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All-optical undulator using array of pulse-front tilted laser beams with alternated phases

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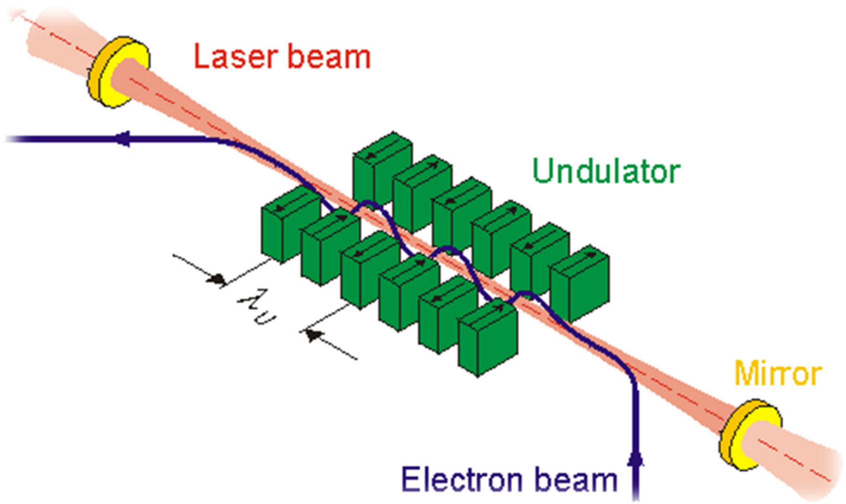
Outline

I. Background

Conventional undulator



**Tremendous in cost,
Huge in shape**

Alternatives

?

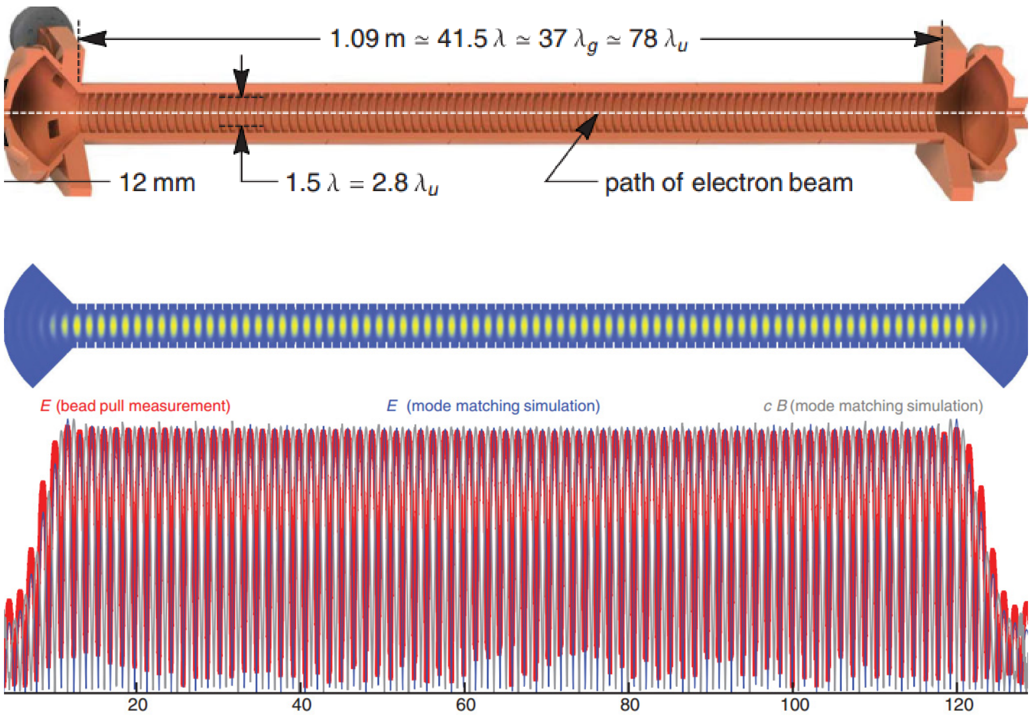
**Low cost,
Compact in shape**

I. Background

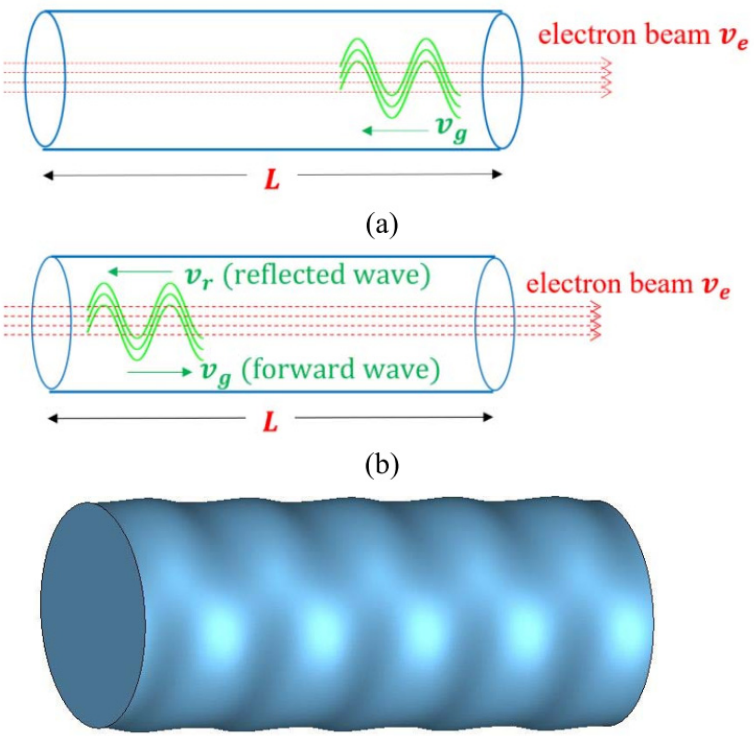
Resonant condition: $$\lambda_\ell = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$$

