Impedance Budget from LINAC to SASE2

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Beam Dynamics Group Meeting

3.12.07

overview

wake sources = geometric & resistive (=surface effects)

definitions (average & rms)

collimator: geometric, surface effects, all	~40%
pipe: surface effects	~40%
kicker: geometric, surface effects, all	~20%

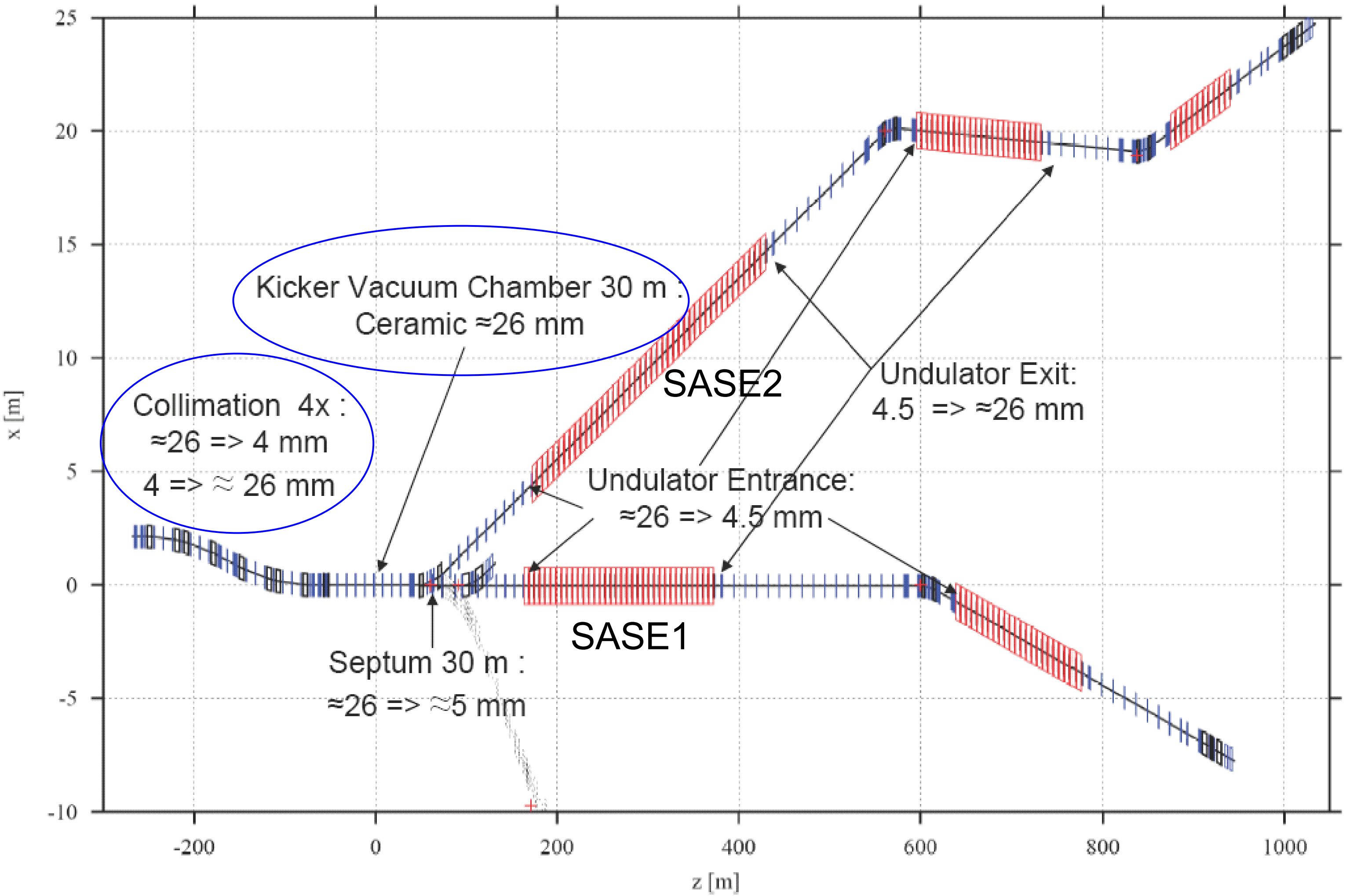
total

total vs. pipe radius

comparison with effects in LINAC

comparison with SASE2 ~SASE2 / 2

total vs. pipe radius normalized to SASE2



	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

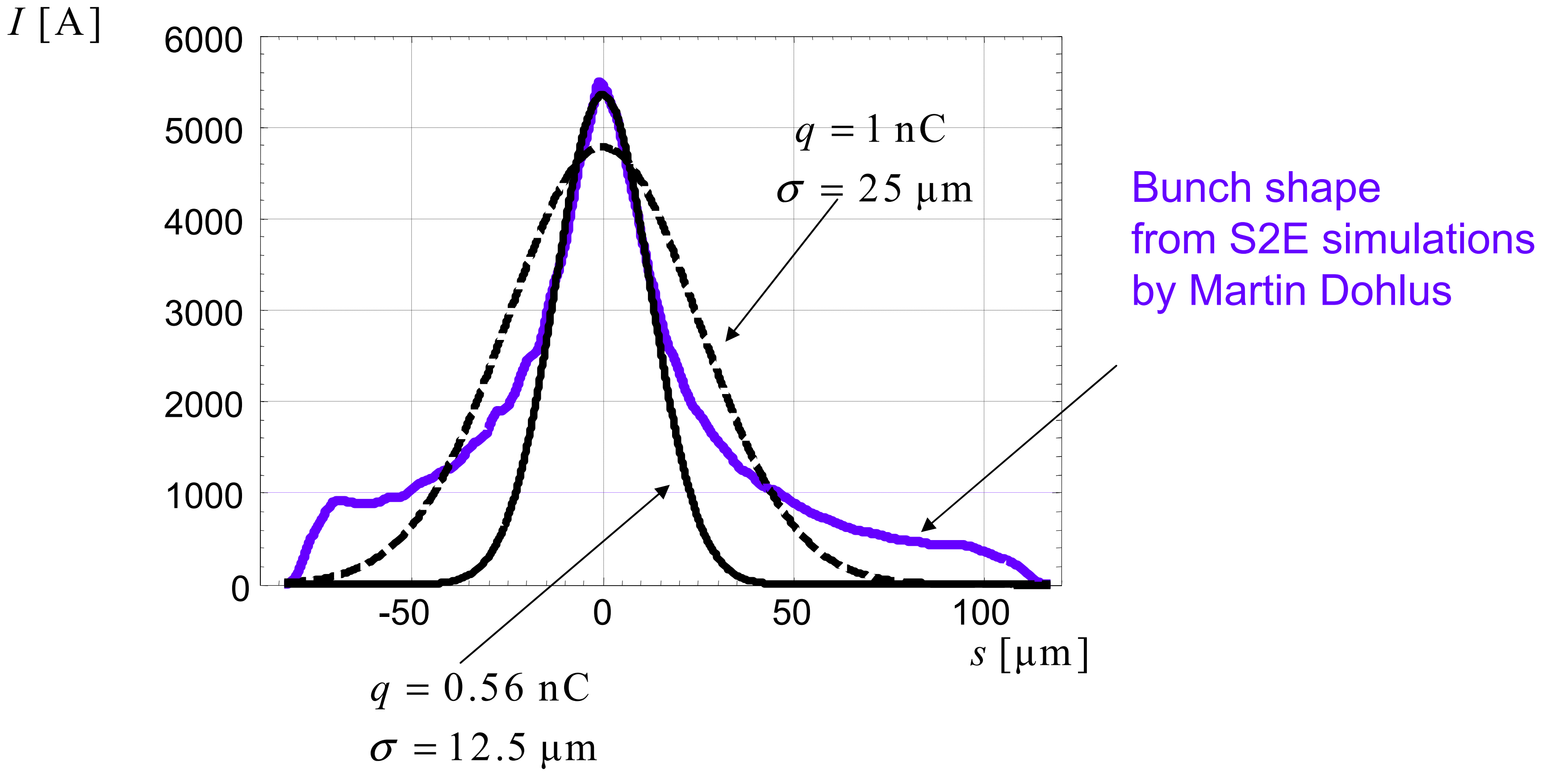
(W.Decking)

Wakefield sources

- Resistance of the pipe (r ~ 20 mm, L=456 m, Aluminium)

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

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

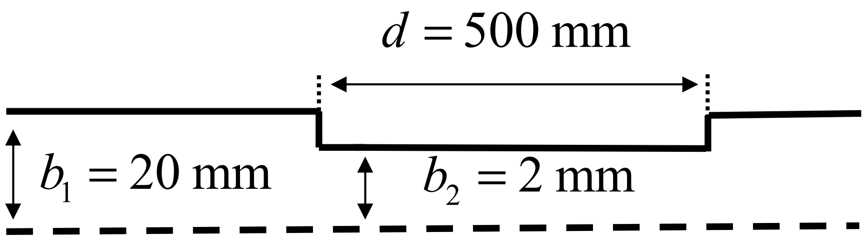


