# Coupler Wakefield and RF Kick Simulations

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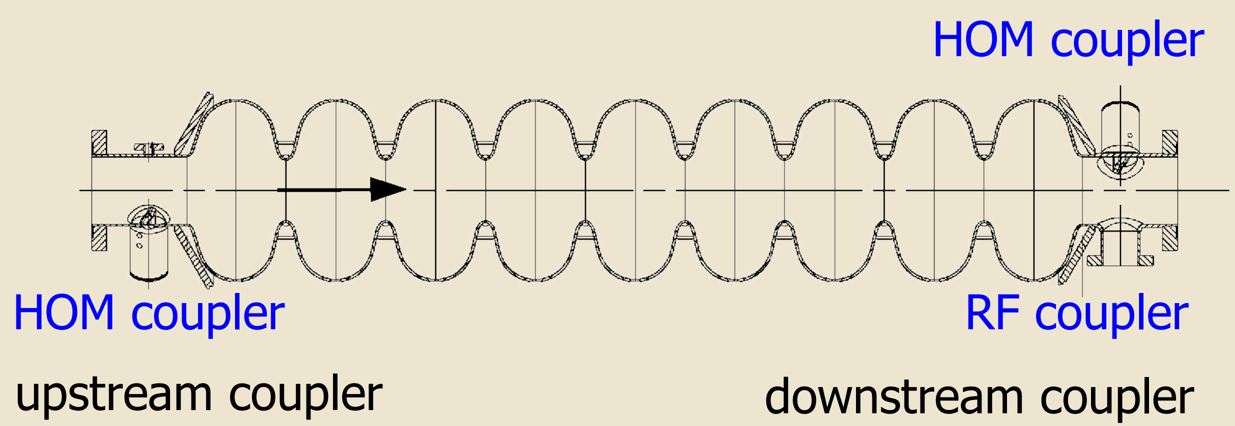
Uppsala, August 2008

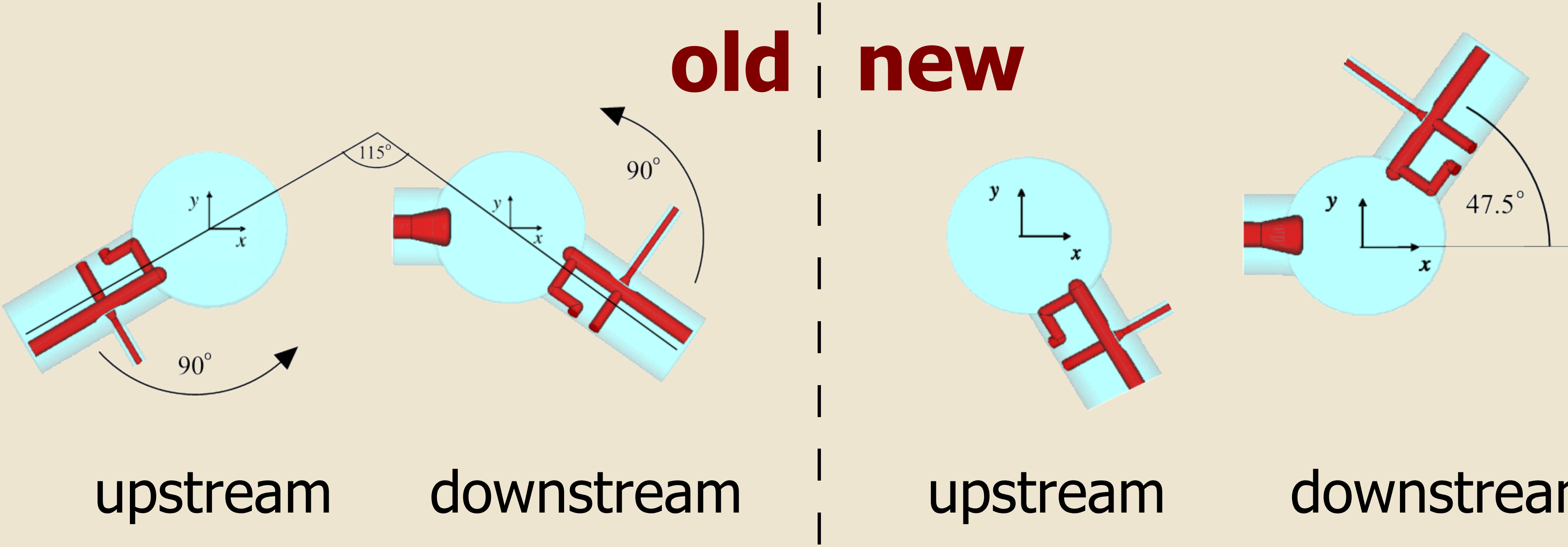
# Reminder on Cavity Couplers

- There are 3 couplers
  - 1 RF or power coupler
  - 2 HOM couplers
- Couplers destroy the rotational symmetry and introduce transverse field components
  - RF fields
  - Wakefields




