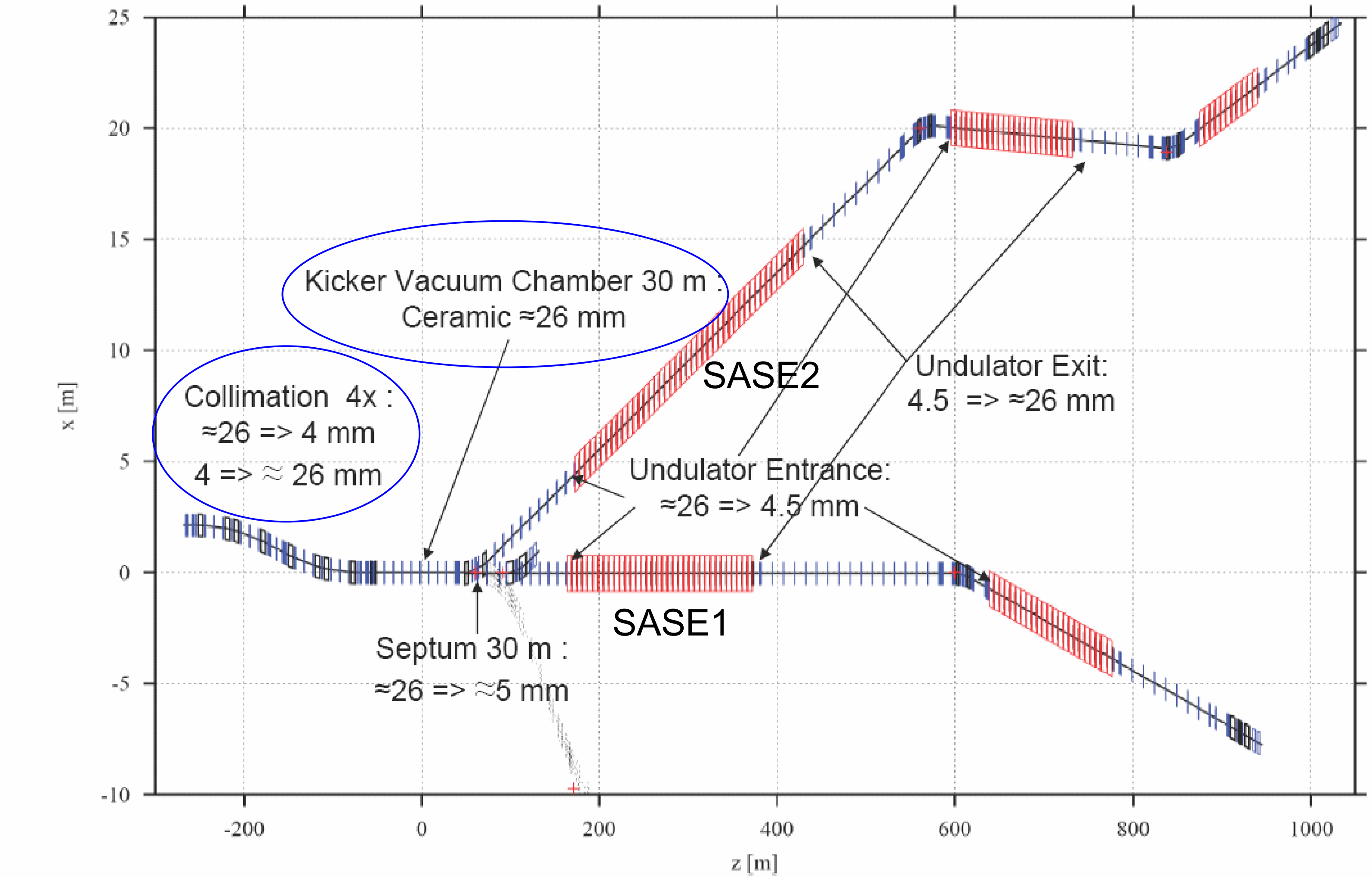
Longitudinal Impedance Budget from LINAC to SASE2

Igor Zagorodnov

Beam Dynamics Group Meeting

13.11.06



	Length [m]	# of Quads	Aperture Radius [mm]	Other Insertions
Linac to SASE2	486	63	25	4 Collimators (2-4 mm aperture) 30 m Ceramic (10 mm aperture) 2 bifurcation/septum chambers

(W.Decking)

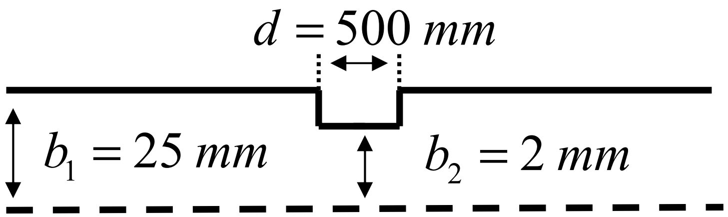
Wakefield sources

- Resistance of the pipe (r=25mm, L=456m, Aluminium)

- Collimators (r=2mm, L=50cm, 4 items, TIMETAL 6-4)

- Kickers (r=10mm, L=10m, 3 items, R/L=10Ω/m)

Collimator (geometrical wake)



$$QW(s) = Z_{||} I(s)$$

$$Z_{||} = 303\,[\Omega]$$

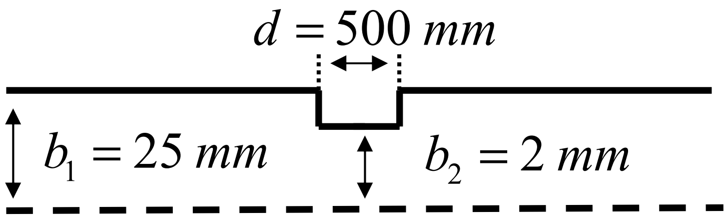
$$Z^e(0) = \frac{Z_0}{2\pi} \ln\left(\frac{b_1}{b_2}\right)$$

$$Z_{||} = 2Z^e(0)$$

Diffractive regime: the geometrical wake repeats the bunch shape

Collimator (resistive wake)

http://www.timet.com/timetal6-4frame.html



TIMETAL 6-4 alloy (Titanium)
(E.Schutz MVA)

$$\sigma = 0.6 \cdot 10^6 \Omega^{-1} m^{-1}$$

$$\tau = 0 [\sec]$$

$$\Delta_{rough} = 0 [\mu\mathrm{m}]$$

$$\Delta_{oxid} = 0 [\mathrm{nm}]$$

$$Z(\omega) = \frac{Z_s(\omega)}{2\pi R} \left[1 + i \frac{\omega}{c} \frac{R}{2} \frac{Z_s(\omega)}{Z_0} \right]^{-1}$$

