Cavity Shape Studies

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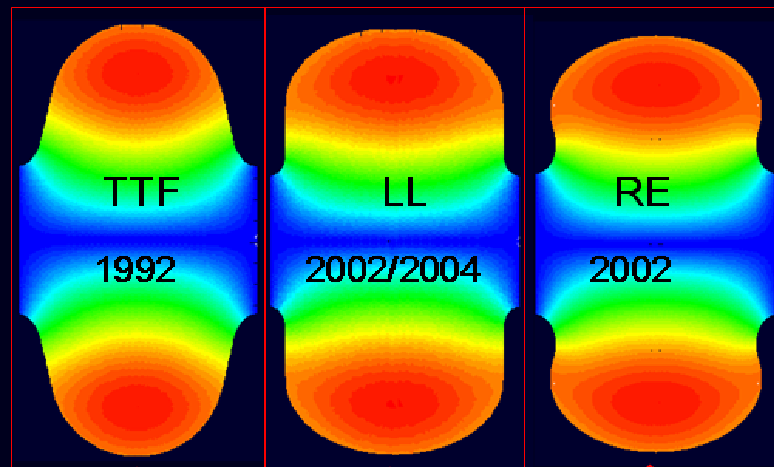
Outline

- TESLA-LL-Reentrant comparison
- Surface field considerations
- Bandwidth and tuning sensitivity
- HOM damping of Low Loss Low Field (LLF) cavity
- Multipacting in HOM coupler
- Coupler asymmetry effects – SW kick

Alternative Cavity Shapes

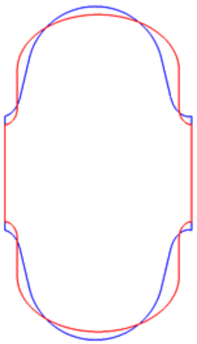
1. Introduction: Evolution of the elliptical cavities cont.

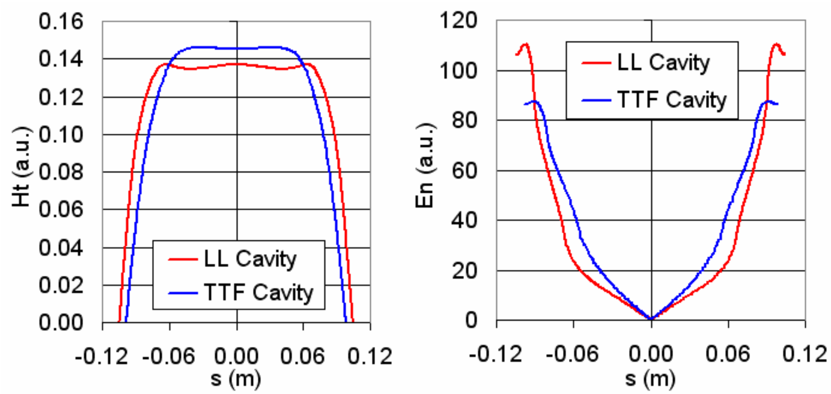
Example: 1.3 GHz inner cells for TESLA and ILC



r_{irisb}	[mm]	35	30	33	
k_{cc}	[%]	1.9	1.52	1.8	field flatness
E_{peak}/E_{acc}	-	1.98	2.36	2.21	max gradient (E limit)
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76	max gradient (B limit)
R/Q	[Ω]	113.8	133.7	126.8	stored energy
G	[Ω]	271	284	277	dissipation
R/Q*G	[Ω*Ω]	30840	37970	35123	dissipation (Cryo limit)

Surface Field Considerations





Original LL cavity (Jacek)

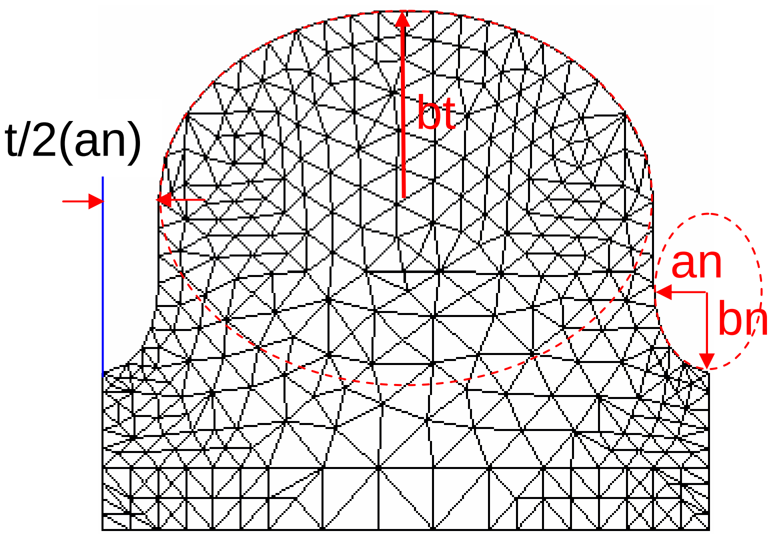
- >15% higher R/Q (1177 ohm/cavity)
- >12% lower Bpeak/Eacc ratio
- > 20% lower cryogenic heating
- >15% higher surface electric field

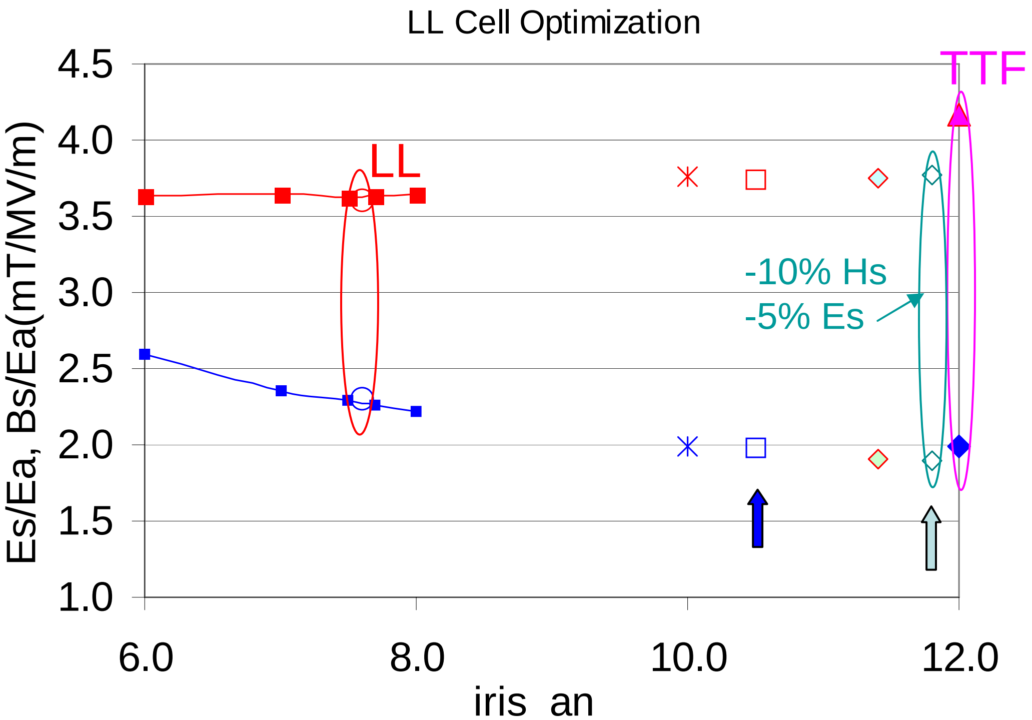
We know B_max is important for high gradient
What's the significance of higher surface E field?

Can we design a cavity with lower surface fields in both E and B?

- Would this help the cavity to perform?
- Can the HOM be damped effectively?

A=30mm LL Cell Comparison

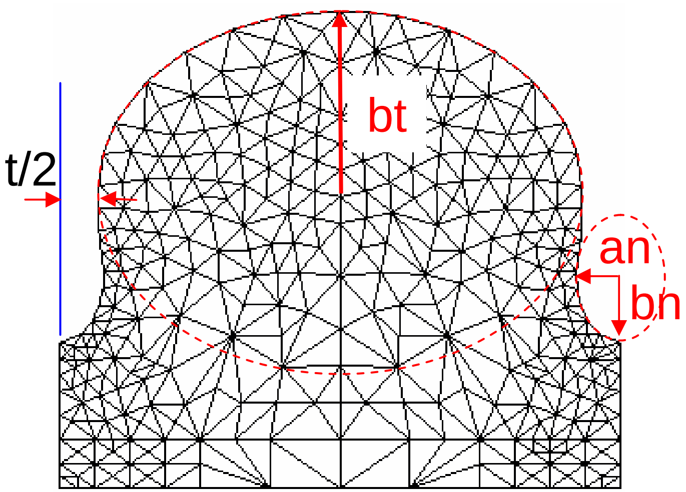


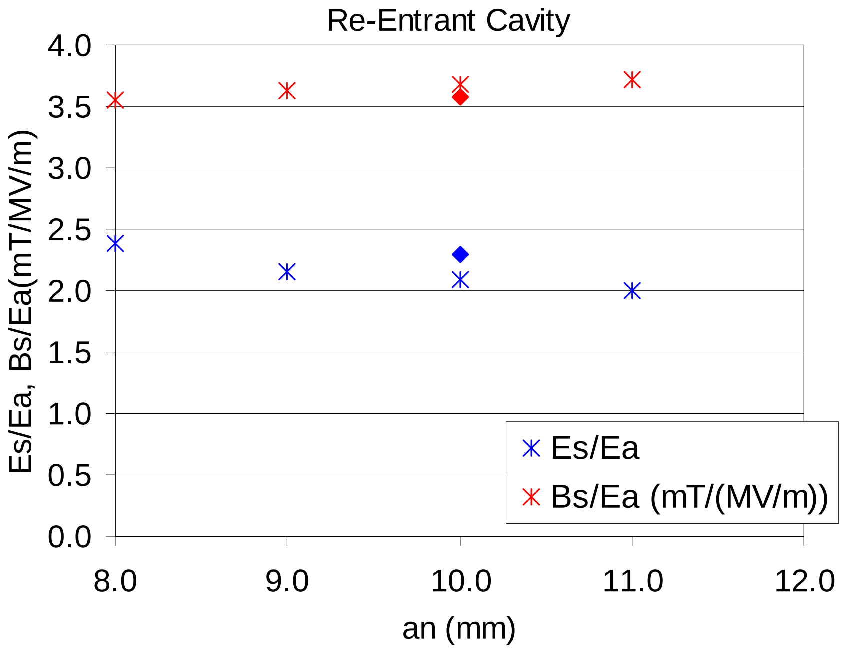


	an	bn	Es/Ea	Hs/Ea	Bs/Ea (mT/(MV/m))	Ea ((MV/m)/180mT)
TTF cell (a=35mm)	12.00	19.00	1.984	0.00332	4.168	43.19
Original LL (a=30mm)	7.60	10.00	2.303	0.00287	3.608	49.88
opt-3 (a=30mm) 0mm slope	10.50	17.10	1.984	0.00295	3.712	48.49
a=30mm 0mm slope	11.80	20.80	1.894	0.00300	3.770	47.75

