# Resistive Wall and Surface Roughness Wakefield Studies for the Bunch Compressor Vacuum Chamber

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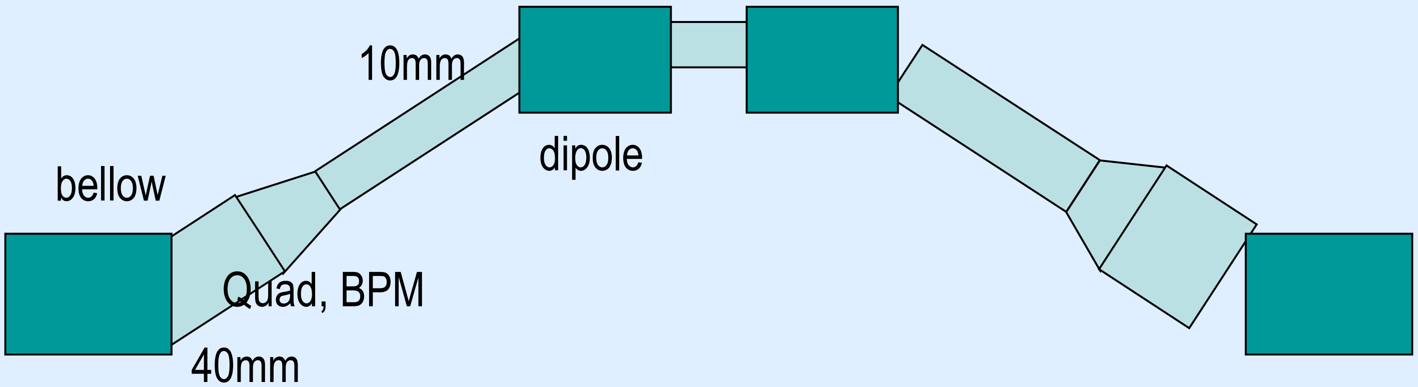
# Introduction

Bunch Compressor Vacuum Chamber




Vacuum Chamber from 40mm to 10mm (RF shielded bellow and magnet size)

Taper to reduce geometric wakes at transition

Copper coating

In this study only longitudinal wakes are considered because of dispersion in BC.

