

WG2 Higgs & EWSB status report

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Theory: Stefania Gori, Francesco Riva,
Experiment: Maria Cepeda, Phil Ilten, Marumi Kado

Workshop on the physics of HL-LHC, and perspectives at HE-LHC

Fermilab, April 4, 2018

Open questions/unknowns

The **LHC discovery of the 125 GeV Higgs boson** has been a milestone for fundamental physics

What's next?

Is the Higgs, the Higgs of the Standard Model? With what precision?

Is the Higgs the only source of Electroweak Symmetry Breaking?

What is the shape of the Higgs potential (Higgs quartic coupling)?

Does the Higgs have new decay modes?

Does the Higgs violate CP?



Many potential answer can be obtained at HL-LHC or HE-LHC

Overview, Higgs & EWSB

Some organization principles of our work in view of the [Yellow report](#):

1. Precision Measurements

(indirect BSM probe through EFT)



1.1 Low energy
Higgs couplings

1.2 High energy
differential measures.

2. Rare Higgs Processes & New resonances



2.1 SM Higgs
boson

2.2 New Higgs
bosons


High lumi


High energy

S.Gori summary talk at the CERN kickoff-meeting, Nov.1, 2017

Structure of the Higgs Chapter

After the CERN Kick-off meeting, we have defined the goals:

1. Introduction: Main goals and timeline
2. Precision Higgs physics (parts in collaboration with **SM WG1**)
3. Di-Higgs production and Higgs self couplings
4. Other high energy probes
5. The Higgs boson mass and width
6. Invisible decays of the Higgs boson
7. Higgs flavor and rare decays (in collaboration with **flavor WG4**)
8. Global view with HE/HL-LHC
9. BSM Higgs (parts in collaboration with **BSM WG3**)
10. Conclusions and outlook

Budget of approximately 150 pages for Higgs

Structure of the Higgs Chapter

More in details:

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHEWG2>

- 1 **Introduction: Main goals and timeline**
- 2 **Precision Higgs physics**
 - a Channels reach in diboson decays, including fiducial and differential measurements.
 - b Channels reach in main Yukawa couplings
 - c Special focus on direct and indirect probe of top Yukawa coupling
 - d Progress on TH uncertainties: what to expect?
 - e Impact from PDFs and α_S on Higgs measurements.
 - f Progress on Higgs specific MC.
 - g HE Cross-sections.
 - h Higgs couplings precision overview.
 - i Probes using differential distributions of CP sensitive observables.
 - j Interpretation in terms of Composite Higgs and the MSSM.
 - k EFT and Pseudo Observables: synthesis.
- 3 **Di-Higgs production and Higgs self couplings**
 - a SM Calculation.
 - b Double Higgs measurements and trilinear coupling.
 - c Indirect probes of the trilinear coupling through differential distributions measurements.
 - d Indirect probes through single Higgs boson production.
 - e Theory Implications
- 4 **Other high energy probes**
 - a Measuring Offshell couplings
 - b $t\bar{t}h$ differential measurements
 - c WH/ZH at high energy/luminosity
 - d $WW WZ$ at high energy/luminosity
 - e VBF
 - f longitudinal VBS and di-Higgs
- 5 **The higgs boson mass and width**
 - a Theory review
 - b Measurement of the Higgs boson mass.
 - c Mass shift from the diphoton interference: constraints on the width.
 - d Direct constraints from the Higgs boson lineshape.
 - e Direct constraints from the Higgs boson lifetime measurements.
 - f Width from Off-Shell higgs boson couplings.
 - g Width from the diphoton interference rate.
- 6 **Invisible decays of the Higgs boson**
 - a Main channels for direct searches.
 - b Interpretation and combination with precision Higgs boson measurements
 - c Higgs portal interpretations.
- 7 **Higgs flavor and rare decays (common with WG4)**
 - a Flavor aspects Yukawa modifications in flavor models.
 - b Exclusive Higgs decays.
 - c Flavor tagging (charm and strange).
 - d LFV decays of the Higgs
 - e Yukawa constraints from Higgs distributions.
 - f CP violation in Higgs couplings (τ , $t\bar{t}h$)
- 8 **Global view of Higgs couplings at the HL/HE-LHC**
- 9 **BSM Higgs**
 - a Searches for additional Higgs bosons in fermionic final states (τ aus, b 's, muons and tops)
 - b Searches for additional Higgs bosons in diboson final states.
 - c Searches for intermediate mass Higgs bosons (60 GeV - 120 GeV).
 - d Searches for low mass Higgs bosons (up to 60 GeV).
 - e Covering the MSSM, 2HDMs and the NMSSM.
 - f Searches for unconventional signatures of additional Higgs bosons.
 - g Searches for exotic decays of the Higgs boson
 - i new techniques for reconstructing highly boosted heavy Higgs bosons
 - j Searches for exotic decays of the Higgs boson
- 10 **Conclusions and outlook**

