FCC-eh
Progress on BSM Higgs Studies

Uta Klein
on behalf of
the LHeC/FCC-eh Higgs Group
Higgs Couplings at pp + ep running concurrently

**ATLAS Simulation Preliminary**

- $h \rightarrow \gamma \gamma$, $h \rightarrow ZZ^* \rightarrow 4l$, $h \rightarrow WW^* \rightarrow l \nu \nu$
- $h \rightarrow \tau \tau$, $h \rightarrow bb$, $h \rightarrow \mu \mu$, $h \rightarrow Z \gamma$

$$\nu_e(e) \rightarrow (Z)W^+H$$

**c.m.s. [TeV]**

<table>
<thead>
<tr>
<th>LHeC 1.3</th>
<th>DLeHC 1.8</th>
<th>FCC–eh 3.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa(H \rightarrow bb)$</td>
<td>0.5%</td>
<td>0.3%</td>
</tr>
<tr>
<td>BR=57%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>$\kappa(H \rightarrow cc)$</td>
<td>4%</td>
<td>2.8%</td>
</tr>
<tr>
<td>BR=3%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- $E_p = 7$ TeV, 14 TeV, 50 TeV
- $\sqrt{s} = 14$ TeV
- $\int \mathcal{L} dt = 300 \text{ fb}^{-1}$
- $\int \mathcal{L} dt = 3000 \text{ fb}^{-1}$

**LHeC @1ab$^{-1}$** results in 2038 ... concurrent with HL-LHC end

- to be improved further
- more couplings to come
- turn pp into ONE powerful Higgs facility by adding an electron beam

- charm!

- $y_{ij} = \frac{g_{Fj}}{\sqrt{2}} = \frac{k_{Fj}}{\nu} = \frac{m_{Fj}}{\nu}$

- $\Delta = \frac{\text{MET}}{3}$

- missing transverse energy (MET) and three jets

- $\nu=0$(\text{Z}) $\rightarrow kW(HZZ)$

- forward jet
Exploring SM EFT & New Physics

M. Trott @ LHeC Workshop 2014

http://lhec.web.cern.ch

In the absence of any explicit new states, or overwhelming theory prejudice, the goal is to systematically study the SM EFT for hints of NP, using all possible future facilities to maximize physics conclusions.

What is the SM EFT? A linear realization of gauge symmetry and the new state is a $0^+$ scalar:

Four fermion operators with leptons and quark fields:

- 59 operators or 2499 parameters experimentally to constraint!
- where nearly 50% of the parameters (1053) are sensitive to lepton-quark interactions – not just about lepto-quarks

Uta Klein, BSM Higgs@FCC-eh
Analysis Framework

- Calculate cross section with tree-level Feynman diagrams (any UFO) using $p_T$ of scattered quark as scale (CDR §) for ep processes like single t, Z, W, H
  - Standard HERA tools can NOT to be used!
  - MadGraph5
- Higgs mass 125 GeV as default
- Fragmentation & hadronisation uses ep-customised Pythia.
- Delphes ‘detector’ → displaced vertices and signed impact parameter distributions → studied for LHeC, and used for extrapolations
  - powerful method to optimise detector tuning and S/N for various Higgs, top and BSM decays
  - Ongoing : Integration of FCCeh into FCC simulation framework

Event generation
- BSM Higgs production
- CC & NC DIS background by MadGraph5/MadEvent

- Fragmentation
- Hadronization
  by PYTHIA (modified for ep)

Fast detector simulation
by Delphes → test of FCCeh detector

S/B analysis → BDT
Double Higgs Production at FCC-eh


\[ \mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{h_{hhh}}^{(3)} + \mathcal{L}_{h_{hWW}}^{(3)} + \mathcal{L}_{h_{hhWW}}^{(4)}. \]

\[ \mathcal{L}_{h_{hhh}}^{(3)} = \frac{m_h^2}{2v}(1 - g_{h_{hhh}}^{(1)})h^3 + \frac{1}{2v}g_{h_{hhh}}^{(2)}h\partial_{\mu}h\partial^{\mu}h, \]

