Terahertz FEL based on photoinjector beam in RF undulator

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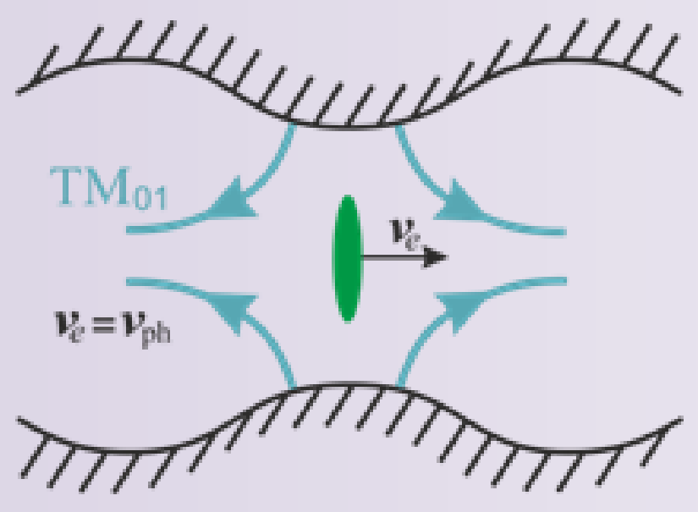
Abstract

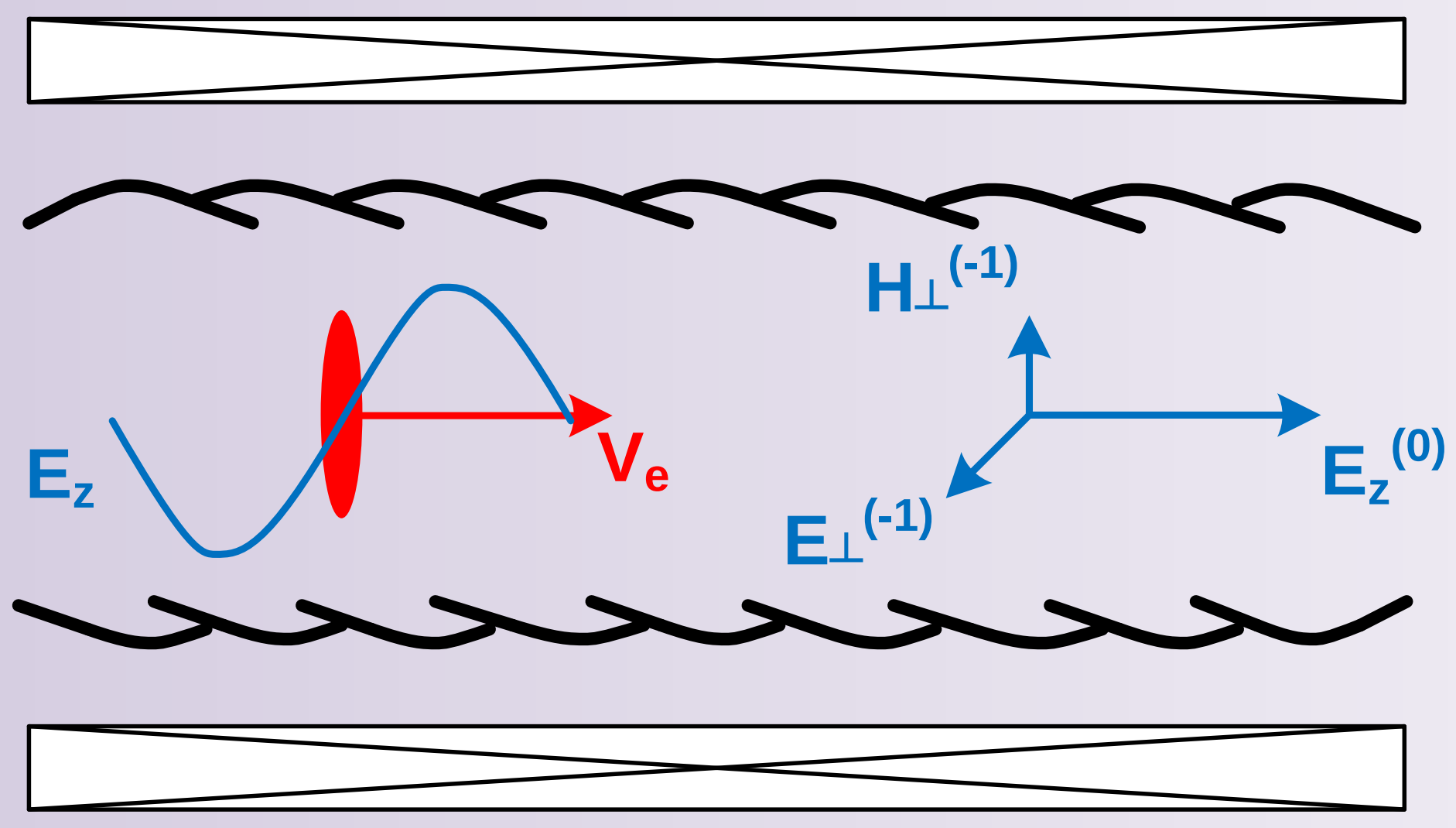
Photoinjectors, which can produce picosecond electron bunches of MeV-level, are attractive for THz generation. Fortunately, a long distance to reach scattering power saturation in FEL is not necessary, if bunch length is shorter than the produced THz half-wavelength. However, the energy of several MeVs does not allow providing long traveling of the flying bunch without longitudinal divergence. That is why, we suggest using specific RF undulator in a form of the normal wave in the helical waveguide at 3 cm wavelength. The mentioned wave has the -1st space harmonic with transverse fields and negative phase velocity (responsible for particle wiggling). This wave has also the 0th harmonic with longitudinal field and positive phase velocity equal to bunch velocity. Due to the synchronous 0th harmonic one can channel low-energy bunches (due to longitudinal focusing field) as far as several meters distance. One might also inject electron bunches in slightly accelerating field, in this case the output THz pulse obtain nearly linear frequency modulation. Such long THz pulses with the mentioned modulation of the frequency can be effectively compressed by pair of diffraction gratings.

