Physical origin of different dynamical stages of the quasiparticle distribution function during pair production by ultrashort laser pulses

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Pair Creation by Spatially uniform time varying laser field : Quantum Kinetic Theory in Quasi particle representation

$$H(t) = \sum_{r,\bar{p}} \omega(\bar{p},t)(B^{\dagger}_{\bar{p},s}(t)B_{\bar{p},r}(t) - D_{-\bar{p},r}(t)D^{\dagger}_{-\bar{p},r}(t))$$

$$f_r(\bar{p},t) = \langle 0_{\text{in}}|B^{\dagger}_{\bar{p}r}(t)B_{\bar{p}s}(t)|0_{\text{in}}\rangle \qquad \Phi_r(\bar{p},t) = \langle 0_{\text{in}}|D_{-\bar{p}r}(t)B_{\bar{p}r}(t)|0_{\text{in}}\rangle$$

$$= u_r(\bar{p},t) + i v_r(\bar{p},t)$$

Distribution function and order parameter for FIPT (t-noninvariant vacuum state)

$$\frac{df(\bar{p},t)}{dt} = \frac{eE(t)\epsilon_{\perp}}{2\omega^2(\bar{p},t)} u(\bar{p},t),$$

u: cause of vacuum polarization

$$\frac{du(\bar{p},t)}{dt} = \frac{eE(t)\epsilon_{\perp}}{\omega^2(\bar{p},t)}[1 - 2f(\bar{p},t)] - 2\omega(\bar{p},t)v(\bar{p},t),$$

v: counter action

$$\frac{dv(\bar{p},t)}{dt} = 2\omega(\bar{p},t)u(\bar{p},t).$$

$$\frac{df(\bar{p},t)}{dt} = \frac{eE(t)\epsilon_\perp^2}{2\omega^2(\bar{p},t)} \int_{-\infty}^{t} dt' \frac{eE(t')}{\omega^2(\bar{p},t')} \quad [1-2f(\bar{p},t')] \cos[2\Theta(\bar{p};t,t')]$$

Non-Markovian character of the dynamics

$$(1-2f(\bar{p},t))^2 + |\Phi(\bar{p},t)|^2 = 1$$

1-2f, u, v : Components of the Bloch Vector

Evolution of modulus and phase of the order parameter

$$\frac{d|\Phi(\bar{p},t)|}{dt} = \frac{eE(t)\epsilon_\perp}{\omega^2(\bar{p},t)} \cos\psi(\bar{p},t) \sqrt{1-|\Phi(\bar{p},t)|^2},$$

$$\frac{d\psi(\bar{p},t)}{dt} = 2\omega(\bar{p},t) - \frac{eE(t)\epsilon_\perp}{\omega^2(\bar{p},t)} \sin\psi(\bar{p},t) \frac{\sqrt{1-|\Phi(\bar{p},t)|^2}}{|\Phi(\bar{p},t)|}$$

