DESIGN OF A QUASI-WAVEGUIDE MULTICELL DEFLECTING CAVITY FOR THE ADVANCED PHOTON SOURCE*

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Abstract

This paper reports the electromagnetic design of a 2815 MHz Quasi-waveguide Multi-cell Resonator (called QMiR) being considered as a transverse RF deflecting cavity for the Advanced Photon Source's (APS) Short Pulse X-ray project. QMiR forms a trapped dipole mode inside a beam vacuum chamber while High Order Modes (HOM) are heavily loaded. It results a sparse HOM spectrum, makes HOM couplers unnecessary and allows simplifying the cavity mechanical design. The form of electrodes is optimized for producing 2 MV of deflecting voltage and keeping low peak surface electric and magnetic fields of 54 MV/m and 75 mT respectively. Results of detailed EM analysis, including HOM damping at the actual geometry of beam vacuum chamber, will be presented.

INTRODUCTION

A superconducting radio frequency (SRF) multi-cell trapped mode cavity is proposed for an implementation in the Short Pulse X-ray (SPX) upgrade of Argonne APS. Proposed technique is based on a beam deflection resulting a correlation between the longitudinal position of an electron within the bunch and its vertical momentum. It allows obtaining a sub-picosecond X-ray pulse without a reduction of a bunch length with existing particles accelerators.

Table 1: Design parameters for the APS deflecting cavity

Parameter	Value
Frequency	2.815 GHz
Optimal beta	1.00
Nominal Kick Voltage	2 MV
Beam aperture	12 mm x 30 mm
Max surface E_{pk}	54, (< 55) MV/m
Max surface B_{pk}	75, (< 80) mT
G-Factor	130 Ω
R/Q, Operating mode	1040 Ω
R_m*F, Monopole modes	<0.44 MΩ * GHz
R_t, Horizontal mode	<1.3 MΩ/m
R_t, Vertical mode	<3.9 MΩ/m

CAVITY EM DESIGN

Multiple electrodes immersed into a waveguide form a trapped mode resonator, the transverse EM-field components of the TE dipole mode allow creating a kick and effectively deflecting charged particles passing through the cavity. Because such a cavity is open, i.e. has no end walls, it helps significantly in reducing the maximum quality factors of HOMs and, thus, avoiding complicate HOM couplers and simplifying a cavity mechanical design in overall. The form of electrode is chosen to be a chain of conjugated elliptical surfaces for optimal distribution of electrical and magnetic field components. The waveguide position is shifted in respect to the inter-cell boundary aiming to break symmetry and provide an adequate high-Q coupling of operating mode with an external RF source.

HOM DAMPING

The fundamental coupler waveguide is used to suppress lower dipole SOM modes. The beam pipe cutoff frequency for the transverse TE11 mode is 3.6 GHz and, thus, all higher frequency dipole modes freely propagate out of the cavity.

