Генерация высоких гармоник на поверхности мишени

Особенности:

1. Сильная модуляция фазы отраженной волны, высокая эффективность преобразования.
2. Необходима резкая граница мишени.
3. Форма поверхности осциллирующего зеркала (усредненная за период) определяет расходимость пучка.
4. Фазы всех гармоник синхронизованы, нет проблем, характерных для генерации в диспергирующей среде.

Этот механизм – идеальный кандидат для генерации аттосекундных импульсов с высокой эффективностью преобразования.

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Два возможных источника, формирующих движение поверхности осциллирующего зеркала:

1. Поле лазера (частота ω) – наклонное падение волны на мишень. Генерируются четные и нечетные гармоники.

2. Пондеромоторная сила давления света (частота 2ω) – нормальное падение волны на мишень. Генерируются нечетные гармоники.

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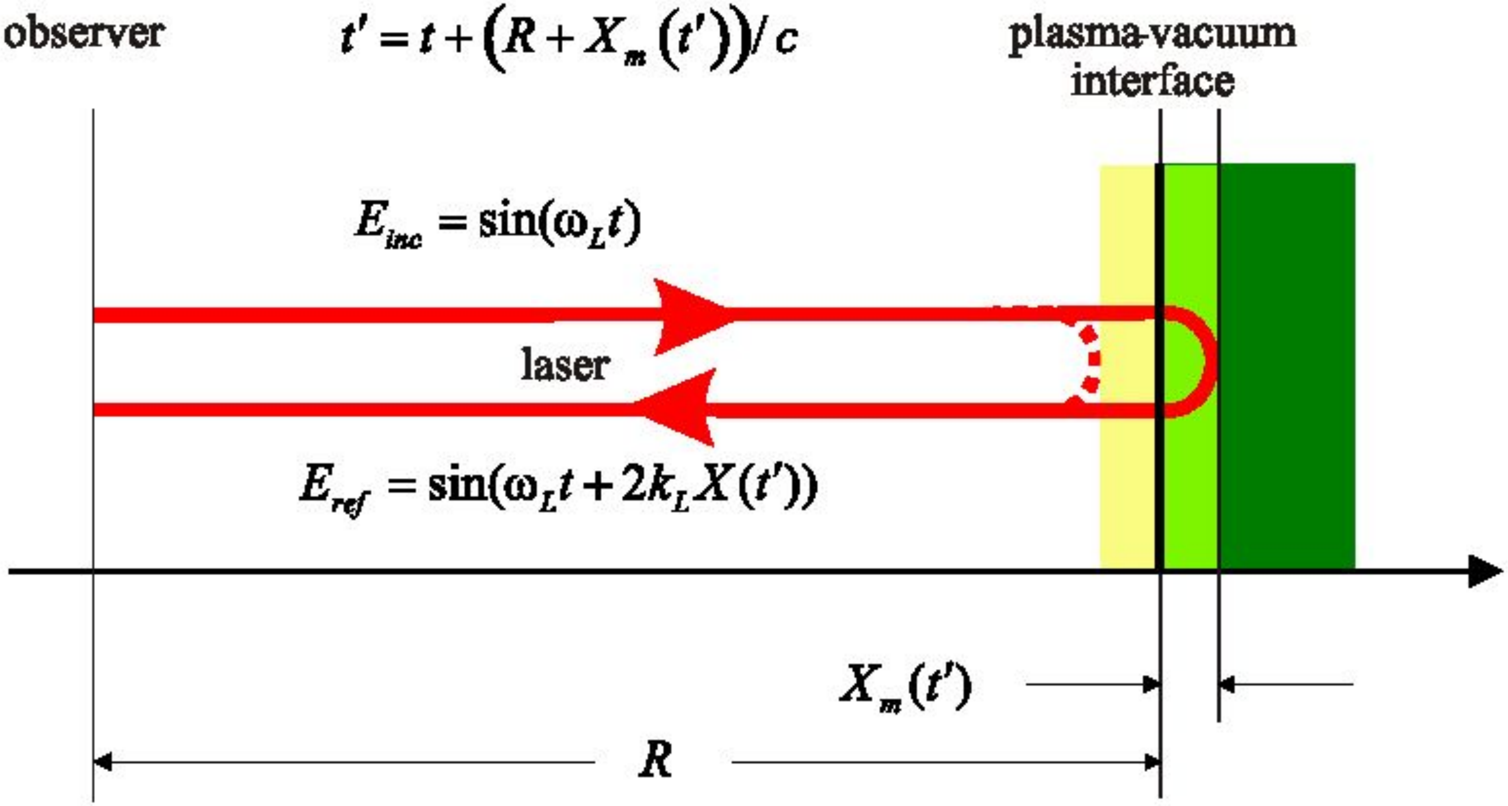

