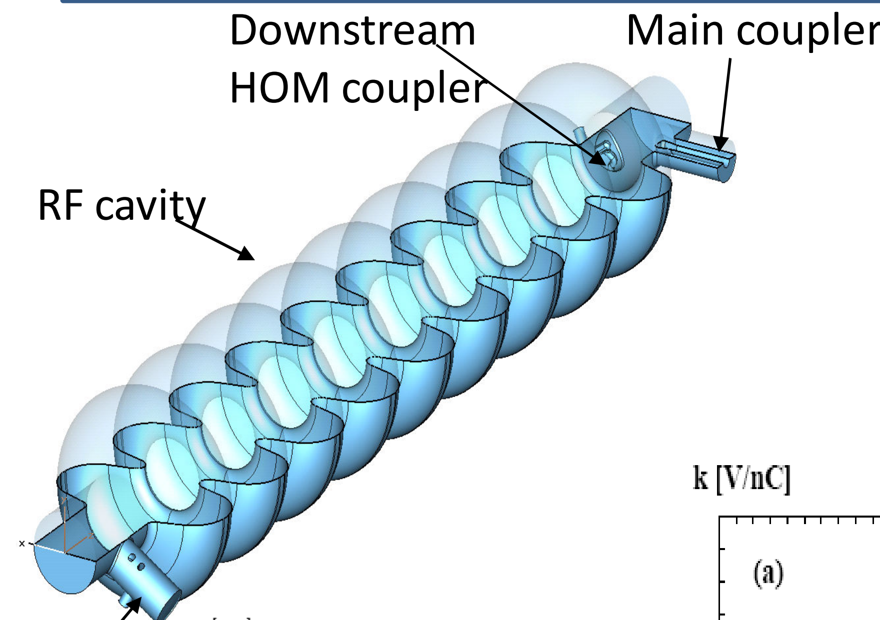
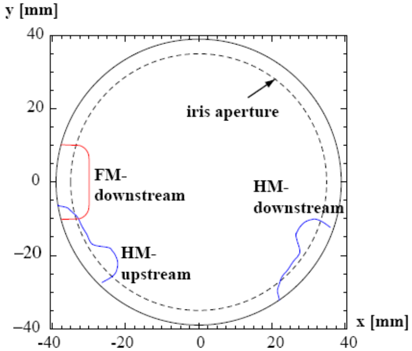
# Coupler kick and wake simulations upgrade

N. Solyak,
Fermilab

(on behalf of the team: N. Solyak
A. Lunin, I. Gonin, and V. Yakovlev)

# Simulations of Coupler Kick and Wakes (2008)



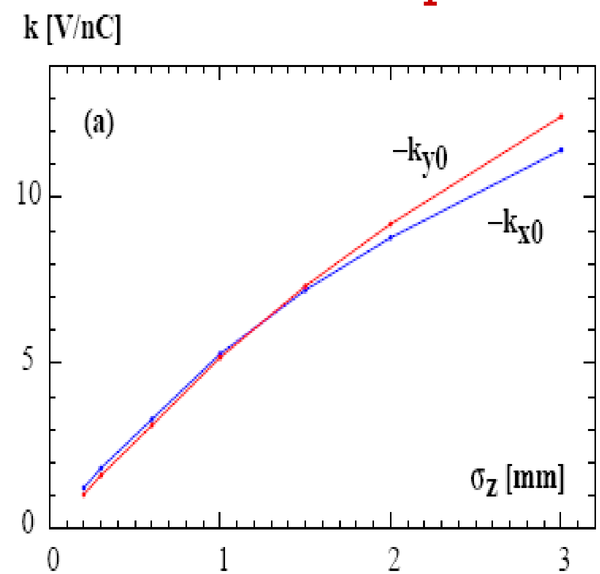

The profiles of the 3 couplers, as seen from the downstream end.