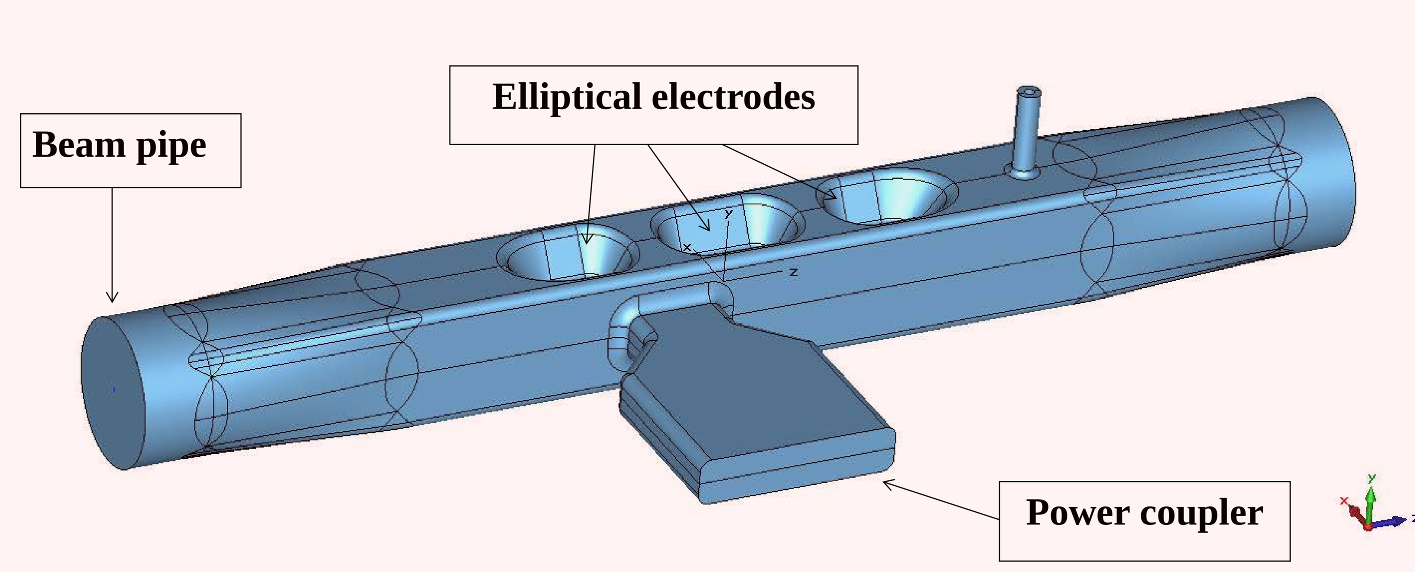
The cavity spectrum of monopole modes is sparse and contains four modes below the beam pipe cutoff frequency of 4.7GHz and two trapped modes above. All monopole modes are well separated from the operating mode and have a relatively low R/Q and loaded Q values. Thus, no multi-bunch instability is expected .

CAVITY PERFORMANCE

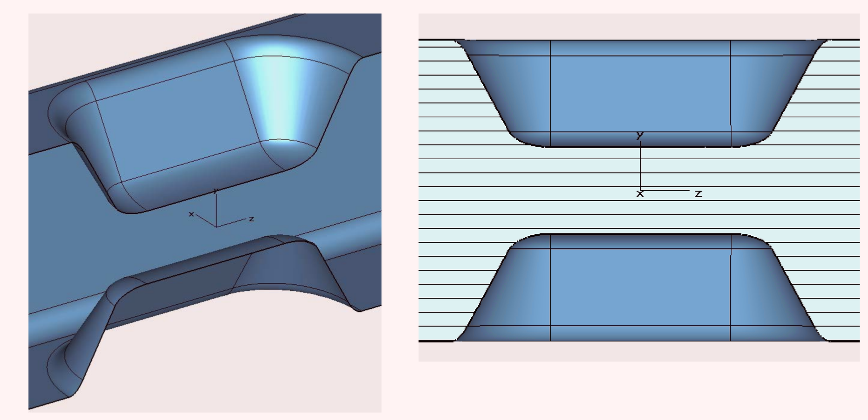
First Nb prototype of QMiR cavity was recently fabricated and tested at ANL. During the preliminary 2 K vertical cold tests the bare QMiR resonator reached the deflecting voltage of 2.7 MV (~100 mT magnetic and 70 MV/m electric surface fields) without been quenched . Field emission wasn't observed [1].

[1] Z.A. Conway, et al., "Development and Test Results of a Quasi-waveguide Multicell Resonator", IPAC14, WEPRI050, Dresden, Germany, 2014

