Exotic Higgs Decays at the LHeC

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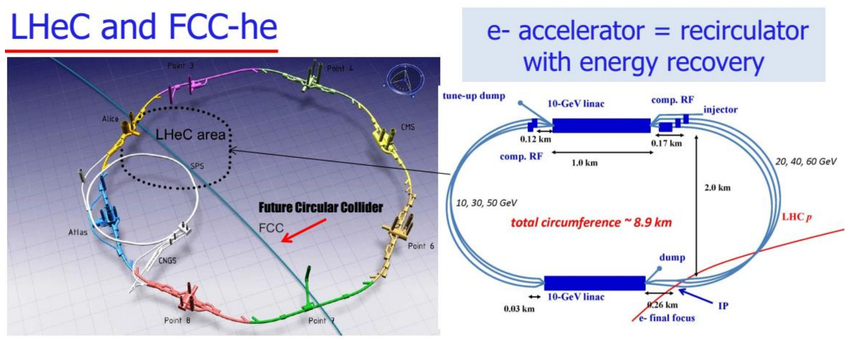
Based on: Yi-Lei Tang, **Chen Zhang**, Shou-hua Zhu, PRD**94**, 011702; Shang Liu, Yi-Lei Tang, **Chen Zhang**, Shou-hua Zhu, arXiv: 1608.08458
Abstract: I will discuss the prospects of searching for exotic Higgs decays at the proposed Large Hadron Electron Collider (LHeC), which is a high luminosity electron-proton collider expected to run synchronously with the HL-LHC. Two examples will be presented, namely the invisible Higgs decay and the Higgs decaying to 4b via intermediate scalars. Compared to the HL-LHC, the LHeC is demonstrated to yield at least comparable sensitivity in the invisible Higgs channel and much better sensitivity in the Higgs to 4b channel. These results are very attractive if there is no available lepton collider which can copiously produce the Higgs boson before the end of the HL-LHC.

Motivation

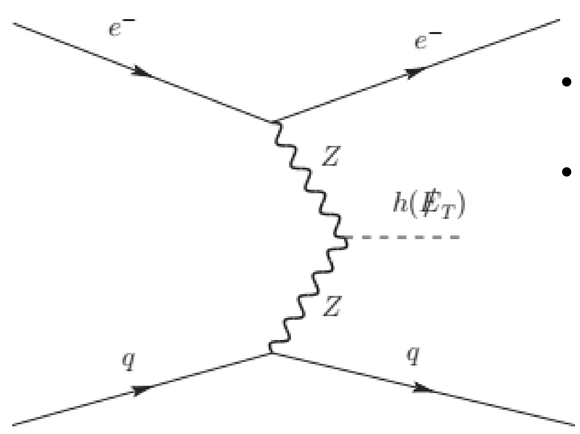
- Exotic Higgs decays are well-motivated signatures in a wide class of BSM theories. They provide interesting probes of light new physics scenarios which are not less important than heavy new physics scenarios.
- Two of the important exotic Higgs decay channels are invisible Higgs decay and h→ϕϕ→4b (ϕ denotes a spin-0 particle).
- Exotic Higgs decay searches at the (HL-)LHC could suffer from large backgrounds, pile-up effects and difficult control of systematics.
- On the other hand, there is non-negligible probability that a lepton collider with sufficient c.m.s energy to produce Higgs bosons won't be available before the end of the HL-LHC.
- Therefore it is important to consider other options to go beyond the HL-LHC sensitivity in the HL-LHC era.

LHeC Facts

- The LHeC[1] is designed to collide a **60 GeV** electron beam (80%~90% left-handed) against the **7 TeV** HL-LHC proton beam.
- The integrated luminosity can reach **1 ab^{-1}**.
- Compared to HL-LHC, the LHeC **does not suffer from pile-up**.
- The tracker and muon detector of the LHeC are expected to have a **very large pseudorapidity coverage**.



Invisible Higgs Decay



- NC channel, ~25fb before Higgs decay
- Backgrounds: Wje, Wjv, Zje, other (top, e+multijet, PHP)
- Parton-level cut-based sensitivity: probing **Br(h->invisible) =6%@2σ** level with 1 ab^{-1} [2].

Cross Section (fb)	Basic Cuts	$\not{E}_T > 70$ GeV	$I > 1$	$\eta_j - \eta_e > 3.0$	$\Delta\phi_{ej} < 1.2$	$\eta_e \in [-1.2, 0.6]$	$y \in [0.06, 0.5]$	Lepton Veto
Signal ($C^2_{\rm MET} = 1$)	16.1	8.80	8.23	4.68	2.37	2.16	1.77	1.77
Wje	816	158	143	51.7	13.9	11.3	9.13	1.96
$Wj\nu$	192	102	101	5.68	2.36	1.33	0.387	0.387
Zje	42.7	13.8	12.1	1.64	0.683	0.464	0.326	0.326

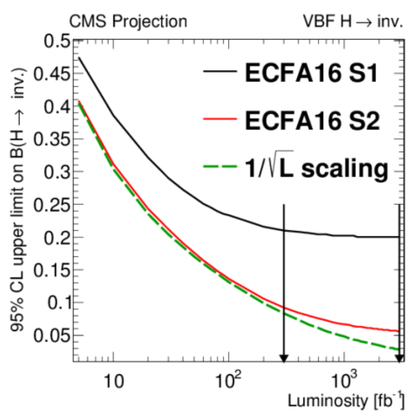
TABLE I: The cross section (in unit of fb) of the signal and major backgrounds after application of each cut in the corresponding column. Other backgrounds contribute less than 0.1 fb in total after all cuts and are not displayed in the table.

