Monotop production in R-Parity Violating Supersymmetry

Josselin Proudom
in collaboration with B. Fuks and I. Schienbein

Laboratoire de Physique Subatomique et de Cosmologie (LPSC), Grenoble
Theory group

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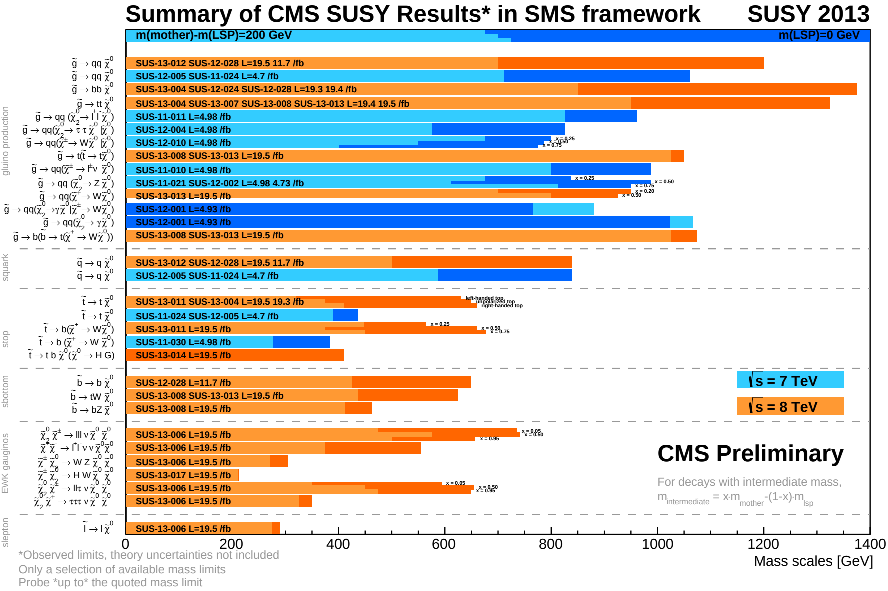
Outline

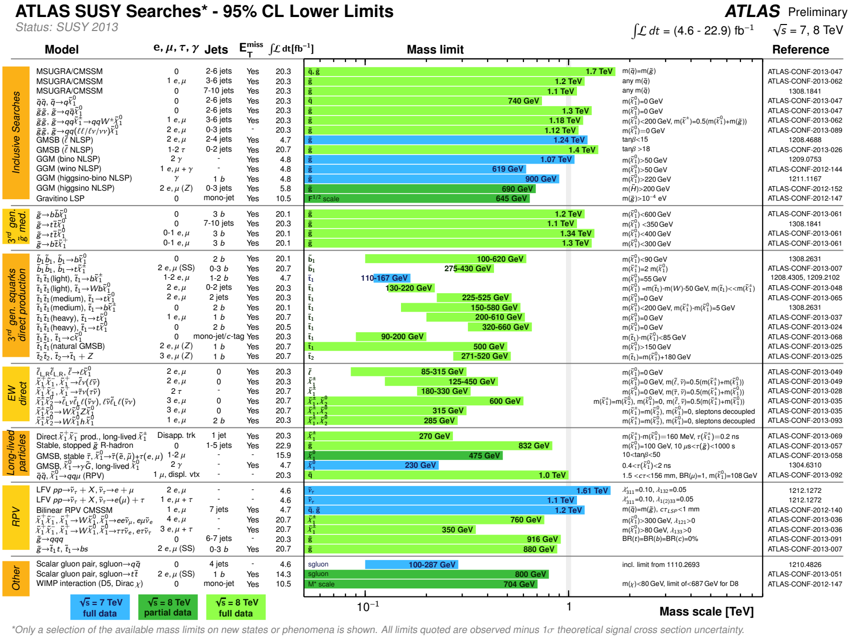
1. Motivations
2. Framework
3. Monotop signature
4. Results
5. Conclusions & Perspectives

Motivations & Status of SUSY searches

- **SUSY most appealing features:**
  - **Stabilization** of the **hierarchy** between the **Planck** and the **Electroweak scale**
  - **Gauge coupling unification**
  - **Possible candidate** for **dark matter** with the **LSP**

- **After 3 years of LHC running...**
  - **No experimental evidences** for **SUSY particles**
  - **Mass exclusion limits** for **SUSY particles** have been **pushed higher and higher in energy**
  - The **Higgs boson** is looking **more and more SM-like**
  - **Significant portions** of the **parameter space** of **constrained models** like the **CMSSM** have been **excluded**


