

Fermion polarisation at a $\gamma\gamma$ collider

as a probe of the CP properties of the Higgs boson

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in collaboration with

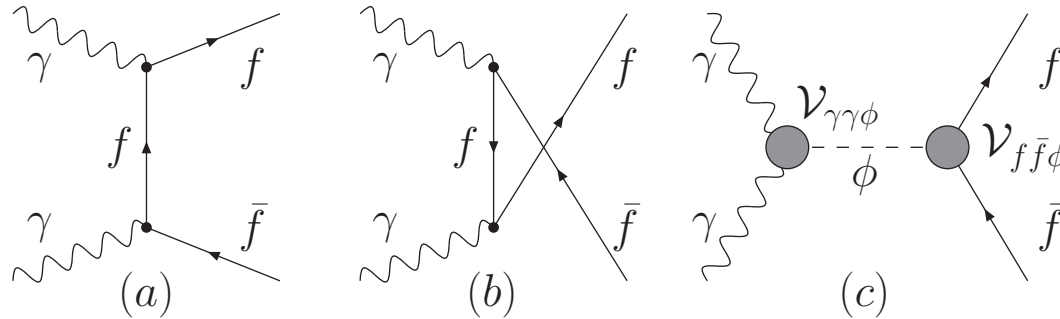
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$$\gamma\gamma \rightarrow f\bar{f}$$

t/τ pair production as a probe of the Higgs contribution.



The Higgs contribution treated in a model independent way.

$$\mathcal{V}_{f\bar{f}\phi} = -ie \frac{m_f}{M_W} (S_f + i\gamma^5 P_f),$$

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

$\{S_f, P_f, S_\gamma, P_\gamma\}$ depend upon m_{H^\pm} , $\tan\beta$, μ , $A_{t,b,\tau}$, $\Phi_{t,b,\tau}$, $M_{\tilde{q}}$, $M_{\tilde{l}}$ etc.

in (CP violating) MSSM.

$$\gamma\gamma \rightarrow f\bar{f}$$

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

Combinations	Aliases	CP-property	Combinations	Aliases	CP-property
$S_f \Re(S_\gamma)$	x_1	even	$S_f \Re(P_\gamma)$	y_1	odd
$S_f \Im(S_\gamma)$	x_2	even	$S_f \Im(P_\gamma)$	y_2	odd
$P_f \Re(P_\gamma)$	x_3	even	$P_f \Re(S_\gamma)$	y_3	odd
$P_f \Im(P_\gamma)$	x_4	even	$P_f \Im(S_\gamma)$	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
fermion-polarisation affected.

MSSM Higgs Sector

MSSM: Three neutral Higgs h, H A
 CP -even CP -odd

CP violation: H_1, H_2, H_3
no fixed CP property $m_{H_1} < m_{H_2} < m_{H_3}$

H_i coupling to gauge bosons and fermions changes with CP violation.

$$g^{VVH_1} < g^{VVH_{SM}} \Rightarrow \sigma(e^+e^- \rightarrow Z^* \rightarrow ZH_1) < \sigma(e^+e^- \rightarrow Z^* \rightarrow ZH_{SM})$$

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

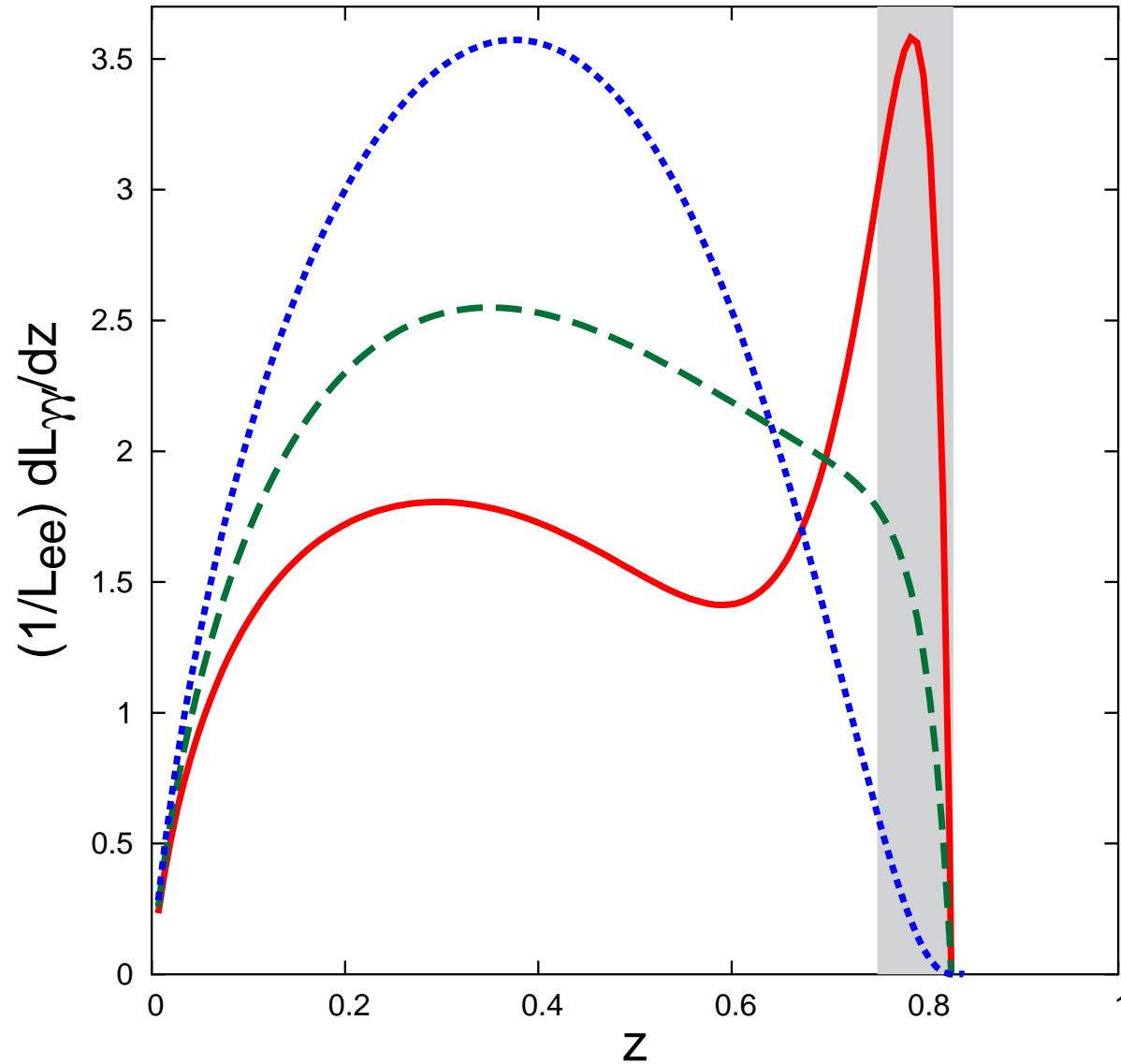
CPX scenario

CPX scenario

MSSM parameters	Values
$\tan \beta$	3 - 40 (used for scan)
m_{H^+}	150-500 GeV (used for scan)
μ	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, $\Phi_{t,b} = 90^\circ$
A_τ	500 GeV, $\Phi_\tau = 90^\circ$

$$\Phi = \Phi_t = \Phi_b = \Phi_\tau = \{0^\circ, 30^\circ, 60^\circ, 90^\circ\}$$

Photon Collider : Luminosity



Unpolarised Photon Collider

Polarisation of f defined as

$$P_f^{IJ} = \frac{N_+^{IJ} - N_-^{IJ}}{N_+^{IJ} + N_-^{IJ}}$$

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

$N_+^{IJ} = \#$ of f_R , $N_-^{IJ} = \#$ of f_L .

Statistical error in P_f^{IJ} :

$$\Delta P_f = \frac{\sqrt{4 N_+^{IJ} N_-^{IJ}}}{(N_+^{IJ} + N_-^{IJ})^{3/2}} = \frac{1}{\sqrt{N_+^{IJ} + N_-^{IJ}}} \sqrt{1 - (P_f^{IJ})^2}$$

Unpolarised Photon Collider

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

Polarised Photon Collider

Move to polarised photons :

- P_f^{++}, P_f^{--} : finite for QED diagrams alone.

$$P \text{ invariance of QED} \Rightarrow P_f^{++} = -P_f^{--} \Rightarrow P_f^{++} + P_f^{--} = 0$$

$$P_f^{++} + P_f^{--} \neq 0 \Rightarrow \text{signal of } \not{P}$$

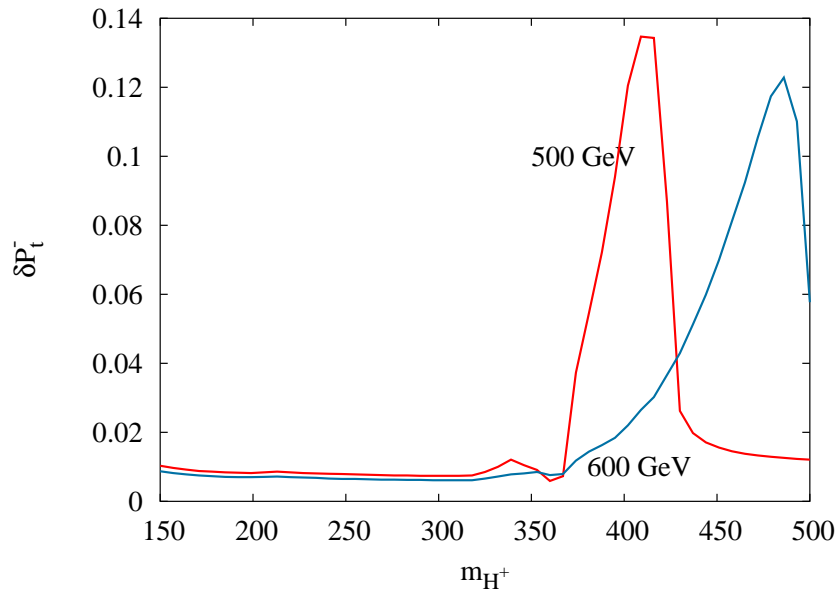
In case of C invariance \Rightarrow signal of CP violation.

- P_f^{++} : modified by the Higgs contribution.

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

Polarisation Observables

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

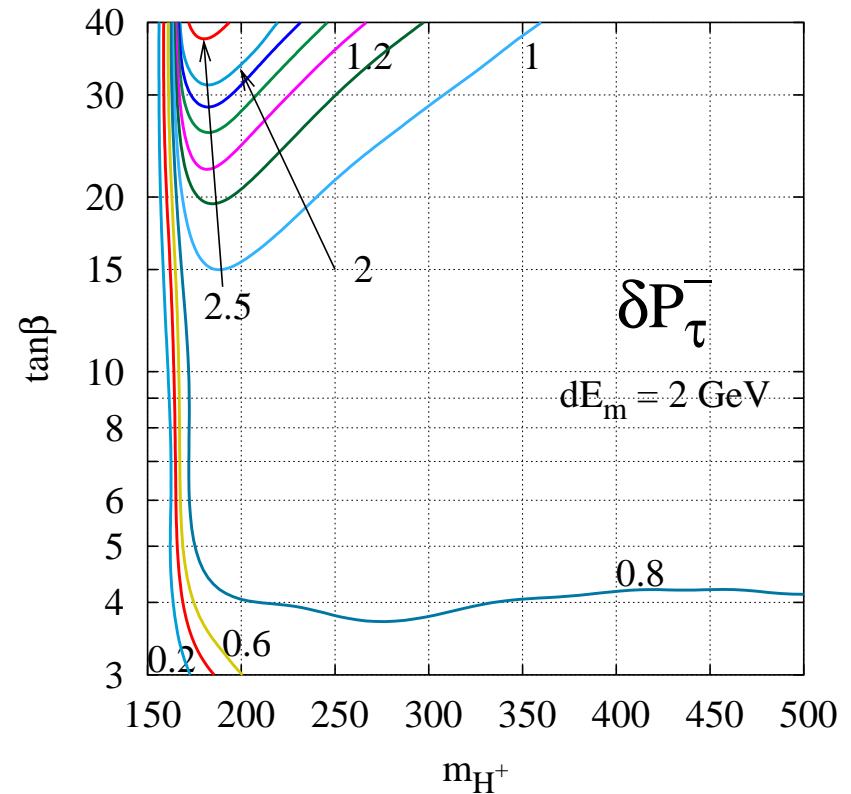
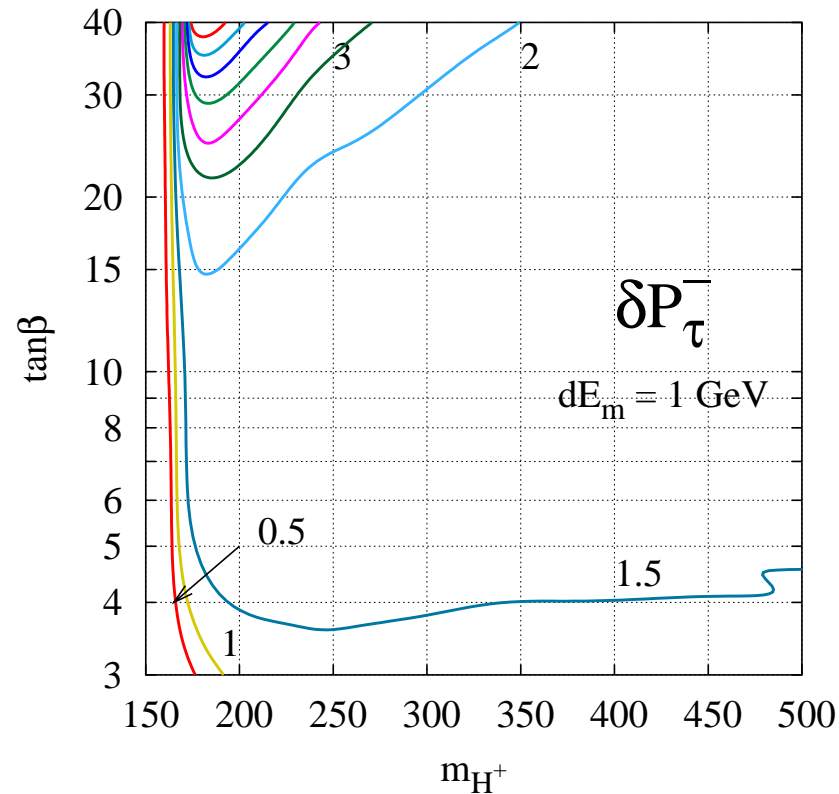


δP_t^- as a function of m_{H^+} for $E_{cm} = 500$ GeV and 600 GeV.

