Mono-Higgs Dark Matter Phenomenology at 100 TeV

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Abstract

The phenomenology of the Higgs plus missing transverse energy – mono-Higgs – detector signiture is studied at a center of mass energy of 100 TeV, the operating center of mass energy of a proposed new hadron collider. The detection sensitivity in the Higgs to two photon channel is shown to be increased over that found in previous studies at center of mass energies of 8 TeV and 14 TeV, further motivating the design and construction of a 100 TeV collider.

I. Introduction

The dark matter (DM) mono-Higgs signature consists of a pair of dark matter particles recoiling against a Higgs boson (H), which can decay through the standard processes. The decay products of H are reconstructed in the detector and the DM escapes undetected, resulting in missing transverse energy (MET).

The theoretical sensitivity to the mono-H signiture at the LHC at center of mass energies of 8 TeV and 14 TeV is 100 fb – 1 pb over a range of dark matter (DM) models [1]. These models consist of effective field theories (EFTs) and simplified models, which include a new massive mediator particle, plus the standard model (SM). The H diphoton decay channel was found to be the most sensitive at the 8 TeV and 14 TeV LHC.

In contrast to other mono-X processes, which yield a particle X (photon [2], jet [3], lepton [4], etc) via initial state radiation (ISR) of X, the mono-H process couples DM to the Higgs at the same vertex. Therefore, this process explores the direct coupling of DM to the SM, a very exciting prospect theoretically.

While LHC mono-H analyses at 8 TeV are currently underway at both CMS [5] and ATLAS [6], and 13 TeV analyses are being prepared for multiple Higgs decay channels, the current study will explore the sensitivity of these DM models at a proposed new collider operating at a center of mass (COM) energy of 100 TeV. Since the previous study has shown the Higgs diphoton decay channel to be the most sensitive, this channel will be the focus of the current study.

II. Methods

To explore the phenomenology of the DM mono-H to diphoton signature at 100 TeV, the analysis will parallel the 8 TeV and 14 TeV analyses given in section IIIA of [1]. Background and signal Monte Carlo (MC) samples are produced using the matrix element generator MADGRAPH5 [7], using PYTHIA [8] for showering and DELPHES [9] for the detector simulation. These samples are analyzed using DELPHES plugins to the ROOT [10] software package.

The backgrounds that are expected to be dominiant in the mono-H to diphoton channel are (1) ZH, Z $\rightarrow \nu\bar{\nu}$, (2) WH, W $\rightarrow l\nu$, (3) H $\rightarrow \gamma\gamma$, (4) Non-resonant $\gamma\gamma$ production, and (5) Z$\gamma\gamma$, Z $\rightarrow \nu\bar{\nu}$. MET arrises from neutrinos escaping the detector and from the mismeasurement of leptons and photons.

The signal models used to generate MC are the benchmark models given in Table 1 of [1]. These include EFT models with operators up to dimension eight, and simplified models containing either a Z' boson or a new scalar S which couples only to the H field. The mass of the DM particle χ is varied over the values $m_\chi = 1, 10, 100, 500, 1000$ GeV.

The cross sections and branching ratios for the background channels (1), (2), and (5) at 100 TeV are obtained from [11] and [12]. The cross sections for

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background channels (3) and (4) are obtained using MADGRAPH5, and corrected to NLO with k-factors obtained from [13] and [14]. The cross section times branching ratio used for a signal model will be shown in plot legends or table description where necessary. Kinematic distributions are normalized assuming 3000 fb^{-1} of data.

Expected limits are set using the HiggsAnalysis CombinedLimit tool [15] using a non-shape based Bayesian 95% one-sided credible interval (upper limit) as a function of m_χ.

