XFEL
X-Ray Free-Electron Laser

Collimator Wakefields

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25.09.06

Codes

- ECHO
- CST MS

Used by me

- ABCI
- MAFIA
- GdfidL
- VORPAL
- PBCI
- Tau3P

References

- K. Yokoya, CERN-SL/90-88, 1990
- F.-J.Decker et al., SLAC-PUB-7261, 1996
- G.V. Stupakov, SLAC-PUB-8857, 2001
- P. Tenenbaum et al, PAC’01, 2001
- B. Podobedov, S. Krinsky, EPAC’06, 2006
- I. Zagorodnov, K.L.F. Bane, EPAC‘06, 2006
- K.L.F. Bane, I.A. Zagorodnov, SLAC-PUB-11388, 2006
- I. Zagorodnov et al, PAC‘03, 2003
- and others

Outline

- Round collimators
  - Inductive regime
  - Diffractive regime
  - Near wall wakefields
  - Resistive wakefields
- 3D collimators (rectangular, elliptical)
  - Diffractive regime
  - Inductive regime
- Simulation of SLAC experiments
- XFEL collimators
  - Effect of tapering and form optimization
  - Kick dependence on collimator length

Effect of the kick

By rounding the edges (r = 9 mm) the geometric wakefield component of the tapered collimator (R = 10 m) is reduced by a factor of 2. This then gives an expected maximum dipole kick for our flat jaws of $\Delta y'$= 1.3 μrad. A $3\sigma_y'$ kick gives an emittance growth of about 30% and $5\sigma_y'$ about 60%.

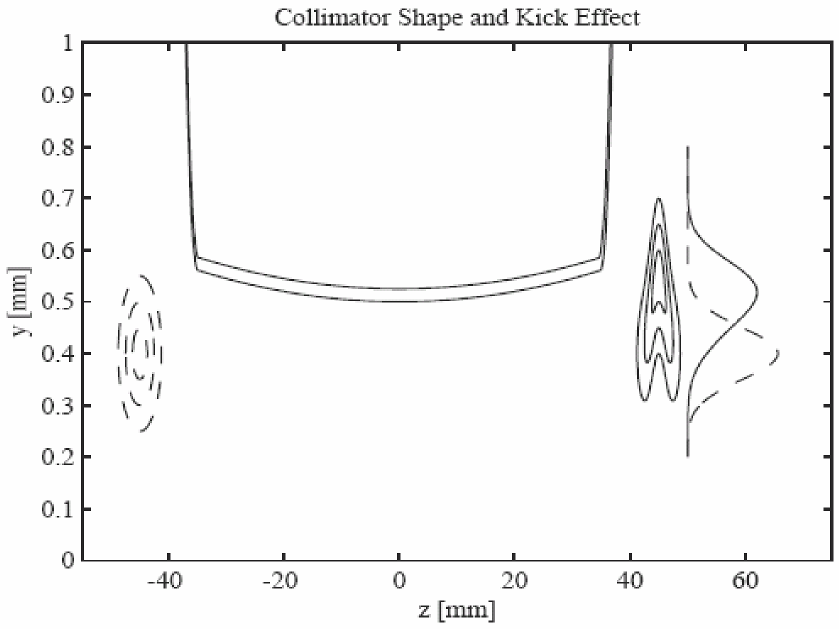


Fig. 2: Tapered collimator and a resultant wakefield kick of $3\cdot\sigma_y$. The contour lines and projections of the incoming (dashed), and outgoing beam (solid) are shown.

Design and Wakefield Performance of the New SLC Collimators

F.-J. Decker, K. Bane, P. Emma, E. Hoyt, C. Ng, G. Stupakov, J. Turner, T. Usher, S. Virostek, D. Walz

SLAC*, California, USA

Round collimator. Regimes

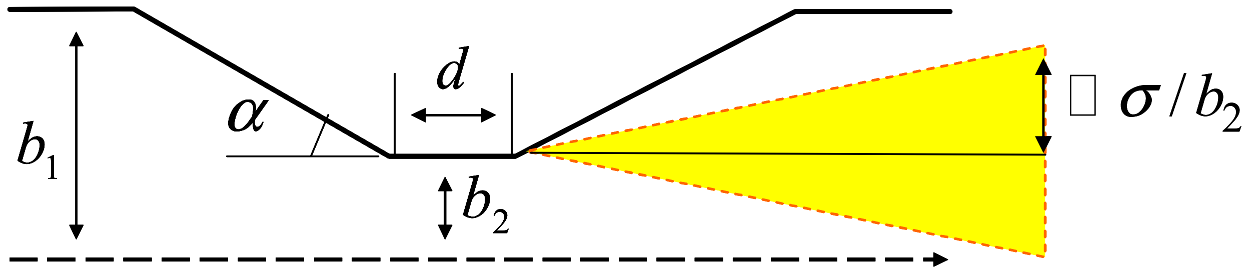


Figure 1: Top half of a symmetric collimator.

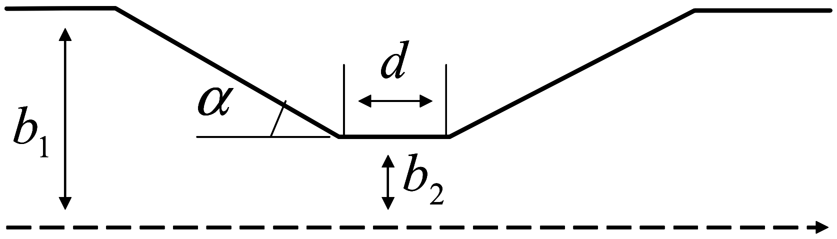
Inductive

$\rho_1 \equiv \alpha b_2 \sigma^{-1}$ □ 1

Diffractive

ρ_1 □ 1

Round collimator. Inductive



$$\Theta = Z_0 c / 4\pi$$

Inductive $\rho_1 \equiv \alpha b_2 \sigma^{-1} \ll 1$

$$Z_{\parallel}^{0} = \Theta \frac{i\omega}{c^2} \int_{-\infty}^{\infty} \left(f' \right)^2 dz$$

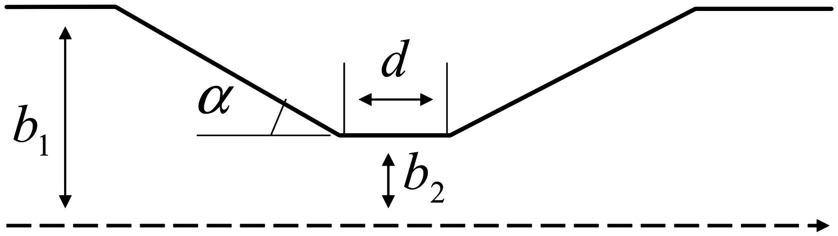
$$Z_{\perp}^{1} = \Theta \frac{2i}{c} \int_{-\infty}^{\infty} \left(\frac{f'}{f} \right)^2 dz$$

$$k_{\parallel} = 0$$

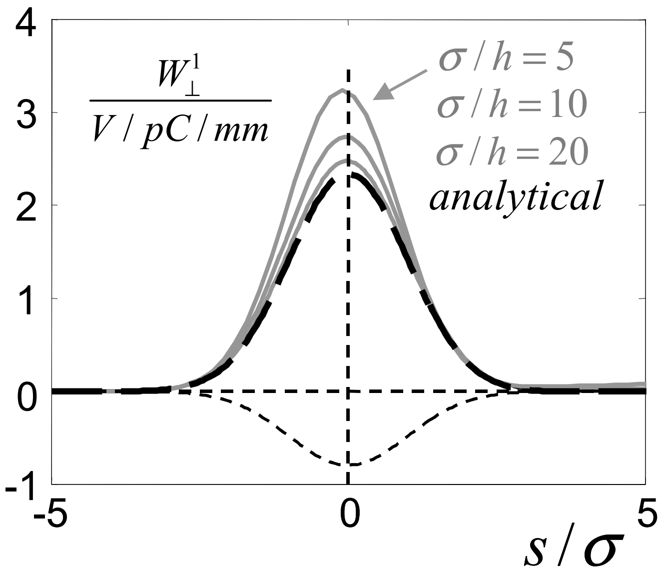
$$k_{\perp} = \frac{2\alpha}{\sqrt{\pi}\sigma} \left(\frac{1}{b_2} - \frac{1}{b_1} \right) \frac{Z_0 c}{4\pi}$$

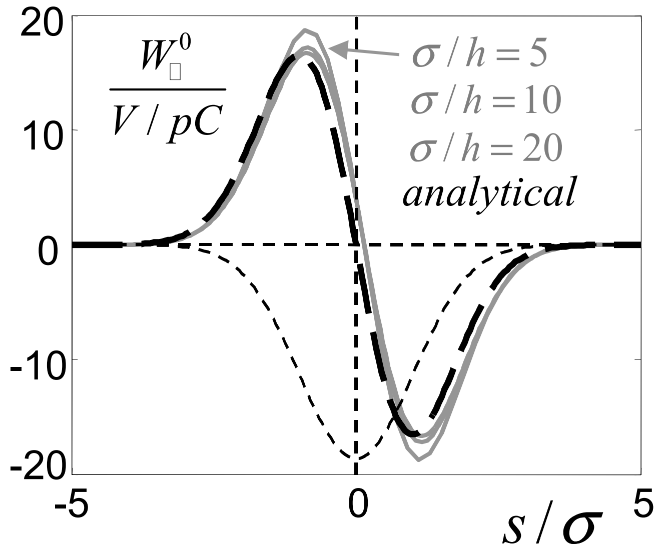
$$k_{\perp} = O\left(\frac{\alpha}{b_2} \right)$$

