Coupler RF Kick Simulation Using Omega3P and S3P

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Outline

- Introduction
- Works by others on RF kick
- High accuracy parallel finite element modeling of the end-groups using Omega3P and S3P
- Transverse kick calculation
- RF kick of TDR cavity and cavities with modified HOM orientations
- Kick cancellation using cavity pairs (?)
- Summary

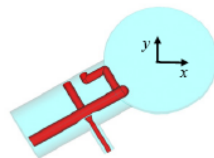
Introduction

- FM and HOM couplers at the end groups breaks the symmetry of the accelerating mode.
- Dipole field content of the asymmetry field cause transverse deflection of the beam centroid and bunch head-tail transverse kicks.
- Important to understand effect on beam dynamics.
- Mitigate the effects if effect larger than acceptable.

Dohlus's RF Kick Simulation

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

$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = 2$
$\frac{Vx}{10^{-6}} = -50.479 + 6.799i$
$\frac{Vy}{10^{-6}} = -42.924 - 2.275i$

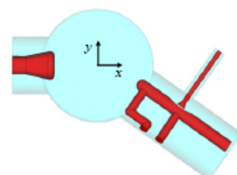
$10^3 \cdot xoff = -2 \quad 10^3 \cdot yoff = 0$
$\frac{Vx}{10^{-6}} = -59.102 + 8.202i$
$\frac{Vy}{10^{-6}} = -48.701 - 3.873i$

$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = 0$
$\frac{Vx}{10^{-6}} = -57.112 + 6.649i$
$\frac{Vy}{10^{-6}} = -41.413 - 3.469i$

$10^3 \cdot xoff = 2 \quad 10^3 \cdot yoff$
$\frac{Vx}{10^{-6}} = -54.754 + 5.382i$
$\frac{Vy}{10^{-6}} = -35.112 - 3.051i$

$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = -2$
$\frac{Vx}{10^{-6}} = -64.117 + 6.215i$
$\frac{Vy}{10^{-6}} = -38.919 - 4.676i$

RF kick



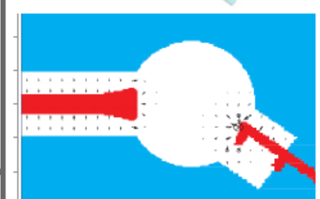
downstream coupler,
new, zpen/mm=6, forward
x/mm =… y/mm=…

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

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

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

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



$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = 2$
$\frac{Vx}{10^{-6}} = -18.925 + 51.83i$
$\frac{Vy}{10^{-6}} = 39.418 + 8.879i$

$10^3 \cdot xoff = -2 \quad 10^3 \cdot yoff = 0$
$\frac{Vx}{10^{-6}} = -16.597 + 56.049i$
$\frac{Vy}{10^{-6}} = 27.217 + 4.356i$

$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = 0$
$\frac{Vx}{10^{-6}} = -25.01 + 51.529i$
$\frac{Vy}{10^{-6}} = 32.166 + 5.242i$

$10^3 \cdot xoff = 2 \quad 10^3 \cdot yoff = 0$
$\frac{Vx}{10^{-6}} = -32.552 + 47.906i$
$\frac{Vy}{10^{-6}} = 38.866 + 6.337i$

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

$10^3 \cdot xoff = 0 \quad 10^3 \cdot yoff = -2$
$\frac{Vx}{10^{-6}} = -30.627 + 50.36i$
$\frac{Vy}{10^{-6}} = 24.394 + 1.725i$

Brandon Buckley - Cornell

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Transverse emittance dilution due to coupler kicks in linear accelerators

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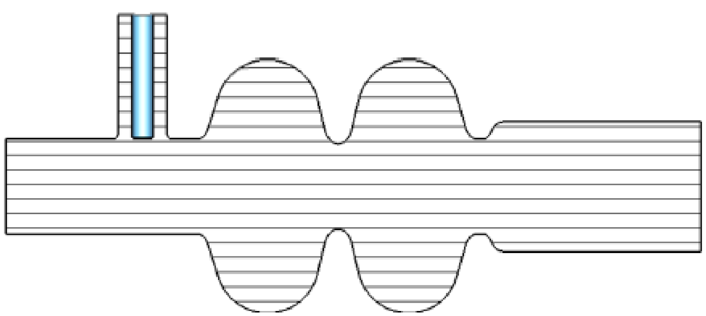
accelerating cavity with the coaxial coupler included (Fig. 1). The cavity used for simulation is a two cell model of the seven cell TESLA-type cavity to be used in the proposed Cornell ERL. A two cell cavity instead of a seven cell cavity is used in order to limit the simulation time. From the standing wave profiles of MWS, complex traveling waves are modeled of which the real parts represent the true waves in the cavity. A numerical integration of these waves is performed along the central cavity axis to calculate the total change in momentum of a charged particle traveling through the cavity. The coupler kick, defined as the ratio of the transverse change in momentum and the change in momentum along the cavity axis, is calculated and input into a lattice representing the proposed Cornell ERL. A simulation of an electron bunch through the lattice is done with BMAD [9] and the total normalized emittance growth is calculated and compared for all mentioned configurations.

We find that, due to the high Q_{ext} values of the accelerating cavities, the fields on the cavity axis, including those in the vicinity of the coupler, are very well approximated by standing waves. From this approximation we formulate analytical arguments to support the results from our simulation, namely, that the orbit distortion is canceled. Furthermore, from the standing wave approximation, we present arguments to back up the results from simulations indicating that the coupler kick is independent of reflected waves in the coupler and of relative phase differences between incoming and reflected waves. Thus, our result of the cancellation of the coupler kick between adjacent cavities is unaffected by cavity detuning.

Last, we show that placing the coupler at a distance from the entrance of the cavity so as to match the phases of the coupler kick and accelerating kick minimizes the emittance increase, as does the addition of a symmetrizing stub which effectively minimizes the amplitudes of the off axis fields in the beam pipe. This additionally minimizes the orbit distortion. Important to note is that emittance growth due to higher order mode couplers can be dealt with using all of the above techniques in an analogous way.

