WAKEFIELDS AND TRANSVERSE BUNCH DYNAMICS STUDIES OF A PLASMA–DIELECTRIC ACCELERATING STRUCTURE

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Introduction

–One of the key issues of the accelerators development is the transverse stability of bunches (BBU).

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–In the case of dielectric wakefield accelerators, this issue is especially important, because the accelerating field is created here by the drive bunches, rather than by an external RF source, as in conventional accelerators.

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–As a consequence of the instability, aside from the bunch parameters degradation, it is also possible that particles may deposit on the dielectric surface.

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–The important case of transverse instability is the asymmetric bunch injection.

Previous studies (in the dielectric–loaded structures)

PHYSICAL REVIEW D VOLUME 42, NUMBER 5 1 SEPTEMBER 1990

Longitudinal- and transverse-wake-field effects in dielectric structures

M. Rosing and W. Gai
High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois 60439
(Received 8 March 1990)

PHYSICAL REVIEW D VOLUME 42, NUMBER 5 1 SEPTEMBER 1990

Wake fields in a dielectric-lined waveguide

King-Yuen Ng
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(Received 12 February 1990; revised manuscript received 21 May 1990)

Transverse wake fields due to nonaxisymmetric drive beams in the dielectric wake-field accelerator

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(Received 18 April 1990; accepted 20 December 1990)

PHYSICAL REVIEW E VOLUME 55, NUMBER 3 MARCH 1997

Numerical simulations of intense charged-particle beam propagation in a dielectric wake-field accelerator

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(Received 24 July 1995; revised manuscript received 5 August 1996)

PHYSICAL REVIEW E VOLUME 62, NUMBER 1 JULY 2000

Theory of wakefields in a dielectric-lined waveguide

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(Received 18 February 2000)

Previous studies (in a plasma)

– The focusing properties of plasma, which allow a drive bunch to be focused, have long been known

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A PLASMA WAKE FIELD ACCELERATOR†

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PHYSICAL REVIEW A VOLUME 44, NUMBER 10 15 NOVEMBER 1991

Acceleration and focusing of electrons in two-dimensional nonlinear plasma wake fields

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Department of Physics, University of California at Los Angeles, Los Angeles, California 90024
(Received 10 June 1991)

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– As an alternative to the quadrupole focusing in dielectric wakefield accelerator, the plasma filling the drift channel in a dielectric structure can be used

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– A combination of plasma and a dielectric structure also makes it possible to focus an accelerated bunch. Focusing in such a plasma-dielectric structure in the linear plasma mode is ensured by a Langmuir wave, and acceleration is provided by a modified eigenwave of the dielectric structure

Previous studies (in the plasma–dielectric structures)

– It was shown that at a certain plasma density the superposition of the plasma wave and the dielectric waves allows the acceleration of the witness bunch by the field of the dielectric wave together with simultaneous focusing by the plasma wave

Nuclear Instruments and Methods in Physics Research A 740 (2014) 124–129

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journal homepage: www.elsevier.com/locate/nima

Analytical and numerical studies of underdense and overdense regimes in plasma-dielectric wakefield accelerators

CrossMark

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Focusing of Drive and Test Bunches in a Dielectric Waveguide Filled with Inhomogeneous Plasma

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Wake fields effects in dielectric capillary

Check for updates

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–SPARC_LAB studies

Statement of the problem

– The structure under investigation is a round dielectric-loaded metal waveguide with channel for the charged particles, filled with homogeneous cold plasma

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–In the plasma a relativistic electron bunch is injected with an offset into the wave-guide in parallel to the axis

