Beyond the Standard Model: Non-minimal SUSY at the LHC.

Philip Diessner

Colloquium GK1504

Berlin, 09.03.18

HELMHOLTZ GEMEINSCHAFT

DESY

GK and me

Work on interface theory/experiment

- In GK from Okt 2013 - Nov 2016
- Block courses and lectures
- Exchange with fellow (experimental) students

GK and me

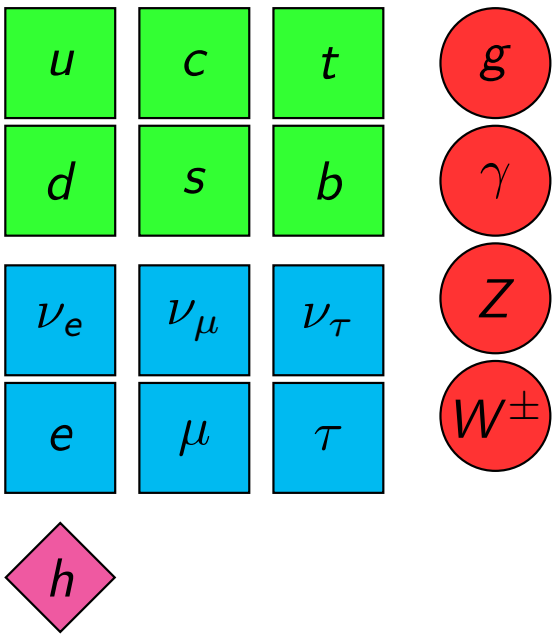
Work on interface theory/experiment

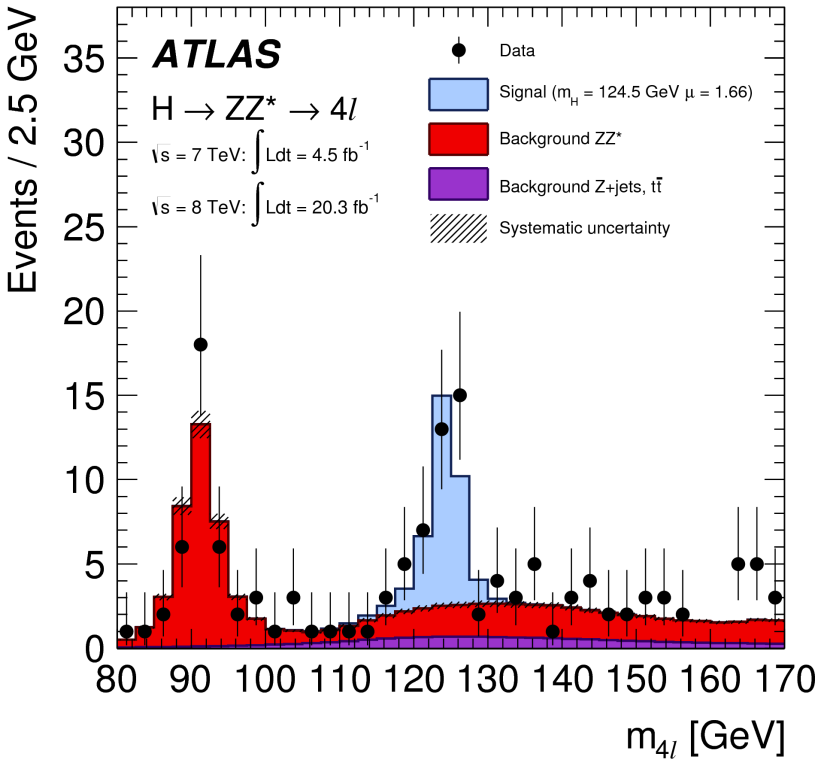
- In GK from Okt 2013 - Nov 2016
- Block courses and lectures
- Exchange with fellow (experimental) students

Slogan of the GK: ”Mass, Spectrum, Symmetry“

- Supersymmetry and R-Symmetry
- (Mass) Spectra of BSM states
- Mass of the Higgs boson

From the SM





Dark matter? Hierarchy problem? ...

Minimal Supersymmetry

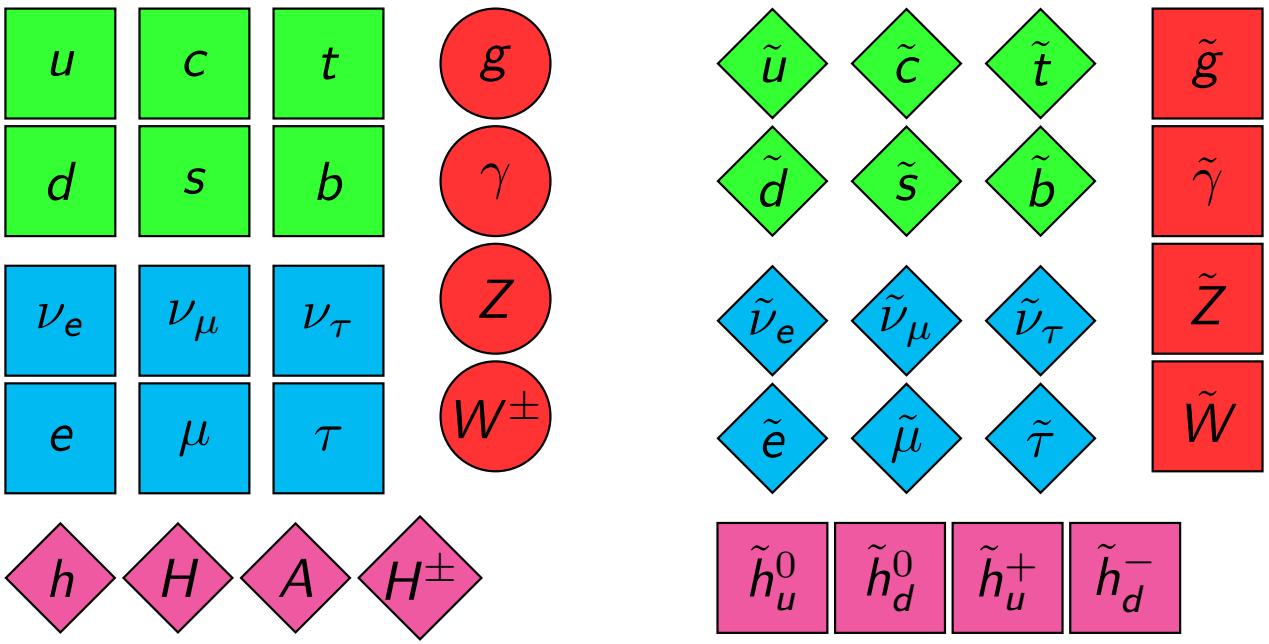
Supersymmetry

- Extension of Poincare group of QFT
- Exchange symmetry between bosons and fermions

