Near or Far Detectors? Searching for Long-Lived ALPs at the ILC

Schäfer, Tillinger, Westhoff; 2022

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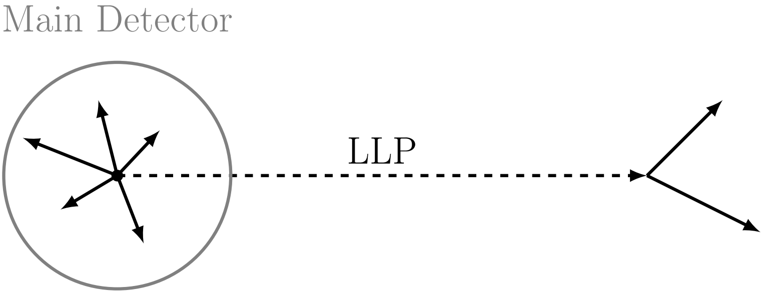
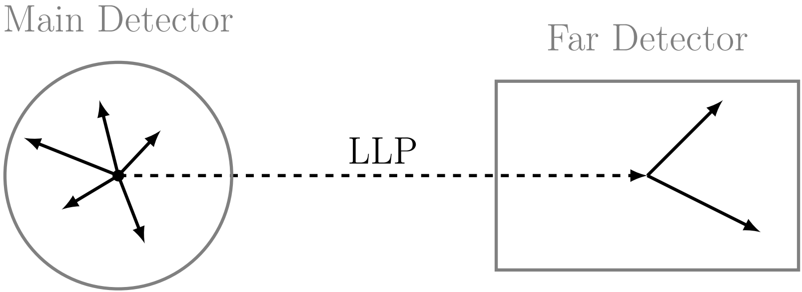
DISCRETE 2022, November 8

Heidelberg University



Main Detector
LLP


Main Detector
Far Detector
LLP

Axion-Like Particles at the ILC

ALP Model

Above electroweak scale:

$$\mathcal{L}_{\text{eff}}(\mu > \mu_w) = \frac{c_{\ell\ell}}{2}\,\frac{\partial^\mu a}{f_a}\left(\bar{\ell}\gamma_\mu\gamma_5\ell\right) + c_{WW}\,\frac{\alpha}{4\pi s_w^2}\,\frac{a}{f_a}\,W^\tau_{\mu\nu}\widetilde{W}^{\mu\nu}_\tau$$

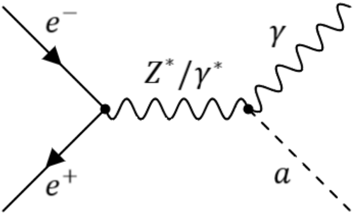
Below electroweak scale:

$$\mathcal{L}_{\text{eff}}(\mu < \mu_w) \supset \frac{\alpha}{4\pi}\frac{a}{f_a}\left(c_{\gamma\gamma}\,F_{\mu\nu}\widetilde{F}^{\mu\nu} + 2\frac{c_{\gamma Z}}{s_w c_w}F_{\mu\nu}\widetilde{Z}^{\mu\nu} + \frac{c_{ZZ}}{s_w^2 c_w^2}Z_{\mu\nu}\widetilde{Z}^{\mu\nu}\right),$$

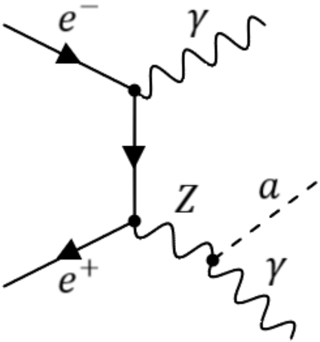
$$c_{\gamma\gamma} = c_{WW}, \qquad c_{\gamma Z} = c_w^2\,c_{WW}, \qquad c_{ZZ} = c_w^4\,c_{WW}$$

Georgi, Kaplan, Randall; 1986; Phys.Lett.B 169

ALP Production at the ILC

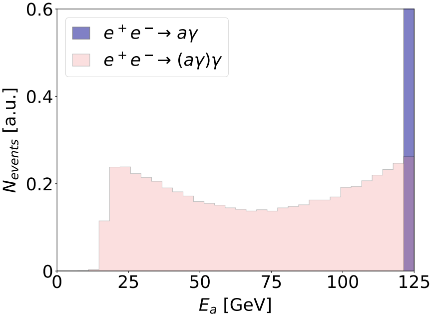


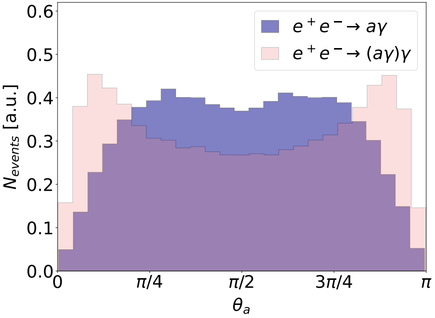
$e^+e^- \to a\gamma$



$e^+e^- \to Z\gamma \to (a\gamma)\gamma$

Kinematic Distributions





$$e^+e^- \to a\gamma : \quad (\beta\gamma)_a \approx E/m_a \approx 400 \quad \text{(central)}$$
$$e^+e^- \to (a\gamma)\gamma : \quad 60 \lesssim (\beta\gamma)_a \lesssim 400 \quad \text{(forward)}$$

