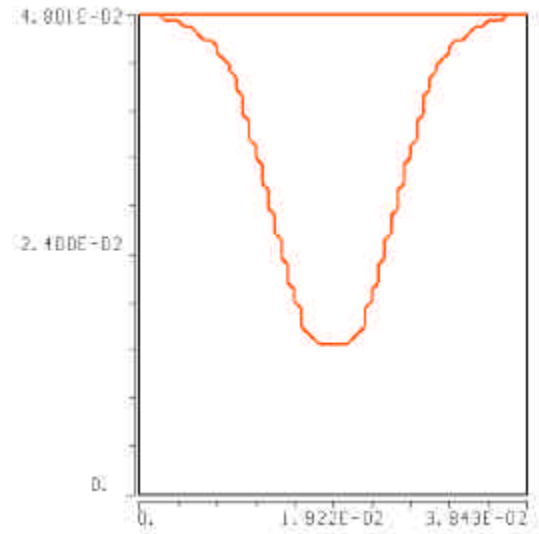
Deflecting cavity design study

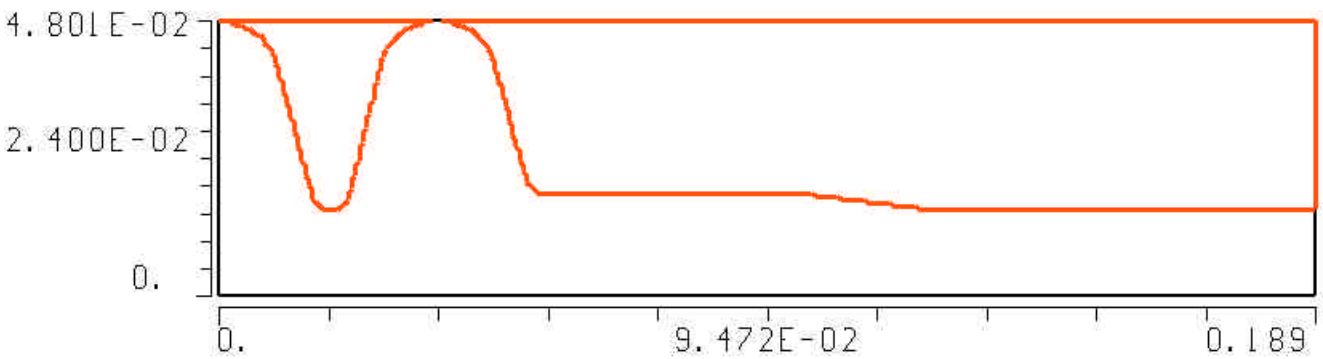
Derun Li, 3/27/2002

- 7-Cell Cavity at 3.9 GHz and 2.6 GHz
  - MAFIA simulations for the deflecting mode
    - Center Cell (not optimized for the geometry yet)
    - End Cell (not optimized for the geometry yet)
    - 7-Cell Cavity (3.5-Cell using symmetry and BC)
  - Field Flatness Adjustments
    - Frequency, Q_{cu}, (R/Q)*, Loss Factor, …
- Lower and Higher Order modes up to $f_{Cut\text{-}off}$

Center cell design →



End-cell design
↓



Deflecting cavity design study (cont'd)

- Monopole and dipole modes below cut-off
  - Using the MAFIA simulation results for computing loss factors, $Q_{SC} \approx 10^{10}$ or 10^{9} to estimate the magnitude of the resulting long range wakefield at steady state (Stefano's talk for more details)
  - Estimate energy spread due to the long range wakefield and determine whether we need to damp these LOMs and HOMs or not.

