Chargino decays in the complex MSSM: full 1-loop analysis

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Chargino decays in the complex MSSM: full 1-loop analysis

- Introduction and Renormalization of the cMSSM
- Chargino decay widths and BRs
- Summary and Outlook

Introduction

Low Energy Supersymmetry (here MSSM)

- hierarchy/naturalness problem:
  quadratic divergences to the self energy of scalars cancel out and stabilise the Higgs mass against radiative corrections
- Provides a natural candidate for CDM:
  here the neutralino $\tilde{\chi}_1^0$ (other groups, other candidates)
- Unification of gauge couplings:
  GUT scale M_{GUT} below the Plank mass M_{Plank}

CP-violation

- Baryon asymmetry: CP-violation in the SM not large enough

  MSSM with complex couplings (cMSSM)
  $\Rightarrow$ new sources of CP-violation

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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need ILC experimental precision
& matching theoretical precision

Higgs sector in the cMSSM

- CP-conserving at tree-level
- Complex parameters enter via loop corrections:

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

with

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

$\Rightarrow$ computed in FeynHiggs

Chargino and neutralino sectors

Chargino and neutralino mass matrices:

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

$$+ \left(\tilde{B}^0 \tilde{W}^0 \tilde{H}_1^0 \tilde{H}_2^0\right) \cdot \begin{pmatrix} M_1 & 0 & -M_Z\, s_\text{W} \cos\beta & M_Z\, s_\text{W} \sin\beta \\ 0 & M_2 & M_Z\, c_\text{W} \cos\beta & -M_Z\, c_\text{W} \sin\beta \\ -M_Z\, s_\text{W} \cos\beta & M_Z\, c_\text{W} \cos\beta & 0 & -\mu \\ M_Z\, s_\text{W} \sin\beta & -M_Z\, c_\text{W} \sin\beta & -\mu & 0 \end{pmatrix} \cdot \begin{pmatrix} \tilde{B}^0 \\ \tilde{W}^0 \\ \tilde{H}_1^0 \\ \tilde{H}_2^0 \end{pmatrix}$$

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 $\Rightarrow$
relations between masses and couplings of $\tilde{\chi}^{\pm}$ and $\tilde{\chi}^0$

Renormalization of the cMSSM

Aim: simultaneous renormalization of the whole cMSSM

$\longrightarrow$ results for chargino/neutralino sector

- renormalize 3 parameters: $M_1,\ M_2,\ \mu$
- $\Rightarrow 3$ on-shell renormalization conditions:
  use 3 observables $m_{\tilde{\chi}_1^\pm}$, $m_{\tilde{\chi}_2^\pm}$, $m_{\tilde{\chi}_1^0}$

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Rest of cMSSM: on-shell renormalization $+ \tan\beta\ \overline{\rm DR}$

Chargino decays

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

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No hadronic decays yet:

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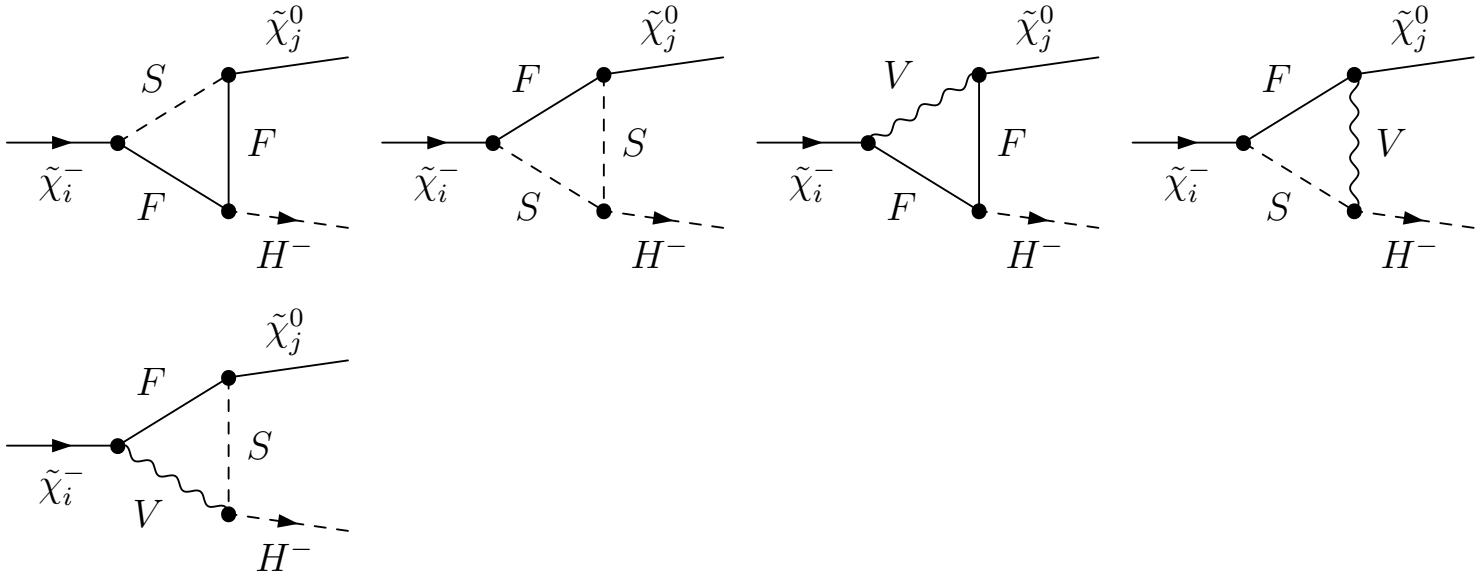
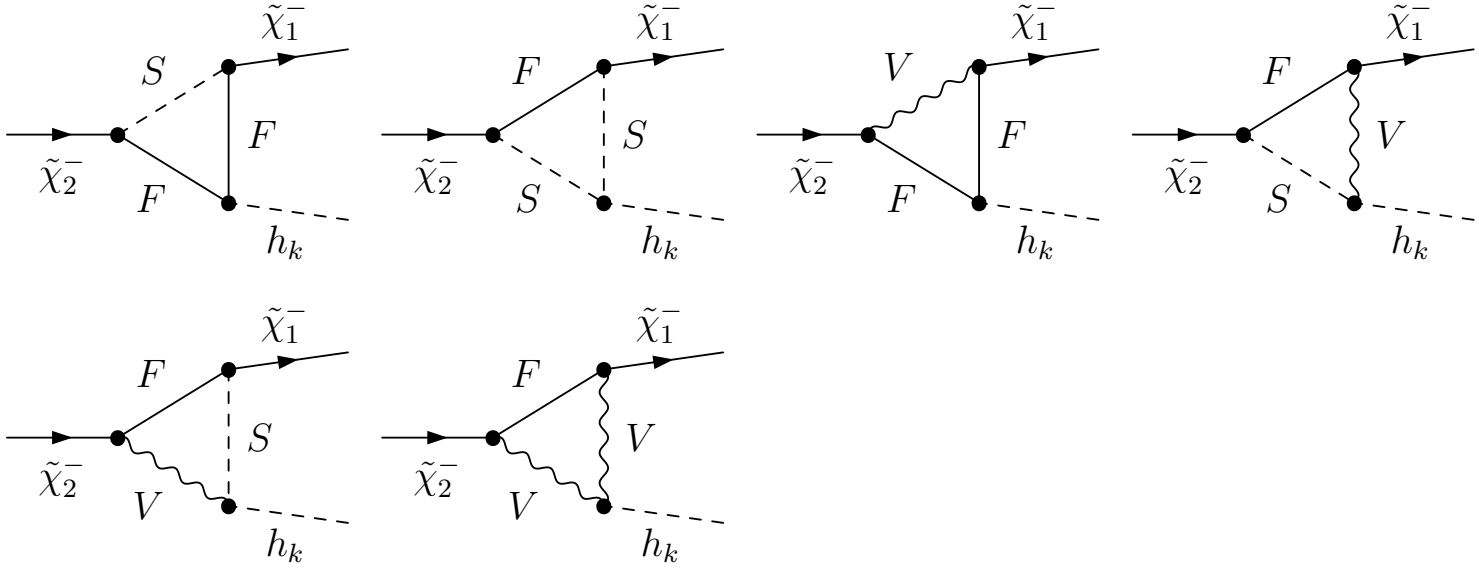
Branching Ratios: compute all decay widths

