Design and Application of the High-Efficiency HOM Absorbers at PEP-II.

Sasha Novokhatski
SLAC National Accelerator Laboratory

International Workshop on Higher-Order-Mode Damping Superconducting RF Cavities
October 11-13, 2010
Cornell University, Clark Hall, 7th Floor

On behalf of

- *J.Seeman, M.Sullivan, U.Wienands S. Ecklund, A.Kulikov,*
- *S.Weathersby*
- *S.DeBarger, N.Kurita, Ho Dong, J.Langton, N.Reeck, M. Kosovsky, J. Defever, A. Sheng*
- *And all other PEP-II and MFD staff*

Outline

Sasha Novokhatski "Design and Application of the High-Efficiency HOM Absorbers at PEP-II"

- *Why did we need HOM absorbers at PEP-II?*
  - *Evidence of the HOM heating. Transverse wake fields.*
- *The design of the HOM absorbers:*
  - *MAFIA simulations*
  - *Ceramic tiles property measurement*
  - *Fabrication and installation.*
- *Efficiency of the HOM absorbers.*
  - *Measurement results*

Temperature raise in IR vertex bellows

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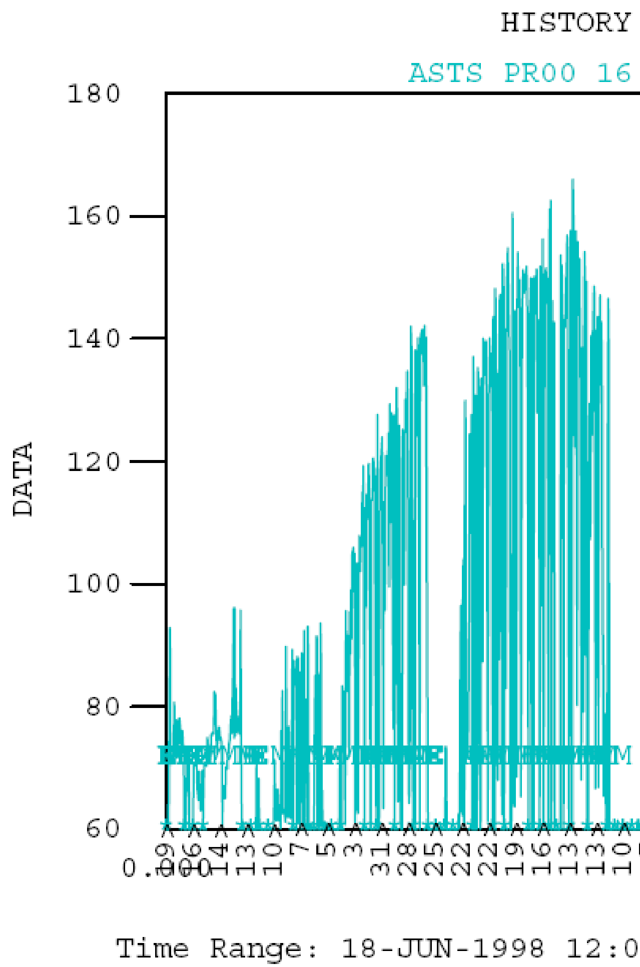
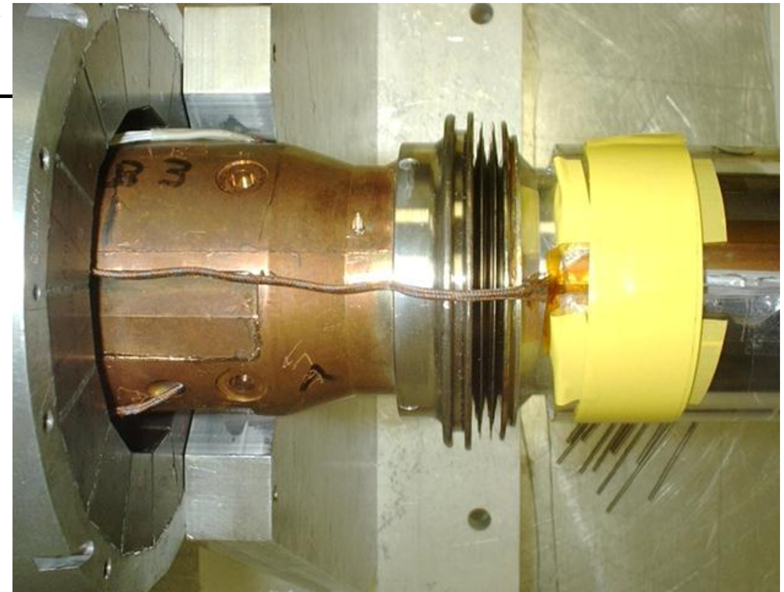
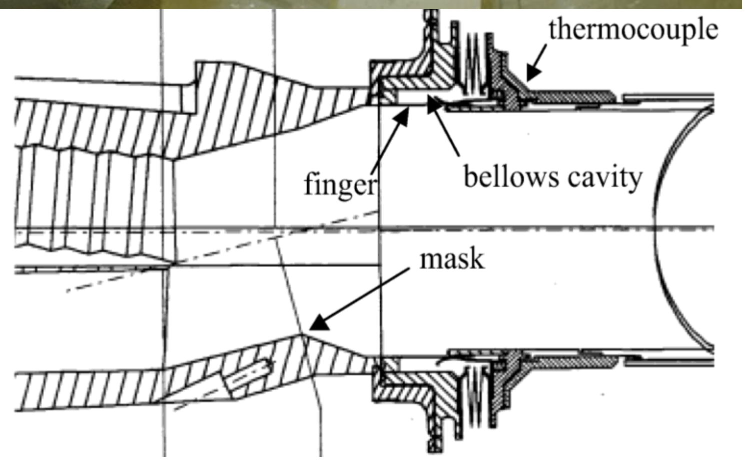
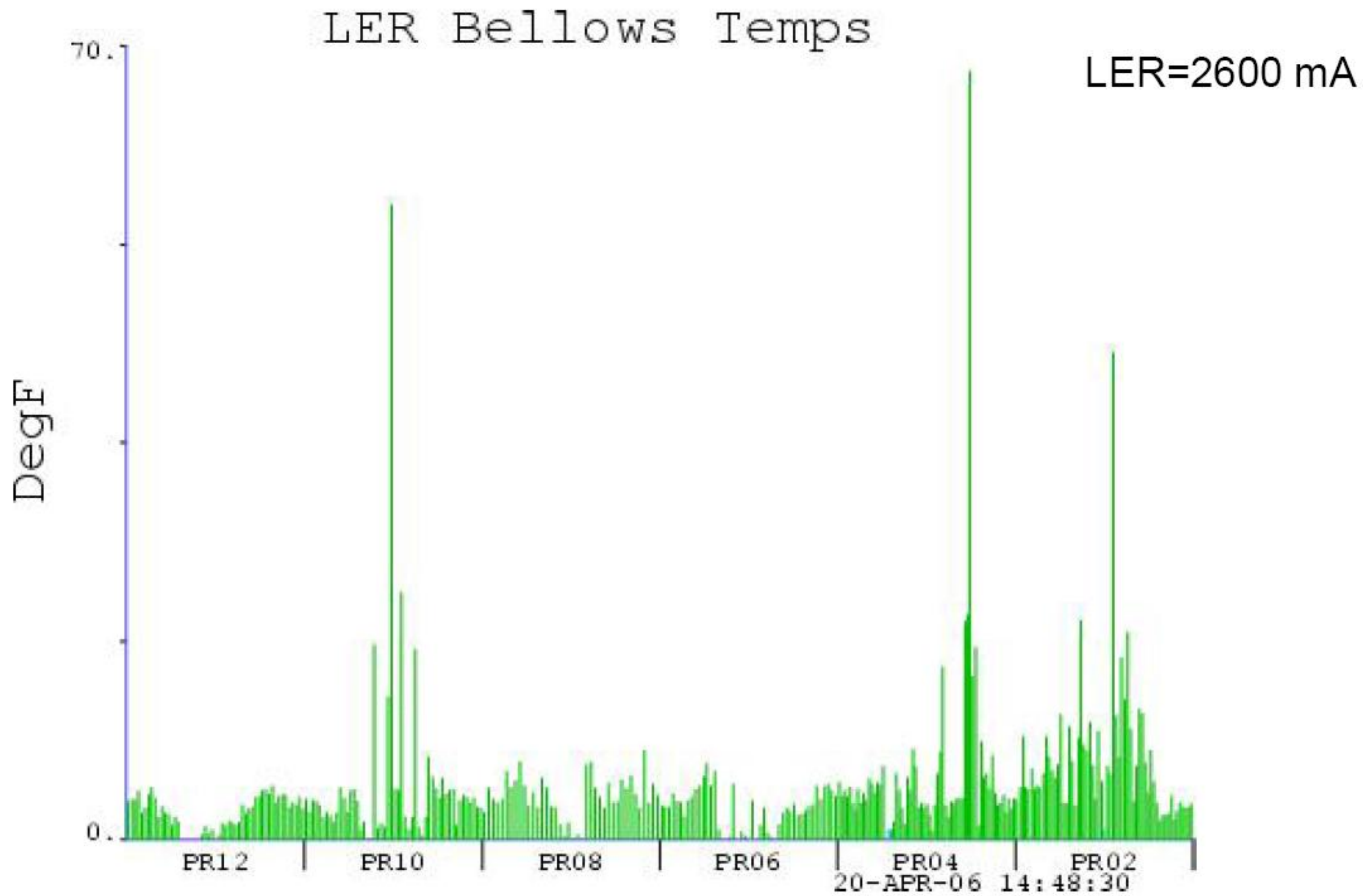






Temperature raise in bellows



The Hottest Bellows

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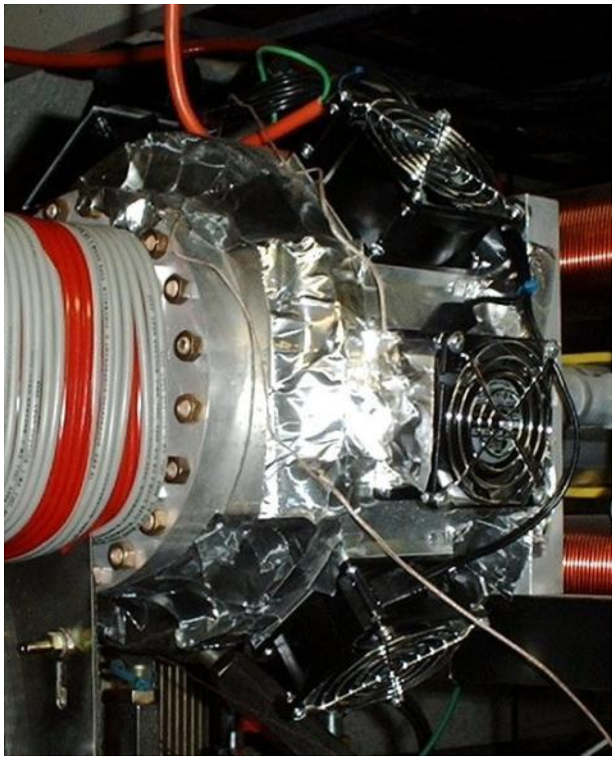
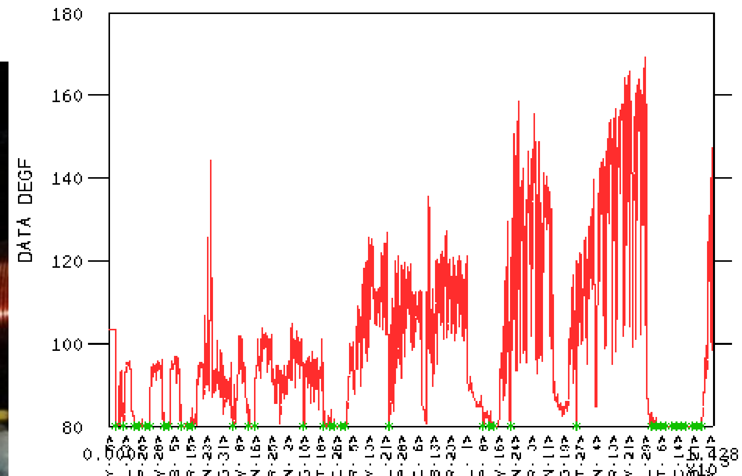
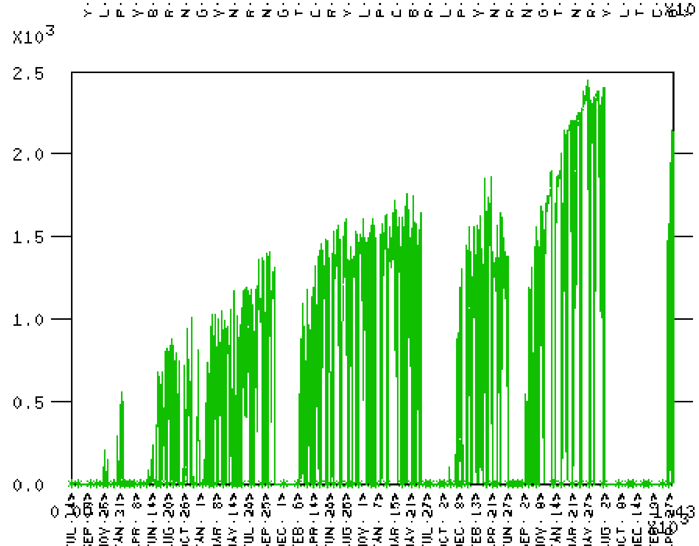