Summary of CMS SUSY Results* in SMS framework
SUSY 2013
m(mother)-m(LSP)=200 GeV
m(LSP)=0 GeV
gluino production
SUS-13-012 SUS-12-028 L=19.5 11.7 /fb
SUS-12-005 SUS-11-024 L=4.7 /fb
SUS-13-004 SUS-12-024 SUS-12-028 L=19.3 19.4 /fb
SUS-13-004 SUS-13-007 SUS-13-008 SUS-13-013 L=19.4 19.5 /fb
SUS-11-011 L=4.98 /fb
SUS-12-004 L=4.98 /fb
SUS-12-010 L=4.98 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-11-010 L=4.98 /fb
SUS-11-021 SUS-12-002 L=4.98 4.73 /fb
SUS-13-013 L=19.5 /fb
SUS-12-001 L=4.93 /fb
SUS-12-001 L=4.93 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
squark
SUS-13-012 SUS-12-028 L=19.5 11.7 /fb
SUS-12-005 SUS-11-024 L=4.7 /fb
stop
SUS-13-011 SUS-13-004 L=19.5 19.3 /fb
left-handed top
unpolarized top
right-handed top
SUS-11-024 SUS-12-005 L=4.7 /fb
SUS-13-011 L=19.5 /fb
SUS-11-030 L=4.98 /fb
SUS-13-014 L=19.5 /fb
sbottom
SUS-12-028 L=11.7 /fb
SUS-13-008 SUS-13-013 L=19.5 /fb
SUS-13-008 L=19.5 /fb
EWK gauginos
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-017 L=19.5 /fb
SUS-13-006 L=19.5 /fb
SUS-13-006 L=19.5 /fb
slepton
SUS-13-006 L=19.5 /fb
√s = 7 TeV
√s = 8 TeV
CMS Preliminary
For decays with intermediate mass,
m_intermediate = x·m_mother -(1-x)·m_lsp
0
200
400
600
800
1000
1200
1400
Mass scales [GeV]
*Observed limits, theory uncertainties not included
Only a selection of available mass limits
Probe *up to* the quoted mass limit