Feynman diagrams for $\tilde{\chi}_i^- \to \tilde{\chi}_j^0 H^-$



+ including all hard QED diagrams

Feynman diagrams for $\tilde{\chi}_2^- \to \tilde{\chi}_1^- h_k$



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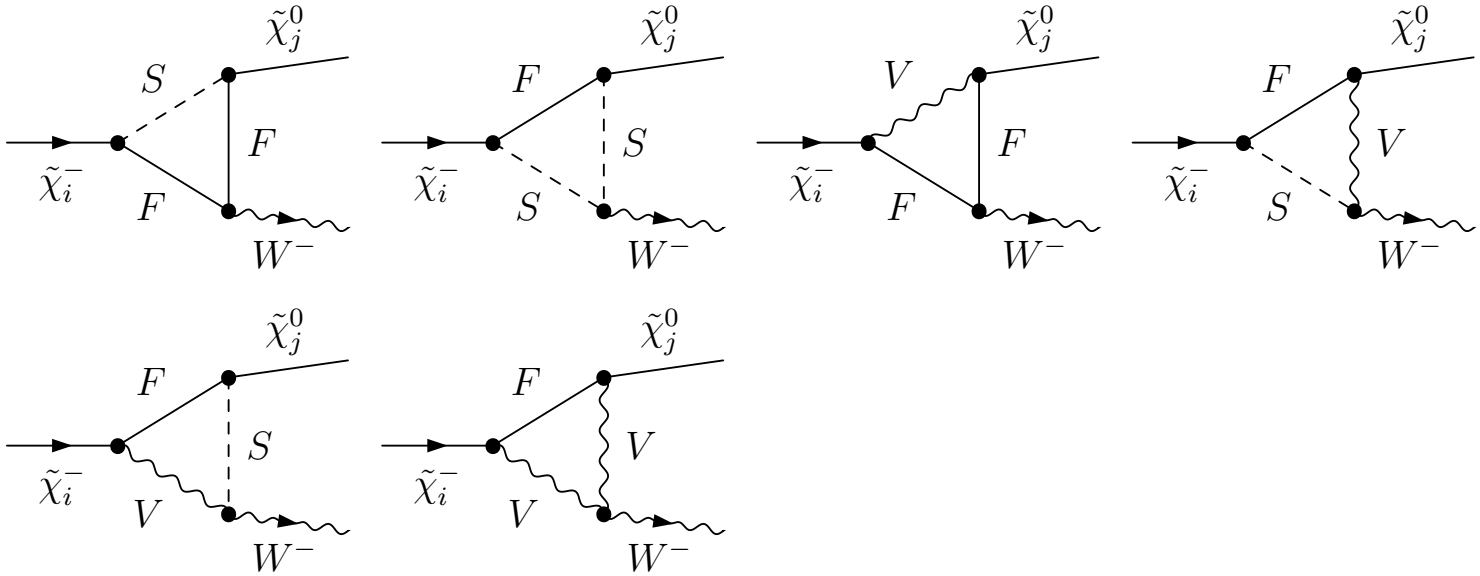

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Calculation of widths and branching ratios

Framework:

- create all diagrams with FeynArts $\longrightarrow$ model file with all counterterms in the cMSSM
- include all soft & hard QED (& QCD) diagrams
- further evaluation with FormCalc and LoopTools
- Dimensional REDuction
- all UV and IR divergencies cancel
- results to be included in FeynHiggs (www.feynhiggs.de)

