DM production from SUSY decays at the LC

Federico von der Pahlen

IFCA (CSIC, Santander)

in collaboration with A. Bharucha, S. Heinemeyer and C. Schappacher

Based on

Phys. Rev. D 86 (2012) 075023

Eur. Phys. J. C 72 (2012) 1892

ECFA LC2013, DESY, 30.05.2013

DM from SUSY production at the LC

- Introduction
  - The complex MSSM and CPV
  - LHC searches for DM
- Decays to neutralinos: precision calculations
  - Our framework
  - Numerical results
- Summary and Conclusions

Introduction

Low Energy Supersymmetry (here MSSM)

- Solves hierarchy/naturalness problem:
  Higgs mass stable against rad.corr. $m_H \sim \mathcal{O}(M_Z)$
- Provides a natural candidate for CDM:
  here the neutralino $\tilde{\chi}_1^0$ $m_{\tilde{\chi}^0/\tilde{\chi}^\pm} < \mathcal{O}(\mathrm{TeV})$
- Unification of gauge couplings @ M_{GUT}: GUT relations?

CP-violation

- Baryon asymmetry: CP-violation in the SM not large enough
  MSSM with complex couplings (cMSSM)
  $\Rightarrow$ new sources of CP-violation

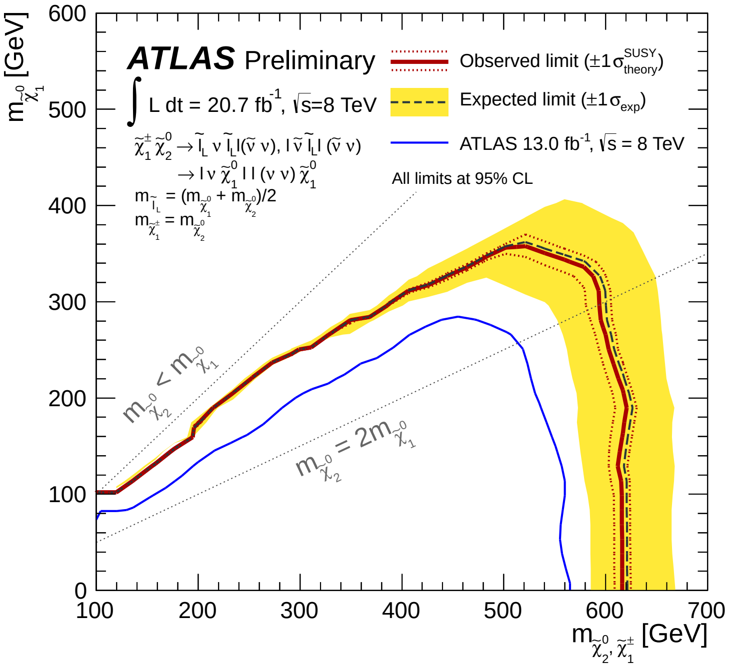
DM production @ coliders

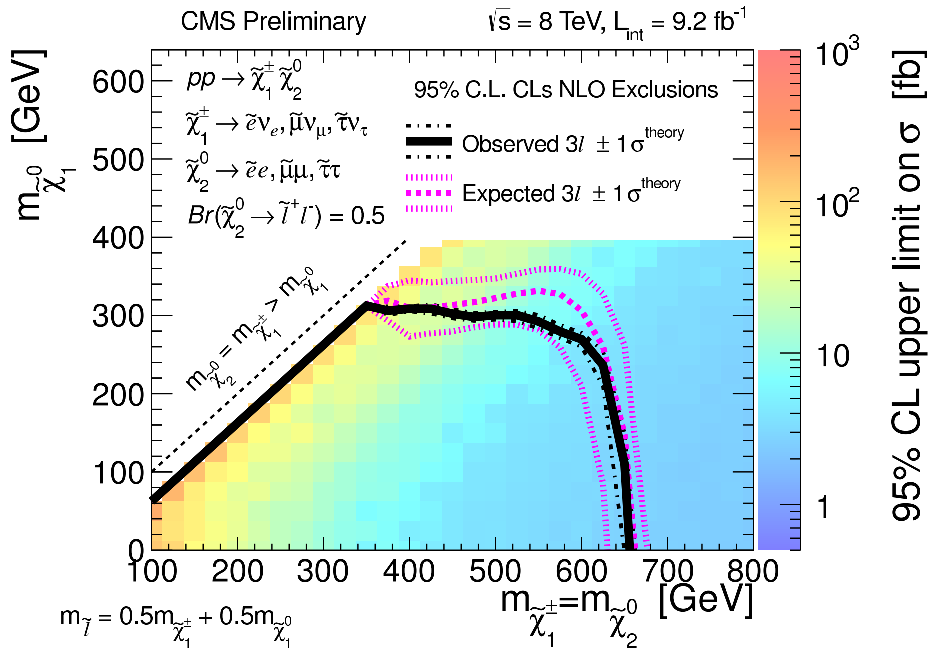
- SUSY cascades to LSP
  - loop corrections must be under control
  - including effects from CP phases
  - Q: determination of fundamental parameters?
- Largest production cross sections at the LHC: colored particles
- Direct $\tilde{\chi}^{\pm}/\tilde{\chi}^{0}$ production: LHC sensitive to lower masses
- SUSY production at ILC: EW production

Chargino/Neutralino searches @LHC

$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to$ sleptons $\to 3\ell\tilde{\chi}_1^0\tilde{\chi}_1^0$:

most sensitive channel for direct $\tilde{\chi}^{\pm}\tilde{\chi}^0$ production





Chargino/Neutralino searches @LHC

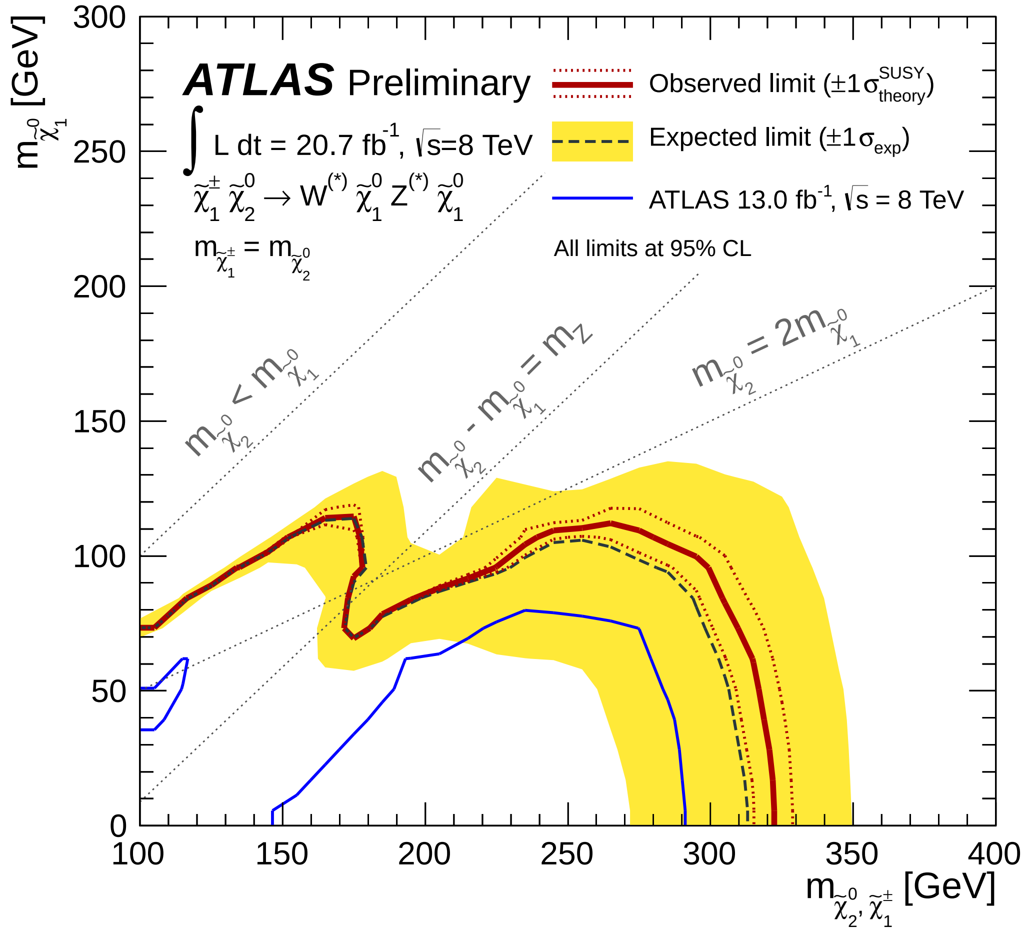
$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$

Assume:

- $m_{\tilde{\chi}_1^{\pm}} \simeq m_{\tilde{\chi}_2^0}$
- heavier sleptons

Exclusion limits for:

- gaugino-like $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$
- bino-like $\tilde{\chi}_1^0$
- $\mathrm{BR}(\tilde{\chi}_1^{\pm} \to W^{\pm}\tilde{\chi}_1^0) = 1$
- $\mathrm{BR}(\tilde{\chi}_2^0 \to Z\tilde{\chi}_1^0) = 1$



