Beam Dynamics Study for

PSI –XFEL Linac

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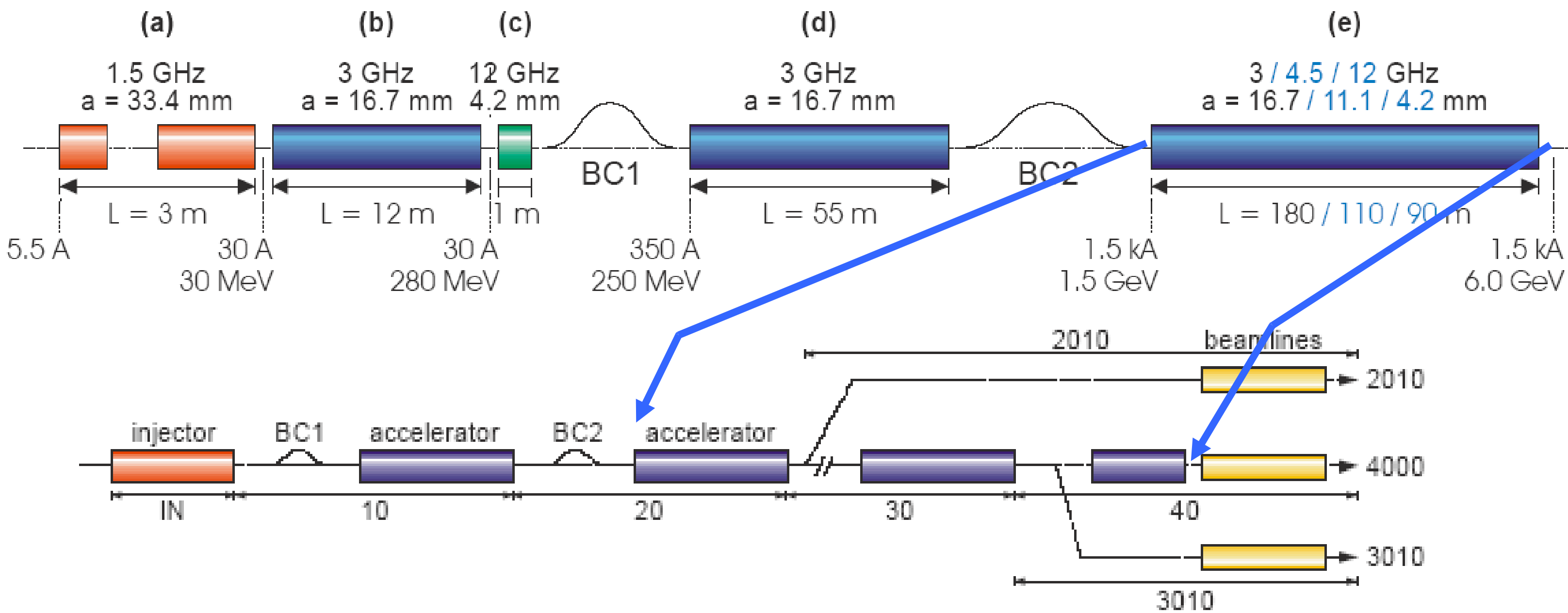
Beam Dynamics Study for PSI -XFEL Linac

- Beam parameters, machine layout
- Beam model for tracking calculations
- Wakefields and correlated energy spread
- Coherent oscillations. Emittance dilution
- Accelerating sections misalignments
- RF phase error
- Conclusion

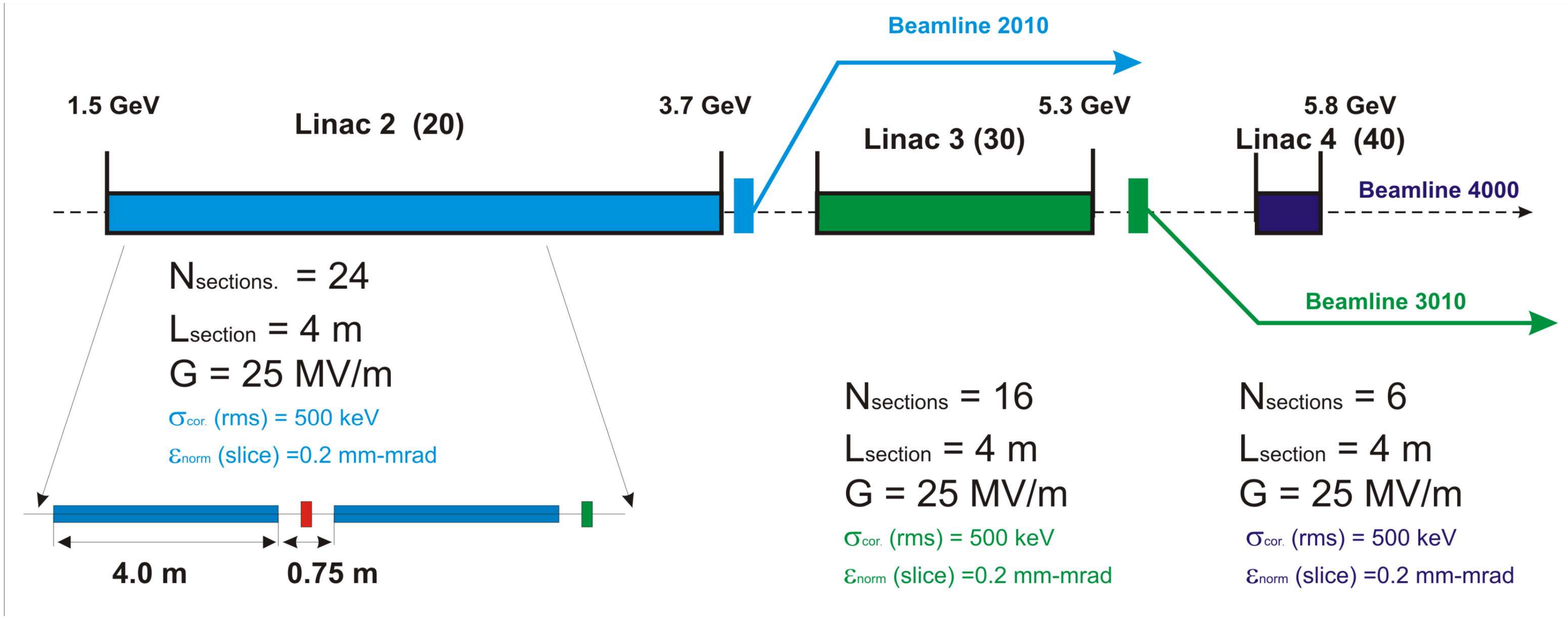
Beam parameters and machine layout



section	(a)	(b)	(c)	(d)	(e)	total	
average gradient	11.2	21.2	30.5	22.7	25.0		MV/m
phase	-25	-10.2	170	0	0		deg
bunch length	2.7	2.0	2.0	0.17	0.04		mm
linac induced energy chirp	1.1	5.7	-0.7	0.0	0.0	6.0	MV
wakefield induced energy chirp	-0.0	-0.2	-0.1	-1.3	-4.5	-6.0	MV

