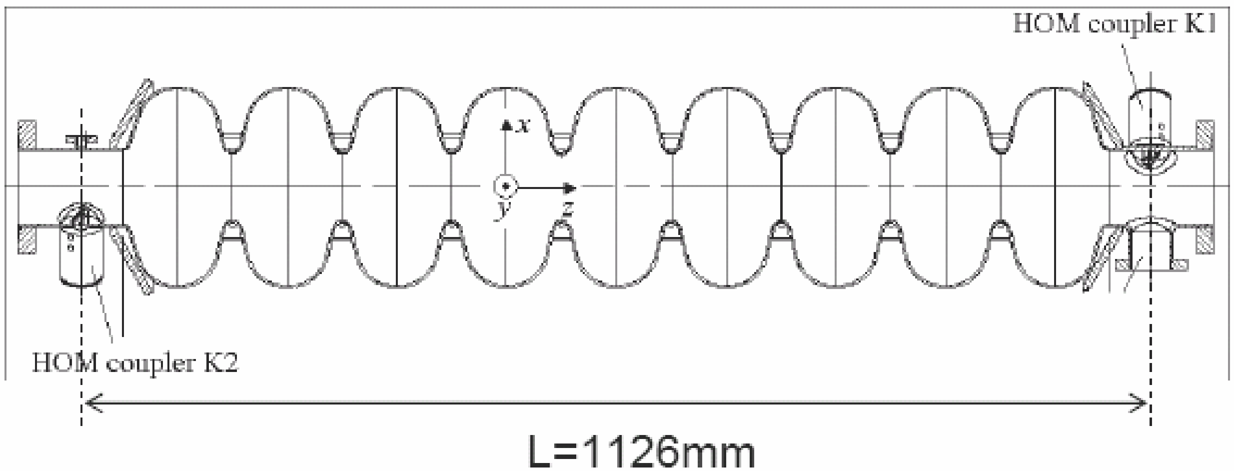
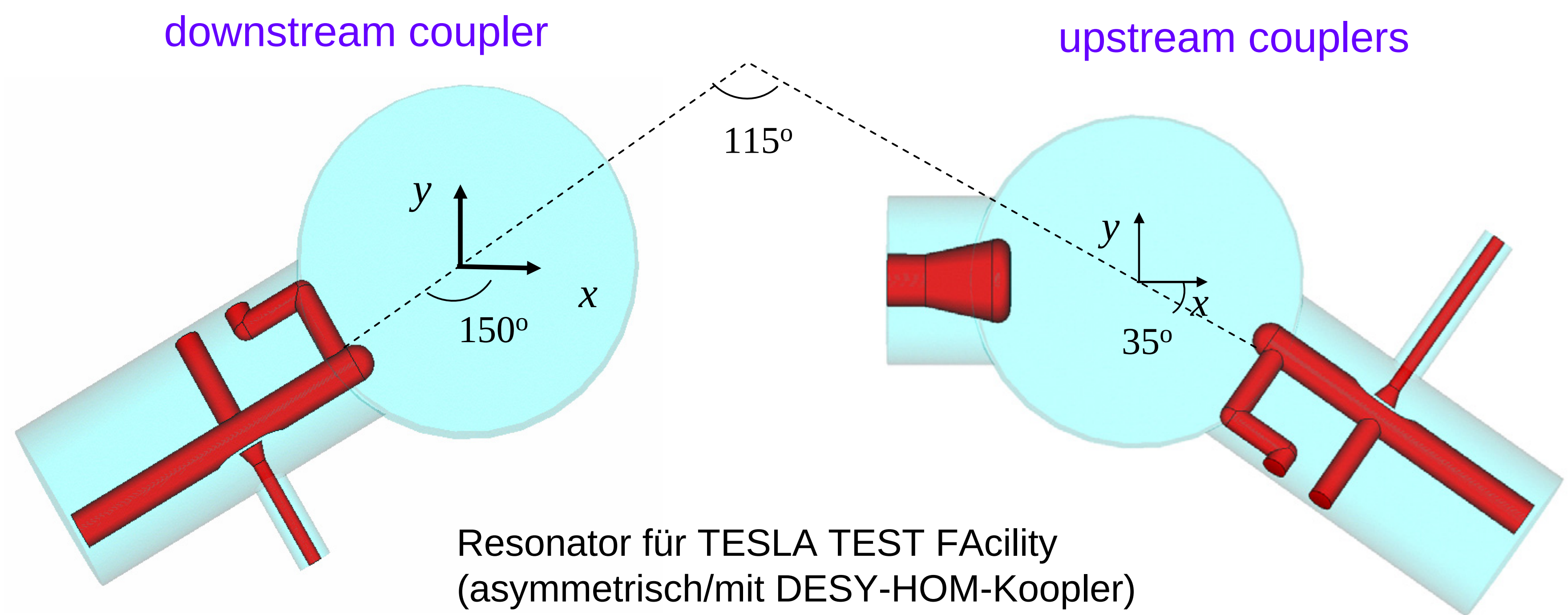
Short Range Wakefields of the Couplers

Igor Zagorodnov and Martin Dohlus
DESY, HOM Workshop,
22.01.07





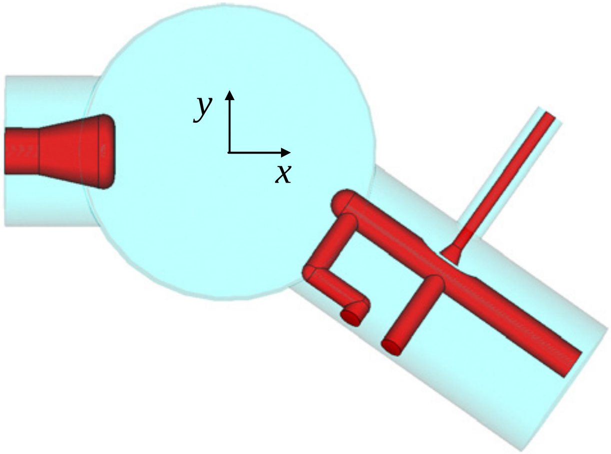
Resonator für TESLA TEST FAcility
(asymmetrisch/mit DESY-HOM-Koopler)
0 93 2214/0.000

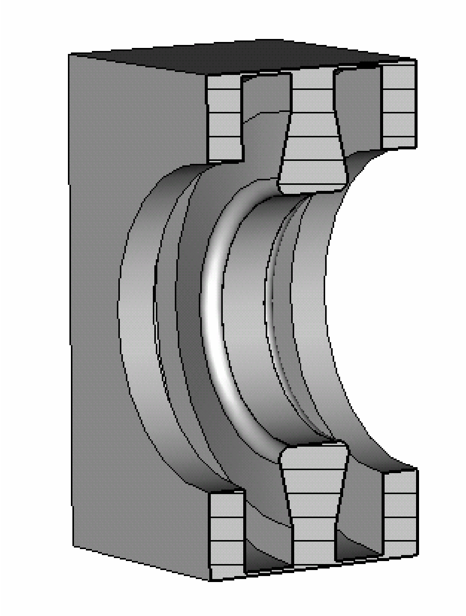
Numerical methods

1. Zagorodnov I, Weiland T., *TE/TM Field Solver for Particle Beam Simulations without Numerical Cherenkov Radiation*// Physical Review – STAB,8, **2005**.

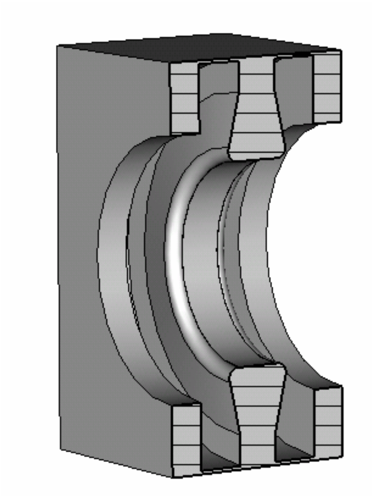
2. Zagorodnov I., *Indirect Methods for Wake Potential Integration* // Physical Review -STAB, 9, **2006.**