\[ \mathcal{L}_{h_{hWW}}^{(3)} = -g\left[ \frac{g_{h_{hWW}}^{(1)}}{2m_W} W^{\mu\nu} W_{\mu\nu}^{\dagger} h + \frac{g_{h_{hWW}}^{(2)}}{m_W} (W^\nu \partial^\mu W_{\mu\nu}^{\dagger} h + h.c) \right. \\
\left. \quad + \frac{\tilde{g}_{h_{hWW}}}{2m_W} W^{\mu\nu} \tilde{W}_{\mu\nu}^{\dagger} h \right] , \]

\[ \mathcal{L}_{h_{hhWW}}^{(4)} = -g^2\left[ \frac{g_{h_{hhWW}}^{(1)}}{4m_W^2} W^{\mu\nu} W_{\mu\nu}^{\dagger} h^2 + \frac{g_{h_{hhWW}}^{(2)}}{2m_W^2} (W^\nu \partial^\mu W_{\mu\nu}^{\dagger} h^2 + h.c) \right. \\
\left. \quad + \frac{\tilde{g}_{h_{hhWW}}}{4m_W^2} W^{\mu\nu} \tilde{W}_{\mu\nu}^{\dagger} h^2 \right] . \]

FCC-eh
SM(P=-0.8) \sigma(HH)=430 ab in VBF!

→ All other \( g \) coefficients are anomalous couplings to the \( hhh, hWW \) and \( hhWW \) anomalous vertices
→ those are 0 in SM
Effective Vertices

\begin{align}
\Gamma_{hhh} &= -6\lambda v \left[ g_{hhh}^{(1)} + \frac{g_{hhh}^{(2)}}{3m_h^2} (p_1 \cdot p_2 + p_2 \cdot p_3 + p_3 \cdot p_1) \right], \\
\Gamma_{hW-W^+} &= g m_W \left[ \left\{ 1 + \frac{g_{hWW}^{(1)}}{m_W^2} p_2 \cdot p_3 + \frac{g_{hWW}^{(2)}}{m_W^2} (p_2^2 + p_3^2) \right\} \eta^{\mu_2 \mu_3}
\right.
\nonumber \\
&\quad - \frac{g_{hWW}^{(1)}}{m_W^2} p_2^{\mu_3} p_2^{\mu_2} - \frac{g_{hWW}^{(2)}}{m_W^2} (p_2^{\mu_2} p_2^{\mu_3} + p_3^{\mu_2} p_3^{\mu_3}) 
\nonumber \\
&\quad \left. - i \frac{\tilde{g}_{hWW}}{m_W^2} \epsilon_{\mu_2 \mu_3 \mu_4} p_2^\mu p_3^\nu \right], \\
\Gamma_{hW-W^-W^+} &= g^2 \left[ \left\{ \frac{1}{2} + \frac{g_{hWW}^{(1)}}{m_W^2} p_3 \cdot p_4 + \frac{g_{hWW}^{(2)}}{m_W^2} (p_3^2 + p_4^2) \right\} \eta^{\mu_3 \mu_4}
\right.
\nonumber \\
&\quad - \frac{g_{hWW}^{(1)}}{m_W^2} p_3^{\mu_4} p_4^{\mu_3} - \frac{g_{hWW}^{(2)}}{m_W^2} (p_3^{\mu_4} p_3^{\mu_3} + p_4^{\mu_4} p_4^{\mu_4}) 
\nonumber \\
&\quad \left. - i \frac{\tilde{g}_{hWW}}{m_W^2} \epsilon_{\mu_3 \mu_4 \mu_5} p_3^\mu p_4^\nu \right].
\end{align}

Note the dependence on momenta in non-SM vertices. This induces significant impact on scattering kinematics.
Event Selection using $h\rightarrow bb$

$P_e=-0.8$, Anti-kt jets $R=0.4$, $E_{\text{miss}}>40$ GeV, $\eta(\text{fwd jet})>5$, $90<mbb(1), mbb(2)<125$ GeV, $m(4b)>290$ GeV

b-tagging for $|\eta|<5$ assumed to be 70% with misidentifications of 10% for charm and 1% for light quarks /gluons