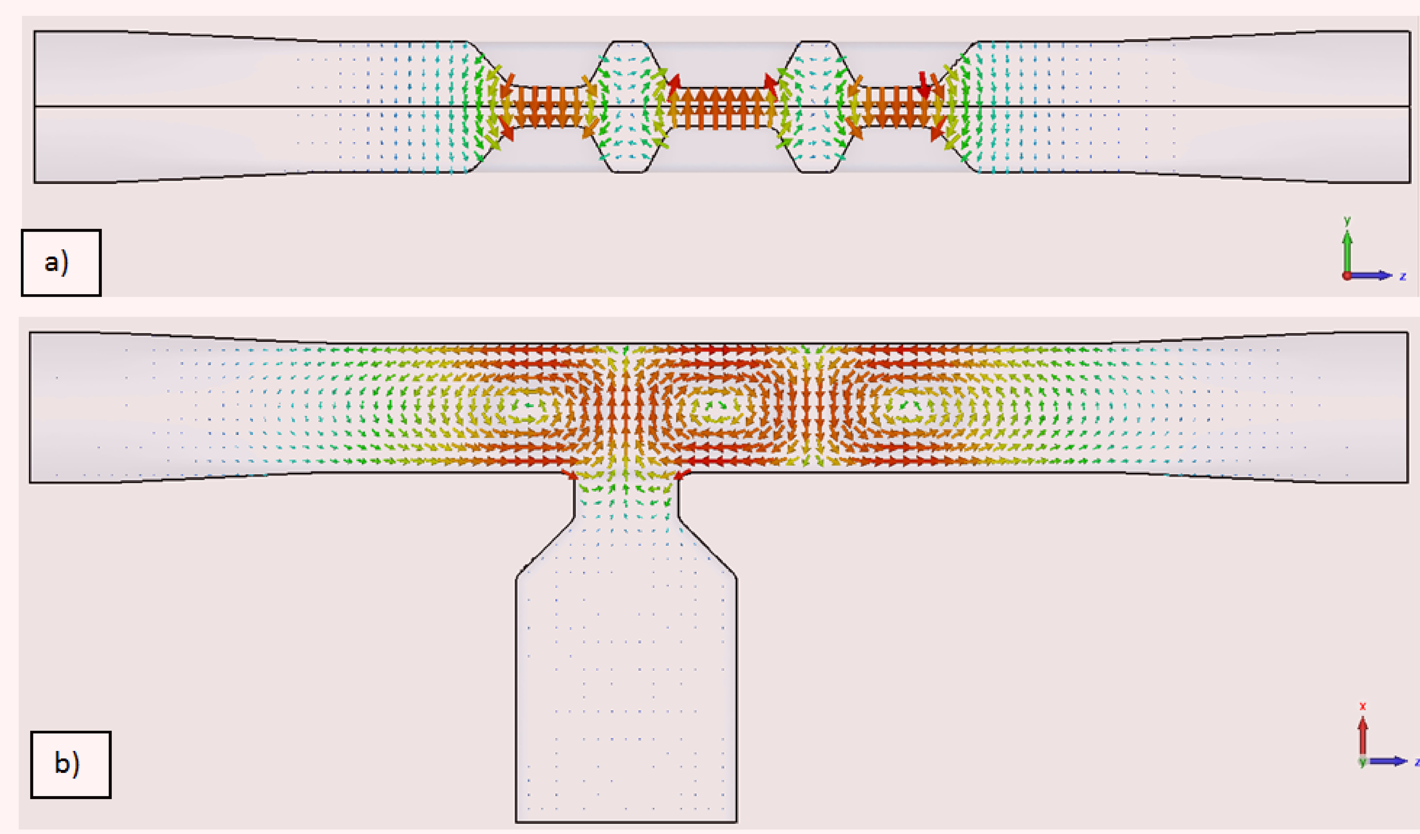
Cavity EM Design (CST Studio & ANSYS HFSS)



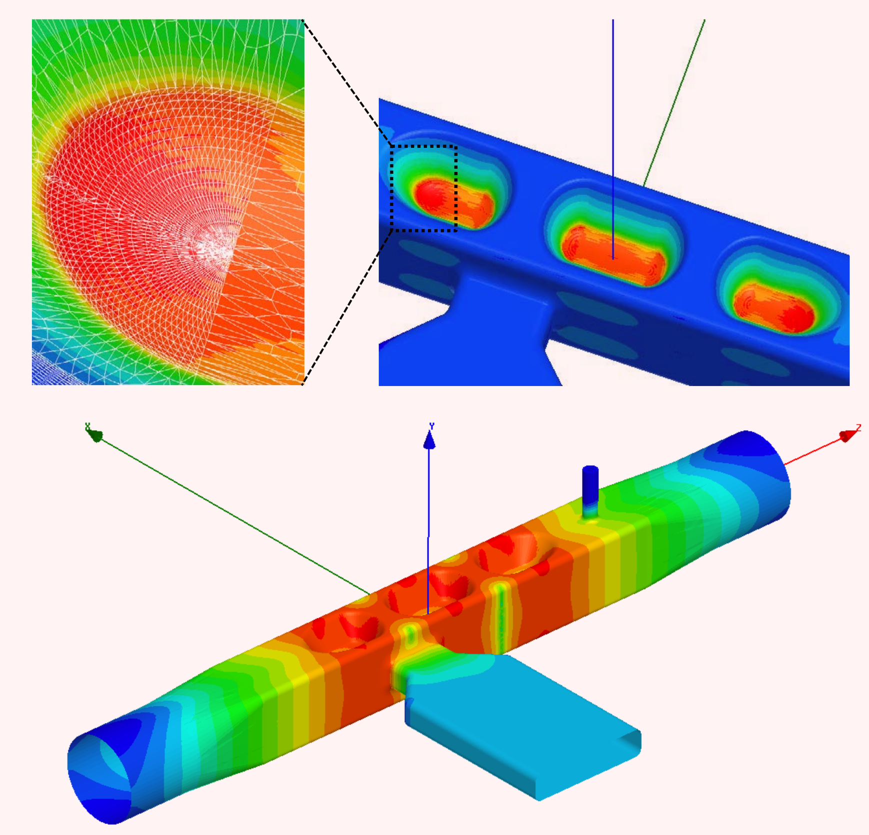
Isometric view of the TE mode quasi-waveguide multi-cell deflecting SC cavity