Numerical results

Parameters for numerical evaluation

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

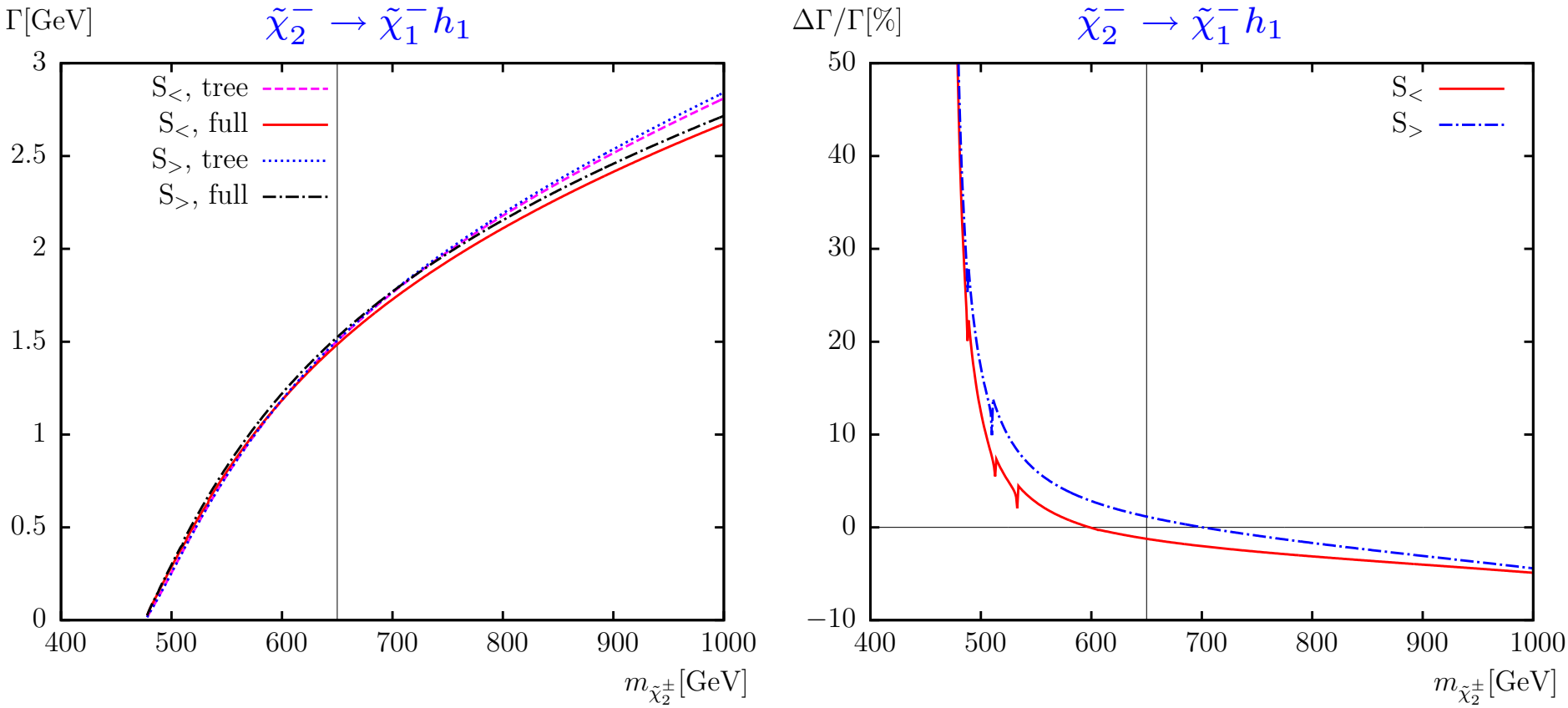
$$S_> := \{\mu > M_2\} \quad \tilde{\chi}_2^\pm \sim \text{Higgsino} - \text{like}$$

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

- $|M_1|$ 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 chargino decay channels are open

Chargino decays: $m_{\tilde{\chi}_2^\pm}$-dependence (preliminary)



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

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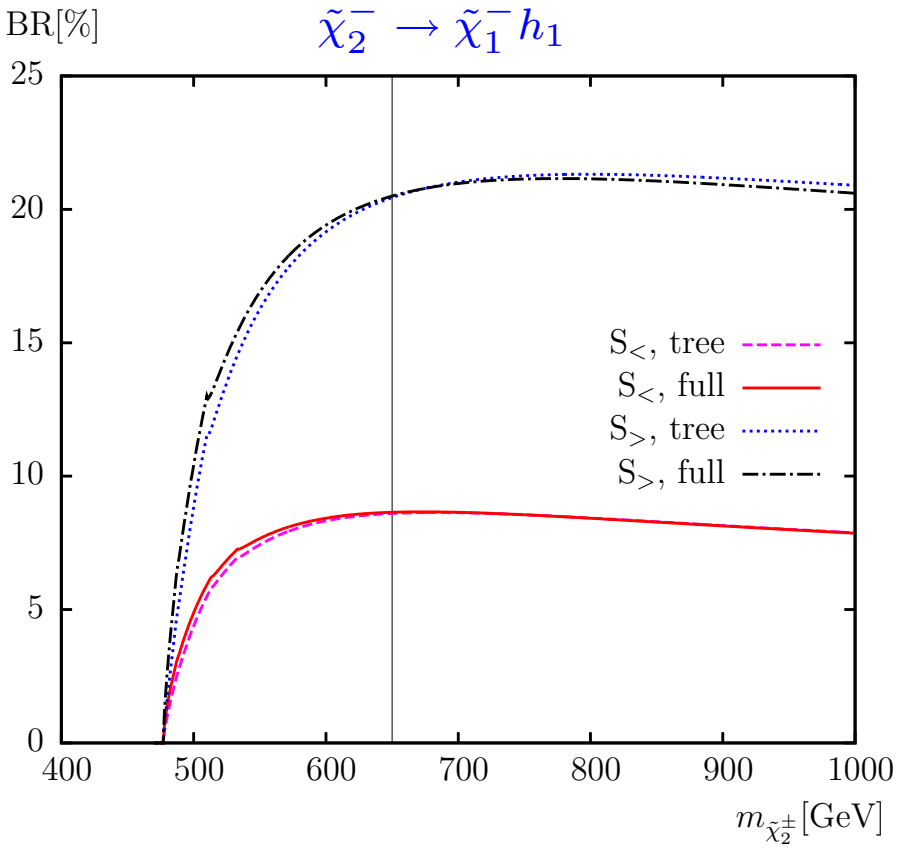

