Wake Fest 07 - ILC wakefield workshop at SLAC

Wakefield simulations for ILC cavity

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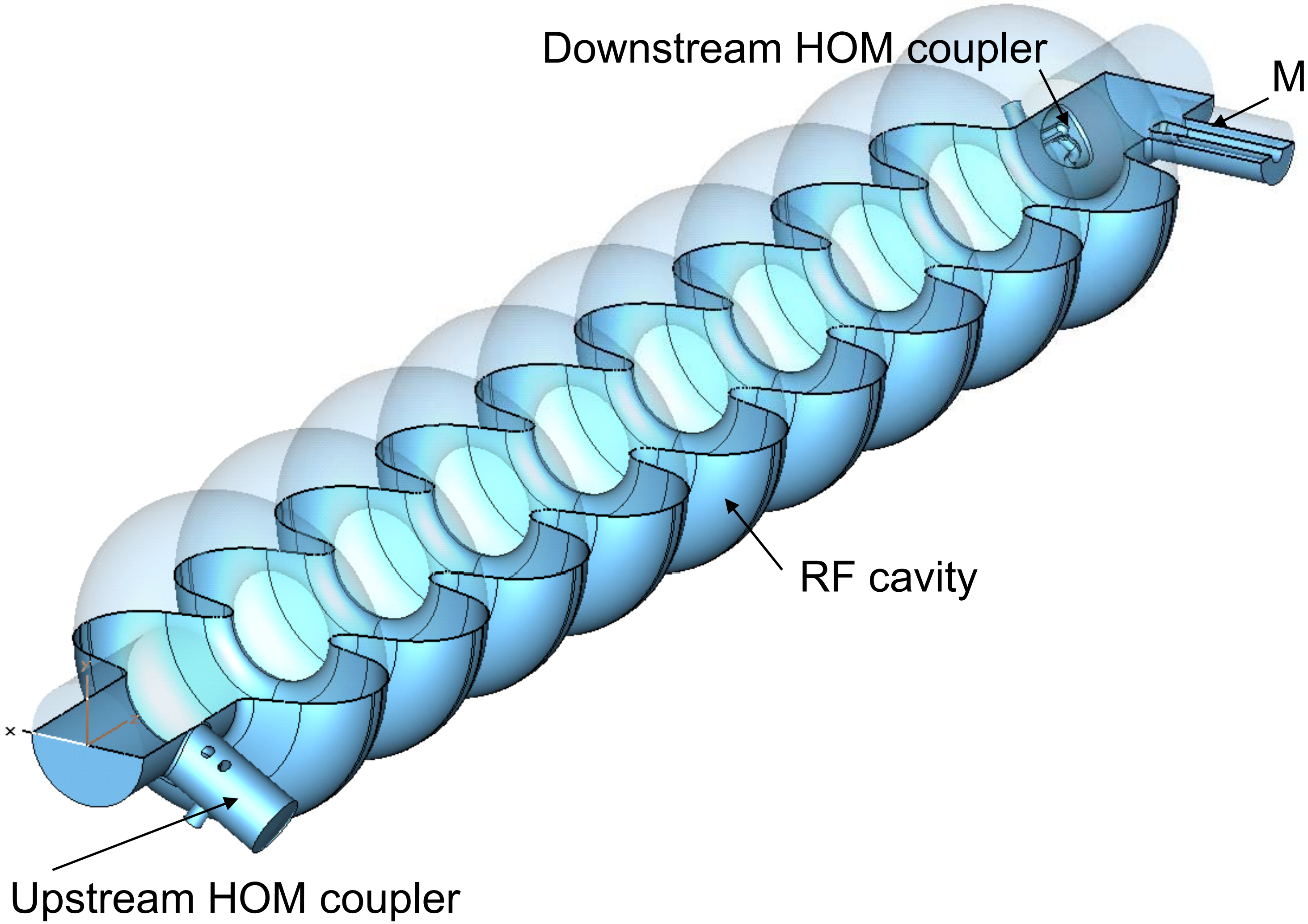
11 December, 2007

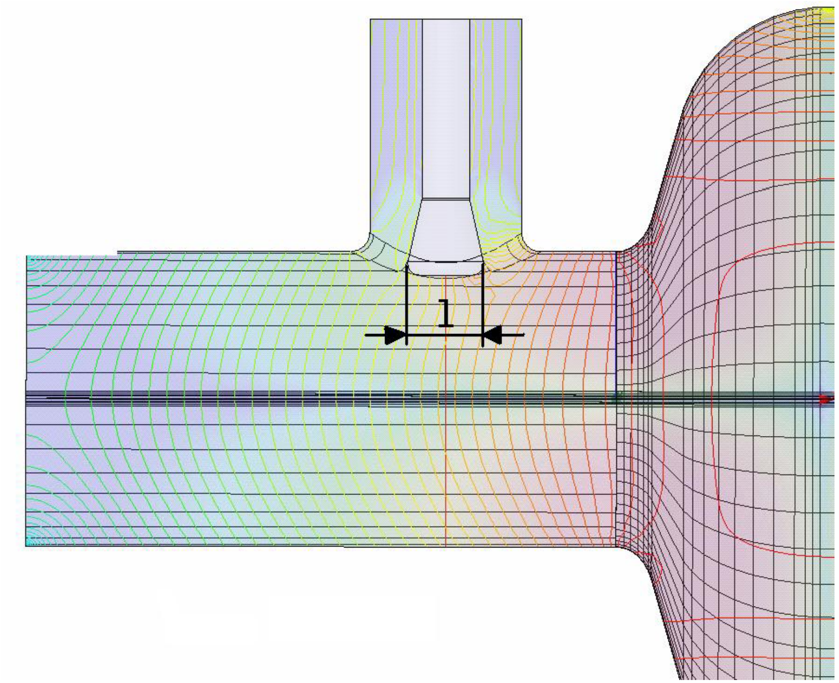
ILC RF cavity with the HOM and input couplers:



- The couplers break the RF field symmetry and cause transverse RF kick.
- The couplers break the symmetry of the cavity and cause transverse wake field.
- Both RF kick and wake fields may be a reason of a beam emittance dilution.
- DESY* made the first calculations of the RF kick and wake fields. The calculations show that both RF kick and wake fields may be a serious problem that could require the cavity improvement.
- More detailed investigations are necessary!

I. Zagorodnov, and M. Dohlus, ILC Workshop, DESY,31 May, 2007

Transverse wakefield:



$$\begin{pmatrix} W_x(x,y) \\ W_y(x,y) \end{pmatrix} = \begin{pmatrix} W_x(0,0) \\ W_y(0,0) \end{pmatrix} + \begin{pmatrix} \frac{\partial W_x}{\partial x} & \frac{\partial W_x}{\partial y} \\ \frac{\partial W_y}{\partial x} & \frac{\partial W_y}{\partial y} \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix}$$

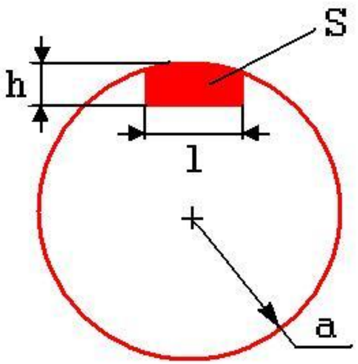
Rough estimation of the transverse wakefields caused by the main coupler:

Optical model: σ<<a, l<<a²/σ

$$k_{\parallel}(0,0) \sim \frac{\varepsilon_0}{2} \int_S \int_{-\infty}^{\infty} E_{\perp}^2 dSds \approx \frac{lh}{2(2\pi)^{5/2} a^2 \sigma \varepsilon_0};$$

$$W_{\perp}(0,0) \approx \frac{lh}{4\pi^2 a^3 \varepsilon_0}$$

(h <<a)



One can see, the transverse wake doesn't depend on the bunch length (it has capacitive character for short bunches*).

*G. Stupakov, K.L.F. Bane and I. Zagorodnov

For a=39 mm, l=20 mm, h=9 mm

$W_\perp \approx 10^{-2}$ V/pC.

For Q=3.2nC $\Delta p_\perp c$ ~**30 V**

It is equivalent to the cavity transverse displacement by 4 mm.

For RF kick $\Delta p_\perp c \sim 2\pi\sigma \cdot \mathrm{Im}(U_y)/\lambda_{RF}$= **3V**

Wake kick is ~ 10 times higher than RF kick!

$$\gamma\varepsilon \approx \gamma(z_{\max}) y_{\max} y'_{\max} \approx \frac{Q^2 W_y^2(0,0)\beta^3\gamma_0}{4U_0^2 L^2}\left[1+\left(\frac{\gamma_0}{\gamma(z)}\right)^{\frac{1}{2}}\right]$$

(L- the cavity + coupler unit length, Q is a bunch charge)

Emittance dilution ~100 times higher, or >20 nm, that is unacceptable.

GdfidL simulations:

- GdfidL was installed on FNAL 80-node cluster (courtesy to Warner Bruns).