<table>
<thead>
<tr>
<th>Cuts / Samples</th>
<th>Signal</th>
<th>$4b+$jets</th>
<th>$2b+$jets</th>
<th>Top</th>
<th>ZZ</th>
<th>$bbH$</th>
<th>$ZH$</th>
<th>Total Bkg</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial</td>
<td>$2.00 \times 10^3$</td>
<td>$3.21 \times 10^7$</td>
<td>$2.32 \times 10^9$</td>
<td>$7.42 \times 10^6$</td>
<td>$7.70 \times 10^3$</td>
<td>$1.94 \times 10^4$</td>
<td>$6.97 \times 10^3$</td>
<td>$2.36 \times 10^9$</td>
<td>0.04</td>
</tr>
<tr>
<td>At least $4b+1j$</td>
<td>$3.11 \times 10^2$</td>
<td>$7.08 \times 10^4$</td>
<td>$2.56 \times 10^4$</td>
<td>$9.87 \times 10^3$</td>
<td>$7.00 \times 10^2$</td>
<td>$6.32 \times 10^2$</td>
<td>$7.23 \times 10^2$</td>
<td>$1.08 \times 10^5$</td>
<td>0.94</td>
</tr>
<tr>
<td>Lepton rejection $p_T^l &gt; 10$ GeV</td>
<td>$3.11 \times 10^2$</td>
<td>$5.95 \times 10^4$</td>
<td>$9.94 \times 10^3$</td>
<td>$6.44 \times 10^3$</td>
<td>$6.92 \times 10^2$</td>
<td>$2.26 \times 10^2$</td>
<td>$7.16 \times 10^2$</td>
<td>$7.75 \times 10^4$</td>
<td>1.12</td>
</tr>
<tr>
<td>Forward jet $\eta_J &gt; 4.0$</td>
<td>233</td>
<td>13007.30</td>
<td>2151.15</td>
<td>307.67</td>
<td>381.04</td>
<td>46.82</td>
<td>503.22</td>
<td>16397.19</td>
<td>1.82</td>
</tr>
<tr>
<td>$E_T &gt; 40$ GeV</td>
<td>155</td>
<td>963.20</td>
<td>129.38</td>
<td>85.81</td>
<td>342.18</td>
<td>19.11</td>
<td>388.25</td>
<td>1927.93</td>
<td>3.48</td>
</tr>
<tr>
<td>$\Delta \phi_{E_T J} &gt; 0.4$</td>
<td>133</td>
<td>439.79</td>
<td>61.80</td>
<td>63.99</td>
<td>287.10</td>
<td>14.53</td>
<td>337.14</td>
<td>1204.35</td>
<td>3.76</td>
</tr>
<tr>
<td>$m_{bb}^1 \in [95, 125], m_{bb}^2 \in [90, 125]$</td>
<td>54.5</td>
<td>28.69</td>
<td>5.89</td>
<td>6.68</td>
<td>5.14</td>
<td>1.42</td>
<td>17.41</td>
<td>65.23</td>
<td>6.04</td>
</tr>
<tr>
<td>$m_{4b} &gt; 290$ GeV</td>
<td>49.2</td>
<td>10.98</td>
<td>1.74</td>
<td>2.90</td>
<td>1.39</td>
<td>1.21</td>
<td>11.01</td>
<td>29.23</td>
<td>7.51</td>
</tr>
</tbody>
</table>

Table 2: A summary table of event selections to optimise the signal with respect to the backgrounds in terms of the weights at 10 ab$^{-1}$. In the first column the selection criteria are given as described in the text. The second column contains the weights of the signal process $p e^- \rightarrow hh j_\nu_e$, where both the Higgs bosons decay to $b\bar{b}$ pair. In the next columns the sum of weights of all individual prominent backgrounds in charged current, neutral current and photo-production are given with each selection, whereas in the penultimate column all backgrounds’ weights are added. The significance is calculated at each stage of the optimised selection criteria using the formula $S = \sqrt{2[(S + B) \log(1 + S/B) - S]}$, where $S$ and $B$ are the expected signal and background yields at a luminosity of 10 ab$^{-1}$ respectively. This optimisation has been performed for $E_e = 60$ GeV and $E_n = 50$ TeV.

Uta Klein, BSM Higgs@FCC-eh
Azimuthal Angle Distributions

between missing transverse energy and forward jet, at Delphes detector-level, including background : bbbbj, bbjjj, Z(bb)h(bb)j, ttj, h(bb)bbj

→ For signal, we consider hh → bbbb decays motivated by h → bb studies.

⇒ normalised DIS cross sections are sensitive to non-BSM vertices
⇒ initial study published for this novel variable
⇒ potential for a deeper analysis and interpretation

[arXiv:1509.04016]
5% systematic uncertainty included

Limits of couplings at 95% C.L.

