Near or Far Detectors? Optimizing Long-Lived Particle Searches at Electron-Positron Colliders

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Based on [2202.11714] with F. Tillinger and S. Westhoff
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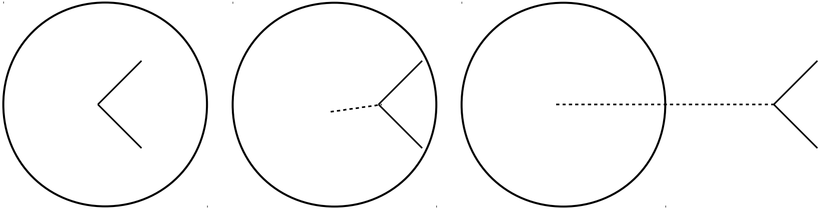
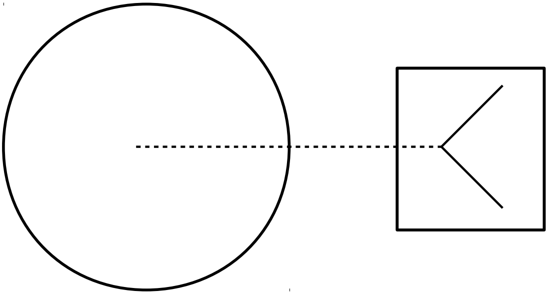
Long-lived Particles

- Non-prompt decays
- Weakly coupled new physics
  - $c\tau \propto \frac{1}{\text{coupling}^2}$
- Complementary detector signatures:
  - Prompt decays
  - Displaced decays
  - Missing energy
  - Other signatures



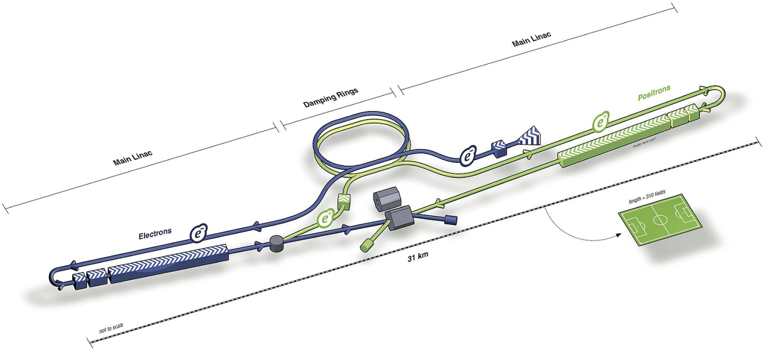
Far detectors?



- Many promising proposals, e. g.:
  - FASER @ ATLAS (built!)
  - CODEXb @ LHCb
  - MATHUSLA @ CMS
- So far “afterthoughts”, but what about future detectors?

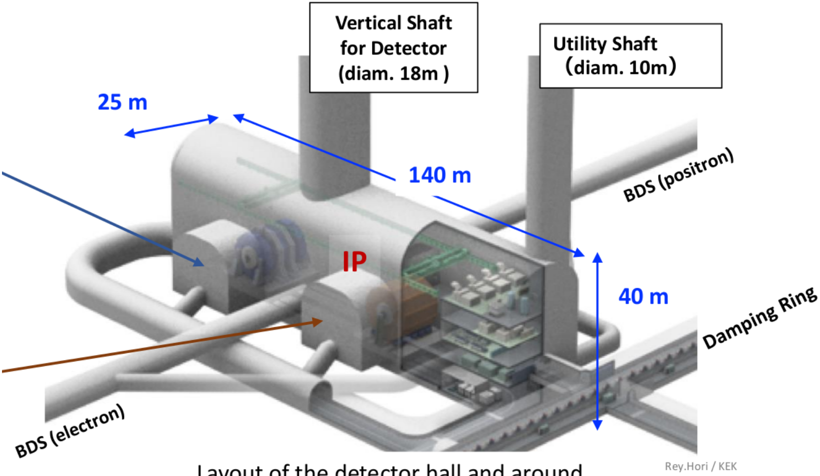
The International Linear Collider (ILC)

