CEPC Circular Electron Positron Collider

SRF Cavity Design for CEPC PDR Scheme

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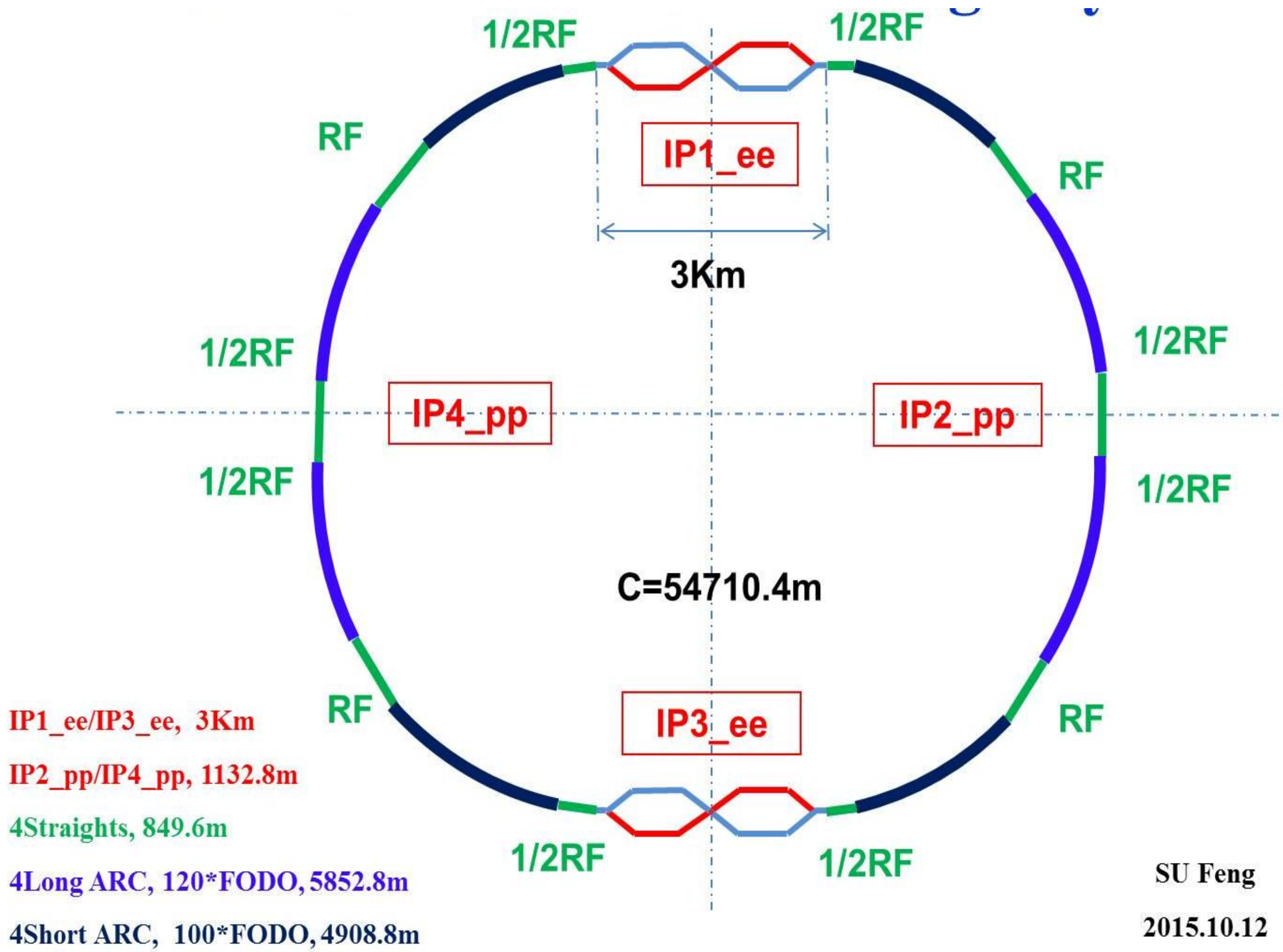
Outline

- Cavity design
  - Cell number
  - Cavity type
- HOM power analysis for multiple time-structure
- Multi-bunch instability caused by RF cavity
- Summary

CEPC PDR scheme



Beam parameters

(wangdou20160219)

	Pre-CDR	H-high lumi.		H-low power		Z
Number of IPs	2	2		2		2
Energy (GeV)	120	120		120		45.5
Circumference (km)	54	54		54		54
SR loss/turn (GeV)	3.1	2.96		2.96		0.062
Half crossing angle (mrad)	0	14.5	**15**	11.5	**15**	**15**
Piwinski angle	0	2	**2.5**	2	**2.6**	**8.5**
N_e/bunch (10^{11})	3.79	3.79	**2.85**	2.81	**2.67**	**0.46**
Bunch number	50	50	**50**	40	**44**	**1100**
Beam current (mA)	16.6	16.9	**16.9**	10.1	**10.5**	**45.4**
SR power /beam (MW)	51.7	50	**50**	30	**31.2**	**2.8**
Bending radius (km)	6.1	6.2	**6.2**	6.2	**6.2**	**6.1**
Momentum compaction (10^{-5})	3.4	3.0	**2.5**	2.6	**2.2**	**3.5**
β_{IP} x/y (m)	0.8/0.0012	0.306/0.0012	**0.25/0.00136**	0.22/0.001	**0.268 /0.00124**	**0.08/0.001**
Emittance x/y (nm)	6.12/0.018	3.34/0.01	**2.45/0.0074**	2.67/0.008	**2.06 /0.0062**	**0.62/0.002**
Transverse σ_{IP} (um)	69.97/0.15	32/0.11	**24.8/0.1**	24.3/0.09	**23.5/0.088**	**7/0.046**
ξ_x/IP	0.118	0.04	**0.03**	0.04	**0.032**	**0.005**
ξ_y/IP	0.083	0.11	**0.11**	0.11	**0.11**	**0.084**
V_{RF} (GV)	6.87	3.7	**3.62**	3.6	**3.53**	**0.12**
f_{RF} (MHz)	650	650	**650**	650	**650**	**650**
Nature σ_z (mm)	2.14	**3.3**	**3.1**	**3.2**	**3.0**	**3.9**
Total σ_z (mm)	2.65	4.4	**4.1**	4.2	**4.0**	**4.0**
HOM power/cavity (kw)	3.6	3.3	**2.2**	1.5	**1.3**	**0.99**
Energy spread (%)	0.13	0.13	**0.13**	0.13	**0.13**	**0.05**
Energy acceptance (%)	2	2	**2**	2	**2**	
Energy acceptance by RF (%)	6	**2.2**	**2.2**	**2.2**	**2.1**	**1.1**
n_γ	0.23	0.49	**0.47**	0.47	**0.47**	**0.27**
Life time due to beamstrahlung_cal (minute)	47	53	**36**	41	**32**	
F (hour glass)	0.68	0.73	**0.82**	0.69	**0.81**	**0.95**
L_{max}/IP ($10^{34}cm^{-2}s^{-1}$)	2.04	2.97	**2.96**	2.03	**2.01**	**3.61**

Cell number

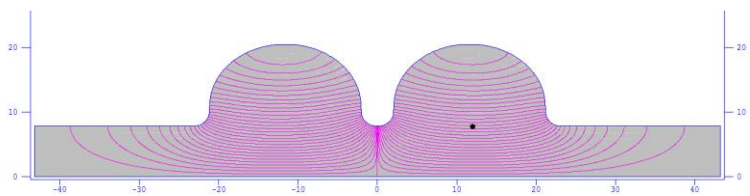
- 5 cell cavity was designed for Pre-CDR scheme. Is it suitable for PDR scheme?
- Selection basis:
  - Accelerating gradient
  - HOMs
  - HOM power
  - HOM power coupler
  - Impedance
  - Cryogenic
  - Transient beam loading
  - Cost
  - ....

