Scattering matrix approach to dynamical Sauter-Schwinger process

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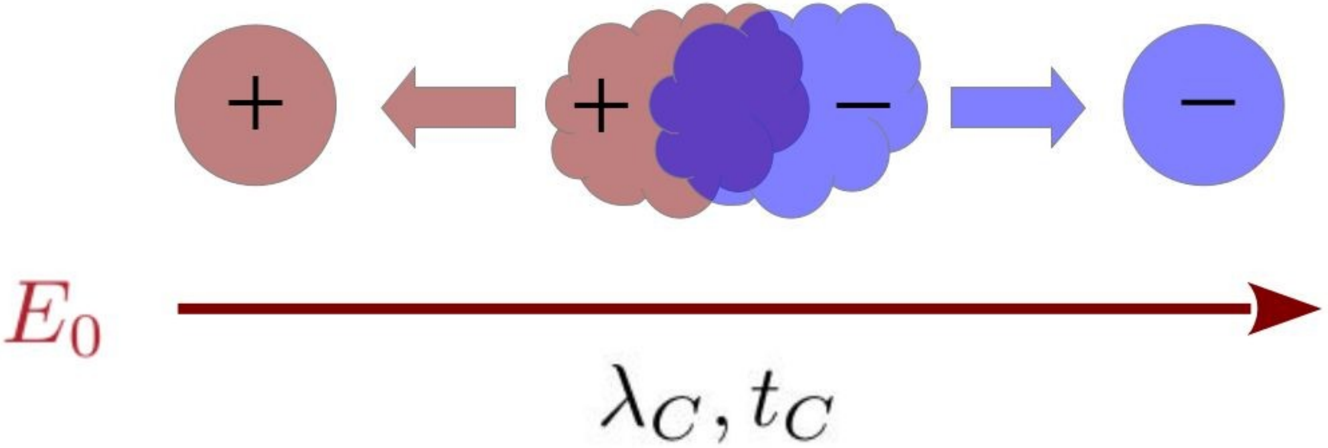
Sauter-Schwinger process

The Sauter-Schwinger effect is a theoretical prediction of quantum electrodynamics, where electron-positron pairs are created from the vacuum by an external electromagnetic field.

F. Sauter, Zeit. Phys. **69**, 742 (1931)
W. Heisenberg and H. Euler, Z. Phys. **98**, 714 (1936)
J. Schwinger, Phys. Rev. **82**, 664 (1951)

Schwinger limit

E_0=1.32×10^18 V/m



S-matrix approach vs. other methods

DHW formalism

- spin information is lost

+ any polarization of the laser pulse

- information about the phase of probability amplitude is lost

Spinorial approach

- spin information is lost

- only linear polarization of the laser pulse

+ information about the phase of probability amplitude

S-matrix approach

+ spin (helicity) information

+ any polarization of the laser pulse

+ information about the phase of probability amplitude

„Scattering matrix approach to dynamical Sauter-Schwinger process: Spin- and helicity-resolved momentum distributions”, *M. M. Majczak, K. Krajewska, J. Z. Kamiński, A. Bechler*, Phys. Rev. D in print (arXiv:2403.15206)

Scattering matrix approach

Our method of describing the Sauter-Schwinger process comes down to solving the Dirac equation

$$[-\mathrm{i}\gamma^0\partial_0 - \boldsymbol{\gamma}\cdot\boldsymbol{p}_+ + e\not{A}(x^0) + m_{\mathrm{e}}c]\Phi^{(-)}_{\mathrm{F};\boldsymbol{p}_+,\lambda_+}(x^0) = 0,$$

where Feynman-type wave function was introduced

$$\Phi^{(-)}_{\mathrm{F};\boldsymbol{p}_+,\lambda_+}(x^0) = \sum_{\lambda=\pm}\left[C^{(+)}_{\mathrm{F};\boldsymbol{p}_+,\lambda_+,\lambda}(x^0)u^{(+)}_{-\boldsymbol{p}_+,\lambda}\mathrm{e}^{-\mathrm{i}p^0_+x^0} + C^{(-)}_{\mathrm{F};\boldsymbol{p}_+,\lambda_+,\lambda}(x^0)u^{(-)}_{\boldsymbol{p}_+,\lambda}\mathrm{e}^{\mathrm{i}p^0_+x^0}\right],$$

with the boundary conditions:

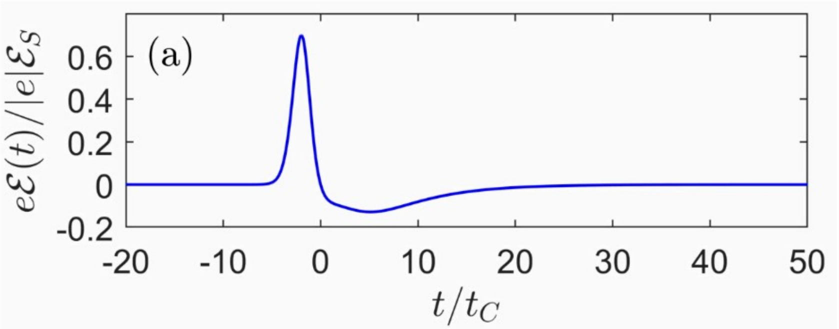
$$C^{(+)}_{\mathrm{F};\boldsymbol{p}_+,\lambda_+,\lambda}(-\infty) = 0\,, \qquad C^{(-)}_{\mathrm{F};\boldsymbol{p}_+,\lambda_+,\lambda}(\infty) = \delta_{\lambda_+\lambda}.$$

