Sauter Schwinger effect

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QFT in strong external fields

Electromagnetic Background
Strong field QED: Fields intense enough to modify the vacuum

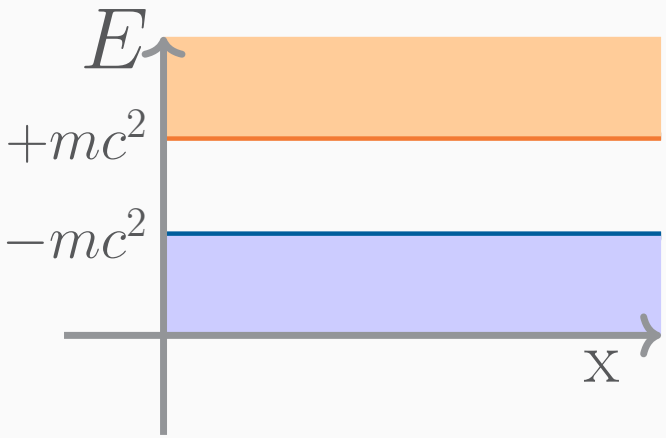
- Sauter-Schwinger effect
- Vacuum birefringence
- Non-linear Breit Wheeler
- Sources:
  - High power Lasers
  - Plasma wakefield accelerators
  - Astrophysicsal environments

Gravitational Background: QFT in curved space time

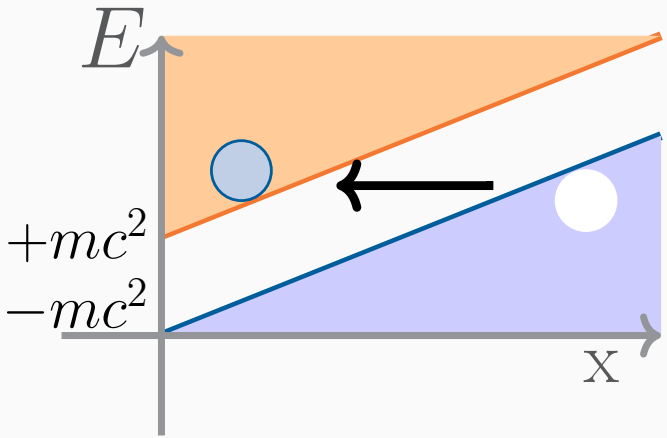
- Hawking Radiation
- Unruh effect
- Particle creation in an expanding universe

Strong field QED

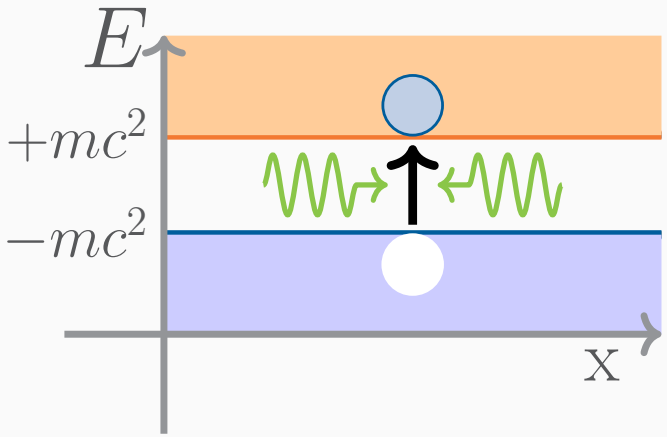
Dirac sea



Sauter Schwinger effect



Multiphoton pair production, Breit Wheeler



Many more strong field QED effects:

- Trident pair production
- Non-linear Compton scattering
- Light-by-light scattering

Sauter-Schwinger effect

- Spontaneous creation of electron-positron pairs from the vacuum in ultrastrong electromagnetic fields

Pair production rate:

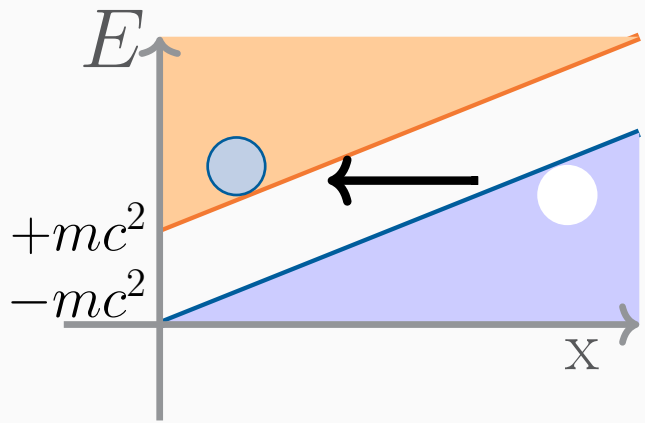
$$\Gamma = \frac{2(eE)^2}{(2\pi)^3} \exp\left(-\frac{\pi m^2}{eE}\right)$$

Non-perturbative

Schwinger limit:

$$E_{\mathrm{crit}} = \frac{m_{\mathrm{e}}^2 c^3}{e\hbar} \approx 1.3 \times 10^{18} \frac{\mathrm{V}}{\mathrm{m}}$$

- Compton length
  $\lambda\!\!\!^{-}_c = 3.86 \times 10^{-13}\mathrm{m}$
- Compton time
  $t_c = \frac{\lambda\!\!\!^{-}_c}{c} = 1.29 \times 10^{-21}\mathrm{s}$



Not yet experimentally verified

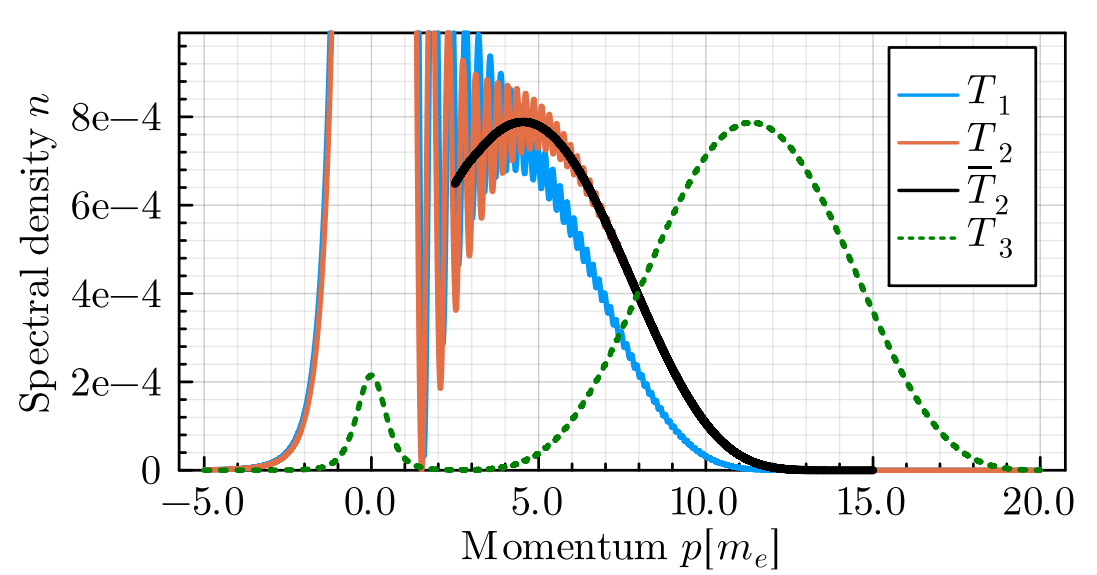
Fritz Sauter, Z. Physik 69, 742–764 (1931)

Julian Schwinger, Phys. Rev. 82, 664 (1951)

