# Coupler Kick

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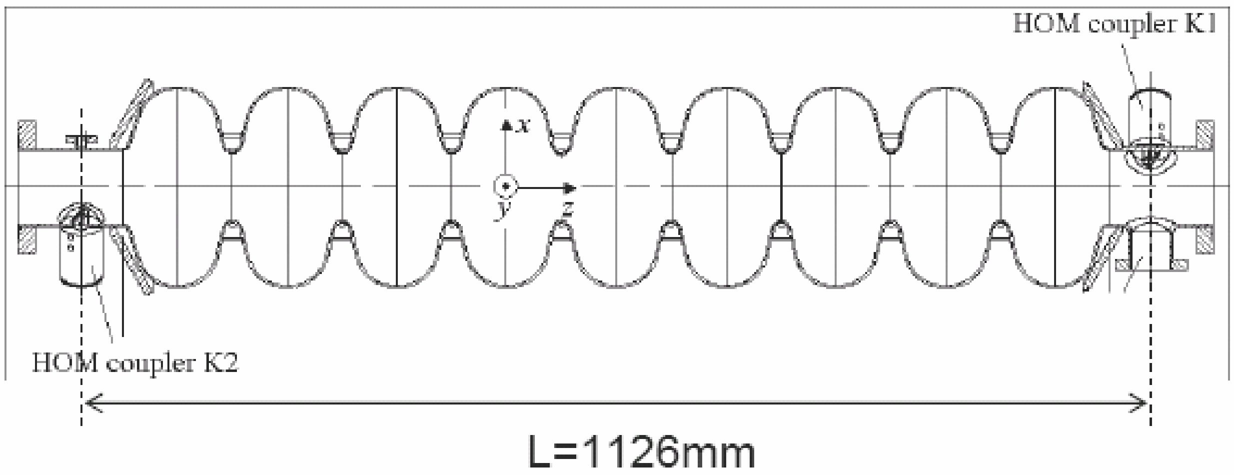
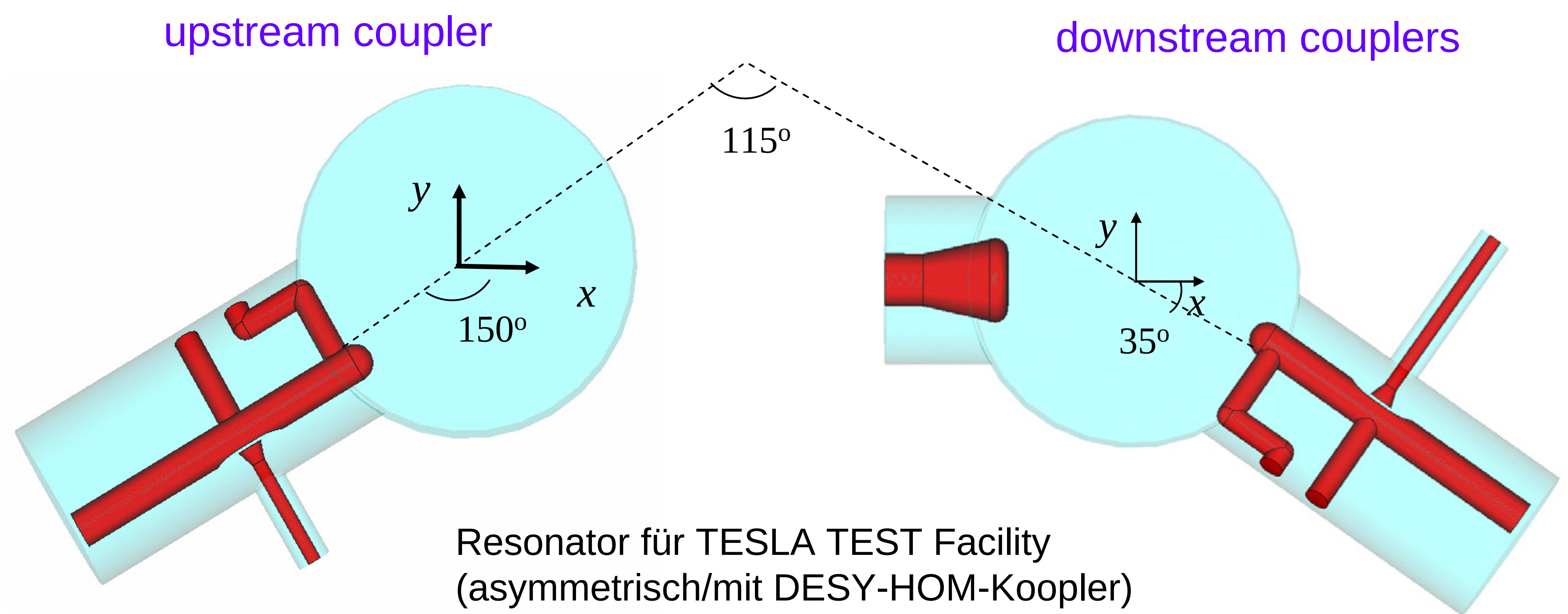
ILC Workshop, DESY

31 May, 2007




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

# Outlook

- Coupler kick due to short-range wakefield (**coupler wake**)
- Coupler kick due to asymmerty  of the external RF field (**coupler RF kick**)
- Comparison to the kick of the TESLA cavity (**cavity wake**)

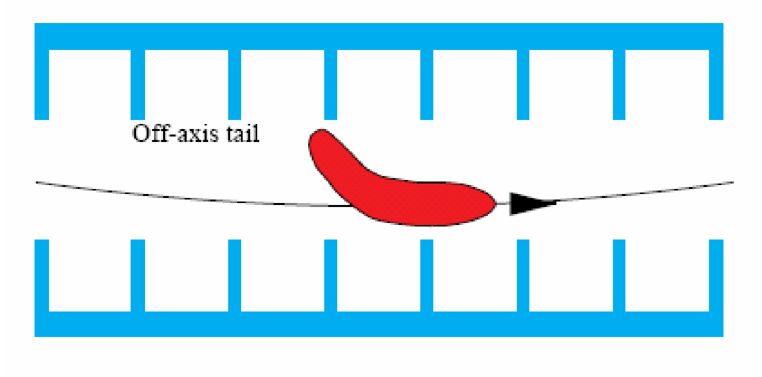
# Notation and Definitions

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

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

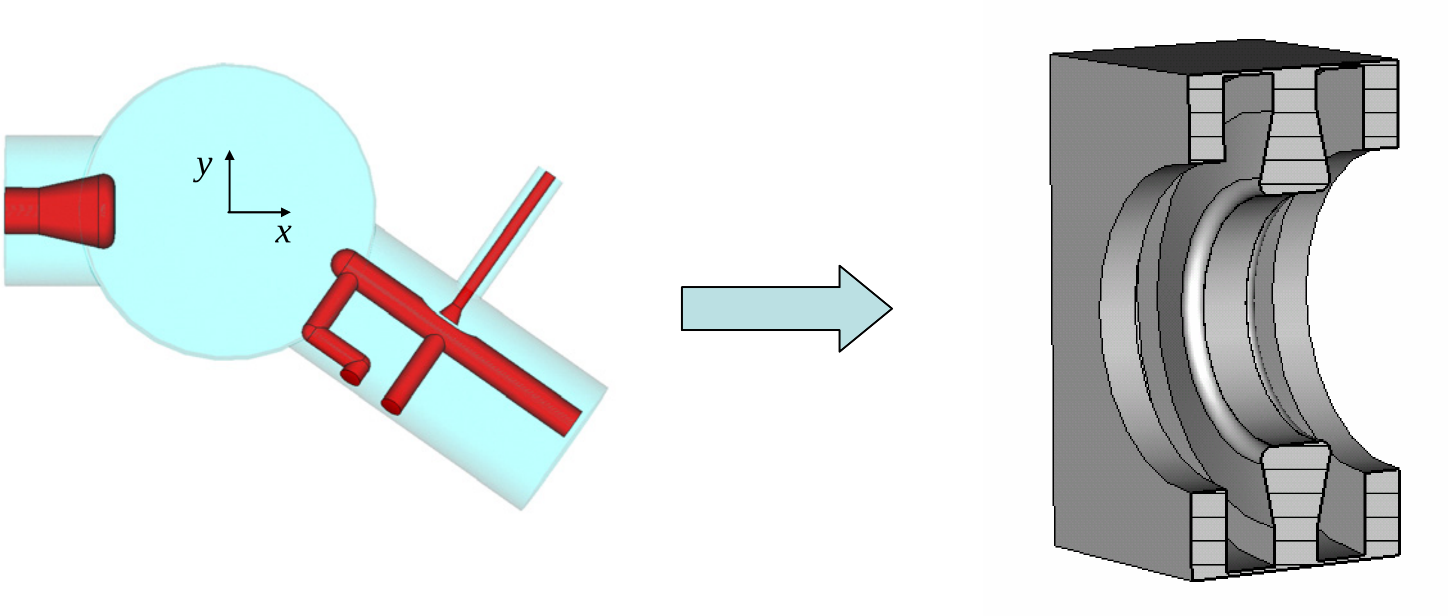
$$k_\perp^{\text{rms}} = \left\langle (W - k_\perp)^2 \right\rangle^{0.5} = \left[ \int \left( W(s) - k_\perp \right)^2 \lambda(s) ds \right]^{0.5} - \text{rms kick factor}$$