. Simulations: DESY/FNAL/SLAC

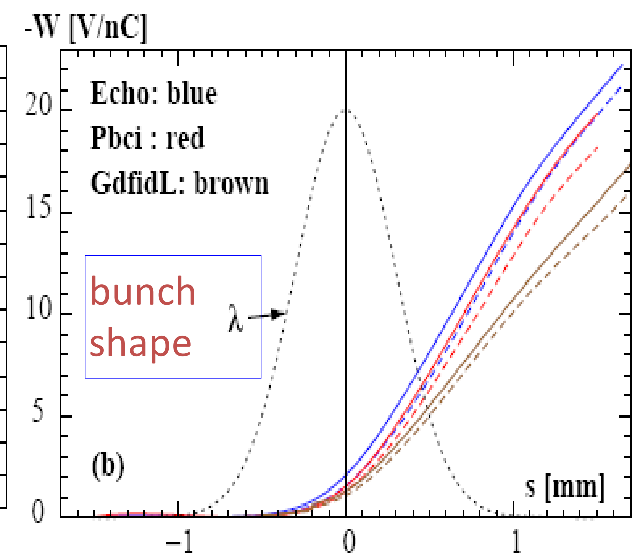
**Total RF KICK (FNAL):**

$$\frac{\vec{V}_{\perp}}{V_a} \times 10^6 = \begin{pmatrix} -105.3 + 69.8i \\ -7.3 + 11.1i \end{pmatrix}$$

## Coupler Transverse Wakefield




On-axis kick factor vs. $\sigma_z$




$W_x(s)$-solid,, $W_y(s)$-dashed for $\sigma_z$ = 300 μm.

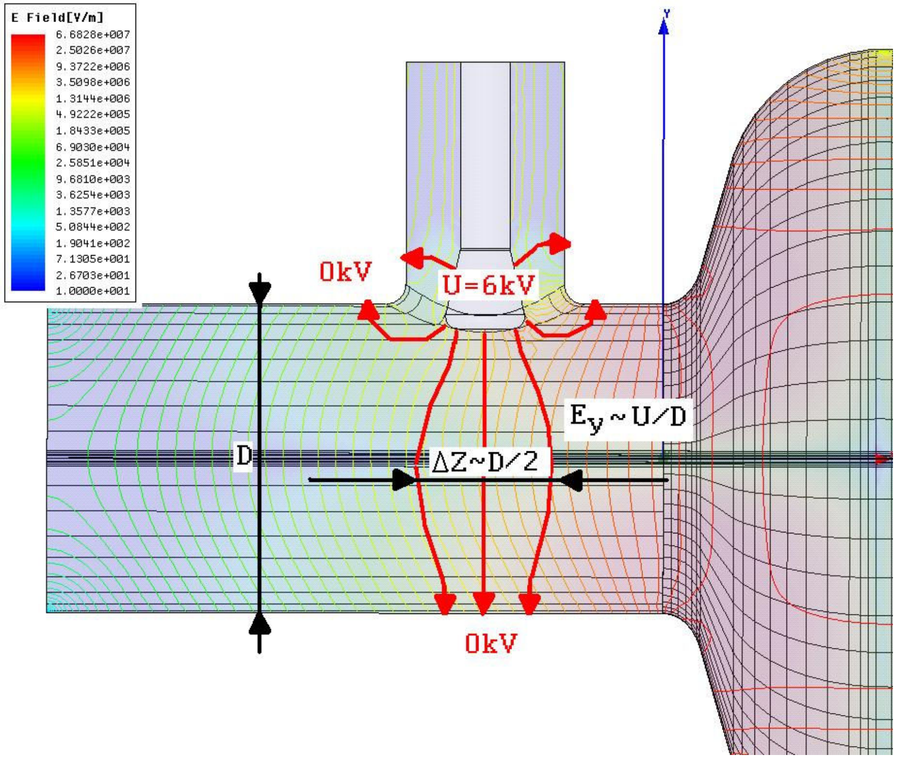
# Effect of asymmetry, caused by couplers

- The couplers break the RF field symmetry and cause transverse RF kick and Wake fields. Both RF kick and wake fields may be a reason of a beam emittance dilution in ILC BC and ML.
- DESY* made the first calculations of the RF kick and Wake fields.
- FNAL, SLAC, DESY, and TEMPF completed the calculations**

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

***K.L.F. Bane, C. Adolphsen, Z. Li, M. Dohlus, I. Zagorodnov, I. Gonin, A. Lunin, N. Solyak, V. Yakovlev, E. Gjonaj, T. Weiland, EPAC2008, TUPP019.*

# Estimation of RF kick from the main coupler




Simple estimations of the transverse fields caused by the main coupler:

- RF voltage: $U=(2PZ)^{1/2}$, $Z$–coax impedance; For $P$=300 kW and $Z\approx$70 Ohms → $U \approx$ 6 kV
- Transverse kick:

$\Delta p_y \cdot c \approx eE_y\,\Delta Z \approx eU/D \cdot D/2 = eU/2.$

$$\frac{\Delta p_y c}{\Delta U_{acc}} \approx \frac{U}{2U_{acc}} = \frac{6kV}{2 \times 30MV} = 100 \times 10^{-6}$$

- The RF field calculation precision should be better than $10^{-5}$ !!!

