Coupler Kick

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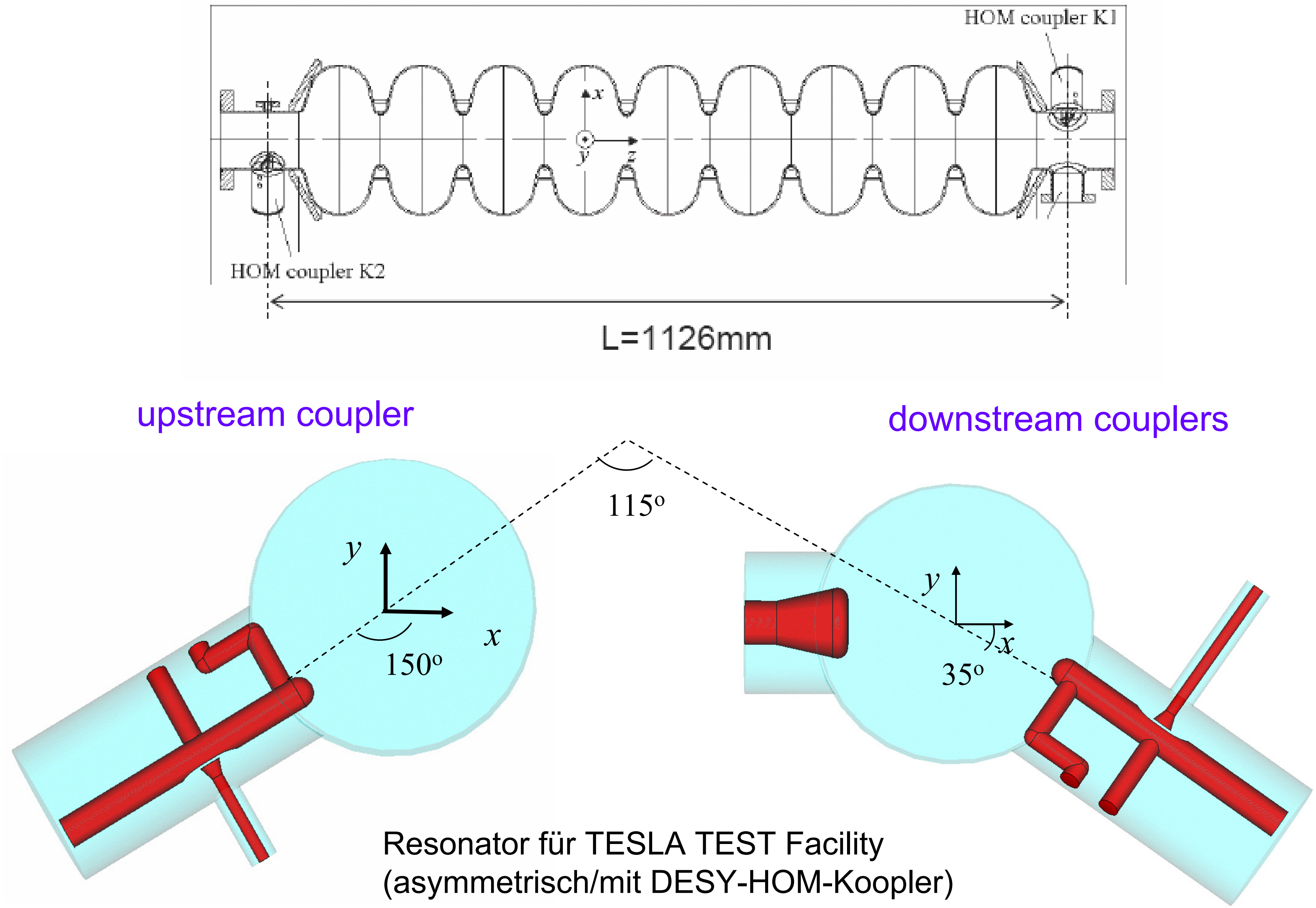
DESY, BDM,
2 April, 2007



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

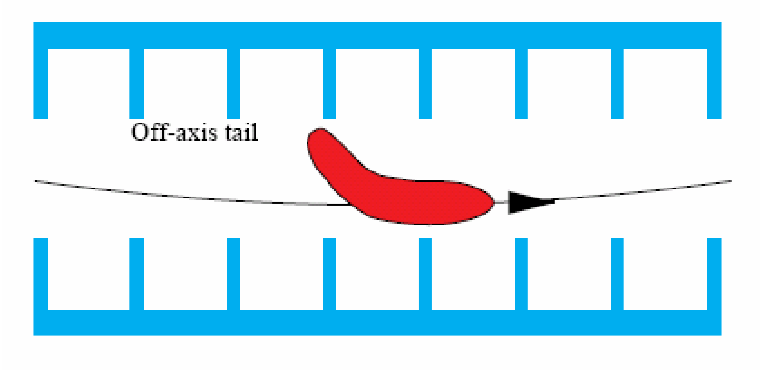
Notation and Definitions

$$\lambda(s) - \text{Gaussian bunch with rms width } \sigma$$

$$k_\perp = \langle W \rangle = \int W(s)\lambda(s)ds - \text{kick factor}$$

$$k_\perp^{\text{rms}} = \left\langle (W - k_\perp)^2 \right\rangle^{0.5} = \left[\int \left(W(s) - k_\perp \right)^2 \lambda(s)ds \right]^{0.5} - \text{rms kick factor}$$

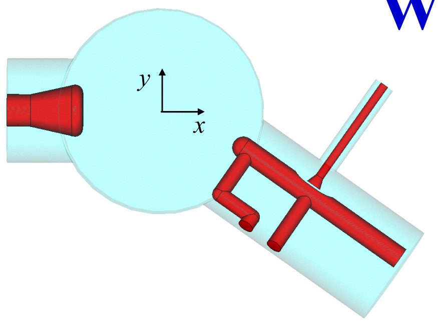
It gives an estimation for the head-tail difference in the kick (banana shape)



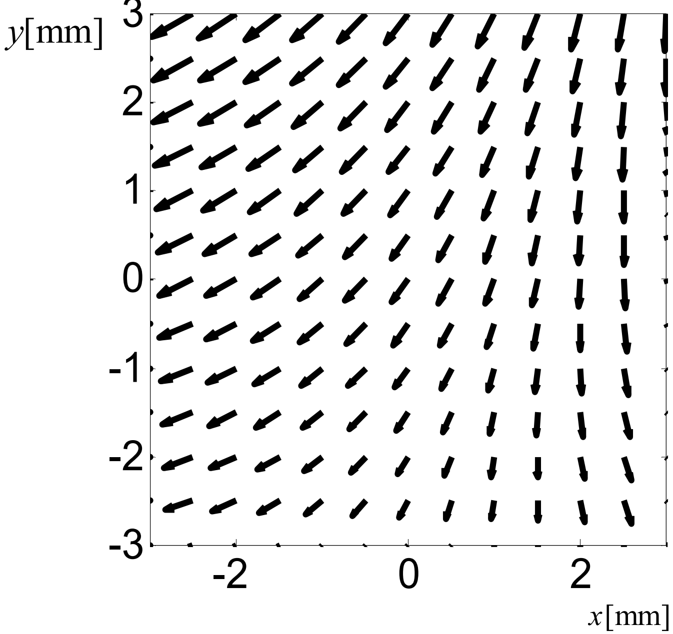
The picture from
R. Wanzenberg,
Review of beam dynamics …,
Linac Conference, 1996

