CP Violation in Sfermion Decays

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The 13th International Conference on Supersymmetry and
Unification of Fundamental Interactions

July 18-23, 2005, IPPP Durham

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  Phys. Lett. B **538**, 137 (2002), Phys. Rev. D **66**, 115009 (2002),
  Phys. Lett. B **573**, 153 (2003), Phys. Rev. D **70**, 035003 (2004).

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  Phys. Rev. D **70**, 095007 (2004).

Motivation

Standpoint:
Study of phenomenological aspects $\Rightarrow$ hints for experimental situations $\Rightarrow$ its important to pin down the underlying model parameters (parameters in the Lagrangian) $\Rightarrow$ SUSY breaking mechanism $\Rightarrow$ new insights $\Rightarrow$ new questions.

How many model parameters? $\Rightarrow$ is CP violated? $\Rightarrow$ if yes, there would be more parameters than compared to the case of CP conservation.

1) Propose new (measurable) observables (!) which give yes/no answer to this question.
2) How well can the model parameters be determined from the data (measured masses, cross sections, branching ratios, etc.)?

The MSSM with Complex Parameters

Complex Parameters (in the Lagrangian) which cannot be made real by field redefinitions $\Longleftrightarrow$ CP violation.

Complex Parameters in the MSSM (without FV):

$$\mu, A_f, M_1, M_3$$

μ: Higgs-higgsino mass parameter
A_f: trilinear couplings
M_i: gaugino mass parameters ($i = 1, 3$)

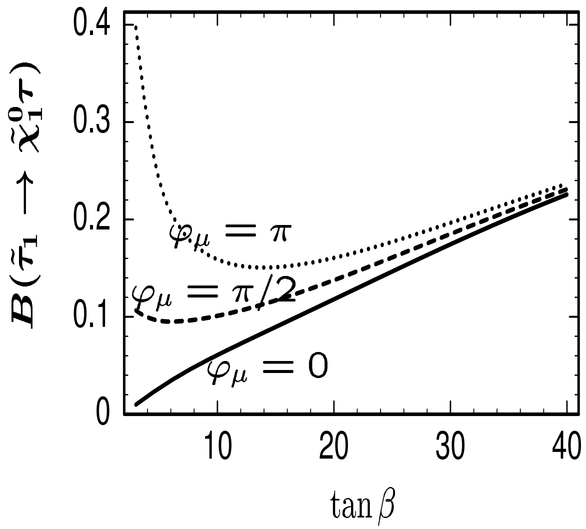
EDM's (e, n,Hg,Tl) Constraints $\Rightarrow \Re e(\mu) \gg \Im m(\mu)$.
But: $\Im m(A_\tau)$, $\Im m(A_t)$, $\Im m(A_b)$ can be sizable.

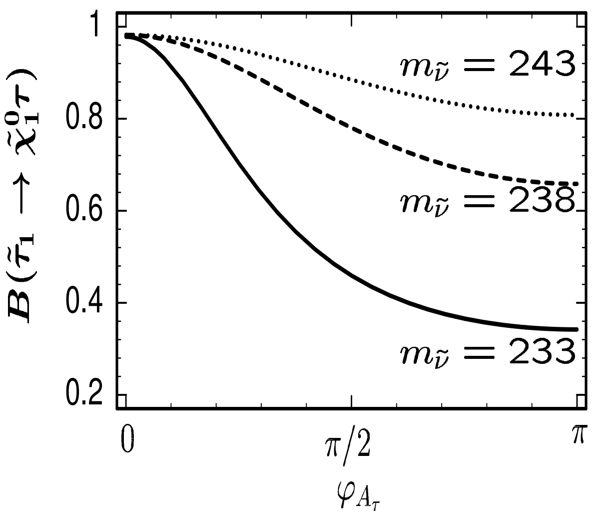
CP-even Observables

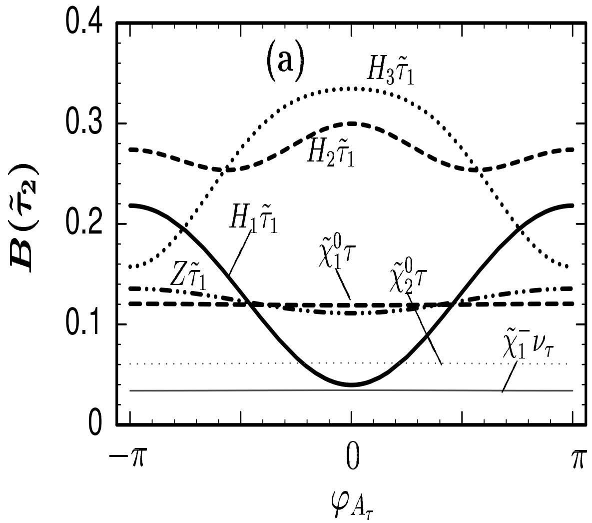
Def.: Observables which are zero when CP is maintained, but non-zero when CP is violated are CP-odd observables. All other observables are CP-even observables.

