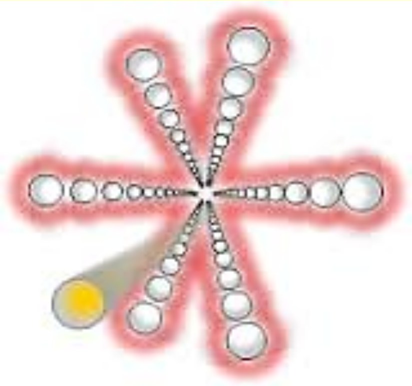

RADIATION OF A CHARGE MOVING IN A WIRE STRUCTURE

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Motivation

PHYSICAL REVIEW LETTERS **120,** 164801 (2018)

Experimental Characterization of Electron-Beam-Driven Wakefield Modes in a Dielectric-Woodpile Cartesian Symmetric Structure

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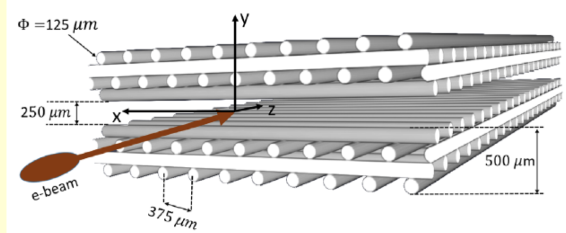

FIG. 1. Computer rendered model of the woodpile structure with relevant dimensions.

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Cherenkov and parametric (quasi-Cherenkov) radiation produced by a relativistic charged particle moving through a crystal built from metallic wires

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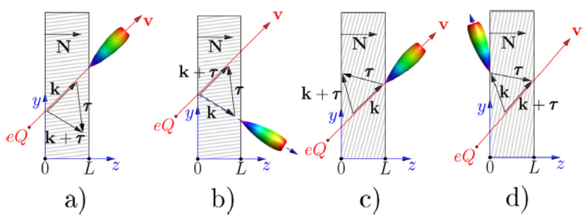

Fig. 2. Parametric radiation for the case of two-wave diffraction in Laue (a, b) and Bragg (c, d) geometries. Wire axes are perpendicular to the figure's plane.

PRL **108,** 184801 (2012) PHYSICAL REVIEW LETTERS week ending 4 MAY 2012

Nondivergent Cherenkov Radiation in a Wire Metamaterial

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(Received 11 January 2012; published 1 May 2012)