Wake kick near to the axis

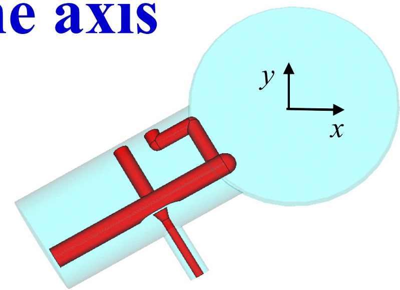
downstream couplers



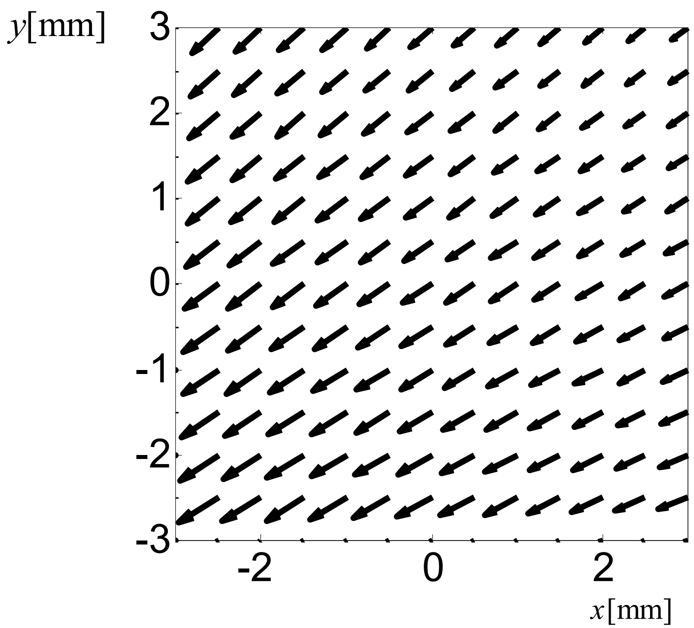
$$\mathbf{k}_{\perp}(x,y)=\begin{pmatrix}-0.0069\\-0.0094\end{pmatrix}+\begin{pmatrix}3.2 & -1.1\\-1.1 & -1.0\end{pmatrix}\begin{pmatrix}x[\mathrm{m}]\\y[\mathrm{m}]\end{pmatrix}\left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$



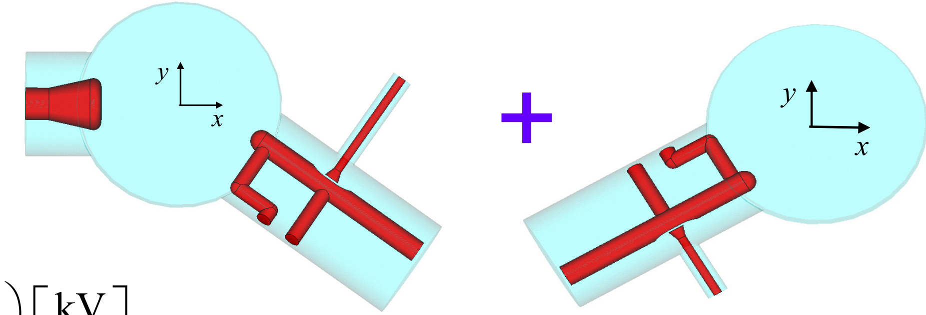
upstream coupler



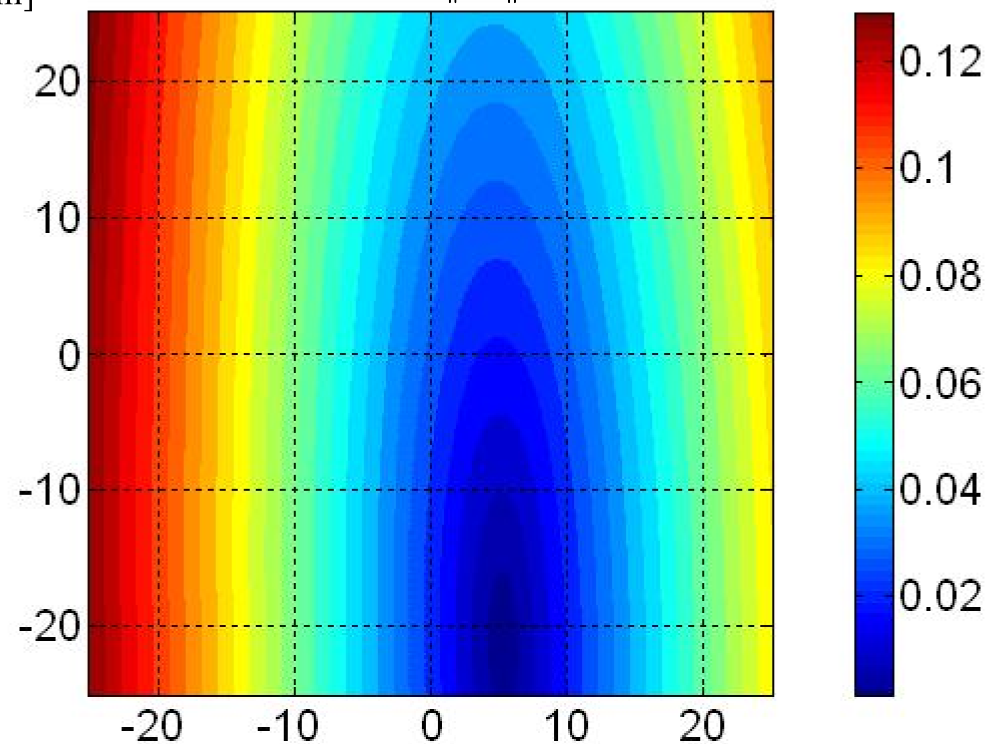
$$\mathbf{k}_{\perp}(x,y)=\begin{pmatrix}-0.0142\\-0.0095\end{pmatrix}+\begin{pmatrix}1.02 & 1.15\\1.15 & 0.07\end{pmatrix}\begin{pmatrix}x[\mathrm{m}]\\y[\mathrm{m}]\end{pmatrix}\left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$