Nevertheless: CP-even observables are functions of $\Im m$(parameters) and they can depend quite strongly on them (in general) $\Rightarrow$ Measuring CP-odd phases with CP-even observables (twofold ambiguity).

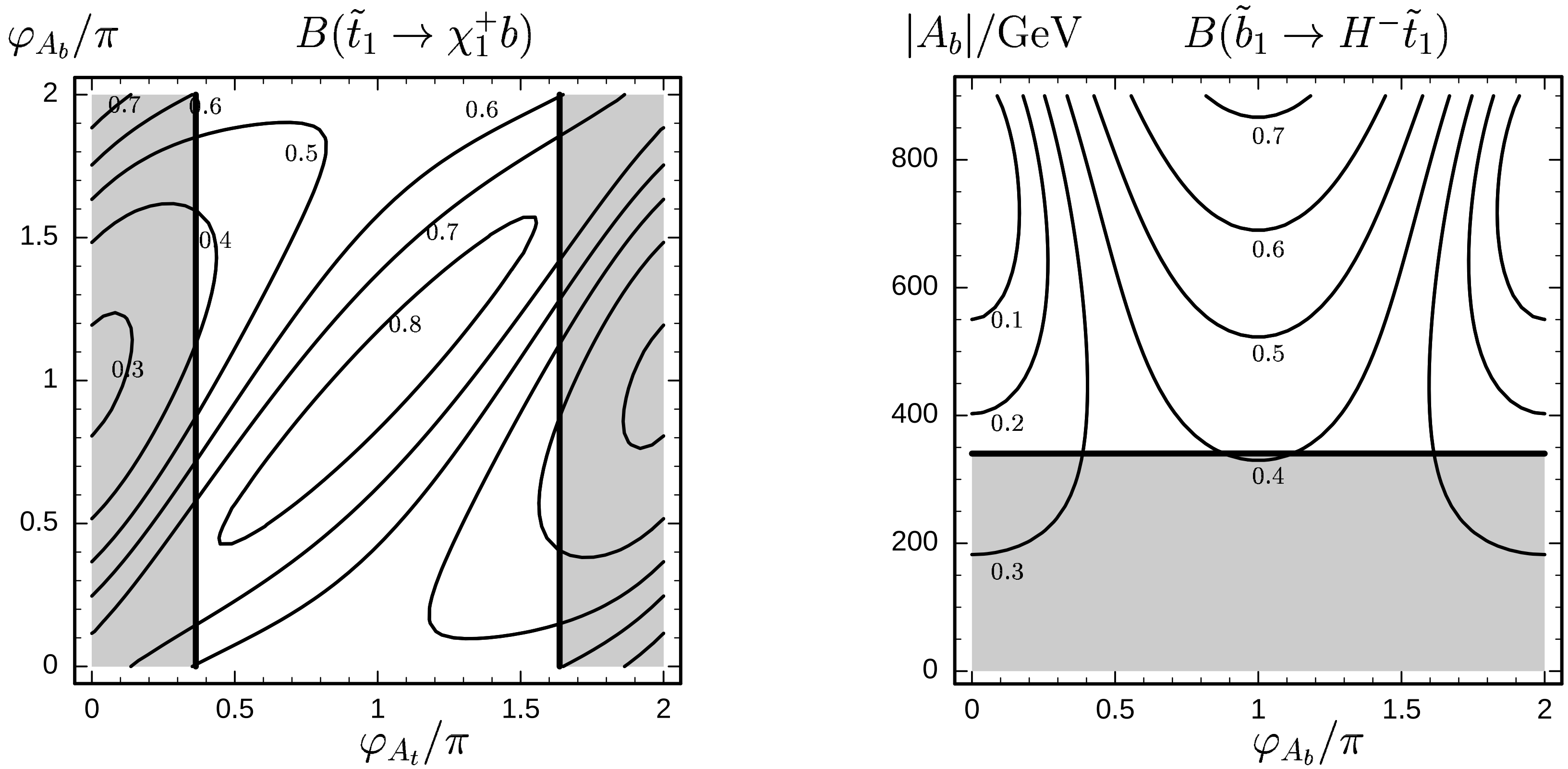
Consider $\tilde{\tau}_i$ **Two-Body Decays**:







Consider $\tilde{t}_1$ and $\tilde{b}_1$ Two-Body Decays:



Example for parameter determination - a case study

Assume: LC with $\sqrt{s} = 2$ TeV and $\mathcal{L} = 1$ ab^{-1} including beam pol. (CLIC).

