Overall HOM Measurement at High Beam Currents in the PEP-II SLAC B-factory

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Antimatter on the SLAC site

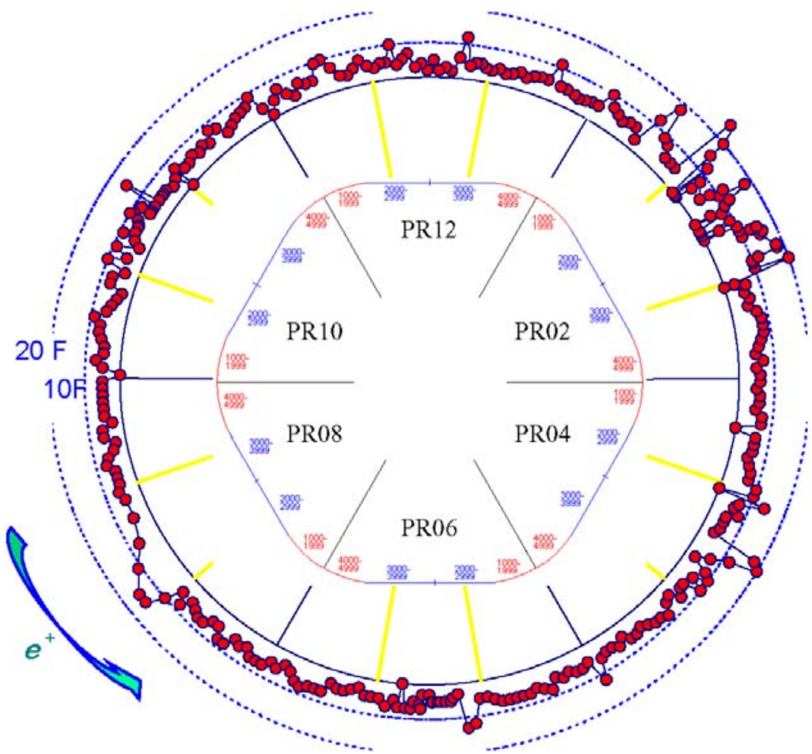
A beautifully designed vacuum chamber
of the PEP-II SLAC B-factory
allowed to achieve
record beam current - **2.9 A**

The record number of the antimatter particles - positrons - stored in the ring - **$1.3 \cdot 10^{14}$**

More currents

However, we need higher currents of shorter bunches to get more luminosity

Temperature rise due to the RF voltage elevation



In 2006 we raised the rf voltage by 33% from 4.05 to 5.4MV.

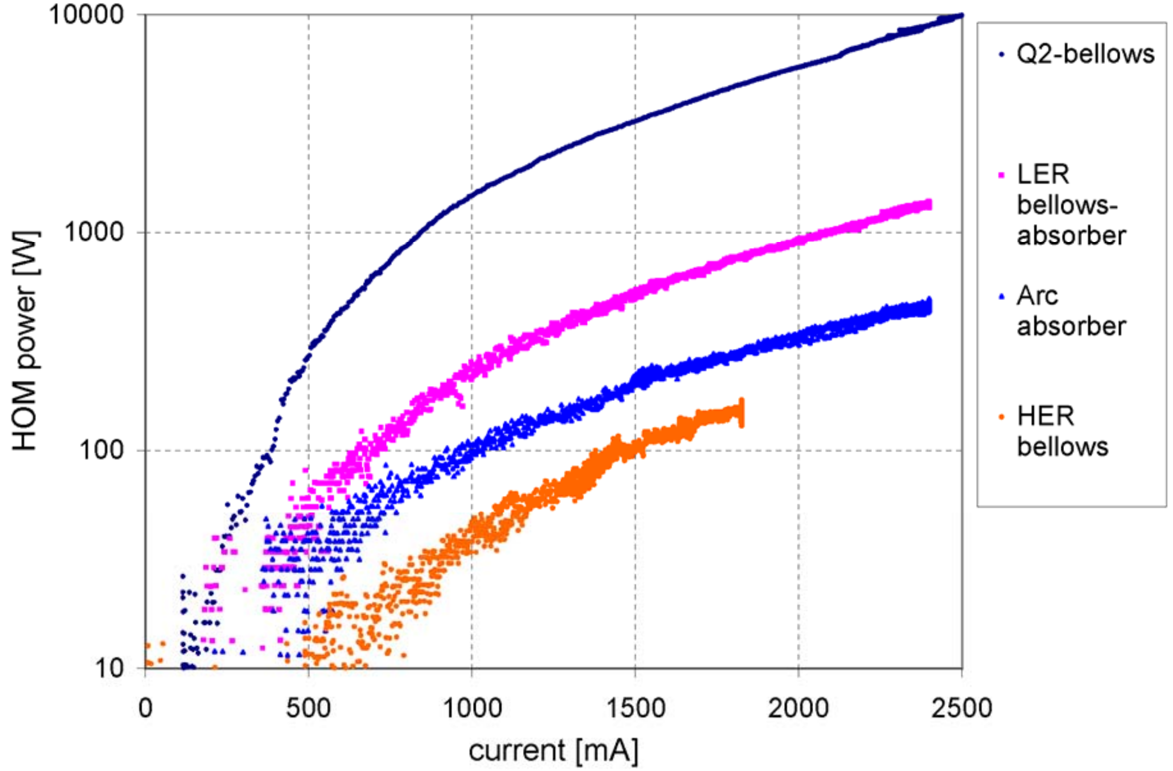
Additional HOM power due to the bunch shortening.

The quad chambers got in average additional 4 F.

Main negative HOM effects

- Heating of the vacuum elements
  - Temperature and vacuum rise
  - Chamber deformations and vacuum leaks
  - Decreasing the pumping speed
  - Outgassing
- Multipacting, sparking and breakdowns
  - Vacuum leaks
  - Melting thin shielded fingers
  - Longitudinal instabilities
  - High backgrounds (high radiation level in the detector)
- Electromagnetic waves outside vacuum chamber
  - Interaction with sensitive electronics

HOM power in PEP-II absorbers



We measured some part of HOM power captured in different absorbers at the level of several kilowatts; however the total power may be much higher.

