Nonlinear trident pair production in a plane wave: properties of the transition amplitude

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MPI for the Physics of Complex Systems

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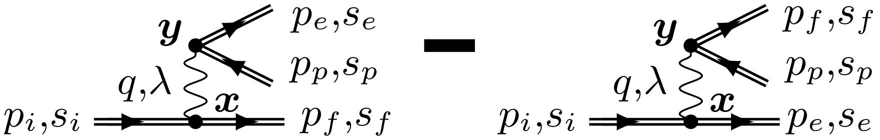
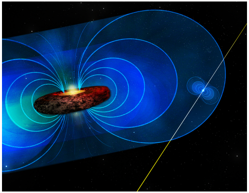


DESY, Hamburg, August 22nd 2018

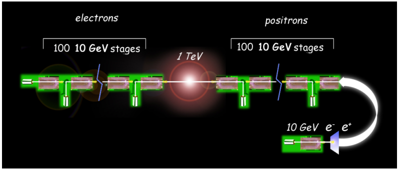
Outline of the talk

1. Laser-driven positron production
2. Transition amplitude
3. Numerical studies
4. Take home message

applications

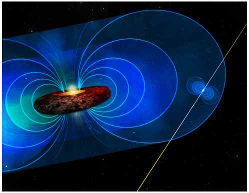


astrophysics

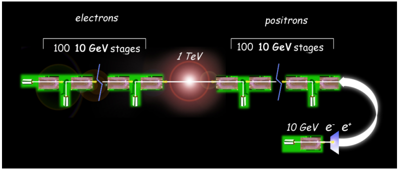


particle physics

applications



astrophysics

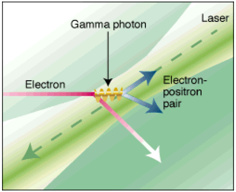


particle physics

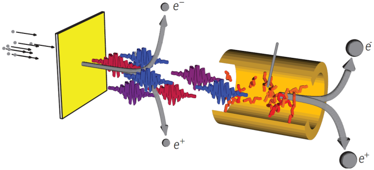
renewed theoretical interest

- Dinu, Torgrimsson, Phys. Rev. D 97, 036021 (2018)
- King, Fedotov, Phys. Rev. D 98, 016005 (2018)
- Del Gaudio et al., arXiv:1807.06968 (2018)

laser-produced pairs

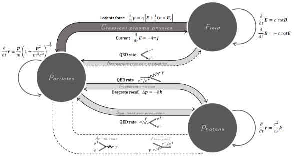


Credit: E144, SLAC



Numerical simulations

numerical schemes



Credit: A. Gonoskov

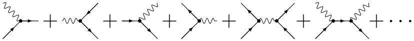
particles

- point sources
- trajectories/ currents

radiation

- fields
- forces on particles

quantum electrodynamics

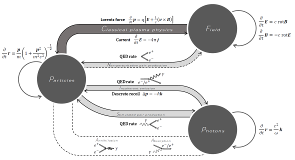


QED series

- no trajectories
- quantised radiation
- few particles

Numerical simulations

numerical schemes



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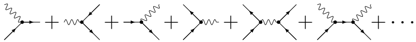

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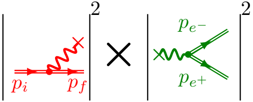
sequential approximation for $\xi \gg 1$



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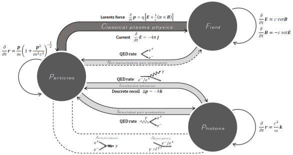

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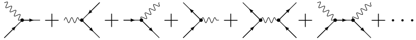

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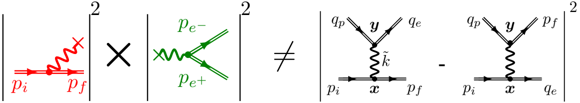

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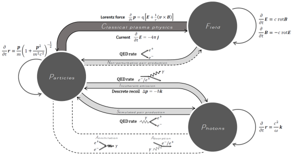

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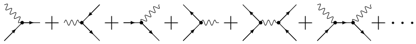
quantum electrodynamics



