17TH ADVANCED BEAM DYNAMICS WORKSHOP ON
FUTURE LIGHT SOURCES

Wakefields in the LCLS

K. Bane, SLAC

APRIL 6-9, 1999
ARGONNE NATIONAL LABORATORY, ARGONNE, IL U.S.A.

<u>Wakefields in the LCLS</u>

K. Bane
6 April 99

- Linac
- Undulator

- Longitudinal - correlated energy variation; worse for short bunches
- Transverse - orbit error => emittance growth; better for short bunches

- in linac - wakefields can help cancel rf curvature effect, increase sensitivity to injection conditions, N, σ_z, φ_0 etc

<u>effect on lasing</u>

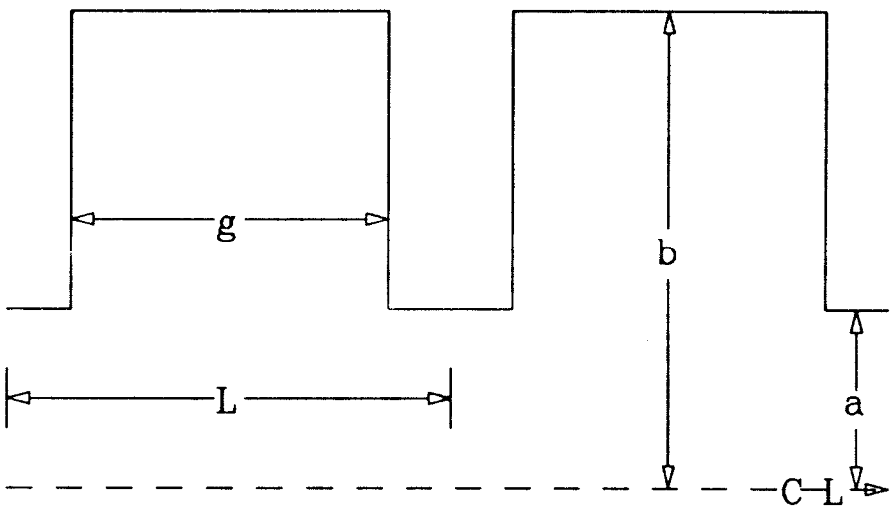
wakefield effect on scale of bunch length $\sigma_z \approx 20\mu m$
lasing over co-operation length $\approx \frac{1}{2}\mu m$
=> factor of 40 reduction in sensitivity

<u>except</u>

<u>within</u> LCLS undulator induced voltage change tolerance $\lesssim 0.1\%$
H-D Nuhn, FEL98
Aug 1998.

- <u>Sources</u>:
  - linac accelerating structures *
  - resistive wall - linac, transfer line, undulator *
  - flange gaps, pumping slots, bellows - undulator
  - roughness - linac, undulator **

Short-Range Wakefields of an Linac Accelerating Structure

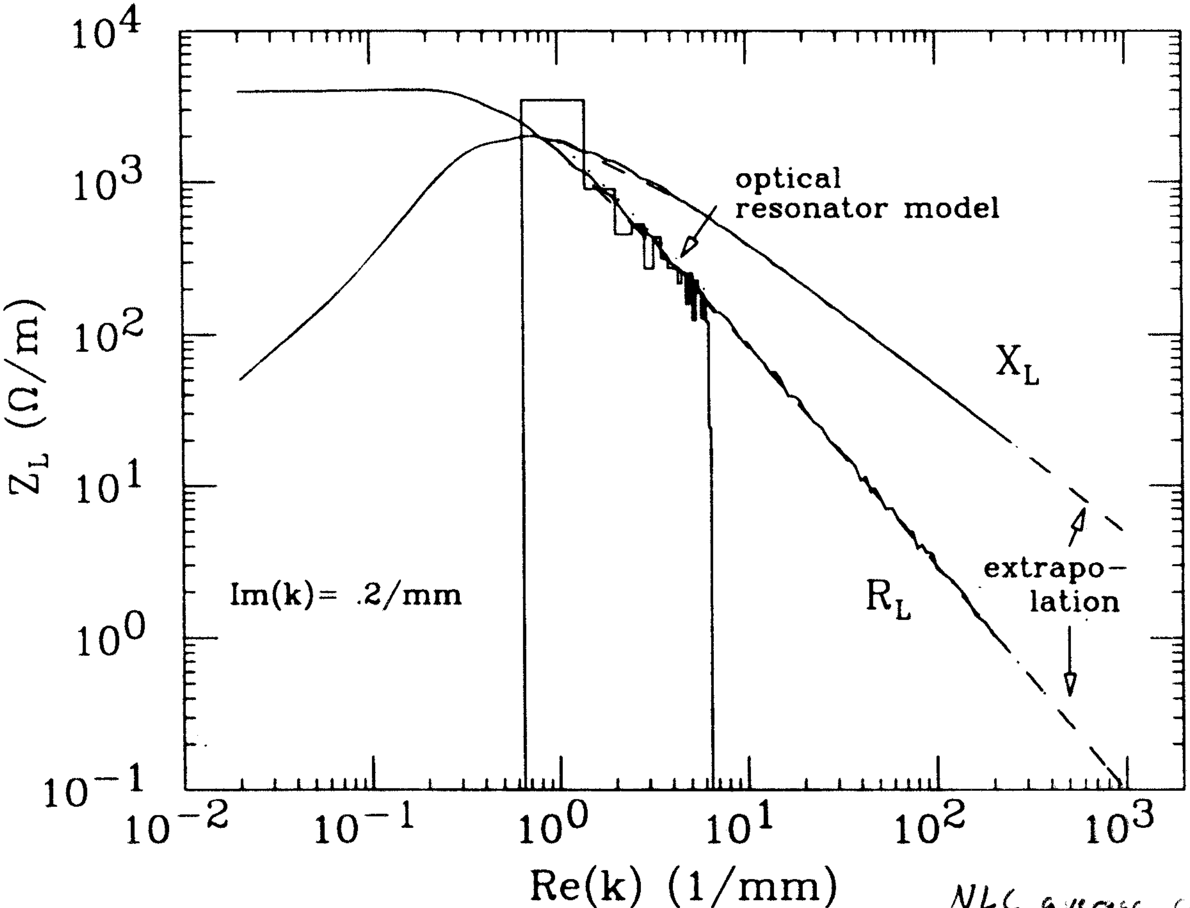


Schematic of Disk-Loaded Accelerating Structure

For SLAC linac — K. Bane + P B Wilson, Int. High Energy Conf. Proceedings, 1980, p. 592