I. Background

Microwave undulator



Sami Tantawi, et al., PRL 112, 164802 (2014)

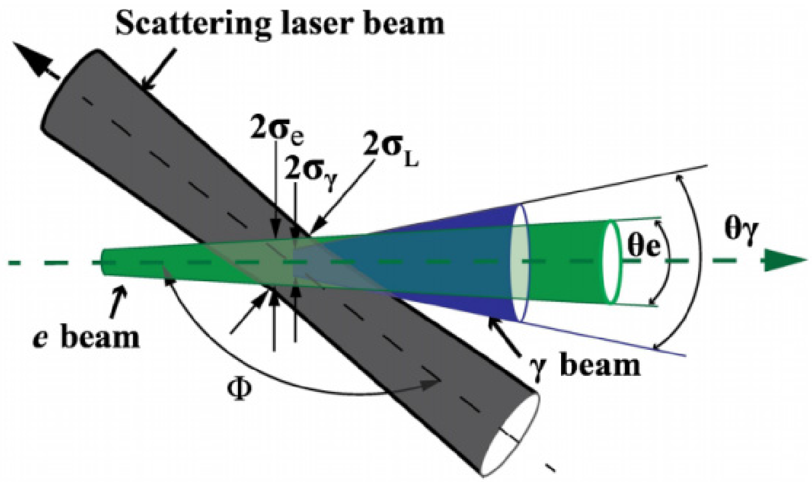


Liang Zhang, et al. IEEE TRANSACTIONS ON ELECTRON DEVICES 2018.

Relies on high power microwave sources;
Breakdown threshold of the metallic waveguides!

I. Background

Optical undulator
(inverse Compton scattering)



S. Chen, et al., PRL 110, 155003 (2013)

$$K = \frac{2\pi\lambda_u}{mc^2} F_{\perp}$$

$$\lambda_u \approx \lambda_l / 2$$

Tremendous laser field intensity,
Undulating length is not enough long.

I. Background

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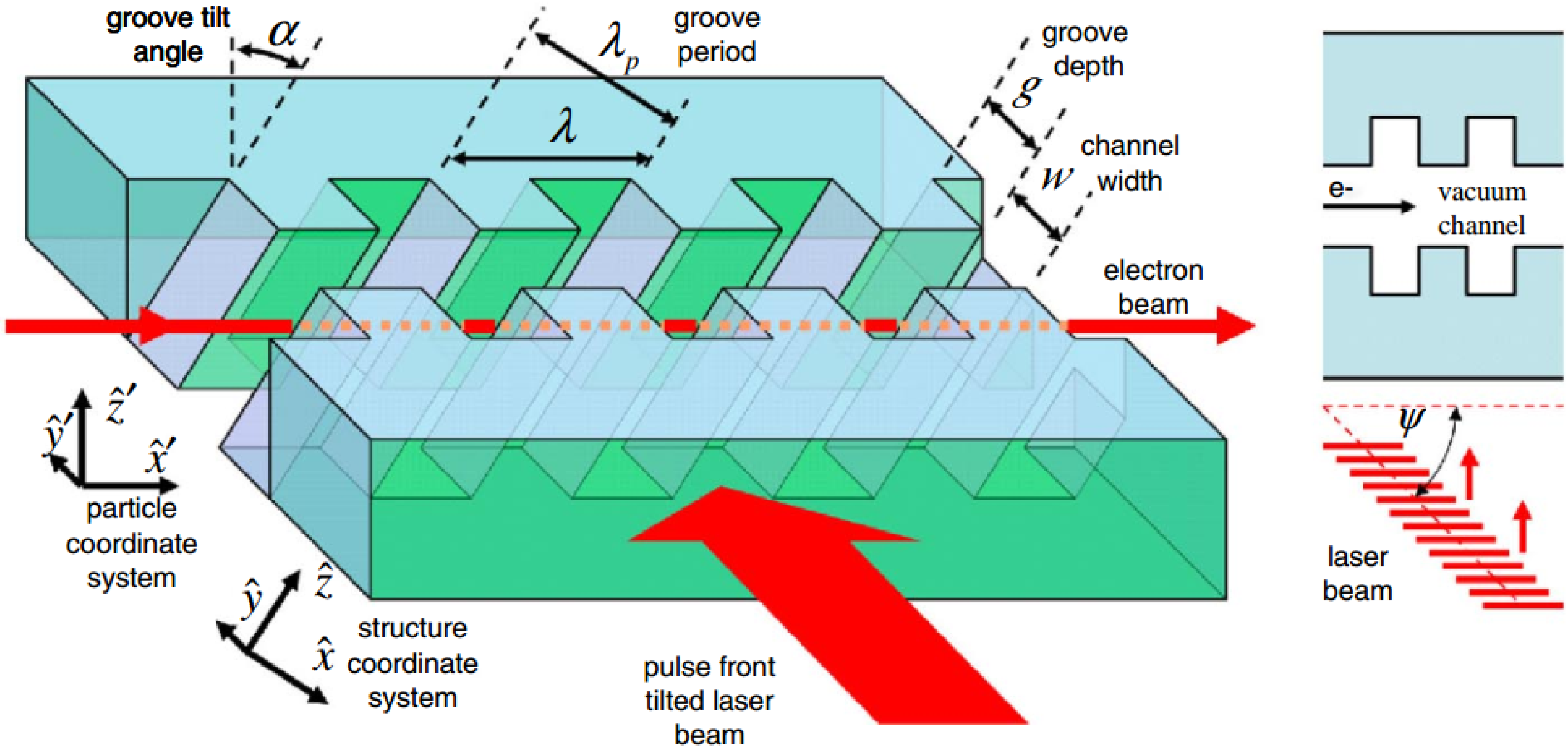
Micro dielectric undulator



T. Plettner and R. L. Byer, PRst-AB **11**, 030704 (2008)

Small beam channel; breakdown; low efficiency; deflection.

