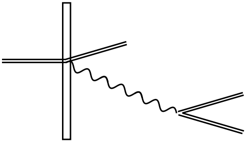
Simple Pair Creation Approximation for LUXE

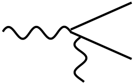
LUXE-meeting
21-05-2019



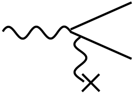
Pair Creation: Physics

$$\underbrace{\xi = \frac{m}{\omega}\frac{E}{E_{\mathrm{Q}}} \equiv a_0;}_{\text{Field Parameter}} \qquad \underbrace{\eta_\gamma = \frac{k \cdot l}{m^2}}_{\text{Energy parameter}}$$

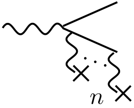
$$(\chi = \xi\eta)$$



$\mathsf{P} \sim \alpha^2$ $\left(\alpha \approx \frac{1}{137}\right)$

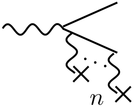


$\mathsf{P} \sim \alpha\xi^2$



$\mathsf{P} \sim \alpha\xi^{2n}$

Pair Creation: Physics



$$\mathrm{P} \sim \alpha \xi^{2n}$$

$$k^\mu + n l^\mu = \underbrace{P^\mu + Q^\mu}_{\text{quasimomenta}}$$

$$P^2 = m_*^2 = \underbrace{m^2(1 + u_{\text{pol.}}\xi^2)}_{\text{effective mass (squared)}}$$

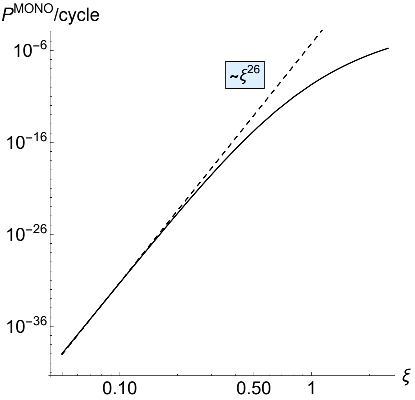
linear polarisation: $u_{\text{pol.}} = 0.5$; circular polarisation: $u_{\text{pol.}} = 1$;

$$n \geq \underbrace{\frac{2(1+\xi^2)}{\eta_\gamma}}_{\text{threshold harmonic}}$$

$$\eta_\gamma[15\,\mathrm{GeV}] = 0.18; \quad \xi \ll 1 \quad \Rightarrow \quad n \geq 12$$

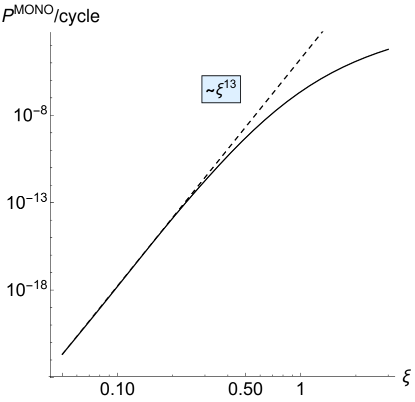
Pair Creation: Monochromatic Background

$$\xi \ll 1 \quad \Rightarrow \quad \mathsf{P} \sim \alpha\xi^{\frac{4(1+\xi^2)}{\eta}}, \alpha\xi^{2\left(\frac{2(1+\xi^2)}{\eta}+1\right)}$$



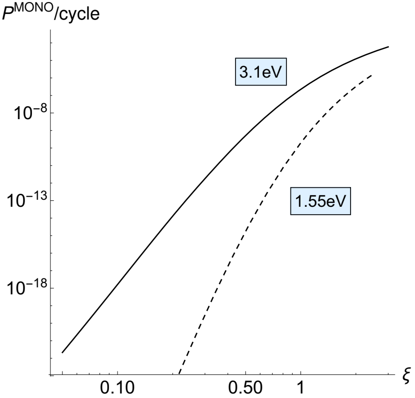
$\eta_\gamma[15\,\mathrm{GeV}] = 0.18; \quad \omega_l = 1.55\,\mathrm{eV}$

Pair Creation: Monochromatic Background



$\eta_\gamma[15\,\mathrm{GeV}] = 0.36; \quad \omega_l = 3.1\,\mathrm{eV}; \quad \xi \to \frac{\xi}{2}$

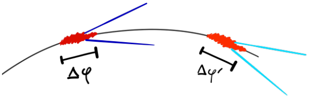
Pair Creation: Monochromatic Background



$$\xi < \sqrt{\frac{1}{2}} \approx 0.71 \quad \Rightarrow \quad \mathsf{P}_{3.1\,\mathrm{eV}} > \mathsf{P}_{1.55\,\mathrm{eV}}$$

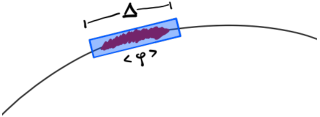
Locally-Constant-Field-Approximation (LCFA)

$$\mathsf{P} \quad \sim \quad \left| \int d^4x \; \mathcal{L}(x) \right|^2$$



$$\mathsf{P} \quad \sim \quad \int d\varphi \, d\varphi' \; \mathsf{I}(\varphi, \varphi')$$

$$\mathsf{P} \quad \sim \quad \int d\langle\varphi\rangle \, d\Delta \; \mathsf{I}\left(\langle\varphi\rangle + \frac{\Delta}{2\xi}, \langle\varphi\rangle - \frac{\Delta}{2\xi}\right)$$