Ideal back-scattered photons, $x_c = 4.8$.

δP_t^- peak for $E_{cm} * 0.8 \approx (m_{H_2} + m_{H_3})/2$.

τ -polarization in MSSM



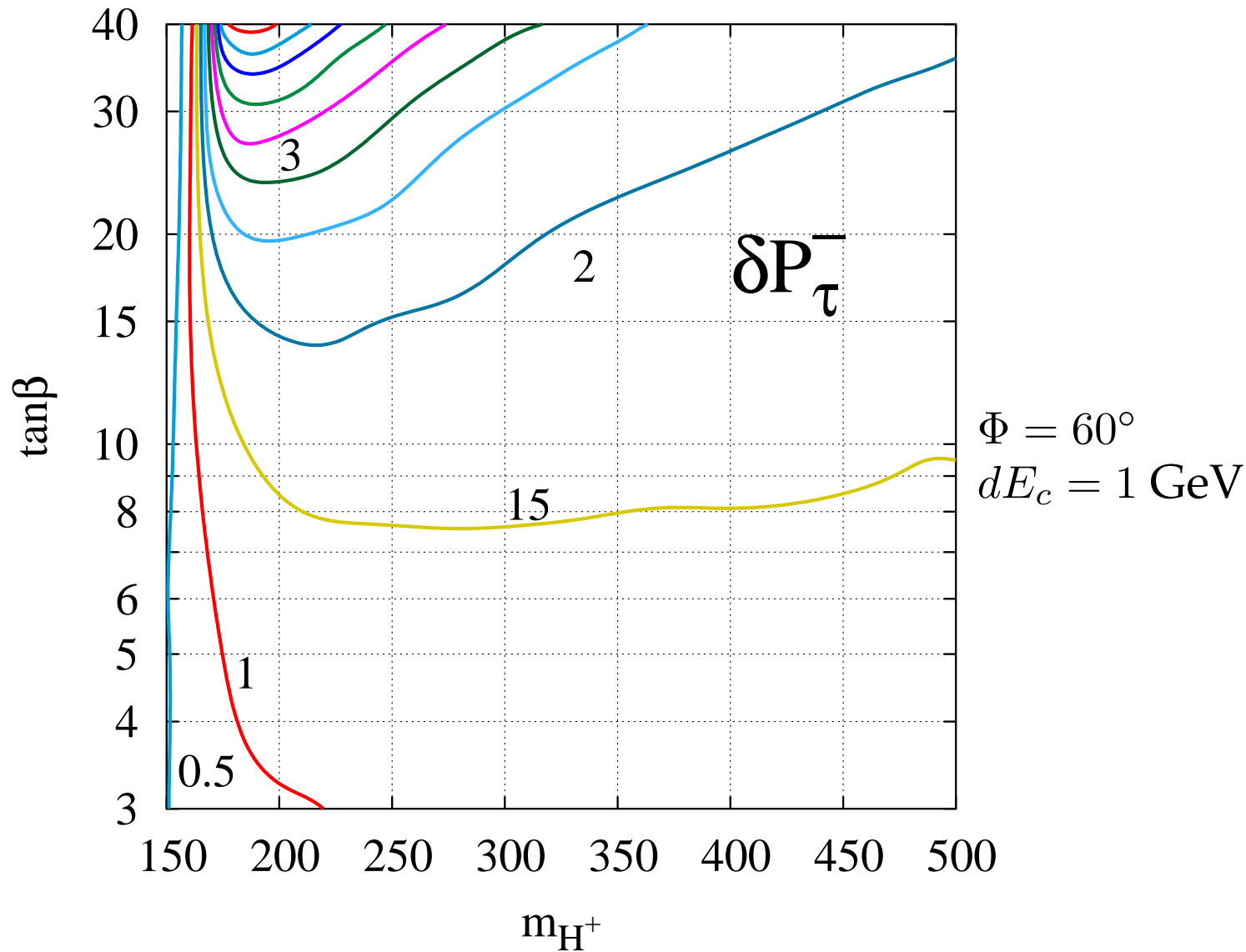
$E_b = (m_{H_1}/2)/0.8$ for each point in the scan and $|m_{\tau\tau} - m_{H_1}| < dE_c$.

$dE_c = 1 \text{ GeV}$ (Left panel)

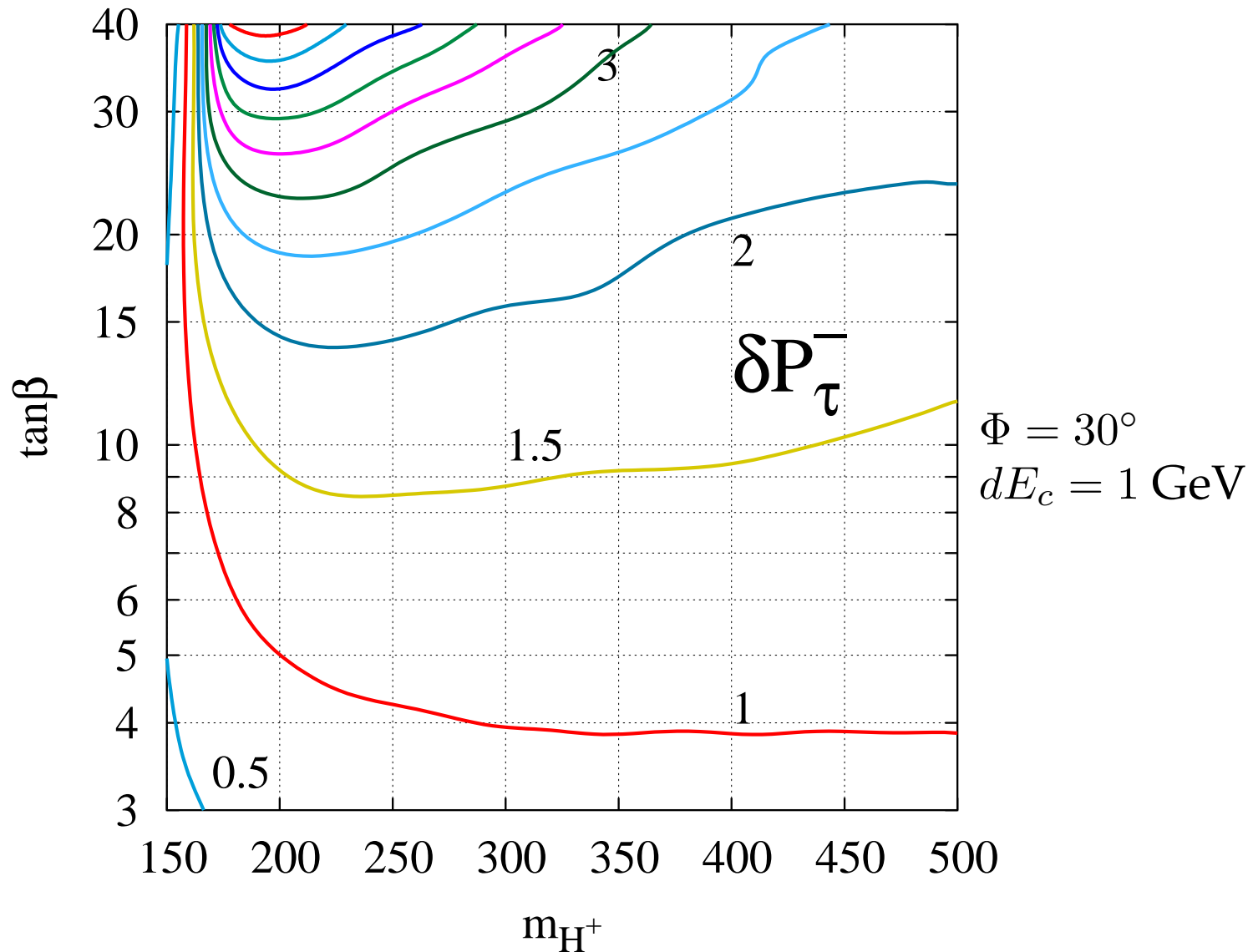
$dE_c = 2 \text{ GeV}$ (Right panel)