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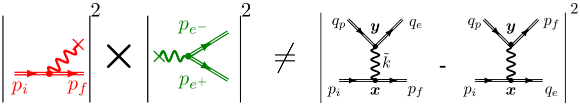
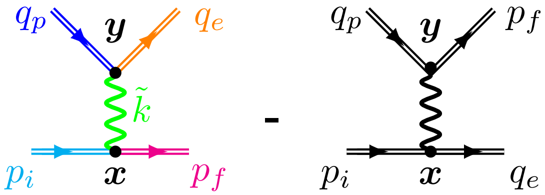
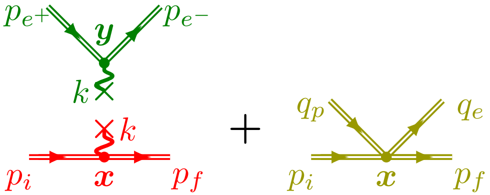


test non-sequential contributions



Scattering matrix amplitude

$$S_{fi} = -e^2 \int d^4x d^4y \overline{\Psi}_{q_e}(y)\gamma_\mu \Psi_{-q_p}(y)\mathcal{D}^{\mu\nu}(y,x)\overline{\Psi}_{p_f}(x)\gamma_\nu \Psi_{p_i}(x)$$



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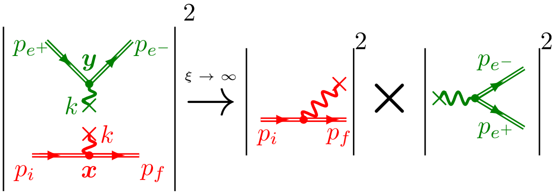
$$= \underbrace{\int dx^\eta dy^\eta \Theta(y^\eta - x^\eta) M_{BW}(y^\eta) M_C(x^\eta)}_{\text{cascade}} + \underbrace{\int dx^\eta \mu_d(x^\eta)}_{\text{direct}}$$

Photon propagator splits up

$$\mathcal{D}^{\mu\nu}(y^\eta, x^\eta) \to \eta^{\mu\nu}\Theta(y^\eta - x^\eta)$$

$$\eta^{\mu\nu} = \frac{(n^\mu k^\nu + n^\nu k^\mu)}{k_-} - \Lambda_1^\mu \Lambda_1^\nu - \Lambda_2^\mu \Lambda_2^\nu, \ (k_\mu \Lambda_i^\mu) \equiv (n_\mu \Lambda_i^\mu) \equiv 0$$



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Photon propagator splits up - study polarization dynamics

D. Seipt et al., Phys. Rev. A 98, 023417 (2018)

$$\mathcal{D}^{\mu\nu}(y^\eta, x^\eta) \to \eta^{\mu\nu} \Theta(y^\eta - x^\eta)$$

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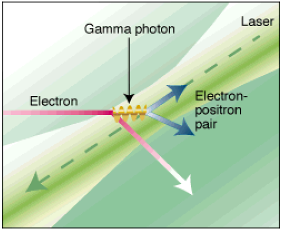
$\xi \approx 0.5$, $\lambda = 527$ nm, $\varepsilon_i = 46.6$ GeV, $\theta_{\mathrm{coll}} = 17^\circ$, $\tau_{\mathrm{eff}} = 40$ fs

Hu, Müller, Keitel, Phys. Rev. Lett. 105, 080401 (2010)

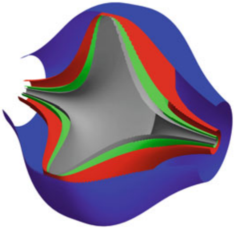


SLAC E144 - experimental data

$\xi \approx 0.5$, $\lambda = 527$ nm, $\varepsilon_i = 46.6$ GeV, $\theta_{\text{coll}} = 17^\circ$, $\tau_{\text{eff}} = 40$ fs

Hu, Müller, Keitel, Phys. Rev. Lett. 105, 080401 (2010)

averaging over **Gaussian focus**



field strength isosurfaces

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Hu, Müller, Keitel, Phys. Rev. Lett. 105, 080401 (2010)

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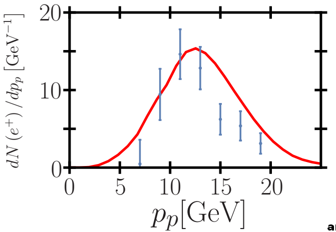


arXiv:1805.01731

- 21962 used shots
- 5×10^9 electrons per bunch

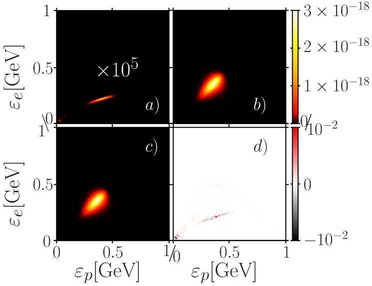
Integrating spectrum:

prodution probability	$\mathcal{P}_{e^+} \approx 8 \times 10^{-3}$ per shot
total positron number	$N_{e^+} \approx 176$
SLAC E144	$N_{e^+} = 175 \pm 13$

Consider always ultra-short pulses $\tau \approx 5.4$ fs

$\varepsilon_i = 1$ GeV, $I_L = 2 \times 10^{21}$ W/cm^2 ($\xi \approx 22, \chi \approx 0.25$)

positron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, \pi/2)$, electron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, 0)$

