Coupler Effects in High Energy Part of XFEL Linac

Laboratory Report

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- Injector and Linac 1
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- High Energy Linac – 2-20 GeV
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Introduction

Couplers : Wake Field , RF Distortion

Notation and Definitions

$$\lambda(s) - \text{Gaussian bunch with rms width } \sigma$$

$$k_\perp = \langle W \rangle = \int W(s)\lambda(s)ds - \text{kick factor}$$

$$k_\perp^{\text{rms}} = \left\langle (W - k_\perp)^2 \right\rangle^{0.5} = \left[\int \left(W(s) - k_\perp \right)^2 \lambda(s) ds \right]^{0.5} - \text{rms kick factor}$$

$$W_\perp(s, r) = k\ (s) + k^D r$$

k - Monopole term k^D -Dipole term

- Beam coherent oscillations
- Head-Tail Relative kick

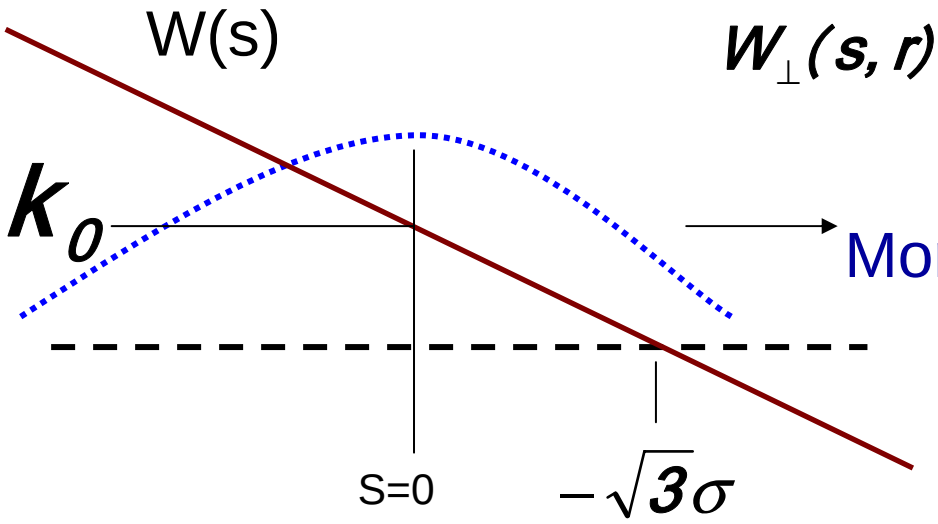
k

k_{rms}

- Wakefield Emittance dilution (Cavity wake)
- Chromatic Emittance dilution (Energy spread)

Model for Transverse Potential

The field potential - linear variation within the bunch



$$W_\perp(s,r) = k_0 + k_{rms}\frac{s}{\sigma} + \left(k_0^D + k_{rms}^D\frac{s}{\sigma}\right)r$$

Monopole term Dipole term

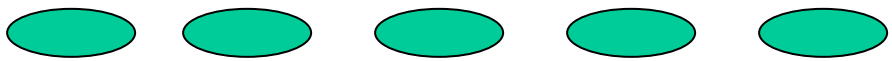
$$|k_0| \approx \sqrt{3}k_{rms}$$

- Coupler RF kick –

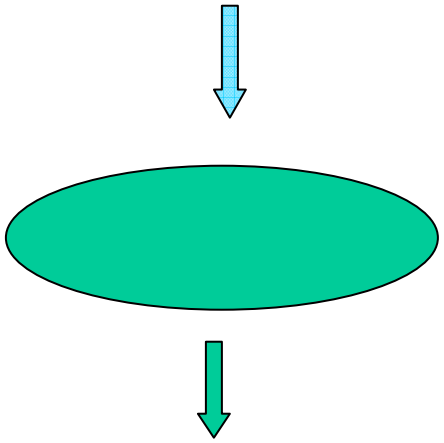
Scaling with accel grad and bunch length

