Answers to Jeff and Liling concerning the simulations of trapped modes of the SLAC Phase 2 collimator, and news on impedance for the Phase 1 and 2 at CERN

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- **Reminder on the trapped modes simulations performed in 2003 by A. Grudiev for a LHC Phase 1 secondary collimator (http://cdsweb.cern.ch/record/911962/files/ab-note-2005-042.pdf)**
- **Trapped modes of the SLAC Phase 2 collimator: Answers & comments on the talk by Liling at the last LCWG held on 01/03/2010 (and data sent)**
- **News on the impedance for the Phase 2 at CERN**
- **News on the impedance for the Phase 1 at CERN (or in fact for the rest of the machine)**
- **Status of the answers to our actions => Assess (1) when (beam intensity) transverse dampers have to be used, and (2) at which beam energy the octupoles have to be switched on**

Trapped modes of the LHC Phase 1 secondary collimator (1/8)

- **Simulations performed in 2003 by A. Grudiev for a LHC secondary collimator (http://cdsweb.cern.ch/record/911962/files/ab-note-2005-042.pdf)**

Abstract

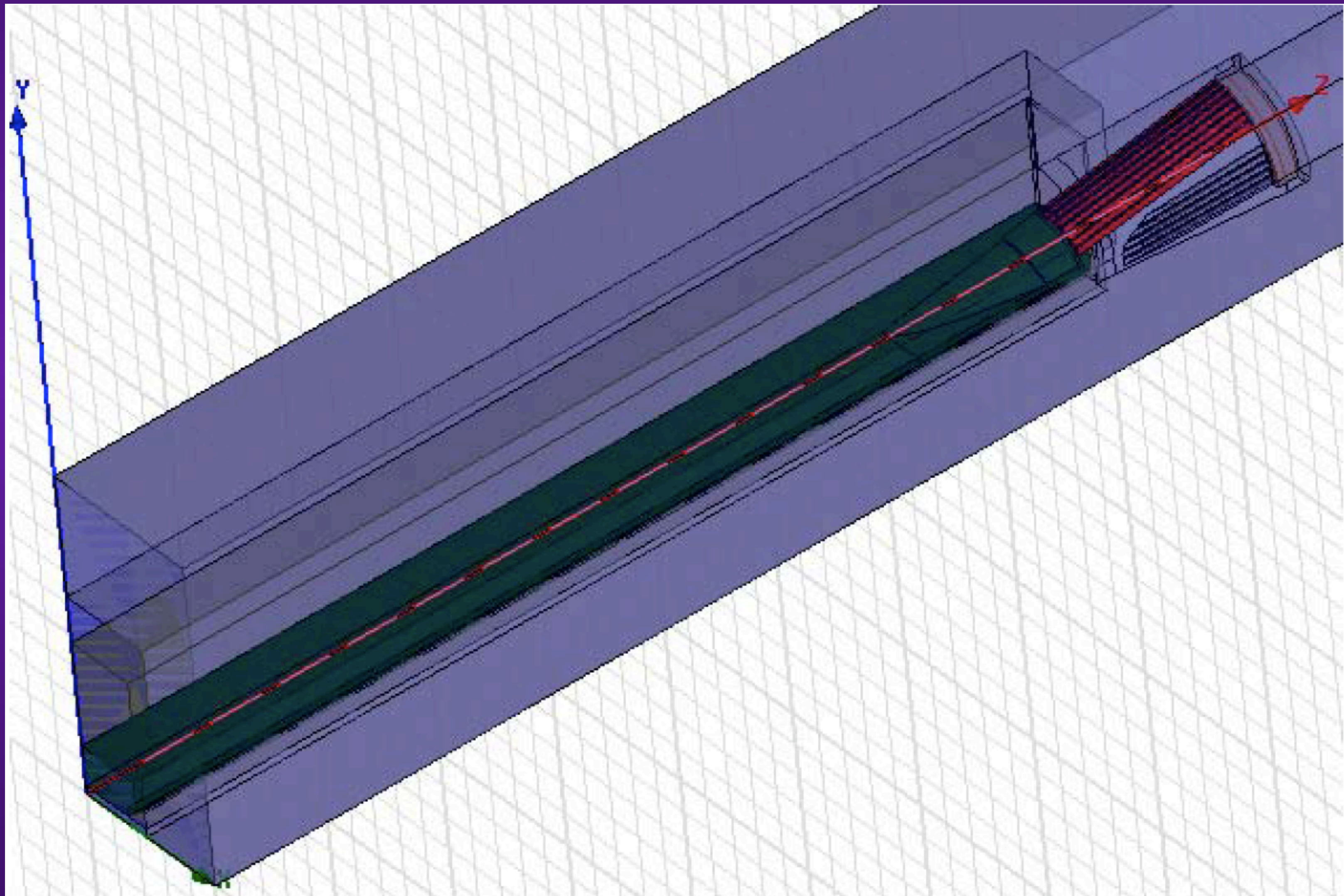
The results of simulation of trapped modes in LHC (phase 1) secondary collimators are presented. Both monopole and dipole modes have been analyzed giving estimates of the longitudinal and transverse impedances for different values of the collimator gap. The comparison with available measurement data shows good agreement. It has been found that a monopole mode at 1.25 GHz gives the main contribution to the longitudinal impedance resulting mainly in heat deposition in the region of sliding RF finger. Estimated maximum losses are 65 mW per finger for nominal LHC beam intensity. Several dipole modes which give non-negligible contribution to the transverse impedance at frequencies below 2 GHz have been found and analyzed.

CONCLUSIONS

Longitudinal and transverse impedances of the collimator trapped modes have been calculated. The longitudinal impedance results mainly in heating of the collimator. The estimated heating power for the nominal LHC beam is 13 W for the dominant trapped mode. The maximum power per RF finger is 65 mW, which can be doubled in the case of disappearance of the silver-coating. Damping of the dominant monopole mode is possible by placing absorbing material in the region of RF fingers to beam pipe transition. The transverse impedance of the trapped modes is of the order of the resistive wall transverse impedance ($\sim 10^5$ Ω/m) in the frequency range 1.6 GHz to 2 GHz.

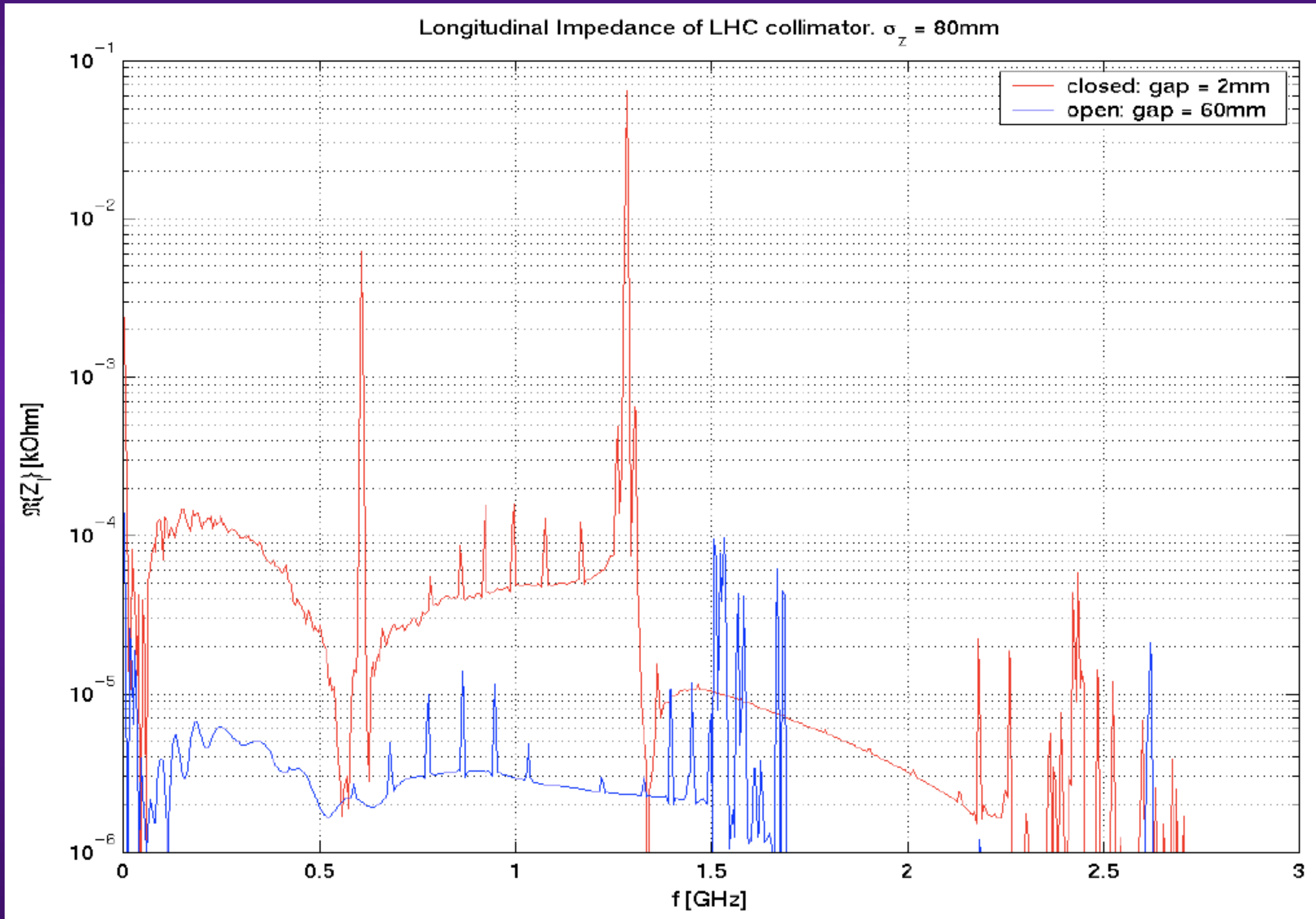
Trapped modes of the LHC Phase 1 secondary collimator (2/8)