1σ for SM hhh for $E_e$ 60 (120)GeV and 10ab$^{-1}$

$g_{hhh}^{(1)} = 1.00^{+0.24}_{-0.17}(0.14)$

Probing anomalous couplings: limits are obtained by scanning one of the non-BSM coupling while keeping other couplings to their SM values.

Here $g_{...}^{(i)}$, $i = 1, 2$, and $\tilde{g}_{...}$ are real coefficients corresponding to the CP-even and CP-odd couplings respectively, of the $hhh$, $hWW$ and $hhWW$ anomalous vertices.
**Invisible Higgs@LHeC**

relating the Higgs and the ‘dark’ sectors

**HL-LHC @ 3 ab⁻¹ [arXiv:1411.7699]**

\[ \text{Br}(h \rightarrow E_T) < 3.5\% \text{ @95\% C.L., MVA based} \]

For LHeC, assume : 1ab⁻¹, \( P_e = -0.9 \), cut based

\[ \text{Br}(h \rightarrow E_T) < 6\% \text{ @ 95\% C.L.} \]

\[ C_M^2 = \kappa_Z^2 \times \text{Br}(h \rightarrow E_T) \]

\( \kappa_Z \): BSM w.r.t. SM HZZ coupling

\[ \rightarrow \text{potential much enhanced for FCC-eh @ 3.5 TeV and HE-LHC-eh @ 1.8 TeV} \]

\[ \rightarrow \text{NEW studies performed on Delphes detector-level using our Madevent framework} \]

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Y.-L. Tang et al., arXiv: 1508.01095
CC production of an invisible Higgs

\[
\begin{aligned}
e^- & \rightarrow W^\pm \\
W^\pm & \rightarrow h \\
h & \rightarrow \chi^0
\end{aligned}
\]

\[
\begin{aligned}
\bar{u} & \rightarrow W^\pm \\
W^\pm & \rightarrow \chi^0
\end{aligned}
\]

NC production of an invisible Higgs

\[
\begin{aligned}
e^- & \rightarrow Z \\
Z & \rightarrow h \\
h & \rightarrow \chi^0
\end{aligned}
\]

\[
\begin{aligned}
\bar{u} & \rightarrow Z \\
Z & \rightarrow \chi^0
\end{aligned}
\]

→ We focus currently on NC DIS channel: employ that kinematic is over constrained using jet and electron information in the final state
→ We use the idea from C. Zhang and Y.-L. Tang: We emulate Higgs to invisible by assuming a branching of 100% for \( H \rightarrow ZZ \rightarrow 4\nu \)
→ We started to study signals and backgrounds using CMS-style and FCC-eh-style ‘Delphes’ detectors, using same analysis strategies as developed for LHeC (C. Zhang and BSc thesis S. Kawaguchi)
Dominant Background (1)

for faking our signal feature:
one electron, one jet, and missing transverse energy (Etmiss)

\[ W^+_\nu \text{ background} \]
\[ p + e^- \rightarrow W^- + j + \nu_e \]
\[ W^- \rightarrow e^- + \nu_e \]

\[ Z^+e^- \text{ background} \]
\[ p + e^- \rightarrow Z + j + e^- \]
\[ Z \rightarrow \nu + \bar{\nu} \]
$Wj_e$ background

$p + e^- \rightarrow W + j + e^- \quad W \rightarrow \ell \rightarrow \nu_\ell$

one electron

one jet

W+ and W- separately generated

ETmiss

undetected
Selection Requirements

Basic cuts (Cut 0)

- $N(\text{jets})$ for the jet and the electron
- $p_T$ for the leading jet and the leading electron
- for the leading jet and the leading electron
- for the leading jet and the leading electron

Cut 1: $|\Delta \phi_{\text{jet}, \text{Etmiss}}| > 1 \text{ rad}$
Cut 2: $\text{Etmiss} > 50 \text{ GeV}$
Cut 3: $\eta_{\text{jet}} - \eta_{\text{e}} > 3$
Cut 4: $\phi_{\text{jet}} - \phi_{\text{e}} < 2.4$
Cut 5: $-1.3 < \eta_{\text{e}} < 1.1$
Cut 6: $0.08 < y_{\text{e}} < 0.55$
Cut 7: require 1 electron, 1 jet, and veto tau’s and muons

