Spatial-Angular Distributions of Relativistic Electrons Under Channeling in Half-Wave Crystals and Corresponding Radiation

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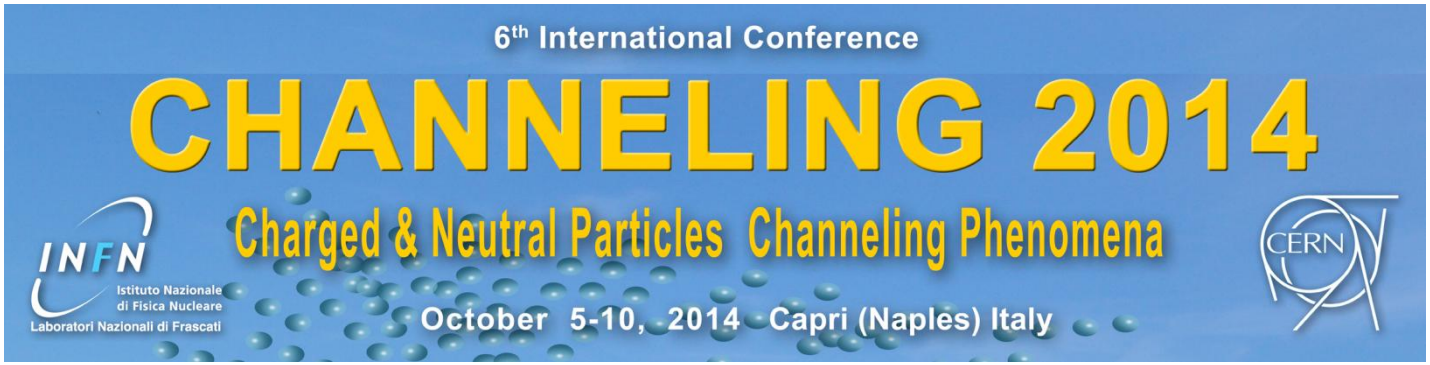


Outline

- Motivation
- Experimental results on channeling in HWC and comparison with computer simulation
- Simulation results of channeling radiation spectra in HWC

Motivation

- Suggestion that straight half-wave crystal (HWC) may serve for particle deflection, due to effect of particle "mirroring" was made in (E.Tsyganov, A.Taratin, Nucl. Instrum. Methods Phys. Res., Sect. A, 363 (1995) 511.) The effect occurs for positively charged particles because of a peculiarity of their dynamics.
- The hypothesis of particle mirroring was proven in (V. Guidi, A.Mazzolari, D. De Salvador and L. Bacci, Phys. Rev. Lett. (2012), 108, 014801) where authors experimentally demonstrated that channeled 2 MeV protons were mirrored by a HWC - ultra-thin silicon unbent crystal.
- In the letter (W. Scandale et al. Physics Letters B734 (2014) 1–6) was demonstrated that the effect of mirroring holds with ultra relativistic 400GeV/c protons in a suitably sized silicon crystal.

Motivation

- Since 2011 at SAGA LS facility & Tomsk Polytechnic University we perform experimental and theoretical studies on interaction of relativistic electrons with crystals (see e.g. Y.Takabayashi, Yu.L. Pivovarov,T.A. Tukhfatullin Phys. Lett. A378 (2014) 1520 and References therein)
- In our work (Yu.L. Pivovarov and T.A. Tukhfatullin, Journ. of Phys. Conf. Ser. 517 (2014)) we performed the detailed computer simulations of channeling in HWC of relativistic light charged particles (electrons\positrons)
- Recently the new experiments on channeling of 255 MeV in a HWC were performed at SAGA LS facilities
- Here we present the experimental results on channeling in HWC and comparison with computer simulation
- Also the simulation of channeling radiation spectra in HWC is performed.

SAGA Light Source (SAGA-LS)

Operated by Saga Prefecture in Japan

In 2004, the accelerators were completed.

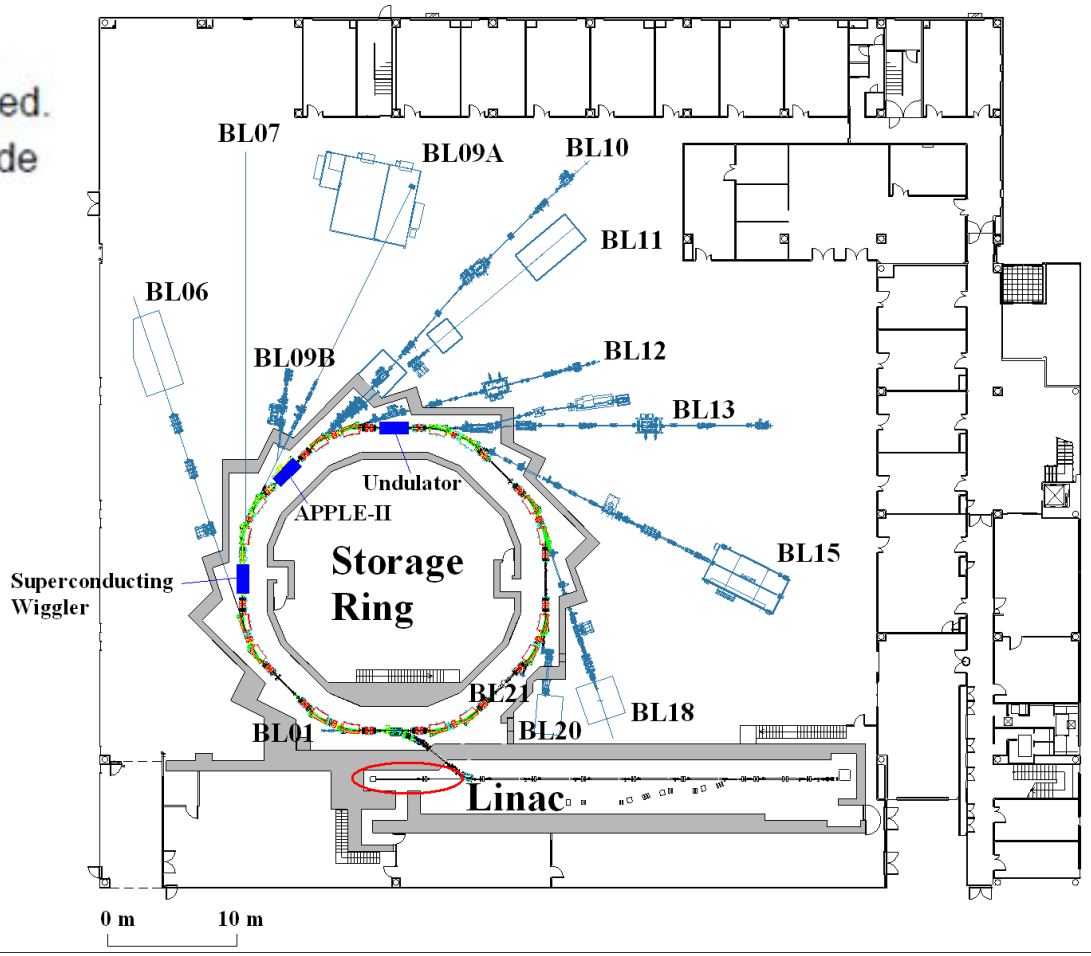
In 2006, the SAGA-LS started user-mode operation.

