Higgcision Updated 2014

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Outlines

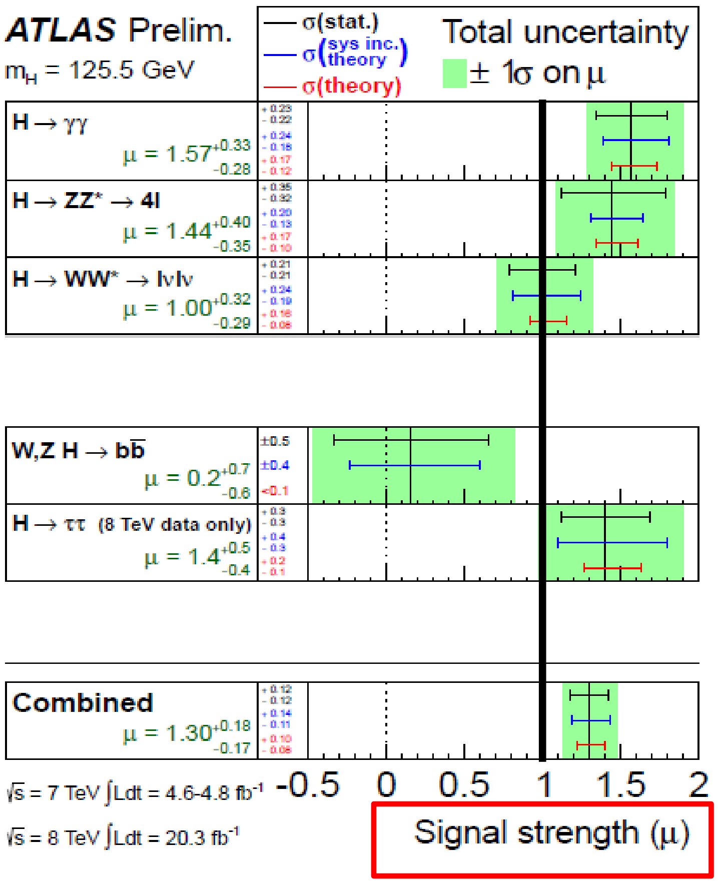
- Introduction
- *Higgcision:* Formalism
- *Higgcision:* Fitting
- Summary

Introduction

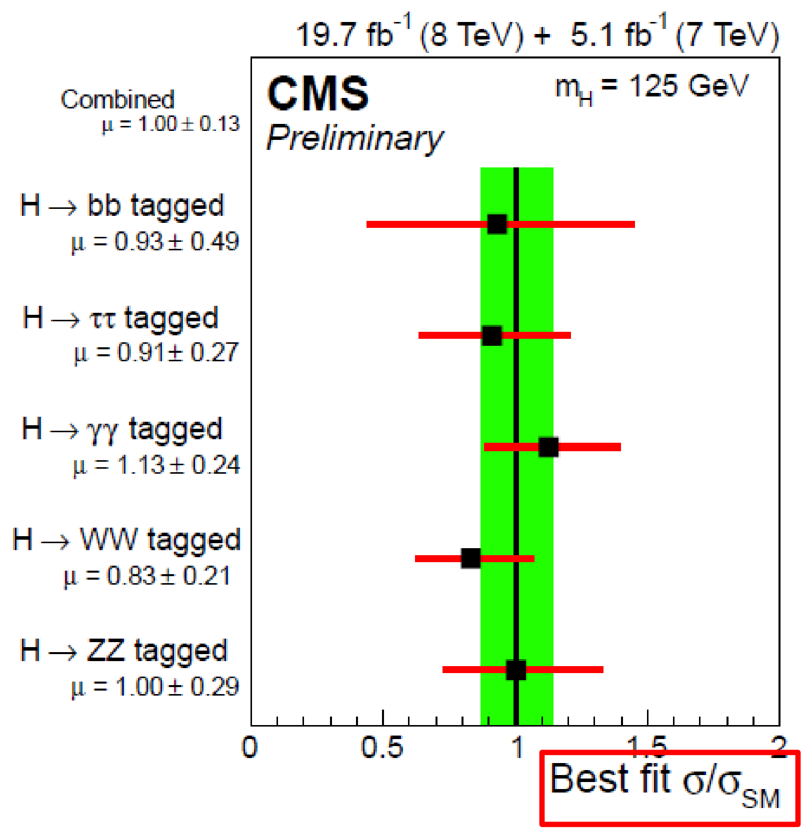
Introduction

- The signal strength data of 125GeV Higgs boson from **ICHEP2014** (summer 2014):

ATLAS-CONF-2014-009



CMS PAS HIG-14-009



Introduction

- New Higgs boson data presented in **ICHEP 2014.**
- Higgs to diphoton channel:

$$\text{ATLAS:}\quad 1.6\pm0.4 \;\rightarrow\; 1.17\pm0.27$$
$$\text{CMS:}\quad 0.78^{+0.28}_{-0.16} \;\rightarrow\; 1.12^{+0.37}_{-0.32}$$

- ATLAS ZZ* increase from $1.5\pm0.4 \rightarrow 1.66^{+0.45}_{-0.38}$. CMS stays about the same. The ZZ* channel become more and more important in the overall fitting.
- CMS WW* channel, the μ_{VBF} and μ_{VH} show positive center values.

Introduction

- The SM deviation from the data in terms of χ^2_{SM} .

- The total $\chi^2_{SM}/\mathrm{d.o.f}$ for SM now is 16.76/29, compare to previous one 18.92/22.

  d.o.f = # of data - # of free parameters for model

- P-value of SM improve from 0.650 to 0.966.

Higgcision: Formalism

Higgcision: Formalism

- We follow the conventions of CPsuperH for the general CP-mixed Higgs couplings to SM particles.

- Higgs couplings to fermions:

$$L_{H\bar{f}f} = -\sum_{f=u,d,l} \frac{g m_f}{2M_W} H \bar{f} \left(\underbrace{C_f^S}_{\text{scalar}} + i \underbrace{C_f^P}_{\text{pseudoscalar}} \gamma_5 \right) f$$

For SM couplings $C_f^S = 1$ and $C_f^P = 0$.

- Higgs couplings to massive vector bosons:

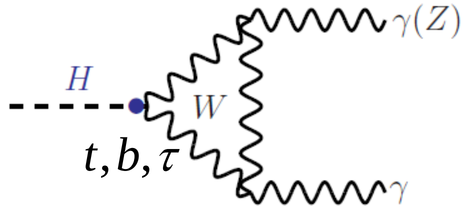
$$L_{HVV} = g M_W \left(C_V W_\mu^+ W^{-\mu} + C_V \frac{1}{2c_W^2} Z_\mu Z^\mu \right) H$$

For SM couplings $C_V = 1$, custodial symmetry.