- e^+e^--collider with $\sqrt{s} = 250\,\text{GeV}$
- Linear collider 20+ km long
- Proposed to be built in Japan



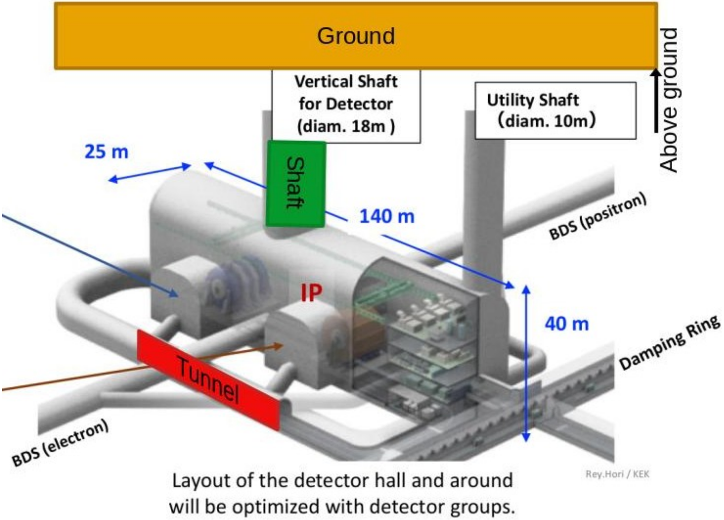
Far detector for the ILC?

- Where could we put one?

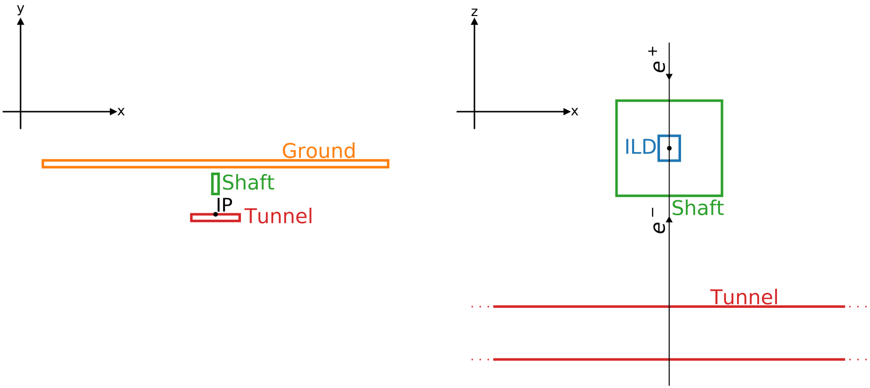


Layout of the detector hall and around
will be optimized with detector groups.

Far detector options for the ILC

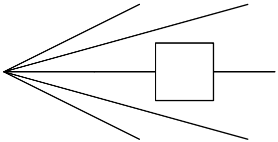


Far detector options for the ILC

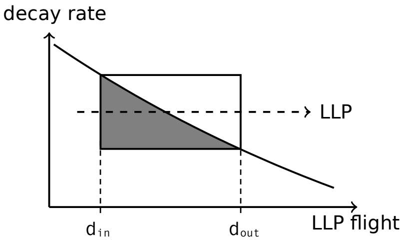


LLP sensitivity

- How many LLPs fly through a detector?



- How many decay in its volume?