5% Es reduction
10% Hs reduction

Re-entrant Shape

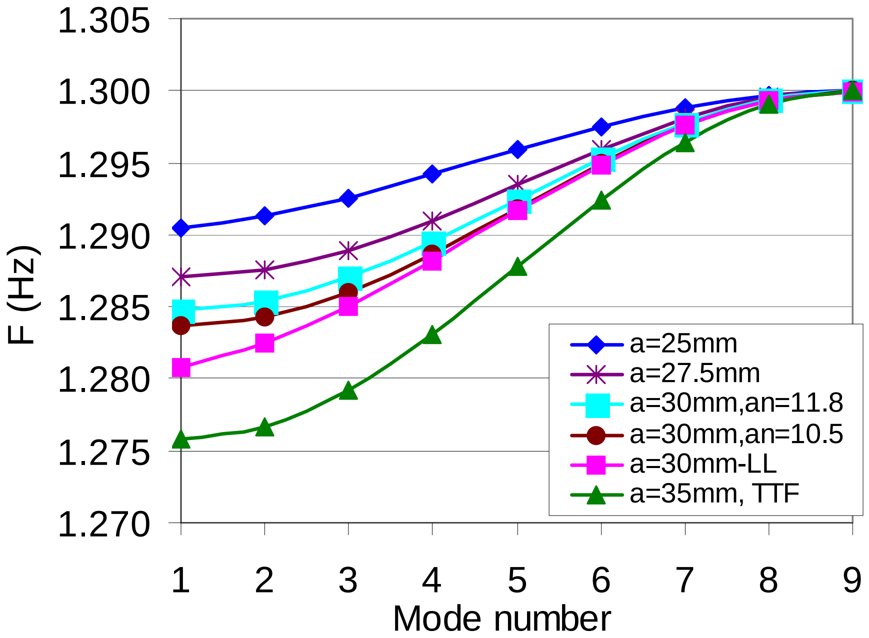


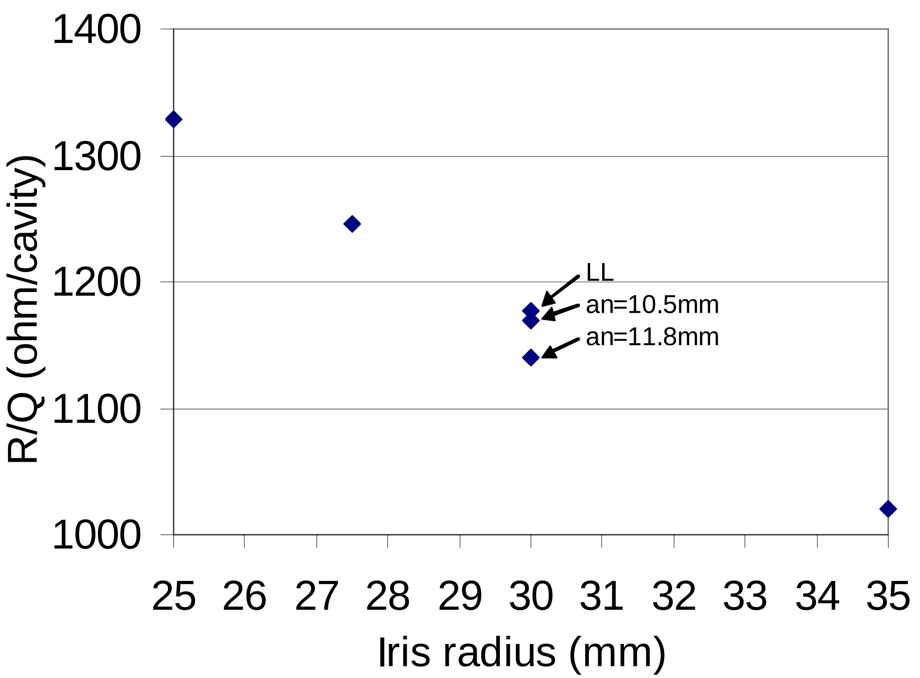


t	an	bn	bt	Es/Ea	Hs/Ea	Bs/Ea (mT/(MV/m))	Ea ((MV/m)/180mT)
12	8	11.0	36.000	2.390	0.002826	3.551	50.69
15	10	11.5	38.000	2.299	0.002850	3.581	50.26
16	9	14.0	36.000	2.153	0.002885	3.625	49.65
16	10	17.0	35.500	2.095	0.002930	3.682	48.89
18	11	17.2	35.000	2.005	0.002960	3.720	48.39

At low Es, re-entrant comparable to LL

Dispersion & R/Q Comparison





Field amplitude deviation in cell "i" due to dfi

$$\frac{\Delta E_i}{E_i} = \frac{N^2}{k_{cc}} \cdot \frac{\Delta f_i}{f_i}$$

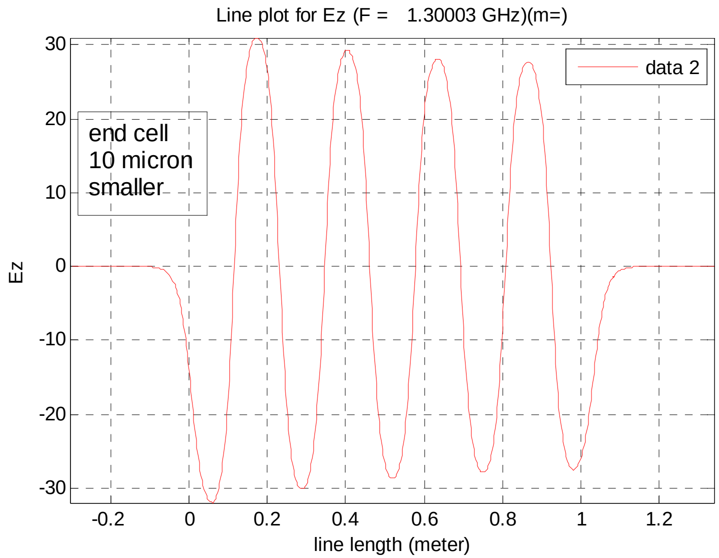
N is total number of cells

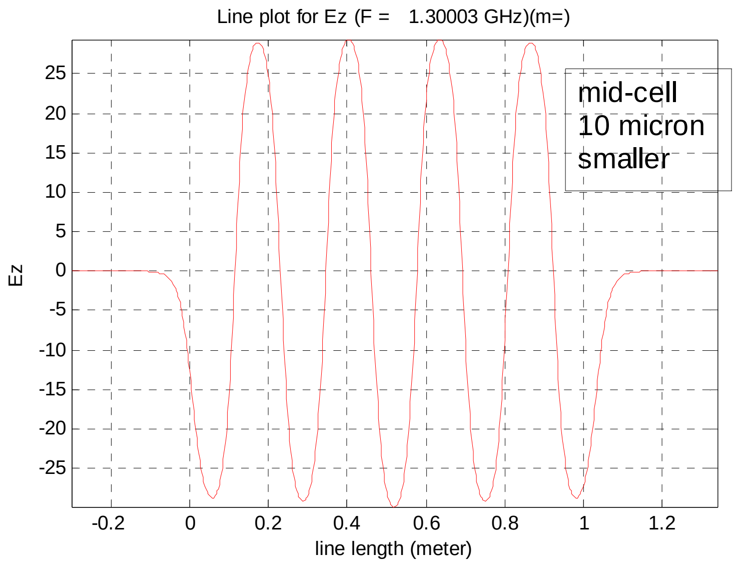
k_{cc} is the cell to cell coupling

	F_0	F_pi	dF(pi-0) (MHz)
A=35mm, TTF	1275.75	1300	24.25
A=30mm (LL)	1280.16	1300	19.84
A=25mm	1290.15	1300	9.85