- Indirect method for the wake calculations;

- Moving mesh;

- Cubic mesh is used ($h_x=h_y=h_z$);

- For the scheme used in GdfidL one should use $\sigma_z/h_z \geq 10$ in order to achieve convergence ;

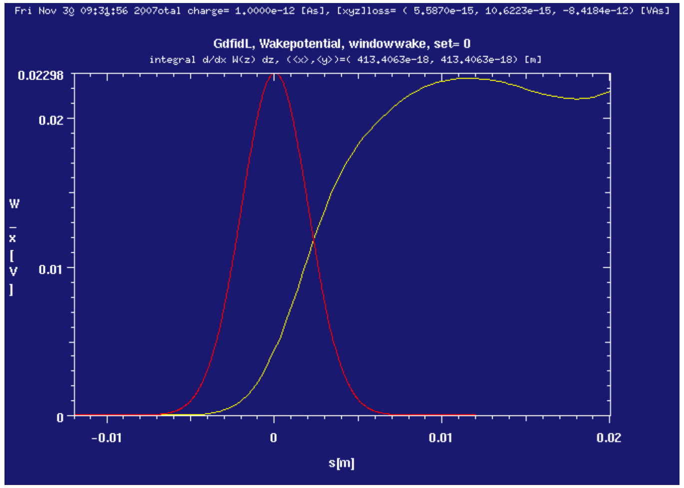
- For fixed geometry the required memory is proportional to $(a/\sigma_z)^3$, and computation time is proportional to $(a/\sigma_z)^4$. For σ_z=300 μm the number of mesh nodes is to be 10^9, and calculation time is about 20 hours for 100-node cluster.

- Because the transverse wake doesn't depend on the bunch length for short bunches, it is natural to use longer bunches for simulations*.

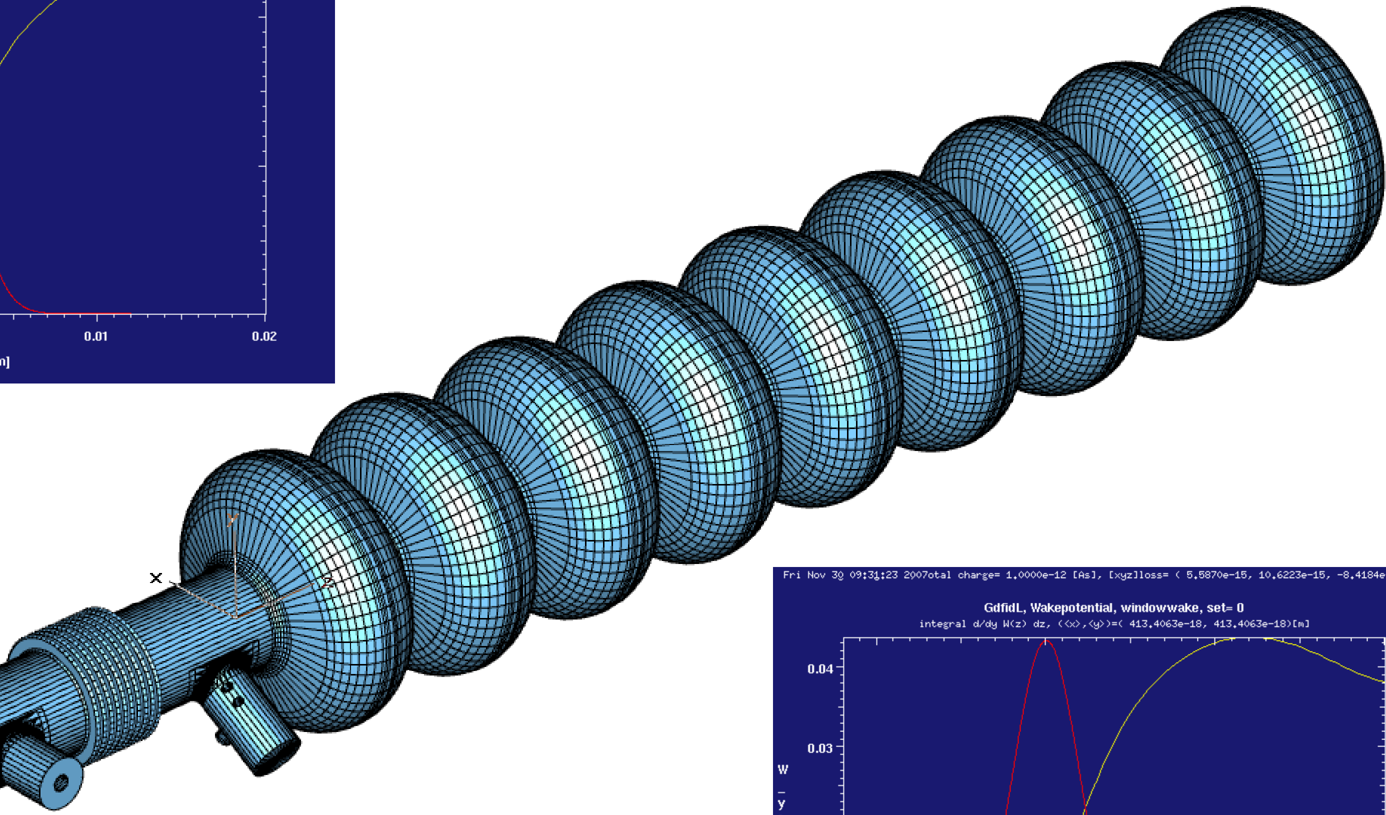
- However, the results should be cross-checked for different bunch lengths, and final calculations should be made for σ_z=300 μm.

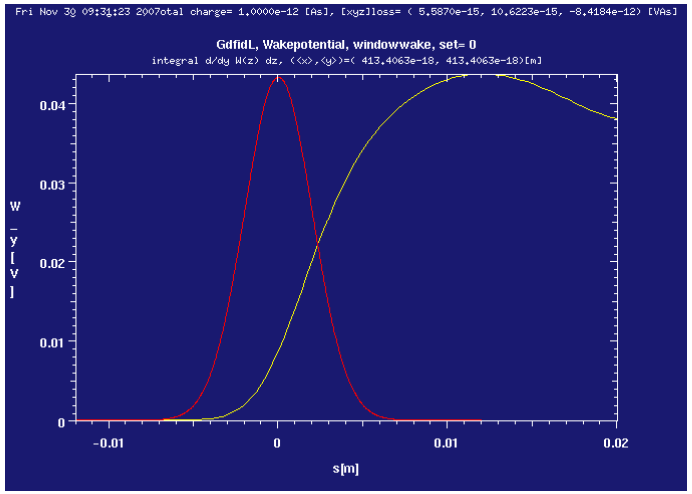
*I. Zagorodnov, M. Dohlus, "Coupler Kick," LCWS/ILC 2007