II. Description of scheme

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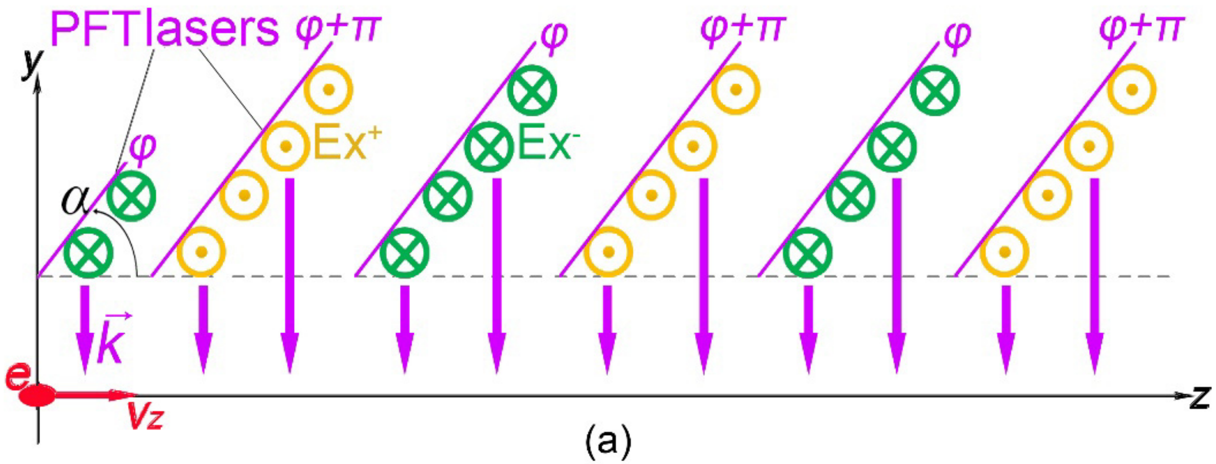
1. Model description



$$\tan\alpha = 1/\beta_z = c/v_z$$

$$L_{\varphi} = L_{\varphi+\pi} = m\beta_z\lambda_l$$

II. Description of scheme

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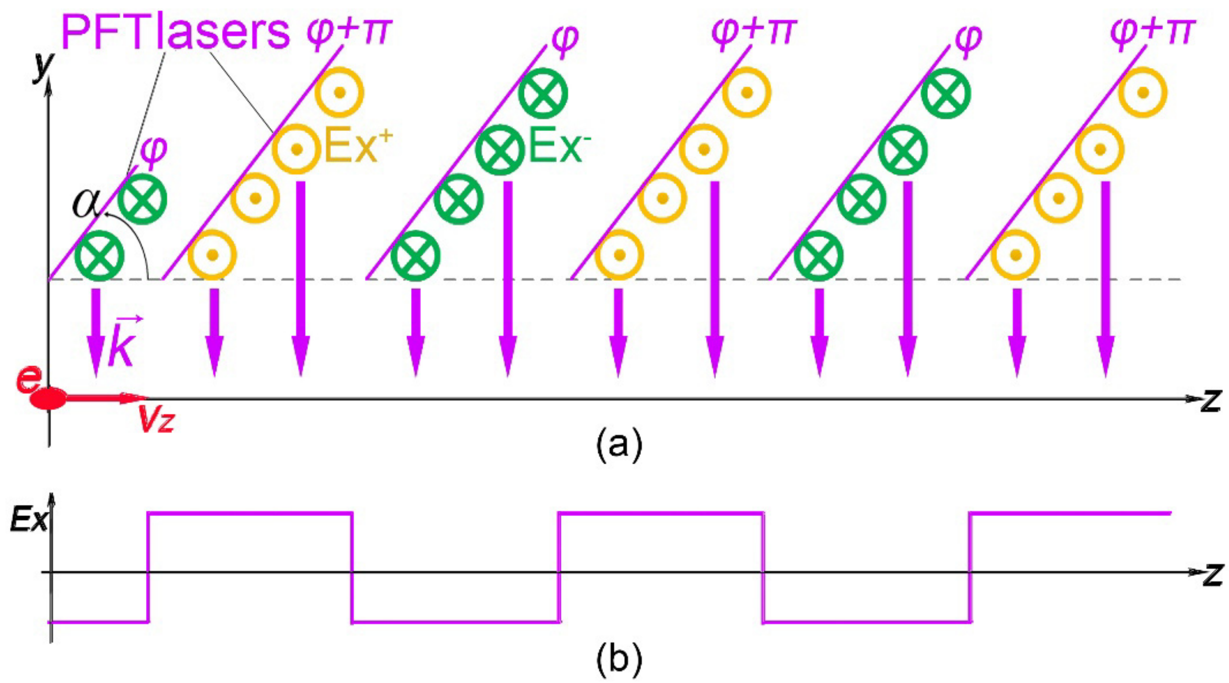
1. Model description



