Wake Fest 07 - ILC wakefield workshop at SLAC

Coupler RF kick simulations.

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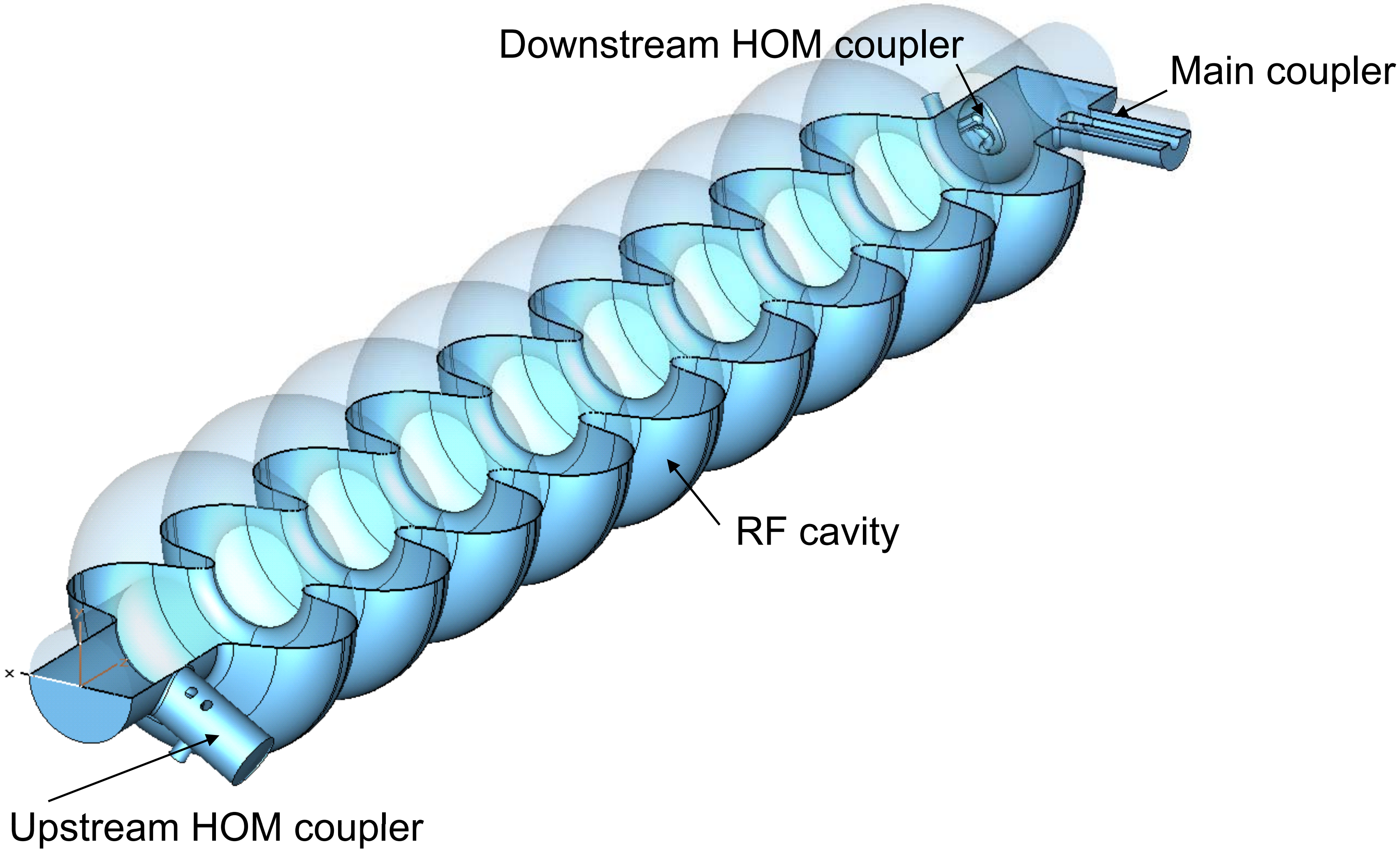
Fermi National Laboratory

11 December, 2007

ILC RF cavity with the HOM and input couplers:

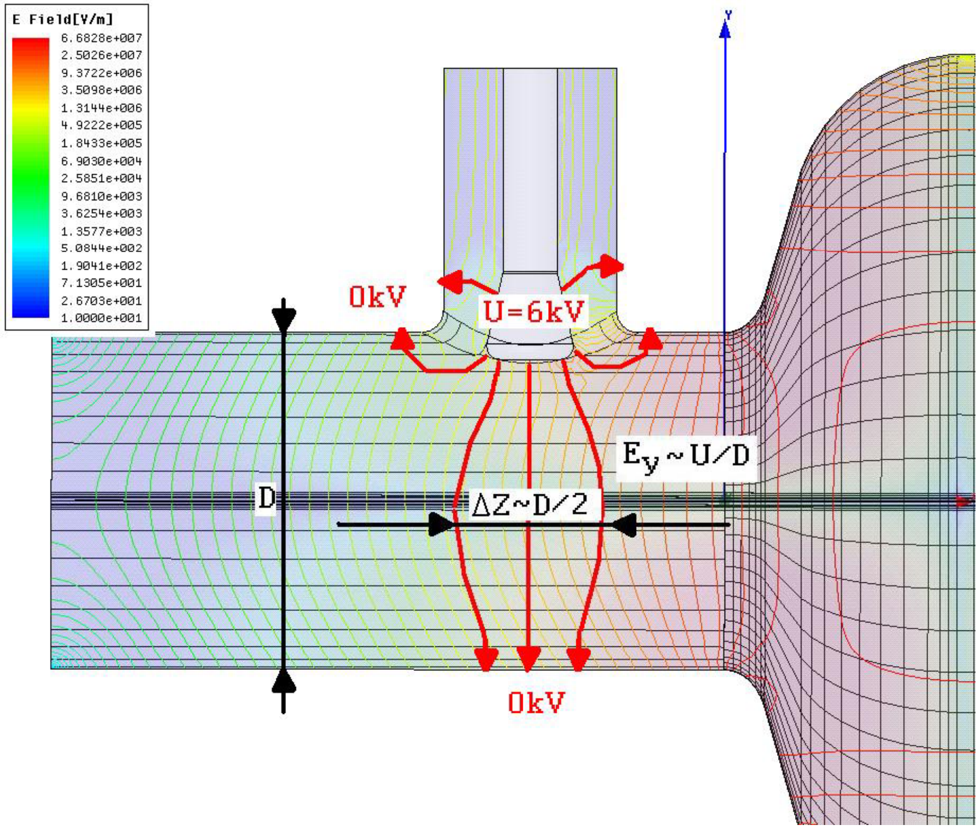


- The couplers break the RF field symmetry and cause transverse RF kick.
- The couplers break the symmetry of the cavity and cause transverse wake field.
- Both RF kick and wake fields may be a reason of a beam emittance dilution.
- DESY* made the first calculations of the RF kick and wake fields. The calculations show that both RF kick and wake fields may be a serious problem that could require the cavity improvement.
- More detailed investigations are necessary!

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

RF kick

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.