LLF Ez Flatness v.s. Cell Error

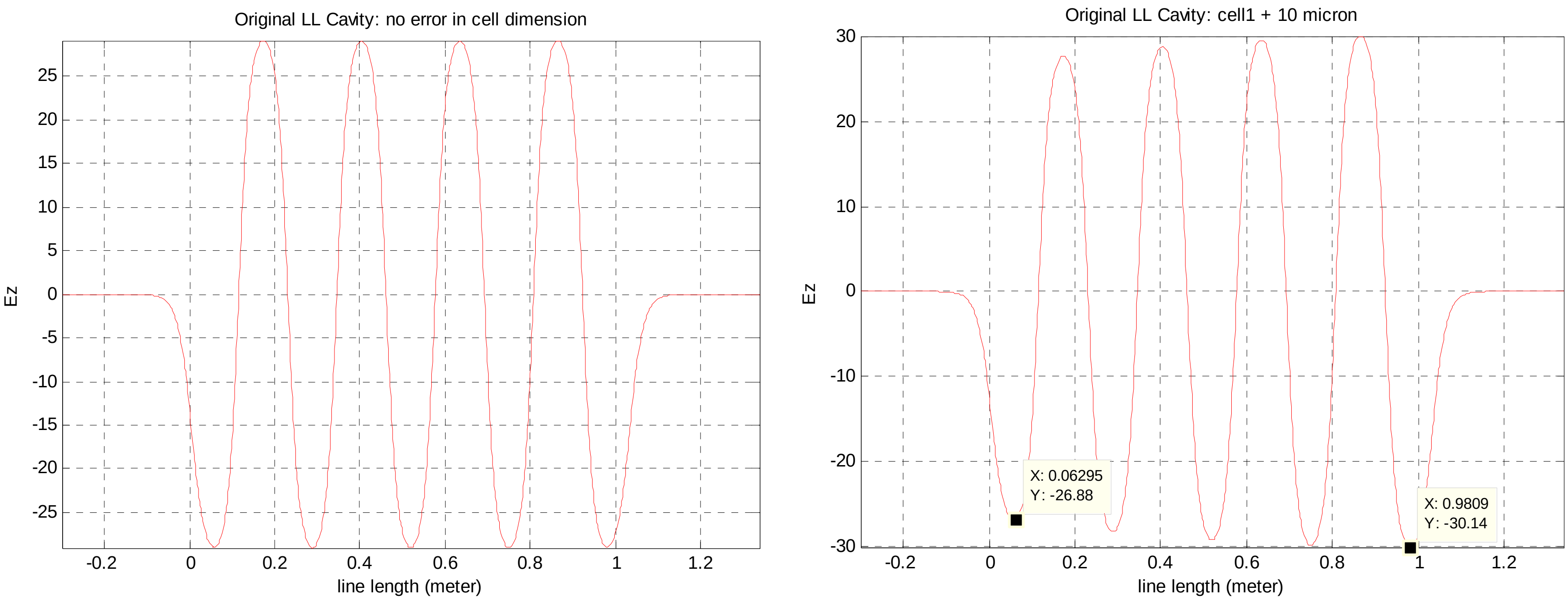
an=10.5mm





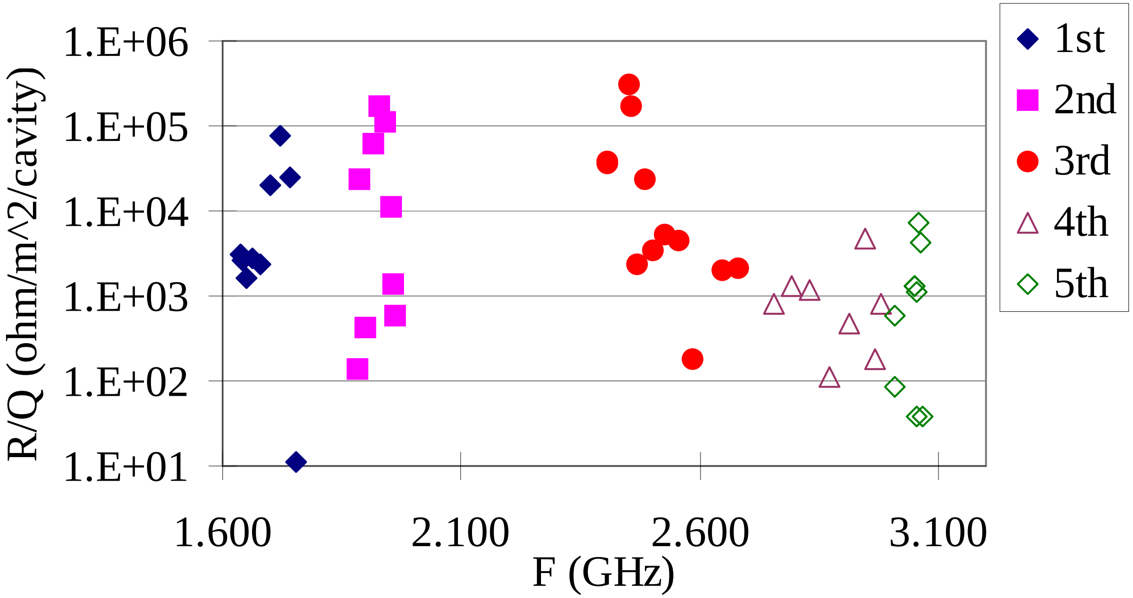
cell error	dF_cell (kHz)	dF_struct (kHz)	A_max	A_min	(+-%)
endcell-10micron	150	18	31.92	27.45	7.5
midcell-10micron	150	16	29.84	28.75	1.9

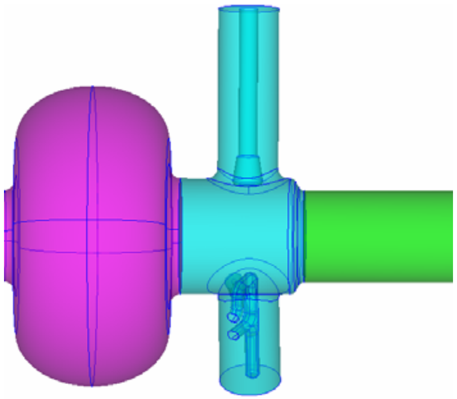
Original LL Cavity



original LL	A_max	A_min	(+-%)
Endcell+10micron	30.14	26.88	5.7

HOM

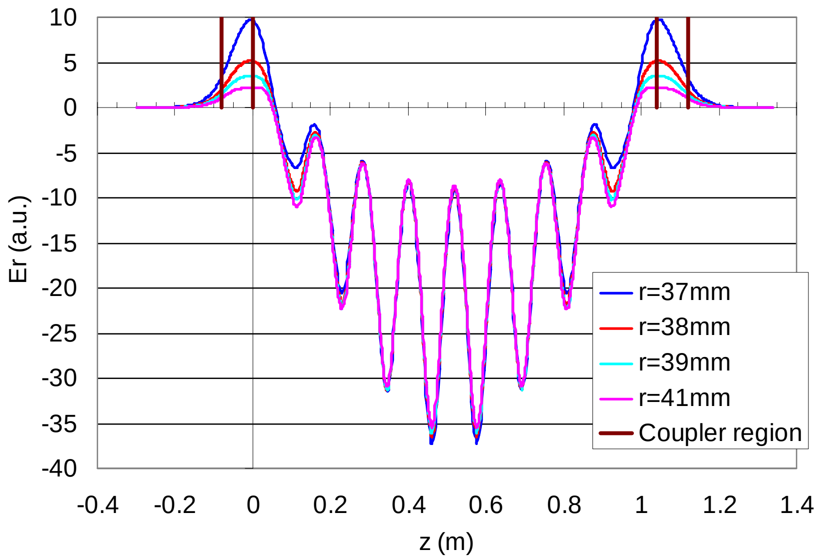


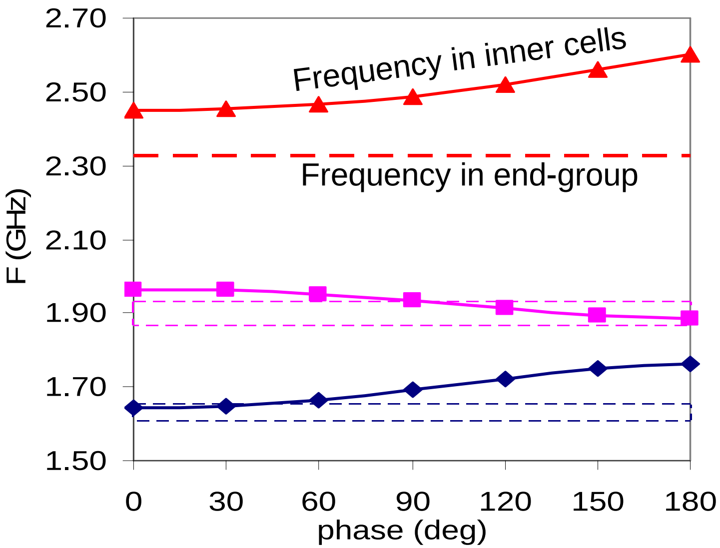


- Most important modes are 0-mode in the 3rd band
- High R/Q in the 1st&2nd bands are up to 1/3 of the 3rd band
- Beam pipe tapers down to 30-mm, 3rd band damped locally by HOM couplers

- Damping criteria: 3rd band mode Qext<10^5 (?)

