Short-Range Wakes in Elliptical Pipe Geometry

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Beam Dynamics Group Meeting

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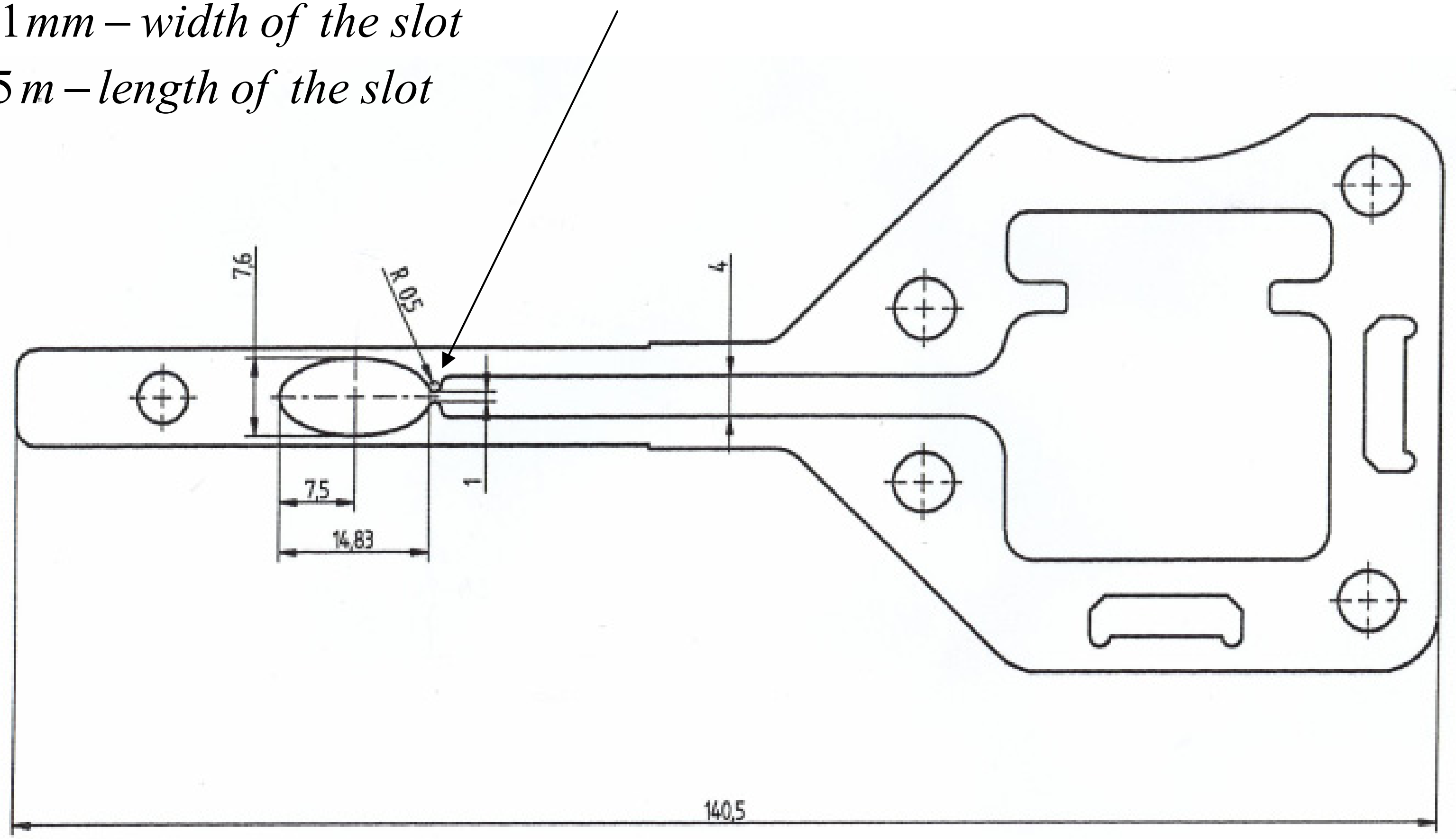
Pumping slot

$w = 1mm - width\ of\ the\ slot$

$L = 5\,m - length\ of\ the\ slot$



$$w\ ?\quad \sigma = 25\mu m$$

Theoretical results (Bethe theory) only for $w \leq \sigma$.

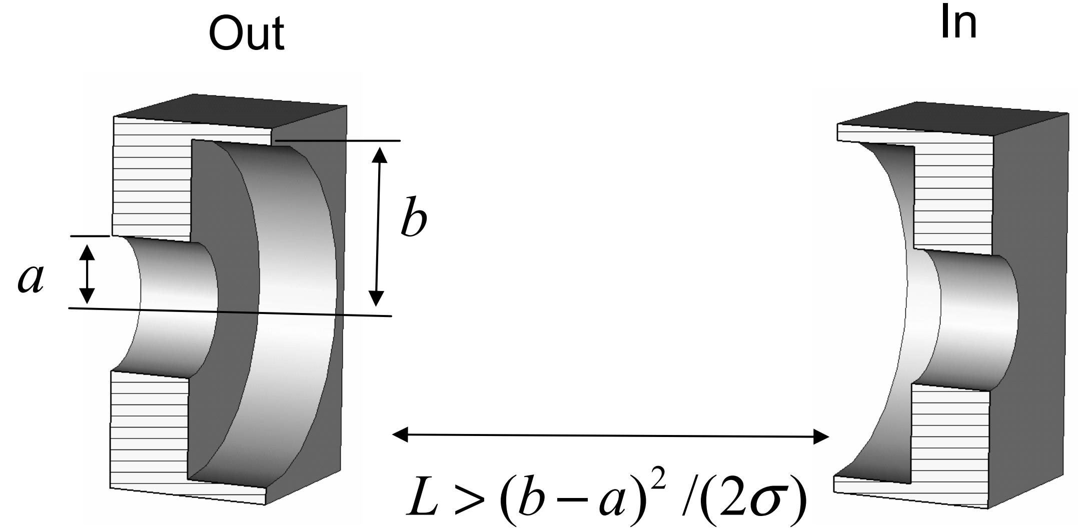
Pumping slot

Effect of the slot is small.

- Accuracy estimation of the numerical results.
- Wake scaling for geometry parameters.

