Intensity and pulse shape effect on the spectral and angular distribution of nonlinear Thomson scattering*

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Background and related

Electron dynamics and radiation in high intensity laser fields

- **Ponderomotive scattering**
- **Violent acceleration**
- **Harmonic and broadband radiation**
- **….**

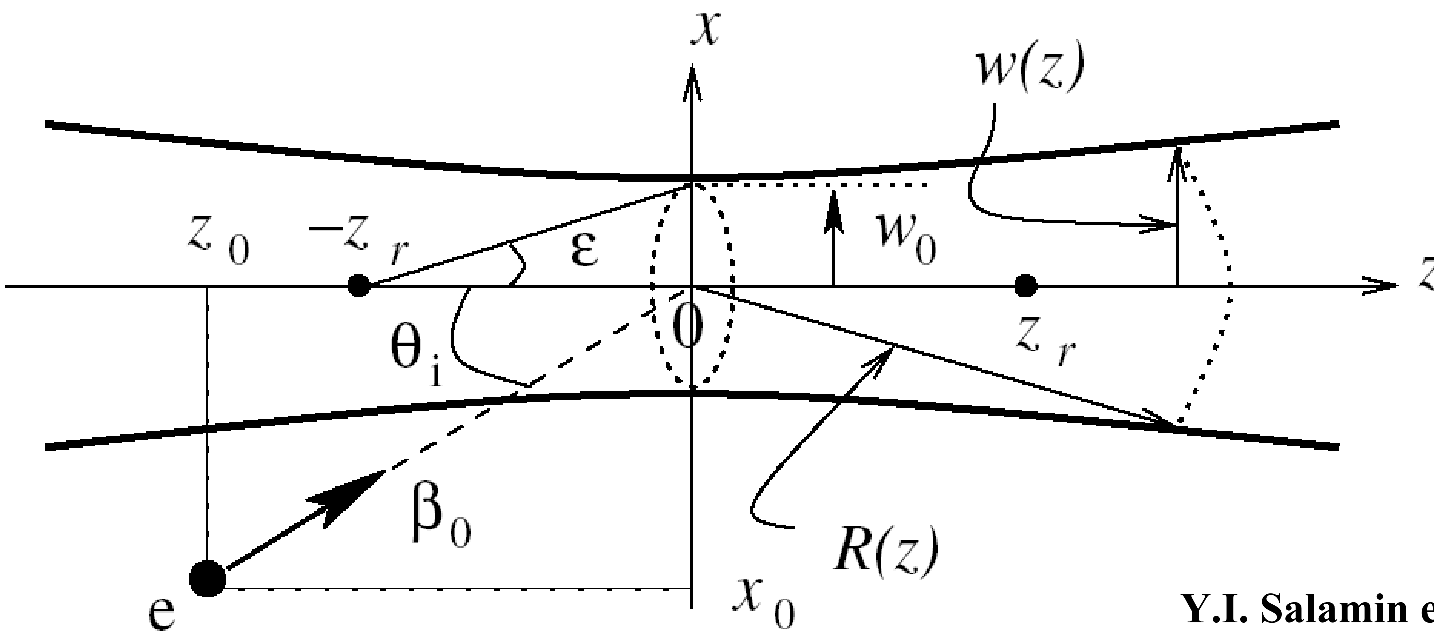
Laser acceleration of electrons

- **MeV and GeV electron acceleration**
- **…..**

Ultrafast X-ray radiation generation

- **Nonliear Thomson scattering into X-ray**
- **Bremsstrahlung X-ray**
- **….**

Geometry



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Only electrons initially at rest and on axis are considered, x_0=0, β_0=0, λ=0.8 μm, w_0=10 μm, Z_r=400 μm.

Formula

Field: angular spectrum representation

$$E_x = \frac{E_0}{4\varepsilon^2}\left(I_1 + \frac{x^2+y^2}{k_0 r^3} I_2 + \frac{y^2}{r^2} I_3\right),$$

$$E_y = \frac{E_0}{4\varepsilon^2}\frac{xy}{k_0 r^3}\left(k_0 r I_3 - 2I_2\right),$$

$$E_z = \frac{E_0}{4\varepsilon^2}\frac{x}{r} I_4,$$

$$B_x = \frac{E_y}{c},$$

$$B_y = \frac{E_0}{4c\varepsilon^2}\left(I_1 + \frac{y^2-x^2}{k_0 r^3} I_2 + \frac{x^2}{r^2} I_3\right),$$

