# Study of Absorber Effectiveness in the ILC Main Linacs

Goal: Compute the HOM monopole losses in the 2K NC beam pipe relative to the losses in the 70 K beamline absorbers.

Procedure: For select frequencies, TM0n modes and cavity spacings, compute relative power losses in a periodic system of cryomodules to assess probability that the beam pipe cryoload is significant due to 'trapped' modes. At worse, such losses would double 2K dynamic load as the HOM power above cutoff is of the order of the 1.3 GHz wall losses.

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SLAC, March 26, 2010

Cascading Through Multiple Beamline Objects

$$S_{n-1,n} \qquad S_{n,n+1}$$

	Object		Object	
$n{-}1$		n		$n{+}1$
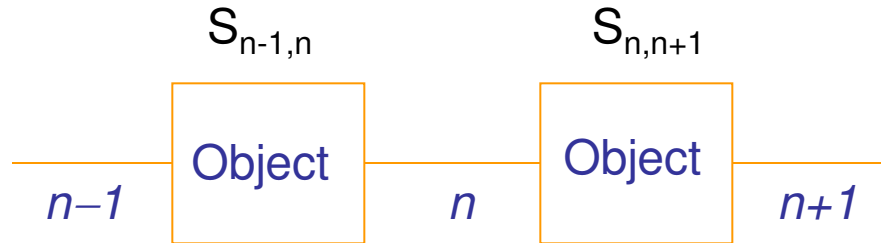
Equations for left (l) and right (r) going fields between objects having transfer matrix S for a given mode:

$$r_n = r_{n-1}(S_{12})_{n-1,n} + l_n(S_{22})_{n-1,n}$$

$$l_n = r_n(S_{11})_{n,n+1} + l_{n+1}(S_{21})_{n,n+1}$$

with $n = 1,\ldots N$, where N is number of objects

Include boundary conditions at ends of the string

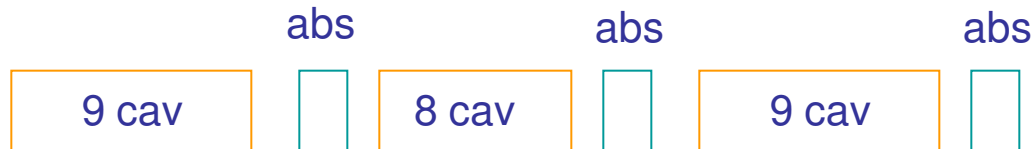Add drive vector, d, to represent beam induced field level

Then solve coupled equations to find fields

With M modes, matrix dimension is $2(N+1)M$

Boundary Conditions and Drive Terms

Consider one ILC rf unit with N objects (N+1 junctions) and apply periodic boundary conditions:

$$r_{1,m} = r_{(N+1),m}\exp(-i\varphi_{tot}) \quad \text{and} \quad l_{(N+1),m} = l_{1,m}\exp(i\varphi_{tot}) \quad \text{with } \varphi_{tot} = \omega L_{tot}/c$$

	abs		abs		abs
9 cav		8 cav		9 cav	

Drive terms:
  - Only include right drive terms at junctions after cavities to represent the beam induced fields from those cavities
  - Drive only lowest mode in most cases

$d_{i,m} = \exp(i\varphi_i)$, $\varphi_i = \omega L_i/c$, with $d_{1,m} = 0$ and

L_i = length along the beamline

Power Loss Calculations

For 4, 8, 12, 16 and 20 GHz, computed S-matrix for ILC cavity (cylindrically symmetric, lossless) and for TESLA lossy absorber.

Added losses for Cu-coated beam pipes at 2K, $S_{mn} \rightarrow C_m S_{mn} C_n$ with $C_m =$ $\exp[-\alpha_m \, l_0 - (\alpha_m + i\beta_m)dz]$, where l_0 is nominal cavity interconnection beam pipe (bellows) length and dz is extra pipe length that is included to gauge sensitivity to trapped modes. Treat bellows as smooth pipe.

$\alpha_m = \omega R_s/(acZ_0\beta_m)$, $\beta_m = [(\omega/c)^2 - (j_{0m}/a)^2]^{1/2}$, $R_s = (Z_0\omega/2\sigma c)^{1/2}$, and $\sigma = 1 \times 10^{10}/\Omega/m$ (Cu at 2 K) or $2 \times 10^8/\Omega/m$ (SS at 2 K) with a = beam pipe radius

Solved for steady state fields and computed power dissipated in each object (note the drive power is subtracted)

$ploss_n = \Sigma_m(|r_{n,m}|^2 + |l_{n+1,m}|^2 - |l_{n,m}|^2 - |r_{n+1,m}|^2) + (|r_{n+1,1}|^2 - |r_{n+1,1} - d_{n+1,1}|^2)$,

As a check, verified that the total losses equal the total drive power (i.e. ρ_{err} as defined below should be zero)

$\rho_{err} = 1 - \Sigma_n (|r_{n,1}|^2 - |r_{n,1} - d_{n,1}|^2)/p_{tot}$

# ILC (TESLA) Cavity Scattering Matrices

Frequencies: 4, 8, 12, 16, 20 GHz

Freq		S:WavePort1:1	S:WavePort2:1	Gamma	Lambda
4 (GHz)	WavePort1:1	(0.086713, -115)	(0.9962, -22.8)	(56.778, 90)	0.11066
	WavePort2:1	(0.9962, -22.8)	(0.086713, -110)	(56.778, 90)	0.11066

Freq		S:WavePort1:1	S:WavePort1:2	S:WavePort2:1	S:WavePort2:2	Gamma	Lambda
8 (GHz)	WavePort1:1	(0.3581, -33.2)	(0.054289, -39.2)	(0.92635, 65.1)	(0.10306, -8.45)	(155.91, 90)	0.0403
	WavePort1:2	(0.054289, -39.2)	(0.46076, 75.8)	(0.10287, -119)	(0.8798, -26.4)	(89.817, 90)	0.069955
	WavePort2:1	(0.92635, 65.1)	(0.10287, -119)	(0.33764, -17)	(0.13124, -81.8)	(155.91, 90)	0.0403
	WavePort2:2	(0.10306, -8.45)	(0.8798, -26.4)	(0.13124, -81.8)	(0.44495, 53.2)	(89.817, 90)	0.069955

