AXICON-BASED CONCENTRATOR FOR CHERENKOV RADIATION

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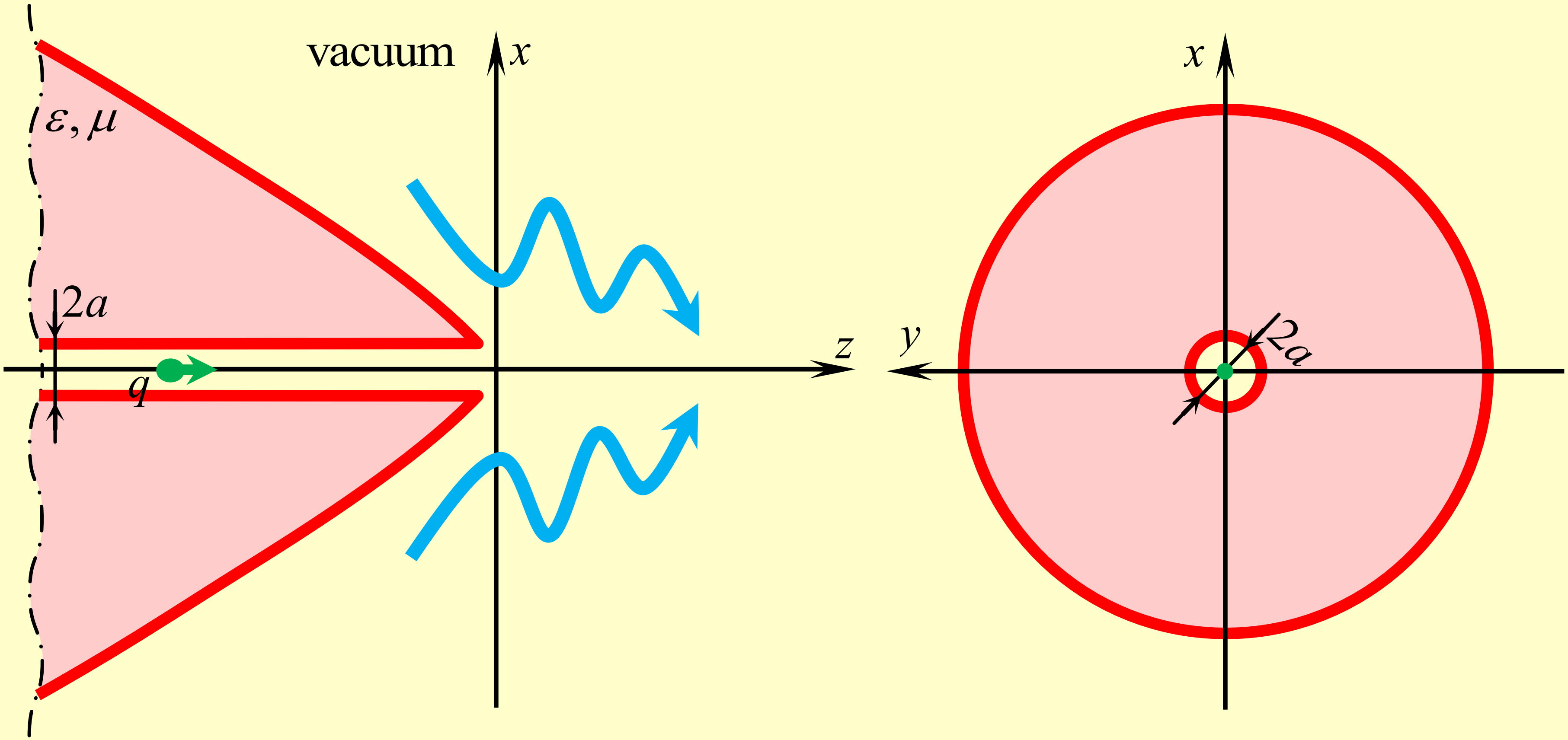
History: single-refraction concentrator



Radiation field under the complex target geometry

Approximate methods

S.N. Galyamin, A.V. Tyukhtin, Phys. Rev. Lett., V. 113, P. 064802, (2014).
S.N. Galyamin et al., Journal of Instrumentation, V. 13, P. C02029, (2018).

Approximate methods

Ray-optics technique:

[1] E. S. Belonogaya, A. V. Tyukhtin, and S. N. Galyamin, "Approximate method for calculating the radiation from a moving charge in the presence of a complex object", Phys. Rev. E, vol. 87, p. 043201, 2013.

[2] E. S. Belonogaya, S. N. Galyamin, and A. V. Tyukhtin, "Short-wavelength radiation of a charge moving in the presence of a dielectric prism", J. Opt. Soc. Am. B, vol. 32, p. 649, 2015.

Aperture technique:

[3] S. N. Galyamin and A.V. Tyukhtin, "Dielectric concentrator for Cherenkov radiation", Phys. Rev. Lett., vol. 113, p. 064802, 2014.

[4] S. N. Galyamin, A. V. Tyukhtin, S. Antipov, and S. S. Baturin, "Terahertz radiation from an ultra-relativistic charge exiting the open end of a waveguide with a dielectric layer", Optics Express, vol. 22, p. 8902. 2014.

