"IR HOM Issues"

Collection of HOM effects

Sasha Novokhatski

SLAC, Stanford University

Parallel Session: RF, HOM, Power

June 15, 2006

Luminosity and wake fields

- We need high current beams of short bunches to achieve super high luminosity
- These beams carry high intensity electromagnetic fields.

Electric field at the beam pipe wall

$$E = \frac{cZ_0}{(2\pi)^{3/2}} * \frac{eN_b}{a\sigma} \qquad E_{\left[\frac{kV}{cm}\right]} = 23. * \frac{N}{10^{11}} * \frac{1}{a_{cm}\sigma_{cm}}$$

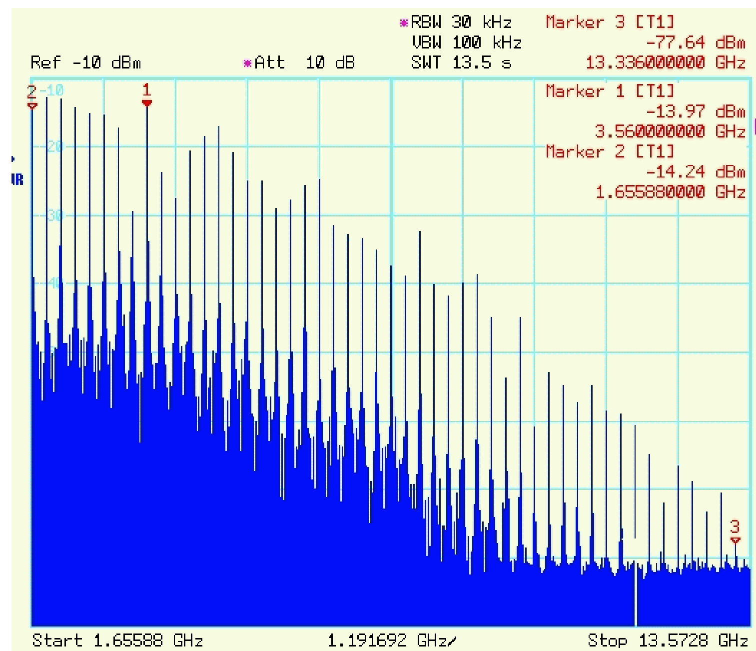
Breakdown limit is around 30 kV/cm on not very well polished surfaces

Luminosity and wake fields

- Field spectrum goes to higher frequency with shorter bunches

$$A(\omega) \sim e^{-\left(\frac{\omega}{c}\sigma\right)^2}$$

Beam spectrum (12 mm bunch)



Bunch spacing resonances

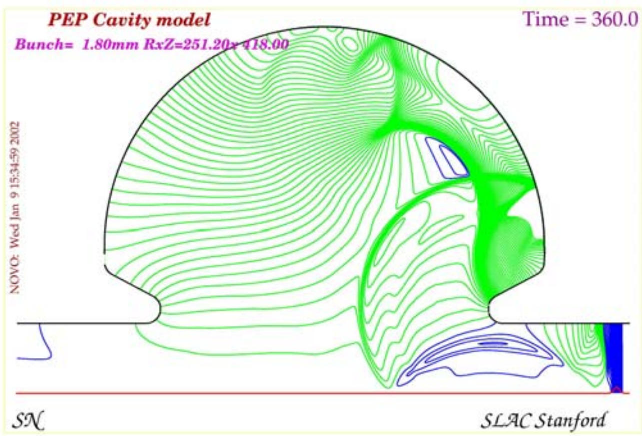
$$f_n = \frac{n}{\tau_b} \qquad n = 1, 2, 3, \ldots$$

Bunch spacing

$$\tau_b = \frac{m}{f_{RF}} \qquad m = 1, 2, 3, \ldots$$

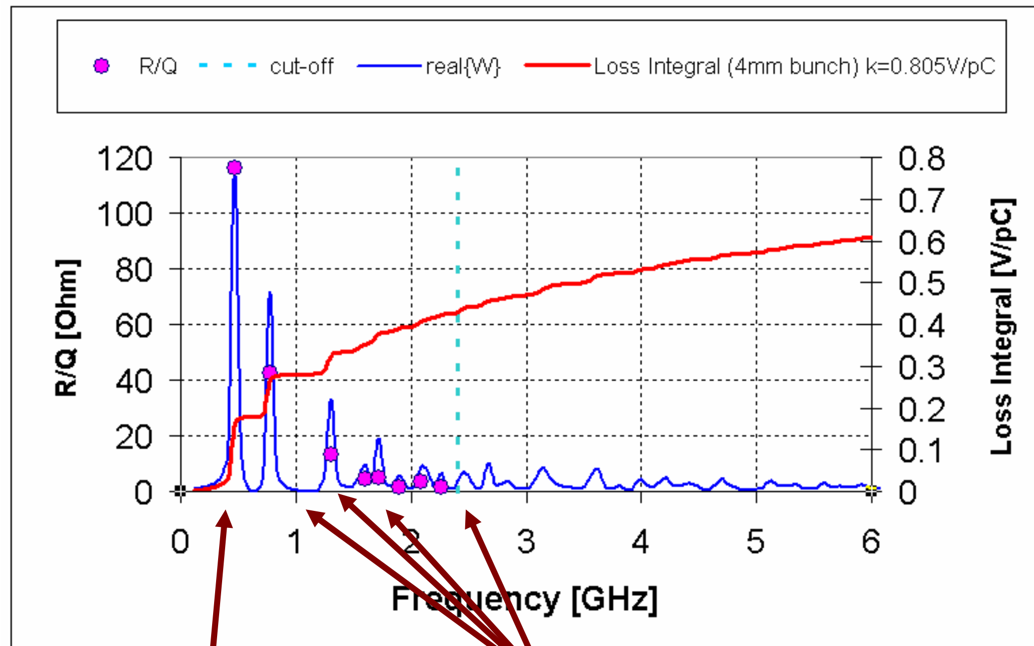
Wake fields and HOMs

Sasha Novokhatski "HOM Effects in the Damping Ring"



Wake fields of a short bunch in a PEP-II cavity

Loss Factor Frequency Integral,



Main mode and Higher Order Modes

HOM power in cavities (2004)

Sasha Novokhatski "HOM Effects in the Damping Ring"

Sasha Novokhatski "HOM Calculations of New Cavities"

f=136kHz h=3492

Cavity type	Frequency [MHz]	Pipe radius [mm]	R/Q [Ohm]	Bunch length [mm]	Total Loss [V/pC]	Above cut-off [V/pC]	Beam current [A]	Bunch charge [nC]	Wake Voltage [kV]	HOM Power [kw]
PEP-II	476	47.6	114	13	0.4699	0.0849	2	11.14	0.95	1.89
CESR-III	500	120	46.2	10	0.175	0.1014	2	11.14	1.13	2.26
PEP-II	476	47.6	116	4	0.805	0.389	11	23.44	9.12	100.32
CESR-III	500	120	46.2	4	0.291	0.2174	11	23.44	5.10	56.06
KEKB-SC	508	110	44.9	4	1.326	1.192	11	23.44	27.95	307.40
with tapers		75								
KEKB-SC-NT	508	110	47.7	4	0.318	0.2373	11	23.44	5.56	61.20
no tapers										
PEP-II-Large	476	95.25	74.9	4	0.35	0.209	11	23.44	4.90	53.90
PEP-II	476	47.6	116	1.8	1.217	0.794	15.5	33.03	26.23	406.56
CESR-III	500	120	46.2	1.8	0.448	0.3744	15.5	33.03	12.37	191.71
KEKB-SC-NT	508	110	47.7	1.8	0.498	0.4173	15.5	33.03	13.79	213.68
PEP-II-Large	476	95.25	74.3	1.8	0.538	0.397	15.5	33.03	13.11	203.28
PEP-II-Large	476	95.25	74.3	1.8	0.538	0.397	23	49.02	19.46	447.60
New PEP-II	952	47.6	66.4	1.8	0.748	0.472	15.5	16.52	7.80	120.84
New PEP-II	952	47.6	66.4	1.8	0.748	0.472	23	24.51	11.57	266.08
PEP-Ellips	952	47.6	75.8	1.8	0.719	0.434	23	24.51	10.64	244.66
PEP-SC	952	77.62	31.6	1.8	0.303	0.208	23	24.51	5.10	117.25

01/20/04

38

Super B Factory Workshop in Hawaii

January 19-22, 2004 East-west Center, Honolulu

10-20%
of RF power
in HOMs

Loss factor and HOM power

$$P = \tau_b \times K \times I^2$$

HOM Power   Bunch Spacing   Loss Factor   Current

$$1_{[kW]} = 4.2_{[n\sec]} \times 0.026_{\frac{V}{pC}} \times 3^2_{[A]}$$

So small value of the loss factor produce a lot of HOM power
Now even small irregularities of the vacuum chamber become very important

Sasha Novokhatski "HOM Effects in the Damping Ring"

Main HOM Effects

- Heating of vacuum elements
  - Temperature and vacuum rise
    - Deformations and vacuum leaks
    - Decreasing the pumping speed due to the large temperature rise
- Breakdowns and multipacting
    - Vacuum leaks
    - Melting thin shielded fingers
    - Longitudinal instabilities
- Electromagnetic waves outside vacuum chamber
    - Interaction with high sensitive electronics

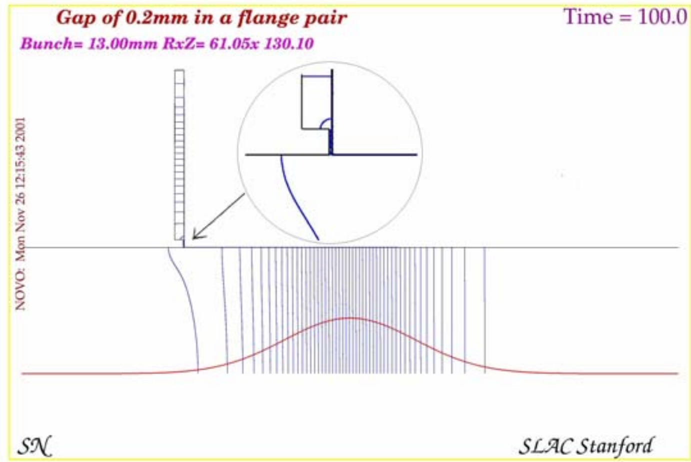
Examples from PEP-II

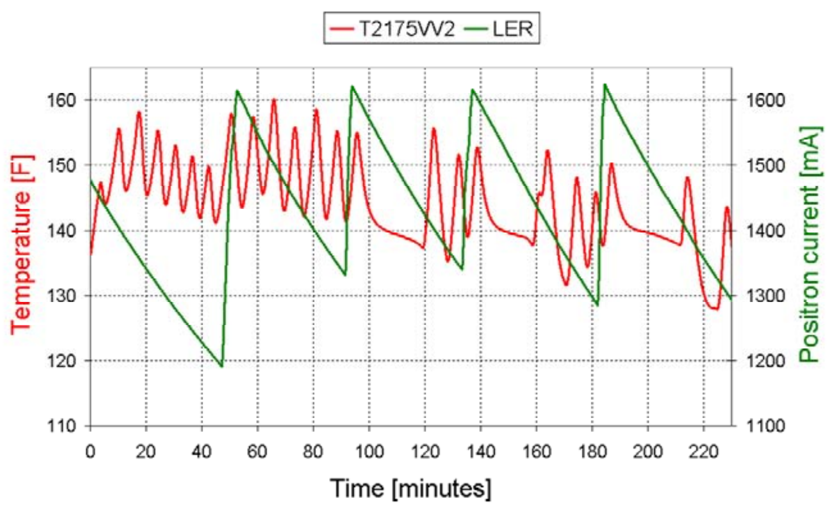
- A very small gap in a vacuum chamber is the source of high intensity wake fields, which cause the electric breakdowns

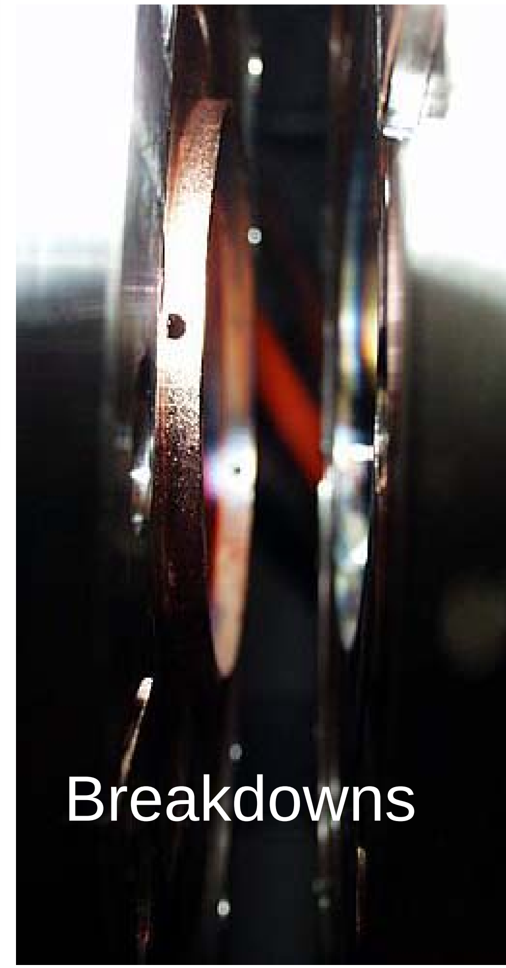
Small Gap, Breakdowns and Temperature Oscillations

Sasha Novokhatski "HOM Effects in the Damping Ring"