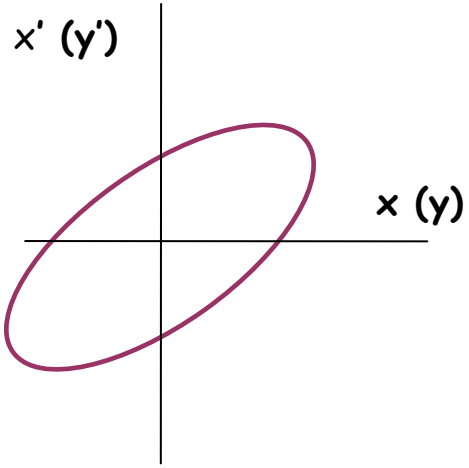
➡ $K_{rf} \sim V_{cav} * \sigma_z$

Beam Model for Particle Tracking



$\rho\,(s, \Delta E/E, x, x', y, y')$

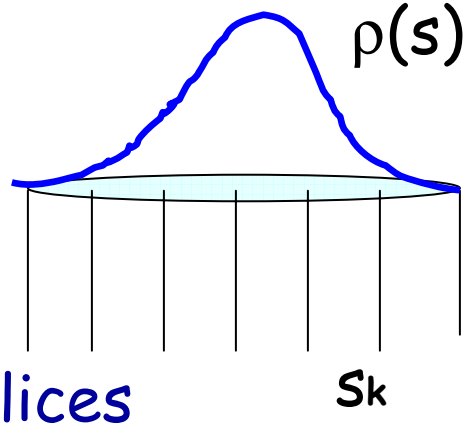




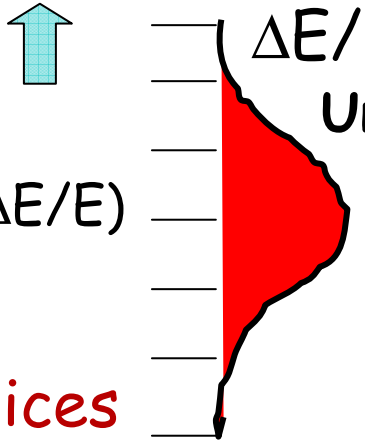
moments

σ_{xx}, $\sigma_{x'x'}$, $\sigma_{xx'}$

σ_{yy}, $\sigma_{y'y'}$, $\sigma_{yy'}$

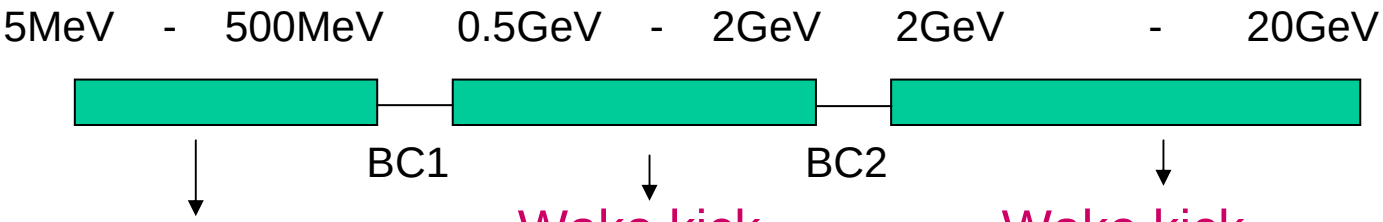


$q(s_k), E(s_k)$



I.Zagorodnov, M. Dohlus

Main Parameters



Monopole	k_{rms}	RF kick	Wake kick	Wake kick
Dipole	k^{D}_{rms}	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

