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The Ternovsky-Shul'ga-Fomin effect of suppression of radiation in aligned crystals

NSC "Kharkiv Institute of Physics and Technology", Kharkiv, Ukraine

Seminar in memory of Professor Nikolai Shul'ga, June 20, 2024, DESY, Hamburg

Spectral Radiation Density (SRD) and its suppression effect

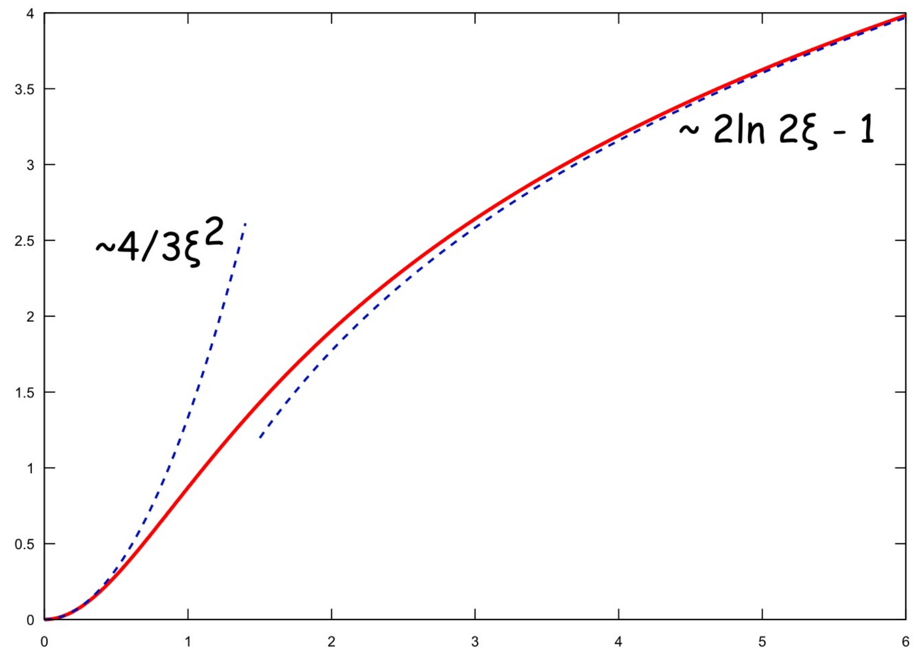
$l_c \sim 2c\gamma^2 / \omega$ Radiation coherence length

Spectral radiation density

$$\frac{d\mathcal{E}}{d\omega} = \frac{2e^2}{\pi c}\left\{\frac{2\xi^2+1}{\xi\sqrt{\xi^2+1}}\ln\left(\xi+\sqrt{\xi^2+1}\right)-1\right\}, \qquad \xi = \gamma\vartheta/2$$

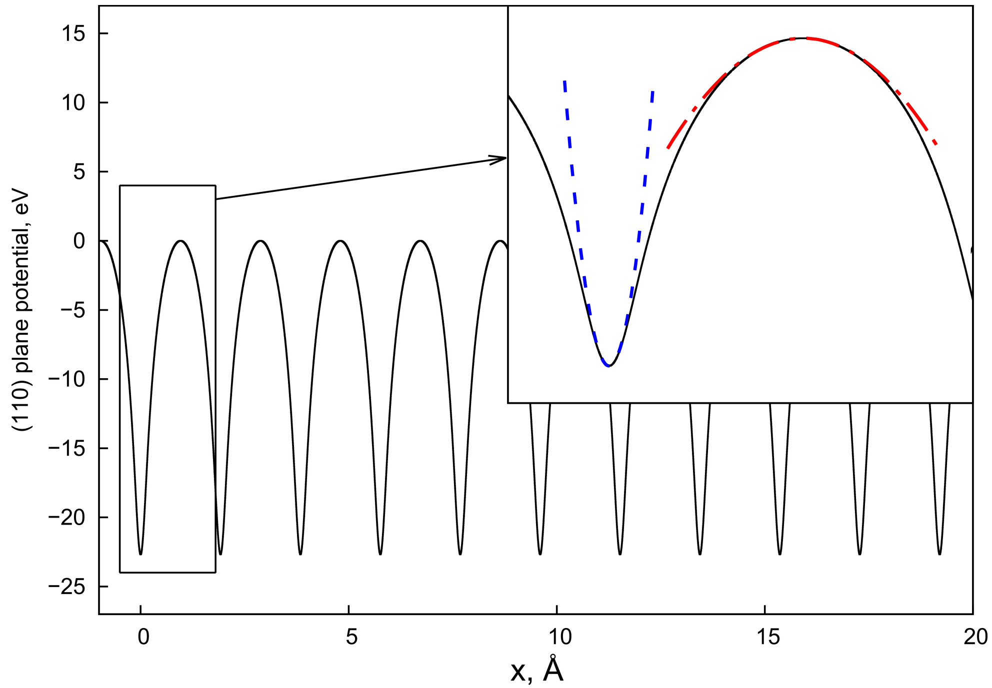
$$L << l_c$$

Radiation suppression effect



Continuous planes potential

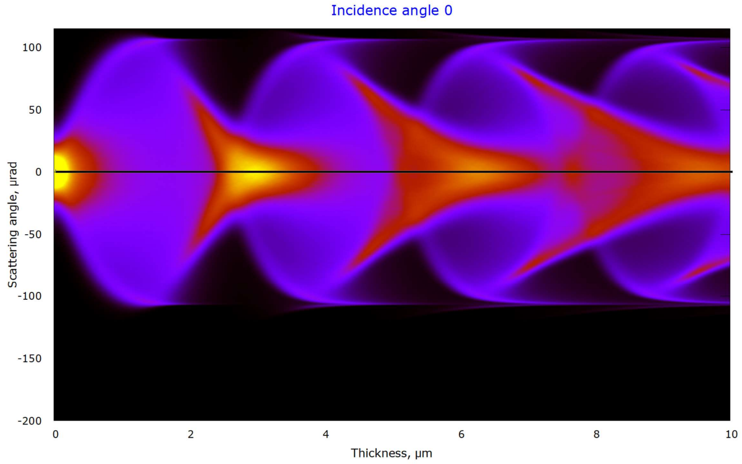
$$U_{pl}(x) = \frac{1}{a_{pl}} \int_0^{a_{pl}} dy\, U_{ax}(x, y)$$



$$U_{ax}(\vec{\rho}) = \frac{1}{a_1 \overline{v}^2} \int d^2 v e^{-v^2/2\overline{v}^2} \int_{-\infty}^{\infty} dz\, u(\vec{\rho} + \vec{v}, z) \quad - \quad \text{string potential}$$