Wake fields due to small 0.2 mm gap In the flange connection





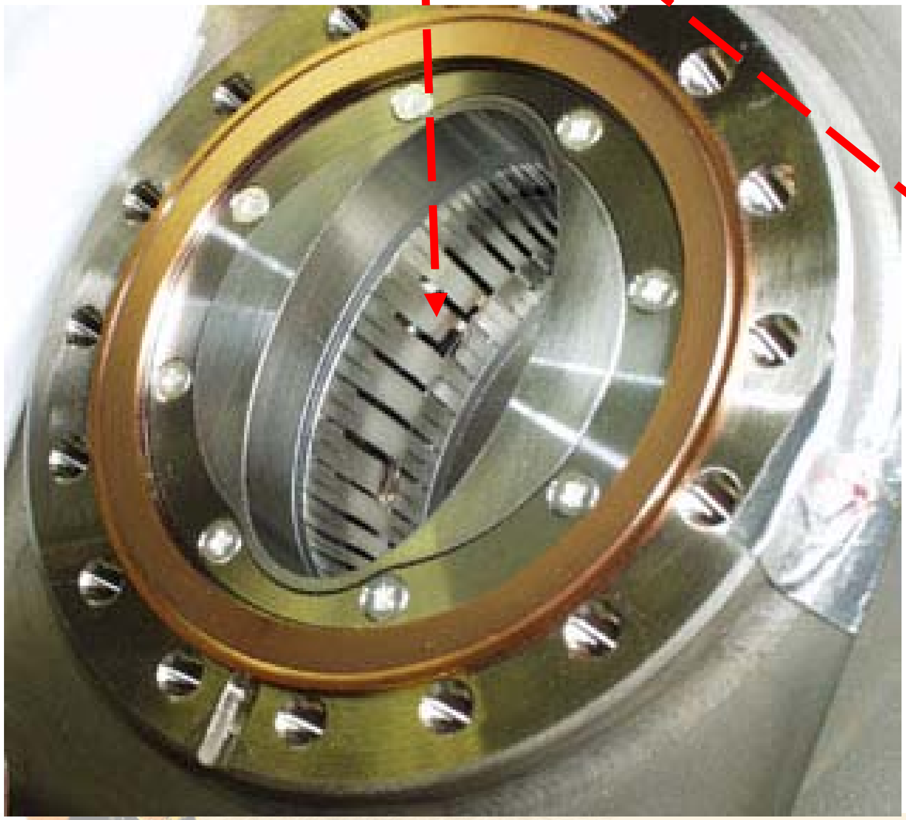


HOMs with transverse components

- Wake fields, which have transverse components may penetrate through small slits of shielded fingers to vacuum valves volumes and excite high voltage resonance fields, which may destroy the fingers

Wake field Evidence from PEP-II

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

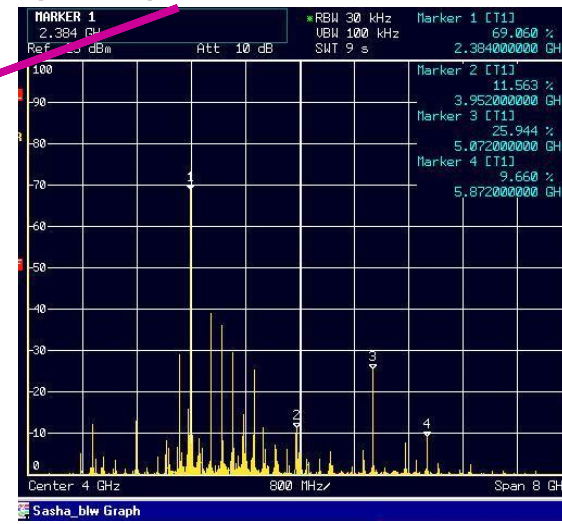


Wake fields outside

- Wake fields can go outside the vacuum chamber through heating wires of TSP pumps.

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).



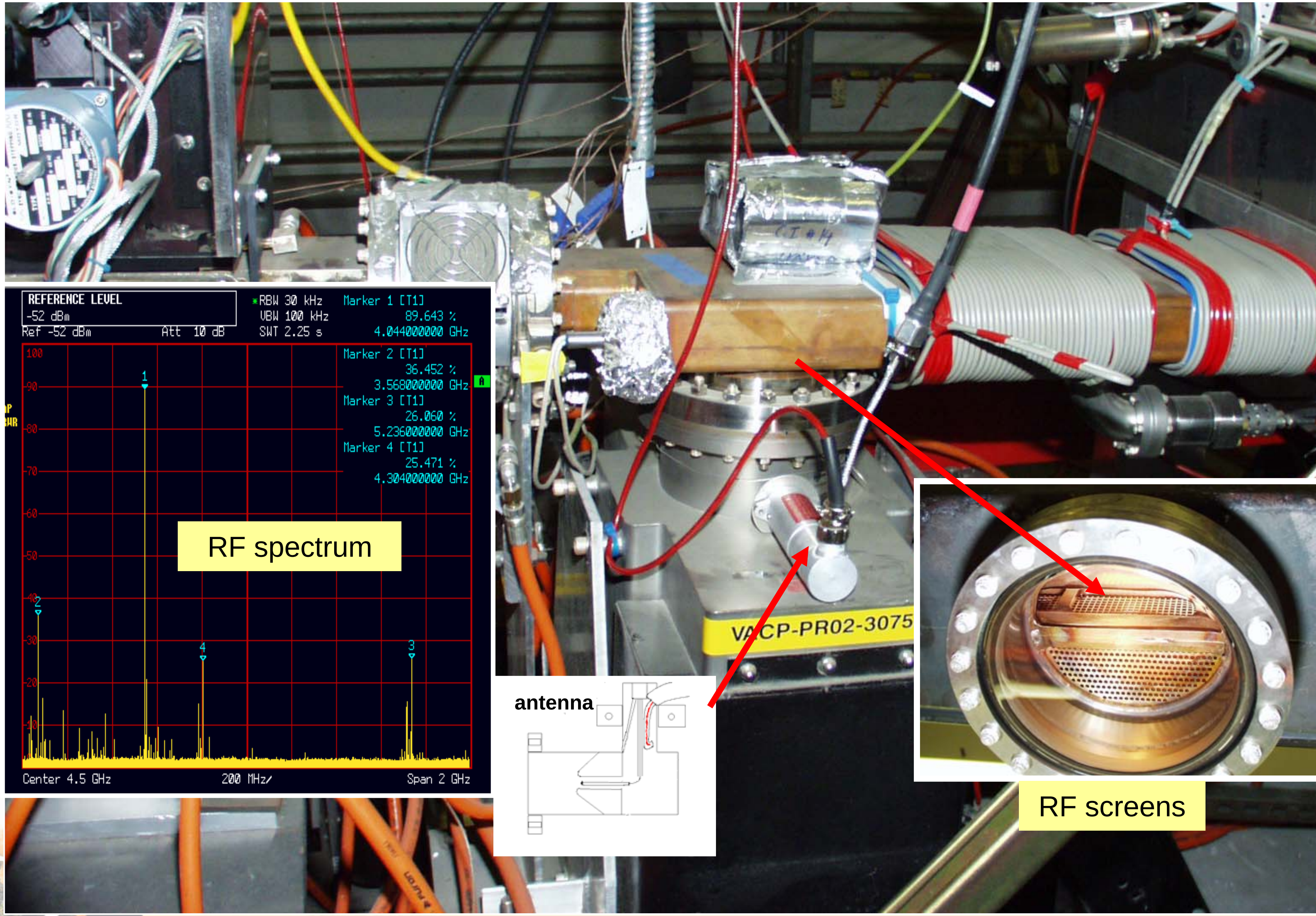
antenna

HOM spectrum from Spectrum analyzer

Wake fields

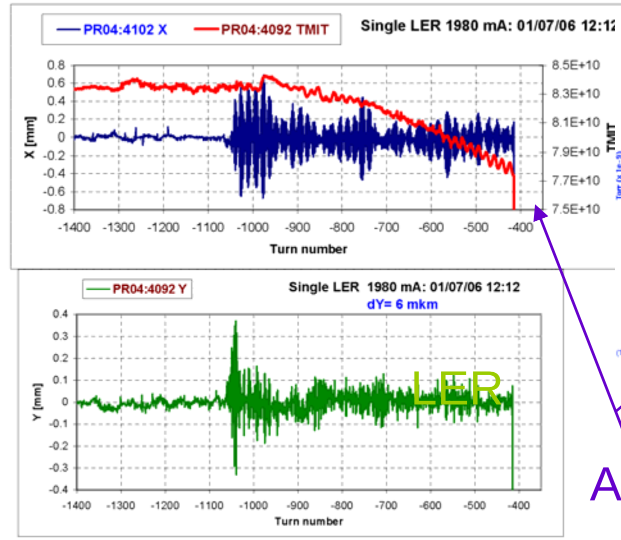
- Other possibilities for wakes to go outside is to escaped from the vacuum pumps through RF screens

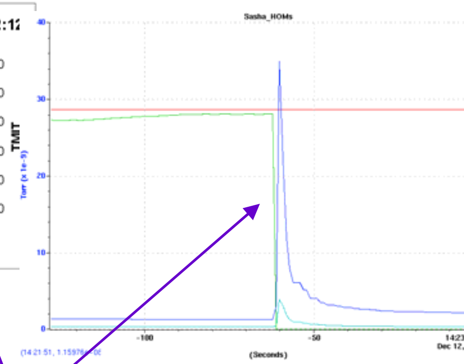
HOMs cam go through RF screens to pumps and then outside via high voltage cable



Sasha Novokhatski "HOM Effects in the Damping Ring"

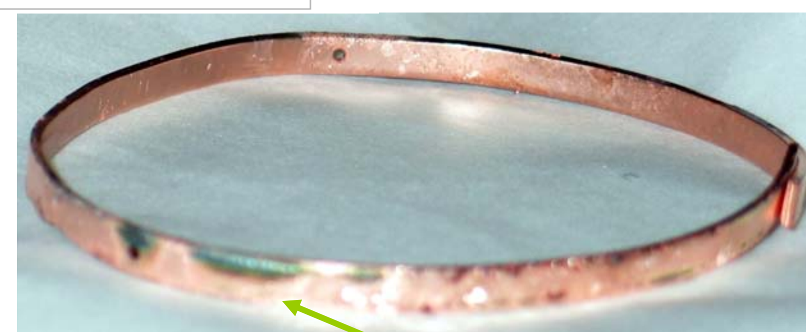
Not well installed gap ring may be a reason for the beam instability





Vacuum bursts

Abort

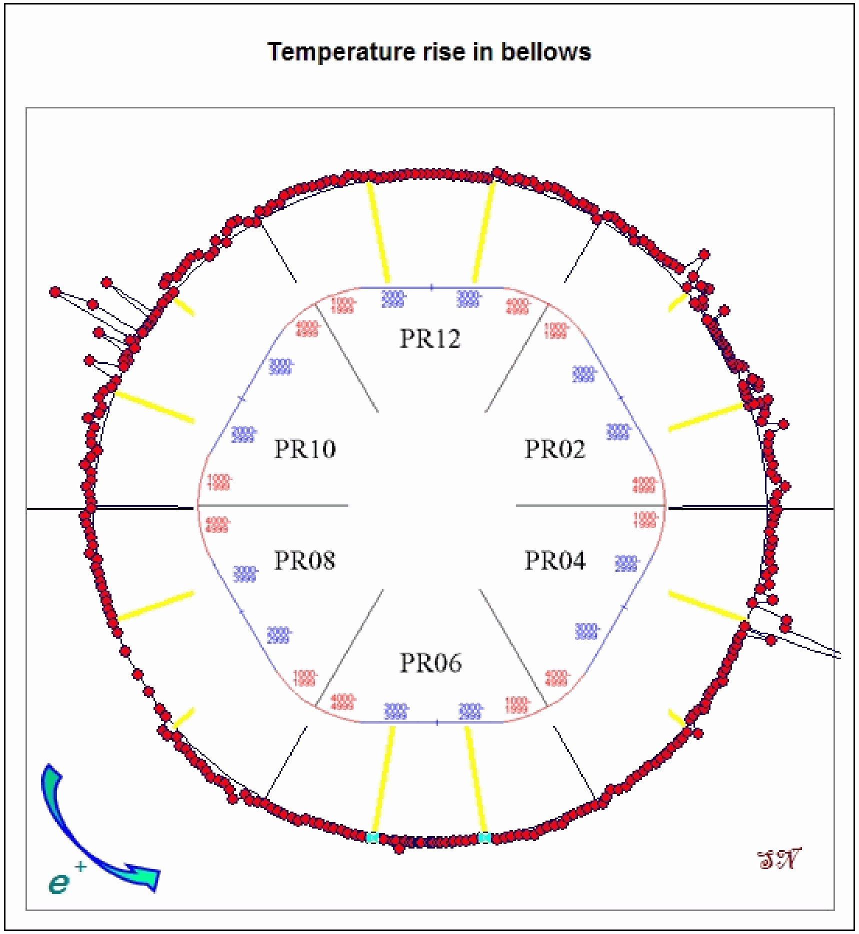


Breakdowns traces

Temperature raise

- Propagating in the vacuum chamber wake fields transfer energy to resonance HOM modes excited in the closed volumes of shielded bellows.
- Main effect is the temperature rise

Change of temperature raise due to RF voltage change in bellows



If we change the RF voltage in the cavities we change only the bunch length and consequently the HOM power.

So all the temperature rise is due only to the HOM power.

Sasha Novokhatski "HOM Effects in the Damping Ring"

Wake field Evidence from PEP-II

- All shielded bellows in LER and HER rings have fans for air cooling to avoid high temperature rise.

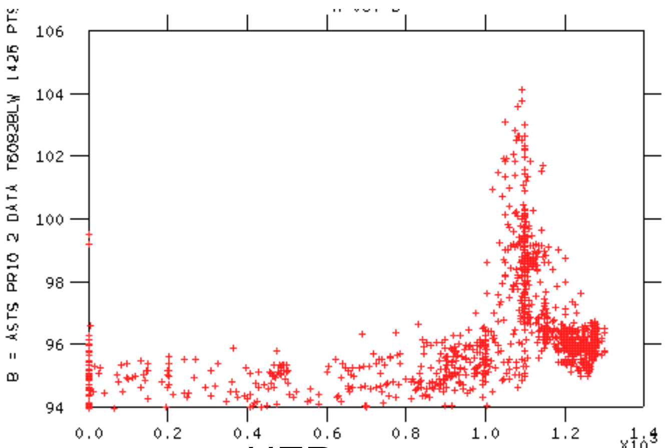
Resonance heating

- Some bellows have RF mode that are in resonance with the bunch spacing frequencies

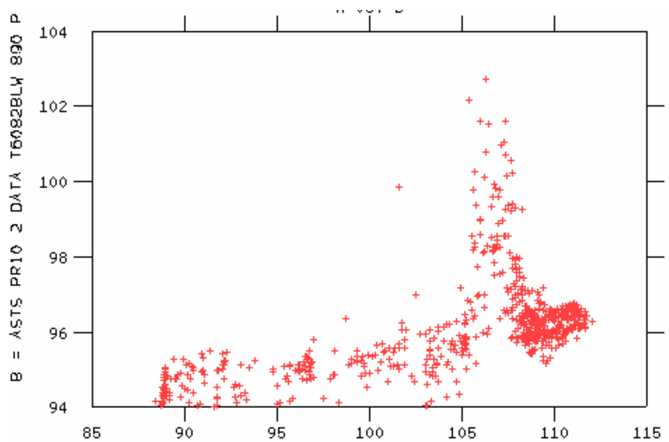
Bunch-spacing resonances in HER bellows

Sasha Novokhatski "HOM Effects in the Damping Ring"