R. J. Bakker "PSI XFEL Specifications for CANDLE". FEL-BR06-014-2

Beam parameters and machine layout



	domain label	n*	energy (GeV) target / max		current (kA)
electron gun	INEG	-	0.001	0.001	0.0055
injector	IN	4	0.25	0.35	0.030
linac-1	10	14	1.5	1.7	0.35
linac-2	20	24	3.7	4.1	1.5
linac-3	30	16	5.3	5.7	1.5
linac-4	40	6	5.8	6.3	1.5

* number of 4-m long S-band accelerating structures

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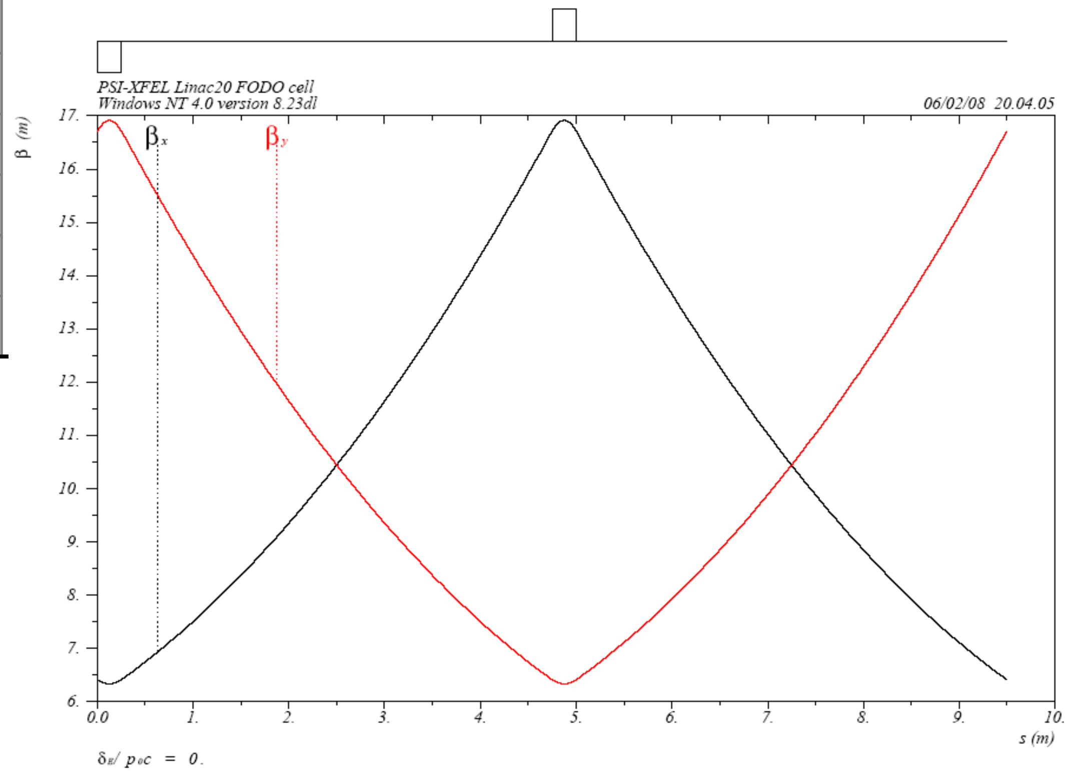
Beam parameters and machine layout

Parameter Linac 20		entrance	exit
Bunch Charge	[pC]	200	200
Energy	[GeV]	1.5	5.8 (max 6.1)
Slice energy spread rms	[keV]	500	500
Norm. transv. emit.	[mm-mrad]	0.2	0.2
Bunch Length	[mm]	40	40
Acc. Grad.	[MeV/m]	25	
RF frequency	[GHz]	3	
Acc Sections		46	
FODO Cells		23	
FODO cell length	[m]	9.5*	
Linac total length	[m]	218.5*	

* Physical length (the interspacing is a subject for further optimization)

Main Twiss parameters.

β_{max} x / y [m]	16. 719
Phase adv. per cell μ	$\pi/2$
Cell Length [m]	9.5
K1 (QD / QF) [m^{-2}]	0.787



