Collaboration workshop

Errors Effects in Long Linac for XFEL

V. Tsakanov

CANDLE

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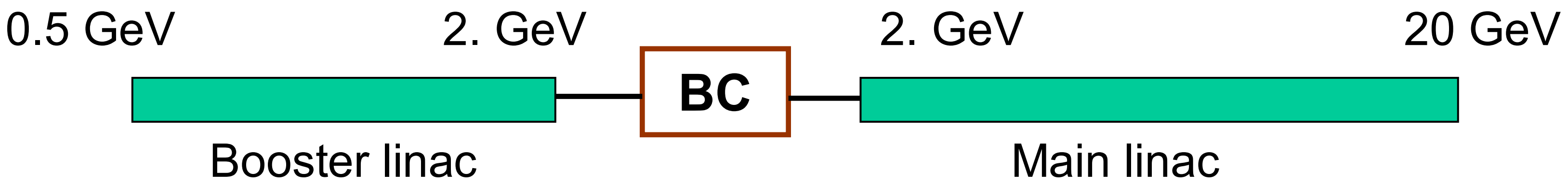
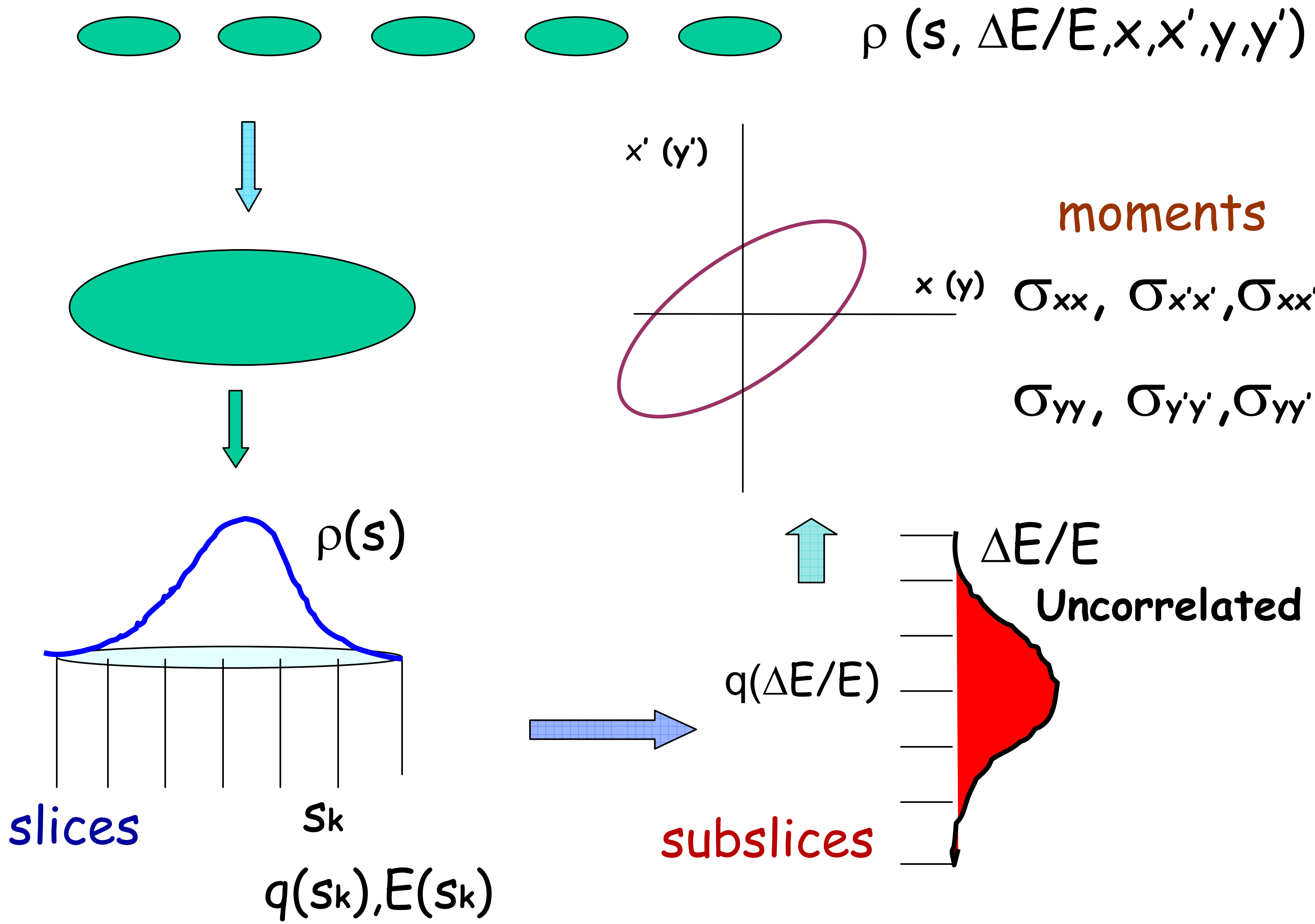
02 July 2010

Parameter list

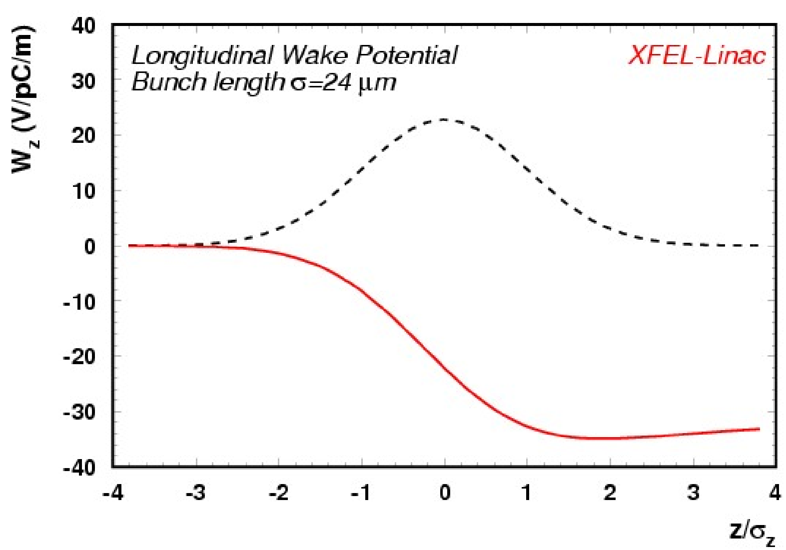


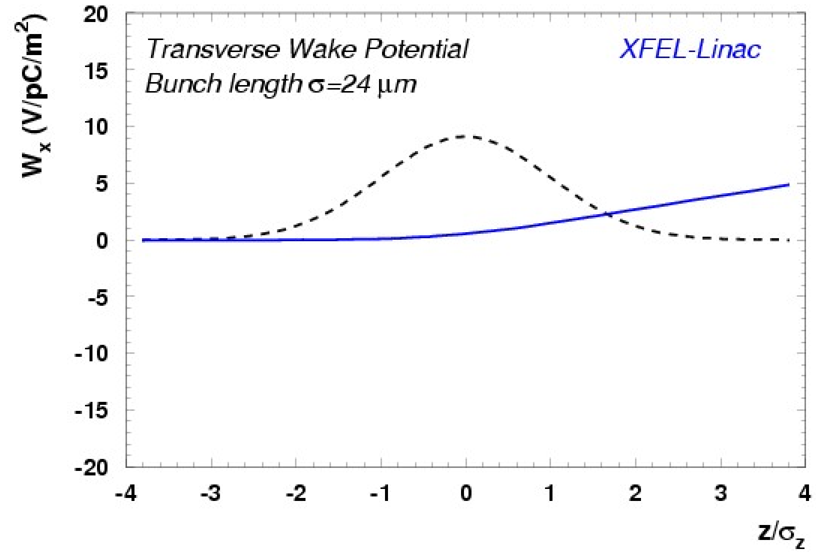
	Booster	Linac
• Energy (GeV)	0.5-2.0	2.0-20
• Accel. Grad (MV/m)	16	20.8
• FODO cells	6	50
• Emittance (mm-mrad)	1.4	1.4
• Bunch charge (nC)	1	1
• Bunch rms length (μm)	112	24
• Initial cor. energy spread	1.75%	0.4%
• Inital uncor. Energy spread (includes laser heater)	500 keV	2500 keV
• Misal. Quads, Cav. (mm)	0.5	0.5
• BPM – 0.1mm, res – 0.02mm		

Beam Model for Particle Tracking



Wake Potentials





Wake functions

$$w_z(s) = 41.5\, exp\left(\sqrt{\frac{s}{1.74mm}}\right), \quad \left[\frac{V}{pC\cdot m}\right]$$

