CP violation in SUSY particle production and decay

Stefan Hesselbach
School of Physics & Astronomy, University of Southampton

based on

Bartl, Fraas, SH, Hohenwarter-Sodek, Moortgat-Pick, JHEP **0408** (2004) 038 [hep-ph/0406190]

Bartl, Fraas, SH, Hohenwarter-Sodek, Kernreiter, Moortgat-Pick, JHEP **0601** (2006) 170 [hep-ph/0510029]

Bartl, Fraas, SH, Hohenwarter-Sodek, Kernreiter, Moortgat-Pick, EPJC **51** (2007) 149 [hep-ph/0608065]

LCWS 2007, Hamburg, 31 May 2007

Outline

- Introduction
  - Supersymmetry with complex parameters
  - Complex parameters in chargino/neutralino sectors
- Aim: determination of the phases $\leftrightarrow$ analysis of CP structure of theory
- CP-even observables (σ, BR, ...) $\leftrightarrow$ ambiguities

  $\Rightarrow$ CP-odd observables needed
- Here: CP-odd asymmetries in chargino/neutralino sectors

  $\longrightarrow$ defined via triple products and transverse beam polarization

  $\longrightarrow$ estimation of measurability
- Outlook: CP violation in Higgs sector
- Summary

Introduction

MSSM with complex parameters

- General MSSM:

  Many parameters can be complex

- New sources 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]
    [Oshima, Nihei, Fujita, ’05; Pospelov, Ritz, ’05; Olive, Pospelov, Ritz, Santoso, ’05]
    [Abel, Lebedev, ’05; Yaser Ayazi, Farzan, ’06, ’07]

- Physical phases of the parameters

  μ : Higgs-higgsino mass parameter

  M_1 : U(1) gaugino mass parameter

  A_f : trilinear couplings of sfermions

  M_3 : SU(3) gaugino mass parameter (gluino mass)

Introduction

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

- Chargino ($\tilde{\chi}^\pm$) mass matrix: $X = \begin{pmatrix} M_2 & \sqrt{2}\, m_W s_\beta \\ \sqrt{2}\, m_W c_\beta & |\mu| e^{i\varphi_\mu} \end{pmatrix}$

- Neutralino ($\tilde{\chi}^0$) mass matrix:

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

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

μ : Higgs-higgsino mass parameter (M_2 : SU(2) gaugino mass parameter)

M_1 : U(1) gaugino mass parameter ($\tan\beta = \frac{v_2}{v_1}$: ratio of Higgs VEVs)

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

$\longrightarrow$ φ_{M_1}, φ_μ dependence of σ, Γ, BR

$\longrightarrow$ CP asymmetries

Introduction

Parameter determination

- Aim: determination of parameters with phases in $\tilde{\chi}^{\pm}$, $\tilde{\chi}^0$ sectors
- CP-even observables: cross sections, masses, ...

  [Choi, Djouadi, Song, Zerwas, '98; Kneur, Moultaka, '99; Barger, Han, Li, Plehn, '99]
  [Choi, Guchait, Kalinowski, Zerwas, '00; Choi, Djouadi, Guchait, Kalinowski, Song, Zerwas, '00]
  [Choi, Kalinowski, Moortgat-Pick, Zerwas, '01, '02; Gounaris, Mouël, '02]
  [Choi, Drees, Gaissmaier, '04]

  $\longrightarrow$ Determination of $|\mu|$, φ_μ, $|M_1|$, φ_{M_1}, M_2, $\tan\beta$ in principle possible

  However: ambiguities for phases remain

- CP-odd/T-odd observables needed

  recent studies e.g. [Choi, Kim, '03; Choi, '03, '04; Aguilar-Saavedra, '04]
  [Eberl, Gajdosik, Majerotto, Schraußer, '05; Choi, Chung, Kalinowski, Kim, Rolbiecki, '05]
  [Frank, Turan, de la Cruz do Oña, '05; Bartl, Christova, Hohenwarter-Sodek, Kernreiter, '06]
  [Bartl, Fraas, Hohenwarter-Sodek, Kernreiter, Moortgat-Pick, Wagner, '06]
  [Langacker, Paz, Wang, Yavin, '07; Osland, Vereshagin, '07]

- Here: T-odd/CP-odd asymmetries in $\tilde{\chi}^{\pm}$, $\tilde{\chi}^0$ production and decay

Triple product asymmetries

- $\tilde{\chi}^{\pm}$, $\tilde{\chi}^0$ production with subsequent 2-body decays
  - Leptonic decays

    [Bartl, Fraas, Kittel, Majerotto,'03]
    [Bartl, Fraas, Kernreiter, Kittel, Majerotto, '03]
    [Bartl, Fraas, Kittel, Majerotto, '04]
  - Decays into W and Z

    [Bartl, Fraas, Kittel, Majerotto, '04]
    [Kittel, Bartl, Fraas, Majerotto, '04]
  - CP asymmetries using tau polarization for $\ell = \tau$

    [Bartl, Kernreiter, Kittel, '03]
    [Choi, Drees, Gaissmaier, Song, '03]
- Monte Carlo study for neutralino production and decay

  [Aguilar-Saavedra, '04]
- Here: $\tilde{\chi}^{\pm}$, $\tilde{\chi}^0$ production with subsequent 3-body decays

Triple product asymmetries

Chargino/neutralino production with subsequent three-body decays

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

- Full spin correlation between production and decay

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

- Amplitude squared $|T|^2 = PD + \sum_{a=1}^{3} \Sigma_P^a \Sigma_D^a$

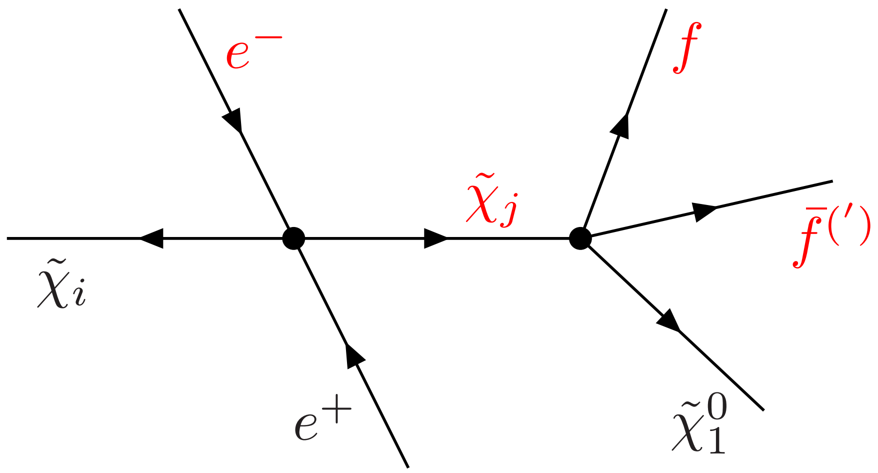
- In Σ_P^a and Σ_D^a: products like $\boxed{i\epsilon_{\mu\nu\rho\sigma} p_i^\mu p_j^\nu p_k^\rho p_l^\sigma}$

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

  $\Rightarrow$ CP violation at tree level

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, finite-widths effects negligible

