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BEAM-INDUCED HOM POWER IN CEPC COLLIDER RING CAVITIES

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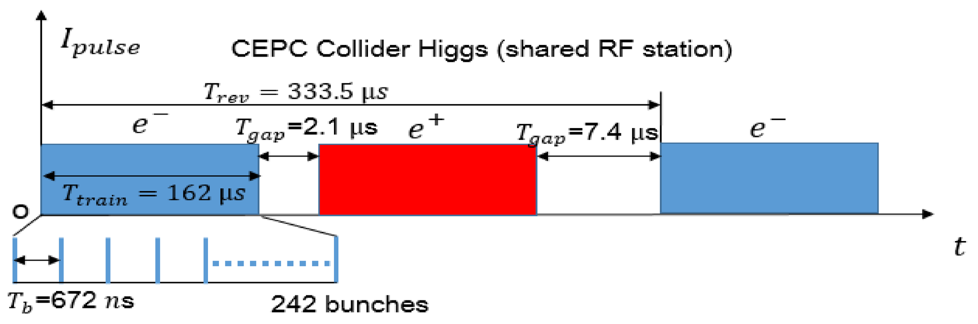
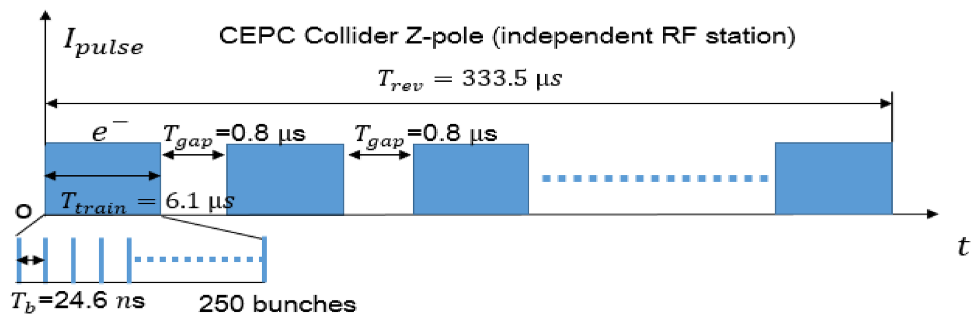
INTRODUCTION

The power loss of cavity high-order modes (HOMs) is a key issue in Circular Electron and Positron Collider (CEPC) RF system design. When the beam spectral lines coincide the cavity HOM frequency, the induced HOM power can be far more than the capacity of each HOM coupler. Too large HOM power can degrade the performance of the RF system. We focus on the beam-induced cavity HOM power for CEPC Collider Ring. First, the bunch filling patterns of Higgs, W and Z-pole are analyzed. The beam spectrum based on multiple beam time structures is deduced. Then the simulated results of longitudinal impedance is also taken, based on CEPC 2-cell 650 MHz cavity. Finally, the cavity HOM power is calculated for Higgs, W and Z-pole designs. The dangerous filling patterns are also identified.

BUNCH FILLING PATTERNS



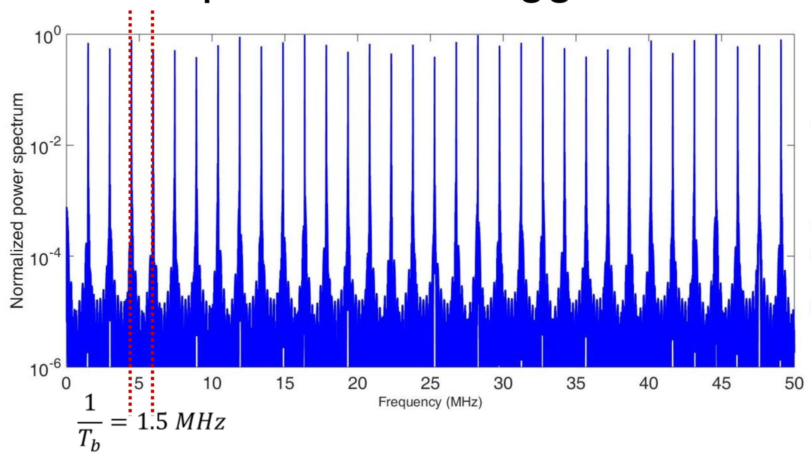
Higgs: Shared RF section for e+ and e-, two unequal gaps, 240 bunches/train.