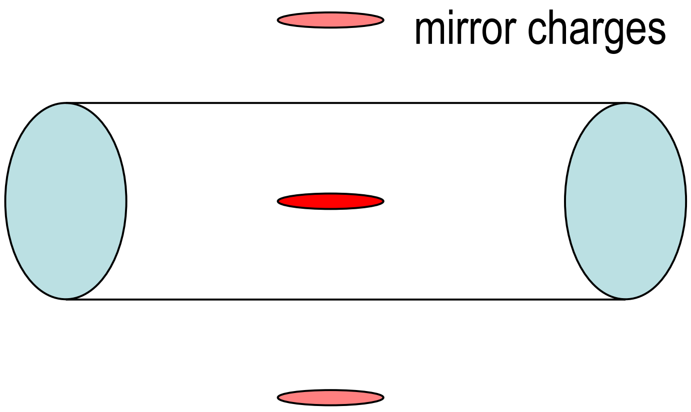
# Introduction

Resistive Wall Wake

Mirror charges of the bunch move through the vacuum chamber surface and

are subject to resistance

⇒energy changes along the bunch



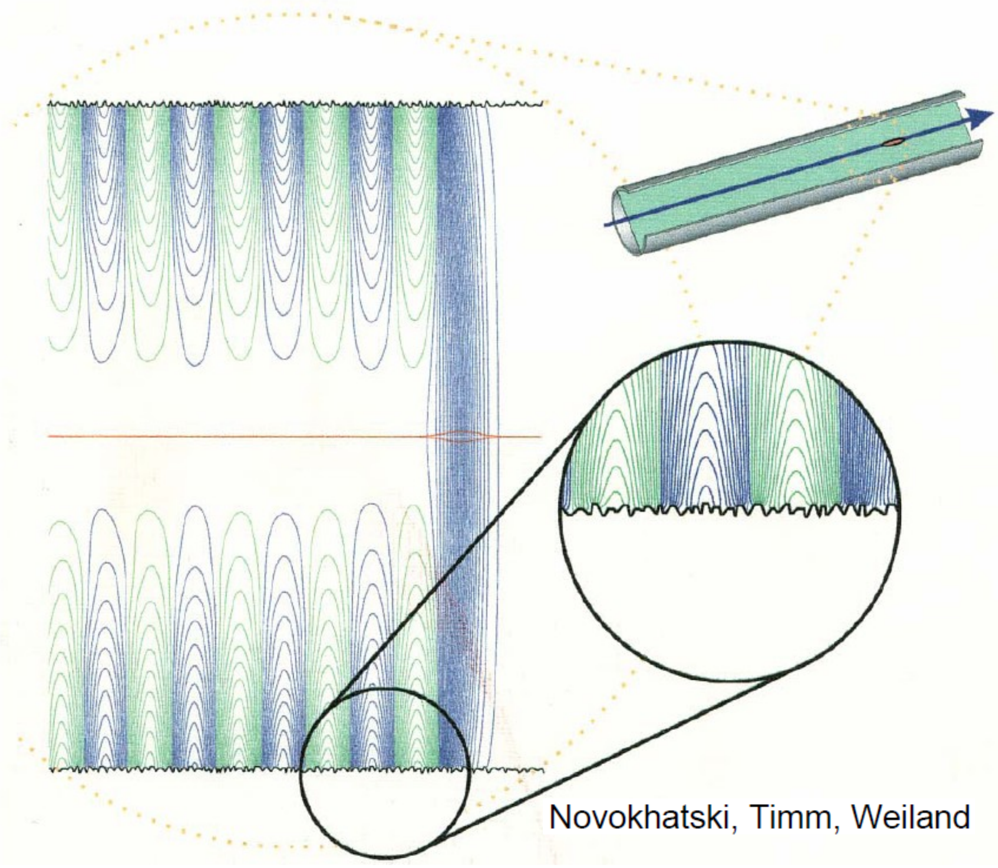
# Introduction

Surface Roughness Wake

Changes of pipe diameter along the chamber results in additional geometric wakes

Diameter transitions (tapers)

Surface Roughness



Novokhatski, Timm, Weiland

# Methods of Wake Calculations

beam impedance and surface impedance

## Surface Impedance of round pipe:

$$Z_s(\omega) = -2\pi R_0 \frac{Z_{\text{beam}}(\omega)}{1 + i\omega\varepsilon_0 \pi R_0^2 Z_{\text{beam}}(\omega)}$$

$$Z_{\text{beam}}(\omega) = -\frac{1}{2\pi R_0}\frac{Z_s(\omega)}{1 + i\omega\varepsilon_0 \frac{R_0}{2} Z_s(\omega)}$$

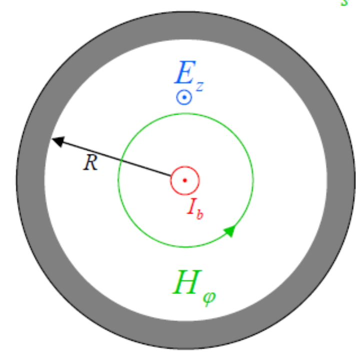
## Smooth pipe (resistive wall):

$$Z_{\text{beam}} = \sqrt{\frac{i\omega\mu}{\sigma + i\omega\varepsilon}} \qquad \sigma(\omega) = \frac{\sigma_0}{1 + i\omega\tau}$$

$$\sigma_0(Cu) = 57 \cdot 10^6 \Omega\text{m} \quad \tau(Cu) = 2.46 \cdot 10^{-14}\text{s}$$

$$\sigma_0(Al) = 36.6 \cdot 10^6 \Omega\text{m} \quad \tau(Al) = 0.71 \cdot 10^{-14}\text{s}$$

$$Z_b' = -\left.\frac{E_z}{I_b}\right|_{r\to 0} \qquad Z_s = -\left.\frac{E_z}{H_\varphi}\right|_{r=R}$$




$$H_\varphi = \frac{I}{2\pi r}\exp(i\omega(t - z/c)) + A\frac{r}{2}\exp(i\omega(t - z/c))$$

$$E_r = Z_0 \frac{I}{2\pi r}\exp(i\omega(t - z/c)) + Z_0 A\frac{r}{2}\exp(i\omega(t - z/c))$$

$$E_z = 0 - \frac{A}{i\omega\varepsilon_0}\exp(i\omega(t - z/c))$$

beam | boundary

Impedance of Beam Pipes with Smooth Shallow Corrugations

M. Dohlus TESLA 2001-26

# Methods of Wake Calculations

Surface Impedance is the sum of resistive wall and surface roughness impedance plus terms of second order in a.