$$\Phi = 90^\circ$$

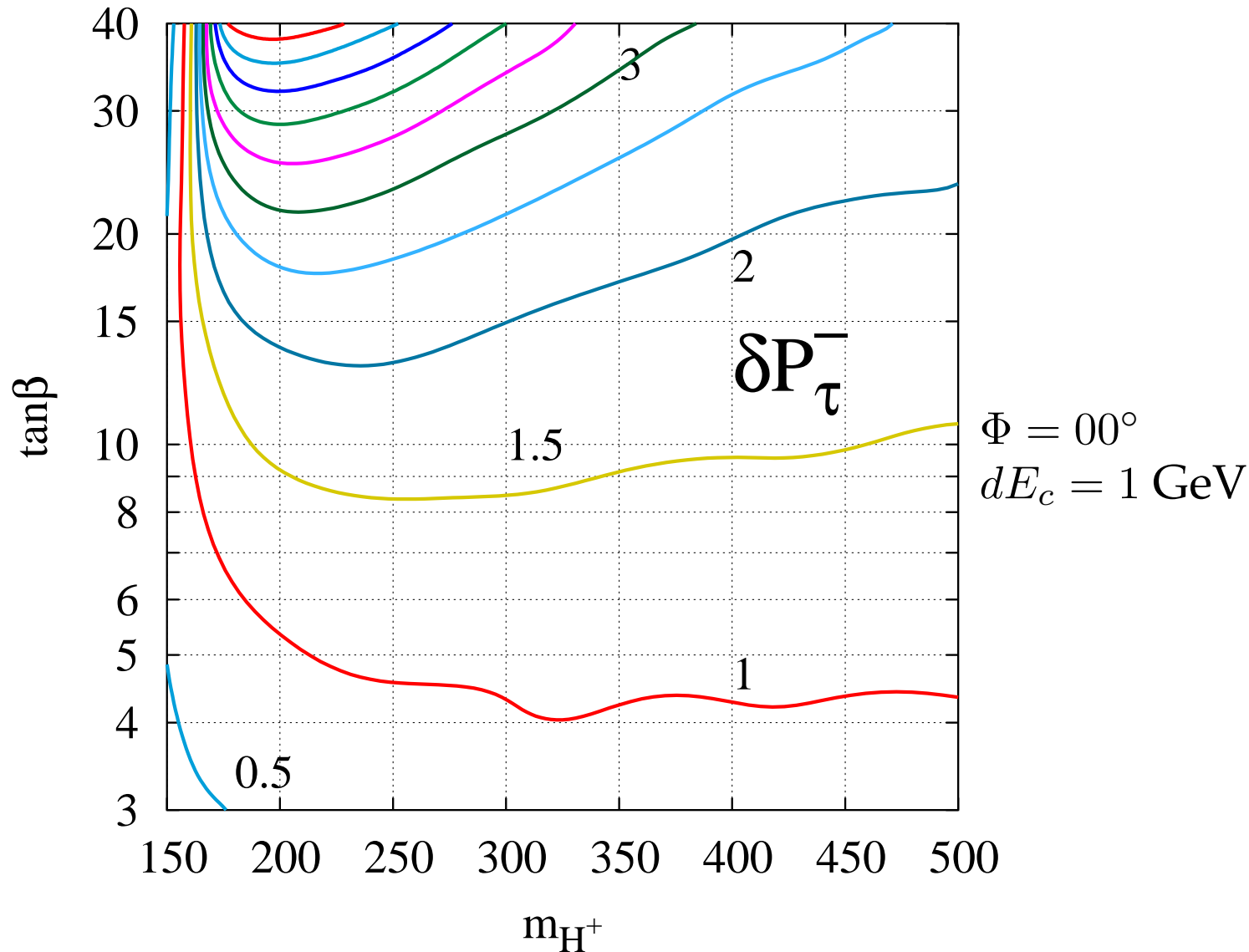
τ -polarization in MSSM



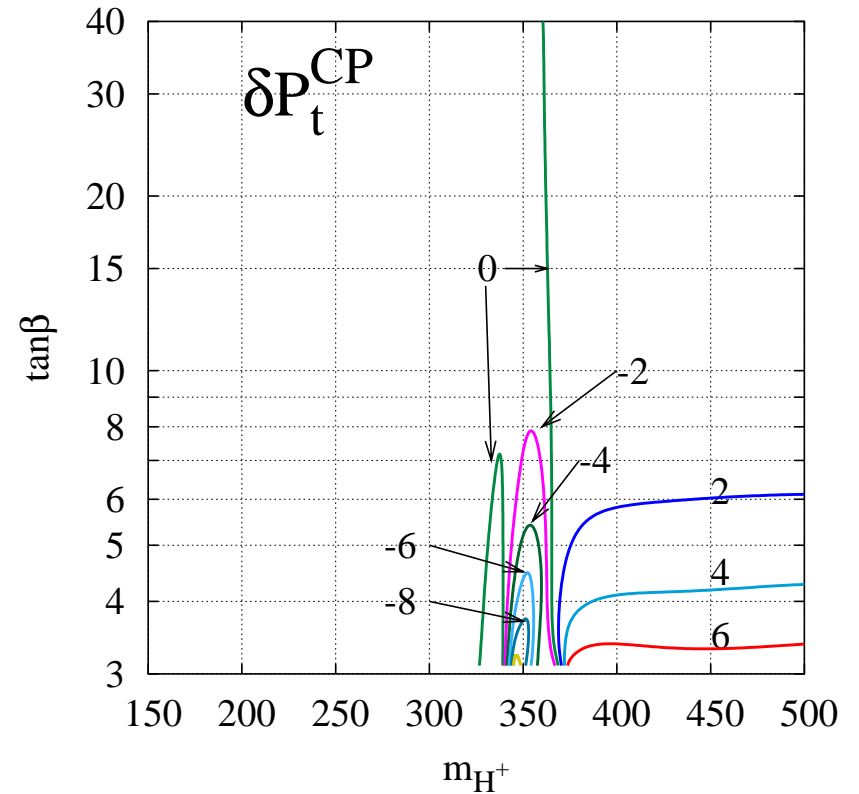
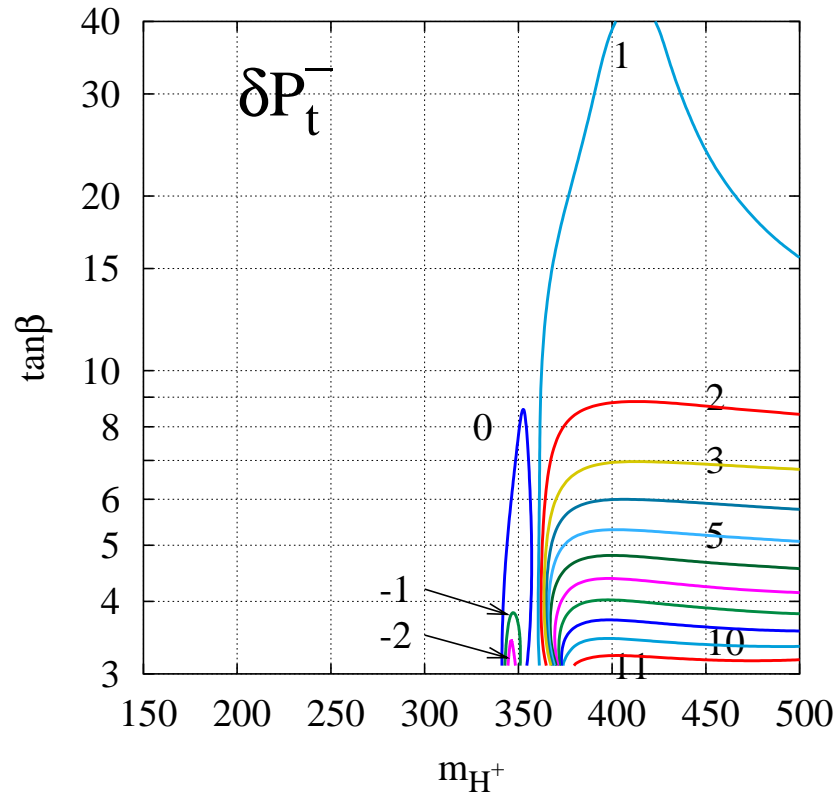
τ -polarization in MSSM



τ -polarization in MSSM



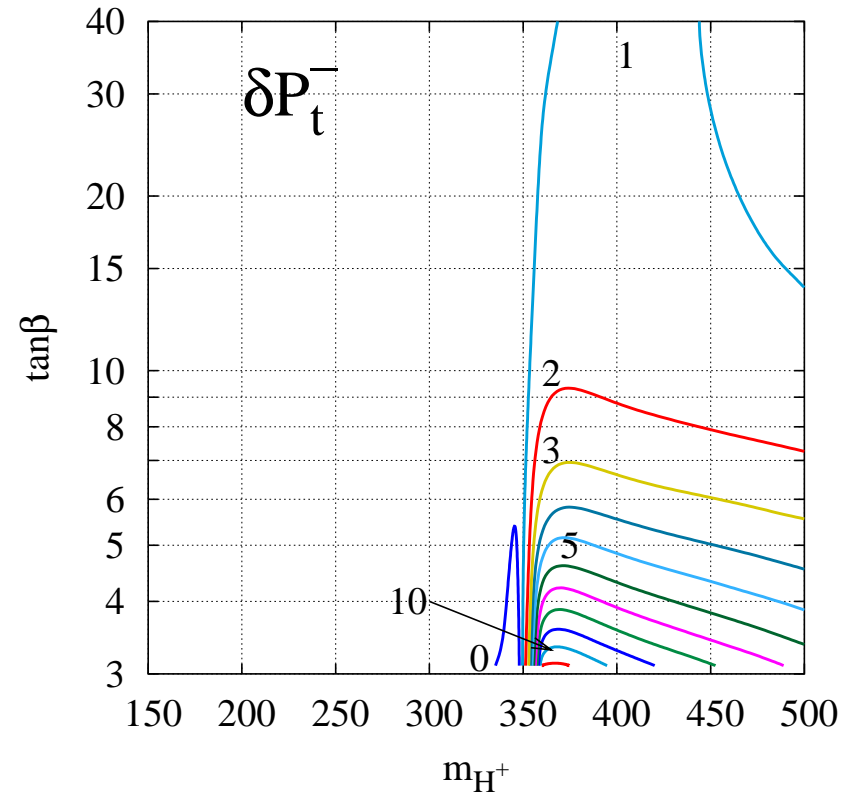
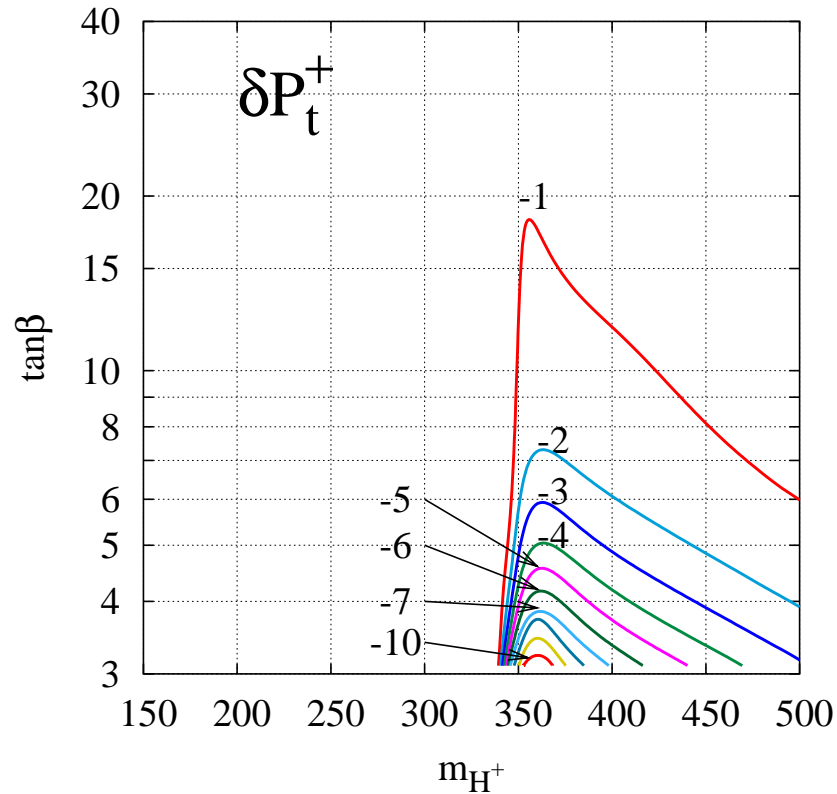
t -polarization in MSSM : Peak E_b



$$\Phi = 90^\circ$$

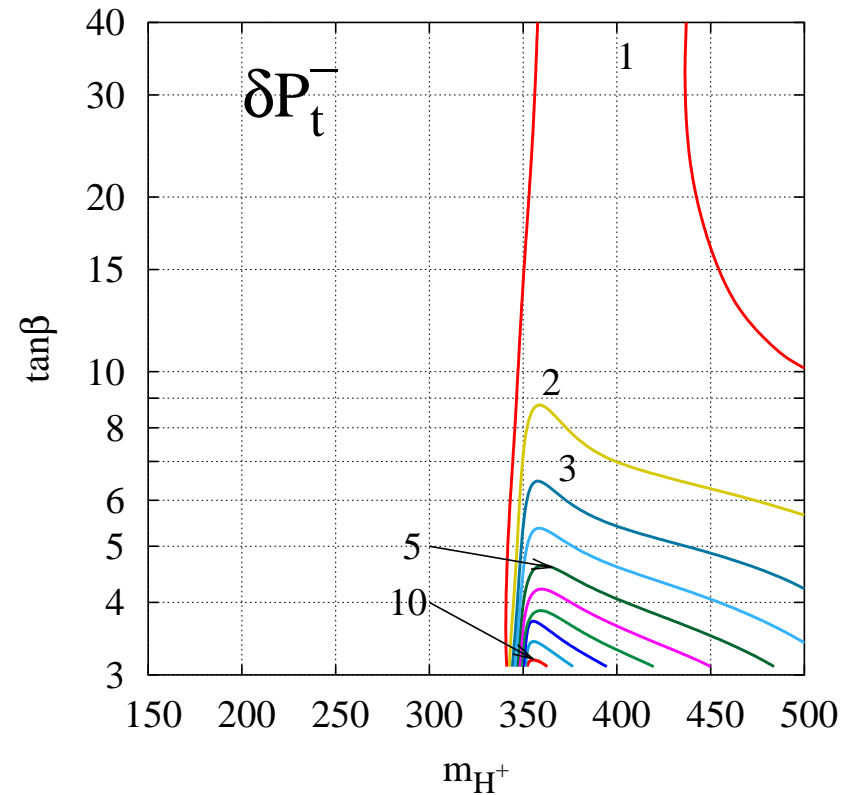
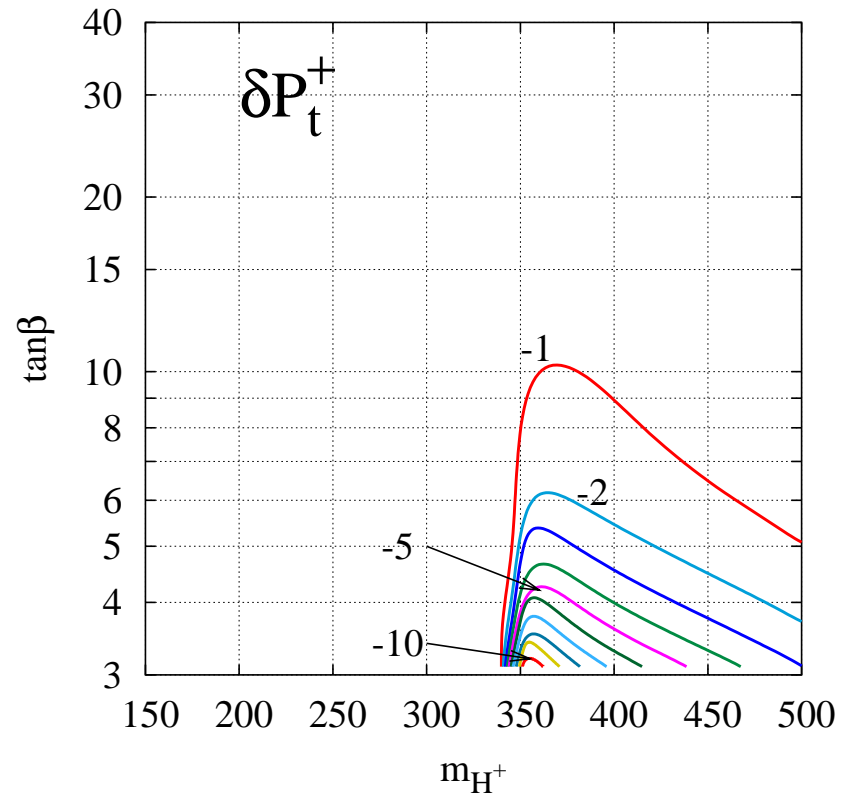
$$E_{cm} = (m_{H_2} + m_{H_3})/2/0.8 \text{ for each point in the scan.}$$