Used tools:

ECHO (time-domain),
CST Microwave Studio (modeling, meshing),
Matlab (pre- and postprocessing).



$$L > (b-a)^2 /(2\sigma)$$

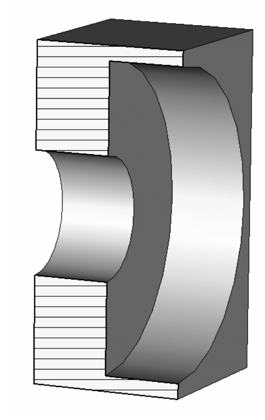
$$Z_{hi} = \frac{Z_0}{\pi} \ln\left(\frac{b}{a}\right) \qquad k_{loss} = \frac{Z_{hi} c}{2\sqrt{\pi}\sigma_z} \qquad k_{loss} = O(\sigma^{-1} \ln(b/a))$$

$$\sigma = 250\,\mu m \qquad k_{loss} = 37.2\,[V/pC]$$

$$\sigma = 25\,\mu m \qquad k_{loss} = 372\,[V/pC]$$

$$W = W^{in} + W^{out}$$

Accuracy of 3D calculations

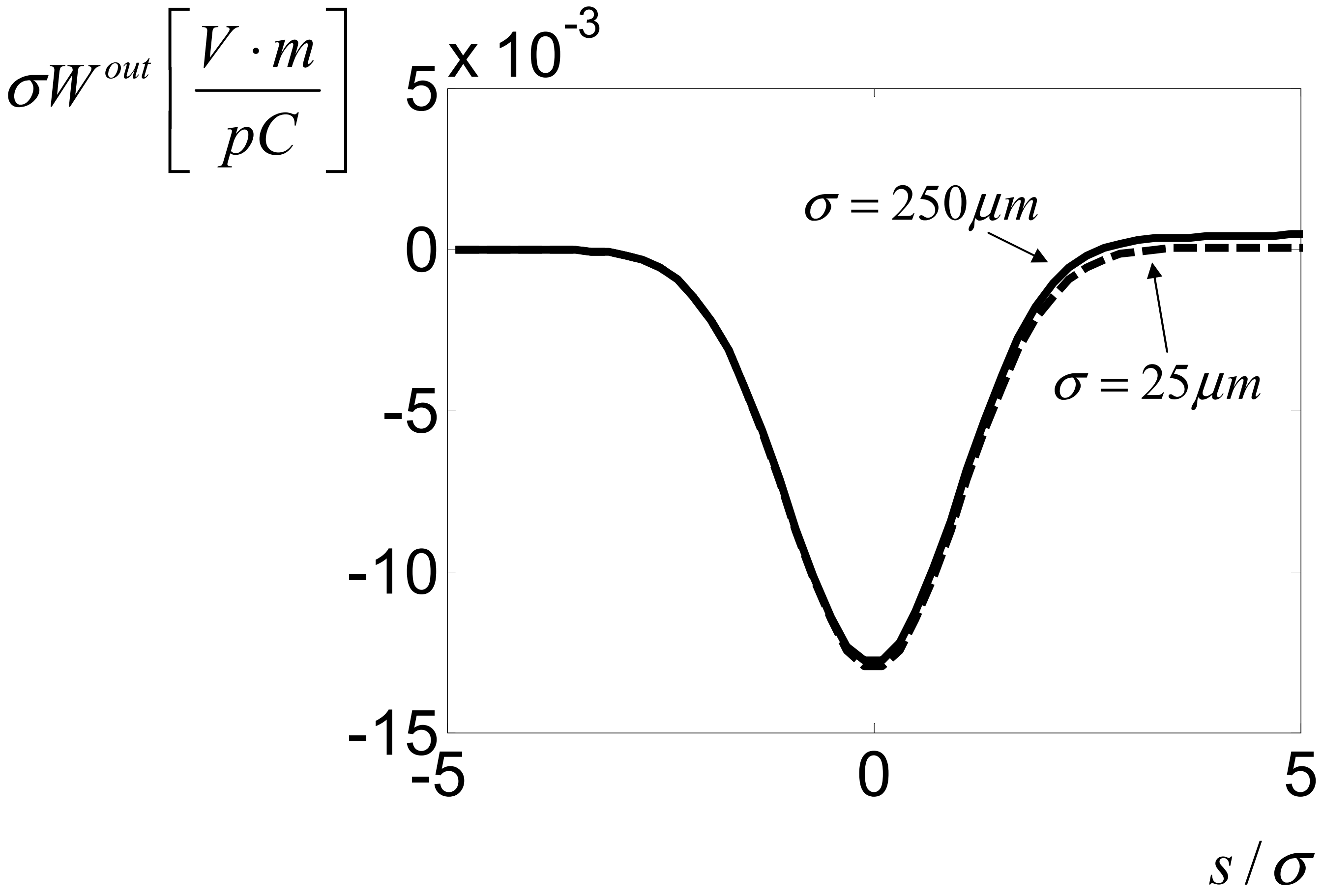


$$k_{loss}^{out}$$

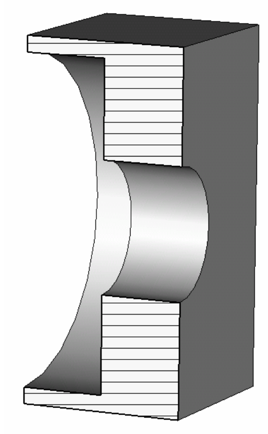
σ [μm]	dx [σ]	dy,dz [σ]	Loss,2D [V/pC]	Error, 2D [V/pC]	Loss, 3D [V/pC]	Error, 3D [V/pC]
250	1/40	1/40	**36.3097**	**ref.**		
250	1/20	1/20	36.2932	0.016		
250	1/5	1/5	36.2369	0.07	**36.2265**	**0.1**
25	1/20	1/20	**370.77**	**ref.**		
25	1/10	1/10	370.60	0.17		
25	1/5	1/5	369.96	0.8		
25	1/5	2			**369.78**	**1**