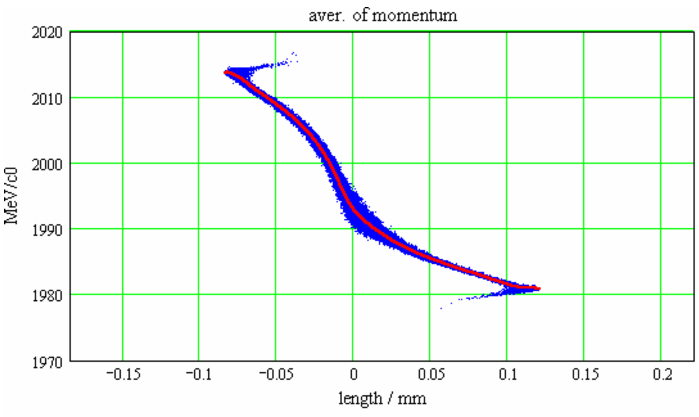
$$w_x(s) = 1211\left[1-\left(1+p(s)\right)e^{-p(s)}\right], \quad \left[\frac{V}{pC\cdot m^2}\right]$$

$$p(s) = \sqrt{s/0.92mm}$$

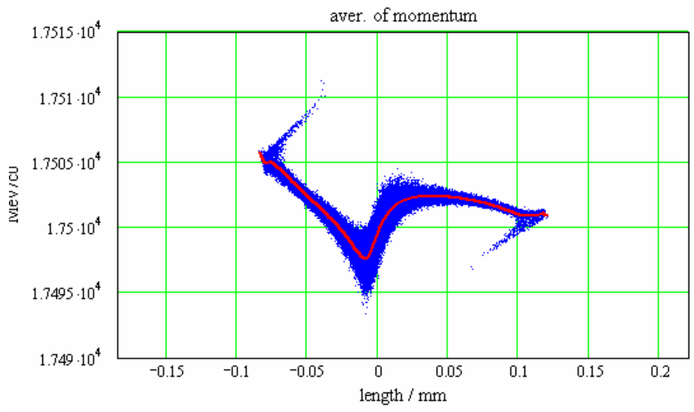
T. Weiland, I. Zagorodnov, TESLA Rep. 2003-19, 2003.

Energy Spread

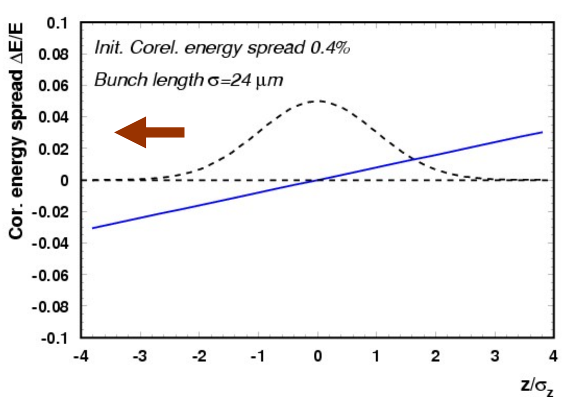
M. Dohlus



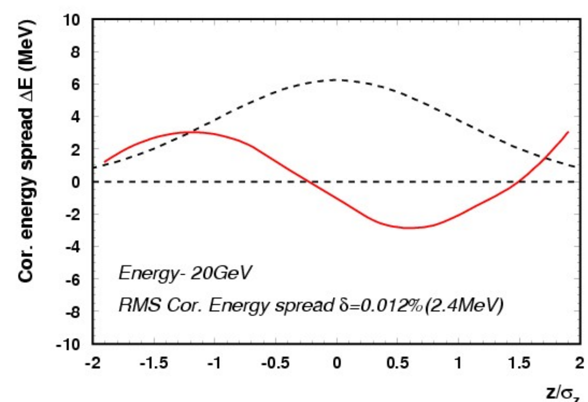
Linac Entrance-2 GeV



Linac End – 20 GeV

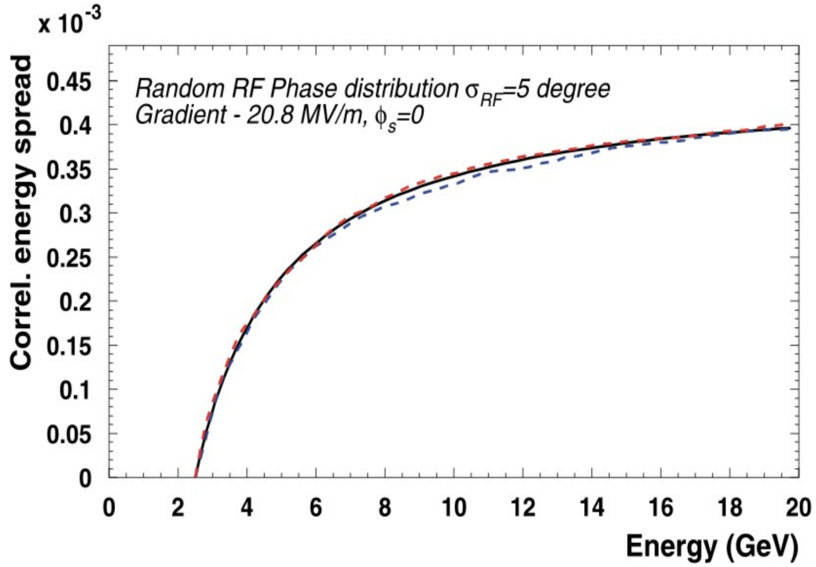


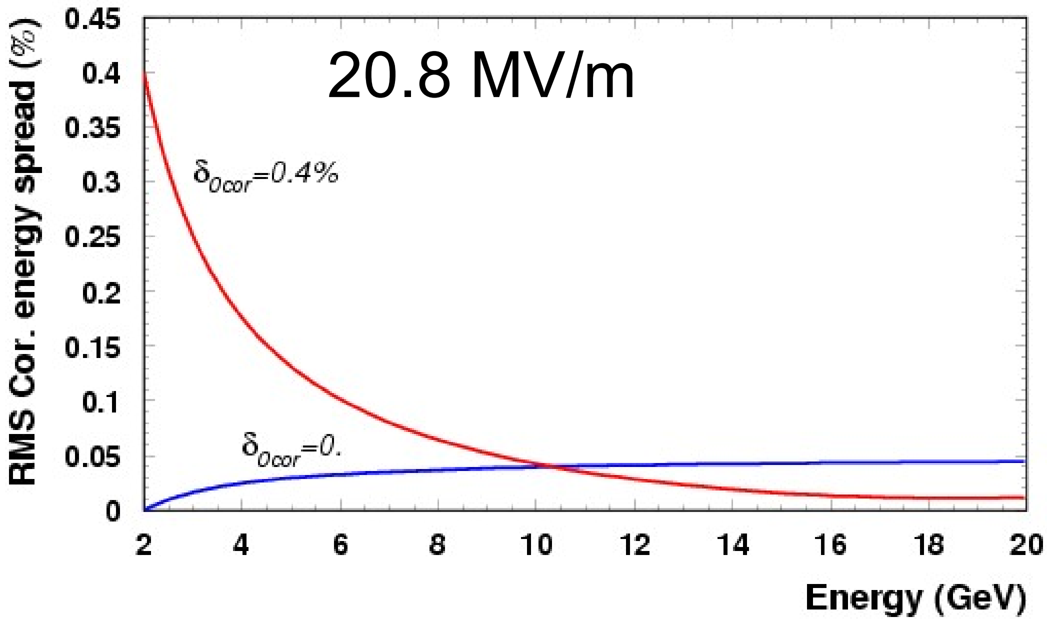
σ_{cor}=0.4%



σ_{cor}=0.012% (2.4 MeV)

