HOM AND IMPEDANCE STUDY OF RF SEPARATORS FOR LCLS-II

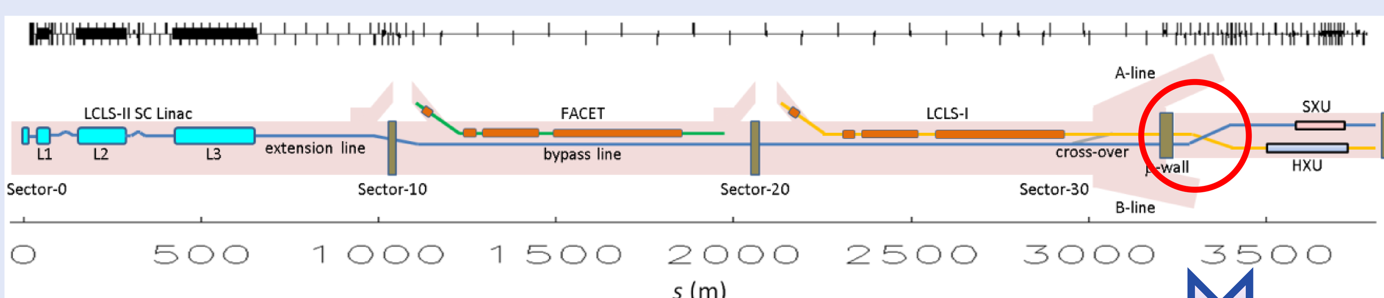
S. U. De Silva #, B. R. P. Gamage, , R. G. Olave, J. R. Delayen, G. A. Krafft, T. Satogata
Center for Accelerator Science, Department of Physics, Old Dominion University, Norfolk, VA 23529, U.S.A

ABSTRACT

The LCLS-II upgrade requires an rf spreader system to guide bunches into a switchyard delivering beam to two undulators and the primary beam dump. The beam pattern therefore needs a 3-way beam spreader. An rf deflecting cavity concept was proposed that includes both superconducting and normal conducting options. We characterize the higher order modes (HOM) of these rf separator cavities and evaluate beam dynamics effects due to potential HOM excitation. This study includes both short term wake and multi-bunch effects.

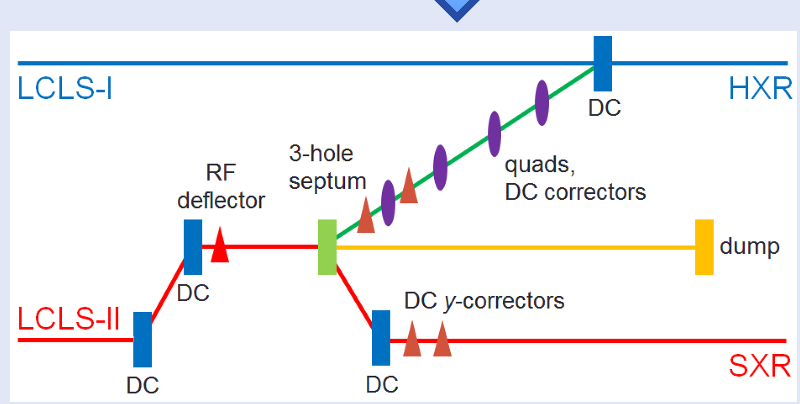
LCLS-II RF – SEPARATOR CAVITY OPTIONS

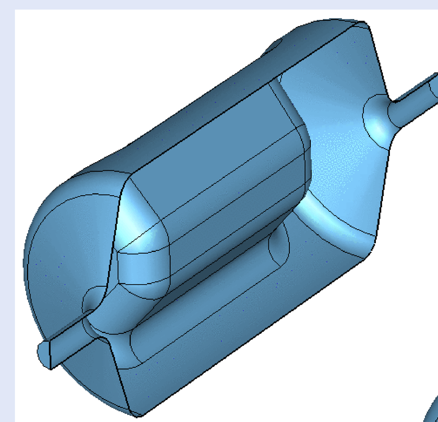
- LCLS-II requires an rf spreader system to transport beam to the undulators or the beam dump
- Considered fast switching devices:
  - Fast bipolar kickers
  - RF deflectors