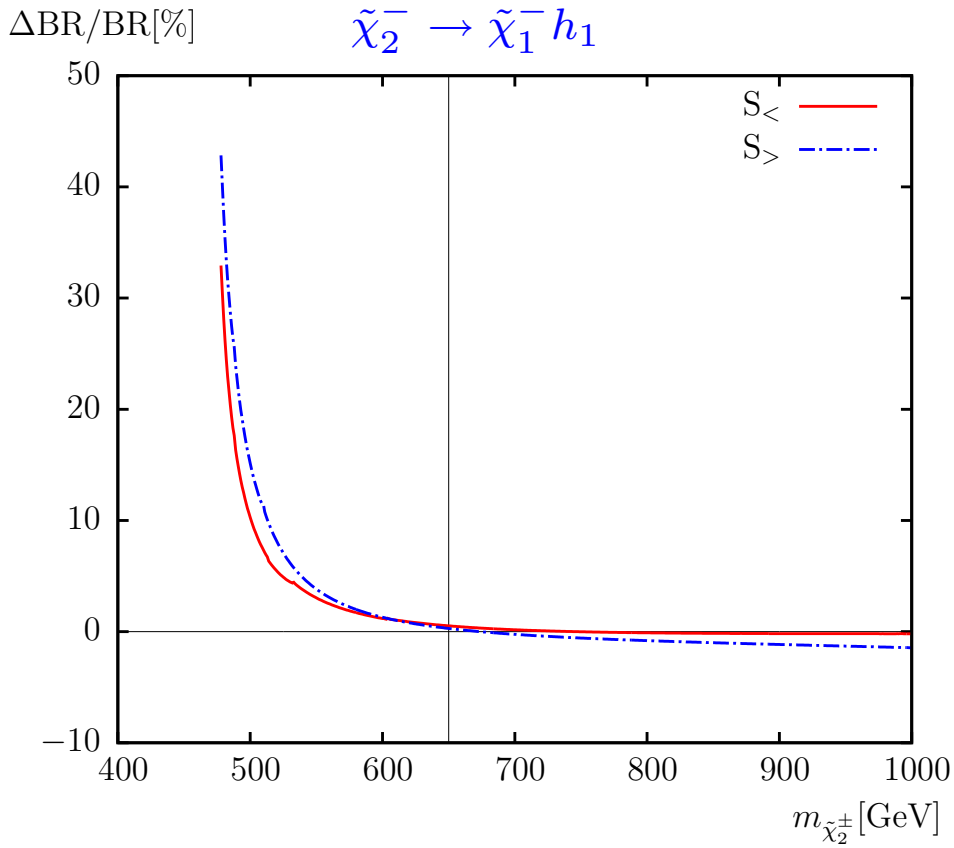

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$\Rightarrow$ size of BR highly scenario dependent

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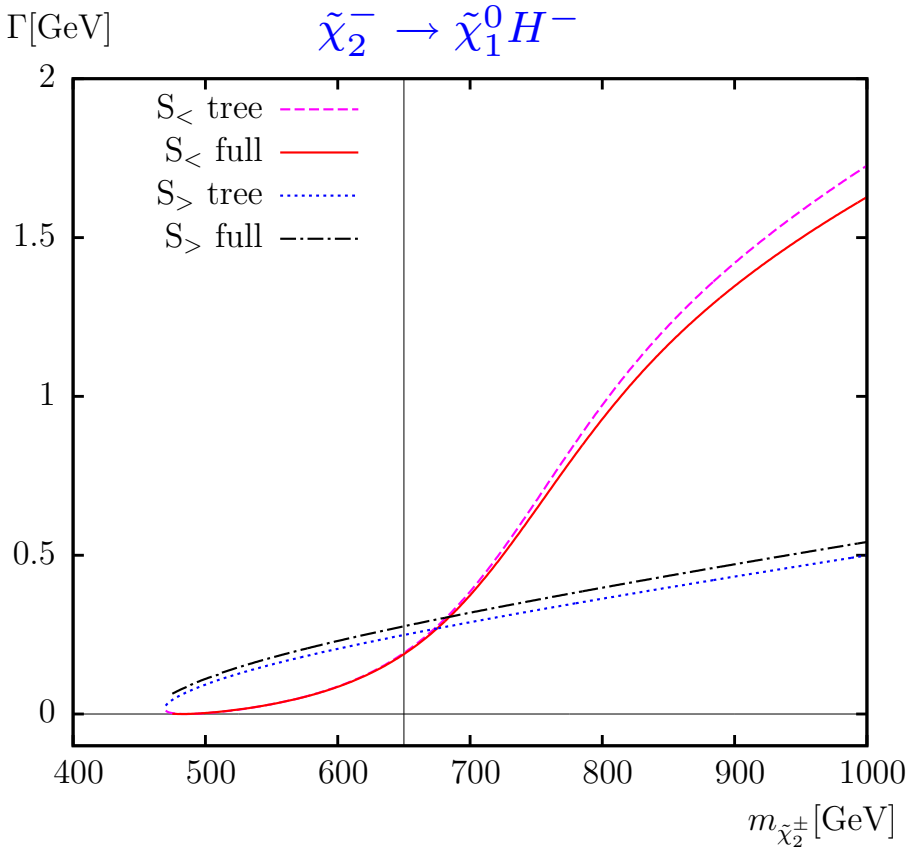

