Massive scalar and pseudoscalar production in electron-laser collisions

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UNIVERSITY OF PLYMOUTH

SQED Workshop, DESY

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Outline

Why massive pseudoscalars?

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Envisaged experimental set-up and parameters

Scalars vs Pseudoscalars

Coherent and mass reach enhancements (scalars)

Conclusion

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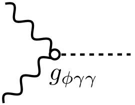

$g_{\phi\gamma\gamma}\, \phi\, \mathrm{tr}\, F \cdot \widetilde{F}$

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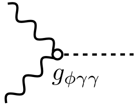

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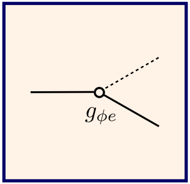

$g_{\phi e}\, \phi\, \overline{\psi} \gamma_5 \psi$

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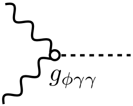

$$g_{\phi\gamma\gamma}\,\phi\,\mathrm{tr}\,F\cdot F$$

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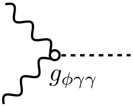

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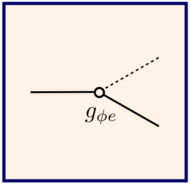

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Envisaged experimental set-up and parameters

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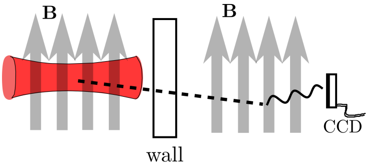

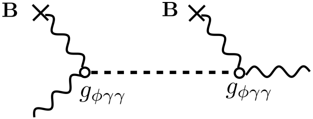

$$\mathsf{P} \propto g_{\phi\gamma\gamma}^4 (BL\bar{\lambda})^4$$

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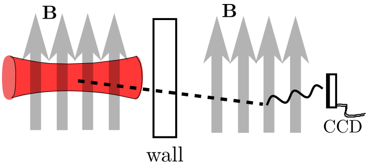

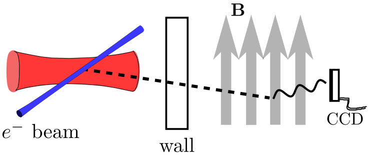

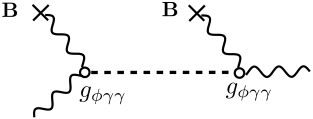

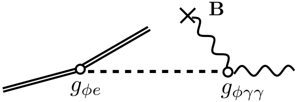

$$P \propto g^4_{\phi\gamma\gamma}(BL\bar{\lambda})^4$$

$$P \propto g^2_{\phi e} g^2_{\phi\gamma\gamma}(\xi\Phi)^2(BL\bar{\lambda})^2$$

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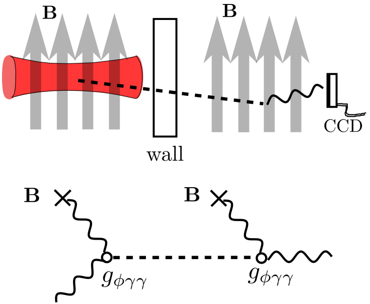

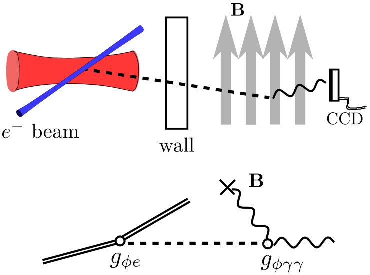

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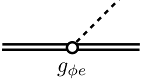
$$\eta = \frac{\varkappa \cdot p}{m^2}, \quad \xi \text{ (or: } a_0), \quad \left[\chi = \xi\,\eta\right]$$

Mass effects



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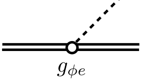