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

# Accuracy estimation / code benchmarking

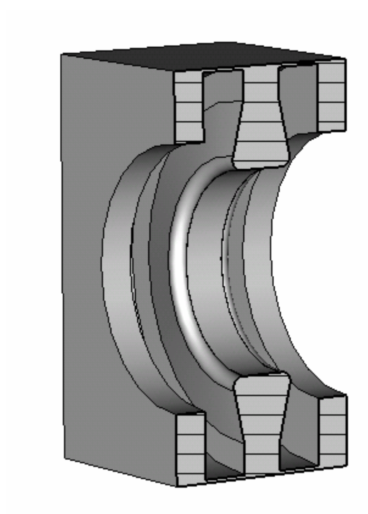


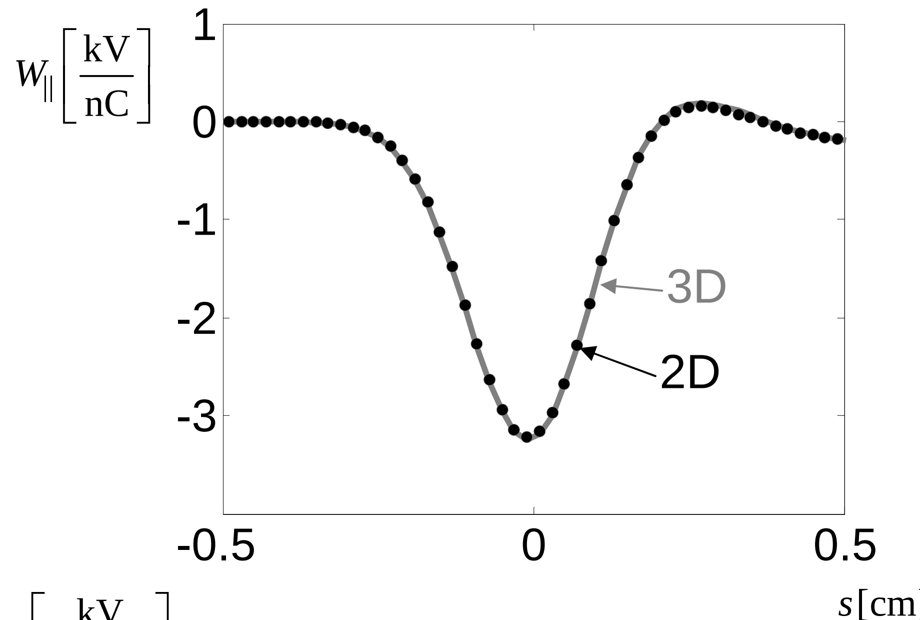

1. Zagorodnov I, Weiland T., *TE/TM Field Solver for Particle Beam Simulations without Numerical Cherenkov Radiation*// Physical Review – STAB,8, **2005**.

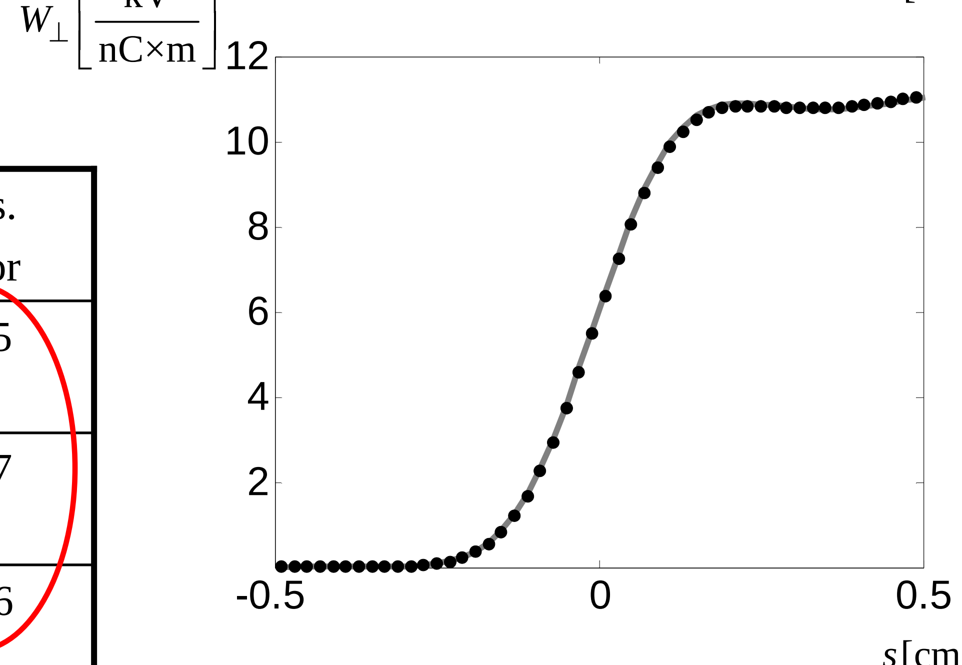
2. Zagorodnov I., *Indirect Methods for Wake Potential Integration* // Physical Review -STAB, 9, **2006.**

3. Bane K.L.F, Stupakov G., Zagorodnov I., *Impedance Calculations of Non-Axisymmetric Transitions Using the Optical Approximation*// Physical Review - STAB, submitted

# Accuracy estimation





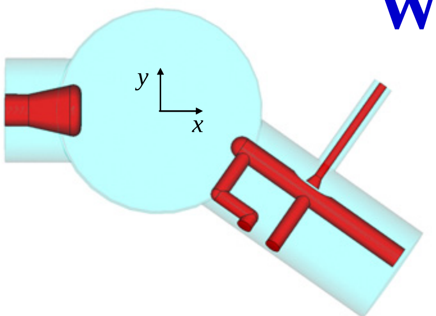

Gaussian bunch with $\sigma = 1\text{mm}$

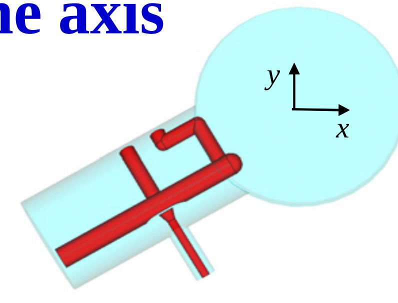
| | 2D, σ/h=5 | 2D, σ/h=10 | 3D, σ/h=5 | Abs. error |
|---|---|---|---|---|
| $k_{\|}$, kV/nC | 2.205 | 2.195 | 2.241 | 0.05 |
| $k_{tr}/\|r\|$, kV/nC/m | 5.820 | 5.817 | 5.89 | 0.07 |
| $\|k_{tr}(0)\|$, kV/nC | 0 | 0 | 1e-6 | 1e-6 |