Storage Ring

Circumference	75.6 m
Energy	1.4 GeV
Stored Current	300 mA
Emittance	25 nm·rad
Lifetime	~7 hours @300 mA
Critical Energy	1.9 keV

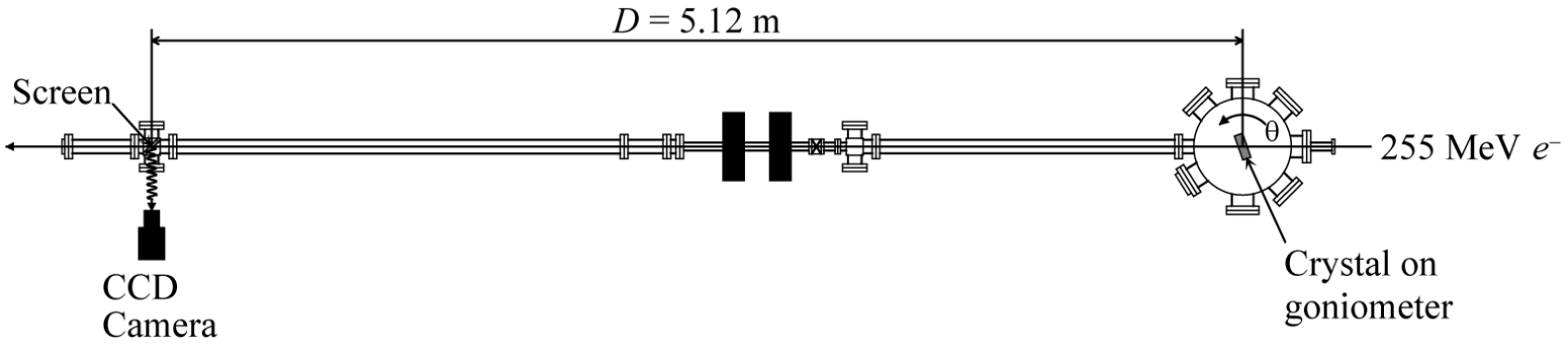
Injector Linac

Total Length	30 m
Energy	255 MeV
Average Current	12 nA
Repetition	1 pps



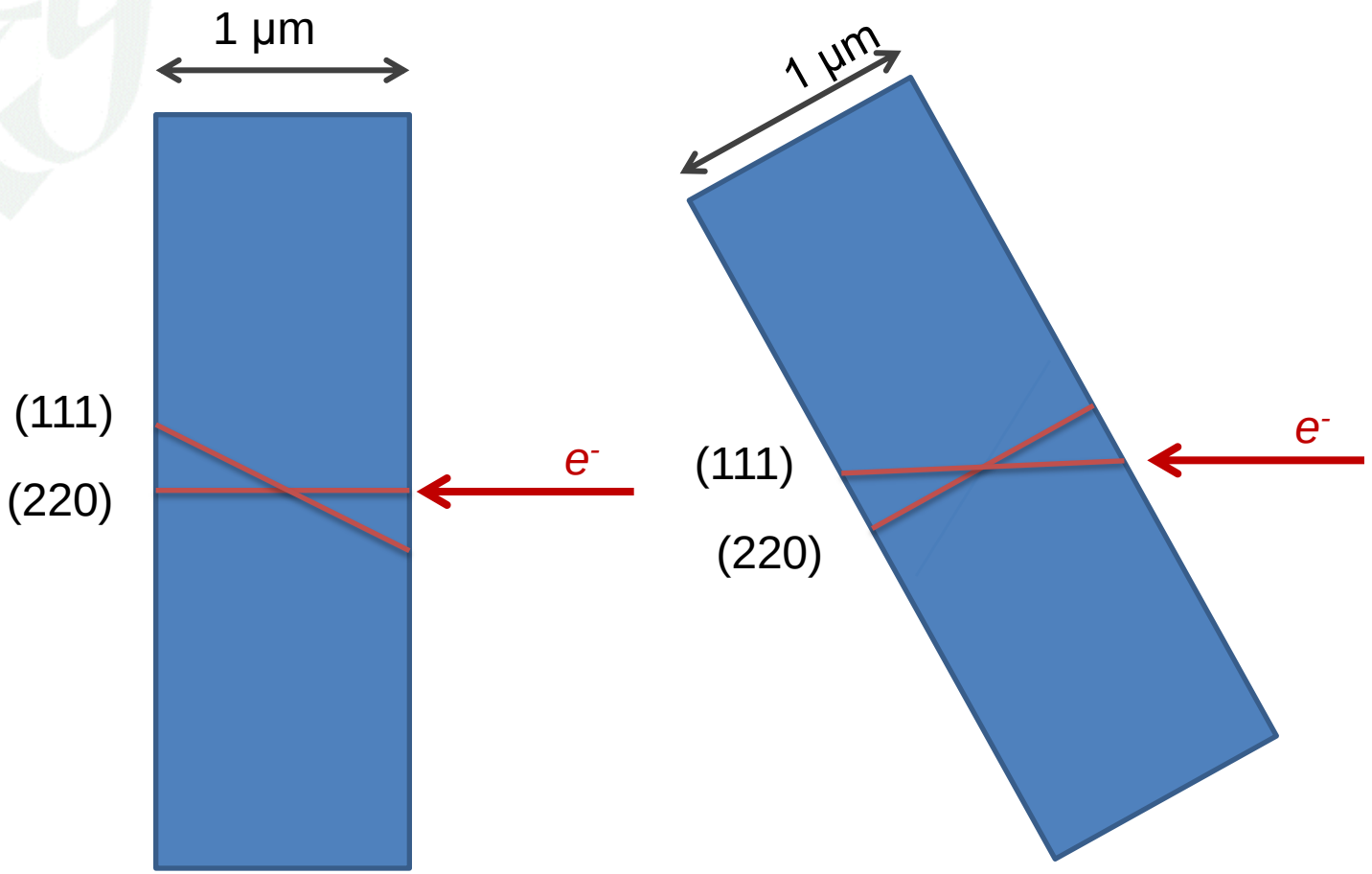
SAGA Light Source, 8-7 Yayoigaoka, Tosu, Saga 841-0005, Japan

Planar Channelling Experiments in Si



- (220) and (111) channeling of 255 MeV e^- in 1-μm-thick Si crystal
- Beam sizes at the crystal:
  $\sigma_x \cong 0.3$ mm (horizontal) and $\sigma_y \cong 0.9$ mm (vertical)
- Angular divergences of the incident beam at the crystal:
  $\sigma'_x \cong 0.1$ mrad (horizontal) and $\sigma'_y \cong 0.1$ mrad (vertical)
- The distance from the crystal to the screen was $D = 5.12$ m.

