Fermion polarisation at a $\gamma\gamma$ collider

as a probe of the CP properties of the Higgs boson

LCWS'06

9-13 March, 2006

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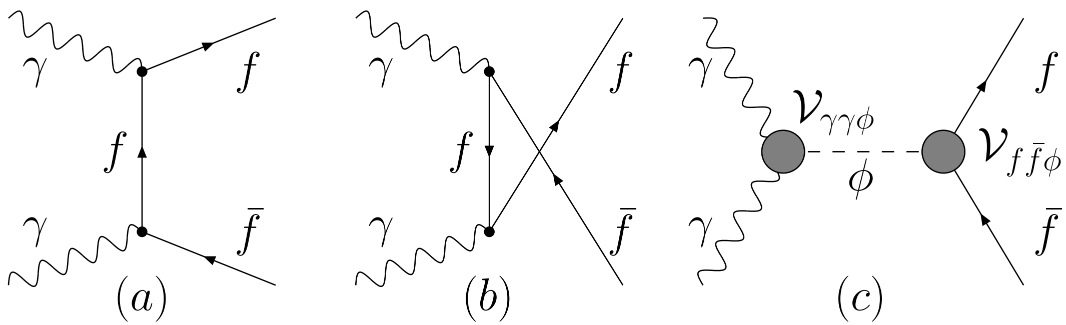
$\gamma\gamma \to f\bar{f}$

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



The Higgs contribution treated in a model independent way.

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

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

$\{S_f, P_f, S_\gamma, P_\gamma\}$ depend upon m_{H^+}, $\tan\beta$, μ, $A_{t,b,\tau}$, $\Phi_{t,b,\tau}$, $M_{\tilde{q}}$, $M_{\tilde{l}}$ etc. in (CP violating) MSSM.

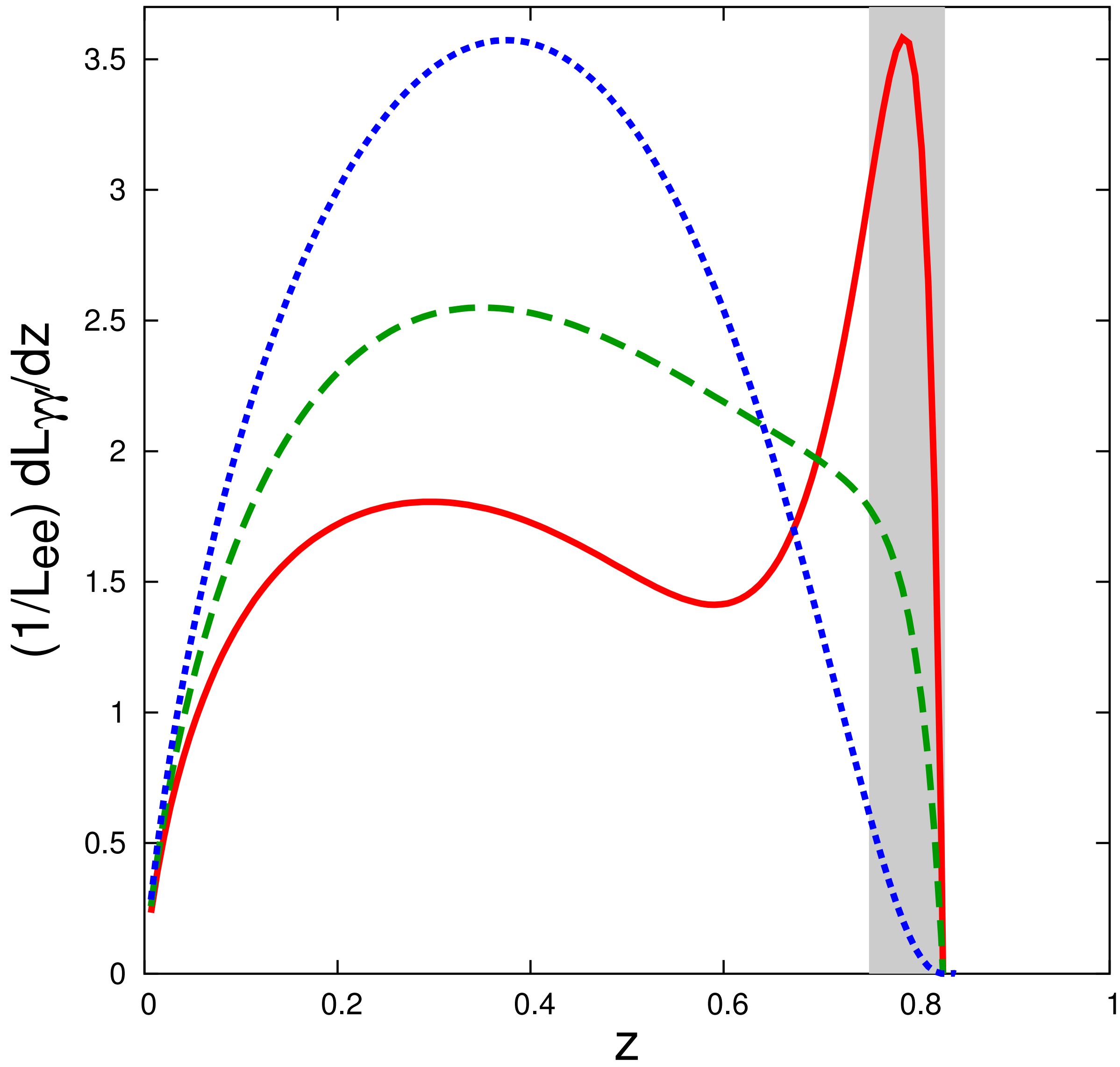
$\gamma\gamma \to f\bar{f}$

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

Combinations	Aliases	CP-property	Combinations	Aliases	CP-properly
$S_f \Re(S_\gamma)$	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.

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} :

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

[Hikasa, PRD60,(1999),114041]

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

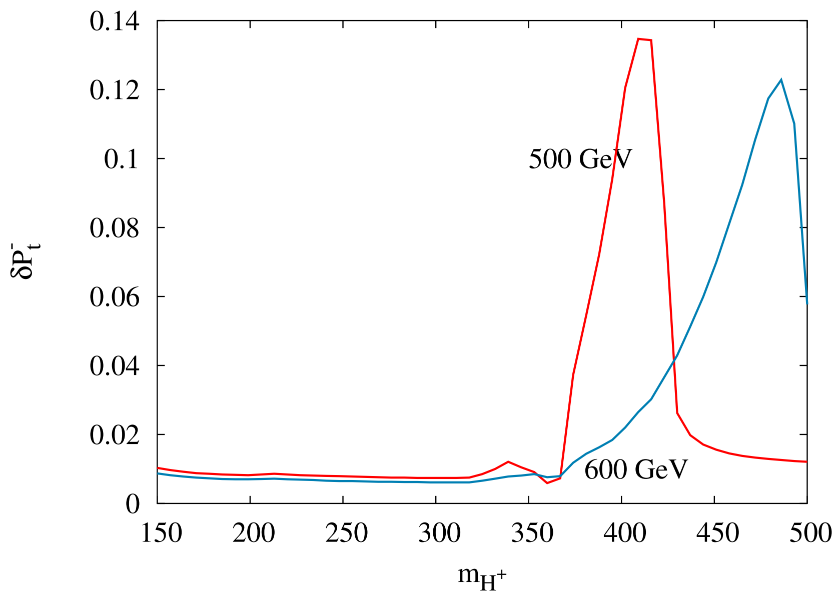
$P_f^{++} + P_f^{--} \neq 0 \Rightarrow$ signal of $\not{P}$
In case of C invariance $\Rightarrow$ signal of CP violation.

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

MSSM Higgs Sector

MSSM : Three neutral Higgs

	h,H	A
	CP-even	CP-odd

CP violation : ϕ_1, ϕ_2, ϕ_3 no fixed CP property $m_{\phi_1} < m_{\phi_2} < m_{\phi_3}$

