status of 2HDM grids and 2HDM interpratation in $A \to Zh \to \ell\ell bb$ analysis

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Intro

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

Status of grid production

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 brifly summarize here.

Grid production details

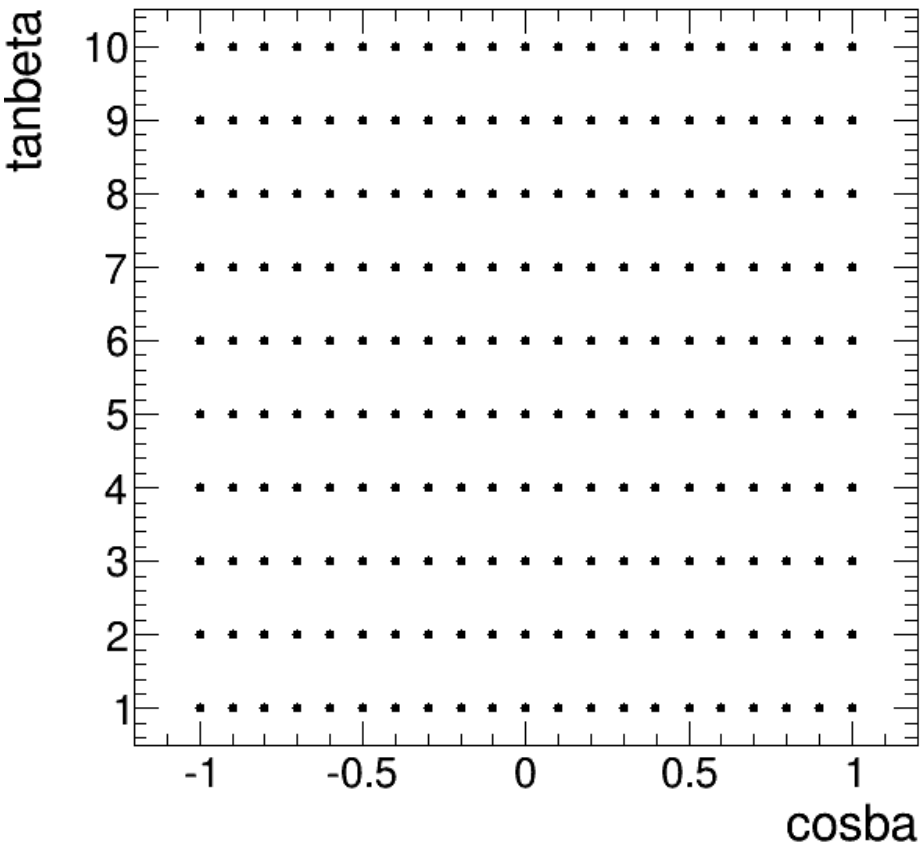
- $\sqrt{s} = 8\ TeV$ (13 TeV can be produced as well);
- 2HDM TypeI and II (not III-IV);
- Physical Basis:
  $m_h, m_H, m_A, m_H^{\pm}, m_{12}, \tan\beta, \cos(\beta-\alpha), \lambda_6, \lambda_7$
- masses:
  - $m_h = 125\ GeV$,
  - $m_H = 200 - 1200\ GeV$,
  - $m_A = 200 - 1200\ GeV$,
  - $m_H^{\pm} = m_H$,
  - $m_{12}^2 = m_A^2 \frac{\tan\beta}{1+\tan^2\beta}$
- 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

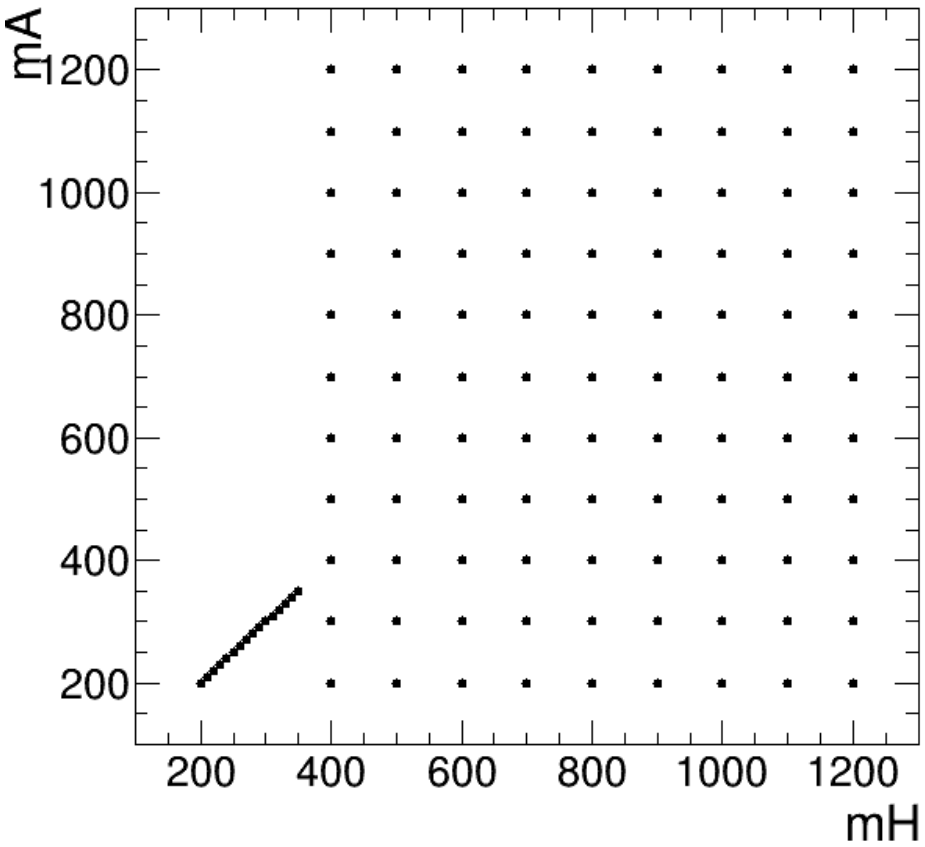
- Renormalization scale:
  - $\mu_F = \mu_R = m_{A/H}/2$ for gluon-fusion process;
  - $\mu_F = m_{A/H}$, $\mu_R = m_{A/H}/4$ for b-associated production;
- 5FS used.