Round collimator. Inductive



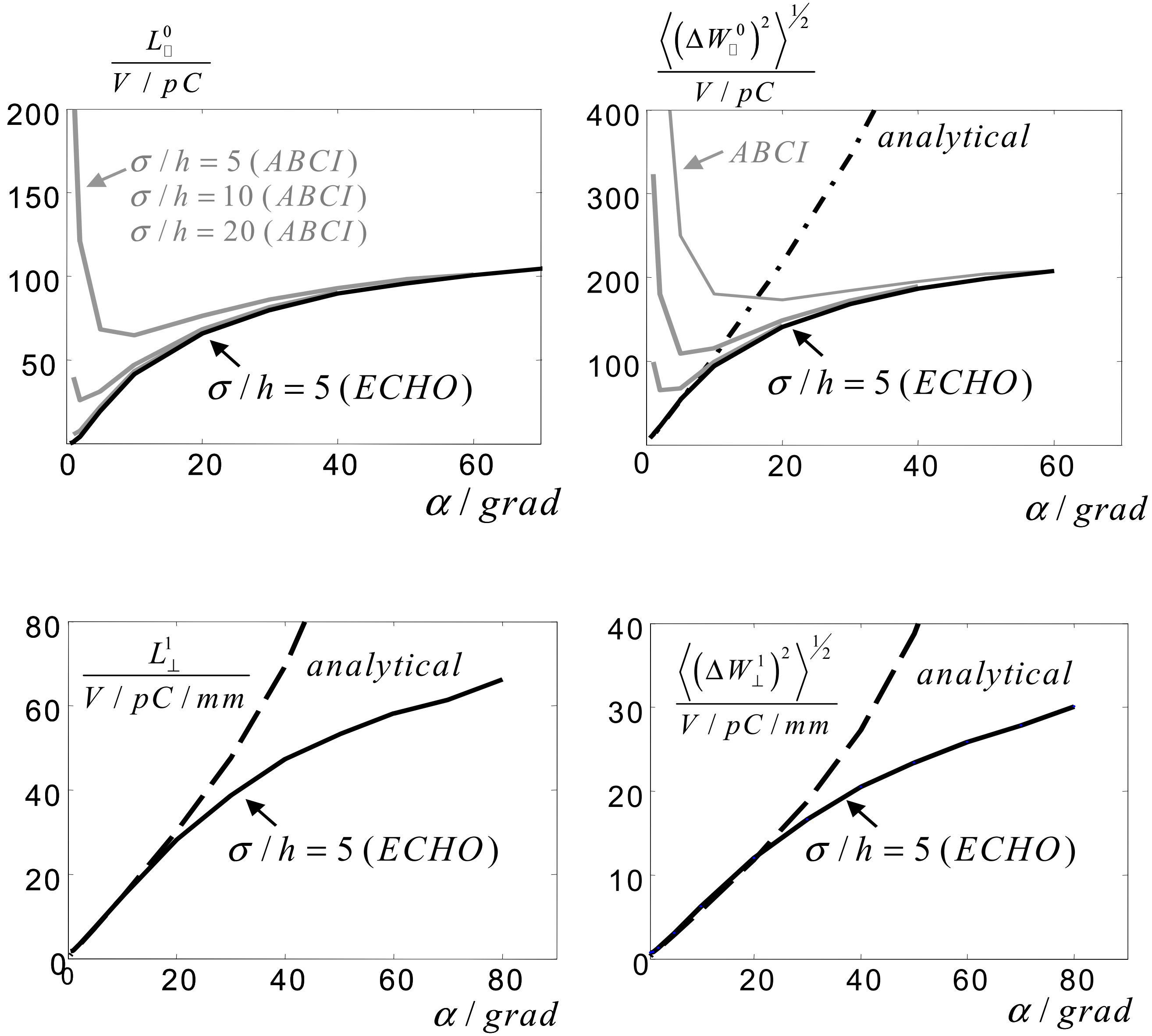
Inductive



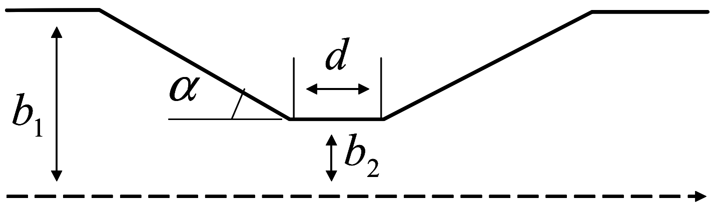


	α [mrad]	a [mm]	b [mm]	l [mm]	Q [nC]	σ [mm]
TESLA	20	17.5	0.4	20	1.	0.3
NLC	20	17.5	0.2	20	1.	0.1

Round collimator. Inductive



Round collimator. Diffractive



$$k_{\|} = 0.5\pi^{-1.5}\sigma^{-1} c Z_0 \log(b_1 b_2^{-1})$$

$$k_{\perp}^{short} = \frac{Z_0 c}{4\pi}\left(\frac{1}{b_2^{\,2}} - \frac{b_2^{\,2}}{b_1^{\,4}}\right) \qquad k_{\perp}^{long} = \frac{Z_0 c}{2\pi}\left(\frac{1}{b_2^{\,2}} - \frac{1}{b_1^{\,2}}\right)$$

$$k_{\perp}^{short} \approx 0.5 k_{\perp}^{long}$$

$$k_{\|} = O(\log(b_2)) \qquad k_{\perp} = O\left(\frac{1}{b_2^{\,2}}\right)$$

I. Zagorodnov, K.L.F. Bane, EPAC'06, 2006

Round collimator. Diffractive

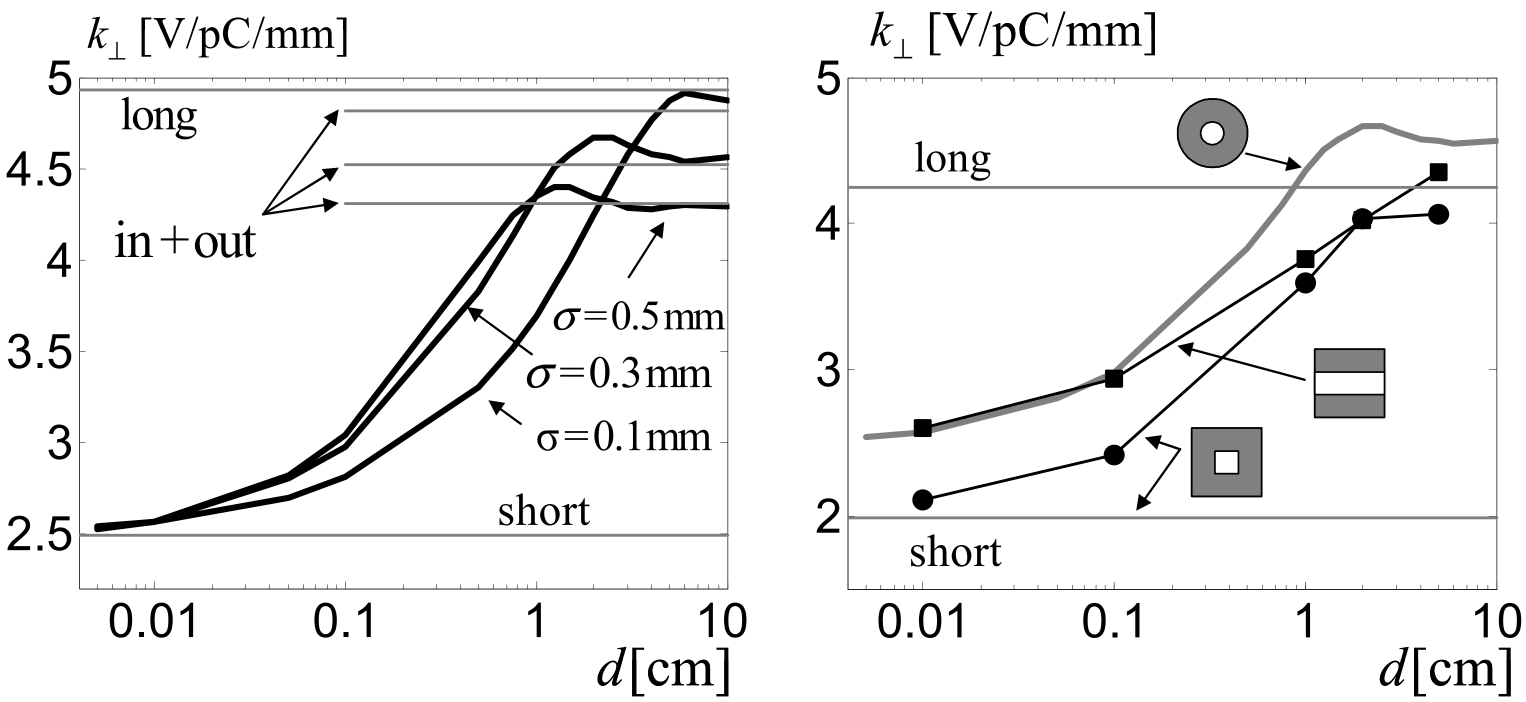
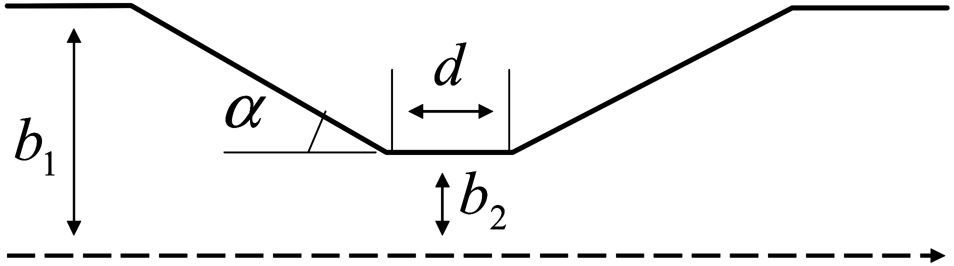


Figure 2:Kick factor *vs.* collimator length. A round collimator (left), a square or rectangular collimator (σ = 0.3 mm, right).

