Higgs Production in Association with a Dark-Z at Future Electron Positron Colliders

arXiv:2012.13404

Pierce Giffin[1] Ian Lewis[2] Ya-Juan Zheng[2]

[1]Department of Physics
University of California, Santa Cruz

[2]Department of Physics and Astronomy
University of Kansas

26th May, 2021

Overview

- Many proposed electron-positron colliders are suited for studies at energies higher than the hZ threshold.

Overview

- Many proposed electron-positron colliders are suited for studies at energies higher than the hZ threshold.
- We propose a new search: $e^+e^- \to hZ_d$ at energies below the hZ threshold to coincide with proposals to run these accelerators near the WW threshold and Z-pole energies.

Overview

- Many proposed electron-positron colliders are suited for studies at energies higher than the hZ threshold.
- We propose a new search: $e^+e^- \to hZ_d$ at energies below the hZ threshold to coincide with proposals to run these accelerators near the WW threshold and Z-pole energies.
- We will show that at $\sqrt{s} = 160$ GeV with 10 ab^{-1}, a search for $e^+e^- \to hZ_d$ is sensitive to $h - Z - Z_d$ couplings of $\delta \sim 8 \times 10^{-3}$ and cross sections of ~ 12 ab for Z_d masses below 1 GeV.

Proposed Colliders

- Many proposed electron colliders such as Circular Electron Positron Collider (CEPC), International Linear Collider (ILC), and Future Circular Collider in electron-positron mode (FCC-ee) propose to conduct precision measurements of EW parameters with runs at the Z-pole and/or WW-threshold.

Proposed Colliders

- Many proposed electron colliders such as Circular Electron Positron Collider (CEPC), International Linear Collider (ILC), and Future Circular Collider in electron-positron mode (FCC-ee) propose to conduct precision measurements of EW parameters with runs at the Z-pole and/or WW-threshold.
- We propose a novel search involving the 125 GeV Higgs boson that can be carried out at energies below 240 GeV: Higgs production in association with a new light gauge boson, Z_d.

Proposed Colliders

- Many proposed electron colliders such as Circular Electron Positron Collider (CEPC), International Linear Collider (ILC), and Future Circular Collider in electron-positron mode (FCC-ee) propose to conduct precision measurements of EW parameters with runs at the Z-pole and/or WW-threshold.
- We propose a novel search involving the 125 GeV Higgs boson that can be carried out at energies below 240 GeV: Higgs production in association with a new light gauge boson, Z_d.
- Such gauge bosons are theoretically well-motivated and are the so-called "dark photons" or "dark-Zs"

Model Constraints

- In general, Z_d can couple with the Higgs boson

$$\mathcal{O}_{A,X} = c_{A,X} h X_\mu Z_d^\mu \qquad X = Z, \gamma, Z_d$$

$$\mathcal{O}_{B,X} = \frac{c_{B,X}}{\Lambda} h X_{\mu\nu} Z_d^{\mu\nu} \qquad X = Z, Z_d$$

Where Λ is a new physics scale. Here, we will consider $\mathcal{O}_{A,Z}$ arising from $Z - Z_d$ mass mixing resulting in the parameterization

$$c_{A,Z} = \frac{g}{\cos\theta_W} m_{Z_d} \delta$$

- We study the process $e^+e^- \to Z^* \to hZ_d$ at $\sqrt{s} = 160$ GeV and 240 GeV.
- For simplicity, we only consider $\mathcal{O}_{A,Z}$ contributions and set $c_{B,Z} = 0$.
- To ensure that the signal can be fully constructed, we consider $Z_d \to \ell^+\ell^-$ with $\ell = e, \mu$.
- To increase rates, we consider hadronic decays of Higgs: $h \to b\bar{b}, g\bar{g}, c\bar{c}$.

Event Generation

- Utilizing **Madgraph5 _AMC@NLO** [2], we generated $\mathcal{O}_{A,Z}$ events implemented by **Feynrules**[1] with signal parameters points

$$\delta \times \sqrt{\mathbf{BR}(\mathbf{Z_d} \to \ell^+\ell^-)} = 1.5 \times 10^{-2} \qquad m_{Z_d} = 0.5 \text{ and } 1 \text{ GeV}$$

