Radiation Energy Loss of Relativistic Electrons at Axial and Planar Channeling in Tungsten Crystal

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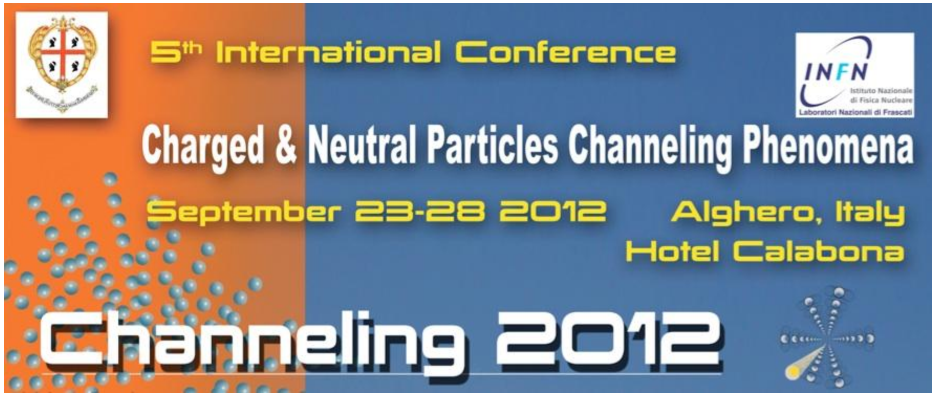


Motivation

- **High-energy electrons penetrate through the single crystal in the direction of the crystal axis or planes**
- **Intense low-energy photons are produced due to channeling radiation and coherent bremsstrahlung**
- **Photons create electron-positron pairs in the crystal target**
- **The possibility of using the crystal target in positron sources was proposed in R. Chehab, F. Couchot, A. R. Nyaiesh, F. Richard, and X. Artru, Proceedings of the 1989 IEEE Particle Accelerator Conference (PAC'89), Chicago, IL, USA, (1989) 283.**
- **The tungsten crystal target was successfully applied for generating an intense positron beam at the positron source of the KEKB injector linac** (Suwada T. et al. //Phys. Rev. ST Accel. Beams 10 (7) (2007) 073501)
- **Calculations are performed in connection with the experimental program for future positron source experiments on SPARC facility at LNF.**

Electron Trajectories Simulation

- System of equations

$$\gamma m\ddot{x} = F_x = -\frac{\partial U(x,y)}{\partial x}$$

$$\gamma m\ddot{y} = F_y = -\frac{\partial U(x,y)}{\partial y}$$

- Initial conditions

$$x(0) \equiv x_0$$

$$y(0) \equiv y_0$$

$$\upsilon_x(0) = c\sqrt{1-\frac{1}{\gamma^2}}\sin(\theta)\cos(\varphi)$$

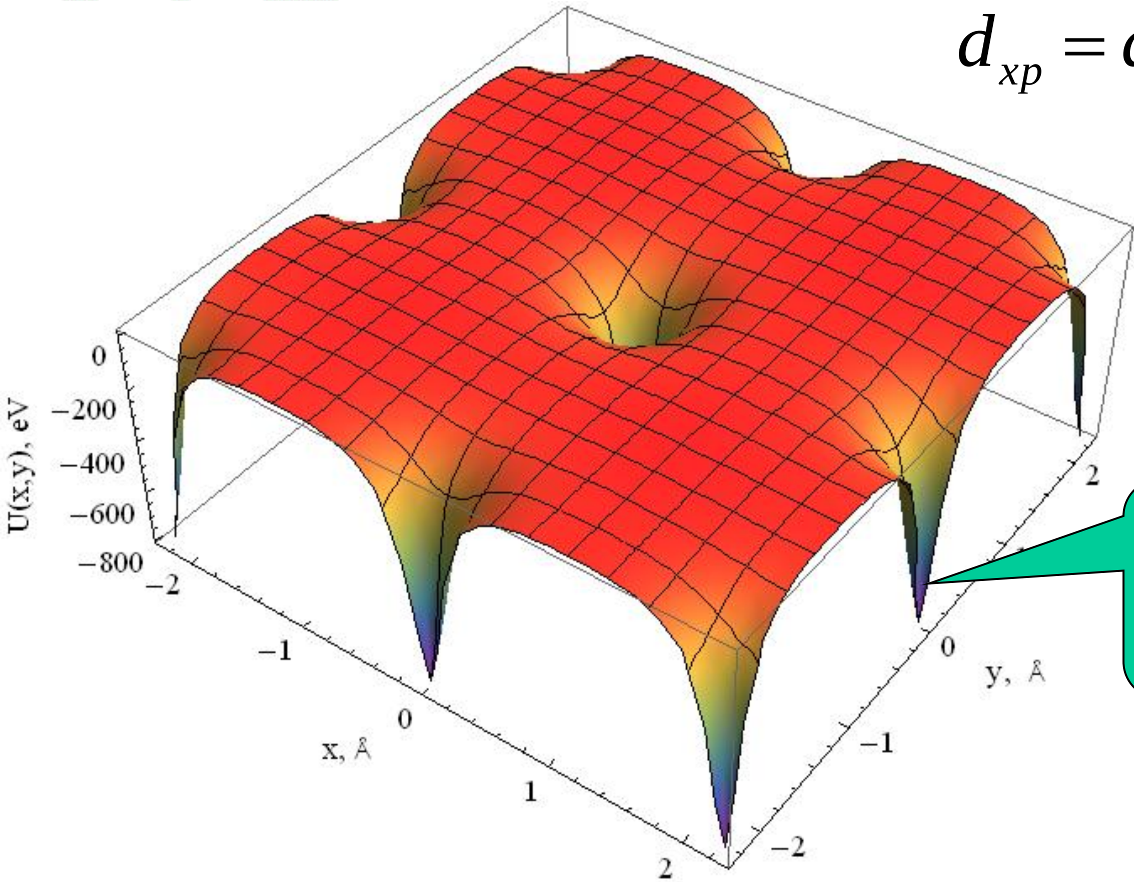
$$\upsilon_y(0) = c\sqrt{1-\frac{1}{\gamma^2}}\sin(\theta)\sin(\varphi)$$

Bogdanov O. V., Fiks E. I., Korotchenko K. B., Pivovarov Yu. L. and Tukhfatullin T. A.// J. Phys.: Conf. Ser. V. 236, 1, 2010, 012029

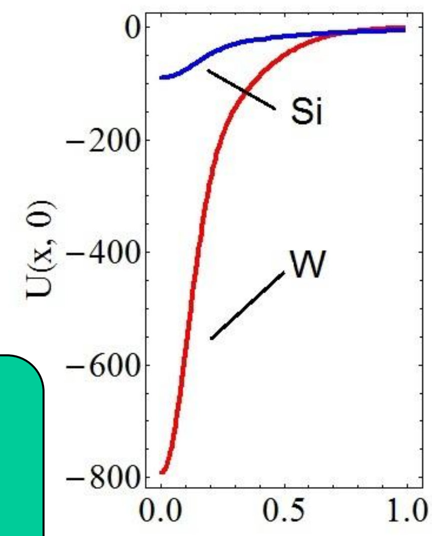
Two-dimensional Potential of the crystallographic axes <100> W