Higgcision: Formalism

- Higgs couples to two photons:

  The amplitude for the decay $H \to \gamma\gamma$ is



A Djouadi, Hep-ph:0503172

$$\mathcal{M}_{\gamma\gamma H} = -\frac{\alpha M_H^2}{4\pi v}\left\{\underbrace{S^\gamma(M_H)\,(\epsilon_{1\perp}^*\cdot\epsilon_{2\perp}^*)}_{\text{scalar}} - \underbrace{P^\gamma(M_H)\frac{2}{M_H^2}\langle\epsilon_1^*\epsilon_2^*k_1k_2\rangle}_{\text{pseudoscalar}}\right\}$$

- The decay rate of $H \to \gamma\gamma$ is proportional to $|S^\gamma|^2 + |P^\gamma|^2$

$$S^\gamma(M_H) = 2\sum_{f=b,t,\tau}\boxed{N_C Q_f^2 C_f^S F_{sf}(\tau_f) - C_V F_1(\tau_W)} + \underline{\Delta S^\gamma}$$

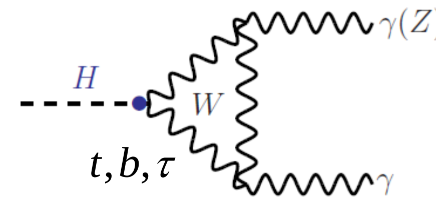
$$P^\gamma(M_H) = 2\sum_{f=b,t,\tau}\boxed{N_C Q_f^2 C_f^P F_{sf}(\tau_f)} + \underline{\Delta P^\gamma}$$

from new charged particles

from SM particle with changing Yukawa

Higgcision: Formalism

- Higgs-diphoton:



A Djouadi, Phys.Rept.457 (2008)1-216

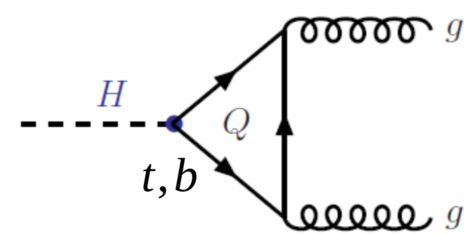
$$\text{CP even}: S^{\gamma} \simeq \underbrace{-8.35C_V}_{\text{W}} + \underbrace{1.76C_u^S}_{\text{top: scalar}} + \underbrace{\Delta S^{\gamma}}_{\text{new particles}}$$

$$\text{CP odd}: P^{\gamma} \simeq \underbrace{2.78C_u^P}_{\text{top: pseudoscalar}} + \Delta P^{\gamma}$$

- Higgs-gluon-gluon:

$$\text{CP even}: S^{g} \simeq 0.688C_u^S + \Delta S^{g}$$

$$\text{CP odd}: P^{g} \simeq 1.047C_u^P + \Delta P^{g}$$



Higgcision: Formalism

- The theoretical signal strength is product:

$$\widehat{\mu}(\mathcal{P},\mathcal{D}) \simeq \widehat{\mu}(\mathcal{P})\ \widehat{\mu}(\mathcal{D})$$

$\mathcal{P} = \mathrm{ggF}, \mathrm{VBF}, \mathrm{VH}, \mathrm{ttH}$

the production modes

$\mathcal{D} = \gamma\gamma, ZZ, WW, b\bar{b}, \tau\bar{\tau}$

the decay modes

$$\mu(\mathrm{ggF}) = \frac{\left|S^g(M_H)\right|^2 + \left|P^g(M_H)\right|^2}{\left|S^g_{SM}(M_H)\right|^2}$$

$$\mu(\mathrm{VBF}) = C_V^2$$

$$\mu(\mathrm{VH}) = C_V^2$$

$$\mu(\mathrm{ttH}) = (C_u^S)^2 + (C_u^P)^2$$

$$\widehat{\mu}(\mathcal{D}) = \frac{B(H \to \mathcal{D})}{B(H_{\mathrm{SM}} \to \mathcal{D})}$$

$$B(H \to \mathcal{D}) = \frac{\Gamma(H \to \mathcal{D})}{\Gamma_{\mathrm{tot}}(H) + \Delta\Gamma_{\mathrm{tot}}}$$

Higgcision: Formalism

- The parameters that will be used in the following fitting:

Scalar: $C_u^S,\ C_d^S,\ C_l^S$

Pseudoscalar: $C_u^P,\ C_d^P,\ C_l^P$

Vector: C_V

New particle: $\Delta S^\gamma, \Delta P^\gamma, \Delta S^g, \Delta P^g$

Invisible decay: $\Delta\Gamma_{\rm tot}$

- SM:

$$C_u^S = C_d^S = C_l^S = 1$$

$$C_u^P = C_d^P = C_l^P = 0$$

$$C_V = 1$$

$$\Delta S^\gamma = \Delta P^\gamma = \Delta S^g = \Delta P^g = \Delta\Gamma_{\rm tot} = 0$$

Higgcision: Fitting

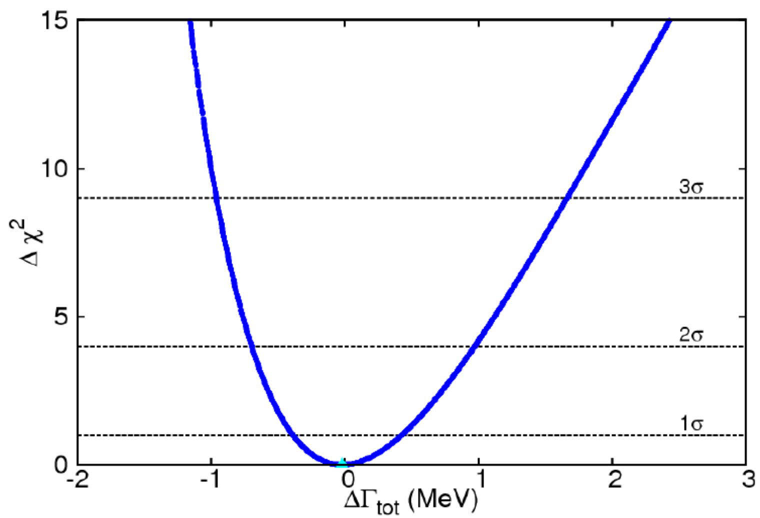
Higgcision: Fitting CPC1

- CP-conserving 1-parameter fit: Higgs invisible decay into hidden sector, DM etc.

$$\begin{cases} \text{varying:} & \Delta\Gamma_{\text{tot}} \\ \text{fixed:} & C_u^S = C_d^S = C_l^S = C_v = 1,\ \Delta S^\gamma = \Delta S^g = 0 \end{cases}$$

- The 95% allowed range from the fitting:

C_u^S	1
C_d^S	1
C_ℓ^S	1
C_v	1
ΔS^γ	0
ΔS^g	0
$\Delta\Gamma_{\text{tot}}$ (MeV)	$-0.020^{+0.45}_{-0.37}$
χ^2/dof	16.76/28
p-value	0.953



$$\Gamma_{SM}^H = 4.2 \text{ MeV}$$

$$B(H \to \text{nonstandand}) < 19\%$$

Higgcision: Fitting CPC1

- Improvement from using 2013 data:

$$B(H \to \text{nonstandard}) < 22\%$$

- Comparing with the direct invisible Higgs decay search:

$$B(H \to \text{nonstandard}) < 50\%$$

- CP-conserving 3-parameter fit:

$$\begin{cases} \text{varying:} & \Delta S^{\gamma}, \Delta S^{g}, \Delta\Gamma_{\text{tot}} \\ \text{fixed:} & C_u^S = C_d^S = C_l^S = C_v = 1 \end{cases} \Rightarrow \quad \Delta\Gamma_{\text{tot}} = 0.39^{+1.13}_{-0.76}\ \text{MeV}$$

$$B(H \to \text{nonstandard}) < 50\%$$

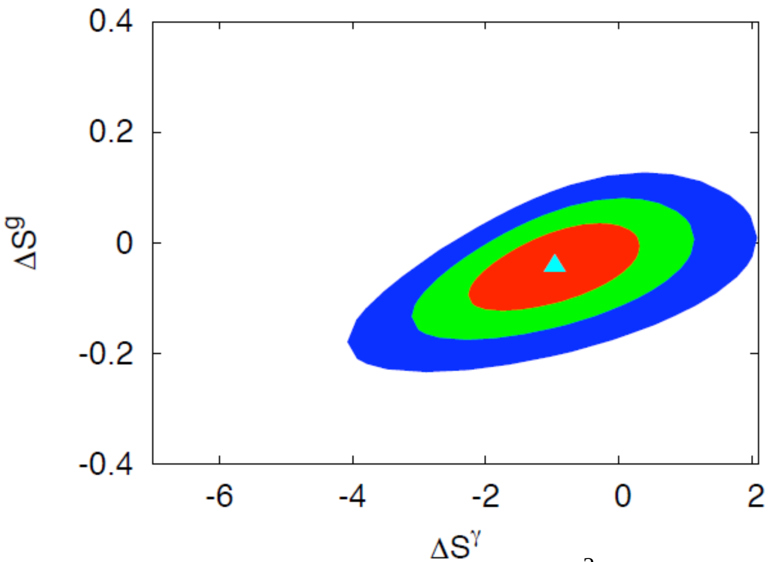
Higgcision: Fitting CPC2

- CP-conserving 2-parameter fit:

$$\begin{cases} \text{varying:} & \Delta S^{\gamma}, \Delta S^{g} \\ \text{fixed:} & C_u^S = C_d^S = C_l^S = C_v = 1,\ \Delta\Gamma_{\text{tot}} = 0 \end{cases}$$

- The best fitting point:

C_u^S	1
C_d^S	1
C_ℓ^S	1
C_v	1
ΔS^γ	$-0.72^{+0.76}_{-0.74}$
ΔS^g	$-0.009^{+0.047}_{-0.048}$
$\Delta\Gamma_{\text{tot}}$ (MeV)	0
χ^2/dof	15.81/27
p-value	0.956



$\Delta\chi^2 \le 2.3$(red 68.3%),
$\Delta\chi^2 \le 5.99$(green 95%),
$\Delta\chi^2 \le 11.83$(blue 99.7%)

Higgcision: Fitting CPC2

- The best fitting point: $\Delta S^{\gamma} = -0.72^{+0.76}_{-0.74}, \ \Delta S^{g} = -0.009^{+0.047}_{-0.048}$
- Higgs-diphoton:

$$\begin{cases} \text{CP even}: S^{\gamma} \simeq -8.35 C_V + 1.76 C_u^S + \Delta S^{\gamma} \approx -7.3 \\ S_{SM}^{\gamma} = -6.64 + 0.043i, \quad \text{and} \quad P_{SM}^{\gamma} = 0 \end{cases}$$

- Higgs-gluon-gluon:

$$\begin{cases} \text{CP even}: S^{g} \simeq 0.688 C_u^S - 0.037 C_d^S + \Delta S^{g} \approx 0.64 \\ S_{SM}^{g} = 0.651 + 0.050i, \quad \text{and} \quad P_{SM}^{g} = 0 \end{cases}$$

- The ratio of $H\gamma\gamma$ and Hgg couplings relative to SM from the best fit points are :

$$C_\gamma = \sqrt{\frac{|S^\gamma|^2 + |P^\gamma|^2}{|S_{SM}^\gamma|^2}}, C_g = \sqrt{\frac{|S^g|^2 + |P^g|^2}{|S_{SM}^g|^2}} \Rightarrow \quad C_\gamma \simeq 1.1, \quad C_g \simeq 1.0$$

Higgcision: Fitting CPC4

- CP-conserving 4-parameter fit:

$$\begin{cases} \text{varying:} & C_u^S, C_d^S, C_l^S, C_v \\ \text{fixed:} & \Delta S^\gamma = \Delta S^g = \Delta\Gamma_{\text{tot}} = 0 \end{cases}$$

- The best fitting point:

C_u^S	$0.92^{+0.15}_{-0.13}$
C_d^S	$-1.00^{+0.29}_{-0.30}$
C_ℓ^S	$0.99^{+0.17}_{-0.17}$
C_v	$0.98^{+0.10}_{-0.11}$
ΔS^γ	0
ΔS^g	0
$\Delta\Gamma_{\rm tot}$ (MeV)	0
χ^2/dof	16.70/25
p-value	0.892

- The uncertainty of gauge coupling has 20% improvement, comparing to the previous results **(summer 2013 data)** :

$$C_V = 1.04^{+0.12}_{-0.14}$$

Higgcision: Fitting CPC4

- CP-conserving 4-parameter fit:

$$\begin{cases} \text{varying:} & C_u^S, C_d^S, C_l^S, C_v \\ \text{fixed:} & \Delta S^\gamma = \Delta S^g = \Delta\Gamma_{\text{tot}} = 0 \end{cases}$$

- The best fitting point:

C_u^S	$0.92^{+0.15}_{-0.13}$
C_d^S	$-1.00^{+0.29}_{-0.30}$
C_ℓ^S	$0.99^{+0.17}_{-0.17}$
C_v	$0.98^{+0.10}_{-0.11}$
ΔS^γ	0
ΔS^g	0
$\Delta\Gamma_{\text{tot}}$ (MeV)	0
χ^2/dof	16.70/25
p-value	0.892

- The uncertainty of gauge coupling has 20% improvement, comparing to the previous results **(summer 2013 data)** :

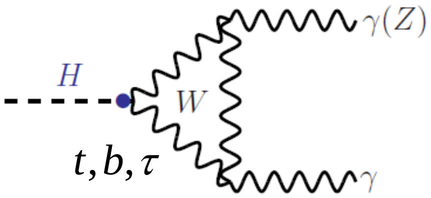
$$C_V = 1.04^{+0.12}_{-0.14}$$

Higgcision: Fitting CPC4

- The magnitude of top-Yukawa coupling C_u^S can be indirectly measured from Hgg coupling, i.e. the S^g.
- The sign of C_u^S can be infer from the $H\gamma\gamma$ coupling, due to the top-quark contribution tends to offset the W contribution, i.e. the S^γ.

