Phenomenology of top-squark in natural SUSY in light of the LHC Higgs data

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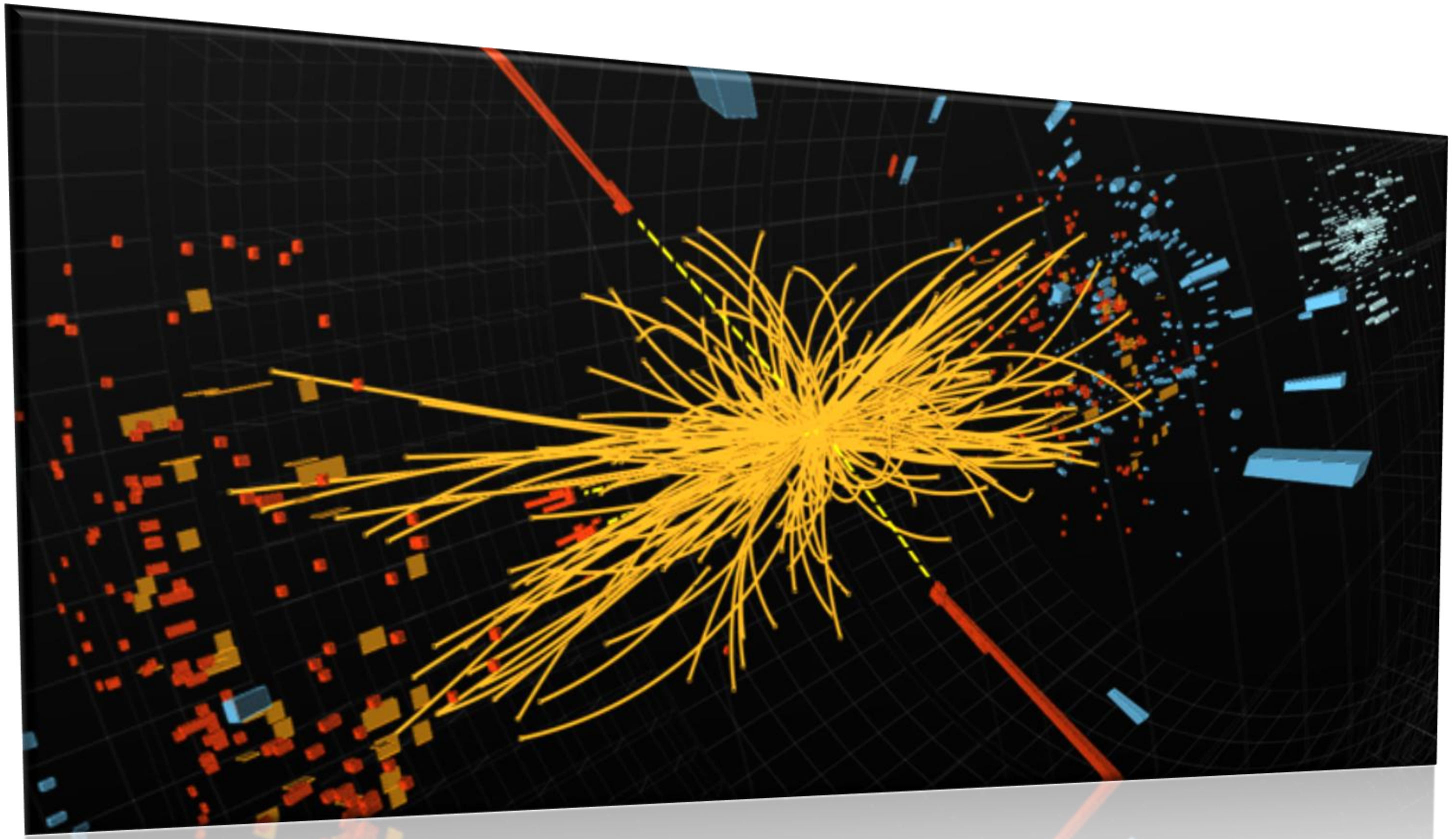
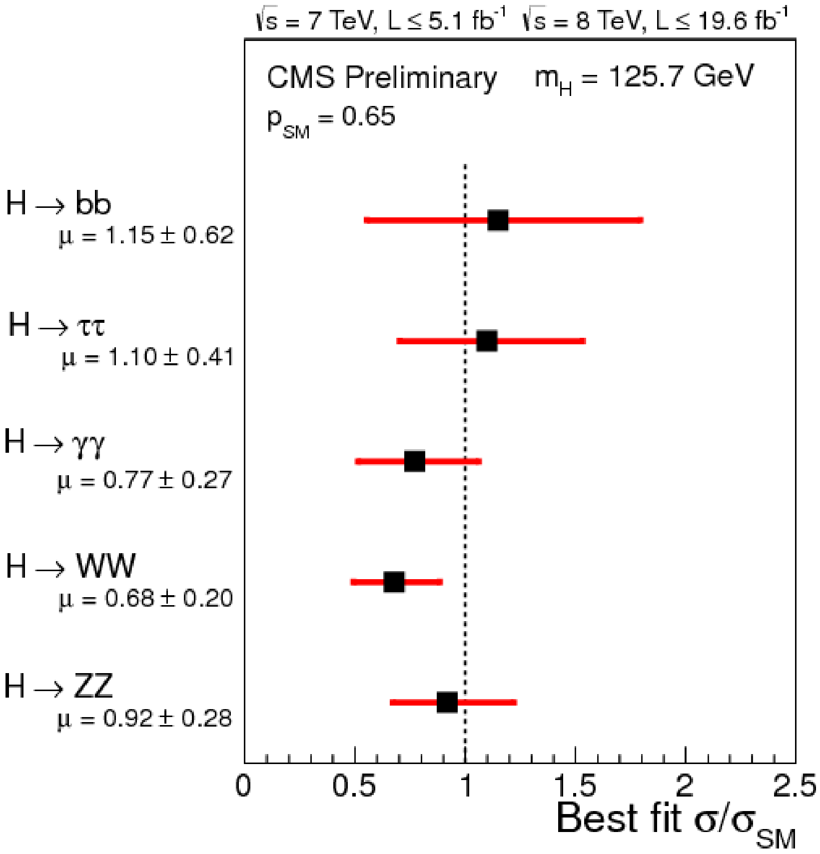
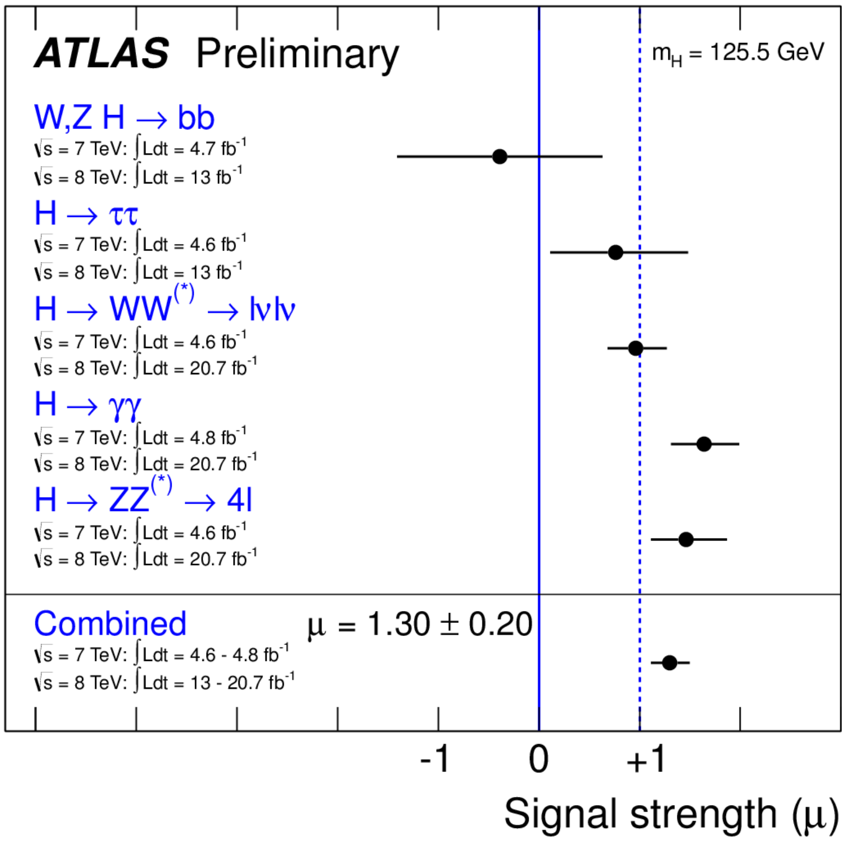
Discovery of the Higgs




