HZB Helmholtz Zentrum Berlin

BESSY II
Transient beam loading with harmonic RF systems

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Workshop SOLEIL
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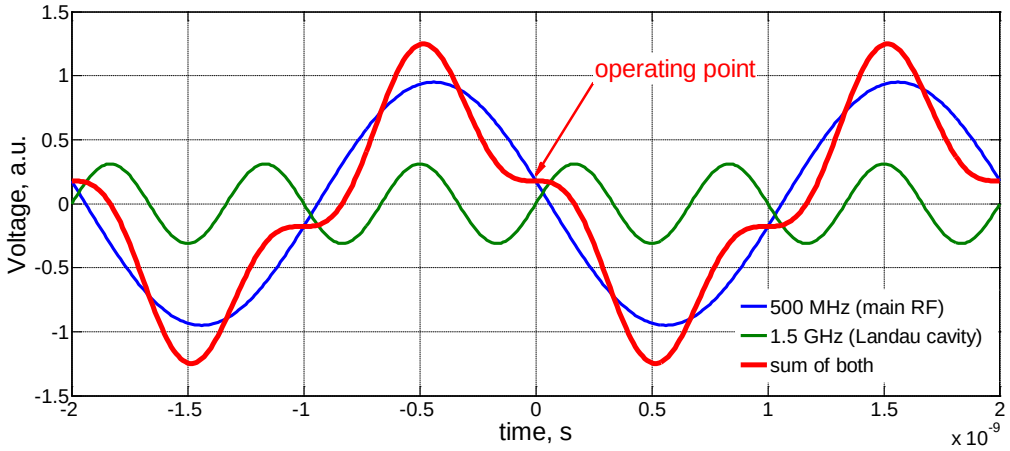
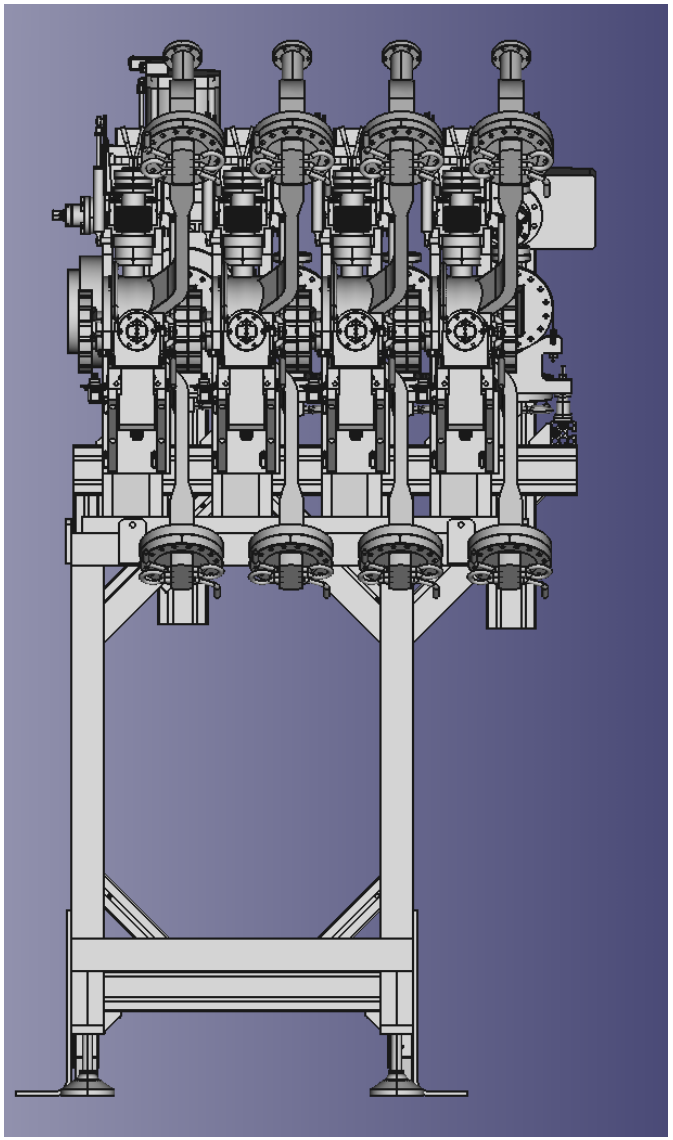
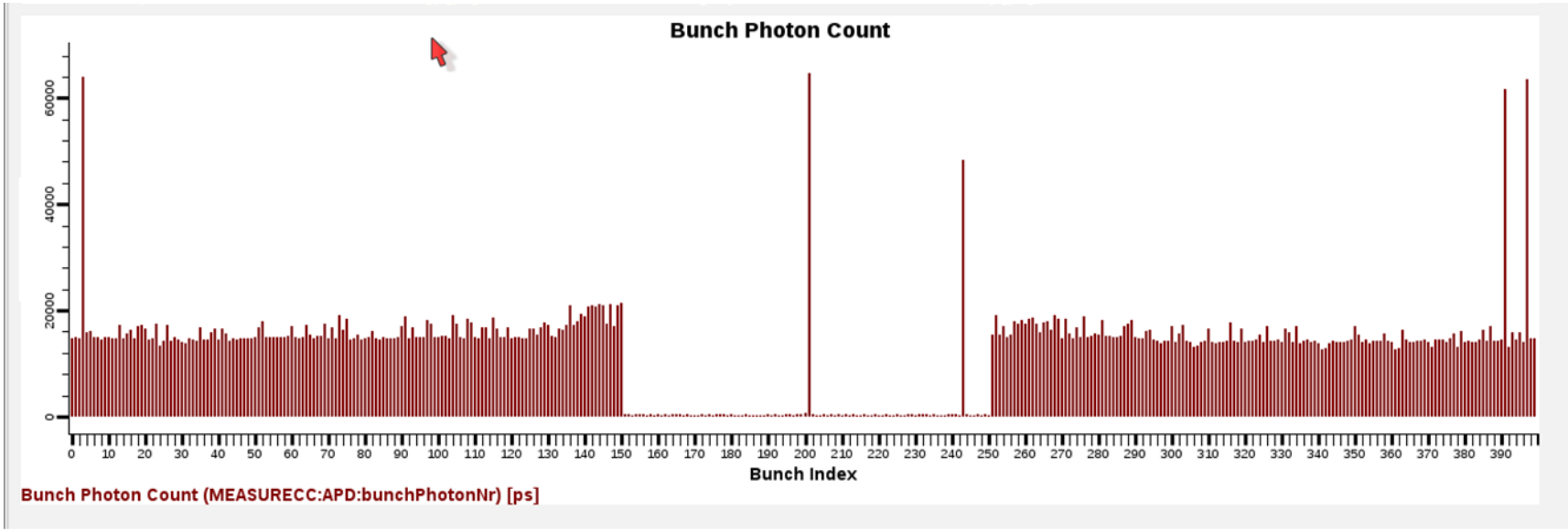
Operating Landau cavities at BESSY-II



