FCCWEEK2016
ROME 11-15 APRIL

Opportunities for Higgs Physics at Future Electron-Proton Colliders

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FCC Week 2016

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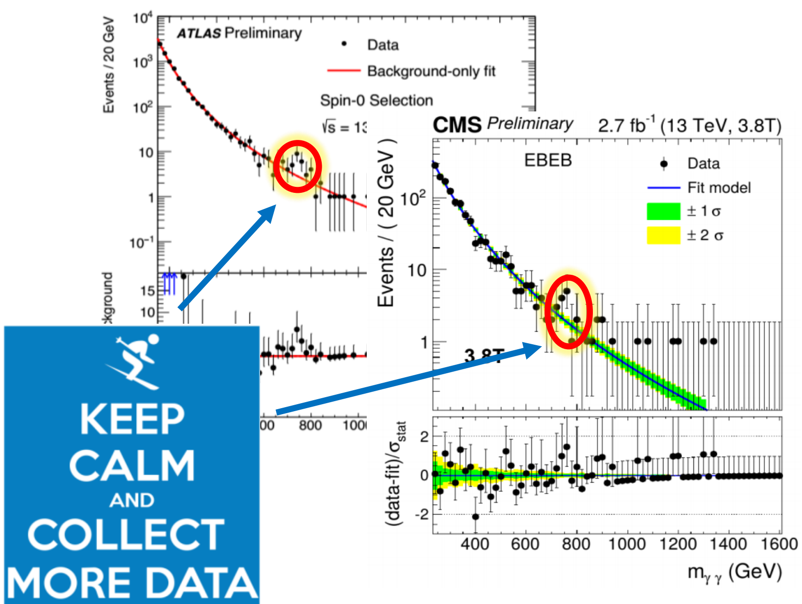
A Critical Point in Search of New Physics

- Experimental status:
  - SM+GR consistent with all observations so far.
- Theoretical side:
  - Naturalness is highly debated.



- Note: Issues like DM, neutrino mass do not necessarily imply new physics which can be probed at forseeable colliders.

A Critical Point in Search of New Physics

- With no definite experimental clue and irrefutable theoretical guideline at hand, measuring precisely what we already have (eg. Higgs) could become progressively important, both as precision tests of SM and avenues to NP.

Physics Letters B 716 (2012) 1–29

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Physics Letters B

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ELSEVIER

Observation of a new particle in the search for the Standard Model Higgs boson with the ATLAS detector at the LHC ☆

ATLAS Collaboration *

This paper is dedicated to the memory of our ATLAS colleagues who did not live to see the full impact and significance of their contributions to the experiment.

ARTICLE INFO

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ABSTRACT

A search for the Standard Model Higgs boson in proton–proton collisions with the ATLAS detector at the LHC is presented. The datasets used correspond to integrated luminosities of approximately 4.8 fb^{-1} collected at $\sqrt{s} = 7$ TeV in 2011 and 5.8 fb^{-1} at $\sqrt{s} = 8$ TeV in 2012. Individual searches in the channels $H \to ZZ^{(*)} \to 4\ell$, $H \to \gamma\gamma$ and $H \to WW^{(*)} \to e\nu\mu\nu$ in the 8 TeV data are combined with previously published results of searches for $H \to ZZ^{(*)}$, $WW^{(*)}$, $b\bar{b}$ and $\tau^+\tau^-$ in the 7 TeV data and results from improved analyses of the $H \to ZZ^{(*)} \to 4\ell$ and $H \to \gamma\gamma$ channels in the 7 TeV data. Clear evidence for the production of a neutral boson with a measured mass of 126.0 ± 0.4 (stat) ± 0.4 (sys) GeV is presented. This observation, which has a significance of 5.9 standard deviations, corresponding to a background fluctuation probability of 1.7×10^{-9}, is compatible with the production and decay of the Standard Model Higgs boson.

Physics Letters B 716 (2012) 30–61

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Physics Letters B

www.elsevier.com/locate/physletb

ELSEVIER

Observation of a new boson at a mass of 125 GeV with the CMS experiment at the LHC ☆

CMS Collaboration *

CERN, Switzerland

This paper is dedicated to the memory of our colleagues who worked on CMS but have since passed away. In recognition of their many contributions to the achievement of this observation.

ARTICLE INFO

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ABSTRACT

Results are presented from searches for the standard model Higgs boson in proton–proton collisions at $\sqrt{s} = 7$ and 8 TeV in the Compact Muon Solenoid experiment at the LHC, using data samples corresponding to integrated luminosities of up to 5.1 fb^{-1} at 7 TeV and 5.3 fb^{-1} at 8 TeV. The search is performed in five decay modes: $\gamma\gamma$, ZZ, W^+W^-, $\tau^+\tau^-$, and $b\bar{b}$. An excess of events is observed above the expected background, with a local significance of 5.0 standard deviations, at a mass near 125 GeV, signalling the production of a new particle. The expected significance for a standard model Higgs boson of that mass is 5.8 standard deviations. The excess is most significant in the two decay modes with the best mass resolution, $\gamma\gamma$ and ZZ; a fit to these signals gives a mass of 125.3 ± 0.4(stat.) ± 0.5(syst.) GeV. The decay to two photons indicates that the new particle is a boson with spin different from one.