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

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

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

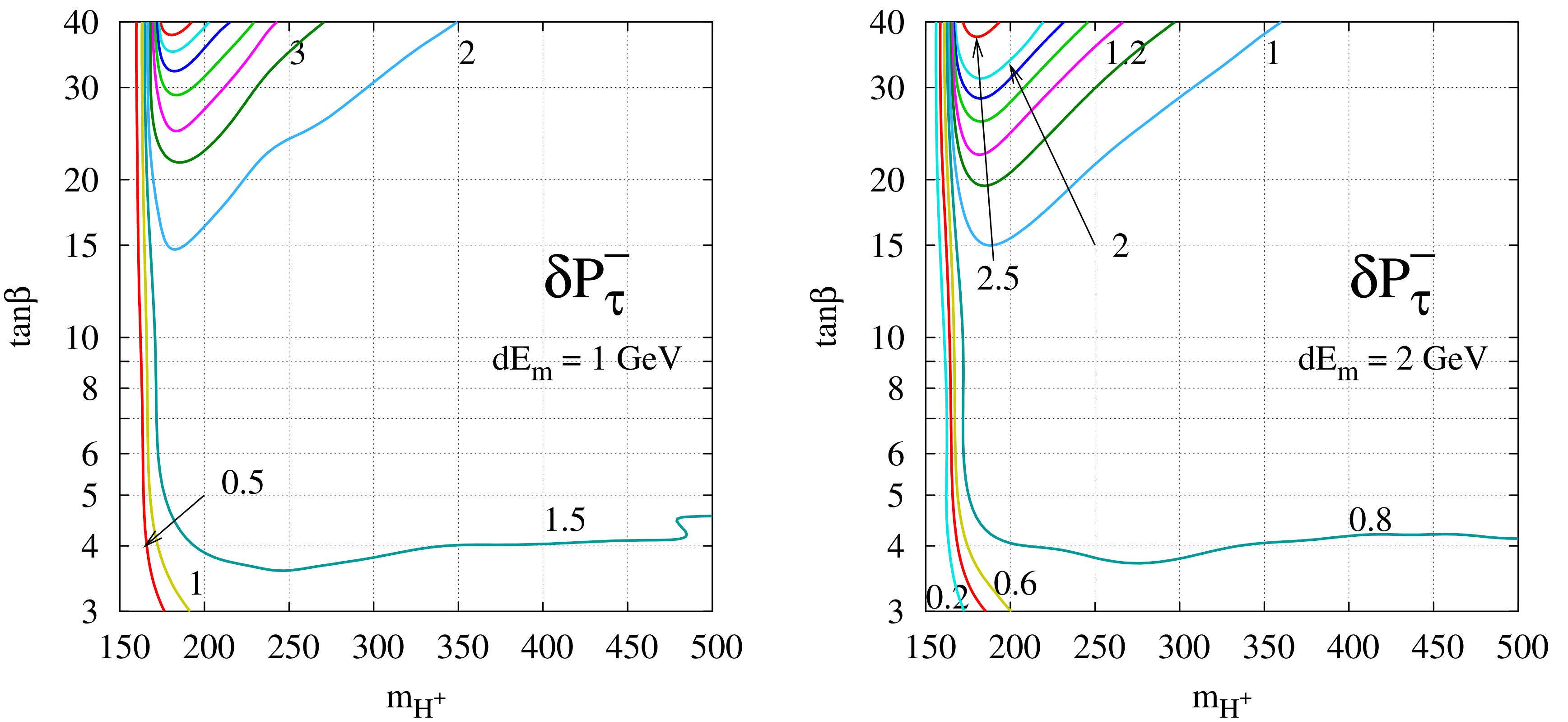
CPX scenario

CPX scenario

MSSM parameters	Values
$\tan\beta$	3 - 40 (used for scan)
m_{H^+}	150-500 GeV (used for scan)
μ	2 TeV, Φ_μ = 0
M_1, M_2	200 GeV, $\Phi_{1,2}$ = 0
M_3	1 TeV, Φ_3 = 90°
$m_{\tilde{q},\tilde{l}}$	500 GeV
$A_{t,b}$	1 TeV, $\Phi_{t,b}$ = 90°
A_τ	500 GeV, Φ_τ = 90°

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

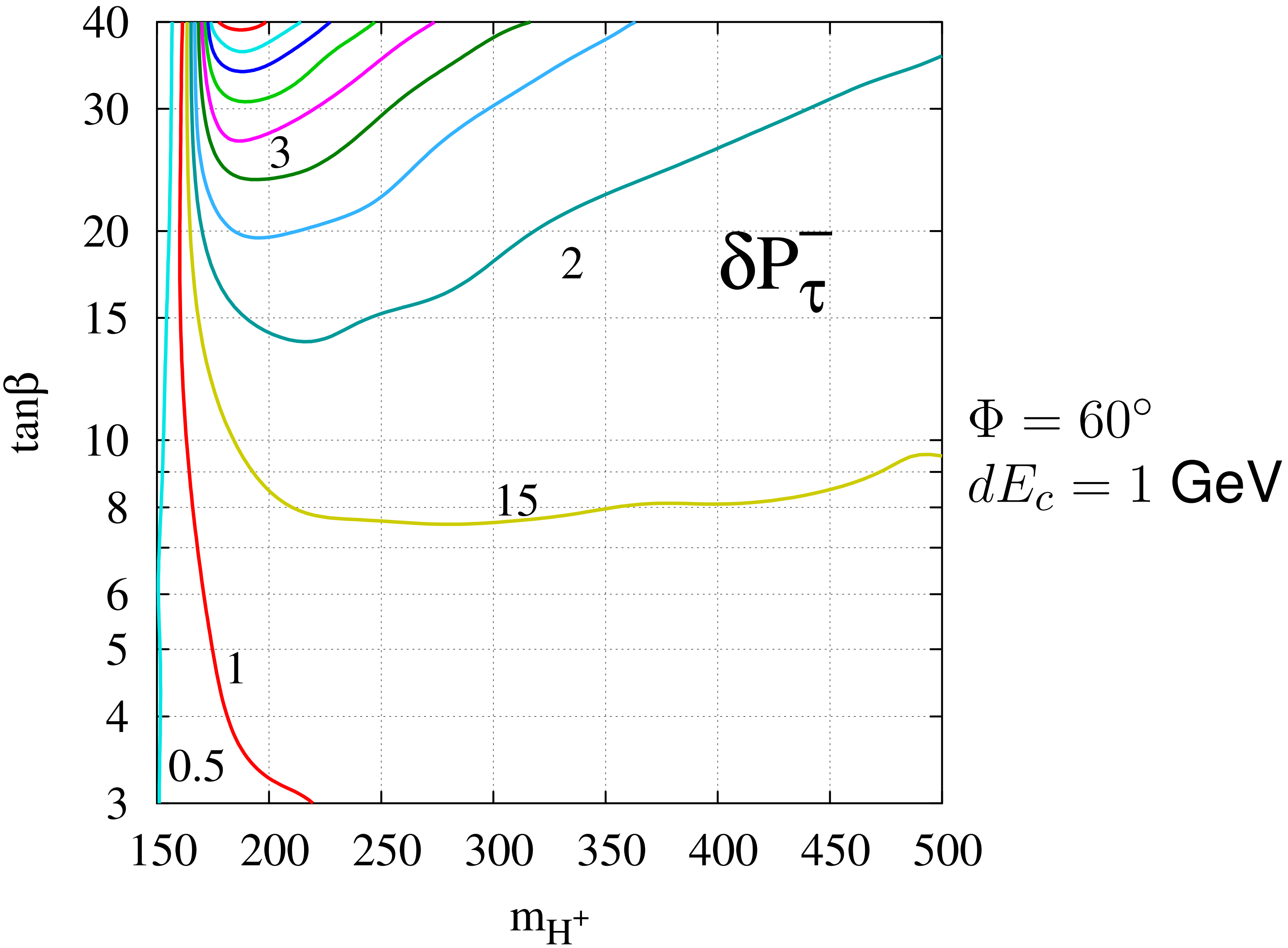
τ-polarization in MSSM



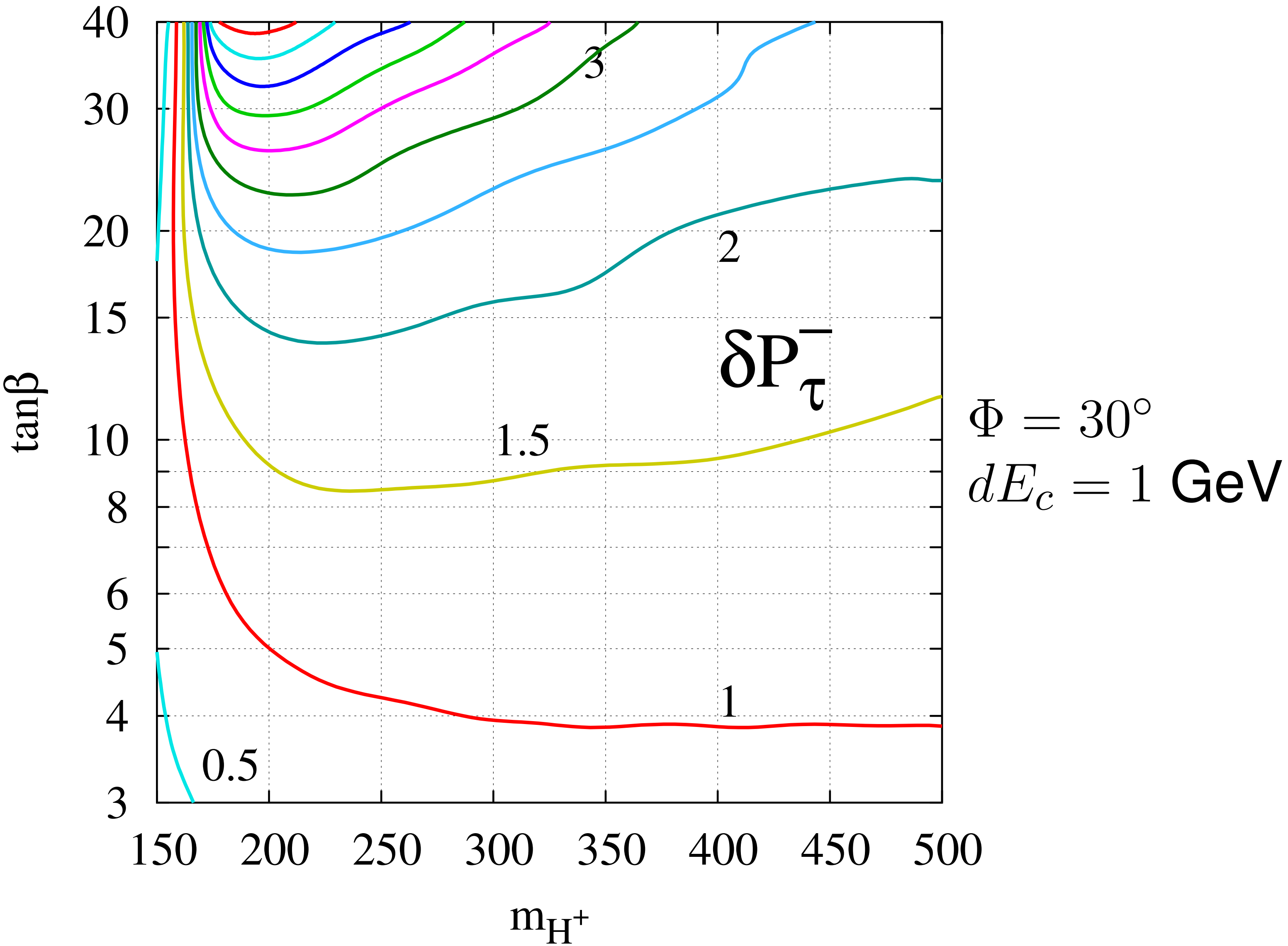
$E_b = (m_{H_1}/2)/0.8$ for each point in the scan and $|m_{\tau\tau} - m_{H_1}| < dE_c$.
$dE_c = 1$ GeV (Left panel) $dE_c = 2$ GeV (Right panel)