Round collimator. Regimes



Inductive

$$\rho_1 \equiv \alpha b_2 \sigma^{-1} \ll 1$$

$$k_{||} = 0$$

$$k_{\perp} = O\left(\frac{\alpha}{b_2}\right)$$

Diffractive

$$\rho_1 \gg 1$$

$$k_{||} = O(\log(b_2))$$

$$k_{\perp} = O\left(\frac{1}{{b_2}^2}\right)$$

Round collimator

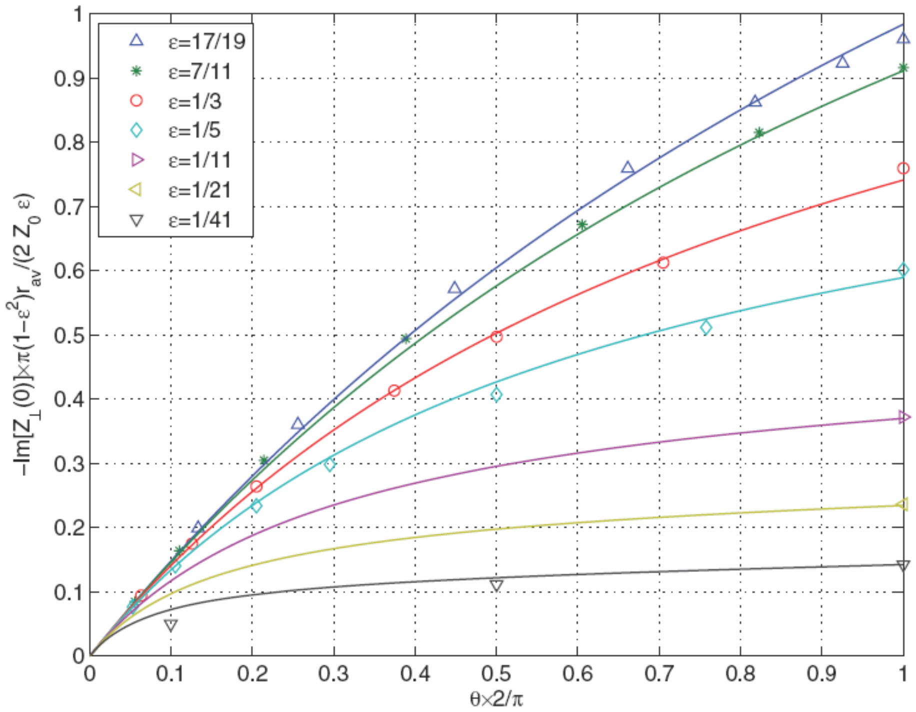


FIG. 4. (Color) The dimensionless scaled impedance as calculated from ABCI (symbols) and the curves corresponding to approximation given in Eqs. (3.5) and (3.6) (solid).

impedance to be expressed in the form

$$Z_{\perp}(0) \cong -(2)\frac{iZ_0\varepsilon}{2\pi r_{av}}\frac{2\theta}{1-\varepsilon^2}\frac{1+(a+b\varepsilon)\frac{\theta}{\varepsilon}}{1+(0.18+a+c\varepsilon)\frac{\theta}{\varepsilon}}, \quad (3.5)$$

and determining the parameters by carrying out a least squares fit to the ABCI data. In this manner, we found

$$a = 2.94 \times 10^{-3}, \qquad b = -3.13 \times 10^{-3}, \qquad c = 1.75 \times 10^{-1}. \quad (3.6)$$

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS
9, 054401 (2006)

Transverse impedance of axially symmetric tapered structures

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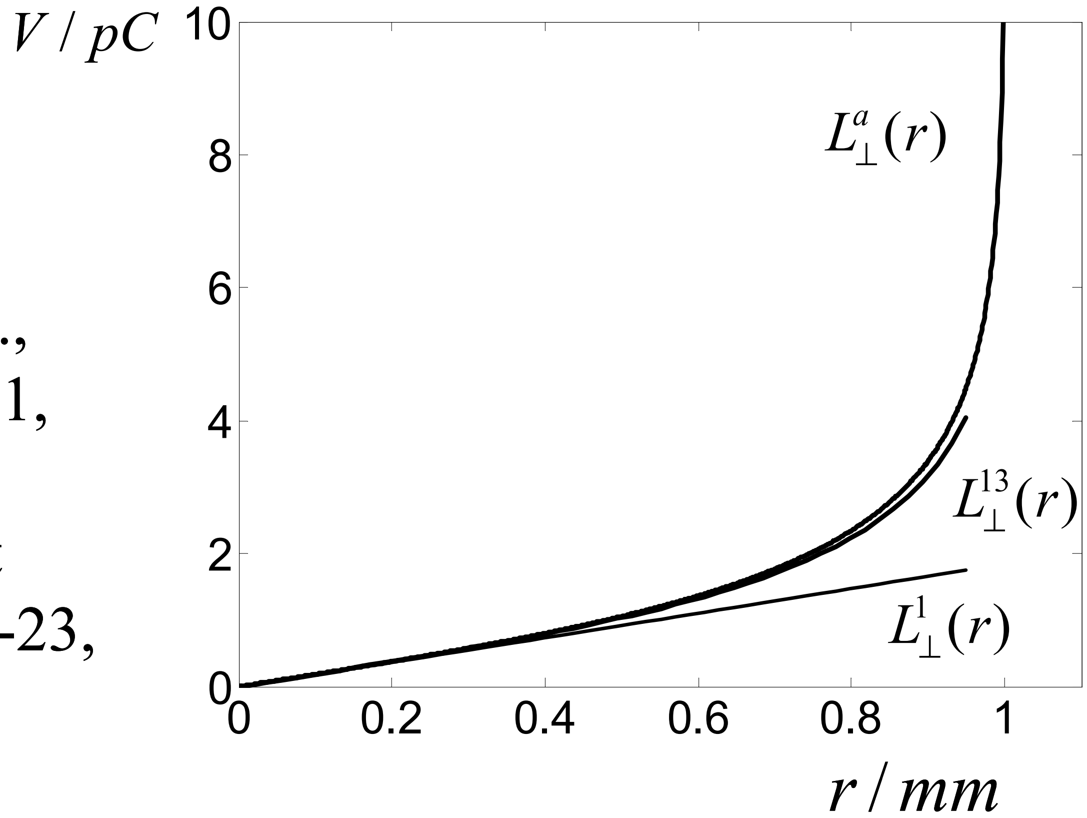
Round collimator. Near-wall wakes

$$L_\perp^a(r) = -\frac{\log\left(1-(r/b_2)^2\right)}{(r/b_2)} \cdot L_\perp^1 \cdot b_2$$

$$L_\perp^{13}(r) = \sum_{m=1}^{13} L_\perp^m \cdot r^{2m-1}$$

References

1. F.-J.Decker et al., SLAC-PUB-7261, Aug 1996.
2. I. Zagorodnov et al.,TESLA 2003-23, 2003.



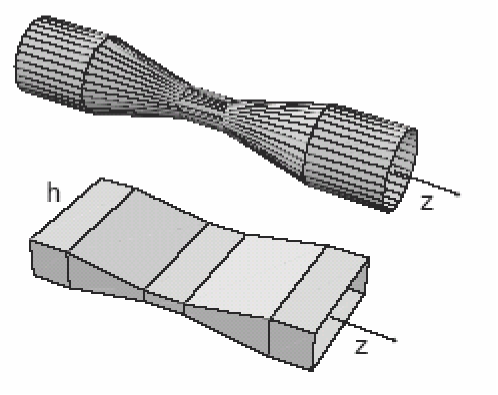
Round collimator. Resistive wall wakes

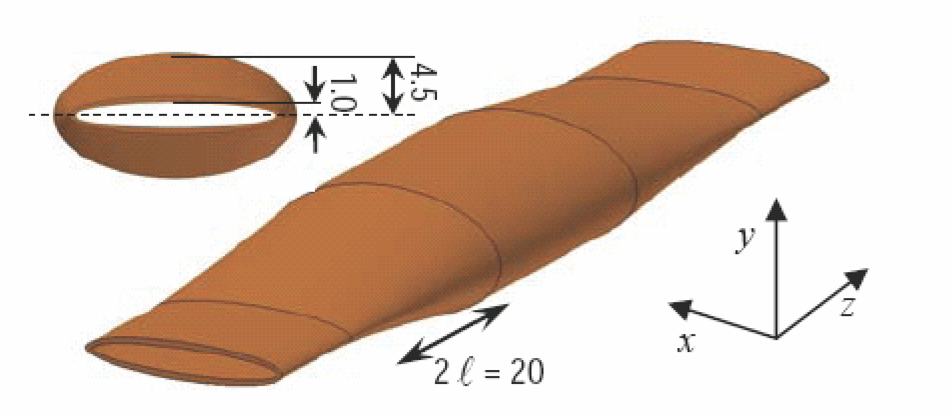
Analytical estimations are available. To be studied.

Can the total wake be treated as the direct sum of the geometric and the resistive wakes? Numerical modeling is required.

Discrepancy between analytical estimations and measurements. Transverse geometric kick for long collimator is approx. two times larger as for the short one.