- **HFSS and GdFidL used**

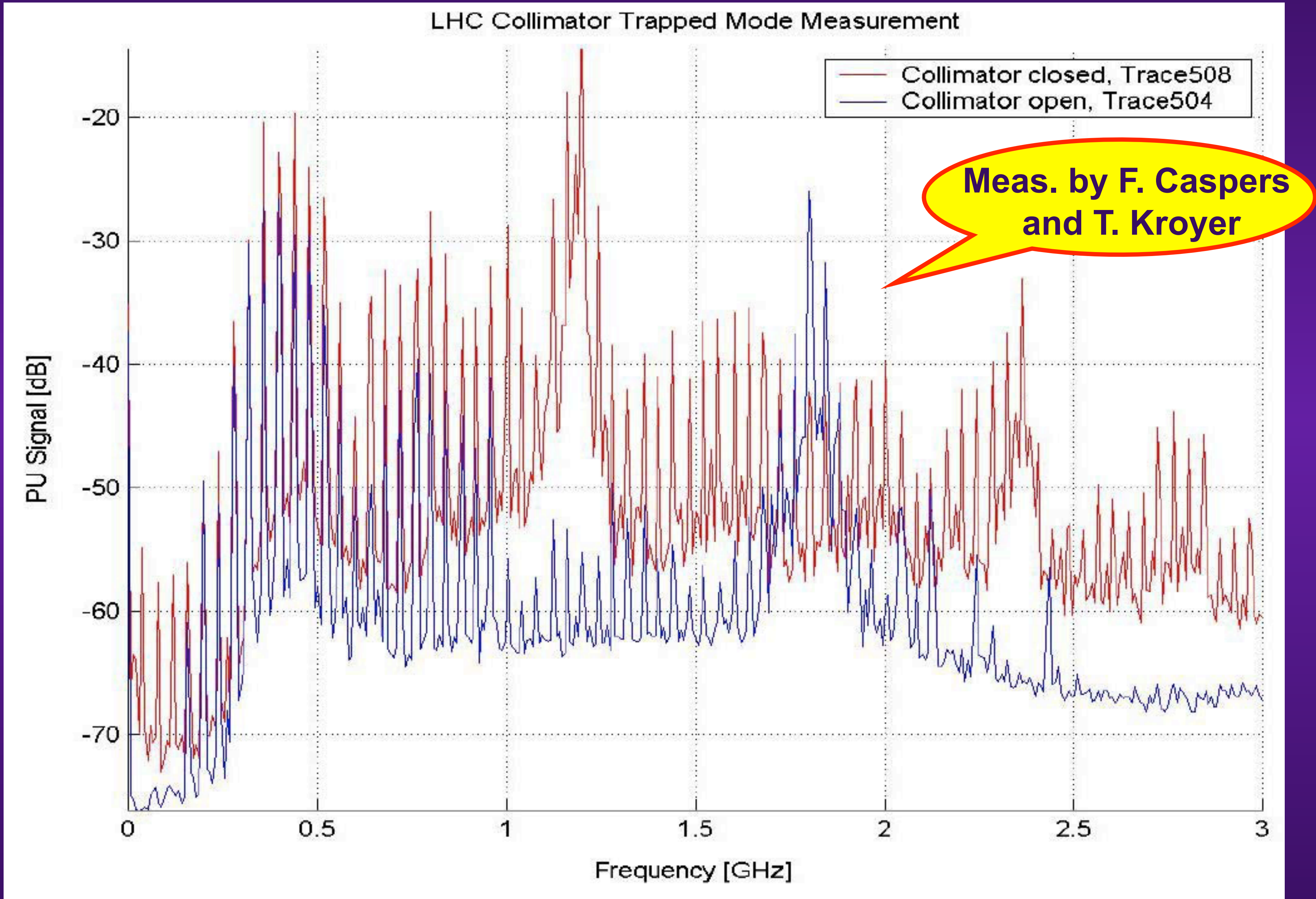


Trapped modes of the LHC Phase 1 secondary collimator (3/8)

- **Longitudinal**



Trapped modes of the LHC Phase 1 secondary collimator (4/8)



Trapped modes of the LHC Phase 1 secondary collimator (5/8)

TABLE 1. Parameters of two dominant monopole modes.

Parameter name	Monopole mode 1	Monopole mode 2
Frequency: f [GHz]	0.6	1.25
Quality factor: Q	136	890
Shunt impedance: r_l [Linac-Ω]	13.6	2380
Loss factor: k_l [V/nC]	0.13	5.2
Power losses: P_{loss} [W]	2.3	13

Divide by 2 for rings!

- **In the paper from AG, it was proposed to add ferrite to reduce the RF finger heating (as there was a maximum power dissipation in the RF finger which was given at that time)**

- **As we were not sure with AG if the ferrite was really installed, I checked with O. Aberle on 05/03/2010: “there are no Ferrites on the single beam LHC collimators (TCP, TCS, TCT), only on the two-beam design collimators TCTVB and TCLIA**

Trapped modes of the LHC Phase 1 secondary collimator (6/8)

- **Transverse**

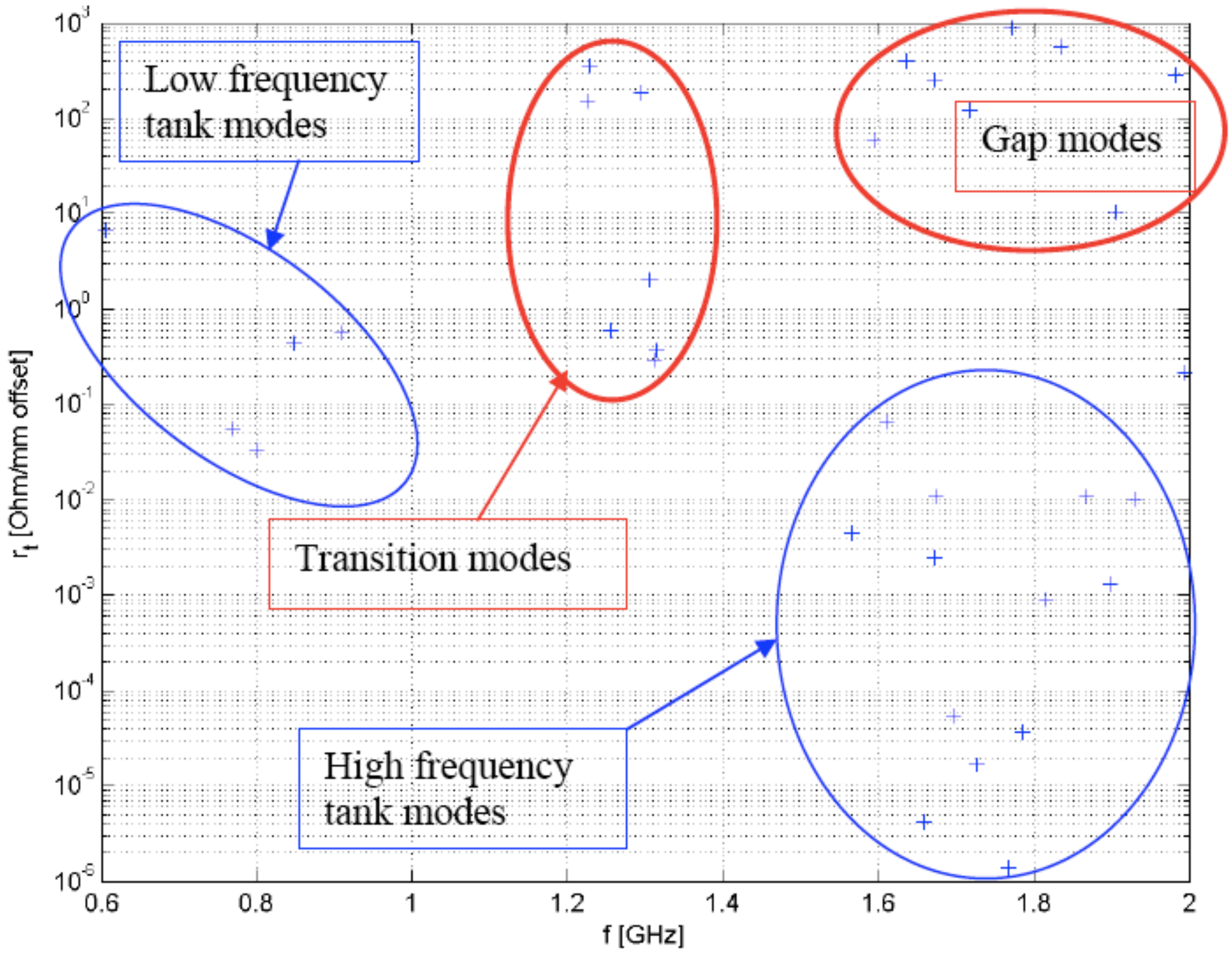


FIGURE 8. Transverse impedance of dipole modes is presented for gap of 5 mm. Different types of modes are shown (see text).

Trapped modes of the LHC Phase 1 secondary collimator (7/8)

TABLE 2. Parameters of the dominant dipole modes for 5 mm gap and for 2.5 mm gap.

#	f_y [GHz]		Q		r_y [LinacΩ/mm]		k_y [V/nC/mm]	
	5mm	**2.5mm**	**5mm**	**2.5mm**	**5mm**	**2.5mm**	**5mm**	**2.5mm**
1	0.605	0.607	140	140	6.7	6.7	0.045	0.046
2	1.226	1.237	930	940	151.7	114.6	0.313	0.237
3	1.228	1.238	960	990	352.5	582.4	0.708	1.144
4	1.295	1.297	810	830	184.5	218.3	0.464	0.536
5	1.306	1.311	570	600	2.0	0.65	0.007	0.002
6	1.595	1.591	172	88	59.6	86.35	0.868	2.452
7	1.611	1.606	171	88	0.06	8.13	0.001	0.233
8	1.636	1.632	170	87	398.2	660.2	6.019	19.45
9	1.672	1.668	169	86	254.1	229.3	3.949	6.985
10	1.717	1.714	168	86	121.5	366.3	1.951	11.47
11	1.772	1.769	167	85	875.9	1342.8	14.60	43.90
12	1.835	1.834	165	84	565.6	619.6	9.881	21.25
13	1.906	1.906	164	83	10.3	6.4	0.188	0.23
14	1.983	1.986	164	83	288.2	618.3	5.474	23.24

Trapped modes of the LHC Phase 1 secondary collimator (8/8)

