Fermilab HG cavity and coupler R&D

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Fermilab

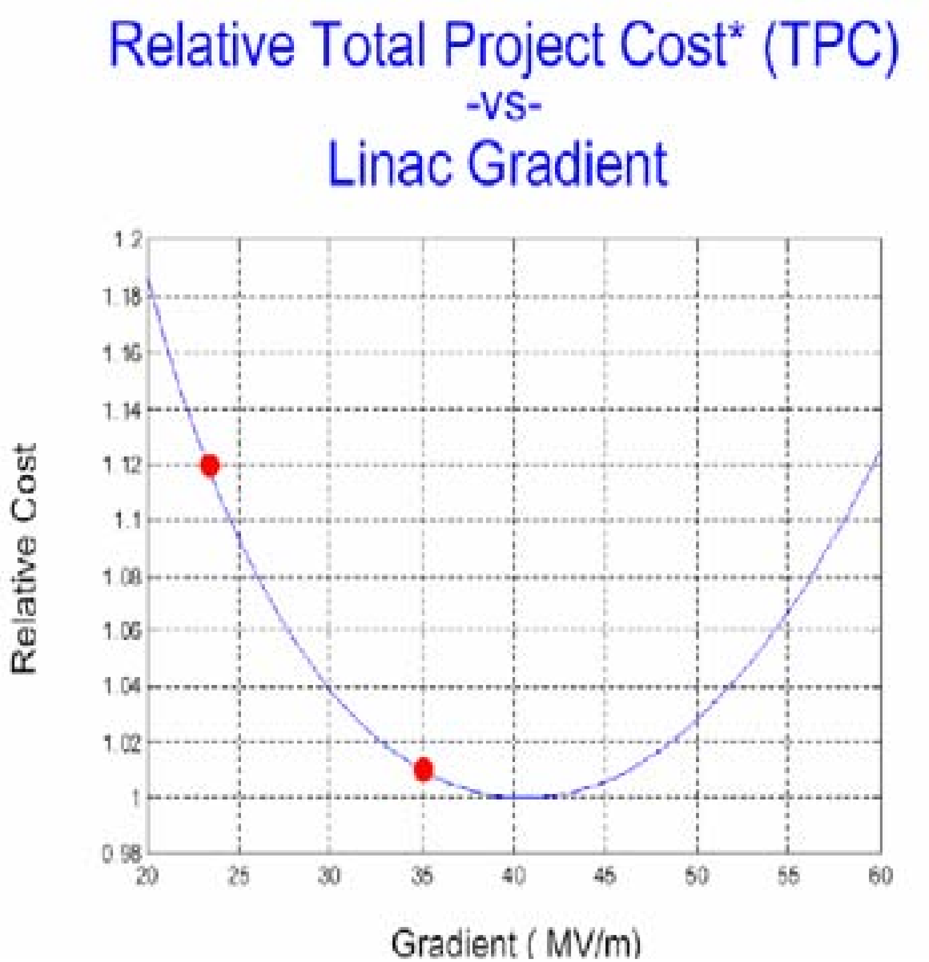
Outline

- Motivation
- HOM calculations
- Main Coupler and HOM dumping
- Multipactor
- Lorentz Forces
- Single bunch beam dynamics
- Summary

RE & Low Loss ILC Cavity

DESY	SLAC	FNAL	JLAB	KEK
J. Sekutowicz	K. Ko	N. Solyak	P. Kneisel	K. Saito
	L. Ge	I. Gonin		F. Furuta
	L. Lee	T. Khabiboulline		Y. Higashi
	Z. Li			T. Higo
	C. Ng			H. Inoue
	L. Xiao			Y. Moro
				T. Saeki
				H. Yamaoka

Motivation for the cavity with gradient higher than 25 MV/m ?



ILC Workshop,
KEK, Dec. 2004

'Summary' of WG5 at ILCWS

- 25 MV/m is in hand
- 35 MV/m need essential work
- 45 MV/m is for upgrade (500 GeV → 1 TeV)

Cost (site independent) minimum is 35 – 40 MV/m

- But 'Flat minimum'.
- Need to review the cost models.
- Site dependent factor will be important.

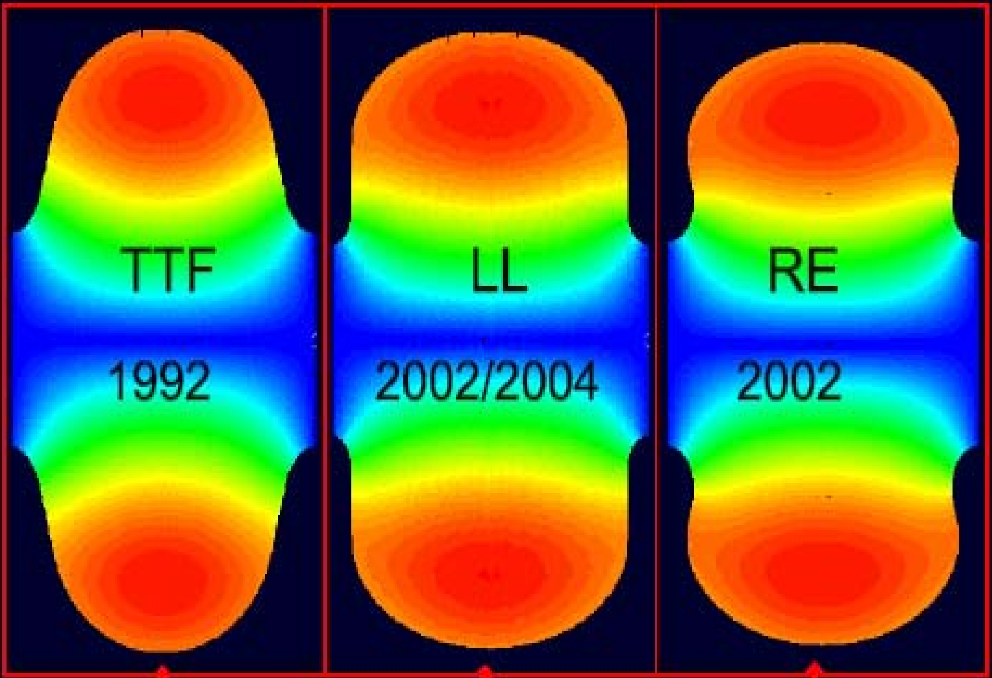
1. Introduction: Evolution of the elliptical cavities cont.

Example: 1.3 GHz inner cells for TESLA and ILC

Example LL cavity:

Epeak/Eacc = 2.36
Epeak=85 MV/m
at Eacc=35 MV/m;

Achieved:
Cornell (RE)=100 MV/m
JLAB (LL)= 90 MV/m

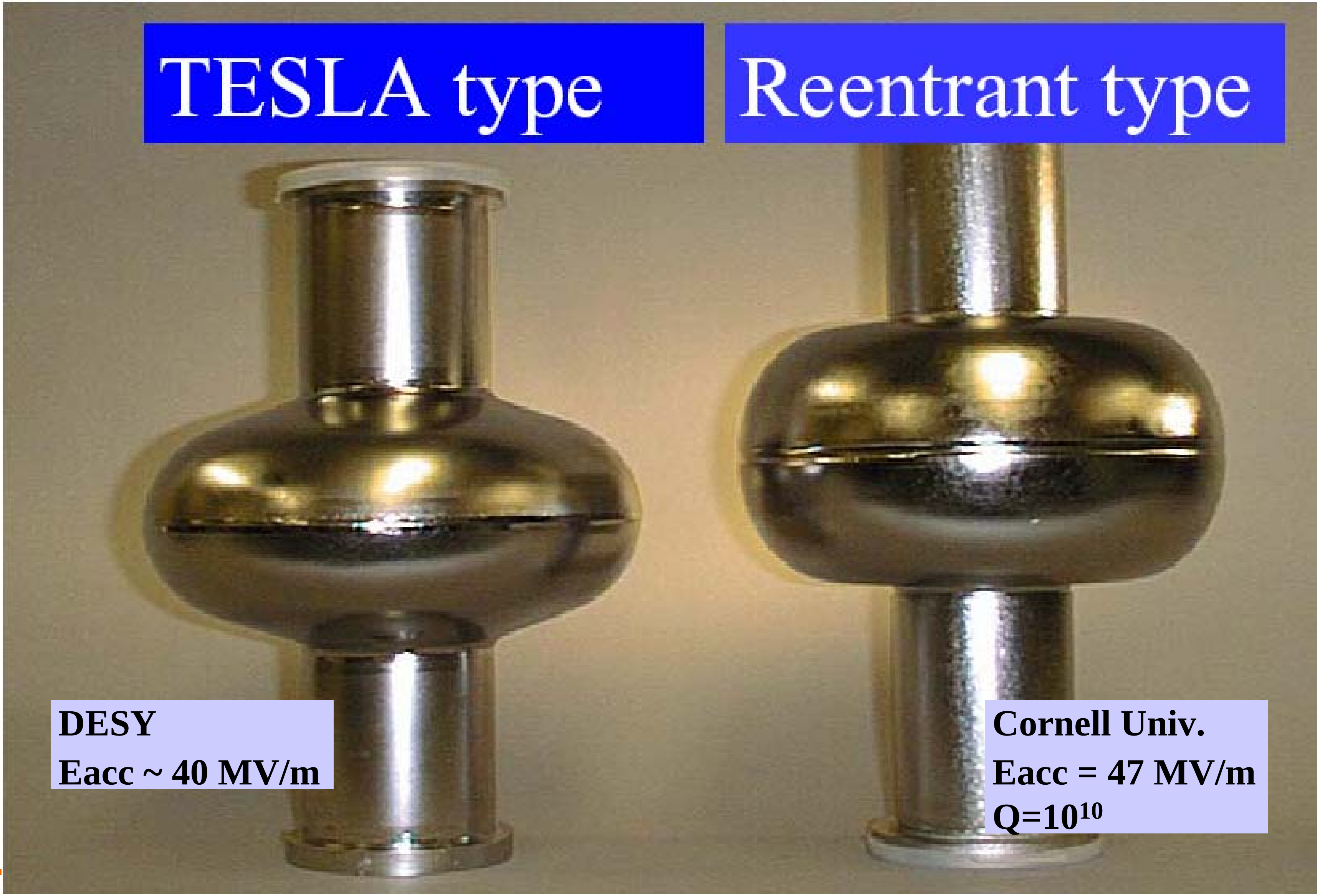


J.Sekutowicz

SLAC,
Jan.25,2005

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)

