CP-VIOLATING HIGGS SECTOR OF MSSM

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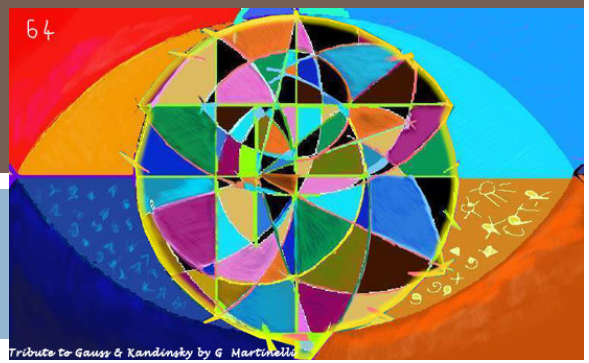
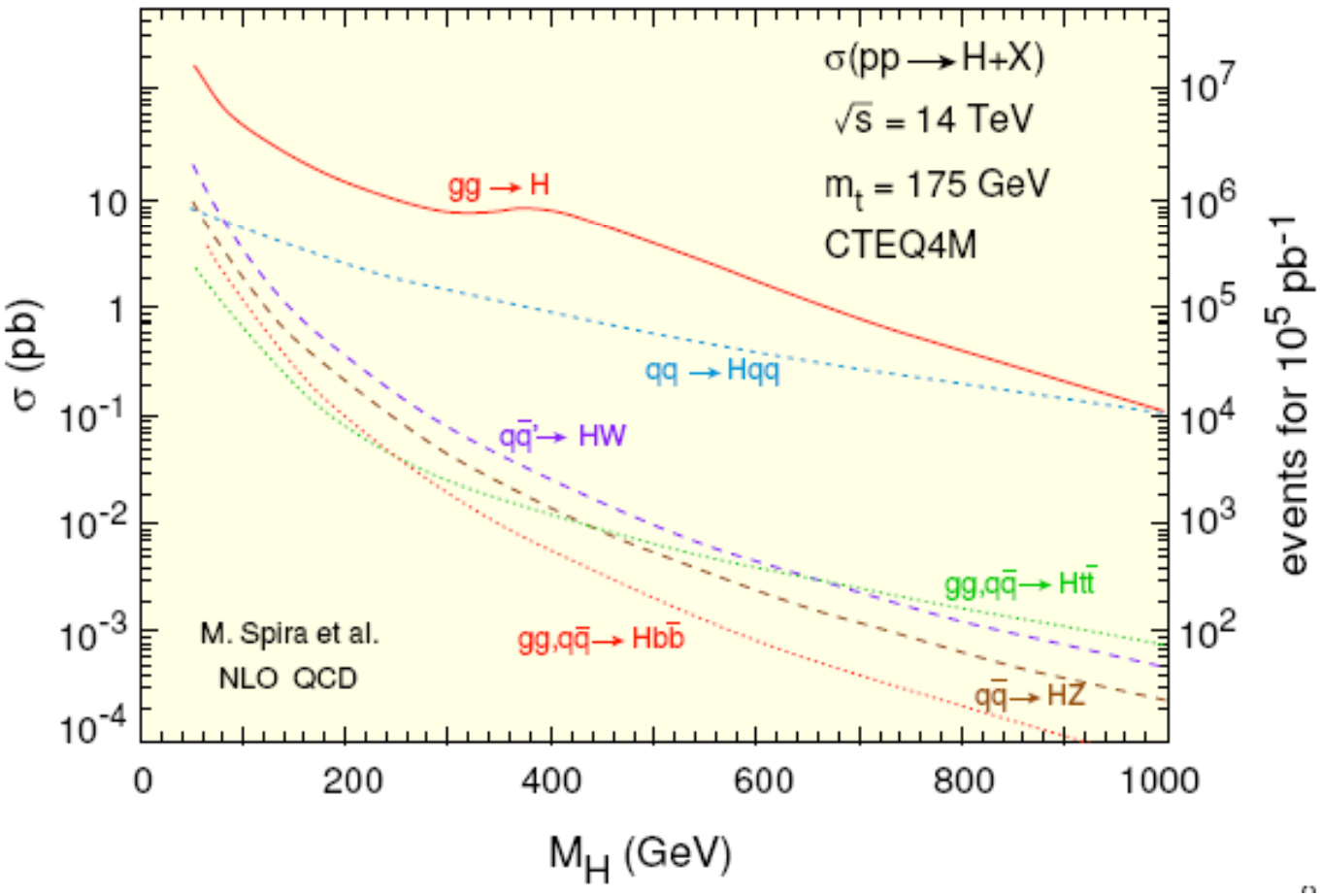
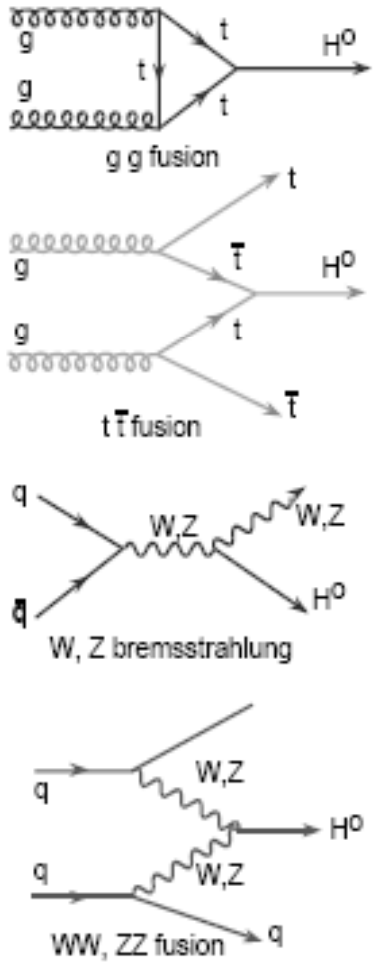