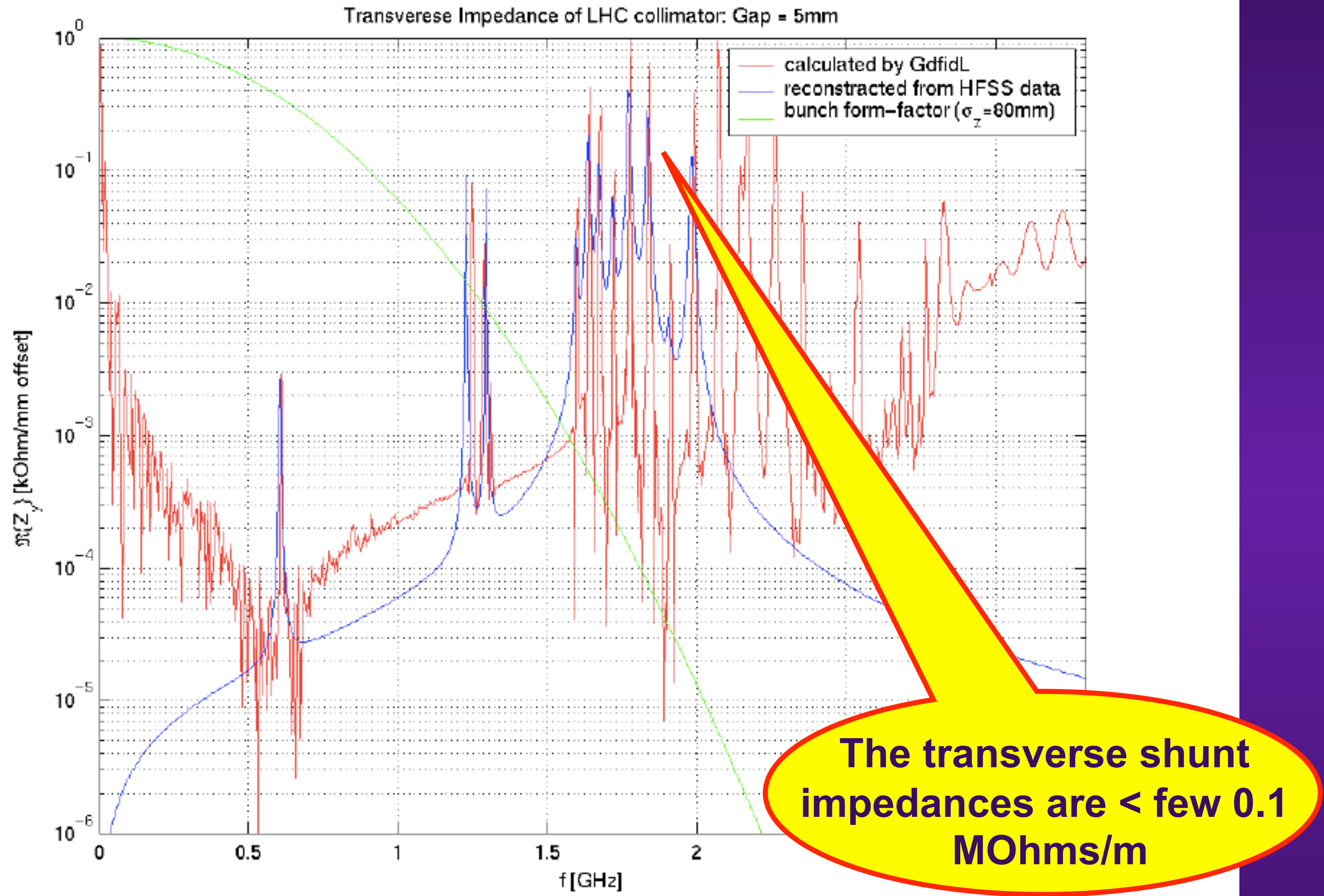


FIGURE 12. Transverse impedance versus frequency of the dipole modes reconstructed from the parameters calculated using HFSS (blue) and calculated using GdfidL (red) is presented for 5 mm gap. Green line shows frequency dependence of the form-factor of a Gaussian bunch of 80 mm RMS length.

Trapped modes of the SLAC Phase 2 collimator (1/11)

- **See talk by Liling at the last LCWG held on 01/03/2010**

Longitudinal trapped modes => Gap = 2 mm

longitudinal trapped modes in the
SLAC rotatable collimator design

f(Hz)	Q-value	R/Q(ohm/collimator)
8.7435E+07	6.3613E+02	2.0979E-01
2.0685E+08	7.4821E+02	1.5183E-01
3.4748E+08	9.1278E+02	1.5702E-01
3.7889E+08	2.1094E+03	9.3140E-03
4.2270E+08	2.1067E+03	7.0052E-04
4.9594E+08	1.1787E+03	1.7859E-01
5.0422E+08	2.0996E+03	4.4603E-02
6.1086E+08	1.9072E+03	9.5616E-02
6.3177E+08	1.5010E+03	3.0156E-01
7.1954E+08	1.4954E+03	1.0638E-01
7.3186E+08	1.6553E+03	9.9809E-02
7.5328E+08	3.2570E+03	1.1895E-02
7.6245E+08	1.5270E+03	2.2917E-02
7.8241E+08	3.6708E+03	6.2648E-02
8.2893E+08	2.6454E+03	1.2599E-01
8.3213E+08	3.8245E+03	1.6998E-02
8.6209E+08	1.3034E+03	2.5318E-02
9.0062E+08	3.9894E+03	2.2130E-01
9.2456E+08	3.6962E+03	3.6748E-01
9.7314E+08	3.1831E+03	6.7816E-01
9.8617E+08	2.2313E+03	7.3197E-03
9.8838E+08	3.2935E+03	1.9508E-01
1.0433E+09	5.0385E+03	9.0967E-01
1.0519E+09	2.0501E+03	2.9610E-01
1.0868E+09	3.8547E+03	1.3632E-02
1.1219E+09	5.0263E+03	1.1390E-01
1.1728E+09	1.6957E+03	2.2174E-01
1.1817E+09	4.2020E+03	2.3828E-03
1.2076E+09	3.8504E+03	1.1186E-01
1.2254E+09	3.6959E+03	1.5960E-02
1.2418E+09	3.7868E+03	1.8936E-05
1.2638E+09	4.6515E+03	6.9748E-01
1.2656E+09	4.2132E+03	2.6111E-02
1.2826E+09	4.7443E+03	4.3522E-01
1.3039E+09	4.6056E+03	1.0890E-01
1.3150E+09	1.8213E+03	3.2122E-02
1.3250E+09	4.4681E+03	1.1739E-03
1.3324E+09	4.6321E+03	1.8580E-01
1.3703E+09	3.4777E+03	9.5454E-03
1.3881E+09	3.3133E+03	1.0985E-01
1.3983E+09	3.7014E+03	1.0163E-01
1.4281E+09	3.9325E+03	2.4655E-01
1.4303E+09	3.2106E+03	6.2396E-03
1.4469E+09	3.2444E+03	6.2070E-04
1.4715E+09	3.7447E+03	6.2802E-04
1.4917E+09	3.7444E+03	1.5043E-02
1.5058E+09	2.2530E+03	1.5715E-01
1.5425E+09	8.4941E+03	6.4434E-01
1.5438E+09	5.8729E+03	4.9030E-03
1.5508E+09	3.5664E+03	8.3232E-03
1.5520E+09	4.5563E+03	3.5349E-02
1.5712E+09	7.5836E+03	1.1372E-01
1.5983E+09	8.2660E+03	3.6710E-04

1.3983E+09	3.7014E+03	1.0163E-01
1.4281E+09	3.9325E+03	2.4655E-01
1.4303E+09	3.2106E+03	6.2396E-03
1.4469E+09	3.2444E+03	6.2070E-04
1.4715E+09	3.7447E+03	6.2802E-04
1.4917E+09	3.7444E+03	1.5043E-02
1.5058E+09	2.2530E+03	1.5715E-01
1.5425E+09	8.4941E+03	6.4434E-01
1.5438E+09	5.8729E+03	4.9030E-03
1.5508E+09	3.5664E+03	8.3232E-03
1.5520E+09	4.5563E+03	3.5349E-02
1.5712E+09	7.5836E+03	1.1372E-01
1.5983E+09	8.2660E+03	3.6710E-04
1.6029E+09	2.2879E+03	1.3026E-02
1.6095E+09	3.6191E+03	3.9481E-05
1.6158E+09	2.3785E+03	3.7660E-01
1.6275E+09	2.1599E+03	2.8521E-02
1.6367E+09	4.3115E+03	7.7676E-03
1.6401E+09	2.4844E+03	1.2305E-01
1.6553E+09	5.3680E+03	4.5416E-03
1.6569E+09	6.0688E+03	1.0163E-01
1.6672E+09	4.0820E+03	2.4655E-01
1.6779E+09	2.6612E+03	6.2396E-03
1.7013E+09	4.3145E+03	6.2070E-04
1.7113E+09	4.8913E+03	6.2802E-04
1.7177E+09	3.3286E+03	1.5043E-02
1.7337E+09	3.1785E+03	1.5715E-01
1.7393E+09	6.0543E+03	6.4434E-01
1.7406E+09	4.6719E+03	4.9030E-03
1.7581E+09	2.4082E+03	8.3232E-03
1.7819E+09	3.1696E+03	3.5349E-02
1.7866E+09	4.8091E+03	1.1372E-01
1.7889E+09	4.0652E+03	3.6710E-04
1.8094E+09	6.1977E+03	1.3026E-02
1.8200E+09	2.6198E+03	3.9481E-05
1.8204E+09	4.9219E+03	3.7660E-01
1.8391E+09	2.8626E+03	2.8521E-02
1.8399E+09	4.2980E+03	7.7676E-03
1.8428E+09	4.5890E+03	1.2305E-01
1.8451E+09	2.8112E+03	4.5416E-03
1.8528E+09	3.8151E+03	2.3326E-03
1.8790E+09	3.5441E+03	4.7815E-03
1.8839E+09	4.0312E+03	5.4668E-01
1.8849E+09	3.0926E+03	5.5174E-02
1.8957E+09	2.5907E+03	8.5810E-02
1.9029E+09	4.0941E+03	8.4640E-05
1.9070E+09	5.5084E+03	6.9172E-04
1.9232E+09	6.4887E+03	3.3606E-01
1.9302E+09	4.4274E+03	2.9239E-01
1.9347E+09	5.4101E+03	4.6654E-06
1.9392E+09	3.2479E+03	3.6029E-03
1.9550E+09	3.1603E+03	8.9153E-02
1.9757E+09	2.9229E+03	6.2583E-03
1.9814E+09	4.7368E+03	6.1176E-03
1.9931E+09	5.2378E+03	1.0237E+00

Trapped modes of the SLAC Phase 2 collimator (2/11)