8 GHz

1.036 m
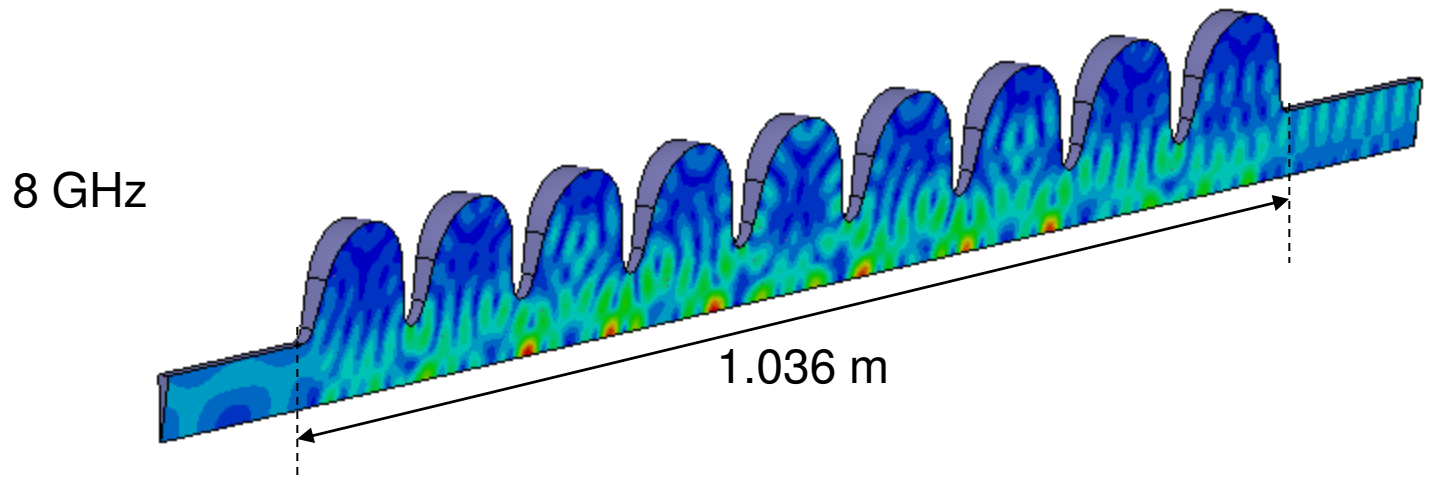
Absorber Parameters

tanδ of Zr10CB5 as a function of frequency
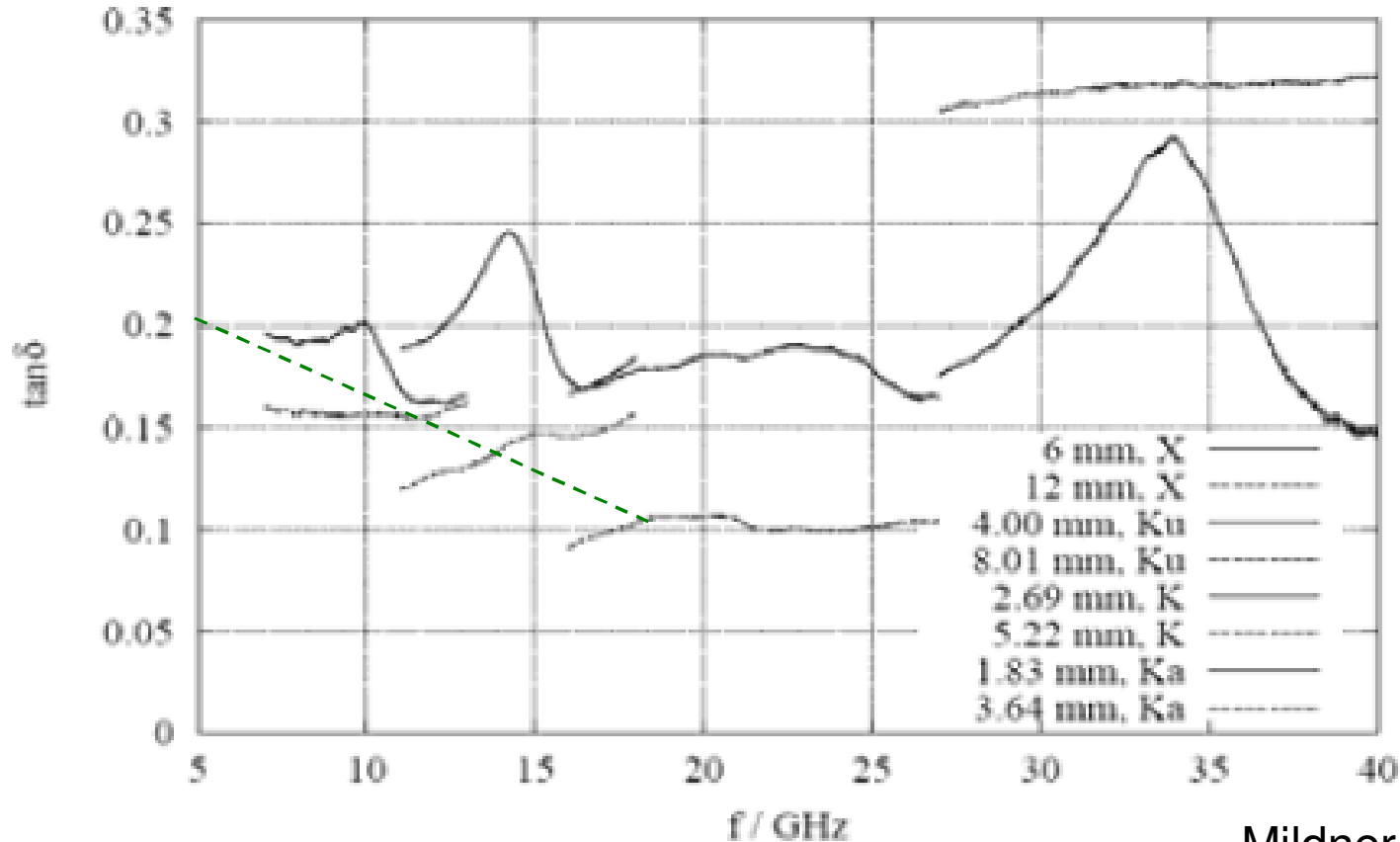
Mildner *et al.*, SRF05

For lack of a better data, approximate $\tan\delta_l$ for 10 mm ring @ 70K as linearly dropping from 0.2 to 0.08 between 4 GHz and 20 GHz.

$\epsilon = 15, \ \tan\delta_l = 0.2$

Freq		S:WavePort1:1		S:WavePort2:1		Gamma		Lambda
4 (GHz)	WavePort1:1	(0.27433,	51)	(0.91448,	-44)	(56.778,	90)	0.11066
	WavePort2:1	(0.91448,	-44)	(0.27422,	50.9)	(56.778,	90)	0.11066

8.85%
absorbed

60 mm

142.3 mm

142.3 mm

r=39 mm

$\epsilon = 15, \ \tan\delta_l = 0.17$
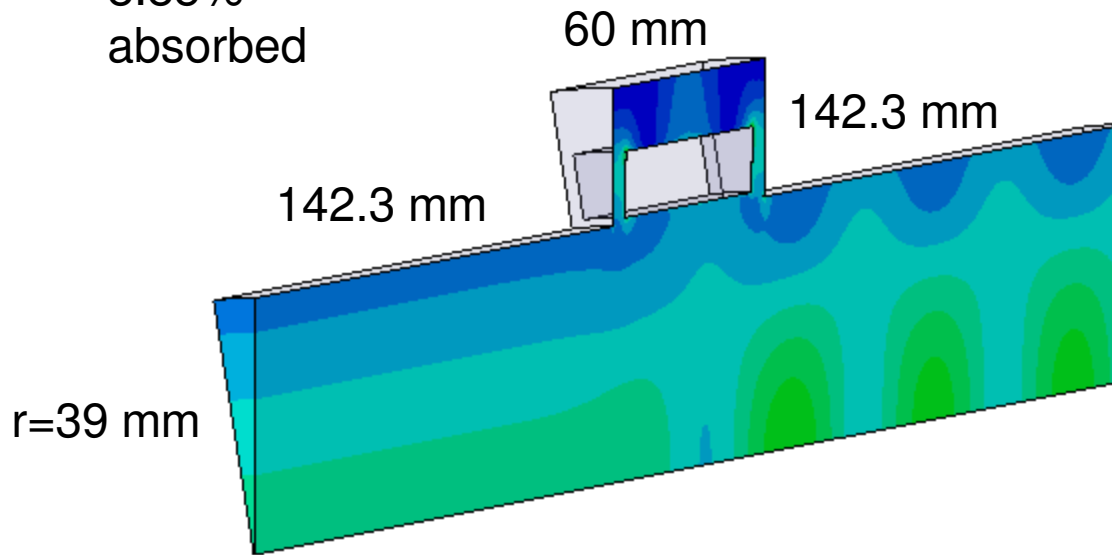
Freq		S:WavePort1:1		S:WavePort1:2		S:WavePort2:1		S:WavePort2:2		Gamma		Lambda
8 (GHz)	WavePort1:1	(0.069138,	136)	(0.19278,	-83.7)	(0.65679,	153)	(0.32602,	-61.9)	(155.91,	90)	0.0403
	WavePort1:2	(0.19278,	-83.7)	(0.10281,	39.9)	(0.32602,	118)	(0.33993,	174)	(89.818,	90)	0.069954
	WavePort2:1	(0.65679,	153)	(0.32602,	118)	(0.069047,	136)	(0.19278,	96.3)	(155.91,	90)	0.0403
	WavePort2:2	(0.32602,	-61.9)	(0.33993,	174)	(0.19278,	96.3)	(0.10282,	39.7)	(89.818,	90)	0.069954