The GdfidL Electromagnetic Field simulator*



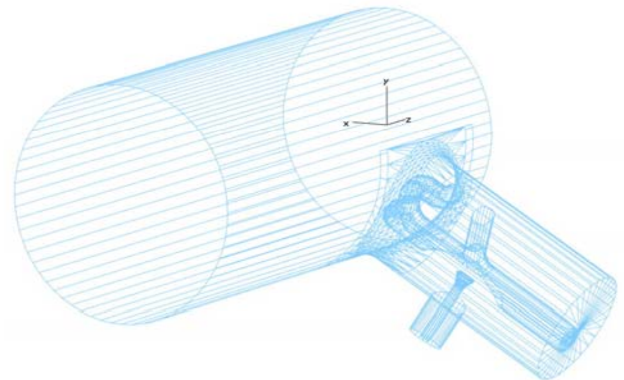
-wakes: longitudinal and transverse

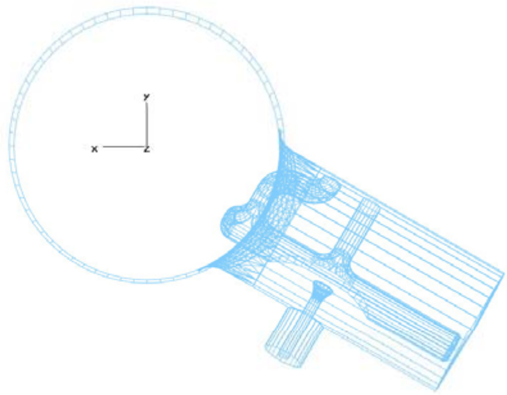


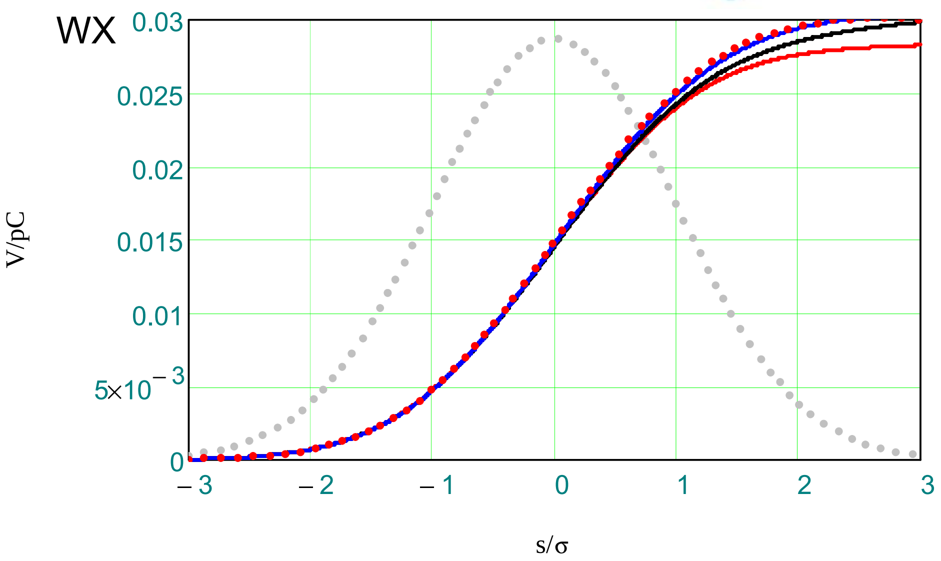


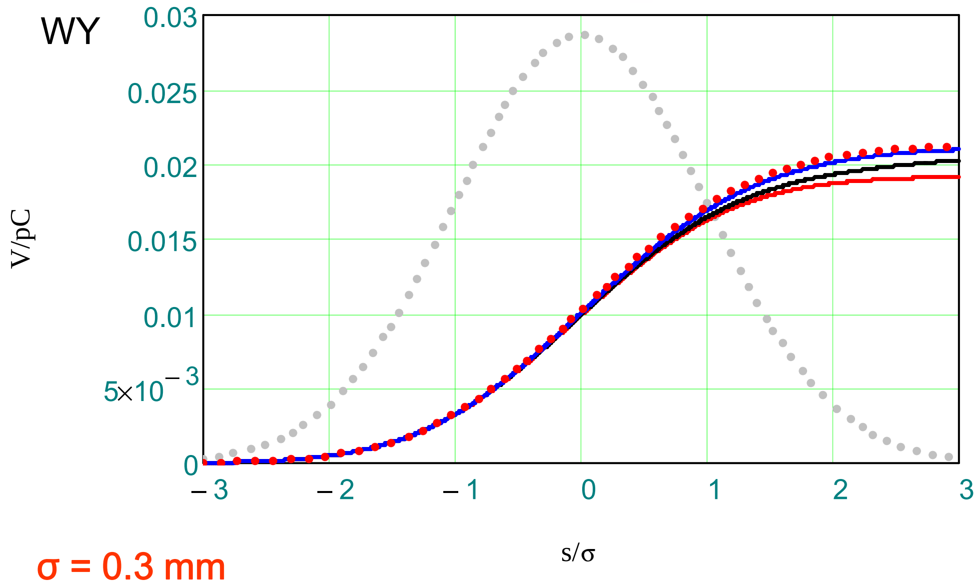
* http://www.gdfidl.de

Transverse wake $W_\perp(0,0)$ dependence on the bunch length (upstream HOM coupler).



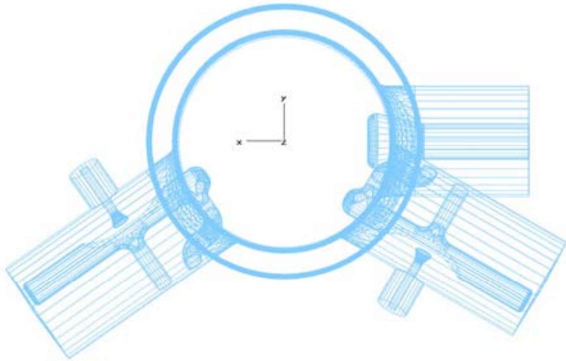


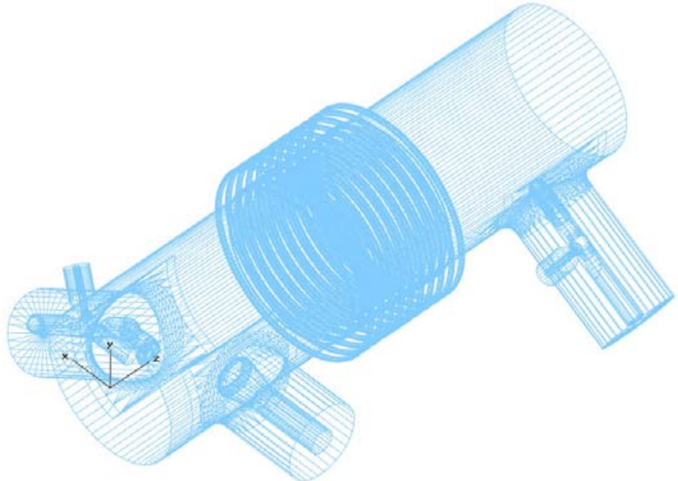


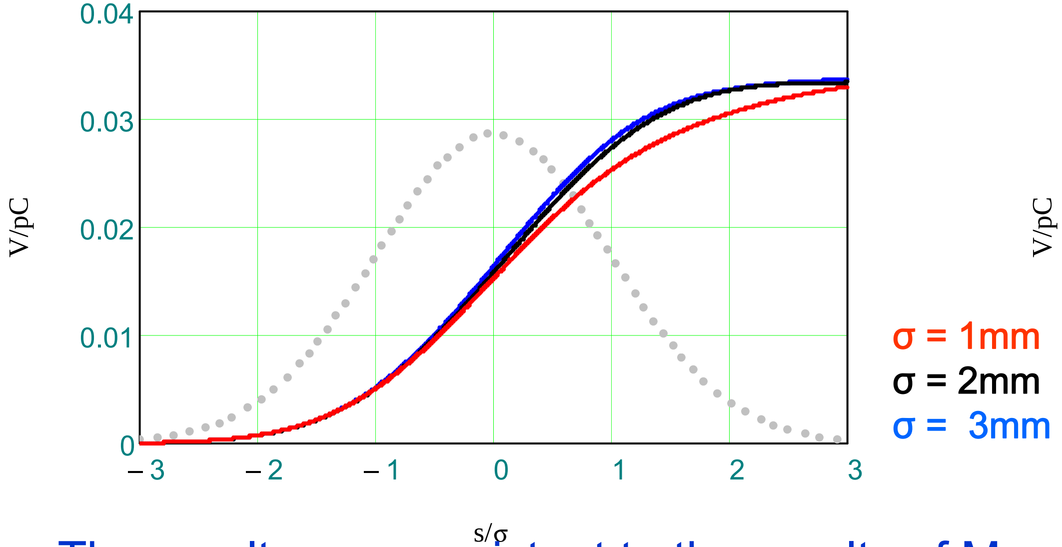


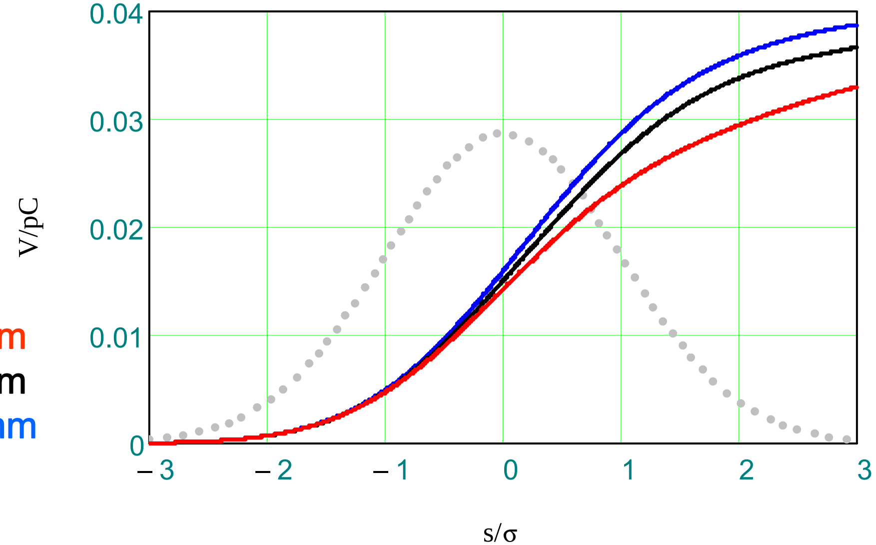
σ = 0.3 mm
σ = 1 mm
σ = 2 mm
σ = 3 mm (dotted)

