Reconstruction of long-lived particles with the ILD detector at the ILC

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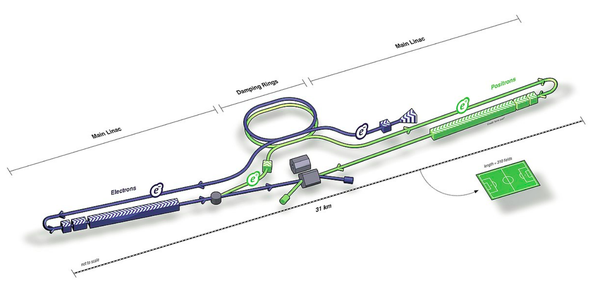
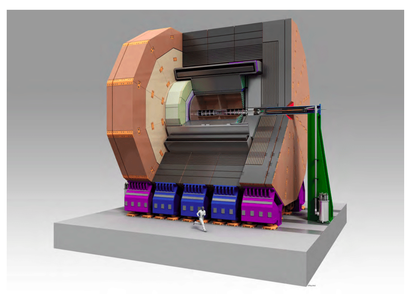
Long-lived particles (LLPs)

- Many states within the SM already have macroscopic lifetimes
- Various BSM models predict LLPs: e.g. SUSY particles, axion-like particles, heavy neutral leptons, dark photons, exotic scalars...
- Multiple searches at the LHC, but:
  → LHC is mostly sensitive to high masses and mass splittings
  → complementary region could be probed at e^+e^- colliders (small masses, mixings, mass splittings, etc.)

International Large Detector (ILD)





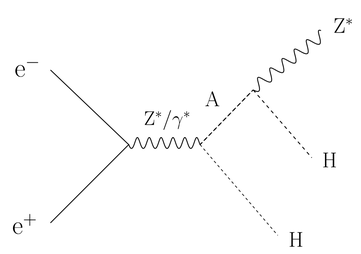
- Experiment proposed for the International e^+e^- Linear Collider (ILC)
- ILC baseline centre-of-mass energy: 250-500 GeV, possible extension to 1 TeV
- The core of ILD tracking systems is a time projection chamber (TPC)
  → almost continous tracking
  → promissing for the LLP studies

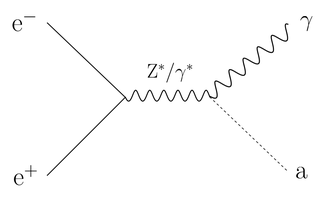
Test signal scenarios

Most challenging case: small-boost, low-p_T track pair, not pointing towards IP

Inert Doublet Model (IDM) as a first test scenario:

- four additional scalars, incl. two neutral: A (heavier) and H (lighter; stable dark matter candidate)
- A can be long-lived for small mass splittings between A and H
- benchmark scenarios: $\mathbf{m_A = 155\ GeV,\ c\tau = 1\ m,\ m_A - m_H = 1, 2, 3, 5\ GeV}$
- dominant decay: $A \to HZ^*$; $Z^* \to \mu\mu$ decays used for vertex reconstruction studies





Exactly opposite case: large-boost, high-p_T track pair, pointing towards IP

Axion-like particle (ALP) production as a second test scenario:

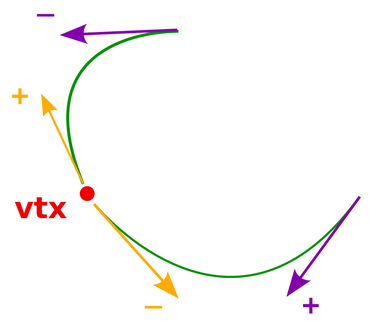
- additional pseudoscalar, coupled to the SM via dimension-6 operators
- ALPs can be long-lived for masses of the order of 1 GeV or smaller
- benchmark scenarios: $\mathbf{m_a = 0.3, 1, 3, 10\ GeV}$ and $\mathbf{c\tau = 10 \cdot m_a\ mm}$
- main production channel at ILC: $e^+e^- \to a\gamma$; $a \to \mu\mu$ decays used for vertex reconstruction studies

Vertex reconstruction

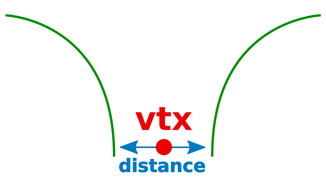
Strategy

Approach as simple and general as possible, to cover wide range of possible scenarios

- Consider tracks in pairs
- As the TPC is not sensitive to track direction:
  → use both track direction (charge) hypothesis for vertex finding
  → consider **opposite-charge** track pairs only
  → select pair with **closest starting points**



- Reconstruct vertex **in between points of closest approach** of helices
- Require that distance between helices is smaller than 25 mm



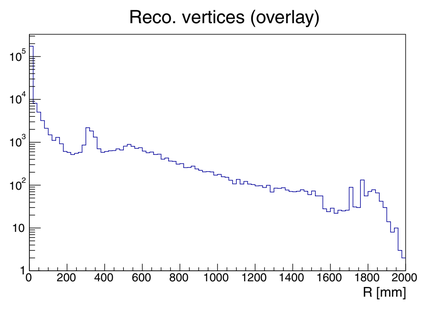
Overlay background

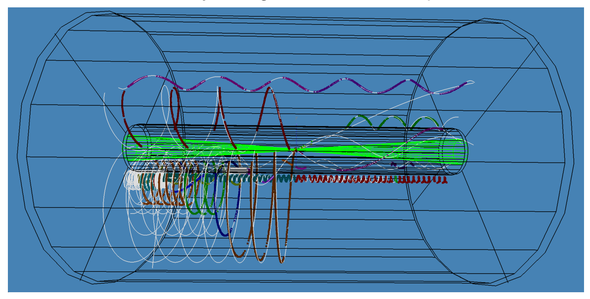
The e^+e^- beams are a source of photons, whose interactions produce:
- **low-pT hadrons**
- **e^+e^- pairs**