- Transverse kick caused by the couplers acts on a bunch the same direction for all the RF cavities of the linac.
  - Real part may be compensated by the linac feedback system;
  - Imaginary part dives the beam emittance dilution.

# First results of RF kick calculation (2008)

Three groups made rf kick simulations:

*1. FNAL: N. Solyak, et al, EPAC2008, MOPP042*
*2. DESY: I. Zagorodnov, and M. Dohlus, LCWS/ILC 2007*
*3. SLAC: K.L.F. Bane, et al, EPAC2008, TUPP019*

*ALL the three groups have different results!*

| | FNAL $Q=3.5\times10^6$ HFSS | DESY $Q=2.5\times10^6$ MAFIA | SLAC $Q=3.5\times10^6$ OMEGA3P |
|---|---|---|---|
| $10^6 \cdot (V_x / V_z)$ | -105.3+69.8i | -82.1+58.1i | -86.0-60.7i* |
| $10^6 \cdot (V_y / V_z)$ | -7.3+11.1i | -9.2+1.8i | -4.6+5.6i |

*Probably, typo in [3]

Big difference in calculated vertical imaginary part of coupler kick !!!

## *Main reasons for difference:*

- ✓ Effect is extremely small, about 5-6 orders of magnitude smaller than the longitudinal fields;
- ✓ In additions, cancelation takes place between upstream and downstream coupler.

It demands very high precision of the field simulations, better than $10^{-6}$, that is a severe challenge for all numerical methods and codes.

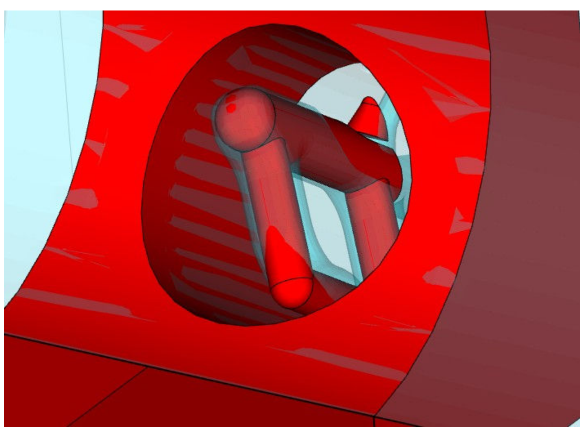
## *Possible other reasons:*

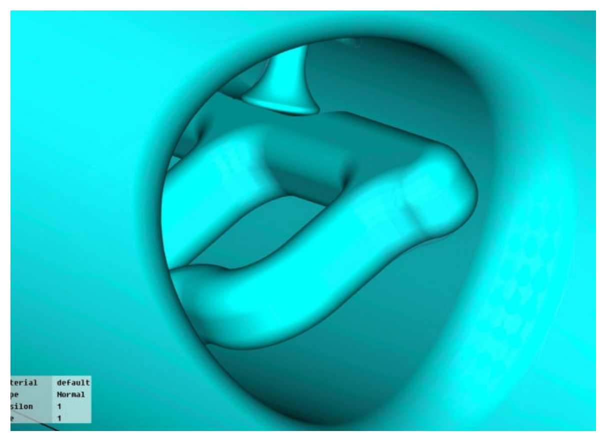
- ✓ Different calculated geometries or numerical models;
- ✓ Different assumptions (loaded Q, etc);
- ✓ Different numerical approximation of the fields (in some codes E and H fields are calculated with different precision that should be taken into account);
- ✓ Different methodical convergence for the methods used.

# Geometry

- DESY provided  to FNAL the geometry used for wake simulations. Geometry is different (no rounding, simplified coupler geometry, etc). We have no information whether it was used for rf kick.
- FNAL and SLAC used same geometries, but results for vertical rf kick is different
- Acceptable vertical (most critical) emittance dilution in BC < 5 nm
- Emitannce dilution is proportional to the rf kick squared. Calculated vertical kick differs ~6 times → ~36 times in emittance growth !