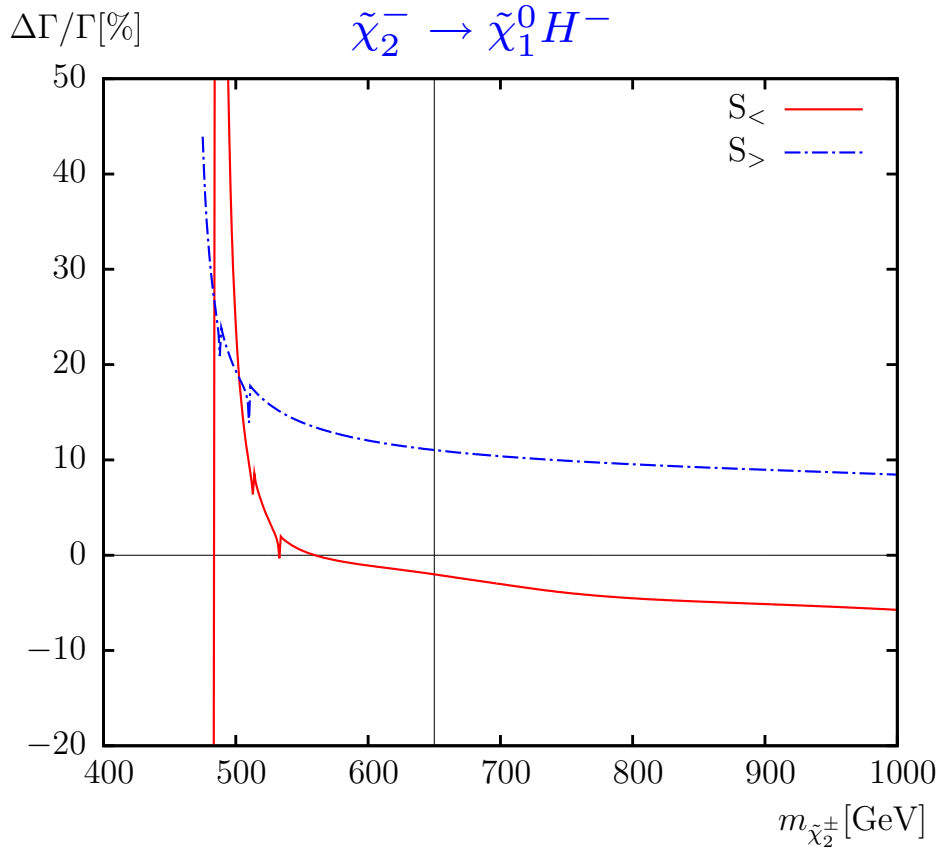

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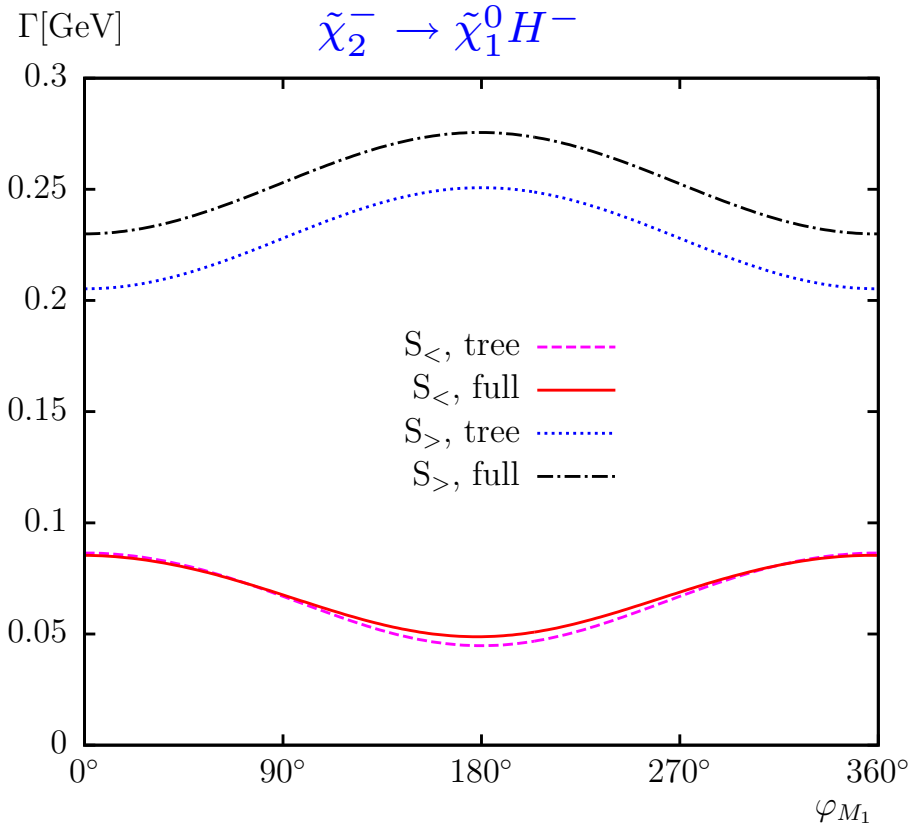
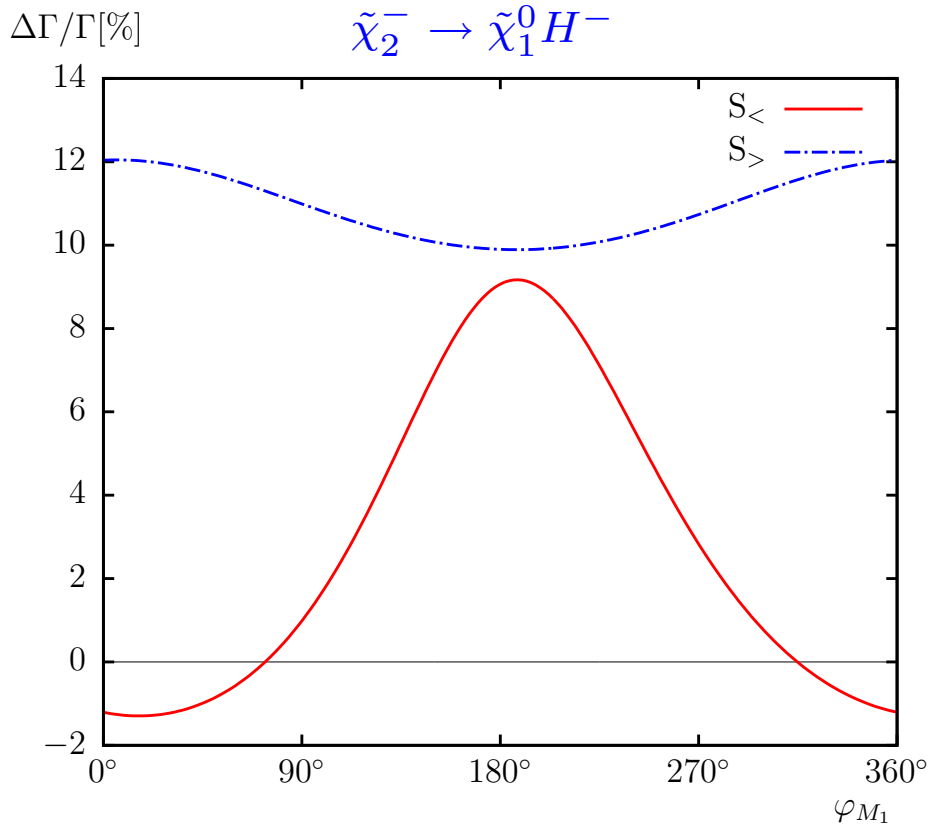
Chargino decays: φ_{M_1}-dependence (preliminary)





