One-loop corrections to chargino decays

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31.05.2007

Outline

Motivation

- radiative corrections in MSSM could be of order 20%
- 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 decay widths, asymmetries of triple products of momenta and/or spins
  - $\rightarrow$ such observables provide unambiguous way of detecting CP violating phases
- here we analyze gaugino/higgsino sectors 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

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

Neutralino sector of MSSM

- neutralino mass matrix in gauge eigenstate basis $(\tilde{B}, \tilde{W}^0, \tilde{H}_d^0, \tilde{H}_u^0)$

$$M_{\tilde{\chi}^0} = \begin{pmatrix} M_1 & 0 & -m_Z c_\beta s_W & m_Z s_\beta s_W \\ 0 & M_2 & m_Z c_\beta c_W & -m_Z s_\beta c_W \\ -m_Z c_\beta s_W & m_Z c_\beta c_W & 0 & -\mu \\ m_Z s_\beta s_W & -m_Z s_\beta c_W & -\mu & 0 \end{pmatrix}$$

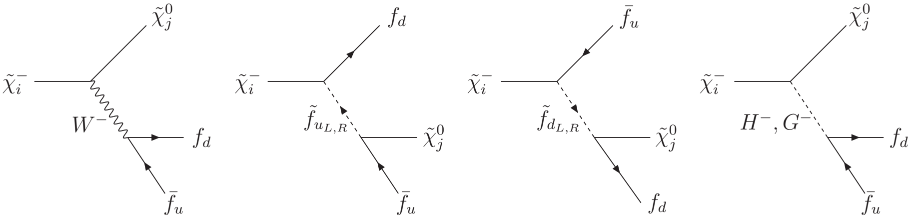
- diagonalization of mass matrix

$$\mathrm{diag}(m_{\tilde{\chi}_1^0}, m_{\tilde{\chi}_2^0}, m_{\tilde{\chi}_3^0}, m_{\tilde{\chi}_4^0}) = N^* M_{\tilde{\chi}^0} N^{-1}$$

- mass eigenstates - Weyl spinors χ_i^0 and Majorana spinors $\tilde{\chi}_i^0$ $(i = 1, 2, 3, 4)$

$$\begin{pmatrix} \chi_1^0 \\ \chi_2^0 \\ \chi_3^0 \\ \chi_4^0 \end{pmatrix} = N \begin{pmatrix} \tilde{B} \\ \tilde{W}^0 \\ \tilde{H}_d^0 \\ \tilde{H}_u^0 \end{pmatrix} \qquad \tilde{\chi}_i^0 = \begin{pmatrix} \chi_i^0 \\ \bar{\chi}_i^0 \end{pmatrix}$$

Chargino decays at the tree-level



- here we consider only genuine 3-body decays
  - ⇒ sleptons heavier than chargino: $m_{\tilde{\ell}}, m_{\tilde{\nu}} > m_{\chi_1^\pm}$
  - ⇒ mass difference between chargino and neutralino smaller than m_W
- in lepton channel only one particle detectable
- diagrams with Higgs exchange relevant only for heavy fermions
- shape of the decay distributions important at ILC for measurement of chargino and lightest neutralino masses

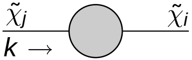
Renormalization scheme

We work in the on-shell scheme:

- regularization by dimensional reduction
- physical masses are input parameters
- renormalization conditions defined at the pole masses
- no mixing between particles on-shell
- renormalization is performed after rotation of fields to mass eigenstate basis
- introduce renormalization constants for fields and mixing matrices
- attention needed: the number of observable masses exceeds the number of free parameters
  - $\Rightarrow$ e.g. in chargino/neutralino sector in the CP conserving case we have 4 parameters (M_1, M_2, μ, $\tan\beta$) and 6 masses

Renormalization of charginos and neutralinos

- 1PI renormalized Green's function



$$= \hat{\Gamma}_{ij}^{\tilde{\chi}} = i(\not{k} - m_{\tilde{\chi}_i})\delta_{ij} + i\hat{\Sigma}_{ij}^{\tilde{\chi}}(k^2)$$

- substitute in Lagrangian wave function and mass counter terms

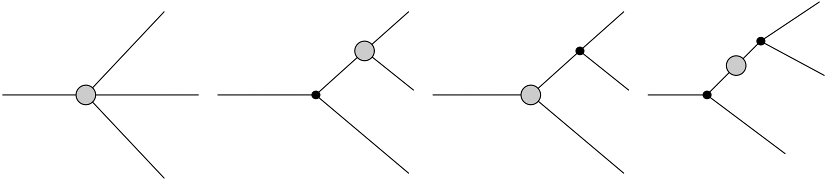
$$\tilde{\chi}_i \rightarrow (\delta_{ij} + \frac{1}{2}\delta\tilde{Z}_{ij}^{L}P_L + \frac{1}{2}\delta\tilde{Z}_{ij}^{R}P_R)\tilde{\chi}_j, \qquad m_{\tilde{\chi}_i} \rightarrow m_{\tilde{\chi}_i} + \delta m_{\tilde{\chi}_i}$$