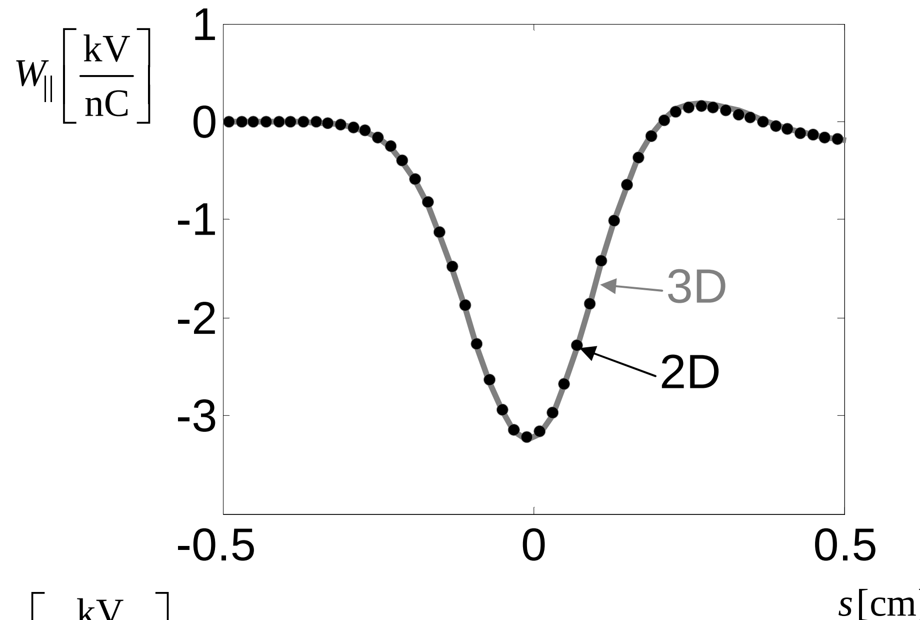
Accuracy estimation

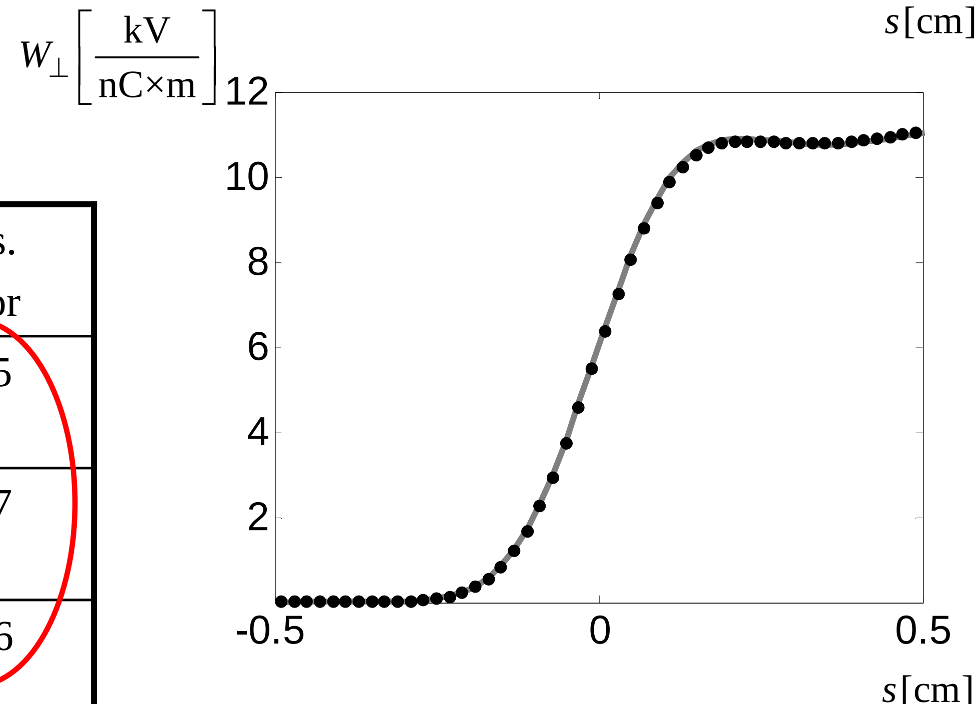




Accuracy estimation



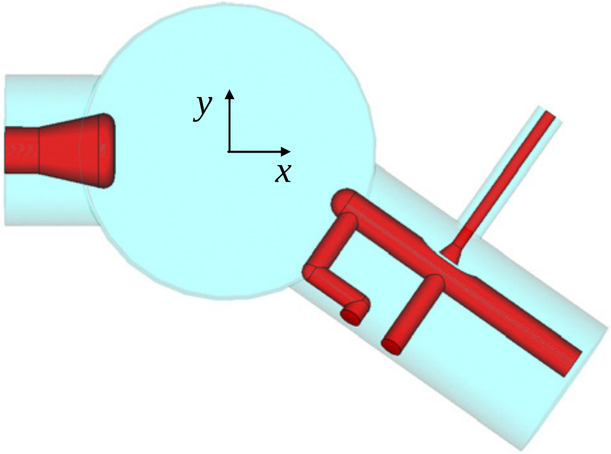




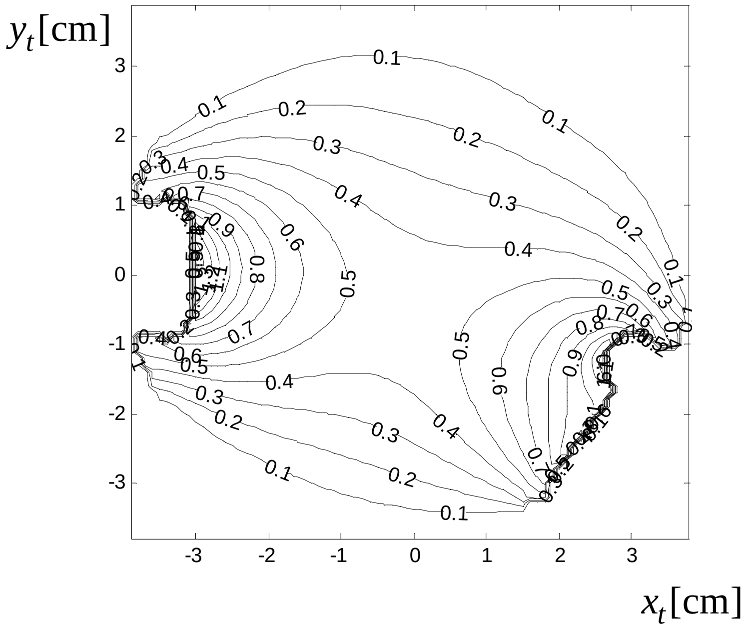
Gaussian bunch with $\sigma = 1\text{mm}$

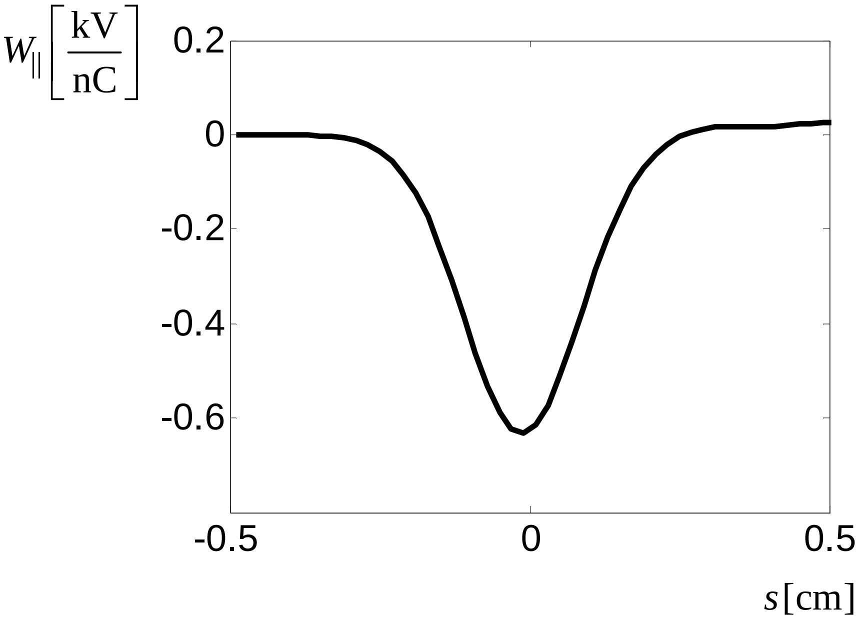
	2D, σ/h=5	2D, σ/h=10	3D, σ/h=5	Abs. error
$k_{\parallel}$, kV/nC	2.205	2.195	2.241	0.05
$k_{tr}/\lvert r\rvert$, nV/nC/m	5.820	5.817	5.89	0.07
$\lvert k_{tr}(0)\rvert$, nV/nC	0	0	1e-6	1e-6

Longitudinal loss factor



$$x_s = y_s = 0$$





$$k_{||}(0,0,0,0) = 0.44 \pm 0.05 \frac{\text{kV}}{\text{nC}}$$

Transverse wake potential (Taylor expansion)

$$\mathbf{W}_\perp(x_s, y_s, x_t, y_t, s) = \mathbf{W}_\perp^0(s) + \overleftrightarrow{\mathbf{W}}_\perp^D(s)\begin{pmatrix} x_s \\ y_s \end{pmatrix} + \overleftrightarrow{\mathbf{W}}_\perp^Q(s)\begin{pmatrix} x_t \\ y_t \end{pmatrix} + O(2)$$

$$\mathbf{W}_\perp^0(s) = \begin{pmatrix} W_x^0(s) \\ W_y^0(s) \end{pmatrix} \qquad \overleftrightarrow{\mathbf{W}}_\perp^D(s) = \begin{pmatrix} W_{xx}^D(s) & W_{xy}^D(s) \\ W_{yx}^D(s) & W_{yy}^D(s) \end{pmatrix}$$

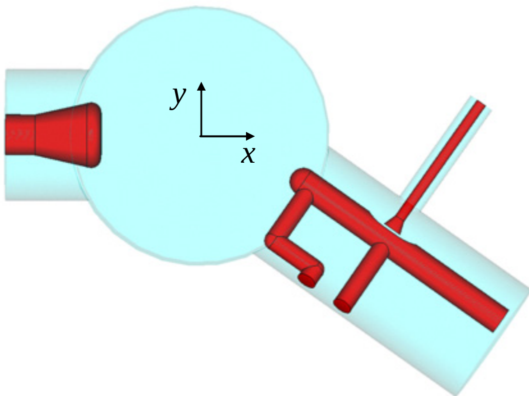
$$\overleftrightarrow{\mathbf{W}}_\perp^Q(s) = \begin{pmatrix} W_{xx}^Q(s) & W_{xy}^Q(s) \\ W_{xy}^Q(s) & W_{yx}^Q(s) \end{pmatrix} = \begin{pmatrix} W_0^Q(s) & W_1^Q(s) \\ W_1^Q(s) & -W_0^Q(s) \end{pmatrix} \qquad \overleftrightarrow{\mathbf{W}}_\perp(s) = \overleftrightarrow{\mathbf{W}}_\perp^D(s) + \overleftrightarrow{\mathbf{W}}_\perp^Q(s)$$

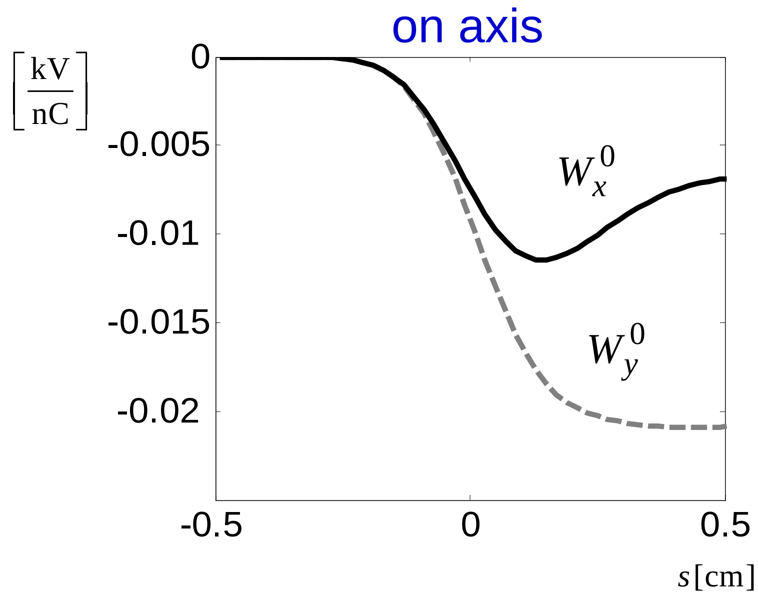
Transverse kick

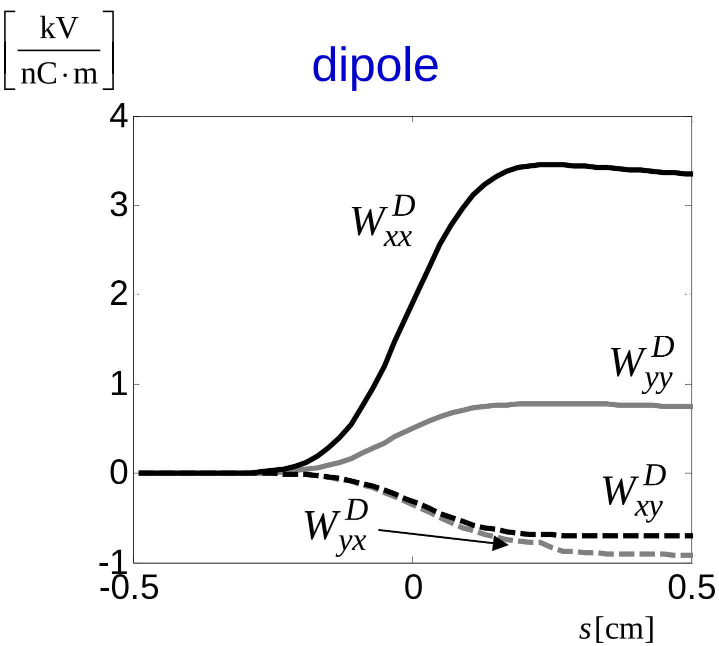
$$\mathbf{k}_\perp(x_s, y_s, x_t, y_t) = \mathbf{k}_\perp^0 + \overleftrightarrow{\mathbf{k}}_\perp^D\begin{pmatrix} x_s \\ y_s \end{pmatrix} + \overleftrightarrow{\mathbf{k}}_\perp^Q\begin{pmatrix} x_t \\ y_t \end{pmatrix} + O(2)$$