Focusing of short electron bunches in long helical waveguide

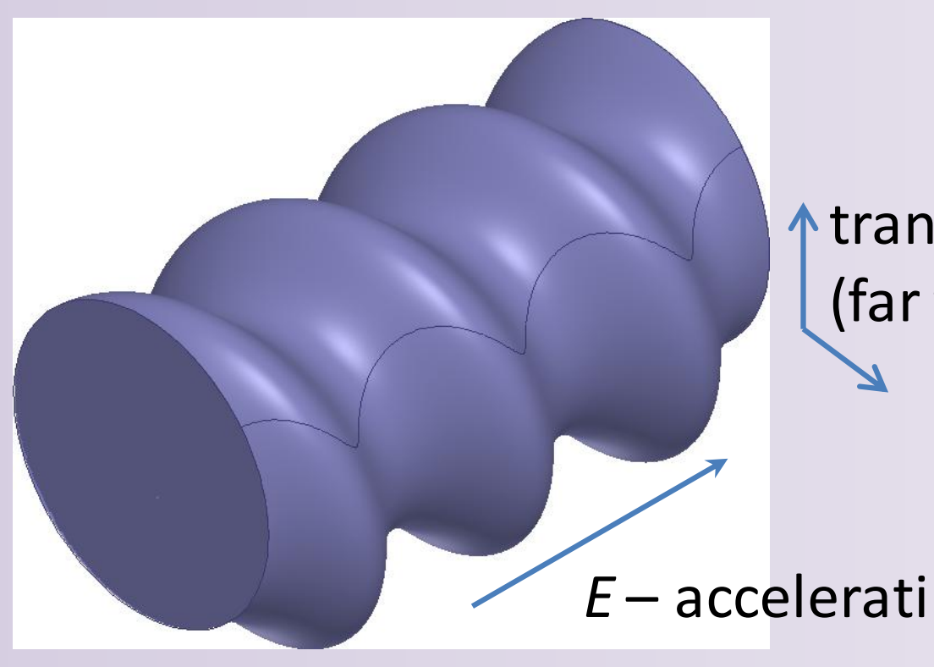


Scheme of bunch focusing in longitudinal direction.