[5] A. V. Tyukhtin, V. V. Vorobev, E. S. Belonogaya, and S. N. Galyamin, "Radiation of a charge in presence of a dielectric object: Aperture method", Journal of Instrumentation, vol. 13, p. C02033, 2018.

[6] S. N. Galyamin, A. V. Tyukhtin and V. V. Vorobev, "Focusing the Cherenkov radiation using dielectric concentrator: simulations and comparison with theory", Journal of Instrumentation, vol. 13, p. C02029, 2018.

[7] A. V. Tyukhtin, V. V. Vorobev, S. N. Galyamin, and E.S. Belonogaya, "Radiation of a charge moving along the boundary of dielectric prism", Phys. Rev. AB, vol. 22, p. 012802, 2019.

[8] A. V. Tyukhtin, S. N. Galyamin, and V. V. Vorobev, Peculiarities of Cherenkov radiation from a charge moving through a dielectric cone, Phys. Rev. A, vol. 99, p. 023810, 2019.

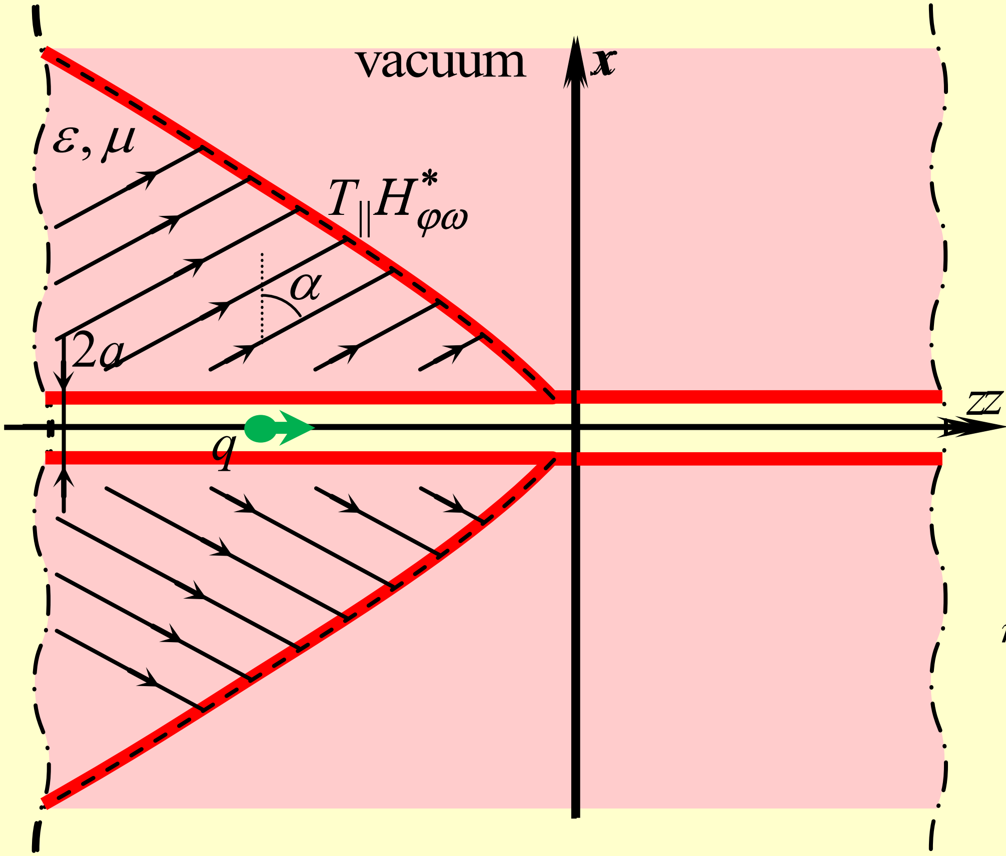
[9] A.V. Tyukhtin, S.N. Galyamin, V.V. Vorobev, A.A. Grigoreva, "Cherenkov radiation of a charge flying through the inverted conical target", Phys. Rev. A, vol. 102(5), p.. 053514, 2020.

[10] A.V. Tyukhtin, S.N. Galyamin, V.V. Vorobev, "Cherenkov radiation from a dielectric ball with a channel", Journal of the Optical Society of America B, vol. 38(3), p. 711-718, 2021.

[11] S.N. Galyamin, A.V. Tyukhtin, "Cherenkov radiation of a charge in axicon-based dielectric concentrator", Physical Review Accelerators and Beams, vol. 23(11), p. 113001, 2020.

