PARTICLE-IN-CELL SIMULATION OF A BUNCHED ELECTRONS BEAM ACCELERATION IN A TE_{113} CYLINDRICAL CAVITY AFFECTED BY A STATIC INHOMOGENEOUS MAGNETIC FIELD

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CONTENT

THEORETICAL FRAMEWORK

Spatial AutoResonance Acceleration (SARA)

The electron acceleration in the autoresonance regime by a standing transversal electric microwave field in an inhomogeneous magnetostatic field

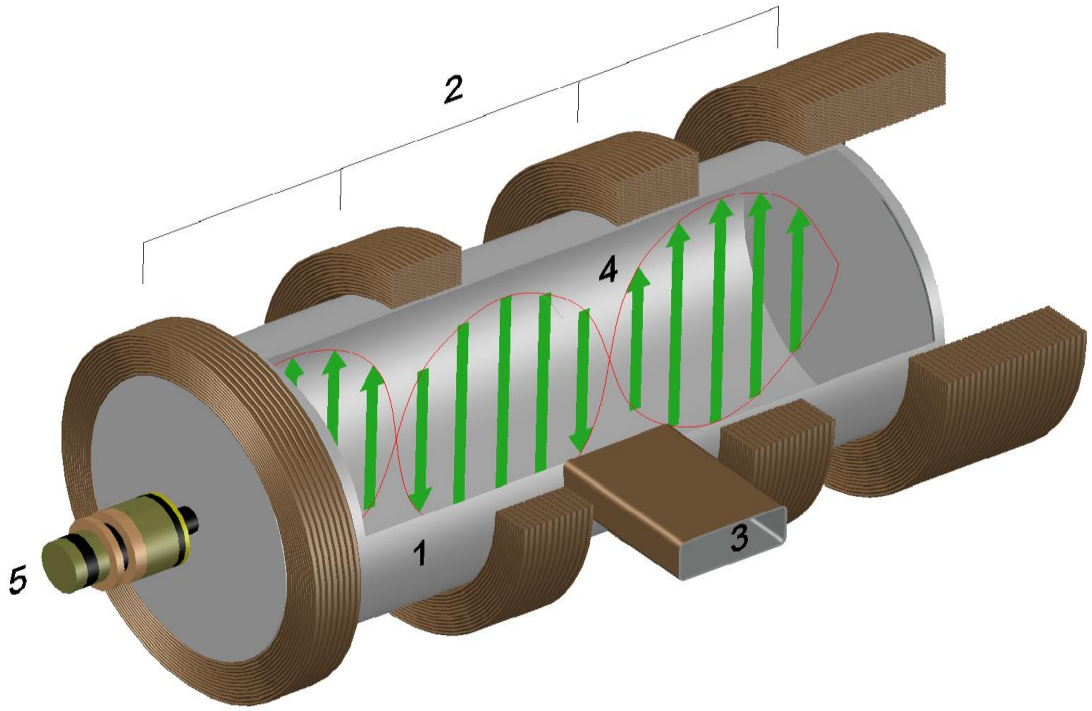


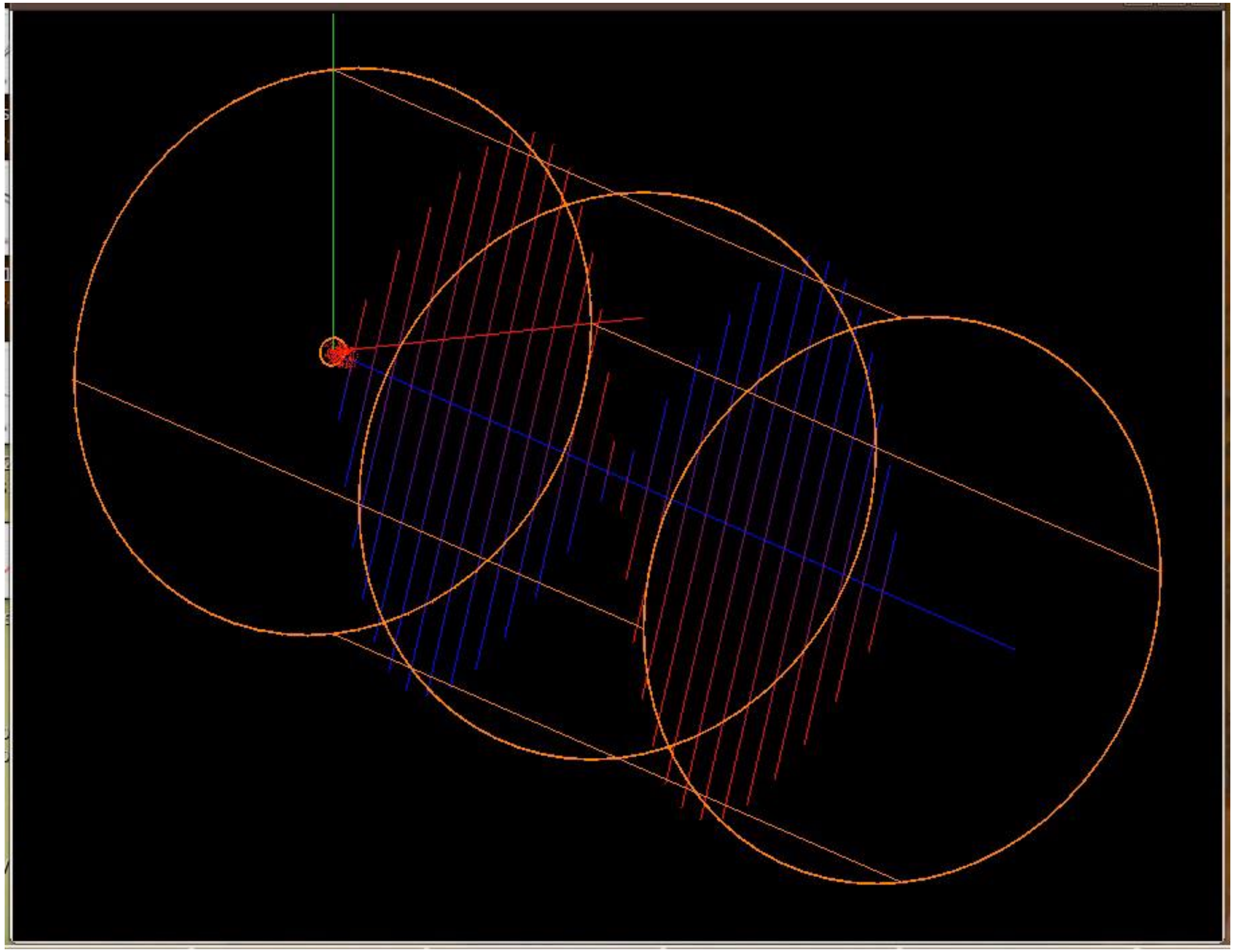
Figure 1: A physical model scheme.

