

# $\tau$ polarisation at a $\gamma\gamma$ collider

*as a probe of the CP properties of the Higgs*

International Conference on Linear Colliders, LCWS'04

*19-23 April, 2004, Paris*

**Rohini M Godbole<sup>1</sup>**

*in collaboration with*

Sabine Kraml<sup>2</sup> & Ritesh K Singh<sup>1</sup>

<sup>1</sup>Centre for High Energy Physics, IISc, Bangalore, India

<sup>2</sup>Theory Division, CERN, Switzerland

# MSSM Higgs Sector

MSSM : Three neutral Higgs

$h, H$   
 $CP\text{-even}$

$A$   
 $CP\text{-odd}$

$CP$  violation :  $\phi_1, \phi_2, \phi_3$   
no fixed  $CP$  property  $m_{\phi_1} < m_{\phi_2} < m_{\phi_3}$

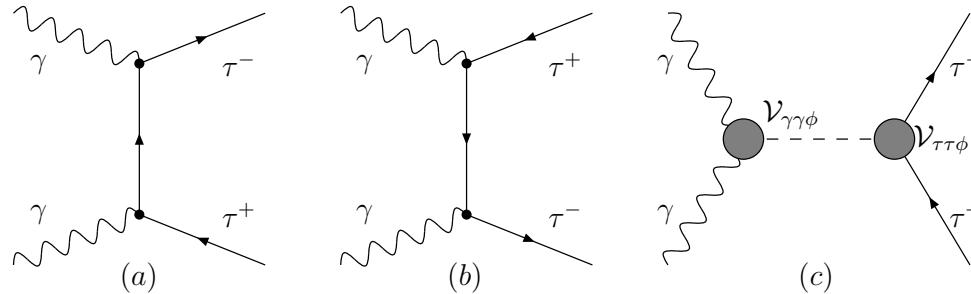
$\phi_i$  coupling to gauge bosons and fermions changes with  $CP$  violation.

$$g^{VV\phi_1} < g^{VVH_{SM}} \Rightarrow \sigma(e^+e^- \rightarrow Z^* \rightarrow Z\phi) < \sigma(e^+e^- \rightarrow Z^* \rightarrow ZH_{SM})$$

May escape detection at  $e^+e^-$  collider, but can still be produced at a  $\gamma\gamma$  collider.

$$\gamma\gamma \rightarrow \tau^+ \tau^-$$

$\tau$  pair production as a probe of the Higgs contribution.



The Higgs contribution treated in a model independent way.

$$\mathcal{V}_{\tau^+ \tau^- \phi} = -ie \frac{m_\tau}{M_W} (S_\tau + i\gamma^5 P_\tau),$$

$$\mathcal{V}_{\gamma\gamma\phi} = \frac{-i\sqrt{s}\alpha}{4\pi} \left[ S_\gamma(s) \left( \epsilon_1 \cdot \epsilon_2 - \frac{2}{s} (\epsilon_1 \cdot k_2)(\epsilon_2 \cdot k_1) \right) - P_\gamma(s) \frac{2}{s} \epsilon_{\mu\nu\alpha\beta} \epsilon_1^\mu \epsilon_2^\nu k_1^\alpha k_2^\beta \right].$$

$\{S_\tau, P_\tau, S_\gamma, P_\gamma\}$  depend upon  $m_{H^+}, \tan\beta, \mu, A_{t,b,\tau},$

$\Phi_{t,b,\tau}, M_{\tilde{q}}, M_{\tilde{l}}$  etc. in ( $CP$  violating) MSSM.

$$\gamma\gamma \rightarrow \tau^+\tau^-$$

Combinations of form-factors that appear in the helicity amplitude.

Combinations	Aliases	CP-property	Combinations	Aliases	CP-property
$S_\tau \Re(S_\gamma)$	$x_1$	even	$S_\tau \Re(P_\gamma)$	$y_1$	odd
$S_\tau \Im(S_\gamma)$	$x_2$	even	$S_\tau \Im(P_\gamma)$	$y_2$	odd
$P_\tau \Re(P_\gamma)$	$x_3$	even	$P_\tau \Re(S_\gamma)$	$y_3$	odd
$P_\tau \Im(P_\gamma)$	$x_4$	even	$P_\tau \Im(S_\gamma)$	$y_4$	odd

QED background :  $P$ ,  $CP$  and chirality conserving.  
Higgs exchange diagram violates these symmetries,  
 $\{x_i, y_j\} \neq 0 \Rightarrow$ . Chirality flipping interaction,  $\Rightarrow \tau$ -polarisation affected.

