Simulation and Design of Low Emittance RF Electron Gun

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Abstract

Generation of high-brightness electron beam is one of the most critical issues in development of advanced electron accelerators and light sources. At the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University, a low emittance RF electron gun is under the development. This RF-gun is planned to be used as an electron source for a future IR/THz FEL facility. An extra resonant cavity is added to the modified design of the existing PBP-CMU RF-gun in order to reduce the transverse sliced emittance. This cell is coupled to the main full-cell via a side-coupling cavity. The electromagnetic field distributions inside the cavities are simulated by using the CST Microwave Studio 2012. Then, beam dynamic simulations utilizing the program PARMELA are performed. Both RF and beam dynamic simulation results are reported and discussed in this contribution.

Introduction

An electron gun of the linac-based THz radiation source at the Plasma and Beam Physics (PBP) Research Facility, Chiang Mai University, is driven by a 7 MW-klystron at the resonant frequency of 2856 MHz. It consists of 1.6 cell S-band standing-wave structure and a tungsten dispenser thermionic cathode with Os/Ru coating. Together with a downstream linac section and related beam transport components, electron beams with the bunch length in order of fermtosecond can be obtained [1]. In order to improve the transverse properties of electron beams, new modified design of the RF-gun is conducted [2]. In this work, an extra resonant cavity is added to the PBP-CMU RF electron gun to modify the dynamics of electrons. The previous study results suggest that by adding TM010 pillbox cavity next to the main full-cell is able to reduce the sliced emittance and line up the sliced phase spaces [3].

Simulation of Electromagnetic fields

The electromagnetic fields inside the resonant cavities are simulated by using the program CST Microwave Studio (MWS) 2012 [4] . An extra cell is added downstream the full-cell and it is coupled via a side coupling cavity in vertical direction as shown in Fig.1 and Fig.2. The mode of acceleration is kept to be at π/2 mode and at this mode the resonant frequency of the whole gun is around 2857.3 MHz. RF parameters of each cell are reported.