TESLA cavity

# Reminder on Cavity Couplers




- A design change had been considered* to reduce the influence of coupler wakefields
  - Rotate HOM couplers relative to RF coupler to minimise the sum of transverse wakefields

*I. Zagorodnov and M. Dohlus, **LCWS/ILC, Hamburg 2007**

# Coupler Wakefields – MERLIN Implementation

- Calculation by I.Z. gives transverse kick not the wake potential
- We assume a purely capacitive wakefield (worst case)
  - A particle in a bunch with distribution $\lambda(s)$ experiences a transverse potential:
  - In MERLIN numerically calculated

$$W(s) = 2k \int_{-\infty}^{0} \lambda(\tilde{s})\, d\tilde{s}$$

$$w = 2k$$

$$\boldsymbol{k}_{old}(x, y) = \begin{bmatrix} -21 \\ -19 \end{bmatrix} + \begin{bmatrix} 4300 & 70 \\ 30 & -900 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

significantly smaller on axis

$$\boldsymbol{k}_{new}(x, y) = \begin{bmatrix} 2.5 \\ -0.2 \end{bmatrix} + \begin{bmatrix} 2330 & 40 \\ -20 & 1100 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

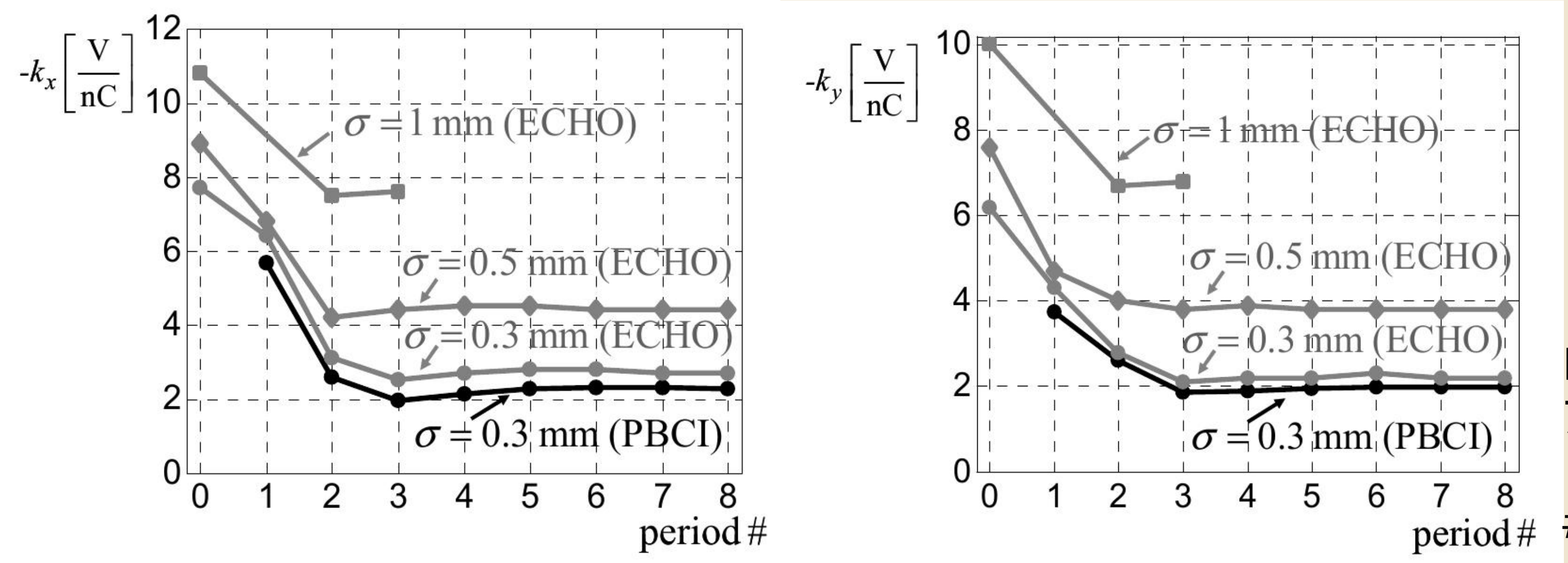
I. Zagorodnov and M. Dohlus,
**LCWS/ILC, Hamburg 2007**

