DYNAMICS OF MOMENTUM DISTRIBUTIONS OF VACUUM EXCITATION IN FOCAL SPOT OF MODERN SUPER-POWER LASERS COUNTER BEAMS

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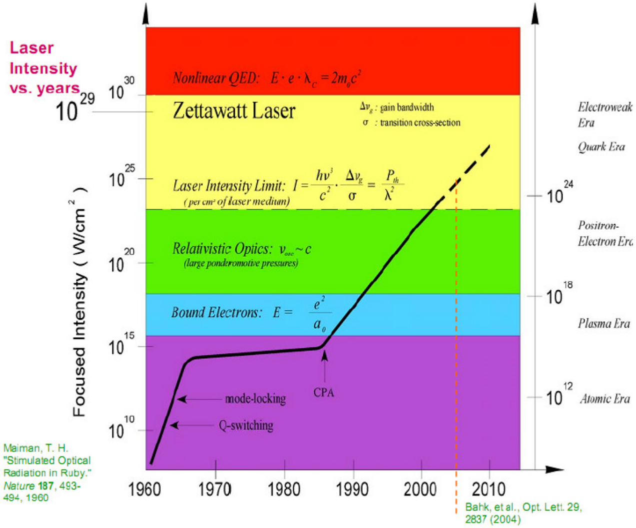
Content

- The vacuum pair creation in the strong electric field is studied
- We numerically solve the nonperturbative kinetic equation of the non-Markovian type
- The momentum distribution and integral characteristics are analyzed
- The analysis of the stability of using the spectrum of Lyapunov exponents

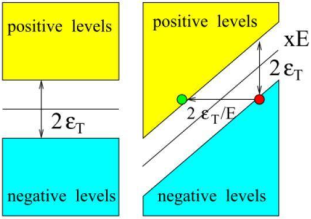
Importance



G.Mourou, C.Barty and M.Parry, Phys. Today 51,22

Schwinger effect: tunnel mechanism

Pair creation as barrier penetration in a strong constant field



Schwinger result (rate for pair production)

$$\frac{dN}{d^3xdt} = \frac{(eE)^2}{4\pi^3}\sum_{n=1}^{\infty}\frac{1}{n^2}\exp\left(-n\pi\frac{E_c}{E}\right),$$

- To "materialize" a virtual e^+e^- pair in a constant electric field E the separation d must be sufficiently large
$$eEd = 2mc^2$$
- Probability for separation d as quantum fluctuation
$$P = \exp\left(-\frac{2E_c}{E}\right)$$
- Emission sufficient for observation when $E \sim E_c$

$$E_c = \frac{m^2c^3}{e\hbar} \simeq 1.3\times 10^{16}\,V/cm$$

J. Schwinger, On Gauge Invariance and Vacuum Polarization, Phys.Rev. 82 (1951) 664

Kinetic description of pair production

Kinetic equation for $A(t) = (0, 0, A(t))$ is a non-perturbative consequence of QED

S.Schmidt, D.Blaschke, G.Ropke, S.A.Smolyansky, A.V.Prozorkevich, V.D.Toneev. Int. J. Mod. Phys. E. 1998, V.7, 709

$$\dot{f}_{\pm}(\vec{p}, t) = \frac{1}{2}\lambda_{\pm}(\vec{p}, t) \int\limits_{t_0}^{t} dt' \lambda_{\pm}(\vec{p}, t')[1 \pm 2f(\vec{p}, t')] \cos\theta(\vec{p}; t, t'),$$

$$\theta(\vec{p}; t, t') = 2 \int\limits_{t'}^{t} \omega(\vec{p}, \tau) d\tau,$$

$$\lambda_{-}(\vec{p}, t) = eE(t)\varepsilon_{\perp}/\omega^2(\mathbf{p}, t),$$

$$\lambda_{+}(\vec{p}, t) = eE(t)(p_{\|} - eA(t))^2/\omega^2(\mathbf{p}, t),$$

$$\omega(\vec{p}, t) = \sqrt{\varepsilon_{\perp}^2(\mathbf{p}) + (p_{\|} - eA(t))^2},$$

$$\varepsilon_{\perp} = (m^2 + p_{\perp}^2)^{1/2}.$$

Integral characteristics: density $n(t)$,current $j(t)$, entropy $S(t)$

Vinik D.V., Mizerny V.A., Prozorkevich A.V., Smolyansky S.A., Toneev V.D. Physics of Atomic Nuclei, 2001, 64 , N4, 836.