Longitudinal Impedance of a Periodic Accelerating Structure

K. Bane, et al, ICAP98



NLC average cell

At high frequencies

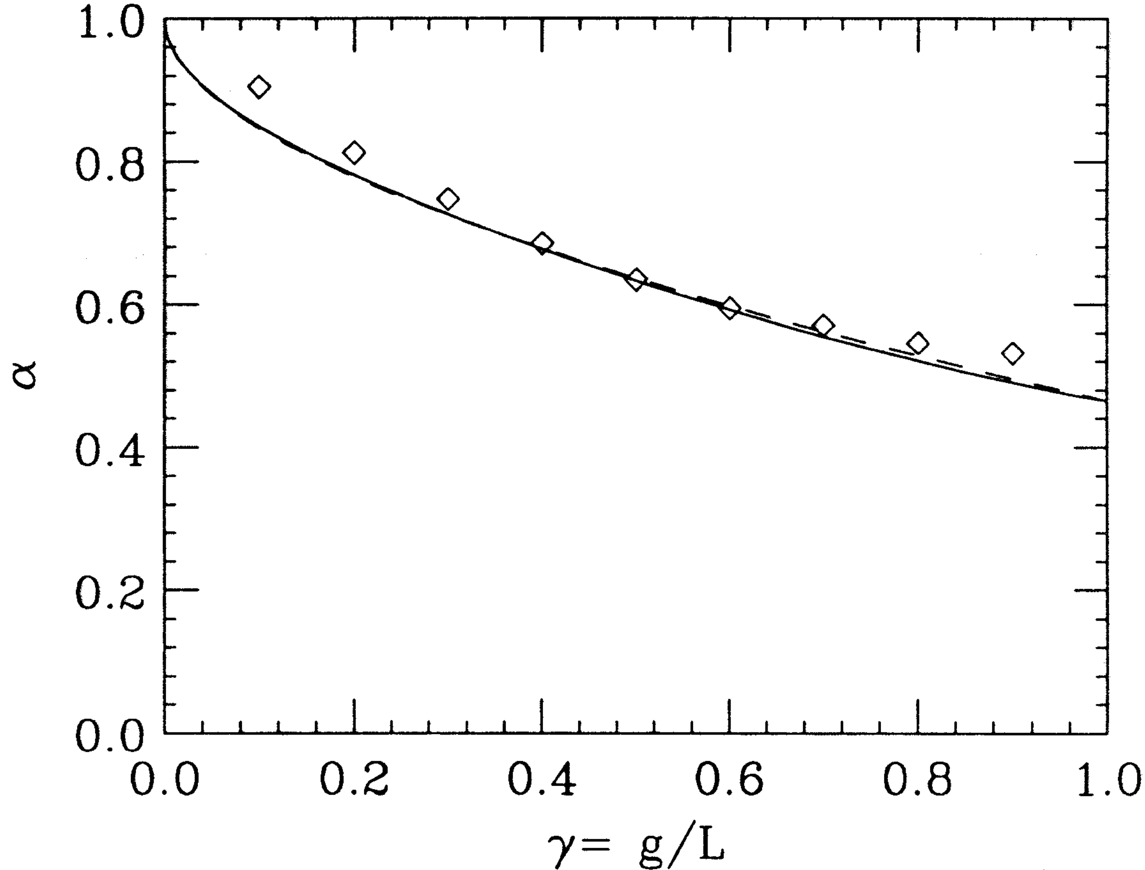
$$Z_L = \frac{i Z_0}{\pi k a^2}\left[1 + (1+i)\frac{\alpha L}{a}\sqrt{\frac{\pi}{k g}}\right]^{-1}$$

R. Gluckstern, Phys Rev D39, 2773 (1989)
2780 (1989)

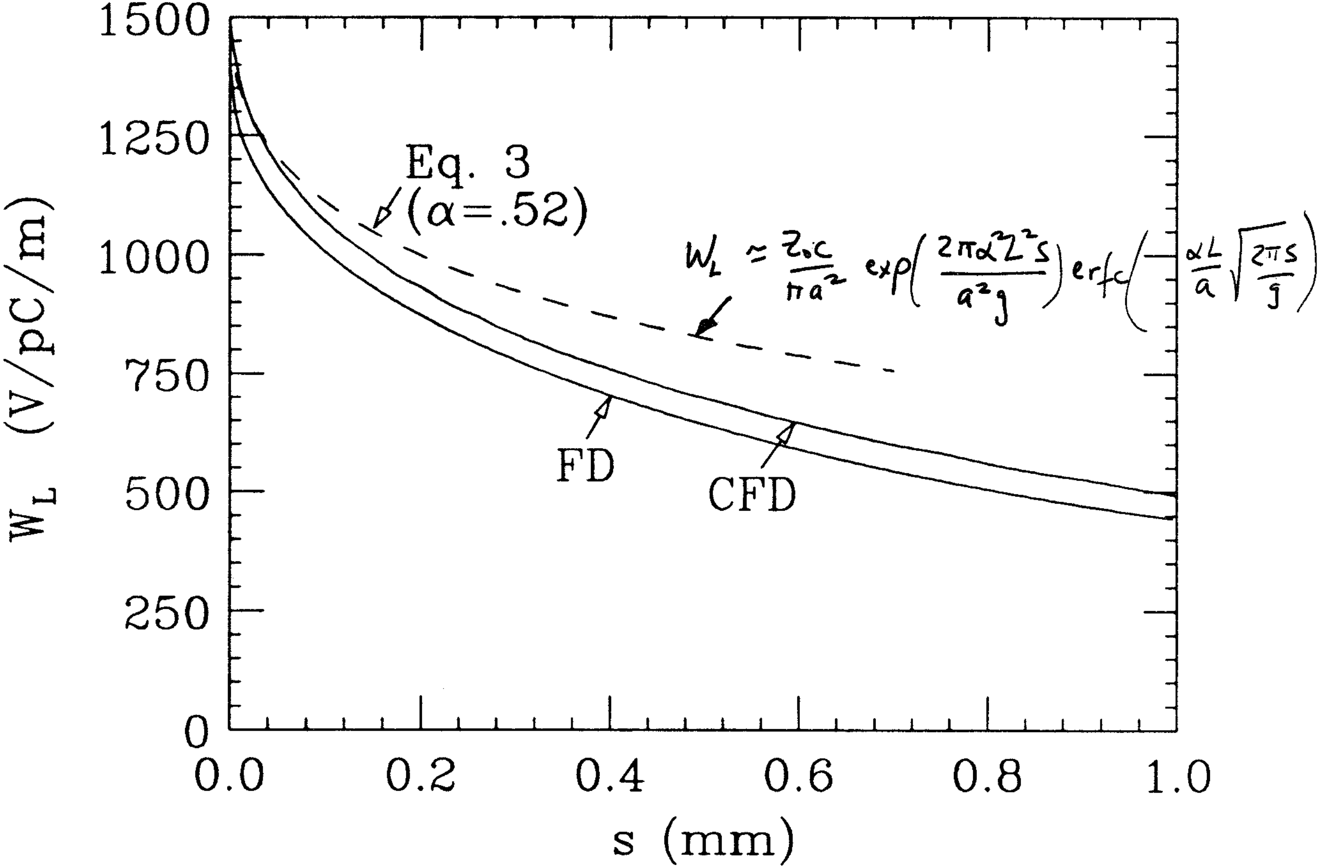
S. Heifets + S. Kheifets 560 (1989)

