学際大規模情報基盤共同利用・共同研究拠点 萌芽型共同研究 平成30年度採択課題

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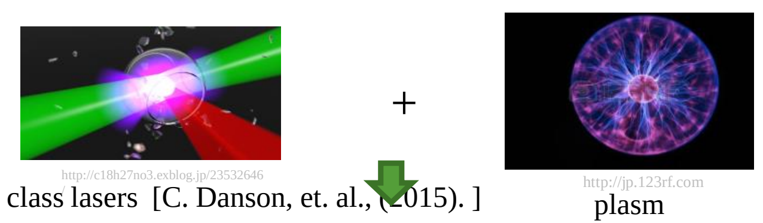
研究課題名

Possibility for observing space-time distortion via the interaction of ultra-high intense laser pulses with plasmas

1.Introduction

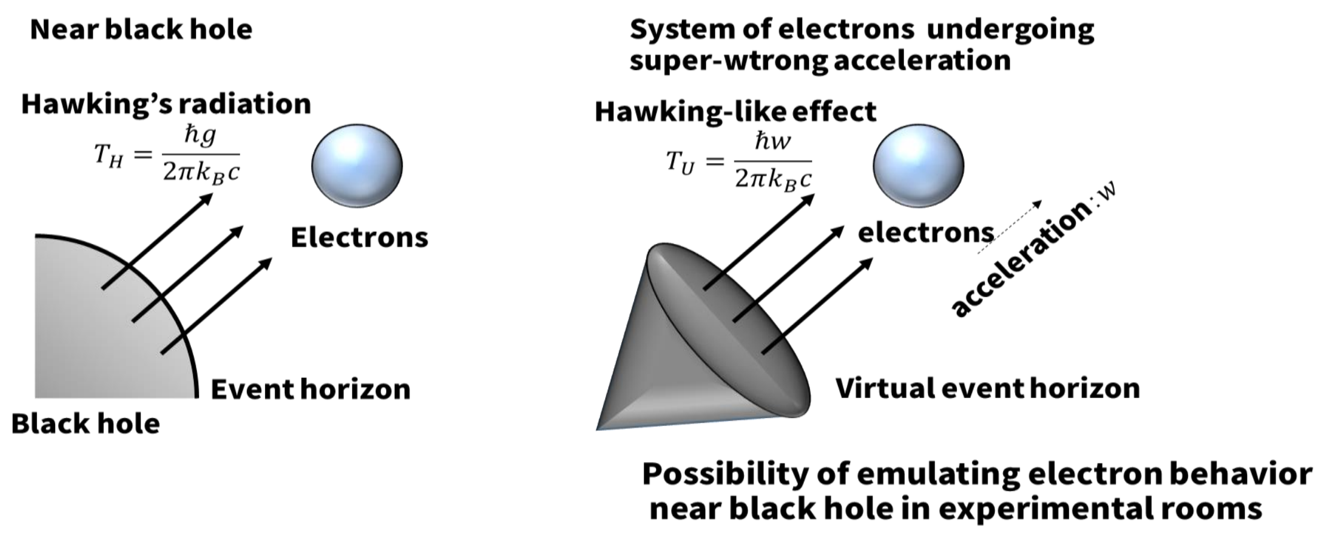


PW class lasers [C. Danson, et. al., (2015).]