With this we can define the conditional probability amplitude of created electrons

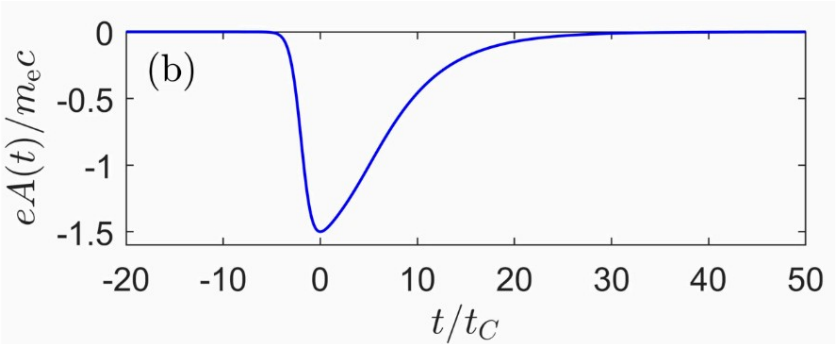
$$\mathcal{A}^{(+)}_{\lambda_+}(\boldsymbol{p}_-,\lambda_-) = C^{(+)}_{\mathrm{F};-\boldsymbol{p}_-,\lambda_+,\lambda_-}(\infty), \qquad f^{(+)}_{\lambda_+}(\boldsymbol{p}_-,\lambda_-) = |A^{(+)}_{\lambda_+}(\boldsymbol{p}_-,\lambda_-)|^2.$$

