Harmonia meeting

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R-symmetry

- additional symmetry of the SUSY algebra allowed by the Haag - Łopuszański - Sohnius theorem

- for N=1 it is a global $U_R(1)$ symmetry under which the SUSY generators are charged

- implies that the spinorial coordinates are also charged $Q_R(\theta) = 1, \; \theta \to e^{\imath\alpha}\theta$

- Superpotential example

$$\mathcal{L} \ni \int d^2\theta \, W$$

- Superpotential is polynomial in fields. For W to transform homogeneously superfields must have definite R-charges

$$\begin{array}{ccccccc} e^{\imath\alpha Q_R} & & e^{\imath\alpha Q_R} & & e^{\imath\alpha(Q_R-1)} & & \\ \Phi & = & \phi(y) & + & \sqrt{2}\theta\psi(y) & + & \theta\theta F(y) \end{array}$$

- Similarly one can work out other parts of the Lagrangian

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(we want it to be)
R-invariant

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Low-energy R-symmetry realization

- Different possible models that one can construct
- "Natural" choice

$$
\begin{array}{lccccccc}
 & e^{\imath\alpha Q_R} & & e^{\imath\alpha Q_R} & & e^{\imath\alpha(Q_R-1)} & & \\
 & \Phi & = & \phi(y) & + & \sqrt{2}\theta\psi(y) & + & \theta\theta F(y) \\
\text{leptons and quarks} & Q_R = 1 & & Q_R = 1 & & Q_R = 0 & & \\
\text{Higgs} & Q_R = 0 & & Q_R = 0 & & Q_R = -1 & &
\end{array}
$$

- Good: no barion and lepton number violating terms
- Bad: No Majorana masses for higgsinos and gauginos

One way to fix it: Dirac masses

Minimal R-Symmetric Supersymmetric Standardmodel (MRSSM)

Kribs et.al. arXiv:0712.2039

			$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_R$
Additional fields:	Singlet	$\hat{S}$	1	1	0	0
	Triplet	$\hat{T}$	1	3	0	0
	Octet	$\hat{O}$	8	1	0	0
	R-Higgses	$\hat{R}_u$	1	2	$-1/2$	2
		$\hat{R}_d$	1	2	$1/2$	2

$$
\begin{aligned}
W = & \mu_d \hat{R}_d \hat{H}_d + \mu_u \hat{R}_u \hat{H}_u \\
& + \Lambda_d \hat{R}_d \hat{T} \hat{H}_d + \Lambda_u \hat{R}_u \hat{T} \hat{H}_u + \lambda_d \hat{S} \hat{R}_d \hat{H}_d + \lambda_u \hat{S} \hat{R}_u \hat{H}_u \\
& - Y_d \hat{d} \hat{q} \hat{H}_d - Y_e \hat{e} \hat{l} \hat{H}_d + Y_u \hat{u} \hat{q} \hat{H}_u
\end{aligned}
$$

MSSM vs. MRSSM

- superpotencial

$$\mu \hat{H}_u \hat{H}_d$$

$$-Y_d\,\hat{d}\,\hat{q}\,\hat{H}_d - Y_e\,\hat{e}\,\hat{l}\,\hat{H}_d + Y_u\,\hat{u}\,\hat{q}\,\hat{H}_u$$

- soft-SUSY breaking terms
  - B_μ - term
  - soft scalar masses
  - Majorana gaugino masses
  - A - terms

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$$\Lambda_d\,\hat{R}_d\,\hat{T}\,\hat{H}_d + \Lambda_u\,\hat{R}_u\,\hat{T}\,\hat{H}_u + \lambda_d\,\hat{S}\,\hat{R}_d\,\hat{H}_d + \lambda_u\,\hat{S}\,\hat{R}_u\,\hat{H}_u$$

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Kribs, Popitz, Weiter (2008)

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$$\Lambda_d\, \hat{R}_d\, \hat{T}\, \hat{H}_d\, + \Lambda_u\, \hat{R}_u\, \hat{T}\, \hat{H}_u\, + \lambda_d\, \hat{S}\, \hat{R}_d\, \hat{H}_d\, + \lambda_u\, \hat{S}\, \hat{R}_u\, \hat{H}_u$$

