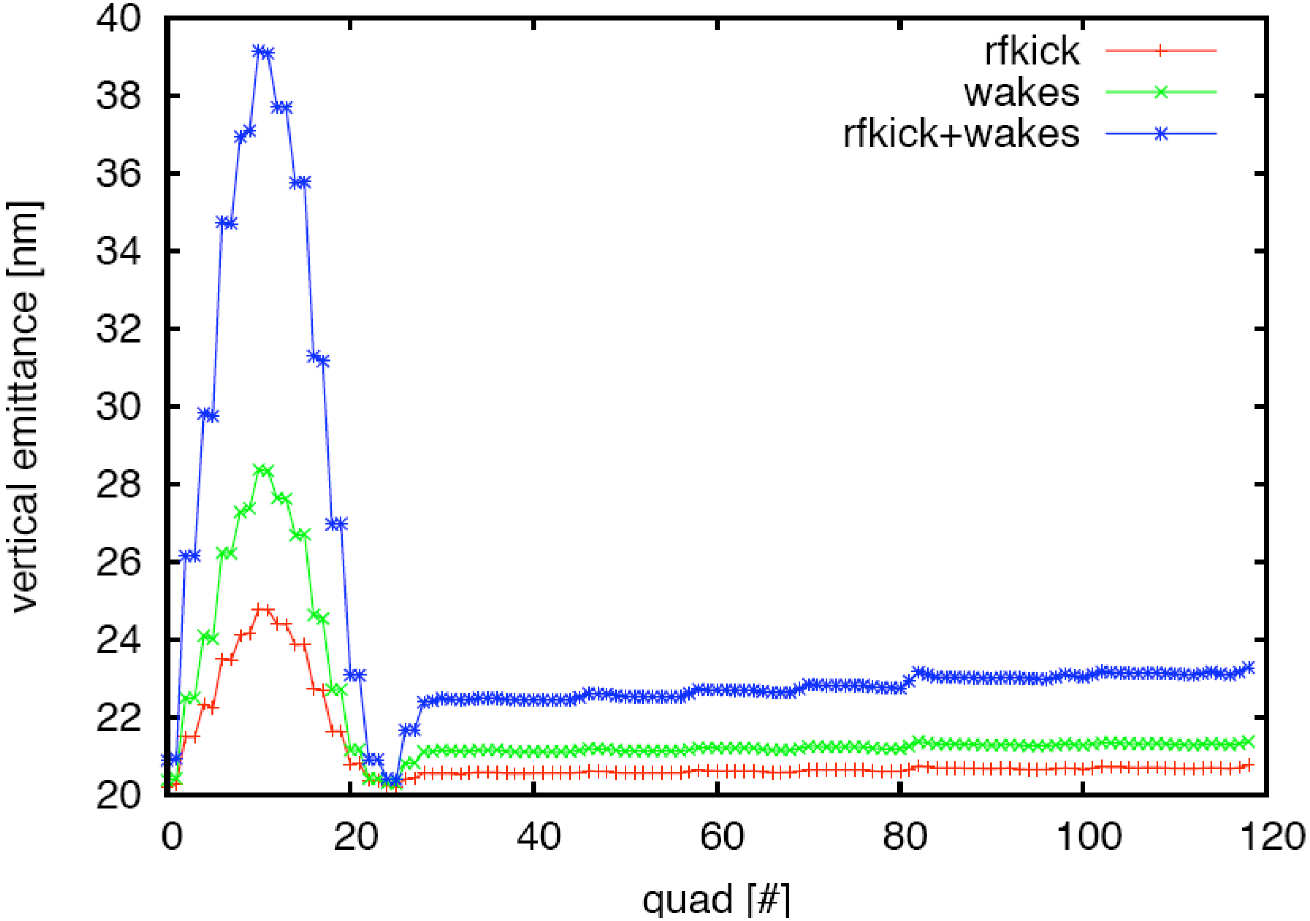
Bunch Compressor: Stage 2

- RF-Kick and Wakes are simulated
- dispersion-free emittance growth after 1-to-1 correction
- “old” configuration performs better : final vertical emittance growth 3.28 nm