- Higgs-diphoton:

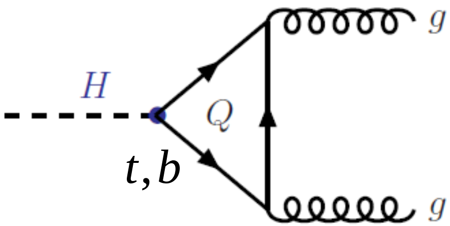
$$\text{CP even}: S^\gamma \simeq -8.35C_V + 1.76C_u^S \simeq -7.3$$



A Djouadi, Phys.Rept.457 (2008)1-216

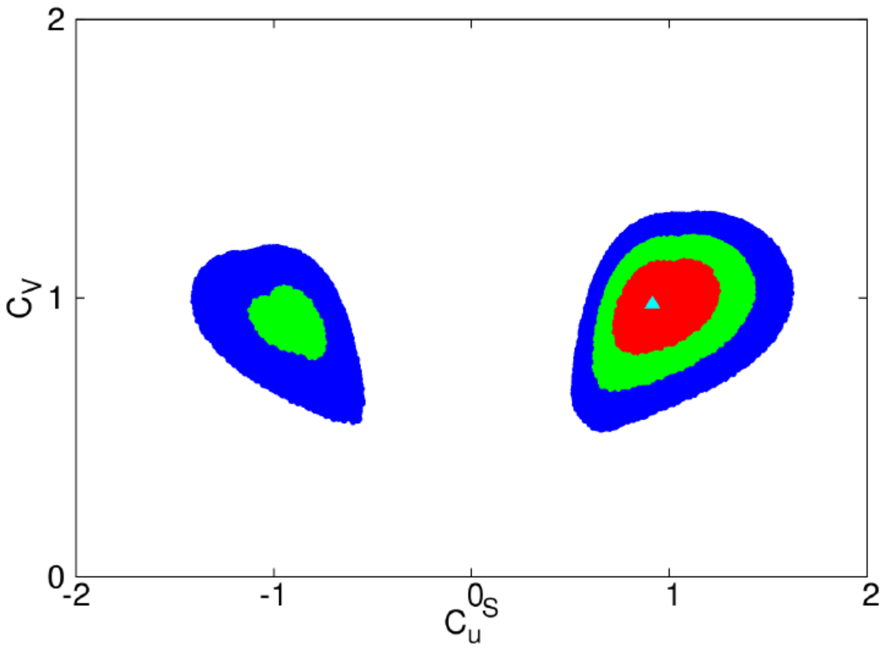
- Higgs-gluon-gluon:

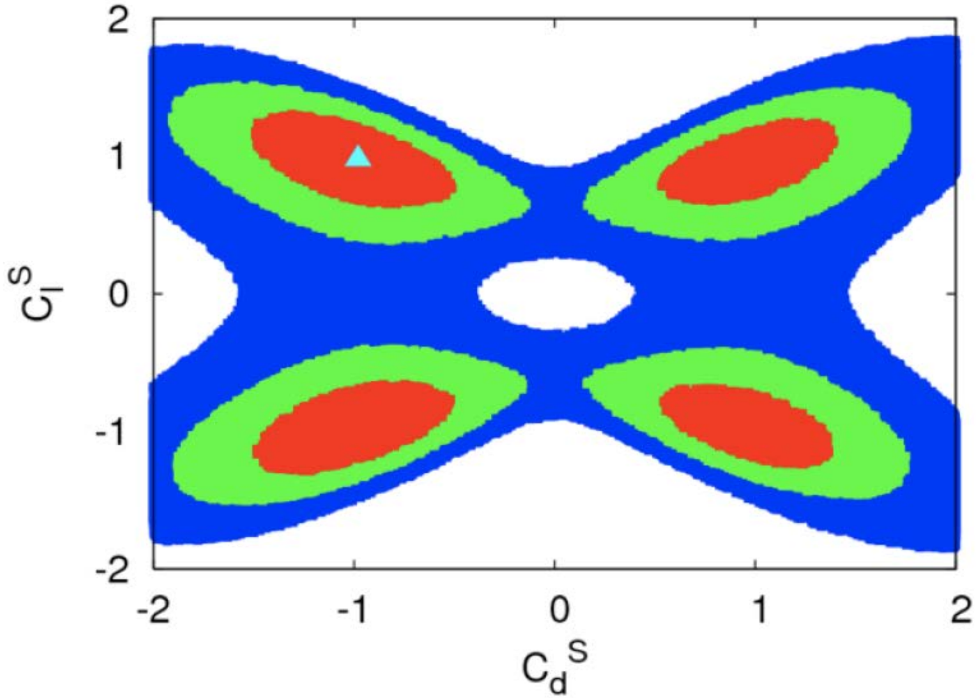
$$\text{CP even}: S^g \simeq 0.688C_u^S \simeq 0.64$$



Higgcision: Fitting CPC4

- The contributions from bottom and tau are much smaller in $H\gamma\gamma$ coupling, accordingly, the sign of C_d^S and C_l^S cannot be determined yet.

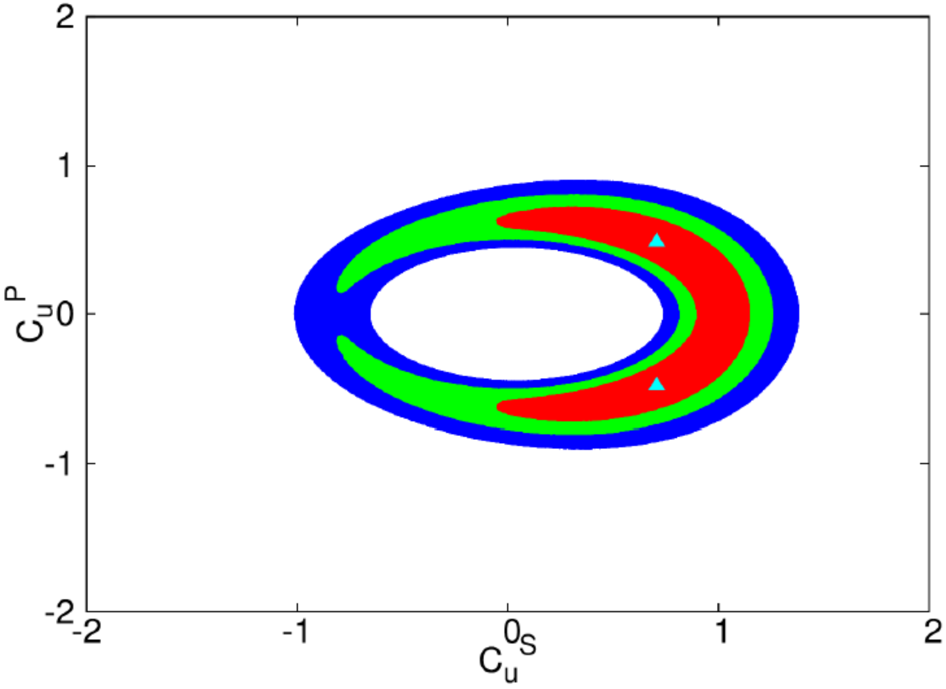




Higgcision: Fitting CPV3

- CP-violating 3-parameter fit: CP-mixed Higgs boson.