How to measure total power?

- Variation of orbit with current
- Variation of synchronous phase with current

We chose:

RF power balance method

Power balance

$$\sum_{cav} P_{cav}^{forward} = \sum_{cav} P_{cav}^{reflected} + \sum_{cav} P_{cav}^{loss} + P_{beam}$$

$$P_{cav}^{loss} = P_{cav}^{loss}(0)\left(\frac{U_{cav}(I)}{U_{cav}(0)}\right)^2$$

$$P_{beam} = U_{S.R.} \times I + Z_{HOMs} \times I^2$$

incoherent radiation (first term) — coherent radiation (second term)

Limitations

There, naturally, can be some limitations on the HOM power measurement.

For example, at the interaction region (IR) the power can be transferred from one beam to another through the excitation of IR parasitic cavities. We observed this effect at several resonant frequencies during the spectrum IR measurement. Fortunately these resonances have low Q-value.

Next effect is a bunch lengthening, which may distort the quadratic current behavior of the HOM losses.

Cornell . 26 years ago.

IEEE Transactions on Nuclear Science, Vol. NS-28, No. 3, June 1981

SINGLE BUNCH CURRENT DEPENDENT PHENOMENA IN CESR*

D. Rice, K. Adams, M. Billing, E. Blum, R. Littauer, B. McDaniel,
R. Meller, D. Morse, S. Peck, S. Peggs, J. Seeman, R. Siemann, R. Talman, M. Tigner, and E. vonBorstel
Cornell University, Ithaca, N.Y. 14853

Summary

Single bunch current dependent phenomena have been examined in CESR, the Cornell Electron Storage Ring. These measurements are described and their results compared with predictions using the broad band resonator model of vacuum chamber impedance. A transient anti-damping effect in the vertical plane has been observed. The influence of various machine parameters on this effect will be described and a possible mechanism suggested.

Introduction

shown in Table I. σ_s is the beam bunch length and K_{pm} is the loss parameter for parasitic modes.

Energy	5.5	4.6	GeV
$\sigma_{s\ I=0}$ (calculated)	2.34	1.74	cm
k_{pm} (pwr)	5.5	7.6	volts/picocoulomb
k_{pm} (phase shift)	4.3	6.6	volts/picocoulomb
R $(=\frac{W}{I^2})$	14	19.5	MΩ
R_s (res. shunt R)	4.2	3.7	kΩ

TABLE I = HML Parameters

RF power balance method was used at Cornell to measure loss factor of a single bunch. The result was in good agreement with the one obtained by a phase shift measurement

Simulations

We performed computer simulations to check the method in a multi-bunch regime.

Reflected amplitude from a cavity

$$U_{refl}(t) = -U_{frwd}(t) + \frac{2\beta}{\beta+1}\int_0^\infty \left[U_{frwd}(t-\tau_l x) + U_b(t-\tau_l x)\right] e^{(i\Delta\omega\tau_l - 1)x}\, dx$$

U_{frwd} forward amplitude of the wave coming from a klystron

U_b amplitude excited by a beam

β coupling coefficient

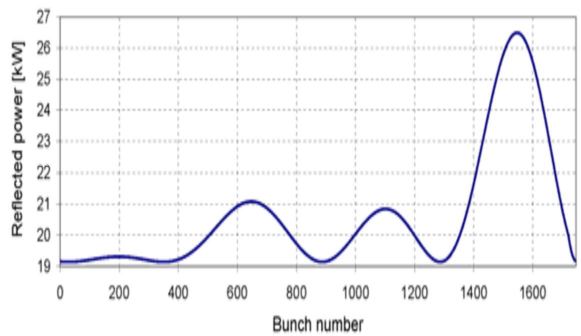
$\Delta\omega$ cavity frequency shift

$\tau_l = \frac{2}{\beta+1}\frac{Q_0}{\omega_{cav}}$ loaded filling time

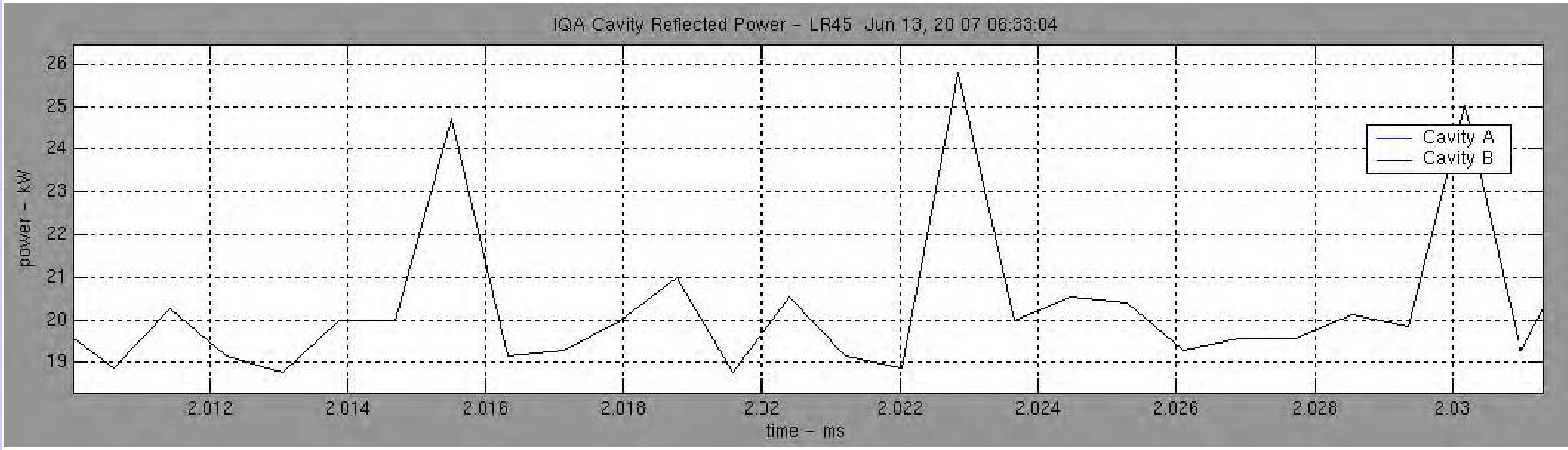
Reflected power

The method works well for the averaged along the beam train RF parameters; even in the case when a reflected power is a very complicated function of time