$\longrightarrow$ for $\tilde{\chi}^\pm$ possible: define CP-odd asymmetry $A_{\text{CP}} = \frac{1}{2}(A_T - \bar{A}_T)$

$\bar{A}_T$: A_T for charge-conjugated process

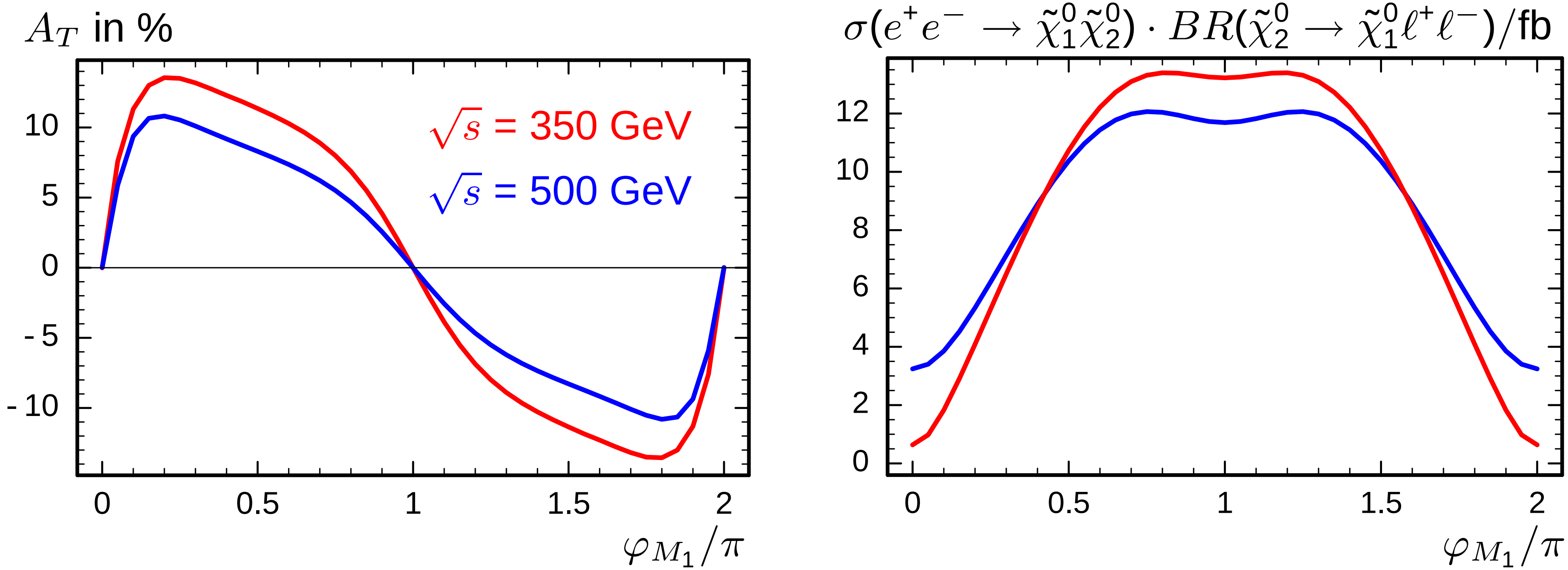
T-odd asymmetry in $\tilde{\chi}^0$ sector

Asymmetry A_T for $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0 \to \tilde{\chi}_1^0\tilde{\chi}_1^0\ell^+\ell^-$, $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\ell^+} \times \vec{p}_{\ell^-})$

[Bartl, Fraas, SH, Hohenwarter-Sodek, Moortgat-Pick, hep-ph/0406190]

$\tan\beta$ = 10, M_2 = 300 GeV, $|M_1|$ = 150 GeV, $|\mu|$ = 200 GeV, φ_μ = 0

$m_{\tilde{e}_L}$ = 267.6 GeV, $m_{\tilde{e}_R}$ = 224.4 GeV, P_{e^-} = -0.8, P_{e^+} = +0.6



$\to$ A_T larger closer to threshold (spin correlations)

T-odd asymmetry in $\tilde{\chi}^0$ sector

Contours of A_T [in %] for $e^+e^- \to \tilde{\chi}^0_1\tilde{\chi}^0_2 \to \tilde{\chi}^0_1\tilde{\chi}^0_1\ell^+\ell^-$

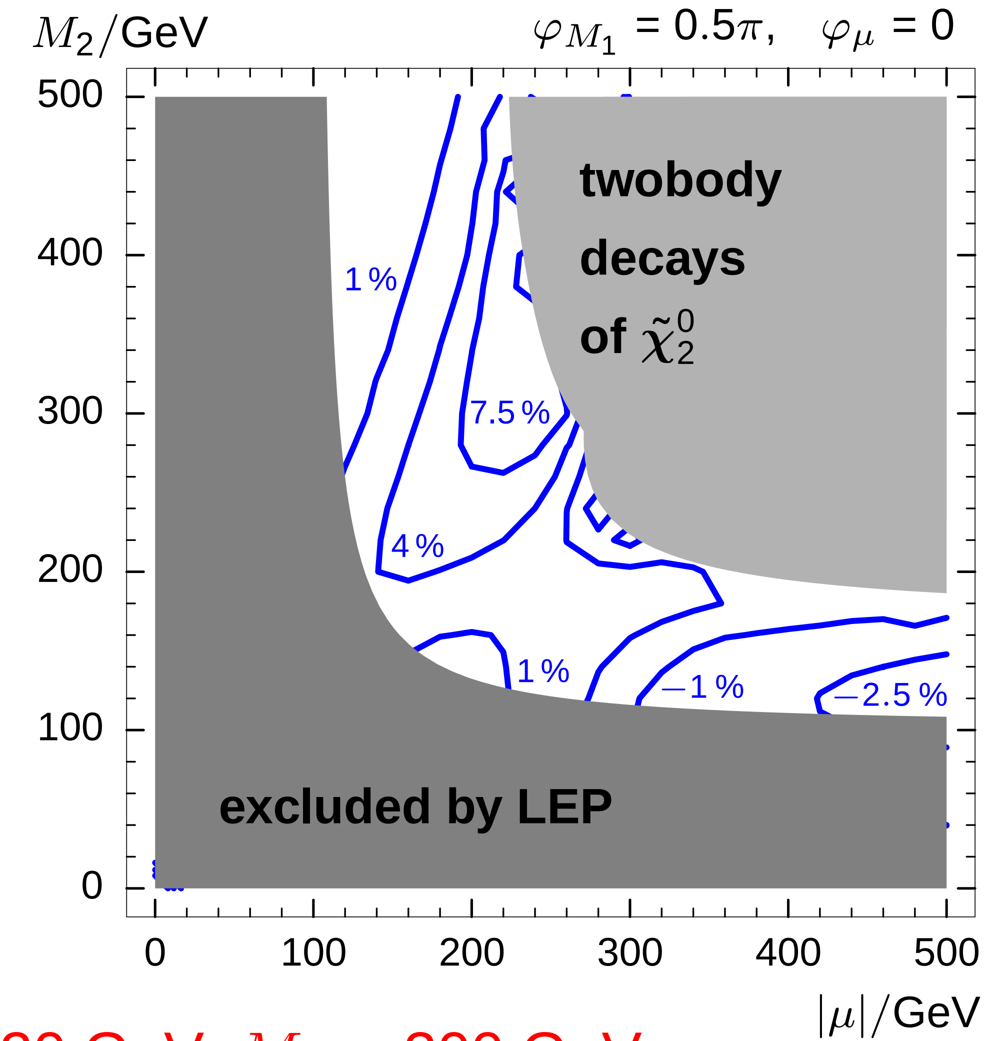
$\tan\beta$ = 10, $|M_1|$ = $M_2\, 5/3 \tan^2\theta_W$,
$m_{\tilde{e}_L}$ = 267.6 GeV, $m_{\tilde{e}_R}$ = 224.4 GeV