DESY (red) and FNAL (blue)





FNAL and SLAC (the same now, but  the results still differ)

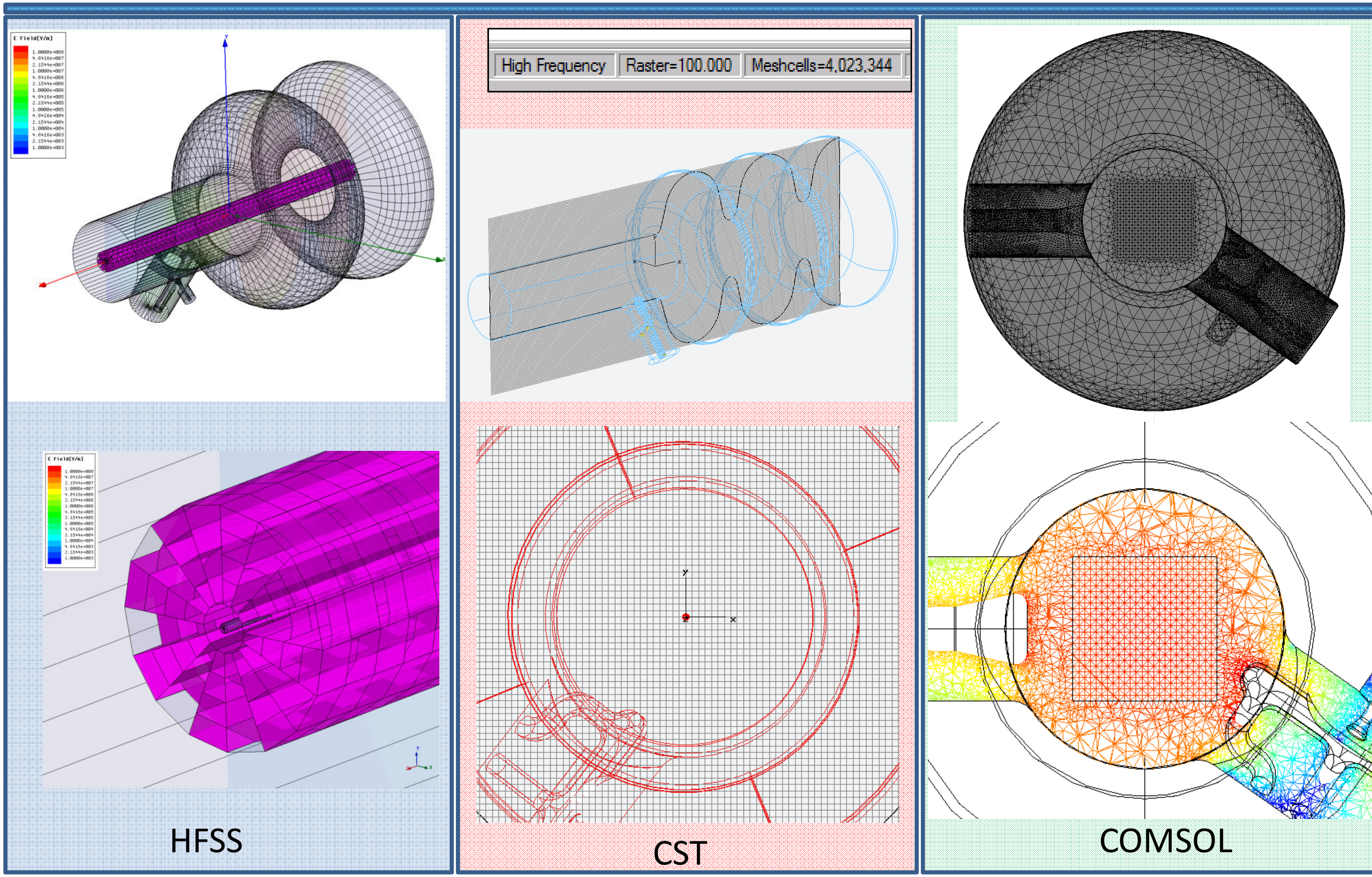
# FNAL approach:

- Different codes were used for calculations – HFSS, CST, COMSOL ;
- A special meshes were used that allows accurate filed description near the axis and eliminate the mesh noise;
- Calculation convergence was investigated and achieved;
- Cross-check of the direct rf kick calculations by Panofsky – Wenzel theorem application;
- Full geometry calculations in order to avoid phase-lock mistakes;
- More accurate normalization was used.

