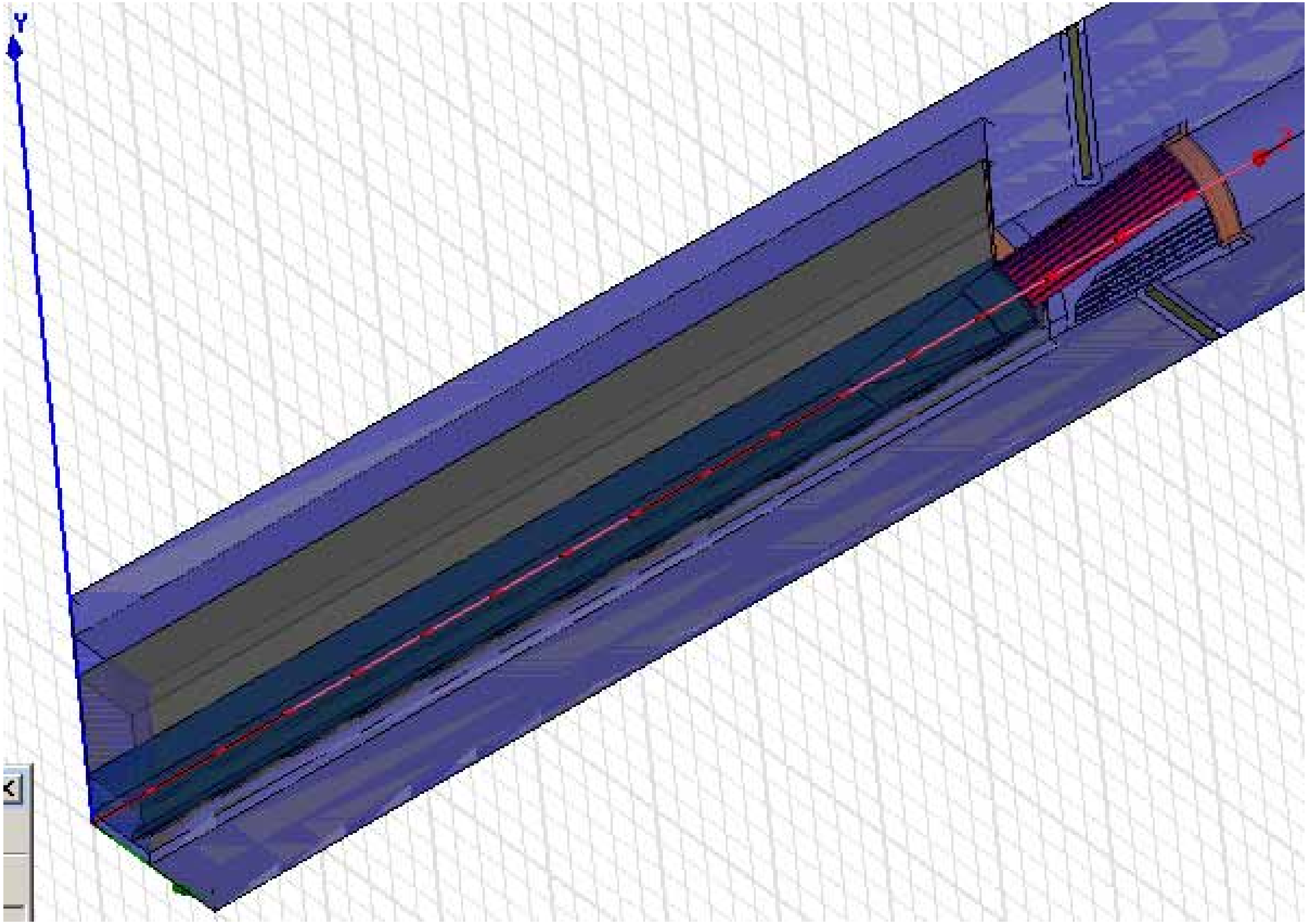
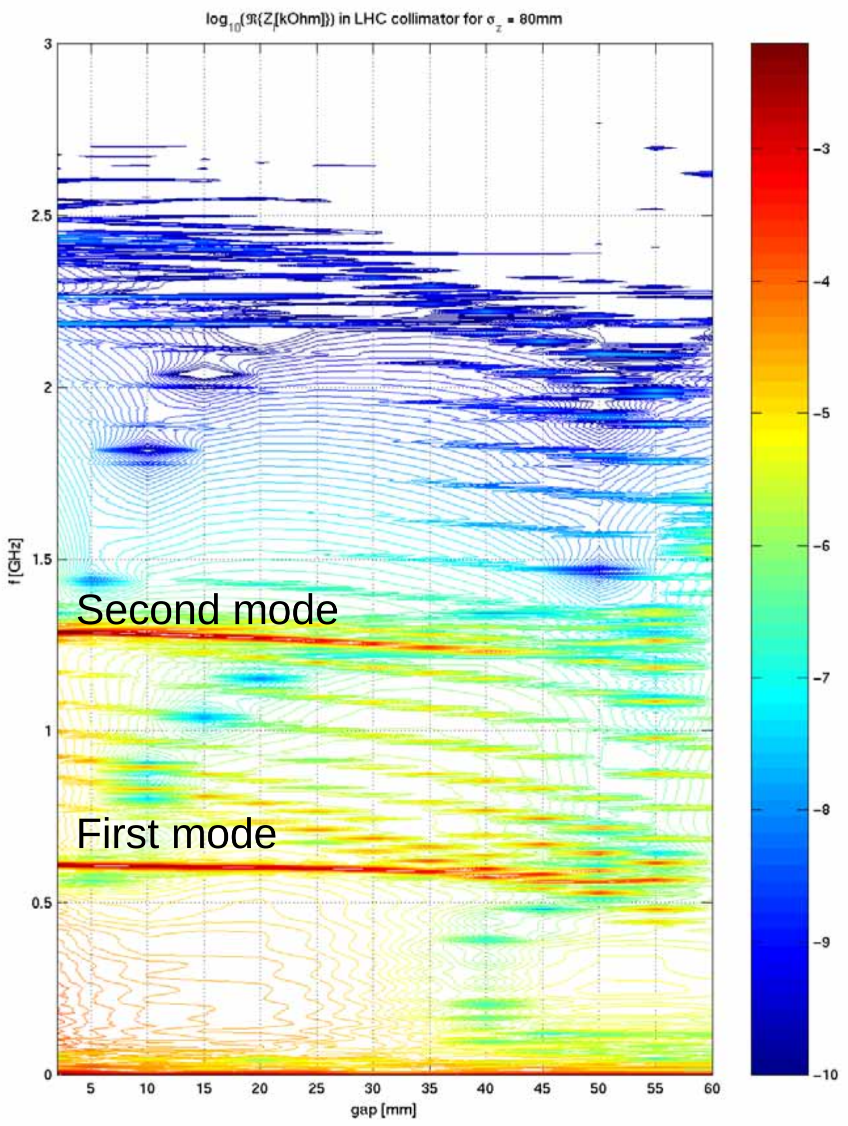
Simulation of trapped modes in LHC collimator

A.Grudiev

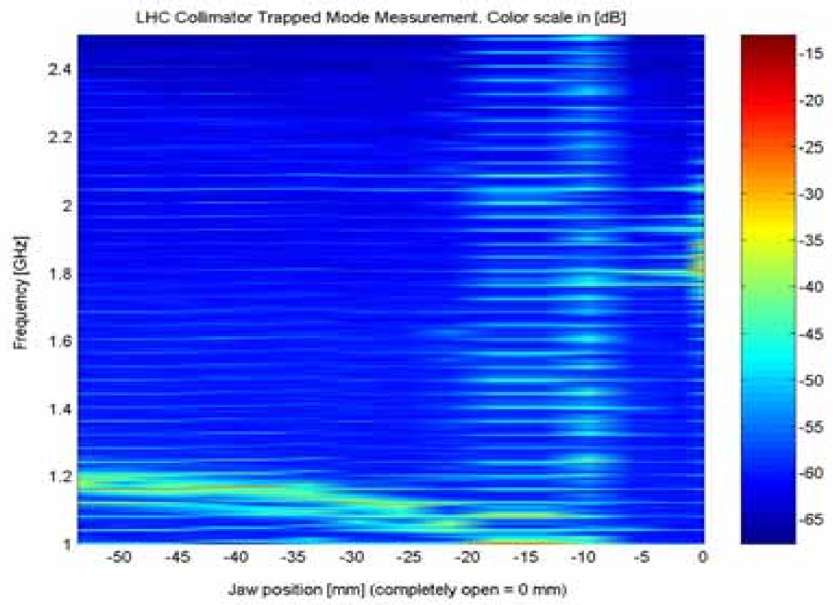
LHC collimator prototype geometry in HFSS