Energy spread

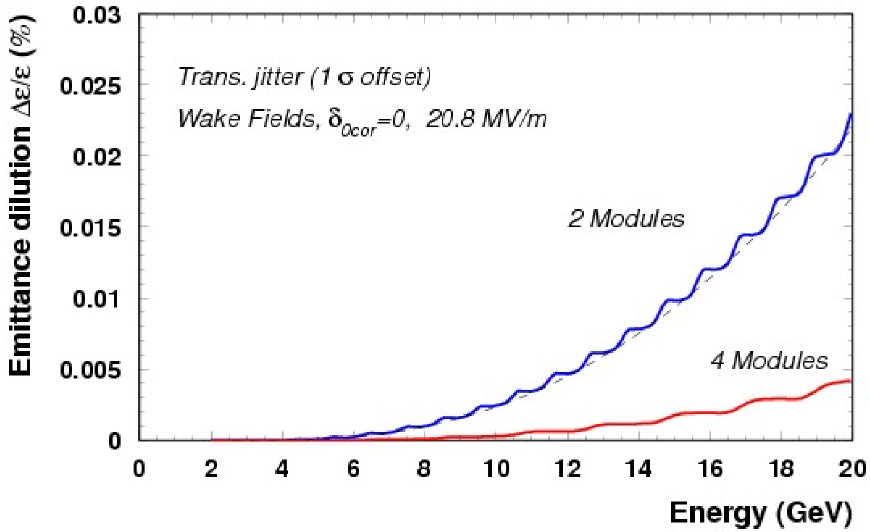


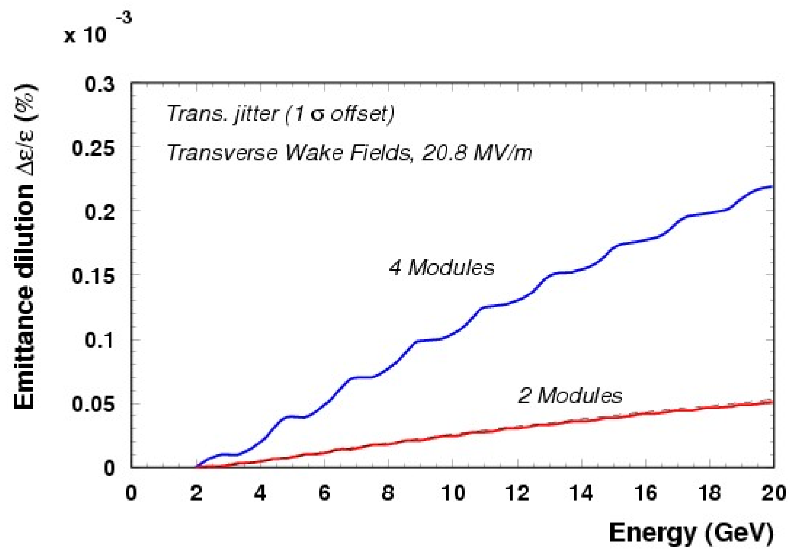


With initial energy spread

Coherent Oscillations

Wakefield Effects (Zero initial energy spread)





Longitudinal Wake (chromatic)

$$\frac{\Delta\varepsilon}{\varepsilon} = 2\sigma_c^2 \boldsymbol{tg}^2(\mu/2)\frac{\gamma_0^2}{\Delta\gamma^2}\left[\frac{\gamma}{\gamma_0} - \ln\frac{\gamma}{\gamma_0} - 1\right]^2$$

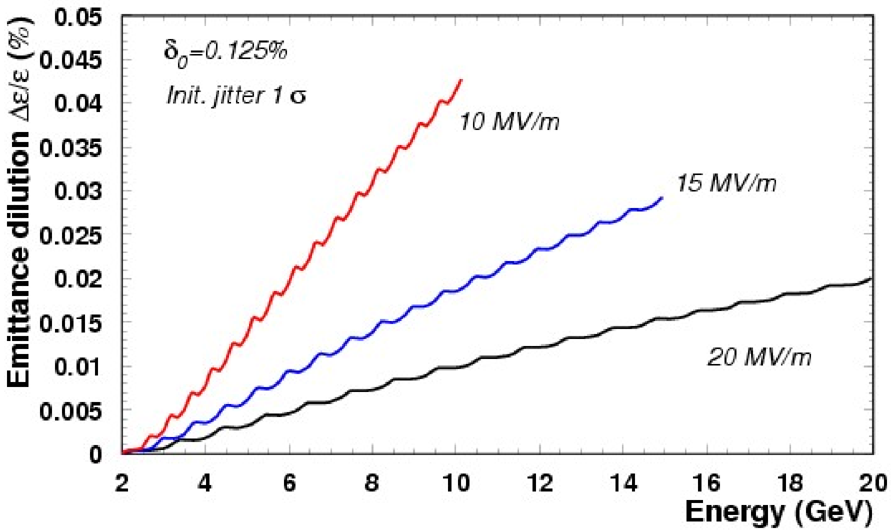
Transverse wake

$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{1}{128}\left(\frac{\boldsymbol{Q}\boldsymbol{W}_D\boldsymbol{L}_{cell}}{\boldsymbol{G}\sin\mu}\right)^2 \ln^2\frac{\gamma}{\gamma_0}$$

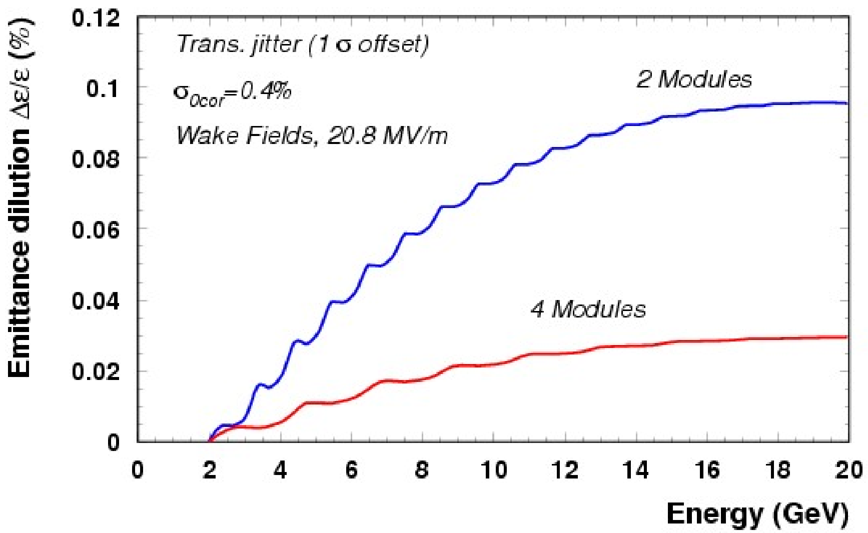
Coherent Oscillations

Chromatic effects (initial energy spread)