Time scales for a single Sauter pulse

- Time evolution of particle spectra in momentum space
- 3 time scales:
  1. $T_1 \approx 0.65\,\tau^{1/4}\,t_C^{3/4}/\varepsilon^2$, Appearance of a Side-peak
  2. $T_2 = T_1 + 0.06\tau^{3/4}t_C^{1/4}/\varepsilon^{3/2}$ side-peak follows a classical trajectory
  3. $T_3 = 1.8\tau$ at which quantum fluctuations fade out

Valid for $0.1 < \varepsilon < 0.5$ and $10t_C < \tau < 50t_C$



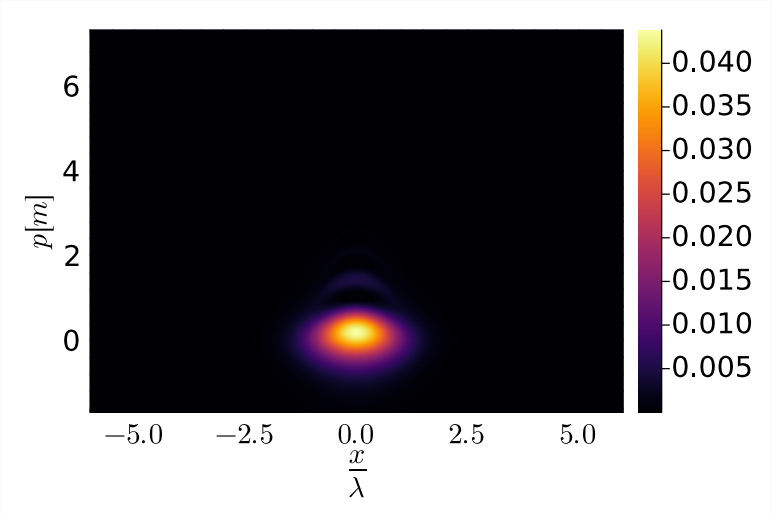
$$E(t) = \varepsilon E_{\text{crit}} \frac{1}{\cosh(t/\tau)^2}$$

[MD, R Alkofer, C Kohlfürst, Physics Letters B, Volume 844, 2023,]