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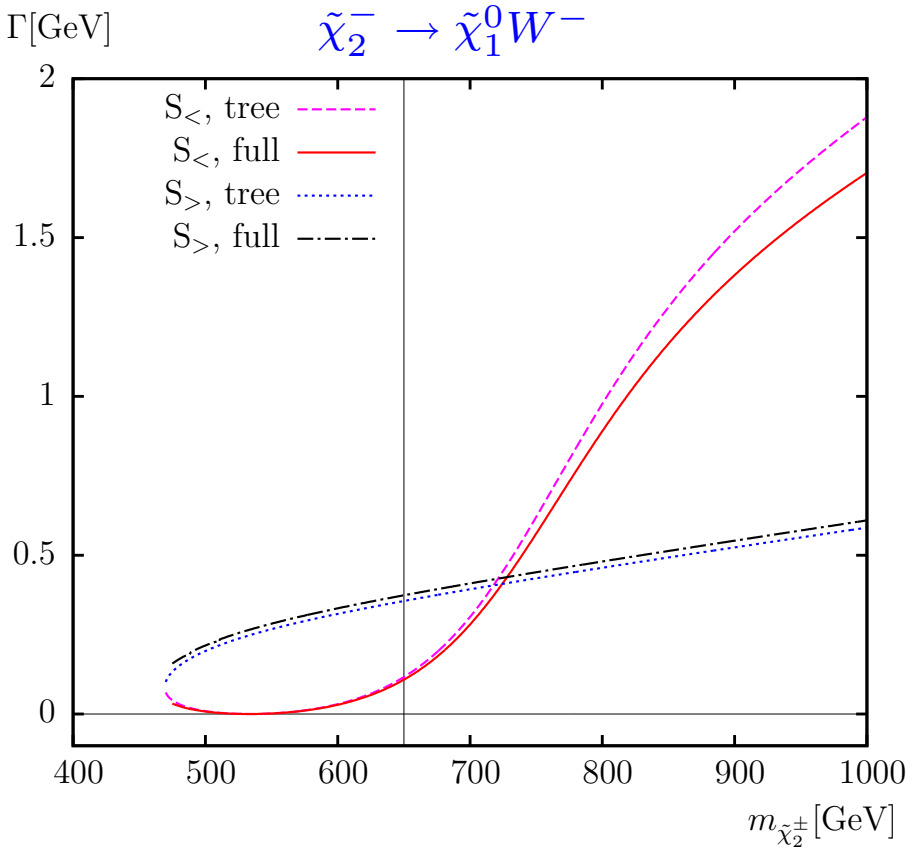
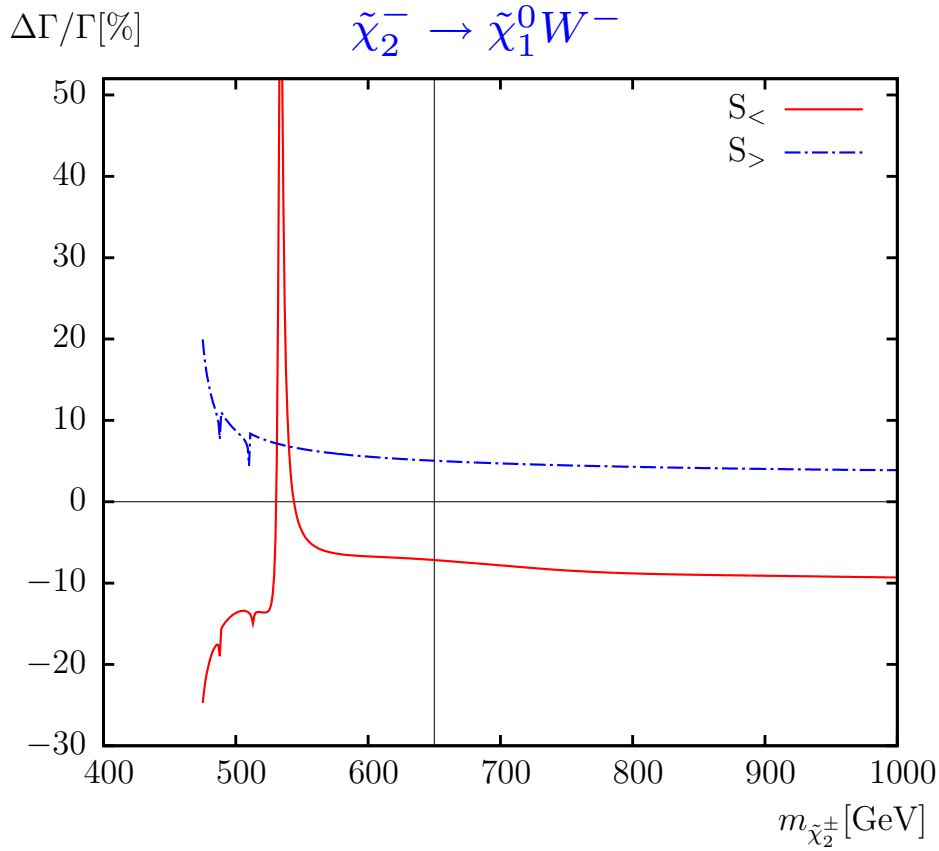
Chargino decays: $m_{\tilde{\chi}_2^\pm}$-dependence (preliminary)