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Particle content summary: MSSM vs. MRSSM

different number of physical states **completely new states**

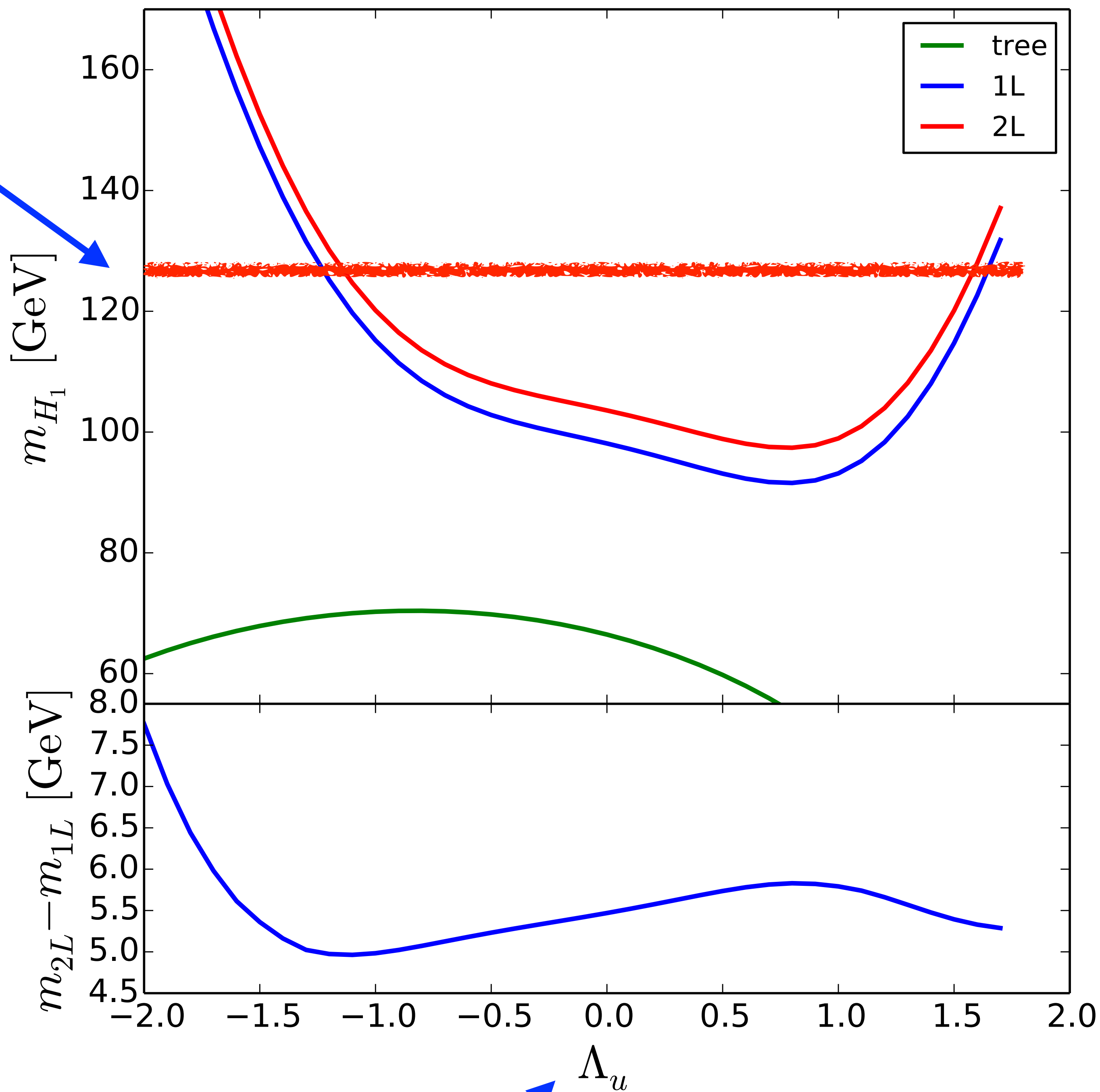
	Higgs				R-Higgs		
	CP-even	**CP-odd**	**charged**	**charginos**	**neutral**	**charged**	**sgluon**
MSSM	2	1	1	2	0	0	0
MRSSM	4	3	3	2+2	2	2	1

	neutralino	**gluino**	
MSSM	4	1	**Majorana fermions**
MRSSM	4	1	**Dirac fermions**

