

# The CP–violating Higgs production in the decoupling regime at the photon colliders

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\*S. Y. Choi, Byungchul Chung, P. Ko and Jae Sik Lee, Phy. Rev. D **66**, 016009 (2002)

## I. INTRODUCTION

- The process  $\gamma\gamma \rightarrow h$  :
  1. Important mechanism for probing the properties of  $h$
  2. Linearly polarized photons
  3. 1-loops of all charged particles
- Decoupling regime
  1. Large pseudoscalar mass :  $m_A \gtrsim 200$  GeV
  2. The lightest Higgs boson :  $m_h \lesssim 116$  GeV  
almost the same properties with  $h_{SM}$ !!
  3.  $h_{SM}$  vs  $h_{MSSM}$ 
    - $h_{SM}$  : Can NOT decay into SUSY particles
    - $h_{MSSM}$  : Can decay into SUSY particles (i.e.  $h_{MSSM} \rightarrow \tilde{\chi}_i^0 \tilde{\chi}_j^0$ )
    - $\gamma\gamma \rightarrow h_{SM}$  : CP-invariant
    - $\gamma\gamma \rightarrow h_{MSSM}$  : CP-noninvariant  
due to **chargino contribution**
- Light charginos  
Experimental lower bound :  $m_{\tilde{\chi}_1^\pm} \gtrsim 104$  GeV

- **MSSM EWBG** J. M. Cline and K. Kainulainen, PRL 85, 5519 (2000); M. Carena, J. M. Moreno, M. Quiros, M. Seco and C. E. Wagner, NPB 599, 158 (2001); H. Murayama and A. Pierce, PRD 67, 071702 (2003)

- Sakharov’s 3 conditions :
  1. B-violating interactions
  2. C and CP violations
  3. Out of equilibrium for B-violating interactions
- To achieve a strong enough 1st order phase transition (need two-loop corrections) :
  1. Need new physics beyond the SM ( $\because$  Higgs mass bound) i.e. MSSM
  2. Constrained stop mass : Light right-handed stop mass and heavy left-handed stop mass i.e.  $120 \text{ GeV} \lesssim m_{\tilde{t}_R} \lesssim m_t$
- The source of the CP violation : **the complex phase  $\Phi_\mu$** 
  1. Sizable  $\Phi_\mu$
  2. Not too heavy chargino mass and  $|M_2| \sim |\mu|$  :
 $m_{\tilde{\chi}^\pm} \lesssim 300 \text{ GeV}$
  3.  $\tan \beta \lesssim 6$
- To evade the EDM bound : Effective SUSY model  
The 1st/2nd generation sfermions are heavy enough.

## II. THE HIGGS COUPLINGS TO CHARGINO PAIRS

- The chargino mass matrix

$$\mathcal{M}_C = \begin{pmatrix} M_2 & \sqrt{2}m_W c_\beta \\ \sqrt{2}m_W s_\beta & \mu \end{pmatrix}. \quad (1)$$

- The diagonalization :  $U^* \mathcal{M}_C V^\dagger = \text{diag}\{m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^\pm}\}$   
( $U$  and  $V$  : Unitary matrices )
- Fields redefinition :  $M_2 \rightarrow \text{Real}$  and  $\mu = |\mu| e^{i\Phi_\mu}$
- The Higgs couplings to chargino pairs in the decoupling regime :

$$\kappa_i = -\frac{g}{\sqrt{2}}(U_{i1}V_{i2} \cos \beta + U_{i2}V_{i1} \sin \beta). \quad (2)$$

- Higgsino-like( $|\mu| \gg |M_2|$ ) or Gaugino-like( $|\mu| \ll |M_2|$ ) :
  - $\kappa_i \rightarrow 0$  ( $\because V_{ij} \simeq 0$  or  $U_{ij} \simeq 0$  for  $i \neq j$ )
  - $|\mu| \simeq M_2$  :  $\kappa_i$  can be significant

Note : In the chargino contributions to  $\gamma\gamma \rightarrow h$ , there is only  $\Phi_\mu$  as a CP violating phase.