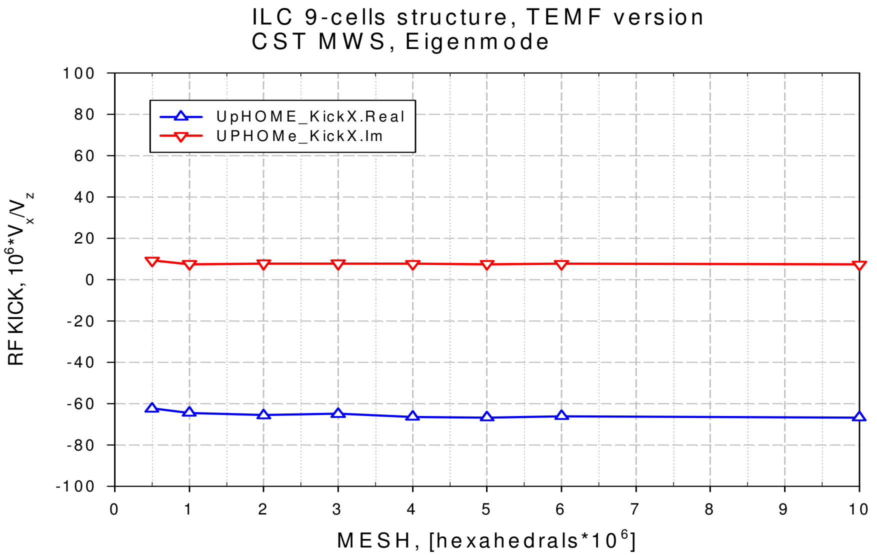
All the three codes gave the same results in simulations done for separate couplers and for full geometry.

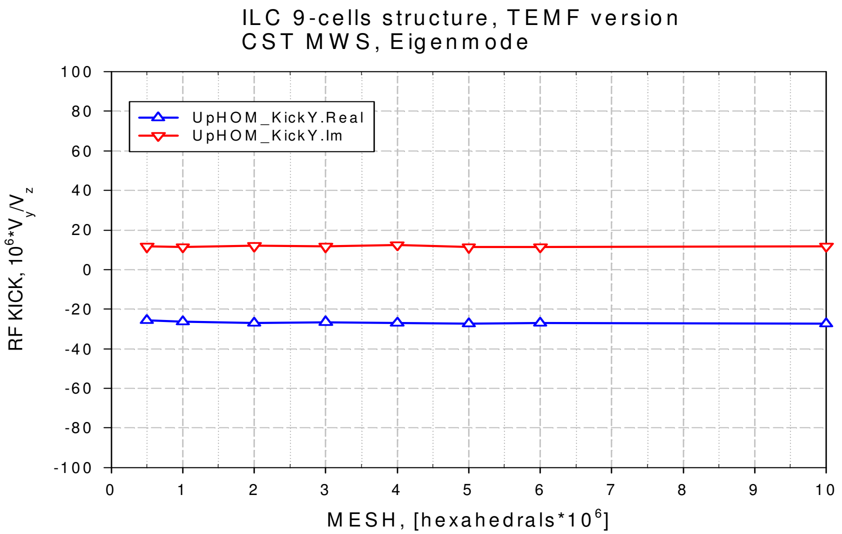
Effect of couplers kick in vertical plane is higher than it was shown in our the first simulations in 2008 !!!