DESY results (MWS, two different meshes)

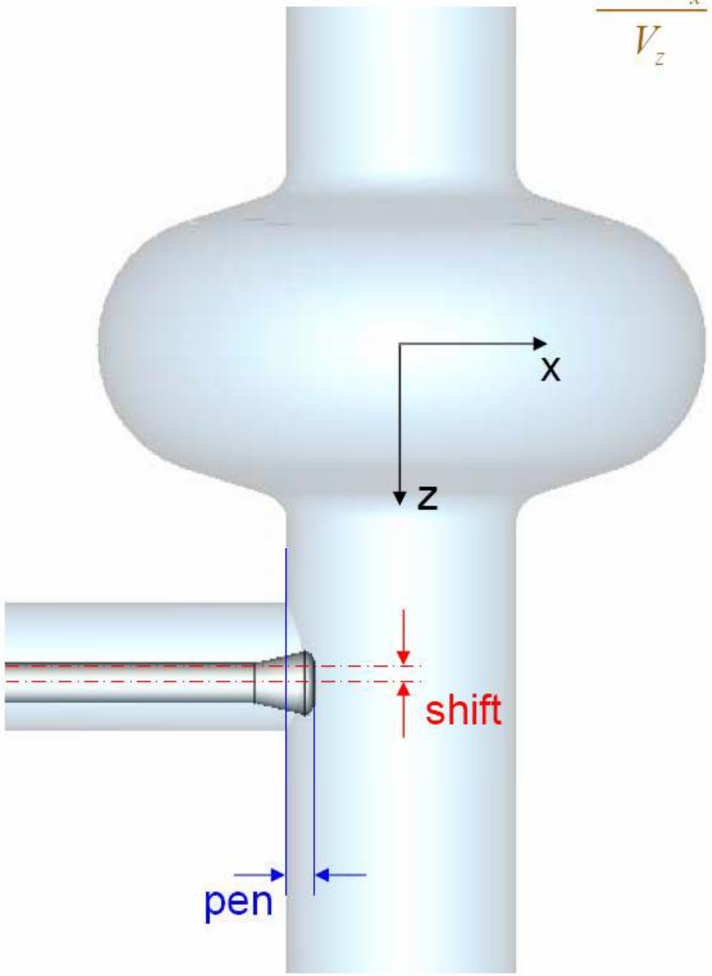
kick of main coupler

scaled for TTF 9 cell cavity

problem: field asym. caused by asym. MWS mesh

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

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



MWS-discretization: 30lines@2GHz

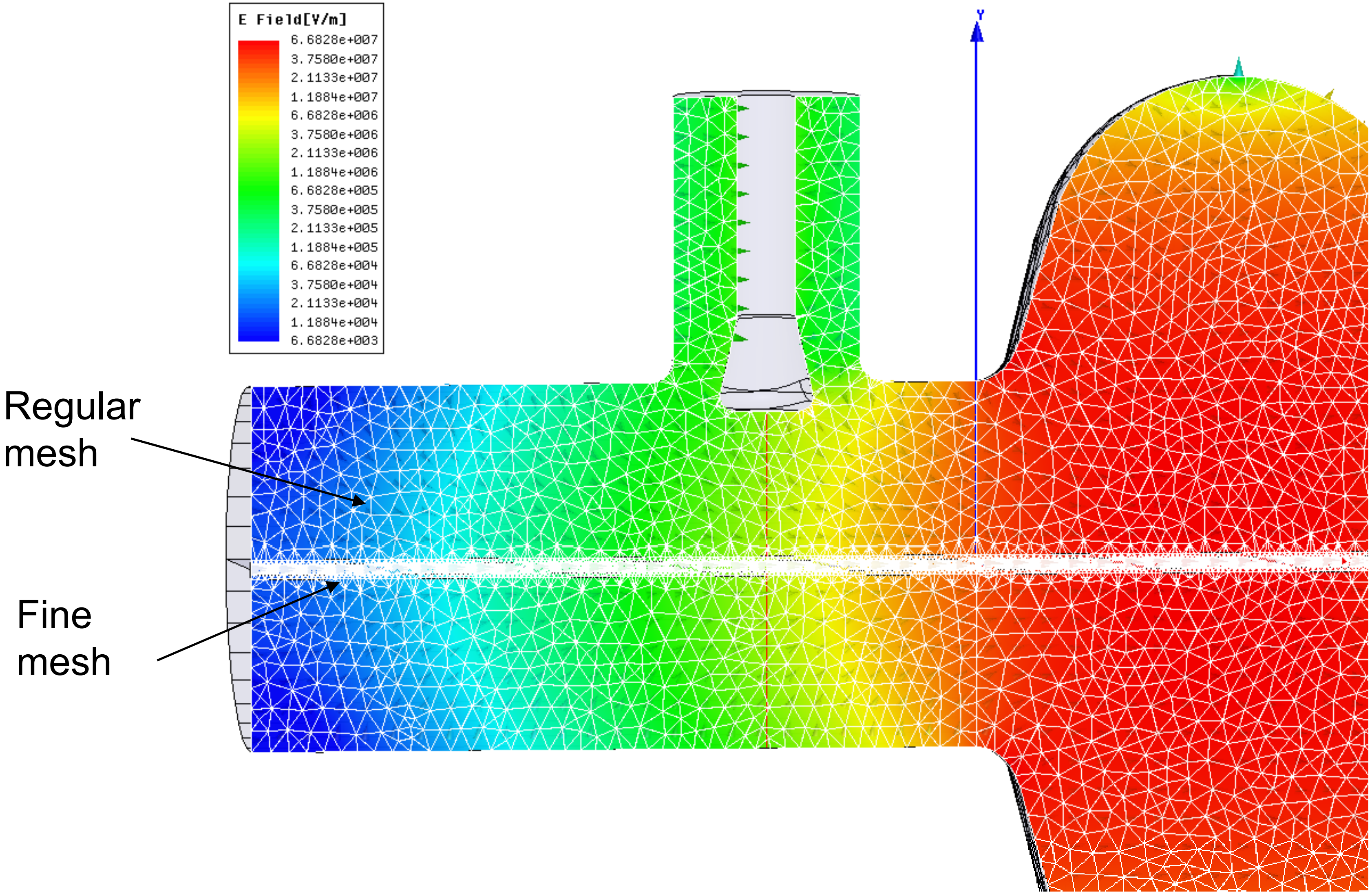
pen/mm \ shift/mm	-5	0	5
4.5	3.347 19.9+j35.9	4.490	
6	2.466 47.6+j40.9	3.384 30.6+j54.3	
7.5	1.781 84.5+j50.0	2.4482 58.7+j65.0	3.987 37.4+j68.1
9	1.272 130.3+j56.9	1.940 93.4+j83.3	3.464 65.1+j88.9
10.5	0.9662	1.663	2.583 100.9+j86.5
12		1.351	2.099 141.1+j65.0

