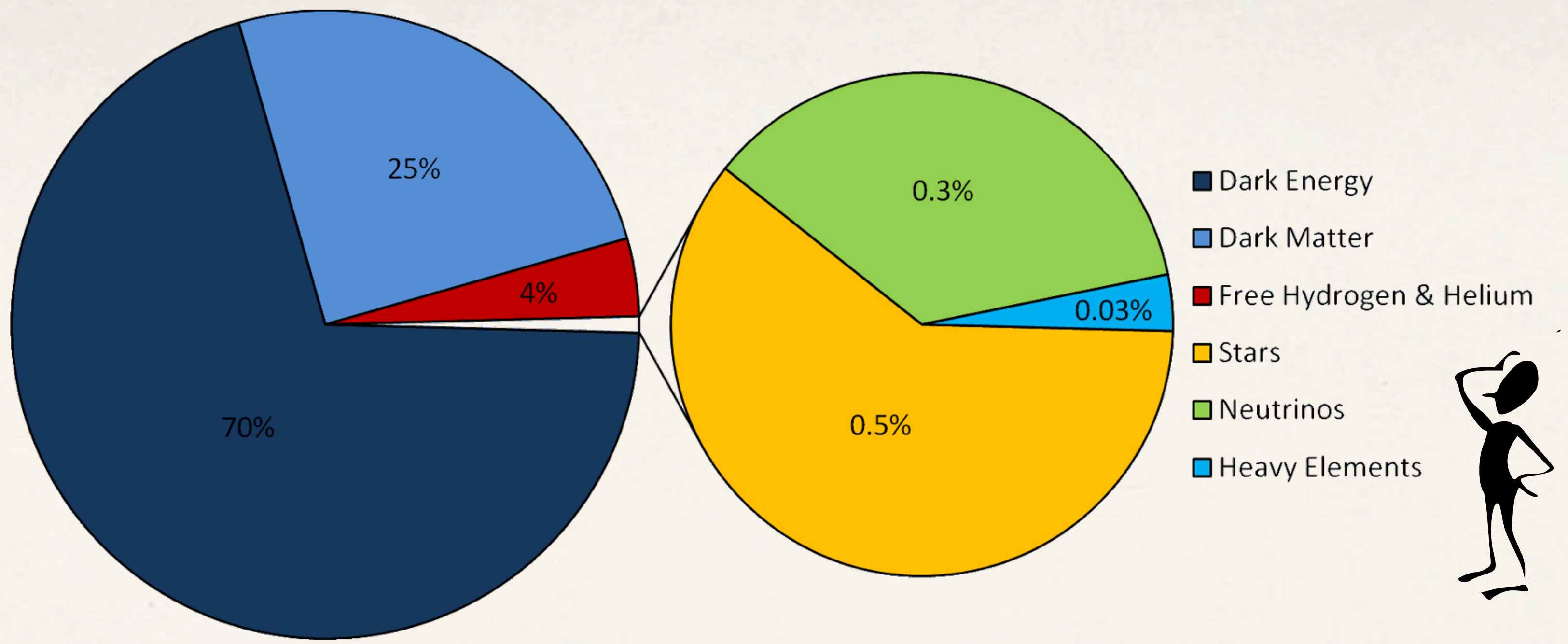

SUSY-QCD corrections to neutralino-stop coannihilation

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SUSY-QCD corrections to neutralino-stop coannihilation

- Introduction to neutralino-stop coannihilation
- Next-to-Leading Order cross-sections
- Impact of the corrections on the relic density
- Conclusions

Introduction to neutralino-stop coannihilation

Relic density of dark matter

- Relic density of dark matter given by WMAP: $\Omega_{\text{CDM}} h^2 \;=\; 0.1126 \;\pm\; 0.0036$ (3%)

  and now by Planck: $\Omega_{\text{CDM}} h^2 \;=\; 0.1199 \;\pm\; 0.0027$ (2%)

- Puts strong constraints on SUSY models. Can be calculated from Boltzmann equation:

$$\frac{\mathrm{d}n}{\mathrm{d}t} \;=\; -3Hn - \langle\sigma_{\text{ann}} v\rangle \left(n^2 - n_{\text{eq}}^2\right)$$

- Where the thermally averaged total cross-section is:

$$\langle\sigma_{\text{ann}} v\rangle \;=\; \sum_{i,j=0}^{N} \langle\sigma_{ij} v_{ij}\rangle \frac{g_i g_j}{g_{\text{eff}}^2} \left(\frac{m_i m_j}{m_0^2}\right)^{3/2} \exp\left\{-\frac{(m_i + m_j - 2m_0)}{T}\right\}$$