$$\lambda(s) - \text{bunch shape}$$

$$Q^2 \langle W \rangle = Q^2 \int W(s)\lambda(s)ds - \text{energy loss}$$

$$Q^2 \left\langle (W - \langle W \rangle)^2 \right\rangle^{0.5} = Q^2 \left[\int \left(W(s) - \langle W \rangle \right)^2 \lambda(s)ds \right]^{0.5} - \text{energy spread}$$

Collimator (geometrical wake)

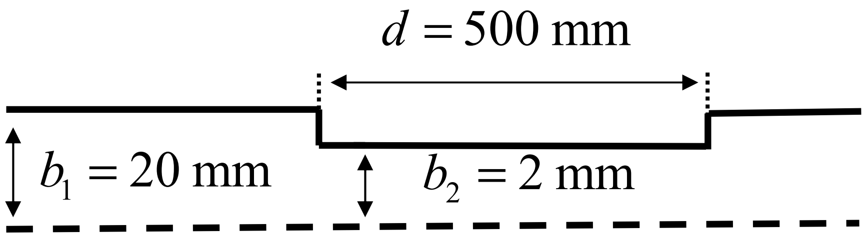


$$QW(s) = Z_{||} I(s) \qquad Z_{||} = 276\,[\Omega]$$

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

Optical approximation: 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)

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

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

$$\Delta_{rough} = 300[\text{nm}]$$

$$\Delta_{oxid} = 5[\text{nm}]$$

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

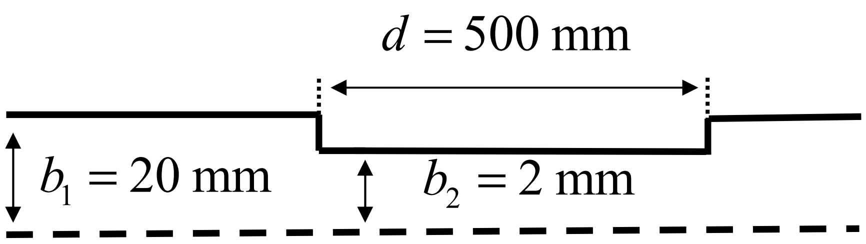
$$Z_s(\omega) = Z_s^{\sigma}(\omega) + Z_s^{L}(\omega)$$