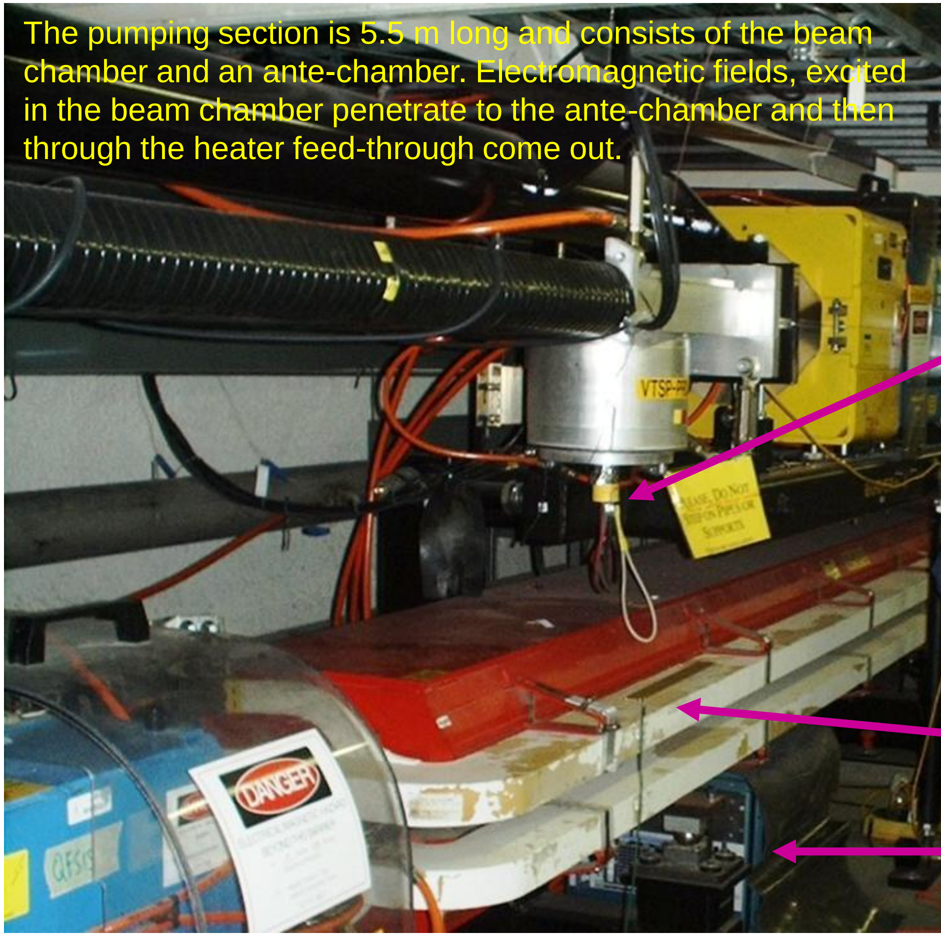


Bellows Temperature



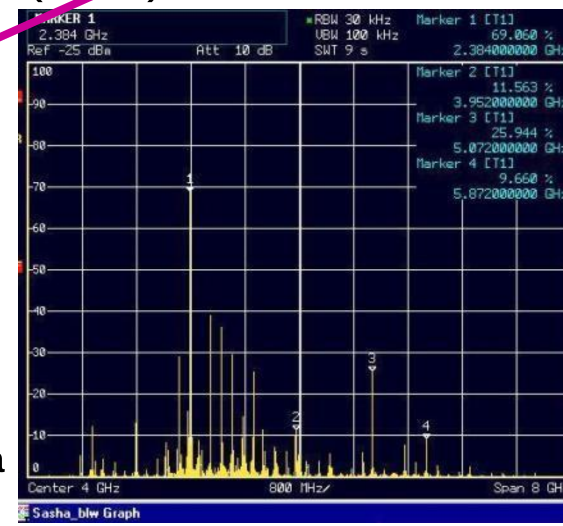
LER Current

HOM leaking from TSP heater connector



The power in the wake fields was high enough to char beyond use the feed-through for the titanium sublimation pump (TSP).

antenna



HOM spectrum from Spectrum analyzer

Water-Cooled Absorber in the First Arc Chamber

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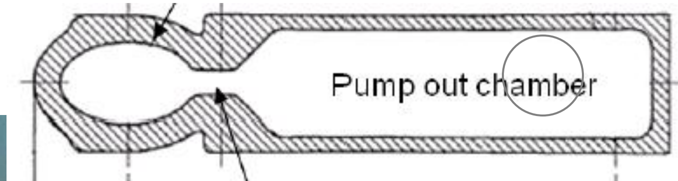
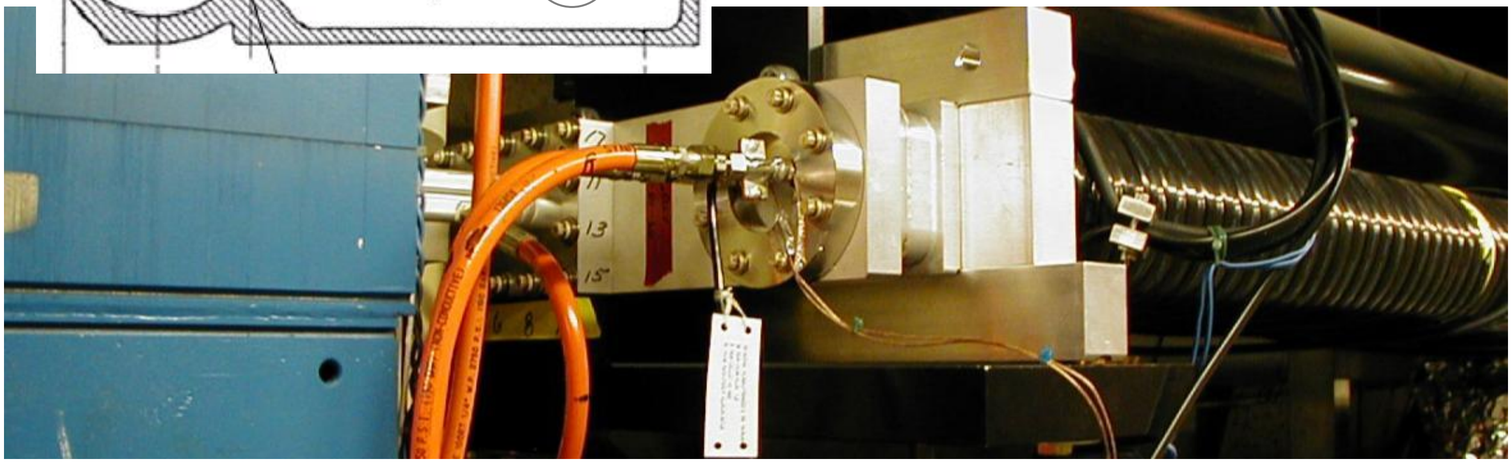
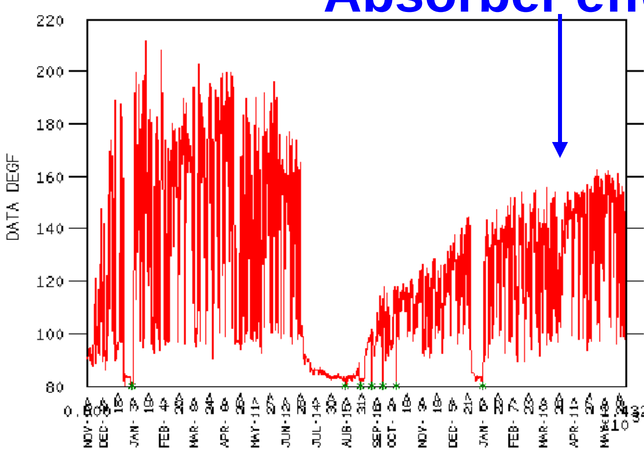




Absorber effect



HOM power in absorber

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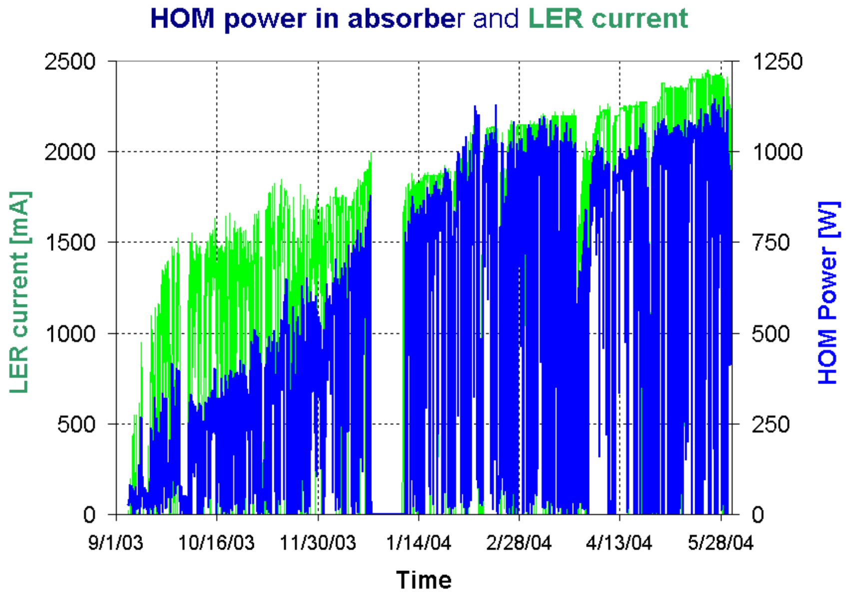
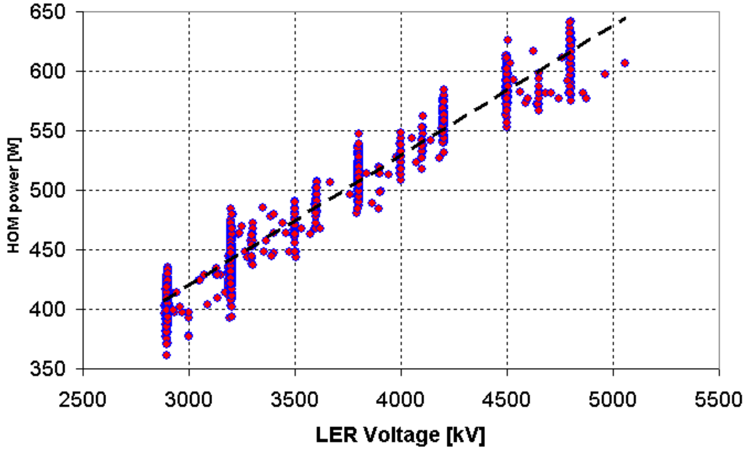
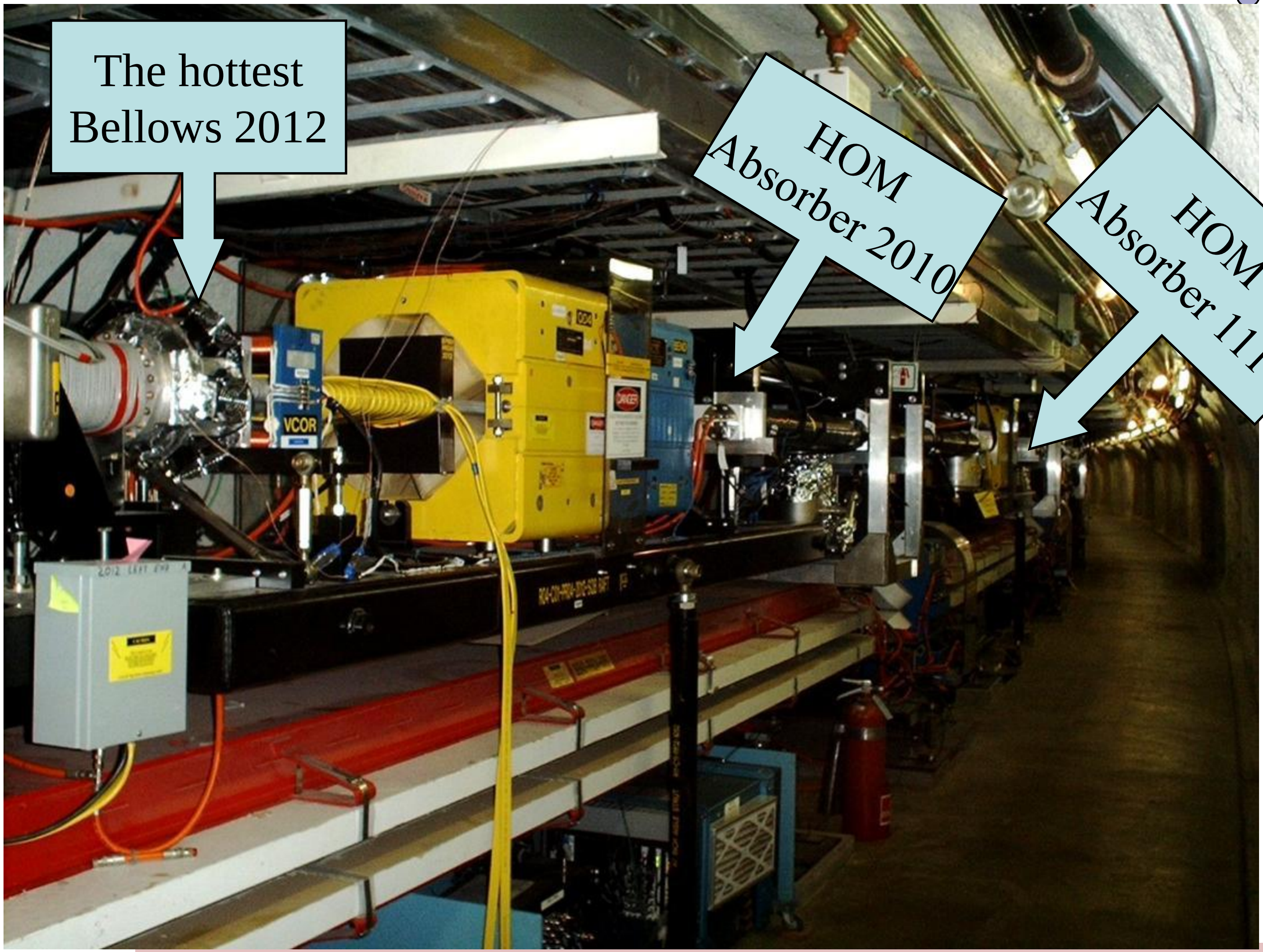
HOM power reached level of 1 kW





$$P = 0.07 \times I^2 \times \frac{V_{RF}}{N_{bunches}}$$

Chamber HOM absorbers in region 4



HOM Source.

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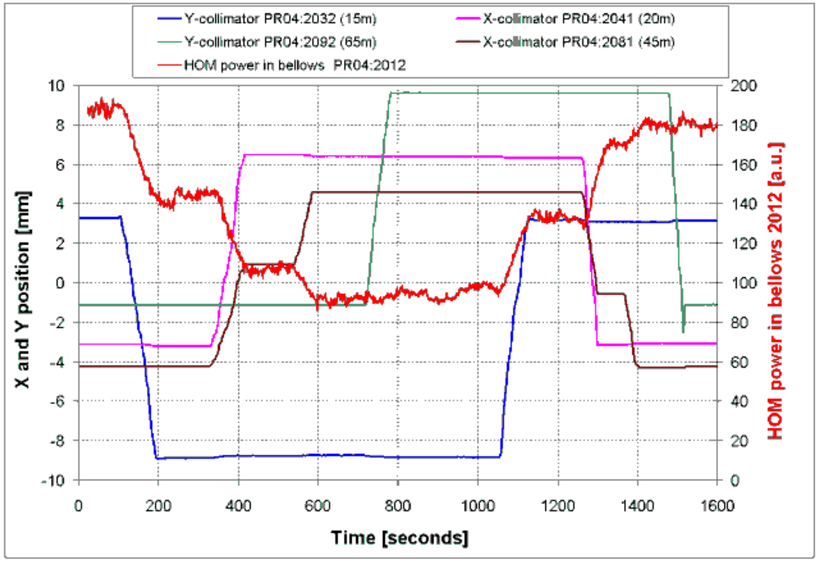
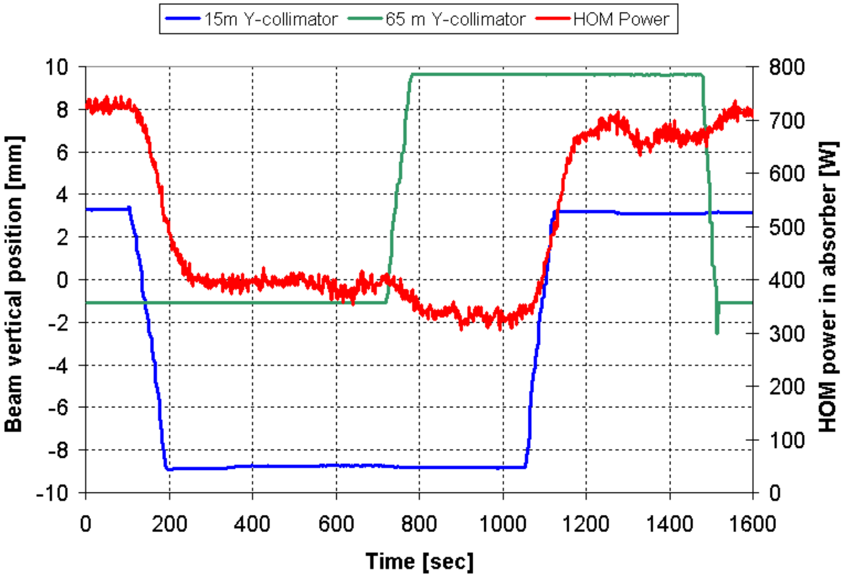
HOM power in bellows



HOM power in absorber



We found a strong correlation with the beam position near collimators which are far away from the bellows and arc chamber.