42%   73%
absorbed absorbed

4 GHz: 1 Mode (TM01)

Field amplitudes with only one cavity driven
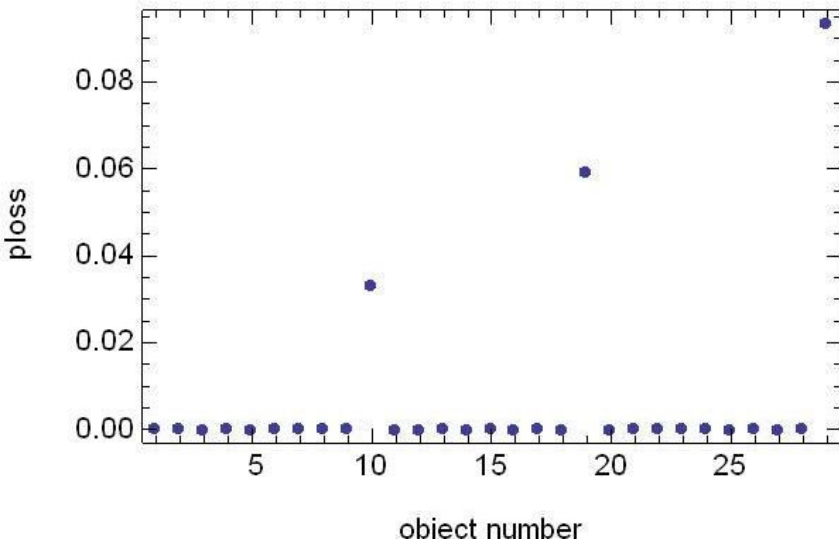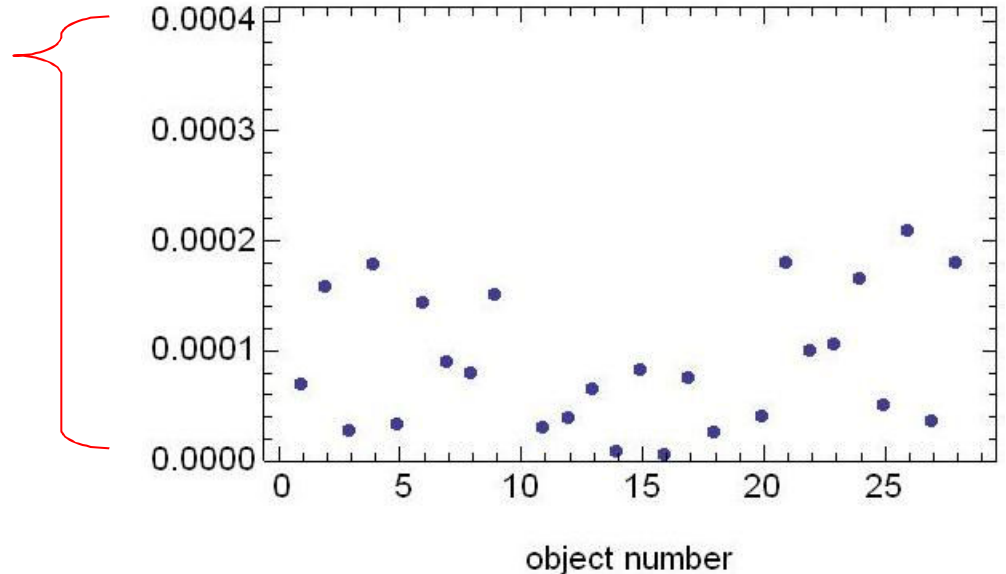(junction 15): right going (blue), left going (cyan)
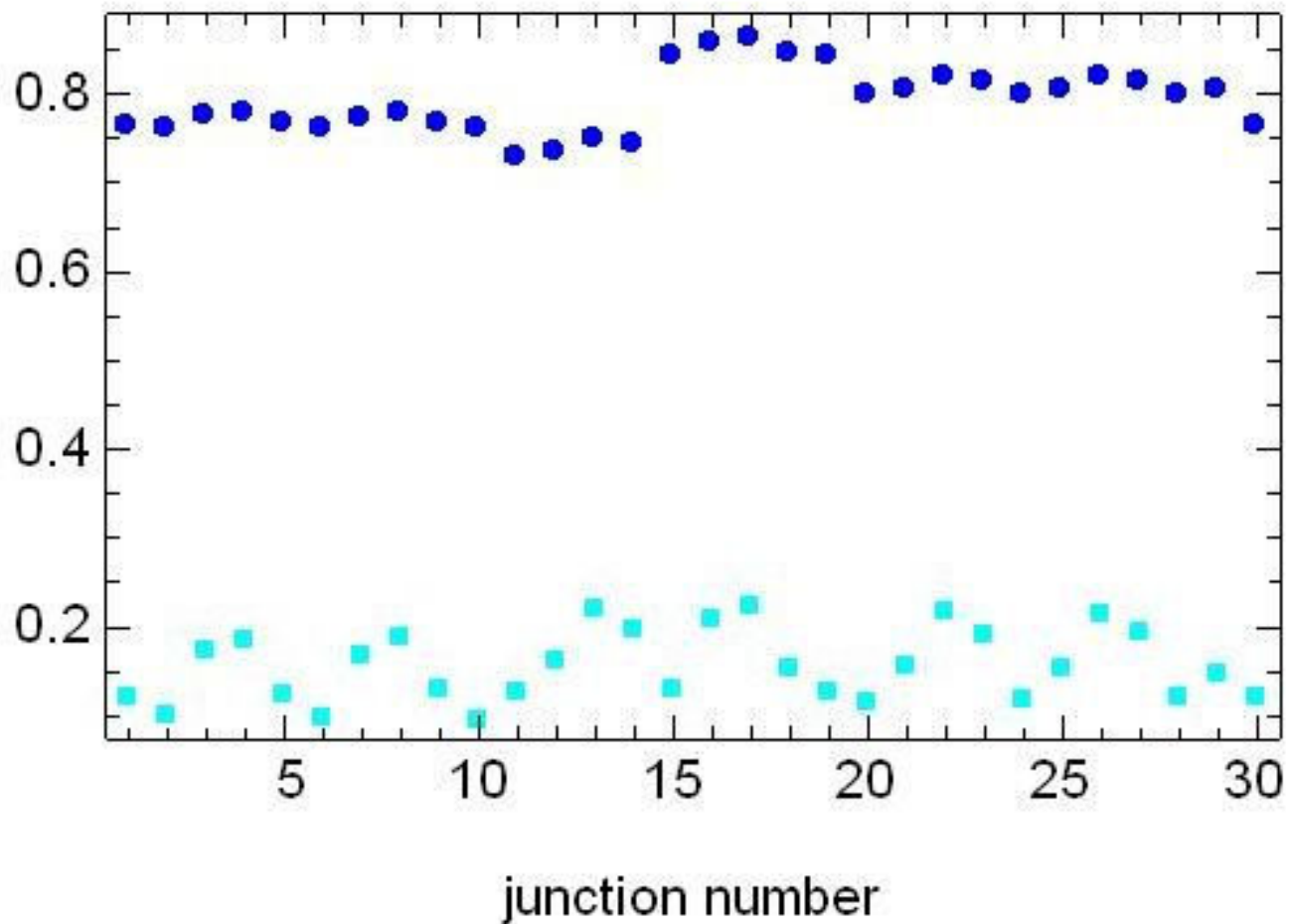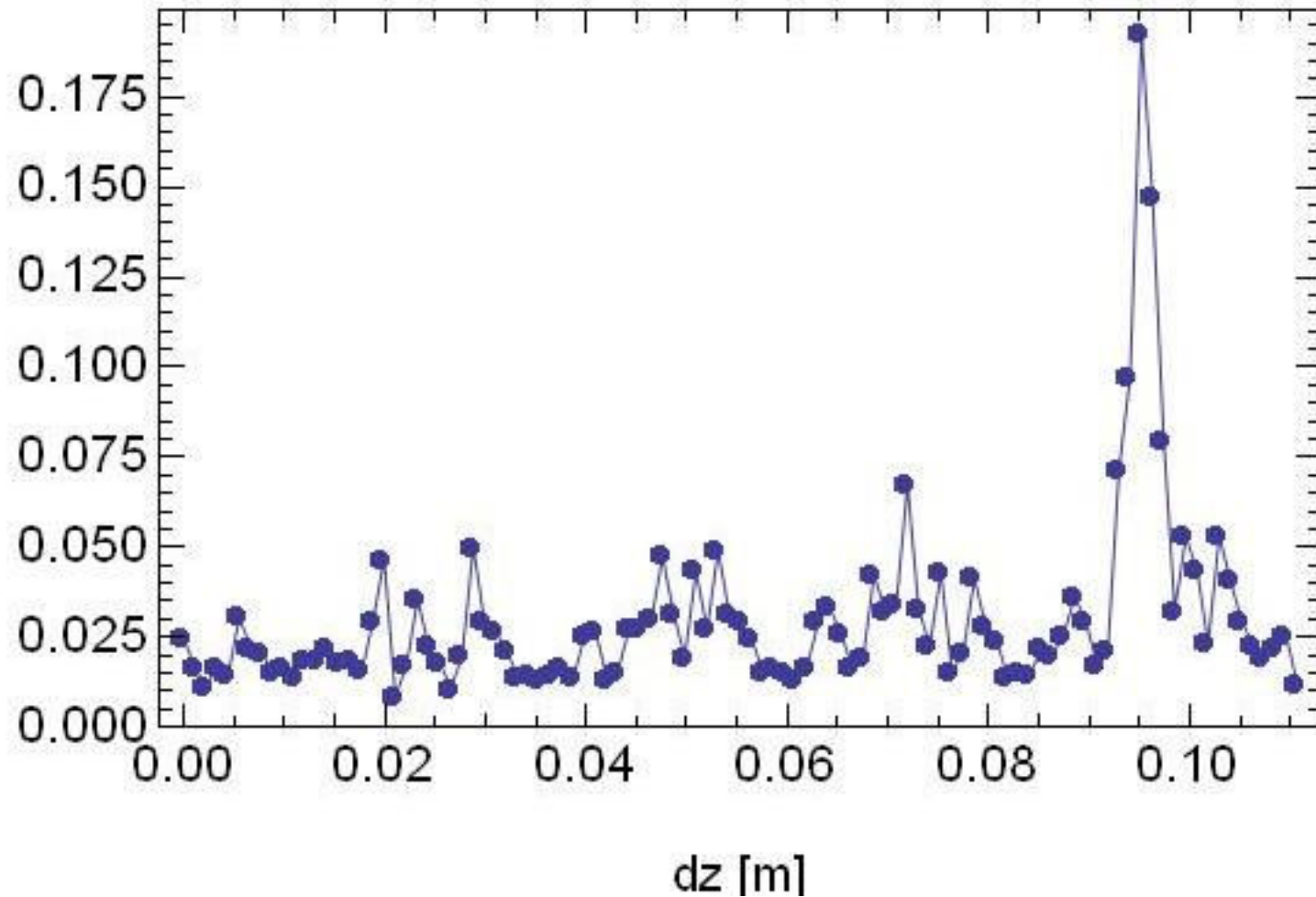
Fractional Power Losses

All cavities driven
Objects 10, 19, 29, are absorbers

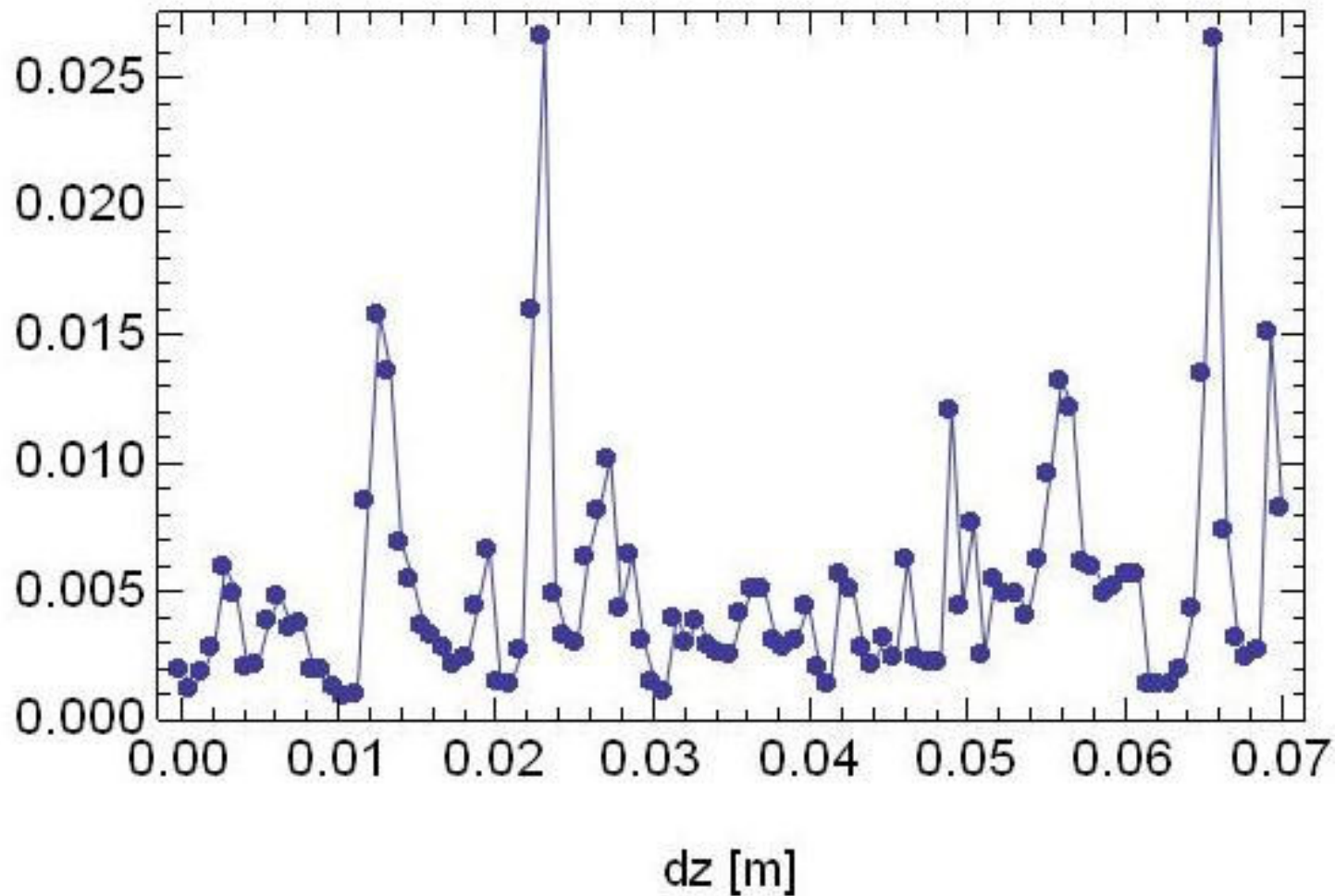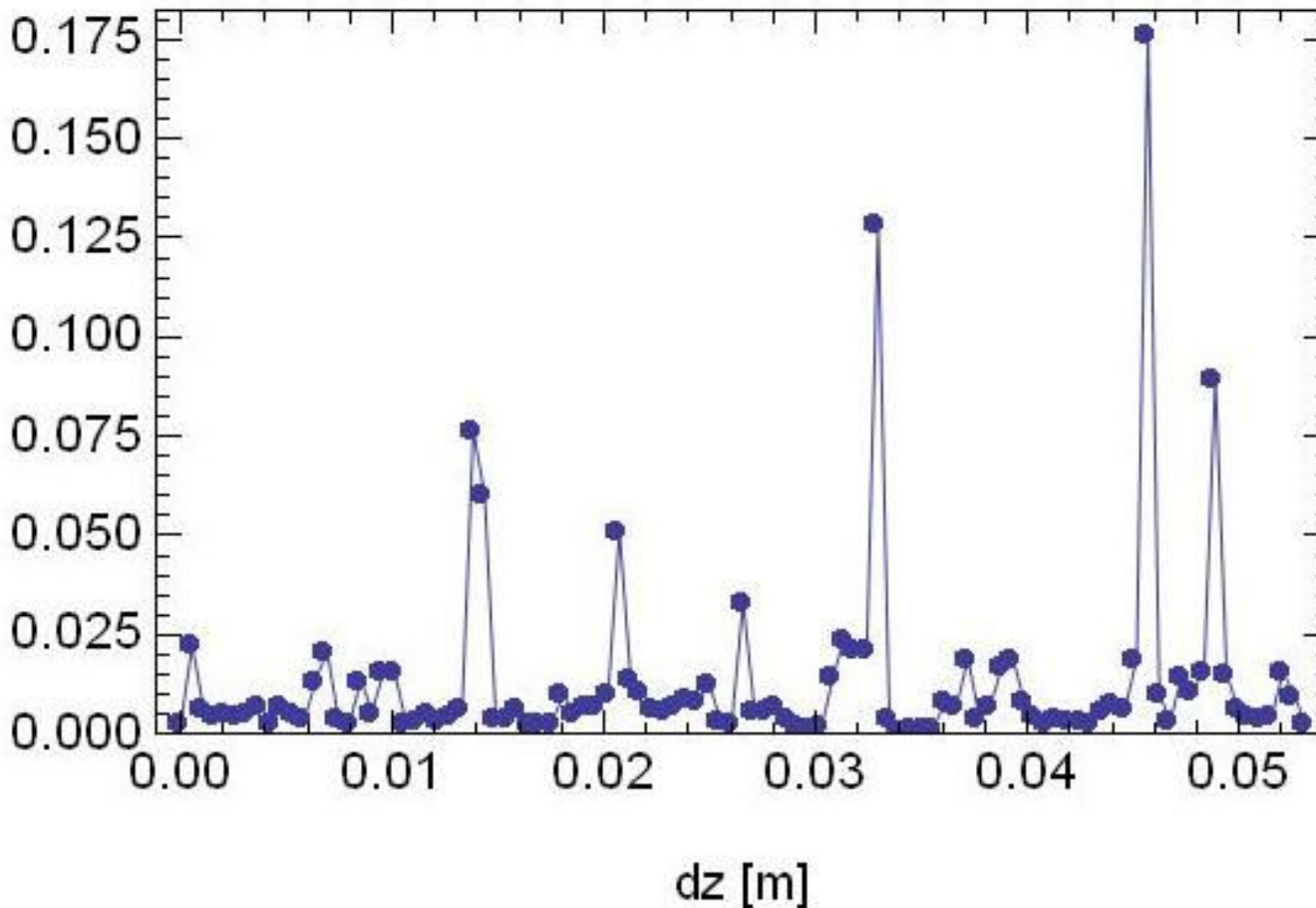$P_{pipe}/p_{tot} = .012$ and $\rho_{err} = 1e\text{-}14$

