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Interference Effects in Angular and Spectral Distributions of X-Ray Transition Radiation from Relativistic Heavy Ions Crossing a Plate: Influence of Absorption and Slowing-Down

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Influence of slowing-down on the spectral and angular distribution of Cherenkov radiation:

[1] Fiks E.I., Bogdanov O.V. and Pivovarov Yu.L. // Journal of Physics: Conference Series, 2012, Vol. 357, p. 1.

[2] O. V. Bogdanov, E. I. Fiks, Yu. L. Pivovarov // J. Exp. Theor. Phys. 115 No. 3 (2012) 392.

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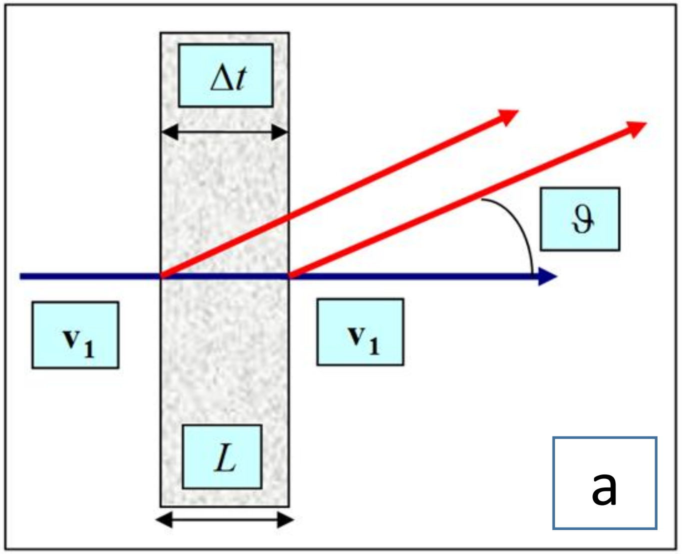
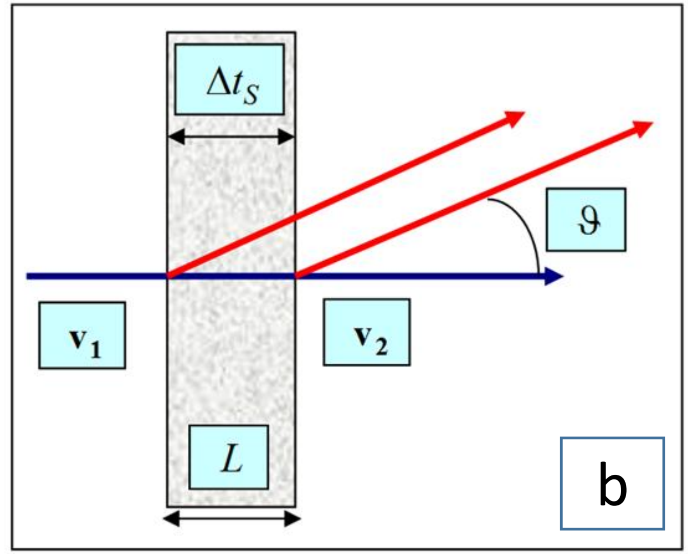
Taking account of Relativistic Heavy Ions (RHI) slowing-down in a plate leads to additional broadening and appearance of the specific diffraction-like structures in both spectral and angular distributions of Cherenkov Radiation (ChR) [1-5] compared to the standard Tamm-Frank theory (without taking account of RHI slowing-down).

TR from a plate: schematics of generation





- In the standard theory of X-Ray Transition Radiation (X-Ray TR) [1-3] there arise two interfering waves emitted at entrance and exit of the plate by a charged particle crossing a plate of thickness L with a constant velocity v_1. The first X-Ray TR wave is partially absorbed on the way to exit from a plate. Δt – RHI penetration time through a plate.

[1] Ginzburg V.L., Tsytovich V.N., Transition Radiation and Transition Scattering, Adam Hilger, Bristol and New York, 1990.
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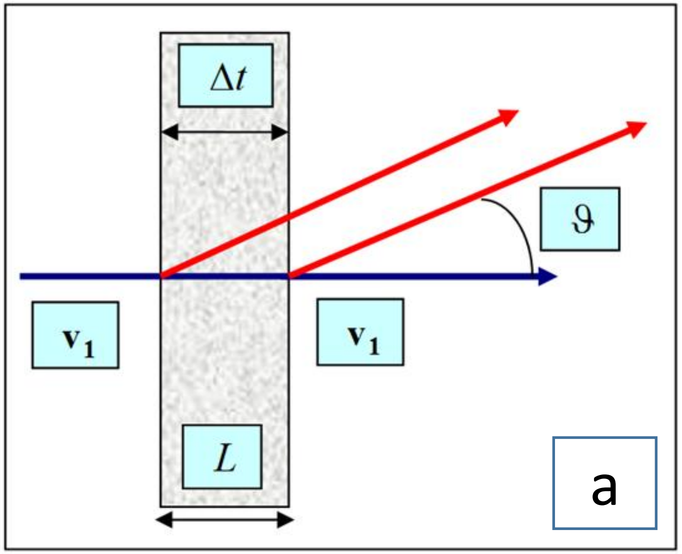
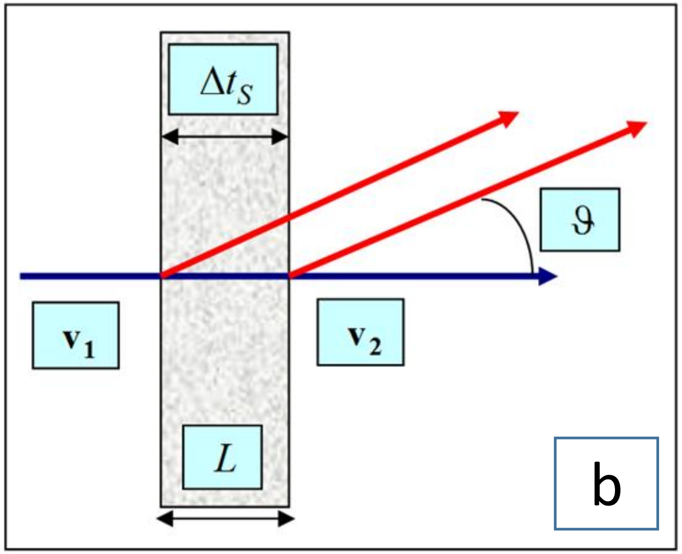
TR from a plate: schematics of generation





- In the case of RHI an influence of slowing-down (ionization energy loss) is not negligible – the RHI velocity decreases during its penetration through a plate (v2 < v1), therefore the two X-Ray TR waves are emitted at slightly different velocities when crossing the boundaries vacuum-plate and plate-vacuum, respectively. In addition, RHI penetration time in a plate increases: $\Delta t_s > \Delta t$ which changes the phase shift between two TR waves.