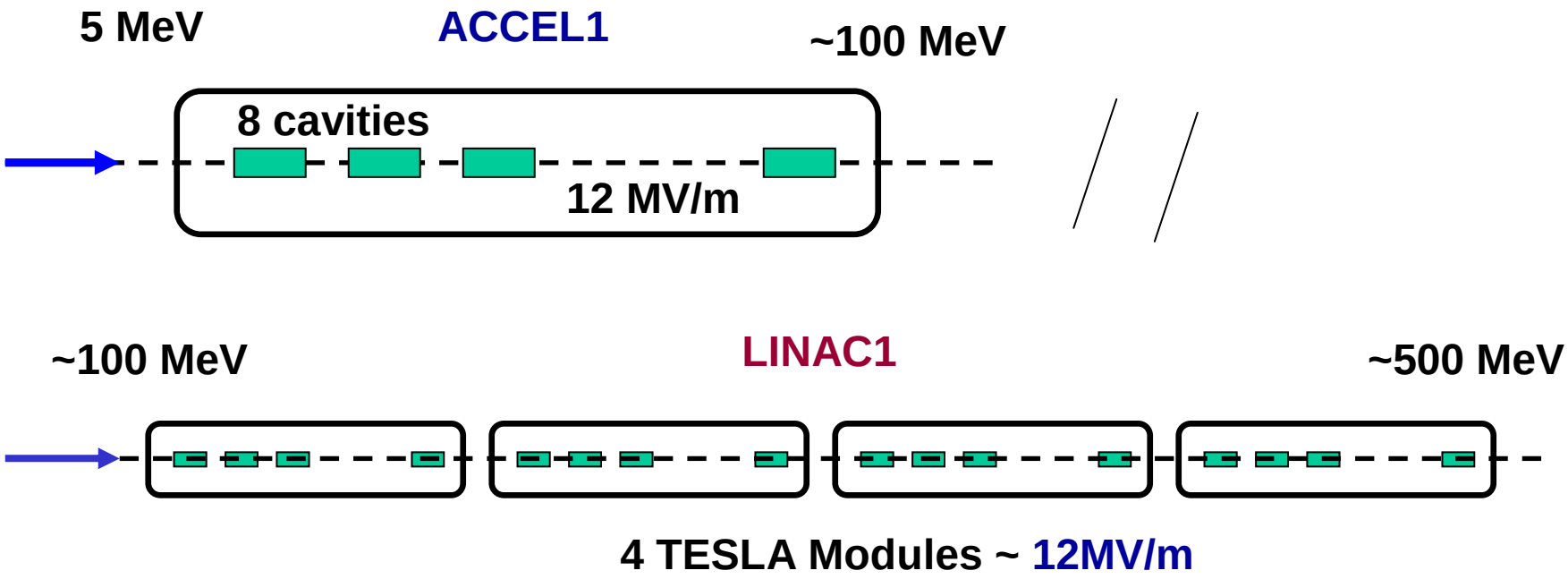
Monopole $k_0 = k_{rms}$

Dipole $k_1 = k^{D}_{rms}$

For cavity $k_0 = 0$

For beam offset < 1mm
monopole term k_0 dominates

Injector Part

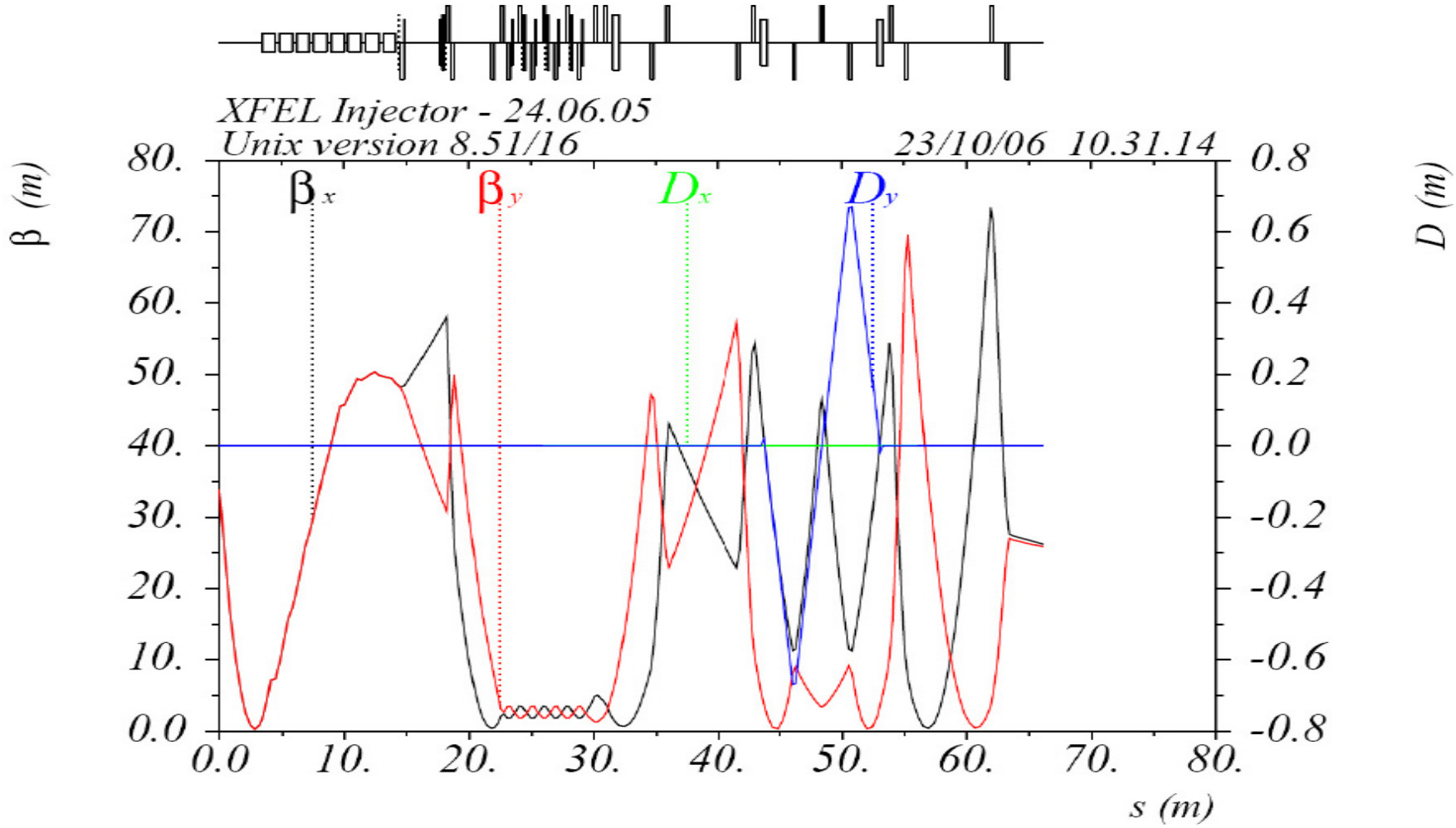


Bunch Charge – 1nC

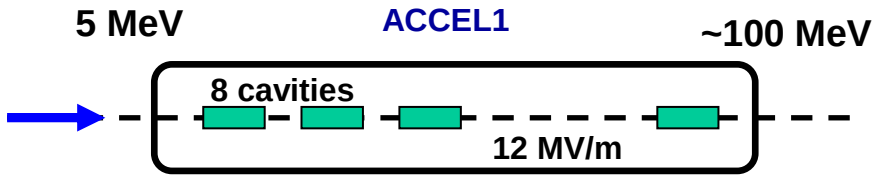
Bunch rms length – 2mm