Downstream Power&HOM + Bellows + UpstreamHOM





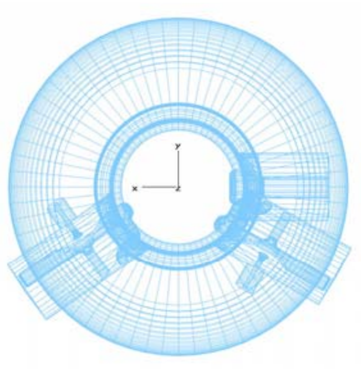


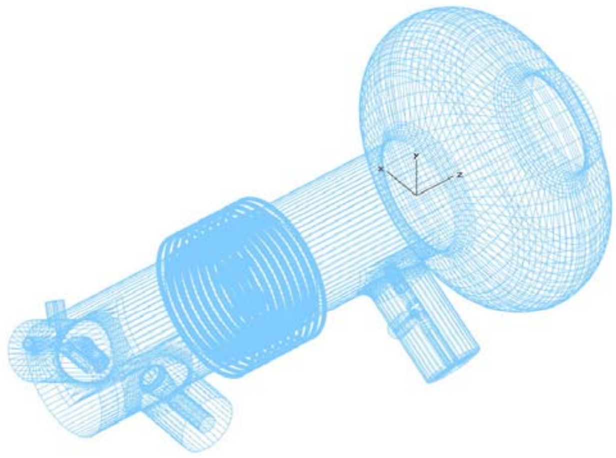


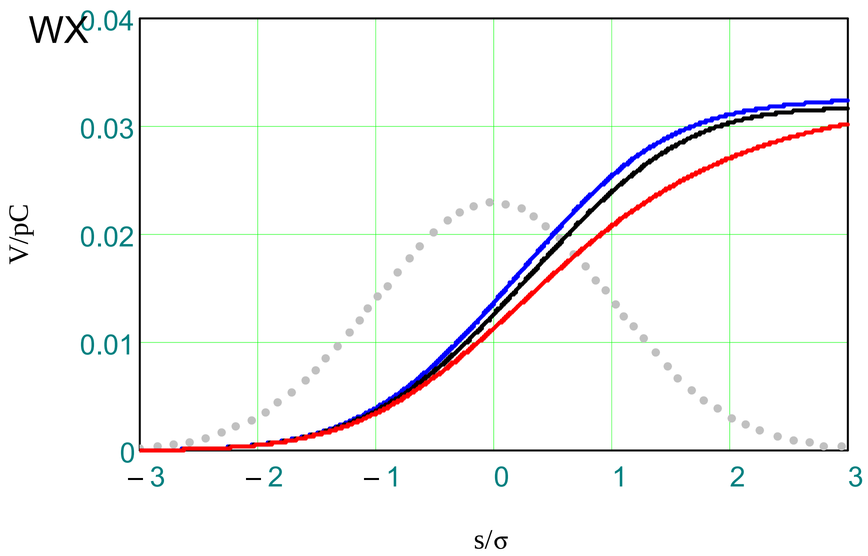
The results are consistent to the results of M. Dohlus and I. Zagorodnov for σ_z=1 mm. See DESY HOM Workshop, 01.22.2007

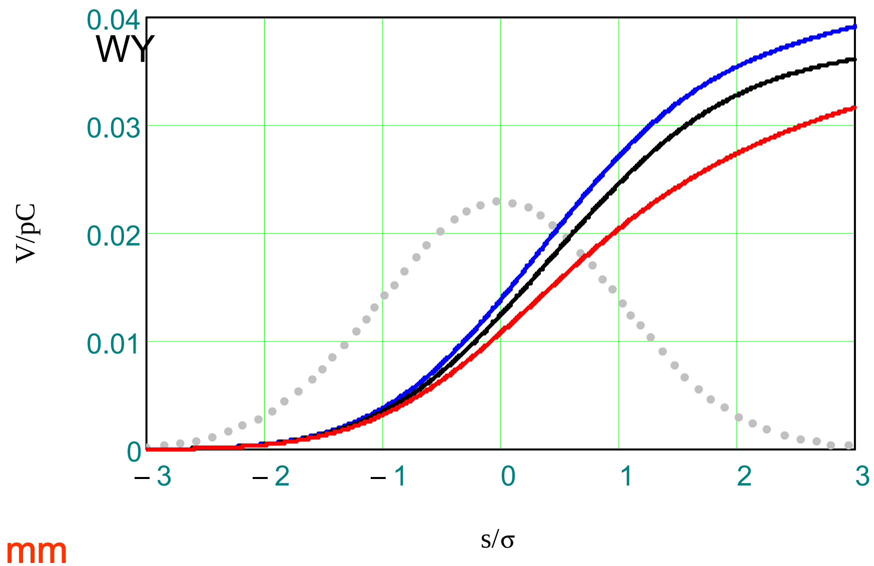
$L \sim a^2/2\sigma$; $L(mm) \sim 800/\sigma(mm)$