Bunch Compressor: Stage 2

- RFKick and Wakes are shown independently
- dispersion-free emittance growth after 1-to-1 correction
- “old” configuration performs better : final vertical emittance growth 3.28 nm



Summary Table 1: RF-Kick

- Emittance growh in nanometers
- Only RF-Kick is considered

ML	old	new	alternate
no correction	46.558	7113.6	611.33
1-to-1	0.15068	11.413	0.95086
1-to-1 disp free	0.10440	3.3591	0.27350
BC1	**old**	**new**	
no correction	4.9668	94.943	
1-to-1	0.76856	101.51	
1-to-1 disp free	0.49620	15.082	
BC2	**old**	**new**	**alternate**
no correction	3.6311	7147.6	3147.6
1-to-1	0.76502	25.821	25.336
1-to-1 disp free	0.76510	25.824	23.824

Summary Table 2: Wakes

- Emittance growh in nanometers
- Only Wakefields are considered

ML	old	new	alternate
no correction	0.30600	0.0051000	0.0037000
1-to-1	0.24895	0.0047394	0.0036542
1-to-1 disp free	0.24780	0.0047000	0.0037000
BC1	**old**	**new**	
no correction	1.8383	0.11380	
1-to-1	1.8717	0.11188	
1-to-1 disp free	0.52550	0.085100	
BC2	**old**	**new**	**alternate**
no correction	1.9660	0.22990	0.02870
1-to-1	1.3773	0.22627	0.02882
1-to-1 disp free	1.3775	0.22640	0.02860

Summary Table 3: RFKick + Wakes

- Emittance growh in nanometers
- RFKick + Wakefields are considered

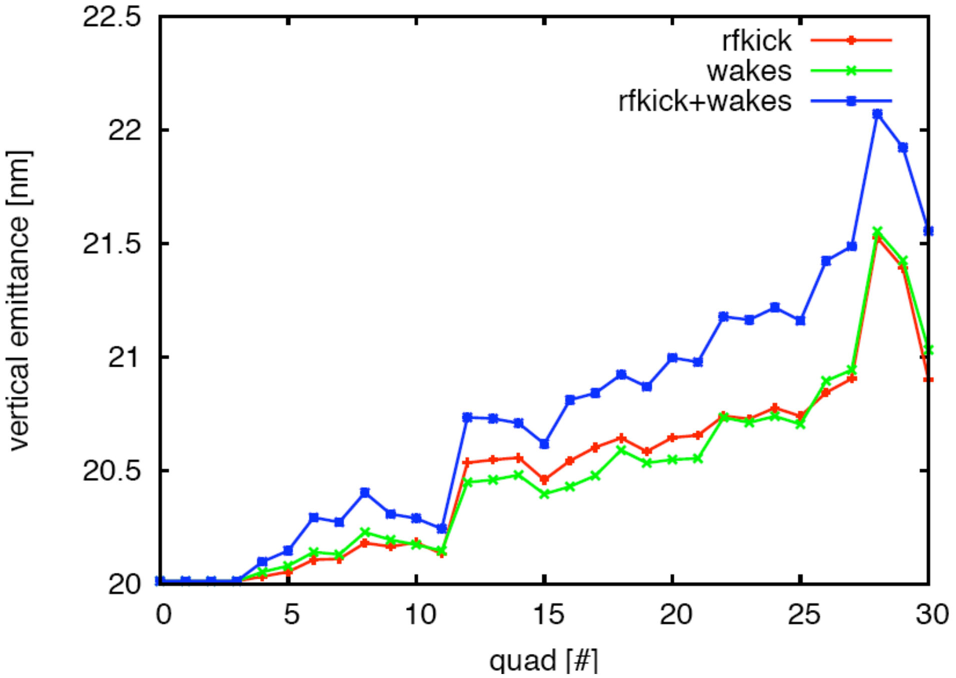
ML	old	new	alternate
no correction	50.168	7111.7	611.17
1-to-1	0.66957	11.429	0.95280
1-to-1 disp free	0.61000	3.3888	0.27690