Effective longitudinal impedance calculated using GdfidL (left) and measured with SPS beam (right)

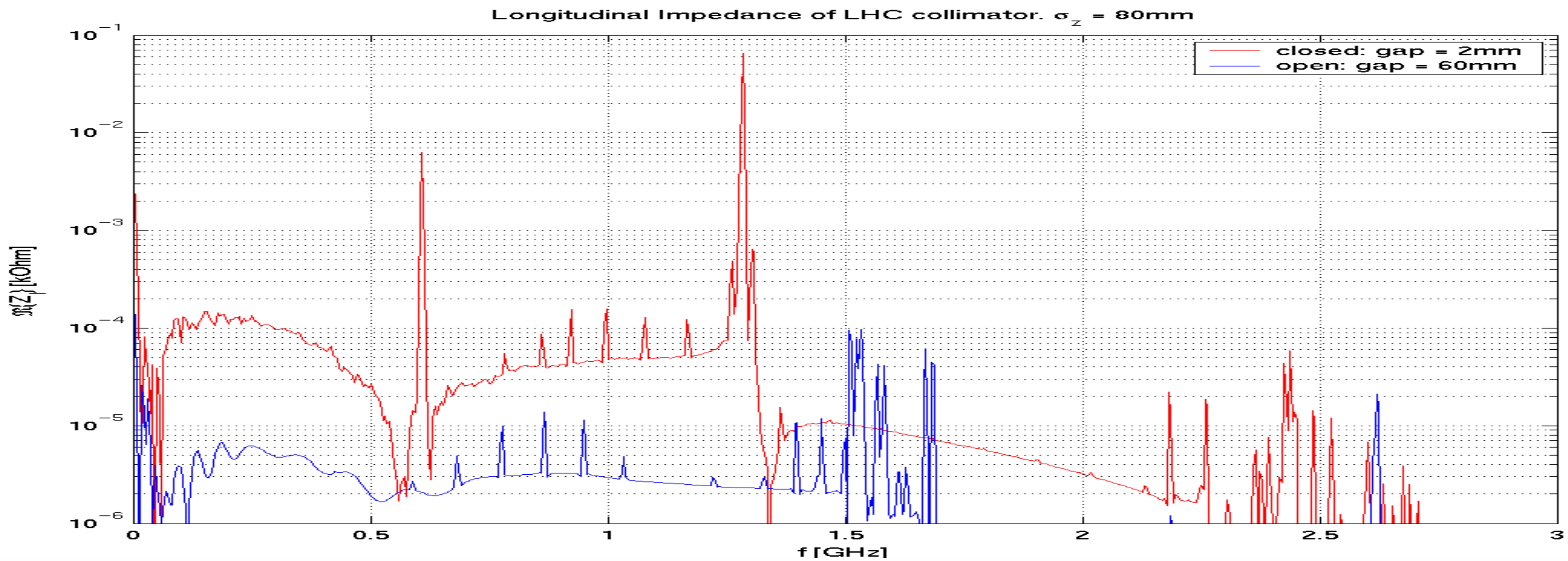


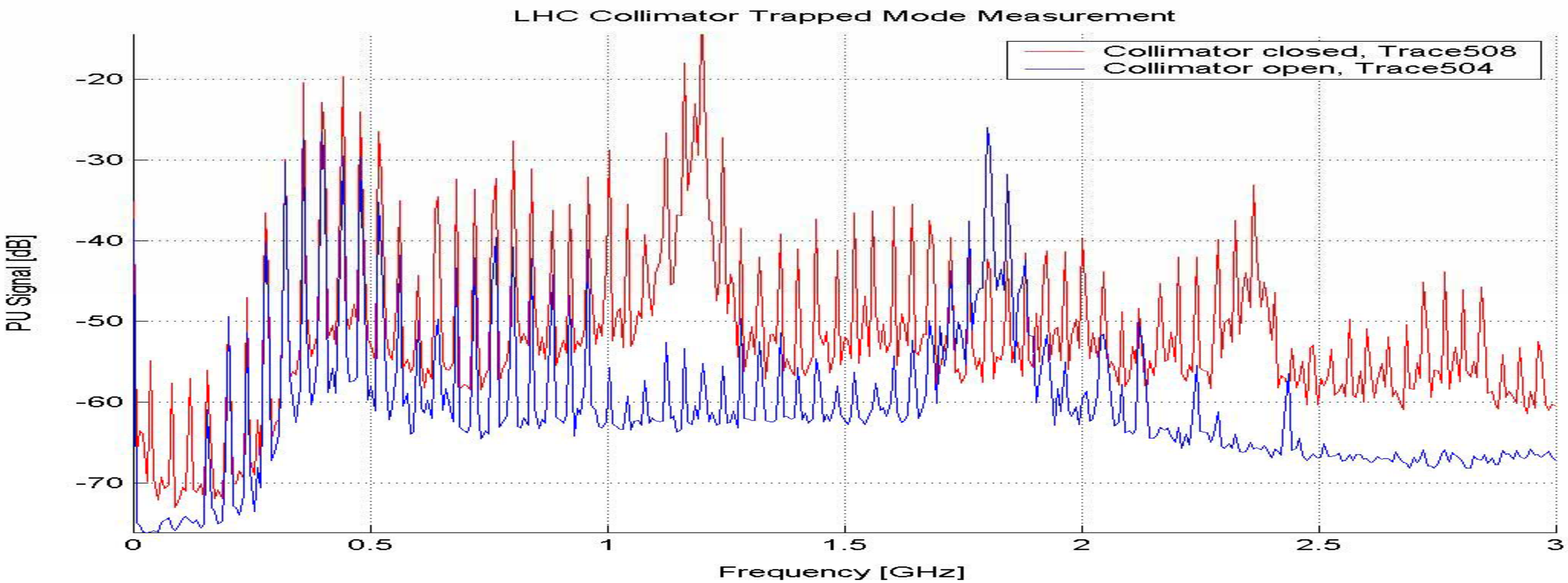
Measured by
F.Caspers and T. Kroyer



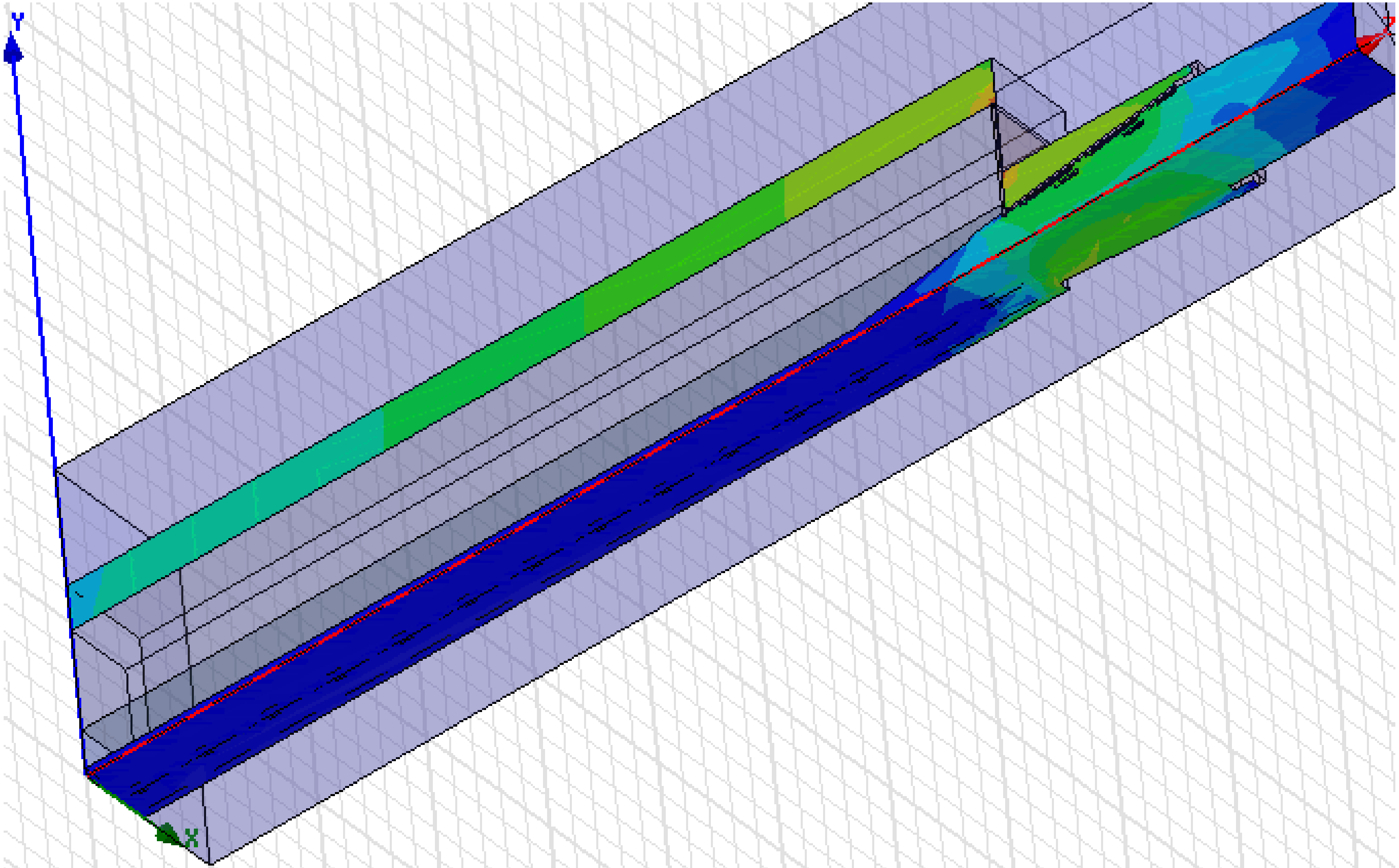
Gap varied from 6 to 60 mm

Effective longitudinal impedance calculated using GdfidL (left) and measured with SPS beam (right)