downstream couplers

upstream coupler

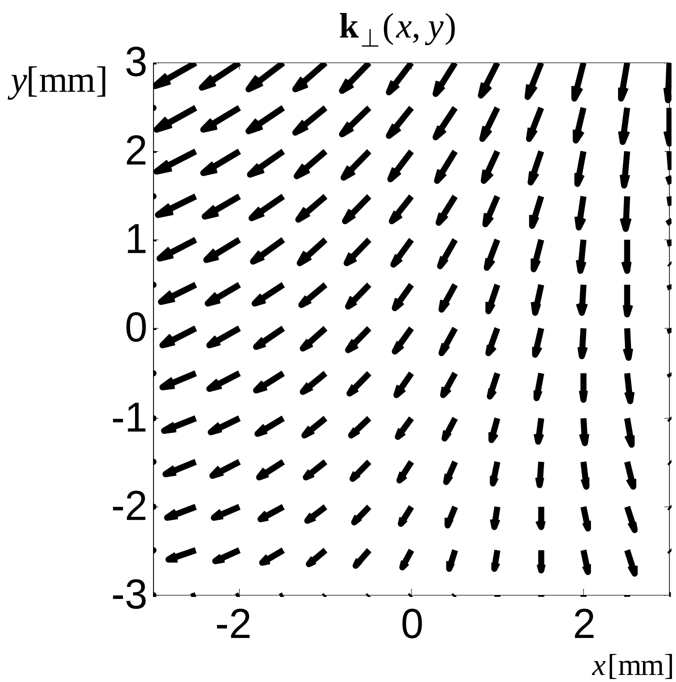
# Wake kick near to the axis

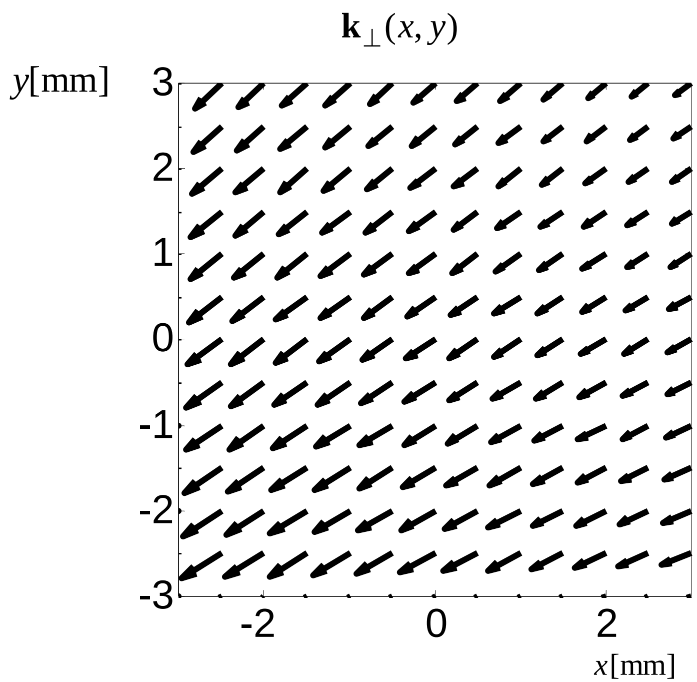


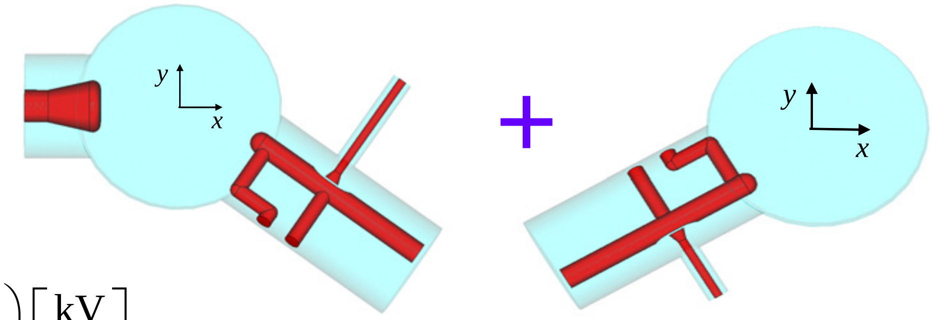

$$\mathbf{k}_\perp(x,y) = \begin{pmatrix} -0.0069 \\ -0.0094 \end{pmatrix} + \begin{pmatrix} 3.2 & -1.1 \\ -1.1 & -1.0 \end{pmatrix} \begin{pmatrix} x[\mathrm{m}] \\ y[\mathrm{m}] \end{pmatrix} \left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$