Figure 1. Scheme showing the basic idea of the oscillating mirror model. An E-M wave is incident on an electron surface oscillating around an immovable ion background. The phase of the reflected E-M wave as seen by the observer depends on the position of the electron surface at the moment of the reflection. This retardation effect gives rise to a distorted waveform rich in harmonics of the fundamental frequency.

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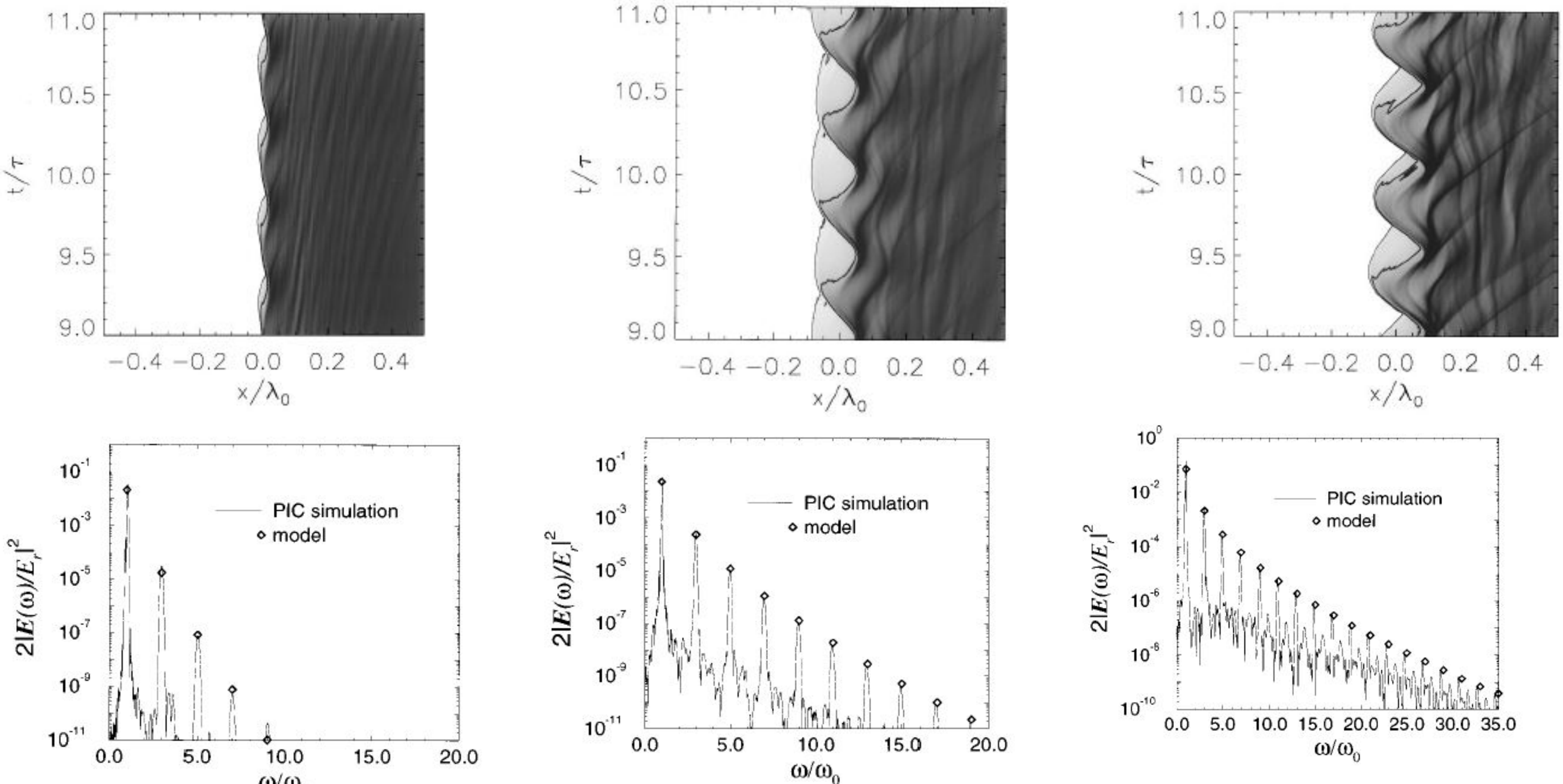

