WG2 Higgs report

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Experiment: Maria Cepeda, Phil Ilten, Marumi Kado

Kickoff meeting
Workshop on the physics of HL-LHC, and perspectives at HE-LHC
November 1, 2017
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

This talk: not a summary! Open questions. Starting a (incomplete) wish list
Overview

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High lumi
High energy

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Precision Program

Low-energy: $\Delta \mathcal{O}/\mathcal{O} \sim m_{\text{EW}}^2 / \Lambda^2 \rightarrow$ Higgs Couplings

High-energy: $\Delta \mathcal{O}/\mathcal{O} \sim E^2 / \Lambda^2 \rightarrow$ VH, VV, tth, VBF, VBS, ...

Typically systematic limited
Statistics limited: Much space for improvement at HL/HE

EFT e.g. $\mathcal{L}^{d=6}$

Precision target: $\ll O(1)$ at high-energy
Low energy: Higgs couplings

From G. Ortona talk

Questions:
- Recent improvement in Run2 analyses not yet propagated to HL-LHC projections. What is the impact?
- Improvement on theory uncertainties?
- What measurements need to be done to improve on limiting systematic uncertainties (fragmentation, hadronisation, underlying event, PDFs, …)
- HE prospects?

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High energy: tth, VH, VBF/VBS

NLO (in SM and BSM) are necessary

Questions:
- can be brought to precision observable?
- accurate high-energy probe?

VH/VBF/VBS

- access to high-E
- systematics reduced by ratios

Questions: backgrounds? Pile-up?
High energy: Di-boson

Equivalence theorem:
vector-bosons $\leftrightarrow$ Higgs boson

Longitudinal Di-bosons:
$pp \rightarrow WZ, Wh, WW, Zh$

Questions:
Other processes? Boosted h?

Transverse Di-bosons:
Measurement of triple gauge couplings

Questions:
Other processes? HE? hadron decays?

Wulzer talk

Elias-Miro talk

S.Gori
Higgs width

Off-shell measurements

$gg \rightarrow VV$, $gg \rightarrow H^* \rightarrow VV$

Questions

- Theory uncertainties?
- (dominant systematic uncertainty)
- Projections for HE
Higgs width

**Off-shell measurements**

\[ \text{gg} \to \text{VV}, \text{gg} \to \text{H}^* \to \text{VV} \]

**Questions**

- Theory uncertainties? (dominant systematic uncertainty)
- Projections for HE

**Interference in**

\[ \text{gg} \to \gamma\gamma, \text{gg} \to \text{H} \to \gamma\gamma \]

**Statistics dominated. Prospects for HE?**

**Ratios between two photons and 4l be used. What precision can be achieved?**
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Higgs & flavor

Higgs couplings to 1\textsuperscript{st} & 2\textsuperscript{nd} generation quarks

Access through:

- Higgs (rare) decays to mesons
- VBF Higgs cross section
- hc associated production
- pT Higgs measurements
- Wh asymmetry
- LHCb: Vh → cc (|κ_{c}| ≤ 2.2)

Questions:

- Prospects in c-tagging; sistematics?
- HL/HE projections for $h → γγ, φγ, ργ$?
- “LHCb @ 27TeV”: access to $κ_{c}$?
- What is the goal for the LHCb s-tagging?
- Additional observables to be exploited?
- $κ_{s}$ measurement at LHeC?
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Higgs flavor violating couplings

Questions:
- How much the HL & HE cut into BSM parameter space?
- How much do we gain with better charm-tagging?
Double Higgs production @ HL

From S. Jezequel talk yesterday

<table>
<thead>
<tr>
<th>HH final state</th>
<th>ATLAS Significance</th>
<th>CMS Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coupling limit (95 % C.L.)</td>
<td></td>
</tr>
<tr>
<td>HH → bbγγ</td>
<td>1.05 σ, -0.8 &lt; λ_{HHH}/λ_{SM} &lt; 7.7</td>
<td>1.43 σ</td>
</tr>
<tr>
<td>HH → bbττ</td>
<td>0.6 σ, -4.0 &lt; λ_{HHH}/λ_{SM} &lt; 12.0</td>
<td>0.39 σ</td>
</tr>
<tr>
<td>HH → bbbb</td>
<td>-3.5 &lt; λ_{HHH}/λ_{SM} &lt; 11.0</td>
<td>0.39 σ</td>
</tr>
<tr>
<td>HH → bbVV</td>
<td></td>
<td>0.45 σ</td>
</tr>
<tr>
<td>ttHH, HH→ bbbb</td>
<td>0.35 σ</td>
<td></td>
</tr>
</tbody>
</table>