$$U(x,y) = eV(x,y) = e\sum_k V_{ax}(x - kd_{xp}, y - kd_{yp})$$

$$d_{xp} = d_{yp} = 2.24\,\mathring{A}$$



U_0 – the depth of potential well 791 eV



Doyle P.A. and Turner P. S.// Acta Cryst. 1967 A24, 390

Radiation Energy Loss

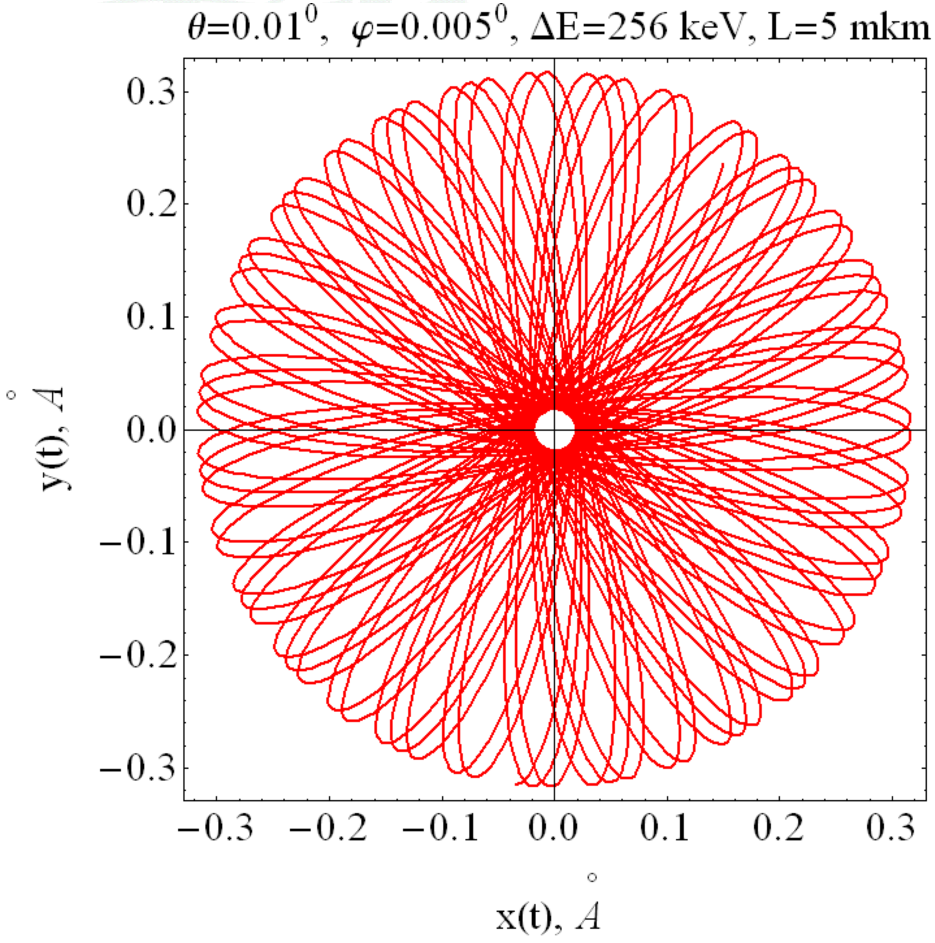
$$\Delta E = \frac{2e^2}{3c^3}\int_0^T \frac{a^2(t) - [\boldsymbol{\beta}(t)\mathbf{a}(t)]^2}{\left(1-\beta^2(t)\right)^3}\,dt$$

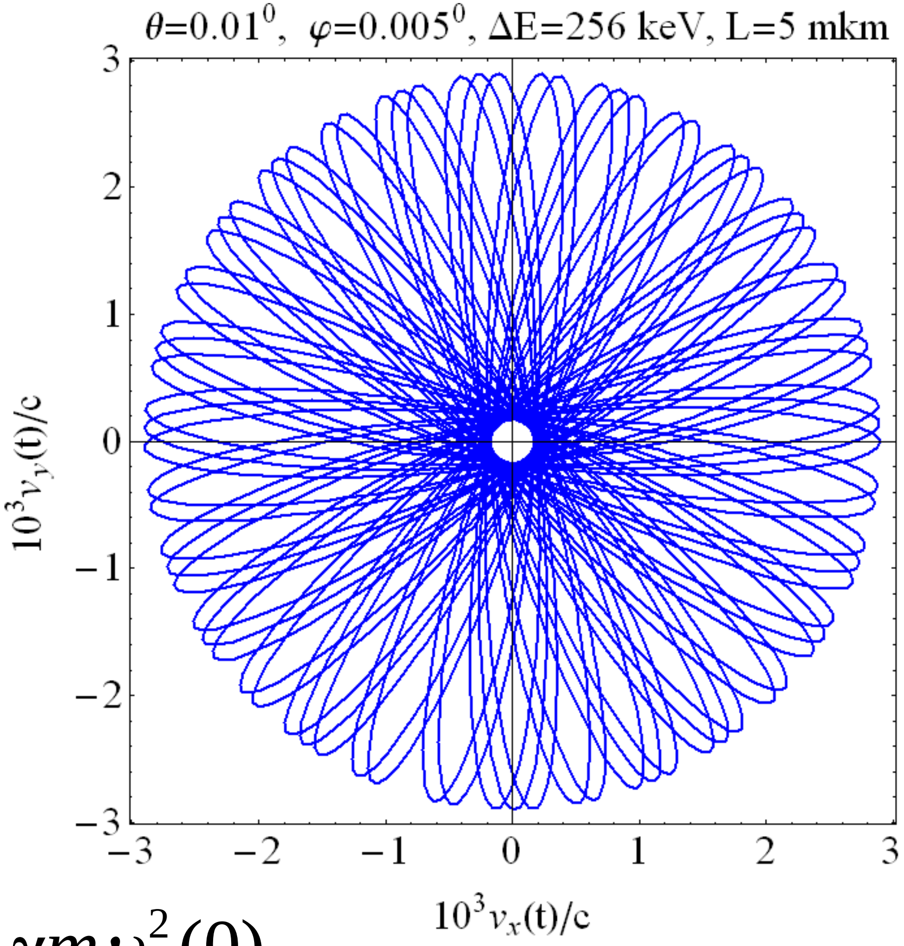
$$\mathbf{a} = \dot{\boldsymbol{\upsilon}}_\perp,\ \ \boldsymbol{\beta} = \boldsymbol{\upsilon}/c,\ \ T = L/\upsilon_{||} \approx L/c$$

L. D. Landau, E.M. Lifshitz The Classical Theory of Fields, Fourth Edition: Volume 2 (Course of Theoretical Physics Series)

