CP violation in chargino production at the one-loop level

Krzysztof Rolbiecki
in collaboration with J. Kalinowski

Phys. Rev. D76, 115006

Institute of Theoretical Physics, University of Warsaw

Seoul, 20 June 2008
16th Conference on Supersymmetry
and Unification of Fundamental Interactions

Outline

Outline

Motivation

- radiative corrections in MSSM could be of order 10%
- so far only CP-conserving case at one loop thoroughly examined
- MSSM with CP violating phases:
  $M_1 = |M_1|e^{i\Phi_1}$, $\mu = |\mu|e^{i\Phi_\mu}$, $A_f = |A_f|e^{i\Phi_f}$
  - $\rightarrow$ strong bounds on these phases from EDMs exist, however
  - $\rightarrow$ large phases possible if accidental cancelations occur
  - $\rightarrow$ or 1st and 2nd generation of squarks are heavy
  - $\rightarrow$ Φ_1 poorly constrained
- calculation of radiative corrections to CP violating observables, e.g. asymmetries in sparticles production, asymmetries of triple products of momenta and/or spins, asymmetries in decay widths
  - $\rightarrow$ such observables provide unambiguous way of detecting CP violating phases
- here we analyze gaugino/higgsino sector of complex MSSM at one loop level

Chargino sector of MSSM

- chargino mass matrix in gauge eigenstate basis $(\tilde{W}^-, \tilde{H}^-)$

$$M_{\tilde{\chi}^\pm} = \begin{pmatrix} M_2 & \sqrt{2} m_W \cos\beta \\ \sqrt{2} m_W \sin\beta & \mu \end{pmatrix}$$

- diagonalization using unitary matrices U and V

$$V^* M_{\tilde{\chi}^\pm} U^\dagger = \begin{pmatrix} m_{\tilde{\chi}_1^\pm} & 0 \\ 0 & m_{\tilde{\chi}_2^\pm} \end{pmatrix}$$

- mass eigenstates in Weyl representation

$$U \begin{pmatrix} \tilde{W}_L^- \\ \tilde{H}_d^- \end{pmatrix} = \begin{pmatrix} \chi_{1L}^- \\ \chi_{2L}^- \end{pmatrix} \quad V \begin{pmatrix} \tilde{W}_R^+ \\ \tilde{H}_u^+ \end{pmatrix} = \begin{pmatrix} \chi_{1R}^+ \\ \chi_{2R}^+ \end{pmatrix}$$

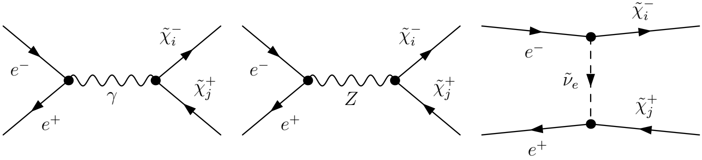
- Dirac spinors

$$\tilde{\chi}_1^- = \begin{pmatrix} \chi_{1L}^- \\ \chi_{1R}^- \end{pmatrix}, \quad \tilde{\chi}_2^- = \begin{pmatrix} \chi_{2L}^- \\ \chi_{2R}^- \end{pmatrix}$$

Outline

Production mechanism

- chargino production at the tree-level in e^+e^- collisions



- for non-diagonal pair $\tilde{\chi}_1^\pm \tilde{\chi}_2^\mp$ no contribution from photon exchange
- production amplitude after Fierz transformation

$$\mathcal{A}[e^+e^- \to \tilde{\chi}_i^- \tilde{\chi}_j^+] = \frac{e^2}{s} Q_{\alpha\beta}^{ij} \Big(\bar{v}(e^+)\gamma_\mu P_\alpha u(e^-)\Big)\Big(\bar{u}(\tilde{\chi}_i^-)\gamma^\mu P_\beta v(\tilde{\chi}_j^+)\Big)$$

- four bilinear couplings Q_{LL}, Q_{RL}, Q_{LR}, Q_{RR} depend on mixing angles of matrices U, V

Amplitude structure

- unpolarized differential cross-section

$$\frac{d\sigma^{\{ij\}}}{d\cos\theta\, d\phi} = \frac{\alpha^2}{4s}\lambda^{1/2}\Big((1-(\mu_i^2-\mu_j^2)^2+\lambda\cos^2\theta)Q_1+4\mu_i\mu_j Q_2+2\lambda^{1/2}Q_3\cos\theta\Big)$$