surface roughness impedance of round pipe with sinusoidal corrugations:

$$R(s) = R_0 + a\,\sin(2\pi s/\lambda_c)$$

$$Z_s(\omega) = i k_0 Z_0 \frac{(a k_1)^2}{4}\left(\frac{J_1(k_{r,-1}R)}{J_0(k_{r,-1}R)k_{r,-1}} + \frac{J_1(k_{r,1}R)}{J_0(k_{r,1}R)k_{r,1}}\right)$$

or

$$Z_s(\omega) = \sum_{n=1}^{\infty} \frac{i\omega\alpha_n}{\omega_{s,n}^2 - \omega^2}$$

$$k_0 = \omega/c_0 \quad k_1 = \frac{2\pi}{\lambda_c} \quad k_{z,n} = K_0 + n k_1 \quad k_{r,n} = \sqrt{k_0^2 - k_{z,n}^2}$$

$$\omega_{s,n} = \frac{k_1 c_0}{2} + j_{0,n}^2 \frac{c_0}{2R_0^2 k_1}$$

$$\alpha_n = \frac{1}{\varepsilon_0 R_0}\left(\frac{a k_1}{2}\right)^2\left(1 + \left(\frac{j_{0,n}}{R k_1}\right)\right)$$

# Methods of Wake Calculations

Surface Roughness wake for sinusoidal corrugations can be generalised for arbitrary periodic surface structures using the spectral power density and the autocorrelation function.

$$R_c(s) = \lim_{S\to\infty} \frac{1}{S}\int_{-S}^{S} \delta r(x)\delta r(x-s)dx$$

$$S_c(k) = \int_{-\infty}^{\infty} R_c(s)\exp(-iks)ds$$

$$Z_s(\omega) = Z_b + \frac{1}{2\pi}\int_{-\infty}^{\infty} S_c(\omega)Z_k(\omega,k)ds$$

$$Z_k(\omega,k) = ik_0 Z_0 \frac{\left(i\frac{Z_b}{Z_0}J_0(k_r,R_0) + \frac{J_1(k_r,R_0)}{k_r}\left(k - \frac{iZ_b}{R_0Z_0}\right)\right)}{J_0(k_rR_0) + ik_0\frac{Z_bJ_1(k_rR_0)}{Z_0k_r}}$$

$$Z_0 = 377\Omega$$

# Impedance

Impedance for copper pipe

3mm radius

Impedance peaks around critical frequency

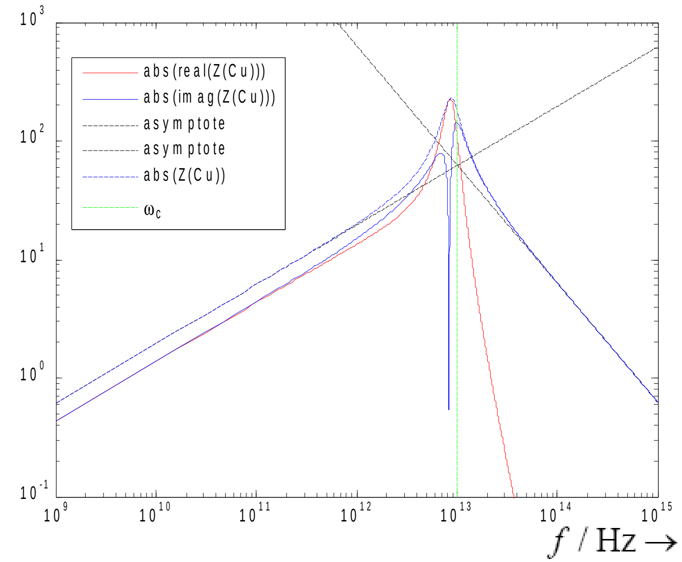
Asymptotic Behaviour:

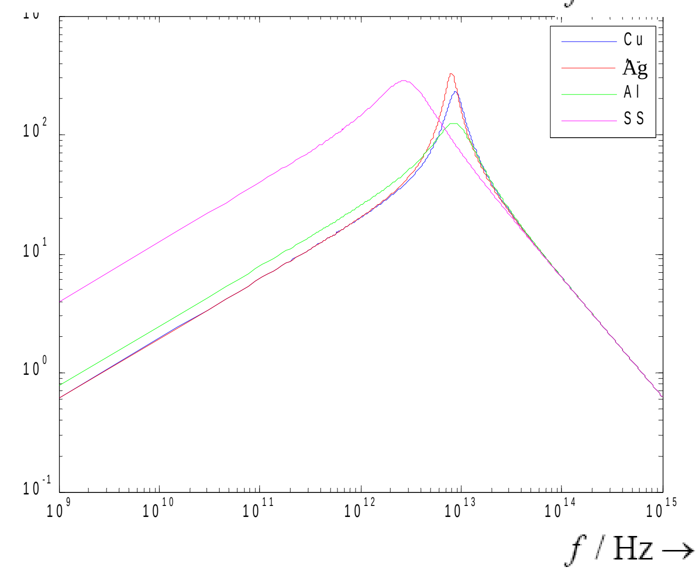
low frequency $\omega << \omega_{\mathrm{ch}}$

$$Z_b'(\omega) \approx \frac{Z_s(\omega)}{2\pi R} \approx \frac{1}{2\pi R}\sqrt{\frac{i\omega\mu}{\kappa_0}}$$

high frequency $\omega >> \omega_{\mathrm{ch}}$

$$Z_b'(\omega) \to \frac{1}{\pi R^2 \varepsilon_0} \frac{1}{i\omega} \qquad \omega_{\mathrm{ch}} = 2c\left(\frac{\kappa_0 Z_0}{2R^2}\right)^{1/3}$$