# Unpolarised Photon Collider

Polarisation of  $\tau$  defined as

$$P_{\tau}^{IJ} = \frac{N_+^{IJ} - N_-^{IJ}}{N_+^{IJ} + N_-^{IJ}}$$

$I, J = +, -, U$  Polarisation of parent  $e^+/e^-$  beam.

$N_+^{IJ}$  = # of  $\tau_R$ ,  $N_-^{IJ}$  = # of  $\tau_L$ .

Statistical error in  $P_{\tau}^{IJ}$  :

$$\Delta P_{\tau} = \frac{\sqrt{2[(N_+^{IJ})^2 + (N_-^{IJ})^2]}}{(N_+^{IJ} + N_-^{IJ})^{3/2}} = \frac{1}{\sqrt{N_+^{IJ} + N_-^{IJ}}} \sqrt{1 + (P_{\tau}^{IJ})^2}$$

[Hikasa, PRD60,(1999),114041]

# Unpolarised Photon Collider

- $P_\tau^U = 0$  : for QED contribution.
- $P_\tau^U = 0$  : even with Higgs contribution, if  $y_j = 0$ ; i.e. Higgs is a  $CP$  eigenstate.
- $P_\tau^U \neq 0$  : if  $CP$  violation in the Higgs sector

# Polarised Photon Collider

Move to polarised photons :

- $P_\tau^{++}, P_\tau^{--}$  : finite for QED diagrams alone.

$P$  invariance of QED  $\Rightarrow P_\tau^{++} = -P_\tau^{--} \Rightarrow P_\tau^{++} + P_\tau^{--} = 0$

$P_\tau^{++} + P_\tau^{--} \neq 0 \Rightarrow$  signal of  $\not{P}$

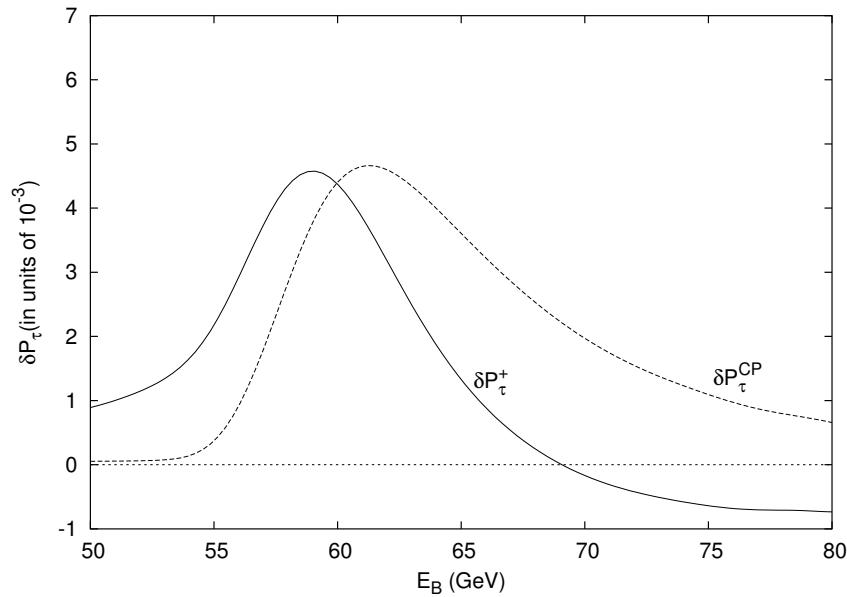
In case of  $C$  invariance  $\Rightarrow$  signal of  $CP$  violation.

- $P_\tau^{++}$  : modified by the Higgs contribution.

$P_\tau^{++} - (P_\tau^{++})^{QED} \neq 0$  even if  $\phi$  is  $CP$  eigenstate,  $\Rightarrow$  probe of chirality flipping amplitude.