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

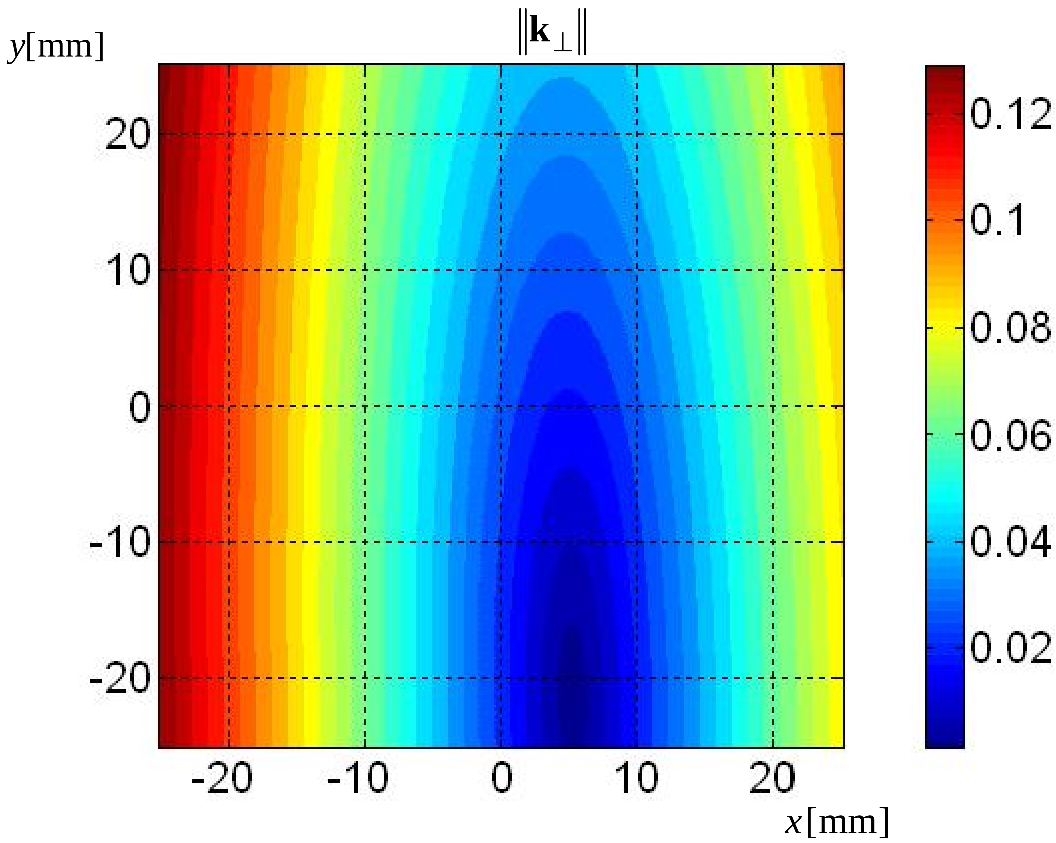


# Wake kick near to the axis




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



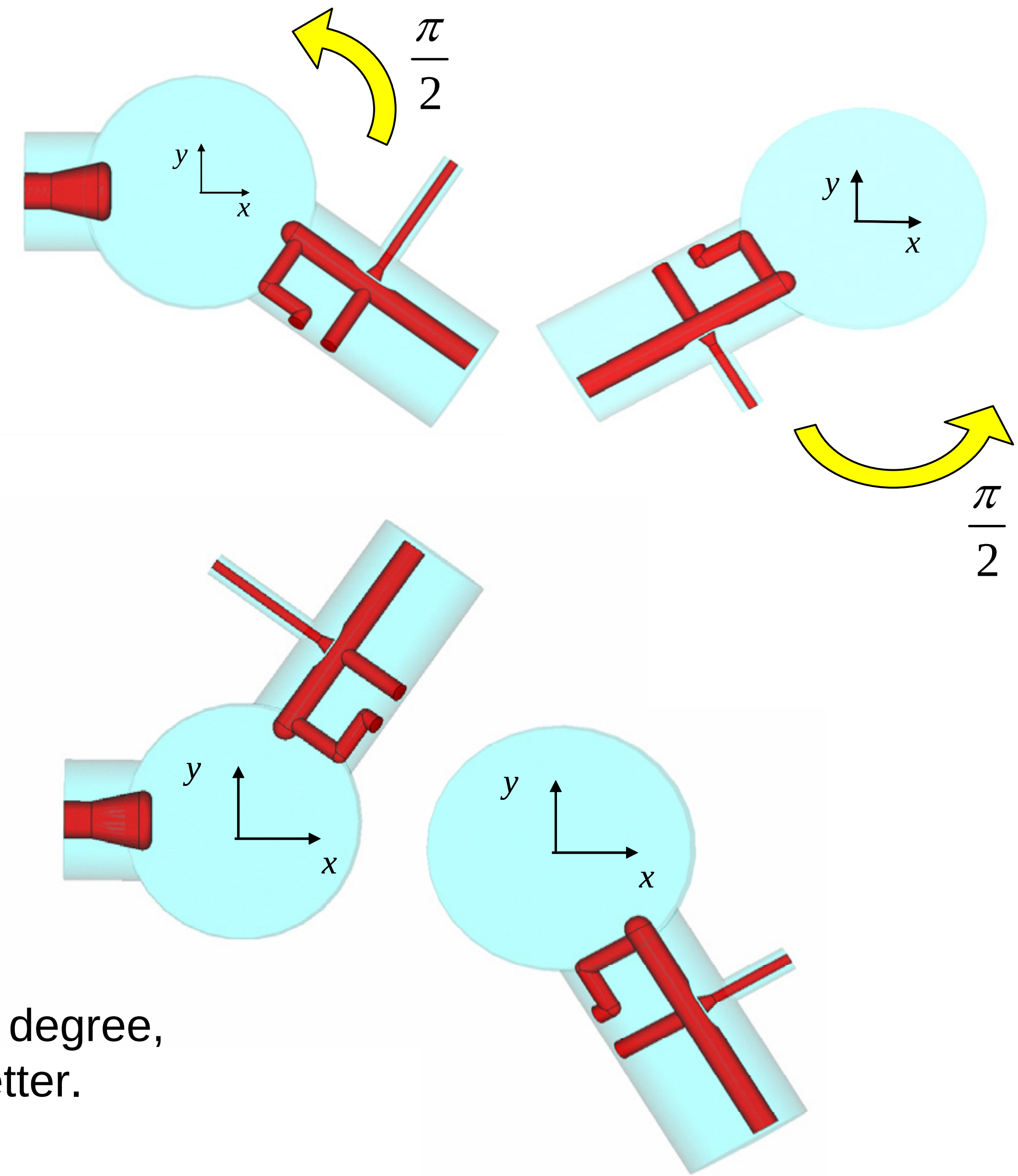

$$\mathbf{r_c} = \begin{pmatrix} 5.3 \\ -21.3 \end{pmatrix} \mathrm{mm}$$

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

# How to compensate the wake kick on the axis?

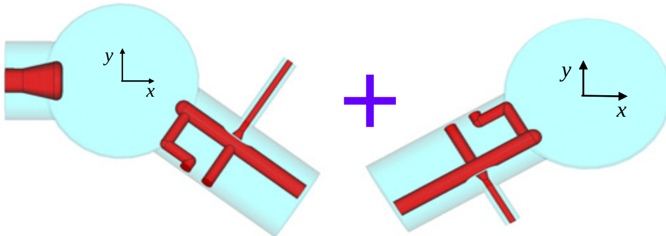
old

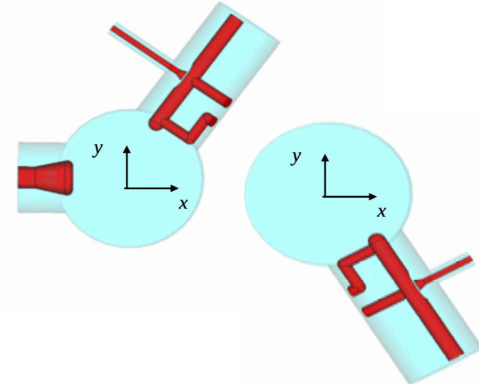
new




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

# Wake kick for the new orientation

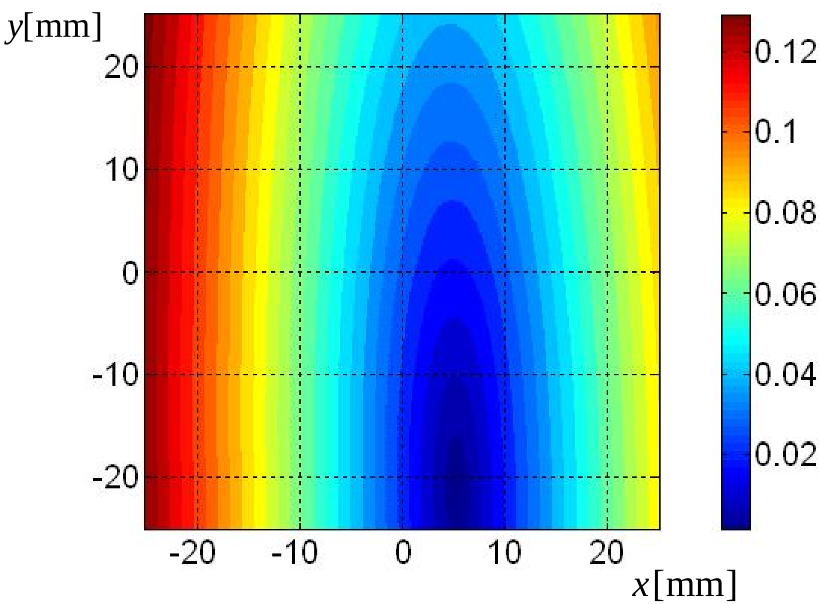


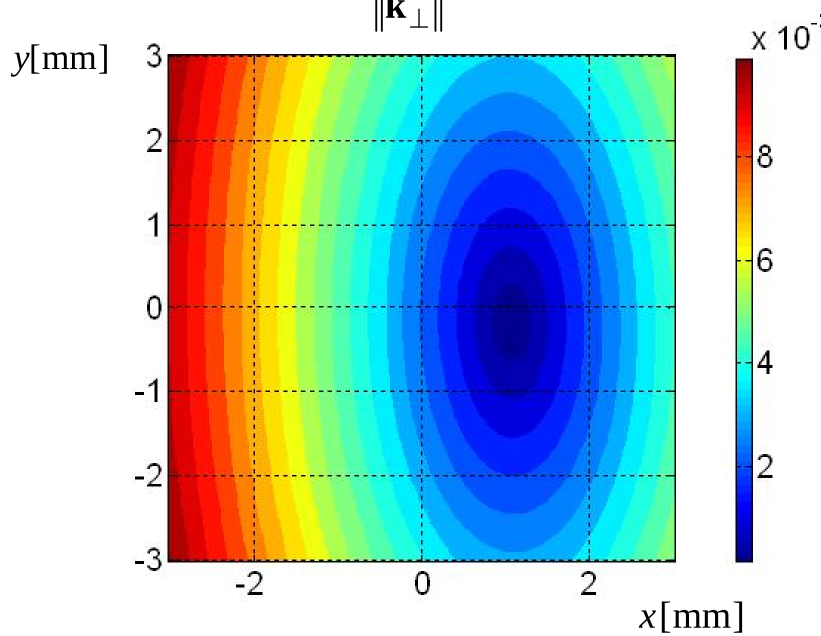

$$\mathbf{k}_{\perp}(x,y)=\begin{pmatrix}-0.021\\-0.019\end{pmatrix}+\begin{pmatrix}4.3 & 0.07\\0.03 & -0.9\end{pmatrix}\begin{pmatrix}x[\mathrm{m}]\\y[\mathrm{m}]\end{pmatrix}\left[\frac{\mathrm{kV}}{\mathrm{nC}}\right]$$

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

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




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

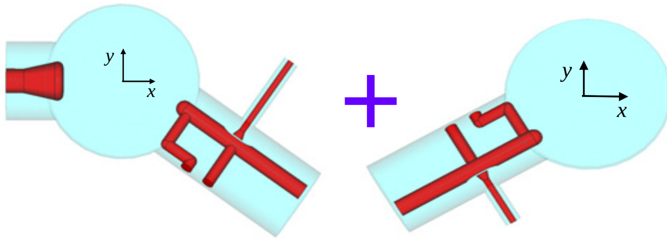


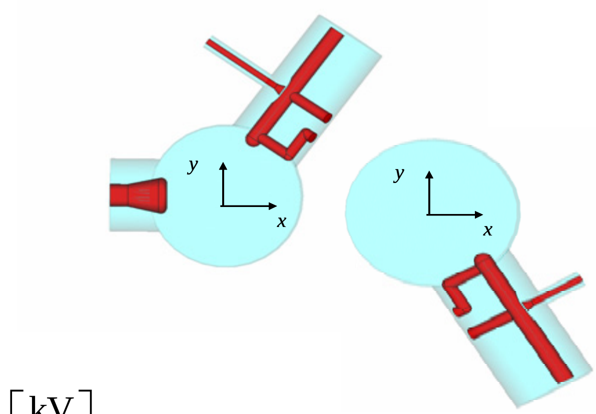

$$\mathbf{r_c}=\begin{pmatrix}5.3\\-21.3\end{pmatrix}\mathrm{mm} \quad\longrightarrow\quad \mathbf{r_c}=\begin{pmatrix}1.1\\-0.2\end{pmatrix}\mathrm{mm}$$