Wake kick near to the axis



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



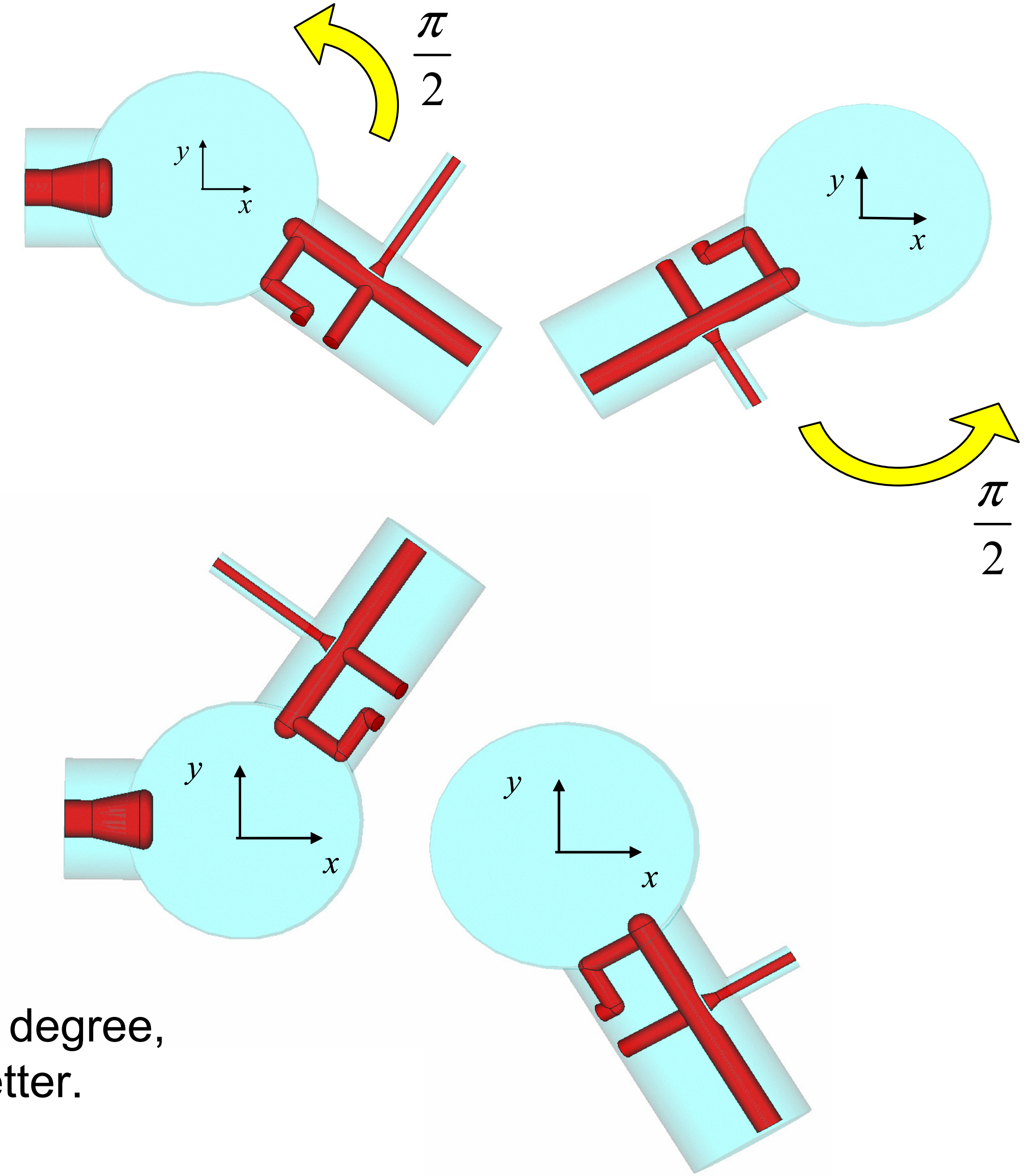
$$\mathbf{r_c}=\begin{pmatrix}5.3\\-21.3\end{pmatrix}\mathrm{mm}$$

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

How to compensate the wake kick on the axis?

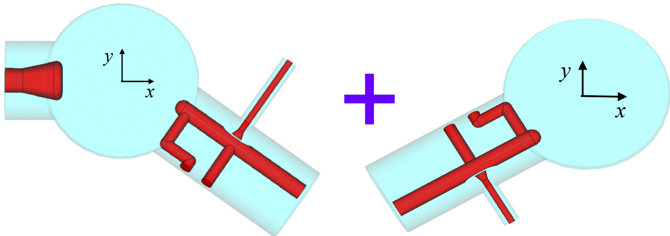
old

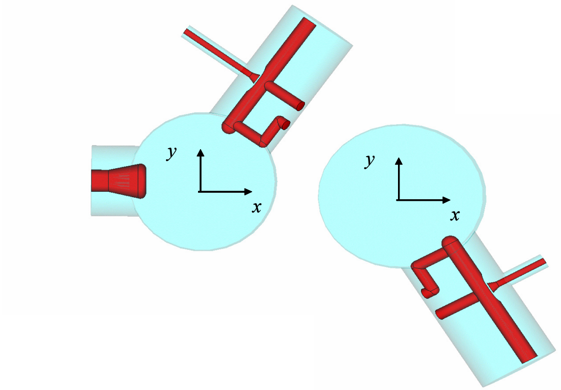
new



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

Wake kick for the new orientation

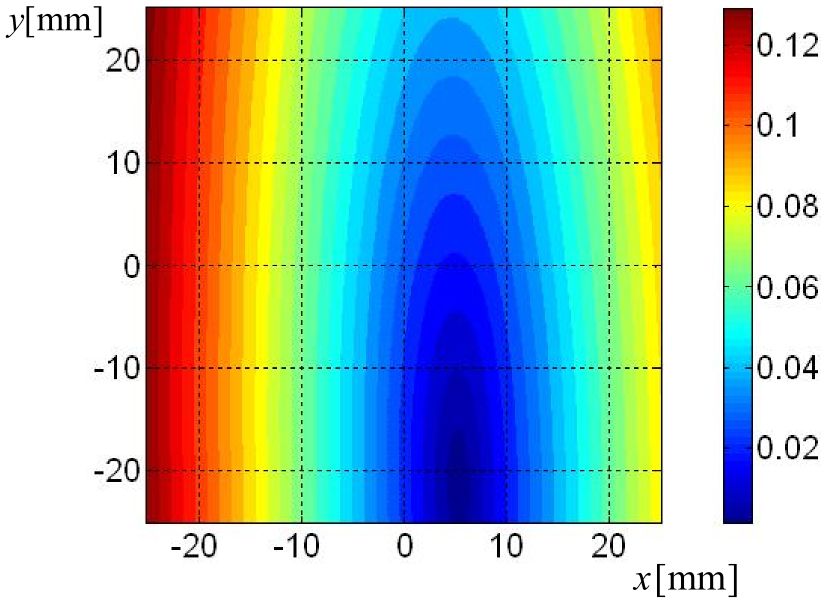




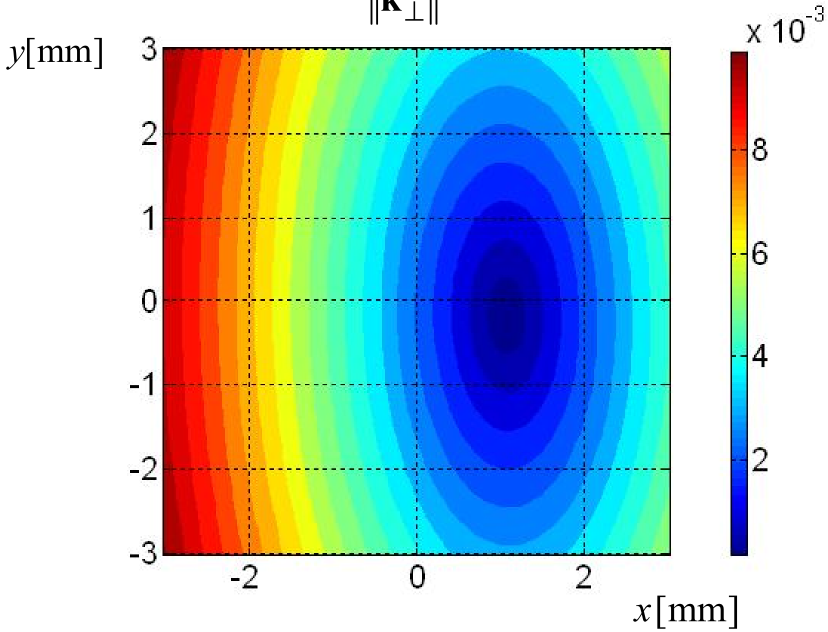
$$\mathbf{k}_{\perp}(x,y)=\begin{pmatrix}-0.021\\-0.019\end{pmatrix}+\begin{pmatrix}4.3 & 0.07\\0.03 & -0.9\end{pmatrix}\begin{pmatrix}x[\mathrm{m}]\\y[\mathrm{m}]\end{pmatrix}\left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$

