status of 2HDM grids and 2HDM interpretation in $A \rightarrow Zh \rightarrow \ell\ell bb$ analysis

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For HIG-14-011 $A \rightarrow Zh \rightarrow \ell\ell bb$ (now PAS-PUB and waiting for green light for CWR) we had to provide a model-dependent limit in addition to model-independent one ($\sigma B$);

As reference model we used 2HDM (TypeI and TypeII);

- Computed cross-section SuShi 1.2.0 and BR 2HDMC 1.6.4 for a grid of points in the parameter space of 2HDM;
- for different values of $m_A$;
- with reasonable assumption to reduce the number of parameters;
- put all values into a TTTree and produce exclusion plots;

Common issue for other analysis, so we are trying to share the tools;
Documentation about 2HDM parameters used, angle and mass grids, location of TTree, and example how to use them are collected on a TWiki page:
https://twiki.cern.ch/twiki/bin/view/Main/XsBr2HDM

Will briefly summarize here.
\( \sqrt{s} = 8 \text{ TeV} \) (13 TeV can be produced as well);

2HDM Type I and II (not III-IV);

Physical Basis:
\( m_h, m_H, m_A, m^\pm_H, m_{12}, \tan \beta, \cos(\beta - \alpha), \lambda_6, \lambda_7 \)

masses:
- \( m_h = 125 \text{ GeV} \),
- \( m_H = 200 - 1200 \text{ GeV} \),
- \( m_A = 200 - 1200 \text{ GeV} \),
- \( m^\pm_H = m_H \),
- \( m_{12}^2 = m_A^2 \frac{\tan \beta}{1 + \tan^2 \beta} \)

angles:
- \( \tan \beta = 1 - 10 \text{ step 1} \),
- \( -1 < \cos(\beta - \alpha) < 1 \text{ step 0.1} \),
- Angle convention \( 0 < \beta - \alpha < \pi \);

\( \lambda_{6,7} = 0 \)

pdf MSTW2008LO90CL, NLO, NNLO

Renormalization scale:
- \( \mu_F = \mu_R = m_{A/H}/2 \) for gluon-fusion process;
- \( \mu_F = m_{A/H}, \mu_R = m_{A/H}/4 \) for b-associated production;

5FS used.
Grid produced

\[ \tan \beta \text{ vs } \cos(\beta - \alpha) \]

\[ m_A \text{ vs } m_H \]

Angles available for each values of masses
Ranges and steps can be extended/changed.

Fine sampling \( m_{A/H} < 2m_{top} \), with \( m_A = m_H \)
Coarser sampling \( m_H > 2m_{top} \), full grid.
Tree structure

Quality
validity
stability
perturbativity
unitarity

Masses
mA
\gamma_A
mH
\gamma_H
m_{HC}
\gamma_{HC}
m_{12}

* do we need also \gamma_H?

Angles
tan\beta
\alpha
\sin\beta
\cos\beta

x-sections
ggA
bbA
ggH
bbH

BR (see next slide)
- BR_h
- BRA
- BRH
- BR_{HC}
### Brancing Ratios

saved as c-struct: `BRh_bb`

<table>
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<tr>
<th>h→ xy</th>
<th>A→ xy</th>
<th>H→ xy</th>
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<table>
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* Some BR are forbidden for some A, H, H± masses (eg. H±→tt, H→hh, ...). Now wrong by a factor 2.
Testing with Scenarios A/B/C

In order to see if all setup was correct, I’ve tested it comparing with the results in D. Eriksson, J. Rathsman, O. Stål, arXiv:1312.5571 for scenarios A/B/C

<table>
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<th>Scenario</th>
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<th>B</th>
<th>C</th>
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<td>ggA</td>
<td>5.4635095</td>
<td>5.3575649</td>
<td>0.0359630</td>
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<td>5.639</td>
<td>5.355</td>
<td>0.03575</td>
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<td>bbA</td>
<td>0.0021459</td>
<td>28.941694</td>
<td>0.0666051</td>
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<td>ggH</td>
<td>0.0982994</td>
<td>2.7602992</td>
<td>0.038460</td>
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<tr>
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<tr>
<td>paper</td>
<td>0.000207</td>
<td>18.4</td>
<td>0.200</td>
</tr>
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</table>

Full tables (including BR) are on the TWiki: results in agreement, although not identical.
Produced a grid of x-section (ggA+bbA)

BR ($A \rightarrow Zh$) and ($h \rightarrow bb$ can be different from SM!). $Z \rightarrow \ell\ell$ from PDG.

