Supersymmetric QCD Effects on Neutralino Dark Matter Annihilation

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Work realized in collaboration with Karol Kovařík and Michael Klasen

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GDR Terascale
Heidelberg, October 15, 2009

Outline

1. Motivation
2. Neutralino annihilation into heavy quarks
3. Supersymmetric QCD corrections
4. Numerical results
5. Conclusion

Supersymmetric Dark Matter

Supersymmetry provides interesting candidates for "WIMPs"

→ Minimal Supersymmetric Standard Model (MSSM) with R-parity conservation
→ Lightest supersymmetric particle (LSP) stable
→ Good candidates: Neutralino or Gravitino (depending on SUSY-breaking mechanism)

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In "mSUGRA-like" models based on gravity-mediation the LSP is a neutralino

$$\tilde{\chi}_1^0 = \mathcal{N}_{11}\tilde{B}^0 + \mathcal{N}_{12}\tilde{W}^0 + \mathcal{N}_{13}\tilde{H}_1^0 + \mathcal{N}_{14}\tilde{H}_2^0$$

Universal parameters at the grand unification scale: $m_0,\ m_{1/2},\ A_0,\ \tan\beta,\ \mathrm{sgn}(\mu)$

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Cosmology allows to constrain the (large) MSSM parameter space

→ Additional information w.r.t. collider and precision data

→ Identify (dis)favoured regions of parameter space

→ Scenario should include viable candidate for cold dark matter

→ Relic density of cold dark matter required to agree with WMAP+SN+BAO data

$$0.1097 \;<\; \Omega_{\mathrm{CDM}}h^2 \;<\; 0.1165 \qquad\qquad (\mathrm{at}\ 2\sigma)$$

[Hinshaw *et al.* (WMAP) 2008]

Relic Density Calculation

Number density of relic particle governed by the Boltzmann equation

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

$$\Omega_{\mathrm{CDM}}h^2 \propto n_0 \propto \frac{1}{\langle\sigma_{\mathrm{ann}}v\rangle}$$

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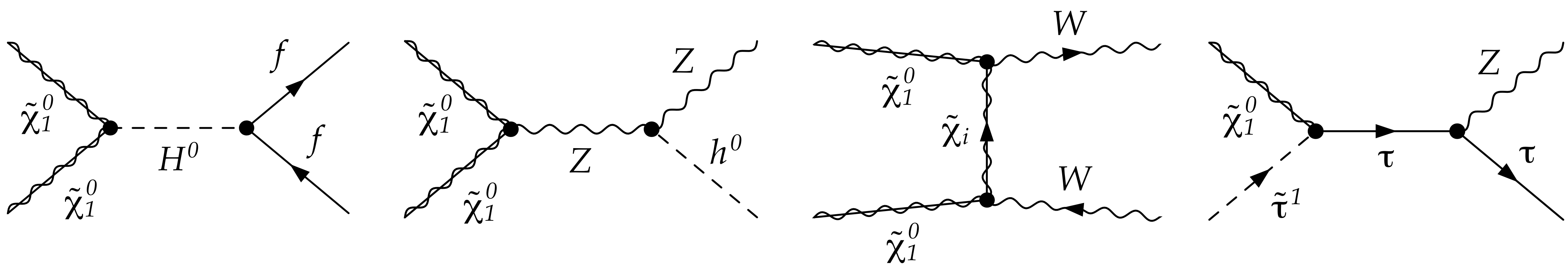
Cross section σ_{ann} includes all annihilation and coannihilation processes



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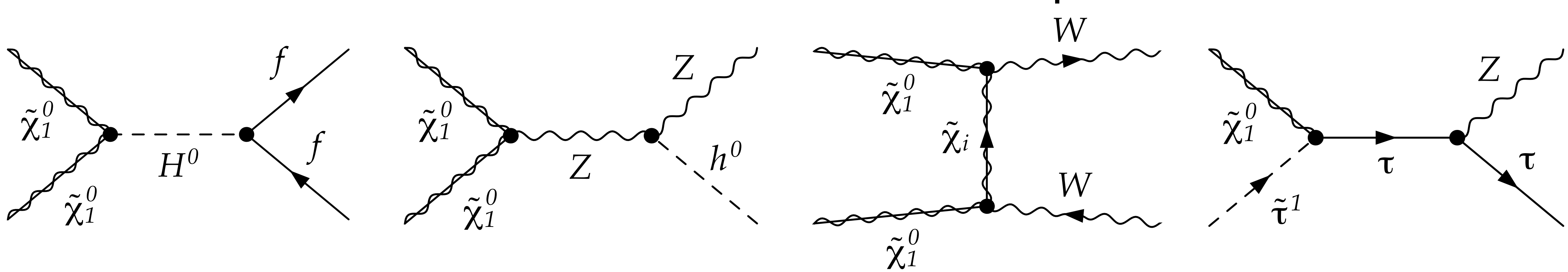

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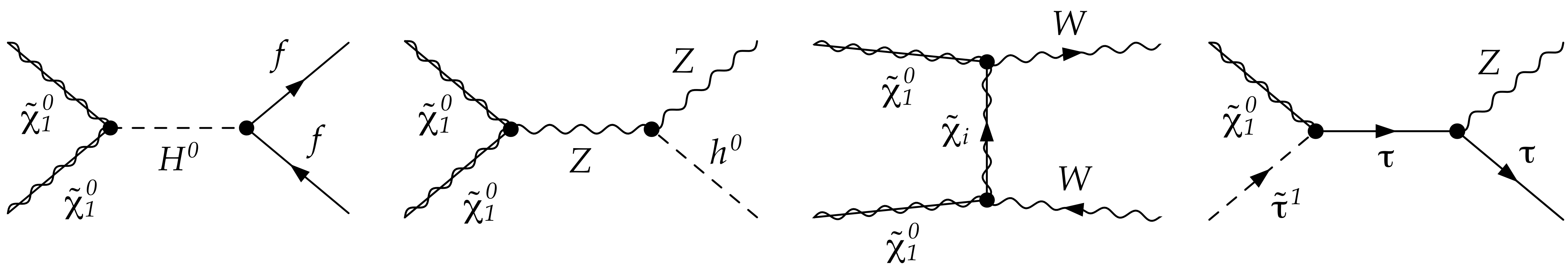

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Public computer codes perform a calculation of the relic density

- → DarkSUSY (neutralino in the MSSM) [Gondolo *et al.* 2004]
- → micrOMEGAs (all kinds of LSP in any model) [Bélanger *et al.* 2003]
- → SuperIso Relic (possibility to modify cosmological model) [Arbey 2009]

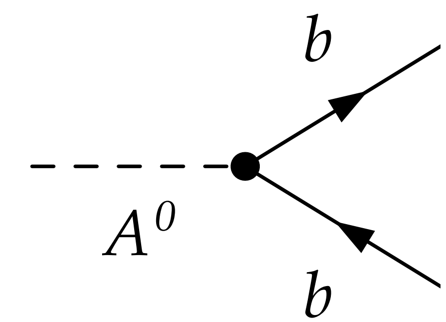
Motivation for Radiative Corrections

(Co)annihilation processes only implemented in public codes at tree-level

→ Corrections included only for some very sensitive quantities

→ e.g. bottom Yukawa-coupling

$$h_{Abb} \propto \frac{\overline{m}_b(Q)}{1+\Delta_b} \tan\beta$$



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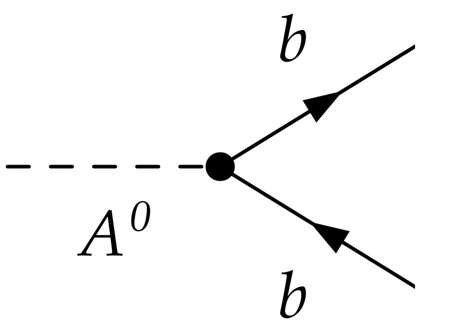

Higher order corrections can have important impact on cross-sections

→ QCD corrections significant due to strong coupling constant

→ Quark final states give sizeable contributions to neutralino annihilation

→ Radiative corrections affect the prediction of the relic density

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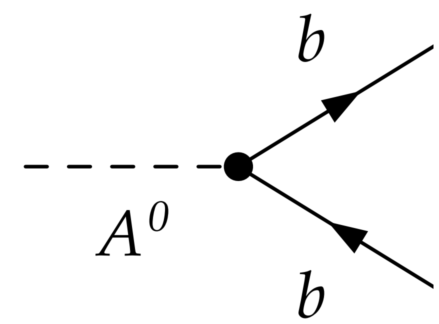

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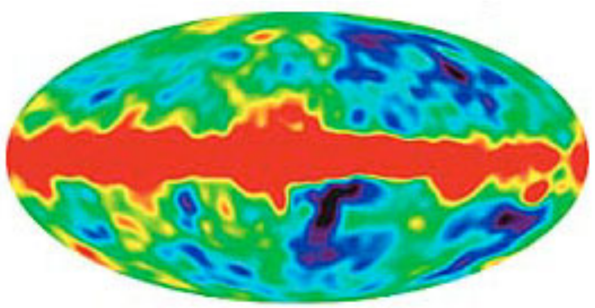
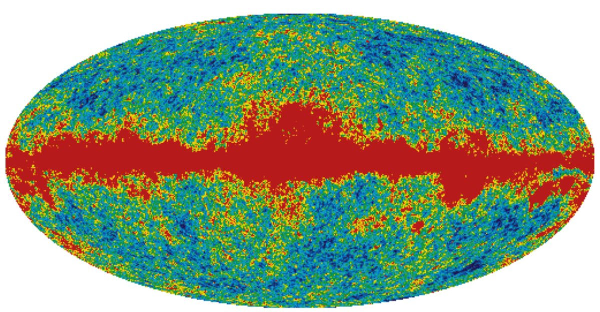
Planck satellite will deliver new cosmological data in near future