The linac parameters used for simulations of the Cornell ERL are listed in Table I.

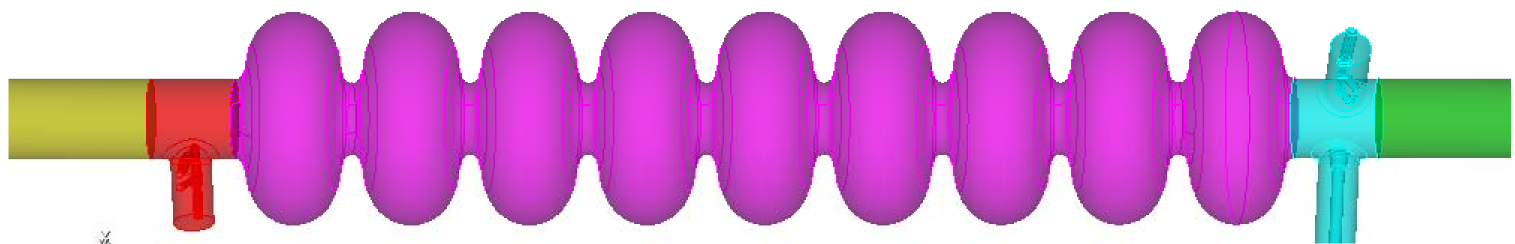


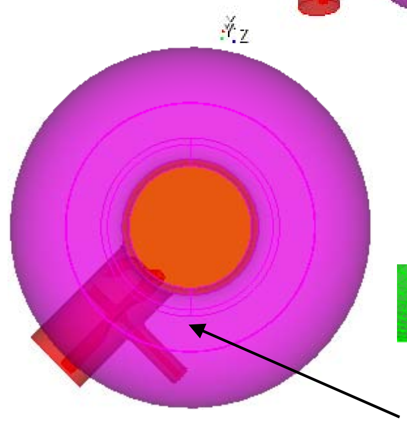
II. EMITTANCE GROWTH DUE TO COUPLER KICK

In this section an analytical expression is derived for the change in emittance of a relativistic, Gaussian distributed bunch due to a transverse rf kick in an accelerating rf cavity. We begin by defining the change in transverse momentum, in this case the y component:

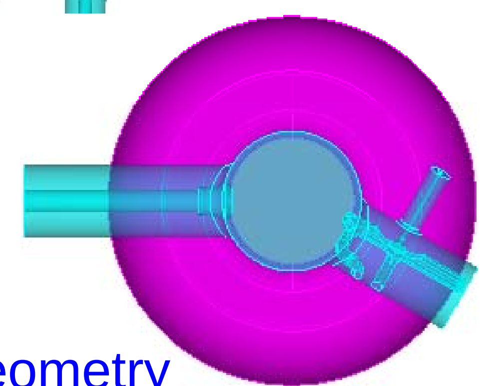
High Fidelity Geometry & Field Modeling In Omega3P & S3P

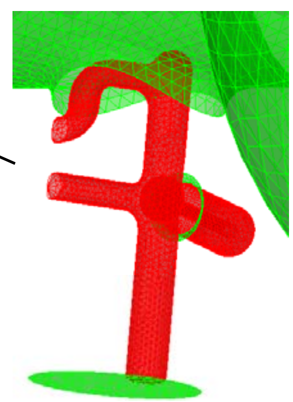
Fields in coupler regions are orders smaller than fields in the regular cells. High accuracy field modeling needed.





Complicated geometries in end groups



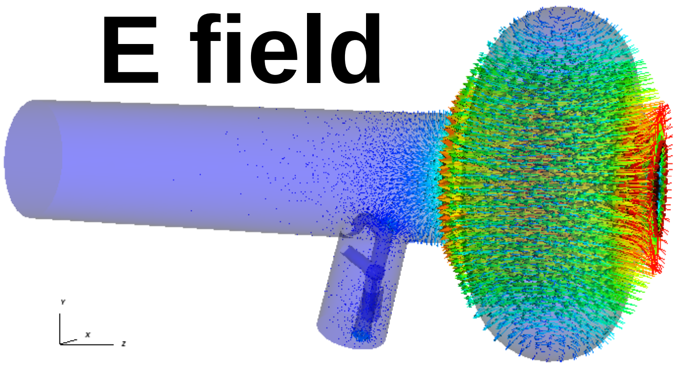


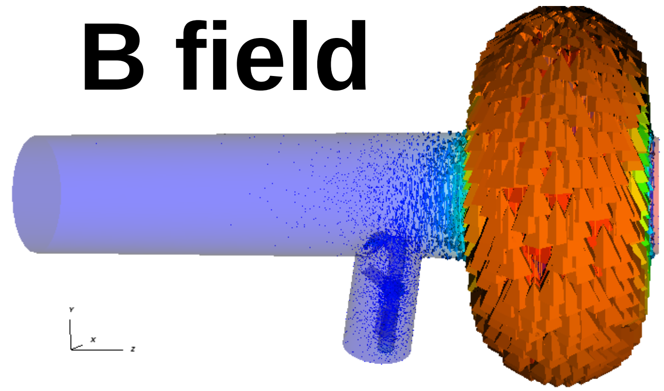
- High fidelity modeling of geometry using unstructured tet mesh
- High field accuracy using higher order interpolation base function

