Transversely and Longitudinally Polarized Beams and SUSY CP Searches

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Outline

- Introduction
  - MSSM with complex parameters
  - Complex parameters in chargino/neutralino sectors
- CP-odd and T-odd asymmetries using transverse beam polarization
- T-odd triple product asymmetries and longitudinal beam polarization
- Summary and outlook

Introduction MSSM with complex parameters

- General MSSM:

  Complex parameters in Higgs potential and soft SUSY breaking terms

- Physical phases of the parameters

  M_1 : U(1) gaugino mass parameter

  μ : Higgs-higgsino mass parameter

  A_f : trilinear couplings of sfermions

  $m_{\tilde{g}}$: gluino mass

- Introduction of CP violation
  - May help to explain baryon asymmetry of universe
  - Constraints from electric dipole moments (EDMs) of e, n, Hg, Tl

    [Ibrahim, Nath, '99; Barger, Falk, Han, Jiang, Li, Plehn, '01; Abel, Khalil, Lebedev, '01]
    [Oshimo, Nihei, Fujita, '05; Pospelov, Ritz, '05; Olive, Pospelov, Ritz, Santoso, '05]

- Aim: analysis the CP structure of theory and determination of phases

Introduction — Complex parameters in $\tilde{\chi}^{\pm,0}$ sectors

- Chargino mass matrix: $X = \begin{pmatrix} M_2 & \sqrt{2}\, m_W s_\beta \\ \sqrt{2}\, m_W c_\beta & \mu \end{pmatrix}$
- Neutralino mass matrix:

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

$s_\beta \equiv \sin\beta$, $c_\beta \equiv \cos\beta$

μ : Higgs-higgsino mass parameter $\longrightarrow$ $|\mu|$, φ_μ

M_1 : U(1) gaugino mass parameter $\longrightarrow$ $|M_1|$, φ_{M_1}

M_2 : SU(2) gaugino mass parameter

- Diagonalization $\Rightarrow$ complex mixing matrices $\longrightarrow$ enter $\tilde{\chi}^\pm$, $\tilde{\chi}^0$ couplings

Transverse beam polarization

Chargino/neutralino production

$$e^+e^- \longrightarrow \tilde{\chi}_i + \tilde{\chi}_j$$

with transverse beam polarization (4-vector $t^\mu_\pm$, polarization degree $\mathcal{P}^T_{e^\pm}$)

- Terms in amplitude squared $|T|^2 = P$ depending on $\mathcal{P}^T_{e^\pm}$:
  $P_T \sim \mathcal{P}^T_{e^-}\mathcal{P}^T_{e^+}\,[f_1\Delta_1 r_1 + f_2\Delta_2 r_2]$ (in limit $m_e = 0$!)
  f_i: couplings; Δ_i: propagators; r_i: products of $t_\pm$ and momenta
  $\Rightarrow$ both beams have to be polarized [POWER report, hep-ph/0507011]
- r_1 is real; r_2 is imaginary, consisting of products like $i\epsilon_{\mu\nu\rho\sigma}t^\mu_\pm p^\nu_i p^\rho_j p^\sigma_k$
  $\Rightarrow$ with complex couplings f_2: real contributions to observables
  $\Rightarrow$ CP-odd terms $\sim$ Im($f_2\Delta_2$)Im(r_2) at tree level
  $\Rightarrow$ CP-odd asymmetries $\sim \mathcal{P}^T_{e^-}\mathcal{P}^T_{e^+}$

Transverse beam polarization

- Chargino production: [Bartl, Hohenwarter-Sodek, Kernreiter, Rud, hep-ph/0403265]

  Dirac particles: couplings $f_2\Delta_2$ have to be real (CPT invariance)

  $\Rightarrow$ CP-odd terms $f_2\Delta_2 r_2$ vanish

  $\rightarrow$ CP-even asymmetries can be defined with help of $f_1\Delta_1 r_1$

- Neutralino production:
  [Bartl, Fraas, SH, Hohenwarter-Sodek, Kernreiter, Moortgat-Pick, hep-ph/0510029]