Sauter pulse having oscillatory structure with linear and quadratic chirp

$$E(t) = E_0 \cosh^{-2}(t/\tau) \cos(\alpha t^3 + \beta t^2 + \omega_0 t)$$

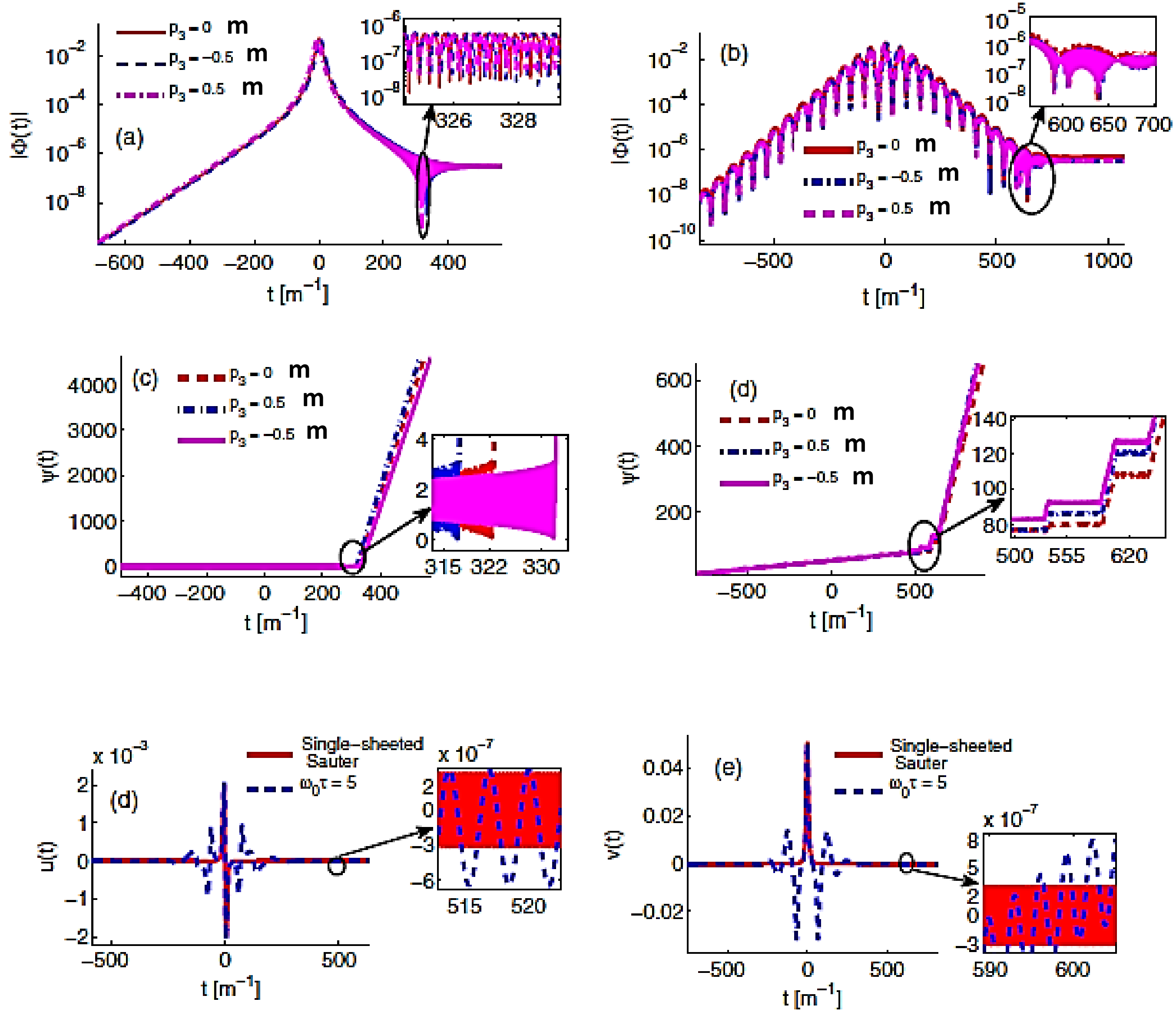
Sauter pulses without and with few cycle oscillations (α=0,β=0,τ=100,ω=0.05)

Dynamical Stages
QEPP governed by *E(t)*
REPP by *A(t)*
Transient Stage by *E, A, u, v, ……* Complex, fast oscillations