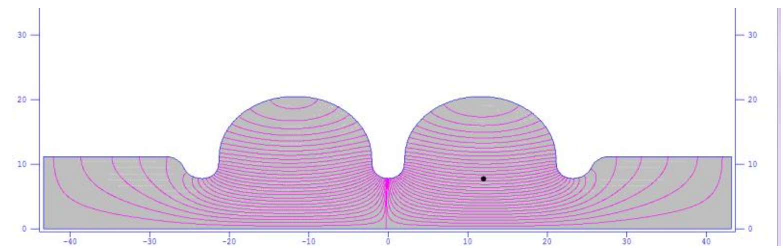
Comparison of different schemes

	High-lumi crossing angle=30mrad		Low power crossing angle=30mrad	
Cell no.	5	2	5	2
Q_0	4×10^{10}	2×10^{10}	4×10^{10}	2×10^{10}
R/Q (Ω)	514	212.7	514	212.7
k_{HOM}/cavity (V/pC)	1.4	0.55	1.47	0.59
Ave. RF power/cavity (kW)	263.29	261.56	163.83	163.04
HOM power/cavity (kW)	2.87	1.14	1.33	0.54
Cavity voltage (MV)	9.6	9.6	9.2	9.2
Gradient (MV/m)	8.4	20.9	8.0	19.9
Detuning frequency (kHz)	-2.97	-1.23	-1.76	-0.73
Cavity bandwidth (kHz)	7.9	3.3	5.4	2.2
Cavity effective length (m)	1.153	0.461	1.153	0.461
Stored energy/cavity (J)	44.2	106.9	40.3	97.3
Cavity wall loss/cavity (W)	4.5	21.8	4.1	19.9

Cavity design

- R_{tube}=78 mm
- R_{tube}=112.2 mm



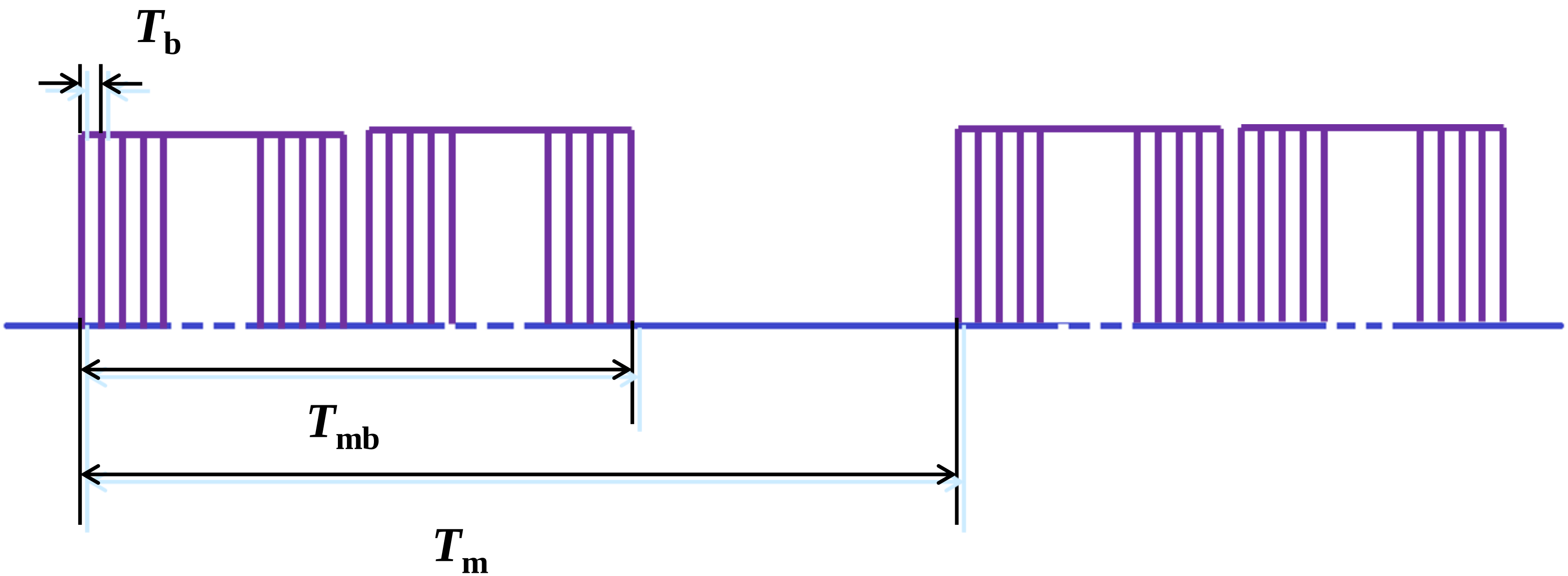


		R_{tube}=78 mm	R_{tube}=112.2 mm
Cut off frequency	MHz	TM01: 1471 TE11: 1126	TM01: 1022 TE11: 783
R/Q	Ω	212.7	206.3
k_{HOM} (σ=4 mm)	(V/pC)	0.593	1.346
Average HOM power (low power 30mrad scheme)	kW	0.54	1.226
Pulsed HOM power	kW	9.11	20.68

