FLS2006 , 15-19 May, DESY, Hamburg

Single Bunch Emittance Preservation in XFEL Linac

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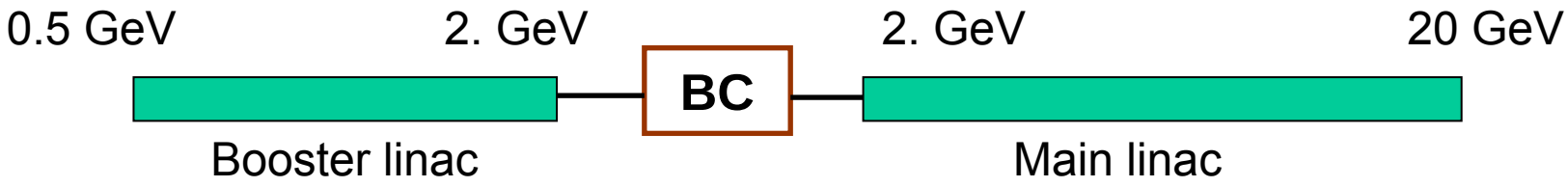
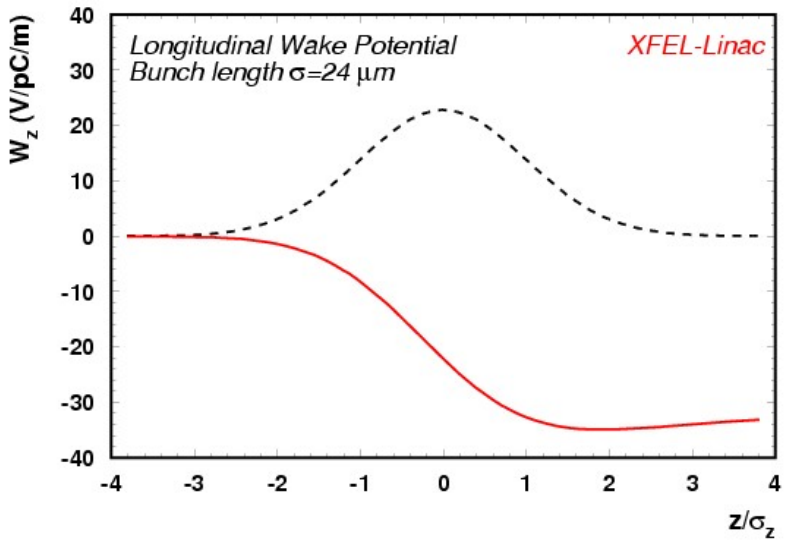
DESY, CANDLE

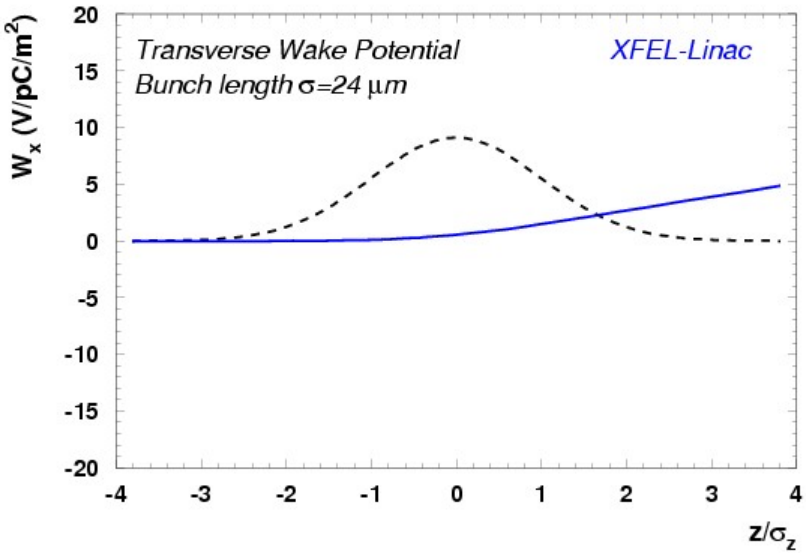
Parameter list



	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		

Wake Potentials





Wake functions

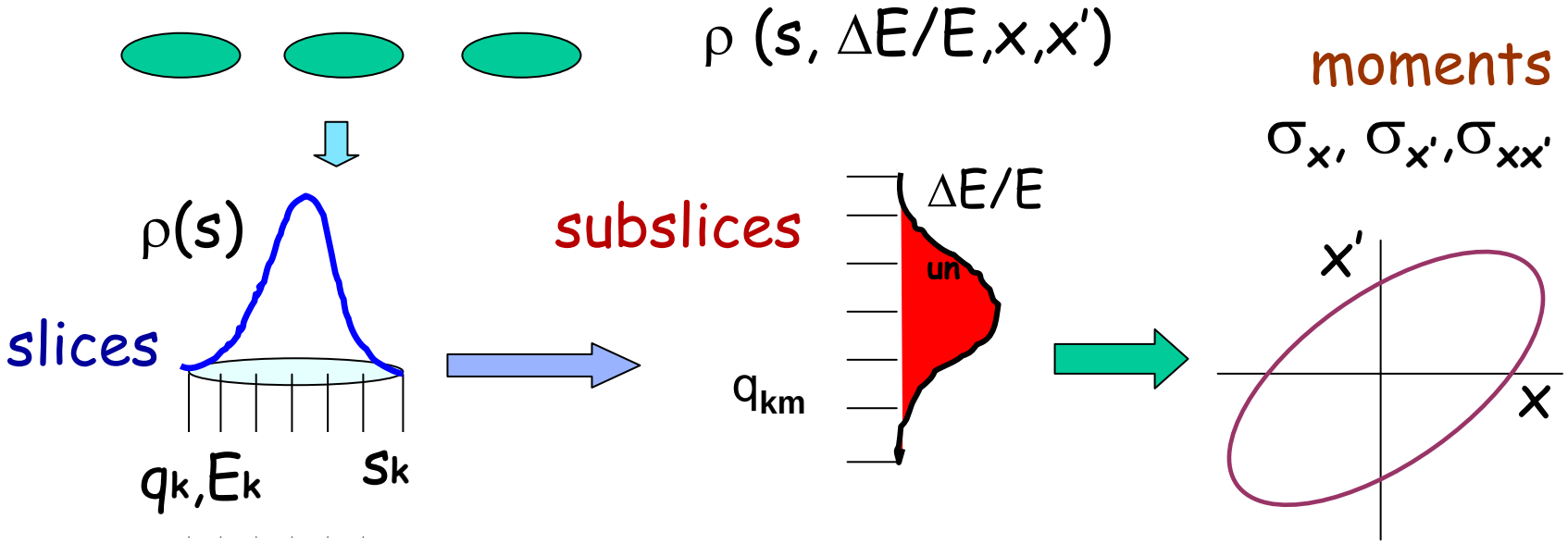
$$w_z(s) = 41.5\exp\left(-\sqrt{\frac{s}{1.74mm}}\right), \quad \left[\frac{V}{pC\cdot m}\right]$$

