Consistent on-shell renormalisation of the charginos/neutralinos in the complex MSSM: predictions for $e^+e^- \to \chi_i^+\chi_j^-$@LC

Aoife Bharucha

in collaboration with Alison Fowler,
Gudrid Moortgat-Pick and Georg Weiglein

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Universität Hamburg

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Outline

- Why calculate 1-loop corrections to $e^+e^- \longrightarrow \tilde{\chi}_i^+ \tilde{\chi}_j^-$?

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  - Field Renormalization issues
  - Parameter Renormalization issues

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- Why MSSM with complex phases?
- Renormalising the chargino and neutralino sector on-shell:
  - Field Renormalization issues
  - Parameter Renormalization issues
- 1-loop results for phase dependence of $\sigma(e^+e^- \to \tilde{\chi}_i{}^+ \tilde{\chi}_j{}^-)$

Motivation

- Chargino production@LC allows precise parameter determination at tree level[1]
- 1-loop corrections large in MSSM: important for precision measurements
- On-shell scheme ⇒ Parameters have clear physical meaning, correct **IR** properties
- cMSSM⇒BSM CP violation⇒ Baryon asymmetry
- Strong bounds on certain phases via EDMs (n, e, Hg, Tl) [2]

Important contributing phases:

$$\phi_{t/b/\tau},\ \phi_{\mu}{}^{a},\ \phi_{M_{1/3}}$$

[a] Note that higgsino phase is also strongly constrained by the EDM's

[1] e.g. K. Desch, J. Kalinowski, G. A. Moortgat-Pick, M. M. Nojiri and G. Polesello, [arXiv:hep-ph/0312069].

[2] for review see J. R. Ellis, J. S. Lee and A. Pilaftsis, [arXiv:0808.1819 [hep-ph]].

Quick recap: Chargino and Neutralino Sector

$$\mathcal{L}_{\tilde{\chi}} = \overline{\tilde{\chi}_i^-}(\not{p}\,\delta_{ij} - \omega_L (U^* X V^\dagger)_{ij} - \omega_R (V X^\dagger U^T)_{ij})\tilde{\chi}_j^- + \frac{1}{2}\overline{\tilde{\chi}_i^0}(\not{p}\,\delta_{ij} - \omega_L (N^* Y N^\dagger)_{ij} - \omega_R (N Y^\dagger N^T)_{ij})\tilde{\chi}_j^0$$

$$X = \begin{pmatrix} M_2 & \sqrt{2} M_W \sin\beta \\ \sqrt{2} M_W \cos\beta & \mu \end{pmatrix}$$

diagonalised via $\mathbf{M}_{\tilde{\chi}^+} = U^* X V^\dagger$

[2] where we define $\omega_{L/R} = \frac{1}{2}(1 \mp \gamma_5)$

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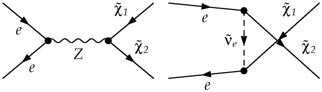
$$Y = \begin{pmatrix} M_1 & 0 & -M_Z c_\beta s_W & M_Z s_\beta s_W \\ 0 & M_2 & M_Z c_\beta c_W & -M_Z s_\beta c_W \\ -M_Z c_\beta s_W & M_Z c_\beta c_W & 0 & -\mu \\ M_Z s_\beta s_W & -M_Z s_\beta c_W & -\mu & 0 \end{pmatrix}$$

diagonalised via $\mathbf{M}_{\tilde{\chi}^0} = N^* Y N^\dagger$

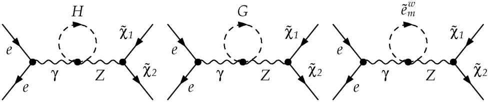
[2] where we define $\omega_{L/R} = \frac{1}{2}(1 \mp \gamma_5)$

Example diagrams for $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_2^-$ at one-loop

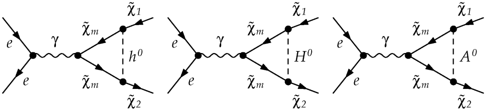
Tree:



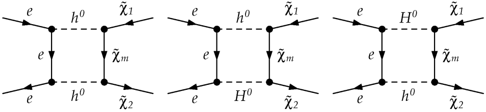
Self-energy:



Vertex:

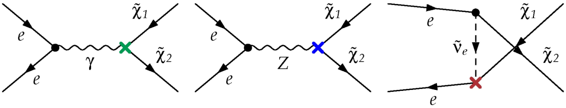


Box:



Calculate using `FeynArts`, `FormCalc`, `LoopTools`

Getting finite results: selected counter-terms



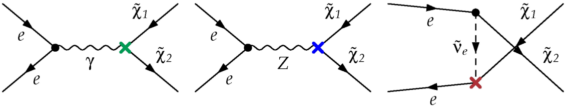
Renormalize $\gamma\tilde{\chi}_i^+\tilde{\chi}_j^-$, $Z\tilde{\chi}_i^+\tilde{\chi}_j^-$ and $e\tilde{\nu}_e\tilde{\chi}_i^+$ vertices:

$$\delta\Gamma^L_{\tilde{\chi}_i^+\tilde{\chi}_j^-\gamma} = \frac{ie}{2}\left(\delta_{ij}\left(2\delta Z_e + \delta Z_{\gamma\gamma}\right) - \frac{\delta Z_{Z\gamma}}{c_W s_W} C^L_{\tilde{\chi}_i^+\tilde{\chi}_j^- Z} + \delta Z^L_{ij} + \delta \bar{Z}^L_{ij}\right),$$

$$\delta\Gamma^L_{\tilde{\chi}_i^+\tilde{\chi}_j^- Z} = \frac{-ie}{c_W s_W}\left(\delta C^L_{\tilde{\chi}_i^+\tilde{\chi}_j^- Z} + C^L_{\tilde{\chi}_i^+\tilde{\chi}_j^- Z}\left(\delta Z_e - \frac{\delta c_W}{c_W} - \frac{\delta s_W}{s_W} + \frac{\delta Z_{ZZ}}{2}\right)\right.$$
$$\left. - \delta_{ij}\frac{c_W s_W}{2}\delta Z_{\gamma Z} + \frac{1}{2}\sum_{n=1,2}\left(\delta Z^L_{nj} C^L_{\tilde{\chi}_i^+\tilde{\chi}_n^- Z} + C^L_{\tilde{\chi}_n^+\tilde{\chi}_j^- Z}\delta\bar{Z}^L_{in}\right)\right)$$

$$\delta\Gamma^L_{\tilde{\nu}_e e^+\tilde{\chi}_i^-} = \frac{ie\delta_{ij}}{s_W}\left(C^L_{\tilde{\nu}_e e^+\tilde{\chi}_i^-}\left(\delta Z_e - \frac{\delta s_W}{s_W} + \frac{1}{2}\left(\delta Z_{\tilde{\nu}_e} + \delta Z_e^{R*}\right)\right.\right.$$
$$\left.\left. + \frac{1}{2}\left(\delta Z^L_{1i} U^*_{12} + \delta Z^L_{2i} U^*_{22}\right)\right) + \delta C^L_{\tilde{\nu}_e e^+\tilde{\chi}_i^-}\right).$$

Getting finite results: selected counter-terms



Renormalize $\gamma\tilde{\chi}^+_i\tilde{\chi}^-_j$, $Z\tilde{\chi}^+_i\tilde{\chi}^-_j$ and $e\tilde{\nu}_e\tilde{\chi}^+_i$ vertices:

$$\delta\Gamma^L_{\tilde{\chi}^+_i\tilde{\chi}^-_j\gamma} = \frac{ie}{2}\left(\delta_{ij}\left(2\delta Z_e + \delta Z_{\gamma\gamma}\right) - \frac{\delta Z_{Z\gamma}}{c_W s_W} C^L_{\tilde{\chi}^+_i\tilde{\chi}^-_j Z} + \delta Z^L_{ij} + \delta\bar{Z}^L_{ij}\right),$$