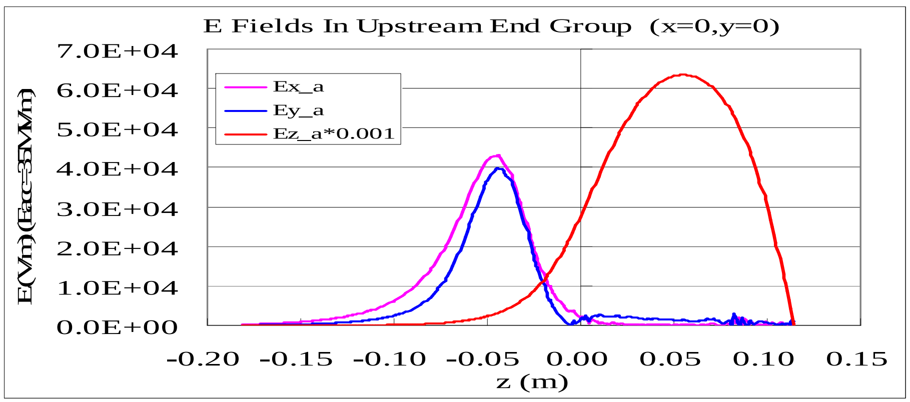
End Group Modeling

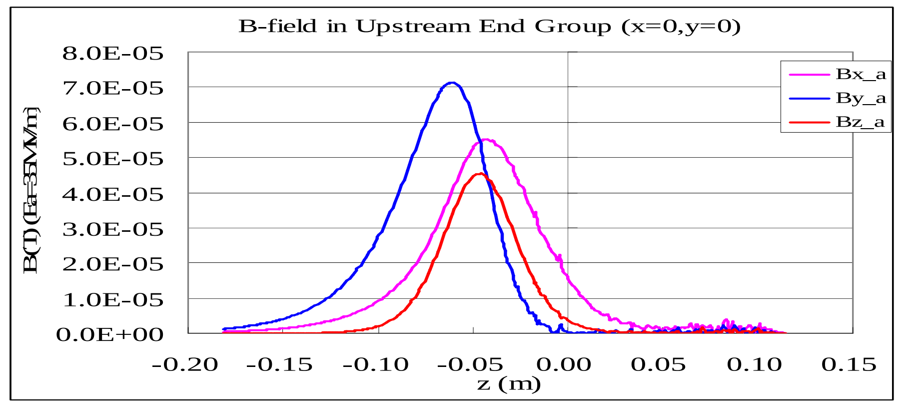
- FM coupler nominal operation condition
  - Average beam current: 0.011 A
  - Gradient: 31.5 MV/m
  - Beam loading matched coupling: Qext ~ 3.4E6
- Two ends modeled separately to study coupler orientation combinations
  - Upstream: only the HOM coupler
    - SW fields.
    - Fields obtained by Omega3P eigen mode calculation
  - Downstream: FM coupler + HOM coupler
    - Matched coupling – beta=1 with beam loading
    - TW fields in coupler region
    - Fields obtained by port excitation using S3P

Fields In Upstream End Group







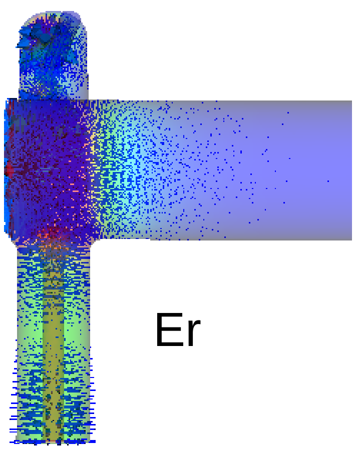


Fields on axis

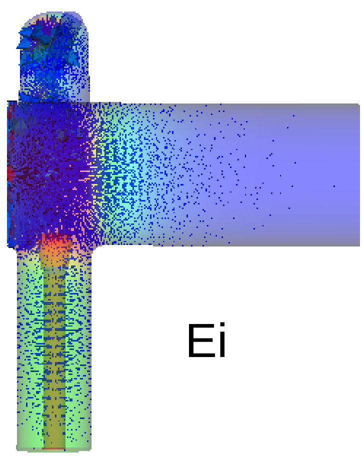
- Standing wave field.
- Ex, Ey 3-orders of magnitude smaller than Eacc

Fields In Downstream End Group

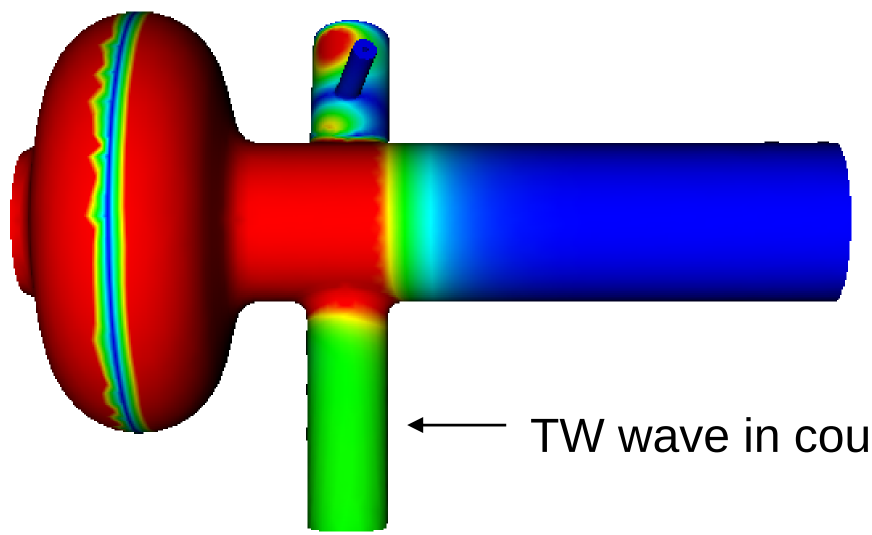
- FM coupler matched to nominal current
- No reflection when loaded by the beam
- S3P to drive through the coupler to simulate nominal operation condition (beta=1 with beam loading)