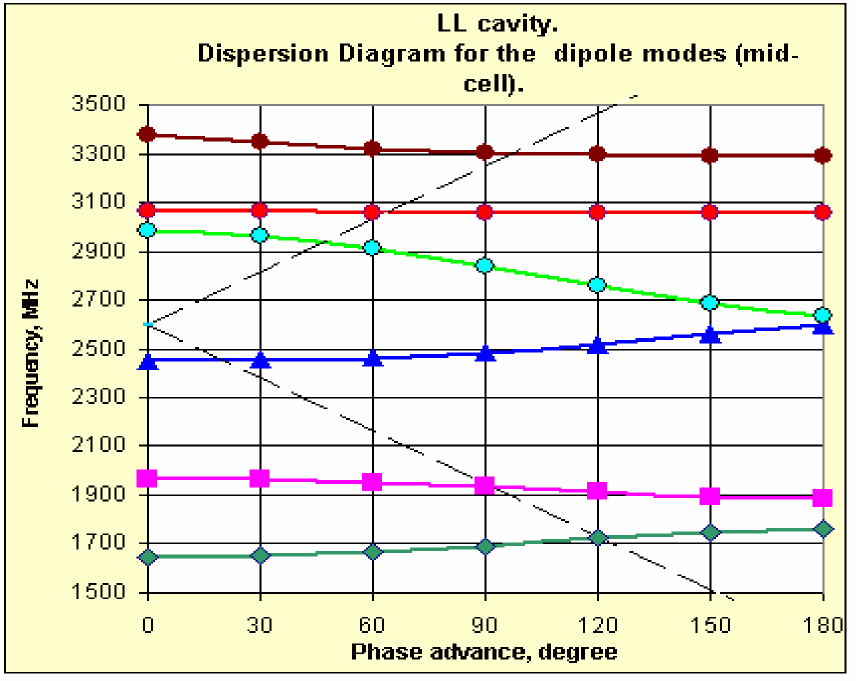
TESLA vs. Reentrant cavity

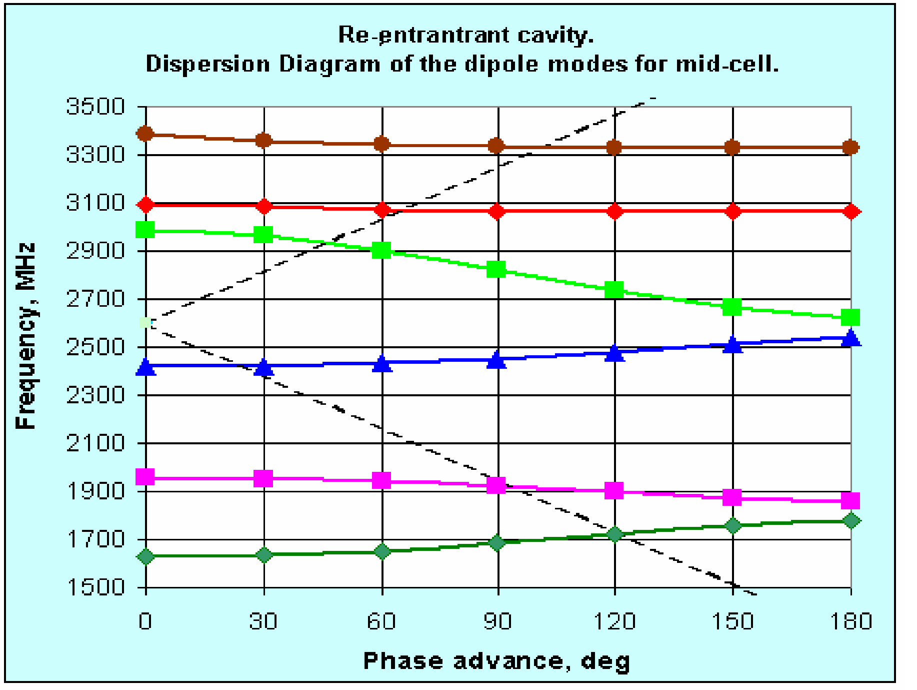


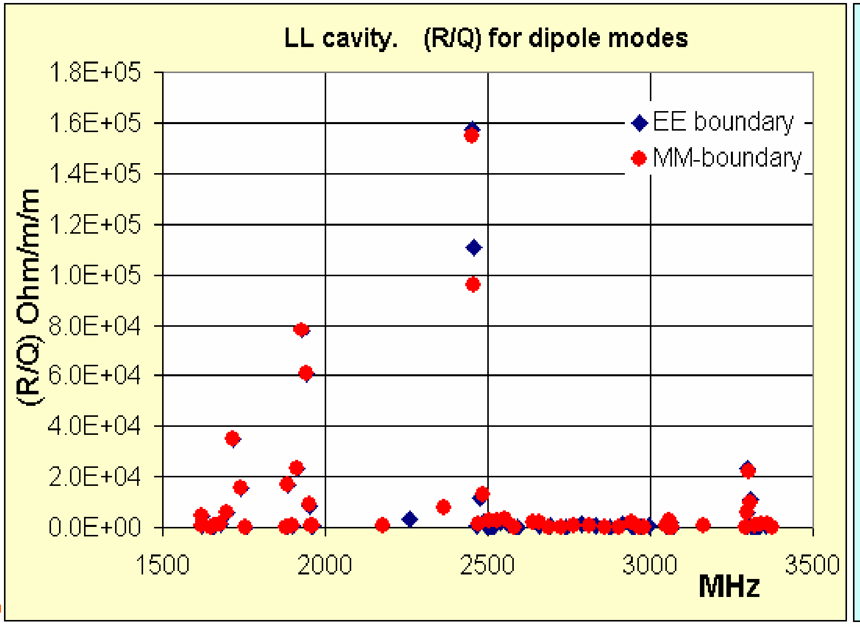
R&D needs for LL &RE cavity design.

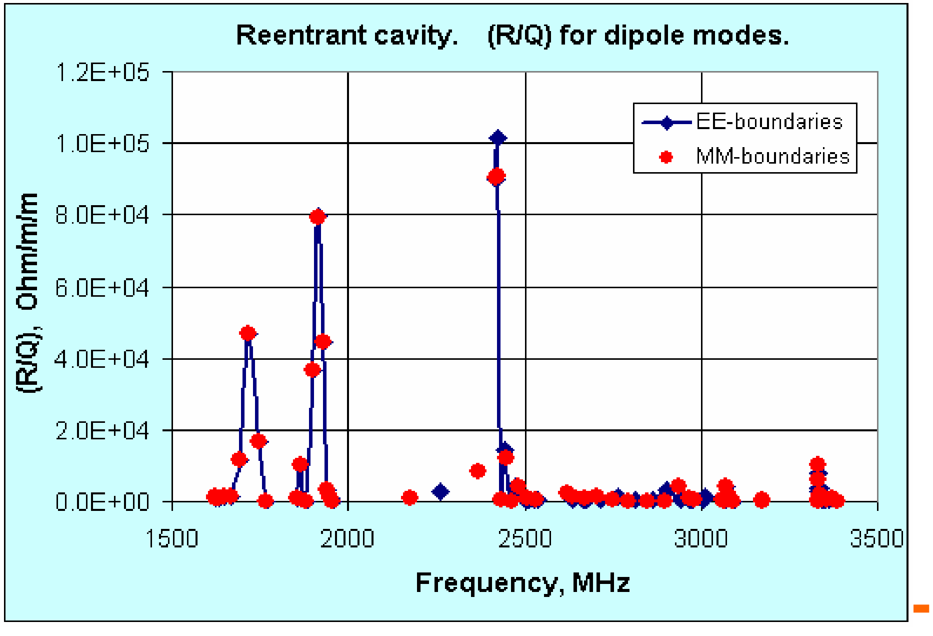
- Cavity optimization for fundamental mode
- ✓ Monopole High Order Modes (cryogenic losses)
- ✓ Dipole HOM's (R/Q, field distribution, trapped modes, etc.)
- ✓ Multipactor studies
- ✓ Mechanical properties:
  - Detuning due to Lorentz forces, stiffening rings.
  - Mechanical resonances, Vibrations
- ✓ Main coupler (position, coupling, …)
- Fabrication, Hydroforming, Processing, Cleaning, Tuning, Testing, Cost
- ✓ Wake fields (incl.coupler) and beam dynamics in Linac
- Etc…

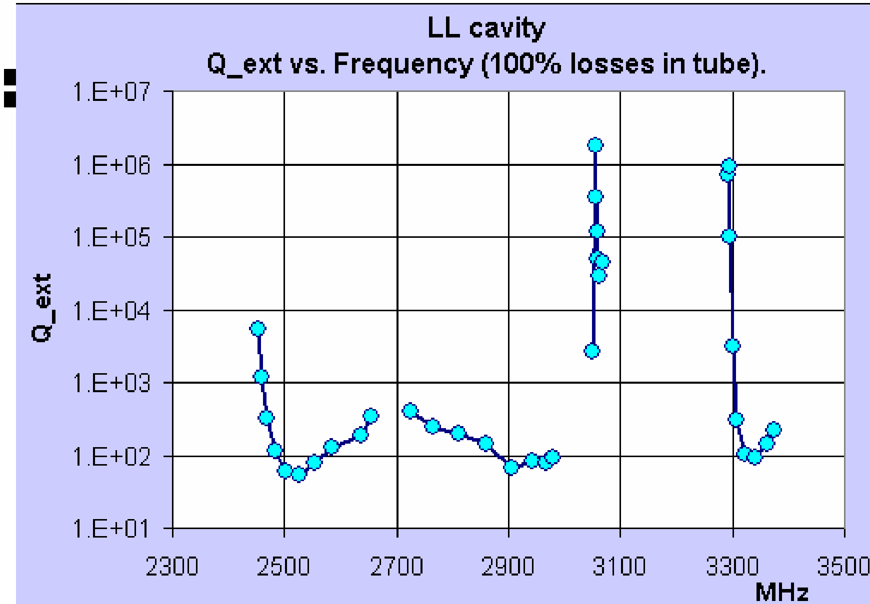
✓ FNAL …All calculation need cross-check

