Simplified template cross sections for Higgs boson decays

Authorlist

Abstract
Definition of STXS Higgs decay modes and bins

Keywords
Higgs, decay, STXS

1 Introduction

For a STXS classification of Higgs boson decays, it is essential to be able to determine for each event, which decay mode it should be assigned to. The classification should be made based on the number and type of final state particles from the Higgs decay and their kinematic properties.

The aim of this document is to establish such a categorization with categories that capture the bulk of the decay events within a certain decay process. In analogy to the STXS scheme in the Higgs production modes [1–3], this categorization would be called Stage 0 STXS decay bins. As a secondary goal, additional kinematic Stage 1 sub-bins are proposed for the $H \to ZZ^* \to 4\ell$ and $H \to WW^* \to \ell\nu\ell\nu$ processes.

2 Stage 0: Definition of final state

Table 1 gives an overview of the kinematic definition of Higgs decay modes. THE TABLE IS NOT COMPLETE, ESPECIALLY THERE WAS NO CARE YET HOW TO CORRECTLY TREAT CASES WITH AND WITHOUT SAME FLAVOUR, OPPOSITE CHARGE FERMION PAIRS. All numbers and definitions are first placeholders defined almost without any studies or plots to back them up!

Label	Final state	Kinematic selection	Comment
$H \to ee$	$H \to ee + X$	$m_{ee} \geq 120$ GeV	Section 2.1
$H \to ff$	$H \to f\bar{f} + X$	$m_{ff} \geq 105$ GeV	Section 2.1
$H \to Z\gamma$	$H \to ee + \gamma + X$	$50 \leq m_{ff} < 120$ GeV, $m_{ff\gamma} \geq 120$ GeV	Section 2.1
$H \to Z\gamma$	$H \to ff + \gamma + X$	$50 \leq m_{ff} < 105$ GeV, $m_{ff\gamma} \geq 120$ GeV	Section 2.1
$H \to \gamma^*\gamma$	$H \to ff + \gamma + X$	$m_{ff} < 50$ GeV, $m_{ff\gamma} > 120$ GeV	Section 2.1
$H \to \gamma\gamma$	$H \to \gamma\gamma$	$m_{\gamma\gamma} = 125$ GeV	Section 2.1
$H \to 4\ell$	$H \to 4\ell + X$	$m_{34} \geq 10$ GeV, $m_{34} \leq m_{12} < 105$ GeV	Section 2.2
$H \to 2e2\mu$	$H \to 2e2\mu + X$	$m_{34} \geq 10$ GeV, $m_{34} \leq m_{12} < 105$ GeV	Section 2.2
$H \to 2\ell 2\nu$	$H \to \ell\ell\nu\nu + X$	$80 \leq m_{2\ell} < 105$ GeV	Section 2.3
$H \to 2\ell 2f$	$H \to \ell\ell ff + X$	$80 \leq m_{2\ell} < 105$ GeV, $ff! = ee, \mu\mu, \nu\nu$	Section 2.4
$H \to \ell\nu\ell\nu$	$H \to \ell\nu\ell\nu + X$	$10 < m_{\ell\ell} < 80$ GeV	Section 2.3
$H \to e\nu\mu\nu$	$H \to e\nu\mu\nu + X$	$10 < m_{e\mu} < 105$ GeV	Section 2.3
$H \to \ell\nu ff'$	$H \to \ell\nu ff' + X$	$10 < m_{\ell\nu} <?$ GeV	Section 2.4
$H \to fff'f'$	$H \to fff'f' + X$	$10 < m_{12} < 105$ GeV, $fff'f'! =$modes above	Section 2.5
$H \to f_1f_2f_3f_4$	$H \to f_1f_2f_3f_4 + X$	$f_1f_2f_3f_4! =$modes above	Section 2.5

Table 1: Kinematic definition of Higgs decay modes. Only particles originating from the Higgs decay are considered. Definitions: $4\ell = 4e, 4\mu$; $2\ell = ee, \mu\mu$

2.1 $H \to ff$, $H \to Z\gamma$, $H \to \gamma^*\gamma$ and $H \to \gamma\gamma$

Figure 4 in Ref. [4] show the transition between $H \to ee$ and $H \to Z(\to ee)\gamma$ around 120 GeV. The transition for $\mu\mu$ is around 105 GeV (Figure 5 in Ref. [4]). The transition between the $H \to \gamma^*\gamma$ and $H \to Z\gamma$ process is around 50 GeV in both cases. Open questions:

- Exact value of transitions
- Is the $m_{ff\gamma}$ cut needed for $H \to Z\gamma$ and $H \to \gamma^*\gamma$?
- What is the distinction between $H \to \gamma^*\gamma$ and $H \to \gamma\gamma$ with converted photons?
- How to treat $\tau\tau$ decays. Figure 6 in Ref. [4] would indicate that the tree level $H \to \tau\tau$ decay is dominating for almost the whole mass range
- How should final state QCD radiation be handled for processes like $H \to bb$ for a kinematic separation from 4-fermion processes?
- More in general: if f is a quark, will the binning be done according to the quarks or according to some final state jets?

2.2 $H \to 4\ell$

Open questions:

- Exact value of transitions
- Which lepton pairing choice to make if all four leptons have the same flavour
- How to treat $\tau\tau$ decays

2.2.1 *Lepton pairing definition in $H \to 4\ell$*

To be worked out by ATLAS and CMS

2.2.2 *Stage 1: Definition of additional bins in m_{34}*

To be worked out by ATLAS and CMS. Starting point of discussion: Bin boundaries at

m_{34}	[10,20)	[20,35)	[35,m_{12})

Table 2: Bin definitions for $H \to 4\ell$

2.3 $H \to \ell\ell\nu\nu$, $H \to \ell\nu\ell\nu$ and $H \to e\nu\mu\nu$

Open questions:

- Exact value of transitions, especially for the kinematic separation of $H \to ZZ^* \to \ell\ell\nu\nu$ from $H \to WW^* \to \ell\nu\ell\nu$
- How to treat $\tau\tau$ decays

2.3.1 *Stage 1: Definition of additional bins in $m_{\ell\ell}$*

To be worked out by ATLAS and CMS. Starting point of discussion: Bin boundaries at

$m_{\ell\ell}$	[10,30)	[30,50)	[50,80)
$m_{e\mu}$	[10,30)	[30,50)	[50,105)

Table 3: Bin definitions for $H \to \ell\nu\ell\nu$

2.4 Semileptonic 4-fermion decays

Semileptonic Higgs decays of the type $H \to ZZ^* \to \ell\ell ff$ or $H \to WW^* \to \ell\nu ff$ are currently not well constrained experimentally. The ttH multi-lepton channel and the $VH, H \to WW^*$ measurements likely have the largest signal components. Open questions:

- How to treat $\tau\tau$ decays
- How to best treat the large number of possible fermion combinations
- What to do about $H \to ZZ^* \to \nu\nu ff$?

2.5 Hadronic 4-fermion decays

Hadronic Higgs decays of the type $H \to ZZ^* \to ffff$ or $H \to WW^* \to ffff$ are currently not constrained experimentally. Open questions:

- How to treat $\tau\tau$ decays
- How to best treat the large number of possible fermion combinations

Acknowledgements

Bibliography

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