Normalized emittance – 1mm*mrad

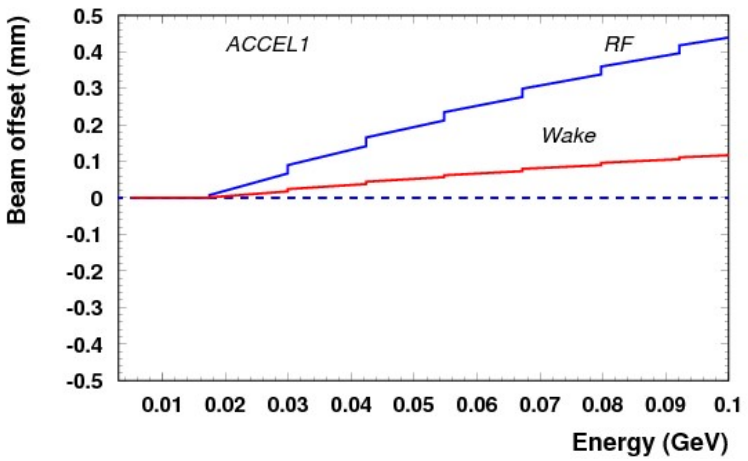
Optics (W. Decking)



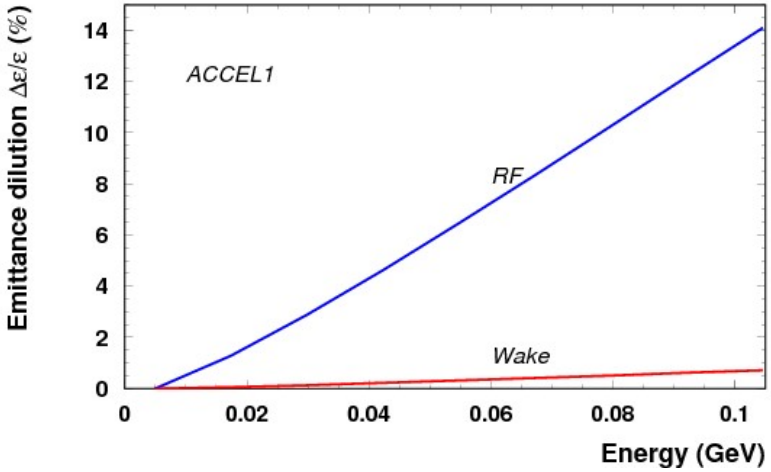
ACCEL 1



Coupler RF Field & Wake



Trajectory



Emittance dilution

Dominate by RF Head –tail kick by monopole term

Cavity wake effect - < 0.1%

Other Options (??)