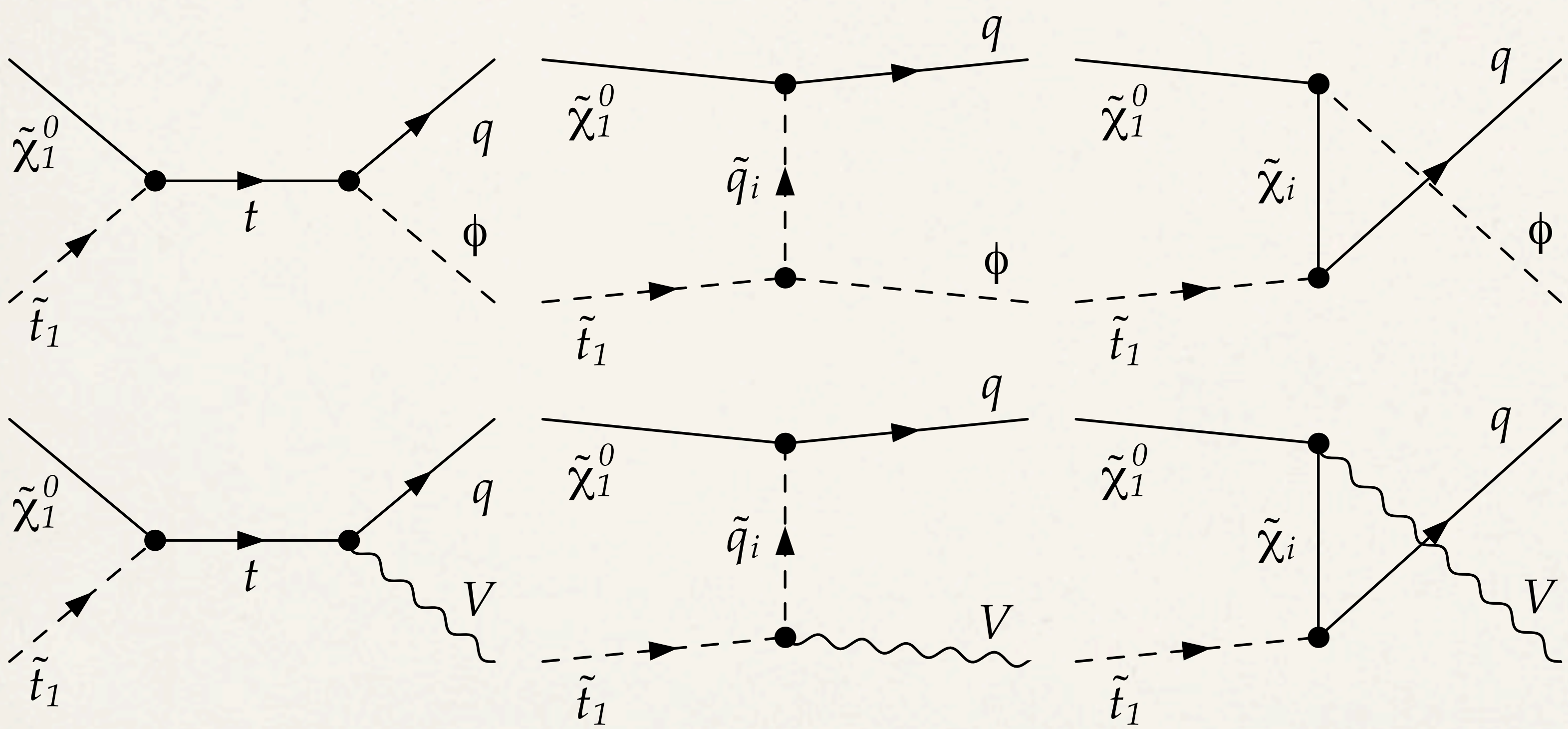
(co)annihilation cross-sections

only degenerate NLSP contributes

- Different tools calculating dark matter relic density exists, such as MicrOmegas, DarkSUSY and SuperIso Relic.

Neutralino-stop coannihilation

- Neutralino LSP is the most studied dark matter candidate.
- It can coannihilate with a close-in-mass-NLSP, the top squark for example.
- Neutralino-stop coannihilation can reduce relic density to the experimental value.
- Gives a very thin compatible region in parameter space, expected to be shifted by NLO corrections.



$$t\ h^0,\ t\ H^0,\ t\ A^0,\ b\ H^+$$

$$t\ g,\ t\ \gamma,\ t\ Z^0,\ b\ W^+$$

- The total contribution depends on the neutralino-stop mass difference
- The relative contributions will depend on the spectrum (masses and couplings)

A light stop?

- Neutralino-stop coannihilation require a **rather light stop**
- Possible because large top Yukawa coupling enhance mixing and RGE running

$$\mathcal{M}^2_{\tilde{t}} = \begin{pmatrix} M^2_{\tilde{Q}_3} + m_t^2 + \Delta_L & m_t(A_t - \mu \cot\beta) \\ m_t(A_t - \mu\cot\beta) & M^2_{\tilde{U}_3} + m_t^2 + \Delta_R \end{pmatrix}$$

- Still compatible with experimental constraints
  - Flavour constraints are OK if MFV assumed since the lightest stop is mostly right-handed (RGE).
  - LHC limit on production not very stringent since if stop is a degenerate NLSP, produced jets are soft, i.e. hard to trigger and detect.
  - Stop sector is constrained by the Higgs boson mass observation (maximal mixing), lightest stop can be as light as 200 GeV, if the other stop is heavy enough.

Realistic light stop scenario with relevant constraints discussed in arXiv:1212.6847
(A. Delgado, G. F. Giudice, G. Isidori, M. Pierini, A. Strumia)

pMSSM scenarios

- We choose 2 realistic scenarios with different features
  - Masses of first generation squarks, μ and tanβ are significantly different:

	M_1	$M_{\tilde{q}_{1,2}}$	$M_{\tilde{q}_3}$	$M_{\tilde{\ell}}$	T_t	m_A	μ	$\tan\beta$
I	306.9	2037.7	709.7	1499.3	1806.5	1495.6	2616.1	9.0
II	470.6	1261.2	905.3	1963.2	1514.8	1343.1	725.9	18.3

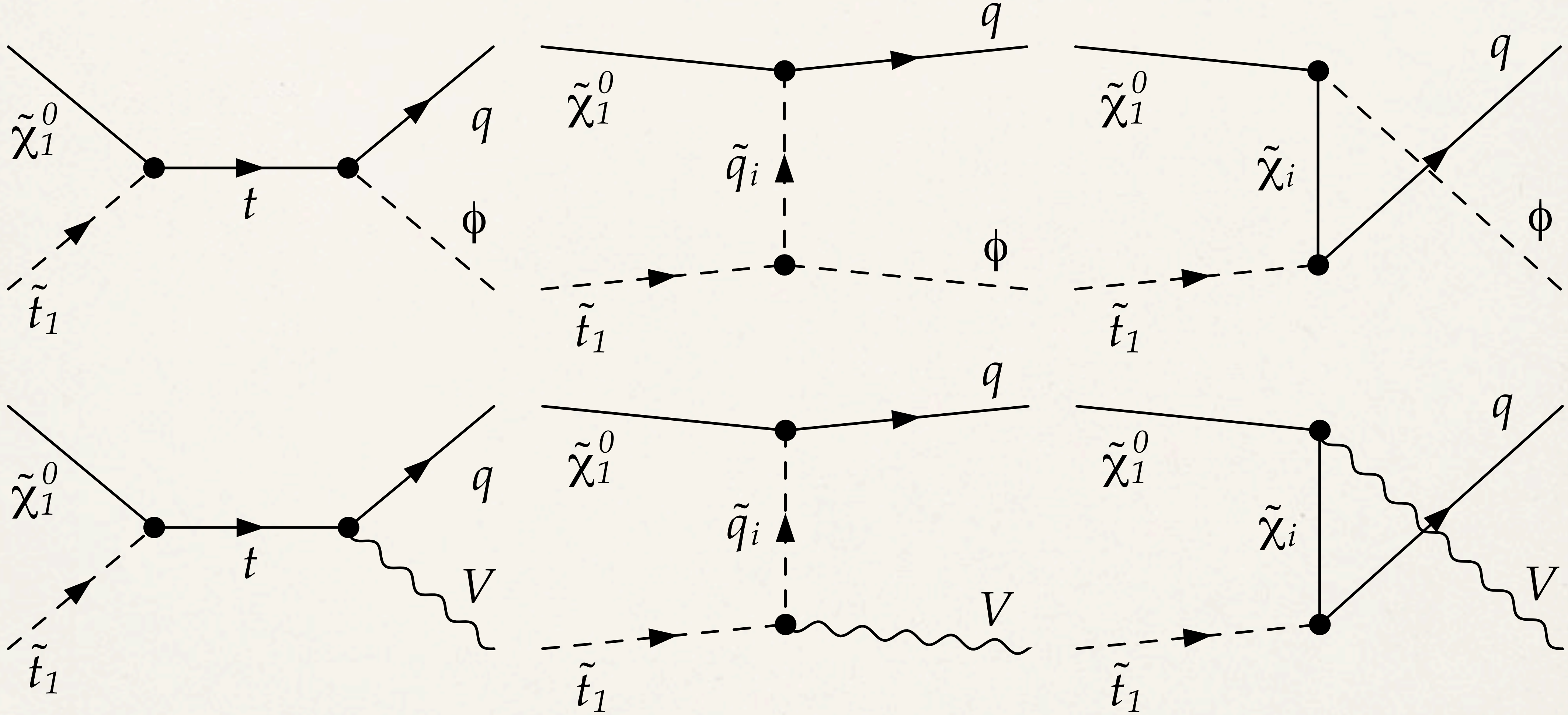
  - Higgs final state is dominant in both, but in the scenario II vector bosons final states also contribute significantly:

	$m_{\tilde{\chi}_1^0}$	$m_{\tilde{t}_1}$	$\Omega_\chi h^2$	$\tilde{\chi}_1^0\tilde{t}_1 \to th^0$	$\tilde{\chi}_1^0\tilde{t}_1 \to tZ^0$	$\tilde{\chi}_1^0\tilde{t}_1 \to bW^+$
I	307.1	350.0	0.114	38.5%	3.4%	5.9%
II	467.3	509.4	0.116	24.6%	10.7%	3.4%

Next-to-Leading Order cross-sections

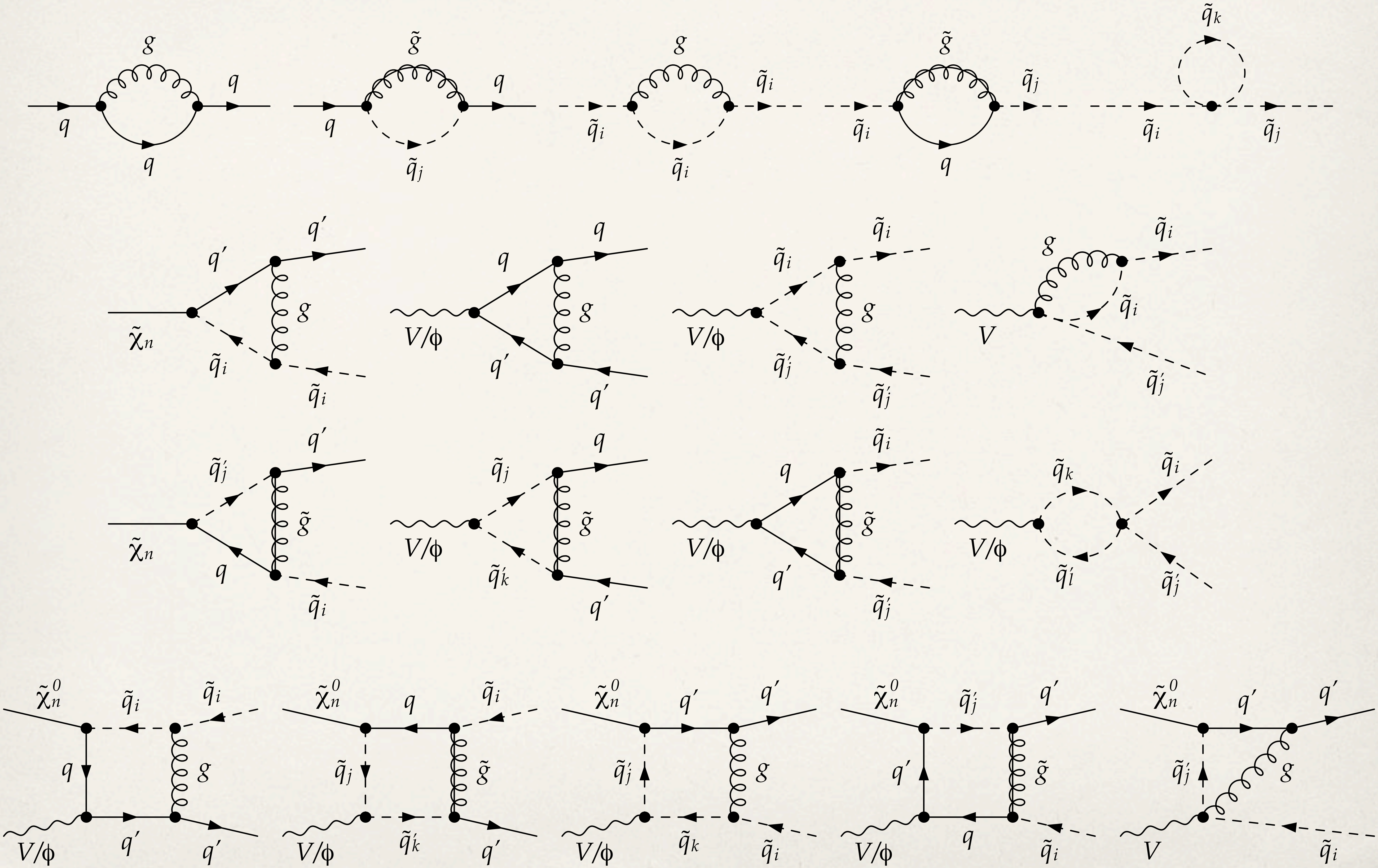
Tree-level diagrams

- We have calculated the cross-sections at NLO in SUSY-QCD for neutralino-stop coannihilation into electroweak gauge bosons, and Higgs bosons.