Grid produced

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



m_A 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
gammaA
mH
gammaH
mHC
gammaHC
m12
* do we need also gammah?

Angles

tanbeta
alpha
sinba
cosba

x-sections

ggA
bbA
ggH
bbH

BR (see next slide)

- BRh
- BRA
- BRH
- BRHC

Brancing Ratios

saved as c-struct: `BRh.bb`

h→ *xy*
BRh

ss
cc
bb
ee
mumu
tautau
gamgam
ZZ
WW
Zgam
gluglu

A→ *xy*
BRA

ss
cc
bb
tt
ee
mumu
tautau
gamgam
Zgam
gluglu
Zh

H→ *xy*
BRH

ss
cc
bb
tt
ee
mumu
tautau
gamgam
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, ...)

Testing with Scenarios A/B/C

Scenarios A/B/C

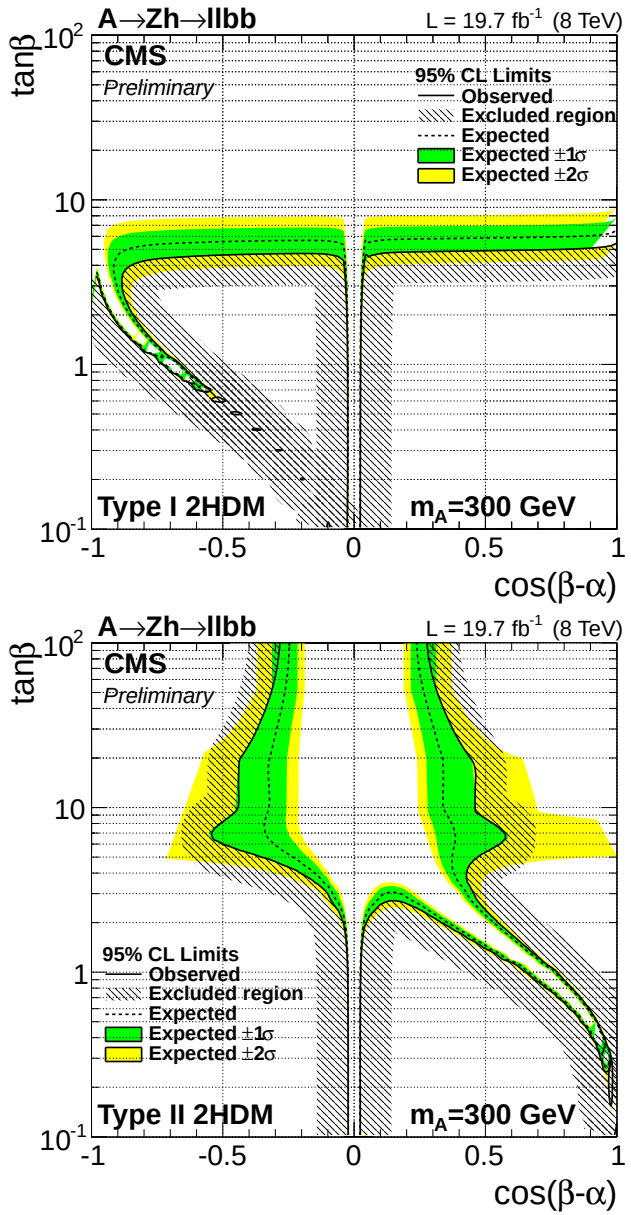
In order to see if all setup was correct, I've tested it comparing with the results in D.Eriksson, J.Rathsman, O.Stål, arXiv:1312.5571 for scenarios A/B/C

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, altough not identical

Example of usage for HIG-14-011 $A \to Zh \to \ell\ell bb$

- Produced a grid of x-section (ggA+bbA)
- BR ($A \to Zh$) and ($h \to bb$ can be different from SM!). $Z \to \ell\ell$ from PDG.
- Check agains literature (visually)
- Understand valley for $\mathcal{B}(h \to bb) = 0$
- Use the $\sigma \times \mathcal{B}$ expected and observed limit to produce the final exclusion plot for various m_A.



