P.N.Lebedev Physical Institute of the Russian Academy of Sciences

Radiation of Laser-Channeled electron

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Special thanks to M. Ferrario[4]

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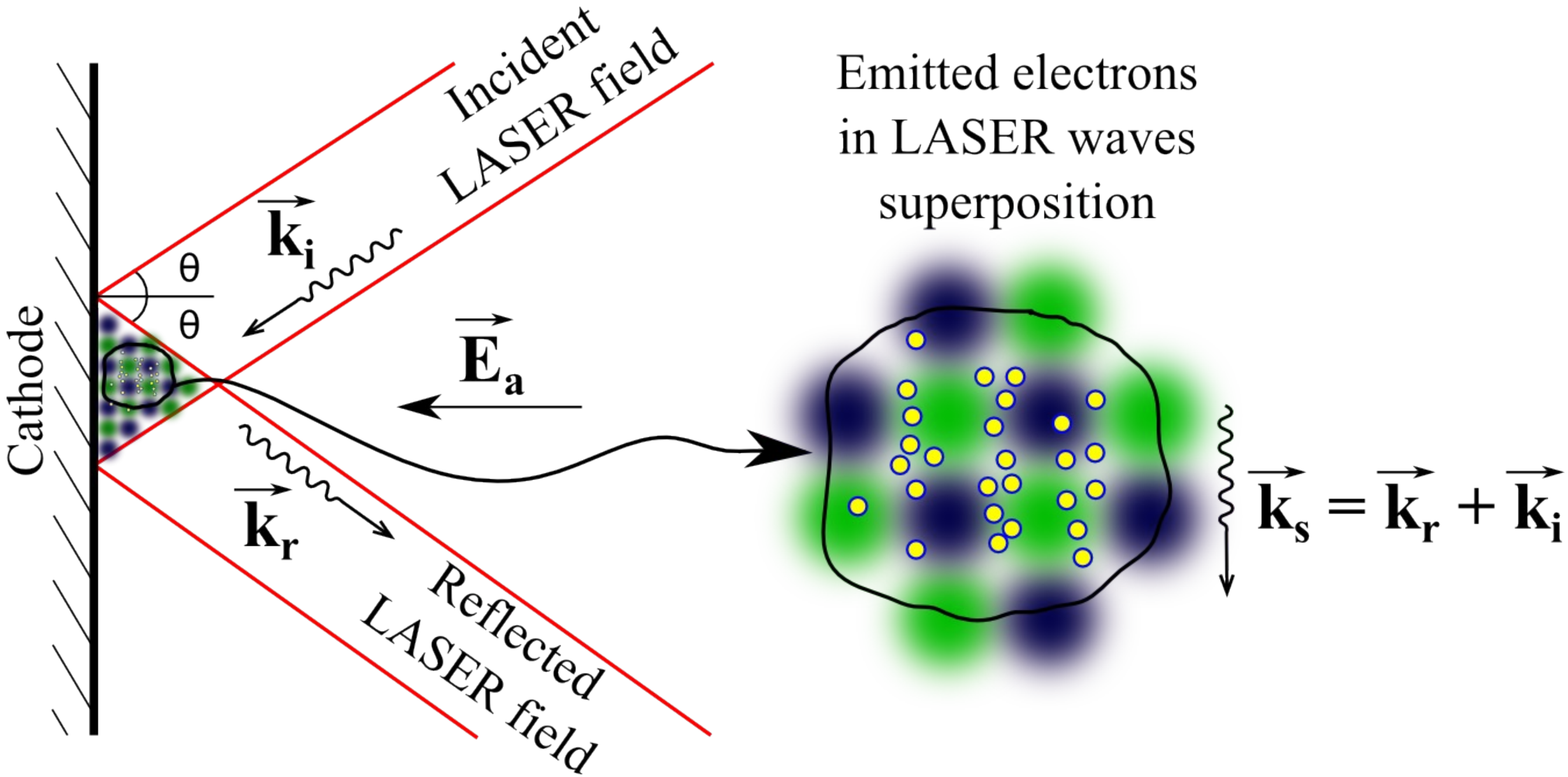
Outline

- Parent work
- Considered system geometry
- Particle dynamics and effective potential energy in the considered system
- First results in discrepancy of laser-channeled electron radiation

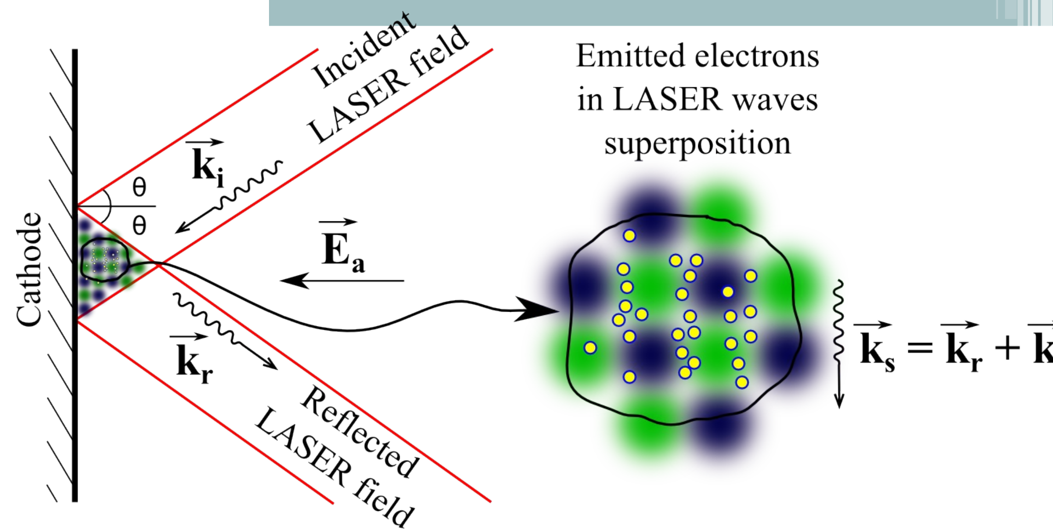
Parent work

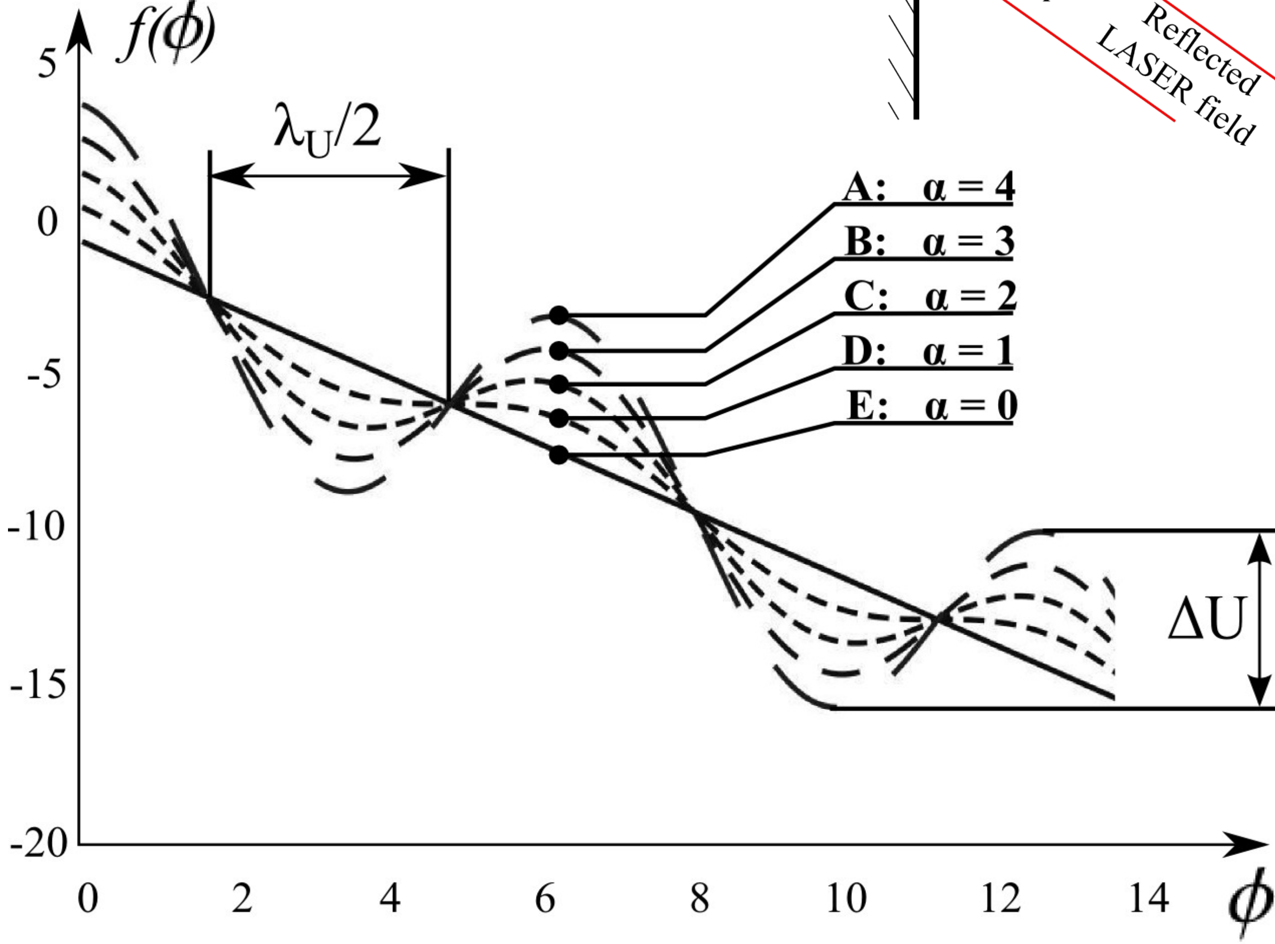


Incident
LASER field
Emitted electrons
in LASER waves
superposition
Cathode
θ
θ
$\vec{k}_i$
$\vec{E}_a$
$\vec{k}_r$
Reflected
LASER field
$\vec{k}_s = \vec{k}_r + \vec{k}_i$