Approximate method

1st step: "Etalon problem"



Excluding the outer boundary

$$H^{*}_{\varphi\omega} = \frac{iq}{2c} \eta s H_1^{(1)}\left(s\rho^{*}\right) \exp\left(i\frac{\omega}{\beta c} z^{*}\right)$$

$$s = \omega(\beta c)^{-1}\sqrt{\varepsilon\mu\beta^2 - 1} \qquad \operatorname{Im} s \geq 0$$

$$k = |\omega| (\beta c)^{-1}\sqrt{1-\beta^2} \qquad \sin\alpha = (n\beta)^{-1}$$

$$\eta = \frac{-2i/(\pi\alpha)}{\dfrac{\left(1-\varepsilon\mu\beta^2\right)}{\left(1-\beta^2\right)\varepsilon} I_1(ka) H_0^{(1)}(sa) + s I_0(ka) H_1^{(1)}(sa)}$$

B. M. Bolotovskii, Theory of the Vavilov-Cherenkov effect (III) // Phys. Uspekhi **4** (1962) 781.

Far-field approximation

$$H^{*}_{\varphi\omega} \sim \exp\left(\frac{i\omega}{c}\psi\right) \qquad \psi = \left(z^{*} + \sqrt{\varepsilon\mu\beta^2 - 1}\rho^{*}\right)/\beta$$

Ray optics approach (Fresnel coefficients)

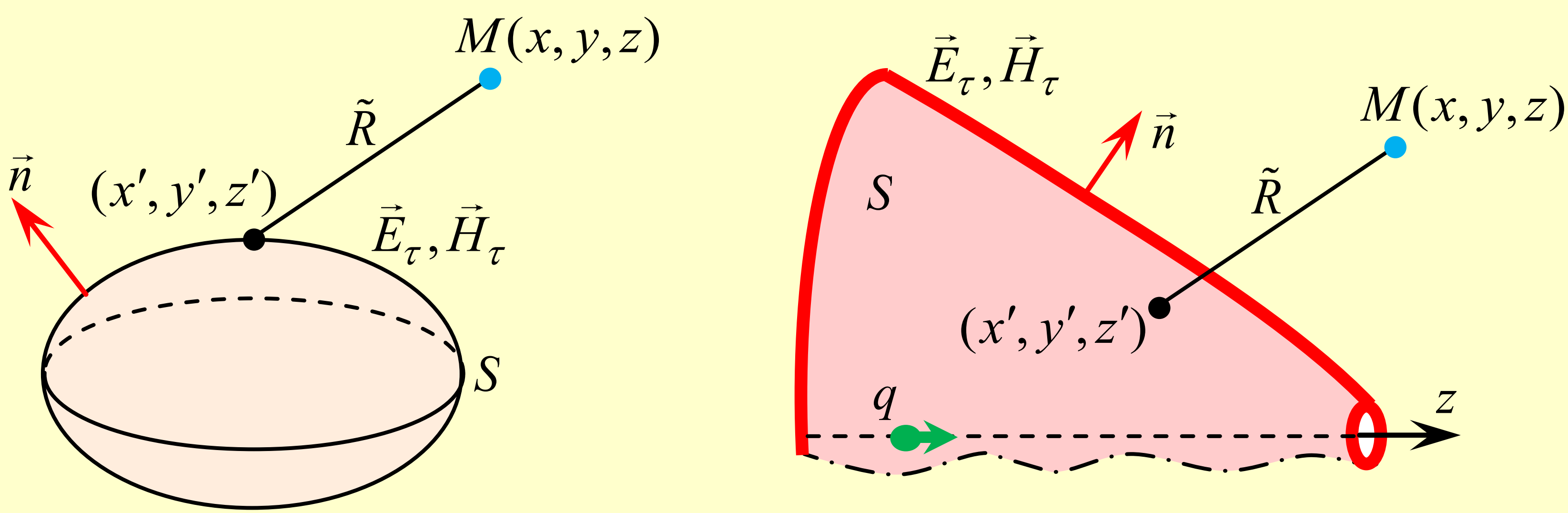
$$T_{\parallel} = \frac{2n\cos\theta_i}{n\cos\theta_i + \cos\theta^{*}}$$

Approximate method

2nd step: Field in the vacuum area

Aperture integration approach (Stratton-Chu formulas)

J.A. Stratton and L.J. Chu, Diffraction Theory of Electromagnetic Waves // Phys. Rev. **56** (1939) 99



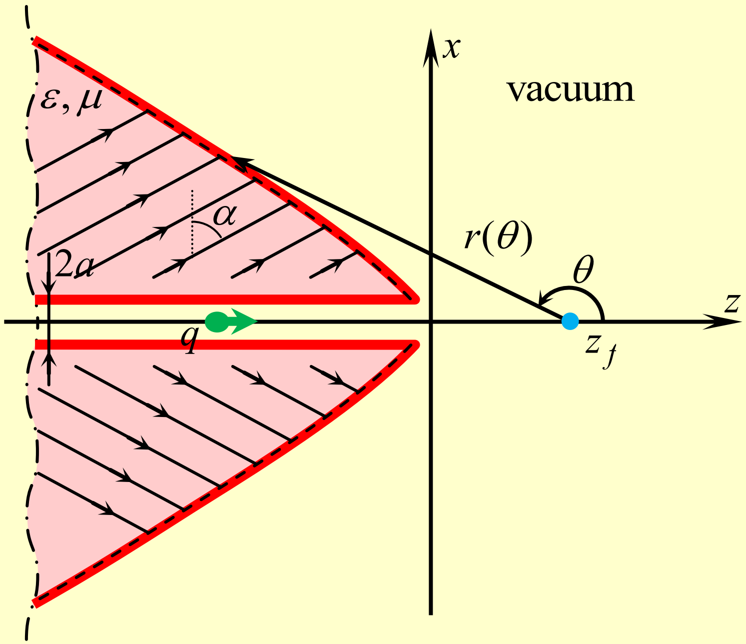
$$\vec{E}(M) = \frac{ikZ_0}{4\pi}\int_S \vec{j}_e^{\,s}\,\frac{e^{ik\tilde{R}}}{\tilde{R}}\,ds' + \frac{iZ_0}{4\pi k}\int_S (\vec{j}_e^{\,s}\,\nabla')\,\nabla'\frac{e^{ik\tilde{R}}}{\tilde{R}}\,ds' - \frac{1}{4\pi}\int_S \left[\vec{j}_m^{\,s}\,\nabla'\frac{e^{ik\tilde{R}}}{\tilde{R}}\right] ds'$$