Minimal Supersymmetry

Supersymmetry

- Extension of Poincare group of QFT
- Exchange symmetry between bosons and fermions



Going beyond the MSSM

Theory

- DM candidate
- Solves Hierarchy problem
- GUT

Going beyond the MSSM

Theory

- DM candidate
- Solves Hierarchy problem
- GUT

MSSM didn't light up LHC experiments

Going beyond the MSSM

Theory

- DM candidate
- Solves Hierarchy problem
- GUT

MSSM didn't light up LHC experiments

Motivation

- LHC Run 1 on-going
- Look into non-minimal models for wide spectrum of alternative predictions

Going beyond the MSSM

Theory

- DM candidate
- Solves Hierarchy problem
- GUT

MSSM didn't light up LHC experiments

Motivation

- LHC Run 2 on-going
- Look into non-minimal models for wide spectrum of alternative predictions

Going beyond the MSSM

Theory

- DM candidate
- Solves Hierarchy problem
- GUT

MSSM didn't light up LHC experiments

Motivation

- LHC Run 2 on-going
- Look into non-minimal models for wide spectrum of alternative predictions
- Here: **R-Symmetry**
  - Includes solution to flavor problem of the MSSM
  - Dirac gauginos (esp. gluino) might explain SUSY non-discovery
  - Extended Higgs sector, different predictions than (N)MSSM

R-symmetry

- additional symmetry allowed by SUSY algebra:
  $[Q_\alpha, R] = Q_\alpha \ , \quad \left[\overline{Q}_{\dot{\alpha}}, R\right] = -\overline{Q}_{\dot{\alpha}}$
- For $N = 1$ SUSY it is a global $U(1)_\mathrm{R}$ symmetry
  $\rightarrow$ Different charges for Superpartners
- SM fields have $Q_\mathrm{R} = 0$
- SUSY partners carry charge
- Lagrangian has to be invariant (MRSSM Kribs et.al. (Phys.Rev. D78 (2008) 055010))
- Forbids Majorana mass terms and A terms

Assume R-symmetry to be unbroken.