All these factors – partial absorption of the first X-Ray TR wave in the bulk of the plate, different velocities at entrance and exit (defining two formation lengths), and extended penetration time – lead to a change of the condition of constructive interference between two X-Ray TR waves compared to the standard (without slowing-down) theory of X-Ray TR in a plate

TR from a plate: general formulae [1]
Constant RHI velocity

$$\boxed{\frac{d^2 W}{d\omega d\Omega} = F_0 \cdot F_1}$$

- Spectral-angular distribution of TR intensity

$$\boxed{F_0(\beta) = \left(\frac{Z^2 \alpha \hbar \omega^2 \sin^2 \vartheta}{16 \pi^2 c^2}\right)\left(\mathrm{L}_0(\beta) - \mathrm{L}_1(\beta)\right)^2}$$

- corresponds to TR from a single interface of a plate

$$\boxed{F_1(\beta) = 1 + \exp\left(-\frac{\mu(\omega) L}{\cos\vartheta}\right) - 2\exp\left(-\frac{\mu(\omega) L}{2\cos\vartheta}\right)\cos\left(\frac{2L}{\mathrm{L}_1(\beta)}\right)}$$

- corresponds to the coherent summation of TR waves emitted at entrance and exit of a plate.

$$L_i(\beta) = \frac{2\beta c}{\omega(1 - \beta\cos\vartheta\sqrt{\varepsilon_i(\omega)})}, i = 0,1$$

- formation length in vacuum and plate material

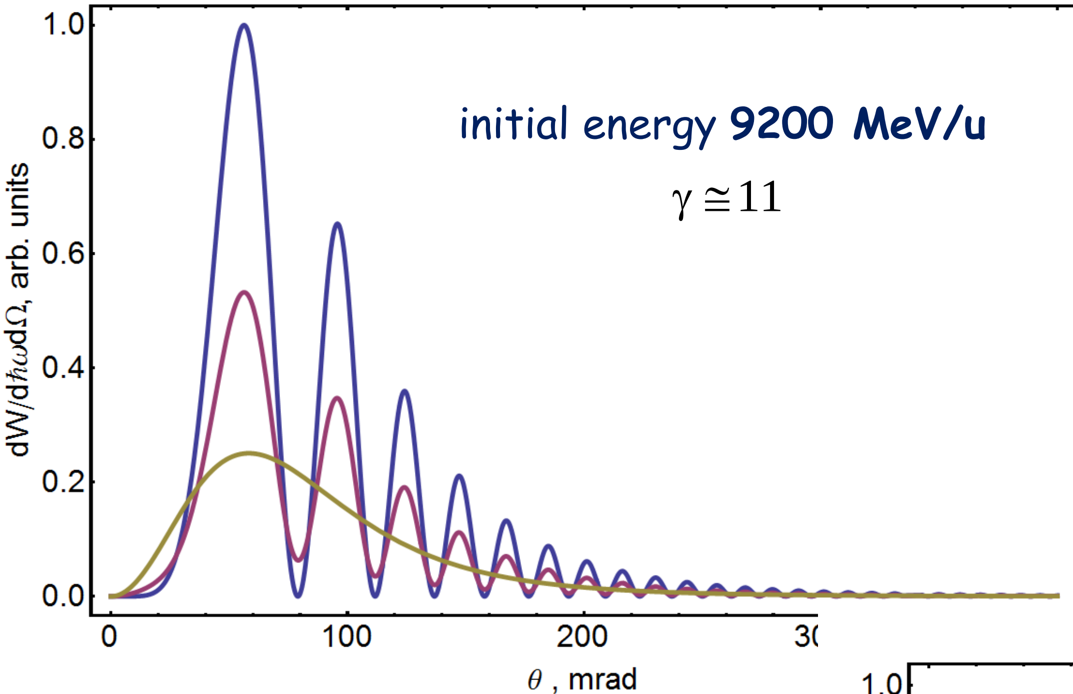
$$\varepsilon_0 = 1 \quad \varepsilon_1(\omega) = 1 - \omega_p^2 / \omega^2$$

- refractive index depending on the radiation frequency

$$\mu(\omega)$$

- X-Ray linear absorption coefficient of a plate material

[1] M. Moran et.al. // Proceedings of RREPS-93, 1993, c. 96.



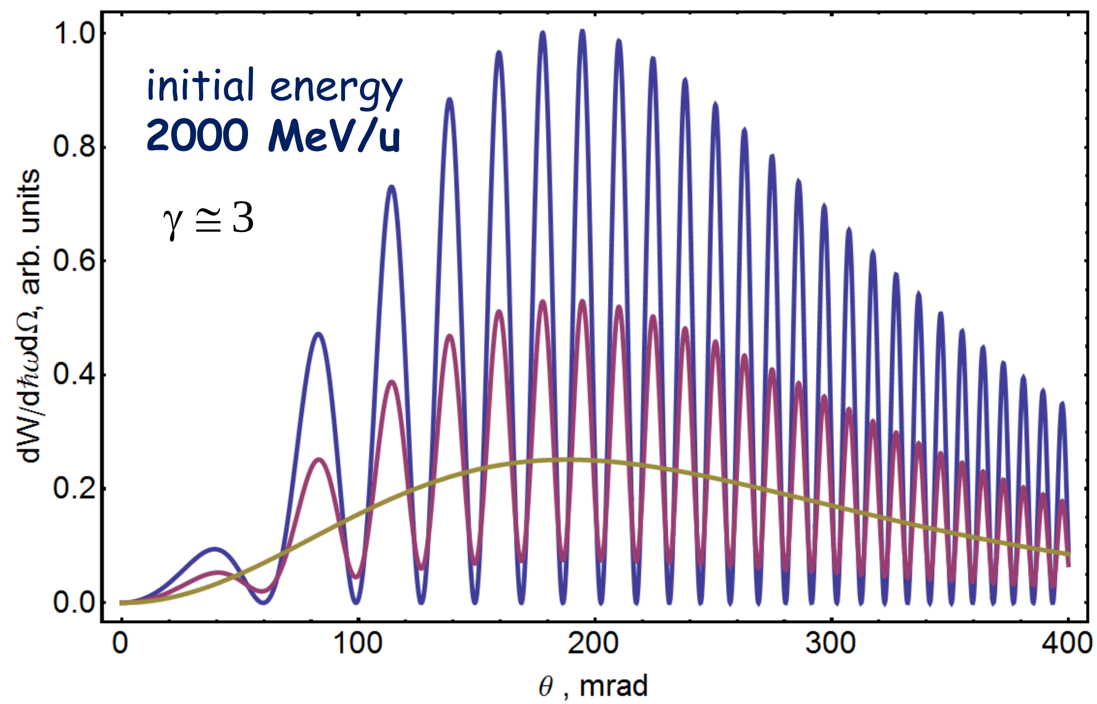
X-Ray TR angular distributions
Constant RHI velocity