ATLAS SUSY Searches* - 95% CL Lower Limits
Status: SUSY 2013
ATLAS Preliminary
∫L dt = (4.6 - 22.9) fb^-1   √s = 7, 8 TeV
Model | e, μ, τ, γ | Jets | E_T^miss | ∫L dt[fb^-1] | Mass limit | Reference
Inclusive Searches
MSUGRA/CMSSM | 0 | 2-6 jets | Yes | 20.3 | q̃, g̃ 1.7 TeV | m(q̃)=m(g̃) | ATLAS-CONF-2013-047
MSUGRA/CMSSM | 1 e, μ | 3-6 jets | Yes | 20.3 | g̃ 1.2 TeV | any m(q̃) | ATLAS-CONF-2013-062
MSUGRA/CMSSM | 0 | 7-10 jets | Yes | 20.3 | g̃ 1.1 TeV | any m(q̃) | 1308.1841
q̃q̃, q̃→qχ̃⁰₁ | 0 | 2-6 jets | Yes | 20.3 | q̃ 740 GeV | m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2013-047
g̃g̃, g̃→qq̄χ̃⁰₁ | 0 | 2-6 jets | Yes | 20.3 | g̃ 1.3 TeV | m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2013-047
g̃g̃, g̃→qqχ̃±₁→qqW±χ̃⁰₁ | 1 e, μ | 3-6 jets | Yes | 20.3 | g̃ 1.18 TeV | m(χ̃⁰₁)<200 GeV, m(χ̃±)=0.5(m(χ̃⁰₁)+m(g̃)) | ATLAS-CONF-2013-062
g̃g̃, g̃→qq(ℓℓ/ℓν/νν)χ̃⁰₁ | 2 e, μ | 0-3 jets | - | 20.3 | g̃ 1.12 TeV | m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2013-089
GMSB (ℓ̃ NLSP) | 2 e, μ | 2-4 jets | Yes | 4.7 | g̃ 1.24 TeV | tanβ<15 | 1208.4688
GMSB (ℓ̃ NLSP) | 1-2 τ | 0-2 jets | Yes | 20.7 | g̃ 1.4 TeV | tanβ>18 | ATLAS-CONF-2013-026
GGM (bino NLSP) | 2 γ | - | Yes | 4.8 | g̃ 1.07 TeV | m(χ̃⁰₁)>50 GeV | 1209.0753
GGM (wino NLSP) | 1 e, μ + γ | - | Yes | 4.8 | g̃ 619 GeV | m(χ̃⁰₁)>50 GeV | ATLAS-CONF-2012-144
GGM (higgsino-bino NLSP) | γ | 1 b | Yes | 4.8 | g̃ 900 GeV | m(χ̃⁰₁)>220 GeV | 1211.1167
GGM (higgsino NLSP) | 2 e, μ (Z) | 0-3 jets | Yes | 5.8 | g̃ 690 GeV | m(H̃)>200 GeV | ATLAS-CONF-2012-152
Gravitino LSP | 0 | mono-jet | Yes | 10.5 | F^1/2 scale 645 GeV | m(g̃)>10^-4 eV | ATLAS-CONF-2012-147
3rd gen. g̃ med.
g̃→bb̄χ̃⁰₁ | 0 | 3 b | Yes | 20.1 | g̃ 1.2 TeV | m(χ̃⁰₁)<600 GeV | ATLAS-CONF-2013-061
g̃→tt̄χ̃⁰₁ | 0 | 7-10 jets | Yes | 20.3 | g̃ 1.1 TeV | m(χ̃⁰₁) <350 GeV | 1308.1841
g̃→tt̄χ̃⁰₁ | 0-1 e, μ | 3 b | Yes | 20.1 | g̃ 1.34 TeV | m(χ̃⁰₁)<400 GeV | ATLAS-CONF-2013-061
g̃→bt̄χ̃⁺₁ | 0-1 e, μ | 3 b | Yes | 20.1 | g̃ 1.3 TeV | m(χ̃⁰₁)<300 GeV | ATLAS-CONF-2013-061
3rd gen. squarks direct production
b̃₁b̃₁, b̃₁→bχ̃⁰₁ | 0 | 2 b | Yes | 20.1 | b̃₁ 100-620 GeV | m(χ̃⁰₁)<90 GeV | 1308.2631
b̃₁b̃₁, b̃₁→tχ̃±₁ | 2 e, μ (SS) | 0-3 b | Yes | 20.7 | b̃₁ 275-430 GeV | m(χ̃±₁)=2 m(χ̃⁰₁) | ATLAS-CONF-2013-007
t̃₁t̃₁(light), t̃₁→bχ̃±₁ | 1-2 e, μ | 1-2 b | Yes | 4.7 | t̃₁ 110-167 GeV | m(χ̃⁰₁)=55 GeV | 1208.4305, 1209.2102
t̃₁t̃₁(light), t̃₁→Wbχ̃⁰₁ | 2 e, μ | 0-2 jets | Yes | 20.3 | t̃₁ 130-220 GeV | m(χ̃⁰₁) =m(t̃₁)-m(W)-50 GeV, m(t̃₁)<<m(χ̃±₁) | ATLAS-CONF-2013-048
t̃₁t̃₁(medium), t̃₁→tχ̃⁰₁ | 2 e, μ | 2 jets | Yes | 20.3 | t̃₁ 225-525 GeV | m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2013-065
t̃₁t̃₁(medium), t̃₁→bχ̃±₁ | 0 | 2 b | Yes | 20.1 | t̃₁ 150-580 GeV | m(χ̃⁰₁)<200 GeV, m(χ̃±₁)-m(χ̃⁰₁)=5 GeV | 1308.2631
t̃₁t̃₁(heavy), t̃₁→tχ̃⁰₁ | 1 e, μ | 1 b | Yes | 20.7 | t̃₁ 200-610 GeV | m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2013-037
t̃₁t̃₁(heavy), t̃₁→tχ̃⁰₁ | 0 | 2 b | Yes | 20.5 | t̃₁ 320-660 GeV | m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2013-024