Simulation Results

trajectories, E=155 MeV

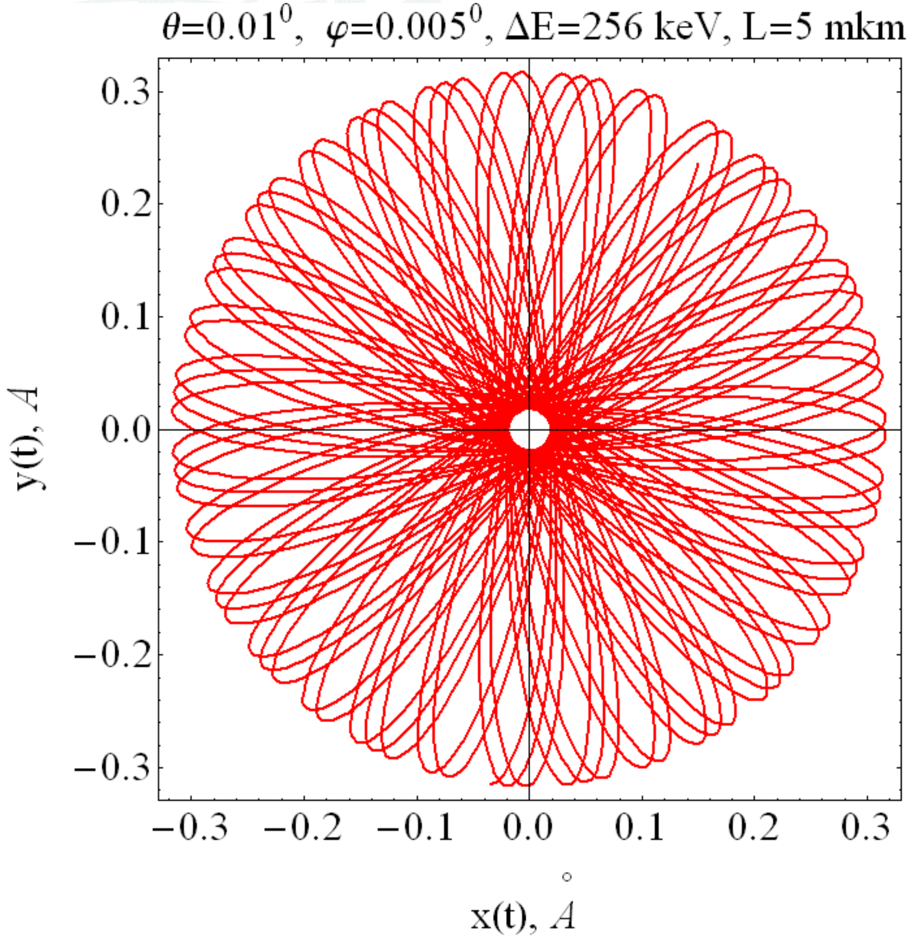


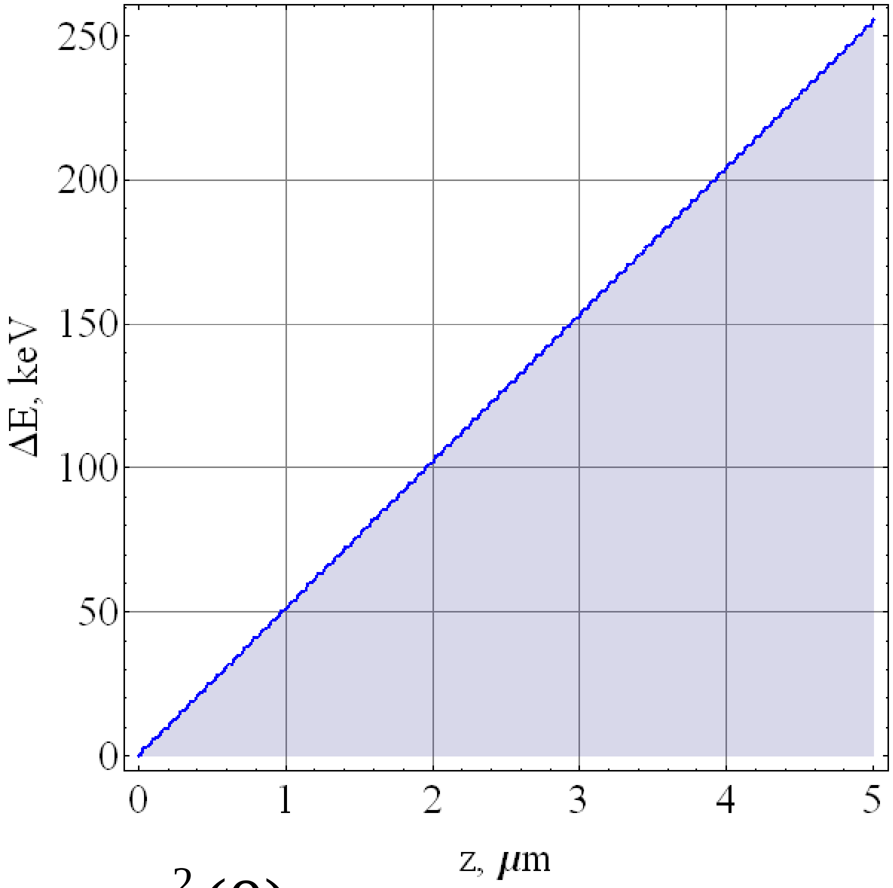


$$E_{\perp} = U(x_0, y_0) + \frac{\gamma m \upsilon_{\perp}^2(0)}{2} < U_d$$

Simulation Results

trajectories, E=155 MeV





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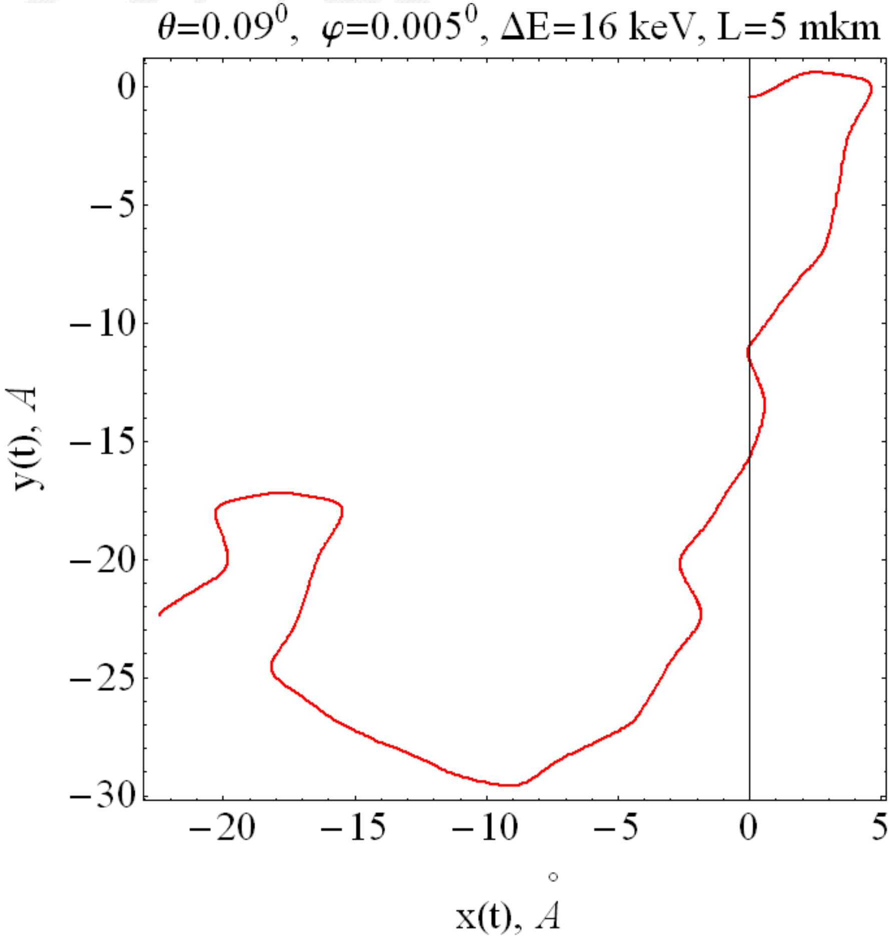