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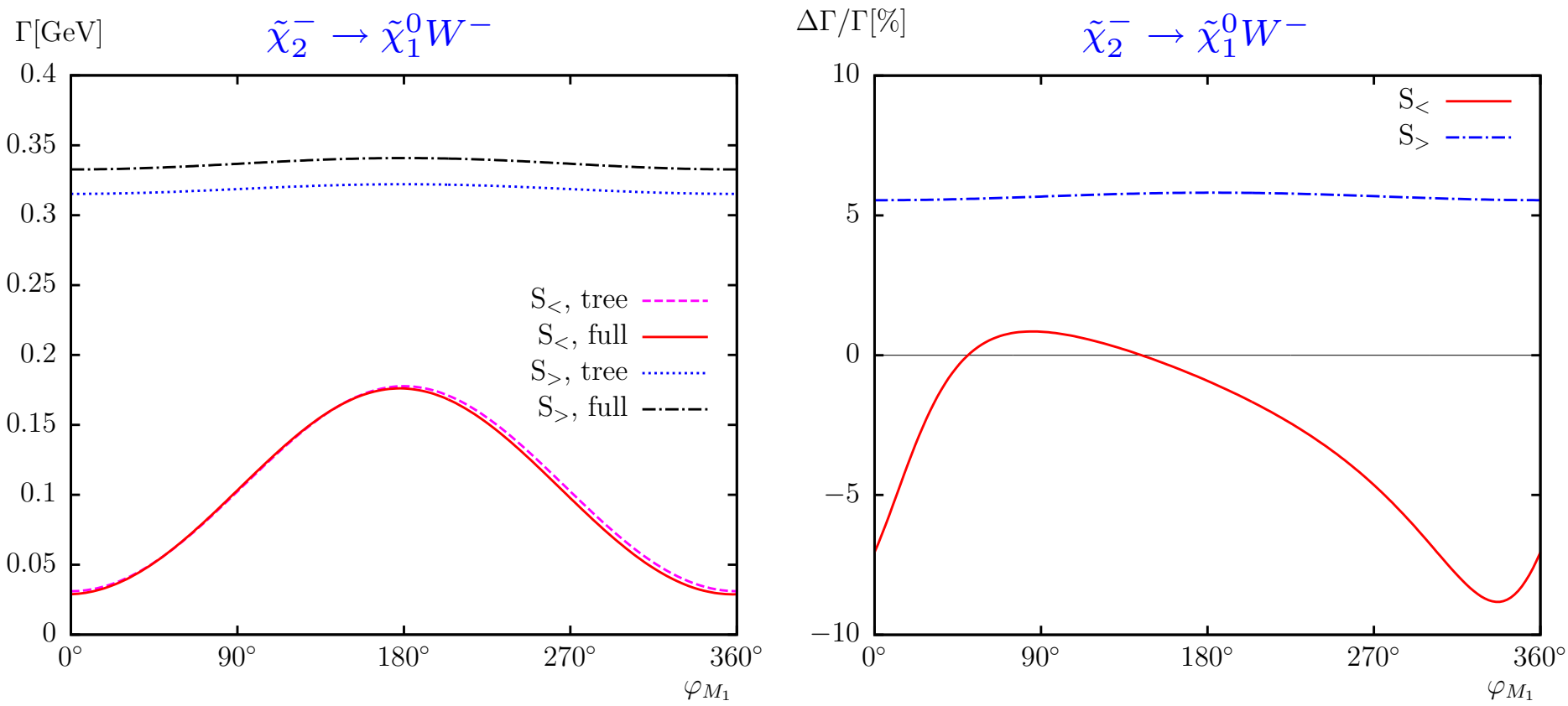


$\Rightarrow$ one-loop corrections under control and non-negligible

$\Rightarrow$ size of BR highly scenario dependent

Chargino decays: φ_{M_1}-dependence: $\mathcal{CP}$ Asymmetry (prel.)

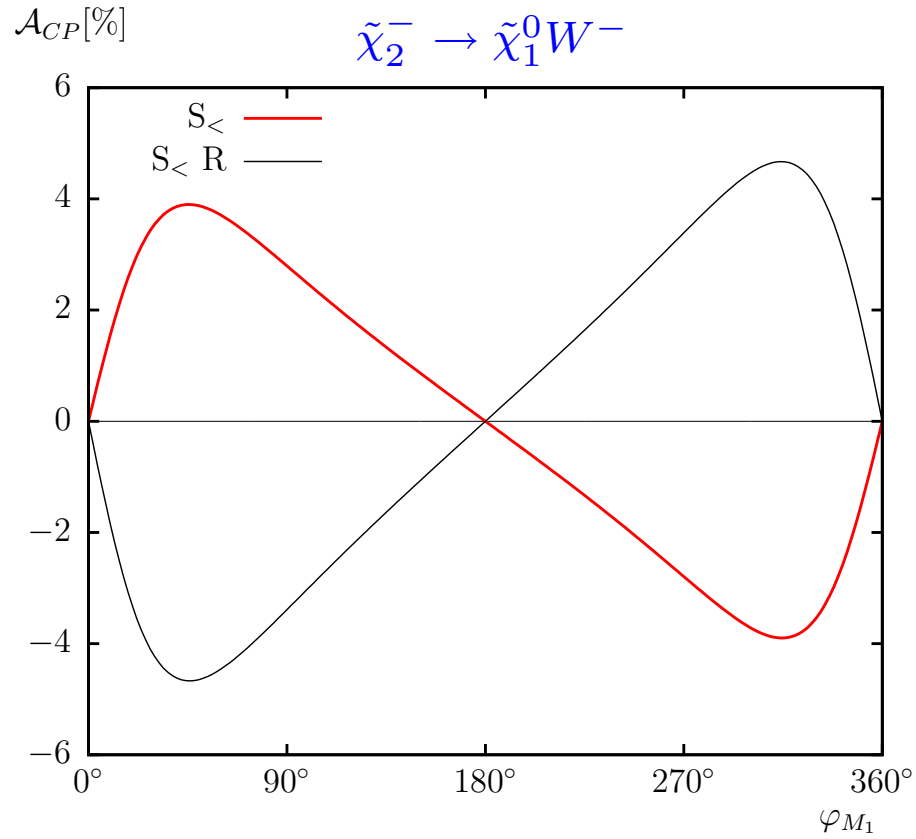
$$\mathcal{A}_{\mathcal{CP}} = \frac{\Gamma(\tilde{\chi}_2^- \to \tilde{\chi}_1^0 W^-) - \Gamma(\tilde{\chi}_2^+ \to \tilde{\chi}_1^0 W^+)}{\Gamma(\tilde{\chi}_2^- \to \tilde{\chi}_1^0 W^-) + \Gamma(\tilde{\chi}_2^+ \to \tilde{\chi}_1^0 W^+)}$$