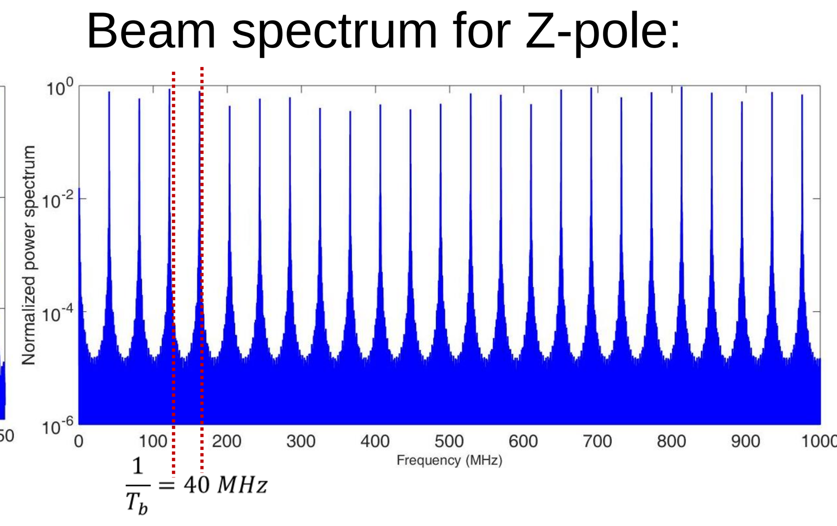
Z-pole: Independent RF sections for e+ and e-, 48 trains * 250 bunches/train.

BEAM SPECTRUM

Beam spectrum for Higgs:

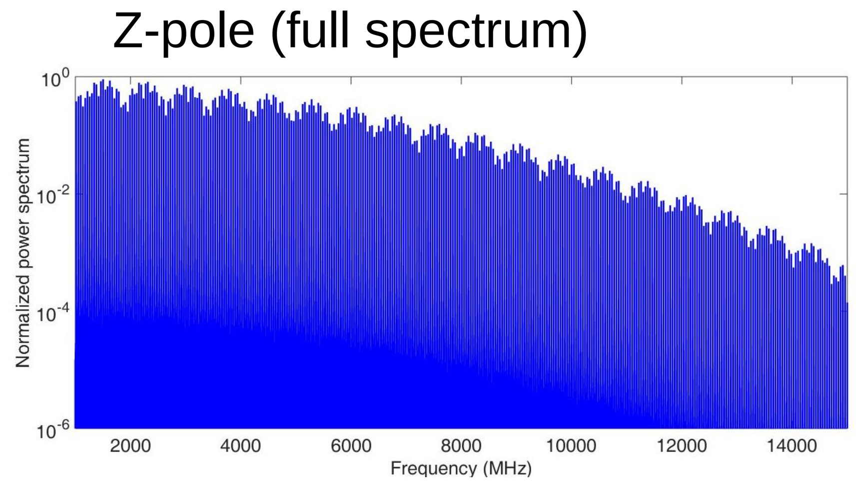


Beam spectrum for Z-pole:



When train number is smaller than bunch number per train, the spacing between two adjacent spectral lines is dominated by $1/T_b$.
The envelop of the beam spectrum is dominated by the bunch length σ_t. The bandwidth of the spectrum is $1/2\pi\sigma_t$.

Z-pole (full spectrum)