Gaussian energy smearing for quarks and gluons

$$\frac{\Delta E_j}{E_j} = \frac{0.34}{\sqrt{E/GeV}}$$

Gaussian p_T smearing for leptons

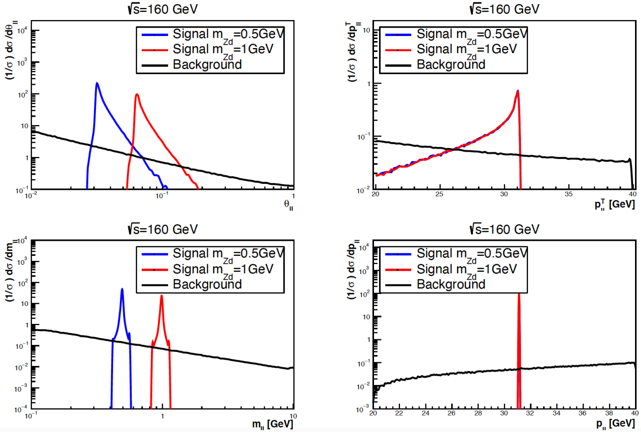
$$\Delta\left(\frac{1}{p_{T,\ell}}\right) = 2\times 10^{-5}\mathrm{GeV} \otimes \frac{10^{-3}}{p_{T,\ell}\sqrt{\sin\theta}}$$

Pre-selection cuts:

$$p_{T,j} > 20\mathrm{GeV}, \quad p_{T,\ell} > 0.5\mathrm{GeV}$$

$$|\cos\theta_{\ell,j}| < 0.98, \quad \Delta R_{i,j} > 0.005, \quad p_{T,\ell\ell} > 20\mathrm{GeV}$$

$\sqrt{s} = 160$ GeV Signal Requirements



$$30.5\text{GeV} < |\vec{p}_{\ell\ell}| < 31.5\text{GeV}$$

$$25\text{GeV} < p_{T,\ell\ell} < 31.5\text{GeV}$$

$m_{Z_d} = 1\text{GeV}$:

$$0.051 < \theta_{\ell\ell} < 0.02$$

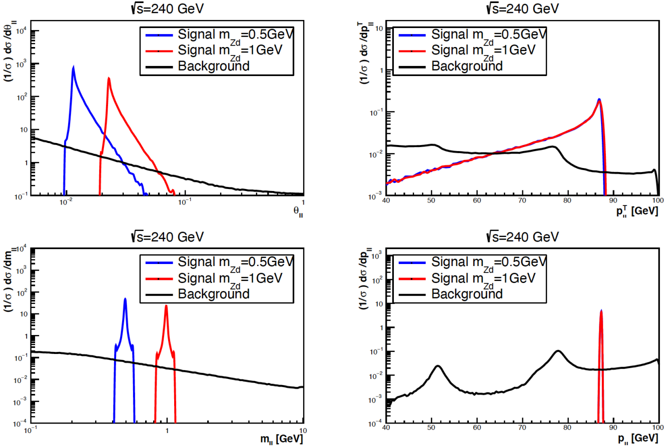
$$0.8\text{GeV} < m_{\ell\ell} < 1.25\text{GeV}$$

$m_{Z_d} = 0.5\text{GeV}$:

$$0.03 < \theta_{\ell\ell} < 0.1$$

$$0.4\text{GeV} < m_{\ell\ell} < 0.6\text{GeV}$$

$\sqrt{s} = 240$ GeV Signal Requirements



$$85\text{GeV} < |\vec{p}_{\ell\ell}| < 90\text{GeV}$$

$$60\text{GeV} < p_{T,\ell\ell} < 90\text{GeV}$$

$\underline{m_{Z_d} = 1\text{GeV}:}$

$$0.018 < \theta_{\ell\ell} < 0.0089$$

$$0.75\text{GeV} < m_{\ell\ell} < 1.25\text{GeV}$$

$\underline{m_{Z_d} = 0.5\text{GeV}:}$

$$0.009 < \theta_{\ell\ell} < 0.045$$

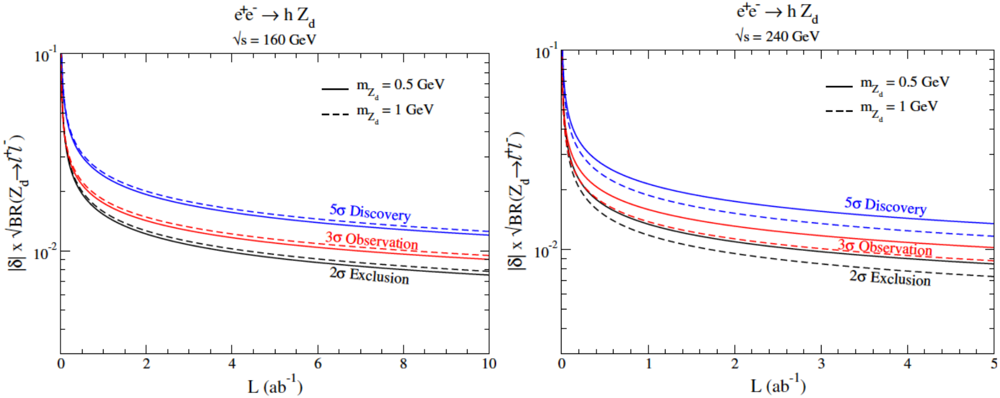
$$0.25\text{GeV} < m_{\ell\ell} < 0.75\text{GeV}$$

