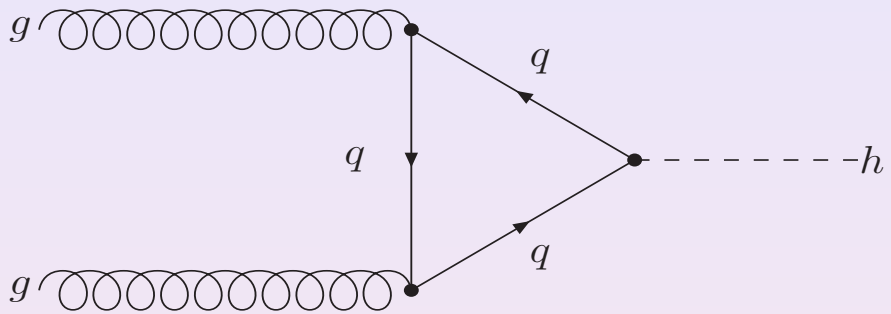
The LHC Searches for The Heavy Higgs via Two B-jets plus Di-photon

Ning Chen, Chun Du, Yaquan Fang, Lan-Chun Lü. [arXiv: 1312.7212].Phys.Rev.D(submitted)

2014.02.25

Higgs productions

- Gluon fusion.



$$\mathcal{R}_{ggF} = \frac{\sigma[\, gg \to h\,]}{\sigma[\, gg \to h\,]_{\rm SM}} = \frac{\left|\sum\limits_q \xi_{hq\bar{q}}\ A^H_{1/2}(\tau_q)\right|^2}{\left|\sum\limits_q A^H_{1/2}(\tau_q)\right|^2},$$

where $\tau_q \equiv M_h^2/(4m_q^2)$. $\mathcal{R}$ is production cross section ratio, ξ is Higgs coupling ratio, A is loop-level form factor.

$$A_{1/2}^{H}(\tau) = 2[\tau + (\tau - 1)f(\tau)]\tau^{-2}\,,$$

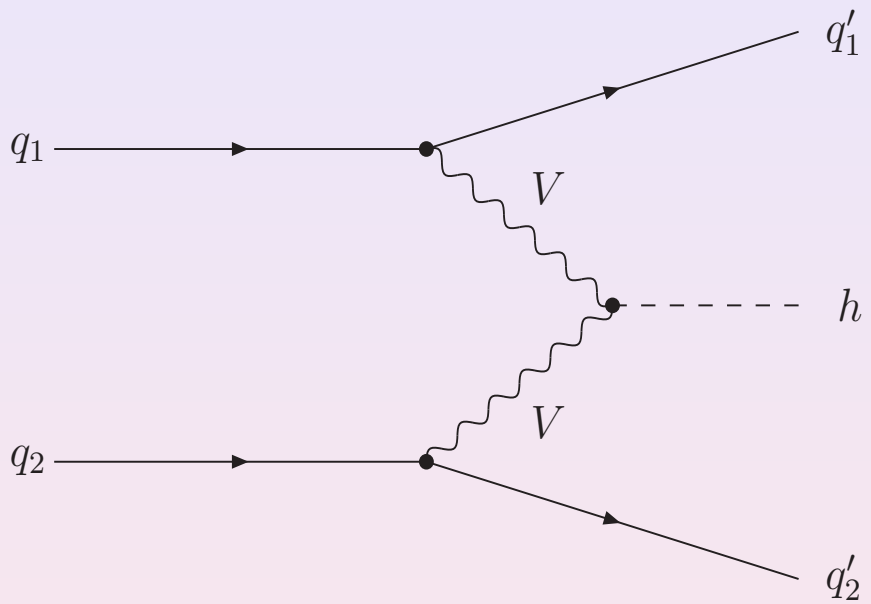
$$f(\tau) = \begin{cases} \arcsin^2\sqrt{\tau}\,, & \tau \leqq 1\,, \\ -\frac{1}{4}\left[\ln\dfrac{1+\sqrt{1-\tau^{-1}}}{1-\sqrt{1-\tau^{-1}}} - i\pi\right]^2. & \tau > 1\,, \end{cases}$$

when $M_h^2 \ll 4m_q^2$, $A_{1/2}^{H}(\tau) \to 4/3$ and $M_h^2 \gg 4m_q^2$, $A_{1/2}^{H}(\tau) \to 0$.