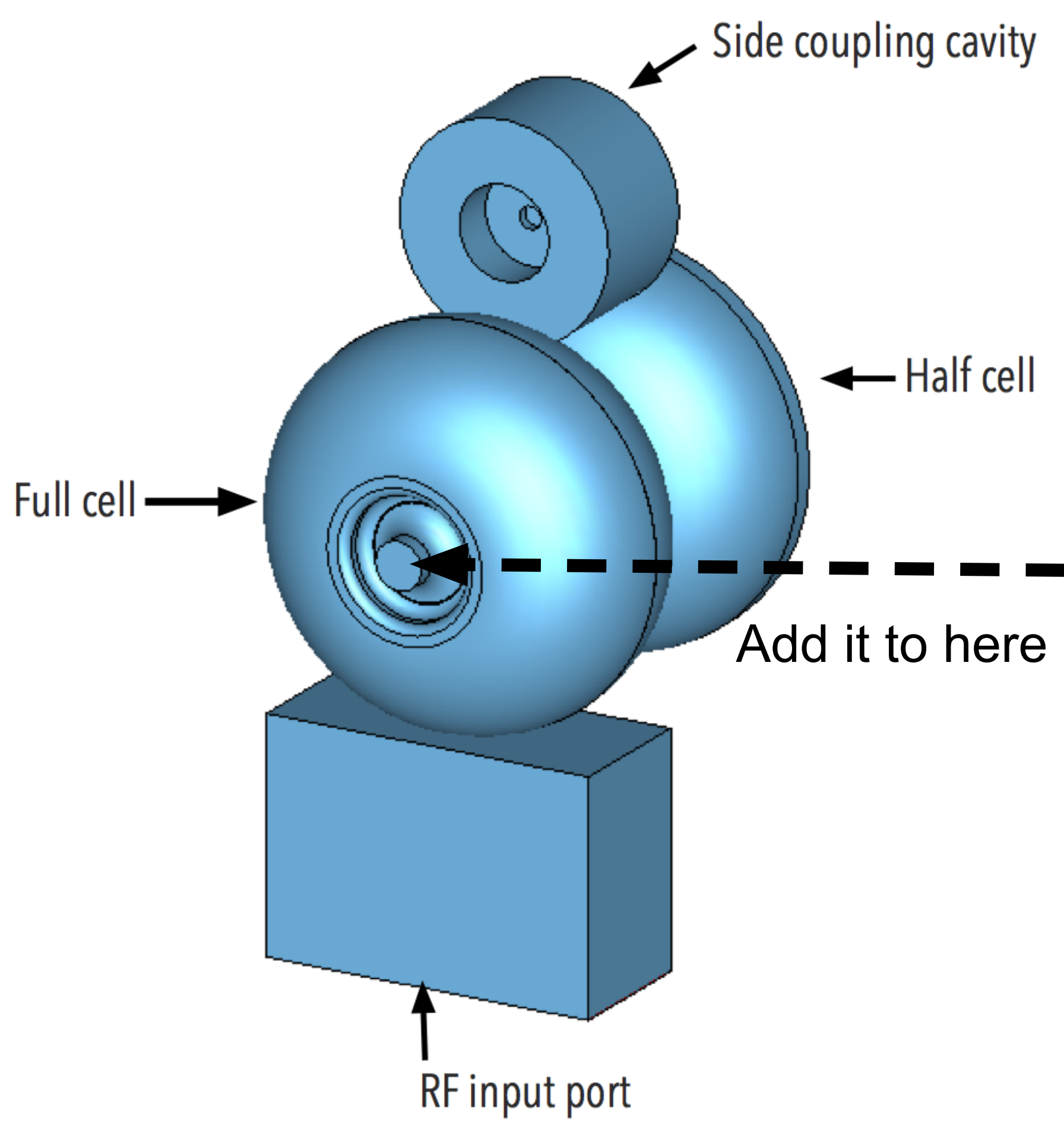

Figure1. 3D CST MWS model of the thermionic RF-gun at the Plasma and Beam Physics Research Facility, Chiang Mai University.

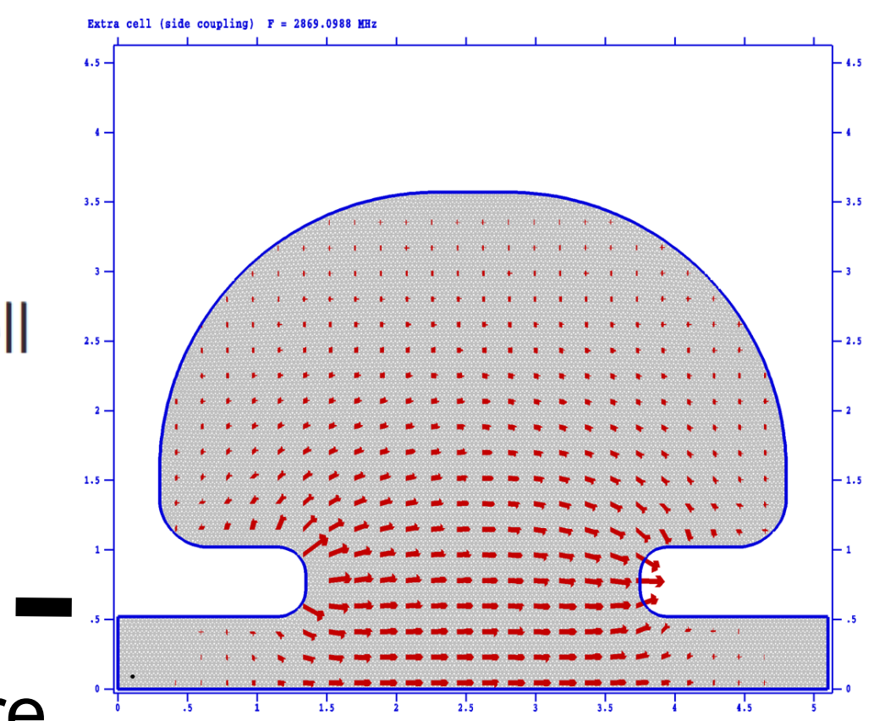

Figure 2. 2D internal geometry and SUPERFISH [6] electric field vectors of the extra-cell (only half of the cell cross-section is shown here).

The axial electric field profile along z-axis can be investigated by varying the tuning rod position inside the side coupling cavity located between the full-cell and the extra-cell. For this work, the field inside the extra-cell is chosen by the length of the tuning rod to be 1.15 mm,