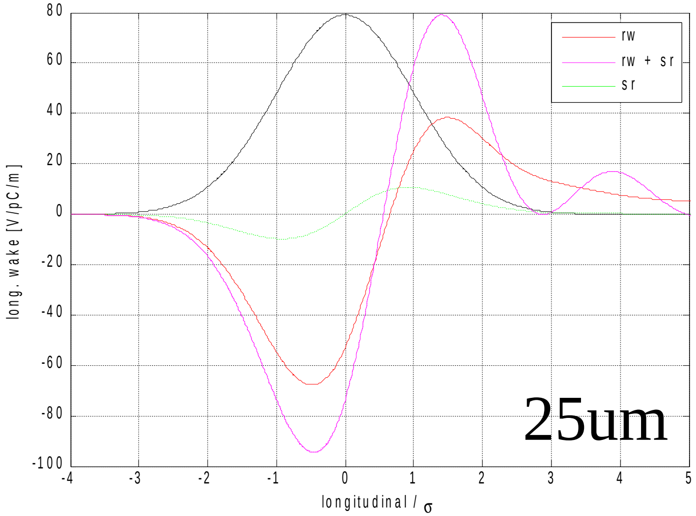


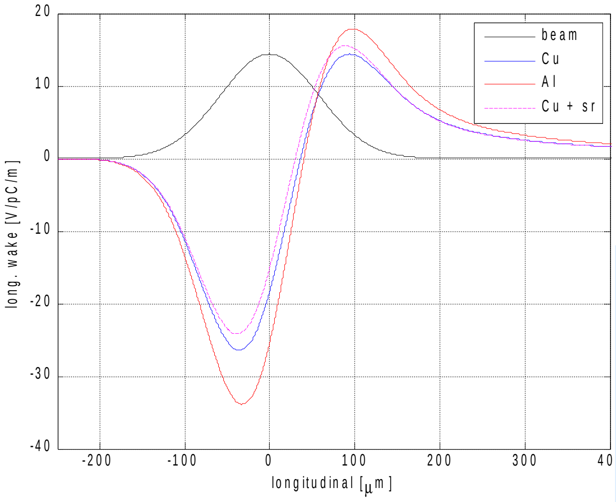



# Wake Fields

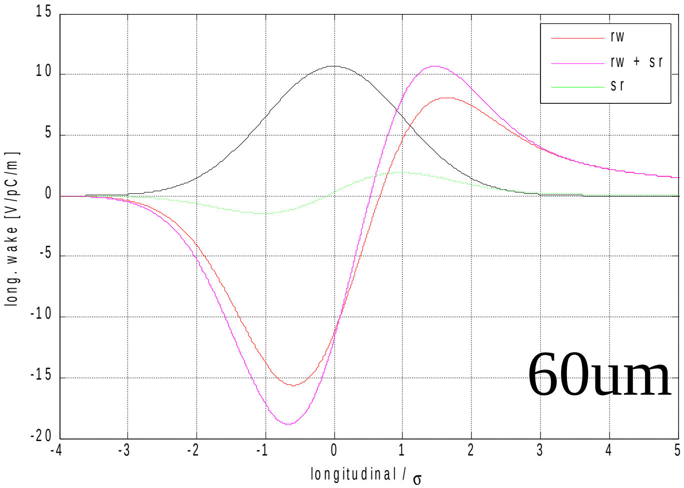
Sum of resistive wall and surface roughness impedance is converted to beam impedance.

Copper pipe, 5mm radius, lambda=10um, a=0.2um, bunch length of 25um and 60um




3mm radius, lambda=500um, a=1um, bunch length = 58um



# Loss Factor and Energy Spread

Effect from the wake fields on the beam are characterised by the energy loss and the energy spread factor. The wake is weighted with the bunch profile (Gaussian in this study) and the mean and RMS is calculated.

Energy loss factor:

$$\langle W \rangle = \frac{1}{Q} \int_{-\infty}^{\infty} W(s) q(s) ds$$

Energy spread factor:

$$\mathrm{rms}\,(W) = \frac{1}{Q} \int_{-\infty}^{\infty} W(s)^2 q(s) ds$$

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# Estimation of Emittance Growth:

Simple estimation of emittance growth by assuming a spot size increase due to dispersion and the wake induced energy spread.

Energy spread factor is then used as a basis for the calculations

$$\sqrt{\varepsilon\beta + (\eta\sigma_E)^2} = \sqrt{\varepsilon'\beta}$$

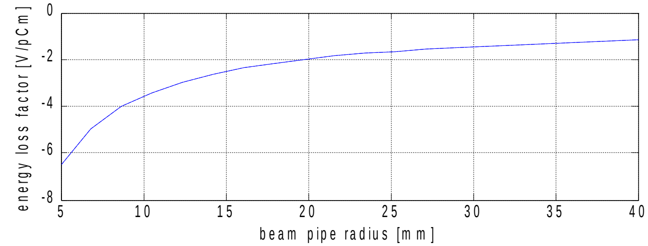
$$\varepsilon' = \varepsilon + \frac{(\eta\sigma_E)^2}{\beta}$$

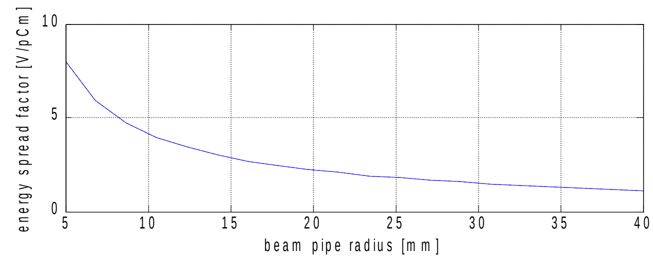
$$\frac{\varepsilon'}{\varepsilon} = 1 + \frac{(\eta\sigma_E)^2}{\beta\varepsilon}$$