HOM power for multiple time-structure

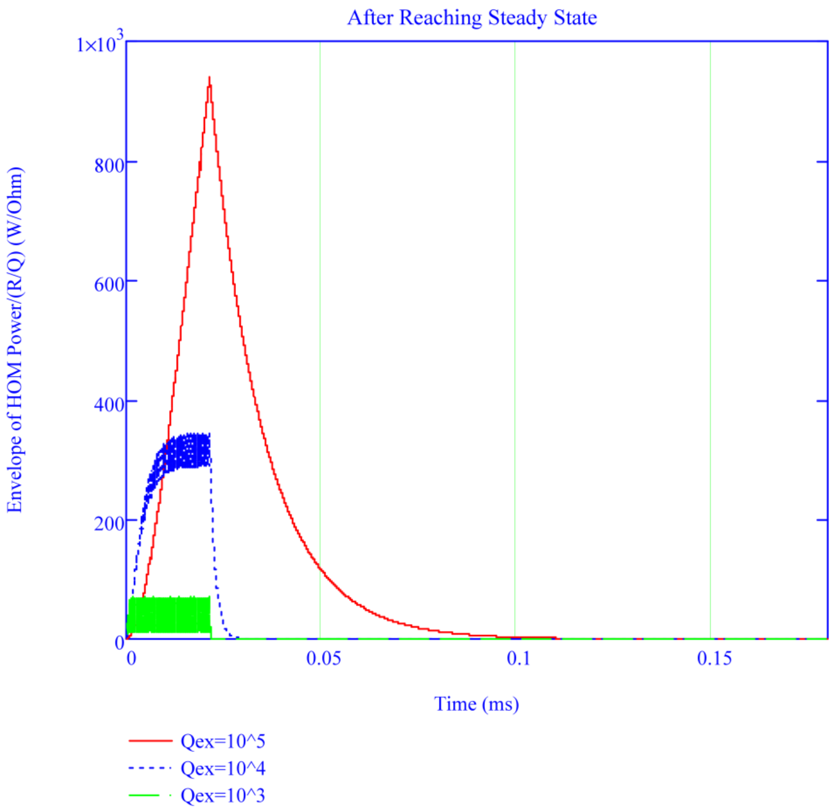
- Beam parameters:
  - H-Low power & crossing angle=30 mrad scheme
- Time structure:
  - Cavity location: IP1 & IP3
  - Cavity location: IP2 & IP4

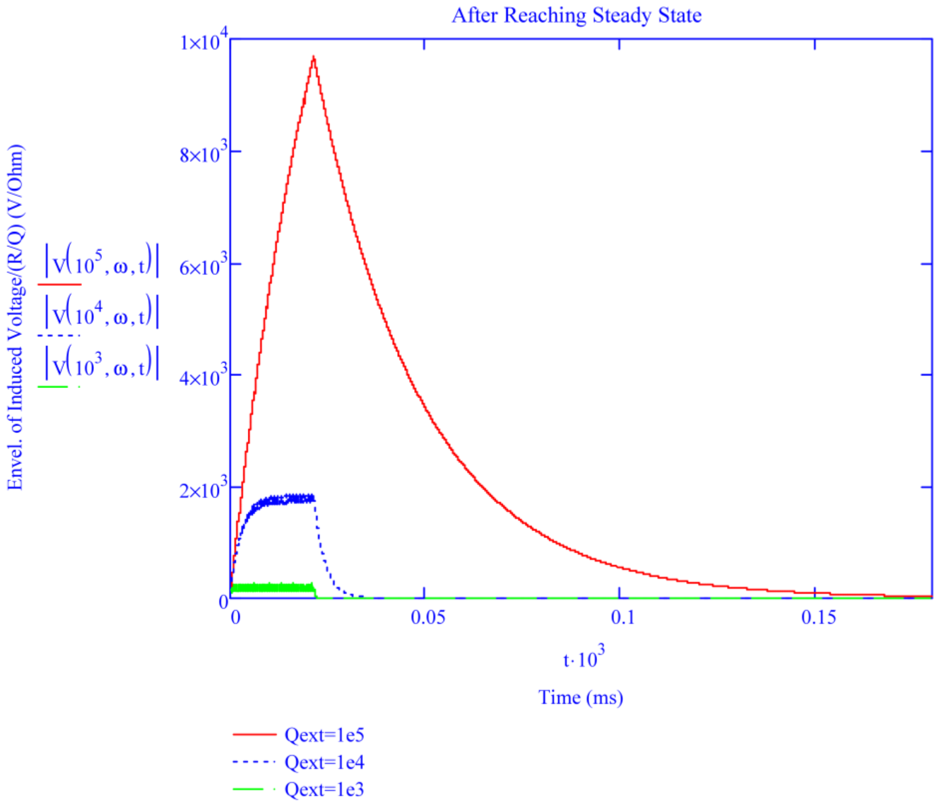
Time structure 1: IP1 & IP3



Macro-pulse period: T_m= 180 μs
Pulse length: T_{mb}=21.4 μs
Macro-pulse gap length : T_G= T_m -T_{mb}=158.4 μs
Time spacing between bunches: T_b=243.1 ns