  Majorana particles: t and u channels contribute

  $\Rightarrow$ CP-odd terms $f_2\Delta_2 r_2 \neq 0$ allowed

  $\Rightarrow$ CP-odd observables can be defined

$\rightarrow$ more details $\rightarrow$ Karl Hohenwarter-Sodek's talk in SUSY session

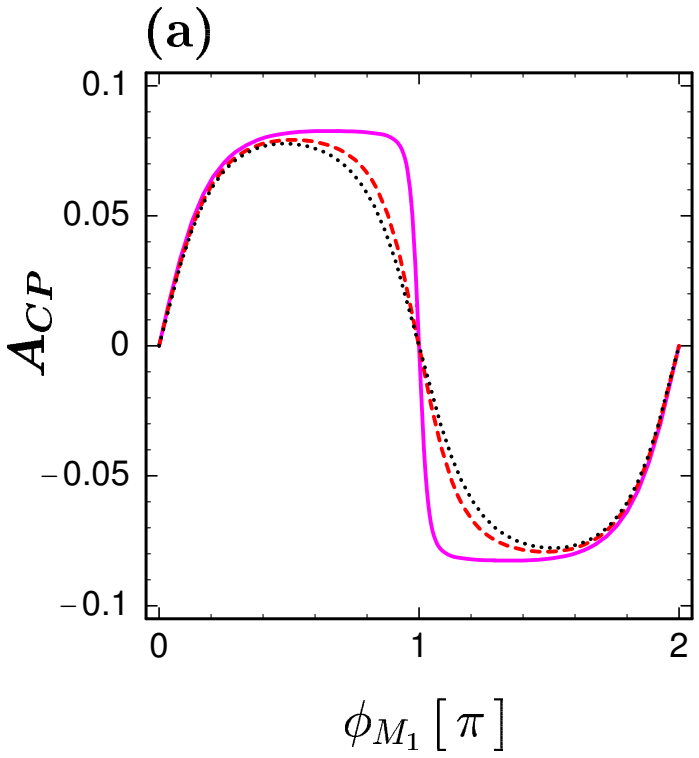
Transverse beam polarization

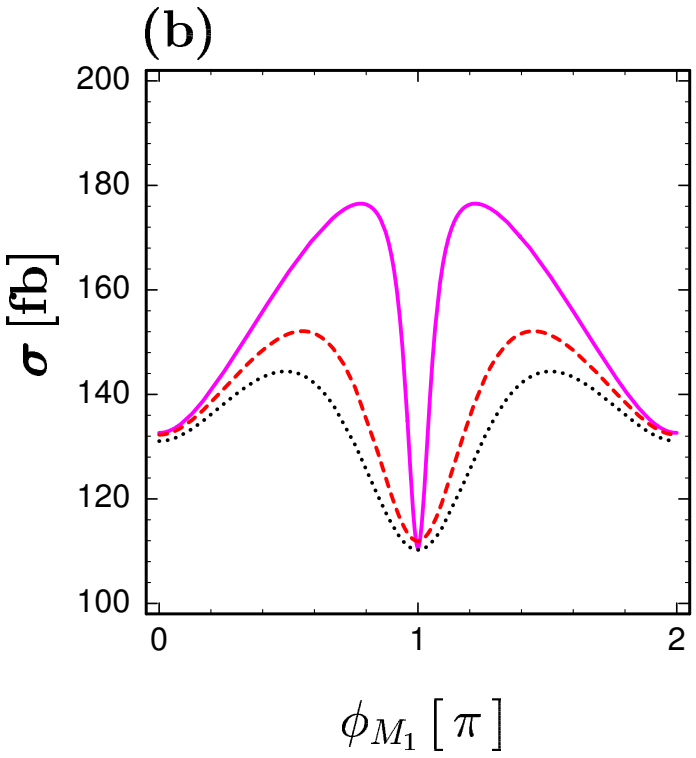
Example for CP-odd asymmetry A_{CP} for $e^+e^- \to \tilde{\chi}_1^0 \tilde{\chi}_2^0$