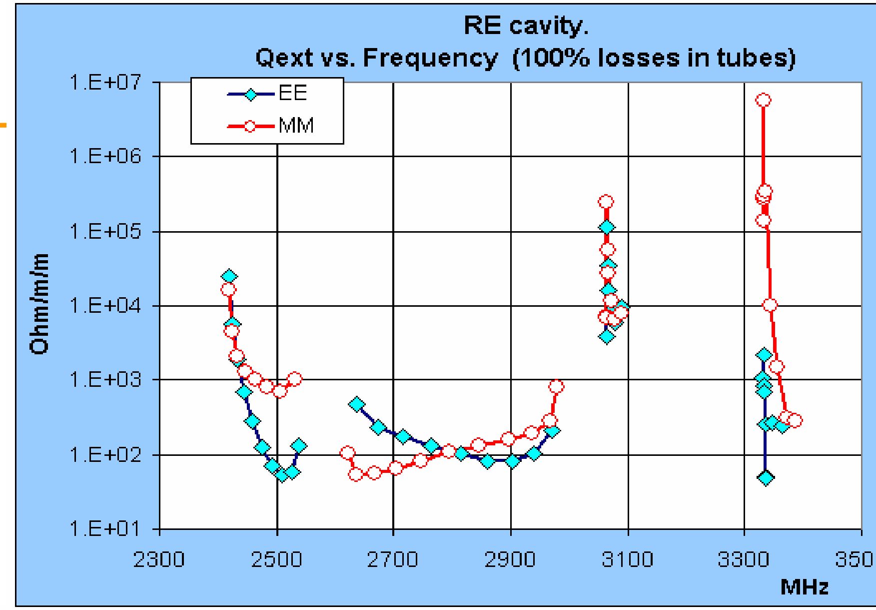

LL cavity.
Dispersion Diagram for the dipole modes (mid-cell).
Frequency, MHz
Phase advance, degree
3500
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
0
30
60
90
120
150
180

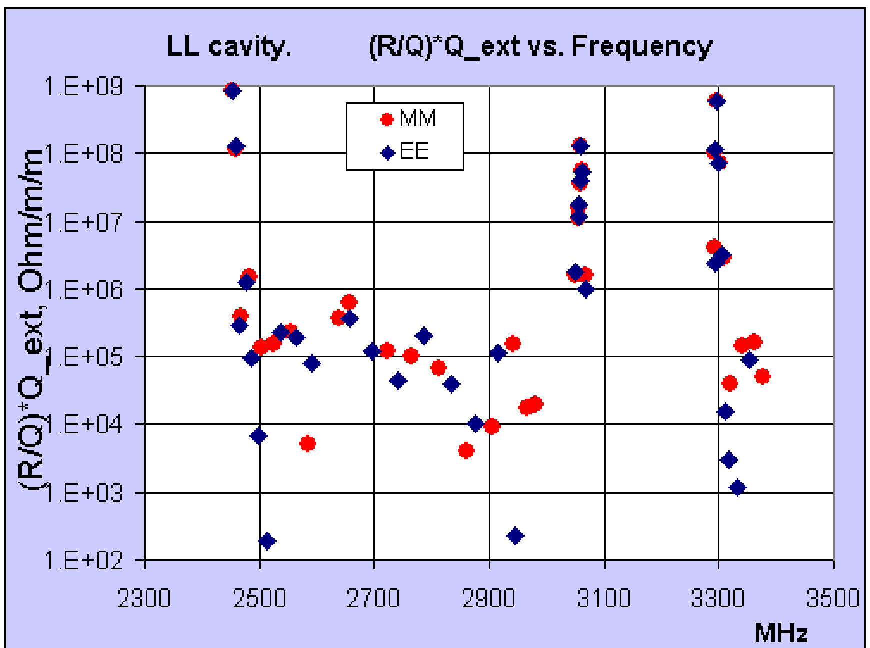

Re-entrantrant cavity.
Dispersion Diagram of the dipole modes for mid-cell.
Frequency, MHz
Phase advance, deg
3500
3300
3100
2900
2700
2500
2300
2100
1900
1700
1500
0
30
60
90
120
150
180

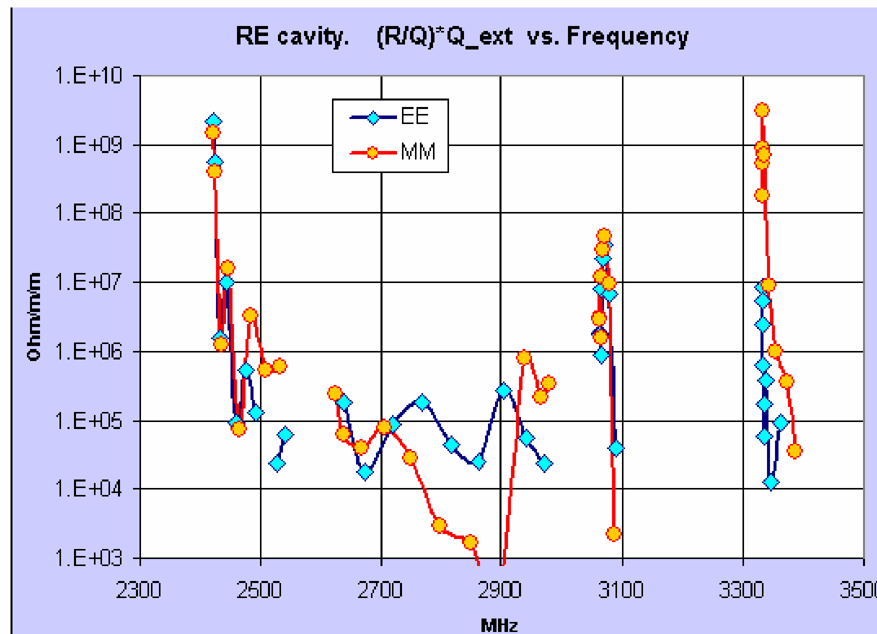

LL cavity. (R/Q) for dipole modes
(R/Q) Ohm/m/m
MHz
EE boundary
MM-boundary
1.8E+05
1.6E+05
1.4E+05
1.2E+05
1.0E+05
8.0E+04
6.0E+04
4.0E+04
2.0E+04
0.0E+00
1500
2000
2500
3000
3500


Reentrant cavity. (R/Q) for dipole modes.
(R/Q), Ohm/m/m
Frequency, MHz
EE-boundaries
MM-boundaries
1.2E+05
1.0E+05
8.0E+04
6.0E+04
4.0E+04
2.0E+04
0.0E+00
1500
2000
2500
3000
3500

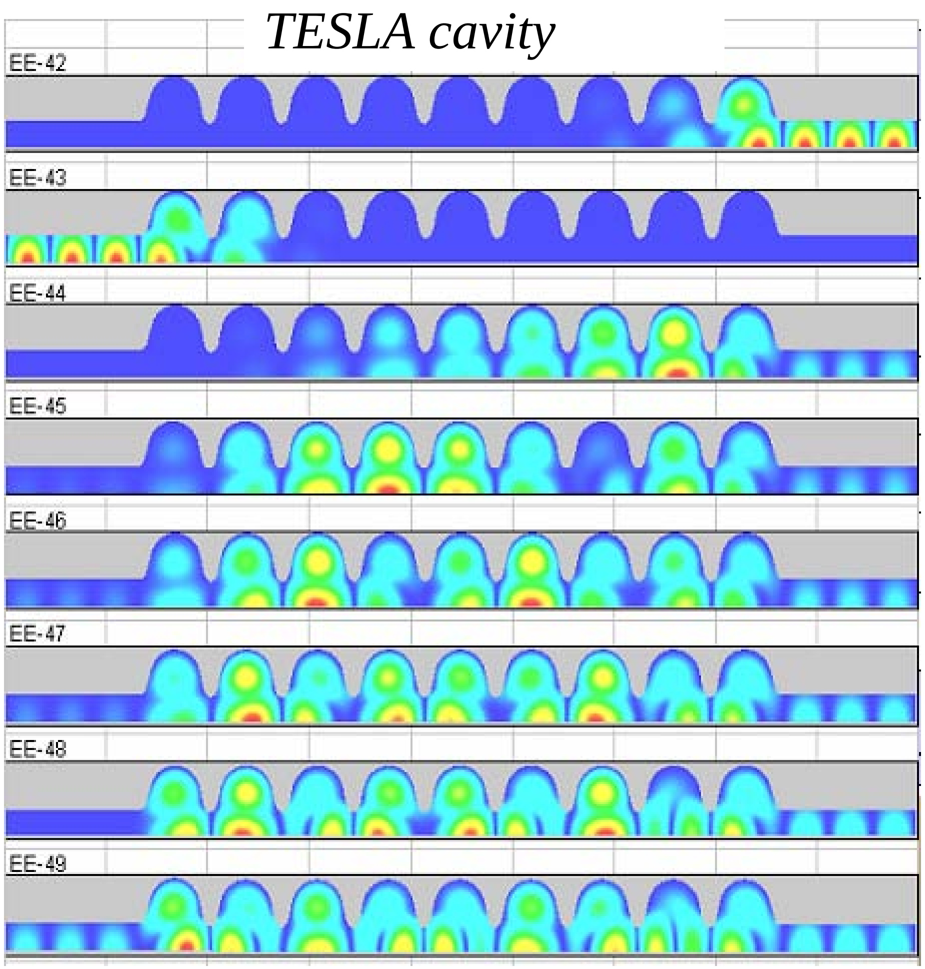

LL cavity
Q_ext vs. Frequency (100% losses in tube).
Q_ext
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
2300
2500
2700
2900
3100
3300
3500
MHz