Induced voltage & HOM power



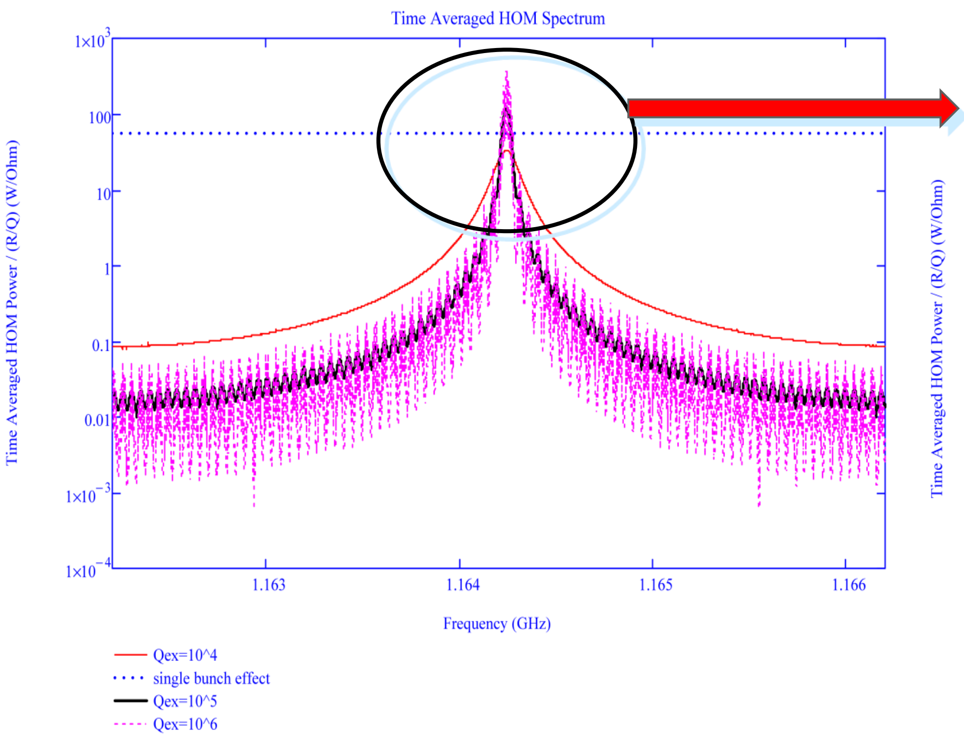


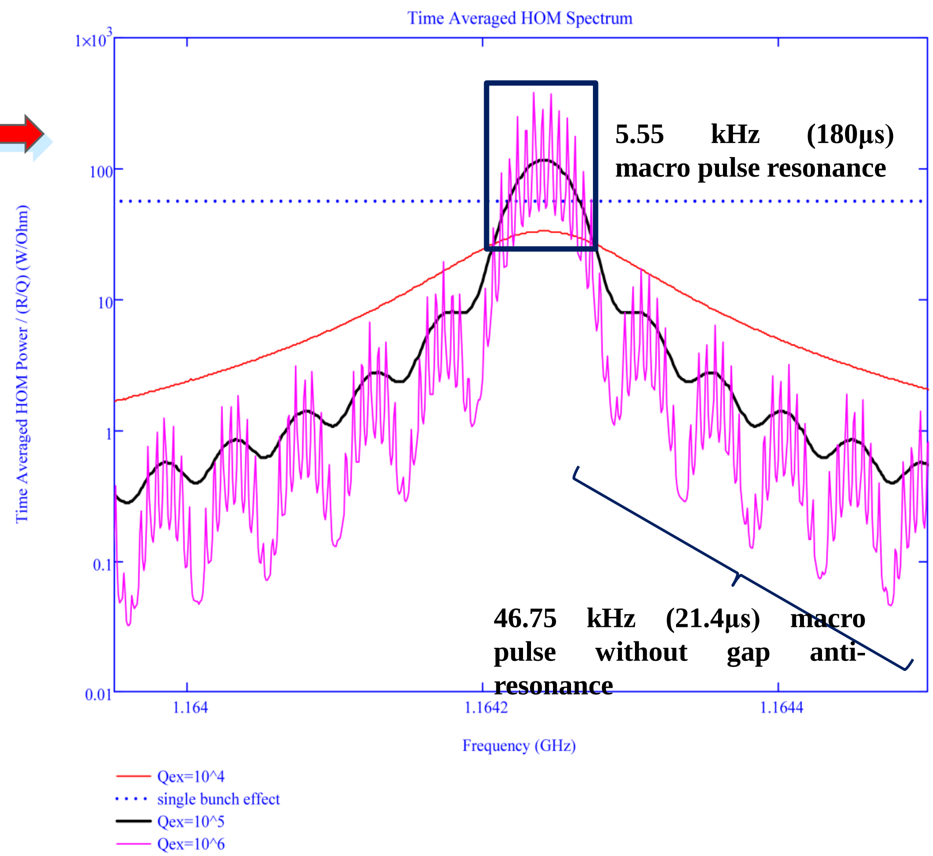
Induced voltage in T_m

Induced power in T_m

f=1.164 GHz, near TM011 mode !