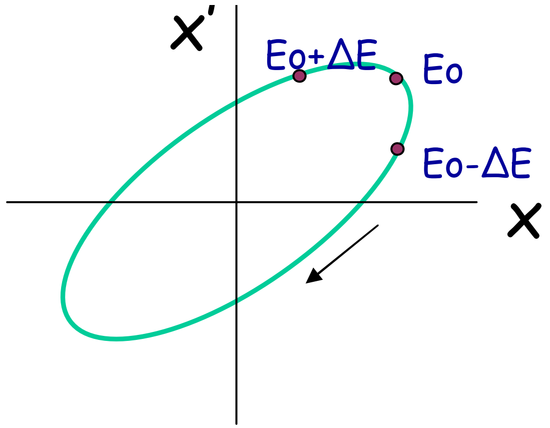
Uncorrelated



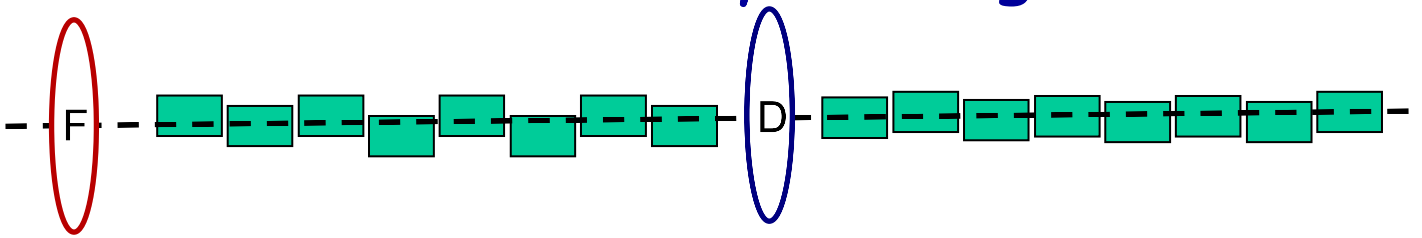
Correlated



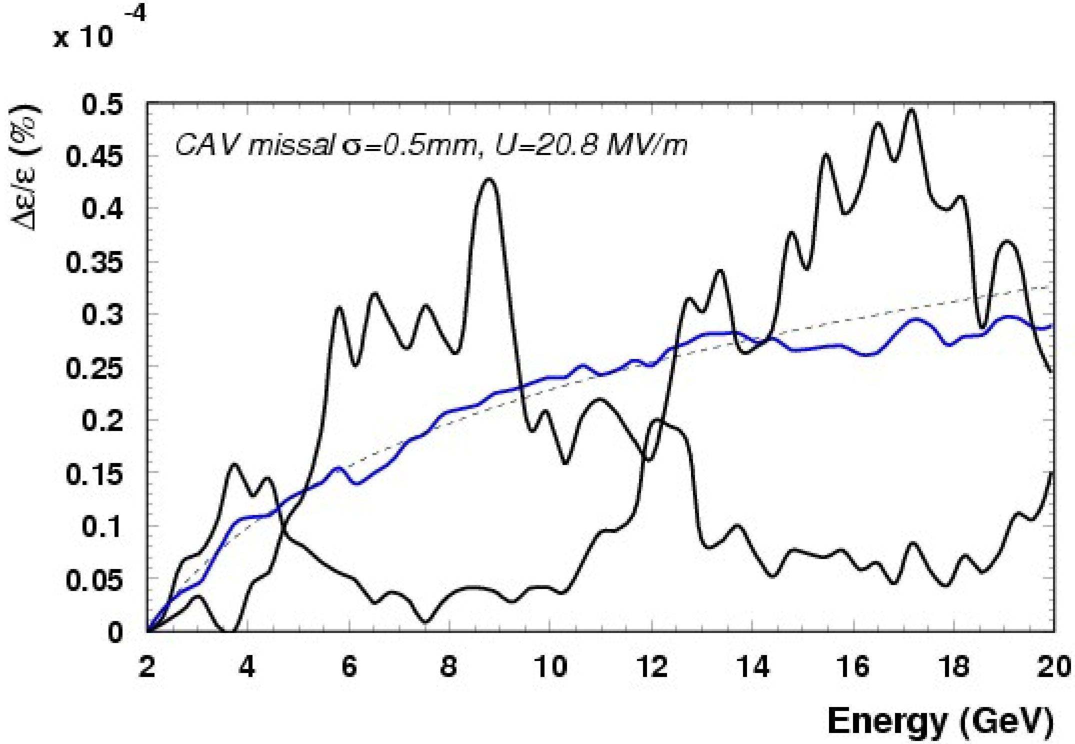
$$\frac{\Delta\varepsilon}{\varepsilon} = 2\sigma_0^2 \tan^2(\mu/2)\frac{\gamma_0^2}{\Delta\gamma^2}\ln^2\frac{\gamma}{\gamma_0}$$



Cavity Misalignments

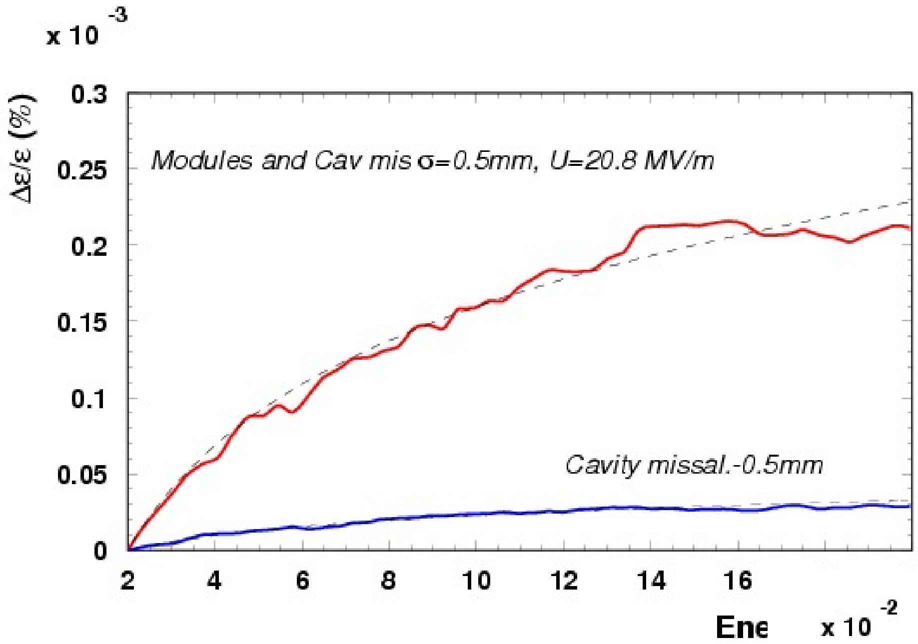


σ_{cavity}=0.5mm



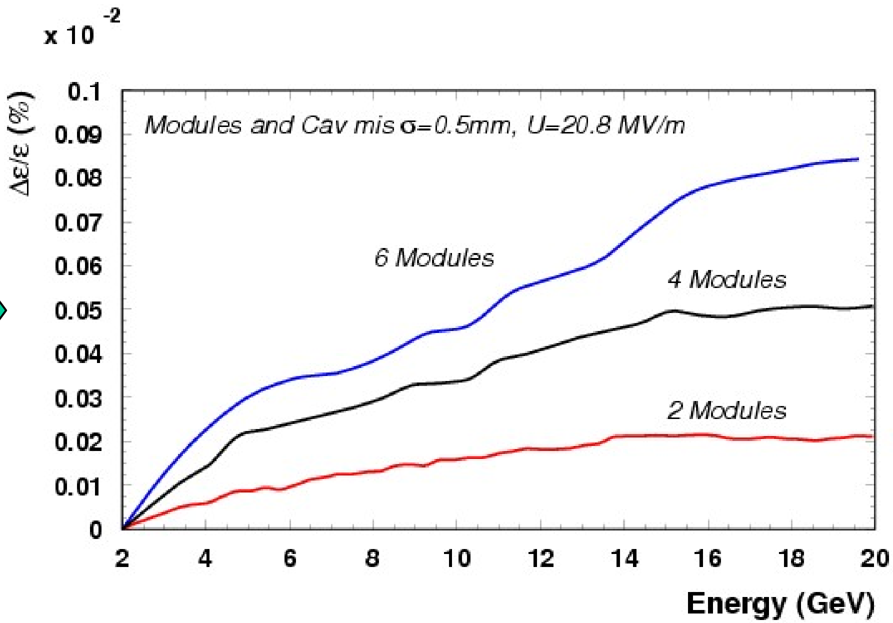
$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{< x_A^2 >}{32 N_{cav} \varepsilon_0} \left(\frac{Q W_D}{G} \right)^2 \frac{L_{cell}}{\sin\mu} \frac{\Delta\gamma}{\gamma_0} \ln\frac{\gamma}{\gamma_0}$$

Modules Misalignments

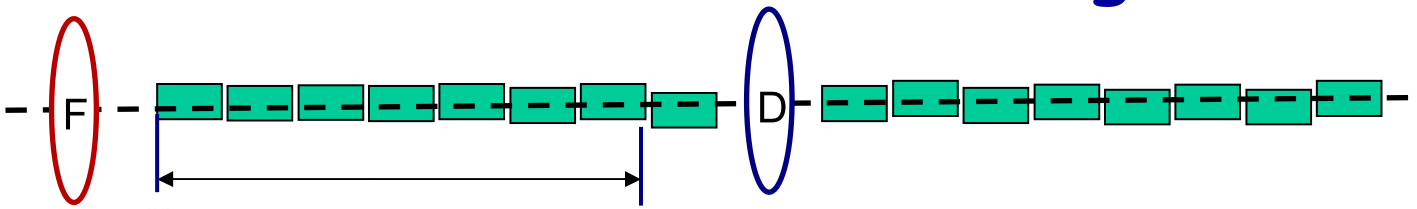


Standard cell

2,4 and 6 modules per FODO cell

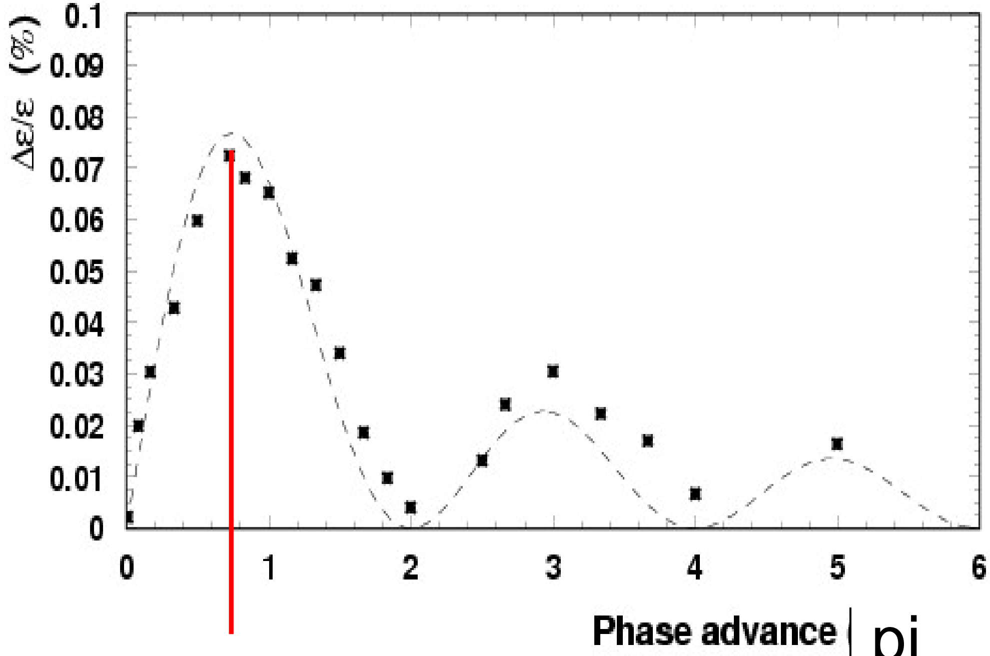


Correlated Misalignments



σ_{cor}=0.5mm

Δμ- phase advance per cor. length



Δμ=130° (~4 modules)

Betatron phase contrib.