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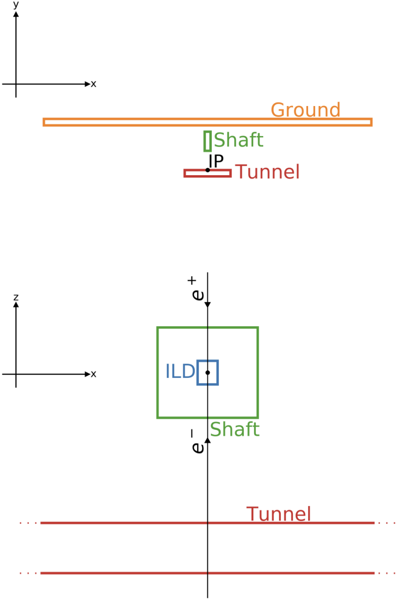
Far Detectors at the ILC

Far Detector Geometries



- Shaft: $(18 \times 30 \times 18)\,\mathrm{m}$
- Tunnel: $(140 \times 10 \times 10)\,\mathrm{m}$
- Ground: $(1000 \times 10 \times 1000)\,\mathrm{m}$

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Methodology

Setup

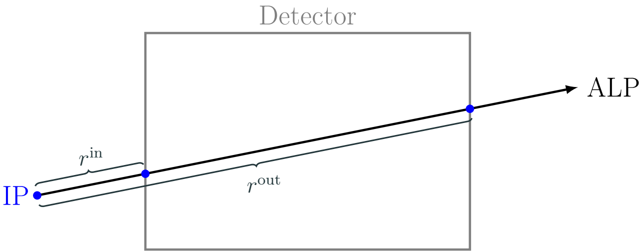
- **ILC:** $\sqrt{s} = 250\,\text{GeV}$ and $\mathcal{L}_{\text{int}} = 250\,\text{fb}^{-1}$
- **ALPs:** $m_a = 300\,\text{MeV}$
- **zero background** and **100% detection efficiency** assumption
- **event simulations** from `MadGraph5_aMC@NLO`

Calculations

Mean probability to decay in detector:

$$\mathbb{P}_a(\vec{r}_a;\tau) = \exp\left(-\frac{r_a^{\text{in}}}{\beta\gamma c\tau}\right) - \exp\left(-\frac{r_a^{\text{out}}}{\beta\gamma c\tau}\right)$$

$$\langle\mathbb{P}(\tau)\rangle = \frac{1}{N}\sum_{a=1}^{N}\mathbb{P}_a\left(\vec{r}_a;\tau\right)$$



Calculations

Number of detected ALPs:

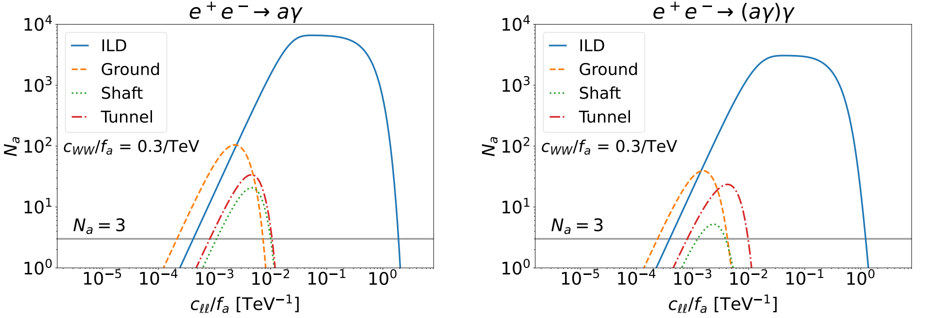
$$N_a = \mathcal{L}_{\text{int}} \times \sigma(e^+e^- \to aX) \times \langle \mathbb{P} \rangle \times \mathcal{B}_\ell$$

Exclude no-ALP hypothesis for $N_a \geq 3$ at 95% CL

$\Rightarrow$ defines sensitive region in parameter space for detectors

Analysis

ILD vs. Far Detectors



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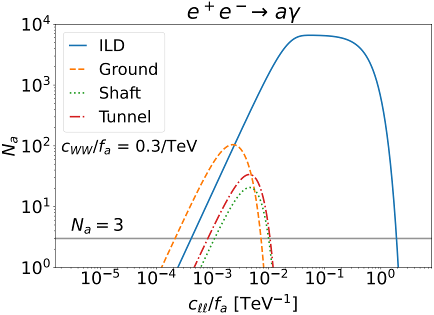
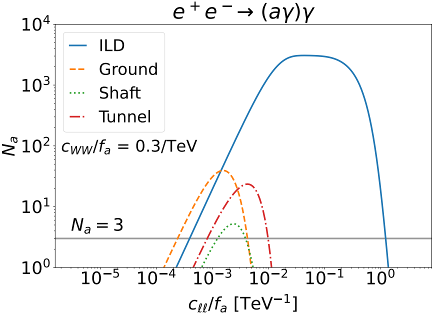
ILD vs. Far Detectors