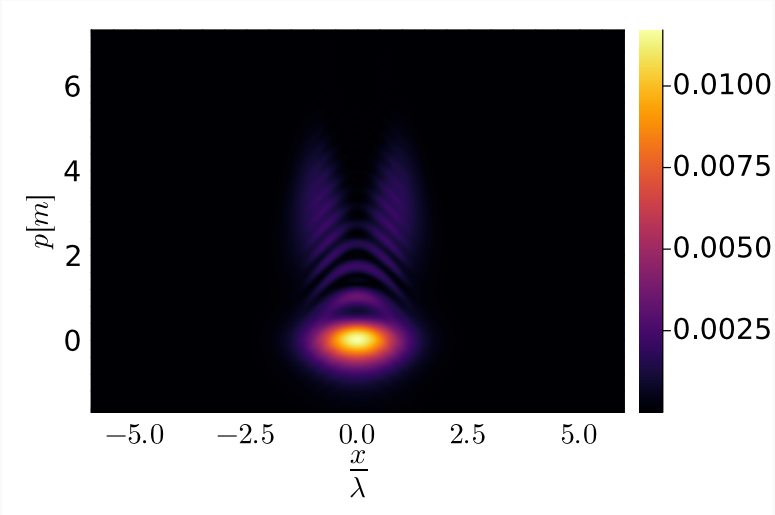
Time evolution in phase space

Pair density $N(x, p, t)$

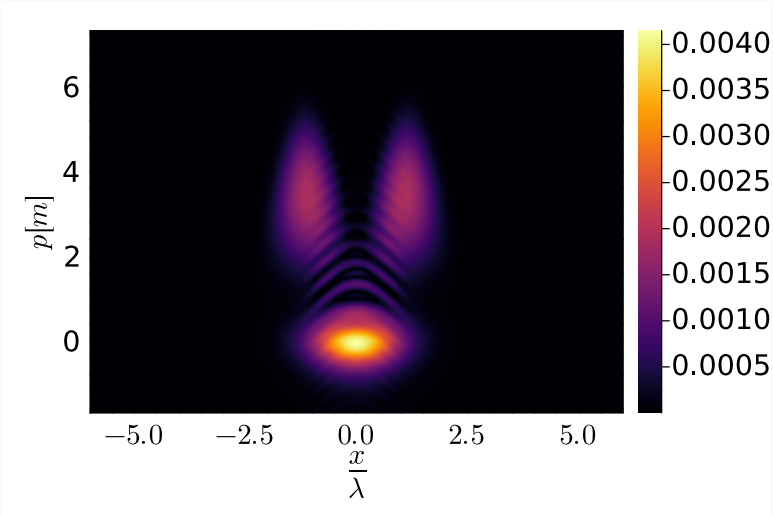
$t = 0 \cdot \tau$



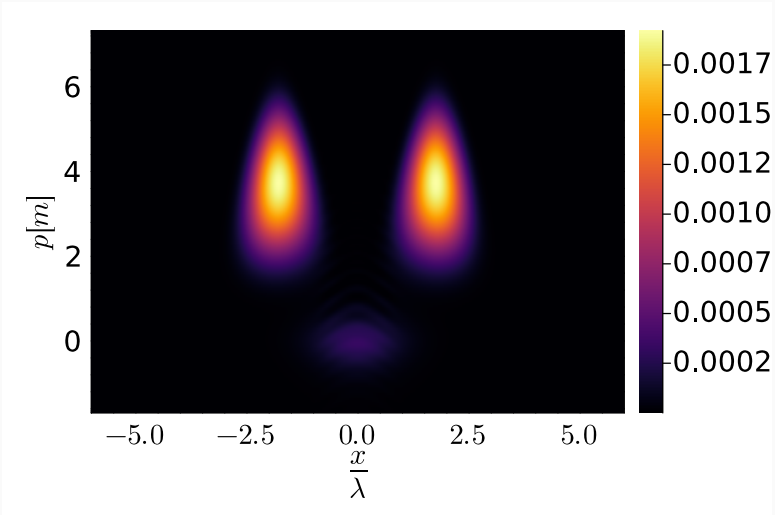
$t = 0.8 \cdot \tau$



$t = 1.1 \cdot \tau$

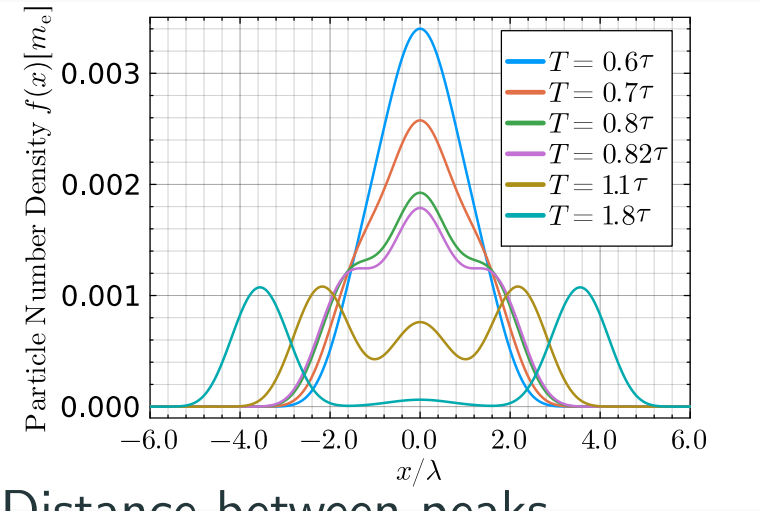