K. Yokoya + K. Bane, PAC 99

- recently $Z_\perp$ also solved
Gluckstern, et al PAC 99

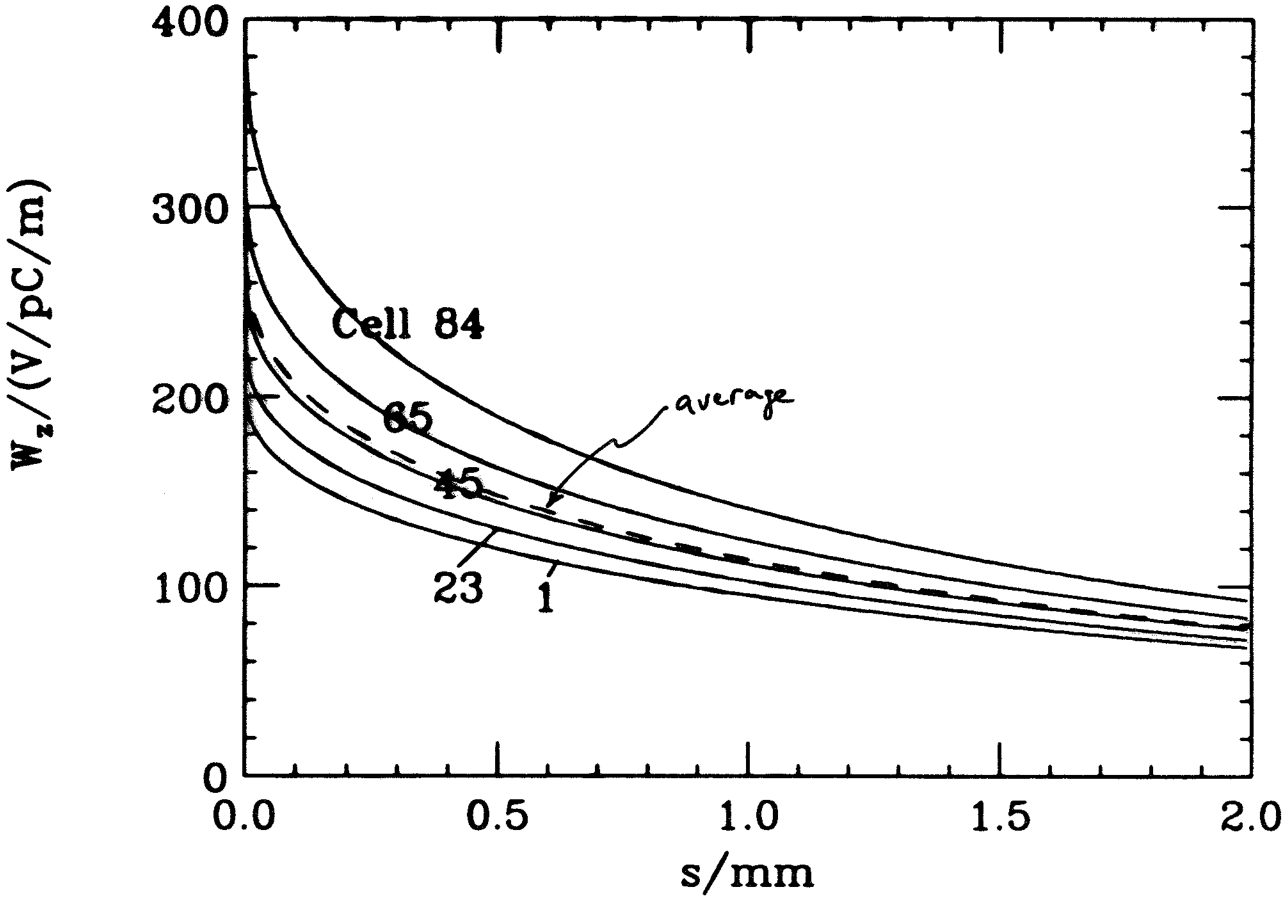


◇ numerical results

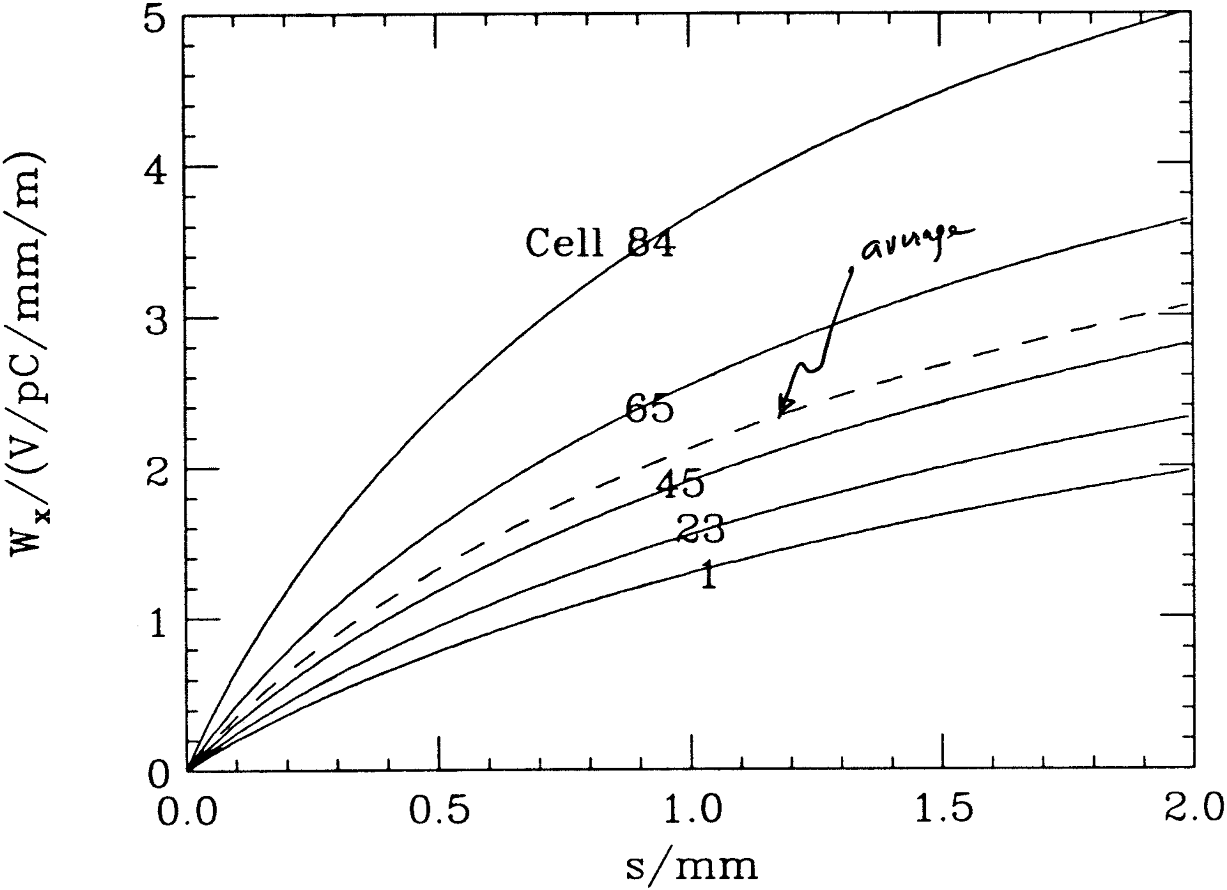


NLC average cell

SLAC structure - 84 cells



Longitudinal Wake



SLAC structure, Transverse Wake

Impedance of a Rough Surface

① K. Bane, C.K. Ng, A. Chao, PAC97, p. 1738

② A. Mosnier + A. Novokhatski, PAC97, p1661.

see also: more papers by A. Novokhatski, etal, EPAC98, PAC99, ICAP98

G. Stupakov, Phys Rev ST-AB 1, 064401 (1998)

K. Bane + G. Stupakov, ICAP98.

K. Bane + A. Novokhatski LCLS-TN-99-1, SLAC-AP-117, March 1998

① Inductive Model

rough surface - smooth surface with collection of simple, noninteracting bumps