t -polarization in MSSM : Peak E_b



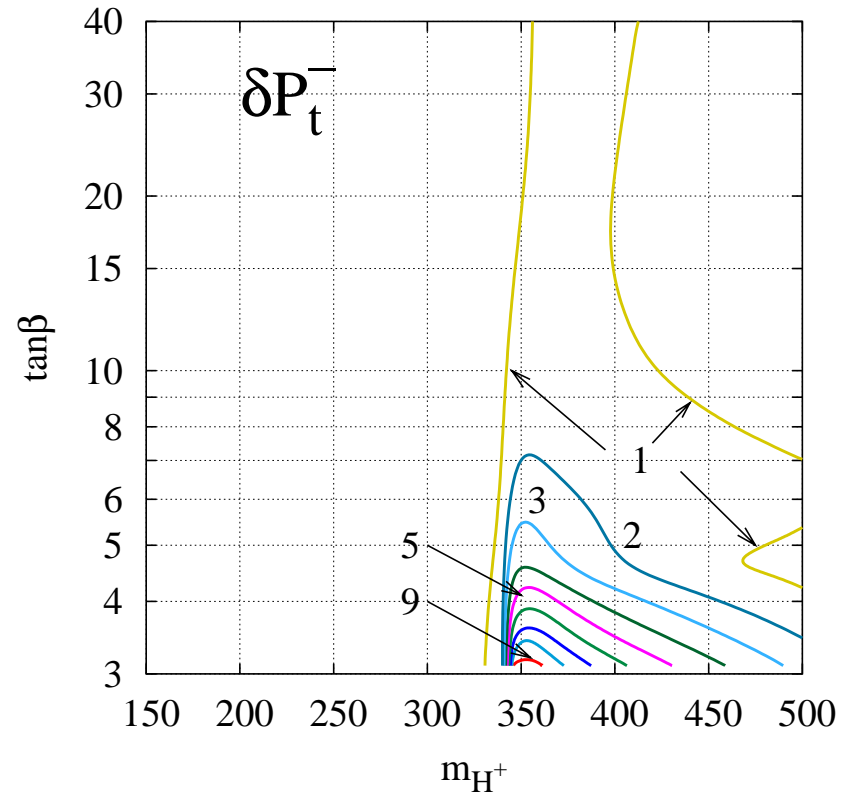
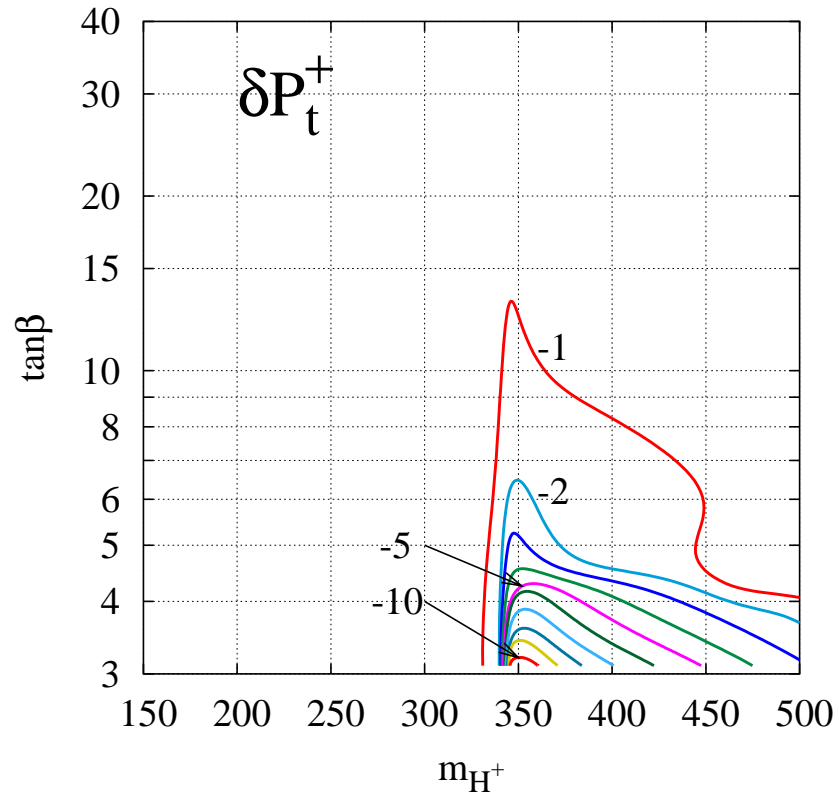
$$\Phi = 60^\circ$$

t -polarization in MSSM : Peak E_b



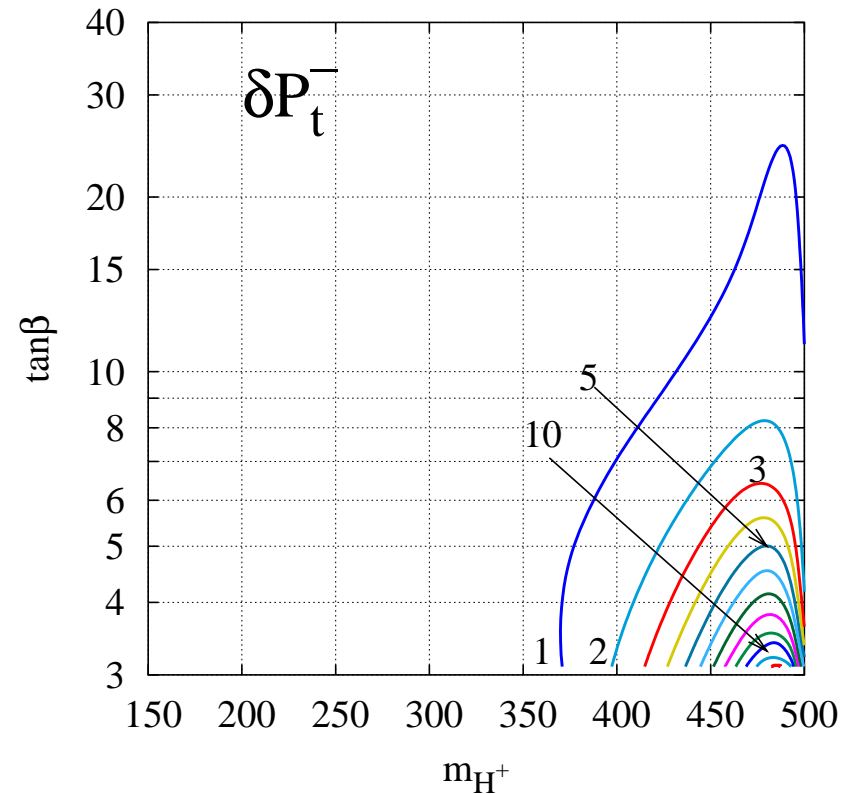
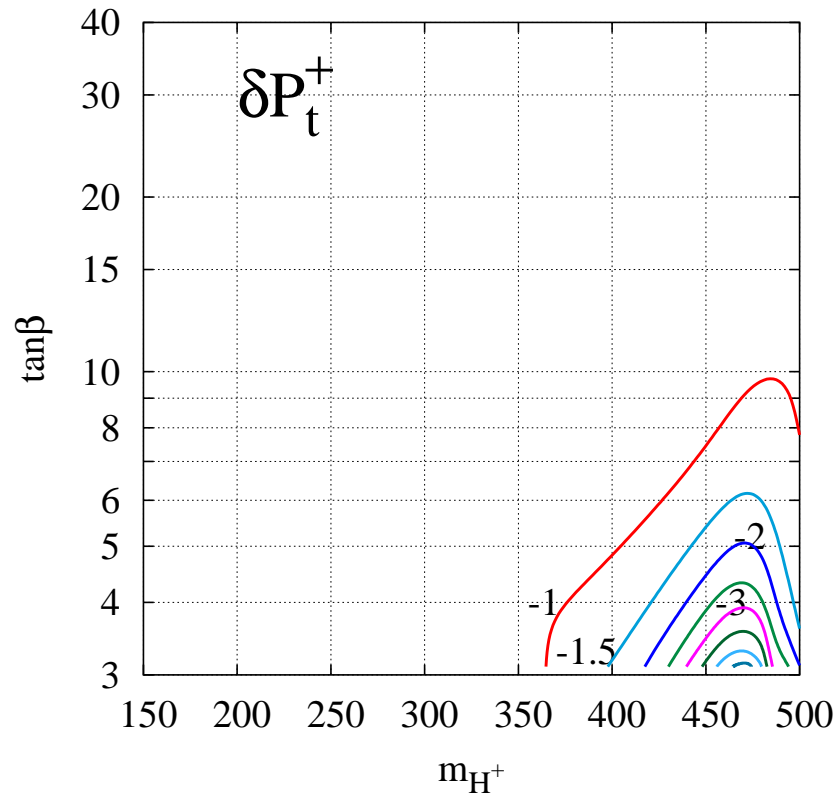
$$\Phi = 30^\circ$$

t -polarization in MSSM : Peak E_b



$$\Phi = 00^\circ$$

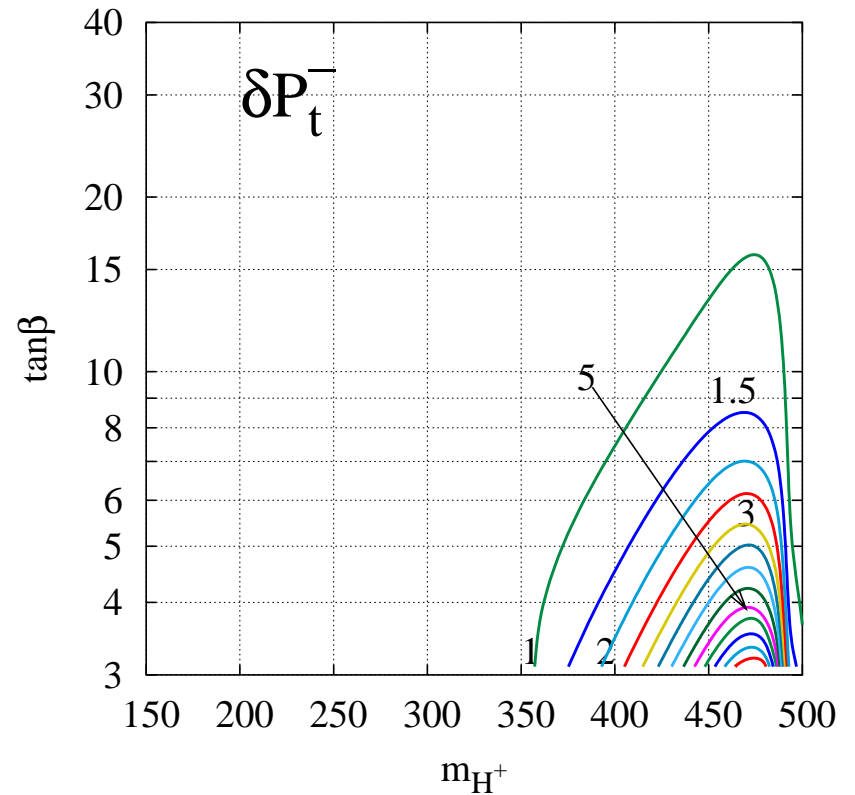
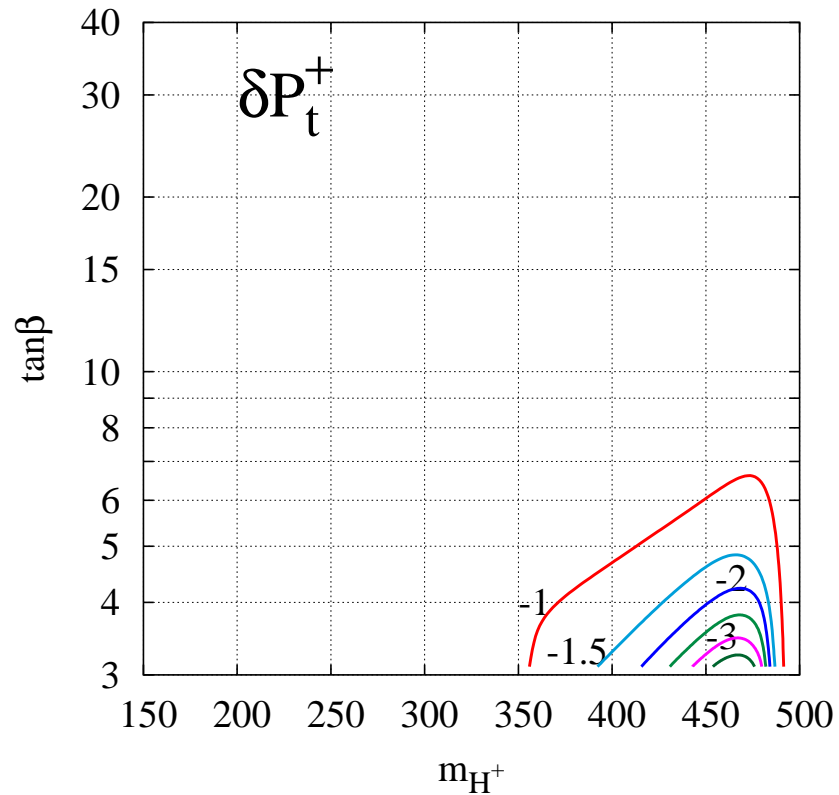
t -polarization in MSSM : Fixed E_b