$$\delta\Gamma^L_{\tilde{\chi}^+_i\tilde{\chi}^-_j Z} = \frac{-ie}{c_W s_W}\left(\delta C^L_{\tilde{\chi}^+_i\tilde{\chi}^-_j Z} + C^L_{\tilde{\chi}^+_i\tilde{\chi}^-_j Z}\left(\delta Z_e - \frac{\delta c_W}{c_W} - \frac{\delta s_W}{s_W}\frac{\delta Z_{ZZ}}{2}\right)\right.$$
$$\left. - \delta_{ij}\frac{c_W s_W}{2}\delta Z_{\gamma Z} + \frac{1}{2}\sum_{n=1,2}\left(\delta Z^L_{nj} C^L_{\tilde{\chi}^+_i\tilde{\chi}^-_n Z} + C^L_{\tilde{\chi}^+_n\tilde{\chi}^-_j Z}\delta\bar{Z}^L_{in}\right)\right)$$

$$\delta\Gamma^L_{\tilde{\nu}_e e^+\tilde{\chi}^-_i} = \frac{ie\delta_{ij}}{s_W}\left(C^L_{\tilde{\nu}_e e^+\tilde{\chi}^-_i}\left(\delta Z_e - \frac{\delta s_W}{s_W} + \frac{1}{2}\left(\delta Z_{\tilde{\nu}_e} + \delta Z^{R*}_e\right)\right.\right.$$
$$\left.\left. + \frac{1}{2}\left(\delta Z^L_{1i}U^*_{12} + \delta Z^L_{2i}U^*_{22}\right)\right) + \delta C^L_{\tilde{\nu}_e e^+\tilde{\chi}^-_i}\right).$$

Field renormalisation

Require correct on-shell properties for **renormalised two point vertex functions** $\hat{\Gamma}^{(2)}_{ij}(p^2) = i(\not{p} - m_i)\delta_{ij} + i\hat{\Sigma}_{ij}(p^2)$ and **propagator** $\hat{S}^{(2)}_{ij}(p^2) = (\hat{\Gamma}^{(2)}_{ij}(p^2))^{-1}$

- $\hat{\Gamma}^{(2)}_{ij}$ should be diagonal, e.g. $\hat{\Gamma}^{(2)}_{ij}\tilde{\chi}_i(p)|_{p^2=m^2_{\tilde{\chi}_j}} = 0$
- $\hat{S}^{(2)}_{ij}$ should have a unity residue, e.g. $\lim\limits_{p^2 \to m^2_{\tilde{\chi}_i}} \frac{1}{\not{p} - m_{\tilde{\chi}_i}} \hat{\Gamma}^{(2)}_{ii}\tilde{\chi}_i(p) = i\tilde{\chi}_i$
- Demand renormalised propagator to have same Lorentz structure as at tree-level in on-shell limit, i.e. $\hat{\Sigma}^{SL}_{ii}(m^2_{\tilde{\chi}_i}) = \hat{\Sigma}^{SR}_{ii}(m^2_{\tilde{\chi}_i})$

Where does our approach differ?

Usual approach: Assume $\delta\bar{Z}_{ij} = \delta Z^{\dagger}_{ij}$
$\Rightarrow$ Expressions for the wave-function renormalisation e.g. for charginos

$$\delta Z^{L/R}_{-,ij} = \frac{2}{m^2_{\tilde{\chi}^\pm_i} - m^2_{\tilde{\chi}^\pm_j}} \widetilde{\mathrm{Re}} \Big[m^2_{\tilde{\chi}^\pm_j} \Sigma^{L/R}_{-,ij}(m^2_{\tilde{\chi}^\pm_j}) + m_{\tilde{\chi}^\pm_i} m_{\tilde{\chi}^\pm_j} \Sigma^{R/L}_{-,ij}(m^2_{\tilde{\chi}^\pm_j}) + m_{\tilde{\chi}^\pm_i} \Sigma^{SL/SR}_{-,ij}(m^2_{\tilde{\chi}^\pm_j}) + m_{\tilde{\chi}^\pm_j} \Sigma^{SR/SL}_{-,ij}(m^2_{\tilde{\chi}^\pm_j}) - m_{\tilde{\chi}^\pm_{i/j}} \big(U^* \delta X V^\dagger \big)_{ij} - m_{\tilde{\chi}^\pm_{j/i}} \big(V \delta X^\dagger U^T \big)_{ij} \Big],$$