3D collimators. Regimes





Proceedings of the 2001 Particle Accelerator Conference, Chicago

High-Frequency Impedance of Small-Angle Collimators

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Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

TRANSVERSE IMPEDANCE OF ELLIPTICAL CROSS-SECTION TAPERS*

Boris Podobedov#, Samuel Krinsky, BNL/NSLS, Upton, New York

Wakefield Calculations for 3D Collimators *

Igor Zagorodnov, DESY, Hamburg, Germany
Karl L.F. Bane, SLAC, Menlo Park, CA 94025, USA

3D collimators. Regimes

round | **rectangular**

Inductive

Round: $\rho_1 \equiv \alpha b_2 \sigma^{-1} \ll 1$

Rectangular: $\rho_1 \ll 1, \quad \rho_2 \equiv \alpha h^2 \sigma^{-1} b_2^{-1} \ll 1$

$$k_\perp = \frac{2\alpha}{\sqrt{\pi}\sigma}\left(\frac{1}{b_2} - \frac{1}{b_1}\right)\frac{Z_0 c}{4\pi} \quad (1)$$

$$k_\perp = \frac{\sqrt{\pi}\alpha h}{\sigma}\left(\frac{1}{b_2^2} - \frac{1}{b_1^2}\right)\frac{Z_0 c}{4\pi} \quad (2)$$

Intermediate

Rectangular: $\rho_1 \ll 1, \qquad \rho_2 \geq \pi^2$

$$k_\perp = 2.7 A \sigma^{-0.5} b_2^{-1.5} \sqrt{\alpha}\, Z_0 c (4\pi)^{-1} \quad (3)$$

Diffractive

Round: $\rho_1 >> 1$

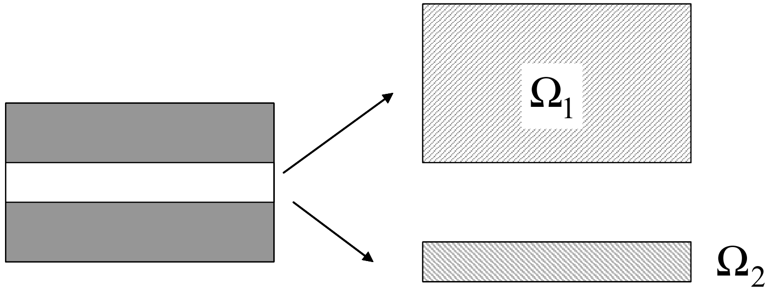
Rectangular: $\rho_1 >> 1$

3D Collimators. Diffractive Regime

Diffractive Regime

$$k_{\perp}^{short} \approx 0.5 k_{\perp}^{long}$$

$$Z_{||} = 2Z^{e} \qquad (4)$$



$$\Delta\varphi_i(\vec{x}) = Z_0 Q \delta(\vec{x} - \vec{x}_0) \qquad \vec{x}_i \in \Omega_i$$

$$\varphi_i(\vec{x}) = 0 \qquad \vec{x}_i \in \partial\Omega_i \qquad i = 1, 2$$

long

$$Z^{e} = \frac{1}{Q^2 Z_0}\left(\int_{\Omega_1} \nabla\varphi_1^{\,2} ds - \int_{\Omega_2} \nabla\varphi_2^{\,2} ds \right) \qquad (5)$$

short

$$Z^{e} = \frac{1}{Q^2 Z_0}\left(\int_{\Omega_1 - \Omega_2} \nabla\varphi_1^{\,2} ds \right) \qquad (6)$$

S.Heifets and S.Kheifets, Rev Mod Phys 63,631 (1991)
I. Zagorodnov, K.L.F. Bane, EPAC‘06, 2006

3D collimators. Diffractive Regime

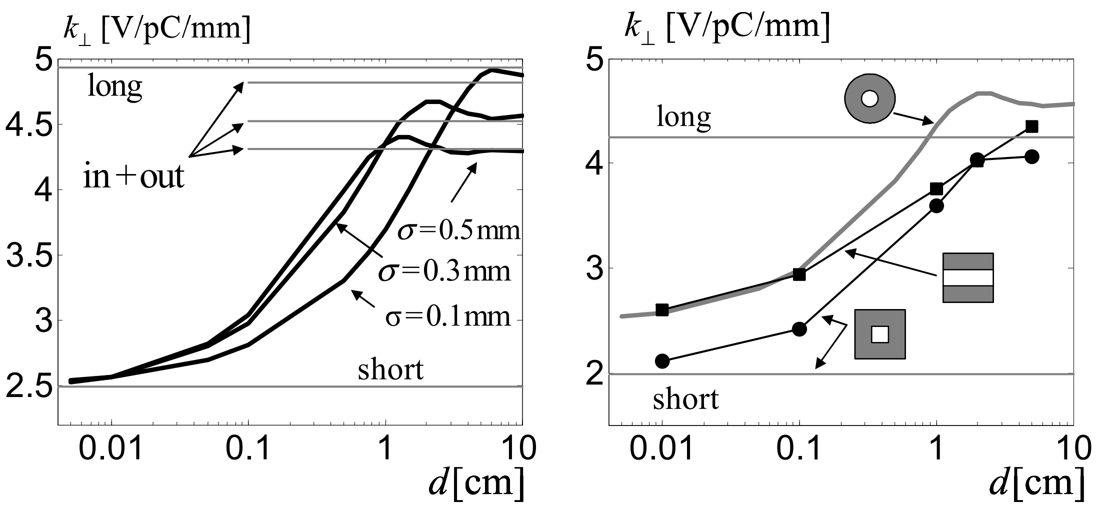


Figure 2:Kick factor *vs.* collimator length. A round collimator (left), a square or rectangular collimator (σ = 0.3 mm, right).

Table1: Loss and kick factors as estimated by 2D electrostatic calculation. The bunch length σ = 0.3 mm. ``Short'' means using Eq. 6, ``long'' Eq. 5

Type	$k_{\|\|}$ [V/pC]		k_{tr} [V/pC/mm]	
	short	long	short	long
round	78	78	2.50	5.01
rect.	56	72	2.43	6.11
square	74	78	1.99	4.25

The good agreement we have found between direct time-domain calculation [1] and the approximations (5, 6), suggests that the latter method can be used to approximate short-bunch wakes for a large class of 3D collimators.

3D collimators. Inductive Regime

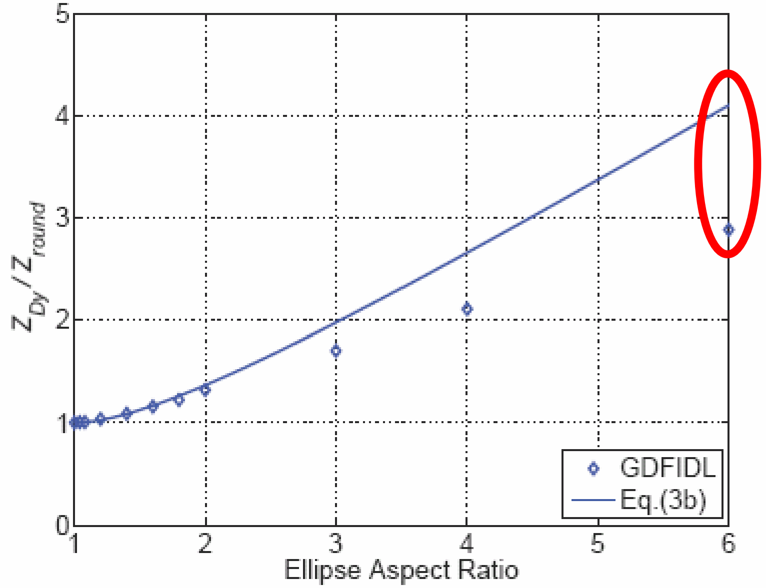


Figure 2: Dipolar vertical impedance.

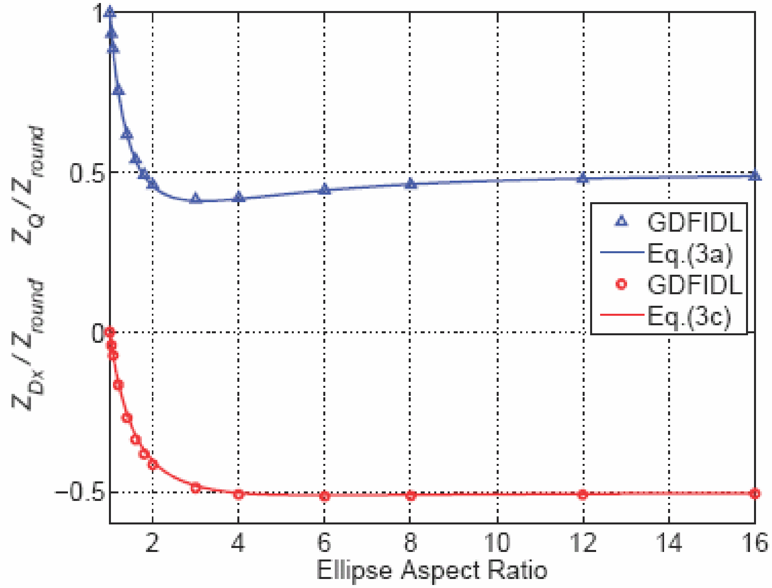


Figure 3: Dipolar horizontal and quadrupolar impedances

$$Z_{Dx} = -\sum_{n=1,3,\cdots} \int_{-\infty}^{\infty} dz\, f_n(z) \left[\frac{n}{\cosh^2 n\rho} + \frac{n+2}{\cosh^2 (n+2)\rho} \right]^2 \quad (3a)$$

$$Z_{Dy} = -\sum_{n=1,3,\cdots} \int_{-\infty}^{\infty} dz\, f_n(z) \left[\frac{n}{\sinh^2 n\rho} + \frac{n+2}{\sinh^2 (n+2)\rho} \right]^2 \quad (3b)$$

$$Z_Q = \sum_{n=0,2,\cdots} \int_{-\infty}^{\infty} dz\, f_n(z) \left[\frac{1}{\cosh^2 n\rho} + \frac{1}{\cosh^2 (n+2)\rho} \right] \times \left[\frac{n^2}{\cosh^2 n\rho} + \frac{(n+2)^2}{\cosh^2 (n+2)\rho} \right] \quad (3c)$$

where

$$f_n(z) = \frac{i Z_0}{4\pi} \frac{\rho'(z)^2}{2(n+1)} \sinh 2(n+1)\rho\,, \quad (4)$$

Z_0 is the free space impedance and $k = 0$ is assumed.