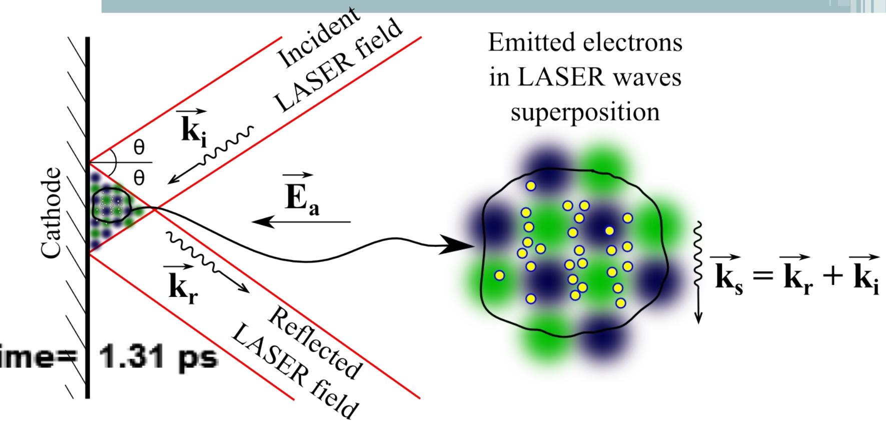
Standing waves animation

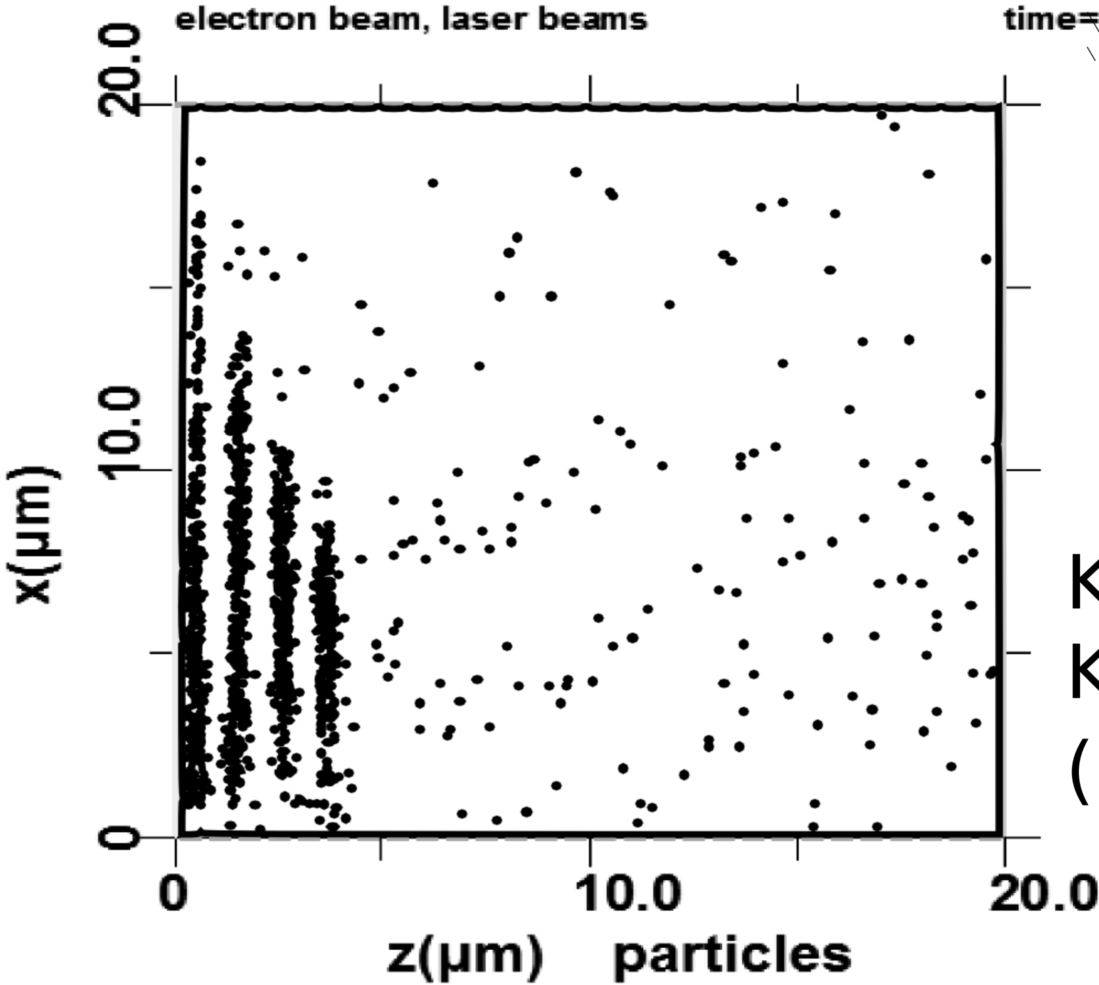
Parent work


Cathode
Incident
LASER field
Reflected
LASER field
θ
θ
$\vec{k}_i$
$\vec{k}_r$
$\vec{E}_a$
Emitted electrons
in LASER waves
superposition
$\vec{k}_s = \vec{k}_r + \vec{k}$


$f(\phi)$
$\lambda_U/2$
A: α = 4
B: α = 3
C: α = 2
D: α = 1
E: α = 0
ΔU
5
0
-5
-10
-15
-20
0
2
4
6
8
10
12
14
ϕ

Parent work

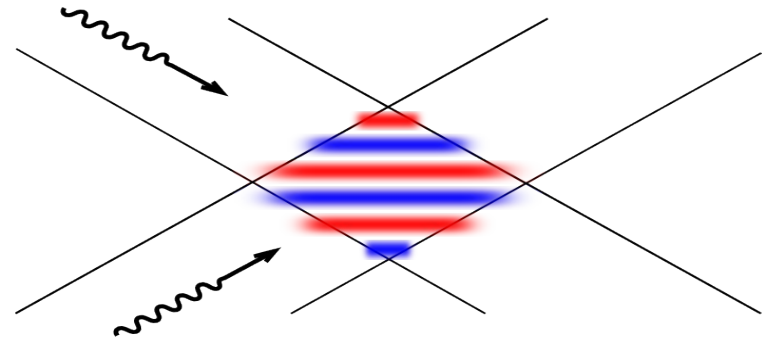




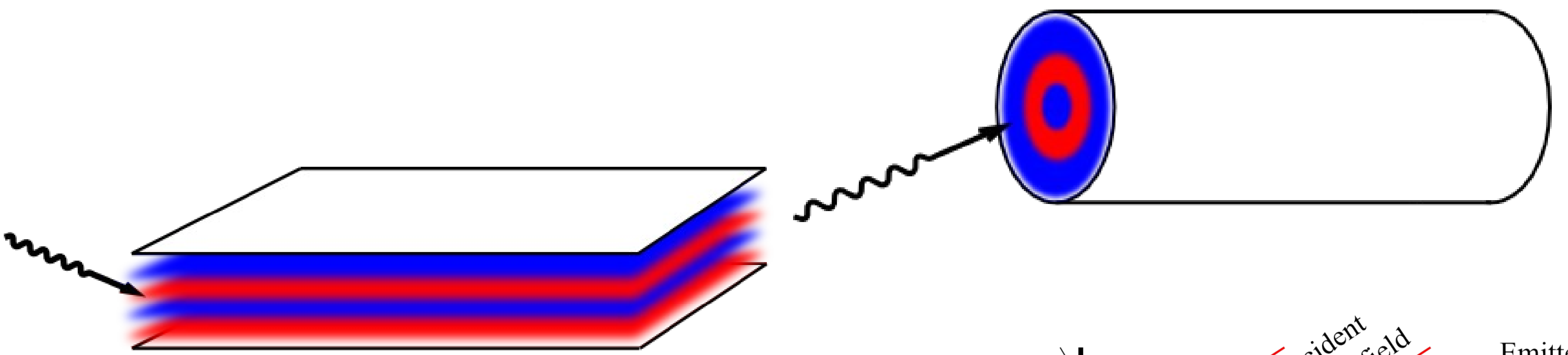
KARAT-results by
K. Artyomov
(IHCE SB RAS, Tomsk)