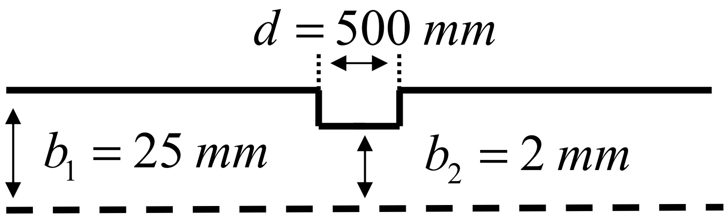
$$Z_s(\omega) = Z_s^{\sigma}(\omega) + Z_s^{L}(\omega)$$

$$Z_s^{\sigma}(\omega) \approx \sqrt{\frac{i\omega\mu}{\sigma(\omega)}} \qquad \sigma(\omega) \approx \frac{\sigma_0}{1 + i\omega\tau}$$

$$Z_s^{L}(\omega) \approx i\omega L \qquad L \approx 0.5\mu(\Delta_{oxid} + 0.02\Delta_{rough})$$

M.Dohlus. TESLA 2001-26, 2001
K.L.F.Bane, G.V.Stupakov, SLAC-PUB-10707, 2004

Collimator



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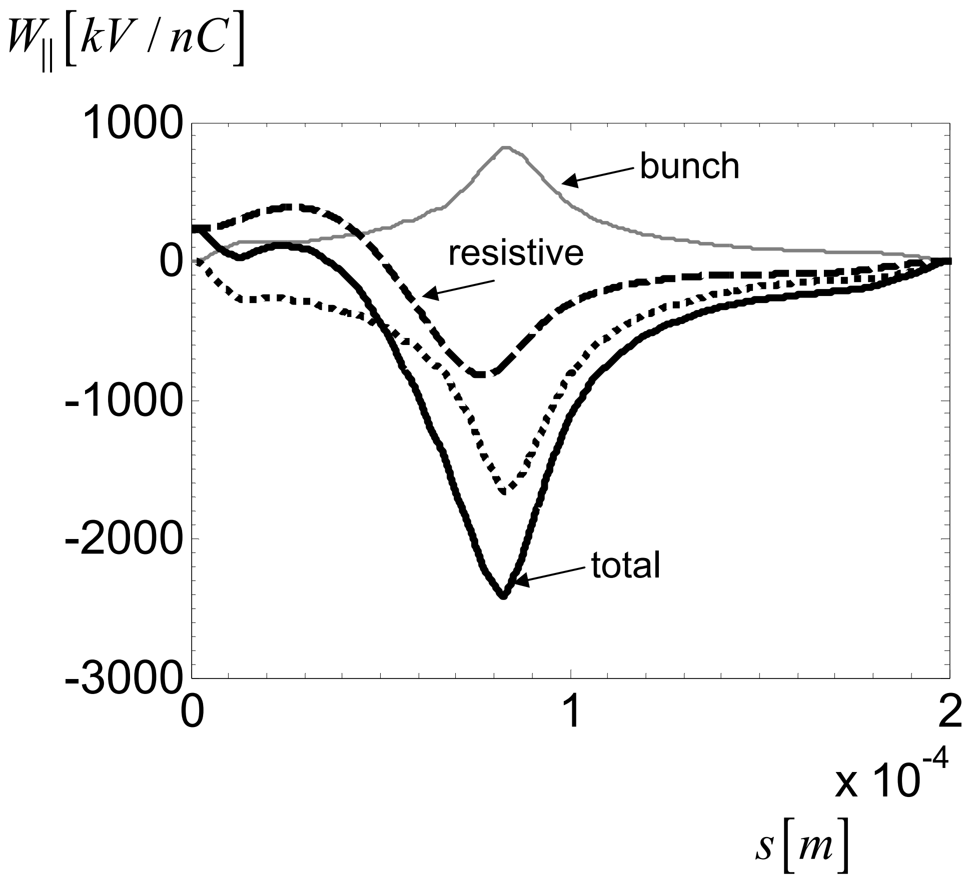
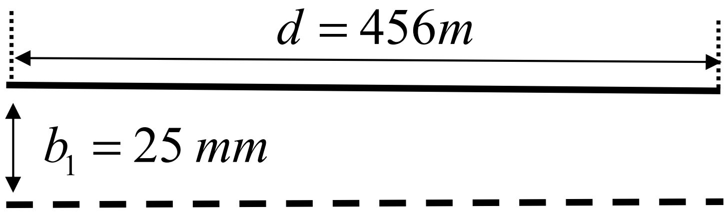


kV/nC

	Geom.	Res.	Total
Loss	827	329	1156
Spread	501	359	829
Peak	-1665	-823	-2411

(T.Wohlenberg)

Pipe (resistive+oxid layer+roughness)



Materialauswahl:	zu erwartende Oxidschicht:
Aluminium:	5nm
Kupfer:	nach 10min ca. 1nm bis 5nm
Gold	Annahme 0nm

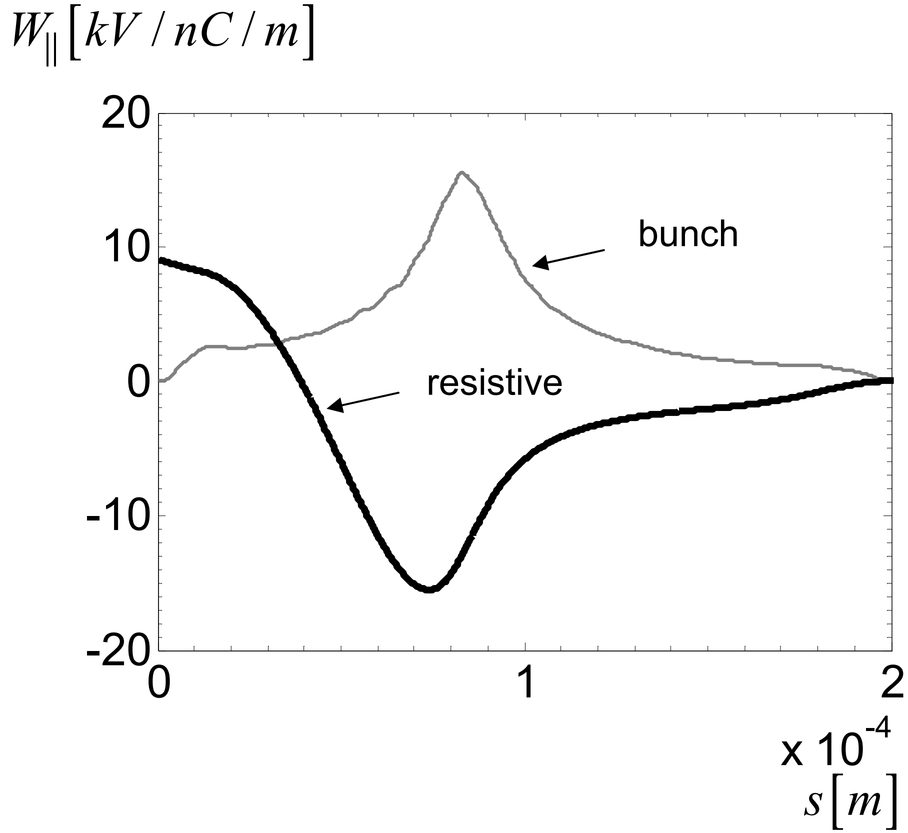
Aluminium

$$\sigma = 3.66 \cdot 10^{7}\,\Omega^{-1} m^{-1}$$

$$\tau = 7.1 \cdot 10^{-15}\,[\mathrm{sec}]$$

$$\Delta_{rough} = 600\,[\mu \mathrm{m}]$$

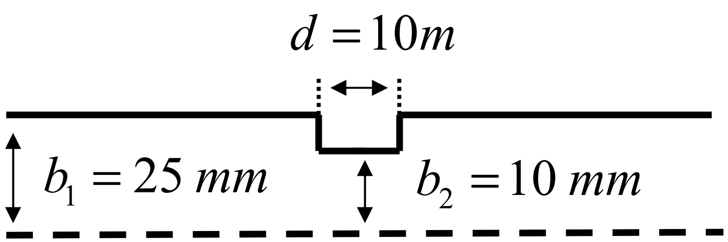
$$\Delta_{oxid} = 5\,[\mathrm{nm}]$$



$kV/nC/m$

	resistive	total
Loss	6.6	7.4
Spread	5.9	6.5
Peak	-14.5	-15.9

Kicker (geometrical wake)