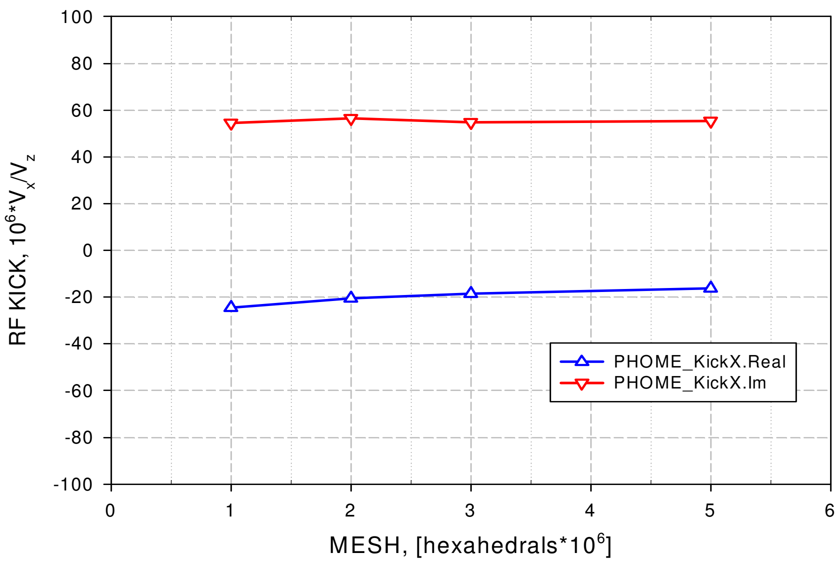
# Model for Meshes used in different codes