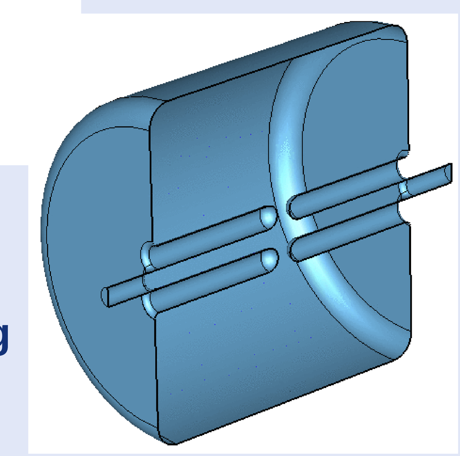
RF Separator Parameters

Parameter	Nominal Value	Units
Final electron energy (E_f)	4.0	GeV
RF frequency (f_d)	325	MHz
Angle of deflection	1.0	Mrad
Transverse voltage (V_t)	4.0	MV

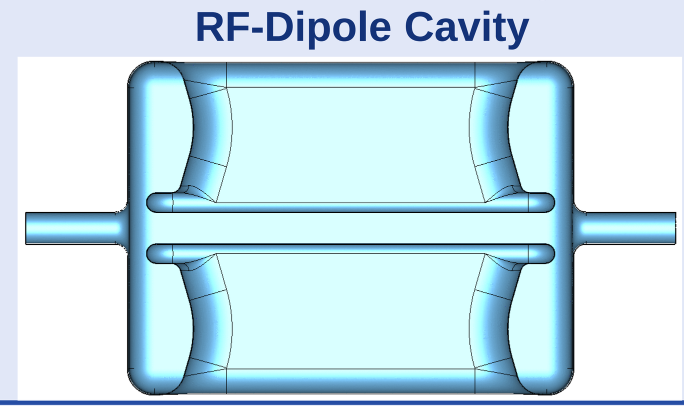




Superconducting RF-Dipole Cavity



Normal Conducting 4-Rod Cavity

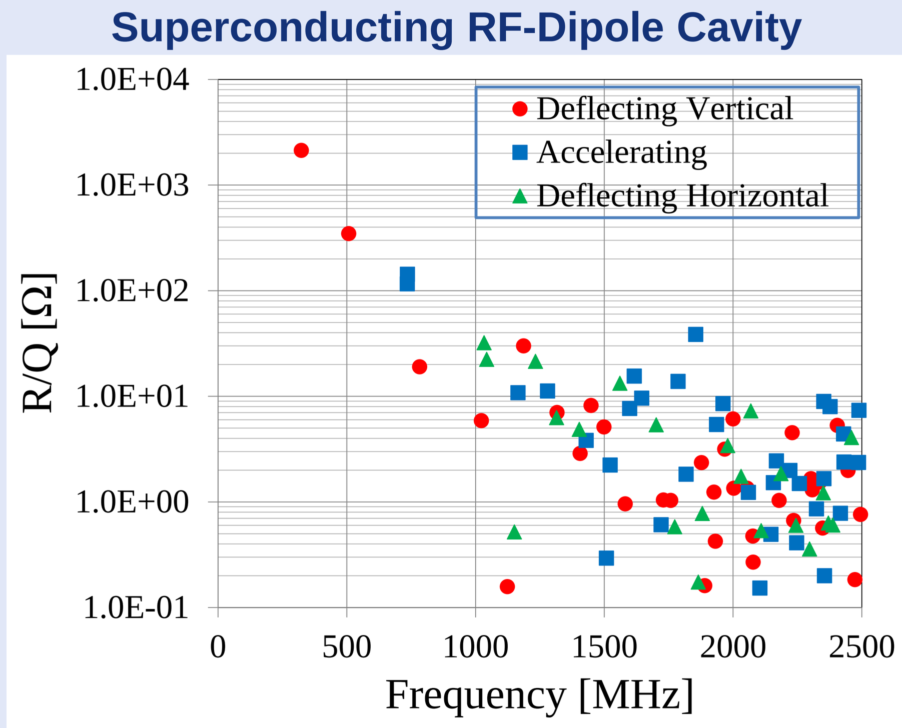


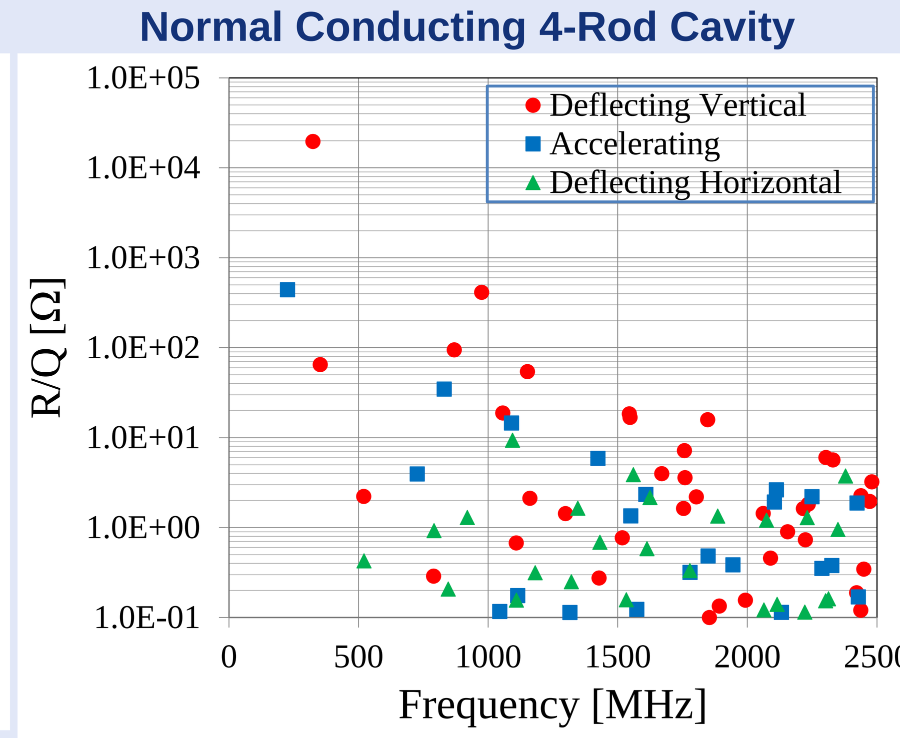
Normal Conducting RF-Dipole Cavity

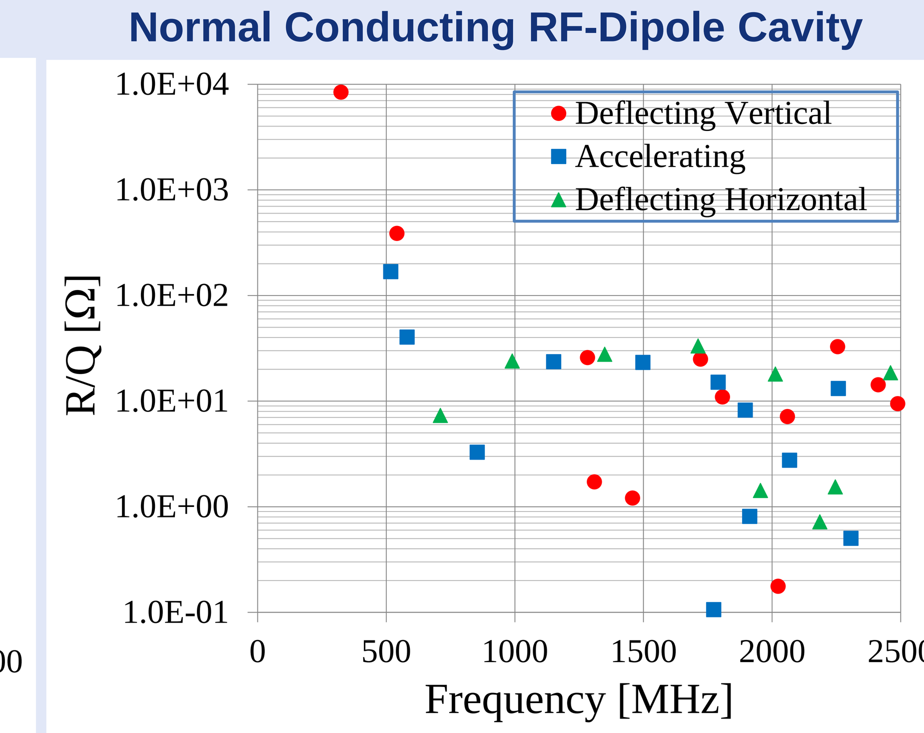
Parameter	SC-RFD	NC-4ROD	NC-RFD	Units
No. of cavities	1	6	6	
Aperture diameter	40.0	25.0	25.0	mm
λ/2	461.2			mm
Deflecting voltage (V_T)	4.0			MV