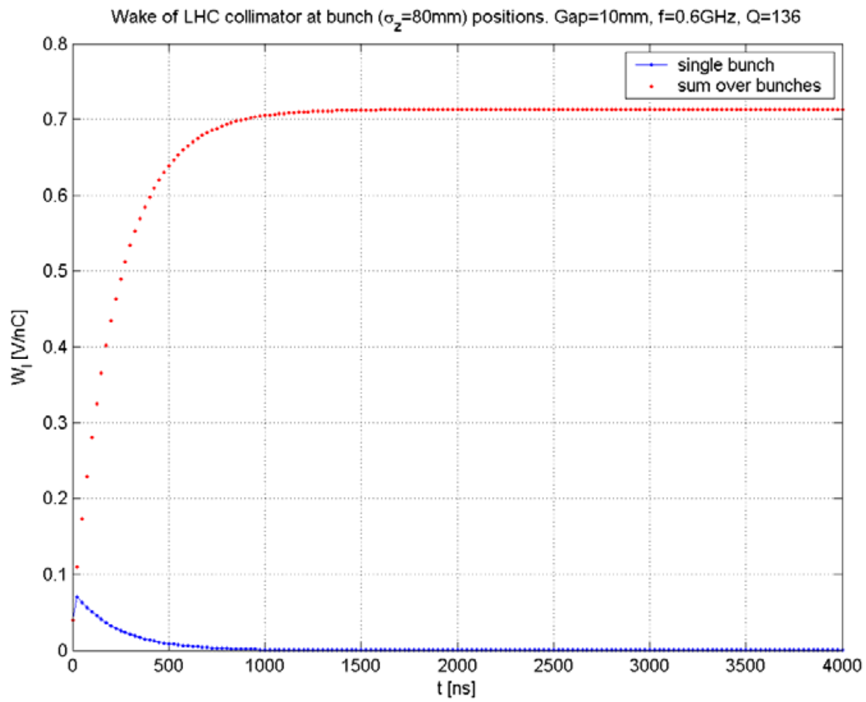




Electric field of the first m=0 mode in log scale (gap=10mm)



First bunch (blue) and total wake (red) along the train for the first m=0 mode



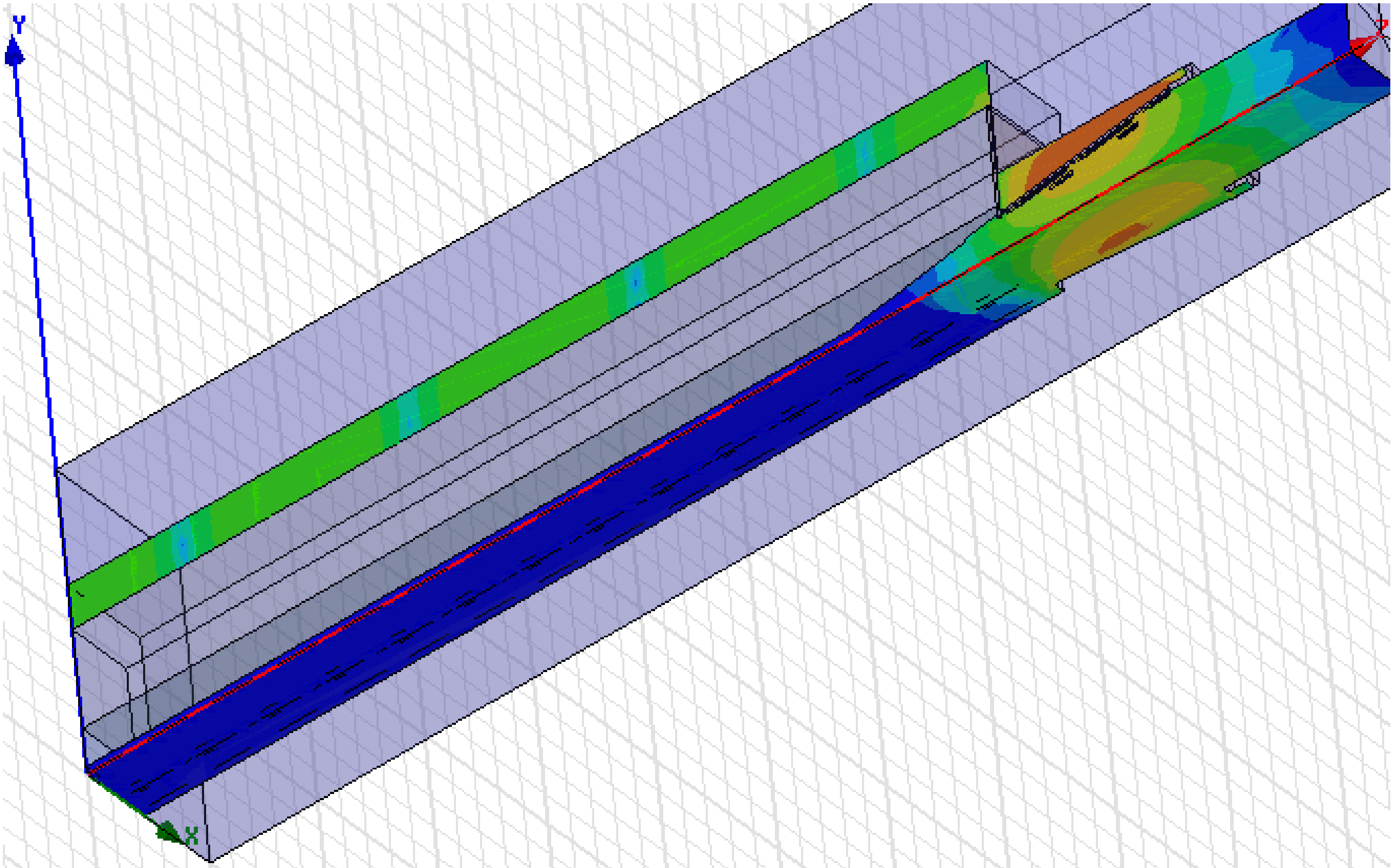
f=0.6GHz
(15^{th}-harmonic of bunch frequency)
Q=136
r/Q = 0.1 Ohm (accelerator impedance)
k = 0.13 V/nC (loss factor)