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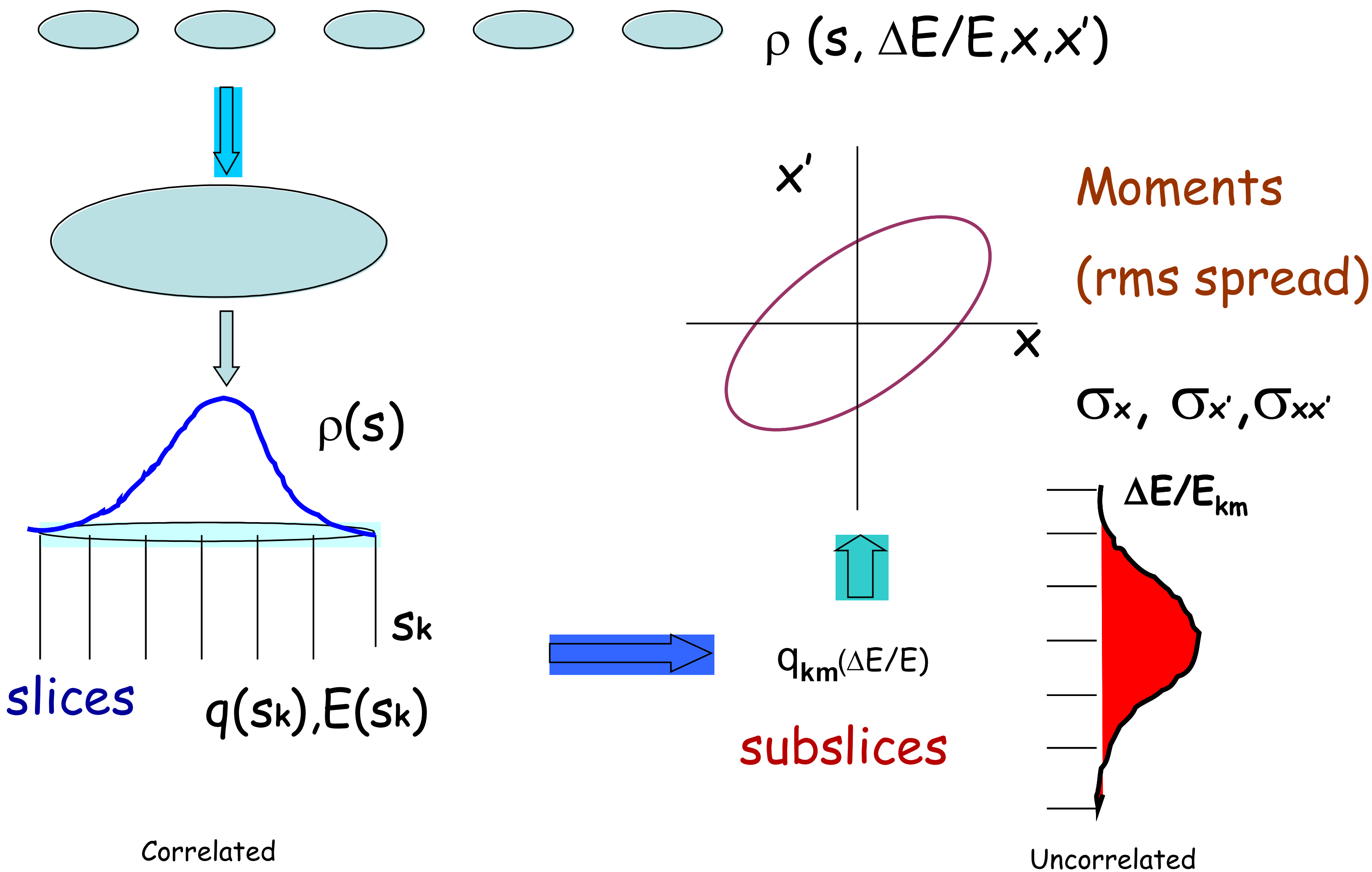
Beam model for tracking calculations



Longitudinal and transverse wake functions for S-Band structure

K. L. Bane, M. Timm, T. Weiland, SLAC-PUB-9798

Transverse and longitudinal point wake functions for S-band structure

$$W_x = 4.10 \cdot \left[1 - \left(1 + 1.15 [s / mm]^{\frac{1}{2}} \right) \cdot \exp\left(-1.15 [s / mm]^{\frac{1}{2}} \right) \right], \left[\frac{V}{pC \cdot mm \cdot m} \right]$$

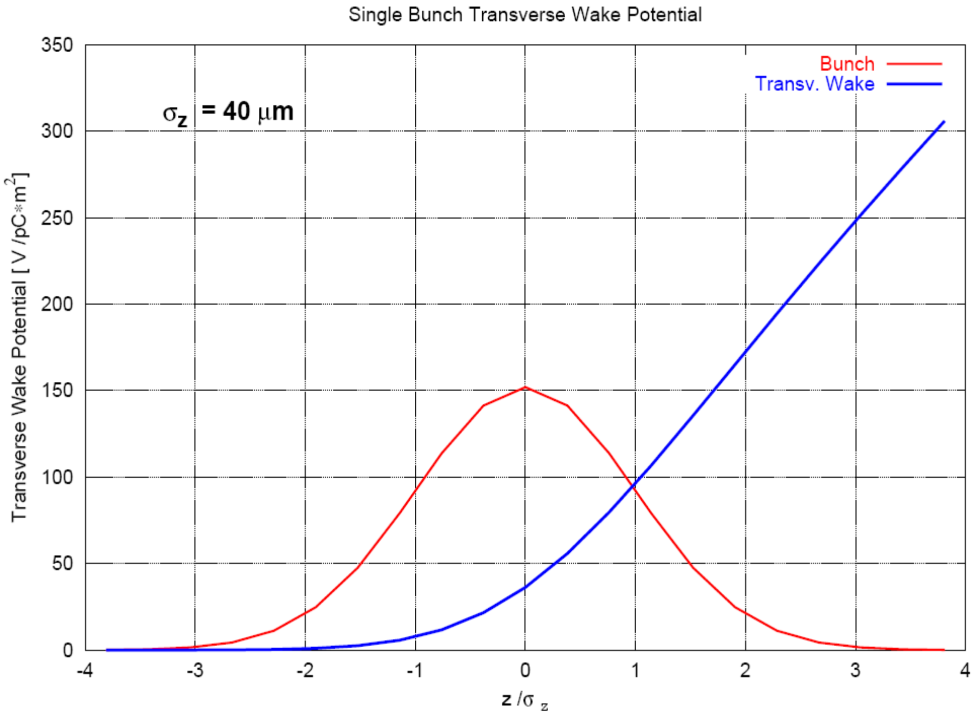
$$W_z = 200 \cdot \exp\left[-0.77 (s / mm)^{\frac{1}{2}} \right], \left[\frac{V}{pC \cdot m} \right]$$