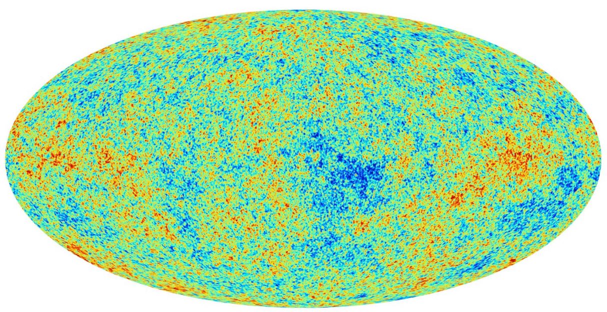
→ Higher precision in theoretical predictions needed to match experimental improvements



COBE 1989



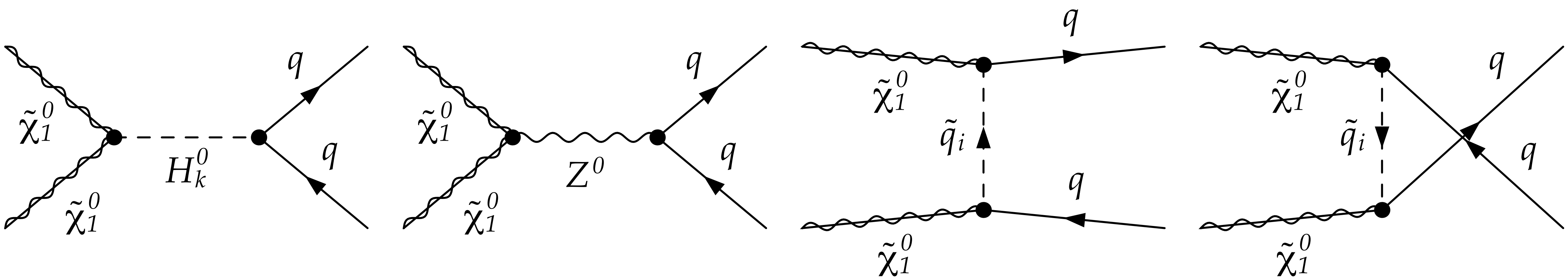
WMAP 2002



Planck 2009

Neutralino Annihilation into (Heavy) Quarks

Annihilation cross-section receives sizeable contributions from quark final states



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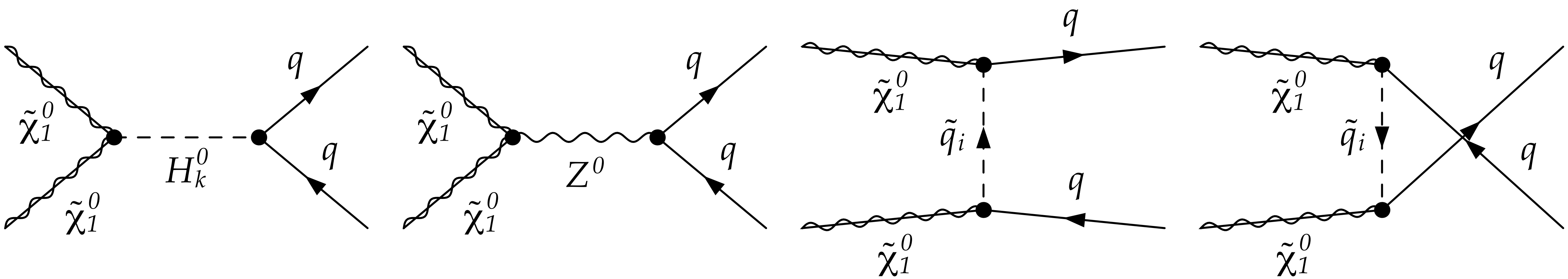

Higgs-exchange dominant in mSUGRA

- Low $m_{1/2}$ (if not excluded by LEP)

$$\tilde{\chi}\tilde{\chi} \to h^0 \to b\bar{b}$$

- A-Funnel at high tanb

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- Focus point region

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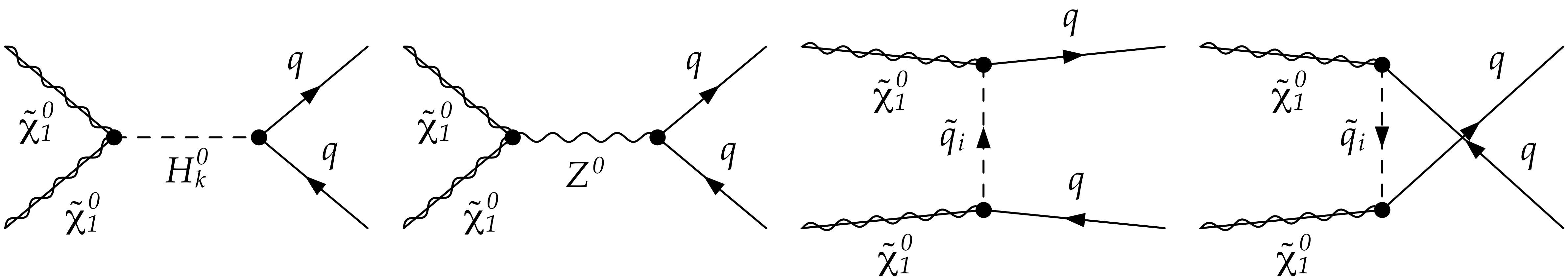

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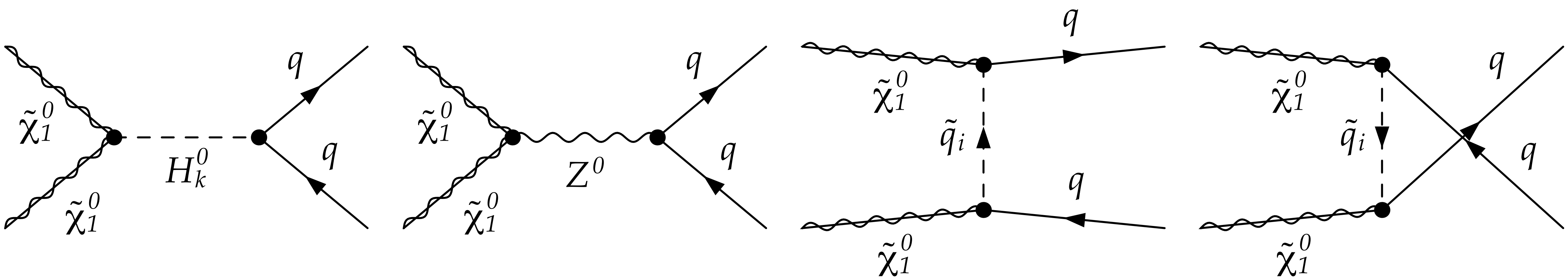

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Large mass splitting favours squark exchange

- Large trilinear coupling A_0

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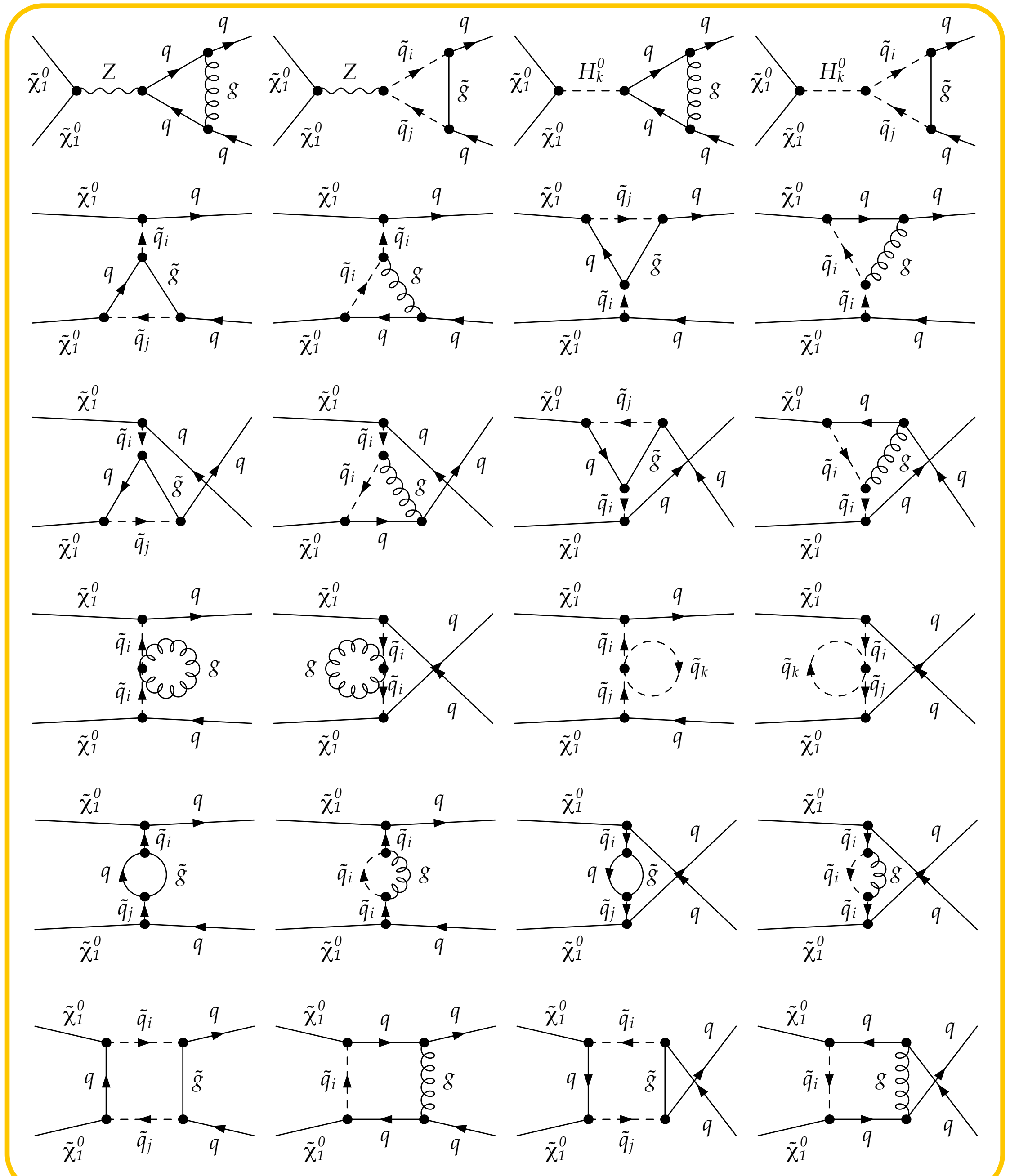
Supersymmetric QCD Corrections