$\sqrt{s}$ = 500 GeV,

P_{e^-} = −0.8, P_{e^+} = +0.6

Dark shaded area:
$m_{\tilde{\chi}^\pm_1} < 103$ GeV

Light shaded area:
$m_{\tilde{\chi}^0_2} - m_{\tilde{\chi}^0_1} > m_Z$, $m_{\tilde{\chi}^0_2} > m_{\tilde{e}_R}$



$A_T > 7.5$ % for $|\mu| \sim 220$ GeV, $M_2 \sim 300$ GeV

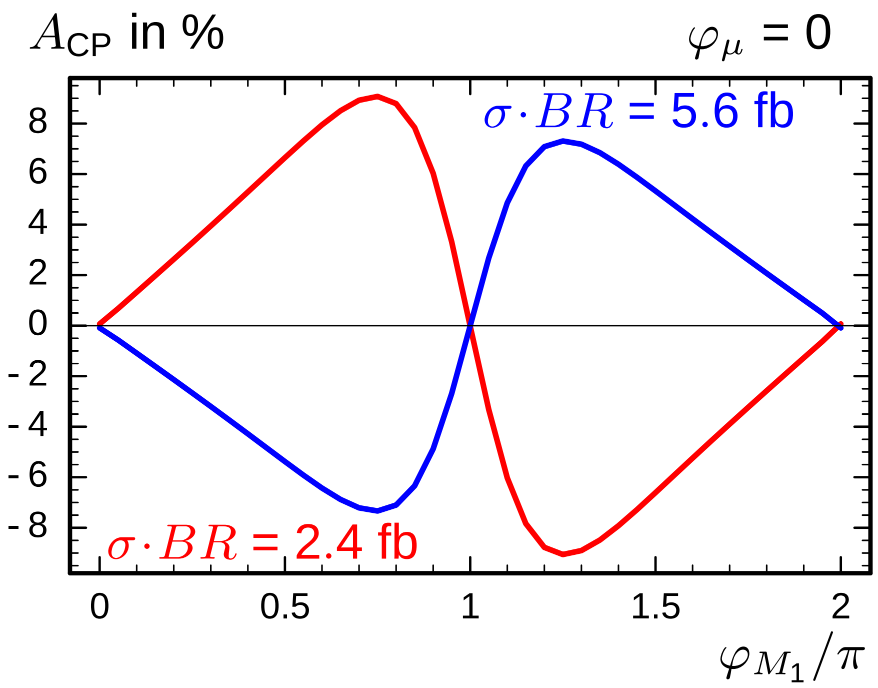
CP-odd asymmetry in $\tilde{\chi}^{\pm}$ sector

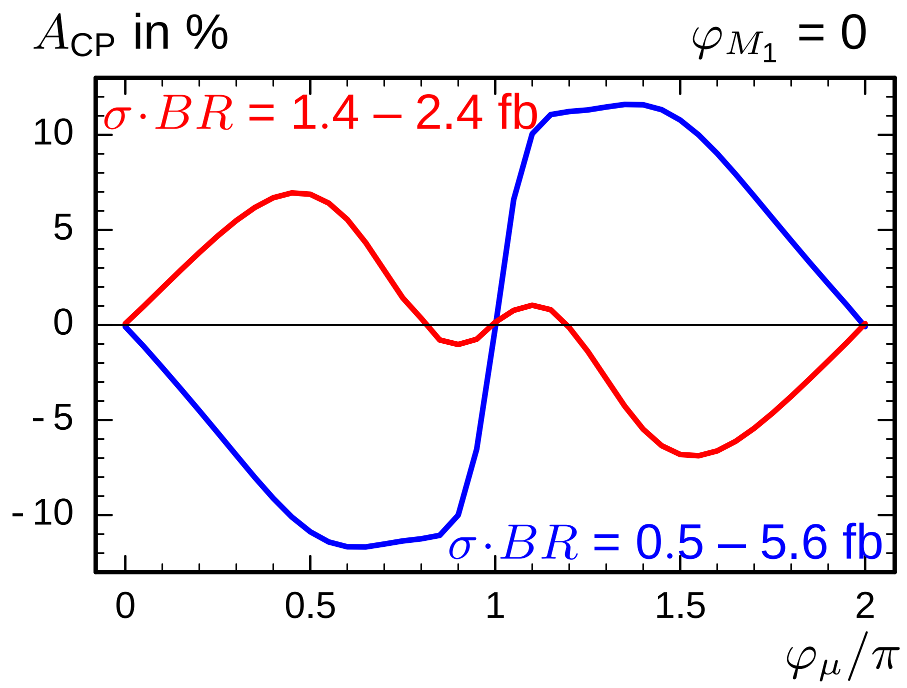
Asymmetry $A_{\rm CP}$ for $e^+e^- \to \tilde{\chi}_2^- \tilde{\chi}_1^+ \to \tilde{\chi}_2^- \tilde{\chi}_1^0 c\bar{s}$, $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\bar{s}} \times \vec{p}_c)$

[Bartl, Fraas, SH, Hohenwarter-Sodek, Kernreiter, Moortgat-Pick, hep-ph/0608065]

$\longrightarrow$ tagging of c jet important

$\tan\beta = 5$, $M_2 = 150$ GeV, $|M_1| = M_2\, 5/3 \tan^2\theta_W$, $|\mu| = 320$ GeV, $m_{\tilde{\nu}} = 250$ GeV, $m_{\tilde{u}_L} = 500$ GeV,
$\sqrt{s} = 500$ GeV, $P_{e^-} = -0.8$, $P_{e^+} = +0.6$, $P_{e^-} = +0.8$, $P_{e^+} = -0.6$



