Top Physics at FCC-eh

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Precise measurements of couplings between SM gauge bosons and quarks and leptons are sensitive test of new physics (search for deviations), due to its large mass the top quark is expected to be the most sensitive to BSM physics.

The future ep colliders offers excellent prospects for top physics.
TOP QUARK ANOMALOUS CC/NC INTERACTIONS

1) CC
High precision measurements of $V_{tb}$ and search for anomalous $Wtb$ couplings

2) NC
Measurement of top charge/isospin and anomalous $tt\gamma/ttZ$ (EDM,MDM)

3) CC
Search for anomalous top-Higgs couplings

4) NC
Sensitive search for FCNC couplings will constrain BSM models

1) $\bar{b}$

2) $b$ $tt\gamma/ttZ$

3) $\bar{b}$ $tt\gamma/ttZ$

4) $\bar{b}$ $tt\gamma/ttZ$
MEASUREMENT OF $V_{tb}$

The results can also be applied conservatively to the FCC-ep.

The CKM matrix element $V_{tb}$ can be measured with a precision of 0.5%.

arXiv:1307.1688
The updated plots for FCC-eh (a conservative estimate). The errors are systematically limited (assumed to be similar for LHeC and FCC-eh). A better sensitivity to the hadronic channel.

\[ \mathcal{L}_{Wtb} = \frac{g}{\sqrt{2}} \left[ W_{\mu} \bar{t} \gamma^{\mu} (V_{tb} f_{1L}^{L} P_{L} + f_{1R}^{R} P_{R}) b \right. \\
- \frac{1}{2 m_{W}} W_{\mu \nu} \bar{t} \sigma^{\mu \nu} \left( f_{2L}^{L} P_{L} + f_{2R}^{R} P_{R} \right) b \] + h.c.
TOP NC EDM AND MDM

➤ the results can also be applied conservatively to the FCC-ep.

\[ \mathcal{L}_{\bar{t}t\gamma} = e \bar{t} \left( Q_t \gamma^\mu A_\mu + \frac{1}{4m_t} \sigma^{\mu\nu} F_{\mu\nu}(\kappa + i\kappa_5) \right) t \]

Electric dipole moment: \( \tilde{\kappa} \)

LHeC:
8% and 16% accuracy
10% 18%
→ systematically limited

27% accuracy (4.59 fb^{-1}, 7 TeV)

Magnetic dipole moment: \( \kappa \)

Bouzas, Larios,
TOP NC EDM AND MDM

➤ the results can also be applied conservatively to the FCC-ep.

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<table>
<thead>
<tr>
<th>property</th>
<th>precision</th>
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</thead>
<tbody>
<tr>
<td>EDM: $\tilde{K}$ / $\tilde{K}_Z$</td>
<td>0.20–0.28/0.6–0.8</td>
</tr>
<tr>
<td>MDM: $K$ / $K_Z$</td>
<td>0.05–0.09/0.9–1.3</td>
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LHeC: 10% and 18% accuracy
ANOMALOUS FCNC TOP–HIGGS COUPLINGS

H. Sun @DIS17

signal

\[ e^- p \rightarrow \nu_e \bar{t} \rightarrow \nu_e h \bar{q} \rightarrow \nu_e b \bar{b} q, \quad q = u, c \]

background

irreducible backgrounds:

\[ e^- p \rightarrow \nu_e (h \rightarrow b \bar{b}) j \]
\[ e^- p \rightarrow \nu_e (z \rightarrow b \bar{b}) j \]
\[ e^- p \rightarrow \nu_e (g \rightarrow b \bar{b}) j \]

reducible backgrounds:

\[ e^- p \rightarrow \nu_{ejjj} \]
\[ e^- p \rightarrow \nu_{e jjj b / \bar{b}} \]
\[ e^- p \rightarrow \nu_{e \bar{t}} \]
\[ e^- p \rightarrow e^+ jjj \]
\[ e^- p \rightarrow e^- jjj b / \bar{b} \]
\[ e^- p \rightarrow e^- (g \rightarrow b \bar{b}) j \]

- parametrised assumed resolutions for electrons/photons, muons, jets and unclustered energy using ATLAS values
- b-tag rate of 60%, c-jet fake rate of 10%, light-jet fake rate of 1%
- selections optimized for LHeC and FCC–ep scenarios (s/√(S+B))
- cut-based and MVA-based analyses
ANOMALOUS FCNC TOP-HIGGS COUPLINGS

H. Sun, [arXiv:1602.04670]
UPPER LIMITS ON BRANCHINGS

ATLAS, 4.7(20.3) fb$^{-1}@7(8)$ TeV
CMS, 19.5 fb$^{-1}@8$ TeV
LHC, 3000 fb$^{-1}@14$ TeV

→ improves sensitivity of HL-LHC
**TOP QUARK FCNC PRODUCTION**

**Process:** $e^-p\rightarrow e^-Wq+X$.

Signal cross sections at FCC-ep collider depending on FCNC $tq\gamma$ couplings $\lambda_u$ and $\lambda_c$ within the interested range.