Transverse and longitudinal wake potentials of bunch

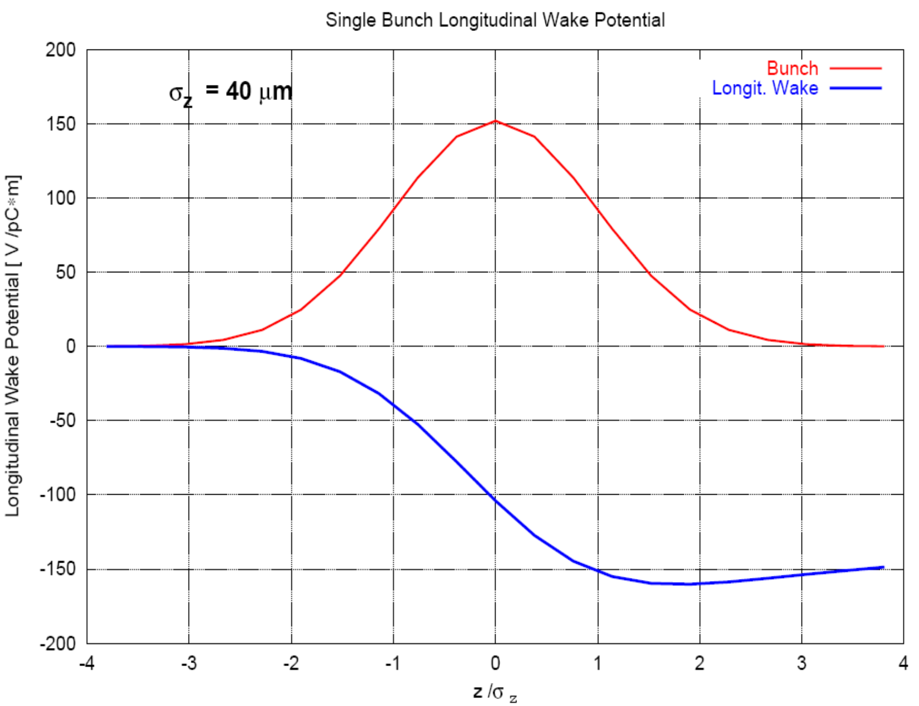
$$W_\perp(s) = \int_{-\infty}^{s} P(s') w_x (s - s') ds$$

$$W_{||}(s) = \int_{-\infty}^{s} P(s') w_z (s - s') ds'$$

Longitudinal and transverse wake functions for S-Band structure



Bunch charge [pC]	200
Bunch length [μm]	40
λ_{RF} [m]	0.1



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Induced correlated energy spread in linac

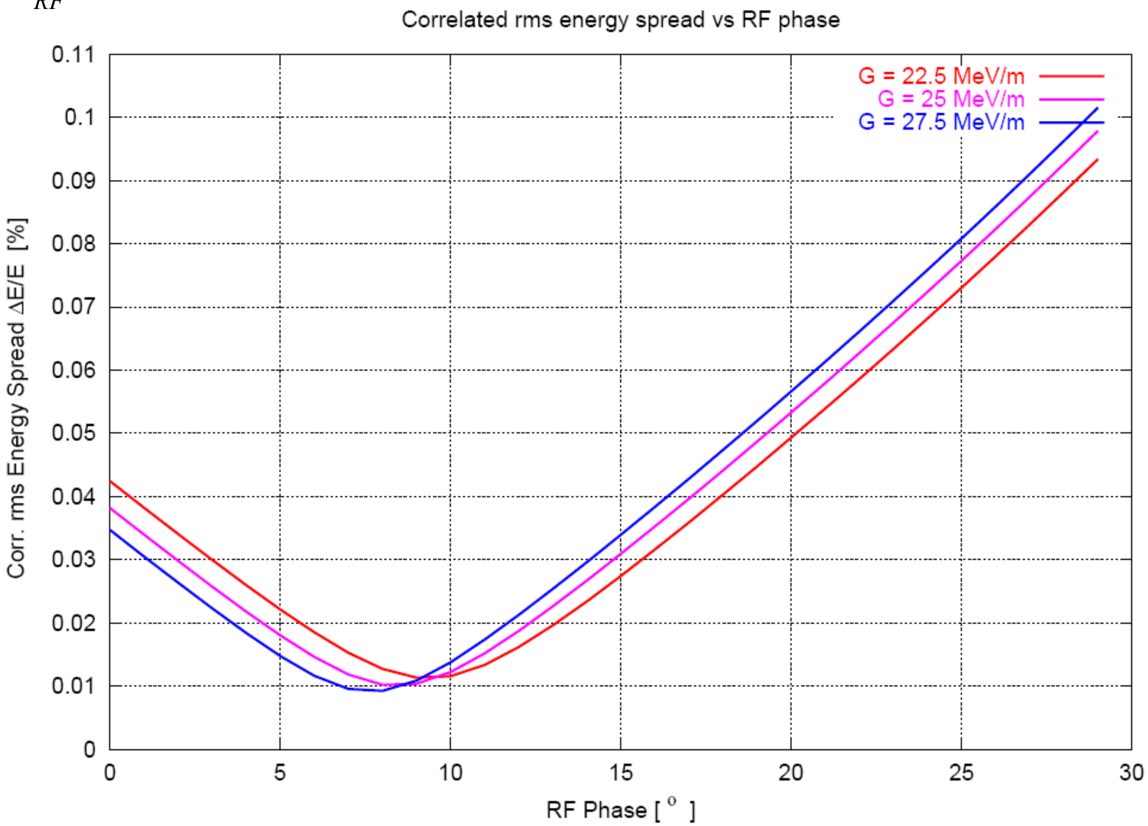
Correlated Energy Spread :

- Interaction with external accelerating RF voltage
- Interaction with accelerating structure - wakefields

$$\Delta E(z,s) = eQzW_z(s) + e\hat{G}z\cos(\phi_0 + \frac{2\pi}{\lambda_{RF}}s) - eGz$$

RMS relative energy spread at the linac end (Upper limit)

For G= 25MeV/m 8° off-crest is G = 24.75 MeV/m. For 46 cells total energy gain is ~ 4554 MeV with rms corr. energy spread 0.01% (600 keV for 6 GeV)