Lightest Higgs boson mass in the MRSSM

measured Higgs mass

mixture of hd,hu,S,T

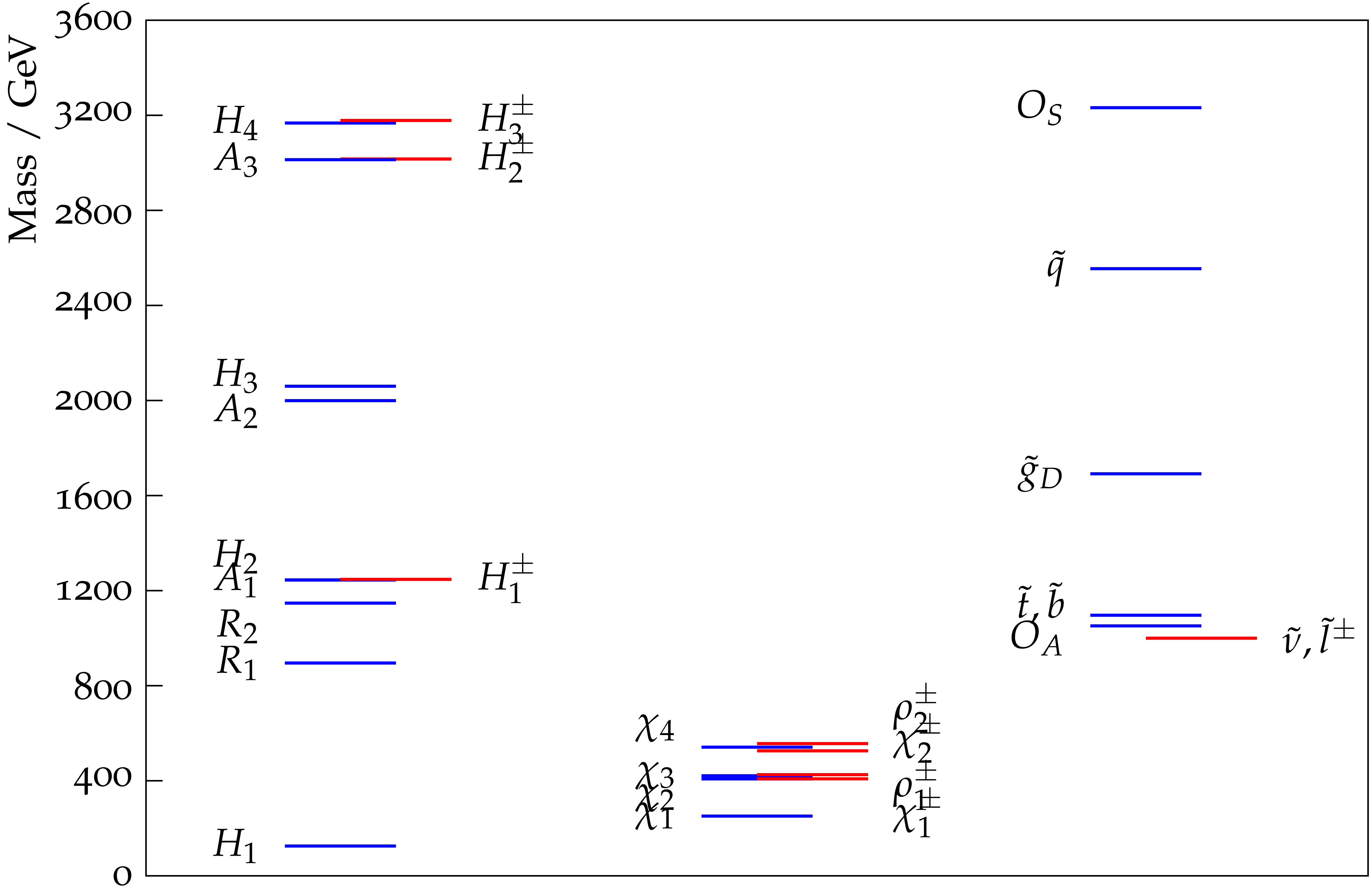


one of dimensionless parameters of the model

- tree-level result
- 1-loop quantum correction
- leading 2-loop corrections

+5 GeV at 2-loop

Exemplary mass spectrum



What has been done

- Higgs masses at 1- and 2-loop order
- analysis of constraints from m_W and STU parameters
- light singlet scenario
- (1 component) dark matter
- analysis of pseudoscalar sgluon production at the LHC

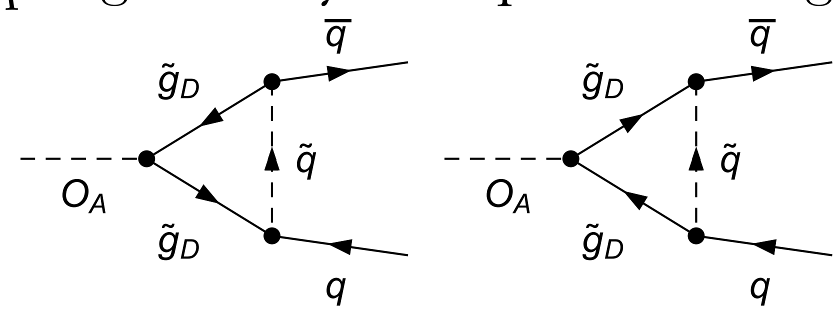
What is to be done

- NLO SQCD corrections to pair production
    - NLO R-symmetric SQCD corrections to squark pair production
    - pheno analysis
    - remaining processes
- 2-component dark matter
- g-2