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

$$w_x(s) = 121\left[1-\left(1+p(s)\right)e^{-p(s)}\right], \quad \left[\frac{V}{pC\cdot m^2}\right]$$

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

Beam Model for Particle Tracking



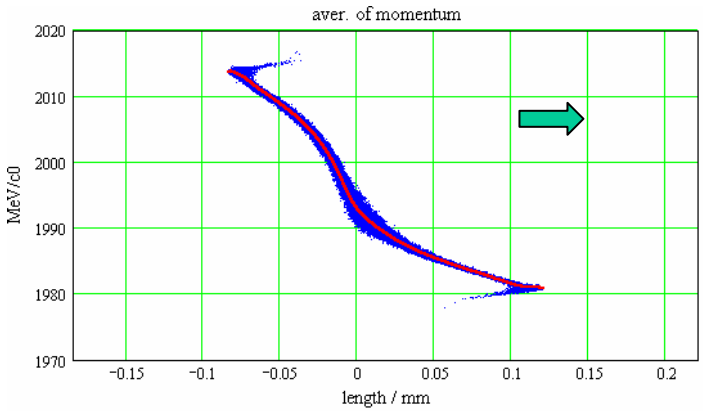
Emittance dilution

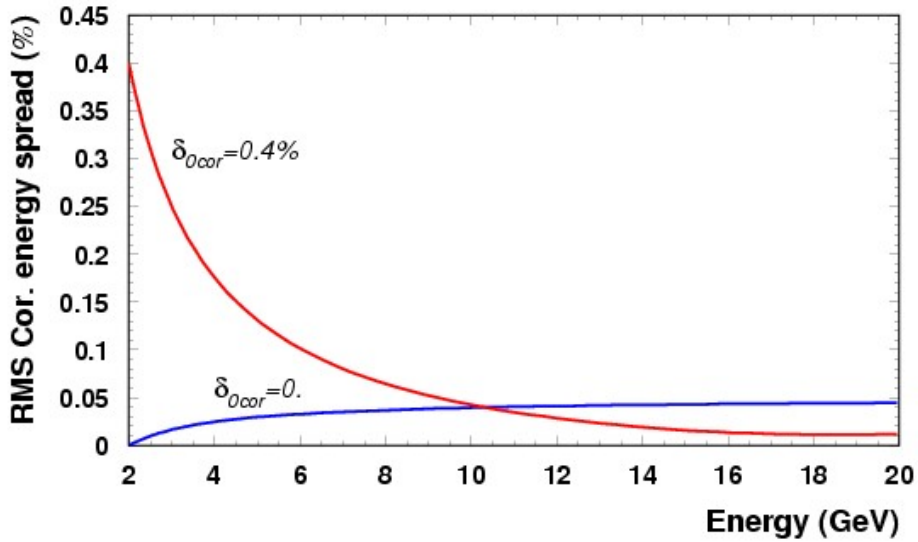
Correlated
(wakes, RF)

Uncorrelated
(uncor. energy spread)