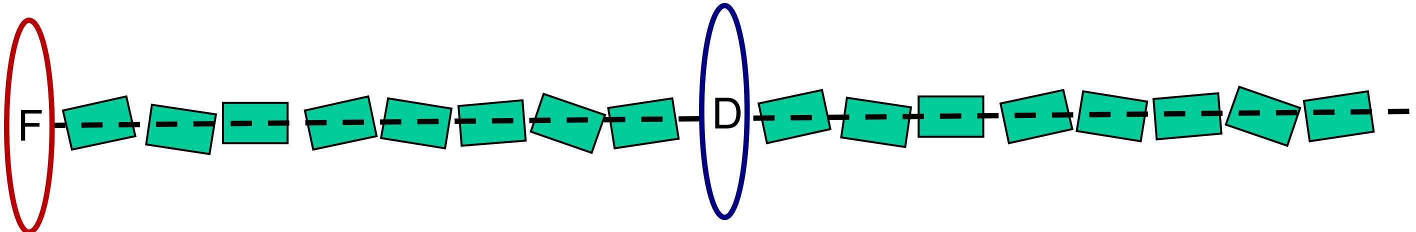
$$F \approx \frac{1}{\Delta\mu^2}\int_0^{\Delta\mu}\int_0^{\Delta\mu}\cos(\phi' - \phi'')d\phi' d\phi''$$

$$F = \frac{4}{\Delta\mu^2}\sin^2\frac{\Delta\mu}{2}$$

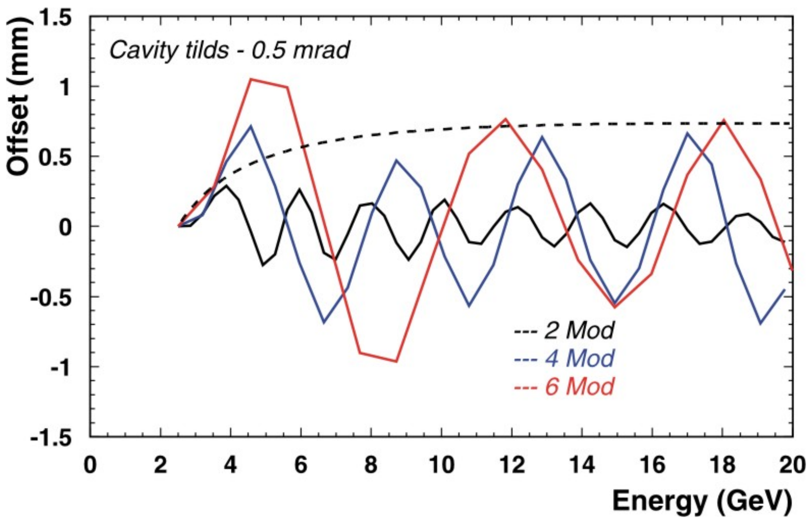
$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{< x_A^2 >}{8\varepsilon_0}\left(\frac{QW_D}{G}\right)^2 \frac{L_{cell}}{\mu \sin\mu}\frac{\sin^2\Delta\mu/2}{\Delta\mu}\frac{\Delta\gamma}{\gamma_0}\ln\frac{\gamma}{\gamma_0}$$