if $\sigma_z \gg \delta$ bump size

one bump is inductive

rough surface $\quad \mathcal{L}/L = \alpha f \dfrac{Z_0 \delta}{4\pi c a}$

α - surface filling factor

f - form factor depending on shape of bumps $(1 \lesssim f \lesssim 2.5)$

δ - bump size

a - tube radius

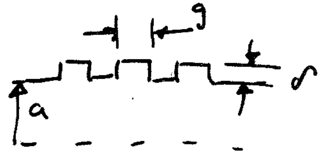
Induced voltage:

$$V_{ind} \simeq -\mathcal{L} e c N \lambda_z'$$

② Resonator Impedance Model

Impedance can be described by one pure, loss-free resonator

$$k \simeq \sqrt{\frac{4}{a\delta}}$$

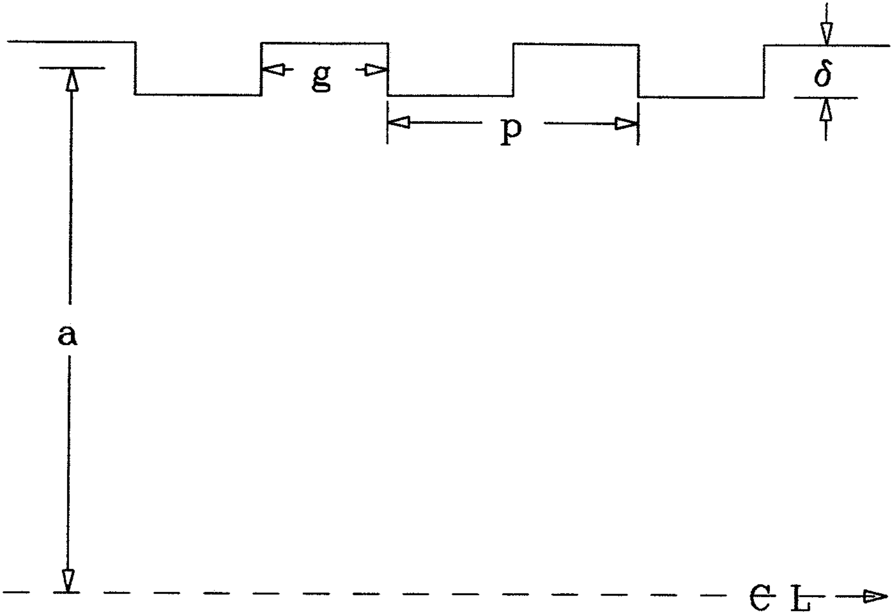


$$W_z(s) = \frac{Z_0 c}{\pi a^2} \cos ks \qquad s > 0$$

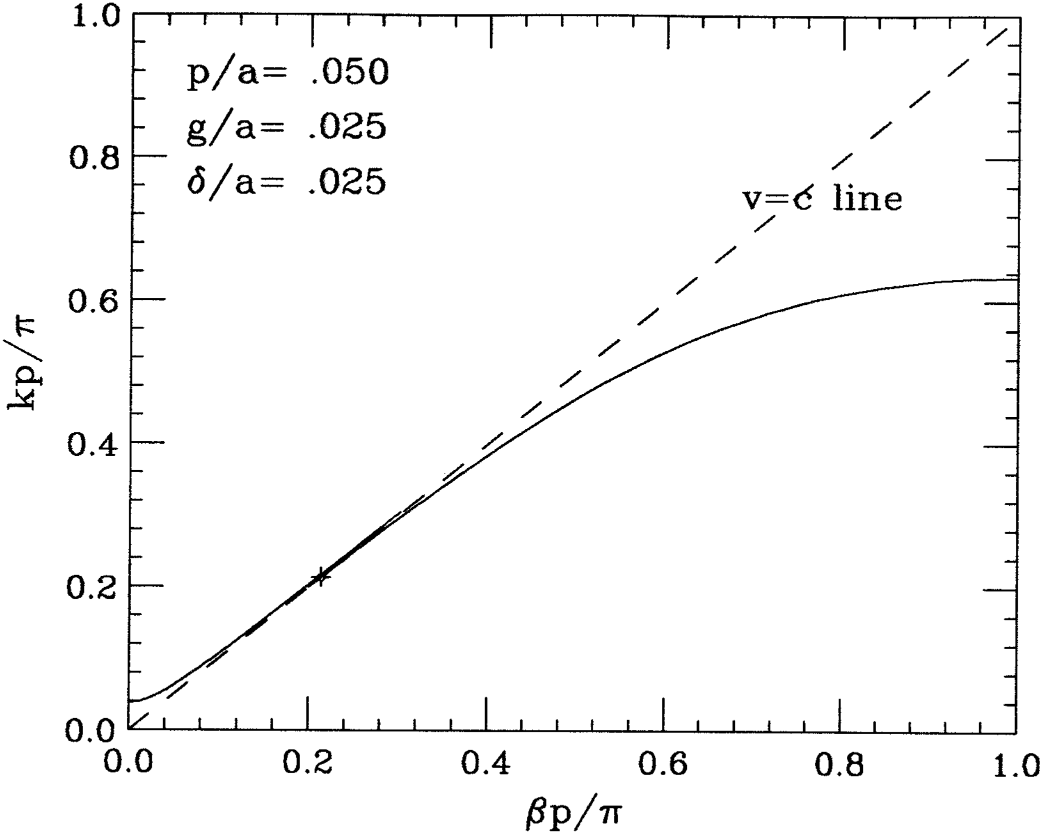
- behavior of thin dielectric layer on ~~metta~~ metallic surface, bellows