$$\frac{d\gamma m_e v_x}{dt} = -eE_x$$

II. Description of scheme

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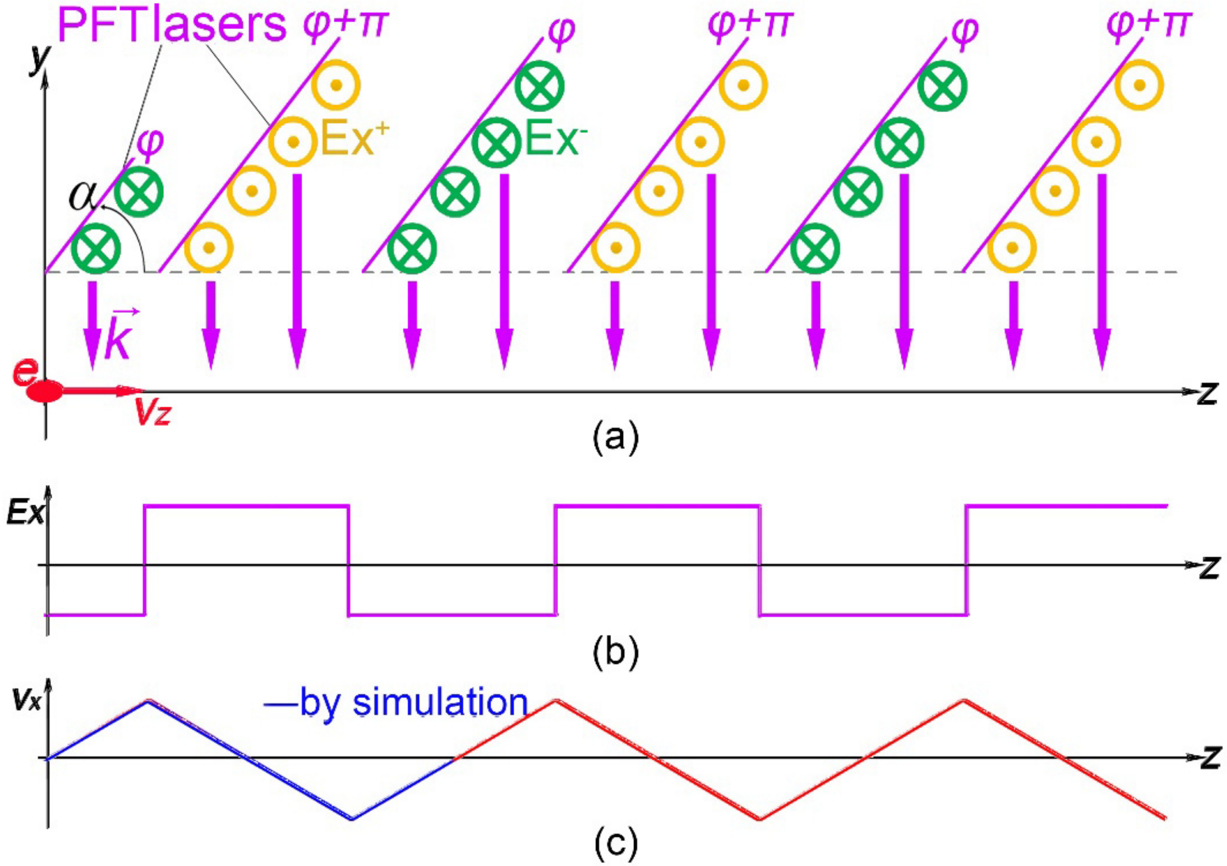
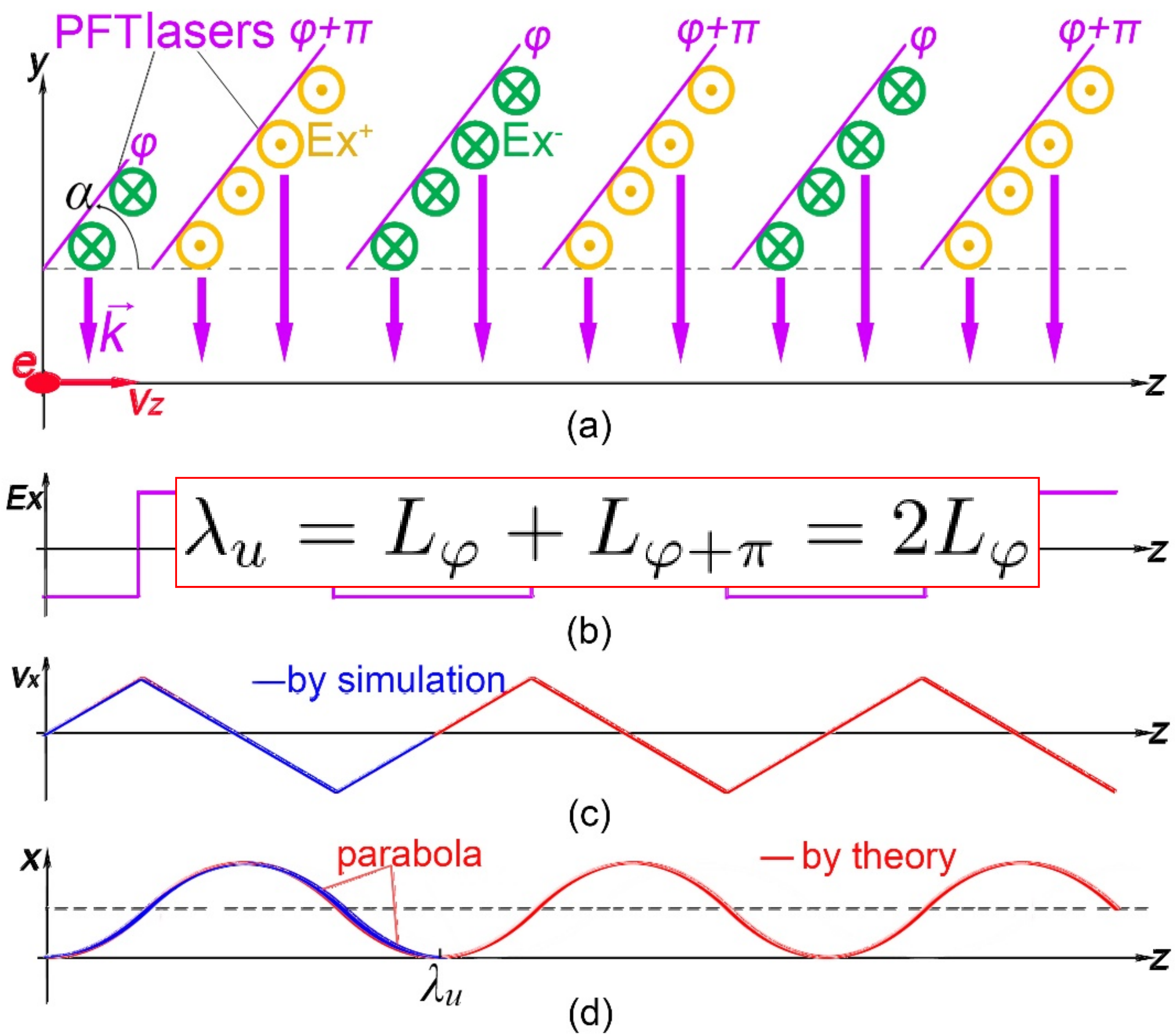
1. Model description