Calculated
I=2.4 A
df=-240 kHz
gap=23 bunches



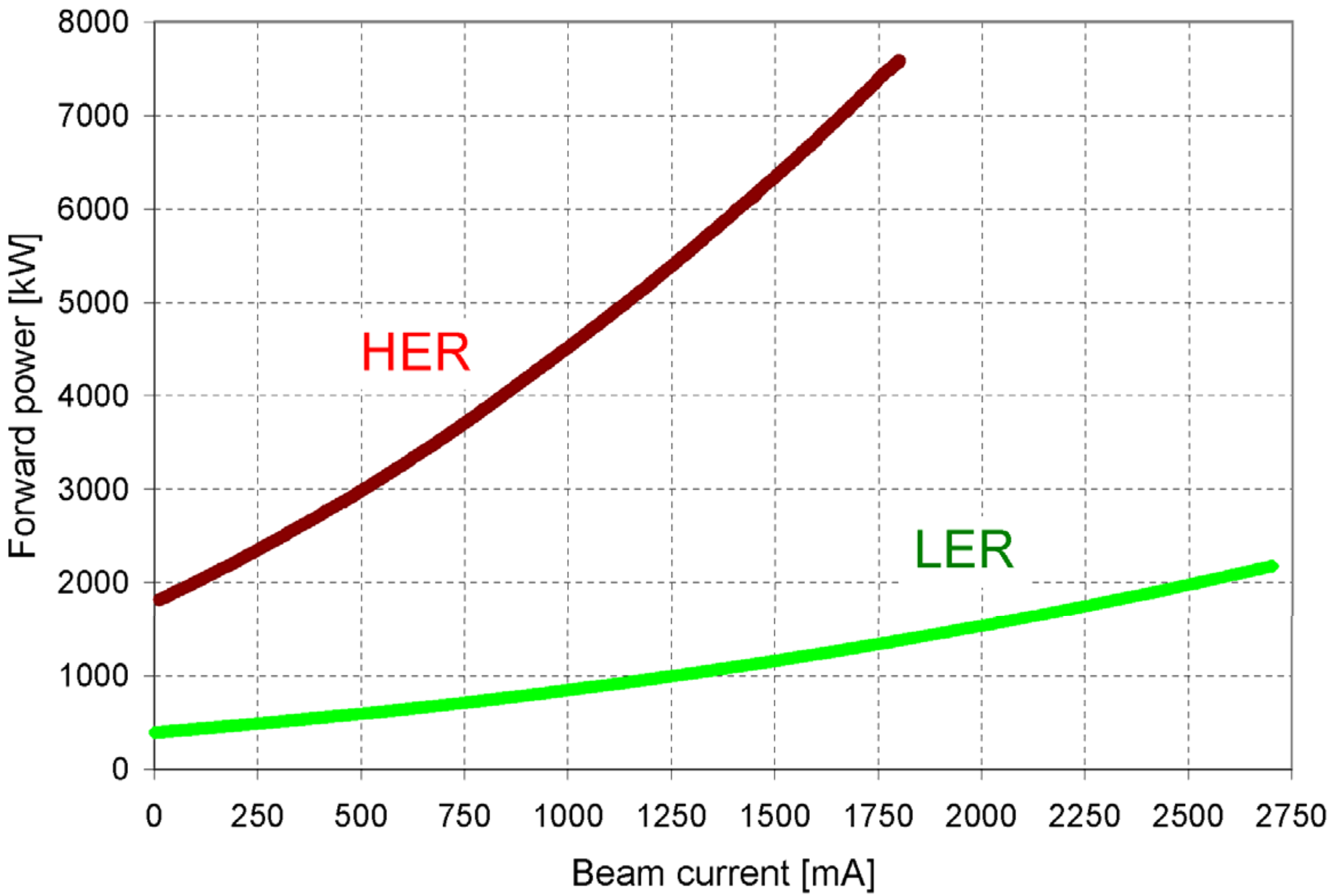
measured



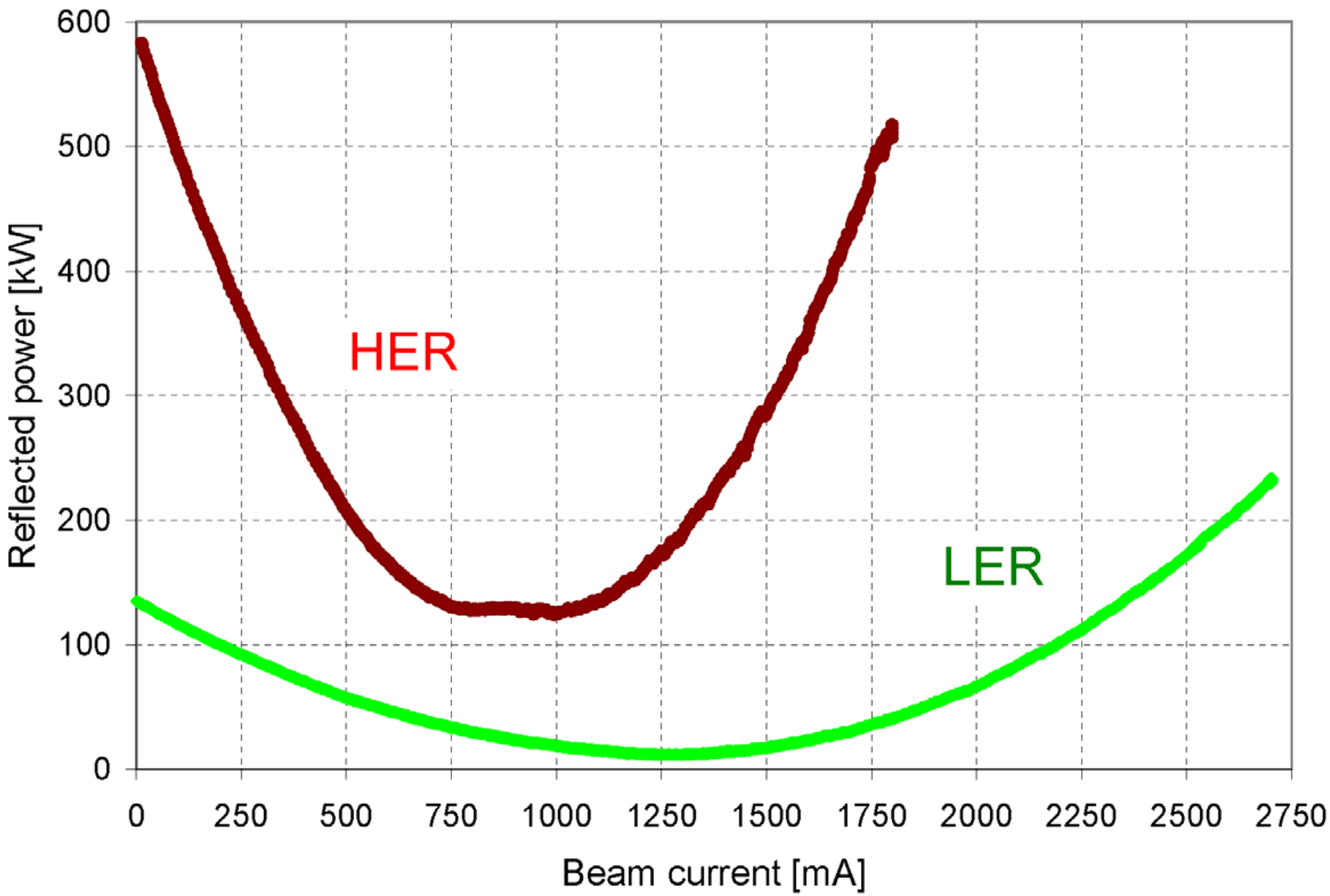
PEP-II RF

HER:	LER:
11 klystrons	4 klystrons
Cavities:	Cavities:
8 X 2 + 3 X 4 = 28	4 X 2 = 8

