STUDY OF HIGGS EFFECTIVE COUPLINGS AT $e^-p$ COLLIDERS

HODA HESARI

SCHOOL OF PARTICLES AND ACCELERATORS, INSTITUTE FOR RESEARCH IN FUNDAMENTAL SCIENCES (IPM)
The LHeC is a proposed deep inelastic electron-nucleon scattering (DIS) machine which has been designed to collide electrons with an energy from 60 GeV to possibly 140 GeV, with protons with an energy of 7 TeV.

The future circular collider (FCC) has the option of colliding electron-proton with the electron energy $E_e = 60$ GeV that possibly goes up to $E_e = 175$ GeV and with the proton energy of $E_p = 50$ TeV.
WHY EFFECTIVE FIELD THEORY?

- There are some reasons (Gravity, neutrino masses, baryon asymmetry, dark matter, … ) to believe that the Standard Model is not the ultimate theory.
- the Standard Model of particle physics has been found to be a successful theory describing nature up to the scale of electroweak.

The standard model is an effective theory valid at TeV scale and there must be a bigger theory.

At energies below $\Lambda$, an EFT approach can be used theory.

e.g Fermi theory of weak interaction $\rightarrow$ standard model
EFFECTIVE FIELD THEORY (EFT)

In the EFT expansion all the operators are composed of all possible combinations of SM field. They have $SU(3)_c \times SU(2)_L \times U(1)_Y$ and Lorentz invariance.

In the EFT approach, the Lagrangian is:

$$\mathcal{L}_{\text{SMEFT}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda} \mathcal{O}_i + \sum_i \frac{c_i}{\Lambda} \mathcal{O}_i + \text{h.c.}$$

just a single operator for dimension-five term. It is violates the lepton number

Assuming baryon number conservation, 59 independent operators.

The EFT is valid up to a scale $\Lambda$, lying around TeV scale.

This approach is renormalizable order by order in the $\frac{E}{\Lambda}$ expansion.
THE MOST GENERAL EFFECTIVE HIGGS LAGRANGIAN IN THE GAUGE BASIS

with the assumption of baryon and lepton number conservation and keeping only dimension-six operators, the most general $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge invariant Lagrangian can be constructed from the SM fields. We concentrate on the dimension-six interactions of the Higgs boson, fermions, and the electroweak gauge bosons in the strongly interacting light Higgs (SILH) basis conventions:

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i = \mathcal{L}_{SM} + \mathcal{L}_{SILH} + \mathcal{L}_{CP} + \mathcal{L}_{F_\chi} + \mathcal{L}_{F_\gamma} + \mathcal{L}_G$$
THE MOST GENERAL EFFECTIVE HIGGS LAGRANGIAN IN THE GAUGE BASIS

with the assumption of baryon and lepton number conservation and keeping only dimension-six operators, the most general $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge invariant Lagrangian can be constructed from the SM fields. We concentrate on the dimension-six interactions of the Higgs boson, fermions, and the electroweak gauge bosons in the strongly interacting light Higgs (SILH) basis conventions:

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_i \overline{c}_i O_i = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{SILH}} + \mathcal{L}_{F_t} + \mathcal{L}_{F_y} + \mathcal{L}_G$$

strongly interacting light Higgs sector
Weak doublet of higgs

Electroweak field strength tensor

Higgs boson quartic coupling

Hermitian covariant derivative

Vacuum expectation value = 246 GeV

Hermitian covariant derivative

Electroweak field strength tensor

Strong field strength tensor

Hermitian covariant derivative
THE MOST GENERAL EFFECTIVE HIGGS LAGRANGIAN IN THE GAUGE BASIS

with the assumption of baryon and lepton number conservation and keeping only dimension-six operators, the most general $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge invariant Lagrangian can be constructed from the SM fields.

