Uncovering Long-Lived Doubly Charged Scalars

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Based on **arXiv:2602.02308** (With Dilip Kumar Ghosh, Nandini Das, Ritesh K. Singh)

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Motivation & Framework

- **Study long-lived doubly charged scalars in the Type-II seesaw model.**
- **Focus on future lepton colliders: the International Linear Collider and a high-energy muon collider.**
- **Existing searches usually assume prompt decays; this work targets the long-lived regime.**

Type-II seesaw model & constraints

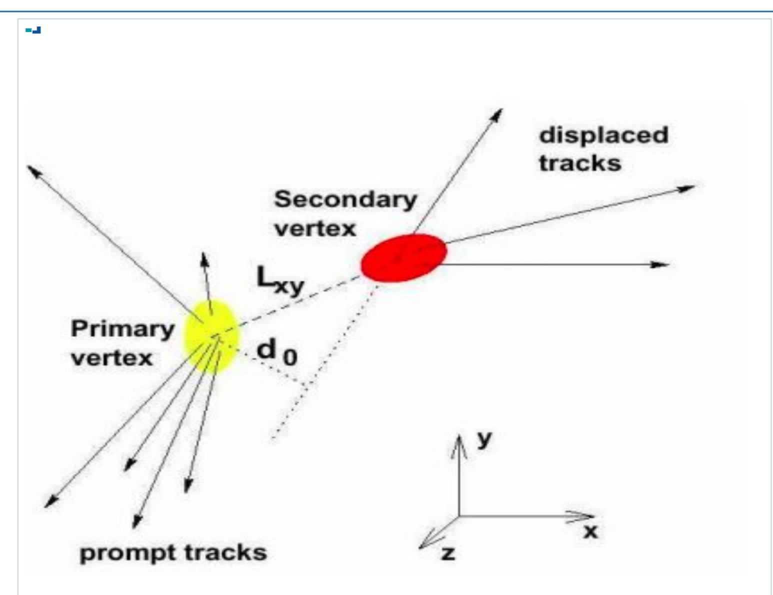
The scalar triplet gives seven physical Higgs bosons: H±±, H±, h, H and A. Key constraints: ρ parameter (v_t < 2 GeV), vacuum stability, perturbative unitarity, electroweak precision tests, Higgs diphoton signal strength and direct LEP/LHC bounds.

Prompt LHC searches do not exclude the full long-lived region.

Long-Lived Parameter Region

- **For $v_t < 10^{-4}$ GeV, H±± mainly decays to dileptons; at larger v_t, dibosons dominate.**
- **In the crossover region, H±± → W±(W±)* → W±ff′.**
- **Tuning v_t and m(H±±) makes the width very small, giving cτ ~ O(mm).**
- **An unconstrained window remains for m(H±±) = 89–200 GeV and $v_t = 10^{-4}$–10^{-3} GeV.**

Displaced-vertex signature



Why does the lifetime grow?

Near the crossover of leptonic and diboson decay modes, the total width is minimized. The result is a macroscopic proper decay length and a clean displaced-track signature.

cτ ≥ millimeters

Surviving window:
m(H±±) = 89–200 GeV
$v_t = 10^{-4}$–10^{-3} GeV

Benchmark points

BP	m(H±±) GeV	v_t GeV	cτ mm
BP1	100	9.0×10^{-4}	26.2
BP2	120	5.0×10^{-4}	8.6
BP3	180	1.6×10^{-4}	0.14

The three points span long, intermediate and short lifetimes.

Observable handles

Larger cτ produces broader displaced-impact-parameter tails. Larger m(H±±) gives sharper same-sign dimuon mass peaks. Together, d_0 and m(μ±μ±) separate the signal benchmarks.