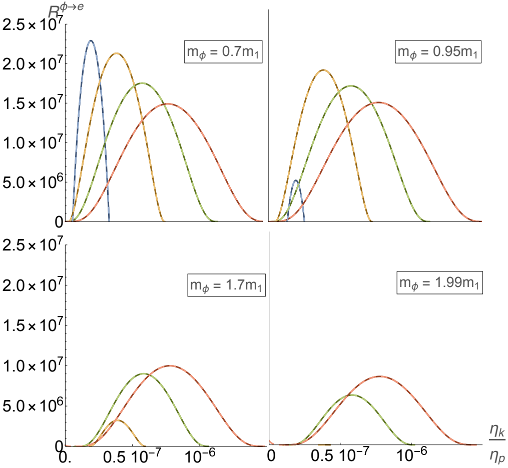

$$\varkappa^0 = 1.55\,\mathrm{eV}, \quad p^0 = 1.6\,\mathrm{MeV}$$

$$\xi = 10, \quad m_1 = 1\,\mathrm{eV}$$

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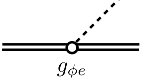

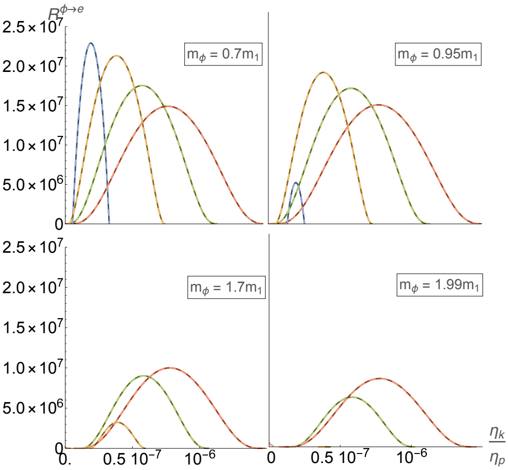

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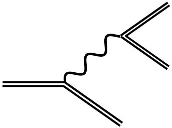
- $\eta_p \ll 1$:
  Channel-closing at
  $\delta_s^* = \frac{s\eta_p}{\sqrt{1+\xi^2}}$

- $\xi \gg 1$, (CCF limit)
  $\mathrm{P} \sim \int d\chi_k(\ldots)\mathrm{Ai}(z)$
  $z = z_{\mathrm{trident}}(k^2 \to m_\phi^2)$



Scalar vs Pseudoscalar production

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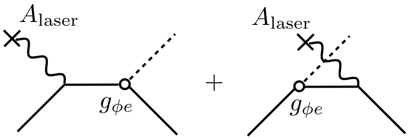
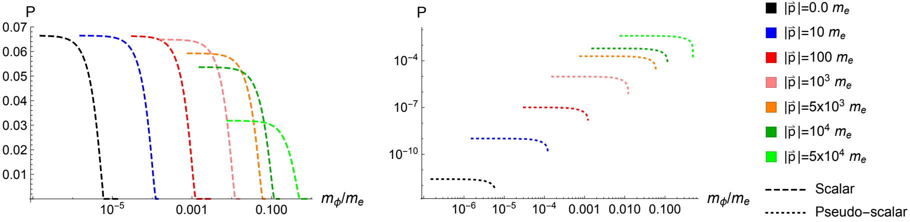
$\boxed{\xi \ll 1}$ perturbative regime

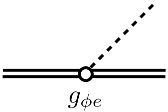
$S_{fi} \sim$ 

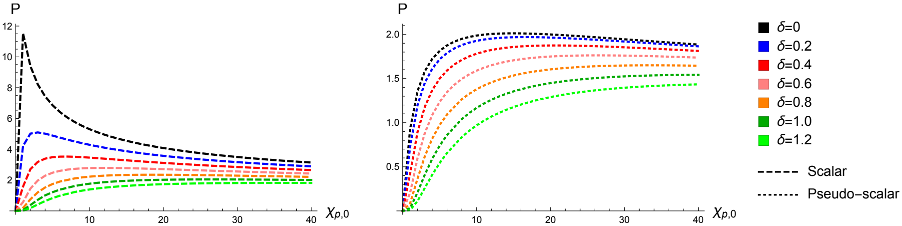


$$g_{\phi e} = 1,\ \xi = 0.1,\ \varkappa^0 = 2.33\,\text{eV},\ \Phi = 100\ \ (16\ \text{cycles},\ 22\,\text{fs})$$