Er

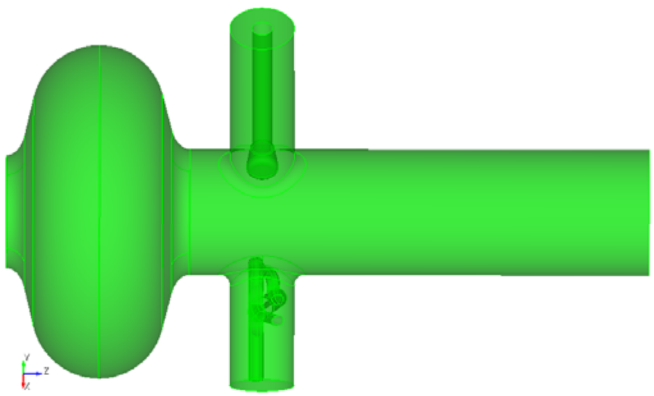


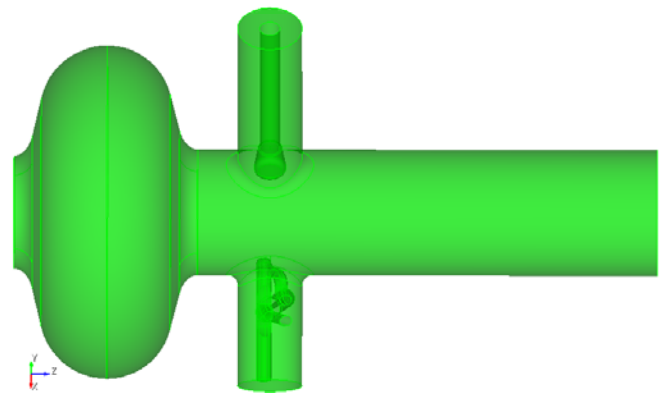
Ei

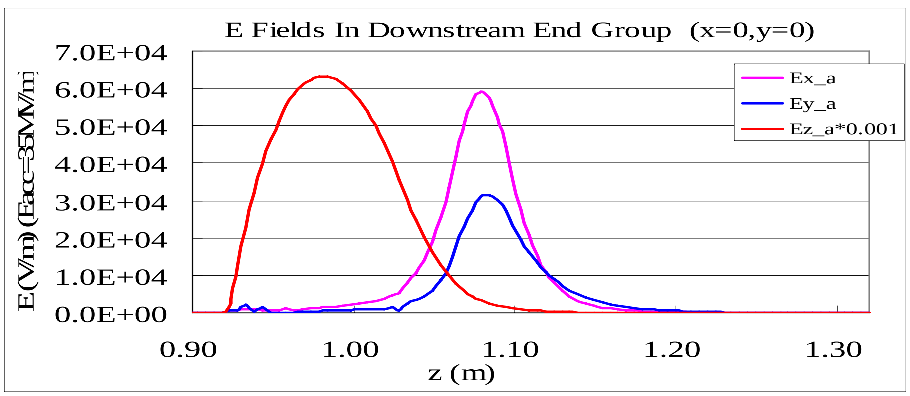


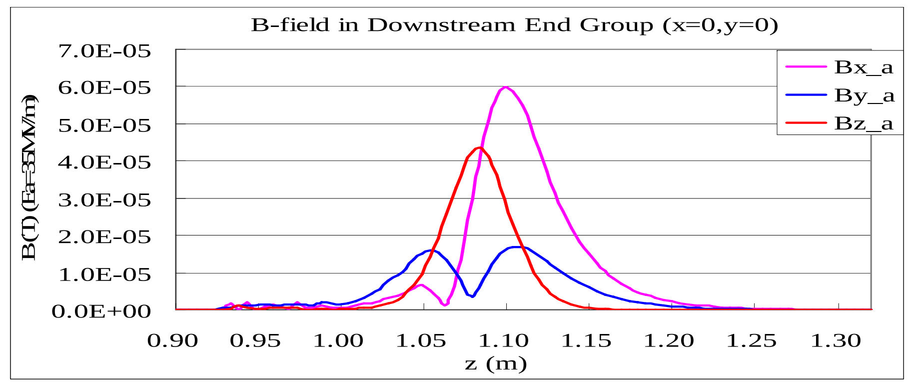
TW wave in coupler

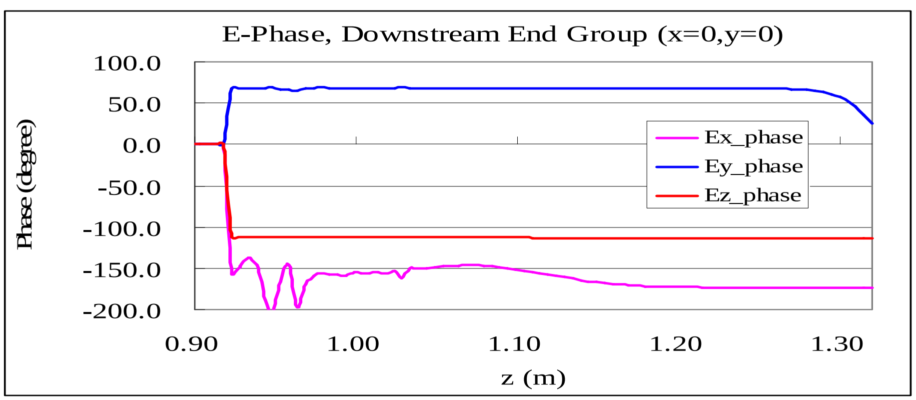
Fields in Downstream End Group

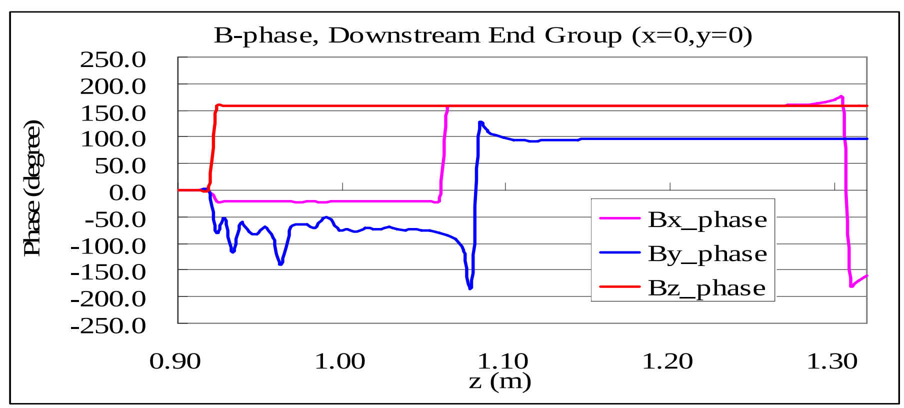












Multipole Analysis

Beam dynamics

$$\Delta(\gamma\vec{\beta}) = \frac{e}{m_0 c^2}\int_0^L (\vec{E} + c\vec{\beta}\times\vec{B})\bullet d\vec{z}$$