plasm

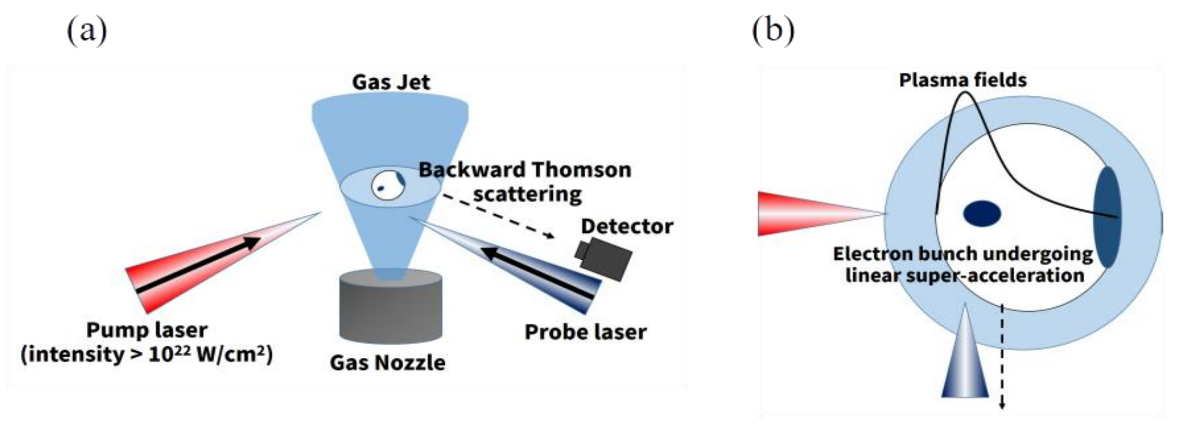
Electrons undergoing super-strong acceleration produced by the laser plasma interactions
Open up new approaches to studying
Space-time physics, vacuum physics,
particle physics, Quantum electrodynamics

For Earth, $g \approx 10^3$ [cm/s^2], produces 4×10^{-24} [eV]. In the laser pulse wake, $w > 10^{26}$ g[cm/s^2



[W. G. Unruh, Phys. Rev. D14, 870 (1976); B. J. B. Crowley et. al. Sci. Rep. 2, 491 (2012).; P. Chen and G. Mourou, Phys. Rev. Lett. 118, 045001 (2017); M. Yano et. al., arXiv:1709.01659 (2017).]

Hawking-like effect: a detector moving with a constant acceleration w sees a boson's thermal bath with its temperature $k_B T_U = \frac{\hbar}{2\pi c} w$ [eV]. For Earth, $g \approx 10^3$ [cm/s^2], produces 4×10^{-24} [eV]. In the laser pulse wake, $w > 10^{26}$ g[cm/s^2].



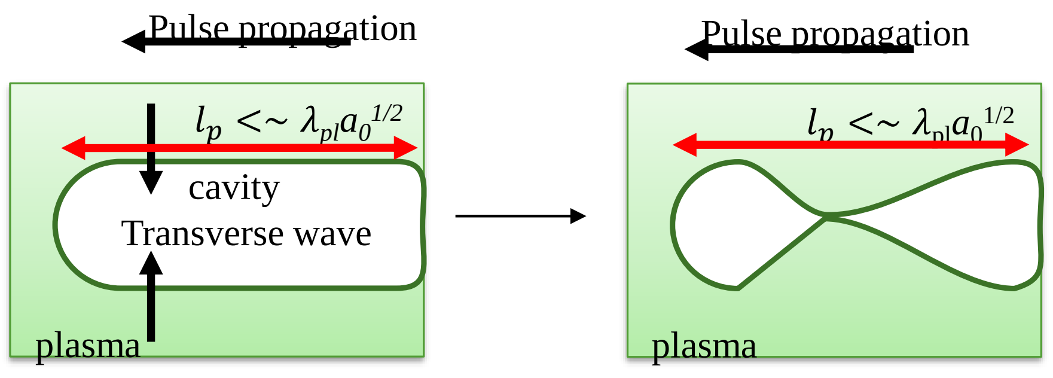
Possibility of observing Hawking-like effect by the spectral broadening of Thomson scattering induced by the effect.
[M. Yano *et. al*. (2017)]

The experimental setup using Thomson scattering from the electron bunch undergoing extremely high acceleration is shown. For detection of Hawking-like effect, required strength of the acceleration field is *a*0~100.