$$\Phi = 90^\circ$$

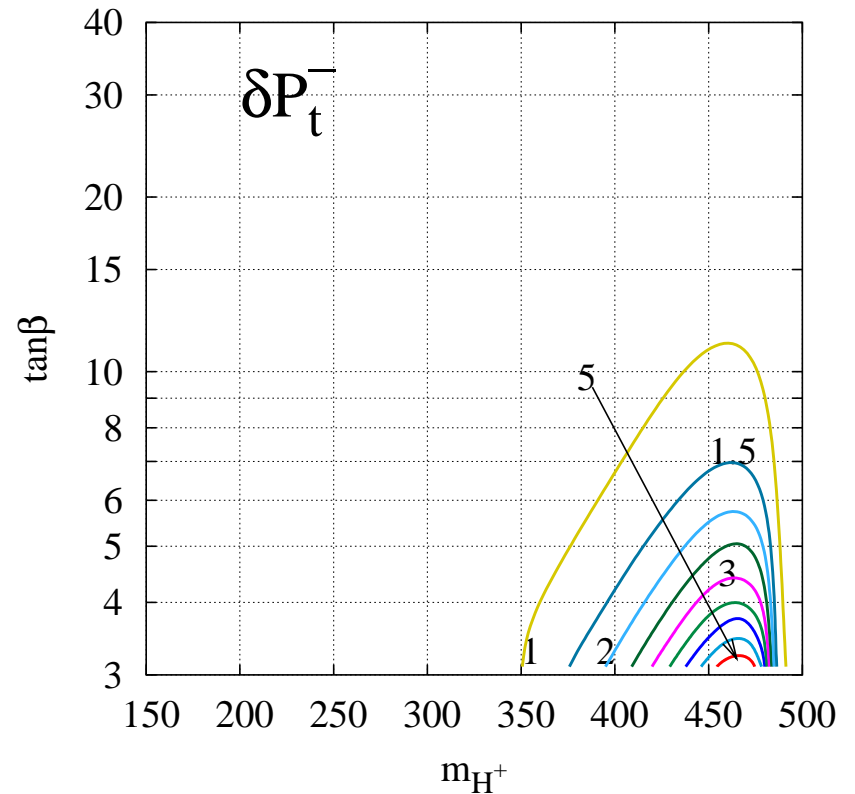
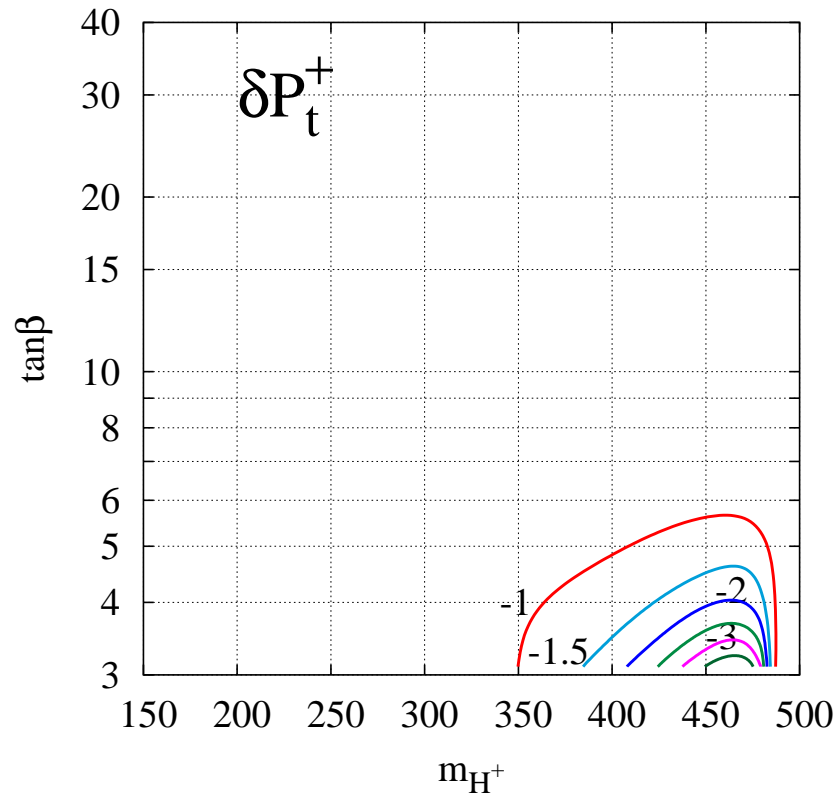
$E_{cm} = 600$ GeV for each point in the scan.

t -polarization in MSSM : Fixed E_b



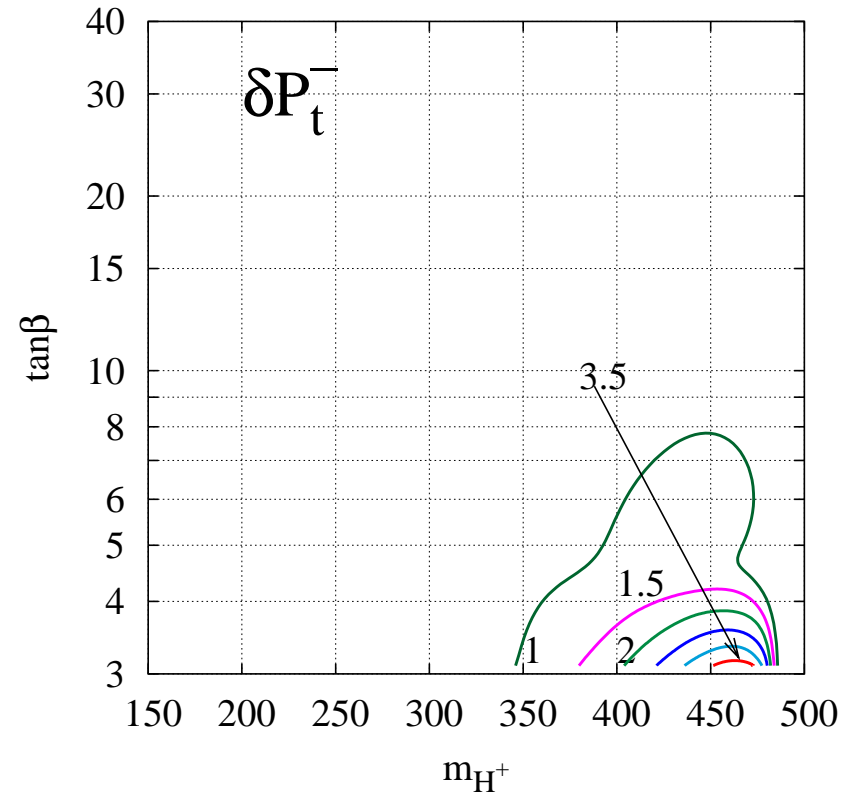
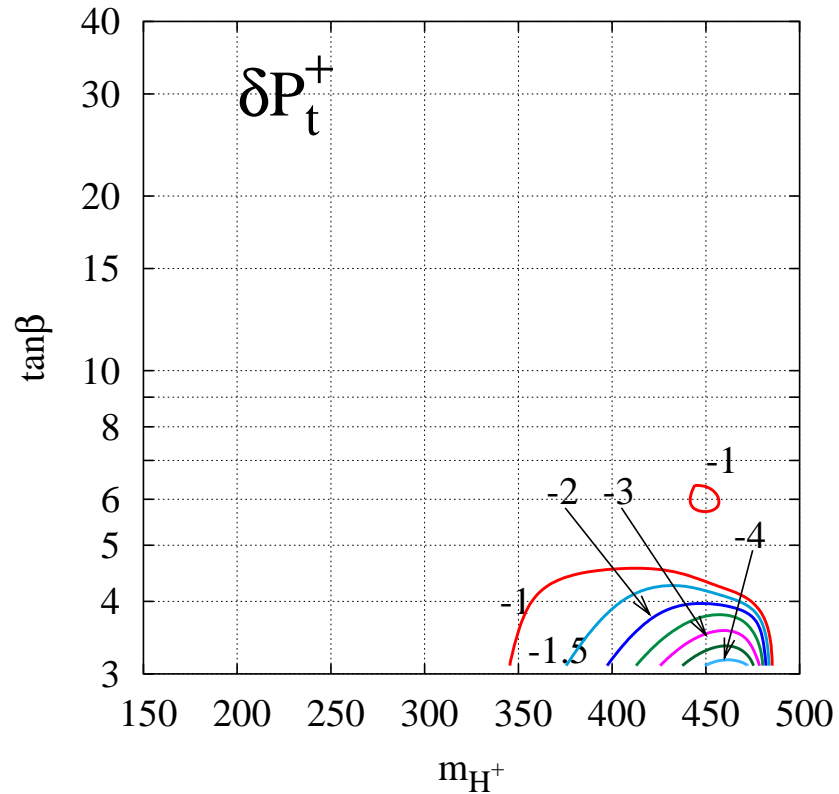
$$\Phi = 60^\circ$$

t -polarization in MSSM : Fixed E_b



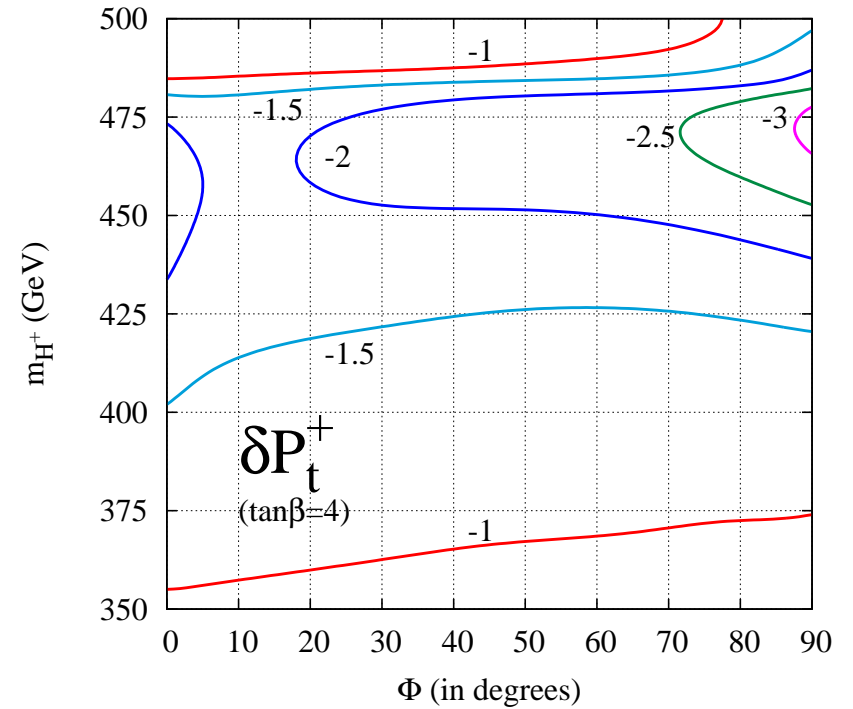
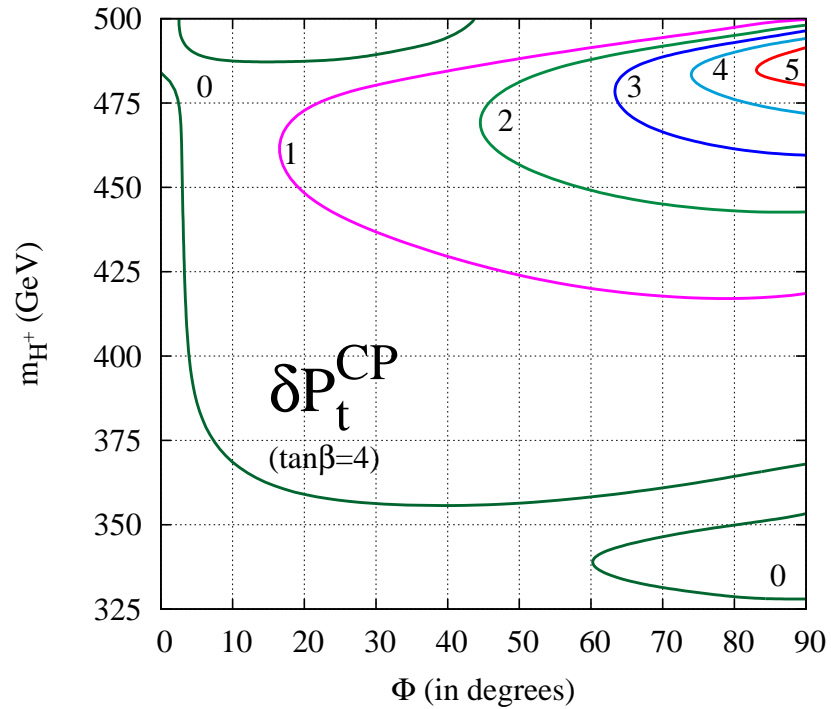
$$\Phi = 30^\circ$$