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

$\|\mathbf{k}_{\perp}\|$



$\|\mathbf{k}_{\perp}\|$

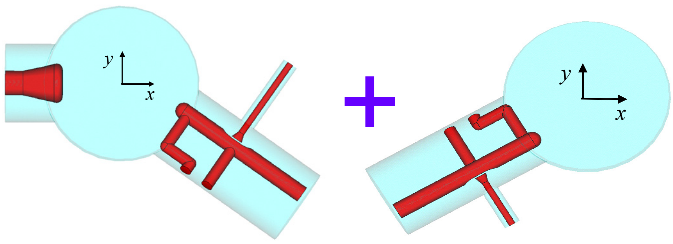


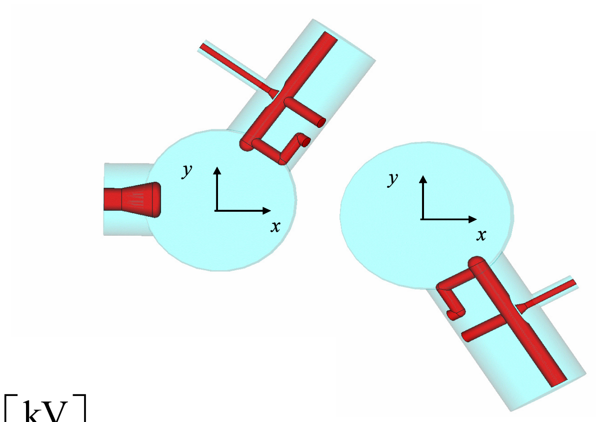
$$\mathbf{r_c}=\begin{pmatrix}5.3\\-21.3\end{pmatrix}\mathrm{mm} \quad\Longrightarrow\quad \mathbf{r_c}=\begin{pmatrix}1.1\\-0.2\end{pmatrix}\mathrm{mm}$$

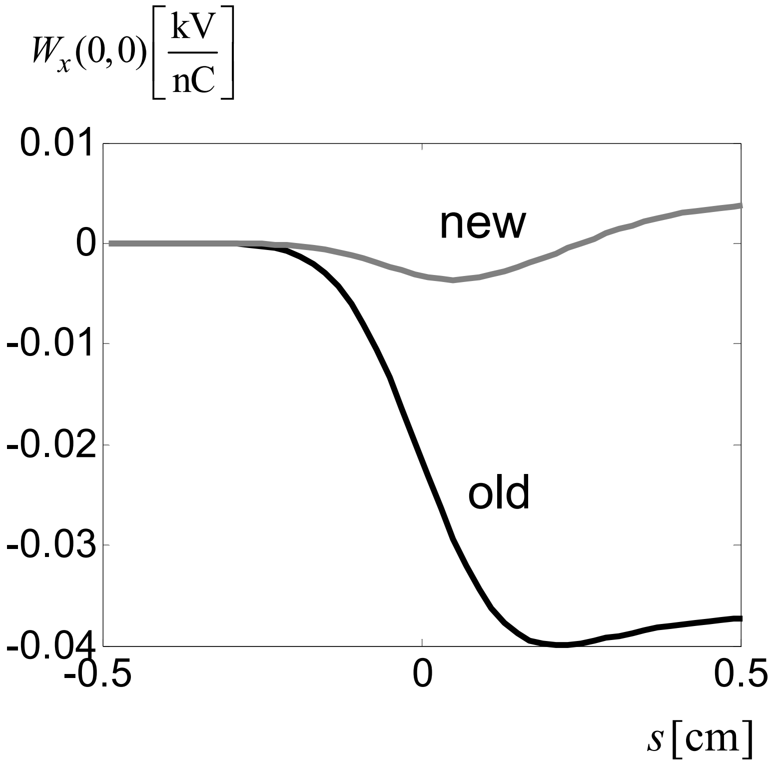
$$\|\mathbf{k}_{\perp}\|_{\min}=5e-5\frac{\mathrm{kV}}{\mathrm{nC}}$$

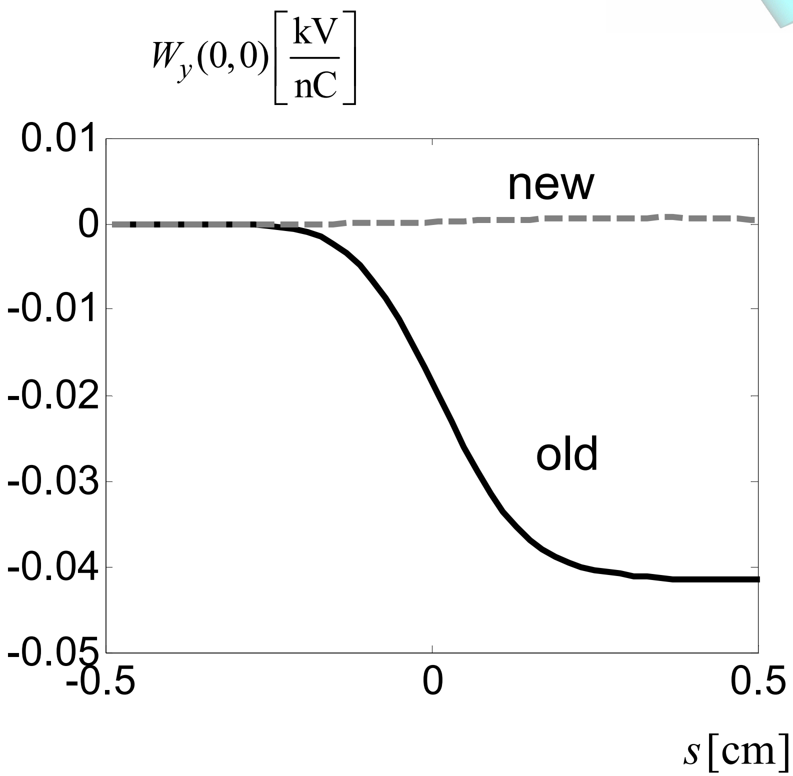
$$\|\mathbf{k}_{\perp}\|_{\min}=8e-5\frac{\mathrm{kV}}{\mathrm{nC}}$$