[Bartl, Fraas, SH, Hohenwarter-Sodek, Kernreiter, Moortgat-Pick, hep-ph/0510029]

M_2 = 245 GeV, $|M_1|$ = 123.3 GeV, $|\mu|$ = 160 GeV, ϕ_μ = 0, $m_{\tilde{e}_L}$ = 400 GeV, $m_{\tilde{e}_R}$ = 150 GeV

$\sqrt{s}$ = 500 GeV, $(\mathcal{P}^T_{e^-}, \mathcal{P}^T_{e^+})$ = (100%, 100%), tan β = 3, 10, 30





(factor 0.54 for $(\mathcal{P}^T_{e^-}, \mathcal{P}^T_{e^+})$ = (90%, 60%))

T-odd triple product asymmetries

Chargino and neutralino production and decay

$$e^+e^- \longrightarrow \tilde{\chi}_i + \tilde{\chi}_j \longrightarrow \tilde{\chi}_i + \tilde{\chi}_1^0 f \bar{f}^{(\prime)}$$

- Full spin correlation between production and decay

  [Moortgat-Pick, Fraas, '97; Moortgat-Pick, Fraas, Bartl, Majerotto, '98, '99; Choi, Song, Song, '99]

- Amplitude squared $|T|^2 = PD + \Sigma_P^a \Sigma_D^a$

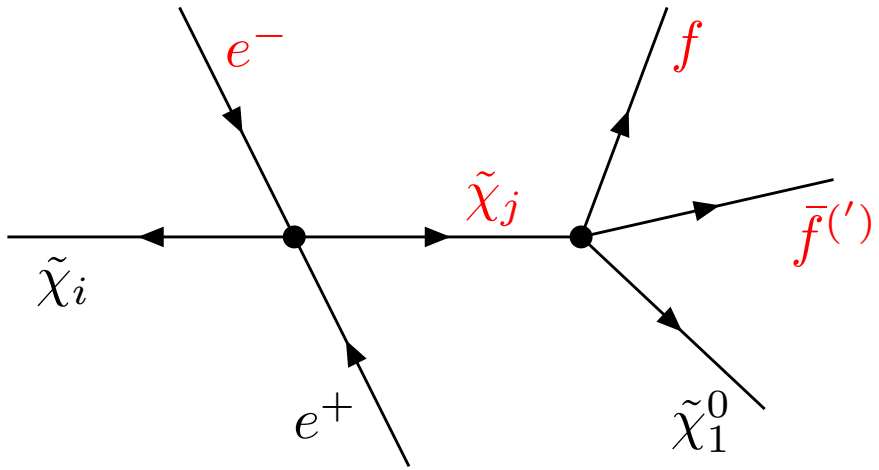
- In Σ_P^a and Σ_D^a: products like $i\epsilon_{\mu\nu\rho\sigma} p_i^\mu p_j^\nu p_k^\rho p_l^\sigma$

  $\Rightarrow$ with complex couplings: real contributions to observables

  $\Rightarrow$ CP violation at tree level

T-odd triple product asymmetries

Triple products: $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_f \times \vec{p}_{\bar{f}^{(\prime)}})$ or $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\tilde{\chi}_j} \times \vec{p}_f)$



$\longrightarrow$ T-odd asymmetry:

$$A_T = \frac{\sigma(\mathcal{T} > 0) - \sigma(\mathcal{T} < 0)}{\sigma(\mathcal{T} > 0) + \sigma(\mathcal{T} < 0)} = \frac{\int \text{sign}(\mathcal{T}) |T|^2 d\text{Lips}}{\int |T|^2 d\text{Lips}}$$

$\longrightarrow$ CP-odd, if final state interactions and finite-widths effects can be neglected