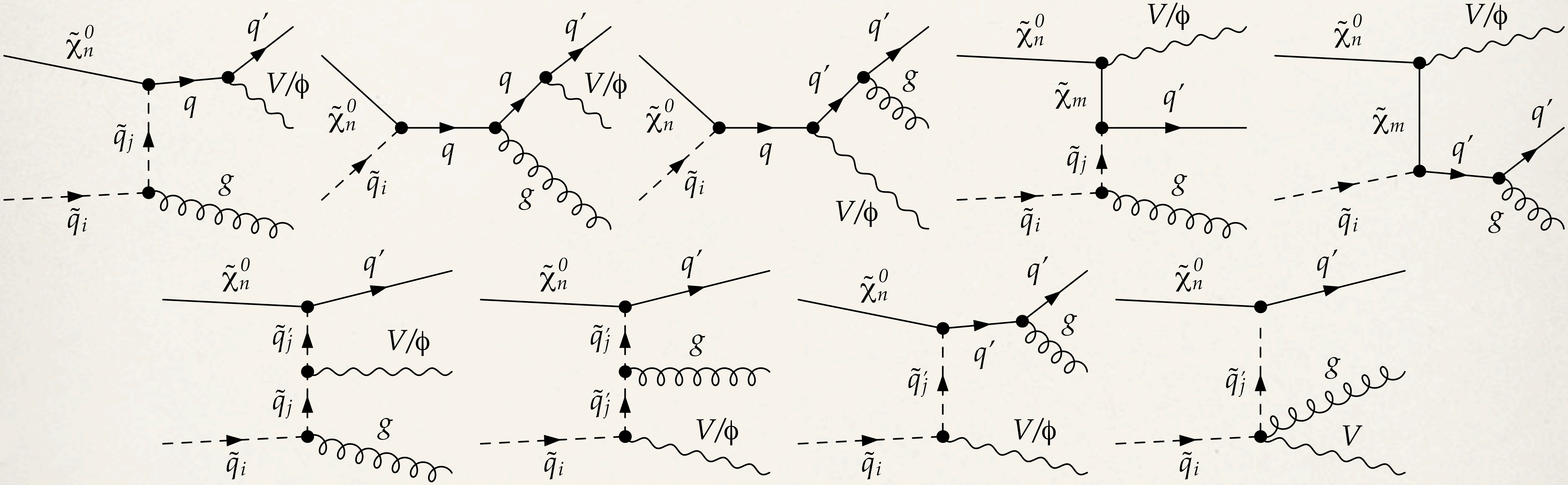


$$\phi \equiv h^0,\ H^0,\ A^0,\ H^+$$
$$V \equiv \gamma,\ Z,\ W$$

Virtual correction diagrams



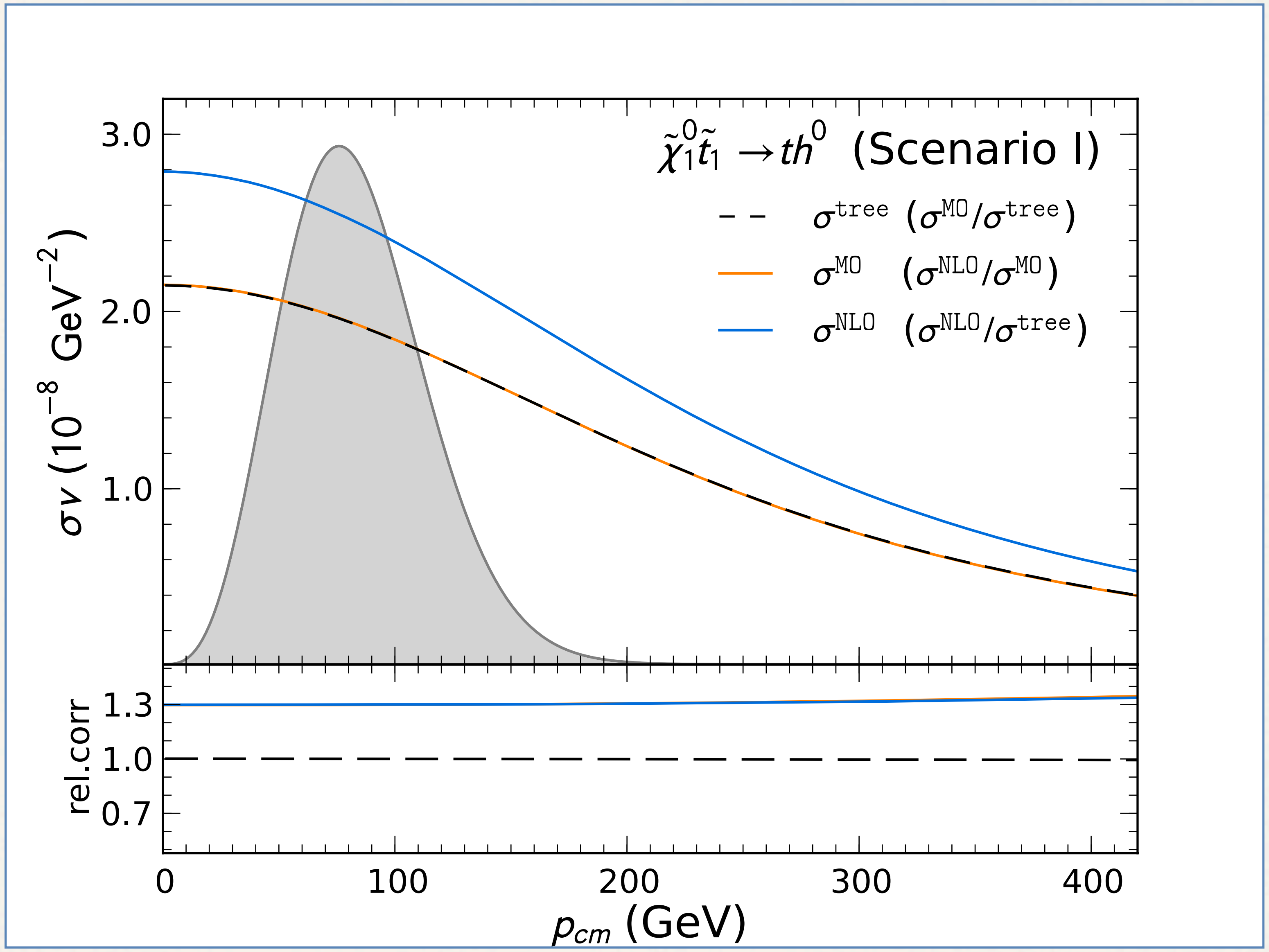
Real correction diagrams



Summary of the calculation

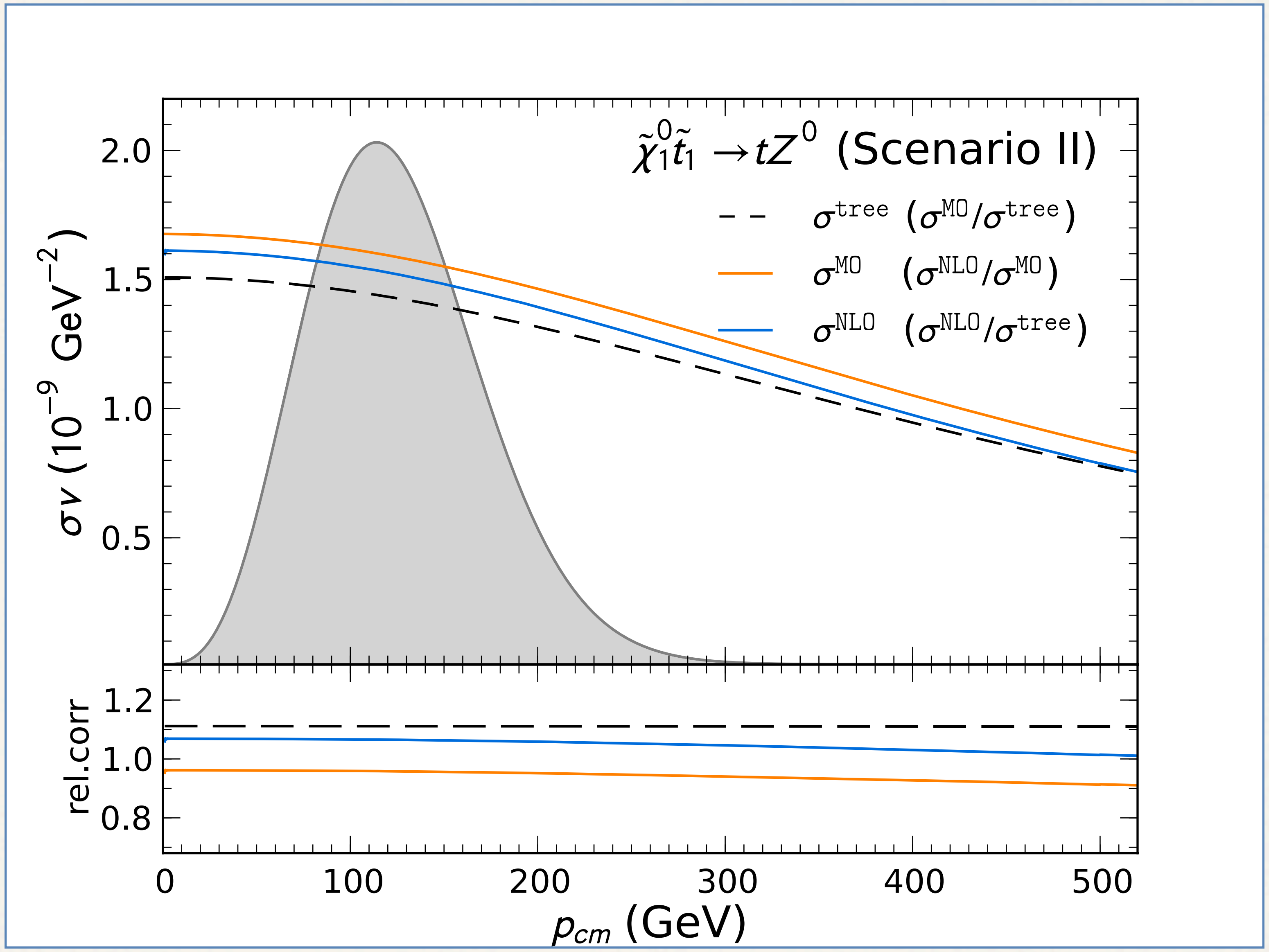
- All divergences are regularized in $\overline{\text{DR}}$, using Passarino-Veltman integrals.
- Renormalization of UV divergences is done in a mixed On-Shell/$\overline{\text{DR}}$ scheme, valid in large regions of the MSSM parameter space.
- IR divergences are treated with a one-cutoff Phase Space Slicing method.
- Results have been implemented in a numerical fortran code, part of the DM@NLO project.
- The code is linked to MicrOmegas which compute the relic density.