Longitudinal trapped modes => Gap = 60 mm

longitudinal trapped modes in the current collimator design for the SPS testing
fully retracted jaws: gap=60mm

f(Hz)	q	r.q-z(ohm/cavity)
7.3621E+07	4.6224E+02	3.6490E-01
1.9530E+08	5.0493E+02	1.0116E-01
3.4312E+08	6.1102E+02	5.1901E-02
4.8700E+08	1.0106E+03	9.1015E-03
4.9266E+08	7.3811E+02	6.3937E-02
5.2482E+08	1.0576E+03	8.7218E-03
5.9170E+08	1.1813E+03	1.1637E-03
6.2158E+08	8.5868E+02	2.5935E-02
6.6345E+08	2.3419E+03	4.1443E-03
6.6375E+08	9.8682E+02	2.1486E-01
6.8450E+08	1.4124E+03	2.41E-01
6.9934E+08	2.0920E+03	1.66E-01
7.0751E+08	9.7807E+02	1.31E-02
7.4695E+08	2.1347E+03	7.15E-01
8.0097E+08	1.6984E+03	5.62E-02
8.1403E+08	1.4463E+03	9.66E-02
8.3875E+08	1.3391E+03	6.27E-03
9.0914E+08	1.6581E+03	6.34E-02
9.0983E+08	1.9654E+03	4.83E-01
9.6533E+08	1.9347E+03	7.84E-01
1.0019E+09	1.6910E+03	1.43E+00
1.0036E+09	1.8893E+03	7.99E-01
1.0333E+09	2.6102E+03	7.77E-01
1.0636E+09	2.3918E+03	2.66E-01
1.0790E+09	2.3056E+03	1.84E-02
1.1055E+09	2.4584E+03	6.08E-01
1.1579E+09	1.7327E+03	1.05E-03
1.1596E+09	2.2007E+03	2.35E-01
1.1685E+09	1.8933E+03	1.69E+00
1.2123E+09	3.3509E+03	8.14E-01
1.2280E+09	2.5283E+03	2.21E+00
1.2281E+09	2.4969E+03	8.94E-01
1.2342E+09	3.4174E+03	1.40E+00
1.2444E+09	2.4923E+03	3.02E-01
1.2779E+09	2.3739E+03	3.60E-03
1.2783E+09	2.5093E+03	2.03E-01
1.2887E+09	2.6237E+03	3.61E-01
1.3162E+09	1.4096E+03	1.84E-01
1.3325E+09	2.2066E+03	5.92E-03
1.3491E+09	3.3977E+03	2.31E-02
1.3692E+09	1.0072E+04	4.28E-02
1.3779E+09	2.5823E+03	1.05E-02
1.3926E+09	2.2880E+03	7.68E-05
1.3955E+09	7.2950E+03	2.17E-03
1.4057E+09	2.3991E+03	8.65E-03
1.4195E+09	2.3448E+03	1.23E-01
1.4242E+09	2.1317E+03	7.72E-02
1.4385E+09	6.6986E+03	1.53E-01
1.4504E+09	2.3839E+03	1.70E-02
1.4525E+09	2.8425E+03	1.07E-05
1.4691E+09	2.0286E+03	7.25E-02
1.4823E+09	3.3898E+03	7.55E-01
1.4992E+09	2.6117E+03	2.29E-04
1.5114E+09	3.2948E+03	4.12E-02

1.3926E+09	2.2880E+03	7.68E-05
1.3955E+09	7.2950E+03	2.17E-03
1.4057E+09	2.3991E+03	8.65E-03
1.4195E+09	2.3448E+03	1.23E-01
1.4242E+09	2.1317E+03	7.72E-02
1.4385E+09	6.6986E+03	1.53E-01
1.4504E+09	2.3839E+03	1.70E-02
1.4525E+09	2.8425E+03	1.07E-05
1.4691E+09	2.0286E+03	7.25E-02
1.4823E+09	3.3898E+03	7.55E-01
1.4992E+09	2.6117E+03	2.29E-04
1.5114E+09	3.2948E+03	4.12E-02
1.5234E+09	2.8875E+03	1.86E-01
1.5362E+09	3.0883E+03	7.19E-02
1.5537E+09	2.5445E+03	1.88E-01
1.5660E+09	3.6287E+03	3.96E-02
1.5782E+09	3.3275E+03	2.66E-02
1.5835E+09	2.3602E+03	3.39E-01
1.6151E+09	2.4825E+03	5.01E-01
1.6173E+09	3.7919E+03	1.04E-02
1.6234E+09	2.5556E+03	9.27E-02
1.6272E+09	2.1852E+03	1.05E-04
1.6644E+09	3.9812E+03	2.68E-01
1.6701E+09	2.8259E+03	1.31E-02
1.6754E+09	4.9761E+03	2.97E-01
1.6982E+09	2.6447E+03	2.30E-01
1.7051E+09	2.4532E+03	4.27E-05
1.7253E+09	2.5236E+03	2.53E-02
1.7325E+09	2.9637E+03	8.30E-01
1.7383E+09	2.2775E+03	2.01E-01
1.7432E+09	2.2040E+03	4.41E-04
1.7476E+09	2.8478E+03	2.08E-01
1.7530E+09	2.1812E+03	1.01E-02
1.7720E+09	2.3562E+03	1.53E-01
1.7785E+09	2.7194E+03	3.83E-02
1.7832E+09	2.6329E+03	2.03E-02
1.7853E+09	2.3649E+03	4.93E-02
1.7873E+09	2.3140E+03	1.84E-01
1.8057E+09	4.8585E+03	1.40E+00
1.8156E+09	3.3082E+03	2.78E-01
1.8219E+09	2.6899E+03	1.05E-01
1.8364E+09	3.0652E+03	4.84E-02
1.8525E+09	3.0820E+03	8.31E-01
1.8582E+09	2.7690E+03	7.90E-01
1.8659E+09	2.8343E+03	1.42E-01
1.8692E+09	3.1759E+03	6.89E-04
1.8719E+09	3.1427E+03	8.20E-02
1.8962E+09	4.6047E+03	1.26E-03
1.9001E+09	3.1026E+03	4.60E-01
1.9016E+09	8.1158E+03	6.07E-02
1.9109E+09	2.1676E+03	2.38E-01
1.9125E+09	4.5764E+03	9.86E-04
1.9175E+09	2.5793E+03	2.92E-03
1.9308E+09	4.6765E+03	7.14E-03
1.9335E+09	5.3753E+03	9.21E-02
1.9524E+09	4.0622E+03	3.43E-01
1.9555E+09	3.9932E+03	6.30E-02
1.9709E+09	2.8090E+03	2.28E-02

Resonant Heating from Trapped Modes

Resonant power losses are due to the excitation of these trapped modes. Assuming all bunches are in phase with them and mode decay is lower from bunch to bunch ($T_d >> T_b$):

$$P = I^2 \sum \left(\frac{R}{Q}\right)_i e^{-\omega_i^2 \sigma^2 / c^2} * Q_i,$$

$$I = q / T_b = 0.582 A$$

$$P(cir.) = 65W$$

$$P(rec.) = 6.5W$$

$$P(part - cir.) = 38W$$

Seems to be quite similar to what AG obtained (13 W for the 2nd most critical mode)

L. Xiao

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LARP

Trapped modes of the SLAC Phase 2 collimator (4/11)

Transverse trapped modes
=> Gap = 2 mm

Transverse trapped modes in the current
collimator design for the SPS testing
Jaws are fully inserted with gap=2mm

f(Hz)	q	r.q-t(ohm/cavity)
6.30E+07	6.84E+02	5.52E+06
1.91E+08	6.69E+02	3.17E+04
1.91E+08	6.69E+02	3.17E+04
3.46E+08	8.36E+02	9.99E+01
3.90E+08	1.82E+03	4.05E+03
4.32E+08	1.80E+03	1.59E+04
5.05E+08	1.03E+03	1.88E+03
5.15E+08	1.78E+03	2.66E+04
5.60E+08	2.59E+03	1.32E+03
5.93E+08	2.31E+03	6.29E+01
6.25E+08	1.87E+03	1.29E+04
6.46E+08	1.47E+03	3.50E+03
6.68E+08	1.76E+03	2.69E+02
7.32E+08	1.50E+03	1.68E+03
7.34E+08	1.49E+03	1.67E+03
7.55E+08	1.84E+03	2.81E+03
7.92E+08	1.78E+03	2.26E+02
8.41E+08	1.43E+03	1.39E+03
8.57E+08	1.67E+03	6.05E+02
8.92E+08	2.62E+03	1.34E+03
9.46E+08	2.37E+03	3.87E+02
9.68E+08	1.68E+03	2.52E+02
9.87E+08	3.18E+03	4.53E+01
9.89E+08	4.06E+03	3.91E+01
9.96E+08	2.83E+03	1.11E+03
1.01E+09	3.95E+03	2.66E+02
1.05E+09	3.42E+03	6.05E-01
1.07E+09	2.84E+03	8.85E+00
1.08E+09	1.92E+03	4.36E+01
1.08E+09	2.47E+03	4.45E+01
1.11E+09	4.28E+03	4.79E+01
1.15E+09	4.33E+03	1.46E-04
1.16E+09	2.14E+03	2.09E+02
1.18E+09	3.89E+03	1.77E+02
1.20E+09	1.69E+03	2.66E+01
1.22E+09	5.24E+03	1.86E+01
1.25E+09	3.50E+03	8.13E+00
1.28E+09	2.92E+03	2.47E+02
1.30E+09	2.33E+03	7.62E+01
1.30E+09	6.50E+03	8.11E-01
1.33E+09	3.16E+03	2.08E+01
1.33E+09	6.30E+03	1.79E+00
1.34E+09	4.01E+03	1.48E+01
1.36E+09	3.31E+03	1.39E+01
1.39E+09	5.92E+03	1.82E+01
1.40E+09	2.78E+03	1.07E+01
1.43E+09	4.22E+03	2.64E+00
1.43E+09	1.93E+03	7.12E+01
1.44E+09	5.79E+03	1.64E+01
1.46E+09	3.97E+03	3.63E+00
1.47E+09	3.57E+03	3.90E+01
1.48E+09	4.01E+03	2.09E+00
1.49E+09	3.29E+03	1.52E+01
1.49E+09	5.49E+03	1.65E+00

$$\left(\frac{R}{Q}\right)_t \times Q_t = R_t$$

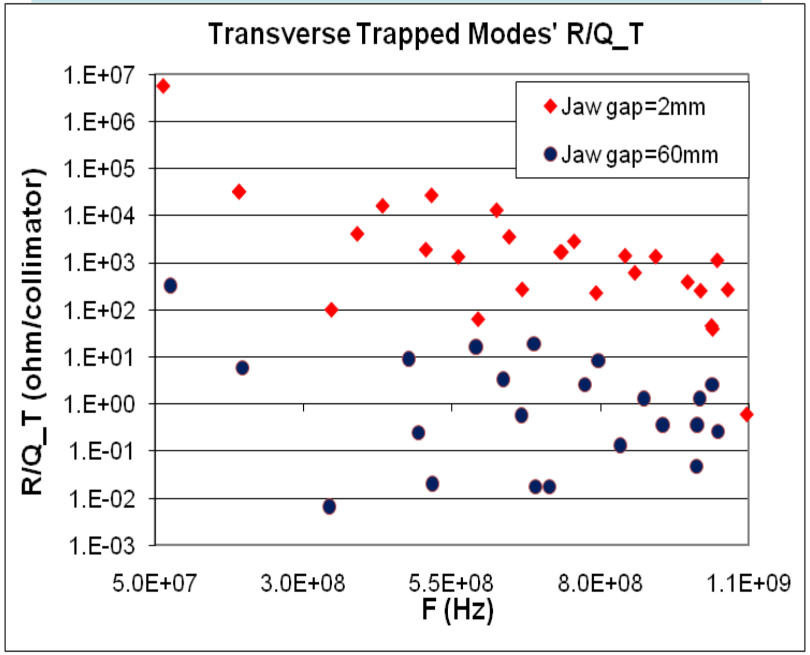
$$= 5.52 \times 10^6 \times 684$$

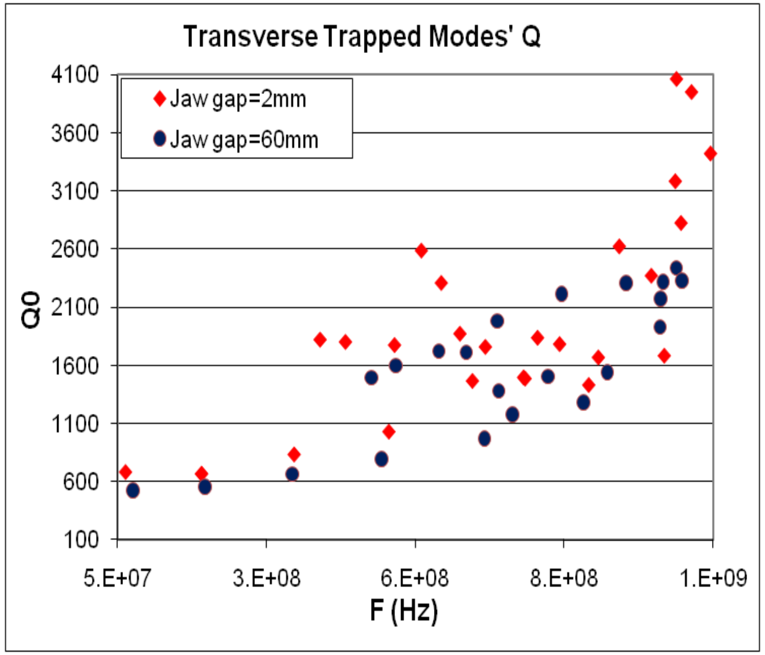
$$= 3.8\ \mathrm{G\Omega/m!}$$

Trapped modes of the SLAC Phase 2 collimator (5/11)