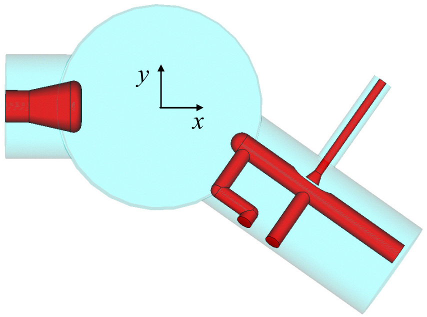
Wake kick for the new orientation





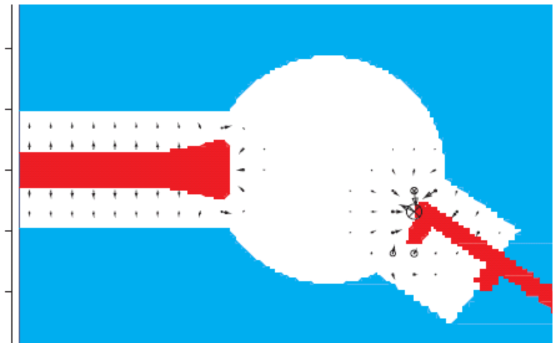


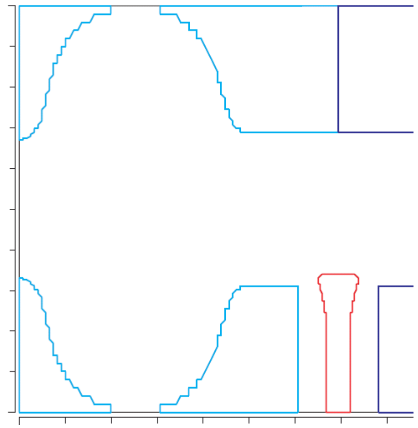




RF kick

downstream coupler,
new, zpen/mm=6, forward
x/mm =… y/mm=…





$10^3 \cdot xoff = 0 \qquad 10^3 \cdot yoff = 2$

$$\frac{Vx}{10^{-6}} = -18.925 + 51.83i$$

$$\frac{Vy}{10^{-6}} = 39.418 + 8.879i$$

$10^3 \cdot xoff = -2 \qquad 10^3 \cdot yoff = 0$

$$\frac{Vx}{10^{-6}} = -16.597 + 56.049i$$

$$\frac{Vy}{10^{-6}} = 27.217 + 4.356i$$

$10^3 \cdot xoff = 0 \qquad 10^3 \cdot yoff = 0$

$$\frac{Vx}{10^{-6}} = -25.01 + 51.529i$$

$$\frac{Vy}{10^{-6}} = 32.166 + 5.242i$$

$10^3 \cdot xoff = 2 \qquad 10^3 \cdot yoff = 0$

$$\frac{Vx}{10^{-6}} = -32.552 + 47.906i$$

$$\frac{Vy}{10^{-6}} = 38.866 + 6.337i$$

$10^3 \cdot xoff = 0 \qquad 10^3 \cdot yoff = -2$

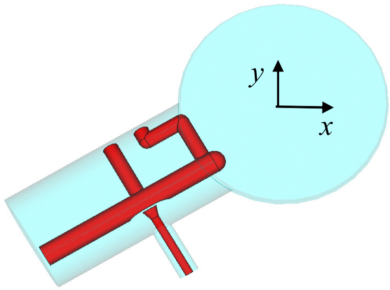
$$\frac{Vx}{10^{-6}} = -30.627 + 50.36i$$

$$\frac{Vy}{10^{-6}} = 24.394 + 1.725i$$

RF kick

upstream coupler

x/mm =…   y/mm=…



$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = 2$

$\frac{Vx}{10^{-6}} = -50.479 + 6.799i$

$\frac{Vy}{10^{-6}} = -42.924 - 2.275i$

$10^3 \cdot xoff = -2 \quad 10^3 \cdot yoff = 0$

$\frac{Vx}{10^{-6}} = -59.102 + 8.202i$

$\frac{Vy}{10^{-6}} = -48.701 - 3.873i$

$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = 0$

$\frac{Vx}{10^{-6}} = -57.112 + 6.649i$

$\frac{Vy}{10^{-6}} = -41.413 - 3.469i$

$10^3 \cdot xoff = 2 \quad 10^3 \cdot yoff = 0$

$\frac{Vx}{10^{-6}} = -54.754 + 5.382i$

$\frac{Vy}{10^{-6}} = -35.112 - 3.051i$

$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = -2$

$\frac{Vx}{10^{-6}} = -64.117 + 6.215i$

$\frac{Vy}{10^{-6}} = -38.919 - 4.676i$

TESLA Cavity in Cryomodule

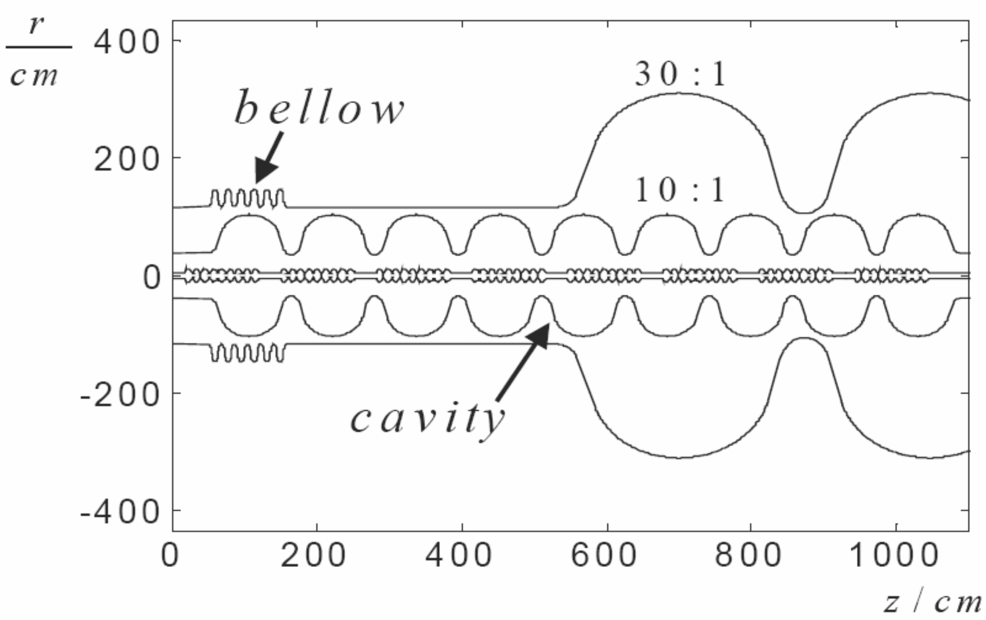


Fig1. Geometry of the TESLA cryomodule.

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**.