$$B_z = \frac{E_0}{4c\varepsilon^2}\frac{y}{r} I_4$$

$$I_1 = \int_0^1 e^{-b^2/4\varepsilon^2}\left(1+\sqrt{1-b^2}\right)\sin(\phi_b) J_0(k_0 r b) b \, db,$$

$$I_2 = \int_0^1 e^{-b^2/4\varepsilon^2}\frac{\sin(\phi_b)}{\sqrt{1-b^2}} J_1(k_0 r b) b^2 \, db,$$

$$I_3 = \int_0^1 e^{-b^2/4\varepsilon^2}\frac{\sin(\phi_b)}{\sqrt{1-b^2}} J_0(k_0 r b) b^3 \, db,$$

$$I_4 = \int_0^1 e^{-b^2/4\varepsilon^2}\left(1+\frac{1}{\sqrt{1-b^2}}\right)\cos(\phi_b) J_1(k_0 r b) b^2 \, db,$$

$$\phi_b = \omega_0 t - k_0 z\sqrt{1-b^2} + \phi,$$

$$\varepsilon = \frac{1}{k_0 w_0},$$

$$r = \sqrt{x^2+y^2}.$$

Formula

The dynamics is solved numerically

$$\vec{r} = \int_0 \frac{\vec{p}}{\gamma} dt, \quad \vec{p} = \vec{p}_0 + \int_0 \dot{\vec{p}} dt, \quad \dot{\vec{p}} = e(\vec{E} + \frac{\vec{p}}{\gamma m} \times \vec{B}).$$

Energy spectrum calculation by Lienard-Wiechert potentials

$$\frac{d^2 I}{d\omega d\Omega} = \frac{e^2 \omega^2}{4\pi^2 c} \left| \int \vec{n} \times (\vec{n} \times \vec{\beta}) e^{i\omega(t - \vec{n}\cdot\vec{r}/c)} dt \right|^2 .$$