- Masses of $\tilde{\chi}_i^0, \tilde{\chi}_j^+$ can be determined rather precisely [Martyn & Blair '99].

- Masses of squarks and Higgs bosons ($\lesssim$ 500 GeV) with acurracy 1% and 1.5 GeV; for ($m >$ 500 GeV) with acurracy 3% ($\tilde{q}_i$) and 1% (H_i).

- Take the statistical error for the σ's and BR's (double it).

Strategy

1. Take a specific set of values of the underlying parameters

2. Calculate the masses of $\tilde{t}_i$, $\tilde{b}_i$, $\tilde{\chi}^0_j$, $\tilde{\chi}^\pm_k$, H_ℓ, the production cross sections for $e^+e^- \to \tilde{t}_i\bar{\tilde{t}}_j$, and $e^+e^- \to \tilde{b}_i\bar{\tilde{b}}_j$, and the branching ratios of the $\tilde{t}_i$ and $\tilde{b}_i$ decays.

3. Regard these calculated values as real experimental data with definite errors.

4. Determine the underlyings by a least square fit.

Results

scenario	$\tan\beta = 6$ scenario	$\tan\beta = 30$ scenario
$M^2_{\tilde{D}}$	$(2.88 \pm 0.06) \times 10^4$	$(1.30 \pm 0.02) \times 10^5$
$M^2_{\tilde{U}}$	$(1.67 \pm 0.04) \times 10^5$	$(3.93 \pm 0.12) \times 10^4$
$M^2_{\tilde{Q}}$	$(3.88 \pm 0.04) \times 10^5$	$(4.79 \pm 0.04) \times 10^5$
$\mathrm{Re}(A_t)$	565.0 ± 13.0	424.0 ± 14.0
$\mathrm{Im}(A_t)$	$\pm 566.0 \pm 14.0$	$\pm 425.0 \pm 15.0$
$\mathrm{Re}(A_b)$	620.0 ± 190.0	6.5 ± 420.0
$\mathrm{Im}(A_b)$	$\pm 230.0 \pm 580.0$	$\pm 999.0 \pm 52.0$
$\tan\beta$	6.0 ± 0.2	30.0 ± 0.8
$m_{H^\pm}$	900.0 ± 5.0	350.0 ± 0.8

$\Rightarrow$ $\tan\beta$ with 3%, $M_{\tilde{Q}}, M_{\tilde{U}}, M_{\tilde{D}}$ with 1% to 3%, A_t with 2% to 3%, A_b very much dependent on scenario.

Note: For real parameters the fit is worse giving $\Delta\chi^2 = 286.6(22.5)$.

CP-odd Observables

Consider decays:

$$\tilde{t}_i \to t\tilde{\chi}_k^0$$

CP viol. gives rise to terms $\propto \Im m(L^* R)\ \mathbf{p}_t \cdot (\mathbf{s}_t \times \mathbf{s}_\chi)$
where $\mathbf{p}_t \cdot (\mathbf{s}_t \times \mathbf{s}_\chi)$ is a so-called triple prod.

Note: stop mixing "natural" large $\Rightarrow L \sim R$.

Consider subsequent decays:

$$t \to bW \to b\ell\nu \ (bcs)$$

$$\tilde{\chi}_k^0 \to \tilde{l}_j^\pm l_1^\mp \to l_2^\pm l_1^\mp \tilde{\chi}_1^0$$

Analyzing the pol. of t and $\tilde{\chi}_k^0 \Rightarrow \mathbf{s}_t$ and $\mathbf{s}_\chi$ can be expressed in terms of momentum vectors of the corresponding decay products.

CP-odd Observables - Up-down asymmetries

$$A_T \equiv \frac{\int d\Omega \;\; sgn(\mathcal{O}) \;\; d\Gamma/d\Omega}{\int d\Omega \;\; d\Gamma/d\Omega} = \frac{N[\mathcal{O} > 0] - N[\mathcal{O} < 0]}{N[\mathcal{O} > 0] + N[\mathcal{O} < 0]}$$