$$\boldsymbol{k}_{rescaled}(x, y) = 0.11 \cdot \boldsymbol{k}_{old}(x, y); \quad x, y\,[\mathrm{m}]; \quad k\,[\mathrm{V/nC}]$$

to approximate the steady state solution

Technical implementation:
talk on MERLIN status this meeting

# Coupler Wakefields – Steady state solution




PBCI:408 CPUs
7 days

#Cavities

M. Dohlus, I. Zagorodnov, DESY; E. Gjonaj, T. Weiland, TEMF, TU-Darmstadt; EPAC08, MOPP013

*Self Induced Coupler Kick (Wake)*

It can be seen that the kick factor at both coordinate plans for σ = 0.3 mm is about 2 V/nC, that is an order of magnitude lower than a preliminary estimation of Ref. [5]. This is a consequence of a shadowing effect of the cavity and of a linear decrease of the steady-state wake with the decrease of the bunch length [6, 9].

# Coupler RF kick – MERLIN Implementation

- RF kick is given as a complex ratio wrt the accelerating voltage
- The kick is given by for example

$$\mathbf{v} = (v_x, v_y) := 10^6 \cdot \mathbf{V} / V_{\parallel} \qquad x, y\,[\mathrm{cm}]$$

$$\mathbf{v}_{old}(x, y) = \begin{bmatrix} -82+58i \\ -9.2+1.8i \end{bmatrix} + \begin{bmatrix} -29-27i & 63+5.1i \\ 63+7.0i & 28+24i \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$$\mathbf{v}_{new}(x, y) = \begin{bmatrix} -82+58i \\ -74-8.7i \end{bmatrix} + \begin{bmatrix} -29-27i & 63+5.1i \\ 4.9+2.9i & -48-12i \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

MAFIA calculation by M.Dohlus

$$\Delta y' = \frac{\Delta E}{E} |v_y| \Re \left\{ e^{i(\phi_c - \varphi - k \Delta z)} \right\}, \qquad v_y = |v_y| e^{i \phi_c}$$

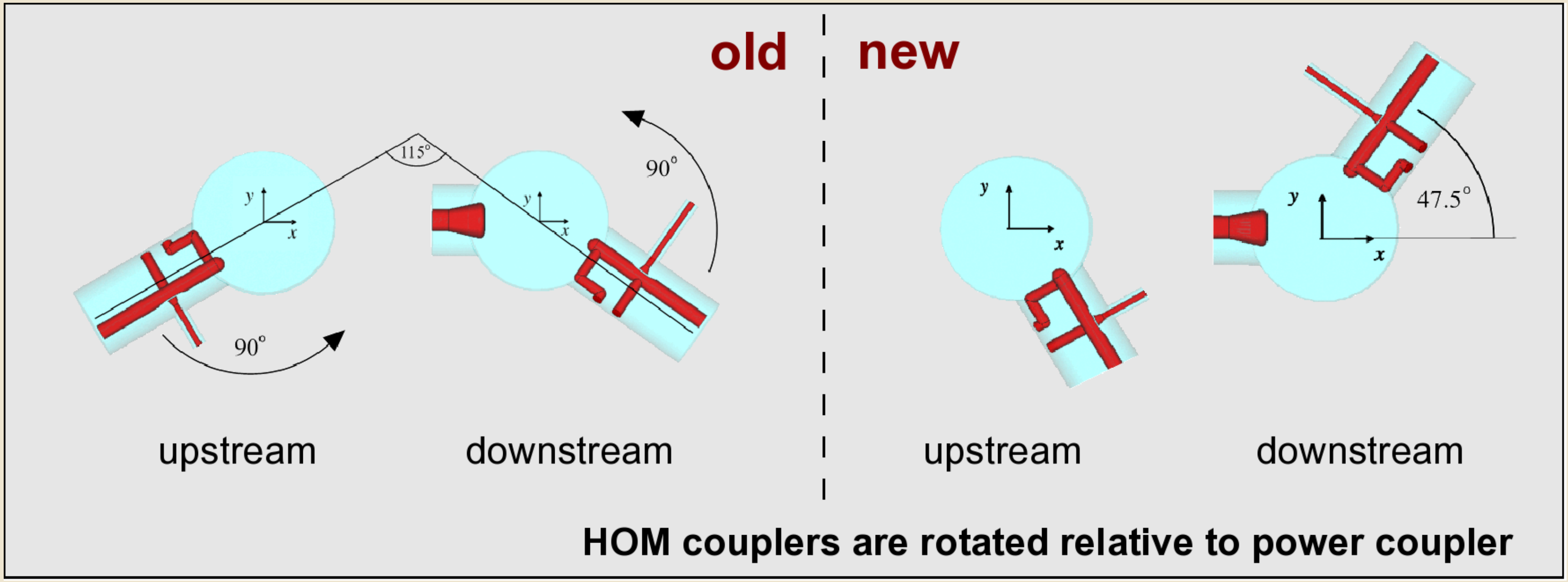
$\Delta z = -\Delta ct$, longitudinal position for a particle at $\varphi$