MWS-discretization: 50lines@2GHz

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

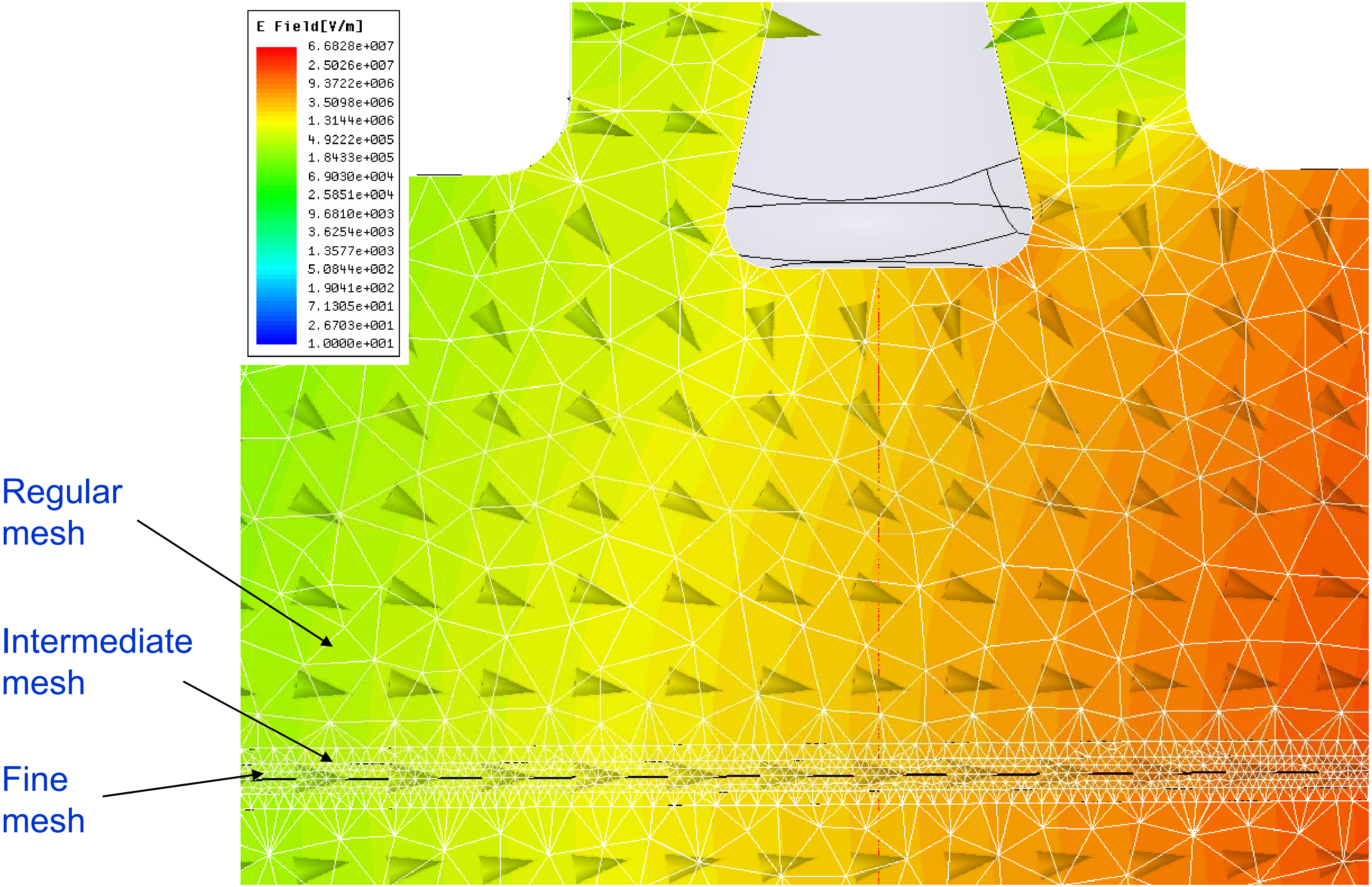
DESY M. Dohlus Sep 2003

Mesh generation for HFSS for high-precision field calculations near the axis:

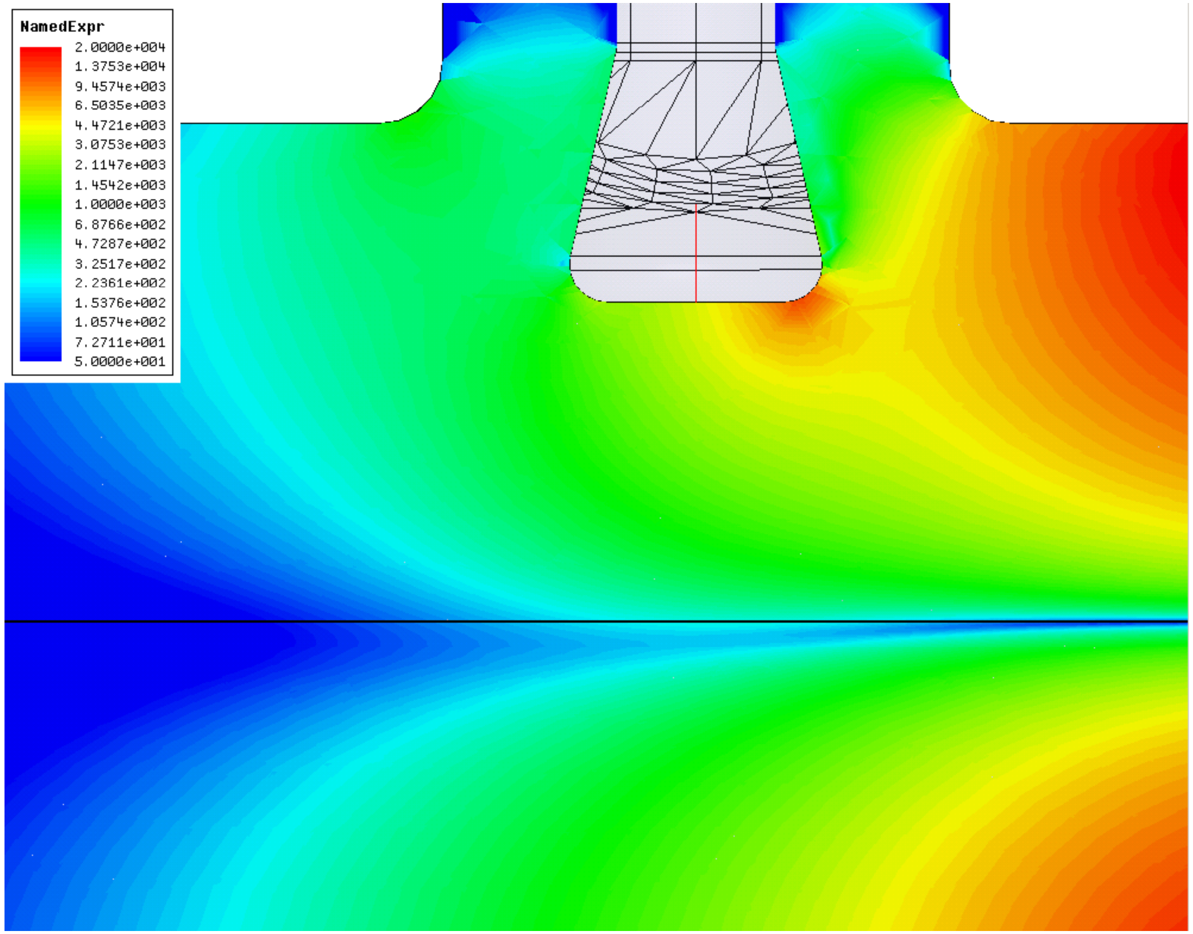


Total number of the mesh nodes is up to 500,000

Zoomed mesh near the axis:

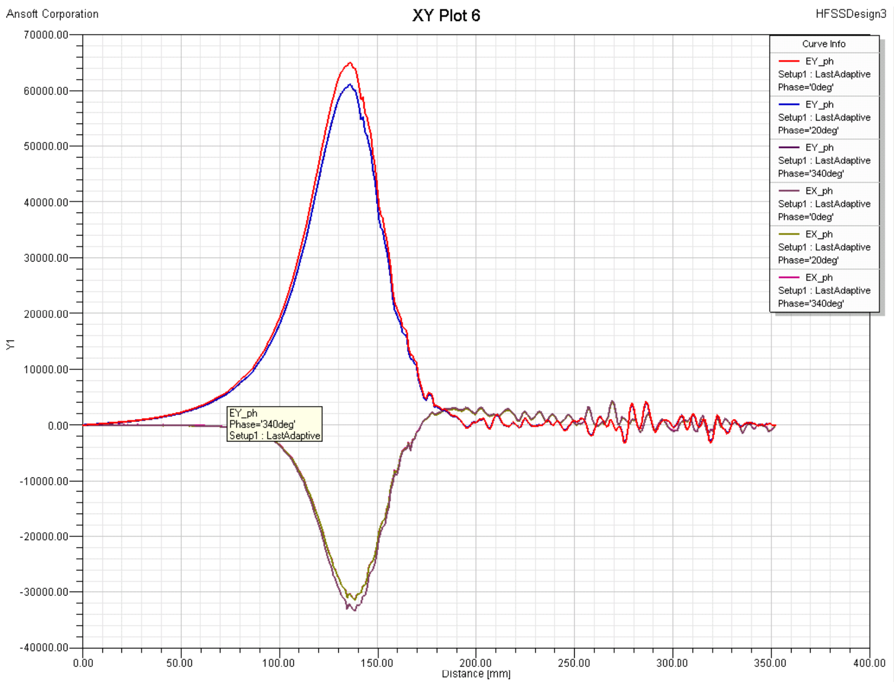


Results of the main coupler simulations:

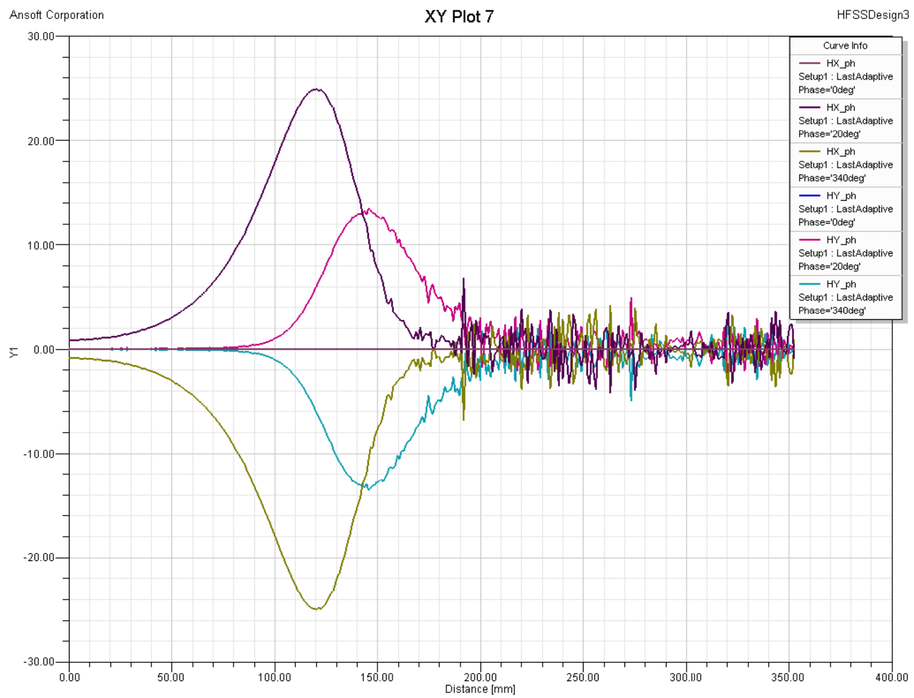


(Strong coupling case)

Axial transverse fields for HOM coupler at different RF phases:



Electric field



Magnetic field

CALCULATION OF RF KICK. UPSTREAM END

$$Vx := \int_0^{Zend} \left[(EX(z) - HY(z)) \cdot \exp\left[i \cdot (\kappa \cdot z - \phi)\right] \right] dz$$

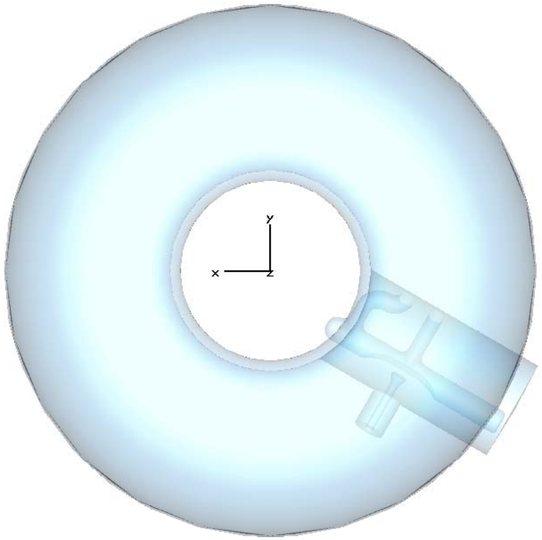
$$Vy := \int_0^{Zend} \left[(EY(z) + HX(z)) \cdot \exp\left[i \cdot (\kappa \cdot z - \phi)\right] \right] dz$$

Direct integration of fields component
(Lorentz force equation)

$$\Delta \vec{V}_\perp = i \frac{v}{\omega} \vec{\nabla}_\perp (\Delta V_{II})$$

Panofsky-Wenzel (PW) theorem

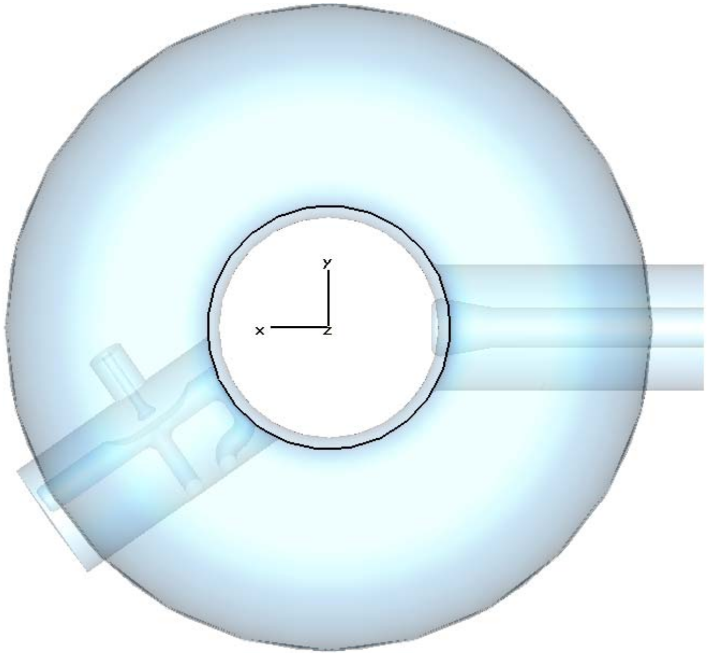
(in order to cross-check direct calculations only)



	Direct	PW	M.Dohlus
$\frac{10^6 \cdot V_x}{V_z}$	-68.8+3.7i	-65.6+7.6i	-57.1+6.6i
$\frac{10^6 \cdot V_y}{V_z}$	-48.3-3.4i	-53.1-2.1i	-41.4-3.5i

Results of calculations and comparison with M. Dohlus (DESY) data.

DOWNSTREAM END

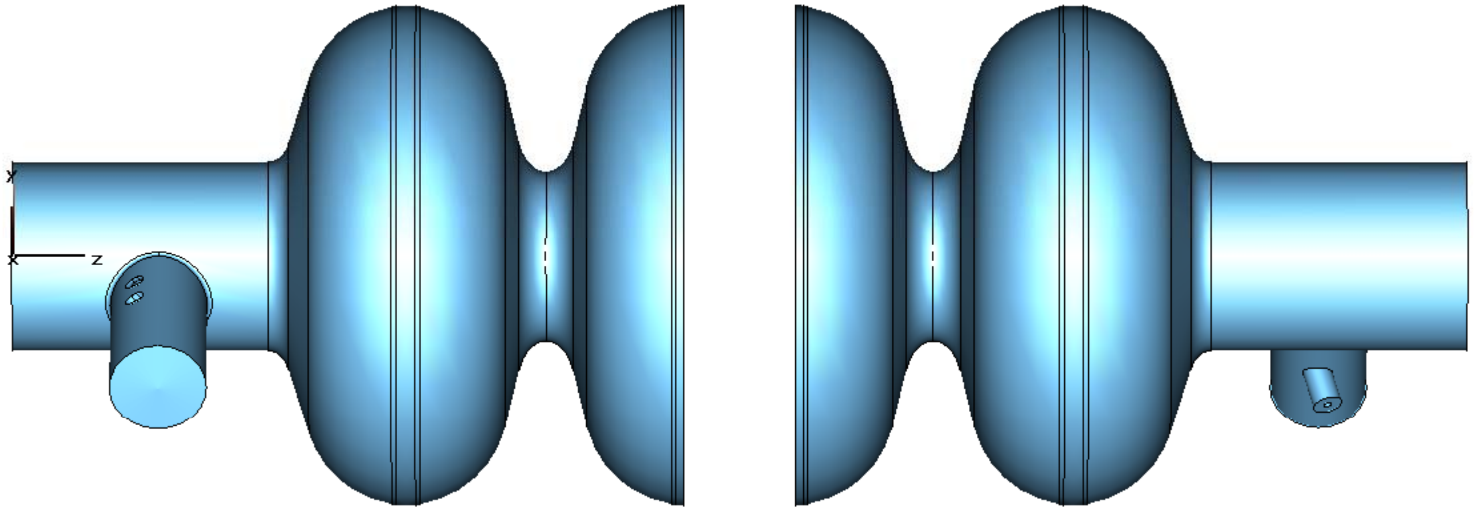


FULL equipped	Direct	PW	M.Dohlus
$\frac{10^6 \cdot V_x}{V_z}$	-36.5+66.1i	-27.3+67.2i	-25.0+51.5i
$\frac{10^6 \cdot V_y}{V_z}$	41.0+14.5i	40.9+12.8i	32.16+5.2i