$$\Phi = 90^\circ$$

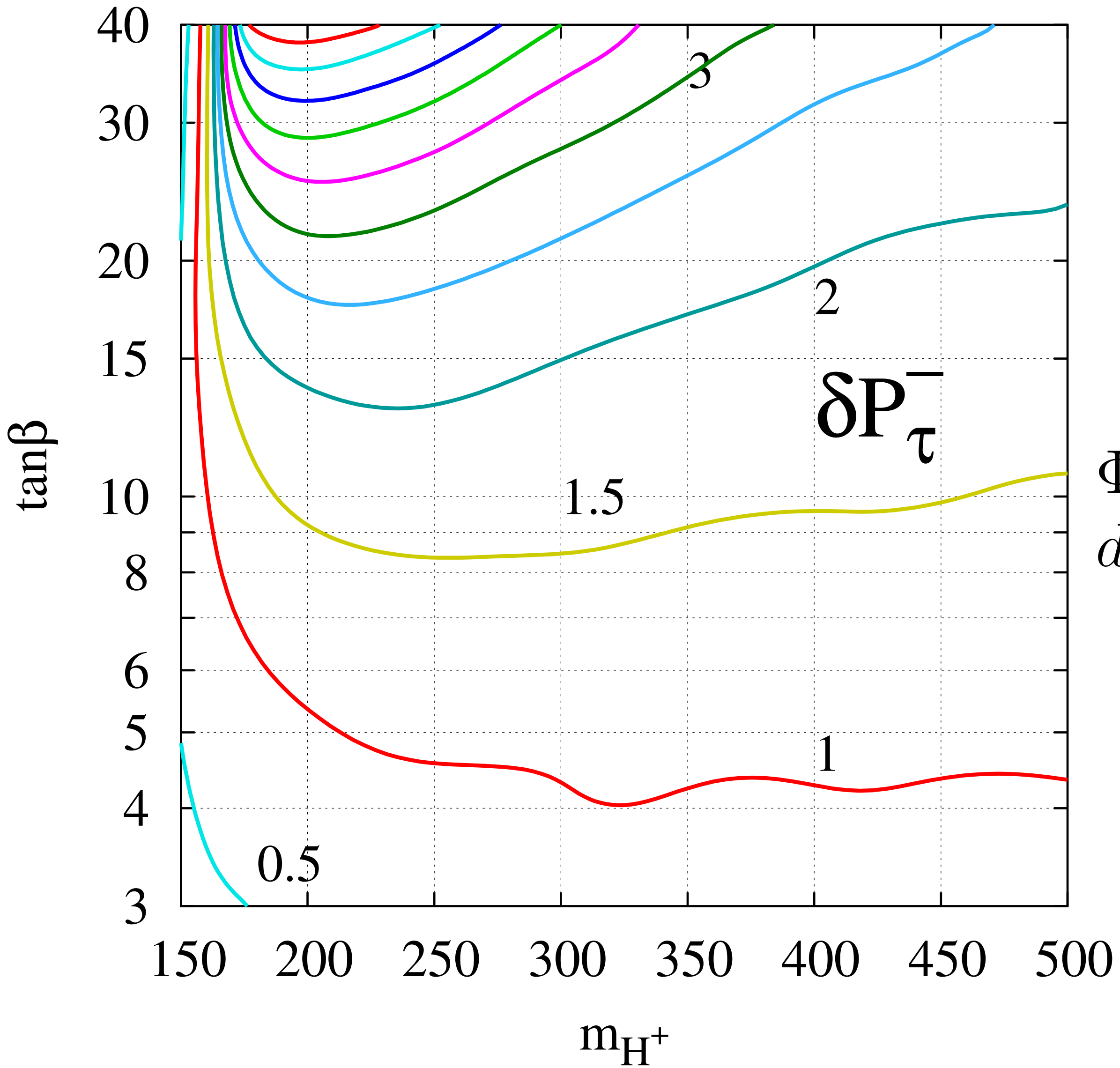
τ-polarization in MSSM



τ-polarization in MSSM

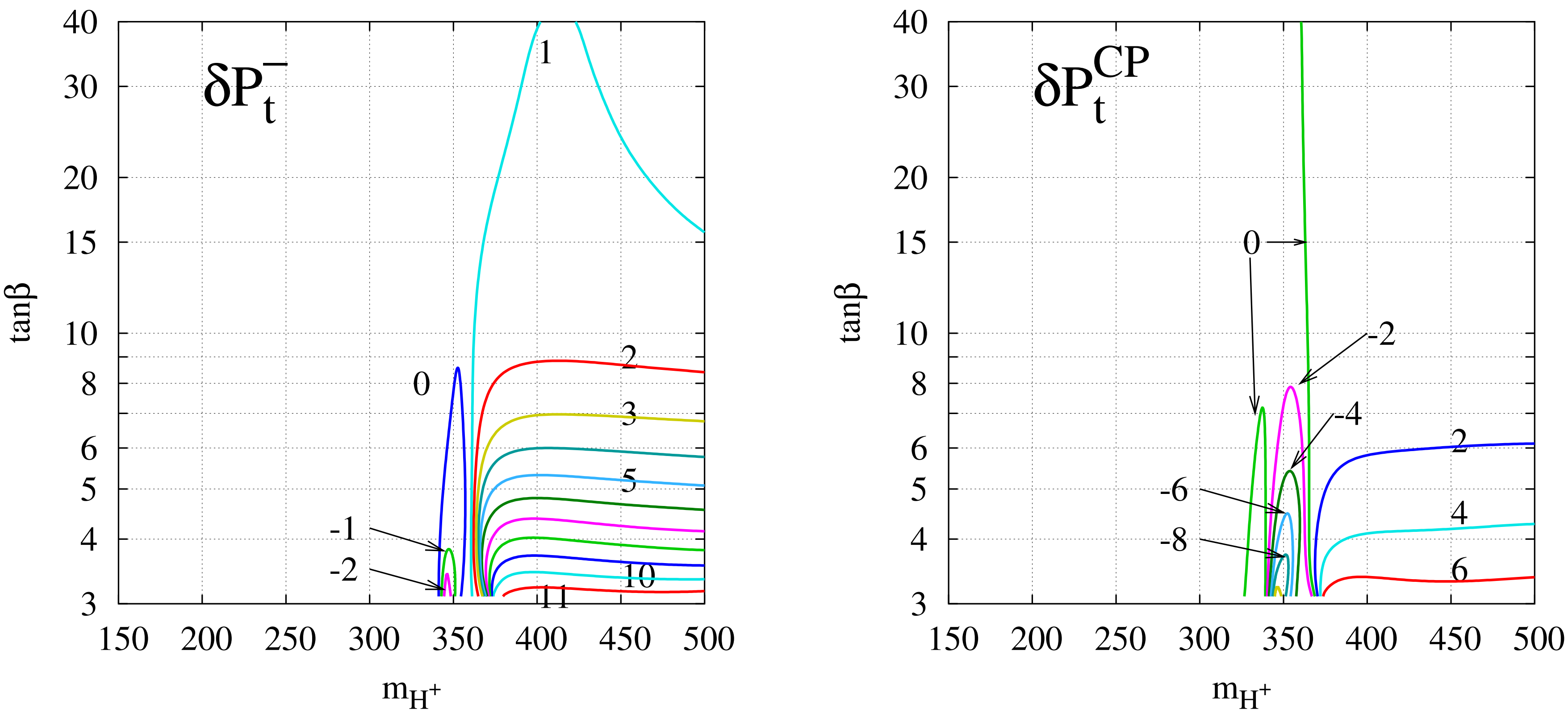


τ-polarization in MSSM



$\Phi = 00^\circ$
$dE_c = 1$ GeV

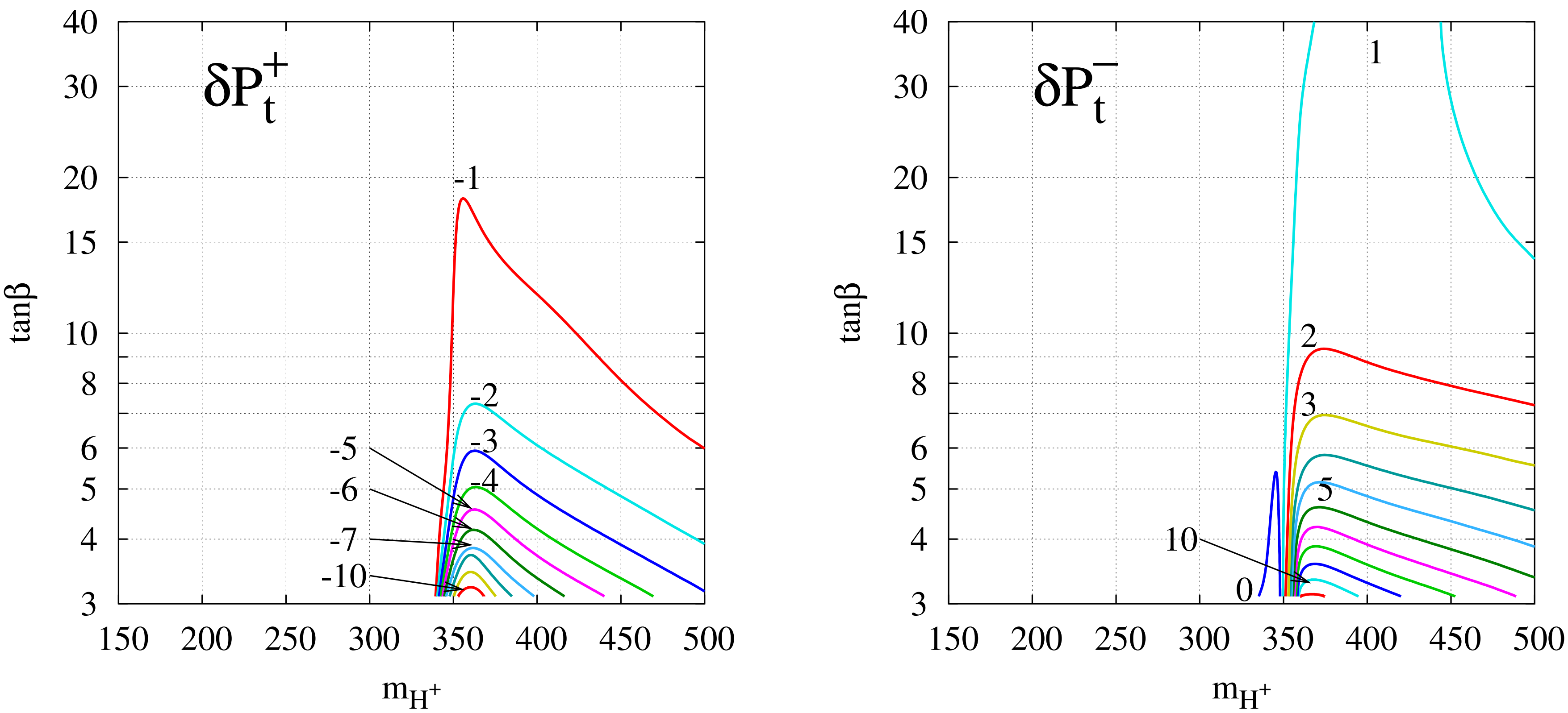
t-polarization in MSSM : Peak E_b



$$\Phi = 90^\circ$$

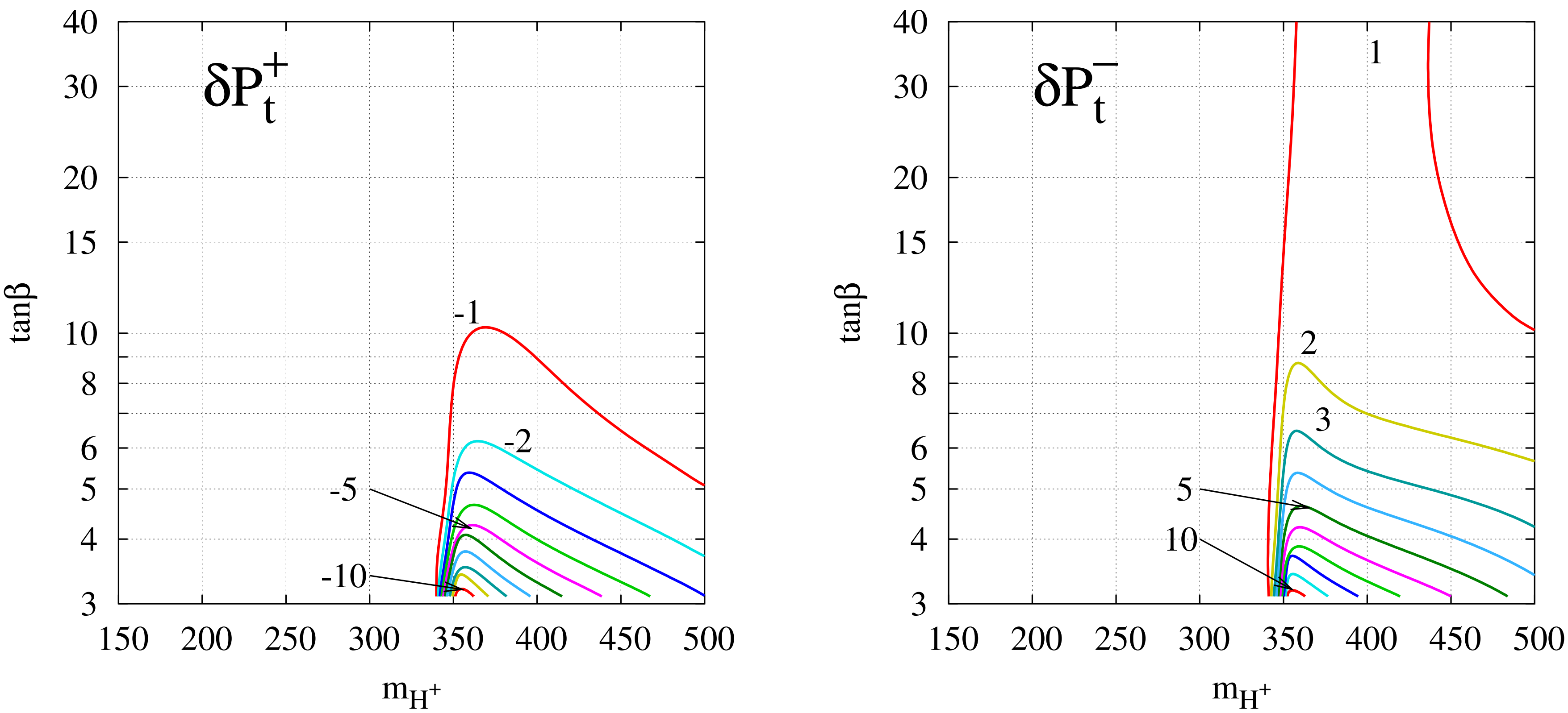
$E_{cm} = (m_{H_2} + m_{H_3})/4/0.8$ for each point in the scan.

