Saint Petersburg Electrotechnical University "LETI"

SOFTWARE COMPLEX "DYNPART" FOR THE CALCULATION OF SELF-CONSISTENT BEAM DYNAMICS IN DIELECTRIC WAKEFIELD ACCELERATING STRUCTURES

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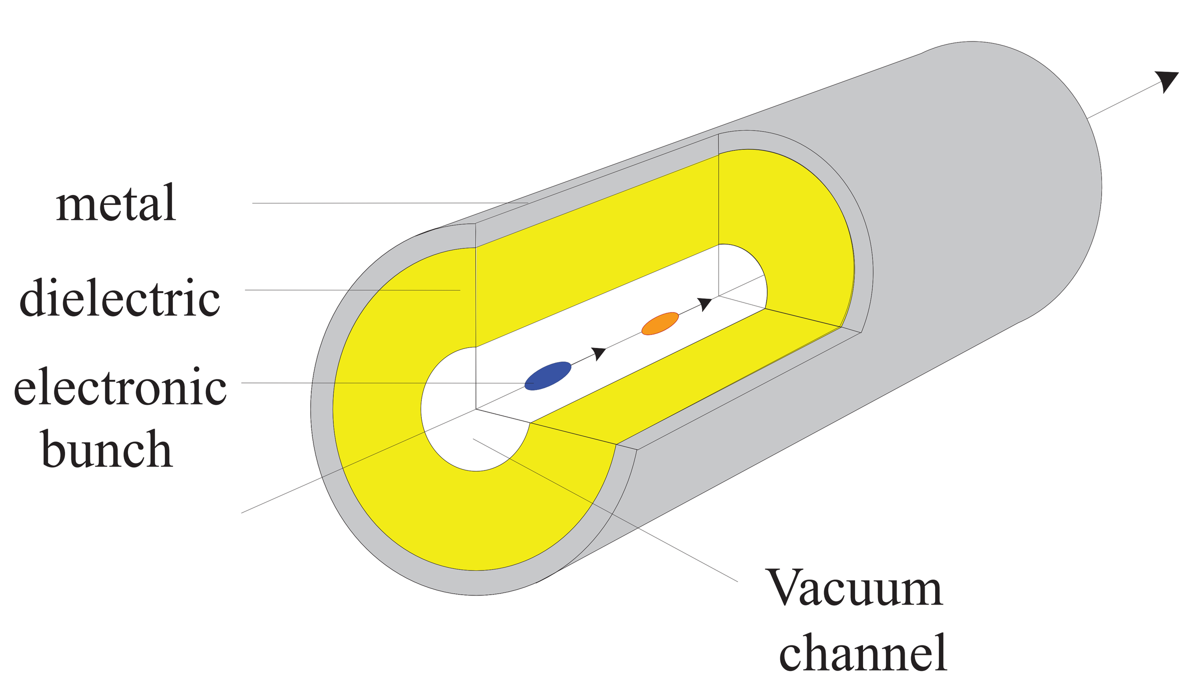
ABSTRACT

Dielectric waveguide structures are a basis for development of new generation of accelerators on the basis of a wakefield method of the charged particle acceleration, beam manipulation, and also free electron lasers. A self-coordinated dynamics of relativistic particle beams in a single layer cylindrical waveguide with dielectric filling is investigated. The computer code is developed based on mathematical expressions for the analysis of the radial dynamics. The possibility of modeling interaction of different types of particles in a bunch is realized. Influence of both own wake fields and external fields of focusing and deflection systems on bunch dynamics is analyzed.

INTRODUCTION

Wakefield acceleration principle is based on a generation by high-current charged particles bunch in the waveguide structure of an electromagnetic wave with a longitudinal component of the electric field up to 100 MV/m. This wake field is used to accelerate a following low-current bunch of high energy. In free electron lasers electromagnetic wave generated by high-current electron bunch is extracted from the waveguide and structure is used as an electromagnetic radiation source.

Dielectric wakefield accelerating structures are single or multilayer dielectric cylindrical waveguides with outer metal covering and vacuum channel along the axis. Along with the longitudinal fields there are transverse fields, leading to bunch deflection from the axis of the waveguide and subsidence of particles on its wall.



Development of new methods of acceleration based on principle of wakefield acceleration, requires a detailed analysis of the self-consistent beam dynamics taking into account both own and external focusing and deflecting fields. Nowadays, wakefield accelerators often use light particles, electrons, as driving bunch, to generate the wakefield for acceleration of another electron bunch (which is usually called “witness”) like it is organized at AWA/APS accelerator complex in Argonne National Laboratory (USA) [1]. Wakefield acceleration of heavier particles, like protons, is not used because of traditional cyclic accelerators like synchrotrons are more effective for acceleration of heavy particles. Nevertheless wake field generated by driving electron bunch in the wakefield structure can be used for energy modulation of long proton bunch [2].