Downstream Power&HOM + Bellows + UpstreamHOM + 1Cell





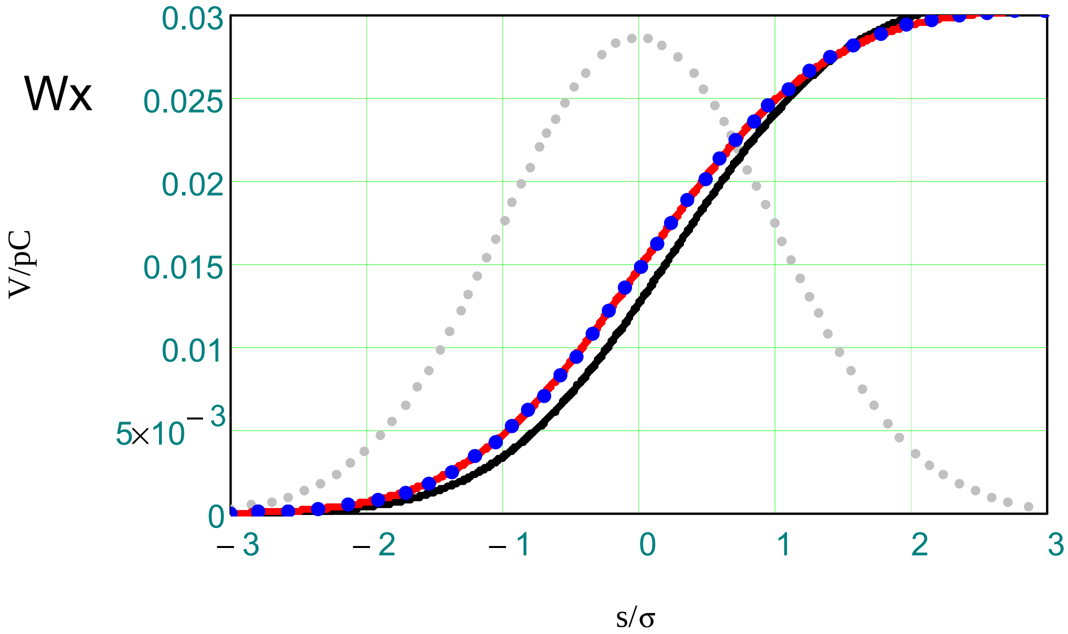


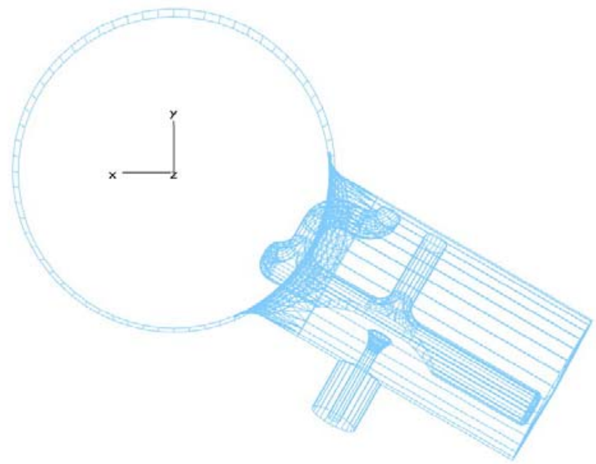


σ = 1mm
σ = 2mm
σ = 3mm

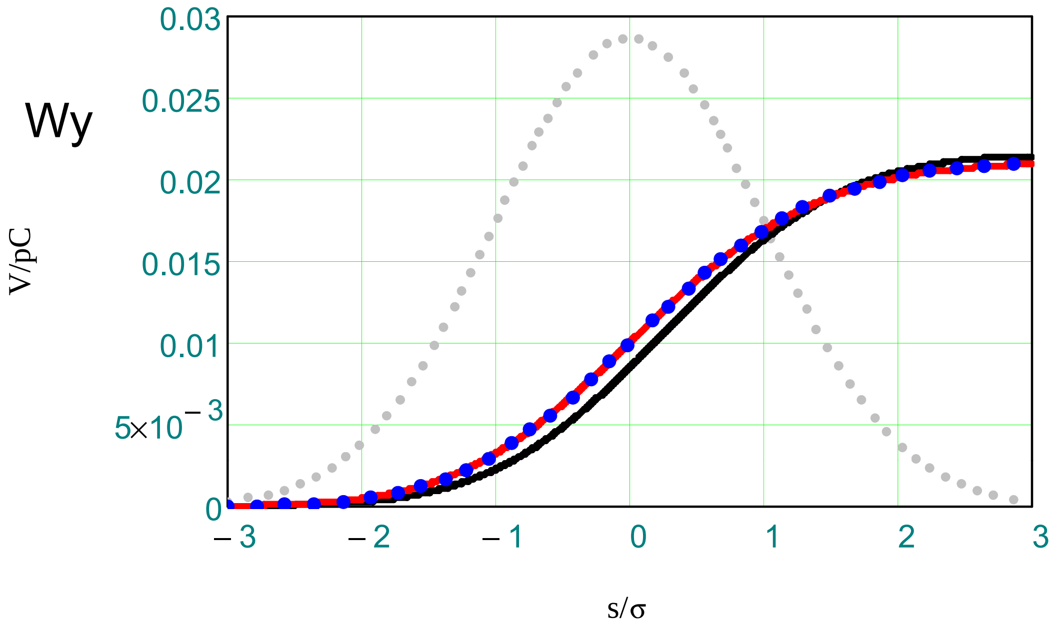
Wake field vs. the mesh size, σ = 2mm

Wx



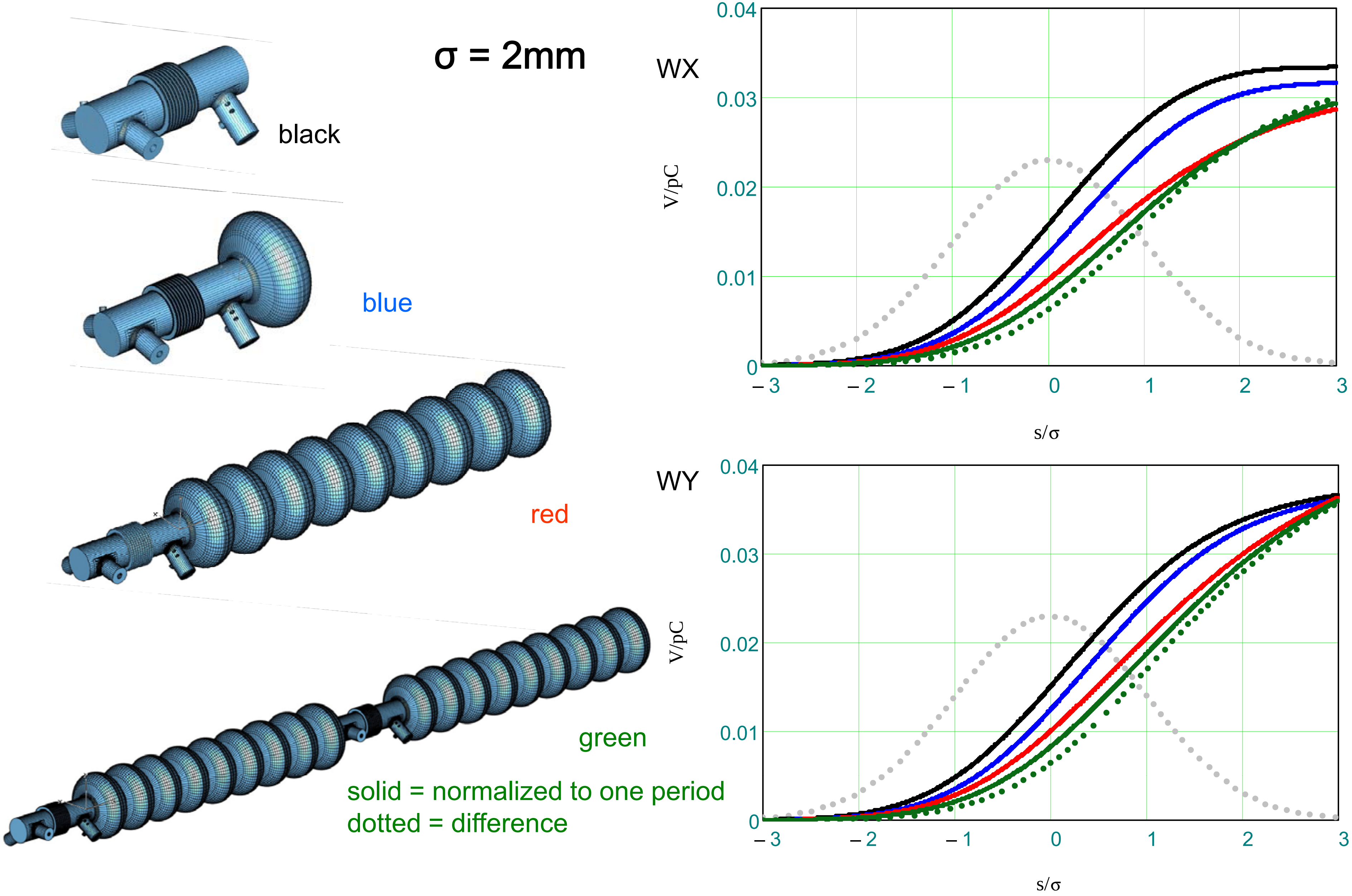


Wy



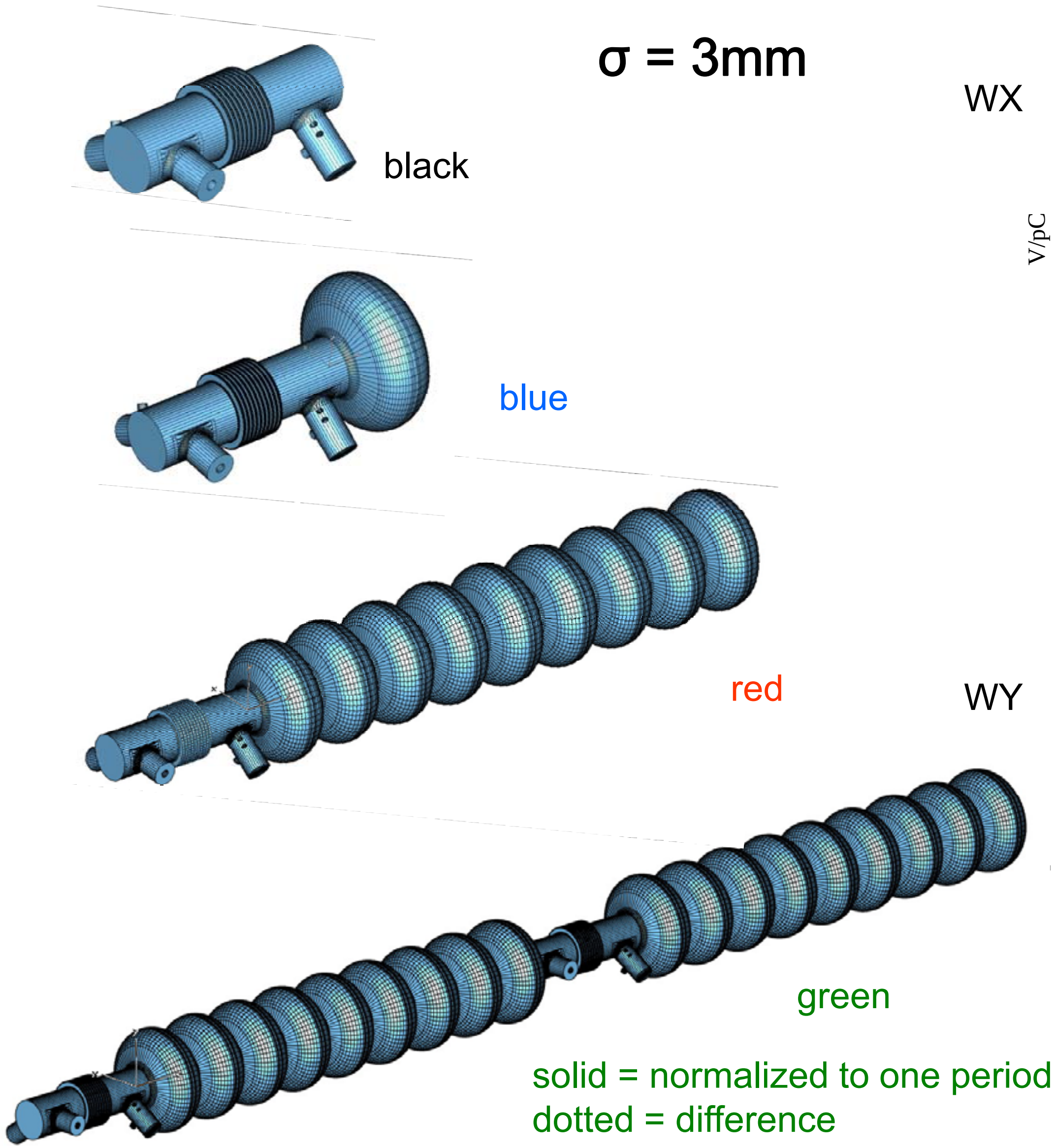
black σ/h=6
blue dots σ/h=8