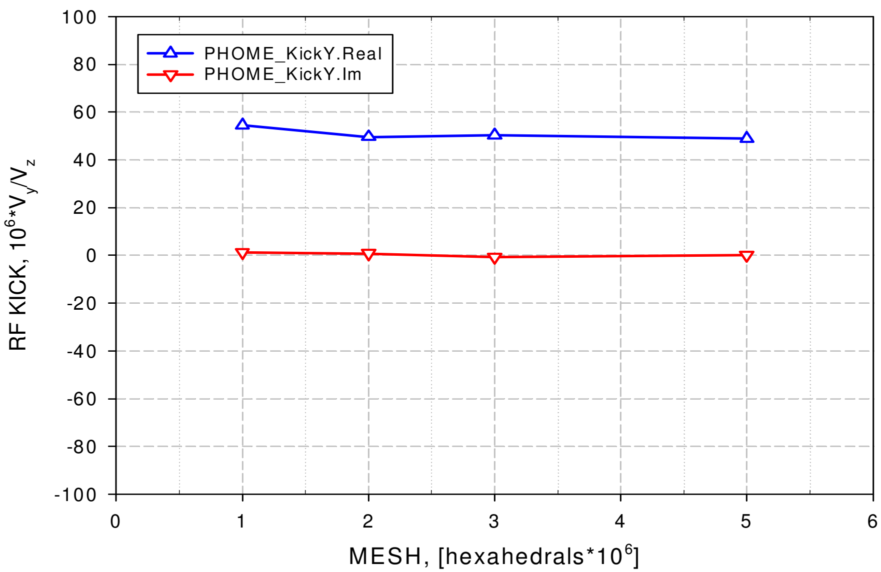


# CST Convergence

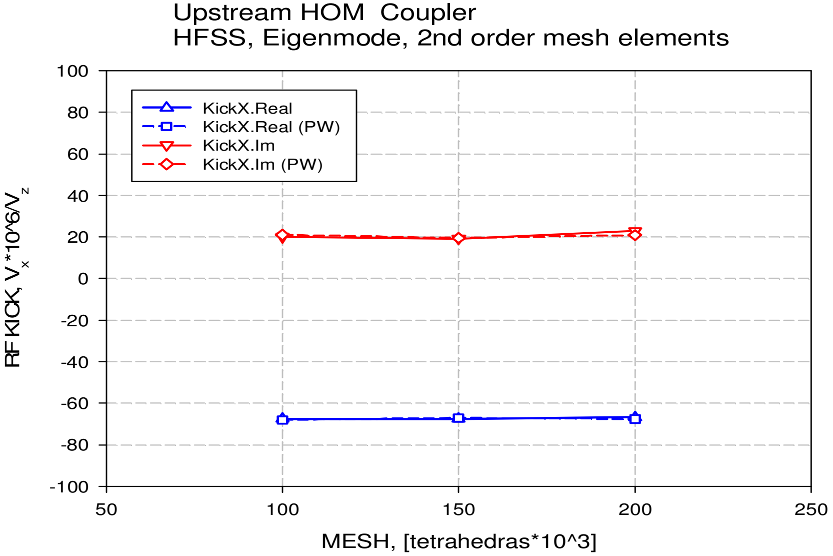


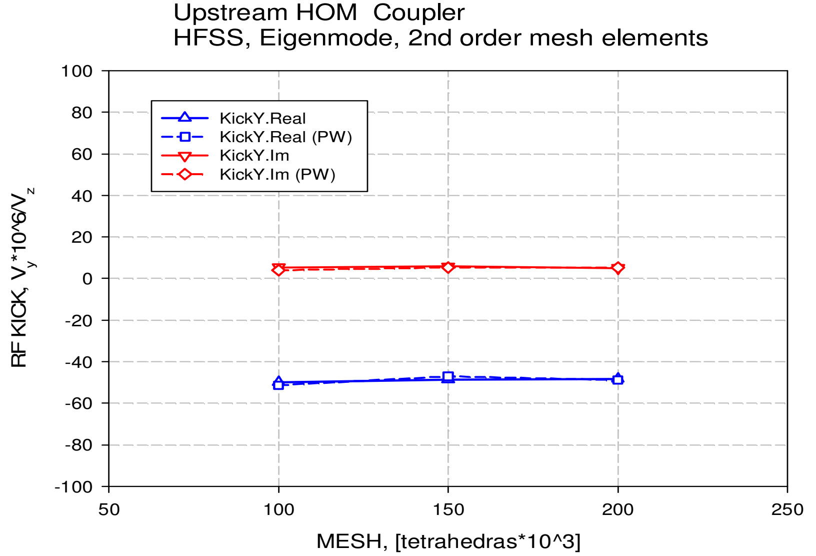



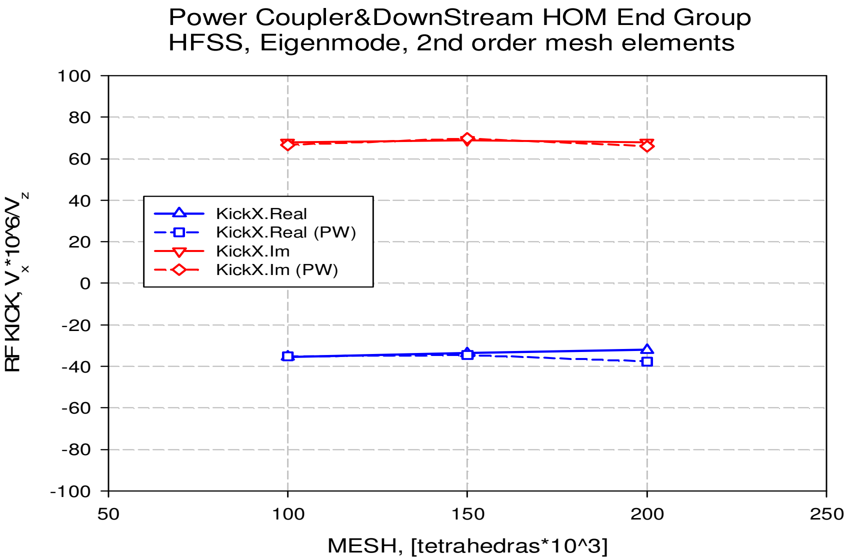



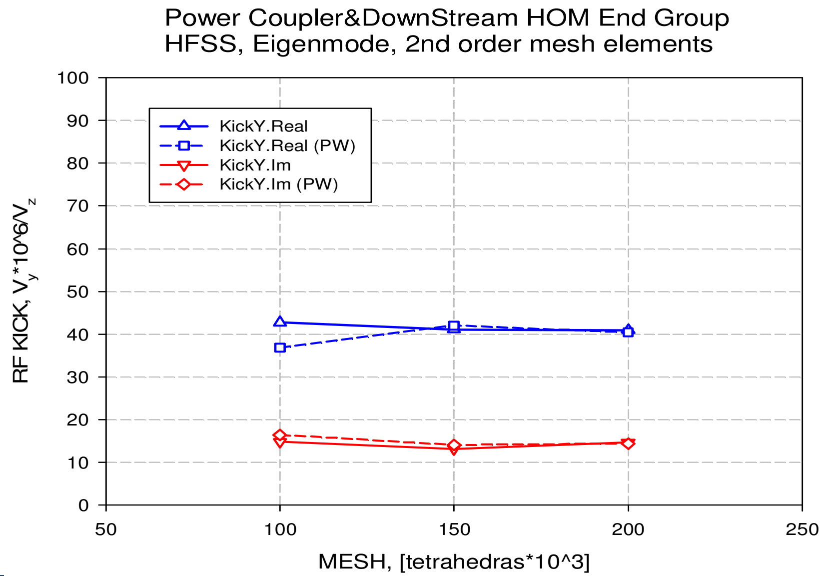



# HFSS Convergence



# Upstream Coupler

| | NEW FNAL* (HFSS & CST MWS) | | OLD FNAL (HFSS) | | SLAC (Omega3P) | DESY (Mafia) |
|---|---|---|---|---|---|---|
| | Direct | PW | Direct | PW | Direct | Direct |
| KickX $\frac{10^6 \cdot V_x}{V_z}$ | -64.5+19.5i (HFSS)<br>-64.8+19.6i (CST)<br>-64.9+18.6i (COMSOL) | -65.1+19.6i<br>-64.8+19.5i<br>-64.9+15.9i | -68.8+3.7i | -65.6+7.6i | -57.8+7.0i | -57.1+6.6i |
| KickY $\frac{10^6 \cdot V_y}{V_z}$ | -47.3+4.6i (HFSS)<br>-46.1+4.8i (CST)<br>-46.5+4.1i (COMSOL) | -46.4+4.8i<br>-46.2+4.9i<br>-46.4+2.7i | -48.3-3.4i | -53.1-2.1i | -40.9-3.5i | -41.4-3.5i |

# Downstream Coupler

| | NEW FNAL* (HFSS & CST&COMSOL) | | OLD FNAL (HFSS) | | SLAC (Omega3P) | DESY (Mafia) |
|---|---|---|---|---|---|---|
| | Direct | PW | Direct | PW | Direct | Direct |
| KickX $\frac{10^6 \cdot V_x}{V_z}$ | -34.0+65.7i (HFSS)<br>-32.2+68.4i (CST)<br>-35.1+68.7i (COMSOL) | -33.1+66.1i<br>-32.2+68.4i<br>-35.5+65.2i | -36.5+66.1i | -27.3+67.2i | -25.1+51.4i | -25.0+51.5i |
| KickY $\frac{10^6 \cdot V_y}{V_z}$ | 39.4+14.9i (HFSS)<br>41.2+15.8i (CST)<br>41.7+14.7i (COMSOL) | 39.8+12.4i<br>41.1+15.9i<br>41.4+15.8i | 41.0+14.5i | 40.9+12.8i | 36.5+8.9i | 32.2+5.2i |