Only PC	Direct	PW	M.Dohlus
$\frac{10^6 \cdot V_x}{V_z}$	35.6+76.5i	36.7+73.6i	34.3+55.7i

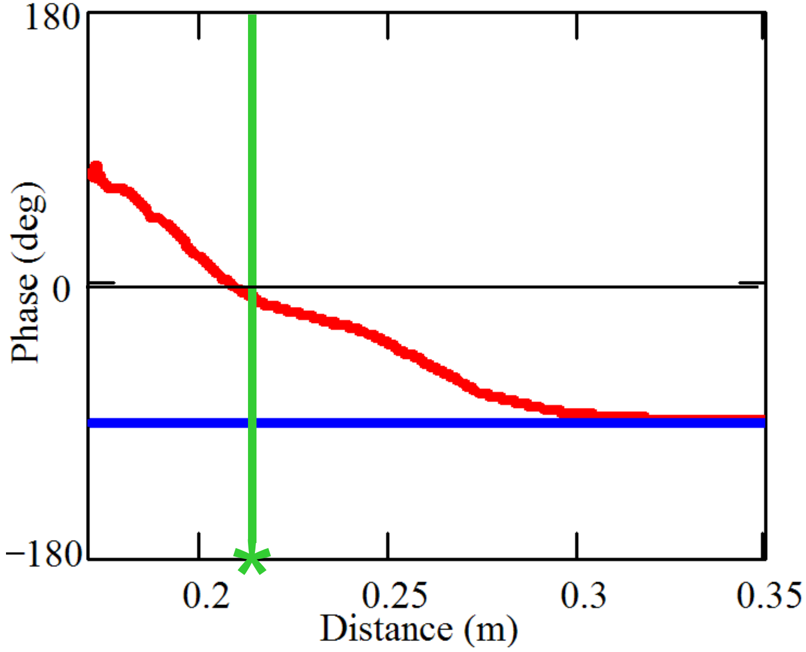
Only HOM	Direct	PW	M.Dohlus
$\frac{10^6 \cdot V_x}{V_z}$	-73.7-13.2i	-71.6-9.7i	n/a
$\frac{10^6 \cdot V_y}{V_z}$	41.1+15.9i	40.3+14.6i	n/a

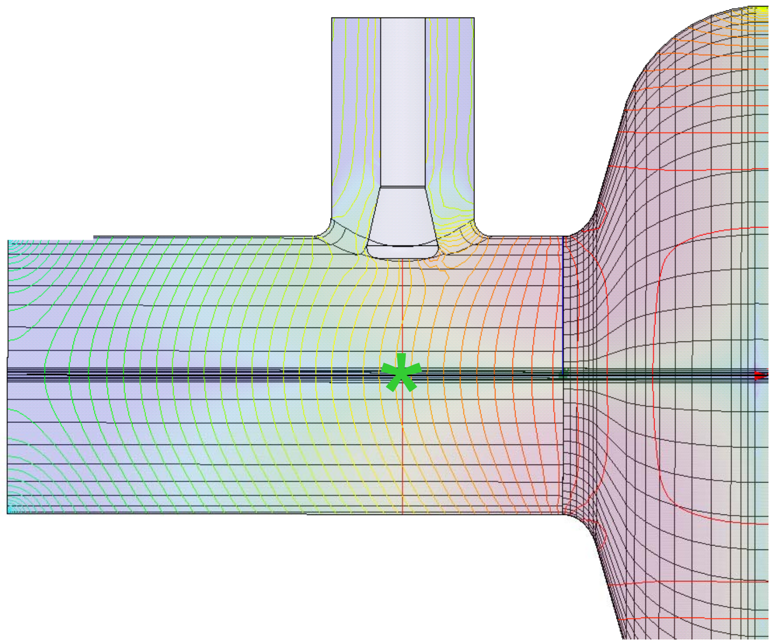
MWS simulations were done as well, and the results are consistent to the result of HFSS simulations.



$$V_x(-z,-x,y) = V_x^*(z,x,y)$$

$$V_y(-z,-x,y) = -V_y^*(z,x,y)$$



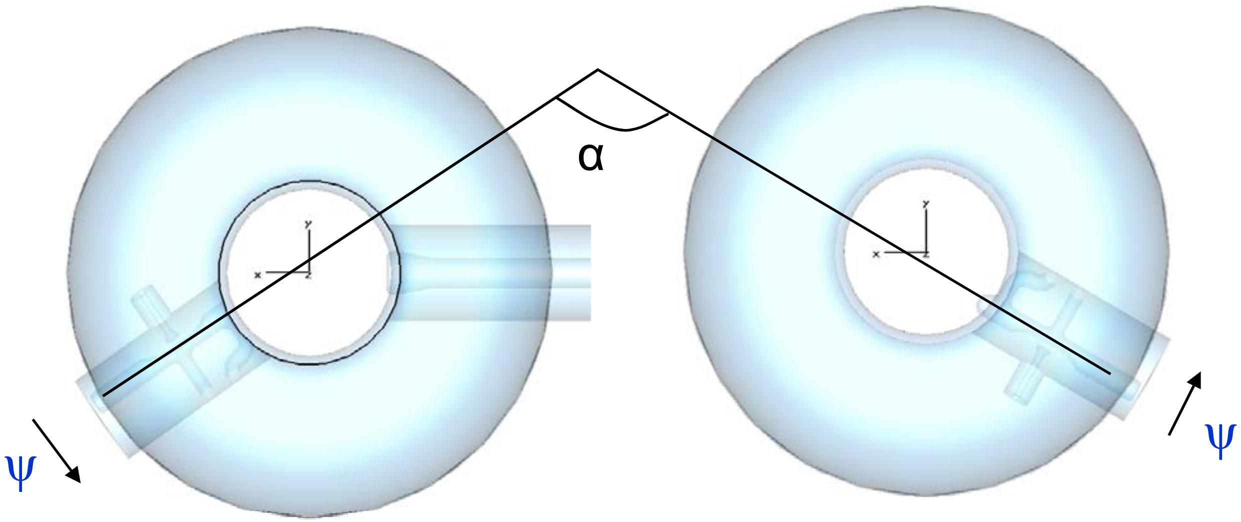


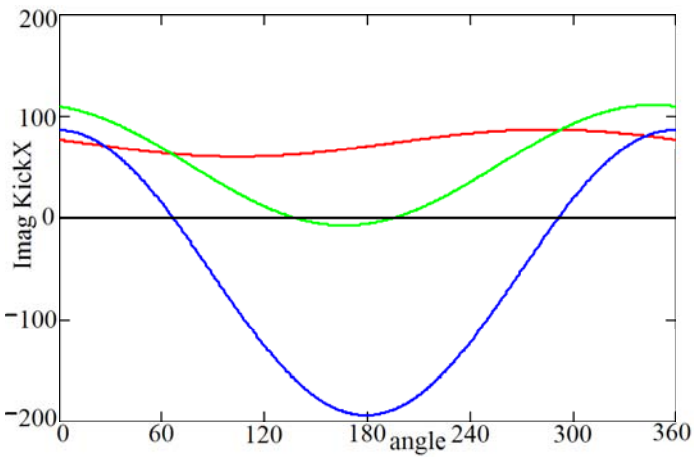
Phase shift between electric and magnetic fields along axis.