The Phenomenological Higgs Landscape

- Mass
- Width
- Spin-Parity
- Coupling
  - hVV, hff
  - 3h,4h, hhVV
  - FCNC Higgs coupling

- Exotic Higgs Decay
  - h to invisible
  - h to 4b
  - …

PHYSICAL REVIEW D **90,** 075004 (2014)

Exotic decays of the 125 GeV Higgs boson

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D. Curtin et al., Phys.Rev. D90 (2014) no.7, 075004

Contents

Well-Motivated & Extremely Rich Signatures!

D. Curtin et al., Phys.Rev. D90 (2014) no.7, 075004

Collider Type Considerations

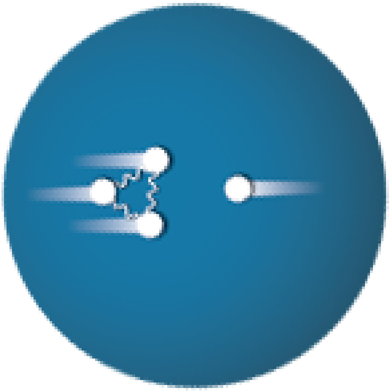
- (HL-)LHC
  - Large signal cross sections
  - Large backgrounds
  - Large pile-up
    - Higher thresholds needed to control systematics
    - Significant impact on the performance of objects like jet and MET

Significant impact on exotic Higgs decay searches due to soft objetcs involved

- Electron-positron collider
  - Small backgrounds
  - Pile-up negligible
  - Small signal cross sections
  - Probably available after the end of HL-LHC

Collider Type Considerations

- LHeC
  - Small backgrounds
  - Pile-up negligible
  - Small signal cross sections



Case Study: Invisible Higgs Decay @ LHeC

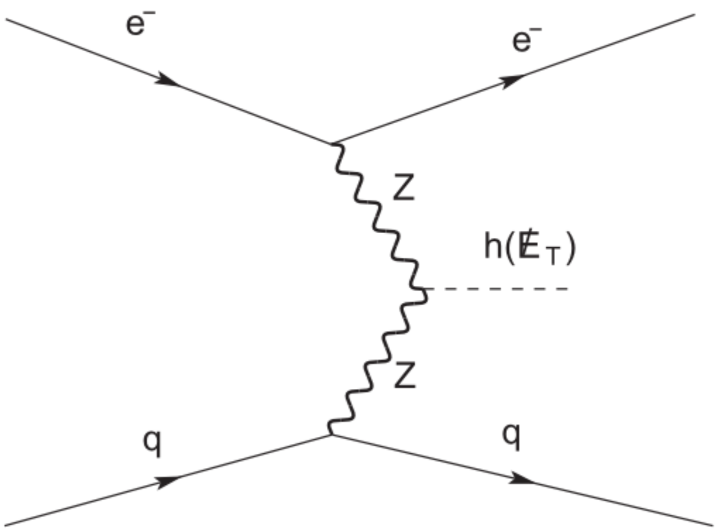
(Based on 1508.01095, Yi-Lei Tang, Chen Zhang and Shou-hua Zhu)

- Important and well-motivated signature in many types of BSM & regular constraint on DM models, complementary to DM direct detection.
- LHeC parameters used in the study:
  - 7 TeV proton
  - 60 GeV electron (-0.9 polarized)
  - Integrated luminosity up to 1 ab^{-1}
  - Very large pseudorapidity coverage (up to 5.0)

Case Study: Invisible Higgs Decay @ LHeC

(Based on 1508.01095, Yi-Lei Tang, Chen Zhang and Shou-hua Zhu)

Signal



Signal cross section ~ 20fb before Higgs decay & cuts

Backgrounds

- Wje
- Wjν
- Zje
- Other (top quark, photoproduction, e+multijet etc.)

No Alpha_s @LO!

Case Study: Invisible Higgs Decay @ LHeC

(Based on 1508.01095, Yi-Lei Tang, Chen Zhang and Shou-hua Zhu)

Signal (100% invisible)~1.8fb
Total background~2.7fb

$$C_{\mathrm{MET}}^{2} = \kappa_V^2 \times \mathrm{Br}(\mathrm{h} \rightarrow invisible)$$

Br(h->inv)=6%@2σ level with 1 ab^{-1}, exceeding ZH@HL-LHC!

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 ($C_{\mathrm{MET}}^2 = 1$)	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.