$$QW(s) = Z_{||} I(s)$$

$$Z_{||} = 110\,[\Omega]$$

$$Z_{||} = 2Z^{e}(0)$$

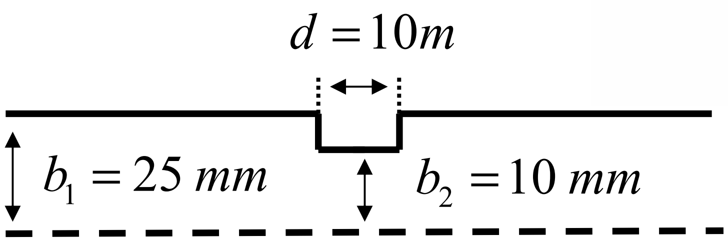
$$Z^{e}(0) = \frac{Z_0}{2\pi} \ln\left(\frac{b_1}{b_2}\right)$$

Kickerkammer:

Verzweigungsstrecke: (T.Wohlenberg)

Keramikrohr mit titanstabilisierten Edelstahl beschichtet, Schichtdicke ca 0,7µm. Elektrischer Widerstand gemessen über die Rohrlänge beträgt 10-12 Ohm/Meter. Die Kammerlänge beträgt ca. 900mm der Innendurchmesser beträgt ca.20mm.

Kicker (resistive wake)



Kickerkammer:

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Keramikrohr mit titanstabilisierten Edelstahl beschichtet, Schichtdicke ca 0,7µm. Elektrischer Widerstand gemessen über die Rohrlänge beträgt 10-12 Ohm/Meter. Die Kammerlänge beträgt ca. 900mm der Innendurchmesser beträgt ca.20mm.

$$\sigma = 0.76 \cdot 10^6 \Omega^{-1} m^{-1}$$

$$\sigma = \rho^{-1}$$

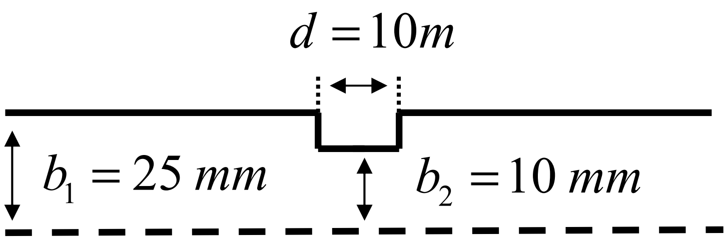
$$\rho = 12 \frac{\Omega}{m} \cdot 1.1 \cdot 10^{-7} m^2 = 1.3 \cdot 10^{-6} \Omega m$$