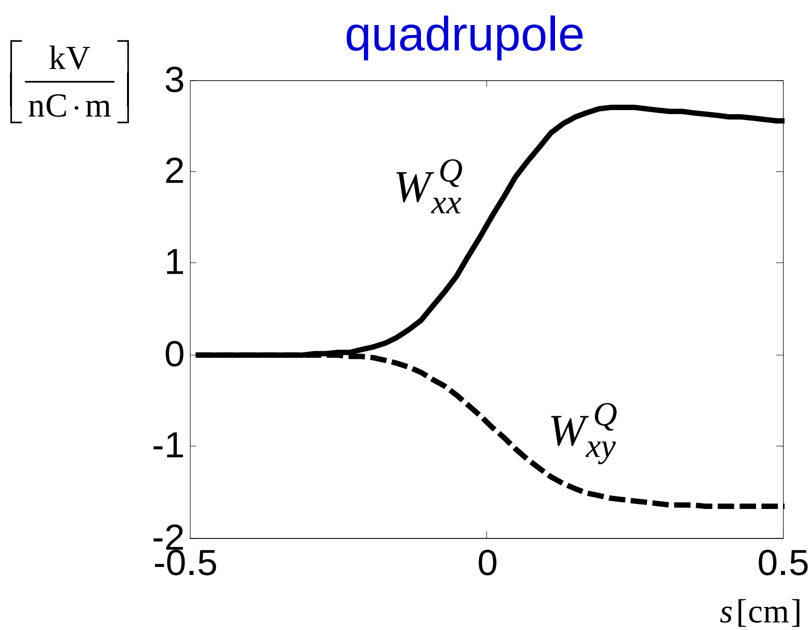
$$\mathbf{k}_\perp^0 = \begin{pmatrix} k_x^0 \\ k_y^0 \end{pmatrix} \qquad \overleftrightarrow{\mathbf{k}}_\perp^D = \begin{pmatrix} k_{xx}^D & k_{xy}^D \\ k_{yx}^D & k_{yy}^D \end{pmatrix} \qquad \overleftrightarrow{\mathbf{k}}_\perp^Q = \begin{pmatrix} k_0^Q & k_1^Q \\ k_1^Q & -k_0^Q \end{pmatrix} \qquad \overleftrightarrow{\mathbf{k}}_\perp = \overleftrightarrow{\mathbf{k}}_\perp^D + \overleftrightarrow{\mathbf{k}}_\perp^Q$$

Transverse wake potential of upstream couplers

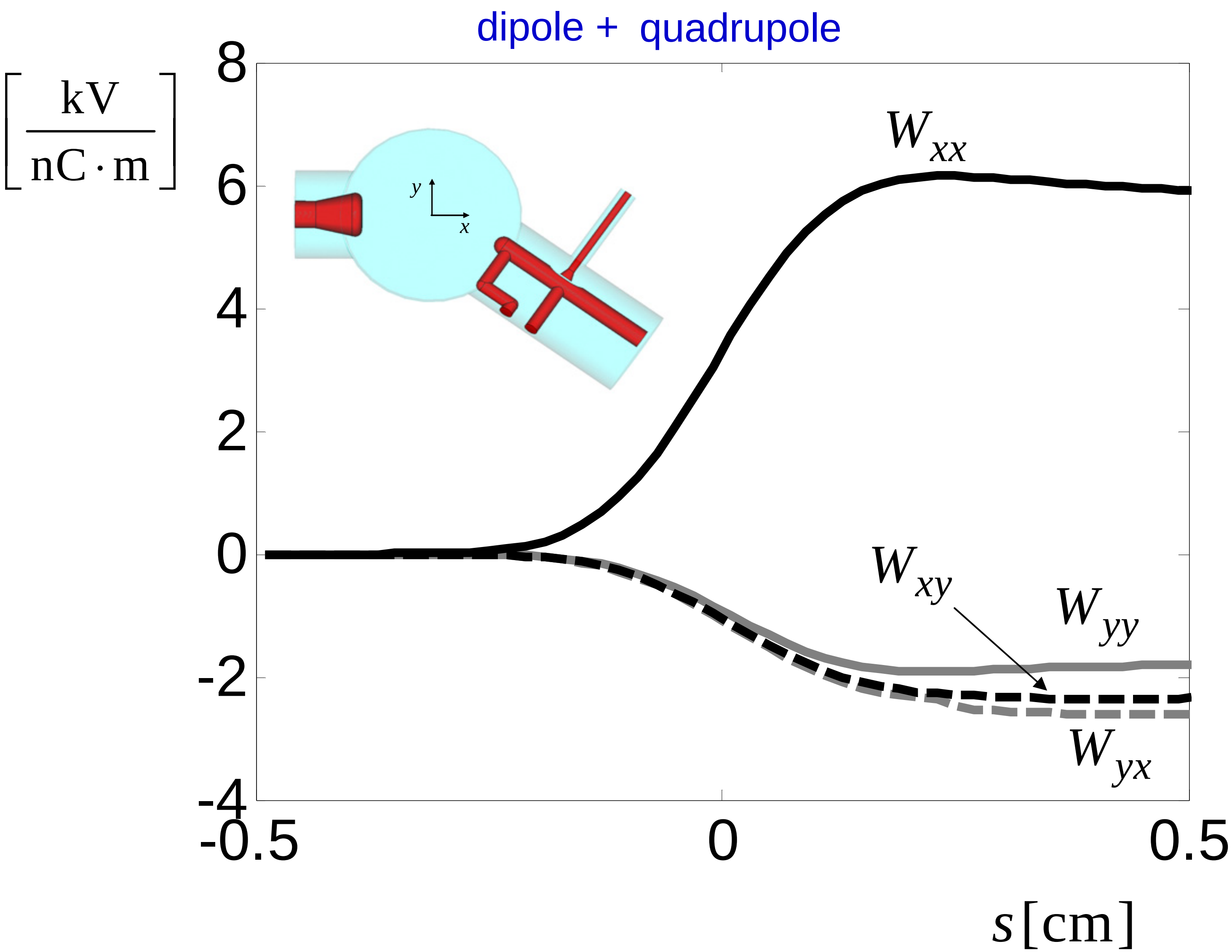








Transverse wake potential of upstream couplers



$$W_{\alpha\beta} = W_{\alpha\beta}^{D} + W_{\alpha\beta}^{Q}$$

Transverse kick of upstream couplers

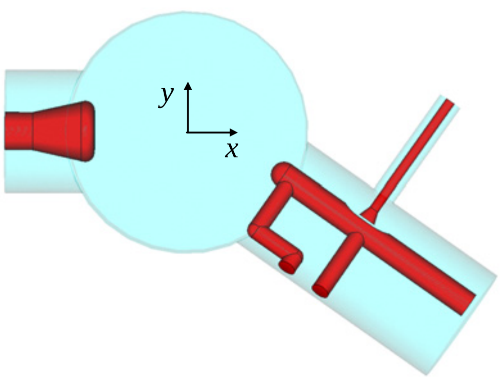
$$\mathbf{k}_\perp(x_s, y_s, x_t, y_t) = \mathbf{k}_\perp^0 + \overleftrightarrow{\mathbf{k}}_\perp^D \begin{pmatrix} x_s \\ y_s \end{pmatrix} + \overleftrightarrow{\mathbf{k}}_\perp^Q \begin{pmatrix} x_t \\ y_t \end{pmatrix} + O(2)$$

on axis

$$\begin{pmatrix} k_x^0 \\ k_y^0 \end{pmatrix} = \begin{pmatrix} -0.0069 \\ -0.0094 \end{pmatrix} \frac{\text{kV}}{\text{nC}}$$

$$\begin{pmatrix} k_{xx}^D & k_{xy}^D \\ k_{yx}^D & k_{yy}^D \end{pmatrix} = \begin{pmatrix} 1.85 & -0.32 \\ -0.37 & 0.47 \end{pmatrix} \frac{\text{kV}}{\text{nC}\times\text{m}}$$

$$\begin{pmatrix} k_{xx}^Q & k_{xy}^Q \\ k_{yx}^Q & k_{yy}^Q \end{pmatrix} = \begin{pmatrix} 1.4 & -0.75 \\ -0.75 & -1.4 \end{pmatrix} \frac{\text{kV}}{\text{nC}\times\text{m}}$$

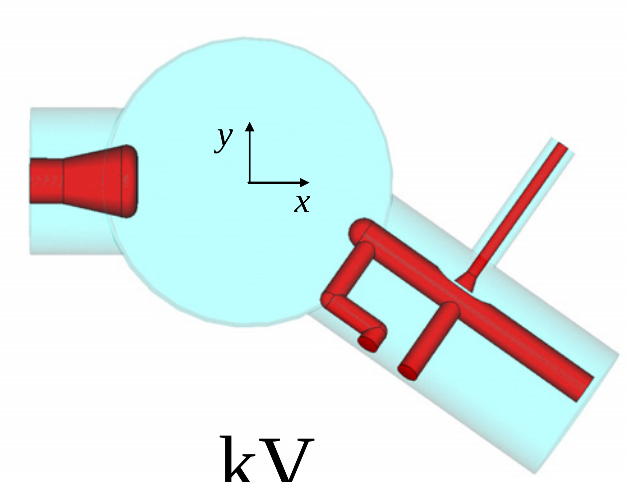


dipole + quadrupole

$$\begin{pmatrix} k_{xx} & k_{xy} \\ k_{yx} & k_{yy} \end{pmatrix} = \begin{pmatrix} 3.2 & -1.1 \\ -1.1 & -1.0 \end{pmatrix} \frac{\text{kV}}{\text{nC}\times\text{m}}$$

$$k_{\alpha\beta} = k_{\alpha\beta}^D + k_{\alpha\beta}^Q$$

Loss and kick factors of upstream couplers

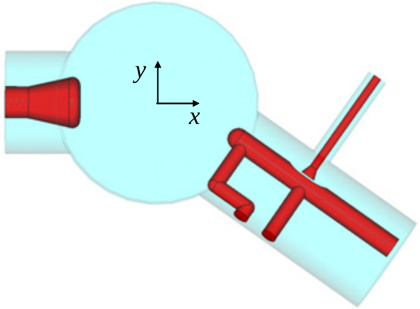


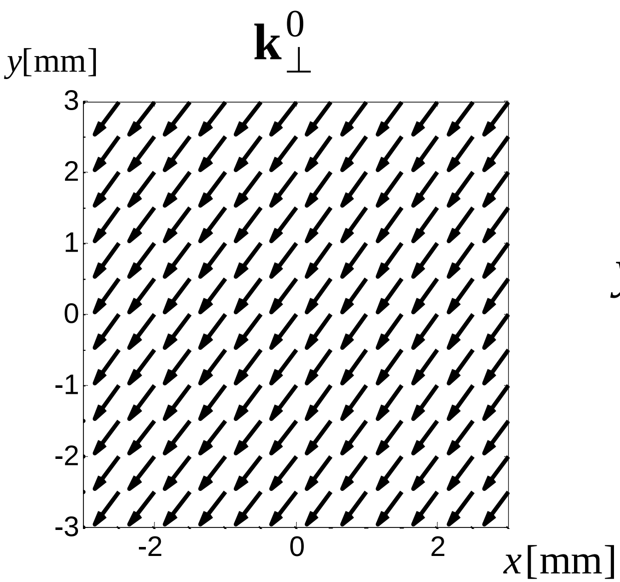
$$k_{||}(0,0) = 0.44 \pm 0.05 \frac{\text{kV}}{\text{nC}}$$