varying: C_u^S, C_u^P, C_v



Higgcision: Fitting CPV3

- The current data prefer the $H\gamma\gamma$ and Hgg couplings:

$$C_\gamma \simeq 1.1, \quad C_g \simeq 1.0$$

- Higgs-diphoton:

$$\text{CP even}: S^\gamma \simeq -8.35 C_V + 1.76 C_u^S$$
$$\text{CP odd}: P^\gamma \simeq 2.78 C_u^P$$

- Higgs-gluon-gluon:

$$\text{CP even}: S^g \simeq 0.688 C_u^S$$
$$\text{CP odd}: P^g \simeq 1.047 C_u^P$$

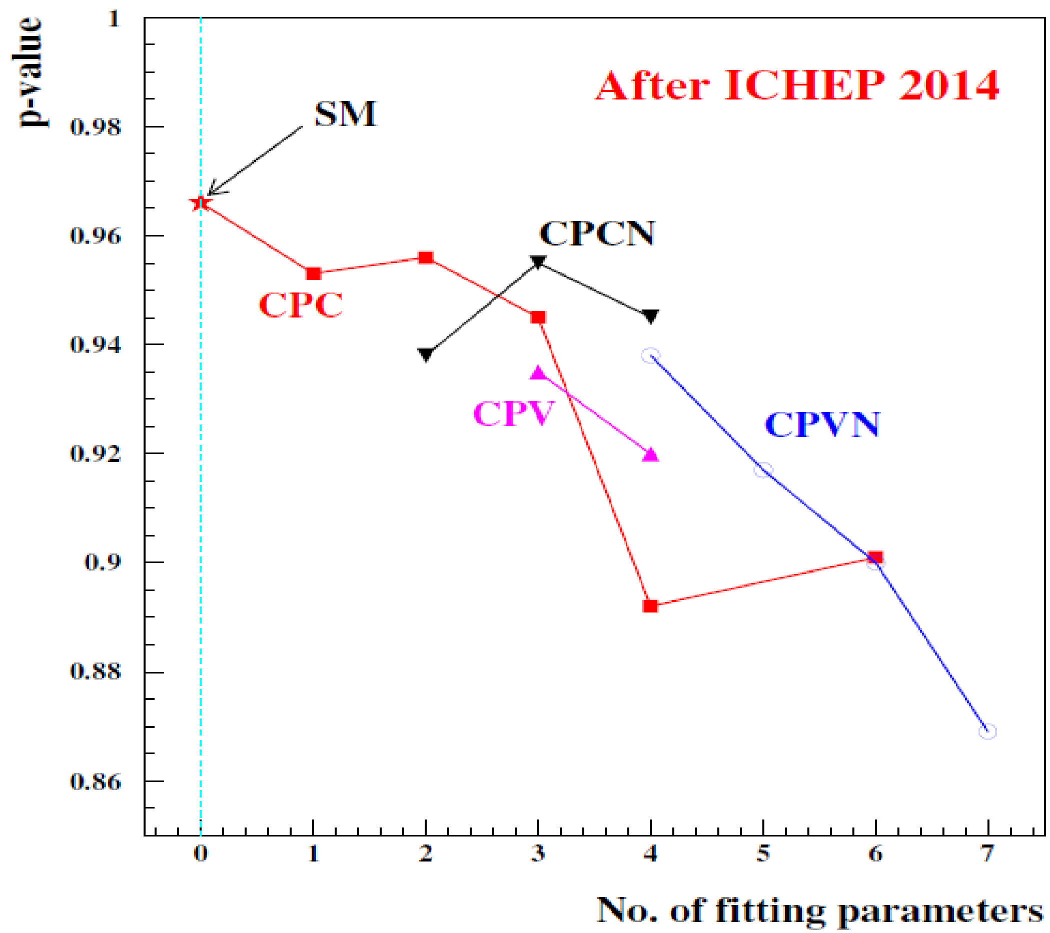
- Two elliptical equations:

$$C_\gamma = \sqrt{\frac{|S^\gamma|^2 + |P^\gamma|^2}{|S_{SM}^\gamma|^2}}, C_g = \sqrt{\frac{|S^g|^2 + |P^g|^2}{|S_{SM}^g|^2}} \Rightarrow \begin{cases} (7.3)^2 = (-8.35 + 1.76 C_u^S)^2 + (2.78 C_u^P)^2 \\ (0.64)^2 = (0.688 C_u^S)^2 + (1.047 C_u^P)^2 \end{cases}$$

Summary

Summary

- SM still provides the best fit to the data, the p-value is even better than the last year.



Summary

- The gauge coupling C_V : In various fits, center value 0.93~1.00 with around 10% uncertainty, which reduce about 10%.

- The data cannot rule out the pseudoscalar coupling, only the combination of C_u^S and C_u^P are constrained in a elliptical shape.

- The implication of the Higgs invisible decay:

$$B(H \to \text{nonstandand}) < 19\%$$

Thank you !

Back up

Introduction

- The initial Higgs data indicate deviations from SM.
- SM provide the best fit to the data after summer 2013.
- The couplings to the heavy gauge boson is restricted to the SM value with 15% uncertainty.
- The Yukawa couplings are loosely constrained.

Introduction

- The SM deviation from the data in terms of χ^2_{SM} . Previously, it is dominated by diphoton channel. Currently, the ZZ* channel becomes more important.

- The total $\chi^2_{SM}/\mathrm{d.o.f}$ for SM now is 16.76/29, compare to previous one 18.92/22.

  $\mathrm{d.o.f} = \#\text{ of data} - \#\text{ of free parameters for model}$

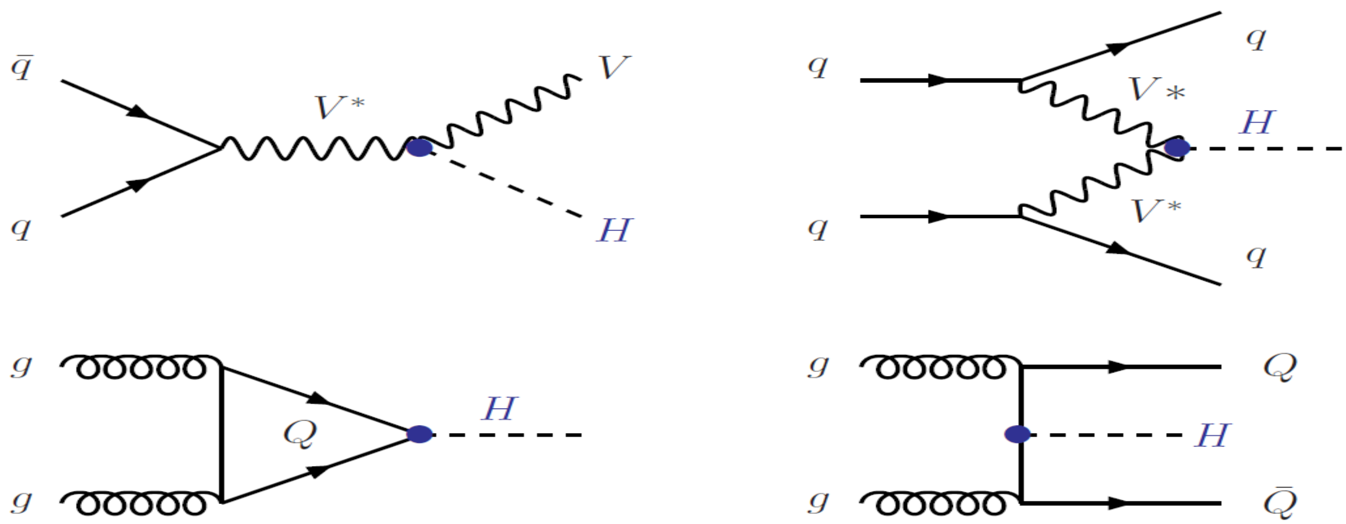
- P-value of SM improve from 0.650 to 0.966.