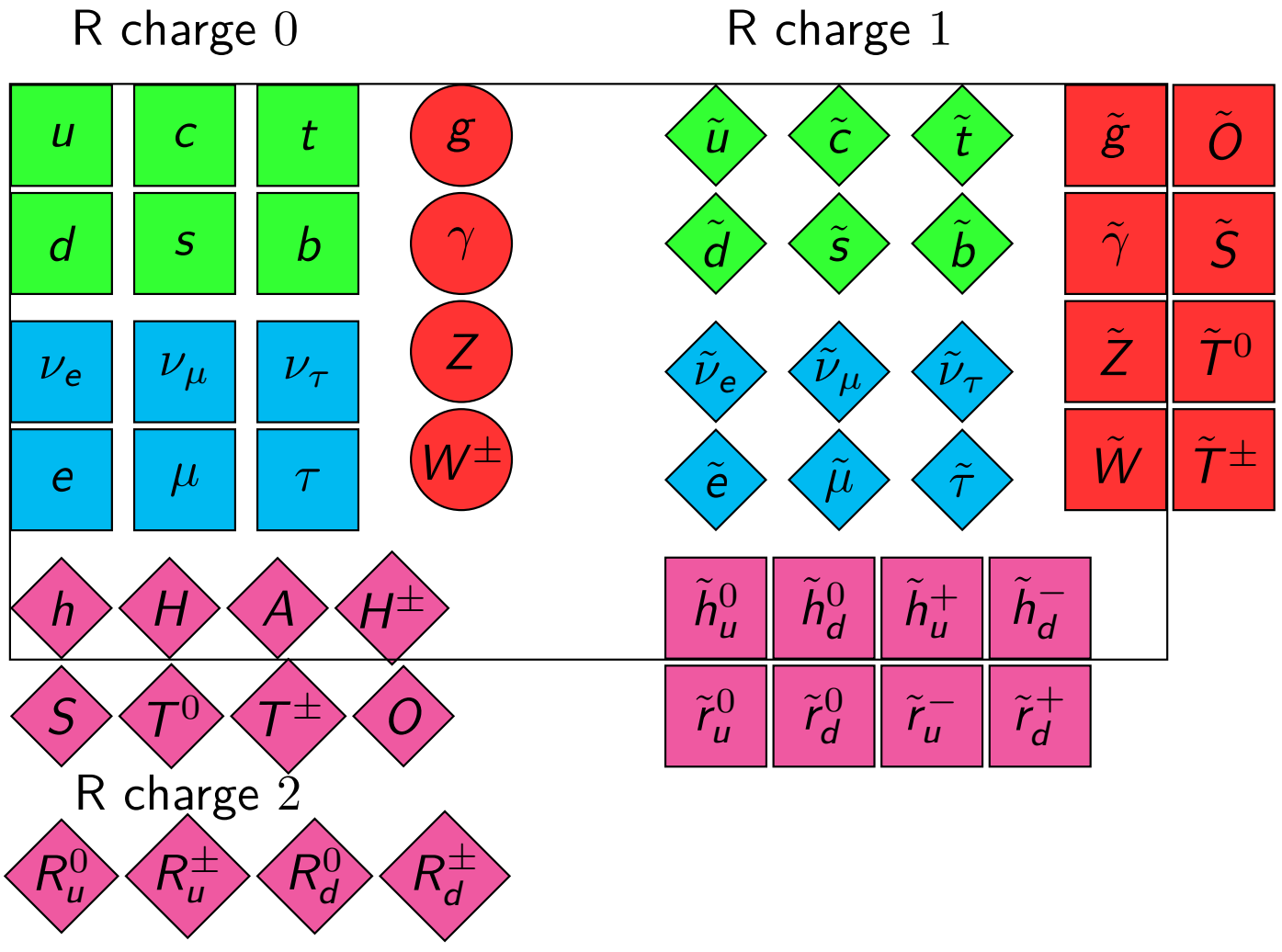
Particles of the MRSSM

Adding to the MSSM

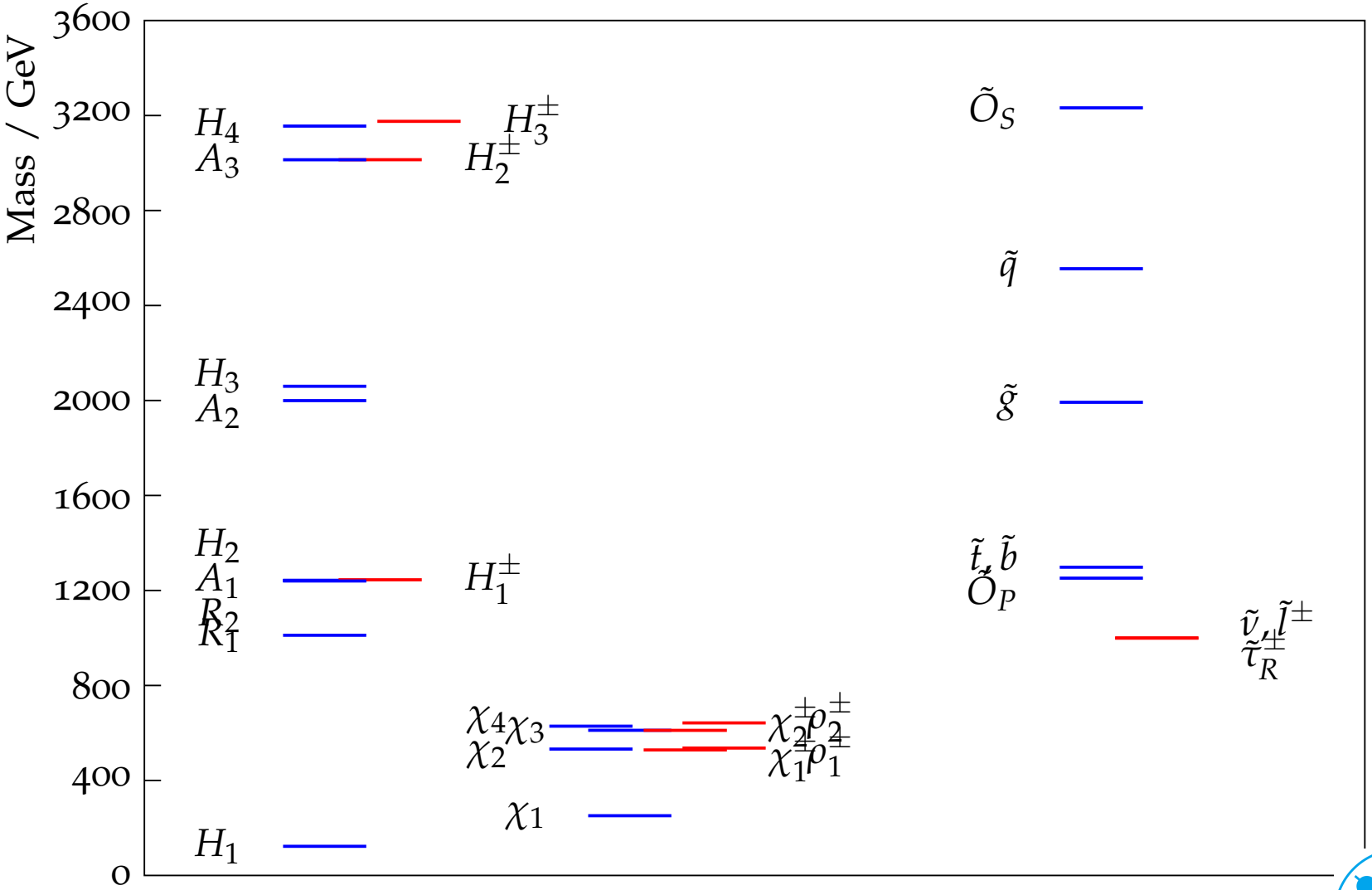
		$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)_R$
Singlet	$\hat{S}$	1	1	0	0
Triplet	$\hat{T}$	1	3	0	0
Octet	$\hat{O}$	8	1	0	0
R-Higgses	$\hat{R}_u$	1	2	$-1/2$	2
	$\hat{R}_d$	1	2	$1/2$	2

$$\begin{aligned}\mathcal{W} =& \mu_d \left(\hat{R}_d H_d\right) + \mu_u \left(\hat{R}_u H_u\right) + \Lambda_d \left(\hat{R}_d \hat{T}\right) H_d + \Lambda_u \left(\hat{R}_u \hat{T}\right) H_u \\ &+ \lambda_d \hat{S} \left(\hat{R}_d H_d\right) + \lambda_u \hat{S} \left(\hat{R}_u H_u\right) \\ &- Y_d \overline{D} \left(Q H_d\right) - Y_e \overline{E} \left(L H_d\right) + Y_u \left(\overline{U} Q H_u\right).\end{aligned}$$

Particles of the MRSSM



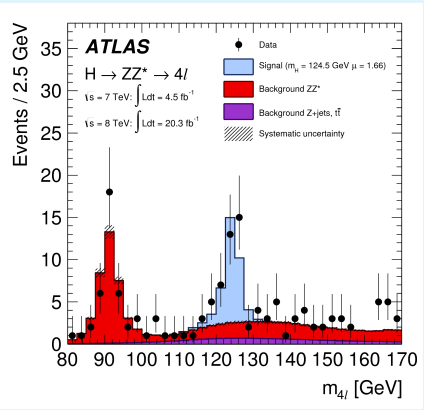
Mass spectrum



The LHC and the MRSSM

Higgs physics

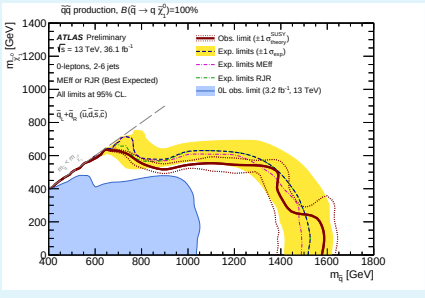
- **Can the 125 GeV Higgs mass be explained?**
- Couplings of Higgs to fermions could deviate
- Extended Higgs sector