Events/1ab
Results for FCC-eh - Using Cuts

We analyzed the signal and the backgrounds by cut-based analysis

<table>
<thead>
<tr>
<th>Event</th>
<th>cut0</th>
<th>cut1</th>
<th>cut2</th>
<th>cut3</th>
<th>cut4</th>
<th>cut5</th>
<th>cut6</th>
<th>cut7</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal (Br=100%)</td>
<td>79626</td>
<td>53263</td>
<td>40134</td>
<td>30299</td>
<td>24558</td>
<td>23640</td>
<td>18774</td>
<td>10862</td>
</tr>
<tr>
<td></td>
<td>2801080</td>
<td>1823611</td>
<td>1009497</td>
<td>45034</td>
<td>30154</td>
<td>26767</td>
<td>5292</td>
<td>3062</td>
</tr>
<tr>
<td></td>
<td>127927</td>
<td>78521</td>
<td>39227</td>
<td>11837</td>
<td>8005</td>
<td>6729</td>
<td>3498</td>
<td>1701</td>
</tr>
<tr>
<td></td>
<td>1599622</td>
<td>875306</td>
<td>395383</td>
<td>216470</td>
<td>118524</td>
<td>106884</td>
<td>72068</td>
<td>4320</td>
</tr>
<tr>
<td></td>
<td>1815491</td>
<td>878388</td>
<td>259793</td>
<td>124438</td>
<td>71995</td>
<td>64375</td>
<td>44522</td>
<td>2706</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9842523</td>
<td>5849216</td>
<td>2562766</td>
<td>426915</td>
<td>246905</td>
<td>221774</td>
<td>126320</td>
<td>12129</td>
</tr>
</tbody>
</table>

The number of events of the signal and the main backgrounds after application of each cut, assuming an integrated luminosity of 1ab⁻¹

Branching ratio calculated by $\frac{S}{\sqrt{S+B}}$ :

$$Z = \frac{10862 \times Br(h \rightarrow E\downarrow T)}{\sqrt{10862 \times Br(h \rightarrow E\downarrow T) + 12129}}$$

In the case of $2\sigma$:

$Br(h \rightarrow E\downarrow T) \sim 2.05\%$
MVA (BDT) using samples after cut 0 and cut 7, and use other variables as a BDT input.

<table>
<thead>
<tr>
<th>BDT</th>
<th>Signal</th>
<th>Z [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>31961</td>
<td>3.25</td>
</tr>
<tr>
<td>0.05</td>
<td>29932</td>
<td>2.81</td>
</tr>
<tr>
<td>0.1</td>
<td>25686</td>
<td>2.40</td>
</tr>
<tr>
<td>0.15</td>
<td>19898</td>
<td>2.08</td>
</tr>
<tr>
<td>0.2</td>
<td>13020</td>
<td>1.93</td>
</tr>
<tr>
<td>0.25</td>
<td>6998</td>
<td>2.04</td>
</tr>
<tr>
<td>0.3</td>
<td>2320</td>
<td>2.82</td>
</tr>
</tbody>
</table>

Branching ratio calculated by $\frac{S}{\sqrt{S+B}}$:

$$Z = 13020 \times \text{Br}(h \rightarrow E \downarrow T) / \sqrt{13020 \times \text{Br}(h \rightarrow E \downarrow T) + 15562}$$

In the case of $2\sigma$, $\text{Br}(h \rightarrow E \downarrow T) \sim 1.93\%$

Uta Klein, BSM Higgs@FCC-eh
Branching for invisible Higgs

Values given in case of 2σ

<table>
<thead>
<tr>
<th>Delphes detectors</th>
<th>LHeC</th>
<th>DLHeC</th>
<th>FCC-eh</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1.3 TeV</td>
<td>1.8 TeV</td>
<td>3.5 TeV</td>
</tr>
<tr>
<td>LHC-style</td>
<td>4.7%</td>
<td>3.2%</td>
<td>1.9%</td>
</tr>
<tr>
<td>First ‘ep-style’</td>
<td>5.7%</td>
<td></td>
<td>2.6%</td>
</tr>
</tbody>
</table>

✓ Results look very encouraging for a measurement of the branching of Higgs to invisible in ep down to 2%.
✓ For 2 different detector options we get similar results.