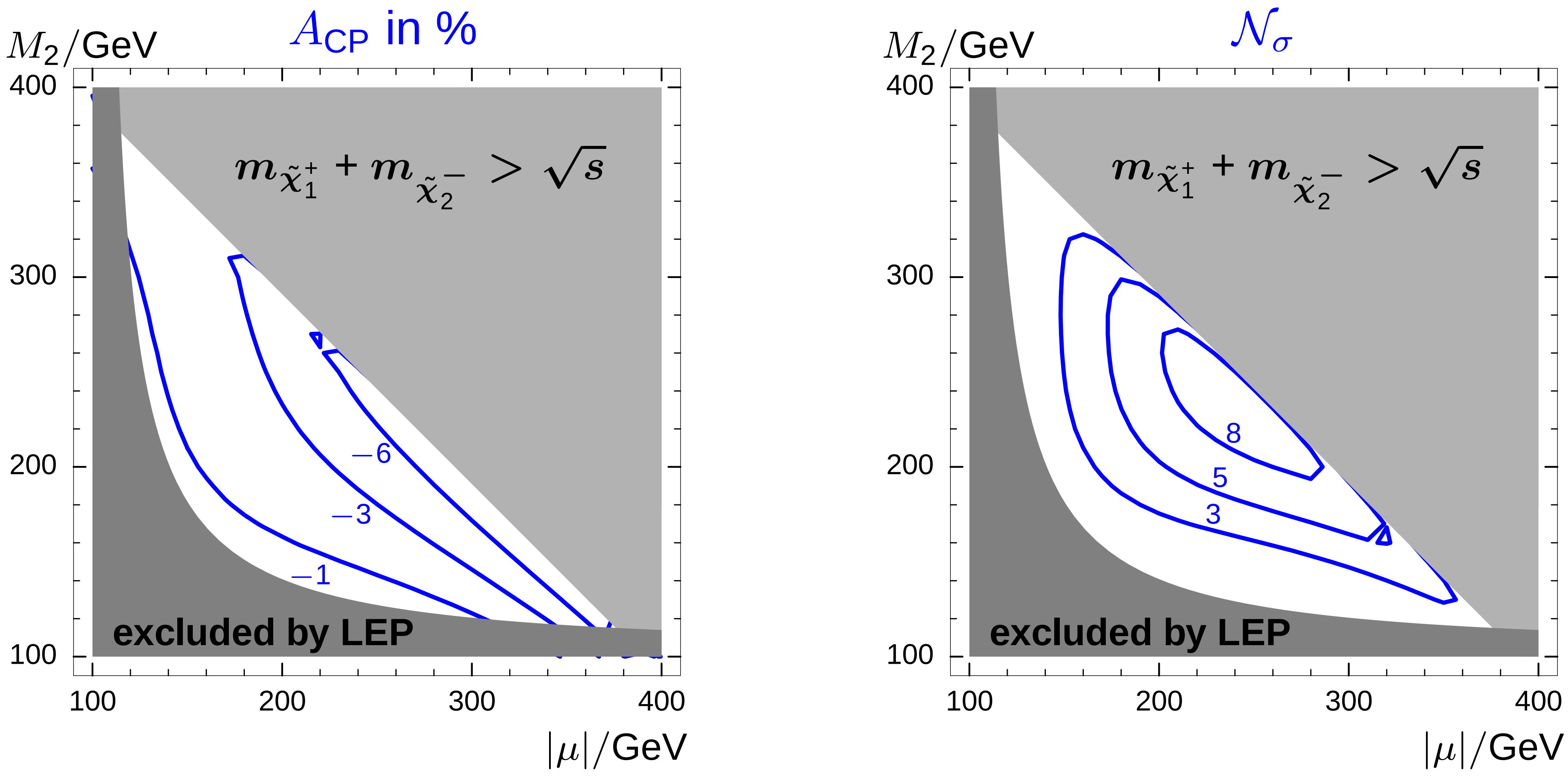


CP-odd asymmetry in $\tilde{\chi}^{\pm}$ sector

Contours of $A_{\rm CP}$ [in %] and $\mathcal{N}_\sigma = \sqrt{2 A_{\rm CP}^2 \sigma \mathcal{L}_{\rm int}}$ for $e^+ e^- \to \tilde{\chi}_2^- \tilde{\chi}_1^+ \to \tilde{\chi}_2^- \tilde{\chi}_1^0 c \bar{s}$

$\tan\beta = 5$, $|M_1| = M_2\, 5/3 \tan^2\theta_W$, $m_{\tilde{\nu}} = 250$ GeV, $m_{\tilde{u}_L} = 500$ GeV, $\varphi_{M_1} = 0.5\pi$, $\varphi_\mu = 0$

$\sqrt{s} = 500$ GeV, $P_{e^-} = -0.8$, $P_{e^+} = +0.6$, $\mathcal{L}_{\rm int} = 500\ {\rm fb}^{-1}$