Numerical results - Higgs



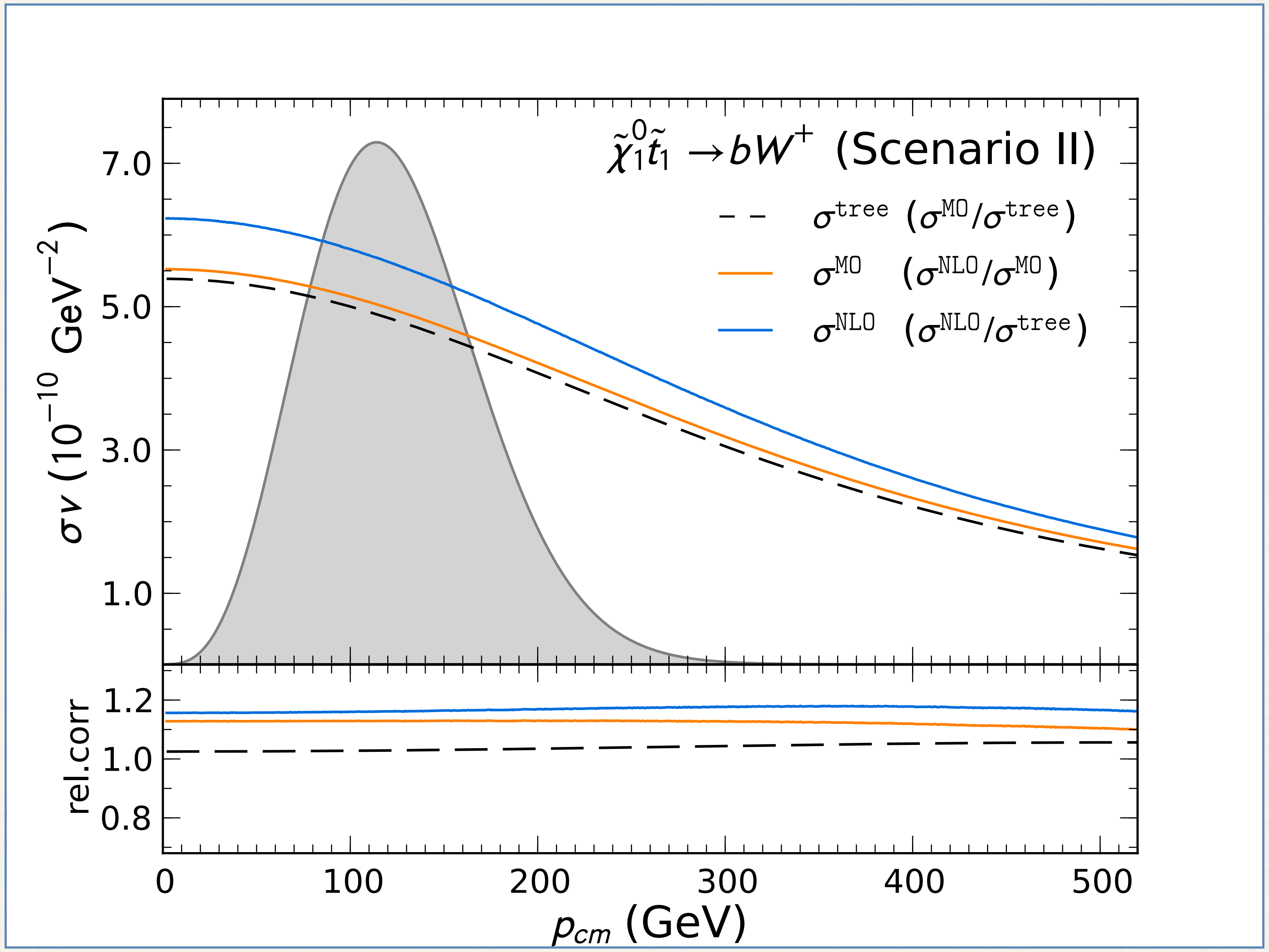
- MO and our tree-level are in perfect agreement
- Relative correction is ~ 30%

Numerical results - Z



- 10% difference between MO and our tree-level due to definition of squark mixing angle
- Relative correction is ~ -5% to -10%