1-cavity, 2-magnetic coils, 3-microwave port,

4-electric field profile (particular case of TE_{113} mode),

5- electrons gun.

THEORETICAL FRAMEWORK



Dugar-Zhabon, V. D. & Orozco, E. A. (2017). U.S. Patent No. 9,666,403. Washington, DC: U.S. Patent and Trademark Office.

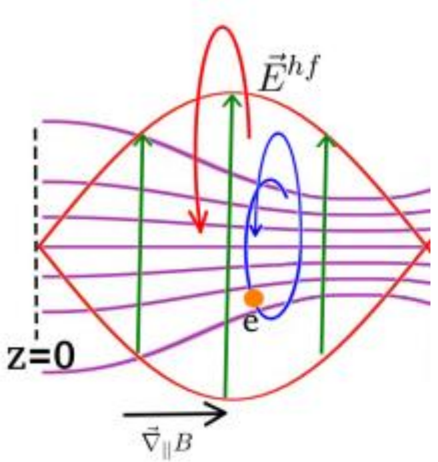
SARA Electrons beam acceleration by a TE_{112} cyclindrical microwave field

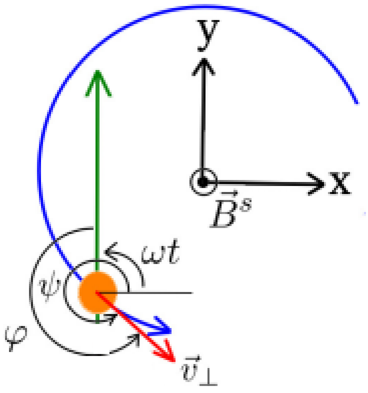
THEORETICAL FRAMEWORK

Spatial AutoResonance Acceleration (SARA)

Cyclotron frequency :

$$\omega_c(z)/\omega = \gamma^{-1} B_z(0,z)/B_0 + \gamma^{-1}(E_0^c/B_0 c)[1-\gamma^{-2}+(v_z/c)^2]^{-1/2} \times |sin(p\pi z/L_c)| sin\varphi$$





ω : Microwave field frequency

γ : Lorentz factor

$B_z(0,z)$: Magnetic field value to obtain clasical resonance.

E_0^c : Electric field strength.

c : Speed of light

v_z : Longitudinal velocity

p : Index of TE_{11p} mode

φ : Phase-shift

L_c : Length of the cavity

z : Longitudinal coordinate of the electron

Dugar-Zhabon, V. D., & Orozco, E. A. (2009). Cyclotron spatial autoresonance acceleration model. Physical Review Special Topics-Accelerators and Beams, 12(4), 041301.

THEORETICAL FRAMEWORK

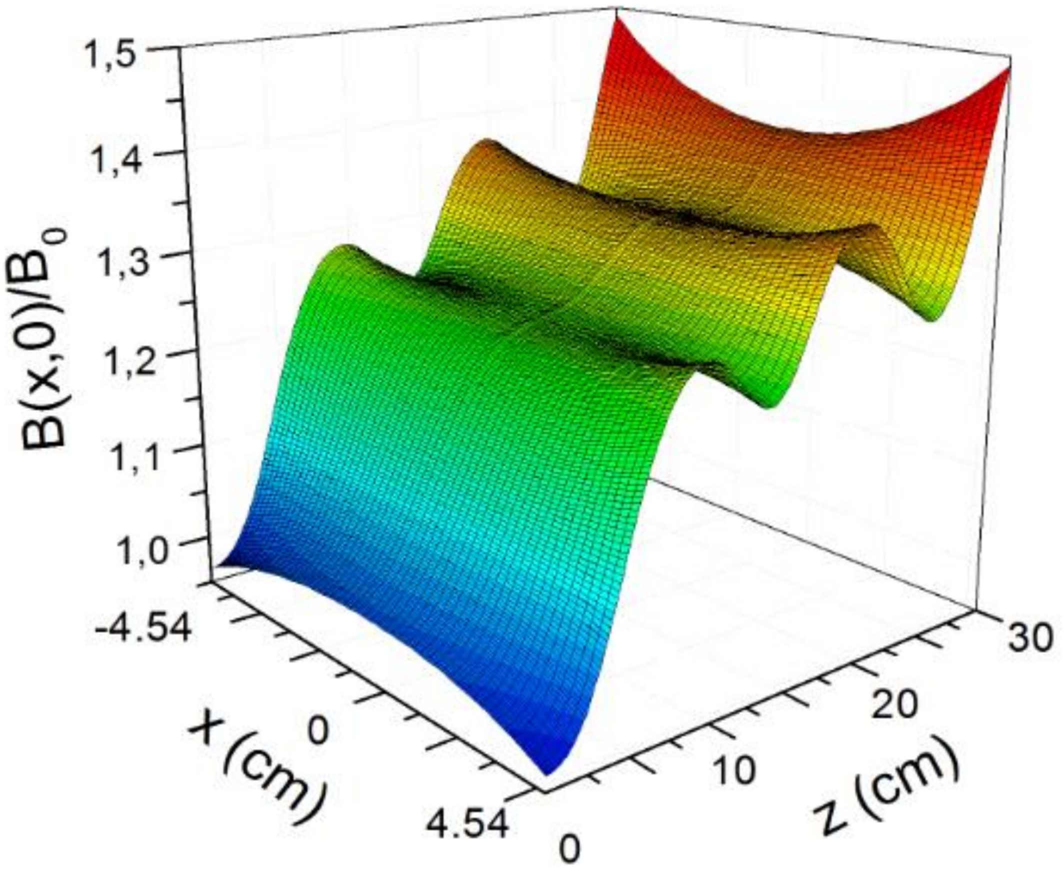


Figure 5: The profile of the magnetostatic field in the $y = 0$ plane.