$a_0 = 0.5 \quad n_0/n_c = 7$ $\qquad a_0 = 0.5,\ n_0/n_c = 4$ $\qquad a_0 = 1,\ n_0/n_c = 4$

S – поляризация, нормальное падение

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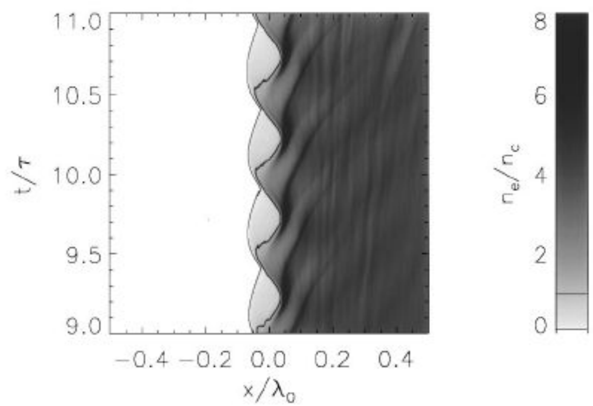


FIG. 8. Electron density for oblique incidence of *s*-polarized light with parameters: $a_0=0.5$, $n_0/n_c=4$, $\alpha=30°$.

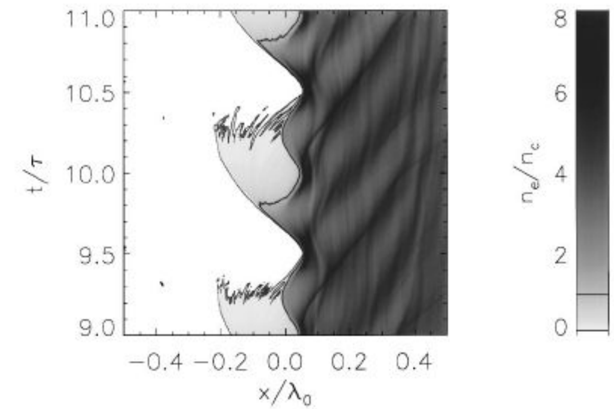
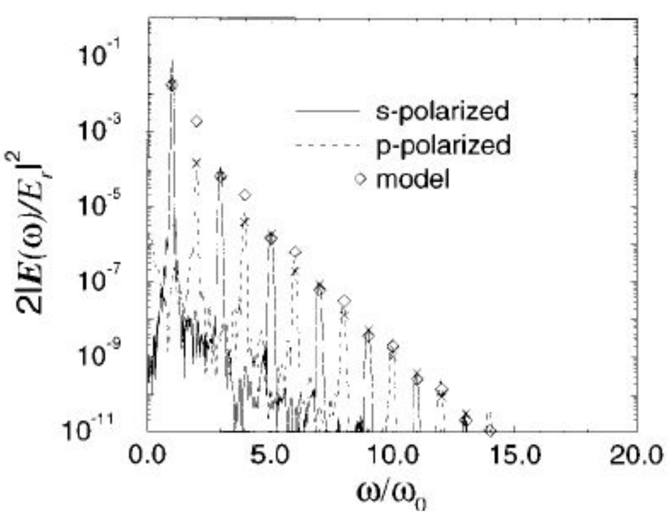
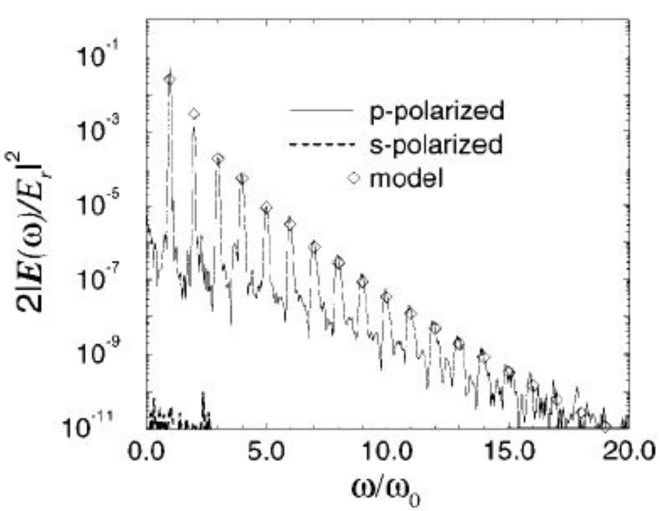
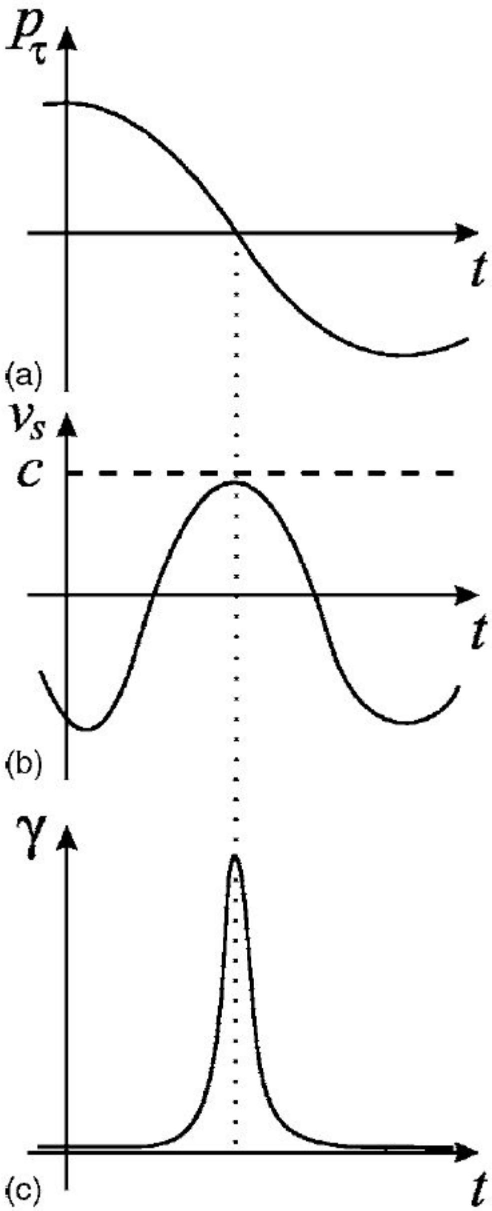


FIG. 10. Electron density for oblique incidence of *p*-polarized light with parameters: $a_0=0.5$, $n_0/n_c=4$, $\alpha=30°$.