- for rough surface take $\delta \simeq \delta_{rms}$
- for 3d use $\delta_{3d} \simeq \frac{\delta}{3}$

- in limit of smooth bunches with $k\sigma \gg 1$, result is inductive, similar to inductive model

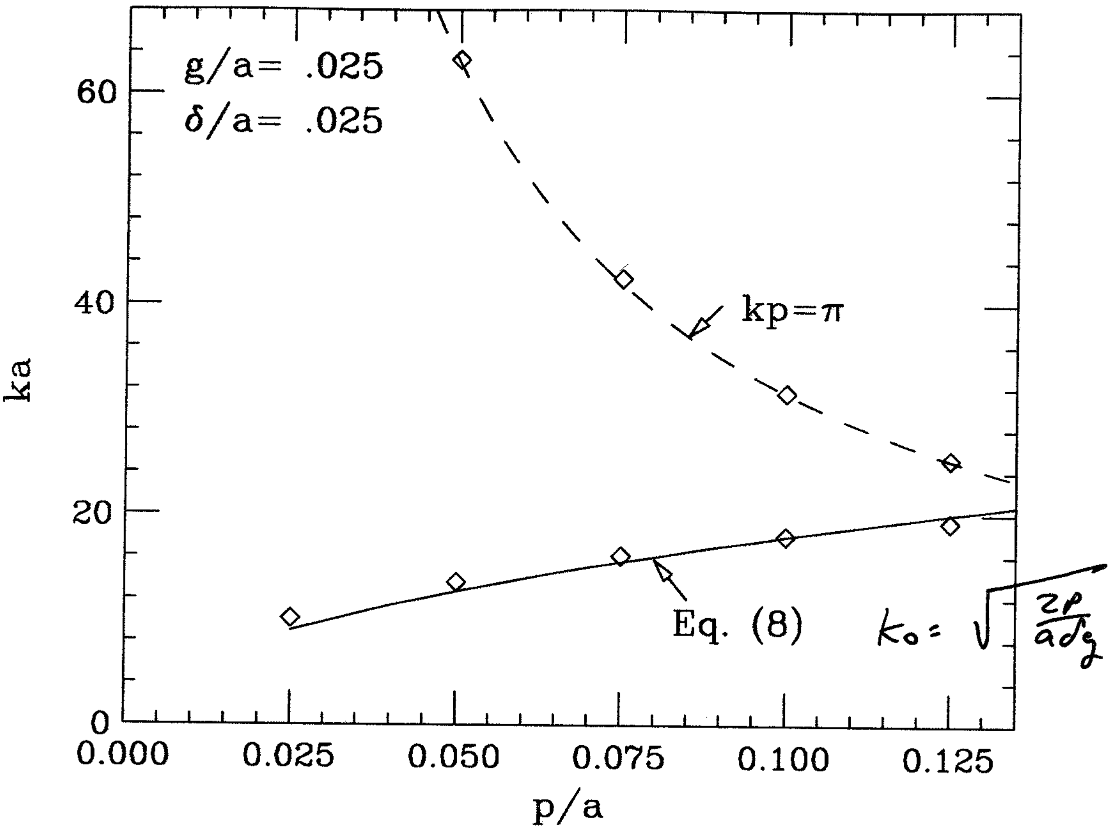


Geometry Used in Simulations