Single electron case

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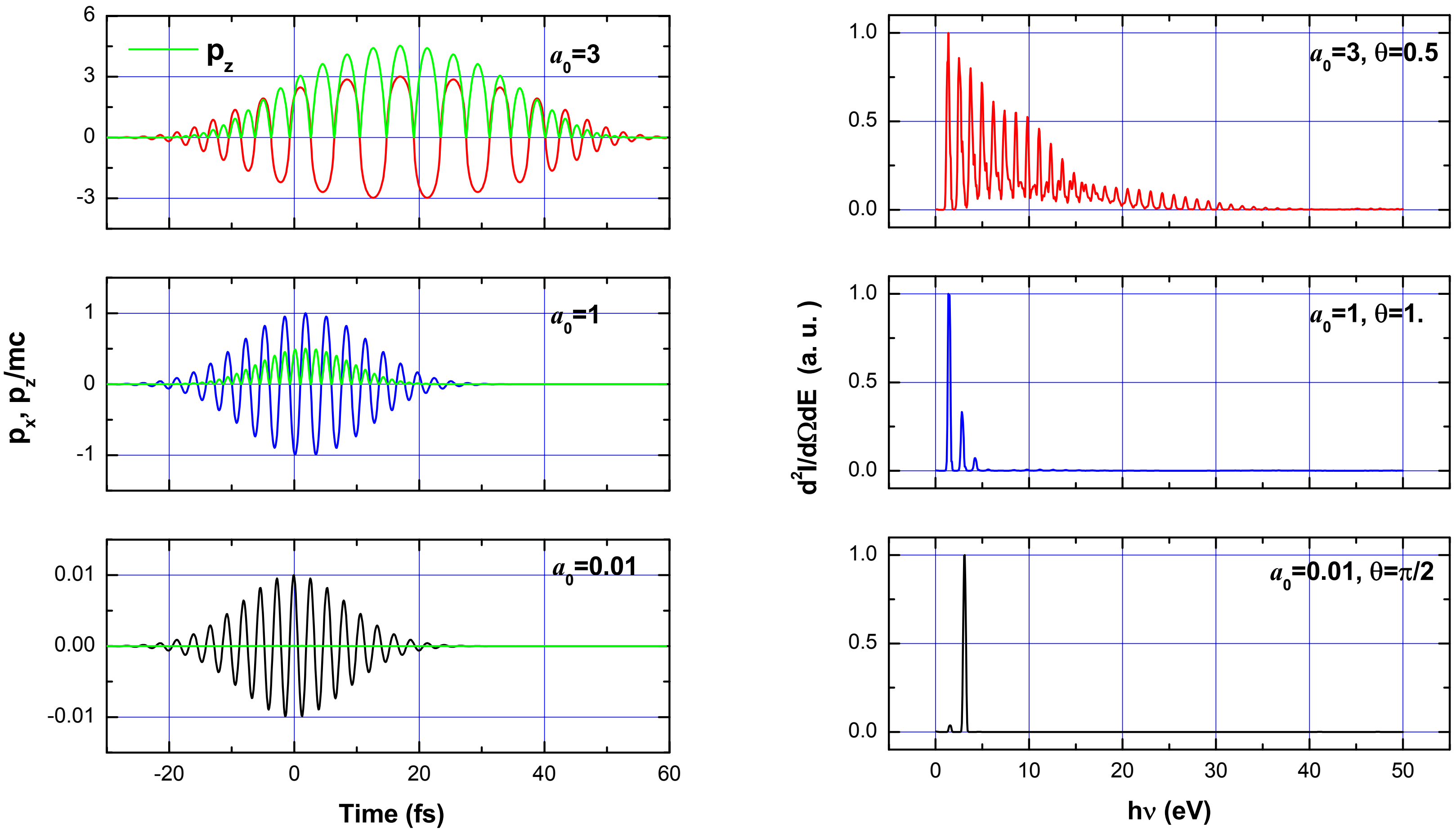
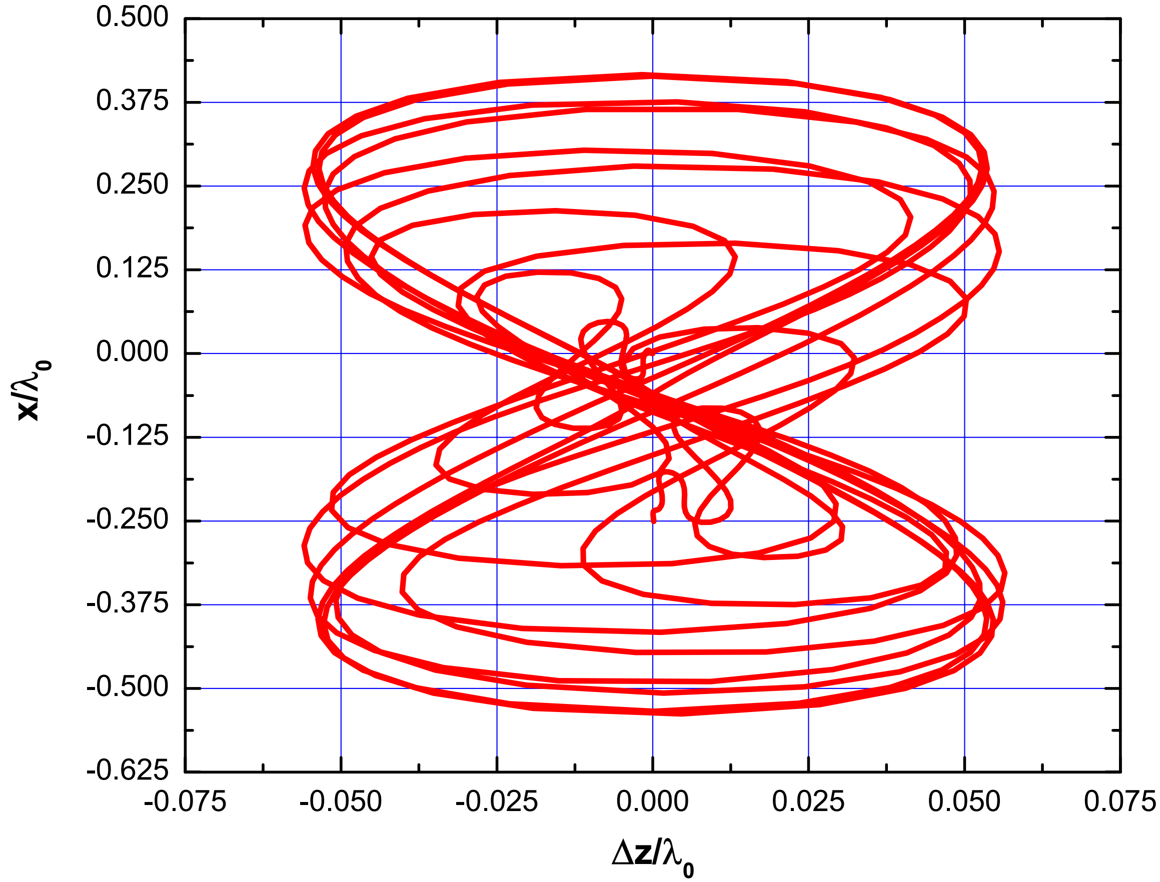
Momentum and spectra