Peak electric field (E_P)	23	29	4.3	MV/m
Peak magnetic field (B_P)	32	63	28	mT
Geometrical factor	91.5	37.3	48.3	Ω
$[R/Q]_T$	2133	1.9×104	8367	Ω
$R_T R_S$	1.95×10^5	7.2×10^5	4.0×10^5	Ω^2
Q_0	1.6×10^9	8.0×10^4	1.0×10^4	
P_{diss} per cavity	4.8	2.9×10^3	5.2×10^3	W
Peak dP_{diss}/dA	-	16.2	4.4	W/cm²

HOM PROPERTIES

- No LOMs in superconducting or normal conducting rf-dipole cavity
- $[R/Q]$ drops with the increasing frequency
- Q_0 of HOMs
  - For superconducting cavities: 10^8~10^{10}
  - For normal conducting cavities: 10^4~10^5
- HOM excitation in normal conducting cavities are negligible compared to superconducting cavities







MULTI-BUNCH EFFECTS

LCLS-II Beam Parameters

Parameter	Nominal Value	Range	Units
Final electron energy (E_f)	4.0	2.0-4.0	GeV
Electron bunch charge (Q_b)	0.1	0.01-0.5	nC
Bunch repetition rate (CW) (f_b)	0.2	0-1	MHz
Average current (I_{avg})	0.02	0.001-0.3	mA
Peak current (I_{pk})	1000	500-1500	A
rms bunch length (σ_z)	8.3	0.6-52	μm

Beam Loading

- Beam induced voltage for the fundamental mode with Q_L=5.5×10⁶ for a beam with I_{avg}=0.02 mA at an offset of Δx=5 mm:

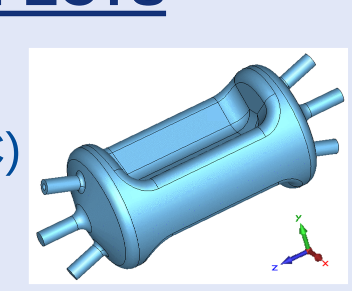
$$V_{t,induced} = \left[\frac{R}{Q}\right] Q_L k \Delta x I_{avg} = 8 \text{ kV}$$