β_0=2.4

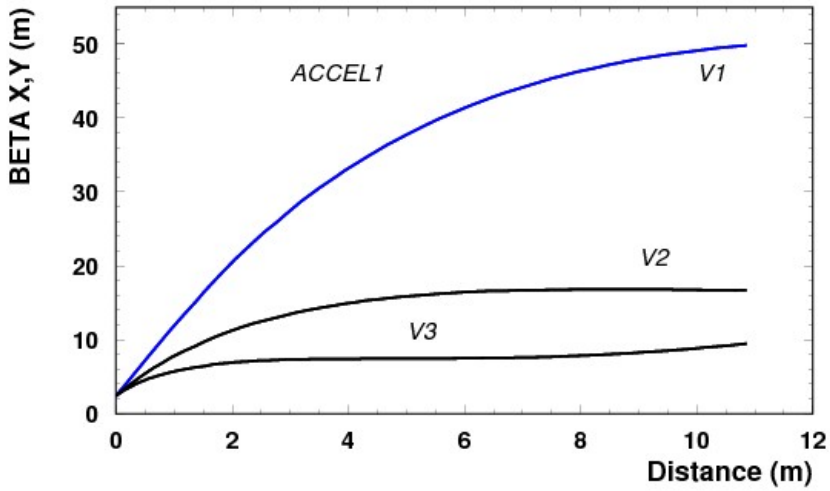
V1: α_0=-4.2

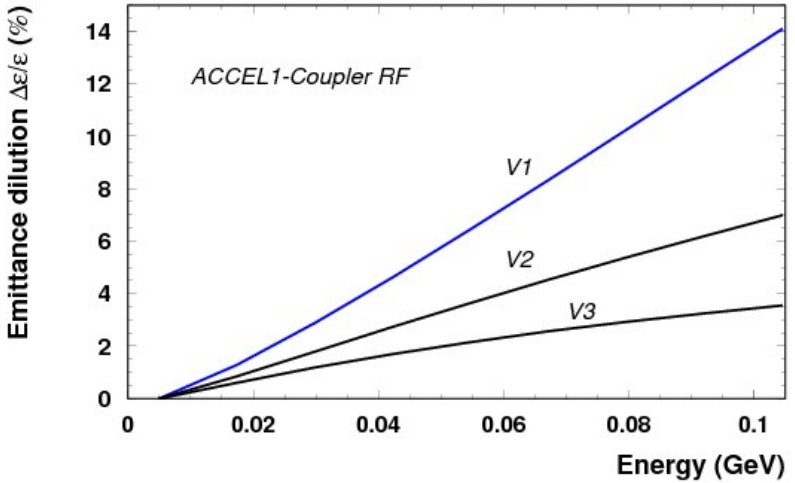
V2: α_0 =-3.0

V3: α_0=-2.3

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

V1- Injector Design





14%

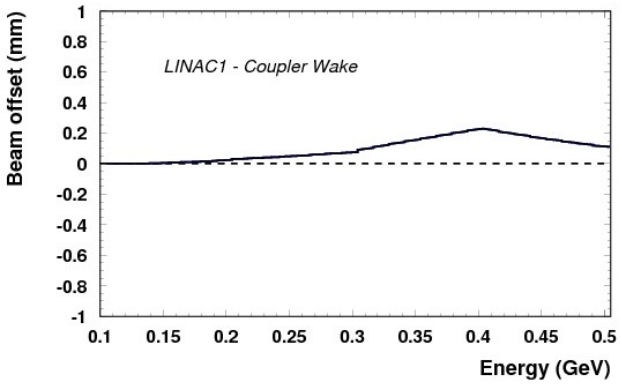
7%

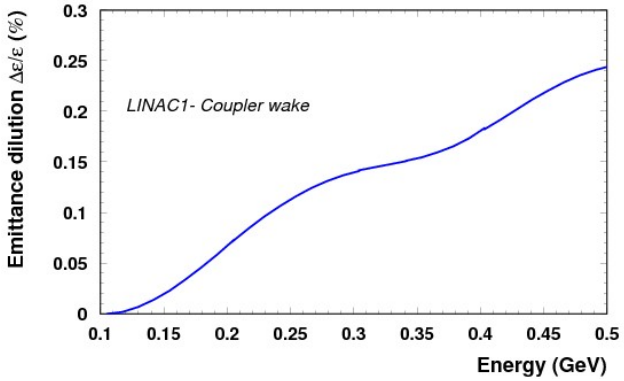
3.5%

LINAC1

4 TESLA Modules ~ 12MV/m

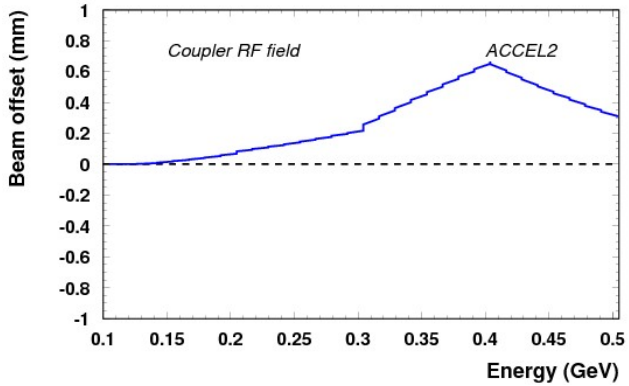
Coupler Wake

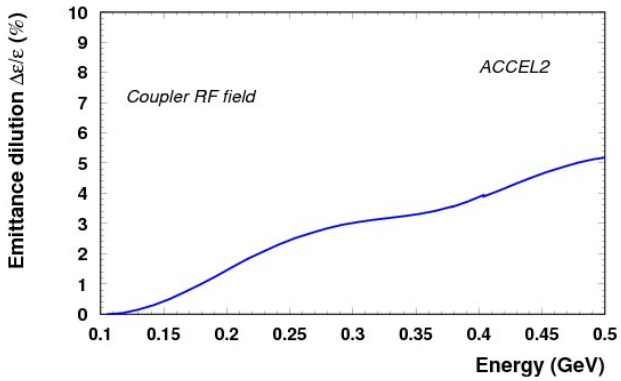




0.25%

Coupler RF





~5%

Summary for Injector