We concentrate on the dimension-six interactions of the Higgs boson, fermions, and the electroweak gauge bosons in the strongly interacting light Higgs (SILH) basis conventions:

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_i \bar{c}_i O_i = \mathcal{L}_{SM} + \mathcal{L}_{SILH} + \mathcal{L}_{F_{\chi}} + \mathcal{L}_{F_{\chi}} + \mathcal{L}_{G}$$

- **strongly interacting light Higgs sector**
- **two Higgs fields and a pair of quarks or leptons**
\[ \mathcal{L}_{F_1} = \frac{i \bar{c}_{HQ}}{v^2} (\bar{q}_L \gamma^\mu q_L) (H^\dagger \overleftrightarrow{D}_\mu H) + \frac{i \bar{c'}_{HQ}}{v^2} (\bar{q}_L \gamma^\mu \sigma^i q_L) (H^\dagger \sigma^i \overleftrightarrow{D}_\mu H) \\
+ \frac{i \bar{c}_{Hu}}{v^2} (\bar{u}_R \gamma^\mu u_R) (H^\dagger \overleftrightarrow{D}_\mu H) \\
+ \frac{i \bar{c}_{Hd}}{v^2} (\bar{d}_R \gamma^\mu d_R) (H^\dagger \overleftrightarrow{D}_\mu H) + \left[ \frac{i \bar{c}_{Hud}}{v^2} (\bar{u}_R \gamma^\mu d_R) (H^c \overleftrightarrow{D}_\mu H) \right] + h.c. \\
+ \frac{i \bar{c}_{HL}}{v^2} (\bar{L}_L \gamma^\mu L_L) (H^\dagger \overleftrightarrow{D}_\mu H) \\
+ \frac{i \bar{c'}_{HL}}{v^2} (\bar{L}_L \gamma^\mu \sigma^i L_L) (H^\dagger \sigma^i \overleftrightarrow{D}_\mu H) + \frac{i \bar{c}_{Hi}}{v^2} (\bar{l}_R \gamma^\mu l_R) (H^\dagger \overleftrightarrow{D}_\mu H). \]
THE MOST GENERAL EFFECTIVE HIGGS LAGRANGIAN IN THE GAUGE BASIS

with the assumption of baryon and lepton number conservation and keeping only dimension-six operators, the most general $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge invariant Lagrangian can be constructed from the SM fields.

We concentrate on the dimension-six interactions of the Higgs boson, fermions, and the electroweak gauge bosons in the strongly interacting light Higgs (SILH) basis conventions:

$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_i \bar{c}_i O_i = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{SILH}} + \mathcal{L}_{F_i} + \mathcal{L}_{F_i'} + \mathcal{L}_G$$

- strongly interacting light Higgs sector
- two Higgs fields and a pair of quarks or leptons
- a pair of quark or lepton, a Higgs field, and a gauge boson
\[ \mathcal{L}_{F_2} = \frac{\bar{c}_{uB} g'}{m_W^2} y_u \bar{q}_L H^c_{\sigma^{\mu\nu}} u_R B_{\mu\nu} + \frac{\bar{c}_{uW} g}{m_W^2} y_u \bar{q}_L \sigma^i H^c_{\sigma^{\mu\nu}} u_R W^i_{\mu\nu} \]

\[ + \frac{\bar{c}_{uG} g_S}{m_W^2} y_u \bar{q}_L H^c_{\sigma^{\mu\nu}} \lambda^a u_R G^a_{\mu\nu} + \frac{\bar{c}_{dB} g'}{m_W^2} y_d \bar{q}_L H_{\sigma^{\mu\nu}} d_R B_{\mu\nu} \]

\[ + \frac{\bar{c}_{dW} g}{m_W^2} y_d \bar{q}_L \sigma^i H_{\sigma^{\mu\nu}} d_R W^i_{\mu\nu} \]

\[ + \frac{\bar{c}_{dG} g_S}{m_W^2} y_d \bar{q}_L H_{\sigma^{\mu\nu}} \lambda^a d_R G^a_{\mu\nu} + \frac{\bar{c}_{lB} g'}{m_W^2} y_l \bar{L}_L H_{\sigma^{\mu\nu}} l_R B_{\mu\nu} \]

\[ + \frac{\bar{c}_{lW} g}{m_W^2} y_l \bar{L}_L \sigma^i H_{\sigma^{\mu\nu}} l_R W^i_{\mu\nu} + h.c. \]
with the assumption of baryon and lepton number conservation and keeping only \textit{dimension-six} operators, the most general $SU(3)_c \times SU(2)_L \times U(1)_Y$ gauge invariant Lagrangian can be constructed from the SM fields.

