Two-beam laser photon merging

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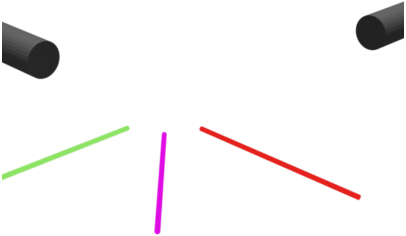
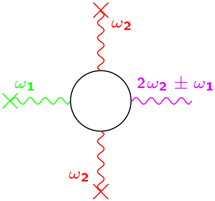




+ Unrivaled emission direction and energy of merged photons
− Suppressed compared to elastic processes

- Macroscopic laser fields stimulate photon emission
- At one-loop order for locally constant, weak fields

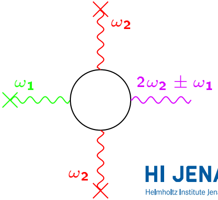
Transition amplitude

$$S_{(p)}(\mathrm{k}) = \langle \gamma_p(\mathrm{k})| \int \mathrm{d}^4x\, f^{\mu\nu}(x) \frac{\partial \mathcal{L}_{HE}^{(1)}}{\partial F^{\mu\nu}}(x) |0\rangle$$

Differential number of merged photons

$$\mathrm{d}^3N = \sum_p \frac{\mathrm{d}^3k}{(2\pi)^3} |\mathcal{S}_{(p)}(\mathrm{k})|^2$$

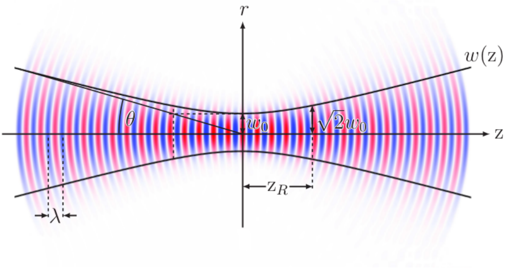
- Restrict ourselves to
  - laser 1 coupling once, laser 2 coupling twice
  - inelastic scattering (explicitly $k \approx 2\omega_2 + \omega_1$)



D. Galtsov, V. Skobelev, Phys. Lett. B 36, 238 (1971)
F. Karbstein, R. Shaisultanov, Phys. Rev. D 91, no. 11, 113002 (2015)

Formalism

Laser beam modelling



Karbstein et al. Phys.Rev. D91 (2015) no.8

Gaussian beam (paraxial approx., $z_R \to \infty$)

$$\mathcal{E}_b(x) = \frac{2}{w_{0,b}} \left(\frac{2}{\pi}\right)^{\frac{3}{4}} \left(\frac{W_b}{\tau_b}\right)^{\frac{1}{2}} \mathrm{e}^{-\left(\frac{\vec{x}\cdot\hat{\vec{\kappa}}_b - t}{\tau_b/2}\right)^2} \mathrm{e}^{-\left(\frac{\vec{x} - \vec{x}\cdot\hat{\vec{\kappa}}_b}{w_{0,b}}\right)^2} \cos\{\omega(\vec{x}\cdot\hat{\vec{\kappa}}_b - t)\}$$

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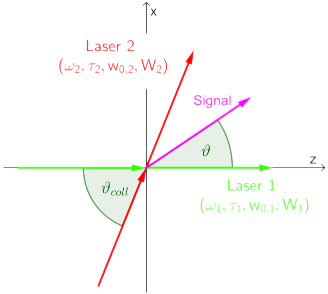
- Analytical expression for $\dfrac{\mathrm{d}^2 N^{\mathrm{merge}}}{\mathrm{d}\varphi \mathrm{d}\cos\vartheta}$
  - → Total number $N(\vartheta_{\mathrm{coll}})$?
  - → Best parameters?
  - → Optimal $\vartheta_{\mathrm{coll}}$?
  - → Main emission direction?
  - → $1/e^2$ width?