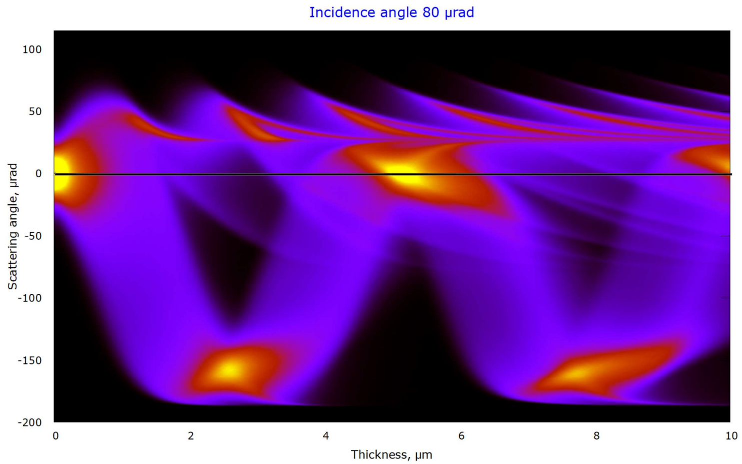
v - heat oscillations of atom coordinates

$$u_m(r) = \sum_i \alpha_i \exp(-\beta_i r / R) \quad - \quad \text{Molière approximation for single atoms}$$



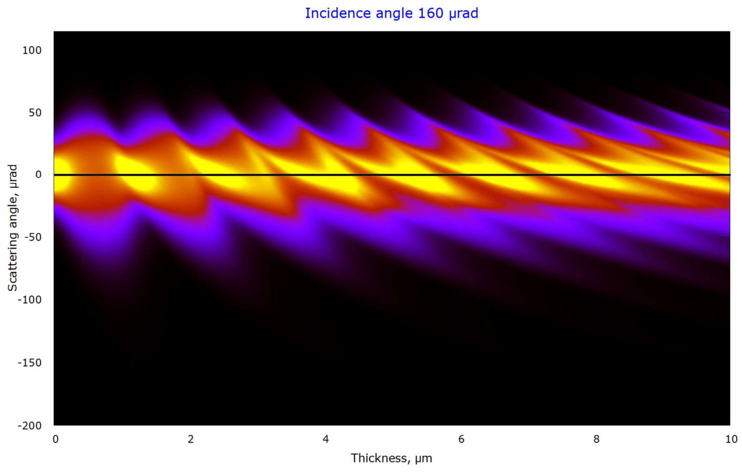
Angular trajectories of positrons in the Si (110) planes potential at different incidence angles

$$T_{1/2}\,[\text{Å}] = b \cdot \beta \sqrt{\varepsilon\,[eV]}$$



$$\theta_c = \sqrt{\frac{2U_0}{pv}} \approx \sqrt{\frac{2U_0}{\varepsilon}}$$

$$T_{\text{ob}} = d/\psi$$

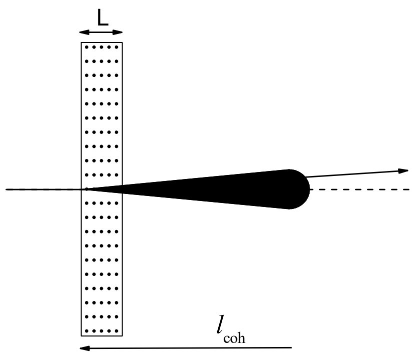


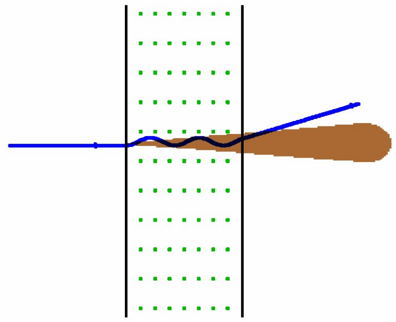
$$\Delta\vartheta = \frac{d \cdot \overline{\nabla U}}{2} \cdot \frac{1}{\psi\, \varepsilon_{\parallel}\, \beta^2}$$

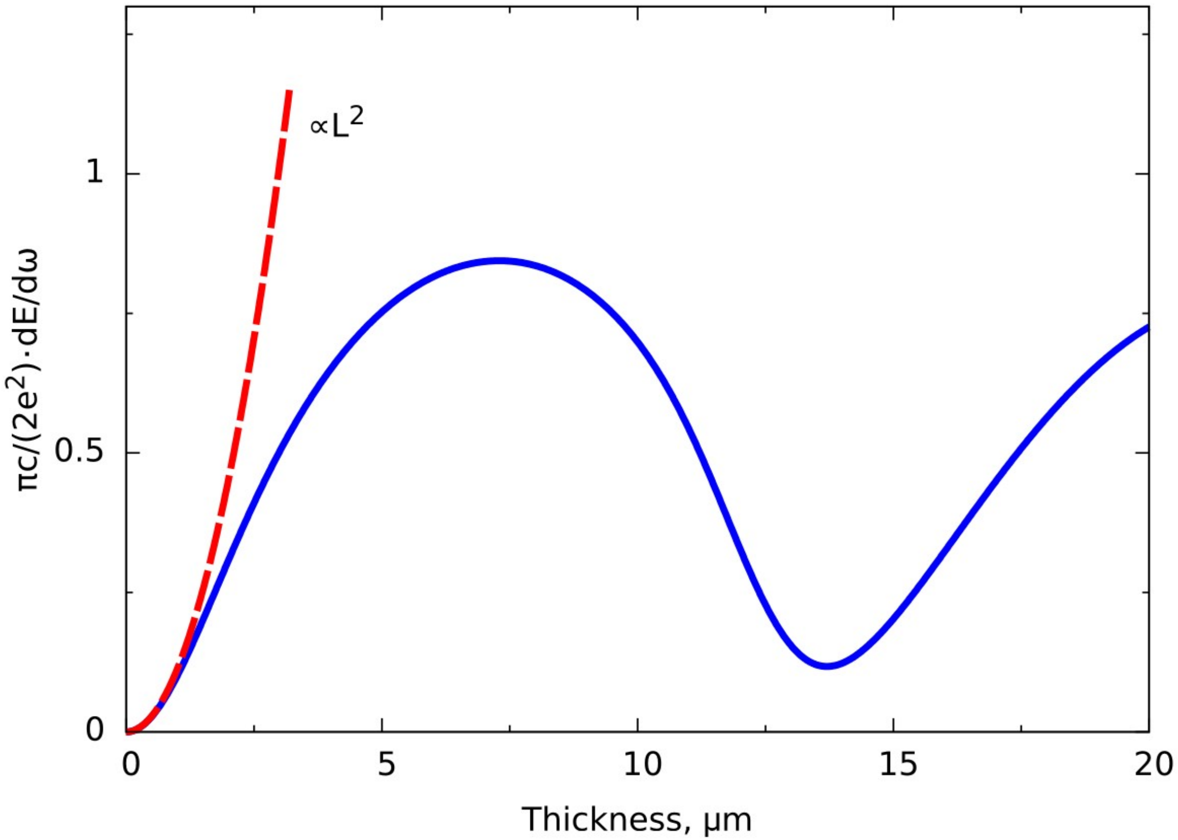
$$\left\langle \frac{d\mathcal{E}}{d\omega} \right\rangle = \frac{1}{N} \sum_n \left(\frac{d\mathcal{E}}{d\omega} \right)_n$$