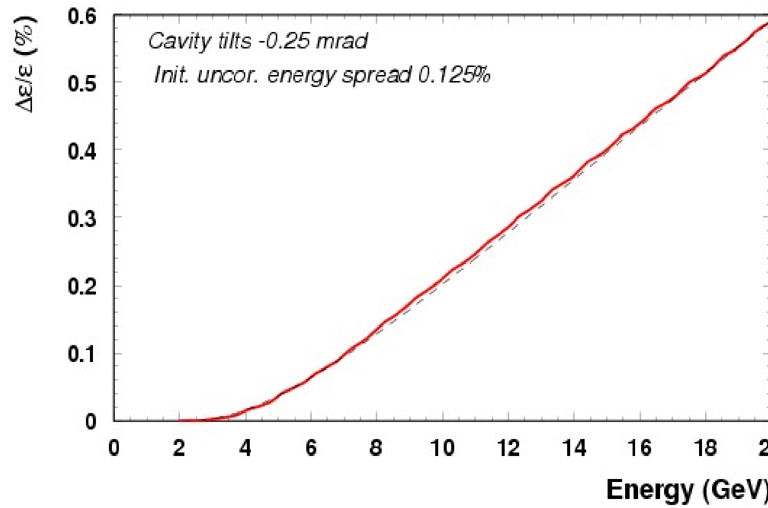
R.Brinkmann, V.Tsakanov, Snowmass, 2001

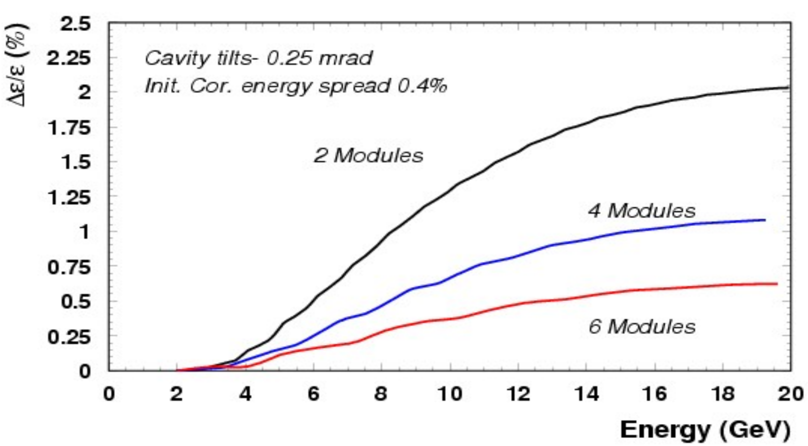
Cavity tilts



σ_{tilt}=0.25mrad

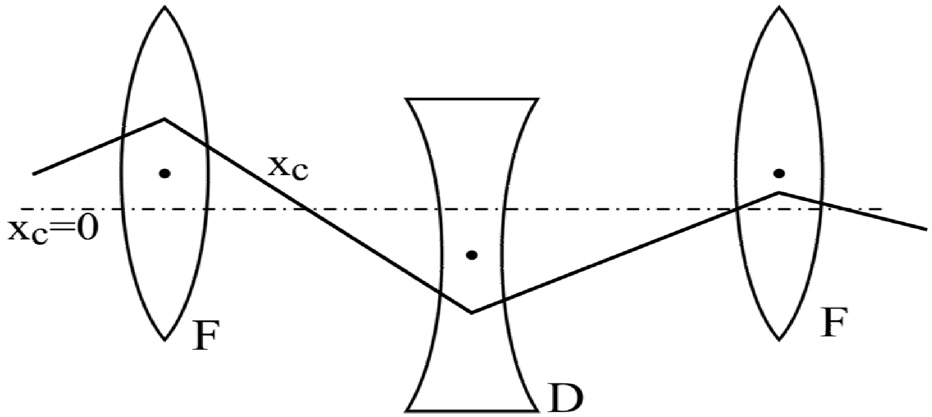


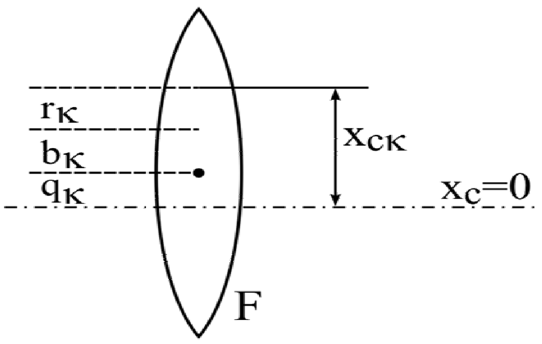


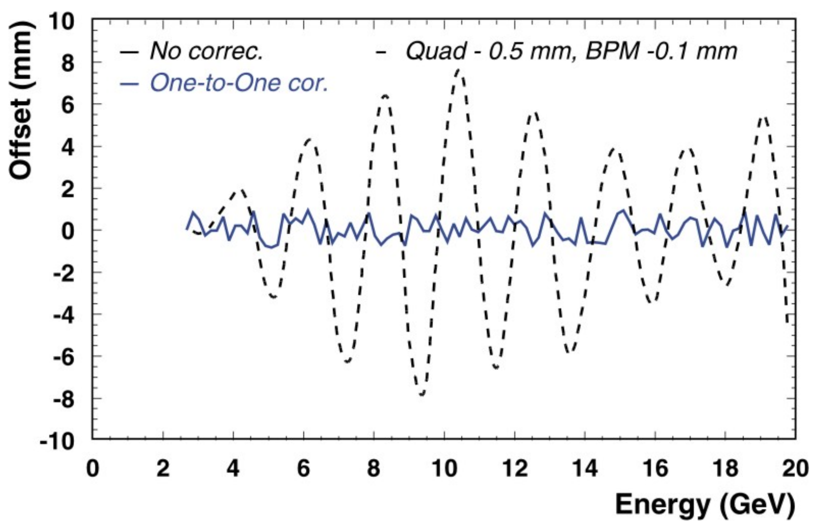


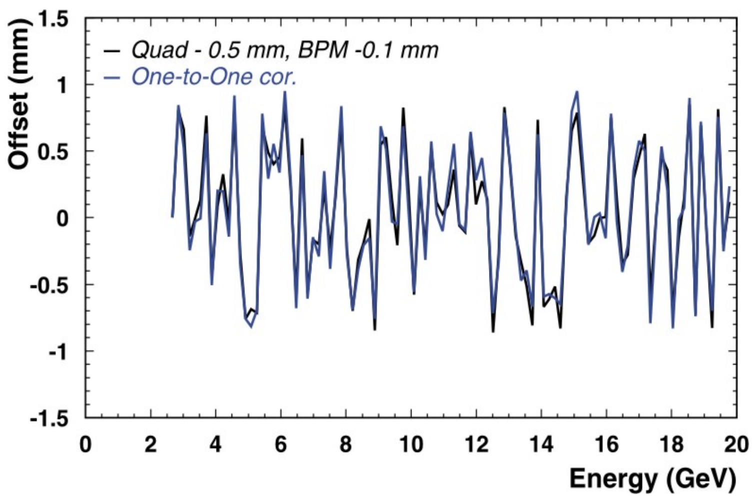
$$\frac{\Delta\varepsilon}{\varepsilon}=\frac{4}{3}<\alpha^2>\frac{\sigma_0^2 \boldsymbol{d}^2 \boldsymbol{N_{cav}}}{\varepsilon_0 \boldsymbol{L_c}\sin\mu}\boldsymbol{tg}^2\frac{\mu}{2}\frac{\gamma_0}{\Delta\gamma}\ln^3\frac{\gamma}{\gamma_0}$$

Quadrupoles misalignments. One-to- One Correction



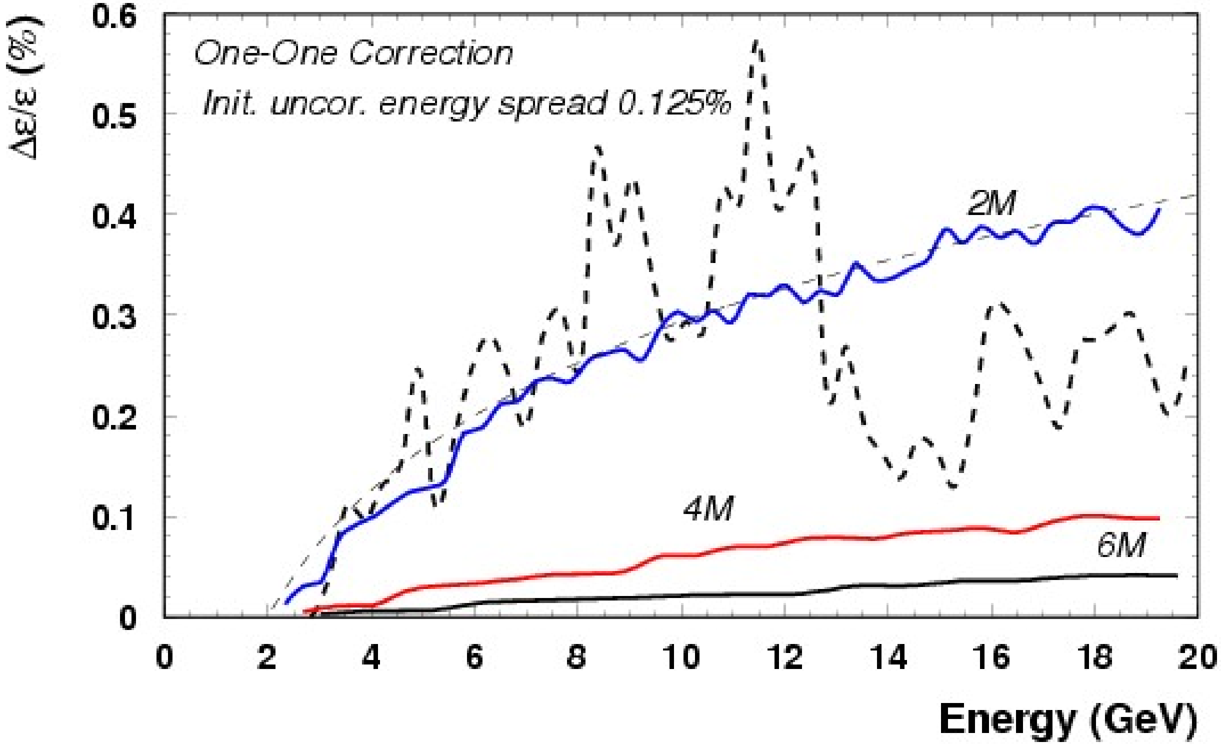






One-to One Correction

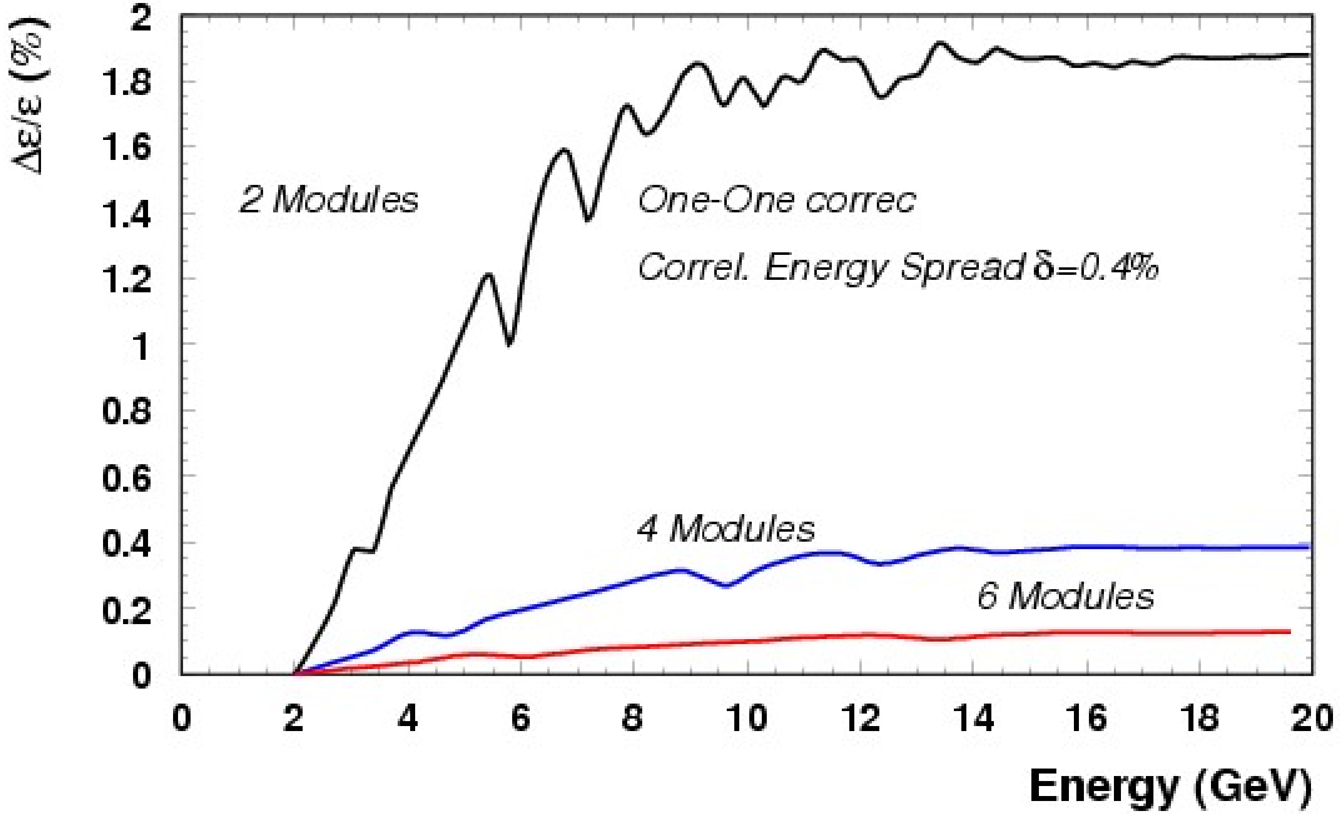
Uncorrelated effects



$$\frac{\Delta\varepsilon}{\varepsilon} = 8\sigma_0^2 \frac{< x_c^2 > \tan\mu/2}{\varepsilon_0 L_{cell}} \frac{\gamma_0}{\Delta\gamma} \ln\frac{\gamma}{\gamma_0}$$