SM picture: Production at LHC

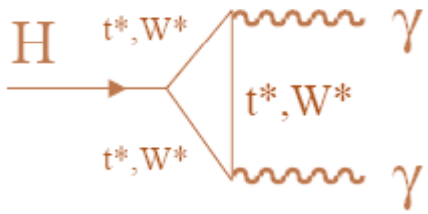




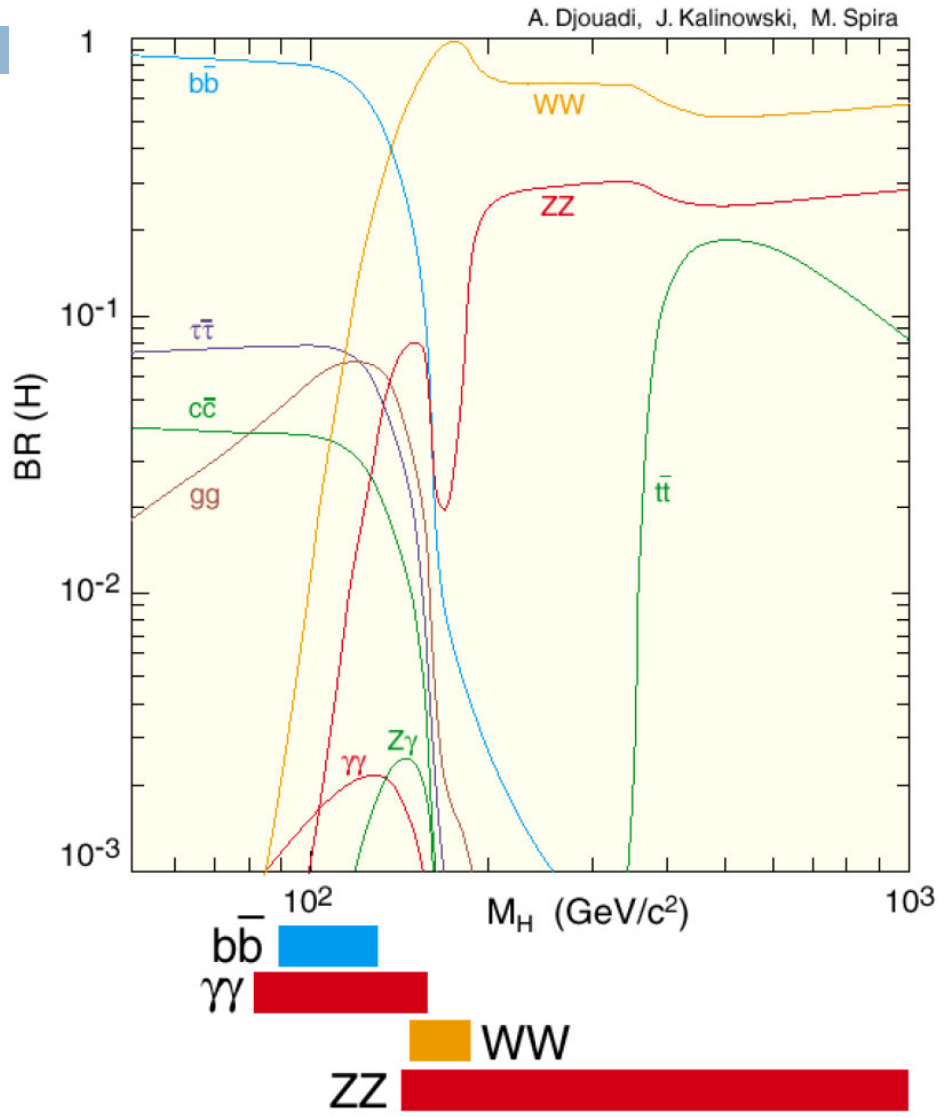
SM picture: decays

For $m_H \approx 100 - 130\ GeV$

$H \longrightarrow \gamma\gamma$ is the discovery channel



If exists, LHC will find it for the entire mass range



CP-conserving MSSM

Two Higgs doublets

$$\begin{pmatrix} H^0_1 \\ H^\pm_1 \end{pmatrix} \quad \begin{pmatrix} H^0_2 \\ H^\pm_2 \end{pmatrix}$$

3 fields are gauged away

$$\varphi_1^0, \varphi_2^0, A^0, H^+, H^-$$

pseudoscalar Higgs

charged Higgs

heavy Higgs

light Higgs

$$\begin{pmatrix} H^0 \\ h^0 \end{pmatrix} = \begin{pmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} \varphi_1^0 \\ \varphi_2^0 \end{pmatrix}$$

Two independent parameters:

tanβ – ratio of vev's of the two doublets

M_A – mass of pseudoscalar Higgs A

An MSSM Higgs will not Escape detection at LHC

MSSM with CP violation

Complex parameters in Higgs-squark sector