PEP-II collimator is the source of the transverse wake fields

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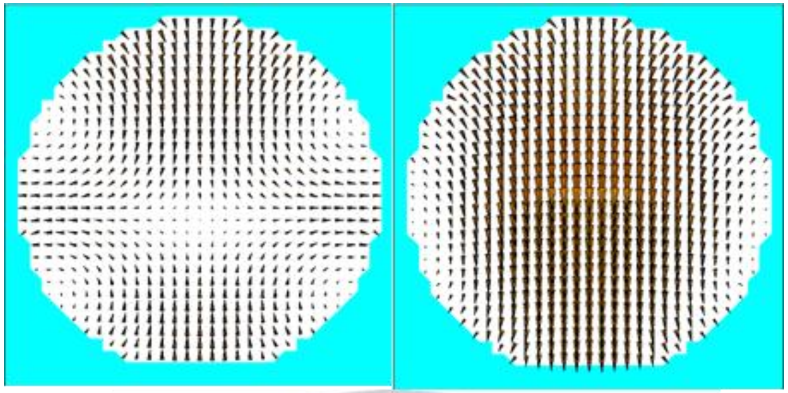
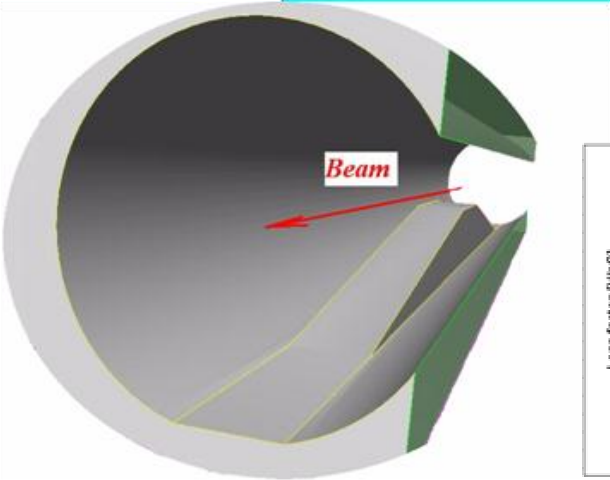
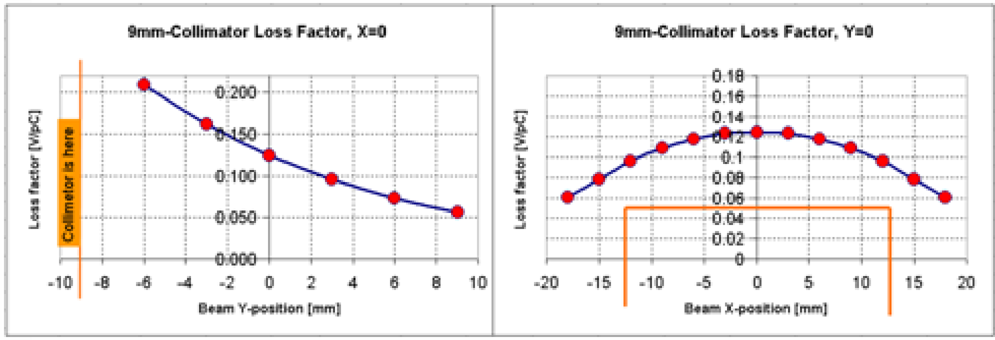


Dipole and quadrupole modes.



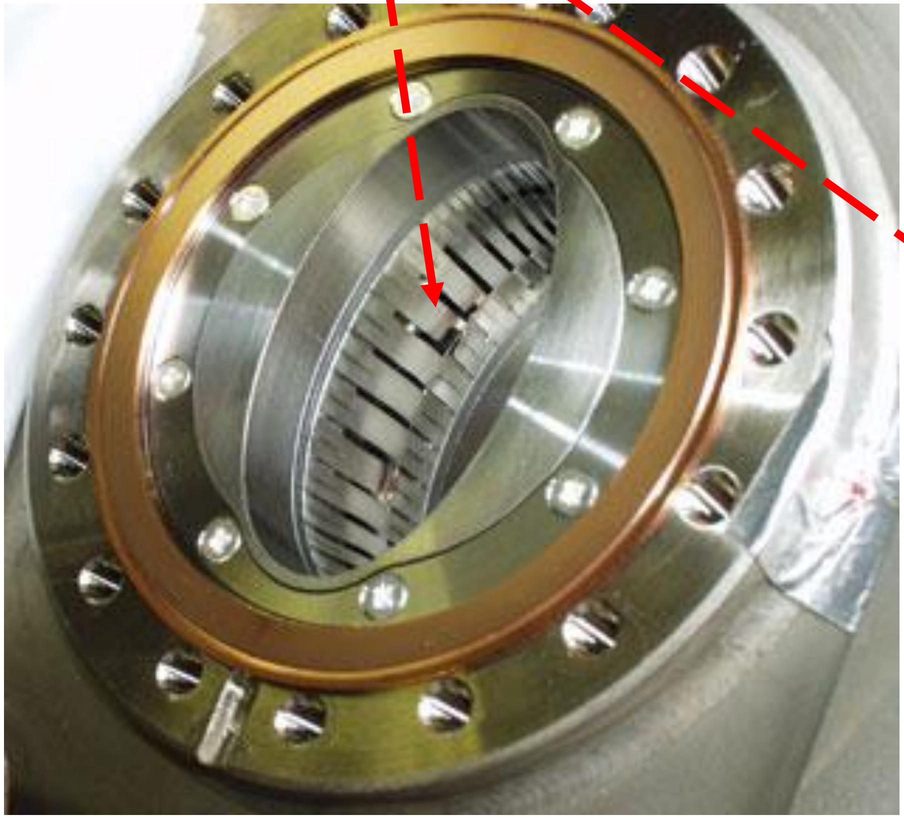


Transverse wake fields

- Transverse wake fields are generated in the asymmetrical parts of the beam pipe.
- Transverse wake fields can penetrate through the small hole in the vacuum chamber or longitudinal slots of shielded bellows, vacuum valves and RF shields.
- Transverse wake fields may propagate long distances.

Transverse wake fields couple to valve cavities

- Shielded fingers of some vacuum valves were destroyed by breakdowns of intensive HOMs excited in the valve cavity.



10 kW HOM power in a Q2-bellows

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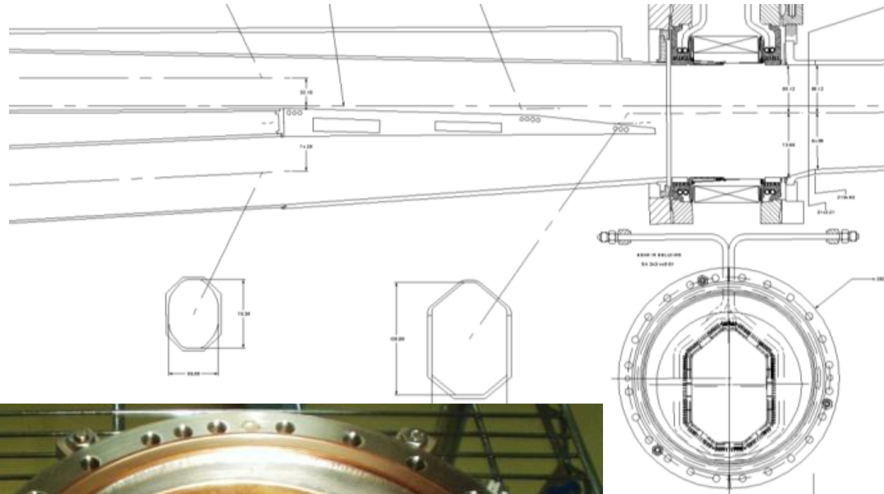

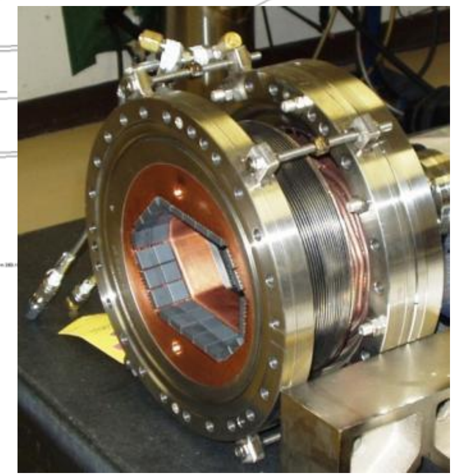

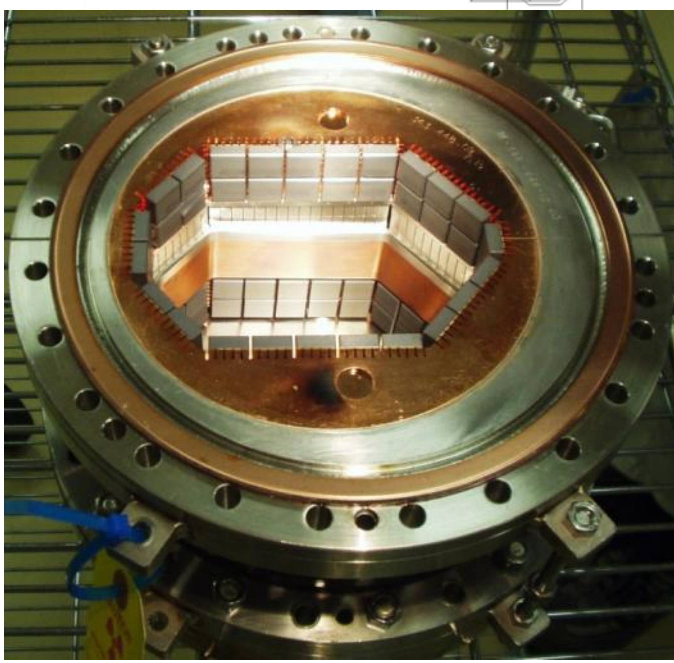

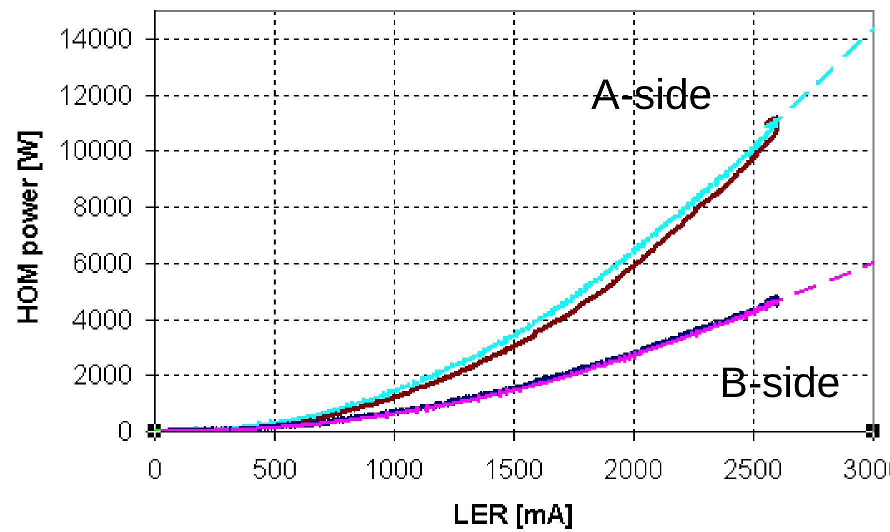

Open to beam absorber ceramic tiles produce more HOMs in Q2-bellows

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- Loss factor

A.Burov and A.Novokhatski
Wake Potential of a dielectric canal,
in Proceedings of HEACC'92,
p.537, Hamburg, Germany, 1992.

$$when \quad \sigma > s = \frac{a\sqrt{\varepsilon - 1}}{2\varepsilon} \approx \frac{a}{2\sqrt{\varepsilon}}$$

$$k = \frac{Z_0 L}{2\pi a^2} \times \frac{s}{\sqrt{\pi}\sigma} = \frac{Z_0 L}{4\pi a} \times \frac{1}{\sqrt{\pi \varepsilon}\sigma}$$