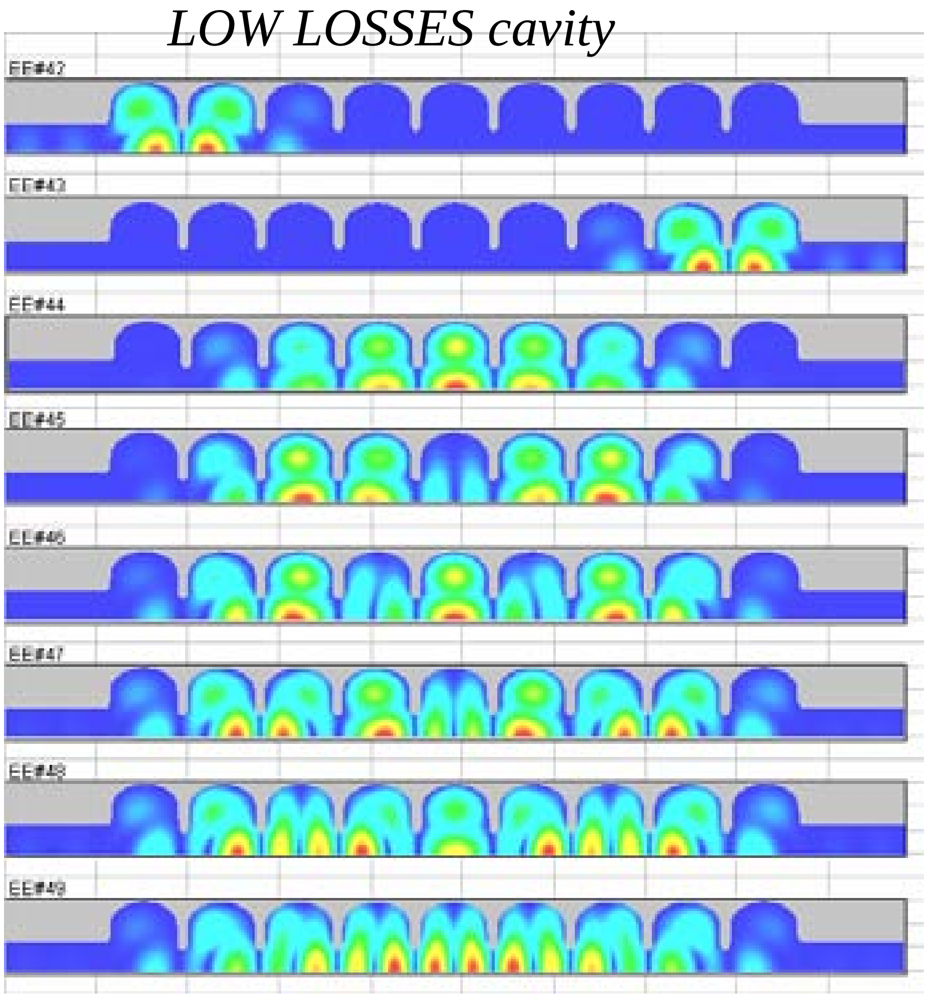

RE cavity.
Qext vs. Frequency (100% losses in tubes)
Ohm/m/m
EE
MM
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
1.E+01
2300
2500
2700
2900
3100
3300
3500
MHz


LL cavity. (R/Q)*Q_ext vs. Frequency
(R/Q)*Q_ext, Ohm/m/m
MM
EE
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
1.E+02
2300
2500
2700
2900
3100
3300
3500
MHz


RE cavity. (R/Q)*Q_ext vs. Frequency
Ohm/m/m
EE
MM
1.E+10
1.E+09
1.E+08
1.E+07
1.E+06
1.E+05
1.E+04
1.E+03
2300
2500
2700
2900
3100
3300
3500
MHz

“Trapped” modes in 5th passband





Asymmetric ends can help to improve dump HOM’s in LL cavity (as TESLA)

Summary

What is good about this structure ?

- Lower cryogenic loss by ~20% (as compared to TTF structure).
- Shorter rise time by 13% due to higher (R/Q) (as compared to TTF structure).
- Less sensitive to microphonics due to higher (R/Q) and thus lower Qext.
- Less stored energy by 13%.
- B_{peak}/E_{acc} lower.

What is critical for this structure ?

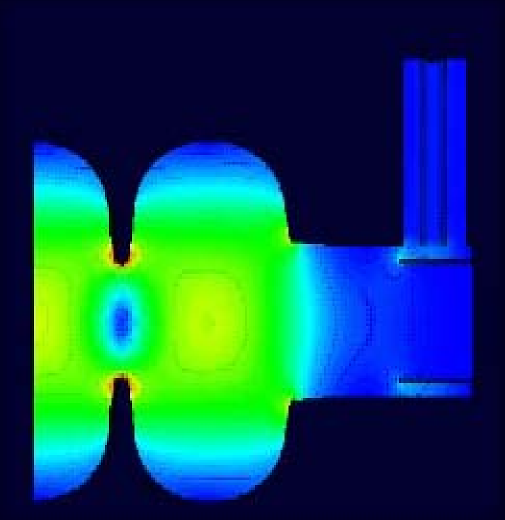
- Higher E_{peak}/E_{acc} = 2.36, (TTF structure 2).
- Weaker cell-to-cell coupling k_{cc}= 1.52% (TTF structure 1.9%).
- HOM loss factors are higher: $k_{\perp}$ by 65% , $k_{\|}$ by 18 %.

Open questions:

- Vibrations ?
- Preparation and cleaning ?

Next steps: *(from J.Sekutowicz presentation Jan,2005)*

- end-cells tuning to improve damping of 3-rd and 5-th dipole passbands or/and make asymmetry (more dyes needed to build prototypes).
- Implementation of alternative coupling methods both for FM and HOMs.

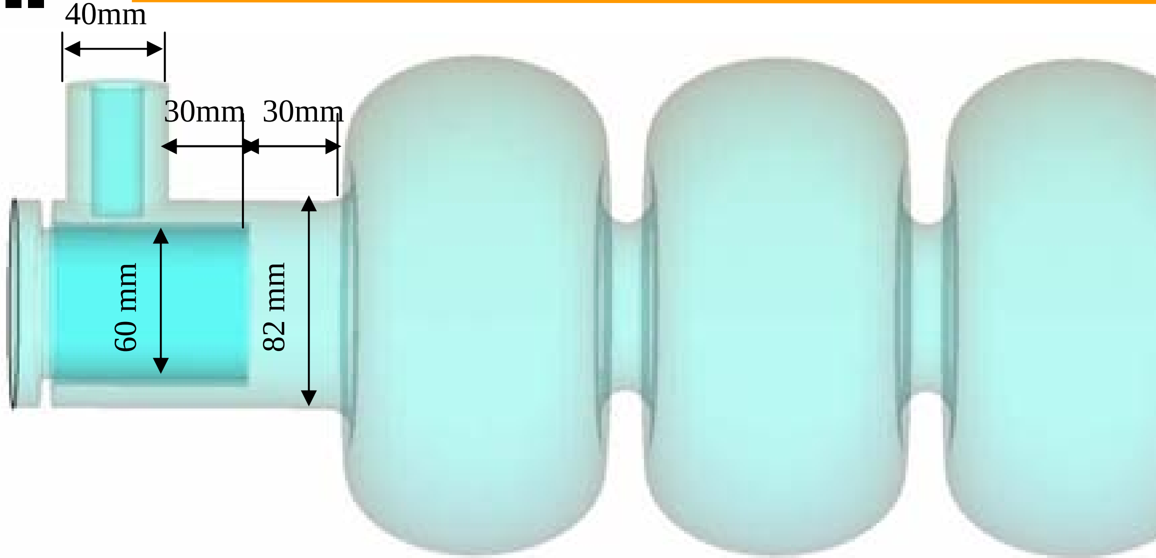


Computer modeling by ACD-SLAC and copper model of similar device built at DESY by MHF-SL group agree very good.

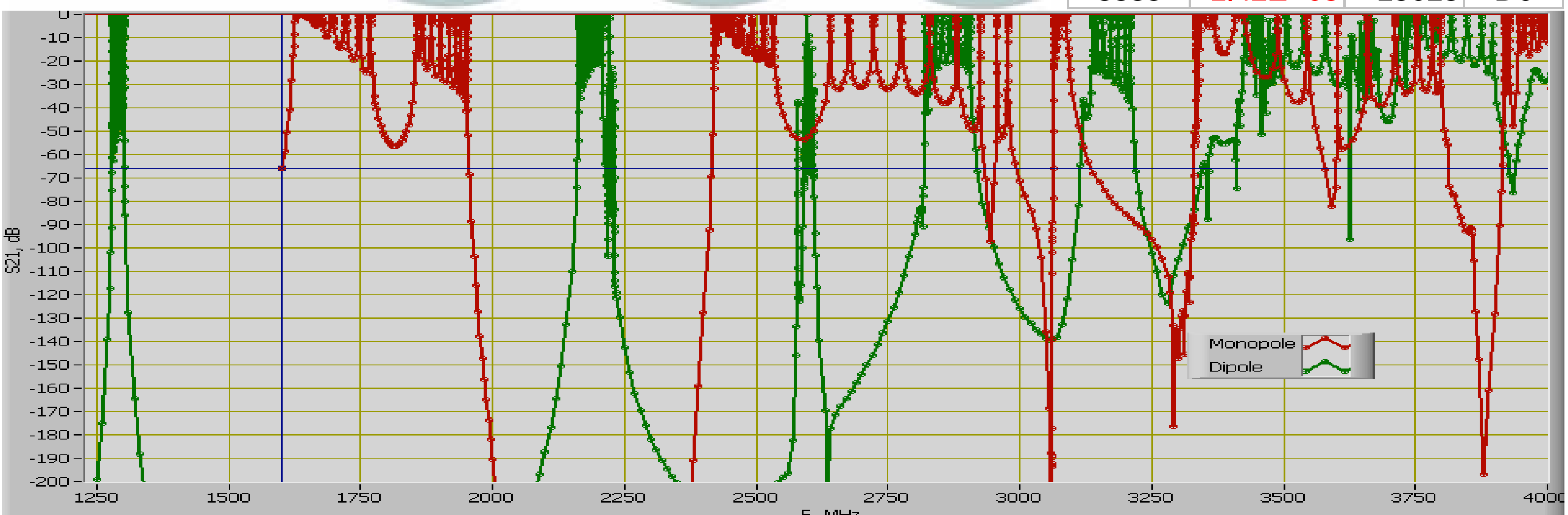
- Qext of FM coupler covers range $2{\cdot}10^5$ to $8{\cdot}10^6$.
- Can we build HOM coupler based on the same idea?