Simplified Model Spectra analysis: interpret carefully

Chargino/Neutralino searches @LHC

$pp \to \tilde{\chi}_1^{\pm}\tilde{\chi}_2^0 \to W\tilde{\chi}_1^0 Z\tilde{\chi}_1^0$

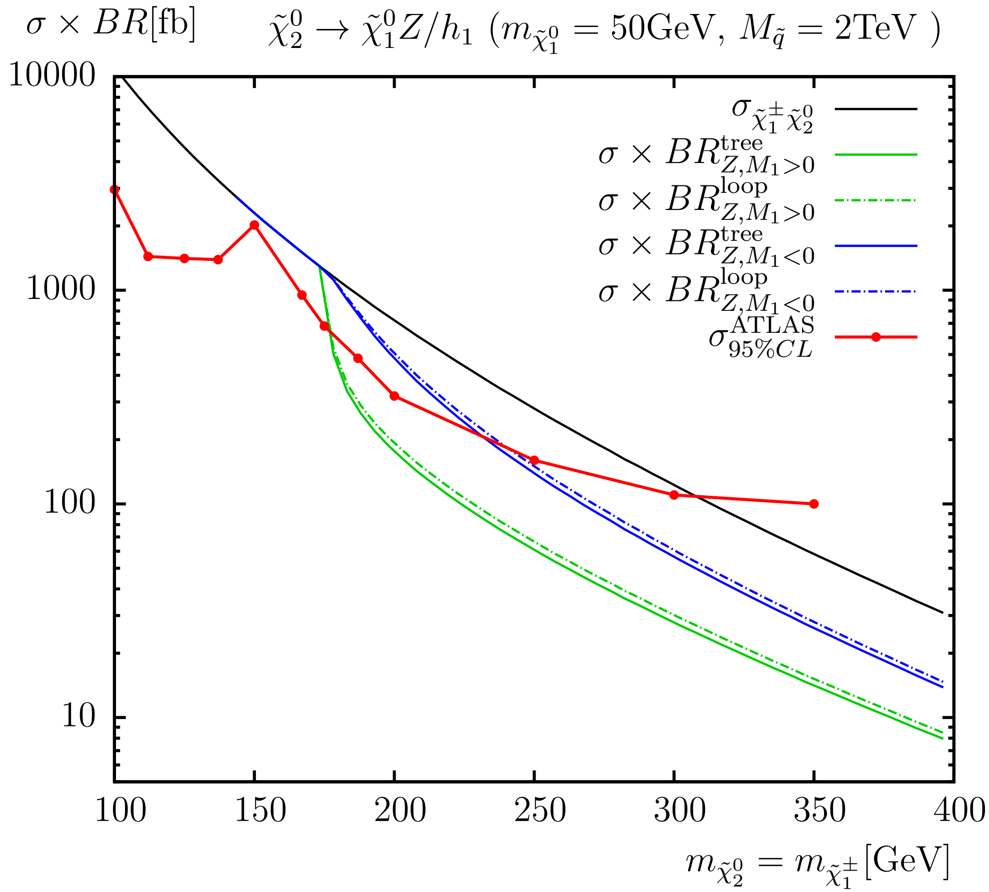
Assume:

- $m_{\tilde{\chi}_1^{\pm}} \simeq m_{\tilde{\chi}_2^0}$
- heavier sleptons

Exclusion limits for:

- gaugino-like $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$
- bino-like $\tilde{\chi}_1^0$
- including $(\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h_1)$

[Bharucha,Heinemeyer,FP]



DM @ILC

How good is the ILC?

Expect precision at the $\mathcal{O}(\%)$ level

$\Rightarrow$ need precision calculations to match experimental accuracy!

(see f.i. talk from M.Chera): $\tilde{\chi}_2^0/\tilde{\chi}_1^\pm$ in hadronic decays to W, Z

* $\mathcal{L} = 500 \text{ fb}^{-1} \quad @500 \text{ GeV}, \; P(e^+e^-) = (30\%, -80\%)$
* $m_{\tilde{\chi}_1^0} \simeq 115 \text{ GeV}$, $m_{\tilde{\chi}_2^0} \simeq m_{\tilde{\chi}_1^\pm} \simeq 215 \text{ GeV}$
* $\sigma(\tilde{\chi}_1^\pm) \simeq 130 \text{ fb}$, $\sigma(\tilde{\chi}_2^0) \simeq 23 \text{ fb}$

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Changing $m_{\tilde{\chi}_1^0} < 90 \text{ GeV} \Rightarrow$ decay to h_1 opens up

* $\tilde{\chi}_2^0 \to \tilde{\chi}_1^0 h_1$ possibly dominant channel, $h_1 \to b\bar{b}$ main channel

Precision calculations: cMSSM @ one-loop

Aim: consistent one-loop calculation of
all two-body decay widths and BRs in the cMSSM
to be implement in FeynHiggs

$\Rightarrow$ need consistent renormalization of the full cMSSM

Previous analyses: restricted to single decay channels.

rMSSM: $\Gamma(\tilde{q} \to q\tilde{\chi}^0_j)$, @1 loop QCD [Djouadi, Hollik, Junger '96]
rMSSM: $\Gamma(\tilde{q} \to q\tilde{\chi}^0_j)$, @1 loop [Guasch, Hollik, Sola '01, '02]
rMSSM: $\Gamma(\tilde{\chi}^0_i \to \tilde{\chi}^0_j \ell^+ \ell^-)$, $\Gamma_{\text{Tot}}(\tilde{\chi}^0_i)$, @1 loop, no QCD [Drees, Hollik, Xu '06]
rMSSM: $\Gamma(\tilde{\chi}^{\pm/0}_i \to W^\pm \tilde{\chi}^{0/\mp}_j)$, @1 loop [Liebler, Porod '10]
cMSSM: $\Gamma(\tilde{\chi}^0_i \to \tilde{\chi}^0_j h_k)$, full 1 loop [Fowler, Weiglein, '09]

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Two-body decays in the cMSSM:

$\tilde{t}$ decays [Fritzsche, Heinemeyer, Rhezak, Schappacher '11]

$\tilde{g}$ decays [Heinemeyer,Schappacher '11]

$\tilde{\tau}$ decays [Heinemeyer, Schappacher '12]

$\tilde{\chi}^{\pm}$ decays [Heinemeyer, Schappacher, FP '11]

$\tilde{\chi}^{0}$ decays [Bharucha, Heinemeyer, Schappacher, FP '12]

Simultaneous renormalization of the full cMSSM under control!

Complex parameters in the MSSM

Enter at tree-level or via loop corrections:

- μ: Higgsino mass parameter
- $A_{t,b,\tau}$: trilinear couplings
  $\Rightarrow X_{t,b,\tau} = A_{t,b} - \mu^*\{\cot\beta\,, \tan\beta\}$ complex
- $M_{1,2}$: gaugino mass parameter (one phase can be eliminated)
- $m_{\tilde{g}}$: gluino mass

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– $M_{1,2}$: gaugino mass parameter (one phase can be eliminated)

– $m_{\tilde{g}}$: gluino mass

$\Rightarrow$ can induce CP-violating effects

$$(A, H, h) \to (h_3, h_2, h_1)$$

with $M_{h_3} > M_{h_2} > M_{h_1}$

$\Rightarrow$ computed by FeynHiggs

Recap: chargino and neutralino sectors

Chargino and neutralino mass matrices:

$$\mathcal{L}_{\tilde{\chi}\text{mass}} = \begin{pmatrix}\tilde{W}^{\pm} & \tilde{H}^{\pm}\end{pmatrix} \cdot \begin{pmatrix} M_2 & \sqrt{2}\sin\beta\, M_W \\ \sqrt{2}\cos\beta\, M_W & \mu \end{pmatrix} \cdot \begin{pmatrix}\tilde{W}^{\pm} \\ \tilde{H}^{\pm}\end{pmatrix}$$

$$+ \begin{pmatrix}\tilde{B}^0 \tilde{W}^0 \tilde{H}_1^0 \tilde{H}_2^0\end{pmatrix} \cdot \begin{pmatrix} M_1 & 0 & -M_Z\, s_W \cos\beta & M_Z\, s_W \sin\beta \\ 0 & M_2 & M_Z\, c_W \cos\beta & -M_Z\, c_W \sin\beta \\ -M_Z\, s_W \cos\beta & M_Z\, c_W \cos\beta & 0 & -\mu \\ M_Z\, s_W \sin\beta & -M_Z\, c_W \sin\beta & -\mu & 0 \end{pmatrix} \cdot \begin{pmatrix}\tilde{B}^0, \\ \tilde{W}^0, \\ \tilde{H}_1^0, \\ \tilde{H}_2^0\end{pmatrix}$$

Diagonalization $\Rightarrow$ Higgsinos and gauginos mix:

$\tilde{W}^{\pm}, \tilde{H}^{\pm} \rightarrow \tilde{\chi}_1^{\pm}, \tilde{\chi}_2^{\pm}$: chargino mass eigenstates

$\tilde{B}^0, \tilde{W}^0, \tilde{H}_1^0, \tilde{H}_2^0 \rightarrow \tilde{\chi}_1^0, \tilde{\chi}_2^0, \tilde{\chi}_3^0, \tilde{\chi}_4^0$: neutralino mass eigenstates

Common parameters (M_1, M_2, μ), 2 independent CP

Chargino and neutralino sectors: renormalization

On-shell renormalization (Santander-Karlsruhe Scheme):

- renormalize 3 (complex) parameters: $M_1,\ M_2,\ \mu$
- chargino-neutralino sector $\Rightarrow$ 6 mass paramters: $m_{\tilde{\chi}_i^\pm},\ i = 1, 2,\ m_{\tilde{\chi}_j^0},\ j = 1, \ldots, 4$

CCN$_j$ scheme: choose $m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^\pm}, m_{\tilde{\chi}_j^0}$ on-shell $\Rightarrow$ $\delta M_1,\ \delta M_2,\ \delta\mu$

$$\left[\widetilde{\mathrm{Re}}\hat{\Sigma}_{\tilde{\chi}_i^\pm}(p)\right]_{ii}\tilde{\chi}_i^\pm(p)\Big|_{p^2=m^2_{\tilde{\chi}_i^\pm}} = 0, \qquad (i = 1, 2),$$

$$\left[\widetilde{\mathrm{Re}}\hat{\Sigma}_{\tilde{\chi}_j^0}(p)\right]_{jj}\tilde{\chi}_j^0(p)\Big|_{p^2=m^2_{\tilde{\chi}_j^0}} = 0,$$

3 eqs. define 3 complex parameters & field renormalization const.