In our case, heavy Higgs(500 GeV) production:

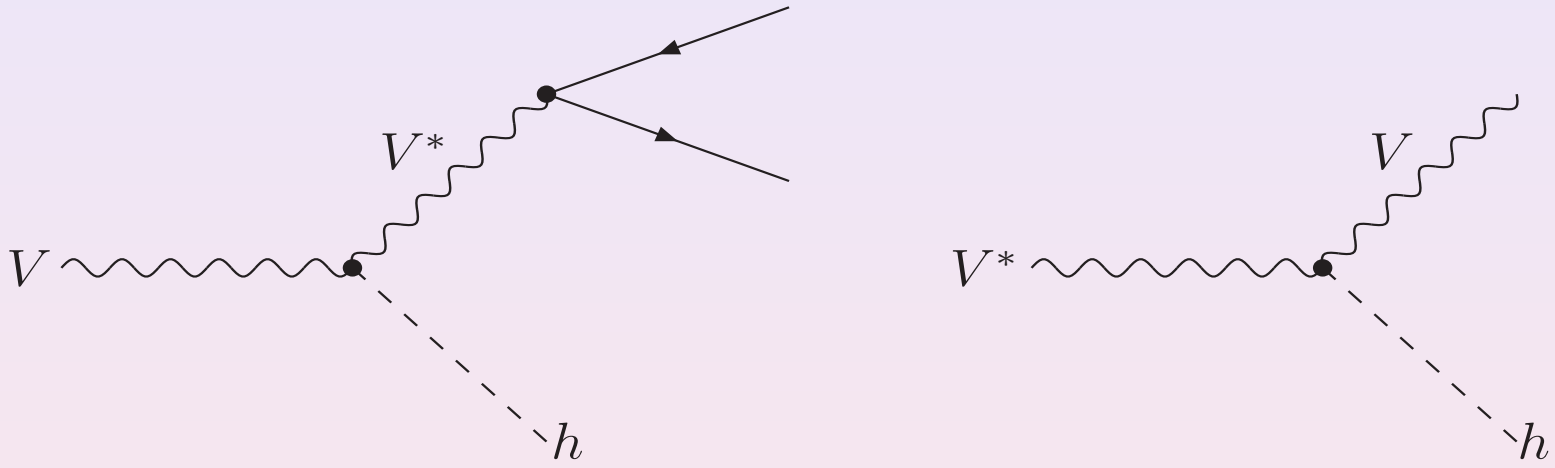
$$\mathcal{R}_{ggF} = \frac{\sigma[\,gg \to H]}{\sigma[\,gg \to H]_{\rm SM}} \approx (\xi_{Ht\bar{t}})^2\,.$$

- Vector boson fusion.



$$\mathcal{R}_{VBF} = \frac{\sigma[\, q_1 q_2 \to h q_1' q_2' \,]}{\sigma[\, q_1 q_2 \to h q_1' q_2' \,]_{\rm SM}} = \xi^2_{hVV}\,.$$

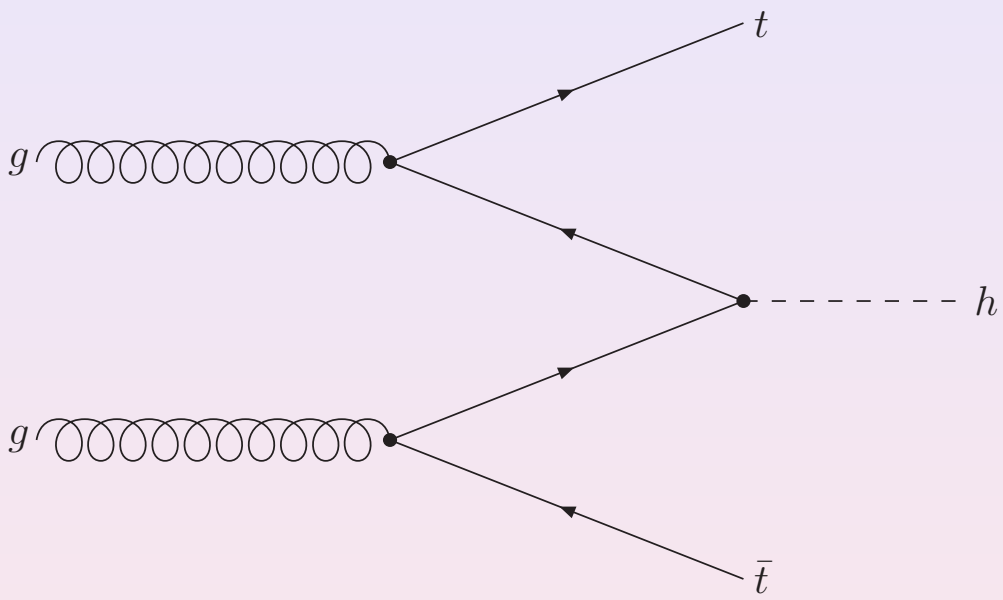
- Associated with vector boson.