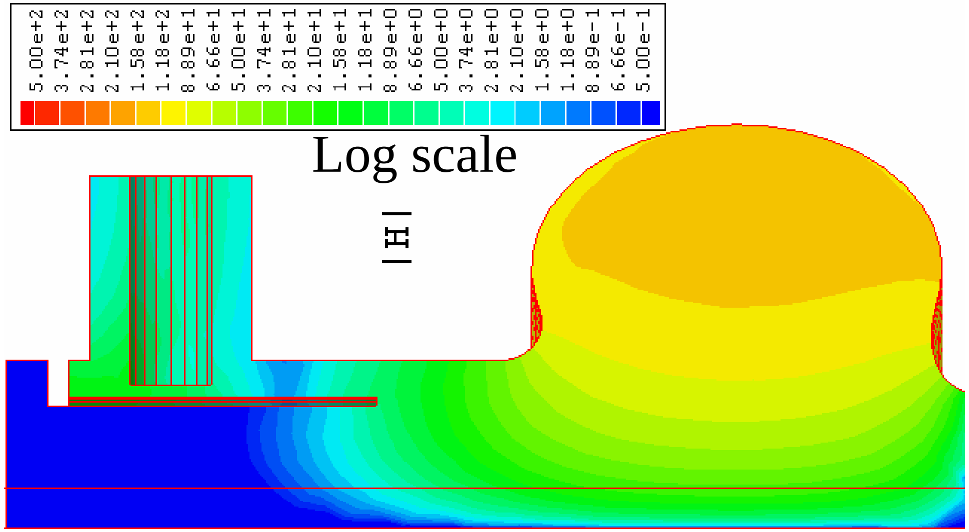
- KEK plans to build four 9-cell LL structures by the end of September 2005.

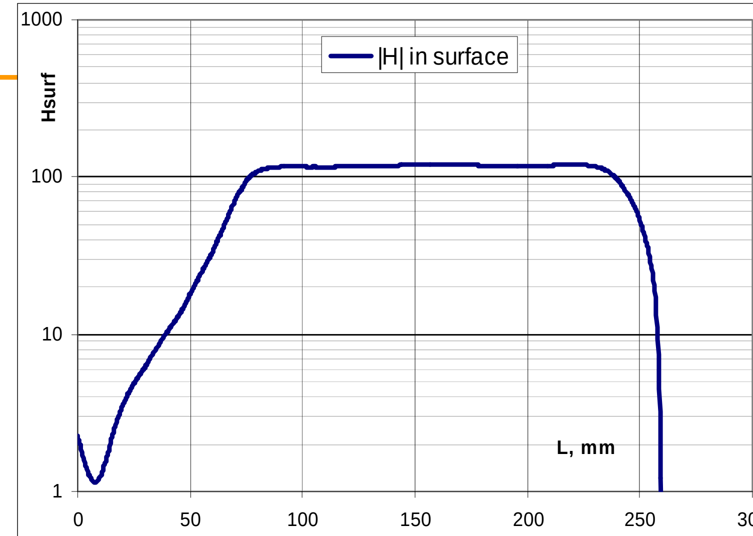
New idea for Fundamental / HOM couplers

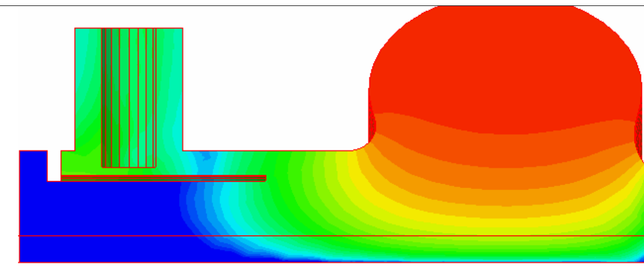


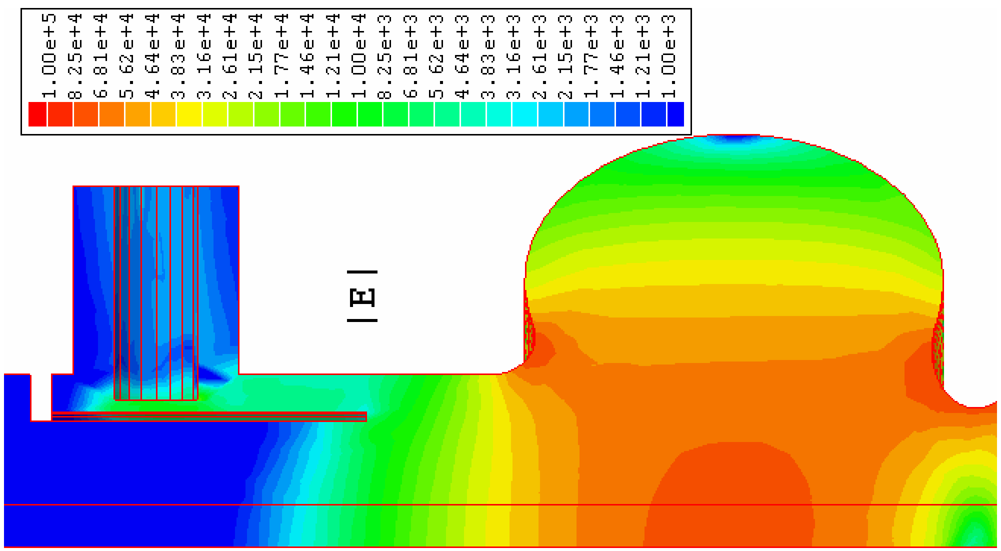
F, MHz	Qext	Rsh/Q Ω/m/m	mode
1300	8.00E+05		M1
1696	1.65E+03	22968	D1
1721	2.88E+03	93247	D1
1747	5.59E+03	32916	D1
1902	1.76E+04	72992	D2
1917	2.77E+04	158985	D2
1931	4.60E+04	89321	D2
2420	1.03E+05	180097	D3
2424	1.96E+04	202969	D3
2829	1.99E+04	8000	D4
3072	1.74E+04	8266	D5
3335	1.42E+05	15618	D6

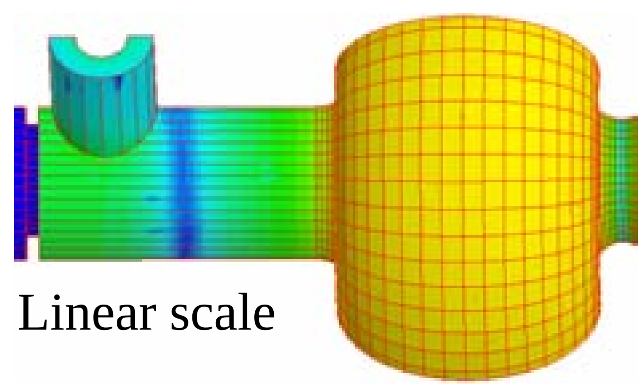



5.00e+2
3.74e+2
2.81e+2
2.10e+2
1.58e+2
1.18e+2
8.89e+1
6.66e+1
5.00e+1
3.74e+1
2.81e+1
2.10e+1
1.58e+1
1.18e+1
8.89e+0
6.66e+0
5.00e+0
3.74e+0
2.81e+0
2.10e+0
1.58e+0
1.18e+0
8.89e-1
6.66e-1
5.00e-1
Log scale
|H|

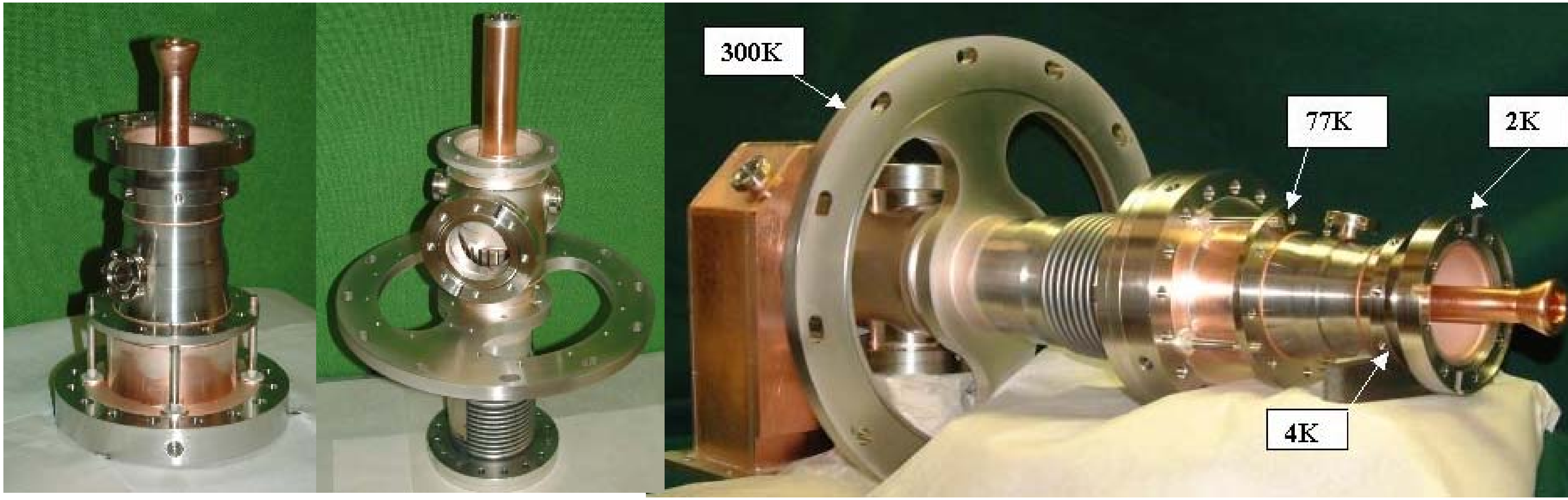

|H| in surface
Hsurf
L, mm
1000
100
10
1
0
50
100
150
200
250
300




1.00e+5
8.25e+4
6.81e+4
5.62e+4
4.64e+4
3.83e+4
3.16e+4
2.61e+4
2.15e+4
1.77e+4
1.46e+4
1.21e+4
1.00e+4
8.25e+3
6.81e+3
5.62e+3
4.64e+3
3.83e+3
3.16e+3
2.61e+3
2.15e+3
1.77e+3
1.46e+3
1.21e+3
1.00e+3
|E|