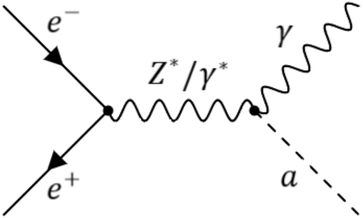


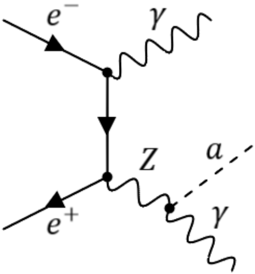
$$N_a = N_{a@e^+e^-} \times \langle \mathbb{P} \rangle \times Br(a \to \ell\ell) \quad \times \varepsilon$$

$$\langle \mathbb{P} \rangle = \frac{1}{N} \sum_i e^{-\frac{d^i_{in}}{\gamma\beta c\tau_i}} - e^{-\frac{d^i_{out}}{\gamma\beta c\tau_i}}$$

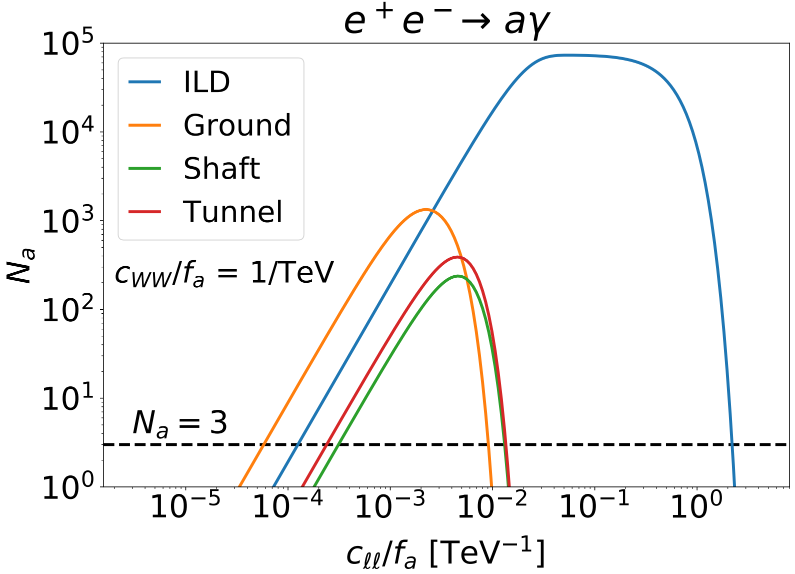
Benchmark model: ALPs

- $\mathcal{L}_{\text{eff}}(\mu > \mu_w) = \frac{c_{\ell\ell}}{2}\,\frac{\partial^\mu a}{f_a}\left(\bar{\ell}\gamma_\mu\gamma_5\ell\right) + c_{WW}\,\frac{\alpha_2}{4\pi}\,\frac{a}{f_a}\,W^\tau_{\mu\nu}\widetilde{W}^{\mu\nu}_\tau$
- $m_a \ll m_W$
- Production in $e^+e^- \to a\gamma$, $e^+e^- \to Z\gamma \to (a\gamma)\gamma$
- Decay to muons $a \to \mu\bar{\mu}$