Bellows temperature



HER current

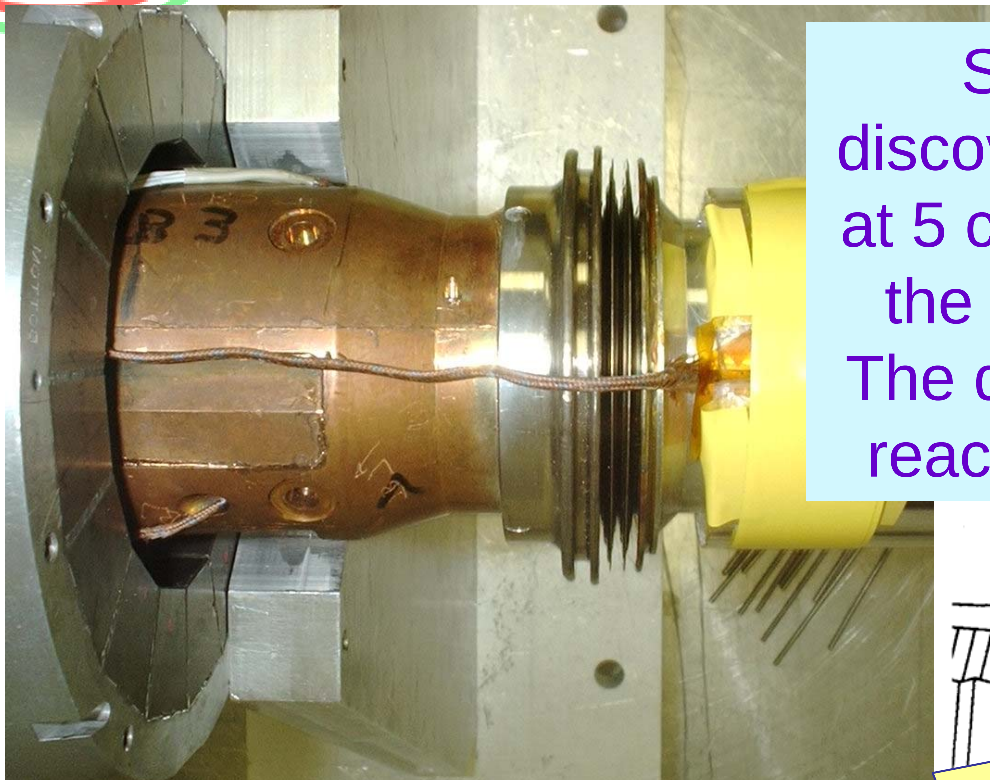


Vacuum chamber temperature

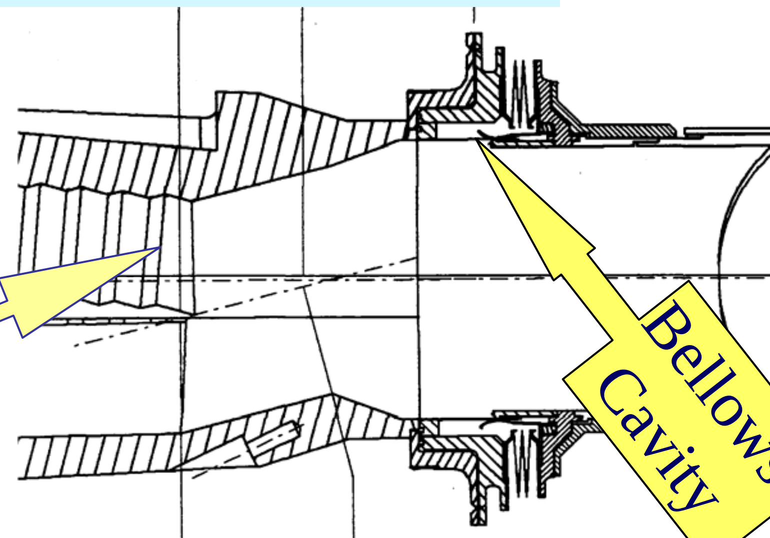
$$\frac{1}{Q} = \frac{\Delta f}{f} \sim \frac{\Delta l_{bellows}}{l_{bellows}} =$$

$$= \frac{\alpha l_{chamber} \times \Delta T_{chamber}}{l_{bellows}} \sim 10^{-3}$$

PEP-II Vertex Bellows



Stan Ecklund discovered resonance at 5 cm wavelength in the vertex bellows. The dissipated power reached 500 W limit

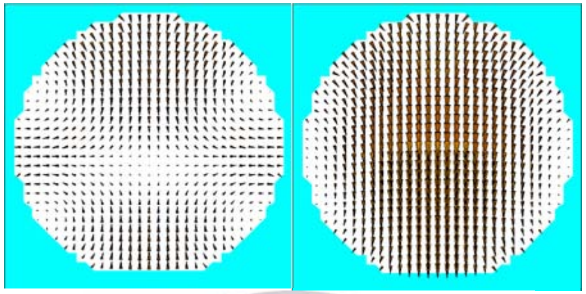


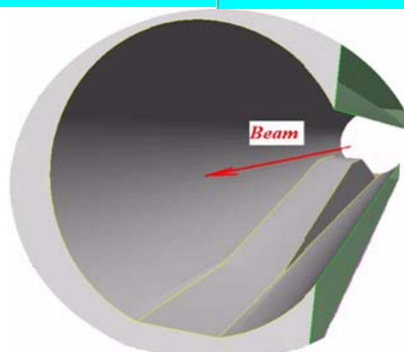
Localized HOM source

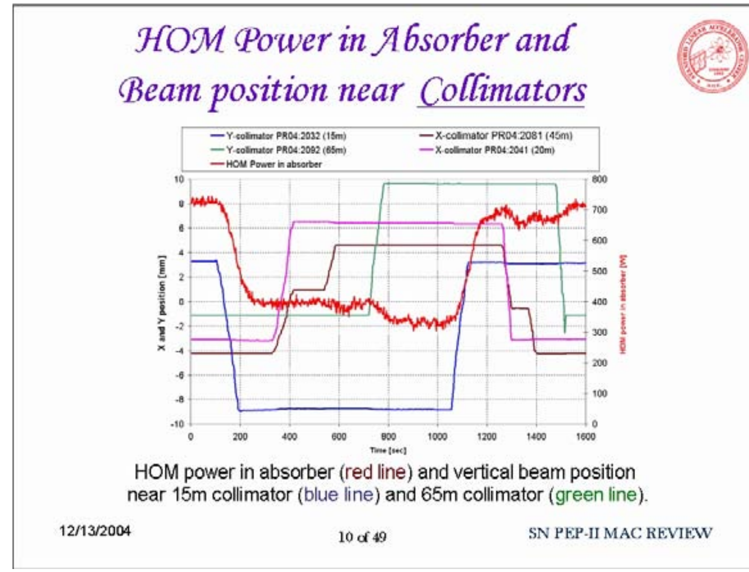
- Beam collimators are the powerful HOM sources in the PEP-II ring

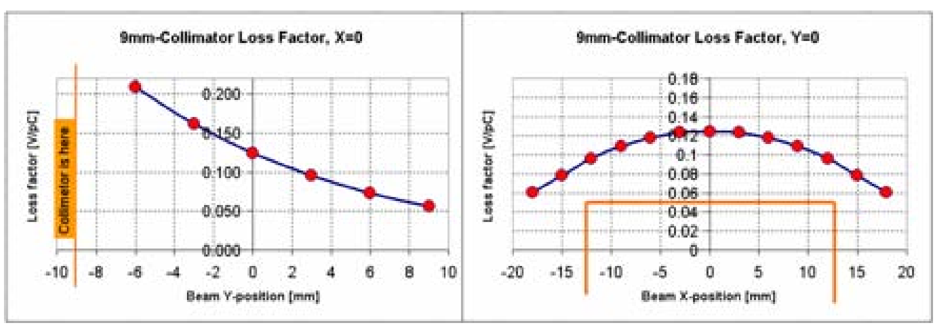
Collimators fields

Sasha Novokhatski "HOM Effects in the Damping Ring"



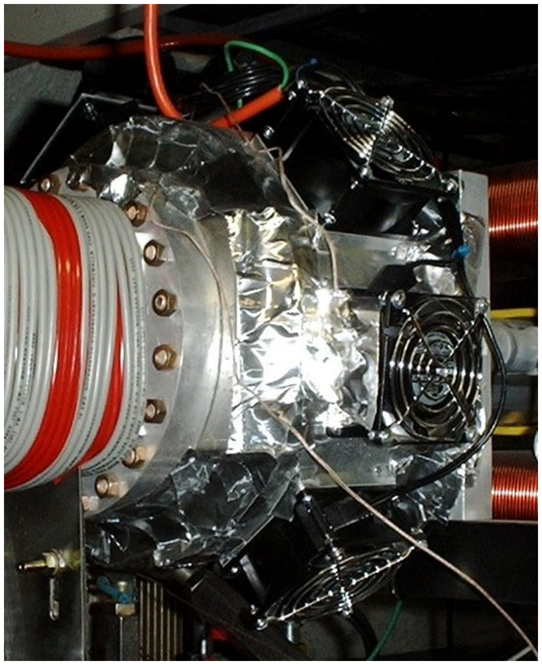


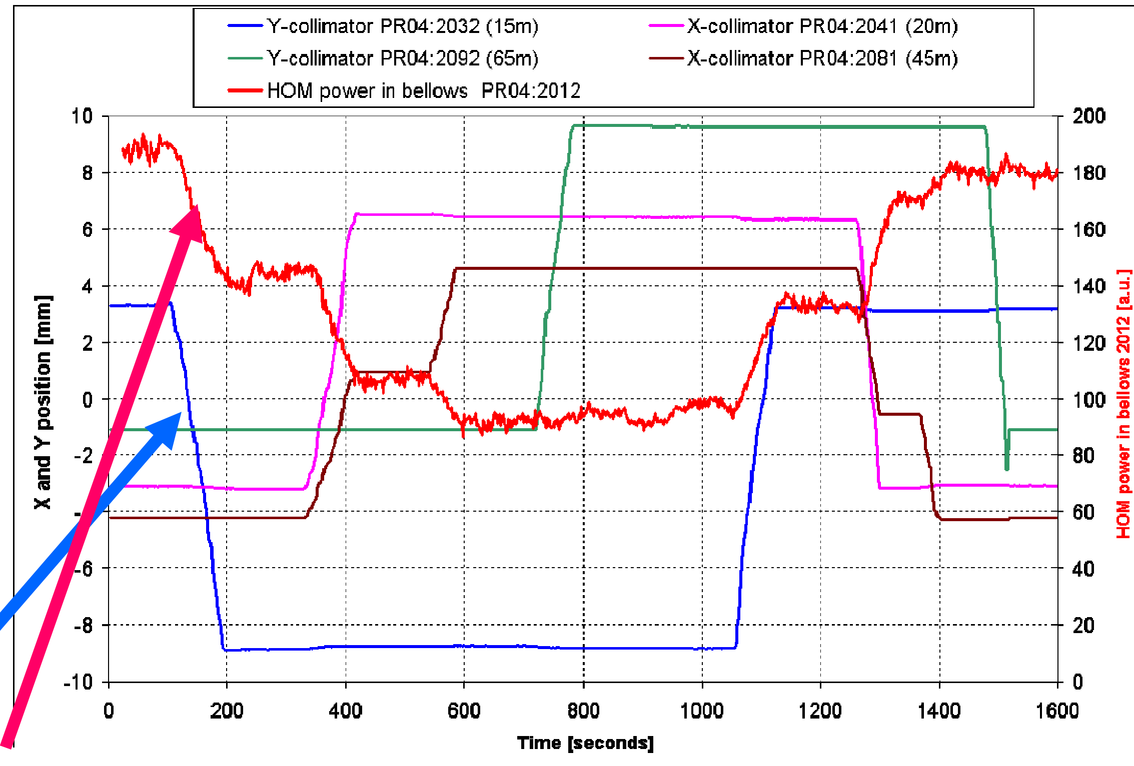




Hottest Bellows 2012 takes HOM power from four Y and X Collimators

Sasha Novokhatski "HOM Effects in the Damping Ring"





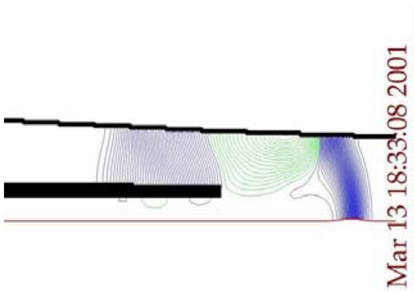
Y and X collimators

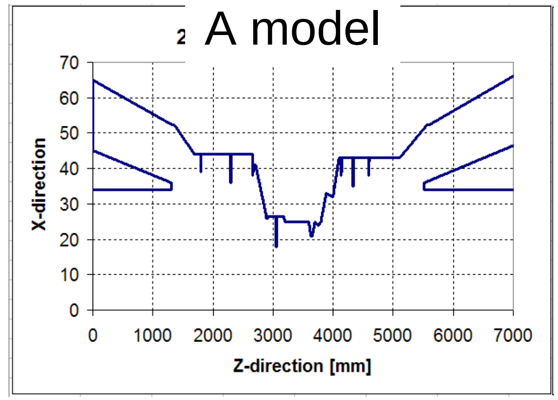
Interection region

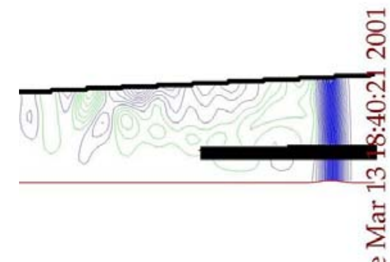
- High power wake fields are generated in a very complicated geometry of the Interaction region

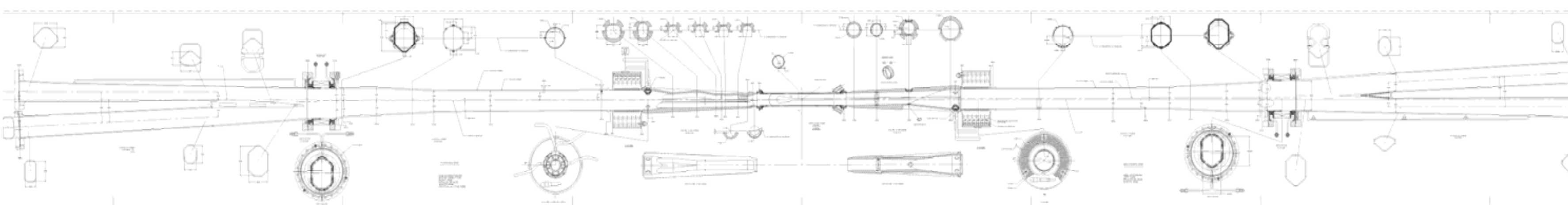
Wake in IP region of PEP-II

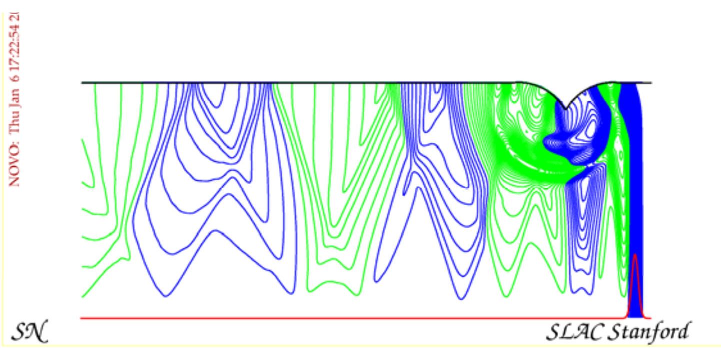
Sasha Novokhatski "HOM Effects in the Damping Ring"