- 3rd harmonic, 4 single cell passive cavities, pill-box type
- max. equivalent voltage of 0.65MV
- bunch lengthening in normal operation ~35%
- improve Touschek lifetime
- increase transient beam loading
- Robinson-unstable
- can be compensated by stability of main RF, Bunch by Bunch Feedback, natural damping



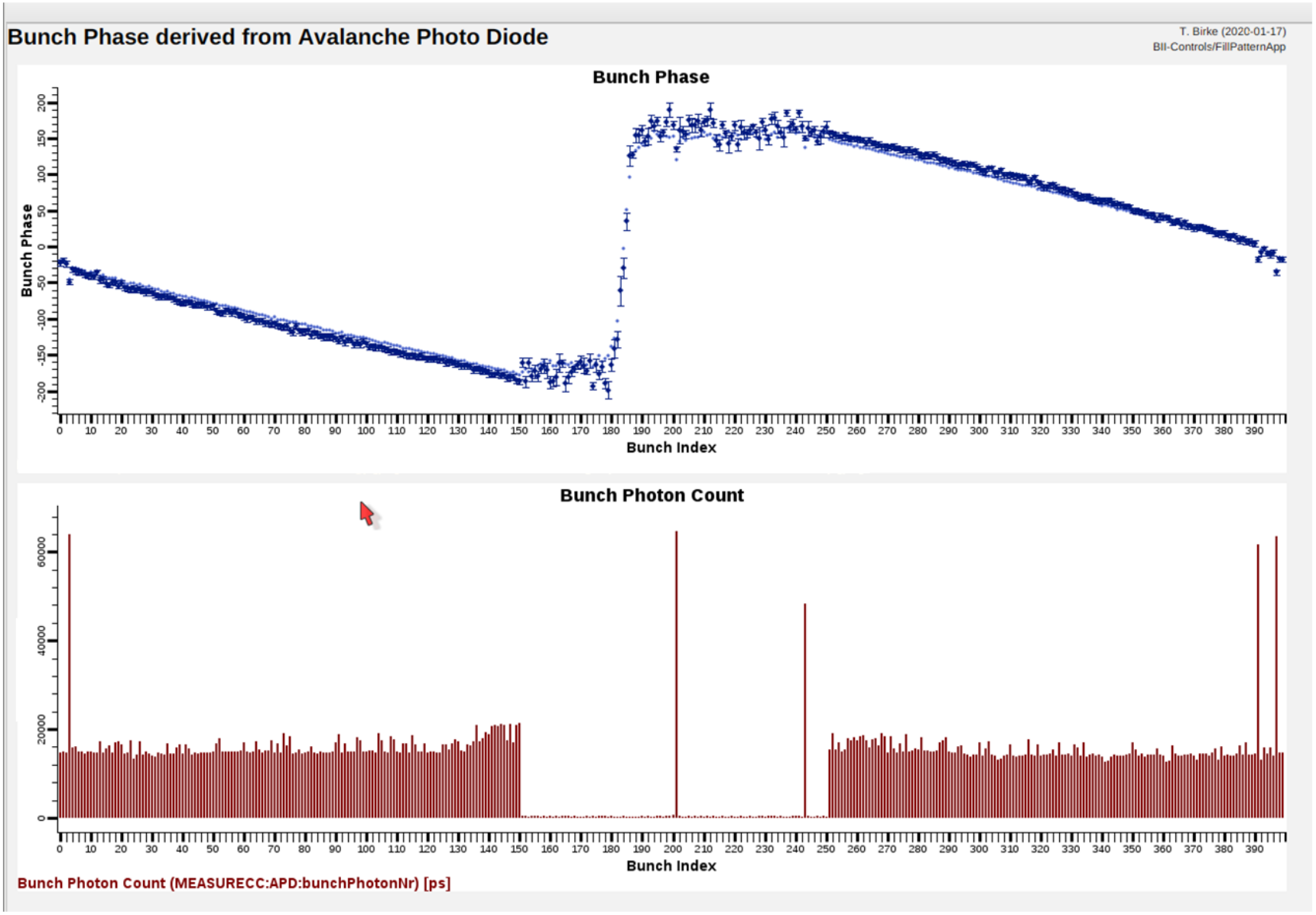
Typical fill pattern at BESSY II, diagnostic tools