Total forward power

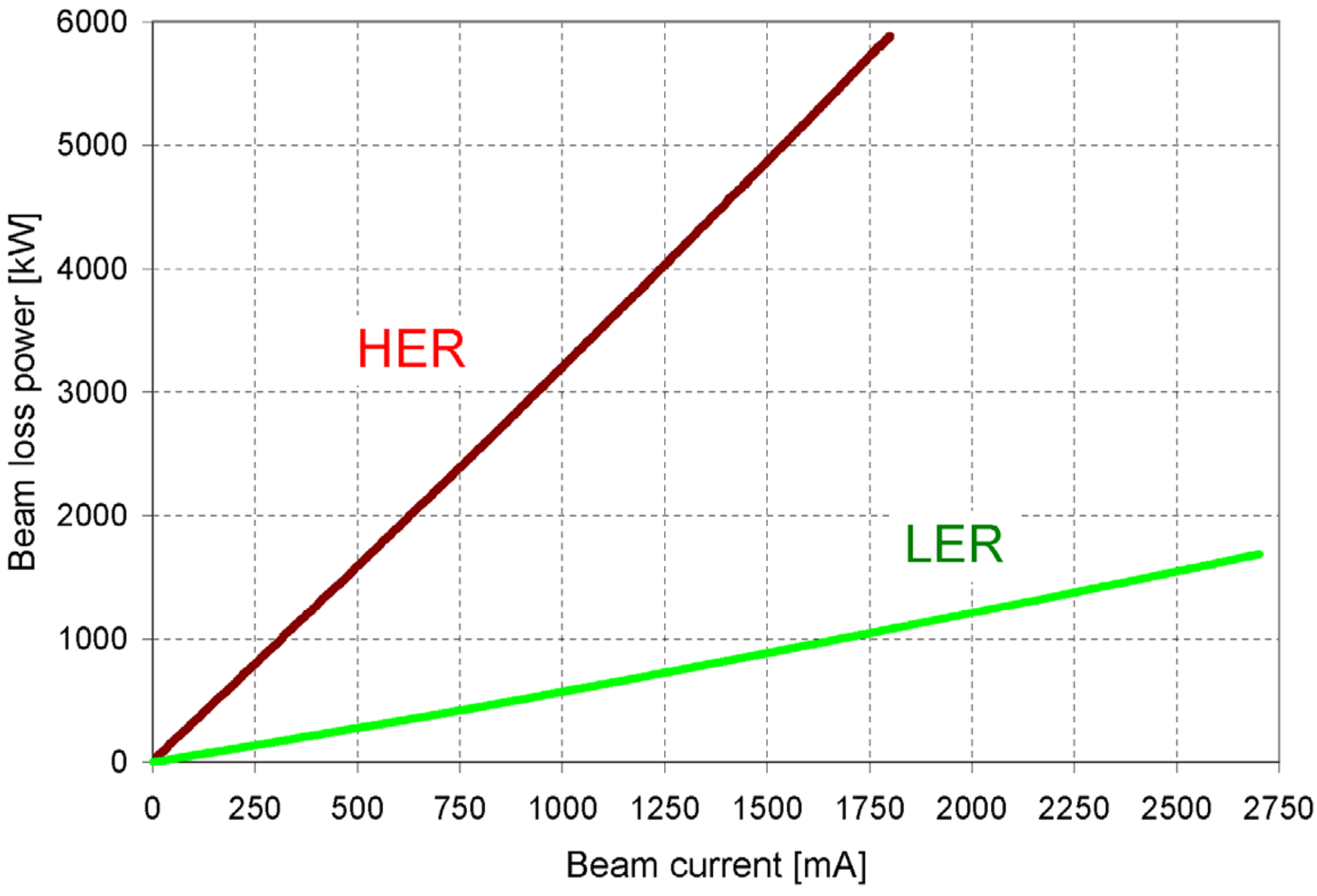


Total reflected power



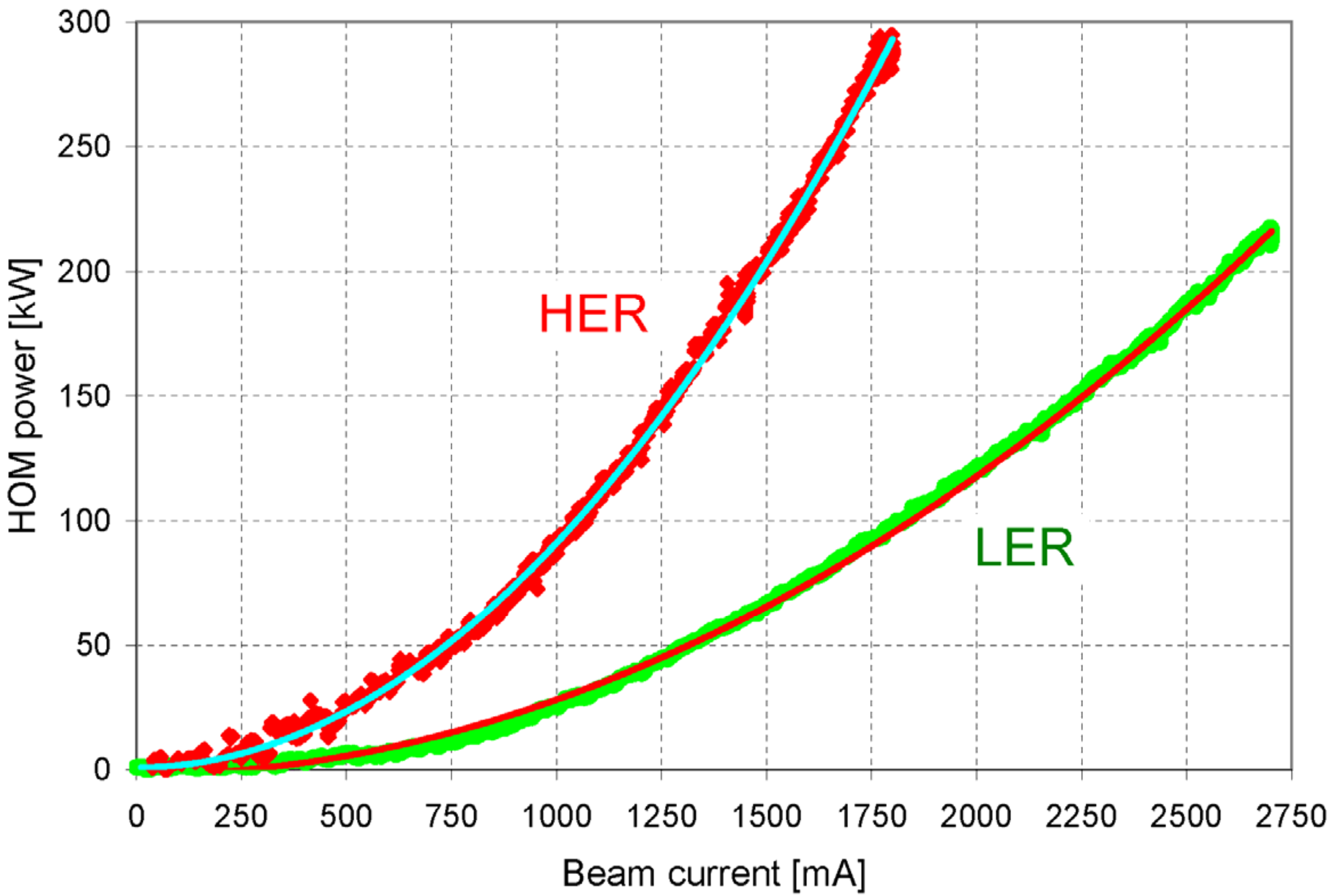
Beam power