Time averaged HOM power-1

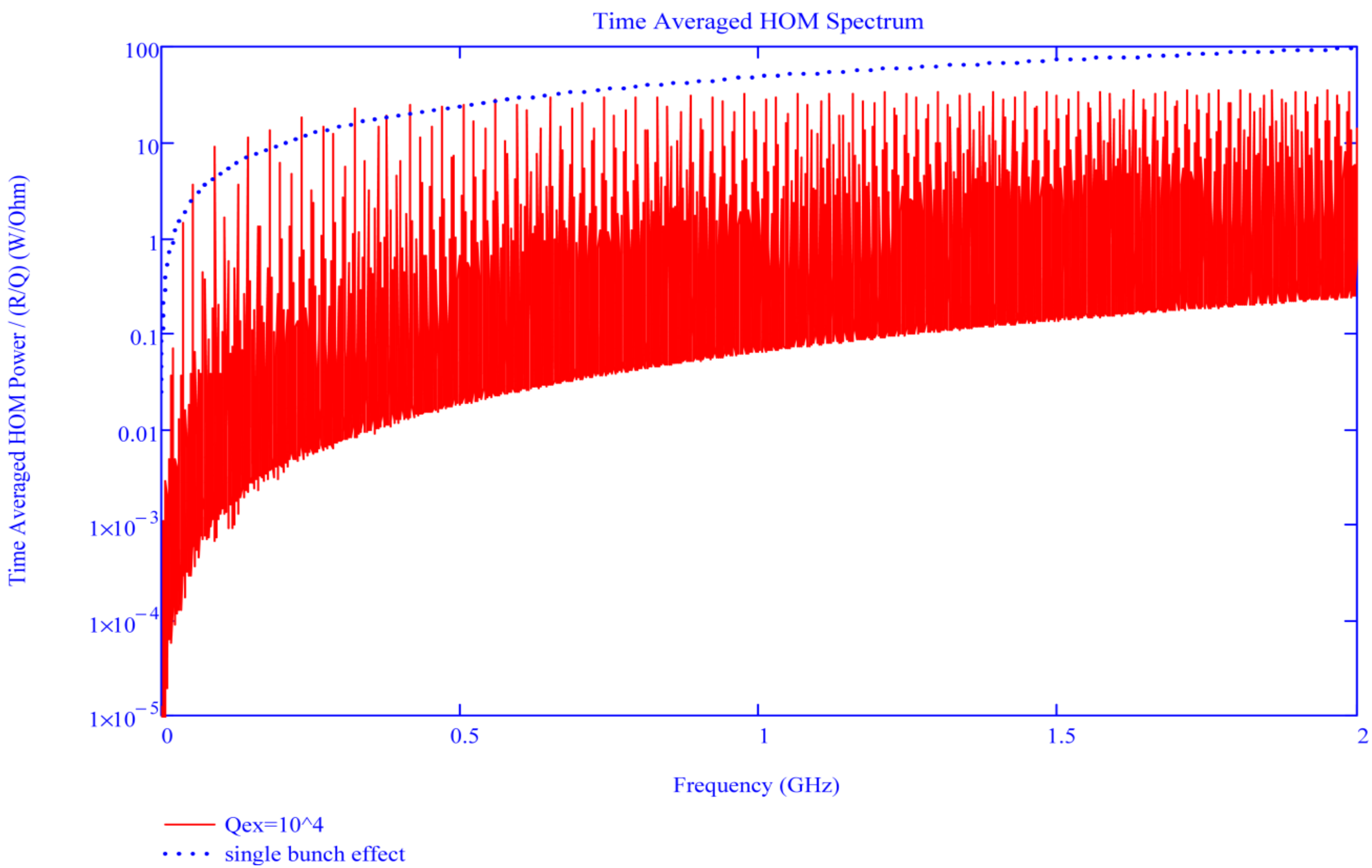




Bandwidth: 4 MHz

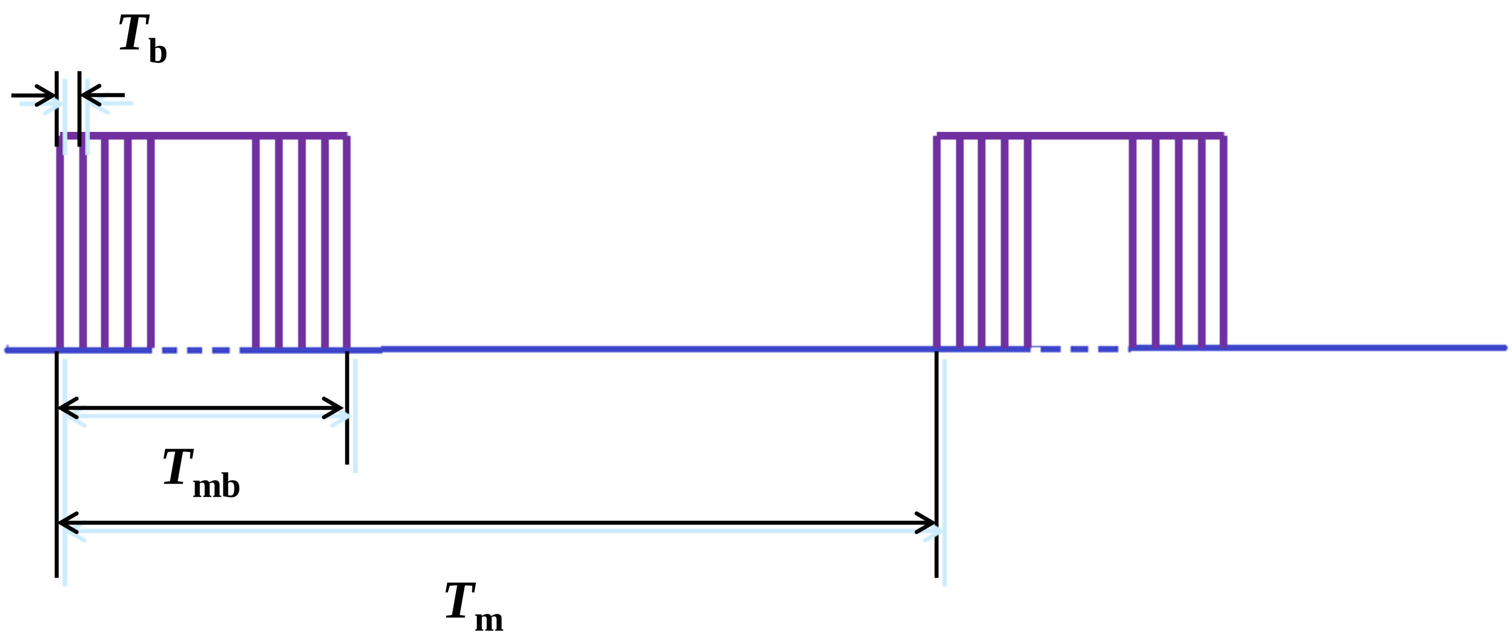
Bandwidth: 0.55 MHz

Time averaged HOM power-2



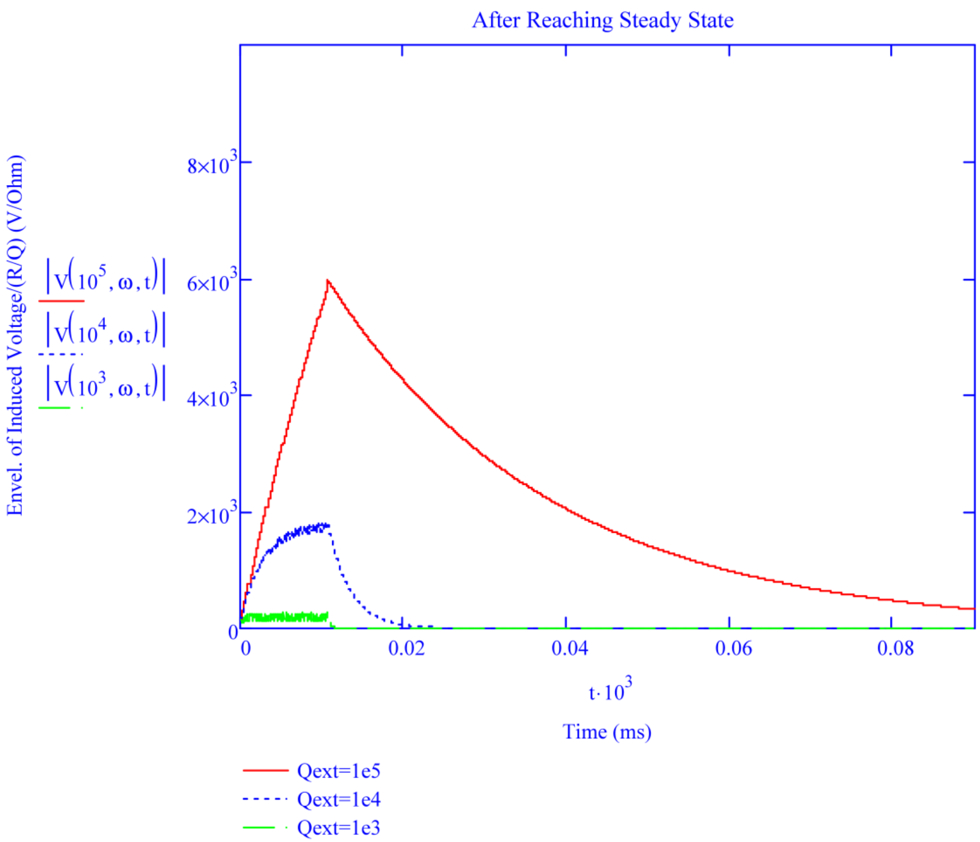
Bandwidth: 2 GHz

Time structure 1: IP2 & IP4

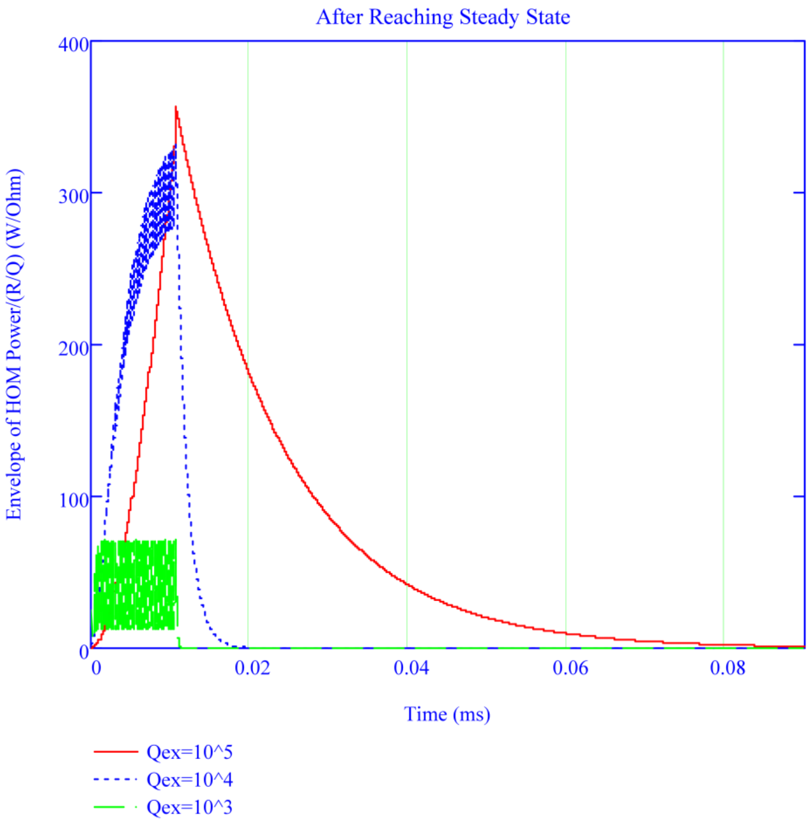


Macro-pulse period: T_m= 90.06 μs
Pulse length: T_{mb}=10.7 μs
Macro-pulse gap length : T_G= T_m -T_{mb}=79.37 μs
Time spacing between bunches: T_b=243.1 ns