- Squark mass matrix: $\mathcal{L}_M^{\tilde{q}} = -(\tilde{q}_L^*, \tilde{q}_R^*) \begin{pmatrix} M^2_{\tilde{q}_{LL}} & M^2_{\tilde{q}_{LR}} \\ M^2_{\tilde{q}_{RL}} & M^2_{\tilde{q}_{RR}} \end{pmatrix} \begin{pmatrix} \tilde{q}_L \\ \tilde{q}_R \end{pmatrix}$

with $\rightarrow M^2_{\tilde{t}_{RL}} = (M^2_{\tilde{t}_{LR}})^* = m_t \left(|A_t| e^{i\varphi_{A_t}} - \frac{|\mu| e^{-i\varphi_\mu}}{\tan\beta} \right)$ for stops $\tilde{t}$

$\rightarrow M^2_{\tilde{b}_{RL}} = (M^2_{\tilde{b}_{LR}})^* = m_b \left(|A_b| e^{i\varphi_{A_b}} - |\mu| e^{-i\varphi_\mu} \tan\beta \right)$ for sbottoms $\tilde{b}$

A_q : trilinear couplings of squarks

($\tan\beta = \frac{v_2}{v_1}$: ratio of Higgs vevs)

μ : Higgs-higgsino mass parameter

- Diagonalization: $\begin{pmatrix} \tilde{q}_1 \\ \tilde{q}_2 \end{pmatrix} = \mathcal{R}^{\tilde{q}} \begin{pmatrix} \tilde{q}_L \\ \tilde{q}_R \end{pmatrix} \rightarrow$ complex mixing matrix $\mathcal{R}^{\tilde{q}}$

Higgs sector of CPV MSSM

Higgs mass eigenstates and mixing

- $\mathcal{R}^{\tilde{q}}$ and A_q, μ enter Higgs-squark couplings
- Higher order: squark loops $\Rightarrow$ explicit CP violation in Higgs sector

