(37) Search for invisible Higgs decays in the VBF channel

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Motivation

- SM H → invisible only possible via H → ZZ* → vvvv (~0.1%) if Higgs boson mass is above 120 GeV.
- Besides the observation of 125 GeV SM Higgs boson, the possibility of non-SM properties remains.
- Visible SM decay modes constrain BF(H → BSM) < 64%.
- Significant BF(H → invisible) would be a strong sign of the BSM theories, e.g. H → 2LSPs in SUSY, Graviscalars in the ADD model, Dark matter and etc.
- VBF production has larger cross-section than VH and tth - potentially better sensitivity.
- Major challenge in backgrounds estimation.

Feynman diagrams of VBF production

Analysis Strategy

- Data from 8TeV collision corresponding to an integrated luminosity of 19.5 fb⁻¹ was collected by dedicated triggers requiring jet pair in a loose VBF-like topology and MET (missing transverse energy).
- Signal extraction:
  - Leptons (e, µ) veto p_T > 10 GeV.
  - Tighter selection of VBF tag jet pair.
  - MET > 130 GeV.
  - Central-jet (η < 4.7) veto p_T > 30 GeV.
  - δΦ < 1.0.
- Perform a single-bin counting experiment using the observed yield in signal region and estimated backgrounds by data-driven method.

Data-driven Backgrounds Estimation

- The dominant backgrounds arise from Vjets processes, Z(vv)+jets and W(vv)+jets when the charged lepton is outside acceptance or not identified, contributing similar topology to VBF (H → invisible) production.
- Data-driven for Vjets: identify background rich control regions and extrapolate to signal region using factors derived from MC simulation.
- The background from QCD multijet processes is also estimated from data due to lack of MC statistic.

Z(vv)+jets Background

- Define Zj(jj) control region as signal region but:
  - Require p_T > 20 GeV and 60 < M_{jj} < 120 GeV.
  - Veto any additional leptons not from Z.
  - Redefine MET to exclude Z and require > 130 GeV.
- The number of Z(vv) events is predicted from:

\[ N_{Z(vv)} = \frac{N_{Z_j(jj)} - N_{Z_{MC}}}{c_{Z(vv)}} \]

- MC factors:
  - Ratio of BF = 5.651 ± 0.023 (MCFM)
  - c_{Z(vv)} = (1.65 ± 0.27) x 10^4
  - c_{Z_{MC}} = (11.1 ± 0.14) x 10^4
- Results:
  - N_{Z(vv)} = 12 events
  - N_{Z_{MC}} = 0.23 ± 0.15 events
  - N_{Z_{inv}} = 99 ± 29 (stat.) ± 25 (syst.)

W(vv)+jets Background

- Define single-lepton control regions.
- The number of W+jets background is estimated from:

\[ N_{W(vv)} = \frac{N_{W_j(jj)} - N_{W_{MC}}}{c_{W(vv)}} \]

- MC factors:
  - Ratio of BF = 1.30 ± 0.03 (MCFM)
  - c_{W(vv)} = (3.5 ± 0.17) x 10^4
  - c_{W_{MC}} = (14.5 ± 0.29) x 10^4
- Results:
  - N_{W(vv)} = 53 ± 18 (stat.) ± 12 (syst.)

W(vv)+jets → tau decays hadronically

- Define control region as signal region and require one hadronic tau p_T > 20 GeV [η < 2.3 but without CJV] to increase the yield, therefore:

\[ N_{W_{had}} = \frac{N_{W_{inv}} - N_{W_{MC}}}{c_{W_{had}}(CJV)} \]

- Results:
  - N_{W_{had}} = 53 ± 18 (stat.) ± 12 (syst.)

W+jets Background

- Defined lepton control regions.
- The number of W+jets background is estimated from:

\[ N_{W} = \frac{N_{W_j(jj)} - N_{W_{MC}}}{c_{W}} \]

- MC factors:
  - Ratio of BF = 30.1 ± 0.32 (MCFM)
  - c_{W} = (11.5 ± 0.27) x 10^4
  - c_{W_{MC}} = (44.5 ± 0.29) x 10^4
- Results:
  - N_{W} = 67 ± 5 (stat.) ± 16 (syst.)
  - N_{W_{inv}} = 63 ± 9 (stat.) ± 18 (syst.)

W+jets → tau decays hadronically

- Define control region as signal region and require one hadronic tau p_T > 20 GeV [η < 2.3 but without CJV] to increase the yield, therefore:

\[ N_{W_{had}} = \frac{N_{W_{inv}} - N_{W_{MC}}}{c_{W_{had}}(CJV)} \]

- Results:
  - N_{W_{had}} = 53 ± 18 (stat.) ± 12 (syst.)

QCD Background

- Effectively reduced to small level by MET, CJV and δΦ.
- “ABCD” method of MET vs. CJV, assuming they are uncorrelated.
- A: fail MET selection, fail CJV selection.
- B: pass MET selection, fail CJV selection.
- C: fail MET selection, pass CJV selection.
- D: pass MET selection, pass CJV selection → Signal.
- Numbers of region A, B, C are estimated from data subtract electroweak backgrounds from MC central-jet E_T.
- Number of QCD background is therefore given by:

\[ N_{QCD} = 31 ± 2 (stat.) ± 23 (syst.) \]

Results

- The main sources of uncertainty are statistics from control samples in data and MC samples.
- Systematic uncertainties include jet/MET scale/resolution, leptons efficiency, CMS cross-section measurements, in minor backgrounds, PDFs and factorization/renormalization scale in signal yields and etc.
- Limits are set using an asymptotic CL_s method.
- Results: for m_H = 125 GeV at 95% CL.

Observed limit = 0.65
Expected limit = 0.49

Expected and observed 95% CL upper limits on the production cross-section times invisible Higgs branching fraction normalized to the SM VBF production cross-section, as a function of m_H.

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