

On THz Radiation from Dielectric Tube

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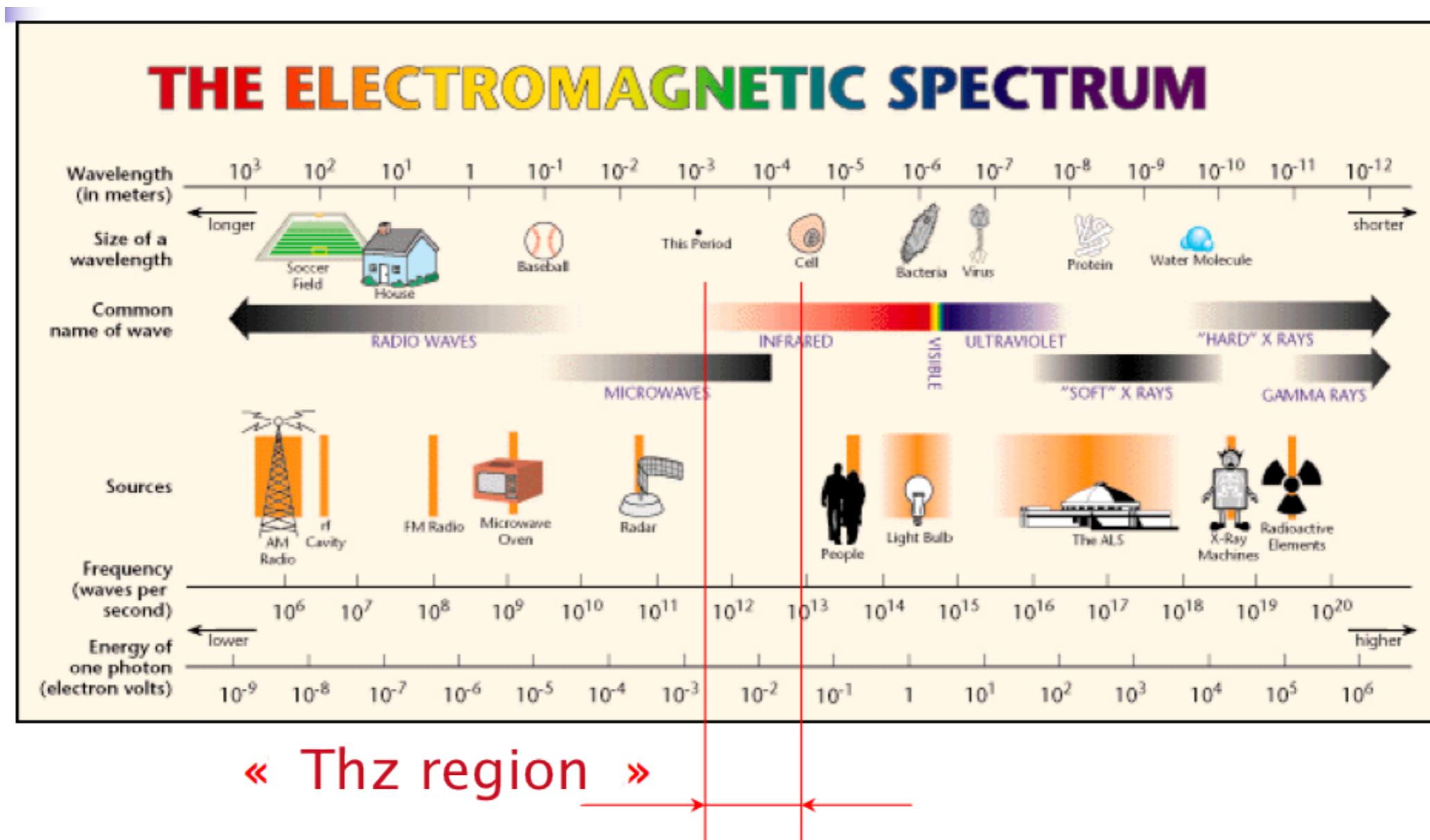
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THz Radiation

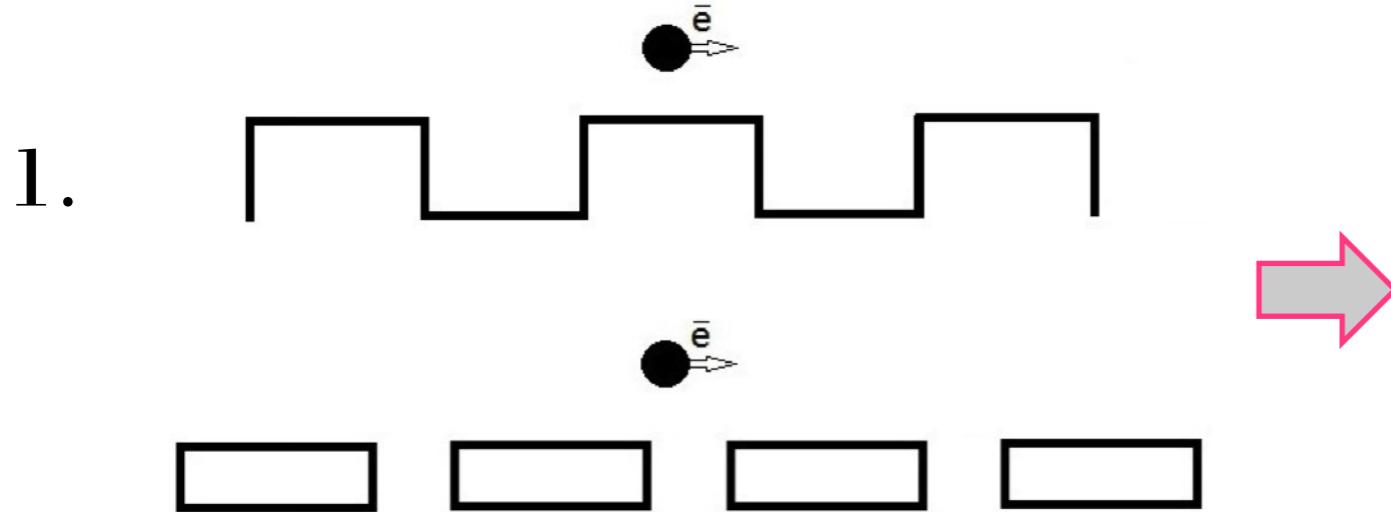
Terahertz: 0.1-10 THz $3\text{ mm} - 30\text{ }\mu\text{m}$

Applications: medicine, meteorology, security systems

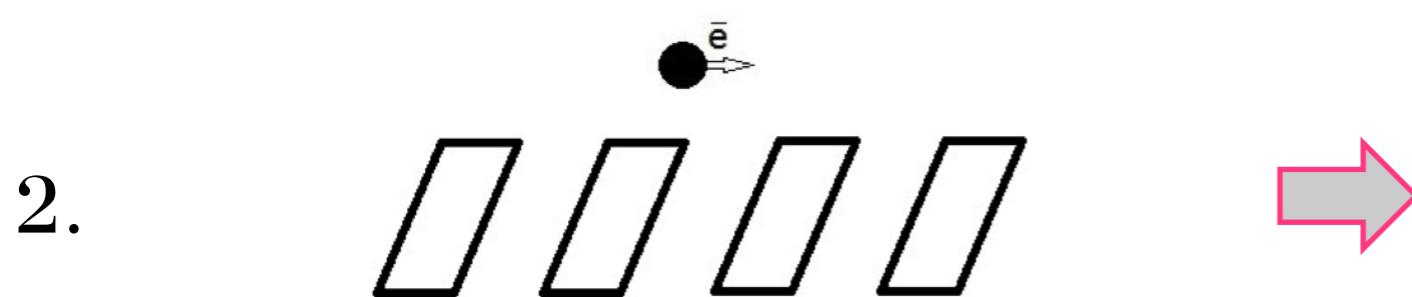


Scheme using for THz radiation generation

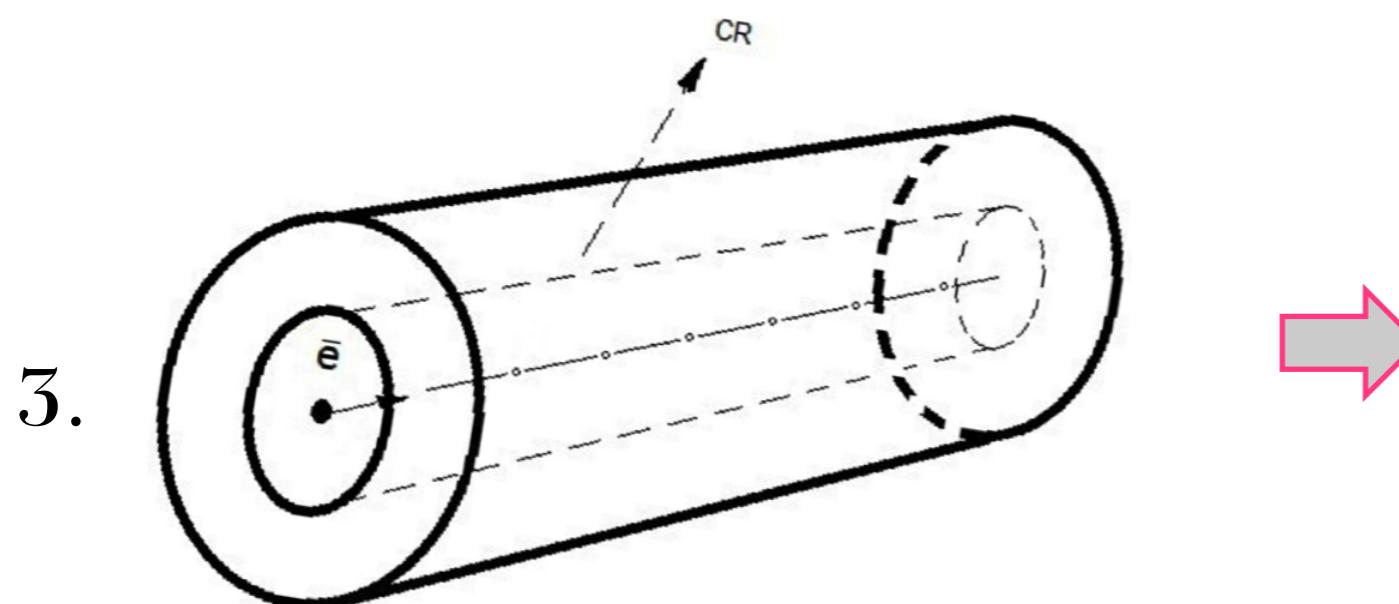
Flat gratings and tilted grating, waveguides:



A.P. Potylitsyn, M.I. Ryazanov, M.N. Strikhanov, A.A. Tishchenko, Diffraction Radiation from Relativistic Particles, Springer-Verlag, 2010.