Continuation with a planar waveguide system

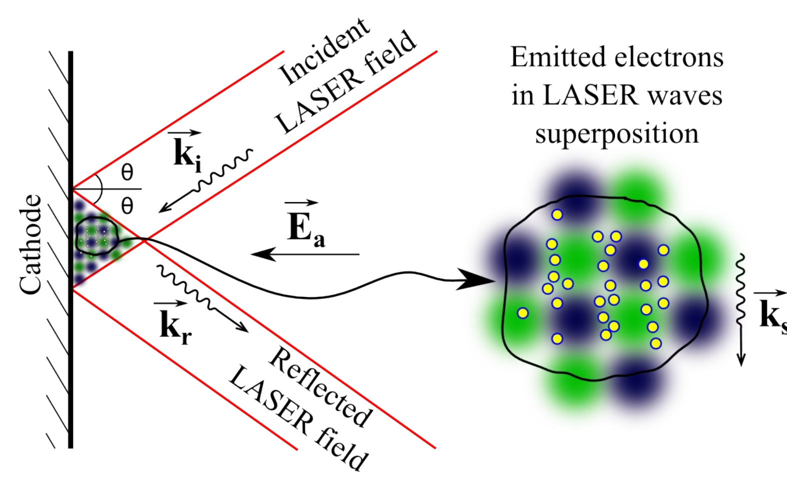
Standing waves



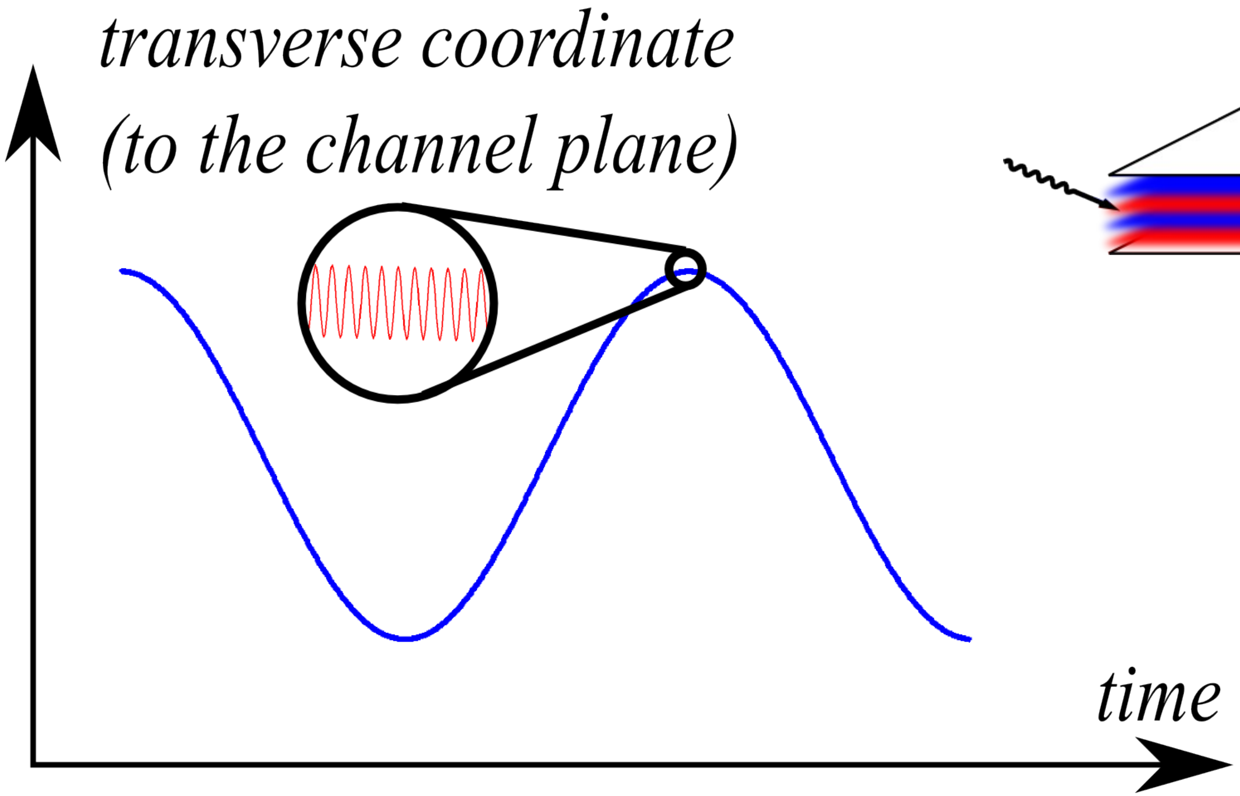
- Crossed laser field

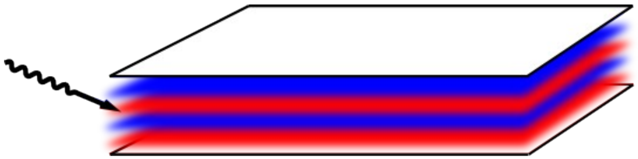


- Waveguides (planar or axial such as capillaries)
- Reflected laser beam (parent work case)



Particle dynamics in modulated field (general)





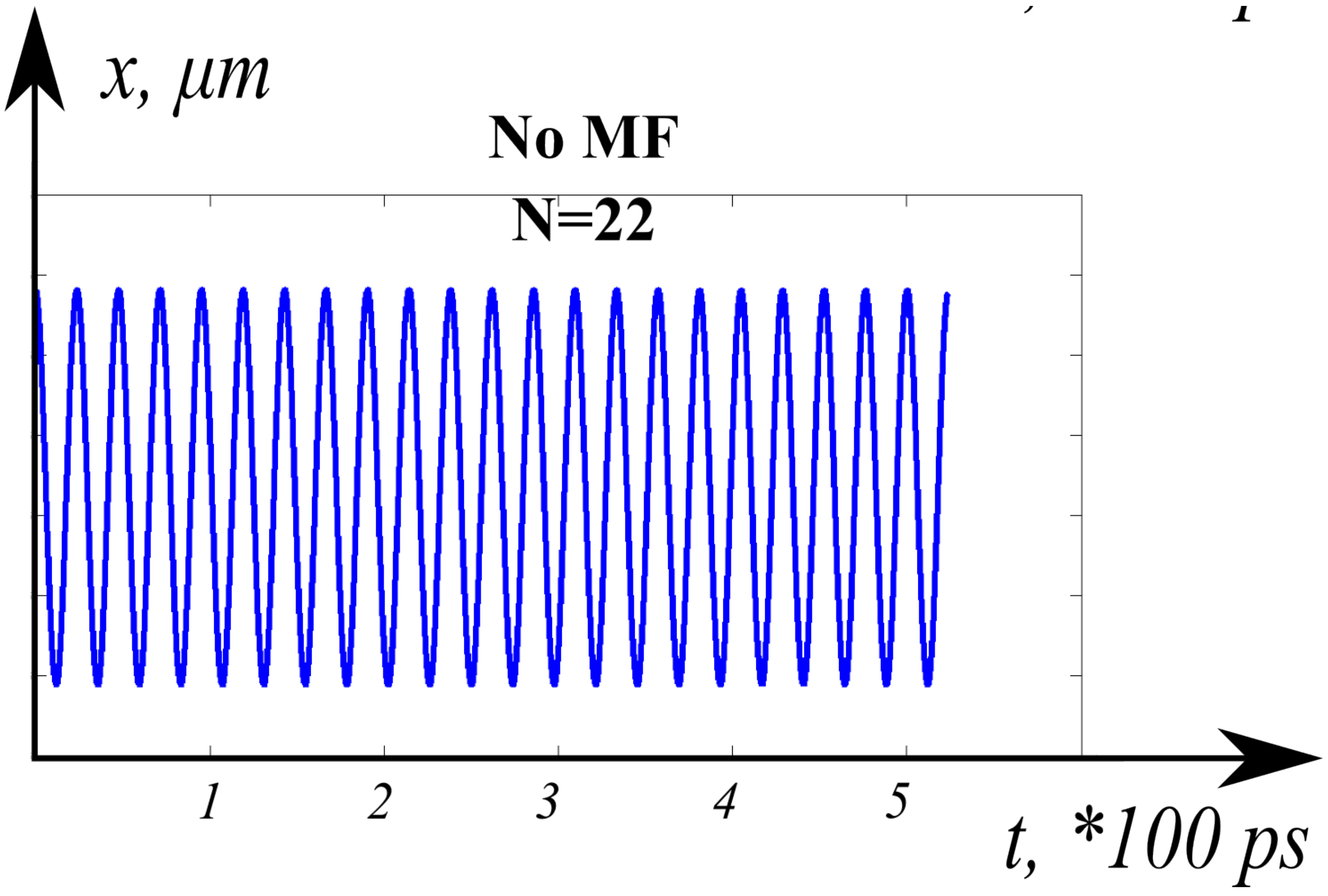
Authors who's workes consider a particle in a standing wave dynamics: Kapitsa, Bolotovsky, Andreev & Akhmanov