$$k_{loss}^{out} = O(\sigma^{-1} \ln(b/a))$$

$$W^{out} = O(\sigma^{-1})$$



Accuracy of 3D calculations



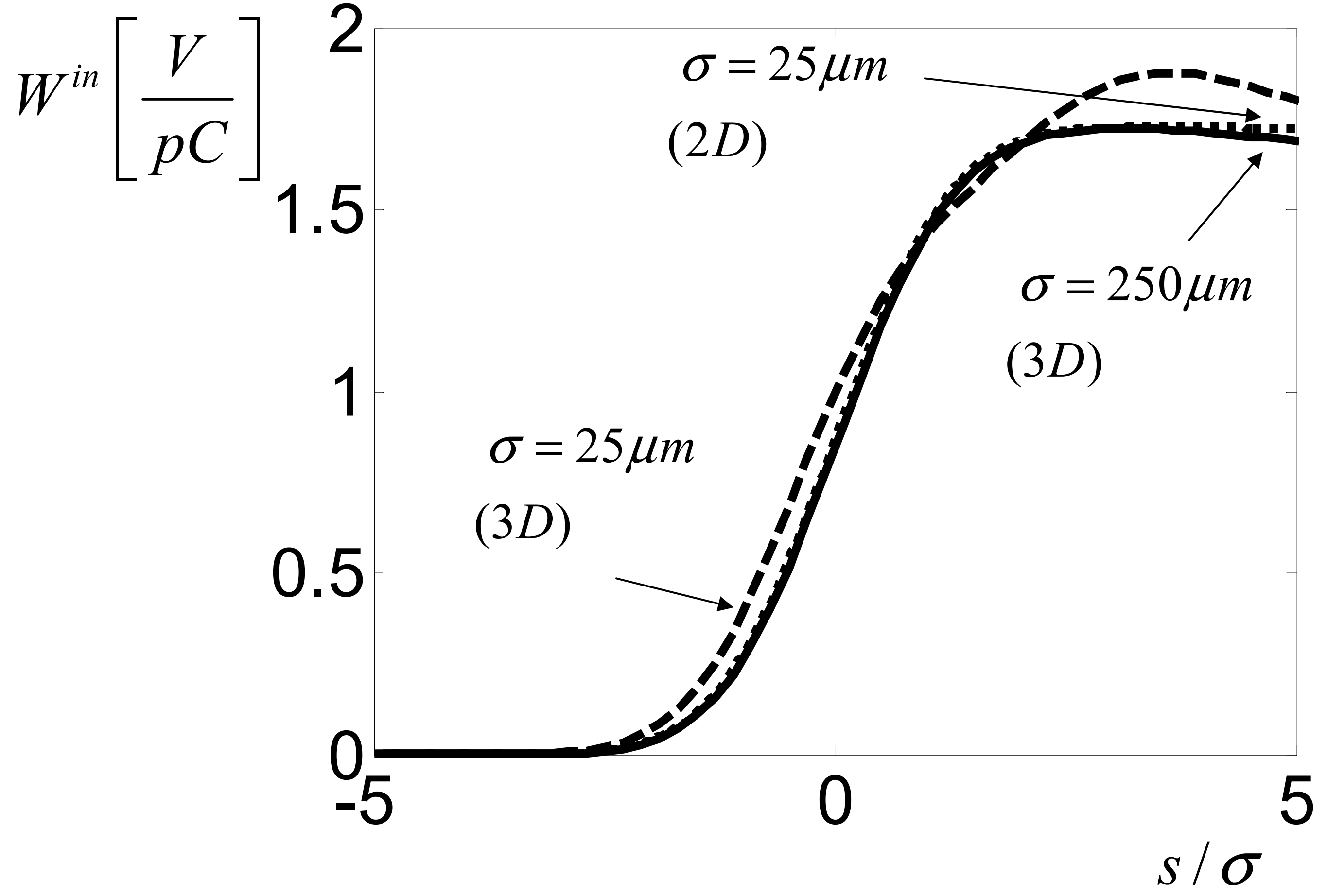
$$k_{loss}^{in}$$

σ [μm]	dx [σ]	dy,dz [σ]	Loss,2D [V/pC]	Error, 2D [V/pC]	Loss, 3D [V/pC]	Error, 3D [V/pC]
250	1/40	1/40	**-0.8606**	**ref.**		
250	1/10	1/10	-0.8678	0.001		
250	1/5	1/5	-0.8802	0.012	**-0.8478**	**0.013**
25	1/20	1/20	**0.8639**	**ref.**		
25	1/10	1/10	-0.8619	0.002		
25	1/5	1/5	-0.8859	0.02		
25	1/5	2			**-0.9380**	**0.17**

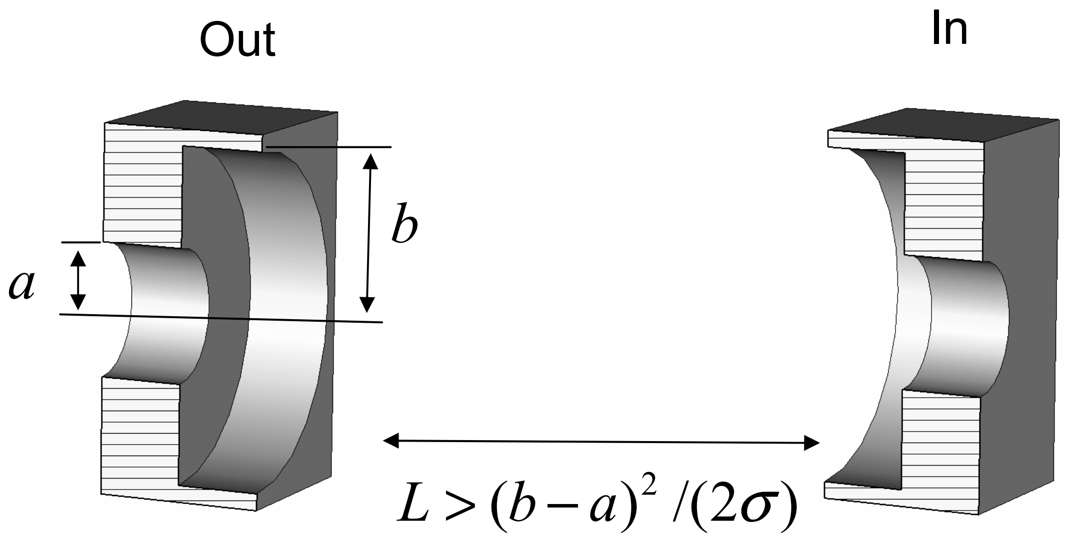
$$k_{loss}^{in} = O(a^{-1})$$

$$k_{loss}^{in} = k_{loss}^{out}$$

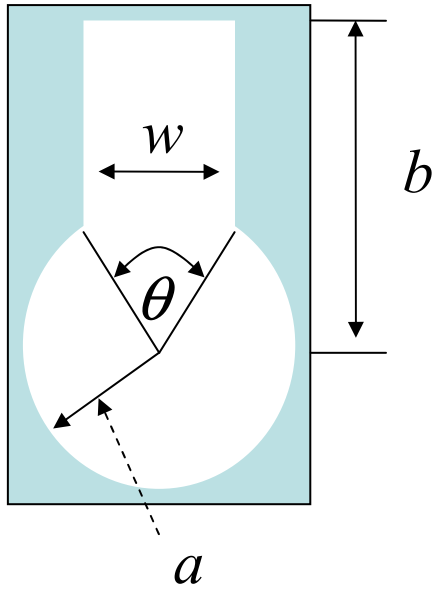
$$W^{in} = O(1), \quad \sigma \to 0$$



Scaling laws



$$k_{loss}^{out} = O\left(\sigma^{-1}\ln\left(\frac{b}{a}\right)\right) \qquad k_{loss}^{in} = O\left(\frac{1}{a}\right)$$