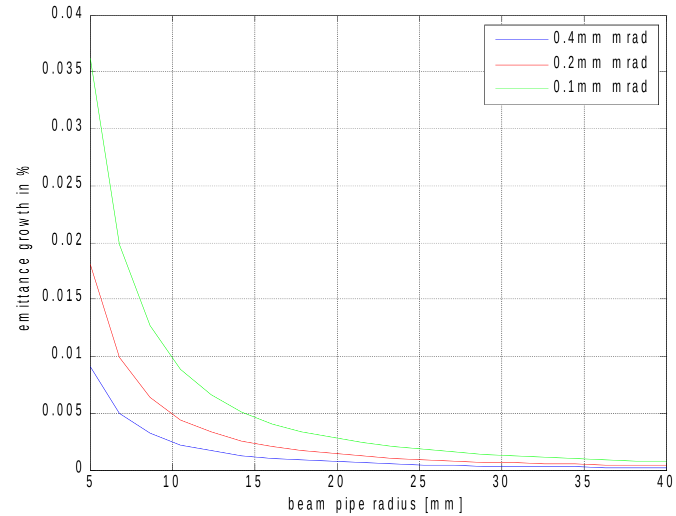
# Results

Resistive wall vs. radius:

- Emittance growth estimated with: beta=20m, q=200pC, l=10.5m, dispersion=0.4m, and bunch length=60um copper chamber, no surface roughness
- If tracking calculations (to be done) confirm this resistive wall emittance growth is tolerable for 10mm vacuum chamber



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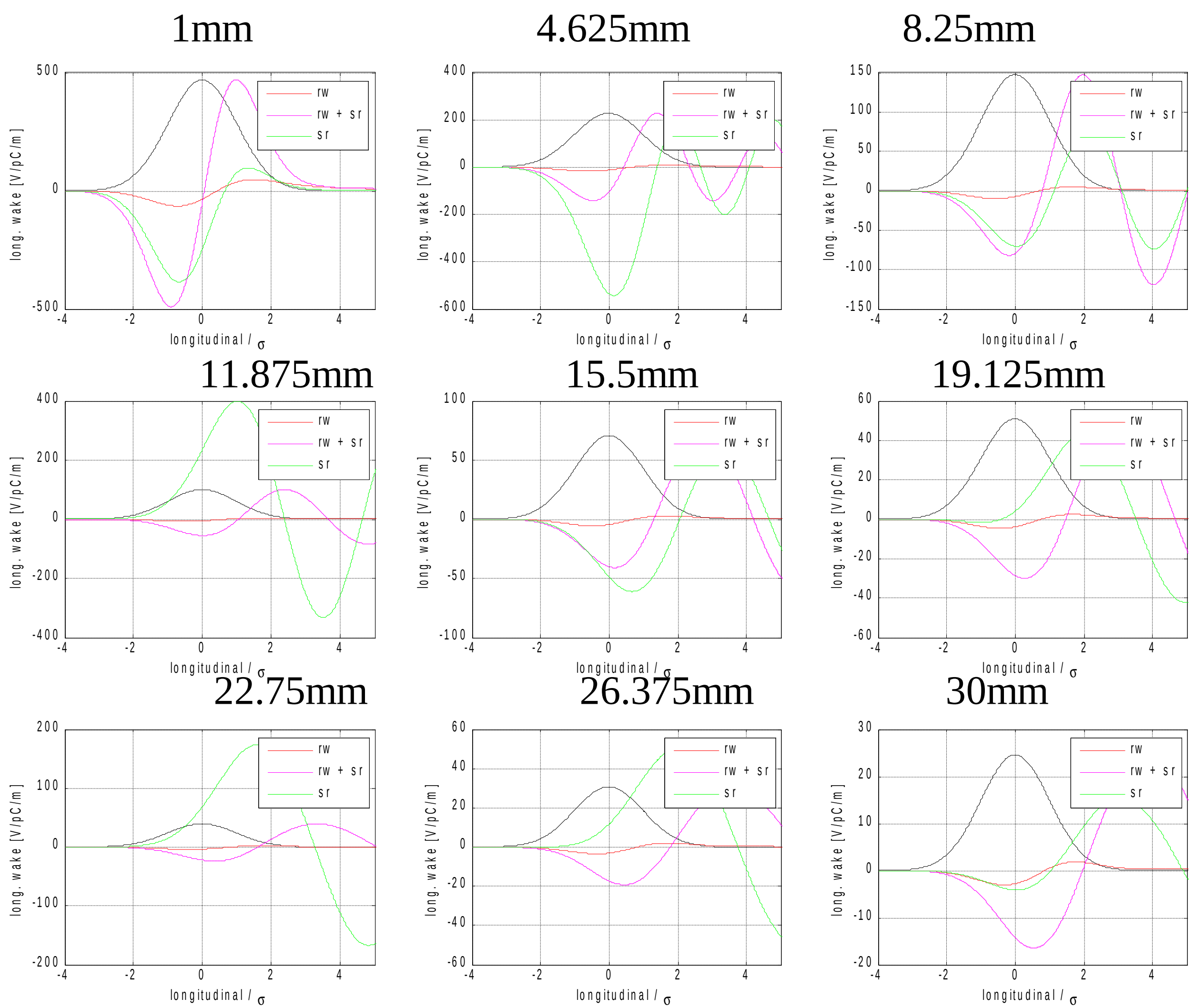
# First Results