# Polarisation Observables

Observables	Description
$P_\tau^U$	Probe of CP violating interaction
$\delta P_\tau^{CP} = P_\tau^{++} + P_\tau^{--}$	Probe of CP violating interaction
$\delta P_\tau^+ = P_\tau^{++} - (P_\tau^{++})^{QED}$	Probe of chirality flipping interaction
$\delta P_\tau^- = P_\tau^{--} - (P_\tau^{--})^{QED}$	Probe of chirality flipping interaction



$\delta P_\tau^+, \delta P_\tau^{CP}$  as a function of  $E_b$   
 $m_{\phi_1} = 97$  GeV for a chosen CP violating  
MSSM point.  
Ideal back-scattered photons,  $x_c = 4.8$ .  
 $\delta P_\tau^+, \delta P_\tau^{CP}$  peak for  $E_b \approx (m_h/2)/0.81$ .

Main contribution from off-shell Higgs  $\Rightarrow$  large statistics available.

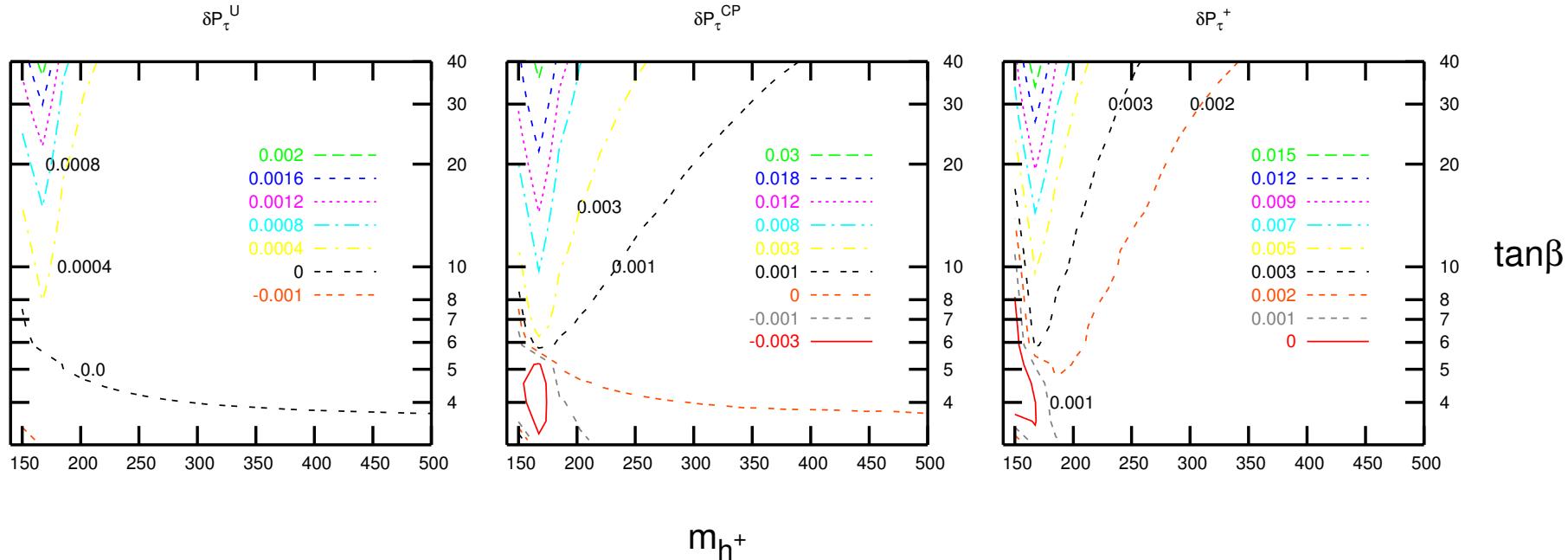
Contribution from  $\phi_2$  may be important.