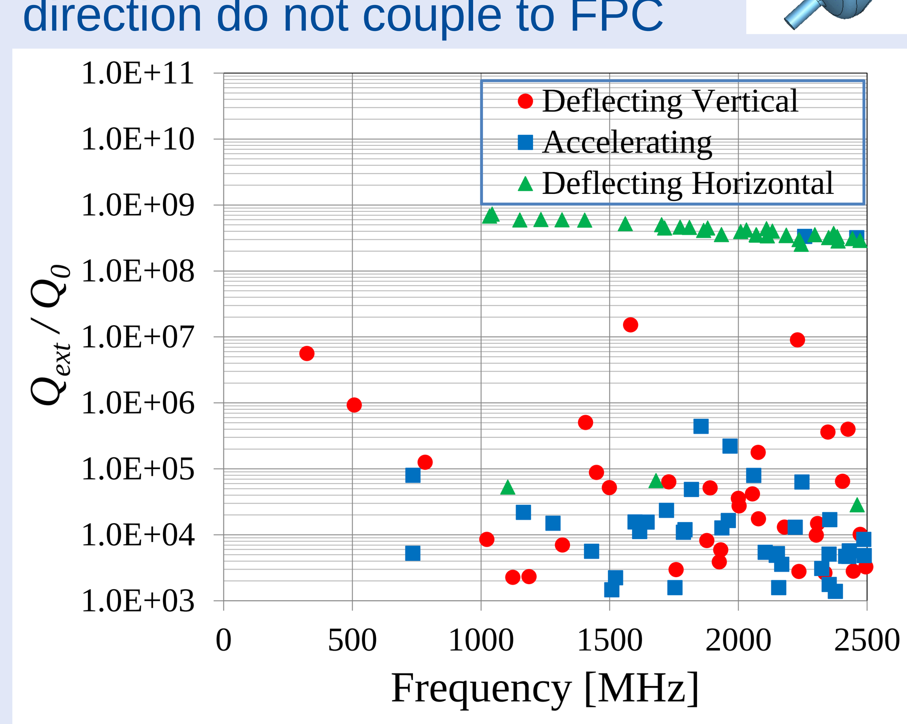
- Induced beam power: 0.16 W

Effects due to HOM Excitation for LCLS-II Beam

- In the superconducting rf-dipole cavity the decay times are higher than bunch separation (1 μs) → Leading to multi-bunch effects
- f_{rms} = 500 GHz for short bunches of 0.6 μm
- In SC-RFD with r_{apt} = 20 mm, HOMs above cut off frequency propagates through the beam pipe

- Q_{ext} with coupling through fundamental power coupler (FPC)
- Deflecting modes in horizontal direction do not couple to FPC