BC1	old	new
no correction	5.3064	96.867
1-to-1	3.1481	103.64
1-to-1 disp free	0.83140	15.444

BC2	old	new	alternate
no correction	9.0382	7147.8	547.6
1-to-1	3.2798	26.009	5.336
1-to-1 disp free	3.2798	26.012	3.424

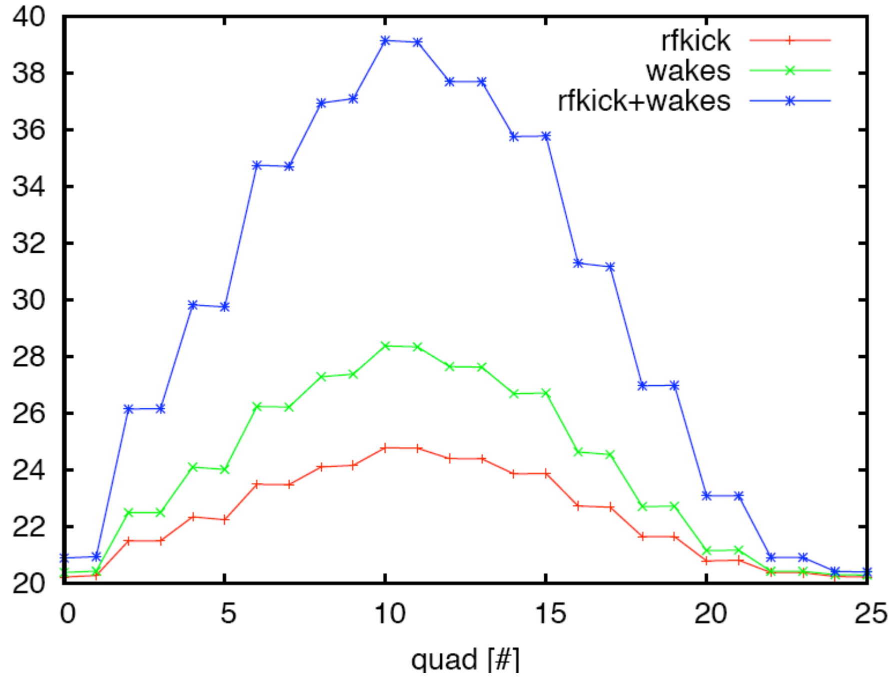
Single Stage Bunch Compressor

- BC, single stage design - by PT, Mark Woodley : from 6 mm to 300 um @ 5 GeV
- RFKick + Wakefields are considered
- Compression stage and accelerating stage are considered independently



(BC 1 stage) 1.55 nm

Accelerating Stage from 5 to 15 GeV (BC2)



(5 to 15 GeV acc. stage) 0.4 nm

Conclusions

- Final vertical emittance growth in the ML due to RF-Kick and Wakes is:
  0.61 nm in case of the “old” configuration
  0.27 nm in case of the “alternate” configuration

- BC1 and BC2 have been studied independently:
  BC1: final emittance growth is 0.83 nm in case of the “old” cofiguration
  BC2: final emittance growth is 3.28 nm in case of the “old” configuration

- In case of a Single Stage Bunch compressor the final vertical emittance growth is: 1.55 nm

- The impact of the couplers is an issue on case of a 2 stages bunch compressor - In case of single stage bunch compressor it ss reduced

References @ EPAC08

1. **RF Kick in the ILC Acceleration Structure** MOPP042.PDF

   V. P. Yakovlev, I. V. Gonin, A. Latina, A. Lunin, K. Ranjan, N. Solyak (Fermilab, Batavia, Illinois)

2. **Transverse Wake Field Simulations for the ILC Acceleration Structure** MOPP043.PDF