These processes can occur simultanously to physics event (and overlay on it)

With **~1.05** ($\gamma\gamma \to$ **had.**) and **~1** ($\mathbf{e^+e^-}$ **pair**) events expected per bunch crossing, they can constitute background themselves

→ have to be taken into account in the low-p_T LLP searches as separate background





Standard selection: only decays in the **TPC volume** considered; cuts based on track curvature, length, opening angle, and first hit distance to vtx

Overlay rejection:

- Overlay background **reduction** at the level of **~10^{-9} required**
- Limitted MC statistics: efficiency estimated assuming cuts are independent
- Cuts on the p_T, distance between first hits in tracks, distance between centres of helix-circles give **total rejection** at the level of **~10^9 (~10^{10})** for **$\gamma\gamma \to$ had. ($\mathbf{e^+e^-}$ pairs)**

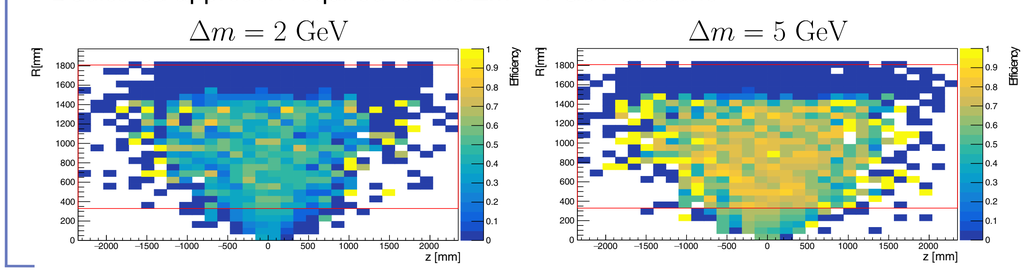
Results

Efficiency: reconstructed vertex within 30 mm from the true vertex, decays within TPC acceptance

IDM

$\Delta m = m_A - m_H$	1 GeV	2 GeV	3 GeV	5 GeV
Signal selection efficiency	3.9%	37%	52.2%	60.4%
Purity	96.4%	97.4%	98.8%	98.6%

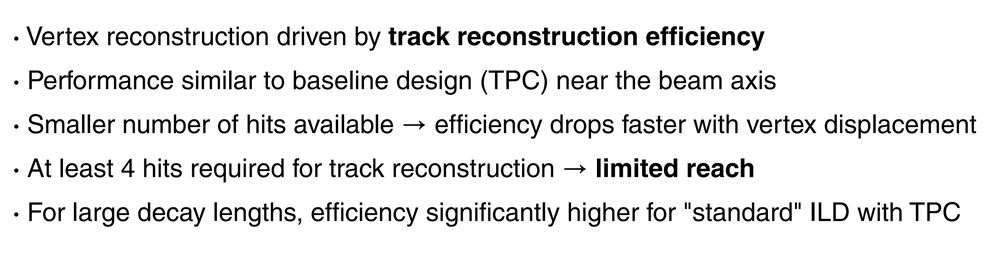
- Signal selection **efficiency depends** strongly on **the mass splitting** (Z^* virtuality)
- Dedicated approach required for the Δm = 1 GeV scenario



ALPs

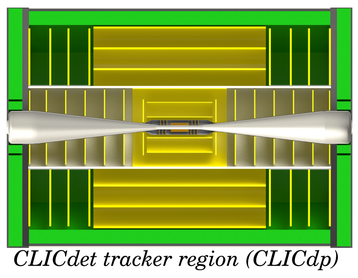
m_a	0.3 GeV	1 GeV	3 GeV	10 GeV
Signal selection efficiency	24%	54%	77%	78%
Purity	41%	78%	97%	99%

- **High efficiency** for masses of **1 GeV** and higher
- Better performance in the silicon tracker (smaller radii)

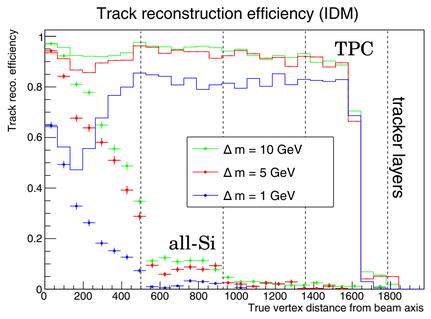


TPC vs. all-silicon tracker (IDM)

- **Alternative ILD design** with TPC replaced by a **silicon tracker** modified from the Compact Linear Collider detector (CLICdet) outer tracker design
- One barrel layer added and endcap layers spacing increased w.r.t. CLICdet
- Tracking algorithm designed for CLICdet used for reconstruction at all-silicon ILD



CLICdet tracker region (CLICdp)



- Vertex reconstruction driven by **track reconstruction efficiency**
- Performance similar to baseline design (TPC) near the beam axis
- Smaller number of hits available → efficiency drops faster with vertex displacement
- At least 4 hits required for track reconstruction → **limited reach**
- For large decay lengths, efficiency significantly higher for "standard" ILD with TPC