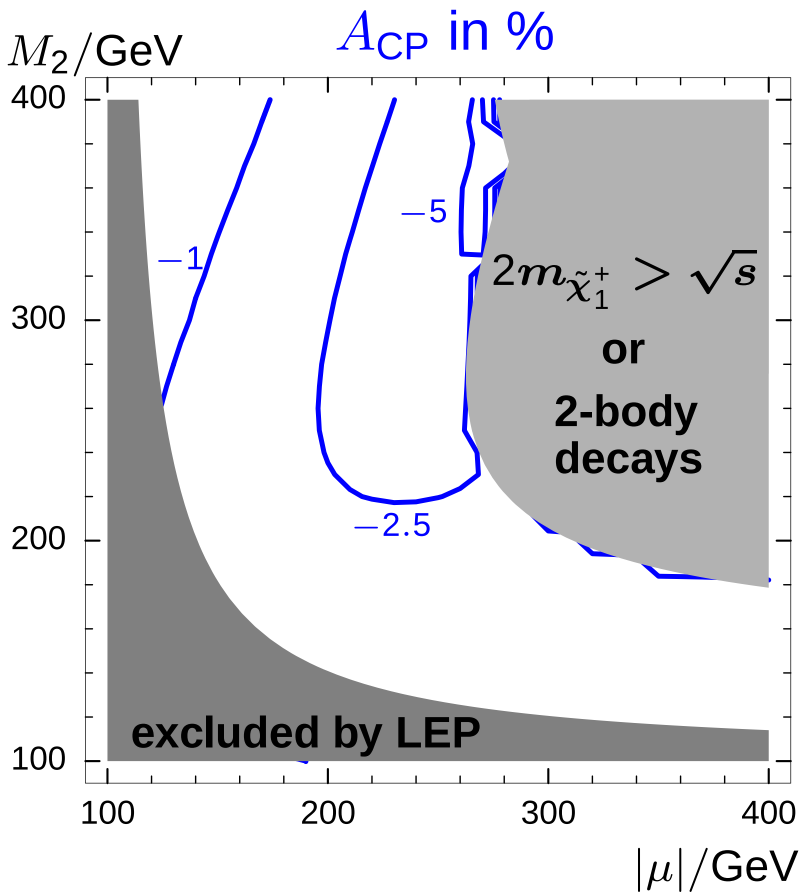


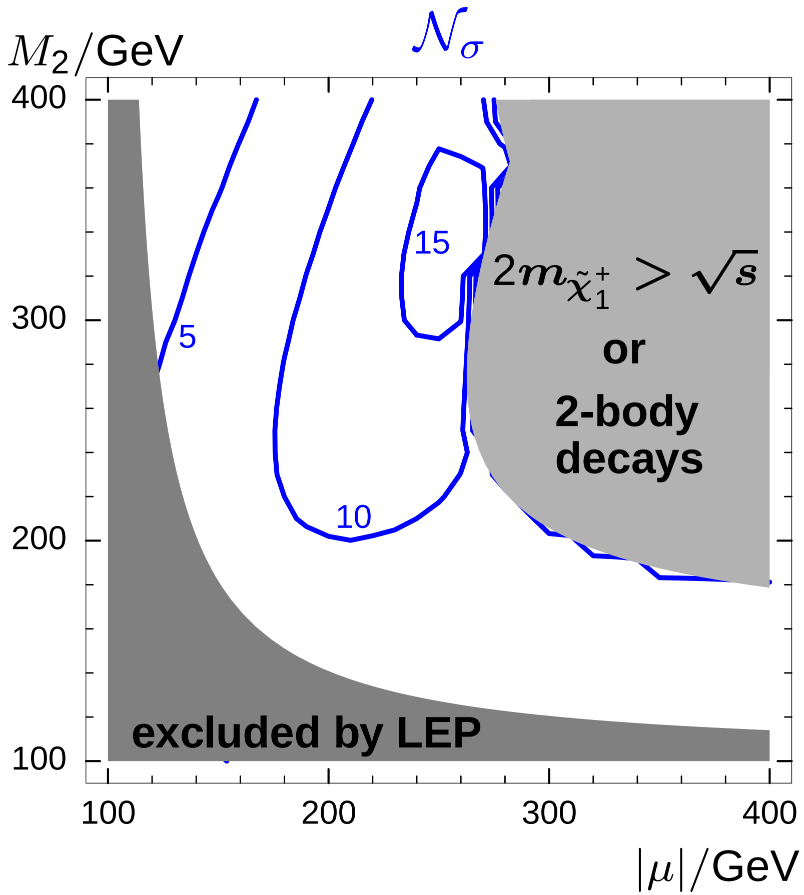
CP-odd asymmetry in $\tilde{\chi}^{\pm}$ sector

Contours of A_{CP} [in %] and $\mathcal{N}_\sigma$ for $e^+e^- \to \tilde{\chi}_1^- \tilde{\chi}_1^+ \to \tilde{\chi}_1^- \tilde{\chi}_1^0 c\bar{s}$

$\tan\beta = 5$, $|M_1| = M_2\, 5/3 \tan^2\theta_W$, $m_{\tilde{\nu}} = 250$ GeV, $m_{\tilde{u}_L} = 500$ GeV, $\varphi_{M_1} = 0.5\pi$, $\varphi_\mu = 0$

$\sqrt{s} = 500$ GeV, $P_{e^-} = -0.8$, $P_{e^+} = +0.6$, $\mathcal{L}_{\text{int}} = 500\ \text{fb}^{-1}$





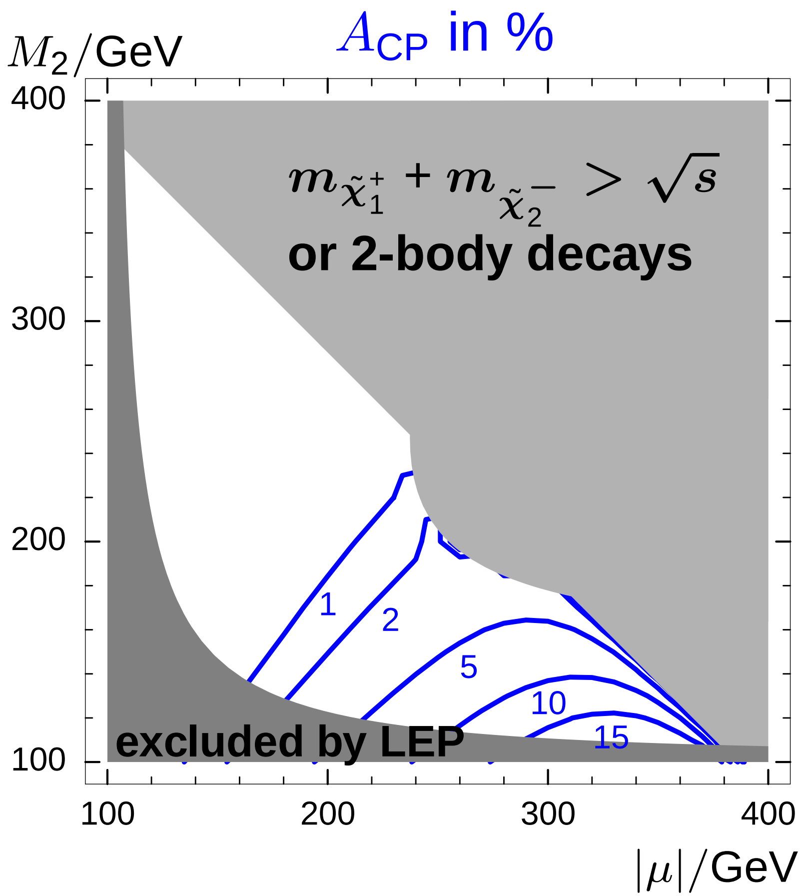
CP-odd asymmetry in $\tilde{\chi}^{\pm}$ sector

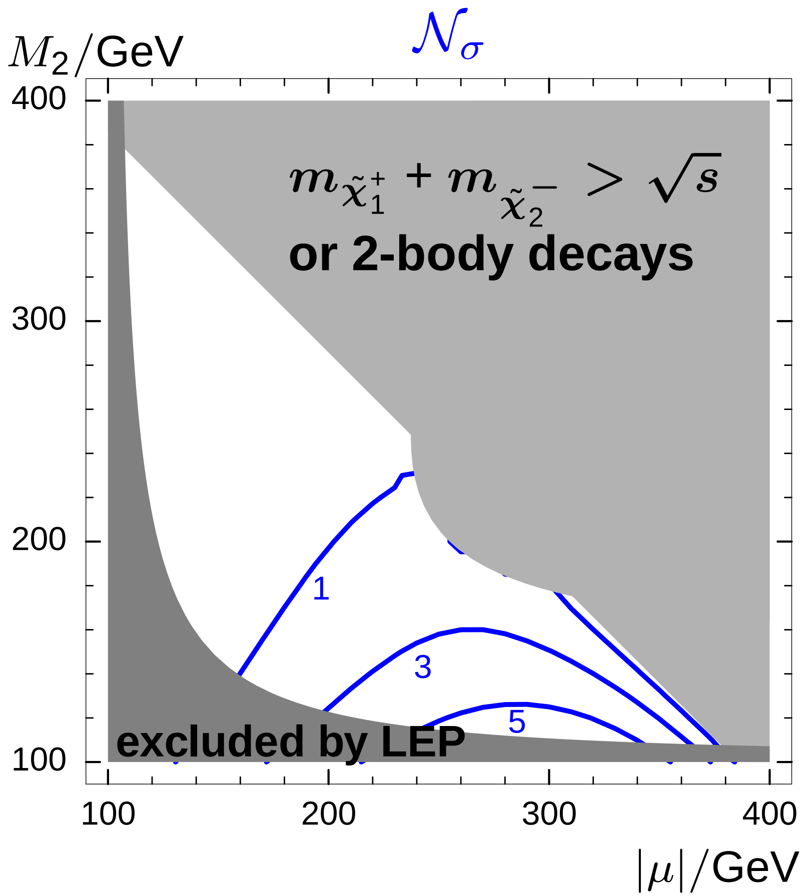
Contours of $\mathcal{A}_{\rm CP}$ [in %] and $\mathcal{N}_\sigma$ for $e^+e^- \to \tilde{\chi}_2^- \tilde{\chi}_1^+ \to \tilde{\chi}_2^- \tilde{\chi}_1^0 \ell^+ \nu$