(Forward power minus reflected minus cavity loss)

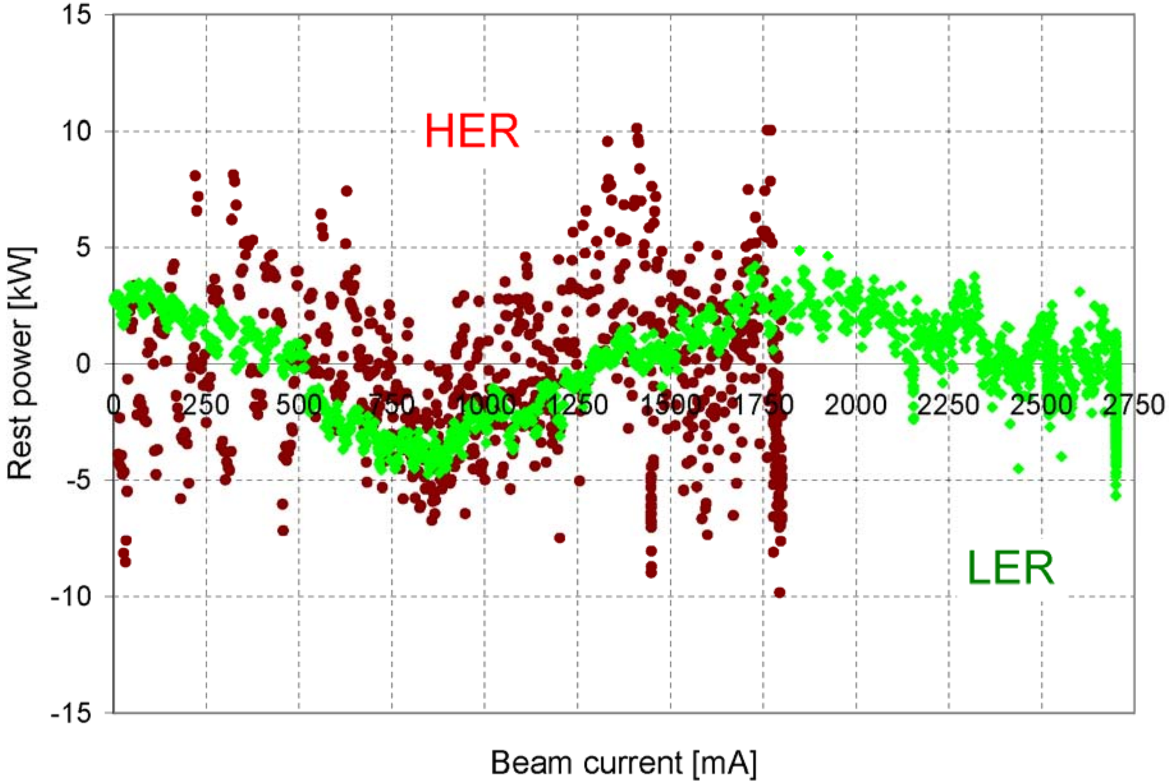


HOM power

(Subtracting linear term form the beam power)