For $\sigma_z = 80mm$
Max. single bunch energy loss:
0.7V/nC x 16nC = 11V

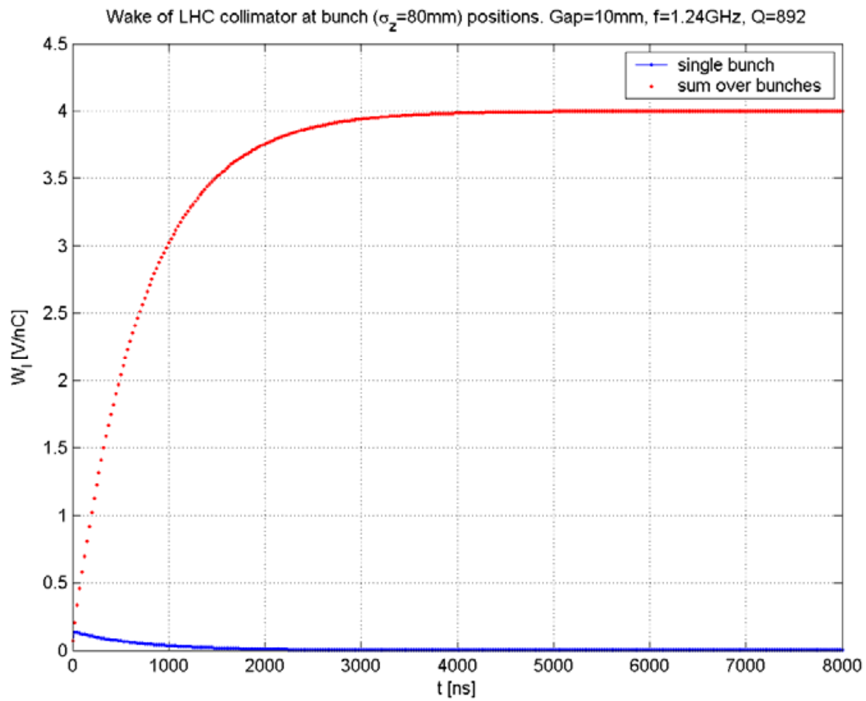
Total energy loss per train (2808 bunches):
dE = 0.5 mJ

Dissipated power: dE x frev = 6 W

Electric field of the second m=0 mode in log scale (gap=10mm)



First bunch (blue) and total wake (red) along the train for the second m=0 mode



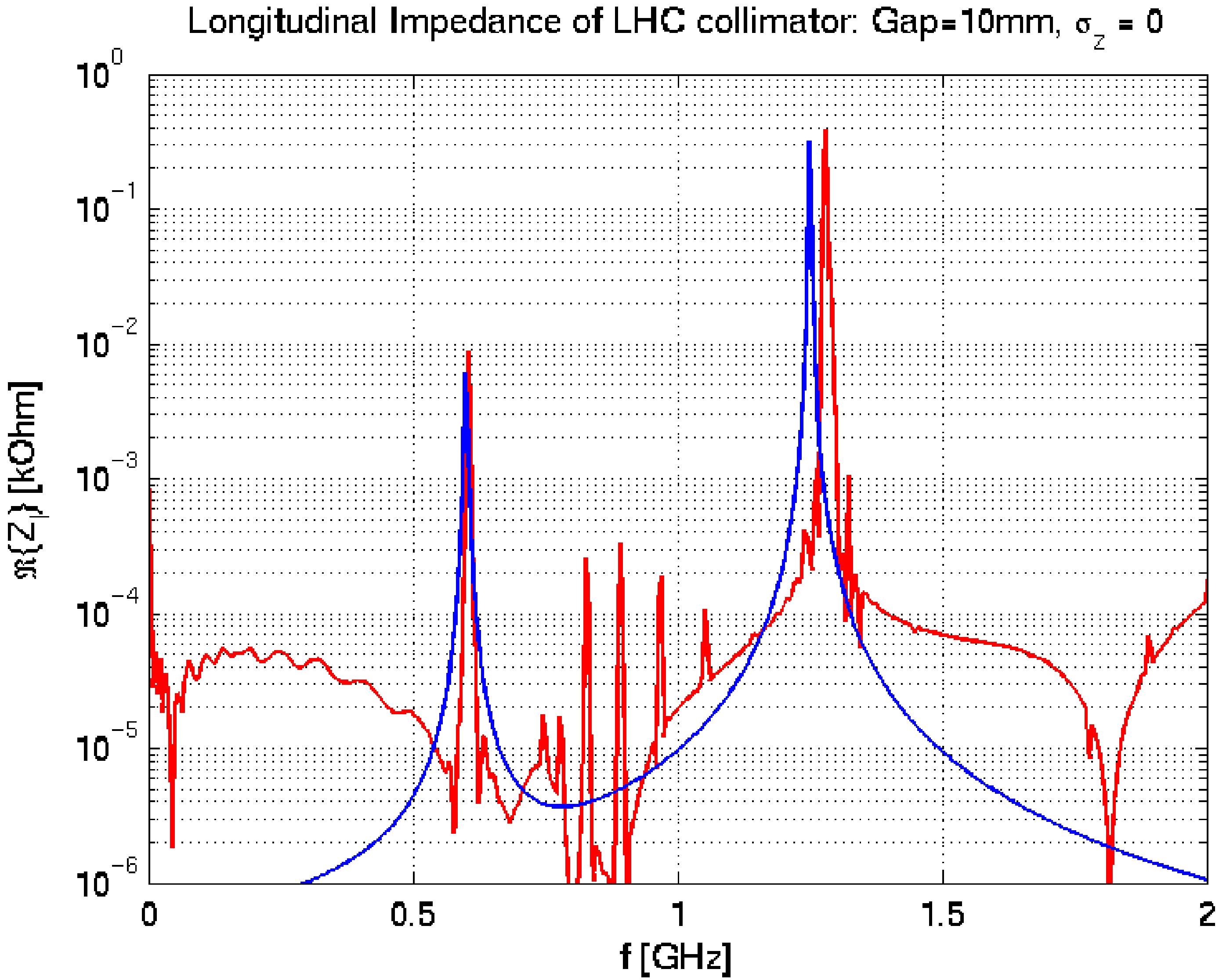
f=1.24GHz
(31^{st}-harmonic of bunch frequency)
Q=892
r/Q = 2.67 Ohm (accelerator impedance)
k = 5.2 V/nC (loss factor)