A.P. Potylitsyn, Smith – Purcell effect as resonant diffraction radiation, NIM B 145 (1998) 60 – 66.

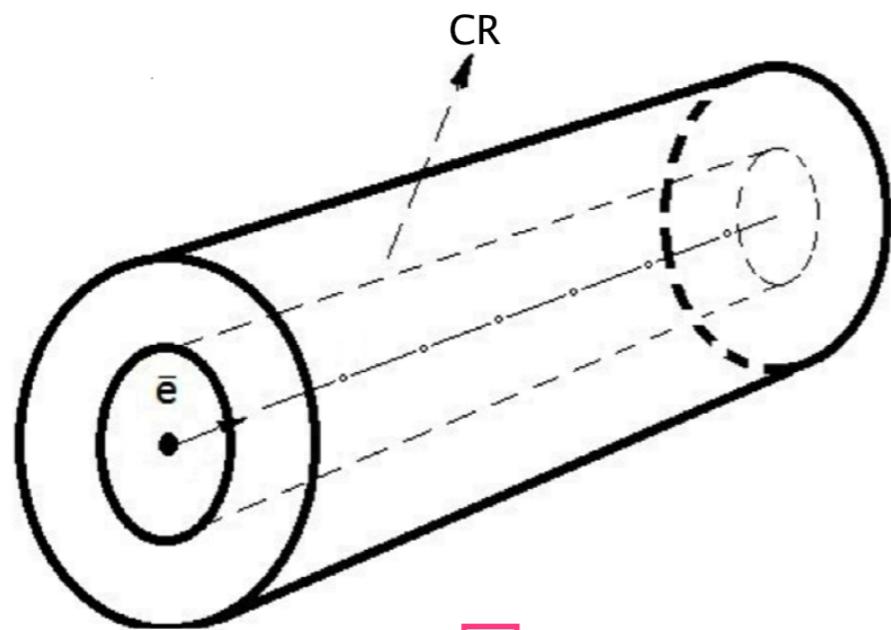


A.V. Smirnov, A high performance, fir radiator based on laser driven e-gun, In: Photonics Research Developments, Ed. by V.P. Nilsson, Nova Science Publishers, Inc., 2008, 247-269.

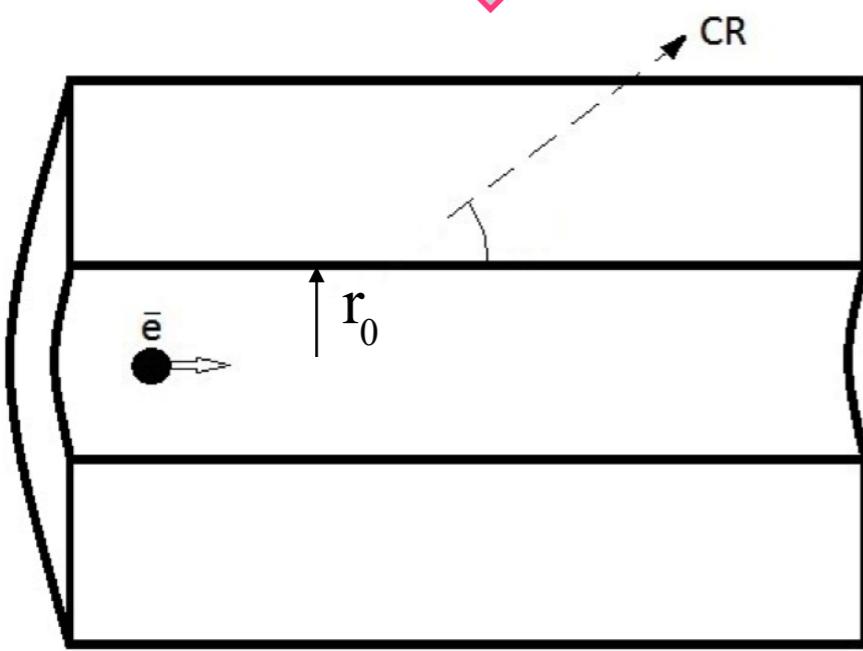
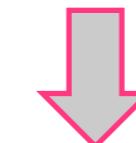
Scheme using for THz radiation generation

Well known scheme

THz generating by CR mechanism:



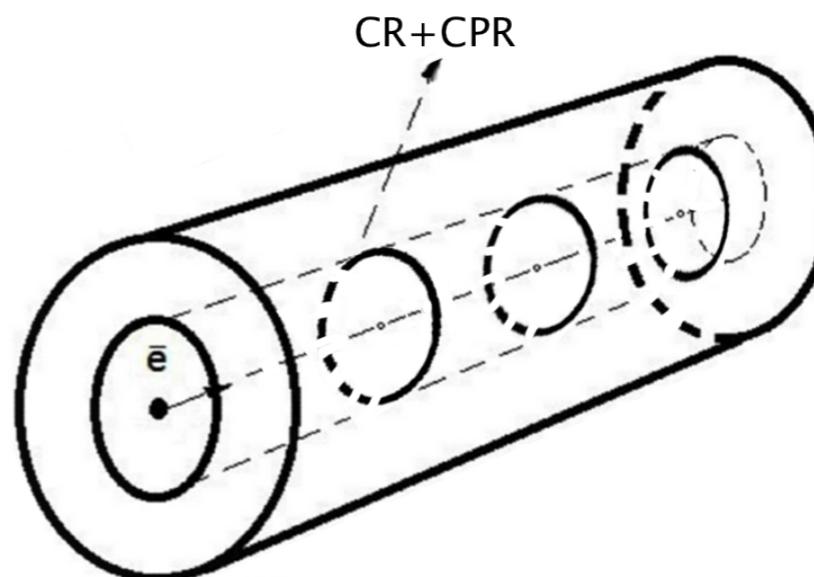
CR



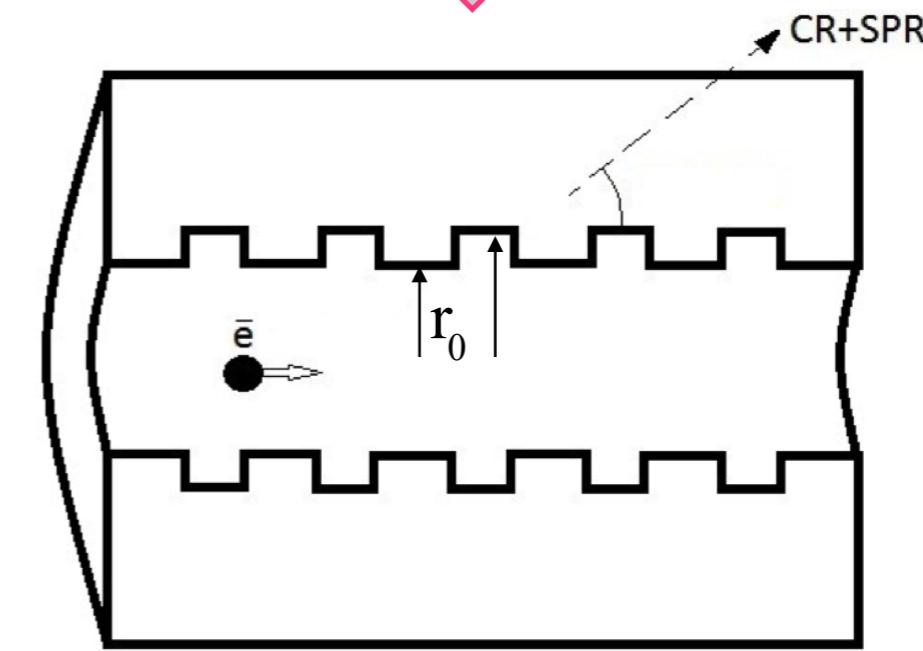
CR

r_0

THz generating by CR+SPR mechanism:



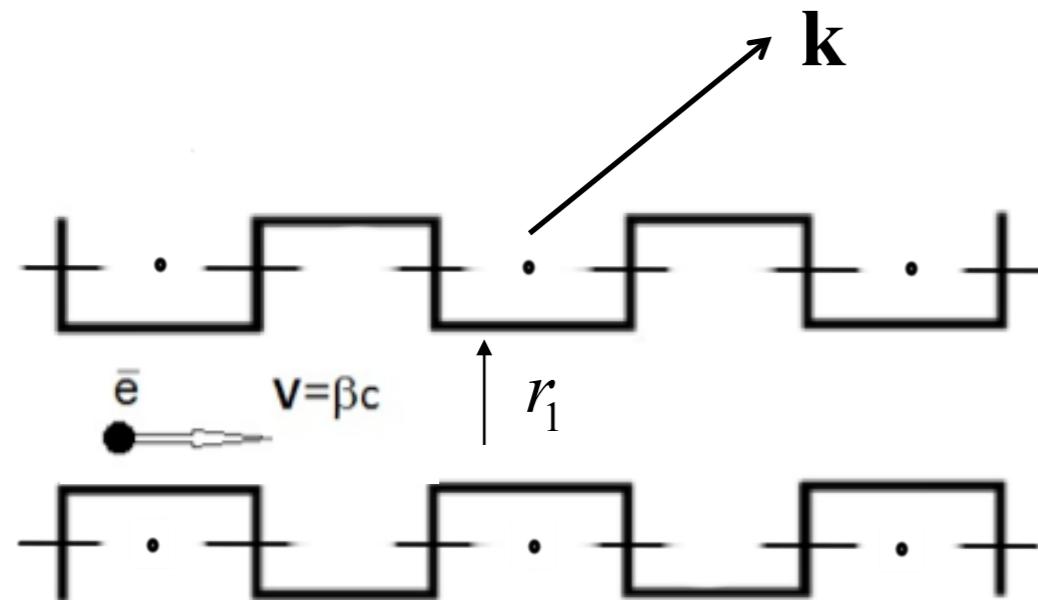
CR+CPR



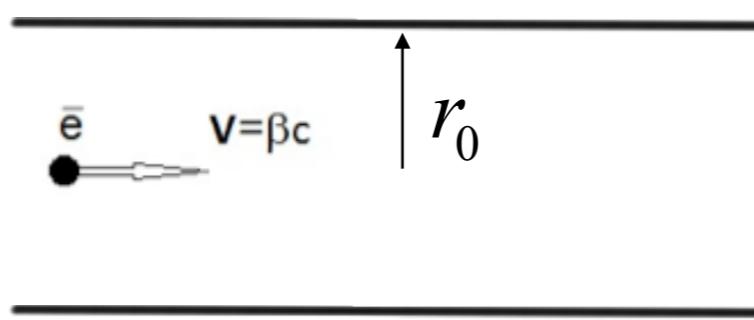
CR+SPR

Part 1. Analysis

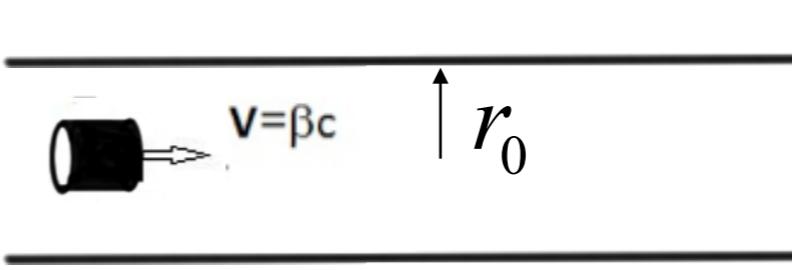
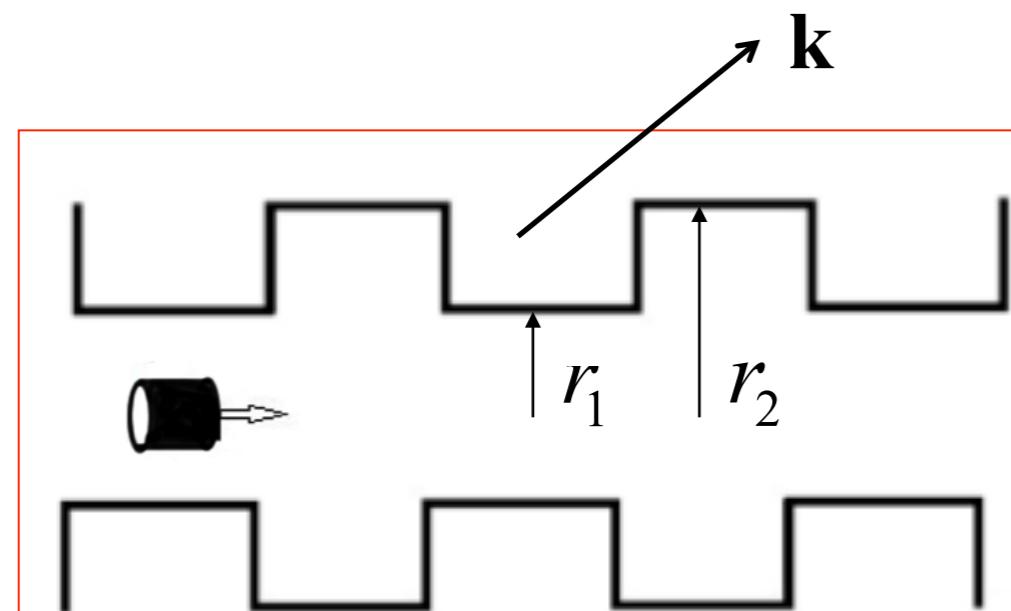
Two types of dependences between waveguides radii:



A.A. Ponomarenko et al, NIM B, 2013.



$$r_0 = \frac{r_1 + r_2}{2}$$



$$r_0 = r_1$$

$$r_2 = r_1 + a$$

Theoretical model

To find the spectral-angular distribution one can use the method of polarization currents from [1,2,3]:

$$\frac{d^2W(\mathbf{n},\omega)}{d\Omega d\omega} = \frac{1}{c\sqrt{\epsilon}} \left[\mathbf{k}, \int_V d^3r \mathbf{j}(\mathbf{r},\omega) \exp(-i\mathbf{kr}) \right]^2$$

where V is the volume of the target, the Fourier transform of polarization current density is

$$\mathbf{j}(\mathbf{r},\omega) = \frac{\omega}{4\pi i} (\epsilon(\omega) - 1) \mathbf{E}_0(\mathbf{r},\omega)$$

$\mathbf{k} = \sqrt{\epsilon(\omega)} (\omega/c) \mathbf{n}$ is the wave vector of the radiation. Fourier transform of electric field of a charged particle moving in vacuum:

$$\mathbf{E}_0(\mathbf{r},\omega) = -\frac{ie}{2\pi^2} \int d^3q \frac{\mathbf{v}\omega/c^2 - \mathbf{q}}{q^2 - \omega^2/c^2} \exp(-iq_x b) \delta(\omega - q_z v) \exp(iqr)$$

[1] A.P. Potylitsyn, M.I. Ryazanov, M.N. Strikhanov, A.A. Tishchenko, Diffraction Radiation from Relativistic Particles, Springer-Verlag, 2010.

[2] A.A. Tishchenko, A.P. Potylitsyn, M.N. Strikhanov, X-ray diffraction radiation in conditions of Cherenkov effect, Phys. Lett. A. 359 (2006) 509.

[3] M. I. Ryazanov, M. N. Strikhanov, A. A. Tishchenko, Diffraction radiation from an inhomogeneous dielectric film on the surface of a perfect conductor, JETP 99 (2004) 311.

Part 1. Results

Spectral-angular distribution for constant radius

$$\frac{d^2W(\mathbf{n}, \omega)}{d\Omega d\omega} = \frac{\alpha}{(2\pi)^2} \frac{|\varepsilon(\omega) - 1|^2}{\sqrt{\varepsilon(\omega)}} \frac{1}{(1 + \gamma^2 \beta^2 \varepsilon(\omega) \sin^2 \theta)^2} \frac{\sin^2(k\varphi L/2)}{(k\varphi/2)^2} \times \\ \times \left[[\mathbf{k}, \mathbf{e}_z] (F_1(r_0) - F_1(R)) + [\mathbf{k}, \mathbf{e}_\perp] \gamma (F_2(r_0) - F_2(R)) \right]^2$$

$$F_1(r) = -kr \sin \theta J_1(kr \sin \theta) K_0\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right) + \frac{k}{\gamma \beta \sqrt{\varepsilon}} r J_0(kr \sin \theta) K_1\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right),$$

$$F_2(r) = kr \sin \theta J_0(kr \sin \theta) K_1\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right) + \frac{k}{\gamma \beta \sqrt{\varepsilon}} r J_1(kr \sin \theta) K_0\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right)$$

D.V. Karlovets, On the theory of polarization radiation in media with sharp boundaries, JETP
113 (2011) 27 [Zh. Eksp. Teor. Fiz. 140 (2011) 36].

Part 1. Results

Spectral-angular distribution for variable radius

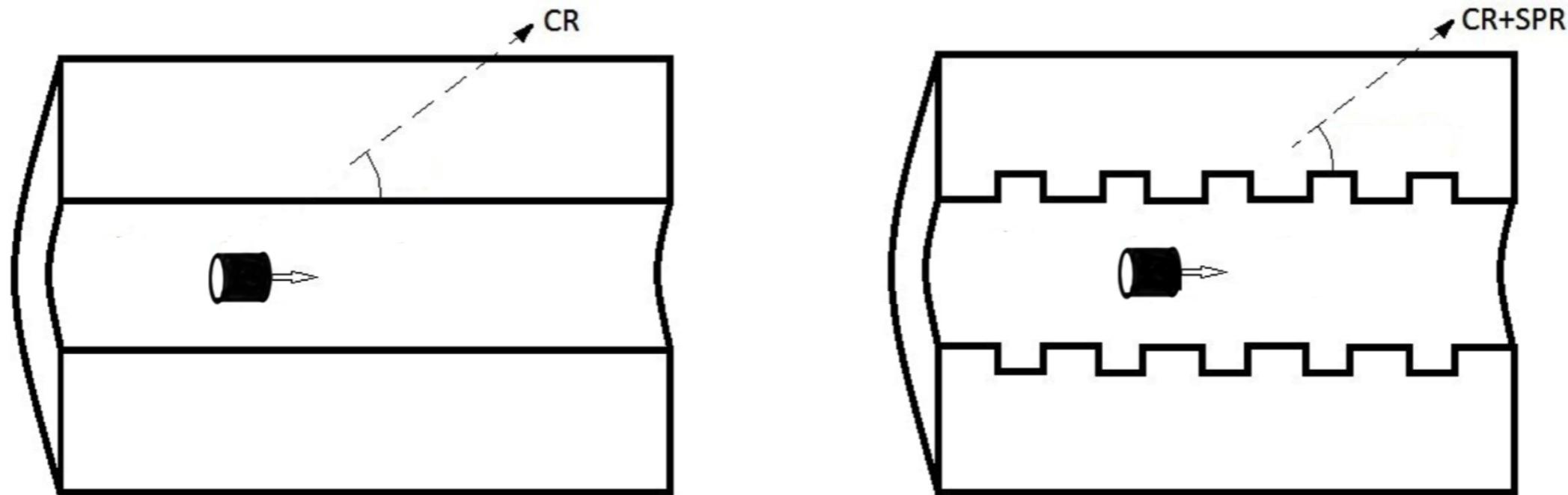
$$\begin{aligned}
 \frac{d^2W(\mathbf{n}, \omega)}{d\Omega dh\omega} = & \frac{\alpha}{(2\pi)^2} \frac{|\varepsilon(\omega) - 1|^2}{\sqrt{\varepsilon(\omega)}} \frac{1}{(1 + \gamma^2 \beta^2 \varepsilon(\omega) \sin^2 \theta)^2} \frac{\sin^2(k\varphi dN/2)}{(k\varphi d/2)^2} \times \\
 & \times \left[[\mathbf{k}, \mathbf{e}_z] \left\{ (e^{-ik\varphi l} - 1)(F_1(r_1) - F_1(R)) + (e^{-ik\varphi d} - e^{-ik\varphi l})(F_1(r_2) - F_1(R)) \right\} + \right. \\
 & \left. + [\mathbf{k}, \mathbf{e}_\perp] \left| \gamma \left\{ (e^{-ik\varphi l} - 1)(F_2(r_1) - F_2(R)) + (e^{-ik\varphi d} - e^{-ik\varphi l})(F_2(r_2) - F_2(R)) \right\} \right|^2 \right]
 \end{aligned}$$