t -polarization in MSSM : Fixed E_b



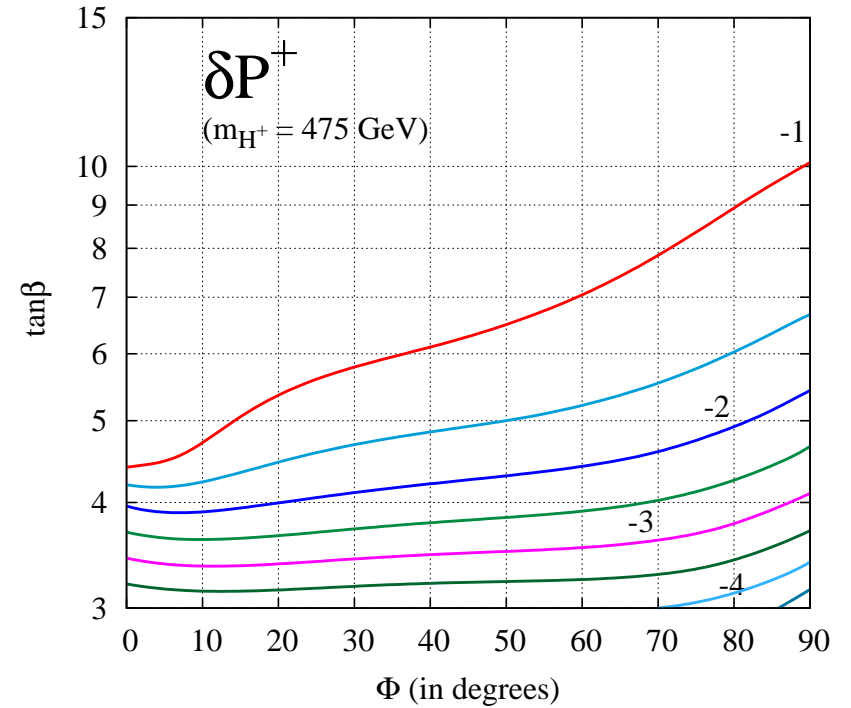
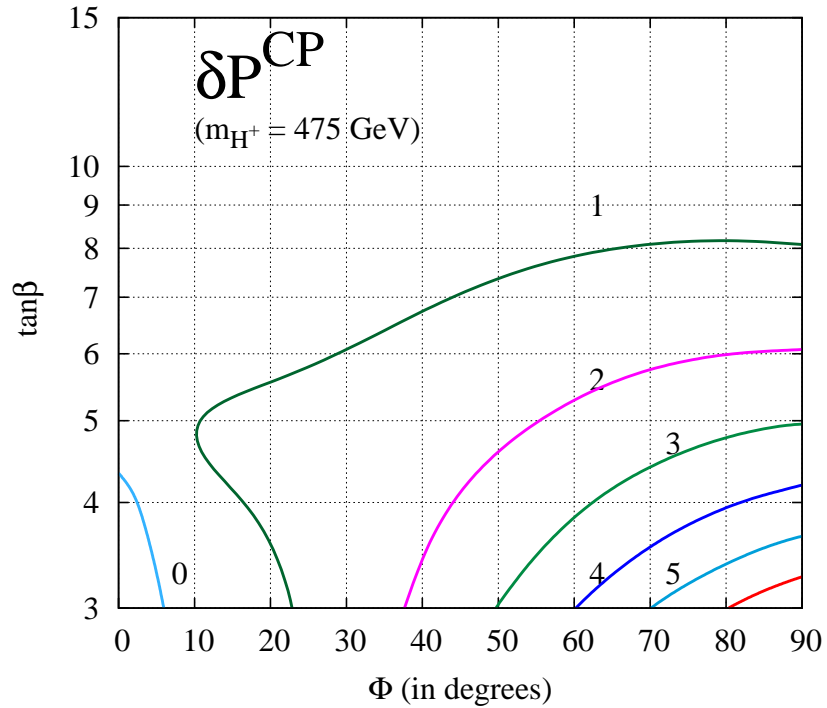
$$\Phi = 00^\circ$$

t -polarization in MSSM : Fixed E_b



$$\tan\beta = 4$$

t -polarization in MSSM : Fixed E_b



$$m_{H^+} = 475 \text{ GeV}$$

Decay Lepton Asymmetry

- The decay leptons from t -quark carry information about its polarization. Can construct asymmetries combining charge of lepton and polarization of initial state e^- of the PLC.
- We chose $\lambda_{e^-} (= \lambda_{e^+}) = -\lambda_1(\lambda_2)$. Thus cross-section can be parametrized as $\sigma(\lambda_{e^-}, Q_\ell)$.

$$\mathcal{A}_1 = \frac{\sigma(++)-\sigma(--)}{\sigma(++)+\sigma(--)}$$

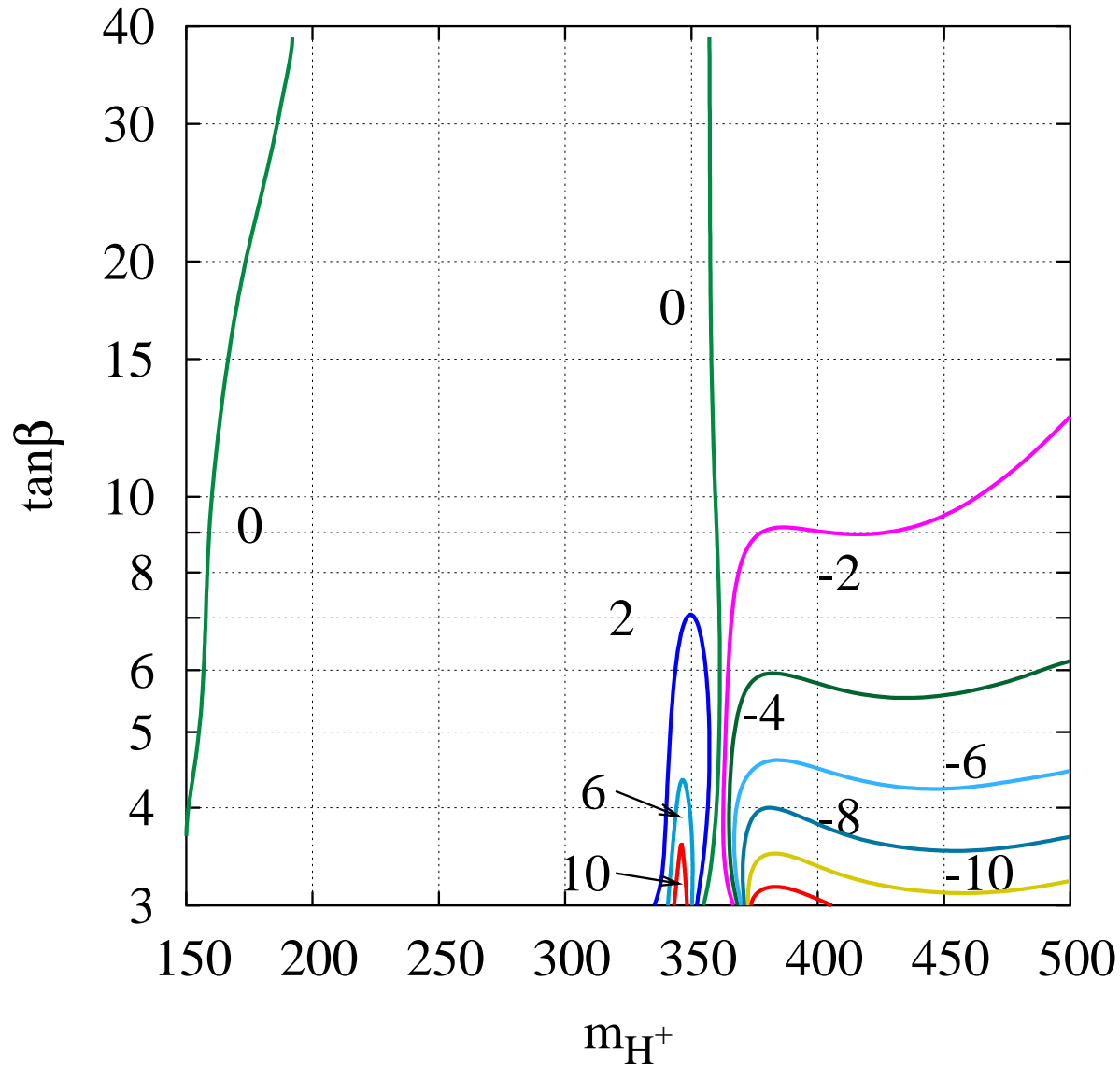
$$\mathcal{A}_2 = \frac{\sigma(+)-\sigma(-)}{\sigma(+)+\sigma(-)}$$

$$\mathcal{A}_3 = \frac{\sigma(++)-\sigma(-)}{\sigma(++)+\sigma(-)}$$

$$\mathcal{A}_4 = \frac{\sigma(+)-\sigma(--)}{\sigma(+)+\sigma(--)}$$

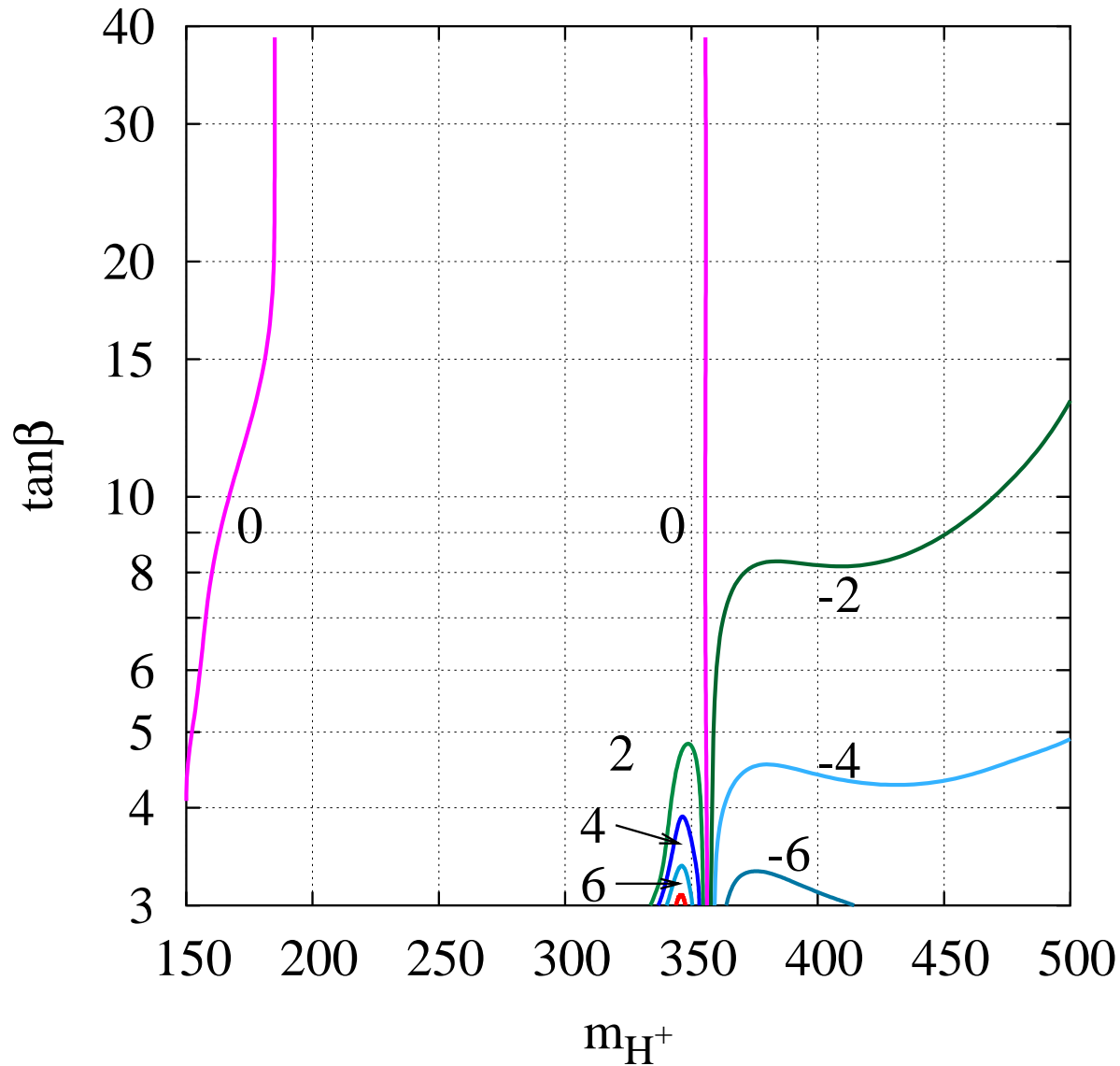
- These simple asymmetries are sensitive to CP -odd combinations y_i 's only; negligible sensitivity to x_i 's.