MRSSM signatures at the LHC

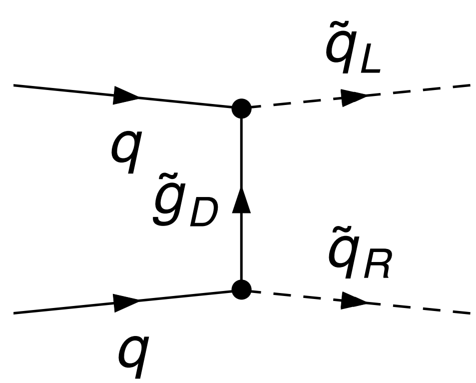
- sgluon pair production $pp \to OO$
  - complex fields O split by D-term contribution into scalar (S) and pseudoscalar (A) parts

$$m^2_{O_A} = m^2_O \qquad\qquad m^2_{O_S} = m^2_O + 4(M^D_O)^2$$

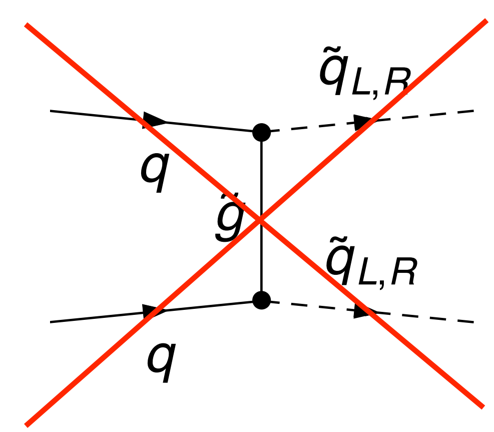
  - O_S naturally heavy, O_A might decay into quarks through loop-induced coupling
  - 

  - Coupling proportional to m_q. If O_A is lighter than other SUSY particles but $m_{O_A} > 2m_t$ O_A decays exclusively to top quarks

- same sign squark pair production $pp \to \tilde{q}_L \tilde{q}_R$
  - diagram present in the MRSSM