Order parameter phase
Sudden increase at Transient stage

Dephasing of e-e+ correlation
Independent particles

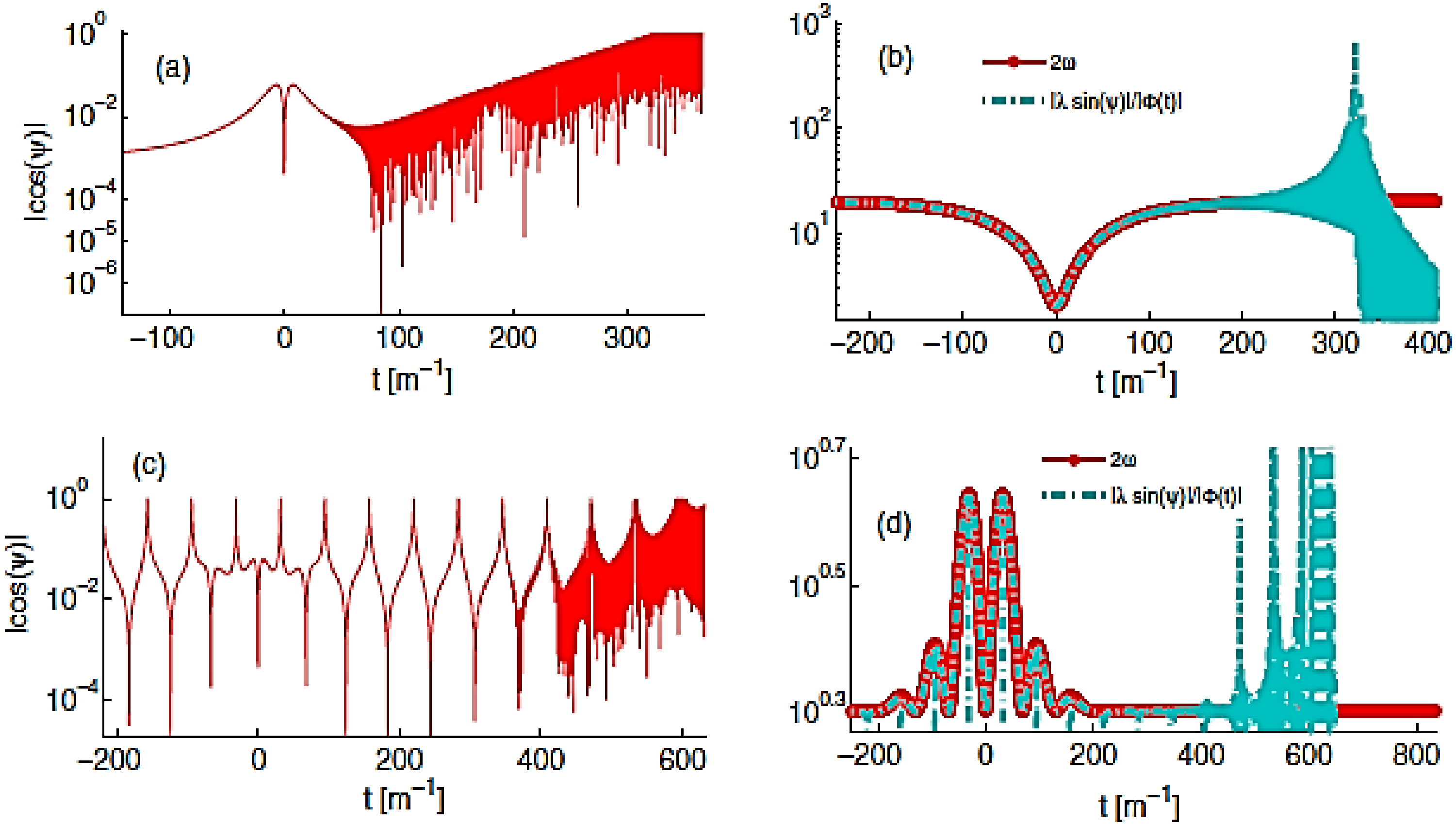
v(t) dominant in QEPP
u(t) catches up in transient stage
u(t), v(t) equal
in REPP



Origin of fast oscillations of $|\phi(t)|$ in the transient stage

Sauter pulse
Without
oscillation

Sauter pulse
With
5 oscillation



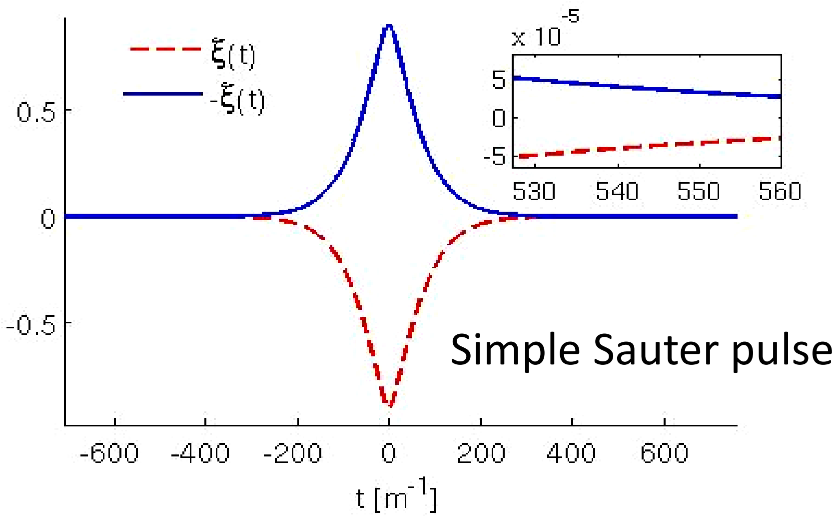
Cosψ oscillation much faster compared to that of E(t)
in the transient stage