- For Q2-bellows parameters

$$L = 4 \times 28mm \qquad k = 0.13 \div 0.16 \quad V/pC$$

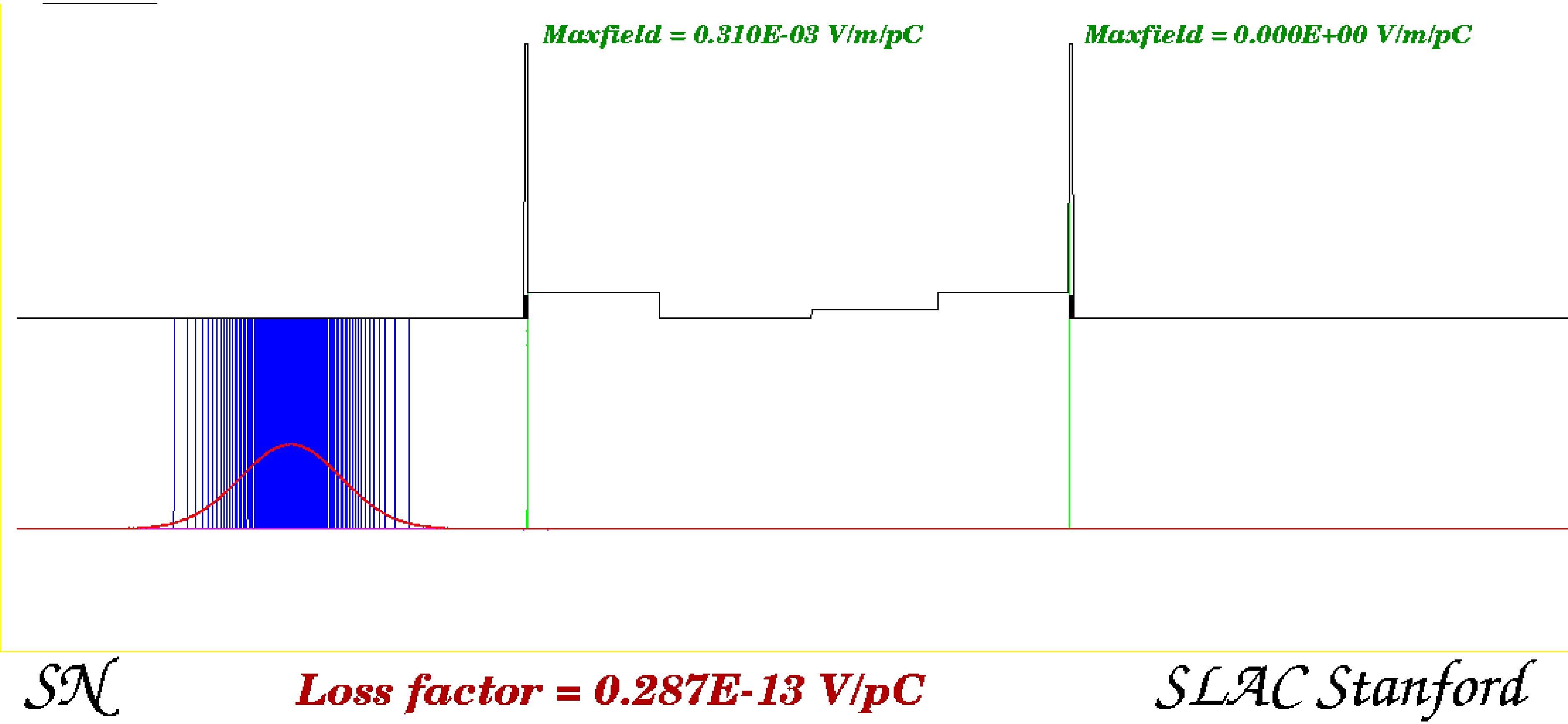
$$a = 60mm$$

$$\sigma = 13mm$$

$$\varepsilon = 30 \div 21 \quad (1 - 10GHz)$$

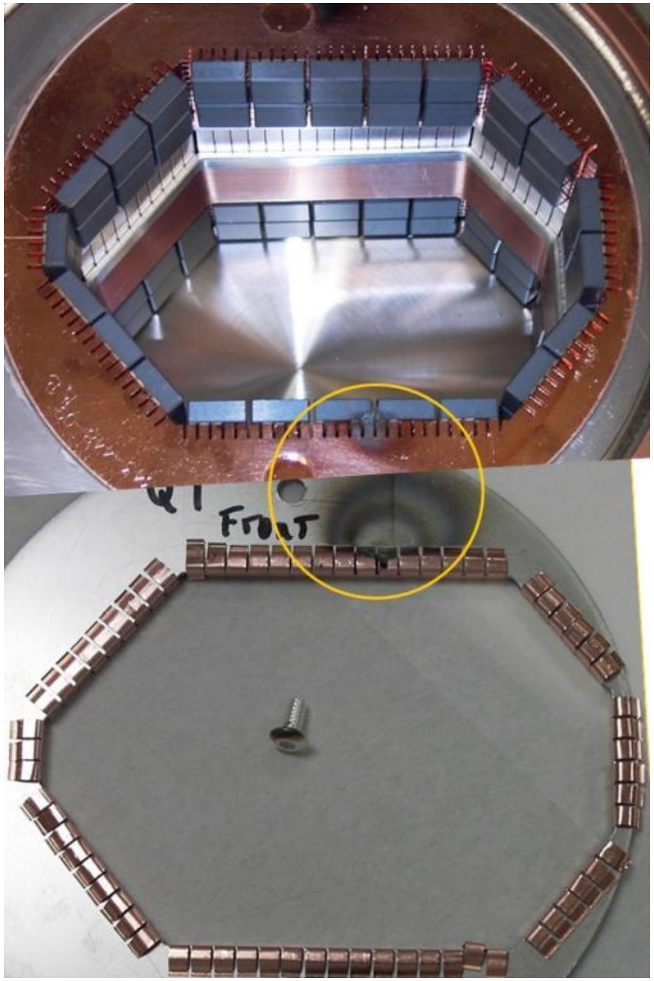
Additional 150% power loss!!!

Electromagnetic fields in ceramic tiles



Sash
High

Sparks in ceramic tiles



The PEP-II B-factory at SLAC had experienced unexpected aborts due to anomalously high radiation levels at the BaBar detector. Before the problem was finally traced, we performed a wake field analysis of the Q-2 bellows, which is located at a distance of 2.2 m from the interaction point. Analysis showed that the electric field in a small gap between a ceramic tile and metal flange can be high enough to produce sparks or even breakdowns. Later traces of sparks were found in this bellows.

3D-simulation: mode scattering.

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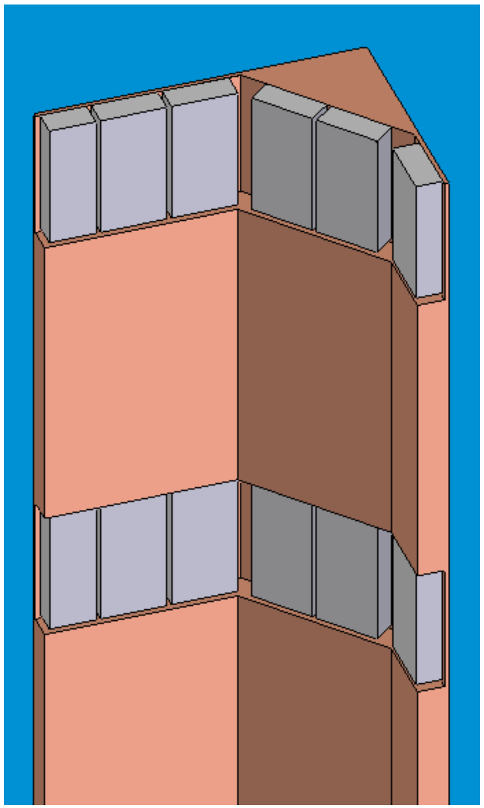
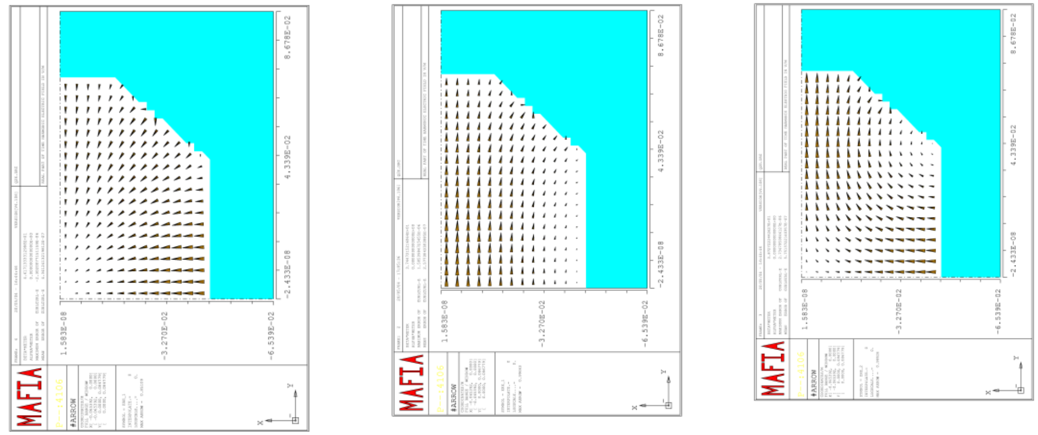
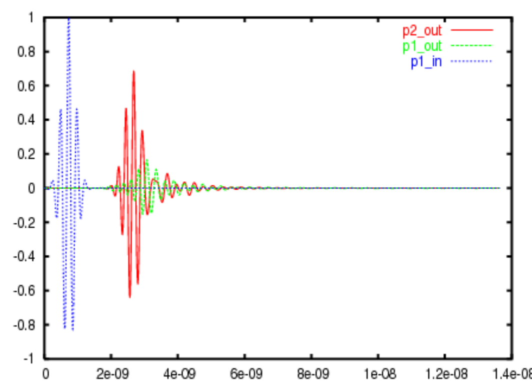
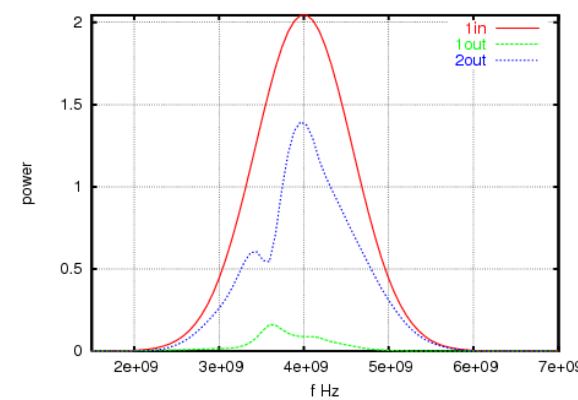




Input waves: mono dipole quad



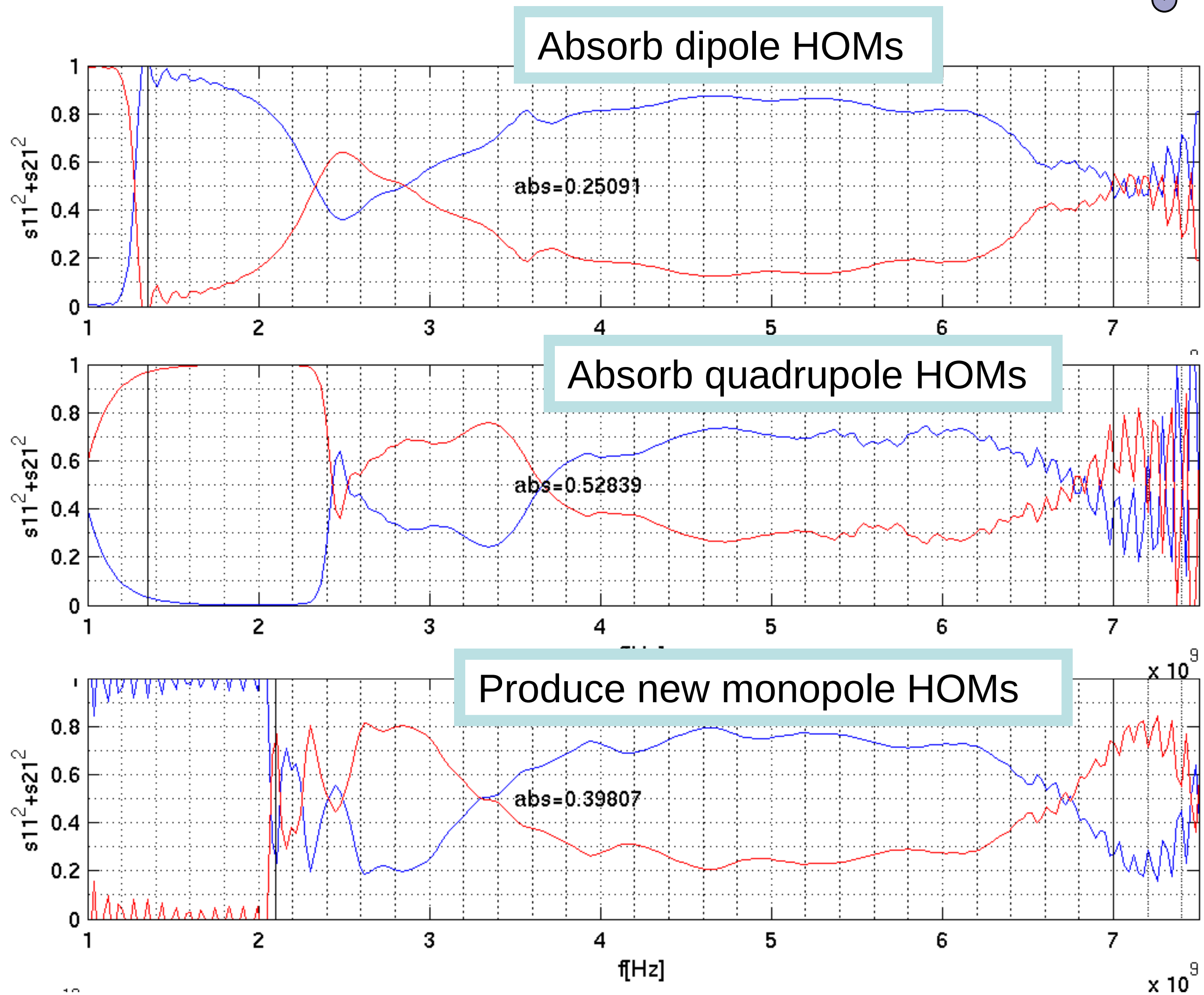
Input, propagated and reflected signals



Fourier transform

Adsorbed power in the ceramic tiles

Red lines: propagating and reflected power



Mode scattering for a round pipe.

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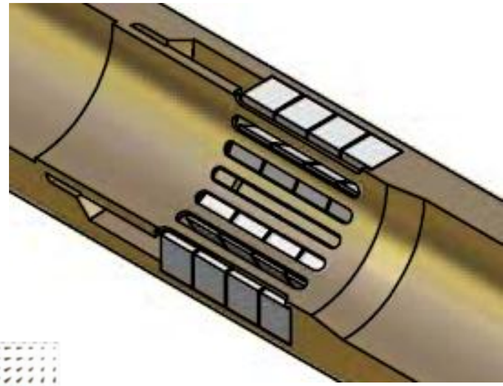
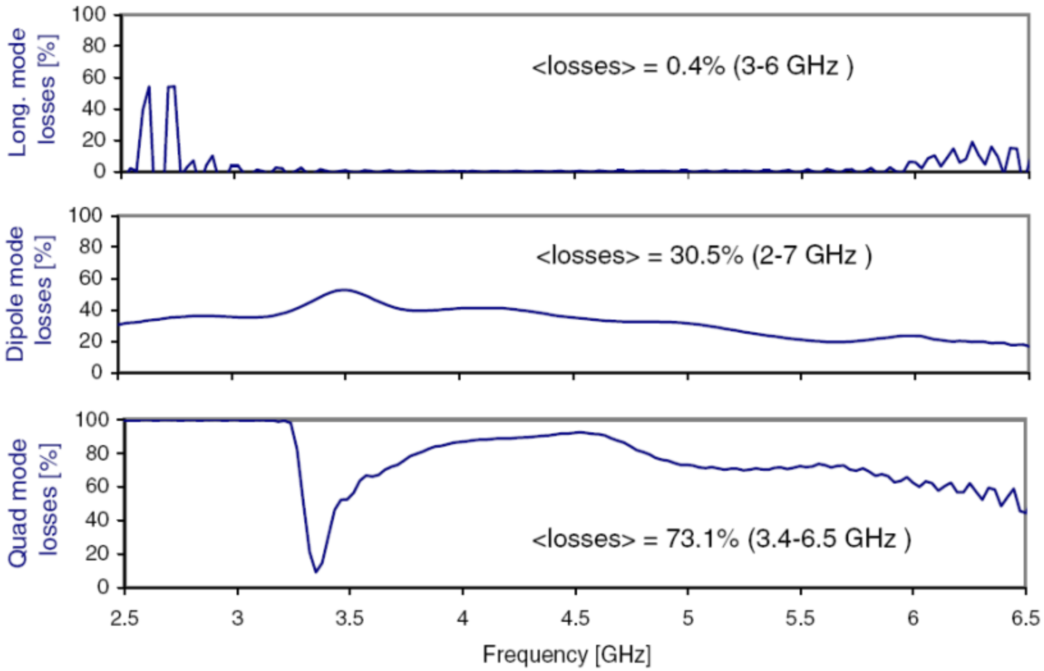
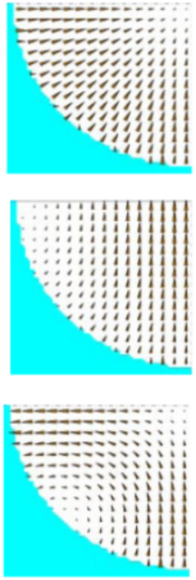