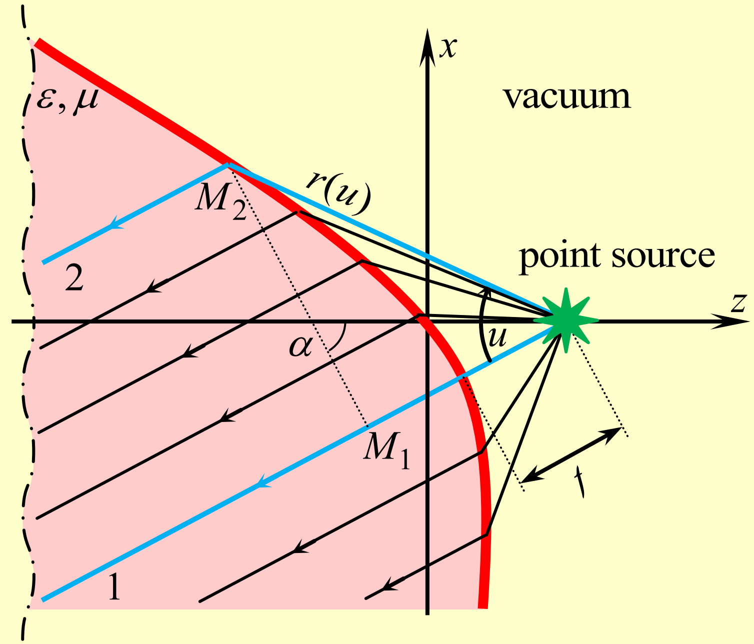
$$\vec{j}_e^{\,s} = [\vec{n}\,\vec{H}\,|_S]; \quad \vec{j}_m^{\,s} = [\vec{E}\,|_S\,\vec{n}].$$

$$\tilde{R} = \sqrt{(x-x')^2 - (y-y')^2 + (z-z')^2} \qquad k = \omega/c, \;\; Z_0 = \sqrt{\mu/\varepsilon}$$