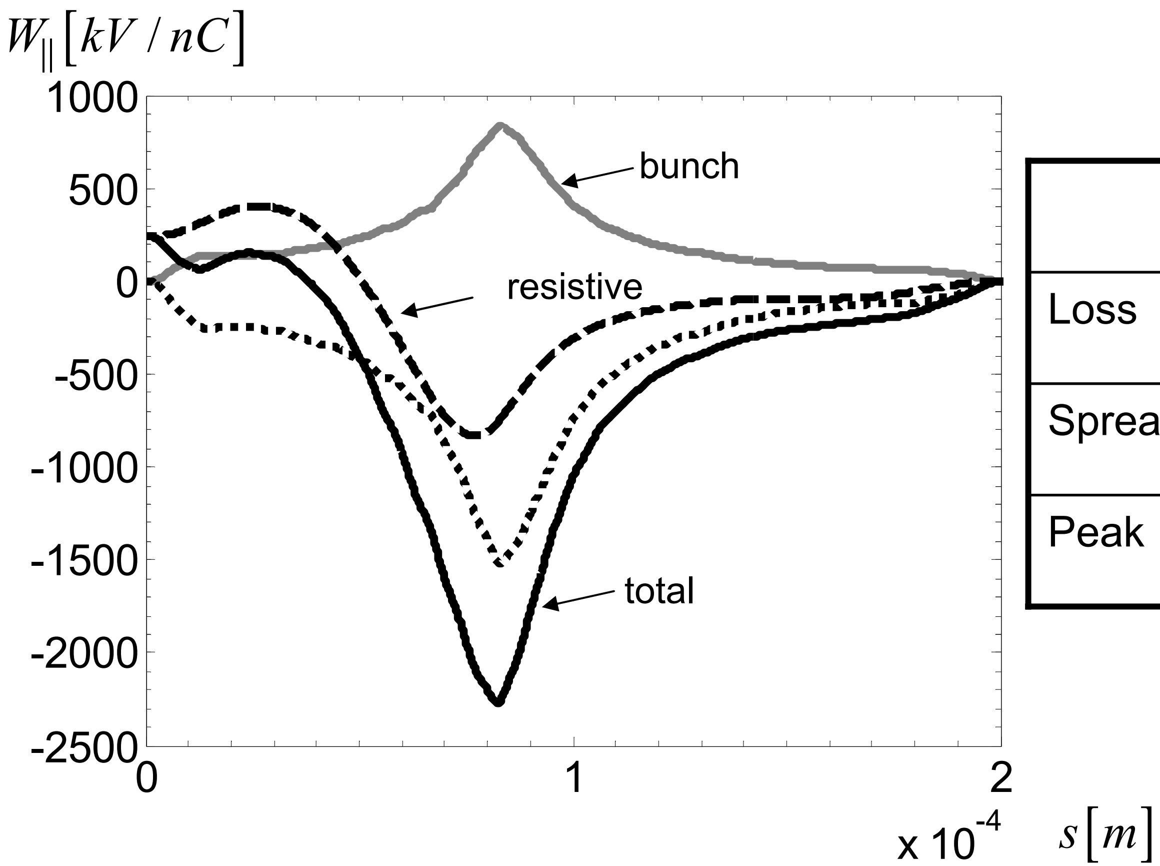
$$Z_s^{\sigma}(\omega) \approx \sqrt{\frac{i\omega\mu}{\sigma(\omega)}} \qquad \sigma(\omega) \approx \frac{\sigma_0}{1 + i\omega\tau}$$

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

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

Collimator

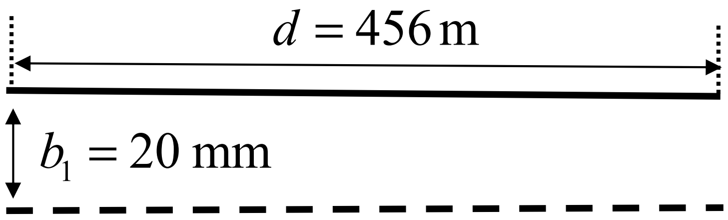


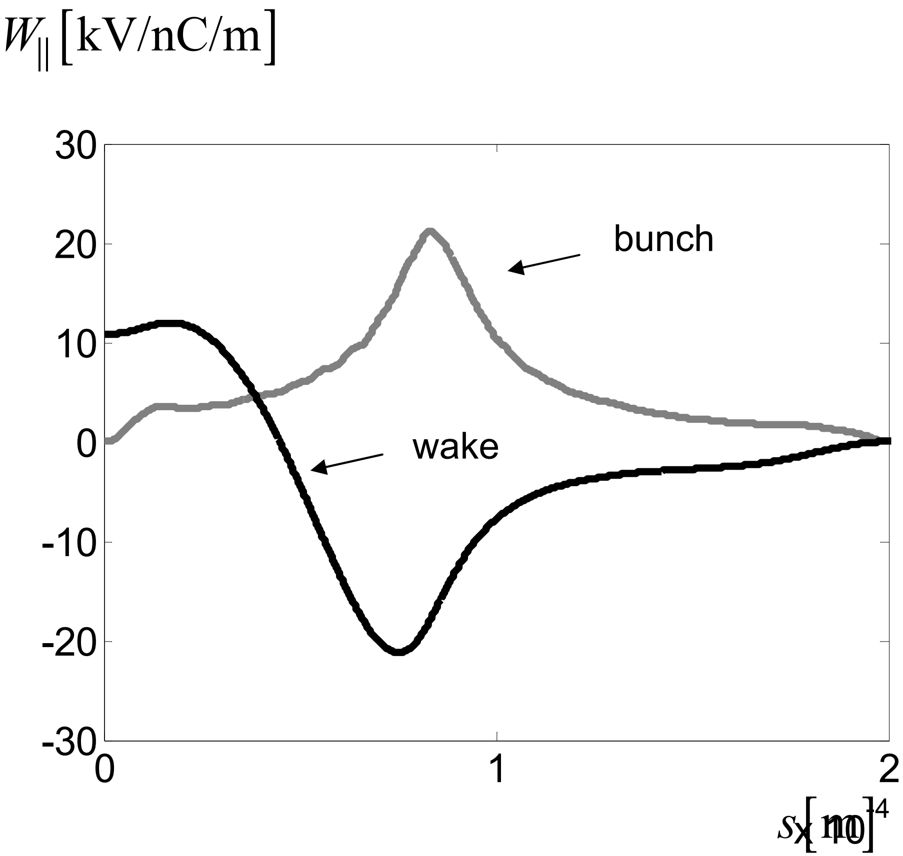


kV/nC

	Geom.	Res.	Total
Loss	754	332	1086
Spread	457	365	791
Peak	-1518	-833	-2272

Pipe (resistive+oxid layer+roughness)