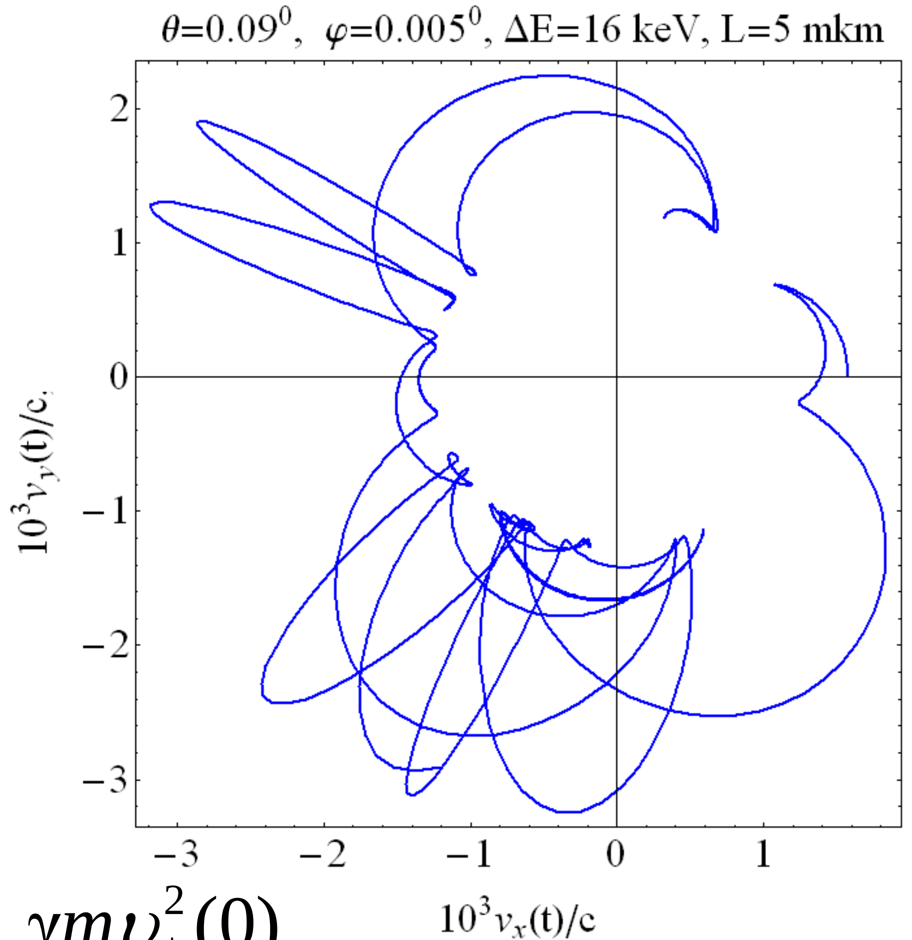

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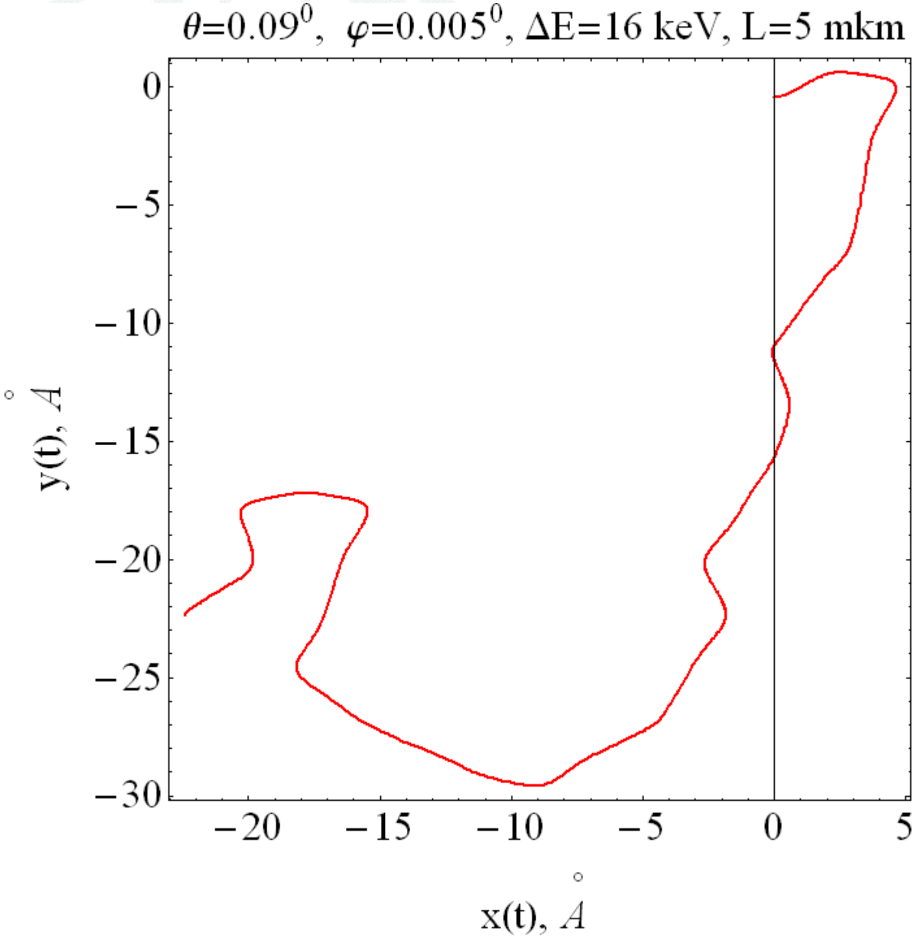
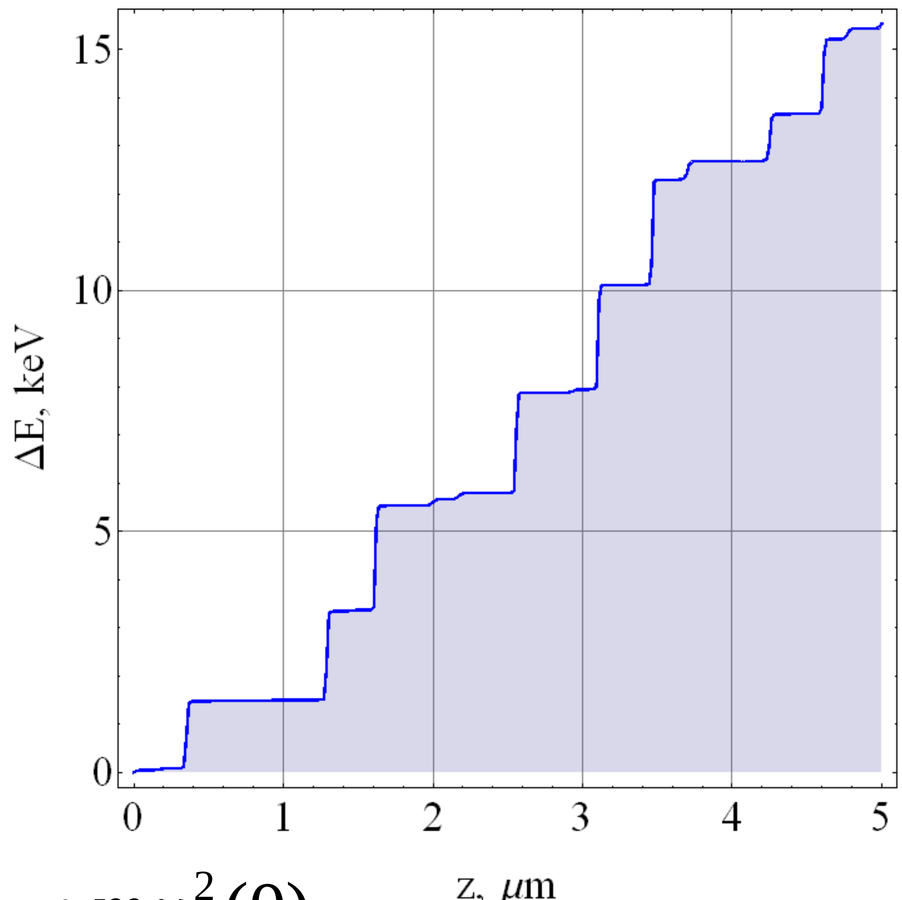
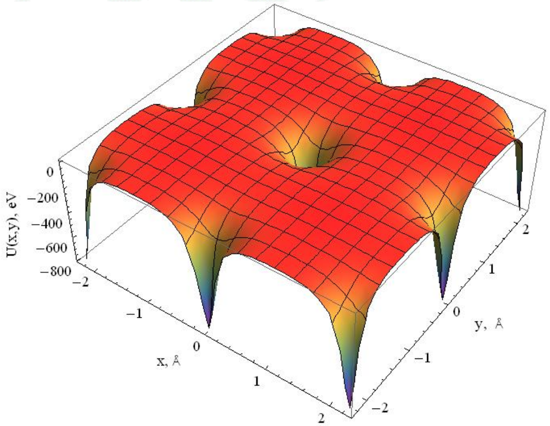