Averaging over impact parameters

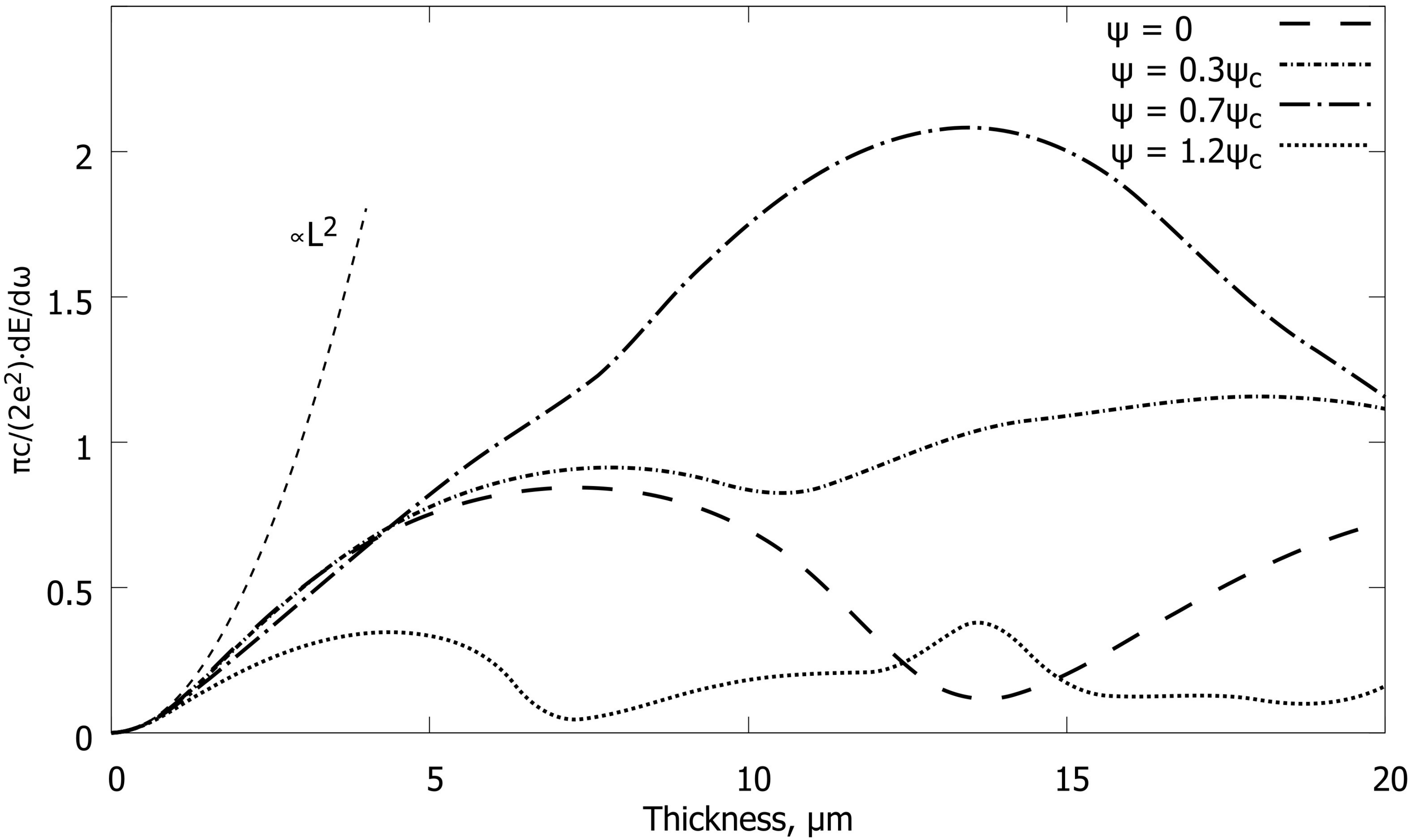
SRD of 100 Gev positrons incident perpendicular to Si (110) plane