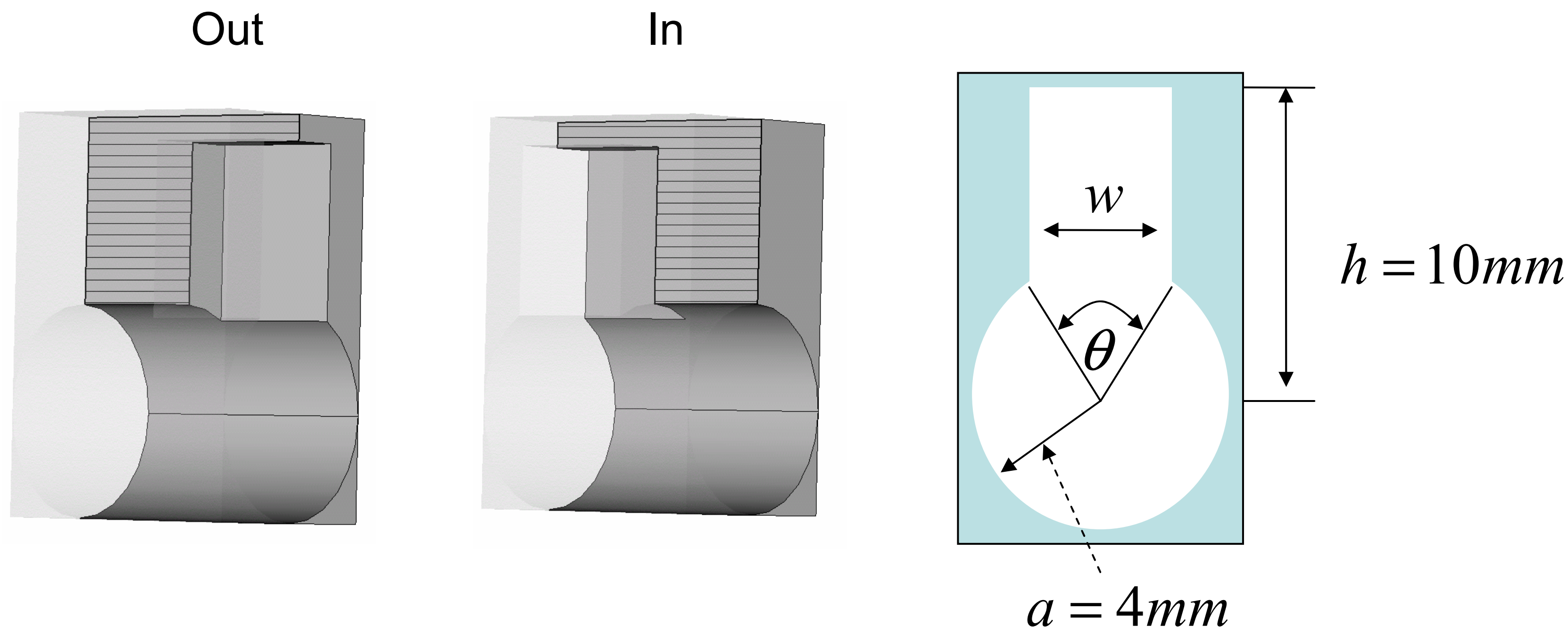


Scaling laws $(w > \sigma)$

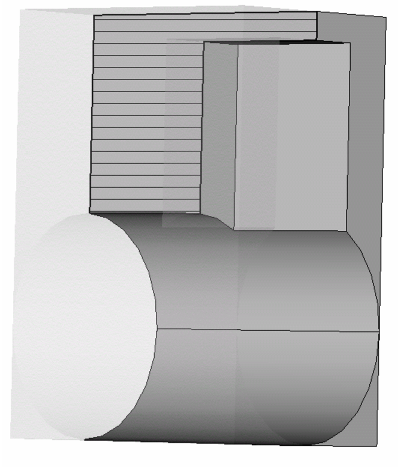
$$k_{loss}^{out} = O\left(\sigma^{-1}\theta^{\alpha}\ln\left(\frac{b}{a}\right)\right)$$

$$k_{loss}^{in} = O\left(\frac{\theta^{\beta}}{a}\right)$$

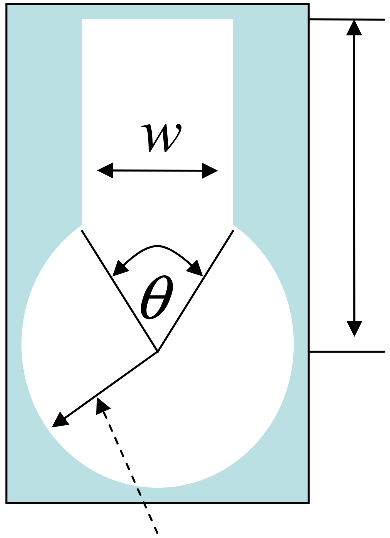
$$\alpha, \beta ?$$



Out
In
w
θ
h = 10mm
a = 4mm



$$k_{loss}^{out}$$



$$h = 10mm$$

$$a = 4mm$$

$$w > \sigma$$

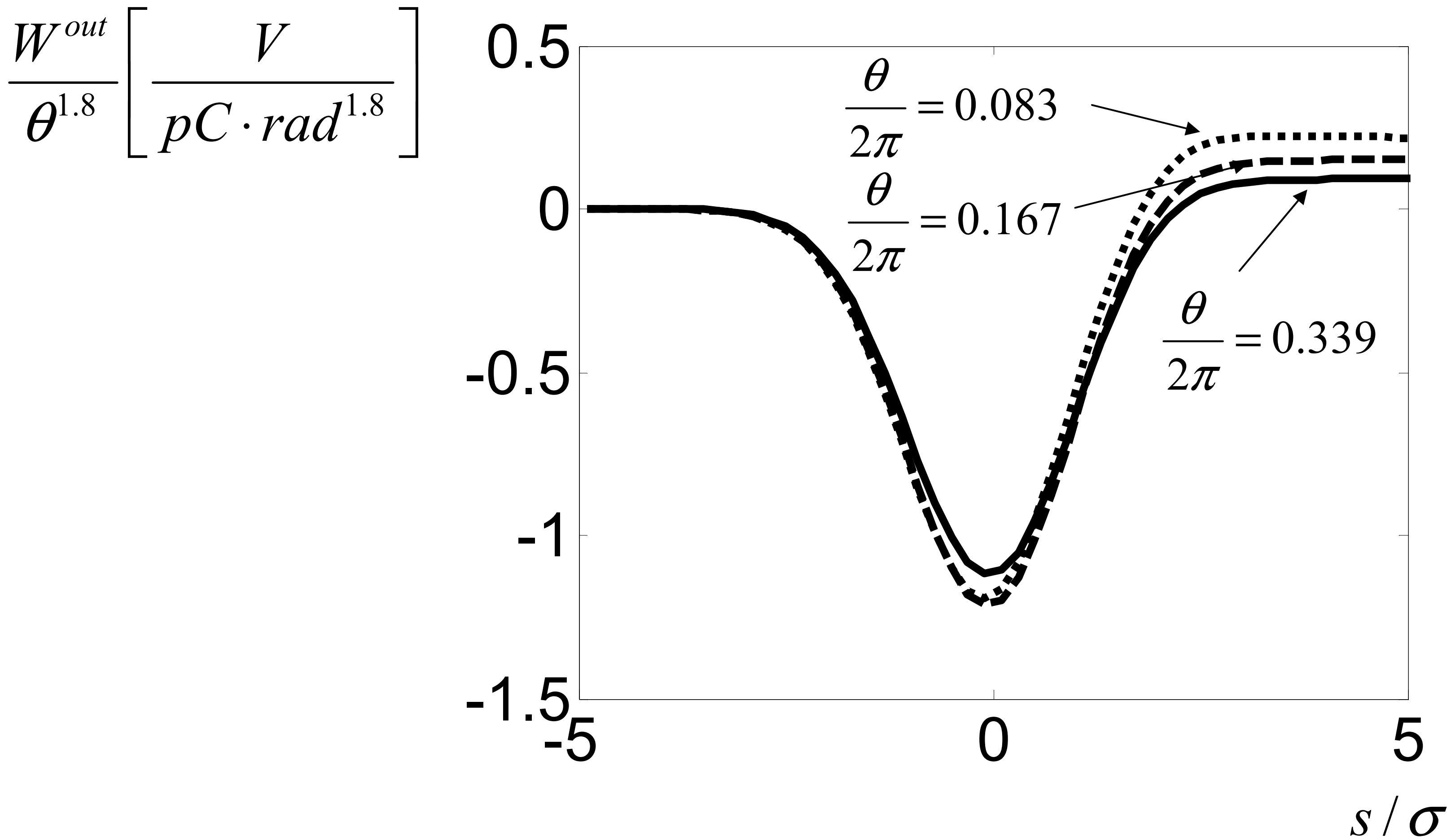
w [mm]	θ/(2π)	σ [μm]	Loss [V/pC]
7	0.339	250	3.04+-0.1
4	0.167	250	0.91+-0.1
2	0.083	250	0.23+-0.1
7	0.339	25	31.8+-1
4	0.167	25	
2	0.083	25	2.8+-1