Introduction

- Higgs production modes: gluon fusion (**ggF**), vector-boson fusion (**VBF**), associated production (**VH**) and (**ttH**).
- At the experimental perspective, these production modes usually mix together.

A Djouadi, Phys.Rept.457 (2008)1-216

VH **VBF**



ggF **ttH**

Introduction

- Current data focus on a few decay channels of the Higgs boson.

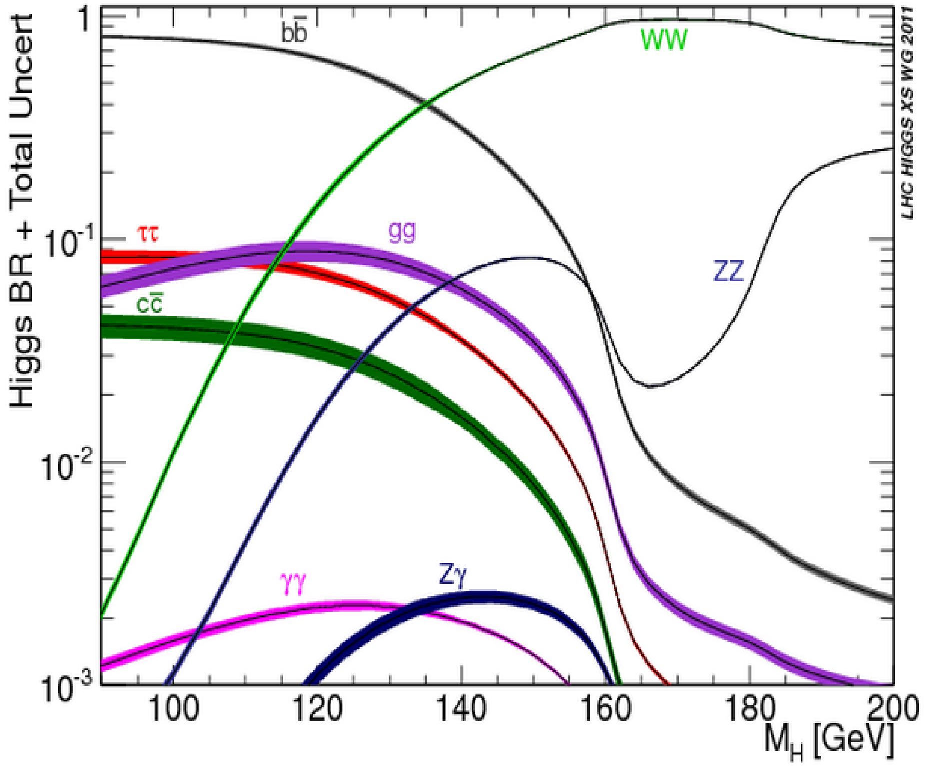
$$h \to \gamma\gamma$$

$$h \to ZZ^* \to l^+ l^- l^+ l^-$$

$$h \to WW^* \to l^+ \bar{\nu} l^- \nu$$

$$h \to b\bar{b}$$

$$h \to \tau^+ \tau^-$$



https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HiggsTheoryPlots

Introduction

TABLE I. Data on signal strengths of $H \to \gamma\gamma$ by the ATLAS and CMS, and at the Tevatron after ICHEP 2014. The luminosity updates at 8 TeV are shown in the parenthesis. The percentages of each production mode in each data are given. The χ^2 of each data with respect to the SM is shown in the last column. The sub-total χ^2 of this decay mode is shown at the end.

Channel	Signal strength μ c.v ± error	M_H(GeV)	Production mode ggF	VBF	VH	ttH	χ^2_{SM}(each)
ATLAS ($4.5 fb^{-1}$ at 7TeV + $20.3 fb^{-1}$ at 8TeV): page 29 of [7] (Aug. 2014)							
μ_{ggH}	1.32 ± 0.38	125.40	100%	-	-	-	0.71
μ_{VBF}	0.8 ± 0.7	125.40	-	100%	-	-	0.08
μ_{WH}	1.0 ± 1.6	125.40	-	-	100%	-	0.00
μ_{ZH}	$0.1^{+3.7}_{-0.1}$	125.40	-	-	100%	-	0.06
μ_{ttH}	$1.6^{+2.7}_{-1.8}$	125.40	-	-	-	100%	0.11
CMS ($5.1 fb^{-1}$ at 7TeV + $19.7 fb^{-1}$ at 8TeV): Fig. 24 of [8] (July 2014)							
μ_{ggH}	$1.12^{+0.37}_{-0.32}$	124.70	100%	-	-	-	0.14
μ_{VBF}	$1.58^{+0.77}_{-0.68}$	124.70	-	100%	-	-	0.73
μ_{VH}	$-0.16^{+1.16}_{-0.79}$	124.70	-	-	100%	-	1.00
μ_{ttH}	$2.69^{+2.51}_{-1.81}$	124.70	-	-	-	100%	0.87
Tevatron ($10.0 fb^{-1}$ at 1.96TeV): page 32 of [26] (Nov. 2012)							
Combined	$6.14^{+3.25}_{-3.19}$	125	78%	5%	17%	-	2.60
							subtot: 6.30

Introduction

TABLE II. The same as Table I but for $H \to ZZ^{(*)}$

Channel	Signal strength μ c.v $\pm$ error	M_H (GeV)	Production mode ggF	VBF	VH	ttH	χ^2_{SM}(each)
ATLAS ($4.5 fb^{-1}$ at 7TeV + $20.3 fb^{-1}$ at 8TeV): page 18 of [9] (June 2014), page 18 of [5]							
Inclusive	$1.66^{+0.45}_{-0.38}$	124.51	87.5%	7.1%	4.9%	0.5%	3.02
CMS ($5.1 fb^{-1}$ at 7TeV + $19.7 fb^{-1}$ at 8TeV): abstract of [10] (Dec. 2013)							
Inclusive	$0.93^{+0.29}_{-0.25}$	125.6	87.5%	7.1%	4.9%	0.5%	0.06
							subtot: 3.07