- renormalization conditions:
  $\Rightarrow$ poles at $k^2 = m_{\tilde{f}}^2$, residues equal 1 and no mixing on-shell
- introduce counterterms for mixing matrices

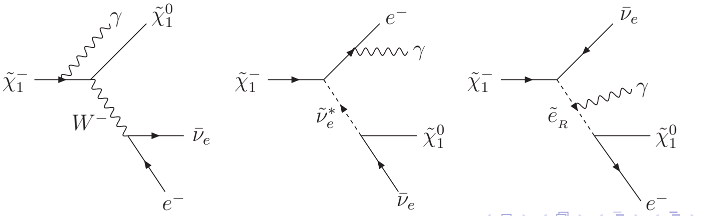
$$\delta U_{ij} = \frac{1}{4}\sum_{k=1}^{2}\left(\delta\tilde{Z}_{ik}^{\pm,R} - (\delta\tilde{Z}_{ki}^{\pm,R})^*\right)U_{kj} \qquad \delta V_{ij} = \frac{1}{4}\sum_{k=1}^{2}\left(\delta\tilde{Z}_{ik}^{\pm,L} - (\delta\tilde{Z}_{ki}^{\pm,L})^*\right)V_{kj}$$

$$\delta N_{ij} = \frac{1}{4}\sum_{k=1}^{4}\left(\delta\tilde{Z}_{ik}^{0,L} - \delta\tilde{Z}_{ki}^{0,R}\right)N_{kj}$$

Structure of corrections



- three types of one-loop contributions: box diagrams, vertex diagrams and self-energy diagrams
- to obtain physically meaningful result inclusion of soft and hard photon bremsstrahlung necessary



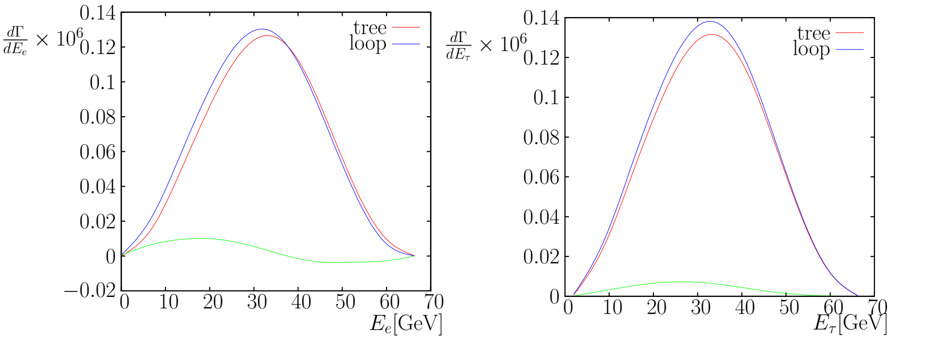
Decay width

particle	$\tilde{\chi}_1^\pm$	$\tilde{\chi}_1^0$	$\tilde{e}_L$	$\tilde{e}_R$	$\tilde{\nu}_e$
mass [GeV]	165.3	97.9	287.9	221.9	276.6
particle	$\tilde{\tau}_1$	$\tilde{\tau}_1$	$\tilde{q}_L$	$\tilde{q}_R$	$H^\pm$
mass [GeV]	211.9	289.0	561.3	544.3	436.4

- only genuine 3-body decays allowed: $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 e^+ \nu_e$, $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \mu^+ \nu_\mu$, $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \tau^+ \nu_\tau$, $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 u\bar{d}$, $\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 c\bar{s}$
- correction in leptonic modes typically of the order of 5%

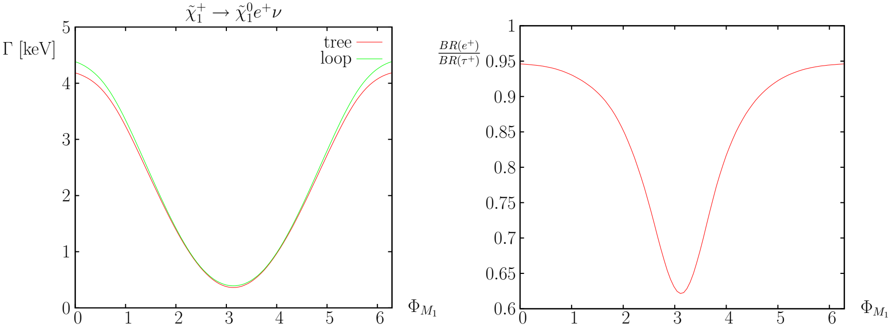
decay mode	tree-level width	one-loop width
$e\nu_e\tilde{\chi}_1^0$	4.18 keV	4.38 keV
$\mu\nu_\mu\tilde{\chi}_1^0$	4.18 keV	4.38 keV
$\tau\nu_\tau\tilde{\chi}_1^0$	4.38 keV	4.61 keV