$\longrightarrow \mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\tilde{\chi}_1^+} \times \vec{p}_{\ell^+}) \leftrightarrow$ reconstruction of $\vec{p}_{\tilde{\chi}_1^+}$ necessary

$\tan\beta = 5$, $|M_1| = M_2\, 5/3 \tan^2\theta_W$, $m_{\tilde{\nu}} = 250$ GeV, $m_{\tilde{u}_L} = 500$ GeV, $\varphi_{M_1} = 0$, $\varphi_\mu = 0.5\pi$

$\sqrt{s} = 500$ GeV, $P_{e^-} = -0.8$, $P_{e^+} = +0.6$, $\mathcal{L}_{\rm int} = 500$ fb^{-1}





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 $\mathcal{P}^T_{e^\pm}$:

  $P_T \sim \mathcal{P}^T_{e^-} \mathcal{P}^T_{e^+} [f_1 \Delta_1 r_1 + f_2 \Delta_2 r_2]$

  f_i: couplings; Δ_i: propagators; r_i: products of $t_\pm$ and momenta

  $\Rightarrow$ both beams have to be polarized (in limit $m_e = 0$!)

  [POWER report, hep-ph/0507011]

- r_1 is real; r_2 is imaginary, consisting of products like $\mathrm{i}\epsilon_{\mu\nu\rho\sigma} t^\mu_\pm p^\nu_i p^\rho_j p^\sigma_k$

  $\Rightarrow$ with complex couplings f_2: real contributions to observables

  $\Rightarrow$ CP-odd terms $\sim \mathrm{Im}(f_2\Delta_2)\mathrm{Im}(r_2)$ at tree level

Transverse beam polarization

- Chargino production:

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

  $\Rightarrow$ CP-odd terms $f_2 \Delta_2 r_2$ vanish [Bartl, Hohenwarter-Sodek, Kernreiter, Rud, '04]

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

- Neutralino production:

  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

  Analysis for subsequent 2-body decays [Choi, Drees, Song, '06]

Transverse beam polarization

- $f_2 \Delta_2 r_2 \sim \sin(\eta - 2\phi)$

  with ϕ: azimuthal angle of scattering plane; η: orientation of transverse polarizations

- CP-odd asymmetry

  - ϕ integration:

$$A_{CP}(\theta) = \frac{1}{\sigma}\left[\int_{\frac{\eta}{2}}^{\frac{\pi}{2}+\frac{\eta}{2}} - \int_{\frac{\pi}{2}+\frac{\eta}{2}}^{\pi+\frac{\eta}{2}} + \int_{\pi+\frac{\eta}{2}}^{\frac{3\pi}{2}+\frac{\eta}{2}} - \int_{\frac{3\pi}{2}+\frac{\eta}{2}}^{2\pi+\frac{\eta}{2}}\right] \frac{d^2\sigma}{d\phi\, d\theta} d\phi$$

  - θ integration:

$$A_{CP} = \left[\int_0^{\pi/2} - \int_{\pi/2}^{\pi}\right] A_{CP}(\theta)\, d\theta$$

$\longrightarrow$ 8 sectors with alternating sign

Transverse beam polarization

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

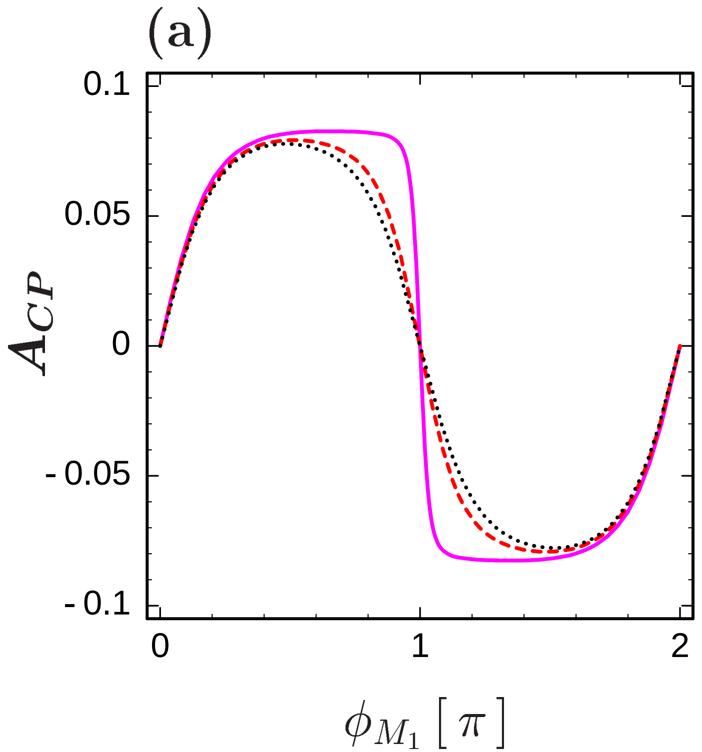
[Bartl, Fraas, SH, Hohenwarter-Sodek, Kernreiter, Moortgat-Pick, hep-ph/0510029]

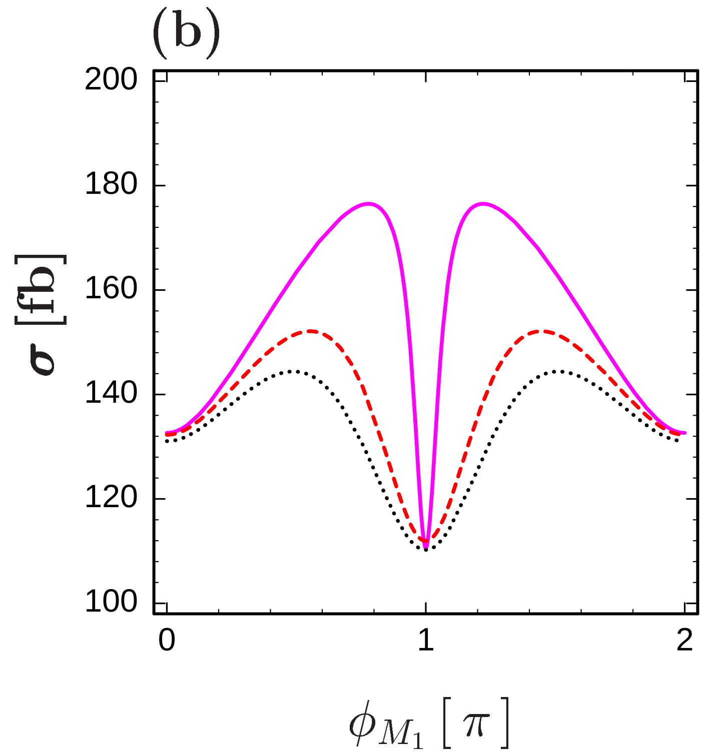
$\longrightarrow$ reconstruction of $\vec{p}_{\tilde{\chi}^0_2}$ necessary

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%)