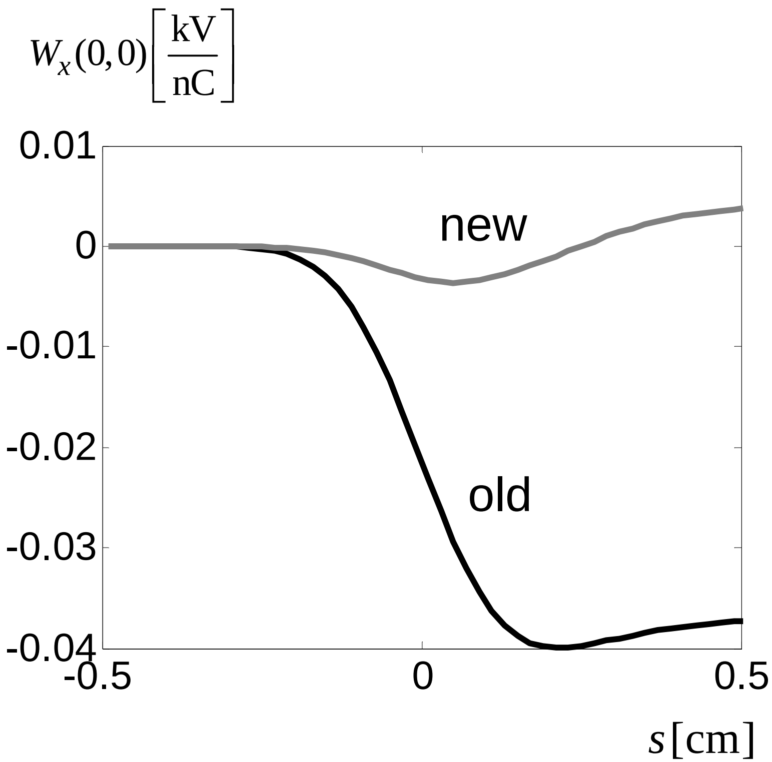
$$\|\mathbf{k}_{\perp}\|_{\min}=5e-5\frac{\mathrm{kV}}{\mathrm{nC}}$$

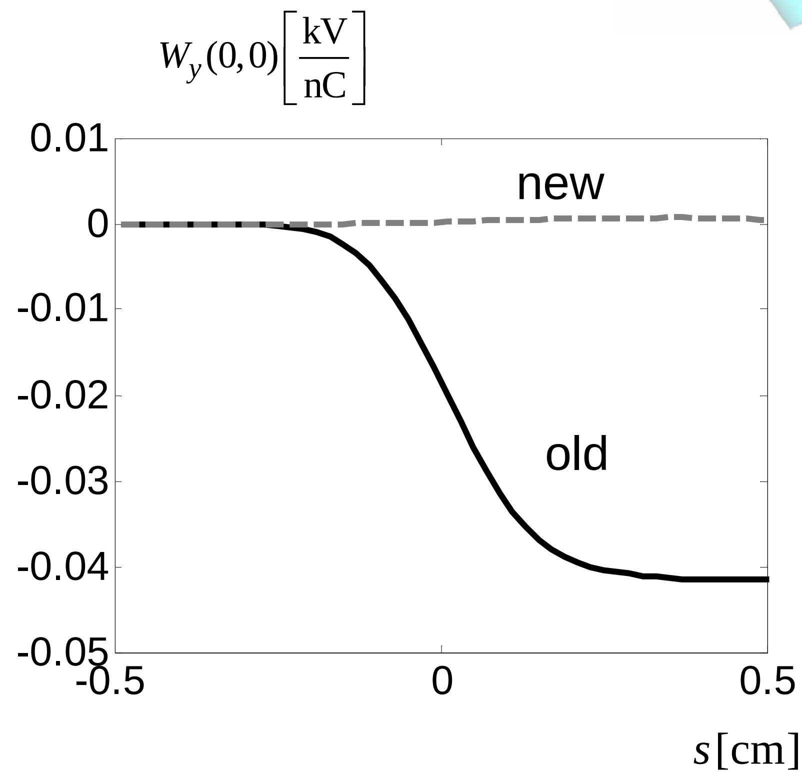
$$\|\mathbf{k}_{\perp}\|_{\min}=8e-5\frac{\mathrm{kV}}{\mathrm{nC}}$$

# Wake kick for the new orientation

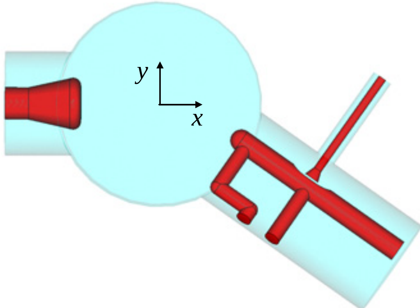


## RF kick



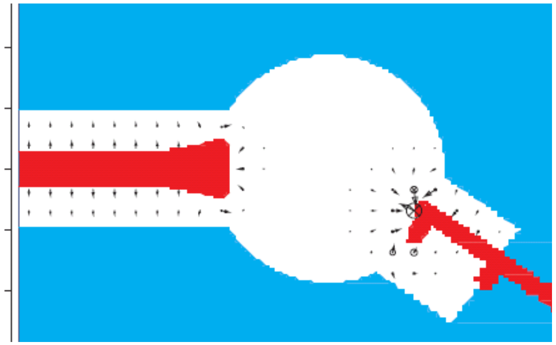

downstream coupler,
new, zpen/mm=6, forward
x/mm =… y/mm=…

$$V_x(s) = \mathrm{Re}(Vx \cdot V_z \cdot e^{-iks})$$

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

$$V_z = 15\,\mathrm{MV}$$

$$k = 2\pi \frac{1.3\,\mathrm{GHz}}{c}$$



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

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

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

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

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

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

$10^3 \cdot \mathrm{xoff} = 0 \qquad 10^3 \cdot \mathrm{yoff} = 0$

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

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

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

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

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

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

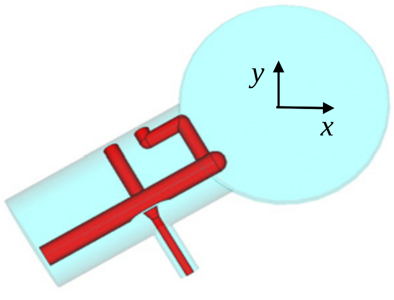
$$\frac{Vx}{10^{-6}} = -30.627 + 50.36i$$

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

M. Dohlus, Field asymmetries & kicks, 2004. http://www.desy.de/~dohlus/2004/2004.09.holgers_seminar/asym&kick_sep2004.pdf

# RF kick

upstream coupler
x/mm =… y/mm=…




M. Dohlus, Field asymmetries & kicks, 2004. http://www.desy.de/~dohlus/2004/2004.09.holgers_seminar/asym&kick_sep2004.pdf

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

# TESLA Cavity in Cryomodule

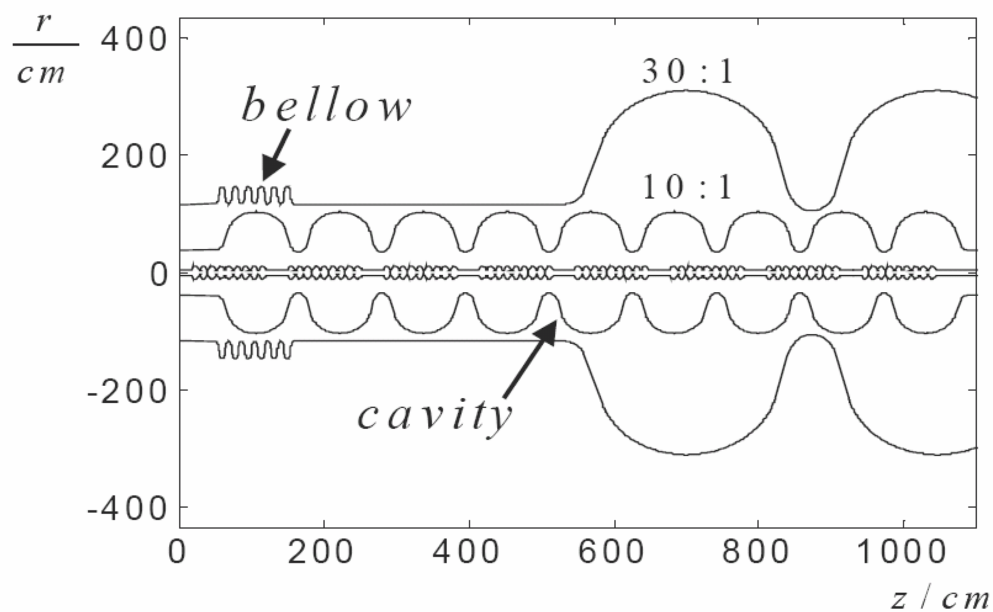



Fig1. Geometry of the TESLA cryomodule.