Relative Beam Pipe Loss Versus Added Pipe Length

dz [m]

8 GHz: 2 Modes
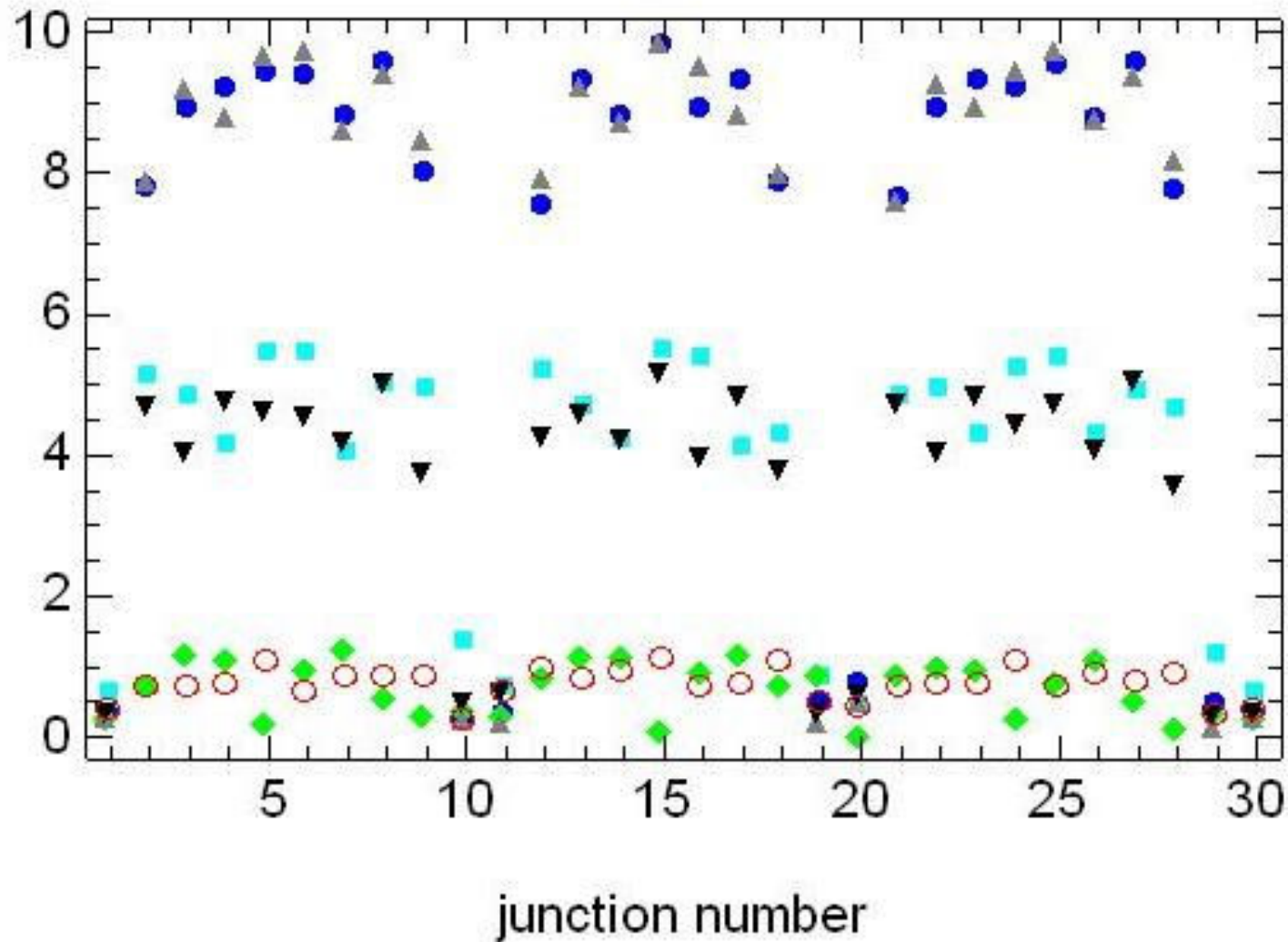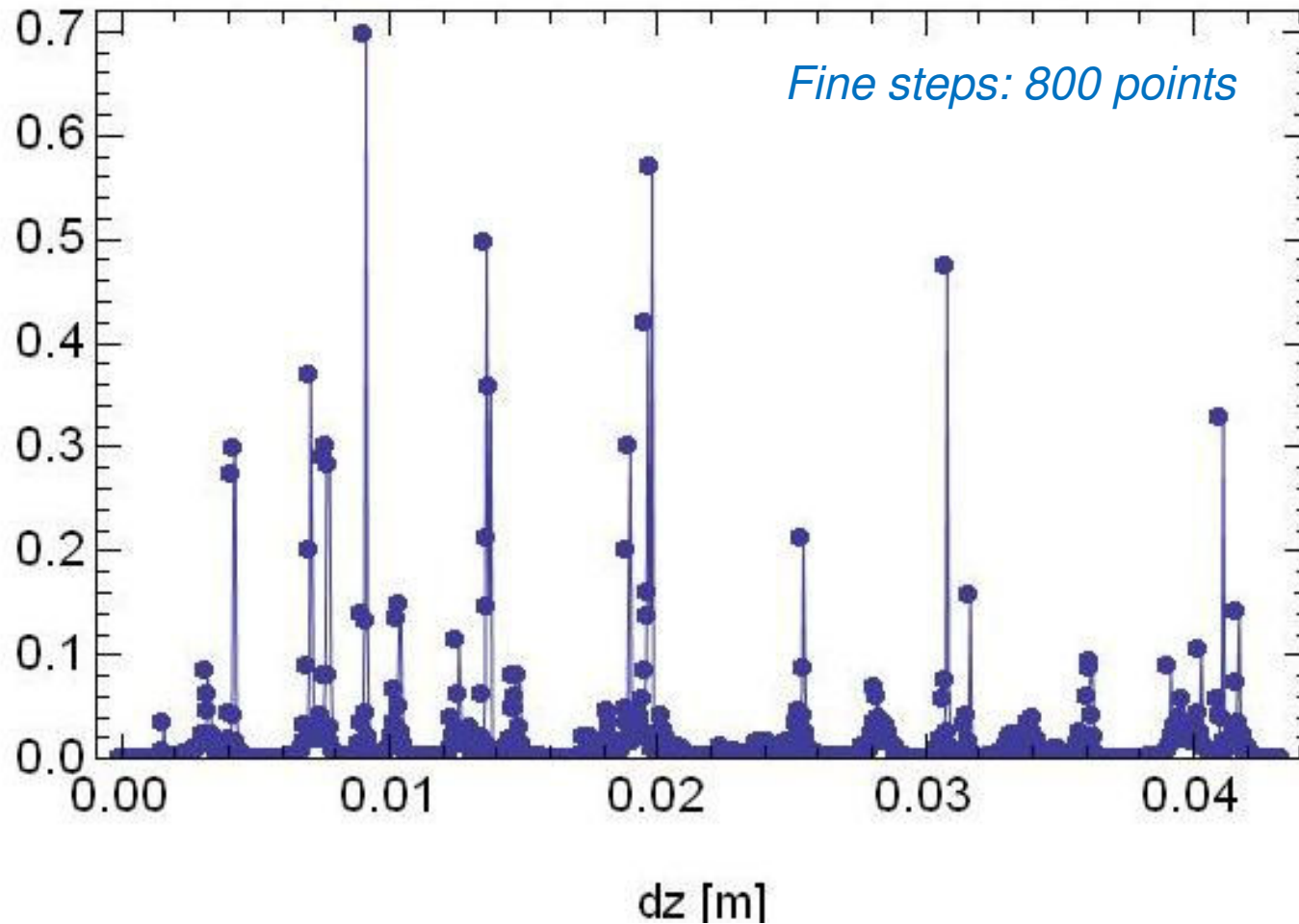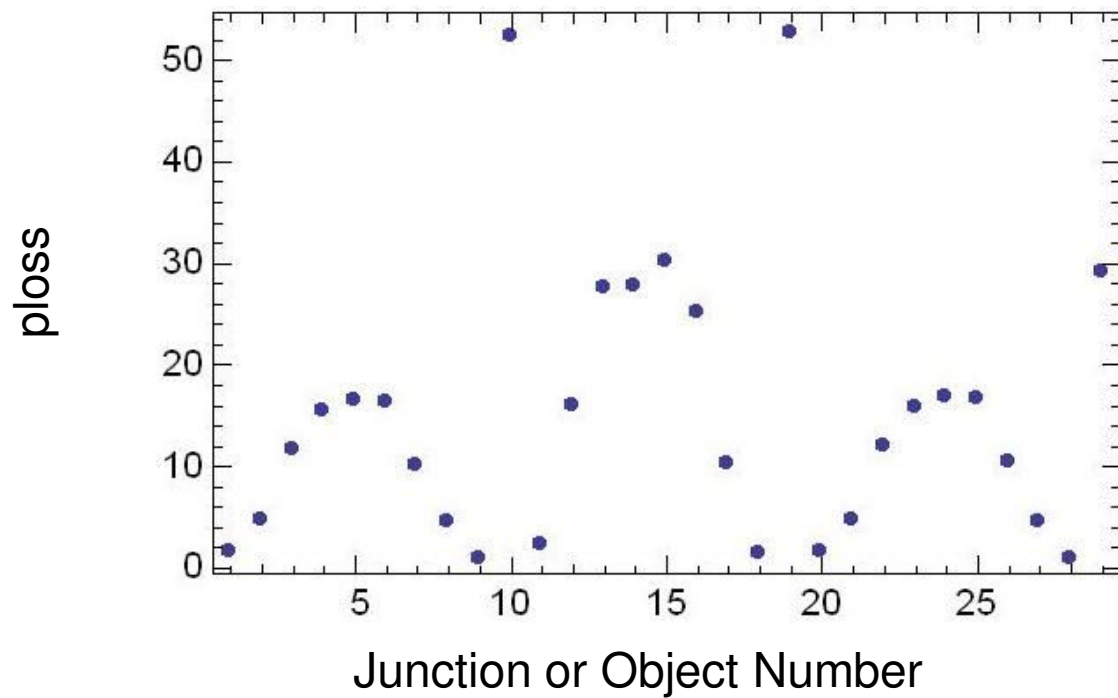
Relative Beam Pipe Loss Versus Added Pipe Length