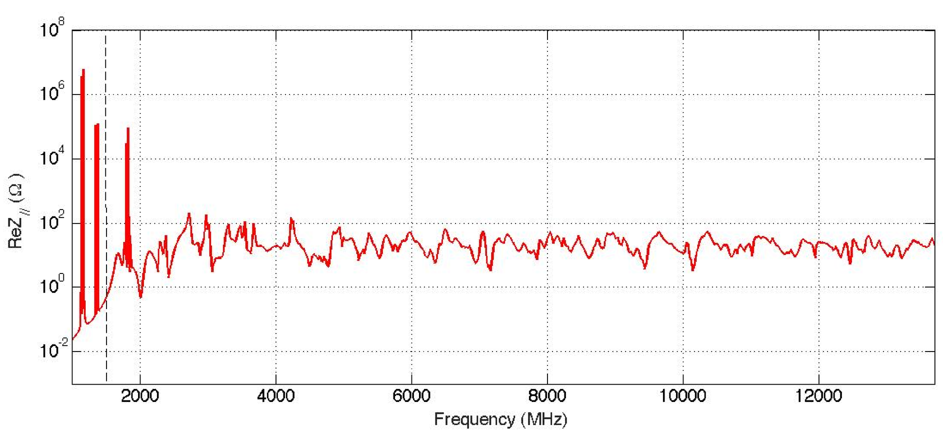
CAVITY LONGITUDINAL IMPEDANCE

CEPC 2-cell 650 MHz cavity

CEPC 2-cell 650 MHz cavity HOMs

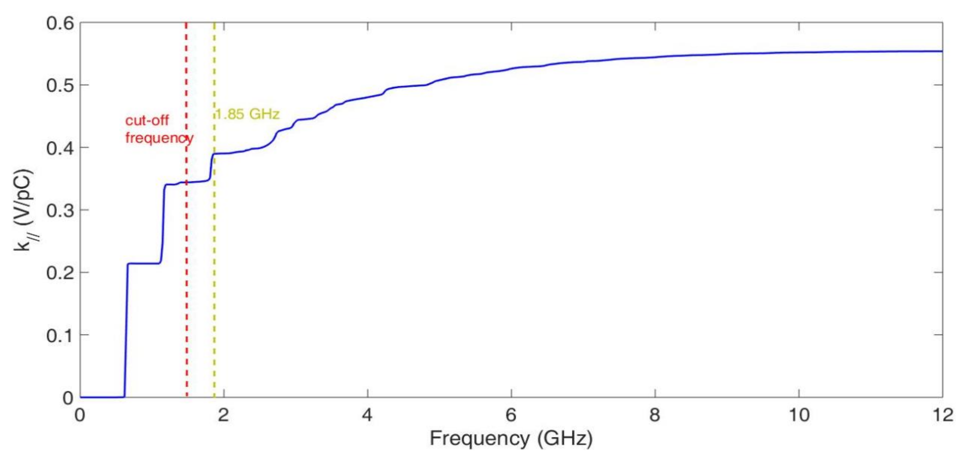
Monopole mode	HOM frequency (MHz)	R/Q (Ω)	Q_e
TM011	1139.871	8.26	3.03E6
TM011	1165.494	63.01	2.51E5
TM020	1349.292	0.91	7.41E5
TM020	1382.854	1.51	1.65E5
TM021	1682.214	1.04	22.75
TM021	1779.840	0.53	90.94
TM012	1805.490	0.32	1.92E5
TM012	1832.677	16.02	1.18E4

Longitudinal impedance over the full spectrum in CEPC 2-cell 650 MHz cavity.



Below 1.85 GHz :
6 narrow-band impedance peaks, varying from 20 $k\Omega$ to 5 MΩ.
Above 1.85 GHz:
wide-band impedance,
the amplitude is less than 100 Ω.

The longitudinal loss factor of CEPC 2-cell 650 MHz cavity.

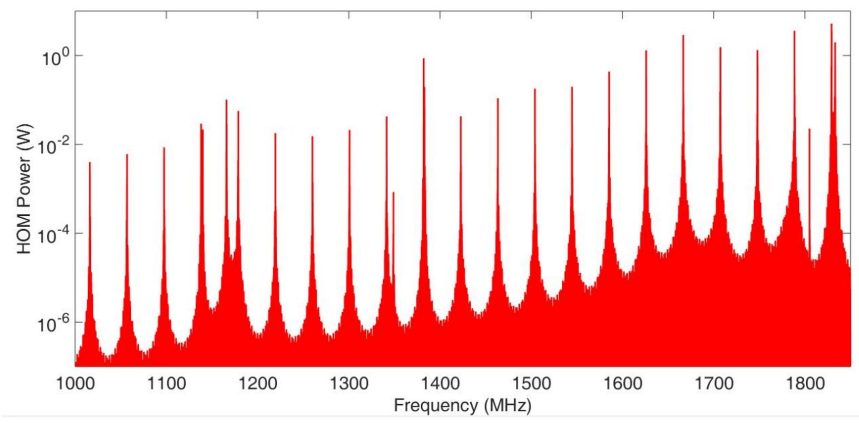


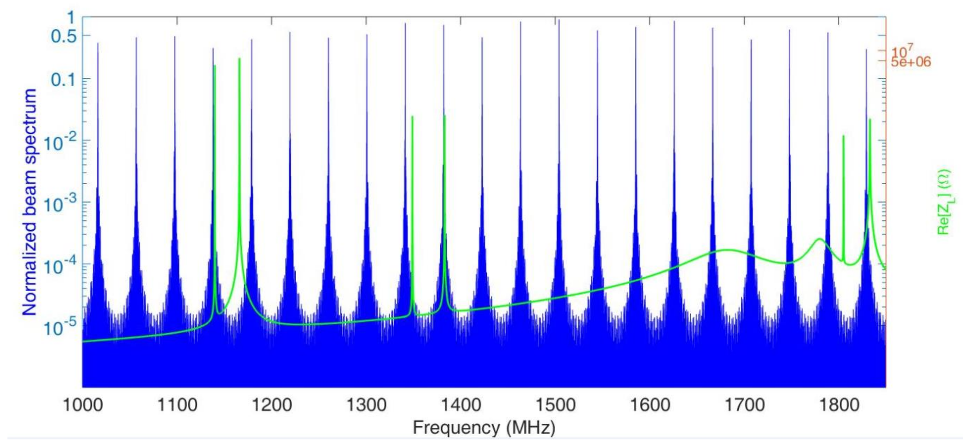
The bunch length is 8.5 mm. The cut-off frequency of the monopole mode for the cavity beam pipe is 1467 MHz.