$$x(z) = -\frac{eE_x}{m_e\gamma}\frac{z^2}{2v_z^2} + \frac{v_0}{v_z}z + x_0$$

II. Description of scheme

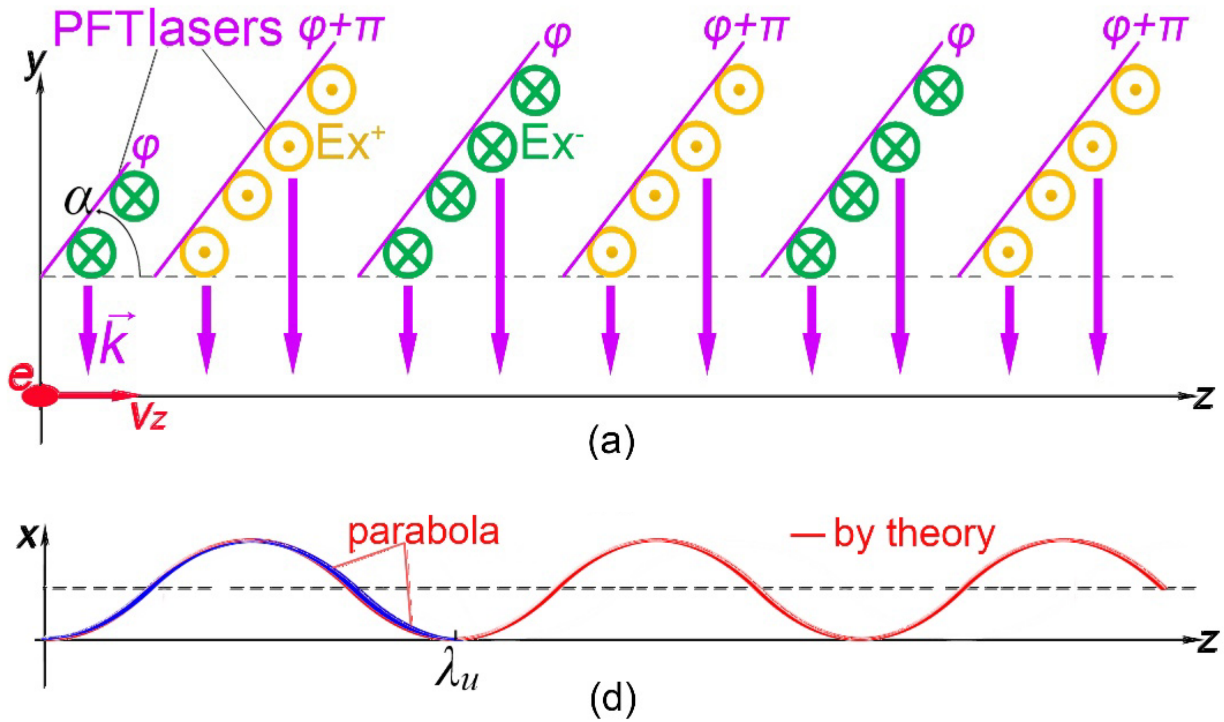
1. Model description



$$\lambda_u = L_\varphi + L_{\varphi+\pi} = 2L_\varphi$$

III. FEL performance

2. analyses



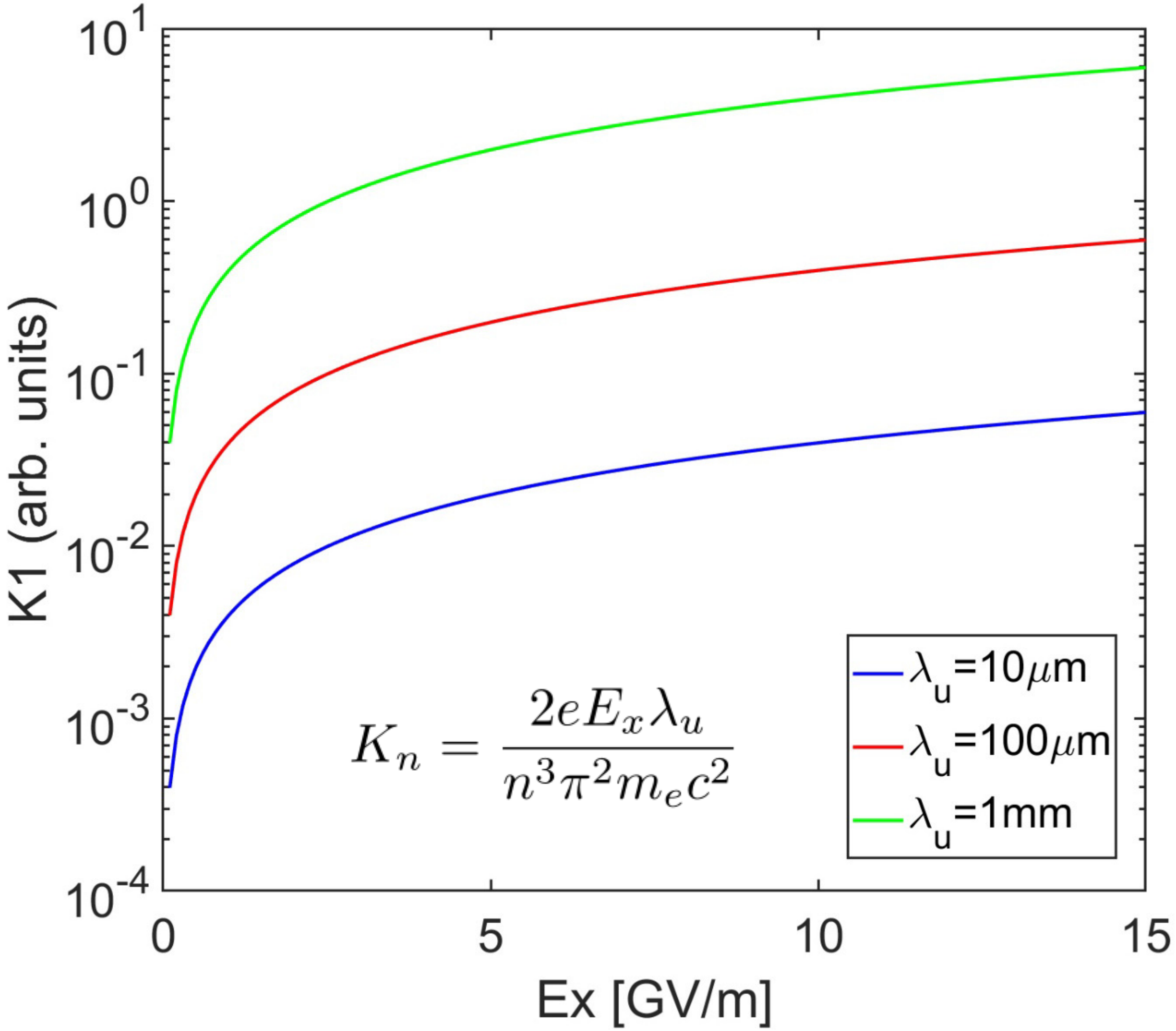
$$X(z) = \sum_{n=1}^{+\infty} \mathrm{S}(n) \frac{K_n}{\gamma \beta_z k_n} \cos k_n z$$