Scalar vs Pseudoscalar production

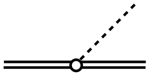
$\boxed{\xi \gg 1}$ non-perturbative regime

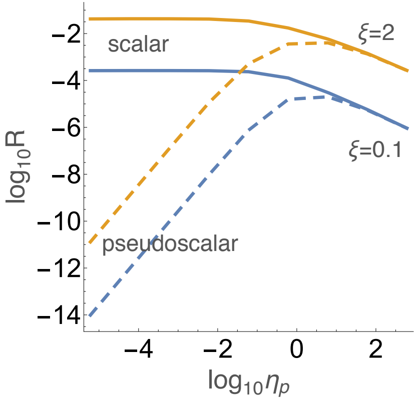




Scalar vs Pseudoscalar production

$\boxed{\xi \sim 1}$ all-order regime





$g_{\phi e} = 1, m_\phi = 1\,\mathrm{meV}$

Scalar vs Pseudoscalar production

$$\text{Scalar:} \quad \overline{\psi}\psi\phi \sim \left[\overline{\psi}_L\psi_L + \overline{\psi}_R\psi_R\right]\phi$$

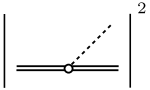
$$\text{Pseudoscalar:} \quad \overline{\psi}\gamma^5\psi\phi \sim \left[\overline{\psi}_L\psi_L - \overline{\psi}_R\psi_R\right]\phi$$

$$\eta = \frac{\hbar\varkappa\cdot p}{mc^2}; \qquad \hbar \to 0 \quad \Rightarrow \quad \eta \to 0$$

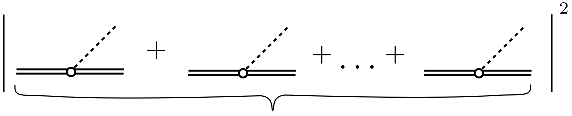
Low light-front momentum = classical limit = pseudoscalar suppression

Coherent enhancements (scalars)

$P_1 \quad \sim$



$P_N \quad \sim$

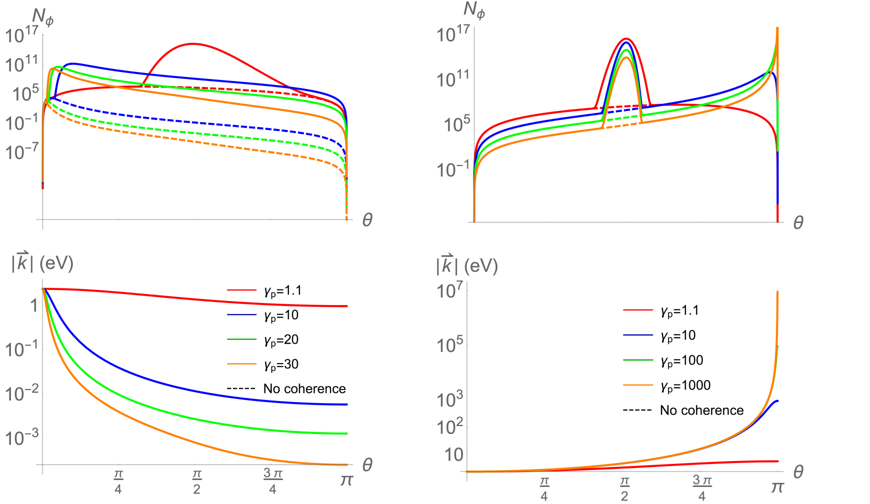


$$P_N \quad \sim \quad \left|P_1\right| \left|e^{ik_1\cdot x} + e^{ik_2\cdot x} + \dots e^{ik_N\cdot x}\right|^2 \begin{cases} N\,P_1 & \text{if } \lambda_i \ll L_{\rm bunch} \\ N^2\,P_1 & \text{if } \lambda_i \gg L_{\rm bunch} \end{cases}$$

e.g. FIREFLY, 5 μm coherently emission, $L_{\rm bunch} = 600\,\mu$m.