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 agains 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.

BACKUP

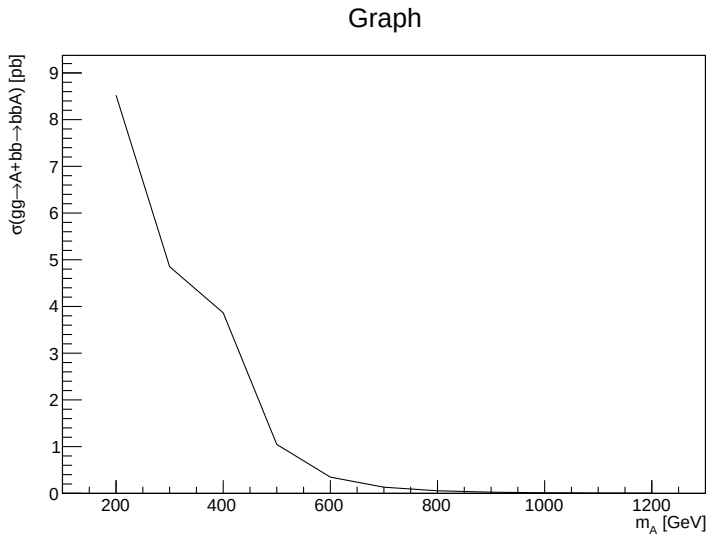
Additional material

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)

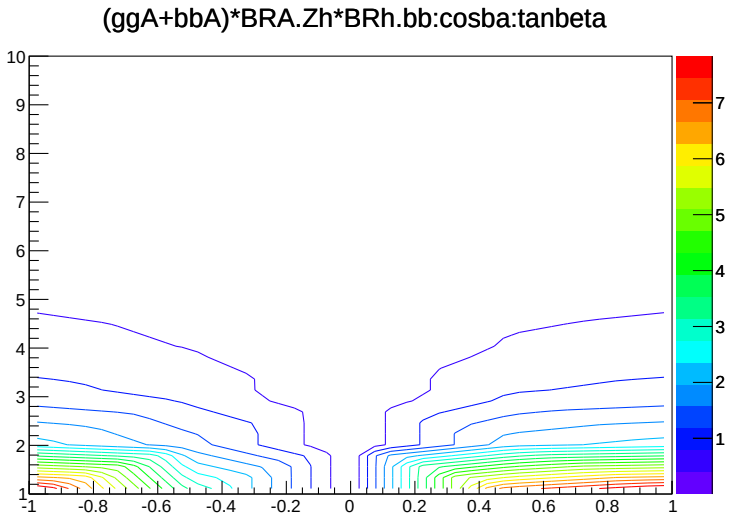
```
Tree2HDM.Draw("ggA+bbA:mA")
TGraph *gr=new TGraph(Tree2HDM.GetSelectedRows(),
    Tree2HDM.GetV2(),
    Tree2HDM.GetV1())
gr->GetYaxis()->SetTitle("#sigma(gg#rightarrowA+bb#rightarrowbbA) [pb]")
gr->GetXaxis()->SetTitle("m_{A} [GeV]")
gr->Draw("al")
```

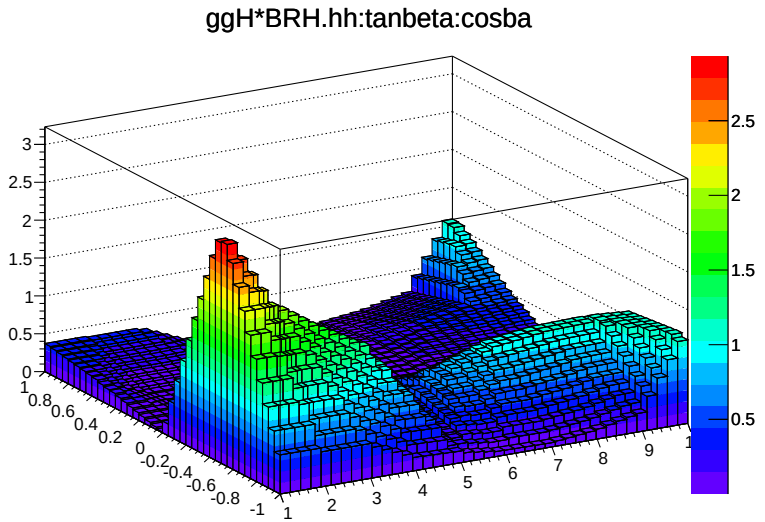


How to use the tree II

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(...)
```





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")
```