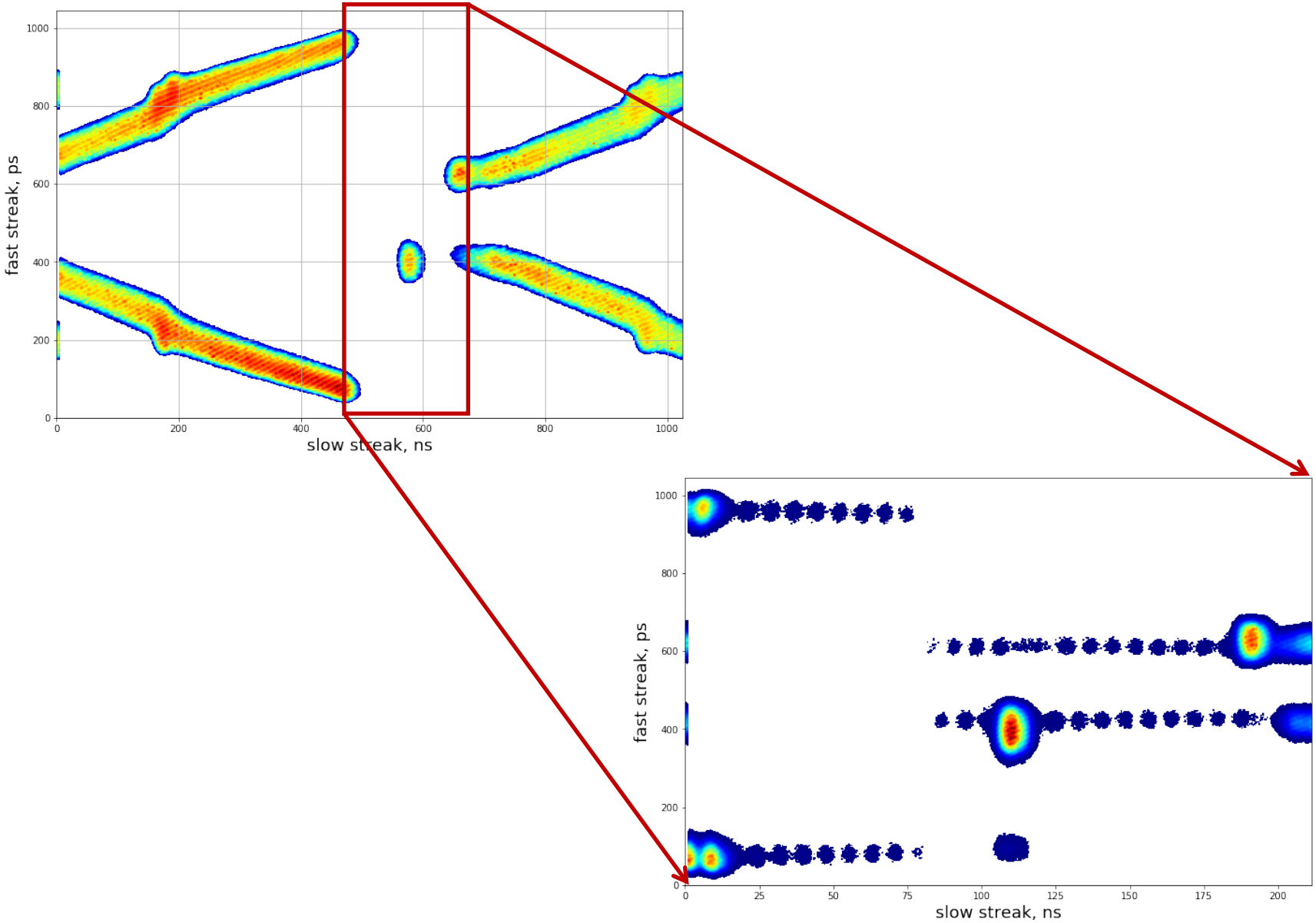
Diagnostic tools available to measure the fill pattern:

- electron beam based (bunch-by-bunch feedback)
- photon beam based (avalanche photodiodes)
- photon beam based (streak-camera)

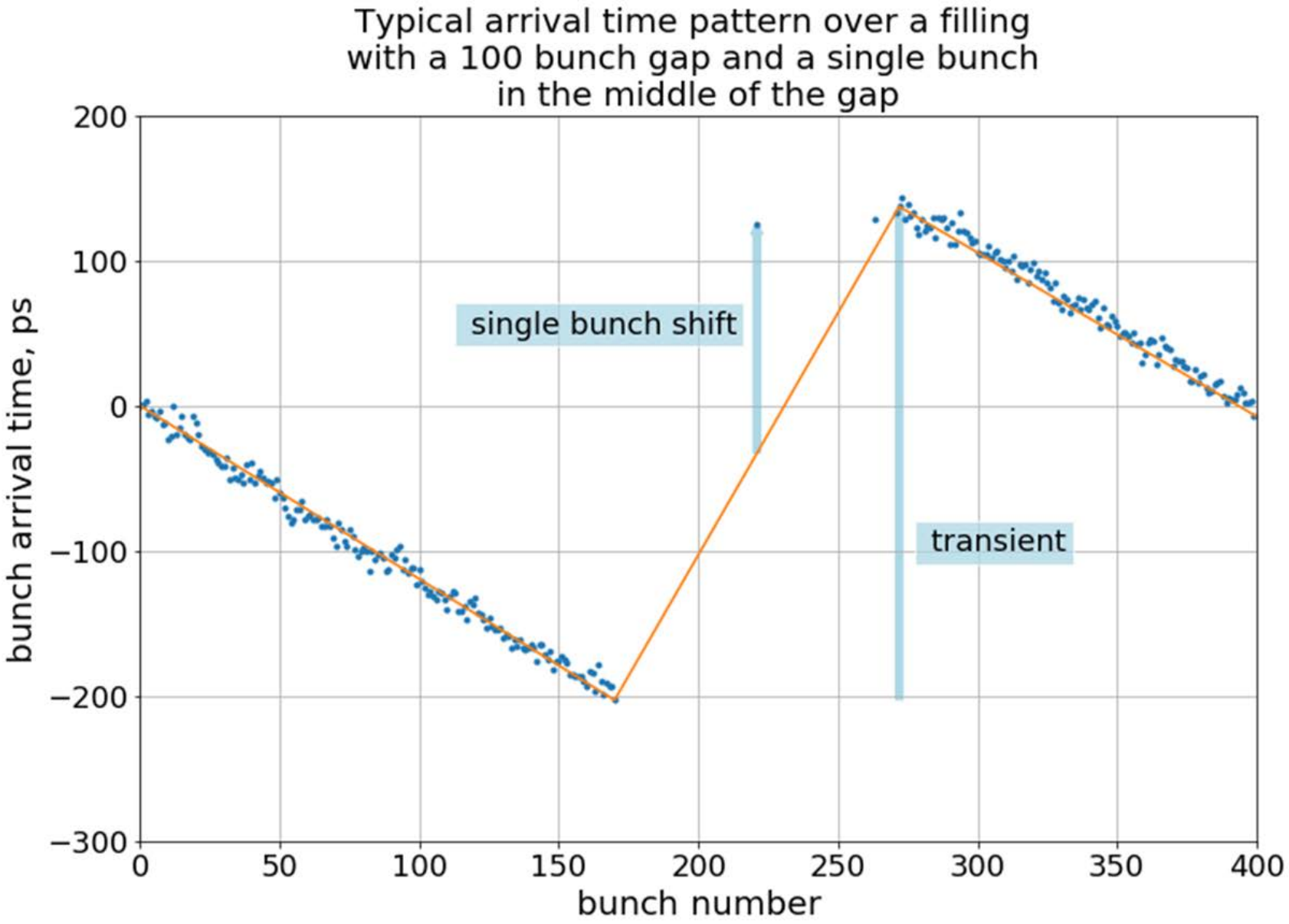
TBL measured with APD, gap filled with low current bunches, 800kV