- Approximate solutions from
  - → plane wave considerations
  - → maximizing the exponent

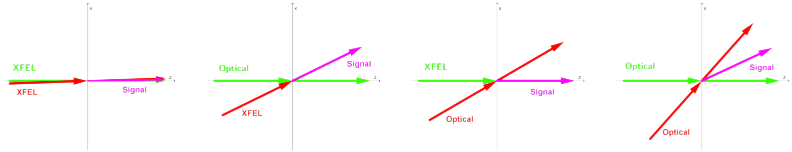
$\Rightarrow$ Numerical analysis (for now)

Test parameters

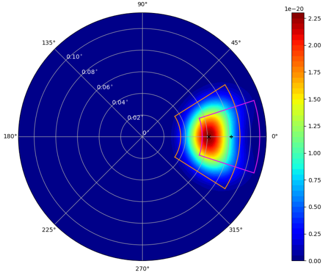
	ω [eV]	τ [fs]	w_0 [nm]	W [J]	R [Hz]
XFEL	9835	107	49.4	2.4×10^{-3}	27000
Optical	1.55	20	800	200	1

Optimal collision geometry

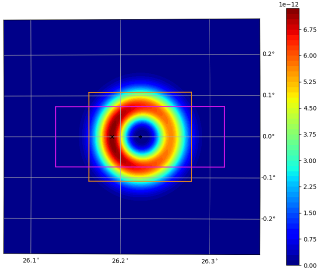
	XFEL/XFEL	Opt./XFEL	XFEL/Opt.	Opt./Opt.
$\vartheta_{\mathrm{coll}}^{\max}$	0.12°	26.22°	30.29°	48.44°
$\vartheta^{\max}$	0.06°	26.19°	0.005°	25.1°



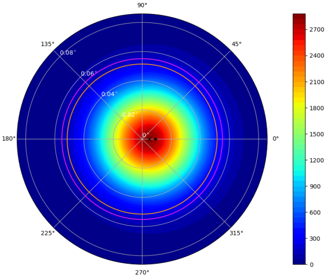
XFEL/XFEL



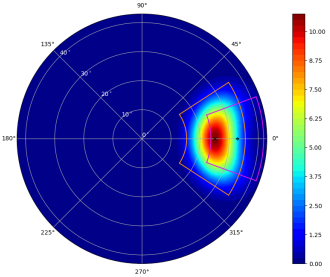
Optical/XFEL



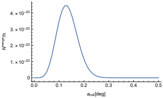
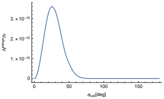
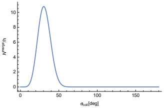
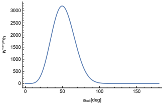
XFEL/Optical



Optical/Optical



Total number of merged photons

	XFEL/XFEL	Opt./XFEL	XFEL/Opt.	Opt./Opt.
$\vartheta_{\mathrm{coll}}^{\mathrm{max}}$	$0.12°$	$26.22°$	$30.29°$	$48.44°$
θ_{max}	$32.2°$	$0.11°$	$0.05°$	$33.1°$
$N_{\mathrm{max}}^{\mathrm{merge}}$/shot	1.2×10^{-26}	1.1×10^{-17}	2.9×10^{-3}	0.86
$N_{\mathrm{max}}^{\mathrm{merge}}$/h	1.2×10^{-18}	4.1×10^{-14}	10.6	3100
				

- With $k \approx 2\omega_1 + \omega_2$ contribution: $N_{\mathrm{max,total}}^{\mathrm{merge}} \approx 2N_{\mathrm{max}}^{\mathrm{merge}}$ for $\omega_1 = \omega_2$

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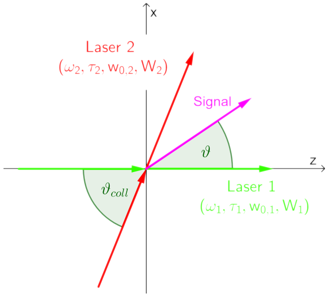
Summary

Two-beam laser photon merging

- Simple setup
    - (only) two laser pulses
    - optimized collision angle



- Promising results, especially for two high-intensity optical lasers ($N^{\mathrm{merge}}_{\mathrm{max,total}} \approx 2 \times 3100$ per hour)

- Open issues:
    - Analytical estimates for $\vartheta^{\mathrm{max}}_{\mathrm{coll}}$, $N^{\mathrm{merge}}(\vartheta_{\mathrm{coll}})$, parameter dependency,...
    - Finite Rayleigh length z_R
    - Effects of focal offsets etc.
    - Experimentally realizable arrangements
    - ...

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