t-polarization in MSSM : Peak E_b



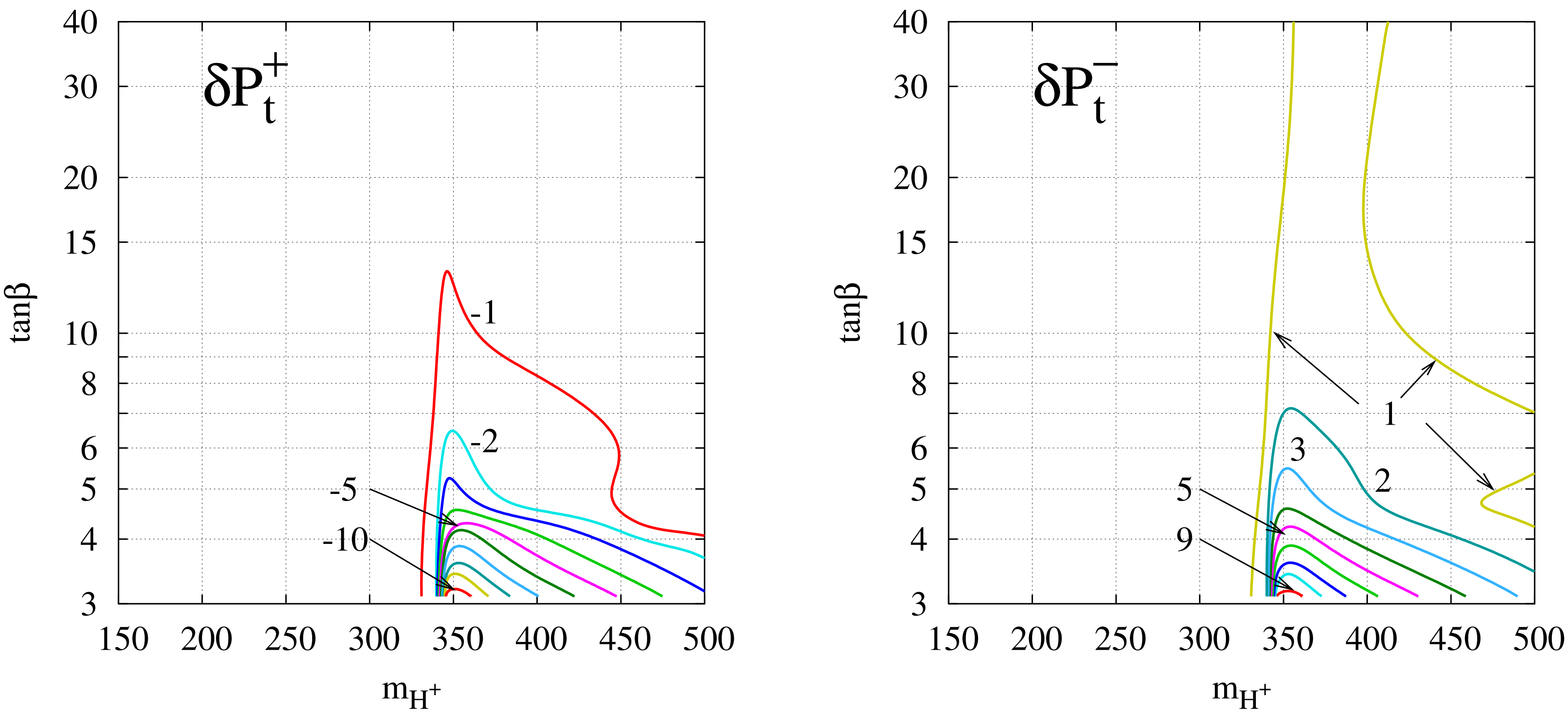
$$\Phi = 60^{\circ}$$

t-polarization in MSSM : Peak E_b



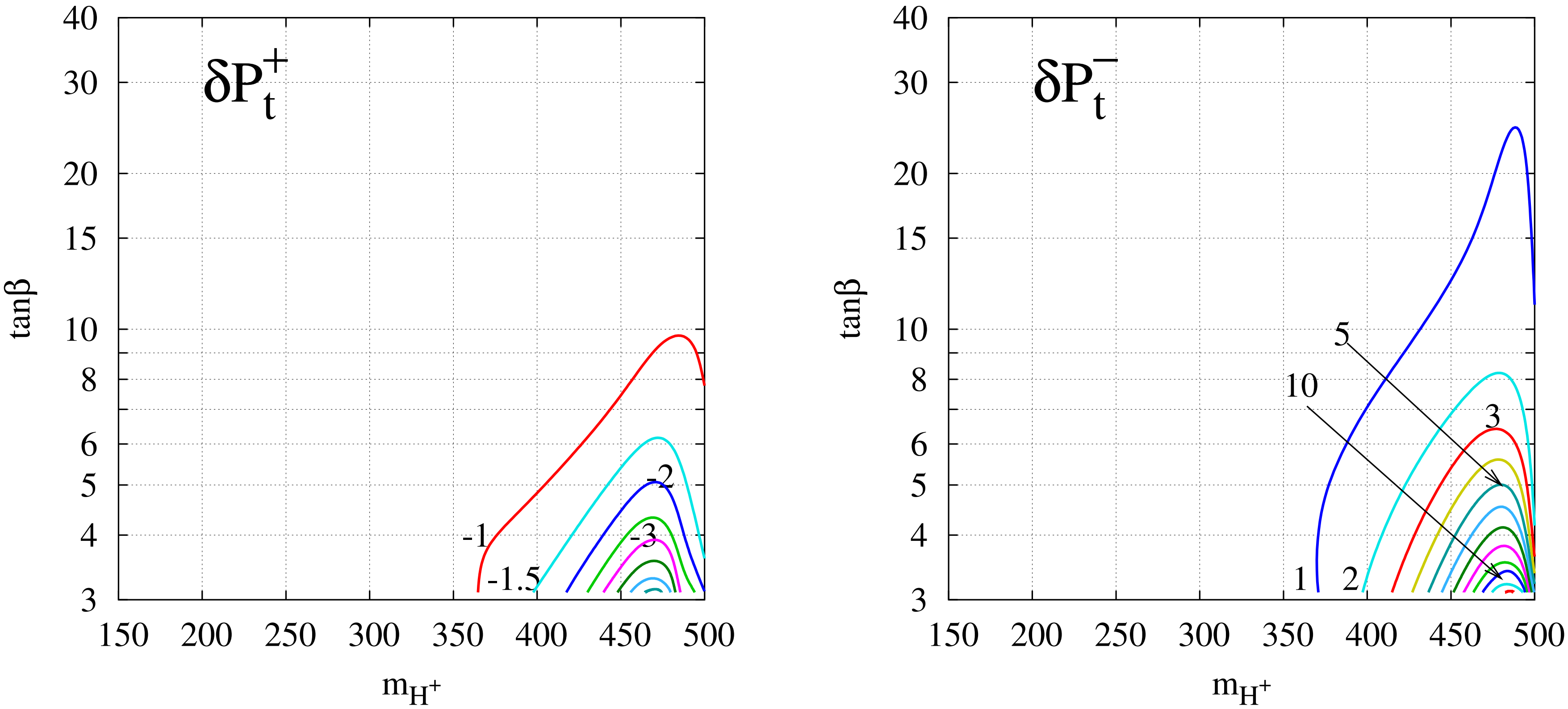
$$\Phi = 30^\circ$$

t-polarization in MSSM : Peak E_b



$$\Phi = 00^\circ$$

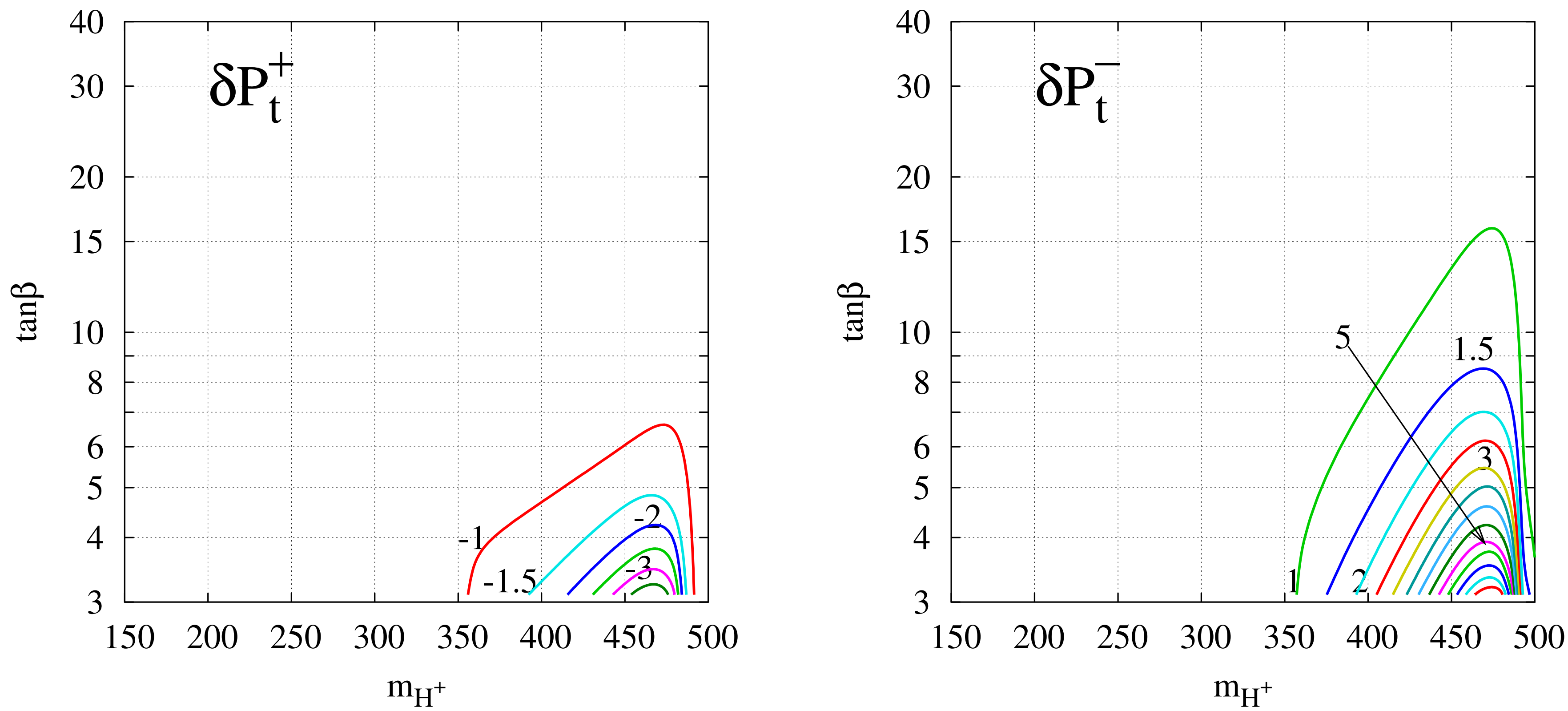
t-polarization in MSSM : Fixed E_b



$$\Phi = 90^\circ$$

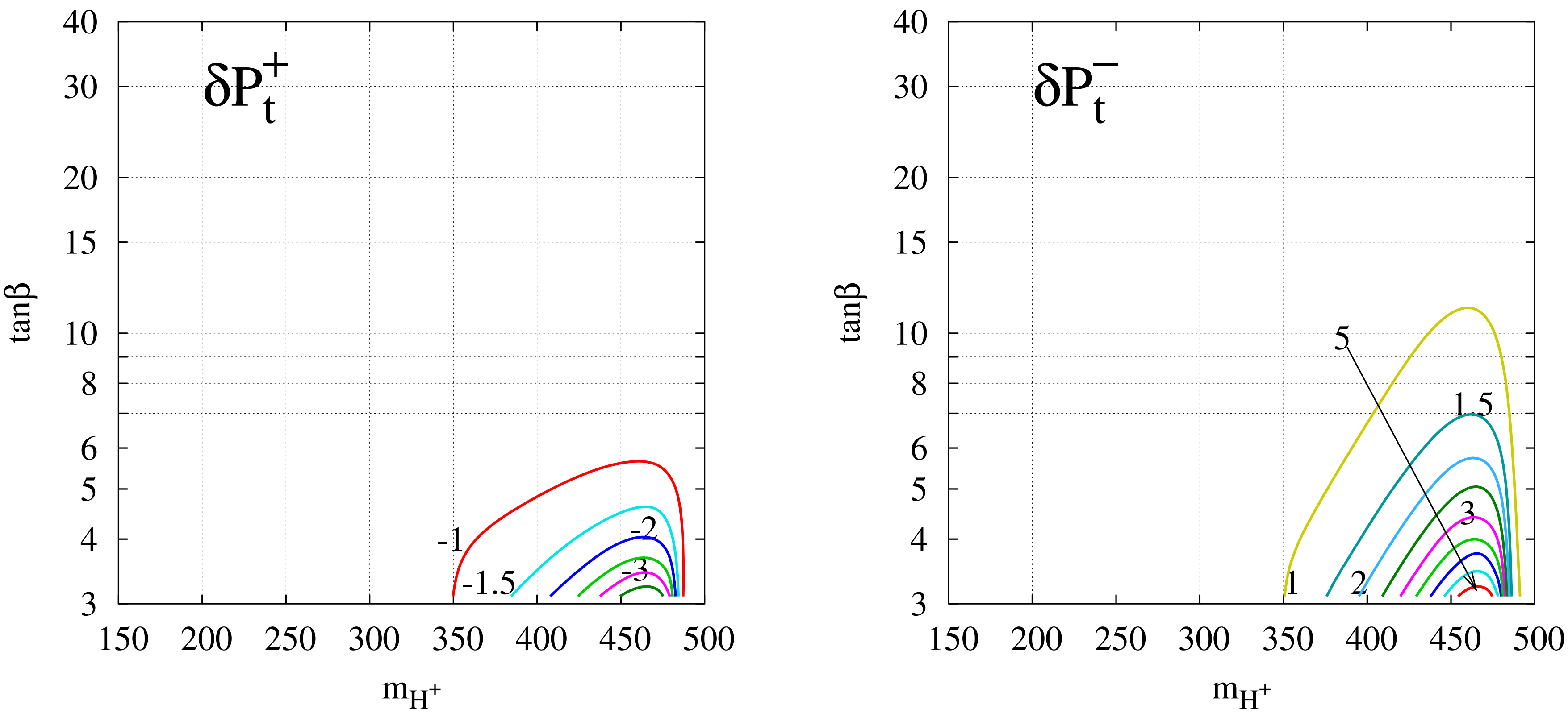
$E_{cm} = 600$ GeV for each point in the scan.