One-loop contributions



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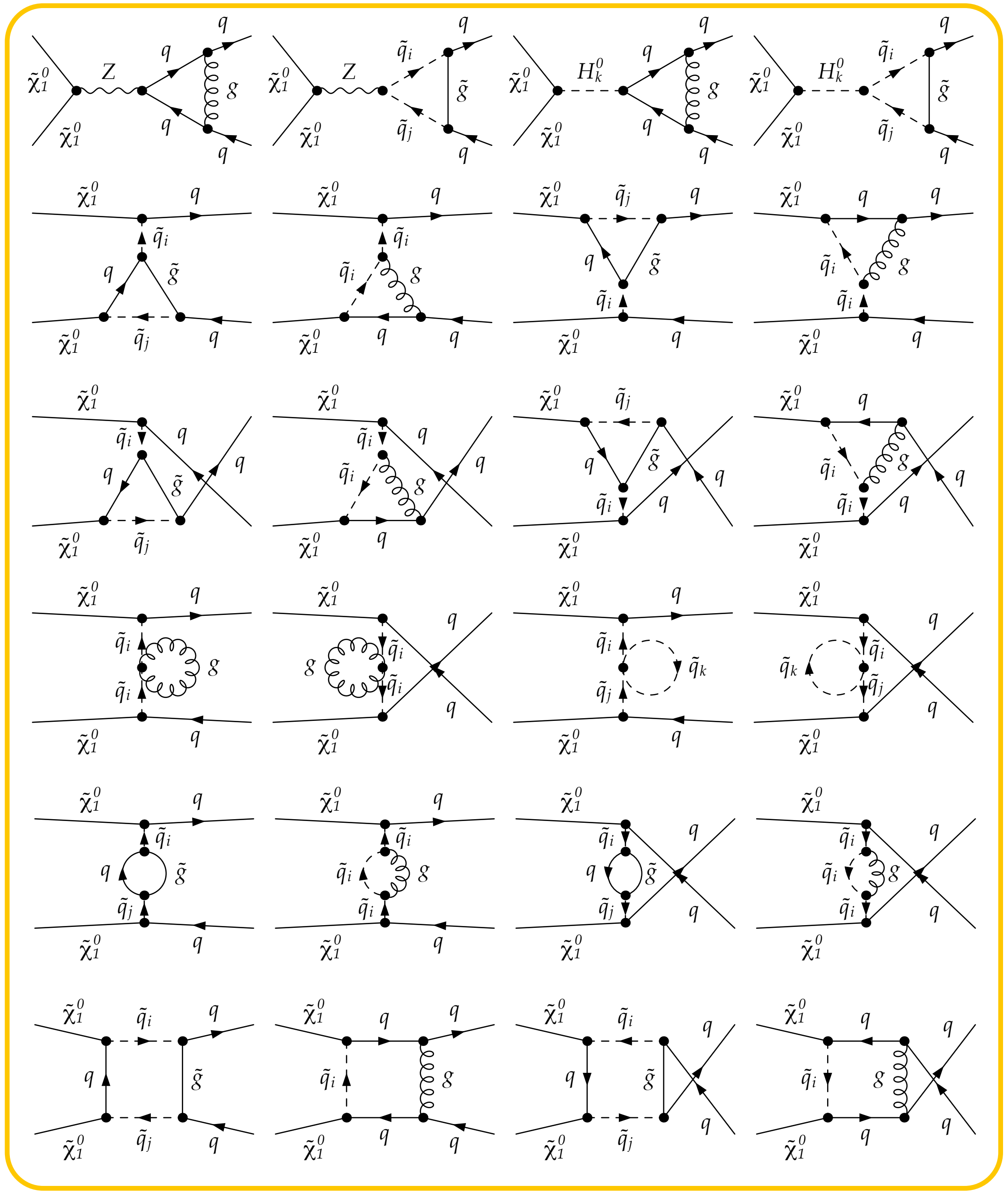
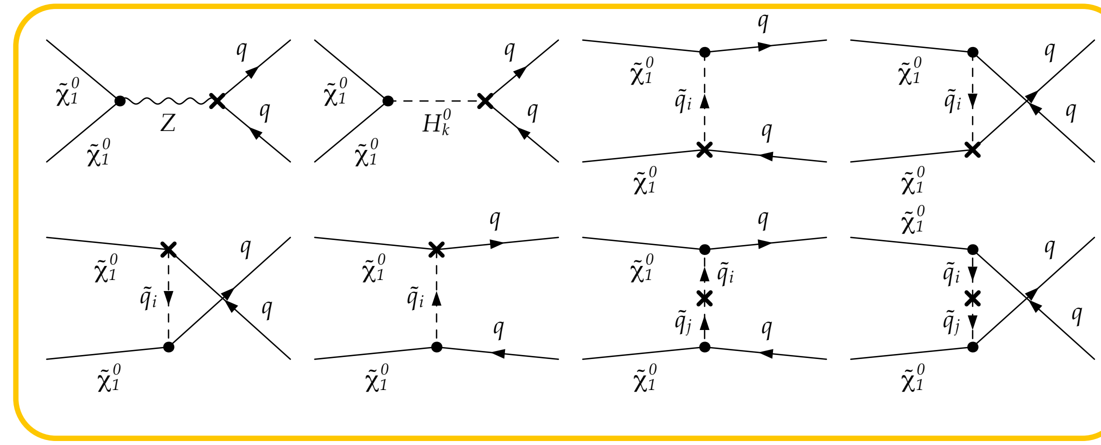


Counterterms [Kovařík *et al.* 2005]



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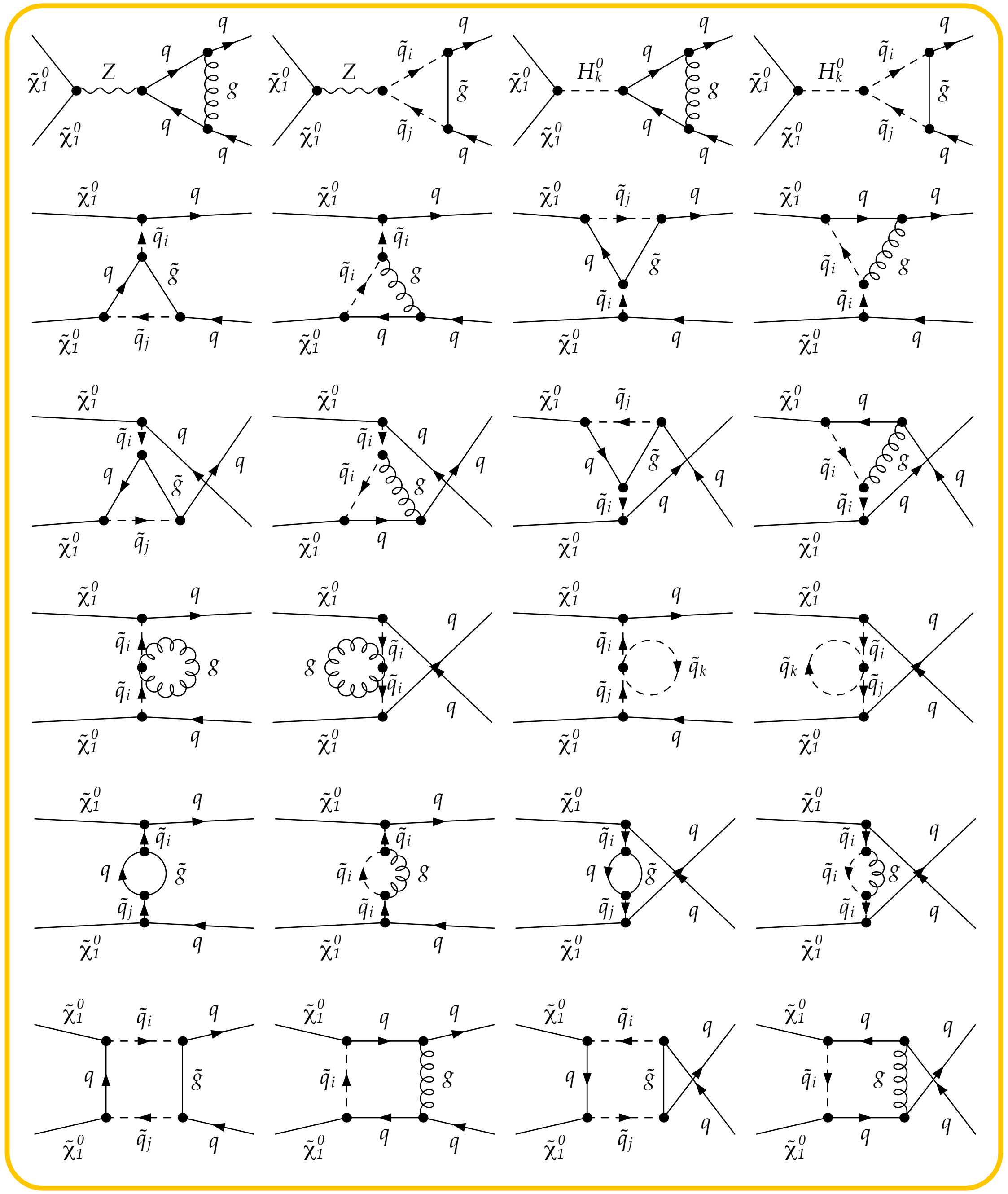