√s = 7 TeV, L ≤ 5.1 fb-1 √s = 8 TeV, L ≤ 19.6 fb-1
CMS Preliminary
mH = 125.7 GeV
pSM = 0.65
H → bb
μ = 1.15 ± 0.62
H → ττ
μ = 1.10 ± 0.41
H → γγ
μ = 0.77 ± 0.27
H → WW
μ = 0.68 ± 0.20
H → ZZ
μ = 0.92 ± 0.28
0 0.5 1 1.5 2 2.5
Best fit σ/σSM


ATLAS Preliminary
mH = 125.5 GeV
W,Z H → bb
√s = 7 TeV: ∫Ldt = 4.7 fb-1
√s = 8 TeV: ∫Ldt = 13 fb-1
H → ττ
√s = 7 TeV: ∫Ldt = 4.6 fb-1
√s = 8 TeV: ∫Ldt = 13 fb-1
H → WW(*) → lνlν
√s = 7 TeV: ∫Ldt = 4.6 fb-1
√s = 8 TeV: ∫Ldt = 20.7 fb-1
H → γγ
√s = 7 TeV: ∫Ldt = 4.8 fb-1
√s = 8 TeV: ∫Ldt = 20.7 fb-1
H → ZZ(*) → 4l
√s = 7 TeV: ∫Ldt = 4.6 fb-1
√s = 8 TeV: ∫Ldt = 20.7 fb-1
Combined
μ = 1.30 ± 0.20
√s = 7 TeV: ∫Ldt = 4.6 - 4.8 fb-1
√s = 8 TeV: ∫Ldt = 13 - 20.7 fb-1
-1 0 +1
Signal strength (μ)