Генерация высоких гармоник на поверхности мишени



When v_s reaches its maximum and γ_s has a sharp peak, high-order harmonics of the incident wave are generated and can be seen in the reflected radiation. Physically this means that the high-order harmonics are due to the collective motion of bunches of fast electrons moving towards the laser pulse [19].

FIG. 2. (a) Electron momentum component parallel to the surface as a function of time. (b) The velocity of the plasma surface v_s is a smooth function of time, unlike the γ factor of the surface (c).

Генерация высоких гармоник на поверхности мишени

Генерация гармоник на осциллирующем зеркале

$$\omega' = 4\gamma_{\max}^2 \omega_0 \qquad \Delta t' = \Delta t / 4\gamma_{\max}^2$$

$$n_c \propto 4\gamma_{\max}^2$$

Механизм генерации ультра-релятивистски расширенного спектра гармоник

$$T_{\text{spike}} \sim T_0/\gamma_{\max}$$

$$T_{\text{burst}} \sim T_{\text{spike}}/\gamma_{\max}^2 \sim T_0/\gamma_{\max}^3$$

$$n_{\text{RO}} \sim 8^{1/2}\gamma_{\max}^3$$

Генерация высоких гармоник на поверхности мишени

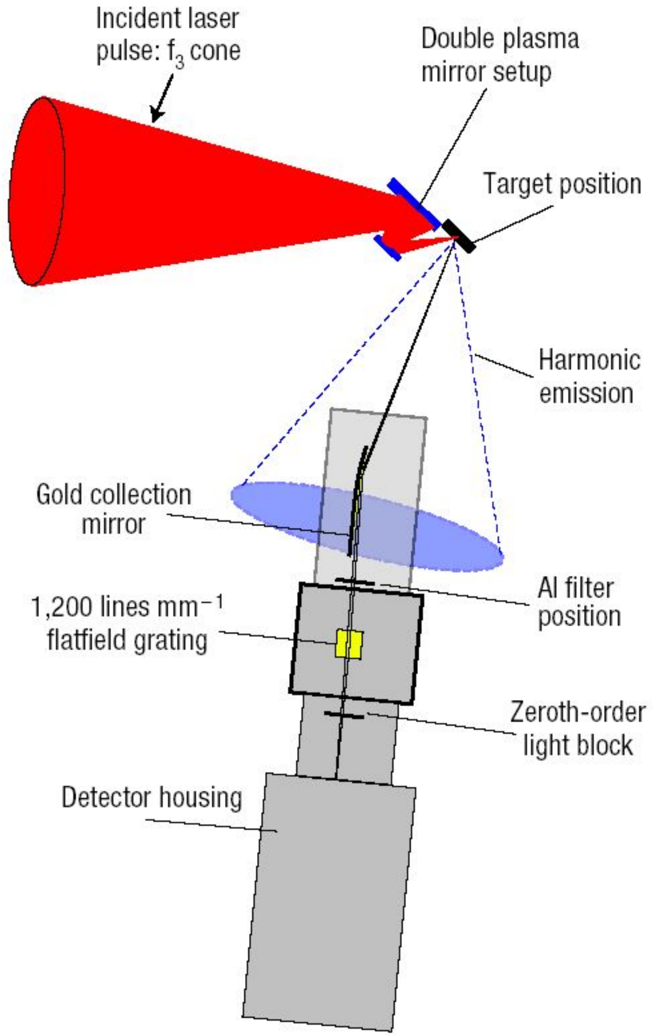
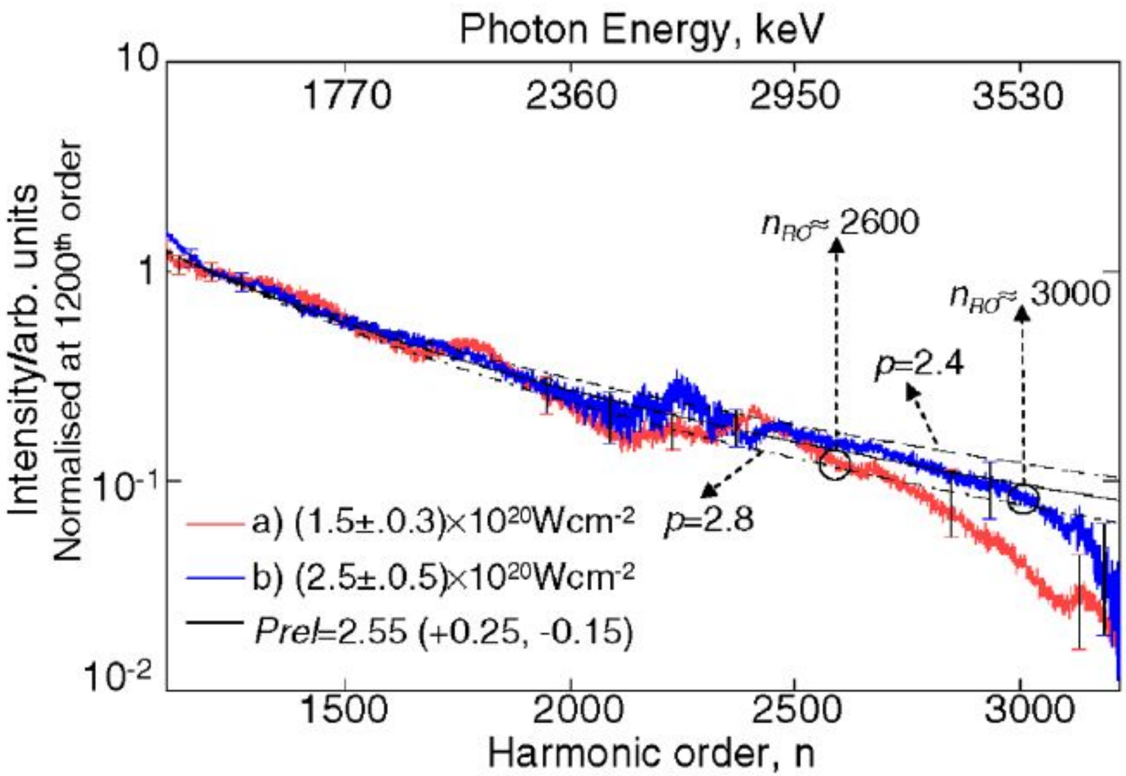