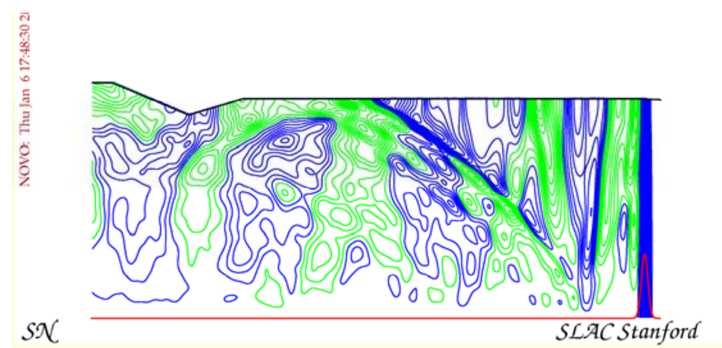






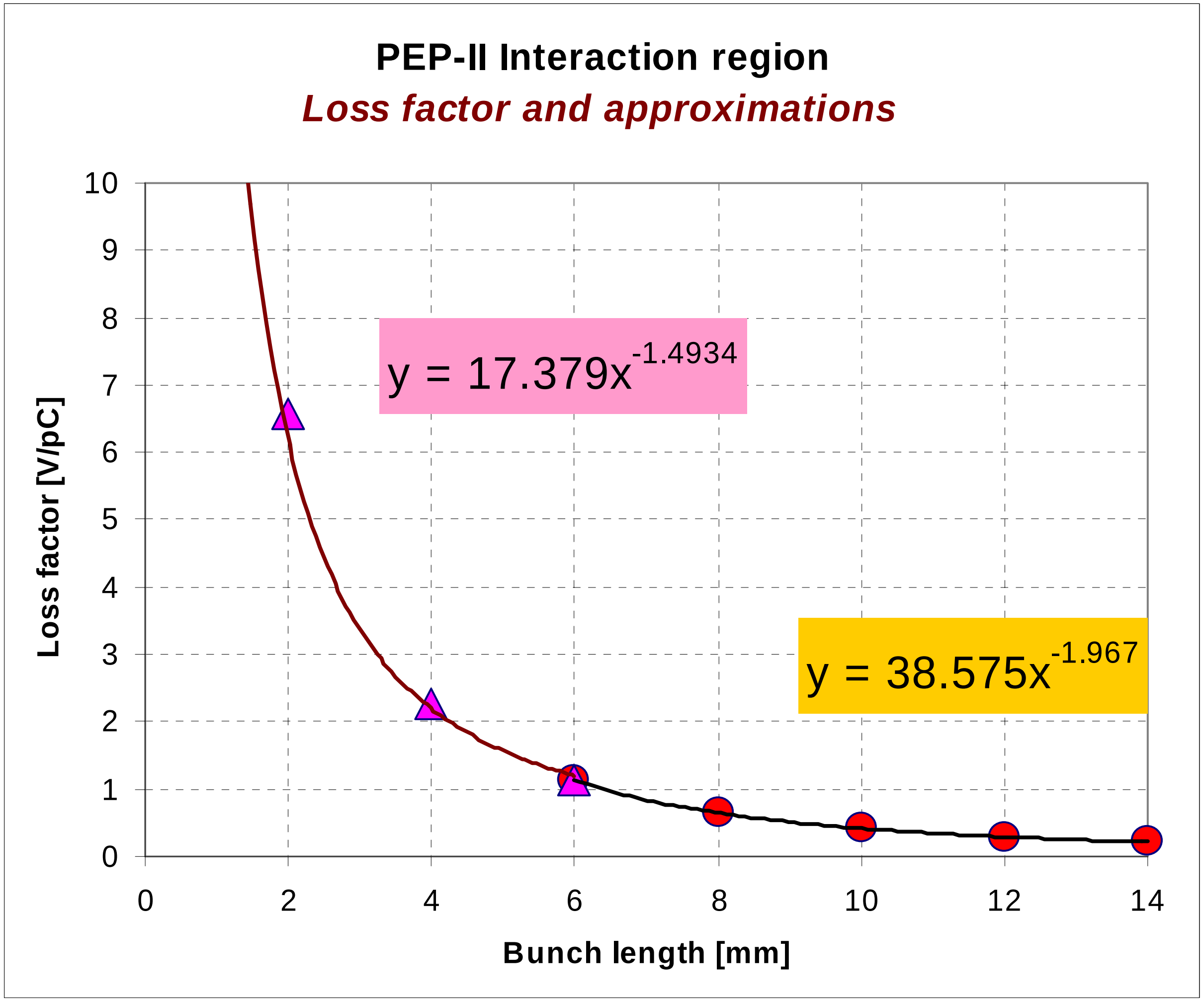






Loss factor for PEP-II IR

Sasha Novokhatski "HOM Effects in the Damping Ring"



Bunch length dependence changes from

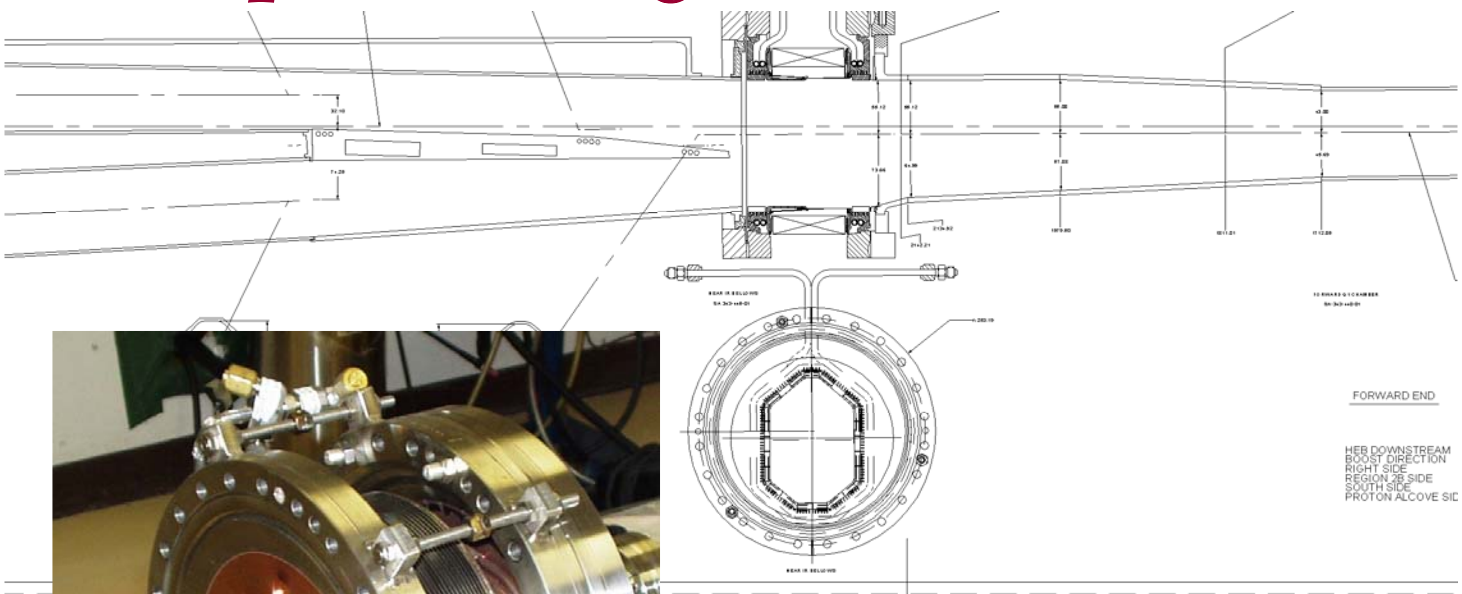
σ^{-2} (14-8 mm)

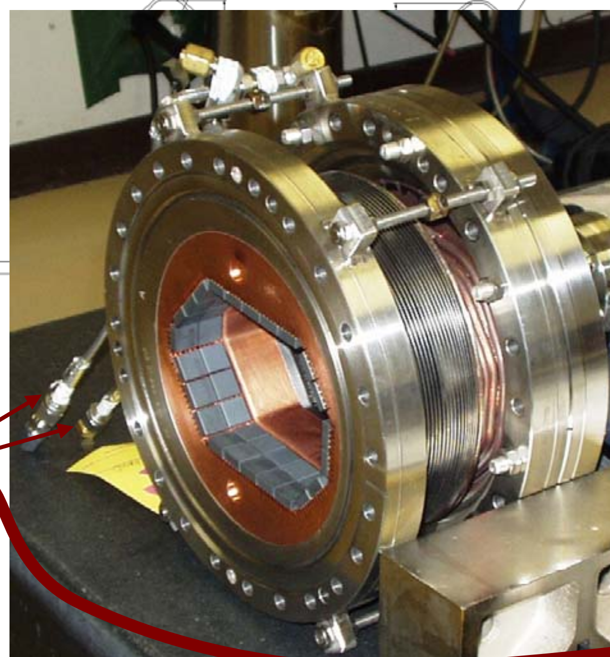
to

$\sigma^{-3/2}$ (6-1 mm)

Measurement of absorbed HOM power in Q2-bellows

Sasha Novokhatski "HOM Effects in the Damping Ring"