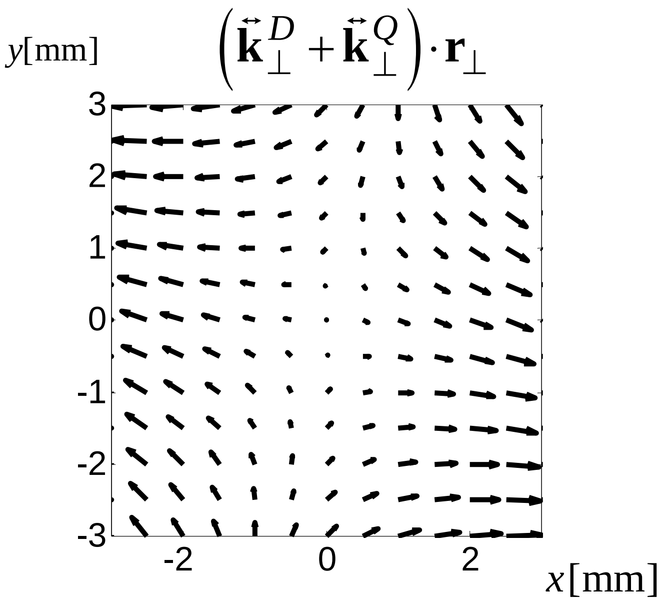
$$\mathbf{k}_{\perp}(x,y) = \begin{pmatrix} -0.0069 \\ -0.0094 \end{pmatrix} + \begin{pmatrix} 3.2 & -1.1 \\ -1.1 & -1.0 \end{pmatrix} \begin{pmatrix} x[\text{m}] \\ y[\text{m}] \end{pmatrix} \left[\frac{\text{kV}}{\text{nC}} \right]$$

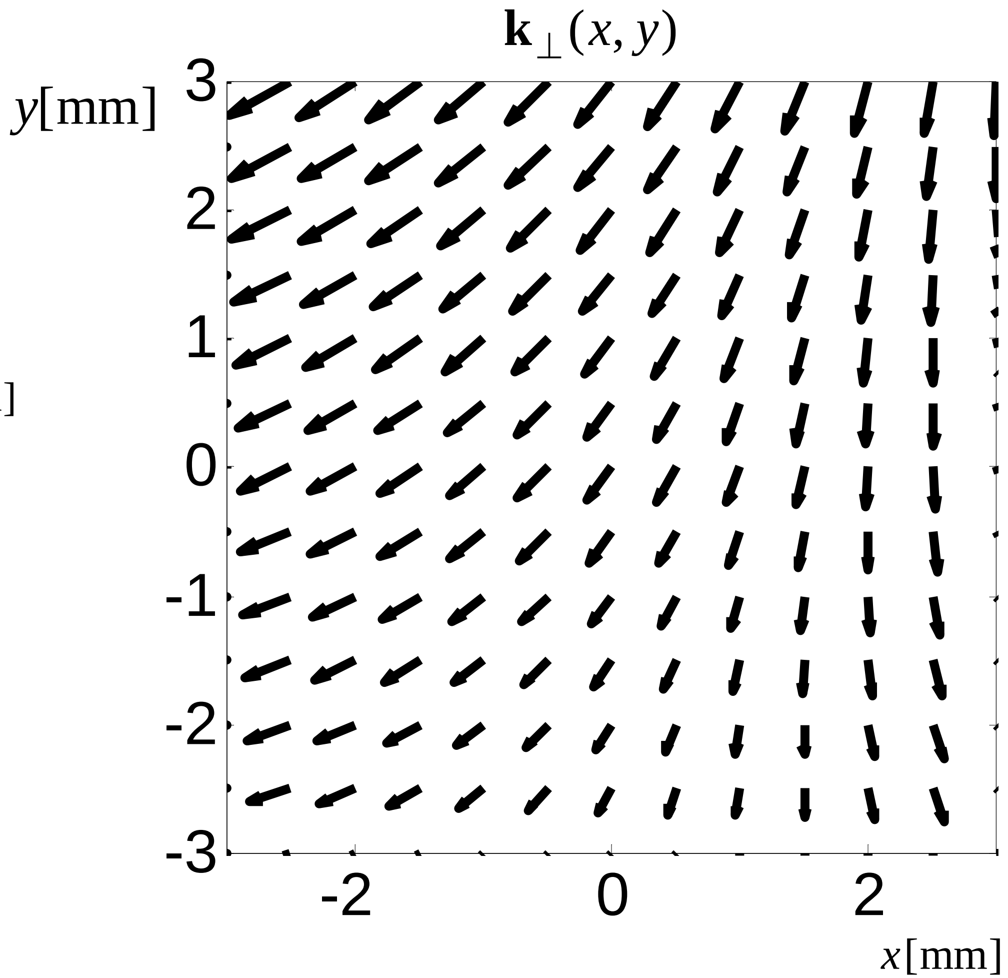
Kick of upstream couplers

$$\mathbf{k}_\perp(\mathbf{r}_\perp) = \mathbf{k}_\perp^0 + \left(\overset{\leftrightarrow}{\mathbf{k}}_\perp^D + \overset{\leftrightarrow}{\mathbf{k}}_\perp^Q\right)\cdot \mathbf{r}_\perp$$

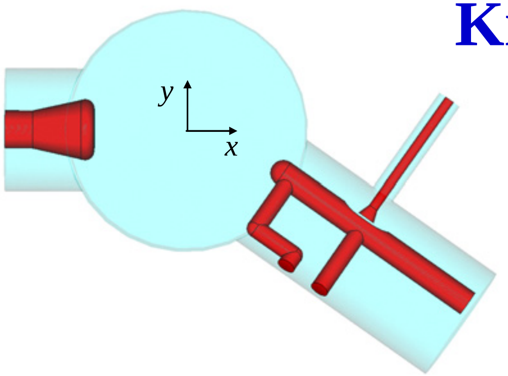




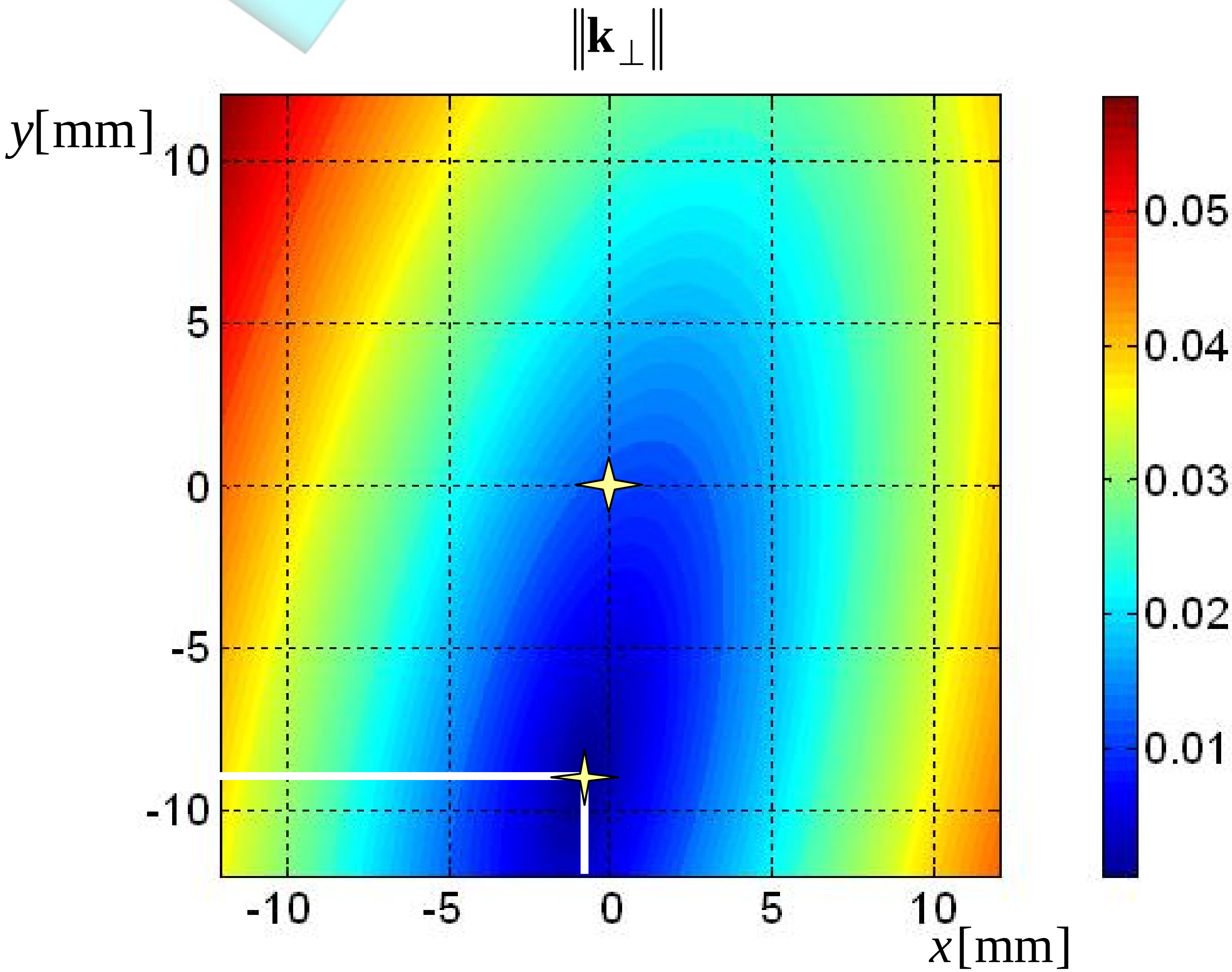




Kick of upstream couplers



$$\mathbf{k}_\perp(x,y) = \begin{pmatrix} -0.0069 \\ -0.0094 \end{pmatrix} + \begin{pmatrix} 3.2 & -1.1 \\ -1.1 & -1.0 \end{pmatrix} \begin{pmatrix} x[\mathrm{m}] \\ y[\mathrm{m}] \end{pmatrix} \left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$