Multipole decomposition

$$A(x,y) = \sum \frac{1}{r_{norm}^n}(a_n u_n - b_n v_n)$$

$$= \sum \left(\frac{r}{r_{norm}}\right)^n \left(a_n \cos(n\phi) - b_n \sin(n\phi)\right)$$

$$a_0 = \frac{1}{2\pi}\int_0^{2\pi} A(r,\phi)d\phi$$

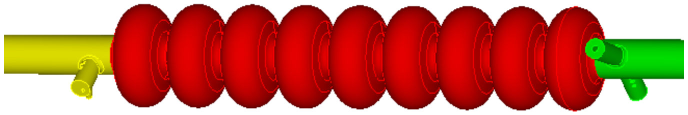
$$b_0 = 0$$

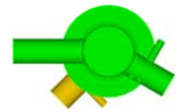
$$a_n = \frac{1}{\pi}\left(\frac{r_{norm}}{r}\right)^n \int_0^{2\pi} A(r,\phi)\cos(n\phi)d\phi$$

$$b_n = \frac{1}{\pi}\left(\frac{r_{norm}}{r}\right)^n \int_0^{2\pi} A(r,\phi)\sin(n\phi)d\phi$$

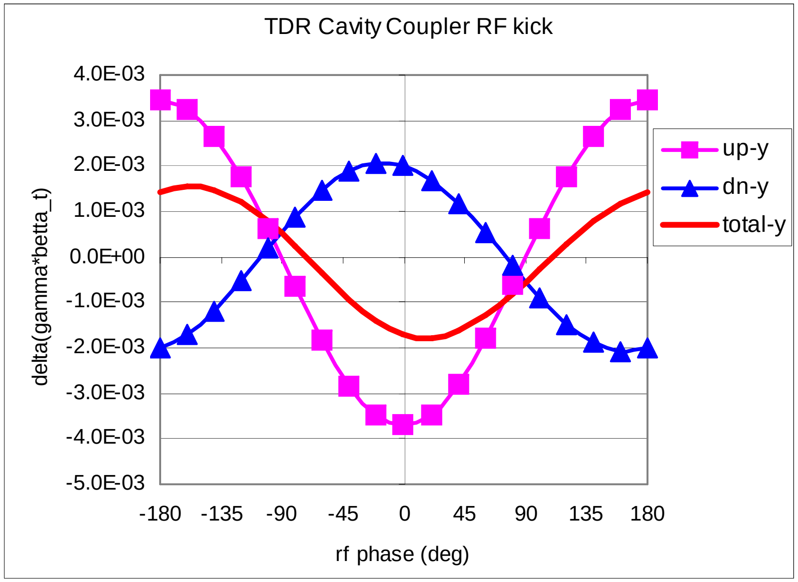
n	u_n	v_n	
1	x	y	dipole
2	$x^2 - y^2$	$2xy$	quadrapole
3	$x^3 - 3xy^2$	$3x^2y - y^3$	sextupole
4	$x^4 - 6x^2y^2 + y^4$	$4x^3y - 4xy^3$	Octupole