For $\sigma_z = 80\,mm$
Max. single bunch energy loss:
4V/nC x 16nC = 64V

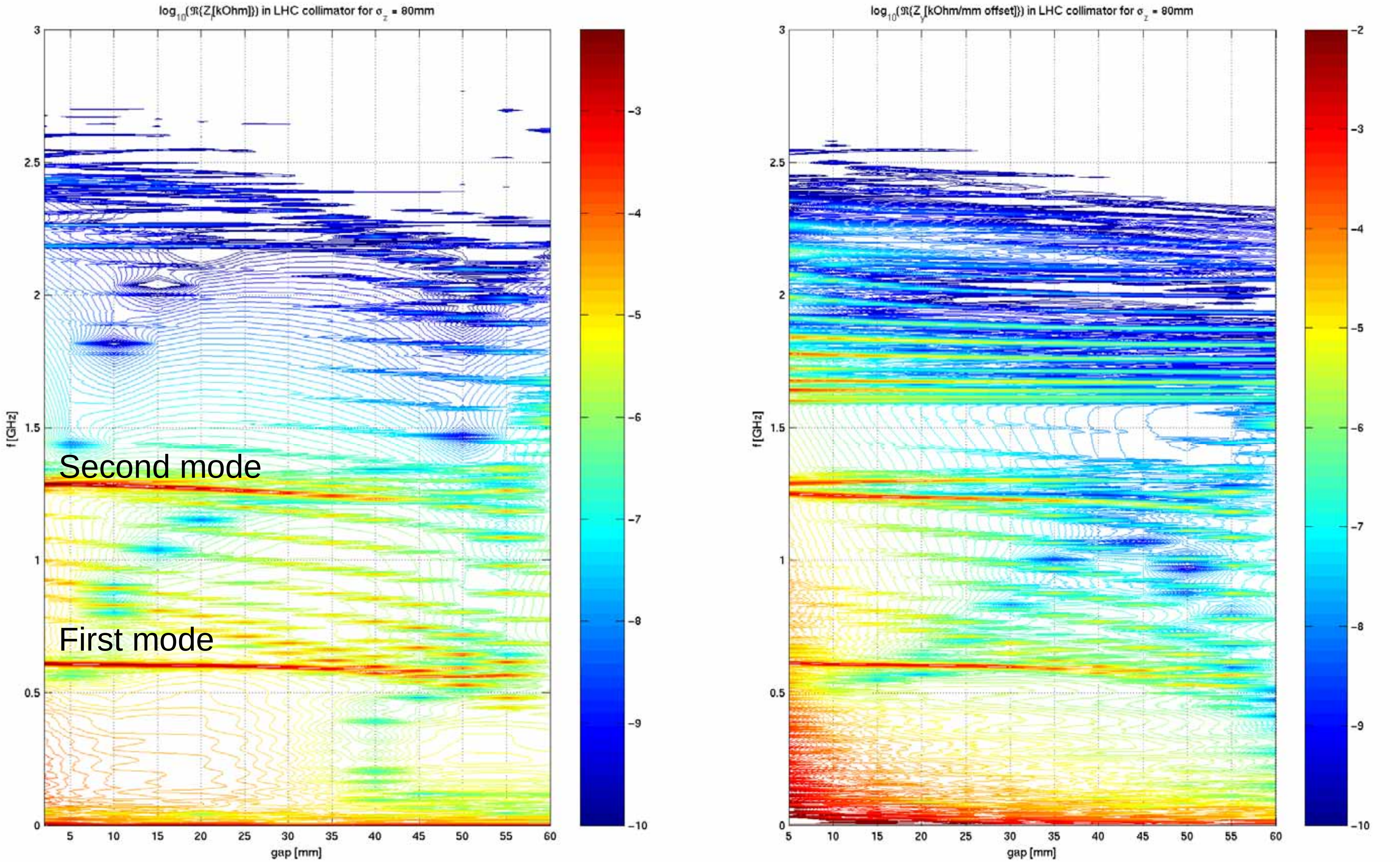
Total energy loss per train:
dE = 2.8 mJ

Dissipated power: dE x frev = **32 W**

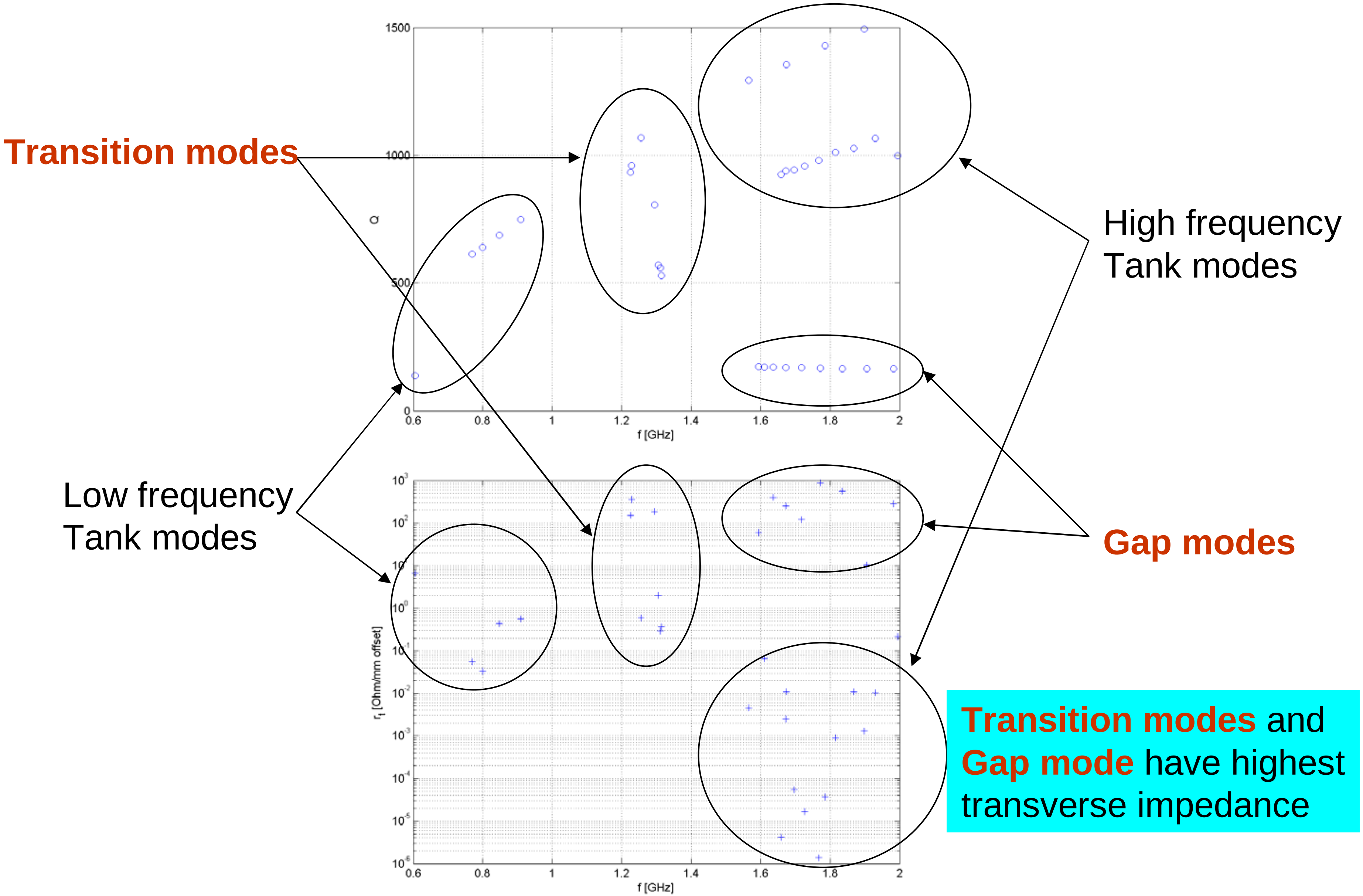
Longitudinal impedance calculated using Gdfidl (red) and reconstructed from HFSS (blue)



Effective longitudinal (left) and transverse (right) impedance calculated by GdfidL



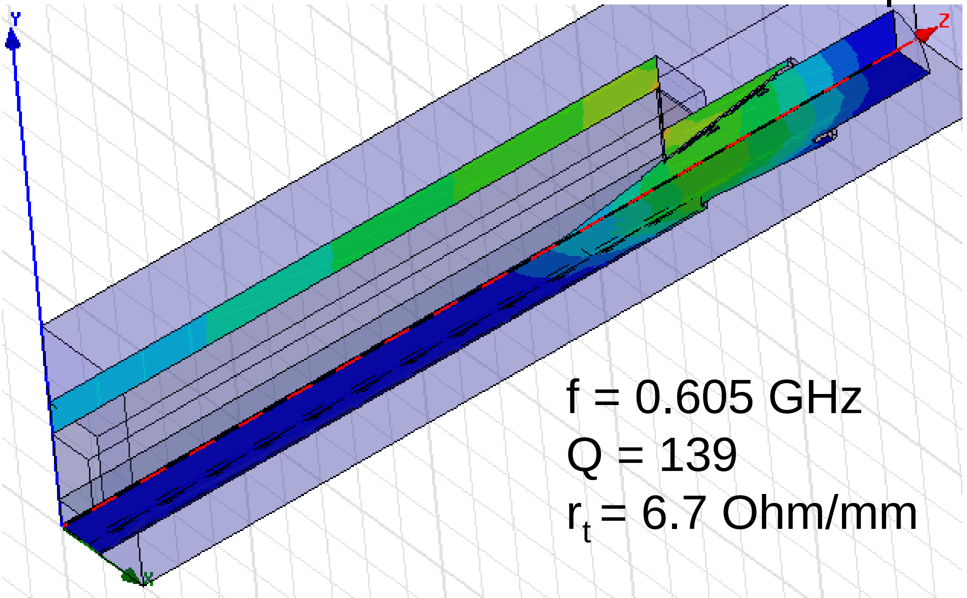
Q-factor and transverse impedance of trapped modes