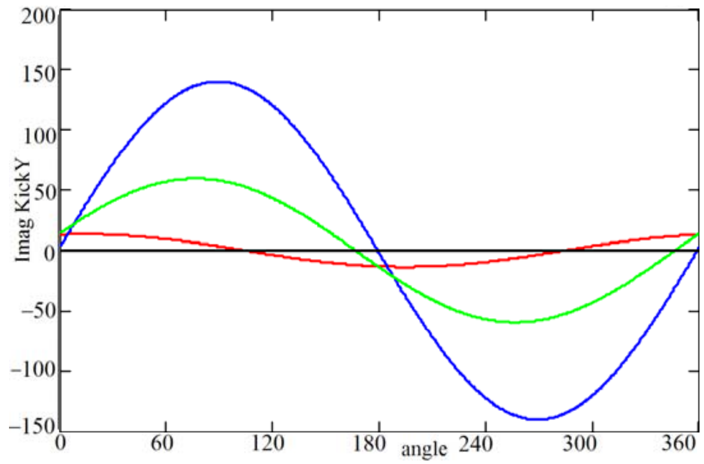
Red line – Power Coupler only (TW).

Blue line – HOM Downstream Coupler only (SW).

* - position of antenna central axis.





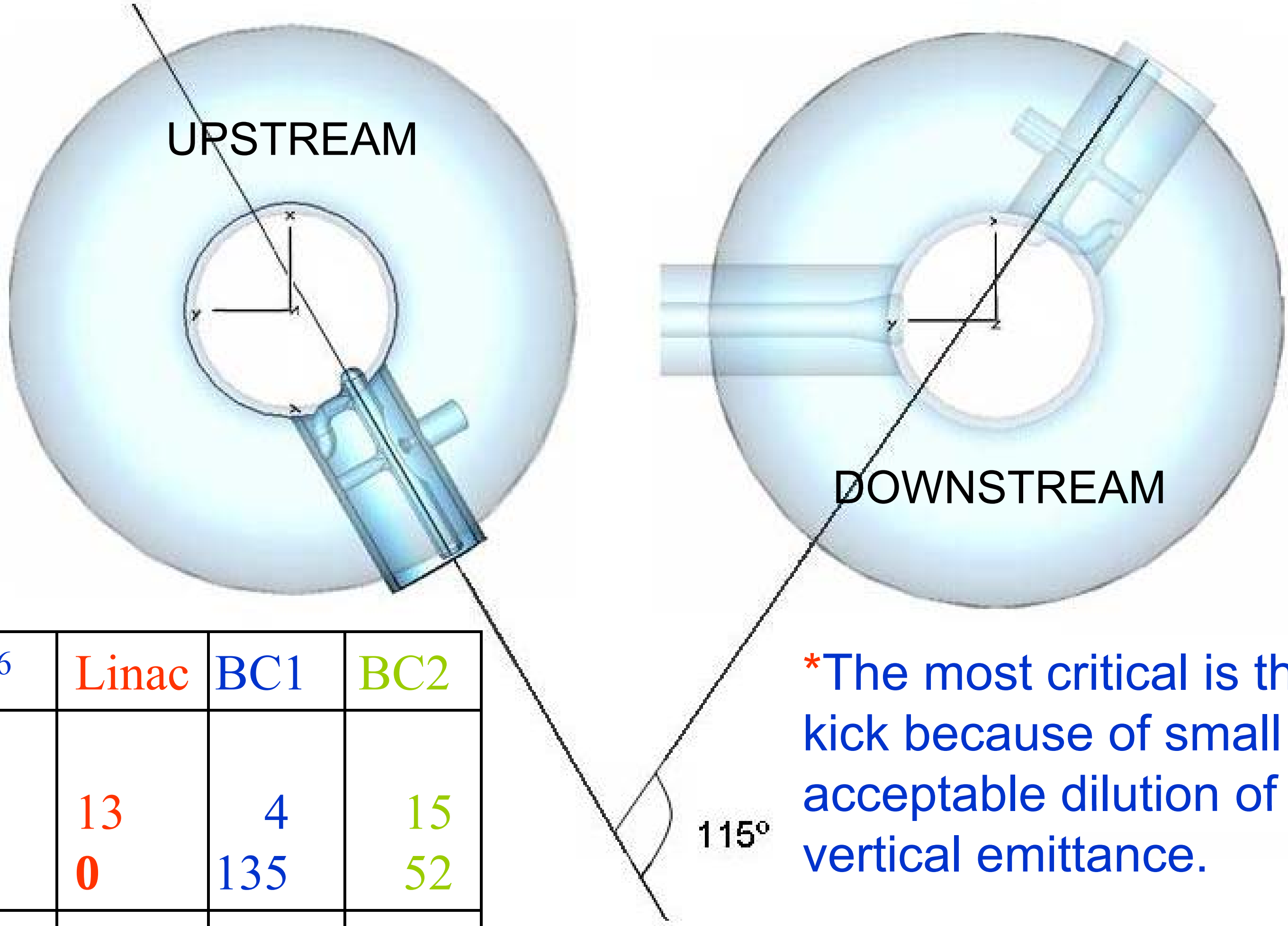


Imaginary parts of V_x (left) and V_y (right) vs. angle of rotation of both HOM couplers simultaneously when the angle between the coupler is fixed and equal to 115º *.

Red curve for Linac (φ=-5.1°), blue for BC1 (φ=-105°), and green for BC2 (φ=-27.6°)

*Angle α=115º provides optimal damping of both polarization of dipole modes and was determined experimentally.

Optimal position of the HOM coupler vs. the main coupler (rotation angle ψ = 104°)



Im(Kick)10^6	Linac	BC1	BC2
Vertical			
ψ =0°	13	4	15
ψ =104°	**0**	135	52
Horizontal			
ψ =0°	76	86	109
ψ =104°	60	-91	24

*The most critical is the vertical kick because of small acceptable dilution of the vertical emittance.

Note, that the kick spread is proportional to the bunch length σ: $\Delta p_{\perp}/p \sim \mathrm{Im(kick)} \cdot 2\pi\sigma/\lambda_{RF}$

Estimations of the vertical emittance dilution caused by RF kick:

Main linac.

Simple model:

$$\frac{\partial^2 y}{\partial z^2}+\frac{1}{\gamma(z)}\cdot\frac{\partial\gamma(z)}{\partial z}\cdot\frac{\partial y}{\partial z}+\frac{y}{\beta^2}=\frac{2\pi\nu G s\gamma_0}{\lambda_{RF}U_0\gamma(z)},$$

(*s*- distance to the bunch center)

$$\gamma\varepsilon\approx\gamma(z_{\max})y_{\max}y'_{\max}=\frac{\pi^2\nu^2G^2\sigma^2\beta^3\gamma_0}{\lambda_{RF}^2U_0^2}\left[1+\left(\frac{\gamma_0}{\gamma(z)}\right)^{\frac{1}{2}}\right]$$

(β = *const* over the linac, $\gamma(z_{max}) >> \gamma_0$)

$\nu = G_y/G = 13\cdot10^{-6}$ (vertical kick per unit length, current design);

G=31.5 MeV/m (acceleration gradient);

σ=0.3 mm (bunch length);

β =80 m (average β–function) ;

U_0=15 GeV (initial energy);

λ_{RF}=0.23 m (RF wavelength);

$\gamma_0 = 3\cdot10^4$ (15 GeV);

$\gamma(z_{max}) = 5\cdot10^5$ (250 GeV).

$\delta(\gamma\varepsilon) \approx$ 2.4·10-10 m = 0.24 nm.

More realistic beam dynamics simulations (LUCTETIA) are in progress.

RTML, Bunch Compressor-1.

One unit, 3 cryo-modules, each CM contains 8 RF cavities and quad.

Present coupler orientation: $\nu_1 = G_y/G = 4\cdot 10^{-6}$ –vertical RF kick.