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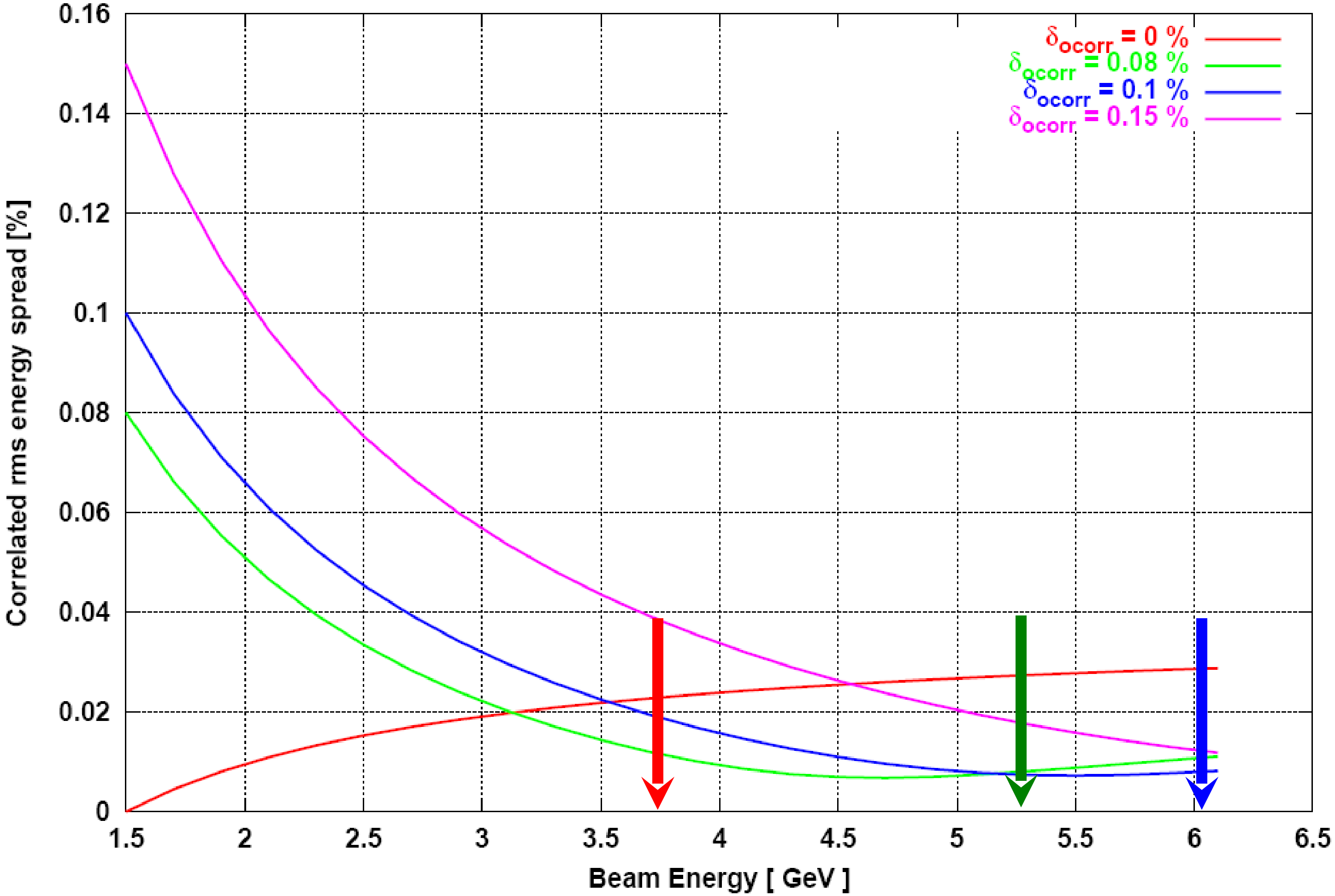
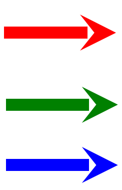
Correlated energy variation along the linac

$$\delta_{cor}(s,z) = \frac{\Delta E(s,z)}{E(z)} = \frac{U(s)}{G}\left[1 - \frac{\gamma_0}{\gamma(z)}\right]$$



RF Phase 0°



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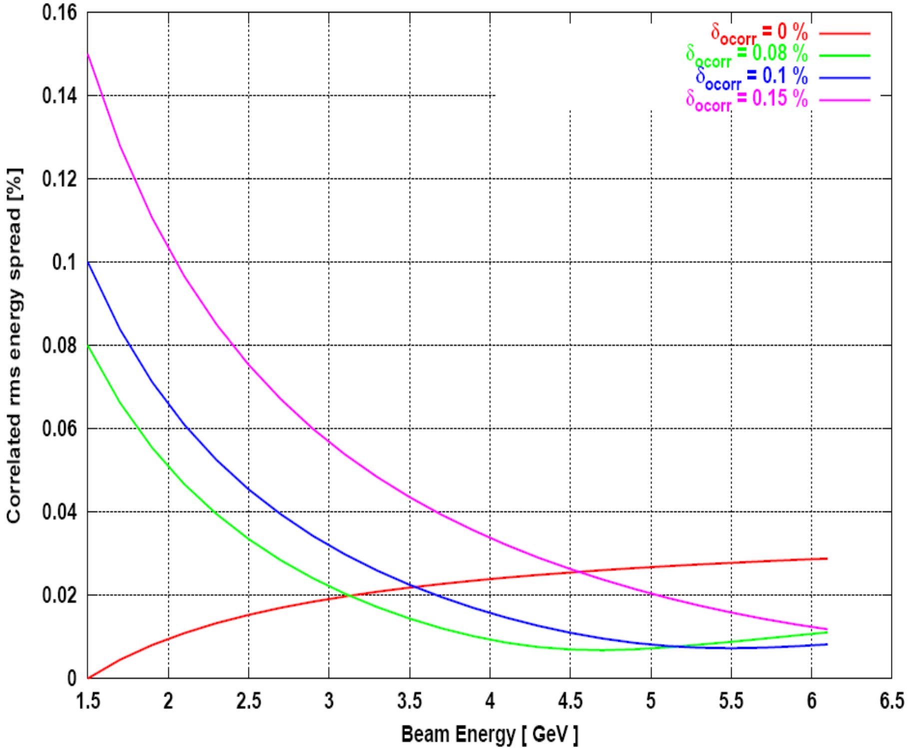
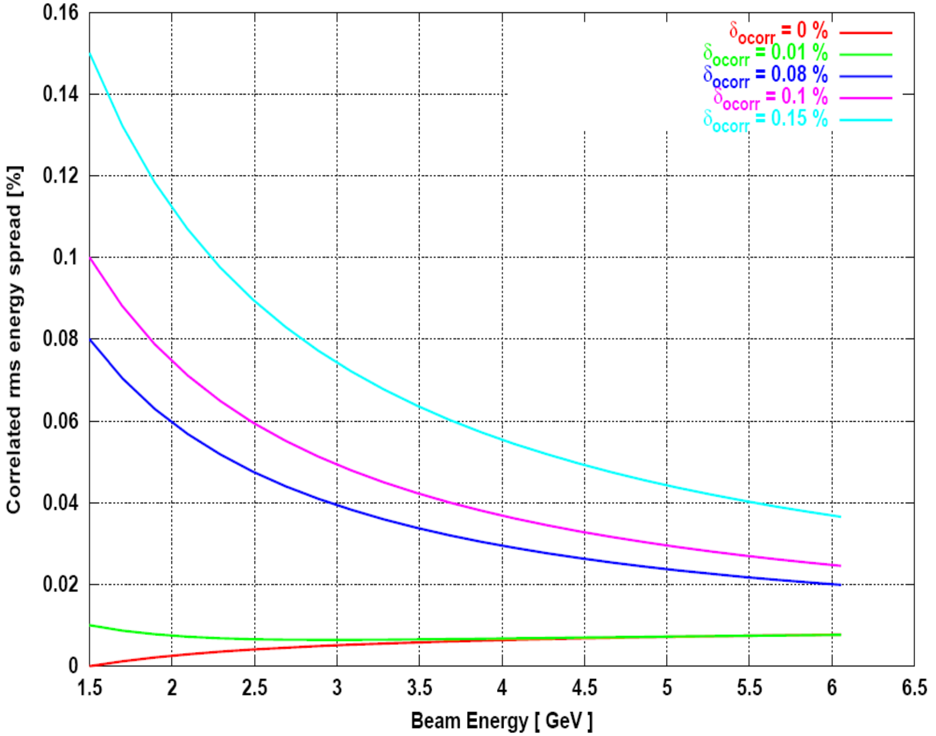
Effect of Initial Correlated Energy Spread (BC)