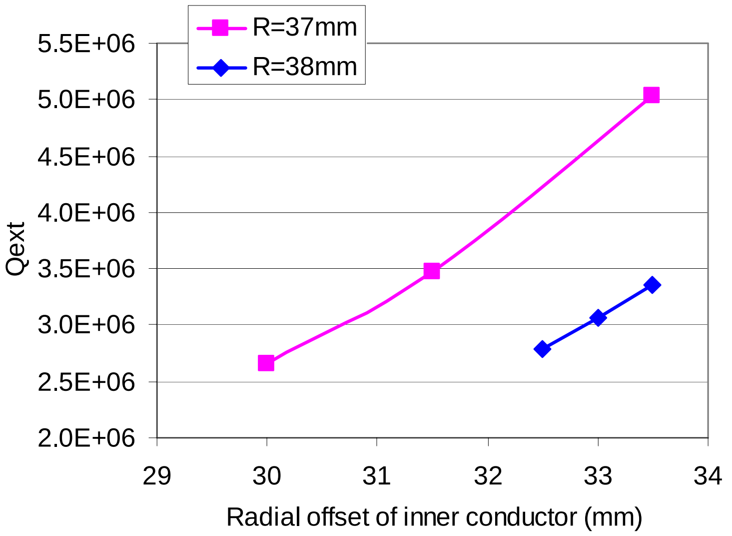
LL HOM Damping



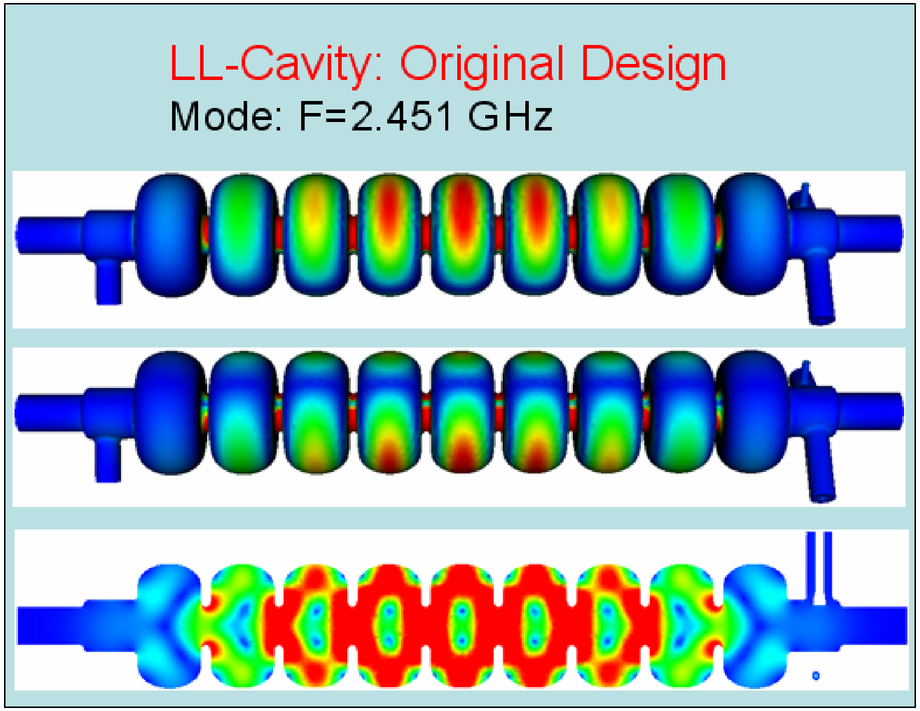


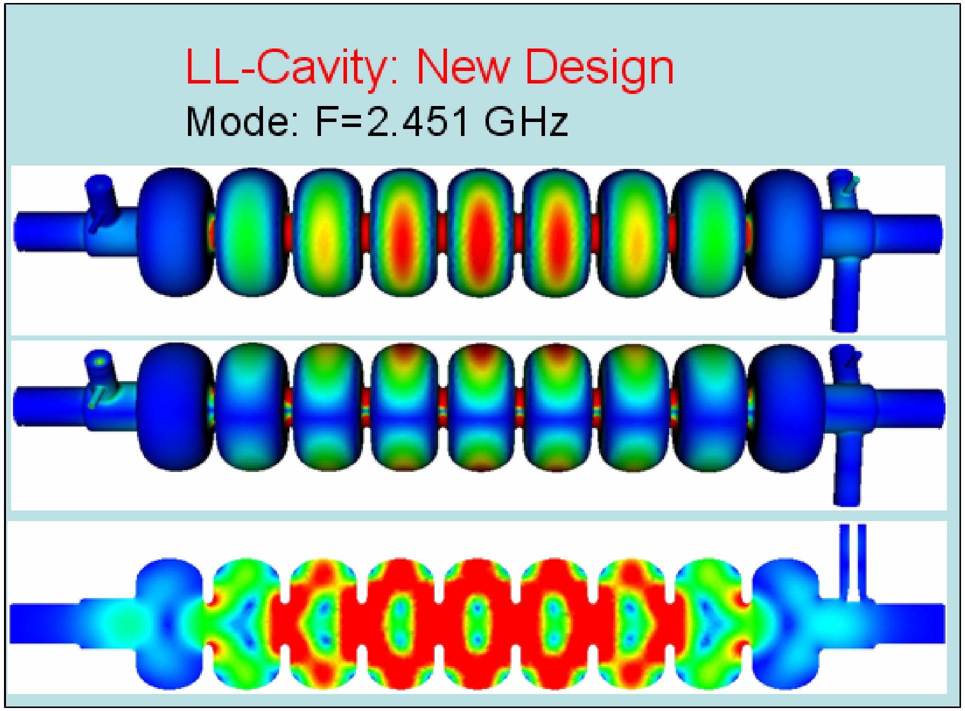
End-group dimensions are important for HOM damping

- 3rd band modes are "more trapped" in the cavity with original 41mm beam pipe due to lower frequency in the end-group
- Smaller radius end-pipe enhances fields in the coupler region, significantly improves the HOM damping.
- However, small end-pipe may significantly reduce FM coupling – need more intrusion



