HIGH-ENERGY MICRO-BUNCHER BASED ON THE mm-WAVELENGTH DIELECTRIC STRUCTURE

A. Petrenko, CERN, Geneva, Switzerland

I. Sheinman, LETI, Saint-Petersburg, Russia

ABSTRACT

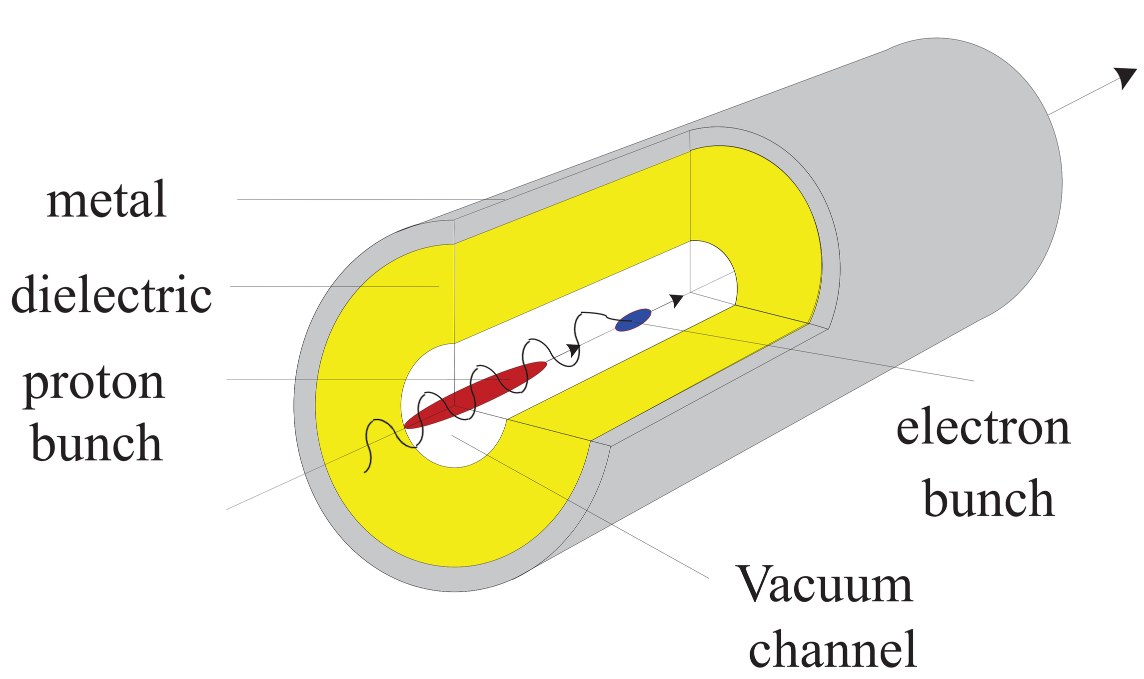
The proton-driven plasma wakefield acceleration is a recently proposed technique promising a GeV/m rate of acceleration to a TeV-scale energy in a single plasma stage. In order to excite high-amplitude plasma wakefields a long proton bunch from a synchrotron should be broken into a sequence of sub-mm long micro-bunches which can drive the plasma oscillations resonantly. We suggest a novel approach to produce the required train of micro-bunches using collinear wakefield acceleration in a dielectric-loaded structures. First the energy modulation is introduced into the proton beam with the help of the mm-wavelength dielectric accelerating structure. Then the energy modulation is transformed into the longitudinal micro-bunching using proton beamline with magnetic dipoles. Beam dynamics simulations were used to find the appropriate parameters of the dielectric accelerating structure, driving electron bunch and the beam focusing system.