Check against literature (visually)

Understand valley for $\mathcal{B}(h \rightarrow bb) = 0$

Use the $\sigma \times \mathcal{B}$ expected and observed limit to produce the final exclusion plot for various $m_A$. 

- Type I 2HDM = 300 GeV

- Type II 2HDM = 300 GeV

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Summary

- System is set-up and first grid production is available;
  - Trees in afs: ~slacapra/public/2HDM
  - details on TWiki page: https://twiki.cern.ch/twiki/bin/view/Main/XsBr2HDM#Trees_produced

- Setup has been tested against Scenarios A/B/C of: D.Eriksson, J.Rathsman, O.Stål, arXiv:1312.5571

- Feedback welcome! already got some, thanks!

- Extended of finer grid can be produced easily (it’s basically just CPU) upon request.
How to use the tree

The simplest way is to Draw directly from the three the wanted quantities as a function of whatever, then create a TGraph(2D) and fill it with the drawn points, and finally draw the TGraph(2D) according to your need.

Example 1D: (Example 2D next slide)

Tree2HDM.Draw("ggA+bbA:mA")
TGraph *gr=new TGraph(Tree2HDM.GetSelectedRows(),
    Tree2HDM.GetV2(),
    Tree2HDM.GetV1())
gr->GetYaxis()->SetTitle("#sigma(gg\rightarrow A+bb\rightarrow bbA) [pb]")
gr->GetXaxis()->SetTitle("m_{A} [GeV]"")
gr->Draw("al")
How to use the tree II

Example 2D (I have a simple macro for this):

Tree2HDM.Draw("(ggA+bbA)*BRA.Zh*BRh.bb:tanbeta:cosba")
TGraph2D *gr2=new TGraph2D(Tree2HDM.GetSelectedRows(),
    Tree2HDM.GetV2(), Tree2HDM.GetV3(), Tree2HDM.GetV1())
gr2->Draw("lego2")
gr2->GetXaxis()->SetTitle("#tan#beta")
gr2->GetYaxis()->SetTitle("#cos(#beta-#alpha)")
gr2->GetZaxis()->SetTitle("#sigma(pp#rightarrowA)*BR(A#rightarrowZh)*BR(h#rightarrowbb")
gr2->Draw("")

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Test TTrees and macros

In my afs public area: ~slacapra/public/2HDM

- **Summary_2HDM_ty*_mAXXX_mHXXX.root *=1,2 ; mA==mH==XXX in 200 - 350 with 10 GeV step**

- **Summary_2HDM_ty*_mA200-1200_mHYYY.root *=1,2 ; mH==YYY in (400 - 1200 range with step 100) and with mA in (200 - 1200 with step 100) for every mH.**

Also some example macro to show how to use the TTrees;
Macros

plot.C
to plot 1D or 2D of any variables: you need to change the tree to select the mass you want.

.L plot.C
plot2d("(ggH)*BRH.gamgam:cosba:tanbeta",
        "abs(cosba)<0.6", "COLZ")
plot("(ggH)*BRH.gamgam:cosba","","")

plotChain.C:
Example macro to load a chain of all trees and plot 1D and 2D
You need to create a list with the trees you want to put in the chain: the idea is to have all the TypeI and TypeII separately.

.L plotChain.C
plot2d("(bbA+ggA)*BRA.Zh*BRh.bb:cosba:tanbeta",
        "mA==300 && mH==300","lego2")