\mathcal{A}_3 in MSSM : Peak E_b



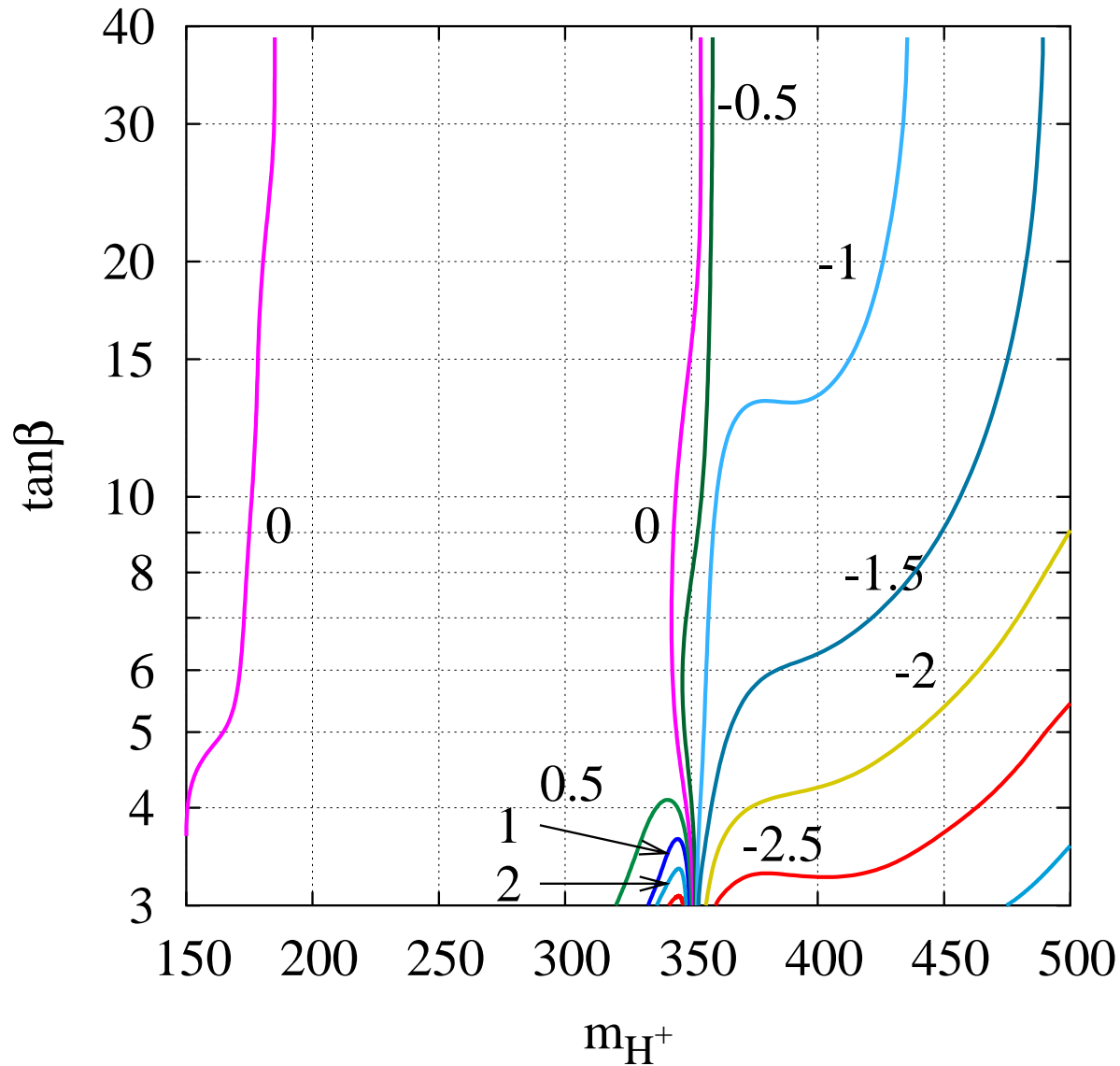
\mathcal{A}_3
 $\Phi = 90^\circ$

\mathcal{A}_3 in MSSM : Peak E_b



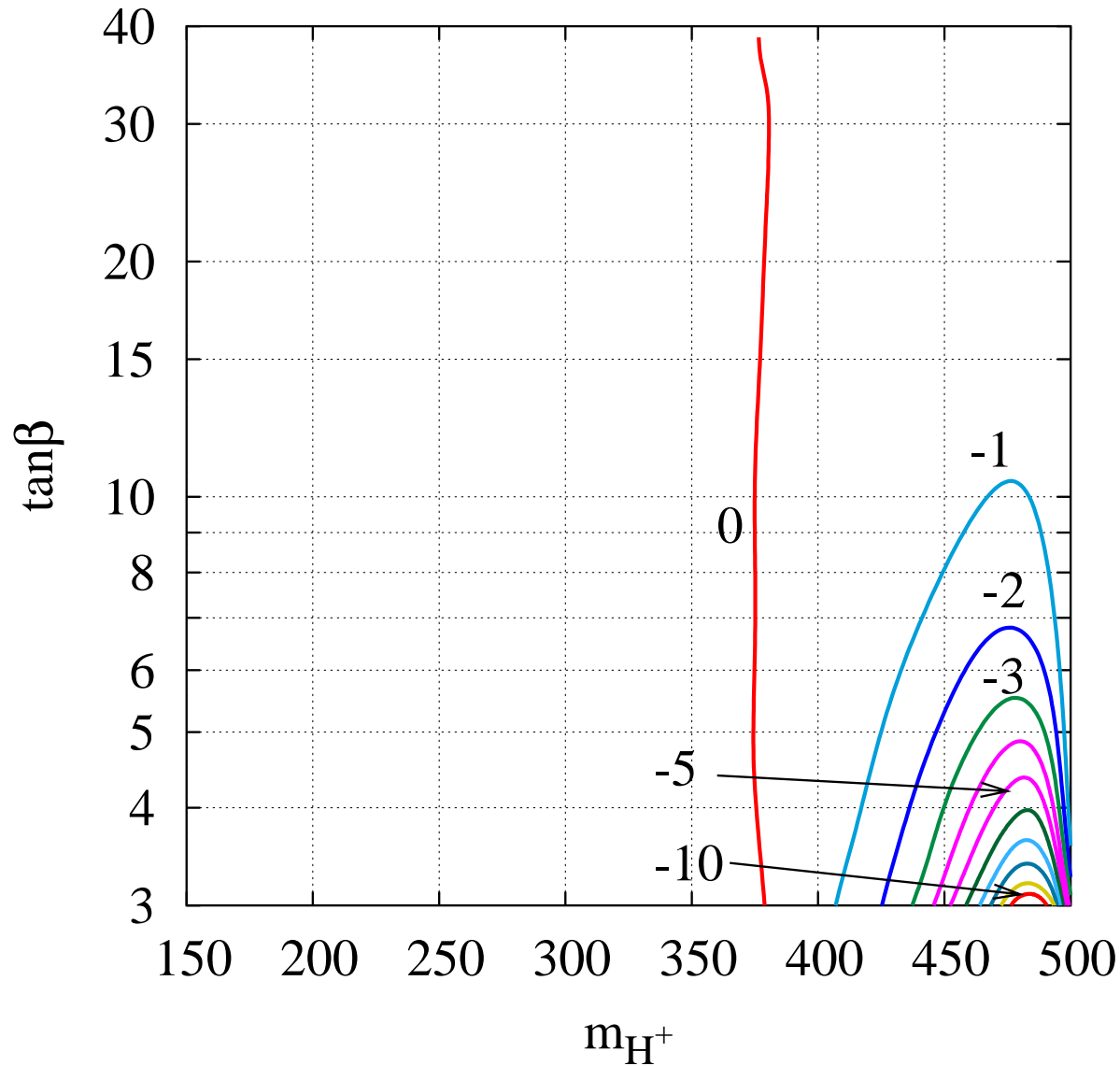
\mathcal{A}_3
 $\Phi = 60^\circ$

\mathcal{A}_3 in MSSM : Peak E_b



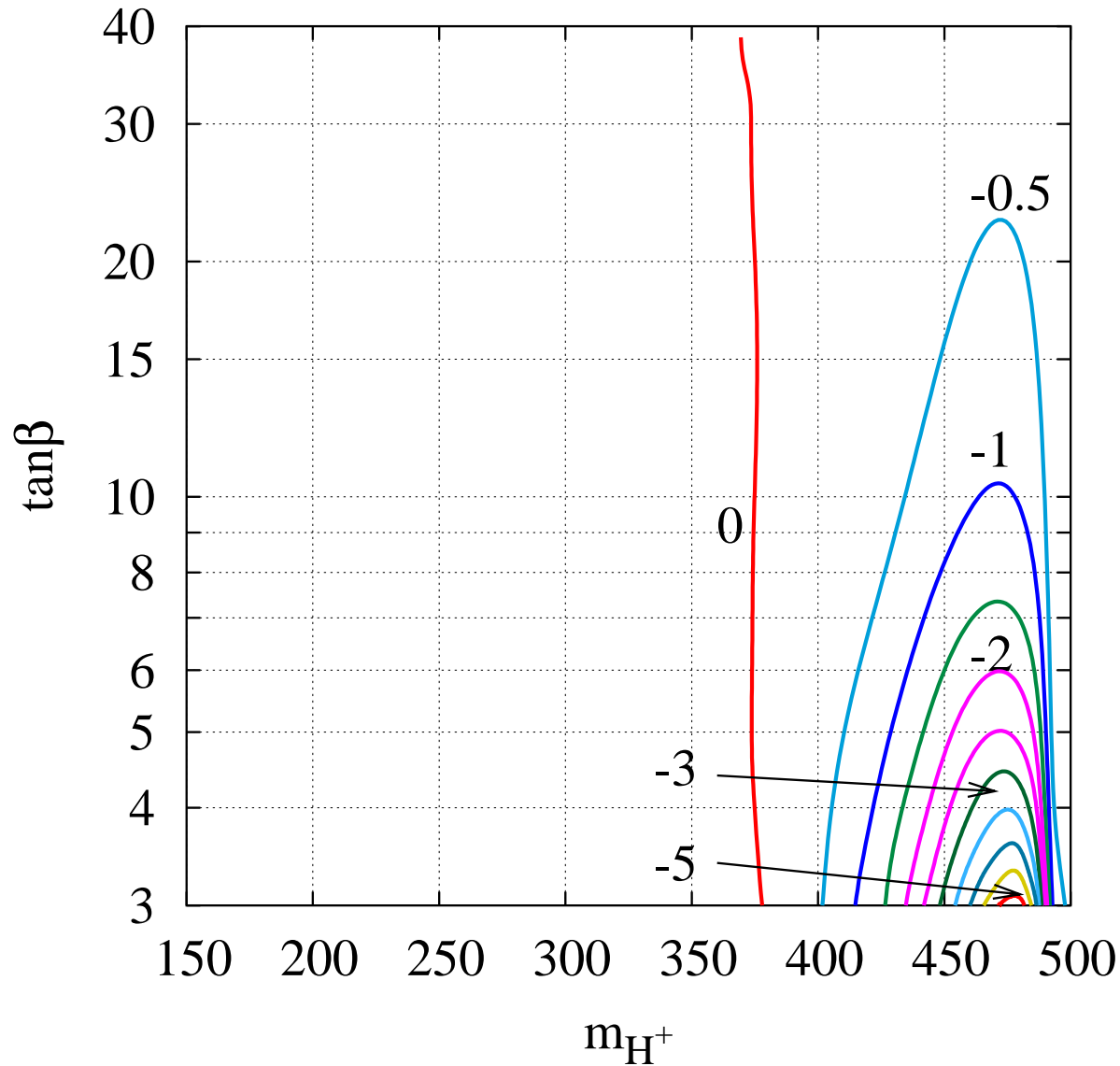
$$\mathcal{A}_3$$
$$\Phi = 30^\circ$$

\mathcal{A}_3 in MSSM : $E_b = 300$ GeV



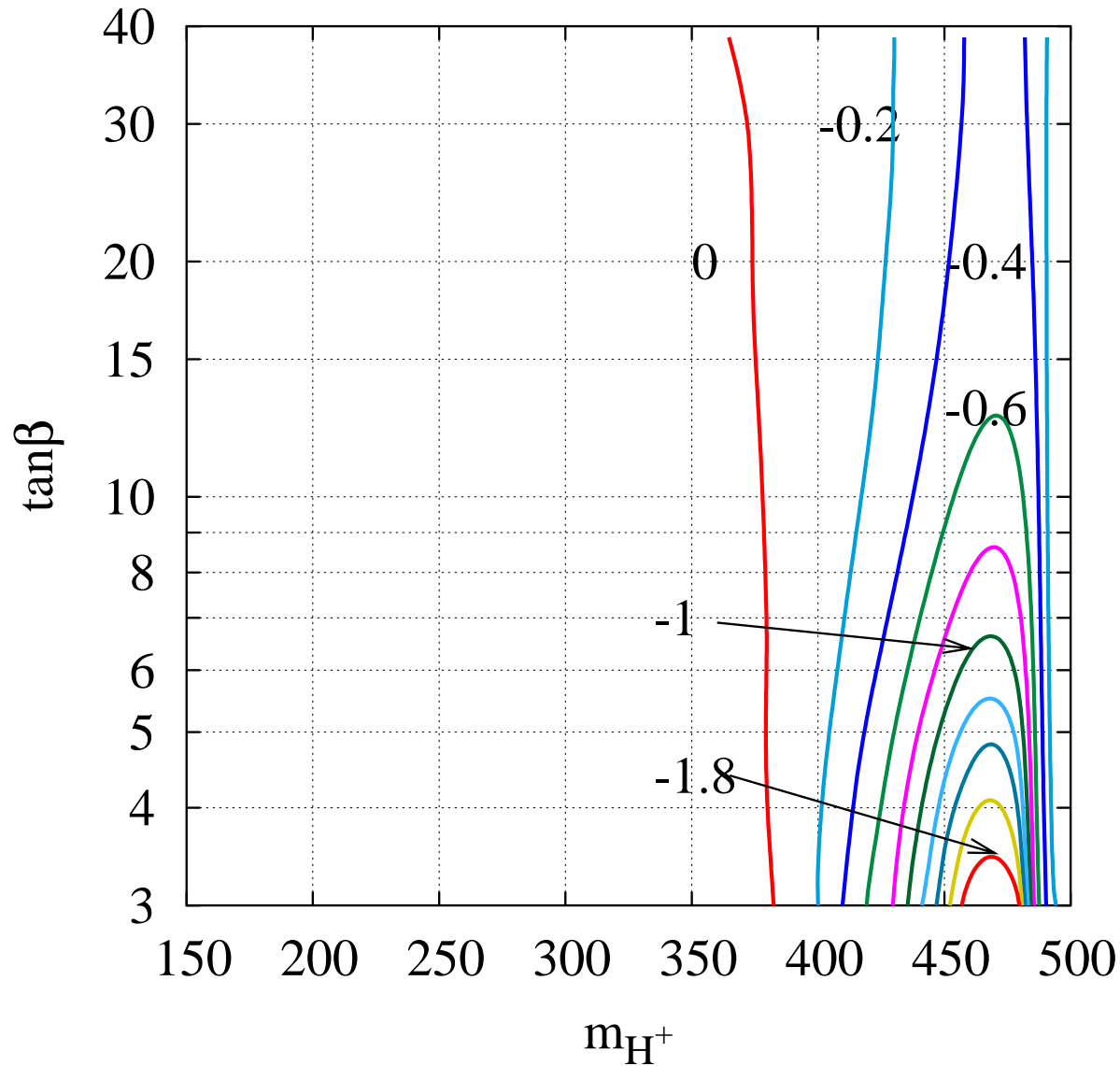
$$\mathcal{A}_3$$
$$\Phi = 90^\circ$$

\mathcal{A}_3 in MSSM : $E_b = 300$ GeV



$$\mathcal{A}_3$$
$$\Phi = 60^\circ$$

\mathcal{A}_3 in MSSM : $E_b = 300$ GeV



$$\mathcal{A}_3$$
$$\Phi = 30^\circ$$

Polarization through angular distribution

For demonstration, we chose $\gamma\gamma \rightarrow t\bar{t}$ process with/without a single Higgs exchange contribution.

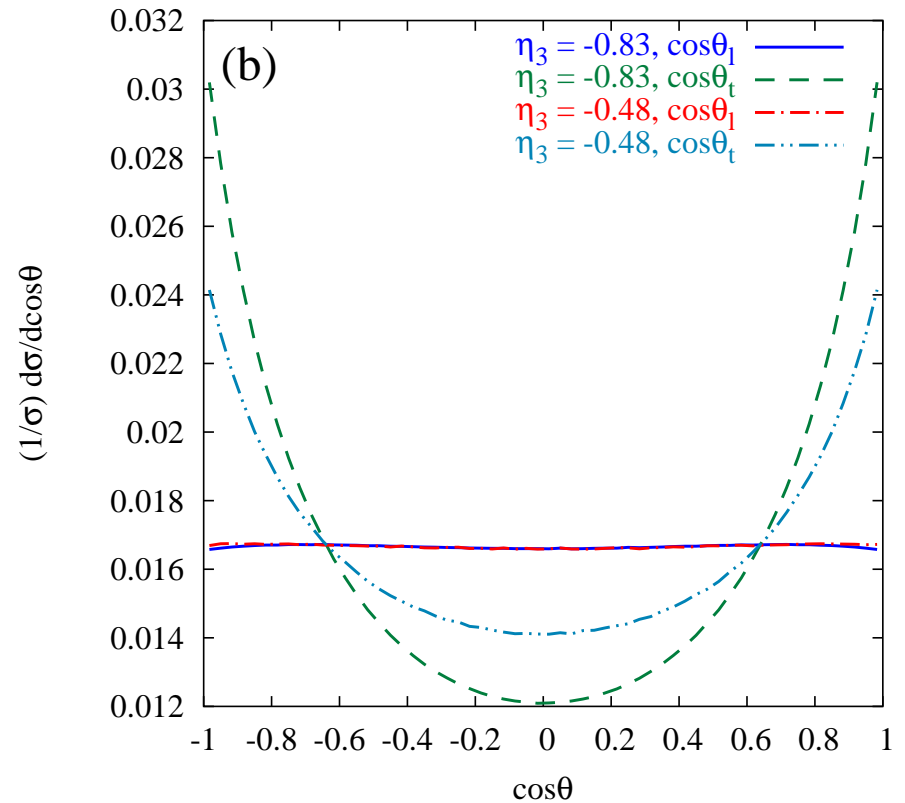
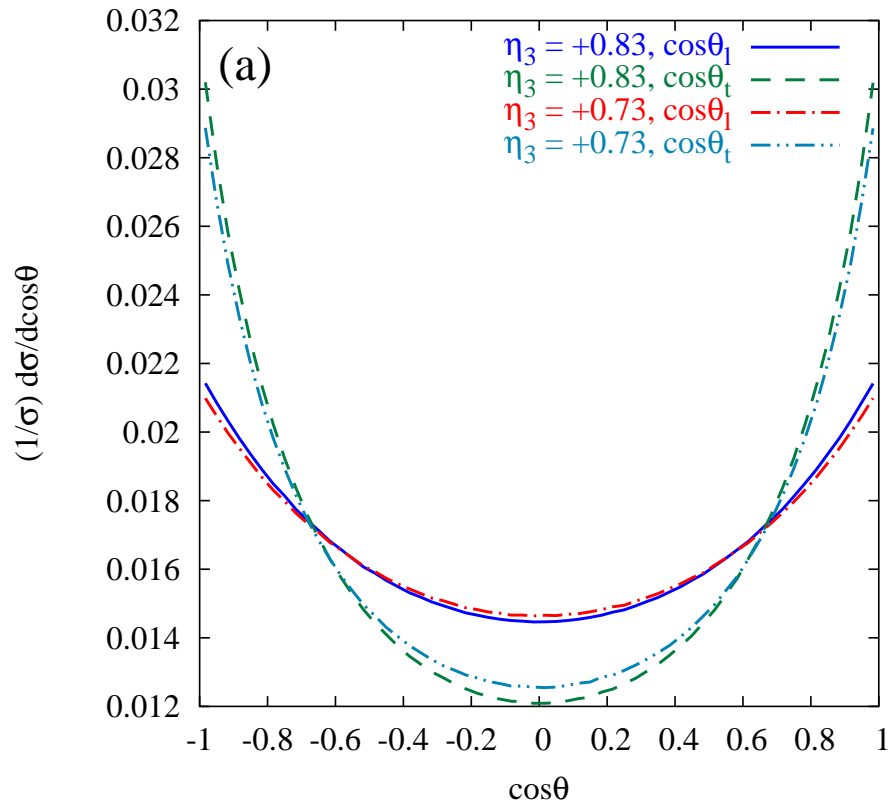
$$m_\phi = 500 \text{ GeV}; \Gamma_\phi = 2.5 \text{ GeV},$$
$$S_t = 0.2, P_t = 0.4, S_\gamma = 4.0 + i 0.5 \text{ and } P_\gamma = 1.25 + i 2.0.$$