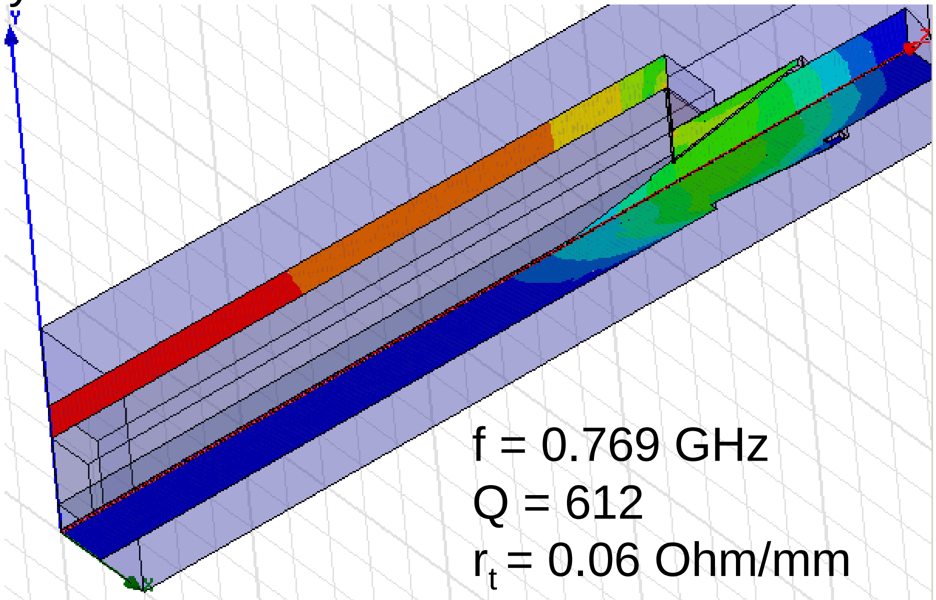


Transition modes and **Gap mode** have highest transverse impedance

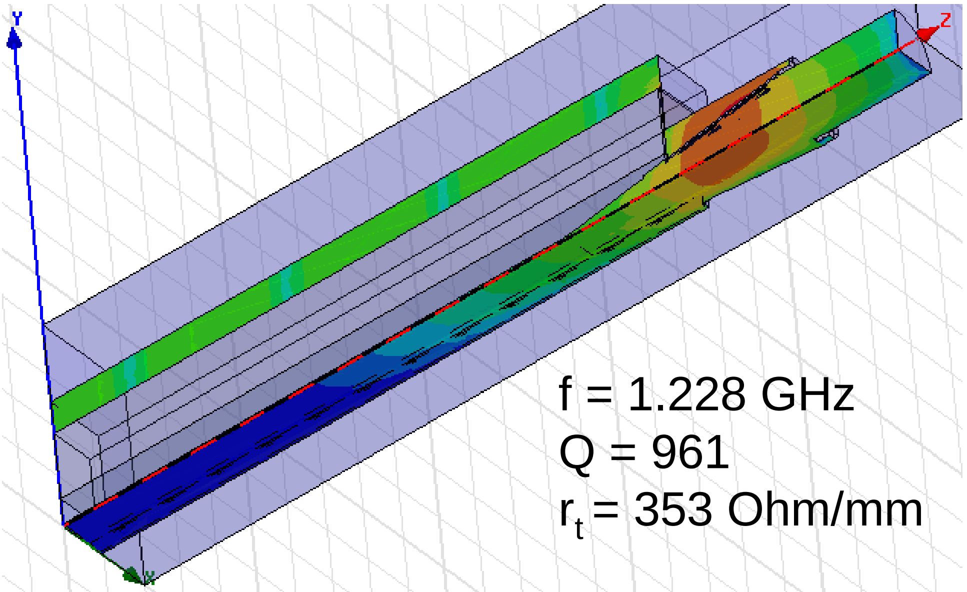
Electric field distribution of some trapped modes (m=1)