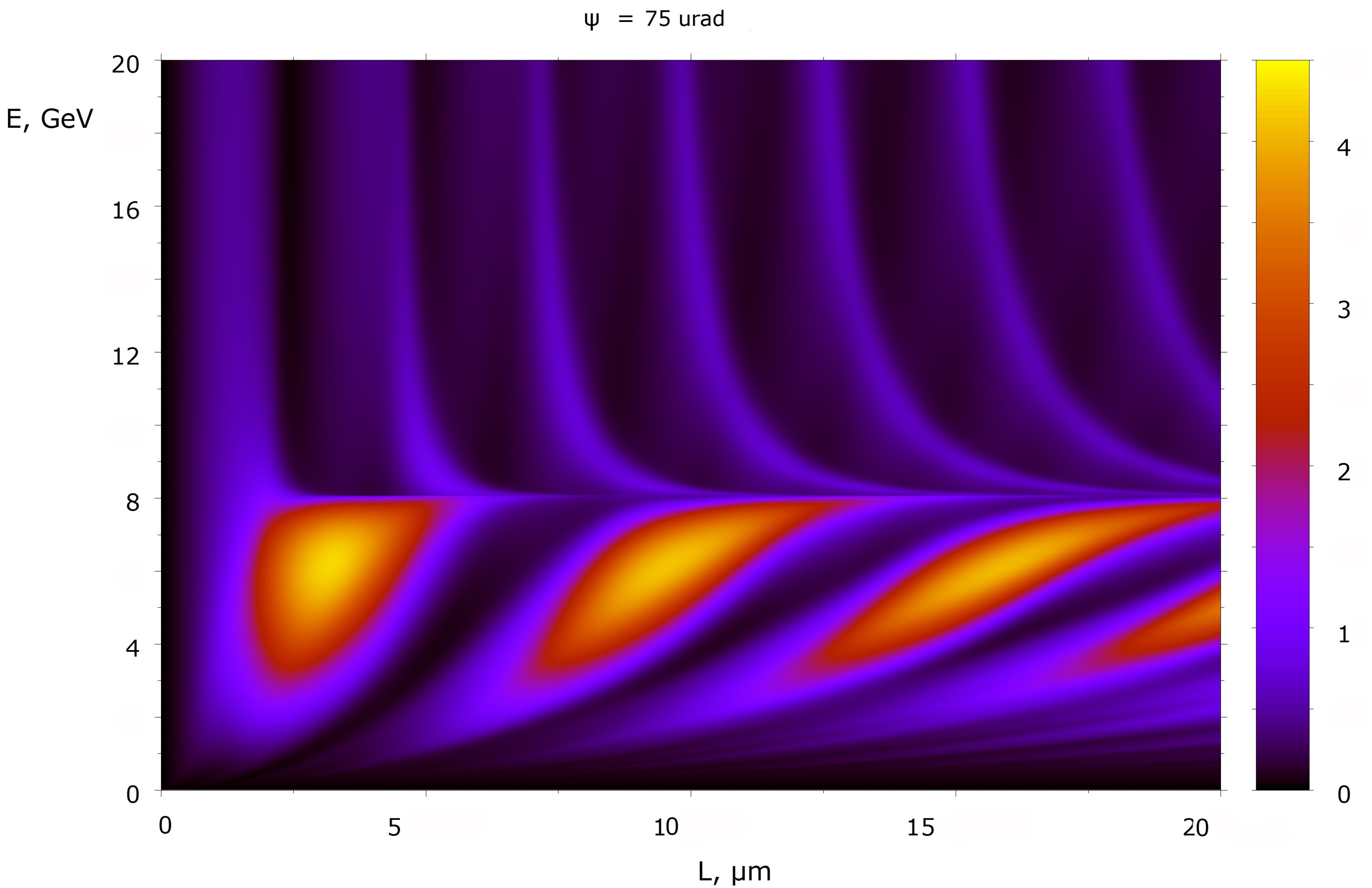




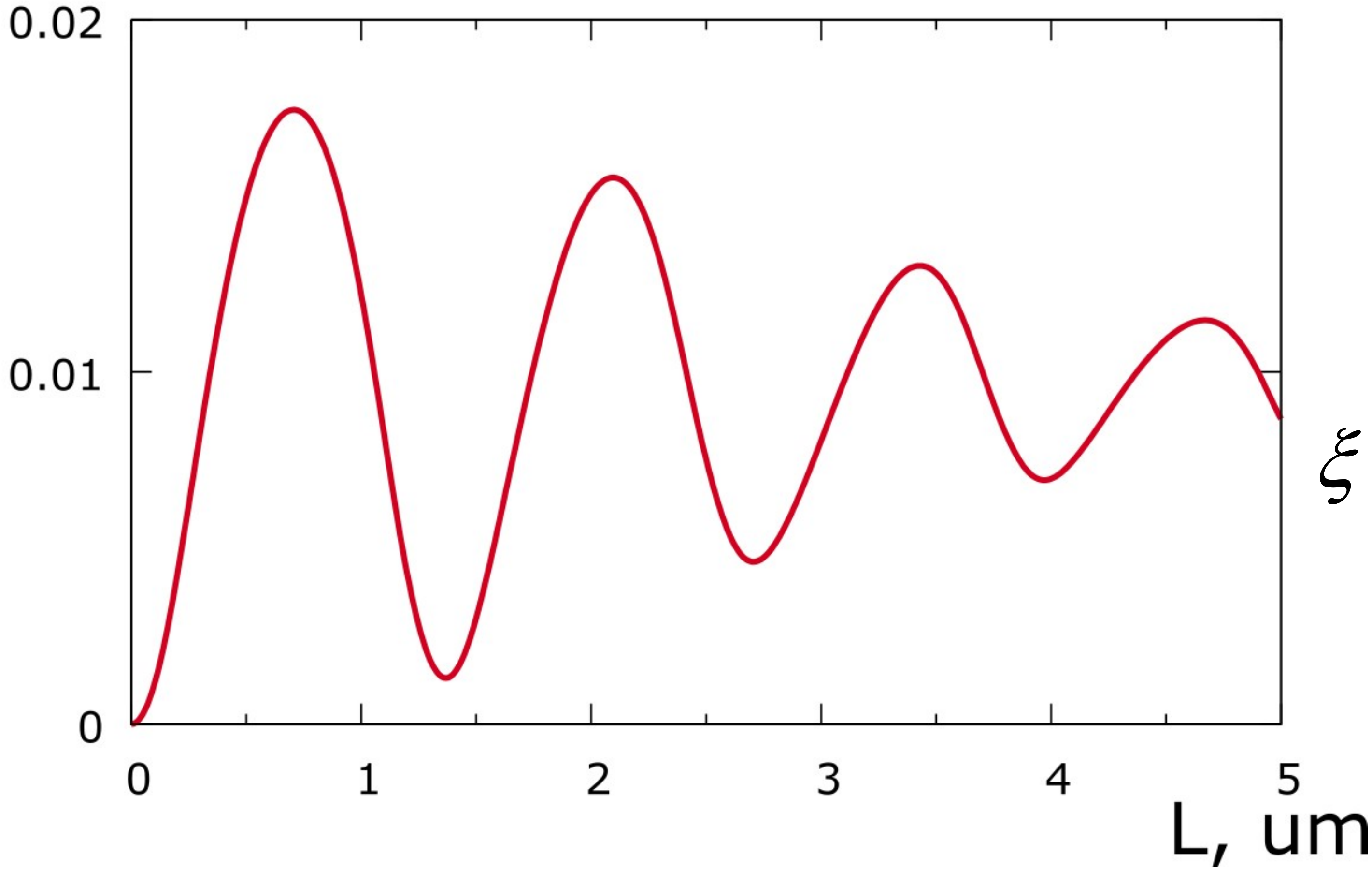
SRD of positrons at different incidence angles relatively Si (110) plane



Dependence of SRD on thickness and particle energy at the incidence angle ψ=75μrad