- Coupler RF Field effects

  ACCEL1 – 5-100 MeV
  Emittance growth ~14 %

  Linac 1 – 100-500 MeV
  Emittance growth ~5%

- Other effects

  RF Wake
  Injection Jitter – 1 sigma offset
  Cavity&Modules misal. -0.5mm
  Cavity tilts – 0.5 mrad

  } <1%

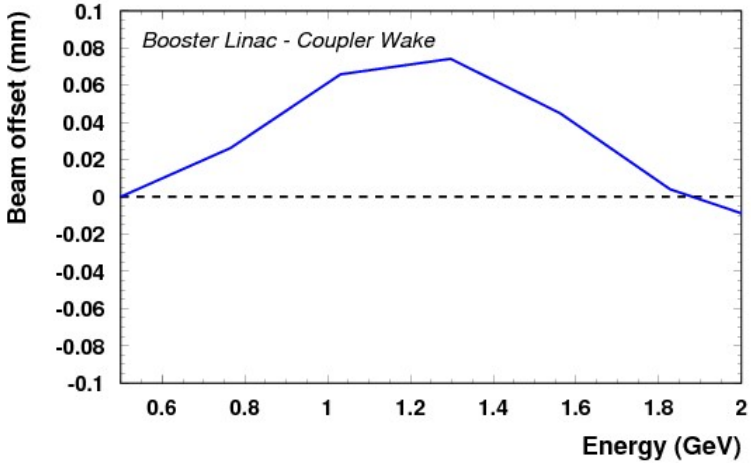
Booster+Main Linac

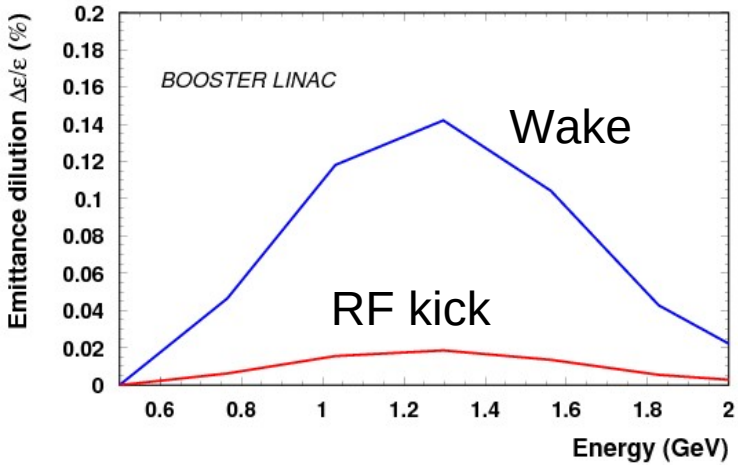
Summary of Emittance Dilution

	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°)	-	$7 \cdot 10^{-6}$
• 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