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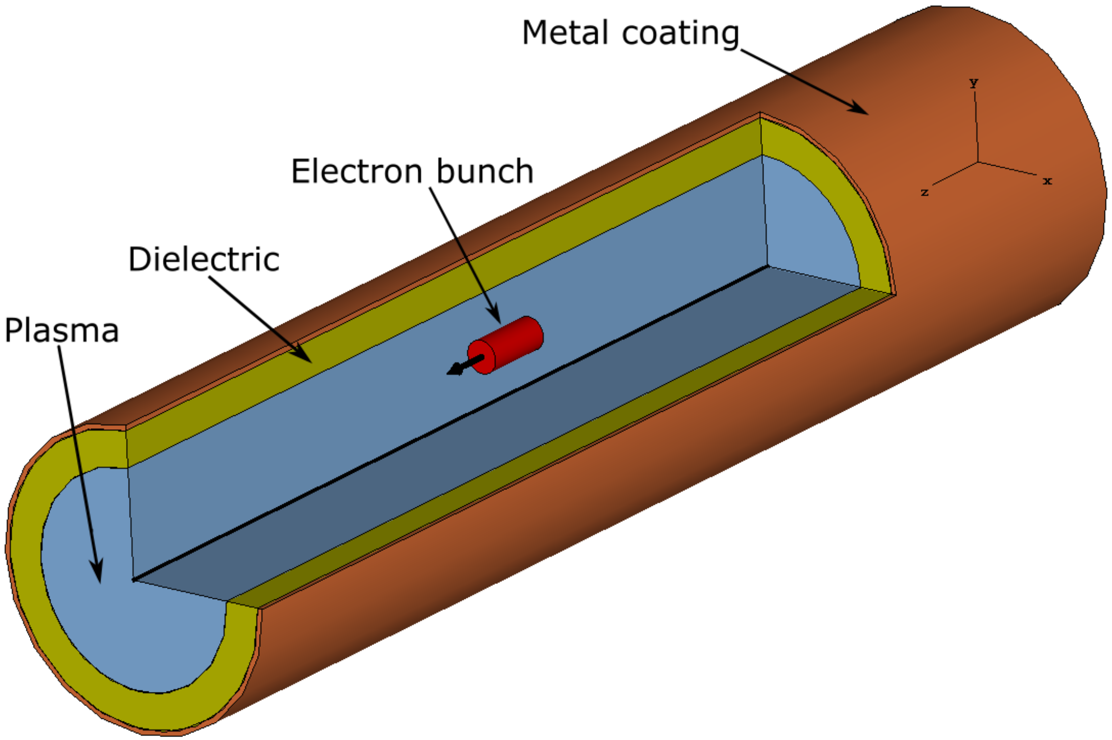
– The main goal is to analyze the dynamics of the drive electron bunch in the case of its off-axis injection into the plasma-dielectric structure



Analitical studies of the wakefield excitation

–Electromagnetic field components can be expressed in terms of its Fourier transforms

$$\mathbf{E}(r,\varphi,t-z/v)=\sum_{m=-\infty}^{+\infty}e^{im\varphi}\int_{-\infty}^{+\infty}d\omega\mathbf{E}_m^{\omega}(r,\omega)e^{-i\omega(t-z/v)},\ \mathbf{D}(r,\varphi,t-z/v)=\sum_{m=-\infty}^{+\infty}e^{im\varphi}\int_{-\infty}^{+\infty}d\omega\varepsilon(\omega)\mathbf{E}_m^{\omega}(r,\omega)e^{-i\omega(t-z/v)},$$

$$\mathbf{H}(r,\varphi,t-z/v)=\sum_{m=-\infty}^{+\infty}e^{im\varphi}\int_{-\infty}^{+\infty}d\omega\mathbf{H}_m^{\omega}(r,\omega)e^{-i\omega(t-z/v)},\ \mathbf{B}(r,\varphi,t-z/v)=\sum_{m=-\infty}^{+\infty}e^{im\varphi}\int_{-\infty}^{+\infty}d\omega\mu(\omega)\mathbf{H}_m^{\omega}(r,\omega)e^{-i\omega(t-z/v)},$$

–A source of the wakefield is a point charge of charge *q* moving with a constant velocity *v* along the waveguide axis with an offset r_0

$$j_z=q\frac{\delta(r-r_0)}{r}\delta(\varphi-\varphi_0)\delta(t-t_0-z/v)$$

–The equations for the longitudinal field components are

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial E_{zm}^{\omega}}{\partial r}\right)-\frac{m^2}{r^2}E_{zm}^{\omega}-\frac{\omega^2}{v^2}(1-\beta^2\varepsilon(\omega))E_{zm}^{\omega}=\frac{4\pi\omega i}{v^2}\frac{1-\beta^2\varepsilon(\omega)}{\varepsilon(\omega)}j_{zm}^{\omega},$$