(T.Wohlenberg)

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

Aluminium

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

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

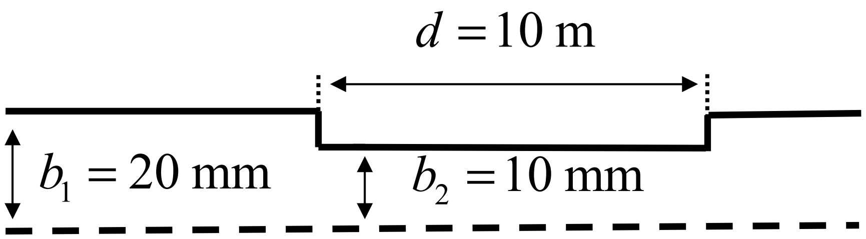
$$\Delta_{rough} = 300\,[\mathrm{nm}]$$

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

$kV / nC / m$

	resistive	total
Loss	8.4	9.0
Spread	8.5	9.3
Peak	-19.8	-21

Kicker (geometrical wake)



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

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

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

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

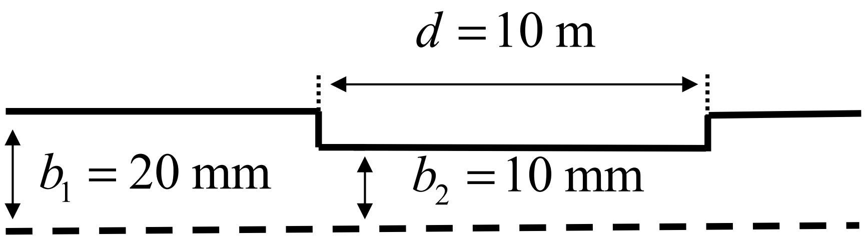
Verzweigungsstrecke: (T.Wohlenberg)

Kickerkammer:

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:



Verzweigungsstrecke: (T.Wohlenberg)

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$$\rho = 12\frac{\Omega}{m}\cdot 4.4\cdot 10^{-8} m^2 = 0.53\cdot 10^{-6}\,\Omega m$$

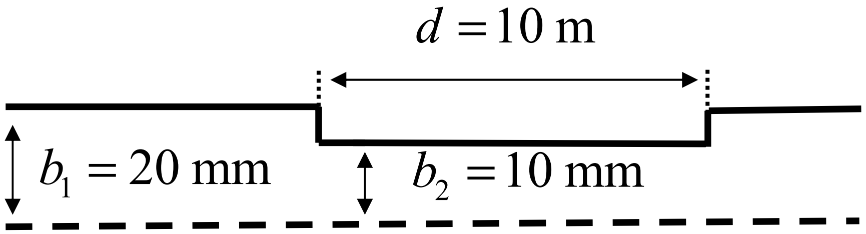
$$\sigma = 1.9\cdot 10^{6}\,\Omega^{-1} m^{-1}$$