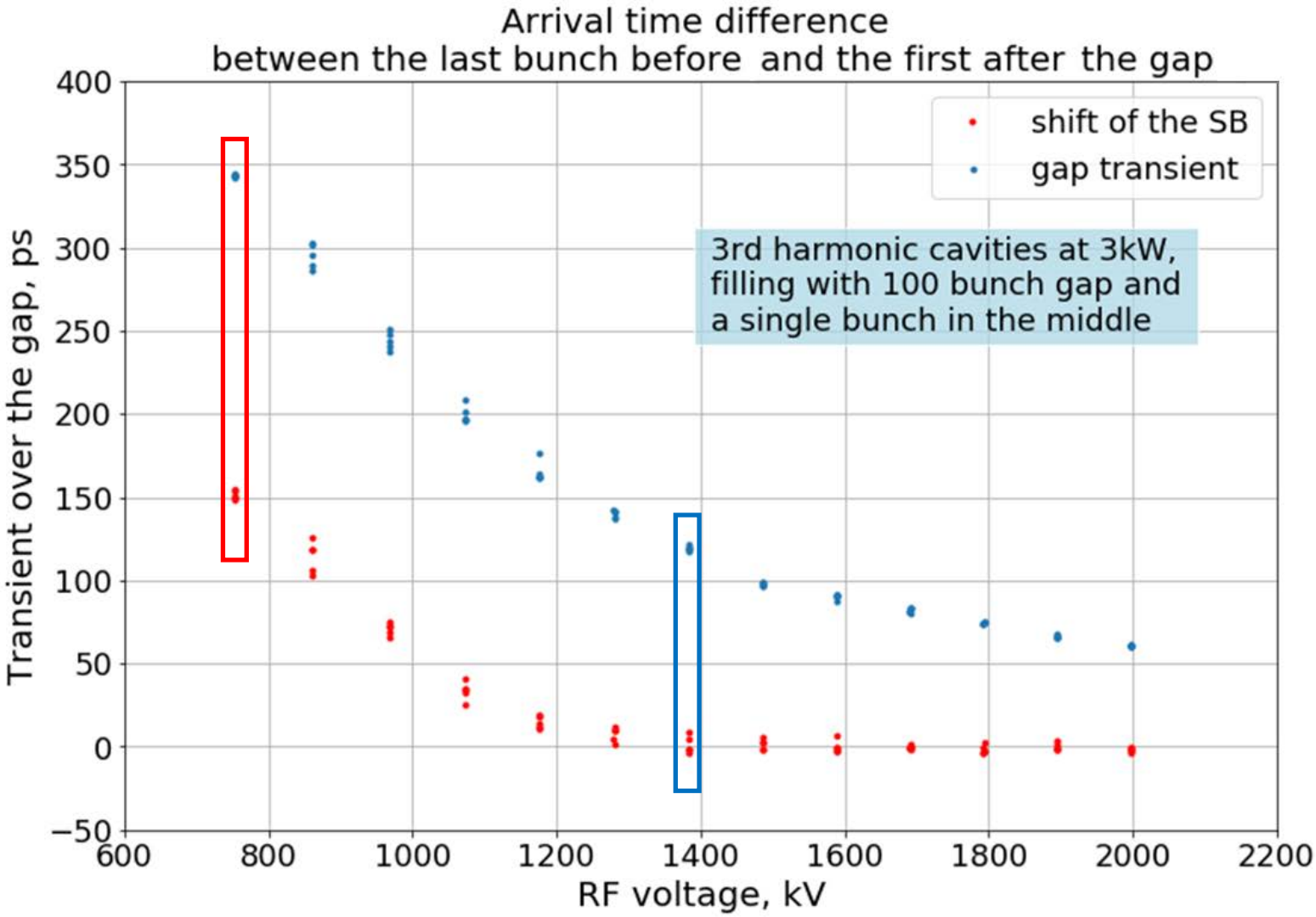
Bunch arrival time in the gap, streak-camera, 800kV



Transient beam loading measured with an avalanche photo diode (APD), 800kV



Transient beam loading vs. RF voltage amplitude of the main RF



Simple model (MATLAB)

$$\mathrm{I(t)} = \sum_{n=1}^{h} q_n \delta(t - nt_0 - \Delta t_n)$$

- short bunches with individual charges q_n and arrival times Δt_n $(dphi(n) = 2\pi f \Delta t_n)$

```
I_k=zeros(size(t));
for n=1:h
for k=1:h
I_k(k)=I_k(k)+I(n)*exp(-1i*(dphi(n)+2*pi*(n-1)*(k-1)/h));
end
end
```

- if Δt_n were all zeros, FFT(I(n)) could be used instead

`U_k=2*I_k*Z_k` - voltages of the harmonics

$$Z(f) = \frac{R_s}{1 + i \cdot \tan\psi}; \tan\psi = Q\left(\frac{f}{f_r} - \frac{f_r}{f}\right) \approx 2Q\frac{\Delta f}{f}$$

- cavity impedance

$$f_\mathrm{k} = \frac{\mathrm{k} - 1}{\mathrm{T}}$$

- frequencies of the harmonics

$U(t_n)$=ifft(U_k)*h - voltages by arrival of bunches

Simple model (MATLAB) , cont.