Linear scale

AMAC SBIR Coupler Project

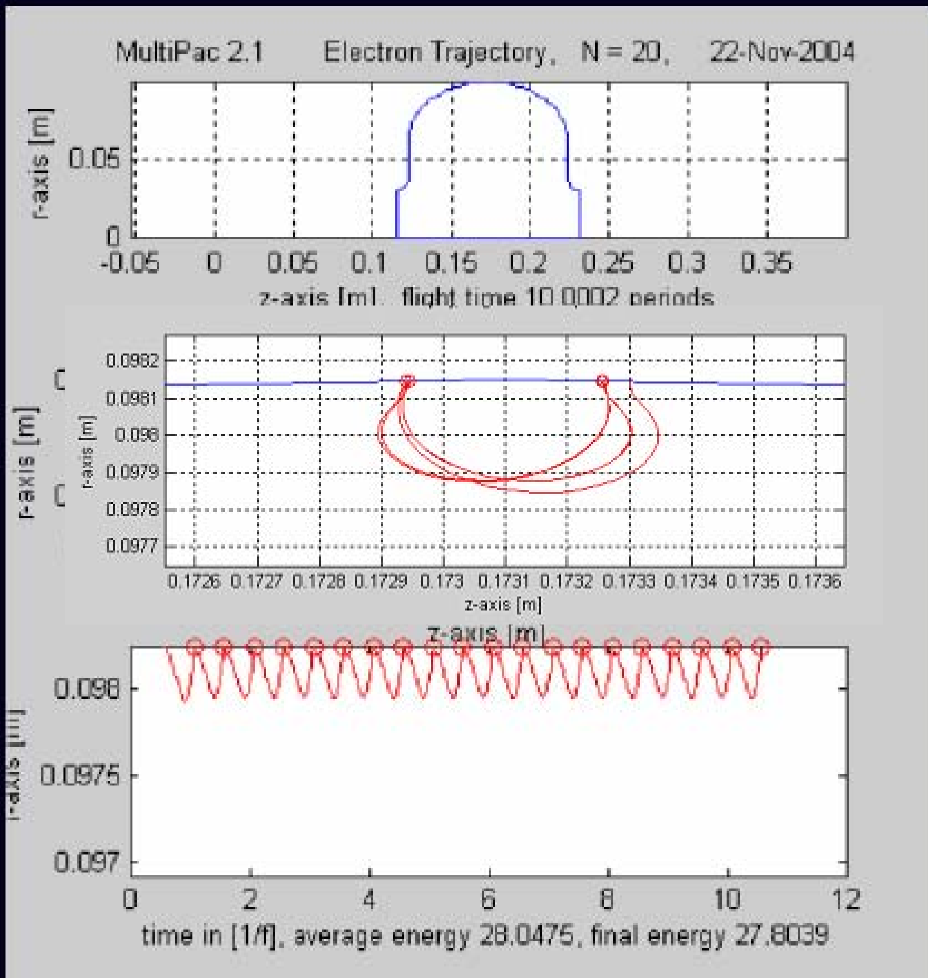


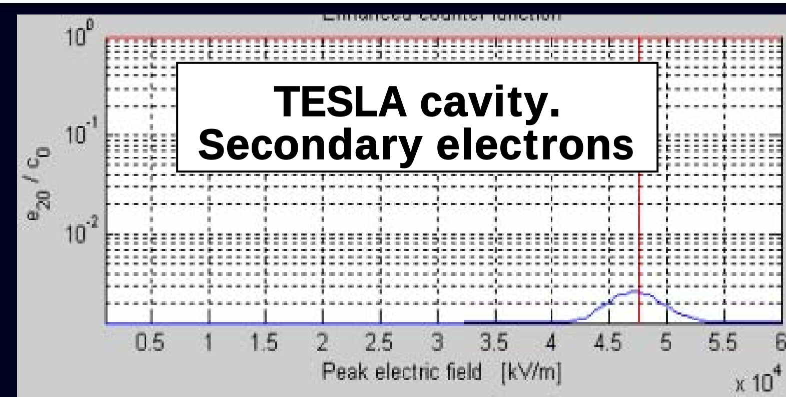
- Two prototypes were built and tested at DESY
- Three new concept designs for the possible use with ILC cavities and cryomoduls are being developed with Fermilab, DESY and CPI.

See WG5 presentation: AMAC's R&D Efforts for ILC High RF Input Couplers and High Gradient Cavities.

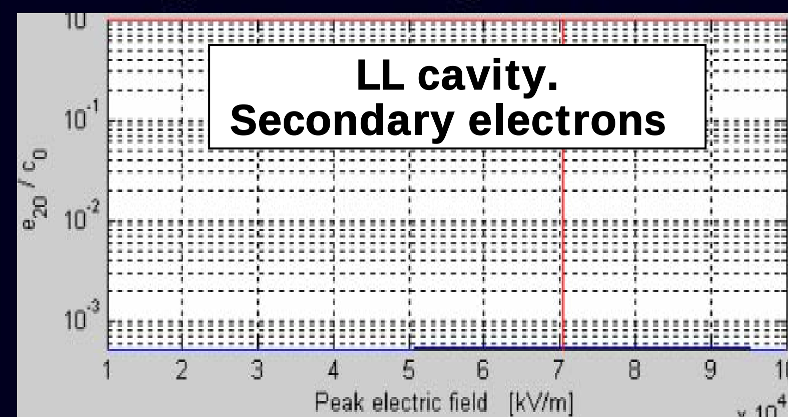
4. Multipacting and the Lorentz force detuning (FNAL Group)

Multipacting

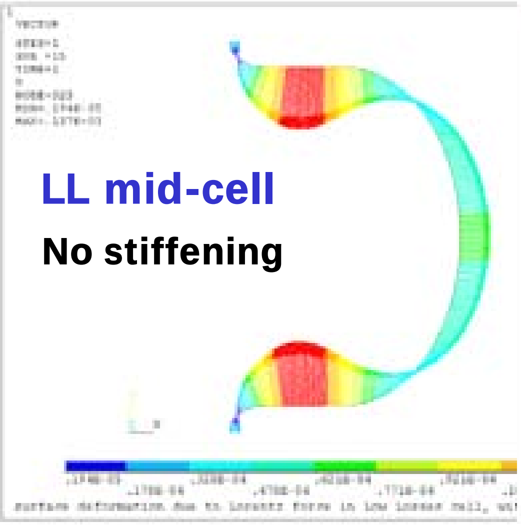


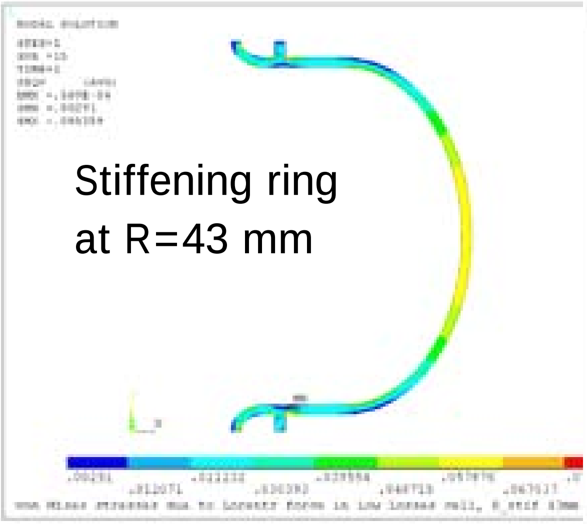


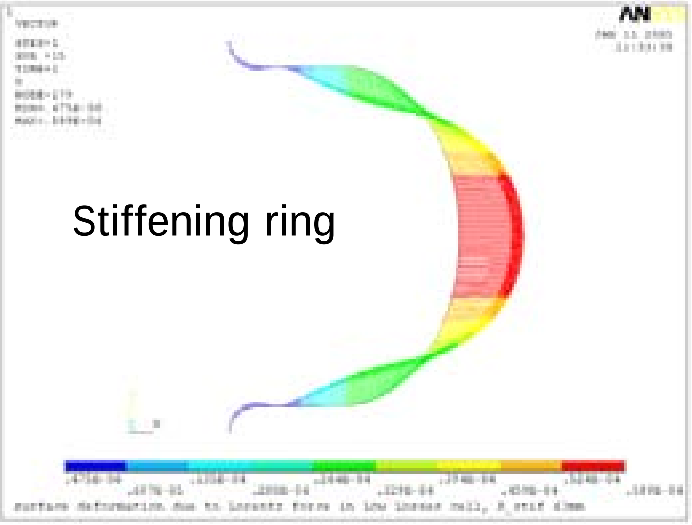
At the equator one resonance trajectory was found, but impact energy is too small, to create enough secondary electrons.