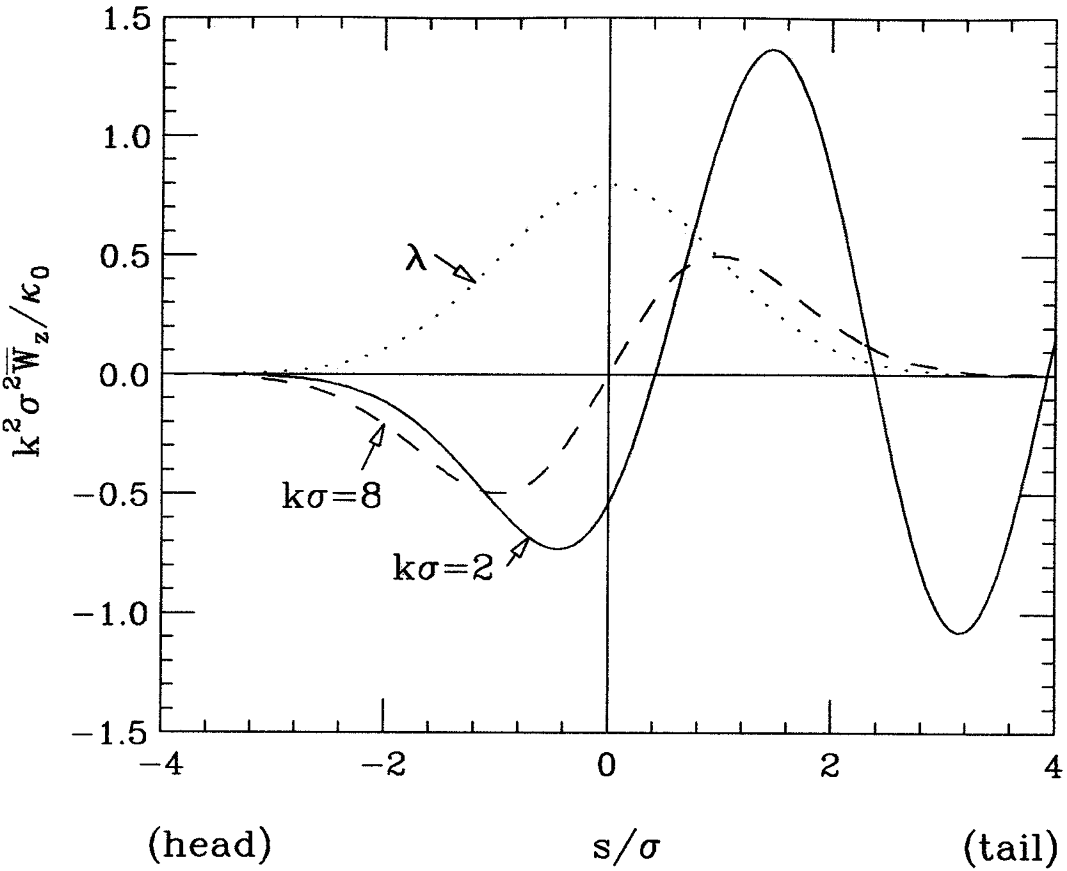


Dispersion Curve

Synchronous frequency: $k_0 = \sqrt{\frac{2p}{4\delta g}}$

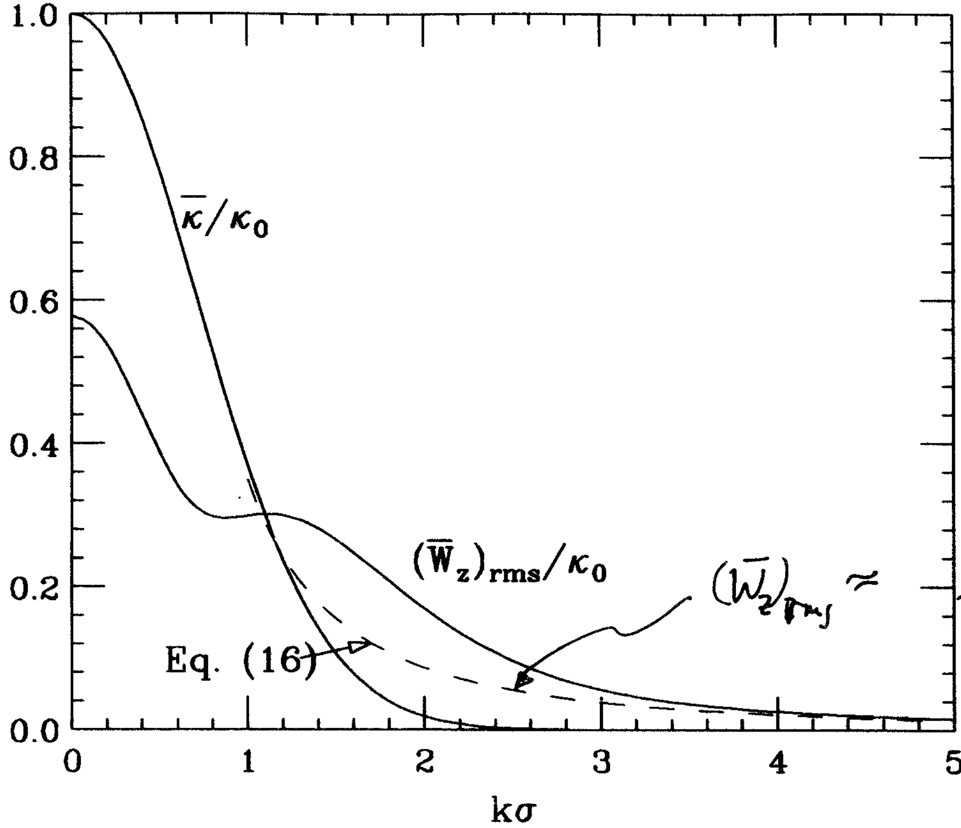


Dependence of synchronous frequency of 1st two modes on period



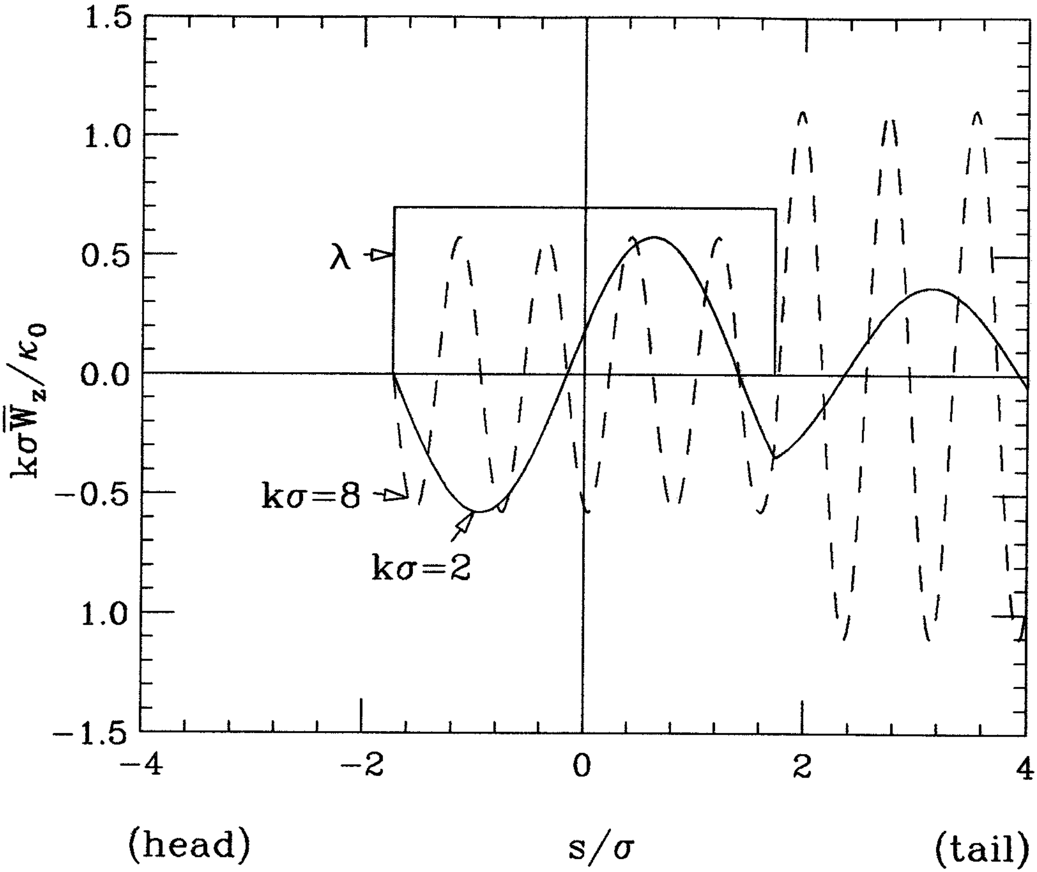