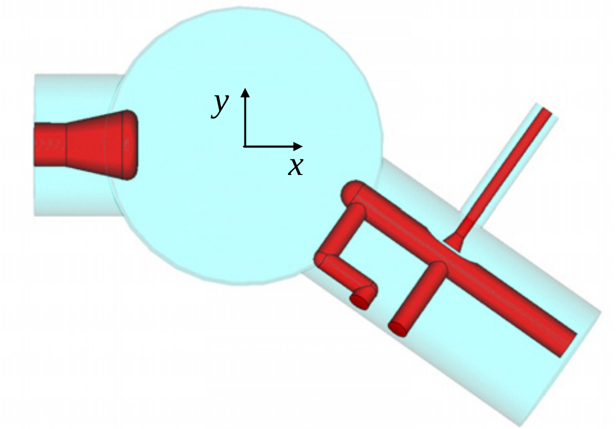


$$\mathbf{r}_\mathbf{c} = \begin{pmatrix} -0.8 \\ -8.9 \end{pmatrix} \mathrm{mm}$$

$$\|\mathbf{k}_\perp\|_{\min} = 3e-5\,\frac{\mathrm{kV}}{\mathrm{nC}}$$

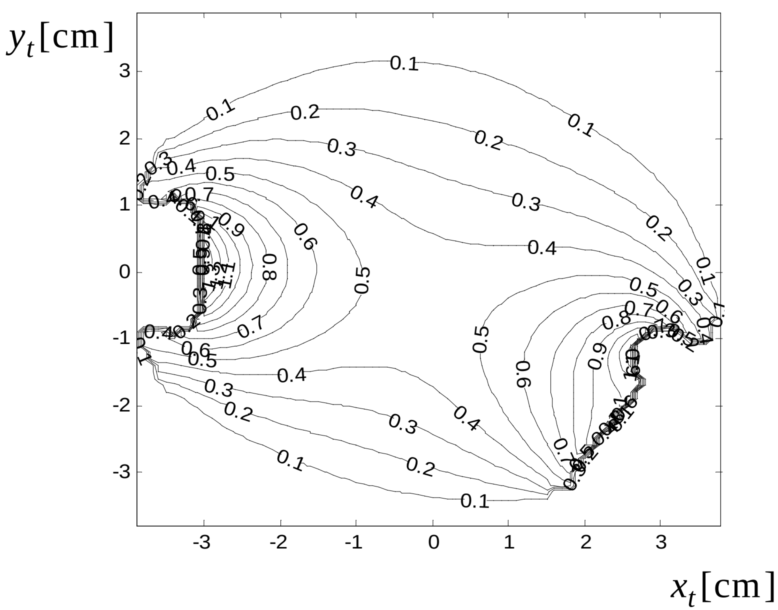
Loss factor

upstream couplers

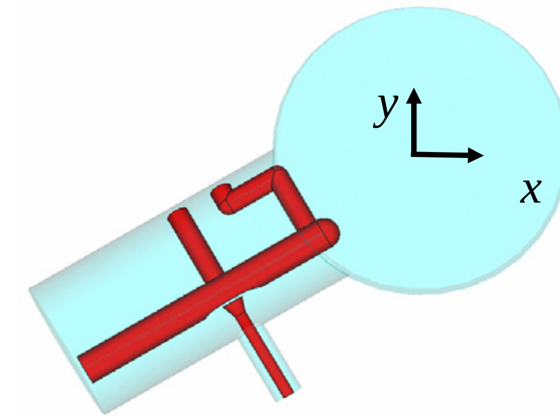


$$k_{||}(0,0) = 0.44 \pm 0.05 \frac{\text{kV}}{\text{nC}}$$

$k_{||}\left[\frac{\text{kV}}{\text{nC}}\right]$

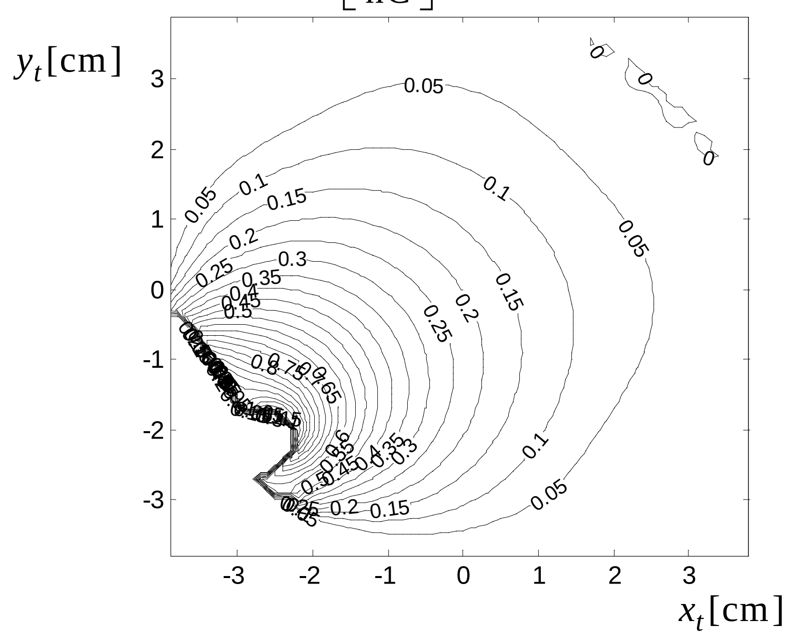


downstream coupler



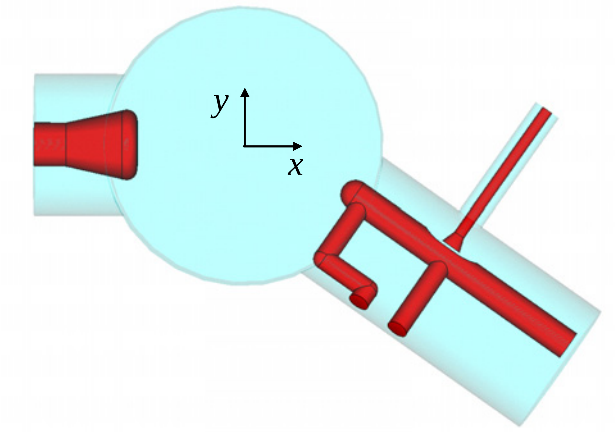
$$k_{||}(0,0) = 0.2 \pm 0.05 \frac{\text{kV}}{\text{nC}}$$