Single electron trajectory, R-frame



Single electron: Spectrum details

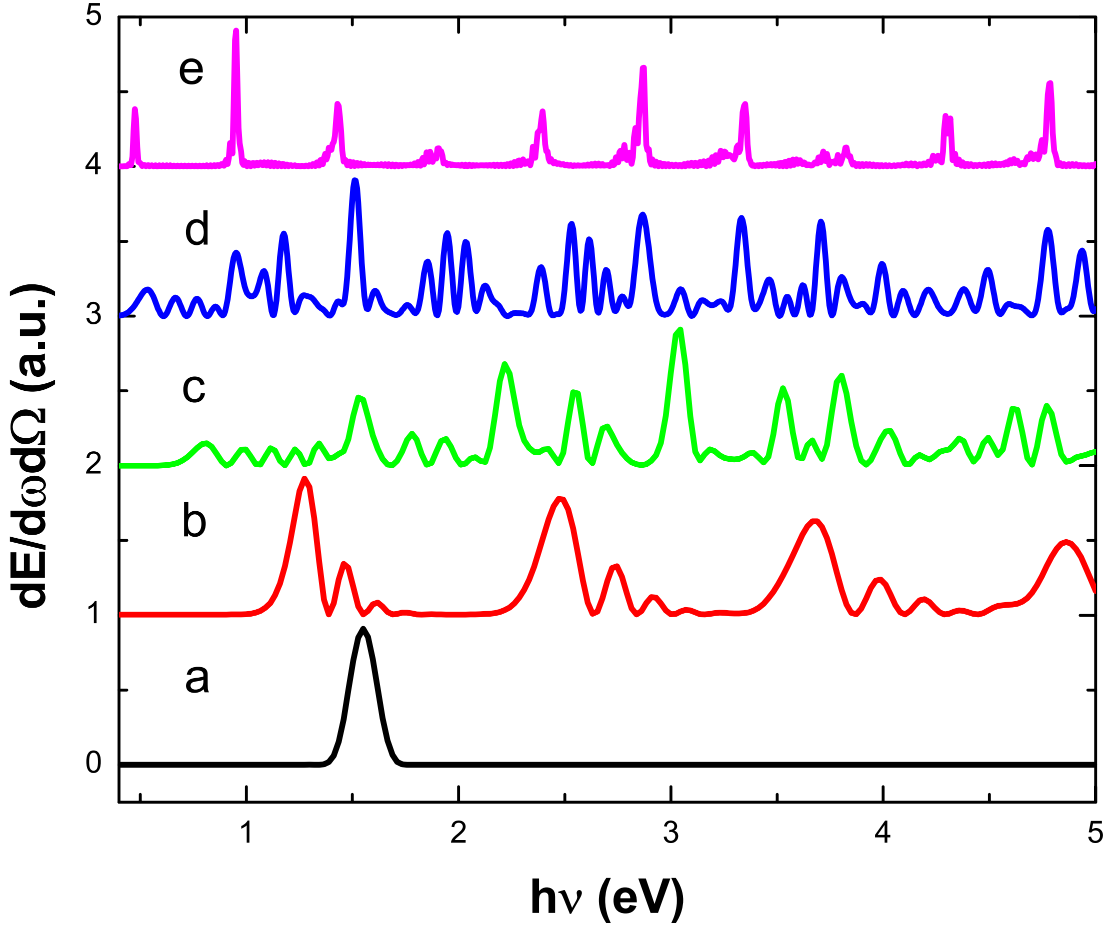


Fig. 1. Spectra of single electron irradiated by (a)-(d) 20-fs laser pulse with a_0=3 for ϕ=40° at θ=0, 30, 60, and 90°, and (e) with quasi-flat-top 80-fs pulse with a_0=3 for ϕ=40° at θ= 90°.