$$\tau = 0 [\mathrm{sec}]$$

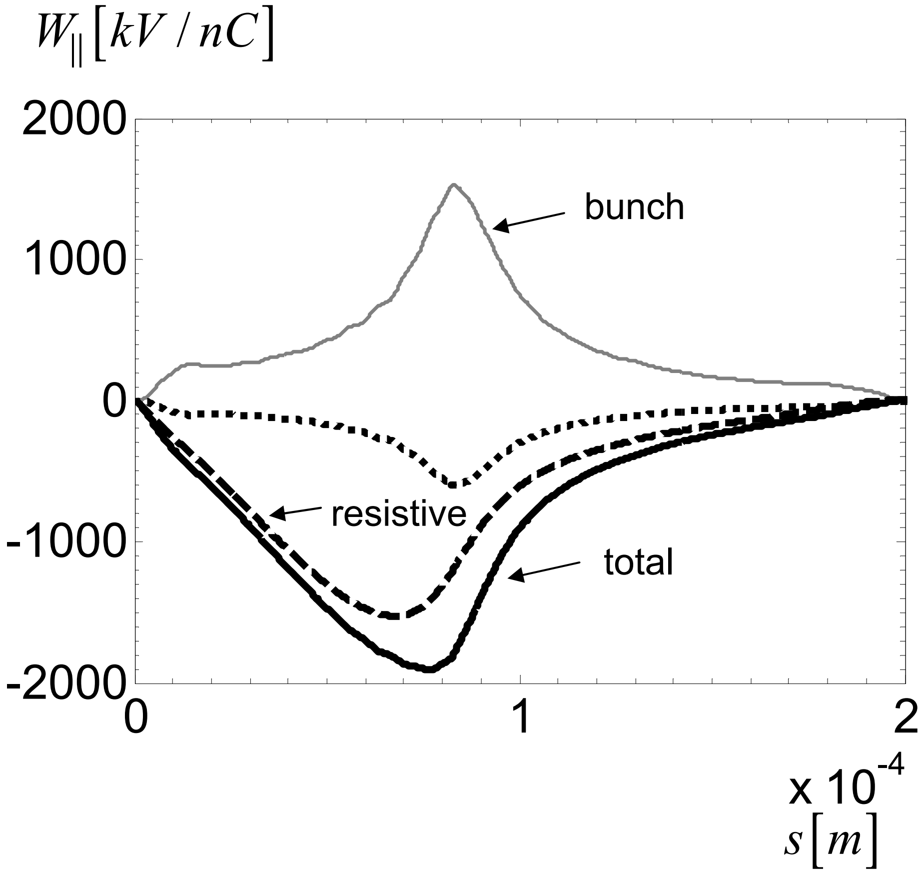
$$\Delta_{rough} = 0 [\mu \mathrm{m}]$$

$$\Delta_{oxid} = 0 [\mathrm{nm}]$$

Kicker



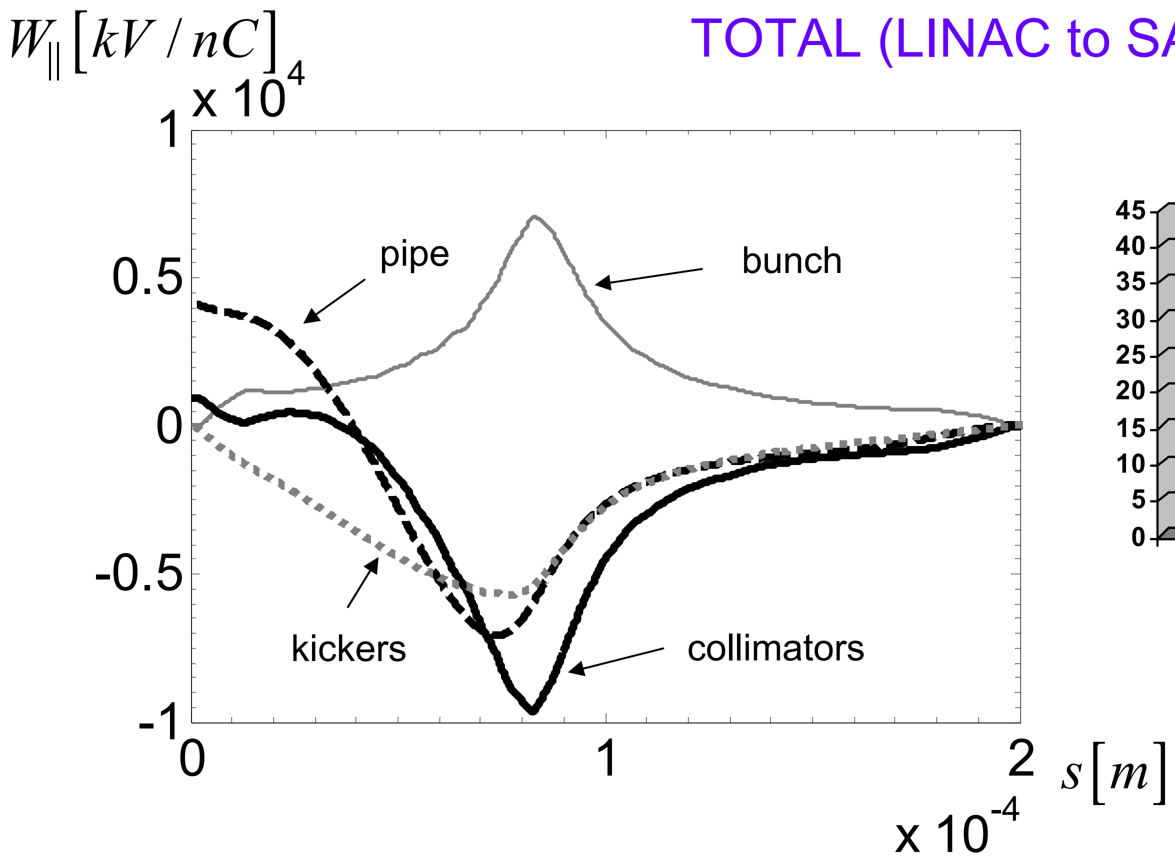
$$\sigma = 0.76 \cdot 10^6 \Omega^{-1} m^{-1}$$

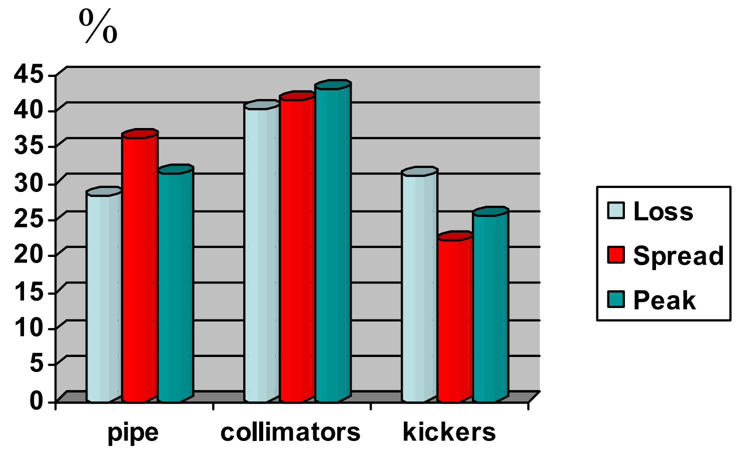


kV/nC

	Geom.	Res.	Total
Loss	300	894	1195
Spread	182	469	592
Peak	-604	-1526	-1905

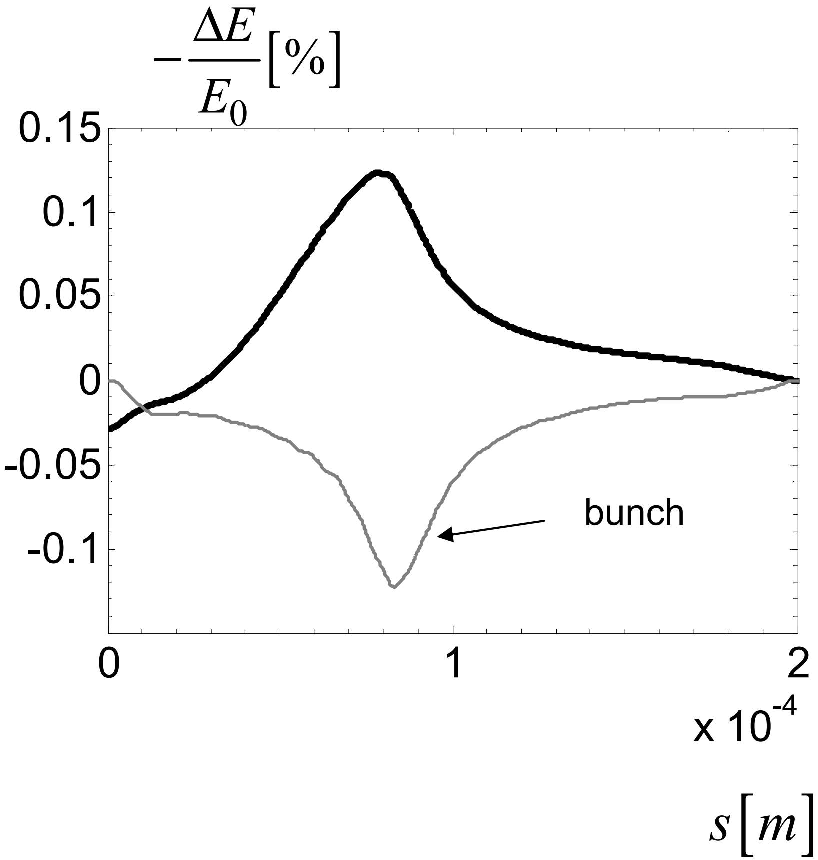
TOTAL (LINAC to SASE2)