$k_{||}\left[\frac{\text{kV}}{\text{nC}}\right]$

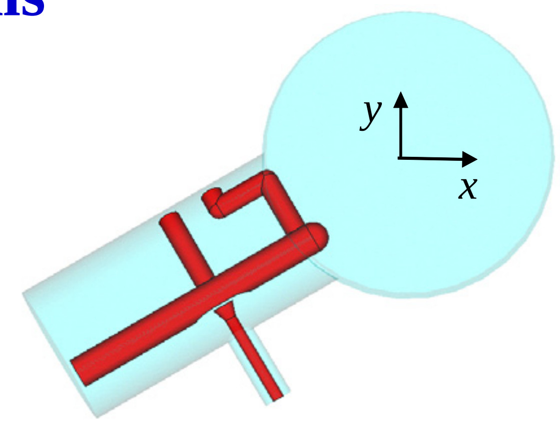


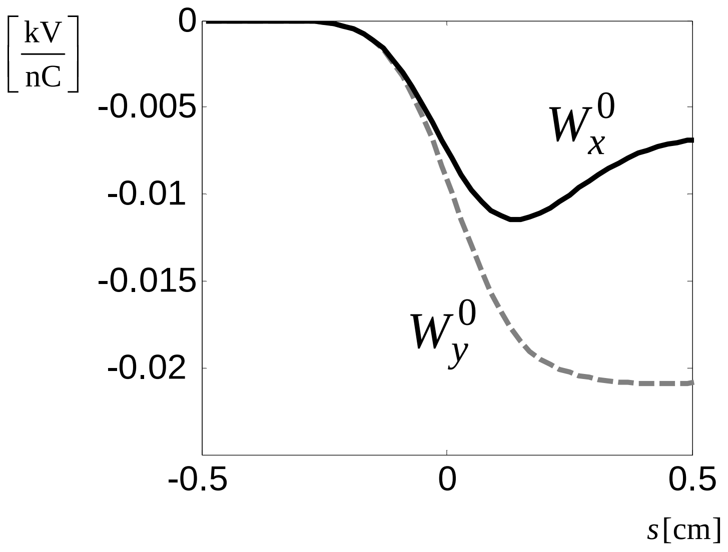
Kick on the axis

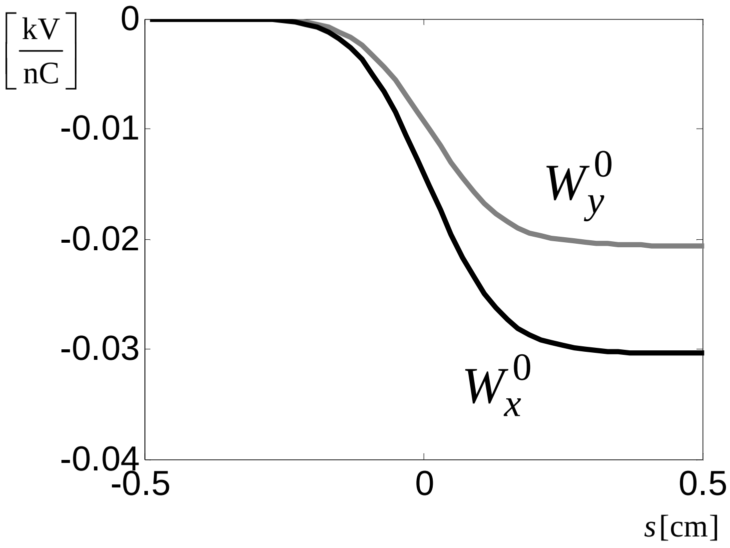
upstream couplers



downstream coupler

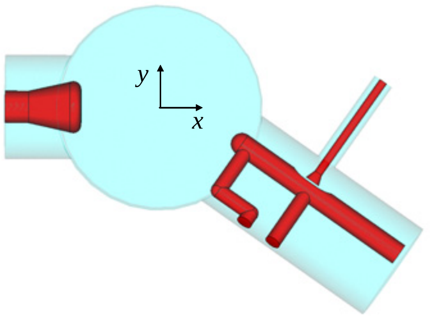




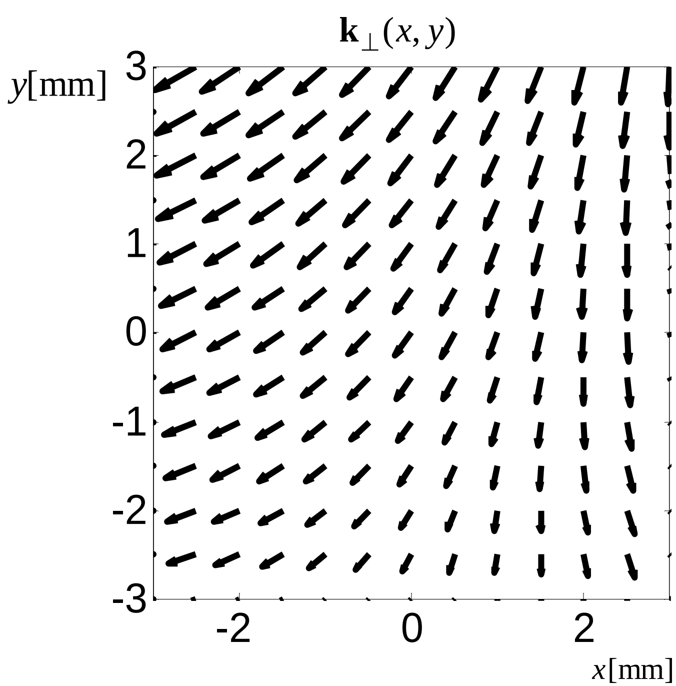


Kick near to the axis

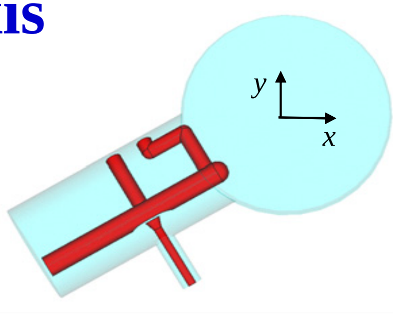
upstream couplers



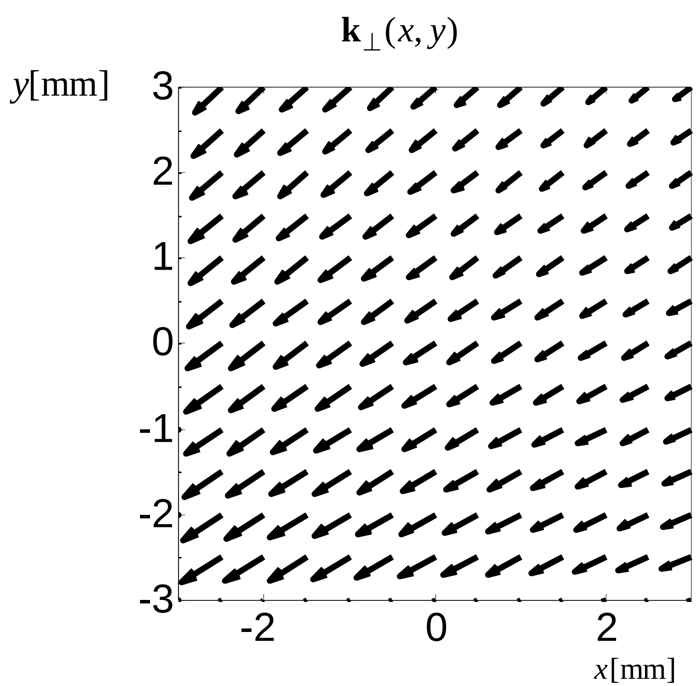
$$\mathbf{k}_\perp(x,y) = \begin{pmatrix} -0.0069 \\ -0.0094 \end{pmatrix} + \begin{pmatrix} 3.2 & -1.1 \\ -1.1 & -1.0 \end{pmatrix} \begin{pmatrix} x[\mathrm{m}] \\ y[\mathrm{m}] \end{pmatrix} \left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$



downstream coupler

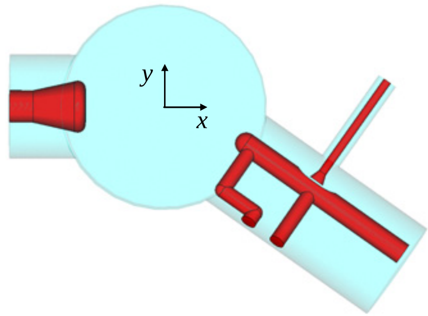


$$\mathbf{k}_\perp(x,y) = \begin{pmatrix} -0.0142 \\ -0.0095 \end{pmatrix} + \begin{pmatrix} 1.02 & 1.15 \\ 1.15 & 0.07 \end{pmatrix} \begin{pmatrix} x[\mathrm{m}] \\ y[\mathrm{m}] \end{pmatrix} \left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$

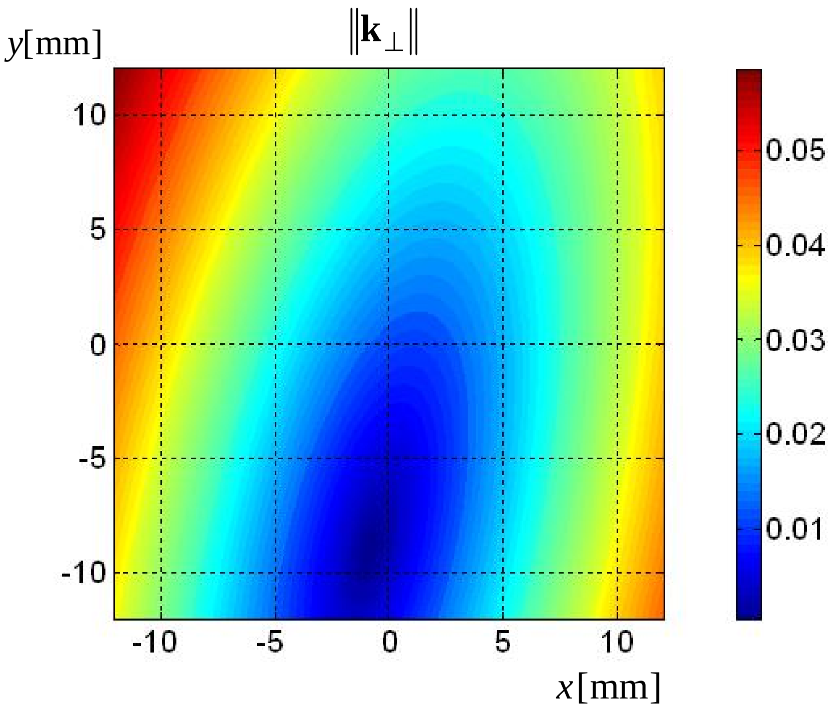


Kick near to the axis

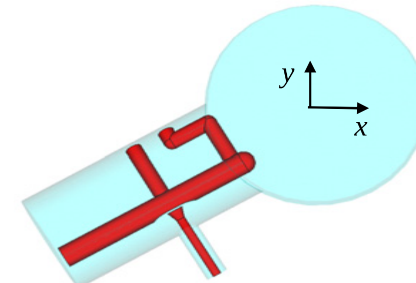
upstream couplers



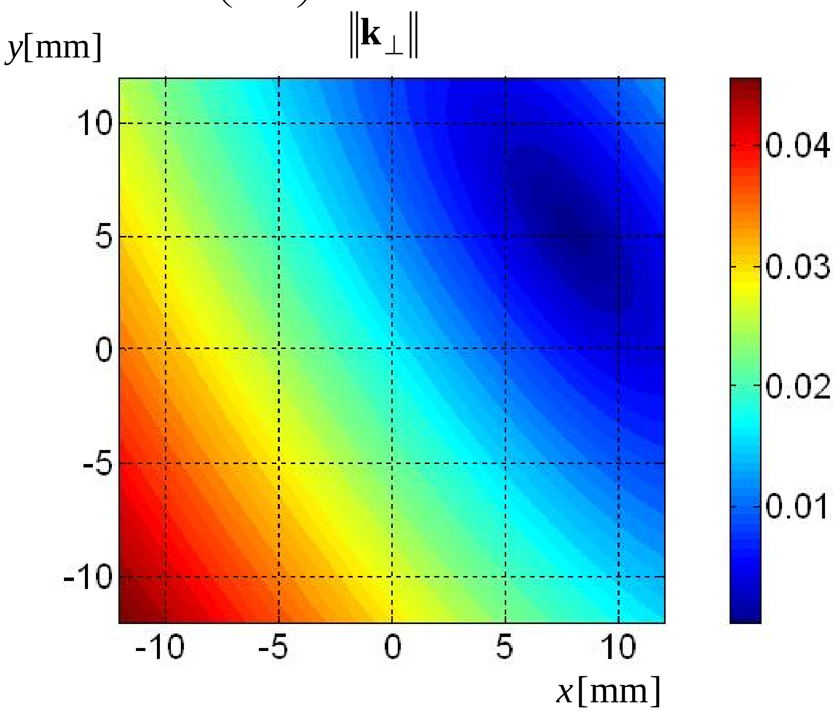
$$\mathbf{r_c} = \begin{pmatrix} -0.8 \\ -8.9 \end{pmatrix} \text{mm} \qquad \|\mathbf{k}_\perp\|_{\min} = 3e-5 \frac{\text{kV}}{\text{nC}}$$