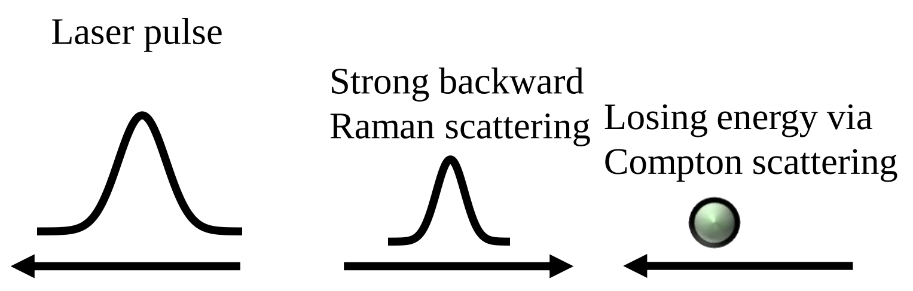
For that, we examine the propagation of femtosecond laser pulses with intensities I=10^{22}-10^{24} W/cm^2 focused in an underdense plasma by fully relativistic 3D particle-in-cell simulations including ion motion and radiation reaction. The possibility of the detection of Hawking-like effects is discussed.

１． Self-focusing.
２． The ion motion.
３． Transverse wave induced by ion motion.
４． Radiation reaction

Transverse plasma wave induced by ion motion



Radiation reaction



The purpose is not to study electron acceleration up to high energies. In contrast, we try to find conditions for formation of a number of electrons undergoing strong linear acceleration and having low spreads in transverse velocities to avoid spectral shift due to Doppler shift.

2.Simulation model

We used Gaussian beam
~30 J- ~3 kJ for 10^{22}-10^{24} W/cm^2 and their power of ~3 - ~300 PW）
We included ion motion and radiation reaction force

$$E_z(x-x_f,r) = -B_y(x-x_f,r) = \{a_0/d(x)\}\exp[-r^2/d^2(x) - 2x^2/(c\tau)^2 + ikx + i\phi(x-x_f,r)]$$

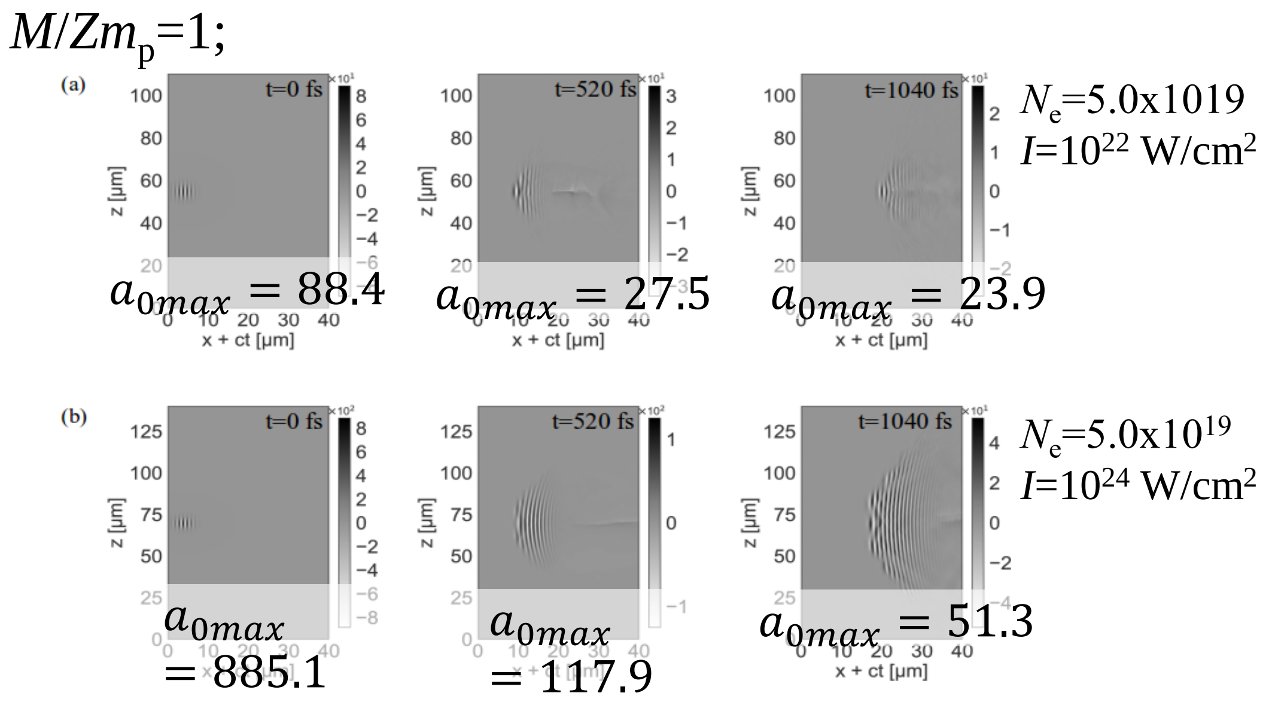
$$\frac{d\vec{p_i}}{dt} = Ze\left(\vec{E} + \frac{\vec{p_i}}{Mc\gamma_i} \times \vec{B}\right)$$