INTRODUCTION

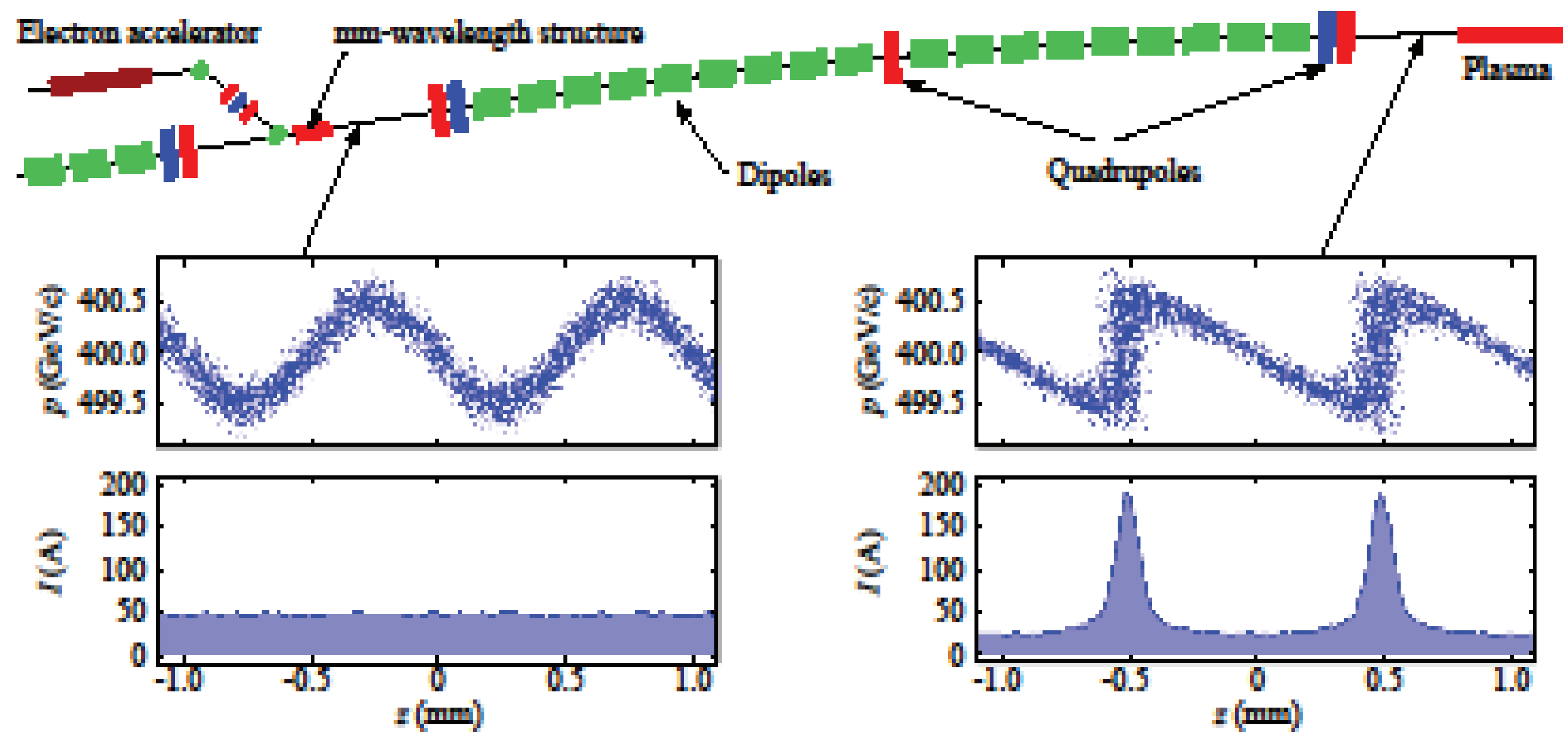
Hadron beams in high-energy synchrotrons provide the highest-energy particles available in laboratories today. Synchrotrons also hold the record for the maximum total energy stored in the beam. For example, both rings of the Large Hadron Collider currently operate at 6.5 TeV with 2200 bunches of $1.1{\cdot}10^{11}$ protons each. This beam has the total energy of 250 MJ which is equivalent to the kinetic energy of a typical fully-loaded airliner (80 t) at the take-off speed of 300 km/h (280 MJ). Even the single bunch ($3{\cdot}10^{11}$ protons at 400 GeV) in the 40 year old Super Proton Synchrotron (SPS) at CERN carries an order of magnitude more energy than the single bunch in the proposed International Linear Collider ($2{\cdot}10^{10}$ electrons or positrons at 250 GeV).