Absorbed power in the tiles





Input waves

Trapped modes in the “tiles” cavities

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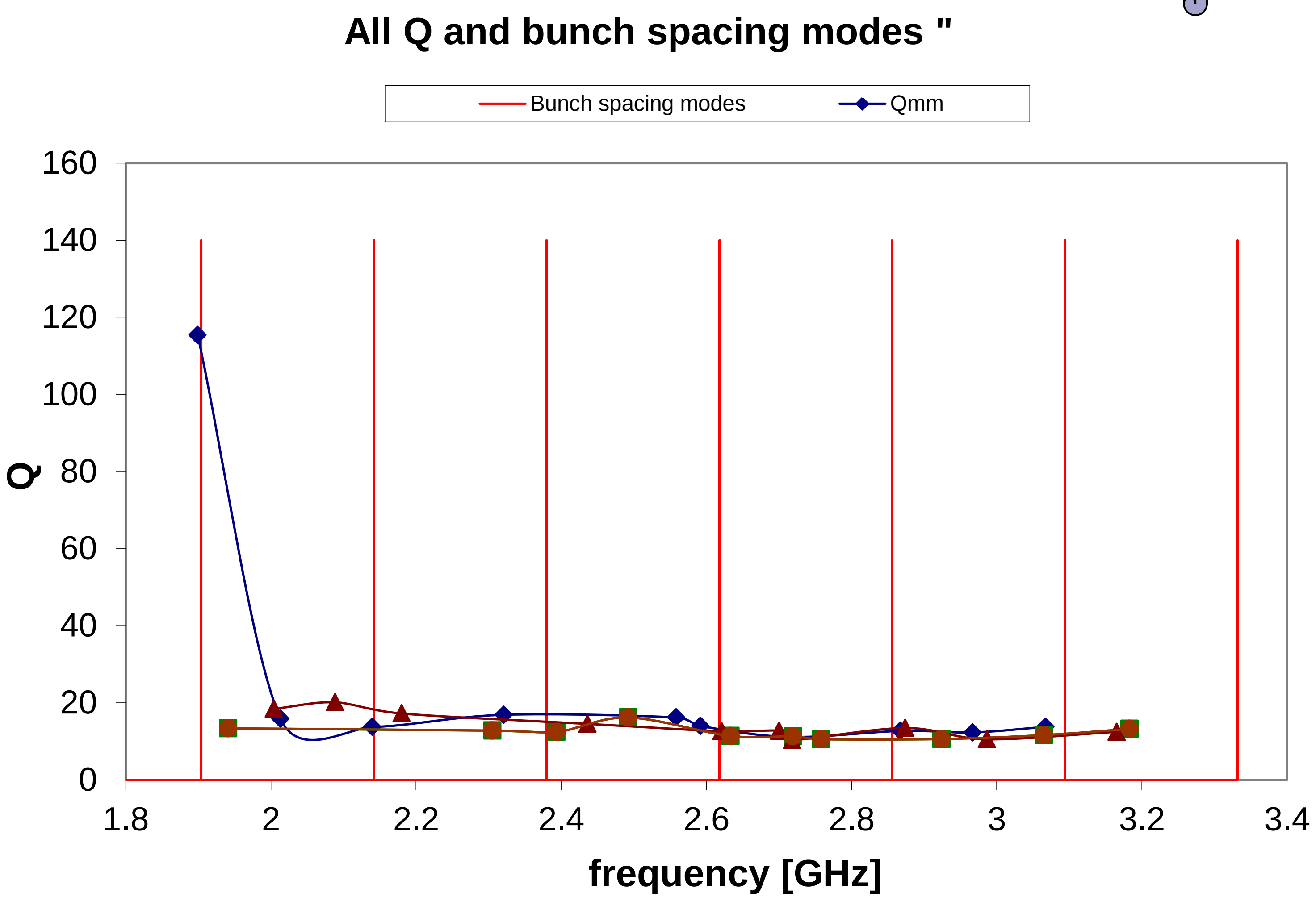

Coupling slots

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- We want to damp TM-type waveguide modes, which have azimuthal wall currents and not to damp longitudinal modes, which have longitudinal currents.
- By adding longitudinal slots parallel to the beam, transverse currents will be intersected and strongly disturbed.
  - The coupling parameter for transverse fields (which we want to be large)

$$k_{\perp} \sim \frac{\pi}{3} \frac{l^3}{\ln \frac{4l}{d} - 1}$$

A slot with an elongated elliptical shape of semi-major axis *l* and semi-minor axis *d* and *l* >> *d*

- The coupling parameter for longitudinal fields (which we want to be small)

$$k_{\parallel} \sim \frac{\pi}{3} l d^2$$

- To satisfy both conditions we need long and narrow slots

Properties of ceramic tiles

Properties of Ceradyne's Advanced Technical Ceramics for Microwave Applications

ceradyne, inc.
ADVANCED TECHNICAL CERAMICS
3169 Redhill Avenue • Costa Mesa, CA 92626
Phone: 714-549-0421 • Fax: 714-549-5787
email: sales@ceradyne.com
internet: www.ceradyne.com

Property	Ceramic Composition									
	Al_2O_3-SiC	MgO-SiC		AlN-SiC		AlN-Composite		BeO-SiC**	AlN	BeO**
GRADE	Ceralloy® 7712	Ceralloy® 6703	Ceralloy® 6705	Ceralloy® 13740	Ceralloy® 13740Y*	Ceralloy® 137 CA*	Ceralloy® 137 CB*	Ceralloy® 2710	Ceralloy® 1370C*	
Composition	Al_2O_3+60%SiC	MgO+2%SiC	MgO+5%SiC	AlN+40%SiC	AlN+40%SiC	AlN Composite	AlN Composite	BeO+40%SiC	AlN	BeO-99.5%
Tailored Compositions Available	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	N/A	
Processing Route	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	Hot Pressing	
Density (g/cc)	3.36	3.50	3.48	3.19	3.19	2.99	2.99	3.02	3.26	
Outgassing	No	No	No	No	No	No	No	No	No	No
Thermal Conductivity (W/m°K) (RT)		30	30	30	53	85	95-105	130	160-200	250
Dielectric Constant										
@ 1.0 GHz				22	30	28	40	33	8-9	7.0
@ 8.0 GHz	130	11.2	12.8	15	22	18	30	24		
@10.0 GHz	83	11.1	12.7	15	21	18	28	23		
@12.0 GHz	69	10.9	12.6							
Loss Tangent										
@ 1.0 GHz				0.11	0.11	0.20	0.15	0.05		
@ 8.0 GHz	0.40	0.02	0.03	0.30	0.30	0.20	0.30	0.25		
@10.0 GHz	0.57	0.02	0.03	0.28	0.28	0.20	0.30	0.25		
@12.0 GHz	0.53	0.02	0.03							
Thermal Expansion Coefficient $x10^{-6}/°C$; (RT-1000°C)		15.4	14.8	5.1	5.1	5.0	5.0	7.0	4.3	8.3
Flexural Strength (MPa)	530	200	200	300	300				260	175
Key Features						Dielectric Loss Independent of Temperature (to 3°K)	Higher Thermal Conductivity than Ceralloy® 2710 @ Temps. >150°C. Close Match in Electrical Properties	Former Industry Standard for Terminations, etc.	Higher Thermal Conductivity than BeO @ High Temperatures	Higher Thermal Conductivity @ RT
Applications	Slot Mode Absorbers	Absorbers, Buttons	Absorbers, Buttons	Replacement for Ceralloy® 2710 BeO-SiC, Terminations, Sever Wedges, Load Pellets, Absorbers	Replacement for Ceralloy® 2710 BeO-SiC, Terminations, Sever Wedges, Load Pellets, Absorbers	Terminations, Sever Wedges, Load Pellets, Absorbers, Cryogenic Environment Applications	Replacement for Ceralloy® 2710 BeO-SiC, Terminations, Sever Wedges, Load Pellets, Absorbers	Terminations, Sever Wedges, Load Pellets, Absorbers	Replacement for 99.5 BeO, Collector Rods, Helix Support Rods, Windows	Collector Rods, Helix Support Rods, Windows

NOTE: Properties are typical and should not be considered as specifications.

* Patent Pending ** BeO and BeO-SiC ceramics are no longer manufactured by Ceradyne. Data is included for reference only.

1/1/01

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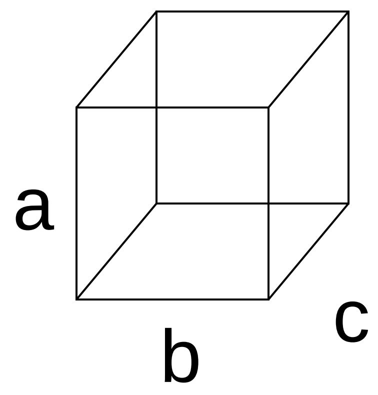
The “cavity” method

- Empty pill-box frequencies

$$f_{ijk} = \frac{c}{2}\sqrt{\left(\frac{i}{a}\right)^2 + \left(\frac{j}{b}\right)^2 + \left(\frac{k}{c}\right)^2}$$



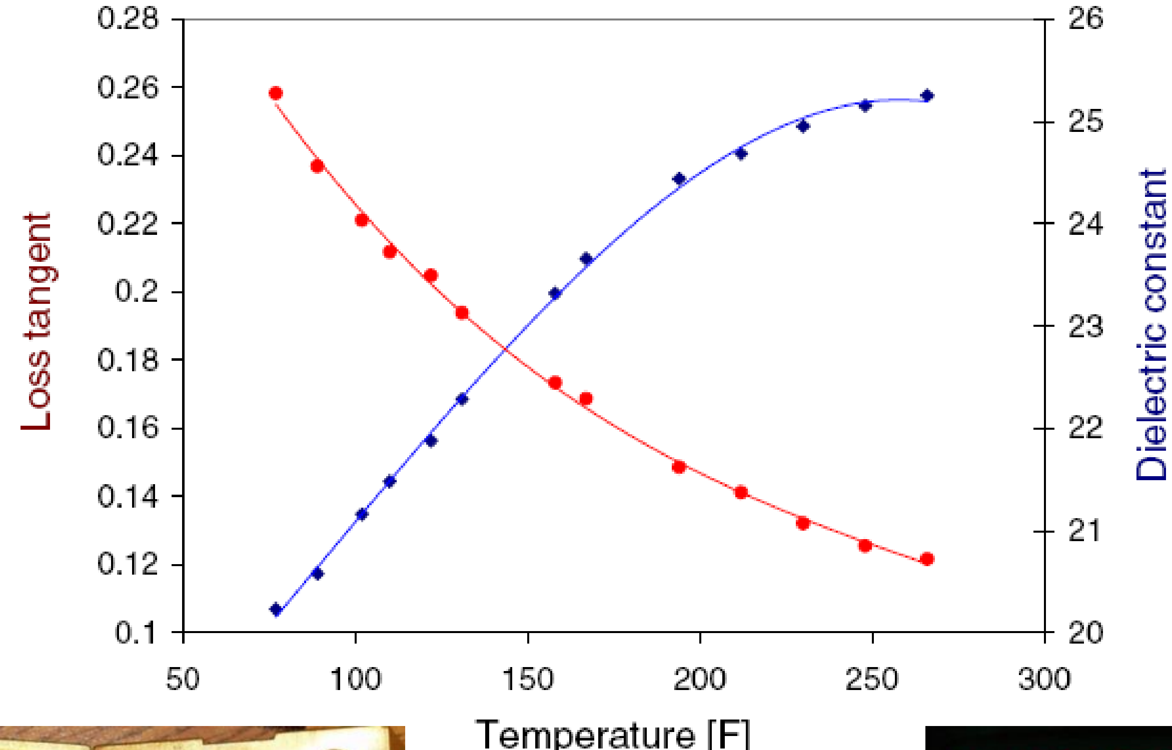
- Box filled with a material

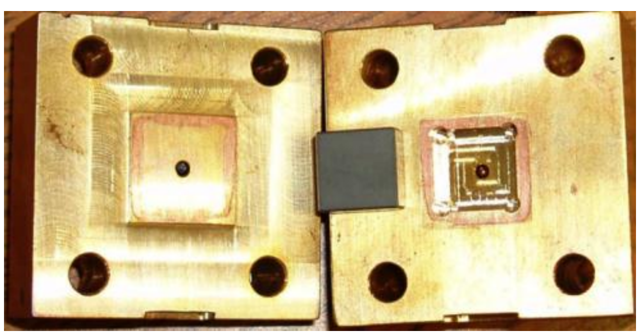
$$f_{ijk}(\varepsilon, \mu) = \frac{1}{\sqrt{\varepsilon\mu}} f_{ijk}$$

- Loss tangent and quality factor

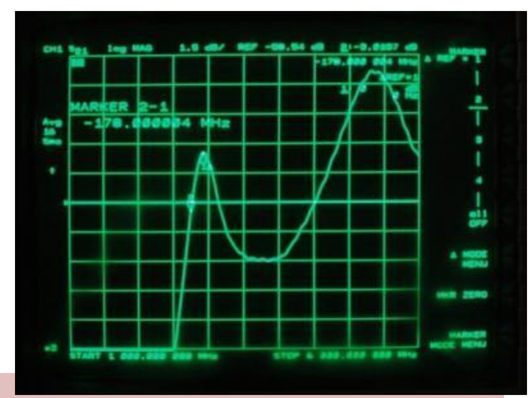
$$\delta = {}^{1}\!/_{Q}$$

Property measurement in a 3 GHz cavity





We assume that main part of the field is concentrated in a ceramic tile, which expands with the temperature as 5.1×10^{-6}/C, when copper box changes its sizes as 1.5×10^{-5}/C



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Straight HOM Bellows -design details

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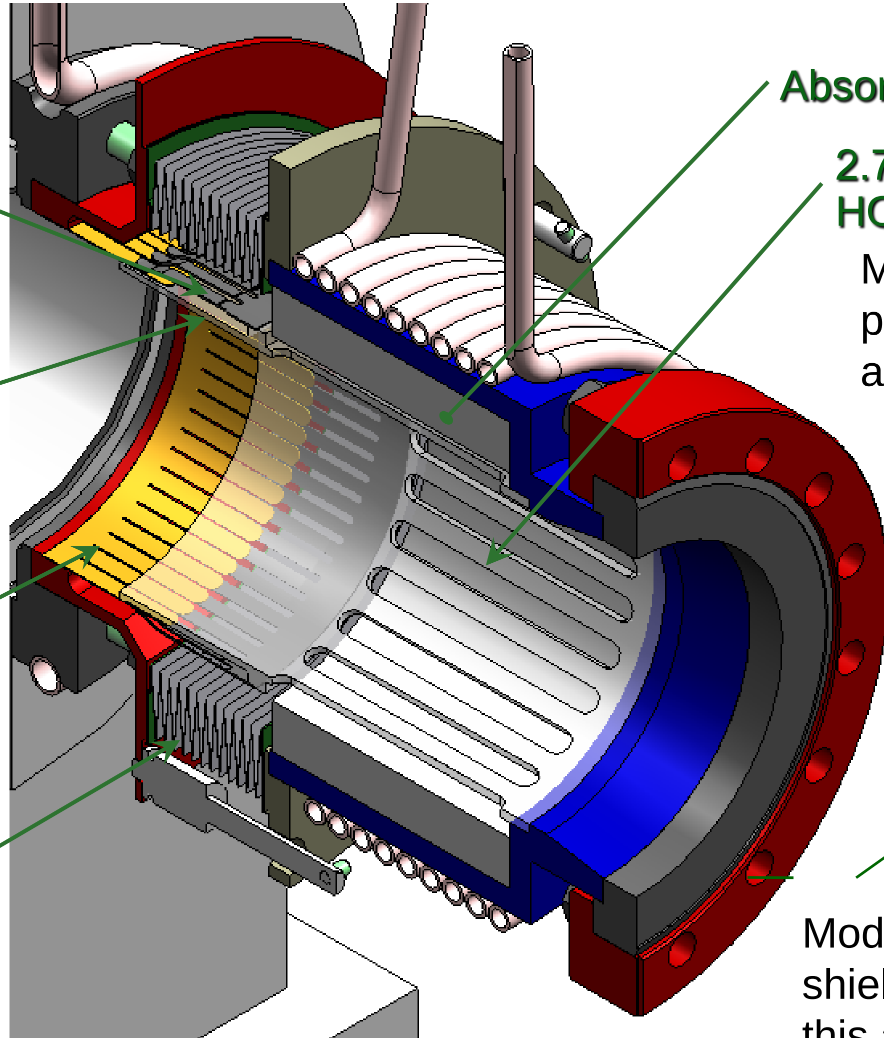
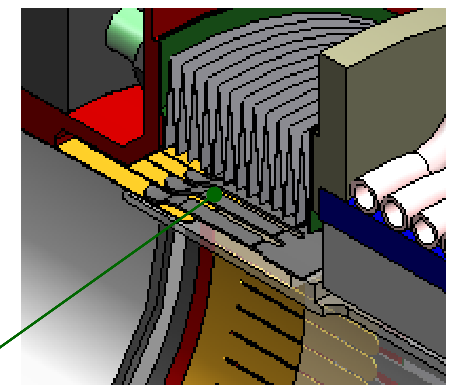
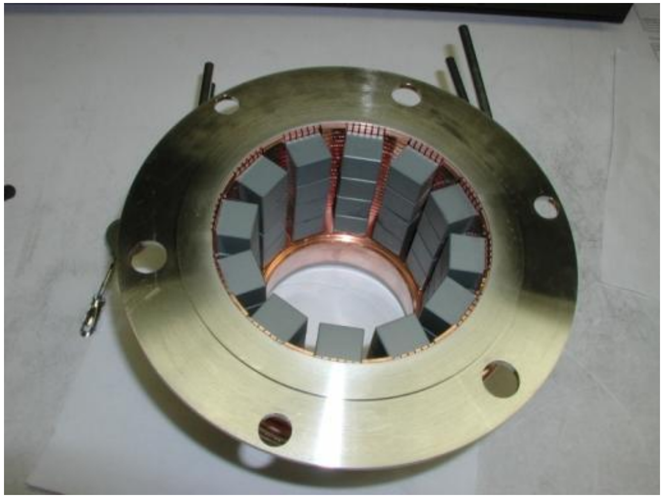