# Total RF-kick

| | NEW FNAL* (HFSS & CST MWS & COMSOL) | | OLD FNAL (HFSS) | SLAC (Omega3P) | DESY (Mafia) |
|---|---|---|---|---|---|
| | Direct | Direct | Direct | Direct | Direct |
| KickX $\frac{10^6 \cdot V_x}{V_z}$ | Up & Down Ends | Full Structure | -105.3+69.8i | -86.0+60.7i | -82.1+58.1i |
| | -98.5+85.2i (HFSS) | - | | | |
| | -97.0+88.0i (CST) | - | | | |
| | -99.9+87.3i (COMSOL) | -104.3+80.0i** | | | |
| KickY $\frac{10^6 \cdot V_y}{V_z}$ | Up & Down Ends | Full Structure | -7.3+11.1i | -4.6+5.6i | -9.2+1.8i |
| | -7.9+19.5i (HFSS) | - | | | |
| | -4.9+20.6i (CST) | 0.1+21.2i** | | | |
| | -4.8+18.8i (COMSOL) | -8.3+17.1i** | | | |

** The End-group effect is taken into account during $V_z$ calculation*
*** A phase-lock mistake was found in a post processing.*
**** For reference only, results were not checked for convergence*

# Conclusions

- Calculation convergence checked and achieved;
- RF kick calculation results made by three codes coincide very well;
- Results for separate coupler calculations and for the full structure are the same;
- Normalization factor is checked and improved;
- Phase lock mistake in upstream coupler calculation was found and fixed;
- The RF kick results may be trusted.

The result for $Q_{ext}=3\times10^6$ (averaged over results of different codes)

$$V_y/V_z = (-5.9+19.6i)\times10^{-6};$$
$$V_x/V_z \approx (-98.5+86.8i)\times10^{-6}.$$