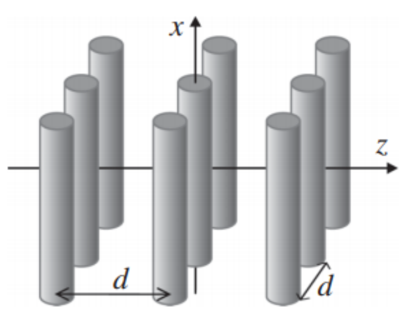
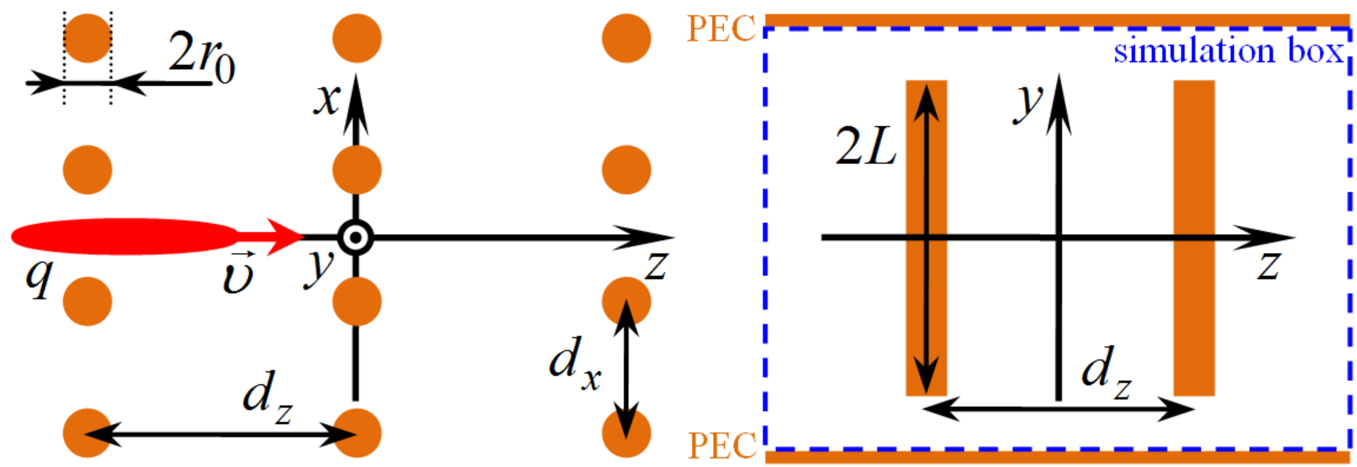
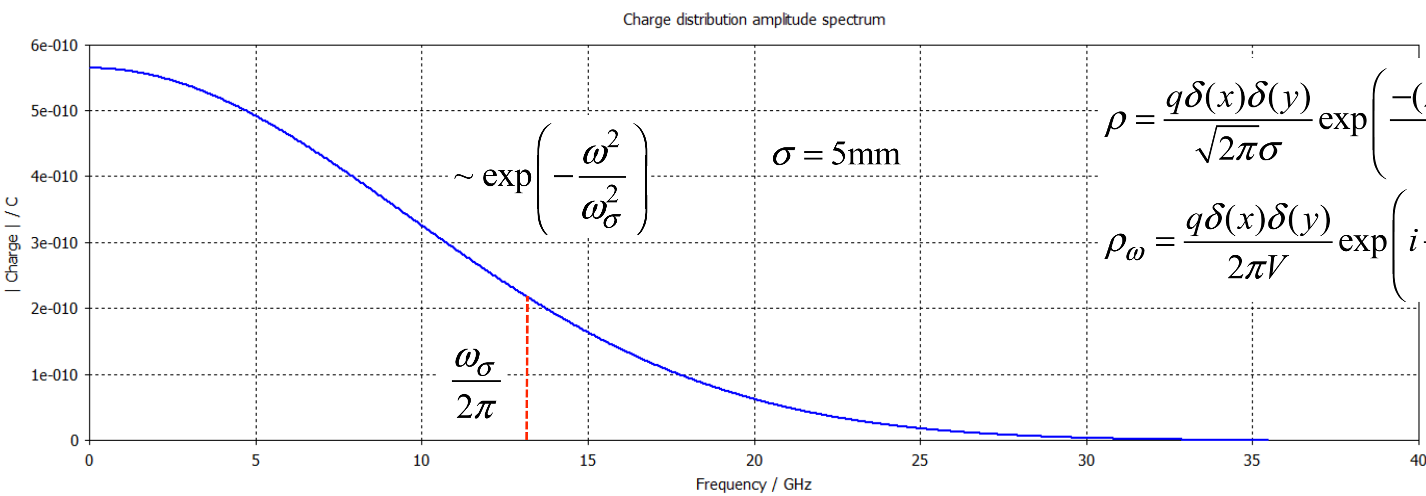


FIG. 1. Scheme of the structure.

