Search for Resonant s-channel Higgs Production at FCC-ee

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What's next for accelerators?

Future colliders – One potential machine is the FCC-ee, a high-precision, high-luminosity e⁺e⁻ machine

Able to probe rare events with high precision due to extreme luminosities
Resonant Higgs Production

- Higgs coupling is proportional to the square of the electron's mass, so it's tiny!!!

- Compare to muon Higgs coupling (~70 pb)

- At any other machine, this cross-section would be unobservable... But we're working with $L_{\text{int}}$ as high as 10 ab$^{-1}$!

- Measure Electron Yukawa coupling!

\[
\text{BR}(H \rightarrow e^+e^-) \approx 5.3 \cdot 10^{-9}, \quad m_H = 125 \text{ GeV}, \quad \Gamma_H = 4.2 \text{ MeV}
\]

\[
\sigma(e^+e^- \rightarrow H) = \frac{4\pi \Gamma_H^2 \text{BR}(H \rightarrow e^+e^-)}{(\hat{s} - M_H^2)^2 + \Gamma_H^2 M_H^2} \approx 1.64 \text{ fb}
\]
How do we see this process?

- My job – simulating different decay pathways to determine event yields, significance
- Using PYTHIA8 and ROOT, I simulate events for signal and background, and find cuts and analysis that maximize significance of the Higgs signal

What channels are visible?

So far, 7 channels are considered:

- $WW^*(2j,l\nu)$ ($\sigma = 166$ ab), continuum background $\sigma \sim O(20$ fb)
- $WW^*(2l2\nu)$ ($\sigma = 39$ ab), continuum background $\sigma \sim O(5$ fb)
- $WW^*(4j)$ ($\sigma = 173$ ab), qqbar background $\sigma \sim O(100$ pb)
- $ZZ^*(2j2\nu)$ ($\sigma = 14$ ab), continuum background $\sigma \sim O(270$ ab)
- $ZZ^*(2l2j)$ ($\sigma = 6.7$ ab), continuum background $\sigma \sim O(134$ ab)
- $bb(2j)$ ($\sigma = 922$ ab) continuum background $\sigma \sim O(20$ pb)
- $gg(2j)$ ($\sigma = 139$ ab) continuum background $\sigma \sim O(100$ pb)
Example Channel: $e^+e^- \rightarrow H(WW^*) \rightarrow 2l2\nu$

- **PYTHIA8** for signal & backgrounds at $\sqrt{s} = m_H = 125$ GeV.
- Final state: 2 isolated ($\Sigma E < 1$ GeV, $\Delta R < 0.25$) leptons $e, \mu, \tau(e), \tau(\mu)$ + Miss. En.
- no unisolated leptons or final state hadrons, within $|\eta| < 5$ (acceptance). This retains 60% of the $\sigma(WW^* (2l2nu)) = 39$ ab.
- Kinematic Cuts: Sphericity $> 0.03$ $\rightarrow$ Kills tautau
  $\Delta R(l, ME) > 1.5$ $\rightarrow$ Kills tautau
  $\cos(\theta_{1l2}) > -0.6$ $\rightarrow$ Kills tautau
- We can exploit different lepton angular correlations from spin-0 decays into $W^- (l_L \nu_L) W^+$ ($l_R \nu_L$) and continuum to reduce the latter. MVA across kinematic and angular variables reduces WW* continuum.

- Signal & backgrounds before kinematics/MVA (left) and after (right):

  - **H(WW*)**: $\sigma = 23$ ab $\Rightarrow$ $\sigma$ (after cuts) $\sim 13$ ab
  - **qqbar**: $\sigma \sim 0^{*}$ pb $\Rightarrow$ $\sigma$ (after cuts) $\sim 0$ ab
  - **$\tau$-$\tau$**: $\sigma \sim 1.3$ pb $\Rightarrow$ $\sigma$ (after cuts) $\sim 1$ ab
  - **WW***: $\sigma = 3.4$ fb $\Rightarrow$ $\sigma$ (after cuts) $\sim 705$ ab
  - **ZZ***: $\sigma = 29$ ab $\Rightarrow$ $\sigma$ (after cuts) $\sim 2.03$ ab

  *preselection kills this channel entirely

For $L_{int} = 1$ ab$^{-1}$

- $S/\sqrt{B} \sim 13/\sqrt{708} \sim 0.5$
- Significance $\sim 0.5$

- BR(Hee) $< 6 \times$ BR$_{SM}^{\text{Hee}}$ (3$\sigma$)
- $g_{\text{Hee}} < 2.6 \times g_{\text{Hee,SM}}$ (3$\sigma$)
• Combining the statistics of different channels, we can see the combined statistical significance for all of our channels!

<table>
<thead>
<tr>
<th>Channel</th>
<th>Significance (1 ab(^{-1}))</th>
<th>Significance (6 ab(^{-1}))</th>
<th>Significance (10 ab(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>WW-&gt;lvjj</td>
<td>0.75</td>
<td>1.85</td>
<td>2.38</td>
</tr>
<tr>
<td>WW-&gt;2l2v</td>
<td>0.49</td>
<td>1.20</td>
<td>1.55</td>
</tr>
<tr>
<td>ZZ-&gt;2j2v</td>
<td>0.60</td>
<td>1.47</td>
<td>1.89</td>
</tr>
<tr>
<td>bb</td>
<td>0.15</td>
<td>0.36</td>
<td>0.46</td>
</tr>
<tr>
<td>WW-&gt;4j</td>
<td>0.18</td>
<td>0.45</td>
<td>0.58</td>
</tr>
<tr>
<td>ZZ-&gt;2l2j</td>
<td>0.24</td>
<td>0.60</td>
<td>0.77</td>
</tr>
<tr>
<td>gg</td>
<td>0.09</td>
<td>0.23</td>
<td>0.30</td>
</tr>
<tr>
<td>Combined</td>
<td>1.14</td>
<td>2.78</td>
<td>3.60</td>
</tr>
</tbody>
</table>
Conclusions

- While a 5σ signal is out of reach, observations (3σ) seem feasible, and our preliminary analysis indicates that (under admittedly ideal conditions), a reasonable upper limit could be detected!

- At $L_{\text{int}}=10 \text{ ab}^{-1}$, our significance gives...
  \[
  3.6\sigma \rightarrow \text{BR}(\text{Hee})<1.39\times\text{BR}_{\text{SM}}(5\sigma) \rightarrow g_{\text{Hee}}<1.18\times g_{\text{Hee,SM}}(5\sigma)
  \]

- Complication: ISR and beam energy spread provide extreme reductions in the signal (~1/4)... Continuing work being done to work around this issue – what limits can we set in a real experiment?
  - Beam polarization
  - Determining ISR effect on background
Fun Stuff!