### III. NEUTRAL HIGGS BOSON PRODUCTIONS AT PHOTON COLLIDERS

- The helicity amplitudes of the reaction  $\gamma\gamma \rightarrow h$  :

$$\mathcal{M}_{\lambda_1\lambda_2} = -M_h \frac{\alpha}{4\pi} \{A(s)\delta_{\lambda_1\lambda_2} + i\lambda_1 B(s)\delta_{\lambda_1\lambda_2}\} \quad (3)$$

$(\lambda_{1,2} = \pm 1 : \text{photon helicities})$

- The signals of CP violation : **The existence of both  $A$  and  $B$  simultaneously**

$(A : \text{CP-even and } B : \text{CP-odd})$

- The unpolarized cross section :

$$\sigma(\gamma\gamma \rightarrow h) = \frac{\pi}{4M_h^4} \left( |\mathcal{M}_{++}|^2 + |\mathcal{M}_{--}|^2 \right) \delta(1-M_h^2/s) \equiv \hat{\sigma}_0(h) \delta(1-M_h^2/s). \quad (4)$$

- Three polarization asymmetries:

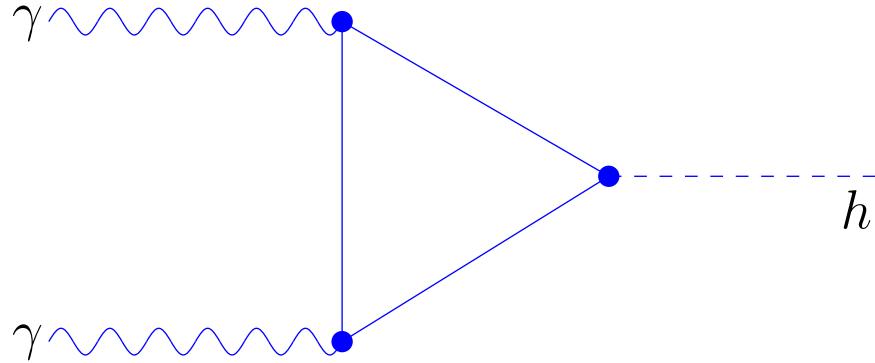
$$\mathcal{A}_1 = \frac{|\mathcal{M}_{++}|^2 - |\mathcal{M}_{--}|^2}{|\mathcal{M}_{++}|^2 + |\mathcal{M}_{--}|^2} = \frac{2\text{Im}(A(s)B(s)^*)}{|A(s)|^2 + |B(s)|^2}, \quad (5)$$

$$\mathcal{A}_2 = \frac{2\text{Im}(\mathcal{M}_{--}^* \mathcal{M}_{++})}{|\mathcal{M}_{++}|^2 + |\mathcal{M}_{--}|^2} = \frac{2\text{Re}(A(s)B(s)^*)}{|A(s)|^2 + |B(s)|^2}, \quad (6)$$

$$\mathcal{A}_3 = \frac{2\text{Re}(\mathcal{M}_{--}^* \mathcal{M}_{++})}{|\mathcal{M}_{++}|^2 + |\mathcal{M}_{--}|^2} = \frac{|A(s)|^2 - |B(s)|^2}{|A(s)|^2 + |B(s)|^2}, \quad (7)$$

**CP-invarint case** :  $\mathcal{A}_1 = \mathcal{A}_2 = 0$  and  $\mathcal{A}_3 = \pm 1$

**CP-violating case** :  $\mathcal{A}_1 \neq 0$ ,  $\mathcal{A}_2 \neq 0$  or  $|\mathcal{A}_3| < 1$



*The Feynman diagram for the lightest Higgs production at photon colliders*

- Decoupling limit :  $\tilde{t}_R$ ,  $t$ ,  $W^\pm$  and  $\tilde{\chi}_j^\pm$

The CP–even form factor :

$$A = A_t + A_{W^\pm} + A_{\tilde{t}_R} + A_{\tilde{\chi}_1^\pm} + A_{\tilde{\chi}_2^\pm}, \quad (1)$$