# Scan over MSSM parameters

## CPX scenario

MSSM parameters	Values
$\tan \beta$	3 - 40 (used for scan)
$m_{H^+}$	150-500 GeV (used for scan)
$\mu$	2 TeV, $\Phi_\mu = 0$
$M_1, M_2$	200 GeV, $\Phi_{1,2} = 0$
$M_3$	1 TeV, $\Phi_3 = 90^\circ$
$m_{\tilde{q}, \tilde{l}}$	500 GeV
$A_{t,b}$	1 TeV, $\Phi_3 = 90^\circ$
$A_\tau$	500 GeV, $\Phi_3 = 90^\circ$

# Scan over MSSM parameters



For  $\mathcal{L} = 100 \text{ fb}^{-1}$  a typical  $\Delta P_\tau = 0.0003$  at  $1\sigma$  level.

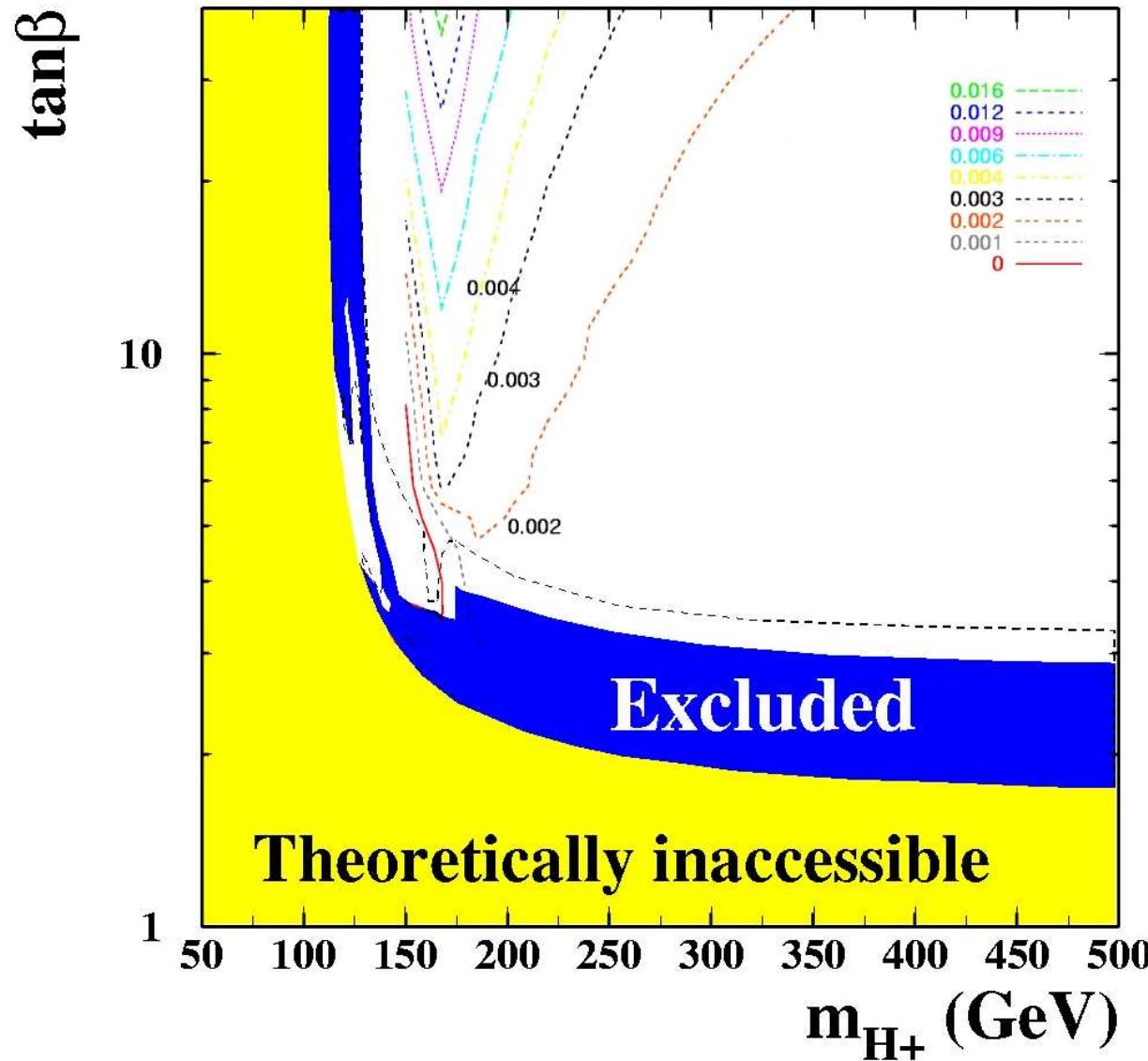
$E_b = (m_h/2)/0.81$  for each point in the scan.