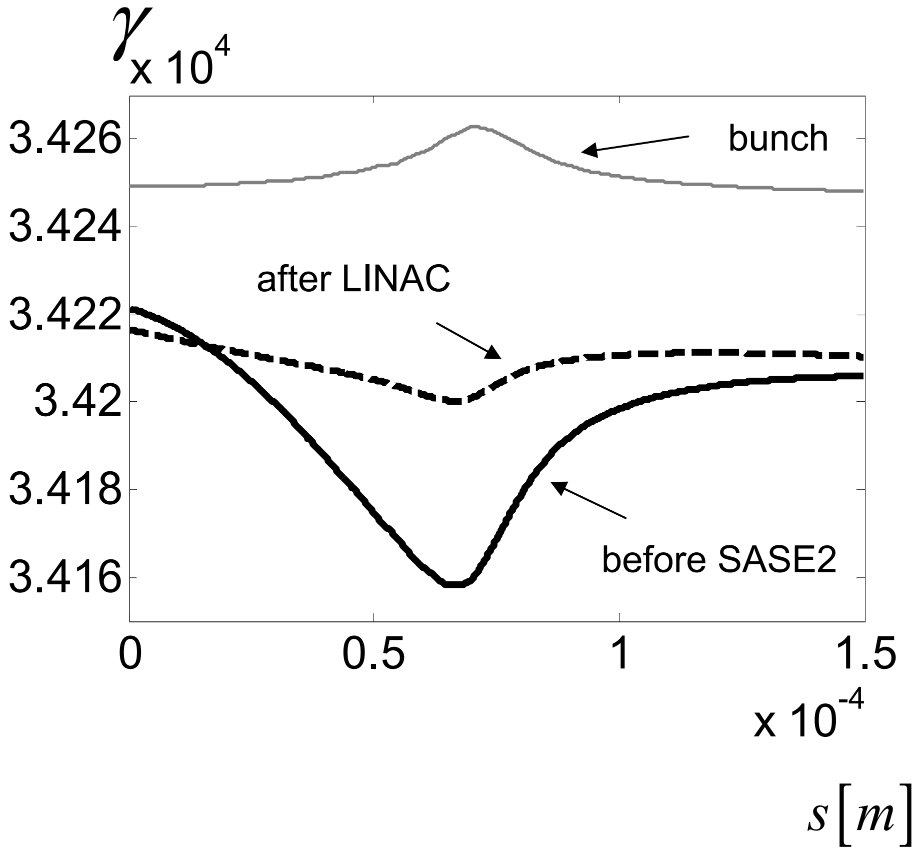




kV/nC	Pipe (456m)	Collimators (4 items)	Kickers (3*10m)	Total
Loss	3359	4623	3584	11565
Spread	**2963**	**3315**	**1777**	**7617**
Peak	-7248	-9645	-5714	-21636

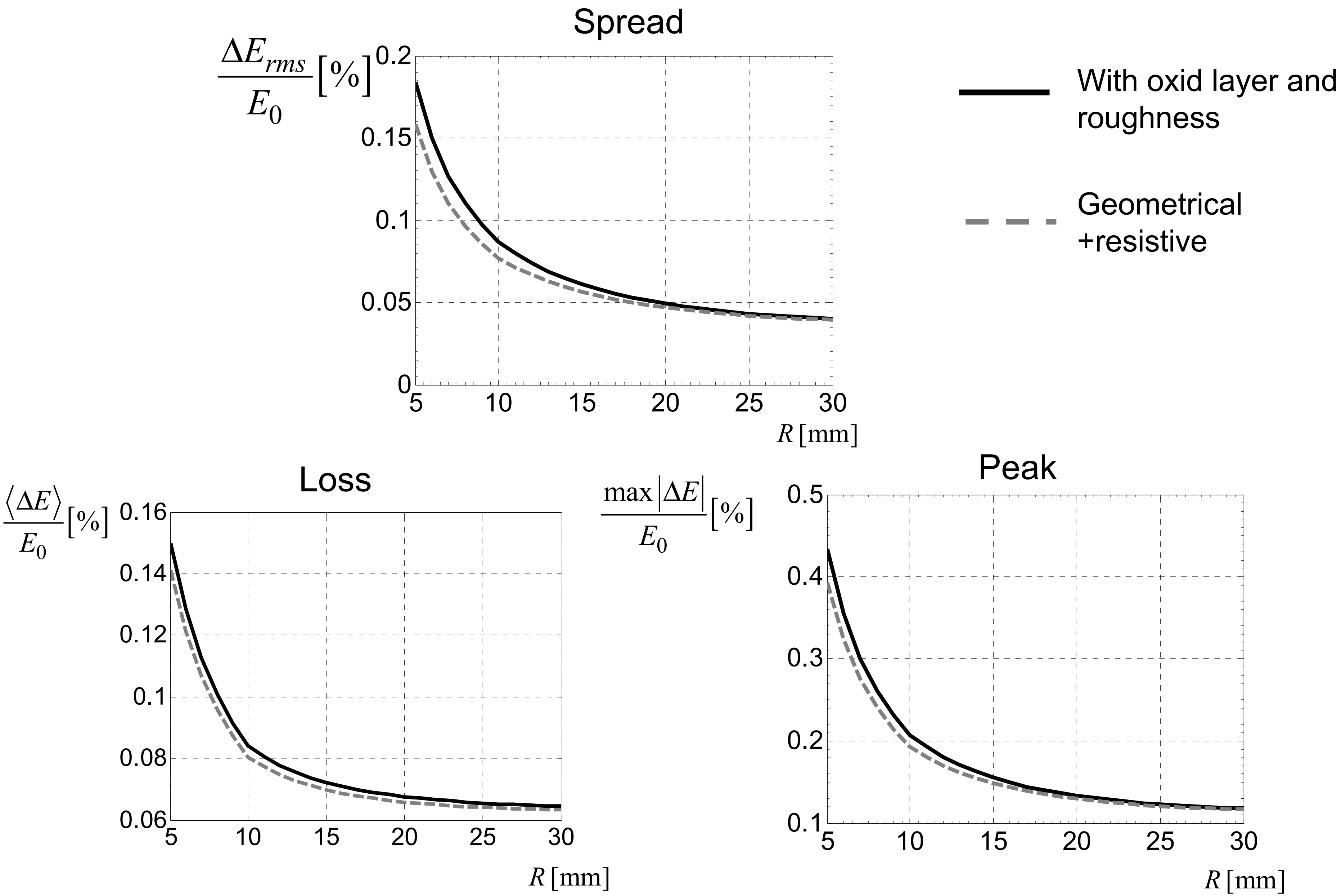
Energy spread due to wakefields between LINAC and SASE 2