Post Higgs Boson Era
What is the situation of SUSY

- Fine-tuning problem
- Dark matter
- Grand Unification
- ……

The minimization conditions of Higgs potential imply

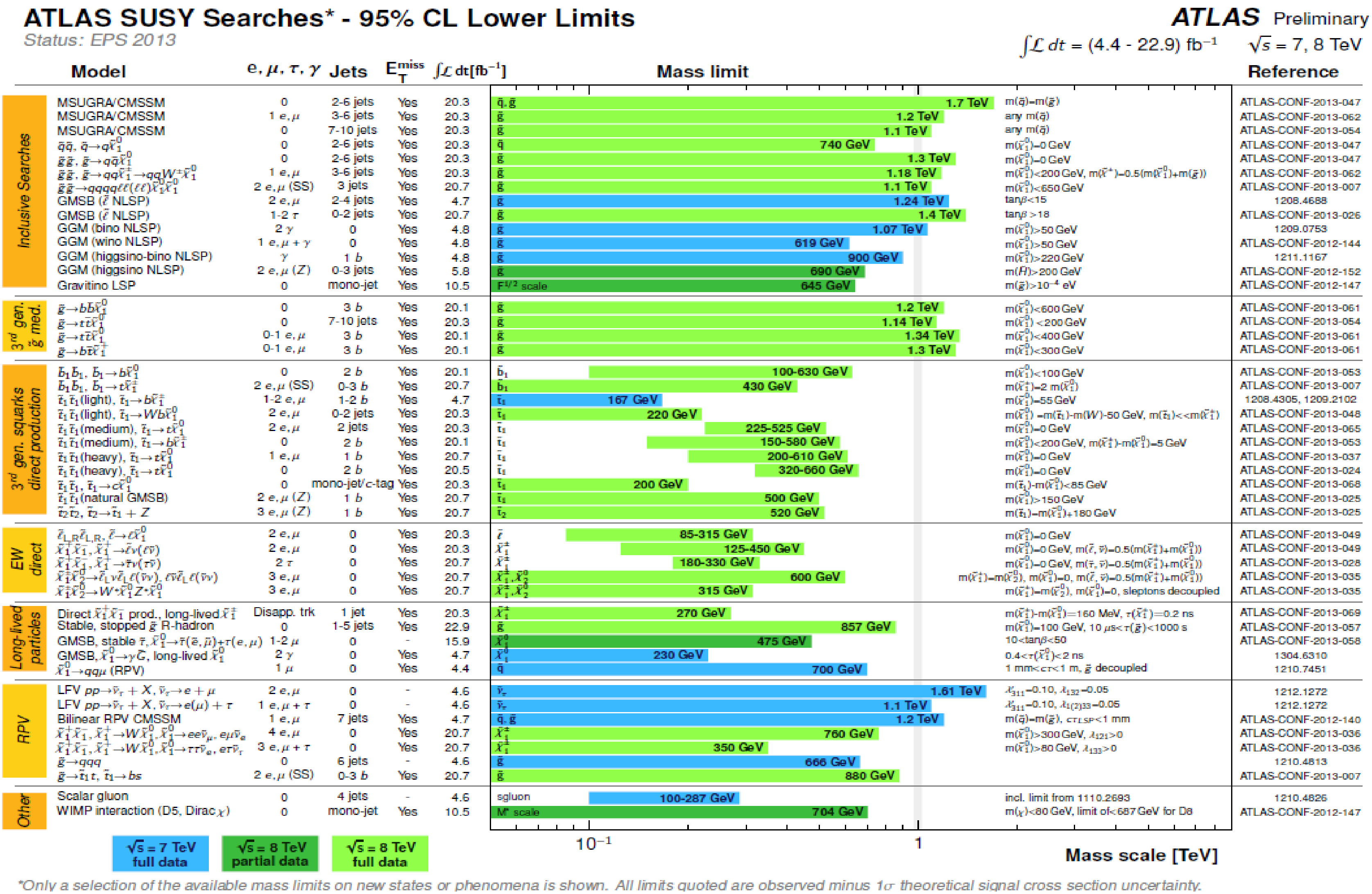
$$\frac{M_Z^2}{2} = \frac{\left(m_{H_d}^2 + \Sigma_d\right) - \left(m_{H_u}^2 + \Sigma_u\right)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

$$\Sigma_u \approx \frac{3Y_t^2}{16\pi^2} \times m_{\tilde{t}_i}^2 \left(\log\frac{m_{\tilde{t}_i}^2}{Q^2} - 1\right)$$

Natural SUSY

- First second generation squark heavy tens of TeV
- Third generation squark light
- Gluino not very heavy (lighter than several TeV)
- 125GeV Higgs mass