Table 1: Magnetic coil system parameters

Coil	R_i	R_e	L_b	J	z
1	6 cm	20 cm	6 cm	1.39 A/mm^2	−5.75 cm
2	6 cm	20 cm	7.5 cm	1.08 A/mm^2	8.25 cm
3	6 cm	20 cm	6.9 cm	1.18 A/mm^2	19.5 cm
4	6 cm	20 cm	6.1 cm	2.07 A/mm^2	32 cm

TE_{113} cylindrical mode

NUMERICAL METHOD

(i) *First stage*: Calculation of the steady state for the microwave field before to inject the electrons beam, and
(ii) *Second stage*: Self-consistent simulation of the bunched electrons beams in the SARA acceleration by the TE_{113} cylindrical microwave field,

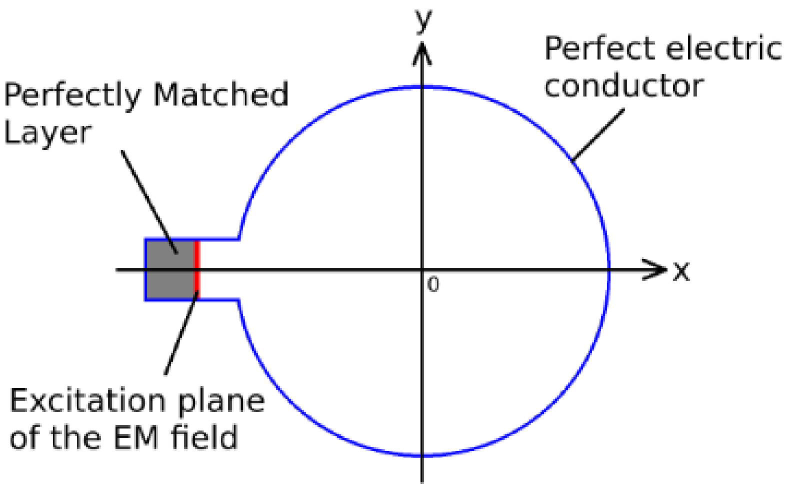


Figure 3: Waveguide-resonant cavity cross section.

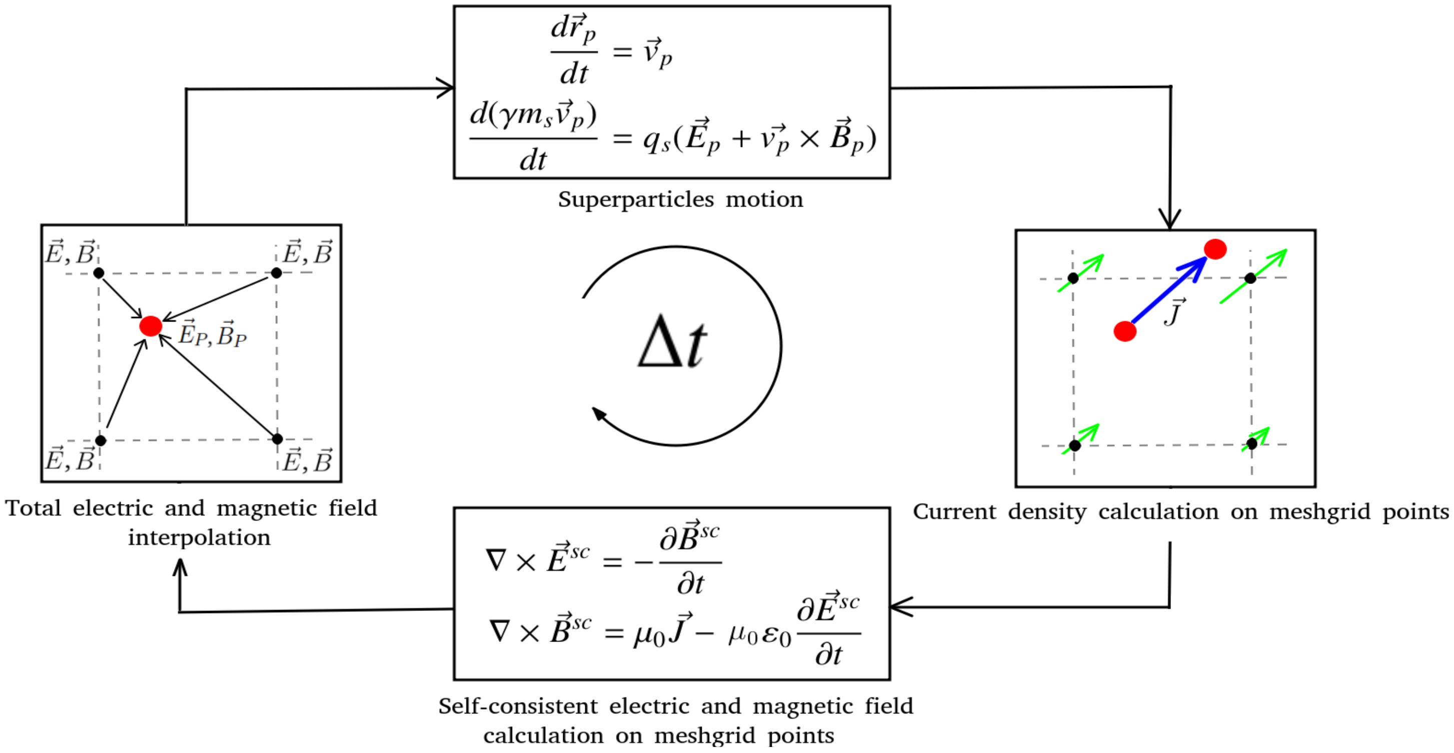


Figure 4: Electromagnetic PIC-algorithm.