P	CP	Quartic charges
even	even	$Q_1 = \frac{1}{4}\left(\|Q_{RR}\|^2+\|Q_{LL}\|^2+\|Q_{RL}\|^2+\|Q_{LR}\|^2\right)$ $Q_2 = \frac{1}{2}\mathrm{Re}\left(Q_{RR}Q_{RL}^*+Q_{LL}Q_{LR}^*\right)$ $Q_3 = \frac{1}{4}\left(\|Q_{RR}\|^2+\|Q_{LL}\|^2-\|Q_{RL}\|^2-\|Q_{LR}\|^2\right)$
	odd	$Q_4 = \frac{1}{2}\mathrm{Im}\left(Q_{RR}Q_{RL}^*+Q_{LL}Q_{LR}^*\right)$

- Q_4 can be probed by observables sensitive to chargino polarization component normal to the production plane

CP transformation in chargino production

- S matrix element for chargino production

$$\langle\tilde{\chi}_i^+(\mathbf{k}_1),\tilde{\chi}_j^-(\mathbf{k}_2)|S|e^+(\mathbf{p}_1),e^-(\mathbf{p}_2)\rangle$$

- P transformation: $\mathbf{p}_{1,2}\leftrightarrow-\mathbf{p}_{1,2}$, $\mathbf{k}_{1,2}\leftrightarrow-\mathbf{k}_{1,2}$

$$\langle\tilde{\chi}_i^+(-\mathbf{k}_1),\tilde{\chi}_j^-(-\mathbf{k}_2)|S|e^+(-\mathbf{p}_1),e^-(-\mathbf{p}_2)\rangle$$

- C transformation

$$\langle\tilde{\chi}_i^-(\mathbf{k}_1),\tilde{\chi}_j^+(\mathbf{k}_2)|S|e^-(\mathbf{p}_1),e^+(\mathbf{p}_2)\rangle$$

- CP transformation

$$\langle\tilde{\chi}_j^+(-\mathbf{k}_2),\tilde{\chi}_i^-(-\mathbf{k}_1)|S|e^+(-\mathbf{p}_2),e^-(-\mathbf{p}_1)\rangle$$

- in center of mass frame: $\mathbf{p}_1=-\mathbf{p}_2$ and $\mathbf{k}_1=-\mathbf{k}_2$

$$\langle\tilde{\chi}_j^+(\mathbf{k}_1),\tilde{\chi}_i^-(\mathbf{k}_2)|S|e^+(\mathbf{p}_1),e^-(\mathbf{p}_2)\rangle$$

- no CP violation in diagonal chargino final states $\tilde{\chi}_1^-\tilde{\chi}_1^+$, $\tilde{\chi}_2^-\tilde{\chi}_2^+$
- at tree level for non-diagonal chargino pair production

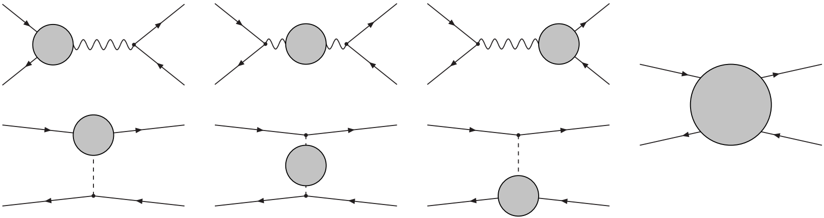
$$\sigma(\tilde{\chi}_1^-\tilde{\chi}_2^+)-\sigma(\tilde{\chi}_1^+\tilde{\chi}_2^-)=0$$

CP-odd observables

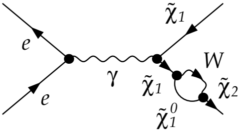
- CP violating effects can be probed by observables sensitive to the chargino polarization component normal to the production plane
  [Choi ea.]
- decay widths difference of charginos $\tilde{\chi}_i^- \to W^- \tilde{\chi}_1^0$ and $\tilde{\chi}_i^+ \to W^+ \tilde{\chi}_1^0$ is sensitive to the phase of μ parameter
  [Eberl ea., Yang, Du]
- CP effects appear also for polarized initial beams when one takes into account also chargino decays $\Rightarrow$ triple products of momenta of initial and final state particles: $\mathbf{p}_{e^-} \cdot (\mathbf{p}_{\tilde{\chi}_i^+} \times \mathbf{p}_W)$
  [Bartl ea., Kittel ea.]
- beyond tree level no reason to expect $\sigma(\tilde{\chi}_1^- \tilde{\chi}_2^+) - \sigma(\tilde{\chi}_1^+ \tilde{\chi}_2^-) = 0$
  $\Rightarrow$ possibility to construct CP sensitive observable without polarization of electron/positron beams at one-loop
  [Osland, Vereshagin, Kalinowski, KR]