The CP–odd form factor  $B$  consists only of the chargino contributions :

$$B = B_{\tilde{\chi}_1^\pm} + B_{\tilde{\chi}_2^\pm} \quad (2)$$

Note : For general MSSM case, one-loop contributions comes from all possible charged particles, i.e. top, bottom, stop, sbottom,  $W^\pm$  bosons, charged Higgs and charginos

## IV. NUMERICAL RESULTS

Motivated by MSSM chargino EWBG scenario and present experimental constraints : I. Laktineh hep-ex/0205088; T. Falk, K.A. Olive, M. Pospelov and R. Robibon NPB 560, 3 (1999) and so on.

$$m_h = 115 \text{ GeV}; \quad \tan \beta = 5; \quad M_2 = 150 \text{ GeV}, \quad |\mu| = 150 \text{ GeV}; \quad \Phi_\mu = \frac{\pi}{2} \quad (8)$$

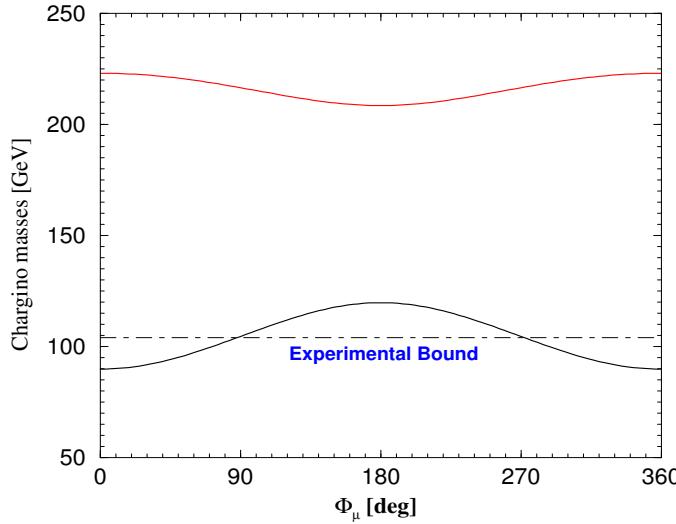


FIG. 1: The chargino masses,  $m_{\tilde{\chi}_{1,2}^\pm}$  as a function of the CP-violating phase  $\Phi_\mu$ .

### RESULTS ;

- Reducing the production cross section for small  $m_{\tilde{t}}$  :  
The right-handed top squark contribution destructively interferes with the SM contribution ( $\hat{\sigma}_{0SM} = 150 \text{ fb}$ ) .
- CP violation due to only chargino contribution :  
The maximal values of the CP phases;  $\mathcal{A}_2 \simeq 0.25$  for  $\Phi_\mu \simeq 80^\circ$  or  $280^\circ$