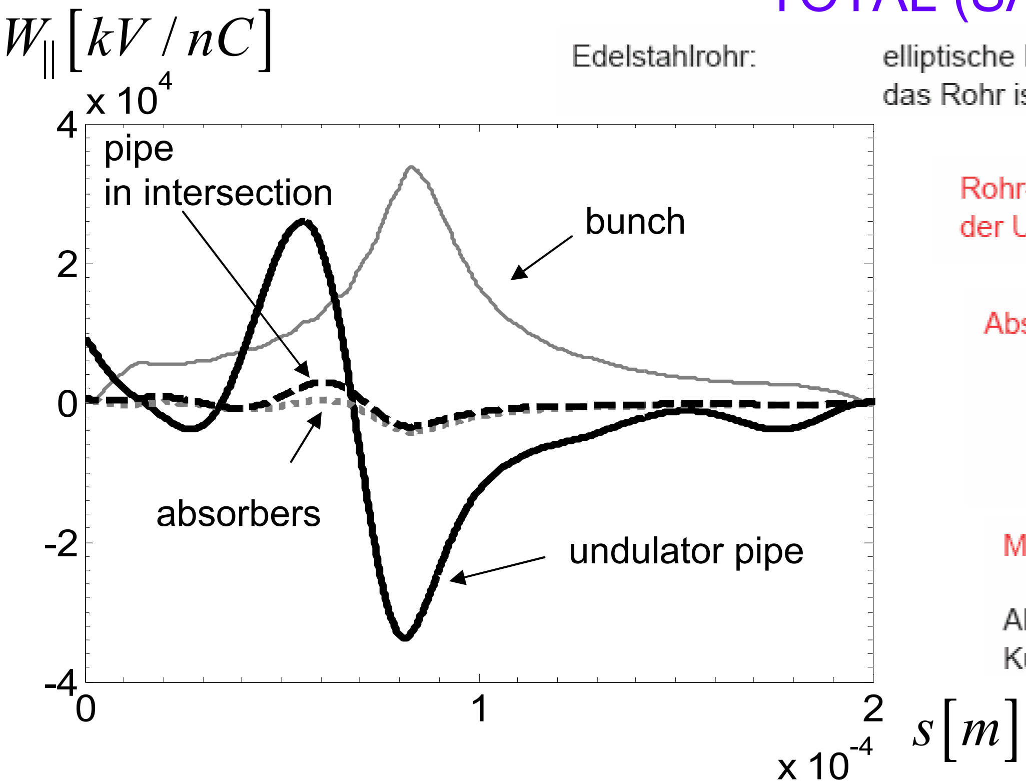


$E_0 = 17.5\ \text{GeV}$

Energy losses between LINAC and SASE2 vs. pipe radius R



TOTAL (SASE2)



Edelstahlrohr: elliptische Rohrgeometrie horzt.Id 15mm x vert.Id 8,8mm Länge ca 0,62m das Rohr ist innen verkupfert.

Rohr-Geometrie der Undulatorkammer: elliptisches Rohr: horz.Id 15,0mm x vert.Id 8,8mm Länge 5,1m

Absorbergeometrie: ca. 23mm lang
Taperung ca. 10mm lang
elliptische Geometrie
Horizontal: 9mm
Vertikal: 8mm

Materialauswahl: zu erwartende Oxidschicht:

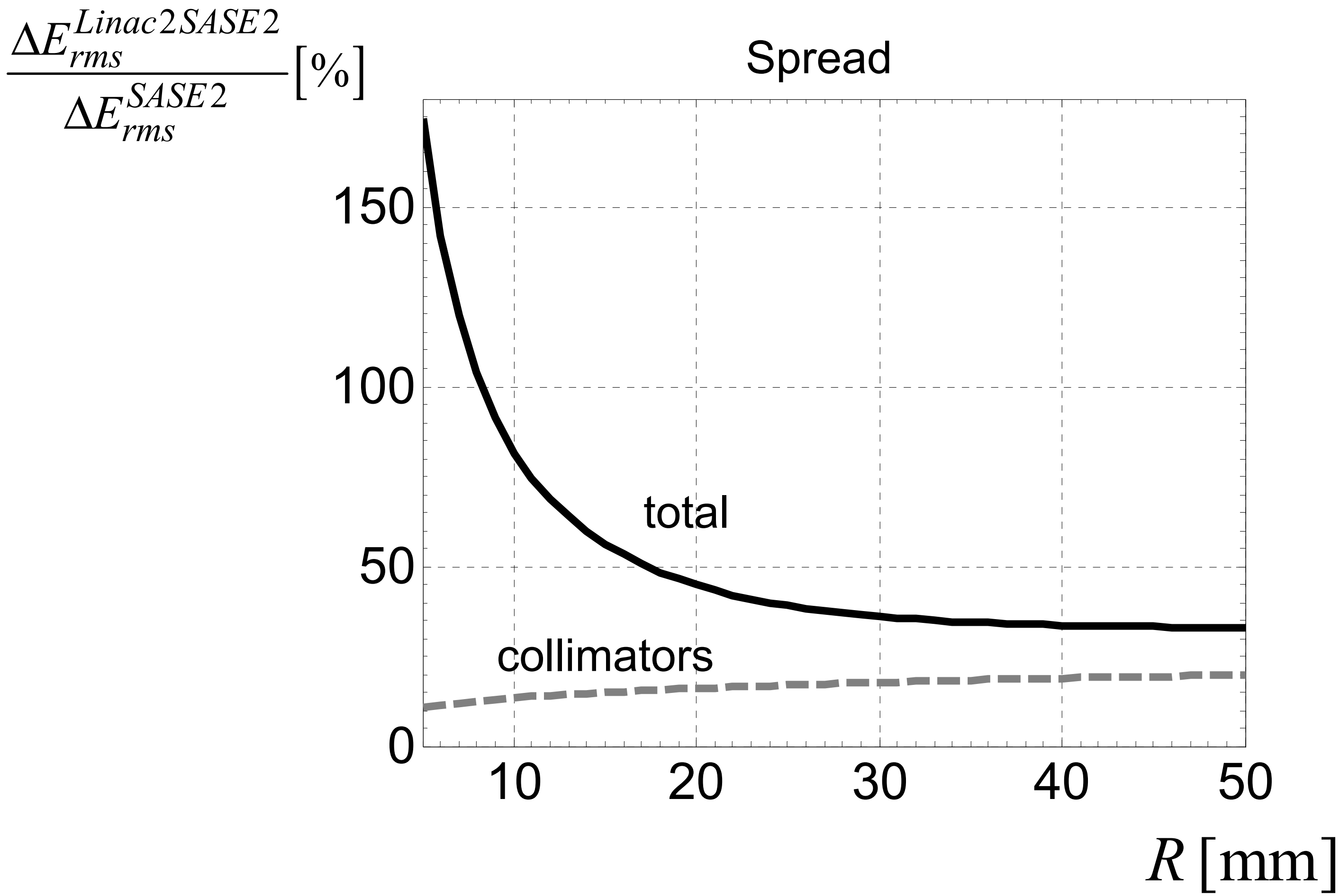
Aluminium:	5nm
Kupfer:	nach 10min ca. 1nm bis 5nm

(T.Wohlenberg)

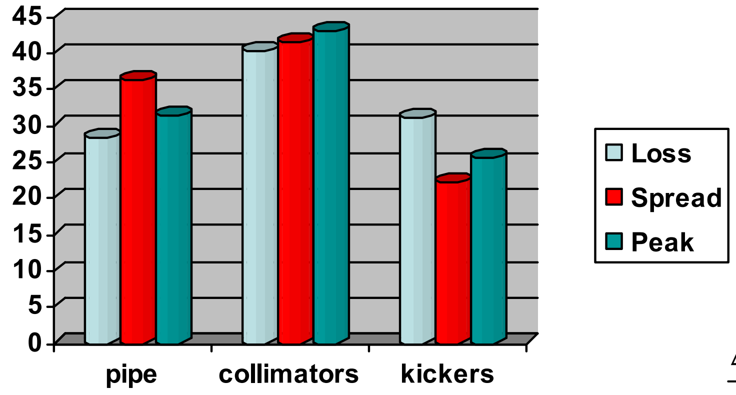
kV/nC	undulator pipe (42*5.1m)	intersection pipe (41*0.7m)	absorbers (41*0.3m items)	Total	Total (old geometry)*
Loss	9395	869	1689	1.19e4	1.11e4
Spread	16560	1723	1470	**1.95e4**	**1.89e4**
Peak	-33789	-3435	-4200	-4.1e4	-4.0e4