Bunch parameters	
Charge, nC	0.1
Energy, MeV	5
Length, mm	0.15
Radius, mm	10



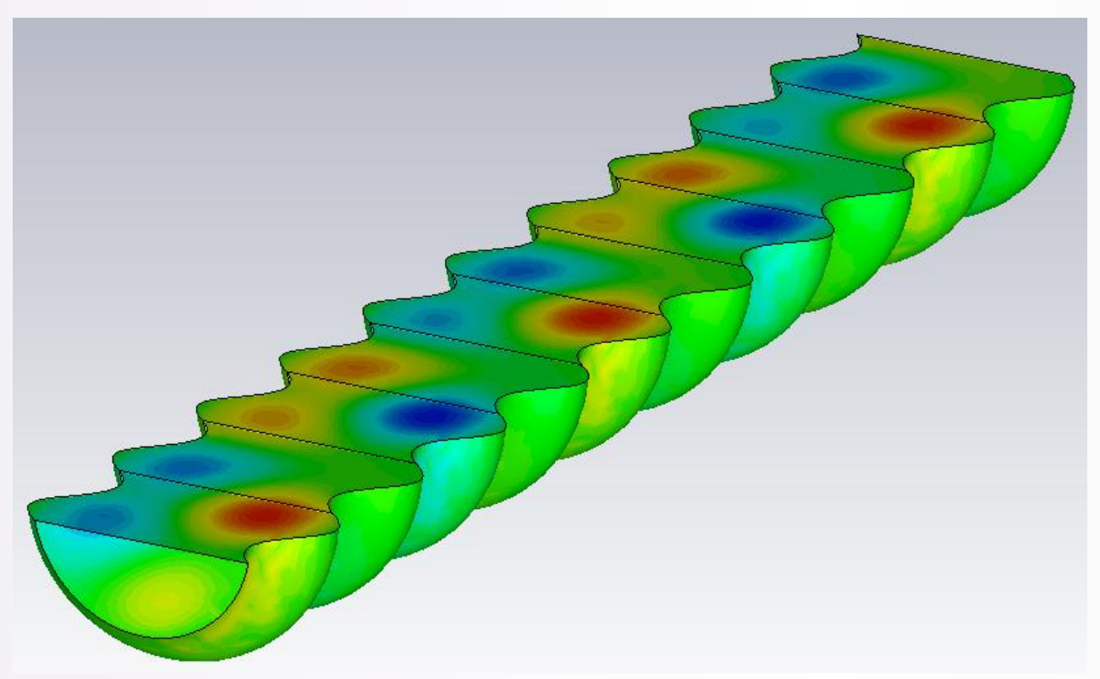
RF undulator based on helical waveguide

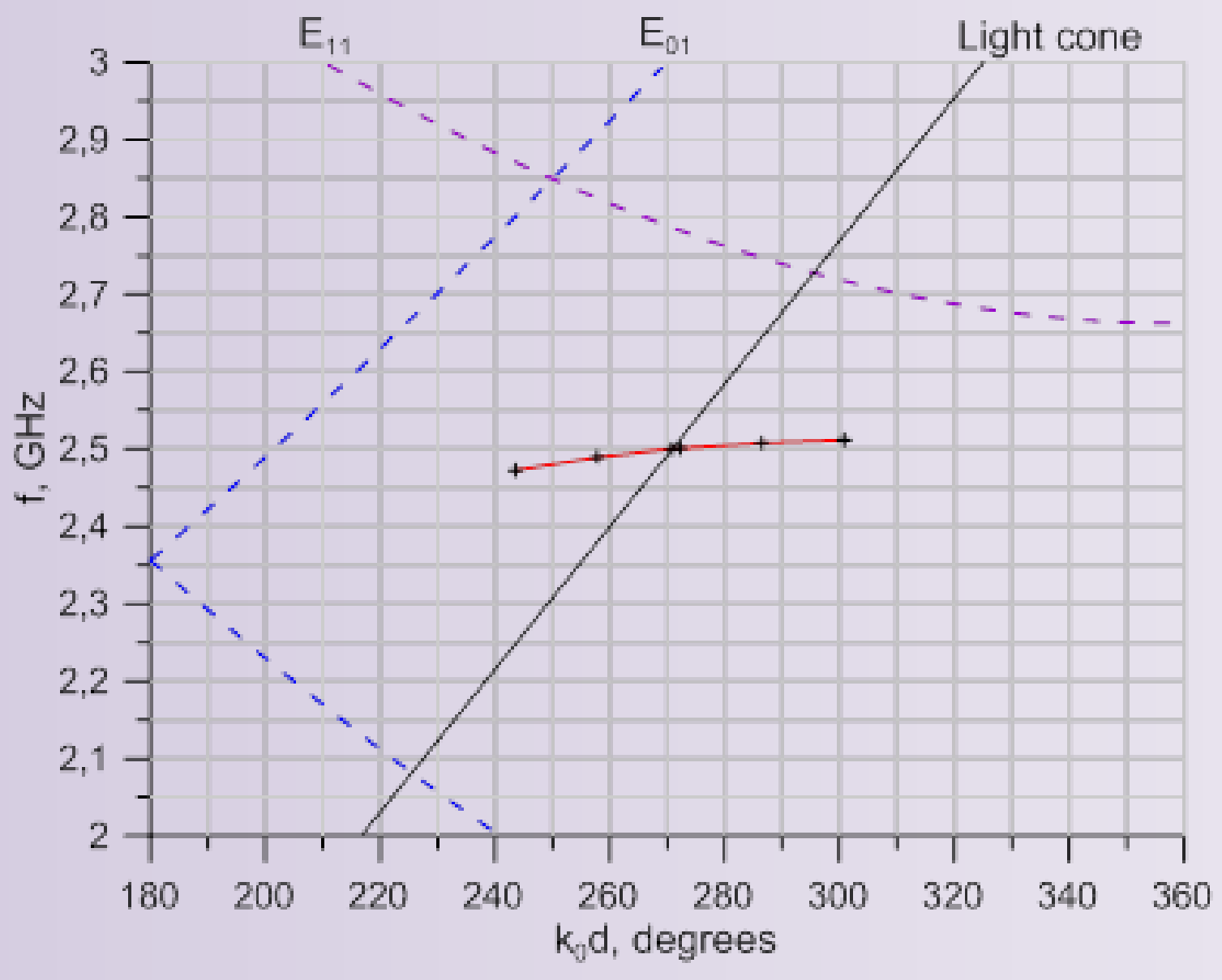


transverse field components
(far from Cherenkov synchronism)

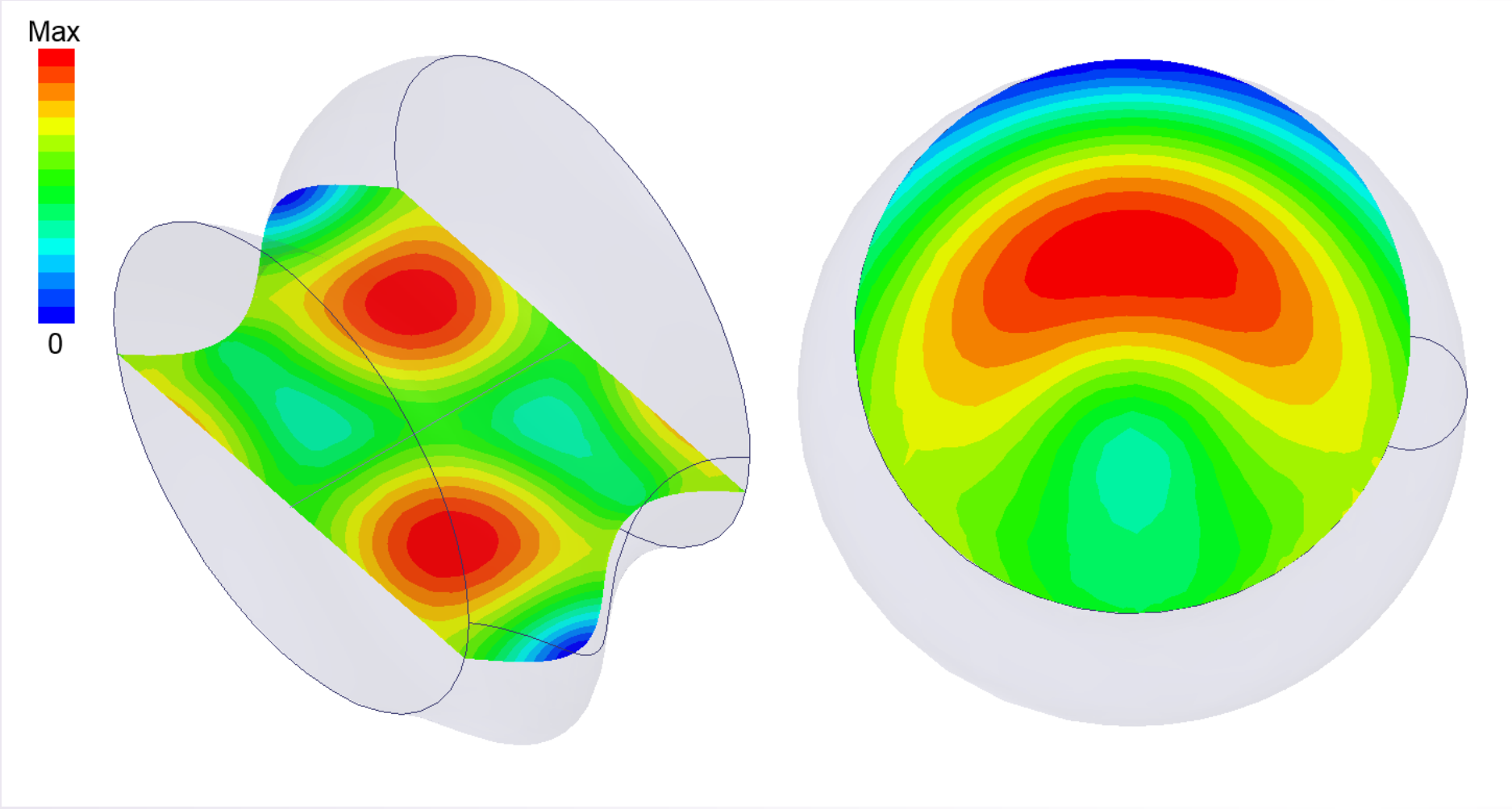
$$r(z,\varphi) = R + a \cdot \sin\left(\frac{2\pi \cdot z}{P} + \varphi\right)$$