Results

Single-refraction concentrator

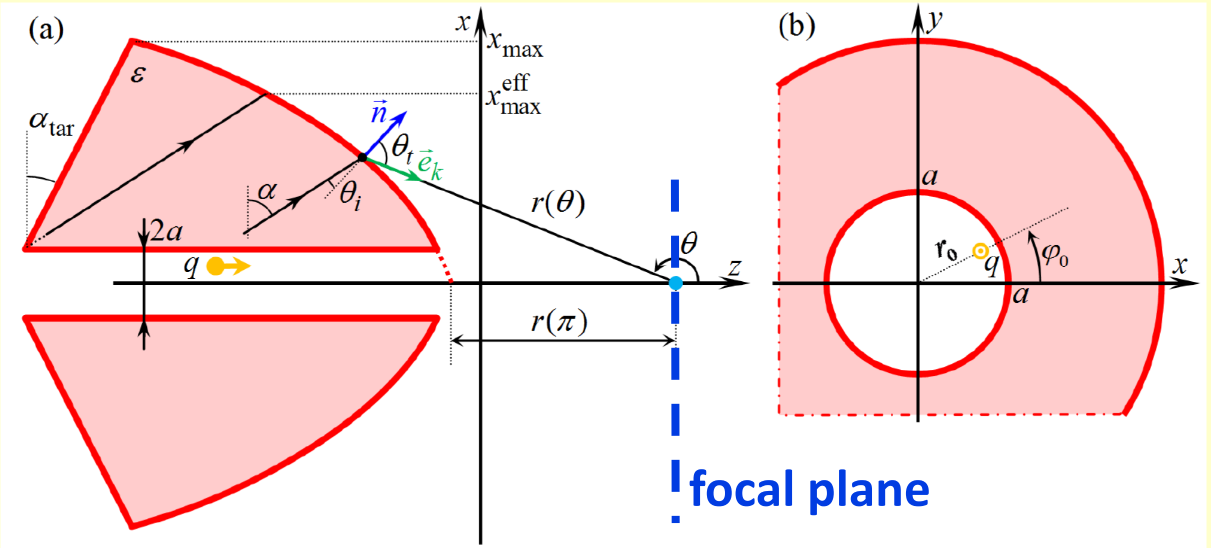




$$r(\theta) = \frac{f(1-n)}{1+n\sin(\theta+\alpha)}$$

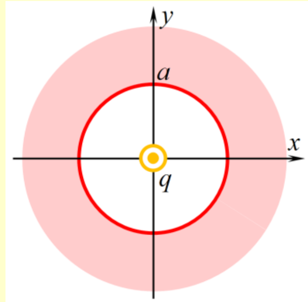
$$\sin\alpha = \frac{1}{n\beta}$$

$$n = \sqrt{\varepsilon\mu}$$

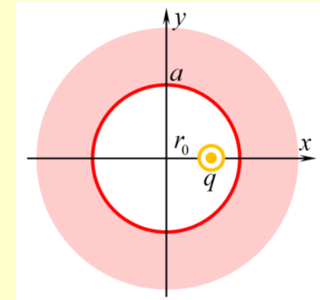


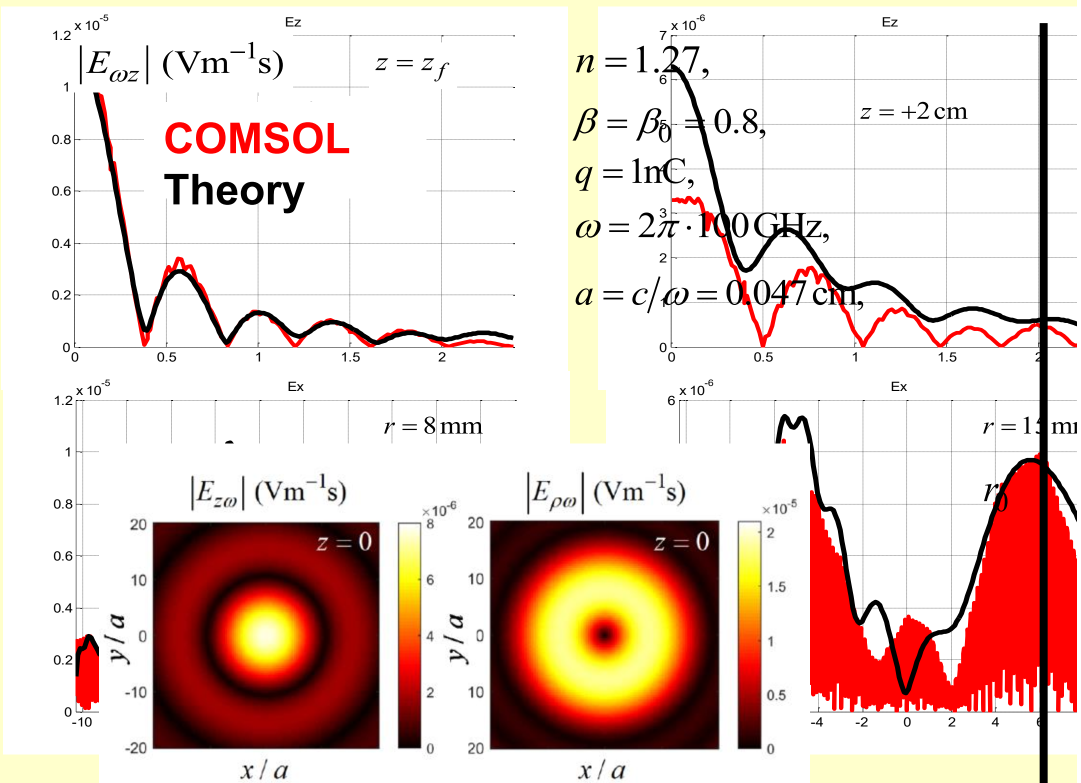
Single-refraction concentrator

Comparison between theory and COMSOL simulations for the charge moving along the symmetry axis.



Field distributions when the charge trajectory is shifted from the symmetry axis.