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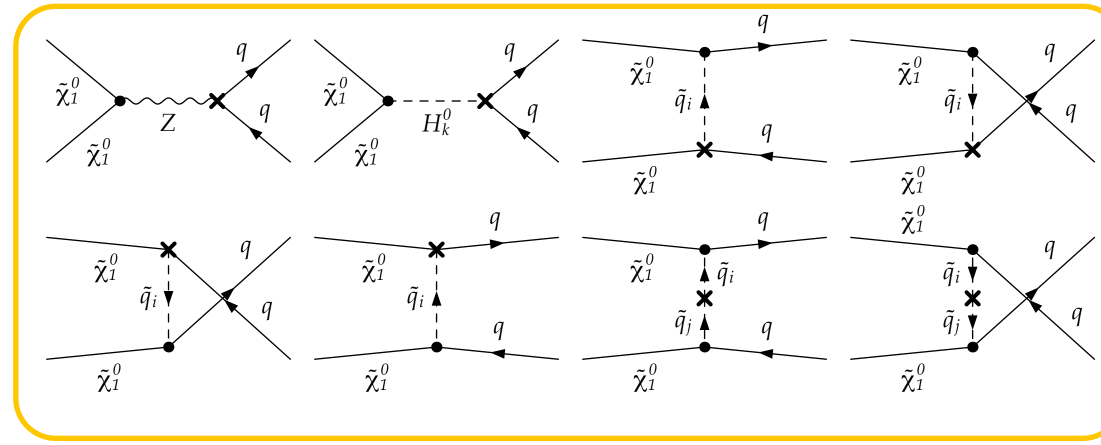

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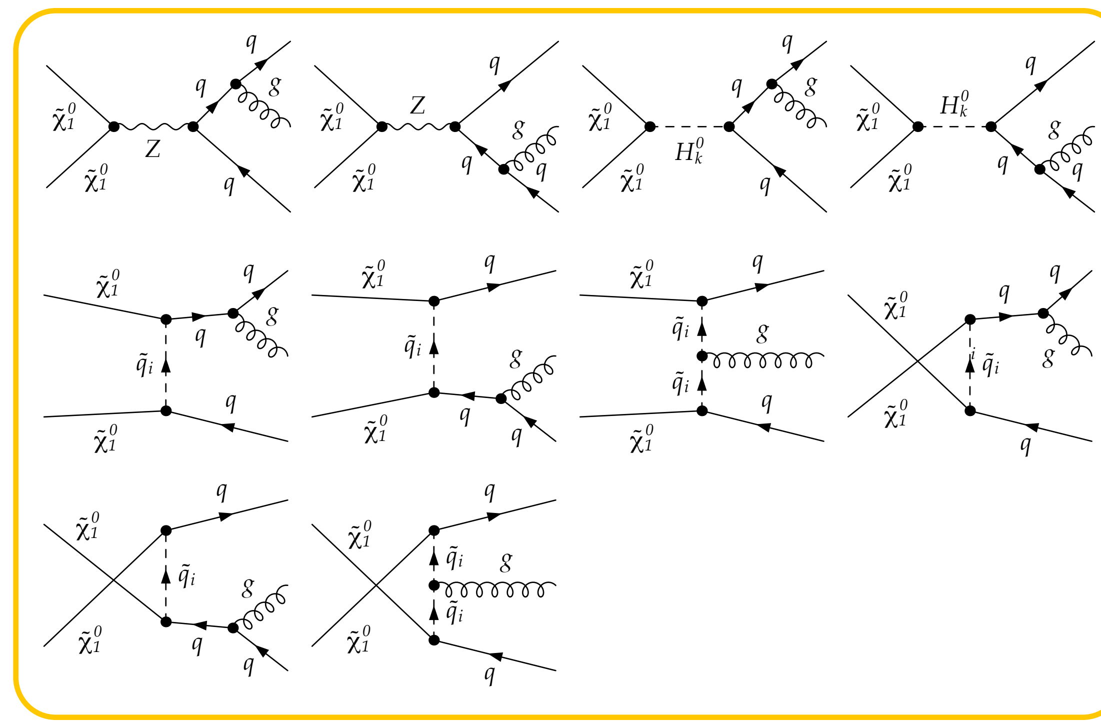

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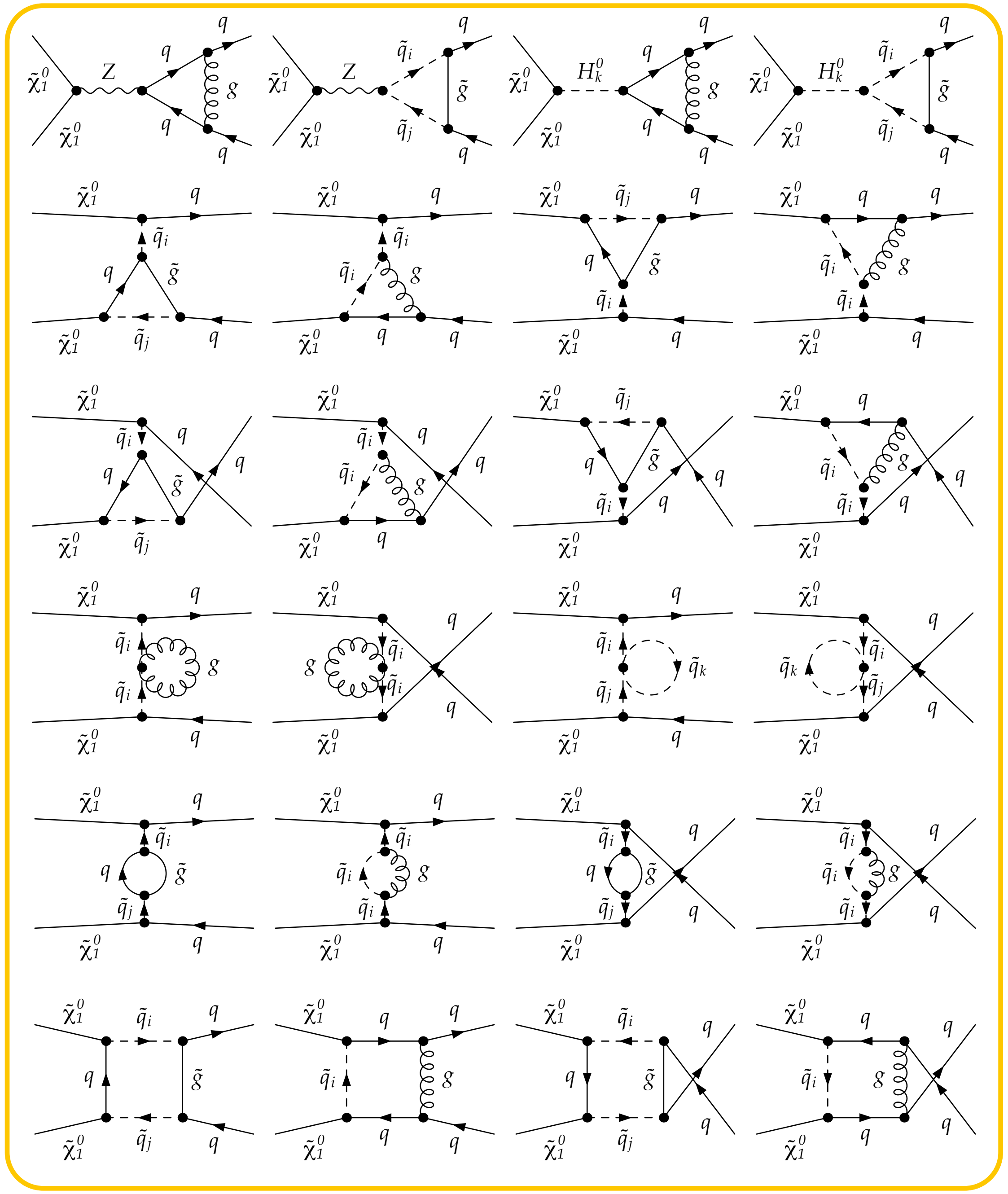

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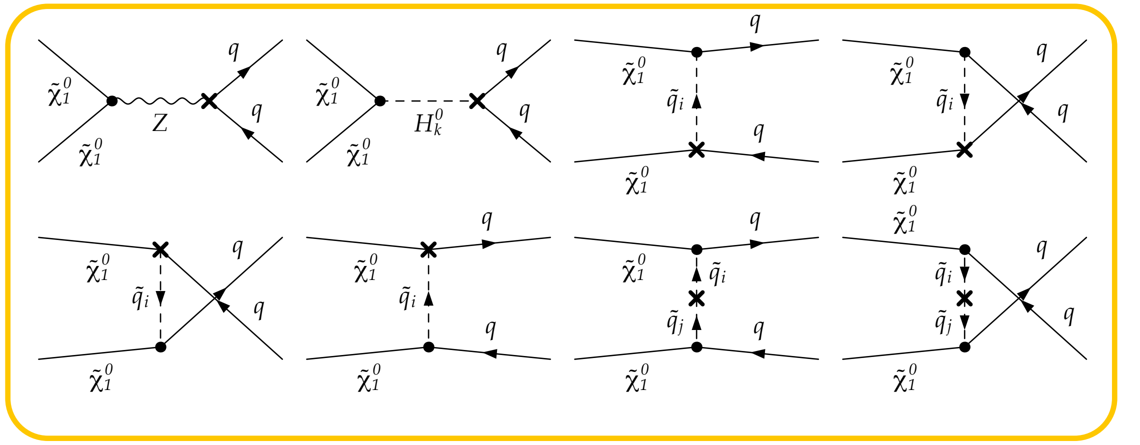