Single electron: Angular distribution

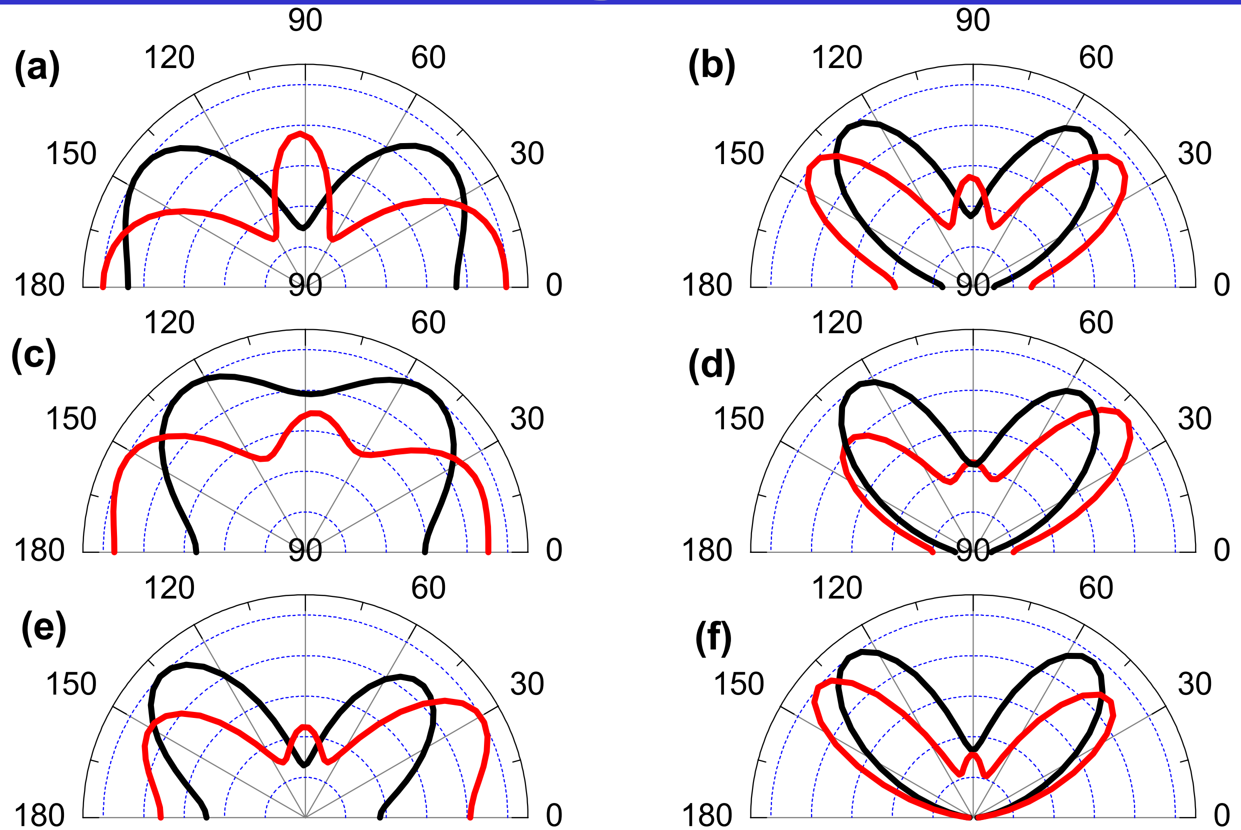
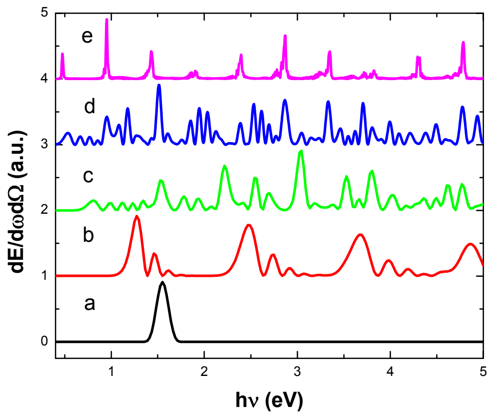
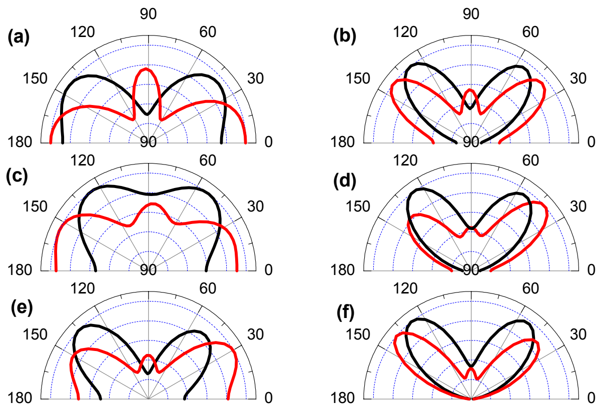


Fig. 2. Radiation pattern of the second (solid) and third (dashed) harmonics at θ=90 (left panels) and 60° (right panels) for (a)-(b) 80-fs quasi-flat-top pulse a_0=3, (c)-(d) 20-fs pulse with a_0=3 and (e-f) 20-fs pulse with a_0=2.

