Probing Slepton CP phases at LHC and ILC

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Outline

Motivation

SUSY CP problem

- Soft terms of MSSM can in general be complex (μ, M_1, M_3, A_f)
- Generate EDM for e, n and $^{199}H_g$ and $^{205}T_l$ - above current experimental limit for any phase $\mathcal{O}(1)$
- To avoid large EDMs
  - CP phases are zero
  - Special hierarchy in the sfermion sector exists
- SUSY CP problem

Are the phases zero or there is a definite hierarchy? $\Rightarrow$ observe CPV at colliders

CP even observables

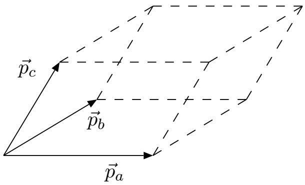
- Total cross-sections (CS)
- Branching ratios (BR)

CP odd observables

- Rate asymmetries eg. BR, CS
- Triple products

Triple products and CP asymmetries

- A combination of momenta and spins of the particle



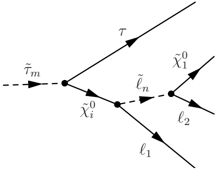
$$[\vec{p}_a,\ \vec{p}_b,\ \vec{p}_c] = (\vec{p}_a \times \vec{p}_b) \cdot \vec{p}^c \equiv \mathcal{T}$$

- CP odd (T-odd) at tree level
- Asymmetry can be defined as

$$\mathcal{A}_\tau^{\mathrm{CP}} = \frac{\sigma(\mathcal{T} > 0) - \sigma(\mathcal{T} < 0)}{\sigma(\mathcal{T} > 0) + \sigma(\mathcal{T} < 0)} \propto \eta_{mi}$$

$$\eta_{mi} = \frac{\mathfrak{Im}\{a^{\tilde{\tau}}_{mi}(b^{\tilde{\tau}}_{mi})^*\}}{\frac{1}{2}(|a^{\tilde{\tau}}_{mi}|^2 + |b^{\tilde{\tau}}_{mi}|^2)}$$

CP violation in stau decays



$$\begin{aligned} \tilde{\tau}_m &\to \tau + \tilde{\chi}_i^0, \\ \tilde{\chi}_i^0 &\to \ell_1 + \tilde{\ell}_n; \\ \tilde{\ell}_n &\to \tilde{\chi}_1^0 + \ell_2 \end{aligned}$$

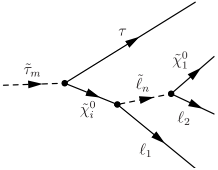
- Staus have sizable mixing, lead to interesting phenomenology
- Staus are scalars $\to$ no spin correlations between production and decay
- Three phases being studied ϕ_μ, ϕ_{A_τ}, ϕ_{M_1} introducing $\phi_{\tilde{\tau}} = \arg[A_\tau - \mu^* \cot\beta]$
- The phase of A_τ rather unconstrained by EDMs

Non-GUT scenario
Benchmark point

ϕ_1	ϕ_μ	ϕ_{A_τ}	M_2	$\lvert\mu\rvert$	A_τ	$\tan\beta$
0	0	$\pi/2$	250	250	2000	3

$M_{\tilde{E}_\tau}$	$M_{\tilde{L}_\tau}$	$M_{\tilde{E}}$	$M_{\tilde{L}}$
495	500	150	200

CP violation in stau decays



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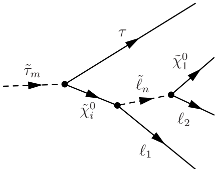
Non-GUT scenario

Mass spectrum

$\tilde{\ell}$	m [GeV]	$\tilde{\chi}$	m [GeV]
$\tilde{e}_R, \tilde{\mu}_R$	155	$\tilde{\chi}_1^0$	112
$\tilde{e}_L, \tilde{\mu}_L$	204	$\tilde{\chi}_2^0$	190
$\tilde{\nu}_e, \tilde{\nu}_\mu$	192	$\tilde{\chi}_3^0$	254
$\tilde{\nu}_\tau$	497	$\tilde{\chi}_4^0$	327
$\tilde{\tau}_1$	495	$\tilde{\chi}_1^\pm$	181