$\vec{E}^{sc} = \vec{E}^{hf} + \vec{E}^{sg}$

$\vec{E}^{hf}$ = microwave field

$\vec{E}^{sg}$ = self-generated electric field

$\vec{E} = \vec{E}^{sc}$ and $\vec{B} = \vec{B}^{sc} + \vec{B}^{s}$

$\vec{B}^{s}$ = magnetostatic field

RESULTS

TE_{113} cylindrical mode

frequency $= 2.45\ GHz$ $\quad r_c = 30\ cm$ $\quad L_c = 30\ cm$

Table 2: Parameters of the simulations

	case 1	**case 2**
Beam parameters		
Electron Bunch Radius	0.5 cm	0.5 cm
Electron concentration	$n_e = 10^8\ cm^{-3}$	$n_e = 10^9\ cm^{-3}$
Injection energy	30 keV	32 keV
Simulation parameters		
Δx	0.07 cm	0.07 cm
Δy	0.07 cm	0.07 cm
Δz	0.3 cm	0.3 cm
Δt	1.58 ps	1.58 ps
PiC merging factor	2×10^4	2×10^5

RESULTS

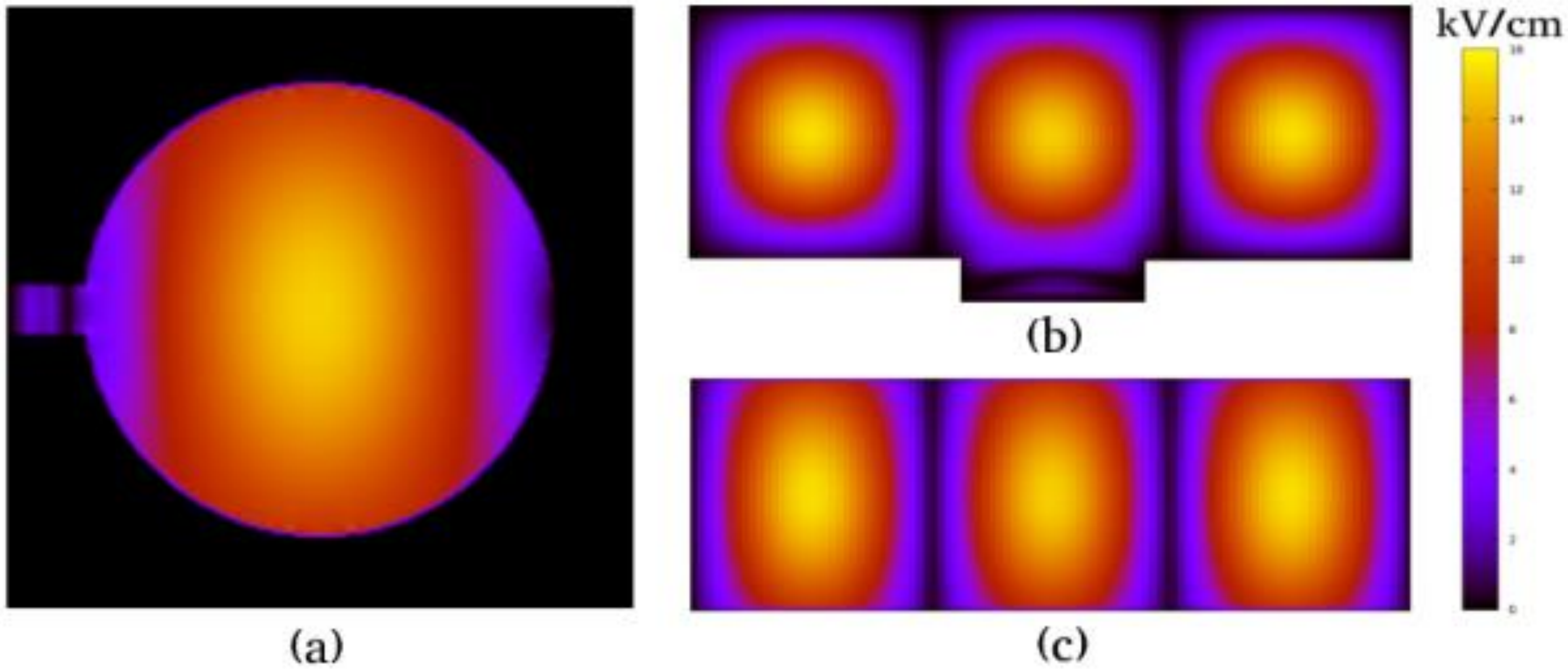


Figure 6: Steady-state electric field distribution in (a) the cross section $z = L_c/2$, (b) the longitudinal plane $y = 0$ and (c) the longitudinal plane $x = 0$.