$$n(t) = 2g \int \frac{d\vec{p}}{(2\pi)^3} f(\vec{p}, t)$$

$$j_{in}(t) = j_{cond}(t) + j_{pol}(t).$$

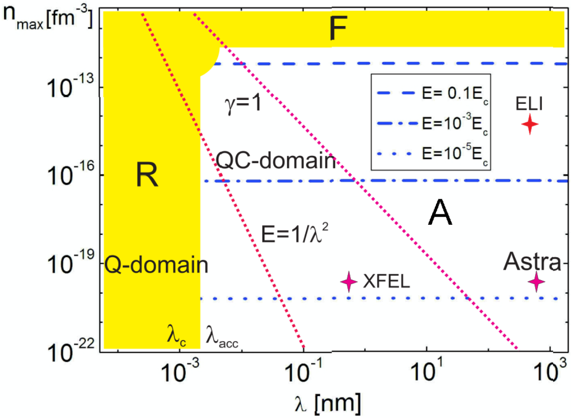
$$j_{cond}(t) = 2e \int \frac{d\vec{p}}{(2\pi)^3 \omega(\vec{p}, t)} p_{\|} f(\vec{p}, t).$$

$$j_{pol}(t) = e \int \frac{d\vec{p}}{(2\pi)^3 \omega(\vec{p}, t)} p_{\|} u(\vec{p}, t) (\frac{p_{\|}}{\omega(\vec{p}, t)})^{g-1}$$

$$S(t) = -g \int \frac{d\vec{p}}{(2\pi)^3} \{ f(\vec{p}, t) \ln f(\vec{p}, t) \pm [1 \pm f(\vec{p}, t)] \ln [1 \pm f(\vec{p}, t)] \}$$

Three creation regimes

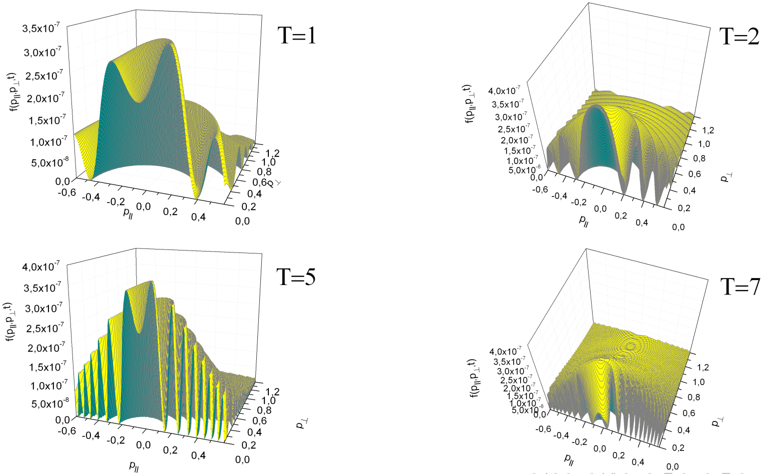
D. B. Blaschke, M. Fedotov, B. Kampfer, M. Schmidt, A. D. Panferov, A. V. Prozorkevich, S. A. Smolyansky.



The overview of vacuum response on periodical electric field $E(t) = E_0 cos(\omega t + \phi)$: the three specific domains on the plane of (n, λ).

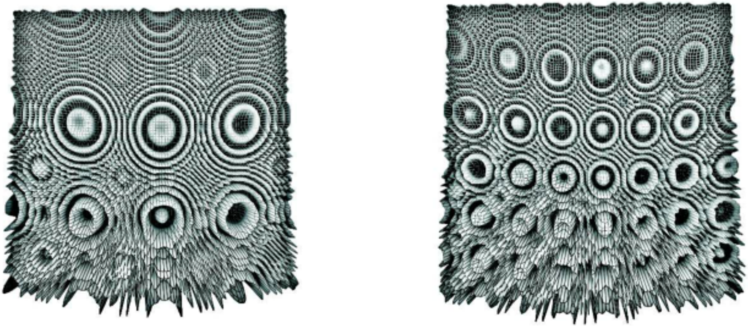
A-domaine. Dynamic of momentum distribution for fermions $f(p_{\parallel}, \vec{p}_{\perp}, t)$. $E_0 = 0.01 E_c, \lambda = 0.01[nm]$

D. B. Blaschke, B. Kaempfer, A. D. Panferov, A. V. Prozorkevich, S. A. Smolyansky // Influence of Laser Pulse Parameters on the Properties of $e^- e^+$ Plasmas Created from Vacuum.



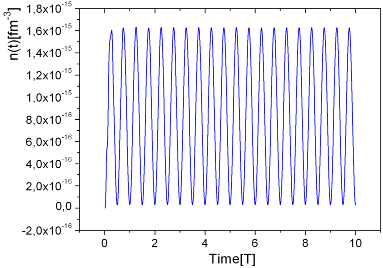
A-domaine. The complex cellular structure of the shape of $f(p_{\|}, \vec{p}_{\perp}, t)$ at large periods T in a survey top view. Left panel: left T=50; right panel: T=100.