$$\delta \bar{Z}^{L/R}_{-,ij} = \frac{2}{m^2_{\tilde{\chi}^\pm_j} - m^2_{\tilde{\chi}^\pm_i}} \widetilde{\mathrm{Re}} \Big[m^2_{\tilde{\chi}^\pm_i} \Sigma^{L/R}_{-,ij}(m^2_{\tilde{\chi}^\pm_i}) + m_{\tilde{\chi}^\pm_i} m_{\tilde{\chi}^\pm_j} \Sigma^{R/L}_{-,ij}(m^2_{\tilde{\chi}^\pm_i}) + m_{\tilde{\chi}^\pm_i} \Sigma^{SL/SR}_{-,ij}(m^2_{\tilde{\chi}^\pm_i}) + m_{\tilde{\chi}^\pm_j} \Sigma^{SR/SL}_{-,ij}(m^2_{\tilde{\chi}^\pm_i}) - m_{\tilde{\chi}^\pm_{i/j}} (U^* \delta X V^\dagger)_{ij} - m_{\tilde{\chi}^\pm_{j/i}} (V \delta X^\dagger U^T)_{ij} \Big]$$

Can only find consistent solutions to OS equations by use of $\widetilde{\mathrm{Re}}$ $\Rightarrow$ take real part of any loop integrals occurring in the self energies, but not of any complex parameters in coefficients of these integrals

Removes absorptive parts of loop integrals
Additional finite renormalisation term would be required to restore on-shell properties of external particles

Where does our approach differ?

We do not require hermiticity condition:

$$\delta Z^{L/R}_{-,ij} = \frac{2}{m^2_{\tilde{\chi}^\pm_i} - m^2_{\tilde{\chi}^\pm_j}} \cancel{\widetilde{\mathrm{Re}}} \Big[m^2_{\tilde{\chi}^\pm_j} \Sigma^{L/R}_{-,ij}(m^2_{\tilde{\chi}^\pm_j}) + m_{\tilde{\chi}^\pm_i} m_{\tilde{\chi}^\pm_j} \Sigma^{R/L}_{-,ij}(m^2_{\tilde{\chi}^\pm_j}) + m_{\tilde{\chi}^\pm_i} \Sigma^{SL/SR}_{-,ij}(m^2_{\tilde{\chi}^\pm_j})$$
$$+ m_{\tilde{\chi}^\pm_j} \Sigma^{SR/SL}_{-,ij}(m^2_{\tilde{\chi}^\pm_j}) - m_{\tilde{\chi}^\pm_{i/j}} \left(U^* \delta X V^\dagger\right)_{ij} - m_{\tilde{\chi}^\pm_{j/i}} \left(V \delta X^\dagger U^T\right)_{ij} \Big],$$

$$\delta \bar{Z}^{L/R}_{-,ij} = \frac{2}{m^2_{\tilde{\chi}^\pm_j} - m^2_{\tilde{\chi}^\pm_i}} \cancel{\widetilde{\mathrm{Re}}} \Big[m^2_{\tilde{\chi}^\pm_i} \Sigma^{L/R}_{-,ij}(m^2_{\tilde{\chi}^\pm_i}) + m_{\tilde{\chi}^\pm_i} m_{\tilde{\chi}^\pm_j} \Sigma^{R/L}_{-,ij}(m^2_{\tilde{\chi}^\pm_i}) + m_{\tilde{\chi}^\pm_i} \Sigma^{SL/SR}_{-,ij}(m^2_{\tilde{\chi}^\pm_i})$$
$$+ m_{\tilde{\chi}^\pm_j} \Sigma^{SR/SL}_{-,ij}(m^2_{\tilde{\chi}^\pm_i}) - m_{\tilde{\chi}^\pm_{i/j}} (U^* \delta X V^\dagger)_{ij} - m_{\tilde{\chi}^\pm_{j/i}} (V \delta X^\dagger U^T)_{ij} \Big]$$