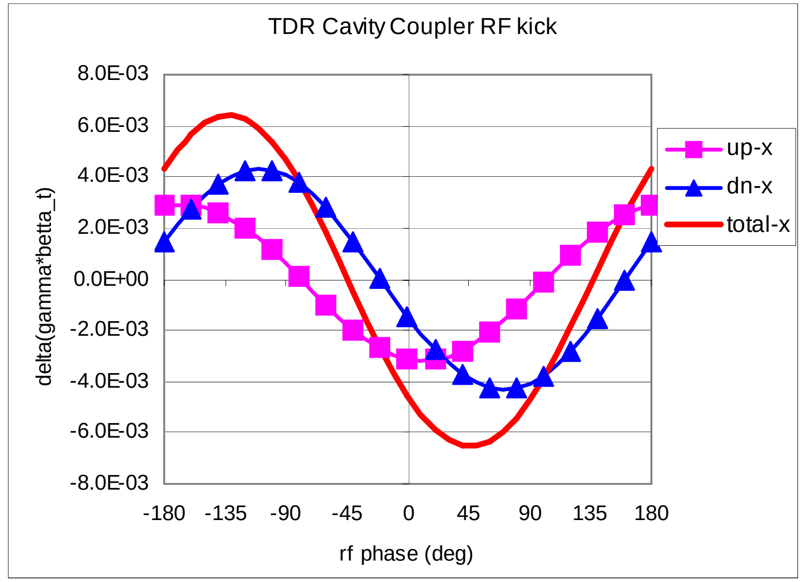
TDR RF Kick





FM coupler: S11=0.013



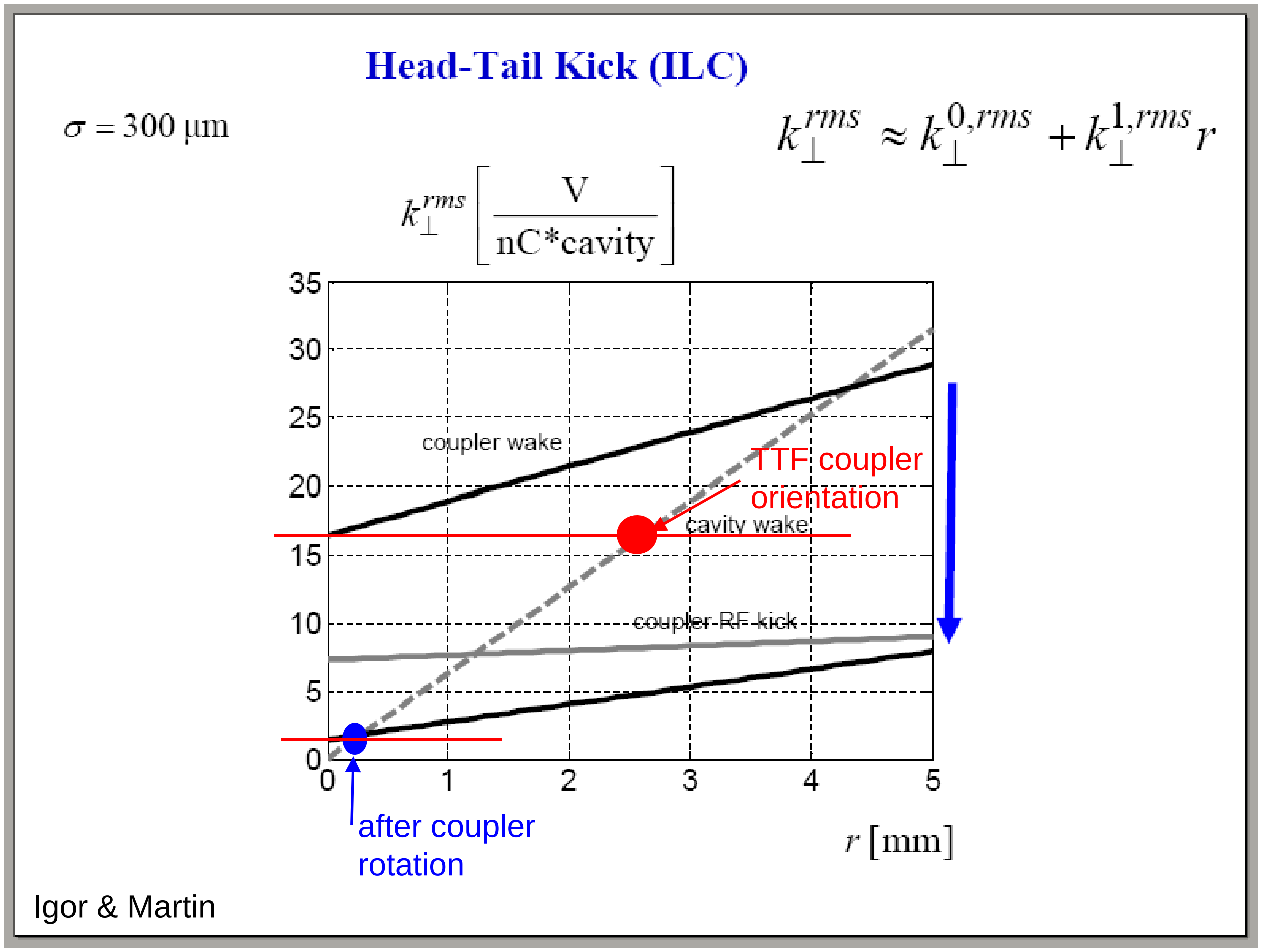


Y-kick: Coupler to cell center about half wave length, y-kick roughly "in" phase with crest

X-kick: upstream and downstream have different phase relative to the crest.
TW field in coupler region resulted in larger head-tail kick

Accelerating Gradient = 35MV/m; Head-tail: +- 1 sigma_z				
Kick unit: Volt	X-centroid	Y-centroid	X-head-tail	Y-head-tail
TDR	-2106	-785	33	3.5

Igor: Coupler SW Kick v.s. Cavity SW

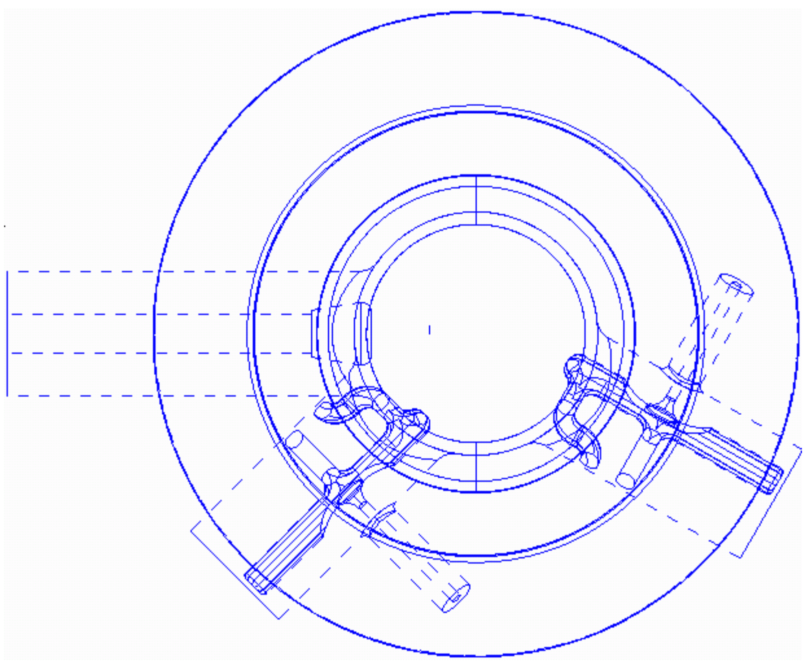


RF kick=7.3V
(Eacc=15MV/m)