High R/Q 3rd Band Modes

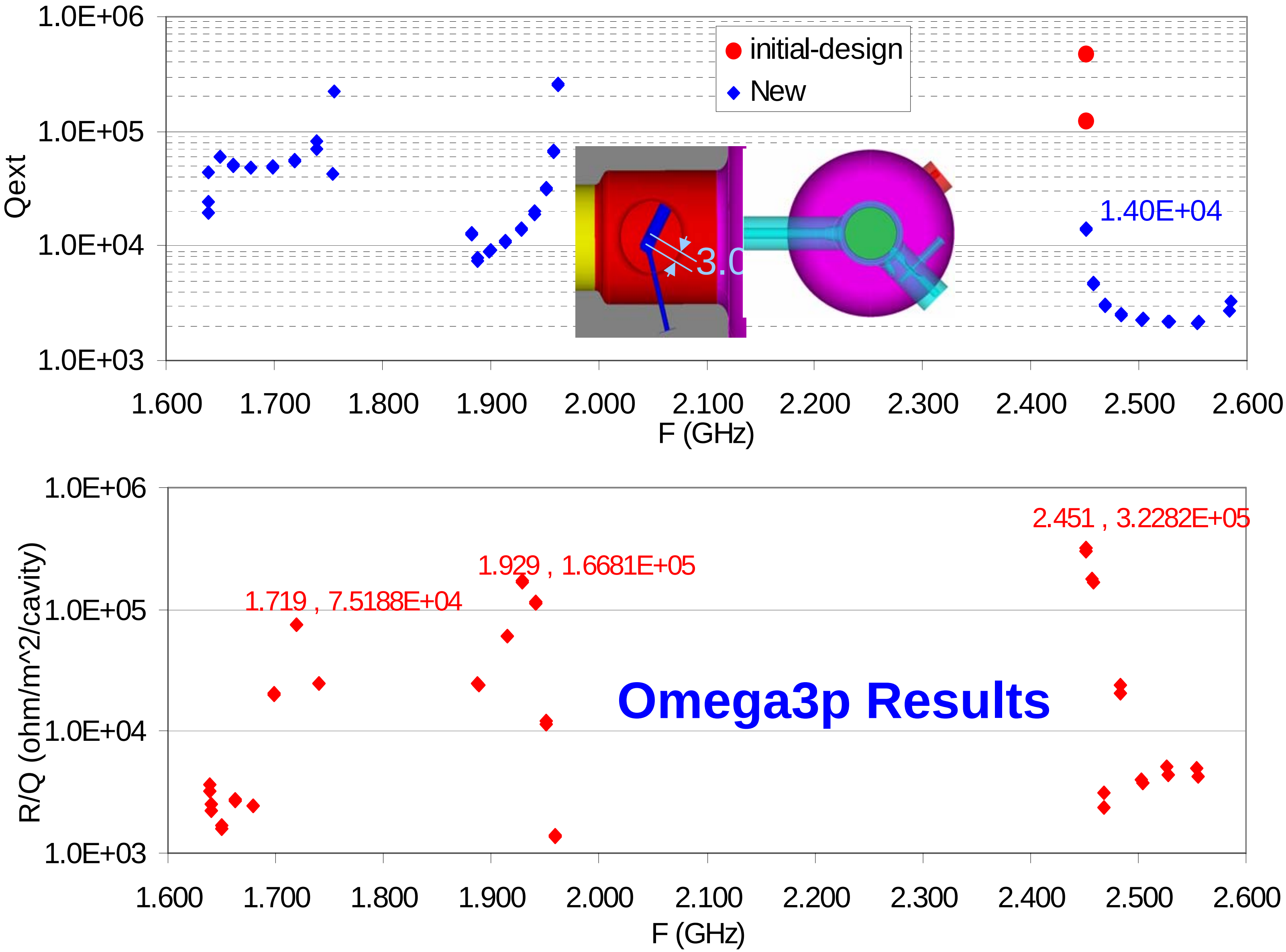




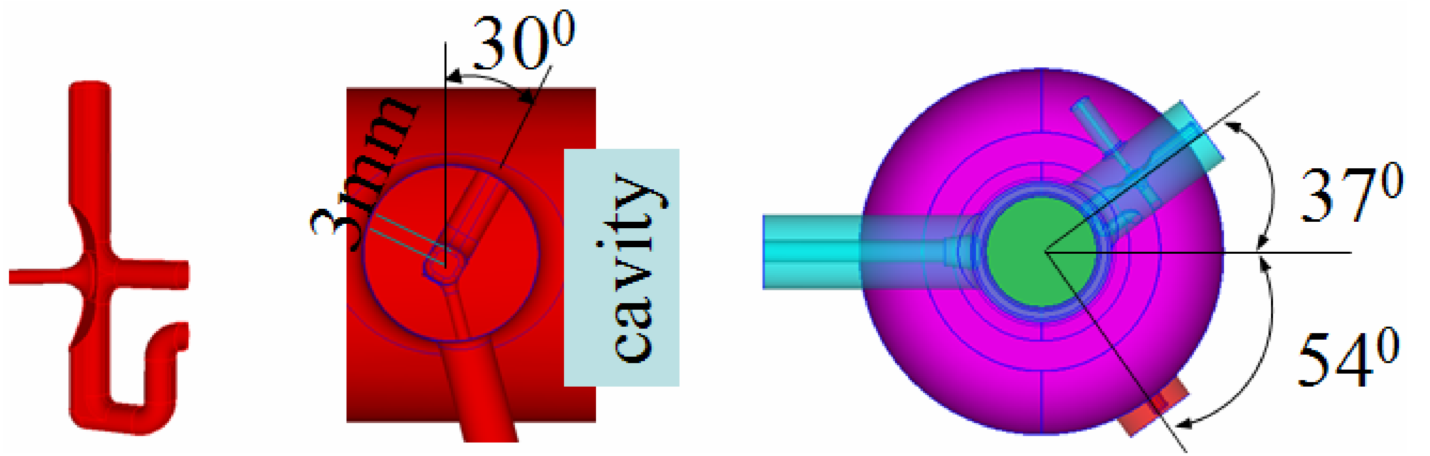
Qext=4.6×10^5

Qext=1.4×10^4

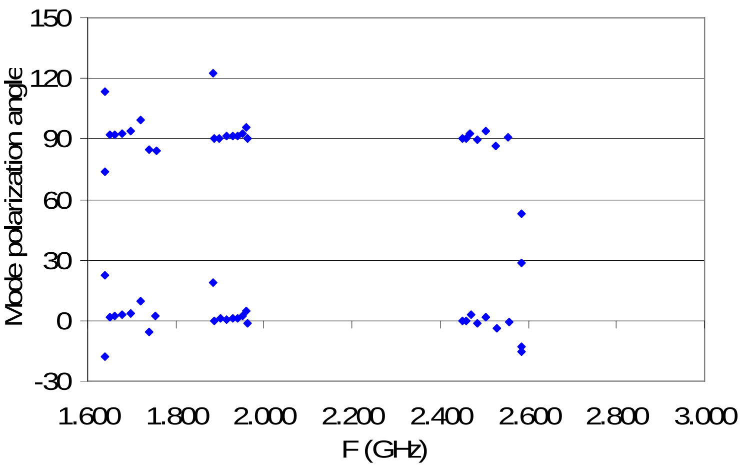
LL HOM Optimization



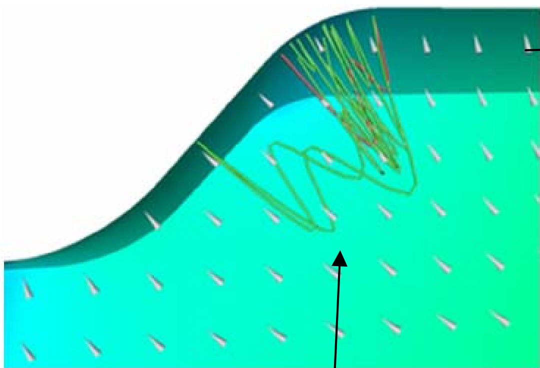
Optimized HOM Coupler for LL

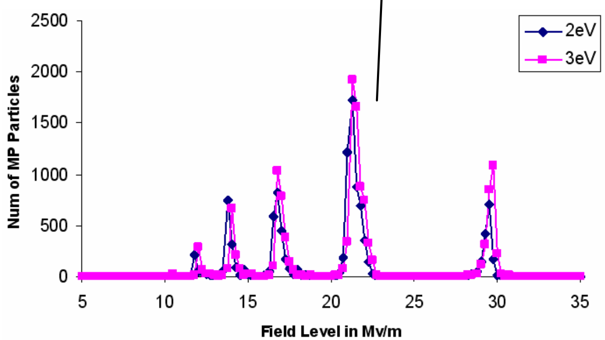


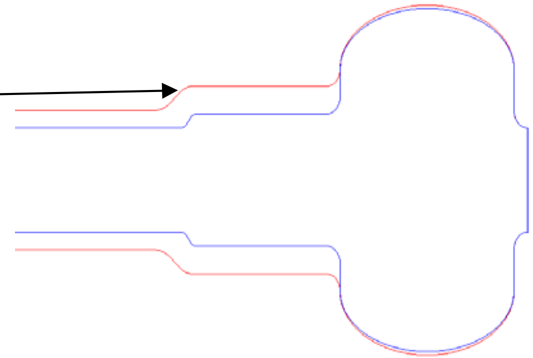
- Modification of coupling loop to enhance 3rd band coupling
- Optimized orientation
  - dominating dipole modes are x/y polarized
  - Minimize kicks of fundamental mode

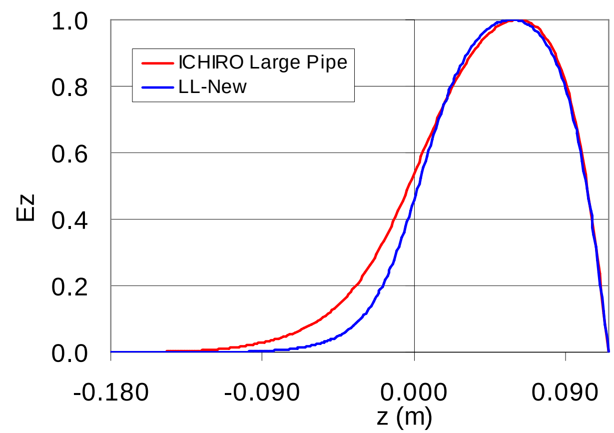


Multipacting at the Beam Pipe Step



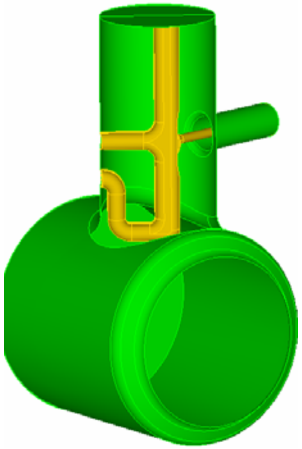


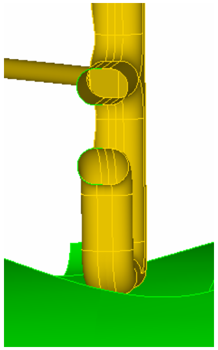


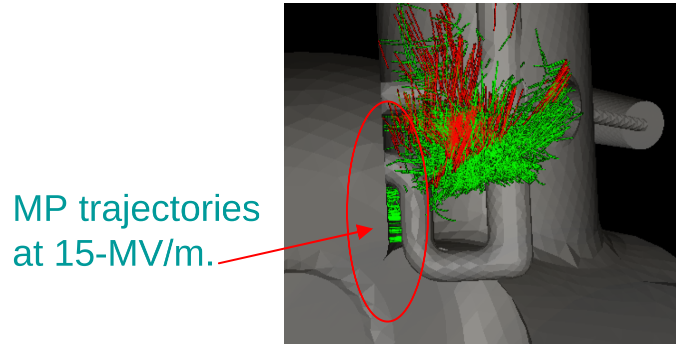


- MP barriers existed in the original ICHIRO cavity due to strong fields in the tapered region.
- The new design has a smaller beam pipe in the coupler region which reduced the field strength in the taper region. Simulations show no multipacting up to 50 MV/m.

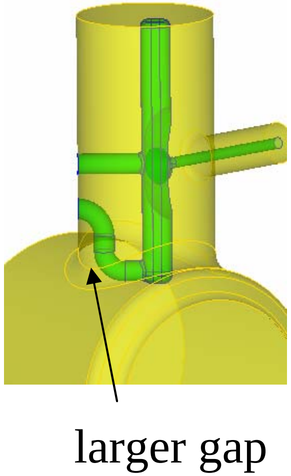
Multipacting in HOM Coupler

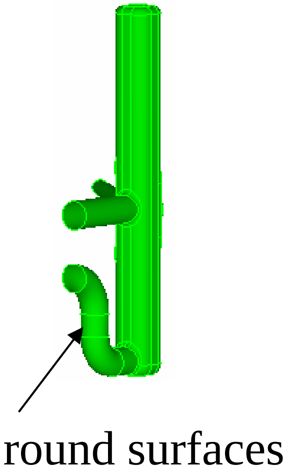






Initial optimized design: multipacting in the gap between the flat surface and outer cylinder at field levels starting from 10-MV/m and up.





Re-optimized loop: with round surfaces and a larger gap.

- No multipacting up to 50MV/m.
- Qext for the 3rd band mode is $3.4x10^4$

Damping Of New Low Field Designs

	an	bn	Es/Ea	Hs/Ea	Bs/Ea (mT/(MV/m))	Ea ((MV/m)/180mT)
TTF cell (a=35mm)	12.00	19.00	1.984	0.00332	4.168	43.19
Original LL (a=30mm)	7.60	10.00	2.303	0.00287	3.608	49.88
opt-3 (a=30mm) 0mm slope	10.50	17.10	1.984	0.00295	3.712	48.49
a=30mm 0mm slope	11.80	20.80	1.894	0.00300	3.770	47.75