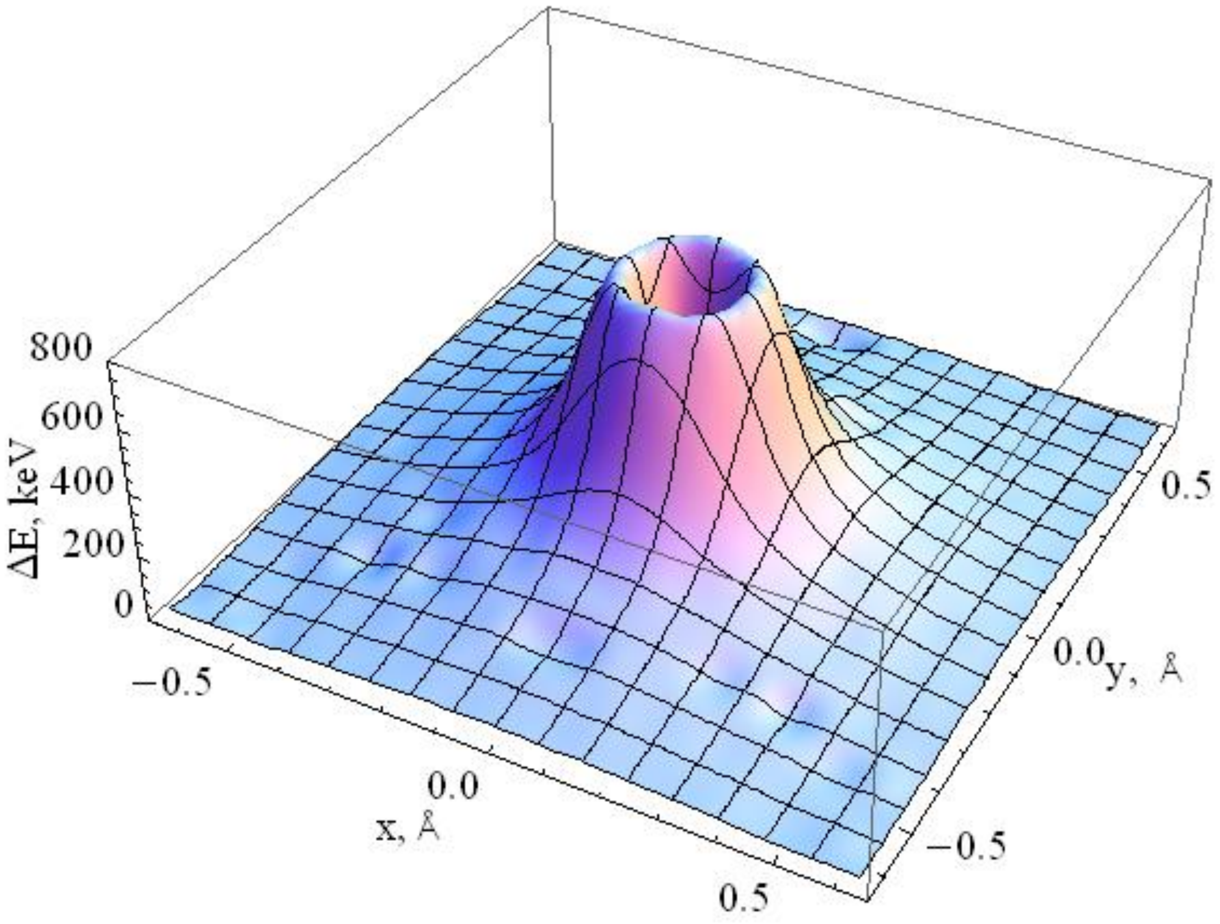


$$E_{\perp} = U(x_0, y_0) + \frac{\gamma m \upsilon_{\perp}^2(0)}{2} > U_d$$

Simulation Results

E=155 MeV, L= 5 μm, θ=0.01°, φ=0.005°



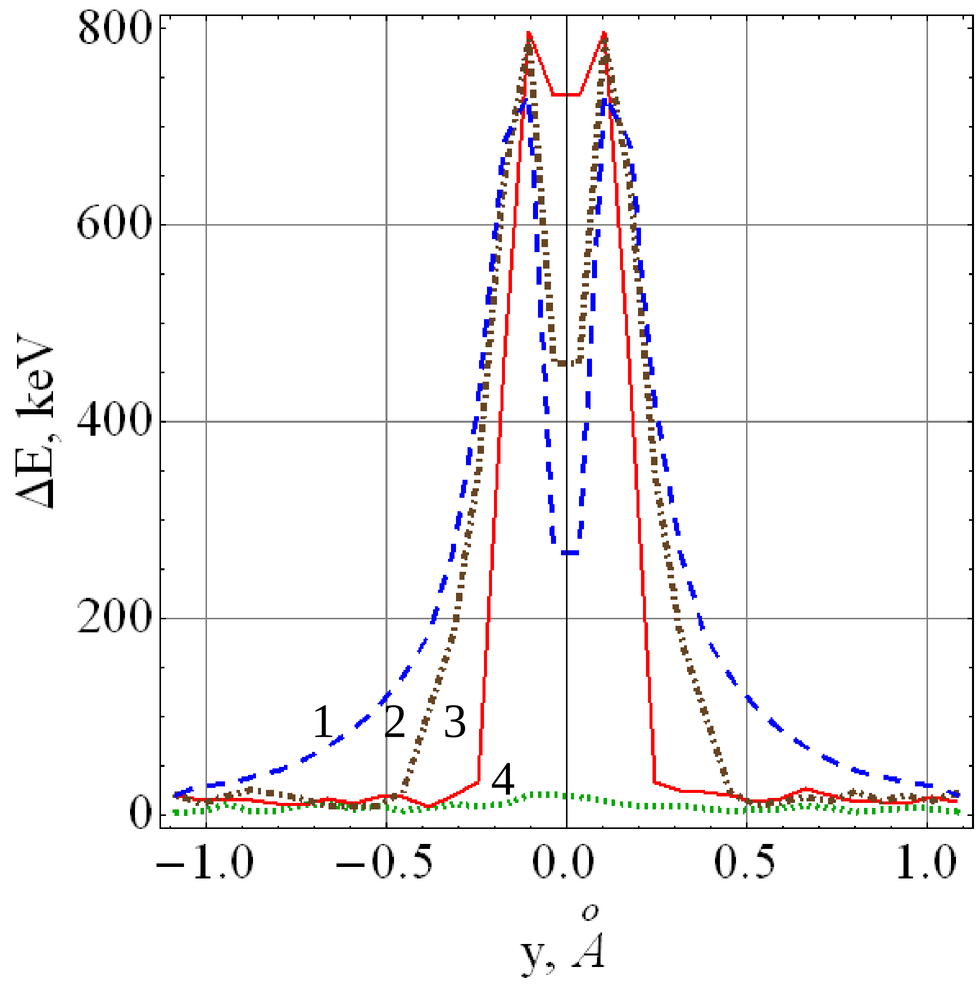


Simulation Results

E=155 MeV, L= 5 μm, θ=0.01°, φ=0.005°

1 - $\theta = 0.02\ \theta_c$,
2 - $\theta = 0.3\ \theta_c$,
3 - $\theta = 0.5\ \theta_c$,
4 - $\theta = 1.0\ \theta_c$.