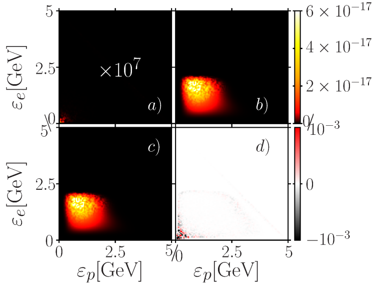


arXiv:1805.01731

- (a) direct
- (b) cascade
- (c) full
- (d) relative error of cascade approximation

$\varepsilon_i = 5$ GeV, $I_L = 10^{22}$ W/cm^2 ($\xi \approx 50, \chi \approx 3$)

positron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, \pi/2)$, electron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, 0)$



arXiv:1805.01731

- (a) direct
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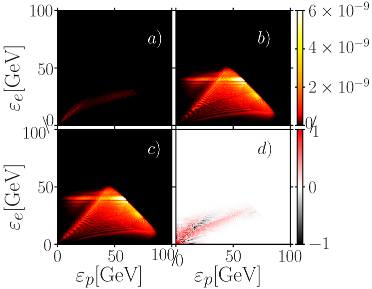
sequential process dominates

$\varepsilon_i = 100$ GeV, $I_L = 2 \times 10^{21}$ W/cm^2 ($\xi \approx 22, \chi \approx 26$)

positron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, \pi)$, electron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, 0)$



arXiv:1805.01731

- (a) direct
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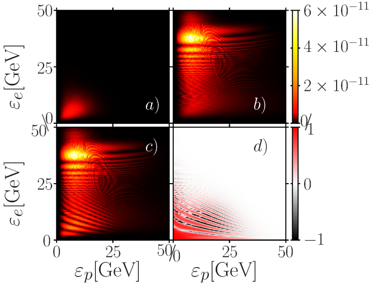
non-sequential contributions at low energies

$\varepsilon_i = 100$ GeV, $I_L = 5 \times 10^{20}$ W/cm^2 ($\xi \approx 11, \chi \approx 13$)

positron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, \pi/2)$, electron: $(\theta_s, \phi_s) = (\pi - m\xi/\varepsilon_i, 0)$



arXiv:1805.01731

- (a) direct
- (b) cascade
- (c) full
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non-sequential modelling needed

take home

nonlinear trident process at high energies features non-sequential contributions

take home

nonlinear trident process at high energies features non-sequential contributions

findings

- prominent low particle energies
- possibly enhanced pair production
- arXiv:1805.01731

take home

nonlinear trident process at high energies features non-sequential contributions

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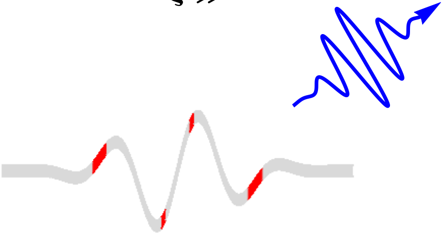
thank you

Backup

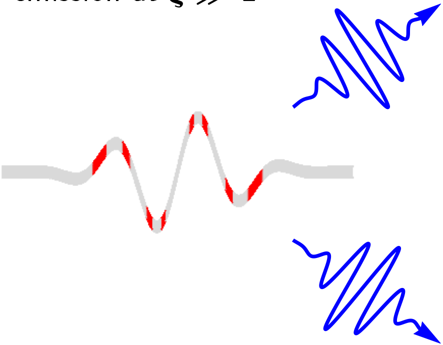
Localized QED emission at $\xi \gg 1$

Localized QED emission at $\xi \gg 1$



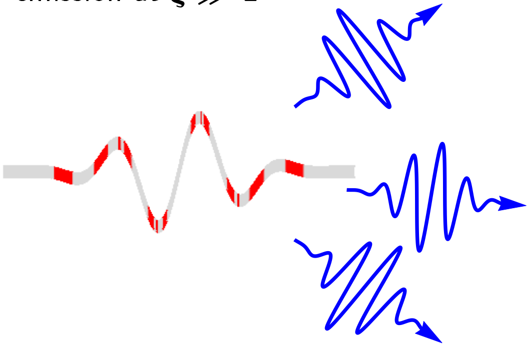
- Relativistic electrons emit in propagation direction

Localized QED emission at $\xi \gg 1$



- Relativistic electrons emit in propagation direction
- Correct for QED emission spectra

Localized QED emission at $\xi \gg 1$



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Trajectory picture valid at $\xi \gg 1$
$\Rightarrow$ **single photon emission** in classical simulations