ATLAS Searches for Higgs Boson Decays to BSM Dark-Z Bosons in Four-Lepton Final States

Theodota LAGOURI (1) on behalf of the ATLAS Collaboration
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Abstract

ATLAS searches for a BSM light boson using events where a Higgs boson with mass 125 GeV decays to four leptons are reported. This decay is presumed to occur via a intermediate state which contains one or two on-shell, promptly decaying bosons: $H \rightarrow ZZ' \rightarrow 4\ell$, where $X$ is a new dark vector boson $Z_d$ (or a pseudo-scalar $s$), with an invariant mass between 1 and 60 GeV. These exotic Higgs decays searches use 139 fb$^{-1}$ of p-p collision (Run-2) data at $\sqrt{s}=13$ TeV collected with the ATLAS detector at the LHC. The results are found to be consistent with SM background predictions and both fiducial model independent limits as well as limits with interpretations in specific benchmark theory models are set.

Introduction & Motivation

• B(Higgs $\rightarrow$ BSM) could be as large as $O(10\%)$
• Dark sector interactions could be mediated by a new massive $U(1)$ gauge boson $Z_d$
• It could couple to SM Higgs via mixing with $Z$ boson or
• Dark sector Higgs $S$ could mix with SM Higgs Boson

Analysis Overview

• Search for exotic decays of the Higgs in four lepton final states, 3 channels, where $\ell = e, \mu$
  1. High-mass (HM): $H \rightarrow XX' \rightarrow 4\ell$, 15 GeV $< m_\ell < 60$ GeV
  2. Low-mass (LM): $H \rightarrow XX' \rightarrow 4\ell$, 1 GeV $< m_\ell < 15$ GeV
  3. ZX channel: (ZX) $H \rightarrow ZZ' \rightarrow 4\ell$, 15 GeV $< m_\ell < 55$ GeV
• Select two pairs of prompt Same Flavor Opposite Sign (SFO) leptons ($|m_{34} - m_{12}| < |m_{34} - m_{12}|$)
• Four-lepton invariant mass: 115 GeV $< m_{4\ell} < 130$ GeV

HM Overview

• Similar di-lepton invariant mass:
  - smallest $\Delta m_{4\ell} = m_{12} - m_{34}$
• Veto Z bosons (applied also to alternative pairings)
• Veto quarkonia
• Signal region: $m_{34} - m_{12} > 0.89 \rightarrow 0.1125/m_{12}$
• 1D display of signal region: $<m_{4\ell}> = 1/2 (m_{12} + m_{34})$

LM Overview

• No Z-veto
• Extended quarkonia veto:
  - $m_{4\ell} \in [2$ GeV,4.4 GeV$]$
  - $m_{4\ell} \in [8$ GeV,12 GeV$]$
• Narrower Higgs mass window:
  - 120 GeV $< m_\ell < 130$ GeV
• Signal region requirement:
  - $m_{34}/m_{12} > 0.85$

Zx Overview

• Quadruplet ranking (if more than one quadruplet in event):
  • In order $4\mu > 2e2\mu > 3\mu 2e > 4e$
  • Resolve ambiguities by:
    - smallest $|m_2 - m_{12}|$, smallest $|m_2 - m_{34}|$
    - One di-lepton pair $m_{12}$ compatible with Z boson mass
    - Signal region: the other di-lepton pair $m_{34}$
  • 50 GeV $< m_{12} < 106$ GeV & 12 GeV $< m_{34} < 115$ GeV

Analysis Results

• Limits at 98% CL on $m_{4\ell}$ distribution for ZX
• Limits at 95% CL on $m_{4\ell}$ distribution for LM

Conclusions

• No significant excess observed above SM background predictions
• Upper limits set on fiducial ($H \rightarrow XX' / ZX$) and total cross sections ($H \rightarrow ZZ', ZZ_d \rightarrow 4\ell$ and $H \rightarrow aa / ZZ \rightarrow 4\ell$)
• Interpretations (2HDM, 2HDM+S) provided on mixing parameters: higgs coupling parameter $\kappa$, $Z_d$ kinetic mixing $\epsilon$, $Z_d-Z$ mass mixing $\delta$

References:
1. JHEP 96 (2018) 166
3. ATLAS-CONF-2020-027

(1) Affiliation: UTA, Chile