The modeling is done iteratively. First, all bunches are assumed to have equilibrium phases defined by the main RF

$$\varphi_0 = 3 \cdot \sin^{-1} \frac{\Delta E}{U_{RF}}$$

Then energy loss to the 3rd harmonic cavity is calculated for each bunch. After that the necessary phase shift is calculated, which would compensate the energy loss

$$\Delta\varphi_n = 3\left(\sin^{-1} \frac{\Delta E + e \cdot Re\big(U(t_n)\big)}{U_{RF}} - \sin^{-1} \frac{\Delta E}{U_{RF}}\right)$$

The calculations are repeated with these starting phases again until convergence.

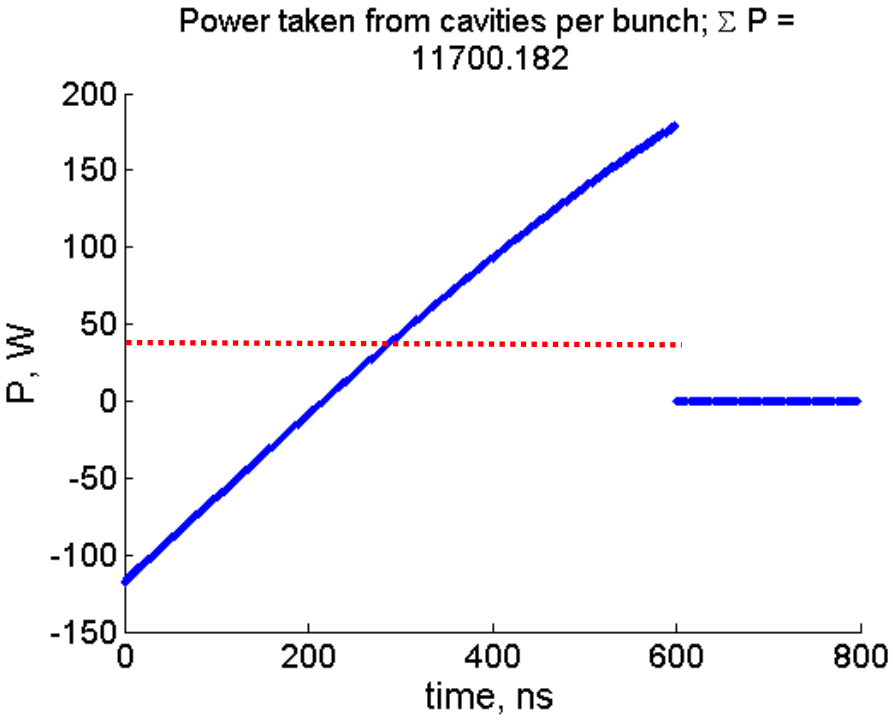
Model parameters:

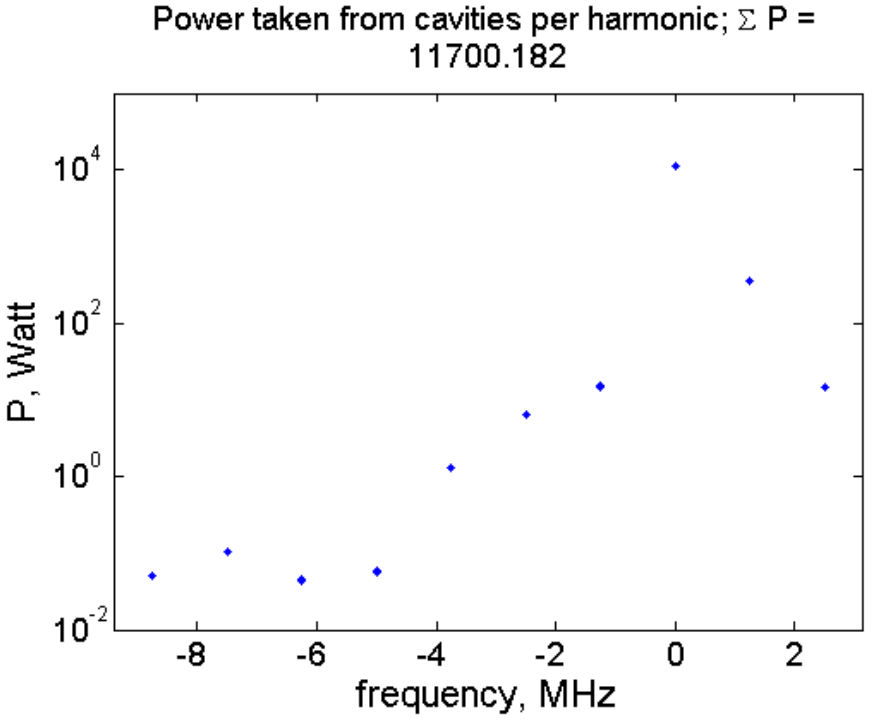
- R/Q, Q – cavity shunt impedance and quality factor
- Δf – detuning
- fill pattern