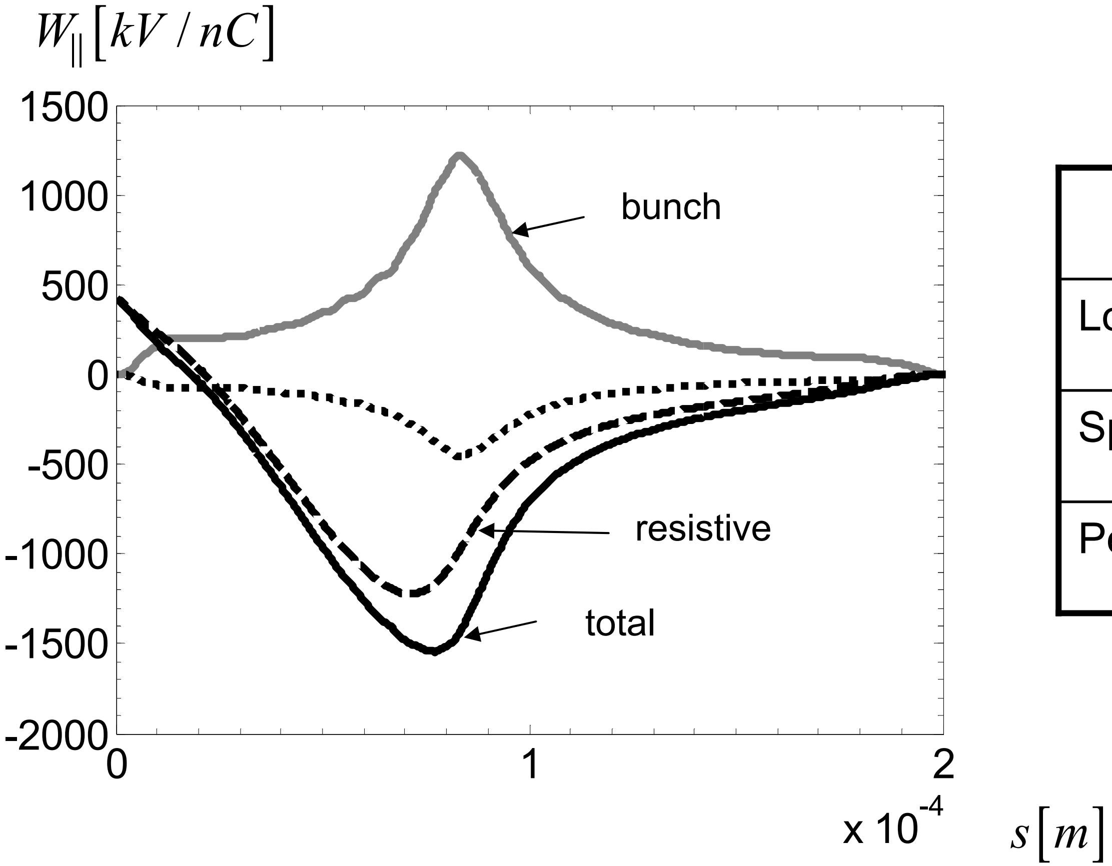
$$\tau = 2.4e-15\,[\mathrm{sec}]$$

$$\Delta_{rough} = 300\,[\mathrm{nm}]$$

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

Kicker





kV/nC

	Geom.	Res.	Total
Loss	227	659	886
Spread	137	412	519
Peak	-457	-1222	-1544

A. Tsakanian

- Tube with finite thickness

B. Zotter, S. Kheifets, 1997.

Method: matching technique

Problem: fields are diverges in outer space for $\gamma \to \infty$

- Usual Approach

A.W. Chao, SLAC-PUB- 2946, 1982
A. Piwinski, DESY-94-068, 1994

skin-depth < tube thickness ➡ Tube with infinite thickness

- Solution in General Case

⇨

- *Analytical solution for the fields inside tube for finite Lorenz factor*
- *Perform the ultrarelativistic limit*

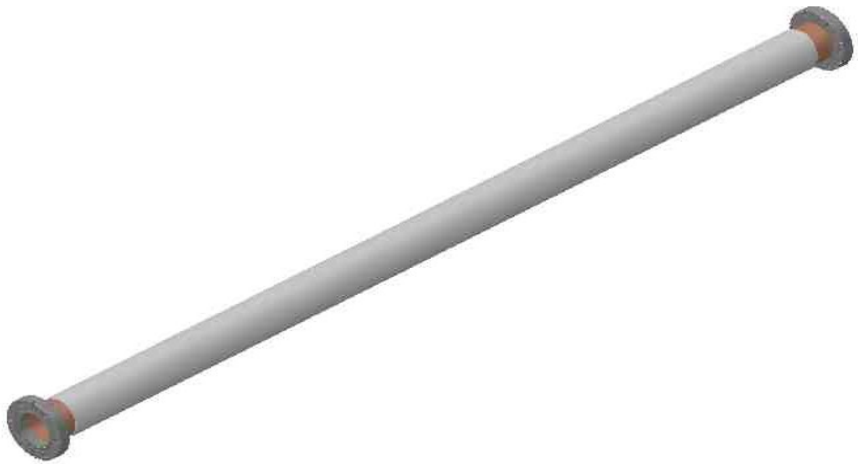
M. Ivanyan, A. Tsakanian, Phys. Rev. ST-AB, 2006

Impedance of XFEL Ceramic Kicker Vacuum Chamber with Metallic Coats.

A. Tsakanian

Ceramic Kicker Vacuum chamber:

Ceramic with Titanium-Stabilized High Gradient Steel (TSHGS) coats



Vacuum Chamber Parameters

Radius - 0.01 m

Lenght - 0.9 m

TSHGS Parameters

Thickness - 0.7 μm

Resistance - R/L = 10 - 12 Ωm^{-1}

$\sigma \approx (2.0841 \pm 0.18946) \times 10^{6}\, \Omega^{-1} m^{-1}$

Ceramic Parameters

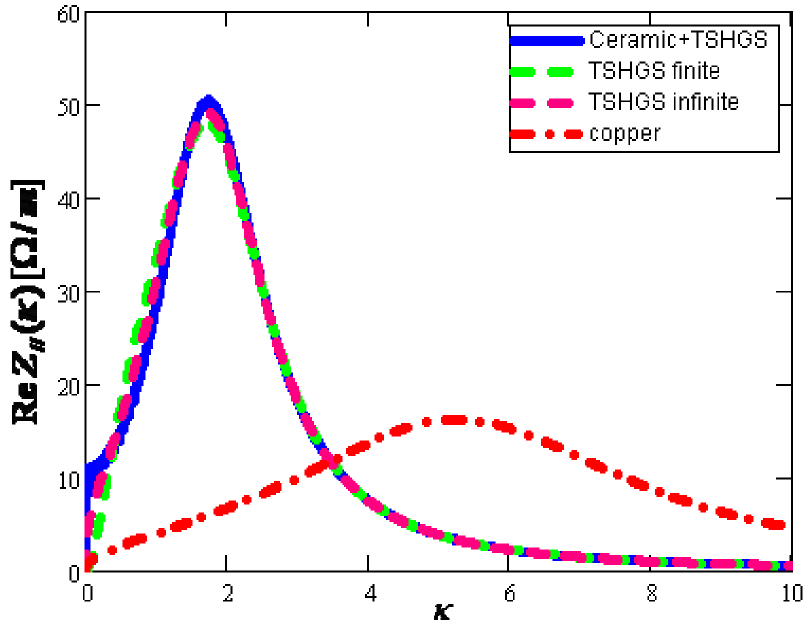
$\varepsilon_r = 9.1$

$\tan\delta \sim 10^{-4}$

A. Tsakanian

Monopole Term

Longitudinal Impedance Per Unit Length



$\kappa = k \cdot s_0$

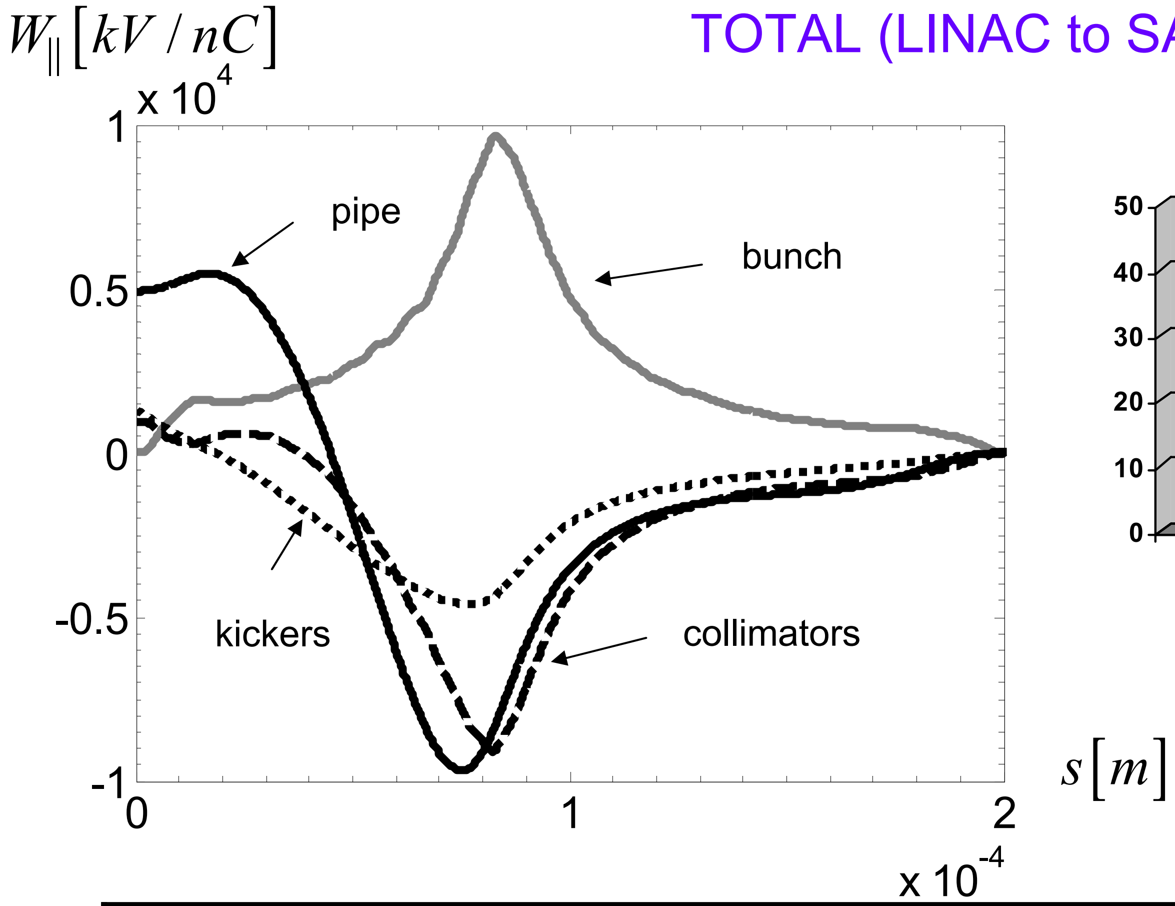
Longitudinal monopole impedance as function of dimensionless wave number for several cases of vacuum chamber material:

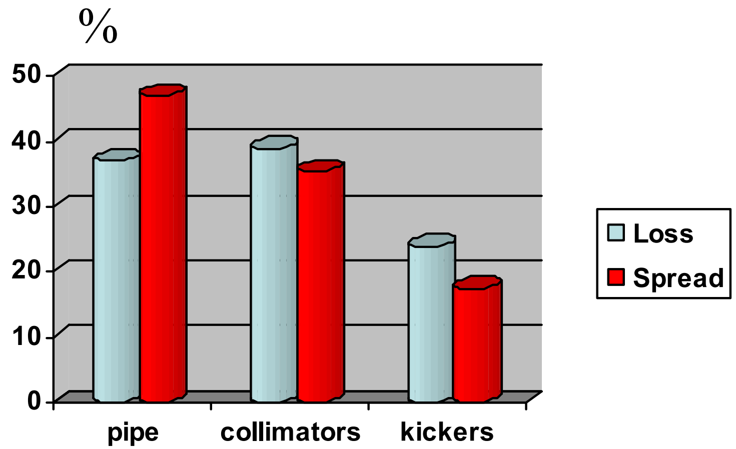
1. Ceramic with TSHGS coats.
2. TSHGS single layer tube with finite and infinite thickness.
3. Copper single layer tube.

s_0 characteristic distance: $s_0 = \left(2ca^2\varepsilon_0 / \sigma\right)^{1/3} \approx 63.4\ \mu m$

transverse → A.T.