  [Pilaftsis, '98; Pilaftsis, Wagner, '99; Demir, '99, Carena, Ellis, Pilaftsis, Wagner, '00, '01]

  [Choi, Drees, Lee, '00; Heinemeyer, '01]

$\rightarrow$ all 3 neutral Higgs states mix: $\begin{pmatrix} H_1 \\ H_2 \\ H_3 \end{pmatrix} = O^T \begin{pmatrix} \phi_1 \\ \phi_2 \\ A \end{pmatrix}$

$\rightarrow$ 3×3 Higgs mixing matrix O

$\rightarrow$ 3 mass eigenstates H_1, H_2, H_3 (with $m_{H_1} < m_{H_2} < m_{H_3}$)

Higgs sector of CPV MSSM

Effective neutral Higgs-squark couplings at tree-level

$$\mathcal{L}_{\tilde{q}\tilde{q}H} = -g\, C(\tilde{q}_k^\dagger H_i \tilde{q}_j)\, \tilde{q}_k^\dagger H_i \tilde{q}_j$$

$$\left(C(\tilde{q}_k^\dagger H_i \tilde{q}_j)\right) = \mathcal{R}^{\tilde{q}} \begin{pmatrix} C(\tilde{q}_L^\dagger H_i \tilde{q}_L) & C(\tilde{q}_L^\dagger H_i \tilde{q}_R) \\ C(\tilde{q}_R^\dagger H_i \tilde{q}_L) & C(\tilde{q}_R^\dagger H_i \tilde{q}_R) \end{pmatrix} \mathcal{R}^{\tilde{q}^\dagger}$$

$\rightarrow$ phases $\varphi_{A_q}, \varphi_\mu$ in $C(\tilde{q}_R^\dagger H_i \tilde{q}_L) = [C(\tilde{q}_L^\dagger H_i \tilde{q}_R)]^*$

for example for stops:

$$C(\tilde{t}_L^\dagger H_i \tilde{t}_R) = \frac{m_t}{2 m_W \sin\beta}\{-i\left(\cos\beta |A_t| e^{-i\varphi_{A_t}} + \sin\beta |\mu| e^{i\varphi_\mu}\right) O_{3i}$$

$$- \left(|\mu| e^{i\varphi_\mu} O_{1i} - |A_t| e^{-i\varphi_{A_t}} O_{2i}\right)\}$$

MSSM with CP violation

- Large number of complex couplings make phenomenological studies difficult.
- Invoke symmetries to round off some of the phases.
- Assume some unification (all the tri-linear couplings have same phase.)
- EDM constraints: first two generation couplings are real.
- Finally we deal with two phases of μ and A.

CPV in production and decay

- Resonant CP violation at LHC in $b\bar{b}, gg, W^+W^- \to H_i \to \tau^+\tau^-$

  Scenarios with $m_{H_1} \sim m_{H_2} \sim m_{H_3}$ [Ellis, Lee, Pilaftsis, '04, '05]

  $\to$ CP effects largest for $W^+W^- \to H_i \to \tau^+\tau^-$

  $\to \sigma$: factor 2

  $\to$ CP asymmetry using τ polarization: 50% possible

- $pp \to H^\pm H_1 \to 4b\ell + \not{E}_T$ at LHC [Gosh, Moretti, '04]

  CPX scenario with light H_1, suppressed H_1ZZ coupling

  $\to H_1 H^\mp W^\pm$ coupling enhanced (sum rule)

  $\Rightarrow pp \to H^\pm H_1 \to 4b\ell + \not{E}_T$ promising channel

- $pp \to H_i \tilde{q}_i \bar{\tilde{q}}_j$ [Li, Li, Li, '06]

  $\to \sigma(pp \to H_i \tilde{t}_i \bar{\tilde{t}}_j)$ can be several orders enhanced