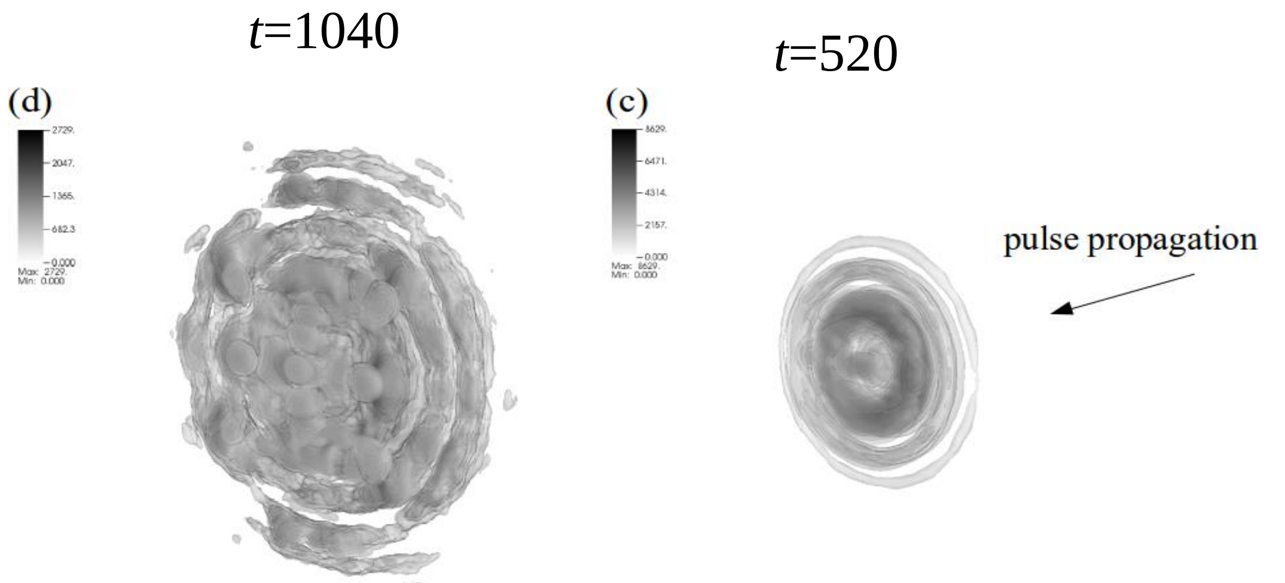
$$F_{RR} \approx -\frac{2e^4}{3m^2c^5}\gamma^2\vec{v}\left\{\left(\vec{E} + \frac{1}{c}\vec{v} \times \vec{H}\right)^2 - \frac{1}{c^2}\left(\vec{v}\cdot\vec{E}\right)^2\right\}$$

[A. Zhidkov et. al. Phys. Rev. Lett. **88**, 185002 (2002).
N. Neitz et. al. , J. Phys. Conf. Ser. 497, 012015 (2014).;]