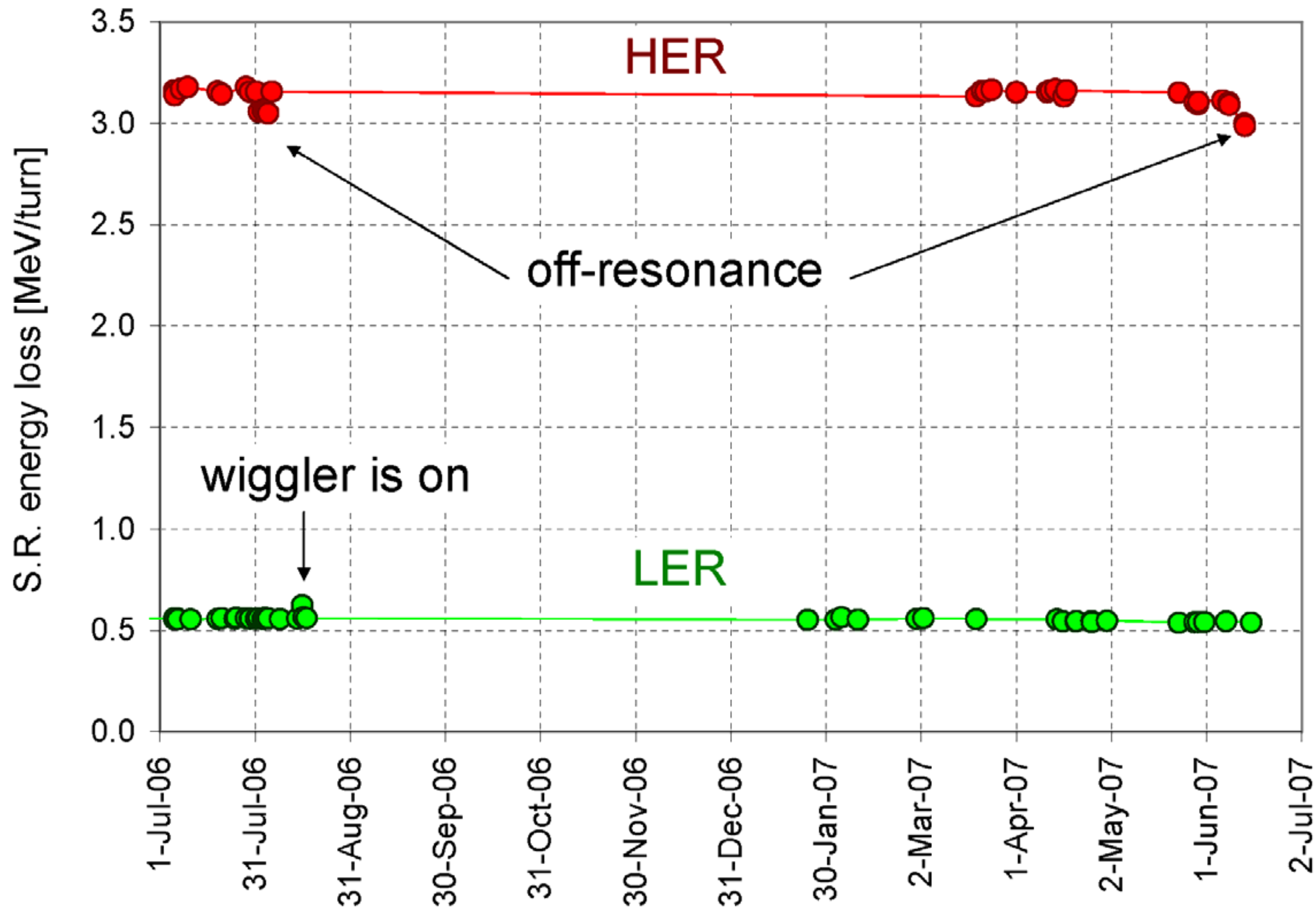


Subtracting quadratic term. What is left?



In average ±3.5 kW in HER and ±2.1kW in LER. May it work like an error? ~1% of the maximum value

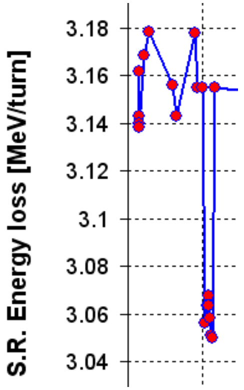
S.R. Energy loss per turn



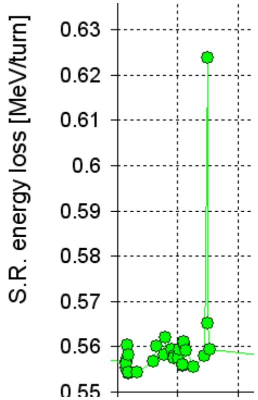
Comparison with project numbers

Averaged measured S.R. numbers are less than the predicted by 10% in the HER and 17% in the LER,