MAFIA simulation results

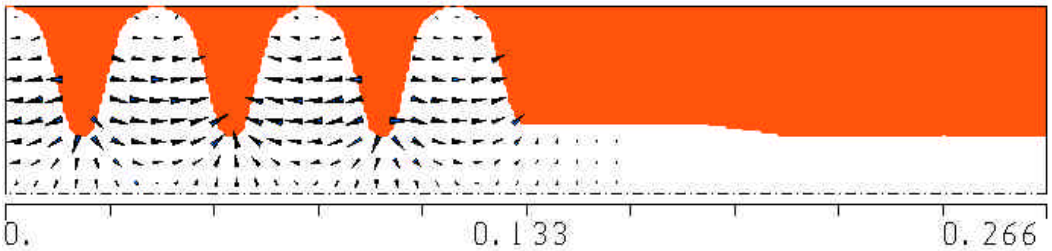
Deflecting RF Cavity at 3.9 GHz (Dipole modes only)					
					Derun Li (3/7/2002)
Cavity Parameters					
Equator radius (cm)			4.795		
Equator radius of end cell (cm)			4.801		
Cavity Iris (cm)			1.5		
TE mode cutoff frequency (GHz)			5.865		
Frerquency [GHz]	R/Q* [Ohom]	k-loss (V/pC/m) [V/pC/m]	Q0 [Copper]	Q0 [SC]	Transverse Impedance [M-Ohom/m]
3.9073	342.1	172.0	13877	1.00E+10	0.279978969
3.9112	0.3	0.1	13979	1.00E+10	0.000205852
3.9212	3.0	1.5	14121	1.00E+10	0.002430867
3.9390	0.2	0.1	14349	1.00E+10	0.000201667
3.9662	0.3	0.1	14702	1.00E+10	0.00022897
4.0045	0.3	0.2	15246	1.00E+10	0.000287811
4.0523	0.0	0.0	16139	1.00E+10	5.8875E-07
4.2213	0.2	0.1	14301	1.00E+10	0.000196049
4.2939	1.2	0.7	15682	1.00E+10	0.001046349
4.4175	0.0	0.0	17135	1.00E+10	5.0746E-06
4.5725	1.7	1.2	18670	1.00E+10	0.001637706
4.7488	2.7	2.0	20391	1.00E+10	0.002657887
4.9336	7.8	6.3	22363	1.00E+10	0.008085616
5.1024	1.2	1.0	24927	1.00E+10	0.00124523
5.3002	0.3	0.2	16424	1.00E+10	0.000291165
5.3058	0.1	0.1	16869	1.00E+10	9.78527E-05
	Sum K:	185.6			

MAFIA simulation results (cont'd)

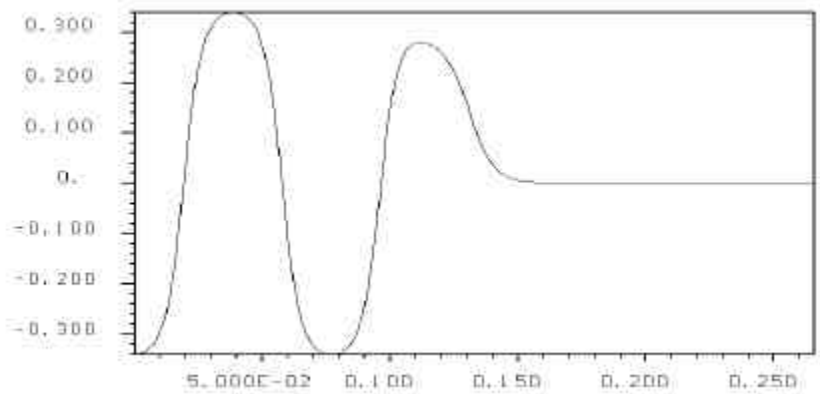
Definitions:

$$\frac{R}{Q}^{*} = \frac{\left|\int_0^d E(r=r_0)e^{j\frac{w}{c}z}dz\right|^2}{Q\left(\frac{w}{c}\right)^2 r_0^{\,2}} \qquad R_T = \frac{\left|\int_0^d E(r=r_0)e^{j\frac{w}{c}z}dz\right|^2}{\left(\frac{w}{c}\right) r_0^{\,2}} \qquad k = \frac{w}{4}\left(\frac{R_T}{Q}\right)^{*}\left(\frac{w}{c}\right)$$