Bunch Wake for a Gaussian Bunch

$W = 2\kappa_0 \cos ks$

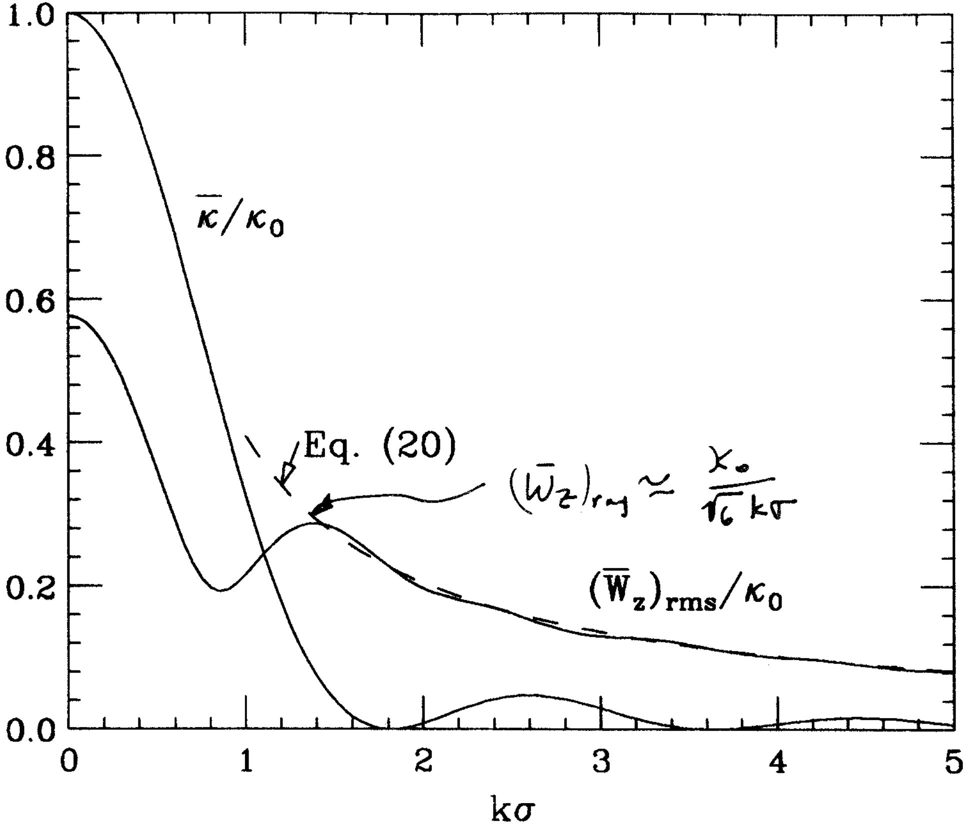


$$(\bar{W}_z)_{rms} \approx \frac{2^{1/2}}{3^{3/4}\pi^{1/2}} \frac{\kappa_0}{k^2\sigma^2}$$

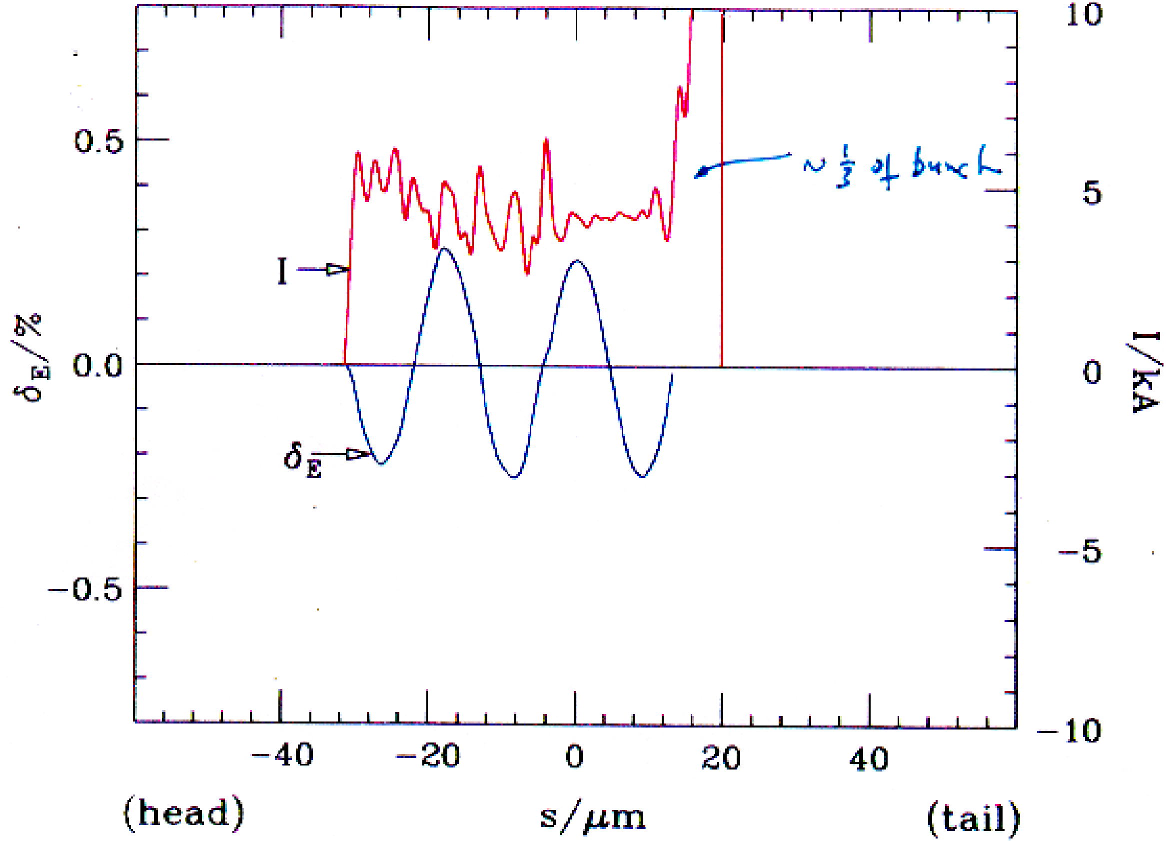
Gaussian Bunch



Rectangular Bunch



Rectangular Bunch.