$\varphi = 5.3^o$ RF phase, $k = 2\pi f / c$, $L = 1.036$ m

$\Delta E = 31.5$ GeV/m$\cdot$L, $E = 15 \cdots 250$ GeV

# Coupler RF kick - Approximation for New Design

- There is no MAFIA field calculation for the modified design. Approximated in MERLIN by $v_y \rightarrow -v_y$ (downstream coupler)
- In this case the angle between HOM coupler and x-axis is only 42.5° instead of 47.5°.



# Coupler RF kick – Differences between Codes

- There are different numerical calculations / different codes for electromagnetic field calculations
  - Omega3P, MAFIA, HFSS
- The numerical result is sensitive
  - cancelation between upstream and downstream coupler
  - the transverse fields are a small effect, about 5 orders of magnitude smaller than the longitudinal fields
  - varies depending on assumptions about
    - input coupler pen depth ~ Q
    - beam loading etc.

# Coupler RF kick – Differences between Codes

| $\|V_y\|$ on axis for 31.5 GeV | Code and $Q_{ext}$ | |
|---|---|---|
| old 284 V<br>new 2350 V | MAFIA - 2.5 · $10^6$ | used for MERLIN simulations |
| TDR(=old) 785 V<br>TDRM* 2621 V | Omega3P - 3.4 · $10^6$ | Zenghai Li's talk, Wakefest 07 |
| TDR 130 V | Omega3P - 3.5 · $10^6$ | Bane et al., EPAC08, TUPP019 |

*TDRM = downstream coupler rotated by 180°

For comparison a 100 $\mu$ *rad* cavity tilt

$$V_y = \frac{1}{2} \alpha V_{\parallel} = 1600 \; V$$

but RF kick is not random

Table 2: RF kick on-axis due to coupler asymmetry in [kV]. Re($V$) is the in-phase, Im($V$) the out-of-phase kick.

| **Region** | $\mathbf{V}_x$ | $\mathbf{V}_y$ |
|---|---|---|
| Upstream | $-1.82 + 0.22i$ | $-1.29 - 0.11i$ |
| Downstream | $-0.79 - 1.62i$ | $+1.15 + 0.28i$ |
| Total | $-2.61 - 1.40i$ | $-0.13 + 0.17i$ |