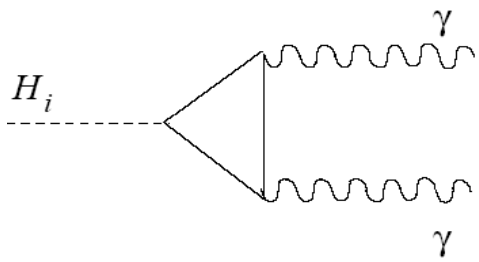
Di-photon decay

- Impact of ϕ_μ on BR($H_1 \to \gamma\gamma$) [Moretti, Munir, Poulose, '07]
- Decay at 1-loop via f, W, $H^\pm$, $\tilde{f}$, $\tilde{\chi}^\pm$ loops
- CPV enters via phase dependence of

  scalar-pseudoscalar mixing

  H_i couplings (also to SM particles)

  $\tilde{f}$, $\tilde{\chi}^\pm$ sector (masses, couplings to H_i)

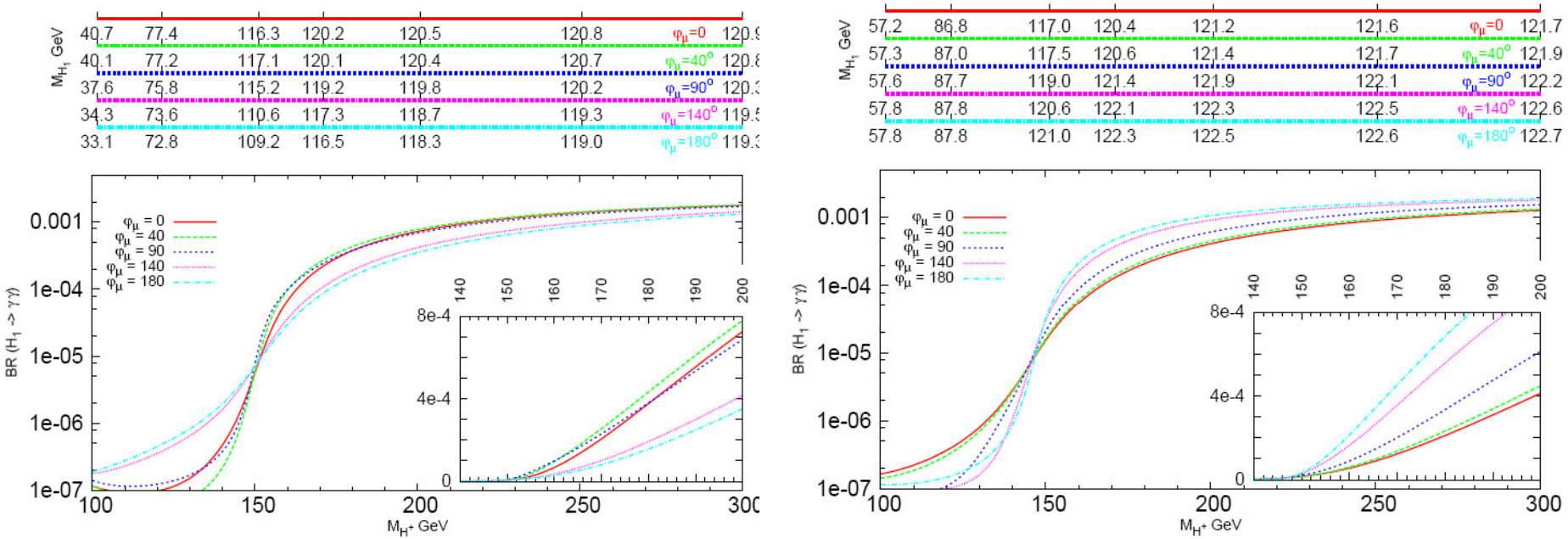


- Scan over MSSM parameters

  → 45% deviation between CPV and CPC case possible for same m_{H_1}

  (assuming 2 GeV mass resolution)

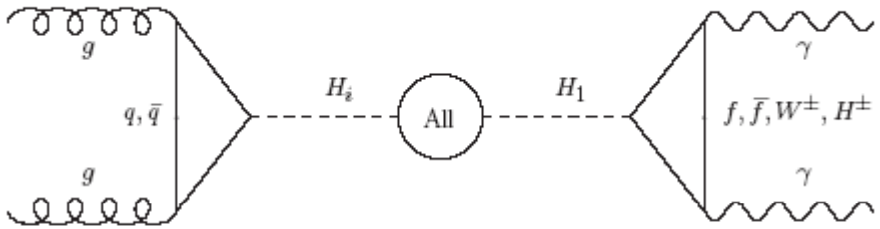
Light Stops in the loop



BR($H \longrightarrow \gamma\gamma$) with and without a light stop.