Figure 1 Schematic diagram of the experimental setup. The 600-fs laser pulses were focused using an f/3 off-axis parabolic mirror, and delivered peak intensities $>10^{20}$ W cm^{-2} onto the target. The reflected harmonic emission is detected using an extreme-ultraviolet spectrometer consisting of a calibrated, cylindrical 1,200 lines mm^{-1} Hitachi flatfield grating imaging the source in the spectral dimension, and a cylindrical mirror to image the source in the transverse dimension. A 0.2-μm aluminium filter was used to block optical emission and a block was inserted after the grating to prevent scattered zero-order diffraction light from reducing the quality of the observed spectra. The PMs could either be inserted or removed to vary the pulse contrast conditions. Using a double PM configuration enhances the intrinsic pulse contrast by $>10^4$ and results in a reduced pulse rise time[18,19]. Approximately 40% of the laser energy incident of the first PM is incident on the target.

Генерация высоких гармоник на поверхности мишени

Experiments were performed at the Vulcan petawatt laser at the Rutherford Appleton Laboratories [18] which reaches peak intensities of $\sim 10^{21}$ W cm^{-2} (up to 600 J on target in $\sim$500 fs). However, with an intrinsic prepulse pedestal that extends for $\sim$5 ns at a contrast of 10^7:1, it is unsuitable for the formation of the short plasma scale length $L_s \sim 0.1\lambda$ required for efficient harmonic generation [14], where λ is the laser wavelength. As a result the contrast of the incident pulse was increased to $>10^{10}$:1 at $\sim$10 ps from the peak of the pulse by the use of a double plasma mirror setup [19–21] to achieve the required sharp plasma-vacuum interface.