Particle dynamics in modulated field (general)

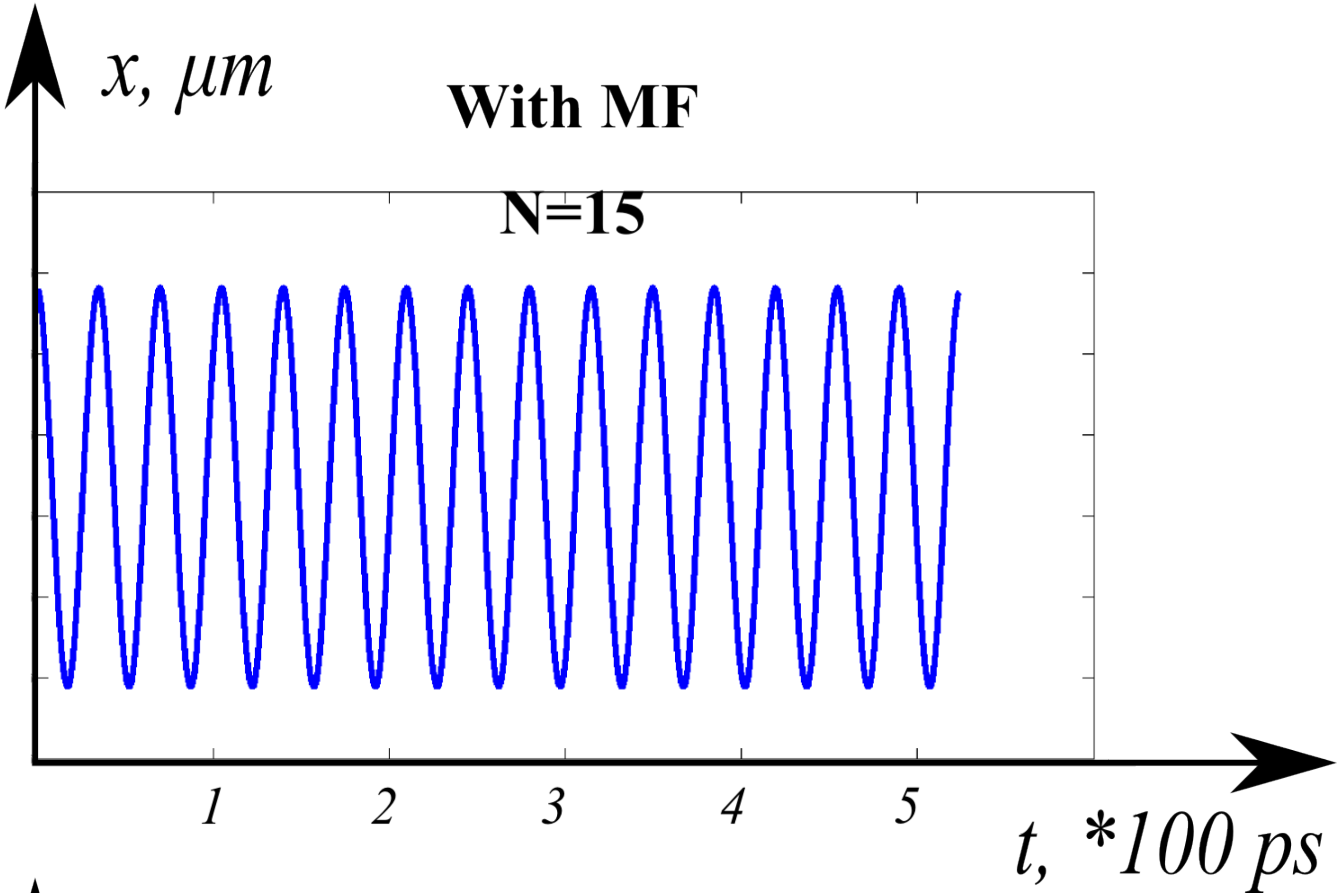
QUESTION: Does magnetic field matter for a non-relativistic case?

ANSWER: Yes, it does! (See the following figures)

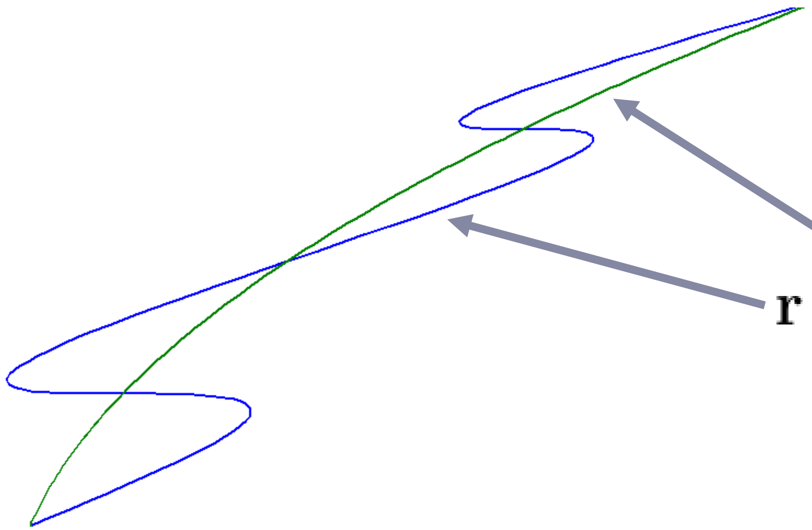
Particle dynamics in modulated field (general)



Particle dynamics in modulated field (general)