T-odd triple product asymmetries

- Chargino/neutralino production with subsequent three-body decays
  [Bartl, Fraas, SH, Hohenwarter-Sodek, Moortgat-Pick, hep-ph/0406190]
  [Bartl, Fraas, SH, Hohenwarter-Sodek, Moortgat-Pick, in preparation]

- Chargino/neutralino production with subsequent two-body decays
  - Leptonic decays
    [Bartl, Fraas, Kittel, Majerotto, hep-ph/0308141, hep-ph/0308143]
    [Bartl, Fraas, Kernreiter, Kittel, Majerotto, hep-ph/0310011]
    [Bartl, Fraas, Kittel, Majerotto, hep-ph/0406309]
  - Decays into W and Z
    [Bartl, Fraas, Kittel, Majerotto, hep-ph/0402016]
    [Kittel, Bartl, Fraas, Majerotto, hep-ph/0410054]
  - CP asymmetries using tau polarization for $\ell = \tau$
    [Bartl, Kernreiter, Kittel, hep-ph/0309340; Choi, Drees, Gaissmaier, Song, hep-ph/0310284]

- Monte Carlo study for neutralino production and decay
  [Aguilar-Saavedra, hep-ph/0404104]

$\longrightarrow$ more details $\longrightarrow$ Olaf Kittel's talk in SUSY session

T-odd asymmetries and beam polarization

Asymmetry A_T

for $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$

[Bartl, Fraas, SH, Hohenwarter-Sodek, Moortgat-Pick, hep-ph/0406190; POWER report, hep-ph/0507011]

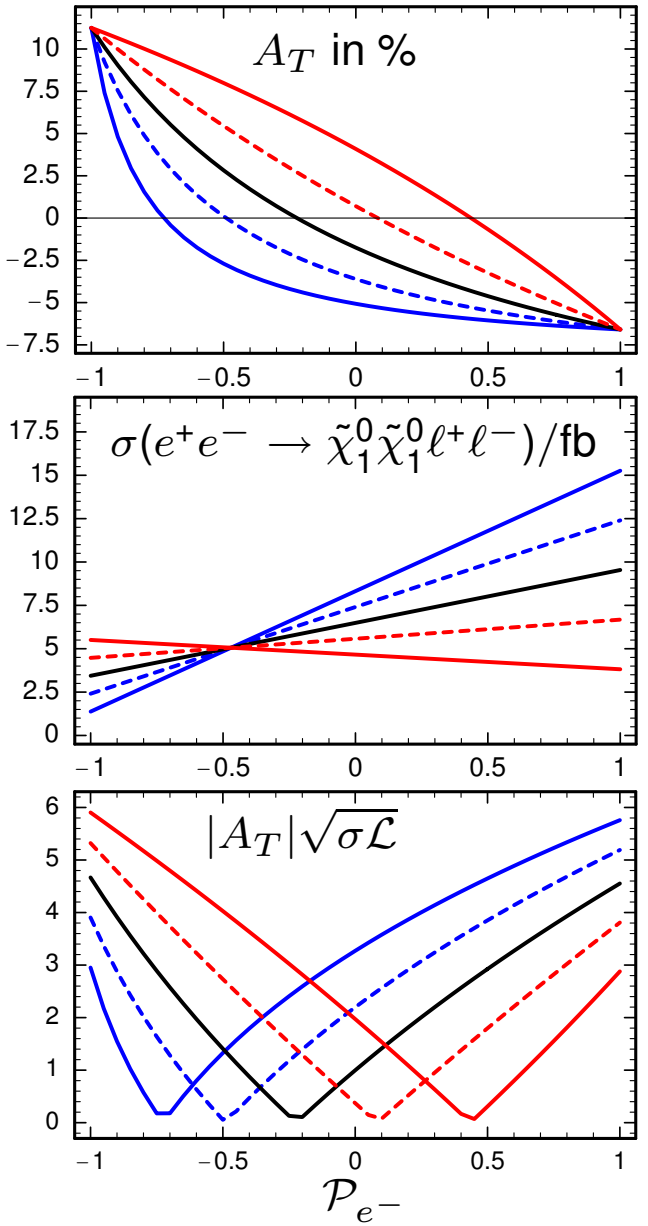
$\tan\beta$ = 10, M_2 = 300 GeV, $|M_1|$ = 150 GeV, $|\mu|$ = 200 GeV
$\varphi_{M_1} = 0.5\pi$, φ_μ = 0, $m_{\tilde{e}_L}$ = 267.6 GeV, $m_{\tilde{e}_R}$ = 224.4 GeV
$\sqrt{s}$ = 500 GeV, $\mathcal{L}$ = 500 fb^{-1}, $\mathcal{P}_{e^+}$ = +0.6, +0.3, 0, −0.3, −0.6