red σ/h=10

Wake shielding by RF structure

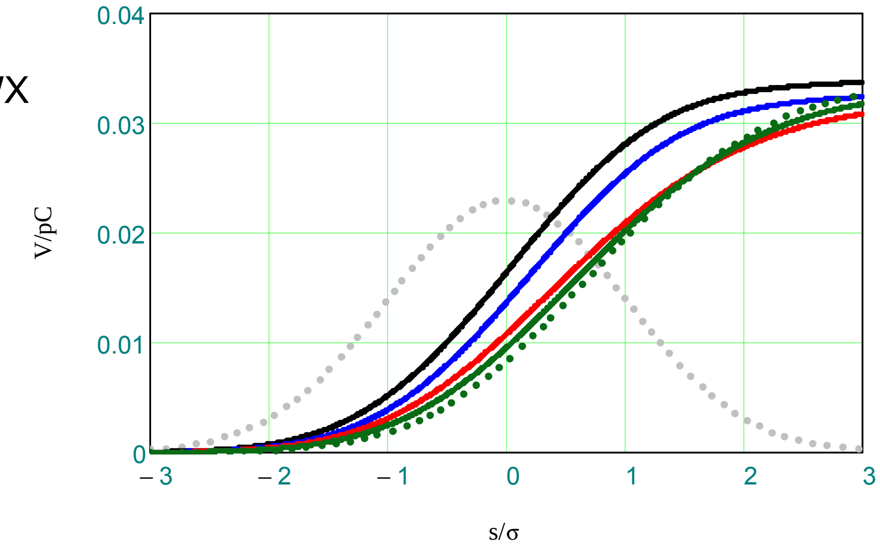


Wake shielding by RF structure

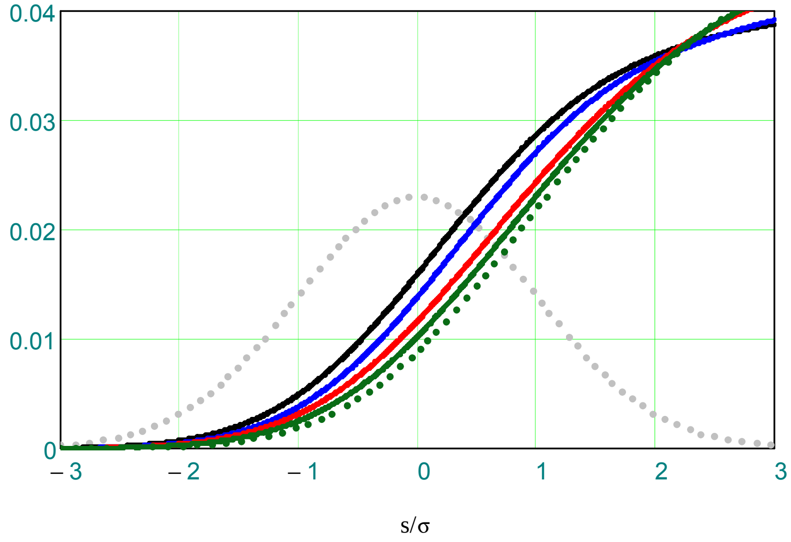
σ = 3mm



WX



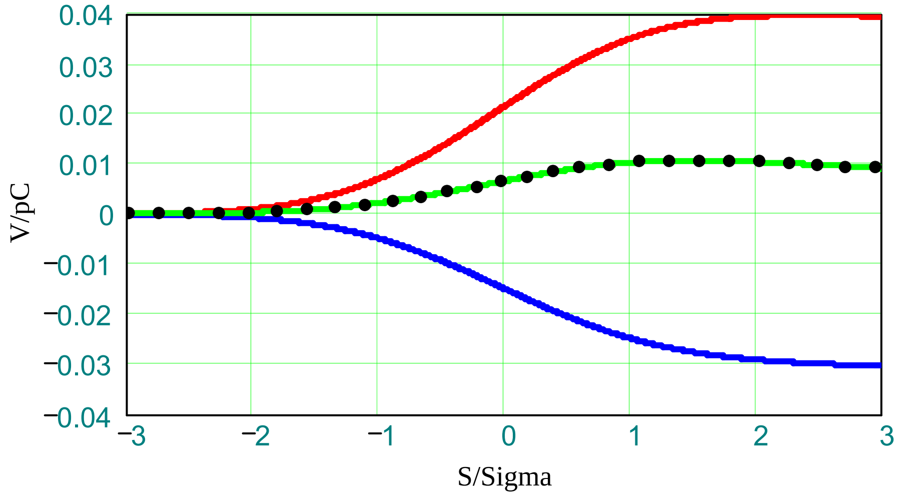
WY



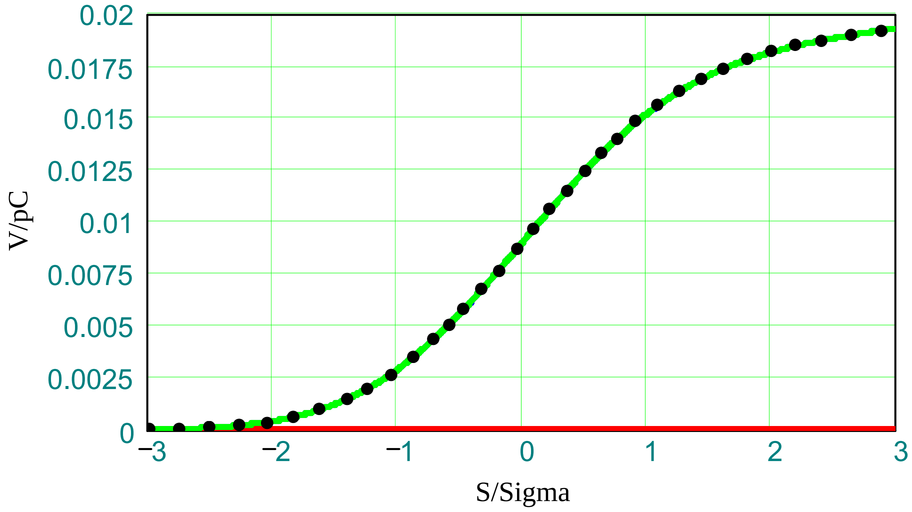
Wake superposition.

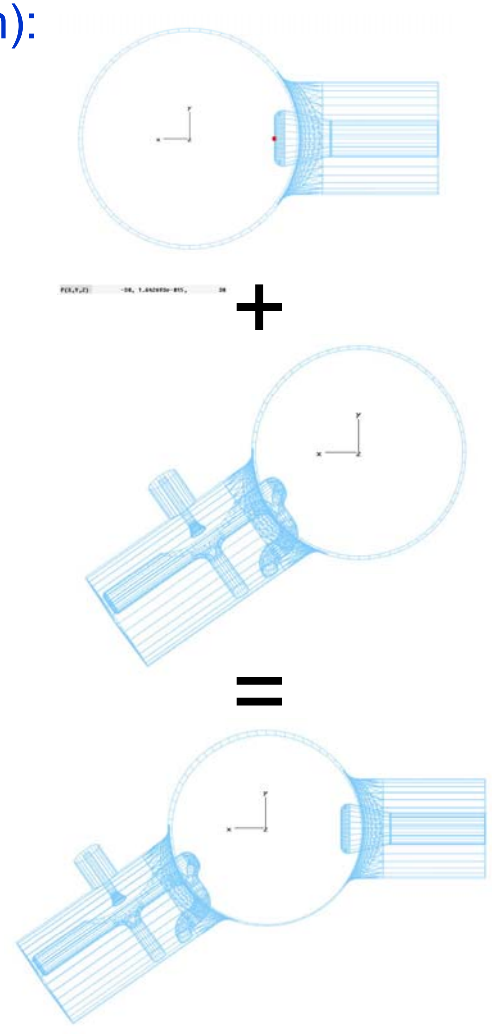
I. Main coupler and downstream HOM coupler (σ=1mm):