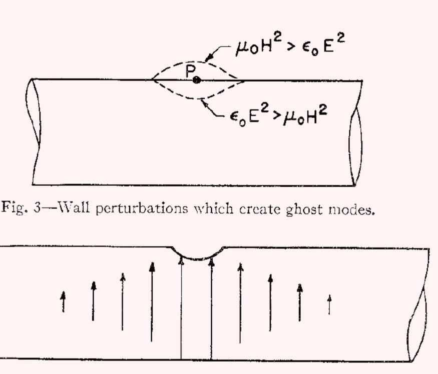
Geometry of the medium cell



Vector electric (a) and magnetic (b) fields of the 2815 MHz operating dipole π-mode

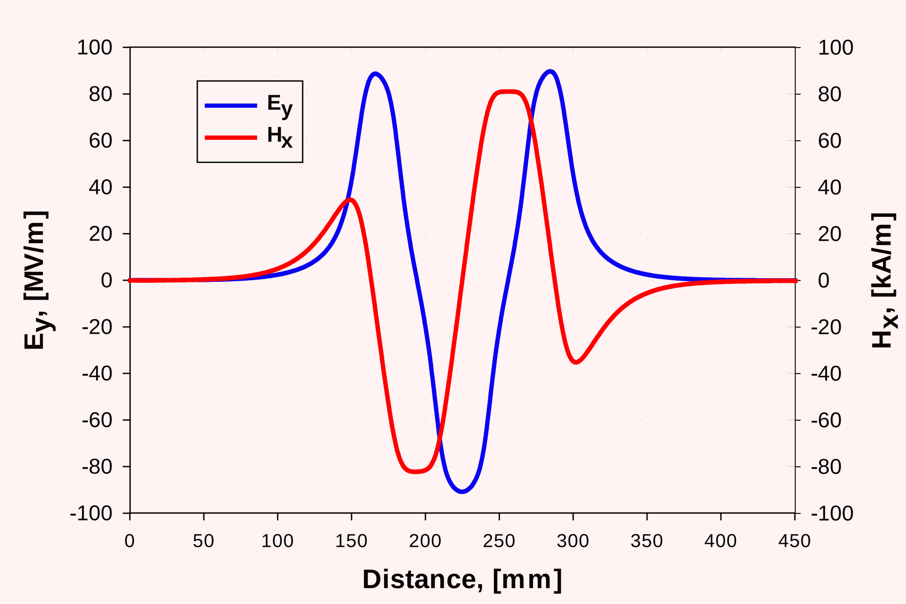


Operating trapped mode surface electric (up) and magnetic (down) fields



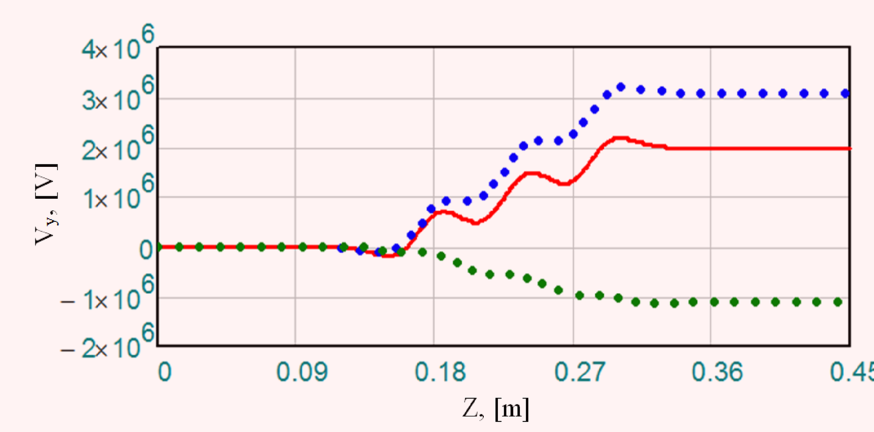
Electric field lines of TE ghost modes [2]