$\to e^-$ polarization considerably enhances A_T

$\to e^+$ polarization enhances σ

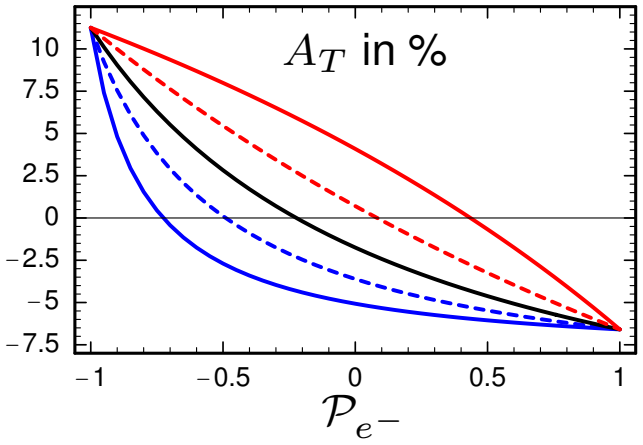
Measurability of A_T: $\sim |A_T|\sqrt{\sigma\mathcal{L}}$

$\to e^+$ polarization enhances measurability by $\sim$ 30%



T-odd asymmetries and beam polarization

Explanation for behavior of A_T



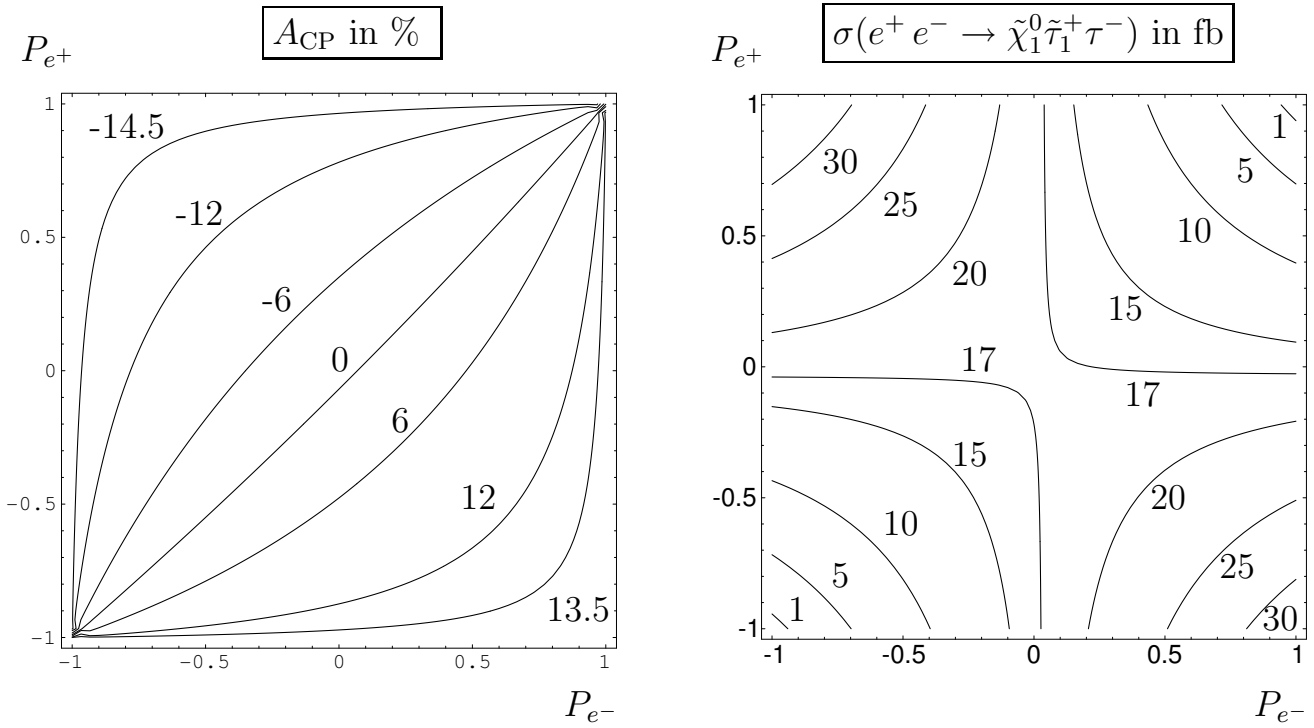
- For $m_{\tilde{e}_L}$ = 267.6 GeV $\sim m_{\tilde{e}_R}$ = 224.4 GeV: contributions from $\tilde{e}_L$ and $\tilde{e}_R$ exchange to A_T have similar size, but opposite sign
- Unpolarized beams: $\tilde{e}_L$ and $\tilde{e}_R$ contributions cancel
  $\Rightarrow$ small asymmetries A_T
- $\mathcal{P}_{e^-}$ = −0.9: $\tilde{e}_L$ contributions dominate $\Rightarrow$ large asymmetries A_T
- $\mathcal{P}_{e^-}$ = +0.9: $\tilde{e}_R$ contributions dominate $\Rightarrow$ large A_T with opposite sign
- Additional e^+ polarization: only small enhancement of A_T

T-odd asymmetries and beam polarization

Asymmetry A_{CP} for $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\tau}_1^+\tau^-$

[Bartl, Fraas, Kernreiter, Kittel, Majerotto, hep-ph/0310011; POWER report, hep-ph/0507011]