Several techniques have been suggested to transfer a fraction of the proton beam energy to other particles which cannot be accelerated in a circular machine either because of the prohibitively high energy loss due to the synchrotron radiation (electrons/positrons) or because of the short life-time of the unstable particles (muons, pions). Such accelerated particles can be used for instance in the collider experiments which do not require high luminosity. The proton-driven plasma wakefield acceleration is the recently proposed method promising a GeV/m rate of acceleration to a TeV-scale energy in a single plasma stage. GV/m plasma wakefields correspond to the plasma wavelength of around 1 mm, while proton bunch in a typical synchrotron is several tens of cm long. In order to excite high-amplitude plasma wakefields the proton bunch should be either compressed longitudinally by a large factor (which is technically very challenging) or the single proton bunch should be broken into the sequence of sub-mm long micro-bunches which can drive the plasma oscillations resonantly. The feasibility of this technique will be tested in the forthcoming AWAKE experiment at CERN.

We propose approach to create the sequence of sub-mm long proton micro-bunches via the longitudinal bunching process. We rescale it down to the mm-wavelength using the collinear wakefield acceleration in the dielectric-loaded structures. A resulting train of sub-mm proton micro-bunches could be useful not only for the plasma wakefield acceleration but also as a powerful source of mm-wavelength radiation or as a driver for the similar dielectric accelerator.