Wish list: combination of channels and experiments

Further ideas:
- Detector optimization documented in the TDRs
- Analysis algorithms developed for Run2
- Optimization of analysis for coupling limits

Question raised during the meeting: what about VBF HH?
Double Higgs production @ HE

From S. Jezequel talk yesterday

Using the NLO cross section from G. Heinrich talk yesterday

(127.88^{+11.6\%}_{-10.5\%} \text{ fb})

5K for (at least) one leptonic Z
Double Higgs production @ HE

From S. Jezequel talk yesterday

Using the NLO cross section from G.Heinrich talk yesterday

\[ \text{Nb @ 27 TeV, 10 ab}^{-1} \]

Wish list:

- Study the bbγγ golden channel
- What about bbZZ with one leptonic Z?
- What about sub-leading hh productions? (tthh: \(~4\text{fb}\) VBF hh: \(~7\text{fb}\))
- What about adding the info from signal Higgs? (talk by S.Di Vita yesterday)

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Higgs exotic decays

NP = a for NMSSM

BRexo ~ 5-10% will be still allowed by Higgs fits at the HL-LHC

Searching for light NP particles produced from Higgs decays

see talk of A. Katz
Higgs exotic decays

Searching for light NP particles produced from Higgs decays

BRexo ~ 5-10% will be still allowed by Higgs fits at the HL-LHC

Signatures:

So far, focus on 2f2f' signatures

Statistics limited. Large rates!

Associated Higgs productions with sizable cross sections (tth, WZh, …)
Higgs exotic decays

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Statistics limited.
Large rates!

Associated Higgs productions with sizable cross sections (tth, WZh, ...)

Questions: HL & HE = Higgs factories How to exploit this huge Higgs statistics?

(ggh: 149M at HL; 1300M at HE with 10ab⁻¹, tth: 1.5M at HL; 33M at HE with 10ab⁻¹)

(numbers from K.Hamilton yesterday)

Complementarity with new detectors/experiments: Codex-b, Mathusla, LHeC, ...

(talks by D.Robinson, D.Curtin)

BRexo ~ 5-10% will be still allowed by Higgs fits at the HL-LHC

See talk of A.Katz

NP = a for NMSSM
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New Higgs bosons (heavy)

from K.Hoepfner talk yesterday

**HL & HE CMS & ATLAS projections for this golden channel?**

\[(bb)H \rightarrow \tau\tau\]
New Higgs bosons (heavy)

Question: What about here?

Branching ratios dominated by $tt$:
- prospects for $H \rightarrow tt$ @ HL and HE? (interference!)
- 4top signature?
- 2b2t signature?

Very statistics limited now!
~ 30 events now

In SUSY spectra, smaller branching ratios into electroweak particles (eg. in the tau-phobic, $m_{h}^{\max}$, ...scenarios)

see B.Shakya talk

from SG, Kim, Shah, Zurek, 1602.02782

from K.Hoepfner talk yesterday

HL & HE CMS & ATLAS projections for this golden channel?

$(bb)H \rightarrow \tau\tau$
New Higgs bosons (light)

At present, only a few searches for light (< 125 GeV) scalars: (more studies for Higgs exotic decays to two of these scalars)

Triggers can be an issue

Warning!

\[
\begin{align*}
\gamma\gamma & \quad bbS, \, S \rightarrow \tau\tau & \quad bbS, \, S \rightarrow \mu\mu \\
(65-110)\text{GeV} & \quad (25-80)\text{GeV} & \quad (70-110)\text{GeV}
\end{align*}
\]

Warning!

+ Interpretation of di-muon spectra in terms of light resonances (see Hoenig, et al. 1408.1075)

Questions:

HL will produce a much larger sample of light scalars

- Study of a boosted light scalar?
- Comparative study of the several production modes?
- How low in mass can we get?
- Comparative study with effects on Higgs physics? \( \kappa |H|^2 |S|^2 \)
- Interplay with LHCb searches?
**Additional ideas/wish list**

Discussing during coffee breaks/lunches/emails…

- Define the LHCb HL-LHC detector, or at least scenarios
- Study $gg \rightarrow H_{SM}$ at large $p_T$ (we can afford hard cuts at 27TeV)
- Any interesting Higgs study for forward objects? (LHCb vs. ATLAS & CMS)
- …
Conclusion

A lot of interesting discussions and ideas

Thanks for participating to the kickoff meeting of our WG2!

Please sign up to the WG2 mailing list at
https://indico.cern.ch/event/647676/page/11302-working-groups-conveners-and-mailing-lists-signup

Plan:
We will document the status of the WG2 at the twiki page
We will post there our coming meetings.

Let us start working!

S.Gori