E – accelerating field (synchronous with particles)

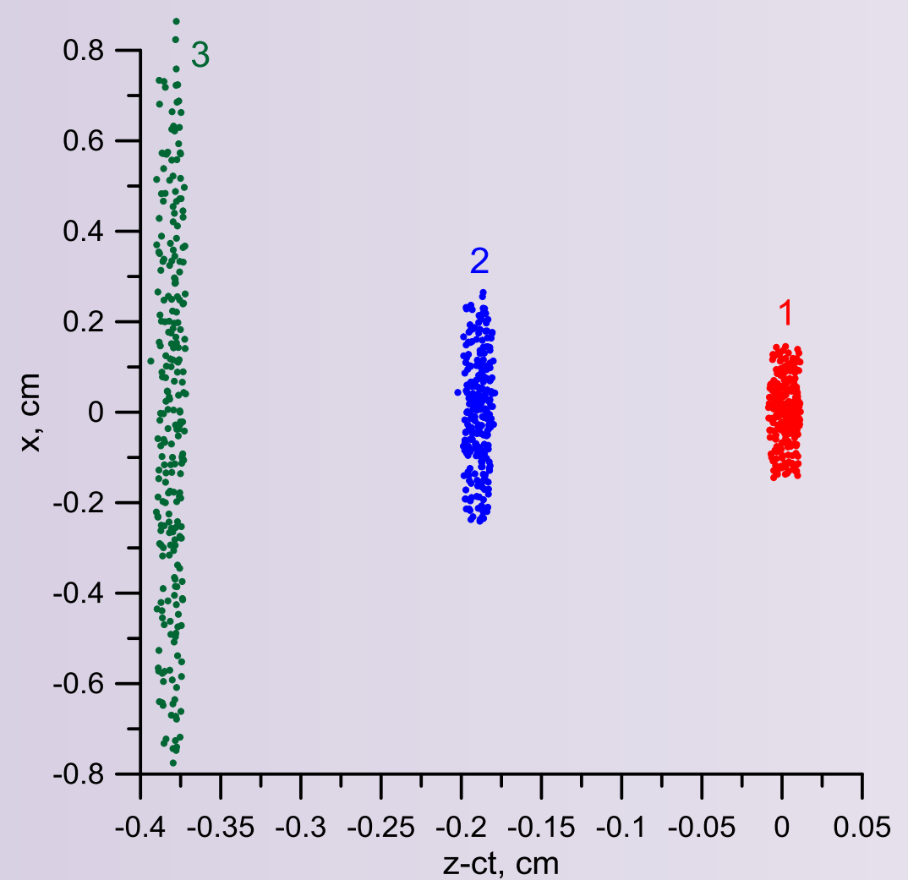




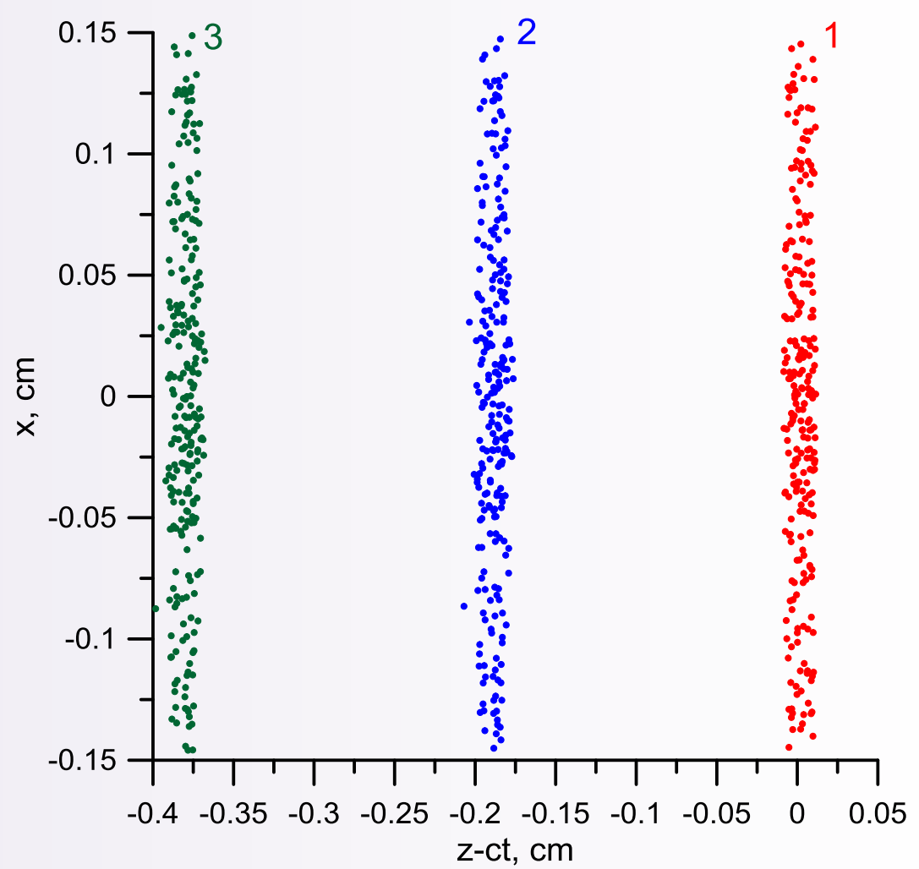
Dispersion of TM_{01}-TM_{11} normal eigen mode in helical accelerating structure (solid red curve) and dispersion curves of partial weaves in cylindrical waveguide (dashed curves).