Consistency check

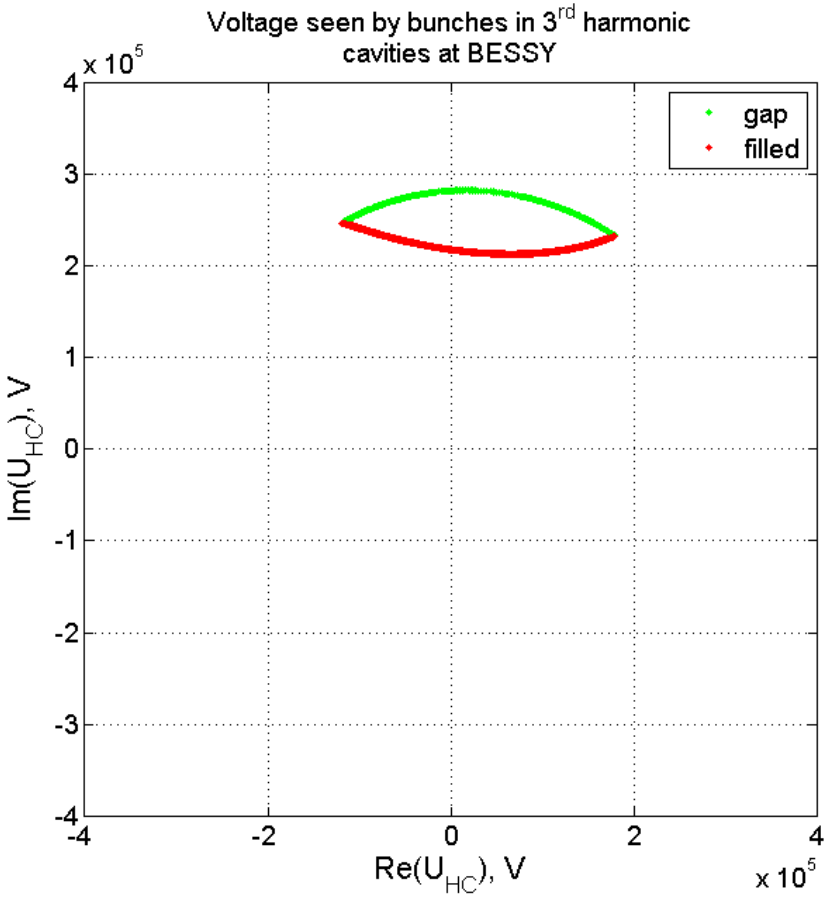
The voltages U(tn) are complex numbers. Real part of it is the voltage seen by the bunch. Amplitude of it is the voltage which should be used to calculate the power losses in the cavity walls. So, if the cavity is passive, energy conservation demands that all energy lost in the cavity walls be derived from the beam:

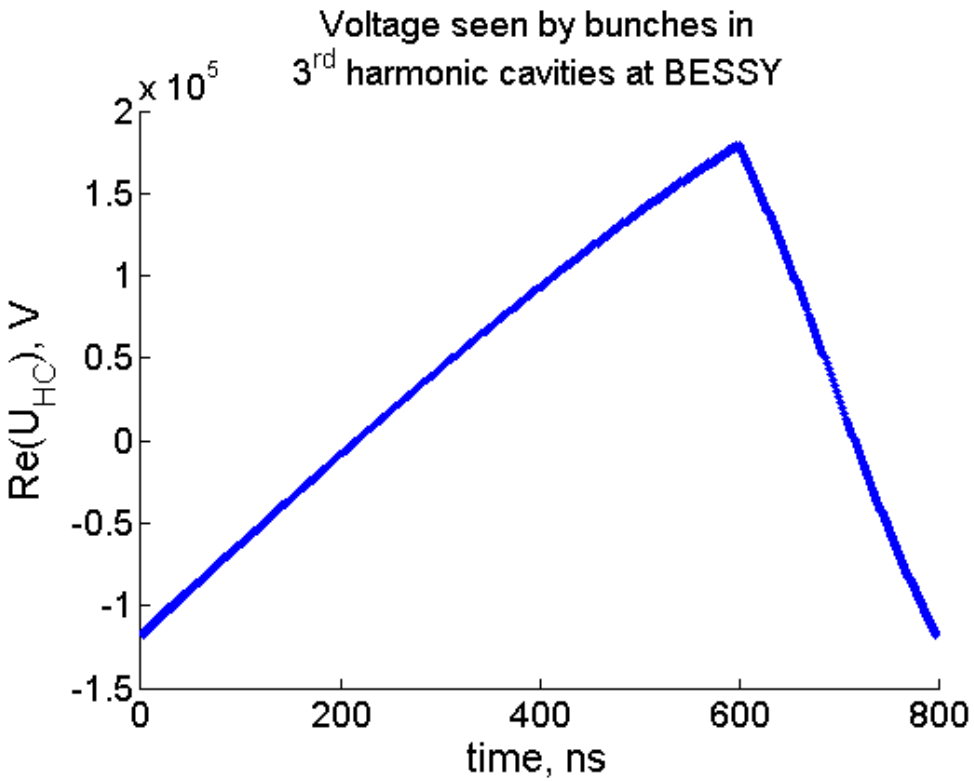
$$P = \sum_n Re\big(U(t_n)\big) \cdot q_n = \sum_k Re(U_k I_k^*)$$





Standard user mode (main RF amplitude 1350kV)