$\mu(\omega) \cong 1.55\,\mu m^{-1}$

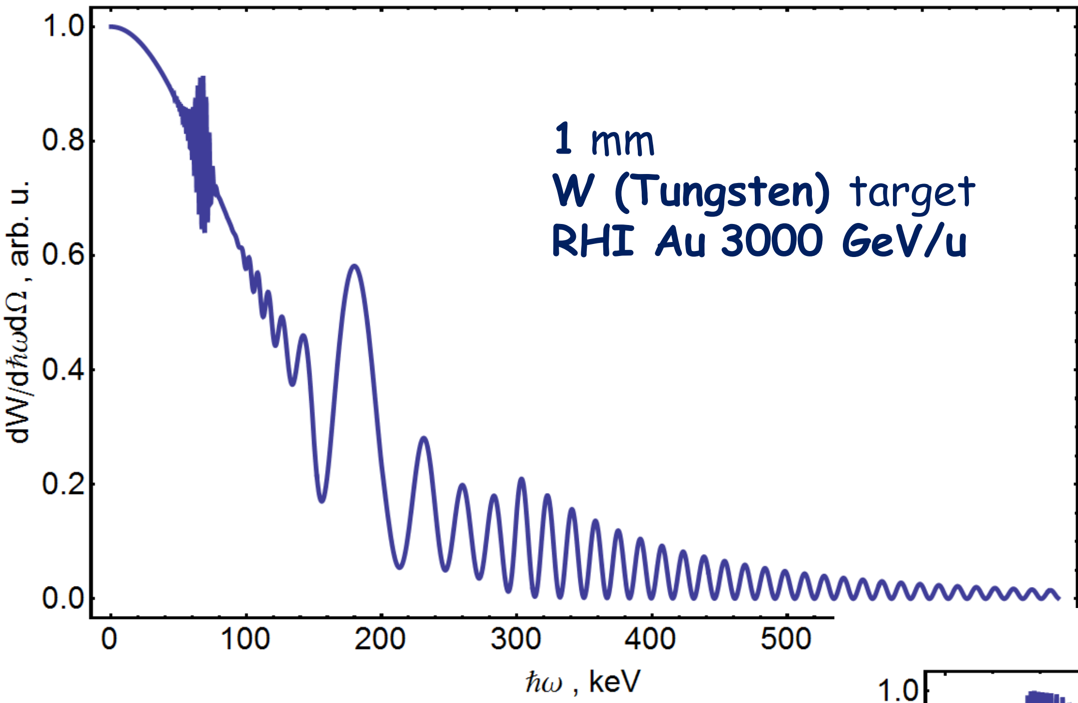
X-Ray TR angular distribution:

- From a plate without taking account of absorption
- From a plate taking account of absorption
- From single interface of a plate

1-μm Be target, RHI **Au**

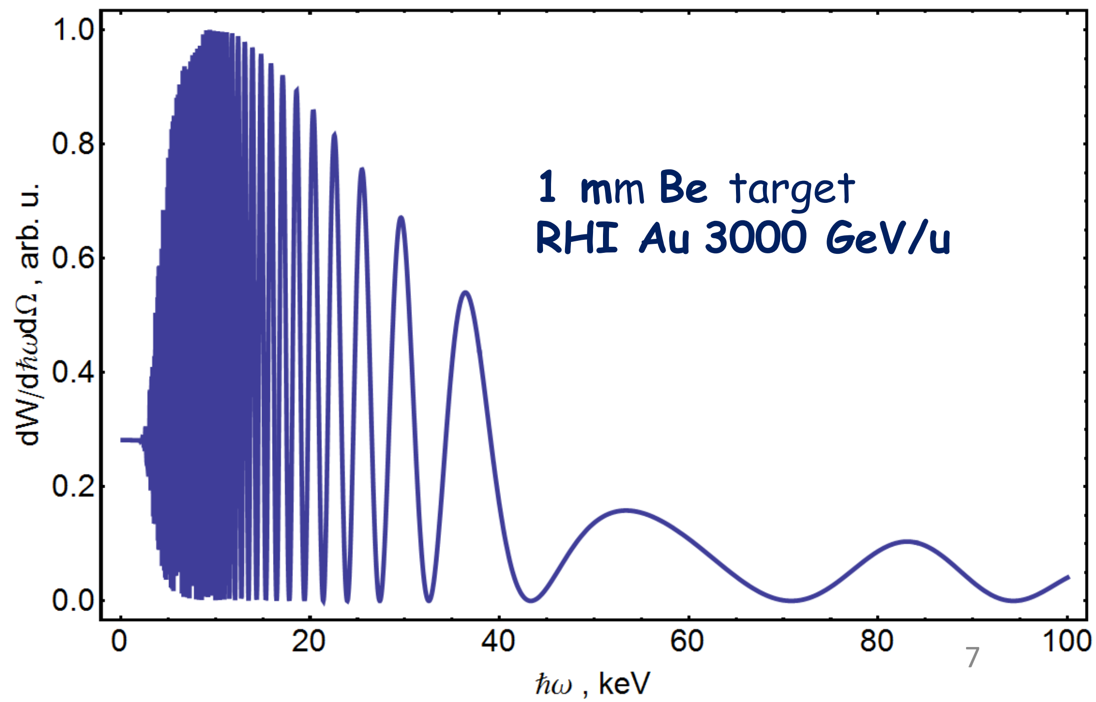


X-Ray TR spectral distribution from a plate:
constant RHI velocity



$\gamma \cong 3000$

emission angle θ=1/ϒ



X-Ray TR spectral-angular distributions Constant RHI velocity

A combination of parameters:

- RHI initial energy
- Plate material and thickness
- Linear absorption coefficient (depends on the plate material)
- X-Ray TR photons energy

define whether the interference effects in X-Ray TR spectral and angular distributions will manifest itself or not.

The X-Ray TR photons absorption leads to the “washing out” of interference structure of X-Ray TR spectral and angular distributions and decreasing of the X-Ray TR intensity.

As our calculations have shown, interferential structure in X-Ray TR spectral distributions appears only at the very high RHI energies.