Induced voltage & HOM power



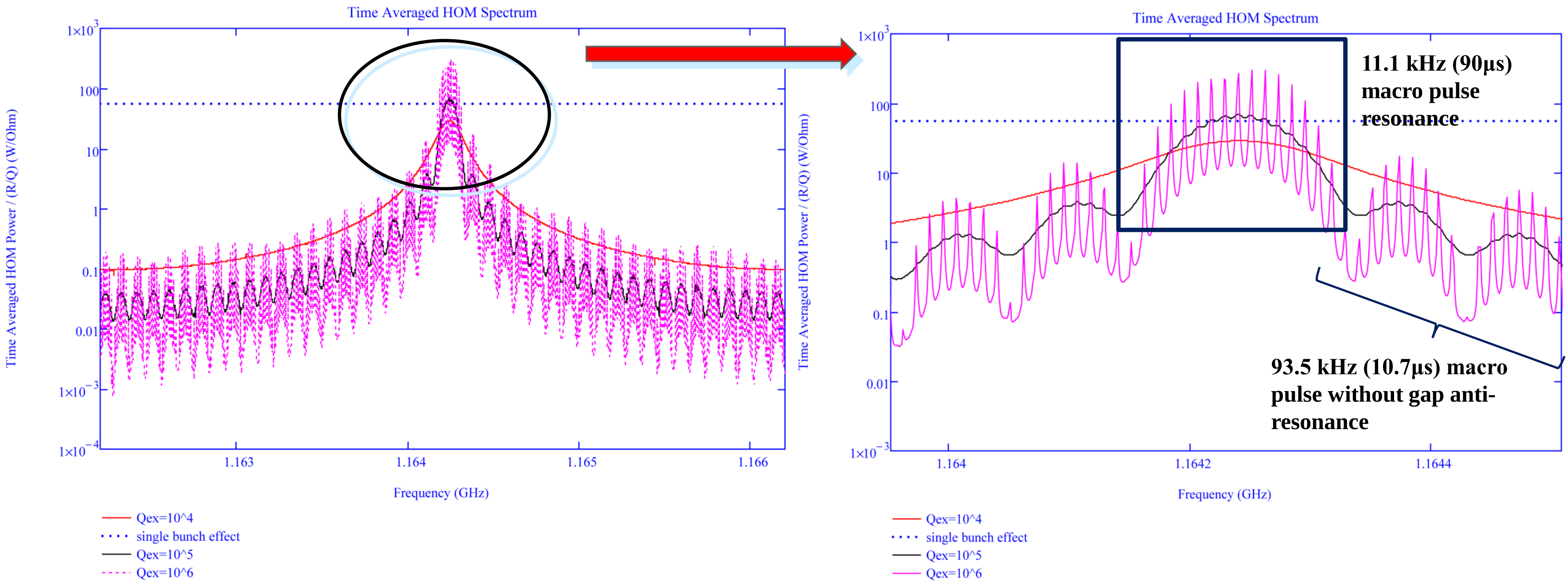
Induced voltage in T_m



Induced power in T_m

f=1.164 GHz, near TM011 mode !