CST Particle Studio simulations

CST model





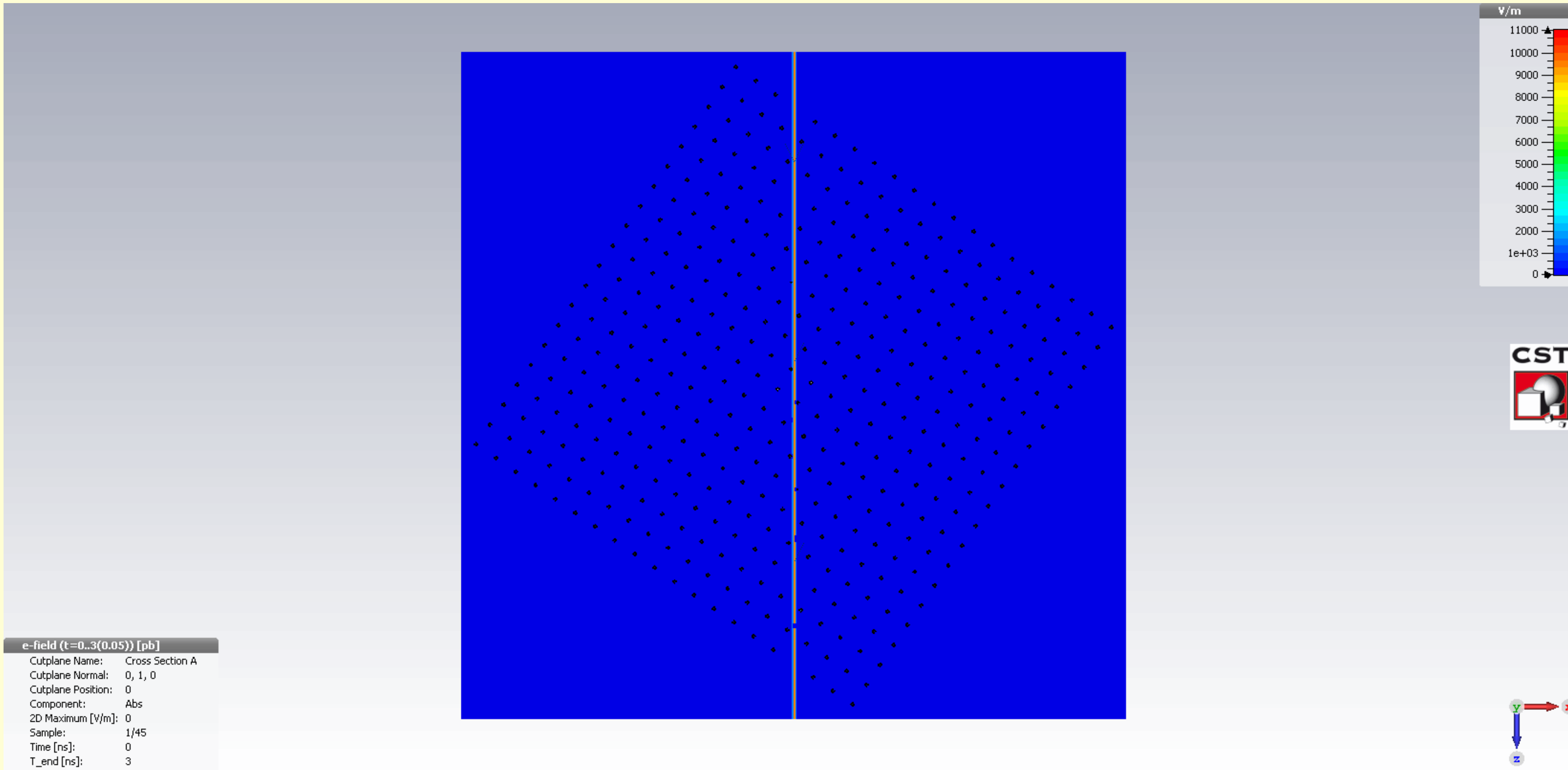
$$\rho = \frac{q\delta(x)\delta(y)}{\sqrt{2\pi}\sigma}\exp\left(\frac{-(z-Vt)^2}{2\sigma^2}\right)$$

$$\rho_\omega = \frac{q\delta(x)\delta(y)}{2\pi V}\exp\left(i\frac{\omega}{V}z-\frac{\omega^2}{\omega_\sigma^2}\right), \quad \omega_\sigma = \frac{\sqrt{2}V}{\sigma}$$