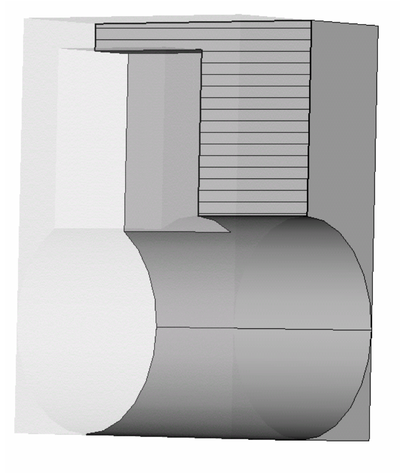
$$k_{loss}^{out} = O(\sigma^{-1})$$

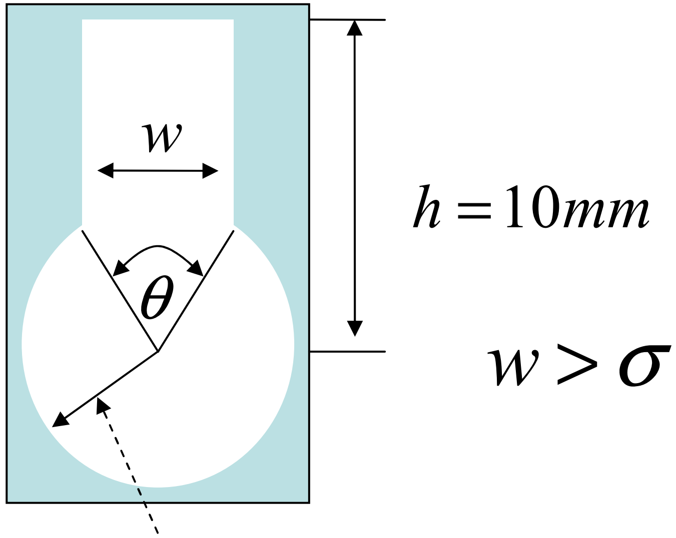
$$k_{loss}^{out} = O(\theta^{1.8}) \quad ?!$$

$\sigma = 250\mu m$

$$W^{out} = O(\theta^{1.8}), \quad \theta \to 0, \quad w > \sigma$$







$$k_{loss}^{in}$$

w [mm]	θ/(2π)	σ [μm]	Loss [V/pC]
7	0.339	250	-0.162+-0.013
4	0.167	250	-0.065+-0.013
2	0.083	250	-0.01+-0.013
7	0.339	25	-0.247+-0.17
4	0.167	25	
2	0.083	25	

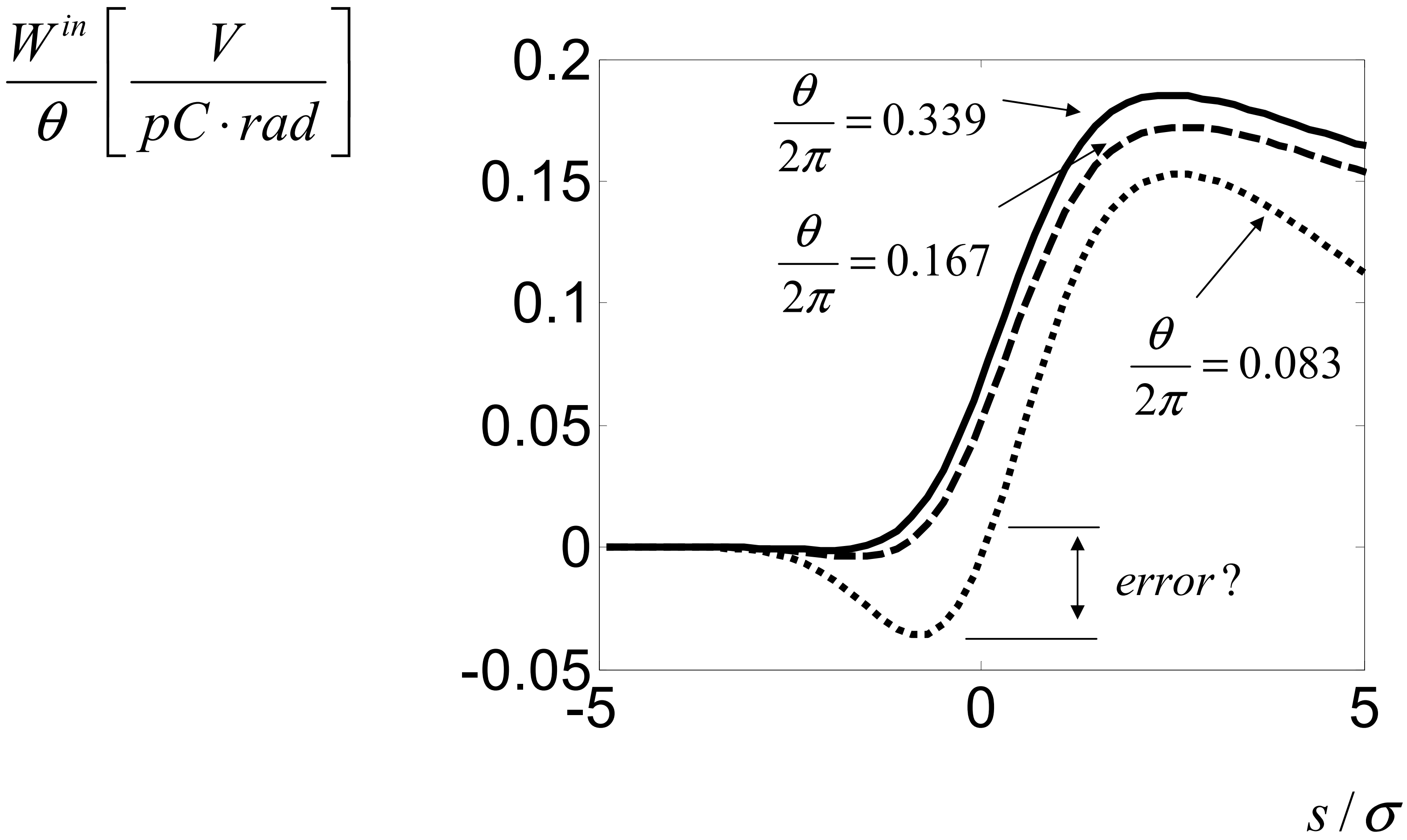
$$k_{loss}^{in} = O(1), \quad \sigma \to 0$$