$$\mathcal{R}_{VH} = \frac{\sigma[\, q_1 \bar{q}_2 \to Vh\,]}{\sigma[\, q_1 \bar{q}_2 \to Vh\,]_{\rm SM}} = \xi^2_{hVV}\,.$$

Higgs productions

- Associated with heavy quarks.



$$\mathcal{R}_{ttH} = \frac{\sigma[\, gg \to t\bar{t}h\,]}{\sigma[\, gg \to t\bar{t}h\,]_{\rm SM}} = \xi^2_{ht\bar{t}}\,.$$

Higgs productions

- Inclusive production of heavy Higgs.

$$\begin{aligned}
\sigma[\,pp \to XH] &= \mathcal{R}_{ggF} \times \sigma[\,gg \to H]_{\rm SM} \\
&\quad + \mathcal{R}_{VBF} \times \sigma[\,q_1 q_2 \to H q_1' q_2'\,]_{\rm SM} \\
&\quad + \mathcal{R}_{VH} \times \sigma[\,q_1 \bar{q}_2 \to VH]_{\rm SM} \\
&\quad + \mathcal{R}_{ttH} \times \sigma[\,gg \to t\bar{t}H]_{\rm SM} \\
&\approx (\xi_{Ht\bar{t}})^2 \times \sigma[\,gg \to H]_{\rm SM}\,,
\end{aligned}$$

we just consider the dominant gluon fusion process.

Signal corss section ratio between different energy

$$\frac{\sigma[\,pp \to H \to hh \to XXX'X'(8\text{TeV})\,]}{\sigma[\,pp \to H \to hh \to XXX'X'(14\text{TeV})\,]}$$

$$= \frac{2 \times \sigma[\,pp \to H(8\text{TeV})\,] \times \text{Br}[\,H \to hh] \times \text{Br}[\,h \to XX] \times \text{Br}[\,h \to X'X'\,]}{2 \times \sigma[\,pp \to H(14\text{TeV})\,] \times \text{Br}[\,H \to hh] \times \text{Br}[\,h \to XX] \times \text{Br}[\,h \to X'X'\,]}$$

$$\approx \frac{\sigma[\,gg \to H(8\text{TeV})\,]}{\sigma[\,gg \to H(14\text{TeV})\,]}$$

$$= \frac{(\xi_{Ht\bar{t}})^2 \times \sigma[\,gg \to H(8\text{TeV})\,]_{\text{SM}}}{(\xi_{Ht\bar{t}})^2 \times \sigma[\,gg \to H(14\text{TeV})\,]_{\text{SM}}}$$

$$= \frac{\sigma[\,gg \to H(8\text{TeV})\,]_{\text{SM}}}{\sigma[\,gg \to H(14\text{TeV})\,]_{\text{SM}}} = 0.244\,,$$

for all parameter space in Type-I and Type-II.