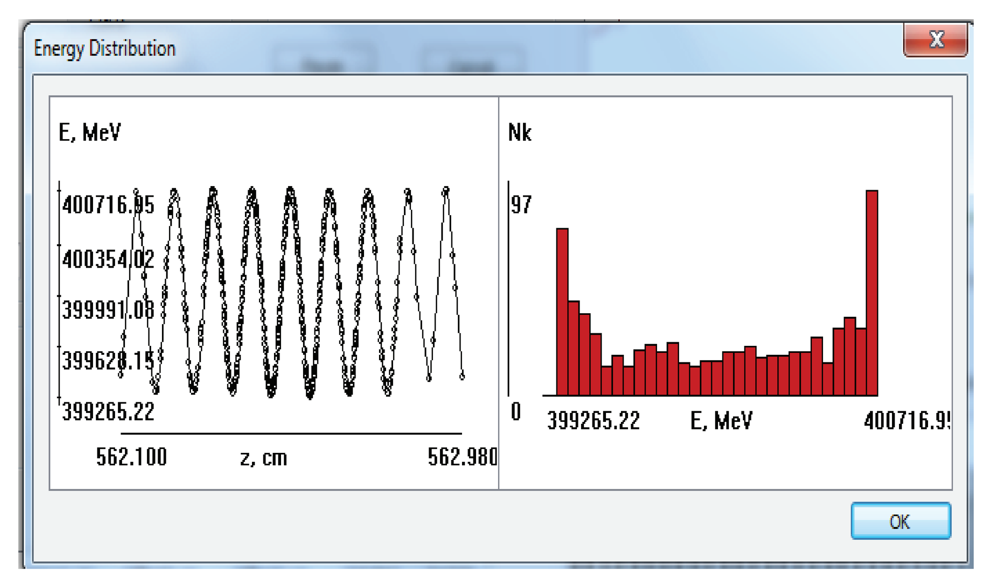
GENERAL DESCRIPTION OF THE METHOD



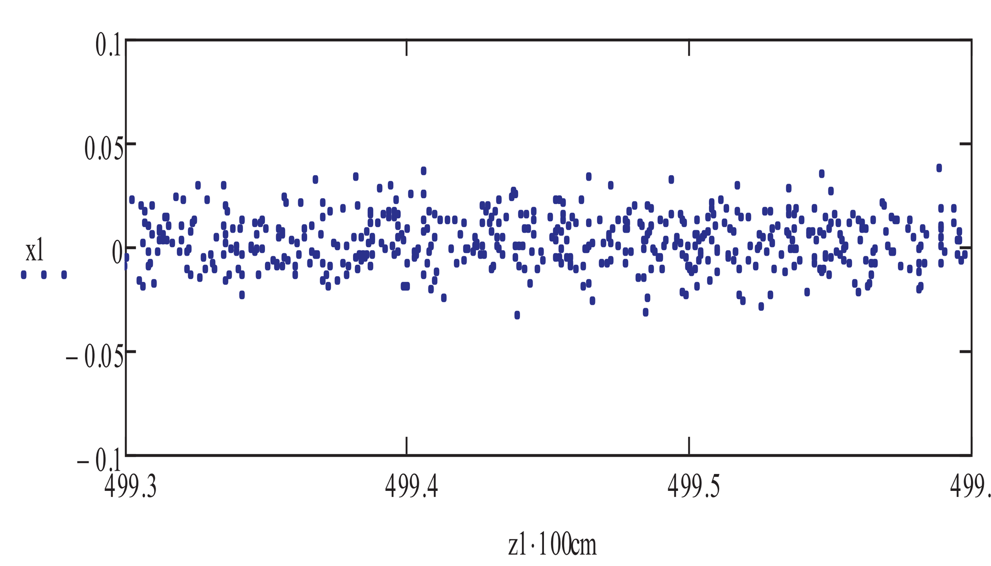
System parameters

Waveguide				
f, GHz	R_c, mm	R_w, mm	ε	E_z, MV/m
300	1	1.0614	3.75	140
Driver electron bunch e^-				
q_d, nC	W_d, MeV	σ_{zd}, mm	σ_{xd}, mm	σ_{yd}, mm
-5	600	0.1	0.05	0.05
Witness proton bunch p^+				
q_w, nC	W_w, GeV	σ_{zw}, cm	σ_{xw}, mm	σ_{yd}, mm
50	400	20	0.16	0.16
Focusing system				
B_0, T	L_{fodo}, cm	L_f/L_0	$B_0{\cdot}L_{fodo}\sim\gamma$	
1.5	11	6	L_{fodo}=const	