X-Ray TR from a plate: taking account of RHI slowing-down

Modification of the standard formula:

$$\boxed{\frac{d^2 W}{d\omega d\Omega} = \left(\frac{Z^2 \alpha \hbar \omega^2 \sin^2\vartheta}{16\pi^2 c^2}\right)\left|\left(L_0(\beta_1) - L_1(\beta_1)\right)\exp\left(-\frac{\mu(\omega)L}{2\cos\vartheta}\right) - \left(L_0(\beta_2) - L_1(\beta_2)\right)\exp\left(-i\Delta\varphi\right)\right|^2}$$

$\beta_{1,2} = v_{1,2}/c$ - RHI velocity at entrance and exit from a plate

Slowing-down leads to increasing of the penetration time through a plate: $\Delta t_S = \int_0^L dx/v(x)$

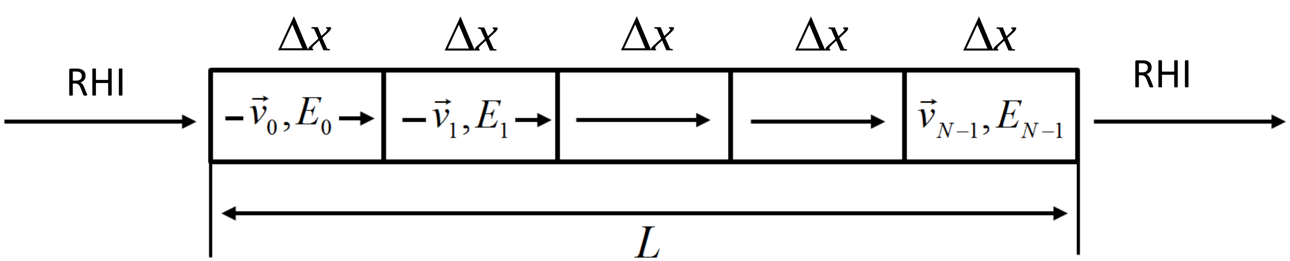
$\Delta\varphi$ - phase shift of the second X-Ray TR wave, calculated taking account of slowing-down

The two effects due to slowing-down are expected: change of constructive interference between two TR waves (due to a change of the phase shift) and a change of emission amplitude at the second (exit) boundary

X-Ray TR from a plate: taking account of RHI slowing-down

$$\Delta\varphi = \omega\left(\Delta t_S - \frac{L}{c}\cos\vartheta\sqrt{\varepsilon(\omega)}\right)$$

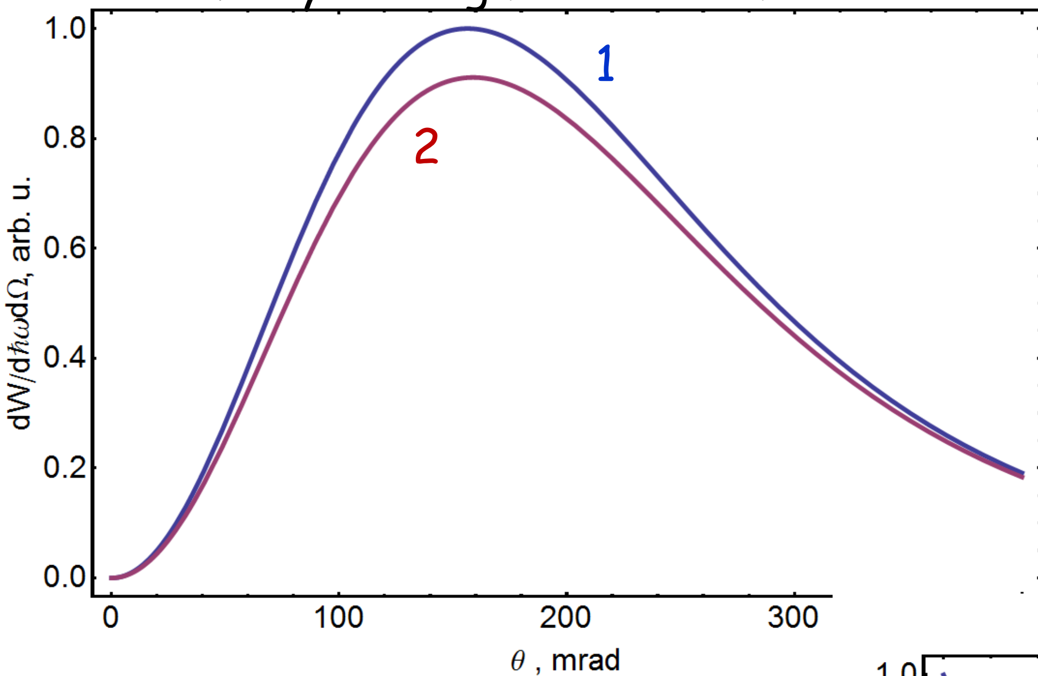
To calculate $\Delta t_S = \int_0^L \mathrm{d}\,x/v(x)$ one can divide a plate into N >> 1 equal slices:



$$\boxed{\Delta\varphi = \omega\left(\sum_{i=1}^{N}\frac{\Delta L_i}{v_i} - \frac{L}{c}\cos\vartheta\sqrt{\varepsilon(\omega)}\right)}$$