dz [m]

12 GHz: 3 Modes

Relative Beam Pipe Loss Versus Added Pipe Length
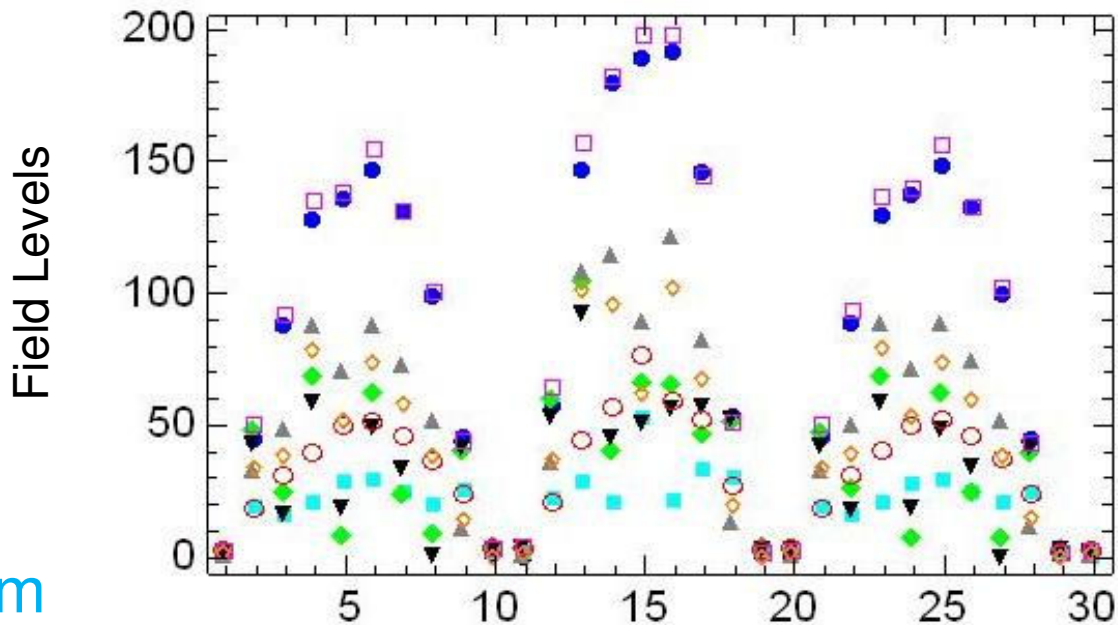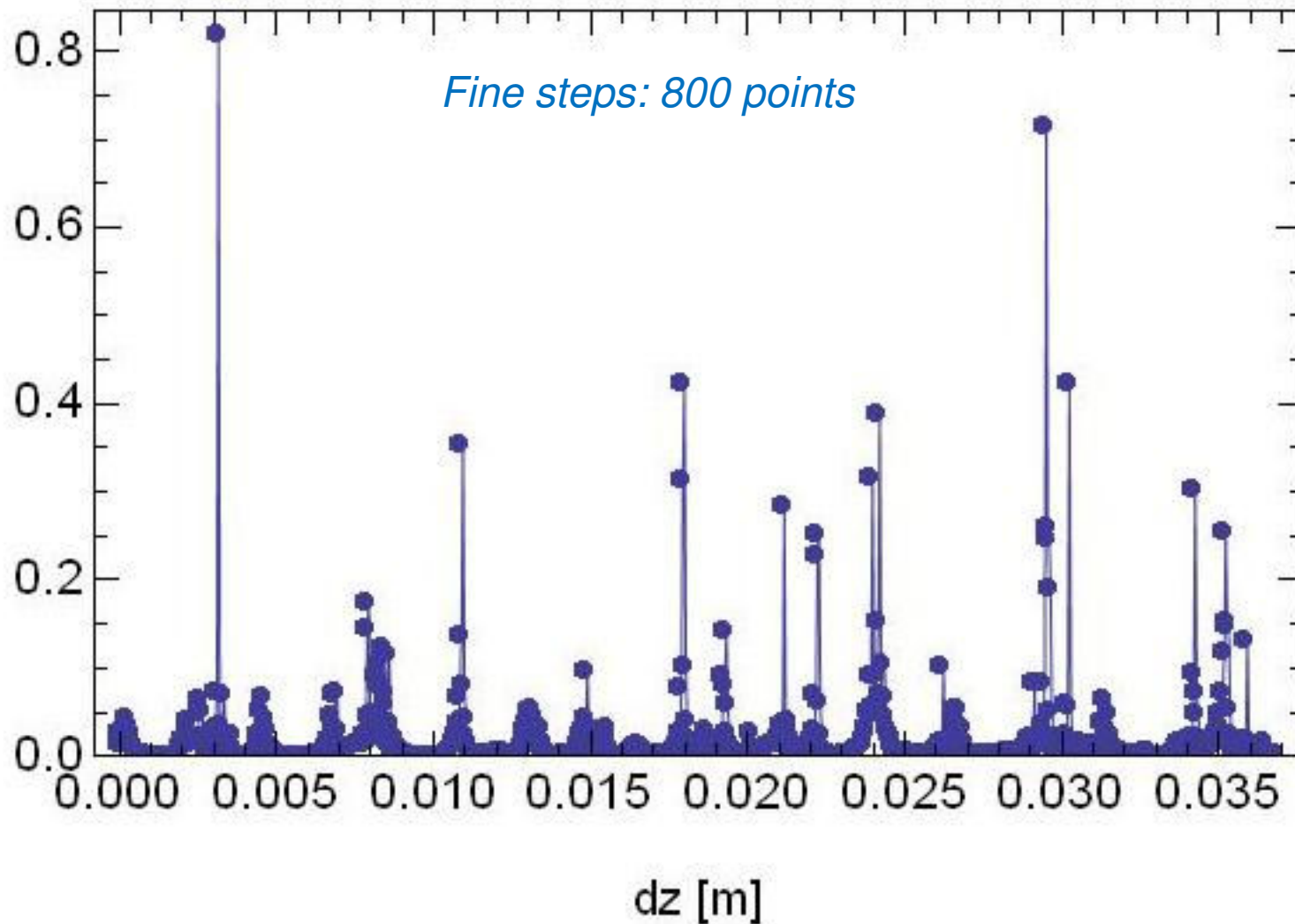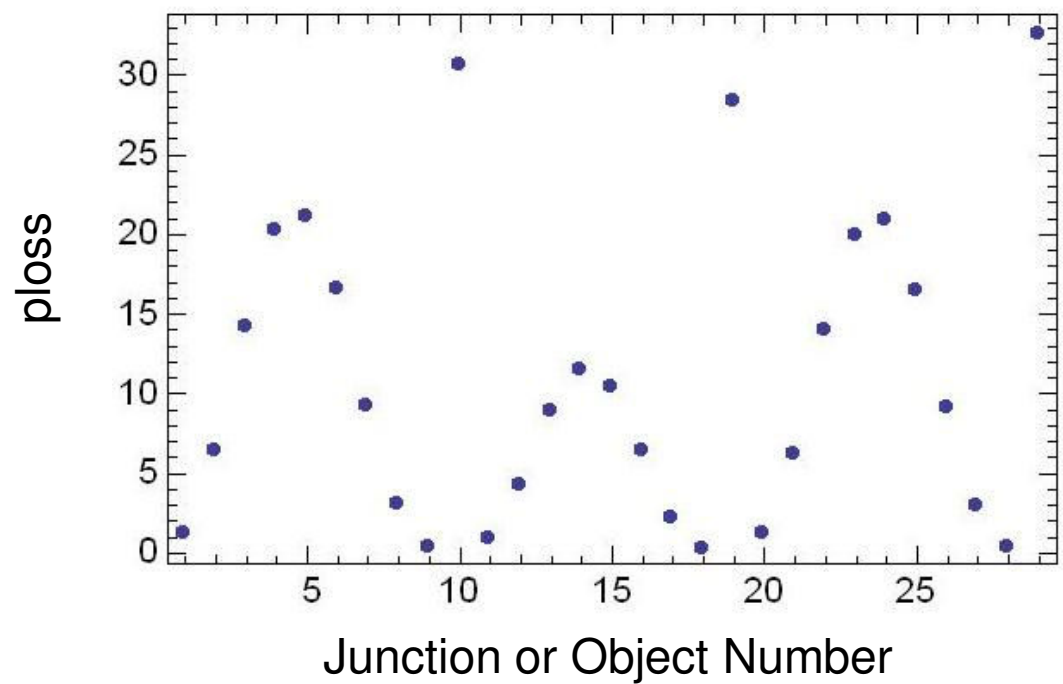
Field Levels vs Junction Number for dz= 4.6 cm