Tool: **CPsuperH**

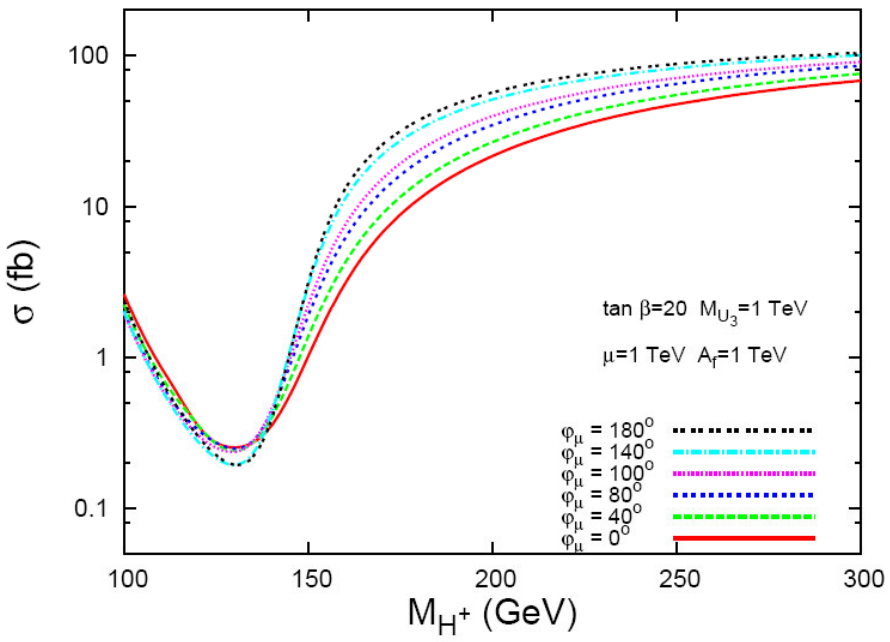
Production through Gluon fusion included

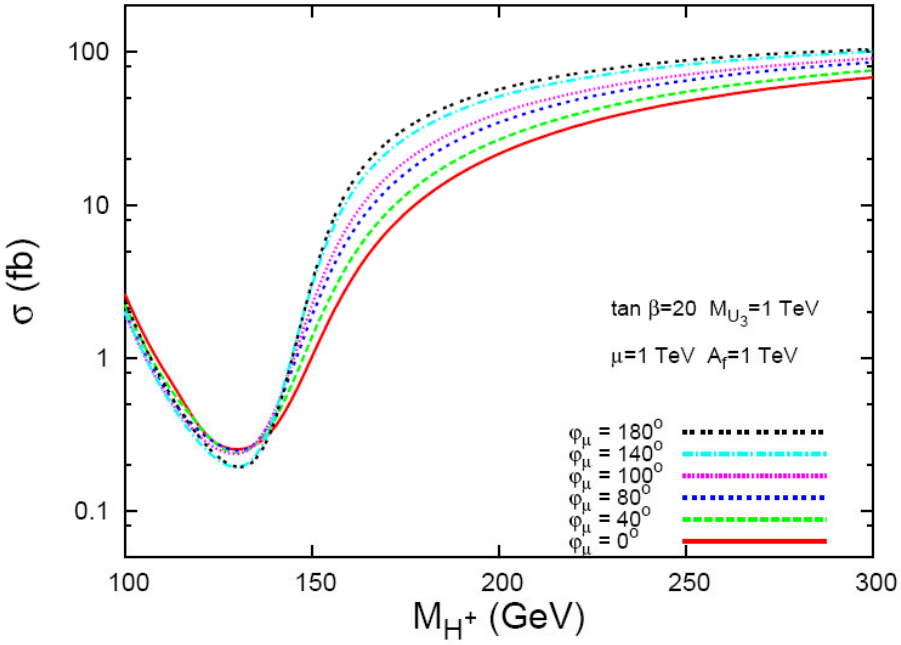


Similar effect is expected in the production through the dominant gluon fusion.