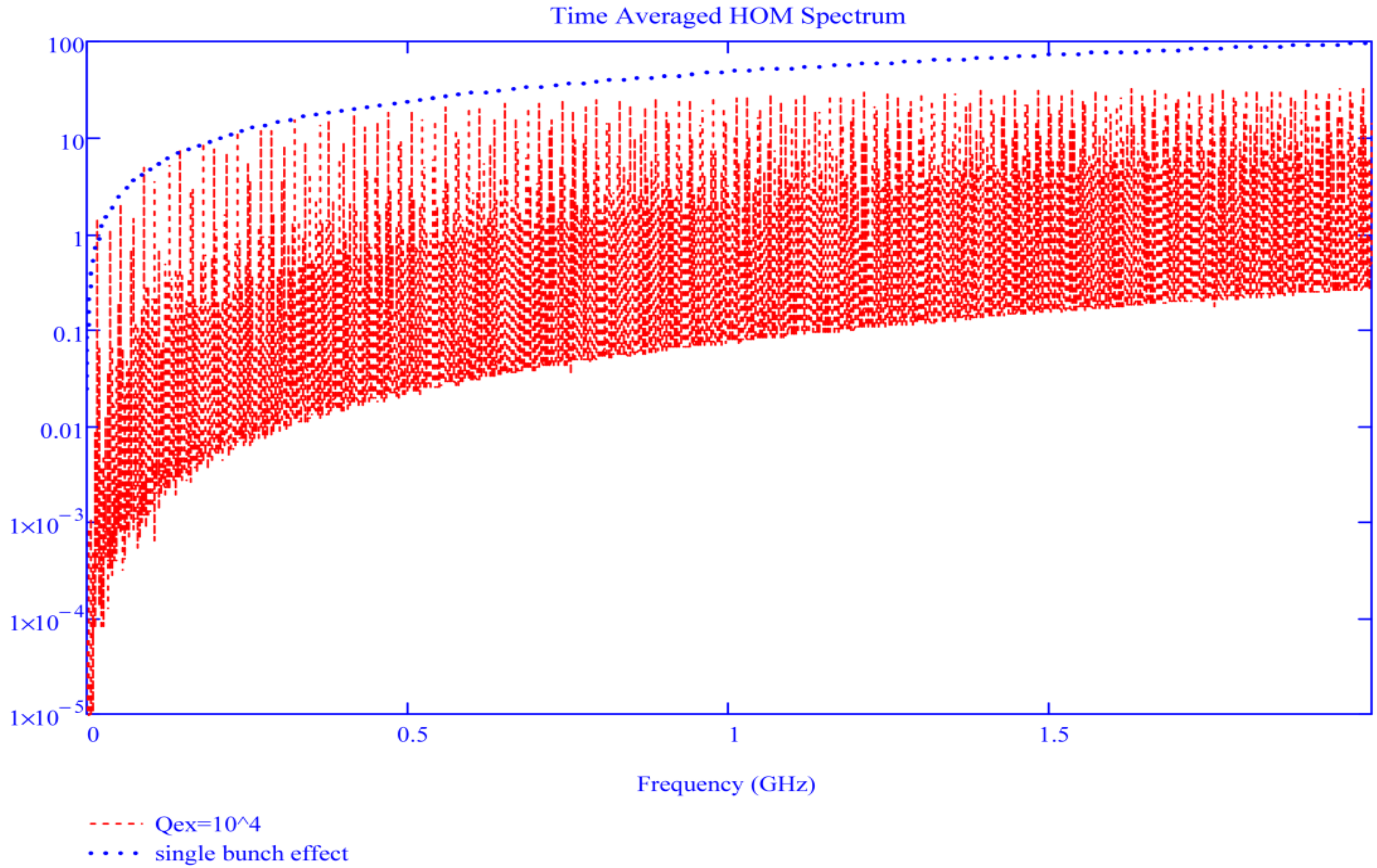
Time averaged HOM power-1



Bandwidth: 4 MHz

Bandwidth: 0.5 MHz

Time averaged HOM power-2



Bandwidth: 2 GHz

Crude estimates of Multi bunch instability caused by RF cavity

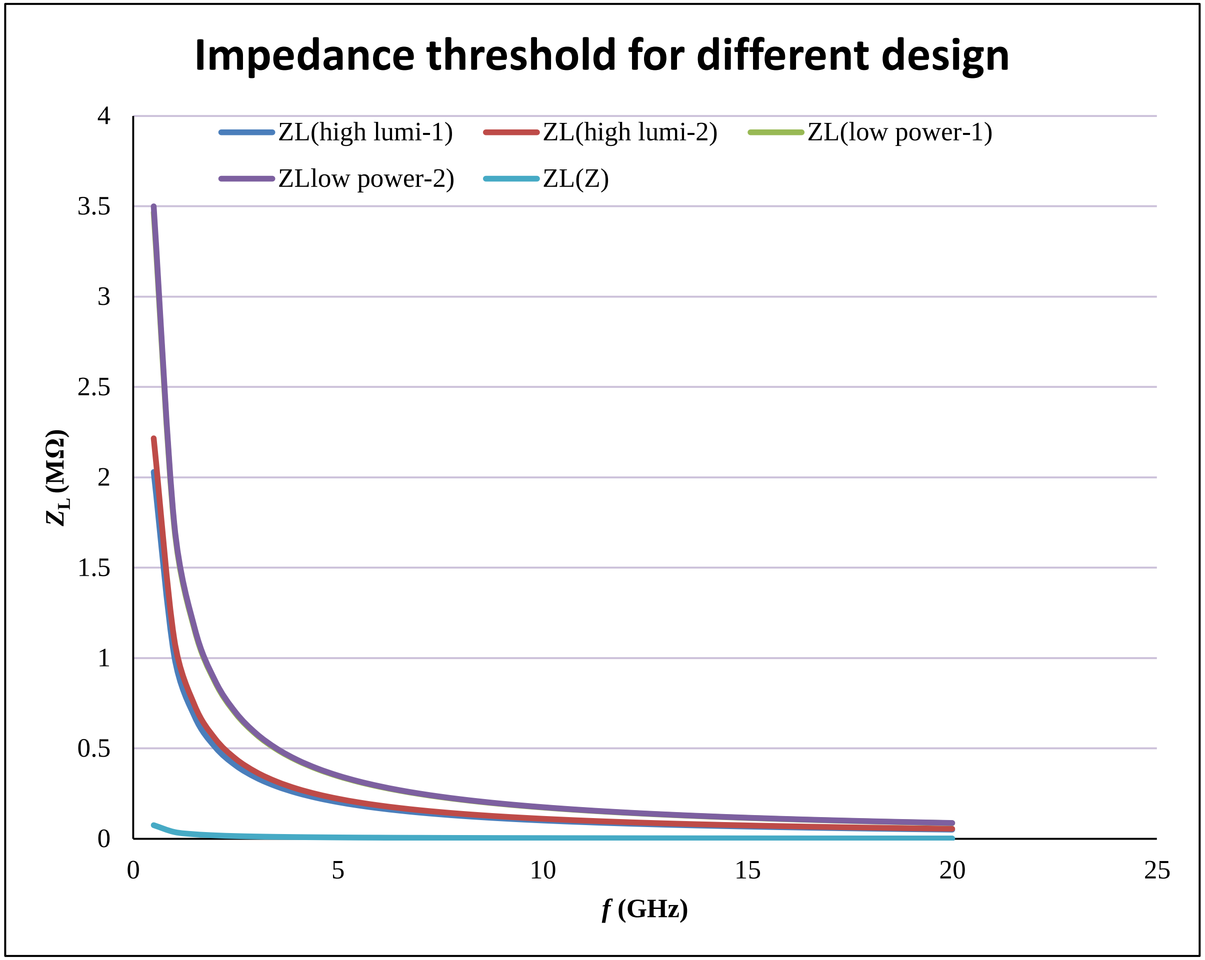
- In the resonant condition, the threshold shunt impedances are

$$R_L^{thresh} = \frac{2(E_0 / e)\nu_s}{N_c f_L I_0 \alpha_p \tau_z} = \frac{2(U_0 / e)\nu_s}{N_c f_L I_0 \alpha_p T_0}$$

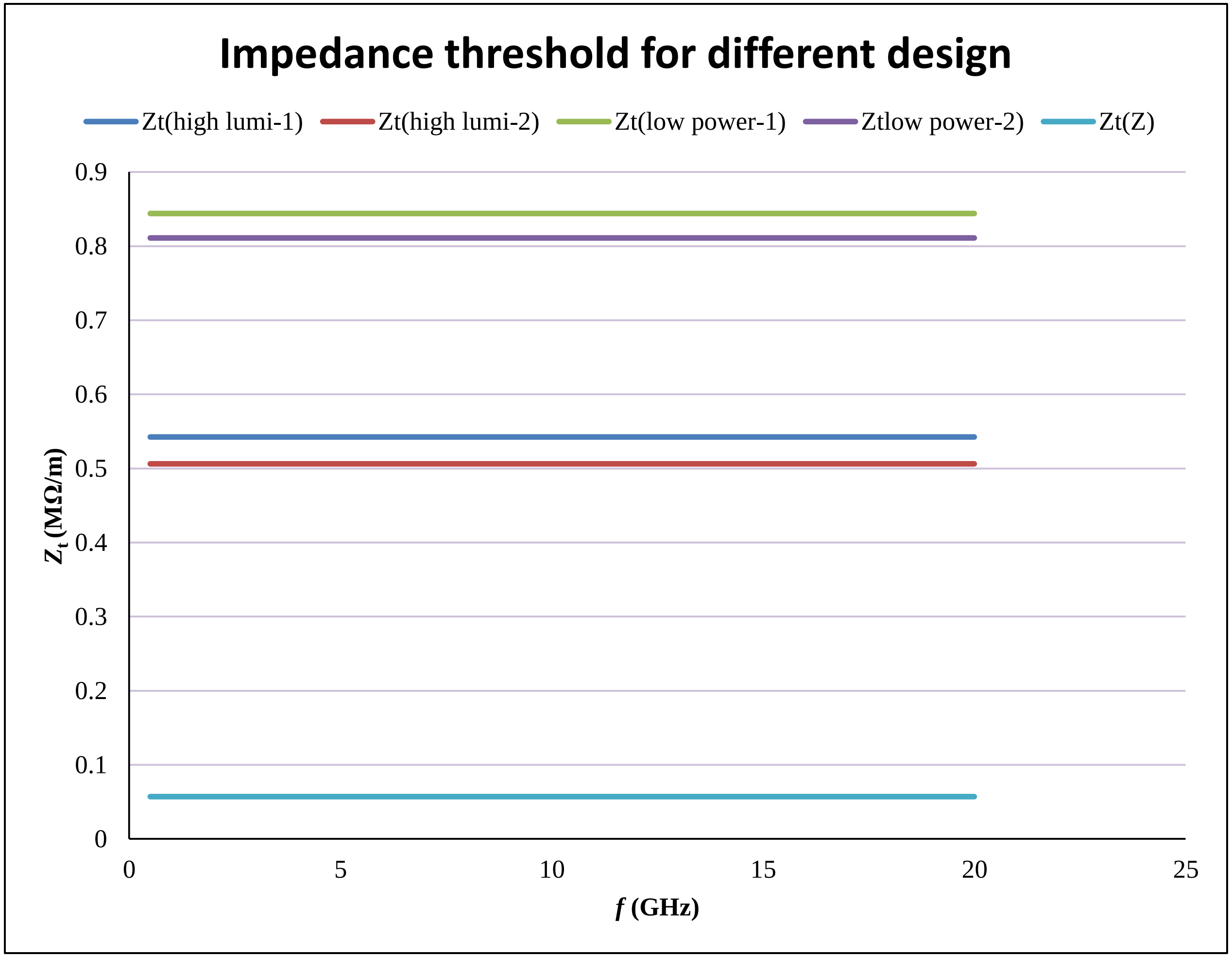
$$R_T^{thresh} = \frac{2(E_0 / e)}{N_c f_{rev} I_0 \beta_{x,y} \tau_{x,y}} = \frac{U_0 / e}{N_c f_{rev} I_0 \beta_{x,y} T_0}$$