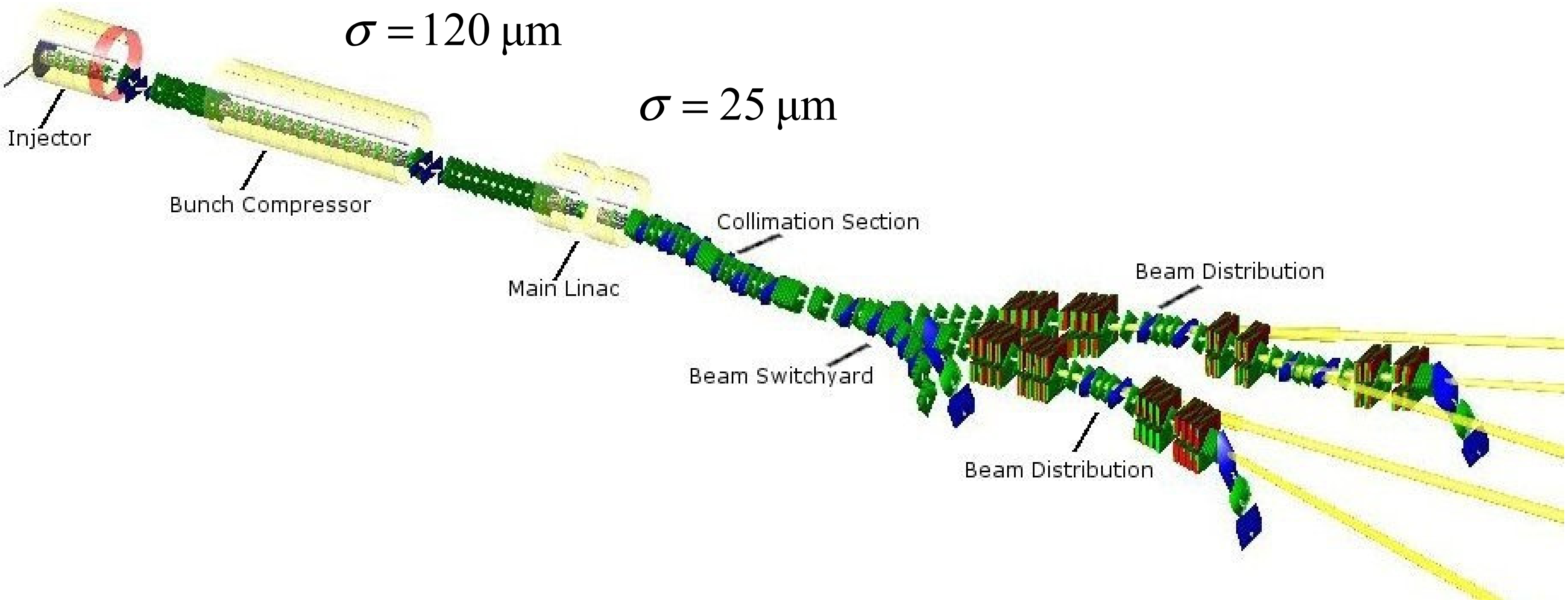
European XFEL Project

http://www.desy.de/xfel-beam/index.html

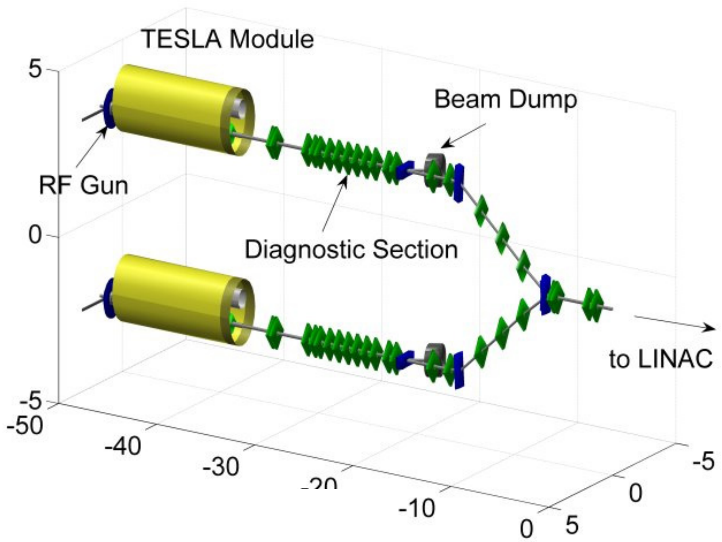
$\sigma = 2400\ \mu\text{m}$

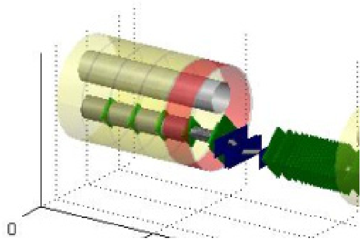
$\sigma = 120\ \mu\text{m}$

$\sigma = 25\ \mu\text{m}$



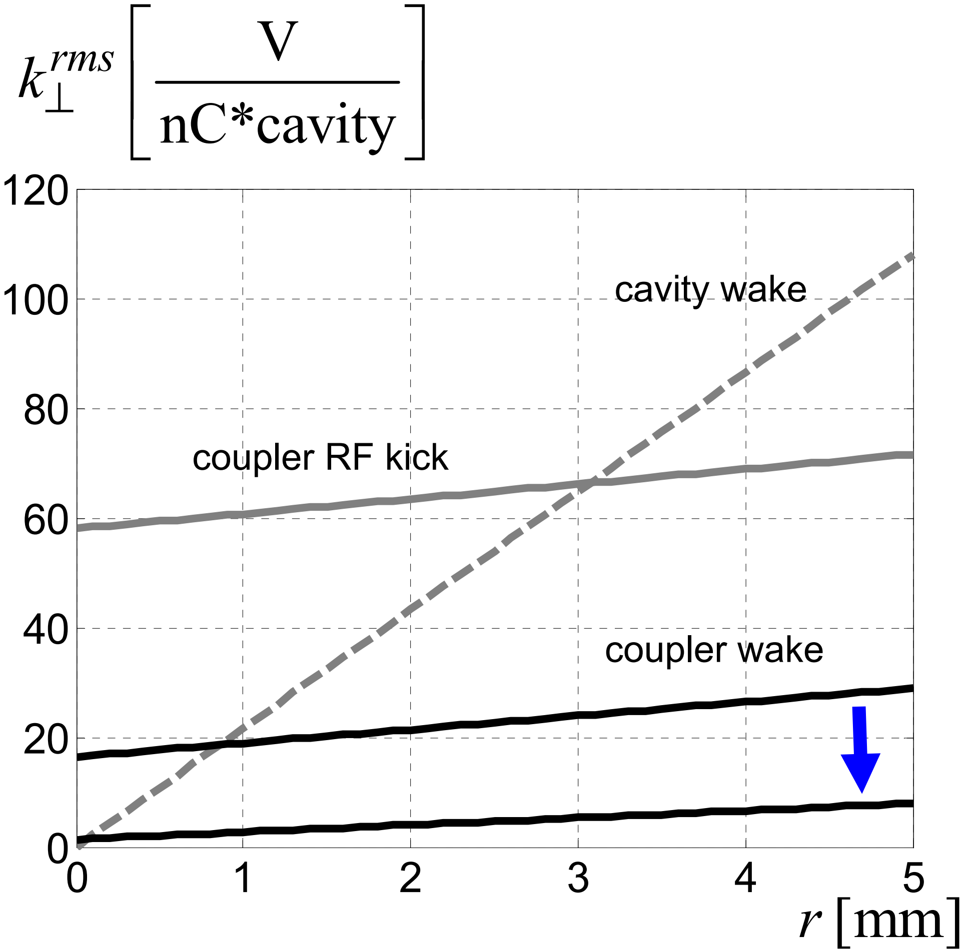
Injector





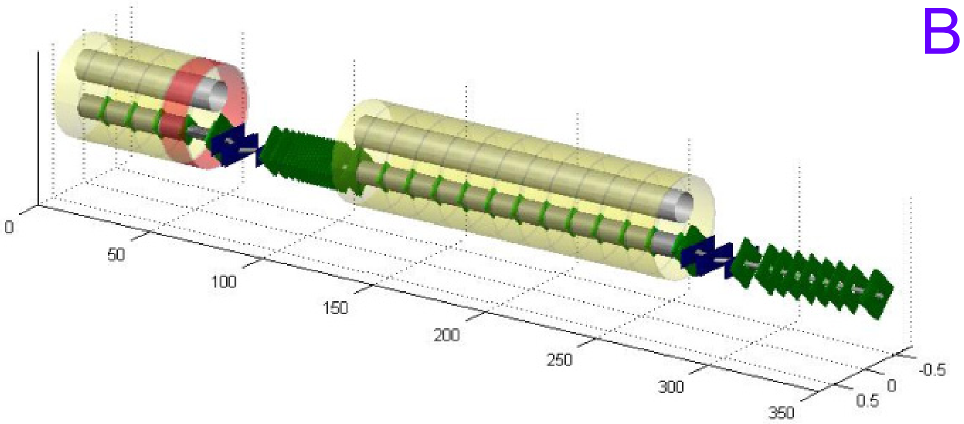
$\sigma = 2400\ \mu\text{m}$

5*8=40 couplers



Coupler RF kick is the most important. It can be reduced by alternative direction orientation of couplers.