In the CP-conserving case one can choose a scheme where (up to purely imaginary terms that do not contribute to squared matrix elements at 1-loop) the hermiticity relation holds: $\delta \bar{Z}_{ij} = \delta Z^\dagger_{ij}$

Keep absorptive parts of loop integrals

Renormalisation of the Chargino/Neutralino sector[3]

Parameter renormalisation:

- $X + \delta X,\ Y + \delta Y \Rightarrow M_1 + \delta M_1,\ M_2 + \delta M_2,\ \mu + \delta\mu$ etc.
- e.g. $\delta X = \begin{pmatrix} \delta M_2 & \frac{\delta M_W^2 s_\beta}{\sqrt{2} M_W} + M_W s_\beta c_\beta^2 \delta t_\beta \\ \frac{\delta M_W^2 c_\beta}{\sqrt{2} M_W} - M_W c_\beta s_\beta^2 \delta t_\beta & \delta\mu \end{pmatrix}$

  where s_β denotes $\sin\beta$ etc.
- More physical masses than independent parameters ⇒ can only choose **three masses on-shell**:
  - $\tilde{\chi}^\pm_{1,2}$, $\tilde{\chi}^0_{1(2/3)}$: NCC(b/c)
  - $\tilde{\chi}^0_{1,2}$, $\tilde{\chi}^\pm_2$: NNC
  - $\tilde{\chi}^0_{1,2}$, $\tilde{\chi}^0_3$: NNN

[3] A. C. Fowler and G. Weiglein, "Precise Predictions for Higgs Production in Neutralino Decays in the Complex MSSM," JHEP **1001**, 108 (2010) [arXiv:0909.5165 [hep-ph]]

Parameter renormalisation cont'd[4]

	NNN	NNC	NCC	
$\delta\lvert M_1\rvert$	-1.468	-1.465	-1.468	
$\delta\lvert M_2\rvert$	-9.265	-9.265	-9.410	
$\delta\lvert\mu\rvert$	-18.494	-18.996	-18.996	
$\Delta m_{\tilde{\chi}_1^0}$	0	0	0	
$\Delta m_{\tilde{\chi}_2^0}$	0	0	0	
$\Delta m_{\tilde{\chi}_3^0}$	0	-0.5012	-0.5016	
$\Delta m_{\tilde{\chi}_4^0}$	0.3237	-0.1775	-0.1775	
$\Delta m_{\tilde{\chi}_1^\pm}$	0.1446	0.1445	0	
$\Delta m_{\tilde{\chi}_2^\pm}$	0.5012	0	0	

- Finite parts of parameter renormalisation constants (RCs) and mass corrections in GeV for the gaugino-like CPX scenario: $|M_2|$=200 GeV, $M_3 = 1000e^{i\pi/2}$ GeV, $|A_f|$=900 GeV, $\phi_{f1,2} = \pi$, $\phi_{f3} = \pi/2$, M_{SUSY}=500 GeV, $\mu = 2000$ GeV with $M_{H^\pm} = 132.1\,\mathrm{GeV}$ and $\tan\beta = 5.5$
- Last two columns, denoted with an asterisk, show the results for a higgsino-like CPX scenario, with $\mu = 200\,\mathrm{GeV}$, $M_1 = (5/3)(s_W^2/c_W^2)M_2$ and $M_2 = 1000\,\mathrm{GeV}$, and all other parameters the same as the CPX scenario

[4] A. C. Fowler, PhD Thesis, 2010, also see A. Chatterjee, M. Drees, S. Kulkarni, Q. Xu, "On the On-Shell Renormalization of the Chargino and Neutralino Masses in the MSSM," [arXiv:1107.5218 [hep-ph]].