$n = 1.27,$

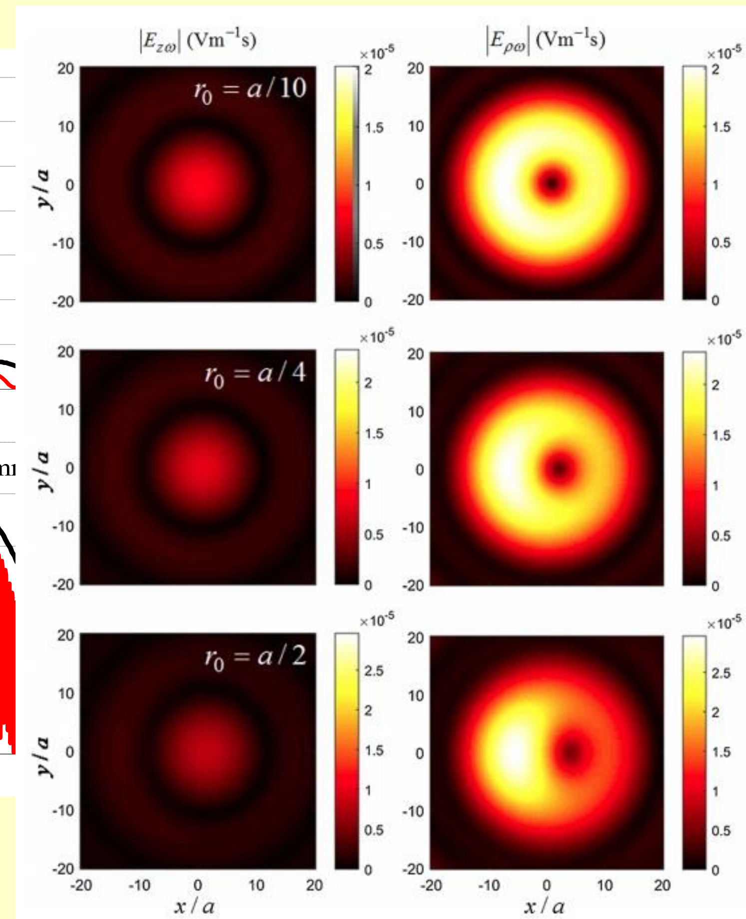
$\beta = \beta_0 = 0.8,$

$q = 1\,\text{nC},$

$\omega = 2\pi \cdot 100\,\text{GHz},$

$a = c/\omega = 0.047\,\text{cm},$

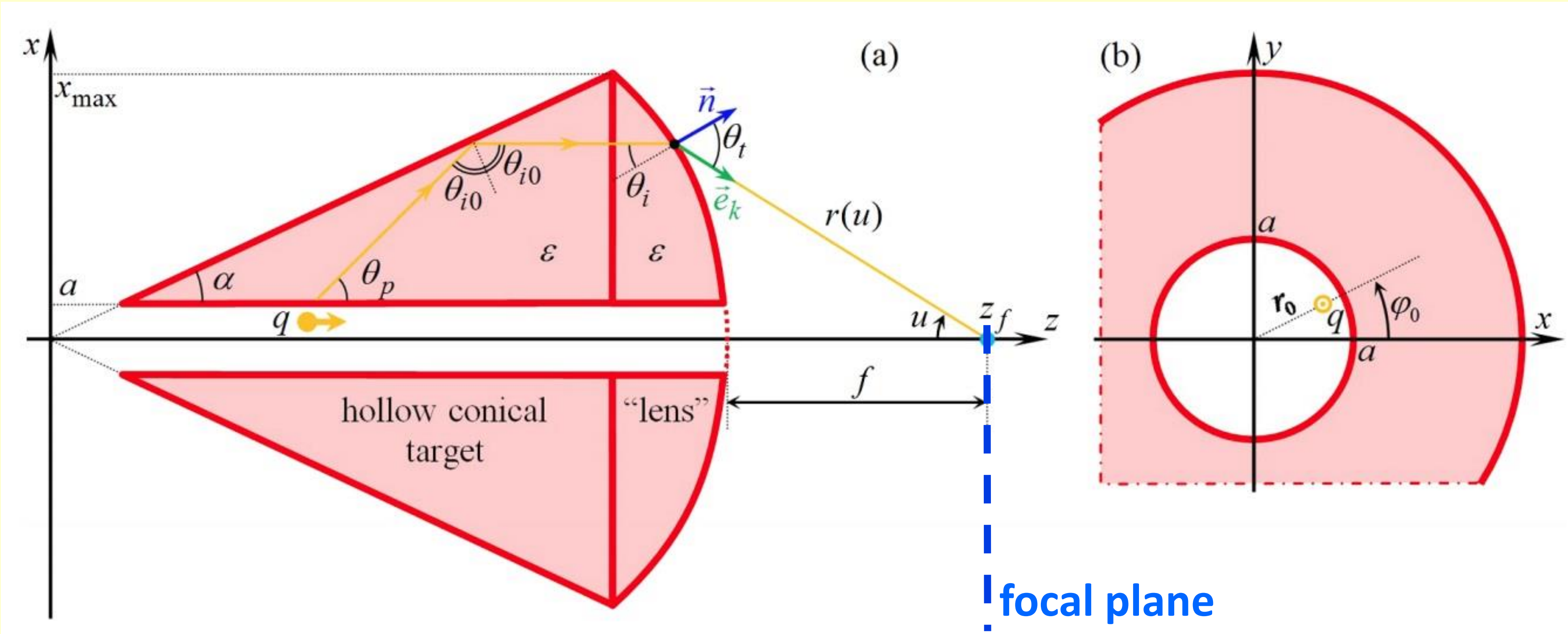
focal plane



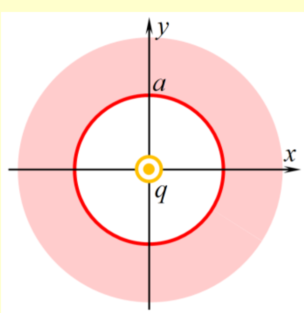
focal plane