[2] E. T. Jaynes, "Ghost Modes in Imperfect Waveguides", "Proc. Inst. Radio Engrs, Vol. 46, NO. 2, 1958



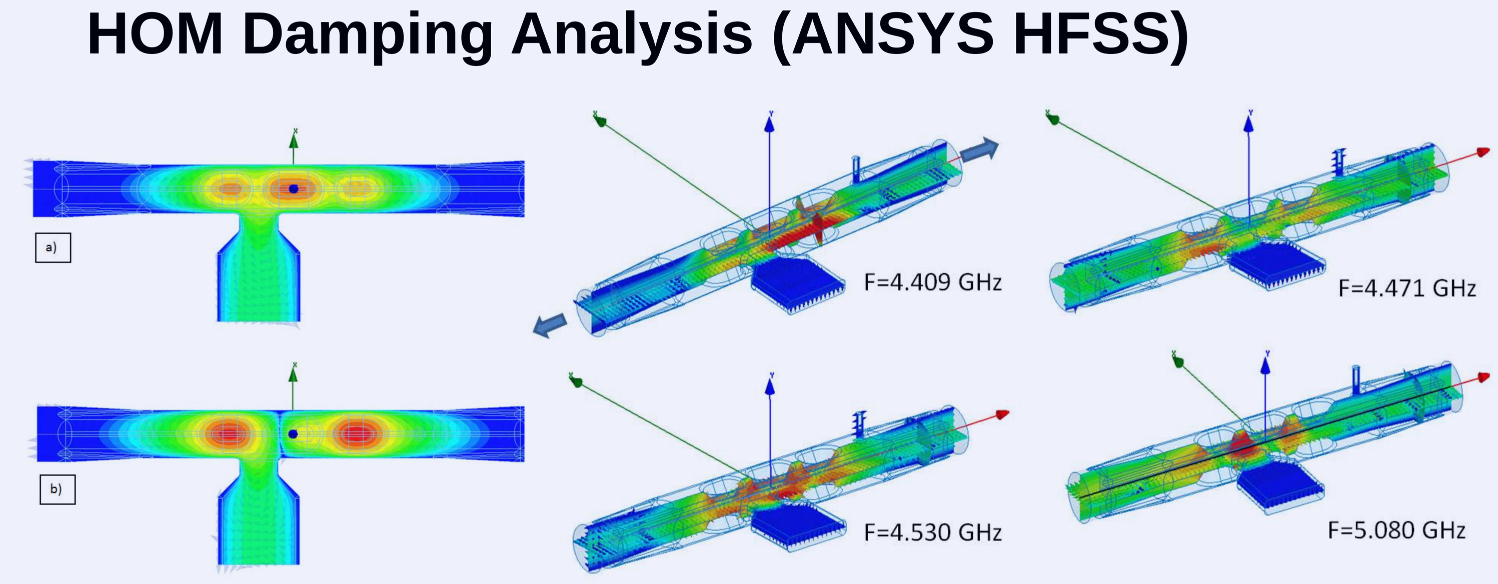
Transverse electric (blue) and magnetic (red) field components along the cavity axis.

$$V_y = Re\int_0^L (E_y + Z_0 H_x)e^{ikz}dz$$



Integrated vertical kick along the cavity axis (solid red curve is the overall kick, dotted blue and green curves are electric and magnetic kicks).