$\tan\beta$ = 5, M_2 = 200 GeV, $|M_1| = 5/3 M_2 \tan^2\theta_W$, $|\mu|$ = 250 GeV, $\varphi_{M_1} = 0$, $\varphi_\mu = 0$
$|A_\tau|$ = 1500 GeV, $\varphi_{A_\tau} = 0.5\pi$, $m_{\tilde{\tau}_1}$ = 143 GeV, $m_{\tilde{\tau}_2}$ = 210 GeV



→ Additional e^+ polarization enhances mainly σ

Summary and outlook

- CP-odd asymmetries and transverse beam polarization
  - Asymmetries in neutralino production and decay $\sim \mathcal{P}^T_{e^-}\mathcal{P}^T_{e^+}$

    $\Rightarrow$ Polarized positrons necessary to measure asymmetries
  - $e^+e^- \to \gamma Z$: asymmetries $\sim \mathcal{P}^T_{e^-}\mathcal{P}^T_{e^+}$ [POWER report, hep-ph/0507011]

    (sensitive to CP-violating $\gamma\gamma Z$, γZZ couplings)
  - $e^+e^- \to t\bar{t}$: asymmetries $\sim \frac{1}{2}(\mathcal{P}^T_{e^-} - \mathcal{P}^T_{e^+})$ [POWER report, hep-ph/0507011]

    (sensitive to new CP-violating (pseudo-)scalar or tensor couplings)

- CP-odd asymmetries and longitudinal beam polarization

  $\to$ Positron polarization enhances cross section

  $\Rightarrow$ For $\mathcal{P}_{e^+}$ = 60%: 30% better measurability of asymmetry possible