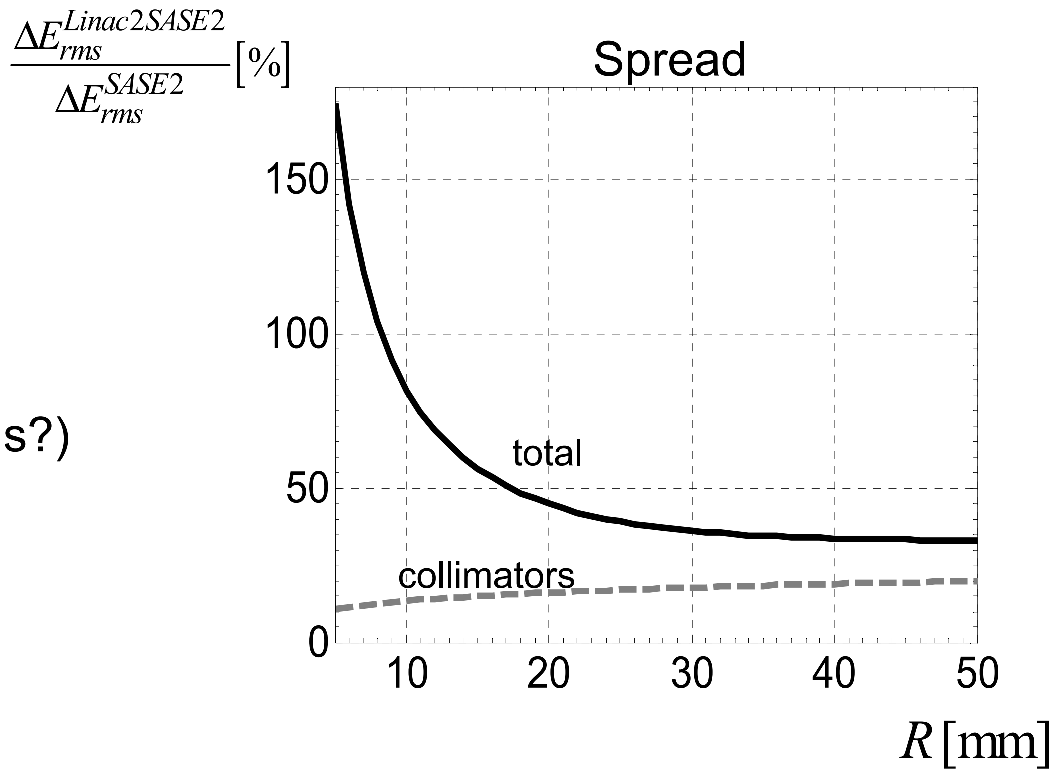
* M. Dohlus et al, TESLA-FEL 2005-10

Energy spread between LINAC and SASE2 vs. pipe radius R
(normalized to the spread in SASE2)



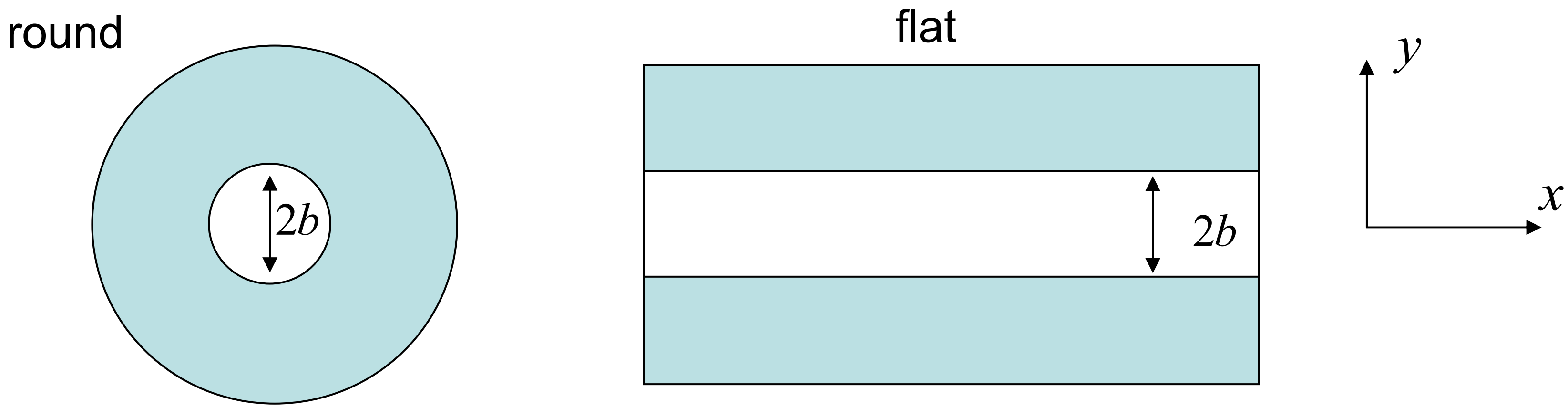
Conclusion





Impact on FEL performance?
(spectrum from SASE simulations?)

Appendix A. Kick factors of flat and round collimators are equal



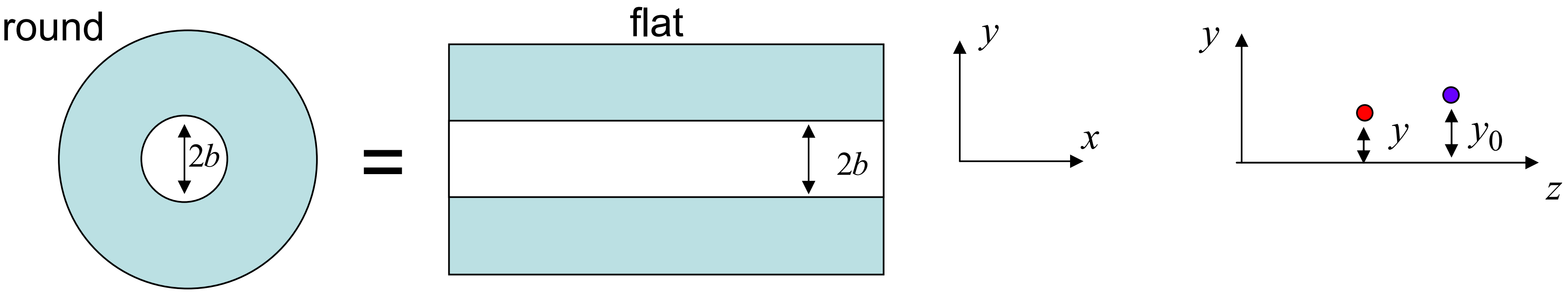
Proceedings of the 2001 Particle Accelerator Conference, Chicago

High-Frequency Impedance of Small-Angle Collimators

G. V. Stupakov
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309

We conclude, that the impedance (kick factor) of the flat collimator in the diffraction regime is equal to half of the impedance (kick factor) for the round collimator with the same minimal gap b_1.