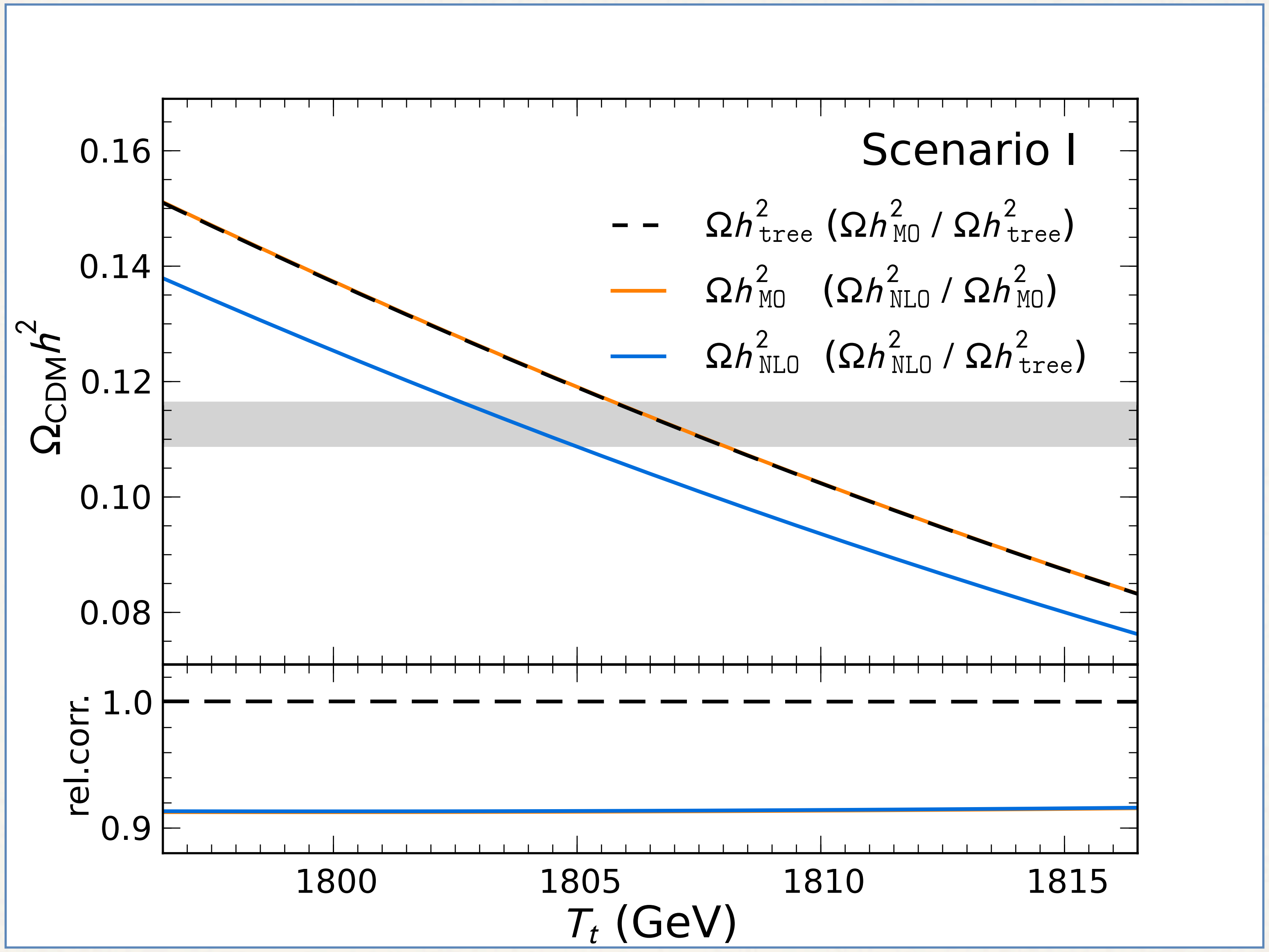
Numerical results - W



- MO and our tree-level are in good agreement
- Relative correction is 10%

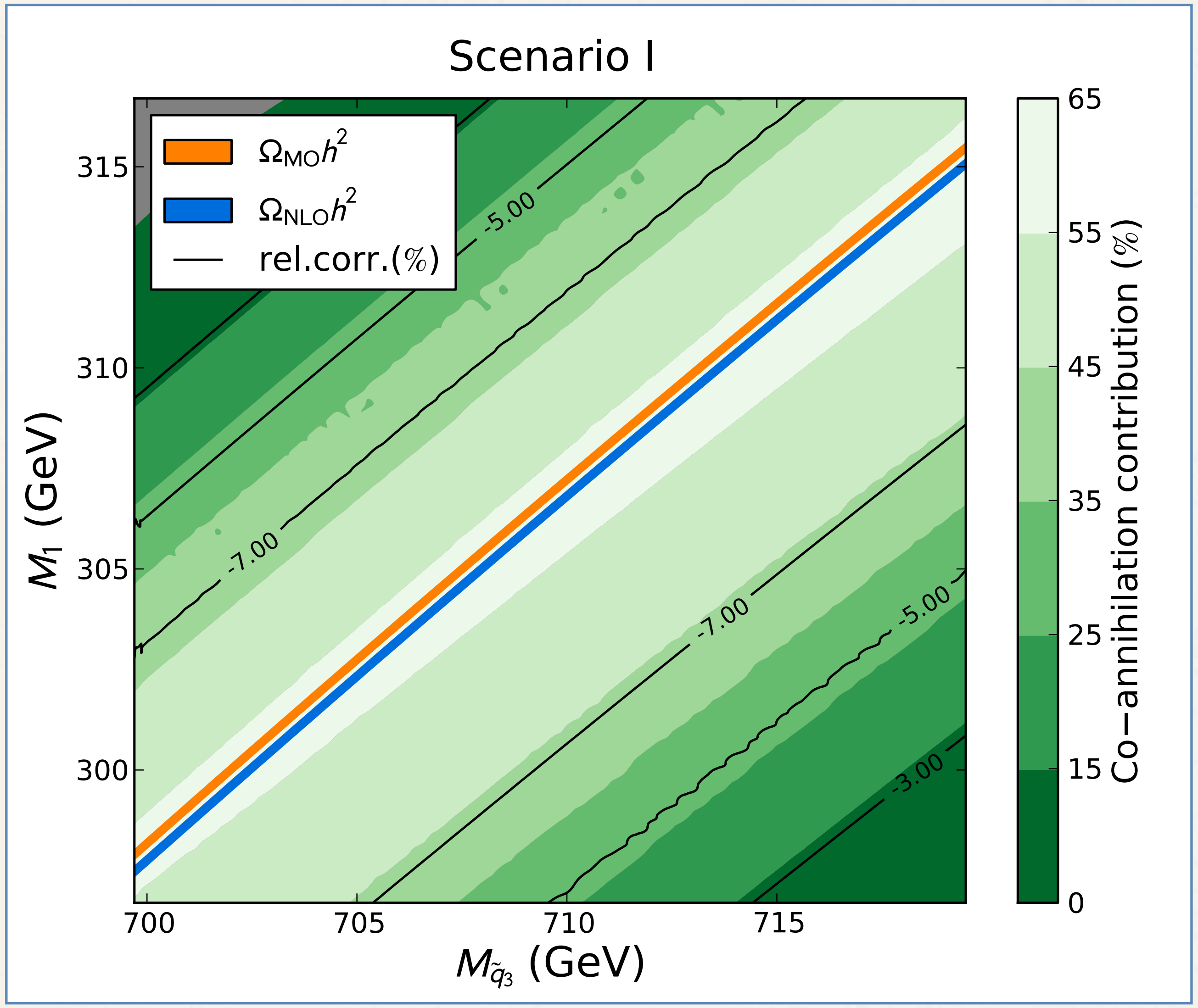
Impact of corrections on the relic density