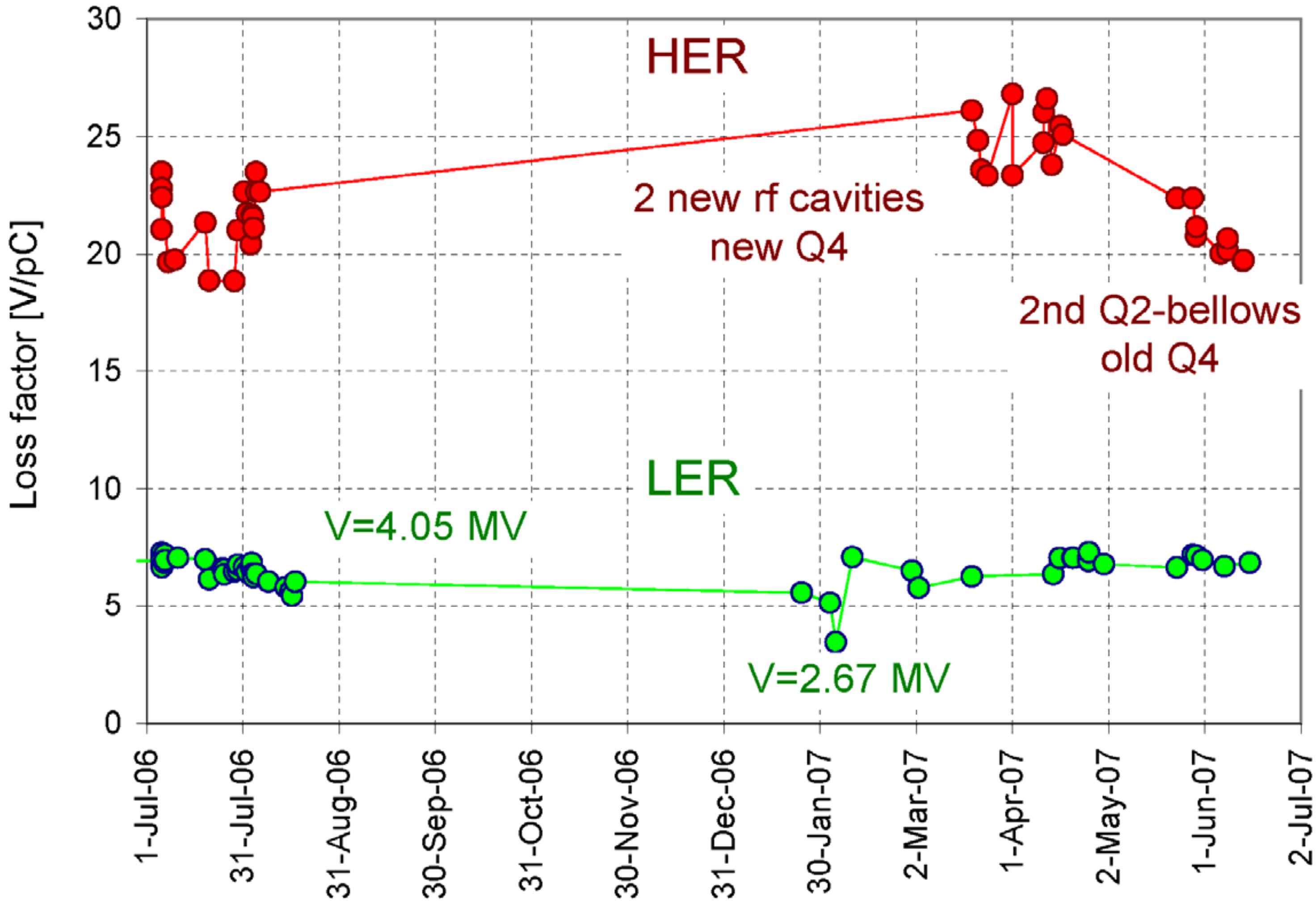
however scaling with a beam energy works with much better accuracy: during off-resonance run, the HER beam energy is 0.75% less, that corresponds to -3% of the S.R. loss. Our method gives -3.2%.



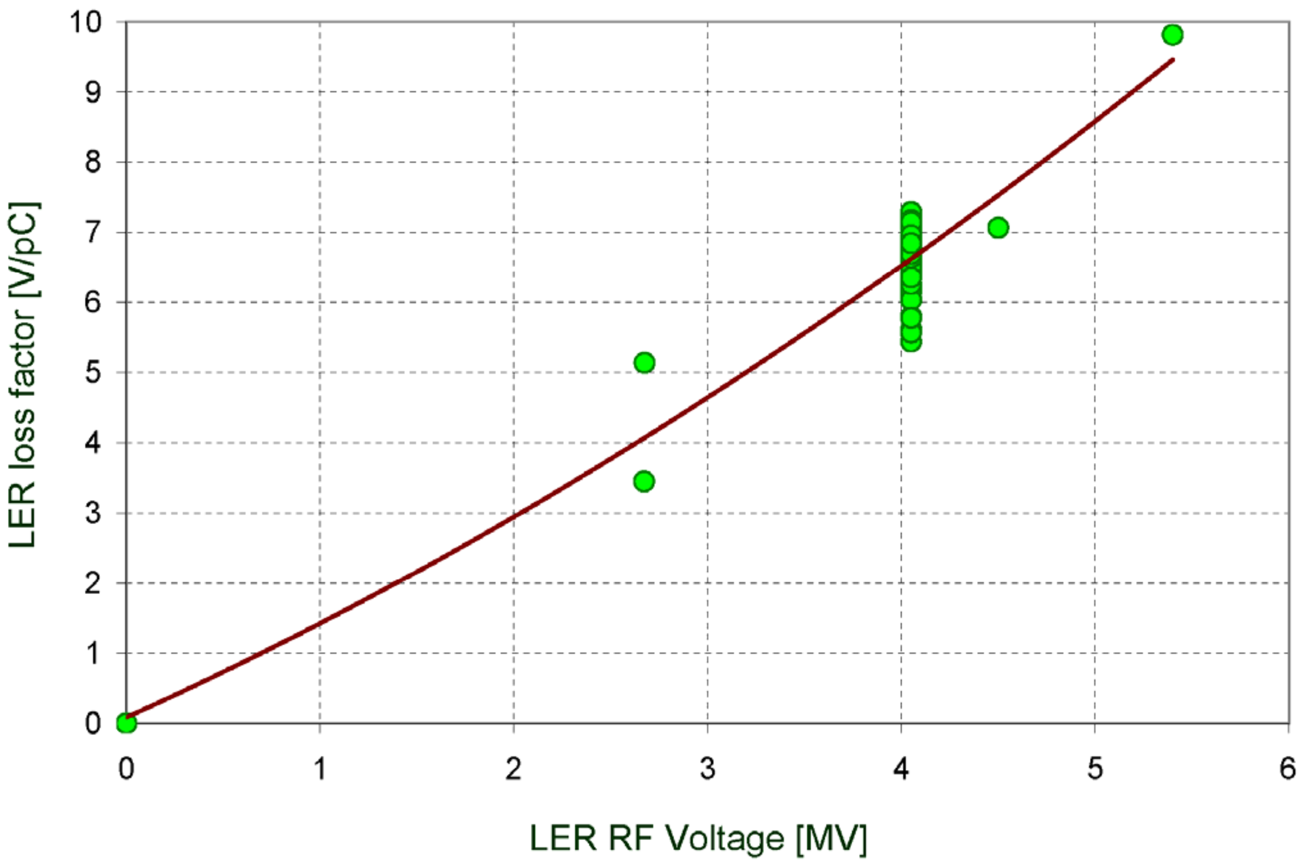
We also found good agreement with predicted additional energy loss for the case when the LER wiggler was partially on. Our measurement showed 11% rise of the energy loss.