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

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

absorptive contributions

and complex couplings



Outlook: Neutralino decays (preliminary)

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

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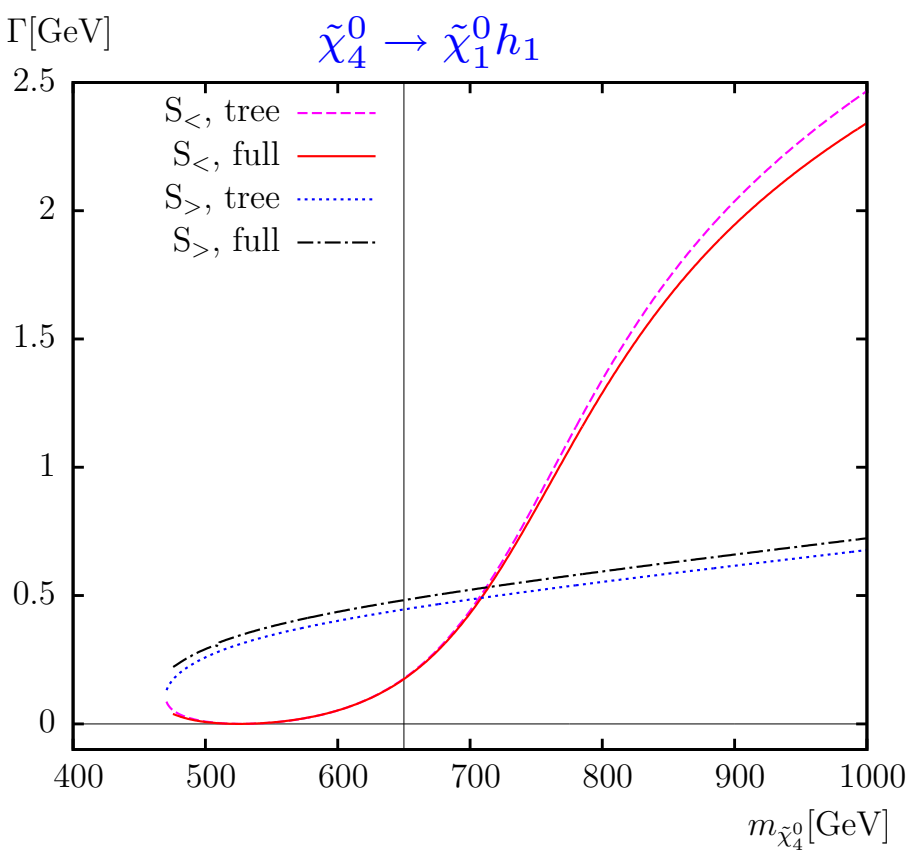
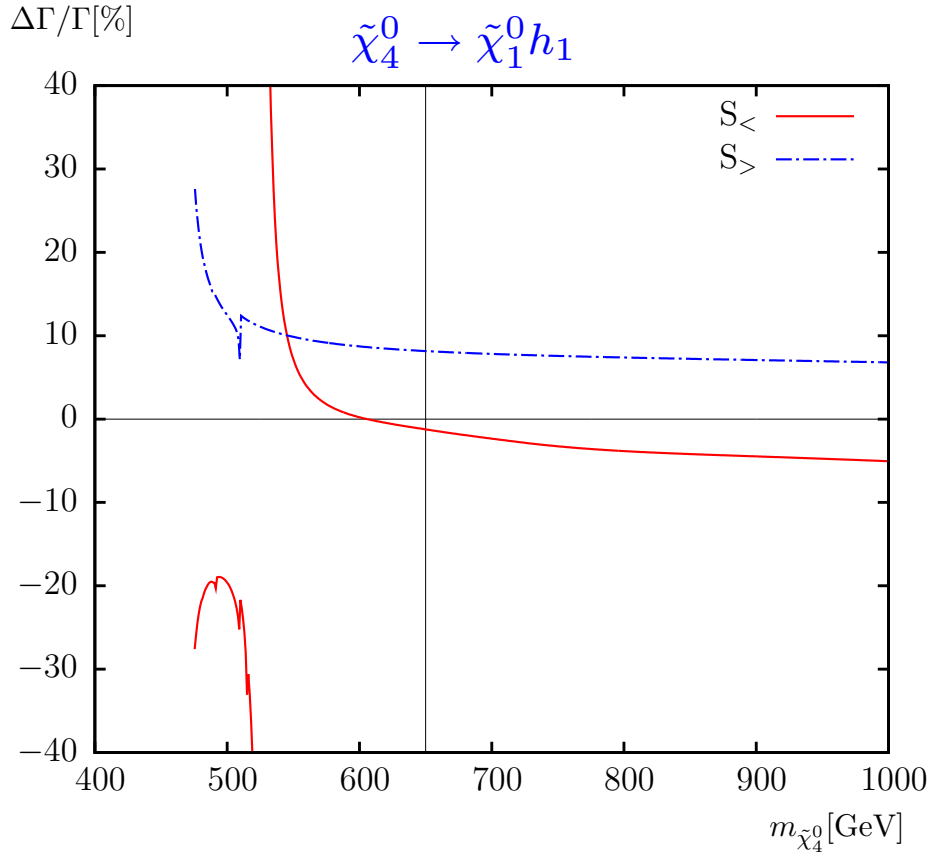
No hadronic decays yet:

$$\Gamma(\tilde{\chi}_i^\pm \to q \tilde{q}_k), \quad k = 1,2$$

Outlook: Neutralino decays: $m_{\tilde{\chi}_4^0}$-dependence (preliminary)





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Conclusions

- Need high precision calculations for the ILC
- Aim of our group: one-loop calculation of two-body decay widths and BRs in the cMSSM
  Results to be implemented into FeynHiggs
- Chargino decays:
  - $\sim 10\%$ loop corrections for EW decays
  - hadronic decays: still missing
  - $\mathcal{CP}$ asymmetries
- Neutralino decays (work in progress):