Planar Channeling Experiments in Si



The effective target thickness for (111) direction
$L_{eff} = L/\cos(35.3°) = (1\ \mu m)/\cos(35.3°) = 1.2\ \mu m$.

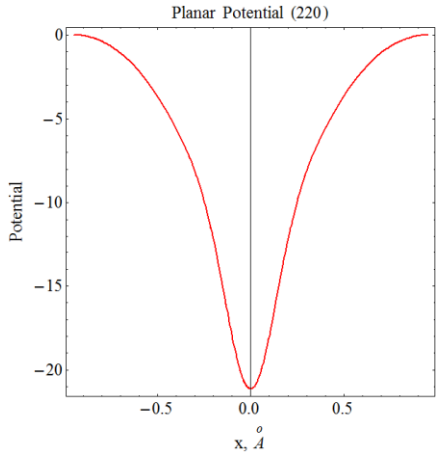
Half-Wave Crystal

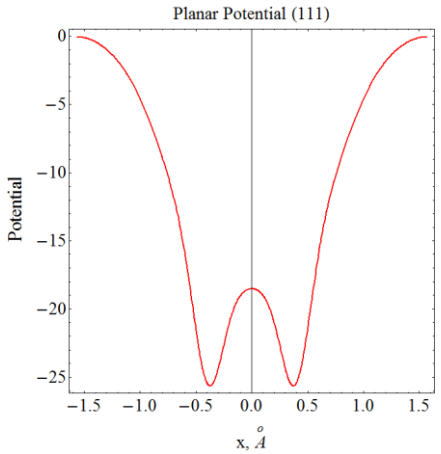
If the planar potential is close to harmonic (this is the case for positively charged particles), the wavelength of planar-channeling oscillation

$$\lambda = \pi \frac{d_p}{\theta_c},$$

$$\theta_c = \sqrt{\frac{2U_0}{E}},$$

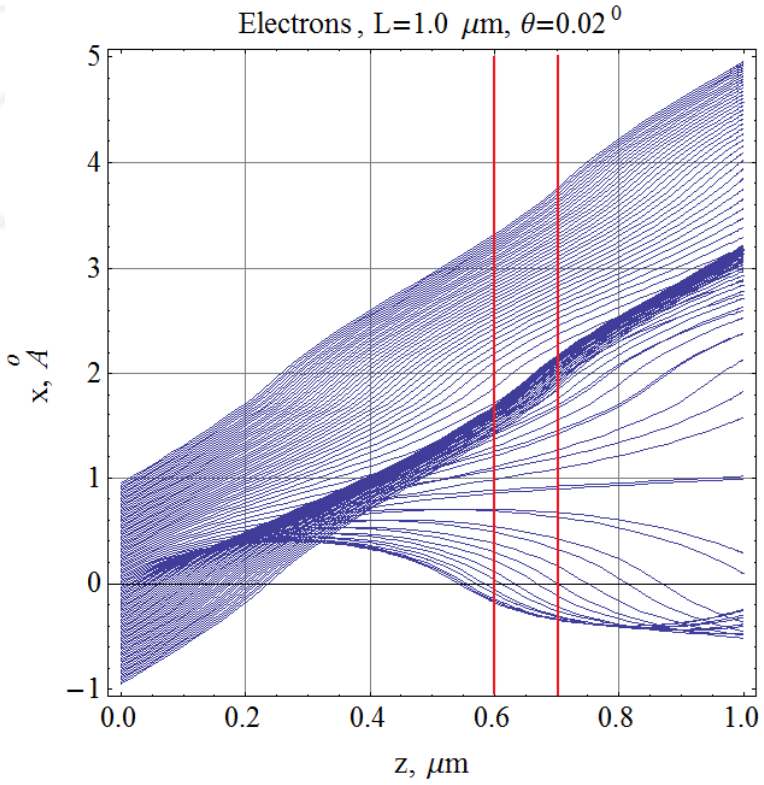
	d_p	θ_c	λ	$\lambda/2$
(220)	1.92 Å	0.43 mrad	1.4 μm	0.7 μm
(111), wide	3.13 Å	0.48 mrad	1.5 μm	0.8 μm
(111), narrow	0.78 Å	0.27 mrad	0.9 μm	0.5 μm



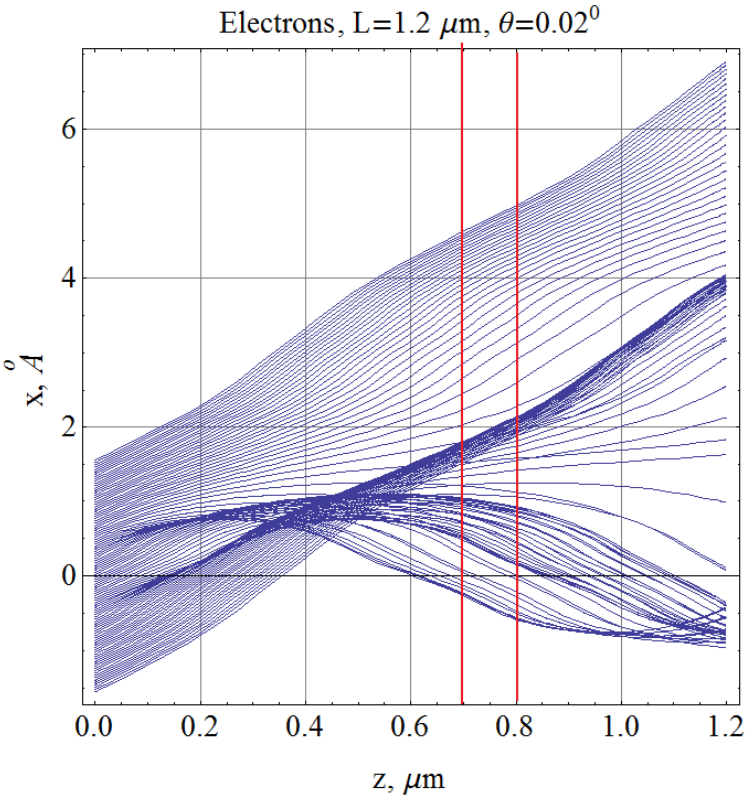


V.M.Biryukov, Y.A. Chesnokov, V.I.Kotov, Crystal Channeling and Its Application at High-Energy Accelerators, Springer-Verlag, Berlin and Heidelberg, 2010.