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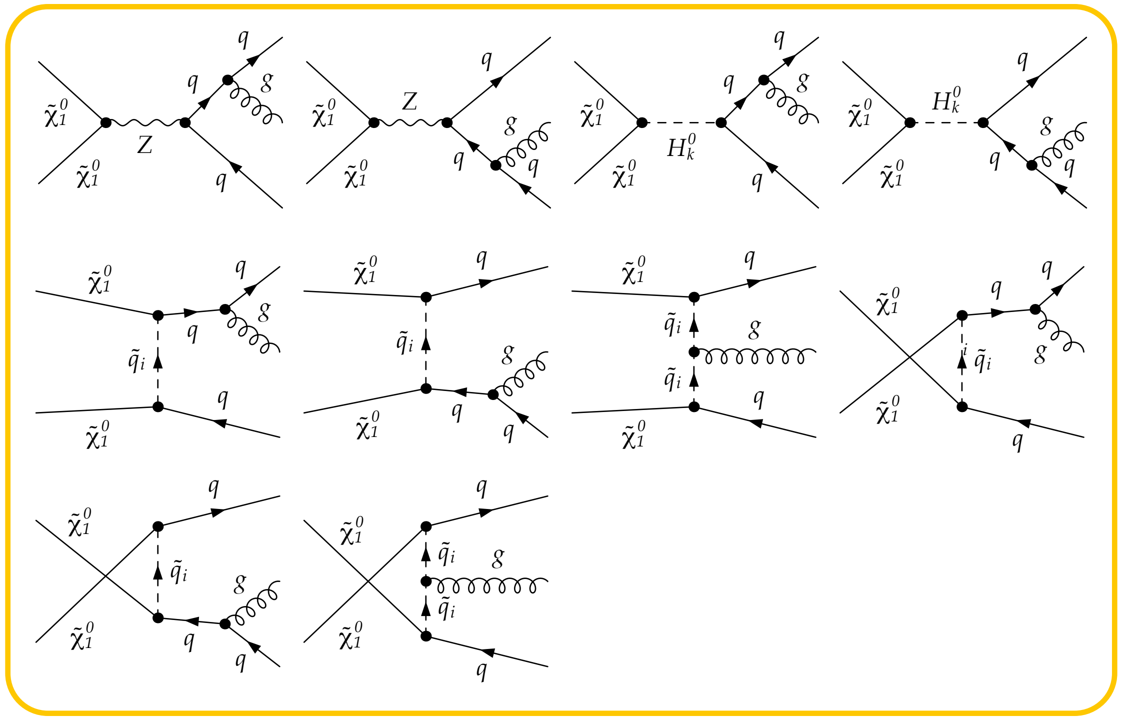

Dipole Subtraction Method

[Catani *et al.* 2000-2002]

$$\sigma_{\rm NLO} \;=\; \int_2 \left[\mathrm{d}\sigma^{\rm V} + \int_1 \mathrm{d}\sigma^{\rm A} \right] + \int_3 \left[\mathrm{d}\sigma^{\rm R} - \mathrm{d}\sigma^{\rm A} \right]$$

Scenario with dominant Z^0-exchange

[Herrmann, Klasen, Kovařík 2009]

A_0	0
$\tan\beta$	10
$\mathrm{sgn}(\mu)$	$+$

m_0	1500 GeV
$M_1 = M_2$	600 GeV
M_3	266 GeV
$\Omega_{\tilde{\chi}}h^2$	0.104
$t\bar{t}$	50.4%
$m_{\tilde{\chi}}$	235.6 GeV
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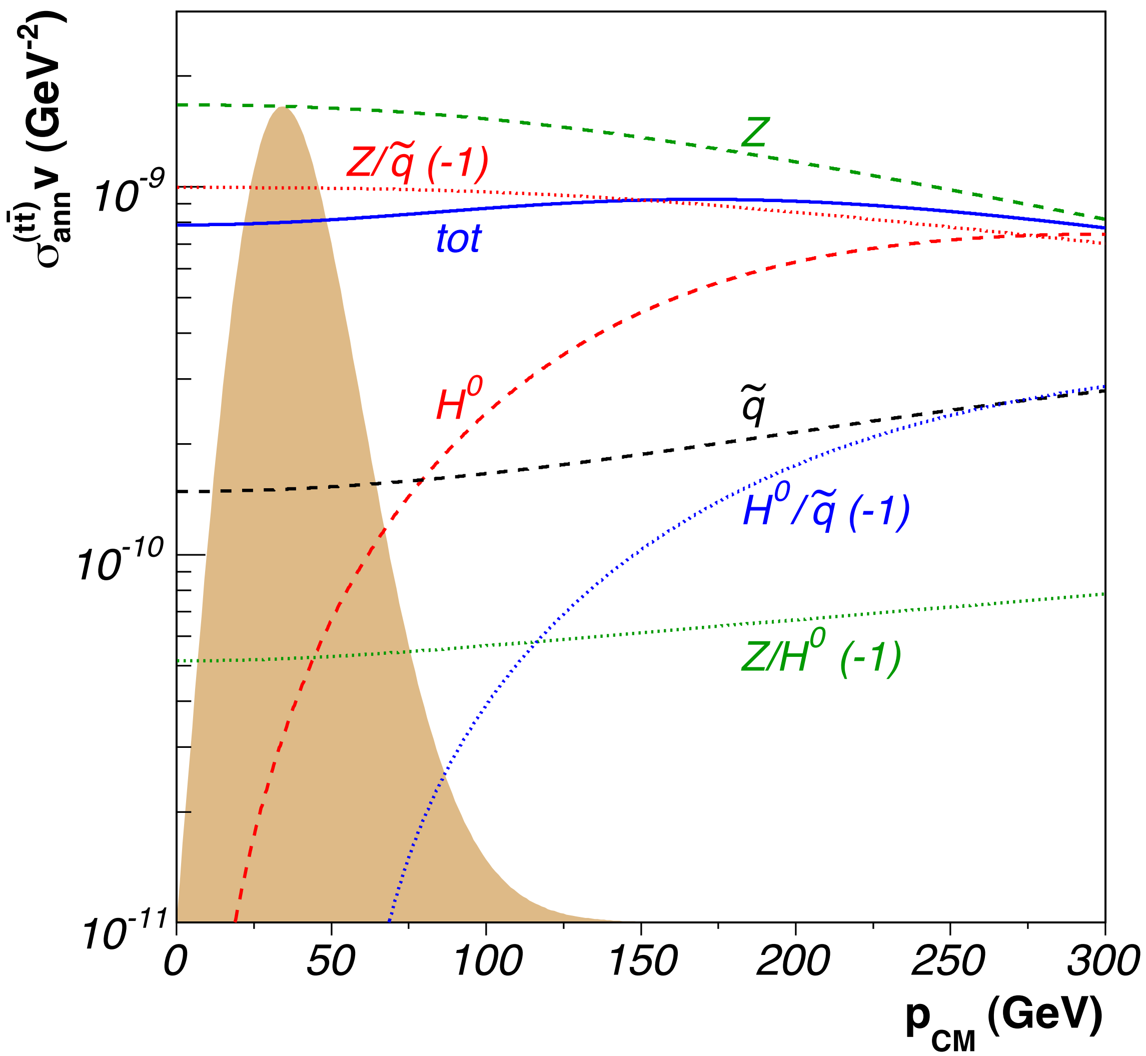

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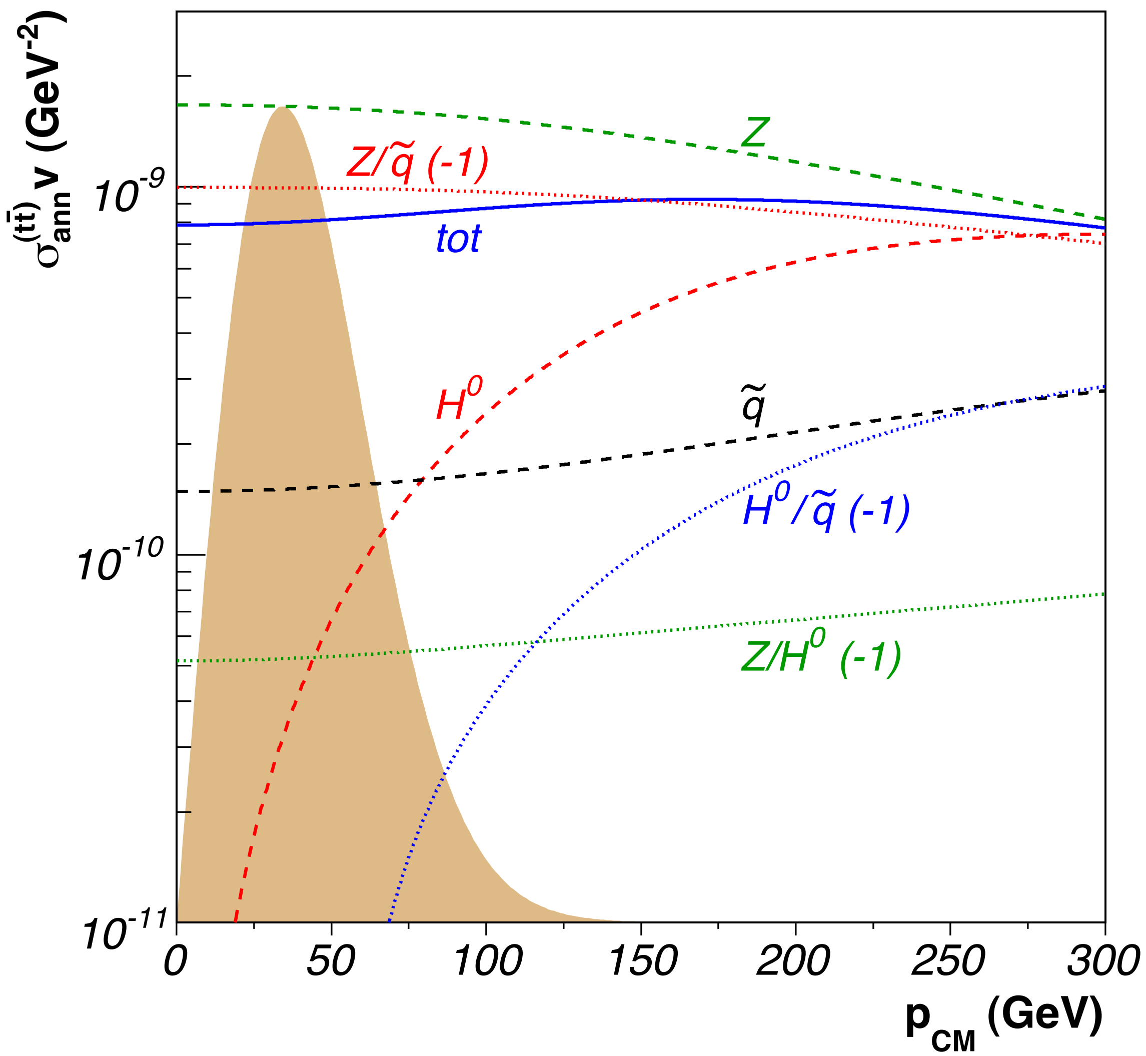