Single electron: conclusion





Observations

1. **Red shift with intensity and polar angle, explained by theory**

$$\omega_n = \frac{n\omega_0}{1+(a/2)^2(1-\cos\theta)}$$

2. **Spectral broadening, modulation, and over lapping are pulse- shape and intensity- dependent and not discussed previously.**

3. **Angular distribution is also intensity-and pulse shape-dependent**

Collective effects

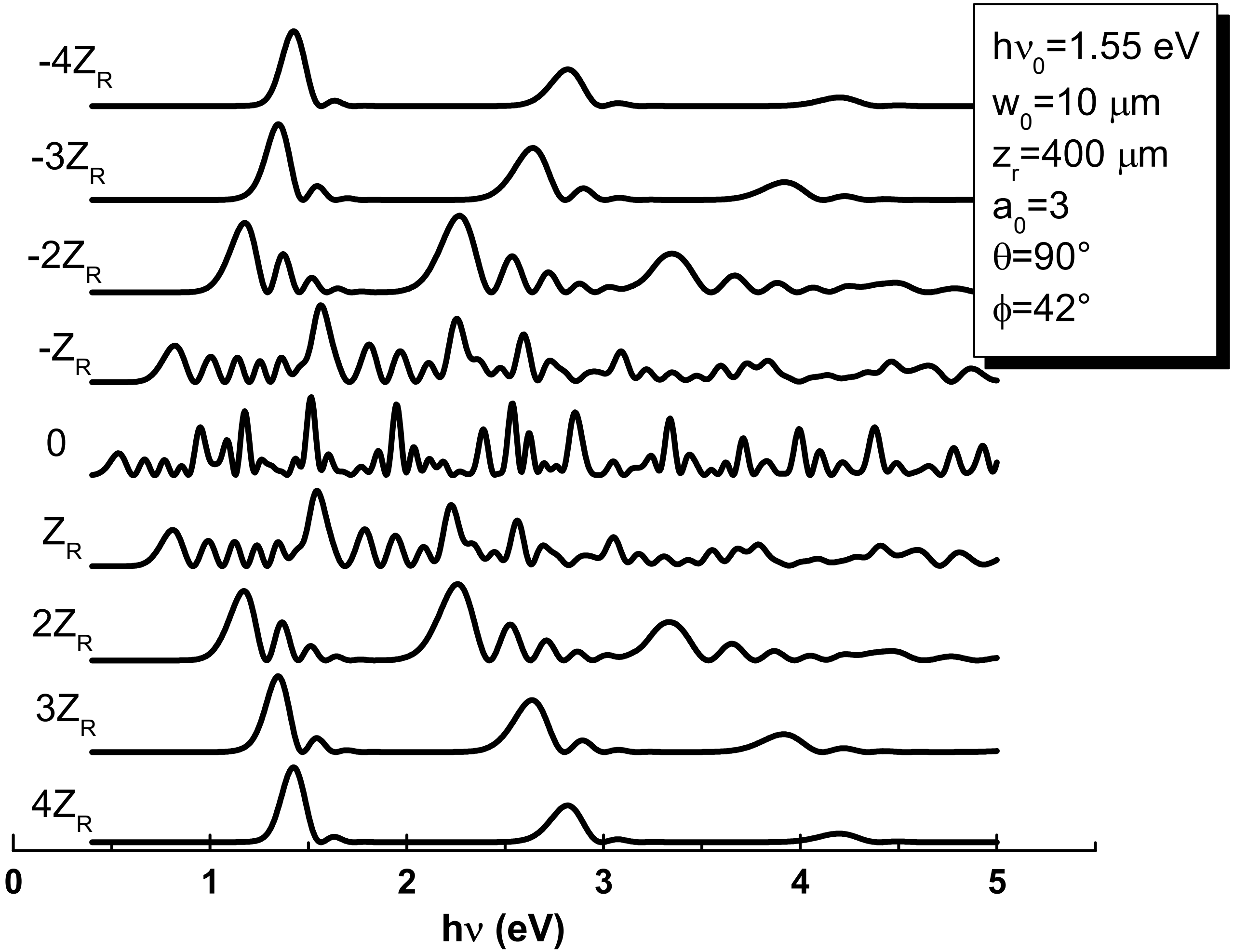
For a collection of electrons, the radiation is calculated as