Impact on the relic density



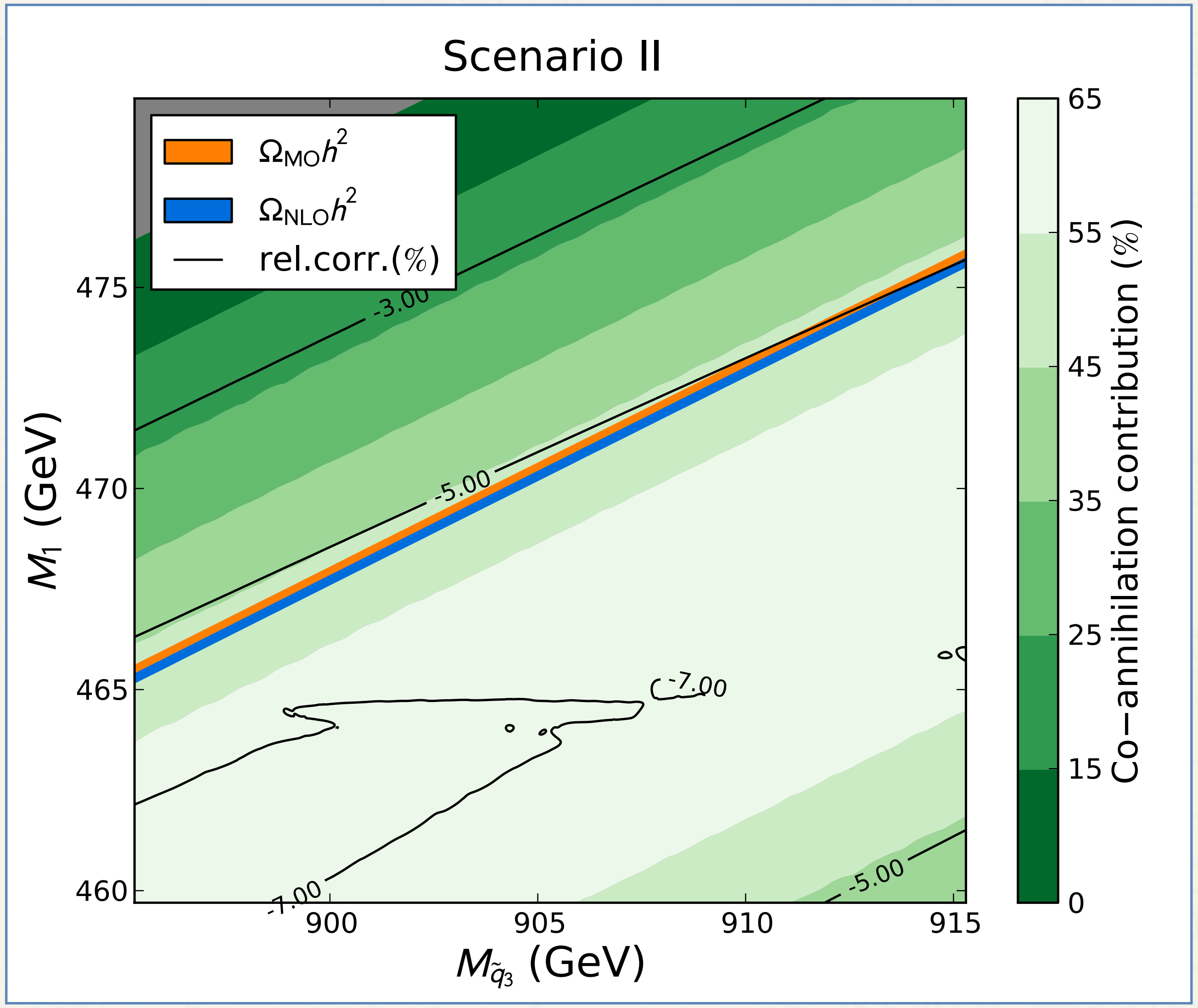
- The corrections reduce the relic density is reduced by 9%
- The difference between MO and NLO relic density in the favored region correspond to a difference in T_t of 3 GeV.

Impact on the relic density



- The impact on the relic density is (obviously) larger when coannihilation is important
- The WMAP band lies precisely in this region
- Impact of corrections is bigger than experimental uncertainty

Impact on the relic density



- The impact is here smaller since correction on the Z final state is small and negative
- The WMAP band does not lies on the region of maximal impact
- Impact of corrections is comparable to experimental uncertainty