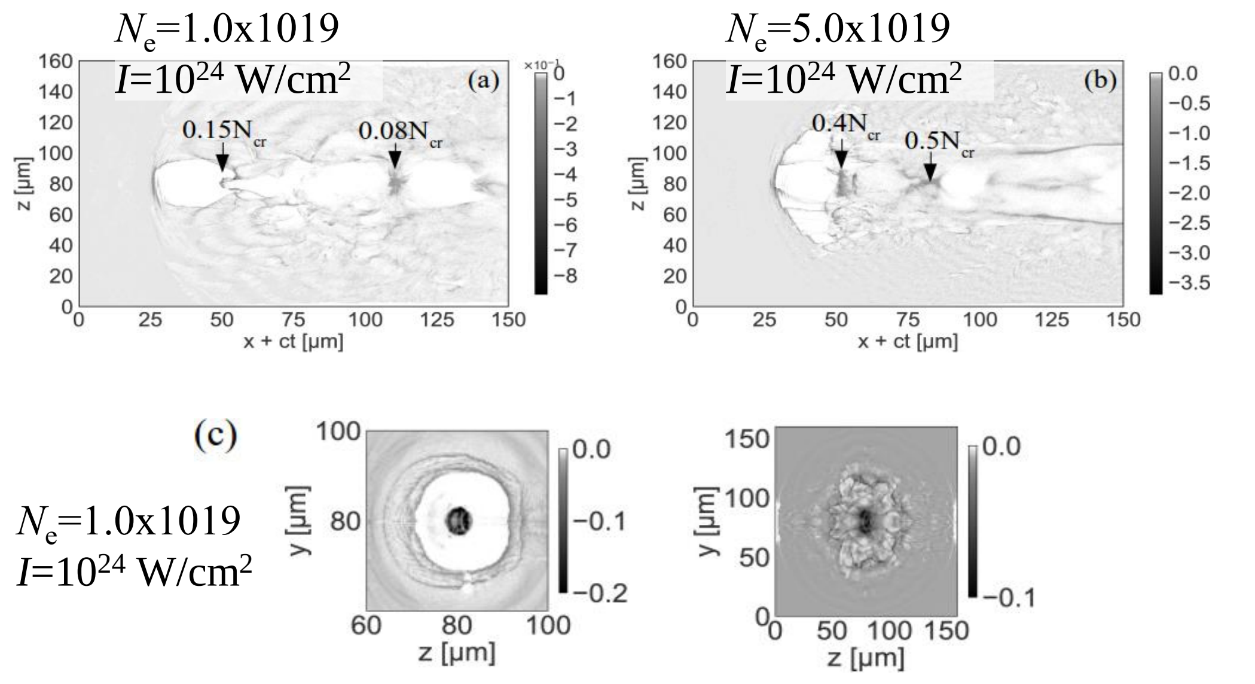
3.Simulation results

plasma density N_e=1.0x10^{19} cm^{-3} to N_e=5.0x10^{20} cm^{-3} , intensity I=10^{24} W/cm^2, and mass-to-charge ratio M/Zm_p=1;