$W_x(s)$



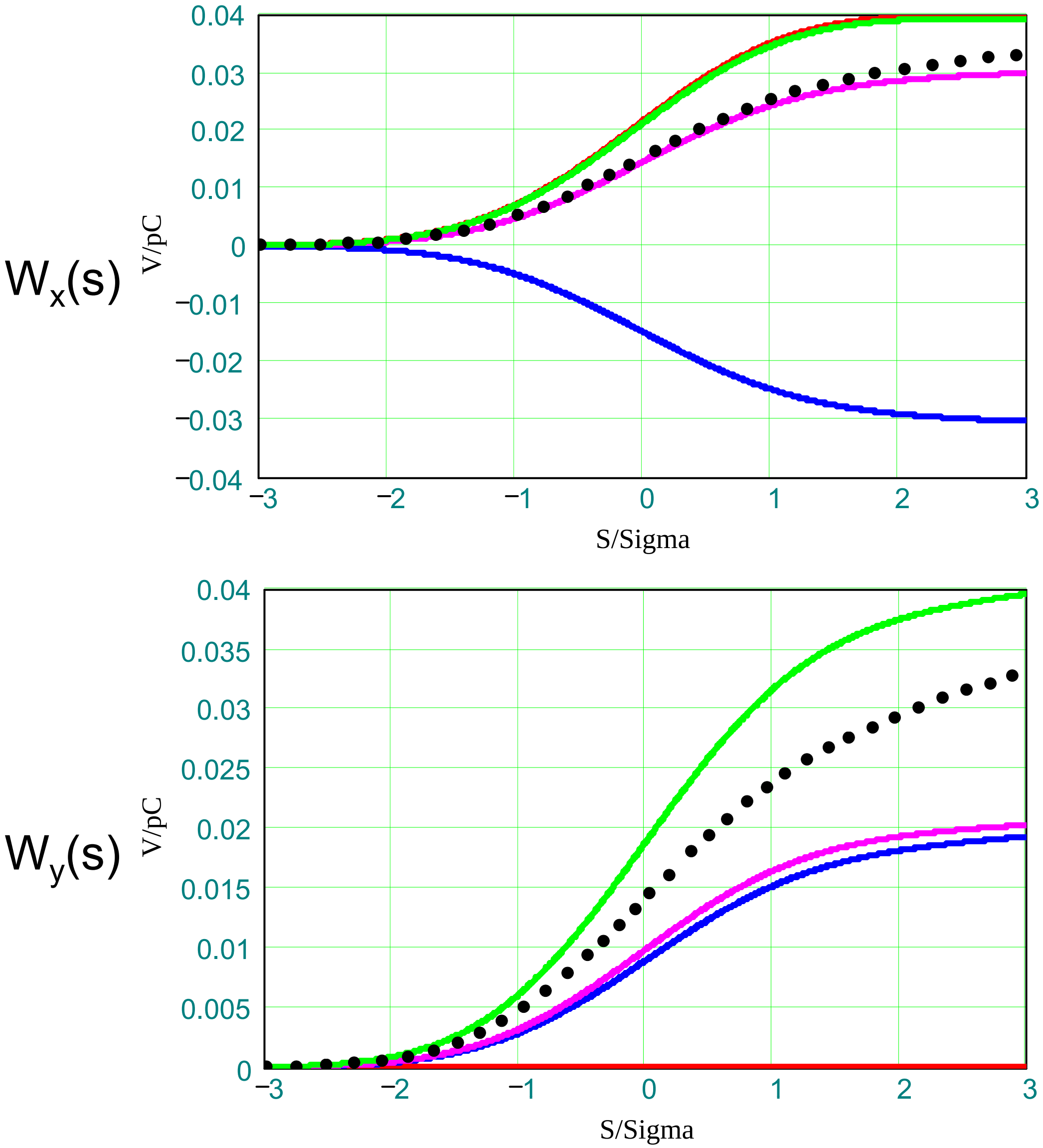
$W_y(s)$

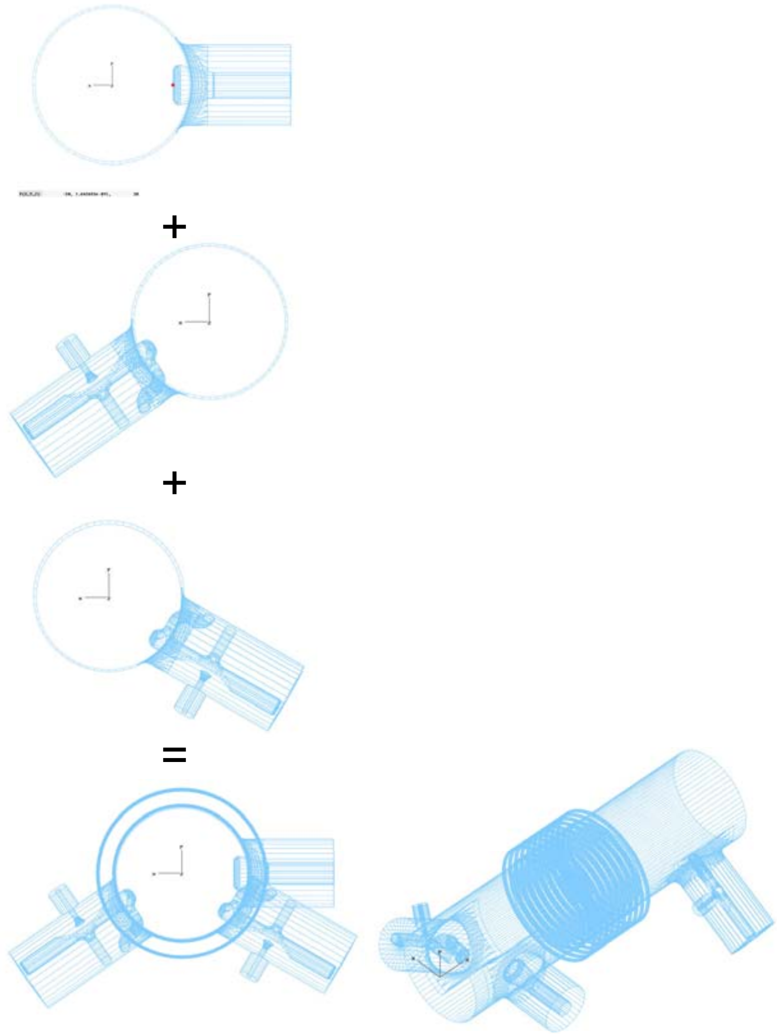




Red - main coupler, blue - downstream HOM, green - sum of them, dots – direct calculations of the entire geometry. Superposition works pretty well.

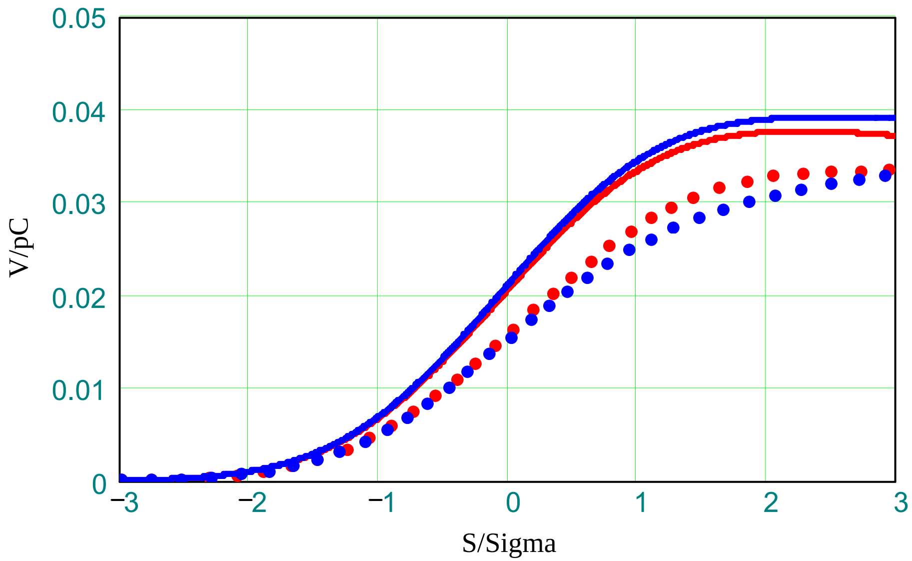
II. Main coupler + downstream HOM coupler + upstream HOM coupler (σ=1mm):



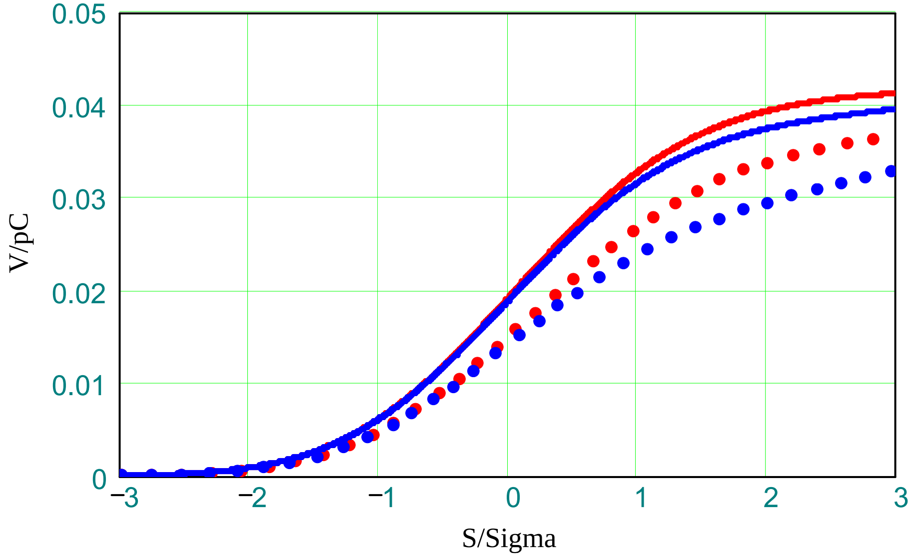


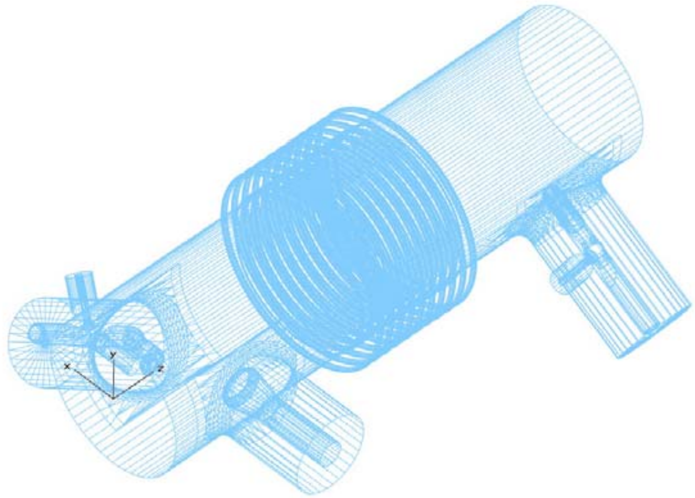
Read - main coupler, blue - downstream HOM, pink - upstream HOM, green-sum of them, dots- direct calculations of the entire geometry.