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.

$$w_{\perp}(s) = 10^{3}\left(1-\left(1+\sqrt{\frac{s}{s_1}}\right)\exp\left(-\sqrt{\frac{s}{s_1}}\right)\right)\left[\frac{V}{pC\cdot m\cdot module}\right]$$

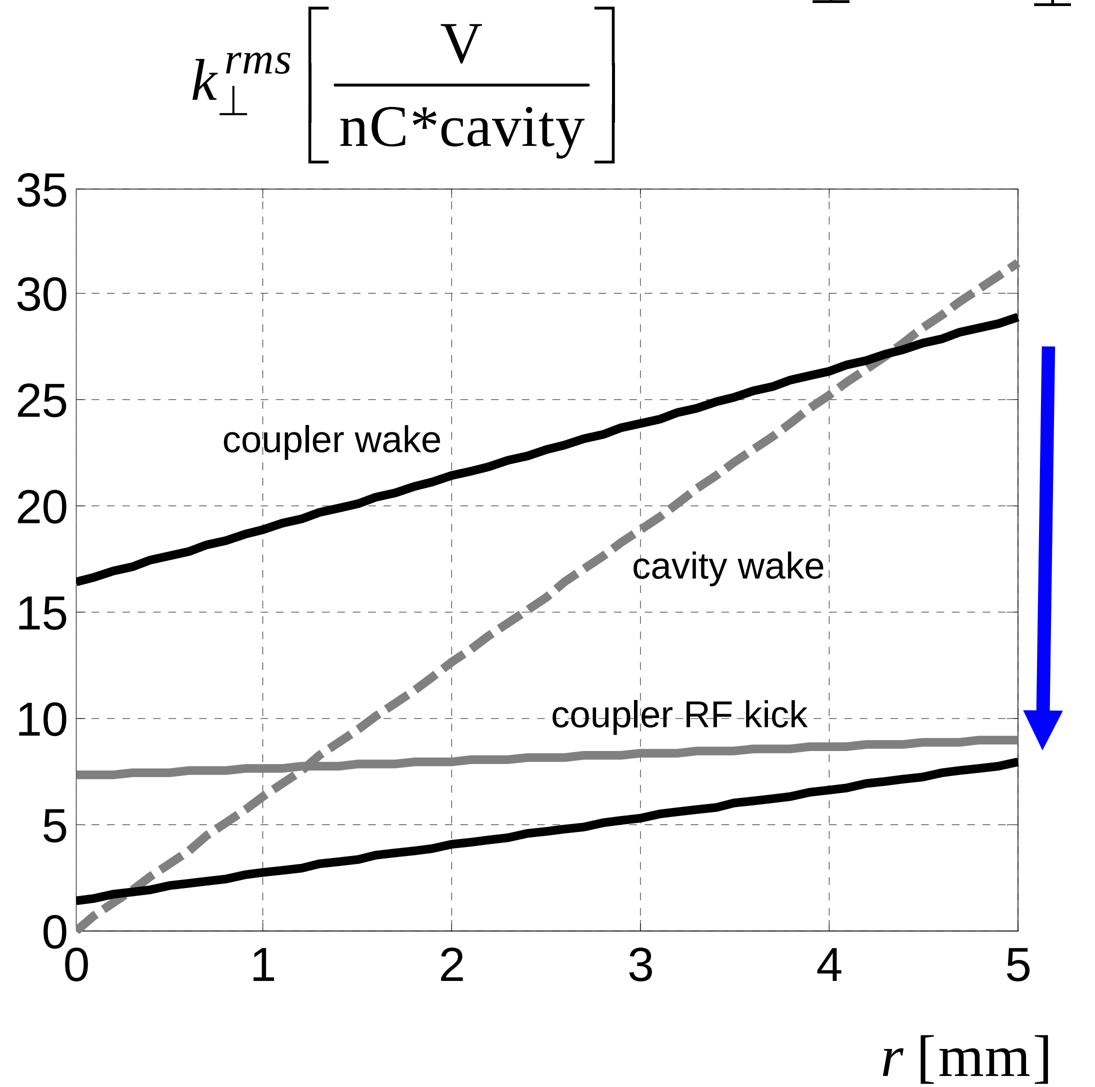
where $s_0 = 1.74\cdot 10^{-3}$ and $s_1 = 0.92\cdot 10^{-3}$


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

# Head-Tail Kick (ILC)

$\sigma = 300\ \mu\text{m}$

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



# Head-Tail Kick (ILC)

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

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

| RMS bunch length, μm | Coupler wake | Coupler RF field | Cavity tilt by 1 mrad (on crest / 10 grad) |
|---|---|---|---|
| 300 | Design= 16.4<br>New=1.4 | 7.3 | 0.35/10.7 |

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

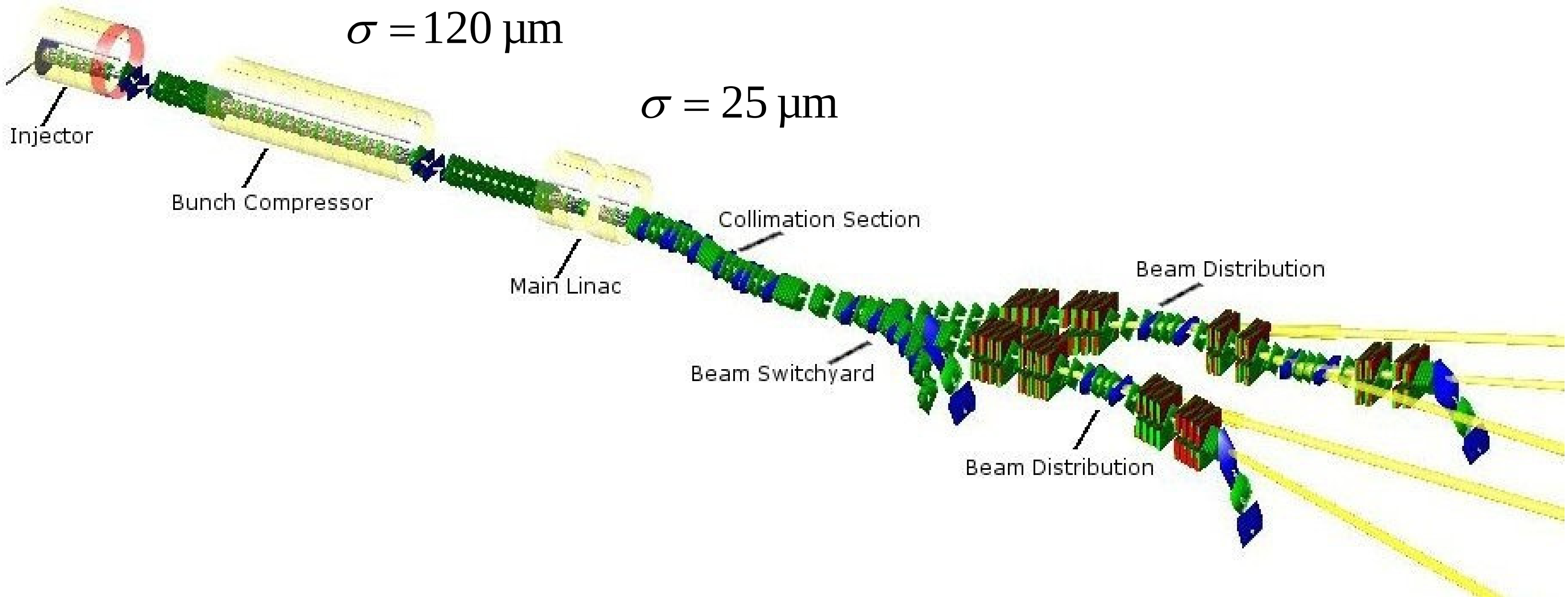
| RMS bunch length, μm | Coupler wake | Coupler RF field | Cavity wake |
|---|---|---|---|
| 300 | Design= 2.5<br>New= 1.3 | 0.34 | 6.3 |