Background corss section for 8TeV

Draft version 1.2

ATLAS NOTE

January 24, 2014

Search for resonant and enhanced non-resonant dihiggs production in the $\gamma\gamma b\bar{b}$ channel with 20.3 fb^{-1} of data at 8 TeV

Jahred Adelman[m], Xabier Anduaga[h], Maria Josefina Alconada Verzini[h], Nancy Andari[e], Cyril Becot[n], Nicolas Berger[b], Florian Bernlochner[u], Maarten Boonekamp[f], Giovanni Calderini[p], Leonardo Carminati[k], Sandro de Cecco[p], Olivier Davignon[p], Marco Delmastro[b], Jean-Baptiste De Vivie[n], David Di Valentino[o], Maria Teresa Dova[h], Johannes Erdmann[m], Marc Escalier[n], Yaquan Fang[c], Marcello Fanti[k], Louis Fayard[n], Daniel Fournier[n], Dag Gillberg[e], Sergei

Background corss section for 8TeV

- Single Higgs Background

DSID	Sample	Calculated Cross Section [pb]
160009	Gluon-Gluon Fusion	19.27
160024	Vector Boson Fusion	1.578
160039	Wh	0.7046
160054	Zh	0.4153
160069	$t\bar{t}h$	0.1293

Table 3: SM Higgs boson MC samples, and their calculated cross-sections at $\sqrt{s} = 8$ TeV, with $m_H = 125$ GeV. The branching ratio $\mathcal{B}(h \to \gamma\gamma) = 0.00228$ is not included in these values. [2]

Background corss section for 8TeV

• Truth D3PDs(Major background processes, allowing for light-flavor jets to fake photons photons and b-tagging: $b\bar{b}\gamma\gamma$, $b\bar{b}j\gamma$, $b\bar{b}jj$, $bj\gamma\gamma$, $bjj\gamma$, $jj\gamma\gamma$.)

Sample	Xsection [fb]
$bb\gamma\gamma$	8.30
$bbj\gamma$	39.58e3
$bbjj$	8.66e6
$bj\gamma\gamma$	79.8
$bjj\gamma$	1.83e5
$jj\gamma\gamma$	1510

Table 4: Samples and generator-level cross sections and samples used for the background decomposition studies. The k-factor of 1.5 or 2.0 is applied on top of these numbers.

Background corss section for 8TeV

D.1 bbaa

```
#*********************************************************************
#                       MadGraph/MadEvent                            *
#                    http://madgraph.hep.uiuc.edu                    *
#                                                                    *
#                         run_card.dat                               *
#                                                                    *
#  This file is used to set the parameters of the run.               *
#                                                                    *
#  Some notation/conventions:                                        *
#                                                                    *
#   Lines starting with a '# ' are info or comments                  *
#                                                                    *
#   mind the format:   value    = variable     ! comment             *
#*********************************************************************
#
#*******************
# Running parameters
#*******************
#
#*********************************************************************
# Tag name for the run (one word)                                    *
#*********************************************************************
  tag_1     = run_tag ! name of the run
#*********************************************************************
# Run to generate the grid pack                                      *
#*********************************************************************
  .false.     = gridpack  !True = setting up the grid pack
#*********************************************************************
# Number of events and rnd seed                                      *
# Warning: Do not generate more than 1M events in a single run       *
# If you want to run Pythia, avoid more than 50k events in a run.    *
#*********************************************************************
  50000 = nevents ! Number of unweighted events requested
      0       = iseed   ! rnd seed (0=assigned automatically=default))
#*********************************************************************
# Collider type and energy                                           *
# lpp: 0=No PDF, 1=proton, -1=antiproton, 2=photon from proton,      *
#                                         3=photon from electron     *
#*********************************************************************
        1     = lpp1    ! beam 1 type
        1     = lpp2    ! beam 2 type
     4000     = ebeam1  ! beam 1 total energy in GeV
     4000     = ebeam2  ! beam 2 total energy in GeV
#*********************************************************************
# Beam polarization from -100 (left-handed) to 100 (right-handed)    *
#*********************************************************************
        0     = polbeam1 ! beam polarization for beam 1
        0     = polbeam2 ! beam polarization for beam 2
```

```
#*********************************************************************
   0  = nhel          ! Number of helicities used per event
#*******************
# Standard Cuts
#*******************
#
#*********************************************************************
# Minimum and maximum pt's (for max, -1 means no cut)                *
#*********************************************************************
  20  = ptj       ! minimum pt for the jets
  20  = ptb       ! minimum pt for the b
  20  = pta       ! minimum pt for the photons
  10  = ptl       ! minimum pt for the charged leptons
   0  = misset    ! minimum missing Et (sum of neutrino's momenta)
   0  = ptheavy   ! minimum pt for one heavy final state
 1.0  = ptonium   ! minimum pt for the quarkonium states
  -1  = ptjmax    ! maximum pt for the jets
  -1  = ptbmax    ! maximum pt for the b
  -1  = ptamax    ! maximum pt for the photons
  -1  = ptlmax    ! maximum pt for the charged leptons
  -1  = missetmax ! maximum missing Et (sum of neutrino's momenta)
#*********************************************************************
# Minimum and maximum E's (in the lab frame)                         *
#*********************************************************************
   0  = ej     ! minimum E for the jets
   0  = eb     ! minimum E for the b
   0  = ea     ! minimum E for the photons
   0  = el     ! minimum E for the charged leptons
  -1   = ejmax ! maximum E for the jets
  -1   = ebmax ! maximum E for the b
  -1   = eamax ! maximum E for the photons
  -1   = elmax ! maximum E for the charged leptons
#*********************************************************************
# Maximum and minimum absolute rapidity (for max, -1 means no cut)   *
#*********************************************************************
 3.0  = etaj    ! max rap for the jets
 3.0  = etab    ! max rap for the b
 2.7  = etaa    ! max rap for the photons
 2.5  = etal    ! max rap for the charged leptons
 0.6  = etaonium ! max rap for the quarkonium states
   0  = etajmin ! min rap for the jets
   0  = etabmin ! min rap for the b
   0  = etaamin ! min rap for the photons
   0  = etalmin ! main rap for the charged leptons
#*********************************************************************
# Minimum and maximum DeltaR distance                                *
#*********************************************************************
 0.2 = drjj    ! min distance between jets
 0.2 = drbb    ! min distance between b's
 0.0 = drll    ! min distance between leptons
```