Particle in a fast oscillating field



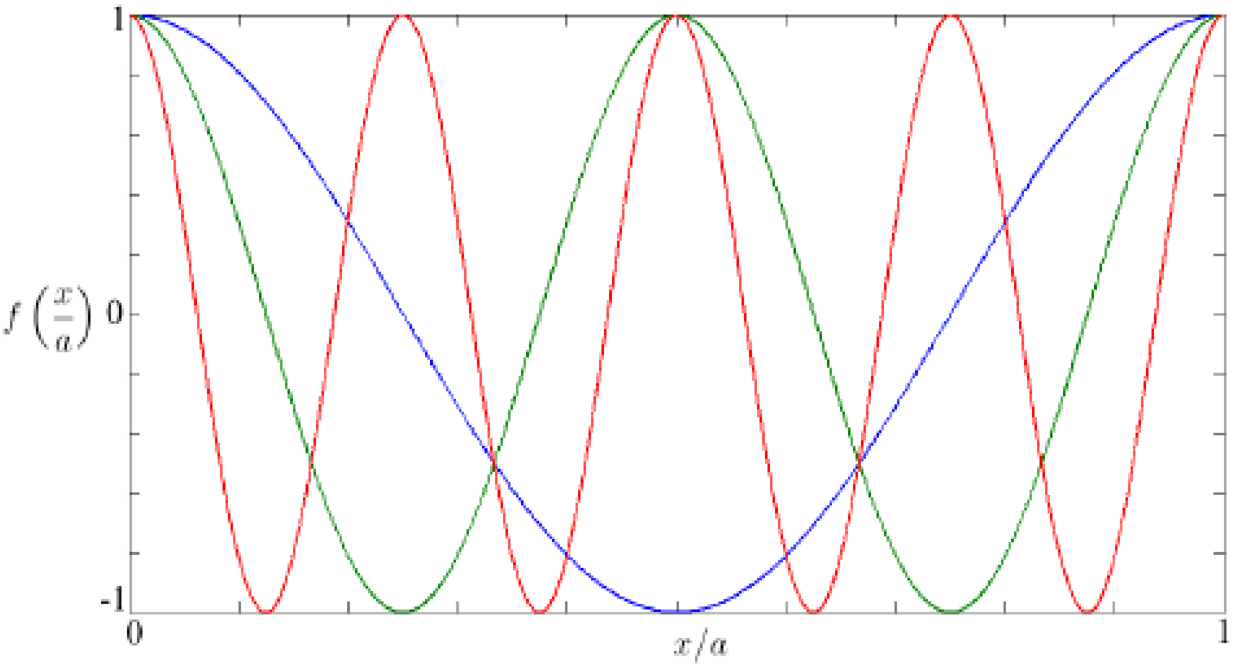
- Kapitza method

$$\mathbf{r} = \overline{\mathbf{r}} + \delta\mathbf{r}$$

Small rapid oscillations

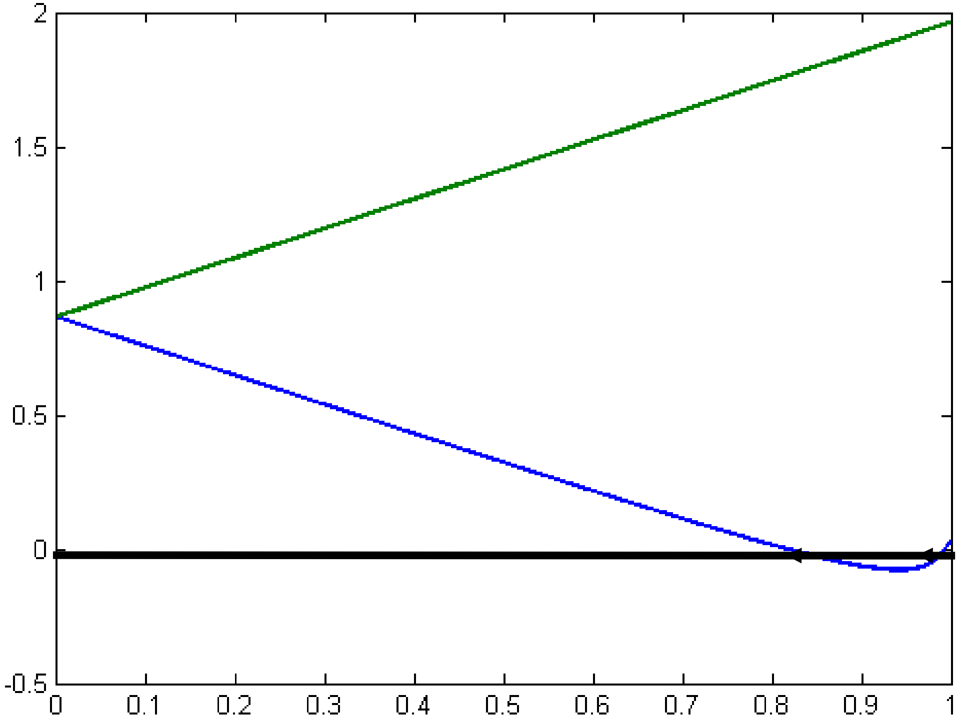
$$U_{eff}(x) = U_0 + \frac{e^2 u_0^2 k^2 (-\cos 2\alpha - 2\beta_0 \sin\alpha + (1+\cos^2\alpha)\beta_0^2)}{8\gamma m \omega^2 (1-\beta_0 \sin\alpha)^2} \cos(2kx\cos\alpha)$$

Effective channel potential



$$U_{eff}(x) = U_0 + \frac{e^2 u_0^2 k^2 (-\cos 2\alpha - 2\beta_0 \sin\alpha + (1+\cos^2\alpha)\beta_0^2)}{8\gamma m \omega^2 (1-\beta_0 \sin\alpha)^2} \cos(2kx\cos\alpha)$$

Effective channel potential



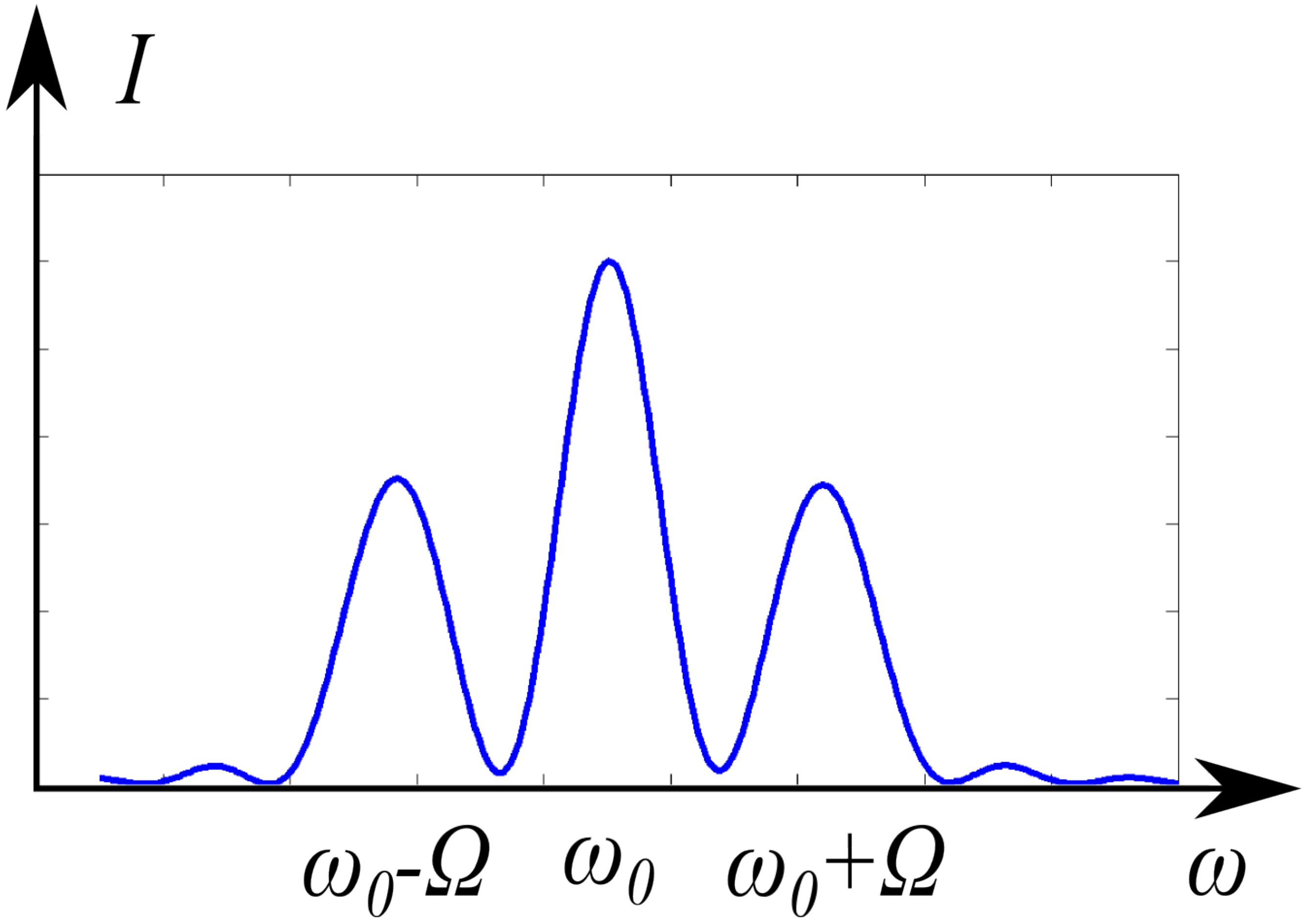
$$U_{eff}(x) = U_0 + \frac{e^2 u_0^2 k^2(-\cos 2\alpha - 2\beta_0 \sin\alpha + (1+\cos^2\alpha)\beta_0^2)}{8\gamma m\omega^2(1-\beta_0\sin\alpha)^2}\cos(2kx\cos\alpha)$$

Radiation of laser-channeled electron

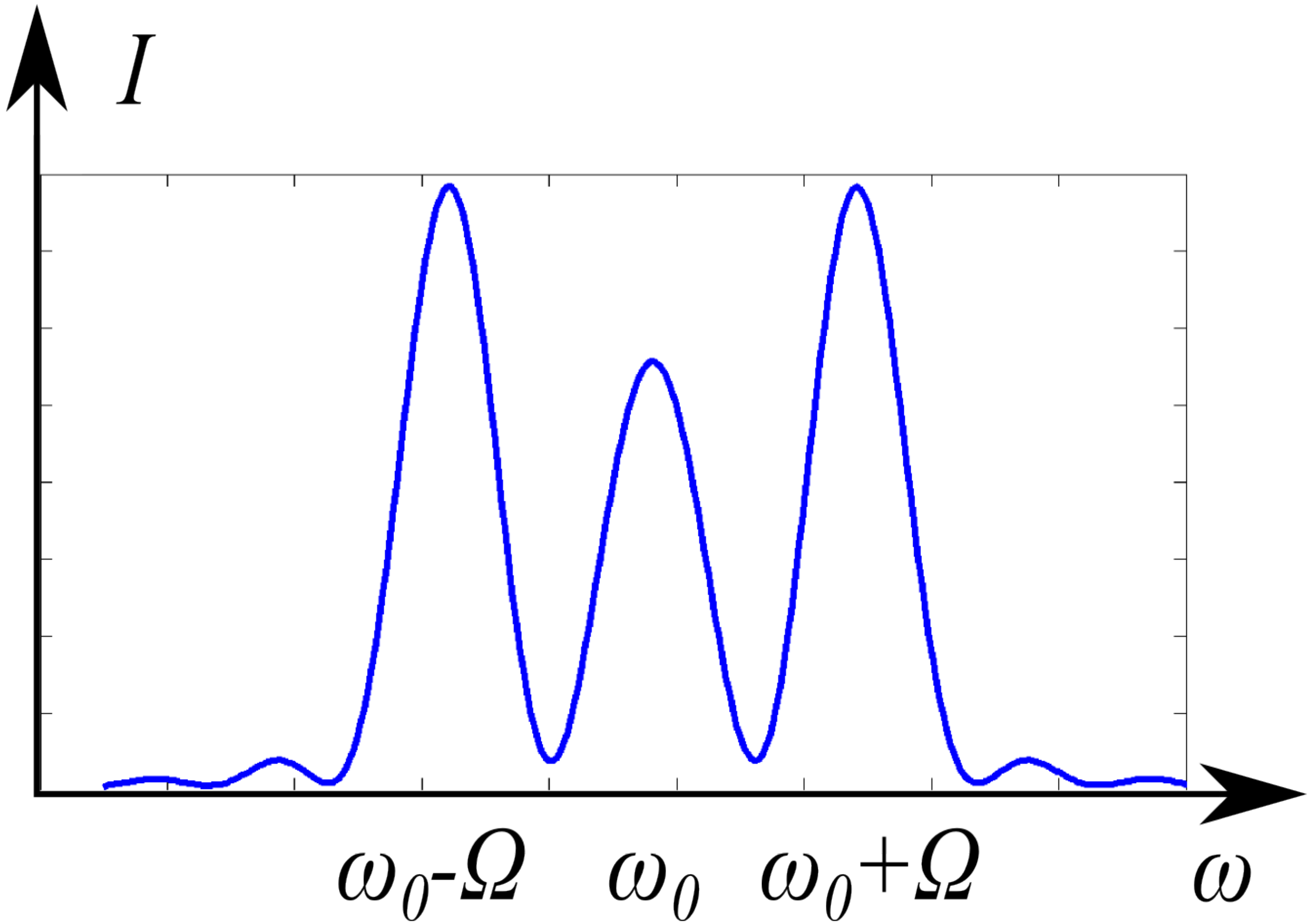
Due to computational difficulties **the results concerning** laser-channeled electron's **radiation are comparatively <u>raw</u>** and completely **<u>qualitative</u>**, not quantitative. Of course we hope to finalize them as soon as possible.