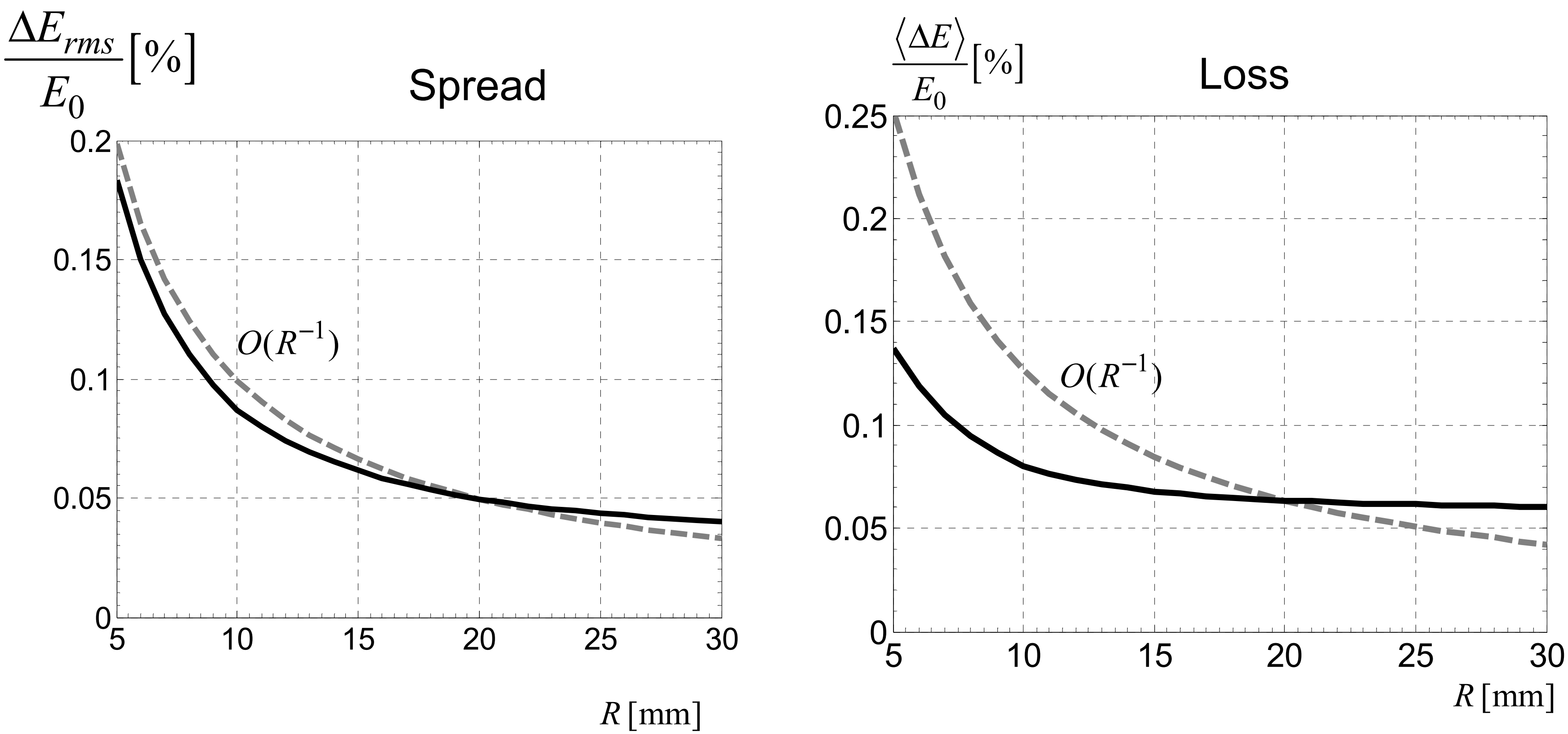
TOTAL (LINAC to SASE2)



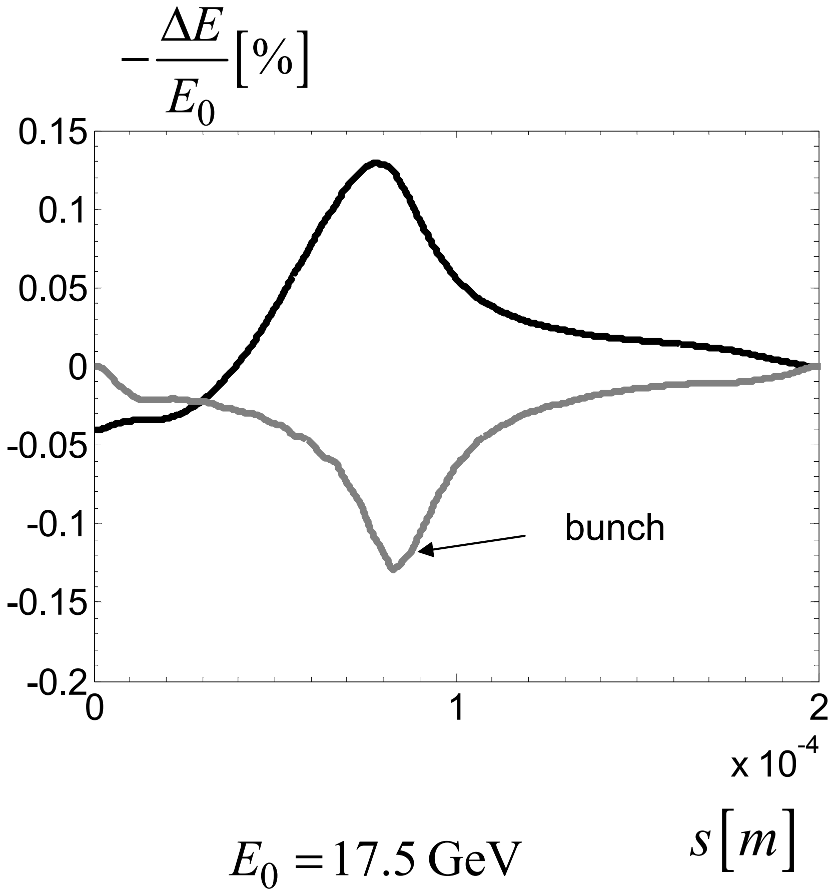


kV/nC	Pipe (456m)	Collimators (4 items)	Kickers (3*10m)	Total
Loss	4103	4343	2659	11105
Spread	**4222**	**3164**	**1557**	**8682**
Peak	-9680	-9088	-4633	-22595