CST Particle Studio simulations

CST result

20x20 structure



$L = 20\text{cm}$

$r_0 = 0.5\text{mm}$

$\alpha = 55.4^{\text{o}}$

$L/r_0 = 400$

$\sigma = 3\text{mm}$

$\omega_\sigma = 2\pi \cdot 22\text{GHz}$

$d_x = d_z = 8\text{mm}$

“Long-wave” response

Effective medium approach

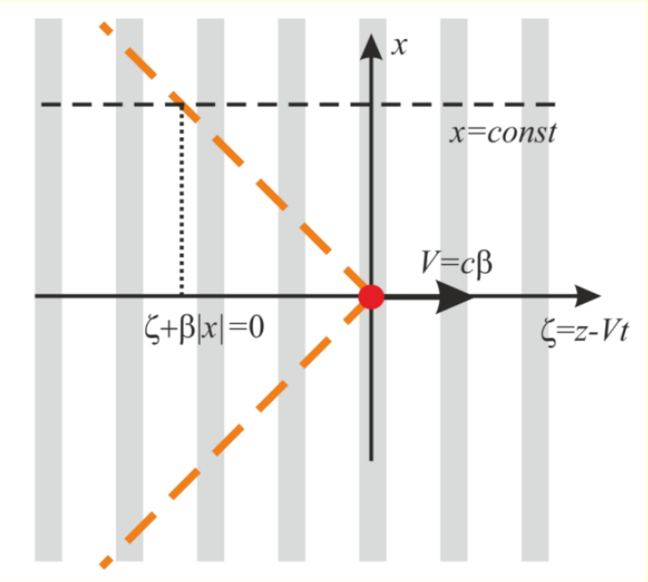
$$d_x, d_z \ll \Lambda, \lambda$$

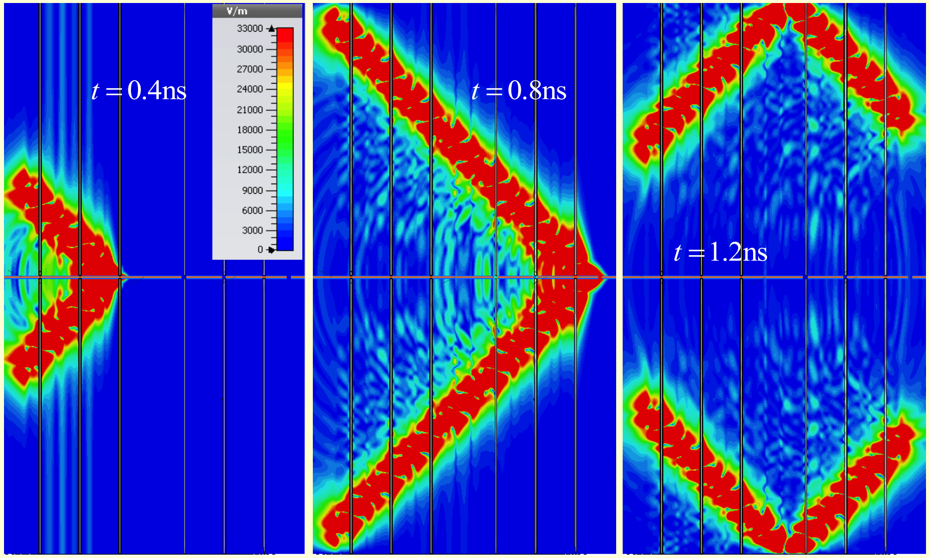
$$\hat{\varepsilon} = \begin{pmatrix} \varepsilon_P & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix}, \quad \varepsilon_P(\omega, k_y) = 1 - \frac{\omega_p^2}{\omega^2 - c^2 k_y^2 - 2i\omega\omega_d},$$

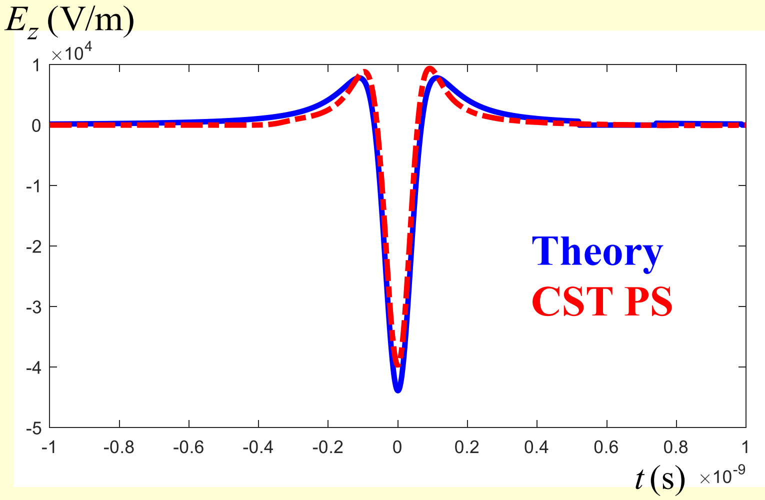
$$\omega_p^2 = \frac{2\pi c^2}{d_x d_z u}, \qquad \omega_d \approx \frac{a^2 \omega_p^2}{8\pi^2 r_0^2 \sigma_{\text{wire}}}$$

Square lattice: $d_x = d_z = a \;\Rightarrow\; u = \ln(a/r_0) - C$

$C \approx 1.0487$ Tyukhtin A. V., Doilnitsina E. G. J. Phys. D: Applied Phys. 2011. V. 44. N. 26. 265401.