t̃₁t̃₁, t̃₁→cχ̃⁰₁ | 0 | mono-jet/c-tag | Yes | 20.3 | t̃₁ 90-200 GeV | m(t̃₁)-m(χ̃⁰₁)<85 GeV | ATLAS-CONF-2013-068
t̃₁t̃₁(natural GMSB) | 2 e, μ (Z) | 1 b | Yes | 20.7 | t̃₁ 500 GeV | m(χ̃⁰₁)>150 GeV | ATLAS-CONF-2013-025
t̃₂t̃₂, t̃₂→t̃₁ + Z | 3 e, μ (Z) | 1 b | Yes | 20.7 | t̃₂ 271-520 GeV | m(t̃₁)=m(χ̃⁰₁)+180 GeV | ATLAS-CONF-2013-025
EW direct
ℓ̃L,Rℓ̃L,R, ℓ̃→ℓχ̃⁰₁ | 2 e, μ | 0 | Yes | 20.3 | ℓ̃ 85-315 GeV | m(χ̃⁰₁)=0 GeV | ATLAS-CONF-2013-049
χ̃⁺₁χ̃⁻₁, χ̃⁺₁→ℓ̃ν(ℓν̃) | 2 e, μ | 0 | Yes | 20.3 | χ̃±₁ 125-450 GeV | m(χ̃⁰₁)=0 GeV, m(ℓ̃, ν̃)=0.5(m(χ̃±₁)+m(χ̃⁰₁)) | ATLAS-CONF-2013-049
χ̃⁺₁χ̃⁻₁, χ̃⁺₁→τ̃ν(τν̃) | 2 τ | - | Yes | 20.7 | χ̃±₁ 180-330 GeV | m(χ̃⁰₁)=0 GeV, m(τ̃, ν̃)=0.5(m(χ̃±₁)+m(χ̃⁰₁)) | ATLAS-CONF-2013-028
χ̃±₁χ̃⁰₂→ℓ̃Lνℓ̃Lℓ(ν̃ν), ℓν̃ℓ̃Lℓ(ν̃ν) | 3 e, μ | 0 | Yes | 20.7 | χ̃±₁, χ̃⁰₂ 600 GeV | m(χ̃±₁)=m(χ̃⁰₂), m(χ̃⁰₁)=0, m(ℓ̃, ν̃)=0.5(m(χ̃±₁)+m(χ̃⁰₁)) | ATLAS-CONF-2013-035
χ̃±₁χ̃⁰₂→Wχ̃⁰₁Zχ̃⁰₁ | 3 e, μ | 0 | Yes | 20.7 | χ̃±₁, χ̃⁰₂ 315 GeV | m(χ̃±₁)=m(χ̃⁰₂), m(χ̃⁰₁)=0, sleptons decoupled | ATLAS-CONF-2013-035
χ̃±₁χ̃⁰₂→Wχ̃⁰₁hχ̃⁰₁ | 1 e, μ | 2 b | Yes | 20.3 | χ̃±₁, χ̃⁰₂ 285 GeV | m(χ̃±₁)=m(χ̃⁰₂), m(χ̃⁰₁)=0, sleptons decoupled | ATLAS-CONF-2013-093
Long-lived particles
Direct χ̃⁺₁χ̃⁻₁ prod., long-lived χ̃±₁ | Disapp. trk | 1 jet | Yes | 20.3 | χ̃±₁ 270 GeV | m(χ̃±₁)-m(χ̃⁰₁)=160 MeV, τ(χ̃±₁)=0.2 ns | ATLAS-CONF-2013-069
Stable, stopped g̃ R-hadron | 0 | 1-5 jets | Yes | 22.9 | g̃ 832 GeV | m(χ̃⁰₁)=100 GeV, 10 μs<τ(g̃)<1000 s | ATLAS-CONF-2013-057
GMSB, stable τ̃, χ̃⁰₁→τ̃(ẽ, μ̃)+τ(e, μ) | 1-2 μ | - | - | 15.9 | χ̃⁰₁ 475 GeV | 10<tanβ<50 | ATLAS-CONF-2013-058
GMSB, χ̃⁰₁→γG̃, long-lived χ̃⁰₁ | 2 γ | - | Yes | 4.7 | χ̃⁰₁ 230 GeV | 0.4<τ(χ̃⁰₁)<2 ns | 1304.6310
q̃q̃, χ̃⁰₁→qqμ (RPV) | 1 μ, displ. vtx | - | - | 20.3 | q̃ 1.0 TeV | 1.5 <cτ<156 mm, BR(μ)=1, m(χ̃⁰₁)=108 GeV | ATLAS-CONF-2013-092
RPV
LFV pp→ν̃τ + X, ν̃τ→e + μ | 2 e, μ | - | - | 4.6 | ν̃τ 1.61 TeV | λ'311=0.10, λ132=0.05 | 1212.1272
LFV pp→ν̃τ + X, ν̃τ→e(μ) + τ | 1 e, μ + τ | - | - | 4.6 | ν̃τ 1.1 TeV | λ'311=0.10, λ1(2)33=0.05 | 1212.1272
Bilinear RPV CMSSM | 1 e, μ | 7 jets | Yes | 4.7 | q̃, g̃ 1.2 TeV | m(q̃)=m(g̃), cτLSP<1 mm | ATLAS-CONF-2012-140
χ̃⁺₁χ̃⁻₁, χ̃⁺₁→Wχ̃⁰₁, χ̃⁰₁→eeν̃μ, eμν̃e | 4 e, μ | - | Yes | 20.7 | χ̃±₁ 760 GeV | m(χ̃⁰₁)>300 GeV, λ121>0 | ATLAS-CONF-2013-036
χ̃⁺₁χ̃⁻₁, χ̃⁺₁→Wχ̃⁰₁, χ̃⁰₁→ττν̃e, eτν̃τ | 3 e, μ + τ | - | Yes | 20.7 | χ̃±₁ 350 GeV | m(χ̃⁰₁)>80 GeV, λ133>0 | ATLAS-CONF-2013-036
g̃→qqq | 0 | 6-7 jets | - | 20.3 | g̃ 916 GeV | BR(t)=BR(b)=BR(c)=0% | ATLAS-CONF-2013-091
g̃→t̃₁t, t̃₁→bs | 2 e, μ (SS) | 0-3 b | Yes | 20.7 | g̃ 880 GeV | | ATLAS-CONF-2013-007
Other
Scalar gluon pair, sgluon→qq̄ | 0 | 4 jets | - | 4.6 | sgluon 100-287 GeV | incl. limit from 1110.2693 | 1210.4826
Scalar gluon pair, sgluon→tt̄ | 2 e, μ (SS) | 1 b | Yes | 14.3 | sgluon 800 GeV | | ATLAS-CONF-2013-051
WIMP interaction (D5, Dirac χ) | 0 | mono-jet | Yes | 10.5 | M* scale 704 GeV | m(χ)<80 GeV, limit of<687 GeV for D8 | ATLAS-CONF-2012-147
√s = 7 TeV full data
√s = 8 TeV partial data
√s = 8 TeV full data
10^-1
1
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