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial H_{zm}^{\omega}}{\partial r}\right)-\frac{m^2}{r^2}H_{zm}^{\omega}-\frac{\omega^2}{v^2}(1-\beta^2\varepsilon(\omega))H_{zm}^{\omega}=0$$

–All the other field components can be derived from the E_z and H_z

Bunch–excited wakefield components (pencil-like bunch; in the plasma region)

$$\frac{F_{zm}}{q} = -\frac{2Q_b k_p}{L_b}\left(\theta(r_0 - r)\frac{I_m(k_p r)}{I_m(k_p a)}\Delta_m(k_p a, k_p r_0) + \theta(r - r_0)\frac{I_m(k_p r_0)}{I_m(k_p a)}\Delta_m(k_p a, k_p r)\right)\Psi_{\parallel}^{p} e^{-im\varphi_0} - \sum_{s=1}^{+\infty}\frac{4Q_b D_2(\omega_s) v}{a\omega_s^2 D'(\omega_s) L_b}\frac{I_m(\kappa_{ps} r) I_m(\kappa_{ps} r_0)}{I_m^2(\kappa_{ps} a)}\Psi_{\parallel}^{s} e^{-im\varphi_0}$$

$$\frac{F_{rm}}{q} = \frac{2Q_b k_p}{L_b}\left(\theta(r_0 - r)\frac{I'_m(k_p r)}{I_m(k_p a)}\Delta_m(k_p a, k_p r_0) + \theta(r - r_0)\frac{I_m(k_p r_0)}{I_m(k_p a)}\Delta'_m(k_p a, k_p r)\right)\Psi_{\perp}^{p} e^{-im\varphi_0} + \sum_{s=1}^{+\infty}\frac{4Q_b D_2(\omega_s)\kappa_{ps} v^2}{a\omega_s^3 D'(\omega_s) L_b}\frac{I_m(\kappa_{ps} r) I_m(\kappa_{ps} r_0)}{I_m^2(\kappa_{ps} a)}\Psi_{\perp}^{s} e^{-im\varphi_0}$$

where: Q_b **is the bunch charge,** L_b **is the bunch length,** ω_p **is the plasma frequency,** k_p **is the plasma wave number,** a **is the inside radius of the dielectric,** I_m **and** K_m **are the modified Bessel and Macdonald functions of the m**th **order ,** $\Delta_m(x,y) = I_m(x)K_m(y) - K_m(x)I_m(y)$ **,** ω_s **are the eigenfrequencies of the waveguide, which are define by the dispersion equation** $D(\omega_s) = 0$ **,** $\kappa_{ps}^2 = (\omega^2 / v^2)(1 - \beta^2 \varepsilon_p(\omega_s))$ **,** $\varepsilon_p(\omega) = 1 - \omega_p^2 / \omega^2$ **is the plasma permittivity,** $\theta(t)$ **is the Heaviside function.**

Parameters for the calculations

–Parameters of the waveguide (THz frequency range):