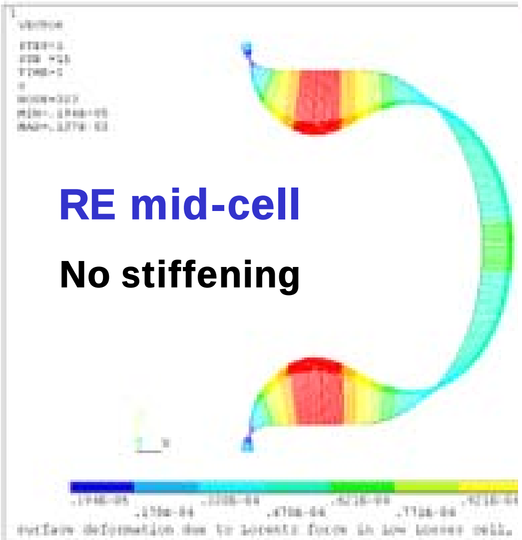
Lorentz forces

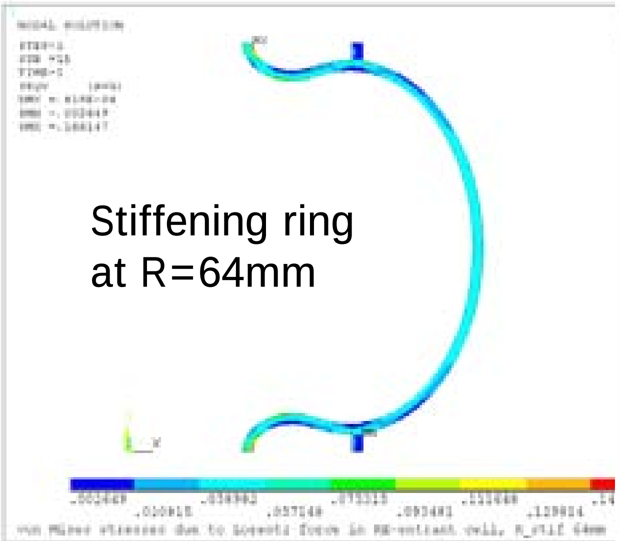


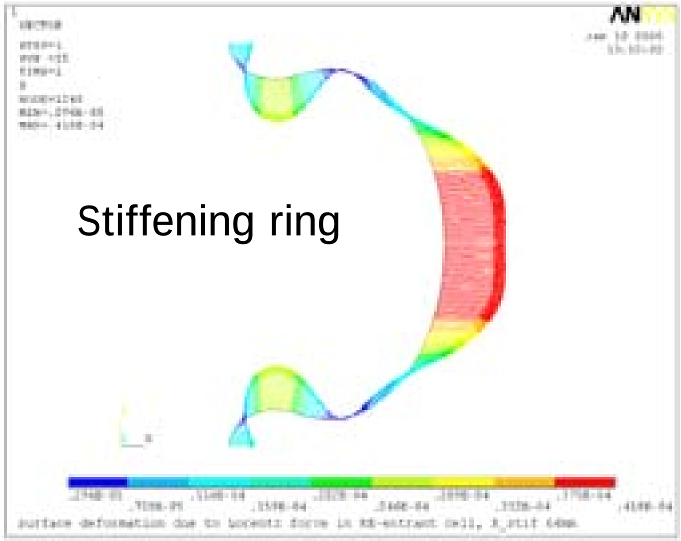




Surface deformation | STRESS | Surface deformation

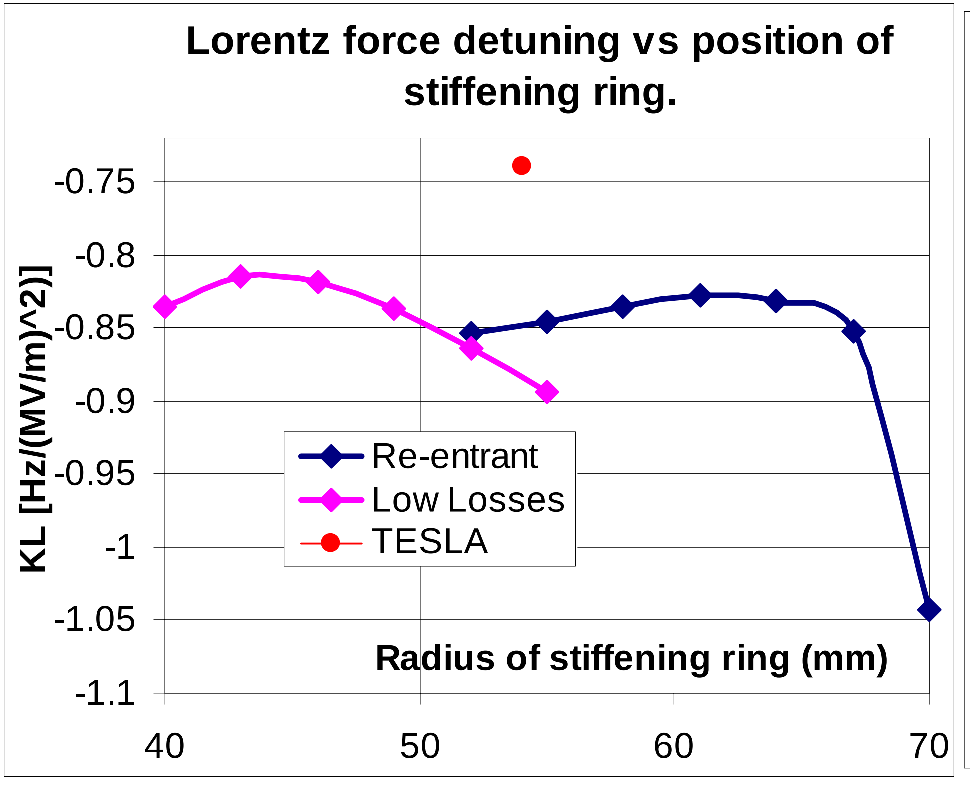


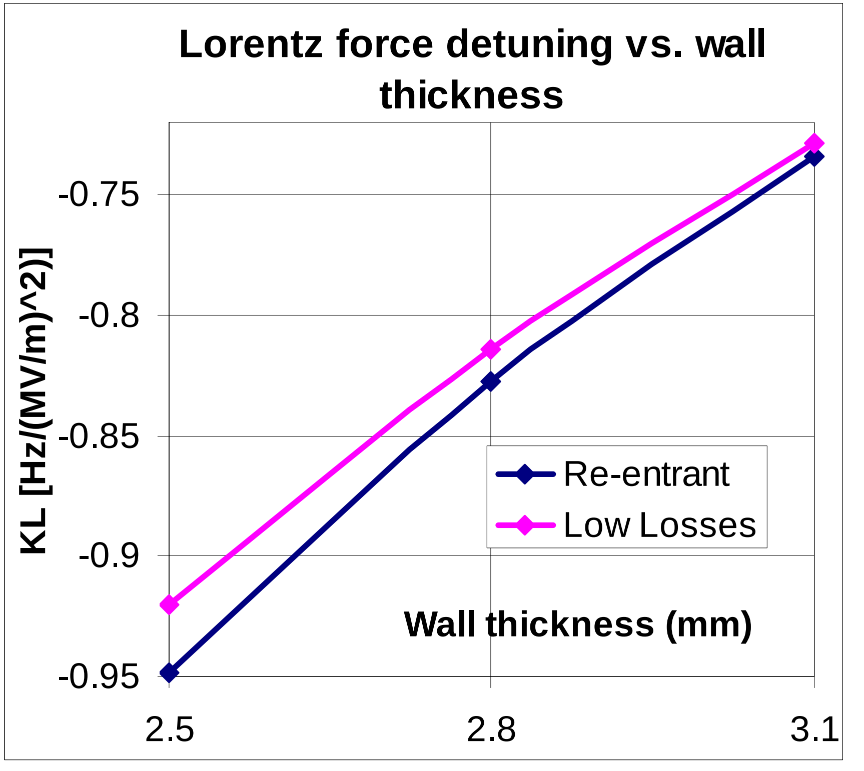




Surface deformation

Lorentz forces (2)



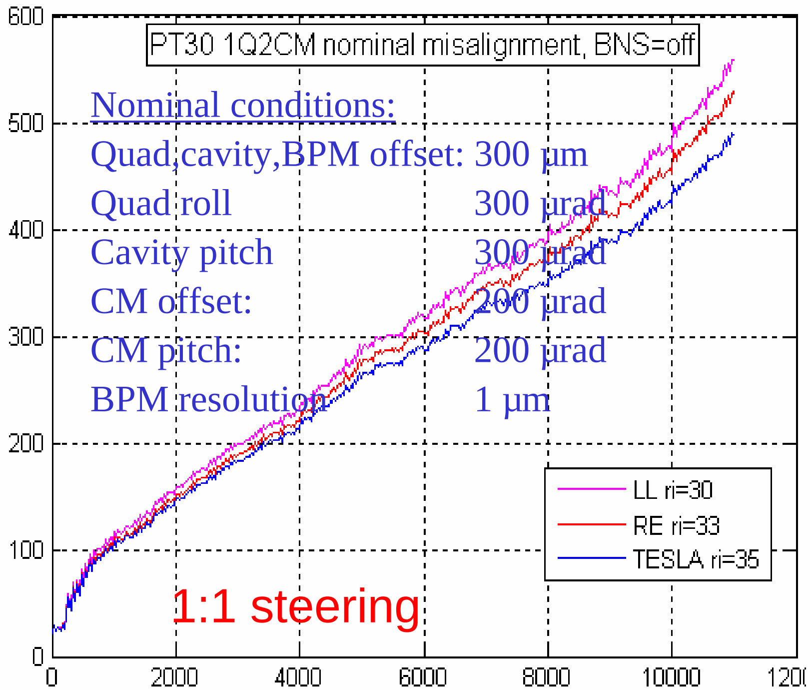


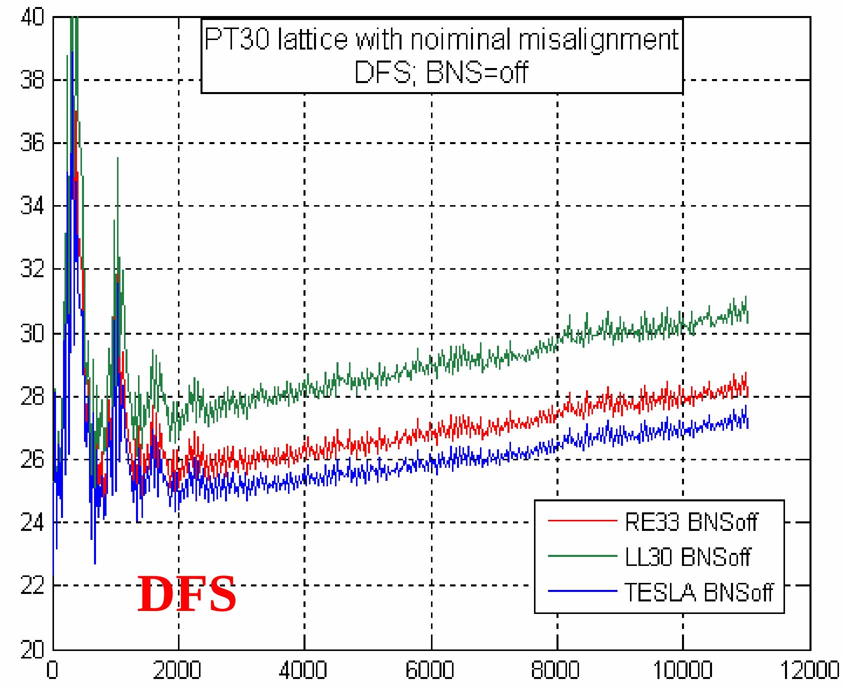
TESLA(wall=2.8mm) ΔF(wo/w ring) = - 801/-463 Hz for 25 MV/m