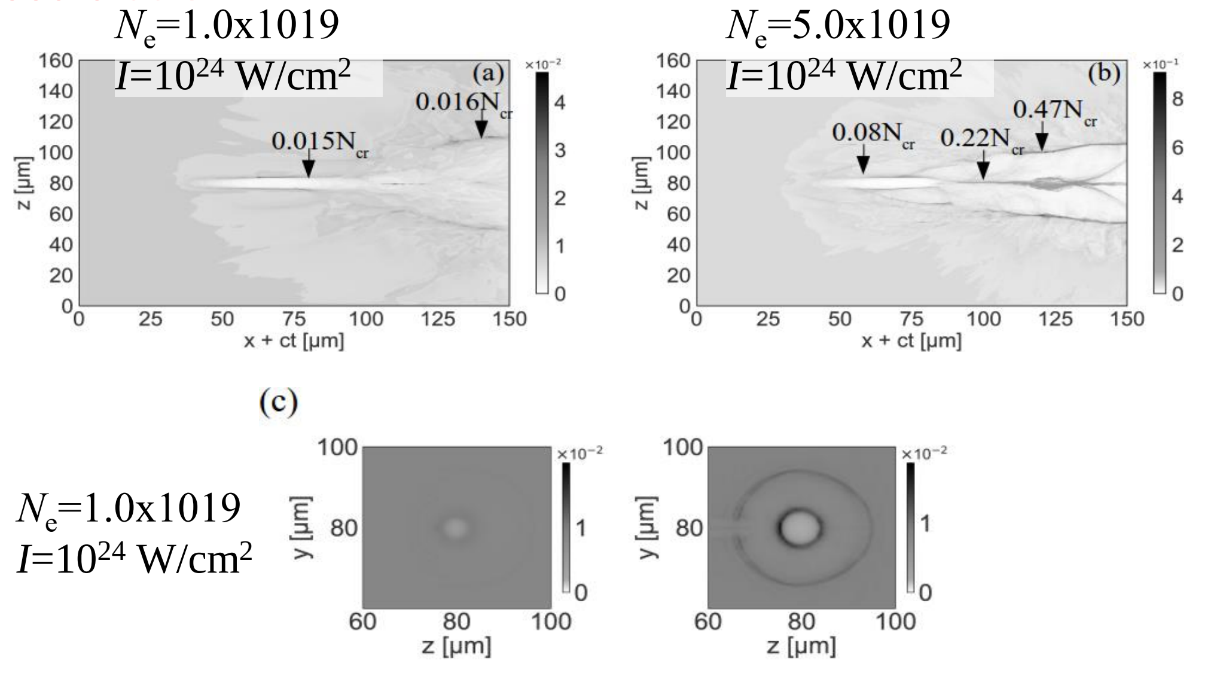




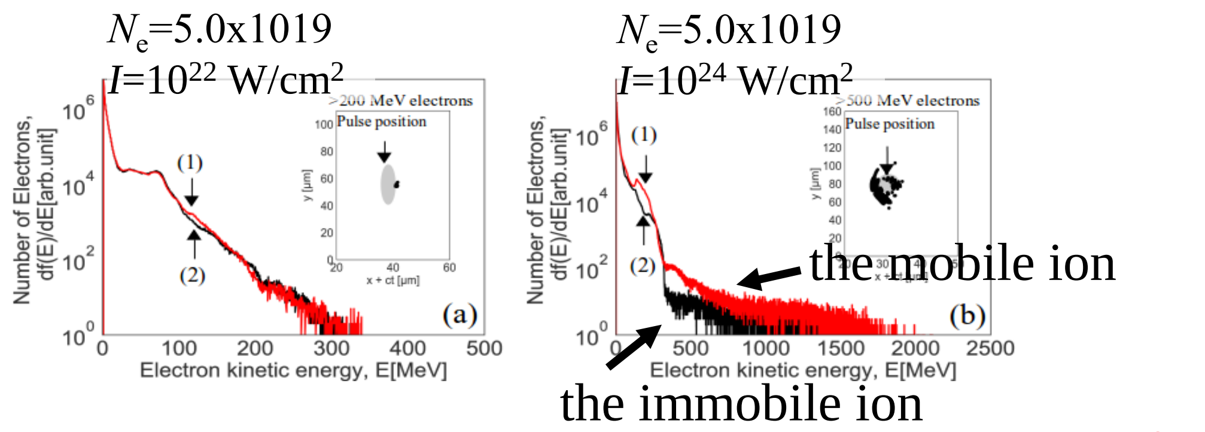
Pulses diffract instantly upon creating vacuum bubble in the plasma