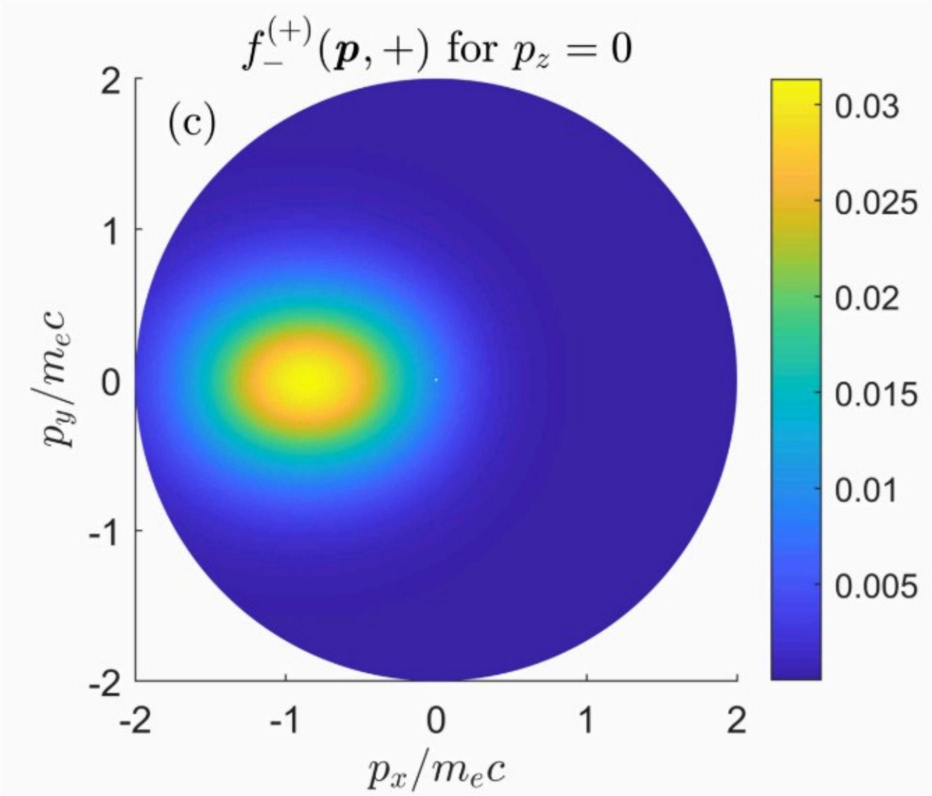
Numerical results

Electric field

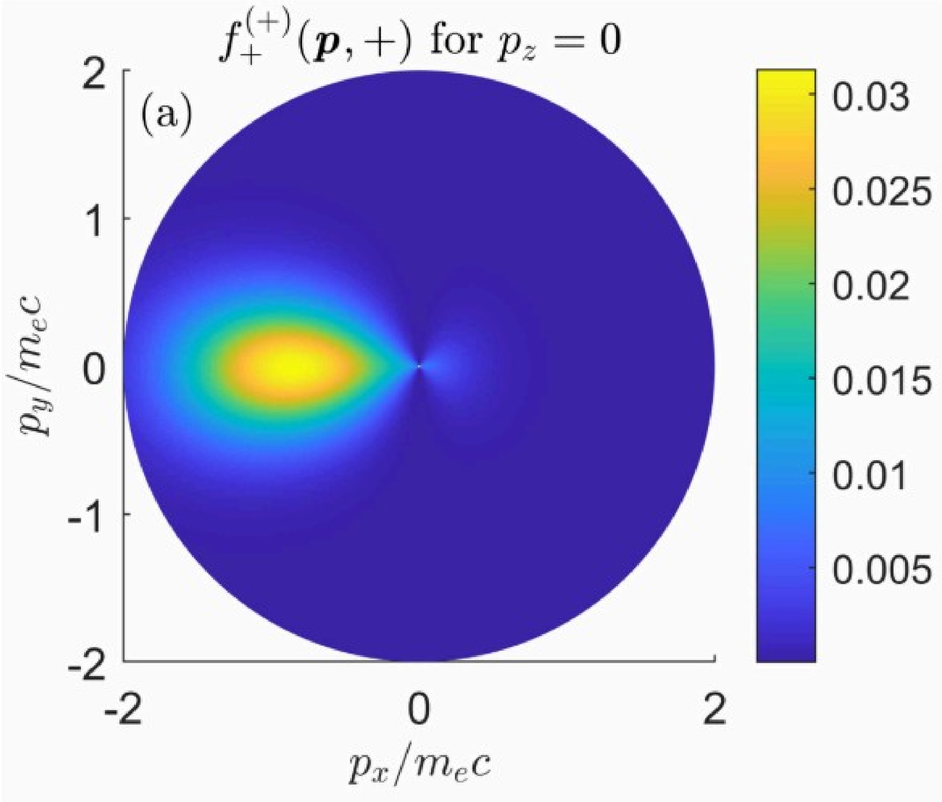


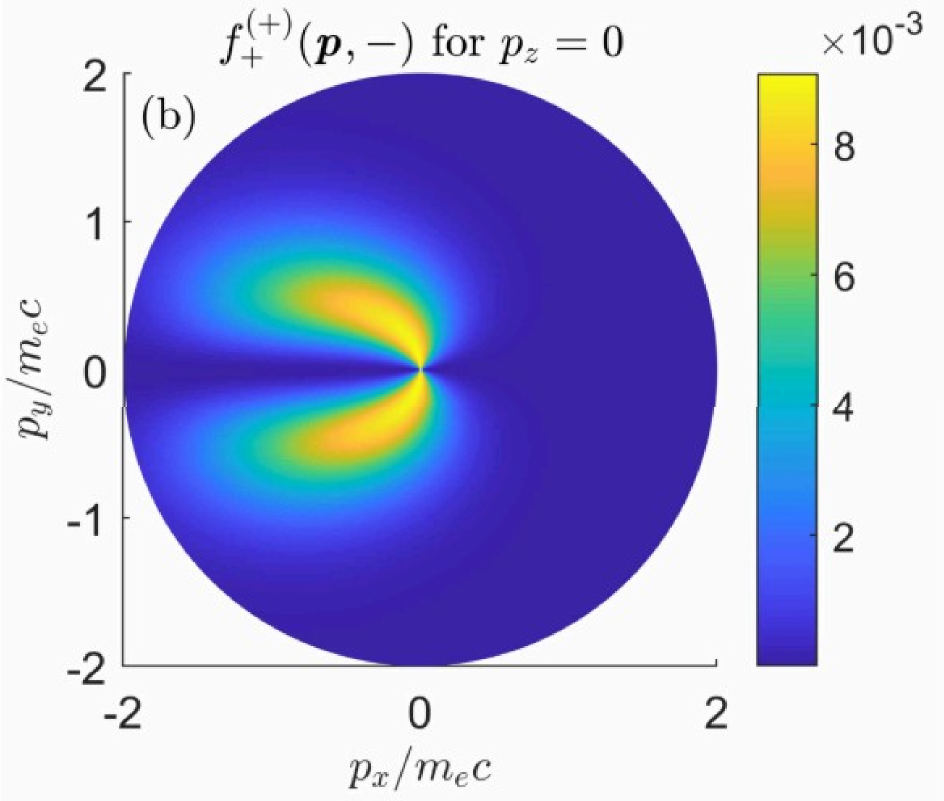
Vector potential





Numerical results - helicity





Summary

- We have developed the **S-matrix formalism for describing Sauter-Schwinger process**.
- With our method we can study the Sauter-Schwinger process driven by an **arbitrary spatially homogenous electric field**.
- The scattering matrix approach preserves **information about the spin (helicity) of created particles**.
- With this method we have **full access to the probability amplitude of pair creation**.

„Scattering matrix approach to dynamical Sauter-Schwinger process: Spin- and helicity-resolved momentum distributions”, *M. M. Majczak, K. Krajewska, J. Z. Kamiński, A. Bechler*, Phys. Rev. D in print (arXiv:2403.15206)