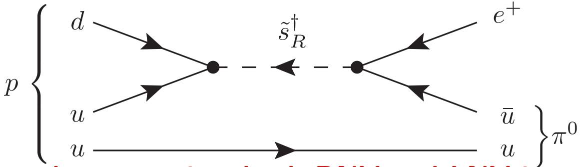
Motivations for beyond Minimal SUSY searches

- **Non-observations of SUSY particles @ the LHC:**
  - **Rekindled the interest** for **non-minimal SUSY models**
- **Idea behind non-minimal SUSY models**
  - **It could be that we are missing an additional ingredient**
    - **R-Parity Violating (RPV) MSSM**
    - NMSSM, Left-Right MSSM, MRSSM, Vector-like MSSM
- **Price to pay for non-minimal SUSY**
  - **More interactions** ⇒ **New free parameters**
  - **Phenomenological analyses** ⇒ **More complicated**
- **Attractive feature of non-minimal SUSY**
  - **May solve problems that minimal SUSY does not**
    - Baryon Asymmetry in the Universe **(BAU)** [Barbier et al.]
    - **Neutrino mass generation** [Barbier et al.]
    - μ **problem**

Motivations for R-Parity Violating SUSY

R-Parity

- **Forbids both BNV and LNV interactions** in the MSSM
- **Imposed** to avoid **fast proton decay:** $\tau_p \gtrsim 10^{33}$ years



- **Proton decay requires both BNV and LNV interactions**
  - **R-parity conservation** is **too restrictive**
  - **Either BNV** or **LNV** are **allowed** ⇒ **No proton decay**
- **RPV-MSSM with BNV model features**
  - **BNV** + lepton number conservation **compatible** with a **GUT**
  - **Provides** the **third Sakharov condition** ⇒ **BAU**
- **Price to pay:** Extremely difficult to accomodate DM

The model

- **BNV superpotential:**

$$W_{BNV} = \frac{1}{2}\lambda''_{ijk} U^i D^j D^k + W_{MSSM}$$

  - λ''_{ijk}: BNV couplings ⇒ 9 new free independent parameters
  - U, D: Superfields
  - i, j and k : Flavor indices

- **BNV Lagrangian:**

$$\begin{aligned}\mathcal{L}_{U_i U_j D_k} &= -\frac{1}{2}\lambda''_{ijk}\varepsilon^{c_1 c_2 c_3}\Big(\widetilde{u}^{0\dagger}_{lc_3} R^u_{l(k+3)} \bar{\Psi}^d_{Dic_1} P_L \Psi^{d\,c}_{Djc_2} \\ &+ \widetilde{d}^{0\dagger}_{lc_2} R^d_{l(k+3)} \bar{\Psi}^u_{Dic_1} P_L \Psi^{d\,c}_{Dkc_2} + \bar{\Psi}^u_{Dic_1} P_L \Psi^{d\,c}_{Djc_2} R^d_{l(k+3)} \widetilde{d}^{0\dagger}_{lc_3}\Big) + \text{h.c.}\end{aligned}$$

Constraints on BNV couplings

Present experimental constraints on λ''_{ijk} couplings:

- Neutron dipole moment [Slavich arXiv:0008270]
- Antinucleon oscillations, double nucleon decays
- Rare hadronic decays of B-mesons, K-K systems
- **Observed flux of cosmic rays antiprotons :** [Gondolo arXiv:9704411]

$$\lambda''_{ijk} < 10^{-19} - 10^{-24}$$

➢ **Yet... Not applicable** to λ''_{3jk} if the **top quark** is **heavier than the Lightest Supersymmetric Particle (LSP)**

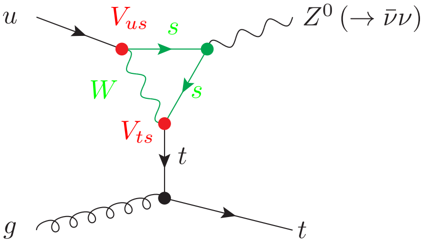
- ▶ λ''_{3jk} is left **almost unconstrained** [Barbier et al.]