Half-Wave Si Crystal 255 MeV electrons



0.6-0.7 μm for (220) plane

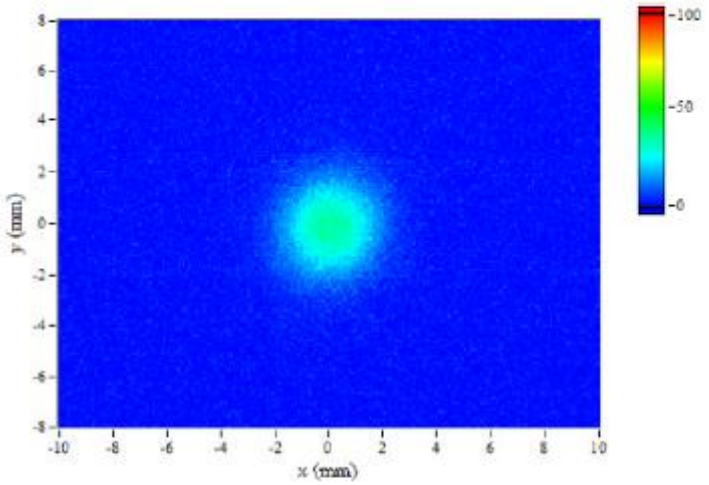


0.7-0.8 μm for (111) plane

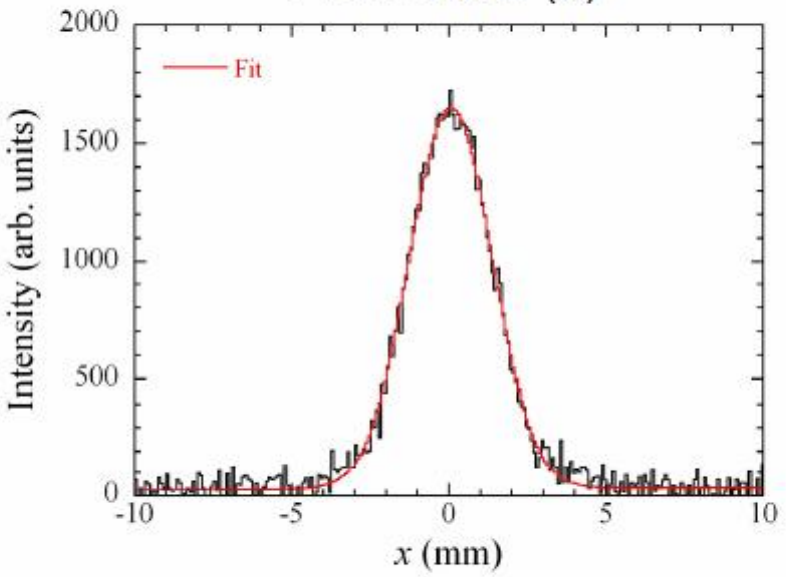
Bogdanov O. V., Fiks E. I., Korotchenko K. B., Pivovarov Yu. L. and Tukhfatullin T. A. Basic channeling with Mathematica©: A new computer code// J. Phys.: Conf. Ser. V. 236, 1, 2010, 012029

Data Analysis

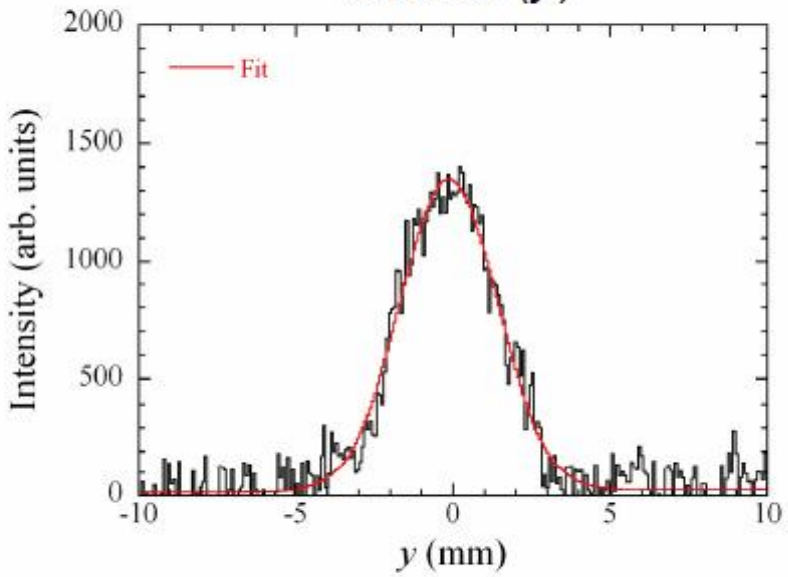
$(\theta, \phi) = (0°, 0°)$



Horizontal (x)



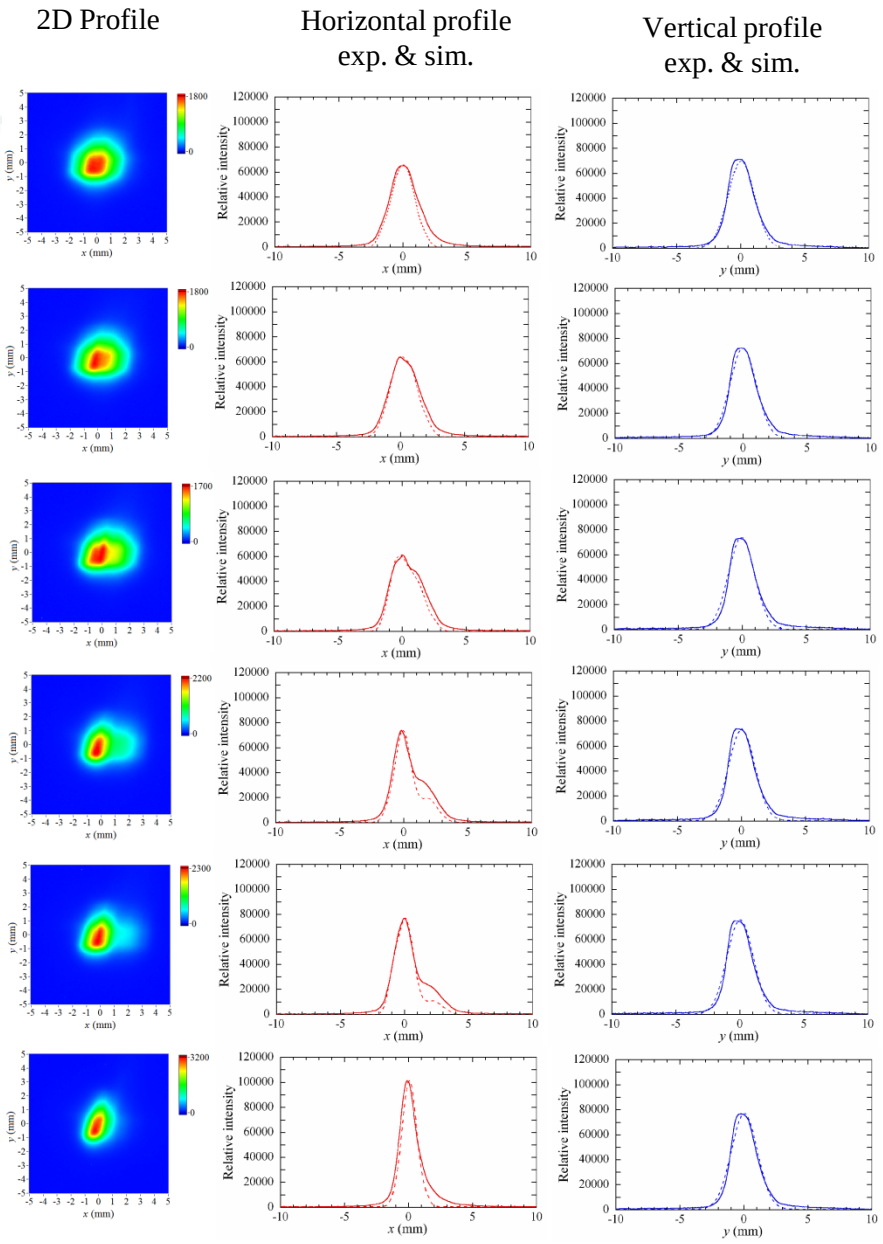
Vertical (y)