**PDF:** NNPDF2.3

+ similar diagrams for $tc\gamma$
(further diagrams for process $e^-p\rightarrow e^-Wq+X$ with the interchange $q\leftarrow q^\sim$)
For the analysis, after pre-selection cuts, we use the analysis cuts for further background suppression

Cut flow

<table>
<thead>
<tr>
<th>Cut</th>
<th>Cut Description</th>
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<tbody>
<tr>
<td>Cut-0</td>
<td>at least one electron and three jets (pre-selection with default MG5 cuts)</td>
</tr>
<tr>
<td>Cut-1</td>
<td>require one of three jets as being b-tag</td>
</tr>
<tr>
<td>Cut-2</td>
<td>b-tagged jet has transverse momentum $p_T&gt;35$ GeV and other jets have $p_T&gt;25$ GeV, and electron has $p_T&gt;20$ GeV</td>
</tr>
<tr>
<td>Cut-3</td>
<td>all jets have pseudo-rapidity $-5.0&lt;\eta&lt;0$; and electron has $-2.5&lt;\eta&lt;2.5$</td>
</tr>
<tr>
<td>Cut-4</td>
<td>invariant mass of two jets within $50&lt;m_{jj}&lt;90$ GeV (for W- boson)</td>
</tr>
<tr>
<td>Cut-5</td>
<td>invariant mass of three jets (for top) between $130&lt;m_{b jj}&lt;200$ GeV</td>
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FCC-EP: (S+B)/B AND RELEVANT Backgrounds

With the relevant backgrounds ($B_T = B_W + B_Z + B_H + B_{tt}$), the ratio $(S+B)/B$ are shown in figure.

Cross sections:
- $\sigma_W = 8.611$ pb
- $\sigma_H = 0.074$ pb
- $\sigma_Z = 0.617$ pb
- $\sigma_{tt} = 0.415$ pb

S: $ep \rightarrow eWj$
Bw: $ep \rightarrow eWj$
Bz: $ep \rightarrow eZj$
BH: $ep \rightarrow eHj$
Btt: $ep \rightarrow tt$

arXiv:1701.06932
FCC-EP: SS PLOT

Statistical significance $SS = \sqrt{2[(S+B_T)\ln(1+S/B_T)-S]}$ for $e^-p\rightarrow e^-+bjet+2j$ with $tq\gamma$ FCNC interactions. Here, we assume equal coupling scenario $\lambda_u = \lambda_c = \lambda$.

All relevant backgrounds ($B_T$) are included, 3$\sigma$ significance: at $\lambda=0.01$ for $L_{int}=40/fb$.

* Compare with LHeC when $\lambda_q=0.01$ for $L_{int}=80/fb$.

We find 3$\sigma$ signal significance result to reach an upper limit $\lambda=0.01$, with integrated luminosity of 40/fb at FCC-ep and 80/fb at LHeC. This limit on the coupling can also be translated to the branching ratio $BR(t\rightarrow q\gamma)=2\times10^{-5}$. 
CONCLUSION

- In this talk we present a short overview of the top physics at the ep colliders, which has a rich top physics programme. The selected results include, but not limited to:
  - Sensitivity to Wtb vertex with $f_V^L \sim 10^{-3}$ and $f_T^L \sim 10^{-2}$
  - The CKM matrix element $V_{tb}$ with a precision of 0.5%
  - Anomalous $tt\gamma$ / $ttZ$ couplings with precision 0.20/0.6 (EDM) and 0.05/0.9 (MDM)
  - Improvement in probing top-Higgs FCNC couplings to have $BR(t \to q\gamma) \sim 10^{-3}$ comparing to current LHC experiments
  - CP nature of $ttH$ couplings can be tested to $\zeta_t \sim \pi/5$ (at LHeC)
  - Top FCNC $tq\gamma$ couplings can be measured down to $\lambda_q \sim 10^{-2}$ and it can be translated into branching ratio $BR(t \to q\gamma) \sim 2 \times 10^{-5}$ at the FCC-eh

- Some of these topics are being studied with the updated LHeC and FCC-eh Delphes detector simulation.
FUTURE PROSPECTS OF EP COLLIDERS

LHeC
7 TeV proton of LHC and 60 GeV electron ($\sqrt{s} \sim 1.3$ TeV)

FCC-he
50 TeV proton of FCC and 60 GeV electron ($\sqrt{s} \sim 3.5$ TeV)
COMPARISON: TOP FCNC AT LHC

Based on proton-proton collisions at 8 TeV within the CMS detector at the LHC at an integrated luminosity of 19.8 fb$^{-1}$, the limits (95% CL) on the top quark FCNC couplings

$$L_{\text{eff}} = -e Q_t \sum_{q=u,c} \frac{i}{\Lambda} \sigma^\mu^\nu q_\mu (\kappa_{tq\gamma}^L P_L + \kappa_{tq\gamma}^R P_R) t A_\mu + \text{h.c.}$$

BR($t \to u\gamma$) = 1.7 x 10^{-4}

BR($t \to c\gamma$) = 2.2 x 10^{-3}

CMS Collab. JHEP04(2016)035