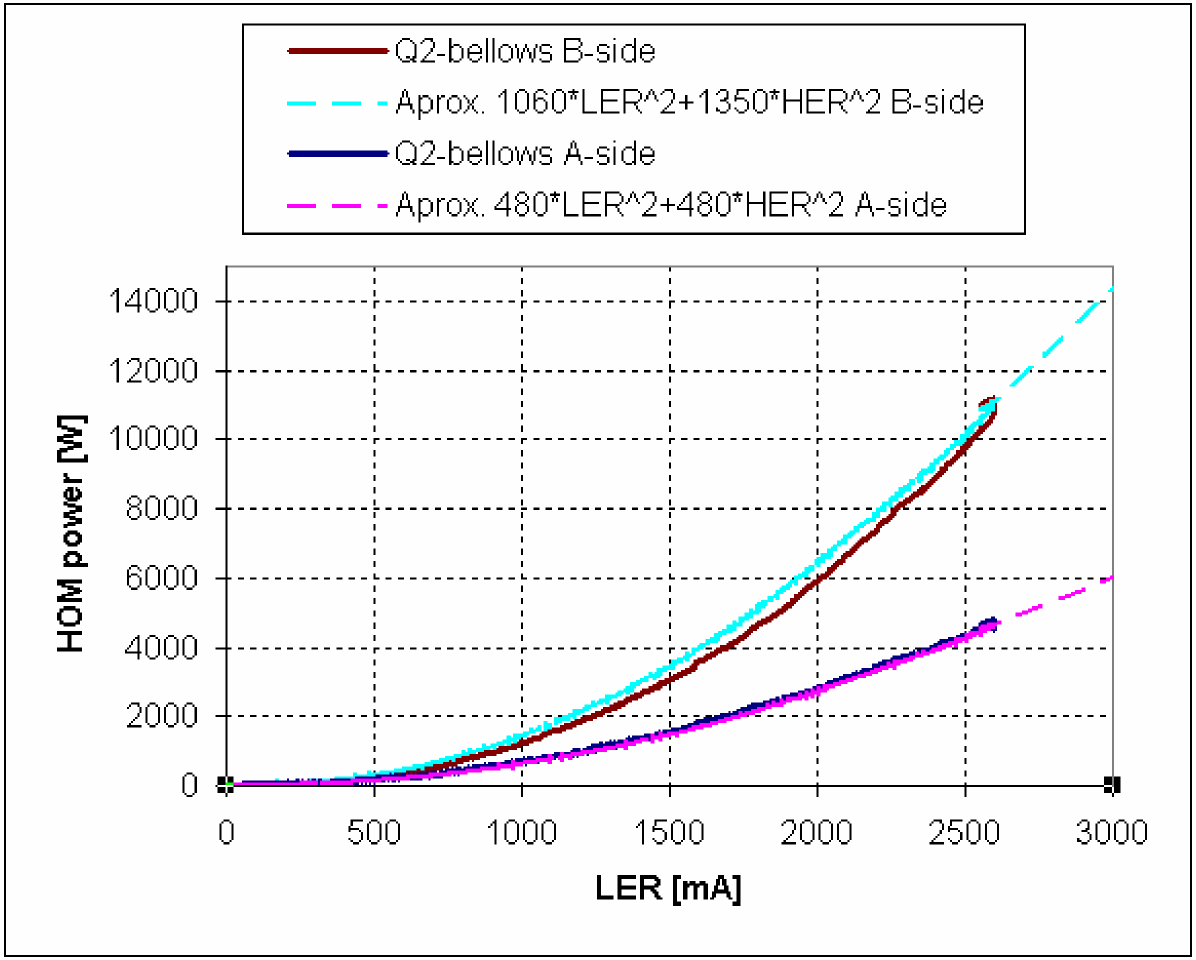




Thermocouples on input and output water pipes

$$P_{[W]} = 146.2 * Q_{[g/m]} * \Delta T_{[F^\circ]}$$

Measurement of the HOM power



B-side
14 kW

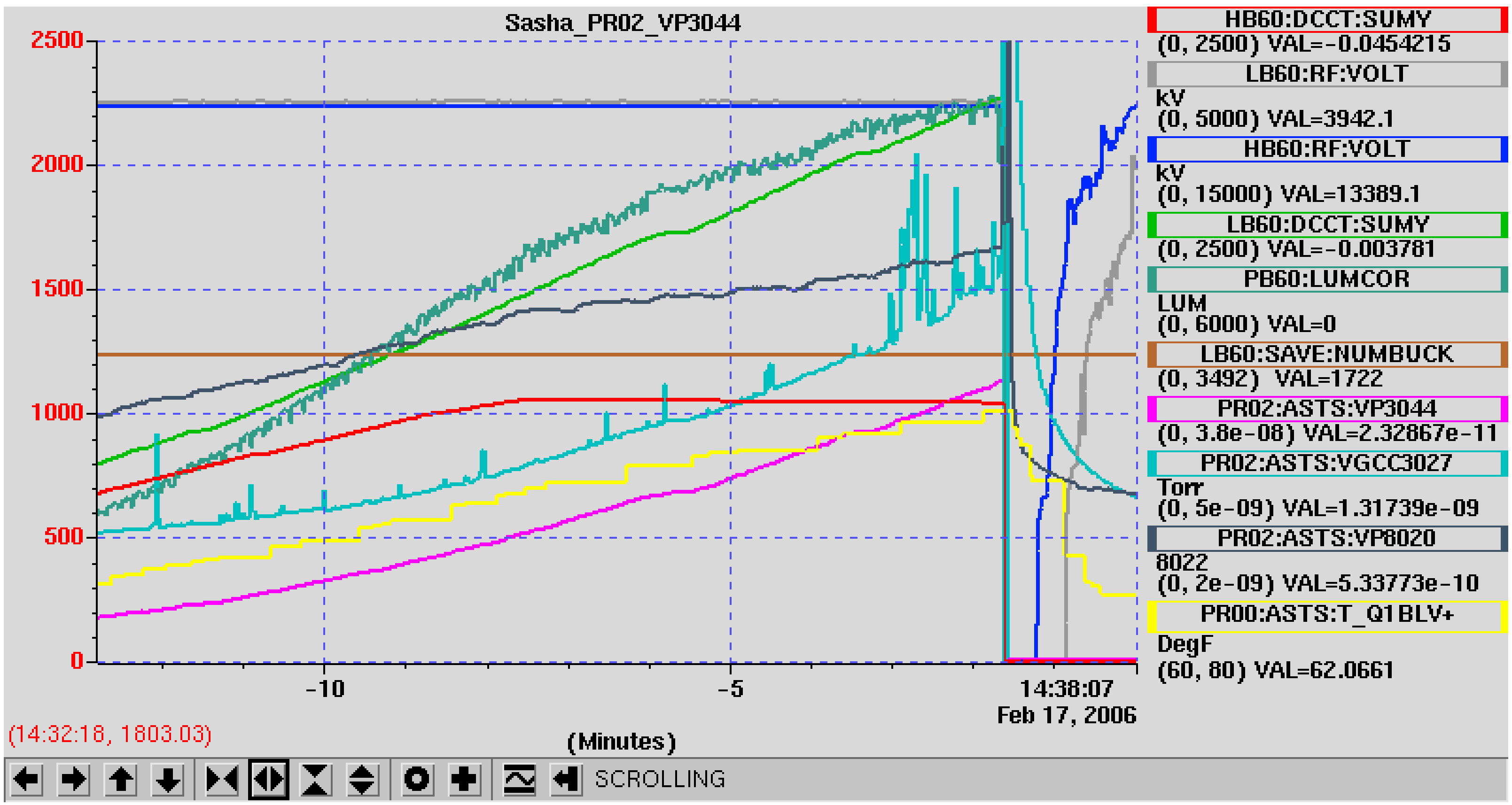
A-side
6 kW

IP HOM Power simulation results

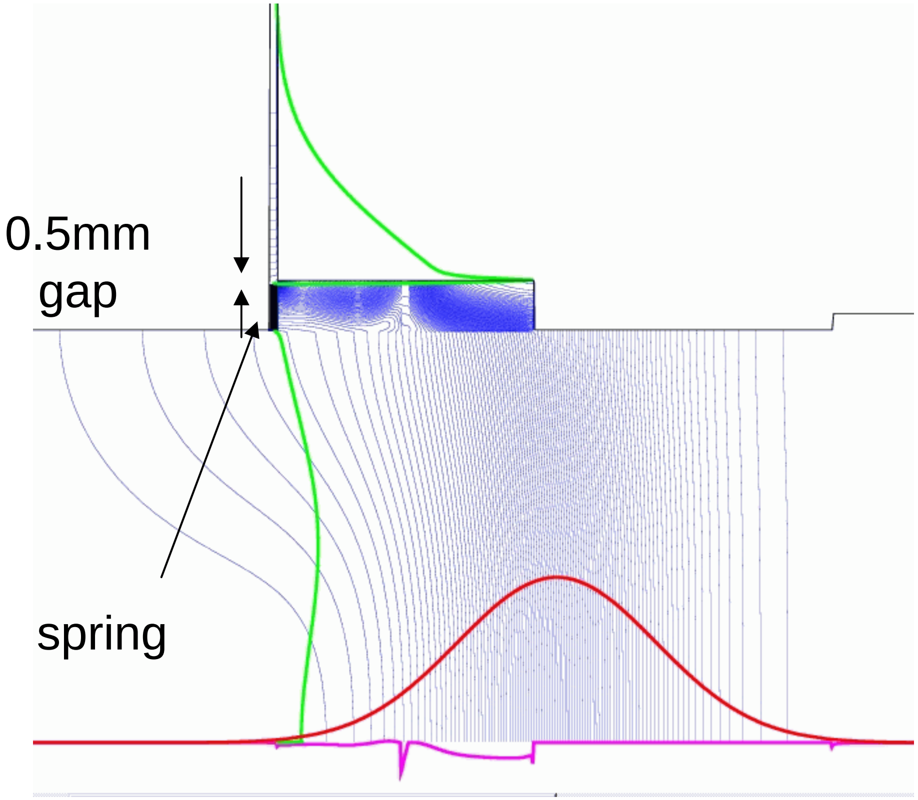
Sasha Novokhatski "HOM Effects in the Damping Ring"

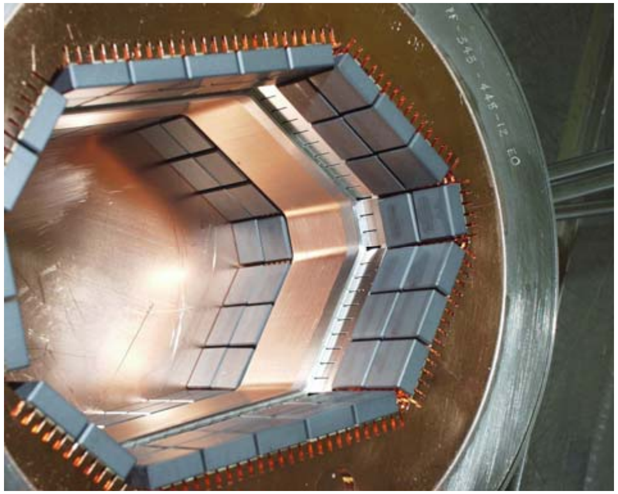
Parameters	PEP-II	Super B
Bunch length [mm] =	11.3	6
Loss factor [V/pC]=	0.327	1.137
LER current [A]	2.6	2.6
HER current [A]	1.7	1.9
Bunch spacing [nsec]	4.2	4.2
Power loss (pulse) [kW]	13.26	49.51

At the end of 2005 and beginning 0f 2006 we got a problem: vacuum spikes and aborts in Interaction Region

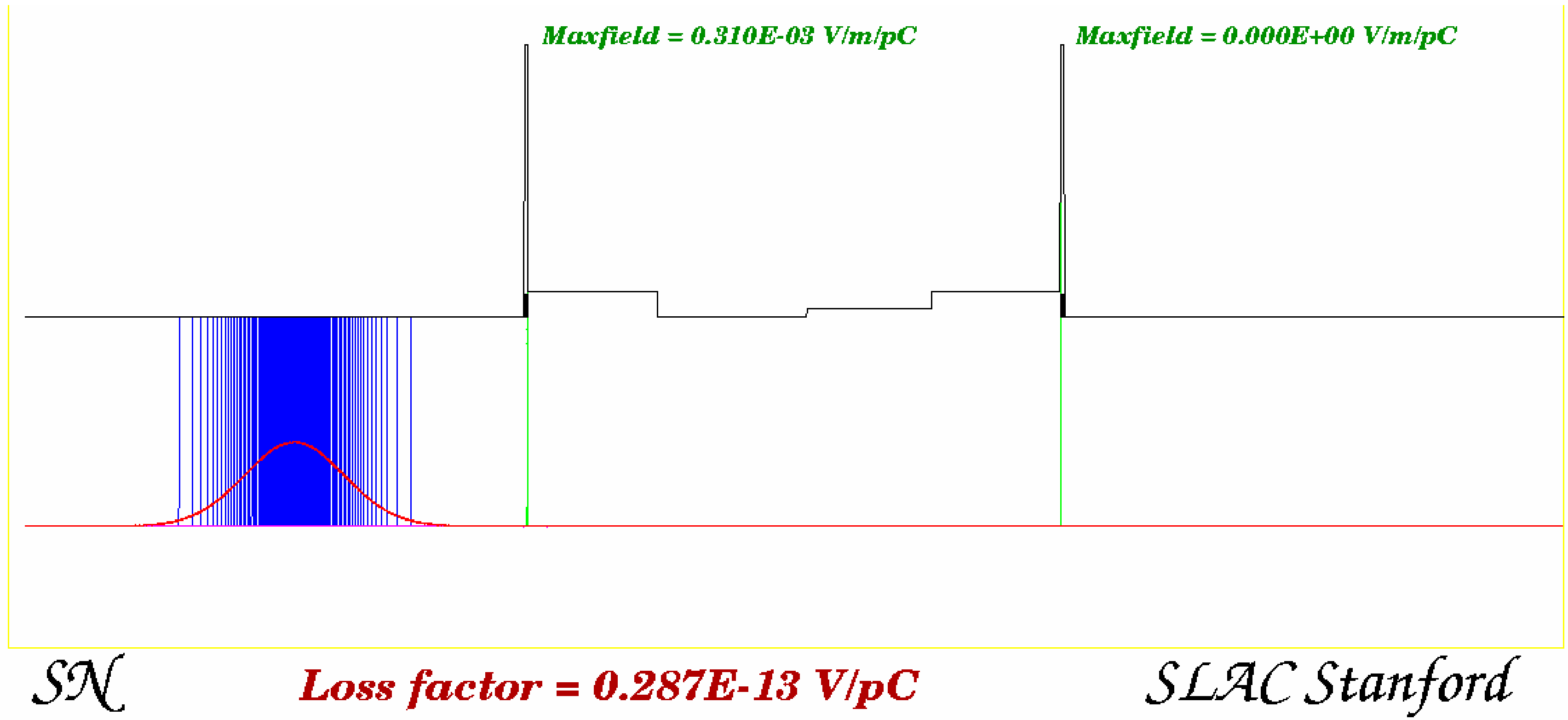


John Seeman suggested that a small gap between a ceramic tile and a metal omega-spring may be the reason for vacuum spikes . Wake electric fields may be above the breakdown limit.