Lepton energy distribution



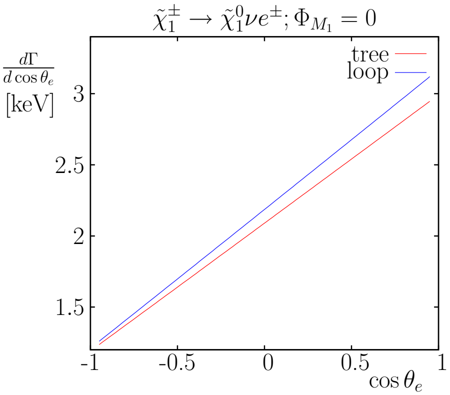
- one-loop corrections to electron and τ energy distributions in 3-body chargino decays
- electron distribution shifted slightly towards lower energies due to photonic corrections

Φ_{M_1} dependence



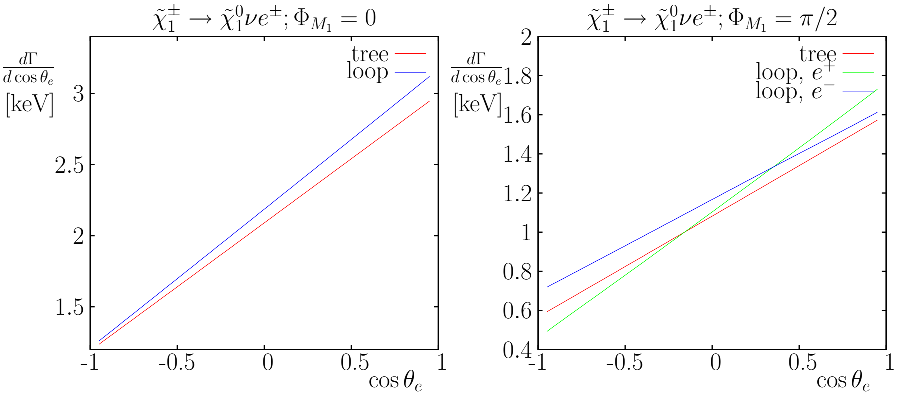
- width $\Gamma(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 e^+ \nu)$ and ratio of branching fractions $BR(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 e^+ \nu)/BR(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 \tau^+ \nu_\tau)$ show strong dependence on the phase Φ_{M_1}
- radiative corrections more significant around $\Phi_{M_1} = 0$

Angular distribution



- angular distribution of e^+/e^- with respect to chargino spin vector
- for $\Phi_{M_1} = \pi/2$ significant difference between corrections to e^+ and e^- distributions

Angular distribution



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Measuring CP violation

Many possible methods to measure CP violating phases:

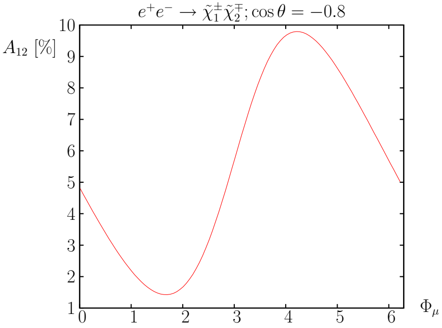
⇒ using CP-even observables – requires high precision of measurement

⇒ looking for CP asymmetries in production, e.g. charginos $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^{\mp}$

→ see Per Osland talk

⇒ constructing CP- or T-odd triple products using momenta and/or spins in production and/or decay processes

→ see Stefan Hesselbach talk



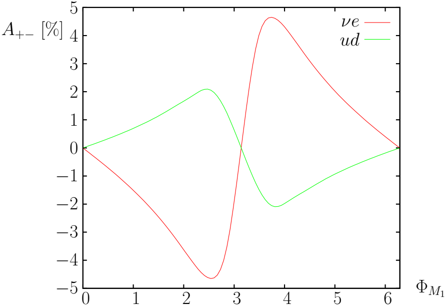
⇒ measure asymmetries in decay widths of charged particle

Charge asymmetry

- asymmetry in decay widths between $\tilde{\chi}_1^+$ and $\tilde{\chi}_1^-$

$$A_{+-}^{e\nu} = \frac{\Gamma(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 e^+ \nu_e) - \Gamma(\tilde{\chi}_1^- \to \tilde{\chi}_1^0 e^- \bar{\nu}_e)}{\Gamma(\tilde{\chi}_1^+ \to \tilde{\chi}_1^0 e^+ \nu_e) + \Gamma(\tilde{\chi}_1^- \to \tilde{\chi}_1^0 e^- \bar{\nu}_e)}$$

- sensitive to the CP phase of the bino mass parameter M_1



- easy:
  - $\longrightarrow$ counting experiment
  - $\longrightarrow$ large chargino production rate ($\sigma \sim$ 200 fb)
- accurate determination of asymmetry possible
- access to CP properties of neutralino sector

Summary and outlook

- one-loop corrections to leptonic chargino decays calculated - important for ILC physics
- loop corrections induce significant CP violation effects in chargino sector
- might be useful for determination of CP phases in chargino/neutralino sector

- Outlook
  - Full analysis of production+decay required.
    $\Rightarrow$ Tania Robens' talk
  - Careful treatment of CP violating case.