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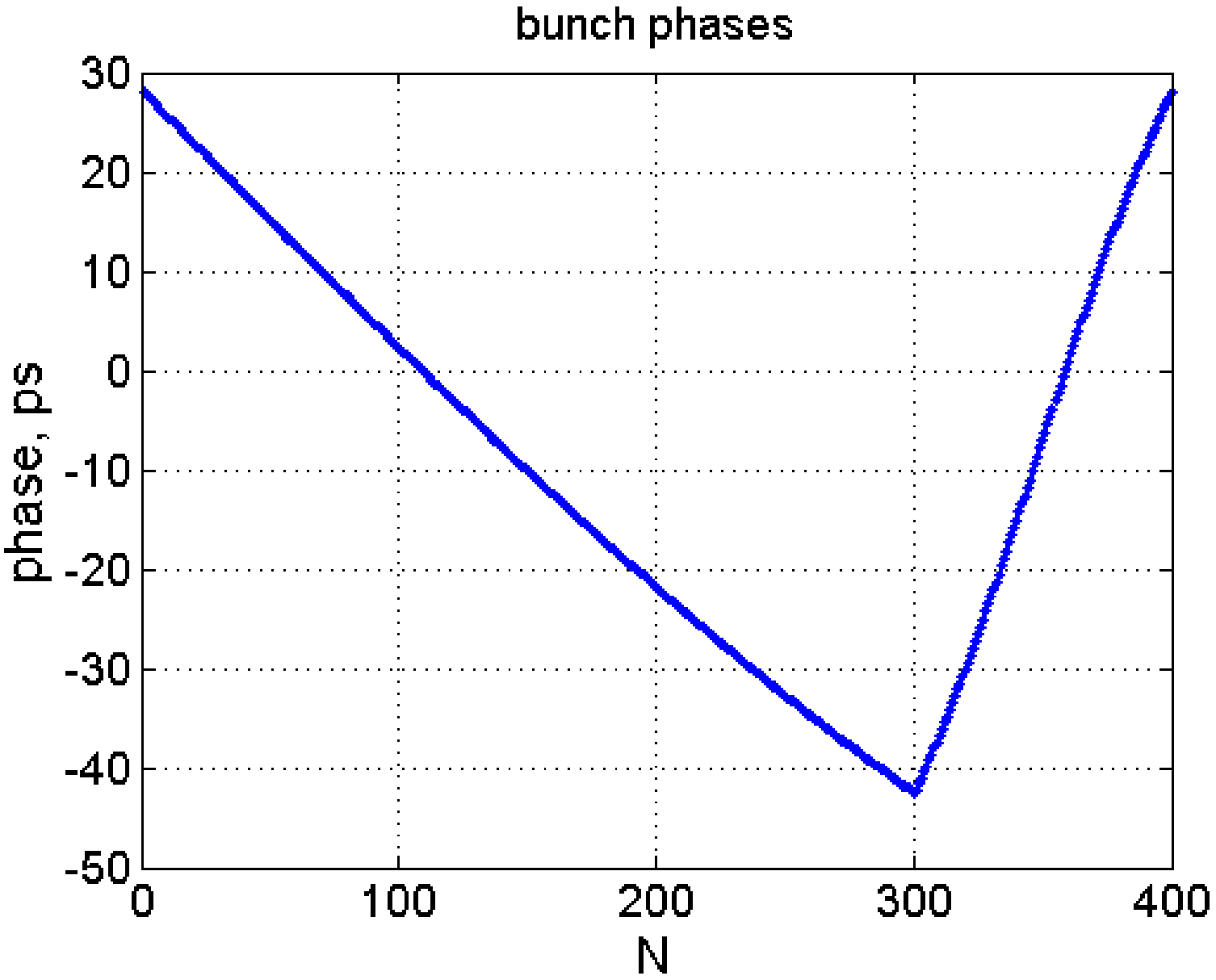
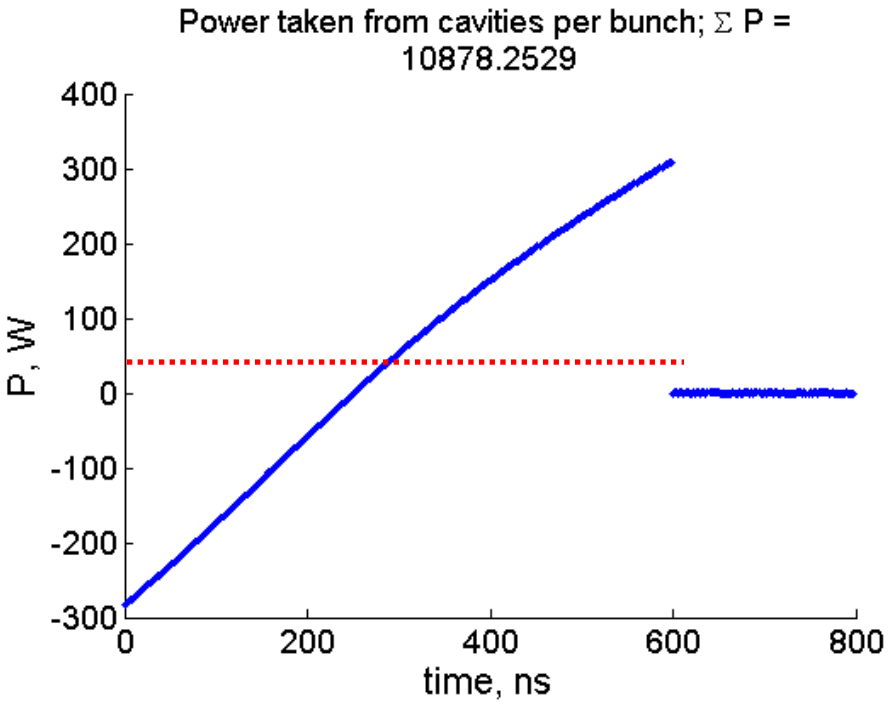
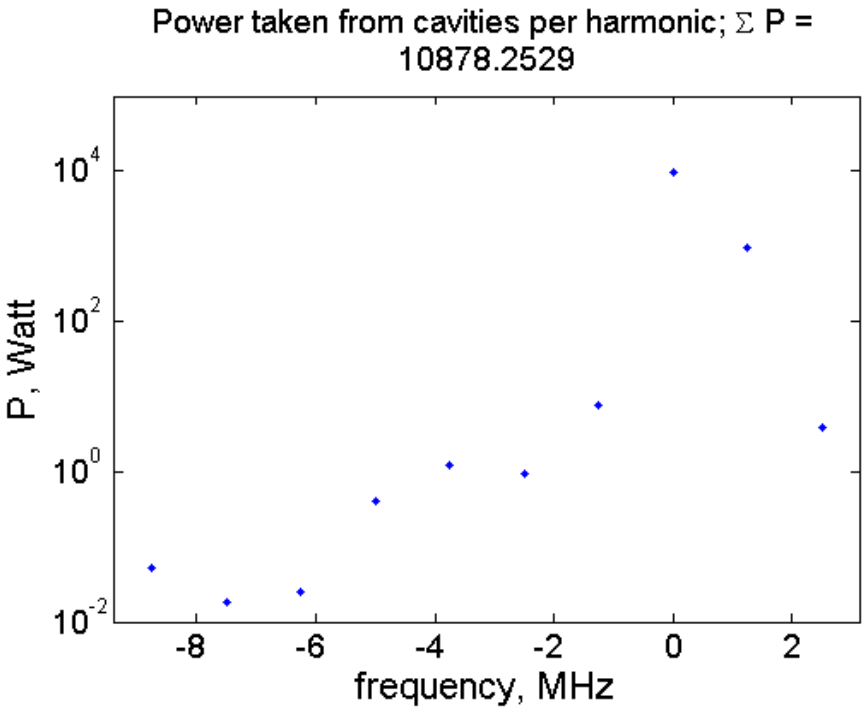
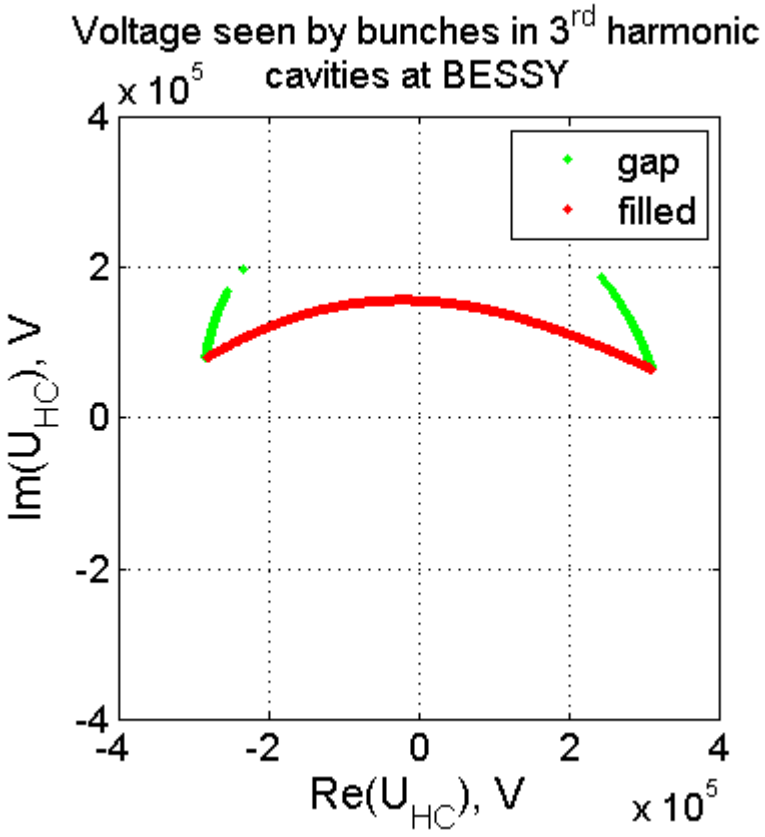