We concentrate on the dimension-six interactions of the Higgs boson, fermions, and the electroweak gauge bosons in the strongly interacting light Higgs (SILH) basis conventions:

\[ \mathcal{L} = \mathcal{L}_{SM} + \sum_i \overline{c}_i O_i = \mathcal{L}_{SM} + \mathcal{L}_{SILH} + \mathcal{L}_{F_+} + \mathcal{L}_{F_+} + \mathcal{L}_G \]

- **strongly interacting light Higgs sector**
- **two Higgs fields and a pair of quarks or leptons**
- **a pair of quark or lepton, a Higgs field, and a gauge boson**
- **gauge boson self-interactions**
\[ \mathcal{L}_G = \frac{g^3}{m_W^2} \bar{c}_{3W} \epsilon_{ijk} W^i_{\mu\nu} W^j_{\rho\nu} W^k_{\rho\mu} + \frac{g^3}{m_W^2} \bar{c}_{3G} f_{abc} G_{\mu\nu}^a G_{\rho\nu}^b G_{\rho\mu}^c + \frac{\bar{c}_{2W}}{m_W^2} D_{\mu} W_{\mu\nu}^k D_{\rho} W_{\rho\nu}^k + \frac{\bar{c}_{2B}}{m_W^2} \partial_\mu B_{\mu\nu} \partial_\rho B_{\rho\nu}^\nu + \frac{\bar{c}_{2G}}{m_W^2} D_{\mu} G_{\mu\nu}^a D_{\rho} G_{\rho\nu}^a , \]
with the assumption of baryon and lepton number conservation and keeping only \textit{dimension-six} operators, the most general \( SU(3)_C \times SU(2)_L \times U(1)_Y \) gauge invariant Lagrangian can be constructed from the SM fields.

We concentrate on the dimension-six interactions of the Higgs boson, fermions, and the electroweak gauge bosons in the strongly interacting light Higgs (SILH) basis conventions:

\[
\mathcal{L} = \mathcal{L}_{\text{SM}} + \sum_i \overline{c}_i O_i = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{SILH}} + \mathcal{L}_{F_i} + \mathcal{L}_{F_i^c} + \mathcal{L}_{G}
\]

\( \mathcal{L}_{\text{SM}} \): strongly interacting light Higgs sector

\( \mathcal{L}_{\text{SILH}} \): two Higgs fields and a pair of quarks or leptons

\( \mathcal{L}_{F_i}, \mathcal{L}_{F_i^c} \): a pair of quark or lepton, a Higgs field, and a gauge boson

\( \mathcal{L}_{G} \): gauge boson self-energies and self-interactions
THE MOST GENERAL EFFECTIVE HIGGS LAGRANGIAN IN THE MASS BASIS

After electroweak symmetry breaking

\[ W^+ \partial^\mu W^\dagger_{\mu\nu} h \]

\[ W^\nu W^\dagger_{\mu\nu} h \]

\[ W^\nu \tilde{W}^\dagger_{\mu\nu} h \]

\[ i \left[ \eta^{\mu\nu} (g m_W + g_{hww}^1 p_2 \cdot p_3 + g_{hww}^2 (p_2^2 + p_3^2)) - g_{hww}^1 p_2^\nu p_3^\mu - g_{hww}^2 (p_2^\nu p_2^\mu + p_3^\nu p_3^\mu) - \epsilon^{\mu\nu\rho\sigma} \tilde{g}_{hww} p_2^\rho p_3^\sigma \right] \]
HIGGS PRODUCTION IN THE FUTURE ELECTRON-PROTON COLLIDER

Feynman diagrams for charge current

Feynman diagrams for neutral current
**HIGGS PRODUCTION IN ELECTRON-PROTON COLLIDER**

Total production cross section of SM Higgs boson in $e^\pm p$ collisions with $E_e = 140 GeV$ and $E_p = 7 TeV$, as a function of the Higgs Mass.