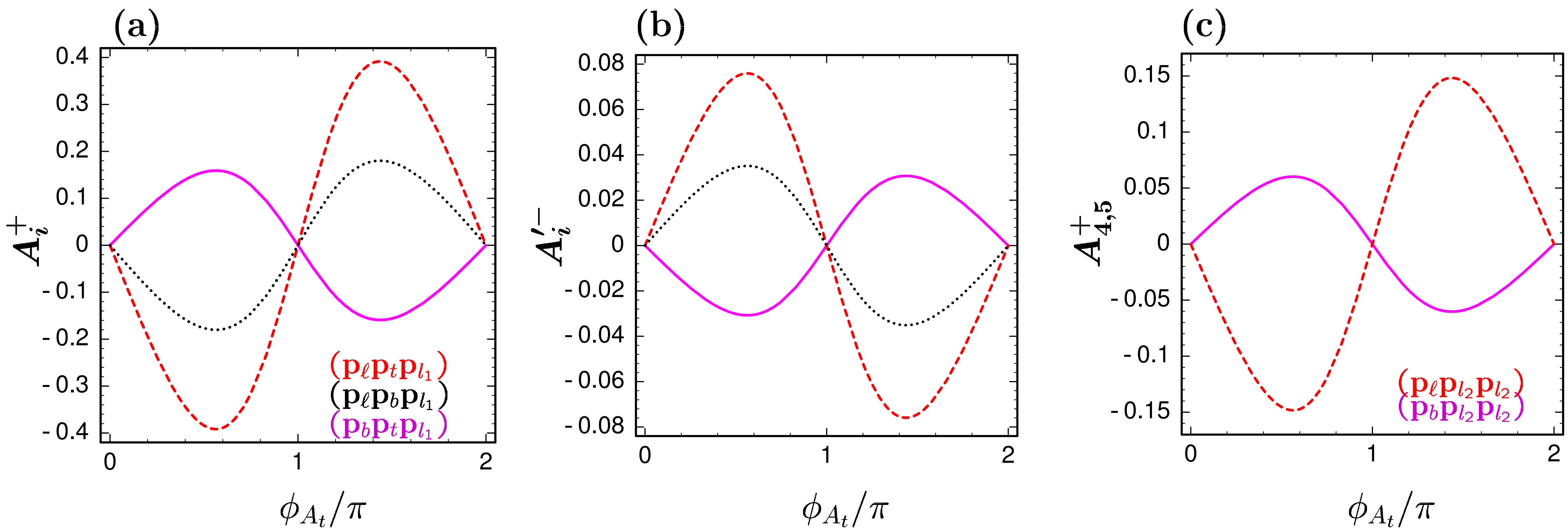
Triple products:

$$\mathcal{O} = \{(\mathbf{p}_b \mathbf{p}_t \mathbf{p}_{l_1}), (\mathbf{p}_\ell \mathbf{p}_t \mathbf{p}_{l_1}), (\mathbf{p}_\ell \mathbf{p}_b \mathbf{p}_{l_1}),$$

$$(\mathbf{p}_b \mathbf{p}_t \mathbf{p}_{l_1}), (\mathbf{p}_\ell \mathbf{p}_t \mathbf{p}_{l_1}), (\mathbf{p}_\ell \mathbf{p}_b \mathbf{p}_{l_1}),$$

$$(\mathbf{p}_b \mathbf{p}_{l_1} \mathbf{p}_{l_2}), (\mathbf{p}_\ell \mathbf{p}_{l_1} \mathbf{p}_{l_2})\}$$

Plots of UP-Down Asymmetries



Estimate of Observability

A_T	value [%]	$N_{\tilde{t}_1} \cdot 10^{-3}$
$(\mathbf{p}_b \mathbf{p}_t \mathbf{p}_{l_1})$	-11.5	4.5
$(\mathbf{p}_\ell \mathbf{p}_t \mathbf{p}_{l_1})$	28.3	1.6
$(\mathbf{p}_\ell \mathbf{p}_b \mathbf{p}_{l_1})$	13.8	6.8
$(\mathbf{p}_b \mathbf{p}_t \mathbf{p}_{l_2})$	-1.3	355.9
$(\mathbf{p}_\ell \mathbf{p}_t \mathbf{p}_{l_2})$	3.2	124.9
$(\mathbf{p}_\ell \mathbf{p}_t \mathbf{p}_{l_2})$	1.6	499.2
$(\mathbf{p}_b \mathbf{p}_{l_1} \mathbf{p}_{l_2})$	-4.7	18.5
$(\mathbf{p}_\ell \mathbf{p}_{l_1} \mathbf{p}_{l_2})$	11.4	9.8

$\Rightarrow$ $\mathcal{O}(10^3 - 10^4)$ produced $\tilde{t}$'s are sufficient to probe CP asymmetries at 90% CL.

Summary

- Branching ratios of $\tilde{\tau}_i, \tilde{t}_i, \tilde{b}_i$ can depend quite strongly on the CP phases which might be present in the MSSM, irrespective of the EDM contraints.

- The parameters in the $\tilde{t}_i$ and $\tilde{b}_i$ sectors [and $\tilde{\tau}_i$ sector; not shown in this talk] can be determined with good precision (1% to 3%) except A_b.

- Up-down asymmetries in $\tilde{t}_i$ decays have been studied $\Rightarrow$ (given favorable conditions) they will be accessible at future collider experiments.

Conclusion

⇒ CP phases can have an important impact on searches for third gen. sfermions and should be taken into account in order not to draw the wrong conclusions, e.g. SUSY breaking mechanism.