SRD of 1GeV positrons at incidence parallel to Si (110) planes



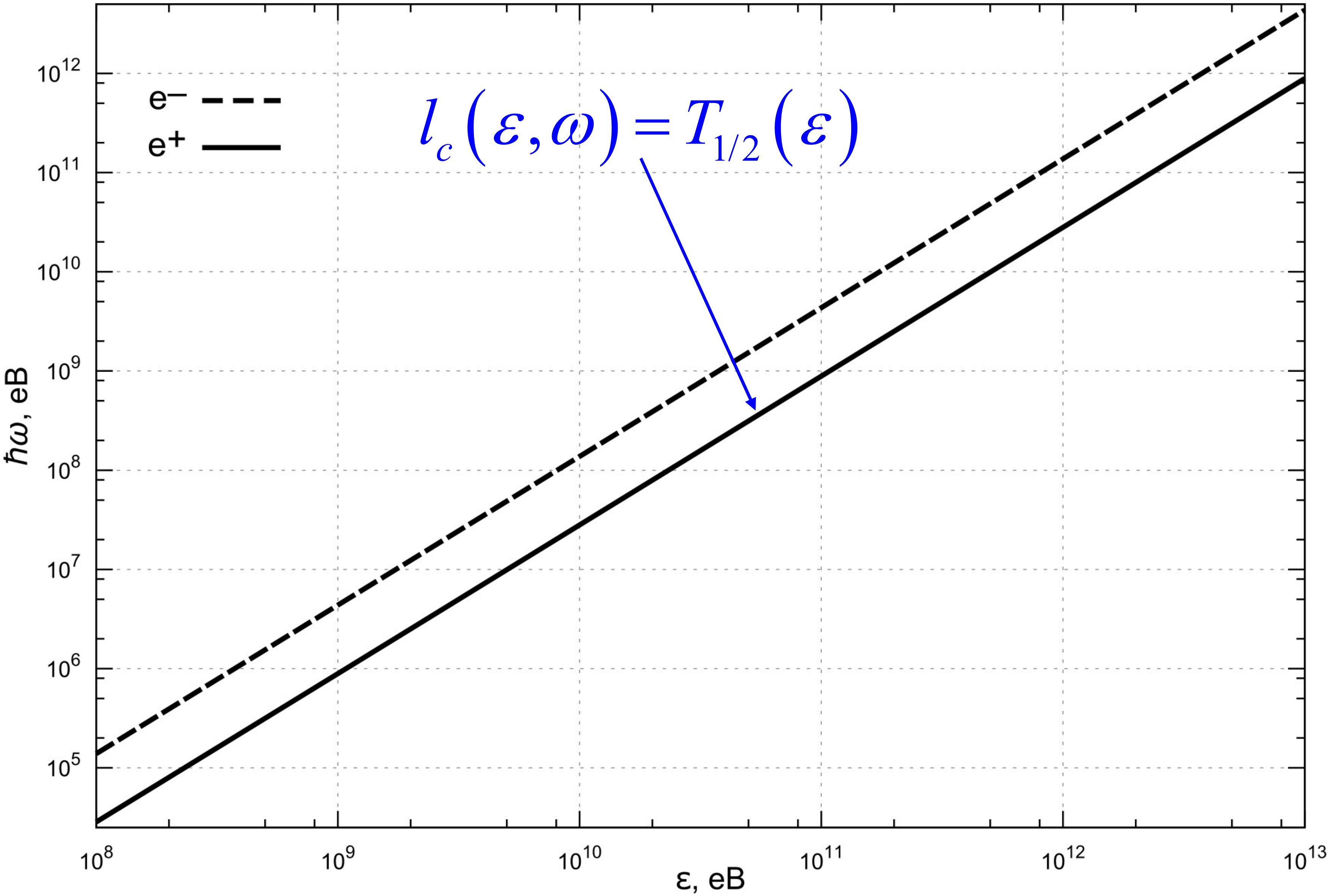
$$T_{1/2} \sim 1.3\mu\text{m}$$

$$\xi = \gamma\vartheta / 2$$

$$\xi(\vartheta_c) \approx 0.21$$

$$T_{1/2} = l_c = 2c\gamma^2 / \omega \quad \Rightarrow \quad \hbar\omega <\sim 0.87\text{MeV}$$

Applicability range Si (110)



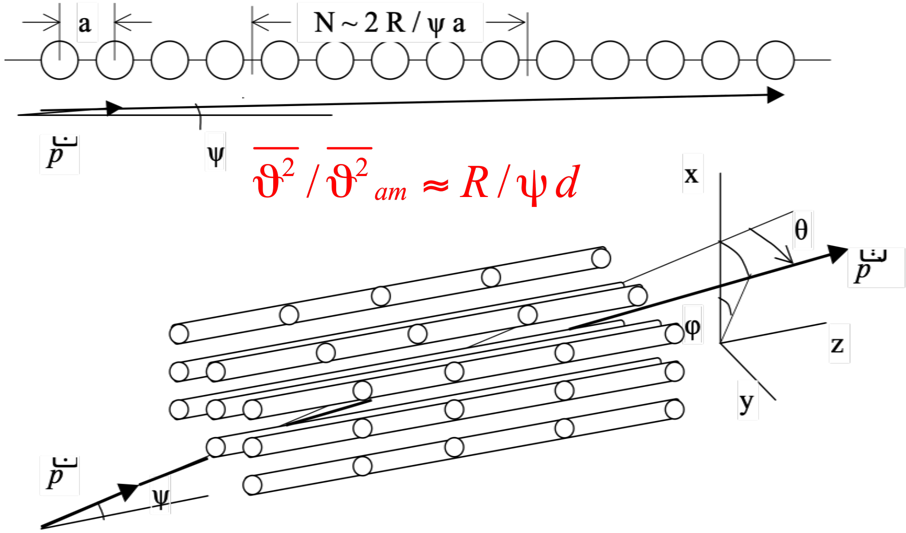
$$l_c(\varepsilon,\omega) = T_{1/2}(\varepsilon)$$

Conclusions

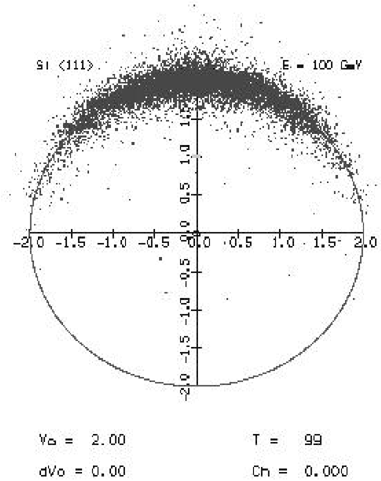
- For the motion of e^+ and, in some cases, e^- in the field of crystal planes, the effect of periodical spatial dependence of the coherent radiation density is possible besides with the effect of the radiation suppression effect
- At the angles ~0.7 of channeling angle the radiation maximum is reached
- At above-barrier motion energies neither spatial period of SRD oscillations, nor its amplitude does not depend on the particle energy if this energy is high enough
- The conditions for observing the considered effect can be reached at high energy experiments on existing experimental setups

TSF effect in a thin crystal: axial orientation

Multiple scattering in crystal: N. Shul'ga, V. Truten', S. Fomin, J. Techn. Phys. **52** (1982) 2279.



$$\overline{\vartheta^2} / \overline{\vartheta^2}_{am} \approx R / \psi d$$

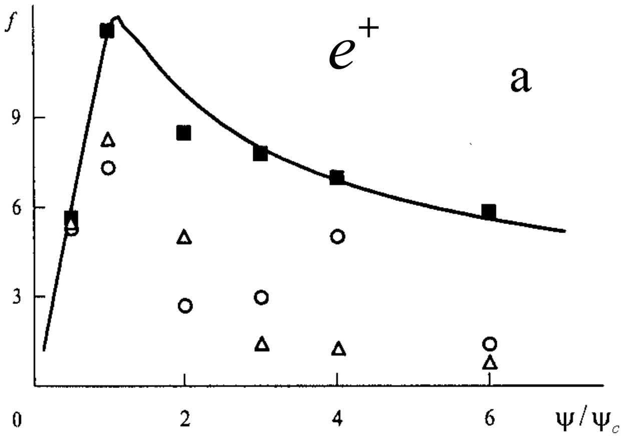


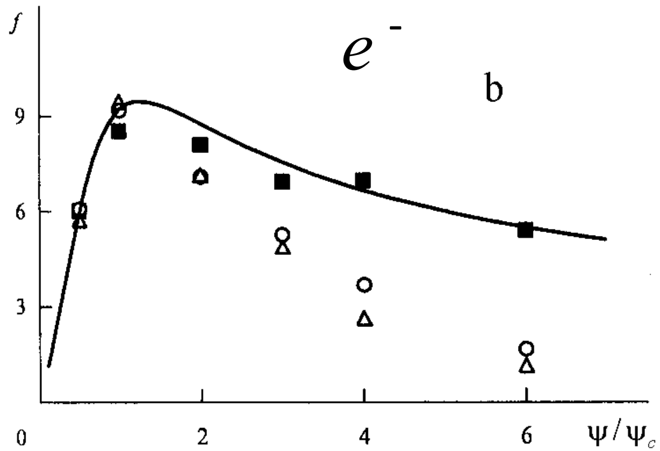
$$f = \sqrt{\langle \vartheta^2 \rangle / \langle \vartheta^2 \rangle_{am}}$$