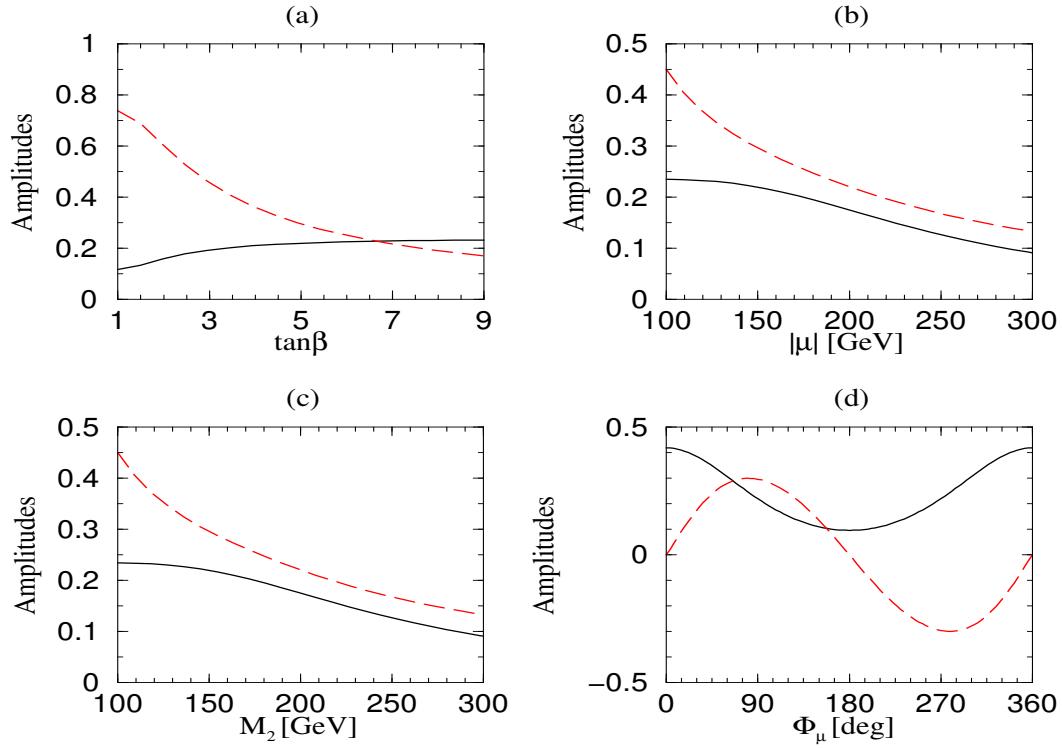


FIG. 2: The  $CP$ -even and  $CP$ -odd amplitudes

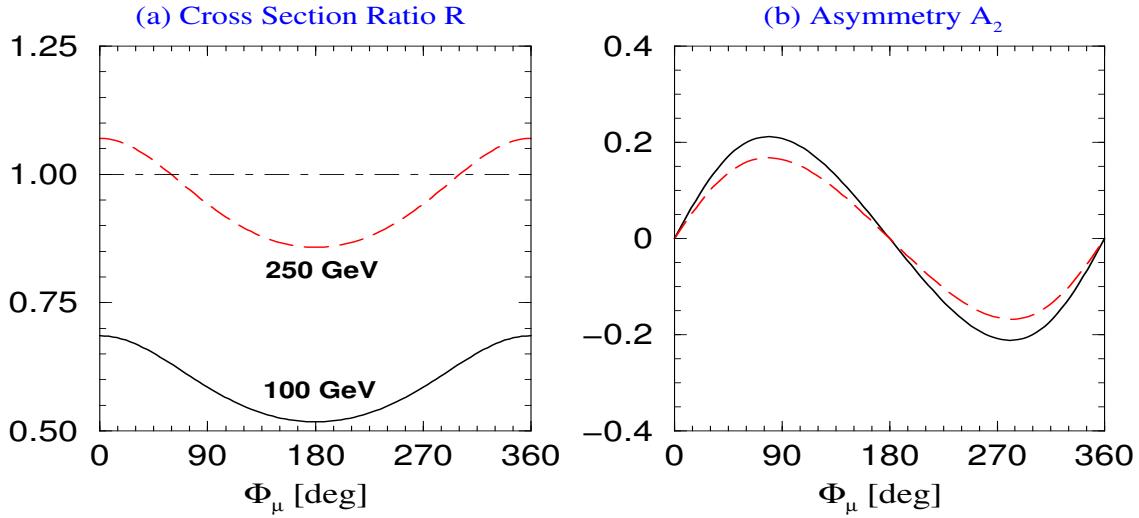


FIG. 3: (a) the ratio  $R$  of  $\hat{\sigma}_0$  to the SM prediction 150 fb and (b) the  $CP$ -odd asymmetry  $A_2$ .

## v. SUMMARY AND CONCLUSIONS

- The photon–photon fusion process is significant for searching the lightest Higgs boson at photon colliders
- The CP-violating phenomenon due to chargino contributions in the decoupling limit is a unique feature of CP-noninvariant SUSY theories.