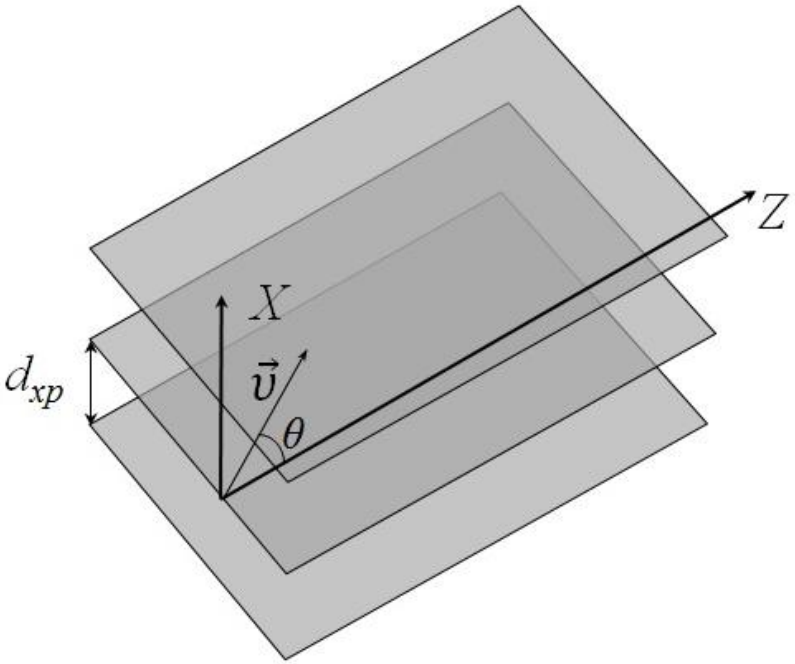
$$I_x = I_{0,x} \exp\left[-\frac{(x - x_{peak})^2}{2\sigma_x^2}\right] + a_x x + b_x$$

$$I_y = I_{0,y} \exp\left[-\frac{(y - y_{peak})^2}{2\sigma_y^2}\right] + a_y y + b_y$$

(220) Planar Channeling Experiment & Simulation



Trajectories Simulation



- Equation of motion

$$\gamma m\ddot{x} = F_x = -\frac{\partial U(x)}{\partial x},\ \gamma m\ddot{z} = 0$$

- Initial conditions

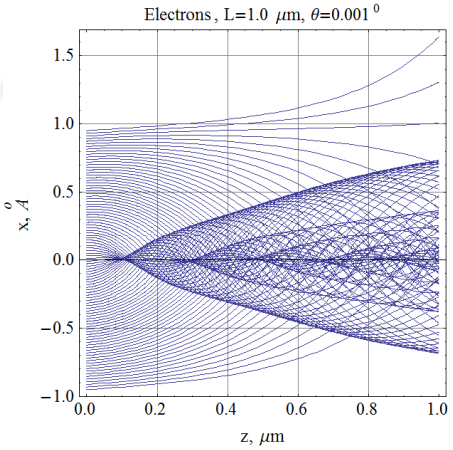
$$x(0) \equiv x_0$$

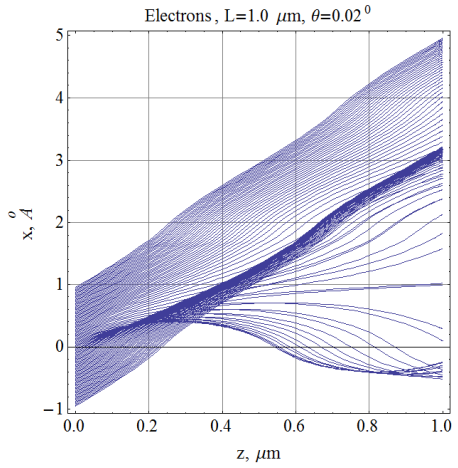
$$\upsilon_x(0) = c\sqrt{1-\frac{1}{\gamma^2}}\sin(\theta)$$

Bogdanov O. V., Fiks E. I., Korotchenko K. B., Pivovarov Yu. L. and Tukhfatullin T. A. Basic channeling with Mathematica©: A new computer code// J. Phys.: Conf. Ser. V. 236, 1, 2010, 012029

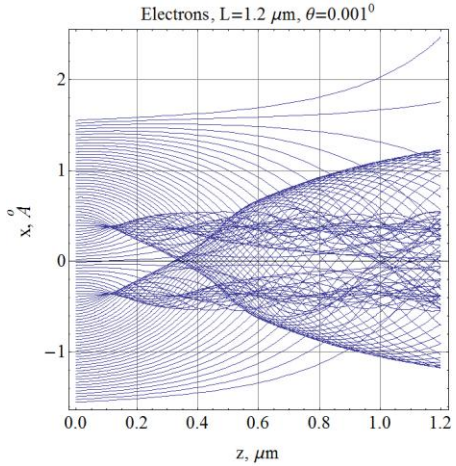
Channeling of 255 MeV e- in 1-μm-thick Si Crystal. Typical Trajectories

