CP-even neutral Heavy Higgs combination for 2HDM with final states of bbbb and bbyy

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HSG6 all-hands 30-01-2014

Overview

- Interested in a resonance search with a dihiggs production H->hh, interpretated as a CP-even neutral heavy Higgs in 2HDM
 - Maybe a reason for the largerthan-one signal strengths for the SM Higgs at the LHC ~1.33
- Two final states are being searched by two analysis groups
 - H->hh->bbbb: largest BR, featured by two boosted dijets, sensitive at high mass regime 500GeV~1.0 TeV
 - H->hh->bbyy: h->bb gives largest BR, h->yy gives high mass resolution
- The two search results are going to be combined at HSG6



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## bbbb search

- Featured by a pair of boosted dijets
- Event selection cuts:
  - Trigger EF\_b45\_medium\_4j45\_a4tchad\_L2FS, EF\_b45\_medium\_j145\_j45\_a4tchad\_ht500, EF\_2b35\_loose\_j145\_j35\_a4tchad, EF\_j360\_a4tchad, EF\_4j80\_a4tchad\_L2FS
  - Jet pT>45GeV, central, MV1 70%
  - Dijet ΔR(jet1,jet2)<1.5, pT>200GeV
  - ttbar veto

$$X_{t\bar{t}} = \sqrt{\left(\frac{m_W - 80.4}{0.1 * m_W}\right)^2 + \left(\frac{m_t - 172.5}{0.1 * m_t}\right)^2}$$

Two boosted dijet systems p<sub>T</sub> > 200 GeV and m<sub>dijet</sub>~m<sub>h</sub>

Jets b-tagged and with p<sub>T</sub> > 40 GeV

Heavy Higgs mass

$$X_{hh} = \sqrt{\left(\frac{m_{2j}^{\text{lead}} - 124.0}{\sigma_{m_{2j}^{\text{lead}}}}\right)^2 + \left(\frac{m_{2j}^{\text{subl}} - 115.0}{\sigma_{m_{2j}^{\text{subl}}}}\right)^2}$$

# bbyy search

- Featured by a yy pair and a bb pair
- Event selection cuts:
  - Trigger EF\_g35\_loose\_g25\_loose
  - Leading(subleading) photon pT > 35(25)% of the diphoton invariant mass [105,160], tight photon ID and isolation
  - Two central b-jets are tagged @ 70% eff, leading(subleading) tagged jet pT > 55(35) GeV, inviriant mass [100,140]
  - Additionally, require m(yy) m(bbyy) window cuts

| $ m_h - \Delta m_h - m_{\gamma\gamma}  < 2\sigma_{\gamma\gamma}$ | Signal Mass Window cut (GeV) |
|------------------------------------------------------------------|------------------------------|
|                                                                  | 260 GeV 238-275              |
| $\sigma_{\gamma\gamma} \equiv 1.6 \text{ GeV}$                   | 300 GeV 272-316              |
| the reconstructed yy peak                                        | 350 GeV 316-369              |
| is 150MeV below the true mh 125                                  | 500 GeV 453-521              |
|                                                                  |                              |

m(yy) cut

m(bbyy) cut @ 95% signal eff

#### Combination @ mH=500GeV

| bbbb                                                                                                                                                                                              | bbyy                                                                                                                                                                                                                                                                                            |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| m(bbbb) template                                                                                                                                                                                  | Event counting in 2 bins;<br>SR - m(yy) and m(bbyy)<br>CR – no m(bbyy) and in m(yy) side band                                                                                                                                                                                                   |
| Signal is graviton for the time-being                                                                                                                                                             | 2HDM signal<br>Gg-fusion ~90% VBF ~10%<br>when low mass and low tanb                                                                                                                                                                                                                            |
| Mass points:<br><b>500</b> ,600,7001500                                                                                                                                                           | Mass points:<br>260,300,350, <b>500</b>                                                                                                                                                                                                                                                         |
| Syst:<br>btag, jer, jes_totalminuscloseby,<br>qcd_norm, qcd_shape                                                                                                                                 | Syst:<br>Dominant – m(yy) cut, m(bbyy) cut, MC stat<br>Others – bjes, jes, jvf, jer, btag, ctag, mistag,<br>trigger, photon id/iso                                                                                                                                                              |
| Correlate jer btag                                                                                                                                                                                | Correlate jer btag                                                                                                                                                                                                                                                                              |
| Preliminary workspaces ready                                                                                                                                                                      | Calculate event numbers by eff provided in the note                                                                                                                                                                                                                                             |
| //afs/cern.ch/atlas/project/HSG6/Zh_hh/v<br>0/bbbb/                                                                                                                                               | ATL-COM-PHYS-2014-009<br>24-01-2014 verion 1.2                                                                                                                                                                                                                                                  |
| 500,600,7001500<br>Syst:<br>btag, jer, jes_totalminuscloseby,<br>qcd_norm, qcd_shape<br>Correlate jer btag<br>Preliminary workspaces ready<br>//afs/cern.ch/atlas/project/HSG6/Zh_hh/v<br>0/bbbb/ | 260,300,350, <b>500</b><br>Syst:<br>Dominant – m(yy) cut, m(bbyy) cut, MC stat<br>Others – bjes, jes, jvf, jer, btag, ctag, mistag,<br>trigger, photon id/iso<br>Correlate jer btag<br>Calculate event numbers by eff provided in the<br>note<br>ATL-COM-PHYS-2014-009<br>24-01-2014 verion 1.2 |

All tests are fit to expectations (with 0 signal), no data involved for now Many thanks to David, Jahred and Jamie!