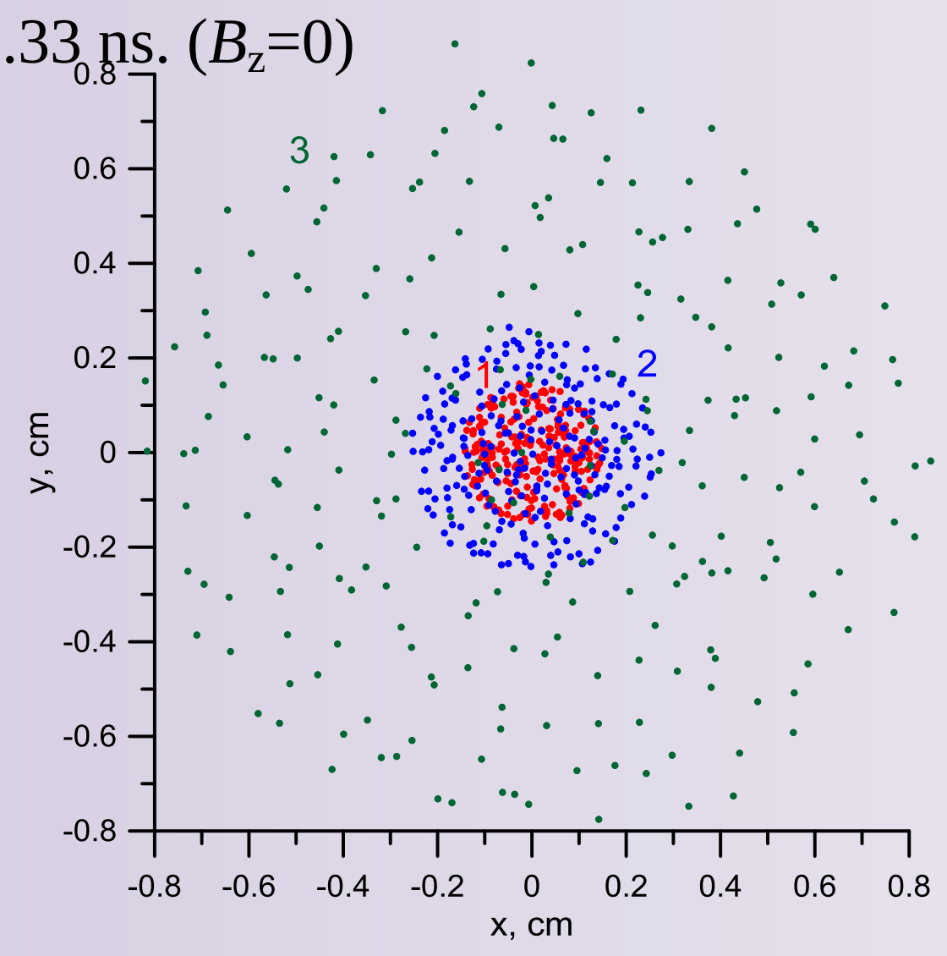
Field structure of operating eigen mode in helical waveguide.



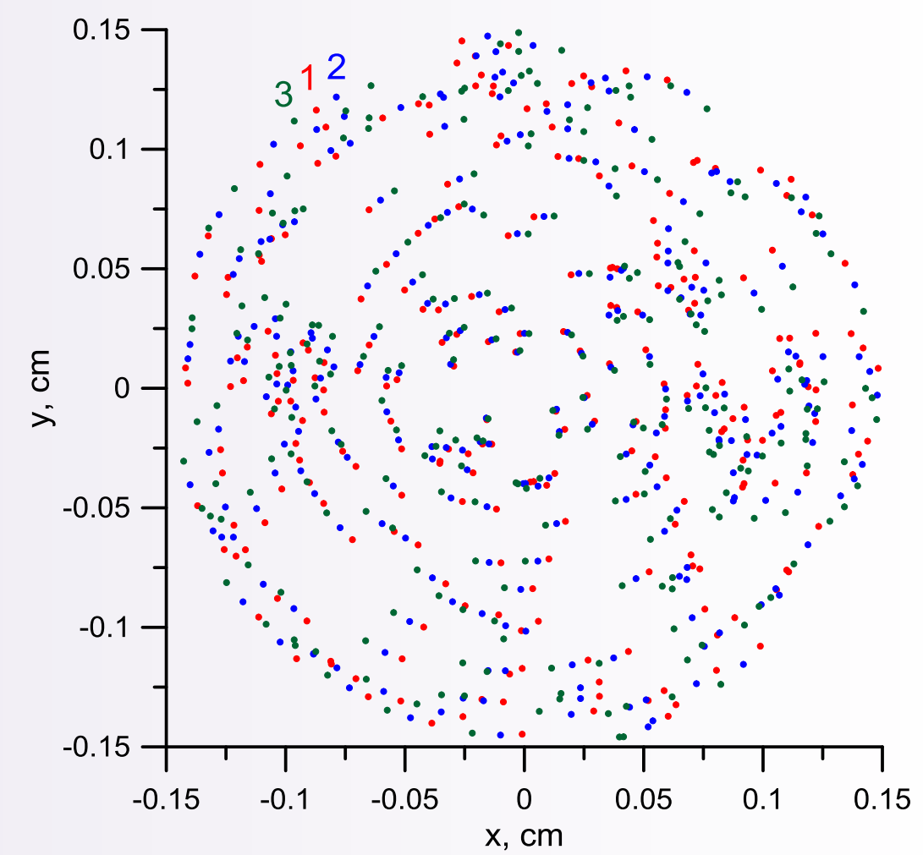
Space distribution of particles in plane XZ for bunch flying in waveguide with focusing TM_{01} wave: 1 – t=0, 2 - t=1.65 ns, 3 - t=3.33 ns. (B_z=0)



Space distribution of particles in plane XZ for bunch flying in waveguide with focusing TM_{01} wave: 1 – t=0, 2 - t=1.65 ns, 3 - t=3.33 ns. (B_z=1 T)