$c_{\ell\ell}/f_a$ [10^{-4}/TeV]	ILD	Shaft	Tunnel	Ground
$e^+e^- \to a\gamma$	4.2	10.8	8.2	2.1
$e^+e^- \to (a\gamma)\gamma$	3.9	12.3	8.0	2.4

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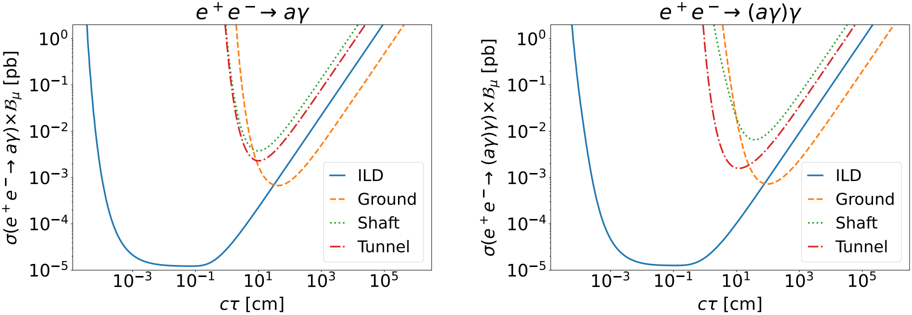
ILD vs. Far Detectors - 2D



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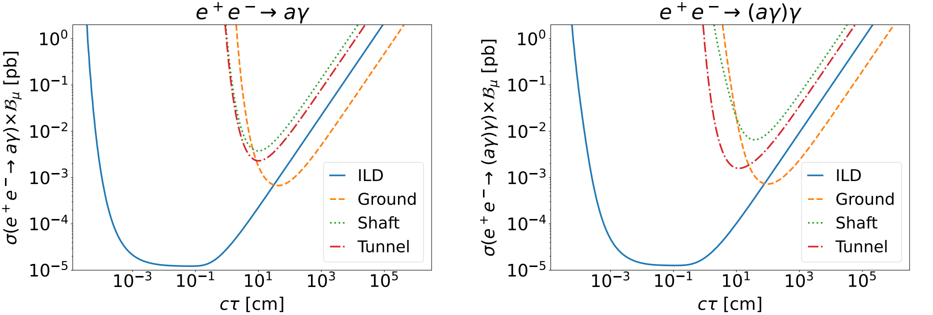
ILD vs. Far Detectors - 2D



No significant gain in sensitivity through far detectors!

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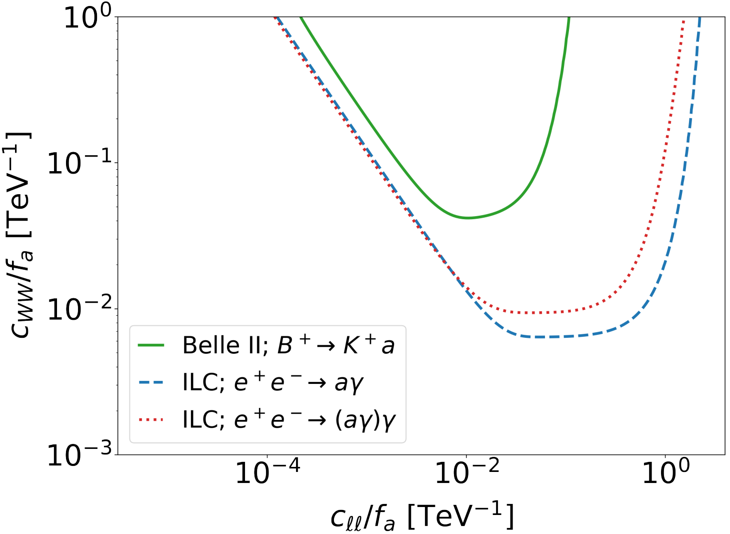
ILC vs. Belle II



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Dreyer et al.; 2021; arXiv: 2105.12962

Conclusion

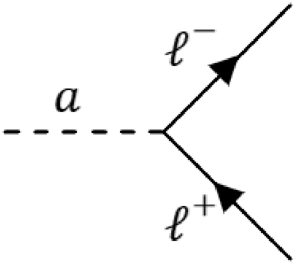
Conclusion

❶ No significant gain in sensitivity through far detectors

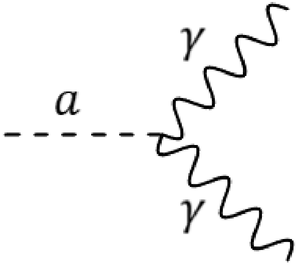
❷ ILC exceeds Belle II's sensitivity for long-lived ALPs

ILC will be excellent experiment to search for LLPs!

ALP Decay



$a \to \ell^+\ell^-$



$a \to \gamma\gamma$

$$\Gamma(a \to \ell^+\ell^-) = \frac{m_a m_\ell^2}{8\pi}\left(\frac{c_{\ell\ell}}{f_a}\right)^2\sqrt{1-\frac{4m_\ell^2}{m_a^2}}$$