$\tan\beta$ = 3, 10, 30



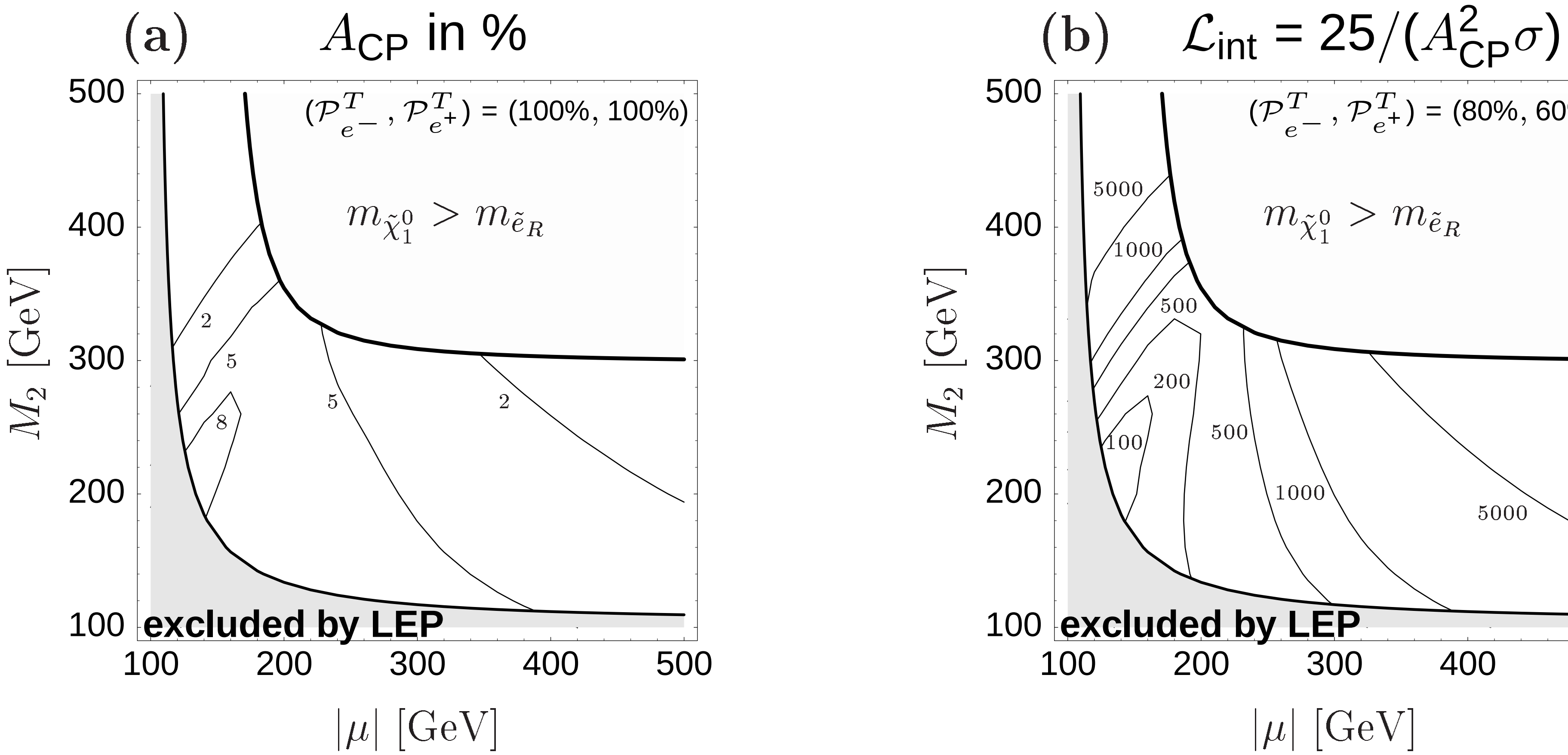


Transverse beam polarization

Contours of A_{CP} [in %] and $\mathcal{L}_{\text{int}} = \mathcal{N}_\sigma^2/(A_{\text{CP}}^2\sigma)$ for $e^+e^- \to \tilde{\chi}_1^0\tilde{\chi}_2^0$

$\tan\beta = 5$, $|M_1| = M_2\, 5/3 \tan^2\theta_W$, $m_{\tilde{e}_L} = 400$ GeV, $m_{\tilde{e}_R} = 150$ GeV $\phi_{M_1} = 0.5\pi$, $\phi_\mu = 0$

$\sqrt{s} = 500$ GeV, $\mathcal{N}_\sigma = 5$



Transverse beam polarization

Asymmetries including neutralino decay

$$e^+e^- \to \tilde{\chi}_i^0 + \tilde{\chi}_j^0 \to \tilde{\chi}_i^0 + \tilde{\ell}^{\pm}_{L,R}\ell_1^{\mp} \to \tilde{\chi}_i^0 + \tilde{\chi}_1^0 \ell_1^{\mp}\ell_2^{\pm}$$

- $A_1^{\mp} = \frac{1}{\sigma_1}\left[\int_{\frac{\eta}{2}}^{\frac{\pi}{2}+\frac{\eta}{2}} - \int_{\frac{\pi}{2}+\frac{\eta}{2}}^{\pi+\frac{\eta}{2}} + \int_{\pi+\frac{\eta}{2}}^{\frac{3\pi}{2}+\frac{\eta}{2}} - \int_{\frac{3\pi}{2}+\frac{\eta}{2}}^{2\pi+\frac{\eta}{2}}\right] \frac{d\sigma_1}{d\phi_{\ell_1^{\mp}}} d\phi_{\ell_1^{\mp}}$

  with $\sigma_1 = \sigma(e^+e^- \to \tilde{\chi}_i^0\tilde{\chi}_j^0) \times BR(\tilde{\chi}_j^0 \to \tilde{\ell}\ell_1)$

- $A_2^{\pm} = \frac{1}{\sigma_2}\left[\int_{\frac{\eta}{2}}^{\frac{\pi}{2}+\frac{\eta}{2}} - \int_{\frac{\pi}{2}+\frac{\eta}{2}}^{\pi+\frac{\eta}{2}} + \int_{\pi+\frac{\eta}{2}}^{\frac{3\pi}{2}+\frac{\eta}{2}} - \int_{\frac{3\pi}{2}+\frac{\eta}{2}}^{2\pi+\frac{\eta}{2}}\right] \frac{d\sigma_2}{d\phi_{\ell_2^{\pm}}} d\phi_{\ell_2^{\pm}}$

  with $\sigma_2 = \sigma(e^+e^- \to \tilde{\chi}_i^0\tilde{\chi}_j^0) \times BR(\tilde{\chi}_j^0 \to \tilde{\ell}\ell_1) \times BR(\tilde{\ell} \to \tilde{\chi}_1^0\ell_2)$

$\longrightarrow$ Distinguishing of ℓ_1 and ℓ_2 necessary (energy/angular distributions)

$\longrightarrow$ $A_i^- = -A_i^+$

Transverse beam polarization

Asymmetries including neutralino decay

- $$A'^{-} = \frac{(\int^{+} - \int^{-})(\frac{d\sigma_1}{d\phi_{\ell_1}} d\phi_{\ell_1} + \frac{d\sigma_2}{d\phi_{\ell_2}} d\phi_{\ell_2})}{\int_0^{2\pi}(\frac{d\sigma_1}{d\phi_{\ell_1}} d\phi_{\ell_1} + \frac{d\sigma_2}{d\phi_{\ell_2}} d\phi_{\ell_2})} = \frac{A_1^{-} + A_2^{-}\ BR(\tilde{\ell} \to \ell \tilde{\chi}_1^0)}{1 + BR(\tilde{\ell} \to \ell \tilde{\chi}_1^0)}$$