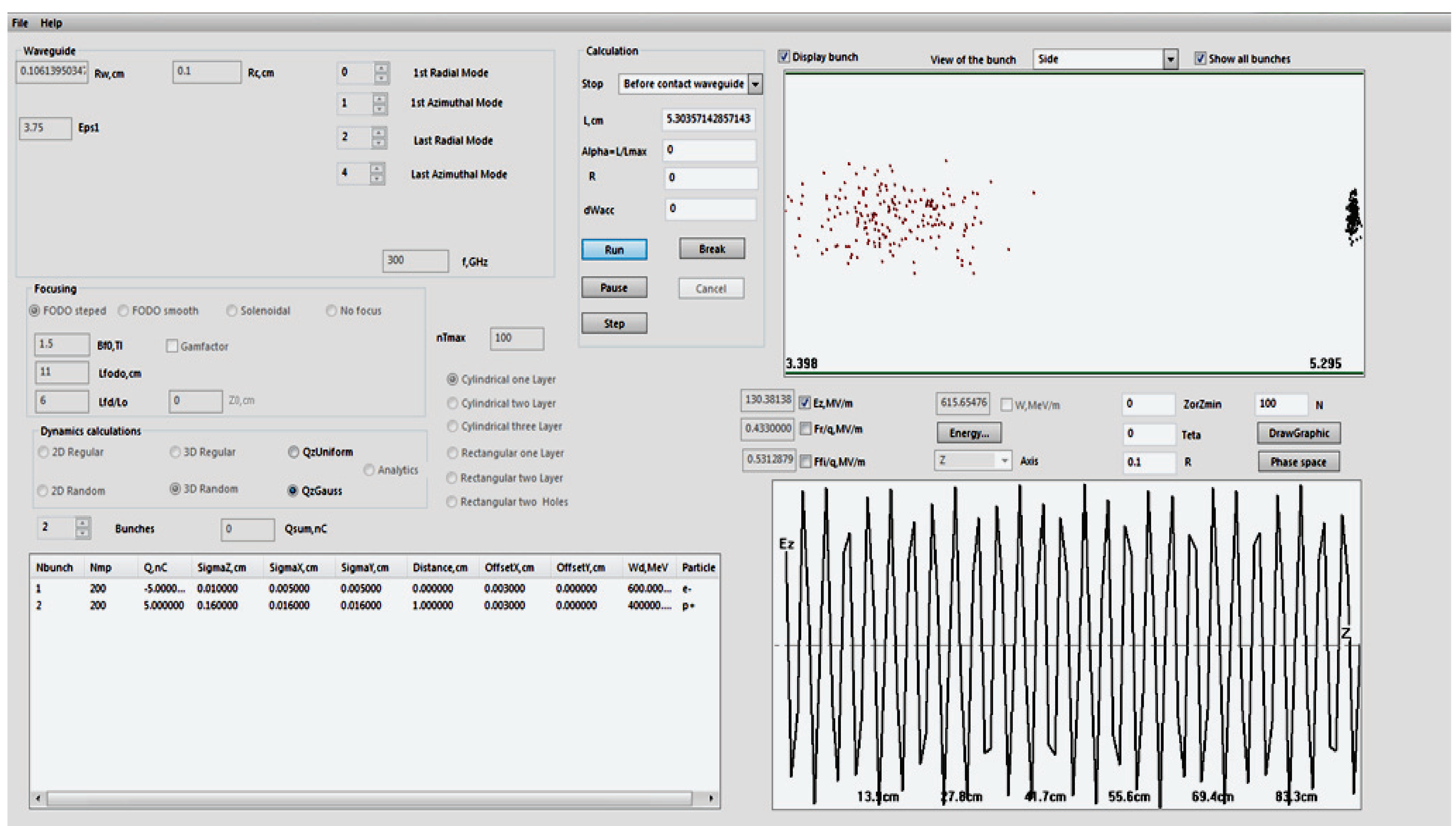
At the same time wakefield acceleration with its high acceleration gradient would be promising in case of muons acceleration which can live in their self-reference system only 2.2 μs.

Effectiveness of wakefield acceleration is limited by “Wakefield’s theorem”. In accordance with "Wakefield's theorem" in the accelerator, where the electron bunches move along the same line, in the case of symmetric driving electron bunch accelerated bunch cannot increase its energy more than twice the value of electron energy of the driving bunch. This limit can be overcome by using a proton beam accelerated in synchrotron as a driver and electron or muon bunch as a witness.