➢ **Enforce MFV** ⇒ **Only** λ''_{312} is **sizable** $\sim \mathcal{O}(0.1)$

Monotop production in the Standard model

[Fuks, Andrea, Maltoni arXiv:11066199]

- Final state signature : $t + \not{E}_T \longrightarrow bjj + \not{E}_T$
- Production mode $\longrightarrow$ **subdominant contribution**
  - **CKM suppressed:** $V_{us} \simeq 0.23$, $V_{ts} \simeq 0.04$
  - **Loop-suppressed**
  - **Branching ratio**: $\mathrm{BR}(Z \to \nu\bar{\nu}) \simeq 0.2$

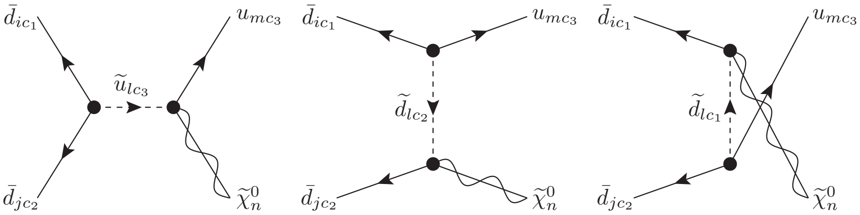


Monotop production within the RPV-MSSM

- **Production @ tree-level through squark exchange**

$$pp \to \tilde{q} \to \tilde{\chi}_1^0 + t$$

  - **6 diagrams** in the **flavor conserving case**
  - $\not{E}_T$ associated to the lightest neutralino
    - Kinematic condition: $m_t > m_{\chi_1^0} \Rightarrow$ Long-lived neutralino
    - Decay far outside of the detector due to its long lifetime



Analytical results

- **Cross section**

Full 2 → 2 process

$$\frac{d\hat{\sigma}_{h_a h_b}}{dt} = \frac{\alpha}{12 s_W^2 c_W^2 s^2} \sum_{l,o=1,2}^{6} \Bigg[(1-h_a)(1-h_b) \left(\frac{Q^{ss}_{lo}}{s_l s_o} + \frac{Q^{tt-}_{lo}}{t_l t_o} + \frac{Q^{uu-}_{lo}}{u_l u_o} + \frac{Q^{st}_{lo}}{s_l t_o} + \frac{Q^{su}_{lo}}{s_l u_o} + \frac{Q^{tu}_{lo}}{t_l u_o} \right) + (1-h_a)(1+h_b) \frac{Q^{tt+}_{lo}}{t_l t_o} + (1+h_a)(1-h_b) \frac{Q^{uu+}_{lo}}{u_l u_o} \Bigg]$$

- **Compactified expression** of the **cross section**
- h_a and h_b $\Longrightarrow$ **helicities** of **incoming particles**
- Q^{ss}: interferences between diagrams in the s-channel

Tool chain

- **SLHA2 input file:** [Allanach et al.]
  - Model and parameters specification

$\Downarrow$

- **SUSY-spectrum:** `SPheno-3.2.1`: [Porod, Staub]
  - Compute **RGEs** at the **two loop level**

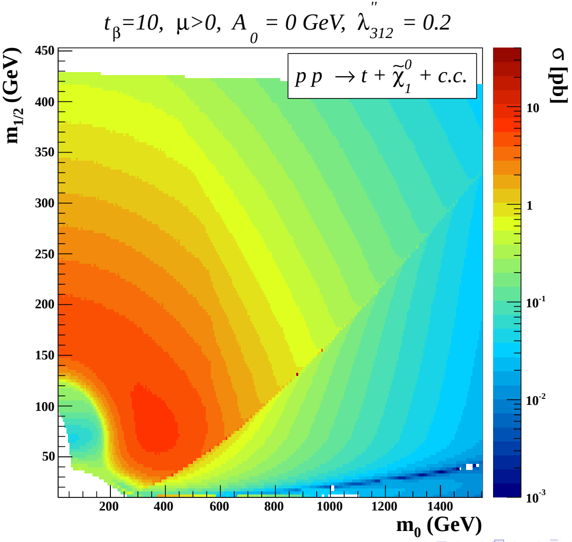
$\Downarrow$

- **Decay Width an Branching Ratios:** `SUSY-HIT-1.3` [Djouadi, Mullheitner,Spira]
  - **Width** and **BRs** of the **MSSM Higgs bosons**: `HDECAY`
  - **Width** and **BRs** of the **SUSY particles**: `SDECAY`

$\Downarrow$

- **Cross section & scans:** `XSUSY-1.9.23` (**Private code**)
  - Original `C++` **code** developped by **B. Fuks** & **B. Herrmann**
  - **Numerical integration** performed using `VEGAS`
  - **Extended** with **new PDF sets**
    - `MRST2002`, `DSSV.2008`, `NNPDFpol1.0`, `BB10`, `NNPDF2.1`
  - **Extended** with **new features**
    - Scans for polarized cross section automated