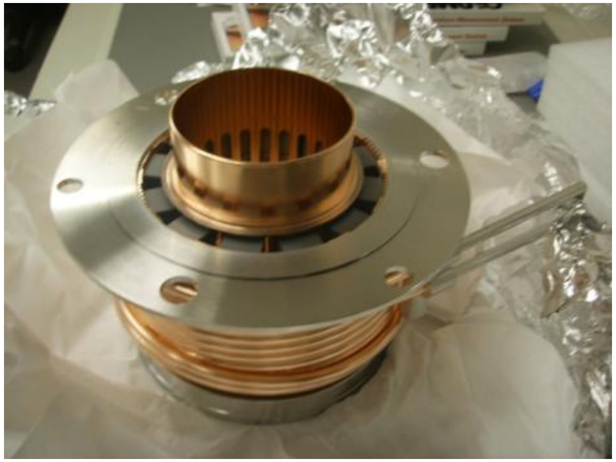


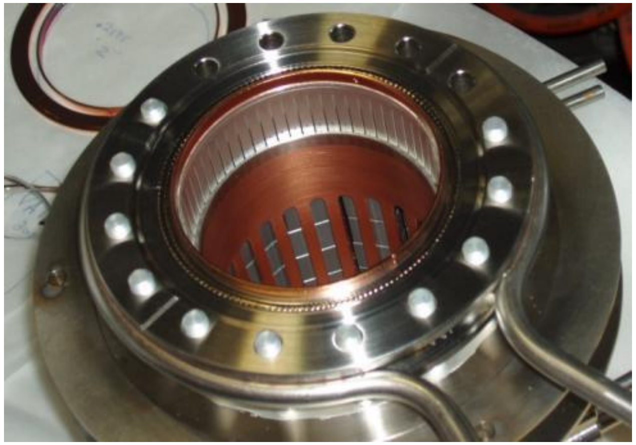
2.75" long by .24" wide HOM Trapping Slots: Modes in the chamber propagate through the slots & are absorbed by the AlNiSiC.

Bellows Cavity: Modes that leak past the RF shield finger and are trapped in this area still see the absorber

State of art technology







Installed absorbers after each LER collimator

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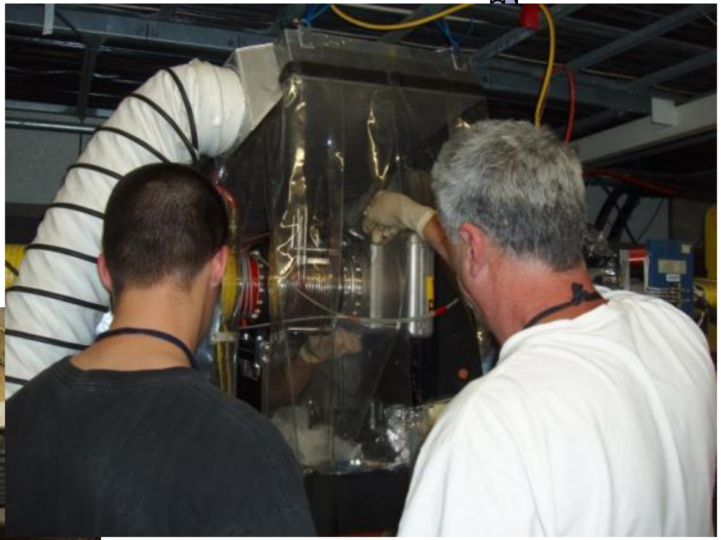
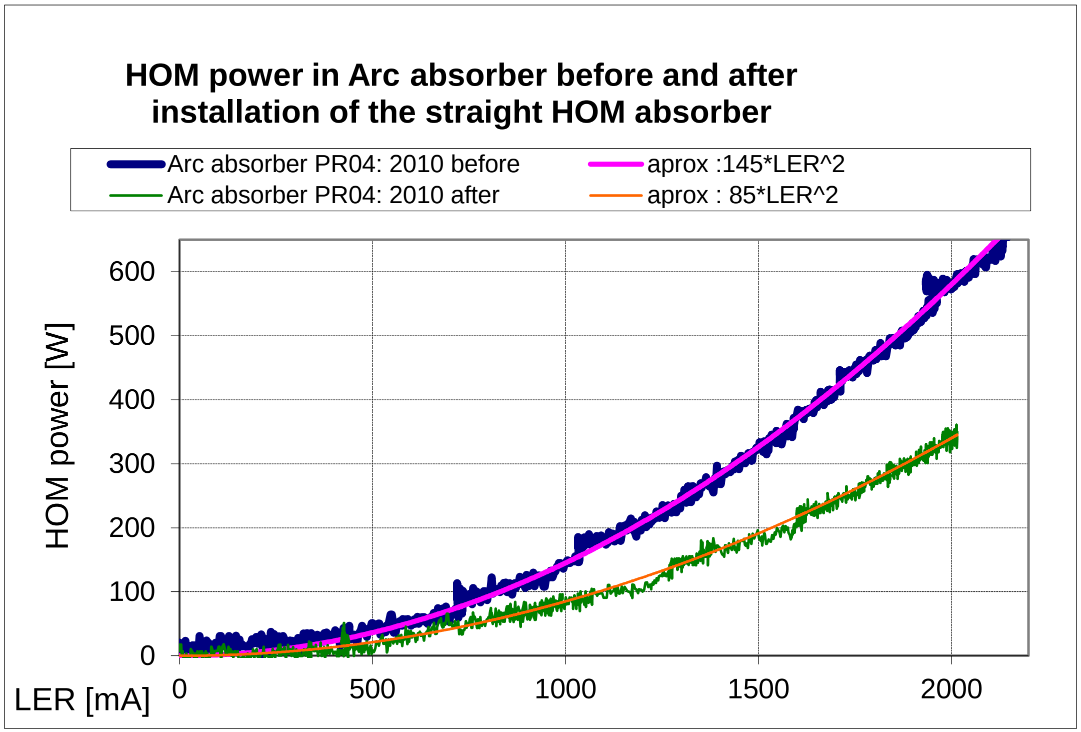
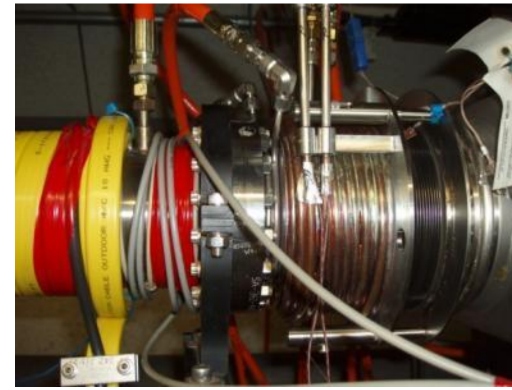


Efficiency of the absorber

$$\eta = \frac{P_{before} - P_{after}}{P_{before}} \cdot 100\% = \frac{145-85}{145} \cdot 100\% = 41\%$$

Almost as it was designed!





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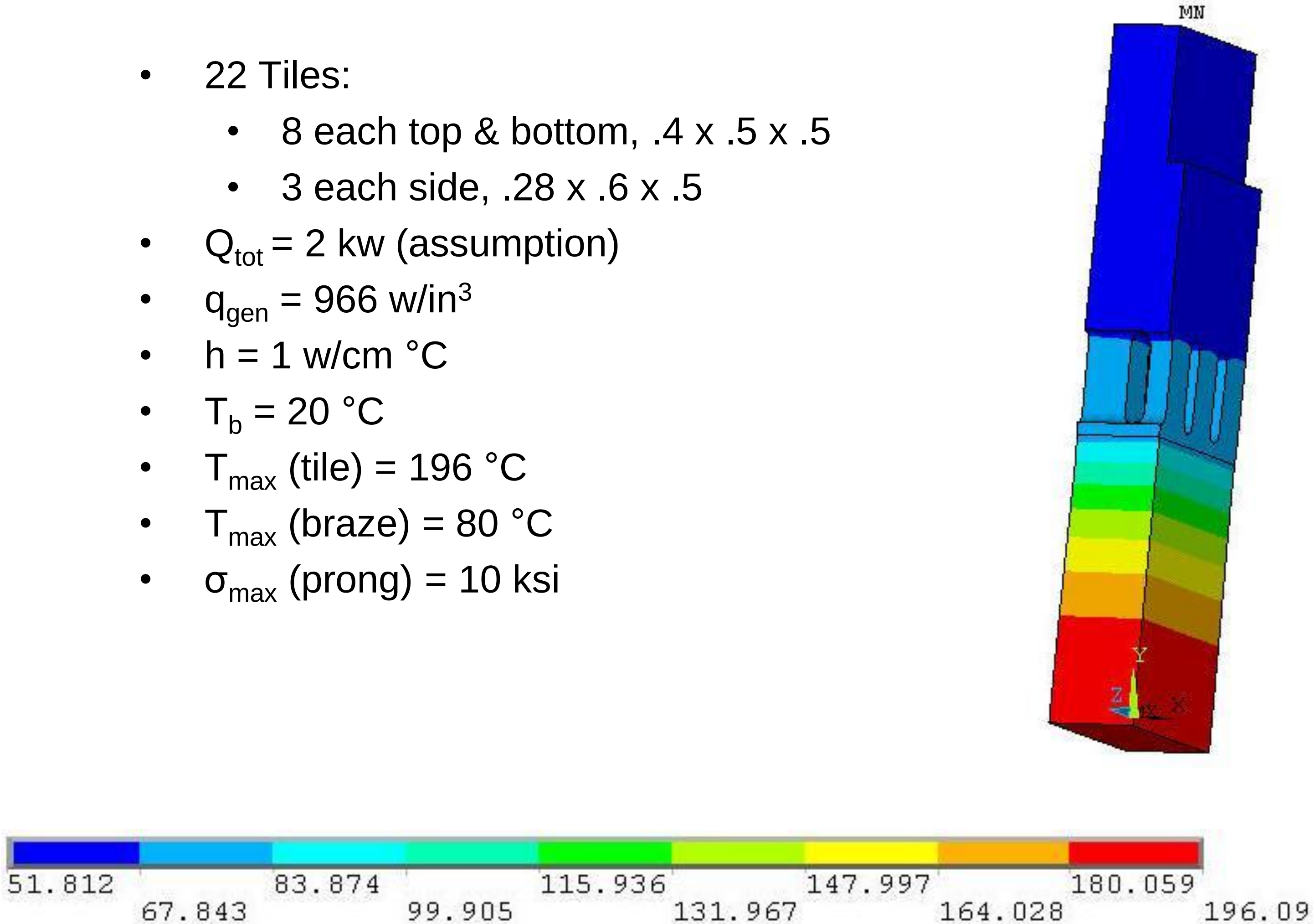
Thermo-analysis

- 22 Tiles:
  - 8 each top & bottom, .4 x .5 x .5
  - 3 each side, .28 x .6 x .5
- Q_{tot} = 2 kw (assumption)
- q_{gen} = 966 w/in^3
- h = 1 w/cm °C
- T_b = 20 °C
- T_{max} (tile) = 196 °C
- T_{max} (braze) = 80 °C
- σ_{max} (prong) = 10 ksi



2 kW absorbed power at 3 A

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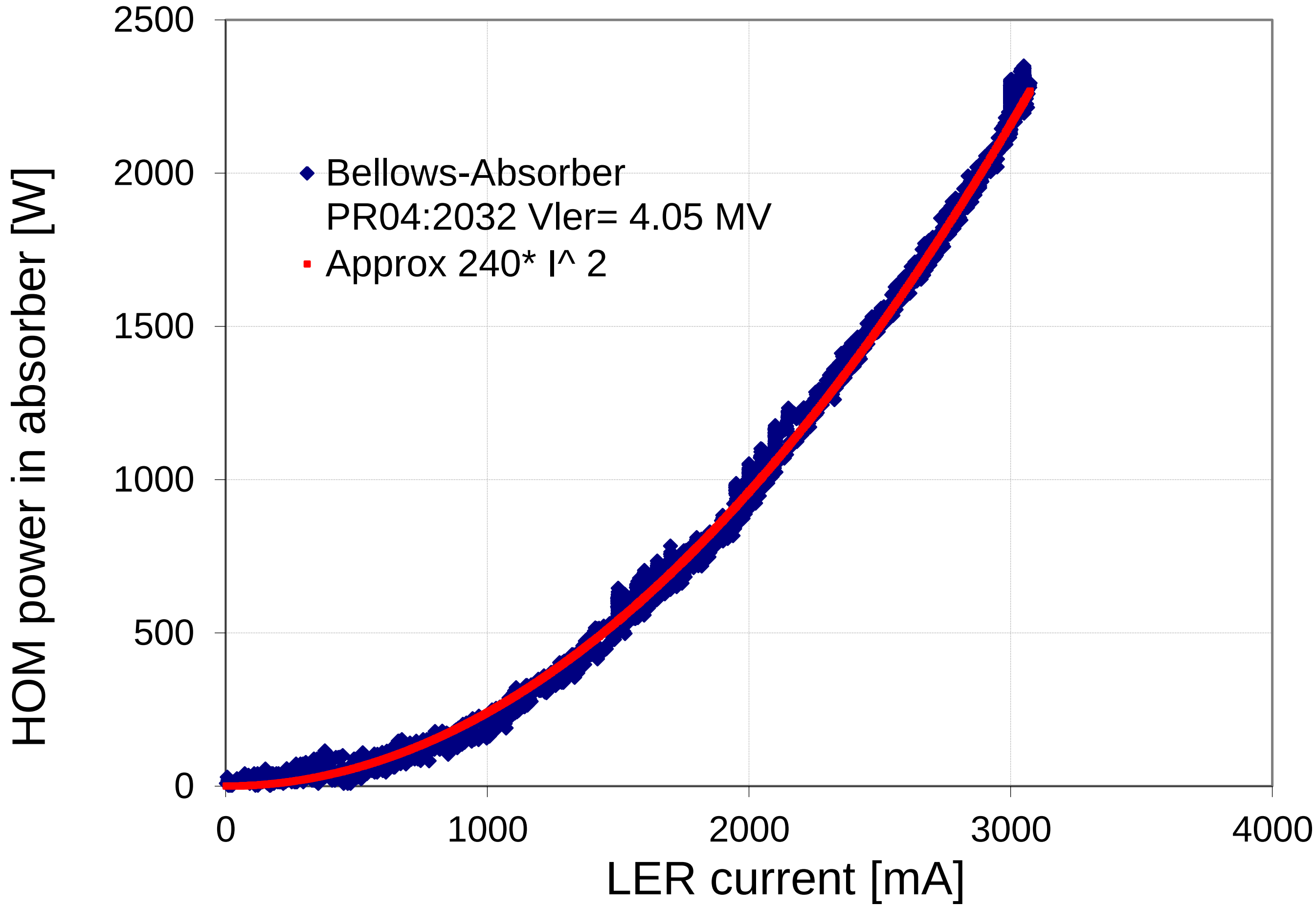