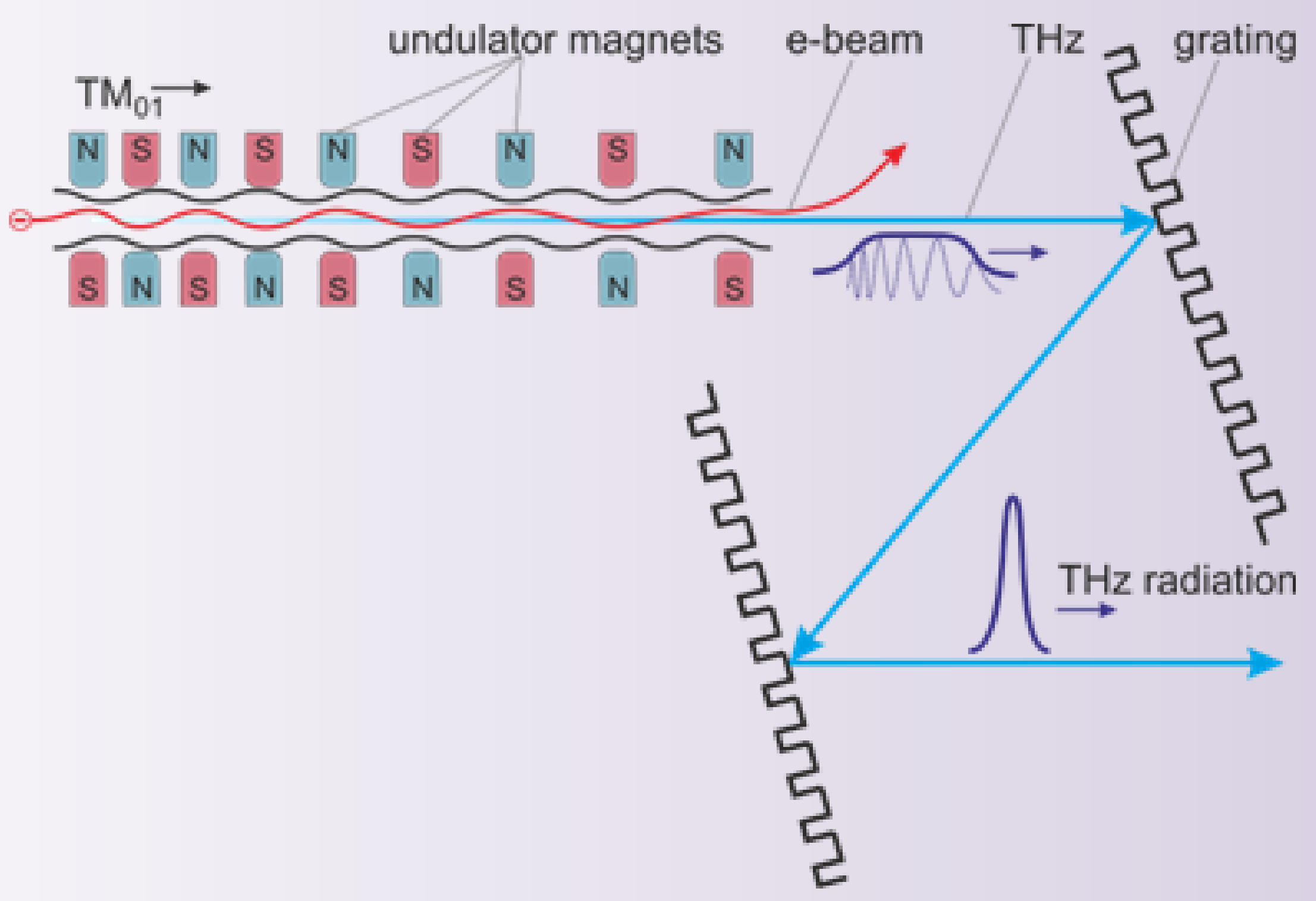


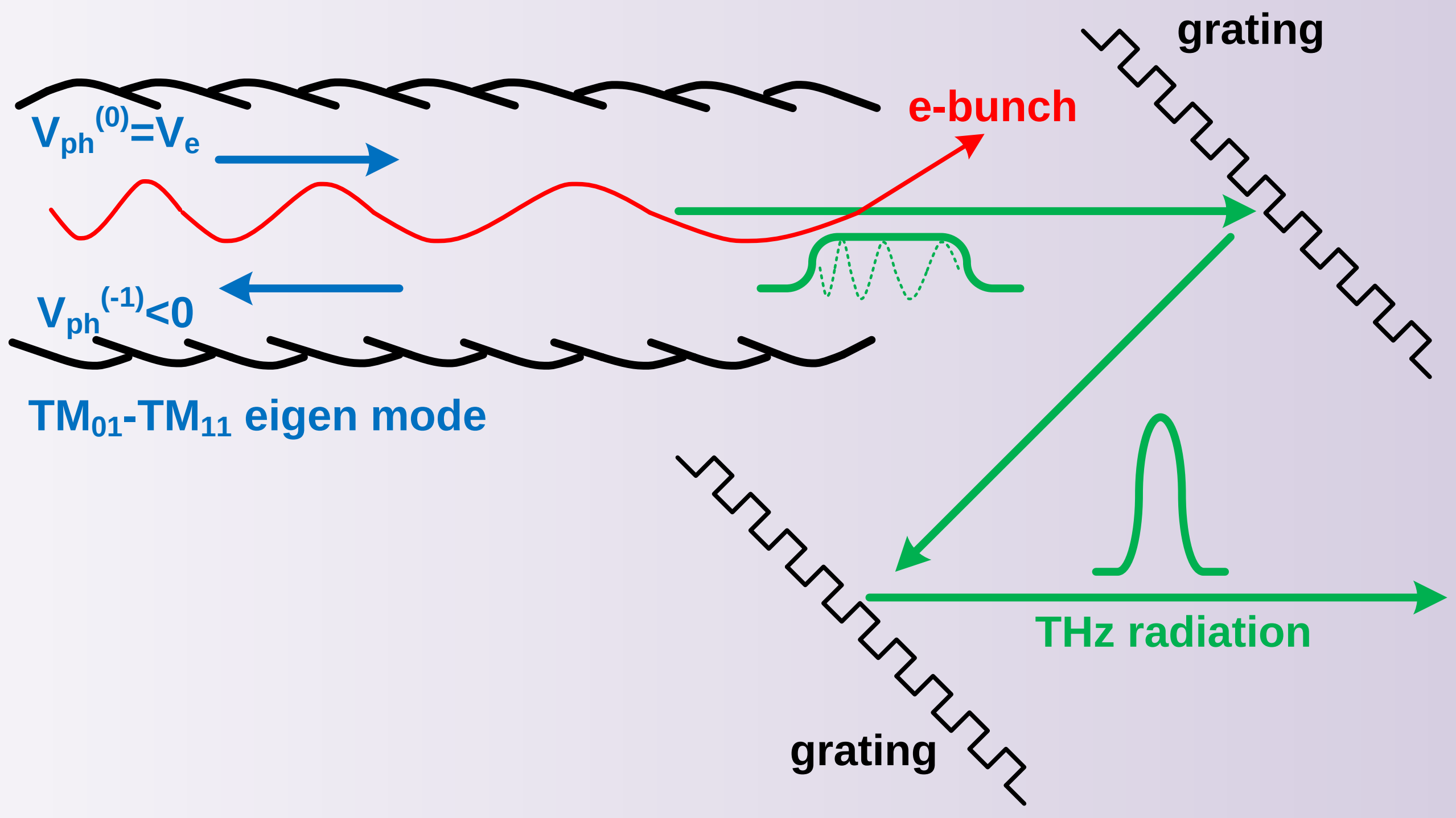
Space distribution of particles in plane XY for bunch flying in waveguide with focusing TM01 wave: 1 – t=0, 2- t=1.65 ns, 3 - t=3.33 ns. (B_z=0)