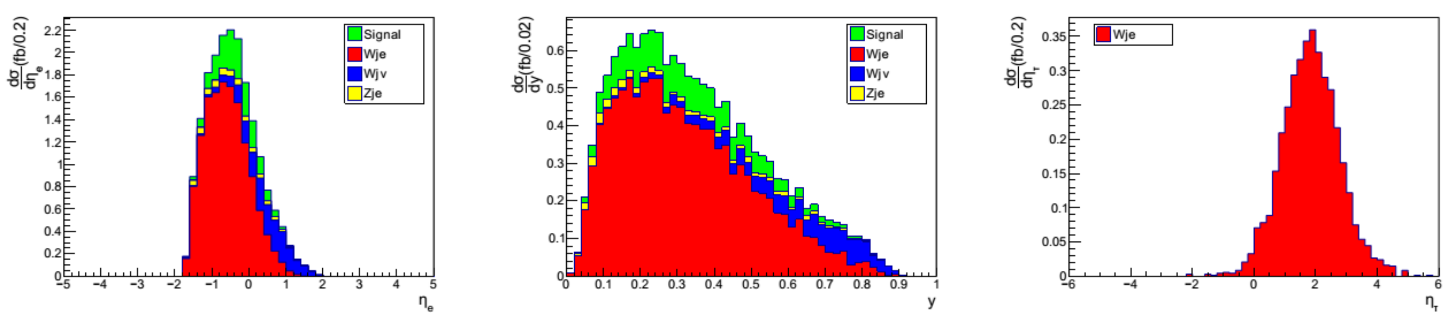
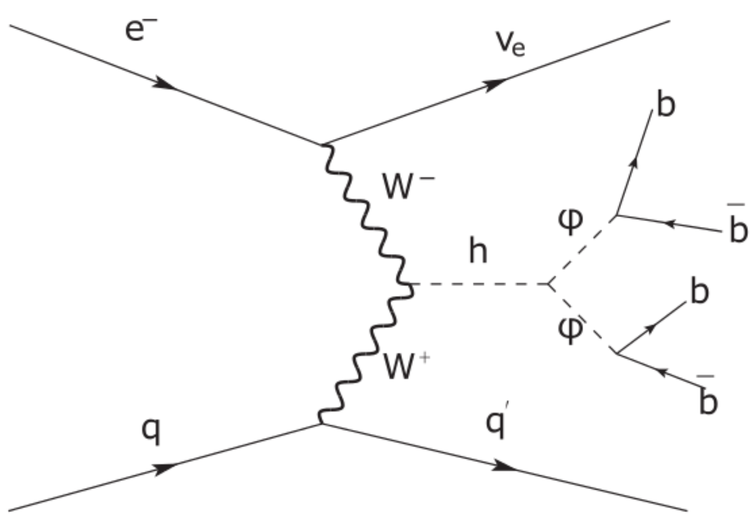


FIG. 2: Left: η_e distribution of the signal and major backgrounds just before the η_e cut. Middle: y distribution of the signal and major backgrounds just before the y cut. Right: τ lepton pseudorapidity distribution of the $Wje(W \rightarrow \tau\nu)$ background just before the lepton veto.

More General Considerations

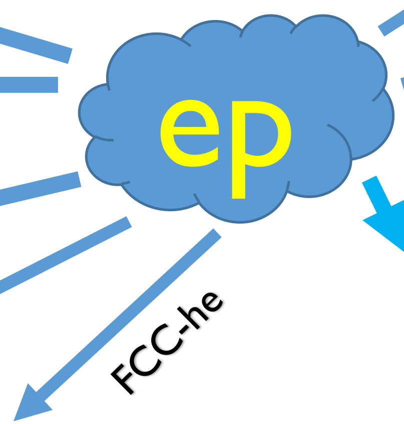
- Lepton-hadron colliders are suited to studying those exotic Higgs decays which suffer from large backgrounds at hadron-hadron colliders, such as h to 4b. (Work in progress)



The Phenomenological Higgs Landscape (Revisited)

Future ep colliders could make important contribution to Higgs physics!

- Mass
- Width **(via VV scattering)**
- Spin-Parity
- Coupling
  - hVV, hff
  - 3h,4h, hhVV
  - FCNC coupling



- Exotic Higgs Decay
  - h to invisible
  - h to 4b
  - …

➢ Reducing PDF & Alpha_s uncertainties in Higgs measurements

See talk given by Voica Radescu

Philosophy could be traced back to
Phys. Rev. D82 (2010) 016009 by T. Han and B. Mellado.

See also:
M. Kumar et al., 1509.04016
S. S. Biswal et al., Phys. Rev. Lett. 109 (2012) 261801
U. Klein, talk given at LHeC Workshop 2015

FCC-he Case

- Most Higgs analyses done at LHeC could be extended to FCC-he in a straightforward manner, with better sensitivity expected.
- Some new channels (e.g. double-Higgs) could be probed at FCC-he (while LHeC does not have enough sensitivity).
- FCC-he might play a role which is unprecedentedly important in boosting precision Higgs studies in conjunction with the concurrent FCC-hh.

Summary

- LHeC is shown to offer promising sensitivity to probe invisible Higgs decay.
- Future electron-proton colliders are suited to studying a lot more well-motivated exotic Higgs decay processes.
- We should not forget high-energy electron-proton colliders when considering future precision Higgs projects.

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Thank you!