Proton bunch energy distribution

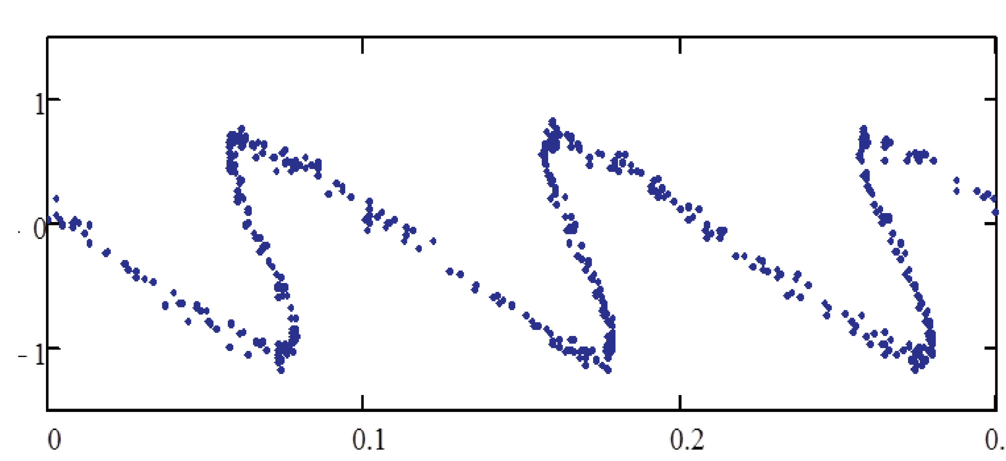


Proton bunch before dipole

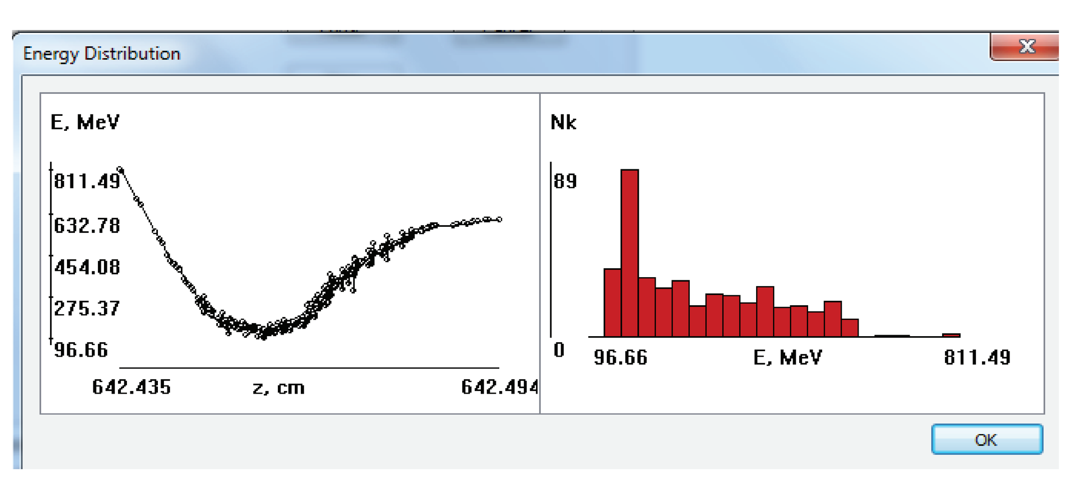


Bunches in dielectric wakefield structure

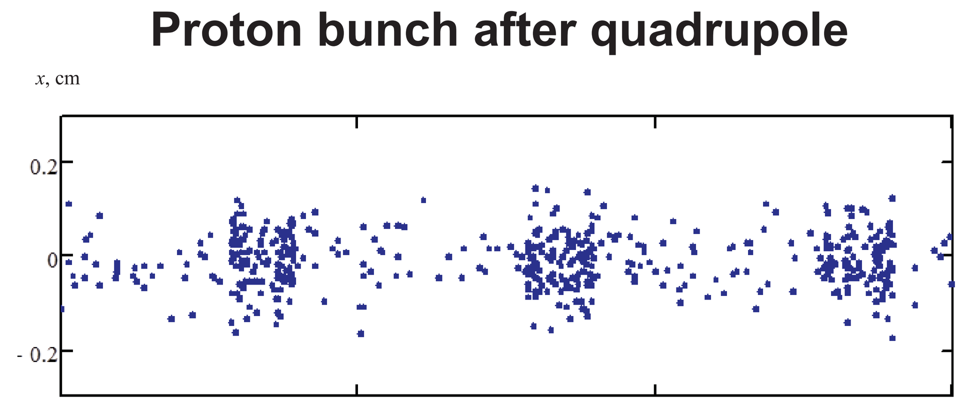
Proton bunch after dipole



Driver bunch energy distribution



Proton bunch after quadrupole



CONCLUSION

We suggested a novel approach to produce the long train of high-energy proton micro-bunches using the mm-wavelength dielectric-loaded structure. For the considered example case of the 400~GeV proton beam from the CERN SPS the requirements on electron drive beam parameters seem to be rather challenging. Such electron beams are normally produced for the soft X-ray Free Electron Lasers and require too much infrastructure investment to be considered for the AWAKE experiment now. Still such option can be very interesting for some eventual application of the proton-driven acceleration using the LHC proton beam for example.