SLAC has developed high efficiency HOMs absorbers for different cross-sections and installed 25 in the rings

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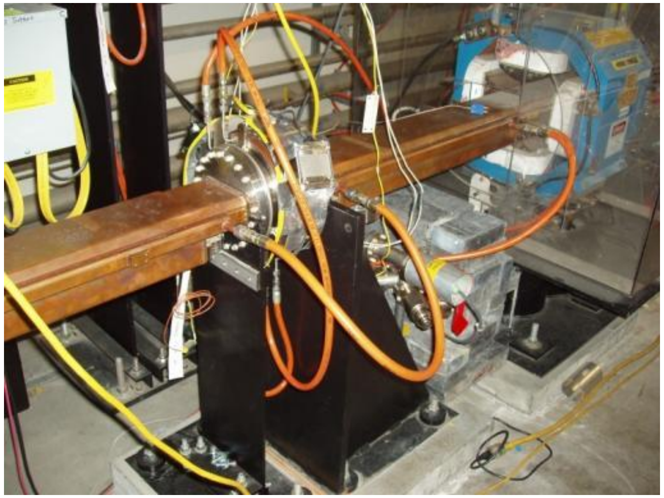

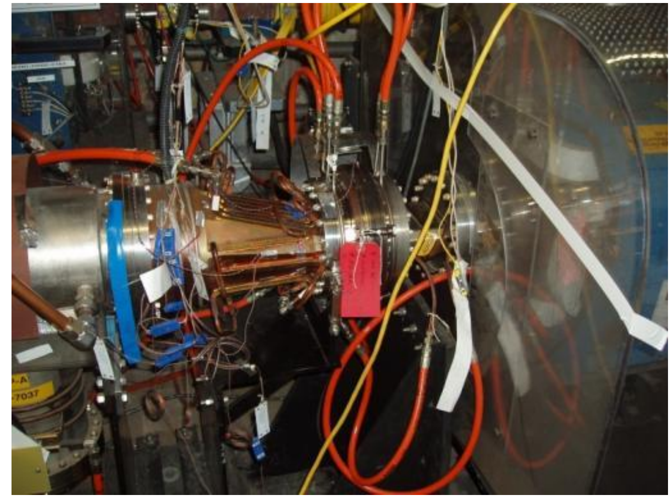

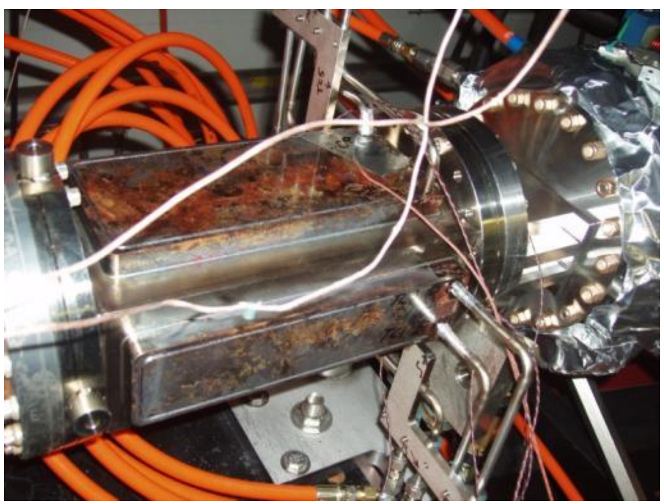

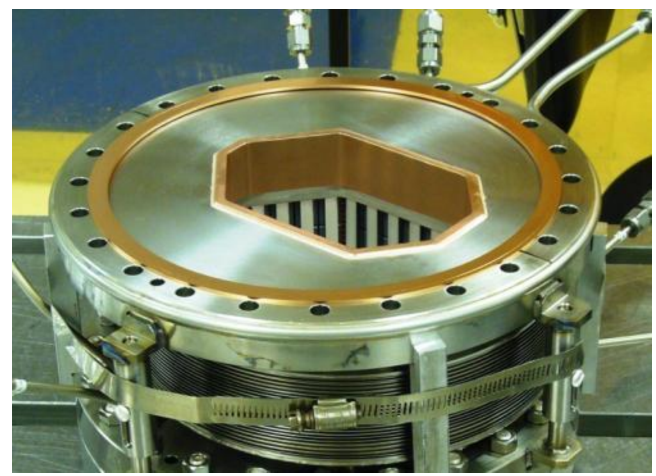

PEP-II LER absorber

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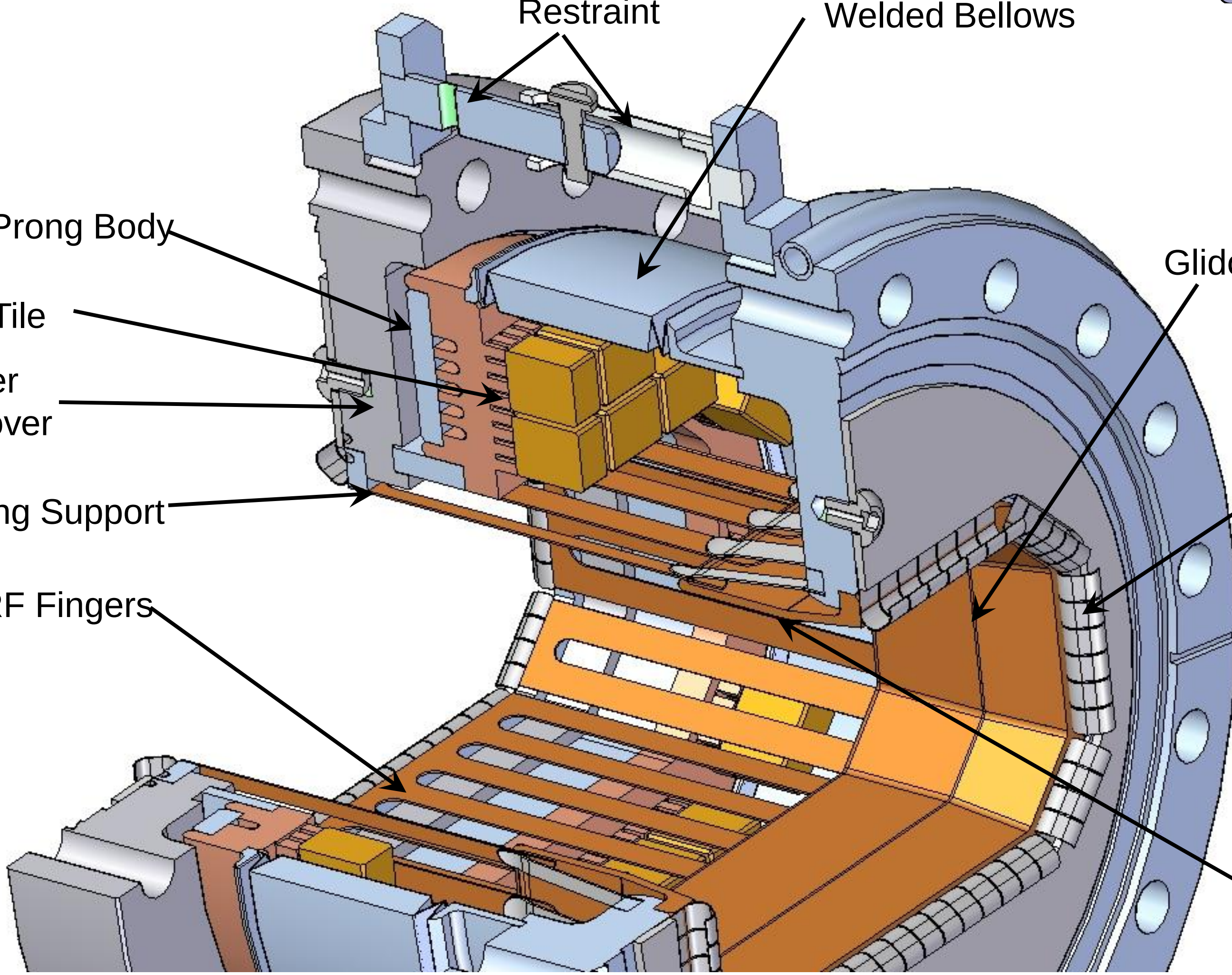

Q4/Q5 Bellows with Absorber

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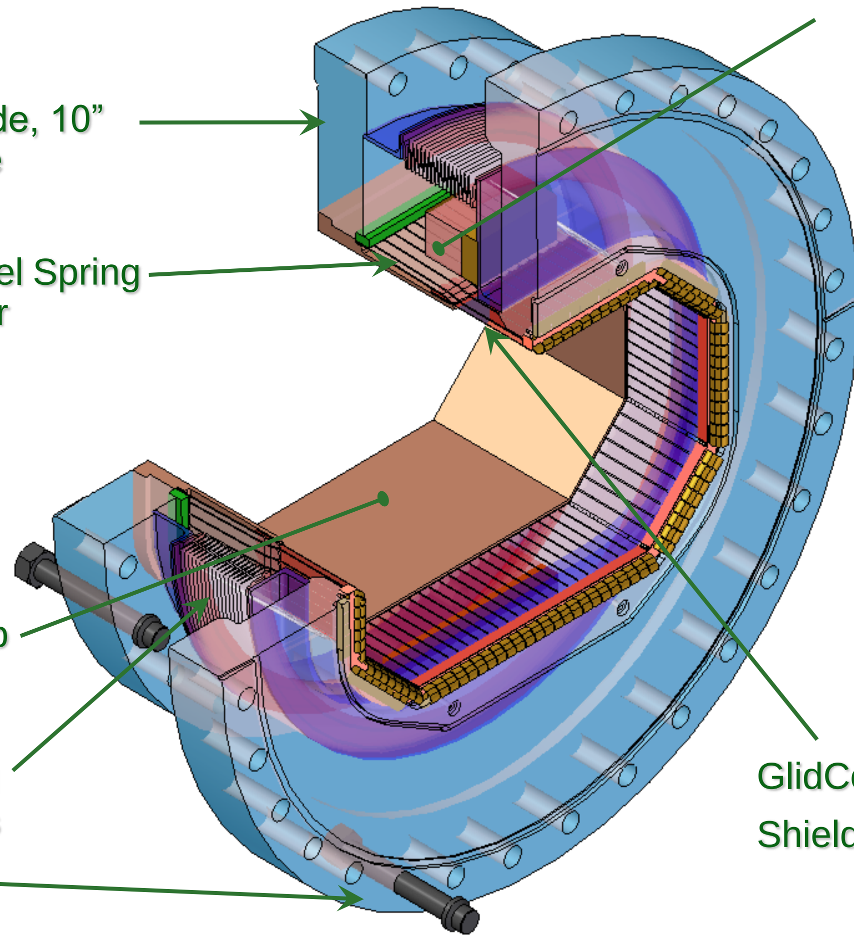
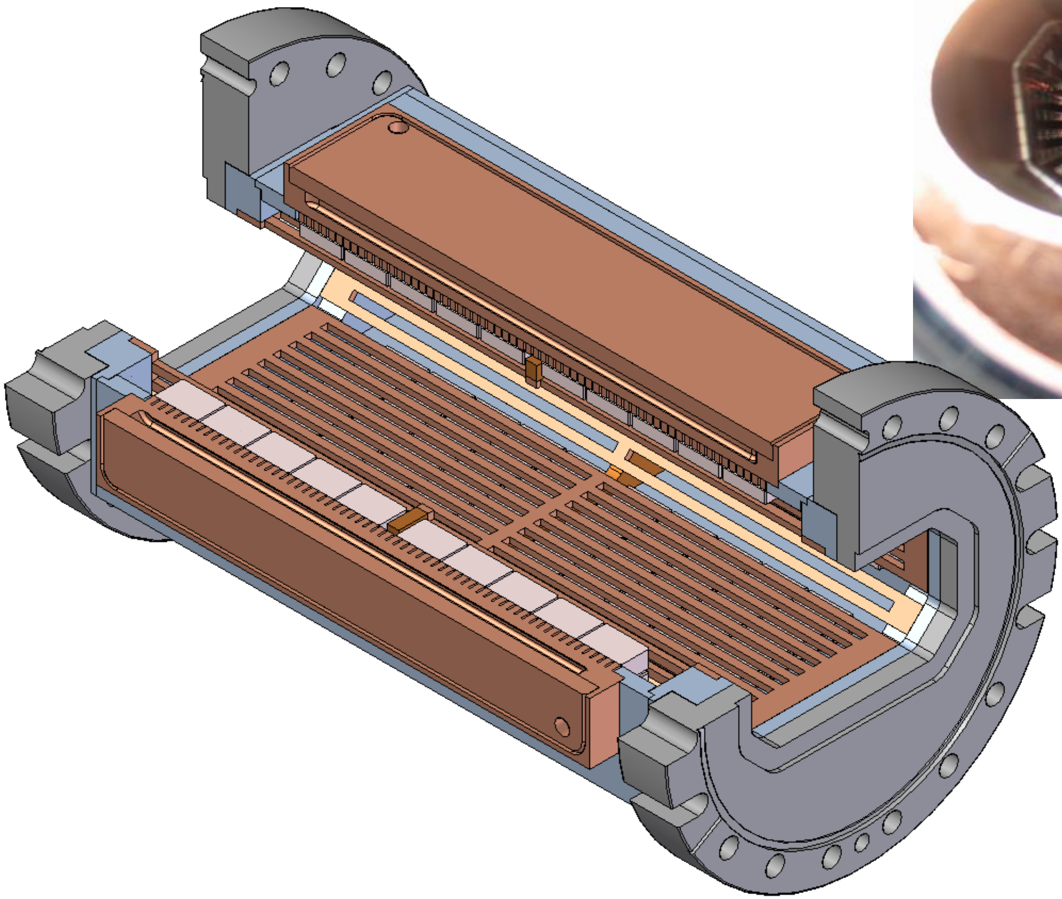
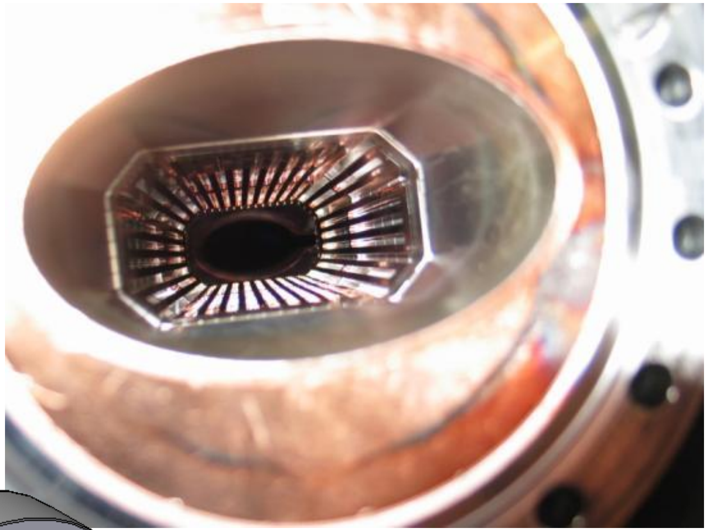
- Mechanically decouples Q4 & Q5 vacuum chambers
- Absorbing tiles above and below beam orbit