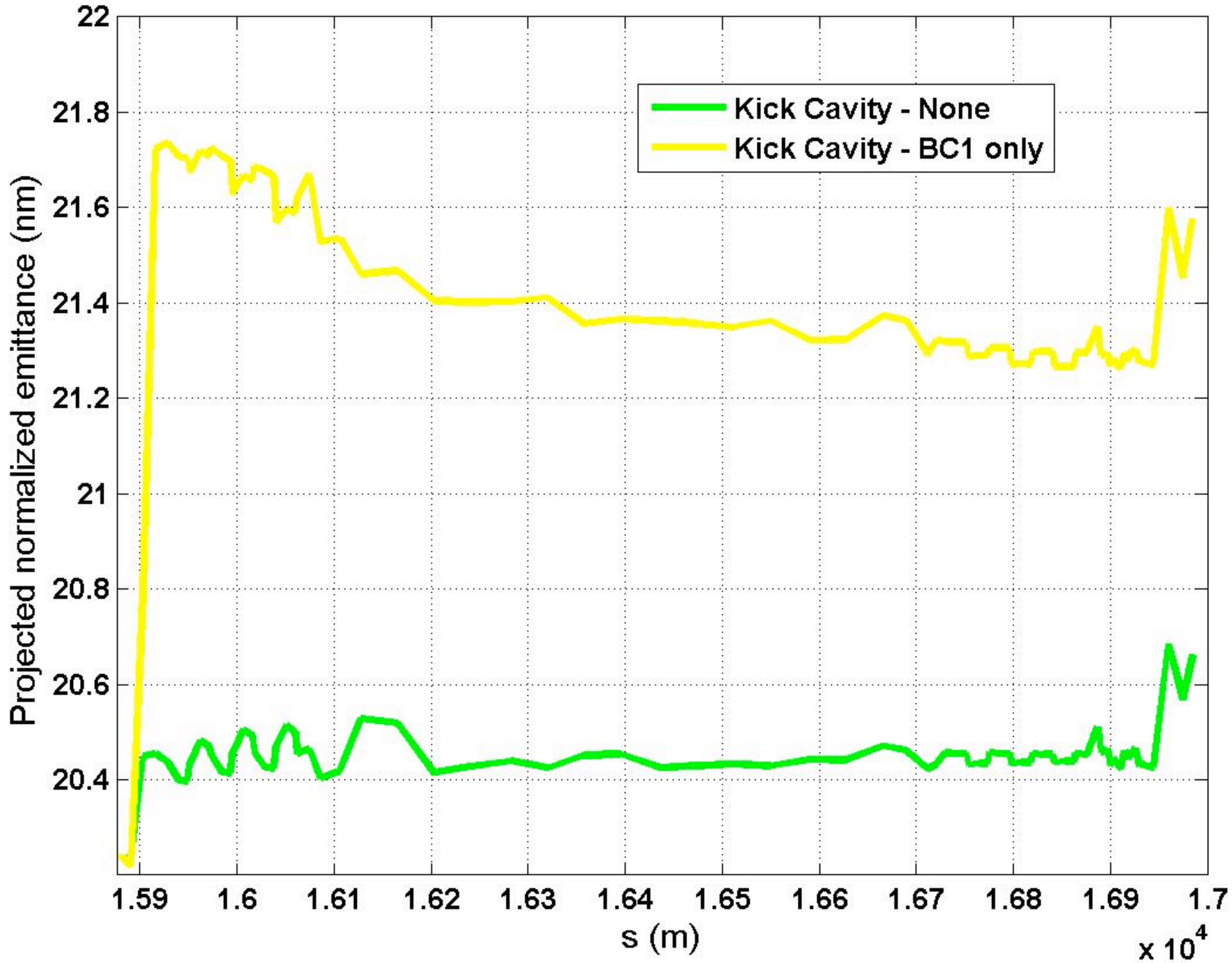
   V. P. Yakovlev, A. Lunin, N. Solyak (Fermilab, Batavia, Illinois)

3. **Simulation Studies on Coupler Wakefield and RF Kicks for the International Linear Collider with MERLIN** TUPP047.PDF

   D. Kruecker, I. Melzer-Pellmann, F. Poirier, N. J. Walker (DESY, Hamburg)

Bunch Compressor 1

LUCRETIA Simulation



Bunch Compressor 1+2

LUCRETIA Simulation