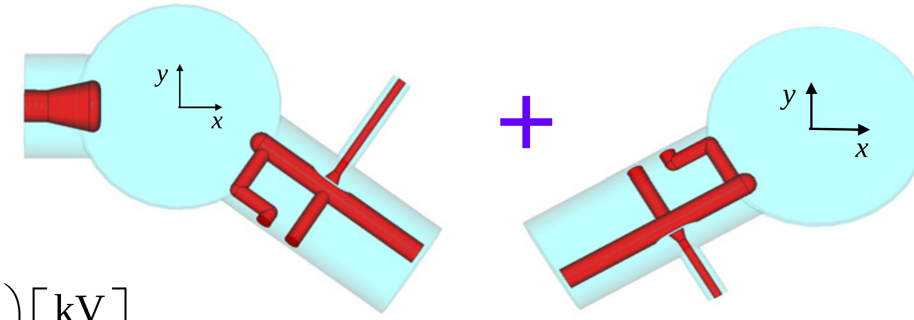
downstream coupler



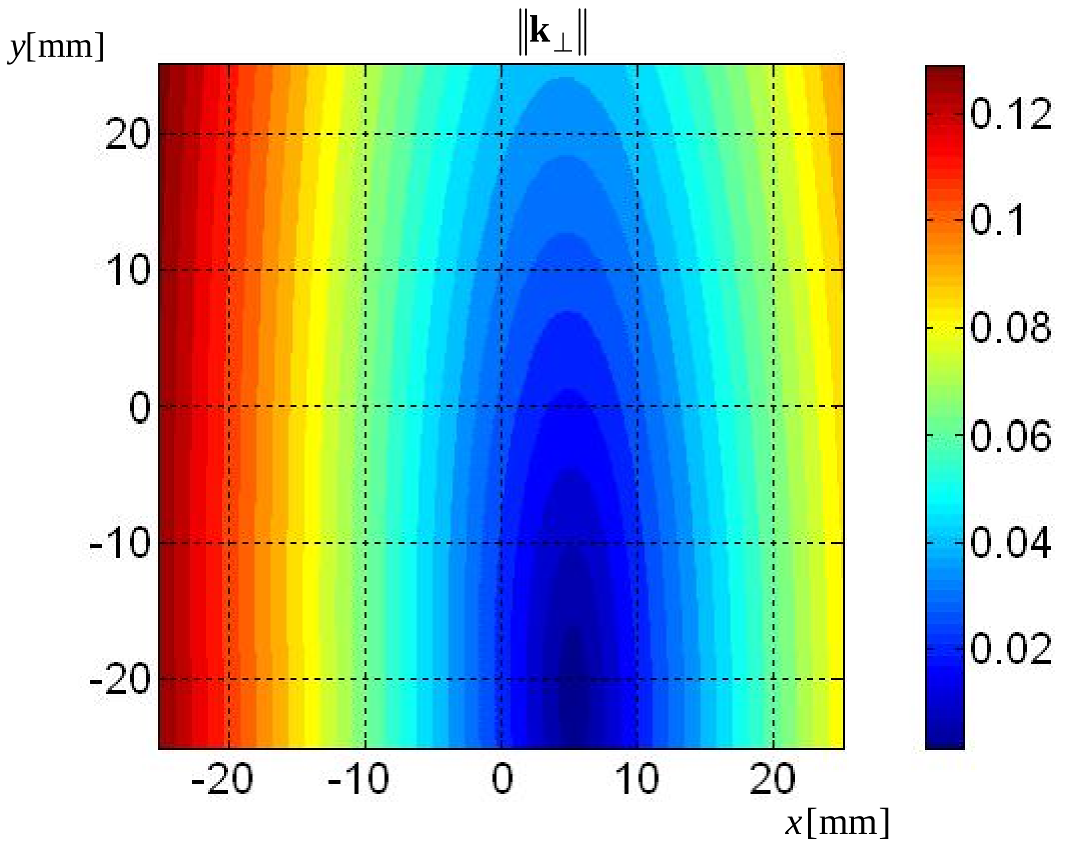
$$\mathbf{r_c} = \begin{pmatrix} 5.3 \\ 7.9 \end{pmatrix} \text{mm} \qquad \|\mathbf{k}_\perp\|_{\min} = 5e-5 \frac{\text{kV}}{\text{nC}}$$



Kick near to the axis



$$\mathbf{k}_\perp(x,y) = \begin{pmatrix} -0.021 \\ -0.019 \end{pmatrix} + \begin{pmatrix} 4.3 & 0.07 \\ 0.03 & -0.9 \end{pmatrix} \begin{pmatrix} x[\mathrm{m}] \\ y[\mathrm{m}] \end{pmatrix} \left[\frac{\mathrm{kV}}{\mathrm{nC}} \right]$$

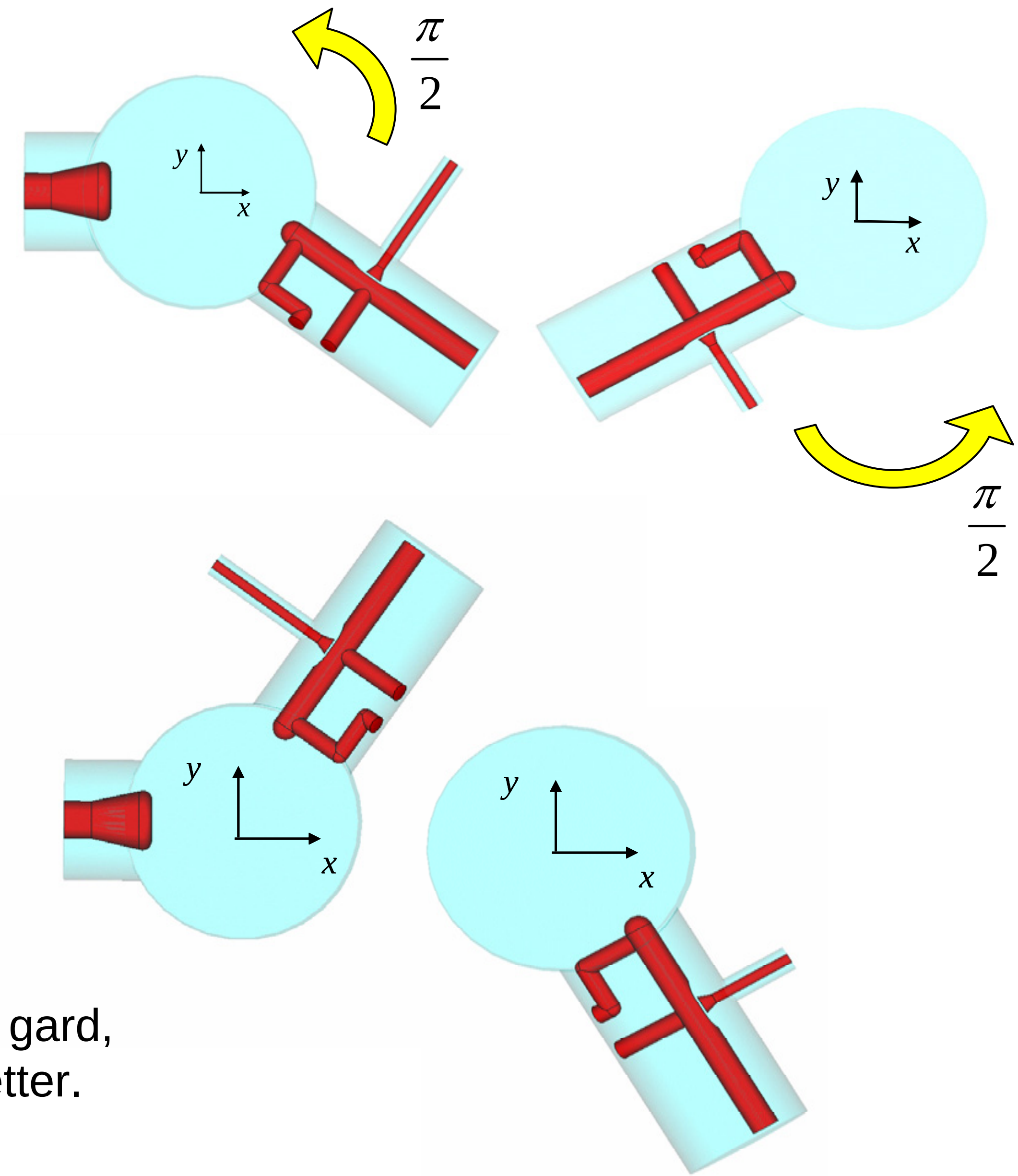


$$\mathbf{r_c} = \begin{pmatrix} 5.3 \\ -21.3 \end{pmatrix} \mathrm{mm}$$

$$\|\mathbf{k}_\perp\|_{\min} = 5e-5 \frac{\mathrm{kV}}{\mathrm{nC}}$$

How to compensate the kick on the axis?

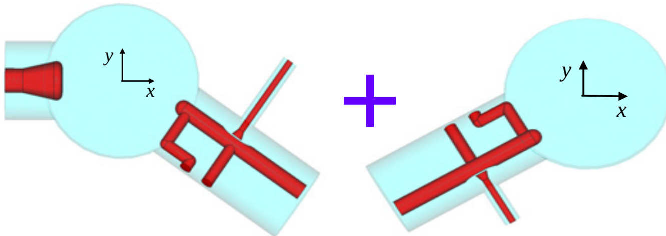
old

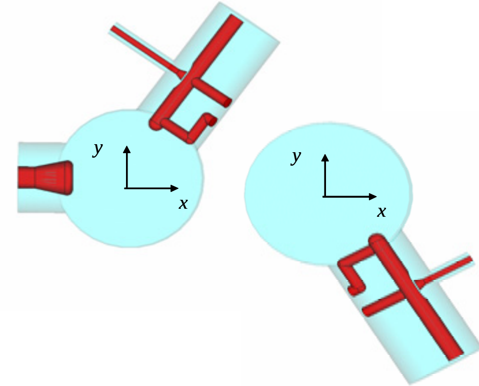


new

We have rotated by 90 gard,
but 92.5 is possible better.

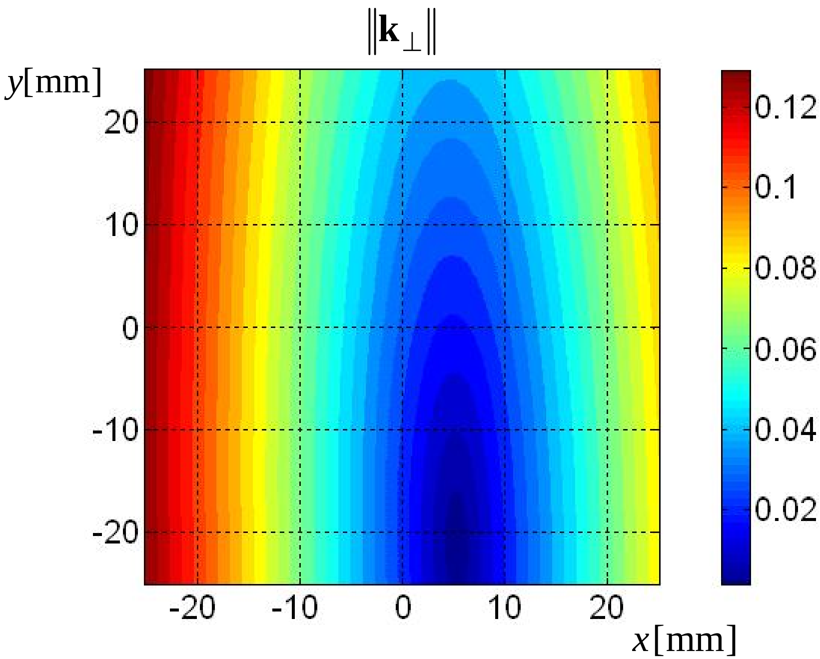
Kick for the new orientation

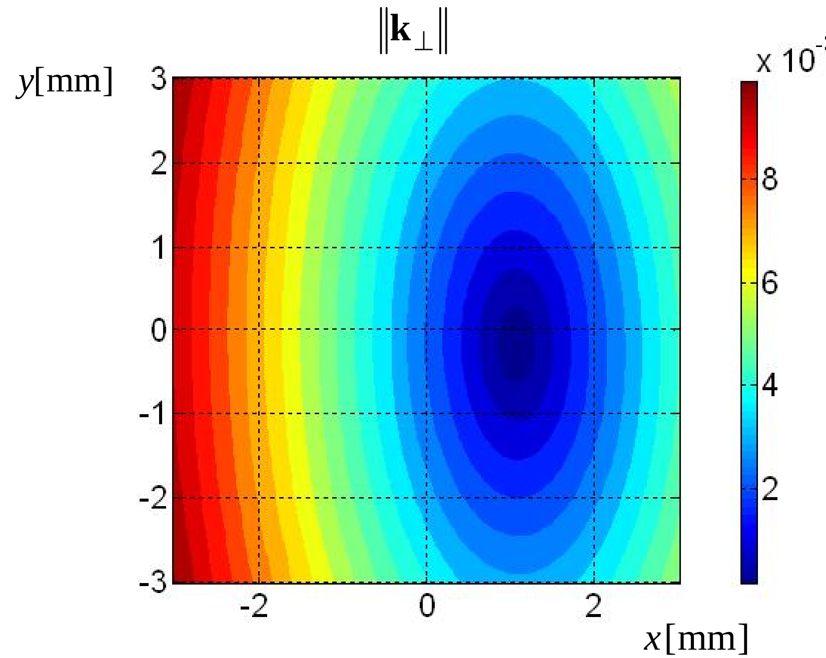




$$\mathbf{k}_\perp(x,y) = \begin{pmatrix} -0.021 \\ -0.019 \end{pmatrix} + \begin{pmatrix} 4.3 & 0.07 \\ 0.03 & -0.9 \end{pmatrix} \begin{pmatrix} x[\mathrm{m}] \\ y[\mathrm{m}] \end{pmatrix} \left[\frac{\mathrm{kV}}{\mathrm{nC}} \right]$$

$$\mathbf{k}_\perp(x,y) = \begin{pmatrix} -0.0025 \\ -0.0002 \end{pmatrix} + \begin{pmatrix} 2.33 & 0.04 \\ -0.02 & 1.1 \end{pmatrix} \begin{pmatrix} x[\mathrm{m}] \\ y[\mathrm{m}] \end{pmatrix} \left[\frac{\mathrm{kV}}{\mathrm{nC}} \right]$$