Direct searches

- New electroweak states (Sleptons, Neutralinos)
- New strongly interacting states (Gluino, Sgluon, Squarks)

⇒ **Focus on squark production**



SM-like Higgs boson mass

$$m_h^2 < m_Z^2 - v^2 \frac{(g_2 M_D + \Lambda\mu)^2}{4M_D^2 + m^2_{\text{adjoint}}}$$

Well-known loop corrections:

$$\Delta m^2_{h,Y_t} = \frac{6v^2}{16\pi^2}\left[Y_t^4 \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right]$$

SM-like Higgs boson mass

$$m_h^2 < m_Z^2 - v^2 \frac{(g_2 M_D + \Lambda\mu)^2}{4M_D^2 + m^2_{\text{adjoint}}}$$

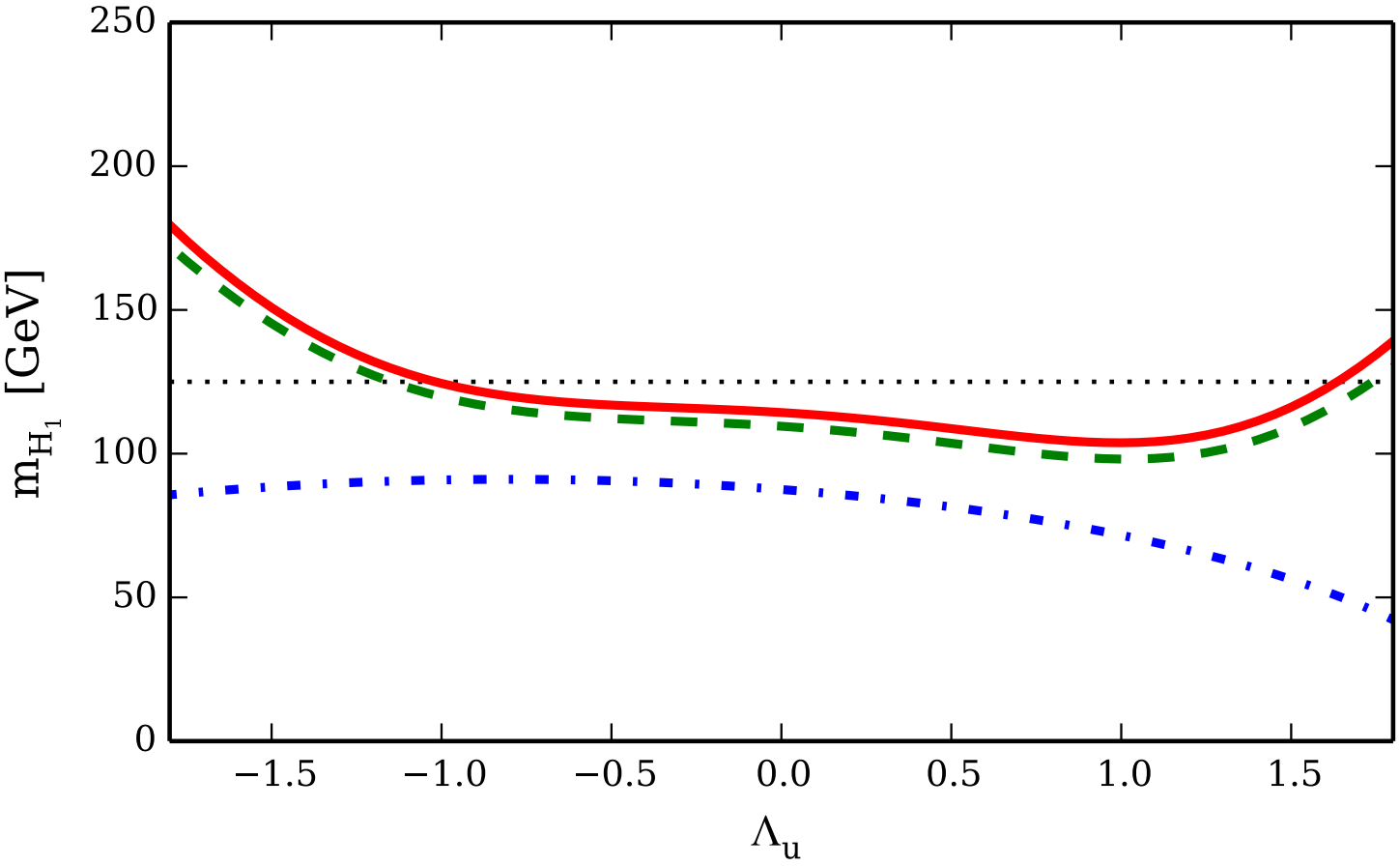
Well-known loop corrections:

$$\Delta m^2_{h,Y_t} = \frac{6v^2}{16\pi^2}\left[Y_t^4 \log \frac{m_{\tilde{t}_1} m_{\tilde{t}_2}}{m_t^2}\right]$$

Also, for new Yukawa-like couplings:

$$\Delta m^2_{h,\Lambda} = \frac{2v^2}{16\pi^2}\left[\frac{5\Lambda^4}{8} \log \frac{m^2_{\text{adjoint}}}{(M_D)^2}\right]$$

The mass prediction



Two-loop contributions add another five GeV

SUSY QCD searches

Different signatures possible

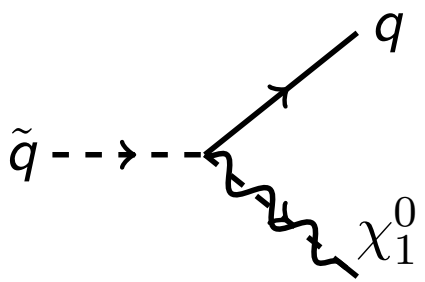
- jets+E_{miss}^{T}
- Third generation
- Compressed spectra
- Displaced vertices
- ...