Choose masses of charged particles as input to avoid IR divergencies

Chargino and neutralino sectors: renormalization

Mass shifts (in CCN_1 Scheme)

$$m_{\tilde{\chi}_j^0} = m^{(0)}_{\tilde{\chi}_j^0} + \Delta m_{\tilde{\chi}_j^0}, \qquad (j = 2, 3, 4)$$

$$\Delta m_{\tilde{\chi}_j^0} = -\tfrac{1}{2}\mathrm{Re}\Big\{\widetilde{\mathrm{Re}}\Big[m_{\tilde{\chi}_j^0}\hat{\Sigma}^L_{\tilde{\chi}_j^0}(m^2_{\tilde{\chi}_j^0}) + \hat{\Sigma}^{SL}_{\tilde{\chi}_j^0}(m^2_{\tilde{\chi}_j^0}) + (L \leftrightarrow R)\Big]\Big\}$$

Shift masses of neutral particles to avoid IR-divergencies (formally of higher order)

Renormalization Scheme comparison

- evaluate with FeynArts/FormCalc/LoopTools/FeynHiggs
- for charged processes: include all hard QED diagrams
- Numerical comparison of all decay channels in both RS

$$\Gamma(\tilde{\chi}^0_i \to \tilde{\chi}^0_j h_k), \quad i,j = 1,...,4,\ k = 1,...,3,$$

$$\Gamma(\tilde{\chi}^0_i \to \tilde{\chi}^0_j Z), \quad i,j = 1,...,4,$$

$$\Gamma(\tilde{\chi}^0_i \to \tilde{\chi}^\pm_j H^\mp), \quad i = 1,2,\ j = 1,...,4,$$

$$\Gamma(\tilde{\chi}^0_i \to \tilde{\chi}^\pm_j W^\mp),$$

$$\Gamma(\tilde{\chi}^0_i \to \ell^\mp \, \tilde{\ell}^\pm_k), \quad i = 1,...,4,\ \ell = \tau,\mu,e,\ k = 1,2$$

$$\Gamma(\tilde{\chi}^0_i \to \nu_\ell \, \tilde{\nu}_\ell), \quad i = 1,...,4,\ \ell = \tau,\mu,e$$

Renormalization Scheme comparison

- evaluate with FeynArts/FormCalc/LoopTools/FeynHiggs
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$$\Gamma(\tilde{\chi}_i^0 \to \tilde{\chi}_j^0 Z), \quad i,j = 1,...,4,$$

$$\Gamma(\tilde{\chi}_i^0 \to \tilde{\chi}_j^\pm H^\mp), \quad i = 1,2, \;\; j = 1,...,4,$$

$$\Gamma(\tilde{\chi}_i^0 \to \tilde{\chi}_j^\pm W^\mp),$$

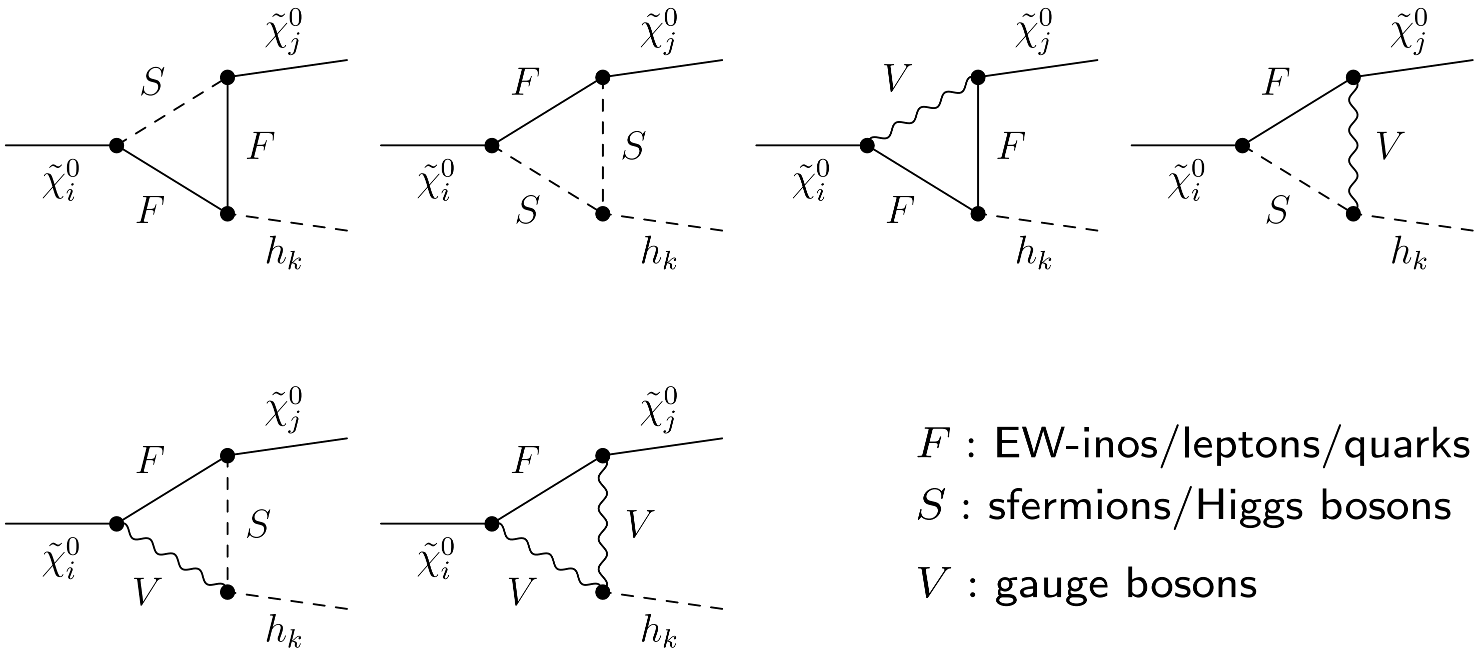
$$\Gamma(\tilde{\chi}_i^0 \to \ell^\mp \tilde{\ell}_k^\pm), \quad i = 1,...,4, \;\; \ell = \tau,\mu,e, \;\; k = 1,2$$

$$\Gamma(\tilde{\chi}_i^0 \to \nu_\ell \tilde{\nu}_\ell), \quad i = 1,...,4, \;\; \ell = \tau,\mu,e$$

- Numerical comparison of all decay channels in both RS

  [Bharucha,Heinemeyer,FP,Schappacher '12]

One loop diagrams: $\tilde{\chi}_4^0 \to \tilde{\chi}_1^0 h_k$



F : EW-inos/leptons/quarks

S : sfermions/Higgs bosons

V : gauge bosons

- evaluate with FeynArts/FormCalc/LoopTools/FeynHiggs
- for charged processes: include all hard QED diagrams

Numerical analysis

Parameters for numerical evaluation

- $m_{\tilde{\chi}_1^\pm} = 350$ GeV, $m_{\tilde{\chi}_2^\pm} = 600$ GeV, $\varphi_\mu = 0$
- μ and M_2 as a function of the chargino masses:

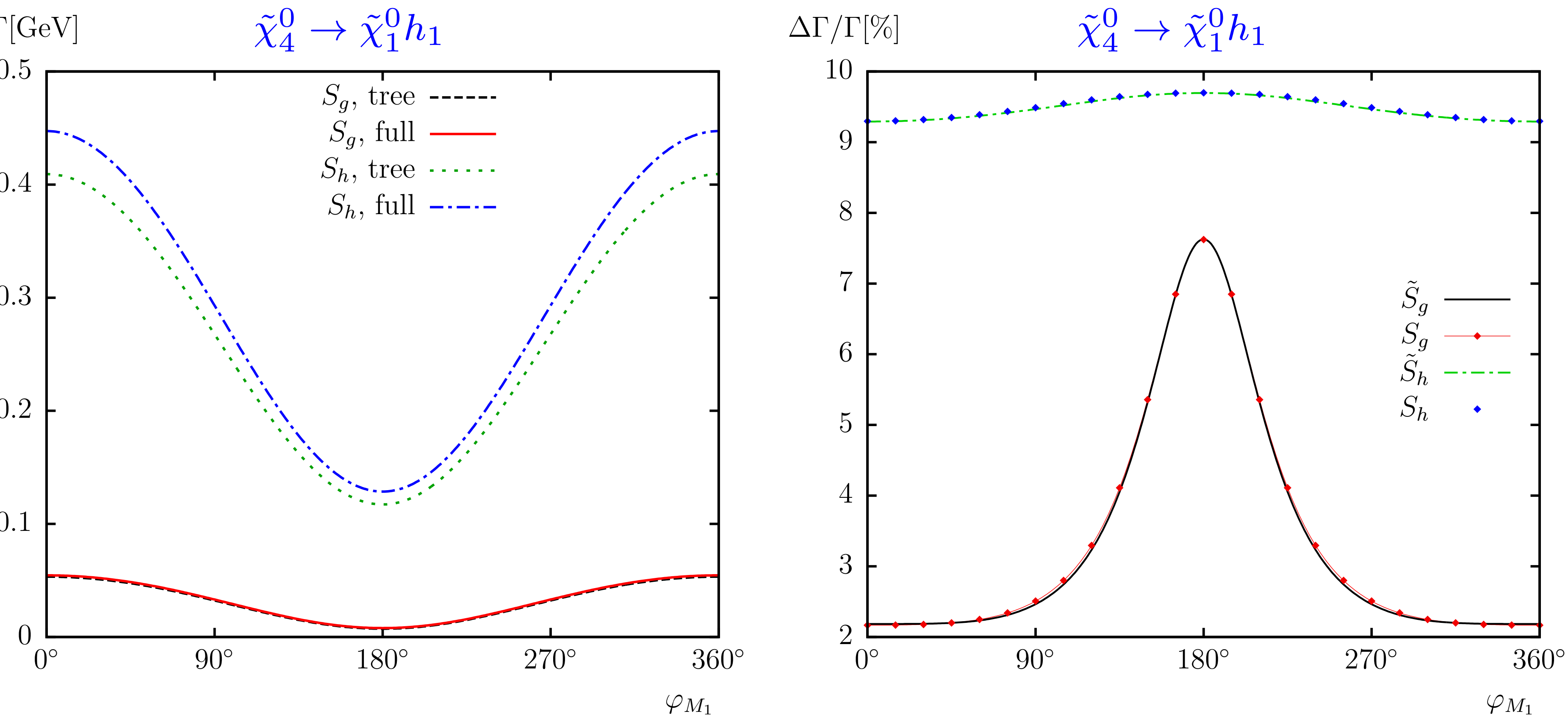
$$S_> = S_h := \{\mu > M_2\} \quad \tilde{\chi}_2^\pm \sim \mathrm{Higgsino-like}$$

$$S_< = S_g := \{\mu < M_2\} \quad \tilde{\chi}_2^\pm \sim \mathrm{wino-like}$$

- $|M_1|$ fixed by GUT relation: $|M_1|/M_2 = 5/3 \tan^2\theta_W \simeq 0.5$
- $\tan\beta = 20$, $\varphi_{M_1} = 0$

Choice of scenario: so that most neutralino decay channels are open

Neutralino decays: φ_{M_1}-dependence

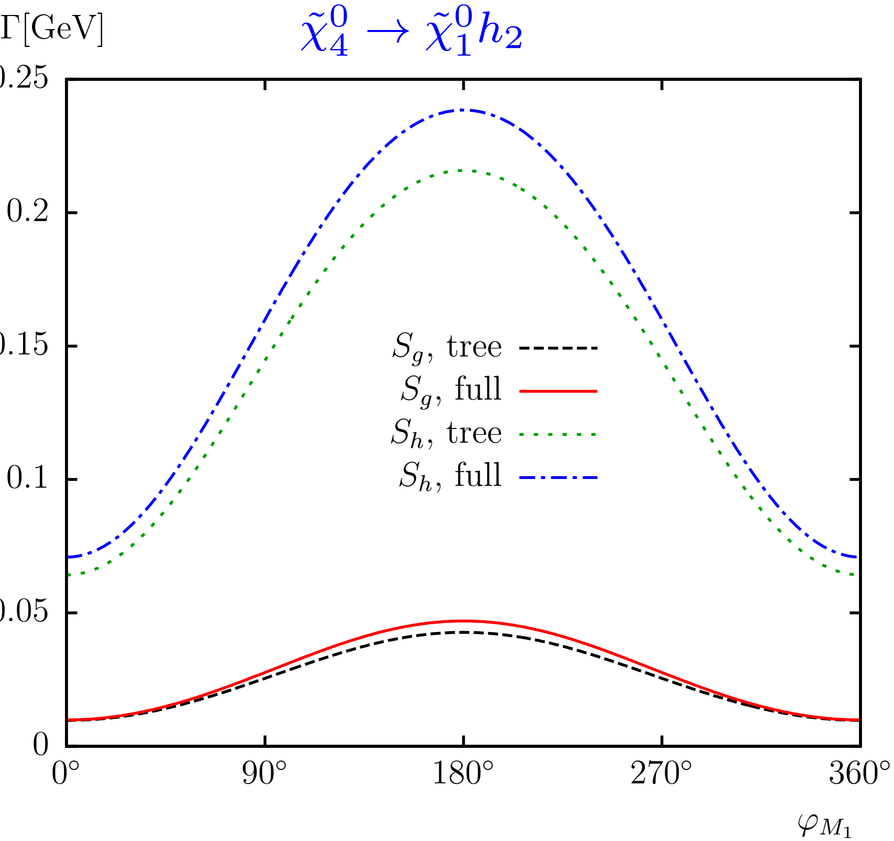


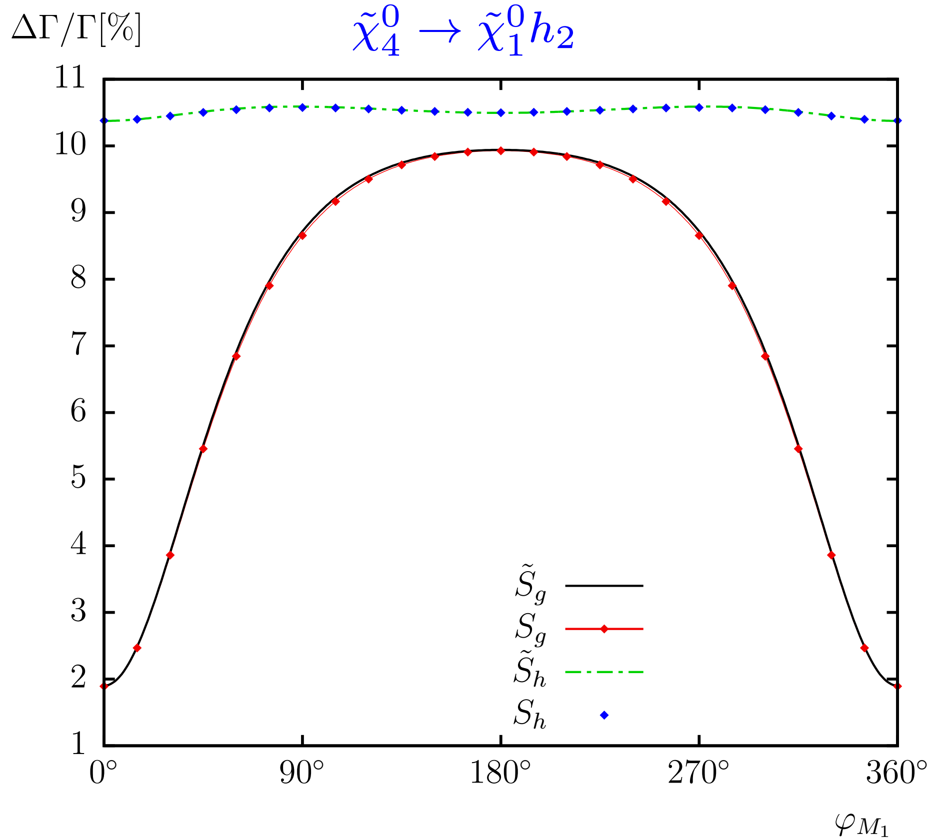
⇒ one-loop corrections under control and non-negligible