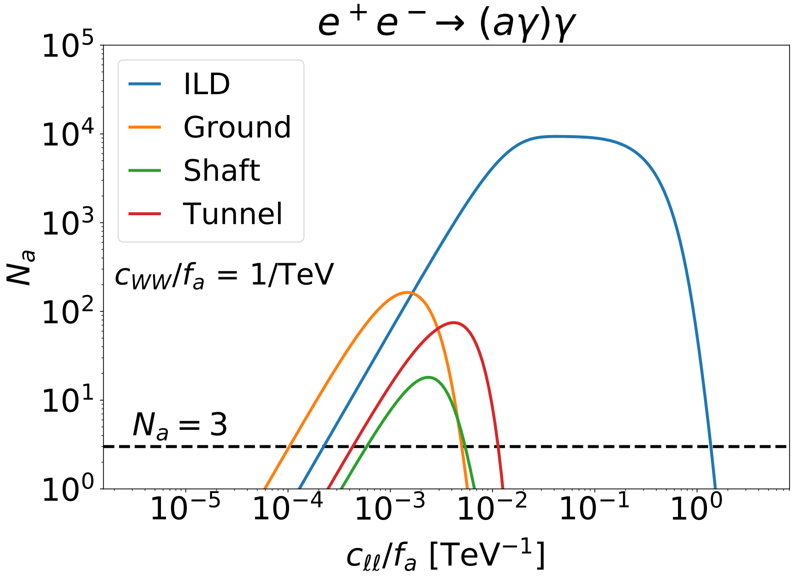




Comparing ILC and Far Detectors

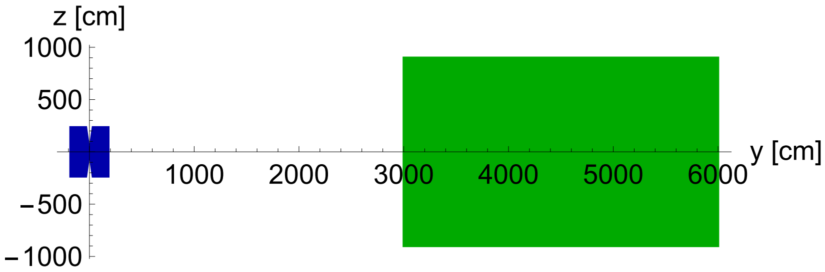


Comparing ILC and Far Detectors



Intuition for ILC vs Far Detectors

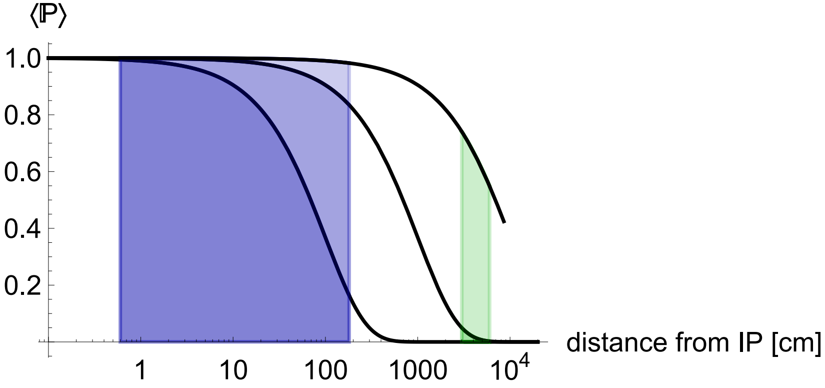
- Solid Angle contribution



  - ILD has near full solid angle Ω
  - Due to distance, realistic far detectors must have smaller Ω

Intuition for ILC vs Far Detectors

- Exponential decay contribution



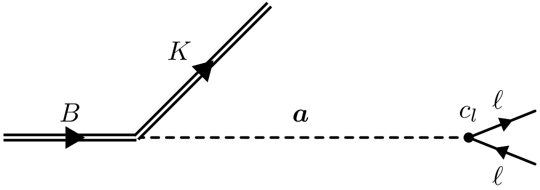
- ILD spans orders of magnitude in relative thickness $(d_{out} - d_{in})/d_{in}$
- Due to distance, $(d_{out} - d_{in}) \ll d_{in}$ for realistic far detectors

ILC vs Far Detectors

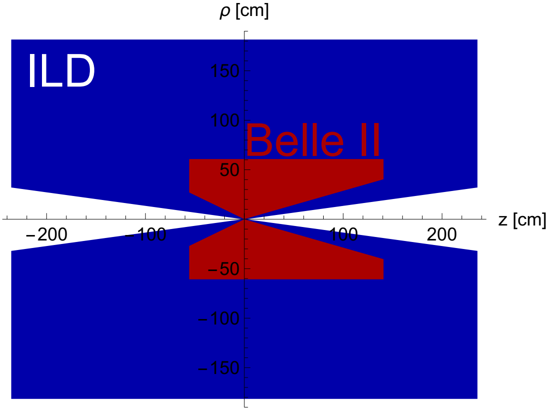
- From geometric arguments, ILD better than realistic far detectors
- There are other factors:
  - Models with preferred LLP production directions
  - Backgrounds differ strongly between detectors