$\frac{\Delta L_i}{v_i}$ RHI penetration time through each slice

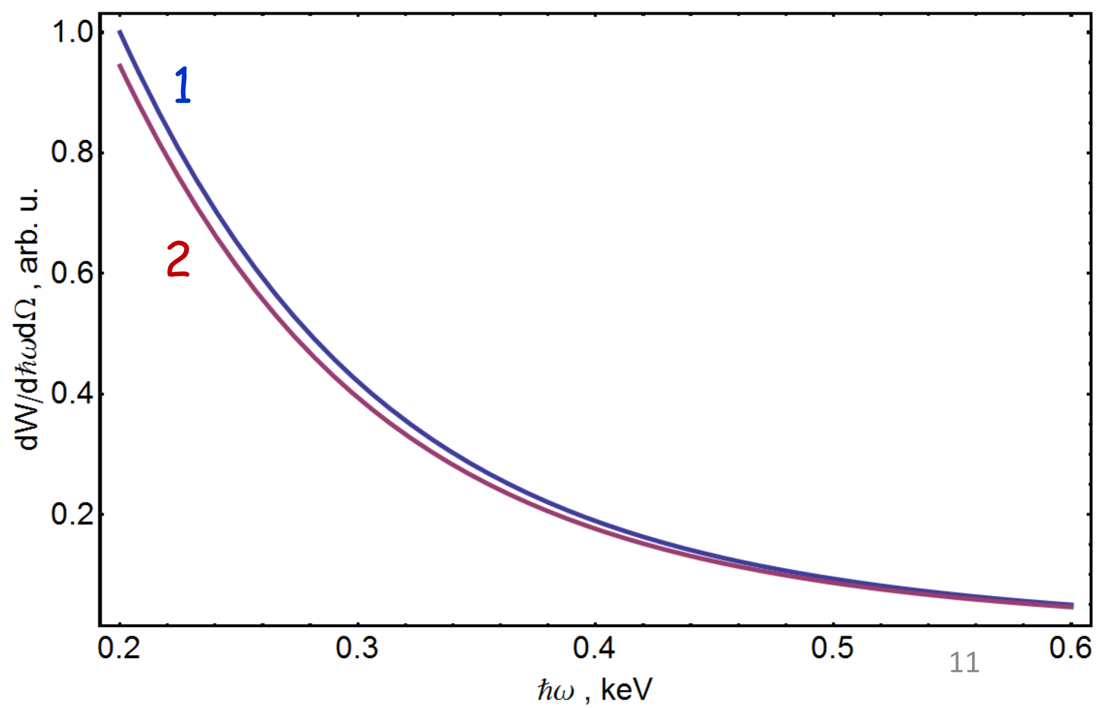
X-Ray TR angular distributions



X-Ray TR Angular and spectral distributions from a plate: taking account of RHI slowing-down

$\gamma \cong 4$

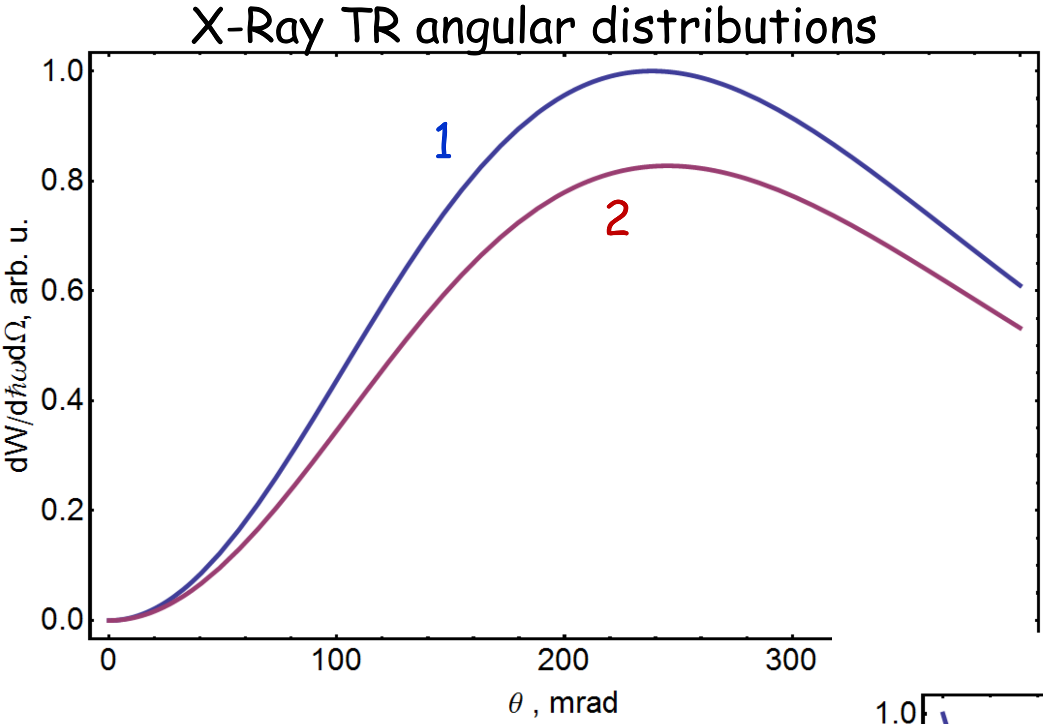
X-Ray TR spectral distributions



Emission angle 1/ϒ

- 1 – without slowing-down
- 2 – taking account of slowing down

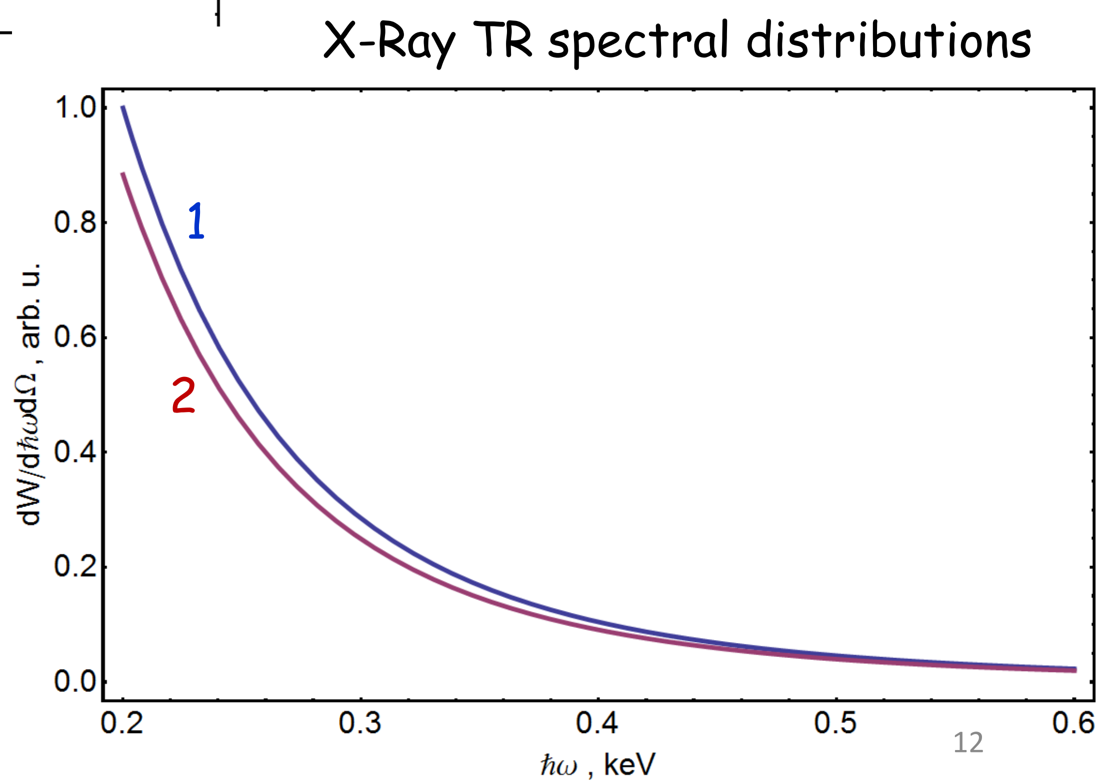
1-mm **W (Tungsten)** target
RHI **Au 3000 MeV/u**



X-Ray TR Angular and spectral distributions from a plate: taking account of RHI slowing-down