RF phase 0°

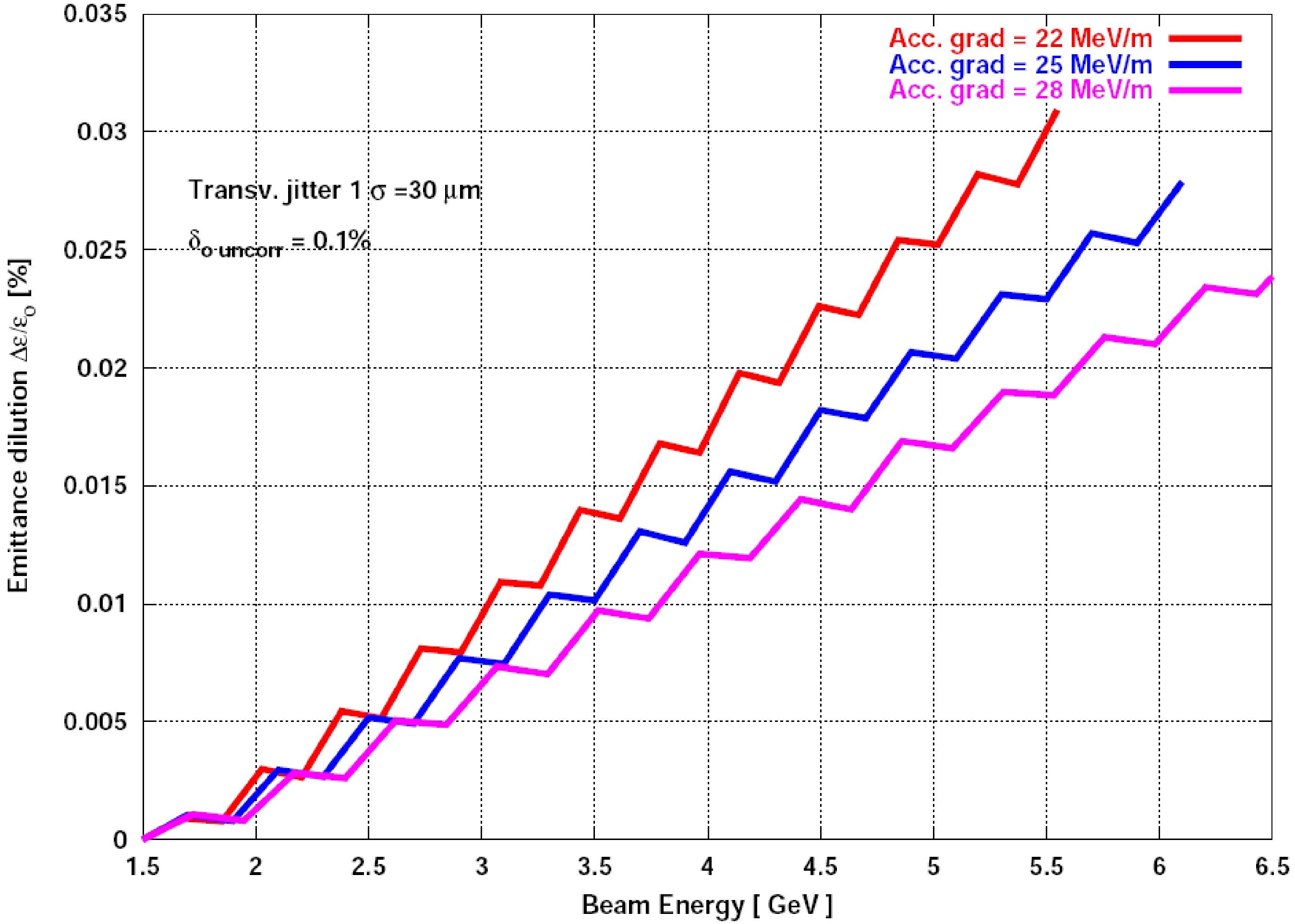


RF phase 8°



Coherent betatron oscillations. Chromatic Effect.