$$\varphi = \cos \theta - (\beta \sqrt{\varepsilon})^{-1} \quad \mathbf{e}_\perp = k_\perp^{-1} (\mathbf{k} - k_z \mathbf{e}_z) \quad \alpha = \frac{1}{137}$$

$$F_1(r) = -kr \sin \theta J_1(kr \sin \theta) K_0\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right) + \frac{k}{\gamma \beta \sqrt{\varepsilon}} r J_0(kr \sin \theta) K_1\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right),$$

$$F_2(r) = kr \sin \theta J_0(kr \sin \theta) K_1\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right) + \frac{k}{\gamma \beta \sqrt{\varepsilon}} r J_1(kr \sin \theta) K_0\left(\frac{k}{\gamma \beta \sqrt{\varepsilon}} r\right)$$

Part 1. Bunch of electrons



Electrons in the bunch are distributed by Gaussian law

$$f_z(z) = \frac{2}{l_b \pi^{1/2}} e^{-\frac{4z^2}{l_b^2}}$$

- Gaussian distribution of electrons in the bunch

$$f_r(r) = \frac{2}{r_b^2 \pi} e^{-\frac{r^2}{r_b^2}}$$

Part 1. Bunch of electrons

Spectral-angular distribution for bunch of electrons

$$\frac{d^2W_{bunch}}{d\Omega d\omega} = \left(N_e + (N_e - 1) N_e e^{-\frac{k^2}{2} \left(r_b^2 + (\beta \sqrt{\epsilon})^{-1} \frac{l_b^2}{4} \right)} \right) \frac{d^2W_1}{d\Omega d\omega}$$

$r_b = 0.01 \text{ mm}$ – bunch radius

$N_e = 10^{10}$ – number of electrons in the bunch

$l_b = 0.03 \text{ mm}$ – bunch length

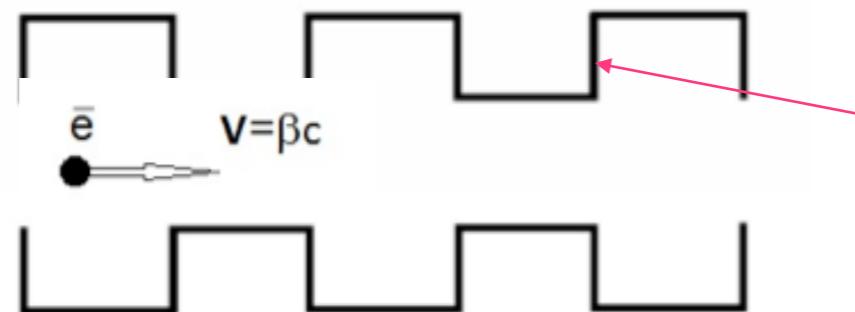
$\frac{d^2W_1}{d\Omega d\omega}$ – spectral-angular distribution
for one particle



Future at LUXS

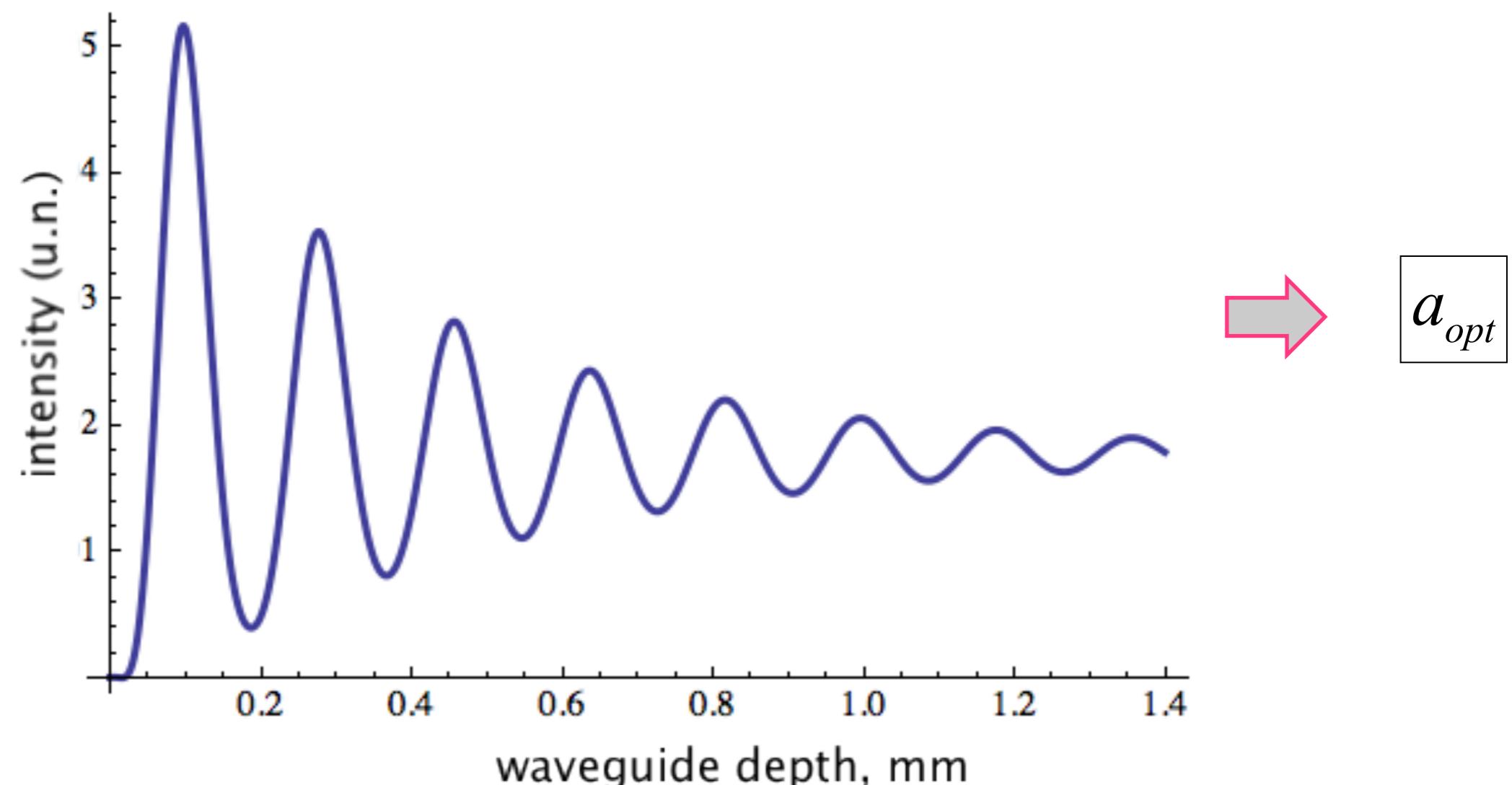
Part 1. Analysis

Intensity dependence on waveguide depth for waveguide with variable radius:



a – waveguide depth

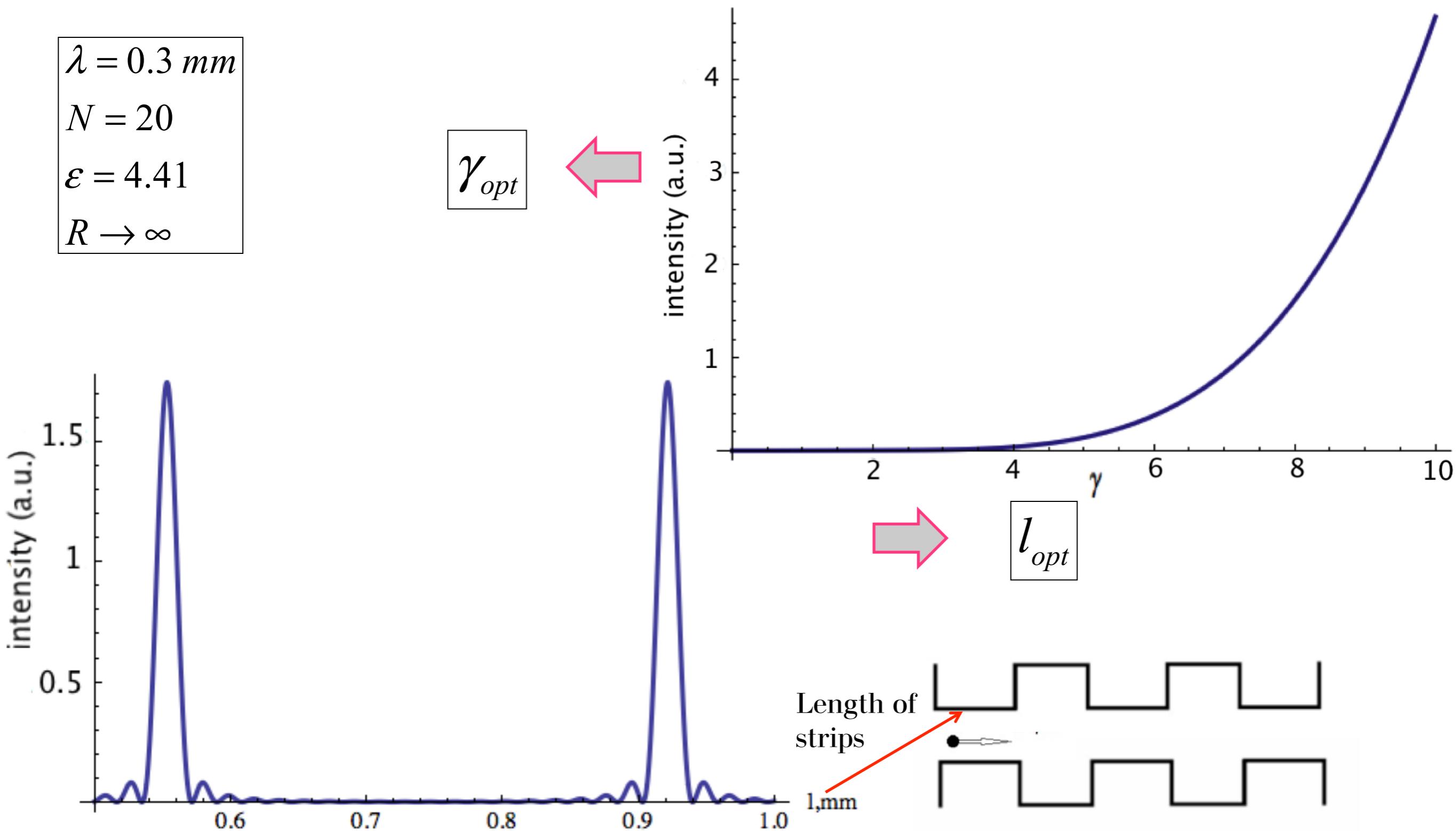
$\lambda = 0.3 \text{ mm}$
 $l = 0.55 \text{ mm}$
 $N = 20$
 $\gamma = 10$
 $\epsilon = 4.41 (\text{quartz})$
 $R \rightarrow \infty$



a_{opt}

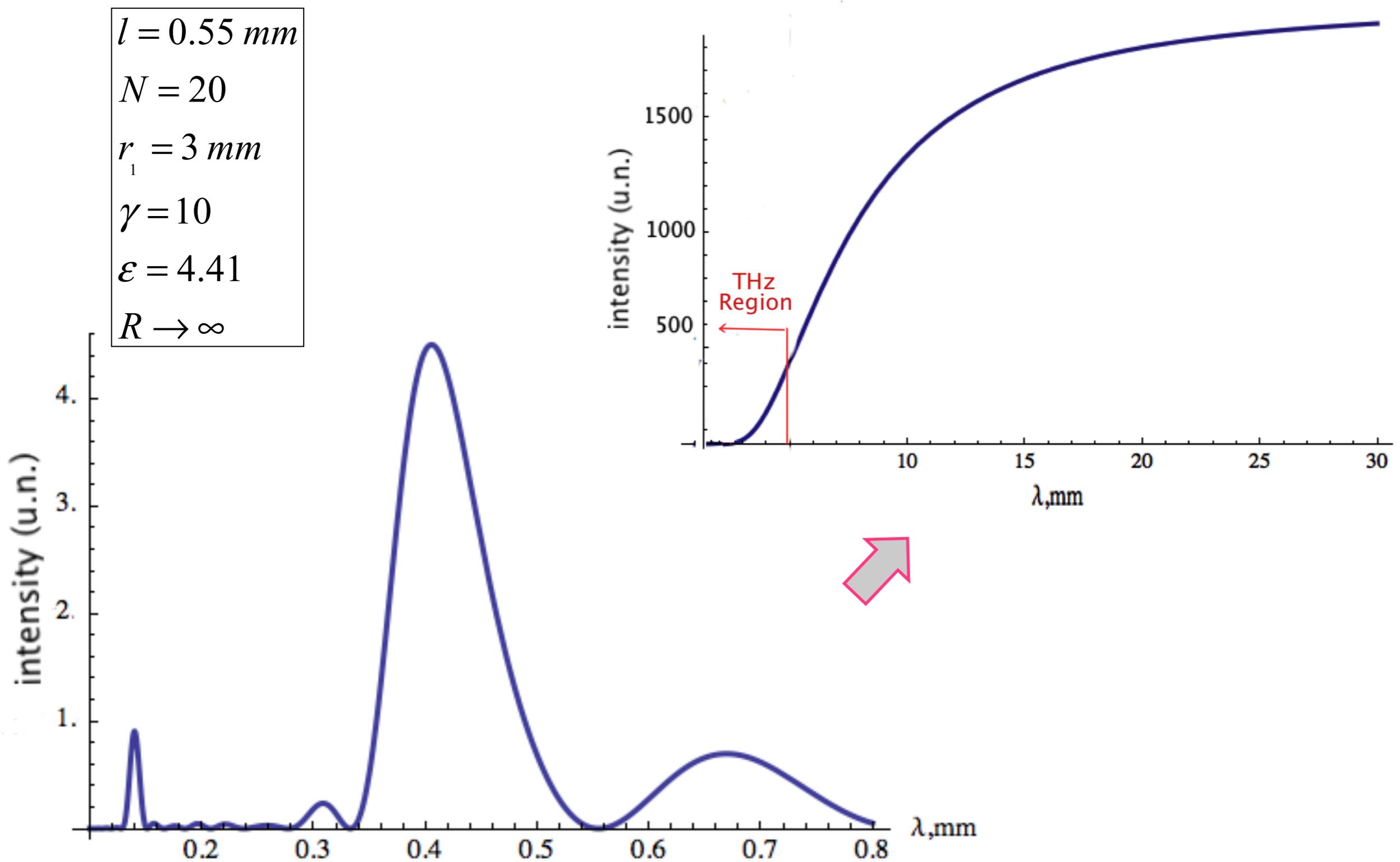
Part 1. Analysis

Waveguide with variable radius different dependences:



Part 1. Analysis

Dependence of intensity on wavelength:

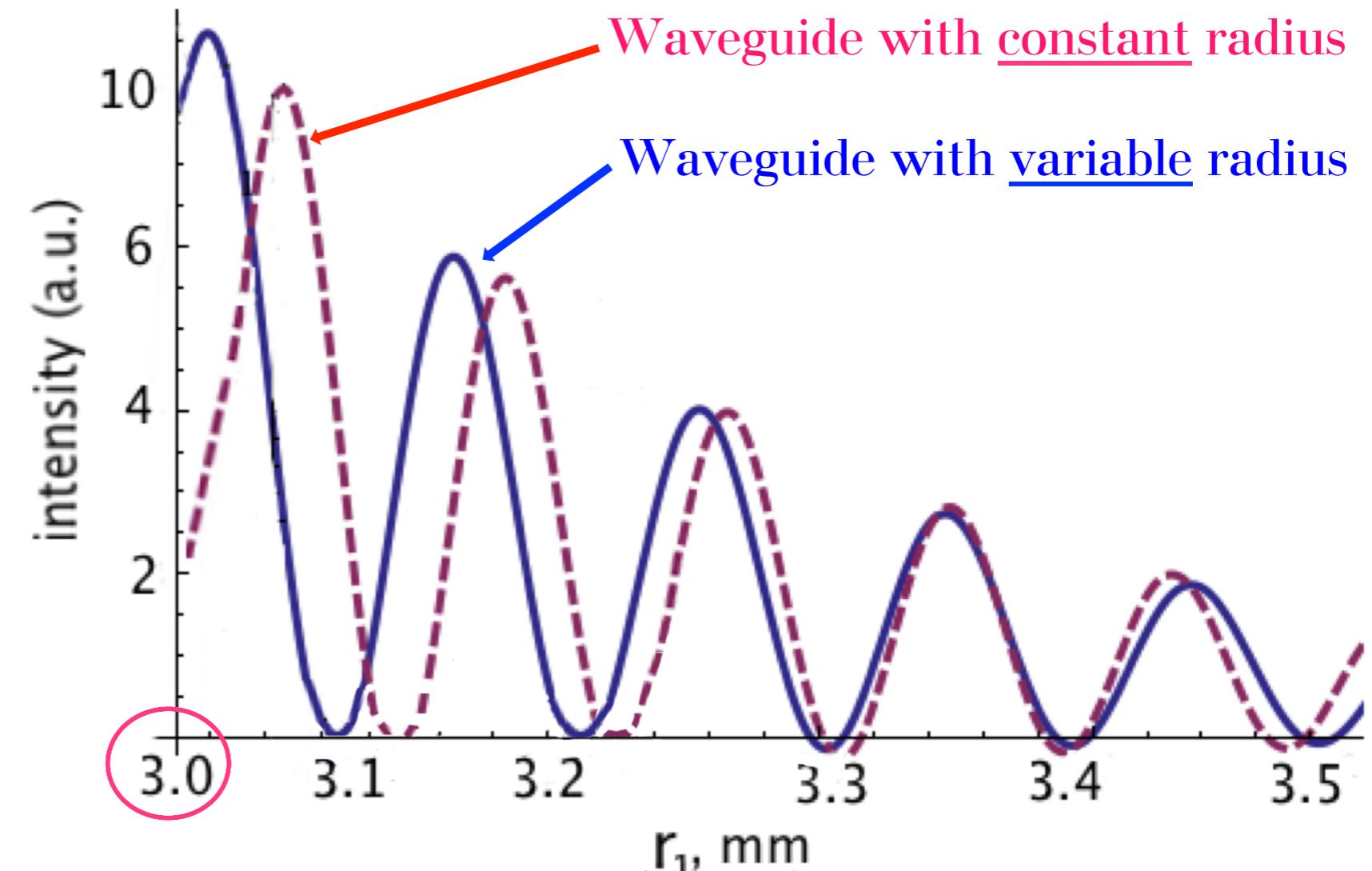
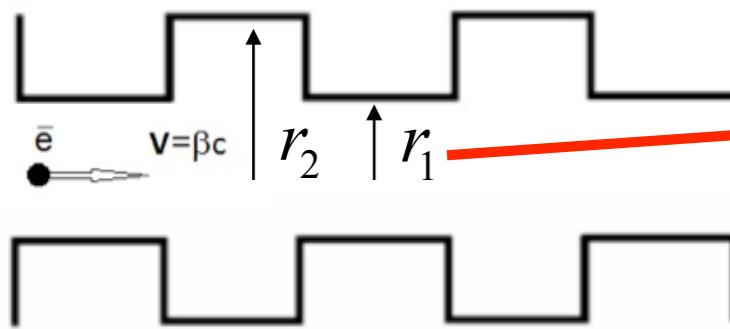