$$\frac{d^2 I}{d\omega d\Omega} = \frac{e^2\omega^2}{4\pi^2 c}\left|\int \sum_j \vec{n}\times(\vec{n}\times\vec{\beta}_j)e^{i\omega(t_j-\vec{n}\cdot\vec{r}_j/c)}dt\right|^2.$$

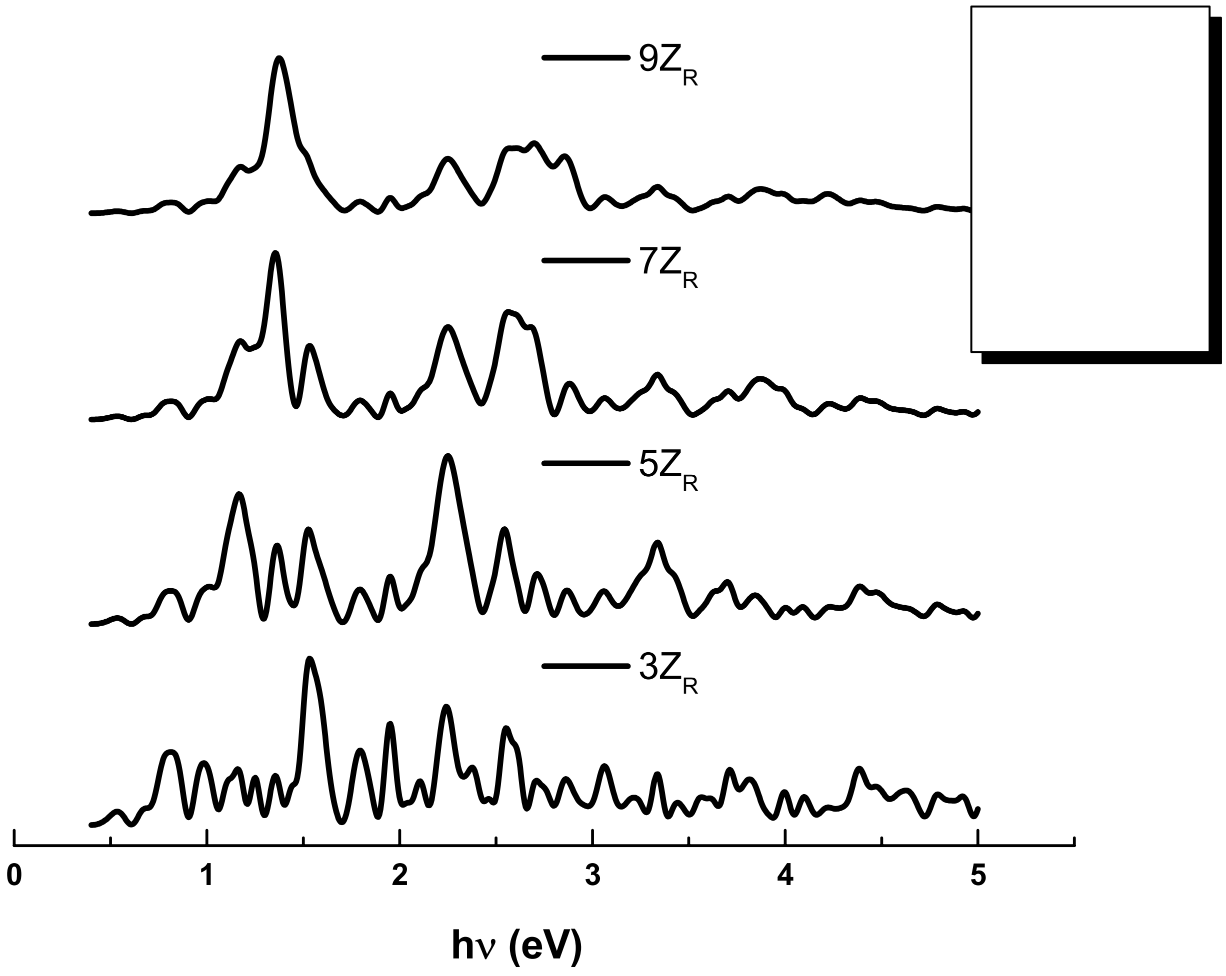
When the positions of the electrons are totally random, the only terms survive the integration are the individual terms of each electrons, hence the radiation for a collection of electrons can be approximated as

$$\frac{d^2 I}{d\omega d\Omega} = \frac{e^2\omega^2}{4\pi^2 c}\sum_j\left|\int \vec{n}\times(\vec{n}\times\vec{\beta}_j)e^{i\omega(t_j-\vec{n}\cdot\vec{r}_j/c)}dt\right|^2.$$