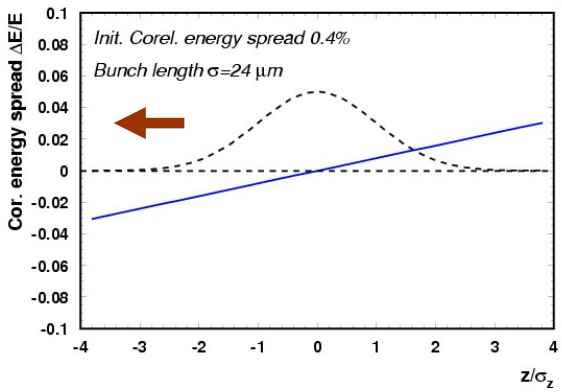
Correlated Energy Spread

T. Limberg et al, PAC'05, 2005.



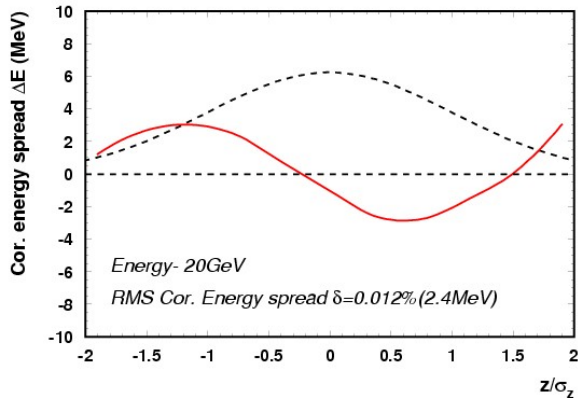


Linac Entrance-2 GeV



σ_{cor}=0.4%

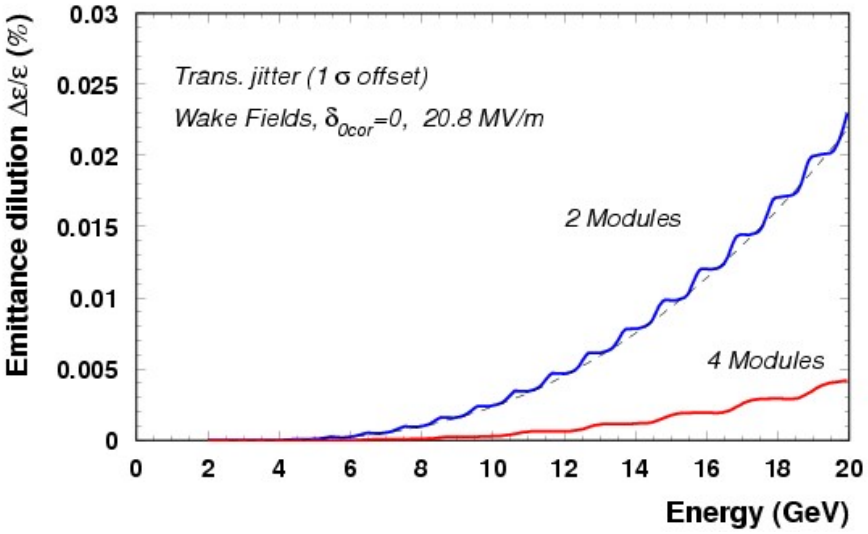
Linac End – 20 GeV

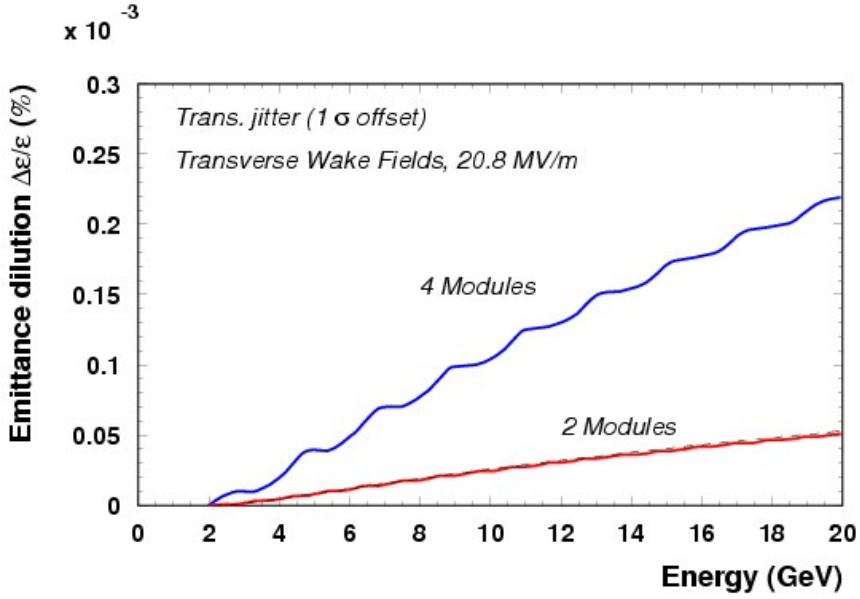


σ_{cor}=0.012% (2.4 MeV)

Coherent Oscillations

Wakefield Effects (Zero initial energy spread)





Longitudinal Wake (chromatic)

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

Transverse wake

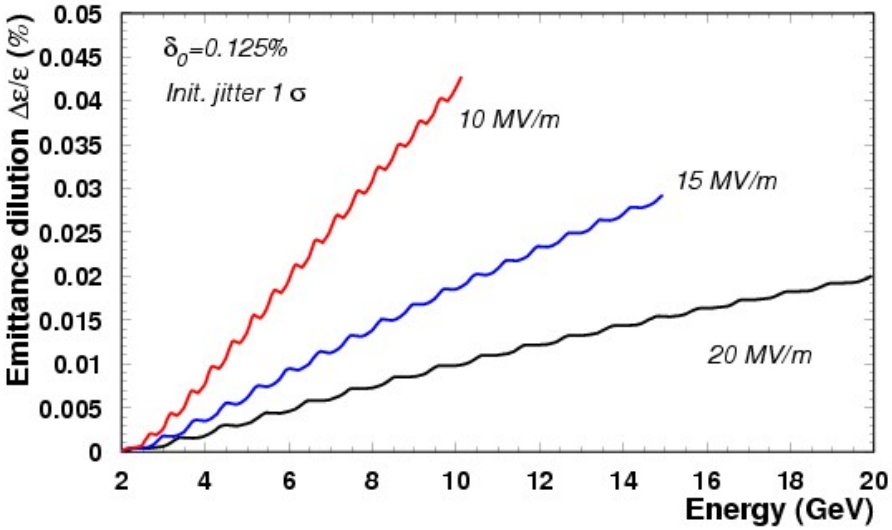
$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{1}{128}\left(\frac{QW_D L_{cell}}{G\sin\mu}\right)^2 \ln^2\frac{\gamma}{\gamma_0}$$

XFEL Lattice : chromatic dominated emittance dilution

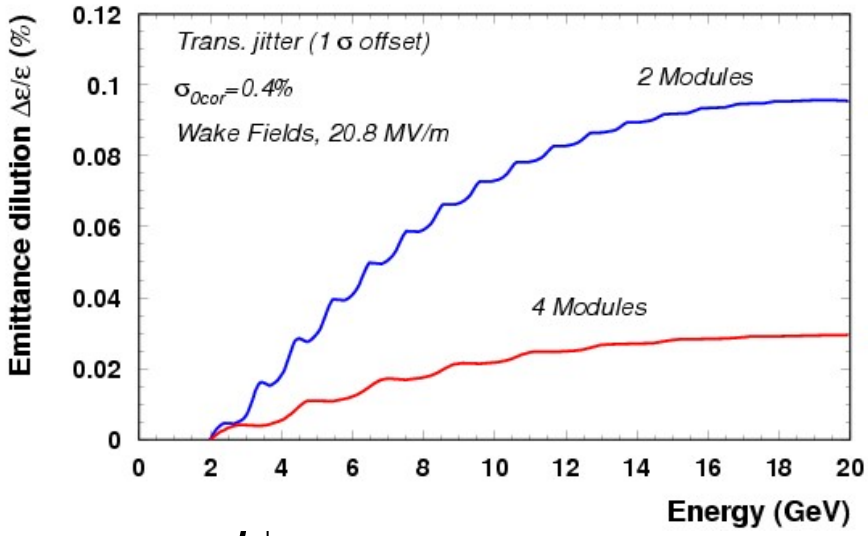
Coherent Oscillations

Chromatic effects (initial energy spread)