The full set of interactions generated by the dimension-six operators mentioned in the Higgs Effective Lagrangian $\mathcal{L}_{\text{SILH}}$, $\mathcal{L}_F$, $\mathcal{L}_{\tilde{F}}$, have been implemented in FeynRules (Alloul, Fuks, Comput. Phys. Com. 185, 2250(2014)) and the model is imported to a Universal FeynRules Output (UFO) module (Alloul, Fuks and Sanz, JHEP 1404 (2014)), then, the UFO model files have been inserted in the MadGraph5-aMC@NLO (J. Alwall, et al. JHEP 1407, 079 (2014)). Monte-Carlo (MC) event generator to calculate the cross sections and generate the signal events. The CTEQ6L1 PDF set (Pumplin, et al, JHEP 0207, 012 (2002)) is used as the proton structure functions. The renormalization and factorization scales are set dynamically by MadGraph5-aMC@NLO default. The next-to-leading order QCD correction to the signal process $e^- p \rightarrow h j \nu_e$ is found to be small (Jager, et al., P.R.D 81, 054018 2010), Therefore, in this work the $k_T$ -factor for the signal is assumed to be one. The events of signal process are generated with MadGraph5-aMC@NLO then the Higgs boson decay into a $b\bar{b}$ pair is done with MadSpin module (Artoisenet, et al. JHEP 1303, 015 (2013)).

Representative Feynman diagrams at tree level for the $e^- p \rightarrow h j \nu_e$
in the presence of dimension six operators

\[
\begin{align*}
W^+_W(p_2) & \quad (p_1) \\
W^-_W(p_3) & \quad h(p_1)
\end{align*}
\]

\[
i \left[ \eta^{\mu \nu} (g_{mW} + g_{hww}^{(1)} p_2 \cdot p_3 + g_{hww}^{(2)} (p_2^2 + p_3^2)) \\
- g_{hww}^{(1)} p_2^\mu p_3^\nu - g_{hww}^{(2)} (p_2^\mu p_3^\nu + p_3^\mu p_2^\nu)) - \epsilon^{\mu \nu \rho \sigma} g_{hww} p_2 \rho p_3 \sigma \right]
\]
Representative Feynman diagrams at tree level for the $e^- p \rightarrow hj\nu_e$
in the presence of dimension six operators

The vertices which receive contributions from the $\mathcal{L}_{\text{eff}}$ are shown by filled circles.
**sensitive parameters:**

<table>
<thead>
<tr>
<th>Mass basis</th>
<th>Gauge basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>$g_{hww}^{(1)}$</td>
<td>$\frac{2g}{m_W} \tilde{c}_{HW}$</td>
</tr>
<tr>
<td>$\tilde{g}_{hww}$</td>
<td>$\frac{2g}{m_W} \tilde{c}_{HW}$</td>
</tr>
<tr>
<td>$g_{hww}^{(2)}$</td>
<td>$\frac{g}{m_W} { \tilde{c}<em>W + \tilde{c}</em>{HW} }$</td>
</tr>
<tr>
<td>$g_{hww}^{(L)}$</td>
<td>$\frac{\sqrt{2}g}{v} \tilde{c}_{HQ} V^{CKM}$</td>
</tr>
<tr>
<td>$g_{hww}^{(R)}$</td>
<td>$\frac{\sqrt{2}g}{v} \tilde{c}_{Hud}$</td>
</tr>
<tr>
<td>$g_{hwve}$</td>
<td>$\frac{\sqrt{2}g}{v} \tilde{c}_{HL}$</td>
</tr>
</tbody>
</table>
Backgrounds

Based on the signal final state that consists of missing transverse energy, a pair of $b\bar{b}$ from the Higgs boson decay and a forward jet, the backgrounds include processes with three jets and large missing energy in the final state.

In particular, the following processes have been taken into account:

1) $b\bar{b}j\nu_e$
2) $b\bar{b}j\nu_e$
3) $j'j''j\nu_e$
4) $t\nu_e$
5) $Wj\nu_e$
6) $Zj\nu_e$

\( j' = u, d, c, s \)
\( j = u, d, c, s, b \)
Signal and Backgrounds Production and Simulation

- The electromagnetic and hadronic calorimeters resolutions are considered by the energy smearing of $\frac{5\%}{\sqrt{E \text{ (GeV)}}} \oplus 1\%$, respectively.