# European XFEL Project

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

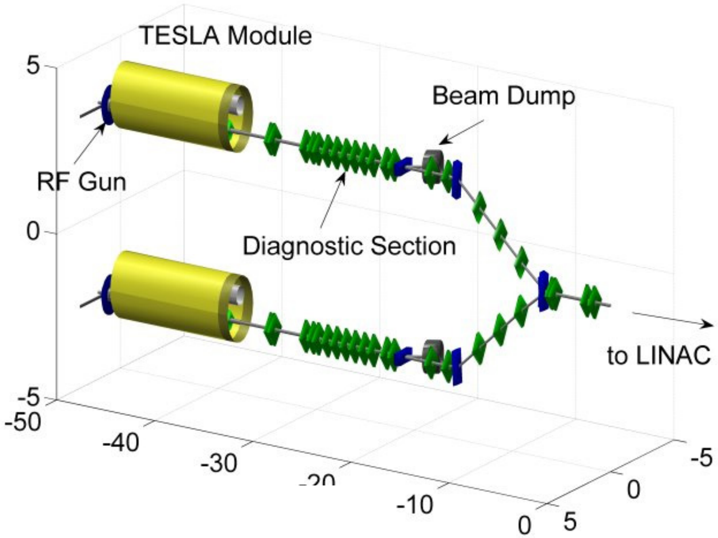
$\sigma = 120\ \mu\text{m}$

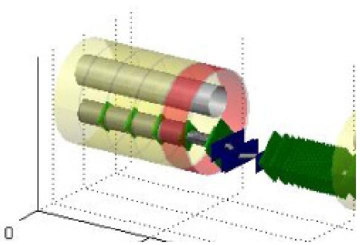
$\sigma = 25\ \mu\text{m}$

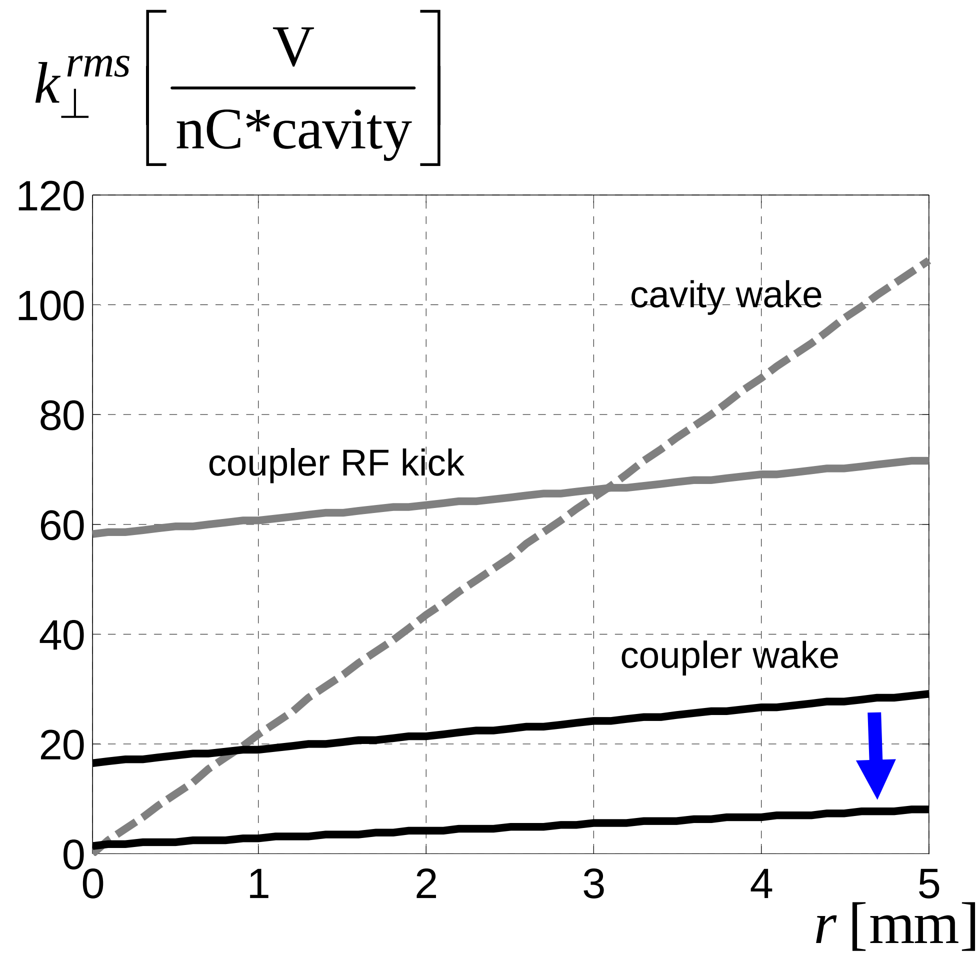



http://www.desy.de/xfel-beam/index.html

# Injector



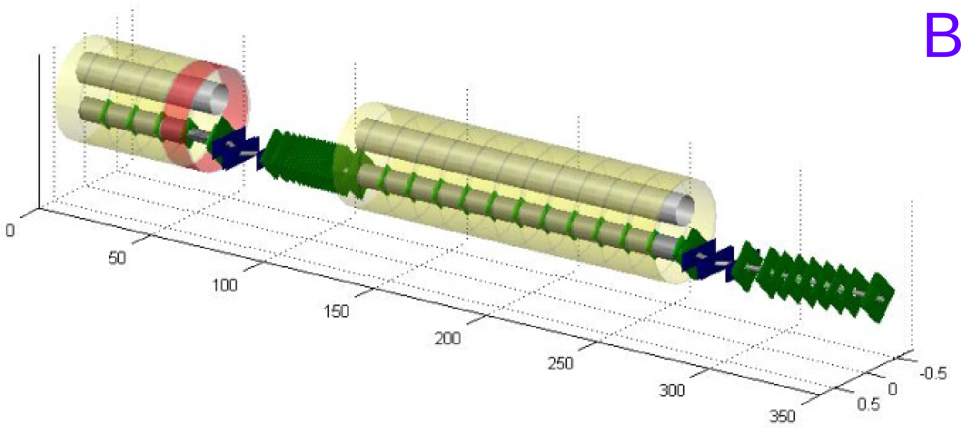



$\sigma = 2400\ \mu\text{m}$

5*8=40 couplers

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

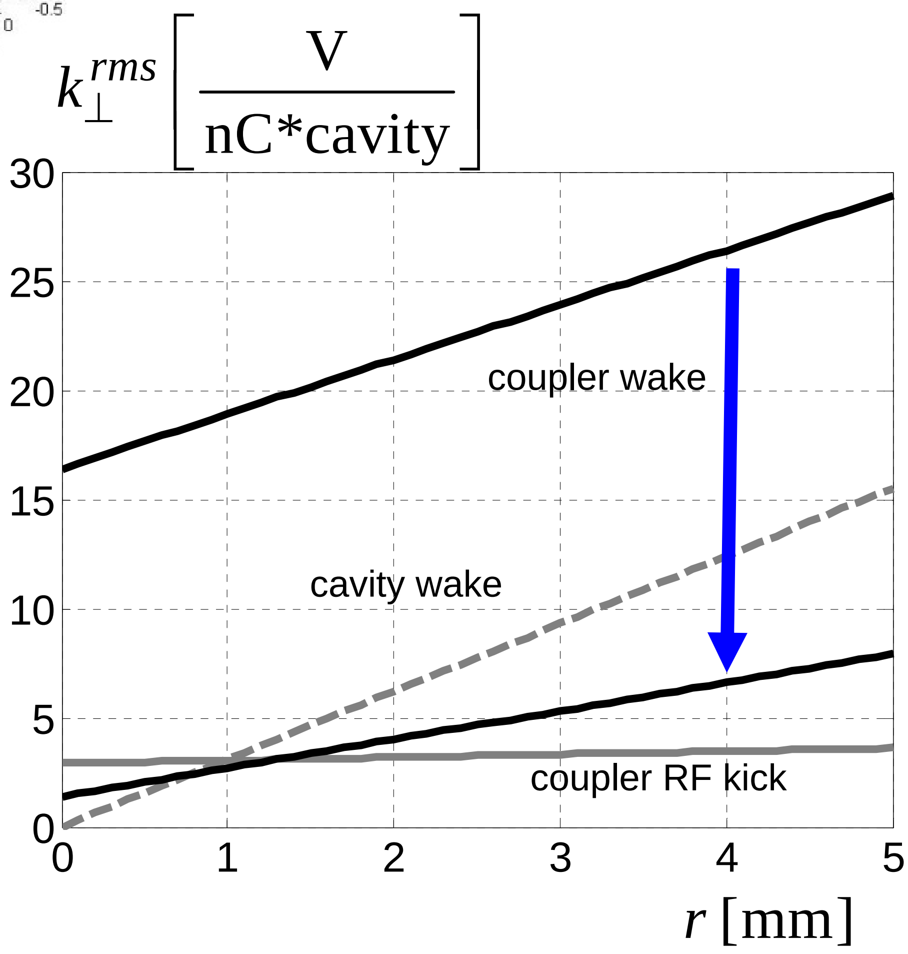
# Bunch Compressor



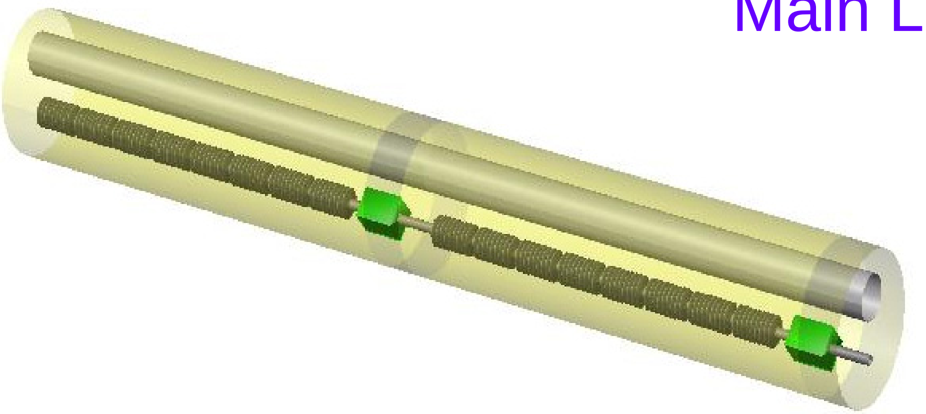
$\sigma = 120\ \mu\text{m}$

12*8=96 couplers

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



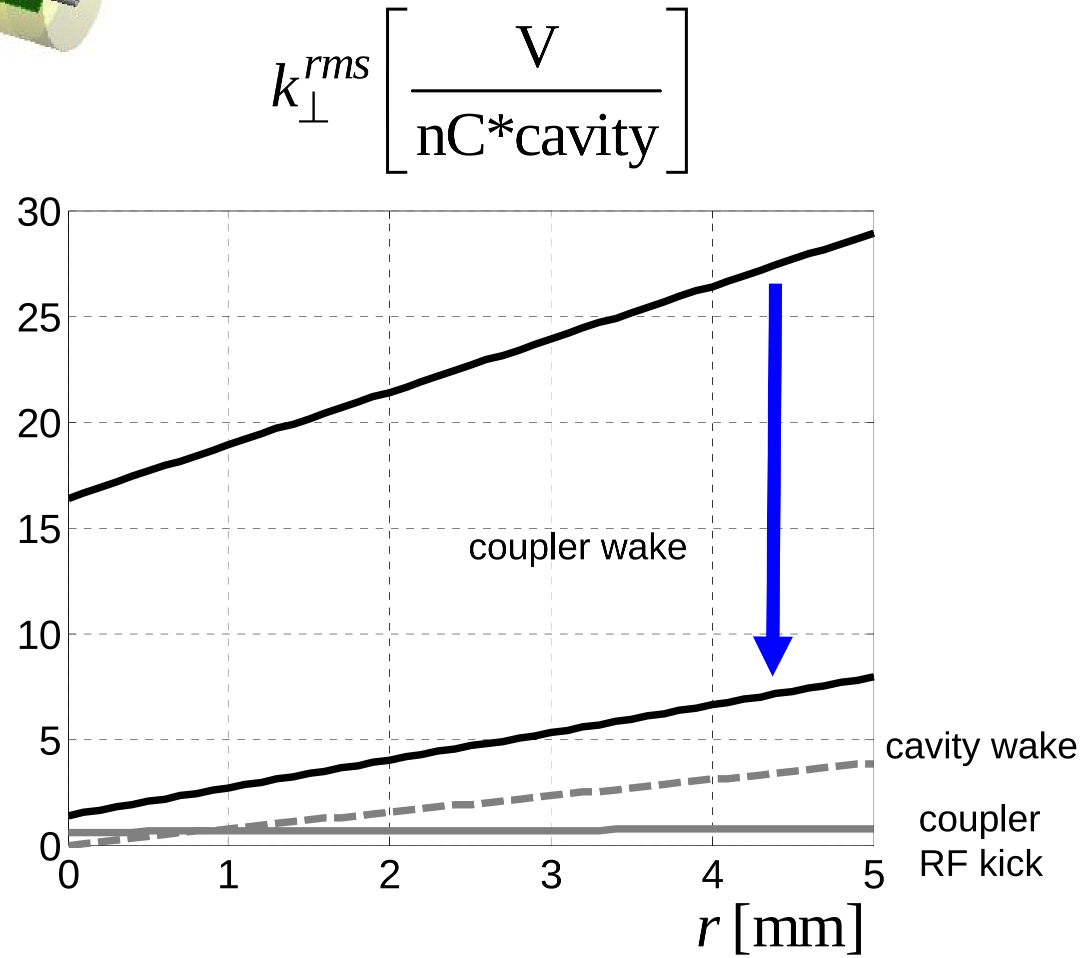
# Main Linac



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

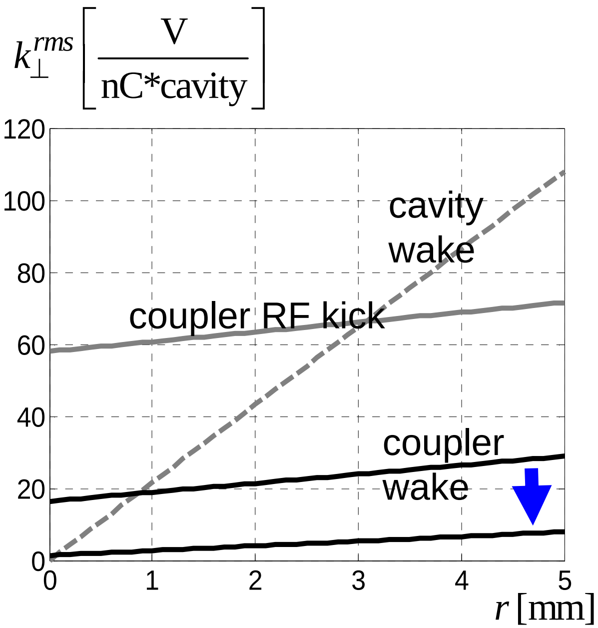
100*8=800 couplers

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



# Effect of new HOM couplers orientation

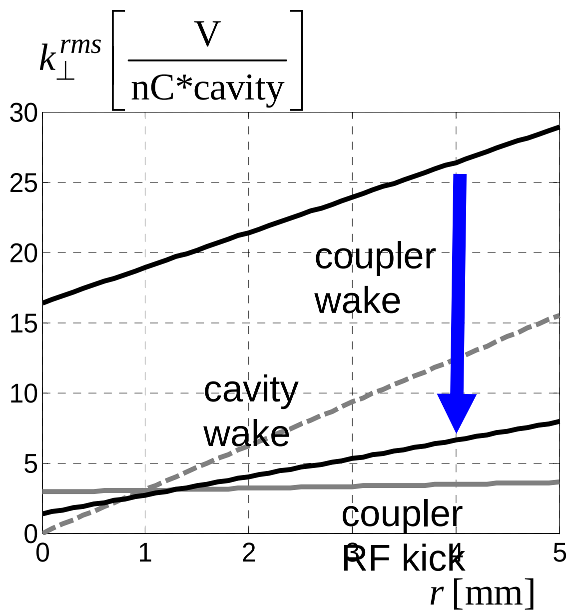
$\sigma = 2400\ \mu\text{m}$




## Injector

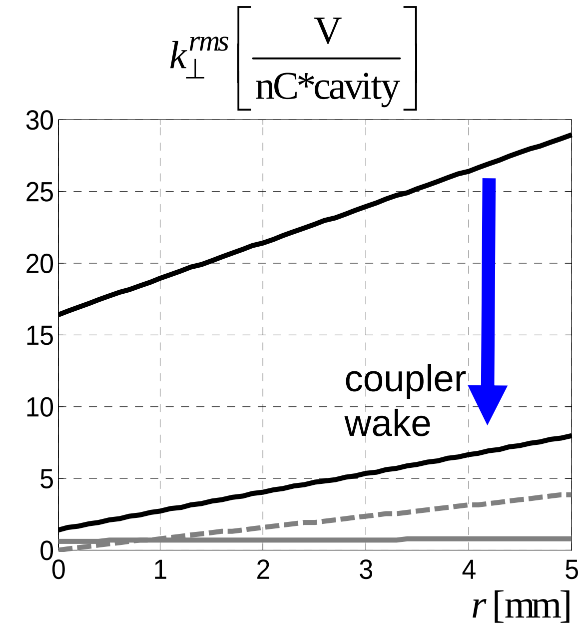
Coupler RF kick is the most important. It can be reduced by alternative direction orientation of couplers.

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




## Bunch Compressor

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