Resonant effects could be expected when the Higgs bosons are degenerate in mass.

Gluon fusion included





σ X BR with and without a light stop. Soft SUSY masses Around 1 TeV.

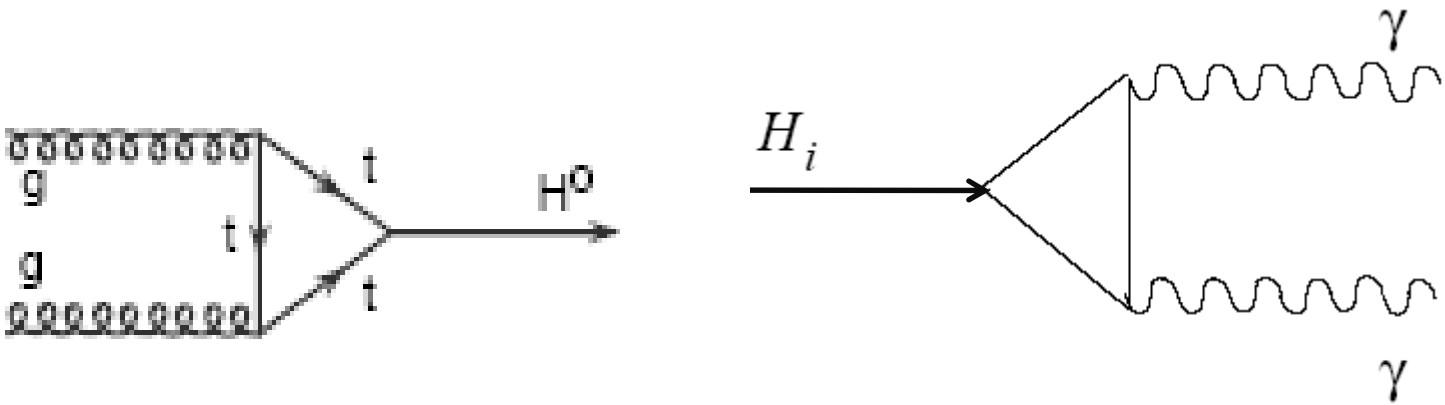
Conclusions

We considered the effect of CP violation in the Higgs sector of MSSM in the gluon fusion production along with the di-photon decay of the lightest Higgs boson.

Our investigation suggests that at large luminosities the process will betray signatures of CP violation in the sector.

The effect of a light stop emerging through the Higgs-stop-stop couplings in the CPV studies of Higgs sector can be studied through this process.

THANK YOU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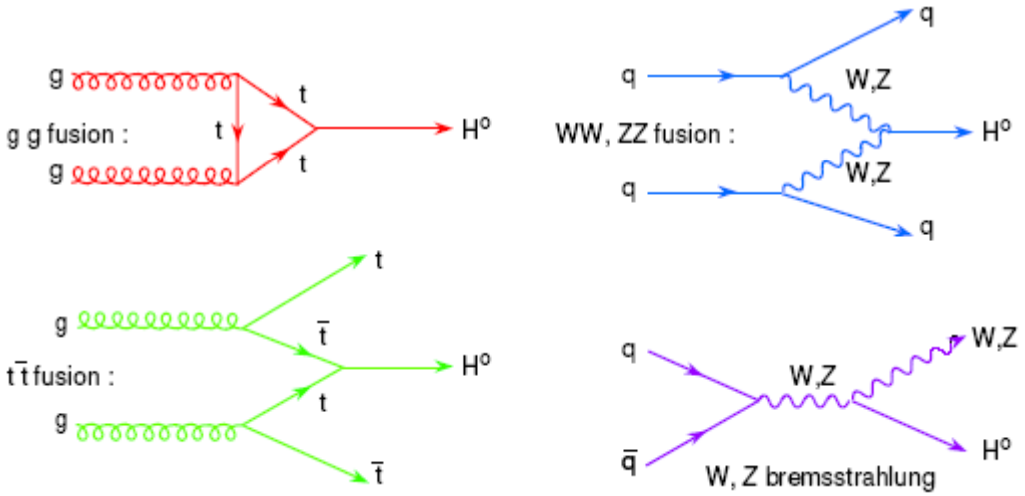
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