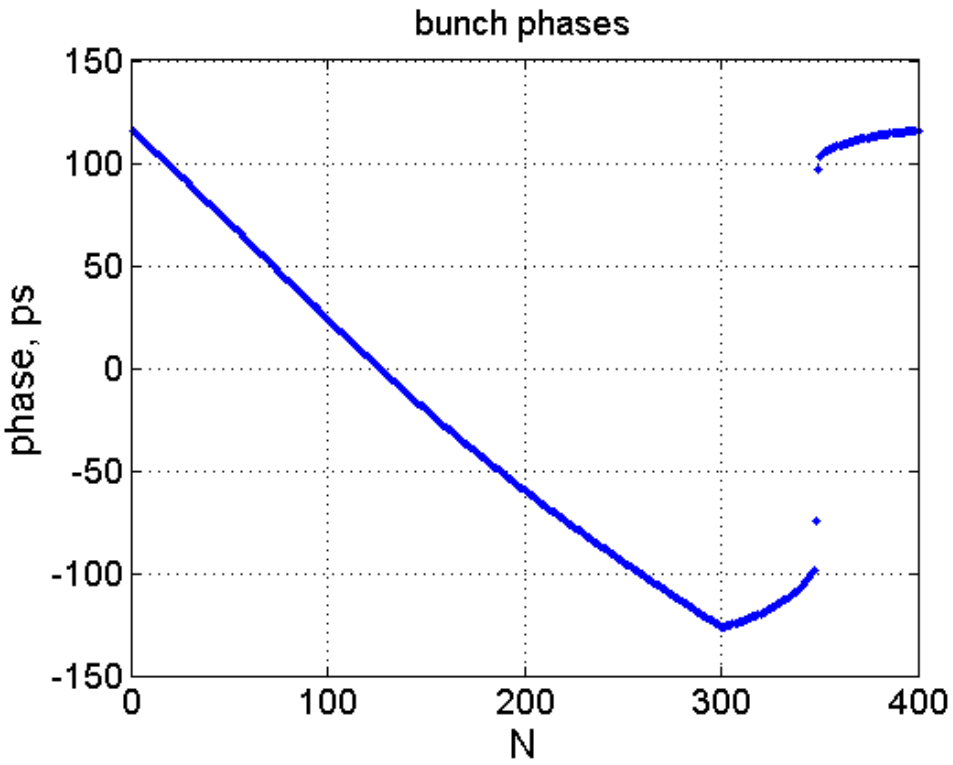
Main RF amplitude 800kV





Main RF voltage 800kV





Conclusion

- BESSY II has quite accurate diagnostic tools to measure transient beam loading
- simple MATLAB model gives an insight into the physics behind it
- for better quantitative accuracy effect of the main RF should be taken into account

Thank You for Your attention!

Bunch phases in TRIBs mode at BESSY II (work in progress)