Z-dependence: Spectra



Target thickness dependence



Target thickness: angular distribution

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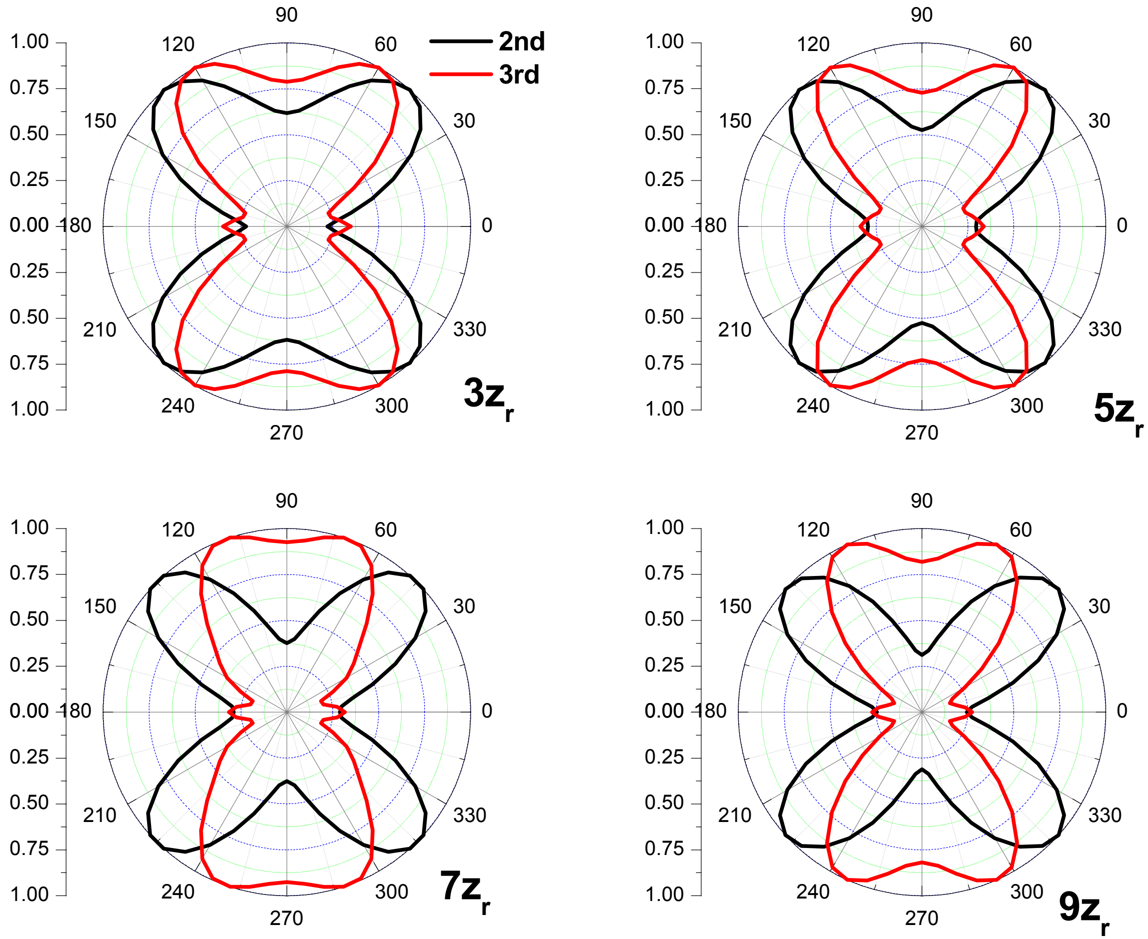

Conclusion

Nonlinear Thomson scattering emission spectra and angular distribution are sensitive to the laser intensity, pulse shape and target configuration both on the microscopic and macroscopic level, showing spectral shift, broadening and mixing between harmonics.

References

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