HOM Loss Factor



LER Loss Factor and Voltage

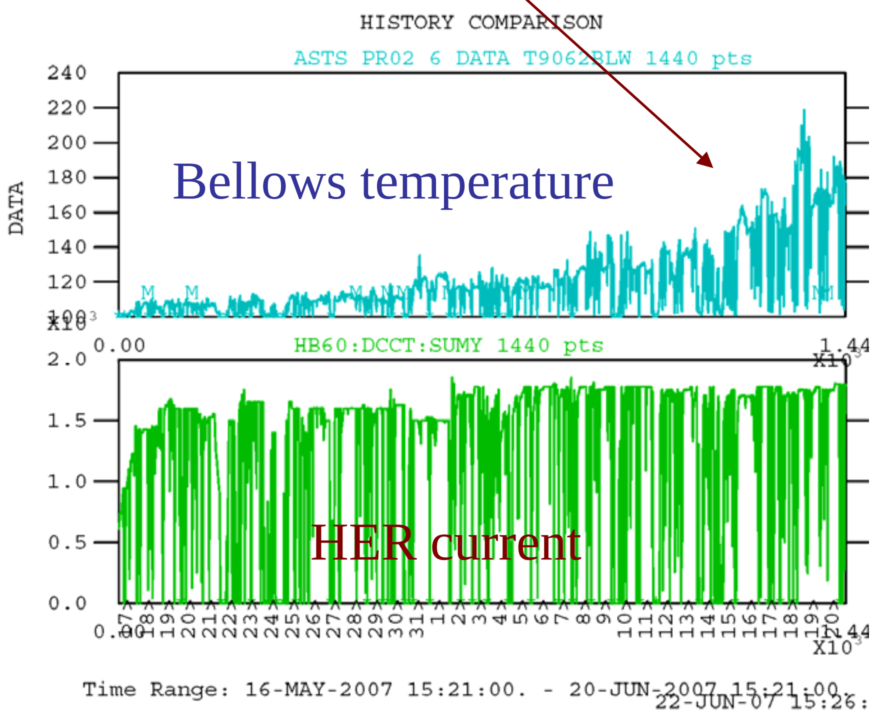


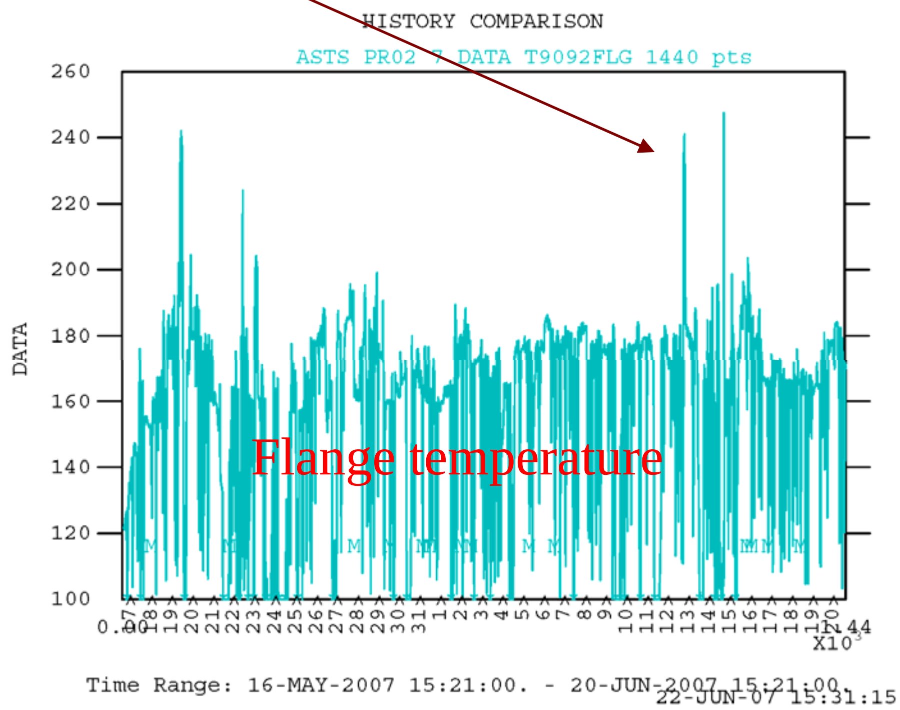
Almost linear function of voltage ($1/\sigma^2$)

Calculated HOM power

	LER 2900 mA	HER 1800 mA
Vacuum element	**Power [KW]**	**Power [KW]**
RF cavities	63.46	76.16
Collimators	18.11	16.7
Kickers	17.3	6.08
Screens	1.24	5.5
BPMs	9.4	3.6
IR wakes	13.66	5.26
Resistive wall	71.74	36.15
Total power	**195**	**167**
Measured power	**210**	**298**

Where is missed HER loss factor ?
Bellows and flanges (rf seals)?





Details in M. Sullivan and U. Wienands presentations

Summary

- Power balance method gives reasonable results for the HOM power in the PEP-II SLAC B-Factory.
- It helps to control the loss factor in operating rings and check the "HOM free" quality of new vacuum elements.
- Detailed error analyzes may help to improve the accuracy of the method.

ACKNOWLEDGEMENT

Thanks to all members
of PEP-II, Electronics and Software,
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of PEP-II rf operation and
beautiful opportunity to carry out this
work.