$\gamma \cong 2$

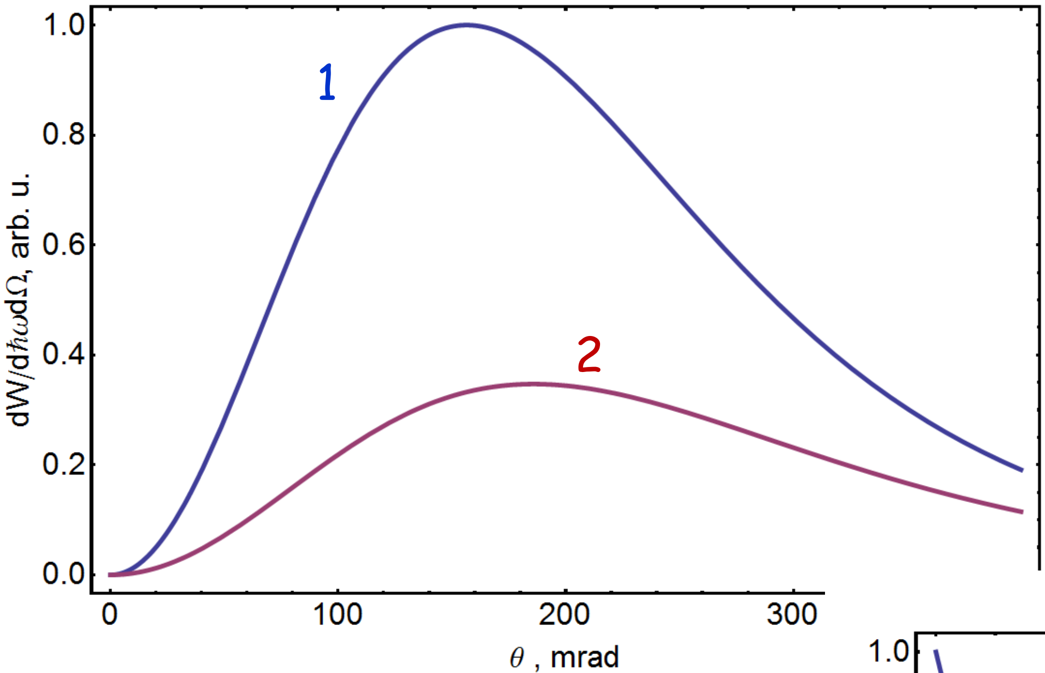
Emission angle 1/ϒ



- 1 – without slowing-down
- 2 – taking account of slowing down

1-mm **W (Tungsten)** target
RHI **Au 1500 MeV/u**

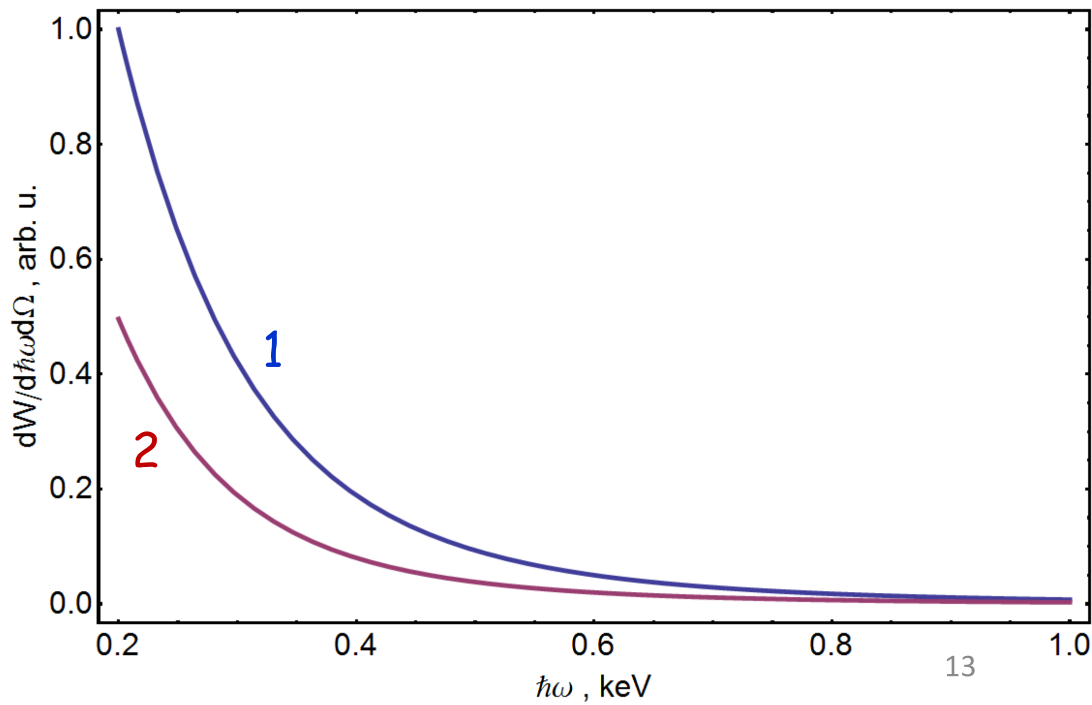
X-Ray TR angular distributions



X-Ray TR Angular and spectral distributions from a plate: taking account of RHI slowing-down

$\gamma \cong 4$

X-Ray TR spectral distributions



Emission angle 1/ϒ

- 1 – without slowing-down
- 2 – taking account of slowing down

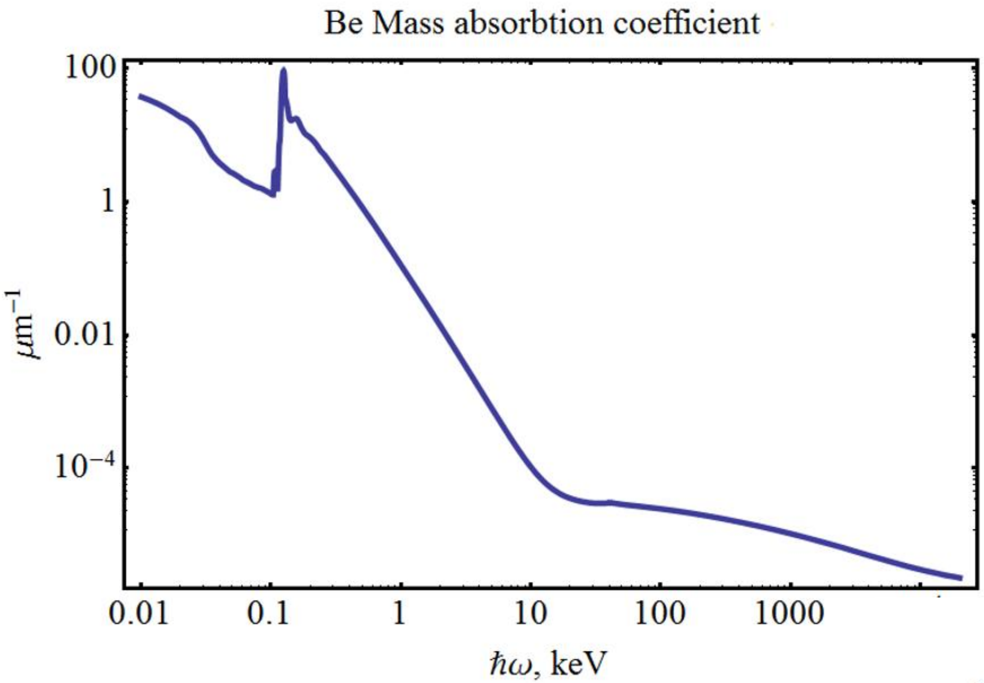
10-mm **W (Tungsten)** target
RHI **Au** 3000 **MeV/u**