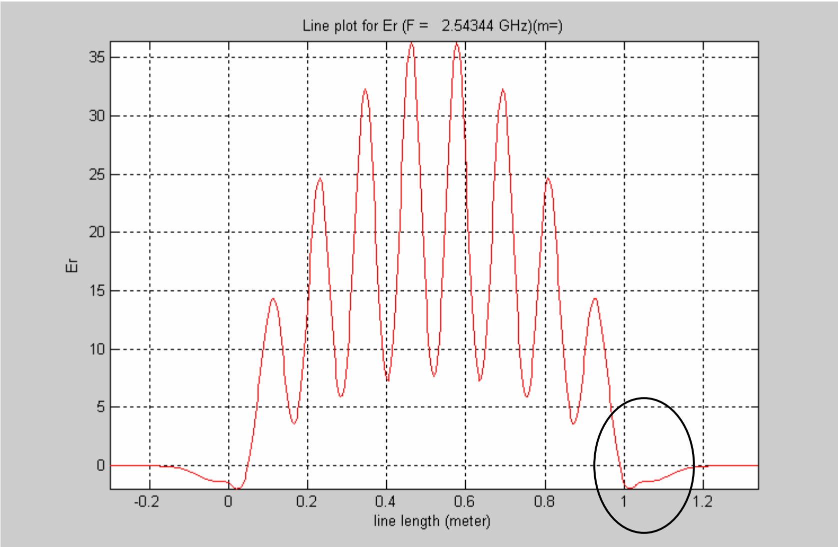
-5% in Es
-10% in Bs

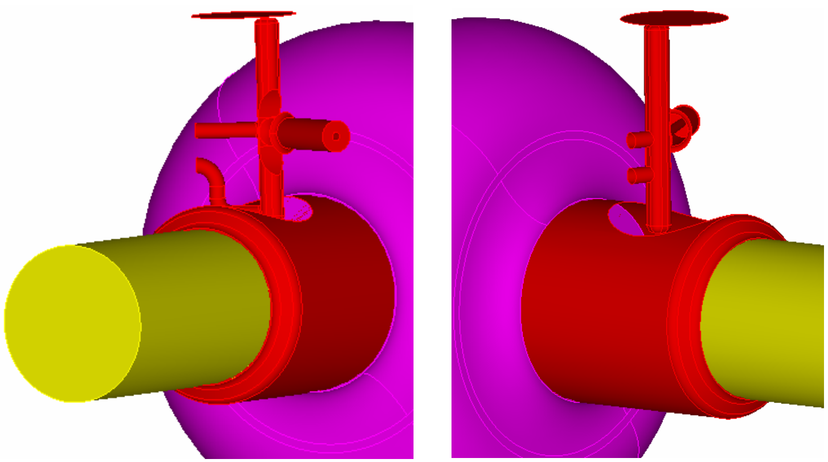
0% in Es
-11% in Bs

LLF Cavity With an=11.8mm

	an	bn	Es/Ea	Hs/Ea	Bs/Ea (mT/(MV/m))	Ea ((MV/m)/180mT)
TTF cell (a=35mm)	12.00	19.00	1.984	0.00332	4.168	43.19
Original LL (a=30mm)	7.60	10.00	2.303	0.00287	3.608	49.88
opt-3 (a=30mm) 0mm slope	10.50	17.10	1.984	0.00295	3.712	48.49
a=30mm 0mm slope	11.80	20.80	1.894	0.00300	3.770	47.75

- Es: 5% reduction; Bs: 10% reduction
- However thicker disk, modes more trapped in cavity
  - Hard to damp
  - More damping study needed

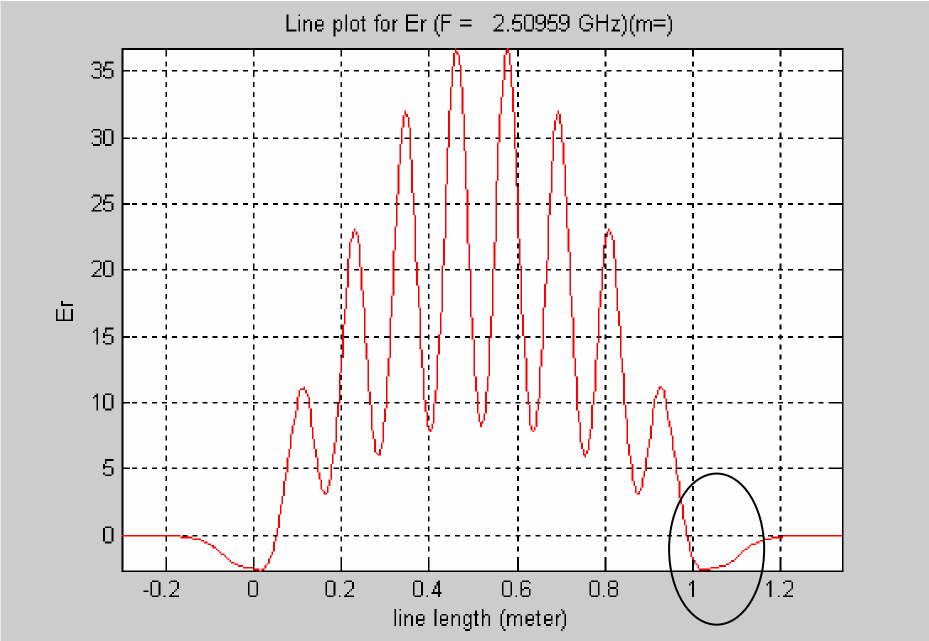


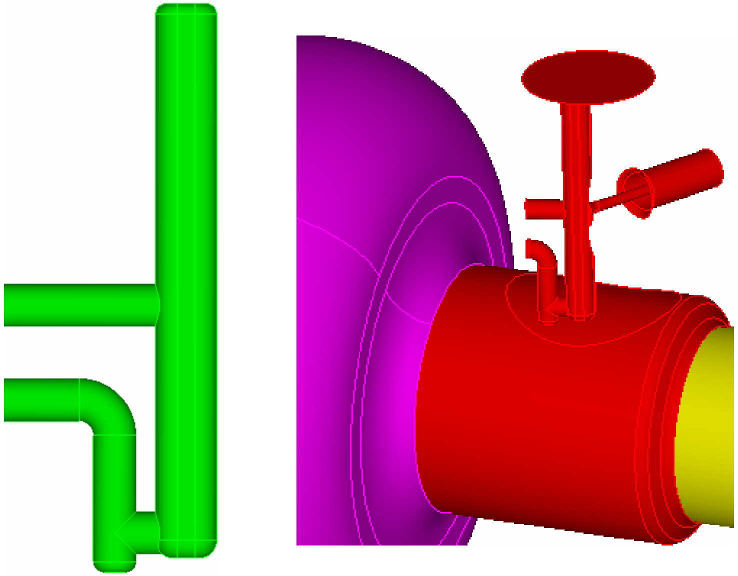


LLF – an=10.5mm

	an	bn	Es/Ea	Hs/Ea	Bs/Ea (mT/(MV/m))	Ea ((MV/m)/180mT)
TTF cell (a=35mm)	12.00	19.00	1.984	0.00332	4.168	43.19
Original LL (a=30mm)	7.60	10.00	2.303	0.00287	3.608	49.88
opt-3 (a=30mm) 0mm slope	10.50	17.10	1.984	0.00295	3.712	48.49
a=30mm 0mm slope	11.80	20.80	1.894	0.00300	3.770	47.75

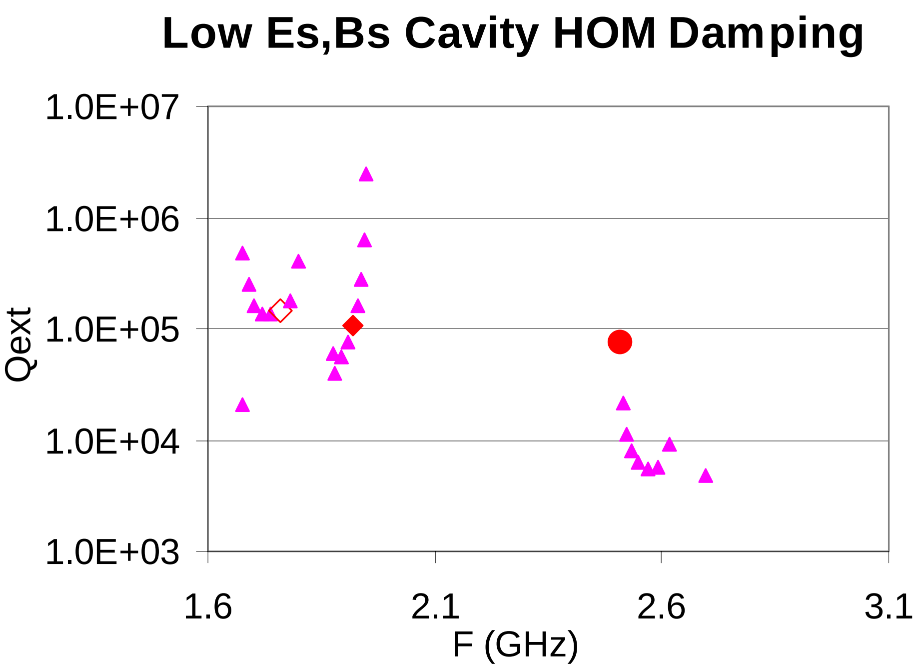
- Es: same as TTF
- Bs: 11% reduction
- Stronger fields in the end-group than the (an=11.8mm) design
- 8×10^4 Qext for the 3rd band mode achieved

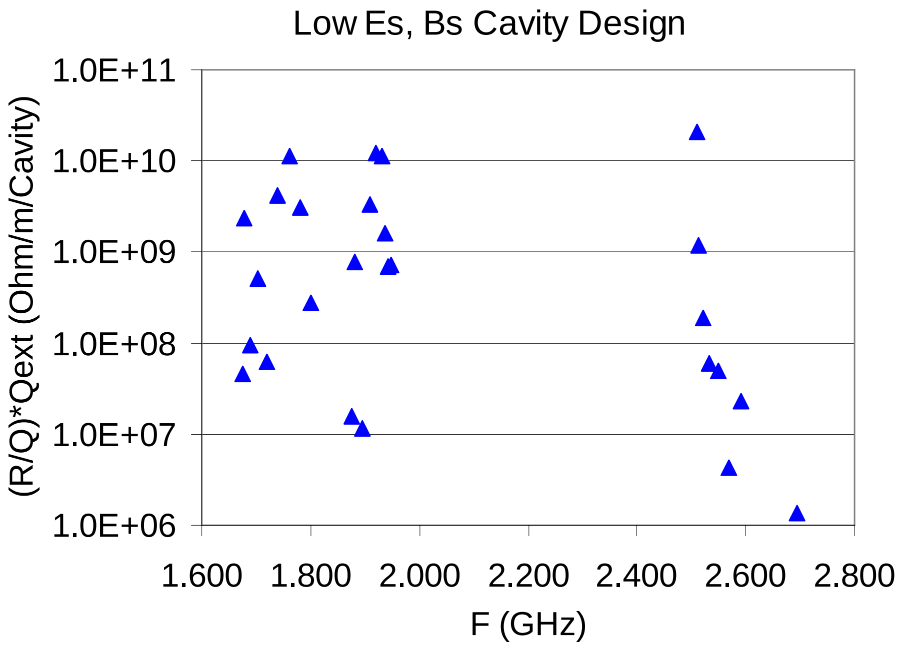




Preliminary loop shape to achieve <1e5 damping.
Simplification possible for machining