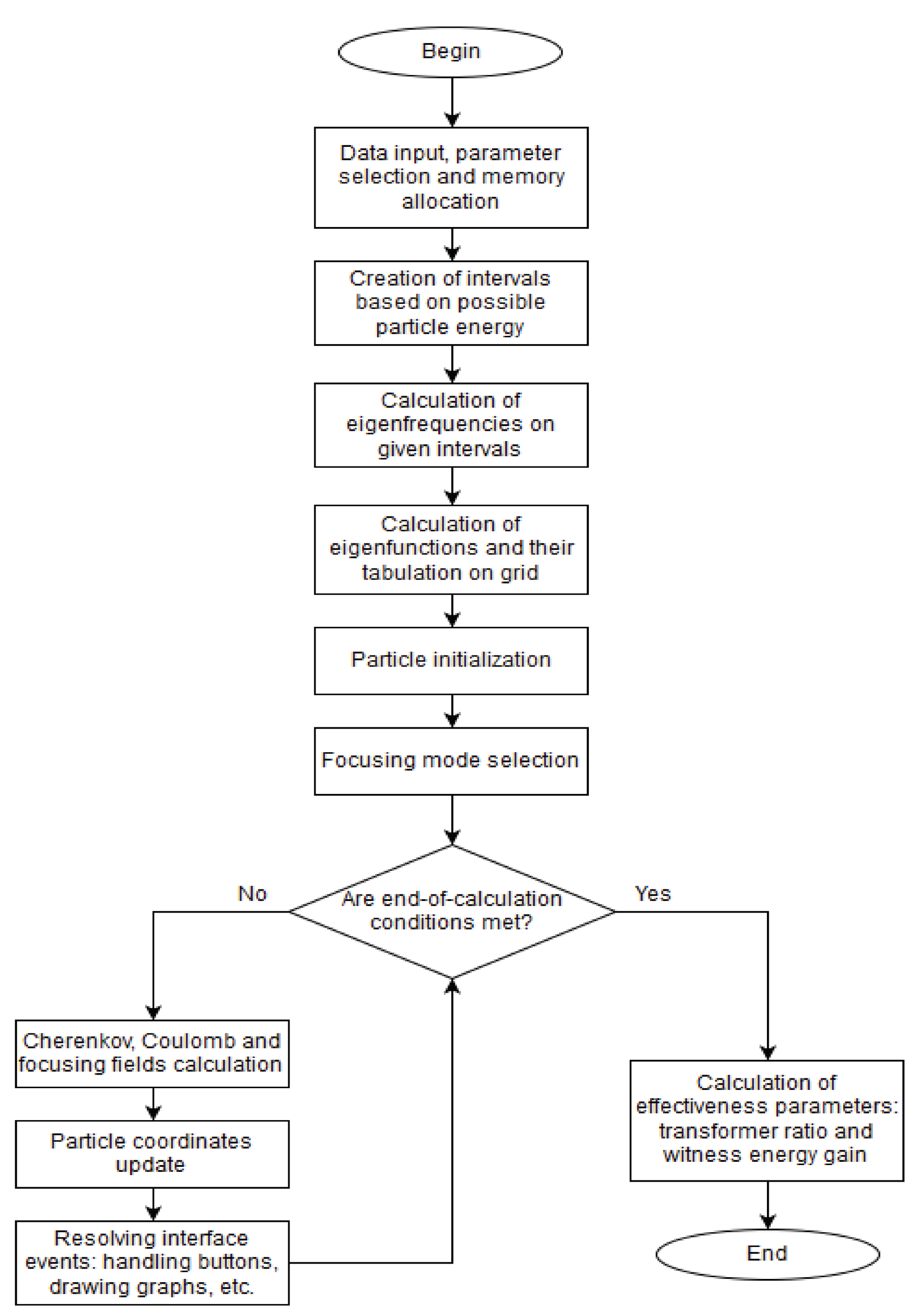
SOFTWARE FEATURES

Developed software allows you to:

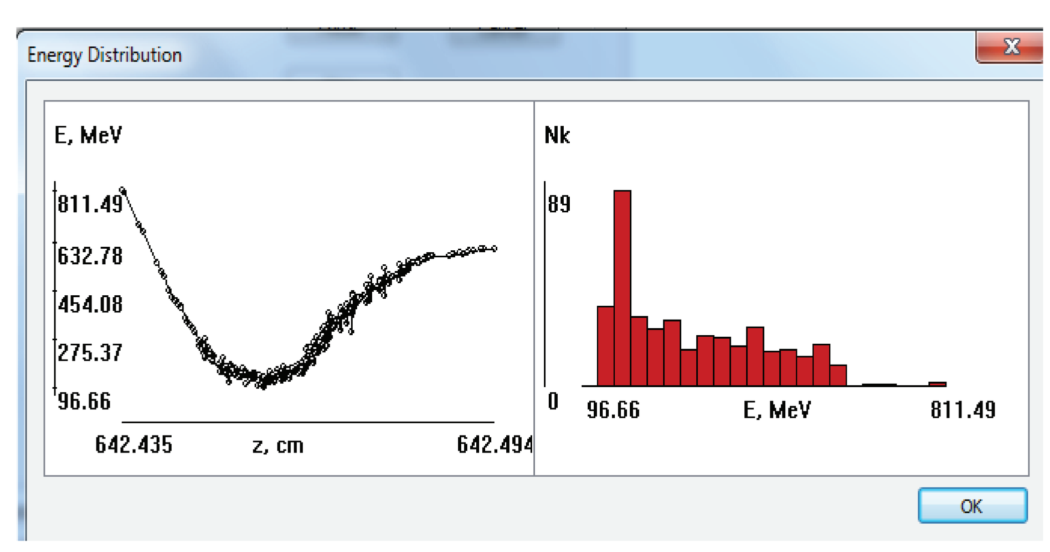
- Calculate of parameters of the cylindrical waveguide with single layer dielectric filling.
- Simulate dynamics for any number of bunches in waveguide.
- Solve the self-consistent equation of dynamics in 2D, and 3D models.
- Choose parameters of alternating-gradient focusing and weak focusing.
- Observe the transformation of the beam shape when it moves in the waveguide in the process of calculating.
- Display the field distribution in the space inside and outside the beam, and construct a vector diagram fields.
- Identify the flight range to prevent beam touching the waveguide wall.
- Perform optimization of the parameters of the waveguide and the beam focusing system for maximization of flying range and energy extraction from the beam.
- Perform parallel computing based on OpenMP for shared memory systems. The result is a substantial increase in performance of about 8 times compared with the linear calculations.



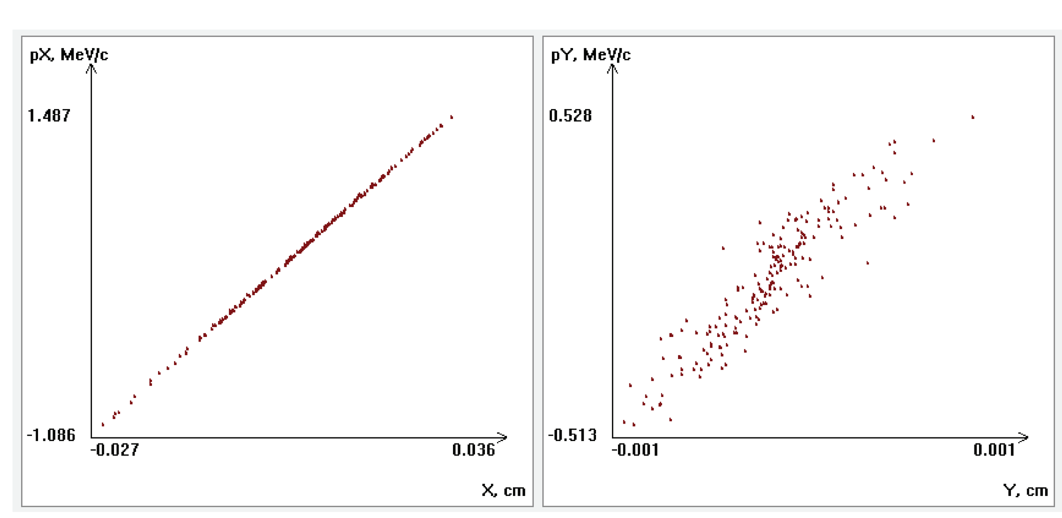
DynPart Interface



DynPart primary workflow chart



Driver bunch energy distribution



Driver bunch phase space graph

CONCLUSION

DynPart code was used for calculation of beam dynamics for Argonne Wakefield Accelerator / Argonne Photon Source (AWA/APS), investigation of interaction of FODO focusing with dielectric loaded wakefield waveguides. DynPart code has also been used to calculate of electron driver beam dynamics and creating of appropriate energy modulation for an mm-wavelength proton high energy microbuncher developed in collaboration with CERN AWAKE experimental group.