Booster Linac





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

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

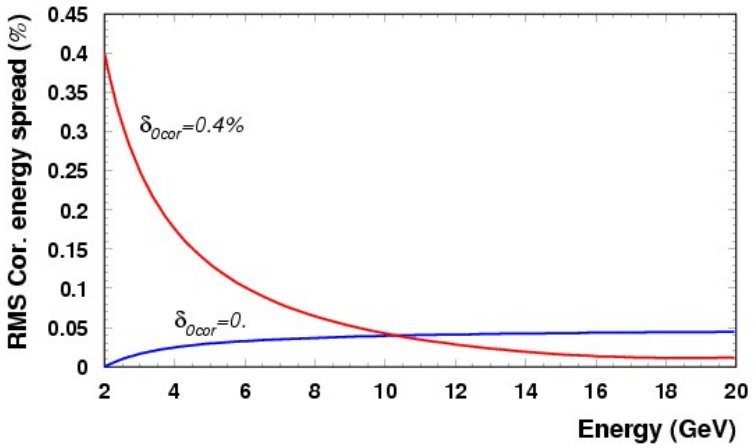
6 FODO cells ➡ $\mu = \pi/3$

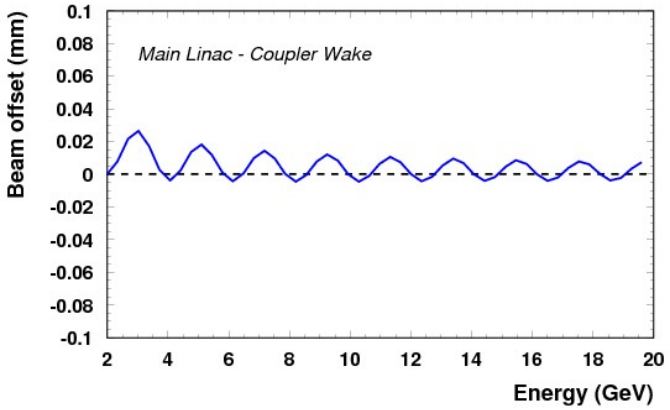
$\Delta\varphi = 2\pi$

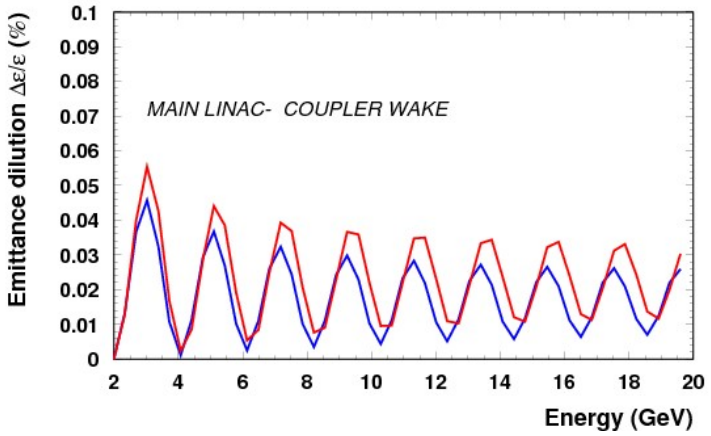
- Dominate by RF Head –tail kick - monopole term
- Natural global compensation