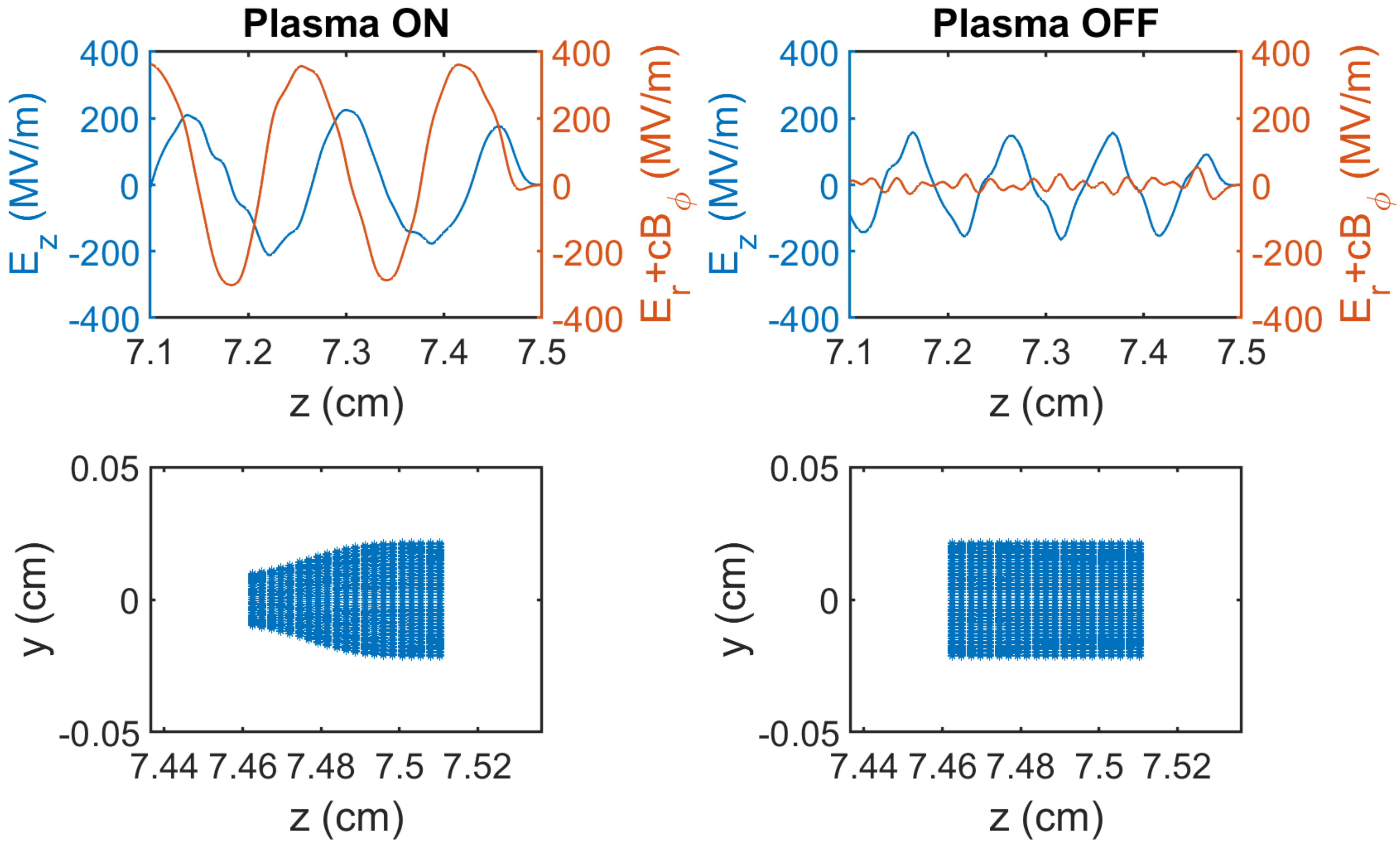
the inner dielectric radius – 0.5 mm
the outer dielectric radius – 0.6 mm
the length of the waveguide – 8 cm
the dielectric material – quartz ($\varepsilon = 3.75$)
the plasma density – $4.41*10^{14}$ cm^{-3}

–Parameters of the bunch (accessible at SLAC):

the energy of bunch electrons – 3 GeV
the bunch charge – 3 nC
the bunch length – 0.5 mm
the bunch radius – 0.23 mm