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RESULTS

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case 1

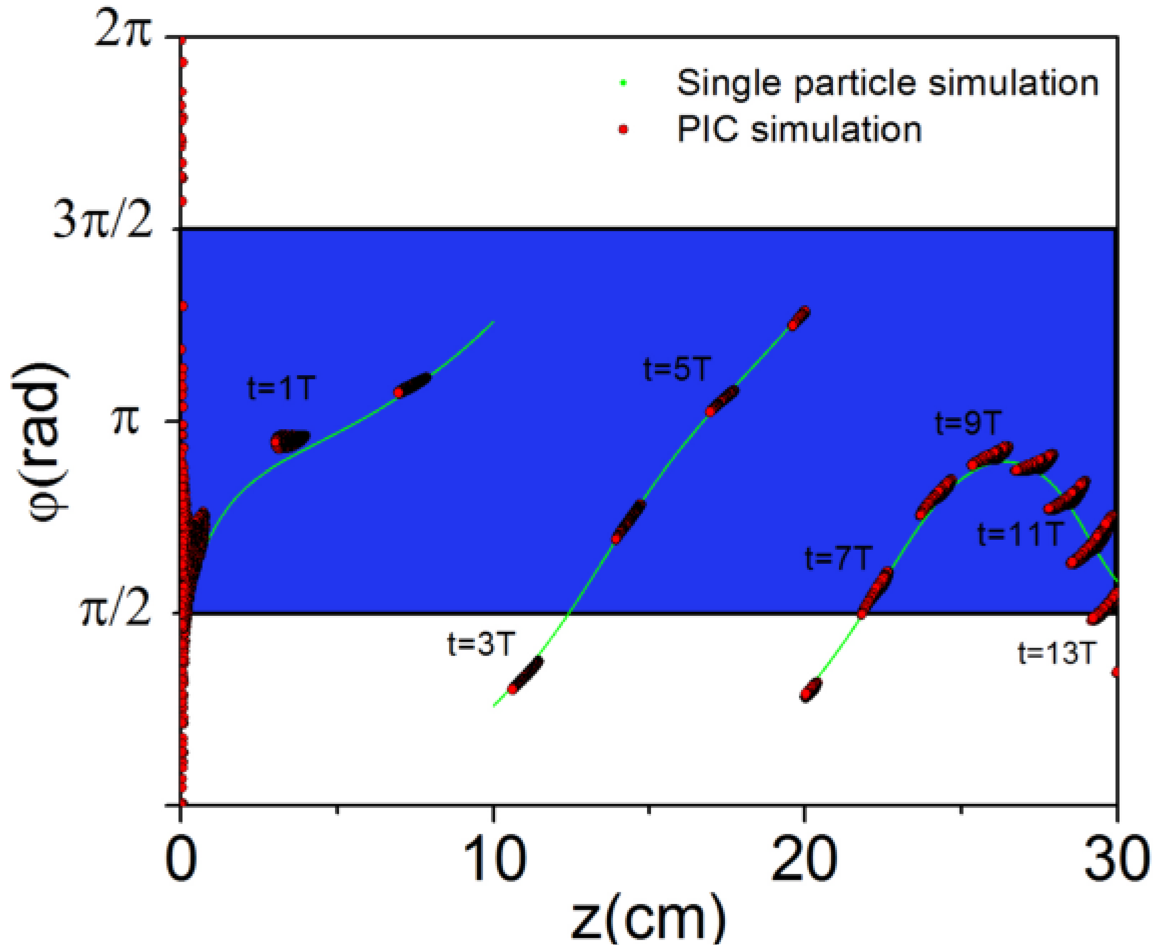

Figure 7: Time evolution of the phase-shift between the electrons transversal velocities and the right-hand circular polarized component of the electric microwave field.

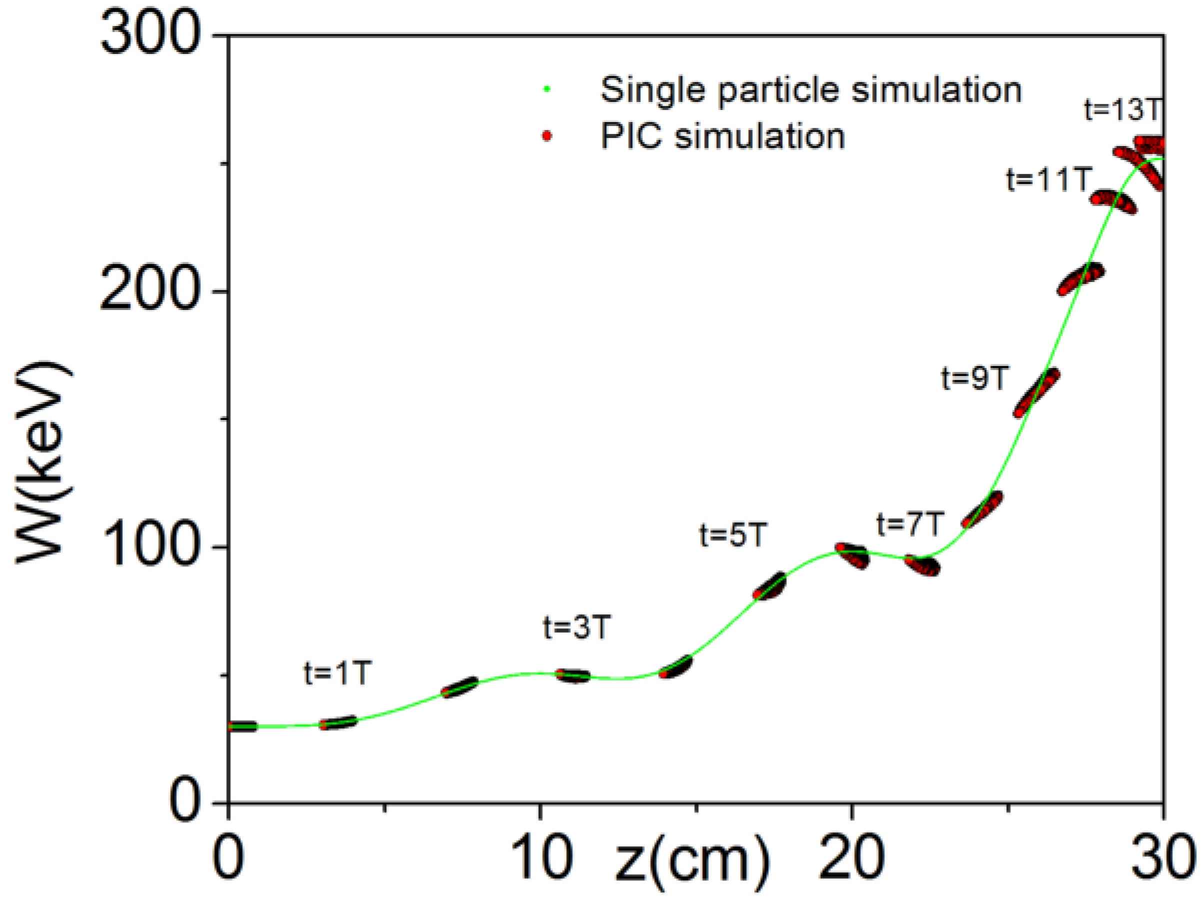

Figure 8: Time evolution of the energy for the $n_e = 10^8$ electrons bunched (red circles) and for the single particle approximation (green line).