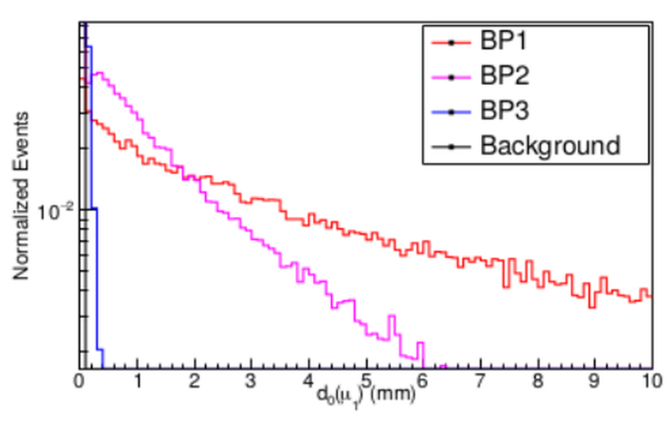
Four displaced muon tracks

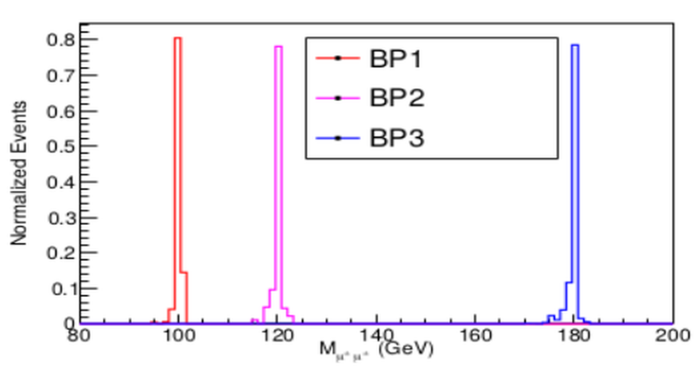
A simple $|d_0|$ > 0.1 mm cut strongly suppresses prompt backgrounds.

Displaced-track searches at future lepton colliders

ILC analysis • √s = 500 GeV

$e^+e^- \to H^{++}H^{--}$ with H±± → μ±μ±. Dominant backgrounds are diboson final states. Require four muons and displaced tracks with $|d_0|$ > 0.1 mm.





σ ILC	BP1	BP2	BP3	SM Bkgd
(fb)	12.18	7.18	0.62	0.64

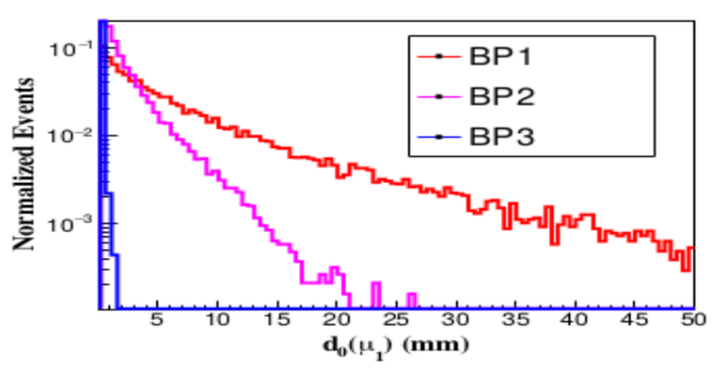
Benchmark Points	Luminosity required for 5 events after $|d_0| > 0.1$mm cut ($\mathcal{L}_5$) (fb^{-1})
BP1	1.1
BP2	2.9
BP3	1111.1

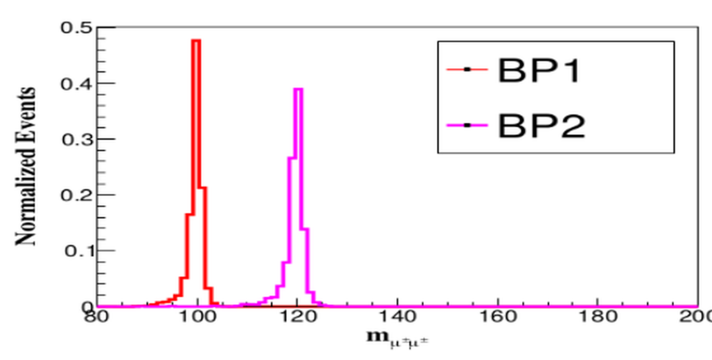
At 4 ab⁻¹ after the d_0 cut:
BP1 16,984 • BP2 7,014 • BP3 18 events

BP1 and BP2 need only a few fb⁻¹ for five displaced events; the shorter-lived BP3 is more challenging.

Muon collider analysis • √s = 10 TeV

$\mu^+\mu^- \to H^{++}H^{--}$+ missing Energy. Displaced-track information again suppresses backgrounds, probing the same long-lived scalar window at much higher energy.





σ IMCC	BP1	BP2	BP3
(fb)	0.09	0.06	0.006

Benchmark Points	$\mathcal{L}_{\rm int}$ required to see 5 events after $|d_0| > 0.1$mm cut (fb^{-1})
BP1	155
BP2	256

At 10 ab⁻¹ after the d_0 cut:
BP1 323 • BP2 195 events

Five displaced events require about 155 fb⁻¹ for BP1 and 256 fb⁻¹ for BP2.