Cooling – not shown



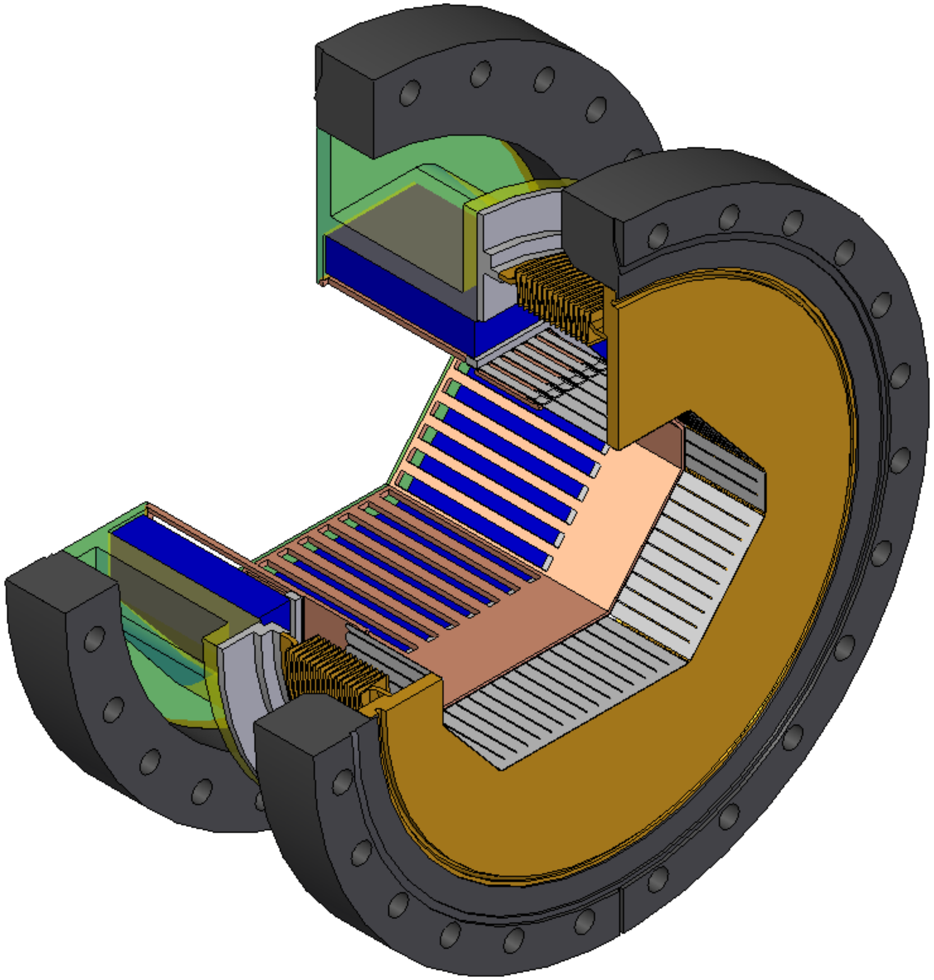
30 kW absorber





Q2-Bellows HOM absorber

- Technically very challenging
  - Limited space available
  - Anticipated high power loads
- Design compromises travel during installation to accommodate new HOM absorption arrangement
- 61 mm maximum tile/slot length
- Absorbing tiles are open to the convolutions
  - No additional tile set needed in bellows cavity
- HER Arc Bellows features
  - Spring, Stub, RF shield



Optimization for a given absorber length

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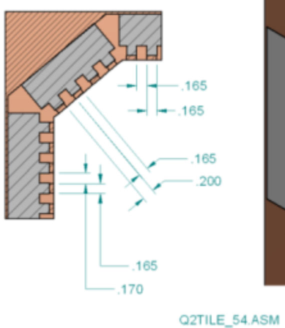
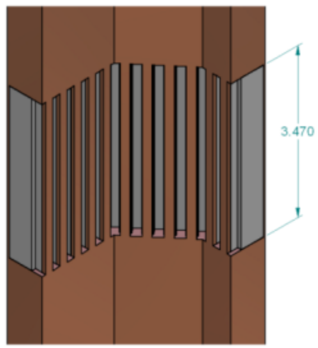
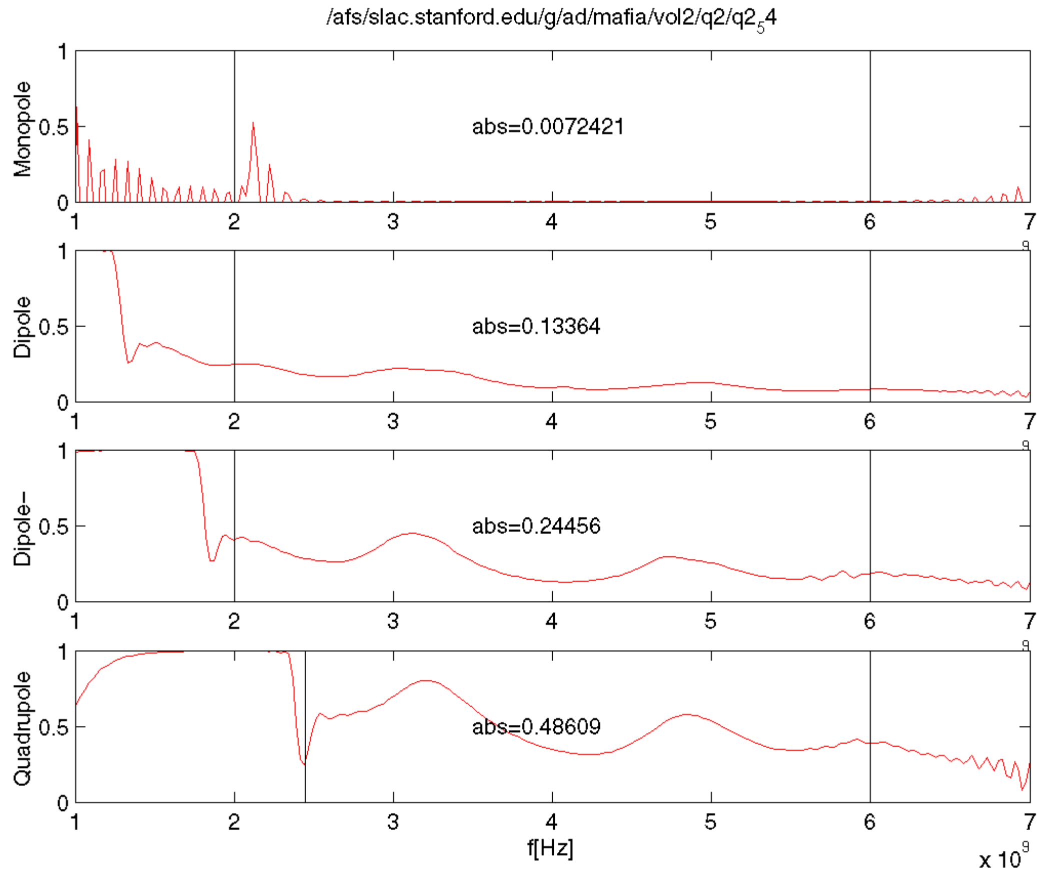
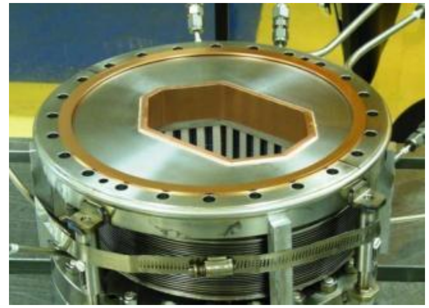
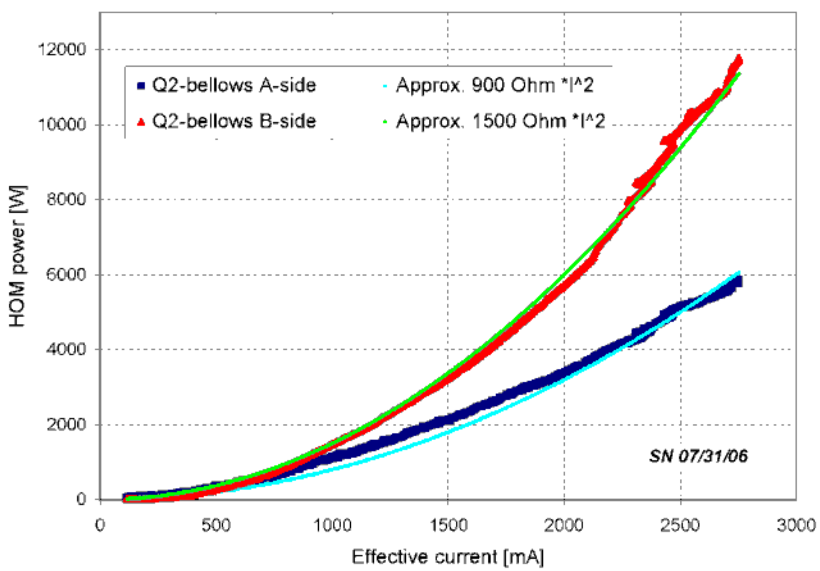


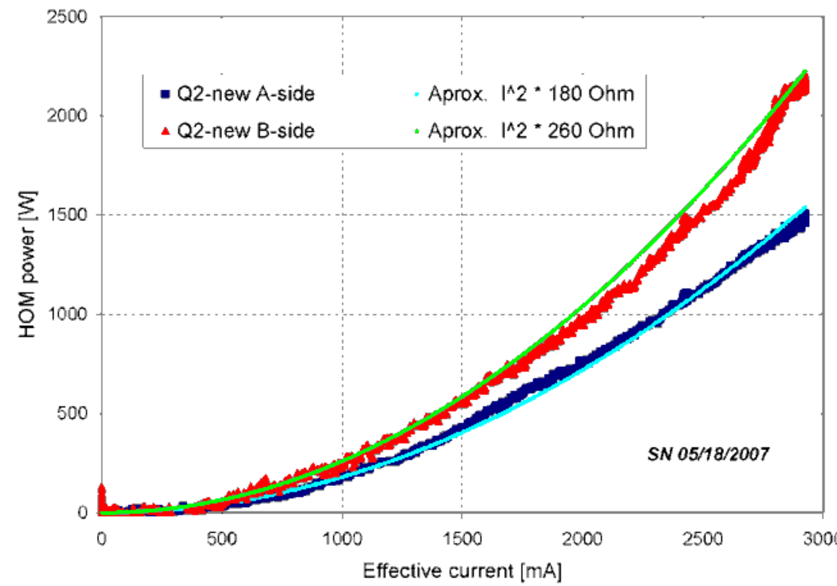




5 times less HOM power in Q2







No addition losses due to open ceramic tiles

At the same time no great changes of the vertex bellows temperature

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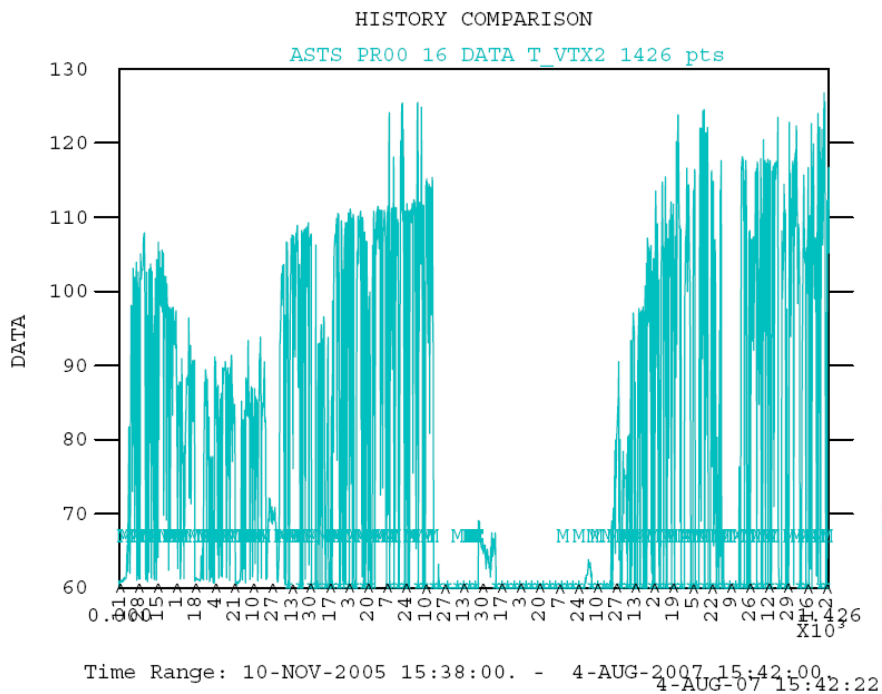
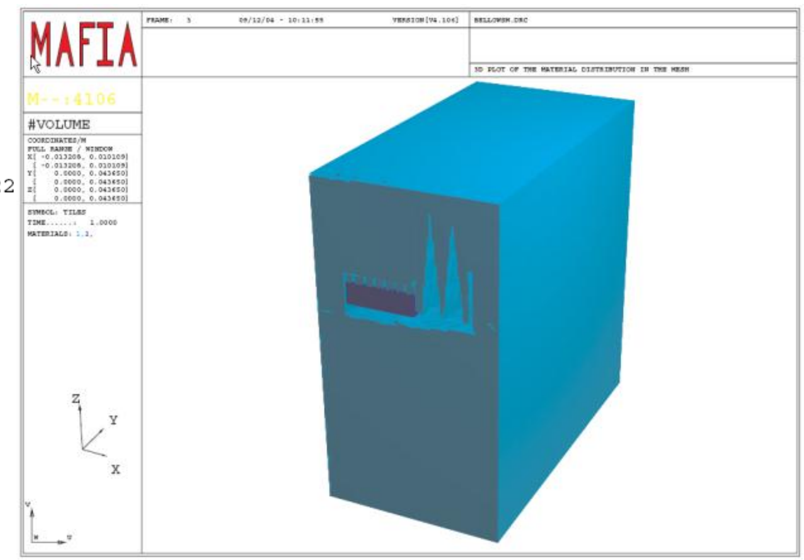


We designed a new vertex bellows, but have not built



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