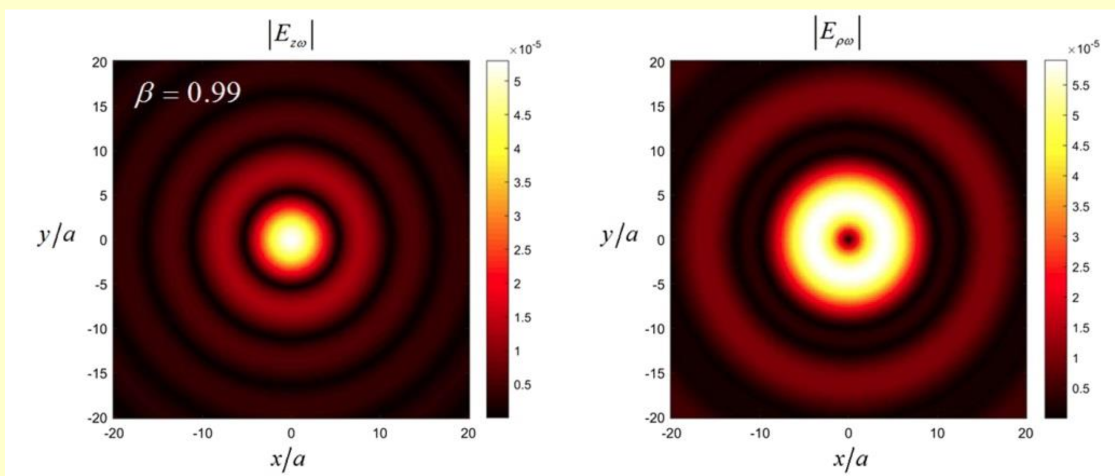
Results

Axicon-based concentrator



$$r(u) = \frac{f(n-1)}{n\cos(u)-1}$$





$n = 1.27,$

$\beta = 0.999$

$q = 1\,\mathrm{nC},$

$\omega = 2\pi \cdot 100\,\mathrm{GHz},$

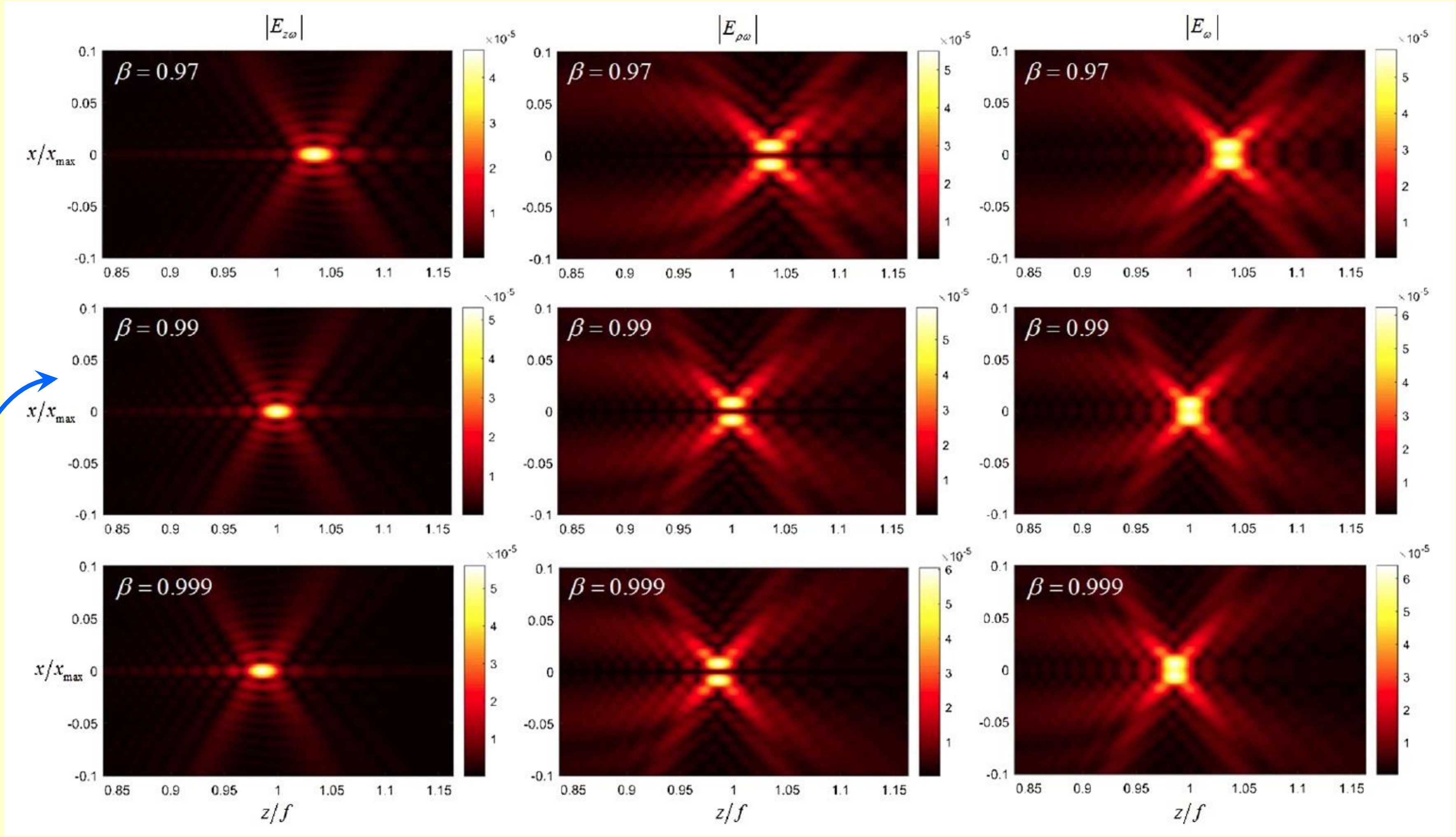
$a = c/\omega = 0.047\,\mathrm{cm}$