$dx = dz = s = 1$cm, $r_0 = 1$mm, $q = 1$ nC, $x = 10$cm, $z = b/2$, $y = 0$, $b = 0.9999$.

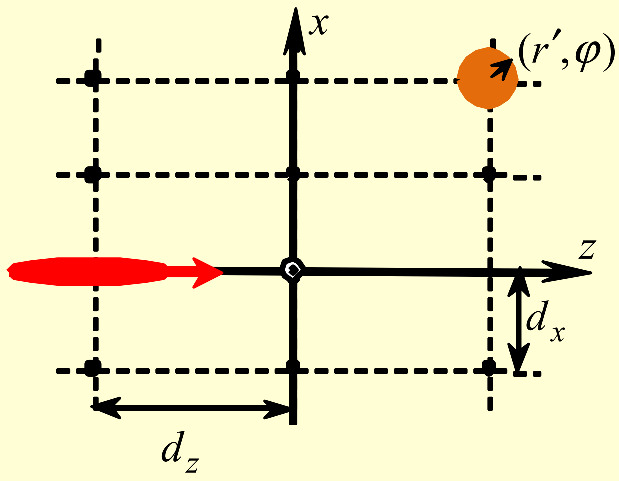
Vibrator antenna approach

"zero-order" approximation:

$$x = x_{lm} = l d_x \qquad z = z_{lm} = m d_z$$

$$\beta \to 1 \qquad L/r_0 >> 1$$

$$E^{(i)}_{\omega ylm} = E^{(i)}_{\omega r}\frac{y}{r_{lm}} = \frac{q}{\pi c}\exp\left(i\frac{\omega}{c}z_{lm} - \frac{\omega^2}{\omega_\sigma^2}\right)\frac{y}{y^2 + x_{lm}^2}$$



Hallen's problem:

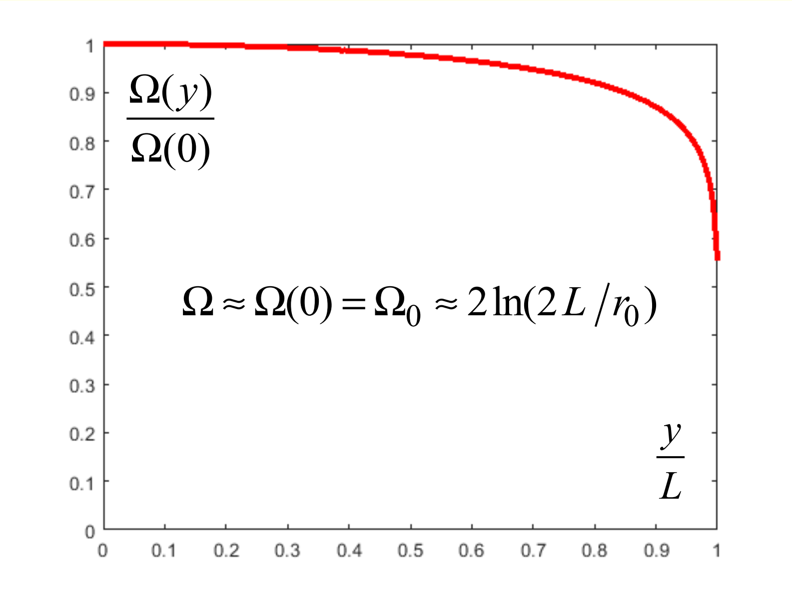
$$\left(\frac{d^2}{dy^2} + k_0^2\right)U(y) = 2ik_0 E^{(i)}_{\omega y}, \qquad k_0 = \omega / c$$