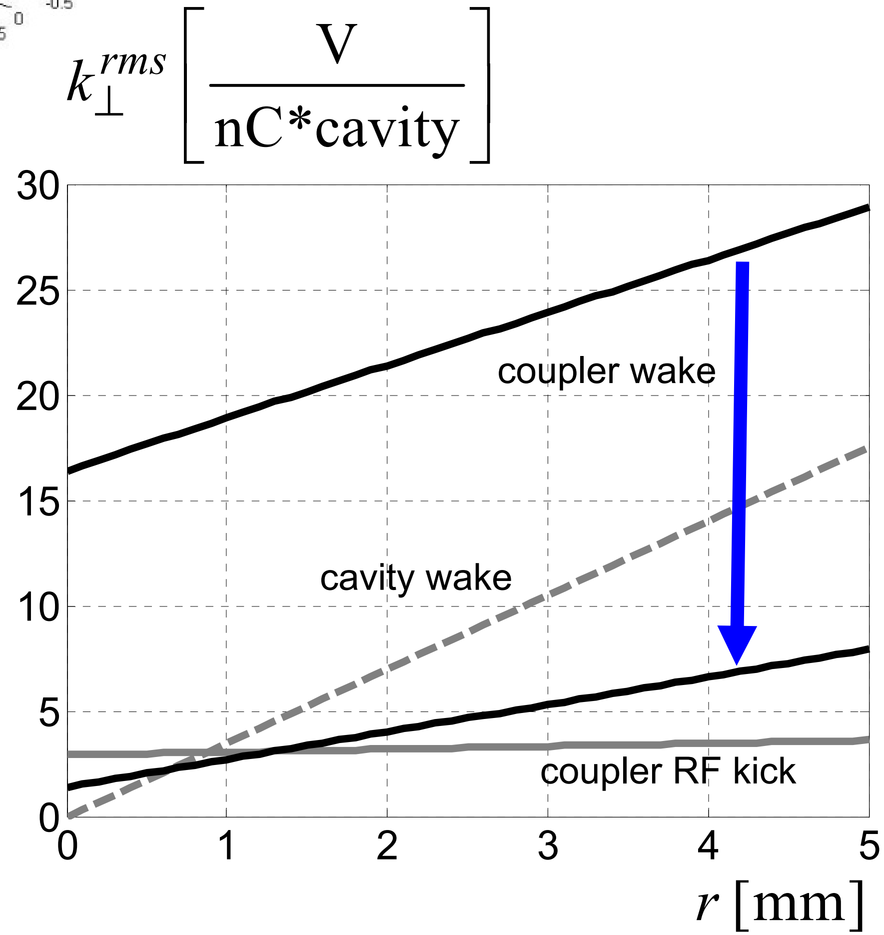
Bunch Compressor



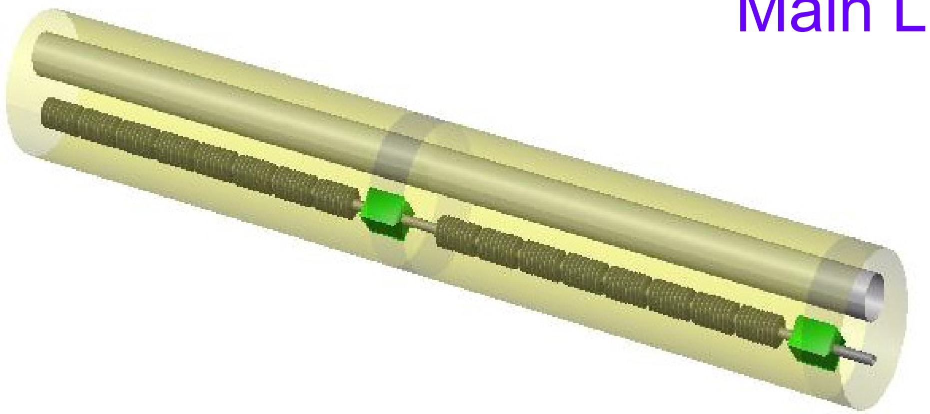
$\sigma = 120\ \mu\text{m}$

12*8=96 couplers

Coupler wake is the most important. It can be reduced with the new orientation of HOM couplers.