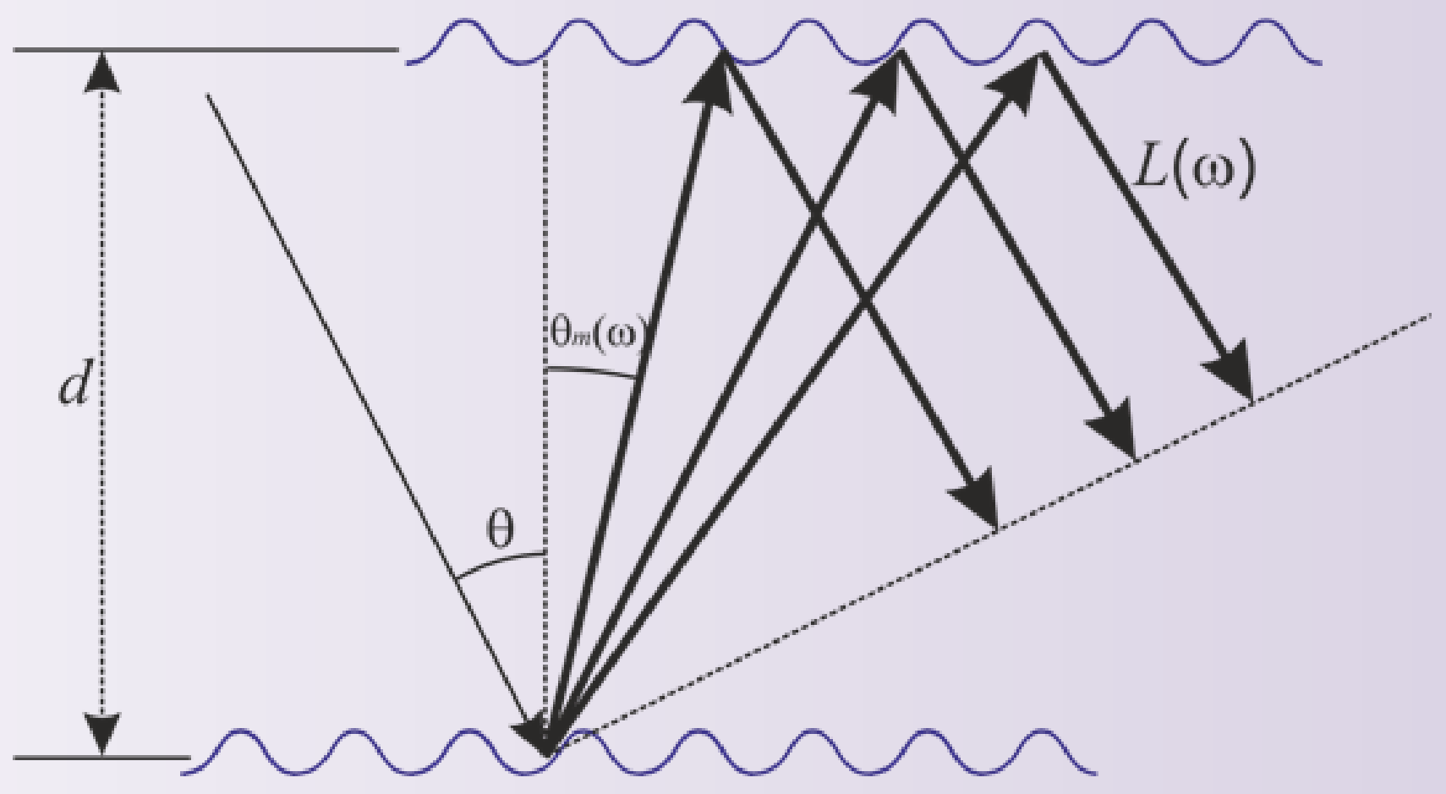


Space distribution of particles in plane XY for bunch flying in waveguide with focusing TM_{01} wave: 1 – t=0, 2- t=1.65 ns, 3 - t=3.33 ns. (B_z=1 T)