Parameter renormalisation cont'd[4]

	NNN	NNC	NCC	NCCb	NCCc	
$\delta\|M_1\|$	-1.468	-1.465	-1.468	2518.7	-3684.6	
$\delta\|M_2\|$	-9.265	-9.265	-9.410	-9.410	-9.410	
$\delta\|\mu\|$	-18.494	-18.996	-18.996	-18.996	-18.996	
$\Delta m_{\tilde{\chi}_1^0}$	0	0	0	2518.8	-3681.1	
$\Delta m_{\tilde{\chi}_2^0}$	0	0	0	0	0.356	
$\Delta m_{\tilde{\chi}_3^0}$	0	-0.5012	-0.5016	-0.8446	0	
$\Delta m_{\tilde{\chi}_4^0}$	0.3237	-0.1775	-0.1775	0.6851	-1.439	
$\Delta m_{\tilde{\chi}_1^\pm}$	0.1446	0.1445	0	0	0	
$\Delta m_{\tilde{\chi}_2^\pm}$	0.5012	0	0	0	0	

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Parameter renormalisation cont'd[4]

	NNN	NNC	NCC	NCCb	NCCc	NCCb*	NCCc*
$\delta\|M_1\|$	-1.468	-1.465	-1.468	2518.7	-3684.6	-355.6	-4.642
$\delta\|M_2\|$	-9.265	-9.265	-9.410	-9.410	-9.410	10.683	10.683
$\delta\|\mu\|$	-18.494	-18.996	-18.996	-18.996	-18.996	-5.136	-5.136
$\Delta m_{\tilde{\chi}_1^0}$	0	0	0	2518.8	-3681.1	-11.44	-0.636
$\Delta m_{\tilde{\chi}_2^0}$	0	0	0	0	0.356	0	-0.671
$\Delta m_{\tilde{\chi}_3^0}$	0	-0.5012	-0.5016	-0.8446	0	-339.5	0
$\Delta m_{\tilde{\chi}_4^0}$	0.3237	-0.1775	-0.1775	0.6851	-1.439	-0.0794	-0.0328
$\Delta m_{\tilde{\chi}_1^\pm}$	0.1446	0.1445	0	0	0	0	0
$\Delta m_{\tilde{\chi}_2^\pm}$	0.5012	0	0	0	0	0	0

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Parameter renormalisation: phases

- Assume standard OS conditions +

$$\delta Z^R_{0,11} = \delta \bar{Z}^R_{0,11}, \quad \delta Z^L_{0,11} = \delta \bar{Z}^L_{0,11},$$
$$\delta Z^R_{\pm,22} = \delta \bar{Z}^R_{-,22}, \quad \delta Z^L_{\pm,22} = \delta \bar{Z}^L_{-,22},$$

- Expression for $\delta\phi_\mu$, $\delta\phi_{M_1}$ UV-convergent

$$\delta\phi^{\rm div}_\mu = 0, \quad \delta\phi^{\rm div}_{M_1} = 0,$$

$\Rightarrow$ Phases do not require renormalization.

- Use $\overline{DR}$ scheme as advocated in the SPA conventions
- No 1-loop contributions to phases: remain at tree-level value, whether zero or non-zero

Results: $e^+e^- \to \tilde{\chi}_\mathbf{i}^+\tilde{\chi}_\mathbf{j}^-$@LC

- Existing results for the total cross-section for chargino production in the real MSSM at SPS1a'[a], NLO corrections $\mathcal{O}(10\%)$

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- We calculate corrections to cross section for $e^+e^- \rightarrow \tilde{\chi}_1^+\tilde{\chi}_2^-$

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- Show relative size of weak corrections as a function of the phase of A_t, with and without $\widetilde{\mathrm{Re}}$