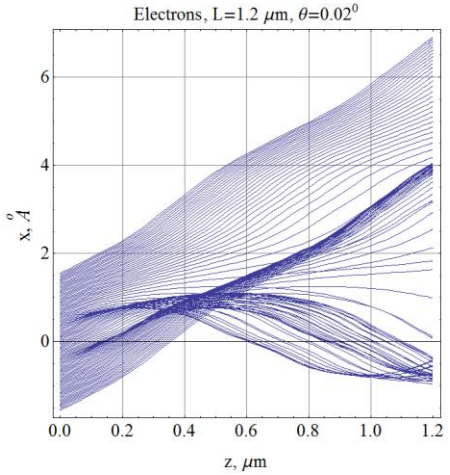
(220) plane





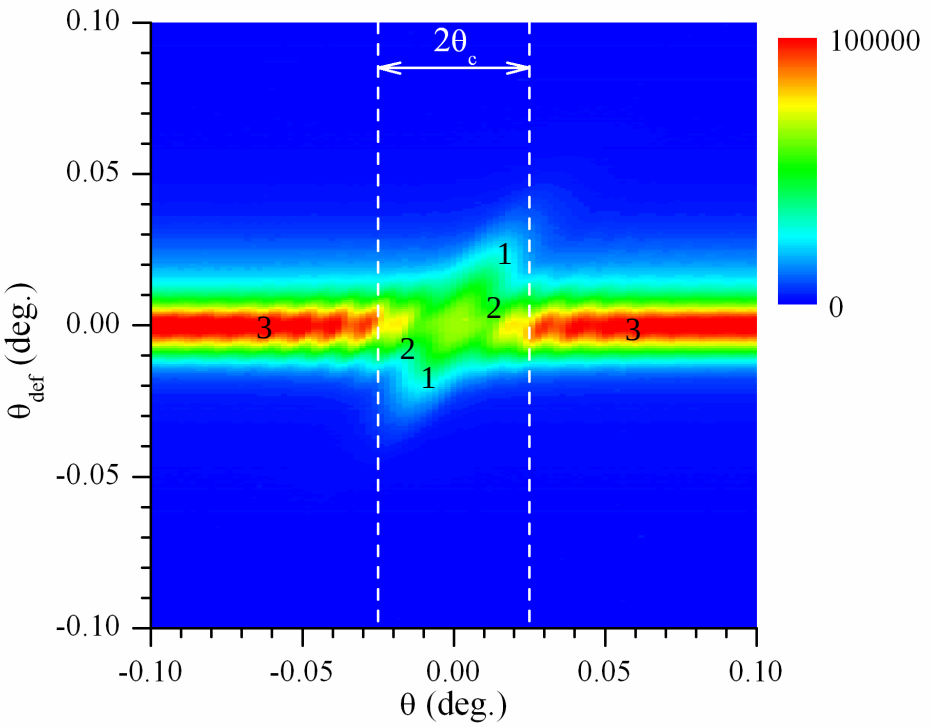
(111) plane



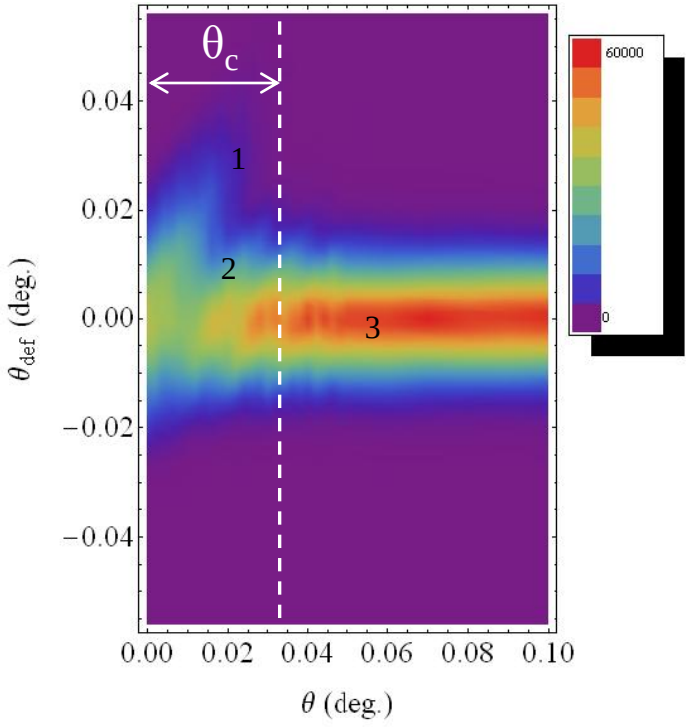


Beam Intensity Distribution as a Function of θ and θ_{def}

Experiment



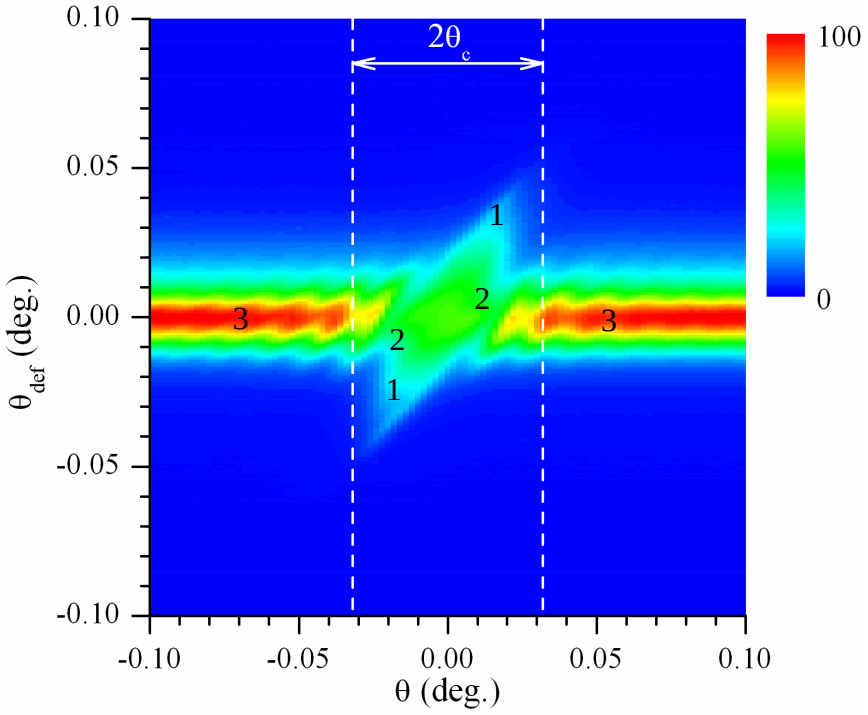
Simulation



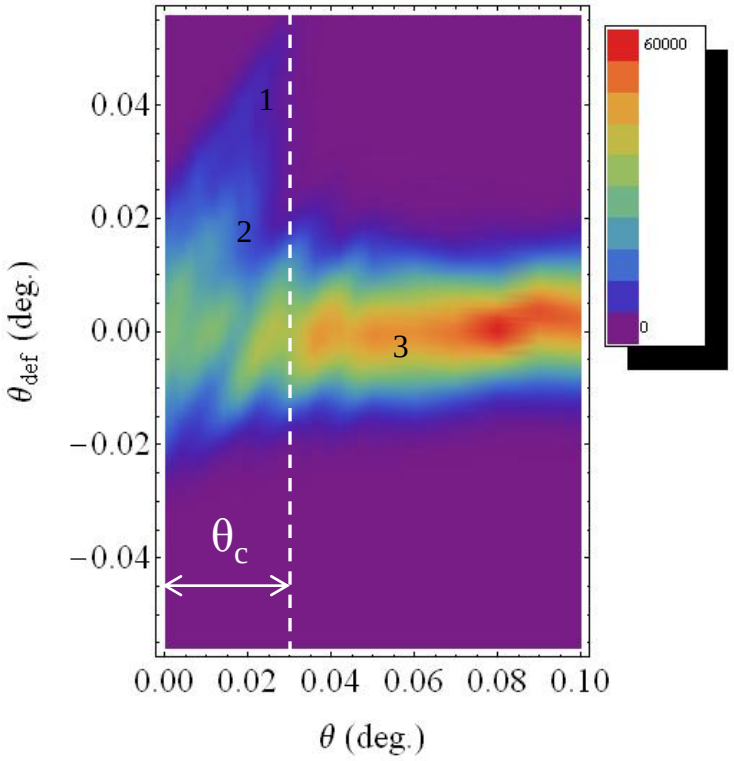
Plane (220), d_p=1.92 Å, θ_c=0.025°=0.43 mrad

Beam Intensity Distribution as a Function of θ and θ_{def}

Experiment



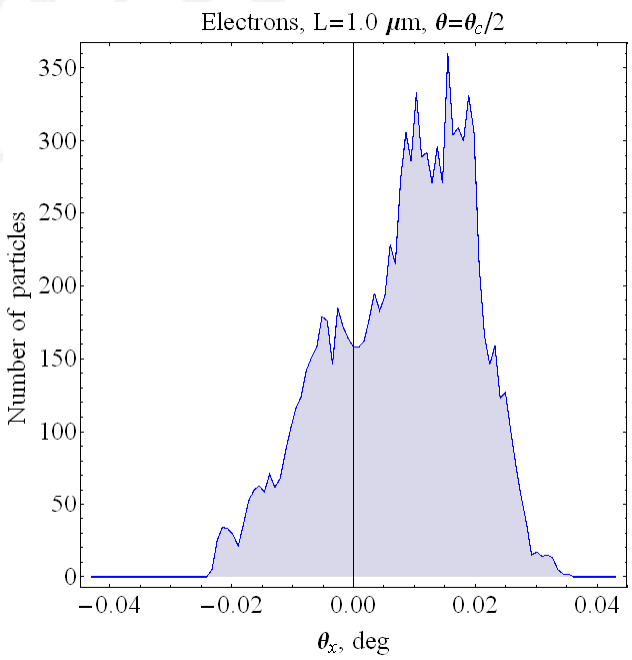
Simulation



Plane (111), d_p=3.14 Å, θ_c=0.026°=0.45 mrad

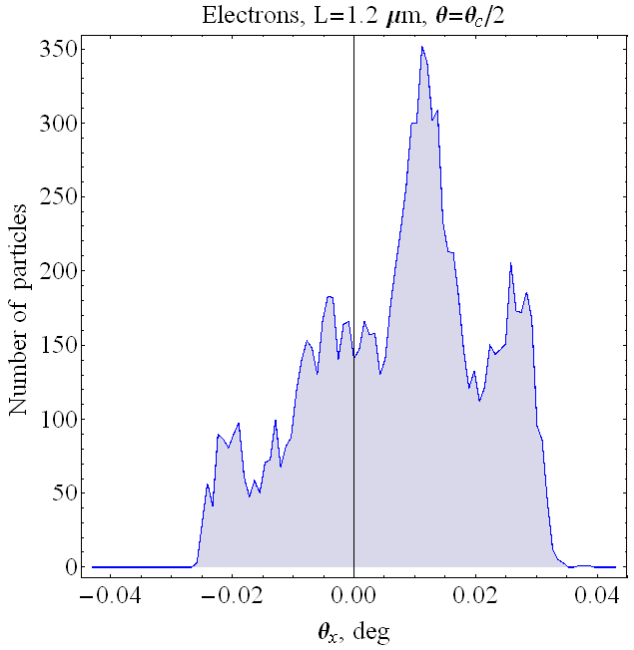
Deflection Efficiency for $\theta=\theta_c/2$

$$\varepsilon = N(\Delta\theta > 0)/N_{tot}$$



$$\varepsilon = 0.57$$

Plane (220), d_p=1.92 Å, θ_c=0.025°=0.43 mrad



$$\varepsilon = 0.62$$