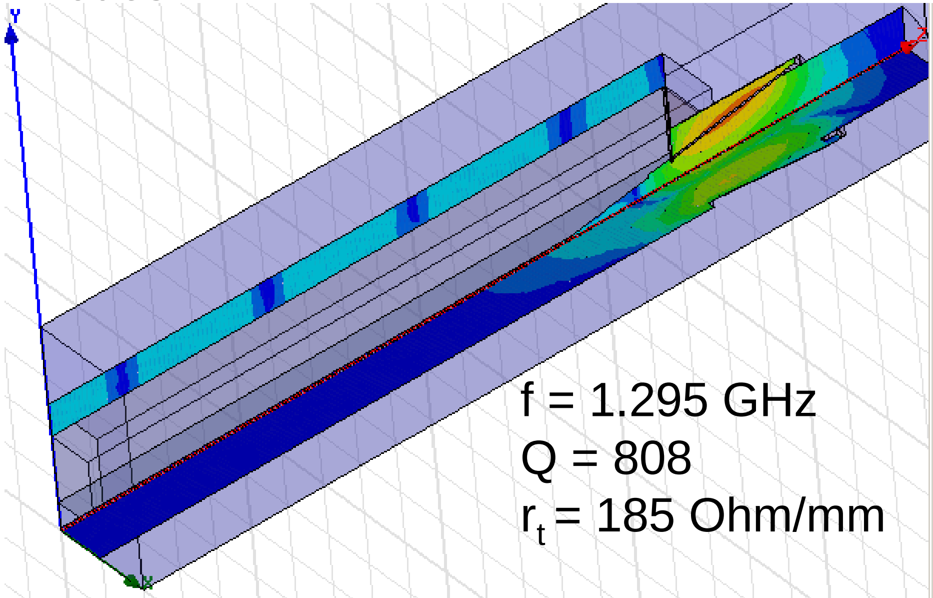
Low frequency tank modes



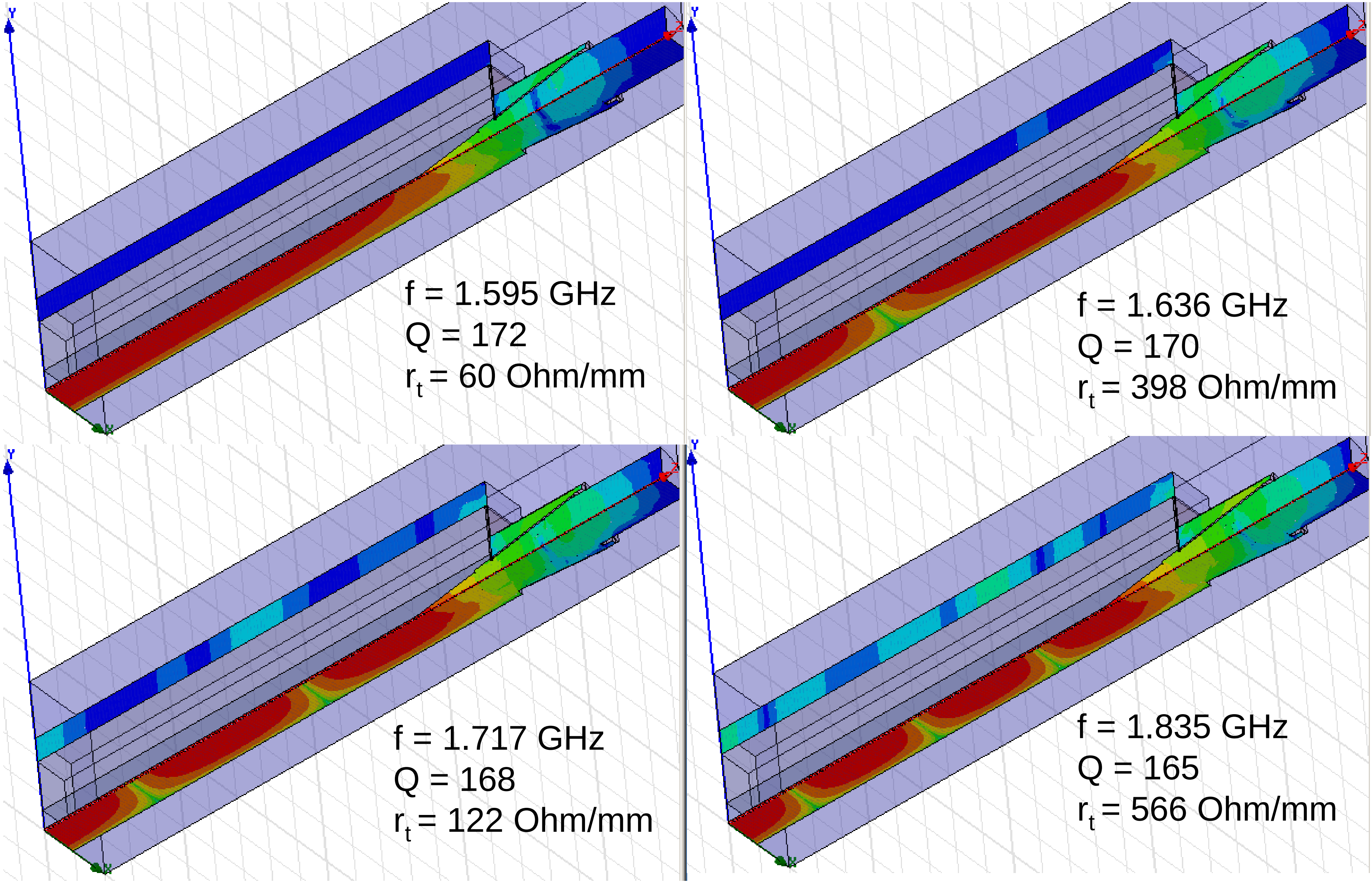


Transition modes





Electric field distribution of gap modes (m=1)



Electric field distribution of high frequency tank modes (m=1)

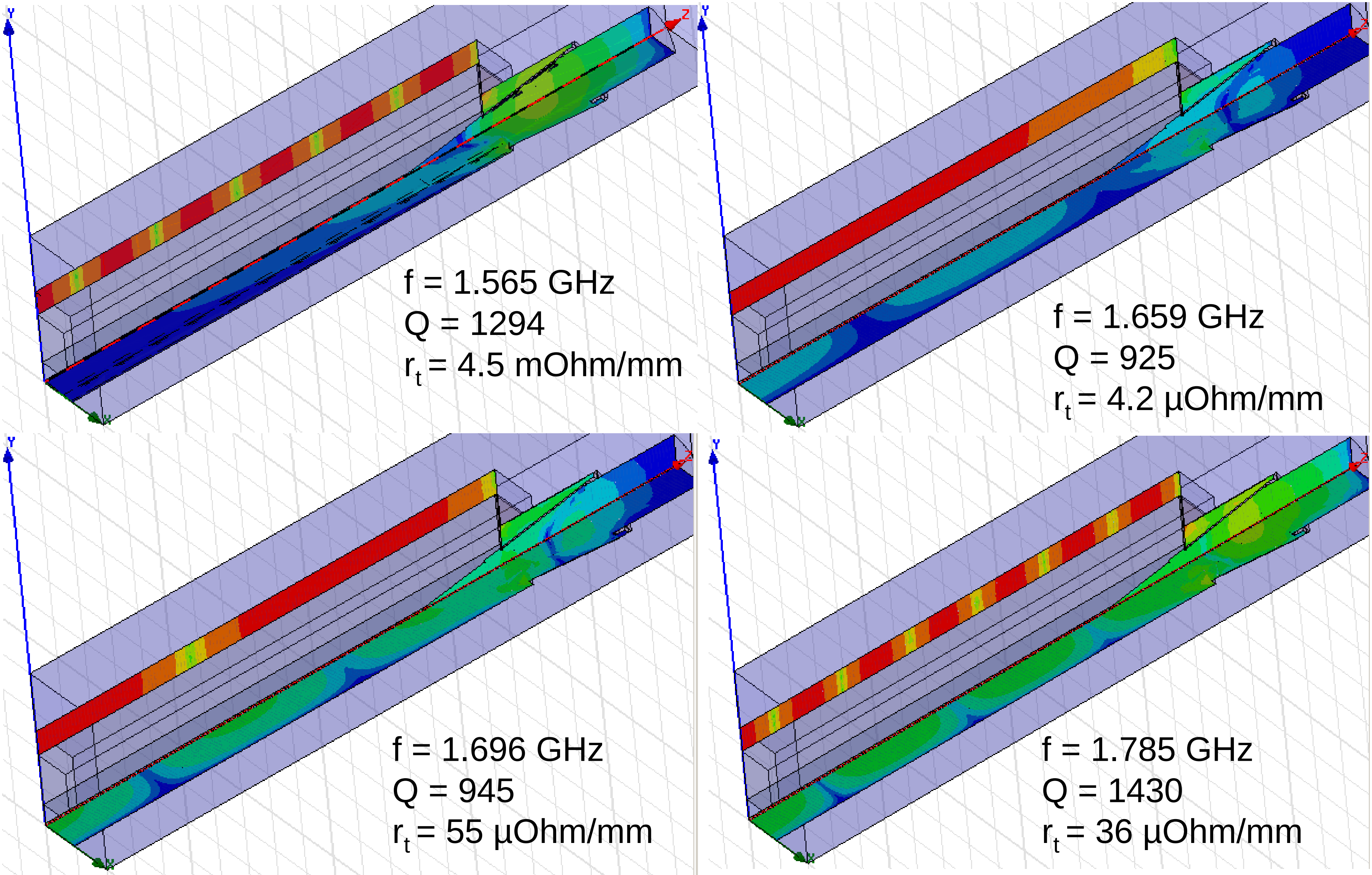
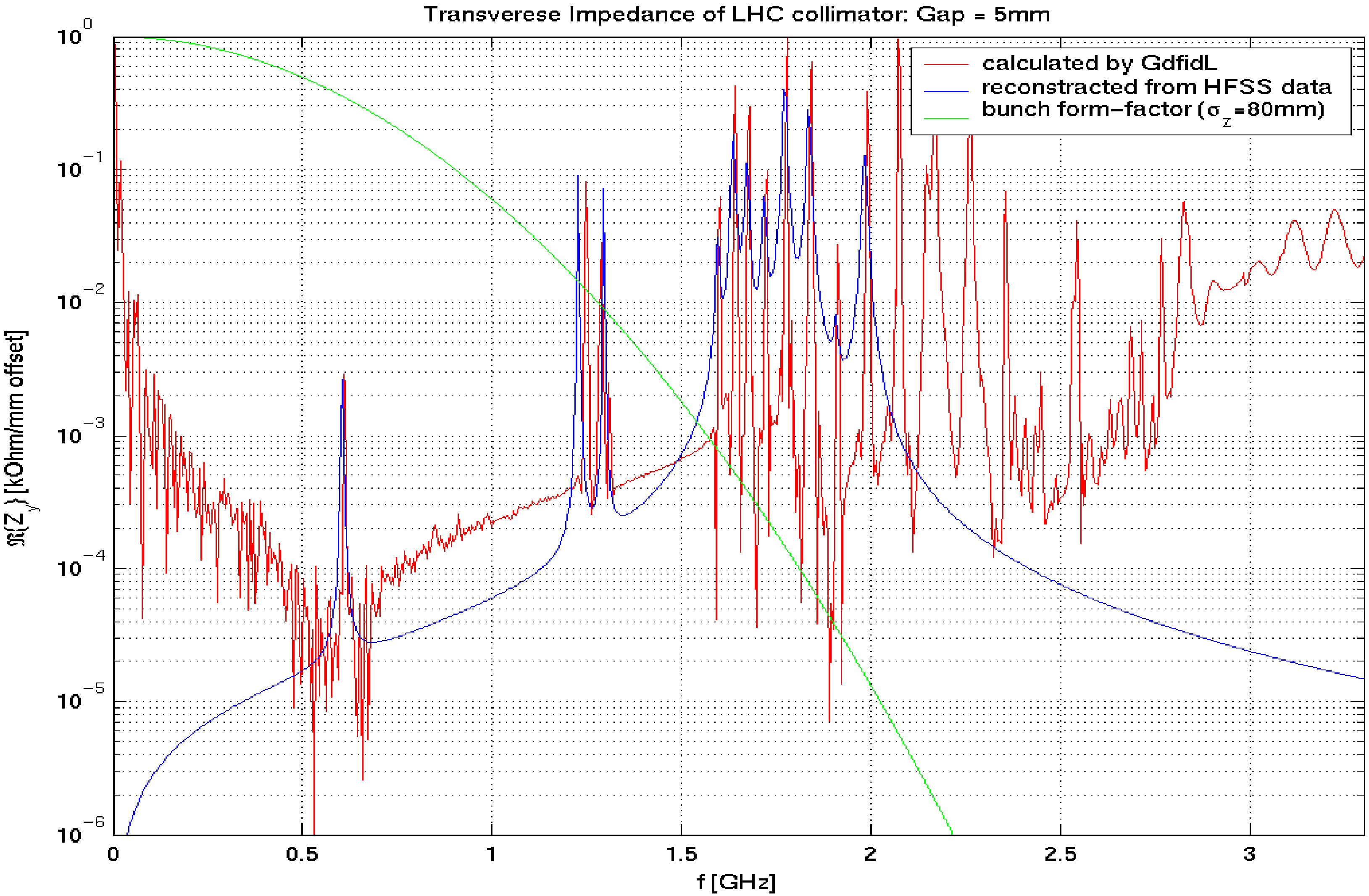