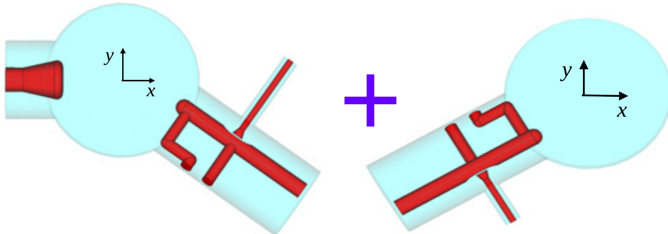


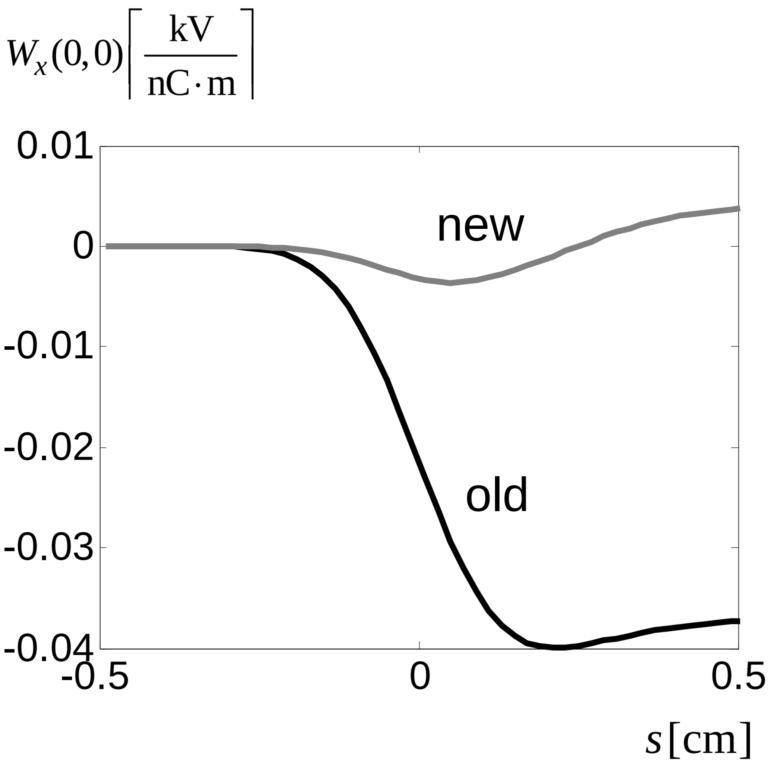


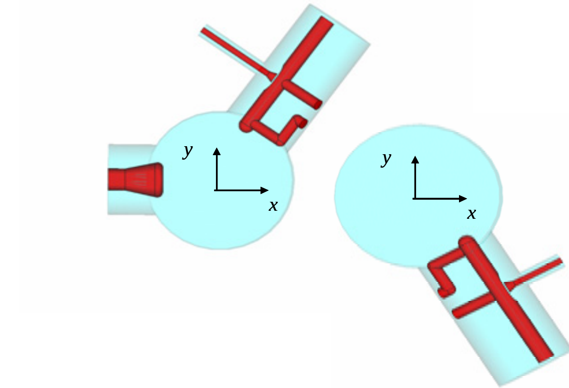
$$\mathbf{r_c} = \begin{pmatrix} 5.3 \\ -21.3 \end{pmatrix} \mathrm{mm} \quad \longrightarrow \quad \mathbf{r_c} = \begin{pmatrix} 1.1 \\ -0.2 \end{pmatrix} \mathrm{mm}$$

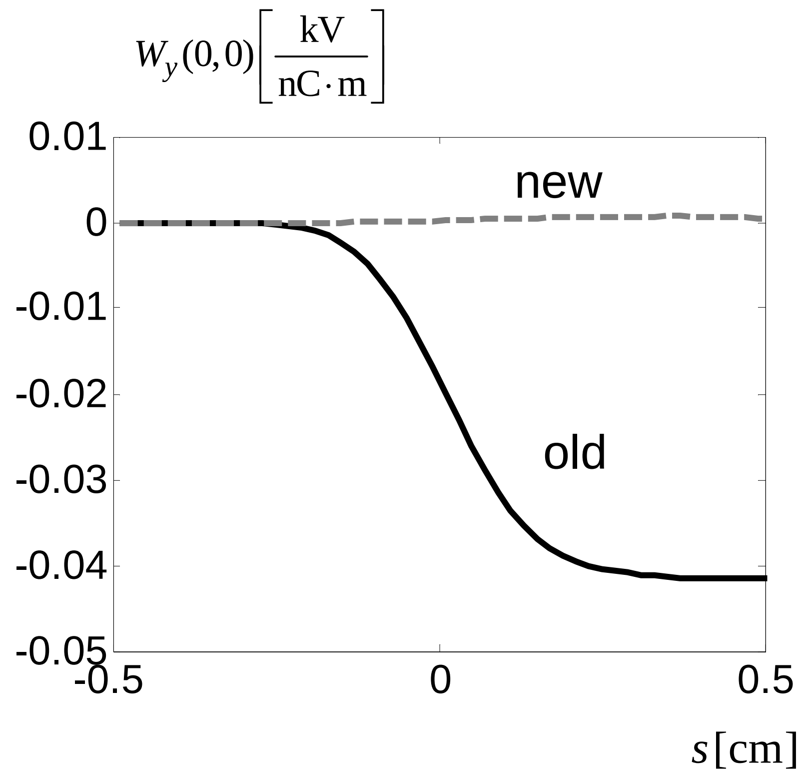
$$\left\|\mathbf{k}_\perp\right\|_{\min} = 5e-5 \frac{\mathrm{kV}}{\mathrm{nC}}$$

$$\left\|\mathbf{k}_\perp\right\|_{\min} = 8e-5 \frac{\mathrm{kV}}{\mathrm{nC}}$$


y
x
+
y
x


$W_x(0,0)\left[\frac{\text{kV}}{\text{nC}\cdot\text{m}}\right]$
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.5
0
0.5
new
old
$s\,[\text{cm}]$


y
x
y
x


$W_y(0,0)\left[\frac{\text{kV}}{\text{nC}\cdot\text{m}}\right]$
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
-0.5
0
0.5
new
old
$s\,[\text{cm}]$

Coupler vs. TESLA Cavity in Cryomodule

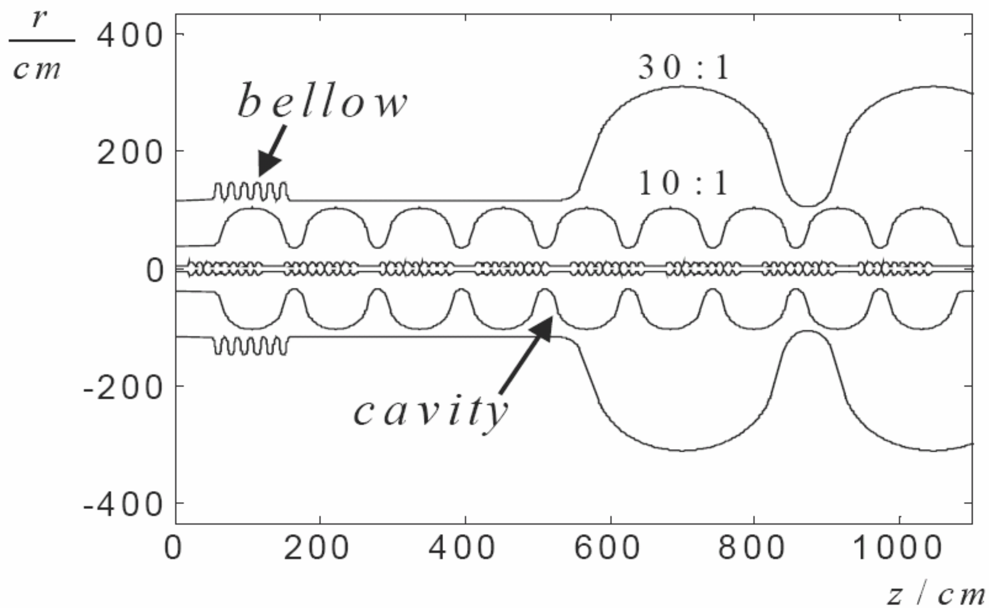


Fig1. Geometry of the TESLA cryomodule.

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 $s_1 = 0.92\cdot 10^{-3}$

Zagorodnov I., Weiland T., *The Short-Range Transverse Wakefields in TESLA Accelerating Structure*// Proceedings of PAC 2003 Conference, USA, **2003**.

Coupler vs. TESLA Cavity in Cryomodule

Kick from cryomodule in kV/nC/m

$\sigma, \mu m$	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

$$k_{cavity}^{300\mu\mathrm{m}} = 0.0073\left[\frac{\mathrm{kV}}{\mathrm{nC}\cdot\mathrm{mm}}\right]$$

Kick from the couplers on the axis
(depends weakly on the bunch length)

$$\mathbf{k}_{\perp}^{old}(0,0) = \begin{pmatrix} -0.021 \\ -0.019 \end{pmatrix}\left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$

$$\mathbf{k}_{\perp}^{new}(0,0) = \begin{pmatrix} -0.0025 \\ -0.0002 \end{pmatrix}\left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$

$$\frac{\left\|\mathbf{k}_{\perp}^{old}(0,0)\right\|}{k_{cavity}^{300\mu\mathrm{m}}} \approx 4[\mathrm{mm}]$$

$$\frac{\left\|\mathbf{k}_{\perp}^{new}(0,0)\right\|}{k_{cavity}^{300\mu\mathrm{m}}} \approx 0.3[\mathrm{mm}]$$

Conclusion

- The kick on the axis from the couplers (in the design configuration) is equivalent to 4 mm offset of the TESLA cavity in cryomodule.

- Rotation of the HOM couplers by 90 grad allows to reduce the kick by factor 10.