$$X(z) = x(z) + eE_x L^2 / 32 \gamma {\beta_z}^2 m_0 c^2$$

$$K_n = \frac{2eE_x \lambda_u}{n^3 \pi^2 m_e c^2}$$

III. FEL performance

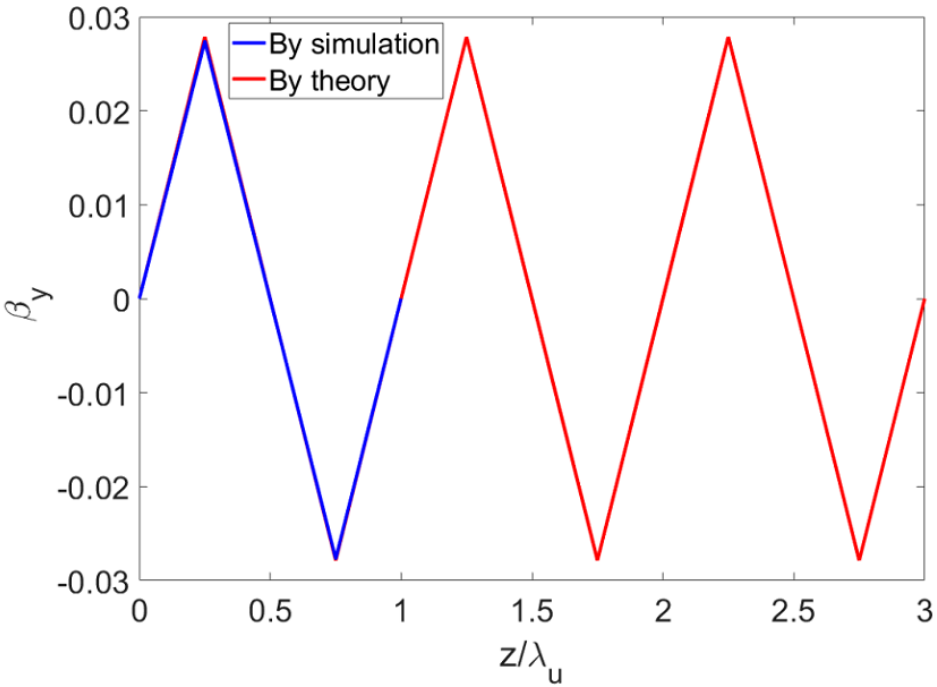
2. analyses

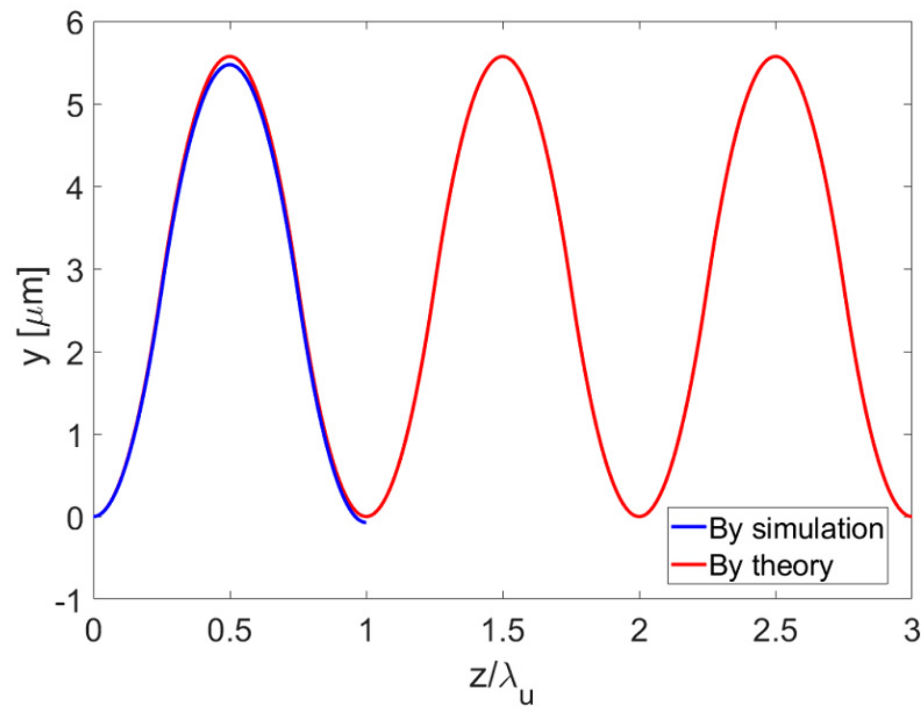


$$K_n = \frac{2eE_x\lambda_u}{n^3\pi^2 m_e c^2}$$