- Certainly: we will use this channel to further optimize analysis strategies (used methods and requirements, e.g. size of jets and electron reconstructions) and to modify our ep-detector
- employ synergies within FCC study group ➔ detector has certainly a significant impact on results
Exotic Higgs Decays

\[ h \rightarrow \phi\phi \rightarrow 4b \]

\( \phi \): a spin-0 particle from new physics.

\[ eq \rightarrow \nu_e h q' \rightarrow \nu_e \phi\phi q' \rightarrow \nu_e b\bar{b}b\bar{b}q' \]

\[ \mathcal{L}_{\text{eff}} = \lambda_h v h \phi^2 + \lambda_b \phi \bar{b}b + \mathcal{L}_{\phi \text{ decay,other}} \]

S. Liu, Y. L. Tang, C. Zhang, S. Zhu, 1608.08458

- Well motivated signature in extended Higgs sector.
- Difficult to probe at hadron colliders.
- LHeC signal: here using CC channel.
- Backgrounds: CC multijet, CC \( t/h/W/Z+\text{jets} \), PHP multijet.
- PHP backgrounds assumed to be negligible after MET requirements and electron tagging.
- Current analysis is done at parton level.

\[ C_{4b}^2 = \kappa_V^2 \times \text{Br}(h \rightarrow \phi\phi) \times \text{Br}^2(\phi \rightarrow b\bar{b}) \]

\( \phi \) mass range targeted in this study: [20,60] GeV, scanned in 1 GeV step.
Exotic Higgs at LHeC@1ab⁻¹

Sensitivity comparison in Higgs Singlet Model

95% CL excluded by LEP

Btag scenarios

(A) $\epsilon_b = 70\%, \epsilon_c = 10\%, \epsilon_{g,u,d,s} = 1\%$

(B) $\epsilon_b = 70\%, \epsilon_c = 20\%, \epsilon_{g,u,d,s} = 1\%$

(C) $\epsilon_b = 60\%, \epsilon_c = 10\%, \epsilon_{g,u,d,s} = 1\%$

(D) $\epsilon_b = 60\%, \epsilon_c = 20\%, \epsilon_{g,u,d,s} = 1\%$

1ab⁻¹, B-tagging and mistagging rates vary.

Dashed lines: 5σ discovery
Solid lines: 95% C.L. exclusions

95% C.L. for $m_\phi$ of 20, 40, 60 GeV for

$C_{4b}^2 = k_V^2 \times Br(h \rightarrow \phi\phi) \times Br^2(\phi \rightarrow b\bar{b})$

is 0.3%, 0.2% and 0.1%

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AhSS

We use as our baseline model (from Sep 2016):

[arXiv:1608.08458]
in close collaboration with C. Zhang & Y.L. Tang

The model assumes same narrow width for higgs and new scalar.

AhSS is the coupling set in MG5 model.
Coupling of new scalar to 125 GeV-Higgs

Variation of Ahss With Mass

Ahss Value

Branching Ratio (%)

10% is a sensible nominal value to study
Coupling of new scalar to b-quarks

Variation of $y_{sbb}$ With Mass

We plan to use 100% as our nominal value.
Variation of Cross Sections

Uta Klein
Michael o’Keefe
Liverpool

→ reflecting coupling of new scalar to 125 GeV higgs
Total Cross Sections vs Masses

BR=10% for h to new scalar and 100% for BR of new scalar to bb

We expect a flat total cross section for the 3 collider options (LHeC, D-LHeC and FCC-he)

Next : Study effect of pT and eta acceptances using our MG5/Madevent simulation
More New Studies

Please see the posters at this workshop

• “Search for Anomalous HVV couplings at the LHeC and the FCC-ep” by M. Altinli et al.
• “Probing FCNC couplings of Higgs-top at FCC-ep and LHeC” by B. Hacisahinoglu et al.
• “Limits on Neutral Diboson and Di-Higgs Interactions for FCC-he Collider” by S. Kuday et al.

➔ we will discuss those in our bi-weekly Higgs-top LHeC/FCC-ep meetings in preparation of FCC week in Berlin.
Conclusions

• We just started to explore the potential of complementary BSM Higgs searches using concurrent ep collisions at FCC-pp in particular for HH and Hφ couplings

→ many more studies ongoing (e.g. anomalous htt coupling) and possible! You are welcome!

• Enhance ep potential further by strengthen analysis techniques and detector developments between p, ep and ee: extended beauty and charm tagging using BDT, jet-substructure, boosted pairs ...