[a] W. Oller, H. Eberl and W. Majerotto, "Precise predictions for chargino and neutralino pair production in e+ e- annihilation," Phys. Rev. D **71** (2005) 115002 [arXiv:hep-ph/0504109]

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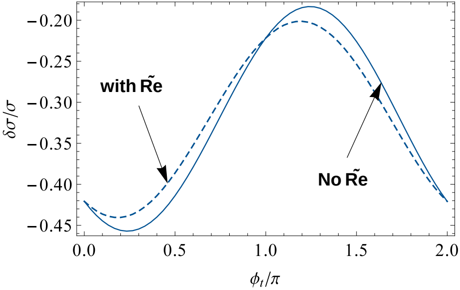
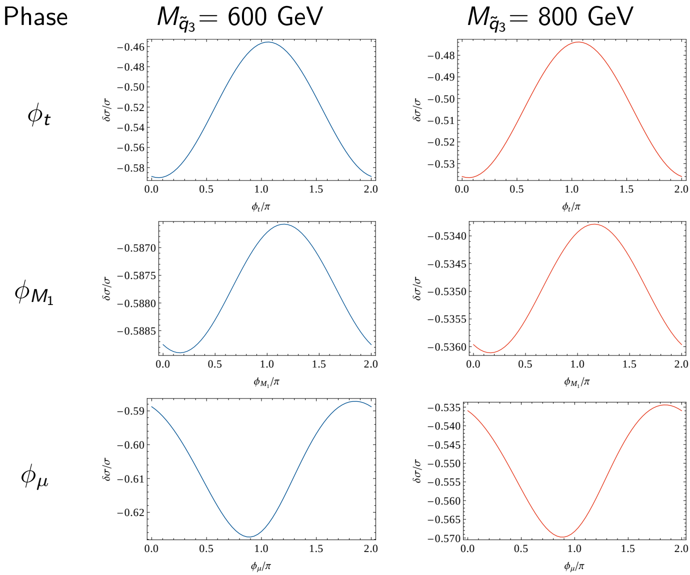
Clear $\sim$ 3% difference between results with/without the absorptive parts



$\delta\sigma/\sigma$ for $e^+e^- \to \tilde{\chi}_1^+\tilde{\chi}_2^-$



Summary and Outlook

Summary

- On-shell renormalisation for Chargino-Neutralino sector non-trivial
- OS conditions fulfilled $\Rightarrow$ Absorptive parts must be included
- Careful choice of 3 OS masses crucial, phases **do not** require renorml'n
- Full $e^+e^- \rightarrow \tilde{\chi}_i^+ \tilde{\chi}_j^-$@NLO calculated, **absorptive parts have an observable effect**
- Phase dependence investigated $\Rightarrow$ Largest effects due to ϕ_t

[5] K. Desch, J. Kalinowski, G. A. Moortgat-Pick, M. M. Nojiri and G. Polesello, [arXiv:hep-ph/0312069]

Summary and Outlook

Summary

- On-shell renormalisation for Chargino-Neutralino sector non-trivial
- OS conditions fulfilled $\Rightarrow$ Absorptive parts must be included
- Careful choice of 3 OS masses crucial, phases **do not** require renorml'n
- Full $e^+e^- \rightarrow \tilde{\chi}_i^+ \tilde{\chi}_j^-$ @NLO calculated, **absorptive parts have an observable effect**
- Phase dependence investigated $\Rightarrow$ Largest effects due to ϕ_t

Outlook

- Tree-level parameter determination possible up to $\mathcal{O}(\%)$ level at a LC via $\tilde{\chi}^0/\tilde{\chi}^\pm$ production[5]
- Goal: match exp. accuracy, investigate sensitivity to ϕ_t

[5] K. Desch, J. Kalinowski, G. A. Moortgat-Pick, M. M. Nojiri and G. Polesello, [arXiv:hep-ph/0312069]

Parameters

Parameter	Value	Parameter	Value
$\|M_1\|$	100 GeV	M_2	200 GeV
$\|\mu\|$	420 GeV	M_{H^+}	800 GeV
$\|M_3\|$	1000 GeV	$\tan\beta$	20
$M_{\tilde{q}_{12}}$	1000 GeV	$M_{\tilde{q}_3}$	500-800 GeV
$M_{\tilde{l}_{12}}$	400 GeV	$M_{\tilde{l}_3}$	500 GeV
$\|A_q\|$	1300 GeV	$\|A_l\|$	1000 GeV

Table: Table of parameters, where A_q/A_l are the common trilinear couplings for the quarks and leptons.