Plasma-dielectric structure VS Dielectric-loaded structure

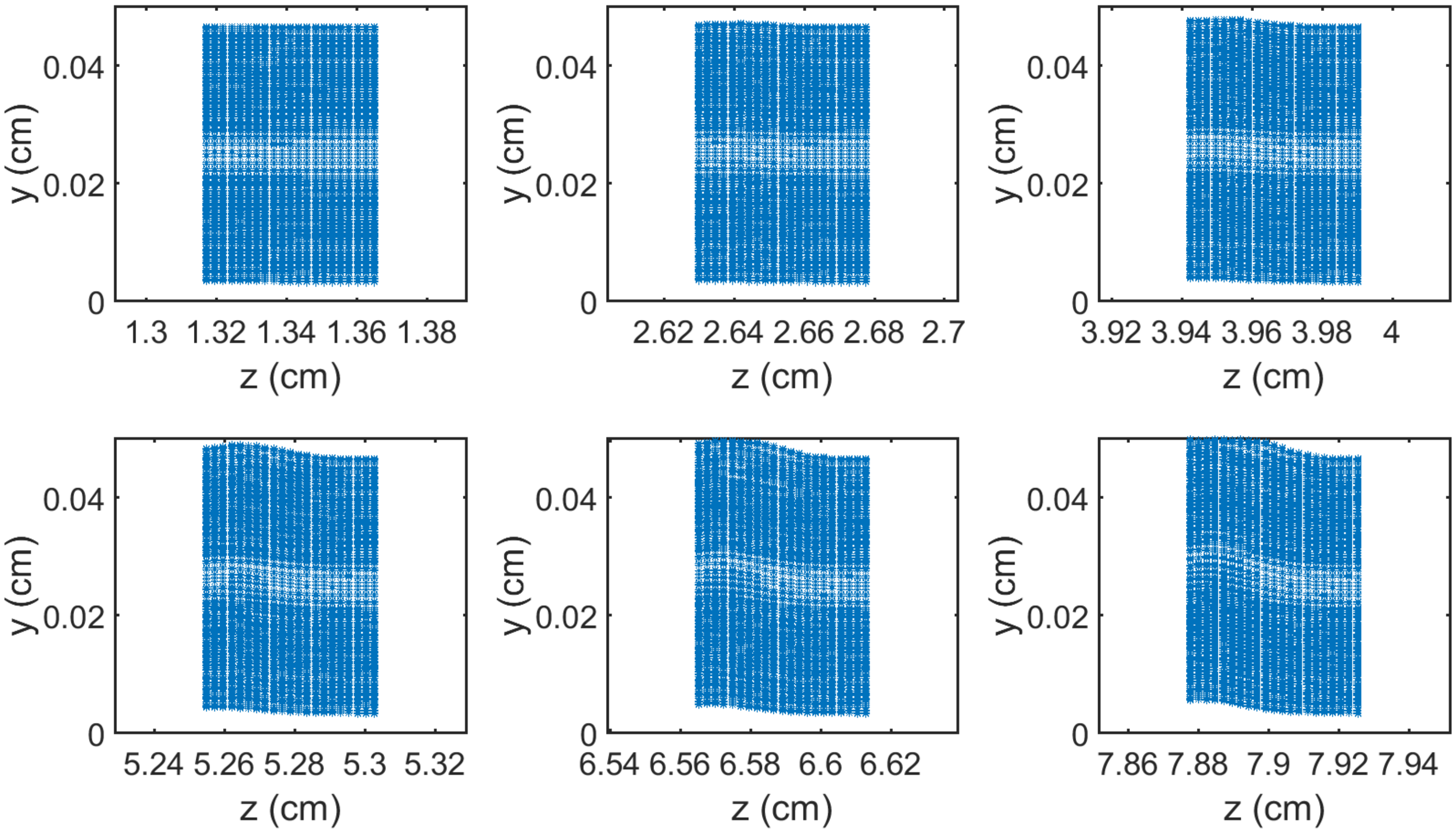
(on-axis bunch)



Transverse bunch dynamics (dielectric–loaded structure)

(off-axis bunch)