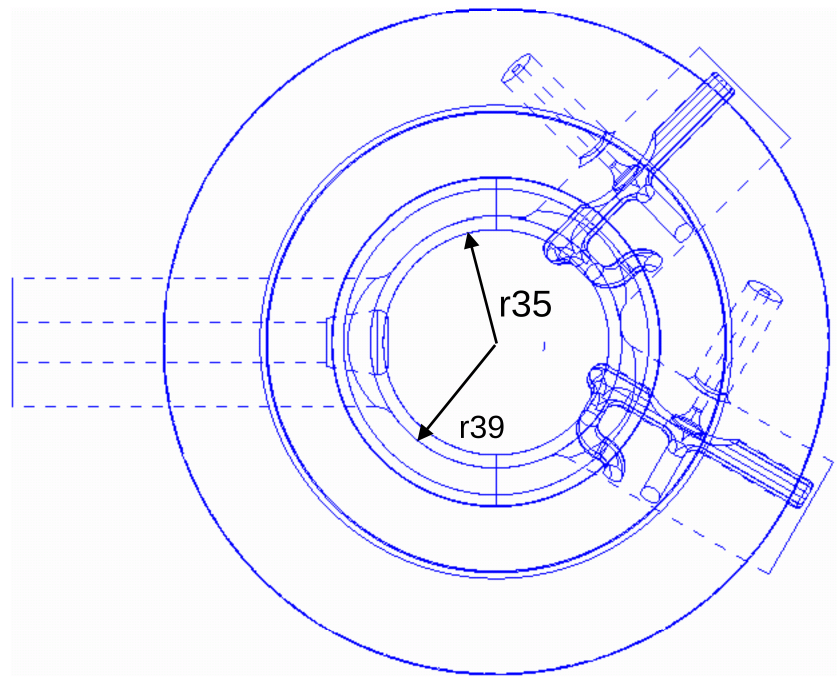
End-group Modification

- Rotate up-hom by 180 degree about z
- To minimize SW kick (Karl's talk)
- Effect on RF kick ?

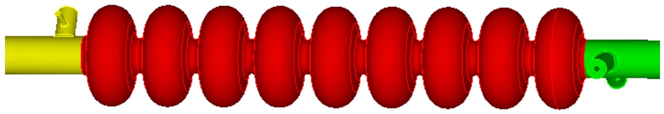
TDR

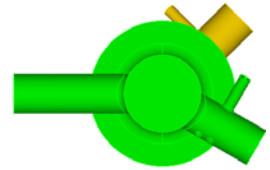


TDRM
(TDR modified)



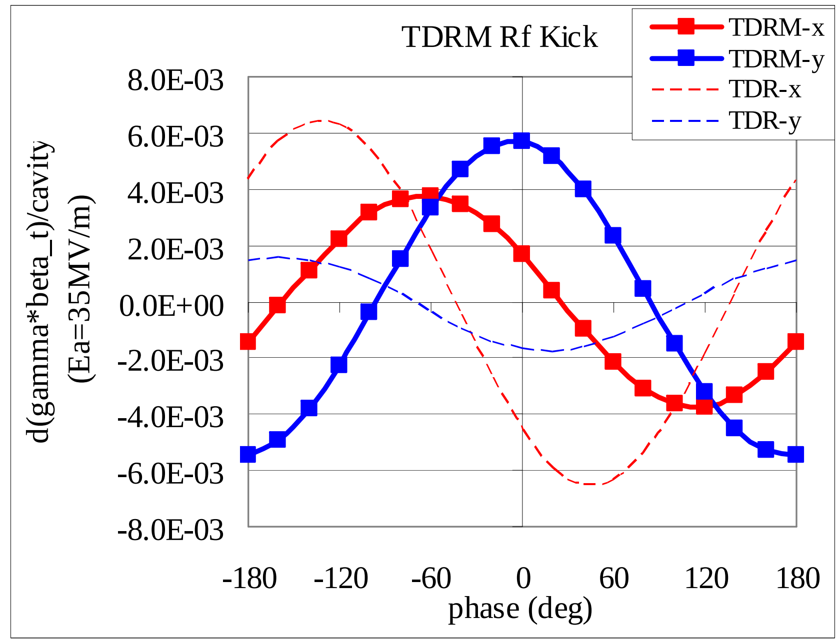
TDRM RF Kick





TDRM = modified TDR

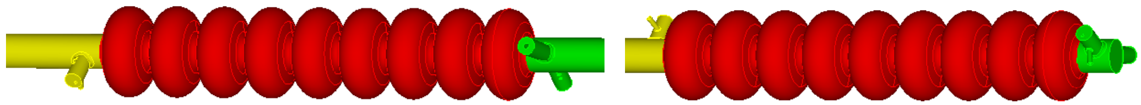
- Upstream HOM rotated 180 degrees about z
- Minimized SW kick
- Reduces x-RF kick
- However “doubles” y-RF kick



Accelerating Gradient = 31.5MV/m; Head-tail: +- 1 sigma_z				
Kick unit: Volt	X-centroid	Y-centroid	X-head-tail	Y-head-tail
TDRM	761	2621	24	4

Using Cavity Pairs To Cancel RF kicks (?)

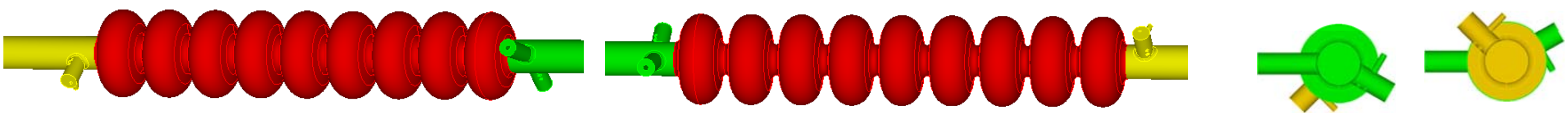
Ultimate pair cancellation (same Ea): cavity + cavity_rotate_pi_aboutz



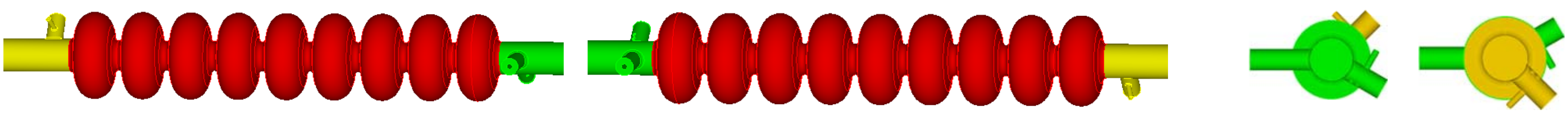
Has big impacts on module and power distribution configuration

Following cases all have FM coupler on the –x side to minimize impacts on module and power distribution design