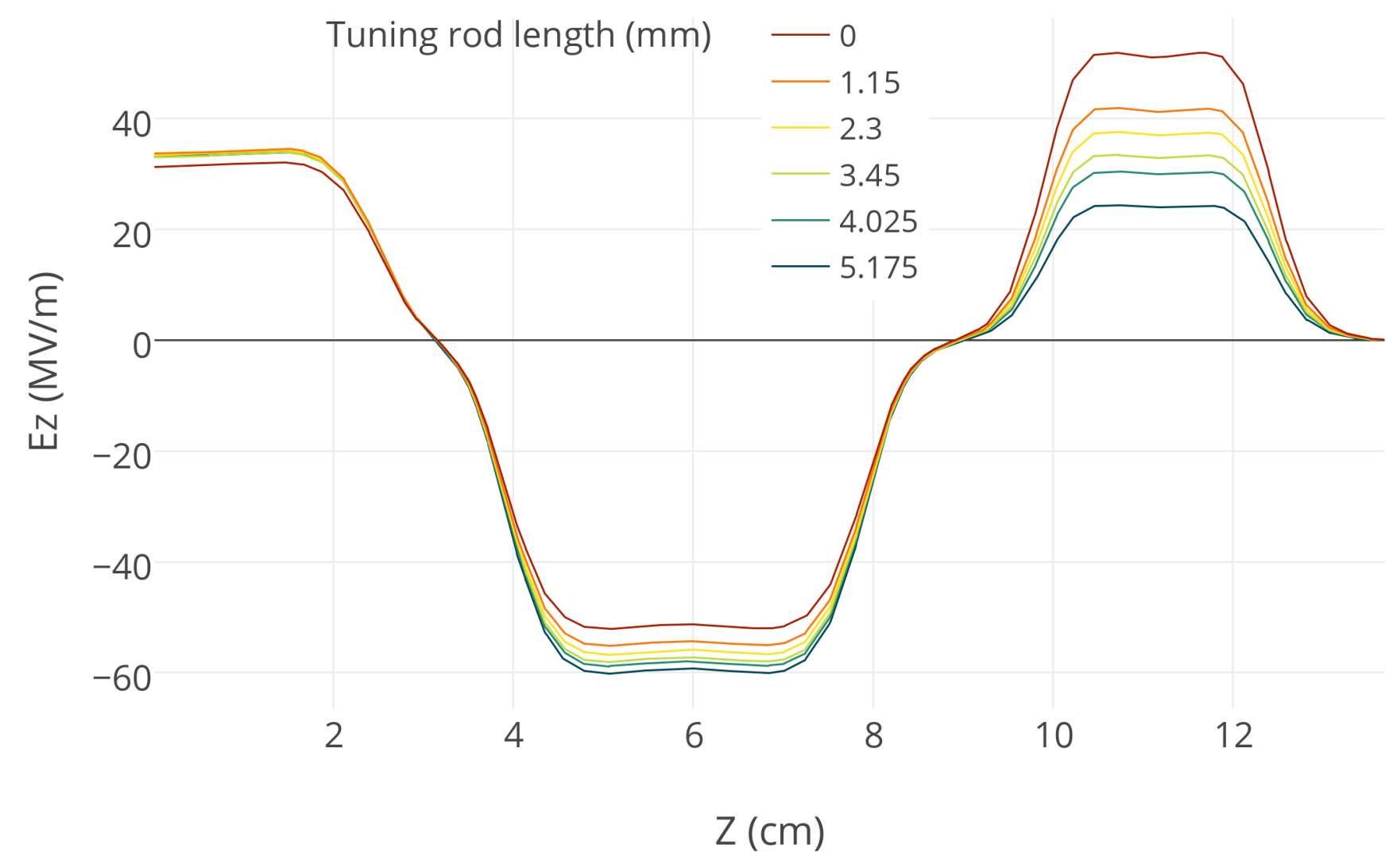

Figure 3. Axial peak electric field along z-direction inside the RF-gun

Beam Dynamics Simulation

We use the particle-in-cell program called PARMELA [5] to study the beam dynamics. In simulations, 100,000 particles are assumed to be uniformly emitted from a 3-mm radius thermionic cathode with a total beam current of 2.9 A. An initial energy of the reference particle is set to be 0.10971 eV, corresponding to the cathode temperature of 1,273 K. Energy spreads in both transverse and temporal directions are included in simulations.

The transverse phase spaces are presented. The vertical phase spaces at the ends of these three cells show asymmetric beam distributions due to non-symmetric magnetic fields in vertical direction (y-axis) as shown in Fig 4(b). This is caused by open holes at the side coupling cavity and the RF input port. The asymmetric beam distribution results in larger transverse beam emittance value and also leads to the off-center of the transverse beam profile. The two sliced phase spaces at the end of the extra cell are more lined up than ones as shown in Figure 5.