$t = 1.8\tau$



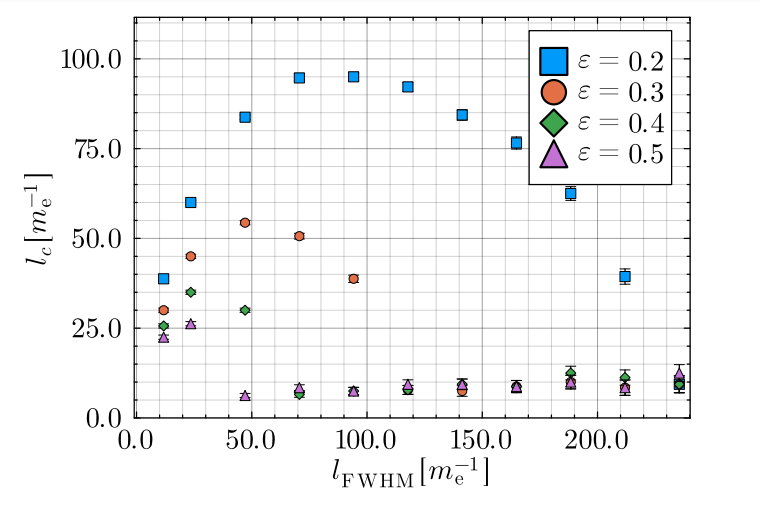
Spatial separation

Time evolution position space

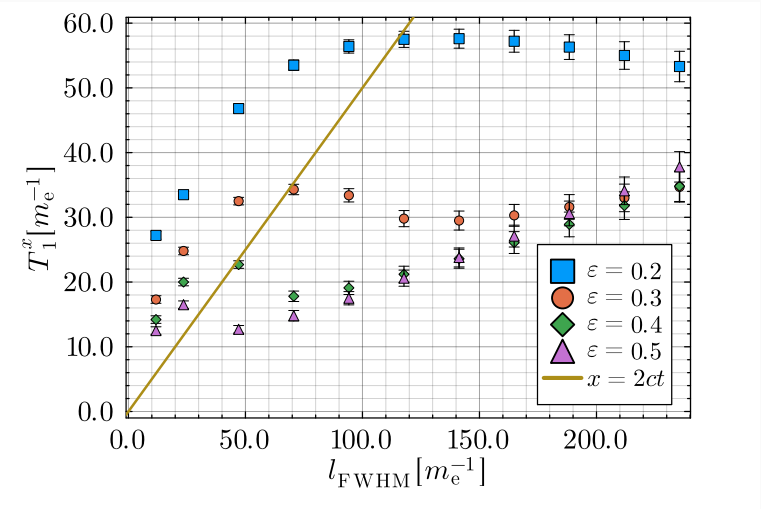


- first moment in time when outgoing peaks in position space can be identified
- a formation at non-vanishing distance (non-local correlation)