$$\theta_C = \sqrt{\frac{2U_d}{E}} = 0.18^\circ$$



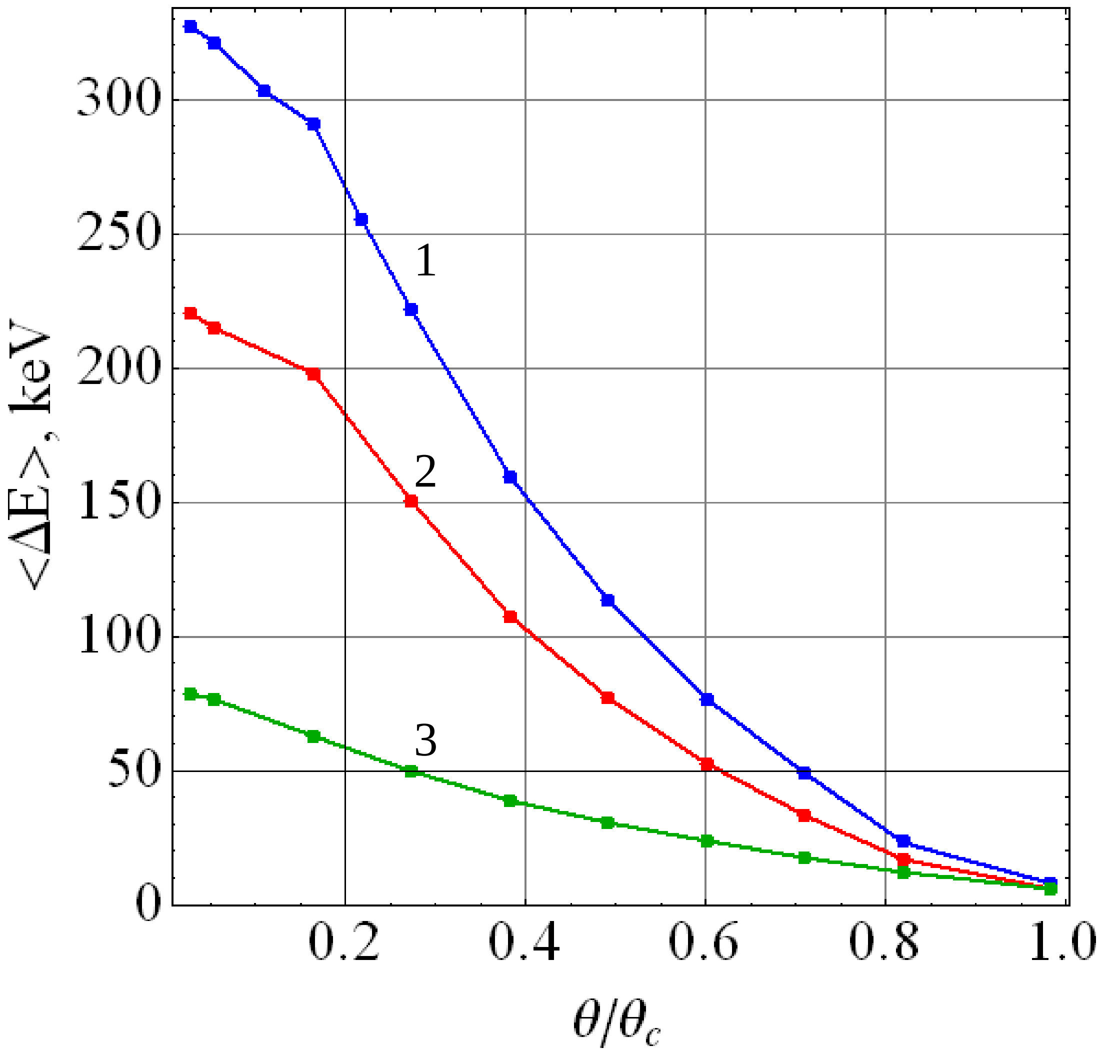
Simulation Results

averaged energy loss, E=155 MeV, φ=0.005°

1 – L=30 μm
2 – L=20 μm
3 – L=5 μm

$$< \Delta E >= \frac{1}{N}\sum_{i=1}^{N}\Delta E_i$$

$$\theta_C = \sqrt{\frac{2U_d}{E}} = 0.18^\circ$$

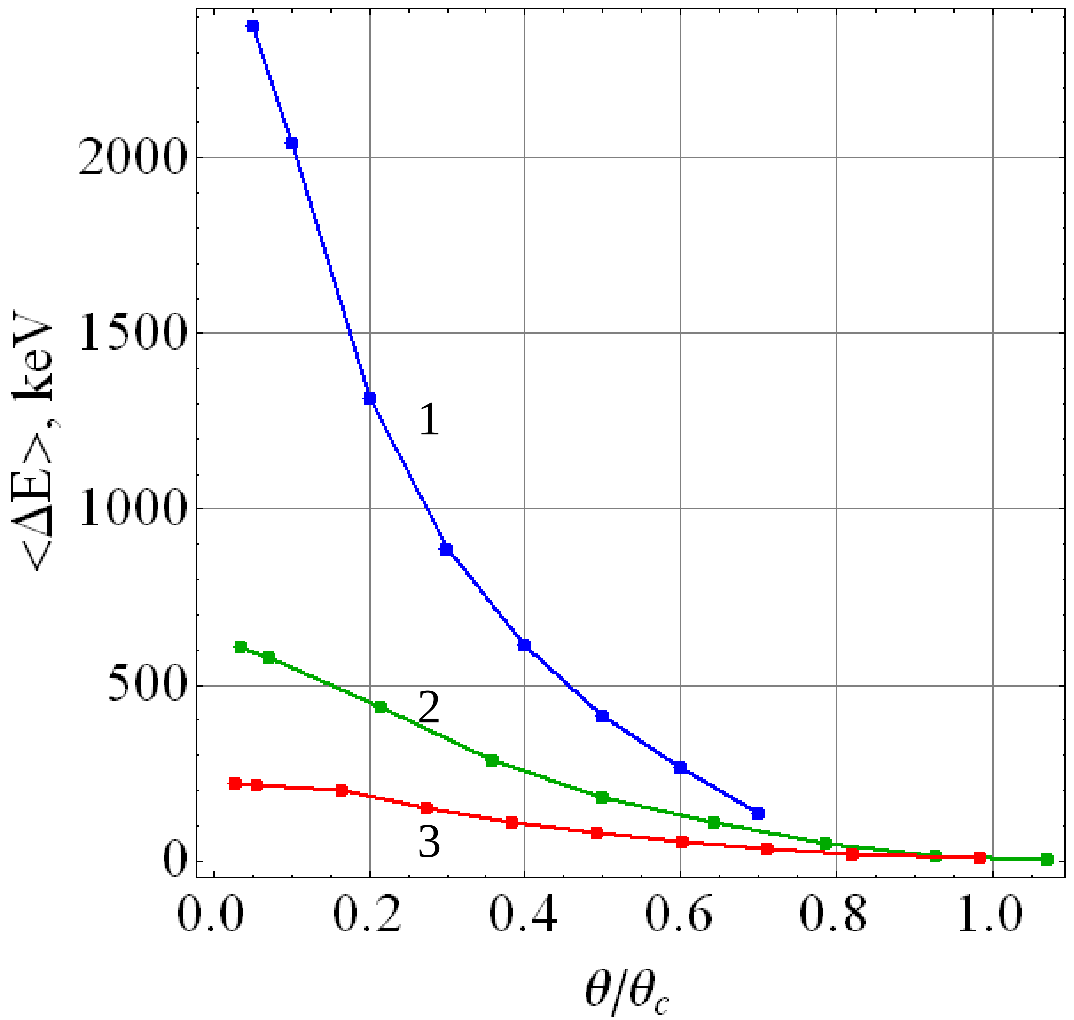


Simulation Results

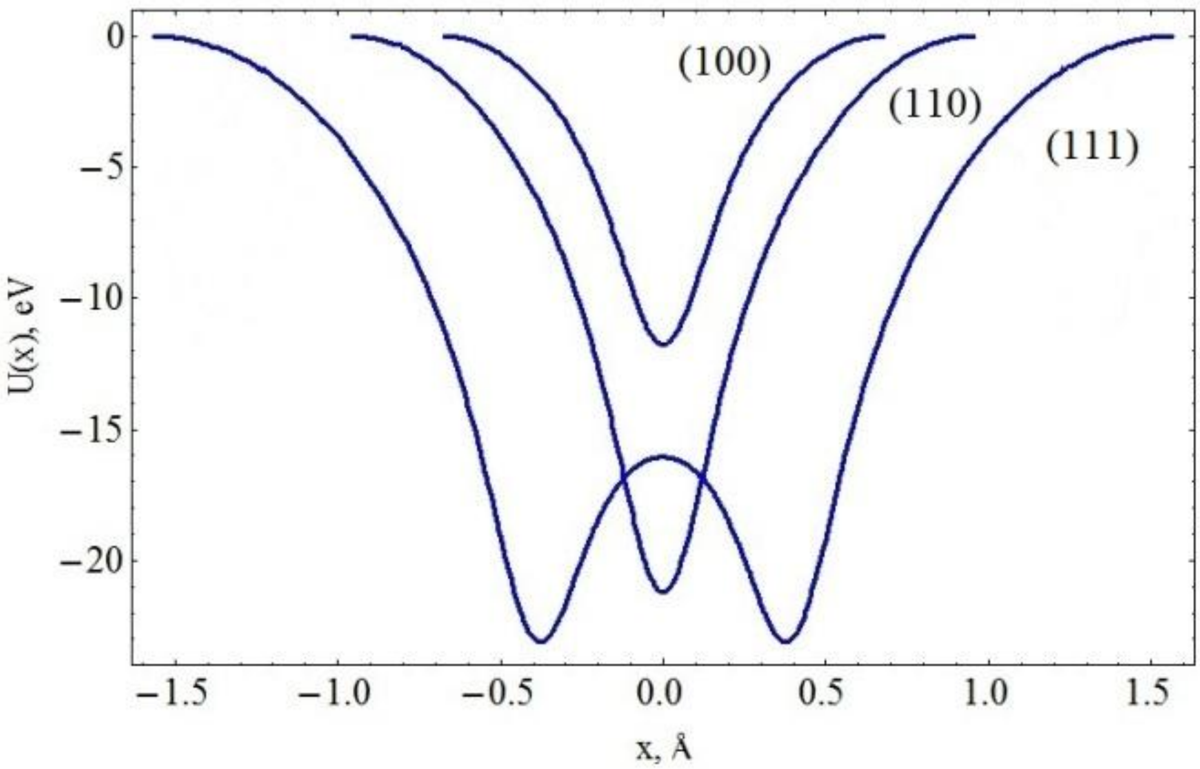
averaged energy loss, L= 20 μm φ=0.005°

1 – E=500 MeV, θ_c=0.10°
2 – E=255 MeV, θ_c=0.14°
3 – E=155 MeV, θ_c=0.18°

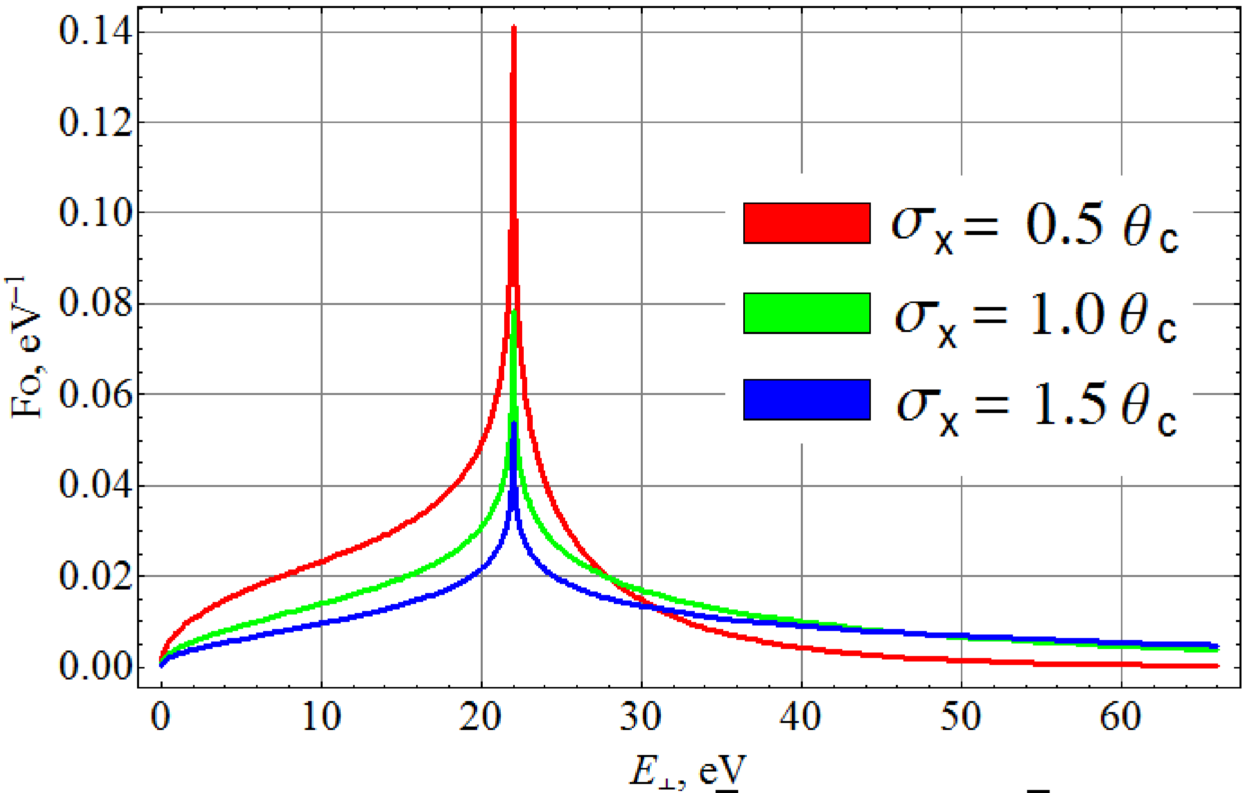