TRANSVERSE IMPEDANCE OF ELLIPTICAL CROSS-SECTION TAPERS*

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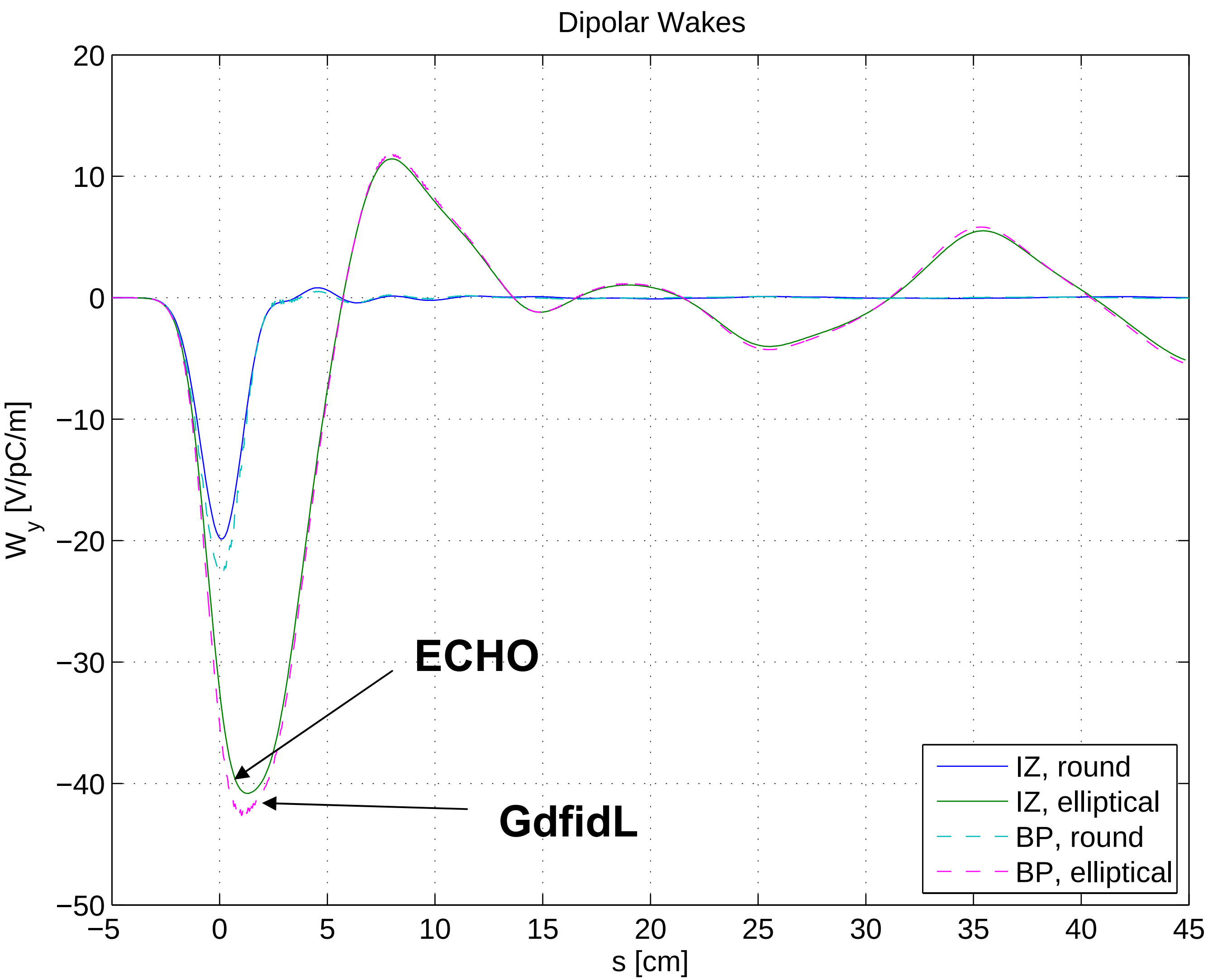
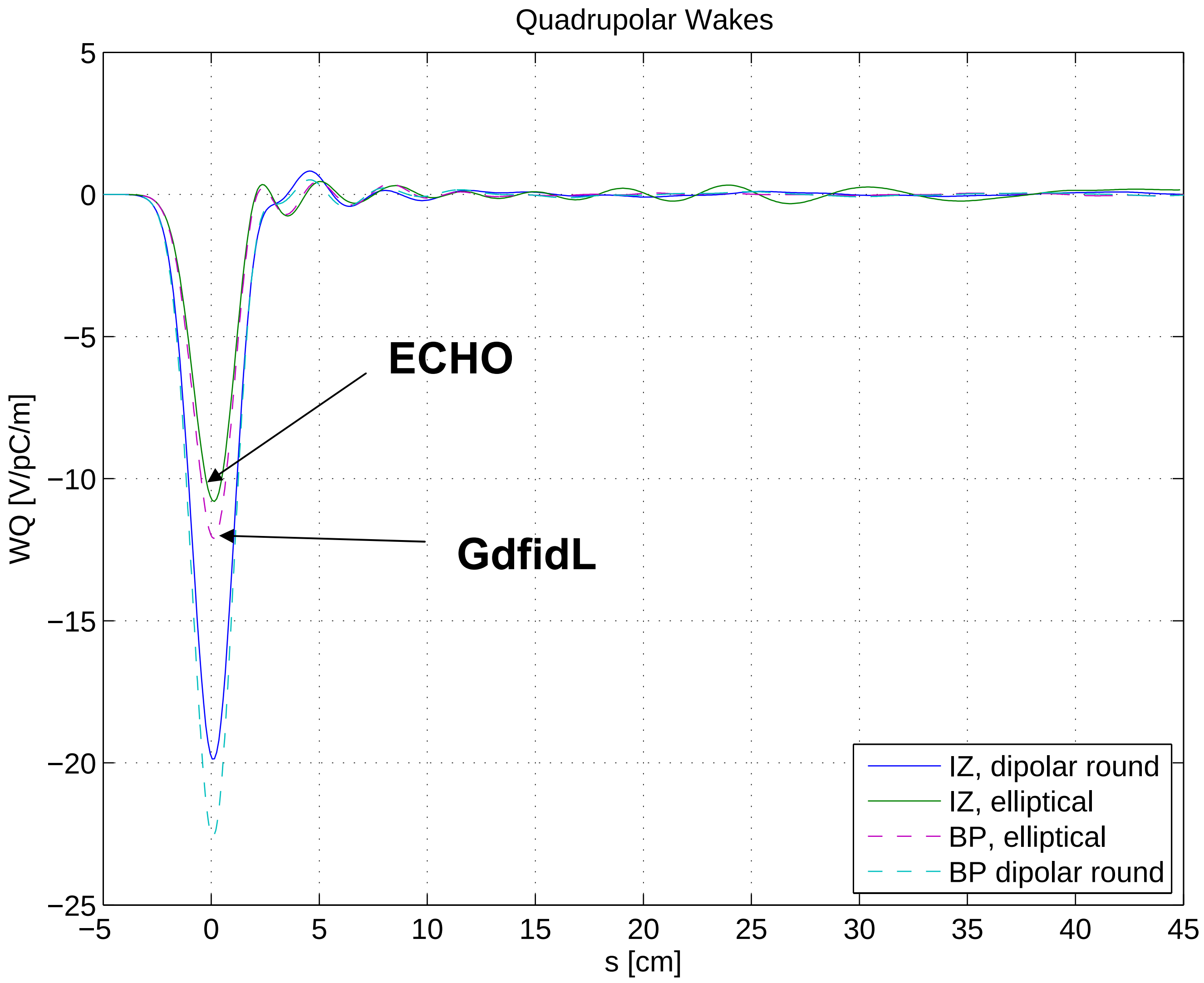
3D collimators. Inductive Regime

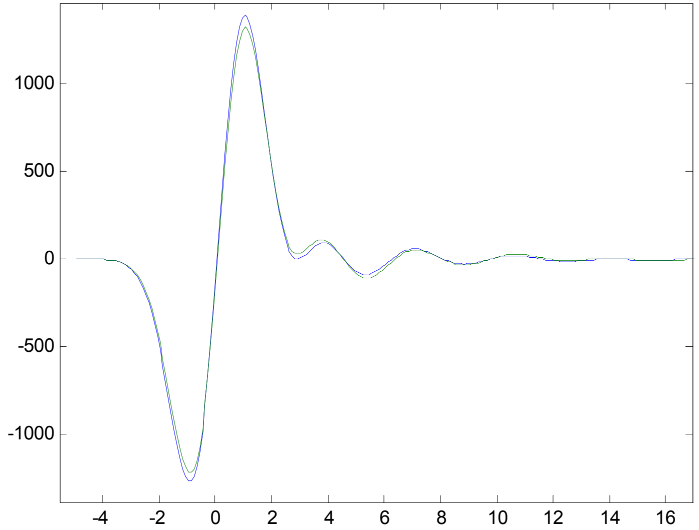


3D collimators. Inductive Regime



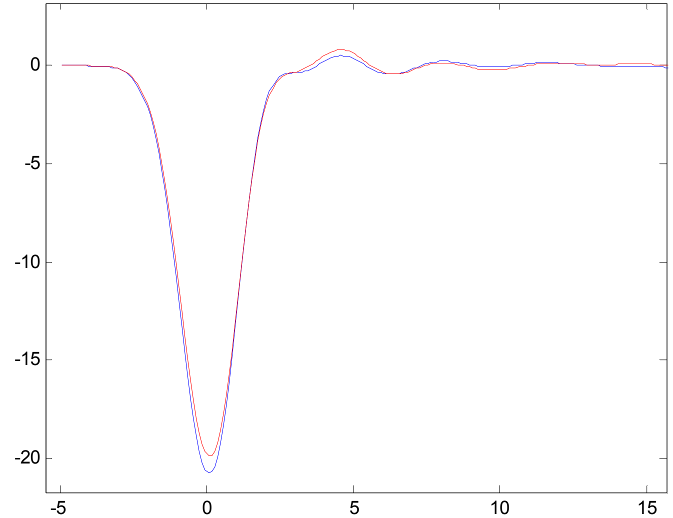
3D collimators. Inductive Regime

Round: 2D vs.3D



$W_{||}^{d}[V/pC/m/m]$

$s[cm]$



$W_{\perp}^{d}[V/pC/m]$

$s[cm]$

$$\frac{\int (W_{\perp}^{3D}(s) - W_{\perp}^{2D}(s))ds}{\int W_{\perp}^{2D}(s)ds} 100\% \approx 5\%$$