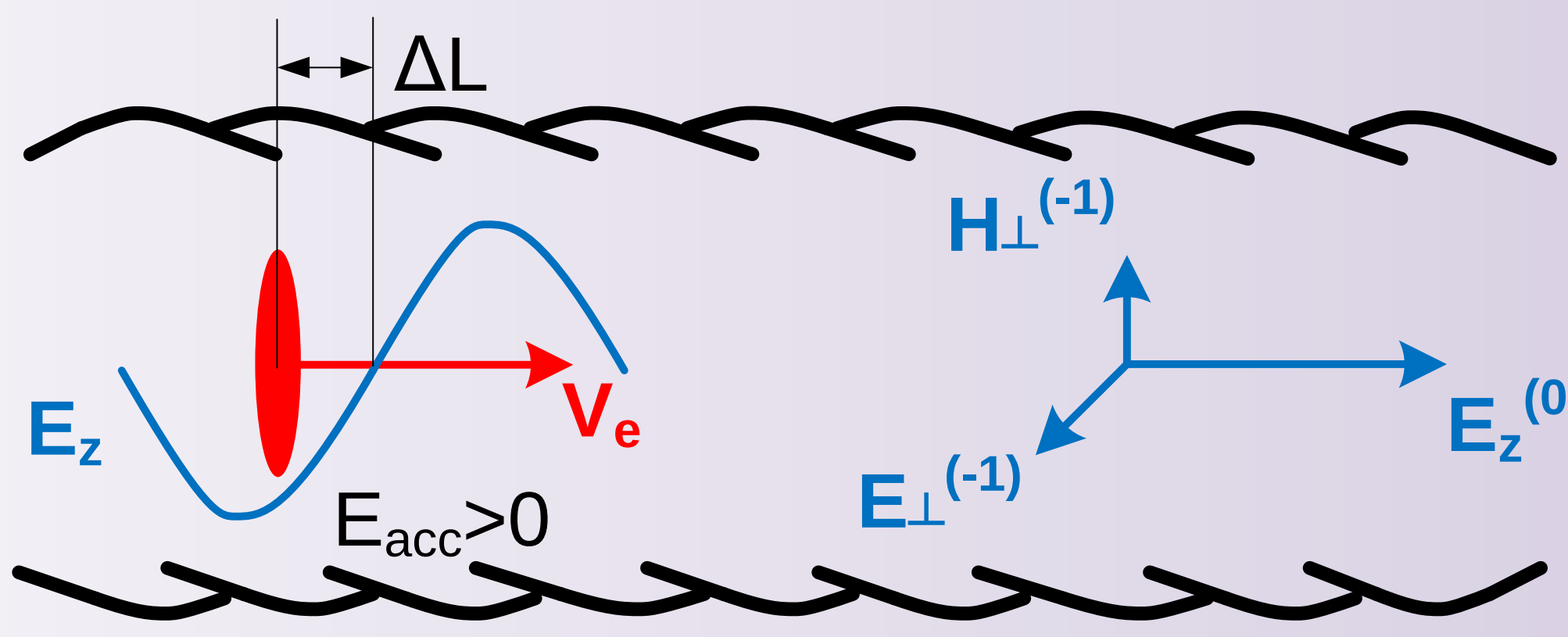
THz pulse compression





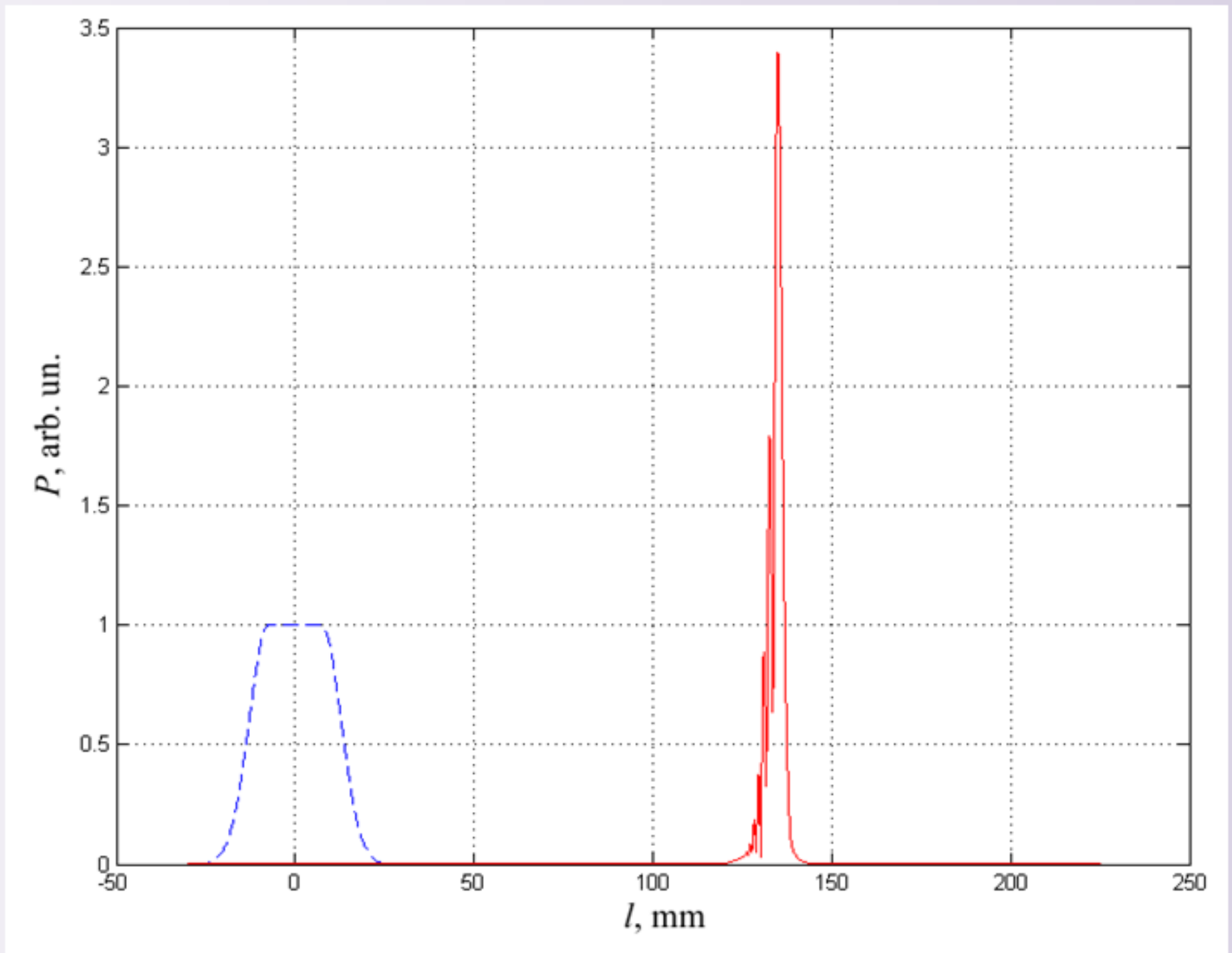


$$L(\omega) = \frac{d}{\cos(\theta_{-1}(\omega))} + \frac{d \cdot \cos(\theta + \theta_{-1}(\omega))}{\cos(\theta_{-1}(\omega))}$$



$$A_{in}(t) = A_0 \exp\left(-\frac{t^2}{2T^2}(1 - i\Omega T) - i\omega t\right)$$

PC parameters	
Undulator length, m	1
Incident wave frequency, GHz	2.5
Normalized frequency modulation	0.1
Optical radiation frequency, THz	1
Optical pulse length, mm	20
Power gain	10



Magnitude of input pulse (dashed line) and output pulse (solid line)