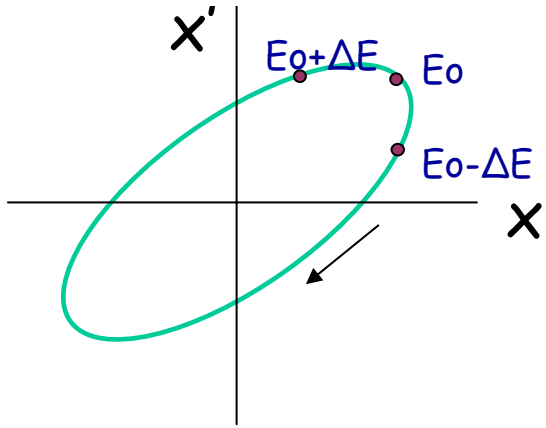
Uncorrelated



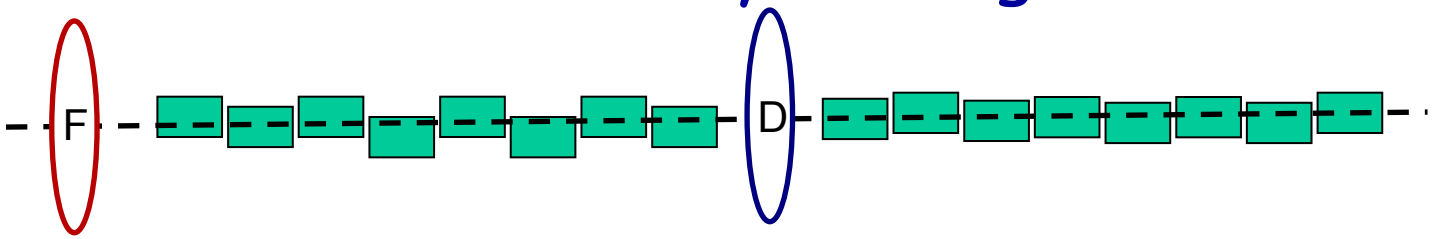
Correlated



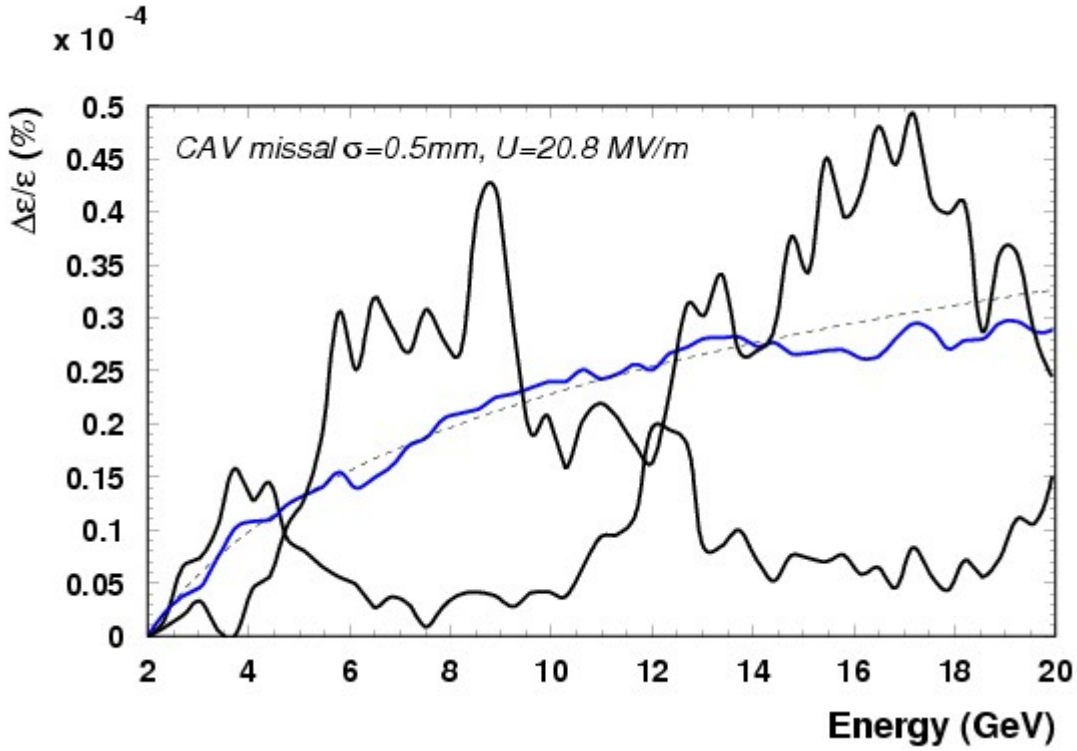
$$\frac{\Delta\varepsilon}{\varepsilon} = 2\sigma_0^2 \tan^2(\mu/2)\frac{\gamma_0^2}{\Delta\gamma^2}\ln^2\frac{\gamma}{\gamma_0}$$