- The b-tagging efficiency is assumed to be 60% while mis-tag probabilities of 10% and 1% for c-quark jets and light-quark jets are considered, respectively.

- The tracker of the LHeC detector is expected to cover pseudorapidity range up to 3. Therefore, for the b-tagging performance is valid up to $|\eta_{\text{b-jet}}| < 3$. For the light-jets, the calorimeter coverage is considered to be $|\eta_{\text{light-jet}}| < 5$.

LHeC sensitivity

Jets are reconstructed with a distance parameter for the jet reconstruction algorithm $R = 0.7$.

- $p_{jet}^T > 20$ GeV.
- $E_{miss}^T > 20$ GeV.
- $E_{total}^T > 100$ GeV.

For $E_p = 7\,\text{TeV}, E_e = 60\,\text{GeV}$.

The Higgs boson is reconstructed using the two b-tagged jets which give the closest mass to the nominal Higgs mass, 125 GeV. The figure show the reconstructed Higgs boson mass.

$$95 \leq M_{\text{Higgs}} \leq 135 \, \text{GeV}$$
**Higgs + jet Mass:**

For $E_p = 7\text{TeV}, E_e = 60\text{GeV}$

Among the light jets, the highest $p_T$ one is taken as the light flavor jet. The figure the invariant mass distribution of the Higgs+jet.

$$260 < M_{\text{Higgs},j} < 1000 \text{ GeV}$$
impacts of all cuts

<table>
<thead>
<tr>
<th>LHeC collider</th>
<th>Signal</th>
<th>Standard Model (SM)</th>
<th>Backgrounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cuts</td>
<td>$\bar{c}_H = 0.1$</td>
<td>$hj\nu_e$</td>
<td>$bjj'\nu_e$ $t\nu_e$ $Wj\nu_e$ $Zj\nu_e$</td>
</tr>
<tr>
<td>Cross sections (in fb)</td>
<td>84.8</td>
<td>94.3</td>
<td>639.5 1287 1885 379.6</td>
</tr>
<tr>
<td>Acceptance cuts</td>
<td>18.10</td>
<td>20.12</td>
<td>12.15 96.76 37.81 16.33</td>
</tr>
<tr>
<td>$95 \leq M_{\text{Higgs}} \leq 135$ (GeV)</td>
<td>9.69</td>
<td>13.07</td>
<td>1.28 23.60 10.08 1.52</td>
</tr>
<tr>
<td>$260 \leq M_{\text{Higgs},j} &lt; 1000$ (GeV)</td>
<td>6.37</td>
<td>7.05</td>
<td>0.45 1.77 0.76 0.72</td>
</tr>
</tbody>
</table>

Cross section (in fb) for signal and background events after applied kinematic cuts used for this analysis at the LHeC with $E_p = 7\text{TeV}, E_e = 60\text{GeV}$.
The sensitivity are obtained using a $\chi^2$ analysis over all bins of $\Delta_{E_{pZ}}$ distribution. It is defined as:

$$\Delta_{E_{pZ}} = (E_{b-jet_1} - p_{z,b-jet_1}) + (E_{b-jet_2} - p_{z,b-jet_2}) + (E_{light-jet_1} - p_{z,light-jet_1}).$$

Normalized distribution for the $\Delta_{E_{pZ}}$ for signal and all background processes after applying all cuts.

$$\chi^2 (\{c_n\}) = \sum_{i=bins}^{N} \frac{\left( f_i (\{c_n\}) - s_{i}^{SM}\right)^2}{\Delta_i^2}.$$ 

$$\{c_n = \overline{c}_H, \overline{c}_{Hud}, \overline{c}_{HW}, \overline{c}_{HL}, \overline{c}_{HQ}, \overline{c}_W, \overline{c}_{HW}\}$$
Sensitivity estimate

\[ \chi^2 (\{c_n\}) = \sum_{i=bins}^{N} \left( \frac{f_i (\{c_n\}) - s_i^{SM}}{\Delta_i^2} \right)^2. \]