Requiring jet b-tagging

$\sqrt{s}$	Luminosity	m_{Z_d}	no b-tag			1 b-tag		
			Signal	Background	σ_{disc}	Signal	Background	σ_{disc}
160 GeV	10 ab^{-1}	0.5 GeV	64	180	4.6	43	23	7.3
		1 GeV	64	210	4.2	43	28	6.8
240 GeV	5 ab^{-1}	0.5 GeV	67	280	3.9	46	43	6.1
		1 GeV	67	140	5.3	46	22	7.7

Number of signal and background events, and discovery significance at both $\sqrt{s} = 160$ and 240 GeV with benchmark luminosities 10 and 5 ab^{-1}, respectively. At a b-tagging rate of 80%, 1 b-tag significantly improves the discovery significance. It was found that requiring two b-tagged jets did not help the significance.

b-tagging


$e^+e^- \to h\,Z_d$
$\sqrt{s}$ = 160 GeV
$|\delta| \times \sqrt{BR(Z_d \to \ell^+\ell^-)}$
L (ab^{-1})
m_{Z_d} = 0.5 GeV
m_{Z_d} = 1 GeV
5σ Discovery
3σ Observation
2σ Exclusion
$e^+e^- \to h\,Z_d$
$\sqrt{s}$ = 240 GeV
$|\delta| \times \sqrt{BR(Z_d \to \ell^+\ell^-)}$
L (ab^{-1})
m_{Z_d} = 0.5 GeV
m_{Z_d} = 1 GeV
5σ Discovery
3σ Observation
2σ Exclusion

b-tagging

$\sqrt{s}$	Luminosity	m_{Z_d}	$\lvert\delta\rvert \times \sqrt{\text{BR}(Z_d \to \ell^+\ell^-)}$			$\sigma(e^-e^+ \to h\,Z_d)\text{BR}(Z_d \to \ell^+\ell^-)$		
			2σ Exc.	3σ Obs.	5σ Disc.	2σ Exc.	3σ Obs.	5σ Disc.
160 GeV	10 ab^{-1}	0.5 GeV	7.5×10^{-3}	9.1×10^{-3}	1.2×10^{-2}	1.6 ab	2.3 ab	4.1 ab
		1 GeV	7.9×10^{-3}	9.5×10^{-3}	1.3×10^{-2}	1.8 ab	2.6 ab	4.5 ab
240 GeV	5 ab^{-1}	0.5 GeV	8.4×10^{-3}	1.0×10^{-2}	1.3×10^{-2}	4.3 ab	6.2 ab	11 ab
		1 GeV	7.3×10^{-3}	8.8×10^{-3}	1.2×10^{-2}	3.2 ab	4.6 ab	8.1 ab

Concluding Remarks

- Many proposed colliders have been proposed to search for new physics associated with the Higgs boson.

Concluding Remarks

- Many proposed colliders have been proposed to search for new physics associated with the Higgs boson.
- A theoretically well-motivated search is proposed for $e^+e^- \to hZ_d$ with a new light gauge boson at high intesity, low energy experiments.

Concluding Remarks

- Many proposed colliders have been proposed to search for new physics associated with the Higgs boson.
- A theoretically well-motivated search is proposed for $e^+e^- \to hZ_d$ with a new light gauge boson at high intesity, low energy experiments.
- Due to the high resolution of the detectors at electron-positron colliders, Z_d masses below 1 GeV can be probed.

Concluding Remarks

- Many proposed colliders have been proposed to search for new physics associated with the Higgs boson.
- A theoretically well-motivated search is proposed for $e^+e^- \to hZ_d$ with a new light gauge boson at high intesity, low energy experiments.
- Due to the high resolution of the detectors at electron-positron colliders, Z_d masses below 1 GeV can be probed.
- Using design luminosities of the FCC-ee, we showed that $e^+e^- \to hZ_d$ can be sensitive to parameters and cross section of

$$\delta \sim 8 \times 10^{-3} \text{ and } \sigma(e^+e^- \to hZ_d) \sim 1 - 2 \text{ ab at } \sqrt{s} = 160 \text{ GeV with } 10 \text{ ab}^{-1}$$

$$\delta \sim 8 \times 10^{-3} \text{ and } \sigma(e^+e^- \to hZ_d) \sim 3 - 4 \text{ ab at } \sqrt{s} = 240 \text{ GeV with } 5 \text{ ab}^{-1}$$

[1] A. Alloul et al. “FeynRules 2.0 - A complete toolbox for tree-level phenomenology”. In: *Cumput. Phys. Commun.* 185 (8 2014), pp. 2250–2300. URL: arXiv:1310.1921 [hep-ph].

[2] J. Alwall et al. “The automated computation of tree-level and next-to-leading order differential cross sections, and their matching to parton shower simulations”. In: *JHEP* 7.79 (2014). URL: arXiv:1405.0301 [hep-ph].

Thank You

Thank You

Questions?