Dipole mode at 3.907 GHz



$E_z(r_0)$ field distribution at r_0=10 mm off axis



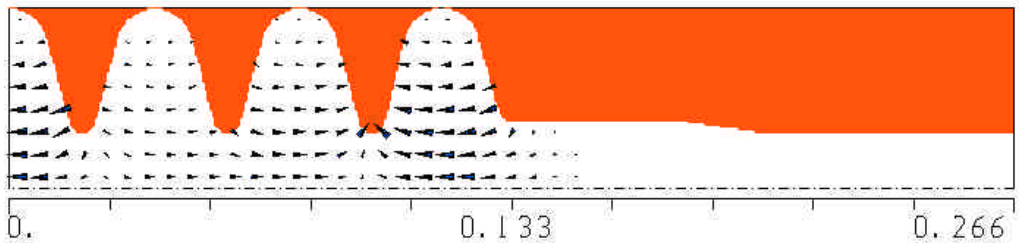
MAFIA simulation results (cont'd)

Deflecting RF Cavity at 3.9 GHz (Monopole modes only)							
					Derun Li (3/19/2002)		
Cavity Parameters							
Equator radius (cm)					4.795		
Equator radius of end cell (cm)					4.801		
Cavity Iris (cm)					1.5		
TM mode cutoff frequency (GHz)					7.634		
Frequency	Q Factor	Q Factor	Impedance	(R/Q)	K-Loss factor	Impedance	Induced Vmax
[GHz]	[Copper]	[SC]	[Cu-Ohom]	[Ohom]	[V/pC]	[SC-Ohom]	[MV]
2.8132	13379	1.00E+10	11582	1	0.0038	8.6567E+09	0.0866
2.8208	13349	1.00E+10	16735	1	0.0056	1.2537E+10	0.1254
2.8321	13311	1.00E+10	178576	13	0.0597	1.3415E+11	1.3415
2.8453	13279	1.00E+10	126859	10	0.0427	9.5534E+10	0.9553
2.8581	13261	1.00E+10	3763649	284	1.2742	2.8381E+12	28.3810
2.8685	13261	1.00E+10	5449179	411	1.8515	4.1091E+12	41.0913
2.8750	13272	1.00E+10	748291	56	0.2546	5.6380E+11	5.6380
5.7836	21507	1.00E+10	4070	0	0.0017	1.8925E+09	0.0189
5.8026	21702	1.00E+10	574	0	0.0002	2.6465E+08	0.0026
5.8348	21898	1.00E+10	85217	4	0.0357	3.8914E+10	0.3891
5.8797	22021	1.00E+10	263399	12	0.1105	1.1961E+11	1.1961
5.9343	22064	1.00E+10	117971	5	0.0498	5.3467E+10	0.5347
5.9912	22035	1.00E+10	361	0	0.0002	1.6383E+08	0.0016
6.0377	21986	1.00E+10	2984	0	0.0013	1.3572E+09	0.0136
6.6123	20872	1.00E+10	46923	2	0.0233	2.2481E+10	0.2248
6.6135	20910	1.00E+10	6616	0	0.0033	3.1642E+09	0.0316
6.7391	18878	1.00E+10	1747	0	0.0010	9.2545E+08	0.0093
6.8025	18806	1.00E+10	39904	2	0.0227	2.1218E+10	0.2122
6.8722	18784	1.00E+10	6369	0	0.0037	3.3905E+09	0.0339
6.9377	18593	1.00E+10	8129	0	0.0048	4.3720E+09	0.0437
7.0615	17374	1.00E+10	549373	32	0.3507	3.1620E+11	3.1620
7.5036	20460	1.00E+10	195160	10	0.1124	9.5385E+10	0.9538
7.5093	19973	1.00E+10	2424	0	0.0014	1.2136E+09	0.0121
SUM					4.2147		84.4594