- number of signal events in the i-th bin
- SM expectation in the i-th bin
- statistical uncertainty

\[ \{c_n = c_H, c_{Hud}, c_{HW}, c_{HL}, c_{HQ}, c_W, c_{HW}\} \]

\[ f_i (\{c_n\}) = s_i^{SM} + \sum_{n=1}^{7} (\alpha_n c_n + \beta_n c_n^2). \]
## Results

<table>
<thead>
<tr>
<th>Wilson coefficients</th>
<th>LHeC-300 (140 GeV)</th>
<th>LHeC-3000 (140 GeV)</th>
<th>LHeC-300 (60 GeV)</th>
<th>LHeC-3000 (60 GeV)</th>
<th>LHC-3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{c}_H [\times 100]$</td>
<td>$[-0.90, 0.95]$</td>
<td>$[-0.29, 0.29]$</td>
<td>$[-7.8, 8.8]$</td>
<td>$[-2.5, 2.6]$</td>
<td>$[-4.40, 3.50]$</td>
</tr>
<tr>
<td>$\bar{c}_{Hud} [\times 100]$</td>
<td>$[-0.80, 0.80]$</td>
<td>$[-0.25, 0.25]$</td>
<td>$[-6.26, 8.33]$</td>
<td>$[-2.40, 2.86]$</td>
<td>---</td>
</tr>
<tr>
<td>$\bar{c}_{HW} [\times 100]$</td>
<td>$[-1.40, 1.70]$</td>
<td>$[-0.47, 0.50]$</td>
<td>$[-2.3, 2.8]$</td>
<td>$[-0.79, 0.83]$</td>
<td>$[-0.4, 0.4]$</td>
</tr>
<tr>
<td>$\bar{c}'_{HL} [\times 100]$</td>
<td>$[-1.30, 1.40]$</td>
<td>$[-0.40, 0.40]$</td>
<td>$[-8.1, 2.7]$</td>
<td>$[-2.6, 2.7]$</td>
<td>---</td>
</tr>
<tr>
<td>$\bar{c}'_{HQ} [\times 100]$</td>
<td>$[-1.50, 1.60]$</td>
<td>$[-0.50, 0.50]$</td>
<td>$[-2.20, 2.70]$</td>
<td>$[-0.79, 0.76]$</td>
<td>---</td>
</tr>
<tr>
<td>$\bar{c}_W [\times 100]$</td>
<td>$[-1.00, 1.00]$</td>
<td>$[-0.36, 0.37]$</td>
<td>$[-1.20, 1.40]$</td>
<td>$[-0.42, 0.44]$</td>
<td>$[-0.40, 0.40]$</td>
</tr>
<tr>
<td>$\bar{c}_{HW} [\times 100]$</td>
<td>$[-0.70, 0.70]$</td>
<td>$[-0.20, 0.20]$</td>
<td>$[-11.4, 9.2]$</td>
<td>$[-4.2, 3.6]$</td>
<td>---</td>
</tr>
</tbody>
</table>

Predicted constraints at 95% C.L. on dimension-six Wilson coefficients for the LHeC with the electrons energy of $E_e = 60\text{GeV}$ and $E_e = 140\text{GeV}$, and for integrated luminosities of 300 fb$^{-1}$ and 3000 fb$^{-1}$.
when the couplings are varying in the range of -0.03 to 0.03, the cross section at the FCC-he increases by a factor of around 5 with respect to the LHeC.
Results

Predicted constraints at 95% C.L. on dimension-six Wilson coefficients for the LHeC and FCC-he colliders and integrated luminosity of $300 \text{ fb}^{-1}$ and $3000 \text{ fb}^{-1}$.