In green the theory contributions

Names of all contributors will be added over the coming weeks

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6 Invisible decays of the Higgs boson

- a Main channels for direct searches.
- b Interpretation and combination with precision Higgs boson measurements
- c Higgs portal interpretations.

**We will share the overleaf draft
with collaborators
in the coming days after the workshop**

- g Searches for exotic decays of the Higgs boson
- i new techniques for reconstructing highly boosted heavy Higgs bosons
- j Searches for exotic decays of the Higgs boson

10 Conclusions and outlook

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Theory effort

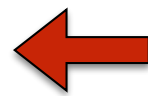
Many activities ongoing:

Precision Higgs

SM theory uncertainties (HL+HE)

SM cross sections (HL+HE)

BSM interpretations of Higgs coupling measurements



In collaboration with WG1 and also with
LHC Higgs cross section working group

EFT interpretations of differential distributions

High energy probes

Di-Higgs

cross section (HL+HE)

feasibility studies (HE)

interpretations in BSM models

Higgs width

Higgs rare and exotic decays (feasibility studies)

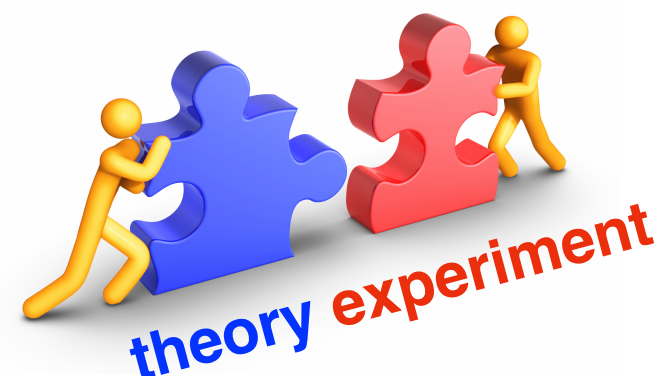
BSM Higgs bosons (feasibility studies + models)



Experimental effort

	CMS	ATLAS	LHCb
Coupling studies	✓✓★	✓✓★	
Differential cross sections	✓★	✓★	
Width		✓	
Anomalous couplings	✓★	✓	
Rare decays	$\mu\mu, CC$	$Z\gamma, J/\psi\gamma, FCNC$ $\mu\mu, \rho\gamma, CC$	H_{cc}/H_{bb}
Exotic decays	LFV; Invisible, DarkSusy; 4jets		
Di-Higgs	✓✓★	✓✓★	
Additional scalars	$A \rightarrow Zh$, high mass $\tau\tau$, low mass $\gamma\gamma$	$\mu\mu, ZZ, A \rightarrow Zh$, $\tau\tau, WW$	

Legend: Past Studies, 2017 TDRs, Wishlist for 2018



Meetings of WG2

More info in the twiki

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHEWG2>

- * CERN kickoff meeting (Oct 30-Nov 1, 2017)
>20 Higgs talks
- * Vidyo meeting (March 20, 2018) <https://indico.cern.ch/event/714119/>
- * Fermilab meeting (April 4-6, 2018)
>20 Higgs talks + 1 discussion session
- * Vidyo meeting (May, 2018, exact date under discussion)
- * CERN plenary meeting (June 18-20, 2018)
- * YR Protodraft ready
- * More vidyo meetings
- * **Yellow Report (end of 2018)**

Conveners (hllhc-wg2-admin@cern.ch):

Theory: Stefania Gori, Francesco Riva,

Experiment: Maria Cepeda (CMS), Phil Ilten (LHCb), Marumi Kado (ATLAS)