⇒ size of BR highly scenario dependent

Very good agreement between RS

Neutralino decays: φ_{M_1}-dependence

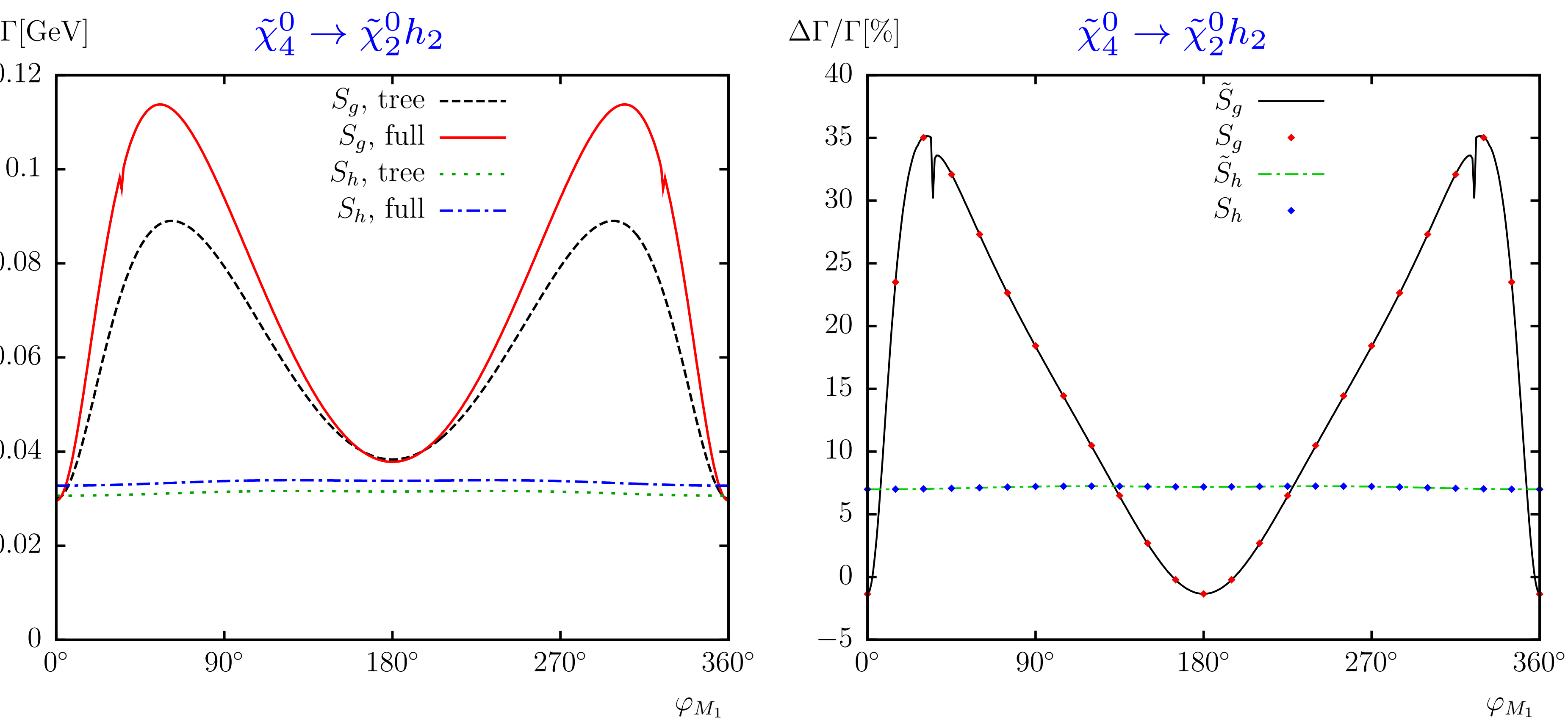




Very good agreement between RS

φ_{M_1}-dependence opposite for h_1 ($\sim h$) and h_2 ($\sim A$) !

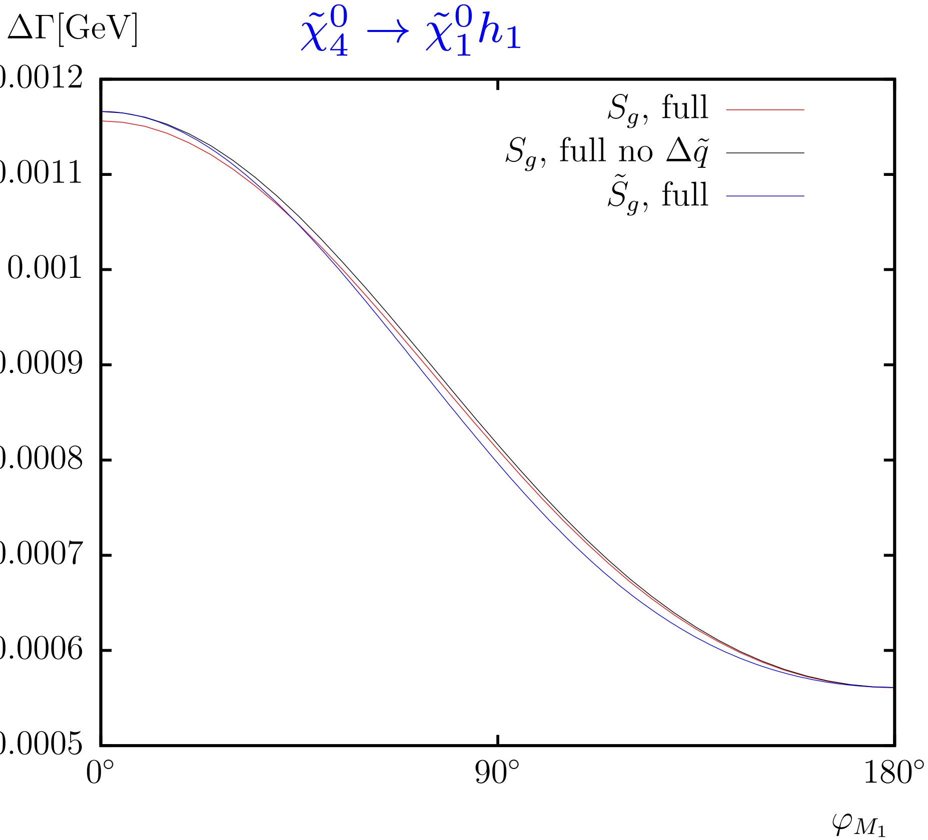
Neutralino decays: φ_{M_1}-dependence



Eventually large corrections to neutralino mixing!

Very good agreement between RS

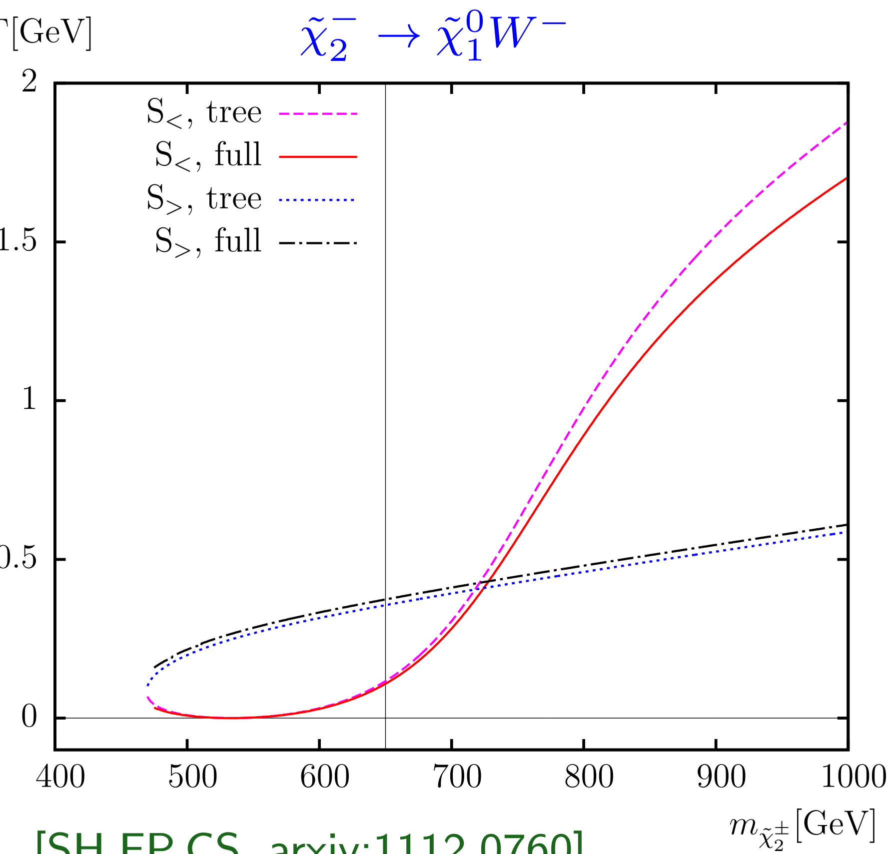
Neutralino decays: comparison of the schemes