junction number

16 GHz: 4 Modes

Relative Beam Pipe Loss Versus Added Pipe Length

Fine steps: 800 points

dz [m]

dz = 9 mm

Field Levels

ploss

Junction or Object Number

20 GHz: 5 Modes

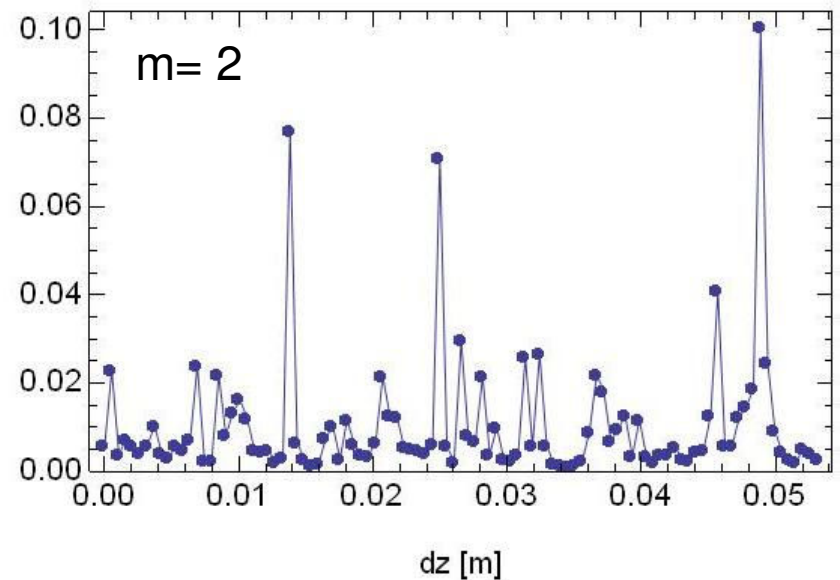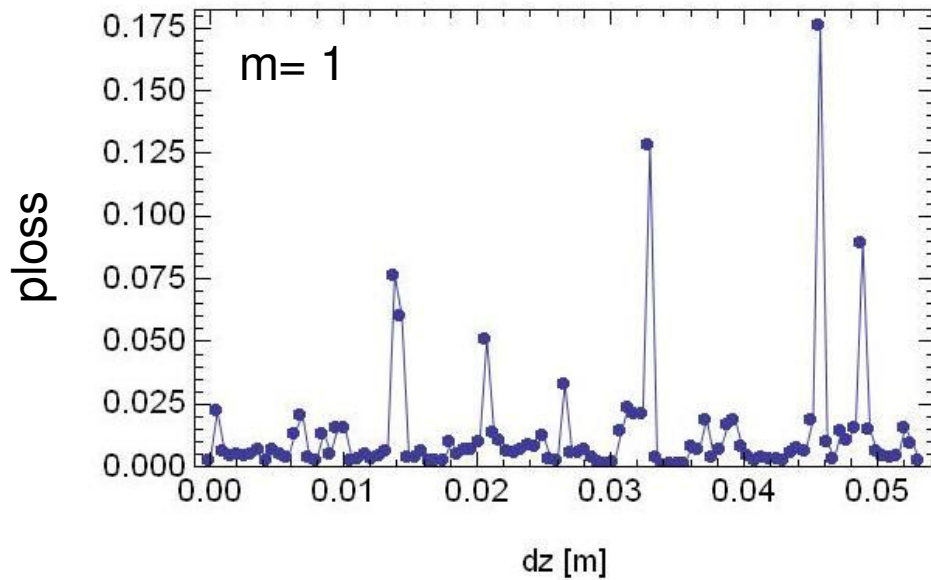## Relative Beam Pipe Loss Versus Added Pipe Length

Fine steps: 800 points

dz [m]

dz = 2.9 mm
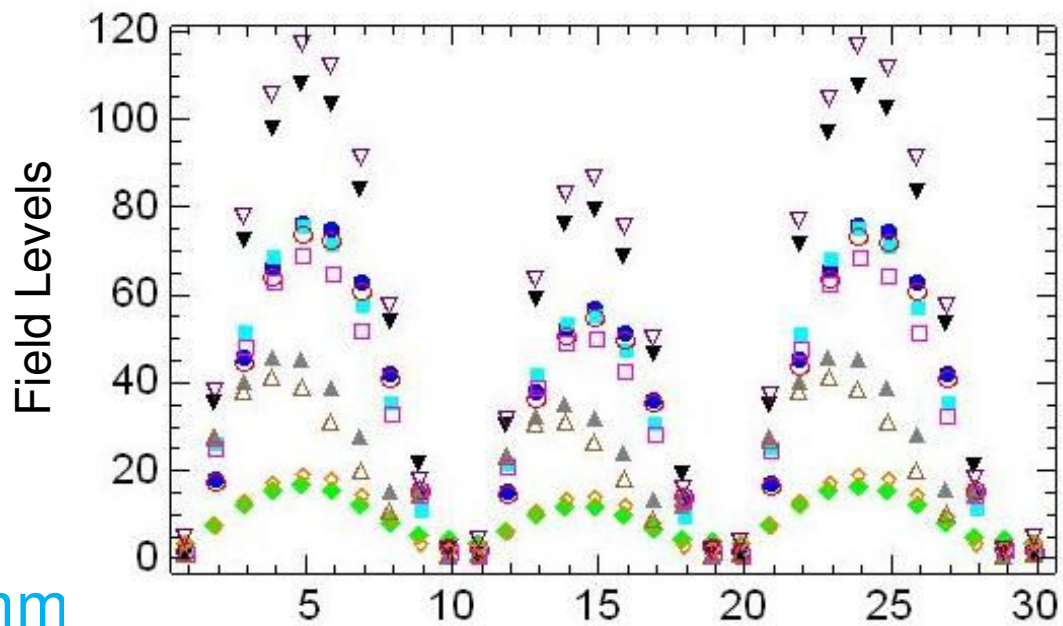
Statistics on p_{pipe}/p_{tot} vs Frequency
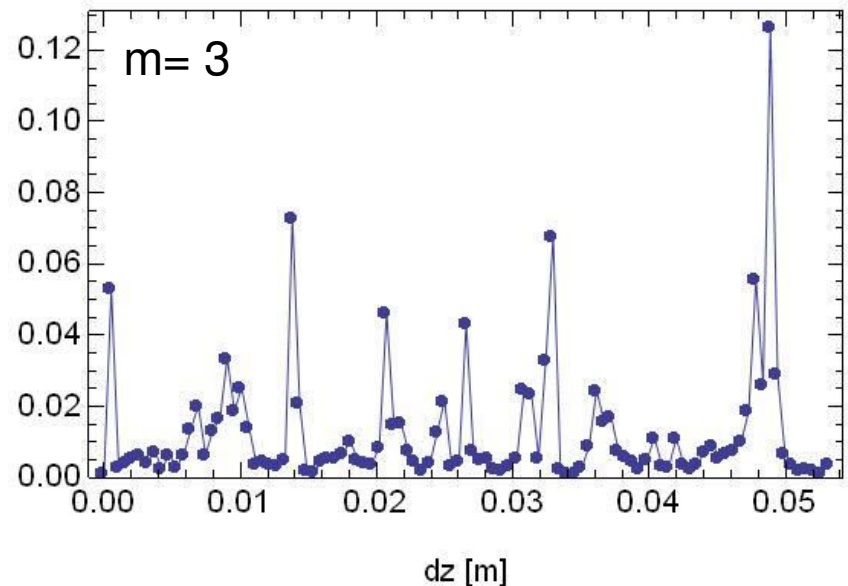
f [GHz]	average	rms	.90 quantile
4	.041	.037	.070
8	.006	.005	.011
12	.014	.030	.025
16	.024	.056	.047
20	.025	.053	.053

12 GHz: Effect of Driving Different Modes

Statistics on p_{pipe}/p_{tot}

| m	average	rms	.90 quant
1	.014	.030	.025
2	.012	.024	.022
3	.012	.023	.023

Summary

Method provides a quick, worst-case estimate of relative losses with different absorber configurations - cavity losses (walls, HOM ports and power couplers) are not included.

Find low probability for trapped modes that produce significant (> 10%) losses in 2K beam pipe versus absorbers. Is the average loss over dz the relevant quantity ?

Should redo with a more realistic beamline model, more frequencies and non-uniform cavity spacings.