$\delta = 50\,nm$ $\quad (\delta_E)_{avg} = .20\%$ $\quad n \pm .1\% = .16$

$\delta = 10\,nm$ $\quad .07\%$ $\quad .63$

Table 1: The average and rms energy spread increase due to the roughness wakefields, and the fraction of beam within a window of $\pm 0.1\%$, at the end of the LCLS undulator, as given by the inductive and the resonator models. Results are given for Gaussian and rectangular bunch shapes with rms length $\sigma = 15\ \mu$m, and for roughness sizes $\delta = 1$, 0.1, 0.01 μm.

δ/μm	$k_{3d}\sigma$	Model	Bunch Shape	$\langle\delta_E\rangle/\%$	$(\delta_E)_{rms}/\%$	$n_{\pm.1\%}$
1.		Inductive	Gaussian	0	.79	.04
	1.0	Resonator	Gaussian	.83	.67	.04
			Rectangular	.73	.49	.06
.1		Inductive	Gaussian	0	.08	.69
	3.2	Resonator	Gaussian	.00	.10	.48
			Rectangular	.03	.29	.16
.01		Inductive	Gaussian	0	.01	1.
	10.	Resonator	Gaussian	.00	.01	1.
			Rectangular	.01	.09	.56

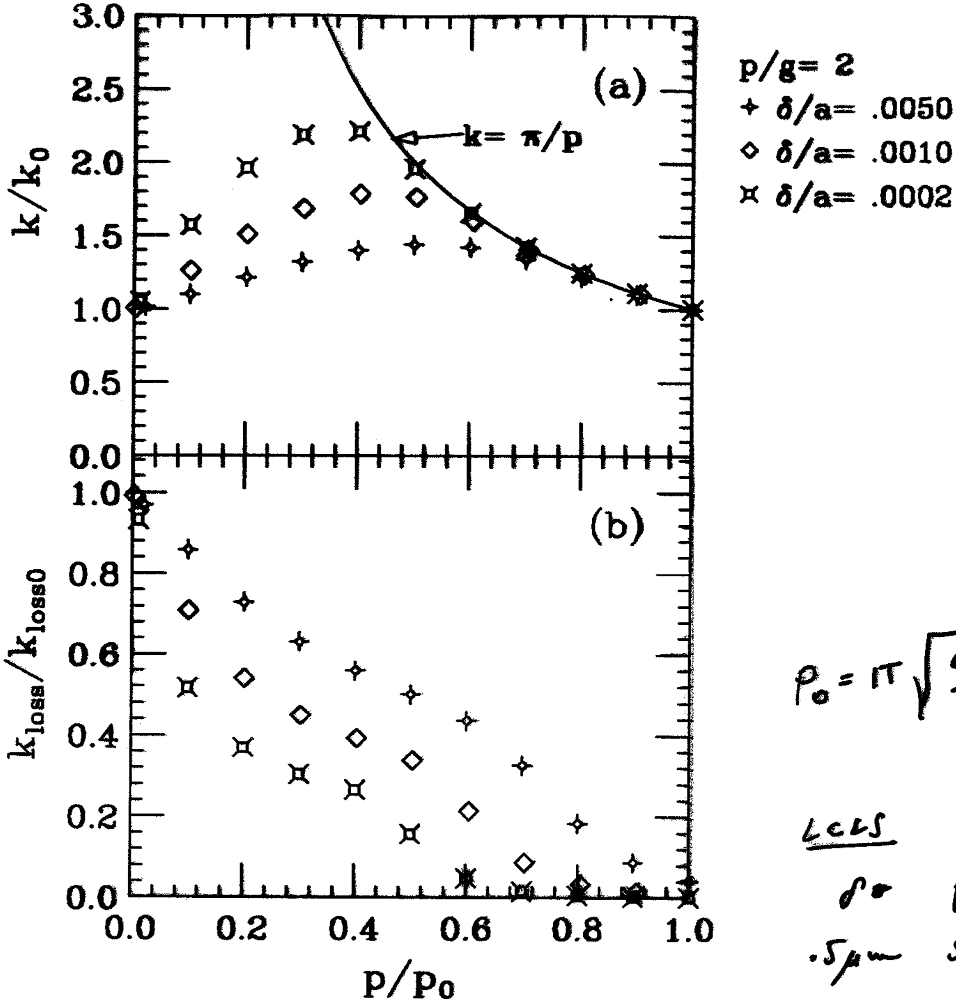
Discussion

These results appear to set severe requirements on the beam tube surface smoothness. How smooth a beam tube surface can we expect to obtain? At present there is a program at SLAC to prepare and measure the inner surface of 2.5 mm radius beam tubes. Two preliminary observations suggest that the surface roughness effect will not be as severe as one might expect from the results above[18]: (1) It appears that, through electro-polishing the surface, the effective depth δ can be reduced to 10–20 nm. (2) The aspect ratio of roughness features, *i.e.* the period to depth of features, instead of being near 1 as assumed here, may be much larger, on the order of 50–100. According to calculations, for such aspect ratios the strength of the first resonance can be greatly suppressed[20].

A Proposal to Measure the Roughness Wake at SLAC

To verify the models of roughness impedance it would be desirable to perform measurements. Since the effects are small a beam tube with an artificially prepared surface, one with enhanced features, will probably be necessary. One program to measure the impedance of surface roughness is being planned for the Collimator Wakefield Test Facility to be constructed

$$\delta_E = \frac{e^2 N \bar{W}_z L}{E}$$



LCLS => $\delta = .5\mu m$

$$\rho_0 = \pi \sqrt{\frac{a\delta g}{2p}}$$

LCLS

δ	ρ_0	$\frac{\rho_0}{\delta}$
$.5\mu m$	$56\mu m$	110
50nm	$18\mu m$	360

eg. rectangular bunch $\sigma = 15\mu m$

$\delta = .1\mu m$

$\rho/\delta = 50$

$$\left.\begin{aligned} \rho/\rho_0 &= .2 \\ k/k_0 &= 2.65 \\ k_{3d}\sigma &= 8.70 \\ \chi/\chi_0 &= .25 \end{aligned}\right\} \quad (\delta_E)_{rms} = .025\% \qquad \eta_{\pm .1\%} = 1$$

Conclusions

- non-smooth bunch shape, inductive model not applicable
- resonator model => roughness tolerance ~10nm
- if $p/\delta \gg 1$ can get suppression of resonator mode

  may increase tolerance $\gtrsim$ 100 nm

  (preliminary measurements suggest 10-20nm

  may be possible)

study is continuing