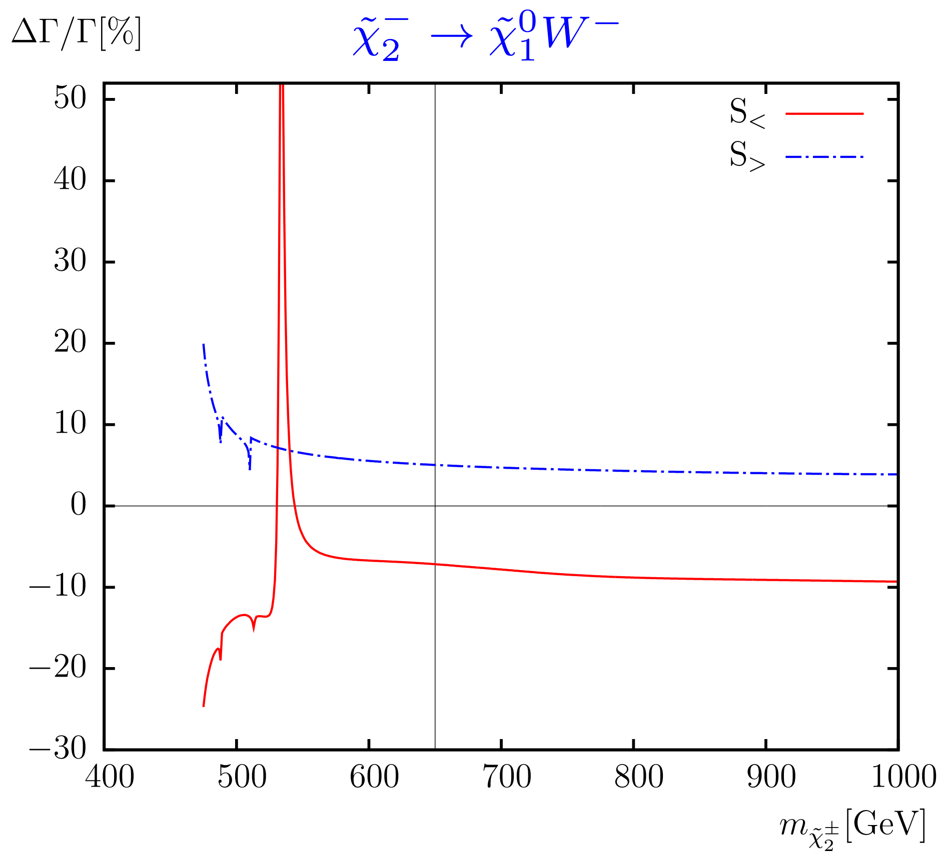


Difference of two-loop order

In CP-conserving limit ($\varphi_{M_1} = 0, \pi$), schemes identical

Chargino decays





[SH,FP,CS, arxiv:1112.0760]

$\Rightarrow$ one-loop corrections under control and non-negligible

$\Rightarrow$ in $\mu \approx M_2$ region need different choice of input parameters

Chargino and neutralino sectors: renormalization

On-Shell scheme have numerical instabilities for some parameters!
$\Rightarrow$ no fundamental problem, need alternative RS conditions

CCN$_j$ scheme: ($m_{\tilde{\chi}_1^\pm}, m_{\tilde{\chi}_2^\pm}, m_{\tilde{\chi}_j^0}$ on-shell)

Mass shifts at one-loop

$$m_{\tilde{\chi}_k^0} = m_{\tilde{\chi}_k^0}^{(0)} + \Delta m_{\tilde{\chi}_k^0}, \qquad (k \neq j)$$

Shift masses of neutral particles to avoid IR-divergencies
(formally of higher order)

CNN$_{i,j,k}$ scheme: ($m_{\tilde{\chi}_i^\pm}, m_{\tilde{\chi}_j^0}, m_{\tilde{\chi}_k^0}$ on-shell)

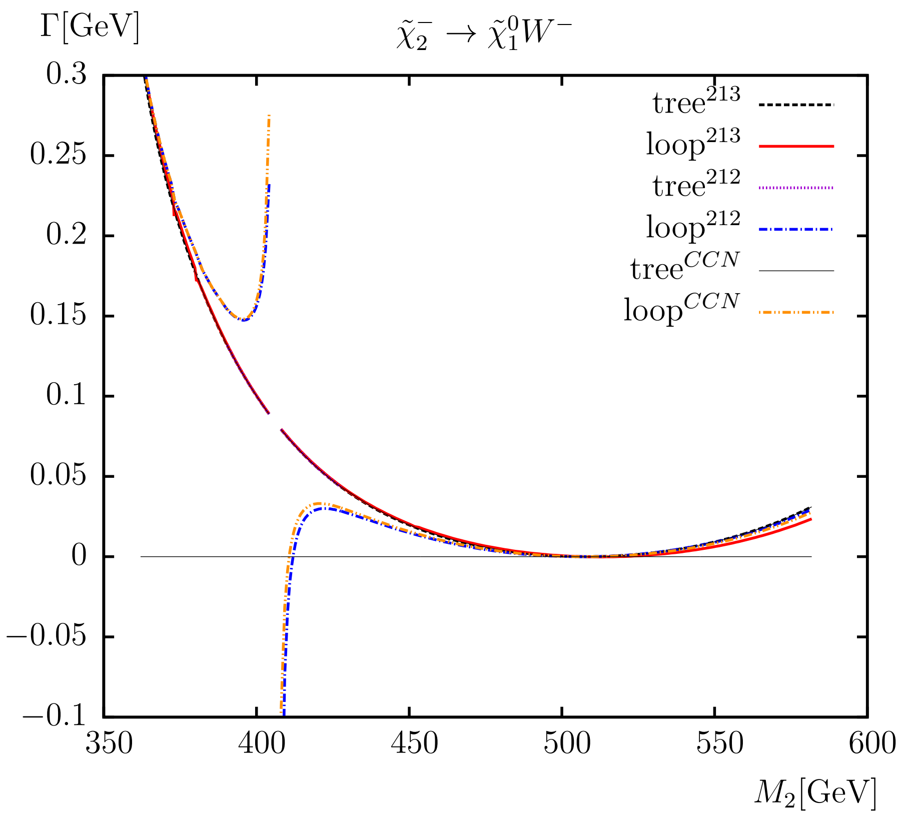
Finite mass shifts for one chargino, two neutralinos

Shift mass of chargino only if not an external particle!

Renormalization schemes: matching

no on-shell scheme works everywhere: here $\mu \simeq M_2$ region

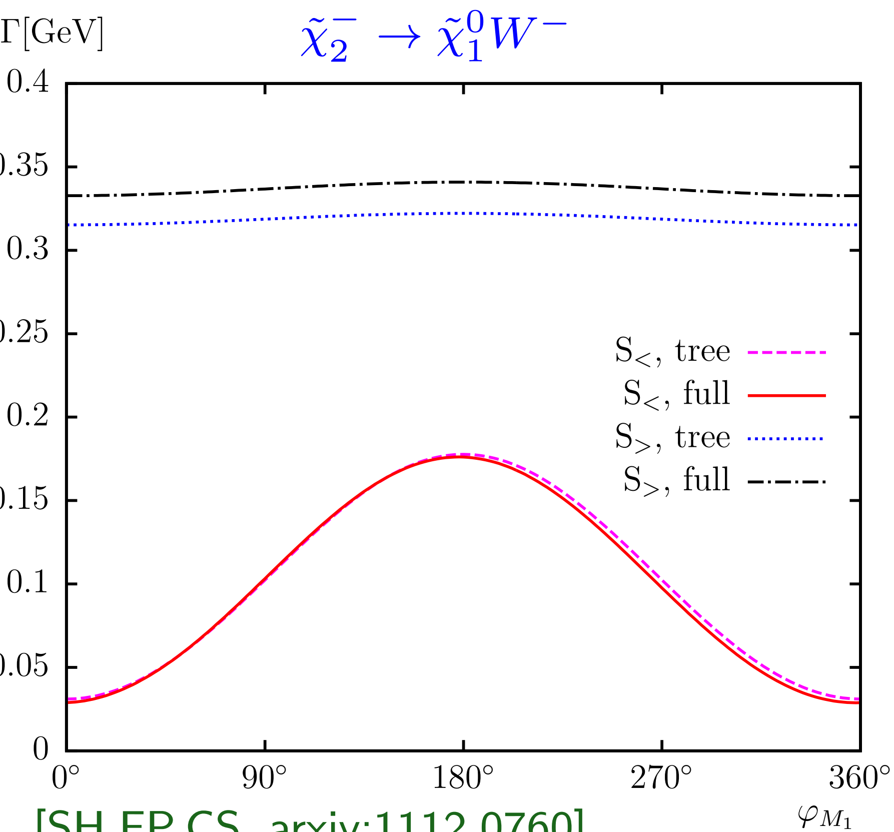
test convergence of perturbative expansion

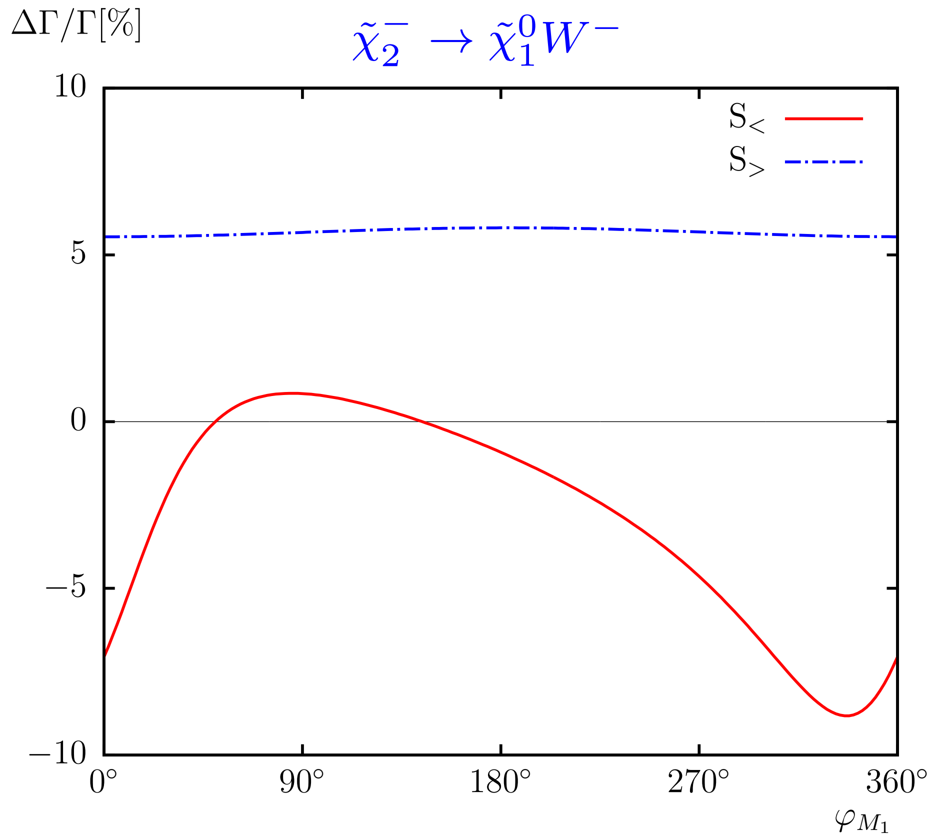


[Heinemeyer,FP]