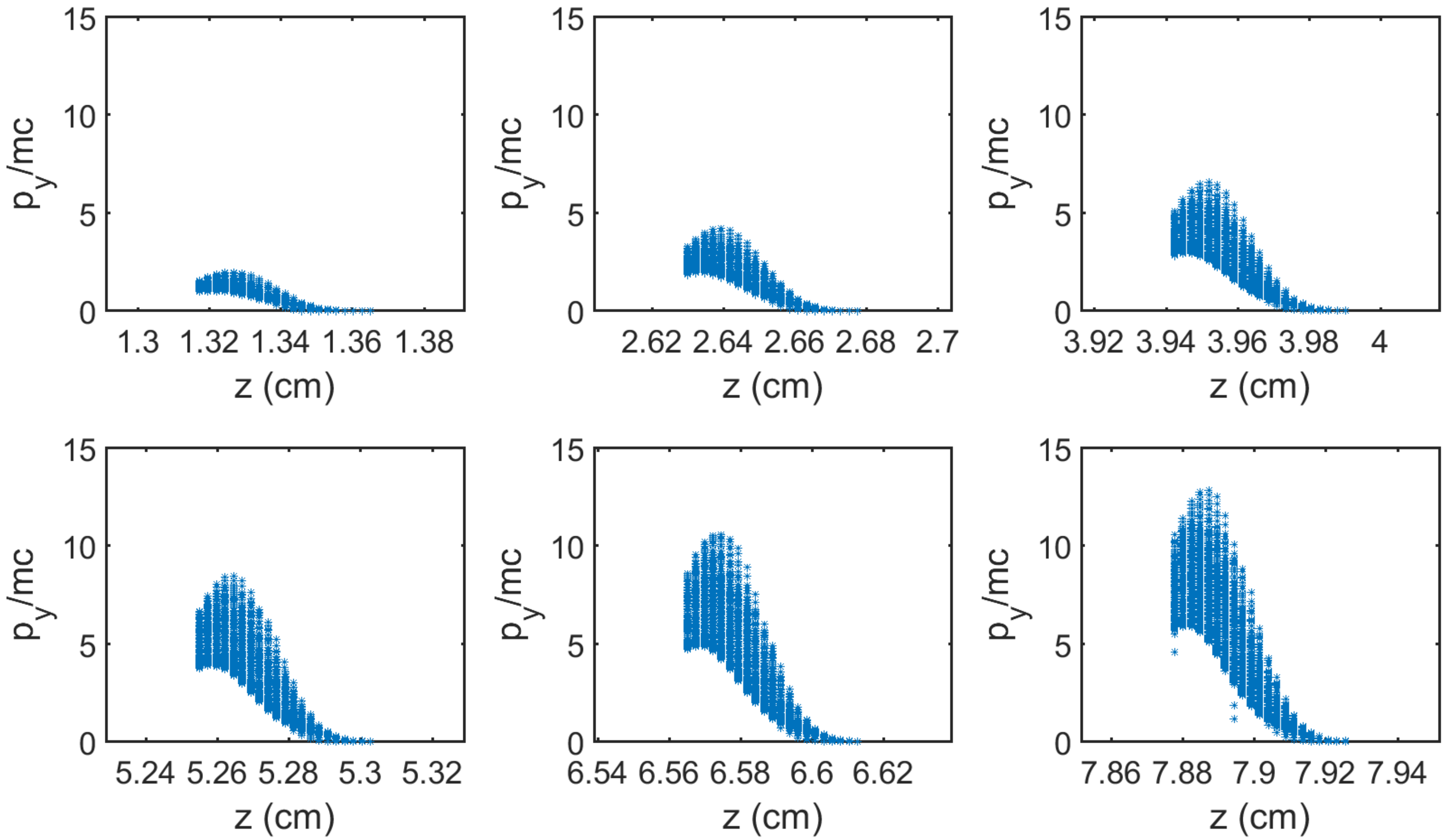
–In order for the effect of the bunch offset to be more pronounced, we injected it near the dielectric



Dynamics of the off-axis bunch on the y – z plane. Vertical axis limits correspond to half of vacuum channel width, horizontal axis limits correspond to the frame around the bunch. The initial vertical offset of the bunch is 0.25 mm, the length of the structure is 8 cm.

Transverse bunch dynamics (dielectric–loaded structure)