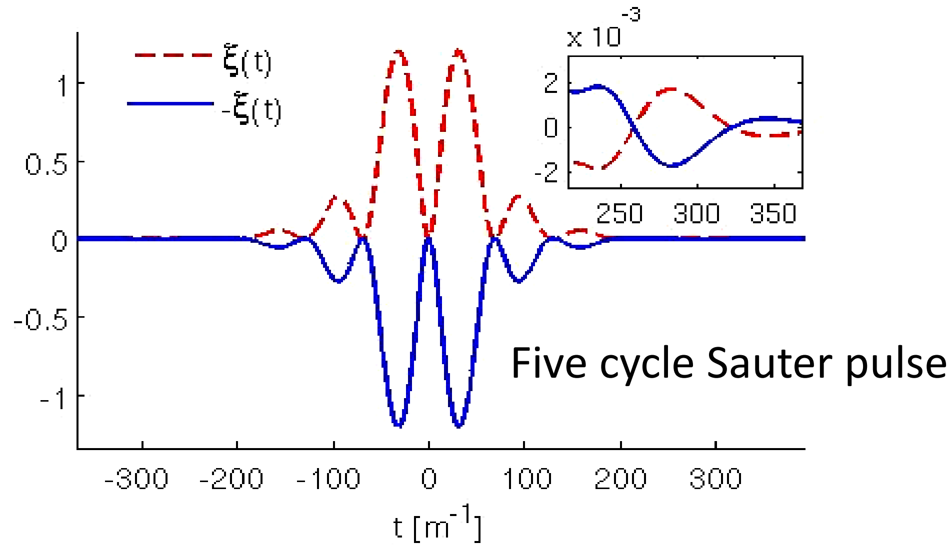
For evolution of phase $\psi(t)$ the two competing source terms exactly balance in QEPP

2^{nd} term with Sinψ dominates in transient stage

1^{st} term (2ω) controls the evolution in REPP

Evolution of mass-shell





$\xi(t)=(m(t)-m0)/m0$

Physical Picture

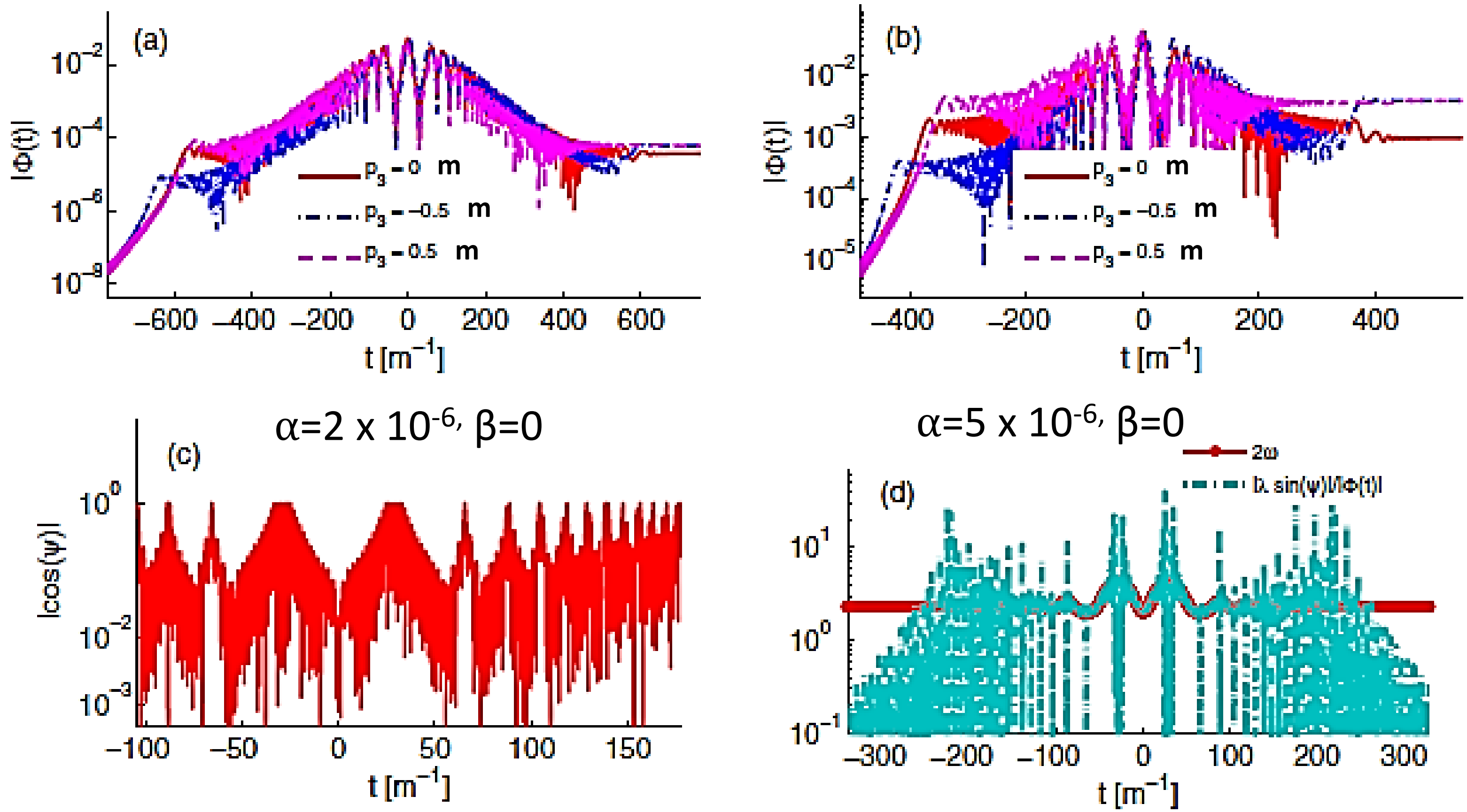
e+e- pairs are off-shell before reaching transient stage