Comparing ILC to Belle II

- How does ILC compare to current e^+e^-?
- Belle II @ SuperKEKB
  - Circular e^+e^--accelerator with $\sqrt{s} = 10.58\,\text{GeV}$
  - ALPs from B decays

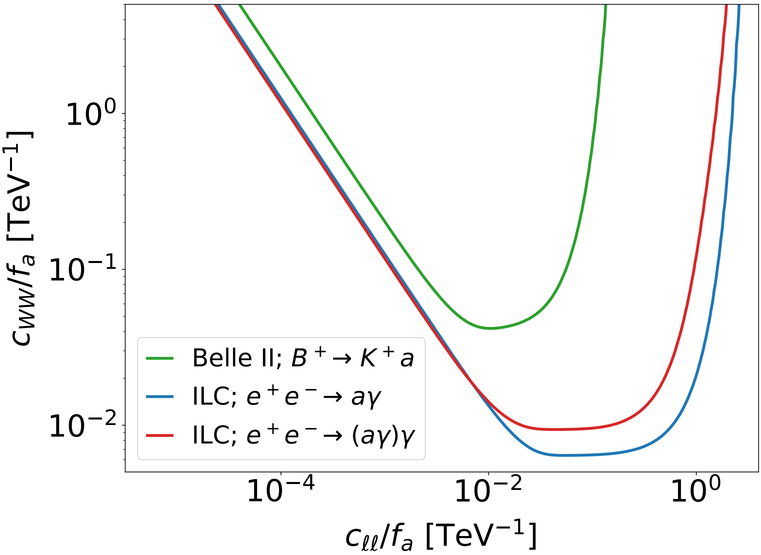


Comparing ILC to Belle II



- Boost of ALP with $m_a = 0.3\,\text{GeV}$
  - Belle II: $\langle\gamma\beta\rangle \approx 5$
  - ILD: $\langle\gamma\beta\rangle \approx 400$

Comparing ILC to Belle II

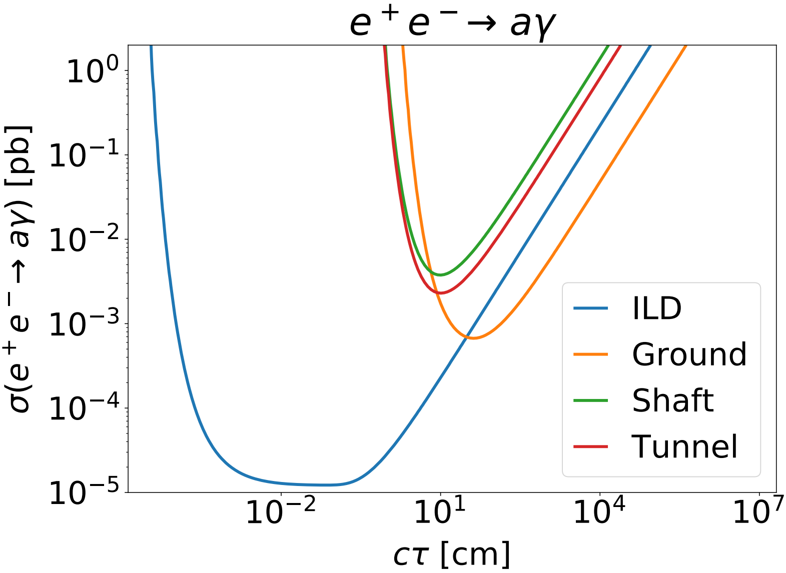


Conclusion

- Future e^+e^--colliders have great potential to look for LLPs
- Far detectors give little additional sensitivity
- Far detectors still relevant, especially if
  - LLPs produced in preferred direction
  - Background reduction better than @ main detector

Backup slides

Comparing ILC and Far Detectors



Comparing ILC and Far Detectors