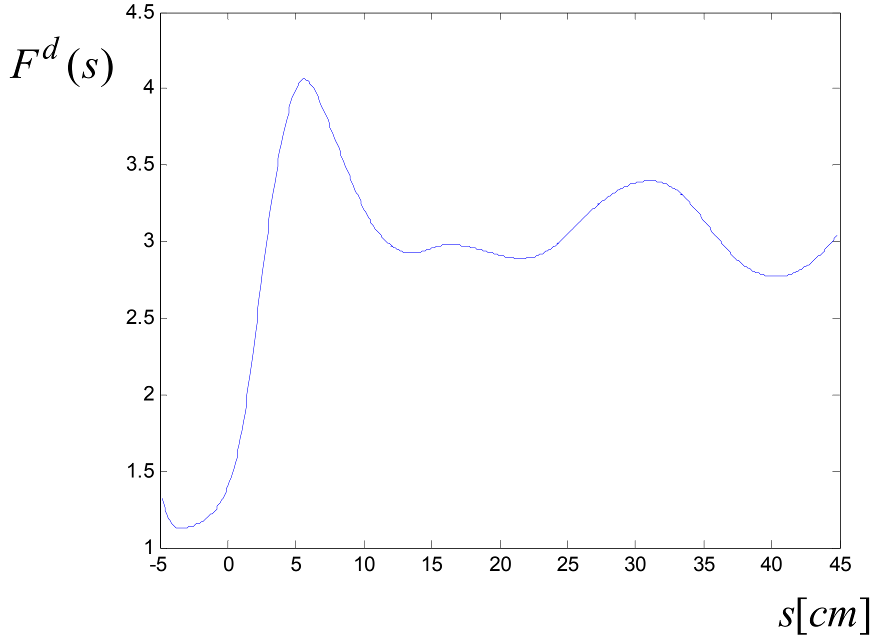
Blue-3D
Green-2D accurate

$dx = dy = dz = 1mm$

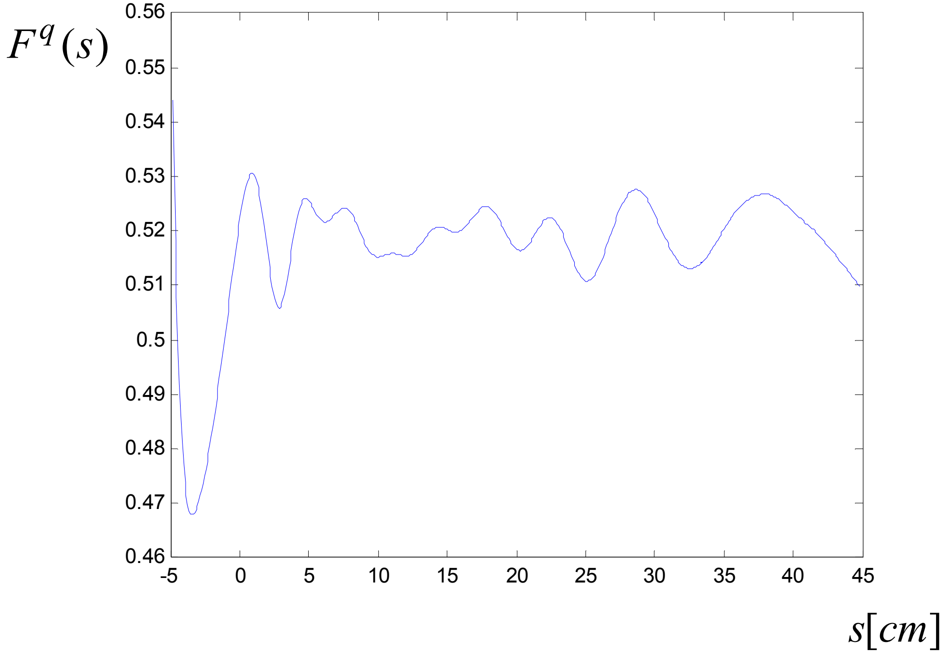
3D collimators. Inductive Regime

$offset = 5mm$

Dipolar



Quadrupolar



$$F^d(s) = \frac{\int_{-5\sigma}^{s} W_\perp^{d,el}(x)dx}{\int_{-5\sigma}^{s} W_\perp^{d,round}(x)dx} \to 3$$

$$F^q(s) = \frac{\int_{-5\sigma}^{s} W_\perp^{q,el}(x)dx}{\int_{-5\sigma}^{s} W_\perp^{d,round}(x)dx} \to 0.52$$

I estimate that error in this numbers is about 5%

Simulations of SLAC experiment 2001

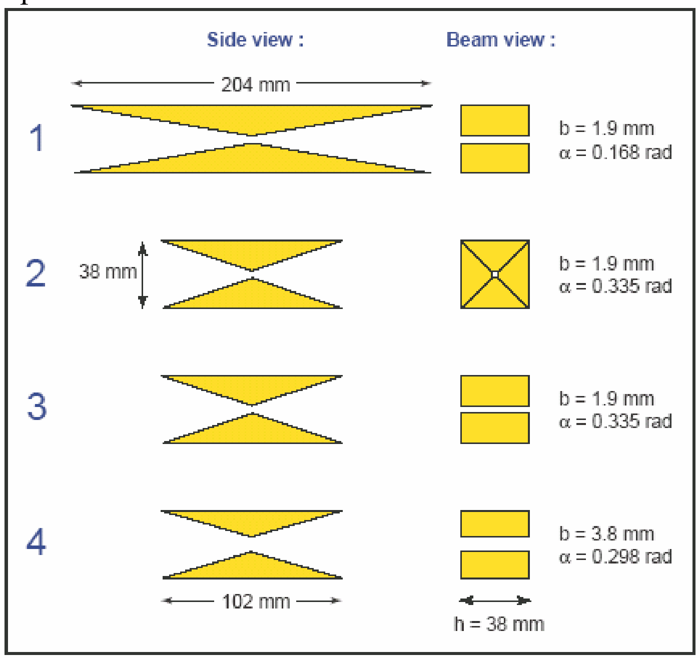
Rectangular Collimators

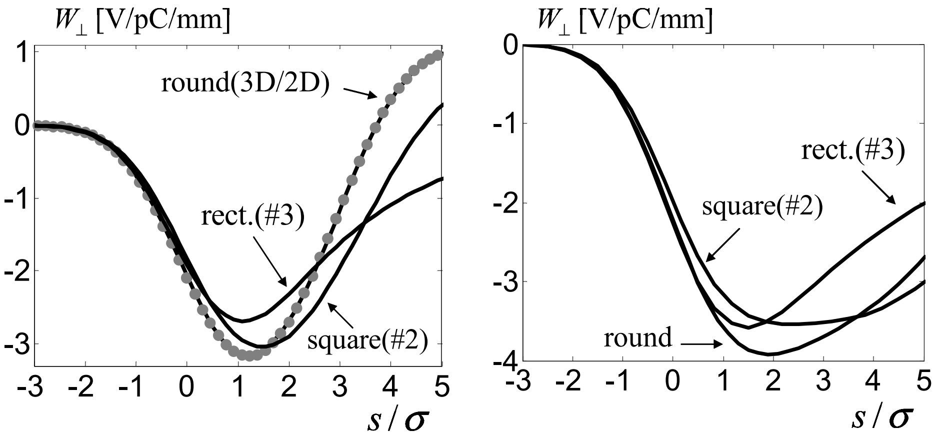
SLAC experiment 2001

Table 2: Geometry of SLAC collimators of 2001

Coll. #	1	2	3	4
Type	rect.	square	rect.	rect.
b_2 [mm]	1.9	1.9	1.9	3.8
α [mrad]	168	335	335	298

$$b_1 = h/2 = 19\,\text{mm}$$





Figire 3: Transverse wake of Gaussian bunch, with σ = 0.65 mm (left) and σ=0.3 mm (right).

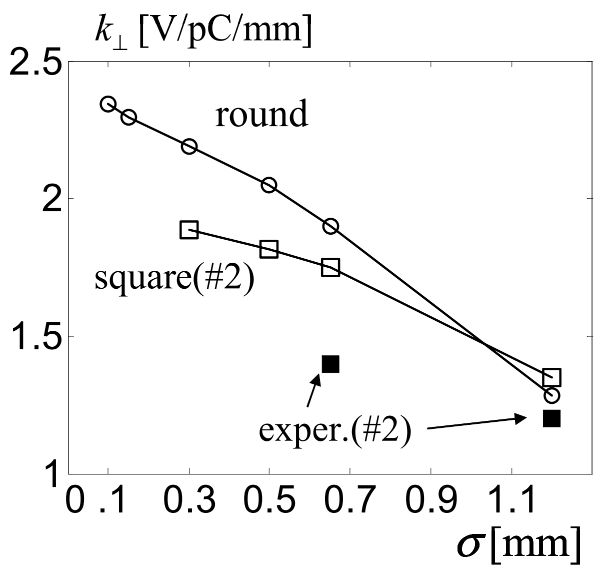
Simulations of SLAC experiment 2001

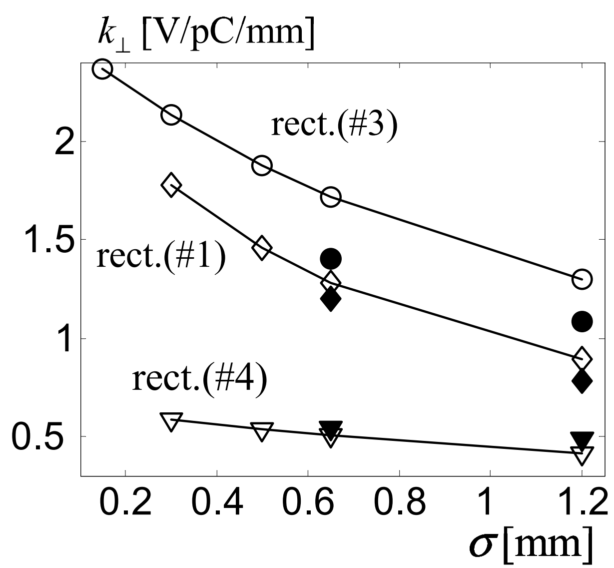
Table 3:Kick factor [V/pC/mm]; σ = 0.65 mm. Measurement errors are given in parentheses.