Low Losses(2.8mm) ΔF(wo/w ring) = - 871/-509 Hz for 25 MV/m

Re-entrant(2.8mm) ΔF(wo/w ring) = - 860/-517 Hz for 25 MV/m

Emittance Growth in Linac with HG cavities (RE or LL)

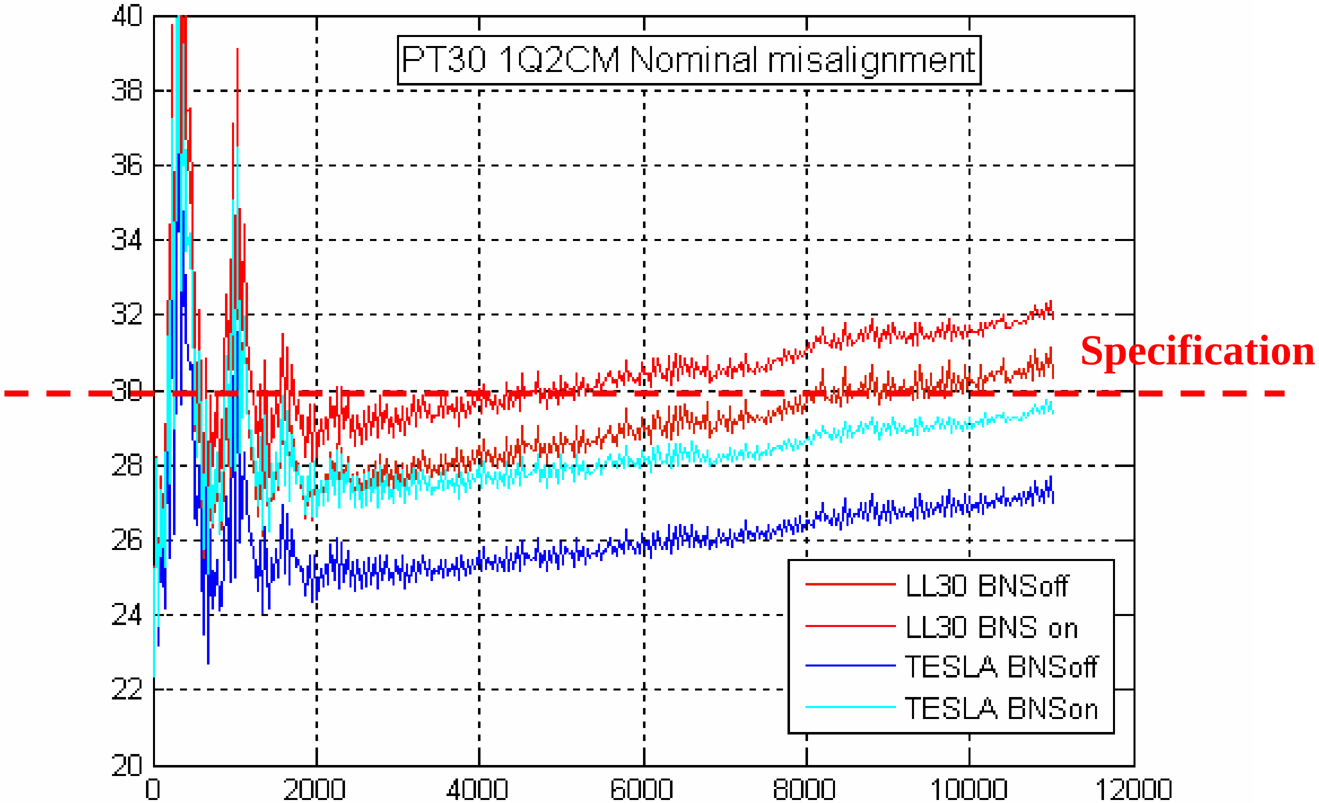




Emittance growth, (nm)	TESLA BNS off / on	RE- entrant BNS off / on	Low Losses BNS off / on
DFS mean (100seeds)	6.53 / 9.30	7.91 / 9.36	10.29 / 11.84
DFS 90%	9.27 / 12.5	12.01 / 13.10	13.99 / 17.44
1:1 mean	470 / 424	510 / 432	540 / 472
1:1 90%	390 / 497	510 / 485	422 / 515

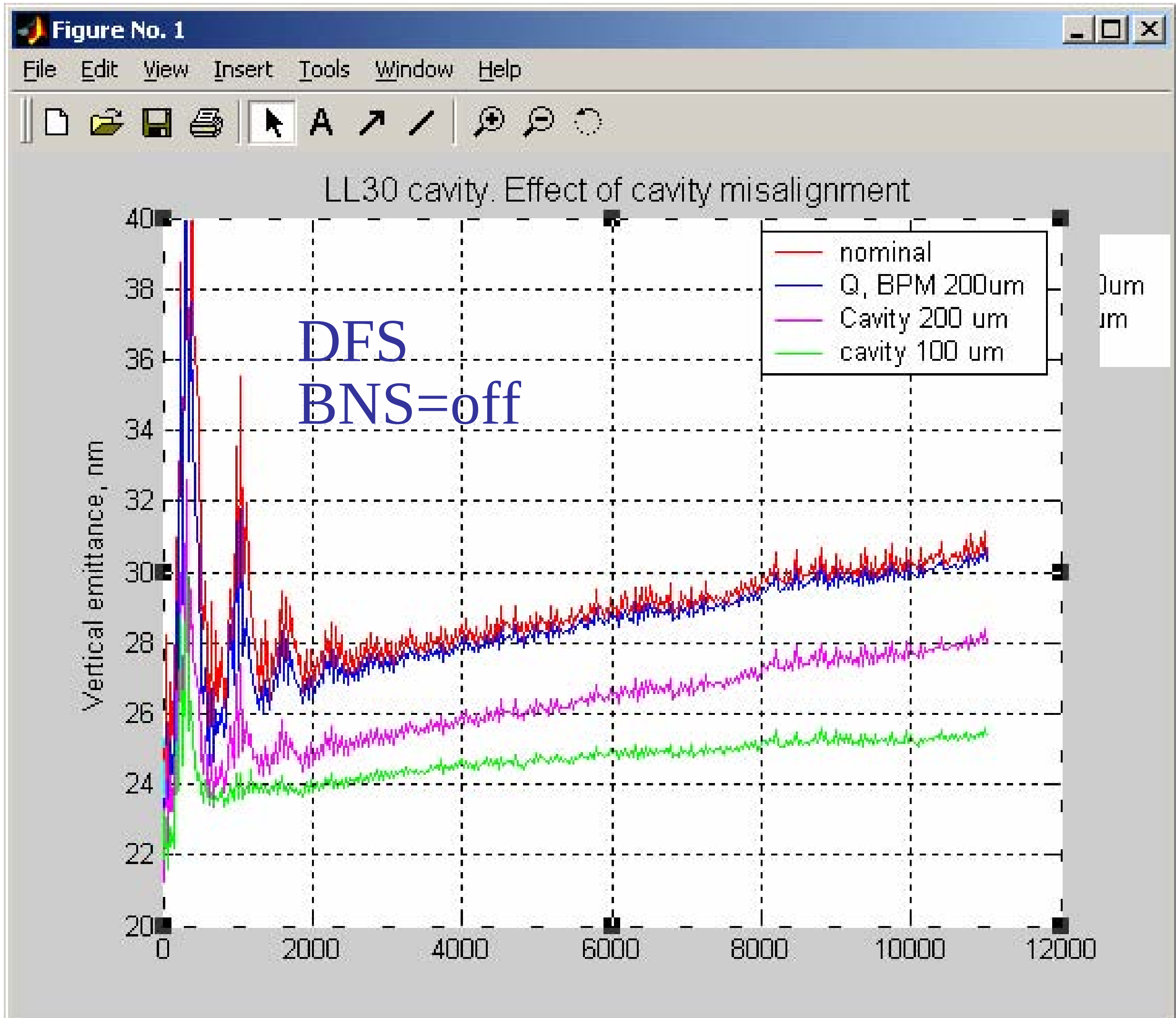
Beam dynamics in Linac with LL cavities

No bumps



- Autophasing needs to reduce ‘banana’ effect in IP
- Not optimized for LL and RE cavity (used the same as for TESLA)
- Need more optimization for HG cavities (quad spacing, nominal conditions)

Effect of cavity misalignment



SUMMARY

- The first results of design studies and experimental tests on HG cavities with a new shape (LL and RE) look promising to consider one of this cavity design for ILC.
- Needs more detailed studies of HOMs and clear specifications for Q_{ext} from multi-beam dynamic studies.
- Developing a new ideas for Fundamental and HOM Coupler for higher reliability and cost saving (?).
- Emittance growth is slightly over specification, but might be reduced by farther lattice optimization, using emittance bumps and revising of misalignment tolerances.
- Need more efforts and support in developing HG cavities.