SUSY search



ATLAS SUSY Searches* - 95% CL Lower Limits
Status: EPS 2013
ATLAS Preliminary
∫L dt = (4.4 - 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) | ATLAS-CONF-2013-054
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→qqqqℓℓ(ℓℓ)χ̃⁰₁χ̃⁰₁ | 2 e, μ (SS) | 3 jets | Yes | 20.7 | g̃ 1.1 TeV | m(χ̃⁰₁)<650 GeV | ATLAS-CONF-2013-007
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 | 0 | Yes | 4.8 | g̃ 1.07 TeV | m(χ̃⁰₁)>50 GeV | 1209.0753
GGM (wino NLSP) | 1 e, μ + γ | 0 | 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 1.14 TeV | m(χ̃⁰₁)<200 GeV | ATLAS-CONF-2013-054
g̃→tt̄χ̃⁰₁ | 0-1 e, μ | 3 b | Yes | 20.1 | g̃ 1.34 TeV | m(χ̃⁰₁)<400 GeV | ATLAS-CONF-2013-061
g̃→btχ̃⁺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 100-630 GeV | m(χ̃⁰₁)<100 GeV | ATLAS-CONF-2013-053
b̃₁b̃₁, b̃₁→tχ̃±₁ | 2 e, μ (SS) | 0-3 b | Yes | 20.7 | b̃₁ 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 167 GeV | m(χ̃⁰₁)=55 GeV | 1208.4305, 1209.2102
t̃₁t̃₁(light), t̃₁→Wbχ̃⁰₁ | 2 e, μ | 0-2 jets | Yes | 20.3 | t̃₁ 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 | ATLAS-CONF-2013-053
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 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 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 | 0 | 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→W*χ̃⁰₁Z*χ̃⁰₁ | 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
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 857 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 | 0 | - | 15.9 | χ̃⁰₁ 475 GeV | 10<tanβ<50 | ATLAS-CONF-2013-058
GMSB, χ̃⁰₁→γG̃, long-lived χ̃⁰₁ | 2 γ | 0 | Yes | 4.7 | χ̃⁰₁ 230 GeV | 0.4<τ(χ̃⁰₁)<2 ns | 1304.6310
χ̃⁰₁→qqμ (RPV) | 1 μ | 0 | Yes | 4.4 | q̃ 700 GeV | 1 mm<cτ<1 m, g̃ decoupled | 1210.7451
RPV
LFV pp→ν̃τ + X, ν̃τ→e + μ | 2 e, μ | 0 | - | 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 | 0 | - | 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 | 0 | 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 | 0 | Yes | 20.7 | χ̃±₁ 350 GeV | m(χ̃⁰₁)>80 GeV, λ133>0 | ATLAS-CONF-2013-036
g̃→qqq | 0 | 6 jets | - | 4.6 | g̃ 666 GeV | | 1210.4813
g̃→t̃₁t, t̃₁→bs | 2 e, μ (SS) | 0-3 b | Yes | 20.7 | g̃ 880 GeV | | ATLAS-CONF-2013-007
Other
Scalar gluon | 0 | 4 jets | - | 4.6 | sgluon 100-287 GeV | incl. limit from 1110.2693 | 1210.4826
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.

- How the experiment constrains the Natural SUSY parameter space?
- Can the stop still be light?

Since the component of the lighter stop will affect its decay modes, we will consider two scenarios:

- **Scenario I** the stop is left-hand like
- **Scenario II** the stop is right-hand like

First, we scan the parameters space

$m_{\tilde{q}_3} < 2\ \text{TeV}$

$m_{\tilde{u}_3} = m_{\tilde{d}_3} < 2\ \text{TeV}$

$m_1 = m_2 = m_3 = 2\ \text{TeV}$

$m_{\tilde{l}_{1,2,3}} = m_{\tilde{q}_{1,2}} = m_{\tilde{e}_{1,2,3}} = 5\ \text{TeV}$