CP violation in stau decays



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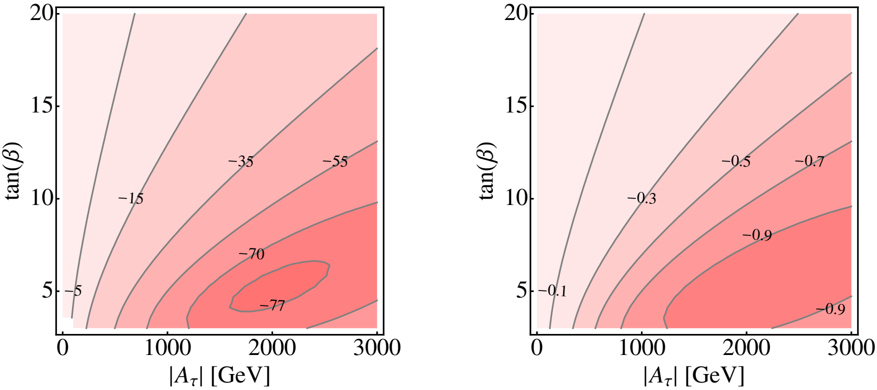
Non-GUT scenario

Triple product definition

In stau rest frame

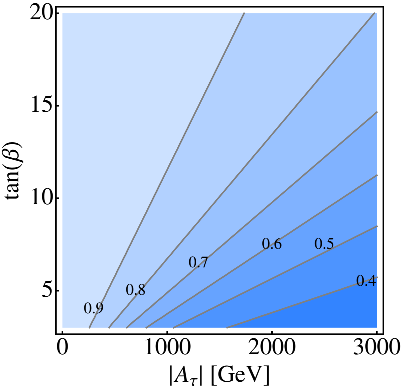
$$[p_{\tilde{\tau}},\ p_{\ell_1},\ p_\tau,\ s_\tau^a] = m_{\tilde{\tau}}\ (\mathbf{p}_{\ell_1} \times \mathbf{p}_\tau) \cdot \mathbf{s}_\tau^a \equiv m_{\tilde{\tau}}\, \mathcal{T}^a.$$

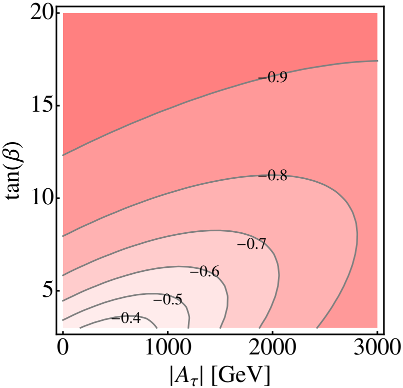
Analysis - Asymmetry (%), coupling factor η



- Asymmetry: Maximal of -77% obtained
- Asymmetry: Increases for $|A_\tau| > |\mu| \tan\beta$
- η factor: Asymmetry maximal for maximal η

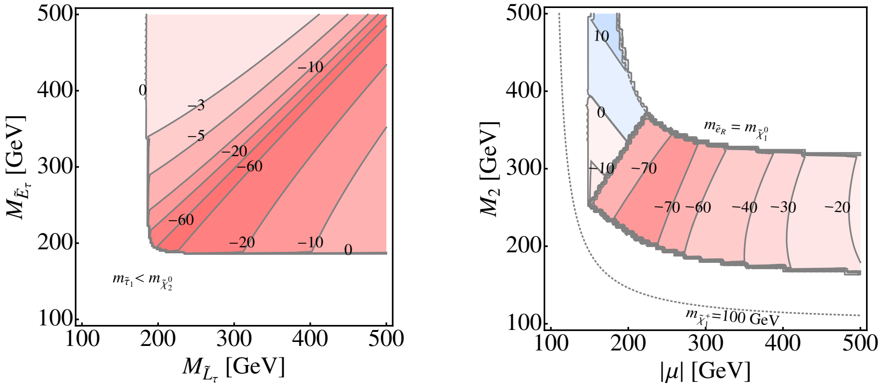
Analysis - CP Phase $\phi_{\tilde{\tau}}$, $\sin(2\theta_{\tilde{\tau}})$





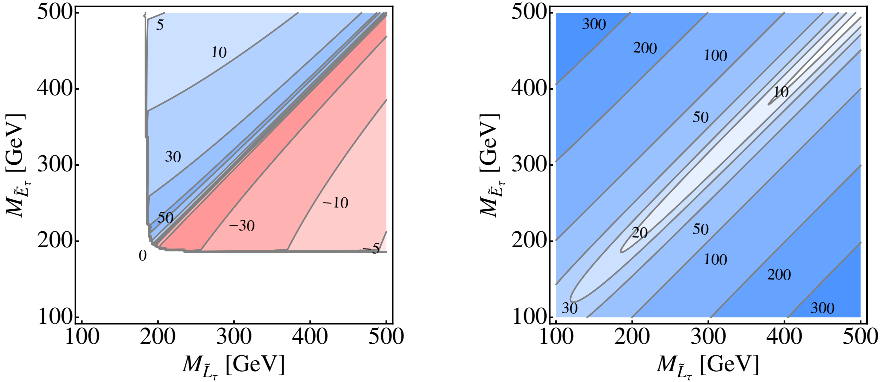
- Phase $\phi_{\tilde{\tau}}$: Maximal asymmetry for maximal $\phi_{\tilde{\tau}}$, suggests strongly mixed stau sector required
- $\sin(2\theta_{\tilde{\tau}})$: Asymmetry not maximal for maximal $\theta_{\tilde{\tau}}$ because of the denominator of η