Table of transverse mode parameters: gap = 5mm

f [GHz]	Q	r_1/Q [Ohm/mm^2]	r_1 [Ohm/mm^2]	k_1 [V/nC/mm^2]	r_t/Q [Ohm/mm]	r_t [Ohm/mm]	k_t [V/nC/mm]	k_t (Fy) [V/nC/mm]
0.605	**139**	**6.105e-004**	**8.486e-002**	**5.802e-004**	**4.815e-002**	**6.693e+000**	**4.576e-002**	**4.507e-002**
0.769	612	1.467e-006	8.976e-004	1.772e-006	9.100e-005	5.570e-002	1.099e-004	1.078e-004
0.799	639	8.823e-007	5.638e-004	1.107e-006	5.269e-005	3.367e-002	6.613e-005	6.769e-005
0.848	687	1.135e-005	7.798e-003	1.512e-005	6.387e-004	4.388e-001	8.508e-004	8.432e-004
0.909	751	1.449e-005	1.088e-002	2.068e-005	7.604e-004	5.710e-001	1.086e-003	1.074e-003
1.226	**934**	**4.174e-003**	**3.898e+000**	**8.037e-003**	**1.624e-001**	**1.517e+002**	**3.128e-001**	**3.154e-001**
1.228	**961**	**9.441e-003**	**9.072e+000**	**1.821e-002**	**3.668e-001**	**3.525e+002**	**7.076e-001**	**7.040e-001**
1.255	1070	1.473e-005	1.576e-002	2.904e-005	5.601e-004	5.993e-001	1.104e-003	1.072e-003
1.295	**808**	**6.198e-003**	**5.008e+000**	**1.261e-002**	**2.283e-001**	**1.845e+002**	**4.645e-001**	**4.513e-001**
1.306	**570**	**9.626e-005**	**5.487e-002**	**1.975e-004**	**3.517e-003**	**2.005e+000**	**7.214e-003**	**6.707e-003**
1.312	560	1.452e-005	8.134e-003	2.993e-005	5.282e-004	2.958e-001	1.089e-003	1.178e-003
1.315	530	1.910e-005	1.012e-002	3.944e-005	6.929e-004	3.672e-001	1.431e-003	1.255e-003
1.565	1294	1.143e-007	1.480e-004	2.811e-007	3.486e-006	4.511e-003	8.570e-006	9.109e-006
1.595	**172**	**1.158e-002**	**1.991e+000**	**2.901e-002**	**3.463e-001**	**5.957e+001**	**8.677e-001**	**8.508e-001**
1.611	171	1.288e-005	2.203e-003	3.259e-005	3.817e-004	6.526e-002	9.656e-004	1.628e-003
1.636	**170**	**8.031e-002**	**1.365e+001**	**2.064e-001**	**2.342e+000**	**3.982e+002**	**6.019e+000**	**5.867e+000**
1.659	925	1.585e-010	1.466e-007	4.130e-010	4.558e-009	4.216e-006	1.188e-008	1.182e-008
1.672	**169**	**5.269e-002**	**8.905e+000**	**1.384e-001**	**1.504e+000**	**2.541e+002**	**3.949e+000**	**3.924e+000**
1.673	940	9.243e-008	8.688e-005	2.429e-007	2.636e-006	2.478e-003	6.927e-006	6.866e-006
1.674	1356	2.806e-007	3.805e-004	7.379e-007	7.998e-006	1.085e-002	2.103e-005	2.075e-005
1.696	945	2.062e-009	1.948e-006	5.492e-009	5.800e-008	5.481e-005	1.545e-007	1.470e-007
1.717	**168**	**2.603e-002**	**4.374e+000**	**7.021e-002**	**7.234e-001**	**1.215e+002**	**1.951e+000**	**1.872e+000**
1.727	958	6.217e-010	5.956e-007	1.687e-009	1.718e-008	1.646e-005	4.660e-008	6.611e-008
1.767	981	5.264e-011	5.164e-008	1.461e-010	1.421e-009	1.394e-006	3.945e-009	4.446e-009
1.772	**167**	**1.948e-001**	**3.253e+001**	**5.422e-001**	**5.245e+000**	**8.759e+002**	**1.460e+001**	**1.429e+001**
1.785	1430	9.523e-010	1.362e-006	2.670e-009	2.546e-008	3.640e-005	7.138e-008	1.497e-007
1.815	1012	3.334e-008	3.374e-005	9.506e-008	8.765e-007	8.870e-004	2.499e-006	2.525e-006
1.835	**165**	**1.318e-001**	**2.175e+001**	**3.800e-001**	**3.428e+000**	**5.656e+002**	**9.881e+000**	**9.742e+000**
1.868	1028	4.096e-007	4.210e-004	1.202e-006	1.046e-005	1.075e-002	3.070e-005	3.003e-005
1.898	1494	3.463e-008	5.173e-005	1.032e-007	8.705e-007	1.300e-003	2.595e-006	2.913e-006
1.906	**164**	**2.506e-003**	**4.109e-001**	**7.502e-003**	**6.272e-002**	**1.029e+001**	**1.878e-001**	**1.866e-001**
1.930	1067	3.838e-007	4.095e-004	1.164e-006	9.489e-006	1.012e-002	2.877e-005	2.992e-005
1.983	**164**	**7.304e-002**	**1.198e+001**	**2.275e-001**	**1.757e+000**	**2.882e+002**	**5.474e+000**	**5.509e+000**
1.995	1000	8.990e-006	8.990e-003	2.817e-005	2.150e-004	2.150e-001	6.738e-004	7.114e-004

Transverse impedance calculated using Gdfidl (red) and reconstructed from HFSS data (blue)



Estimate of tune shift due to l=0 head-tail mode in SPS

$$Z_1^y = \sum_m \frac{f_m}{f} \frac{R_m^y}{1 + iQ_m (f_m / f - f / f_m)}; \quad R_m^y = \left(\frac{r_t}{Q}\right)_m \frac{Q_m}{2}$$

$$Z_{1\,eff}^y = \frac{\sum_p Z_1^y (f_p) h_l (f_p - f_\xi)}{\sum_p h_l (f_p - f_\xi)}; \quad h_l (f_p) = e^{-\left(\frac{2\pi f_p \sigma_z}{c}\right)^2}$$

$$f_p = pf_0 + f_\beta; \quad f_\beta = Q_\beta f_0; \quad f_\xi = \xi f_\beta / \eta; \quad \sigma_z = 80mm$$

$$\eta = 5.55 \times 10^{-4}; \quad Q_\beta = 26.6; \quad \xi = 0; \quad f_0 = 43.4kHz$$

$$\Delta Q = \frac{\Omega - \omega_\beta}{\omega_0} \approx \frac{f_0}{\omega_0} \frac{N_p e c^2}{2\, E / e\, \omega_\beta 2\sqrt{\pi}\sigma_z} \Im (Z_{1\,eff}^y) = 1.2 \times 10^{-6};$$

$$E/e = 26GeV; \quad N_p e = 1nC; \quad \Im (Z_{1\,eff}^y) = 8.7\, k\Omega / m$$