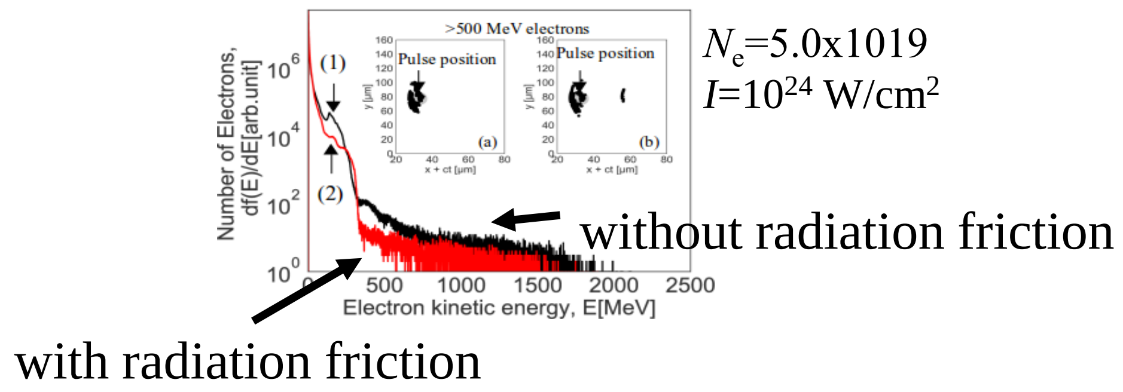
The interference of longitudinal and transverse waves results in the formation of electron structures undergoing strong linear acceleration



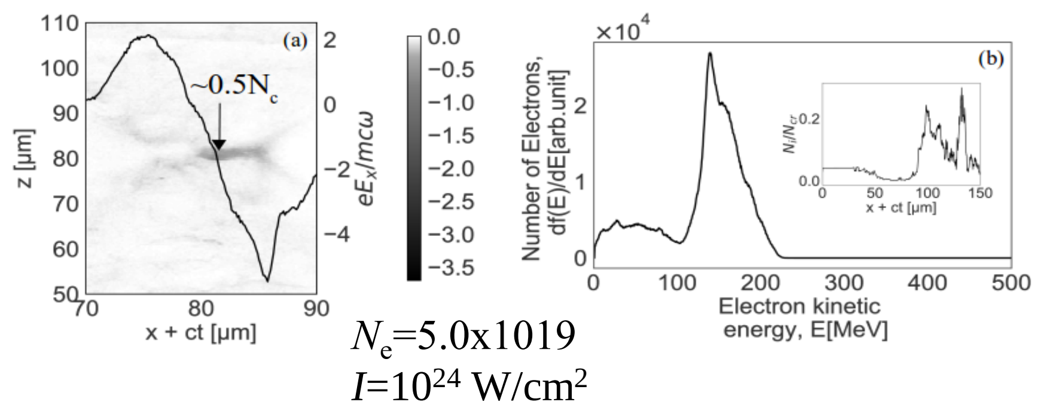
Transverse ion motion originating from a Coulomb explosion results in the formation of a transverse cylindrical plasma wave, which has quite dense electron and ion peaks on the laser axis



The ion motion is not essential to the dynamics of energetic electrons which are mostly located in the first bucket



The radiation reaction dissapates about 10 % of electron energy via Compton scattering of the backward radiation by relativistic electrons



Estimated spectral broadening of the Thomson back scattering light to detect space-time effects gives a value of $\Delta w_S/w_S$~0.2-0.5% (T_U ≈0.5 [eV]).

4.Conclusion

- Classical relativistic self-focusing cannot maintain stable propagation of multi-PW class laser pulses with high intensities because pulses diffract instantly upon creating vacuum bubble in the plasma.
- Transverse ion motion originating from a Coulomb explosion results in the formation of a transverse cylindrical plasma wave. The interference of longitudinal and transverse waves results in the formation of electron structures undergoing strong linear acceleration.
- The radiation reaction effects dissapates about 10 % of electron energy via Compton scattering of the backward radiation by relativistic electrons
- Expected spectral broadening of the Thomson back scattering light with an incident angle of 90 degree for a probe pulse from the electrons undergoing super strong acceleeratino to detect space-time effects gives a value of $\Delta w_S/w_S$~0.2-0.5%.

5.Acknowlegement

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