$$<\Delta E> = \frac{1}{N}\sum_{i=1}^{N}\Delta E_i$$



Potential energy of electron in the (100), (110), and (111) planes of a silicon single crystal



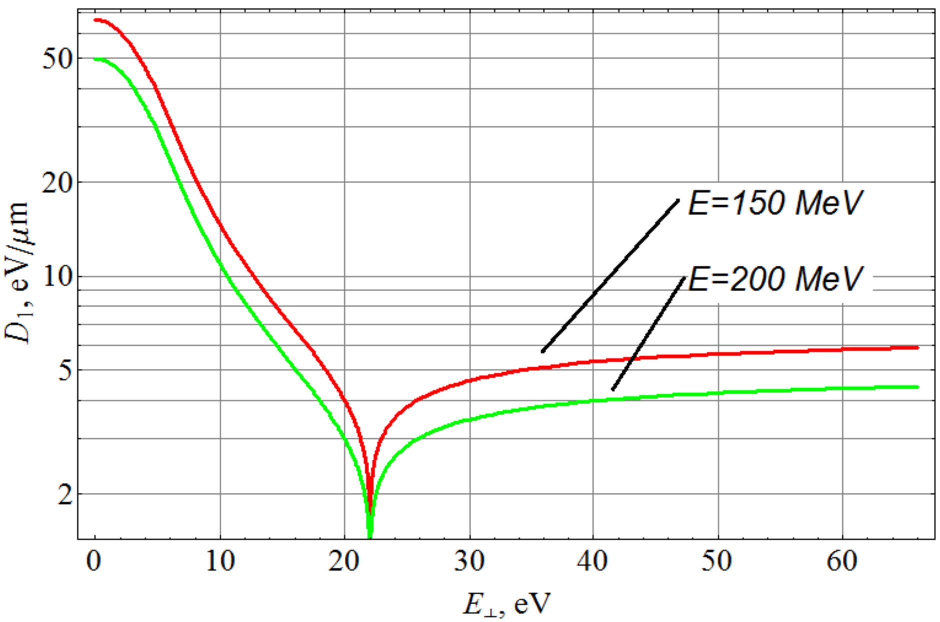
The initial density distribution function of electrons channeled in Si (110) at zero incidence angle



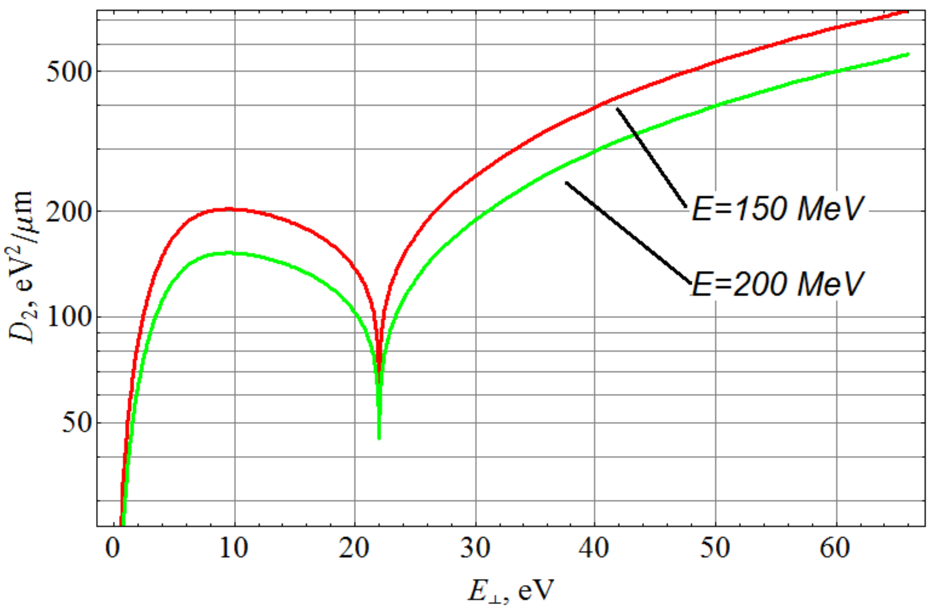
$$\Phi(\theta) = \frac{1}{\sqrt{2\pi\sigma_x}} \exp\left[-\frac{(\theta-\theta_0)^2}{2\sigma_x{}^2}\right]$$

The drift (a) and diffusion (b) coefficients at planar channeling of electrons in a Si (110) crystal.

(a)



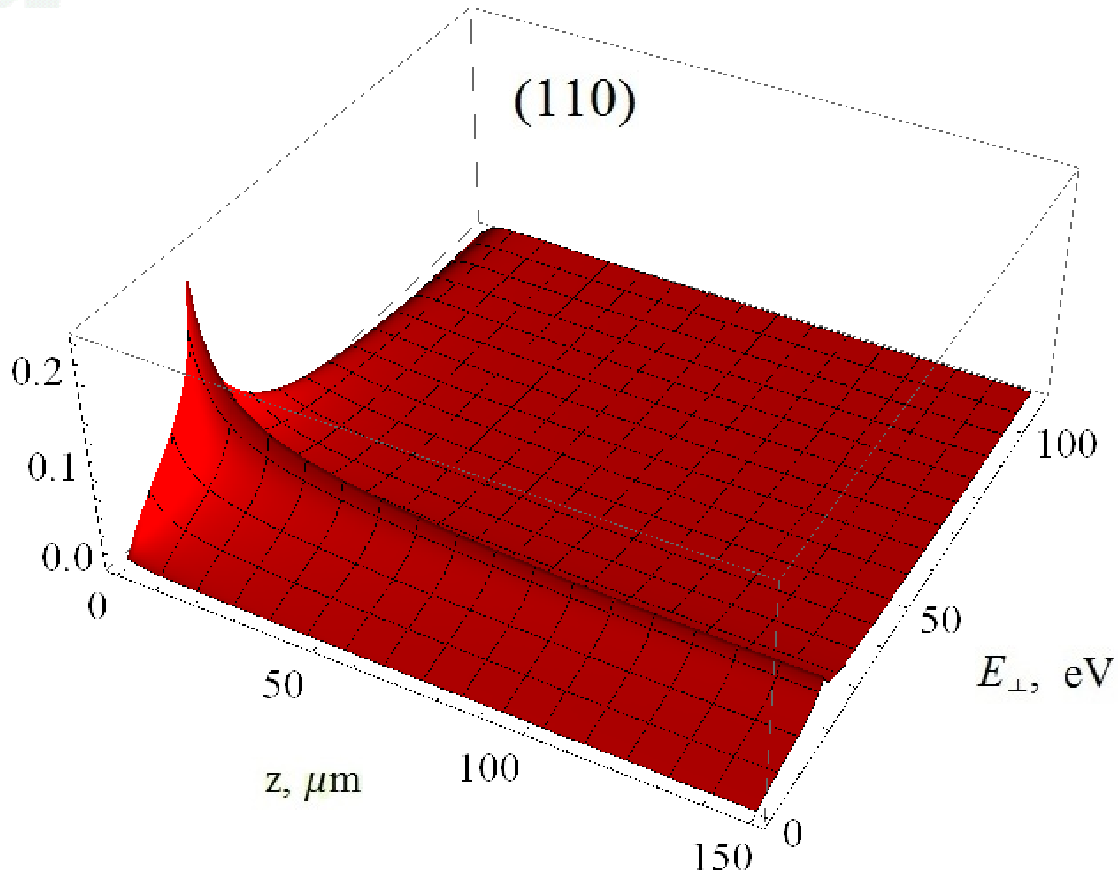
(b)