## 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 σ, μm | Coupler wake, O(1) | Coupler RF field, O(σ) | Cavity tilt by 1 mrad (on crest / 10 grad) | Cavity wake |
|---|---|---|---|---|
| 2400 | | 58 | 23 / 88 | |
| 120 | Design= 16.4<br>New=1.4 | 2.9 | 0.06 / 4 | 0 |
| 25 | | 0.6 | 0.002 / 0.9 | |

# Head-Tail Kick (rms kick)

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

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

| RMS bunch length, μm | Coupler wake, O(1) | Coupler RF field, O(σ) | Cavity wake, O(σ) |
|---|---|---|---|
| 2400 | Design= 2.5<br>New= 1.3 | 2.7 | 21.6 |
| 120 | | 0.14 | 3.1 |
| 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)

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

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

3. Cavity tilt by angle $\alpha$

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

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

# Conclusion

- The coupler **RF** kick is a main effect in the injector. It can be compensated by an alternative direction orientation of couplers.
- The coupler **wake** kick is a main effect after the 1st bunch compressor in XFEL project and for ILC bunch length of 300 μm. Rotation of the HOM couplers by 90 degree allows to reduce the kick by factor 12.
- It is possible that the wake is overestimated. The cavity irises have smaller radius than the pipe. It could make the coupler kick weaker. The full structure modeling is desired.