t-polarization in MSSM : Fixed E_b



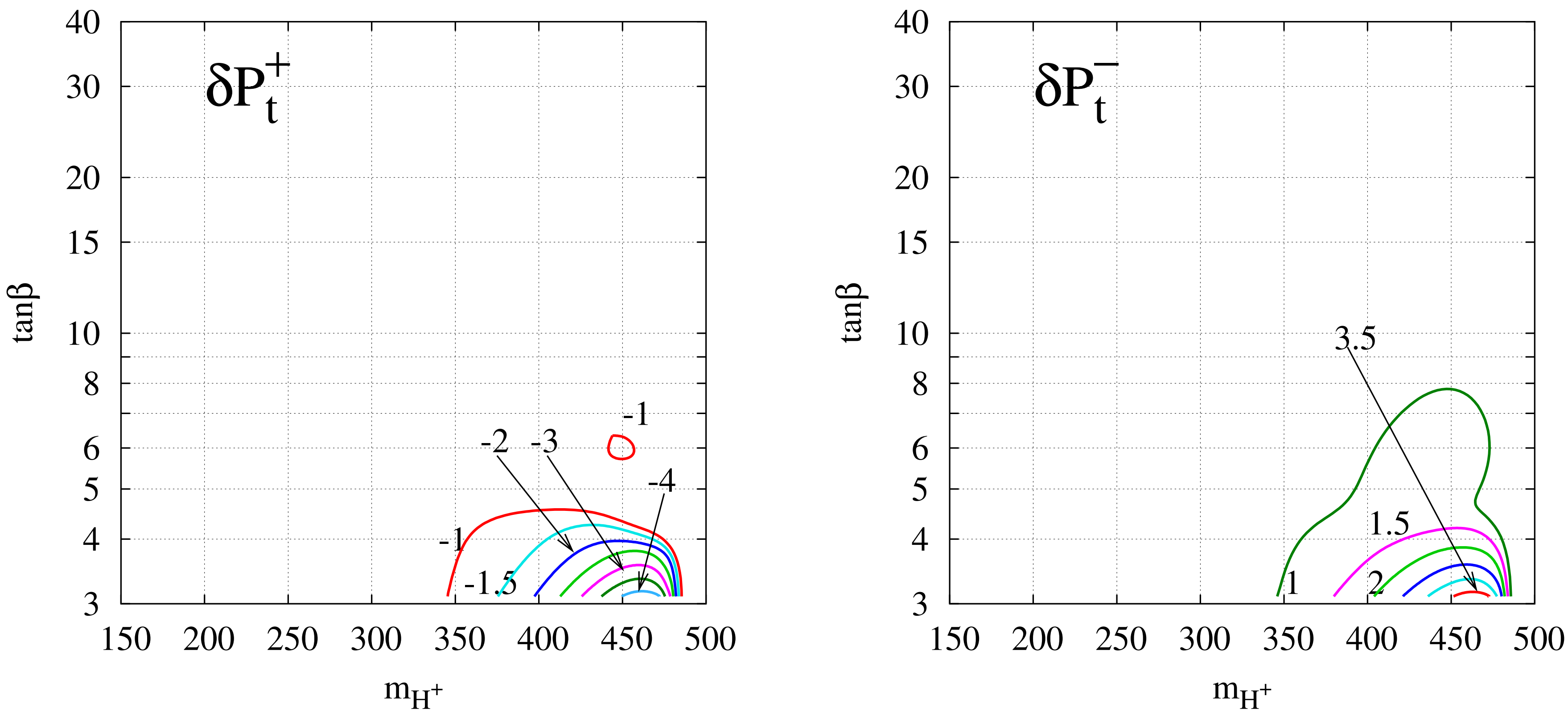
$$\Phi = 60^{\circ}$$

t-polarization in MSSM : Fixed E_b



$$\Phi = 30^\circ$$

t-polarization in MSSM : Fixed E_b



$$\Phi = 00^\circ$$

Decay Lepton Asymmetry

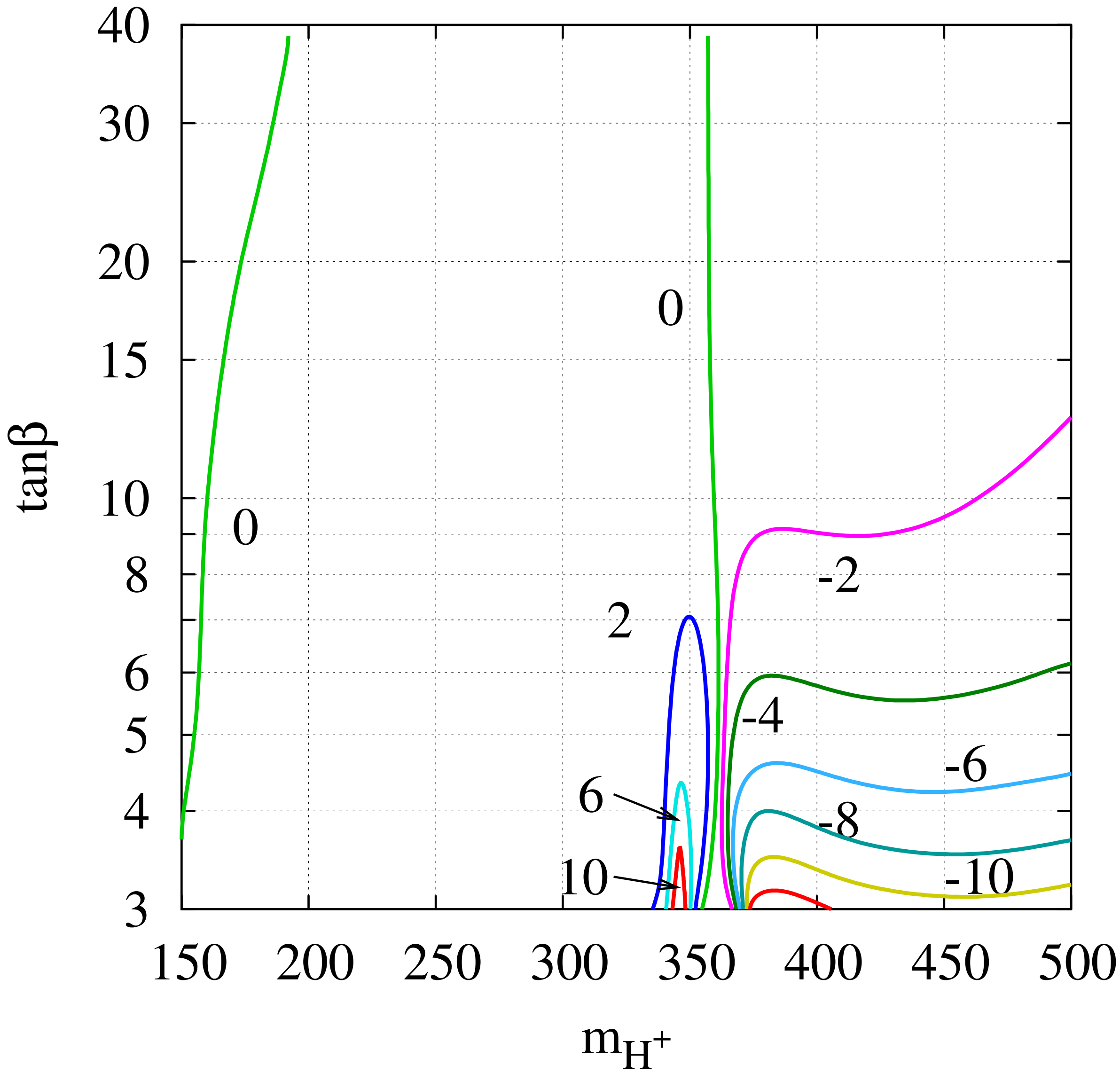
- The decay leptons from t-quark carry information about its polarization. Can construct asymmetries combining charge of lepton and polarization of initial state e^- of the PLC.
- We chose $\lambda_{e^-} (= \lambda_{e^+}) = -\lambda_1(\lambda_2)$. Thus cross-section can be parametrized as $\sigma(\lambda_{e^-},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

$$\mathcal{A}_1 = \frac{\sigma(++) - \sigma(--)}{\sigma(++) + \sigma(--)} \qquad \mathcal{A}_2 = \frac{\sigma(+-) - \sigma(-+)}{\sigma(+-) + \sigma(-+)}$$

$$\mathcal{A}_3 = \frac{\sigma(++) - \sigma(-+)}{\sigma(++) + \sigma(-+)} \qquad \mathcal{A}_4 = \frac{\sigma(+-) - \sigma(--)}{\sigma(+-) + \sigma(--)}$$