Quad misalignments.
One-to-One Correction

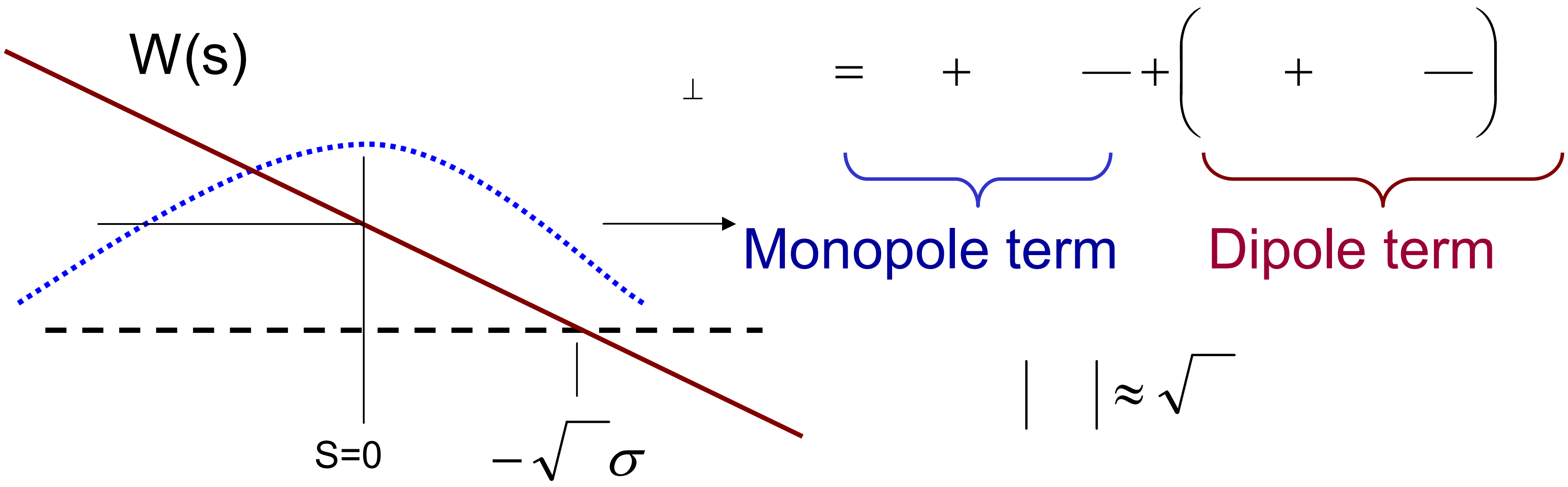
Correlated effects



Coupler Kick and RF Distortion

Model for Transverse Potential

The field potential - linear variation within the bunch



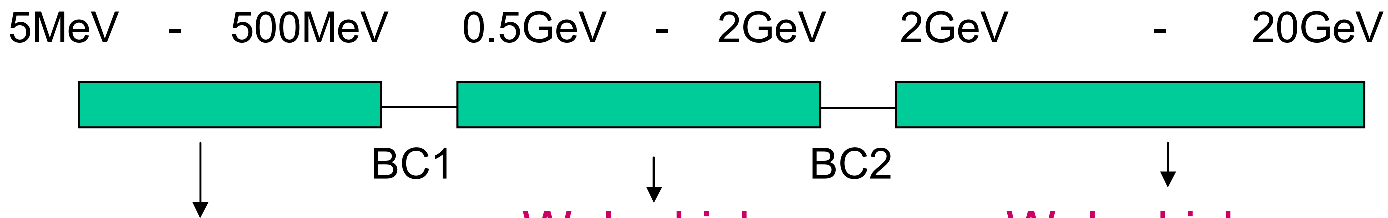
- Coupler RF kick –

Scaling with accel grad and bunch length

$\Rightarrow$ **$K_{rf} \sim V_{cav} * \sigma_z$**

I.Zagorodnov, M. Dohlus

Main Parameters



Monopole	RF kick	Wake kick	Wake kick
Dipole	Cavity kick	Cavity kick	Wake kick

	Bunch Length µm	*Acc. Grad.* MV/m	*Wake rms kick k0* V/nC/cav	*RF rms kick k0* V/nC/cav	*Wake rms kick k1 (dipole)* V/nC/mm/cav	*RF rms kick k1 (dipole)* V/nC/mm/cav	*Cavity rms kick k1(dipole)* V/nC/mm/cav
Injector	**2000**	**12**	**8.2**	**38.4**	**1.25**	**1.8**	**21.6**
Booster	**120**	**16**	**8.2**	**3.0**	**1.25**	**0.14**	**3.5**
Main Linac	**25**	**20.8**	**8.2**	**0.8**	**1.25**	**0.04**	**0.77**

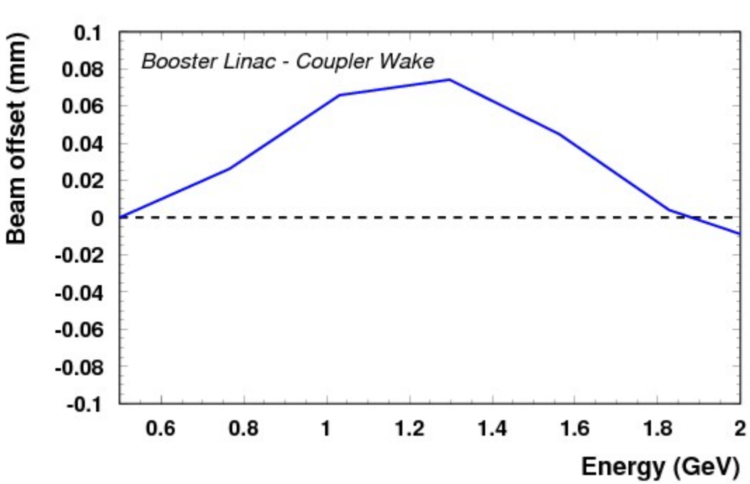
Monopole =

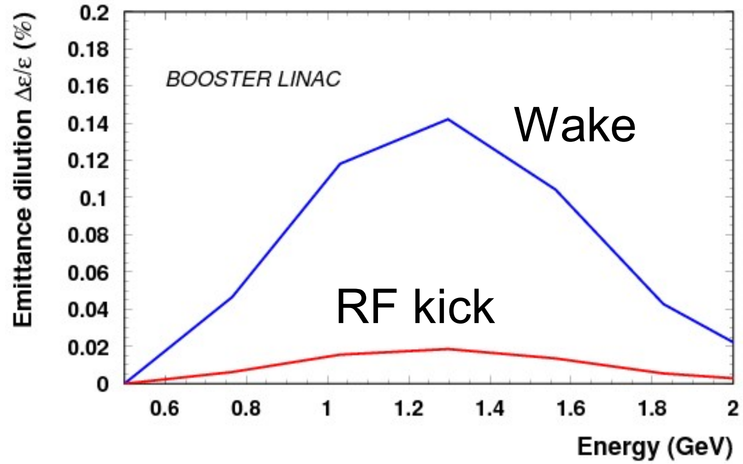
Dipole =

For cavity =

For beam offset < 1mm monopole term k_0 dominates

Booster Linac





$$\frac{x}{\Delta x} \sim \sin^2\frac{\Delta\varphi}{2}$$

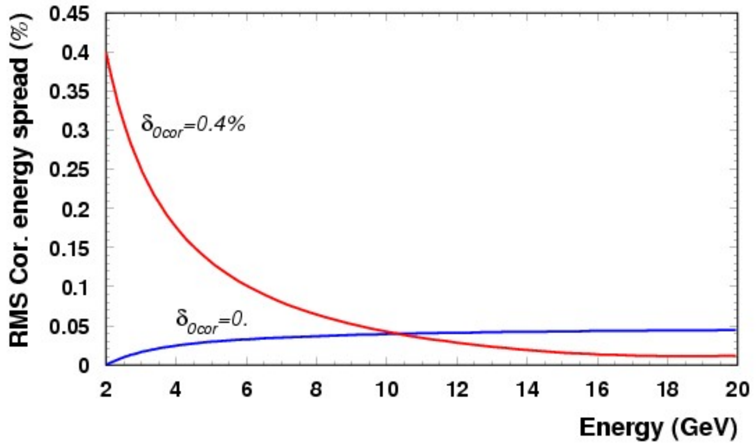
$$\frac{\Delta\varepsilon}{\varepsilon} \sim \frac{\beta_{av}}{L_{cell}} \sin^4\frac{\Delta\varphi}{2}$$