Si <111>

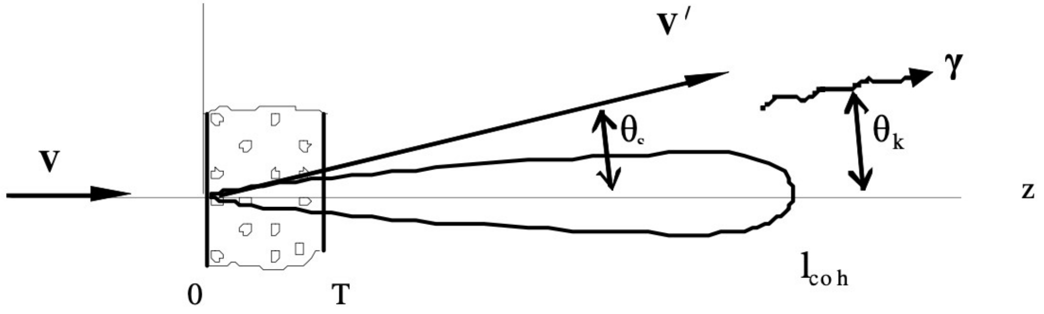
T = 50 μm

E = 30 GeV





TSF effect in a thin crystal: axial orientation



$$l_c >> T$$

$$l_c = \frac{2\varepsilon\varepsilon'}{m^2\omega}$$

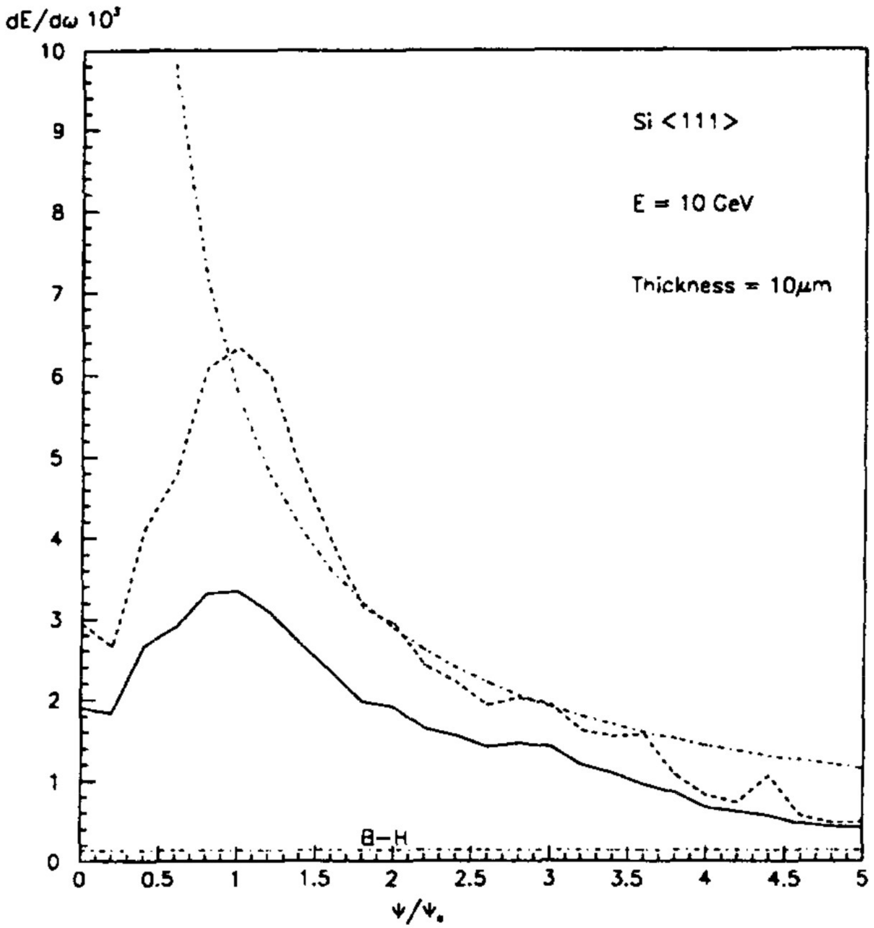
$$\frac{dE}{d\omega} = \frac{2e^2}{\pi c}\left\{\frac{2\xi^2+1}{\xi\sqrt{\xi^2+1}}\ln\left(\xi+\sqrt{\xi^2+1}\right)-1\right\}, \qquad \xi = \gamma\vartheta/2$$