Coherence enhancements (scalars)

Tail-on collision: Head-on collision:



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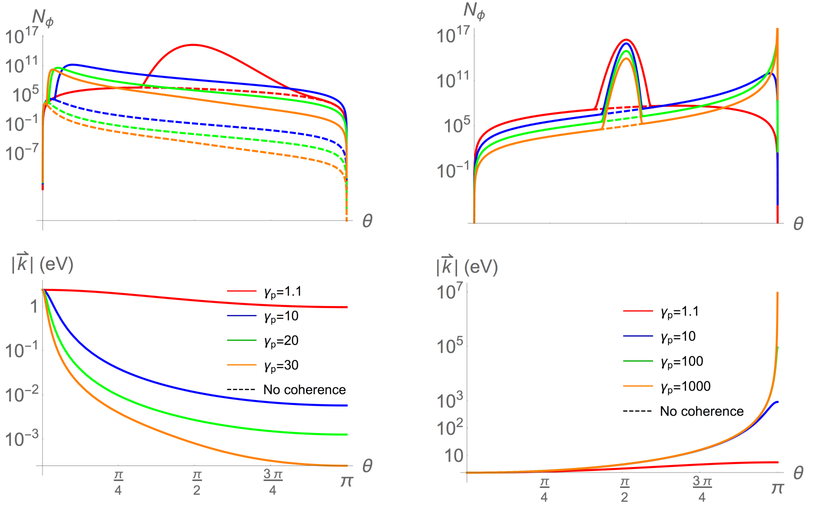

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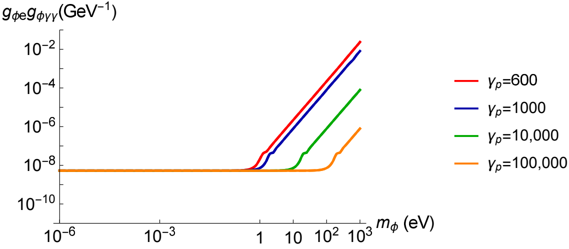
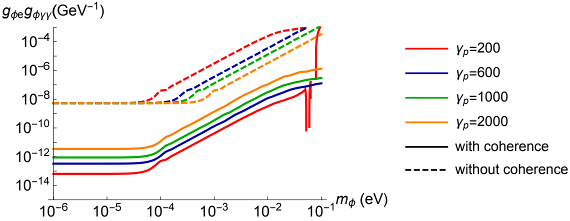
Mass reach enhancements (scalars)





$$10^{10}\ e^-\ \text{in}\ 10\,\mu\text{m};\quad \xi = 0.1\ (@1\,\text{Hz})$$

$$B = 5\,\text{T};\quad L = 4.21\,\text{m};\quad n_b = 10^{-4}\,\text{s};\quad 100\,\text{hours}$$

Conclusion: ALP e^--laser collisions

- − Number of "seed" particles lower than in LSW experiments
- − Pseudoscalar (axion) production only possible at high energy
- + Coherence effects can drastically enhance low-energy scalar ALP production
- + Competitive lab-bounds can be put on heavier $m_\phi > 1\,\mathrm{eV}$ ALPs
- + Relatively unexplored BSM production mechanism, possible further enhancements

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Plymouth SFQED Group:
2 × 24-month postdoc positions