Background corss section for 8TeV

- Other background samples

DSID	Sample	Xsection [fb]	Kfactor
105200	ttbar	112.94	1.2158
169706	tt+photon single lepton	0.5267	1.5
169705	tt+photon dilepton	0.1733	1.5
169703	tt+diphoton single lepton	0.003035	1.5
169702	tt+diphoton dilepton	0.00119	1.5
169701	tt+diphoton all-hadronic	0.001345	1.5
107680	Wenu Np0	8037.8	1.176
107681	Wenu Np1	1479.5	1.176
107682	Wenu Np2	477.31	1.176
107683	Wenu Np3	133.89	1.176
107684	Wenu Np4p	35.614	1.176
146436	W(lep)+photon+Np0	72.11	1.5
146437	W(lep)+photon+Np1	26.6	1.5
146438	W(lep)+photon+Np2	11.6	1.5
146439	W(lep)+photon+Np3	4.47	1.5
169708	W+diphoton	0.1735	1.5
167749	Zee + b	31.046	1.12
167750	Zee + c	314.26	1.12
167751	Zee + noHF	764.41	1.12
147770	Zee	1207.4	1.0277
181080	Zee+photon	4.786	1.5
126584	Ztt+photon	32.317	1.5
167476	Zee+diphoton	9.3e-3	1.5
167477	Zmm+diphoton	9.3e-3	1.5
167478	Ztt+diphoton	9.3e-3	1.5

Table 5: Additional samples and cross sections used for the background decomposition studies. K-factors of 1.5 (or 2.0, when appropriate) were used wherever not otherwise found

Referee reports

- Doing some modification according to the referee reports with Ning Chen. Recalculating, redrawing, ...