$$k_{loss}^{in} = k_{loss}^{out}$$

$$k_{loss}^{in} = O(\theta) \quad ?!$$

$\sigma = 250 \mu m$

$$W^{in} = O(\theta), \quad \theta \to 0, \quad w > \sigma$$



Scaling laws and extrapolation

$$w > \sigma$$

$$k_{loss}^{out} = O\left(\sigma^{-1}\theta^{1.8}\ln\left(\frac{b}{a}\right)\right)$$

$$k_{loss}^{in} = O\left(\frac{\theta}{a}\right)$$

w [mm]	b, [mm]	a, [mm]	θ/(2π)	σ [μm]	Loss [V/pC]
7	10	4	0.339	250	3
1	20	7.5	0.021	25	0.2

w [mm]	a, [mm]	θ/(2π)	σ [μm]	Loss [V/pC]
7	4	0.339	250	-0.16
1	7.5	0.021	25	-0.005

$$k_{loss}^{out} = 3\cdot 10\left(\frac{0.021}{0.339}\right)^{1.8}\frac{\ln\left(\frac{20}{7.5}\right)}{\ln\left(\frac{10}{4}\right)} = 0.2\left[\frac{V}{pC}\right]$$

$$k_{loss}^{in} = -0.16\cdot\left(\frac{0.021\cdot 4}{0.339\cdot 7.5}\right) = -0.005\left[\frac{V}{pC}\right]$$

$$k_{loss} = 0.2\left[\frac{V}{pC}\right]$$

$$w > \sigma$$

$$k_{loss}^{in} = k_{loss}^{out}$$

⇩

Energy method

$$W = W^{in} + W^{out} \qquad W^{out} - W^{in} = 2W^{e}$$

$$W = 2W^{in} + 2W^{e} \approx 2W^{e}, \quad if\ W^{in} \approx 0$$

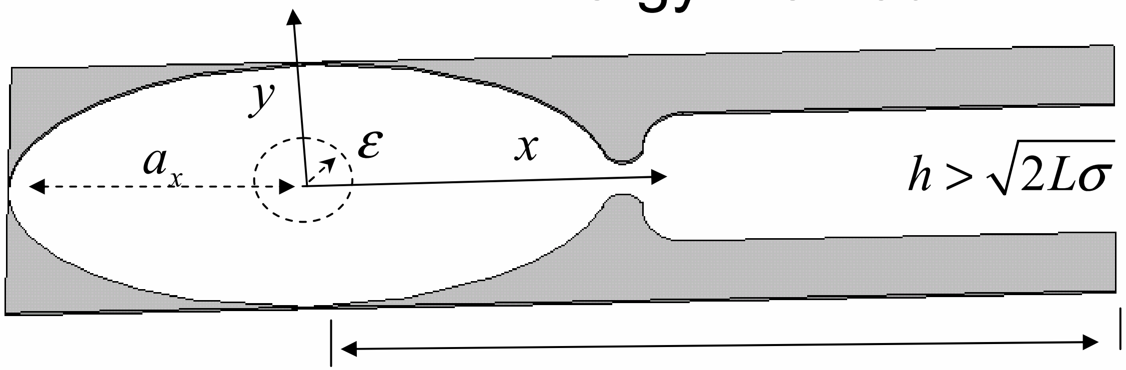
$$W^{e} = \lambda_z (\overline{w}_{ellipse} - \overline{w}_{ellipse+slot}) = \lambda_z \overline{w}$$

(K. Zotter et al. , Impedances and Wakes …, 1998
and
K.L.F.Bane, I.A.Zagorodnov, SLAC-PUB-11388, 2005)

Accuracy of the energy method

w [mm]	σ [μm]	K_loss from time-domain [V/pC]	K_loss from energy [V/pC]	Error, [V/pC]
7	250	2.88	3.10	0.22
7	25	31.5	31.0	0.5
2	250	0.22	0.26	0.04
2	25	2.75	2.63	0.12

Energy method



$$h > \sqrt{2L\sigma} = \sqrt{2 \cdot 5000 \cdot 25e-3} = 16\,[mm]$$

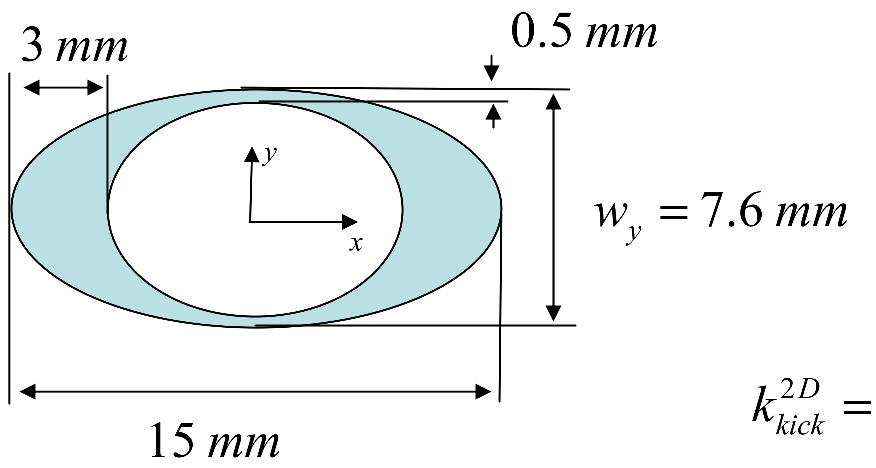
ε[mm]	Mesh step in [σ]	Ellipse	Ellipse with slot	$\frac{2\pi}{Z_0 c}\overline{w}$
0.25	2	2.89161337	2.89165659	4.32e-5
0.25	1	2.90553777	2.90560728	6.95e-5