HOM Damping Of The LLF Cavity





- Qext of 3rd band: 8×10^4
- Some Qext of 1st & 2nd bands higher than 10^5, but (R/Q)*Qext smaller than 3rd band mode

- Design is preliminary, more optimization needed

Coupler Kick Due To SW

- Due to asymmetry of the FM and HOM couplers, wakefields in the couplers produce on-axis kicks

- Coupler kick due to short-range wakefield was found significant by Igor Zagorodnov and Martin Dohlus (ILC Workshop, DESY31 May, 2007)

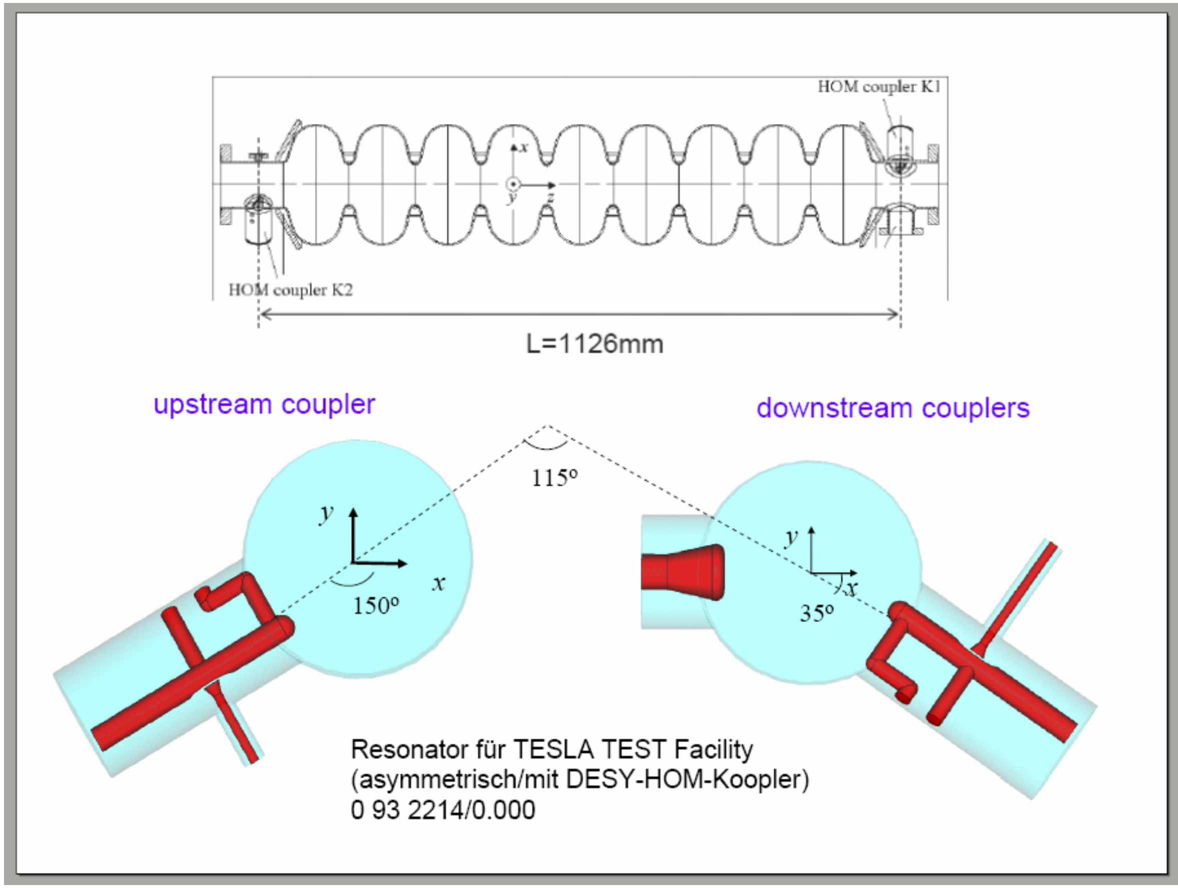
- Coupler SW kick confirmed through different approach by Karl Bane

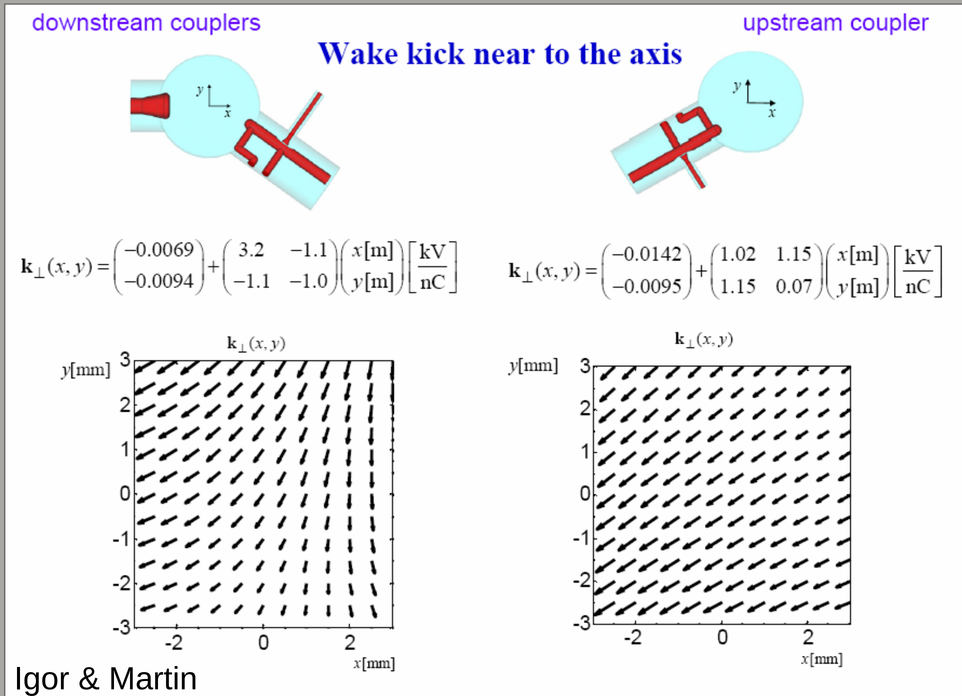
- Coupler SW kicks can be minimized by
  - Symmetrizing the coupler orientations
  - Shadowing with smaller beampipe aperture

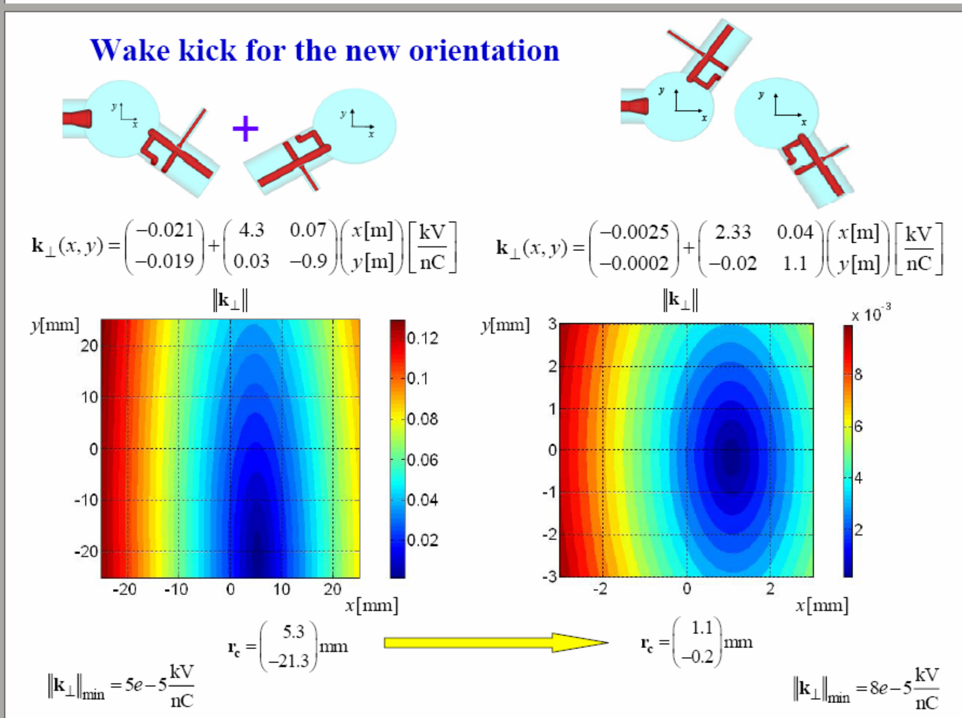
Igor-Martin Simulation & Bane Optical Model

Coupler Kick

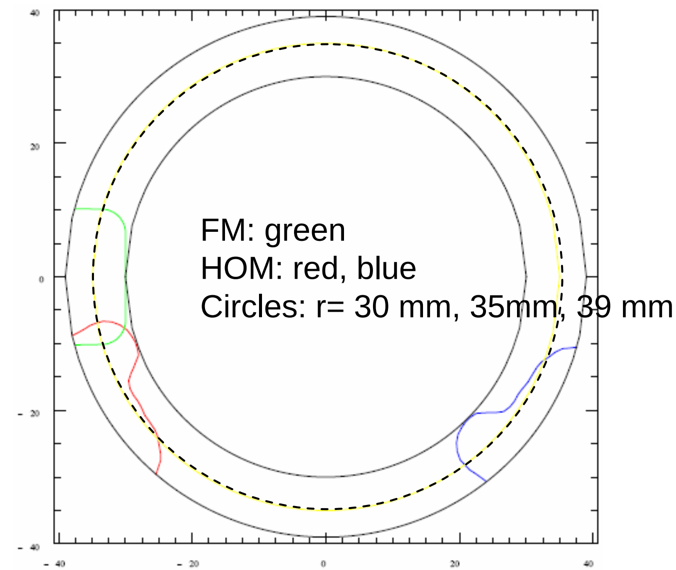
Igor Zagorodnov and Martin Dohlus
ILC Workshop, DESY
31 May, 2007