Conclusion

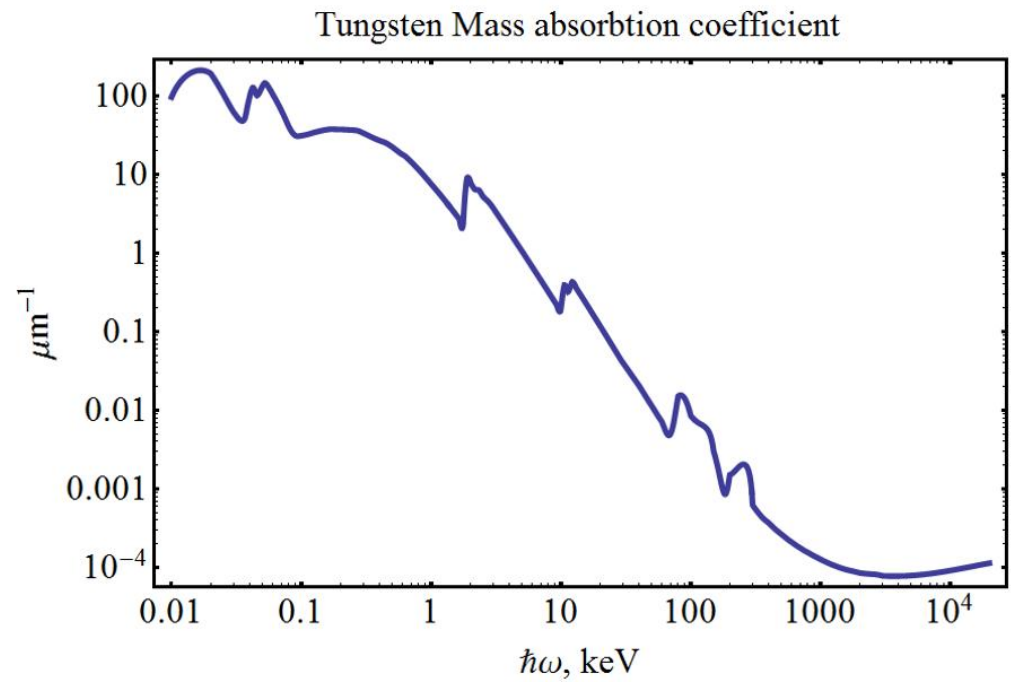
- Besides traditional parameters defining the spectral-angular distribution of X-Ray TR, i.e. a plasma frequency of the plate, TR photon energy, linear photon absorption coefficient, the thickness of a plate, **in the case of RHI there appears a new parameter – the stopping power of RHI in a plate**, which is a complicated function of the RHI energy, charge and mass.

- **The combined effect of RHI slowing down and TR photons absorption leads to the "washing out" of interference structure of TR angular distributions and overall decrease of the TR intensity.**
- The combination of parameters – the plate material and thickness, the linear absorption coefficient (depending on the material of the plate), the slowing-down (strongly depending on the RHI charge and its energy) and X-Ray TR photon energy define whether the interferential effects in angular and spectral distributions of X-Ray TR from RHI will manifest itself or not.

- The RHI energy loss and velocity decrease in the single thin plate are small. The effect of RHI slowing-down should manifest itself more brilliant in the case of a multiple-foil target (Resonant Transition Radiation).

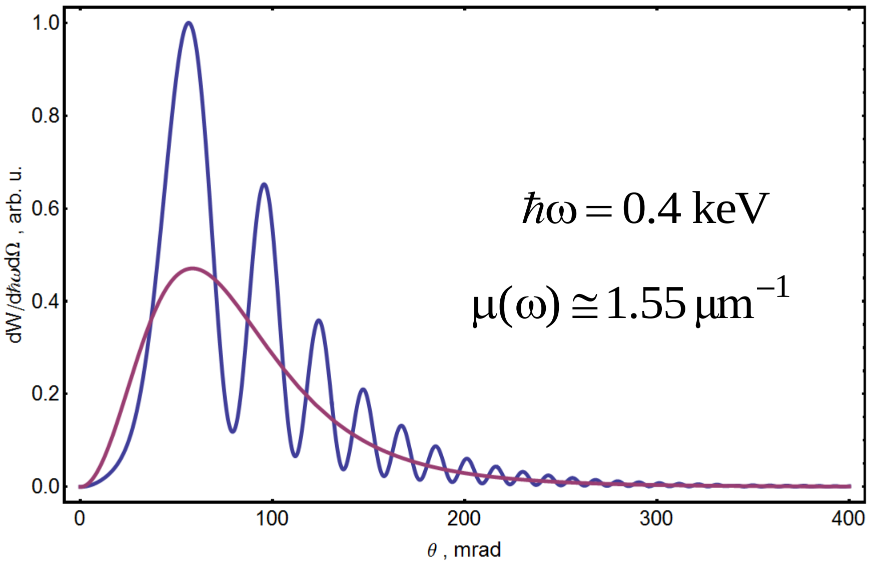


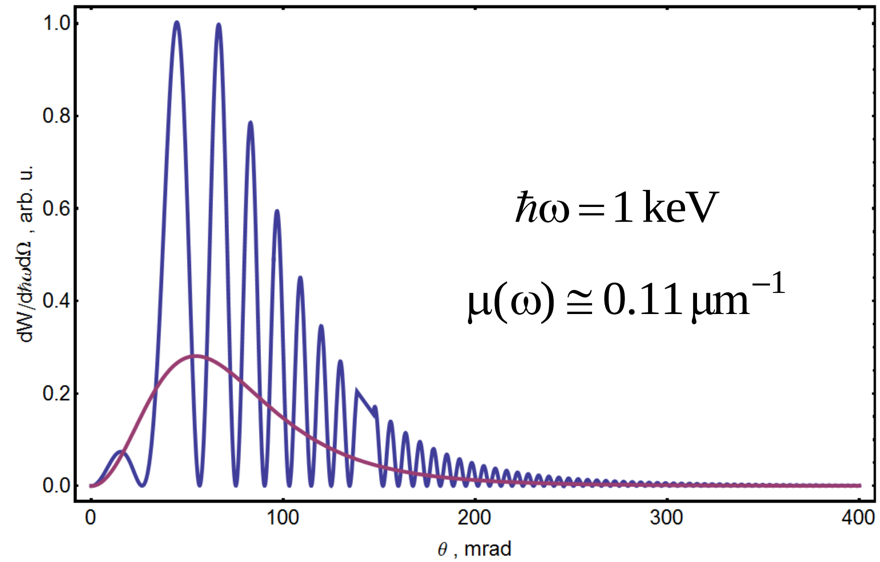
Absorption coefficients for Be and Tungsten targets