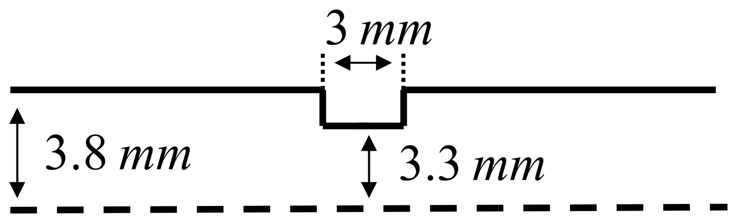
$$k_{loss} = 0.03 \pm 0.12\,[V/pC]$$

$$W_y(s, x=0, y=0) \approx \int_{-\infty}^{s} \frac{W(\overline{s}, x=0, y=0)}{a_x} d\overline{s}$$

$$k_{loss} < 0.2\,[V/pC]$$

$$k_{kick,x} < 0.001\,[V/pC]$$





Round (a=3.8, b=3.3)

$$k_{kick}^{2D} = 351\ [V/(pC \cdot m)]$$

$$k_{kick}^{3D} = 359[V/(pC \cdot m)] \qquad Error:\ 2\%$$

Energy method

$$k_{loss} = 85[V/pC]$$

Old pipe?

$w_y = 7.8\,mm$	$k_{loss} = 85\,[V/pC]$
$w_y = 9\,mm$	$k_{loss} = 91\,[V/pC]$

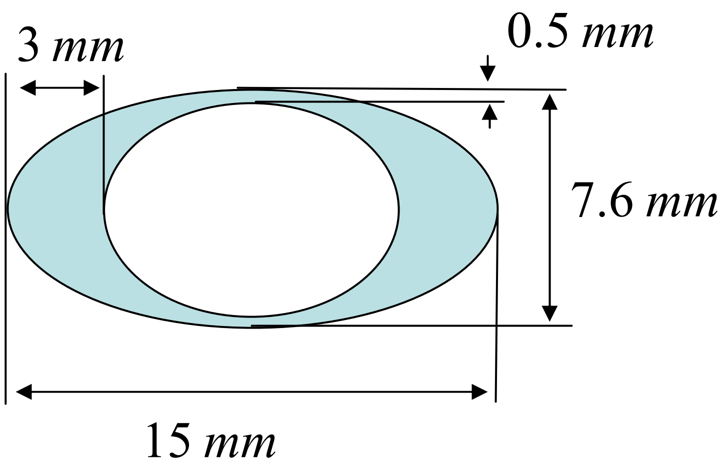
Direct time-domain with ECHO

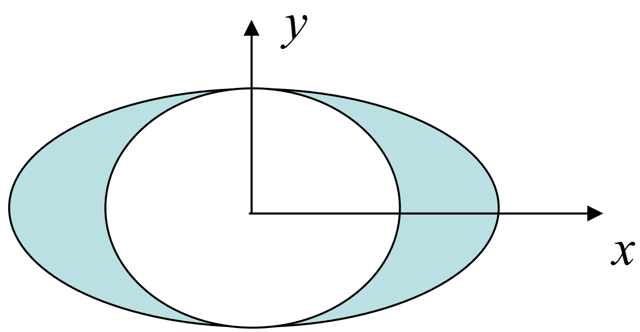
$$k_{loss} = 84 + 248x_s - 257y_s\ [V/pC]$$

$$k_{kick,x} = 390x_s + 46x_w = 436x\,[V/pC]$$

$$k_{kick,y} = 348y_s - 47y_w = 301y\,[V/pC]$$

The energy loss for the new smaller pipe is a little smaller!





$$k_{loss} = 84 + 250x_s - 250y_s \; [V/pC]$$

$$k_{loss} = 42 + 1200x_s - 1200y_s \; [V/pC]$$

$$k_{kick,x} = 390x_s + 46x_w = 436x \; [V/pC]$$

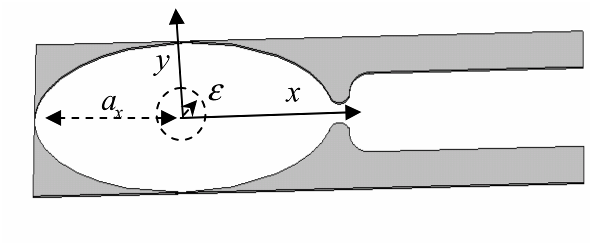
$$k_{kick,y} = 348y_s - 47y_w = 301y \; [V/pC]$$

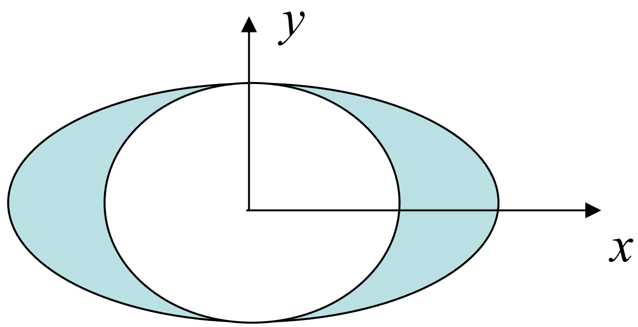
$$k_{kick,x} = 280x_s + 206x_w = 486x \; [V/pC]$$

$$k_{kick,y} = 78y_s - 208y_w = -130y \; [V/pC]$$

	Loss, V/pC	Spread, V/pC	Peak, V/pC
var1	84	33	-118
var2	42	16	-58

Kick





$$k_{kick,x}^{slot} < 0.001 [V/pC]$$

$$k_{kick,x} = 486x [V/pC]$$

$$k_{kick,y} = -130y [V/pC]$$

$$k_{kick,x}^{slot} < 0.0001 = \ 0.01 = k_{kick,x}^{abs}\sigma [V/pC]$$

Longitudinal wake for the case of the elliptical pipe (3.8mm)