Cavity Misalignments

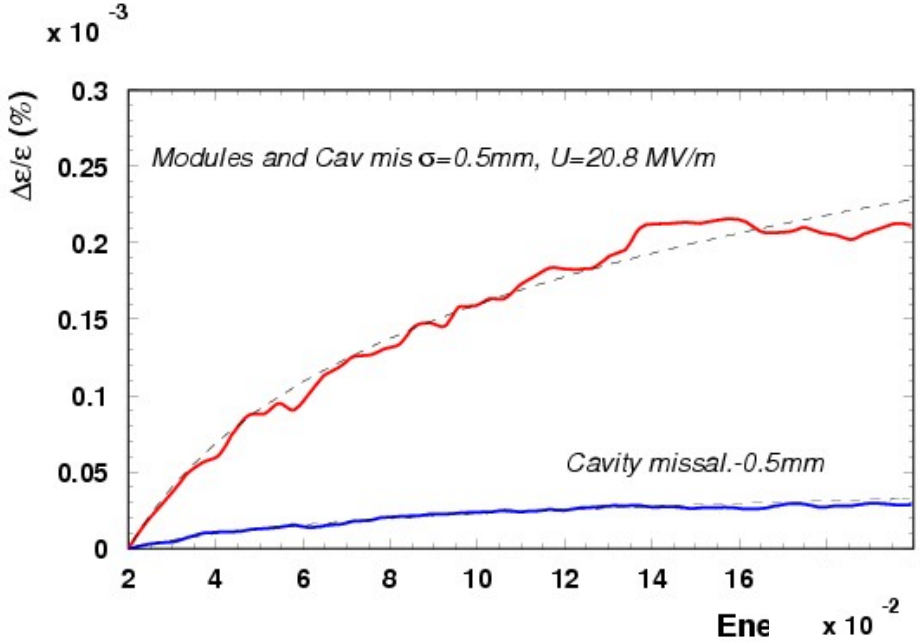


σ_{cavity}=0.5mm



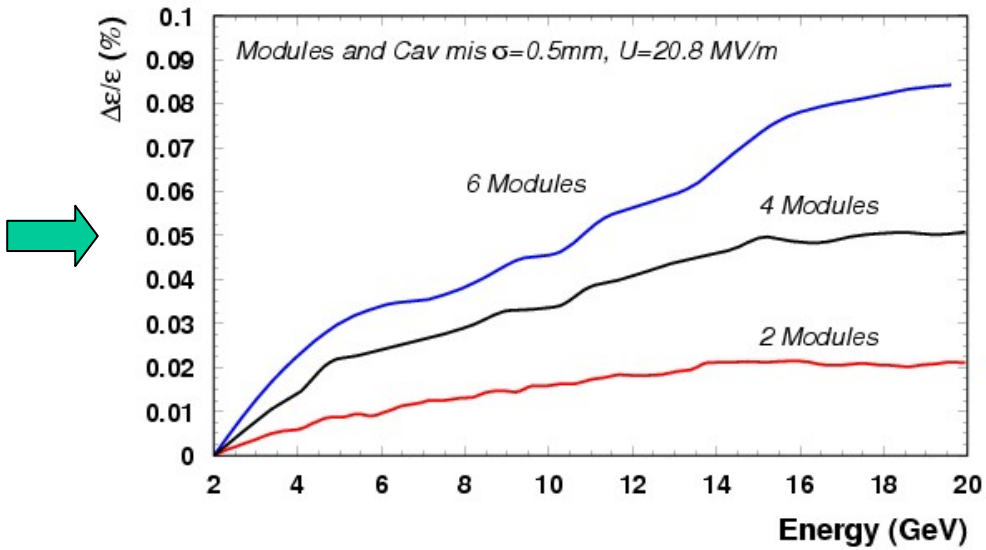
$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{< x_A^2 >}{32 N_{cav} \varepsilon_0} \left(\frac{Q W_D}{G} \right)^2 \frac{L_{cell}}{\sin\mu} \frac{\Delta\gamma}{\gamma_0} \ln\frac{\gamma}{\gamma_0}$$

Modules Misalignments

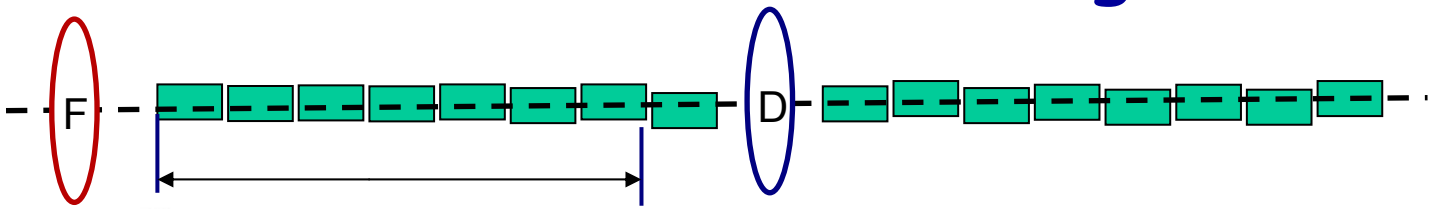


Standard cell

2,4 and 6 modules per FODO cell



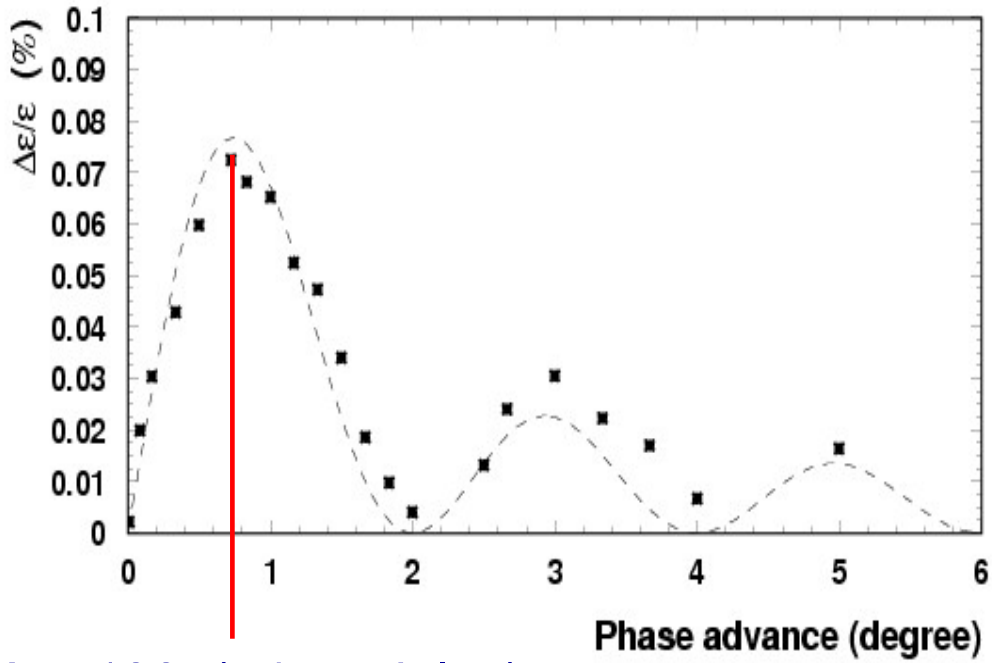
Correlated Misalignments



σ_{cor}=0.5mm

x 10 $^{-2}$

Δμ- phase advance per cor. length



Δμ=130^{o} (~4 modules)

Betatron phase contrib.