Plane (111), d_p=3.13 Å, θ_c=0.026°=0.45 mrad

Spectral Angular Distribution of Electrons Under Channeling in Half-Wave Crystals

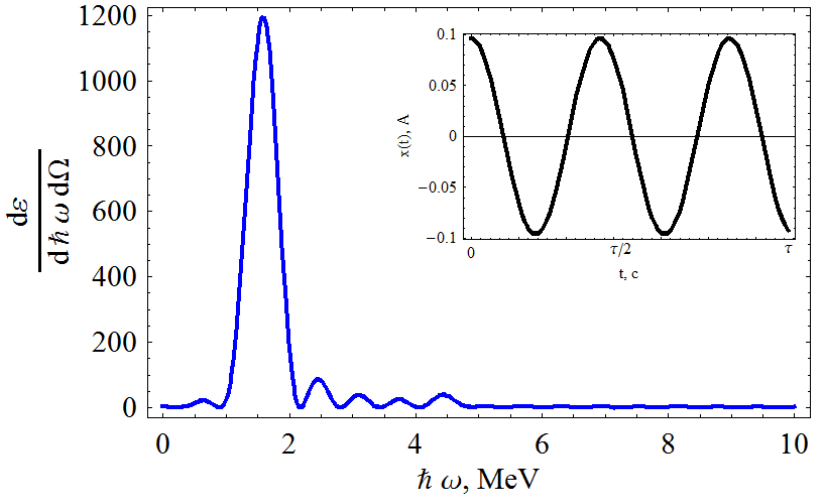
$$\frac{d\varepsilon}{d\Omega d\omega} = \frac{e^2}{4\pi^2 c}\left|\int_0^{\tau} \mathbf{I}(t)\cdot e^{i(\omega t - \mathbf{kr})}dt\right|^2$$

$$\mathbf{I}(t) = \frac{[\mathbf{n}[(\mathbf{n}-\boldsymbol{\beta})\dot{\boldsymbol{\beta}}]]}{(1-\mathbf{n}\boldsymbol{\beta})^2} \qquad \boldsymbol{\beta} = \mathbf{v}/c \qquad \tau = NT + \tau'$$

V. N. Baier, V. M. Katkov, V. M. Strakhovenko, Electromagnetic Processes at High Energies in Oriented Single Crystals. World Scientific Publishing. 1998.
A.I. Akhiezer, N.F. Shul'Ga High Energy Electrodynamics in Matter. Gordon & Breach Publishers. 1996.