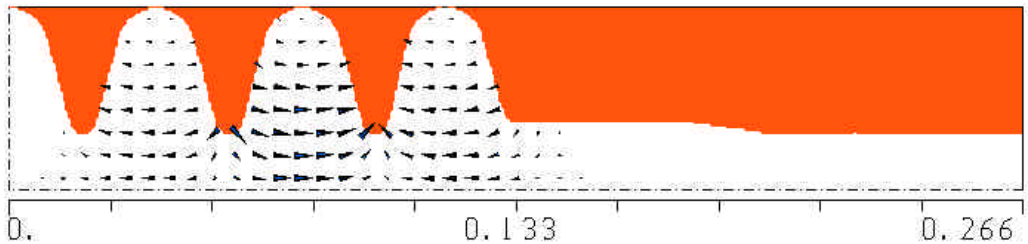
MAFIA simulation results (cont'd)

Field distribution for the two worst modes

f = 2.8581 GHz [(e,e,) boundary conditions]



f = 2.8685 GHz [(m,e) boundary conditions]



Definitions for each mode:

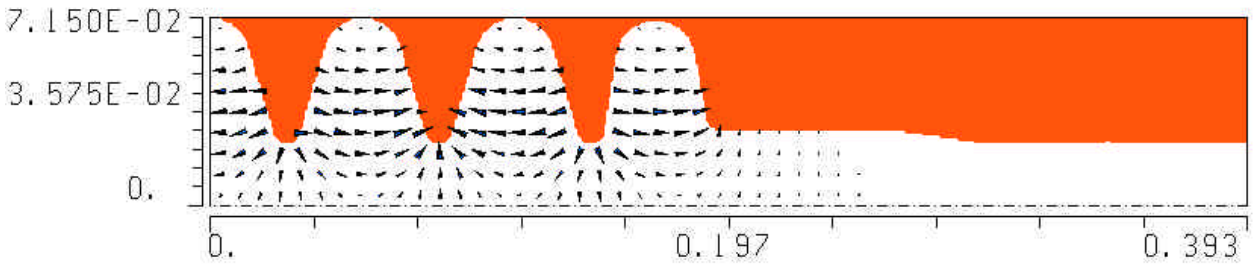
$$\frac{R}{Q} = \frac{\left|\int_0^d E(r=0)e^{j\frac{w}{c}z}dz\right|^2}{P_W Q\,[wU]} \qquad R = \frac{\left|\int_0^d E(r=0)e^{j\frac{w}{c}z}dz\right|^2}{P_W} \qquad k = \frac{w}{4}\left(\frac{R}{Q}\right)$$

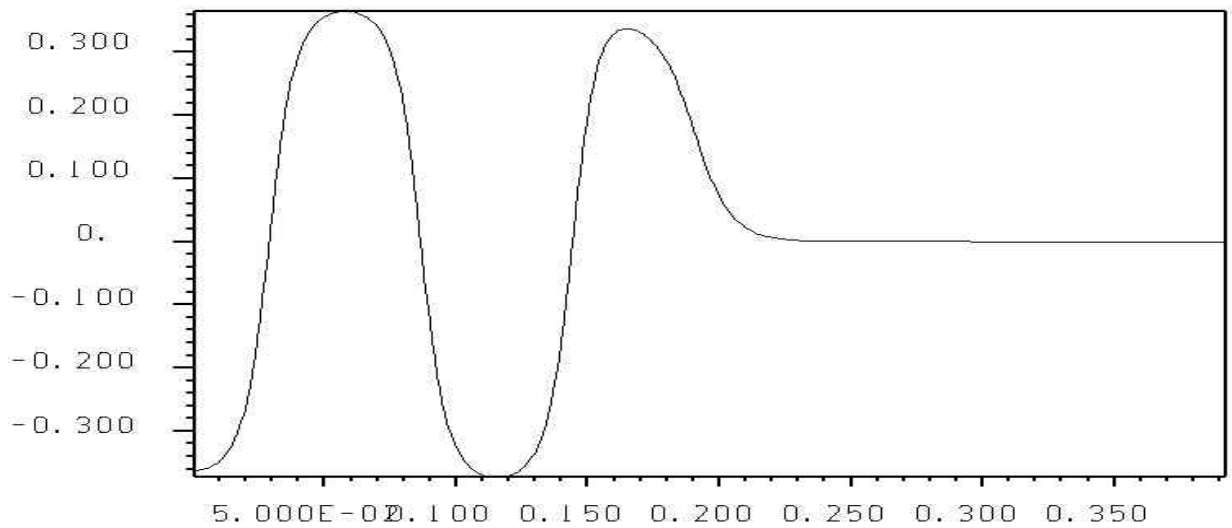
MAFIA simulation results (cont'd)