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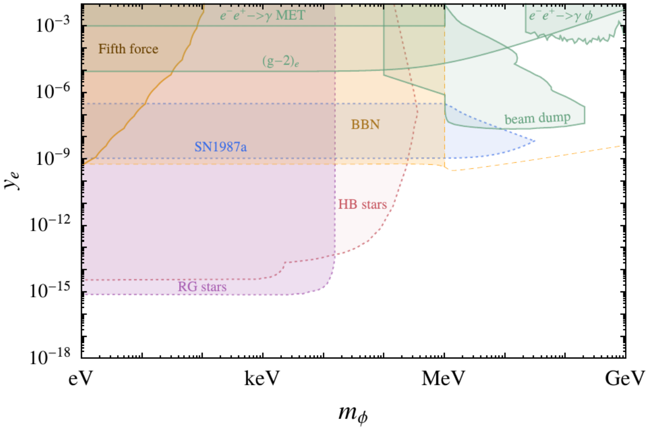
a.ilderton@plymouth.ac.uk

B. M. Dillon and **BK**, (to appear) (2018)

BK, PLB **782**, 737-743 (2018) [arXiv:1802.07507]

B. M. Dillon and **BK**, EPJC (to appear) (2018) [arXiv:1802.07498]

$g_{\phi e}$ bounds (scalars)



S. Knapen, T. Lin and K. M. Zurek, Phys. Rev. D **96**, 115021 (2017)

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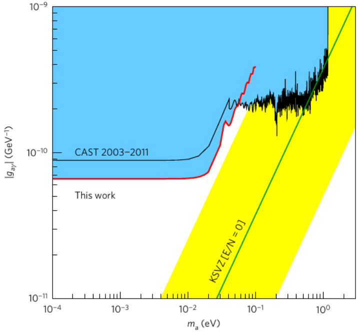
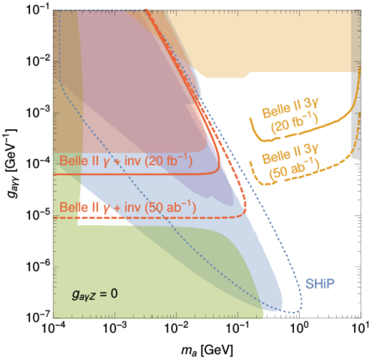
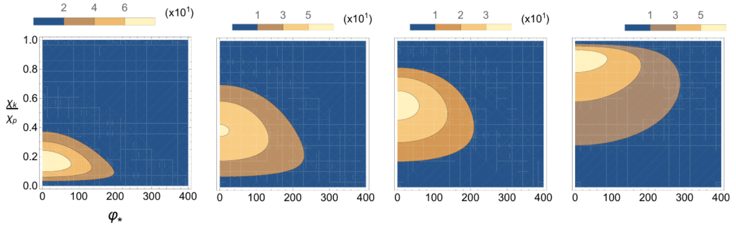


CAST, Nature Phys. **13**, 584-590 (2017)



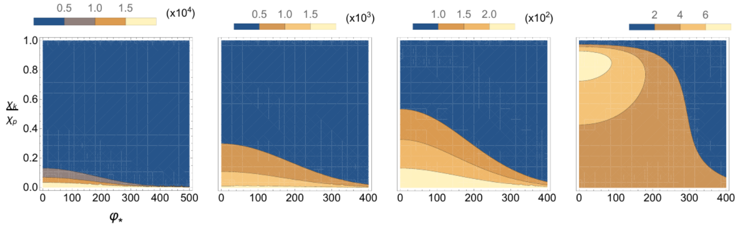
M. J. Dolan *et al.*, JHEP **12**, 94 (2017)

Spectra



(a) $\chi_{p,0} = 0.1$ (b) $\chi_{p,0} = 0.4$ (c) $\chi_{p,0} = 1$ (d) $\chi_{p,0} = 10$

Pseudoscalar spectra, CCF



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Scalar spectra, CCF