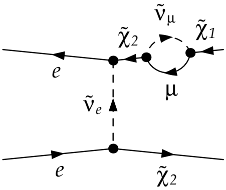
Outline

Structure of corrections



- three types of one-loop contributions: vertex diagrams, self-energy diagrams and box diagrams ⇒ use *FeynArts/FormCalc/LoopTools*
- inclusion of corrections on external chargino lines necessary



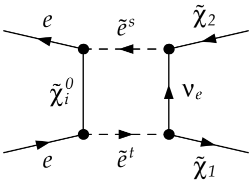


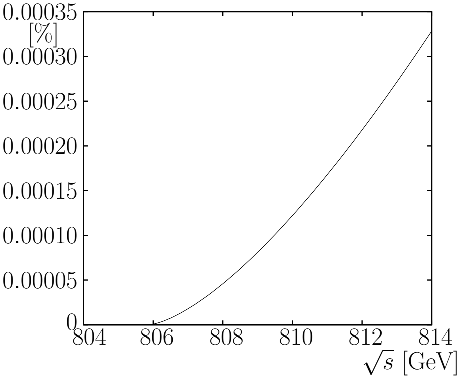
Source of CP asymmetries

- CP violating effects appear due to interference between complex couplings and absorptive parts of loop integrals

⟶ example: box diagram with selectron exchange

⟶ asymmetry appears above selectron production threshold





CP asymmetry in $e^+e^- \to \tilde{\chi}_1^\pm \tilde{\chi}_2^\mp$

- matrix element squared at one loop

$$|\mathcal{M}_{\rm loop}|^2 = |\mathcal{M}_{\rm tree}|^2 + 2\,{\rm Re}(\mathcal{M}^*_{\rm tree}\mathcal{M}_{\rm loop})$$

- asymmetry in production cross section of non-diagonal chargino pairs induced by radiative corrections

$$A_{12} = \frac{\sigma^{\rm loop}(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_2^-) - \sigma^{\rm loop}(e^+e^- \to \tilde{\chi}_2^+\tilde{\chi}_1^-)}{\sigma^{\rm tree}(e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_2^-) + \sigma^{\rm tree}(e^+e^- \to \tilde{\chi}_2^+\tilde{\chi}_1^-)}$$

- asymmetry vanishes at the tree level $\Rightarrow$ it is finite at one loop
- soft and hard QED corrections cancel in the numerator
- A_{12} can be sensitive to the phases of μ, A_t, M_1, A_b, A_τ

Outline

Chosen parameters

- gaugino mass parameters

$$|M_1| = 100\text{ GeV},\ M_2 = 200\text{ GeV},\ |\mu| = 400\text{ GeV},\ \tan\beta = 10$$

- sfermion parameters

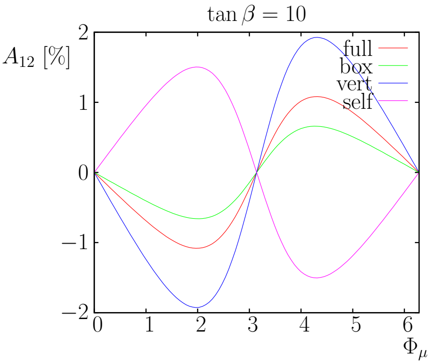
$$m_{\tilde{q}} \equiv M_{\tilde{Q}_{1,2}} = M_{\tilde{U}_{1,2}} = M_{\tilde{D}_{1,2}} = 450\text{ GeV}$$
$$M_{\tilde{Q}} \equiv M_{\tilde{Q}_3} = M_{\tilde{U}_3} = M_{\tilde{D}_3} = 300\text{ GeV}$$
$$m_{\tilde{l}} \equiv M_{\tilde{L}_{1,2,3}} = M_{\tilde{E}_{1,2,3}} = 150\text{ GeV}$$
$$A \equiv |A_t| = -A_b = -A_\tau = 400\text{ GeV}$$

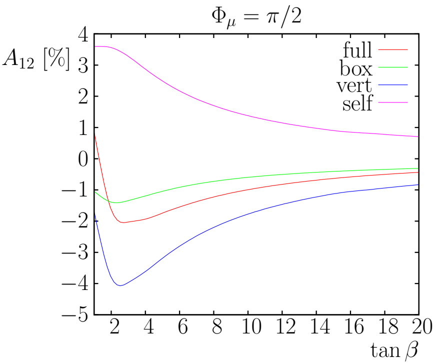
- resulting masses:

$m_{\tilde{\chi}_1^\pm}$	$m_{\tilde{\chi}_2^\pm}$	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{\chi}_2^0}$	$m_{\tilde{\chi}_3^0}$	$m_{\tilde{\chi}_4^0}$	$m_{\tilde{t}_1}$	$m_{\tilde{t}_2}$
186.7	421.8	97.5	187.0	405.8	421.2	204.9	438.6

Asymmetry for $\Phi_\mu \neq 0$

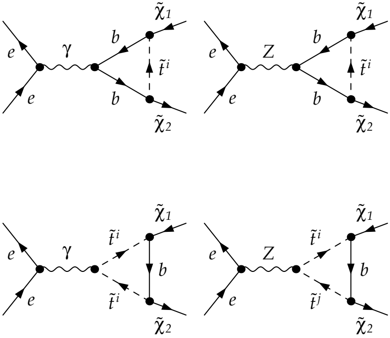
- dependence of asymmetry on the phase of μ parameter
- large cancelations between different contributions
- for low and high $\tan\beta$, asymmetry small due to small value of imaginary parts of couplings

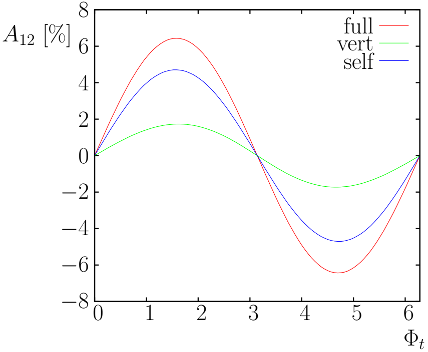




Asymmetry for $A_t \neq 0$

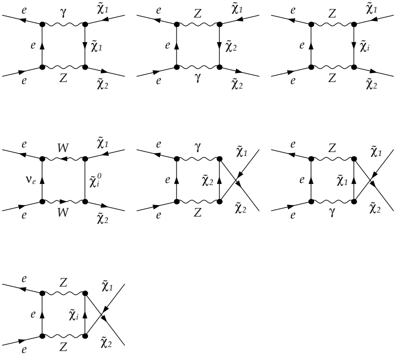
- only contributions from diagrams with stop exchange enter
- asymmetry can reach 6%
- gives access to CP violation in stop sector

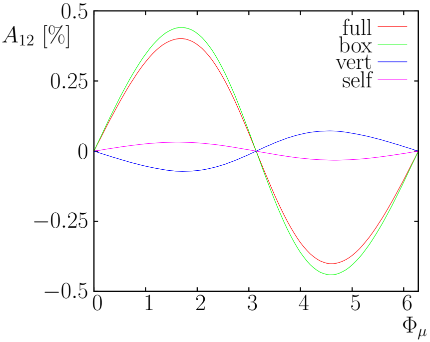




Case of heavy sfermions

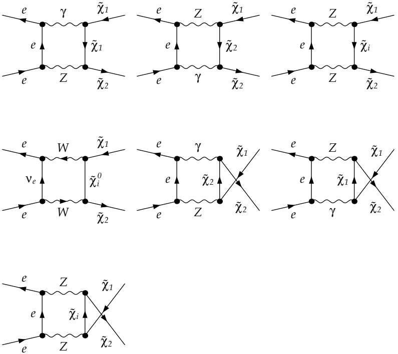
- take heavy sfermions with masses 10 TeV - sfermion contributions can be neglected
- only gauge boson exchange contributes to asymmetry
- dominant contribution from box diagrams

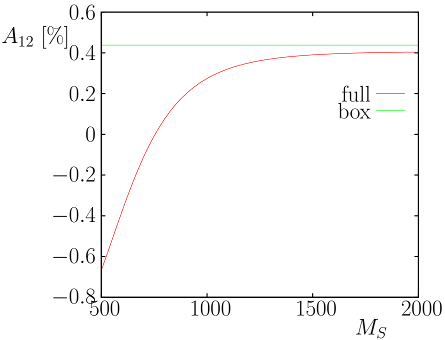




Case of heavy sfermions

- take heavy sfermions with masses 10 TeV - sfermion contributions can be neglected
- only gauge boson exchange contributes to asymmetry
- dominant contribution from box diagrams





Outline

Summary

- non-zero CP-violating asymmetry in chargino production for unpolarized initial e^+e^- beams
- asymmetry induced by loop effects
- could be of the order of few % for phases of μ and A_t
  $\Rightarrow$ access to CP properties of chargino and stop sectors

- Outlook:
  Full analysis of production+decay required at one-loop for precision physics at the ILC