$-3\ \text{TeV} < A_t = A_b < 3\ \text{TeV}$

$100\ \text{GeV} < \mu < 200\ \text{GeV}$

$1 < \tan\beta < 60$

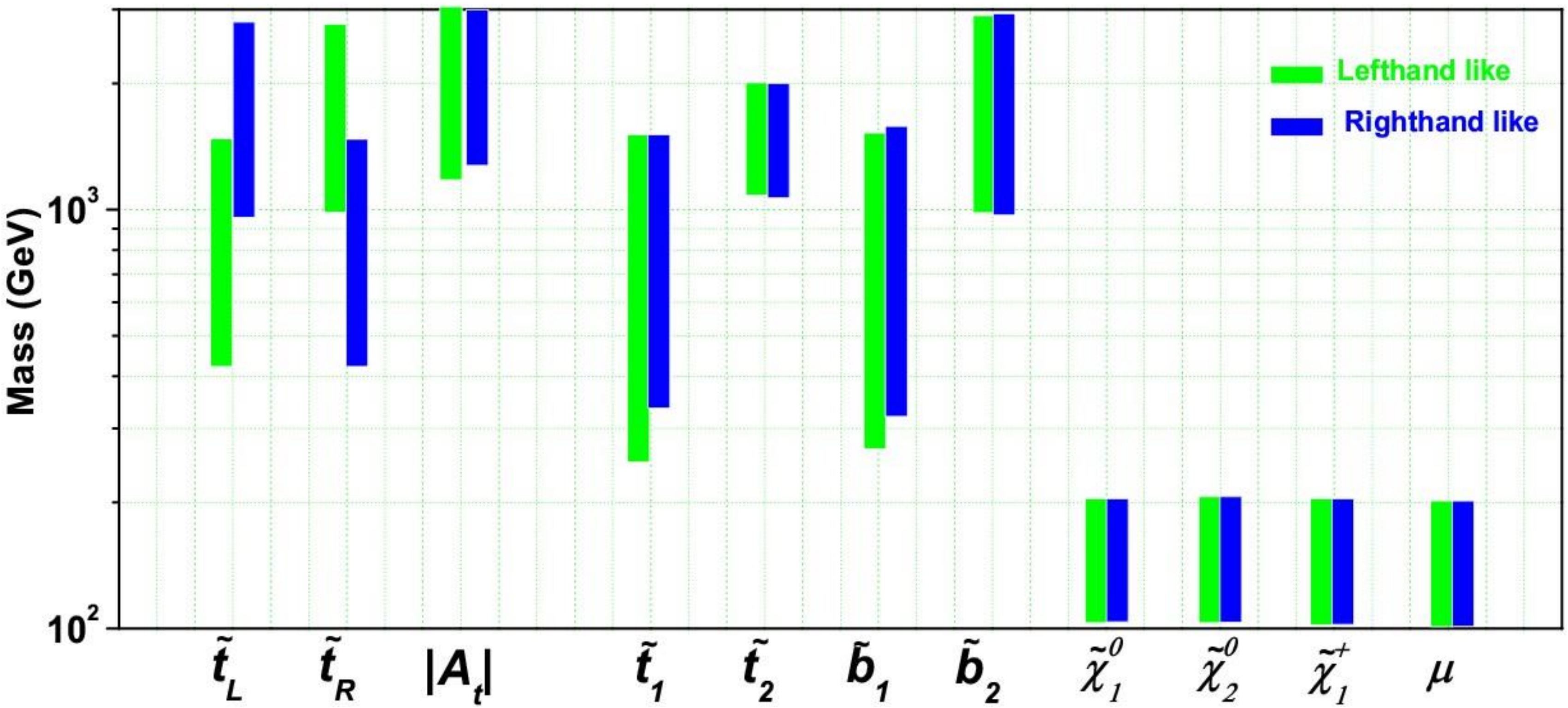
$100\ \text{GeV} < m_A < 2000\ \text{GeV}$

We also require $m_{\tilde{t}_1} < 1.5\ \text{TeV}$, $m_{\tilde{t}_2} < 2\ \text{TeV}$