Coll. #	1	2	3	4
ρ_1/ρ_2	0.5/50	1.0	1/98	1.7/43
simul.	1.28	1.75	1.72	0.50
meas.	1.2(0.1)	1.4(0.1)	1.4(0.1)	0.54(0.05)
Eq. 1	**1.24**	2.5		1.0
Eq. 3	2.4	3.3		1.1
Eq. 12	2.5	**2.5**		**0.62**

Table 4:Kick factor [V/pC/mm]; σ = 1.2 mm. Measurement errors are given in parentheses.

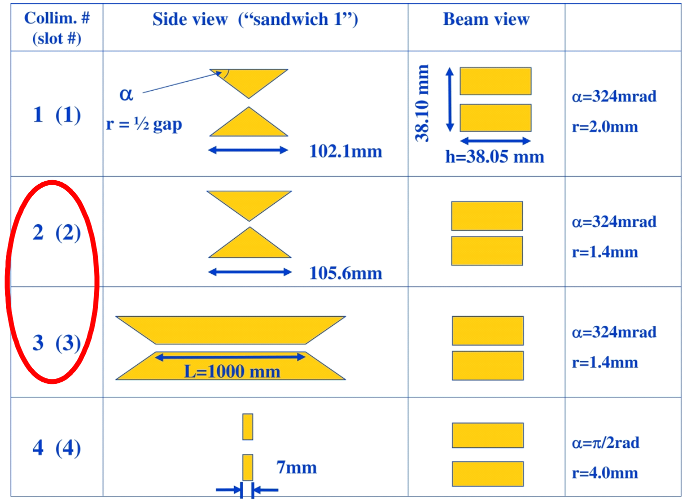
Coll. #	1	2	3	4
ρ_1/ρ_2	0.3/27	0.5	0.5/53	0.9/24
simul.	0.90	1.35	1.30	0.41
meas.	0.78(0.13)	1.2(0.1)	1.08(0.1)	0.49(0.15)
Eq. 1	**0.7**	**1.3**		**0.5**
Eq. 3	1.7	2.4		0.8
Eq. 12	2.5	2.5		0.6





We note good agreement for rectangular collimators #1 and #4. On the other hand the short bunch results for collimators #2 and #3 agree very well with the calculations of the previous section, but they disagree with the experimental data (by 20 %).

SLAC experiment 2006



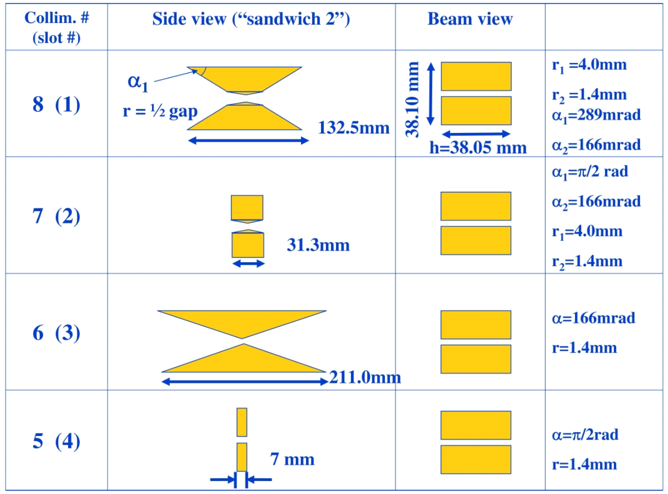
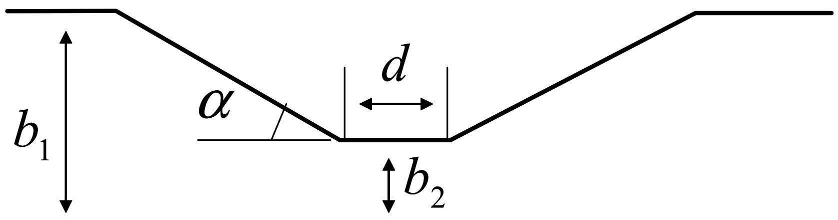


Table 5: Loss and kick factors for new set of collimators.

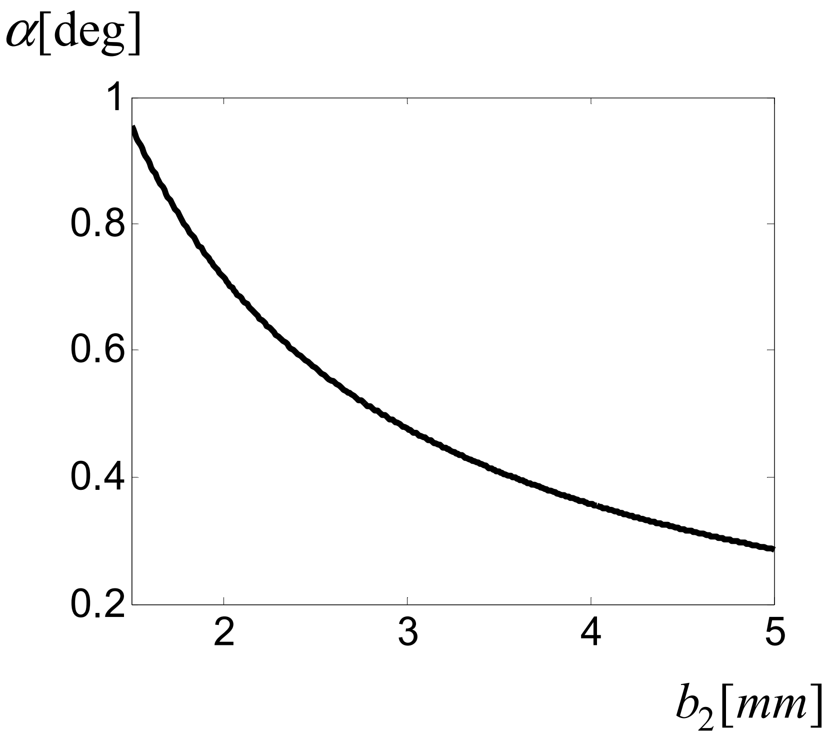
Coll. #	$k_{\parallel}$ [V/pC]		k_{tr} [V/pC/mm]	
	σ=0.3mm	σ=0.5mm	σ=0.3mm	σ=0.5mm
1	50	28	1.9	1.7
2	60	33	3.6	3.1
3	63	33	6.1	5.1
4	40	24	0.74	0.77
5	81	47	7.1	6.8
6	51	24	2.9	2.3
7	60	34	3.1	2.7
8	56	28	3.0	2.4

Perhaps the most interesting result in Table 5 is a noticeable difference in the kicks for collimators #2 and #3. In agreement with the analytic models discussed in the paper, a long collimator length results in a kick factor increase by a factor ~2.

XFEL collimators. Tapering



Inductive



When a short bunch passes by an out-transition, a significan reduction in the wake will not happen until the tapered walls cut into the cone of radiation, i.e until