Appendix A. Kick factors of flat and round collimators are equal



$$k_d(r_0,\theta_0,r,\theta) = k_d r_0 \cos(\theta_0 - \theta)$$

$$k_x(x_0,y_0,x,y) = k_d x_0$$

$$k_y(x_0,y_0,x,y) = k_d y_0$$

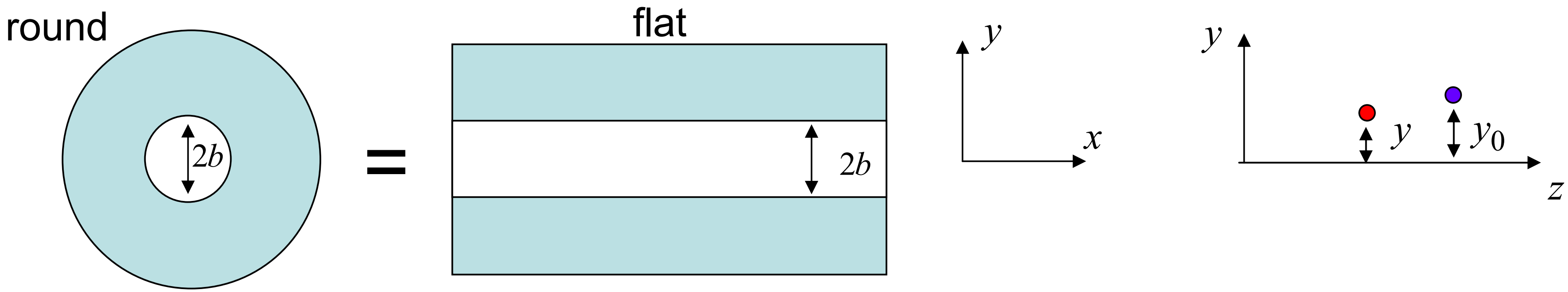
$$k_x(x_0,y_0,x,y) = k_{xd} x_0 - k_{xq} x$$

$$k_y(x_0,y_0,x,y) = k_{yd}\, y_0 + k_{yq}\, y$$

$$k_{xd} = k_{xq} \qquad k_{xq} = k_{yq}$$

$$k_y(x_0,y_0,x,y) = k_{yd}\; y_0 + k_{xd}\; y$$

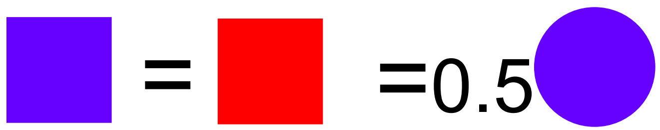
Appendix A. Kick factors of flat and round collimators are equal



$$k_y(x_0, y_0, x, y) = k_d y_0$$

$$k_y(x_0, y_0, x, y) = k_{yd} y_0 + k_{yq} y$$

$$k_{yd} = 0.5 k_d$$



$$k_{xq} = k_{xd} = 0.5 k_d$$

$$k_y = k_{yd} + k_{yq} = k_d$$

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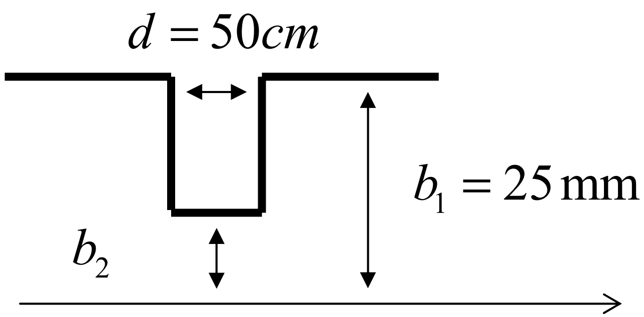
Kick of the flat collimator is equal to the kick of the round one

Appendix B. XFEL collimator vs. cryomodule



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

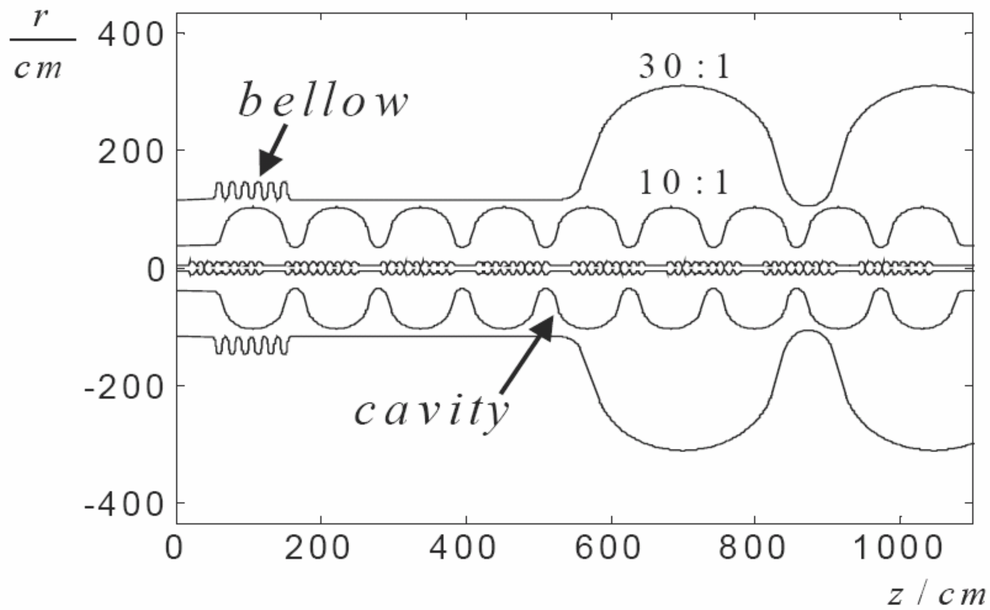


Fig1. Geometry of the TESLA cryomodule.

The TESLA linac consists of a long chain of cryomodules. The cryomodule of total length 12 m contains 8 cavities and 9 bellows as shown in Fig.1. The iris radius is 35 mm and beam tubes radius is 39 mm.

$$w_\perp(s) = 10^3\left(1 - \left(1 + \sqrt{\frac{s}{s_1}}\right)\exp\left(-\sqrt{\frac{s}{s_1}}\right)\right)\left[\frac{V}{pC \cdot m \cdot module}\right]$$

where $s_0 = 1.74 \cdot 10^{-3}$ and $s_1 = 0.92 \cdot 10^{-3}$

Appendix B. XFEL collimator vs. cryomodule

b2, mm	Kick, V/pC/m
1	$18*10^3$
2	$4.5*10^3$
3	$2.0*10^3$
4	$1.1*10^3$
5	$0.7*10^3$

Kick [V/pC/m/module]

$\sigma, \mu m$	Numerical	Analytical	TDR
1000	138	137	153
700	109	108	130
500	85.4	85.1	111
400	72.5	72.2	99.6
300	58.1	57.9	86.8
250	50.2	50.1	79.6
125	28.8	28.3	56.9
75	18.2	18.1	44.3
50	12.8	12.6	36.3
25		~6.5	

For the bunch with sigma=25mkm the kick from the collimator with apperture b_2=2mm is equal to the kick of ~700 cryomoduoles

Emmitance growth?