TABLE III. The same as Table I but for $H \to WW^{(*)}$

Channel	Signal strength μ c.v $\pm$ error	M_H (GeV)	Production mode ggF	VBF	VH	ttH	χ^2_{SM}(each)
ATLAS ($4.6 fb^{-1}$ at 7TeV + $20.7 fb^{-1}$ at 8TeV): page 10 of [11] (July 2014)							
Inclusive	0.99 ± 0.30	125	87.5%	7.1%	4.9%	0.5%	0.00
CMS ($4.9 fb^{-1}$ at 7TeV + $19.4 fb^{-1}$ at 8TeV):Fig. 23 of [12] (Dec. 2013)							
0/1 jet	$0.74^{+0.22}_{-0.20}$	125.6	97%	3%	-	-	1.40
VBF tag	$0.60^{+0.57}_{-0.46}$	125.6	17%	83%	-	-	0.49
VH tag ($2l2\nu2j$)	$0.39^{+1.97}_{-1.87}$	125.6	-	-	100%	-	0.10
WH tag ($3l3\nu$)	$0.56^{+1.27}_{-0.95}$	125.6	-	-	100%	-	0.12
Tevatron ($10.0 fb^{-1}$ at 1.96TeV): Page32 of [26] (Nov. 2012)							
Combined	$0.85^{+0.88}_{-0.81}$	125	78%	5%	17%	-	0.03
							subtot: 2.14

Introduction

TABLE IV. The same as Table I but for $H \to b\bar{b}$

Channel	Signal strength μ c.v $\pm$ error	M_H(GeV)	Production mode ggF	VBF	VH	ttH	$\chi^2_{\rm SM}$(each)
ATLAS (4.7(4.5)fb^{-1} at 7TeV + 20.3fb^{-1} at 8TeV) Fig.19 of [23] (July 2013), page 18 of [15]							
VH tag	$0.2^{+0.7}_{-0.6}$	125.5	-	-	100%	-	1.31
ttH tag	$1.8^{+1.66}_{-1.57}$	125.4	-	-	-	100%	0.26
CMS (5.1fb^{-1} at 7TeV + 18.9fb^{-1} at 8TeV) [13] (Oct. 2013), (19.5fb^{-1} at 8TeV)[16] (July 2014)							
VH tag	1.0 ± 0.5	125	-	-	100%	-	0.00
ttH tag	$0.67^{+1.35}_{-1.33}$	125	-	-	-	100%	0.06
Tevatron (10.0fb^{-1} at 1.96TeV): [17]							
VH tag	$1.59^{+0.69}_{-0.72}$	125	-	-	100%	-	0.67
							subtot: 2.30

TABLE V. The same as Table I but for $H \to \tau\tau$. The correlation for the $\tau\tau$ data of ATLAS is $\rho = -0.51$.

Channel	Signal strength μ	M_H(GeV)	Production mode ggF	VBF	VH	ttH	$\chi^2_{\rm SM}$(each)
ATLAS (20.3fb^{-1} at 8TeV): page 28 of [24] (Nov. 2013)							
$\mu(ggF)$	$1.1^{+1.3}_{-1.0}$	125	100%	-	-	-	0.85
$\mu(VBF+VH)$	$1.6^{+0.8}_{-0.7}$	125	-	59.6%	40.4%	-	
CMS (4.9fb^{-1} at 7TeV + 19.7fb^{-1} at 8TeV) Fig.16 of [14] (Jan. 2014)							
0 jet	0.34 ± 1.09	125	96.9%	1.0%	2.1%	-	0.37
1 jet	1.07 ± 0.46	125	75.7%	14.0%	10.3%	-	0.02
VBF tag	0.94 ± 0.41	125	19.6%	80.4%	-	-	0.02
VH tag	-0.33 ± 1.02	125	-	-	100%	-	1.70
							subtot: 2.96

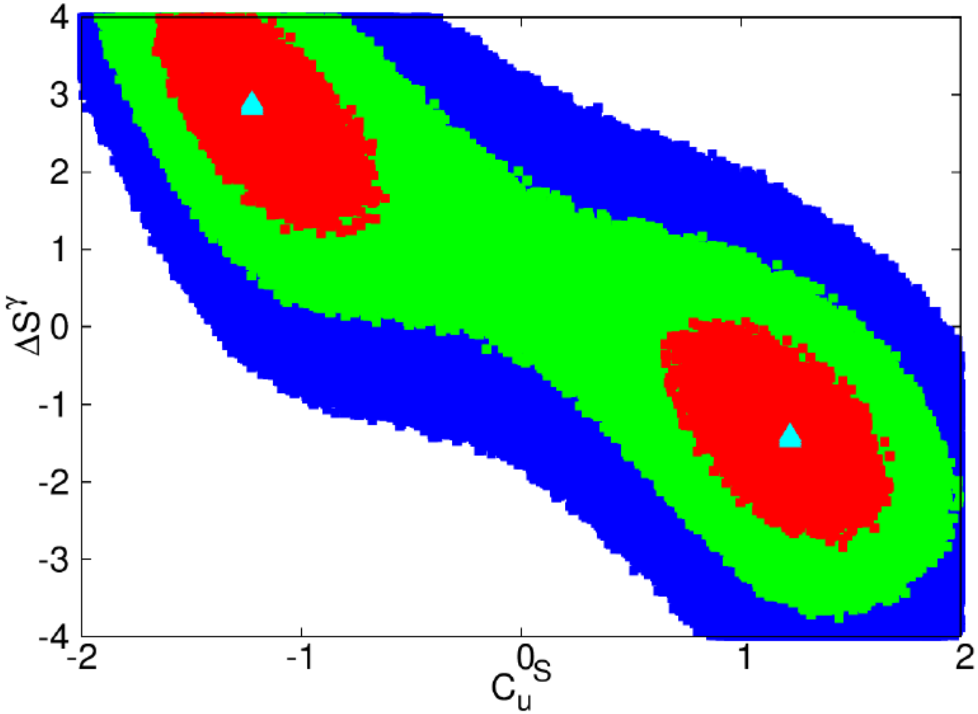
Higgcision: Fitting CPC6

- CP-conserving 6-parameter fit:

$$\begin{cases} \text{varying:} & C_u^S, C_d^S, C_l^S, C_v, \Delta S^\gamma, \Delta S^g \\ \text{fixed:} & \Delta\Gamma_{\text{tot}} = 0 \end{cases}$$

- The best fitting point:

C_u^S	$1.22^{+0.32}_{-0.38}$
C_d^S	$-0.97^{+0.30}_{-0.34}$
C_ℓ^S	$1.00^{+0.18}_{-0.17}$
C_v	$0.94^{+0.11}_{-0.12}$
ΔS^γ	$-1.43^{+1.02}_{-0.95}$
ΔS^g	$-0.22^{+0.28}_{-0.24}$
$\Delta\Gamma_{\text{tot}}$ (MeV)	0
χ^2/dof	14.83/23
p-value	0.901