Two Jaw Gaps – Transverse Modes

$$\left(\frac{R}{Q}\right)_T = \frac{|V_T|^2}{\omega U} = \frac{|V_z|^2/(r_0 * \omega / c)^2}{\omega U}$$





The transverse modes have strong R/Q_T for fully inserted jaws than for fully retracted jaws.

L. Xiao

22

LARP

Trapped modes of the SLAC Phase 2 collimator (6/11)

- **Transverse trapped modes stability criterion for the LHC at top energy (from Landau octupoles) => http://cdsweb.cern.ch/record/1208149/files/CERN-ATS-2009-035.pdf**

Effect of the transverse betatron function

$$N_{coll} \times \left(\frac{\beta_{coll}}{\beta_{avg}} \right) \times R_t << 1 \ \ \mathrm{G\Omega/m}$$

Number of collimators

=> Should aim to values smaller than few MΩ/m

Trapped modes of the SLAC Phase 2 collimator (7/11)

- **Example of computations performed in the past for the trapped modes from the TCTV**

COUPLED-BUNCH INSTABILITY AT LHC TOP ENERGY FOR THE TCTV (TRAPPED MODES) ALONE

E. Métral

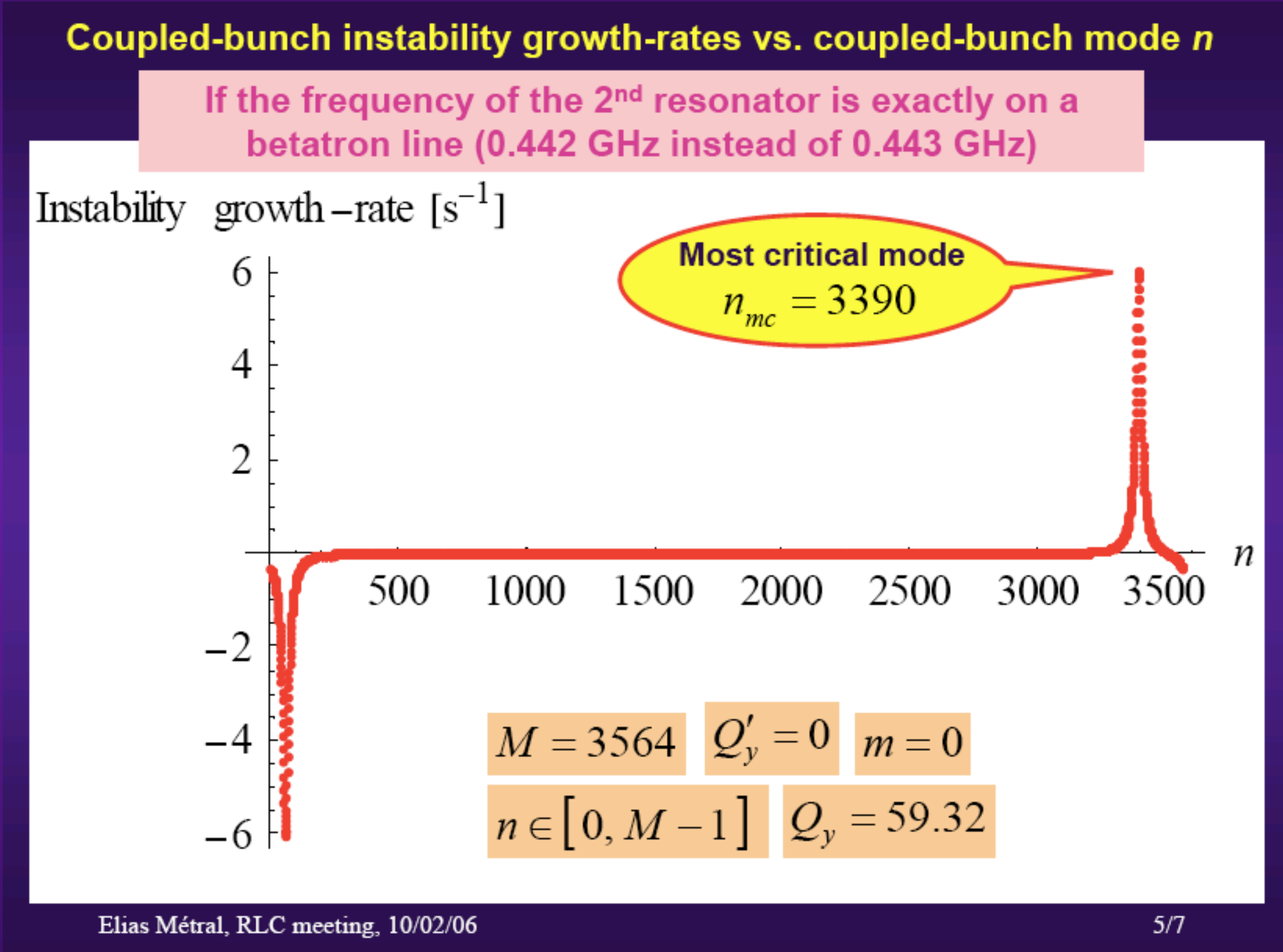
- **AG computed the impedance of transverse modes in the TCTV (W jaw) for a (full) gap of 3 mm**
- **There are few of them**
- **The 2 most critical trapped modes are**

$$f_{r1} = 0.362 \text{ GHz} \quad Q_1 = 1700 \quad R_{y1} = 152.8 \text{ M}\Omega/\text{m}$$

$$f_{r2} = 0.443 \text{ GHz} \quad Q_2 = 1080 \quad R_{y2} = 173.8 \text{ M}\Omega/\text{m}$$

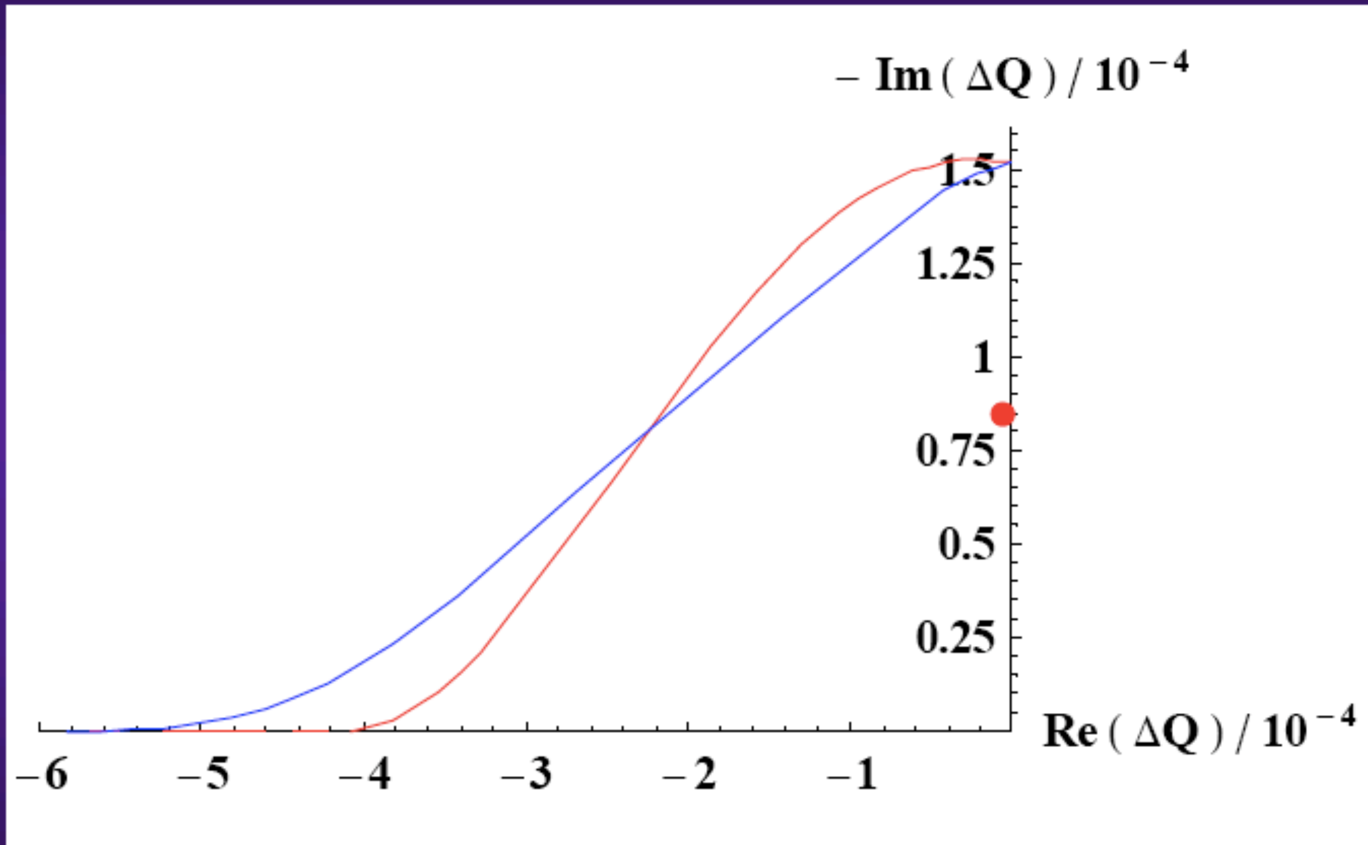
Elias Métral, RLC meeting, 10/02/06 1/7

Trapped modes of the SLAC Phase 2 collimator (8/11)



Trapped modes of the SLAC Phase 2 collimator (9/11)