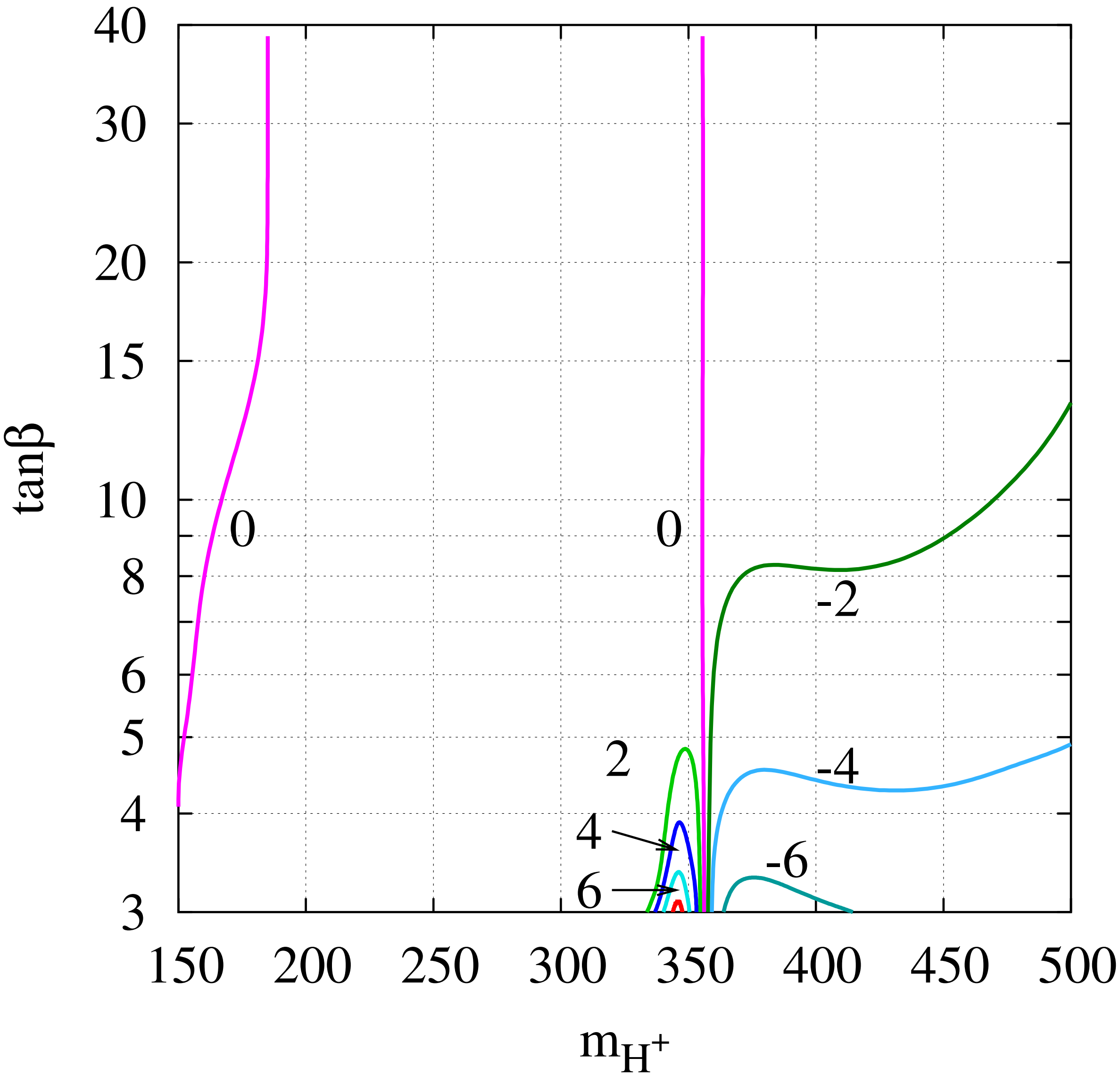
- These simple asymmetries are sensitive to CP-odd combinations y_i's only; negligible sensitivity to x_i's.