$\alpha = 30^\circ$

focal plane

Results

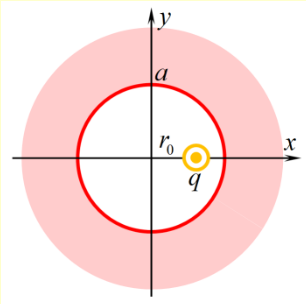
Axicon-based concentrator

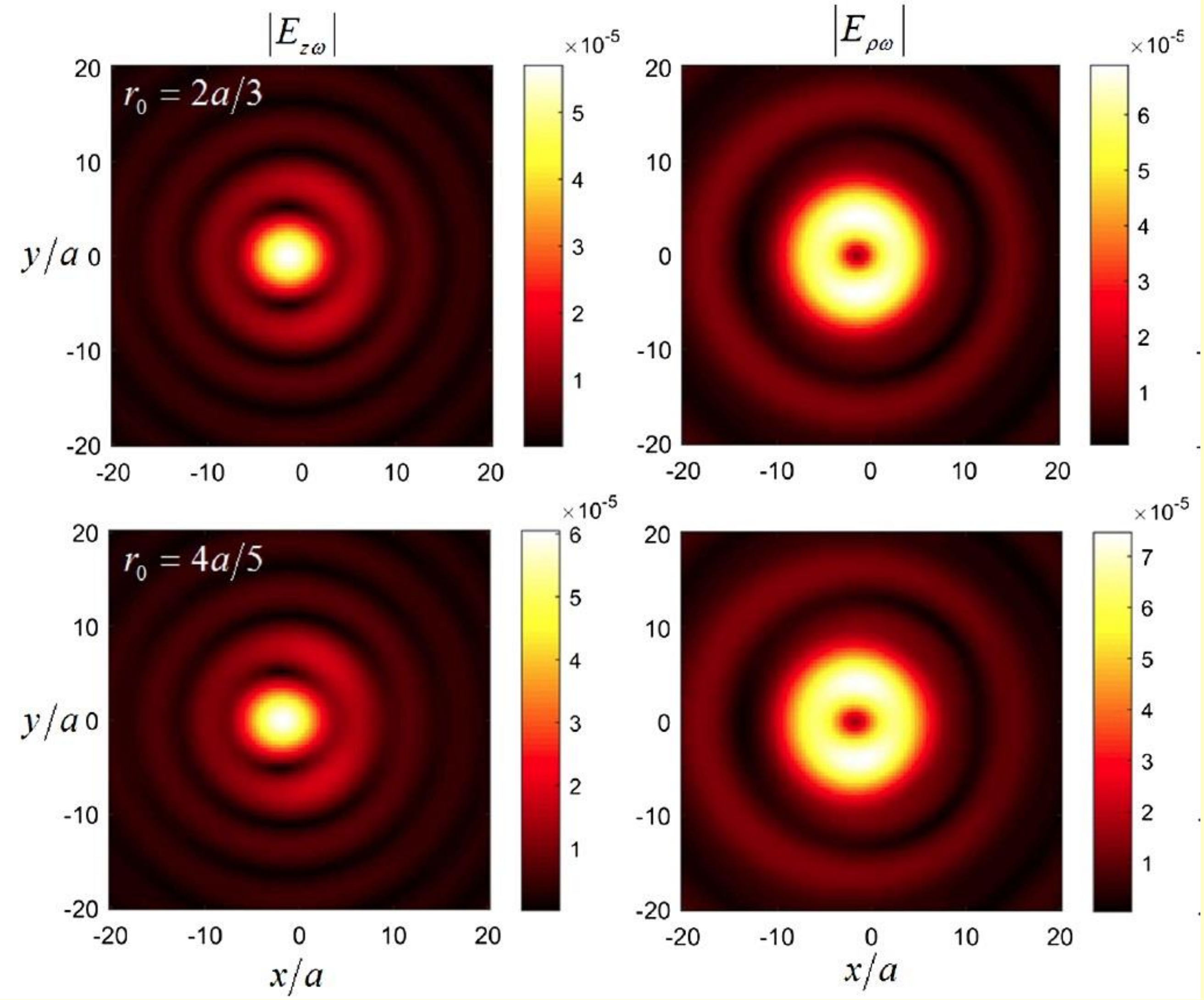


“designed” velocity

longitudinal plane

Axicon-based concentrator





focal plane

Thank you for your attention!