Part 1. Analysis

Dependence of spectral-angular distribution on radius:

$$\begin{aligned}\lambda &= 0.3 \text{ mm} \\ l &= 0.55 \text{ mm} \\ a &= 0.29 \text{ mm} \\ N &= 20 \\ \gamma &= 10 \\ \varepsilon &= 4.41\end{aligned}$$

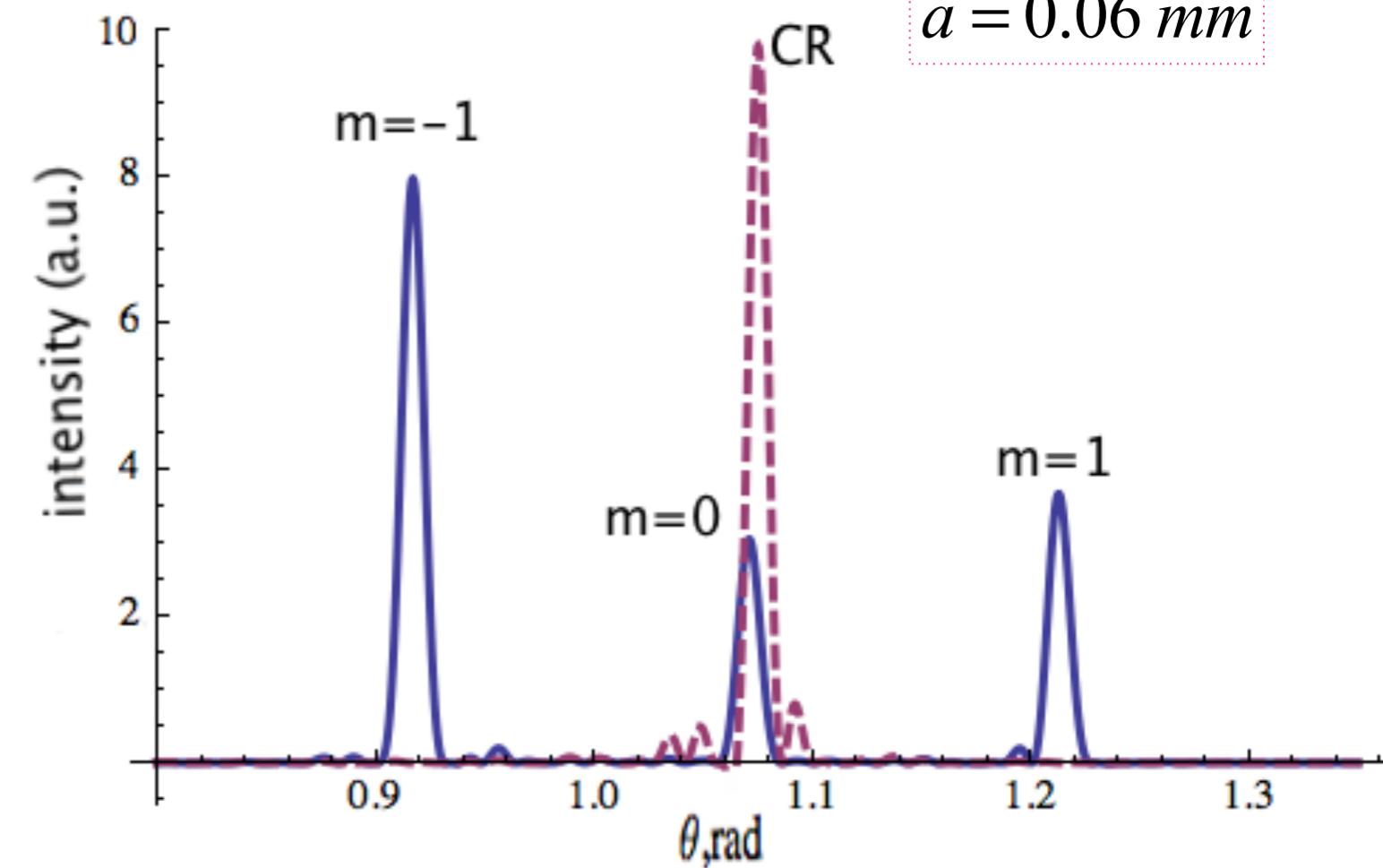
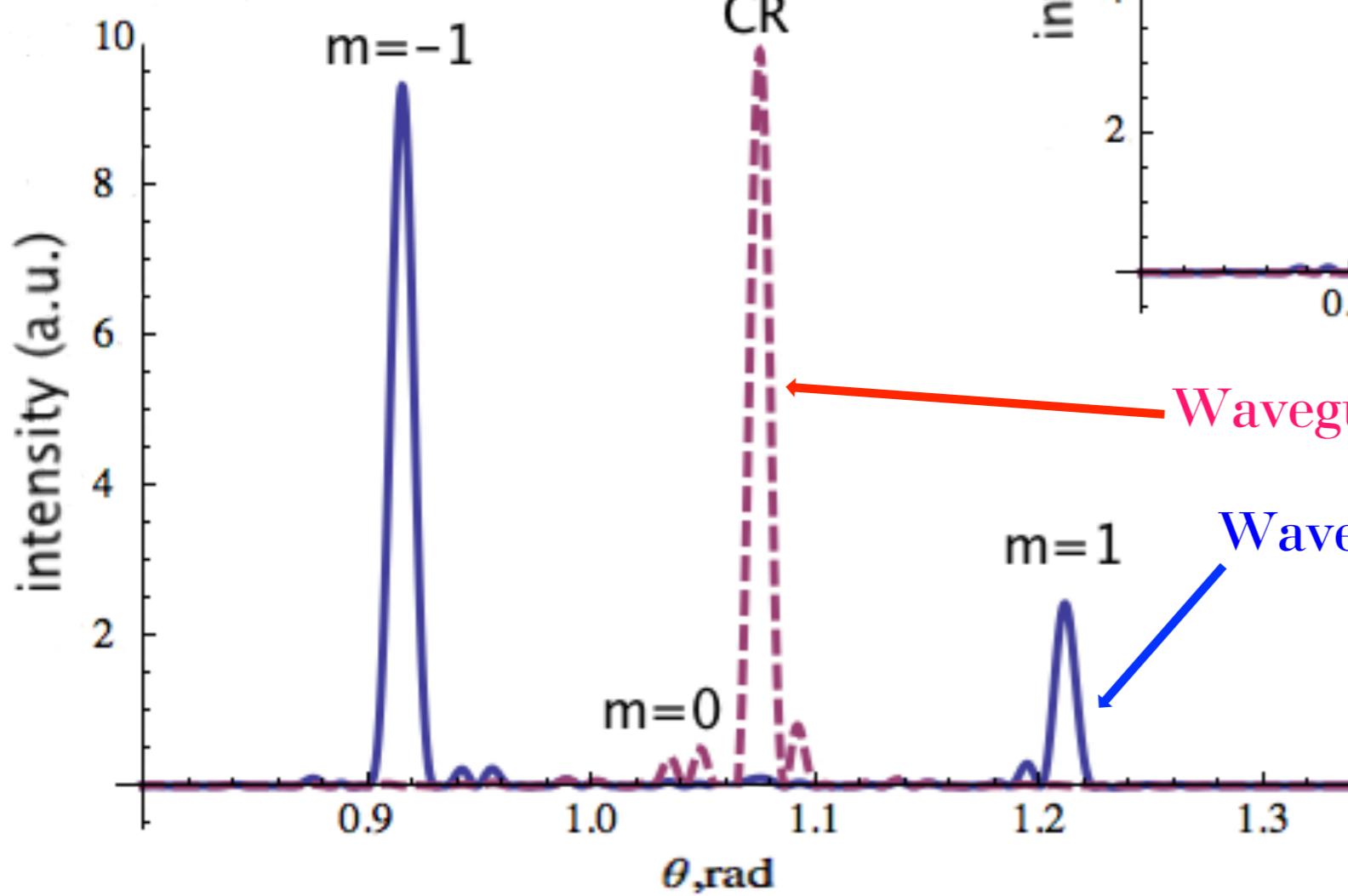
$$\begin{aligned}r_0 &= r_1 \\ r_2 &= r_1 + a\end{aligned}$$



Part 1. Analysis

Dependence on theta for waveguides with variable and constant radii:

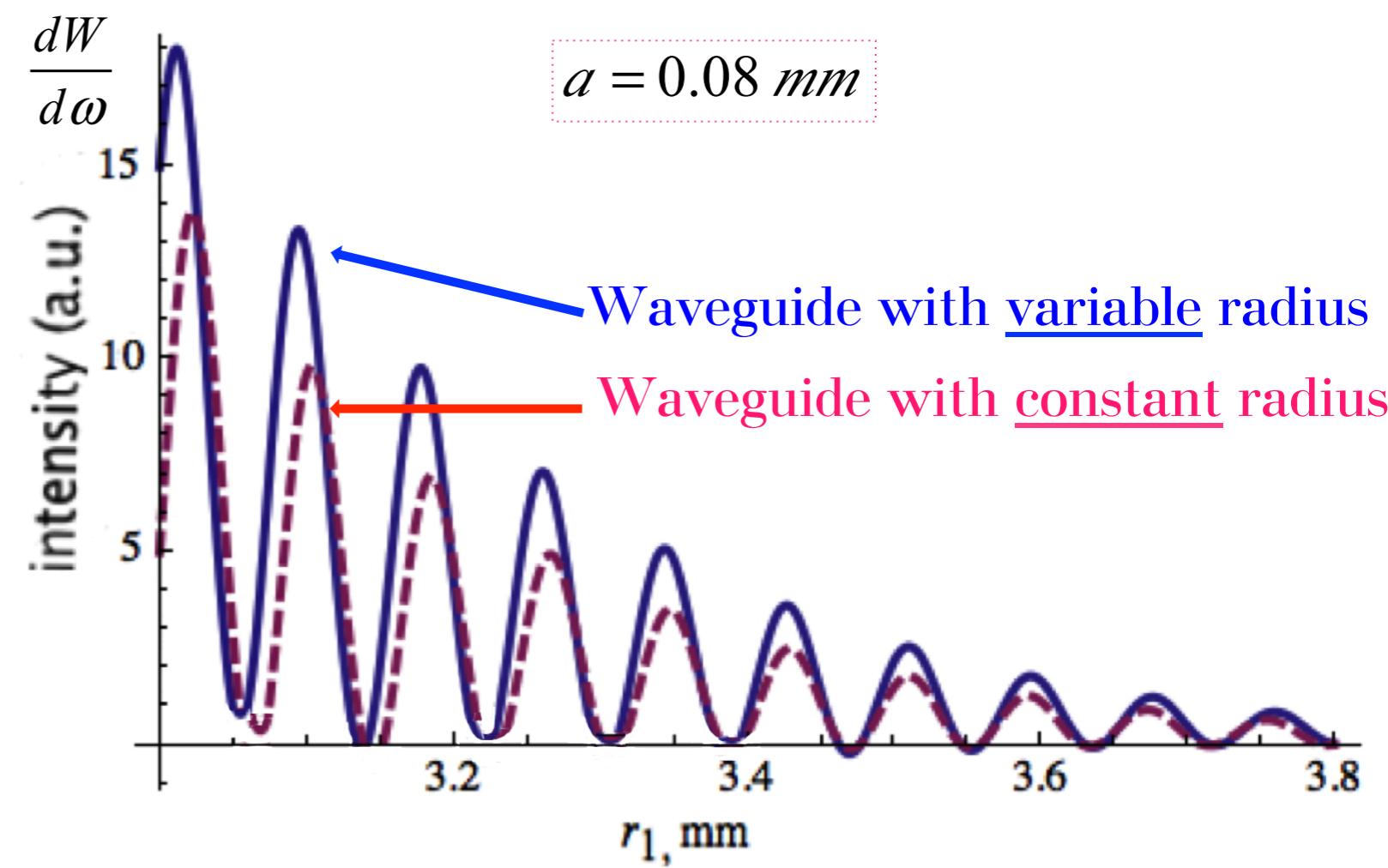
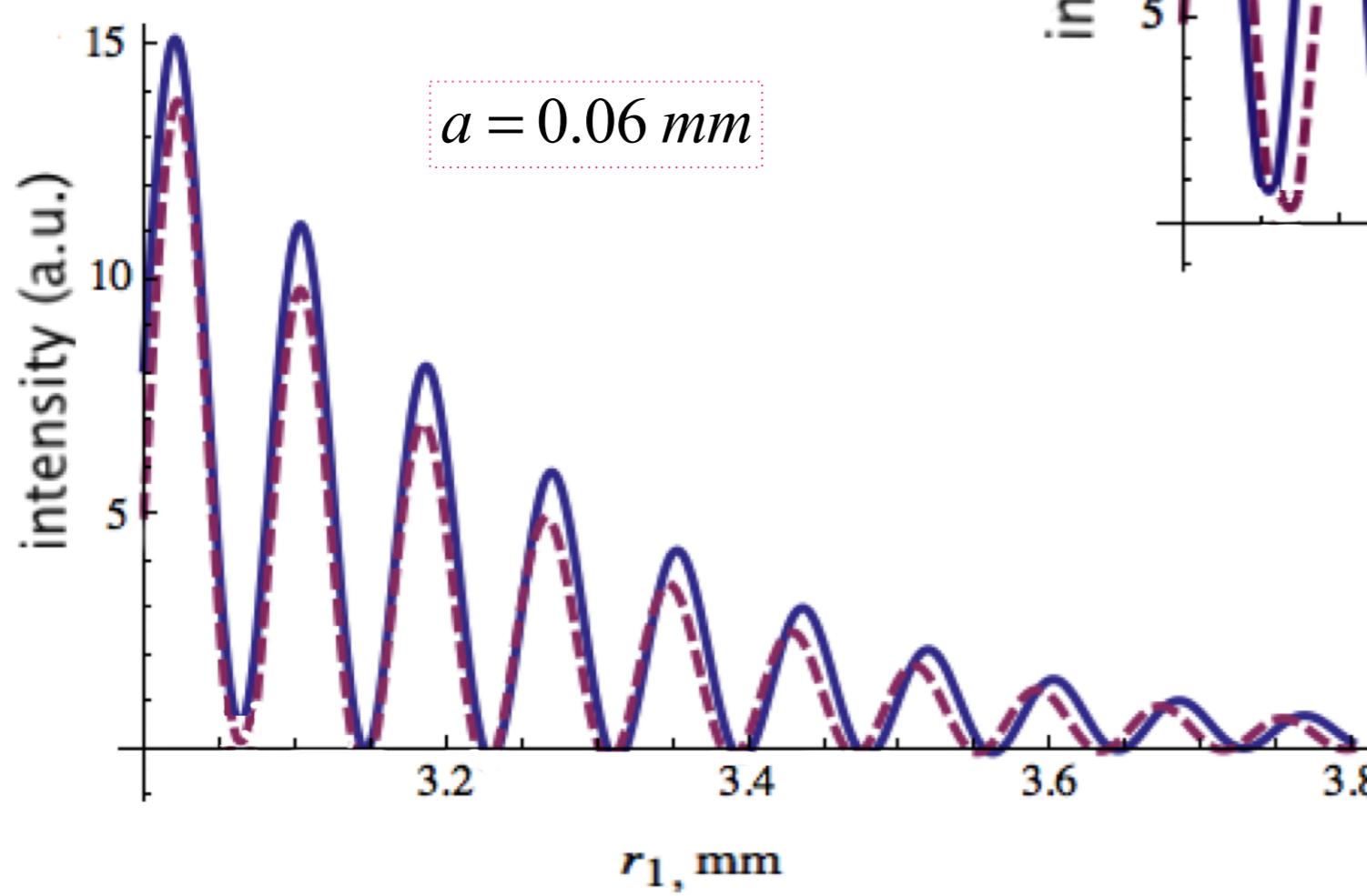
$$\begin{aligned}\lambda &= 0.3 \text{ mm} \\ N &= 20 \\ r_1 &= 3 \text{ mm} \\ \gamma &= 10 \\ \varepsilon &= 4.41 \\ R &\rightarrow \infty\end{aligned}$$