[1]. Byrd, J. and J. Corlett. ***Study of Coupled-bunch Collective Effects in the ALS*. in *Particle Accelerator Conference, Proceedings of the 1993*. IEEE**
[2]. Emery, L. ***Coupled-bunch instability study of multi-cell deflecting mode cavities for the Advanced Photon Source*. in *Particle Accelerator Conference, 2007. PAC. IEEE*.**

Longitudinal impedance threshold



Transverse impedance threshold



Requirement for Q_e

monopole	f (MHz)	R/Q (Ω) (2 cell)	R/Q* (Ω) (1 cell)	Q_e (H-low power)	Q_e (Z-2 cell)	Q_e (Z-1 cell)
TM011	1165.536	63.4	33.63	4.74×10^4	1.02×10^3	1.95×10^3
TM020	1384.302	1.128	0.095	2.24×10^6	4.83×10^4	5.85×10^5
dipole	f (MHz)	R/Q (Ω/m) (2 cell)	R/Q** (Ω/m) (1 cell)	Q_e (H-low power)	Q_e (Z-2 cell)	Q_e (Z-1 cell)
TE111	844.666	276.62	131.03	5.86×10^3	4.13×10^2	8.72×10^2
TM110	907.469	414.84	353.04	3.91×10^3	2.75×10^2	3.23×10^2
TM111	1279.043	----	219.98	----	----	5.19×10^2
TE121	1468.139	12.61	0.749	1.29×10^5	9.06×10^3	1.52×10^5

* $k_{//\,\mathrm{mode}} = 2\pi f \cdot (R/Q) / 4$ [V/pC]
** $k_{\perp\,\mathrm{mode}} = 2\pi f \cdot (R/Q) / 4$ [V/(pC·m)]

- Higgs: low power & 30 mrad crossing angle, 384 2-cell cavity
- Z: 32 2-cell or 1-cell cavity

Summary

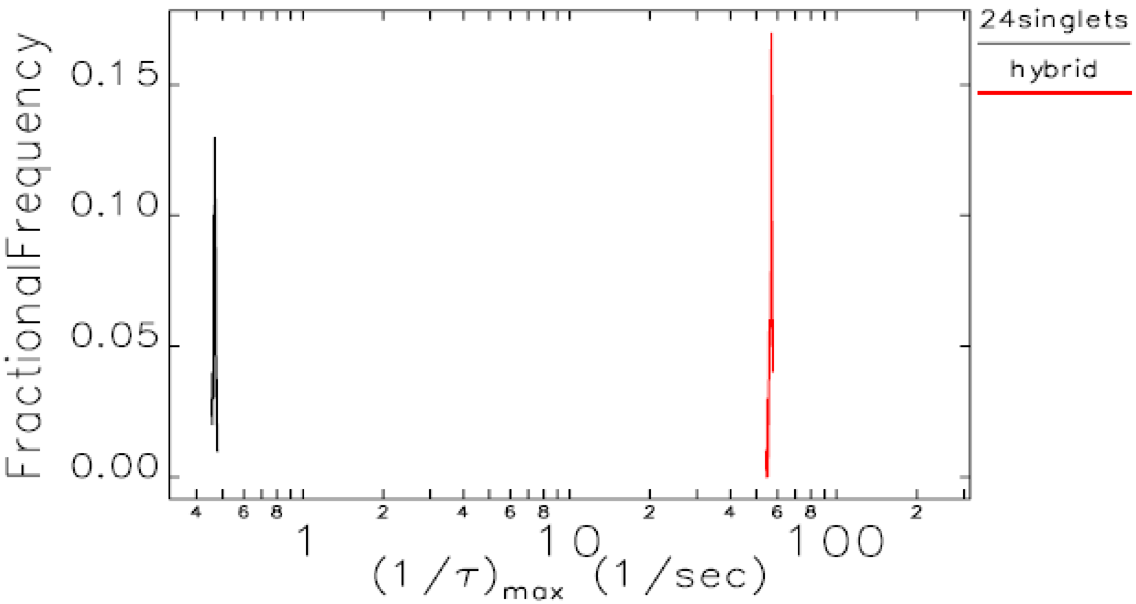
- 2 cell cavity is chosen for PDR-Higgs design.
- Multi-bunch instability caused by the RF cavity need to be further studied.
- HOM coupler considerations.
- ……

Multi-bunch instability for bunch train scheme

- CESR[1]
  - Using a tracking code ‘Oscil’ to study the longitudinal dynamics of multi-bunch beams.
- APS[2]
  - Using a code ‘clinchor’.

[1]. Fromowitz, D. *Simulation of longitudinal multibunch instabilities in CESR*. in *Particle Accelerator Conference, Proceedings of the 1999*. IEEE.
[2]. Emery, L. *Coupled-bunch instability study of multi-cell deflecting mode cavities for the Advanced Photon Source*. in *Particle Accelerator Conference, 2007. PAC. IEEE*.

APS results



Histogram of possible longitudinal growth rate from four 3 cell cavities.

- 24 singlets:
  24 equidistant bunches
- Hybrid
  Single bunch of 16 mA + a 56bunch train . 56 bunch train: 8 groups of 7 consecutive bunches spaced by 24 buckets.

We found that the growth rates were generally greater for the hybrid mode pattern, probably because of so much charge within 500 ns out of the 3.68-μs revolution time.