III. FEL performance

2. analyses





Beam energy: 35 MeV

Incident Laser wavelength: 10 um

$\lambda_u = 0.1mm$

$\lambda_r = 10nm$

III. FEL performance

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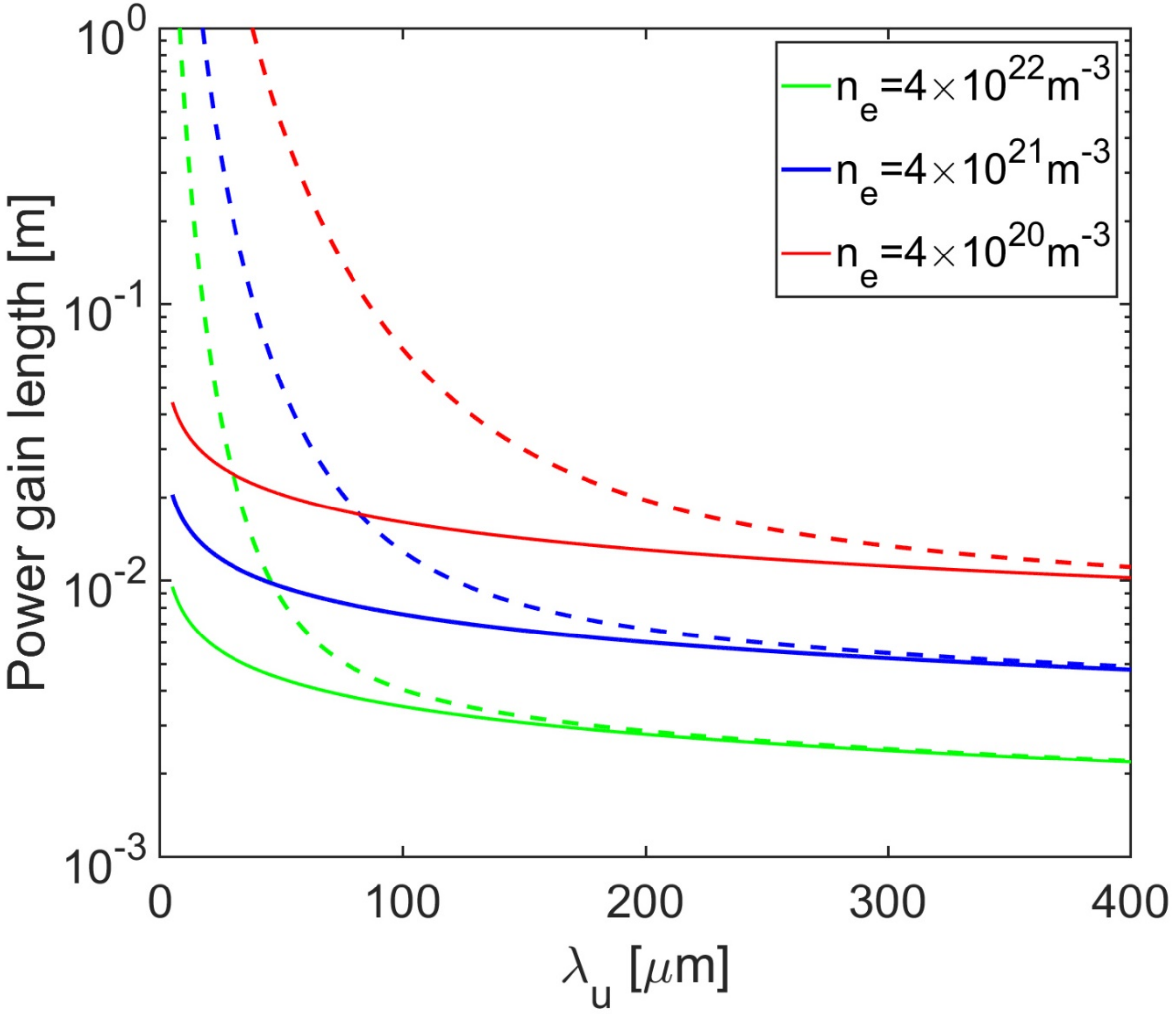
2. analyses