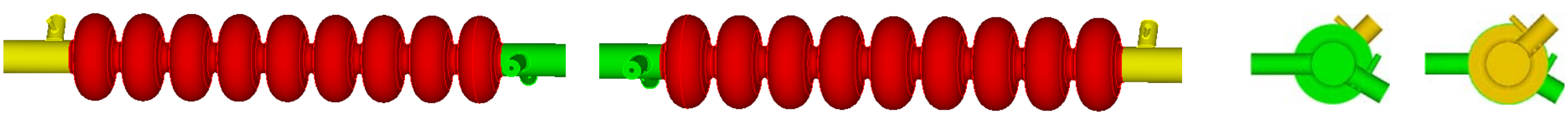
- TDR + TDR-rotx



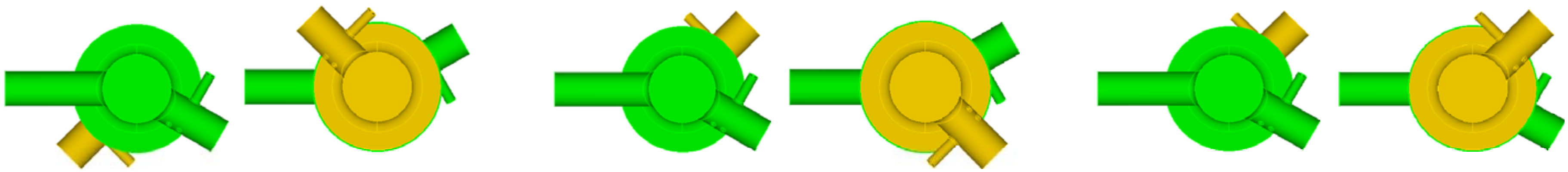
- TDRM + TDRM-rotx

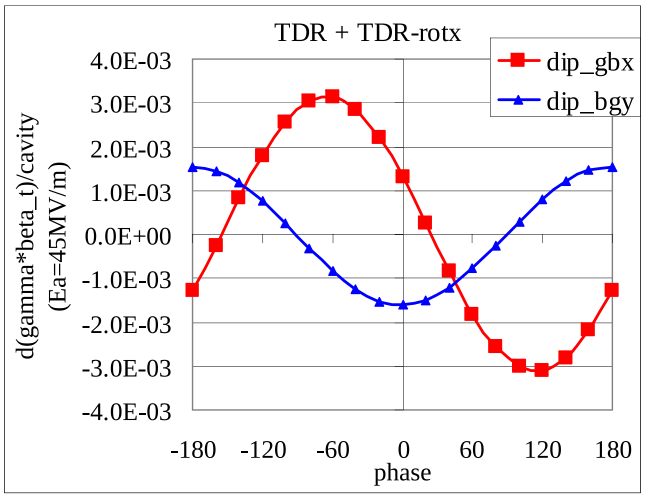


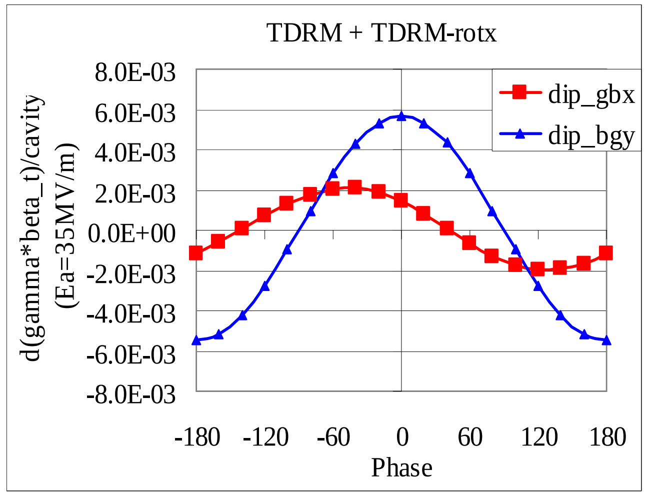
- TDRM + TDRM-mirrorZ

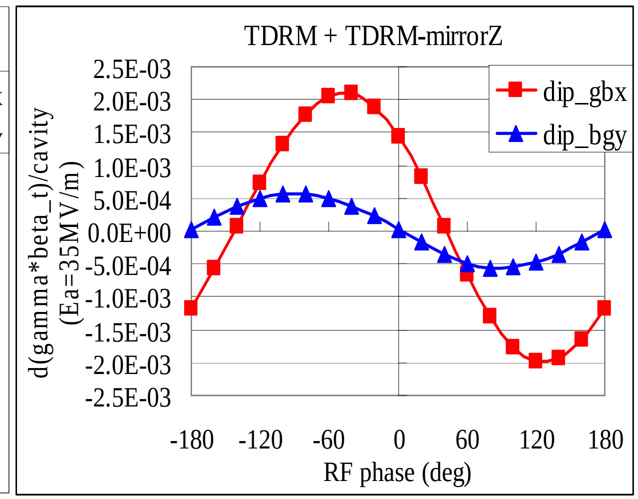


Pair Of Cavities Rotate About X&Z









Accelerating Gradient = 31.5MV/m, Head-tail: +- 1 sigma_z				
Kick unit: Volt	X-centroid	Y-centroid	X-head-tail	Y-head-tail
TDR,TDR-rotx	609	-739	20	0.3
TDRM,TDRM-rotx	664	2606	11	~0
TDRM,TDRM-mirrorZ	664	15	11	4

Summary OF RF Kicks

- Eacc = 31.5MV/m
- Ibeam = 0.011A
- Qext ~ 3.4E6

Accelerating Gradient = 31.5MV/m Head-tail: +- 1 sigma_z Kick unit: Volt				
	X-centroid	Y-centroid	X-head-tail	Y-head-tail
TDR	-2106	-785	33	3.5
TDRM	761	2621	24	4
TDR,TDR-rotx	609	-739	20	0.3
TDRM,TDRM-rotx	664	2606	11	~0
TDRM,TDRM-mirrorZ	664	15	11	4

Summary

- SW and TW wave fields in coupler region are modeled using Omega3P and S3P
- “Significant” beam centroid and head-tail kicks are found due to coupler asymmetry
- Redesign of end group to minimize RF kicks discussed
- Beam simulation needed to understand impact of RF kicks.