- different schemes $\Rightarrow$ theory uncertainty of phys. processes
- implement results in HepTools: matching of Ren.Schemes

Chargino decays: φ_{M_1}-dependence





[SH,FP,CS, arxiv:1112.0760]

⇒ one-loop corrections under control and non-negligible

⇒ absorptive contributions → CP violating effects

Chargino decays: φ_{M_1}-dependence: $\mathcal{CP}$ Asymmetry

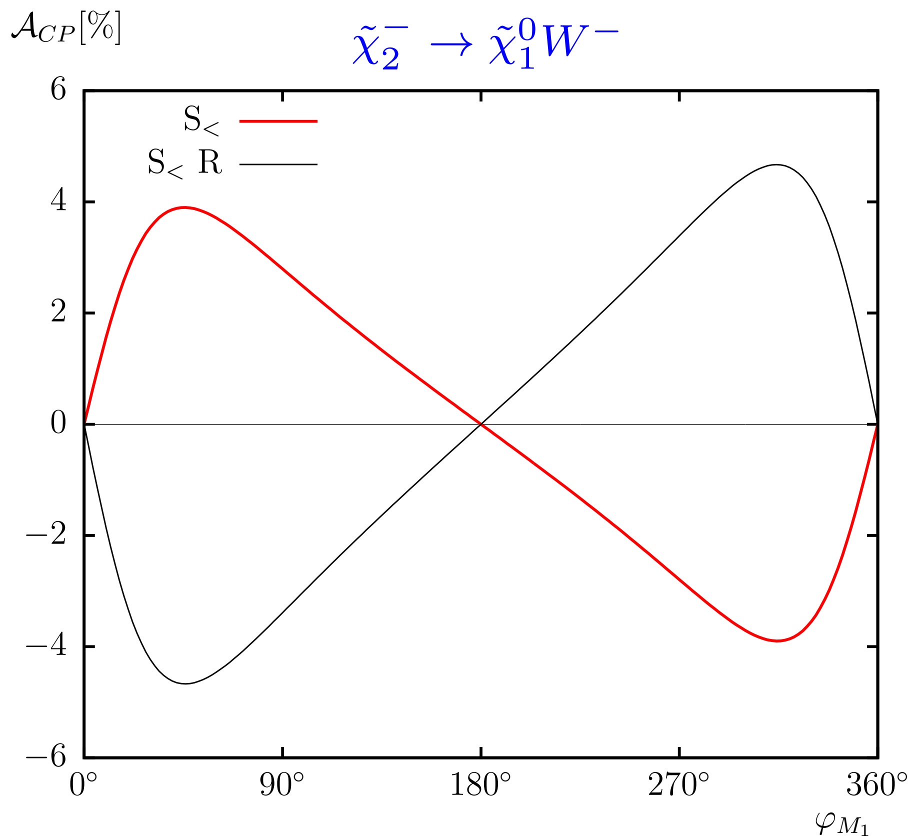
$$\mathcal{A}_{\mathcal{CP}} = \frac{\Gamma(\tilde{\chi}_2^- \to \tilde{\chi}_1^0 W^-) - \Gamma(\tilde{\chi}_2^+ \to \tilde{\chi}_1^0 W^+)}{\Gamma(\tilde{\chi}_2^- \to \tilde{\chi}_1^0 W^-) + \Gamma(\tilde{\chi}_2^+ \to \tilde{\chi}_1^0 W^+)}$$

$$\mathcal{A}_{\mathcal{CP}} \propto \mathcal{M}^*_{\text{tree}} \times (\mathcal{M}^{\text{loop}}_{\tilde{\chi}^-} - \mathcal{M}^{\text{loop}}_{\tilde{\chi}^+})$$

$\mathcal{A}_{\mathcal{CP}} \neq 0 \Rightarrow$

absorptive contributions

and complex couplings



Chargino decays: φ_{M_1}-dependence: $\mathcal{CP}$ Asymmetry

$$\mathcal{A}_{\mathcal{CP}} = \frac{\Gamma(\tilde{\chi}_2^- \to \tilde{\chi}_1^0 W^-) - \Gamma(\tilde{\chi}_2^+ \to \tilde{\chi}_1^0 W^+)}{\Gamma(\tilde{\chi}_2^- \to \tilde{\chi}_1^0 W^-) + \Gamma(\tilde{\chi}_2^+ \to \tilde{\chi}_1^0 W^+)}$$

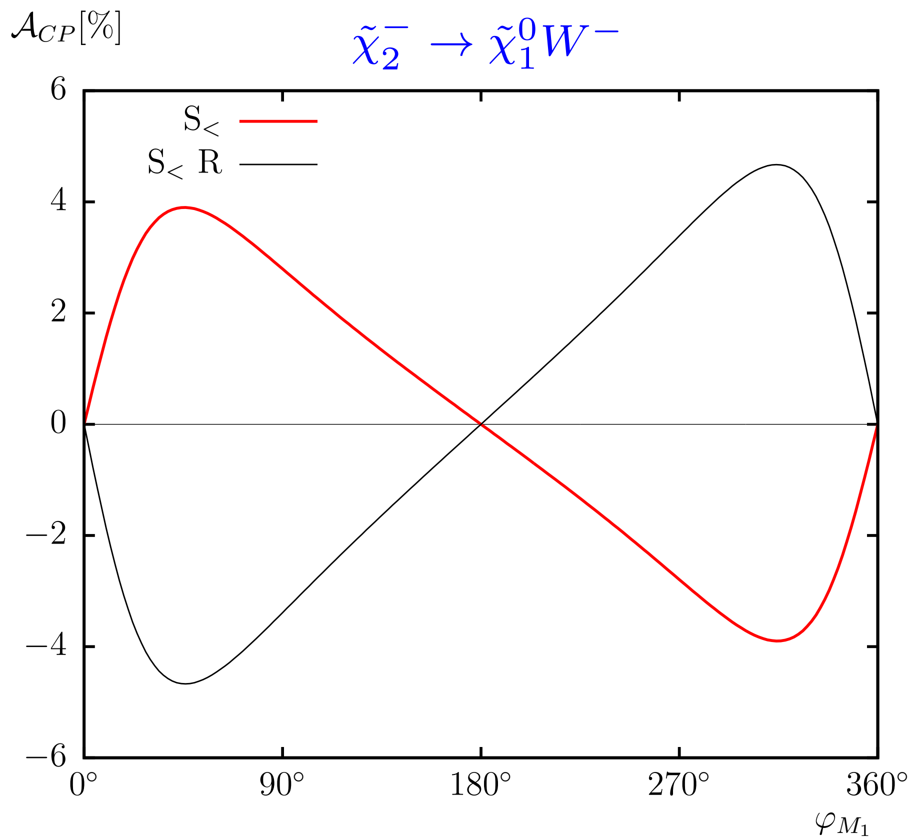
$$\mathcal{A}_{\mathcal{CP}} \propto \mathcal{M}^*_{\rm tree} \times (\mathcal{M}^{\rm loop}_{\tilde{\chi}^-} - \mathcal{M}^{\rm loop}_{\tilde{\chi}^+})$$