More Realistic Geometry at 2K

	abs	quad	abs	abs
9 cav		4 cav	4 cav	9 cav	
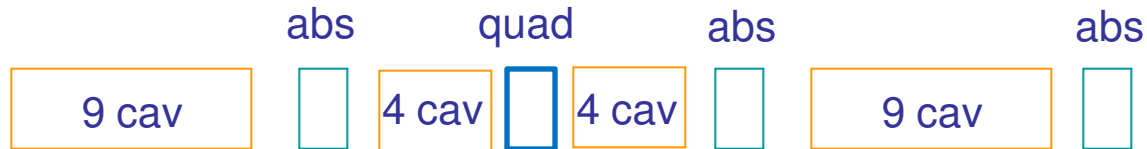
Cu coated beam pipe between cavities (length =145 mm × 2 sections) - assume twice the resistivity due to bellows (effectively twice as long)

SS beam through quad (length =1.3 m)

SS beam pipes on each side of the absorber (length = 330 mm × 2 sections)

Statistics on p_{pipe}/p_{tot} vs Frequency

Original

f [GHz]	Average	RMS	.90 quantile
4	.041	.037	.070
8	.006	.005	.011
12	.014	.030	.025
16	.024	.056	.047
20	.025	.053	.053

More Realistic

f [GHz]	Average	RMS	.90 quantile
4	.081	.086	.108
8	.012	.005	.018
12	.046	.111	.079
16	.084	.144	.216
20	.078	.138	.146

Beam Line Absorber Tests at FLASH
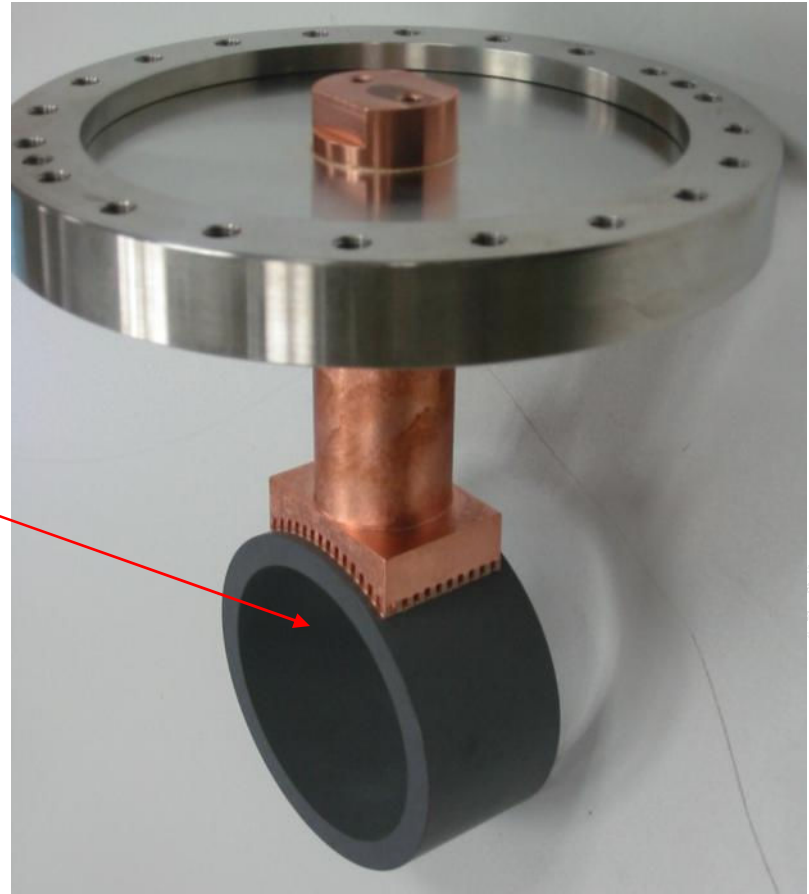
J. Sekutowicz
DESY

Feb 2010 9 mA Workshop

Beam Line Absorber

Mechanical design by Nils Mildner

Ceramic Ring: Ø 90mm
        Length 50 mm
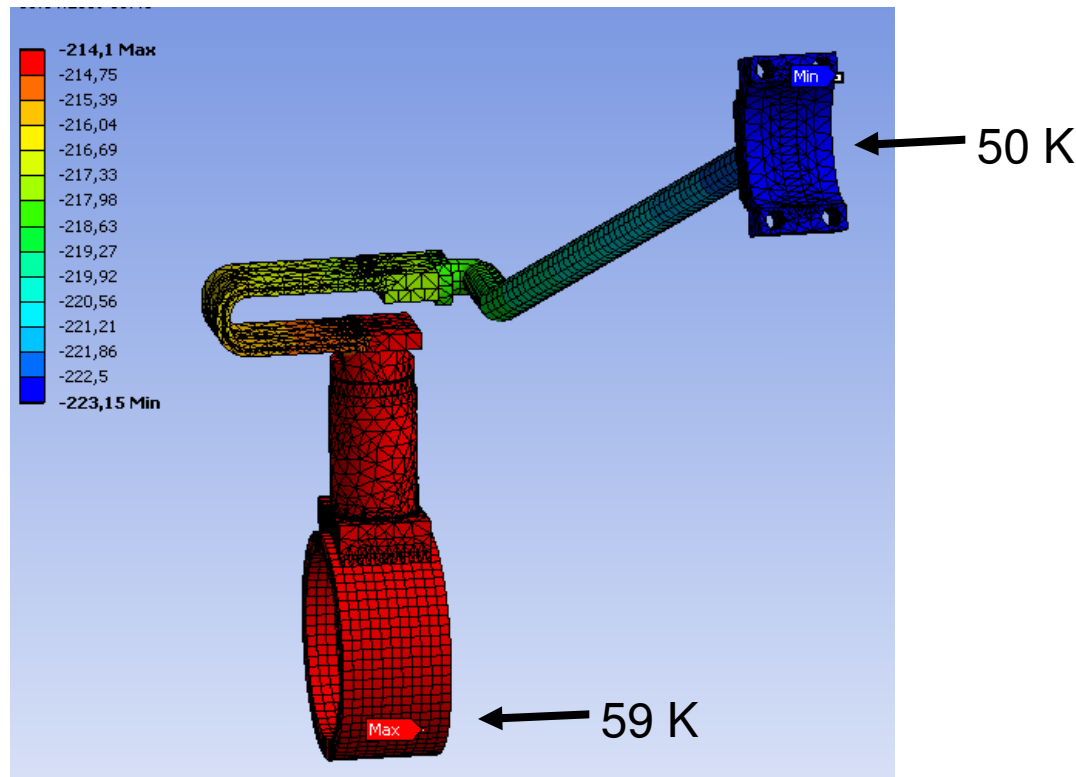   Thickness 10 mm

Lossy ceramic CA137 (Ceradyne):
$\varepsilon' = 15$ and $\varepsilon'' = 4$

Estimated absorption efficiency for the periodic structure:
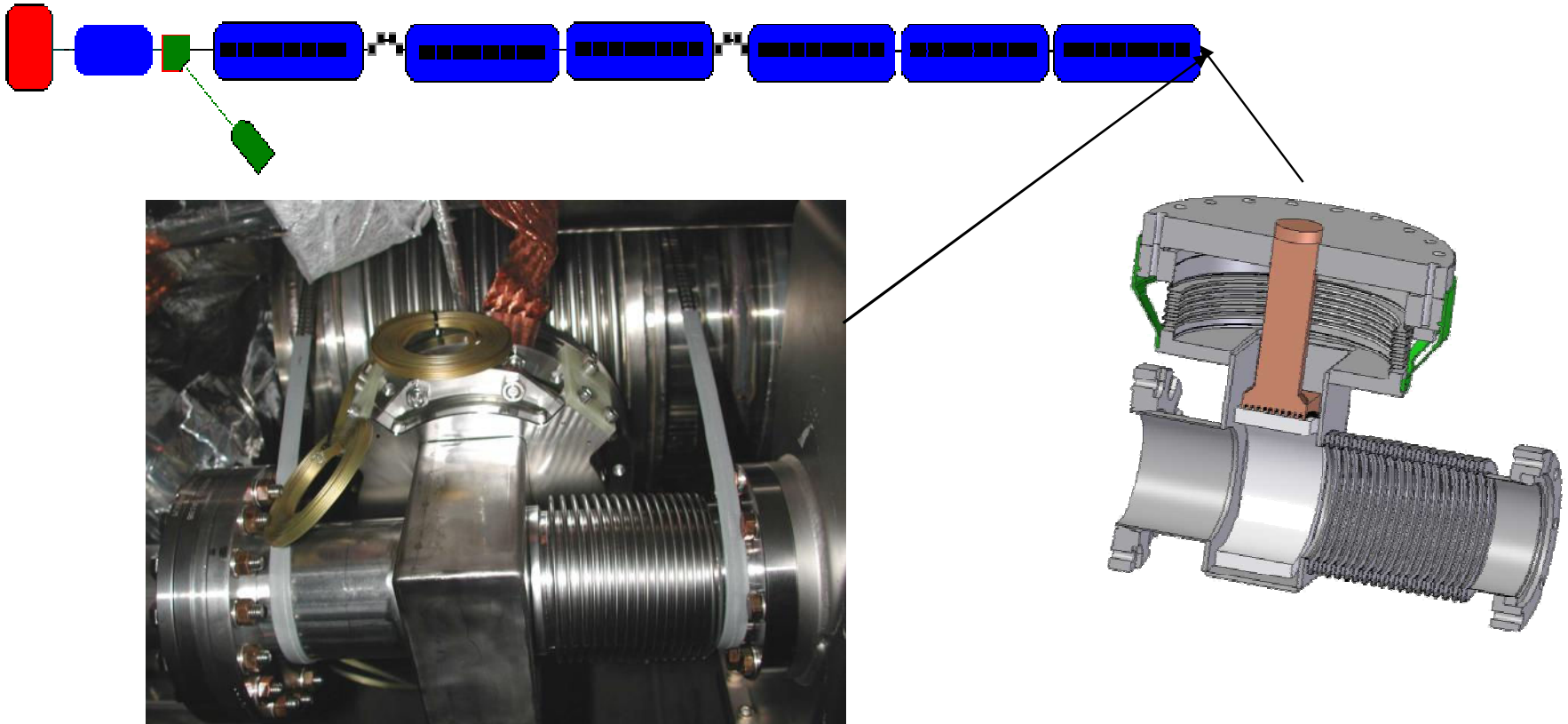one BLA/cryomodule is 83% (M. Dohlus)