<table>
<thead>
<tr>
<th>Wilson coefficients</th>
<th>LHeC-300 (140 GeV)</th>
<th>LHeC-3000 (140 GeV)</th>
<th>FCC-he-300</th>
<th>FCC-he-3000</th>
<th>LHC-3000</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\bar{c}_H [\times 100]$</td>
<td>$[-0.90, 0.95]$</td>
<td>$[-0.29, 0.29]$</td>
<td>$[-1.00, 1.00]$</td>
<td>$[-0.30, 0.35]$</td>
<td>$[-4.40, 3.50]$</td>
</tr>
<tr>
<td>$\bar{c}_{Hud} [\times 100]$</td>
<td>$[-0.80, 0.80]$</td>
<td>$[-0.25, 0.25]$</td>
<td>$[-0.90, 0.90]$</td>
<td>$[-0.29, 0.29]$</td>
<td>—</td>
</tr>
<tr>
<td>$\bar{c}_{HW} [\times 100]$</td>
<td>$[-1.40, 1.70]$</td>
<td>$[-0.47, 0.50]$</td>
<td>$[-0.90, 1.00]$</td>
<td>$[-0.30, 0.30]$</td>
<td>$[-0.40, 0.40]$</td>
</tr>
<tr>
<td>$\bar{c}_{HL} [\times 100]$</td>
<td>$[-1.30, 1.40]$</td>
<td>$[-0.40, 0.40]$</td>
<td>$[-1.80, 2.00]$</td>
<td>$[-0.60, 0.66]$</td>
<td>—</td>
</tr>
<tr>
<td>$\bar{c}_{HQ} [\times 100]$</td>
<td>$[-1.50, 1.60]$</td>
<td>$[-0.50, 0.50]$</td>
<td>$[-1.90, 2.00]$</td>
<td>$[-0.60, 0.60]$</td>
<td>—</td>
</tr>
<tr>
<td>$\bar{c}_W [\times 100]$</td>
<td>$[-1.00, 1.00]$</td>
<td>$[-0.36, 0.37]$</td>
<td>$[-0.70, 0.80]$</td>
<td>$[-0.20, 0.20]$</td>
<td>$[-0.40, 0.40]$</td>
</tr>
<tr>
<td>$\bar{c}_{HW} [\times 100]$</td>
<td>$[-0.70, 0.70]$</td>
<td>$[-0.20, 0.20]$</td>
<td>$[-0.90, 0.90]$</td>
<td>$[-0.28, 0.28]$</td>
<td>—</td>
</tr>
</tbody>
</table>
Thanks!
FCC-he sensitivity

FCC-he employs the 50 TeV proton beam of a proposed circular proton-proton collider.

Similar to the LHeC case, FCC-he is sensitive to $C_H$, $C_{Hud}$, $C_{HW}$, $C_{HL}$, $C_{HQ}$, $C_W$, and $\tilde{C}_{HW}$ Wilson coefficients.

The same analysis strategy as presented for the LHeC is followed for the FCC-he.

The Higgs boson decay into $b\bar{b}$ pair is considered and a $\chi^2$-fit is utilized to estimate the sensitivities.
One of the interesting characteristics of the signal events at the FCC-he, which requires to use a particular strategy for reconstruction of the Higgs boson.

At the FCC-he, Higgs bosons of the signal events are produced highly boosted. From the topological point of view, they have a different decay compared to the Higgs bosons which are not boosted.

The angular separation of a $b\bar{b}$ pair produced in a Higgs boson decay can be written as:

$$\Delta R_{bb} \approx \frac{1}{\sqrt{x(1-x)}} \frac{m_H}{p_T}$$

- $\Delta R_{bb}$: momentum fractions of the b-jets.
- $x$: transverse momentum of the Higgs boson.
FCC-he sensitivity

two dimensional plots of angular separation of $b\bar{b}$ pair $\Delta R_{b\bar{b}}$ in terms of the Higgs boson transverse momentum for signal process with $\tilde{c}_{HW} = 0.1$. If the Higgs boson have a transverse momentum $p_T > 300$ GeV, the angular separation between two b-jets from the Higgs decay is $\Delta R < 0.3$. Then, the common jet reconstruction would not be usable for all of signal events. An alternative method of fat jet algorithm is applied (Butterworth, et al. Phys. Rev. Lett. 100, 242001 (2008).) for the boosted Events.
The normalized distribution of $\Delta R$ between Two b-quarks from the Higgs boson decay for the FCC-he. The distributions for two electron energies $E_e = 60$ and 175 GeV, and $E_p = 50$ TeV proton for two signal scenarios $\overline{c}_H = 0.1$ and $\overline{c}_{HW} = 0.1$.

The plot clearly shows that for the signal scenario of $\overline{c}_{HW}$, by increasing the colliding electron beam energy from 60 GeV to 175 GeV the Higgs bosons are produced in boosted regime.