Resistive wall plus surface roughness vs. beam pipe radius:

- Pipe radius from 1mm to 30mm
- a = 1um
- lambda = 10um
- Sigma = 60um
- Copper



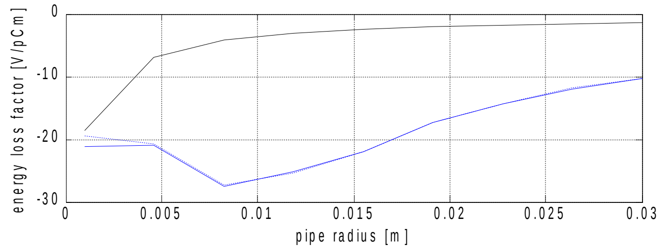
# First Results

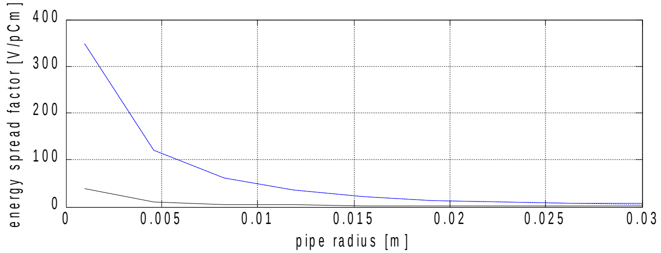
Pipe radius from 1mm to 30mm

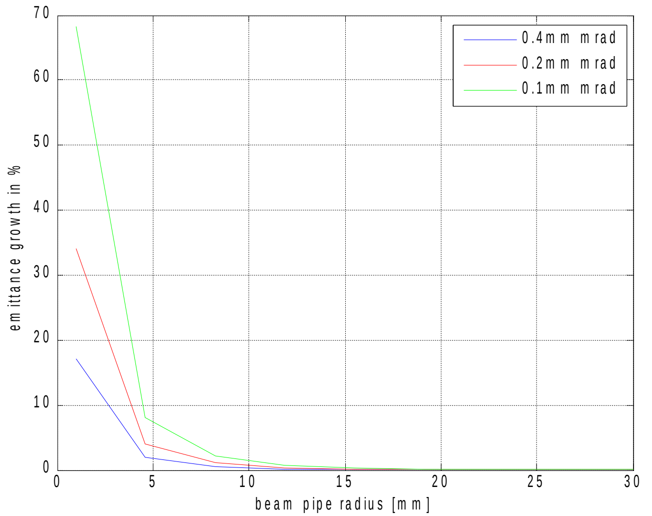
- a = 1um
- lambda = 10um
- sigma = 60um

Copper pipe

With surface roughness the emittance growth might exceed tolerable limits!



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# Summary

- Estimation of wakes for round pipe (overestimate elliptical or rectangular pipe)
- Simple emittance growth estimation
- Resistive wall wakes are probably no issue for smooth pipes
- Surface Roughness might be an issue

# Next Steps

- Realistic Estimation of Surface Roughness
- Emittance growth determination with tracking calculations (CSRTrack)
- Taper Dimensions for the 40mm -> 10mm transition
- CSR shielding effects (CSRTrack)