- ⇒  $\delta P_\tau^U$  is not sensitive to most of the region
- ⇒  $\delta P_\tau^{CP}$  is sensitive to some part of region.
- ⇒  $\delta P_\tau^+$  is sensitive to most of the region.

Note :

- $\delta P_\tau^+/(P_\tau^+)^{QED}$  can go upto 18%.
- $\delta P_\tau^{CP}/(P_\tau^+)^{QED}$  can go upto 32%.

# Scan over MSSM parameters

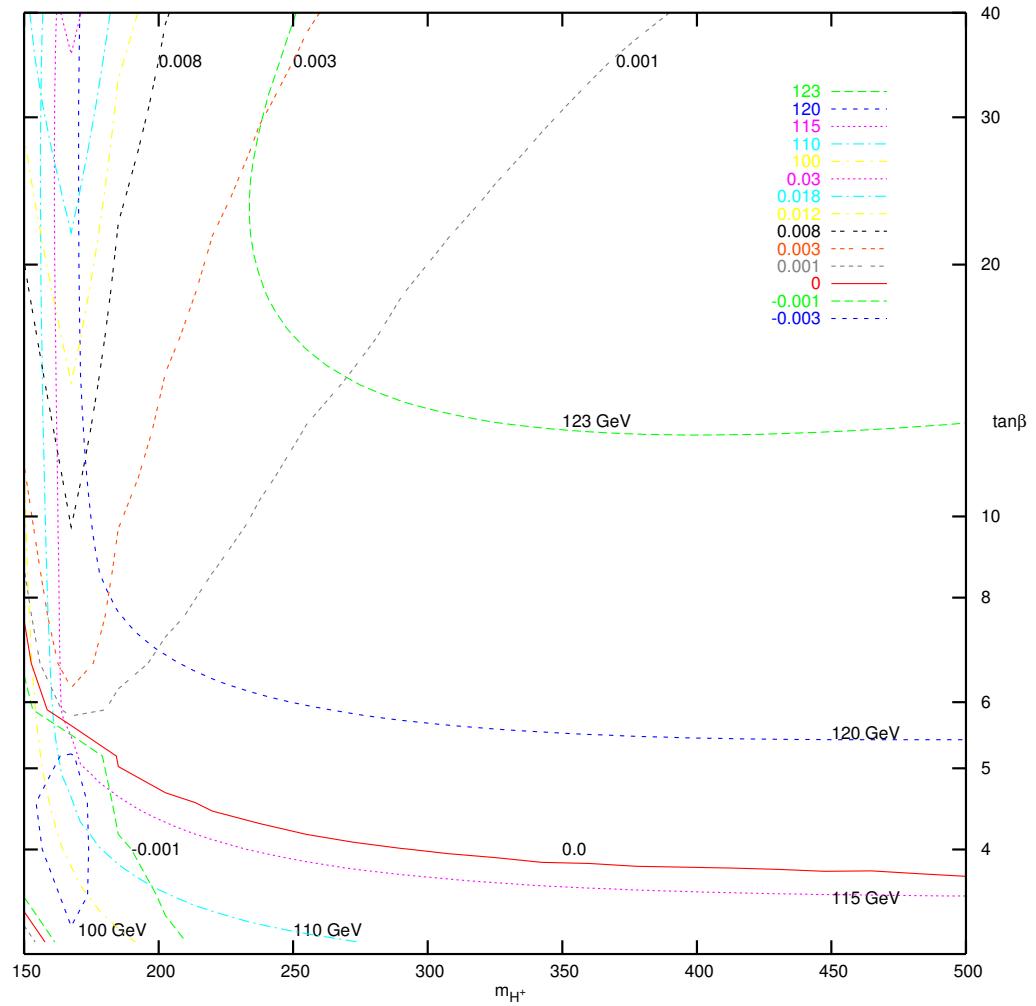


# Conclusions

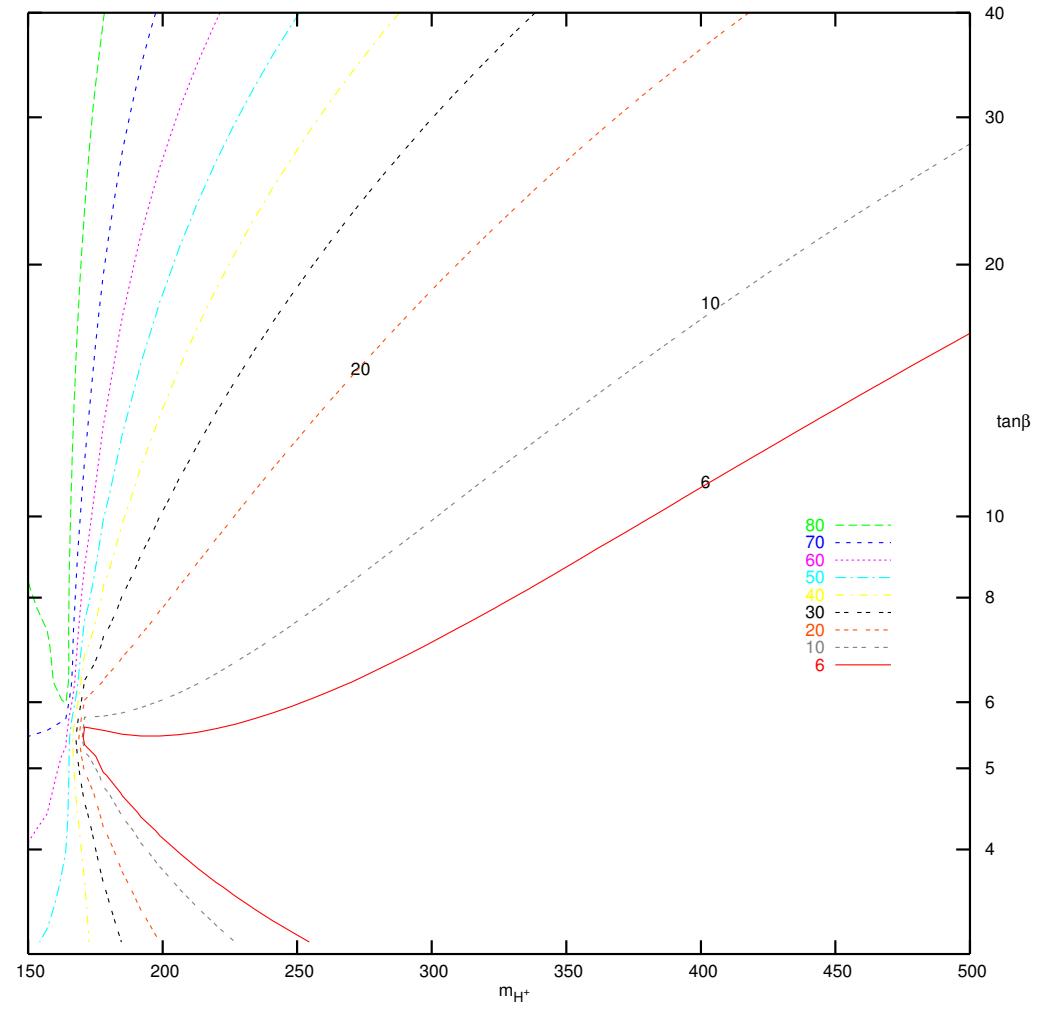
- Have constructed probes of  $CP$  violation and chirality flipping interactions,
- $\delta P_{\tau}^{++}$  can probe most of the OPAL's allowed region of MSSM in CPX scenario. Requires one measurement.
- $\delta P_{\tau}^{CP}$  can probe a large portion of OPAL's allowed region with better sensitivity/confidence level. Requires two measurements.
- $\tau$  polarisation is a promising probe of  $CP$  properties of neutral Higgs.

# Future directions

- Scan other choices within CPX scenario.
- Incorporate the effect of  $\phi_2$ .
- Incorporate the effect of  $\tau$  decay using Tauola.
- Incorporate the effect of higher order QED corrections.



$\delta P_\tau^{CP}$  and  $m_{\phi_1}$



$$\tan^{-1}(g_\tau^P/g_\tau^S)$$