SUSY QCD searches

Different signatures possible

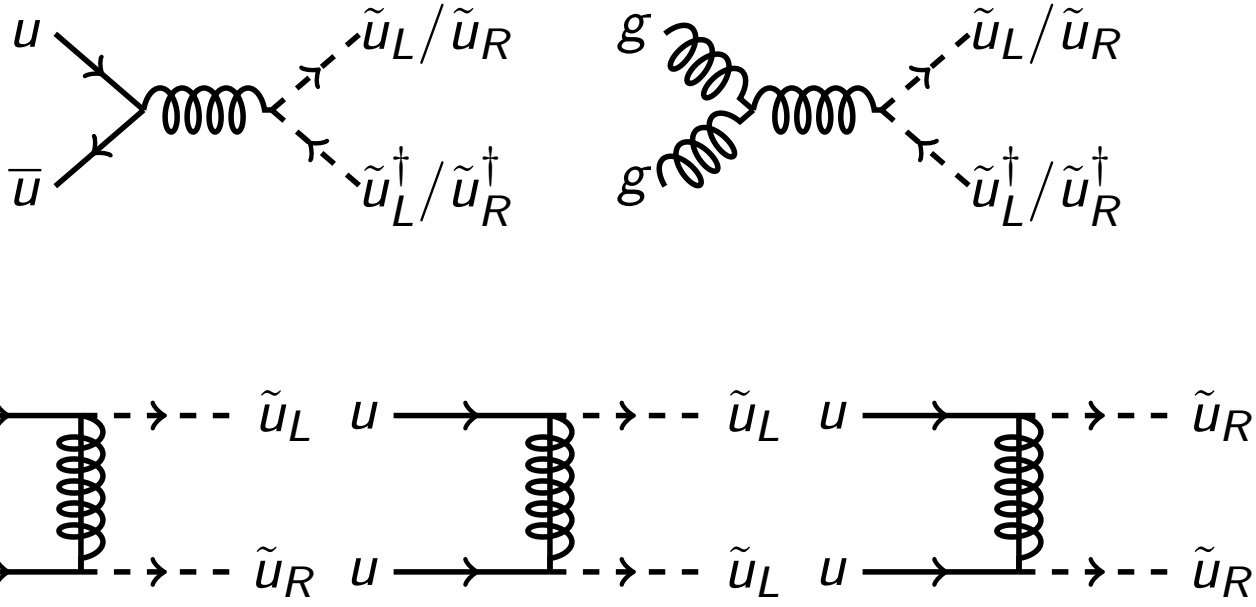
- **jets+$E_{\mathbf{miss}}^{T}$**
- Third generation
- Compressed spectra
- Displaced vertices
- ...

R-Symmetry leads to lightest stable R-symmetric particle
Start with simplest signature:



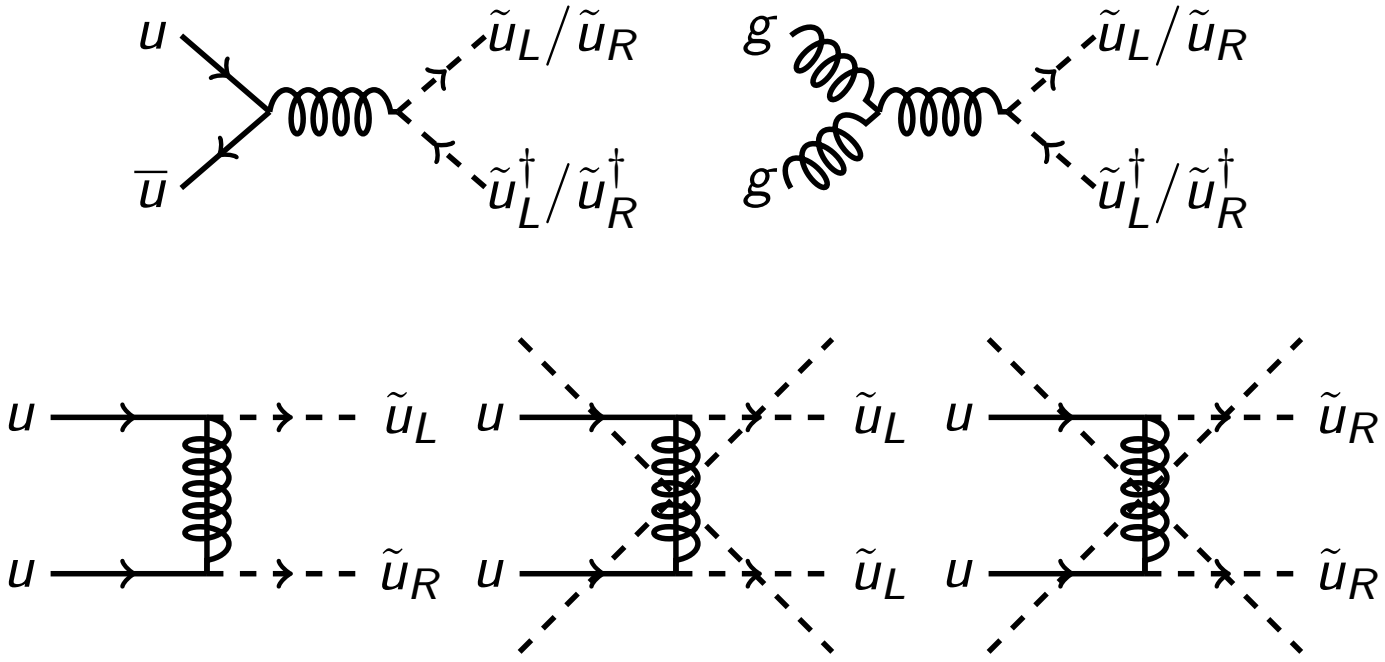
SUSY QCD searches

Production in the MSSM:



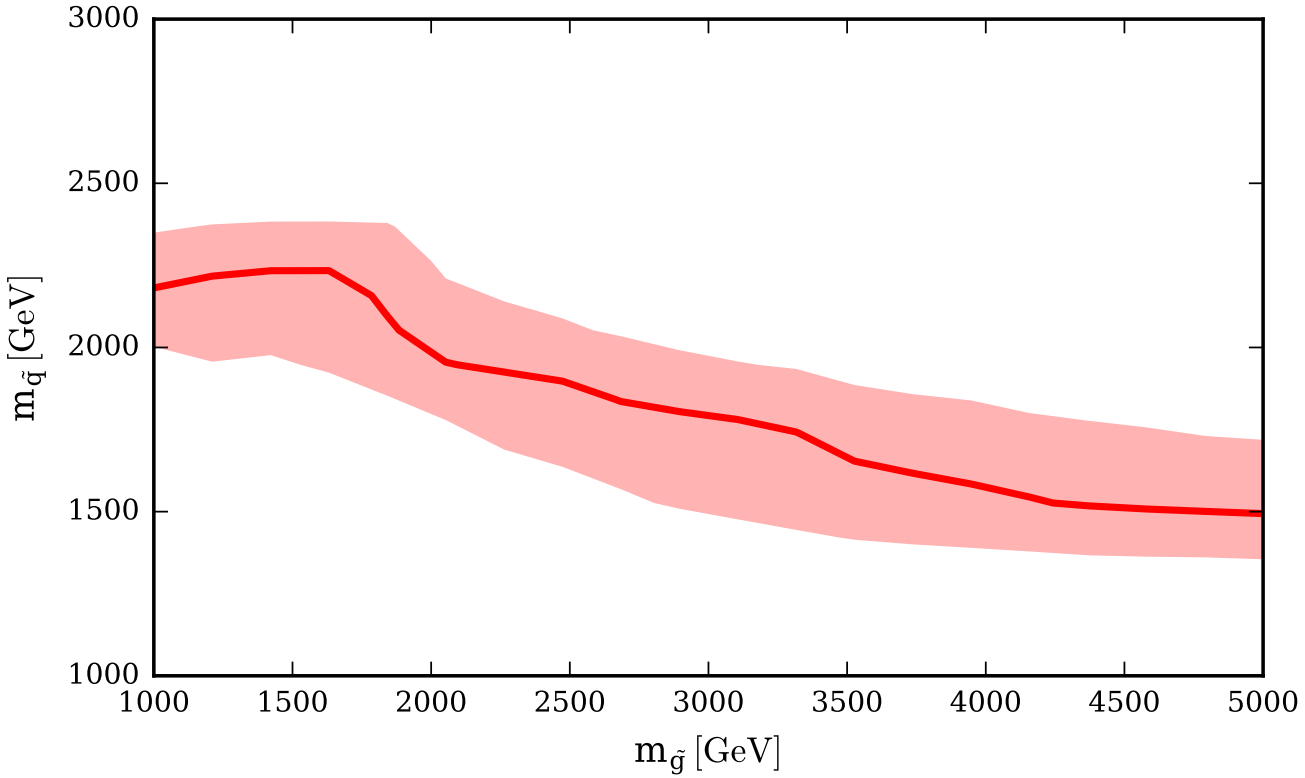
SUSY QCD searches

Production in the MRSSM:



SUSY QCD searches

MRSSM exclusion limit using LO event generation with theory uncertainty (Using numbers of `ATLAS_CONF_2017_22`):



SUSY QCD at NLO

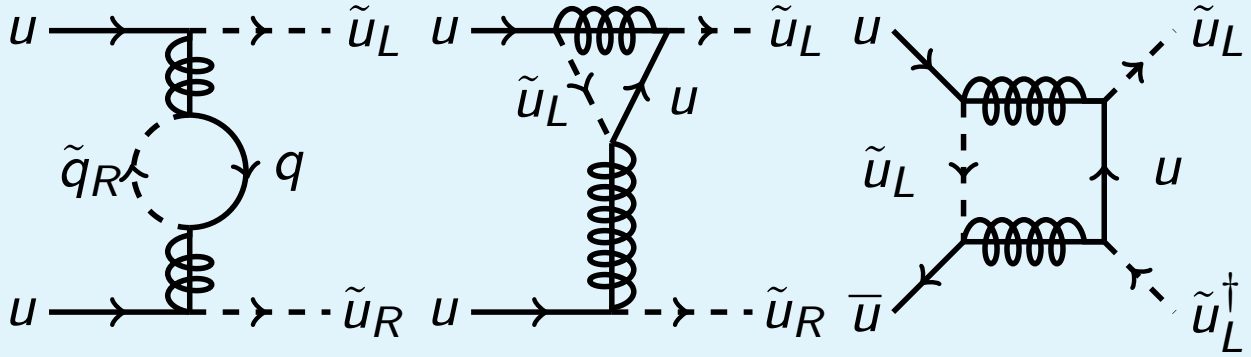
- Next-to leading order (NLO) for more precise prediction
- "NLO revolution" for SM processes allowing fast and reliable calculation
- Application to BSM processes starting

MRSSM

- Known from MSSM that NLO effects important
- Additional scalar octet and Dirac nature of gluino give new effects
- Requires new full calculation for the MRSSM