Pairs are correlated

Interact with electric field and gain energy and reach on-shell during the transient stage

Dephasing turns pairs into independent particles

Pretransient Stage in presence of quadratic frequency chirp

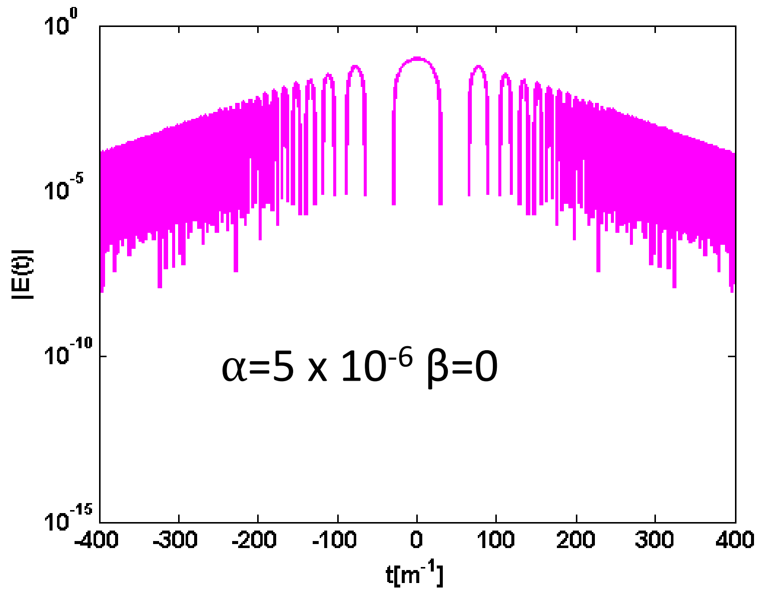


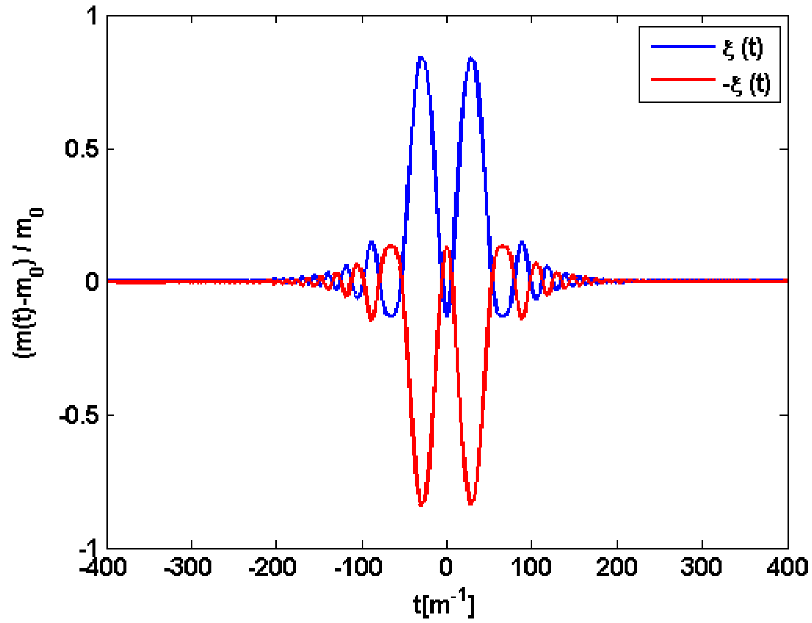
Pretransient stage: Mirror image of transient stage oscillation in accelerating part of pulse

Oscillations in pretransient and transient stage interrupted by central peak region of pulse

Transient and pretransient stages move closer to the pulse centre with increase in the strength of quadratic chirp, resulting into enhancement of pair production

Evolution of mass-shell





System reaches on-shell mass configuration much faster

Increase in frequency on the either side of central region of the pulse opens up another Channel of pair production (multiphoton process) thereby leading to enhancement in Pair production

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