Distance between peaks



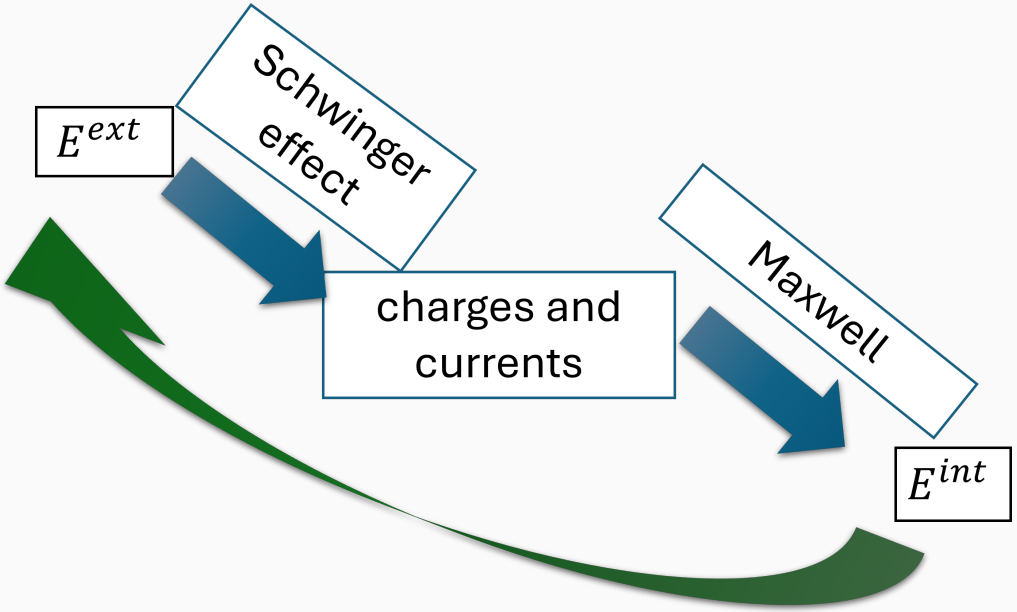
Appearance time



Classical backreaction

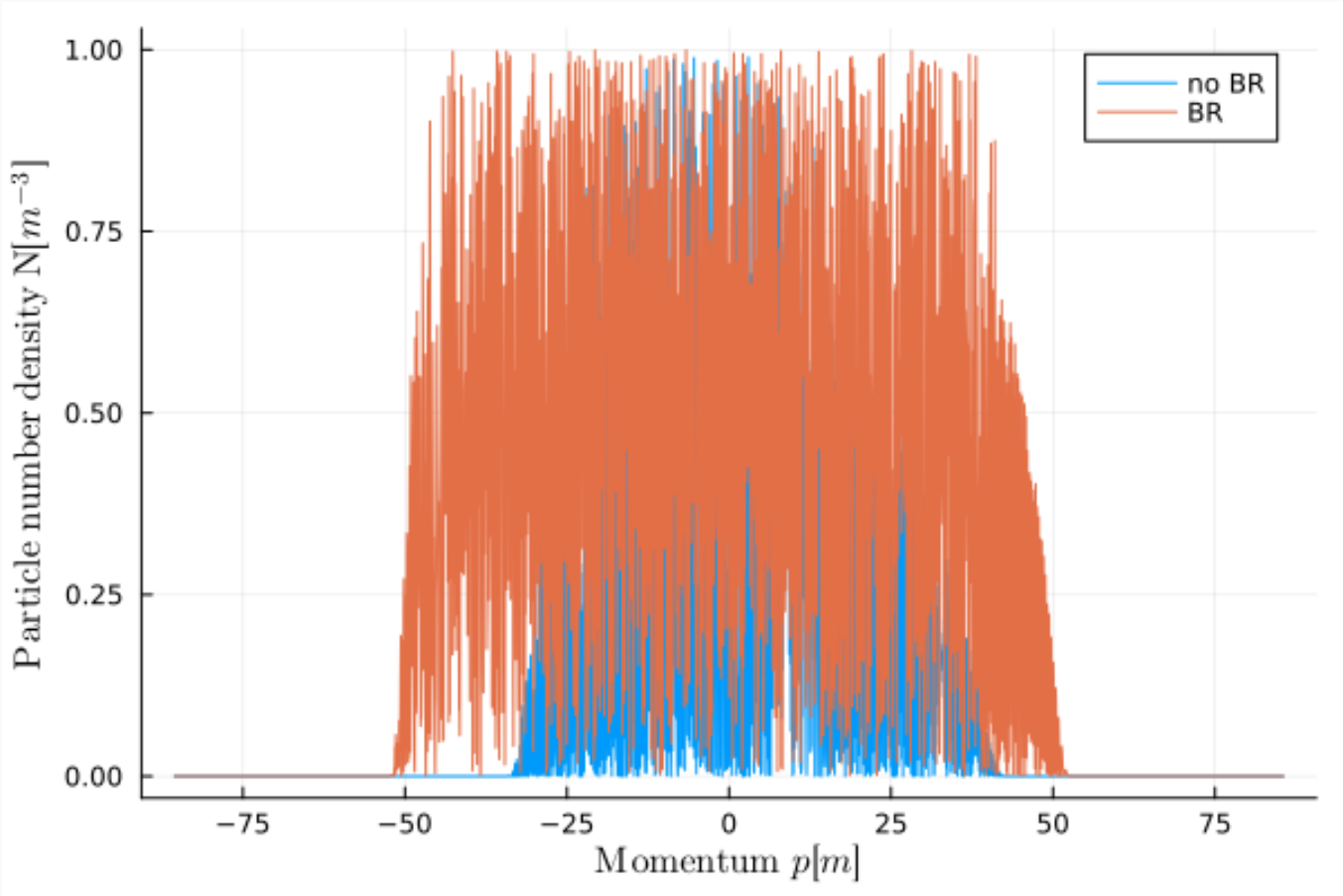
- created pairs are sources of electric field themselves
- mean field treatment of the current (= classical backreaction):