$W_x(s)$



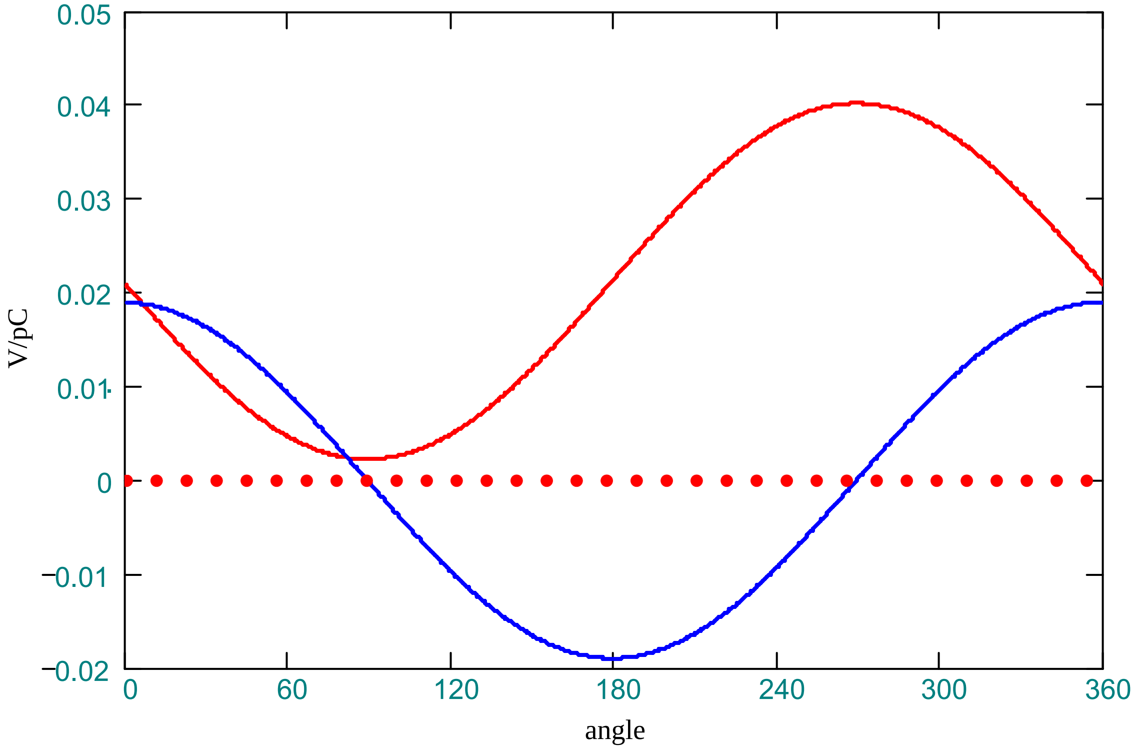
$W_y(s)$





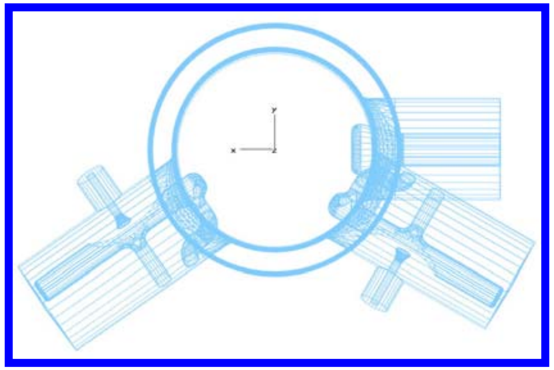
Red – σ=2 mm, blue - σ=1 mm. Solid- superposition, dots- direct calculations.

Wake compensation by HOM couplers rotating (suggested by M. Dohlus and I. Zagorodnov):

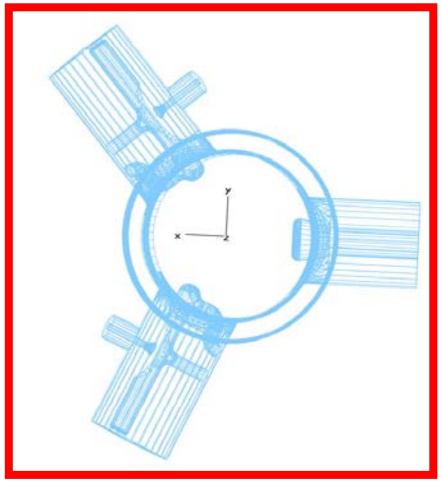


Angle between the HOM couplers is always 115º that provides optimal damping of both polarization of dipole modes and was determined experimentally

HOM couplers rotation (suggested by M. Dohlus, and I. Zagorodnov).
Symmetrical case, rotation angle is 82.5°

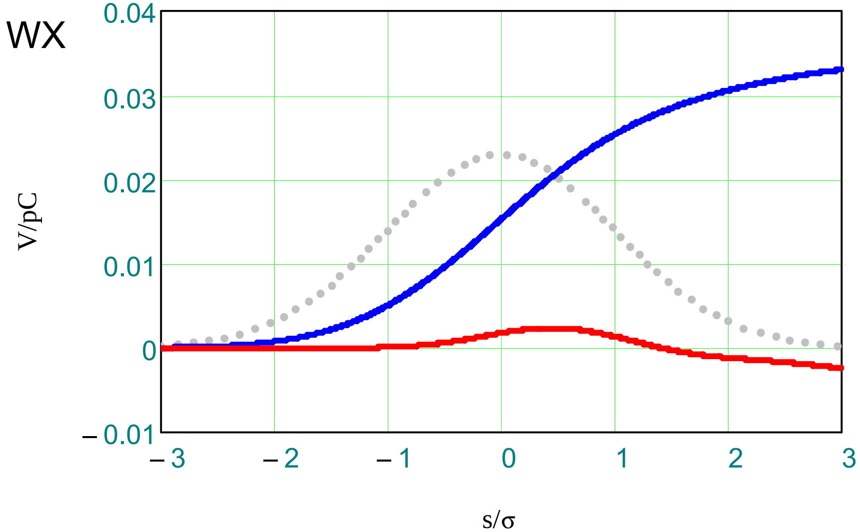


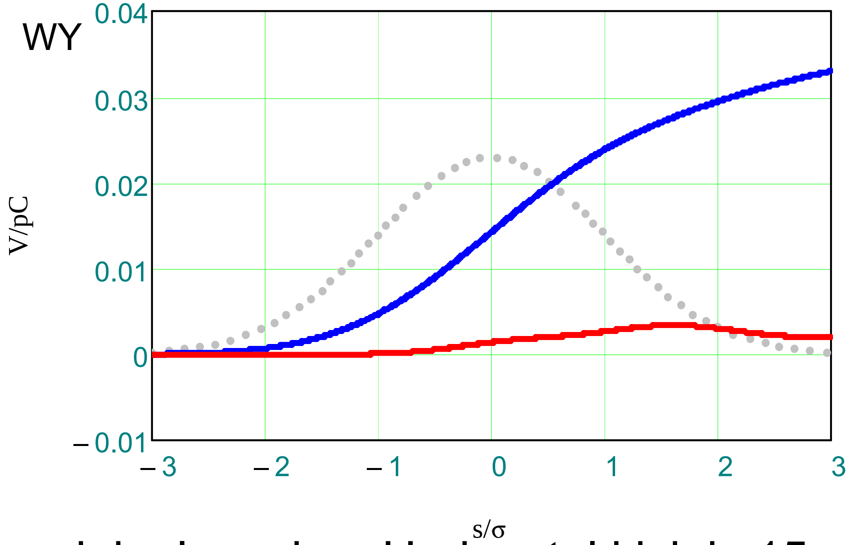
σ = 1mm



kx = 0.015 V/pC
ky = 0.014 V/pC

kx_rot = 0.0010 V/pC
ky_rot = 0.0014 V/pC





Vertical kick is 10 times smaller than in the original version. Horizontal kick is 15 times smaller.

To be done:

- Simulations for shorter beam is to be done in order to cross check the results.
- Green functions will be evaluated for longitudinal and transverse wake filed*.
- Detailed beam dynamics simulations in the main linac, BC1 and BC2 will be done.
- An alternative axi-symmetrical couplers will be considered.

*For example, using approximation suggested by I. Zagorodnov and N. Solyak, see EPAC2006.