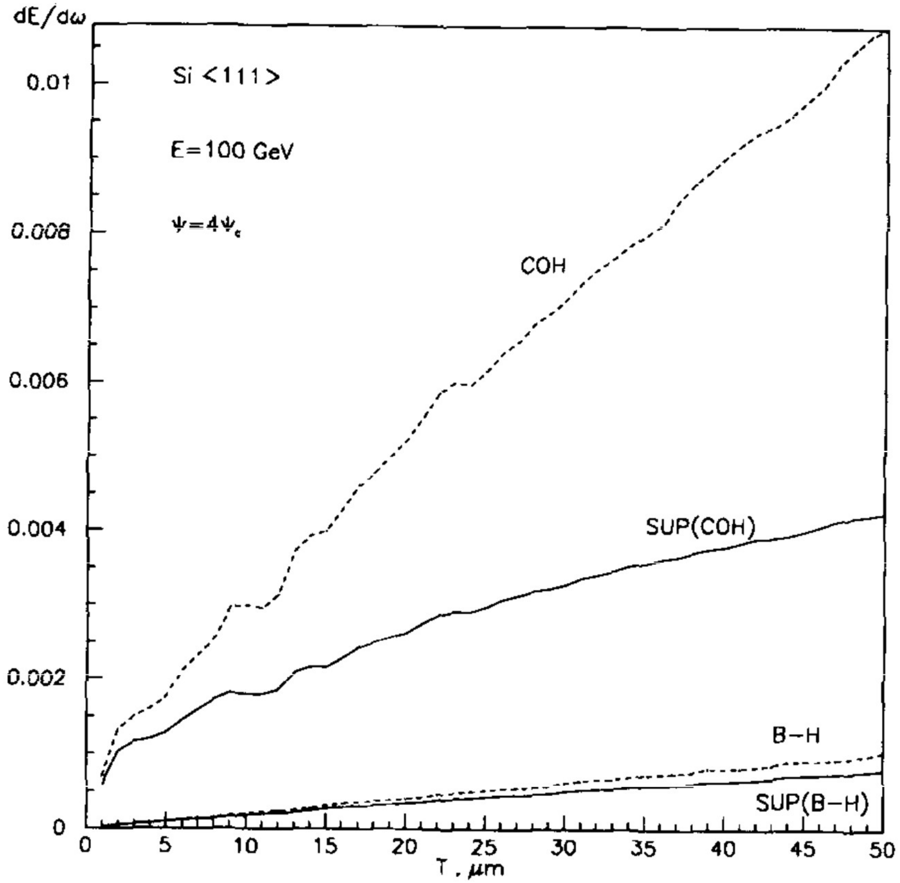
$$\left\langle\frac{dE}{d\omega}\right\rangle_C \approx \frac{R}{8\psi a}\frac{dE_{BH}}{d\omega}, \quad \gamma^2\theta_{cr}^2 \ll 1, \qquad \frac{dE_{BH}}{d\omega} = \frac{4}{3}\frac{T}{X_0}$$

$$\left\langle\frac{dE}{d\omega}\right\rangle_C \approx \frac{2e^2}{\pi}\left[\ln\left(\frac{R}{8\psi a}\gamma^2\theta_{am}^2\right)-1\right], \quad \gamma^2\theta_{cr}^2 \gg 1. \qquad \omega \geq \gamma\omega_p$$

TSF effect in a thin crystal: axial orientation

S. Fomin, A. Jejcic, J. Maillard, N. Shul'ga, J. Silva, NIM B, 115 (1996) 375; 119 (1996) 59.



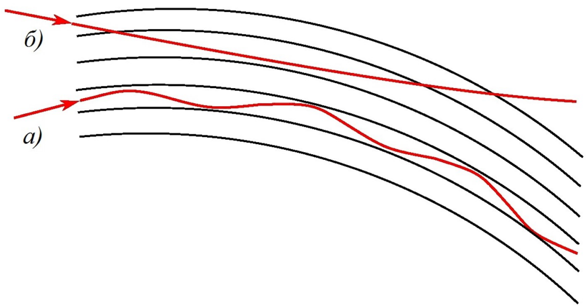


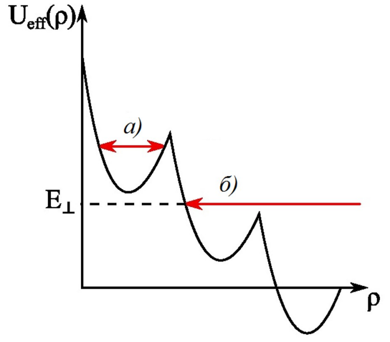
TSF effect in a thin crystal: volume reflection

A. Taratin, S. Vorobyov, Phys. Lett. A, 119 (1987) 425.

$\theta_0 = 62\ \mu\text{rad}$

$\theta_B = \dfrac{L}{R_B}$





$$\theta_L = \sqrt{\frac{2U_0}{\varepsilon}},$$

$$U_0 = 2\pi n d a_{TF} Z e^2$$

Computer simulations

E = 300 GeV

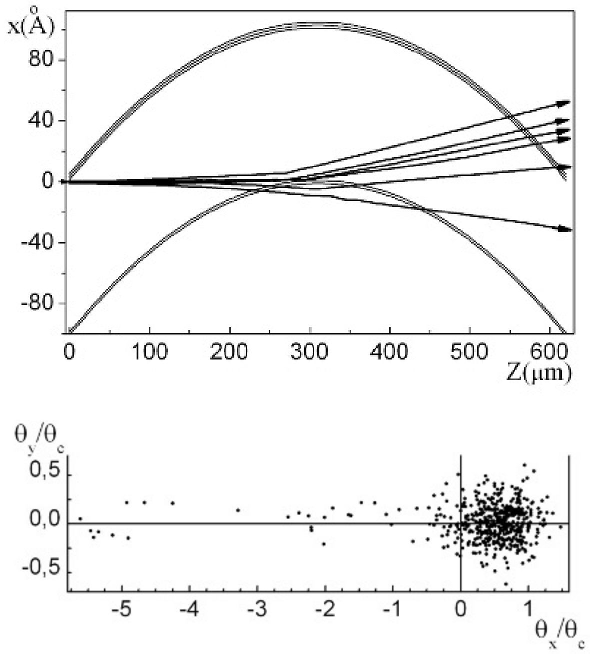
Si (110)