RESULTS

case 1

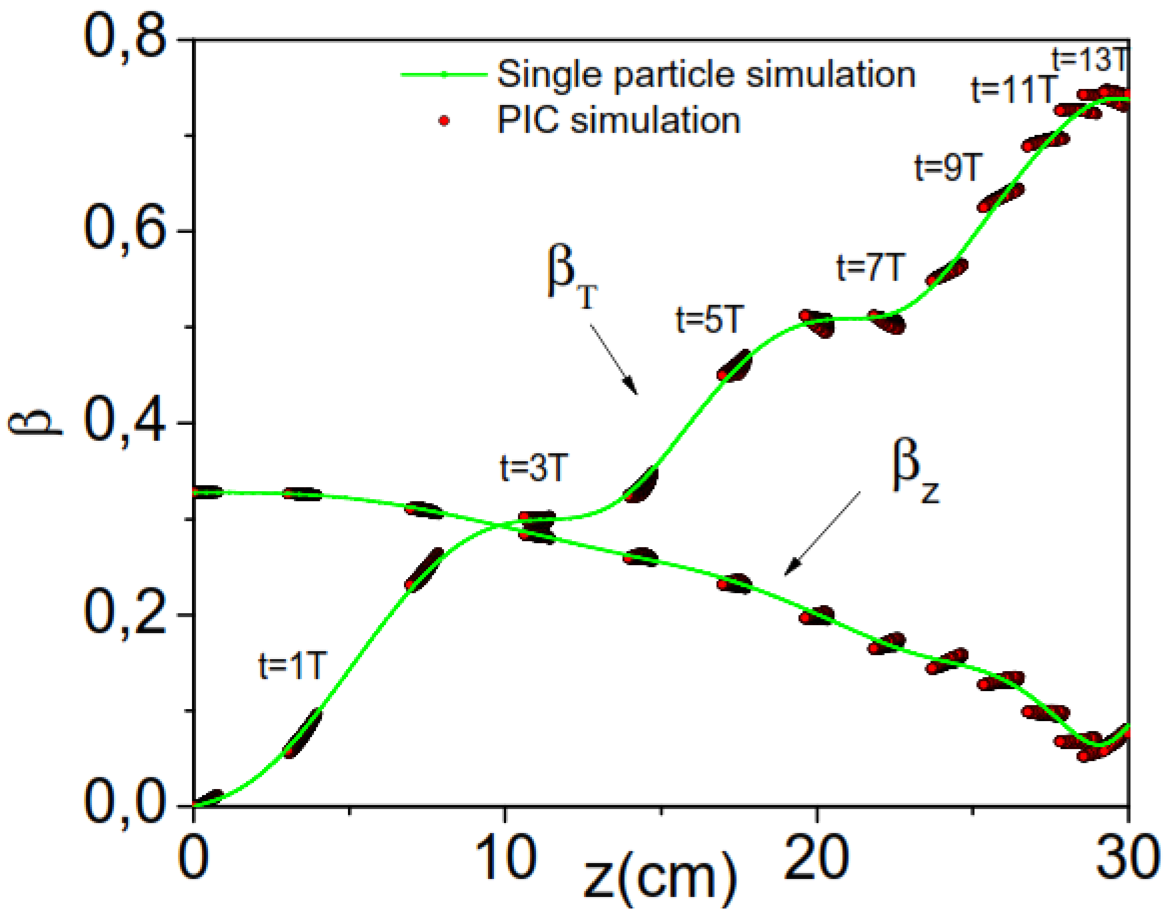

Figure 9: Time evolution of the transversal ($\beta_T = v_T/c$) and longitudinal ($\beta_z = v_z/c$) velocities for the $n_e = 10^8$ electrons bunched.

RESULTS

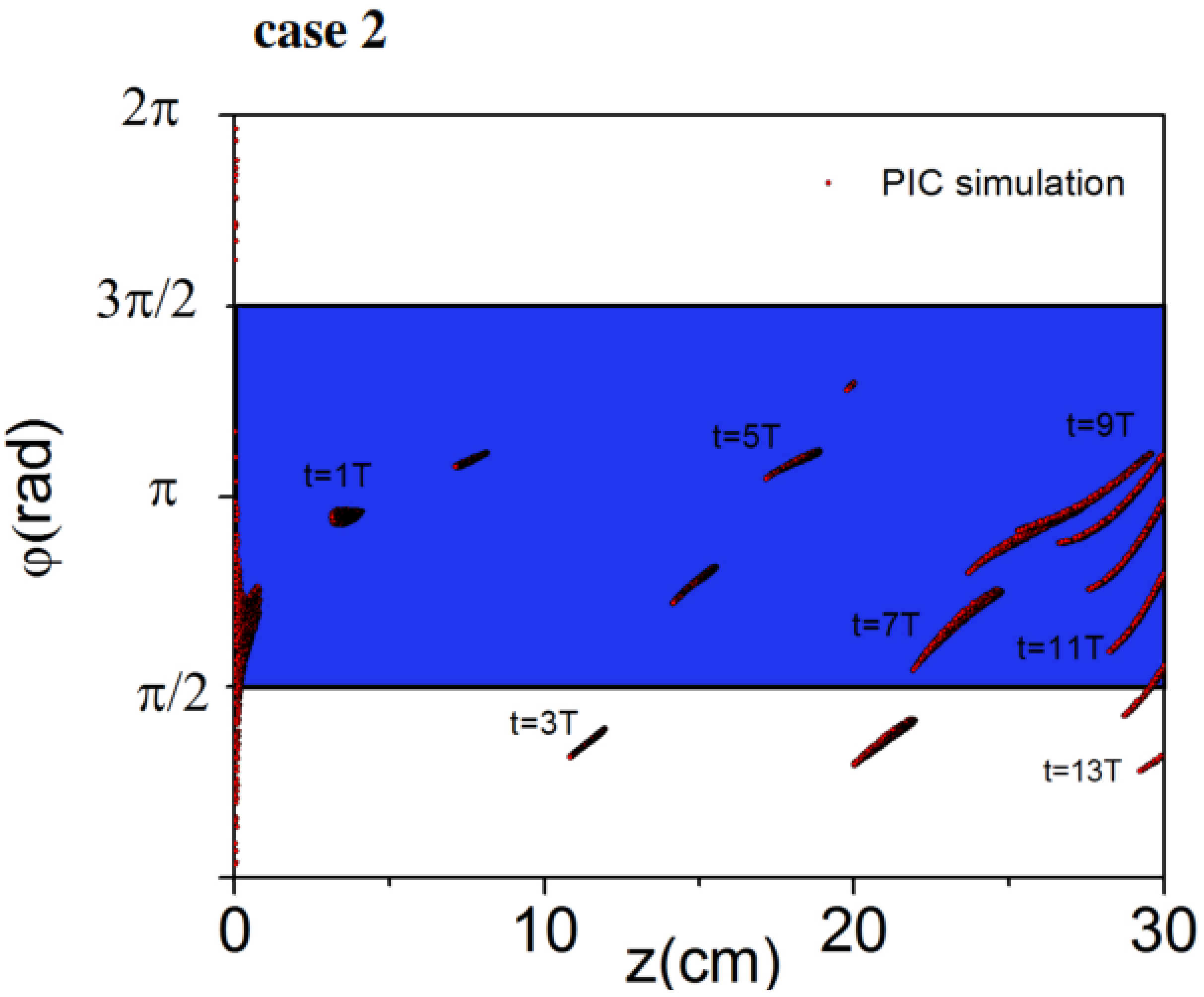

Figure 10: Time evolution of the phase-shift between the electrons transversal velocities and the right-hand circular polarized component of the electric microwave field for the $n_e = 10^9\ cm^{-3}$ electrons bunched.