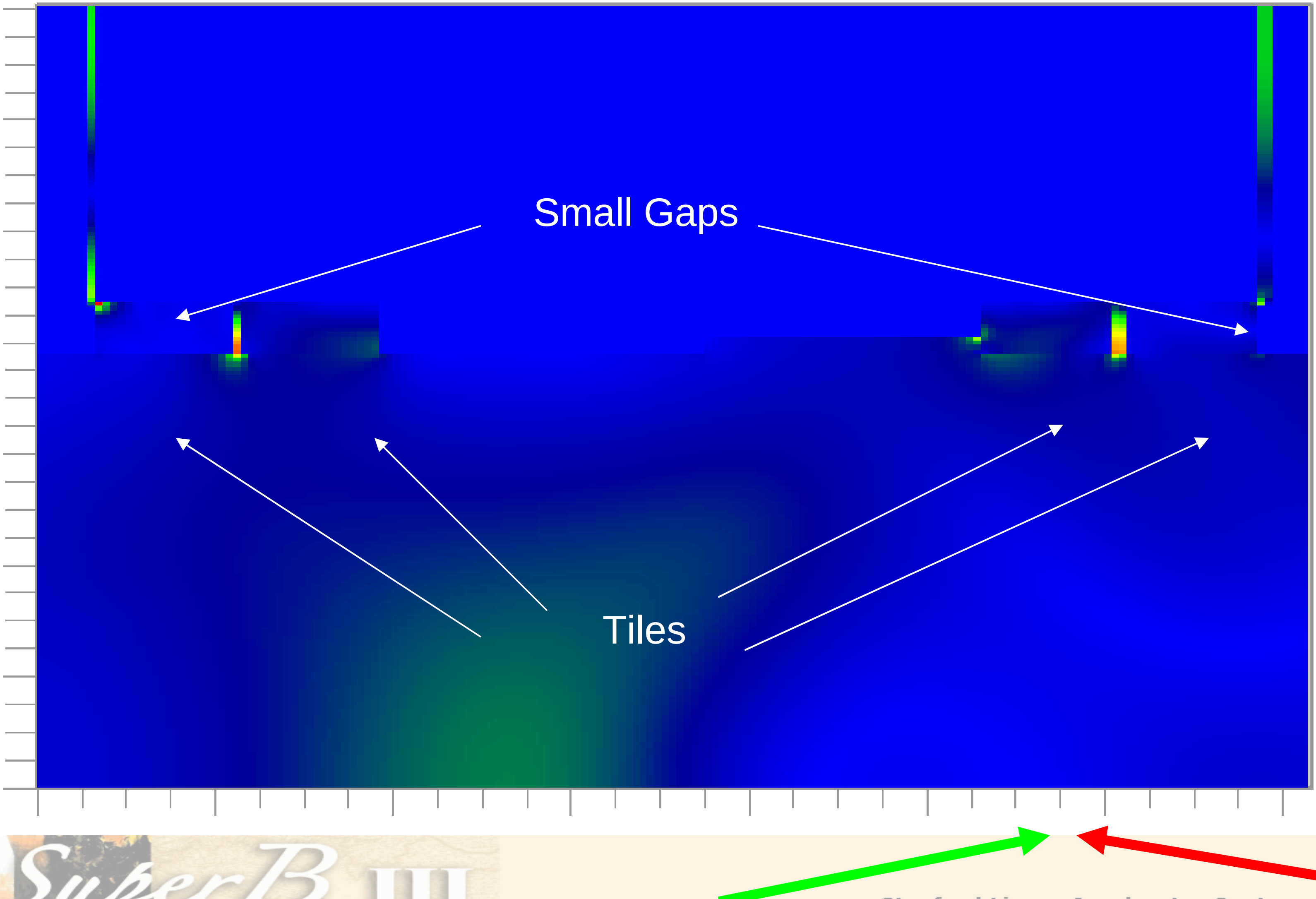


Simulations: Electric displacement force lines



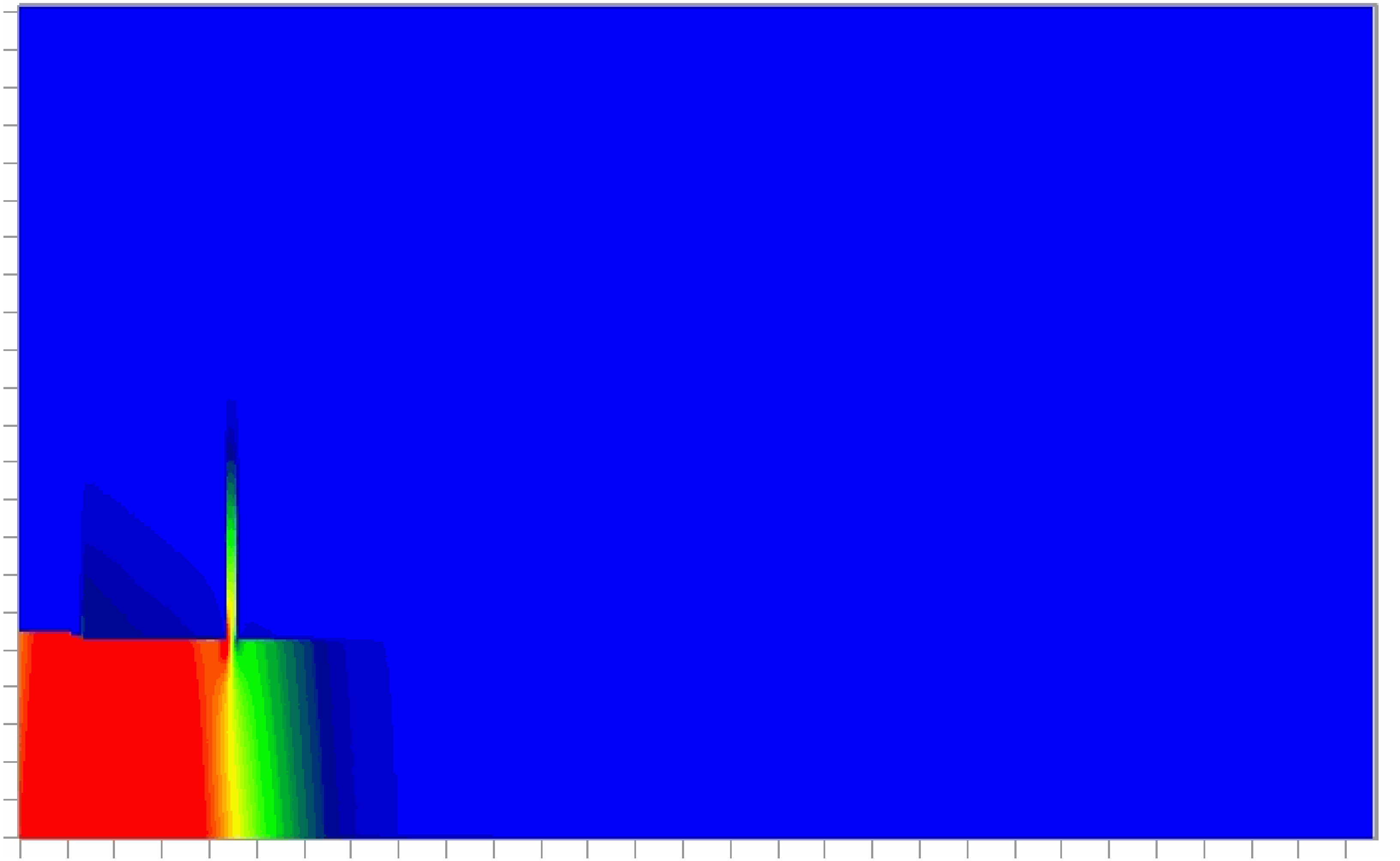
Electric field distribution

Sasha Novokhatski "HOM Effects in the Damping Ring"

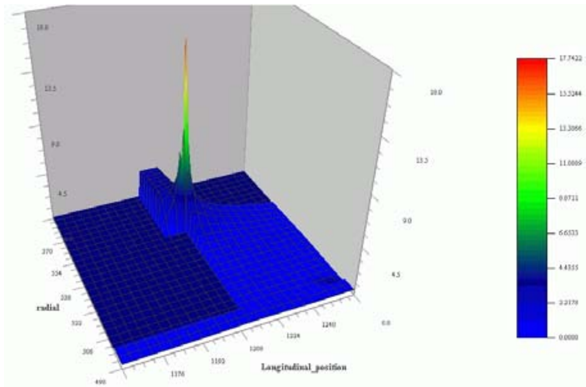


In time

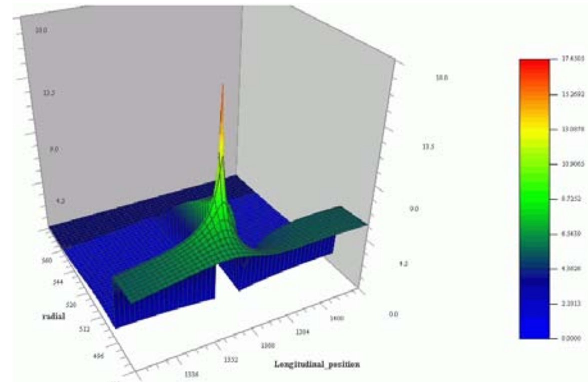
Sasha Novokhatski "HOM Effects in the Damping Ring"



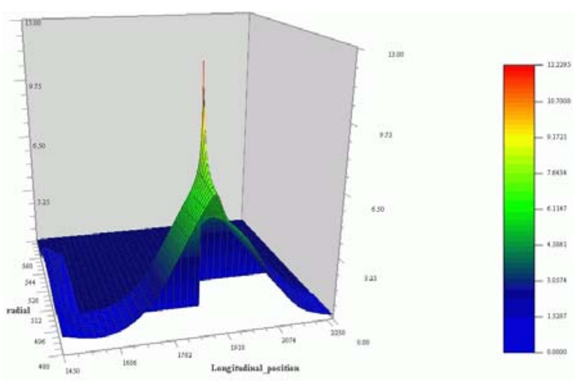
Maximum electric field is near the breakdown limit



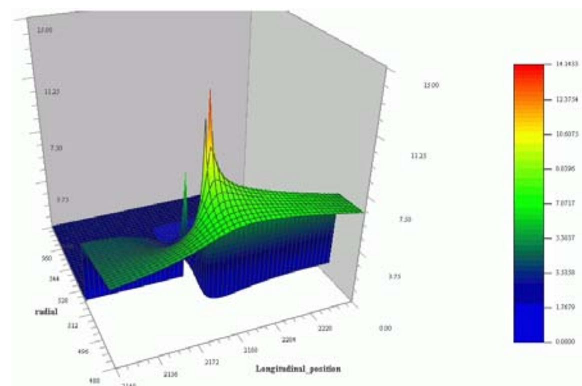
Left spring corner



First tiles gap

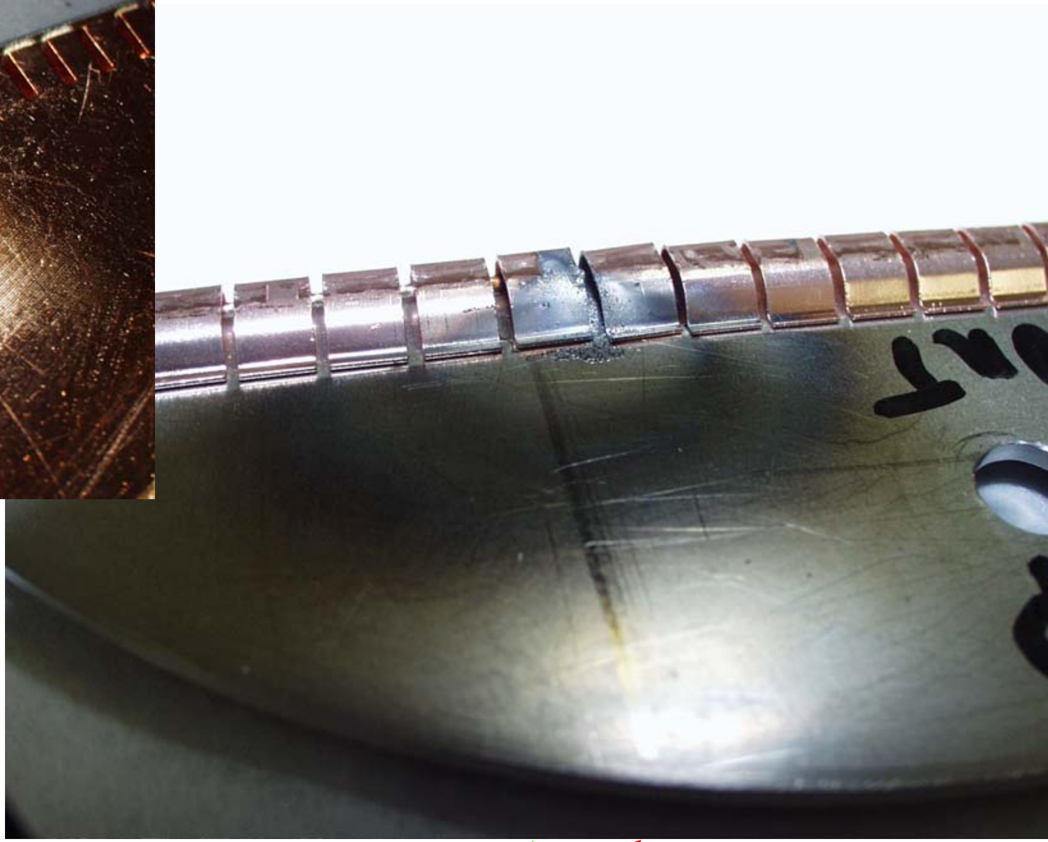


Metal corner

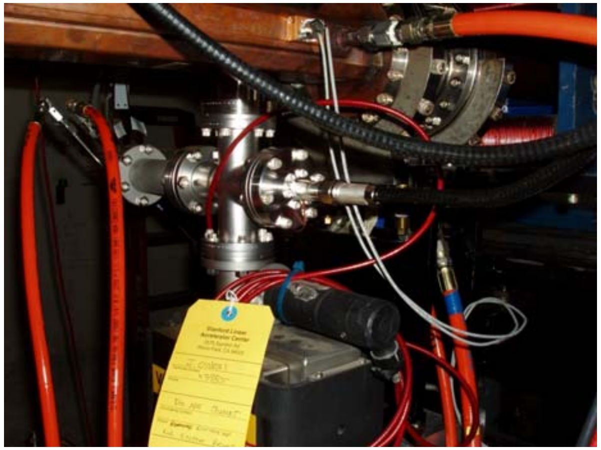


Tile corner

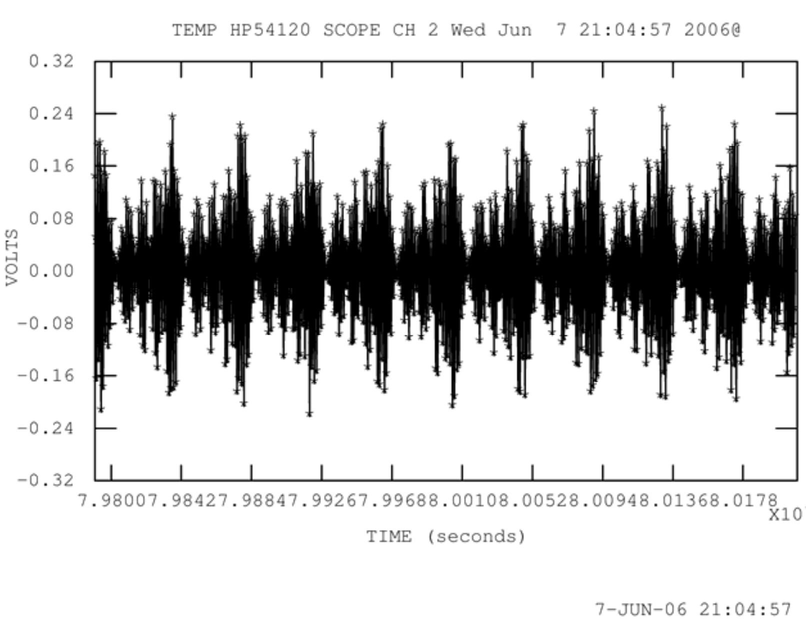
What we later found

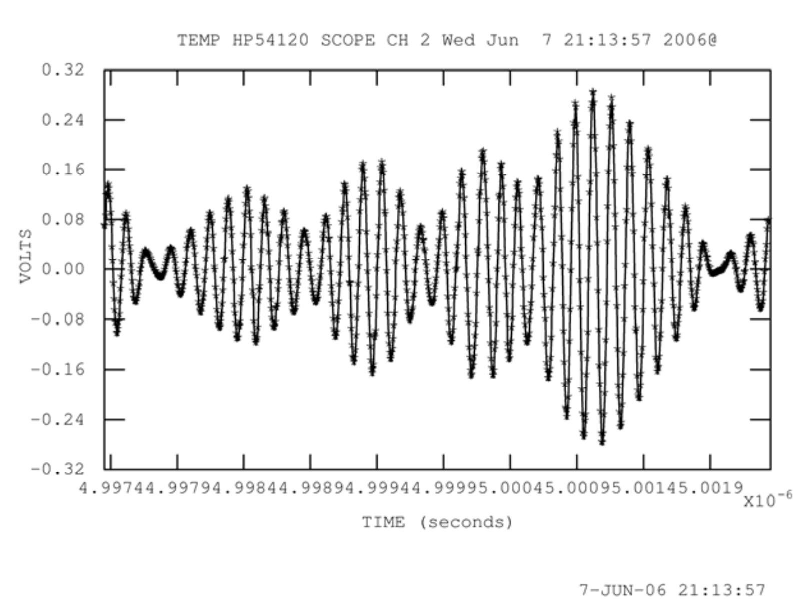


Fields that killed BPMs in PR02:2062



7 GHz beat-waves





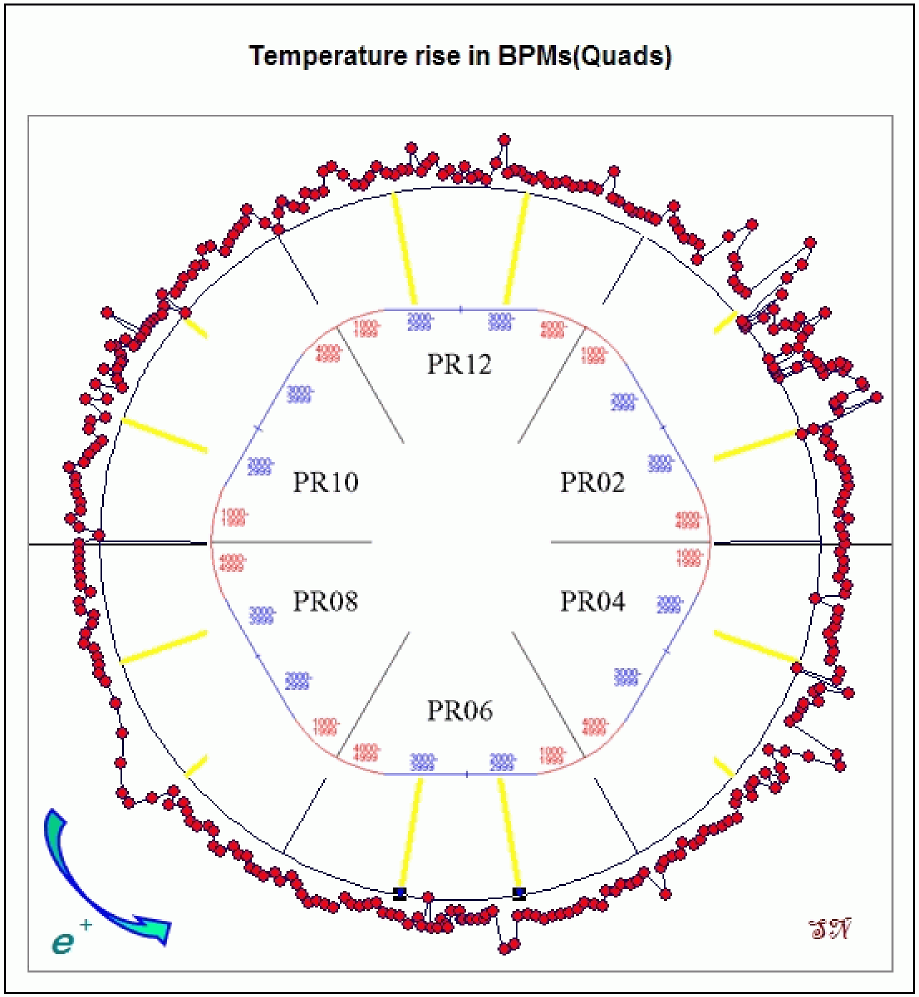
Sasha Novokhatski "HOM Effects in the Damping Ring"