U_0=5 GeV, σ=9mm,$\langle\beta_y\rangle\approx$30m, $\gamma\varepsilon_y$=20 nm.

$\delta(\gamma\varepsilon_y) \approx 1/4 \cdot \gamma\sigma_y\sigma_{y'}$, where

$\sigma_y = \sqrt{(\gamma\varepsilon_y)\beta_y/\gamma} = 13\mu m$ and $\sigma_{y'} = \frac{\Delta p_y c}{U_0} = \frac{2\pi\nu_1 G l \sigma}{U_0 \lambda_{RF}} = 1.5\times 10^{-7} rad;$

l≈25 m – length of RF system. Thus, $\delta(\gamma\varepsilon_y) \approx 5nm$

Required value of the vertical emittance is 20 nm. The HOM coupler rotation by ~180° may reduce the vertical emittance dilution in BC1.

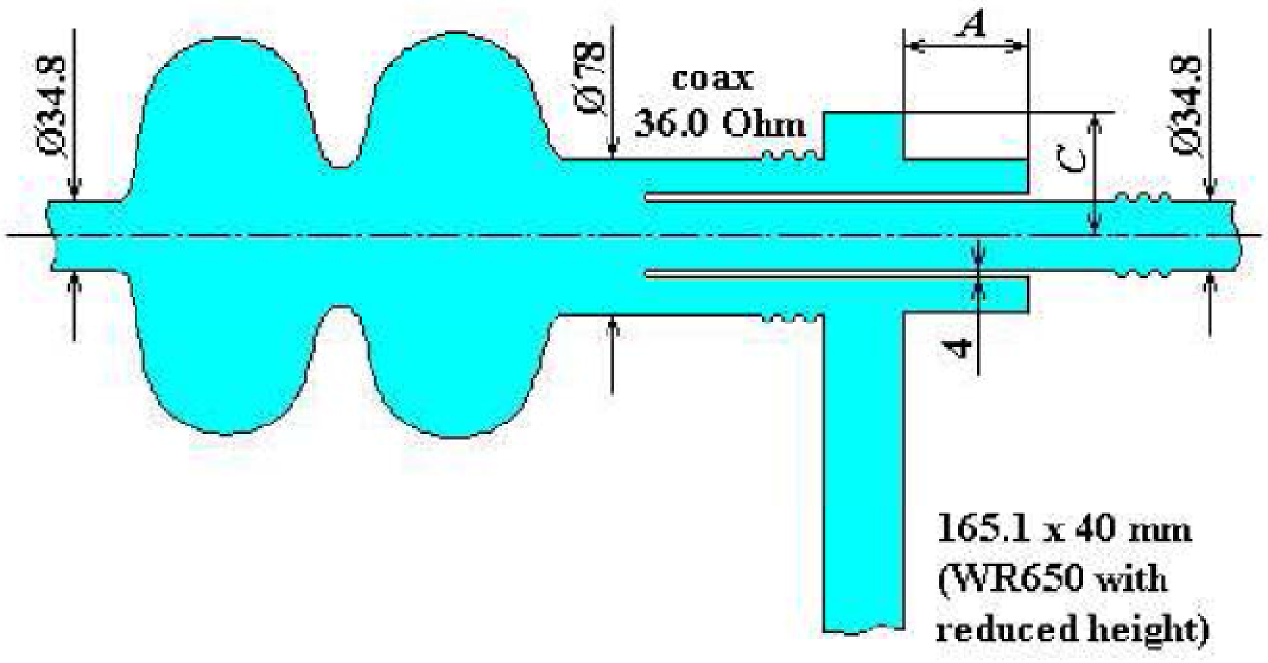
RTML, Bunch Compressor-2.

Present coupler orientation: $\nu_1 = G_y/G = 15\cdot 10^{-6}$ –vertical RF kick.

U_0=5 GeV, U_{max}=15 GeV, σ=1mm,$\langle\beta_y\rangle\approx$80m.

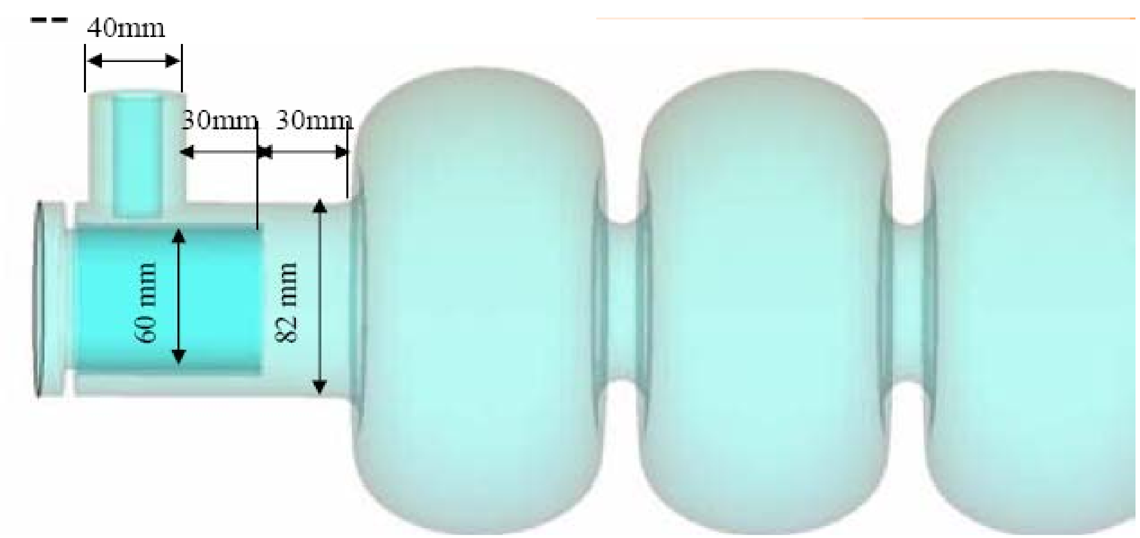
$$\gamma\varepsilon \approx \gamma(z_{\max}) y_{\max} y'_{\max} = \frac{\pi^2\nu^2 G^2\sigma^2\beta^3\gamma_0}{\lambda_{RF}^2 U_0^2}\left[1+\left(\frac{\gamma_0}{\gamma(z)}\right)^{\frac{1}{2}}\right] = 13.5nm$$

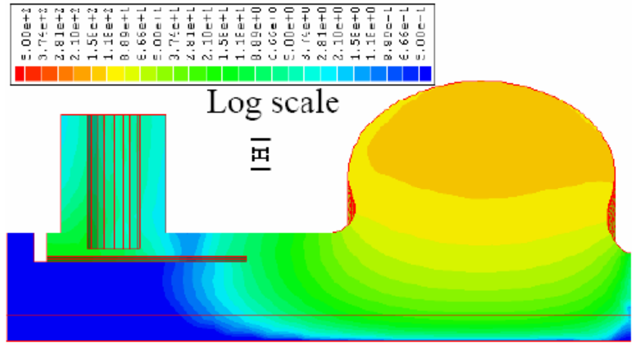
Alternative axi-symmetrical couplers are under consideration.