$\mathcal{A}_{\mathcal{CP}} \neq 0 \Rightarrow$

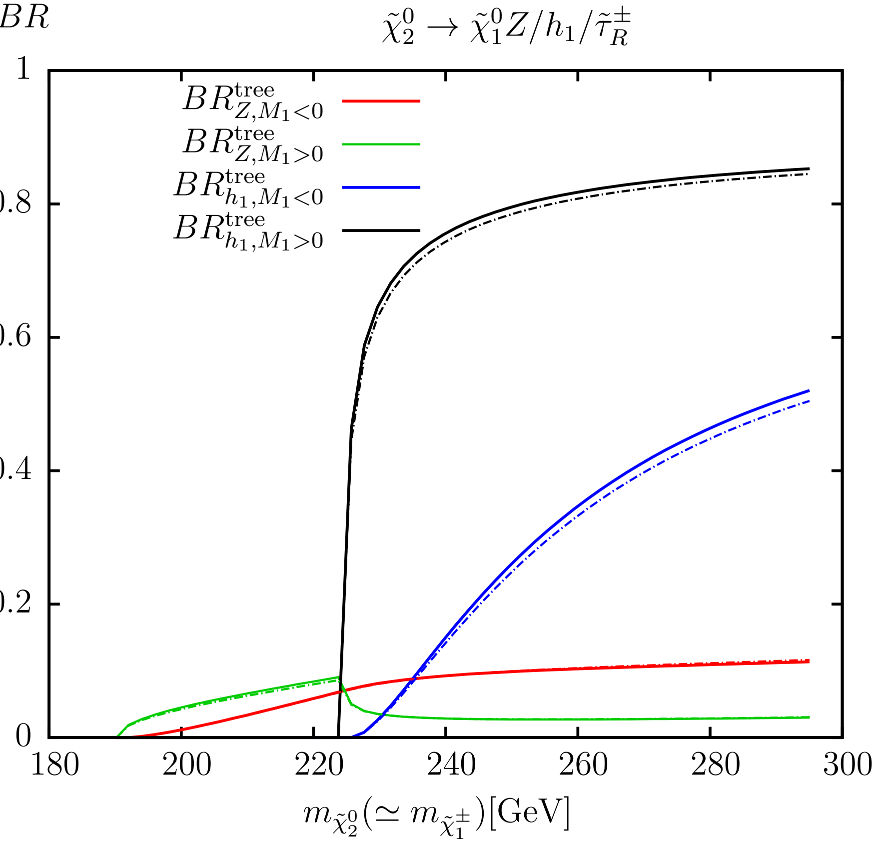
absorptive contributions

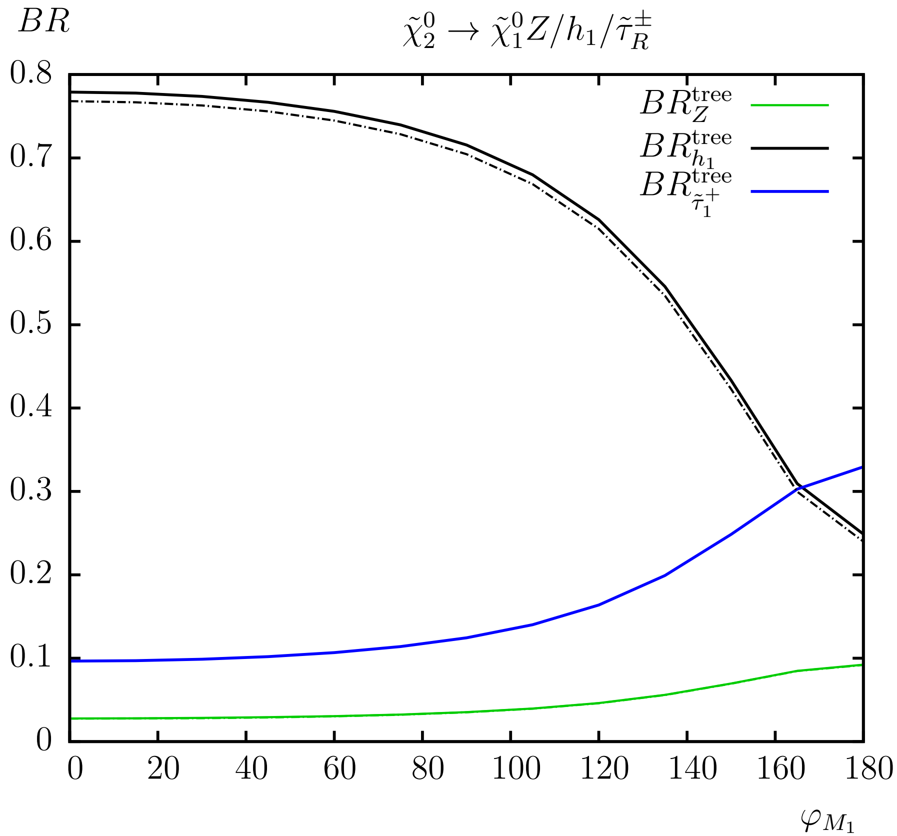
and complex couplings

$\Rightarrow \mathcal{A}_{\mathcal{CP}} \sim \mathcal{O}(\%)$



Neutralino decays: Branching Ratios





$$\mu = 1 \text{ TeV}, \ \tan\beta = 5, \ M_{SUSY} = 2 \text{ TeV}, \ m_{\tilde{\tau}^+_R} = m_{\tilde{\chi}^0_1} + 7 \text{ GeV} \quad (m_{\tilde{\chi}^0_2} = 250 \text{ GeV})$$

- $\Rightarrow$ BR highly dependent on φ_{M_1}
- Parameter determination $\Rightarrow$ measure precisely different decay channels

Conclusions

- DM production @ LC: need precision calculations
- Chargino/Neutralino on-shell renormalization:
  - Compared two on-shell RS: perfect agreeement
- Neutralino and Chargino decays:
  - $\sim 10\%$ loop corrections for EW decays
- Consistent framework for 1-loop calculations in the complex MSSM

backup transparencies

Chargino and neutralino sectors: renormalization

Unity residuum of renormalized propagator $\Rightarrow$

$$\lim_{p^2 \to m^2_{\tilde{\chi}_i^\pm}} \frac{(\not{p} + m_{\tilde{\chi}_i^\pm}) \left[\widetilde{\mathsf{Re}}\hat{\Sigma}_{\tilde{\chi}_i^\pm}(p)\right]_{ii}}{p^2 - m^2_{\tilde{\chi}_i^\pm}} \tilde{\chi}_i^\pm(p) = 0, \qquad (i = 1, 2)$$

$$\lim_{p^2 \to m^2_{\tilde{\chi}_j^0}} \frac{(\not{p} + m_{\tilde{\chi}_j^0}) \left[\widetilde{\mathsf{Re}}\hat{\Sigma}_{\tilde{\chi}_j^0}(p)\right]_{jj}}{p^2 - m^2_{\tilde{\chi}_j^0}} \tilde{\chi}_j^0(p) = 0, \qquad (j = 1, 2, 3, 4)$$

Combine with on-shell conditions $(i = 1, 2,\ j = 1) \Rightarrow \delta M_1, \delta M_2, \delta\mu$
with, f.i.,

$$\delta M_2 = f(U, V, \widetilde{\mathsf{Re}}[\Sigma^{L/R/SL/LR}_{\tilde{\chi}_i^\pm}])$$

$\Rightarrow$ diagonal field renormalization constants

$\mathsf{Im}\,\delta\mathbf{Z}_{(\tilde{\chi}_i^\pm)}^{L/R} := 0,\ \ \mathsf{Im}\,\delta\mathbf{Z}_{(\tilde{\chi}_1^0)}^{L/R} := 0$

Chargino and neutralino sectors: renormalization

Off-diagonal renormalized self energies:

$$\left[\widetilde{\mathrm{Re}}\hat{\Sigma}_{\tilde{\chi}_i^\pm}(p)\right]_{ij}\tilde{\chi}_i^\pm(p)\Big|_{p^2=m^2_{\tilde{\chi}_j^\pm}} = 0, \qquad (i,j=1,2),\ i\neq j$$

$$\left[\widetilde{\mathrm{Re}}\hat{\Sigma}_{\tilde{\chi}_j^0}(p)\right]_{ij}\tilde{\chi}_j^0(p)\Big|_{p^2=m^2_{\tilde{\chi}_1^0}} = 0, \qquad (i,j=1,2,3,4),\ i\neq j$$

$\Rightarrow$ fix off-diagonal field RC

Chargino and neutralino sectors: renormalization

Mass shifts (in CCN_1 Scheme)

$$m_{\tilde{\chi}_j^0} = m_{\tilde{\chi}_j^0}^{(0)} + \Delta m_{\tilde{\chi}_j^0}, \qquad (j = 2, 3, 4)$$

$$\Delta m_{\tilde{\chi}_j^0} = -\tfrac{1}{2}\mathrm{Re}\Big\{\widetilde{\mathrm{Re}}\Big[m_{\tilde{\chi}_j^0}\hat{\Sigma}^L_{\tilde{\chi}_j^0}(m^2_{\tilde{\chi}_j^0}) + \hat{\Sigma}^{SL}_{\tilde{\chi}_j^0}(m^2_{\tilde{\chi}_j^0}) + (L \leftrightarrow R)\Big]\Big\}$$

Shift masses of neutral particles to avoid IR-divergencies (formally of higher order)

Chargino and neutralino sectors: renormalization

Scheme II (Durham-Hamburg): Take real part only:

$$\left[\text{Re}\hat{\Sigma}_{\tilde{\chi}_i^\pm}(p)\right]_{ii}\tilde{\chi}_i^\pm(p)\Big|_{p^2=m^2_{\tilde{\chi}_i^\pm}} = 0, \qquad (i = 1, 2),$$

$$\left[\text{Re}\hat{\Sigma}_{\tilde{\chi}_1^0}(p)\right]_{ii}\tilde{\chi}_j^0(p)\Big|_{p^2=m^2_{\tilde{\chi}_1^0}} = 0,$$

Only 3 real conditions:

Compute $\delta|M_1|, \delta|M_2|, \delta|\mu|$,

set $\delta\varphi_{M_1} = \delta\varphi_{M_2} = \delta\varphi_\mu = 0$, (phase CT's must be finite)
$\text{Im}\,\delta\mathbf{Z}_{(\tilde{\chi}_i^\pm)}^{L/R} \neq 0$, $\text{Im}\,\delta\mathbf{Z}_{(\tilde{\chi}_1^0)}^{L/R} \neq 0$

- Ren.Schemes are equal in the rMSSM
- difference of two-loop order → see numerical results