Tune shift and stability diagram



Elias Métral, RLC meeting, 10/02/06

6/7

Trapped modes of the SLAC Phase 2 collimator (10/11)

Email sent to Jeff and Liling on 05/03/2010

Hi Jeff (and Liling),
Unfortunately we could not discuss it during the last impedance meeting on Wednesday as we had many other topics to discussed (also with some external visitors). However, yesterday we looked at your results together with Alexej Grudiev (AG made the simulations of the trapped modes in the past for our secondary collimators => The results are summarized in the paper Fritz sent you) and my plan was to prepare few slides today or Monday where I would like to summarize our comments, comparing what you obtained with your Phase 2 collimator to what we obtained for our current secondary collimator. In 2 words:

1) For the longitudinal plane:
- Your R/Q seems to increase when the gap is increased, as also found by AG in the past.
- The critical modes are in the transition region.
- AG found the 2 most critical modes at 0.6 GHz and 1.25 GHz. You have much lower frequencies for the trapped modes due to the fact that your cut-off frequency is 0 (due to your coaxial line structure). It would be a good idea to close the volume around the 2 copper cylinders, as this would raise the cut-off frequency significantly and remove a lot of modes. But we can imagine that this might be difficult due to the 2 movements of the cylinders which are required in your design.
- AG found a power loss of 13 W for the 2nd mode and you find values of W or few tens of W. Therefore, these seem to be quite similar results.
- However, we had a concern at that time with the heating of the RF fingers, which could melt (we had an estimate on the maximum power dissipation in the RF finger). This is why it was decided to damp the modes by putting ferrite. In your case, do you know where the power will go? Do you also have in this area (transition region) any limit of power dissipation?
- Damping the 2nd mode by ferrite, the Qvalue went down from 890 to 17 in our case.
- Action for me: I would like to check that the ferrite was really put on the current secondary collimator!
- Question for you: There seems to be an inconsistency between the values we found in page 10 of your talk and the table you sent me. Looking roughly at the figures, we found a factor ~ 1000 for the R of the 1st mode. If we are not mistaken we found ~ 0.1 Ohm from the plot and ~100 Ohms from the table you sent. The unit in page 10 is may be kOhm instead of Ohm?

2) For the transverse plane:
- You found a lot of modes as AG and you also found that the most critical modes are for the smaller gap of 2 mm (as AG).
- Most critical modes are the transition and gap ones => The transition modes are more critical due to the lower frequency.
- We found value of Rt ~ 0.1 MOhm/m (in some frequency range), which was considered to be OK for the SPS and the LHC => See below more explanations for the LHC.
- According to page 22 (and which seems to be in good agreement with the table you sent me), you found a Rt larger than 1 GOhm/m which is much too big. Isn't there also a possible issue of unit here?
If not, this value is much too big and you should damp it fore sure.
In the LHC at top energy, the limit for you is the following: Ncoll * (betaL / betaA) * Rt << 1 GOhm/m, where Ncoll is the number of collimators, betaL is the transverse betatron function at the collimator, betaA is the transverse average betatron function and Rt is the transverse shunt impedance of your collimator. The sign << means much smaller, which means here ~ 2 orders of magnitude (to have a contribution of only at the 1% level of the maximum values). Therefore, to summarize you should aim to Ncoll * (betaL / betaA) * Rt of not more than few MOhm/m.

As I said, I would like to summarize (precisely, to avoid any misunderstanding) our results on few slides, which I would like to send you at the beginning of next week. I will also explain them in detail during the next Collimation Working Group meeting on Monday 15/03/2010.
Please tell me if this is fine with you and many thanks for all your help and these nice simulations!
Cheers, Elias.

Trapped modes of the SLAC Phase 2 collimator (11/11)

Email sent to Jeff and Liling on 10/03/2010

Hi Jeff,
As you mentioned Gianluigi, I put him in cc if he wants to add something.

Concerning the dimensions:
1) The dimensions of the current CERN collimator (full H × V) are: 66 mm × 80 mm.
2) For your SLAC collimator, they should be (full H × V): 60 mm × 60 (or 80) mm.

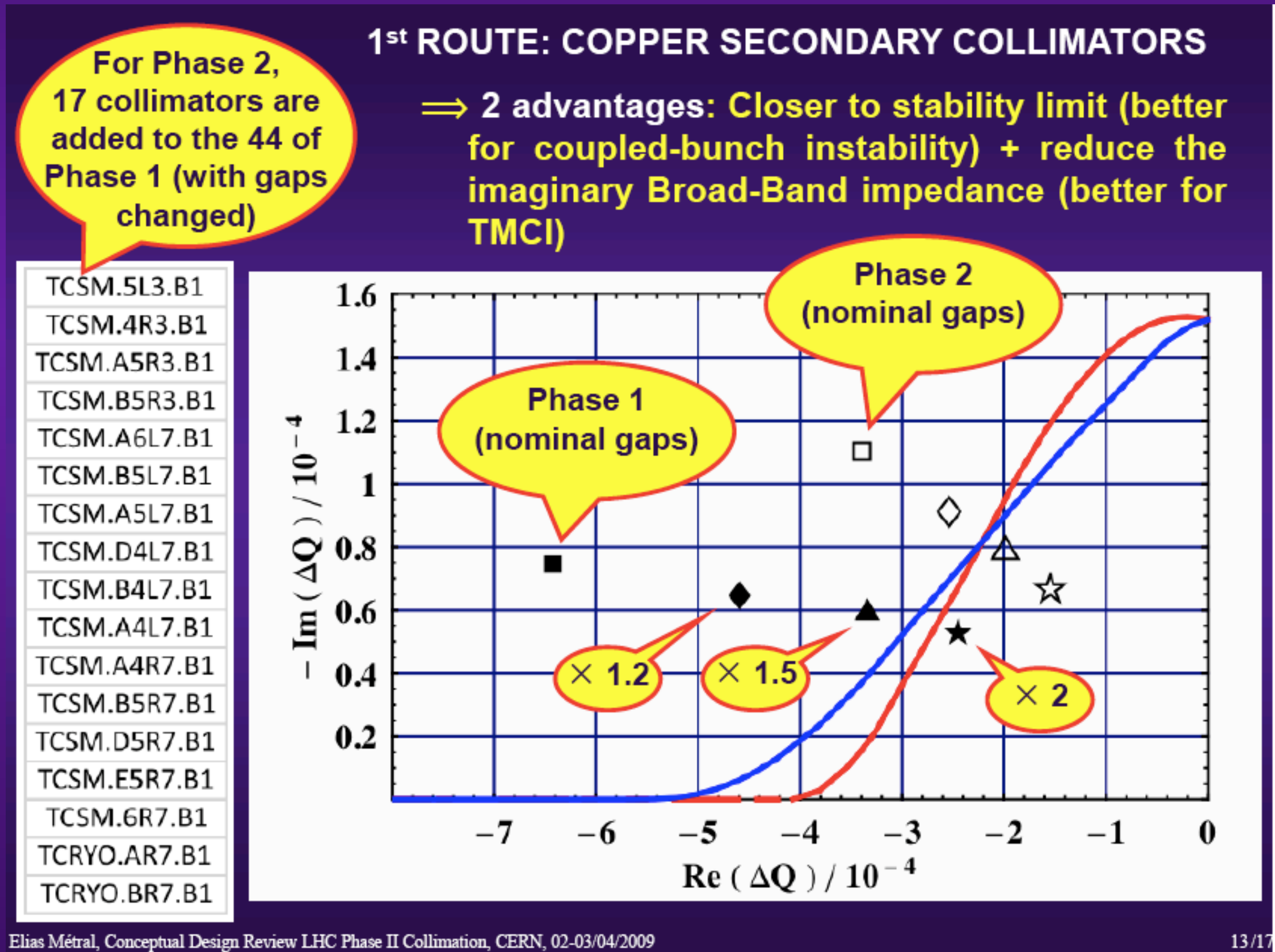
Concerning the position: At the moment, the idea is to put the SLAC collimator in sextant 5 in position 51732 (see http://emetral.web.cern.ch/emetral/CCinS/5thMeeting_16-12-09/PositionOfTheCrabCavityAndTheSPScollimators_2.pdf).

According to me, in normal operation the beam should always remain very close to the beam centre as there are no (injection or extraction) bumps in this area. The bumps are in sextants 2, 4 and 6.

Please do not hesitate if you need more info from us and thanks for all!
Let's discuss more on Monday.
Cheers, Elias.

News on the impedance for the Phase 2 at CERN (1/6)

- Reminder from the "Conceptual Design Review LHC Phase II Collimation", CERN, 2009, (http://indico.cern.ch/getFile.py/access?contribId=7&resId=1&materialId=slides&confId=55195):

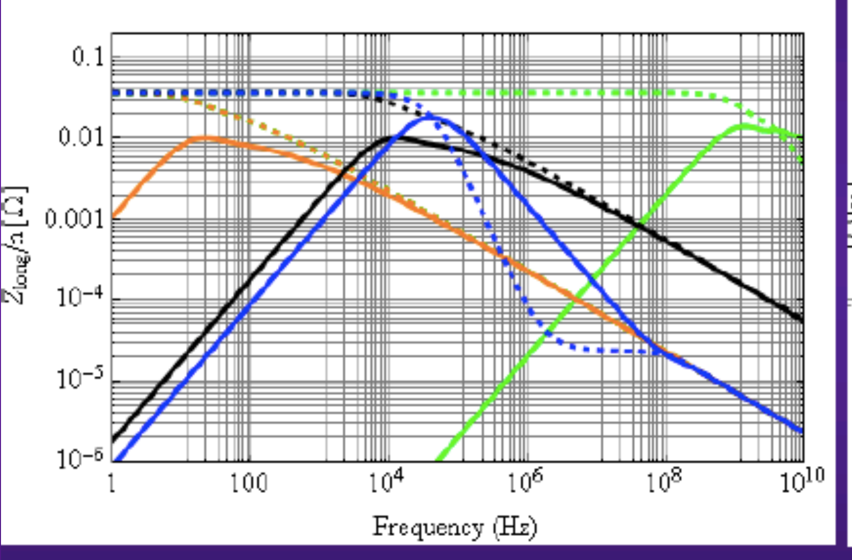


News on the impedance for the Phase 2 at CERN (2/6)

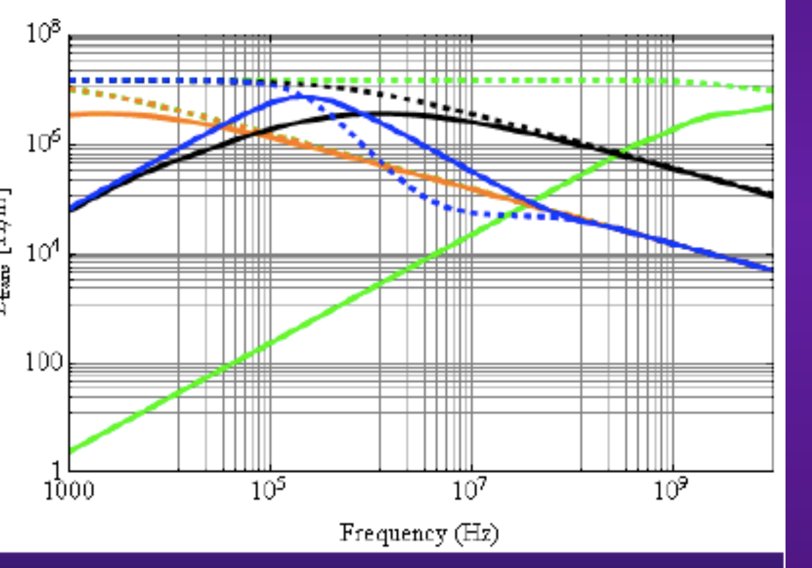
2nd ROUTE: SECONDARY COLLIMATORS MADE OF CERAMICS?