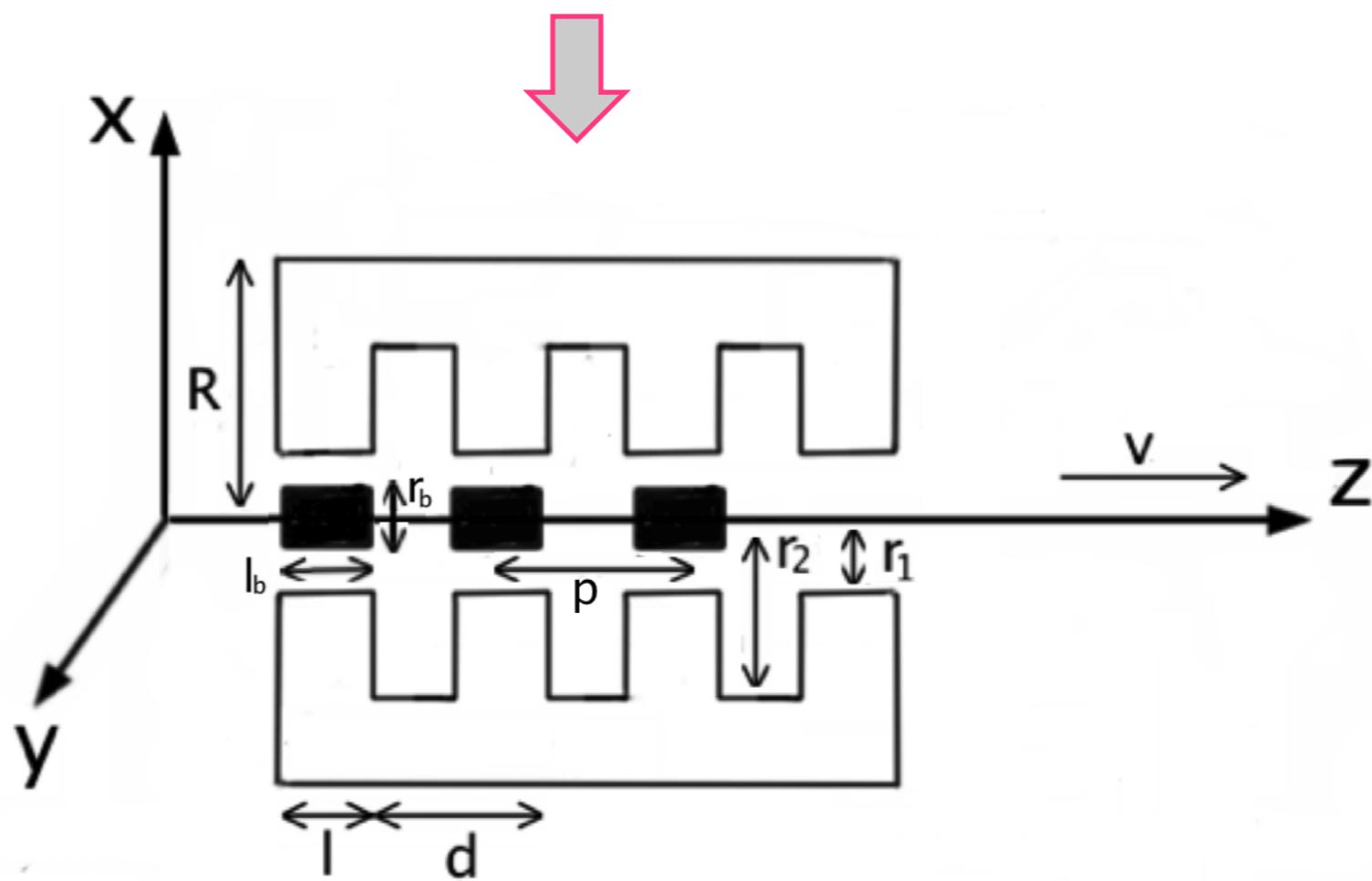
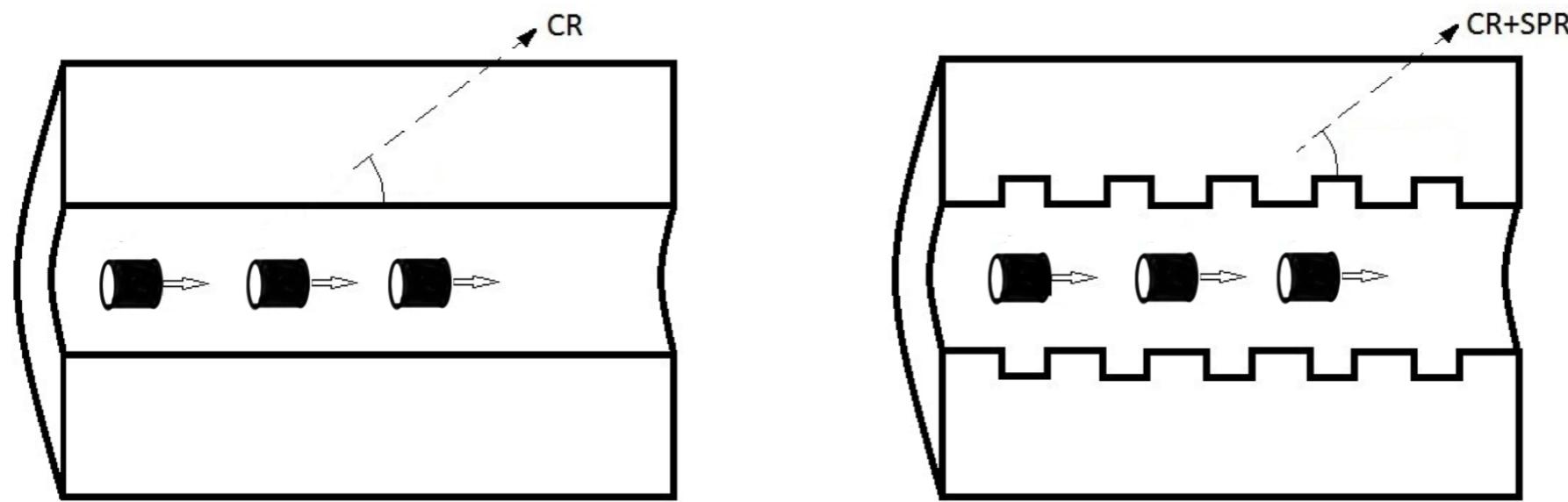
Part 1. Analysis

Integrated over theta for waveguides with variable and constant radius:

$\lambda = 0.3 \text{ mm}$
$l = 0.55 \text{ mm}$
$N = 20$
$\gamma = 10$
$\epsilon = 4.41$



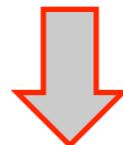
Part 2. Chain of bunches



Part 2. Chain of bunches

Spectral-angular distribution for the chain of electron bunches

$$\frac{d^2W_{chain}}{d\Omega d\omega} = \left(N_e + (N_e - 1)N_e e^{-\frac{k^2}{2} \left(r_b^2 + (\beta\sqrt{\epsilon})^{-1} \frac{l_b^2}{4} \right)} \right) \frac{\sin^2 \left(\frac{\omega p_b N_b}{v} \frac{2}{2} \right)}{\sin^2 \left(\frac{\omega p_b}{v} \frac{2}{2} \right)} \frac{d^2W_1}{d\Omega d\omega}$$



$$p_b = d \left(\cos \theta \beta \sqrt{\epsilon} - 1 \right) \frac{m}{n} \quad m, n = 1, 2, 3, \dots$$

p_b – distance between bunches

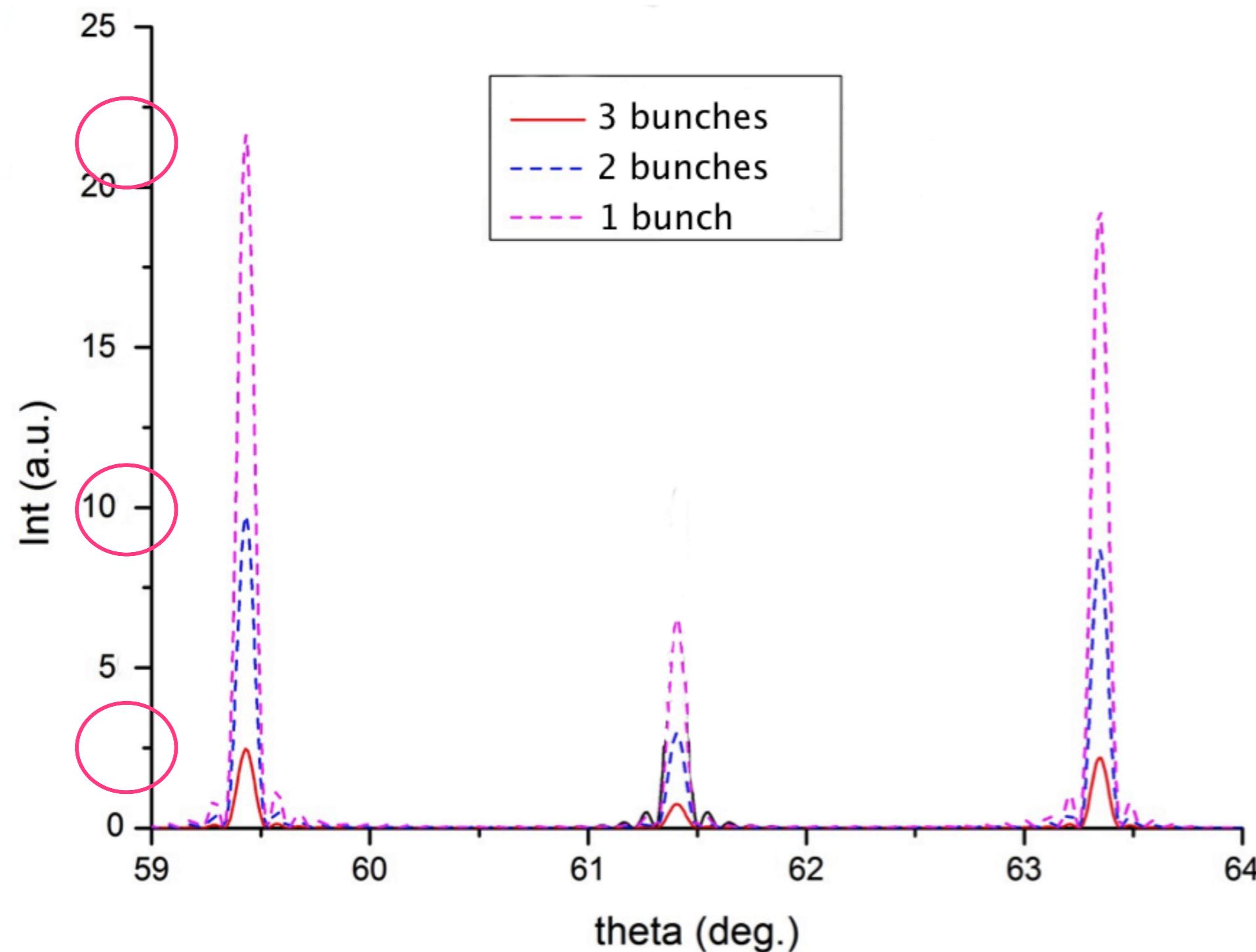
N_b – number of bunches

d – waveguide period

m – SPR diffraction order

Part 2. Analysis

Intensity dependence on theta for different numbers of bunches:



Summary and plans

- The prospective scheme (dielectrical waveguide with variable radius) of THz radiation is investigated
- The strong dependence of radiation on the target parameters (dielectrical properties, internal radius and grating depth) and beam energy is demonstrated

Nearest Plans

- To obtain numerical analysis of expressions
- Optimization of target parameters for LUCX in order to design power THz source

Thank you for your attention!

Bunch of electrons

- Each co-ordinate are independent values at bunch
- There are no interaction in that bunch

$$r>k^{-1}$$

$$\mathrm{Re}\,\varepsilon' \!>\! \mathrm{Im}\,\varepsilon''$$

$$r_1 > 3 r_b$$

$$R\rightarrow\infty$$

- We analyzed process of generation of radiation