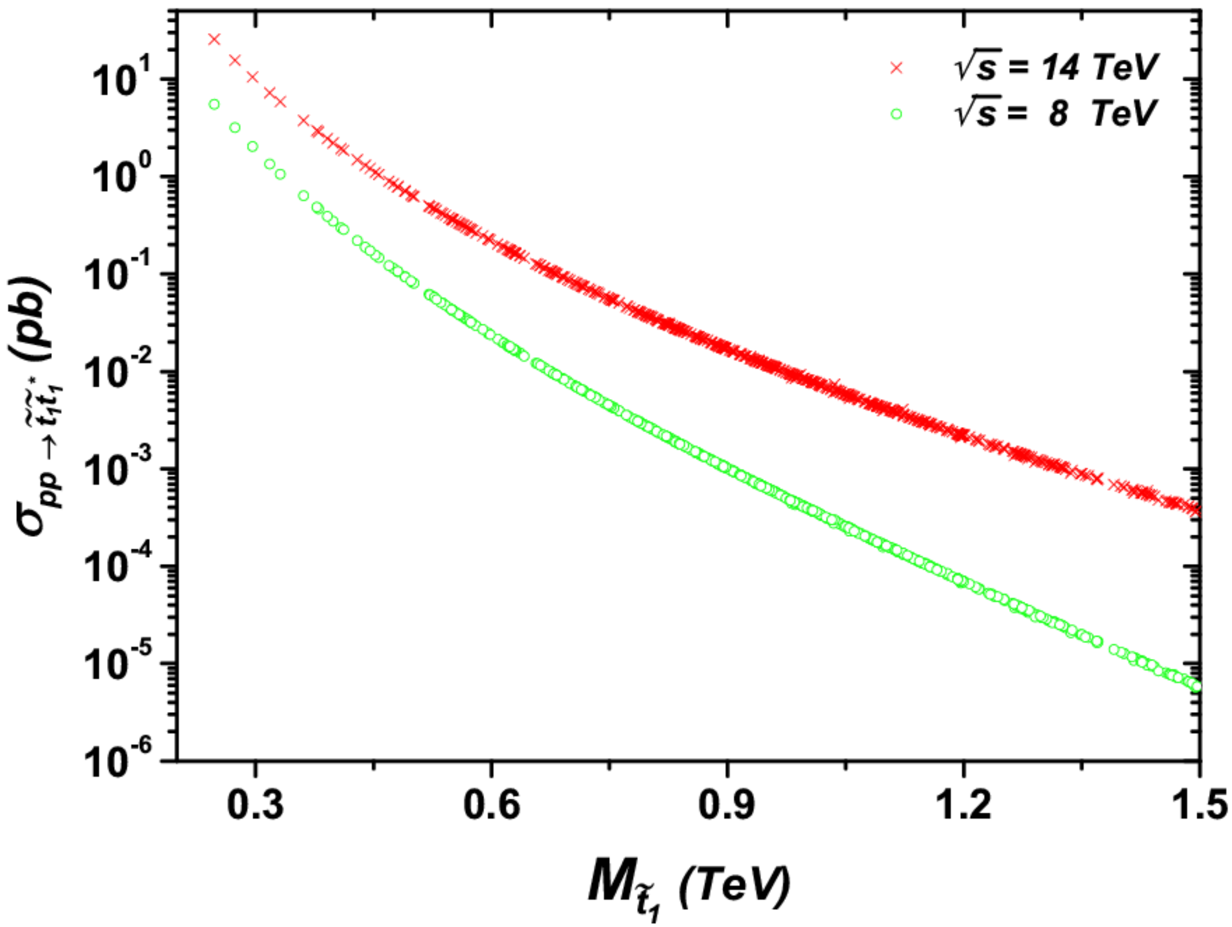
considering the following constraints:

1. Higgs mass 123 ~ 127 GeV,
2. flavor constraints $B \to X_s\gamma$, $B_{s(d)} \to \mu^+\mu^-$, and $B^+ \to \tau^+\nu$,
3. precision electroweak observables,
4. the relic density of the DM.
5. the experimental constraints on the Higgs from LEP, Tevatron and LHC with HiggsBounds.