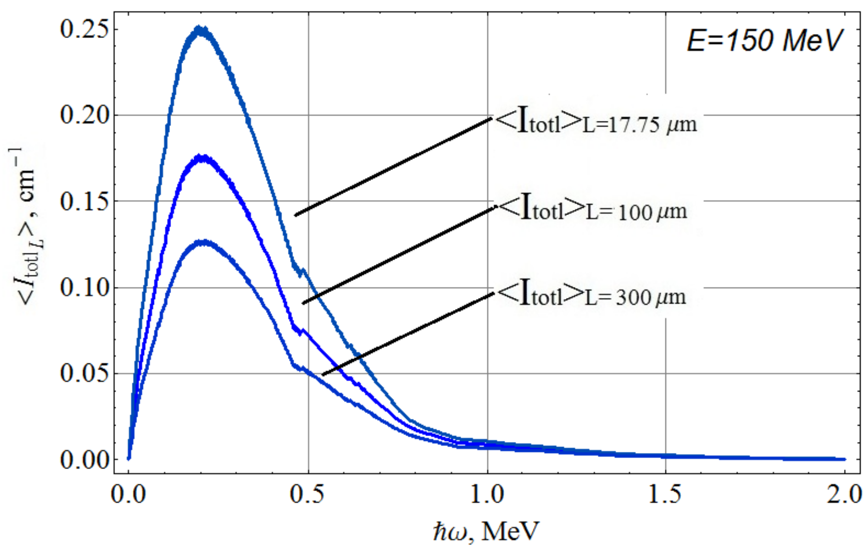
$$\frac{\partial F(z,E_\perp)}{\partial z} = \frac{\partial^2}{\partial E_\perp^{\,2}}\left[D_e^{(2)}(E_\perp)F(z,E_\perp)\right] - \frac{\partial}{\partial E_\perp}\left[D_e^{(1)}(E_\perp)F(z,E_\perp)\right], \quad \frac{\partial F(z,0)}{\partial E_\perp} = 0, \quad \frac{\partial F(z,E_{\perp,C})}{\partial E_\perp} = 0$$

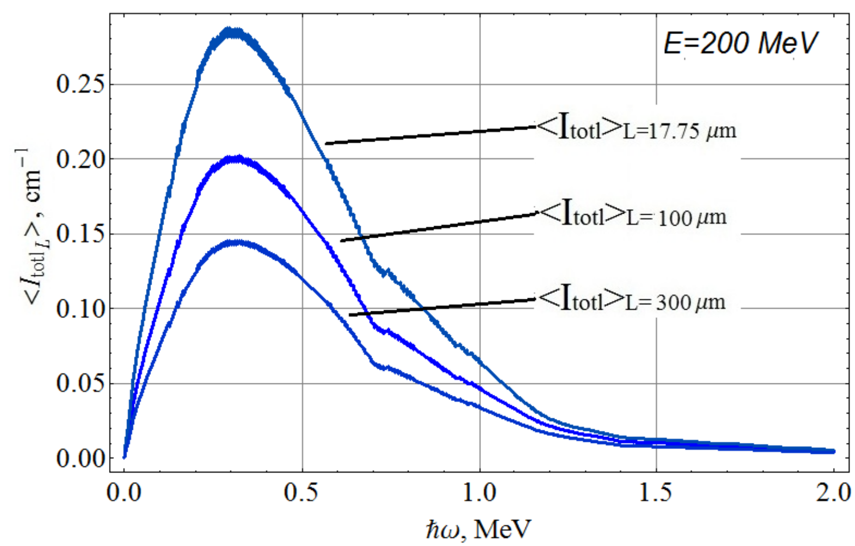
H. Backe et al. NIMB 266, (2008) 3835-3851

Probability density of electrons at planar channeling in Si (110) crystal.



Thickness dependence for radiation spectrum at electrons channeling in a Si (110) crystal





$$I_{thin}\frac{dW}{d\omega dz}=\frac{e^2\omega}{c^4T^2}\sum_{n=1}^{\infty}\Theta\left(1-\frac{\omega T}{4\pi n\gamma^2}\right)\left(1-\frac{T\omega}{2\pi\gamma^2 n}+\frac{1}{2}\left(\frac{T\omega}{2\pi\gamma^2 n}\right)^2\right)\left|\upsilon_{\tilde{\omega}}^T\right|^2,$$

$$\tilde{\omega}=\frac{2\pi n}{T}\qquad \upsilon^T_{\tilde{\omega}}=\int_0^T \upsilon_\perp(t)e^{i\tilde{\omega}t}dt,\qquad I_{thick}(\hbar\omega,E_\perp)=\frac{1}{L}\int_0^L I_{thin}(\hbar\omega,E_\perp)\cdot F(z,E_\perp)dz$$

Total yield of CR by single electron per unit of a Si (110) crystal length (MeV/(e- cm)).

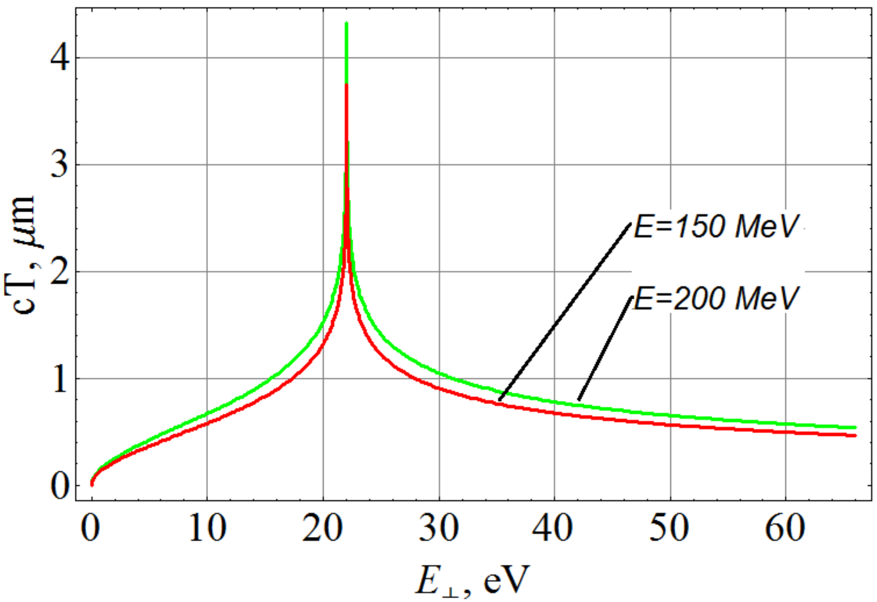
$$Y = \int_0^{\hbar\omega_{\max}} \langle I \rangle_{E_\perp} d(\hbar\omega)$$

Energy of electron, (MeV)	Y_{thin}	Y_{F_0}	$Y_{L=L_d}$	$Y_{L=100\ \mu m}$	$Y_{L=300\ \mu m}$
150	0.14	0.12	0.11	0.08	0.07
200	0.24	0.21	0.19	0.14	0.10
855	2.23	2.19	2.13	1.49	1.09
1500	13.40	11.58	10.32	7.38	5.36
2500	36.61	32.33	22.52	20.33	14.73
3500	74.68	65.27	57.85	41.32	29.98

Conclusions

- Orientation and thickness dependence of radiation energy loss of relativistic electrons at axial channeling in tungsten crystal have investigated.
- Computer code for calculating the main characteristics of the radiation energy loss of electrons at planar channeling with taking into account dechanneling and rechanneling processe have developed.
- The results of calculation allow us to make recommendation for the condition of experiment on SPARC facility at LNF.

Thank you for attention



Time parameter of electron for (110) planar channeling in a silicon crystal.