Nevertheless, I hope they would be of some interest to you.

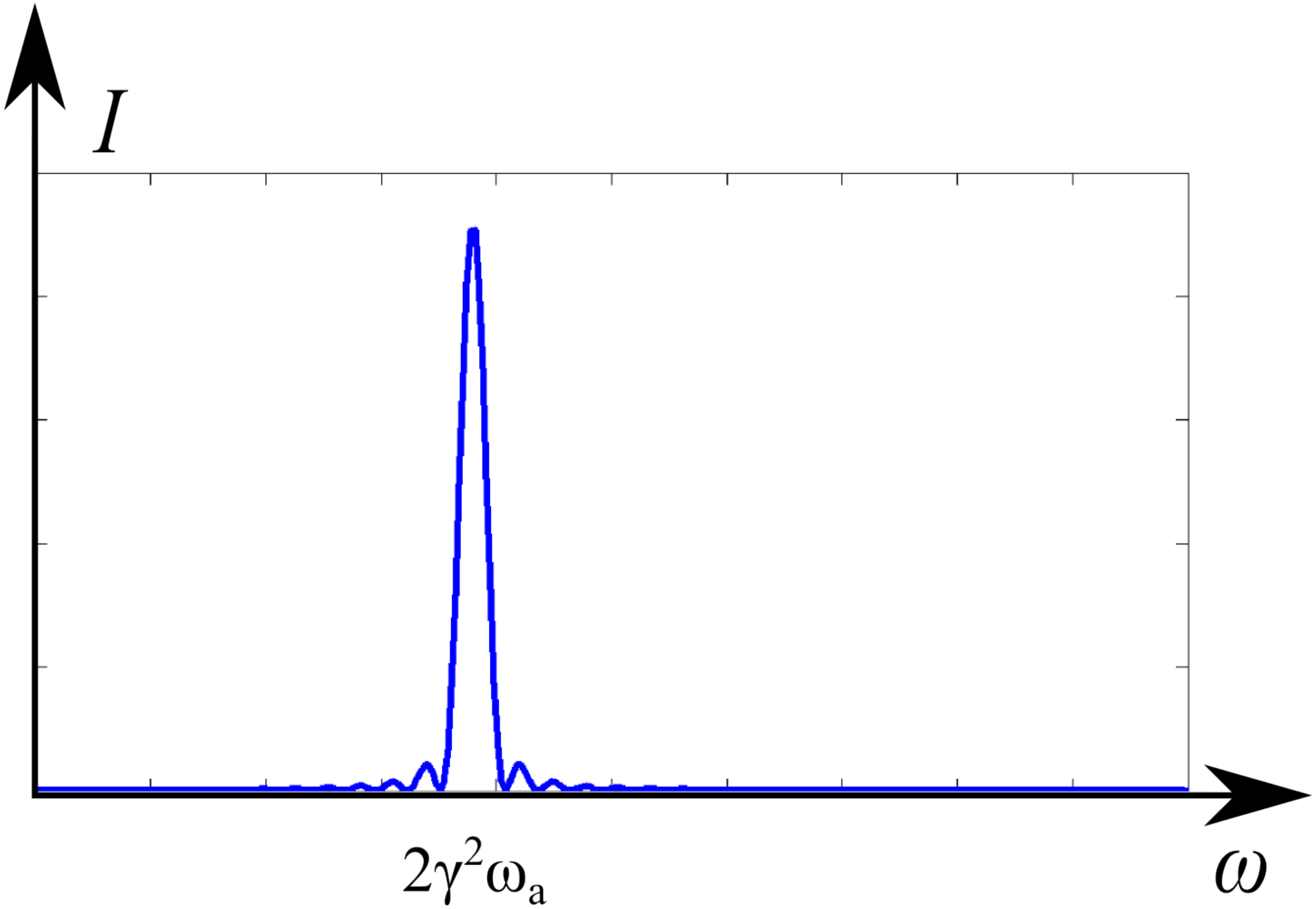
Radiation of non-relativistic laser-channeled electron



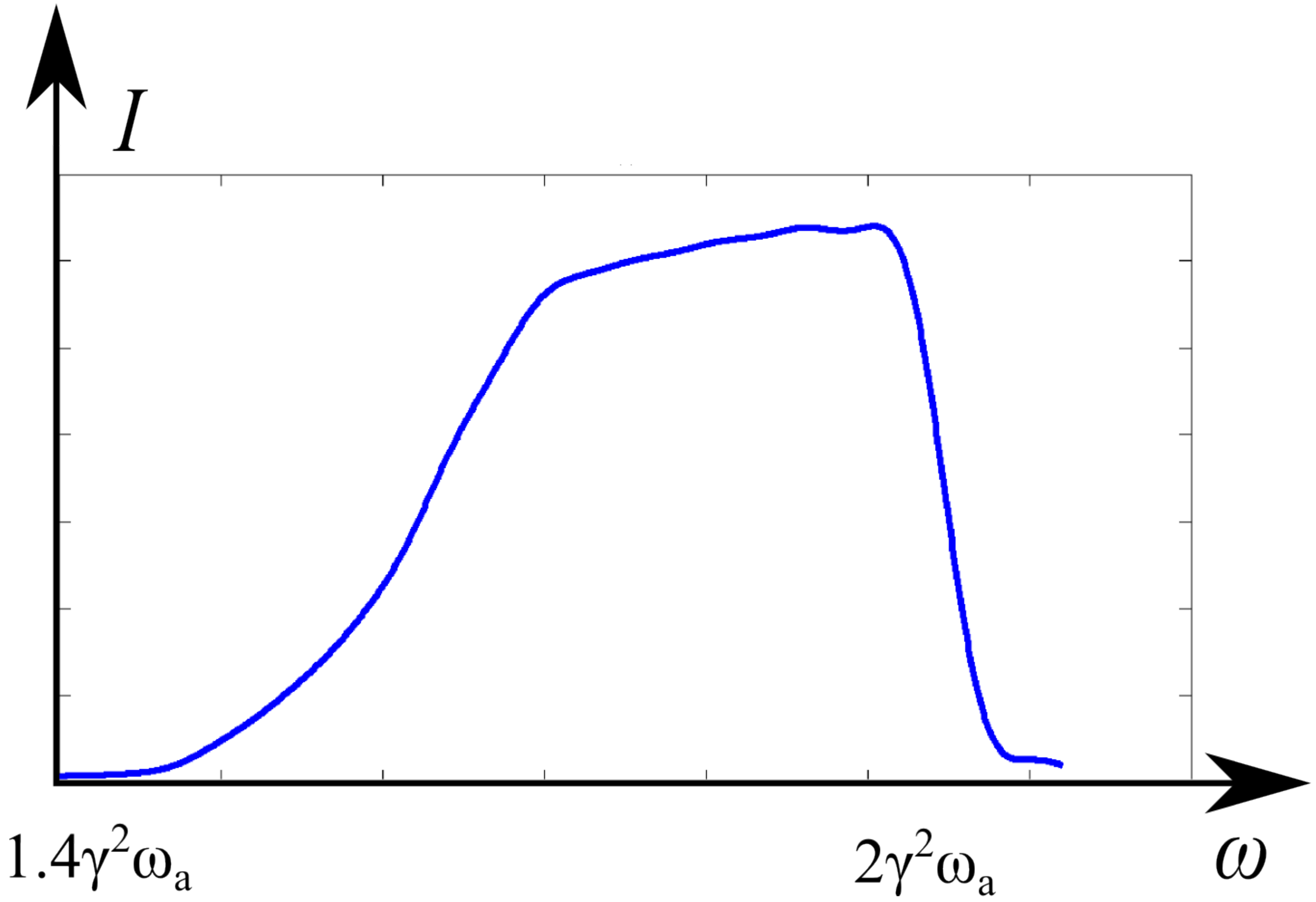
Radiation of non-relativistic laser-channeled electron