Detector level study with MVA Probing **4.6% Br @ 2σ** with 1 ab^{-1}. (Preliminary results by S. Kawaguchi and M. Kuze, Tokyo Institute of Technology)

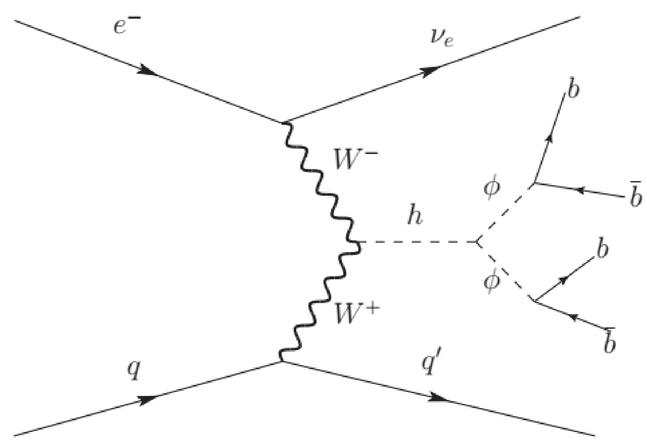
Comparison with the HL-LHC

BR(H →inv.) limits at 95% (90%) CL	300 fb^{-1}	3000 fb^{-1}
Realistic scenario	23% (19%)	8.0% (6.7%)
Conservative scenario	32% (27%)	16% (13%)

ZH Channel (ATLAS) [3]
VBF Channel (CMS) [4]
(Based on extrapolation, probing 5.6% Br @ 95%CL, sensitive to assumptions on systematics.)



h→ϕϕ→4b



- Very difficult decay channel at the HL-LHC
- CC channel, ~200fb before Higgs decay
- Backgrounds: CC multijet, CC t/h/W/Z+jets, PHP multijet.
- PHP backgrounds assumed to be negligible after MET requirements and electron tagging.
- Parton level analysis [5].

$$C^2_{4b} = \kappa_V^2 \times \mathrm{Br}(h \to \phi\phi) \times \mathrm{Br}^2(\phi \to b\bar{b})$$

Event selection

- Basic cuts: $p_{Tj} > 20$ GeV, $|\eta_j| < 5.0, \Delta R_{jj} > 0.4$
- MET > E_0 = 40 GeV
- 4b-tagging: At least 4 b-tagged jets in $|\eta| < 5.0$
- 4b mass window: $|m_{4b} - m_h| < 20$ GeV
- 2b mass window for "correct grouping":

$$|m_{2b,i} - m_\phi| < 10 \text{ GeV}, \; i = 1, 2$$

Jet energy smearing

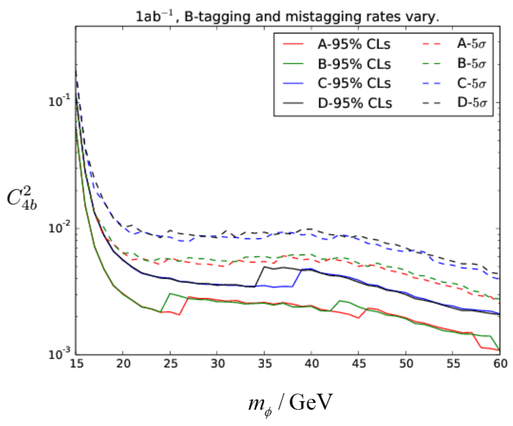
$$\frac{\sigma_E}{E} = \frac{\alpha}{\sqrt{E}} \oplus \beta$$

$$\alpha = 0.45 \text{ GeV}^{1/2}, \beta = 0.03$$

b-tagging 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) $\epsilon_b = 60\%, \epsilon_c = 20\%, \epsilon_{g,u,d,s} = 1\%$

Sensitivity



Conclusion and Discussion

- If a lepton collider Higgs factory is not available before the end of the HL-LHC, then the LHeC will be the only option at our hand to go beyond the original HL-LHC sensitivity for Higgs physics in the HL-LHC era.
- Compared to the HL-LHC, the LHeC may provide competitive sensitivity in the invisible Higgs channel and much better sensitivity in h→ϕϕ→4b channel. It is also valuable to consider other exotic Higgs decay channels at the LHeC.

References

[1] For latest LHeC information, see: lhec.web.cern.ch
[2] Yi-Lei Tang, **Chen Zhang**, Shou-hua Zhu, PRD**94**, 011702
[3] ATLAS-PHYS-PUB-2013-014
[4] CMS DP 2016/064
[5] Shang Liu, Yi-Lei Tang, **Chen Zhang**, Shou-hua Zhu, arXiv: 1608.08458