Messages from the March meeting

- * **Aim:** Complement the existing prospects aiming for a coherent approach of the ATLAS and CMS studies. Obtain the combined performance of ATLAS+CMS for key cases. Explore the LHCb reach.
- * **Methodology** to extend the coverage: use extrapolations from Run 2 analyses to give more realistic projections, supported by TDR-based understanding analyses with realistic detector performance; plus a number of dedicated Delphes-based analyses
- * Extrapolation to 3000 fb^{-1} based on a double approach: conservative (current experimental uncertainties) vs optimistic (expected floor values for uncertainties)
- * **HE-LHC:** Only selected analyses will be performed with an emphasized disclaimer that these are only extrapolations with no account taken for effects such as a different detector and PU conditions.
- * Wish-list of experimental analyses
- * TH systematic uncertainties from the LHC Higgs cross section working group. Montecarlo statistical uncertainties still to be discussed

WG2 goals of this meeting

Overview past HL/HE Higgs studies

Discuss (preliminary) results for the Yellow report

New contributions?

Are you interested participating to one of the sections?

Are we missing any interesting topic?

Please contact us: hllhc-wg2-admin@cern.ch

Join WG mailing list:

<https://twiki.cern.ch/twiki/bin/view/LHCPhysics/HLHEWG2>

More people needed!

Already more than 100 people subscribed



Structure of the Higgs parallel sessions

Today at 2pm

Theory: SM Higgs precision calculations for the HL/HE LHC *Dr. John CAMPBELL*

All channels except main Yukawa *Prof. Sylvie BRAIBANT*

Top and bottom Yukawas *Alessandro CALANDRI*

IARC First Floor Lecture Hall, Fermilab 14:36 - 14:54

Modified bottom and top Yukawas *Prof. Carlos WAGNER*

SM-Higgs couplings

Higgs at LHeC *Uta KLEIN*

IARC First Floor Lecture Hall, Fermilab 15:12 - 15:30

Tomorrow at 9am

Di-Higgs and EW phase transition *Michael RAMSEY-MUSOLF*

Di-Higgs CMS *Caterina VERNIERI*

IARC 1WA/B First Floor, Fermilab 09:18 - 09:36

Di-Higgs ATLAS *Petar BOKAN*

IARC 1WA/B First Floor, Fermilab 09:36 - 09:54

Di-Higgs in singlet extensions

IARC 1WA/B First Floor, Fermilab

Di-Higgs

Di-Higgs at high energy *Mr. Samuel HOMILLER*

IARC 1WA/B First Floor, Fermilab 10:12 - 10:30

Tomorrow at 11am

Measurements of VBS *Bing LI*

IARC First Floor Lecture Hall, Fermilab 11:00 - 11:21

Differential cross sections (ATLAS+CMS) *Thomas KLIJNSMA*

IARC First Floor Lecture Hall, Fermilab 11:21 - 11:44

SMEFT at HL/HE *Dr. Christopher MURPHY*

IARC First Floor Lecture Hall, Fermilab 11:44 - 12:07

EFT at HL/HE *Dr. Felix KLING*

EFT

IARC First Floor Lecture Hall, Fermilab 12:07 - 12:30

Tomorrow at 4pm

Higgs couplings at high energies *Dorival GONCALVES*

Higgs couplings in the Higgs electroweak chiral Lagrangian *Claudius KRAUSE*

Discussion session *Maria CEPEDA et al.*

Higgs couplings & discussion session

IARC 1WA/B First Floor, Fermilab 16:40 - 17:30

Structure of the joined Higgs sessions

Tomorrow at 2pm

Boosted Object Tagging with Precision Timing at HL-LHC	<i>Matthew Klimek KLIMEK</i>
Gaps in new Higgs searches	<i>Christopher VERHAAREN</i>
Exotic and invisible Higgs decays	<i>Mr. Sven DILDICK</i>
Higgs rare and exotic decays at HL/HE	<i>Zhen LIU</i>
<i>IARC First Floor Lecture Hall, Fermilab 14:54 - 15:12</i>	
Common exotic LHC signatures from underlying models with a composite Higgs	<i>Dr. Thomas FLACKE</i>

Higgs & (WG3) BSM

Friday at 9am

TH perspective on Higgs and Flavour	<i>Emmanuel STAMOU</i>
TH perspective on CP violation in Higgs Couplings (tau, ttH)	<i>Adam MARTIN</i>
<i>IARC First Floor Lecture Hall, Fermilab</i>	
EXP prospects for charm tagging and the Higgs	<i>Dr. Daniel CRAIK</i>
EXP prospects for Higgs and CPV	<i>Ms. Isobel OJALVO</i>
<i>IARC First Floor Lecture Hall, Fermilab 10:08 - 10:30</i>	

Higgs & (WG4) flavor