Implications to the LHC searches for H

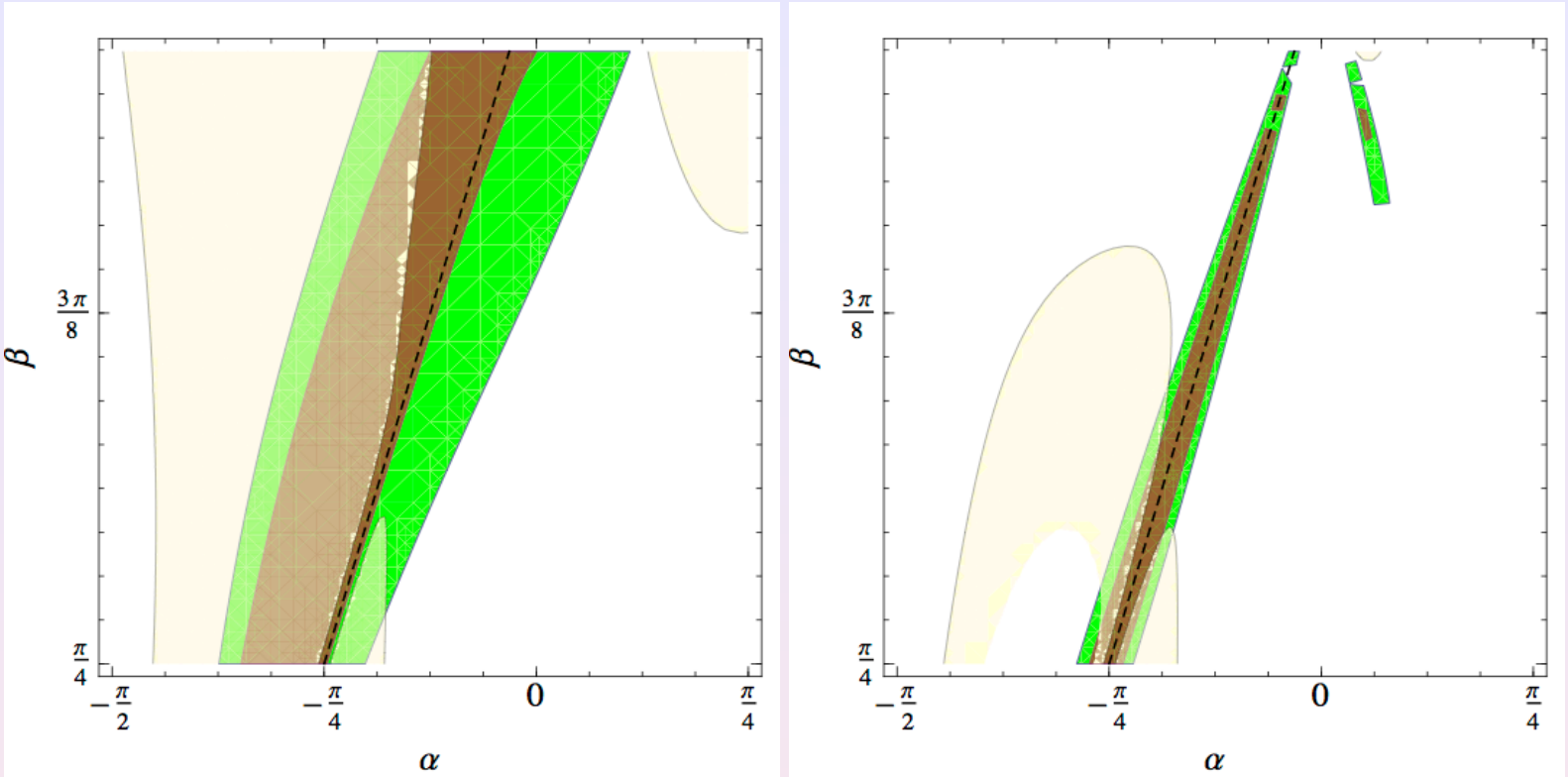


Figure : The LHC-14 search sensitivities to the $H \to b\bar{b}\gamma\gamma$ final states on the $(\alpha\,,\beta)$ parameter space($M_H = 300$ GeV case). *left*: 2HDM-I for the $\int \mathcal{L}dt = 100$ fb^{-1}, and *right*: 2HDM-II for the $\int \mathcal{L}dt = 100$ fb^{-1}. The yellow shadow in each plot represents the parameter regions within the reach via the $b\bar{b}\gamma\gamma$ final states. The green and brown bends are the global fit to the 2HDM parameters $(\alpha\,,\beta)$ at the 68 % and 95 % CLs.