L = 0.62 mm

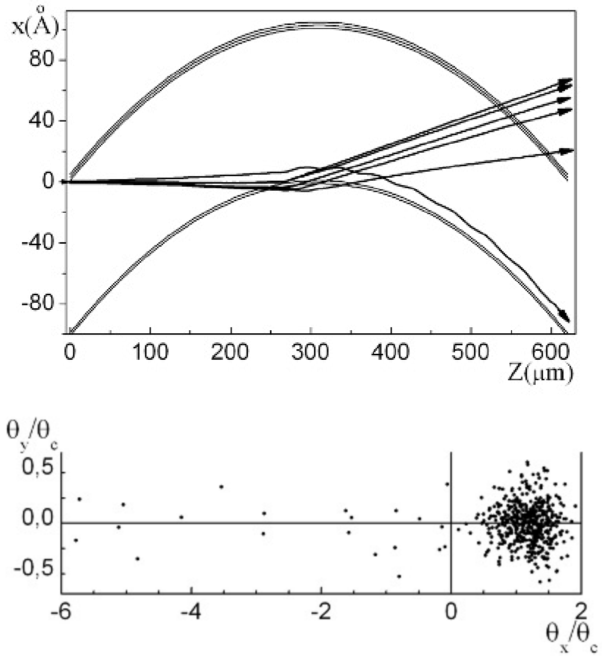
R = 500 m

$\theta_c \equiv \theta_L$

electrons



positrons

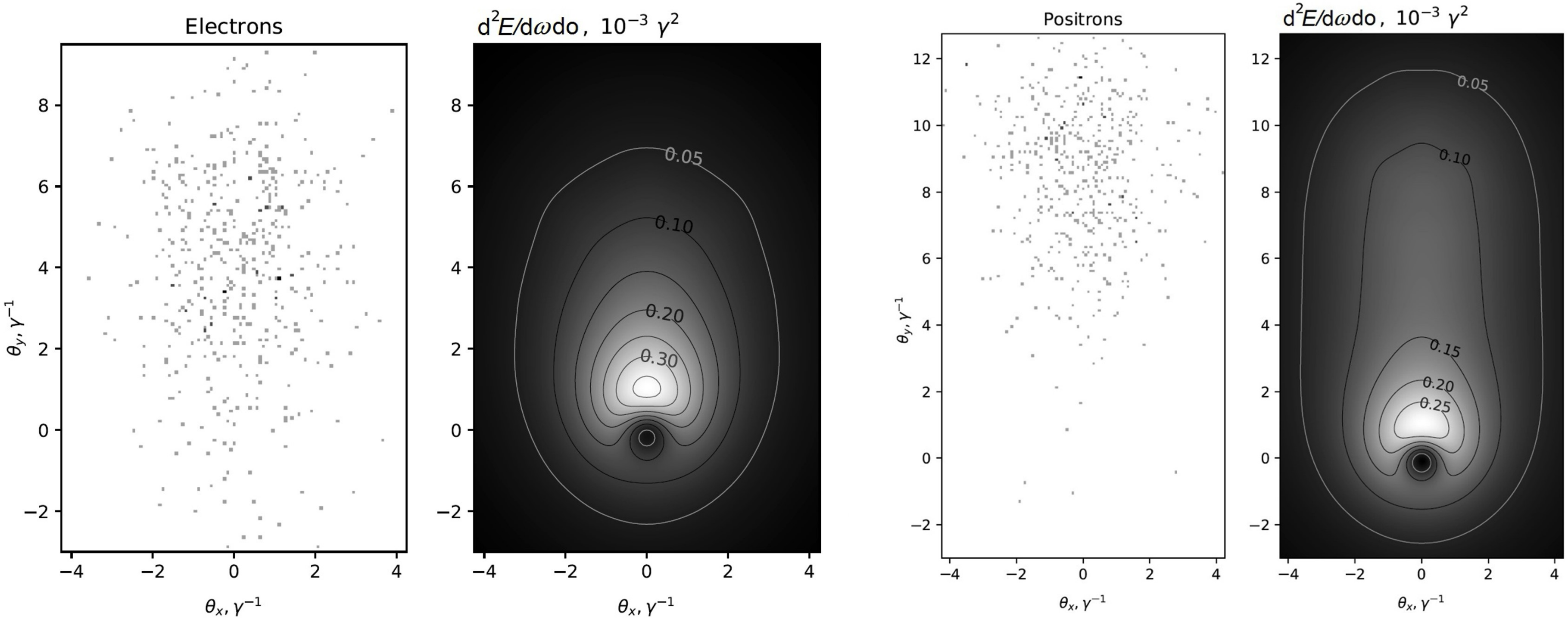


TSF effect in a thin crystal: volume reflection

S. Fomin, M. Malovytsia, V. Truten', N. Shul'ga, East European Physical Journal (2024) in print.

$$\gamma\theta_L \geq 1 \ \& \ T \leq l_c$$

$$\theta_L \approx 16\,\mu\text{rad} \qquad \gamma\theta_L \approx 8$$



TSF effect in a thin crystal: volume reflection

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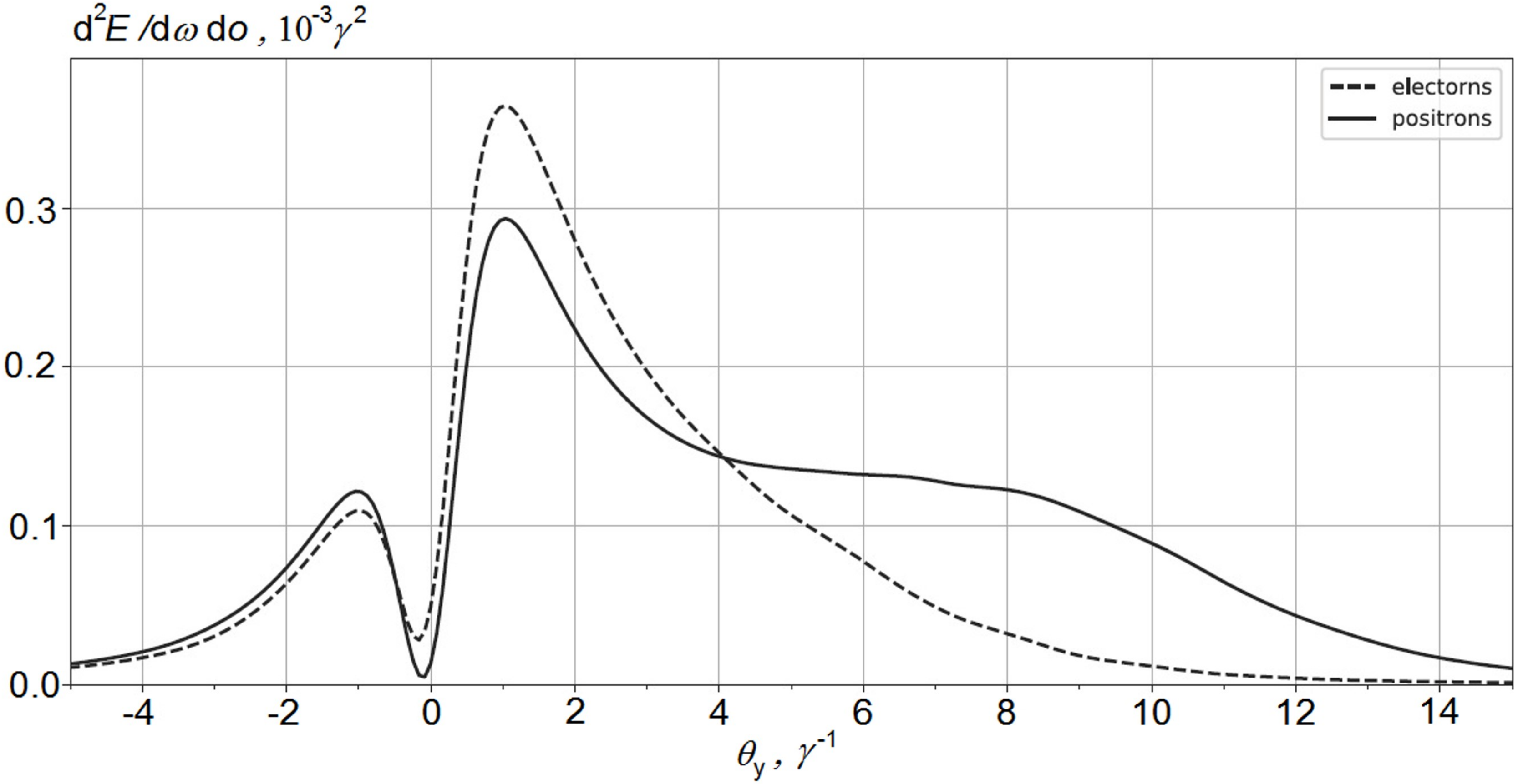

Thank you for attention !