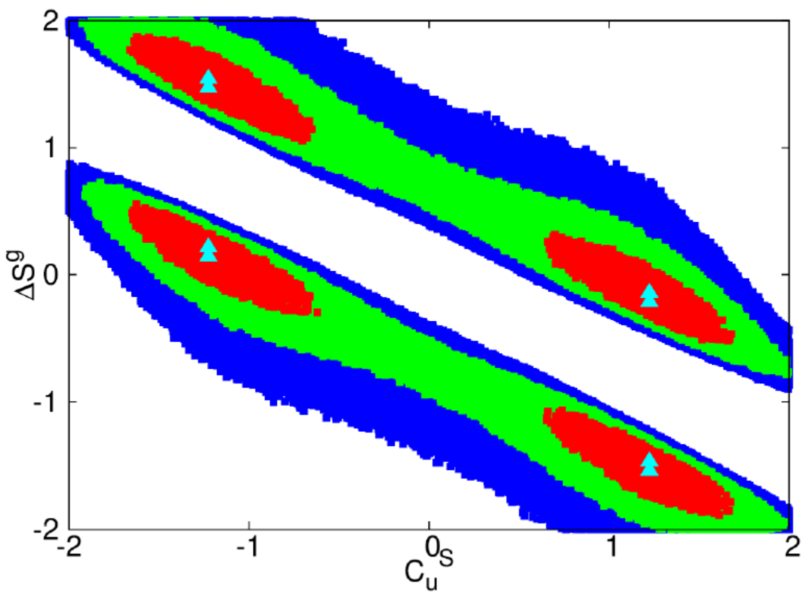
Higgcision: Fitting CPC6

- The sign of top-Yukawa coupling C_u^S **cannot** be determined in this case:

$$S^\gamma \simeq -8.35 C_V + 1.76 C_u^S + \Delta S^\gamma \simeq -7.3$$
$$S^g \simeq 0.688 C_u^S + \Delta S^g \simeq 0.64$$

- There are four minimal Chi-square solutions :

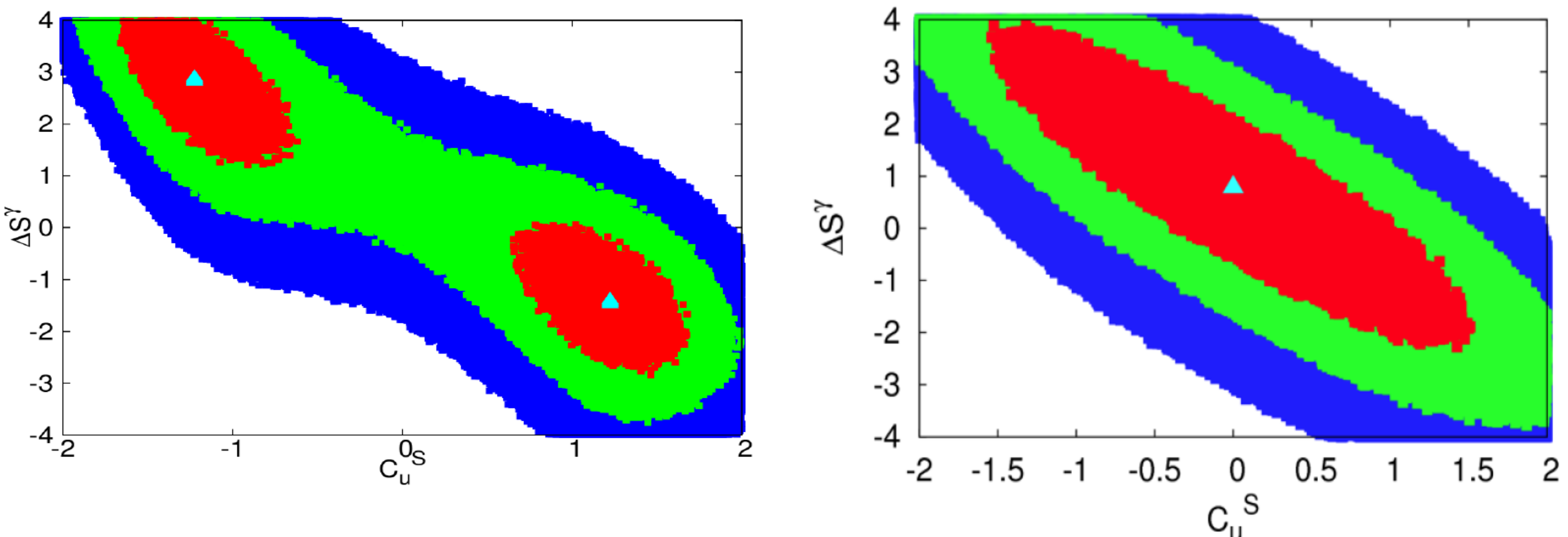
C_u^S	ΔS^γ	ΔS^g
1.22	−1.4	−0.2
1.22	−1.4	−1.5
−1.23	2.8	0.2
−1.23	2.8	1.5



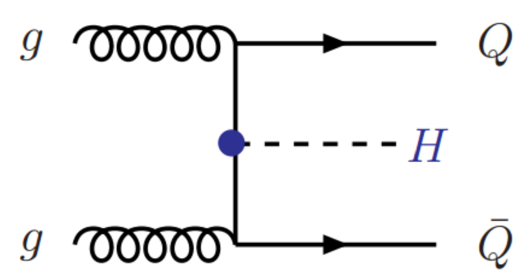
Higgcision: Fitting CPC6

- Comparing with the results from **2013 data** :

The $C_u^S = 0$ hypnosis has been ruled out at 68.3% C.L.



- Due to the new data of ttH Higgs production mode.



ttH

A Djouadi, Phys.Rept.457 (2008)1-216

- **CP-violating 2HDM**, the mixing between the mass eigenstates $h_{1,2,3}$ and the EW eigenstates ϕ_1, ϕ_2, a is described by an orthogonal matrix $O_{\alpha j}$:

$$\left(\phi_1, \phi_2, a\right)_\alpha^T = O_{\alpha j}\left(h_1, h_2, h_3\right)_j^T$$

- The mixing matrix can be expressed by C_u^S, C_u^P, C_V :

$$O_{\phi_2 i} = s_\beta C_u^S, \qquad O_{ai} = -t_\beta C_u^P;$$

$$O_{\phi_1 i} = \pm\left[1 - s_\beta^2 (C_u^S)^2 - t_\beta^2 (C_u^P)^2\right]^{1/2}$$

$$\Rightarrow \begin{cases} O_{\phi_1 i} = 0.883 \\ O_{\phi_2 i} = 0.368 \\ O_{ai} = 0.291 \end{cases}$$

with $s_\beta^2 = \dfrac{\left(1 - C_V^2\right)}{\left(1 - C_V^2\right) + \left(C_u^S - C_V\right)^2 + \left(C_u^P\right)^2}$

where $s_\beta = \sin\beta,\ c_\beta = \cos\beta,\ t_\beta = \tan\beta \equiv$ ratio of two VEV.

Summary

- The most significant update between summer 2013 and 2014 are the diphoton signal strengths.

- Full data set was analyzed for fermionic channels, while more decay channels were published, e.g.
  $WH \rightarrow 3l3\nu$ and $ttH \rightarrow tt\gamma\gamma$

- SM still provides the best fit to the data, the p-value is even better than the last year.

Introduction