• For the FCC CDR: Quantify the joint potential → combined analysis of pp, ep and ee cross sections to constrain BSM physics scenario’s and to design the most powerful and sustainable BSM search complex at the energy frontier.
Additional Sources & Thanks to


Poetic 2016 Workshop, 14.-18.11.2016, Temple University (USA)
https://phys.cst.temple.edu/poetic-cteq-2016/scientific_program.html

1st FCC Physics Workshop, 16.1.-20.1.2017, CERN
https://indico.cern.ch/event/550509/
→ see M. Benedikt’s and F. Zimmermann’s and further eh talks given at this workshop

Special thanks to my colleagues in the LHeC/FCC-eh Higgs group, the project leader Max Klein and our detector expert Peter Kostka.
Additional material
Asymmetries

\[ \mathcal{A}_{\Delta\phi E_T J} = \frac{|A_{\Delta\phi > \pi/2}| - |A_{\Delta\phi < \pi/2}|}{|A_{\Delta\phi > \pi/2}| + |A_{\Delta\phi < \pi/2}|}, \]

<table>
<thead>
<tr>
<th>Samples</th>
<th>( \mathcal{A}_{\Delta\phi E_T J} )</th>
<th>( \sigma ) (fb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SM+Bkg</td>
<td>0.277 ± 0.088</td>
<td></td>
</tr>
<tr>
<td>( g_{hhh}^{(1)} ) = 1.5</td>
<td>0.279 ± 0.052</td>
<td>0.18</td>
</tr>
<tr>
<td>( g_{hhh}^{(1)} ) = 2.0</td>
<td>0.350 ± 0.053</td>
<td>0.21</td>
</tr>
<tr>
<td>( g_{hhh}^{(2)} ) = -0.5</td>
<td>0.381 ± 0.050</td>
<td>0.19</td>
</tr>
<tr>
<td>( g_{hhh}^{(2)} ) = 0.5</td>
<td>0.274 ± 0.024</td>
<td>0.74</td>
</tr>
<tr>
<td>( g_{hWW}^{(1)} ) = -0.5</td>
<td>0.506 ± 0.022</td>
<td>0.88</td>
</tr>
<tr>
<td>( g_{hWW}^{(1)} ) = 0.5</td>
<td>0.493 ± 0.020</td>
<td>0.94</td>
</tr>
<tr>
<td>( g_{hWW}^{(2)} ) = -0.02</td>
<td>0.257 ± 0.025</td>
<td>0.67</td>
</tr>
<tr>
<td>( g_{hWW}^{(2)} ) = 0.02</td>
<td>0.399 ± 0.040</td>
<td>0.33</td>
</tr>
<tr>
<td>( \tilde{g}_{hWW} ) = -1.0</td>
<td>0.219 ± 0.016</td>
<td>1.53</td>
</tr>
<tr>
<td>( \tilde{g}_{hWW} ) = 1.0</td>
<td>0.228 ± 0.016</td>
<td>1.53</td>
</tr>
<tr>
<td>( g_{hWW}^{(1)} ) = -0.05</td>
<td>0.450 ± 0.033</td>
<td>0.52</td>
</tr>
<tr>
<td>( g_{hWW}^{(1)} ) = 0.05</td>
<td>0.254 ± 0.029</td>
<td>0.68</td>
</tr>
<tr>
<td>( g_{hWW}^{(2)} ) = -0.03</td>
<td>0.462 ± 0.022</td>
<td>1.22</td>
</tr>
<tr>
<td>( g_{hWW}^{(2)} ) = 0.03</td>
<td>0.333 ± 0.018</td>
<td>1.46</td>
</tr>
<tr>
<td>( \tilde{g}_{hWW} ) = -0.1</td>
<td>0.351 ± 0.020</td>
<td>1.60</td>
</tr>
<tr>
<td>( \tilde{g}_{hWW} ) = 0.1</td>
<td>0.345 ± 0.020</td>
<td>1.61</td>
</tr>
</tbody>
</table>

Table 3: Estimation of the asymmetry, defined in Eq. (9), and statistical error associated with the kinematic distributions in Fig. 2 at an integrated luminosity of 10 ab\(^{-1}\). The cross section (\( \sigma \)) for the corresponding coupling choice is given in the last column with same parameters as in Table 1.