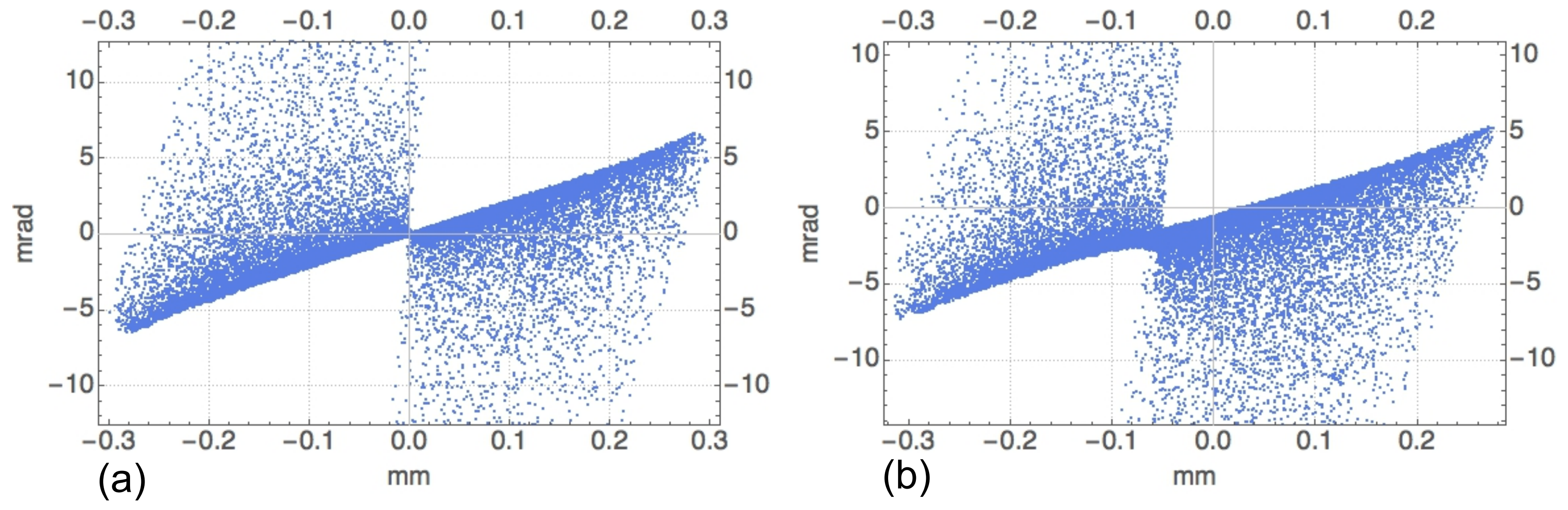

Figure 4. Transverse phase spaces at the end of the extra-cell

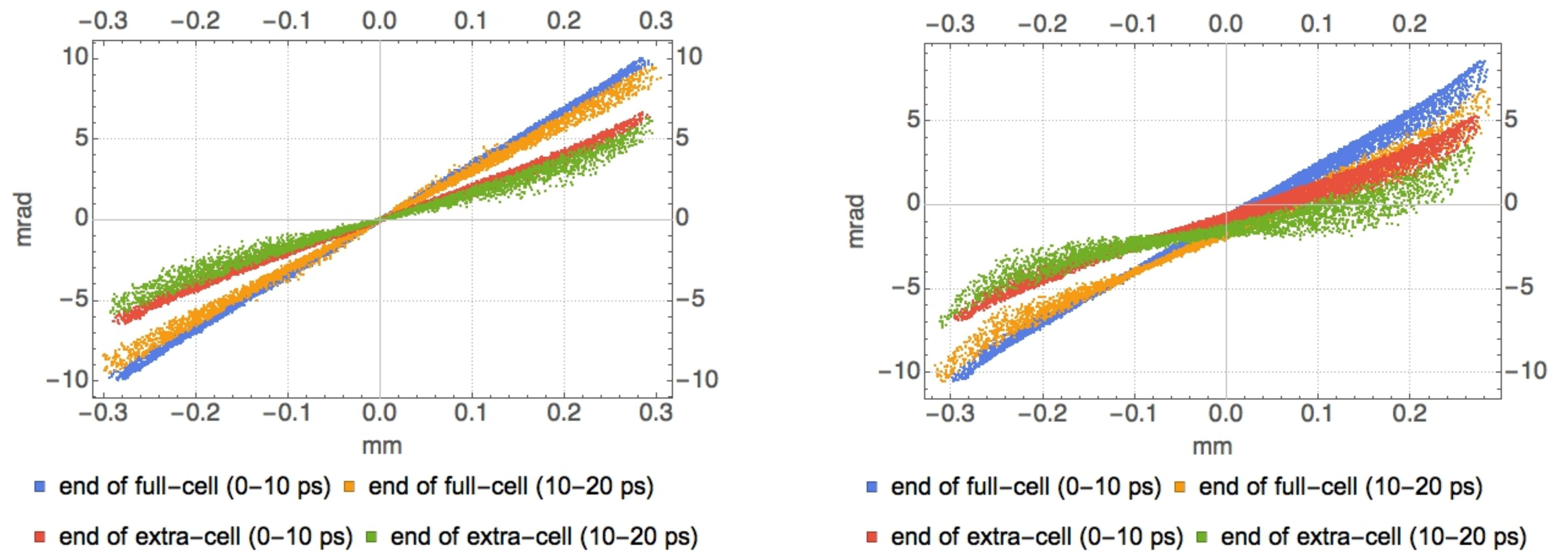

Figure 5. The sliced phase spaces for the time periods of 0-10 ps and 10-20 ps along the bunch at the ends of full-cell and extra-cell.

Obviously, the electrons gain kinetic energy while they are moving inside the extra cell. However, it