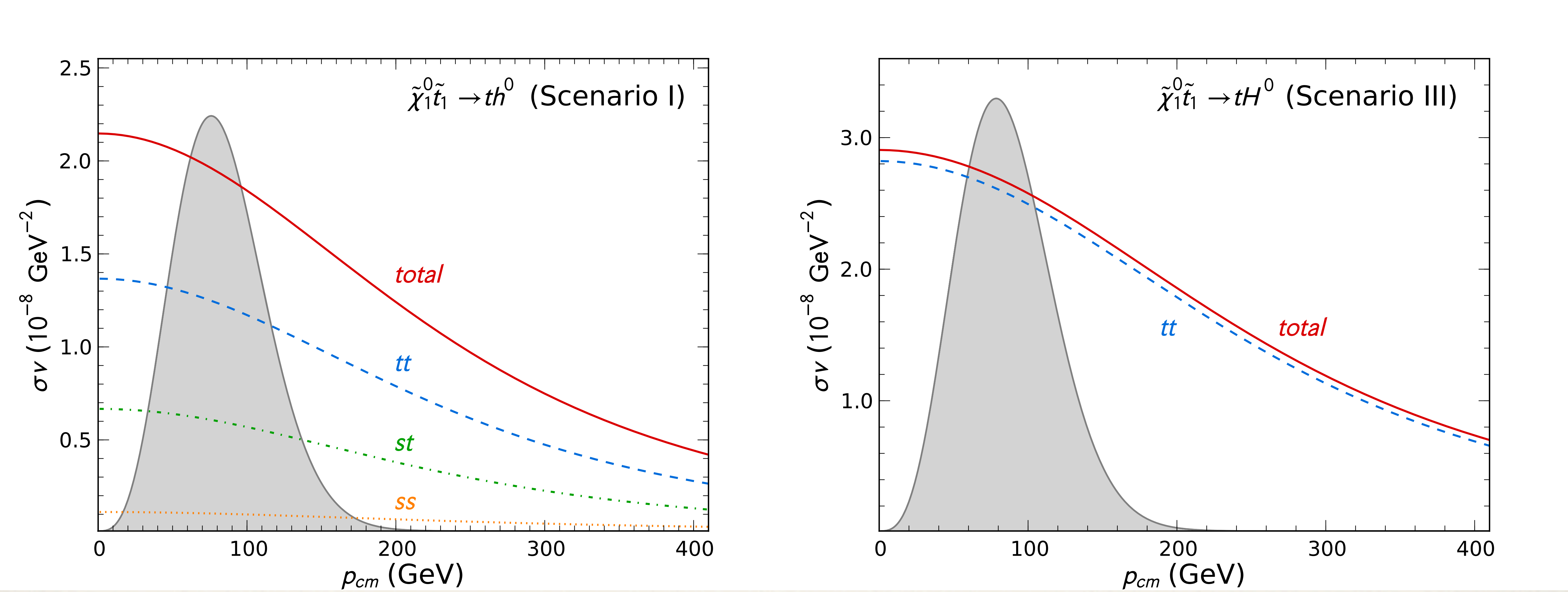
Conclusion

Conclusion

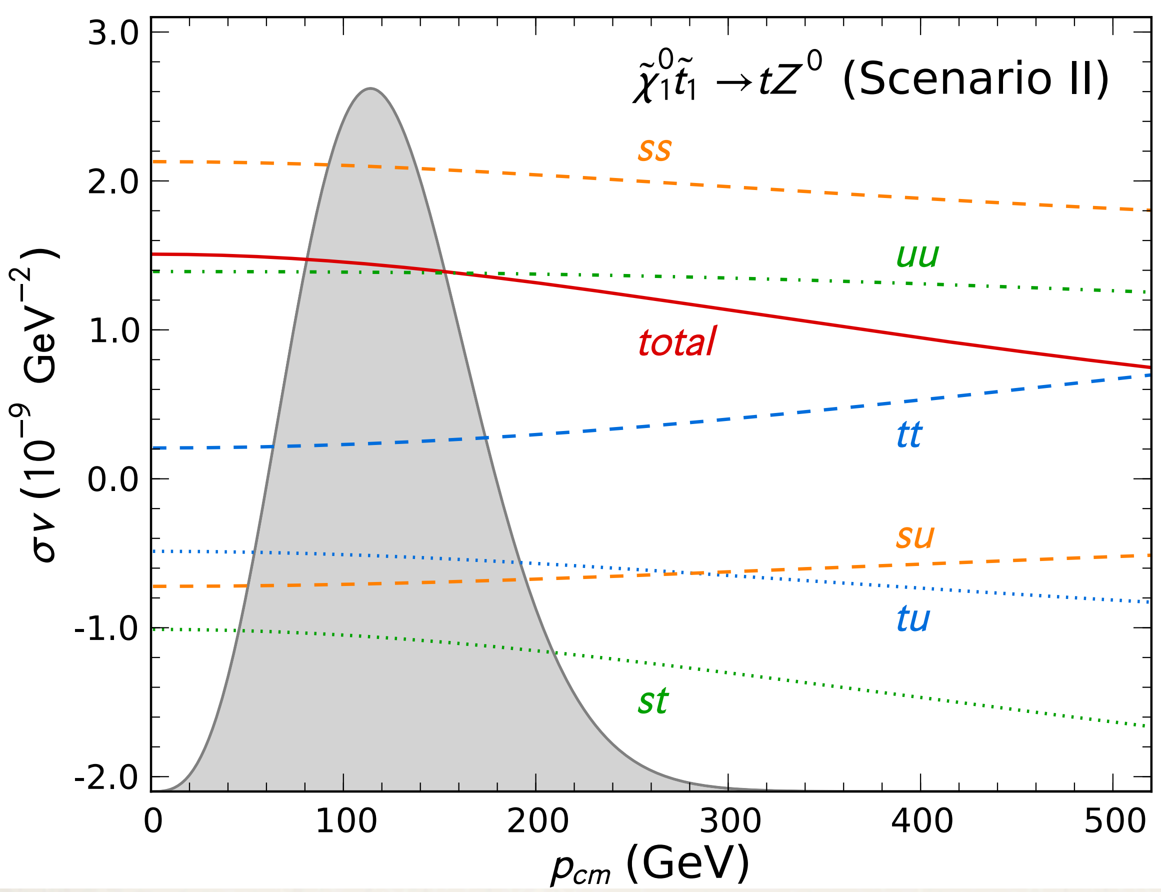
- Relic density of dark matter puts very strong constraints on Supersymmetric models.
- Neutralino stop coannihilation is one solution to achieve the correct relic density in the MSSM, and is still compatible with experimental constraints.
- We have calculated the NLO SUSY-QCD corrections to the electroweak gauge and Higgs boson final states.
- One-loop correction on the cross-section is ~ 5 to 30% depending on the final state.
- Resulting correction on the relic density is ~ 5 to 10%, i.e. larger than the experimental uncertainty from WMAP (~ 3%).
- Considering Planck results these corrections are even more relevant.

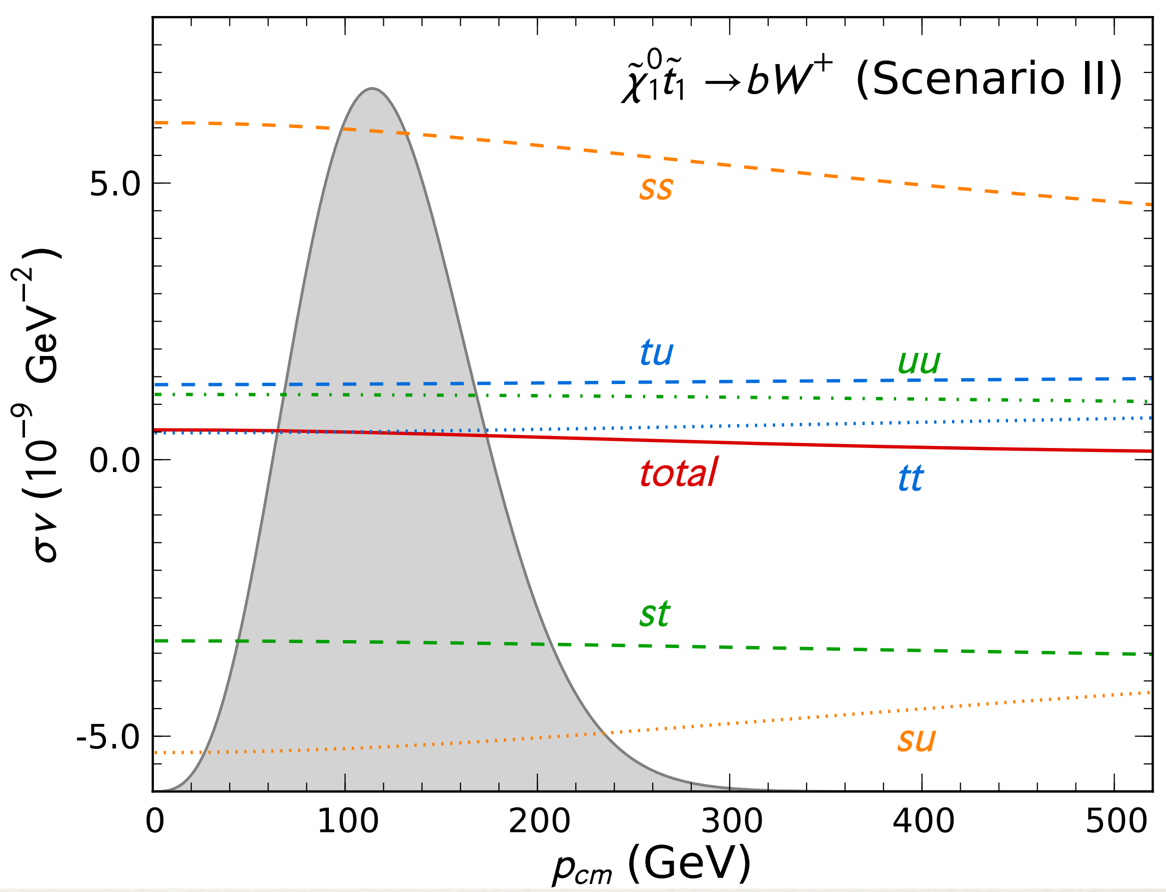
Backup: Tree-level contributions

Tree-level contributions - Higgs



Tree-level contributions - Z/W





Backup: One-loop contributions

One-loop contributions - Higgs/Z