$$U(y) = 2A_{\omega y}\big|_{r'=r_0}$$

$$\frac{c}{2\mu}U(y) = I(y)\Omega(y) - \int_{-L}^{L}\left[I(y) - I(\xi)e^{ik_0|y-\xi|}\right]K_1(y-\xi)d\xi$$

$$K_1(y-\xi) = \frac{1}{2\pi}\int_{-L}^{L}\frac{d\varphi}{\sqrt{(y-\xi)^2 + 4r_0\sin^2(\varphi/2)}},$$

$$\Omega(y) = \int_{-L}^{L}K_1(y-\xi)d\xi$$



Vibrator antenna approach

General solution for longitudinal potential

$$U(y) = A\sin(k_0 y) + B\cos(k_0 y) + C_1(y)\sin(k_0 y) + C_2(y)\cos(k_0 y)$$

$$C_1(y) = \frac{2iC_0}{\pi k_0}\int_0^y \frac{\cos(k_0\xi)\xi}{\xi^2 + x_{lm}^2}d\xi, \qquad C_2(y) = \frac{2C_0}{\pi i k_0}\int_0^y \frac{\sin(k_0\xi)\xi}{\xi^2 + x_{lm}^2}d\xi$$

$$C_0 = qk_0 c^{-1}\exp(ik_0 z_{lm} - \omega^2/\omega_\sigma^2)$$

Boundary condition

$$I_{lm}(\pm L) = 0$$

$$\frac{c}{2\mu}U(y) = I(y)\Omega(y) - \int_{-L}^{L}\left[I(y) - I(\xi)e^{ik_0|y-\xi|}\right]K_1(y-\xi)d\xi$$

$$B = 0, \qquad A = -\frac{C_1(L)\sin(k_0 L) + C_2(L)\cos(k_0 L)}{\sin(k_0 L)}$$

$$j_{lm}^{\mathrm{surf}}(y) = \frac{I_{lm}(y)}{2\pi r_0}, \qquad A_{\omega y}^{(lm)} = \frac{\mu}{c}\int_0^{2\pi} d\phi\, r_0 \int_{-L}^{L} d\xi\, j_{lm}^{\mathrm{surf}}(\xi)\frac{\exp(ik_0 R_{lm})}{R_{lm}}$$

$$R_{lm} = \sqrt{\rho_{lm}^2 + r_0^2 - 2r_0\rho_{lm}\cos\phi + (y-\xi)^2}, \qquad \rho_{lm} = \sqrt{(z - z_{lm})^2 + (x - x_{lm})^2}$$

