

Status of 2HDM grid production and 2HDM interpretation in $A \rightarrow Zh \rightarrow llbb$ analysis

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Intro

- For HIG-14-011 $A \rightarrow Zh \rightarrow llbb$ (now PAS-PUB and waiting for green light for CWR) we had to provide a model-dependent limit in addition to model-independent one ($\sigma * \mathcal{B}$);
- As reference model we used 2HDM (Typel and Typell);
 - ▶ 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 TTree and produce exclusion plots;
- Common issue for other analysis, so we are trying to share the tools;

Documentation

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 Typel and II (not III-IV);
- **Physical Basis:**
 $m_h, m_H, m_A, m_{H^\pm}, m_{12}, \tan \beta,$
 $\cos(\beta - \alpha), \lambda_6, \lambda_7$
- **masses:**
 - ▶ $m_h = 125 \text{ GeV},$
 - ▶ $m_H = 200 - 1200 \text{ GeV},$
 - ▶ $m_A = 200 - 1200 \text{ GeV},$
 - ▶ $m_{H^\pm} = m_H,$
 - ▶ $m_{12}^2 = m_A^2 \frac{\tan \beta}{1 + \tan^2 \beta}$

- **angles:**

- ▶ $\tan \beta = 1 - 10$ step 1;
- ▶ $-1 < \cos(\beta - \alpha) < 1$ step 0.1;
- ▶ Angle convention
 $0 < \beta - \alpha < \pi;$

- $\lambda_{6,7} = 0$

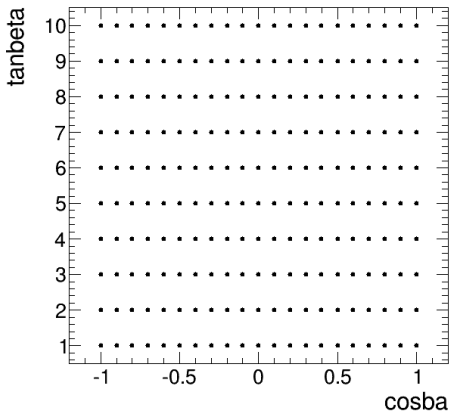
pdf MSTW2008LO90CL, NLO, NNLO

- **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.

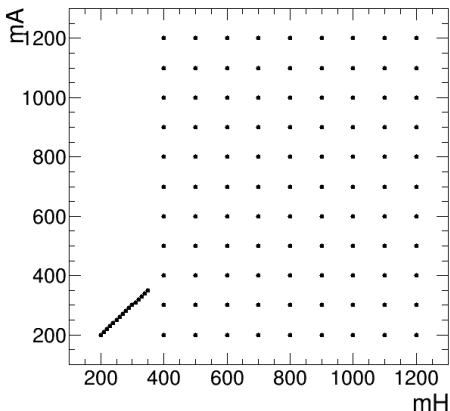
$\tan \beta$ vs $\cos(\beta - \alpha)$



Angles available for each values of masses

Ranges and steps can be extended/changed.

m_A vs m_H



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

m_A
 γA
 m_H
 γH
 m_{HC}
 γHC
 m_{12}
 * do we need also γ_{mah} ?

Angles

$\tan\beta$
 α
 $\sin\beta$
 $\cos\beta$

x-sections

ggA
 bbA
 ggH
 bbH
 * do we need also ggh and bbh ?

BR (see next slide)

- BR $_h$
- BR $_A$
- BR $_H$
- BR $_H C$

$h \rightarrow xy$

BRh

ss
cc
bb
ee
mumu
tautau
gangam
ZZ
WW
Zgam
gluglu

$A \rightarrow xy$

BRA

ss
cc
bb
tt
ee
mumu
tautau
gangam
Zgam
gluglu
Zh

$H \rightarrow xy$

BRH

ss
cc
bb
tt
ee
mumu
tautau
gangam
ZZ
WW
Zgam
gluglu
hh
AA
HCHC
ZA
WHC*

* Now wrong by a factor 2

$H^\pm \rightarrow xy$

BRHC

us
ub
cd
cs
cb
td
ts
tb
enue
munumu
taunutau
Wh

Some BR are forbidden for some A, H, H^\pm masses (eg $\rightarrow tt, H \rightarrow hh, \dots$)

