Study of resonant double-Higgs production in the vector boson fusion process at a 100 TeV pp collider

Ashutosh Kotwal
Fermilab / Duke University

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Why is the Higgs boson light?

- Supersymmetry: links Higgs boson mass to its fermionic partner, protecting it from large corrections

- Alternate, old idea: Higgs doublet (4 fields) is a Goldstone mode generated from the spontaneous breaking of a larger global symmetry
  - Higgs boson and W_L, Z_L are all Goldstone bosons from, eg. Spontaneously breaking global SO(5) -> SO(4)
  - Small, loop effects cause some additional, explicit breaking of SO(5) symmetry, causing Higgs to be not exact (massless) Goldstone but Pseudo-Goldstone (light)
  - Examples: Holographic Higgs, Little Higgs models
  - Electroweak VeV "v" is small compared to SO(5) breaking scale "f"

Motivation

- Assumption is that there is a strong dynamics at the energy scale "f" which causes a condensate to form and break the SO(5) symmetry
- Resonances will be associated with this strong dynamics
- Lightest resonance will decay to the "pseudo-Goldstones" which are much lighter, ie longitudinal gauge bosons and Higgs bosons
  - Similar to QCD $\rho \to \pi\pi$
- Simplified model: arXiv:1109.1570 (Contino *et al.*) "On the effect of resonances in composite Higgs phenomenology"
  - Scalar resonance: $\eta \to hh, V_L V_L$

Motivation

- Lagrangian from Contino *et al.* paper for a scalar resonance η coupling to the Goldstones

$$\mathcal{L}^{(\eta)} = \frac{1}{2}(\partial_\mu \eta)^2 - \frac{1}{2} m_\eta^2 \eta^2 + \frac{f^2}{4}\left(2a_\eta \frac{\eta}{f} + b_\eta \frac{\eta^2}{f^2}\right) \mathrm{Tr}\left[d_\mu d^\mu\right]$$

$$\left(D_\mu \Phi\right)^T \left(D^\mu \Phi\right)$$

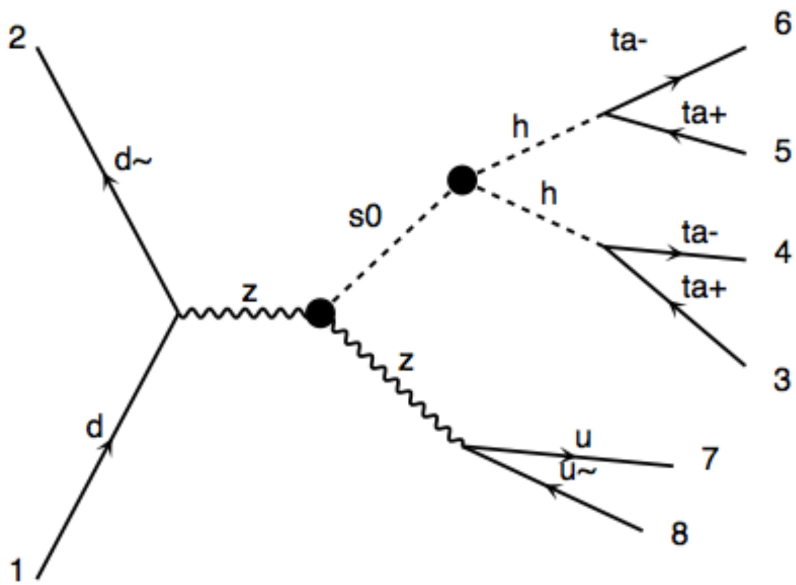
- Width of the resonance:

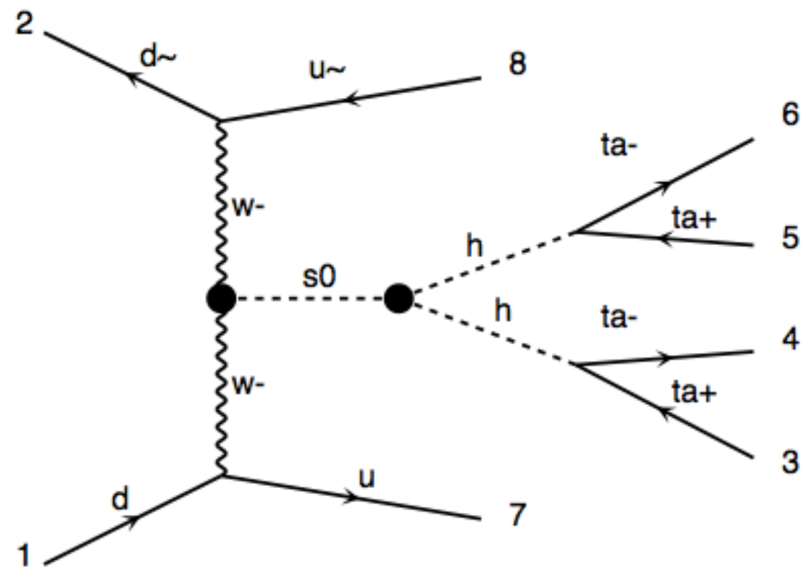
$$\Gamma_\eta = \frac{a_\eta^2 m_\eta^3}{8\pi f^2}$$

Free parameters: mass and width of the resonance

Madgraph Model

- Madgraph model coded by Matthew Low (U. Chicago) which he is also using for the *WW* resonance study