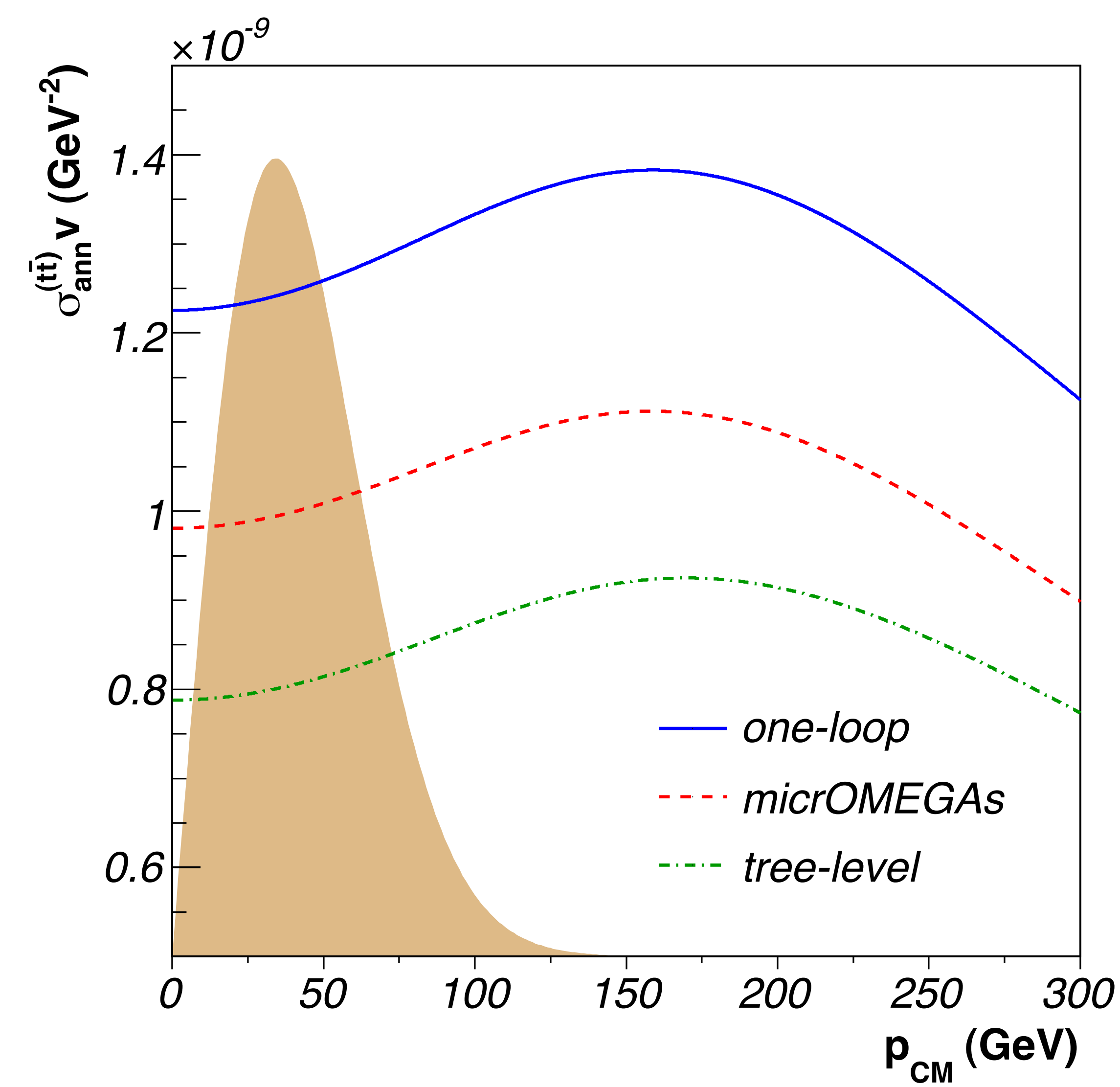

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Full one-loop corrections increase cross-section

→ about 50% w.r.t. tree-level approximation

→ about 25% w.r.t. micrOMEGAs calculation

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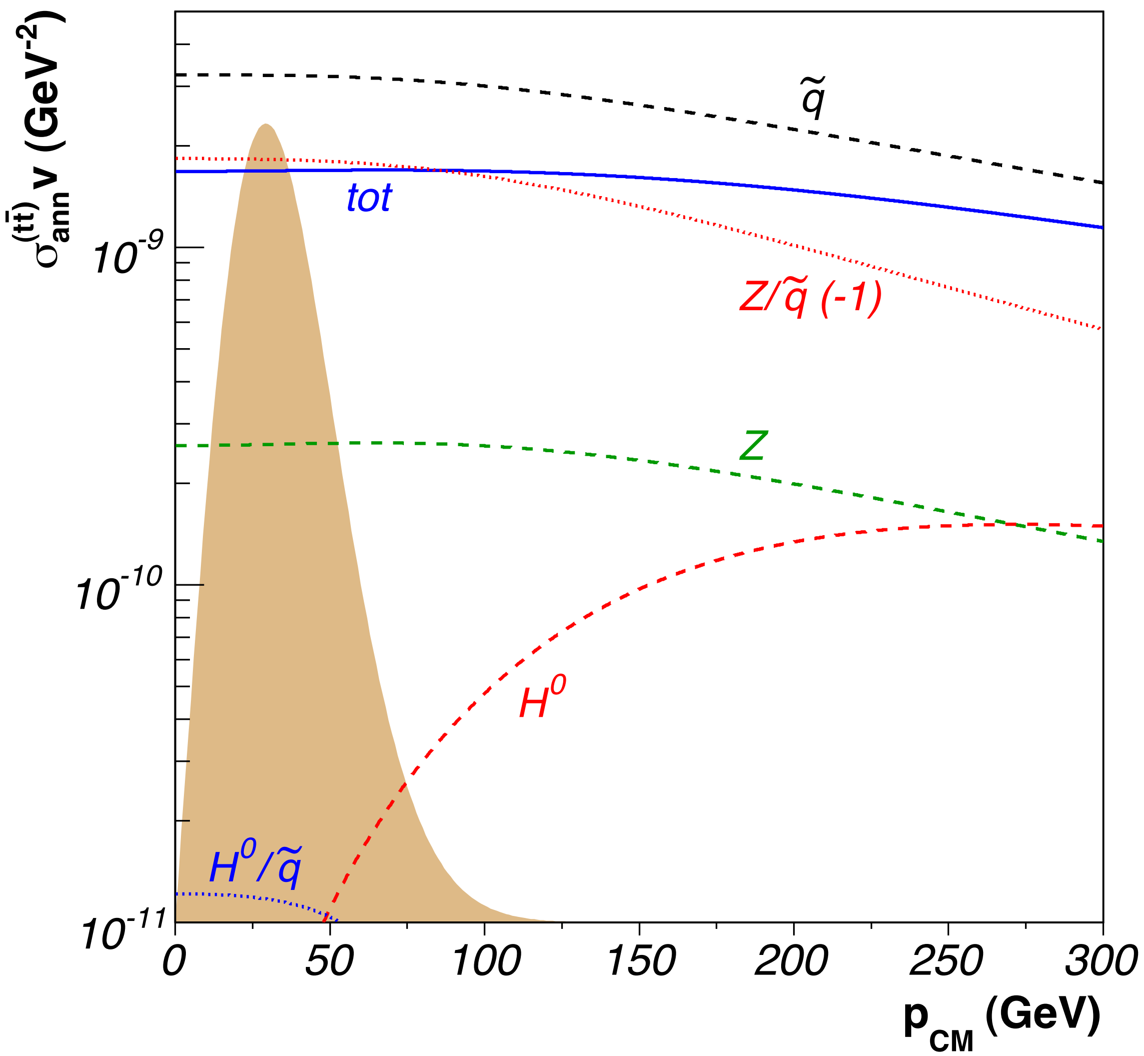