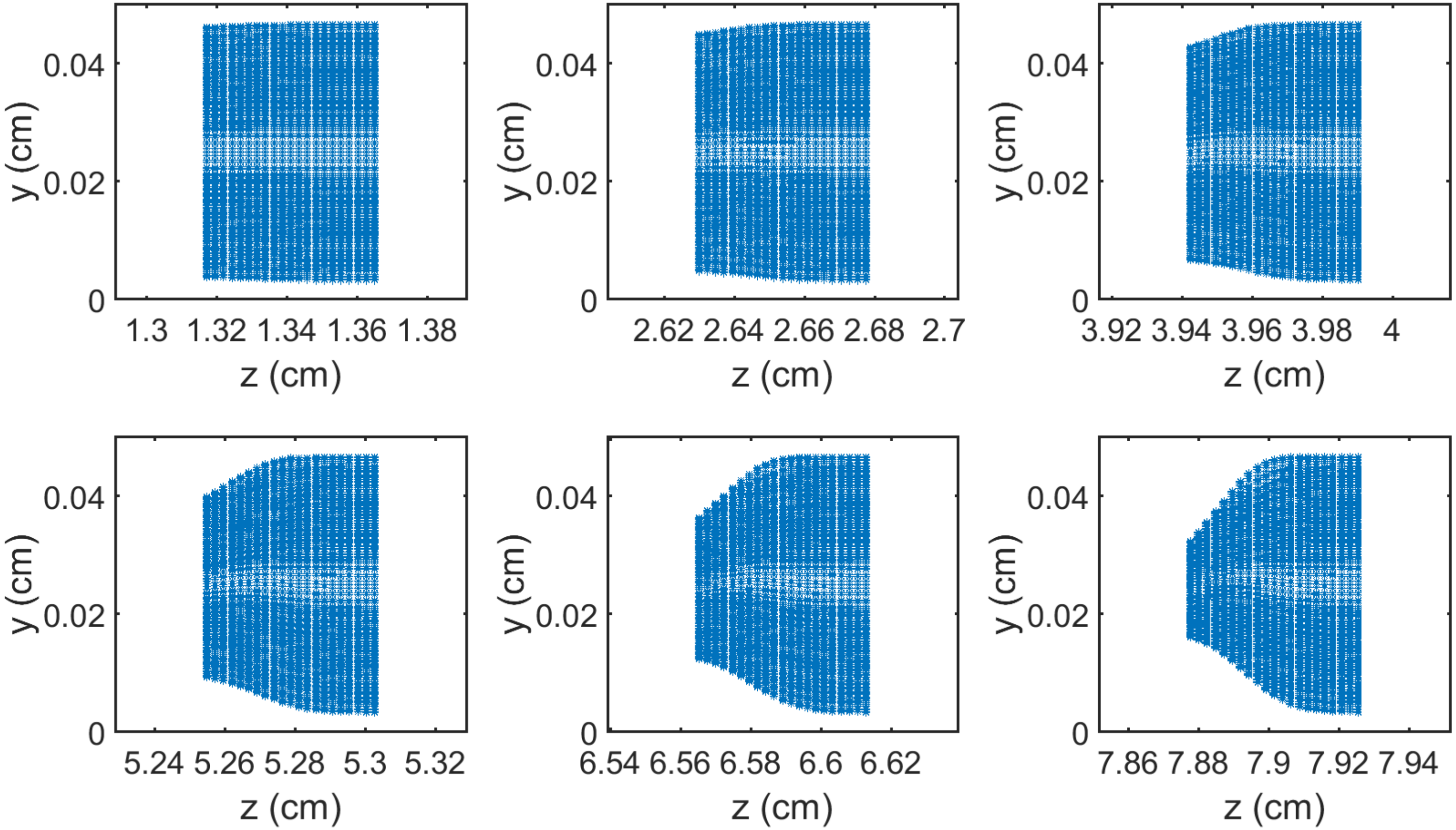
(off-axis bunch)



Bunch particles dynamics in the p_y/mc – z plane in the case of off-axis injection

Transverse bunch dynamics (plasma–dielectric structure)