$\varepsilon_r = 5$ $\rho = 1\ \Omega\text{m}$ $L = 1\ \text{m}$ $b = 2\ \text{mm}$

LONGITUDINAL



TRANSVERSE



Real part → full
Imaginary part → dashed

- 2.5 cm ceramic + vacuum
- 2.5 cm graphite + vacuum
- 2.5 cm copper + vacuum
- 10 µm copper coating + 2.5 cm ceramic + vacuum

Elias Métral, Conceptual Design Review LHC Phase II Collimation, CERN, 02-03/04/2009 14/17

News on the impedance for the Phase 2 at CERN (3/6)

REMINDER ON SINGLE-BUNCH INSTABILITIES (1/2)

LOSS OF LANDAU DAMPING FOR THE LONGITUDINAL DIPOLE MODE

$= \tau_b \, f_{rev} = 1\,\mathrm{ns} \times 11245.5\,\mathrm{Hz}$

35640

16 MV

$$\left| \frac{Z_l(n)}{n} \right|_{eff} \le \left| \frac{Z_l(n)}{n} \right|_{eff}^{max} = \frac{3\pi^2}{32} \times \frac{h^3 \, \hat{V}_{RF} \, B_0^5}{N_b \, e \, f_{rev}} \times F_{PWD} \approx 0.6\,\Omega$$

1.15E11 p/b

~ 1

Reminder: In the LHC Design Report (Vol. 1, chap. 5) the effective Broad-Band impedance was estimated to ~ 0.1 Ω for the squeezed optics ⟹ If the imaginary part of the longitudinal impedance is increased (too much) then one could be limited by this mechanism. To be followed-up with Elena Chapochnikova

News on the impedance for the Phase 2 at CERN (4/6)

REMINDER ON SINGLE-BUNCH INSTABILITIES (2/2)

TMCI FOR THE TRANSVERSE PLANE

$$\frac{\Delta Q^{y}_{0,0}}{Q_s} < -1 \quad \Longrightarrow \quad \mathrm{Im}\left(Z_y^{eff}\right) < \mathrm{Im}\left(Z_y^{eff}\right)_{\max} = \frac{4\,\pi\,(E_t/e)\,\tau_b\,Q_s}{N_b\,e\,\beta_y^{av}} \approx 134\ \mathrm{M\Omega/m}$$

$N_b = 7E12$

$Q_s = 2E-3$

$\beta_y^{av} = R/Q_y = 71.5\ \mathrm{m}$

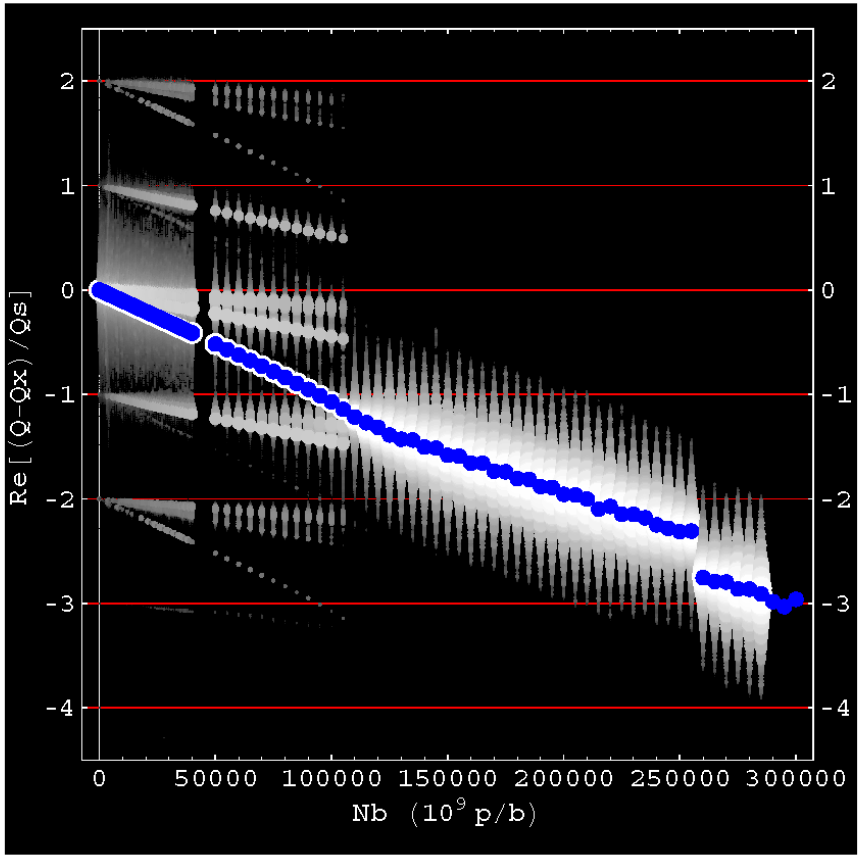
Reminder: The effective Broad-Band impedance is estimated to ~ 30 MΩ/m for the squeezed optics. If the imaginary part of the transverse impedance is increased (too much) then one could be limited by TMCI

Elias Métral, Conceptual Design Review LHC Phase II Collimation, CERN, 02-03/04/2009 16/17

News on the impedance for the Phase 2 at CERN (5/6)

- **Recent results from B. Salvant (<u>https://impedance.web.cern.ch/impedance/documents/TMCI%20for%20LHC%20collimators.ppt</u>: Ongoing work => Preliminary) => To be continued by B. Salvant + H. Day**

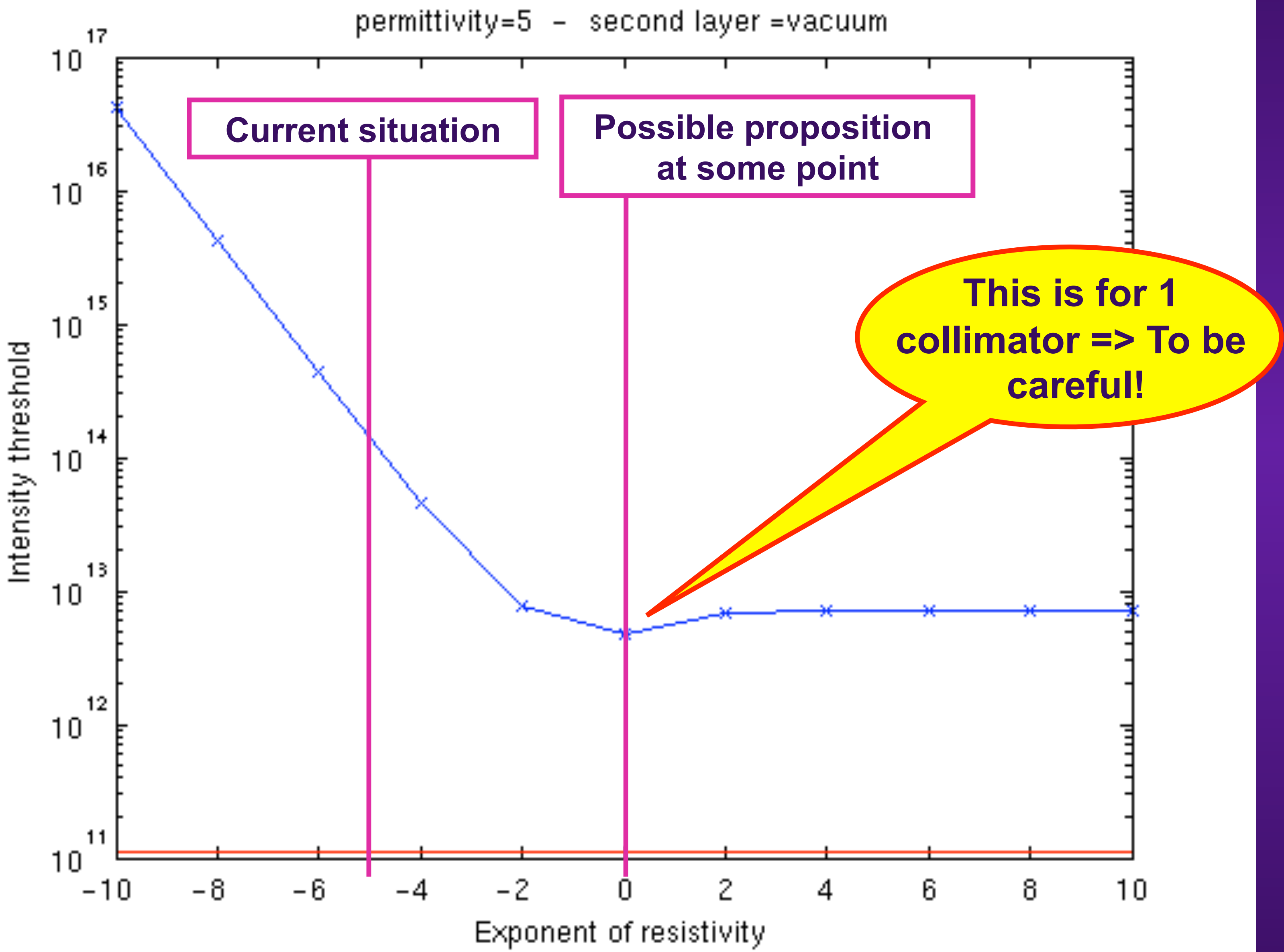
Example of TMCI for a Phase 1 graphite collimator (gap=6 sigma) in IR7



TMCI between modes 0 and -1

Instability threshold at ~10^{14} p/b

News on the impedance for the Phase 2 at CERN (6/6)