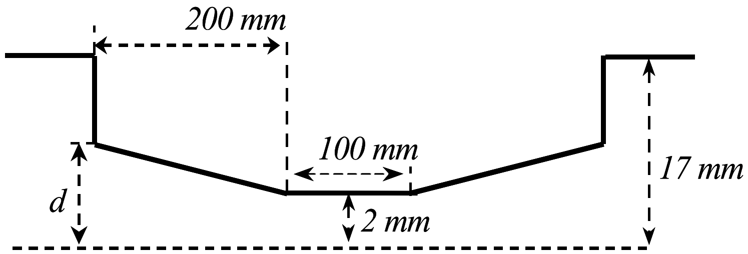
$$\tan\alpha \approx \sigma_z / b_2$$

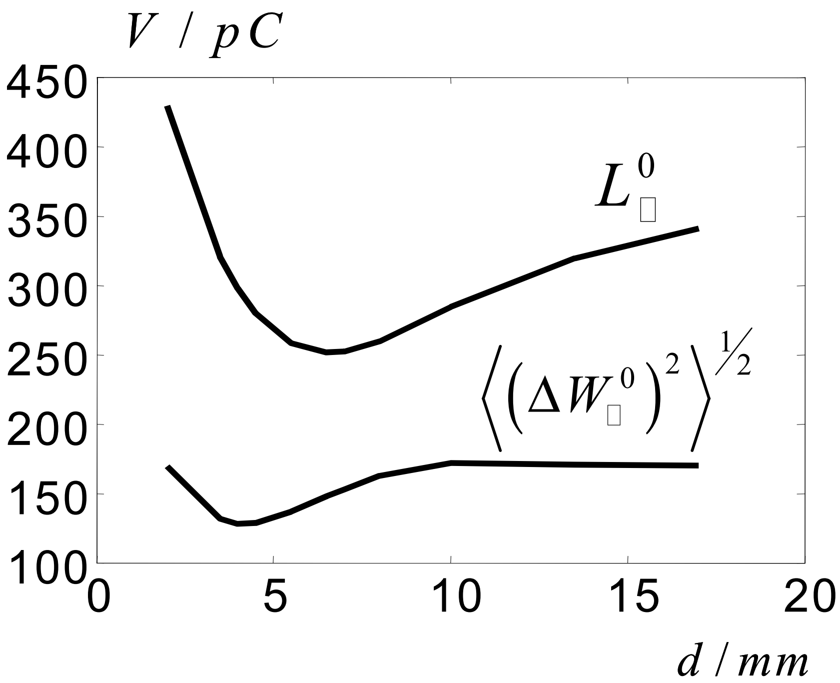
$$\sigma_z = 0.025\ \mathrm{mm}$$

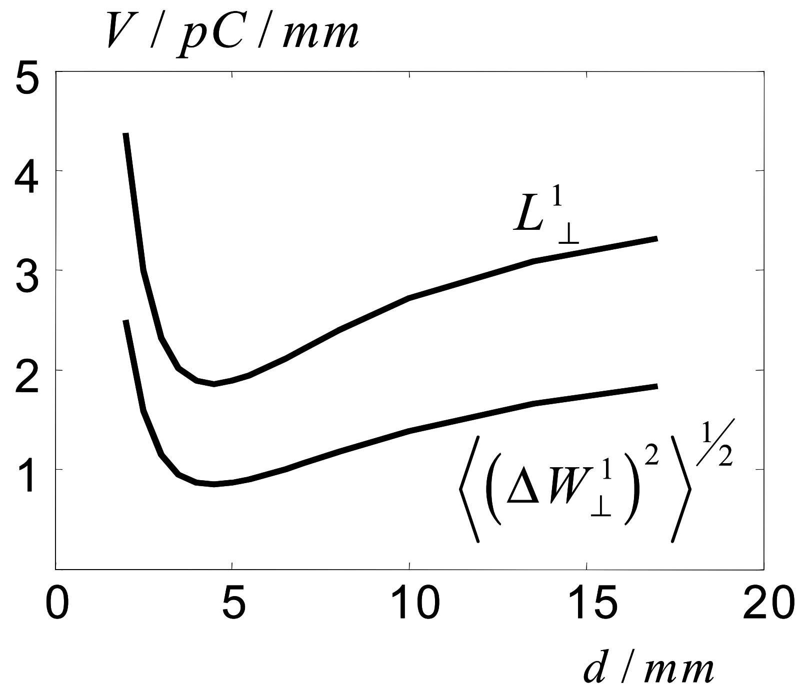
XFEL collimators. Tapering

Geometry of the “step+taper” collimator for TTF2

$$\sigma_z = 0.05 \text{ mm}$$





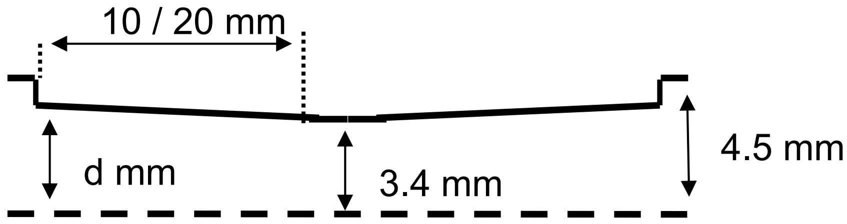


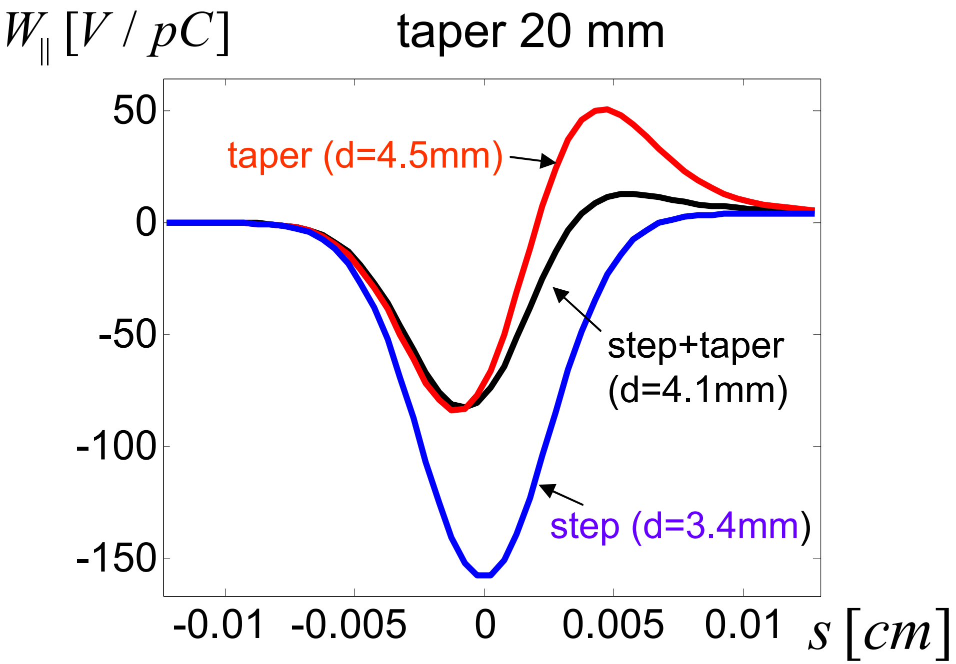
Collimator geometry optimization.
Optimum d ~ 4.5mm

XFEL collimators. Tapering

Geometry of the “step+taper” absorber for XFEL

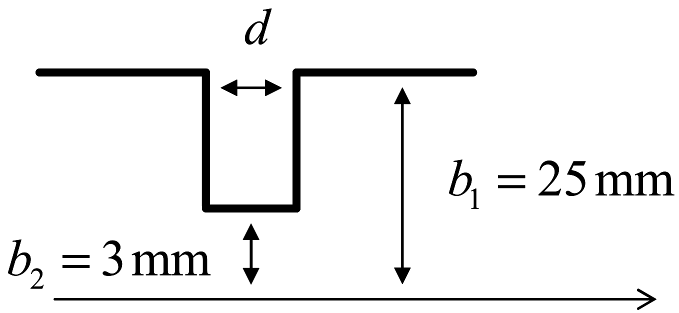
$\sigma = 25\,mkm$



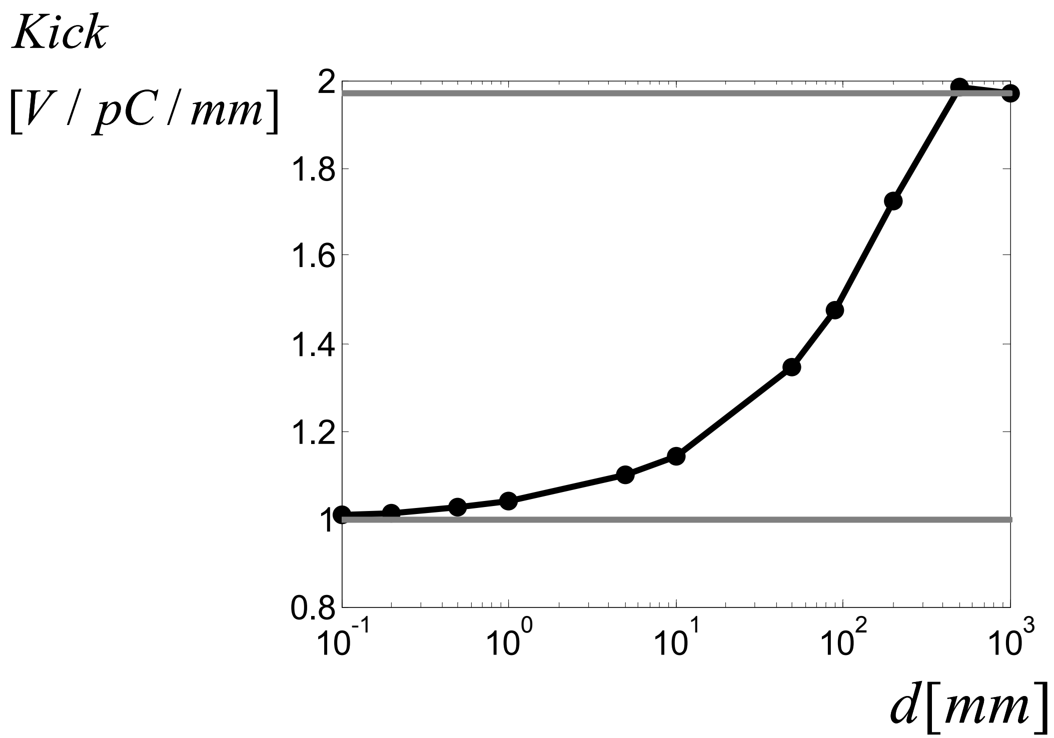


	Loss, V/pC	Spread, V/pC	Peak, V/pC
step	**110**	**43**	**-156**
taper 20mm	38	42	-83
taper 20mm +step	**50 (45%)**	**29 (67%)**	**-82 (53%)**

XFEL collimators. Kick vs. length



d, mm	Kick, V/pC/mm
short	0.998
1	1.04
10	1.14
50	1.35
90	1.48
200	1.73
500	1.98
long	1.9685



$$k_\perp^{short} = \frac{Z_0 c}{4\pi}\left(\frac{1}{b_2^2} - \frac{b_2^2}{b_1^4}\right)$$

$$k_\perp^{long} = \frac{Z_0 c}{2\pi}\left(\frac{1}{b_2^2} - \frac{1}{b_1^2}\right)$$

Form optimization?
Exponetial tapering?

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