$$\langle \Omega | j^{\mu}(x) | \Omega \rangle = e \int \frac{d^3 p}{(2\pi)^3} \mathrm{tr}[\gamma^{\mu} w(x, \boldsymbol{p})]$$



- 4 additional equations.
- quantum corrections of the electromagnetic field are neglected
- must be correctly renormalized

Results for Backreaction for an oscillating pulse



$$E(t) = E_{\text{crit}}\varepsilon\cos(\omega t + \varphi)\exp\left(-\frac{t^2}{2\tau^2}\right)$$

Conclusion & Outlook

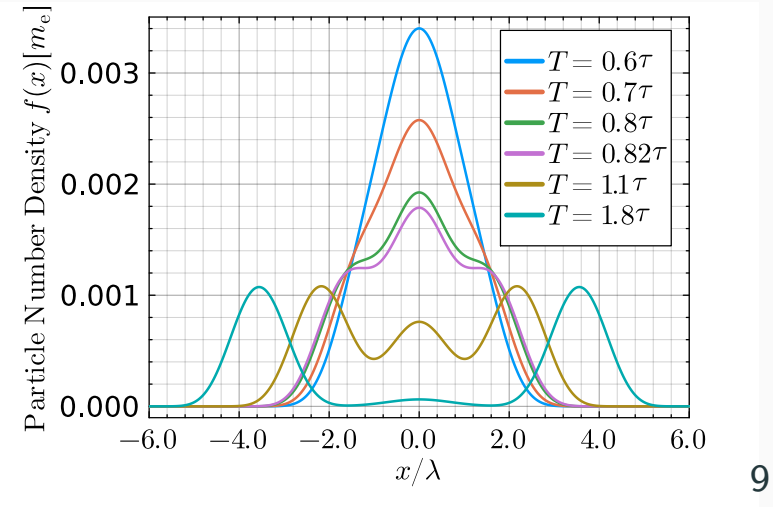
1. Strong field QED is a non-yet experimentally tested area of QFT
2. The quantum distribution function contains sensible physical information even at finite, pre-asymptotic times
3. At least three time-scales identified:
   - Maximum appearance : $T_1 \approx 0.65\,\tau^{1/4}\,t_C^{3/4}/\varepsilon^2$
   - Classical trajectory: $T_2 \approx T_1 + 0.06\tau^{3/4}t_C^{1/4}/\varepsilon^{3/2}$
   - Fading out of quantum fluctuations : $T_3 \approx 1.8\tau$
4. Spatial structure: Non vanishing distance

Currently under investigation:

- Backreaction for carrier phase delay
- Spatial and temporal correlations of emerging scales

Outlook:

- Classical backreaction for fields with spatial inhomogeneities



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