Main Linac- Coupler Wake

52 FODO Cells – Betatron oscillations ~9





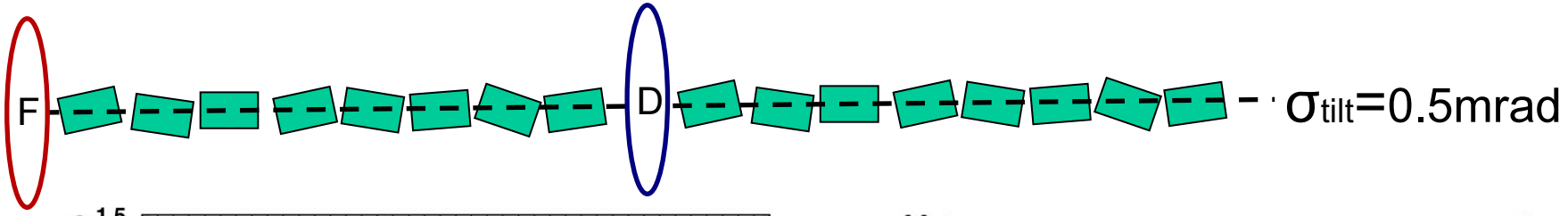


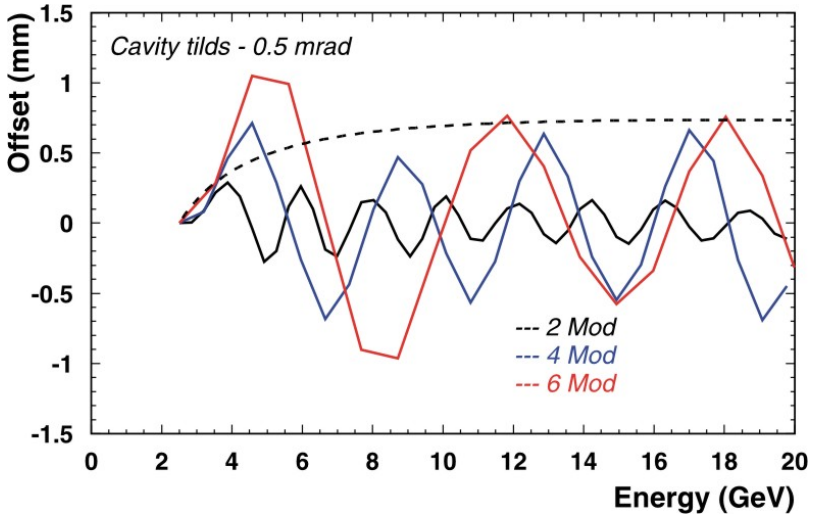
Accum. Emittance Dilution

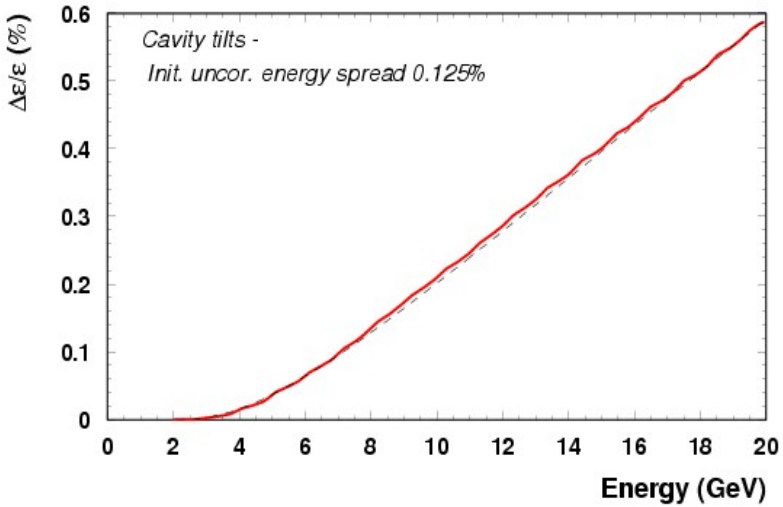
Correlated, Chromatic

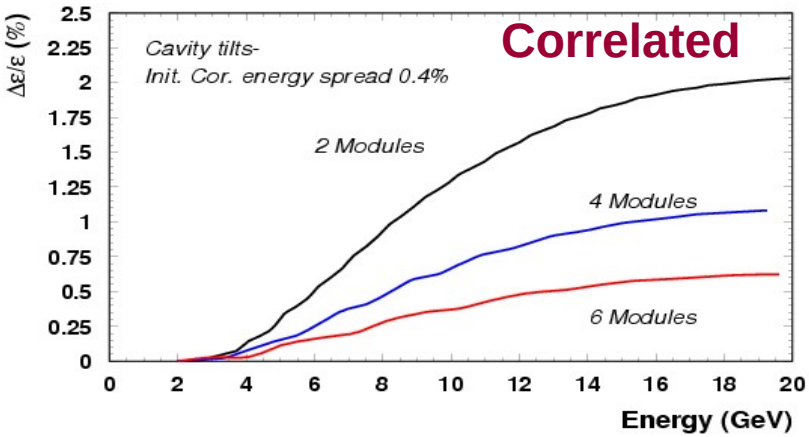
Monopole term - Offset independent wake

Cavity tilts









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

Summary

- **Coupler RF Field effects**

ACCEL1 – 5-100 MeV

Emittance dilution - 14 % (Head Tail kick)

Linac 1 – 100-500 MeV

Emittance dilution – 5% (Head tail Kick)

- **Coupler Wake Effects**

Booster - 0.5-2 GeV

Emittance dilution – 0.02% (Head tail kick)

Main Linac – 2-20 GeV

Emittance dilution – 0.025% (Chromatic)