$$L_{G0} = \frac{1}{\sqrt{3}}\left[\frac{4\gamma^3 m_e}{\mu_0 K^2 e^2 k_u n_e}\right]^{1/3}$$

Ming Xie formula:

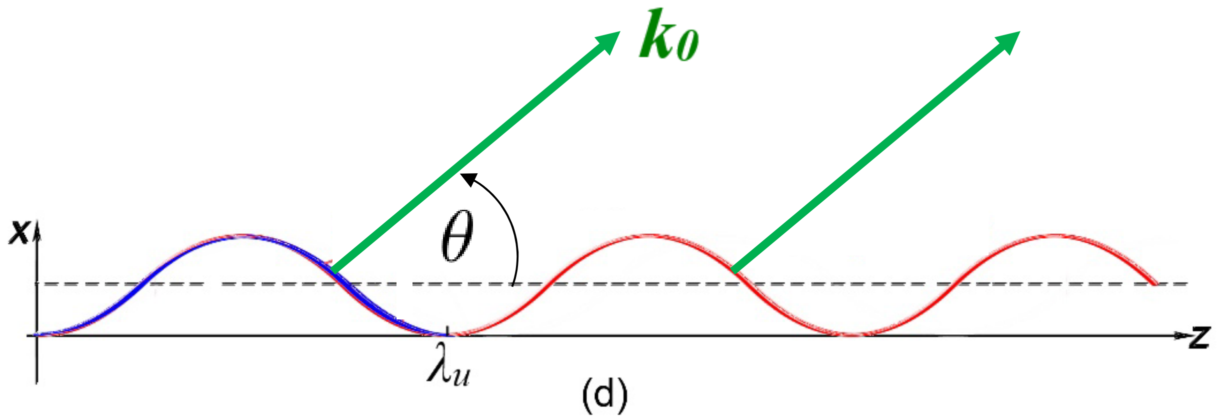
$\varepsilon = 10^{-7}$ m*rad

$\Delta\gamma/\gamma = 5 * 10^{-4}$



III. FEL performance

3. notings



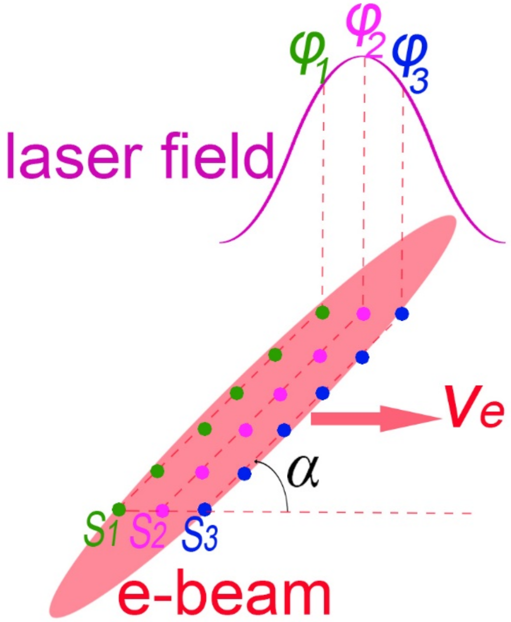
$$\frac{\omega}{c}-\frac{\omega}{v_z}\cos\theta = k_0 - k_z\cos\theta = 2n\pi \quad\Longrightarrow\quad \lambda_n = \frac{\lambda_u}{n}\left(\frac{1}{\beta_z} - \cos\theta\right)$$

In the forward direction with small angle θ:

$$\lambda_n = \frac{\lambda_u}{2n\gamma^2}(1+\gamma^2\theta^2)$$

III. FEL performance

3. notings



$$K_i = K_0 \sin \varphi_i$$

III. FEL performance

3. notings

- Using the optical paths to distribute a single laser beam into an array of beams with phase controlled [1];
- By folding one or two laser beams by using well designed optical paths formed by reflectors.

[1] T. Hughes, et al. Phys. Rev. Applied 9, 054017 (2018).

IV. Conclusion

An option for developing compact undulator with adjustable undulating period and strength.

Thank you for your attention!