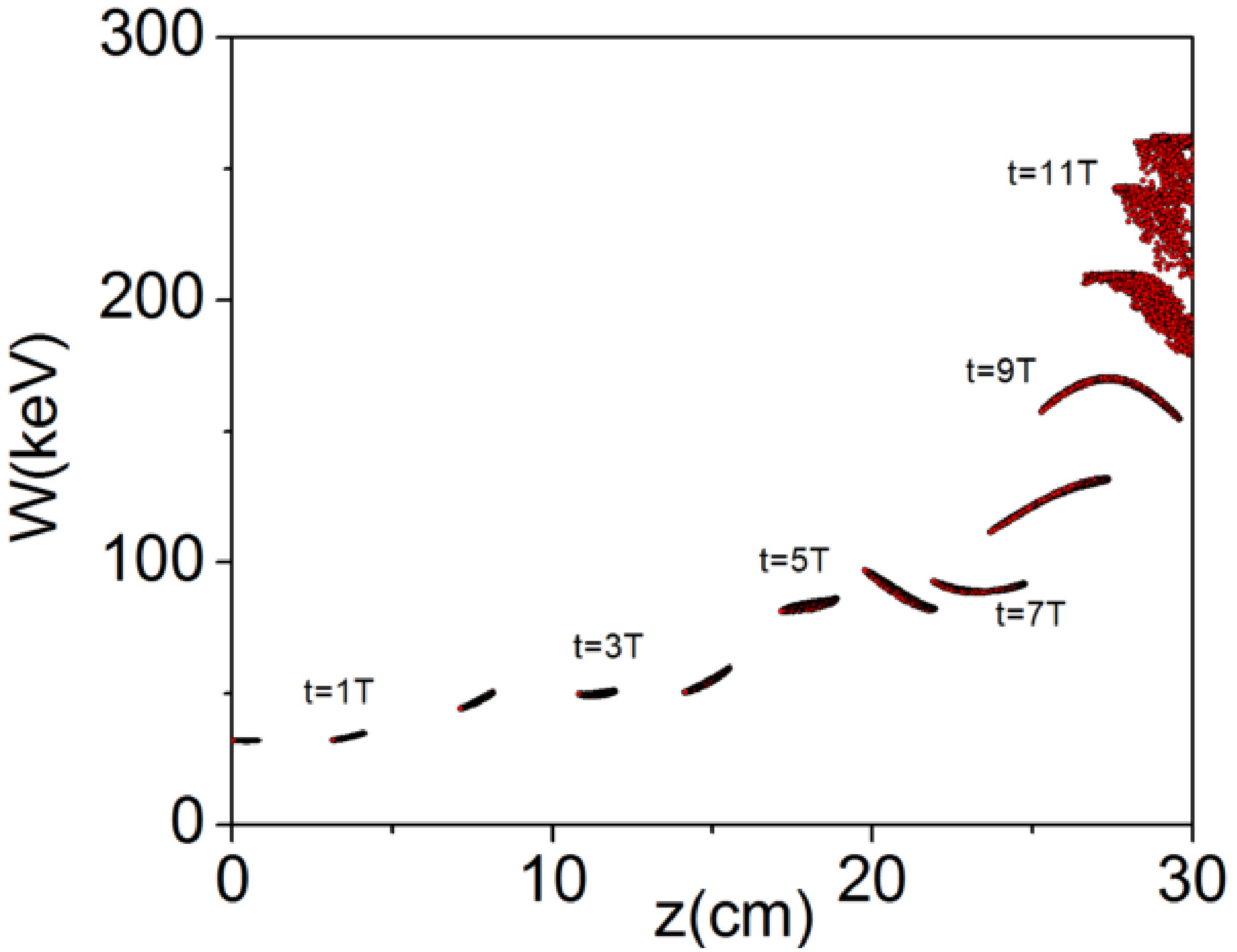

Figure 11: Time evolution of the energy for the $n_e = 10^9$ electrons bunched.