cancelation between upstream and downstream coupler

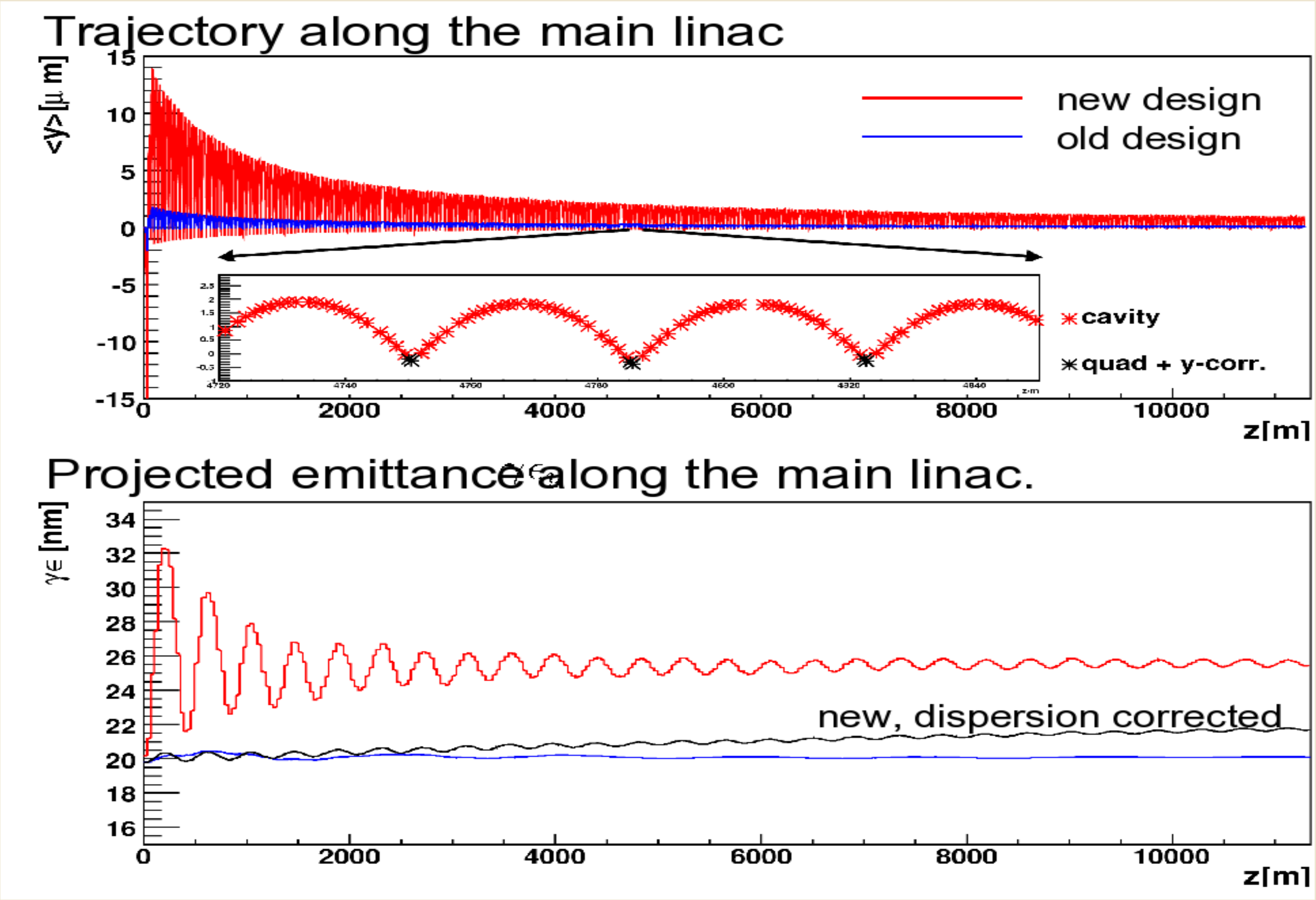
# History of Merlin Simulations

Different Merlin implementations according to the changing numerical input

- My talk at SLAC, Wakefest 07 based on
  - I. Zagorodnov and M. Dohlus, LCWS/ILC Hamburg 2007, paper (sign errors in RF kicks!)
    - Reduced wakefield and (wrong!) RF kicks in new design
- Our paper at Genoa, EPAC08, TUPP047 (corrected) = EUROTeV-Report-2008-003
    - The RF kick is larger in the new design
- This meeting: steady state solution for coupler wakefields about 1/10!

# Simulation Results - RF Kicks

D. Krücker et al., EPAC08, TUPP047, EUROTeV-Report-2008-003




- Perfect linac
- 20 nm initial emittance
- 1-2-1 steering to compensate kicks
- old design negligible
- new design $\gamma \epsilon_y = 25.1\,\mathrm{nm}$
- dispersion corrected $\gamma \epsilon_y^c = 21.8\,\mathrm{nm}$