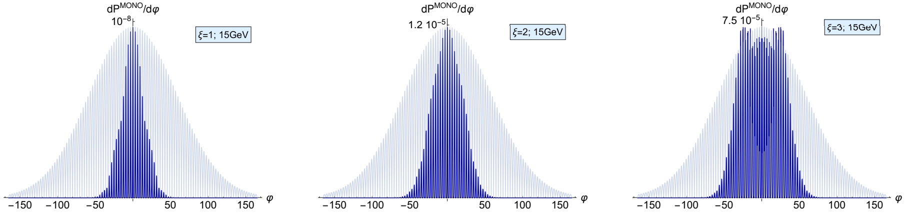
$$\mathsf{P} \quad \overset{\color{red}{\xi \gg 1}}{\sim} \quad \underbrace{\int d\langle\varphi\rangle \, \frac{d\mathsf{P}^{\text{const.}}[\chi(\langle\varphi\rangle)]}{d\langle\varphi\rangle}}_{\text{“Locally Constant Field Approximation”}}$$

The standard LCFA approach does not work for LUXE stage 0 parameters

Instantaneous Monochromatic Approximation

$$R^{\text{MONO}}[\xi, \eta_\gamma] \to \int d\varphi \; R^{\text{MONO}}[\xi(\varphi), \eta_\gamma]$$

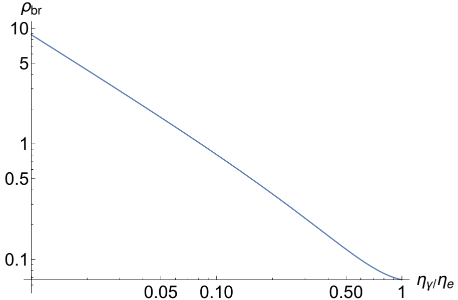
"instantaneous approximation"



35 fs Gaussian Pulse

Bremsstrahlung

$$\int d\varphi \; R^{\text{MONO}}[\xi(\varphi), \eta] \to \int d\eta \int d\varphi \; \rho_\gamma(\eta) \, R^{\text{MONO}}[\xi(\varphi), \eta]$$

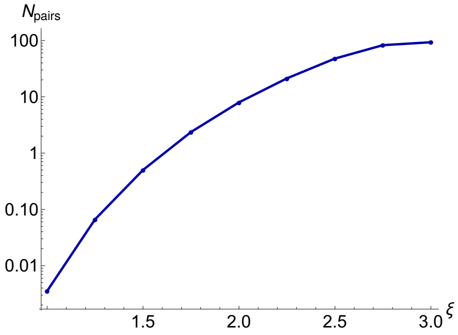


$$\rho_\gamma \approx \frac{1}{\eta_\gamma} \frac{L}{L_{\text{rad.}}} \left[\frac{4}{3} \left(1 - \frac{\eta_\gamma}{\eta_p} \right) + \left(\frac{\eta_\gamma}{\eta_p} \right)^2 \right]$$

“thin target” & “complete screening” & forward-scattered

Colliding photon beam

$$\int d\psi \int d\eta \int d\varphi \; n_\gamma(\psi - \varphi)\rho_\gamma(\eta)\, R^{\mathrm{MONO}}[\xi(\varphi+\psi), \eta]$$



e.g. $6 \times 10^9\, e^-$s, $35\,\mu$m laser pulse, $35\,\mu$m photon pulse, head-on, 3% overlap

Approximations

$$\xi = 2, \quad p^0 = 15\,\mathrm{GeV}, \quad N_e = 6 \times 10^9, \quad \Phi = \Phi[35\,\mathrm{fs}], \quad \theta = 17^\circ$$

Infinite wave train:	$= 1.7 \times 10^6$
Instantaneous approximation:	$= 2.8 \times 10^5$
Bremsstrahlung:	$= 490$
Colliding beams:	$= 190$
Overlap @ $5\,\mathrm{m}$, $\dfrac{w_\gamma}{w_{\mathrm{laser}}} \approx 0.03$:	$= 5.8$
Jitter, lag, crossing angle, focal profile, etc.	< 5.8

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Conclusions

$\boxed{\pm}$ At $\xi = O(1)$, pair-creation estimates sensitive to resolution of:
i) laser pulse; ii) focussing; iii) photon spectra, etc.

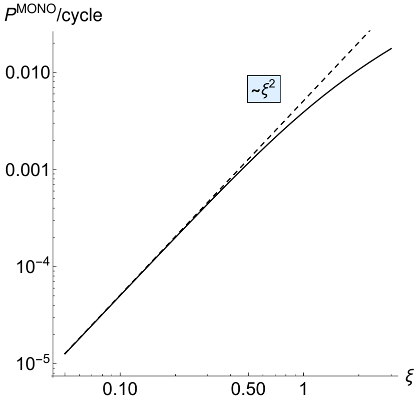
$\boxed{+}$ We can improve/benchmark the instantaneous approximation used in codes (underway).

$\boxed{-}$ Maybe requires some thought how to scan "multiphoton" range ($\xi \lesssim 0.5$)?

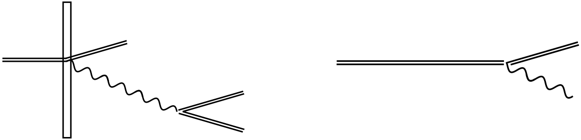
$\boxed{+}$ Still potential improvements to explore:
polarisation of photons, background and frequency-doubling.

- Advantage to design experiment where theory works "well" i.e. the more monochromatic, the better.

Nonlinear Compton: "all-order" (nonperturbative at small coupling)



$\eta_\gamma[15\,\text{GeV}] = 0.18; \quad \omega_l = 1.55\,\text{eV}$



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