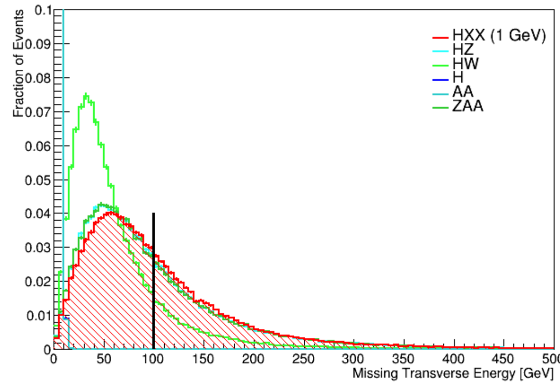

Figure 2: *Missing transverse energy distributions, normalized to one.*

III. Results

The diphoton invariant mass and MET kinematic variables used in the event selection cuts are shown in Figures 1 and 2, respectively. The selected regions are bracketed by vertical lines. The additional cuts made in the event selection are:

- Exactly two final state photons, each with $p_T > 20$ and $|\eta| < 2.5$
- $m_{\gamma\gamma} \in [116, 136]$ GeV
- Final state leptons have $p_T < 20$ and $|\eta| > 2.5$
- MET > 100 GeV

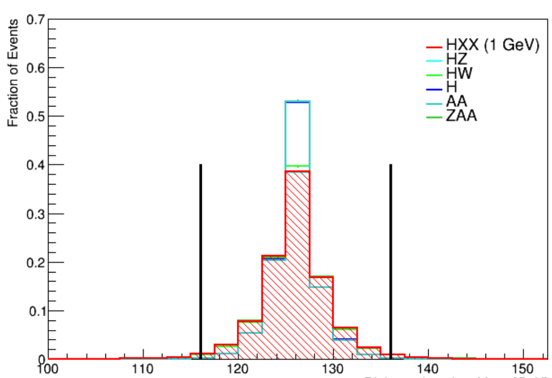

Figure 1: *Dilepton invariant mass distributions, normalized to one.*

The event yields for the background channels and a representative benchmark model are given in Table 1. The significance for this scenerio is $S/\sqrt{B} = 1$

Channel	Yield
ZH, Z $\rightarrow \nu\bar{\nu}$	1
WH, W $\rightarrow l\nu$	1
H $\rightarrow \gamma\gamma$	1
$\gamma\gamma$	1
Z$\gamma\gamma$, Z $\rightarrow \nu\bar{\nu}$	1
Total Background	1
Total Signal	1

Table 1: *Event Yields*

The MET distributions before and after selection cuts are shown in Figures 3 and 4, respectively.

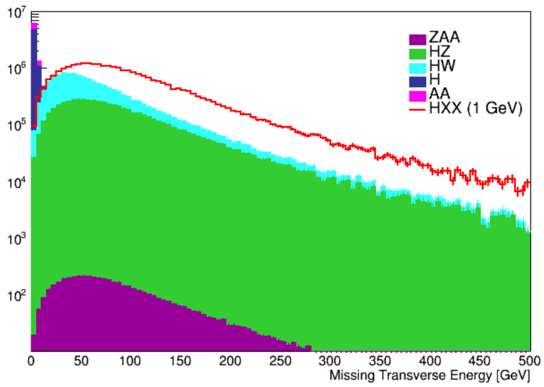

Figure 3: *Missing transverse energy before selection cuts, normalized to 300 fb^{-1}*

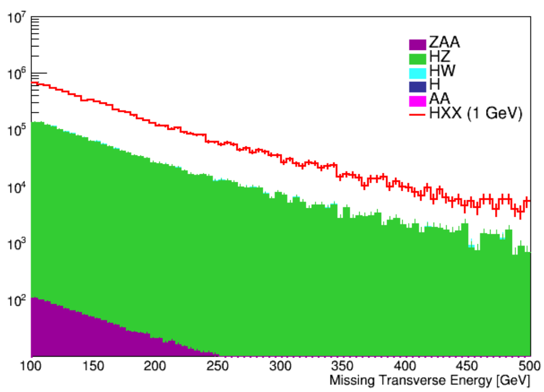

Figure 4: *Missing transverse energy after selection cuts, normalized to 300 fb^{-1}*

The selection efficiency and cross section upper limit for a set of benchmark models versus m_χ is shown in Figures 5 and 6, respectively.

IV. Discussion

The event selection criteria reduce the background events by ?? orders of magnitude while only reducing the signal events by a factor of ?? as shown by the selection efficiencies in Figure 5. This reiterates the point that the diphoton channel is very clean despite the H to diphoton cross section being small compared to other decay channels.

From Figure 6, the sensitivity of this process ranges from ?? to ?? for the various models and values of m_χ, a factor of ?? better than the expected sensitivity at the 14 TeV LHC.

V. Citations

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