Radiation of relativistic laser-channeled electron in forward direction



Radiation of relativistic laser-channeled electron in forward direction



Highlights

- **Laser-channels** that could cause electron channeling have been **described** together with channeling particle's dynamics (with a new method) and a number of **computer experiments** have been conducted
- Great advantage of laser-channeling is the fact that all inelastic processes are completely absent and energy losses are minimized in comparison with crystal channeling
- For such a system **magnetic part** of laser-electron **could not be omitted** for any β
- The first data on laser-channeled electron radiation are obtained

Special thanks to

– G.A. Mesyatz
– A.R. Mkrtchan

And to all the members of the merged symposium organizing committee for their huge work

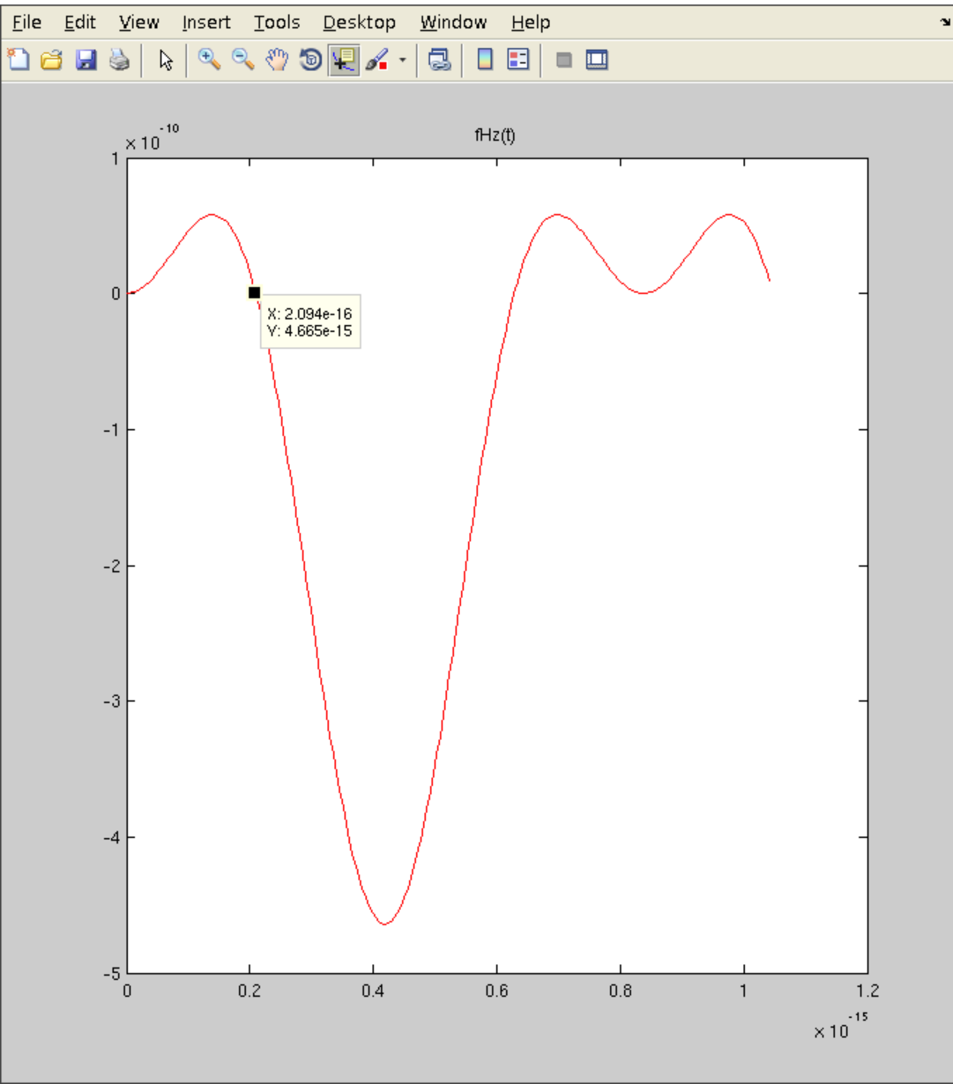
Thanks for your attention!

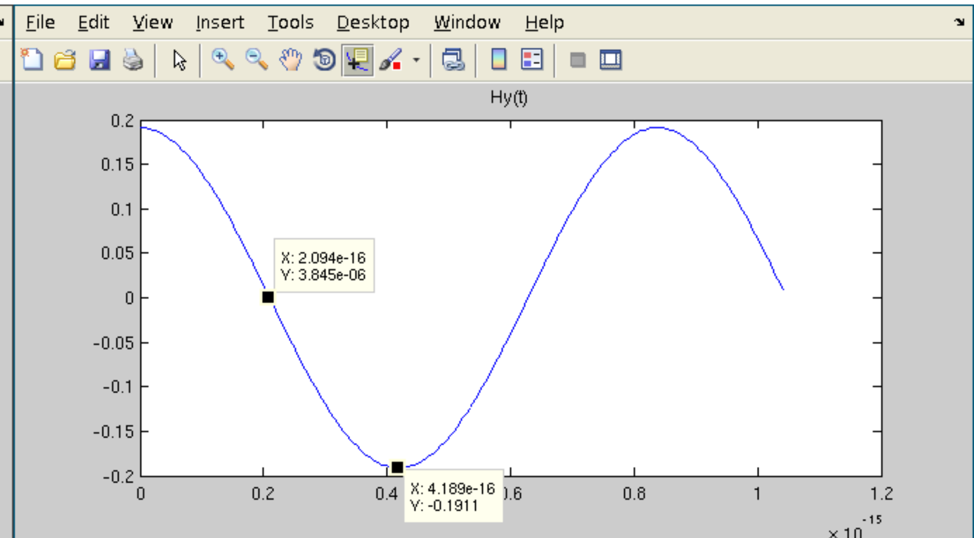
Effective potential and boundary condition (from parent work)

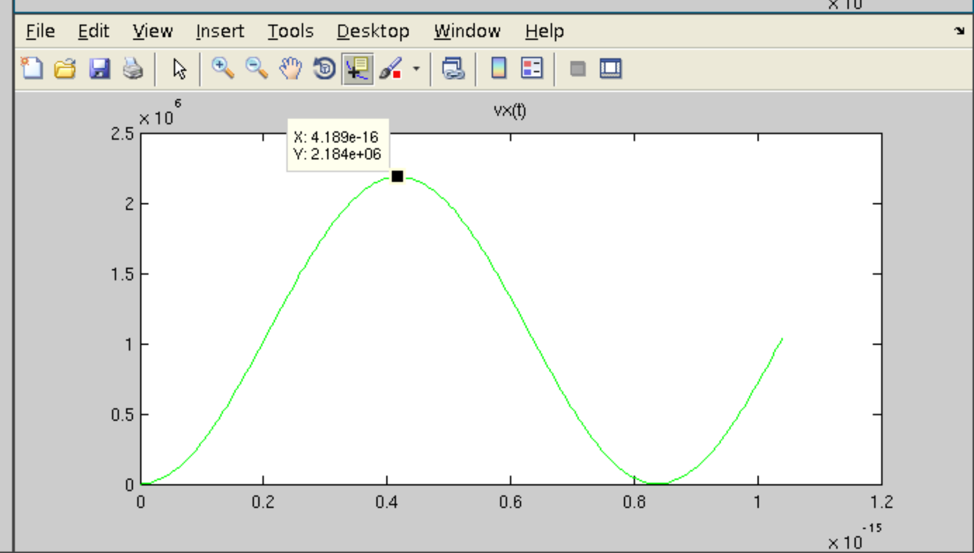
$$\triangle U = \frac{e^2 E_0^2 \sin^2\theta}{m\omega_0^2 \alpha}\left[2\left(\arcsin\left(\alpha^{-1}\right) + \sqrt{\alpha^2 - 1}\right) - \pi\right]$$