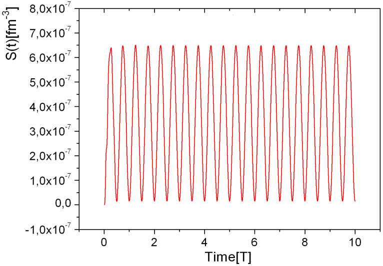
D. B. Blaschke, B. Kaempfer, A. D. Panferov, A. V. Prozorkevich, S. A. Smolyansky // Influence of Laser Pulse Parameters on the Properties of $e^{-}e^{+}$ Plasmas Created from Vacuum.

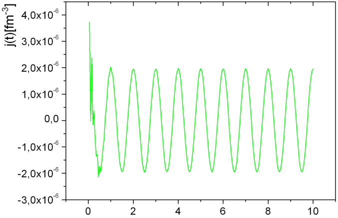


A-domain: periodical regime.

Integral characteristics: $n(t), j(t), S(t)$.







F-domain: Schwinger accumulation

Roberts C.D., Schmidt S.M., Vinnik D.V. // Phys. Rev. Lett. 2002. V.89. P.153901.

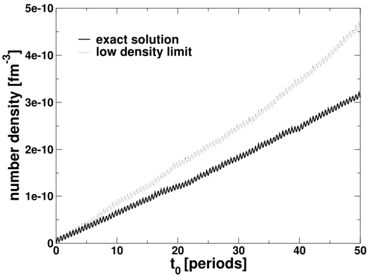


Figure : Number density calculated with $E_0 = 0.5\,E_{cr}$. Solid line: solution of kinetic equation; dotted line: solution obtained using a low density approximation.

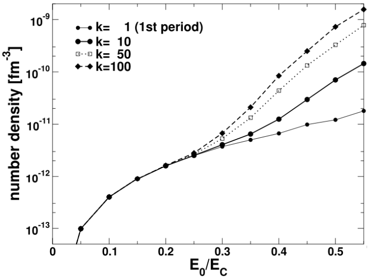
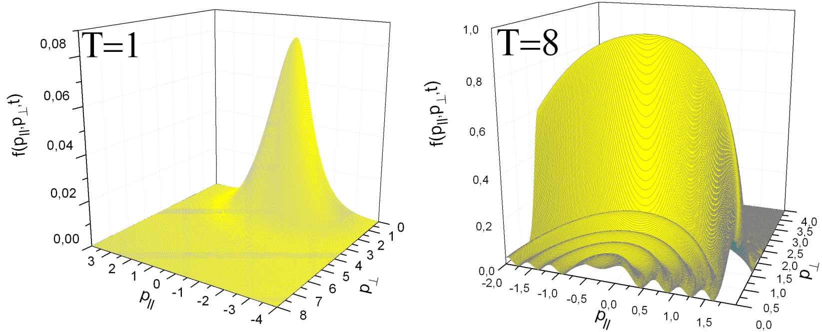


Figure : Peak particle number density versus laser field strength. There is a striking qualitative change at $E_0 \approx 0.25\,E_{\rm cr}$, which marks the onset of particle accumulation.

Dynamic of momentum distribution for bosons $f(p_{\parallel}, \vec{p}_{\perp}, t)$.

$E_0 = 1.2E_c, \lambda = 0.0005[nm]$

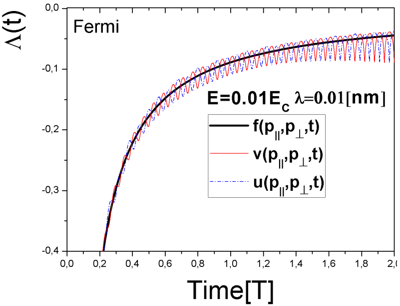
A. A. Grib, S. G. Mamaev, and V. M. Mostepanenko, Vacuum Quantum Effects in Strong External Fields, Friedman Laboratory Publish., St. Petersburg (1994).

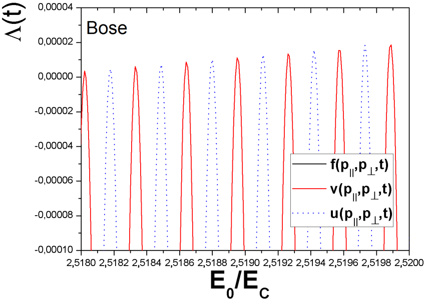


lyapunov characteristic $\Lambda(t)$

$$S_1 = \sum_{i=1}^{M} \ln \parallel f_i(p_{\parallel}, p_{\perp}, t) \parallel, S_1 = \sum_{i=1}^{M} \ln \parallel v_i(p_{\parallel}, p_{\perp}, t) \parallel, S_1 = \sum_{i=1}^{M} \ln \parallel z_i(p_{\parallel}, p_{\perp}, t) \parallel$$

$$\Lambda_i(t) = \frac{S_i}{MT}$$





Thanks for your attention!!!