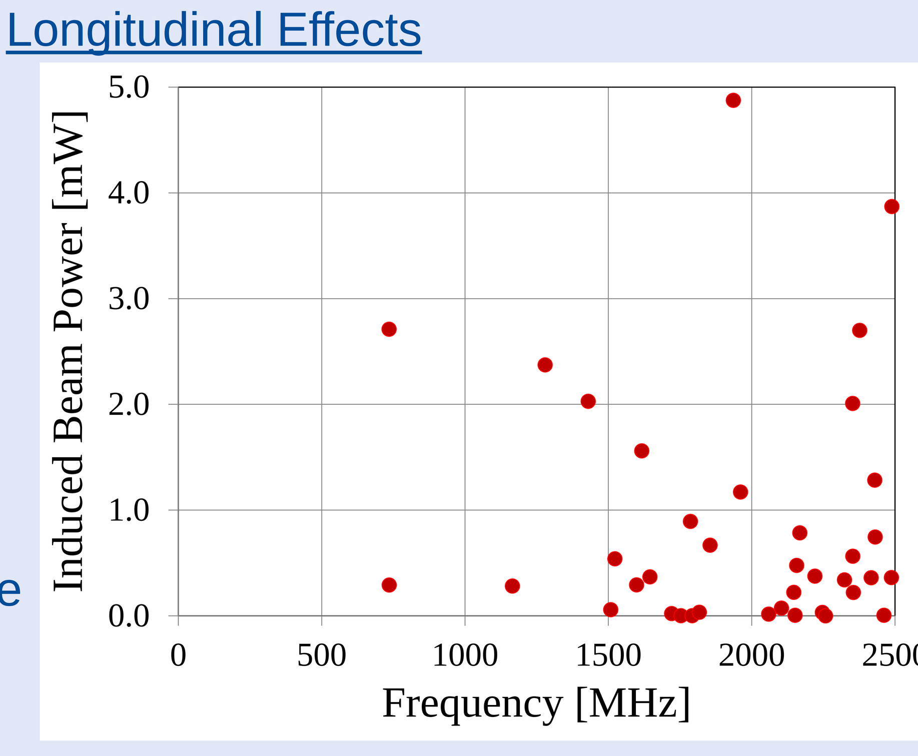




- HOM excitation due to on axis beam

- Total induced beam power ~32 mW
- Induced voltage ~ 0.11 kV → Is negligible to generate energy spread in the beam

Longitudinal Effects



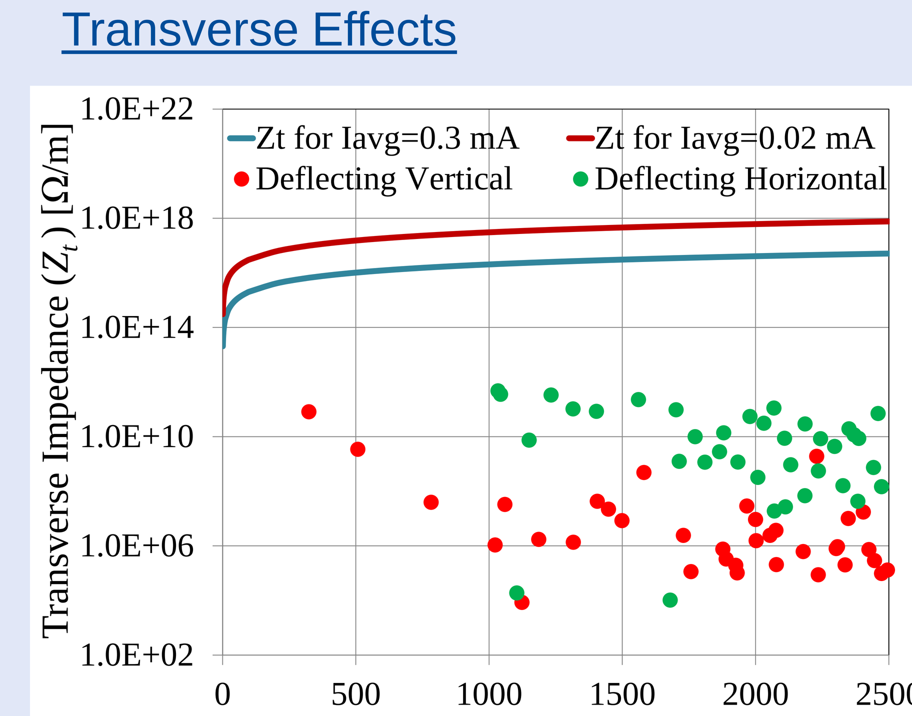
- Effects due to transverse mode excitation
- Threshold current due to regenerative effects: $I_{th} = \dfrac{\pi^3 E_f k}{2 Z_t L}$

- Operational beam current must be below the threshold current (I_{th}) to prevent generating any transverse beam instabilities

$$Z_{t,n} = k_n \left[\frac{R}{Q}\right] Q_{ext} < \frac{\pi^3 E_f k_n}{2 L I_{avg}}$$

k – wave number
L – length of the cavity

Transverse Effects



SUMMARY: HOM excitation in SC-RFD does not lead to beam instabilities. Induced HOM power dissipates through the cavity surface and adds to cryogenic losses.

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#sdesilva@jlab.org