Numerical results



The Narrow Width Approximation

- **The Narrow Width Approximation (NWA):**
  - **Reduction** of the **complexity of scattering amplitudes**
  - **Assumes peaked resonance** with a **Breit-Wigner lineshape**
  - **For small Γ, off-shell effects are suppressed**
    - **Intermediate resonance** can be **approximated** to be **on-shell**
  - **Production** and **decay** of **unstable particles** $\Rightarrow$ **factorized**
  - **Non-resonant contributions** are **neglected**
  - **Introduction** of an **error** of $\mathcal{O}(\Gamma/M)$ for each **Breit-Wigner**

Requirements for the NWA

1. **Total width** of the particle way **smaller** than its **mass**: $\Gamma \ll M$
2. **Propagator separable** from the **matrix element**
3. **No significant interferences** from **non-resonnant processes**
4. **Scattering energy larger** than mass of the **resonance**: $\sqrt{\hat{s}} \gg M$
5. Mass of **resonance larger** than masses of the **daughter** particles

Narrow Width Approximation & New Physics

[Kauer, Rainwater, Berdine arXiv:0703058]

- **Narrow Width Approximation features:**
  - **Drastically simplifies calculations** $\Rightarrow\ \sigma_p \times \mathrm{BR}$
  - **Reduce CPU time** required **for computations**
  - **Works pretty well** in the **case** of the **SM**
  - **Extensively used** for **BSM searches**
- **Is the NWA reliable in the context of BSM searches?**
  - **NWA assumes Breit-Wigner resonance**
    - In the vicinity of kinematical bounds like $\sqrt{\hat{s}} \sim M$
    - For near-degenerate parent-daughter masses $m \sim M$
  - **Breit-Wigner lineshape** is **distorted** by threshold factors
    - phase space factors $\beta = \sqrt{1-(m/M)^2}$
- **Preliminary results for monotop RPV-production**
  - Indicate **substantial discrepancies** between **NWA** and **2→2**
  - Stay tuned...

Conclusions & Perspectives

Conclusions

- ➢ **Monotop production in the SM subdominant**
- ➢ **Observation** of **monotop signature means New physics**
- ➢ **RPV-MSSM** with BNV **allows** for monotop production @ LO
- ➢ **Strictly speaking ruled-out** by LHC constraints
  - ➟ **Meaning** in the case of **RPV-CMSSM**
- ➢ **Not excluded** for **more general models** like the pMSSM
- **NWA** is **not always reliable**

Perspectives:

- **Comparison naive NWA/off-shell effects**
- **Compute spin asymmetries**
- **Compare with ratios of parton-luminosities**

Thanks for your attention

Back-up slides

Matter-Antimatter Asymmetry

Sakharov's conditions :

1. **Baryon number is violated**
2. CP and C symmetries are **violated**
3. **Departure from thermal equilibrium**

- **Standard Model:**
  - **Baryon number is violated** $\Rightarrow$ **Sphalerons**
    - **Non-perturbative processes**
      - **Violates** $B + L$ but **preserve** $B - L$
  - **Departure from thermal equilibrium**
    - **ELECTROWEAK PHASE TRANSITION**
- **Standard electroweak baryogenesis** $\Rightarrow$ **RULED OUT**

Full expressions of the charges

$$
\begin{aligned}
Q^{ss}_{lo} &= s \;\; C_{d_i d_j \tilde{u}_l} C^*_{d_i d_j \tilde{u}_o} \Bigg[\left(s - m^2_{q_m} - m^2_{\tilde{\chi}^0_n} \right) \left(L_{u_m \tilde{u}_l \tilde{\chi}^0_n} L^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} \right. \\
&+ \left. R_{u_m \tilde{u}_l \tilde{\chi}^0_n} R^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} \right) - 2 m_{u_m} m_{\tilde{\chi}^0_n} \left(L_{u_m \tilde{u}_l \tilde{\chi}^0_n} R^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} + R_{u_m \tilde{u}_l \tilde{\chi}^0_n} L^*_{u_m \tilde{u}_o \tilde{\chi}^0_n} \right) \Bigg] \\
Q^{tt+}_{lo} &= C_{u_m d_i \tilde{d}_l} C^*_{u_m d_i \tilde{d}_o} \left(t - m^2_{u_m} \right) \left(t - m^2_{\tilde{\chi}^0_n} \right) \left(L_{d_j \tilde{d}_l \tilde{\chi}^0_n} L^*_{d_j \tilde{d}_o \tilde{\chi}^0_n} \right) \\
Q^{tt-}_{lo} &= C_{u_m d_i \tilde{d}_l} C^*_{u_m d_i \tilde{d}_o} \left(t - m^2_{u_m} \right) \left(t - m^2_{\tilde{\chi}^0_n} \right) \left(R_{d_j \tilde{d}_l \tilde{\chi}^0_n} R^*_{d_j \tilde{d}_o \tilde{\chi}^0_n} \right) \\
Q^{uu+}_{lo} &= C_{u_m d_j \tilde{d}_l} C^*_{u_m d_j \tilde{d}_o} \left(u - m^2_{u_m} \right) \left(u - m^2_{\tilde{\chi}^0_n} \right) \left(L_{d_i \tilde{d}_l \tilde{\chi}^0_n} L^*_{d_i \tilde{d}_o \tilde{\chi}^0_n} \right)
\end{aligned}
$$