# Simulation Results - RF Kicks

## Does the RF kick increased the sensitivity to Voltage instabilities?*

- Random Klystron errors (24 cavities) applied to the steered system

| $\gamma\epsilon_y(\gamma\epsilon_y^c)$ [nm] | 0% | 0.1%* | 1% |
|---|---|---|---|
| old design | 20.3 (20.3) | 20.3 (20.3) | 20.4 (20.3) |
| new design | 25.1 (21.8) | 25.1 (21.8) | 28.3 (22.1) |

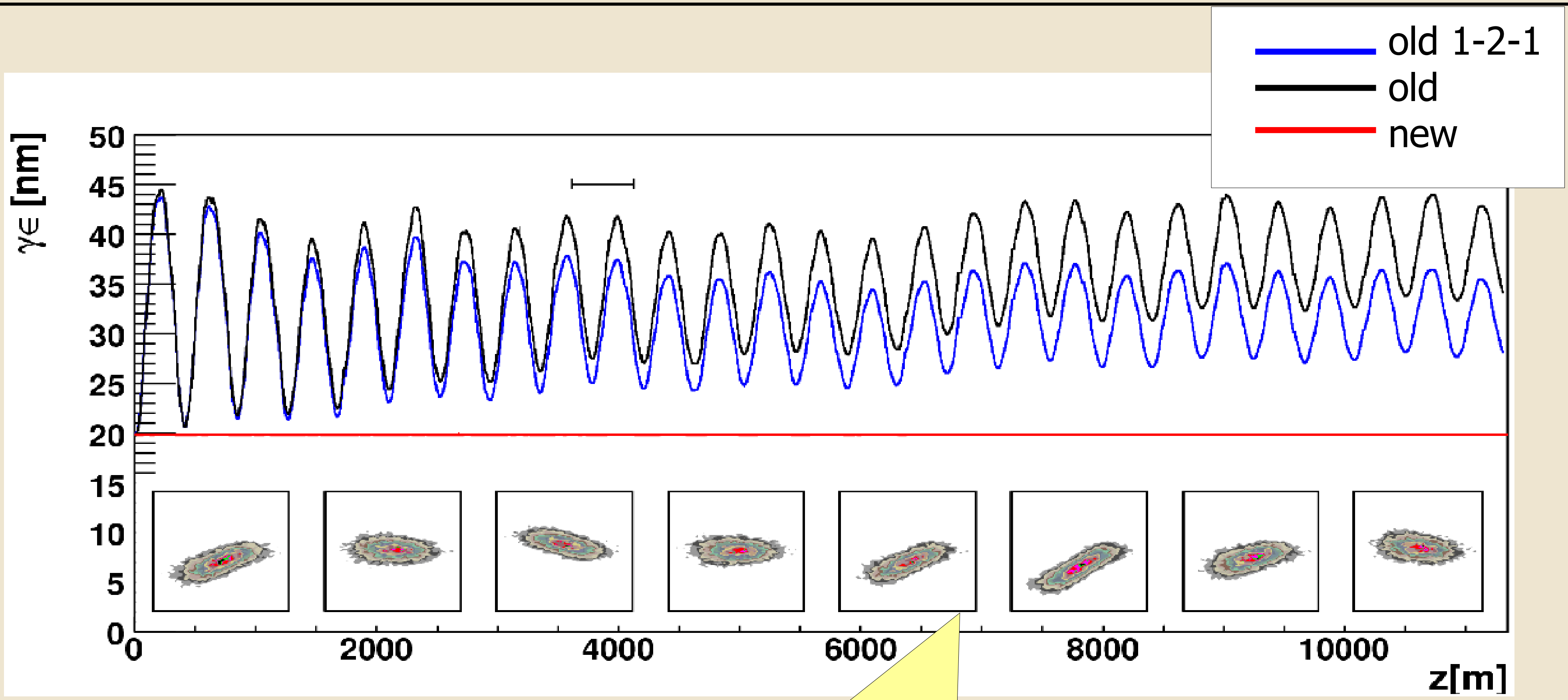
*RDR value

- New design is more sensitive to voltage errors but still acceptable



*Study by Fabian Gross

# Simulation Results -Wake Kicks (old Results)

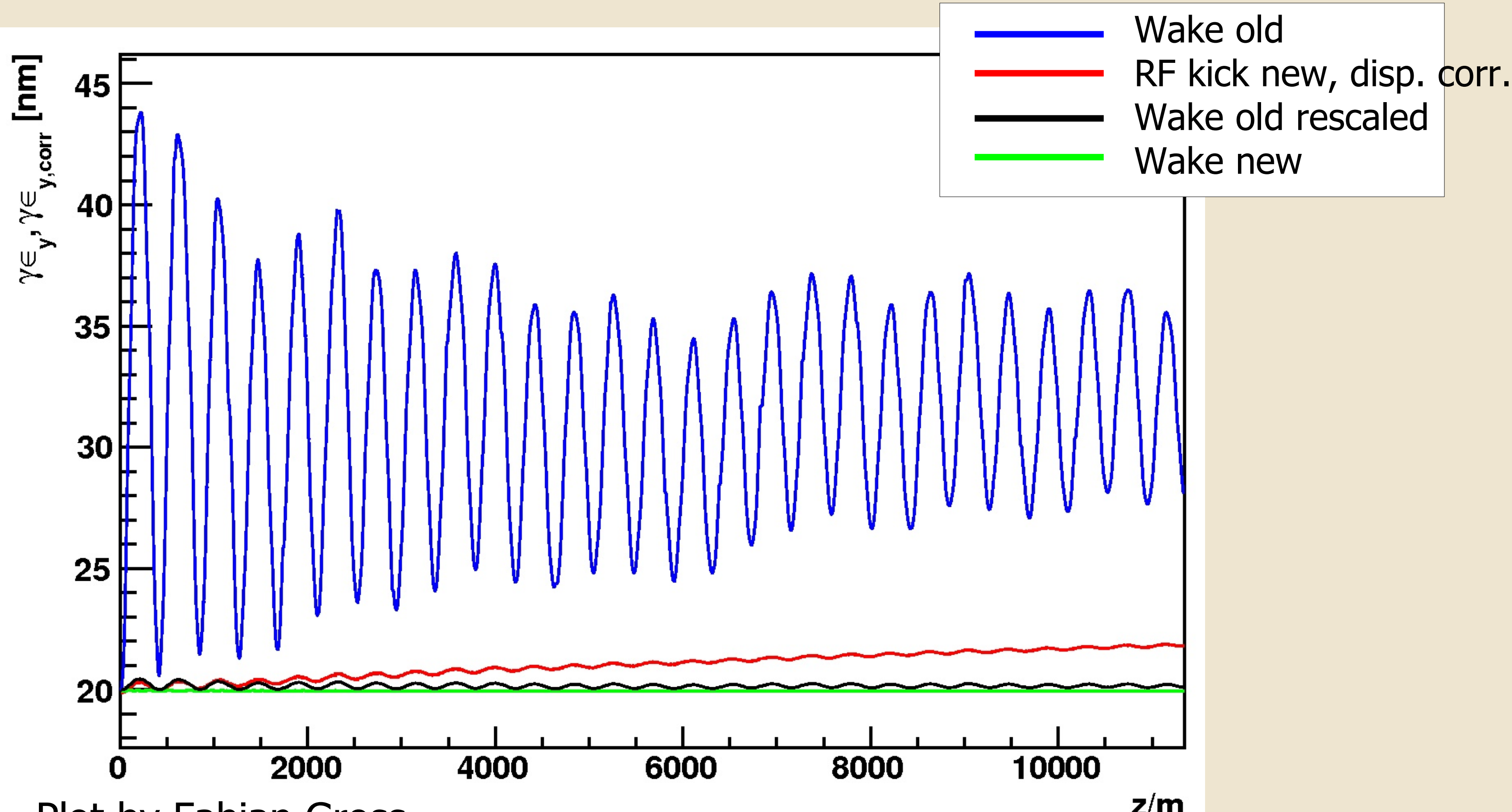



old design

Snashots of the bunch profile (y-ct-plane, at quads 102,104...114). The bunch tail oscillates strongly driven by coupler wakefield.

DK et al., EPAC08 - TUPP047

# Simulation Results – Wake Kicks, Steady State Results




Plot by Fabian Gross

A large RF kick is more problematic than the coupler wakefield kick

# Conclusions

- Collecting the appropriate numerical input for simulating RF and wakefield kicks turned out to be chasing a moving target
  - It seems to converge now
- In the steady state solution the coupler wakefields are no problem anymore
- Modifying the coupler design strongly increases the RF kicks
  - This effect looks worse than the steady state coupler wakefield!