Analysis - Asymmetry (%)



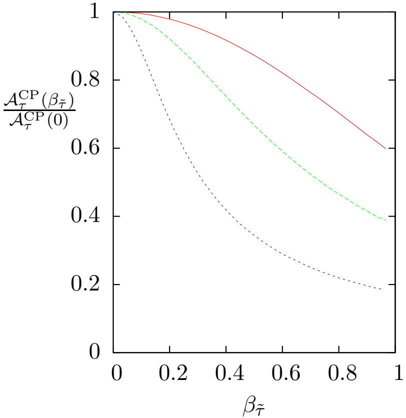
- Slepton soft-masses: Asymmetry almost maximal for maximal CP phase in stau sector $\phi_{\tilde{\tau}} = 0.61\pi$
- Slepton soft-masses: Asymmetry obtains maxima when the stau mixing is maximal $\theta_{\tilde{\tau}} = \pi/4$

Additional complications - Sum of $\tilde{\tau}_1$, $\tilde{\tau}_2$ asymmetry, stau mass splitting



- Sum of asymmetry: Asymmetry due to $\tilde{\tau}_1$ and $\tilde{\tau}_2$ almost equal and opposite in sign
- Sum of asymmetry: Reasonable asymmetry can still be obtained in a narrow corridor just off the complete degenerate scenario

@LHC - asymmetry dilution



$m_{\tilde\tau_{1,2}} \approx 200$ (GeV) (Solid, red)
$m_{\tilde\tau_{1,2}} \approx 400$ (GeV) (Dashed, green)
$m_{\tilde\tau_{1,2}} \approx 1000$ (GeV) (Dotted, blue)

- @LHC: Asymmetry dilution occurs due to boosting
- @LHC: Heavier staus imply more dilution
- @LHC: Asymmetry can dilute by as much as 80% in some cases

Outlook

- Neutrino mass generation within SUSY seesaw model
- Introduces Yukawa couplings for neutrinos and off diagonal term corrections for the soft terms in slepton sector
- Phases in the neutrino sector will propagate in the slepton sector

$$
\begin{aligned}
m_L^2 &= m_0^2\mathbf{1} + (\delta m_L^2)_{\mathrm{MSSM}} + \delta m_L^2 \\
m_R^2 &= m_0^2\mathbf{1} + (\delta m_R^2)_{\mathrm{MSSM}} + \delta m_R^2 \\
A &= A_0 Y_l + \delta A_{\mathrm{MSSM}} + \delta A
\end{aligned}
$$

$$
\begin{aligned}
\delta m_L^2 &= -\frac{1}{8\pi^2}(3m_0^2 + A_0^2)(Y_\nu^\dagger L Y_\nu) \\
\delta m_R^2 &= 0 \\
\delta A &= -\frac{3A_0}{16\pi^2}(Y_l Y_\nu^\dagger L Y_\nu)
\end{aligned}
$$

with

$$L_{ij} = \ln\left(\frac{M_X}{M_i}\right)\delta_{ij},$$

[Deppisch et. al., Phys.Rev.D69:054014,2004]

- Maximal effect for δA term in stau sector due to Yukawa term
- Either calculate rate asymmetries (CP- even) or triple product (CP - odd) for stau decay

[Work in progress Deppisch, Kittel, Eboli, S.K.]

Conclusions

- Stau sector in MSSM contains a rich phenomenology for CP violating studies at LHC and ILC
- Such studies might help us constrain the phase of A_τ, rather unconstrained by EDM otherwise
- Asymemtries reach more than 70% for strongly mixed staus. This should motivate experimental studies.
- At the LHC the asymmetries constructed using triple product are diluted
- To probe A_τ, there is no other chance than to look in stau/tau decays
- Apart from the phases within MSSM the stau sector can also be used to probe the CP phases in the neutrino sector within Seesaw models