  $\int^{\pm}$: integration over regions where $\sin(\eta - 2\phi_{\ell_{1,2}})$ is positive/negative

$\longrightarrow$ Only measurement of charges of ℓ_1 and ℓ_2 necessary

(no distinguishing of ℓ_1 and ℓ_2 required)

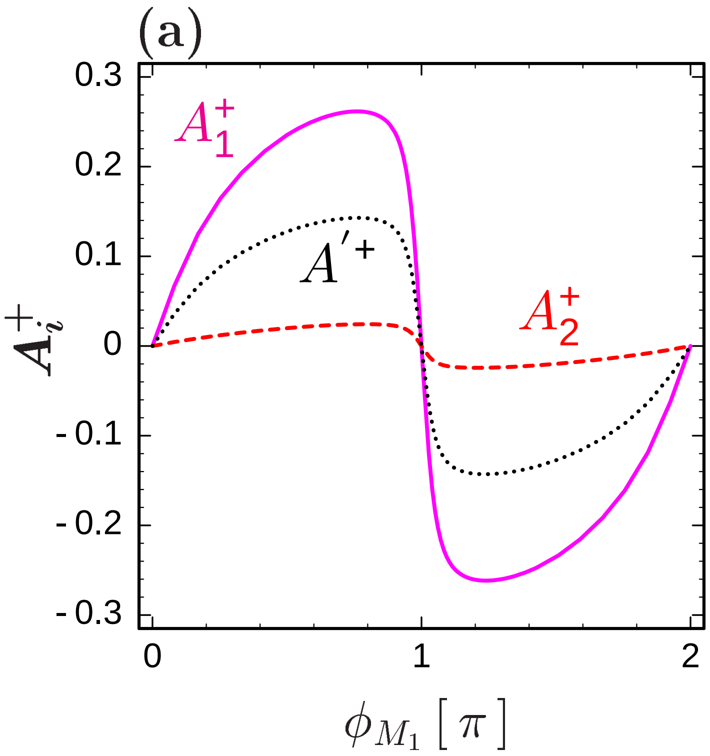
Transverse beam polarization

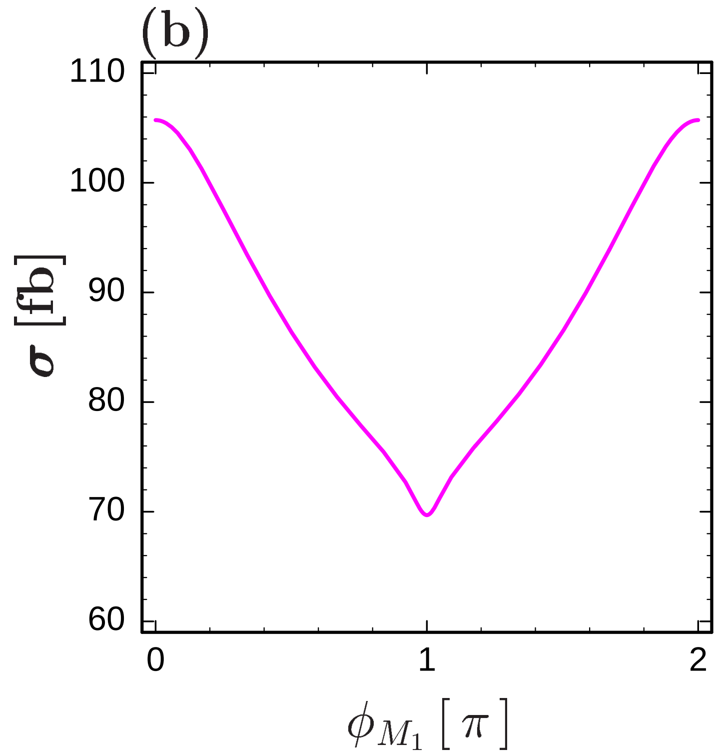
Asymmetries A_1^+, A_2^+, A'^+ for $e^+e^- \to \tilde{\chi}_1^0 + \tilde{\chi}_3^0 \to \tilde{\chi}_1^0 + \tilde{\chi}_1^0 \ell_1^\mp \ell_2^\pm$

[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, tan β = 3

$m_{\tilde{e}_L}$ = 400 GeV, $m_{\tilde{e}_R}$ = 150 GeV; $\sqrt{s}$ = 500 GeV, $(\mathcal{P}^T_{e^-}, \mathcal{P}^T_{e^+})$ = (100%, 100%)





Outlook: SUSY phases in Higgs sector

- $\tilde{t}$ and $\tilde{b}$ loops $\Rightarrow$ explicit CP violation in Higgs sector [Pilaftsis, '98]
  [Pilaftsis, Wagner, '99; Demir, '99, Carena, Ellis, Pilaftsis, Wagner, '00, '01; Choi, Drees, Lee, '00]
  $\longrightarrow h, H, A$ mix $\longrightarrow$ 3 neutral mass eigenstates (H_1, H_2, H_3)
- Possibly strong impact on Higgs search
- Projects within NExT Institute
  (Southampton University $\leftrightarrow$ PPD, RAL)
  http://www.hep.phys.soton.ac.uk/next/NEXT_web/NEXT_web.htm
  - SUSY phase dependence of BR($H_1 \to \gamma\gamma$)
    [Moretti, Munir, Poulose, '07; SH, Moretti, Munir, Poulose, in preparation]
    $\longrightarrow$ strong phase dependence possible
  - Analysis of CPV in MSSM for LHC Higgs search
    $\longrightarrow$ Implications of light Higgs ($m_{H_1} \sim$ 50 GeV) $\leftrightarrow$ NMSSM
  - Analysis of explicit CP violation in NMSSM

Summary

- Aim: revealing the CP structure of the underlying model
  - CP-even observables $\longrightarrow$ ambiguities remain
  - CP-odd observables needed
    $\longrightarrow$ here: T-odd/CP-odd asymmetries in $\tilde{\chi}^{\pm}$, $\tilde{\chi}^0$ production + decay
- Triple product asymmetries
  - Neutralinos: leptonic decays: $\mathcal{T} = \vec{p}_{e^-} \cdot (\vec{p}_{\ell^+} \times \vec{p}_{\ell^-})$
    hadronic decays: discrimination of $c \leftrightarrow \bar{c}$ or $b \leftrightarrow \bar{b}$
  - Charginos: leptonic decays: reconstruction of $p(\tilde{\chi}^+)$
    hadronic decays: discrimination of $c \leftrightarrow s$ jets
- CP-odd asymmetries with transverse beam polarization
  $\longrightarrow$ both beams have to be polarized
- Asymmetries of $\mathcal{O}$(10 %–20 %) possible
  $\Rightarrow$ important tool for $\longrightarrow$ search for CP violation in SUSY
  $\longrightarrow$ unambiguous determination of SUSY phases