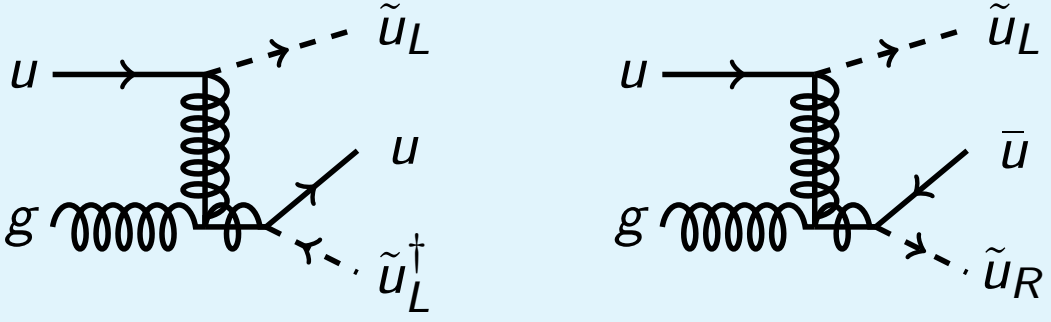
SUSY QCD searches

Virtual corrections



UV (requires renormalisation) and IR divergent

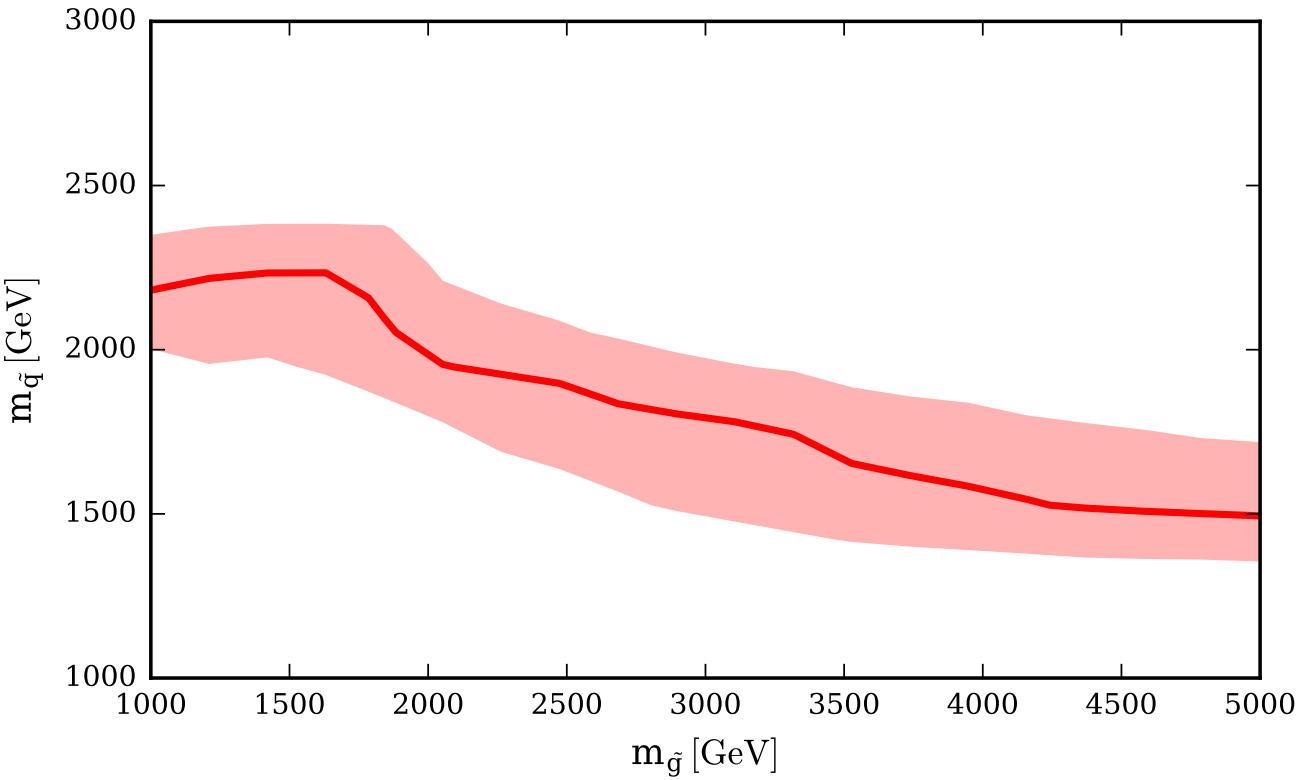
Real corrections



IR divergent

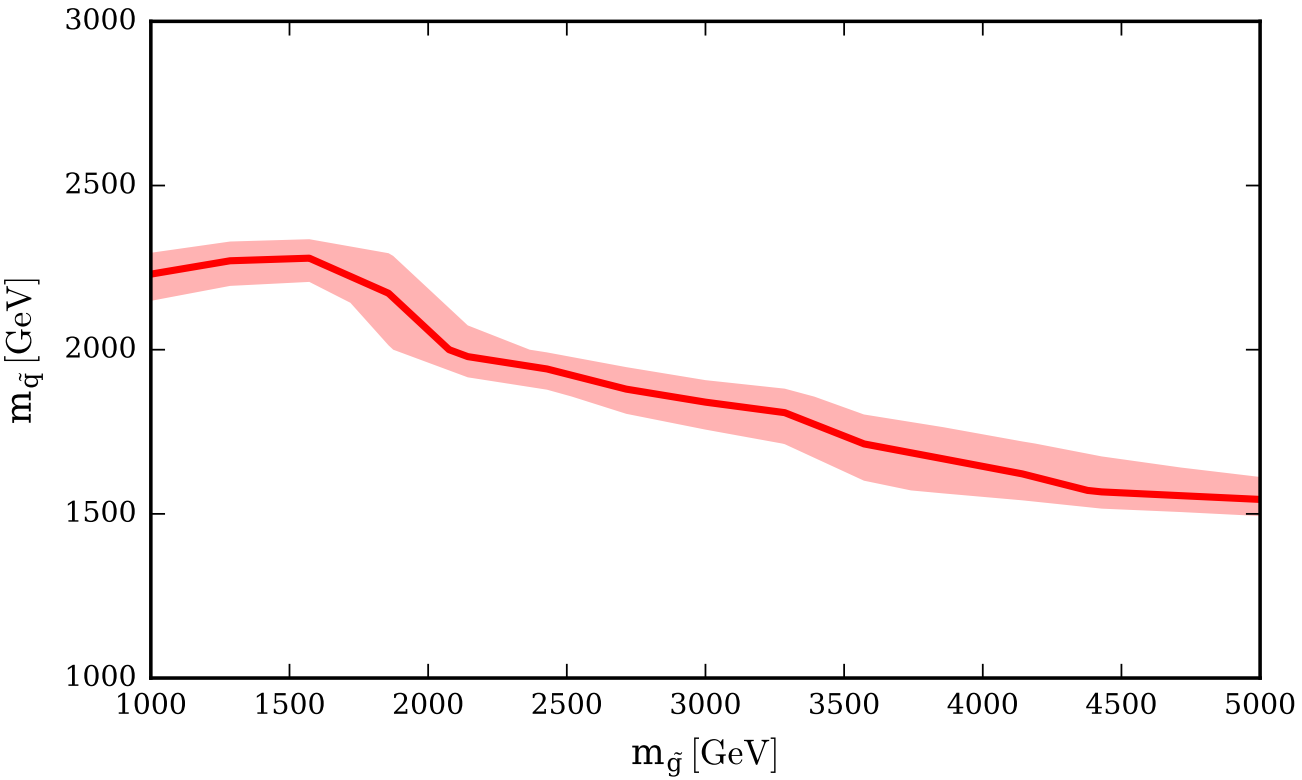
Effects of NLO

MRSSM exclusion limit using LO event generation:

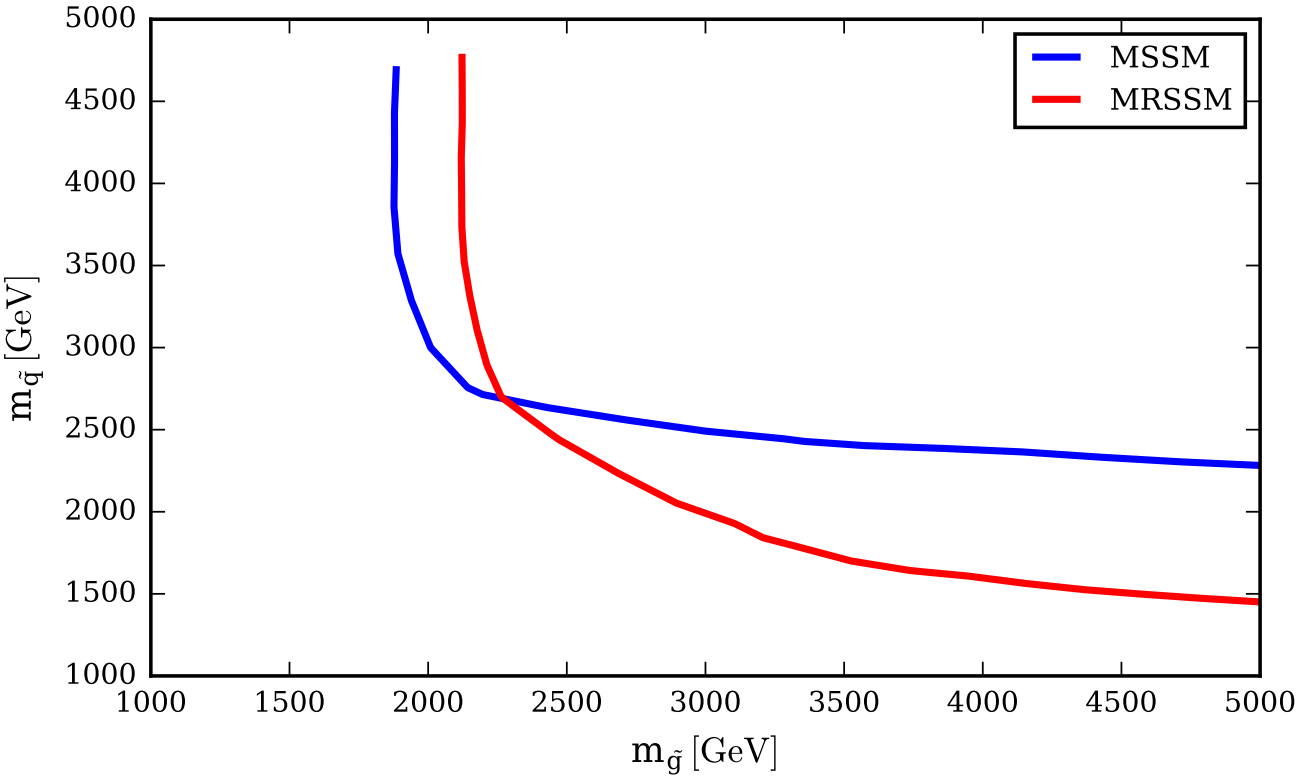


Effects of NLO

MRSSM exclusion limit using NLO event generation:



MRSSM vs. MSSM

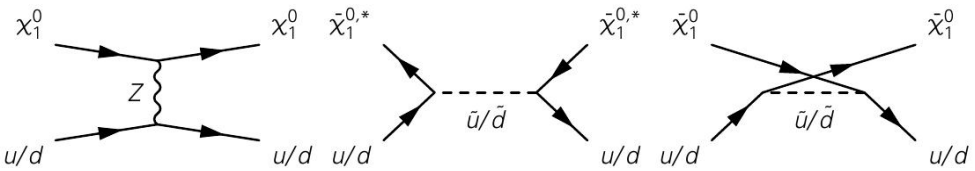


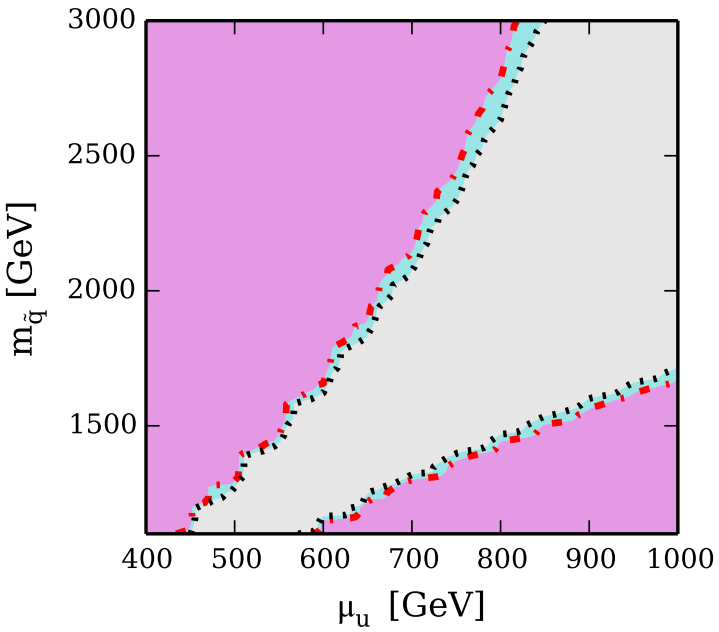
So far only simple MSSM-like decay chains

Connection to dark matter

Direct detection

- Z-exchange
- Also squark exchange
- Taking into account interference





Conclusions

- MRSSM as example of non-minimal SUSY accessible by LHC
- To be studied: distinct signatures different from MSSM
- Higher-order corrections required to have same uncertainty as experiment
- Well studied for MSSM but not so for other BSM models

Conclusions

- MRSSM as example of non-minimal SUSY accessible by LHC
- To be studied: distinct signatures different from MSSM
- Higher-order corrections required to have same uncertainty as experiment
- Well studied for MSSM but not so for other BSM models

Thanks for the attention!