Resonance decaying to two Higgs bosons is a distinctive signature of the Goldstone nature of the Higgs boson

Branching ratio to hh, $W_L W_L$ and $Z_L Z_L$ in the 1:2:1 ratio is a definitive prediction

Final States for Higgs Detection

Channels with three largest branching ratios swamped by QCD and top-antitop production

Started investigation of 4-tau final state

diphoton + bb may also give enough rate

Decay channel	Branching ratio	Uncr. (±)
$b\bar{b}b\bar{b}$	$3.33 \cdot 10^{-01}$	$1.55 \cdot 10^{-02}$
$\tau\tau b\bar{b}$	$3.65 \cdot 10^{-02}$	$2.40 \cdot 10^{-03}$
$W^+(\to l\nu)W^-(\to l\nu)b\bar{b}$	$5.47 \cdot 10^{-03}$	$2.97 \cdot 10^{-04}$
$\tau\tau\tau\tau$	$3.99 \cdot 10^{-03}$	$3.22 \cdot 10^{-04}$
$\gamma\gamma b\bar{b}$	$1.32 \cdot 10^{-03}$	$7.88 \cdot 10^{-05}$
$W^+(\to l\nu)W^-(\to l\nu)\tau\tau$	$5.99 \cdot 10^{-04}$	$4.28 \cdot 10^{-05}$
$\gamma\gamma\tau\tau$	$1.44 \cdot 10^{-04}$	$1.09 \cdot 10^{-05}$
$b\bar{b}\mu^+\mu^-$	$1.26 \cdot 10^{-04}$	$8.65 \cdot 10^{-06}$
$W^+(\to l\nu)W^-(\to l\nu)W^+(\to l\nu)W^-(\to l\nu)$	$8.99 \cdot 10^{-05}$	$5.47 \cdot 10^{-06}$
$Z(\to l^+l^-)Z(\to l^+l^-)b\bar{b}$	$7.04 \cdot 10^{-05}$	$3.82 \cdot 10^{-06}$
$b\bar{b}Z(\to l^+l^-)\gamma$	$6.04 \cdot 10^{-05}$	$5.79 \cdot 10^{-06}$
$\gamma\gamma W^+(\to l\nu)W^-(\to l\nu)$	$2.16 \cdot 10^{-05}$	$1.43 \cdot 10^{-06}$
$\tau\tau\mu^+\mu^-$	$1.38 \cdot 10^{-05}$	$1.15 \cdot 10^{-06}$
$Z(\to l^+l^-)Z(\to l^+l^-)\tau\tau$	$7.72 \cdot 10^{-06}$	$5.51 \cdot 10^{-07}$
$\tau\tau Z(\to l^+l^-)\gamma$	$6.62 \cdot 10^{-06}$	$7.05 \cdot 10^{-07}$
$\gamma\gamma\gamma\gamma$	$5.20 \cdot 10^{-06}$	$3.68 \cdot 10^{-07}$
$W^+(\to l\nu)W^-(\to l\nu)\mu^+\mu^-$	$2.08 \cdot 10^{-06}$	$1.53 \cdot 10^{-07}$
$Z(\to l^+l^-)Z(\to l^+l^-)W^+(\to l\nu)W^-(\to l\nu)$	$1.16 \cdot 10^{-06}$	$7.04 \cdot 10^{-08}$
$W^+(\to l\nu)W^-(\to l\nu)Z(\to l^+l^-)\gamma$	$9.93 \cdot 10^{-07}$	$9.90 \cdot 10^{-08}$
$\gamma\gamma\mu^+\mu^-$	$4.99 \cdot 10^{-07}$	$3.90 \cdot 10^{-08}$
$\gamma\gamma Z(\to l^+l^-)Z(\to l^+l^-)$	$2.78 \cdot 10^{-07}$	$1.84 \cdot 10^{-08}$
$\gamma\gamma Z(\to l^+l^-)\gamma$	$2.39 \cdot 10^{-07}$	$2.46 \cdot 10^{-08}$
$Z(\to l^+l^-)Z(\to l^+l^-)\mu^+\mu^-$	$2.67 \cdot 10^{-08}$	$1.97 \cdot 10^{-09}$
$Z(\to l^+l^-)\gamma\mu^+\mu^-$	$2.29 \cdot 10^{-08}$	$2.48 \cdot 10^{-09}$
$Z(\to l^+l^-)Z(\to l^+l^-)Z(\to l^+l^-)Z(\to l^+l^-)$	$1.49 \cdot 10^{-08}$	$9.06 \cdot 10^{-10}$
$Z(\to l^+l^-)Z(\to l^+l^-)Z(\to l^+l^-)\gamma$	$1.28 \cdot 10^{-08}$	$1.28 \cdot 10^{-09}$
$Z(\to l^+l^-)\gamma Z(\to l^+l^-)\gamma$	$1.10 \cdot 10^{-08}$	$1.40 \cdot 10^{-09}$

Table from Sergei Chekanov

Plan

- Plan to use scalar resonance model mediating VV->η->HH production at high resonance mass
- Distinctive signature, comparison between HH and VV channels can prove Goldstone nature of Higgs doublet
- Detector emphasis:
  - tau lepton triggering and identification
  - Very forward VBS-tagging jets, pseudorapidity ~ 6