Typical Trajectories and Spectral Angular Distribution of Channeling Radiation

Channeling Plane (220), *L*=1 μm, θ=0°

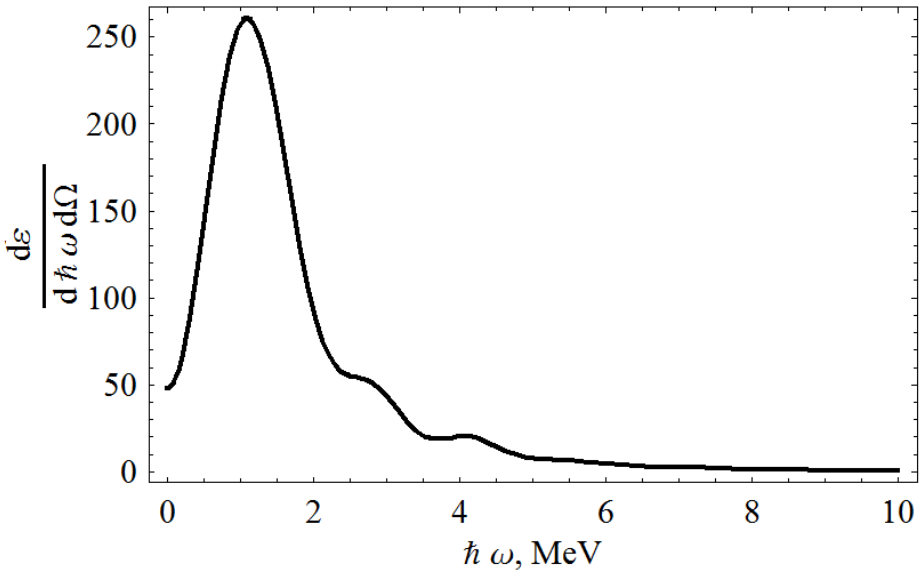


$$E_{\perp} = 3\,\text{eV}$$

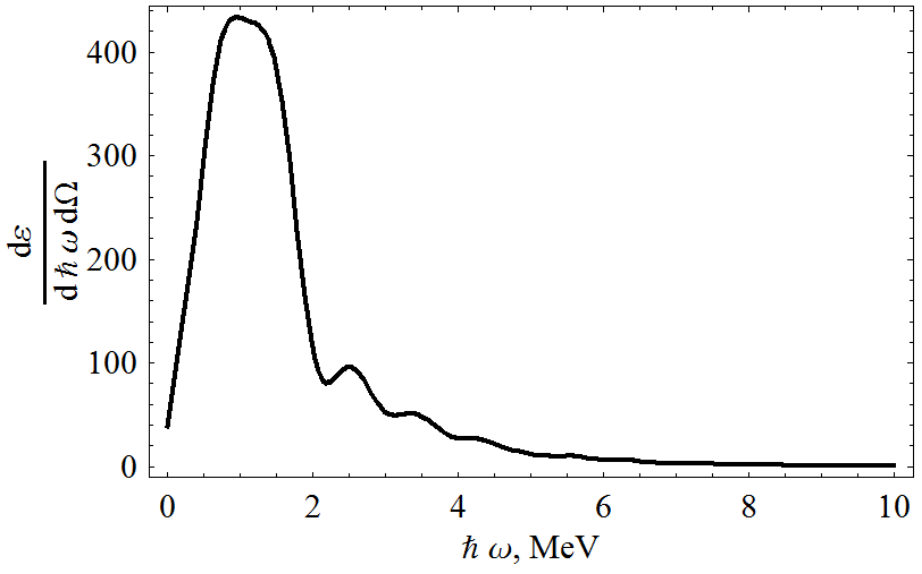
Bogdanov O.V., Pivovarov Yu. L. Formation of spectral characteristics of channeling radiation from 800 to 2000 MeV electrons and positrons in a thin silicon crystal// Nucl. Instr. and Meth. in Phys. Res. B, V 266, 3852-3857 (2008)

Averaged Over Points of Incidence Spectral Angular Distribution of HWC Channeling Radiation

Channeling Plane (220), $\theta_0=0^o$



***L*=0.6 μm, $\theta_0=0^o$**



***L*=1.0 μm, $\theta_0=0^o$**

Conclusions

- The new experiments on channeling of 255 MeV in a HWC were performed at SAGA LS facilities
- The simulations of trajectories at (220) and (111) planar channeling in Si, angular, spatial distributions of electrons have been performed taking into account initial spatial and angular divergence of the electron beam
- Comparison of the experimental and theoretical results shows a good agreement
- Half-Wave Crystals can be used for mirroring of relativistic electrons. Achievable deflection angle through the mirror effect is of the order of θ_c
- The simulation of the spectral angular distribution of HWC channeling radiation of electrons is performed

Future plans (Collaboration SAGA-LS – Tomsk Polytechnic University Experiment & Theory)

- Further studies of penetration and radiation of 255 MeV electrons in a HWC (more thin as used in the present experiment) Si crystal
- Further studies of Parametric X-Ray Radiation (PXRC) & search for Diffracted Channeling Radiation (DCR) from channeled electronsм (probably, using different electron beam energies)
- Experimental studies of Quantum Jumps in Channeling Radiation (see, the Poster presented by K.Korotchenko at this Conference) using varying electron beam energy
- Continuation of experimental (first run recently completed, see the Poster at this Conference) & theoretical investigations of the Cherenkov radiation from 255 MeV electrons in a diamond crystal (probabli, in a LiF crystal): random and aligned crystal (Cherenkov at Channeling - oral talk presented by O.Bogdanov, E.Fiks & Yu.Pivovarov) , another geometry - exploiting total internal reflection (similar to DIRC detectors) ==> precision studies of the fundamental properties of Cherenkov Radiation
- Exotics: angular momentum of channeling radiation from relativistic electrons in a HWC (X-Ray region !) - theory and proposal of experiment

Thank you for your attention !