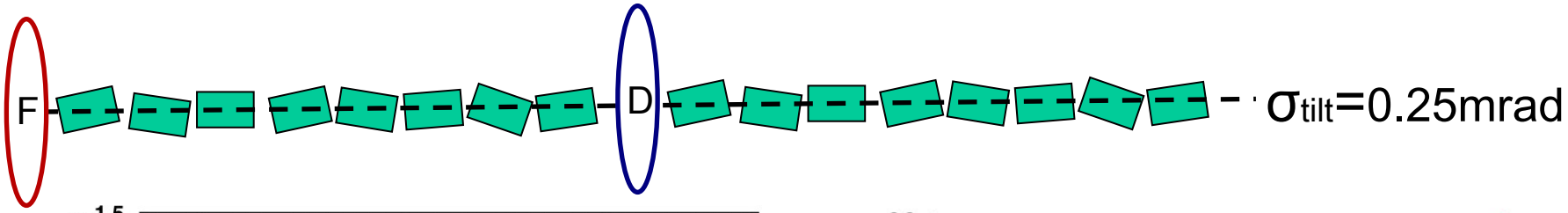
$$F \approx \frac{1}{\Delta\mu^2}\int_0^{\Delta\mu}\int_0^{\Delta\mu}\cos(\phi'-\phi'')d\phi'd\phi''$$

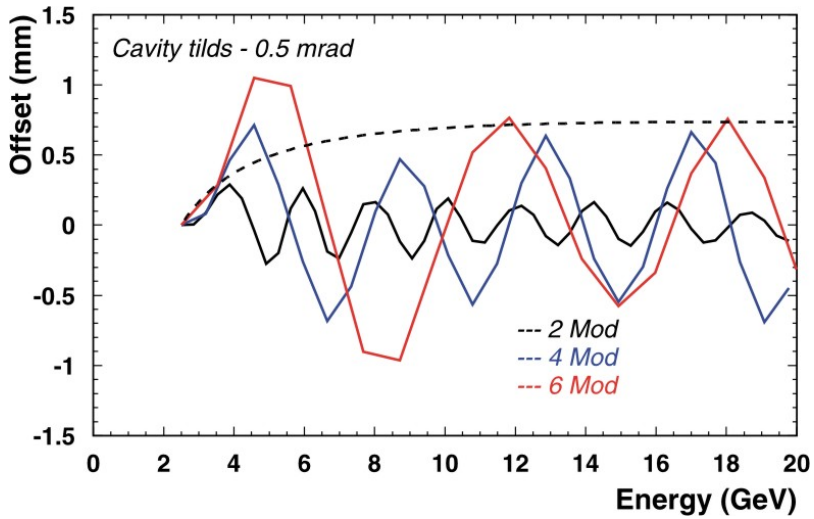
$$F = \frac{4}{\Delta\mu^2}\sin^2\frac{\Delta\mu}{2}$$

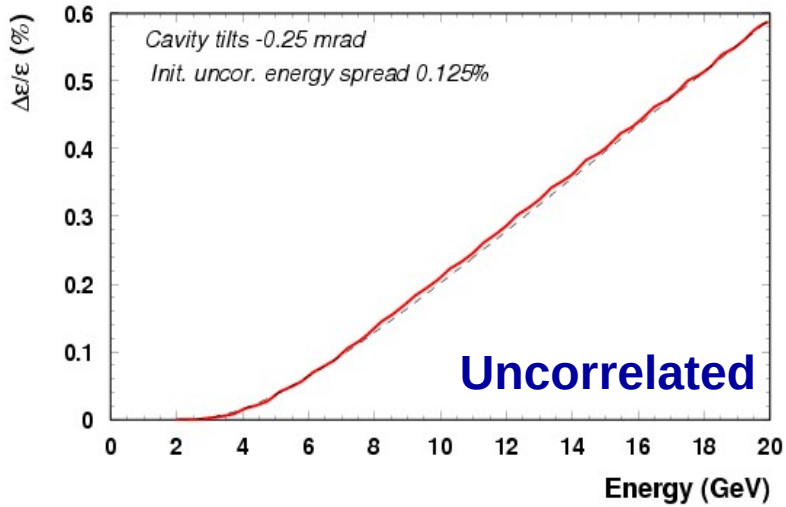
$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{< x_A^2 >}{8\varepsilon_0}\left(\frac{QW_D}{G}\right)^2 \frac{L_{cell}}{\mu \sin\mu}\frac{\sin^2\Delta\mu/2}{\Delta\mu}\frac{\Delta\gamma}{\gamma_0}\ln\frac{\gamma}{\gamma_0}$$