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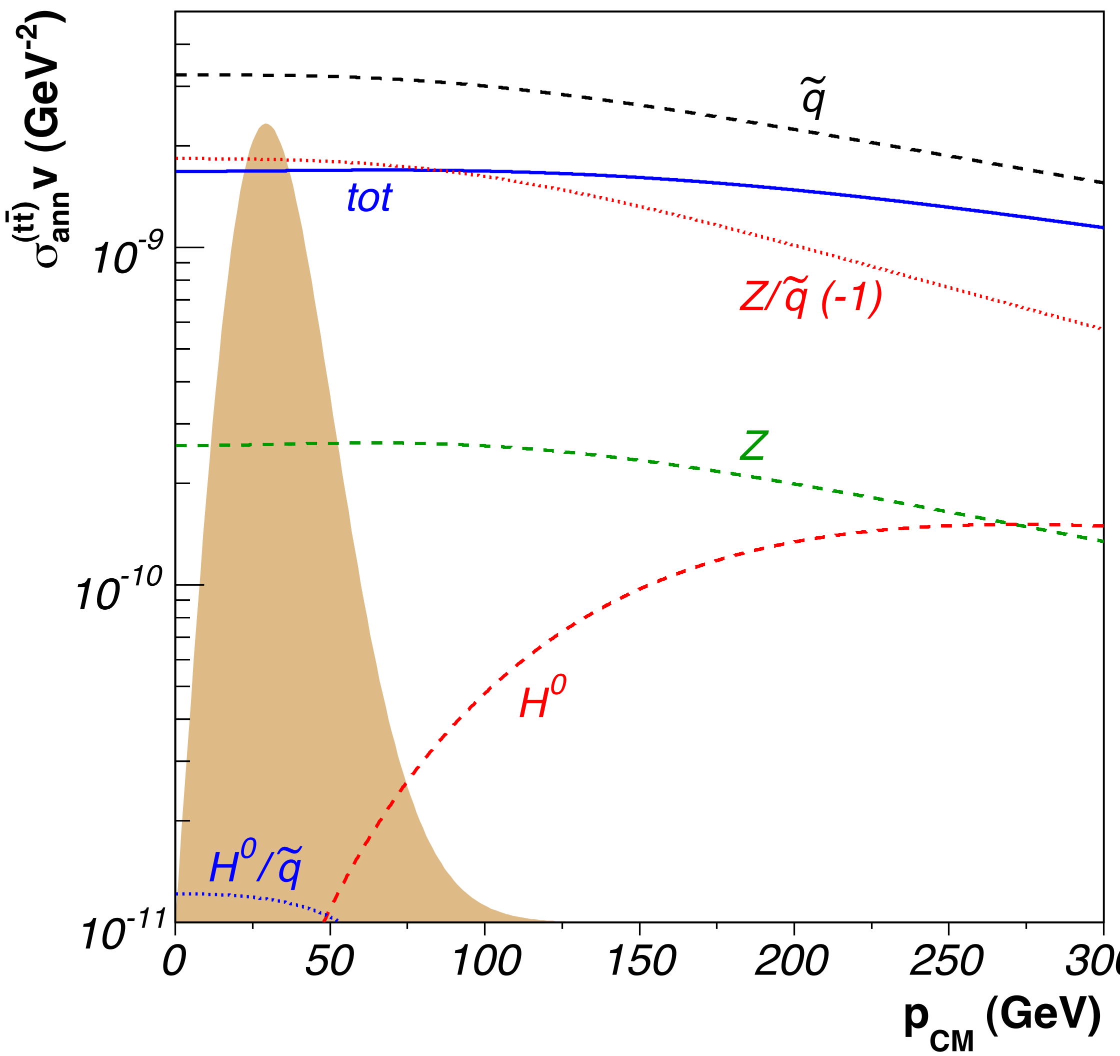