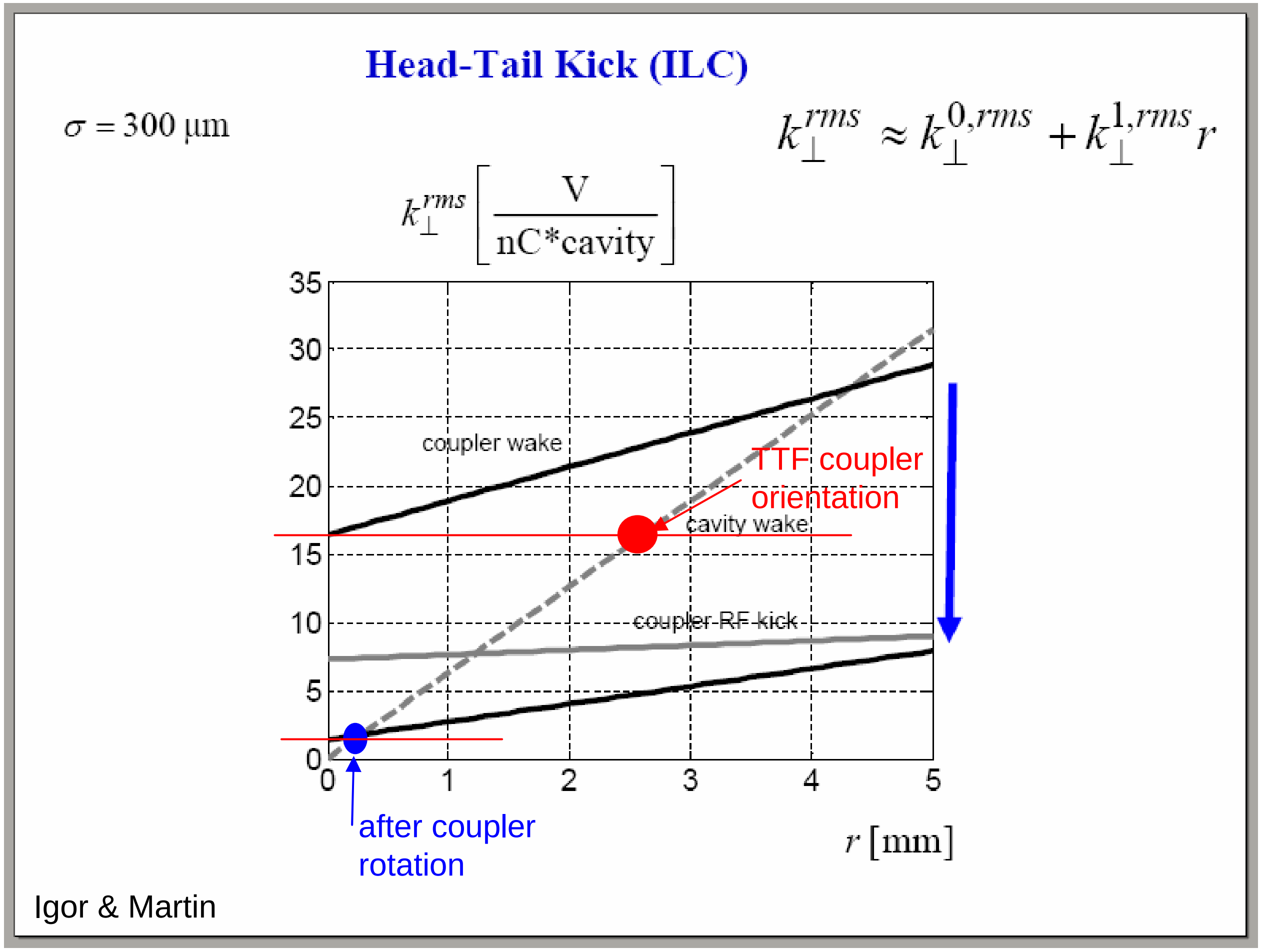


Optics Impedance calculation – K. Bane



Method	On Axis Kick (V/pC) (norm of RMS vector)
Igor with 3D calculation	k1 ~ 0.0165
Optics Impedance calculation	k1x= -0.026 k1y= -0.020
Optics Impedance calculation With iris shadowing	k1x= -0.017 k1y= -0.008
Igor, rotate the HOM by pi/2	k1 ~ 0.0015
Optics Impedance calculation	k1x= -0.004 k1y= -0.0019
Optics Impedance calculation With iris shadowing	k1x= -0.007 k1y= -0.0015

Coupler SW Kick v.s. Cavity SW

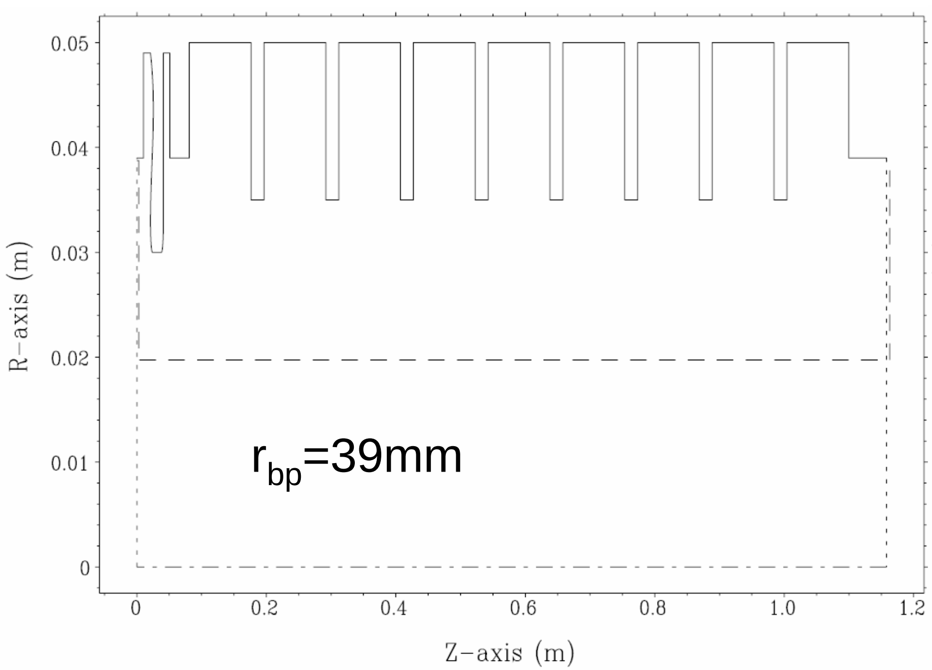


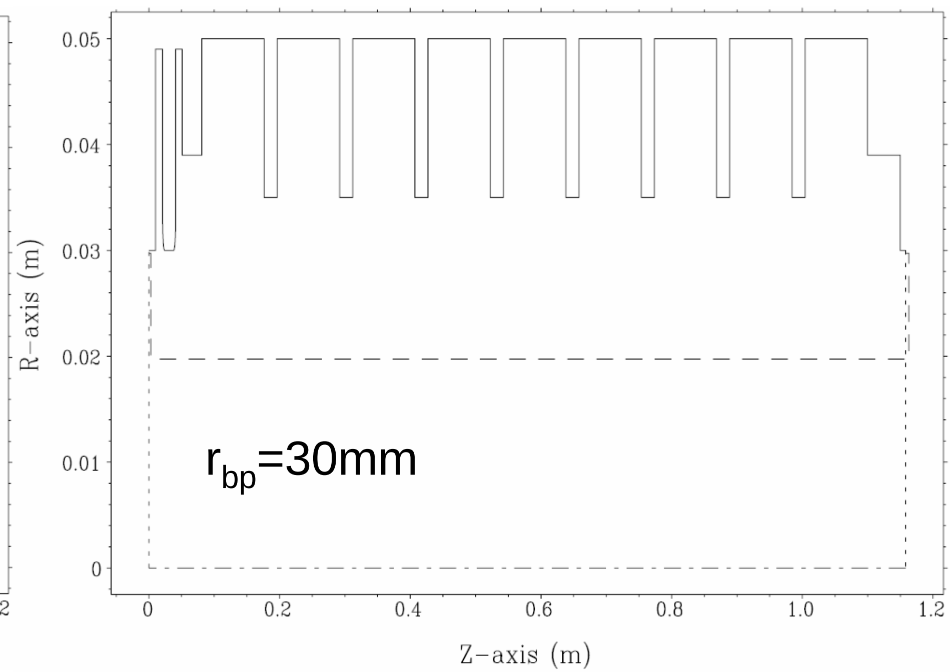
- Symmetrizing HOM orientations reduces the effect by factor of 10

Shadowing With Smaller Beampipe Aperture

- Based on the Optical Impedance model (Bane, et al), if the coupler intrusion is behind the cylindrical symmetric aperture, the short bunch will see “no” effect of the coupler asymmetry.
- The LL design has 30-mm both in beam pipe radius and the cell aperture.
  - Will increase off-axis SW
  - Will reduce the asymmetry effects of the couplers
- Shadowing effect see next with the ABCI run in 2D

Short Range Wakefield – ABCI Runs





Bunch length (mm)	0.3				
Cell radius (mm)	35				
Beam pipe radius (mm)	39		30		
FM intrusion (mm)	30	No coupler	30	32	No coupler
K1_loss (V/pC/m)	12.38	9.87	12.50	12.29	12.31

Minimizing The Coupler Kick

- Coupler on-axis SW kick can be significant
- Ways to minimize the on-axis SW kick
  - Symmetrize HOM coupler orientation
    - May also reduce the coupler RF kick (due to FM)
    - No other side effects
  - Smaller aperture shadowing
    - May improve HOM damping (for small a designs)
    - Side effect: will increase off-axis SW
  - Co-axial coupler – need more understanding on other RF issues
- Combine Symmetrizing and Shadowing can reduce the coupler SW effect

Summary

- LL design with both lower Es and Bs fields is possible with adequate HOM damping
- Coupler SW kick can be significant
  - Mitigate this effect possible by redesigning end-group
  - More study needed