- Initial transverse jitter – 1σ ~ 30 μm
- Initial uncorrelated energy spread (BC20) – 0.1%



Obtained results could be scaled for other energy spread:

$$\frac{\Delta\varepsilon_1}{\Delta\varepsilon_0} \sim \frac{\delta_1^2}{\delta_0^2}$$

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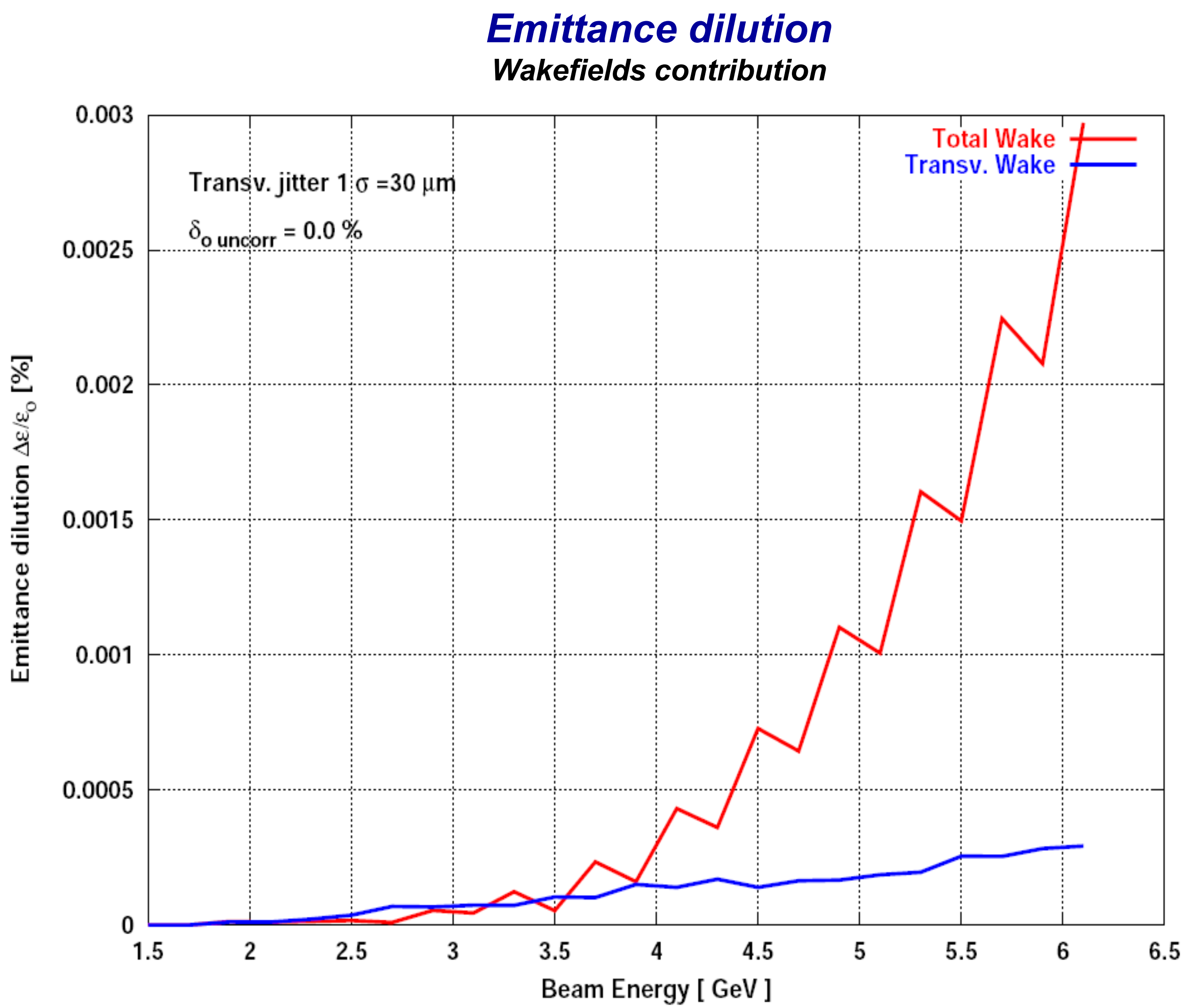
Coherent betatron oscillations. Wakefield effect.



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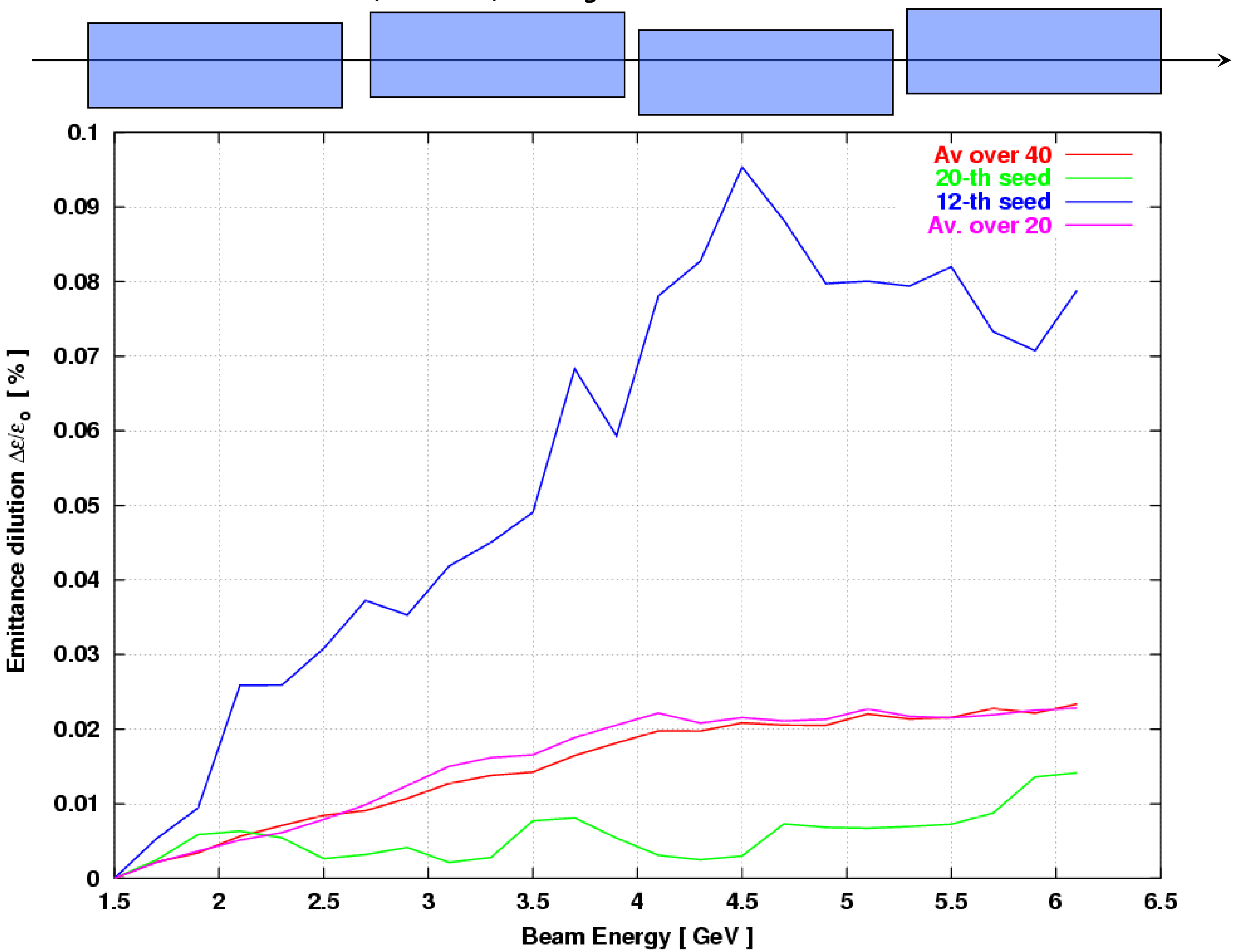
Misalignments. Accelerating section