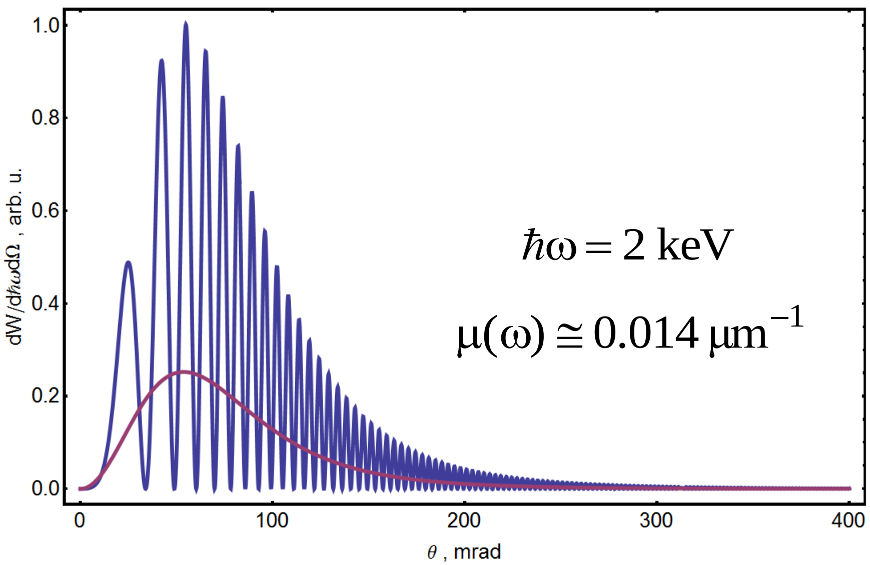


- http://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z04.html
- http://henke.lbl.gov/optical_constants/atten2.html

X-Ray TR angular distributions - different photon energies. Constant RHI velocity (FAIR energy region)







X-Ray TR angular distributions:

- From a plate taking account of absorption
- From a single interface of a plate

1-μm Be target, RHI **Au 9200 MeV/u**

Radiation from Varying Velocity Charge in Flight through a Plate

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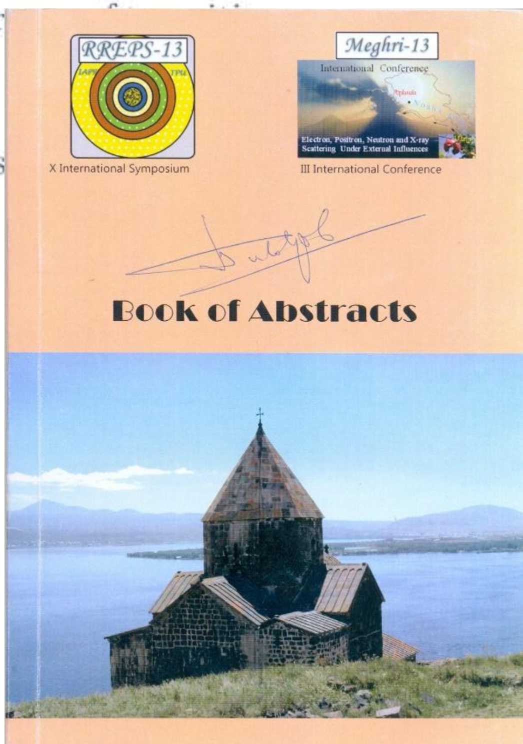
General expressions for the electromagnetic field of a charged particle arbitrarily moving in a medium in the presence of two plane-parallel interfaces are given in [1]. In the present work the electromagnetic field of a particle rectilinearly traversing a plate at variable velocity normal to the surface was determined by means of an accurate and illustrative method (other than that used in [1]). The expressions obtained are simpler than those following from general formulae in [1].

It was shown that the slowing-down of particle may essentially influence (a) the spectral-angular distribution of Cherenkov radiation from the particle and (b) the interfer
radiation generated by the particle at the flight in and out of the plate (these
not been studied in [1]). The results of appropriate numerical calculations
explanations are given. Possible practical application of the obtained results is



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[1] Pafomov V.E., 1969 *Trudy Fiz. Inst. Akad. Nauk SSSR* **44** 28 (in Russian).

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JO-O-02

Influence of Stopping on Transition Radiation of Relativistic Heavy Ions Crossing a Target

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When the relativistic heavy ions (RHI) penetrate through the thin solid amorphous target with a constant velocity, two types of electromagnetic radiation may appear: Cherenkov radiation (CR) (optically transparent target) and transition radiation (TR). The bremsstrahlung is strongly suppressed (compared to relativistic electrons) due to large mass of RHI. In fact, the velocity of RHI slightly decreases due to ionization energy loss (stopping) and it changes the spectral-angular distributions both of CR and TR.

The influence of the stopping on the spectral-angular properties of CR has been investigated recently in [1-4] (see, also our Abstract to this Conference, "Stopping of Relativistic Heavy Ions and its Influence on Angular Distributions of Cherenkov Radiation").The results of calculations show that the stopping of RHI in radiator leads to additional broadening of CR ring and forming of new CR angular distribution which is different compared with Tamm-Frank distribution.

Here, we present theoretical analysis and results of calculations of spectral-angular properties of TR taking into account RHI stopping in a radiator. The physical reason for appearance of new peculiarities is connected with interference of two waves emitted at entrance and exit of the radiator of finite thickness. These waves are emitted by RHI crossing the boundary vacuum-target and target-vacuum with slightly different velocities, which may change the condition of constructive interference compared to a case of relativistic electrons, see, e.g. [5].

The key parameters here are the plasma frequency, photon energy, attenuation length and thickness of the target, and stopping of RHI, which in turn is a complicated function of the energy, charge and mass of RHI.

The possible applications of the considered effect of stopping on TR from RHI are discussed.

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