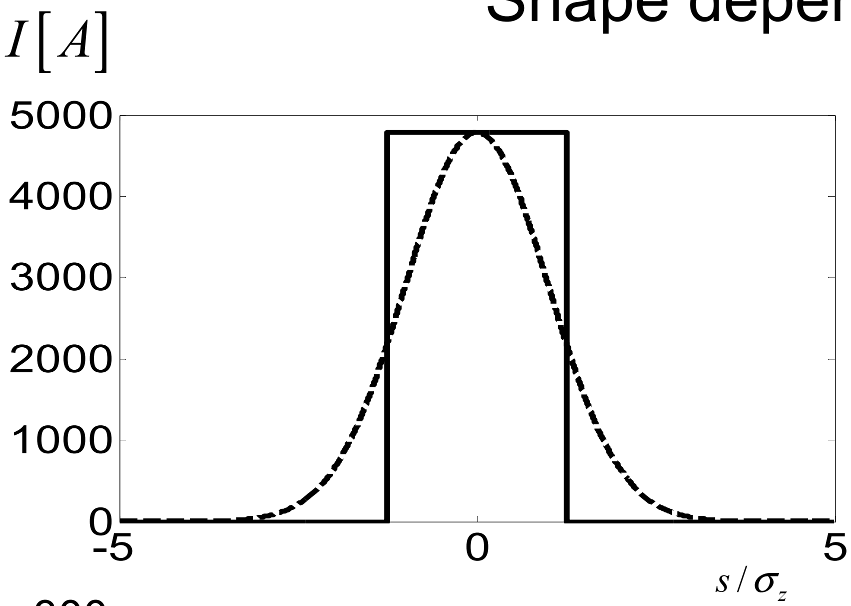
	pro section (6.1 m)	Loss, V/pC	Spread, V/pC	Peak, V/pC
absorber	1	42	16	-58
pumping slot	1	<0.2	<0.1	>-0.3
pump	1	9	4	-13
BPM	1			
bellow	1	13	5	-18
flange gap	1	6	2.4	-8.5
Total geom.		**70**	**25**	**-95**
resistive (Cu)	6.1m	220	279	-542
resistive (Al)	6.1m	**303**	**325**	**-660**

Shape dependence

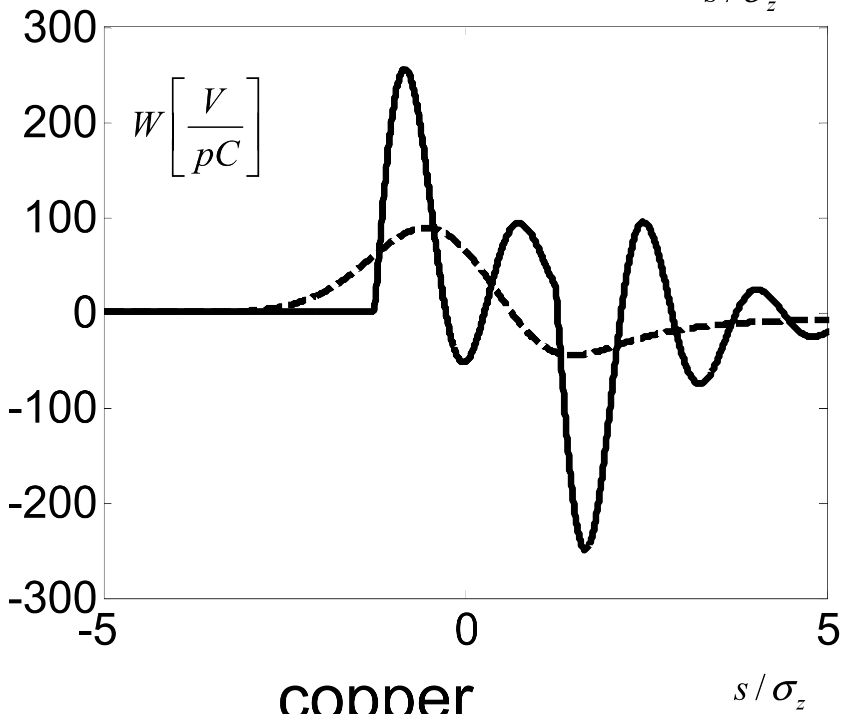
$\sigma_z = 25\mu m$

$cu: \quad \sigma_{cond} = 5.8\text{e+}7[\Omega^{-1} \cdot \text{m}^{-1}], \quad \tau_{relax} = 2.46\text{e-}14[\text{sec}]$

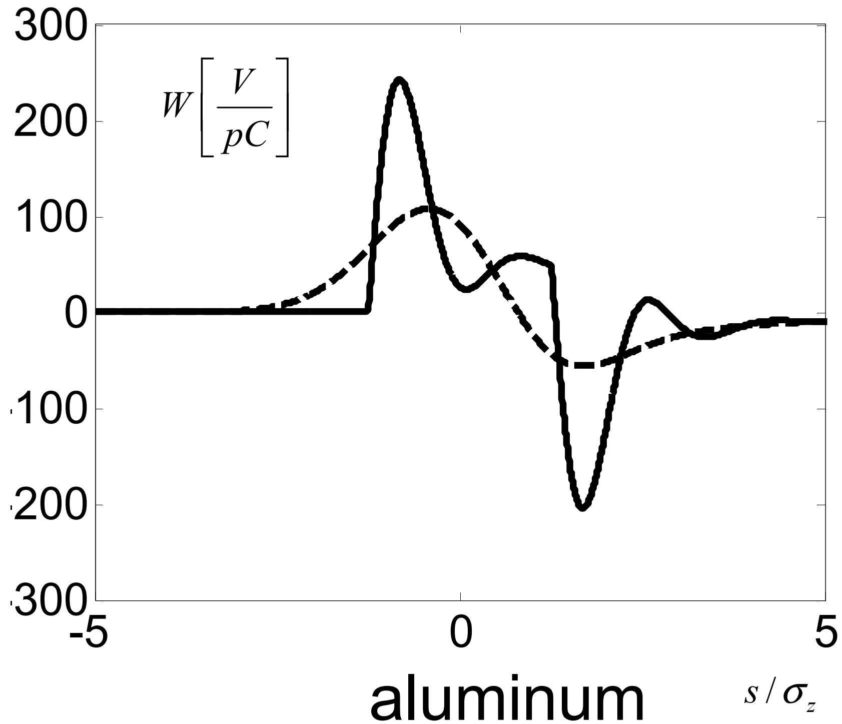
$al: \quad \sigma_{cond} = 3.66\text{e+}7[\Omega^{-1} \cdot \text{m}^{-1}], \quad \tau_{relax} = 7.1\text{e-}15[\text{sec}]$



	Loss, V/pC	Spread, V/pC	Peak, V/pC
Gauss, cu/al	36/50	46/53	-89/108
Rect, cu/al	79/93	**90/72**	-256/243



copper



aluminum

Power Loss (Gaussian bunch)

$$N_b = 4000\,[bunches]$$

$$f_{rep} = 10\,[Hz]$$

$$q = 1\,[nC]$$

$$P = N_b f_{rep} q^2 k_{loss}$$

$$P_{geom} = 0.52\left[\frac{W}{m}\right]$$

$$P_{res,Cu} = 1.4\left[\frac{W}{m}\right]$$

$$P_{res,Al} = 2\left[\frac{W}{m}\right]$$

Conclusion

- Loss and kick of the pumping slot are negligible
- Wake of the absorber is reduced by factor 2
- Resistive wake is dominant
- Non-smooth bunch shape (rectangular) increases the energy spread less than by factor 2