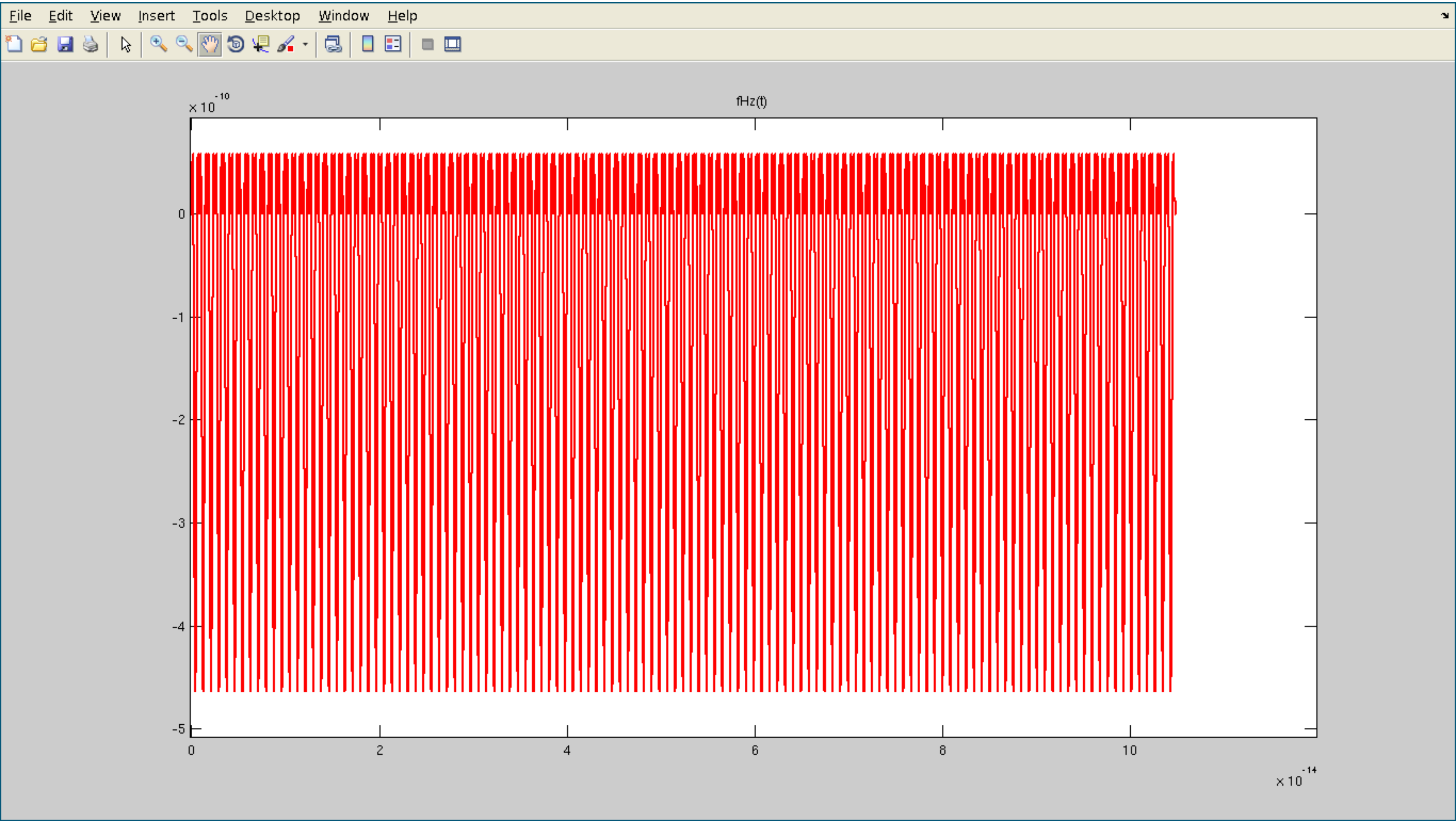
$$\theta = \pi/6$$
$$\omega_0 = 7\cdot 10^{15}\ sec^{-1}$$
$$\alpha = 4$$
$$E_0 = 10^8 \div 10^{11}\ V/m$$

$$\longrightarrow \quad \triangle U \approx 10^{-4} \div 10^2\ eV$$


File Edit View Insert Tools Desktop Window Help
fHz(t)
× 10^-10
1
0
-1
-2
-3
-4
-5
0 0.2 0.4 0.6 0.8 1 1.2
× 10^-15
X: 2.094e-16
Y: 4.665e-15


File Edit View Insert Tools Desktop Window Help
Hy(t)
0.2
0.15
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
0 0.2 0.4 0.6 0.8 1 1.2
× 10^-15
X: 2.094e-16
Y: 3.845e-06
X: 4.189e-16
Y: -0.1911


File Edit View Insert Tools Desktop Window Help
vx(t)
× 10^6
2.5
2
1.5
1
0.5
0
0 0.2 0.4 0.6 0.8 1 1.2
× 10^-15
X: 4.189e-16
Y: 2.184e+06


File Edit View Insert Tools Desktop Window Help
fHz(t)
× 10^-10
0
-1
-2
-3
-4
-5
0
2
4
6
8
10
× 10^-14

Radiation spectrum

Electron trajectory near channel bottom

$$z(t) \approx v_0 t$$

$$x(t) \approx b_0 \sin(\Omega t) + a_x \sin(\omega' t)$$

Spectral radiation intensity

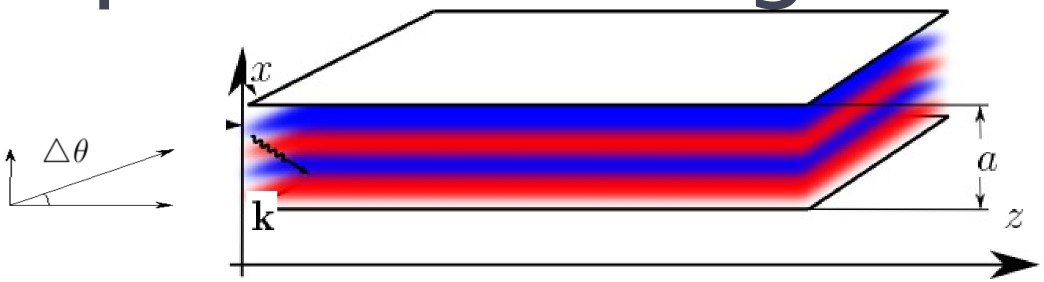
$$\frac{dI_n}{do} = \frac{e^2 \Omega^2 n^2}{2\pi c} \left(\frac{\cos\theta - \beta_0}{\sin\theta (1 - \beta_0 \cos\theta)^2} \right)^2 \left| \sum_m J_{n-mN}(\xi b_0) J_m(\xi a_x) \right|^2$$

$$\xi = \frac{n\Omega}{c(1 - \beta_0 \cos\theta)} \sin\theta \cos\phi$$

Radiation power spectral distribution

$$\frac{dW}{d\omega} = \frac{e^2 \Omega^3 b_0^2 \gamma^2}{c^3} \xi_1 \left(1 - 2\xi_1 + 2\xi_1^2\right) \Theta\left(\pi N_0^{\Omega} (1 - \xi_1)\right) + \frac{e^2 (\omega')^3 a_x^2 \gamma^2}{c^3} \xi_2 \left(1 - 2\xi_2 + 2\xi_2^2\right) \Theta\left(\pi N_0^{\omega'} (1 - \xi_2)\right)$$

Channeling of an electron in a planar waveguide



$$A_z = u_0 \sin(k_x x) \sin(\omega t - k_z z)$$

$$A_x = -u_0 \frac{k_z}{k_x} \cos(k_x x) \cos(\omega t - k_z z)$$

Rapid oscillations:

$$\xi_x(t) = \frac{e u_0 k (\sin\alpha - \beta_0)}{\bar{\gamma} m \omega^2 (1 - \beta_0 \sin\alpha)^2} \cos(k \bar{x} \cos\alpha) \sin(\omega(1 - \beta_0 \sin\alpha) t - k_z \bar{z}_0)$$

$$\xi_z(t) = \frac{e u_0 k \cos\alpha}{\bar{\gamma}^3 m \omega^2 (1 - \beta_0 \sin\alpha)^2} \sin(k \bar{x} \cos\alpha) \cos(\omega(1 - \beta_0 \sin\alpha) t - k_z \bar{z}_0)$$

Angle between wave vector and waveguide plane

$$\frac{d}{dt}(\bar{\gamma} m \dot{\bar{x}}) + A \sin(2k\bar{x}\cos\alpha) = 0$$

$$\frac{d}{dt}(\bar{\gamma} m \dot{\bar{z}}) = 0$$

Averaged movement equation

Rapid oscillations frequency

$$\omega' = \omega - k_z v_0$$

Channeling of an ultra-relativistic electron in a planar waveguide

$$S = (z - v_0 t) P'_z$$

$$\mathbf{P}'_\perp = \mathbf{P}_\perp$$

$$\mathbf{r}'_\perp = \mathbf{r}_\perp$$

$$p'_i = P_i + p_{\xi i}$$

$$x'_i = X_i + \xi_i$$

$$\dot{P}_{xi} = -\left.\frac{\partial U}{\partial x'_i}\right|_{\mathbf{X}} + \overline{\xi_j \left.\frac{\partial f_i}{\partial x'_j}\right|}_{\mathbf{X},\dot{\mathbf{X}}} + \overline{\dot{\xi}_j \left.\frac{\partial f_i}{\partial \dot{x}'_j}\right|}_{\mathbf{X},\dot{\mathbf{X}}}$$

$$\dot{X}_i = \frac{cP_{xi}}{\sqrt{(mc)^2 + P_{xj}P_{xj}}} - v_0 \delta_{i,z}$$

$$\dot{p}_{\xi i} = f_i\left(\mathbf{X}, \frac{\dot{\mathbf{X}}}{c}, t\right)$$

$$\dot{\xi}_i = \frac{cp_{\xi i}}{\sqrt{(mc)^2 + P_{xj}P_{xj}}} - \frac{cP_{xi}P_{xj}p_{\xi j}}{((mc)^2 + P_{xj}P_{xj})^{3/2}}$$