Polarized ideal photon spectrum is used.

Assumptions :

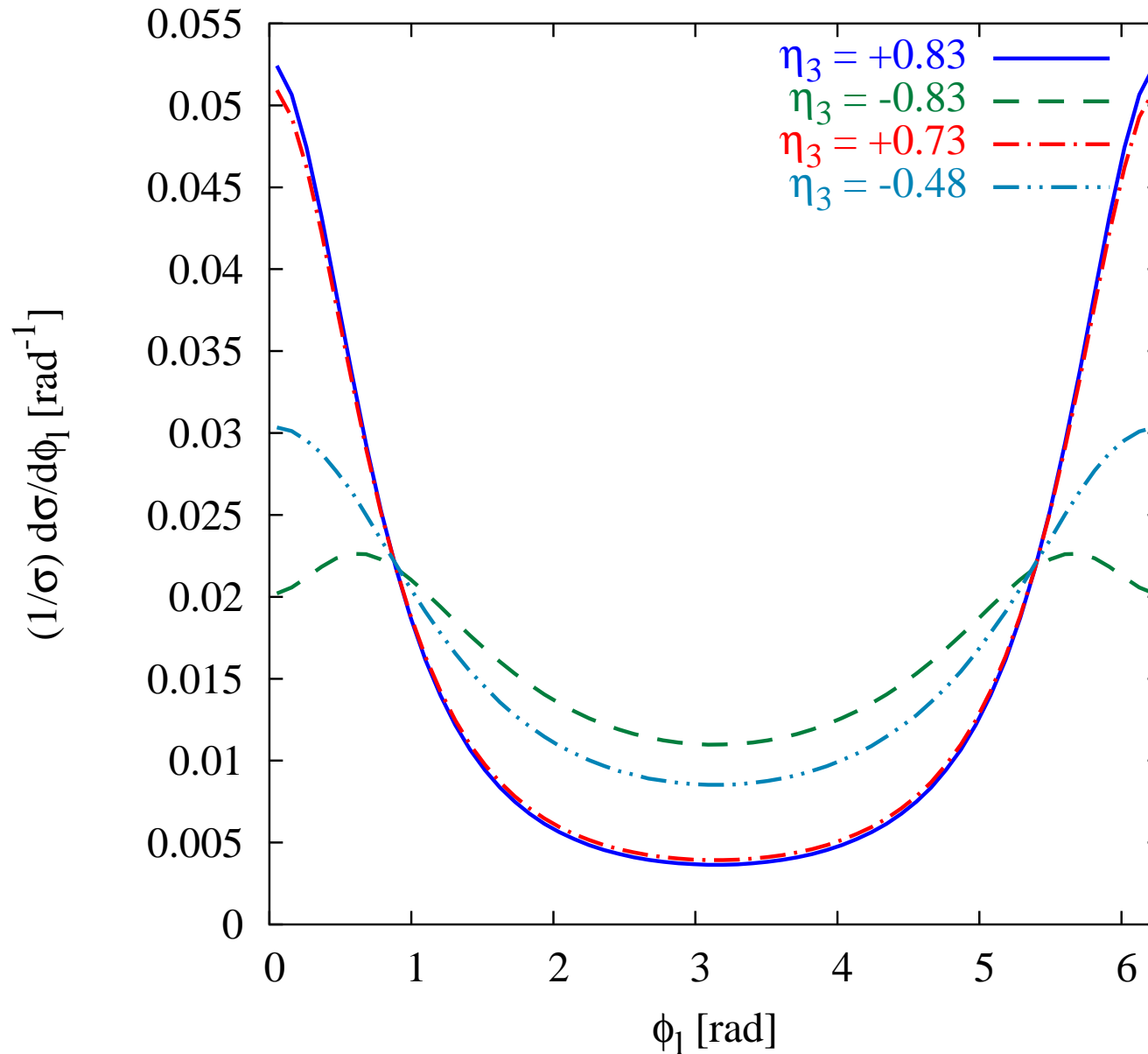
- t -quark is on-shell
- W -boson is on-shell
- b -quark is mass-less and
- $t \rightarrow bW$ is the only decay channel for t -decay

Polarization through angular distribution



$$\eta_1 = 0 \text{ and } \eta_2 = 0$$

Polarization through angular distribution



Conclusions

- Have constructed probes of CP violation and chirality flipping interactions,
- δP_{τ}^{-} can probe high $\tan \beta$ and low m_{H^+} part of the OPAL's allowed region of MSSM in CPX scenario.
- δP_t^{-} can probe low $\tan \beta$ and high m_{H^+} part of the OPAL's allowed region of MSSM in CPX scenario.
- Fermion polarisation is a promising probe of CP properties of neutral Higgs.
- Simple lepton asymmetries can probe only y_i 's, need to use momentum correlators to improve sensitivity.
- Azimuthal asymmetry of leptons w.r.t. top production plane is an easy probe of top polarization.