The Invisible Higgs at the LHC

Heather Logan (UW Madison)

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Why an invisible Higgs?

The SM Higgs is very narrow for $m_h \lesssim 160$ GeV.

If the Higgs couples with electroweak strength to a neutral (quasi)stable particle (e.g., dark matter) with mass $< m_h/2$, then $h \to$ invisible can be the dominant decay mode.

- $h \to \tilde{\chi}_1^0 \tilde{\chi}_1^0$ in MSSM, NMSSM
- $h \to SS$ in simple models of scalar dark matter
- $h \to$ KK neutrinos in extra dimensions
- $h \to$ Majorons
- ...

Existing studies:

LHC:

- WBF $\rightarrow h_{inv}$ Eboli & Zeppenfeld
- $Z + h_{inv}$ Frederiksen, Johnson, Kane & Reid

Tevatron:

- $Z + h_{inv}$ Martin & Wells

We studied:

- $Z + h_{inv}$ at LHC: revisited (this talk)
- WBF at Tevatron (Hooman's talk)
- $h_{inv} + j$ at LHC, Tevatron (overwhelmed by background)

Associated $Z + h_{inv}$ production at LHC

Higgs decays invisibly; look for $Z \to$ leptons.

Signal is $\ell^+\ell^- \not{p}_T$ ($\ell = e, \mu$)

Major backgrounds:

- $Z(\to \ell^+\ell^-)Z(\to \nu\bar{\nu})$
- $W(\to \ell^+\nu)W(\to \ell^-\bar{\nu})$
- $Z(\to \ell^+\ell^-) + j$ with fake $\not{p}_T$

We simulated the $Z + h_{inv}$ signal and the ZZ and WW backgrounds using Madgraph.

The $Z + j$ background with fake $\not{p}_T$ comes from $Z + j$ events in which the jet(s) are missed: either they are too soft or they go down the beampipe. We took results for this background from Frederiksen, Johnson, Kane & Reid.

Cuts:

We start with some "minimal cuts":

$$p_T(\ell^\pm) > 10 \text{ GeV}, \qquad |\eta(\ell^\pm)| < 2.5, \qquad \Delta R(\ell^+\ell^-) > 0.4$$

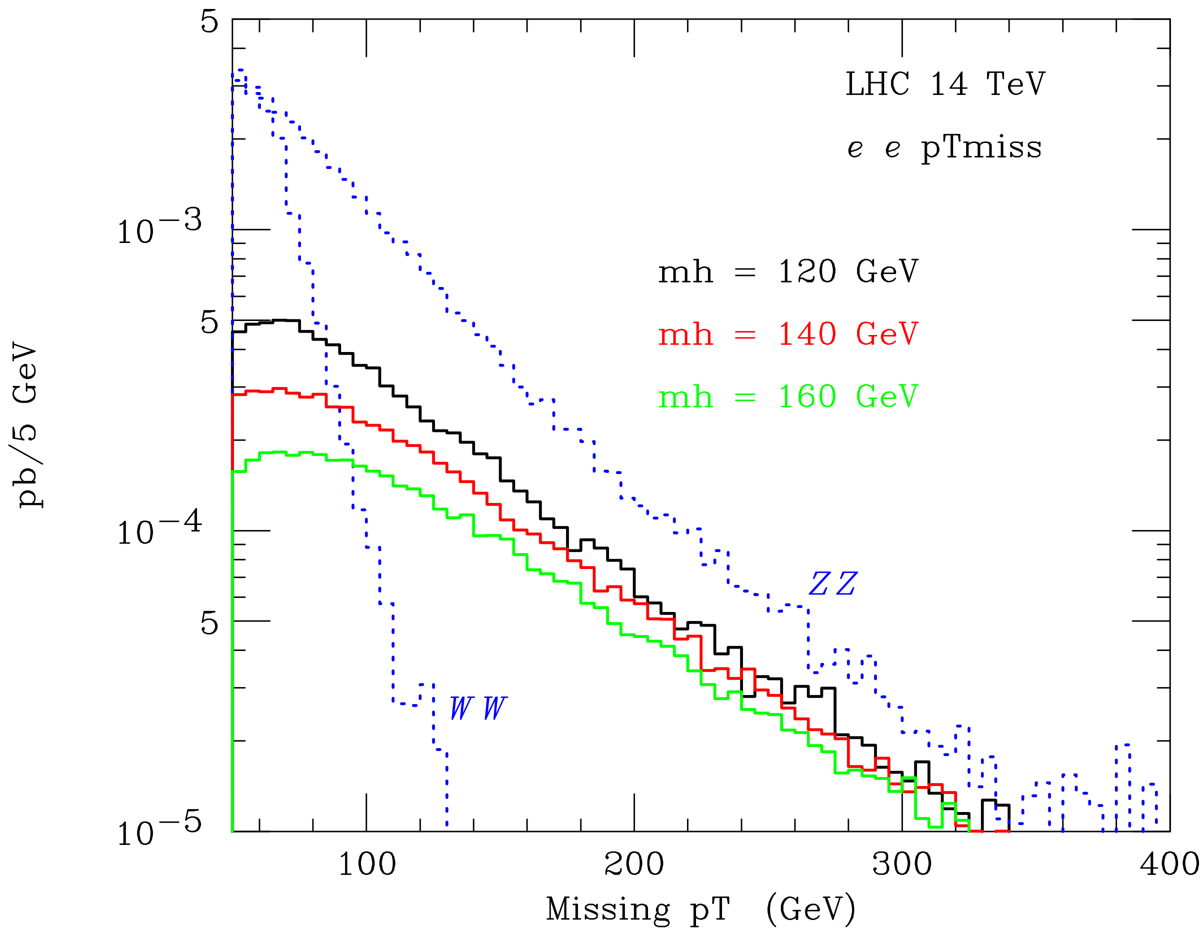
The leptons in the signal reconstruct to the Z mass. The WW background can be largely eliminated by a Z mass cut:

$$|m_{\ell^+\ell^-} - m_Z| < 10 \text{ GeV}$$

The leptons from the WW background also tend to be back-to-back; this background can be further reduced with an angular cut:

$$\Delta\phi_{\ell^+\ell^-} < 2.5$$

This cut also eliminates Drell-Yan with mismeasured $\ell^\pm$ energy.



Final cut is on $\not{p}_T$:

- $\not{p}_T$ of WW background tends to be soft, since it comes from the neutrinos in two independent W decays.
- $\not{p}_T$ of ZZ background is softer than signal: ZZ is t-channel while $Z + h_{inv}$ is s-channel.
- $\not{p}_T$ of Signal increases with m_h.

$Z + j$ background with fake $\not{p}_T$:

Fake $\not{p}_T$ due to missed jets – too soft or too large rapidity
$\longrightarrow$ escape the jet veto
Proper treatment for modern ATLAS/CMS design requires detector simulation – beyond the scope of our study.

Was studied in Frederiksen, Johnson, Kane & Reid (1994) for various $\not{p}_T$ cuts and rapidity coverage of hadronic calorimeter
$\longrightarrow$ we adapt their results for our study.

What's new:

• With $\Delta R(\ell^+\ell^-) > 0.4$, we have larger lepton acceptance by a factor of 1.6 than Frederiksen, Johnson, Kane & Reid (who used $\Delta R(\ell^+\ell^-) > 0.7$)
$\longrightarrow$ better statistics with same luminosity.

• We consider higher $\not{p}_T$ cuts
$\longrightarrow$ improves background rejection

• We include WW background: can be important.

Results (LHC, $ee + \mu\mu$)

$m_h = 120$ GeV, 10 fb^{-1} (parentheses: includes $Z + j$ background)

	S	$B(ZZ)$	$B(WW)$	$B(Z+j)$	S/B	$S/\sqrt{B}$
$\not{p}_T >$ 65 GeV	14.8 fb	48.0 fb	10.6 fb	22 fb	0.25 (0.18)	6.1 (5.2)
$\not{p}_T >$ 75 GeV	12.8 fb	38.5 fb	4.3 fb	9 fb	0.30 (0.25)	6.2 (5.6)
$\not{p}_T >$ 85 GeV	11.1 fb	30.9 fb	1.8 fb		0.34	6.1
$\not{p}_T >$ 100 GeV	8.7 fb	22.1 fb	0.6 fb		0.38	5.8

$m_h = 120$ GeV: $> 5\sigma$ signal with 10 fb^{-1}.

	$S/\sqrt{B}$ (30 fb^{-1})		
	$m_H = 120$	140	160 GeV
$\not{p}_T >$ 75 GeV	10.7 (9.7)	7.9 (7.2)	5.9 (5.3)
$\not{p}_T >$ 85 GeV	10.6	7.9	6.0
$\not{p}_T >$ 100 GeV	10.0	7.8	6.1

With 30 fb^{-1}, 5σ discovery extends out to $m_h = 160$ GeV.

Uses for $Z + h_{inv}$

• WBF $\to h_{inv}$ was studied before [Eboli & Zeppenfeld] and gives better significance ($S/\sqrt{B} \simeq 24$ for $m_h = 120$ GeV and 10 fb^{-1}).

$\to Z + h_{inv}$ can add to the signal significance – improve (slightly) precision of invisible branching fraction measurement.

• Mass of invisibly-decaying Higgs accessible only through production process.

$\to Z + h_{inv}$ cross section falls faster with m_h than WBF – more m_h dependence but less statistics.

$\to$ To extract m_h from a single cross section relies on SM assumption for production couplings.
Ratio of $Z + h_{inv}$ and WBF rates $\to$ more model-independent m_h extraction:
$Z + h_{inv} \sim hZZ$ coupling; WBF $\sim hWW, hZZ$ couplings – related by SU(2) in models with only Higgs doublets/singlets.

$\to \not{p}_T$ distribution in $Z + h_{inv}$ may give slight sensitivity to m_h.

Conclusions

• $Z + h_{inv}$ is a promising channel at the LHC
 10 fb^{-1} $\rightarrow$ $>5\sigma$ for $m_h = 120$ GeV
 30 fb^{-1} $\rightarrow$ $>5\sigma$ for m_h up to 160 GeV

• Adds (slightly) to signal significance of WBF channel studied previously

• Signal cross section (and $\not{p}_T$ distribution?) gives another handle on m_h – Combining with WBF allows more model-independent m_h extraction
Future direction: How well can m_h be extracted?