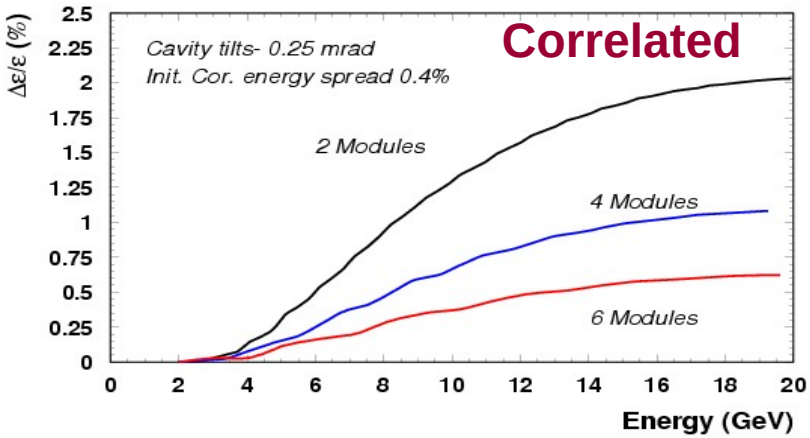
R.Brinkmann, V.Tsakanov, Snowmass, 2001

Cavity tilts



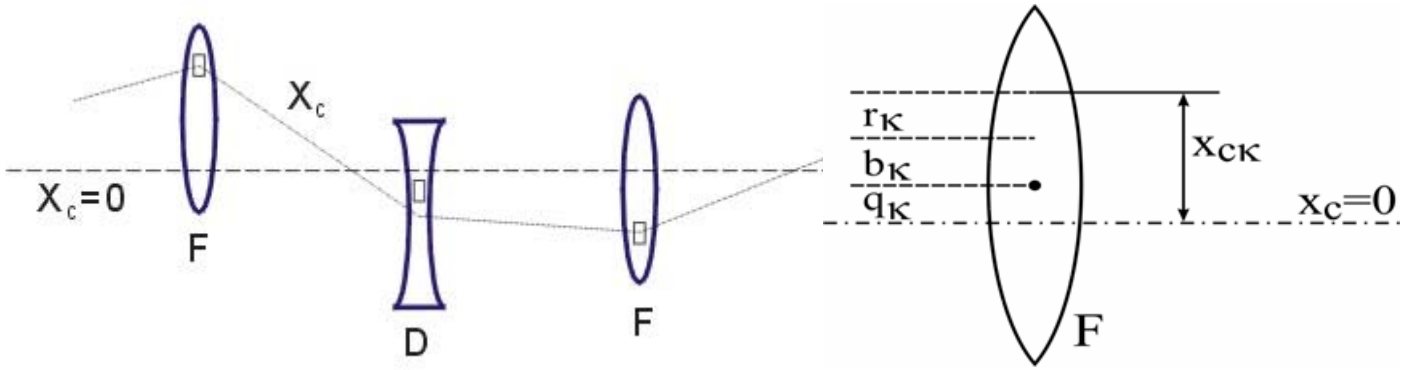


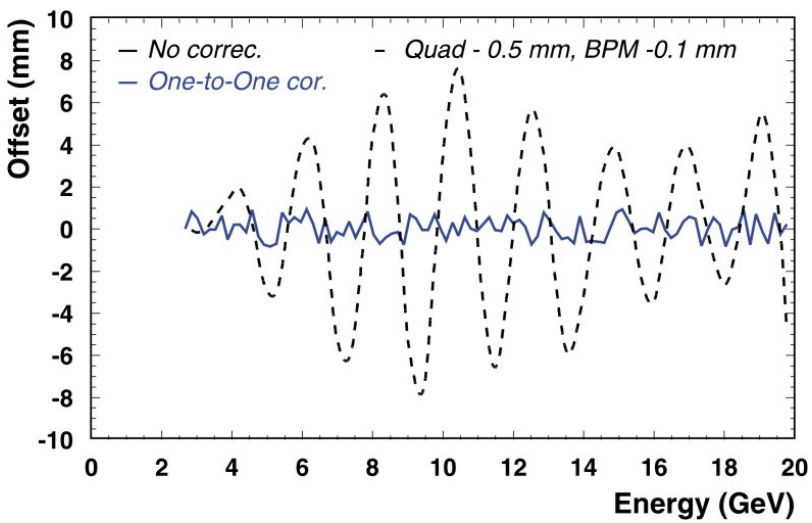


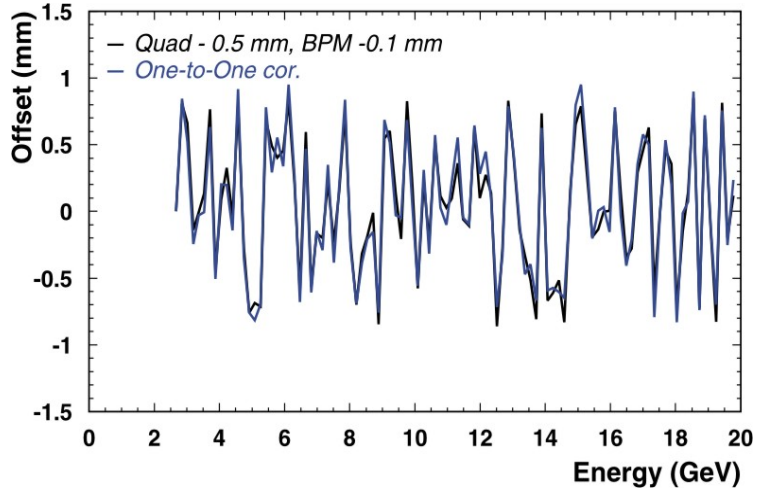


$$\frac{\Delta\varepsilon}{\varepsilon} = \frac{4}{3} < \alpha^2 > \frac{\sigma_0^2 d^2 N_{cav}}{\varepsilon_0 L_c \sin\mu} tg^2 \frac{\mu}{2} \frac{\gamma_0}{\Delta\gamma} \ln^3 \frac{\gamma}{\gamma_0}$$