Full expressions of the charges

$$
\begin{aligned}
Q^{uu-}_{lo} &= C_{u_m d_j \tilde{d}_l} C^*_{u_m d_j \tilde{d}_o} \left(u - m^2_{u_m}\right)\left(u - m^2_{\tilde{\chi}^0_n}\right)\left(R_{d_i \tilde{d}_l \tilde{\chi}^0_n} R^*_{d_i \tilde{d}_o \tilde{\chi}^0_n}\right) \\
Q^{st}_{lo} &= 2 m_{\tilde{\chi}^0_n} m_{u_m} s \Re\left(C_{d_i d_j \tilde{u}_l} L_{u_m \tilde{u}_l \tilde{\chi}^0_n} C^*_{u_m d_i \tilde{d}_o} R^*_{d_j \tilde{d}_o \tilde{\chi}^0_n}\right) \\
&+ 2st \Re\left(C_{d_i d_j \tilde{u}_l} R_{u_m \tilde{u}_l \tilde{\chi}^0_n} C^*_{u_m d_i \tilde{d}_o} R^*_{d_j \tilde{d}_o \tilde{\chi}^0_n}\right) \\
Q^{su}_{lo} &= -2 m_{\tilde{\chi}^0_n} m_{u_m} s \Re\left(C_{d_i d_j \tilde{u}_l} L_{u_m \tilde{u}_l \tilde{\chi}^0_n} C^*_{u_m d_j \tilde{d}_o} R^*_{d_i \tilde{d}_o \tilde{\chi}^0_n}\right) \\
&- 2us \Re\left(C_{d_i d_j \tilde{u}_l} R_{u_m \tilde{u}_l \tilde{\chi}^0_n} C^*_{u_m d_j \tilde{d}_o} R^*_{d_i \tilde{d}_o \tilde{\chi}^0_n}\right) \\
Q^{ut}_{lo} &= 2\left(m^2_{\tilde{\chi}^0_n} m^2_{u_m} - ut\right) \Re\left(C_{u_m d_i \tilde{d}_l} R_{d_j \tilde{d}_l \tilde{\chi}^0_n} C^*_{u_m d_j \tilde{d}_o} R^*_{d_i \tilde{d}_o \tilde{\chi}^0_n}\right)
\end{aligned}
$$

Full expressions for the couplings

$$L_{\tilde{u}_j u_k \tilde{\chi}^0_i} = \left[(e_q - T^3_q)\, s_W\, N_{i1} + T^3_q\, c_W\, N_{i2} \right] R^{u*}_{jk} + \frac{m_{u_k}\, c_W\, N_{i4}\, R^{u*}_{j(k+3)}}{2\, m_W\, \sin\beta}$$

$$R_{\tilde{u}_j u_k \tilde{\chi}^0_i} = -e_q\, s_W\, N^*_{i1}\, R^{u*}_{j(k+3)} + \frac{m_{u_k}\, c_W\, N^*_{i4}\, R^{u*}_{jk}}{2\, m_W\, \sin\beta}$$

$$L_{\tilde{d}_j d_k \tilde{\chi}^0_i} = \left[(e_q - T^3_q)\, s_W\, N_{i1} + T^3_q\, c_W\, N_{i2} \right] R^{d*}_{jk} + \frac{m_{d_k}\, c_W\, N_{i4}\, R^{d*}_{j(k+3)}}{2\, m_W\, \sin\beta}$$

$$R_{\tilde{d}_j d_k \tilde{\chi}^0_i} = -e_q\, s_W\, N^*_{i1}\, R^{d*}_{j(k+3)} + \frac{m_{d_k}\, c_W\, N^*_{i4}\, R^{d*}_{jk}}{2\, m_W\, \sin\beta}$$

$$C_{d_i d_j \widetilde{u}_l} = \lambda''_{ijk} R^{u}_{l(k+3)} \quad \text{and} \quad C_{u_i d_j \widetilde{d}_l} = \lambda''_{ijk} R^{d}_{l(k+3)}$$

With

$$\widetilde{\chi}^0_i = N_{ij} \psi^0_j \quad \text{with} \quad i = 1, 2, 3, 4 \qquad (1)$$