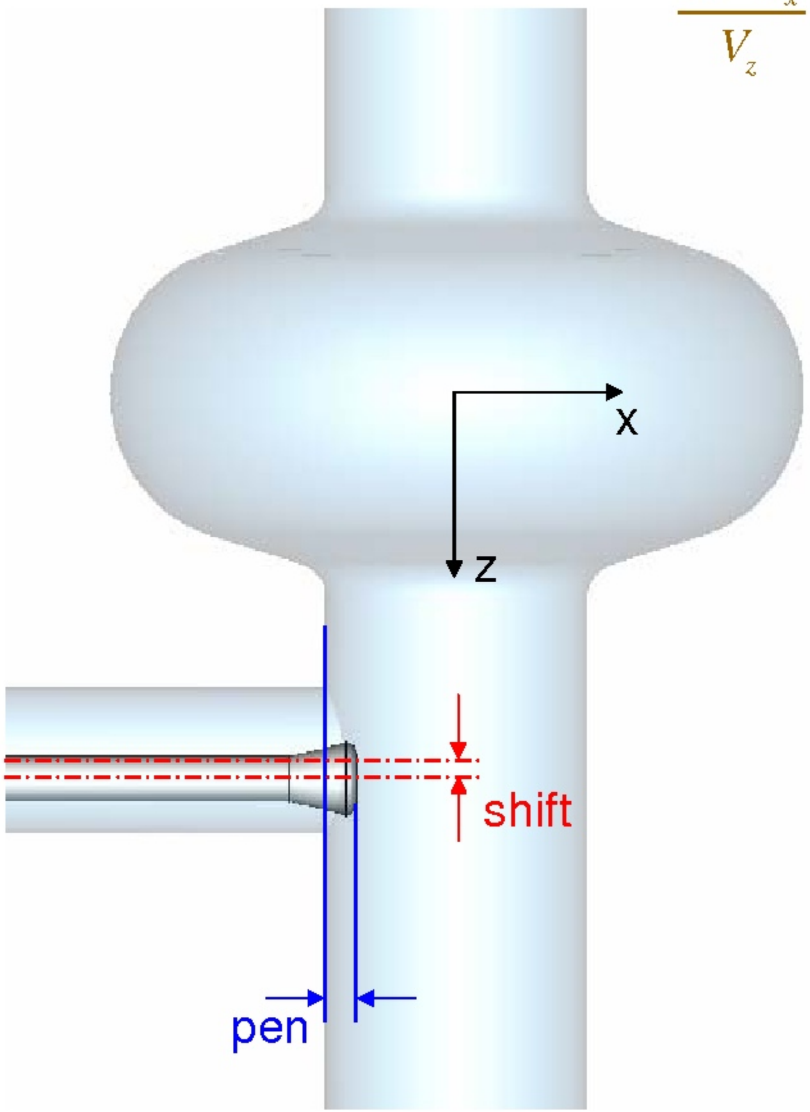
## kick of main coupler

$\frac{Q_{ext}}{10^6}$

$\frac{10^6 \cdot V_x}{V_z}$

scaled for TTF 9 cell cavity

problem: field asym. caused by asym. MWS mesh




MWS-discretization: 30lines@2GHz

| pen/mm \ shift/mm | -5 | 0 | 5 |
|---|---|---|---|
| 4.5 | 3.347<br>19.9+j35.9 | 4.490 | |
| 6 | 2.466<br>47.6+j40.9 | 3.384<br>30.6+j54.3 | |
| 7.5 | 1.781<br>84.5+j50.0 | 2.4482<br>58.7+j65.0 | 3.987<br>37.4+j68.1 |
| 9 | 1.272<br>130.3+j56.9 | 1.940<br>93.4+j83.3 | 3.464<br>65.1+j88.9 |
| 10.5 | 0.9662 | 1.663 | 2.583<br>100.9+j86.5 |
| 12 | | 1.351 | 2.099<br>141.1+j65.0 |

MWS-discretization: 50lines@2GHz

| pen/mm \ shift/mm | -5 | 0 | 5 |
|---|---|---|---|
| 4.5 | 3.405 | | |
| 6 | 2.488 | 3.423 | |
| 7.5 | 1.857<br>83.7+j14.2 | 2.623<br>59.1+j31.7 | 4.242<br>37.1+j35.5 |
| 9 | | 2.008 | 3.237 |
| 10.5 | | 1.570 | 2.542 |
| 12 | | | |

*old values!*