Генерация высоких гармоник на поверхности мишени



$$\eta(n) \sim n^{-\mathrm{Prel}}$$

$$\mathrm{Prel} = 8/3$$

$$n_{\mathrm{RO}} \sim 8^{1/2}\gamma_{\max}^{3}$$

FIG. 1 (color online). The relative intensity of the harmonic spectra for two intensities: (a) $(1.5 \pm 0.3) \times 10^{20}$ W cm^{-2} [gray (red) trace] and (b) $(2.5 \pm 0.5) \times 10^{20}$ W cm^{-2} [black (blue) trace]. Spectra are integrated along the spatial dimension and normalized at the 1200th harmonic ($\sim$ 1.4 keV, 8.8 Å). The lines are fits to the data such that $I(n)/I(1200) = n^{-p}/1200^{-p}$, where p is the fitting parameter. The best fit (solid line) is for a value of Prel = 2.55 for (a) in the range 1.2–3 keV and (b) in the range 1.2–3.5 keV, and is consistent with that expected for harmonic generation in the relativistic limit. The dashed lines represent $p = 2.4$ and $p = 2.8$ scaling, as labeled. Error bars [gray (red) ends for red trace, black (blue) ends for blue trace)] represent the uncertainty in the relative signal strength arising from the detector and filter transmission, taking into account the individual uncertainty in each of the relevant quantities. The absence of strong modulation in the spectra is due to the limited resolution of the crystal spectrometer used.

Генерация высоких гармоник на

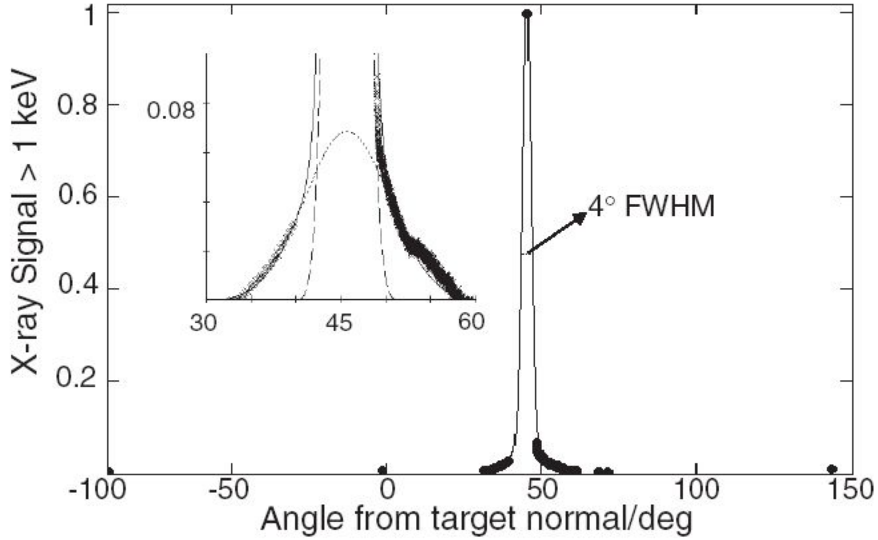


FIG. 3. Angular distribution of >1 keV x-ray signal under high contrast conditions. The signal is emitted into a narrow cone peaked in the specular direction at 45° (the laser incidence angle is −45°). The inset shows a 13° full width at half maximum (FWHM) Gaussian fit to the scattered x-ray halo (black dotted line) and the 4° fit to the strongly peaked HOHG signal (black dashed line). The full width at half maximum of the summed double Gaussian fit to the signal is ~4° (solid black line), which is considerably less than the $f/3$ laser cone angle. The specular emission of the harmonics is clear indication of the coherent nature of the process. It also demonstrates the absence of significant laser induced surface modulation present on previous, lower contrast experiments [26].