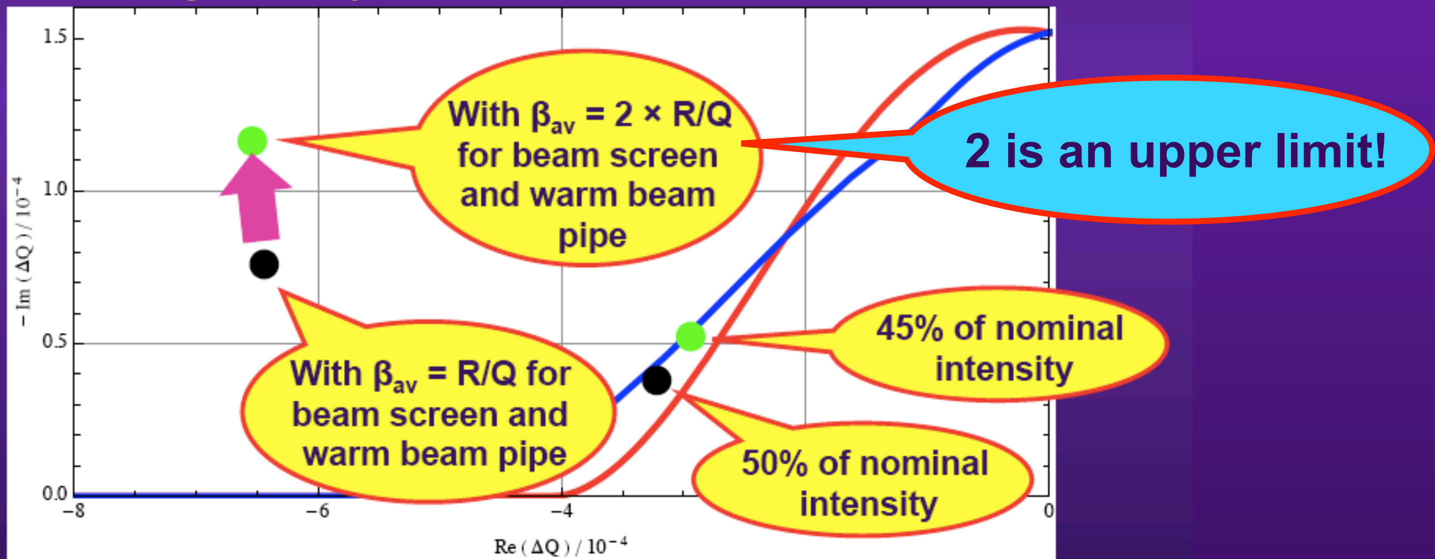


News on the impedance for the Phase 1 at CERN (or in fact for the rest of the machine) (1/4)

=> See https://impedance.web.cern.ch/impedance/documents/PossibleIssuesWithTheLHCBeamScreens.pdf

Exact length, transverse dimensions and betatron functions of the different beam screens

- Will be updated soon with Nicolas (with inputs from N. Kos and M. Giovannozzi) => Within a factor ~ 2, it should be OK and the usual conclusion of a stability reached for ~ 50% remains the same
  - Reminder: R/Q ~ 70 m and the "real" average transverse betas are larger by a factor ~ 1.3 at injection and ~ 2 at top energy (re-checked by Nicolas)



Elias Métral, Impedance Meeting, 25/02/2010 12/17

News on the impedance for the Phase 1 at CERN (or in fact for the rest of the machine) (2/4)

- Effect of the longitudinal weld in the beam screen => The effect for the longitudinal impedance (and associated power loss) was re-discussed for the LHC IR Upgrade Phase 1: https://impedance.web.cern.ch/impedance/LHC/PumpingSlots_AnswersToNicolaasKos_Final.pdf

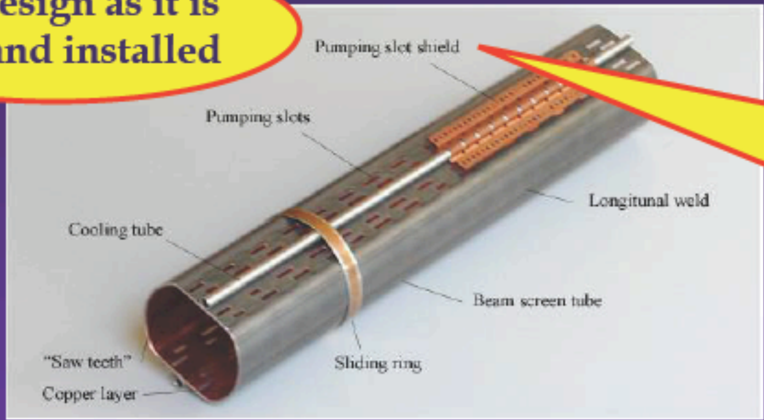
- The transverse plane was not discussed much in the past and it is re-investigated in detail => Carlo Zannini is performing some EM simulation

News on the impedance for the Phase 1 at CERN (or in fact for the rest of the machine) (3/4)

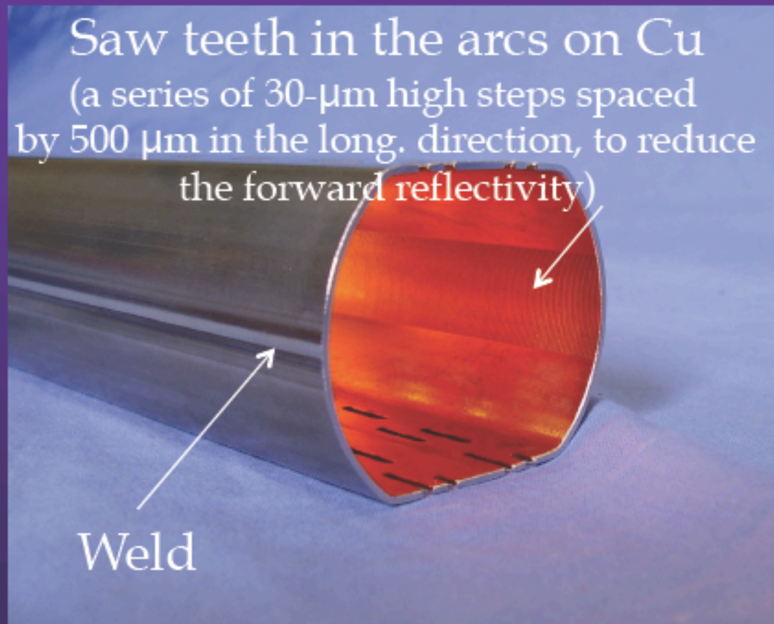
CURRENT BEAM SCREEN (1/14)

LHC design as it is built and installed

Courtesy of N. Kos



In dipoles, also called baffles, to avoid direct e⁻ path along magnetic field lines to the cold bore (which would then add to the heat load)



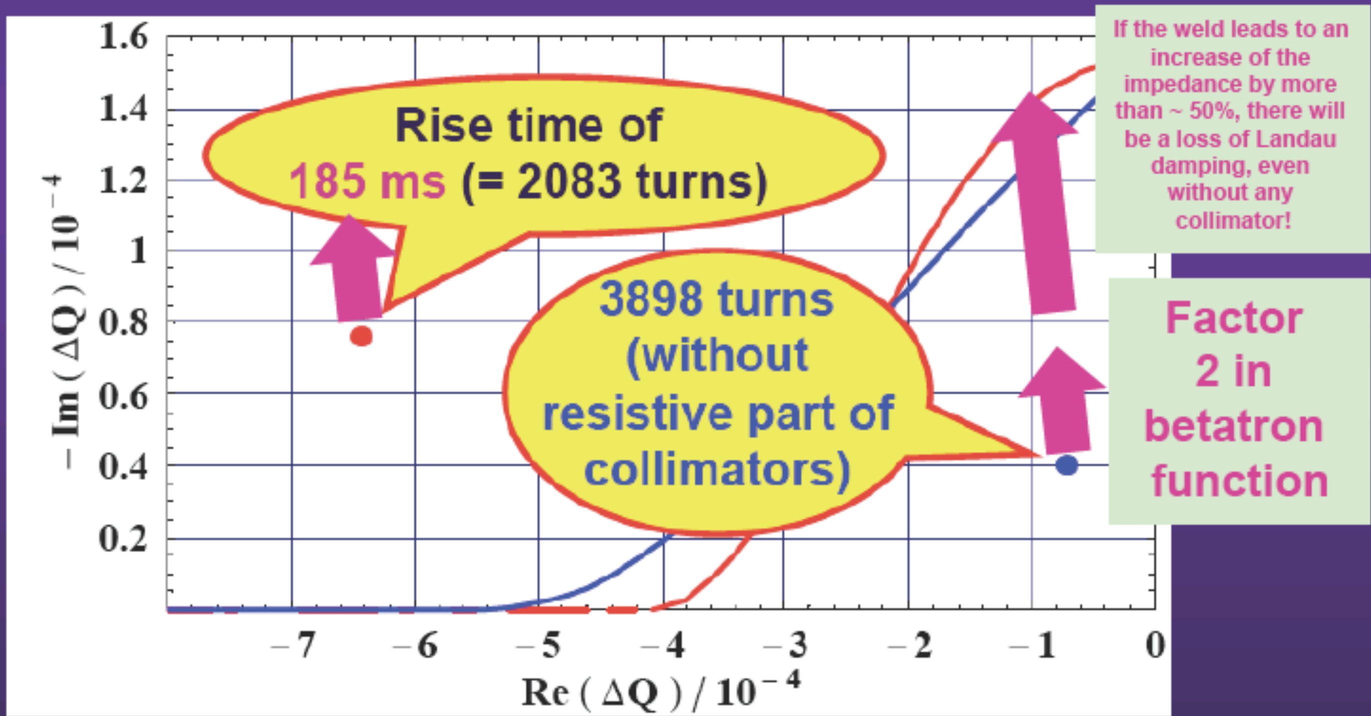
Elias Métral, 02/02/2010

3/28

News on the impedance for the Phase 1 at CERN (or in fact for the rest of the machine) (4/4)

Effect of the longitudinal weld on the horizontal plane (4/4)

- Carlo is performing some EM simulations (see next talk) => If the effect is too big, then the Landau octupoles will not be enough in the horizontal plane even without any collimators! => Illustration shown below but with data of the vertical plane… To be redone properly for the horizontal plane (should be close, except for the effect of the weld)



Elias Métral, Impedance Meeting, 25/02/2010 16/17

STATUS OF THE ANSWERS TO OUR ACTIONS

- **Assess when (beam intensity) transverse dampers have to be used**

⇒ Still to be assessed, but it is a difficult question as it depends on the natural damping (and therefore the natural nonlinearities)…

⇒ In the SPS for instance (which is a very linear machine), the transverse dampers need to be set up after 12 bunches spaced by 25 ns! Reminder: There are 924 possible (25 ns) buckets in the SPS and 4 × 72 = 288 bunches will be sent at maximum in 1 batch to the LHC

⇒ Our current plan is to estimate the number of bunches in the LHC which yields a similar instability rise-time as the one of the SPS when it starts to be unstable => Waiting to have a better model of the LHC (with the correct beam screens and welds): Ongoing (N. Mounet)

- **Assess at which beam energy the octupoles have to be switched on**

⇒ At the moment (see also the conclusion of my talk at the "Conceptual Design Review LHC Phase II Collimation"), the idea is to use the octupoles only at top energy in case of problem with the transverse dampers (transverse emittance blow-up induced by too much noise)