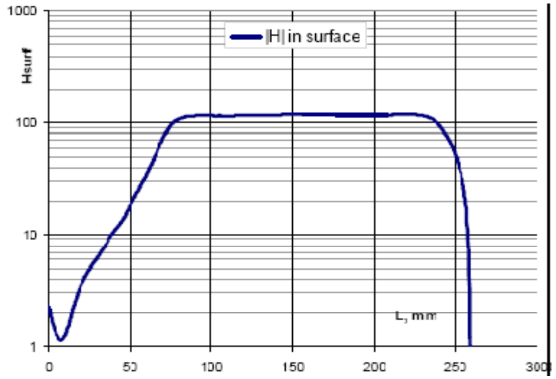


An example of waveguide-coaxial coupler
(S. Belomestnykh, et al. ERL 02-8, Cornell, 2002)

A new idea of a compact detachable coupler unit* that provides axial symmetry of the RF field and the cavity geometry in the beam channel:





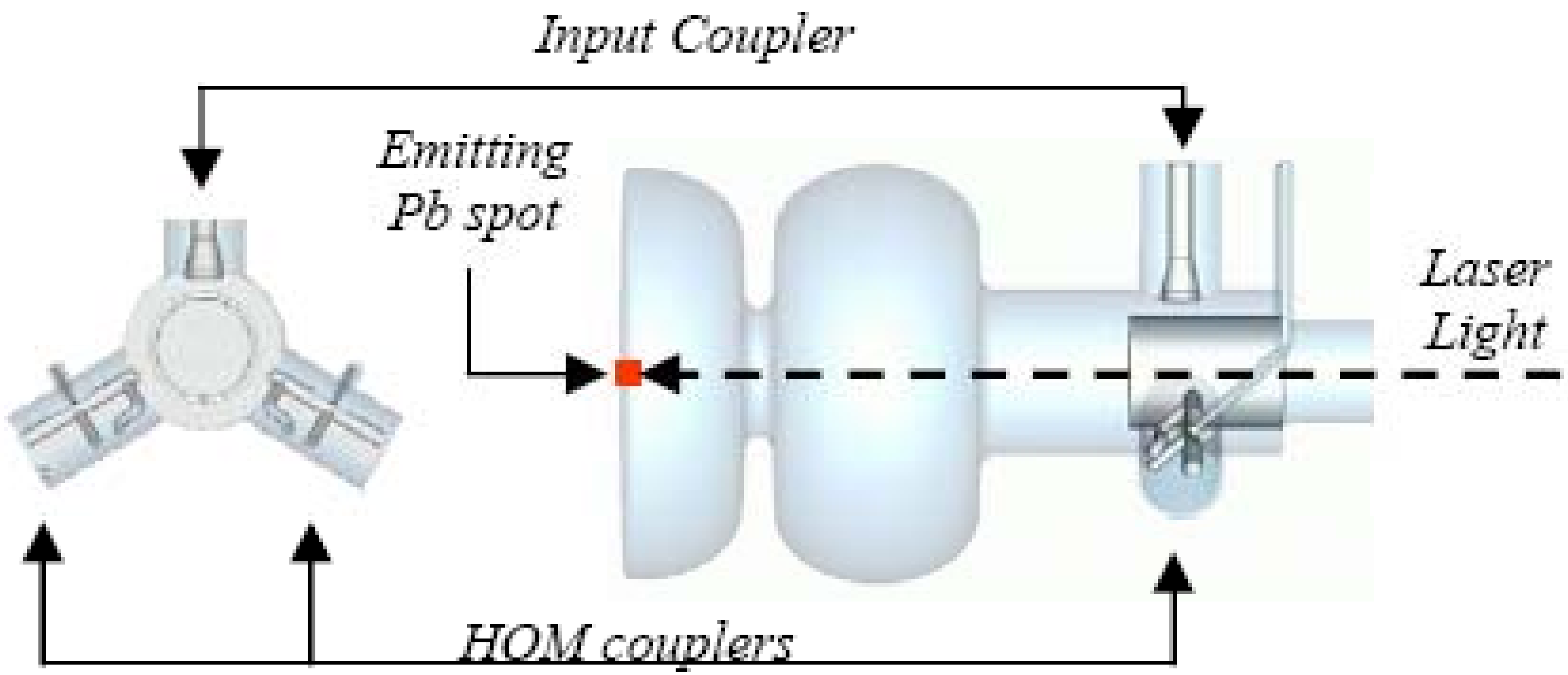


➢The unit provides both required coupling of the operating mode and suppression of the HOMs;

➢Simulations show that it is free of multipacting.

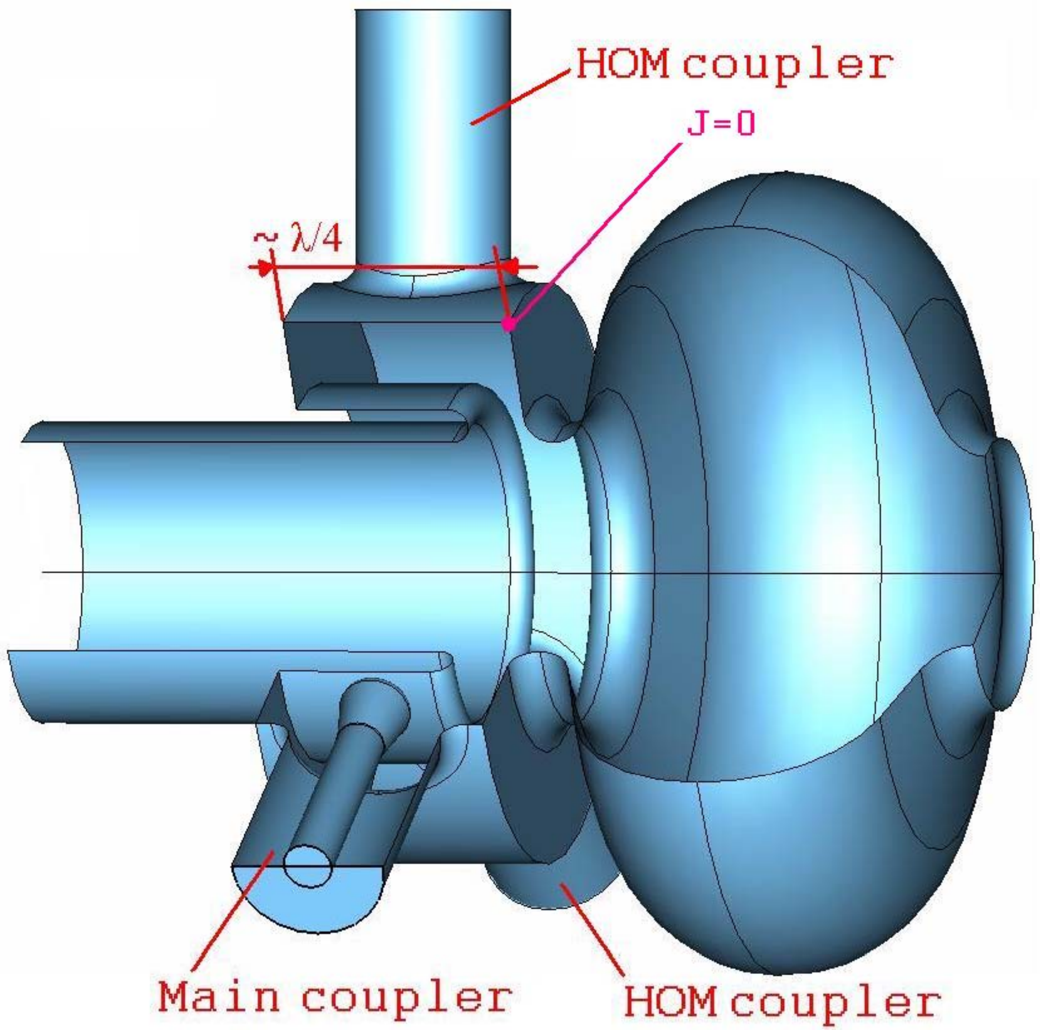
*N. Solyak, T. Khabiboulline, 2d ILC Workshop, Snowmass, Aug 14-18, 2005

The coupler for Nb-Pb superconducting RF gun*:



*J. Sekutowicz et al, PAC 2007.

An idea of a compact detachable quarter wave coupler unit that provides axial symmetry of the RF field and the cavity geometry in the beam channel:



Summary

- The beam emittance dilution caused by RF kick looks to be significant for the main linac. For BC1 and BC2 the emittance dilution caused by RF kick is unacceptable and should be reduces.

- The active part of the RF kick should be compensated by the linac feedback system. Further investigations are necessary.

- Detailed beam dynamics simulations in the main linac, BC1 and BC2 are in progress.

- An alternative axi-symmetrical couplers are under consideration.