Scenarios A/B/C

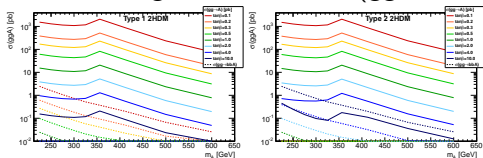
In order to see if all setup was correct, I've tested it comparing with the results in D.Eriksson, J.Rathsman, O.Stål, arXiv:1312.5571 for scenarios A/B/C

Scenario	A	B	C
ggA	5.4635095	5.3575649	0.0359630
paper	5.639	5.355	0.03575
bbA	0.0021459	28.941694	0.0666051
paper	0.00215	28.9	0.0666
ggH	0.0982994	2.7602992	0.038460
paper	0.09897	2.759	0.03821
bbH	0.0002069	18.394941	0.2003229
paper	0.000207	18.4	0.200

Full tables (including BR) are on the TWiki: results in agreement, although not identical

Example of usage for HIG-14-011 $A \rightarrow Zh \rightarrow llbb$

- Produced a grid of x-section ($ggA+bbA$)



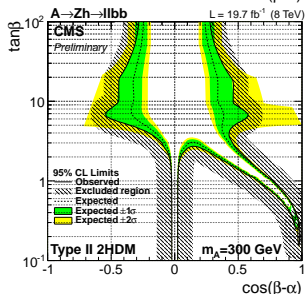
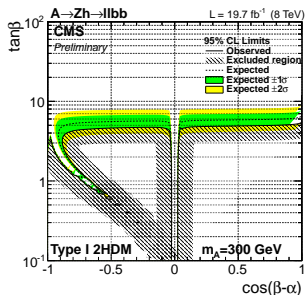
- and $\mathcal{B}(A \rightarrow Zh)$ and $(h \rightarrow bb)$; $Z \rightarrow ll$ from PDG.

- Check results against literature (visually),
- Understand valley for $\mathcal{B}(h \rightarrow bb) = 0$, due to coupling to b-type quarks

Type I $hQd \sim \cos \alpha / \sin \beta$

Type II $hQd \sim -\sin \alpha / \cos \beta$

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



- 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!
 - ▶ Will add Γ_h ;
 - ▶ Error in $\mathcal{B}(H \rightarrow W^\pm H^\mp)$ factor 2.
 - ▶ Should we add also $\sigma(gg \rightarrow h)$ and $\sigma(gg \rightarrow bbh)$?
- Extended of finer grid can be produced easily (it's basically just CPU) upon request.



BACKUP

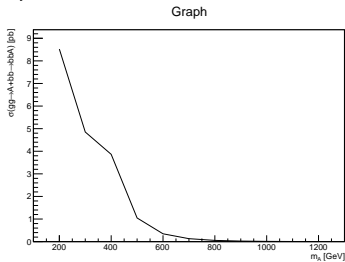
Additional material

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)

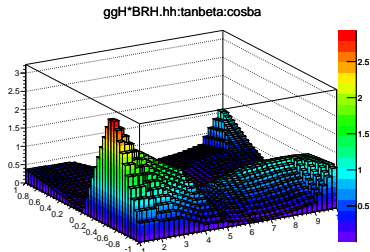
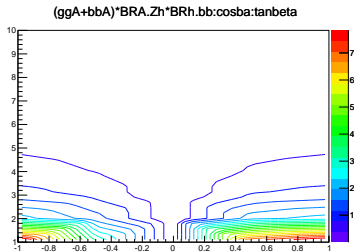
```
Tree2HDM.Draw("ggA+bbA:mA")
TGraph *gr=new TGraph(Tree2HDM.GetSelectedRows(),
    Tree2HDM.GetV2(),
    Tree2HDM.GetV1())
gr->GetYaxis()->SetTitle("#sigma(gg#rightarrowA+bb#rightarrowbbA) [pb]")
gr->GetXaxis()->SetTitle("m_{A} [GeV]")
gr->Draw("al")
```



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(...)
```



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

- `Summary_2HDM_ty*_mA***_mH***.root * = 1,2 ; mA==mH==XXX`
in 200 - 350 with 10 GeV step
- `Summary_2HDM_ty*_mA200-1200_mH***.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;

```
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 Typel and Typell separately.

```
.L plotChain.C
```

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