still has the linear relation between energy and time at both directions, which is required for the bunch compression by using the alpha magnet. The geometry emittace and normal emittance values are calculated as listed in the Table 1.

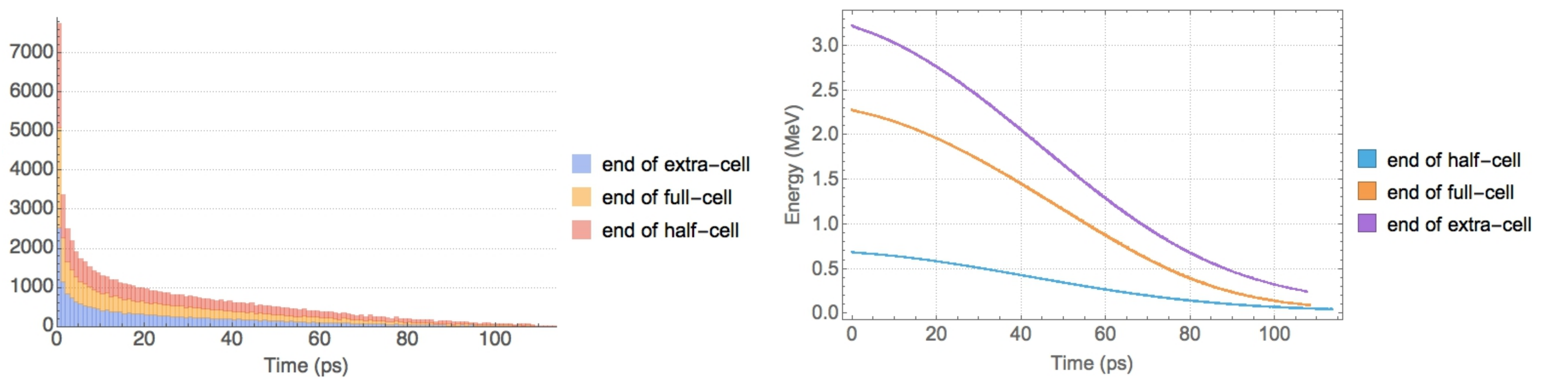

Figure 5. Longitudinal phase spaces and histograms at the ends of the half-cell, full-cell and extra-cell.