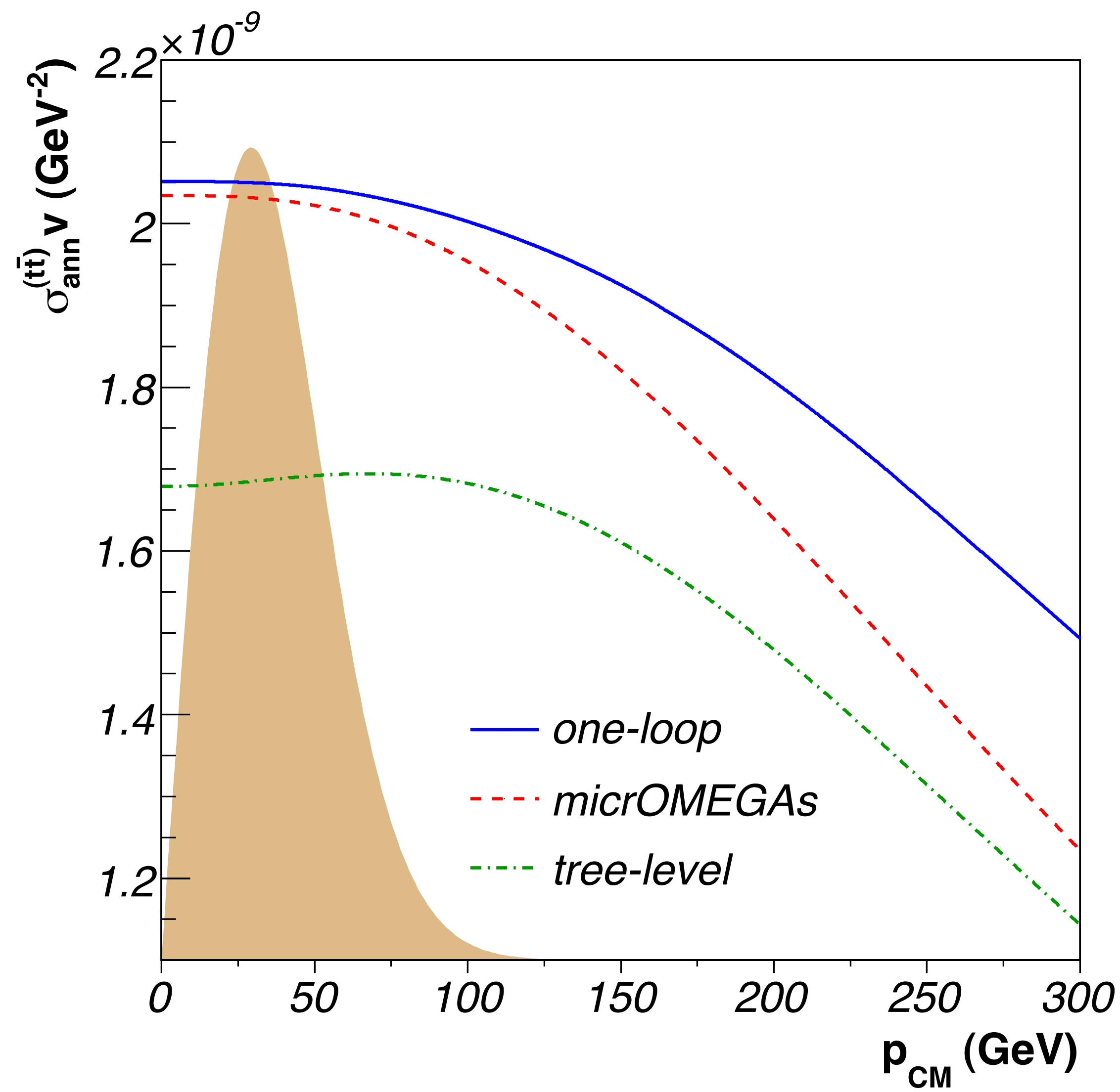

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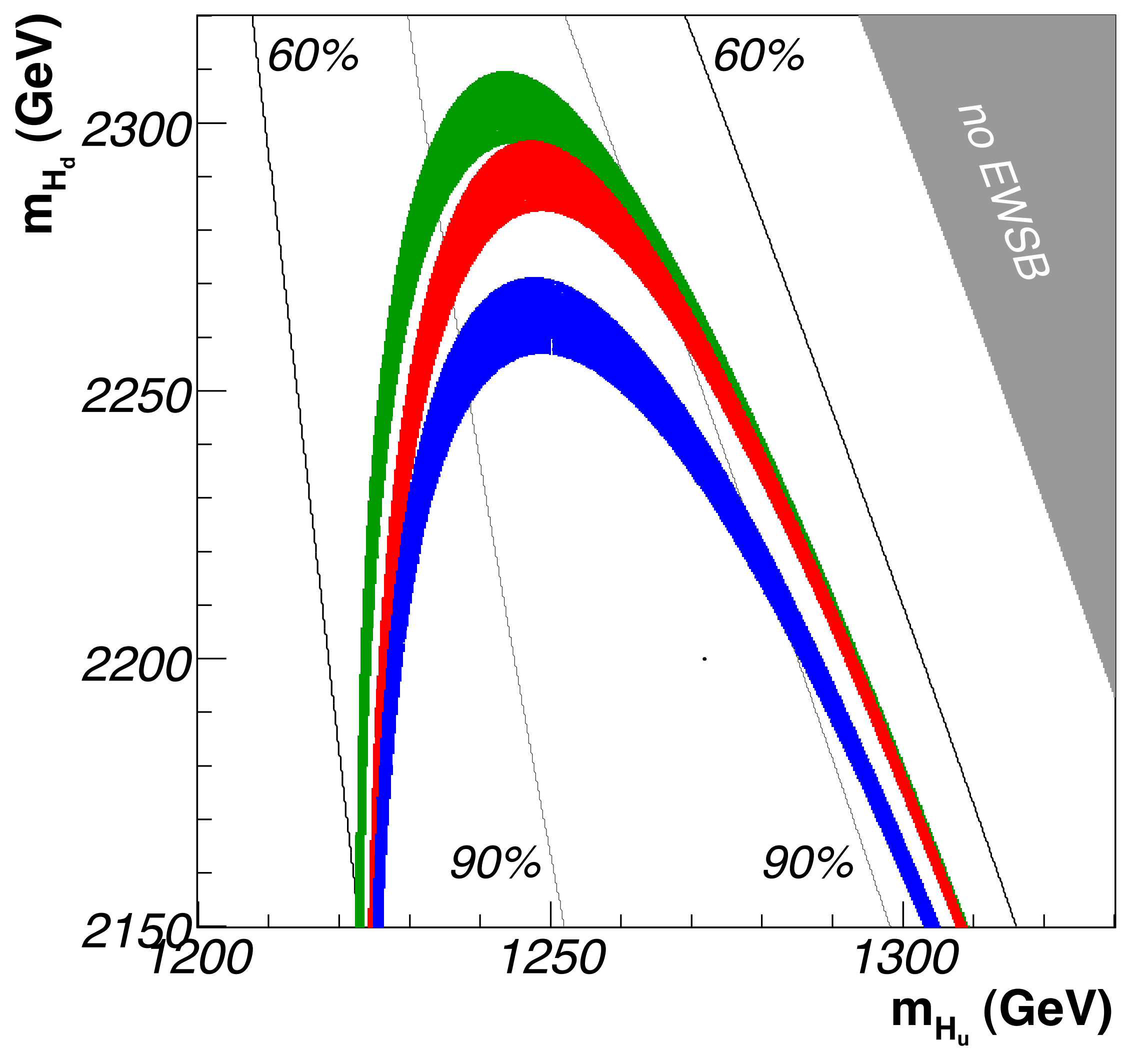
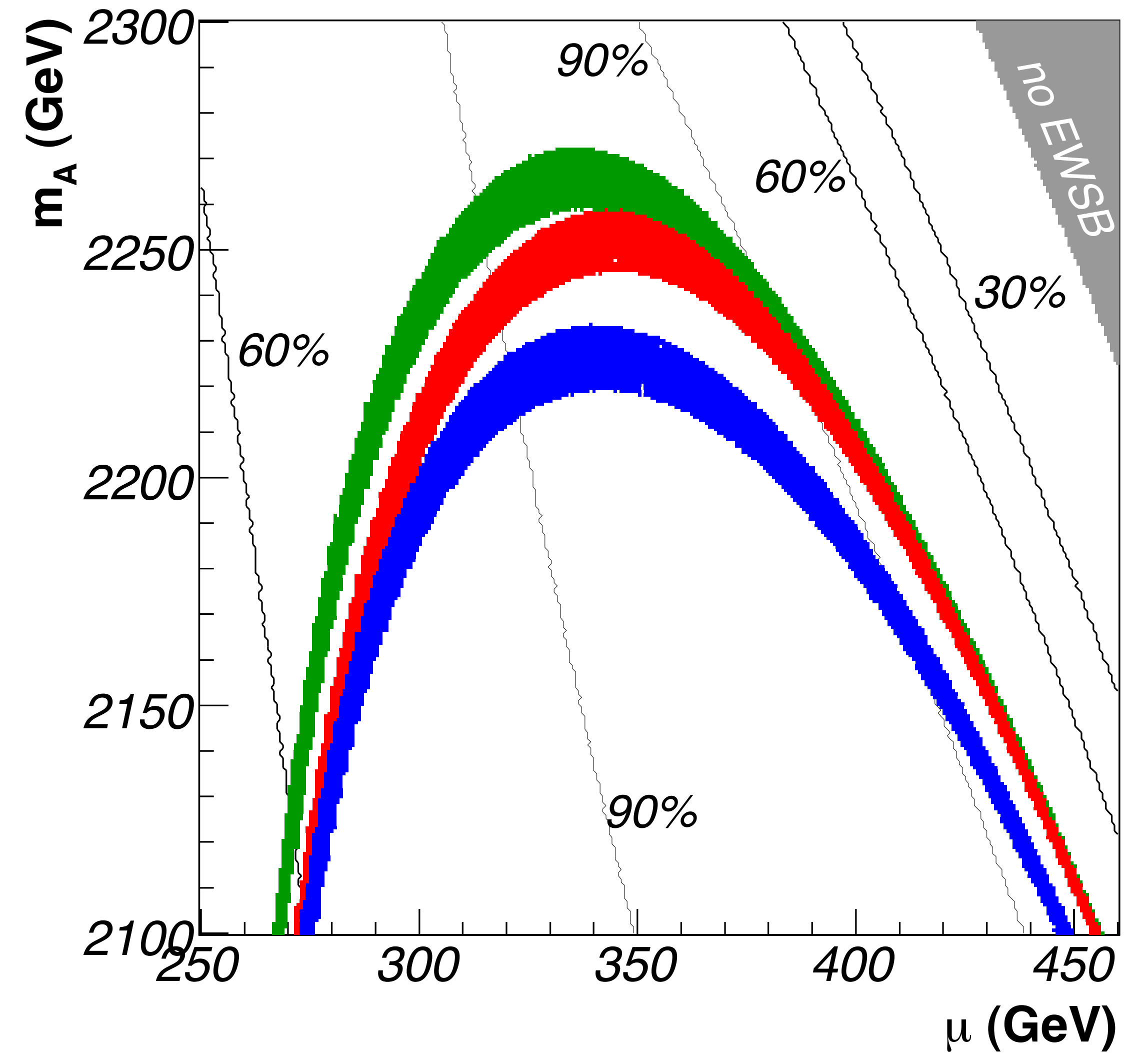
→ about 25% w.r.t. tree-level approximation

Favoured regions of parameter space





Scenario with dominant squark-exchange

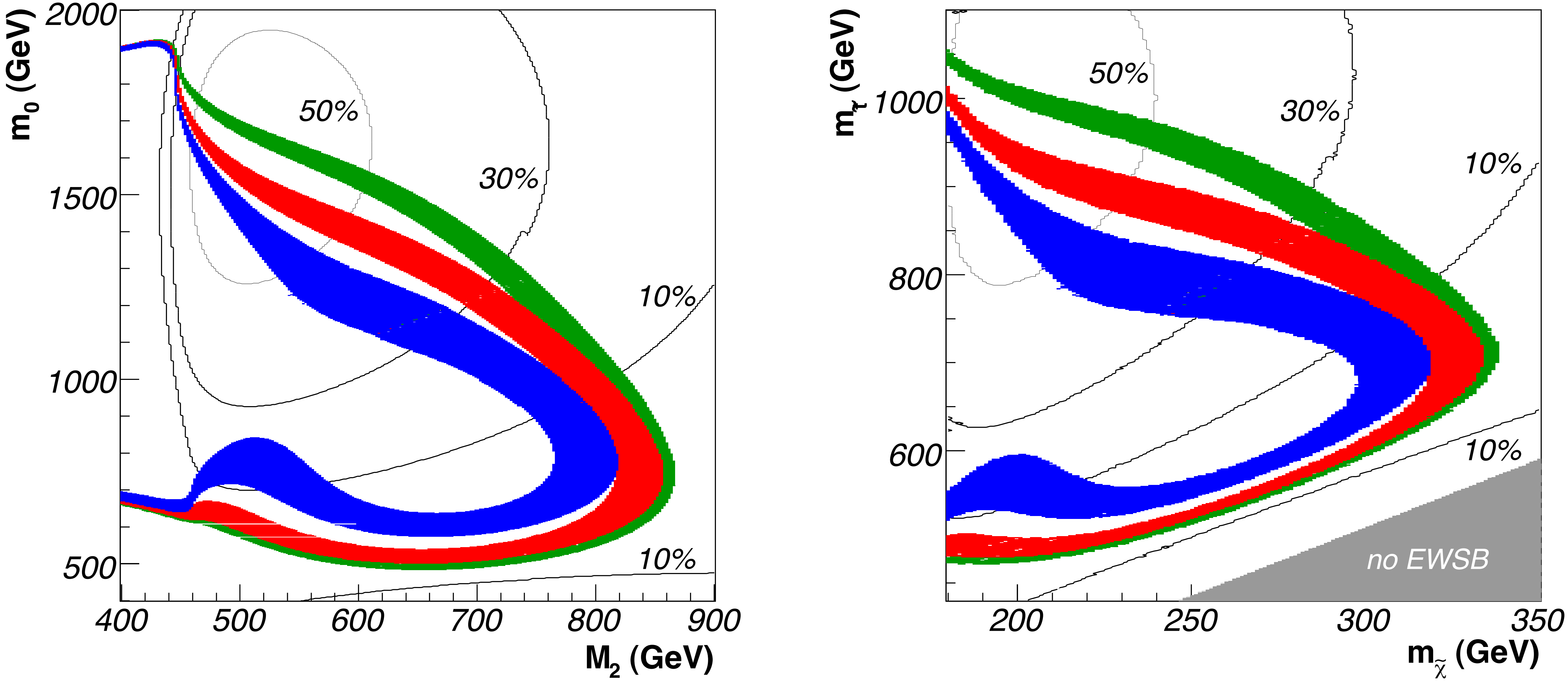
→ cross-section increased by about 25% w.r.t. tree-level calculation

Effect on annihilation cross-section direcly reflected in the prediction of the relic density

→ about 20% decrease w.r.t. tree-level approximation

→ important shifts (~50 GeV) of the favoured regions of parameter space

Favoured regions of parameter space



Scenario with dominant Z^0-exchange

- → cross-section increased by about 50% w.r.t. tree-level calculation
- → important shifts (up to 200 GeV) of the favoured regions of parameter space

Effect of SUSY-QCD corrections is larger than experimental uncertainty

- → distinct bands corresponding to different levels of correction
- → corrections even more important when Planck will deliver new cosmological data

Conclusions

Relic density calculation interesting tool to constrain SUSY models

→ Additional information w.r.t. collider and precision data

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We have analyzed annihilation into "heavy" quark final states

→ Higgs-resonances in mSUGRA scenarios [Herrmann & Klasen 2007; Herrmann, Klasen, Kovařík 2009]

→ Z^0-boson and squark exchanges in NUHM and "compressed SUSY" scenarios

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Outlook

→ Study "light" quark final states in "EW-scale" MSSM [Herrmann, Klasen, Kovařík *in preparation*]

→ Study effects on indirect dark matter detection

→ Consider other uncertainties in relic density calculation [Bélanger *et al.* 2005, Arbey *et al.* 2009]

→ Include also EW corrections [Baro, Boudjema, Chalons, Hao, Semenov 2008-2009; Talk by Guillaume Chalons]