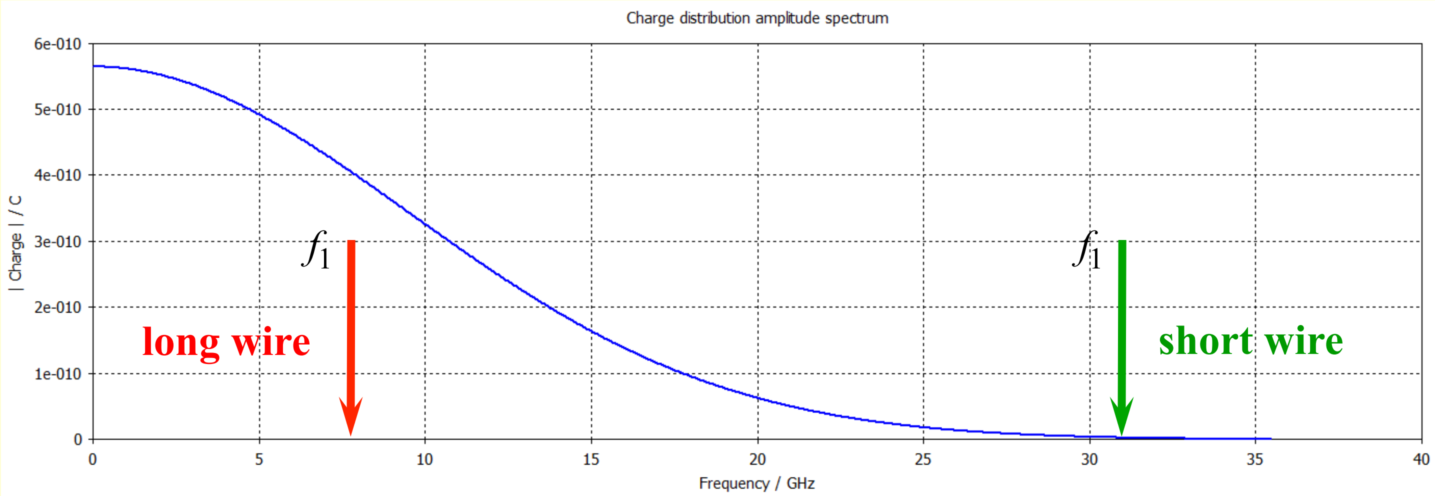
Vibrator antenna approach

General solution for surface current

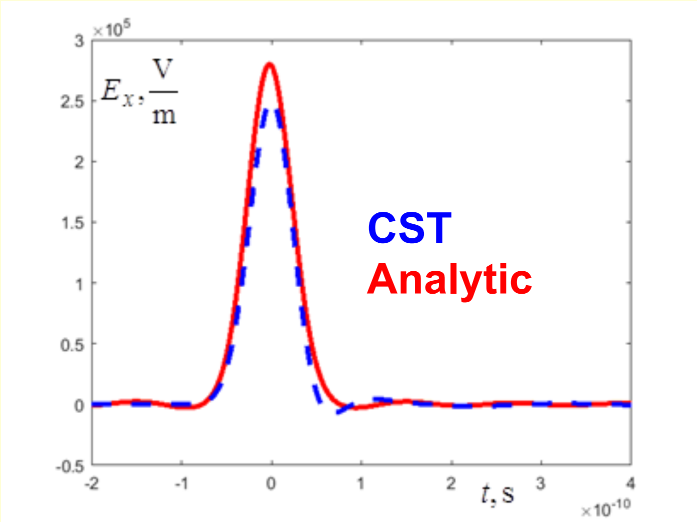
$$I(y)=\frac{c}{2\mu\Omega_0}\left[-\frac{C_1(L)\sin(k_0L)+C_2(L)\cos(k_0L)}{\sin(k_0L)}\sin(k_0y)+C_1(y)\sin(k_0y)+C_2(y)\cos(k_0y)\right]$$

Resonant frequencies

$$k_0L=\pm\pi m,\quad m=1,2,\ldots\quad\Rightarrow\quad\omega_m=\frac{\pi c}{L}m\quad\Rightarrow\quad f_m=\frac{c}{2L}m\cdot$$



Numerical results



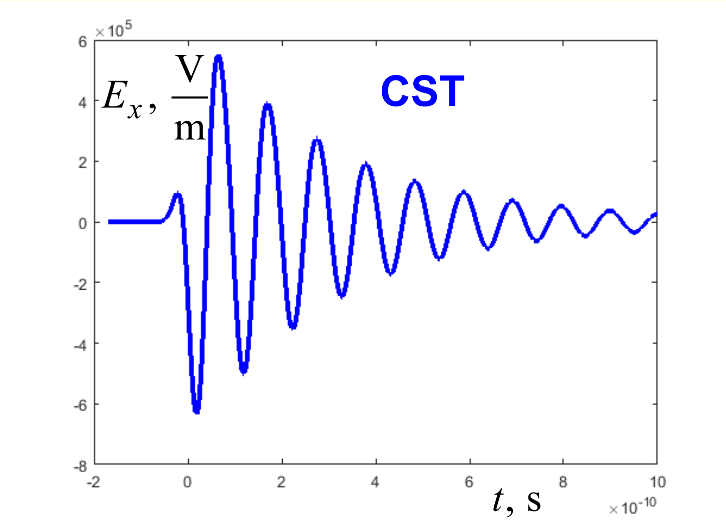
short wire

$z_{lm} = 0,\ x_{lm} = d_x$

$d_x = 1.5\text{mm},\ \sigma = 7\text{mm},\ L = 4\text{mm},\ r_0 = 0.05\text{mm}$

$q = 1\ \text{n}C,\ \beta = 0.9999(34\ \text{MeV})$

$y = z = 0,\ x = 1.5 d_x$



long wire

$\sigma = 5\text{mm},\ L = 15\text{mm}$

Resonant response results in radiation

$f_1 \approx 10\text{GHz}$

Thank you for your attention!