Parameter determination at tree-level

- Analyse $\sigma^{\pm}_{L/R}\{i,j\}$ i.e. L/R polarised $\tilde{\chi}^+_i \tilde{\chi}^-_j$ production cross-section[6]
- From $\sigma^{\pm}_{L/R}\{1,1\}$ determine M_2, μ and $\tan\beta$[7]
- M_1 then extracted from $\sigma^{0}_{L/R}\{1,2\}$ and $\sigma^{0}_{L/R}\{2,2\}$
- Assume $\sqrt{s} \leq 500$ GeV, $500\,\mathrm{fb}^{-1}$, $P_{e^-} = \mp 80\%$ and $P_{e^+} = \pm 60\%$

SUSY Parameters				Mass Predictions		
M_1	M_2	μ	$\tan\beta$	$m_{\tilde{\chi}^{\pm}_2}$	$m_{\tilde{\chi}^0_3}$	$m_{\tilde{\chi}^0_4}$
99.1 ± 0.2	192.7 ± 0.6	352.8 ± 8.9	10.3 ± 1.5	378.8 ± 7.8	359.2 ± 8.6	378.2 ± 8.1

Table: SUSY parameters with 1σ errors derived from the analysis of the assumed LC data collected at the first phase of operation. Shown are also the predictions for the heavier chargino/neutralino masses.

[6] K. Desch, J. Kalinowski, G. A. Moortgat-Pick, M. M. Nojiri and G. Polesello, [arXiv:hep-ph/0312069].

[7] Input SPS1a: $M_1 = 99.13$ GeV, $M_2 = 192.7$ GeV, $\mu = 352.4$ GeV and $\tan\beta = 10$

Parameter renormalisation details

- Requiring these masses to be on-shell, 1-loop correction must vanish,

$$\Delta m_{\tilde{\chi}_i} = \frac{m_{\tilde{\chi}_i}}{2}\mathrm{Re}[\hat{\Sigma}^{L}_{ii}(m^2_{\tilde{\chi}_i})+\hat{\Sigma}^{R}_{ii}(m^2_{\tilde{\chi}_i})]+\frac{1}{2}\mathrm{Re}[\hat{\Sigma}^{SL}_{ii}(m^2_{\tilde{\chi}_i})+\hat{\Sigma}^{SR}_{ii}(m^2_{\tilde{\chi}_i})] = 0,$$

  results in renormalisation conditions fixing $\delta|M_1|$, $\delta|M_2|$, $\delta|\mu|$

- Here the self energy is written via

$$\Sigma_{ij}(p^2) = \not{p}\omega_L\Sigma^{L}_{ij}(p^2) + \not{p}\omega_R\Sigma^{R}_{ij}(p^2) + \omega_L\Sigma^{SL}_{ij}(p^2) + \omega_R\Sigma^{SR}_{ij}(p^2)$$

  and $\omega_{L/R} = \frac{1}{2}(1 \mp \gamma_5)$

Analogy to the CKM Matrix

- On-shell conditions result in inconsistent equations due to branch cuts in self energies[8]
- Ignore absorptive parts $\Rightarrow$ gauge dependence of δV_{CKM}
- Possible solutions via mass renormalization[9], but not fully on-shell
- Require separate **incoming and out-going** wfr constants [10], 0.5% observable difference

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[10] D. Espriu, J. Manzano and P. Talavera, Phys. Rev. D **66**, 076002 (2002)