Resistive-wall wake fields

- Other type of wake fields is due to the finite conductivity of vacuum chamber walls.
- Resistive-wall wake fields usually give temperature rise of the chamber walls.
- In all cases the beams energy loss has to be restored by the additional power the klystrons

Change of temperature raise due to RF voltage change in chambers

Sasha Novokhatski "HOM Effects in the Damping Ring"



RF Voltage was changed from
4.5 MV to 5.4 MV

Temperature of the vacuum chamber changed by 4F around the ring

Estimation of the total Resistive wake loss

Sasha Novokhatski "HOM Effects in the Damping Ring"

$$P = \frac{C}{\sigma^{3/2}}$$

$$\Delta P = -\frac{3}{2}\frac{C}{\sigma^{3/2}} * \frac{\Delta\sigma}{\sigma}$$

$$C = -\frac{2}{3}\frac{\Delta P * \sigma^{3/2}}{\frac{\Delta\sigma}{\sigma}}$$

V2 [MV]	5.40
sigma at V1 [mm]	12.00
sigma at V2 [mm]	10.39
V2/V1	1.33
sqrt(V2/V1)-1	0.15
Water-cooled circuits	200.00
Water flow g/m	1.00
delta T [F]	4.00
Delta power [Kw]	**116.80**
C	20923.37
Total Power at V1 [kW]	**503.34**
Total Power at V2 [kW]	**624.55**

Resistive Wall Wakefield Losses- formulas

Loss factor asymptotic (M. Sands, K. Bane)

$$s_0 = \left(2a^2 \frac{\rho}{Z_0}\right)^{1/3} \text{ when } \frac{s_0}{\sigma_z} << 1$$

$$K \approx 0.2 * \frac{Z_0 c}{4\pi a^2} * \left(\frac{s_0}{\sigma_z}\right)^{3/2} = 0.2 * \frac{Z_0 c}{4\pi a^2} * \left(\frac{1}{\sigma_z}\right)^{3/2} * \sqrt{2\frac{\rho}{Z_0}}$$

Resistive Wall Wakefield Power in PEP-II

pipe Radius [m]	0.045	0.035	0.045
Material	Cu	Al	SS
resistivity [Ohm m]	1.69492E-08	2.8571E-08	7.14E-07
S0 [m]	5.66792E-05	5.705E-05	0.000197
bunch length [m]	0.012	0.012	0.012
loss factor [V/pC]	0.000288255	0.00048119	0.001871
Bunch spacing [nsec]	4.2	4.2	4.2
beam current [A]	2.2	2.2	2.2
power [kW/m]	**0.024610531**	**0.04108255**	**0.159765**
Total (20/30/50) [kW]	**213.68516**		
Current=3A	**397.3484337**		

Resistive Wall Wakefield Power for super-B

pipe Radius [m]	0.045	0.045	0.045
Material	Cu	Al	SS
resistivity [Ohm m]	1.69E-08	2.86E-08	7.14E-07
S0 [m]	5.67E-05	6.75E-05	1.97E-04
bunch length [m]	0.003	0.003	0.003
loss factor [V/pC]	0.002	0.003	0.015
Bunch spacing [nsec]	2.1	2.1	2.1
beam current [A]	2.4	2.4	2.4
power [kW/m]	**0.059**	**0.076**	**0.380**

Comparison of 2.5, 1, and 0.5 cm pipes for vertex pipe.

Material	Cu	Cu	Cu
resistivity [Ohm m]	1.69E-08	1.69E-08	1.69E-08
S0 [m]	3.83E-05	2.08E-05	1.31E-05
bunch length [m]	0.004	0.004	0.004
Loss factor	0.003	0.007	0.013
Bunch spacing [nsec]	2.1	2.1	2.1
beam current [A]	2.4	2.4	2.4
power [kW/m]	**0.068**	**0.171**	**0.342**

This is only resistive-wall power!

What we can do

- There is only one way :

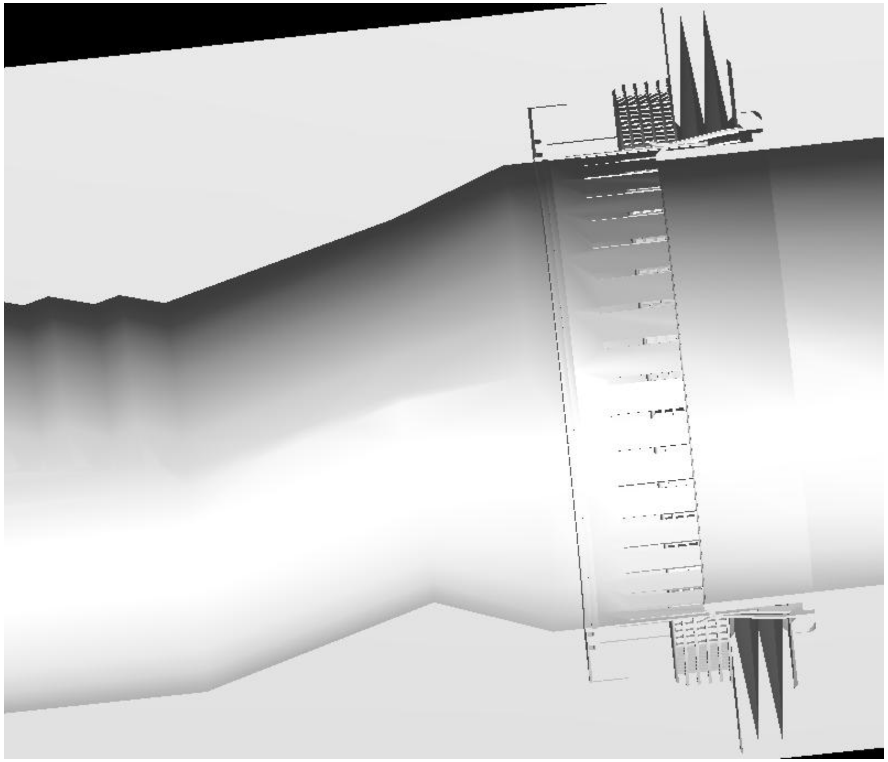
  absorb HOM power

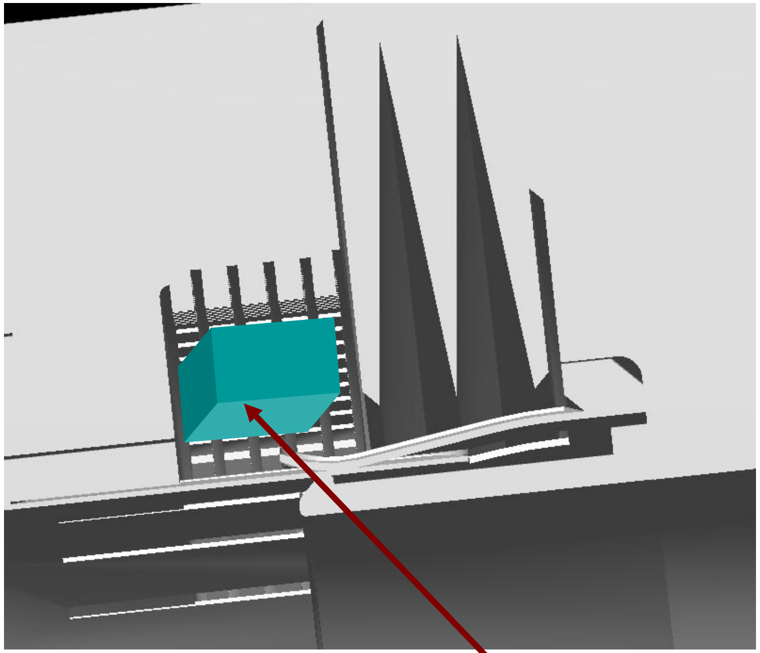
  in the specially designed water-cooled HOM absorbers

Water-cooled absorbers in bellows

Sasha Novokhatski "HOM Effects in the Damping Ring"

Field leakage though bellows fingers

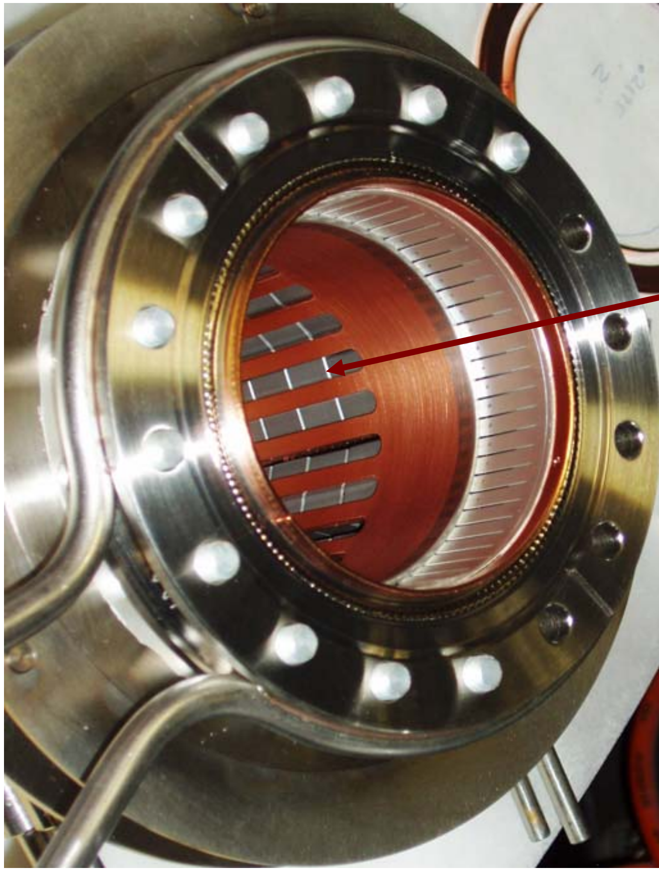




HOMs are be captured by ceramic absorbing tiles brazed to cupper block

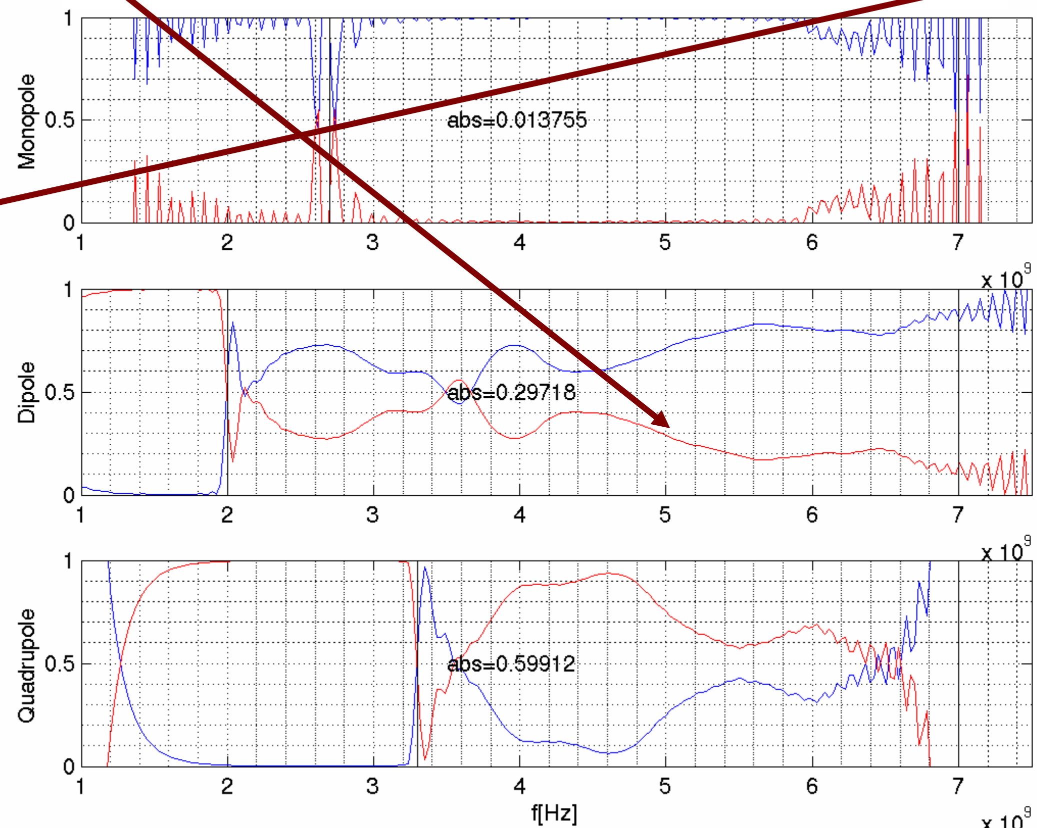
Selective absorber device to capture the collimator HOMs

Sasha Novokhatski "HOM Effects in the Damping Ring"