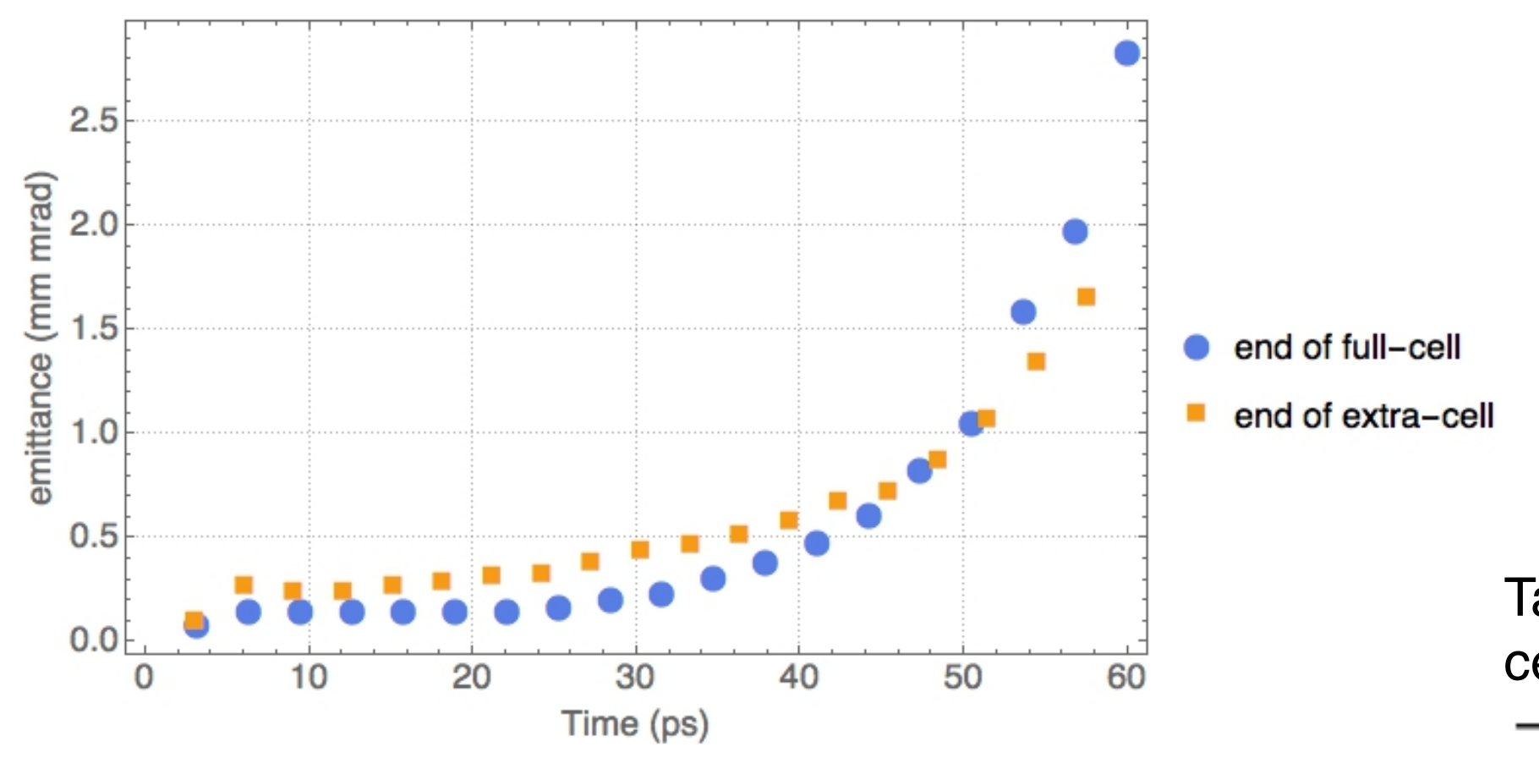

Figure 6. The sliced transverse emittance values along electron bunch at the ends of the full-cell and the extra-cell.

It is clearly seen that at the tail of electron bunch with the time longer than 45 ps, the transverse projected emittance values at the end of the extra-cell are lower than the beam at the end of the full-cell. The number of electron within 45 ps is approximately

Table 1. Transverse emittance values at the ends of full-cell and extra-cell.

Exit of		**100% beam**		**90% beam**	
		x	y	x	y
ϵ (mm mrad)	full-cell	19.3	20.7	5.45	6.85
	extra-cell	9.6	10.4	3.57	4.75
ϵ_n (mm mrad)	full-cell	63.3	68.0	19.4	24.4
	extra-cell	46.5	50.4	18.6	24.8

Conclusion

The extra-cell is added to the full-cell to reduce the transverse emittance in both x and y directions. Although the force due to the electric field inside the extra-cell accelerates the beam, the linear relation between energy-time, which is necessary for bunch compression, still remains. The transverse projected emittance values at the end of the extra-cell are lower than at the end of the full-cell in both x and y directions. The sliced phase spaces within 0-10 ps and 10-20 ps for the x-direction at the extra-cell exit are more lined up than that y-direction.This is due to asymmetric vertical magnetic field distribution which is effected by the opening holes of the side coupling cavity. Furthermore, the sliced emittance values of the particles at the tail of the bunch (> 45 ps) at the end of the extra-cell are lower than that at the end of the full-cell. The trend of the growth of sliced emittance along the whole bunch at the end of extra-cell is also lower.

Ackknowledge

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