Quadrupoles misalignments. One-to- One Correction

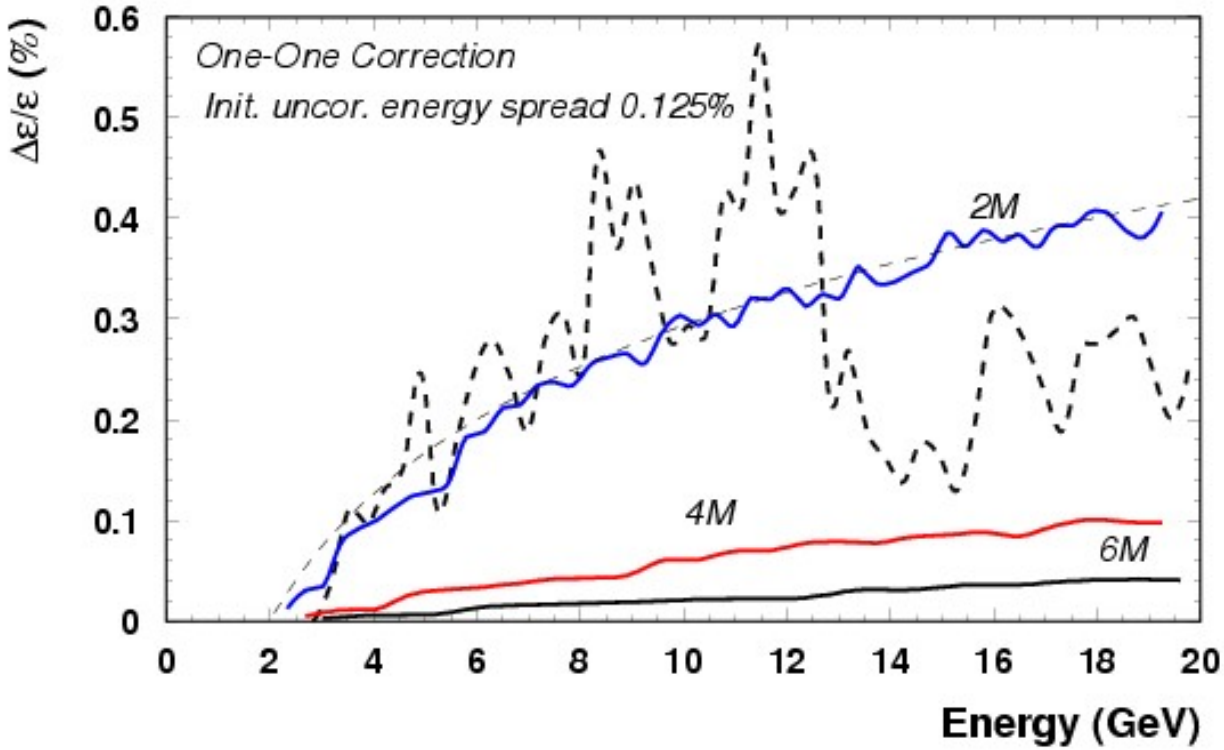






One-to One Correction

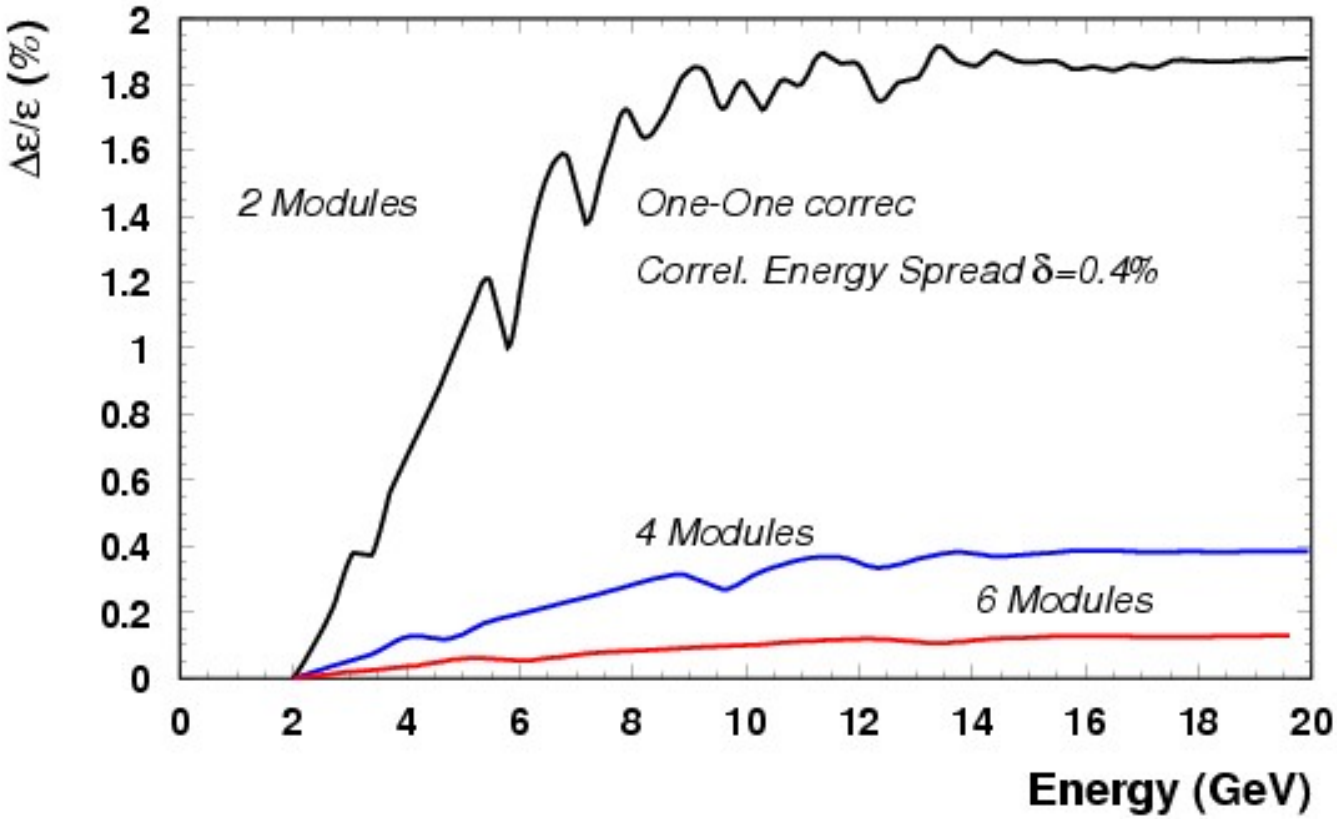
Uncorrelated effects



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

Quad misalignments. One-to-One Correction

Correlated effects

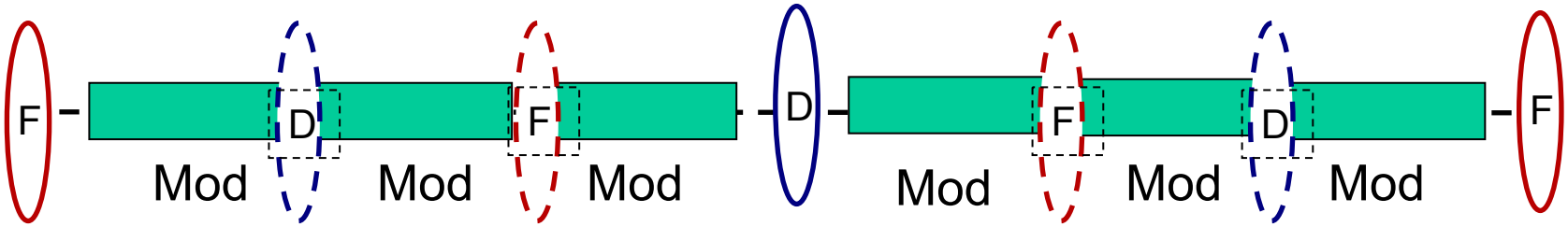


Summary of Emittance Dilution (Standard Cell)

	Booster	Linac
• Coherent oscillations		
uncorrelated	$6 \cdot 10^{-6}$	$2 \cdot 10^{-4}$
correlated	$2 \cdot 10^{-3}$	$1.2 \cdot 10^{-3}$
• Cavity Misalignments	$5 \cdot 10^{-6}$	$3 \cdot 10^{-7}$
• Modules Misalignments	$4 \cdot 10^{-5}$	$2.5 \cdot 10^{-6}$
• Correlated Misal. (130^{o})	-	$7 \cdot 10^{-6}$
• Cavity tilts		
uncorrelated	$5.8 \cdot 10^{-5}$	0.6%
correlated	0.6%	1.9%
• One-to-One correction		
uncorrelated	$6.3 \cdot 10^{-5}$	0.4%
correlated	1.7%	2%

Total Emittance dilution <5% with 2 Modules/Cell

Operation Modes (commissioning)



Modules per cell	2 Mod	4 Mod	6 Mod
Emittance preservation	<5%	< 2%	~ 1%
Beta max	40m	~ 75 m	~110m
Number of FODO cells	52	26	18
Active quads	104	52	36
Quad Strength K (m^{-2})	0.28	~0.17	~0.12