BEAM-INDUCED HOM POWER

$$P = J_A^2 \sum_{k=-\infty}^{+\infty} \mathrm{Re}\left[Z_{\parallel}(k\omega_0)\right] \left|\hat{J}_k\right|^2 \qquad P = k_{||}qI$$

The HOM power of CEPC Z-pole as a function of frequency.





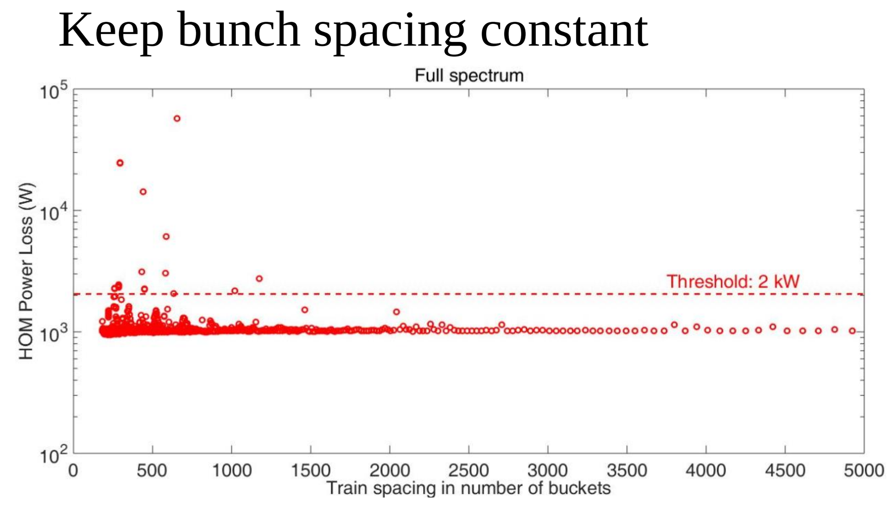
No overlap between the beam spectrum lines and the resonance frequency of cavity longitudinal impedance. But the distance is very small (~1 MHz for TM010).

HOM power of full spectrum in CEPC Collider Higgs, W and Z-pole.

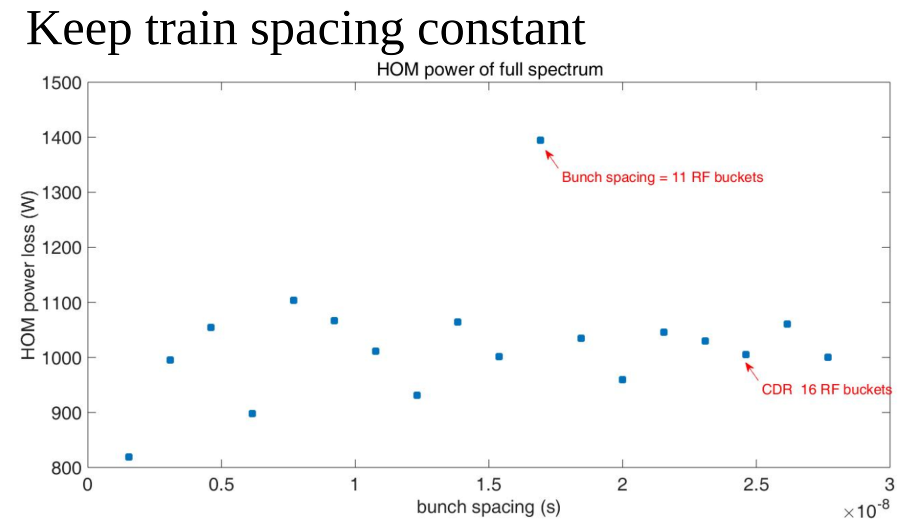
Operation mode	Frequency	Beam spectrum calculation (W)	Average formula calculation (W)
Higgs	< 1.85 GHz	19	131
	> 1.85 GHz	440	440
	Total	459	571
W	< 1.85 GHz	18	231
	> 1.85 GHz	488	516
	Total	506	747
Z-pole	< 1.85 GHz	50	970
	> 1.85 GHz	976	966
	Total	1026	1936