RESULTS

case 2

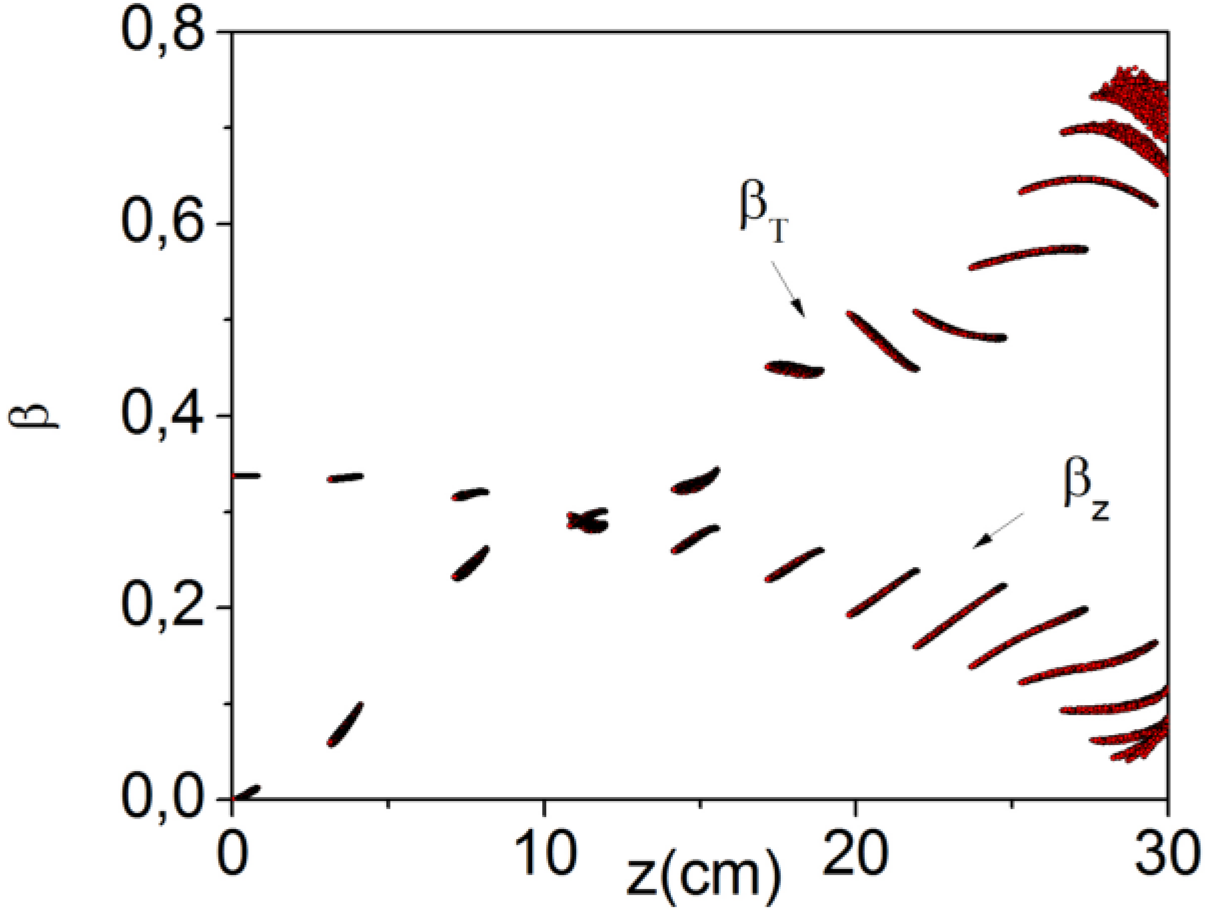

Figure 12: Time evolution of the transversal ($\beta_T = v_T/c$) and longitudinal ($\beta_z = v_z/c$) velocities for the $n_e = 10^9$ electrons bunched.

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RESULTS

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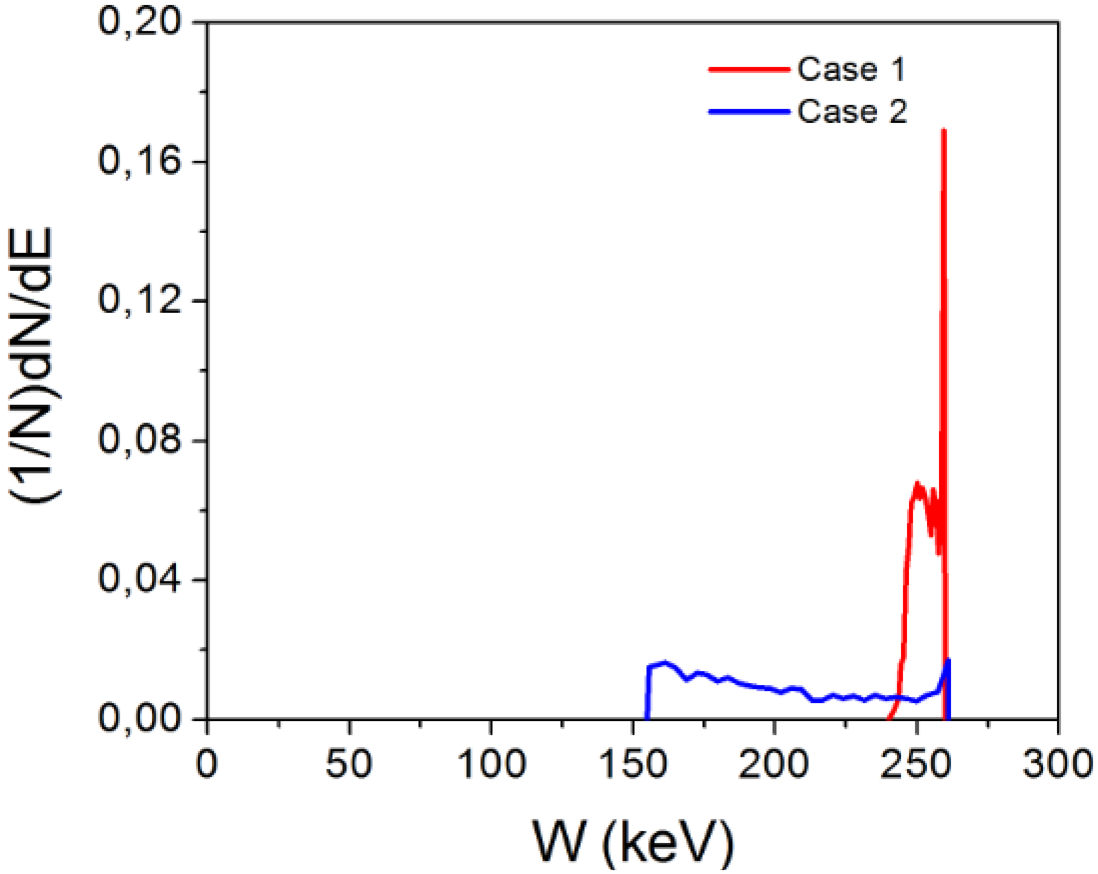

Figure 13: Numerical predictions of the energy spectrum for the electrons impacting on the cavity wall, $z_{wall} = L_c$, for the $n_e = 10^8$ electrons bunched and for the $n_e = 10^9$ electrons bunched.

CONCLUSIONS

Electrons bunched can be accelerated up to energies of 250 keV in spatial autoresonance acceleration conditions by using a cyclindrical TE113 mode

For the $n_e = 10^8 \ cm^{-3}$ electrons bunched there is not present serious defocalization effect.

For the $n_e = 10^9 \ cm^{-3}$ electrons bunched, the self-generated electric field spread the bunch in longitudinal direction, which affect the acceleration regime. However, this effect can be reduced by using a continuos electron beam in the injection process.

THANK YOU VERY MUCH FOR YOUR ATTENTION

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QUESTIONS…?