Beam Line Absorber Temperature

Heat: 3W
Temperature for the BLA connected to 50 K tube
Maximum T on the ceramic is 59 K

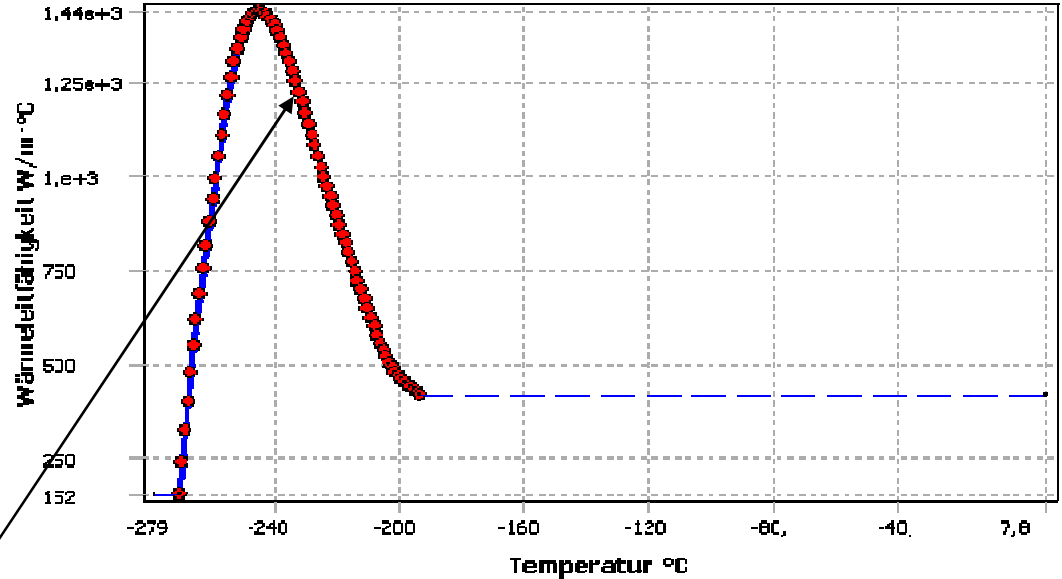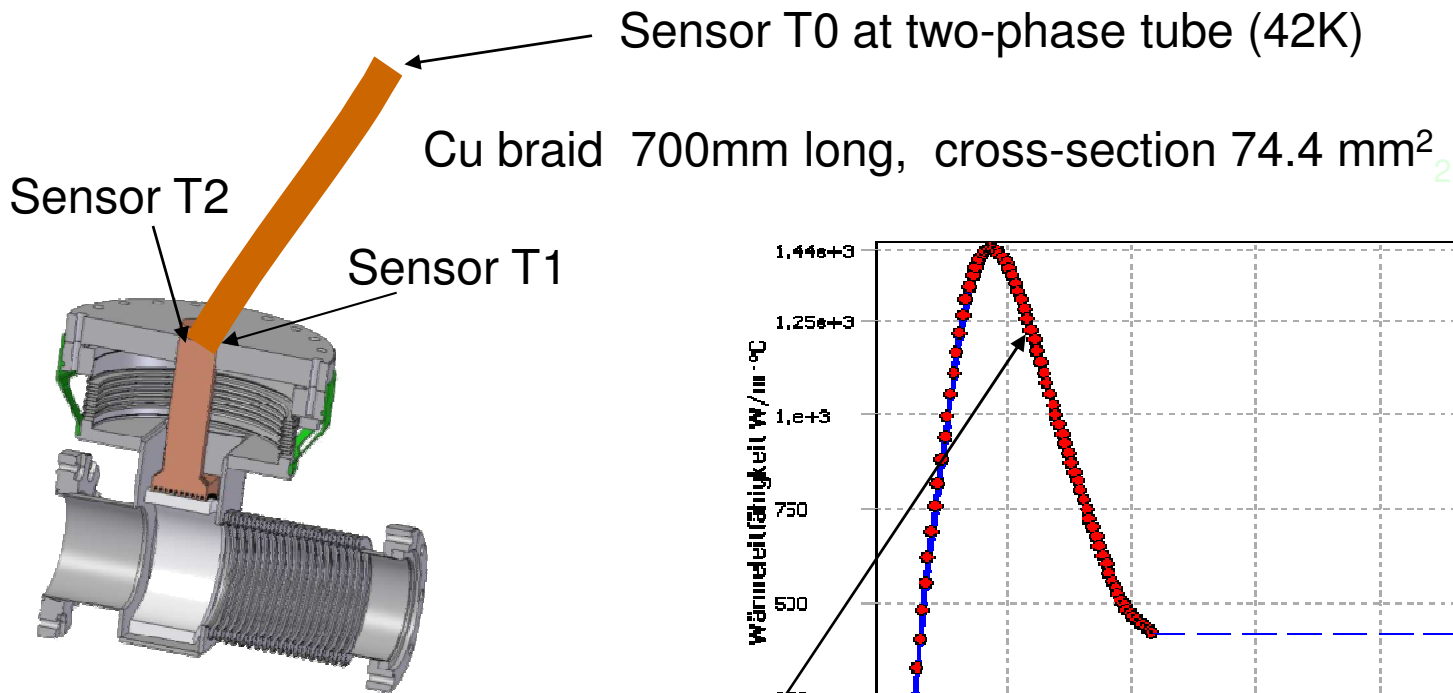Computer modeling by Thorsten Ramm

Test Setup at TTF-II

2 Beam Tests in September 2008 and 2009

Computer modeling for the location of BLA (*M. Dohlus*):
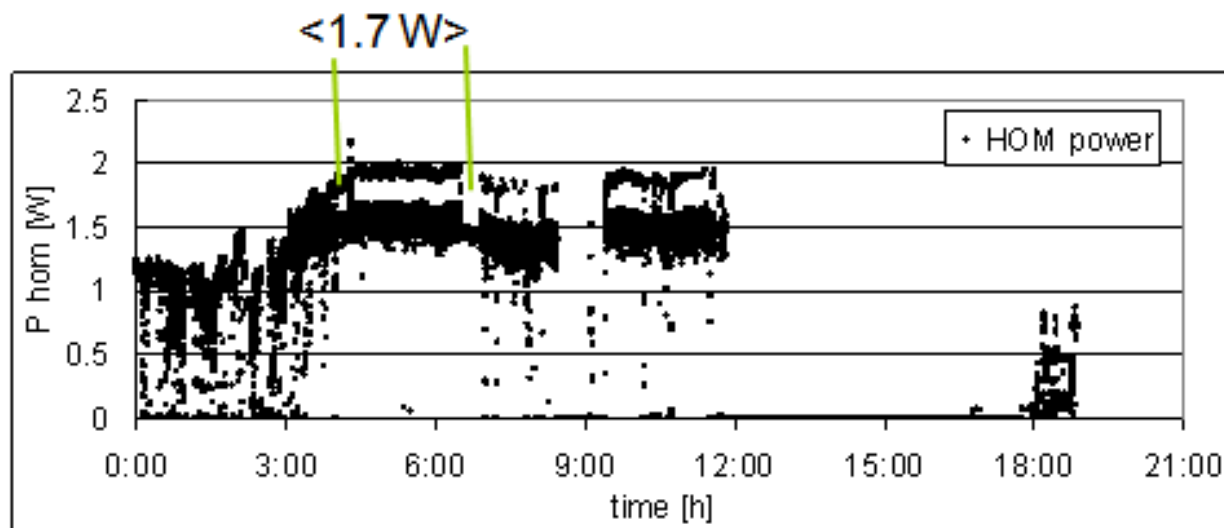15% of the HOM power should be absorbed in the BLA.

Test Setup at TTF-II

Sensor T0 at two-phase tube (42K)

Cu braid 700mm long, cross-section 74.4 mm^2

Sensor T2

Sensor T1

Heat conductance of the braid :

$$\kappa = 1250 \ \frac{W}{m \cdot K} \cdot \frac{74.4 \cdot 10^{-6} m^2}{0.7m} = 0.13 \ \frac{W}{K}$$
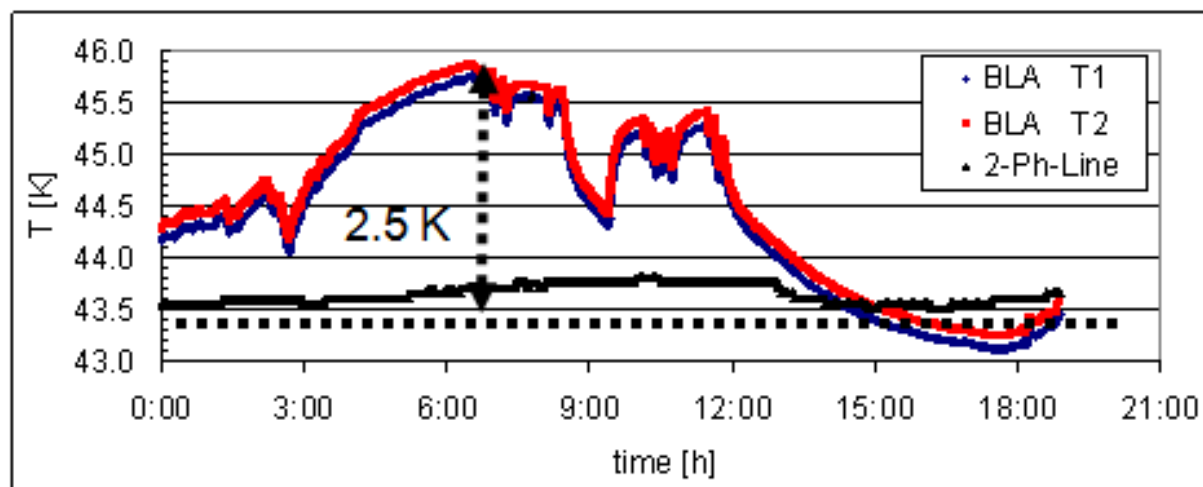
Tests in September 2008 and 2009

9 mA run in 2009

HOM Power in
Cryomodule ACC6

Monitored BLA
Temperature

Tests in September 2008 and 2009

Results of two tests at TTF-II

	September 08	September 09
Computed Absorbed Power [W]	0.180	0.255
Measured Absorbed Power [W]	0.143	0.325