### Combination – nuisance parameteres

 Check on the correlations of nuisance parameters in the combined workspace correlation\_matrix



## Combination – nuisance parameteres



# Upper limit

- The combination between bbbb and bbyy analysis will lead to an upper limit of the heavy Higgs cross section
- For now, although the signal sampple is not correct, one can still run with the expectation to have a test with the machinary
- An upper limit is obtained using toys

(although the inputs are not correct for the time being!)



## To intepret 2HDM

- TWO Higgs doublets under SU(2) are introduced
- The general potential reads

 $V(\Phi_1, \Phi_2) = m_{11}^2 \Phi_1^{\dagger} \Phi_1 + m_{22}^2 \Phi_2^{\dagger} \Phi_2 - (m_{12}^2 \Phi_1^{\dagger} \Phi_2 + \text{h.c}) + \frac{1}{2} \lambda_1 (\Phi_1^{\dagger} \Phi_1)^2 + \frac{1}{2} \lambda_2 (\Phi_2^{\dagger} \Phi_2)^2 + \lambda_3 (\Phi_1^{\dagger} \Phi_1) (\Phi_2^{\dagger} \Phi_2) + \frac{1}{2} \lambda_2 (\Phi_2^{\dagger} \Phi_2)^2 + \lambda_3 (\Phi_1^{\dagger} \Phi_1) (\Phi_2^{\dagger} \Phi_2) + \frac{1}{2} \lambda_2 (\Phi_2^{\dagger} \Phi_2)^2 + \lambda_3 (\Phi_1^{\dagger} \Phi_1) (\Phi_2^{\dagger} \Phi_2) + \frac{1}{2} \lambda_2 (\Phi_2^{\dagger} \Phi_2)^2 + \lambda_3 (\Phi_1^{\dagger} \Phi_1) (\Phi_2^{\dagger} \Phi_2) + \frac{1}{2} \lambda_2 (\Phi_2^{\dagger} \Phi_2)^2 + \frac{1}{2} \lambda_3 (\Phi_1^{\dagger} \Phi_1) (\Phi_2^{\dagger} \Phi_2) + \frac{1}{2} \lambda_4 (\Phi_1^{\dagger} \Phi_1)^2 + \frac{1}{2} \lambda_4 (\Phi_2^{\dagger} \Phi_2)^2 + \frac{$ 

 $+\lambda_4(\Phi_1^{\dagger}\Phi_2)(\Phi_2^{\dagger}\Phi_1) + \left\{ \frac{1}{2}\lambda_5(\Phi_1^{\dagger}\Phi_2)^2 + [\lambda_6(\Phi_1^{\dagger}\Phi_1) + \lambda_7(\Phi_2^{\dagger}\Phi_2)](\Phi_1^{\dagger}\Phi_2) + h.c \right\}$ **10 parameters** 

- Very large parameter phase space
  - One can narrow it down by theoretical inaccessibilities and experimental constraints
- Learning from the ECFA note **ATLAS-PHYS-PUB-2013-016**
- The reduced phase space has only 7 free parameters
  - Masses for: h < H = A = H<sup>+-</sup>
  - Angles: tanβ, cos(β-α)
  - $Z_2$  symmetry breaking scale factor:  $m_{12}^2$  MSSM-type ( $\lambda_6 = \lambda_7 = 0$ )

SM-like limit

\*another parameter is vev of the SM Higgs doublet v = 246

## To intepret 2HDM

- A first try on interpretation with the upper limit obtained
- Explore the grid file of phase space: thdm\_grid\_v140.root
  - expand tanb [0,45], cos(b-a) [-0.31,0.31]
- Enclosed area is excluded



10

#### Explore the phase space

- Run over all the point in the grid file: thdm\_grid\_v140.root
- Make the contours, which look consistent with the exclusion contour last page



## Summary

- Machinary is in place
  - Workspace combination
  - Nuisance parameter checking
  - Upper limit setting
  - Interpretation in the phase space
  - Problems: nuisance parameter Lumi behaviours strangely
    - probably a bug in workspace combination...investigating...
- Waiting for inputs eagerly



#### Explore the phase space



Made from thdm\_grid\_v140.root

#### Explore the phase space



#### Made from thdm\_grid\_v140.root

## Introduction to bbyy search

Background components (from MC as a reference) •



the number extracted from data using sideband fits,  $2.4 \pm 0.8$  (still blinded)

|            | Sample           | Predicted events (kfactor $= 2$ | 2.0) |
|------------|------------------|---------------------------------|------|
| S          | yybj             | 6.3                             |      |
| k <u>ç</u> | уујј             | 26.4                            |      |
| q          | ybbj             | 2.3                             |      |
| JS<br>S    | ybjj             | 6.5                             |      |
| 0          | bbjj             | 0.4                             |      |
| Ξ          | yybb             | 1.1                             |      |
| Ļ          | ttbar            | 1.8                             |      |
| ο          | W                | 0.2                             |      |
|            | Z                | 0.4                             |      |
| Ц<br>Ц     | Total (simulatio | 45.4                            |      |
| 2          | Data             | 50                              |      |
|            | ·                |                                 |      |

The backgrounds are estimated by data-driven methods from control regions

SR and CR correspond to two bins for event counting in the statistical combination

0.03

0.006

0.001

0.03

0.14

0.21

Exactly one btagged let