Implications to the LHC searches for H

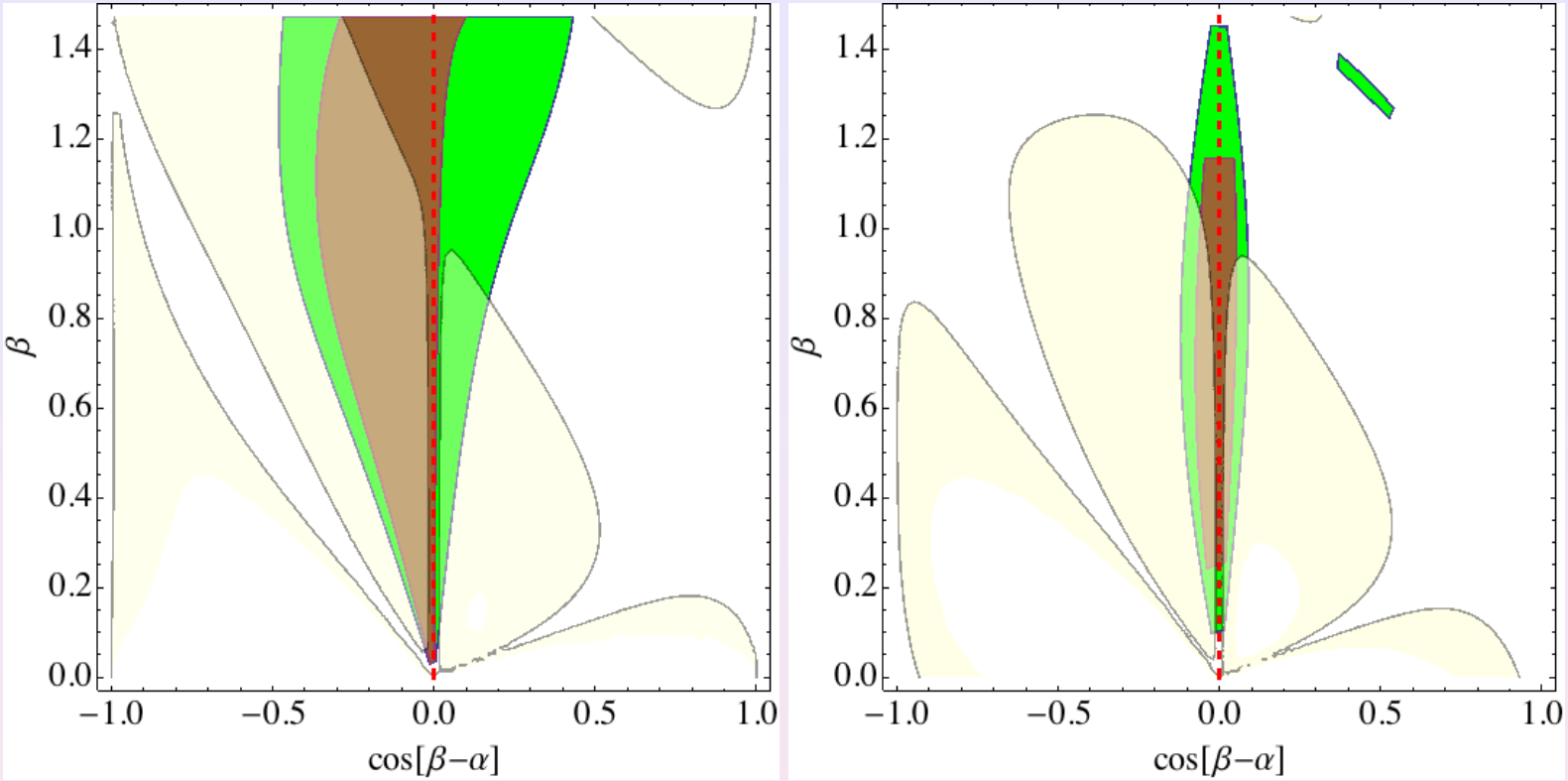


Figure : The LHC-14 search sensitivities to the $H \to b\bar{b}\gamma\gamma$ final states on the $(\cos[\beta-\alpha], \beta)$ parameter space($M_H = 300$ GeV case). *left*: 2HDM-I for the $\int \mathcal{L}dt = 100$ fb^{-1}, and *right*: 2HDM-II for the $\int \mathcal{L}dt = 100$ fb^{-1}. The yellow shadow in each plot represents the parameter regions within the reach via the $b\bar{b}\gamma\gamma$ final states. The green and brown bends are the global fit to the 2HDM parameters $(\cos[\beta-\alpha], \beta)$ at the 68 % and 95 % CLs.