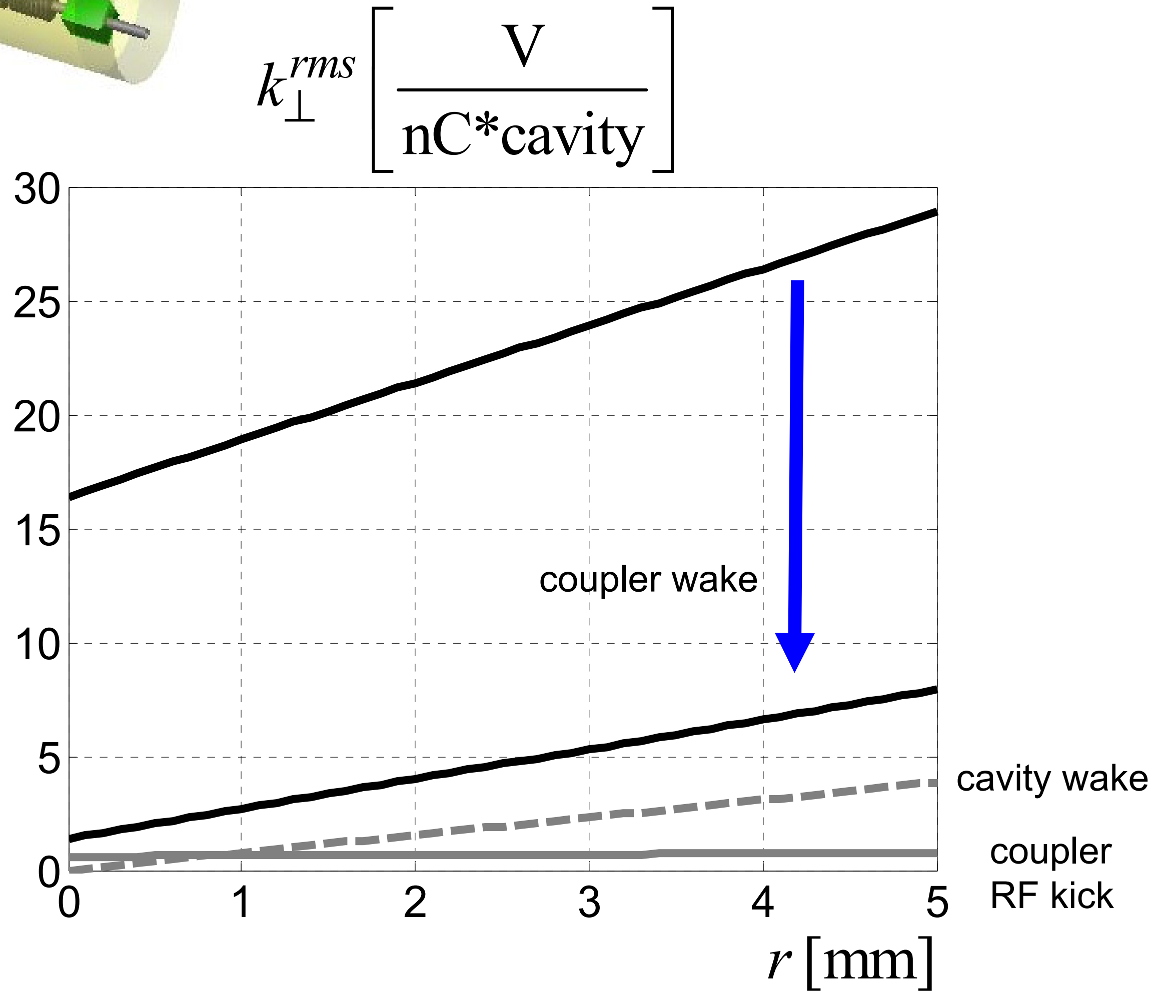
Main Linac



$\sigma = 25\ \mu\text{m}$

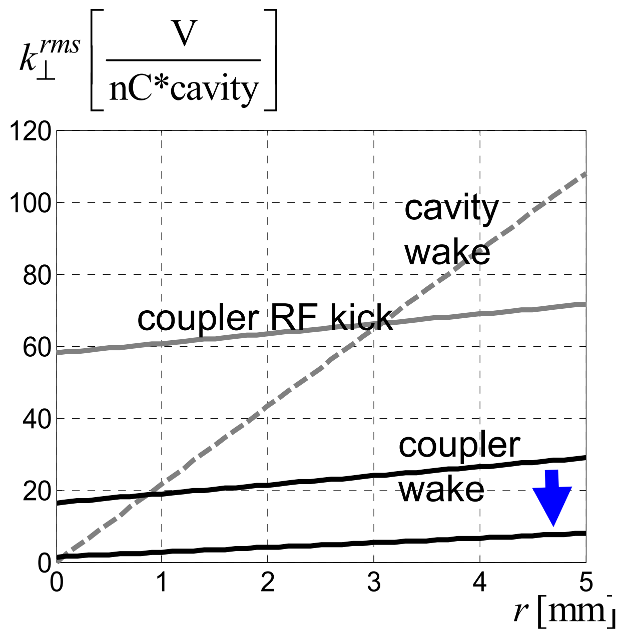
100*8=800 couplers

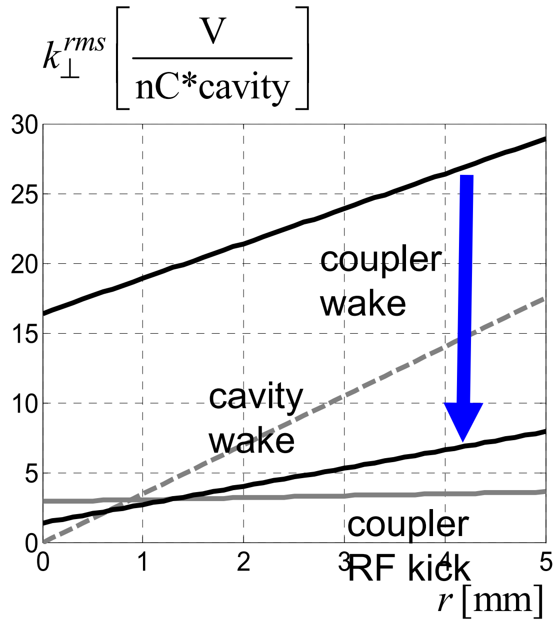
Coupler wake is the most important. It can be reduced w the new orientation of HOM couplers.

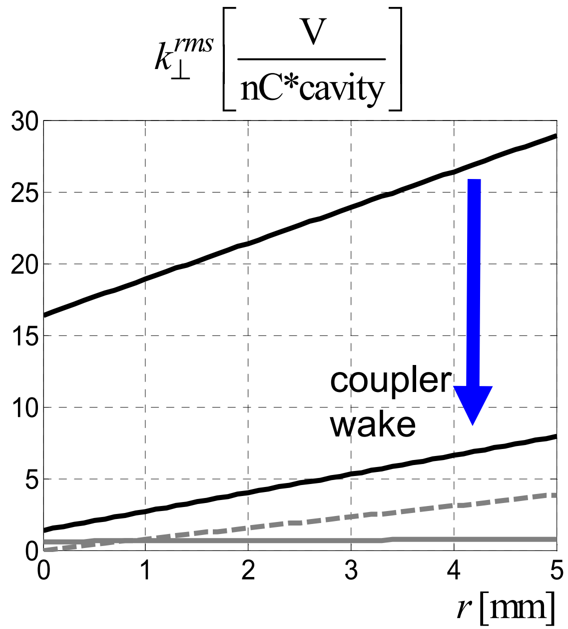


Effect of new HOM couplers orientation

$\sigma = 2400\ \mu m$ | $\sigma = 120\ \mu m$ | $\sigma = 25\ \mu m$







Injector

Coupler RF kick is the most important. It can be reduced by alternative direction orientation of couplers.

Bunch Compressor

Main Linac

Coupler wake kick is the most important. It can be reduced with the new orientation of HOM couplers.

Head-Tail Kick (rms kick)

$$k_{\perp}^{rms} \approx k_{\perp}^{0,rms} + k_{\perp}^{1,rms} r$$

$$k_{\perp}^{0,rms} \left[\frac{V}{nC * cavity} \right]$$

RMS bunch length,µm	Coupler wake	Coupler RF field	Cavity tilt by 1 mrad (on crest / 10 grad)	Cavity wake
2400	Design= 16.4 New=1.4	58	23 / 88	0
120		2.9	0.06 / 4	
25		0.6	0.002 / 0.9	

$$k_{\perp}^{1,rms} \left[\frac{V}{nC * mm * cavity} \right]$$

RMS bunch length, µm	Coupler wake	Coupler RF field	Cavity wake
2400	Design= 2.5 New= 1.3	2.7	21.6
120		0.14	3.5
25		0.03	0.77

Head-Tail Kick (rms kick)

1. Transverse Coupler Wake is capacitive (integral from bunch shape)

$$\mathbf{k}_\perp \approx \mathbf{k}_\perp^0 + \mathbf{k}_\perp^1 \mathbf{r} \qquad k_\perp^{0,rms} \approx \frac{1}{\sqrt{3}}\left\|\mathbf{k}_\perp^0\right\| \qquad k_\perp^{1,rms} \approx \frac{1}{\sqrt{3}}\left\|\mathbf{k}_\perp^1\right\|$$

2. RF Coupler Kick (on crest)

$$V_x(s) = \mathrm{Re}(Vx \cdot V_z \cdot e^{-iks}) \qquad V_z = 15\mathrm{MV} \qquad k = 2\pi \frac{1.3\,\mathrm{GHz}}{c}$$

$$k_\perp^{0,rms} \approx \mathrm{Im}(Vx) \cdot k \cdot \sigma$$

3. Cavity tilt by angle α

$$V(s) = \mathrm{Re}(0.5\alpha V_z \cdot e^{-i(ks-\varphi_0)})$$

$$k_\perp^{0,rms} \approx \left(\int \left[\mathrm{Re}\, V(s) - \left\langle \mathrm{Re}\, V(s) \right\rangle \right]^2 \lambda(s) ds \right)^{1/2}$$

Conclusion

➢Coupler RF kick is a main effect in the injector. It can be compensated by an alternative direction orientation of couplers.

➢Coupler wake kick is a main effect after the 1st bunch compressor. Rotation of the HOM couplers by 90 degree allows to reduce the kick by factor 12.