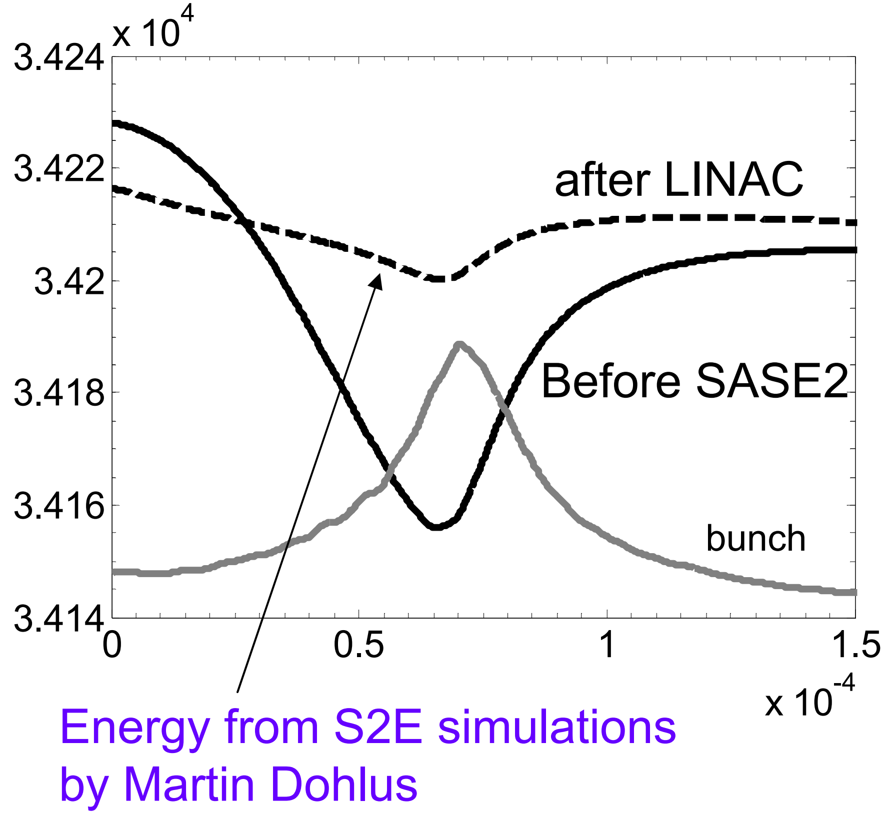
Energy losses between LINAC and SASE2 vs. pipe radius R



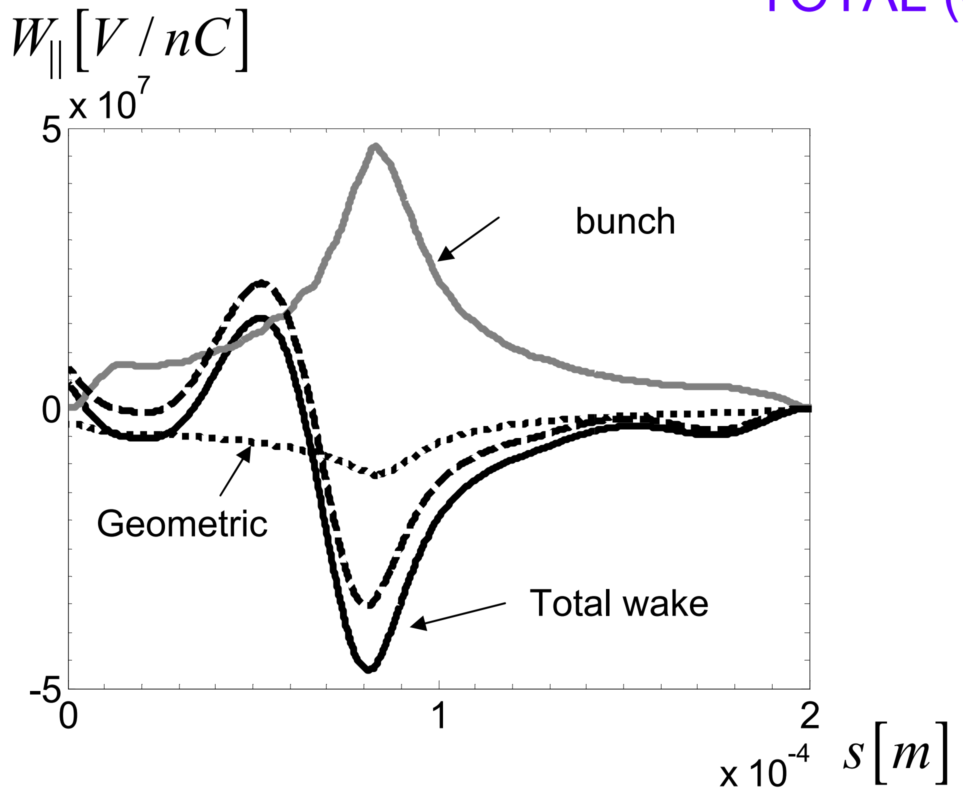
Energy spread due to wakefields between LINAC and SASE 2



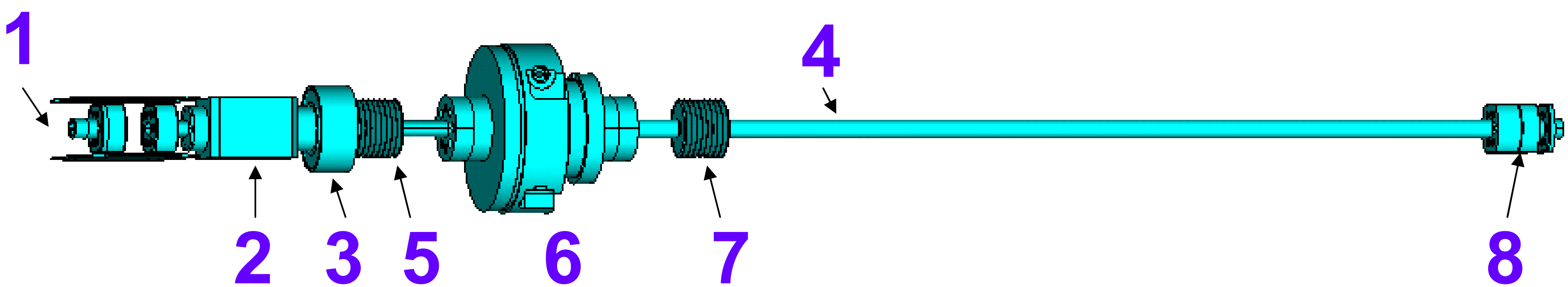
$E_0 = 17.5$ GeV



TOTAL (SASE2)



kV/nC	Geometric	Total
Loss	0.69e4	1.77e4
Spread	0.33e4	1.89e4
Peak	-1.2e3	-4.67e4



Katrin Schuett, ZM1
Dirk Lipka, MDI

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