Random (statistic) misalignment rms offset 500 um



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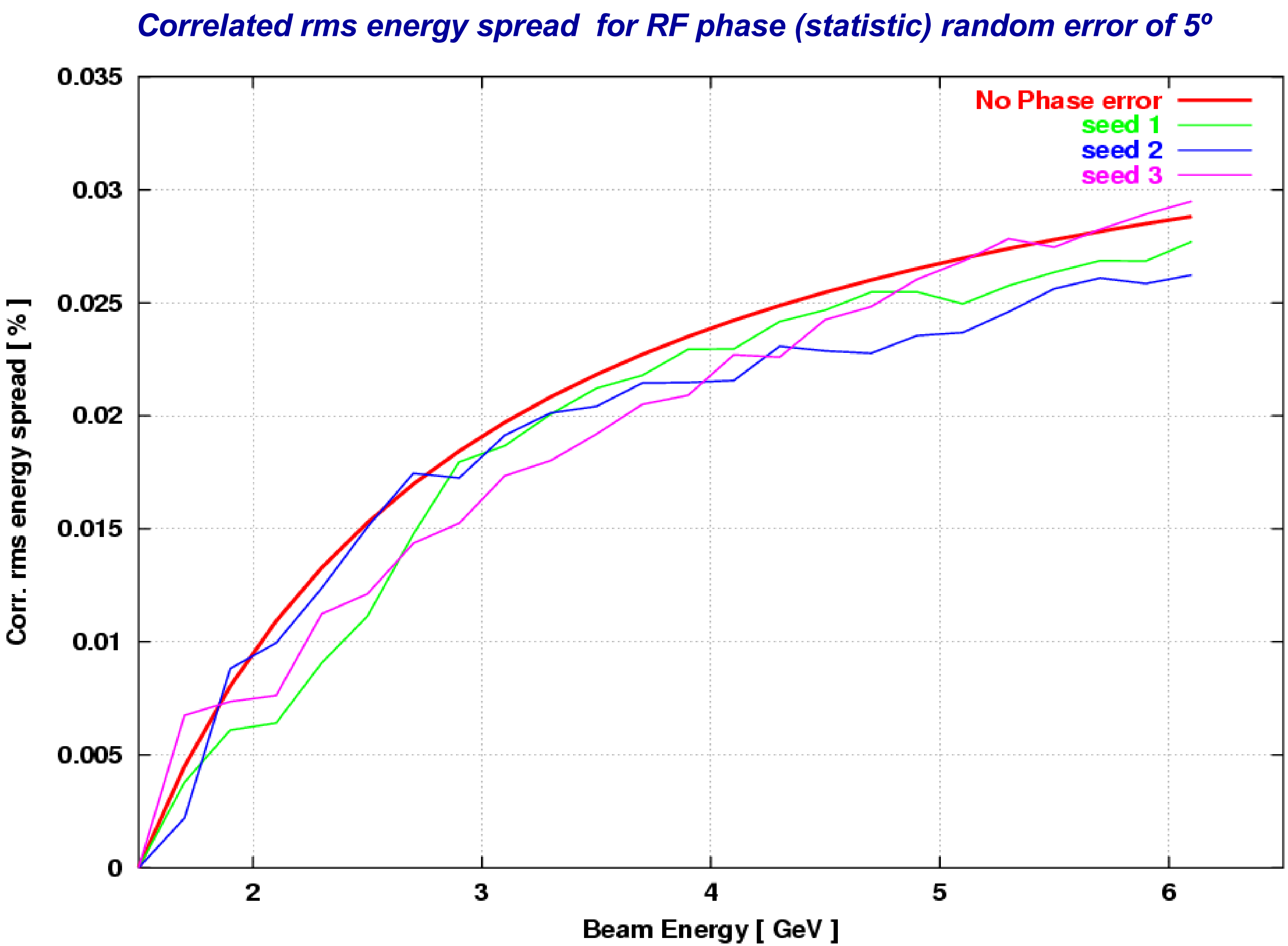
Misalignments. RF phase



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Conclusion.

- Coherent oscillations.
  - Chromatic emittance dilution <0.04%
  - Wakefield emittance dilution <0.003%

- Correlated energy Spread.
  - 0.01% correlated energy spread is achievable
  - Need further optimizations for initial corr. energy spread, RF phase and BC design.

- Accel. Sections misalignments. For 500 μm rms offset
  rms emittance dilution <0.025%

- For rms RF phase errors 5 degree
  rms corr. energy spread deviation is <0.005%

Conclusion 2

- Energy spread in BC10/BC20.
- Parameters for bunch compressors
- Reduce number of FODO cells by factor 2-3

Under Study

- Quadrupole misalignments and trajectory correction
- Accel. section tilts.
- Emittance dilution in low-energy part of S-band accelerator (0.25-1.5 GeV)
- Optimization of machine performance and beam optics