$\mathcal{A}_3$ in MSSM : Peak E_b



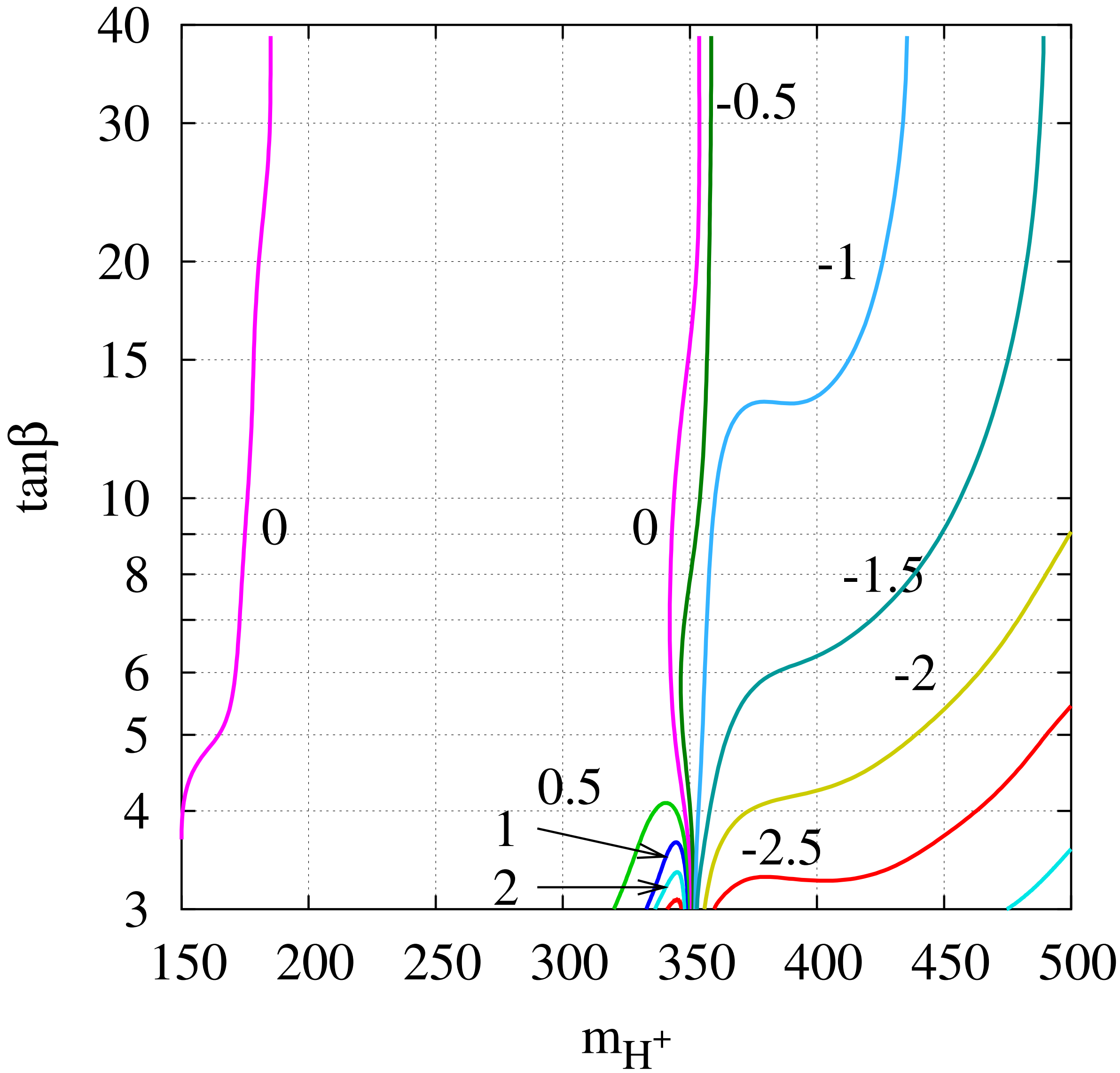
$\mathcal{A}_3$
$\Phi = 90^\circ$

$\mathcal{A}_3$ in MSSM : Peak E_b



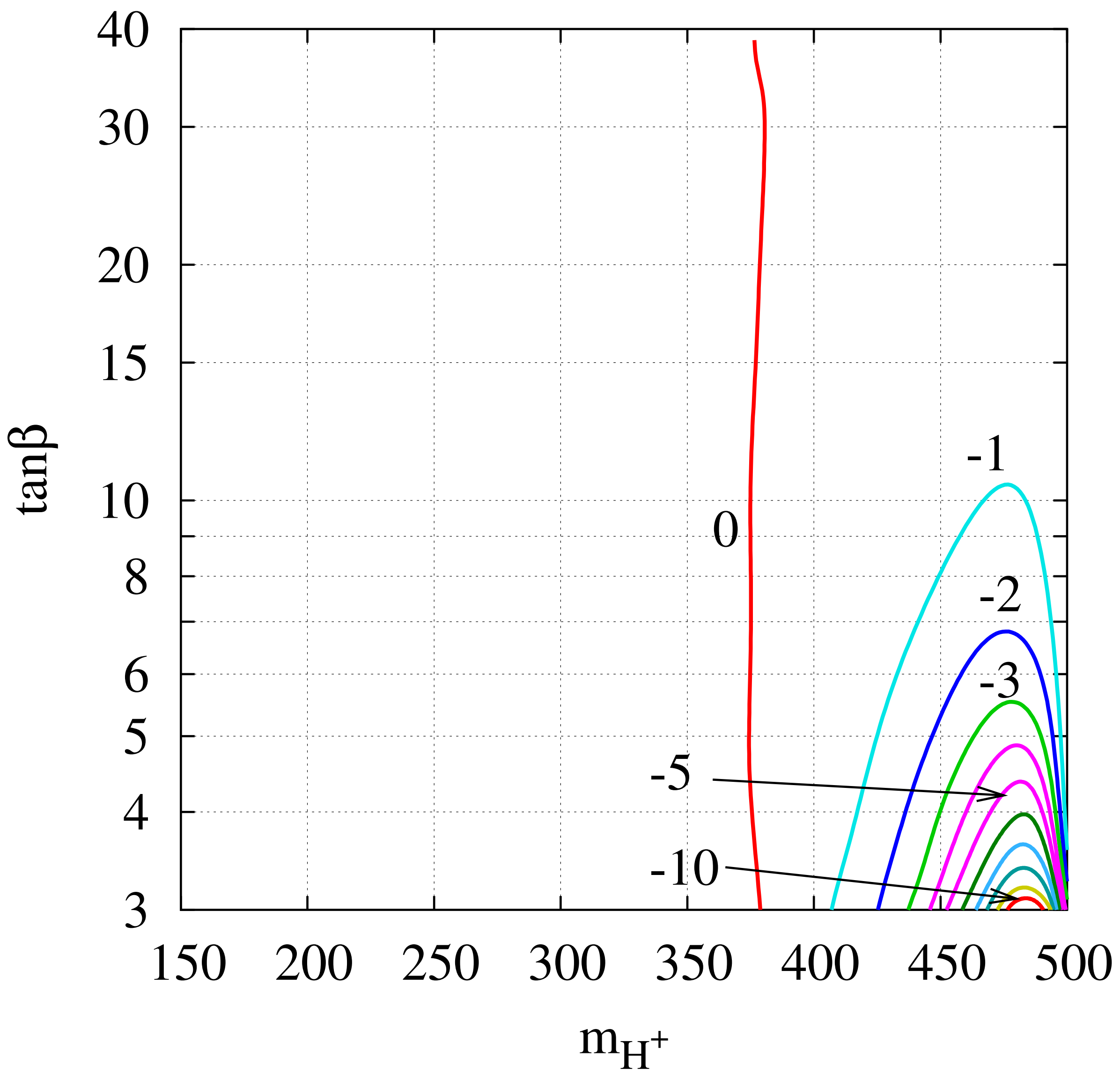
$\mathcal{A}_3$
$\Phi = 60^\circ$

$\mathcal{A}_3$ in MSSM : Peak E_b



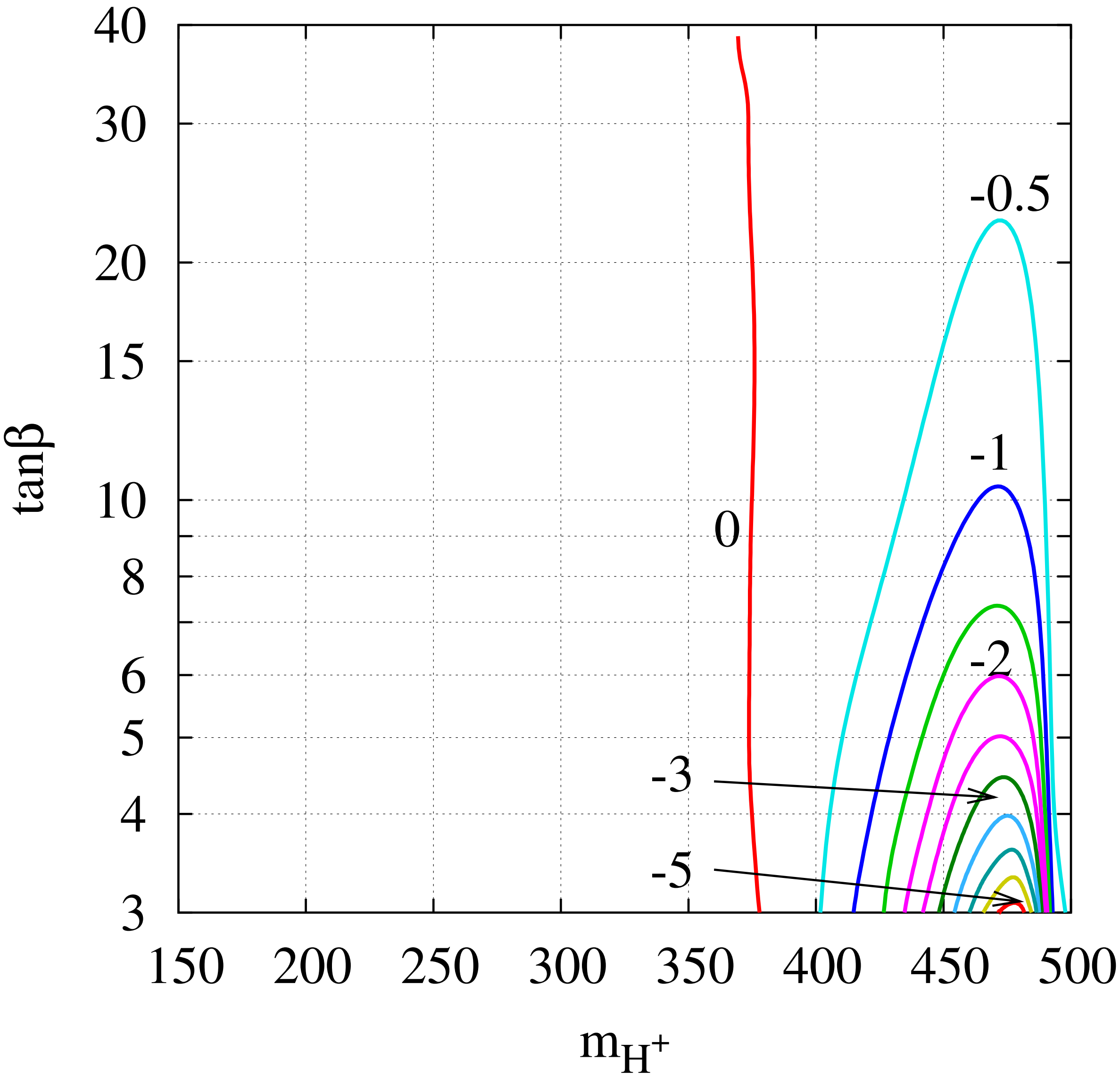
$\mathcal{A}_3$
$\Phi = 30^\circ$

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



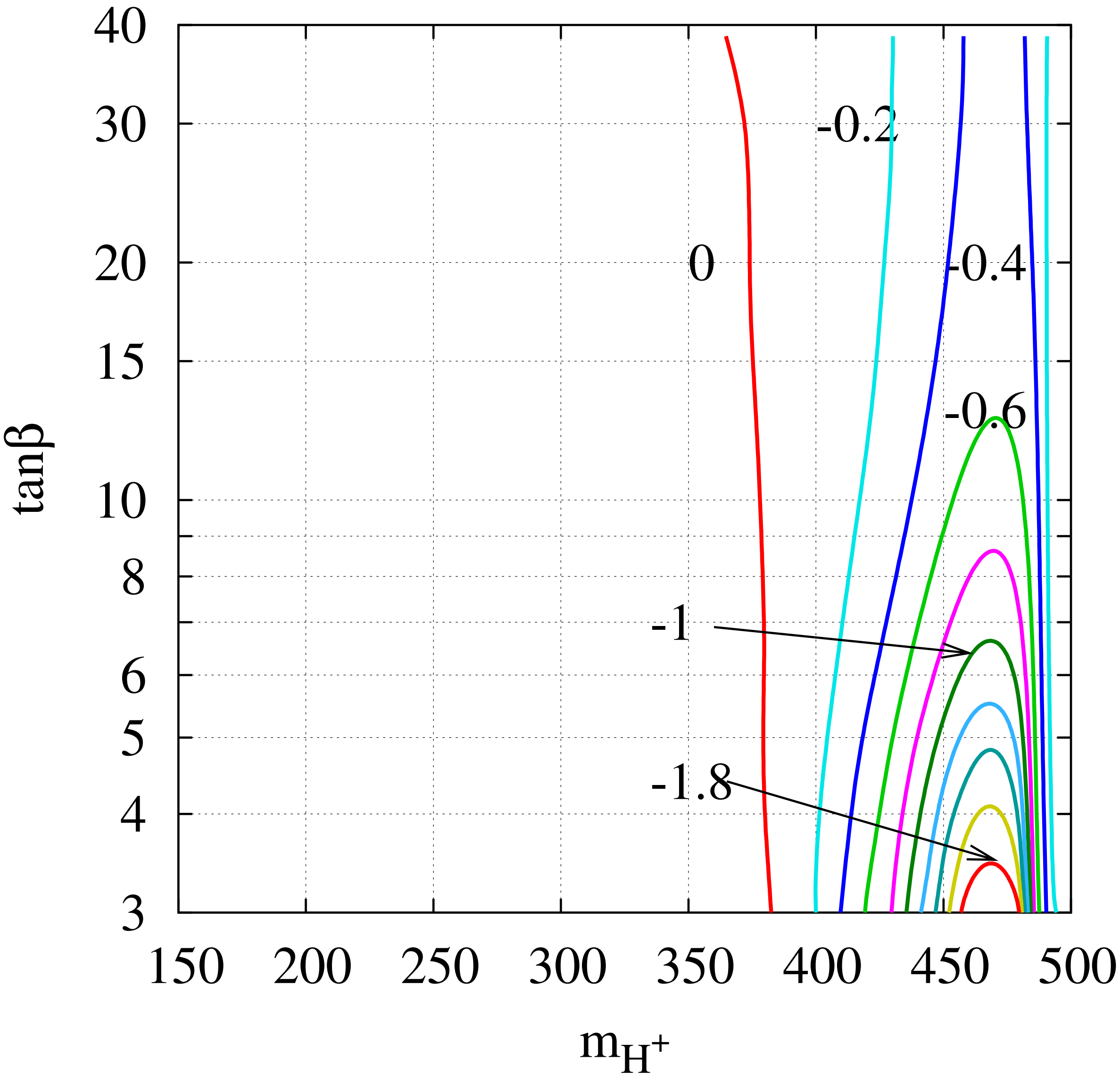
$\mathcal{A}_3$
$\Phi = 90^\circ$

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



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

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



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

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.

Future directions

- Scan other choices within CPX scenario.
- Incorporate feasible momentum correlators for t decay products.
- Incorporate the effect of τ decay using `Tauola`.
- Incorporate the effect of higher order QED/QCD corrections.