HOM Damping Analysis (ANSYS HFSS)



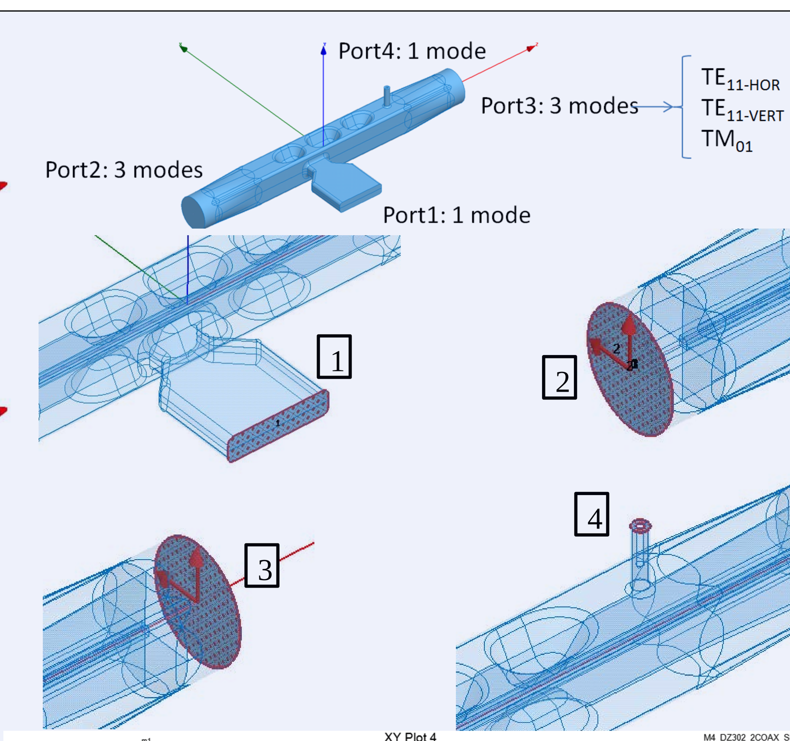


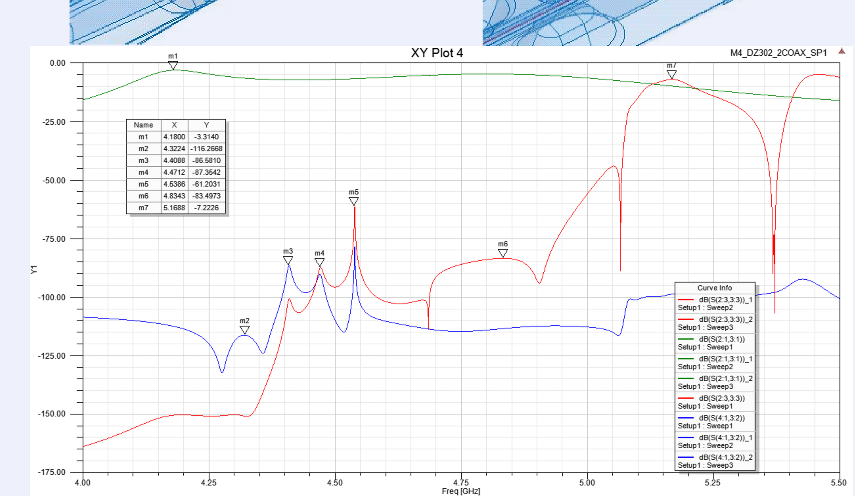
Table 2: Transverse dipole modes

Freq., [GHz]	$(R/Q)_t$, [Ω]	Q_{ext}	R_t [MΩ/m]
2.476	0.03	2400	3e-3
2.675	5.0	6800	1.9

Table 3: Monopole modes

Freq., [GHz]	R/Q, [Ω]	Q_{ext}	R_m*F, [MΩ*GHz]
4.304	1.3	55	3e-4
4.409	39	530	0.09
4.471	37	400	0.07
4.530	0.35	5900	8e-3
5.080	132	390	0.26
5.114	39	108	0.02

Dipole SOM (left) and monopole HOM (right) complex eigenmode simulations. Ends of the beam pipe are matched by proper impedance boundary conditions.



Simulation of trapped monopole HOM with driven modal HFSS solver

Conclusions

The present design of the TE-mode superconducting deflecting cavity with the open ends avoids complicated HOM couplers and creates a higher operating gradient at the same time, thereby, producing a more compact cryomodule design. The QMiR cavity has a low parasitic HOM RF losses and a higher beam instability threshold due to HOM excitation. Thus, it may be beneficially operated for various beam manipulation projects under high beam current and high repetition rate scenarios.

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