Deflecting RF Cavity at 2.6 GHz (Dipole modes only)						
						Derun Li (3/20/2002)
Cavity Parameters						
Equator radius (cm)			7.15			
Equator radius of end cell (cm)			7.05			
Cavity Iris (cm)			2.41			
TE mode cutoff frequency (GHz)			3.651			
Frerquency [GHz]	Q0 [Copper]	Transverse R [Cu] [Ohom]	K-Loss [V/pC/m]	(R/Q)* [Ohom]	Q0 [SC]	Transverse R [SC] [M-Ohom/m]
2.6025	16807	5.586E+06	7.411E+01	332.4	1.00E+10	3.324E+06
2.6035	16772	5.082E+03	6.761E-02	0.3	1.00E+10	3.030E+03
2.6070	16876	3.148E+03	4.174E-02	0.2	1.00E+10	1.865E+03
2.6142	17049	3.880E+03	5.120E-02	0.2	1.00E+10	2.276E+03
2.6273	17307	6.111E+03	8.024E-02	0.4	1.00E+10	3.531E+03
2.6500	17638	4.910E+02	6.436E-03	0.0	1.00E+10	2.784E+02
2.7009	19124	4.305E+03	5.406E-02	0.2	1.00E+10	2.251E+03
2.7221	18394	1.173E+03	1.556E-02	0.1	1.00E+10	6.379E+02
2.8153	20858	9.061E+02	1.134E-02	0.0	1.00E+10	4.344E+02
2.9092	21999	3.292E+02	4.169E-03	0.0	1.00E+10	1.496E+02
3.0150	23350	2.129E+04	2.728E-01	0.9	1.00E+10	9.117E+03
3.1225	24702	3.000E+04	3.898E-01	1.2	1.00E+10	1.214E+04
3.2267	25819	9.805E+04	1.302E+00	3.8	1.00E+10	3.798E+04
3.3267	26076	2.689E+04	3.757E-01	1.0	1.00E+10	1.031E+04
3.4073	23162	1.669E+04	2.754E-01	0.7	1.00E+10	7.206E+03
3.4309	26953	4.797E+02	6.896E-03	0.0	1.00E+10	1.780E+02
		SUM of K	77.06			

MAFIA simulation results (cont'd)

Field distribution for the deflecting mode at 2.6 GHz





MAFIA simulation results (cont'd)