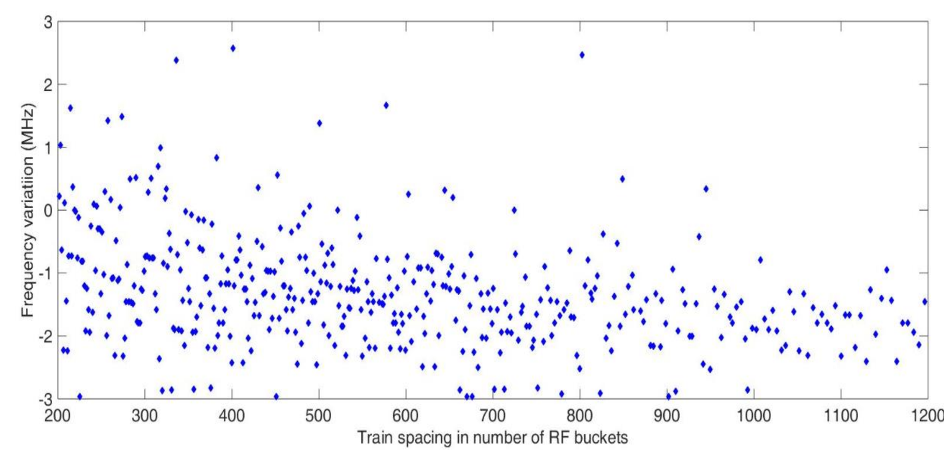
FILLING PATTERNS AND BEAM-INDUCED HOM POWER

Keep bunch spacing constant

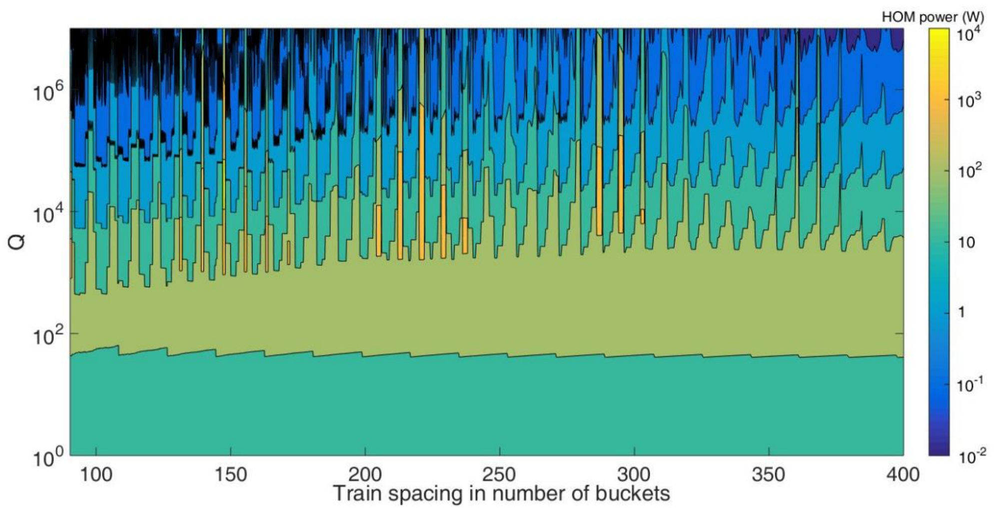


Keep train spacing constant





For TM011 (mode 1), the case when the HOM frequency hits the beam spectrum line is analyzed. The variation of HOM resonance frequency is scanned from -3 MHz to 3 MHz, the step is 1 kHz.



HOM power of TM011 (mode 1) for different Q and train spacing.
When Q is small, the HOM power is low and dependent of bunch filling pattern. When Q is high(>1000), HOM power of some filling patterns is more than 1 kW.

CONCLUSION

For CEPC CDR design scheme, the HOM power, when the actual beam spectrum is considered. The HOM power is 459 W for Higgs, 506 W for W and 1026 W for Z-pole. The actual HOM power for different operation modes are smaller than the average value. That's because the beam spectral lines are not coincide with the cavity HOM resonance frequency.

Below 1.85 GHz, the HOW power is dependent on bunch filling patterns. While, above 1.85 GHz, the HOM power is related to average beam current instead of bunch filling patterns.

Finally, we change the bunch filling patterns for CEPC Z-pole by scanning different bunch spacing and train spacing. All dangerous patterns are identified and they should be avoided during the operation of CEPC.

REFERENCES

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