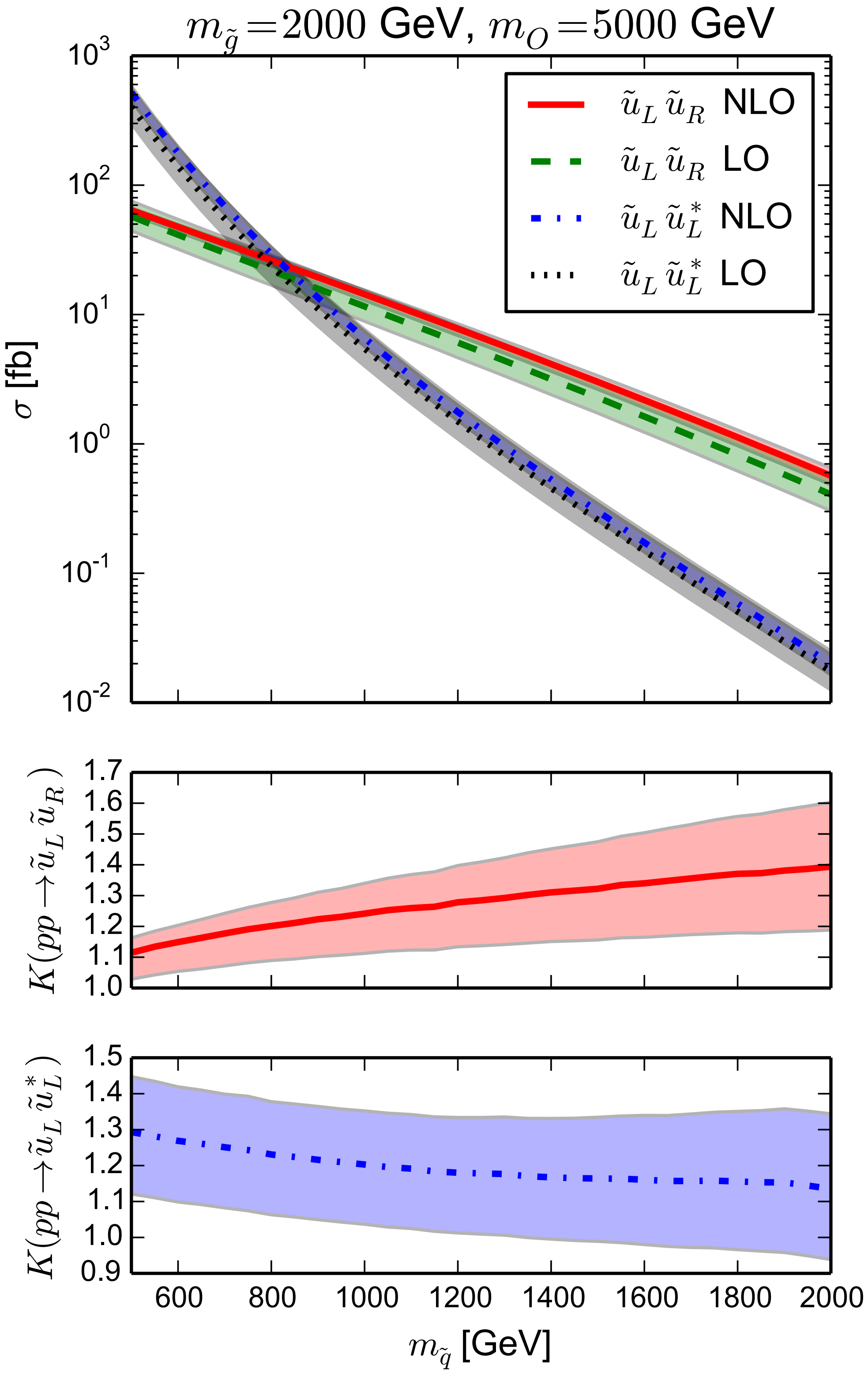


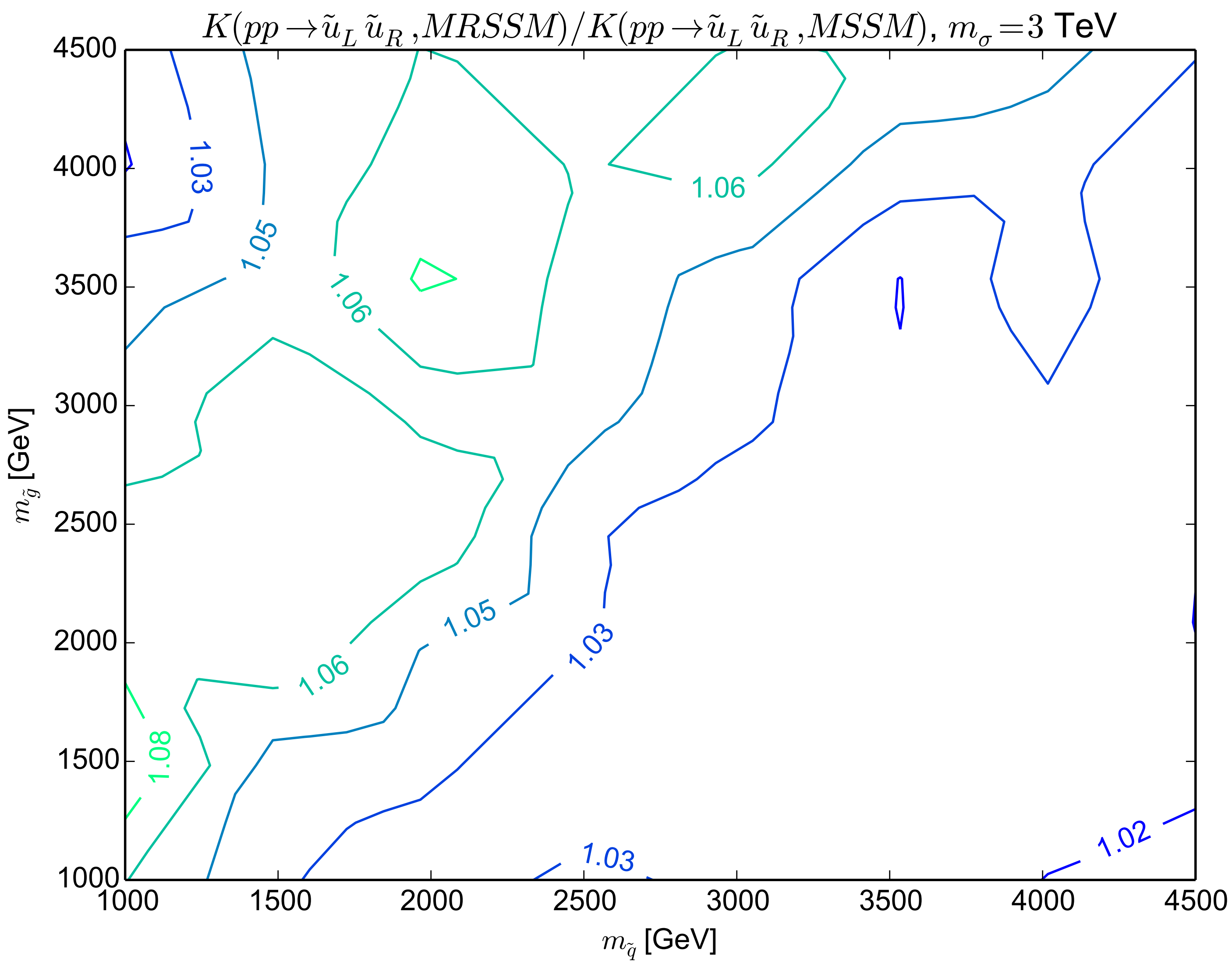
MSSM diagram with Majorana mass insertion doesn't exist



- Dirac gluino $\tilde{g}_D$ pair production, with cross section roughly twice as large as in the MSSM