Deflecting RF Cavity at 2.6 GHz (Monopole modes only)						
					Derun Li (3/20/2002)	
Cavity Parameters						
Equator radius (cm)					7.15	
Equator radius of end cell (cm)					7.05	
Cavity Iris (cm)					2.41	
TM mode cutoff frequency (GHz)					4.751	
Frequency [GHz]	Q Factor [Copper]	Q Factor [SC]	Impedance [Cu-Ohom]	(R/Q) [Ohom]	K-Loss factor [V/pC]	Impedance [SC-Ohom]
1.8941	16597	1.00E+10	8.241E+04	4.97	0.015	4.97E+10
1.8991	16362	1.00E+10	2.483E+04	1.52	0.005	1.518E+10
1.9084	16232	1.00E+10	4.934E+05	30.40	0.091	3.040E+11
1.9206	16200	1.00E+10	3.449E+04	2.13	0.006	2.129E+10
1.9332	16244	1.00E+10	3.687E+06	226.95	0.689	2.270E+12
1.9435	16350	1.00E+10	6.279E+06	384.05	1.172	3.841E+12
1.9500	16479	1.00E+10	1.315E+06	79.78	0.244	7.978E+11
3.8651	27118	1.00E+10	1.190E+03	0.04	0.000	4.388E+08
3.8876	27285	1.00E+10	1.050E+04	0.38	0.002	3.849E+09
3.9211	27511	1.00E+10	8.922E+04	3.24	0.020	3.243E+10
3.9592	27854	1.00E+10	1.072E+05	3.85	0.024	3.849E+10
3.9972	27890	1.00E+10	2.031E+04	0.73	0.005	7.281E+09
4.0346	27918	1.00E+10	1.789E+03	0.06	0.000	6.409E+08
4.0723	27886	1.00E+10	2.877E+03	0.10	0.001	1.032E+09
4.2138	27019	1.00E+10	2.251E+04	0.83	0.006	8.330E+09
4.2149	27062	1.00E+10	6.582E+02	0.02	0.000	2.432E+08
4.4508	24257	1.00E+10	1.710E+04	0.71	0.005	7.050E+09
4.5162	24248	1.00E+10	9.848E+03	0.41	0.003	4.061E+09
4.5808	23992	1.00E+10	3.394E+04	1.41	0.010	1.415E+10
4.6504	23000	1.00E+10	7.981E+05	34.70	0.253	3.470E+11
4.6725	24923	1.00E+10	1.469E+04	0.59	0.004	5.894E+09
				SUM of K	2.557	

Wakefield at Steady State

<u>Analytical approach:</u>

- Voltage induced by a point charge q to mode n,

$$V_n(s) = \begin{cases} 2qk_n \cos(\frac{w_n}{c} s) e^{-\frac{w_n}{2Q_0}\left(\frac{s}{c}\right)} & s > 0 \\ qk_n & s = 0 \\ 0 & s < 0 \end{cases}$$

- The resulting voltage of mode n at steady state,

$$V_n(\infty) \approx 2qk_n \frac{2Q_0}{wT}$$

Wakefield at Steady State (cont'd)

<u>Analytical approach:</u>

where $f = 1/T$ repetition rate ($f = 10$ kHz for us), Q_0 is quality factor for mode n.

- For all the modes at steady state,

$$V(s) = \sum_{i}^{\infty} \left\{ \sum_{n=1}^{n_c} 2qk_n \cos\left[w_n\left(\tfrac{s}{c} + iT\right)\right] e^{-\frac{w_n}{2Q_{n,0}}\left[\frac{s}{c}+iT\right]} \right\}$$

$$V(\infty) = \sum_{n=1}^{n_c} 2k_n q\left(\frac{2Q_{n,0}}{w_n T}\right)$$

n_c is the last mode number below beam pipe cut-off frequency

Wakefield at Steady State (cont'd)

<u>Analytical approach:</u>

An Example of monopole modes for 7-cell cavity at 3.9 GHz :

$$V(\infty) = \sum_{n=1}^{n_c} 2k_n q\left(\frac{2Q_{n,0}}{w_n T}\right) \approx 84.5[\mathrm{MeV}]$$

V(¥) ≈ 69.5 by considering only two highest *k* modes at 2.8581 and 2.8685 GHz, respectively and assuming $Q_0=10^{10}$. We may 4 cavities at 3.9 GHz and *V(¥)* μ $Q_0 f_{rep}$! Energy spread for 2.5 GeV beam due to the monopole modes of 4 cavities can be as high as 14%. **<u>We need to damp these modes, in particular at higher repetition rate case.</u>**