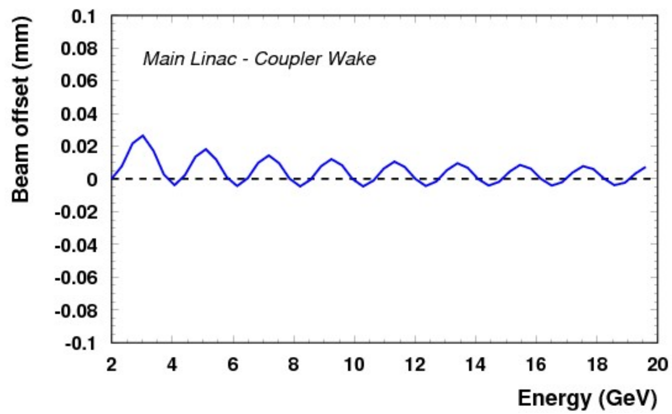
6 FODO cells ➡ $\mu = \pi/3$, $\Delta\varphi = 2\pi$

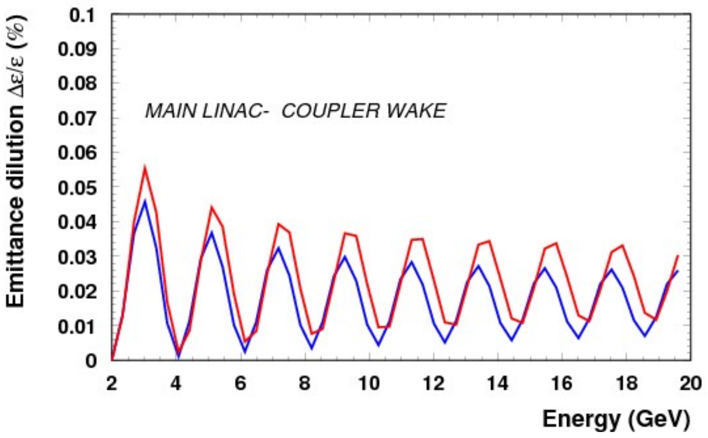
- Dominate by RF Head –tail kick - monopole term
- Natural global compensation

Main Linac- Coupler Wake

52 FODO Cells – Betatron oscillations ~9





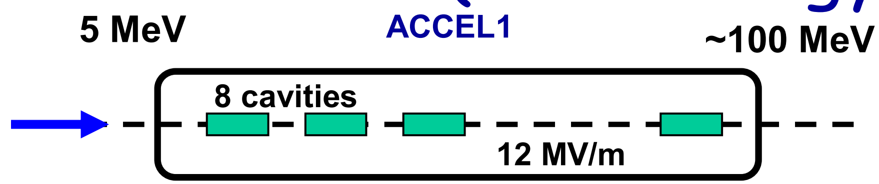


Accum. Emittance Dilution

Correlated, Chromatic

Monopole term - Offset independent wake

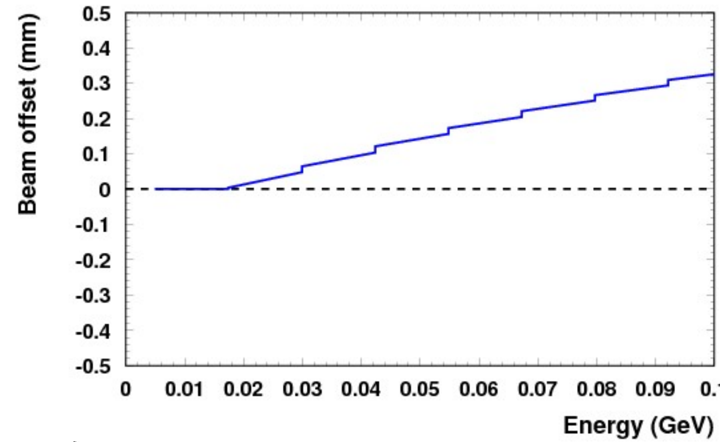
Coupler RF Field (Low energy part)



Monopole term

K_o=66.4 V/nC/cavity

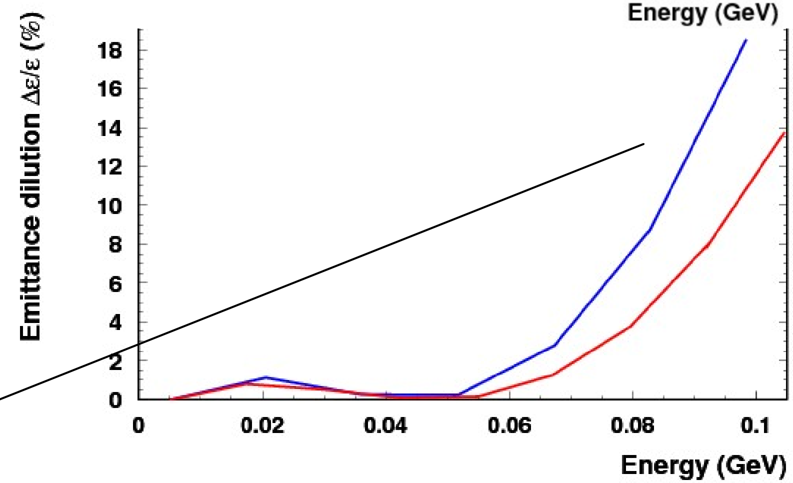
K_{rms}=38.4 V/nC/cavity



Dipole term

K_{rms}=1.8 V/nC/mm/cav

K_o=3.0 V/nC/mm/cav



U=15 MV/m, σ=2.4 mm

Summary of Emittance Dilution (Standard Cell)

	Booster	Linac
• Coherent oscillations		
uncorrelated	$6\cdot10^{-6}$	$2\cdot10^{-4}$
correlated	$2\cdot10^{-3}$	$1.2\cdot10^{-3}$
• Cavity Misalignments	$5\cdot10^{-6}$	$3\cdot10^{-7}$
• Modules Misalignments	$4\cdot10^{-5}$	$2.5\cdot10^{-6}$
• Correlated Misal. (130°)	-	$7\cdot10^{-6}$
• Cavity tilts		
uncorrelated	$5.8\cdot10^{-5}$	0.6%
correlated	0.6%	1.9%
• One-to-One correction		
uncorrelated	$6.3\cdot10^{-5}$	0.4%
correlated	1.7%	2%

⇒ Total Emittance dilution <5% with 2 Modules/Cell

Collection of formulas

Injection jitter

Uncorrelated chromatic

$$\frac{\Delta\varepsilon}{\varepsilon} = 2\sigma_0^2 \tan^2(\mu/2)\frac{\gamma_0^2}{\Delta\gamma^2}\ln^2\frac{\gamma}{\gamma_0}$$

Correlated chromatic

$$\frac{\Delta\varepsilon}{\varepsilon} = 2\sigma_c^2 \boldsymbol{tg}^2(\mu/2)\frac{\gamma_0^2}{\Delta\gamma^2}\left[\frac{\gamma}{\gamma_0} - \ln\frac{\gamma}{\gamma_0} - 1\right]^2$$

Correlated chromatic

$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{1}{128}\left(\frac{\boldsymbol{Q}\boldsymbol{W}_{\boldsymbol{D}}\boldsymbol{L}_{\boldsymbol{cell}}}{\boldsymbol{G}\sin\mu}\right)^2 \ln^2\frac{\gamma}{\gamma_0}$$

Cavity , accelerator section misalignment

Transverse wake fields effects

Cavity misalign.

$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{< \boldsymbol{x}_A^2 >}{32 \boldsymbol{N}_{cav} \varepsilon_0} \left(\frac{\boldsymbol{Q} \boldsymbol{W}_D}{\boldsymbol{G}} \right)^2 \frac{\boldsymbol{L}_{cell}}{\sin \mu} \frac{\Delta\gamma}{\gamma_0} \ln \frac{\gamma}{\gamma_0}$$

Correlated misalignment

$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{< \boldsymbol{x}_A^2 >}{8 \varepsilon_0} \left(\frac{\boldsymbol{Q} \boldsymbol{W}_D}{\boldsymbol{G}} \right)^2 \frac{\boldsymbol{L}_{cell}}{\mu \sin \mu} \frac{\sin^2 \Delta\mu / 2}{\Delta\mu} \frac{\Delta\gamma}{\gamma_0} \ln \frac{\gamma}{\gamma_0}$$

Cavity tilts

$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{4}{3} < \alpha^2 > \frac{\sigma_0^2 \boldsymbol{d}^2 \boldsymbol{N}_{cav}}{\varepsilon_0 \boldsymbol{L}_c \sin \mu} \boldsymbol{tg}^2 \frac{\mu}{2} \frac{\gamma_0}{\Delta\gamma} \ln^3 \frac{\gamma}{\gamma_0}$$

Summary 2

European XFEL – What other effects study on beam dynamics is actual

SwissFEL –

- Point charge longitudinal and transverse wake potentials

-Final design

- Misalignments and errosr budget (RMS) for single bunch

- Two bunch operation –trans, long wake

- Beam dynamics