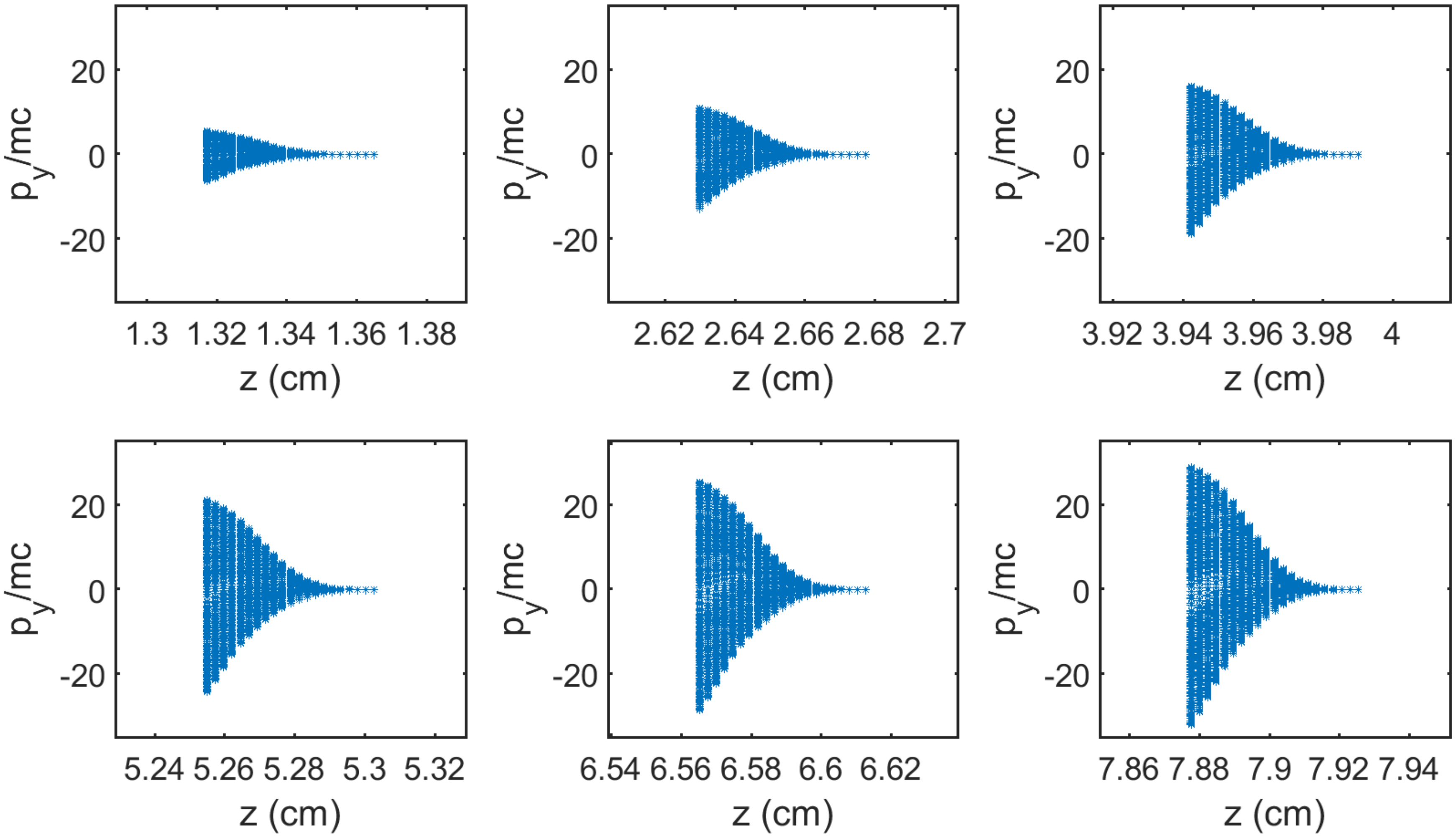
(off-axis bunch)



Dynamics of the off-axis bunch on the y – z plane. Vertical axis limits correspond to half of plasma channel width, horizontal axis limits correspond to the frame around the bunch. The initial vertical offset of the bunch is 0.25 mm, the length of the structure is 8 cm.

Transverse bunch dynamics (plasma–dielectric structure)

(off-axis bunch)



Bunch particles dynamics in the p_y/mc – z plane in the case of off-axis injection

Conclusions

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–An analytical theory of wakefield excitation by off-axis particle bunch in a plasma-dielectric waveguide has been formulated. Constructed theory allows carrying out numerical analysis in the rigid bunch approximation

***

– It was presented the detailed simulation studies of the BBU instability in the plasma-dielectric accelerating structure, excited by a relativistic electron bunch

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– A comparison of the off-axis drive bunch transverse dynamics for the cases of the absence and presence of plasma in the channel for charged particles is carried out

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– It has been demonstrated that for the plasma-dielectric accelerating structure (unlike the dielectric-loaded structure without plasma) the presence of the initial bunch offset does not lead to the BBU instability. Thus, it is not the critical point, which requires high injection accuracy for the future development and operation of the plasma-dielectric wakefield accelerator

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Thank you for your attention !

Questions are welcome !