NLO R-symmetric SQCD corrections



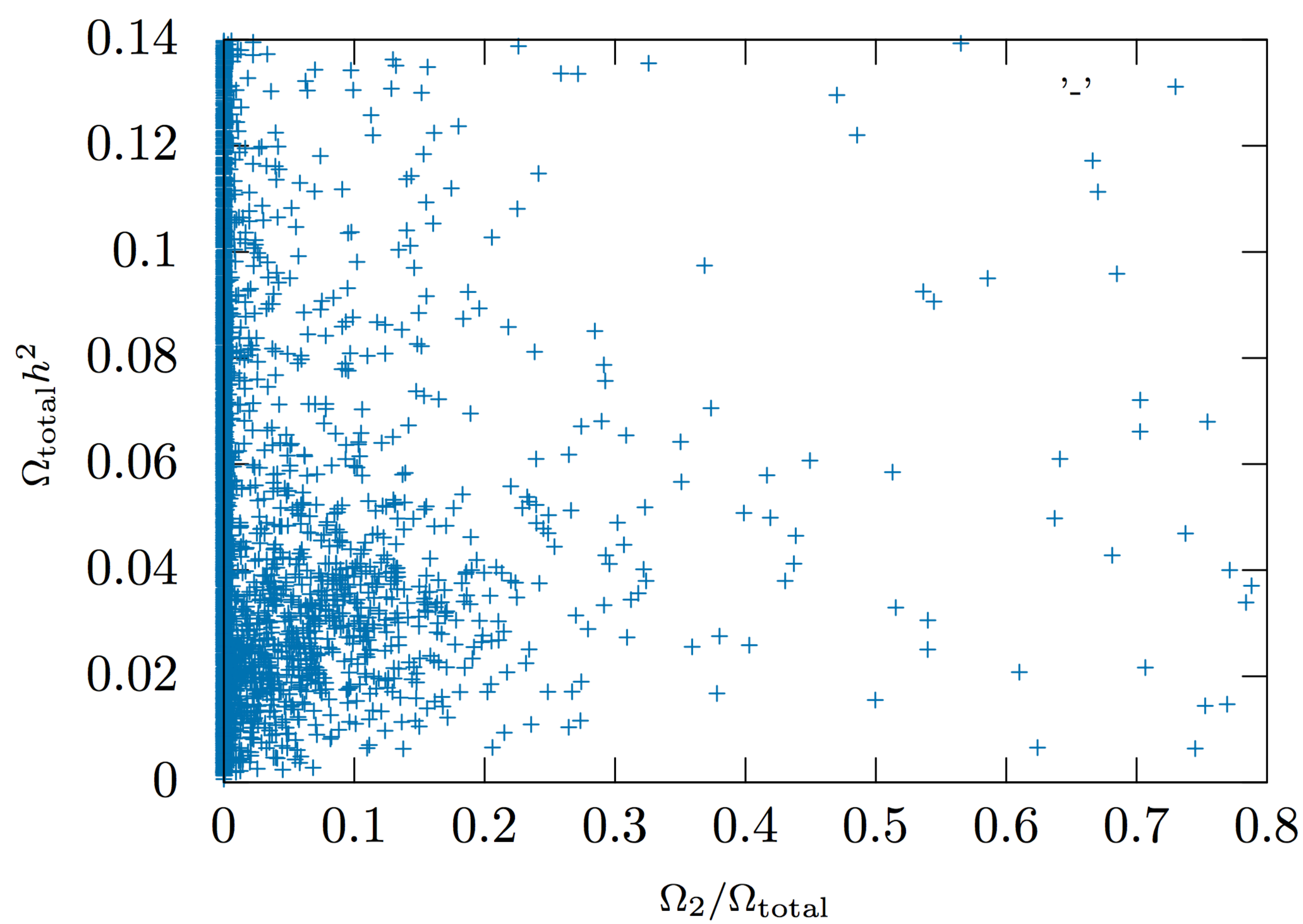


2 component dark matter

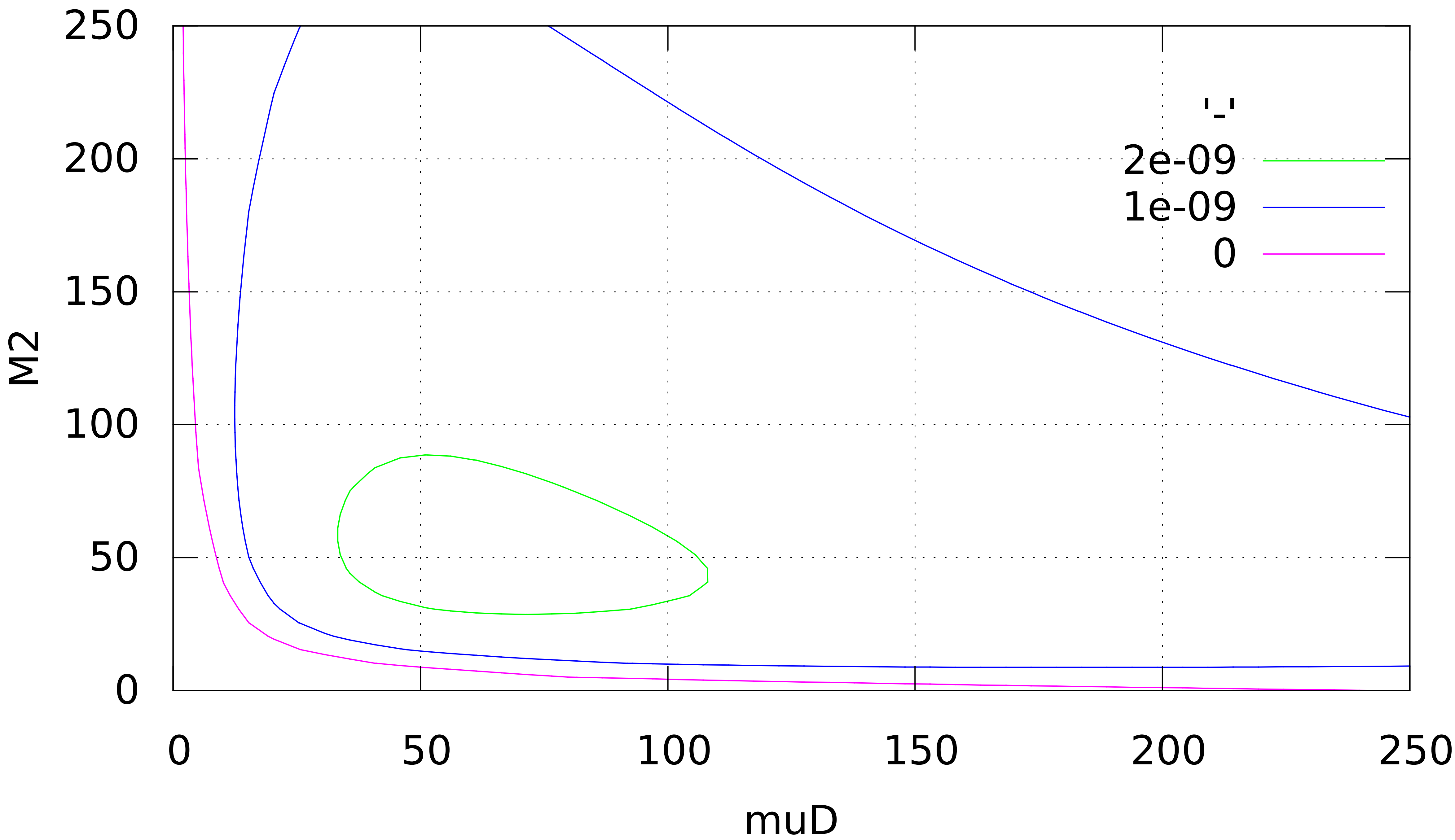
- consider scenarios where the lightest particle with R=1 is neutralino or sneutrino with mass m_{LSP1}
- if $m_{R_1^0} < 2\, m_{\mathrm{LSP1}}$, lightest neutral R-Higgs is also stable
- two SUSY dark matter candidates with relic densities Ω_1 and Ω_2
- requirements
  - $\Omega_{total}h^2 \equiv (\Omega_1 + \Omega_2)h^2 \simeq 0.11$
  - substantial fraction Ω_2/Ω_{total}
- (for now) best points are not collinear friendly:

$$m_{\tilde{\chi}_1^0} = 367 \text{ GeV}$$

$$m_{R_1^0} = 571 \text{ GeV}$$



$g-2$

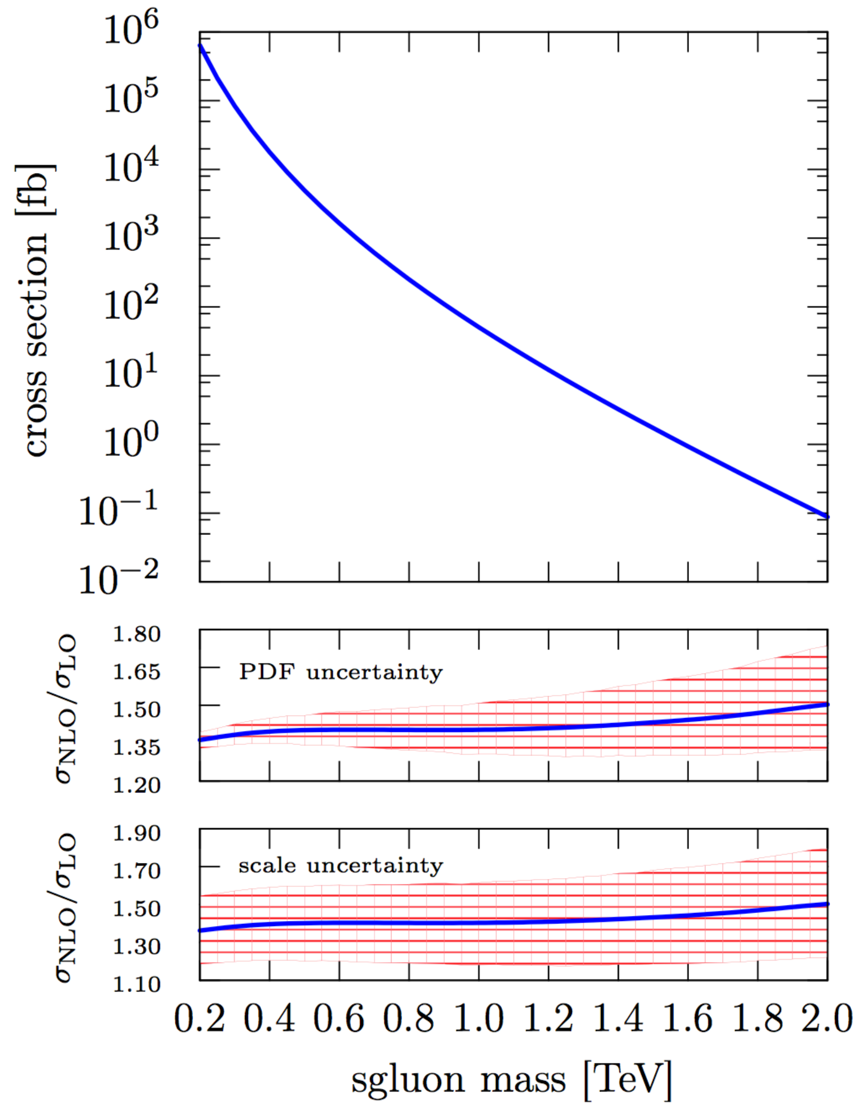


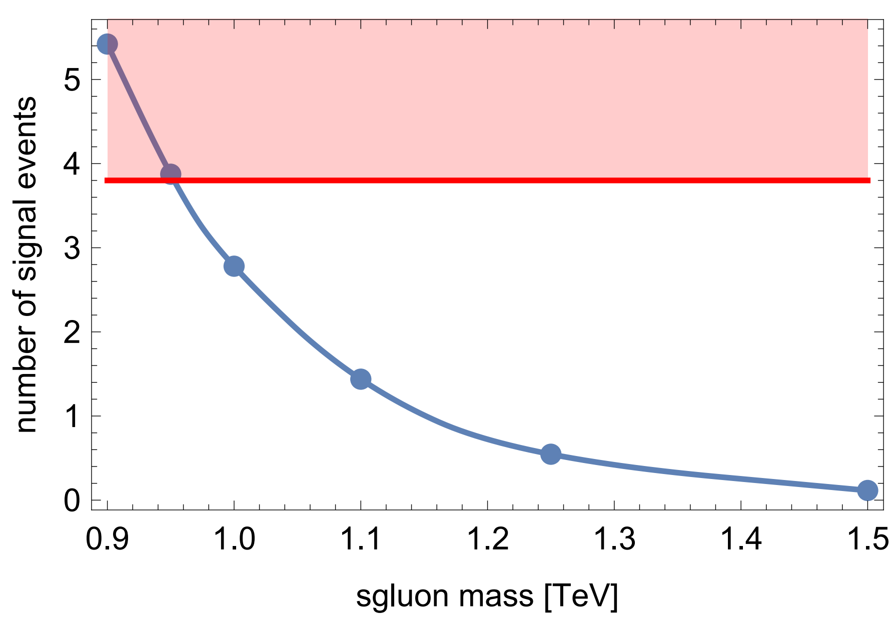
Backup

Sgluon pair production at 13 TeV LHC

W. Kotlarski [arXiv:1608.00915]

- Analysis of the sgluon pair production with subsequent decay into $t\bar{t}$ pairs. Recasting ATLAS search in the same-sign lepton channel using 3.2/fb of integrated luminosity
- Signal simulated at NLO using **MadGraph5_aMC@NLO** + **FeynRules** + **NLOCT** and matched to parton shower in the MC@NLO scheme
- Detector response parametrized using **Delphes3**
- Analysis validated on background processes $t\bar{t}l^+l^-, t\bar{t}l^\pm\nu$
- Mass of pair produced real sgluons decaying with $\mathrm{BR}(O \to t\bar{t}) = 1$ excluded up to 950 GeV





Leading order analysis

LO cross-sections for sparticle production at the LHC at $\sqrt{s}=13$TeV