J. Seeman, M. Kosovsky and N. Kurita

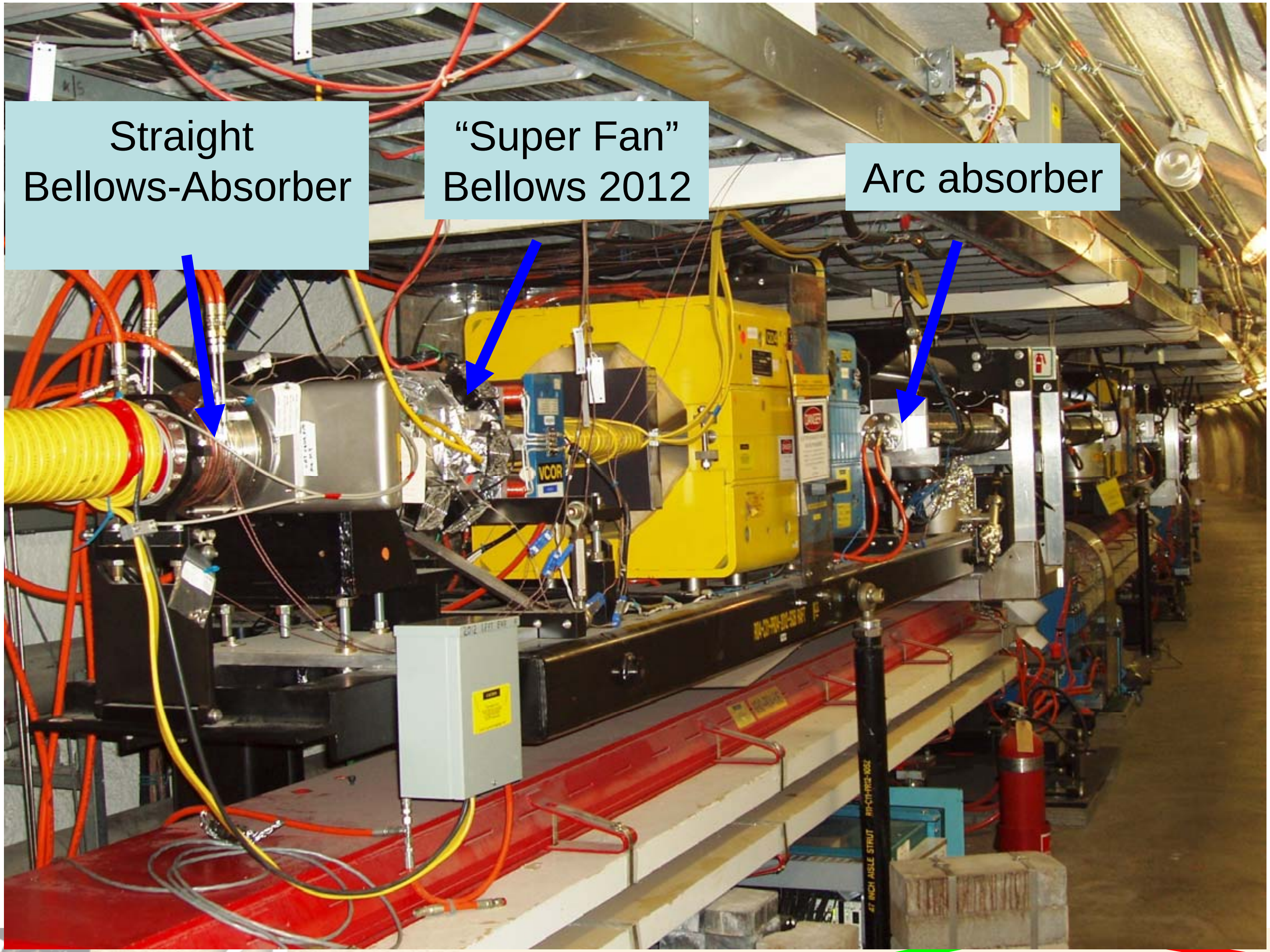
Red line shows absorption in ceramic tiles



S.Novokhatski and S. Weathersby

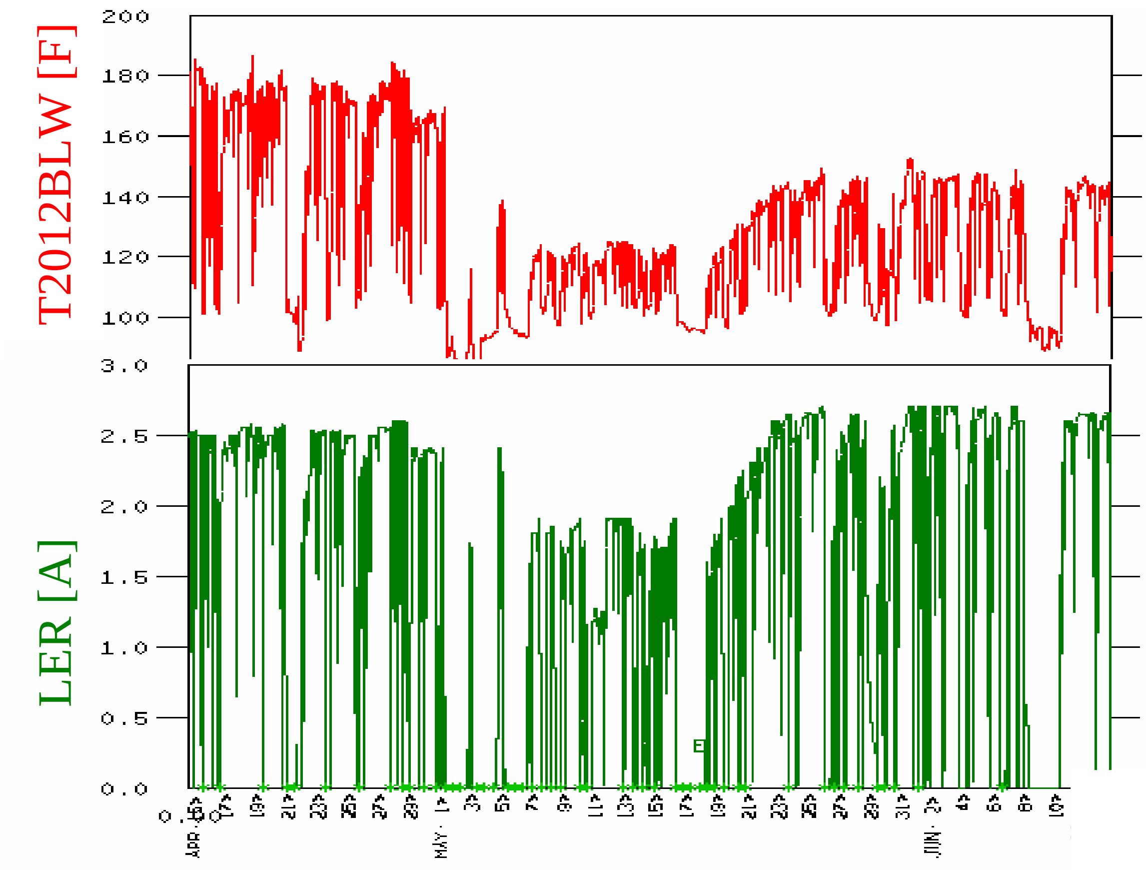
Diagnostic for absorber efficiency

Sasha Novokhatski "HOM Effects in the Damping Ring"



Effect of the straight bellows-absorber: temperature in the "super fan" bellows

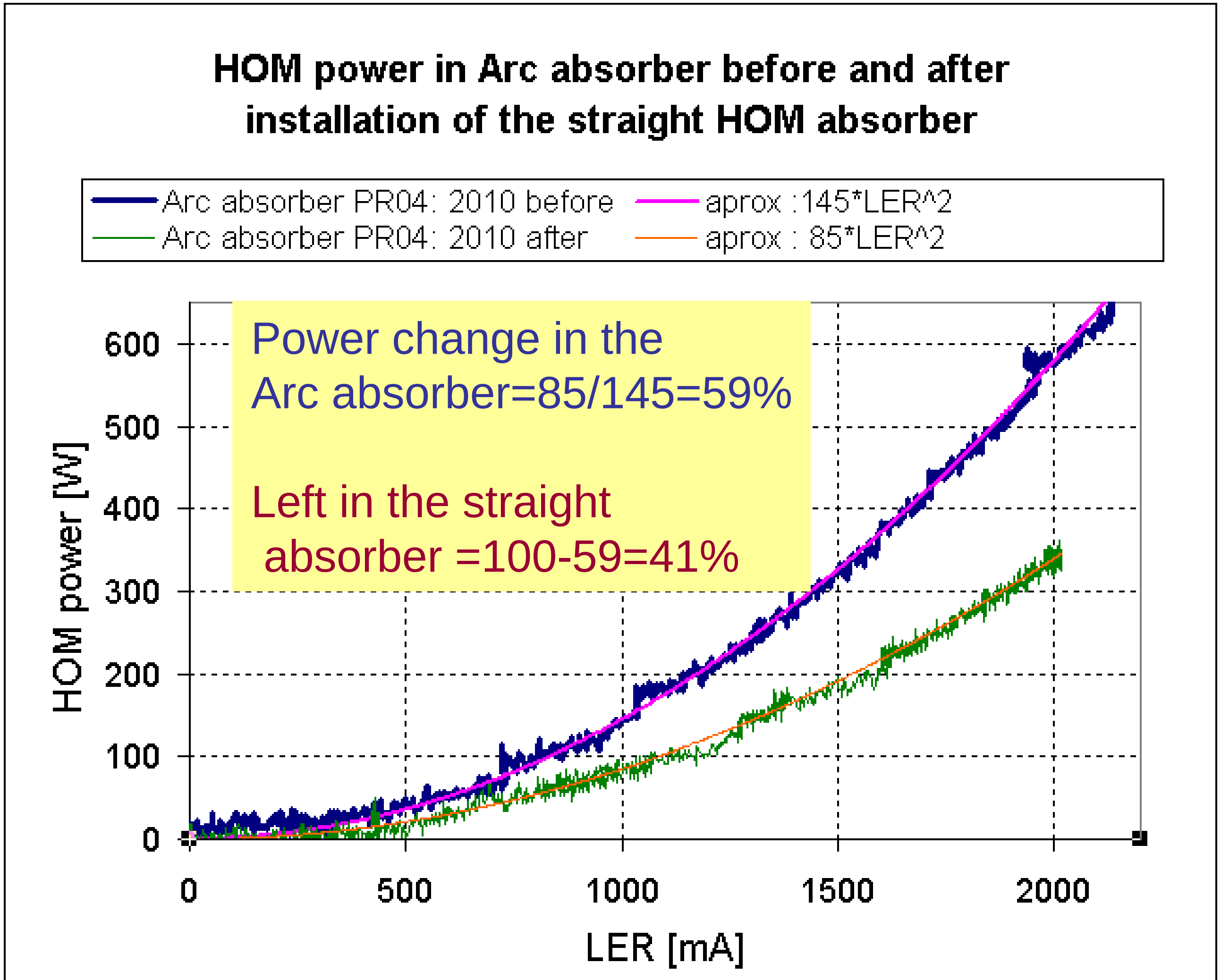
Sasha Novokhatski "HOM Effects in the Damping Ring"



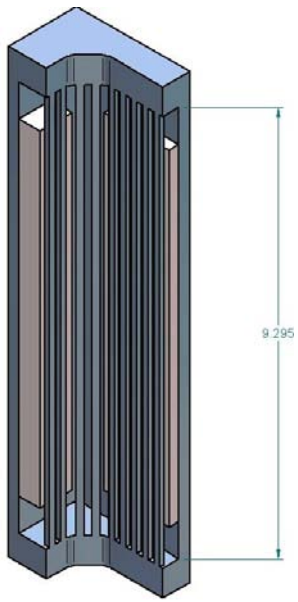
Temperature rise

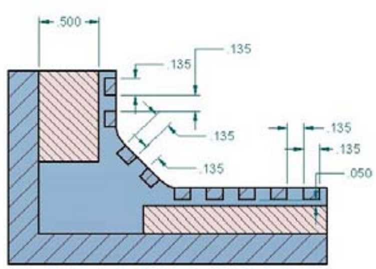
50% less!!!

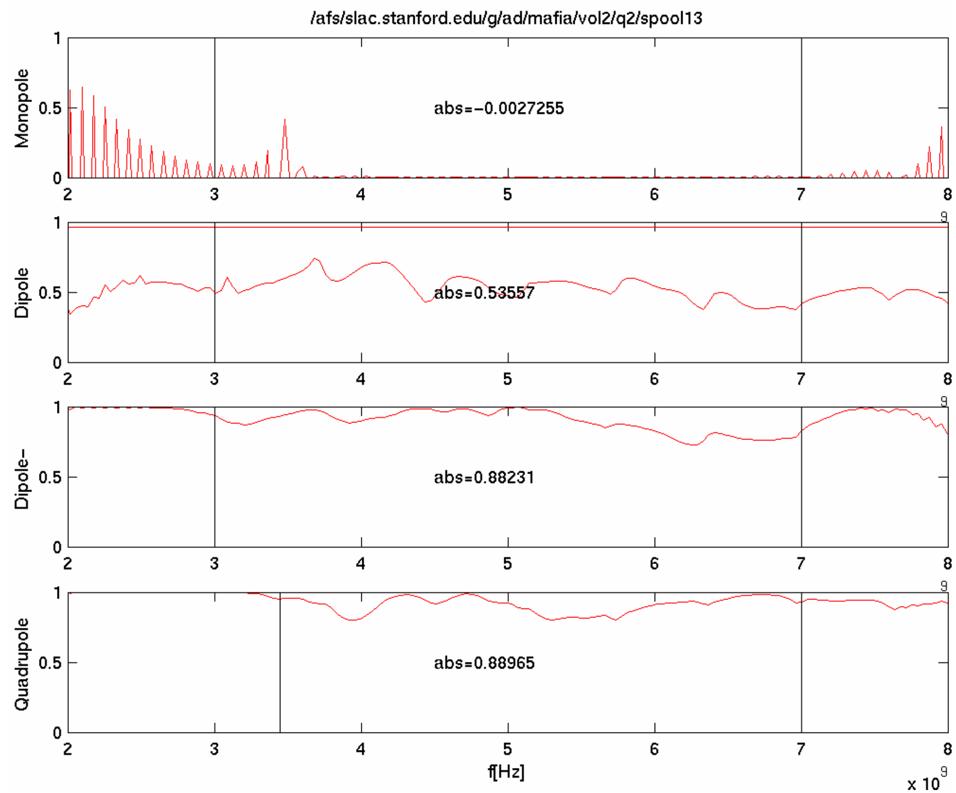
Efficiency of the absorber



A new more efficient and high power absorber is in the design







54%

88%

89%

J.Seeman, S. Novokhatski, S. Weathersby, N. Kurita and N. Reeck

Summary for Super-B

- All shielded bellows as vacuum valves must have water-cooled absorber behind the shielded fingers.
- IP vertex region must include at least two HOM absorber of straight bellows-absorber type and two high power absorbers near the crotches.
- NEG pumps must include absorber inside.
- All beam chambers are water-cooled against resistive wakes