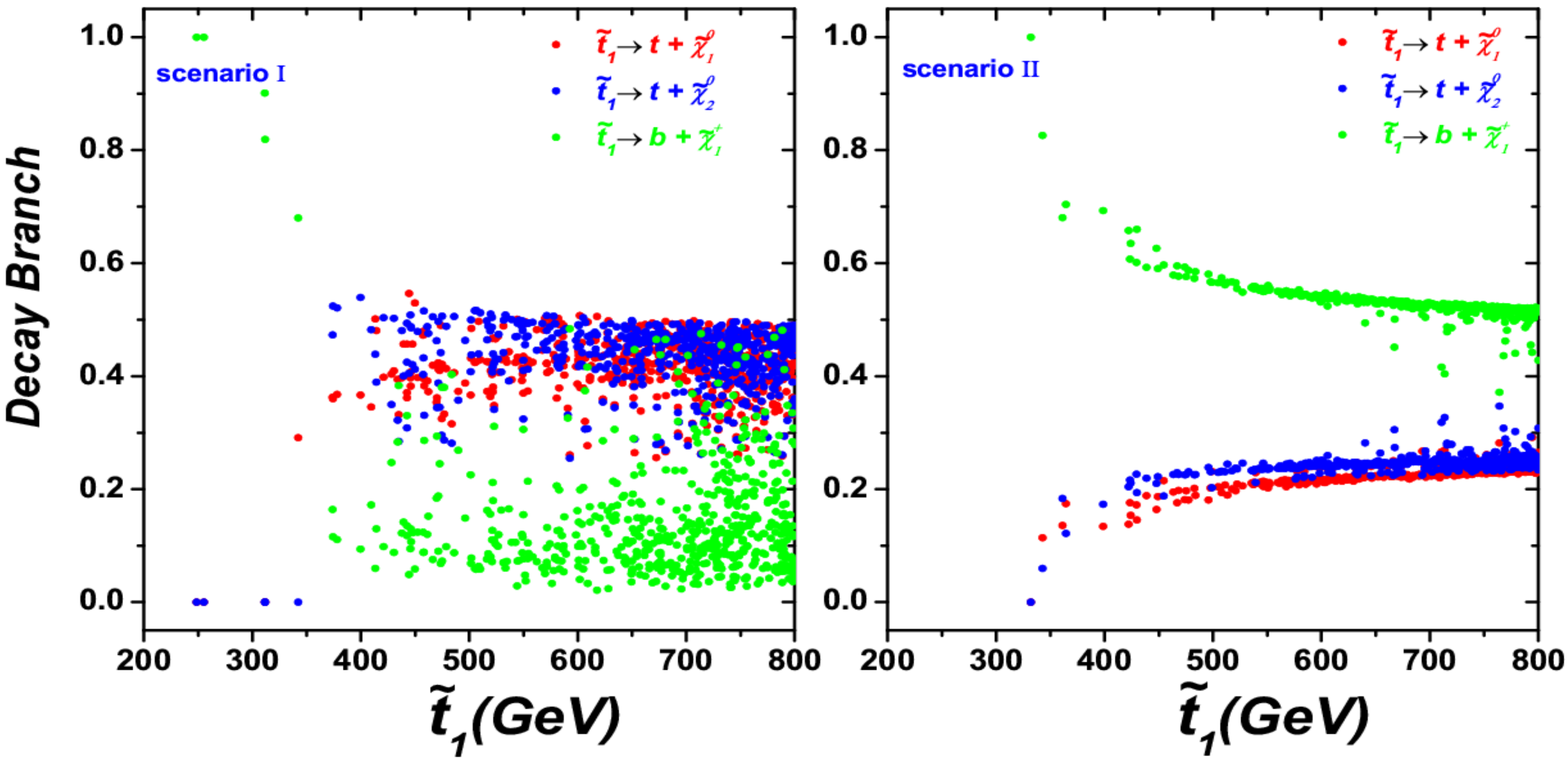
The spectrum



Stop (sbottom) pair production

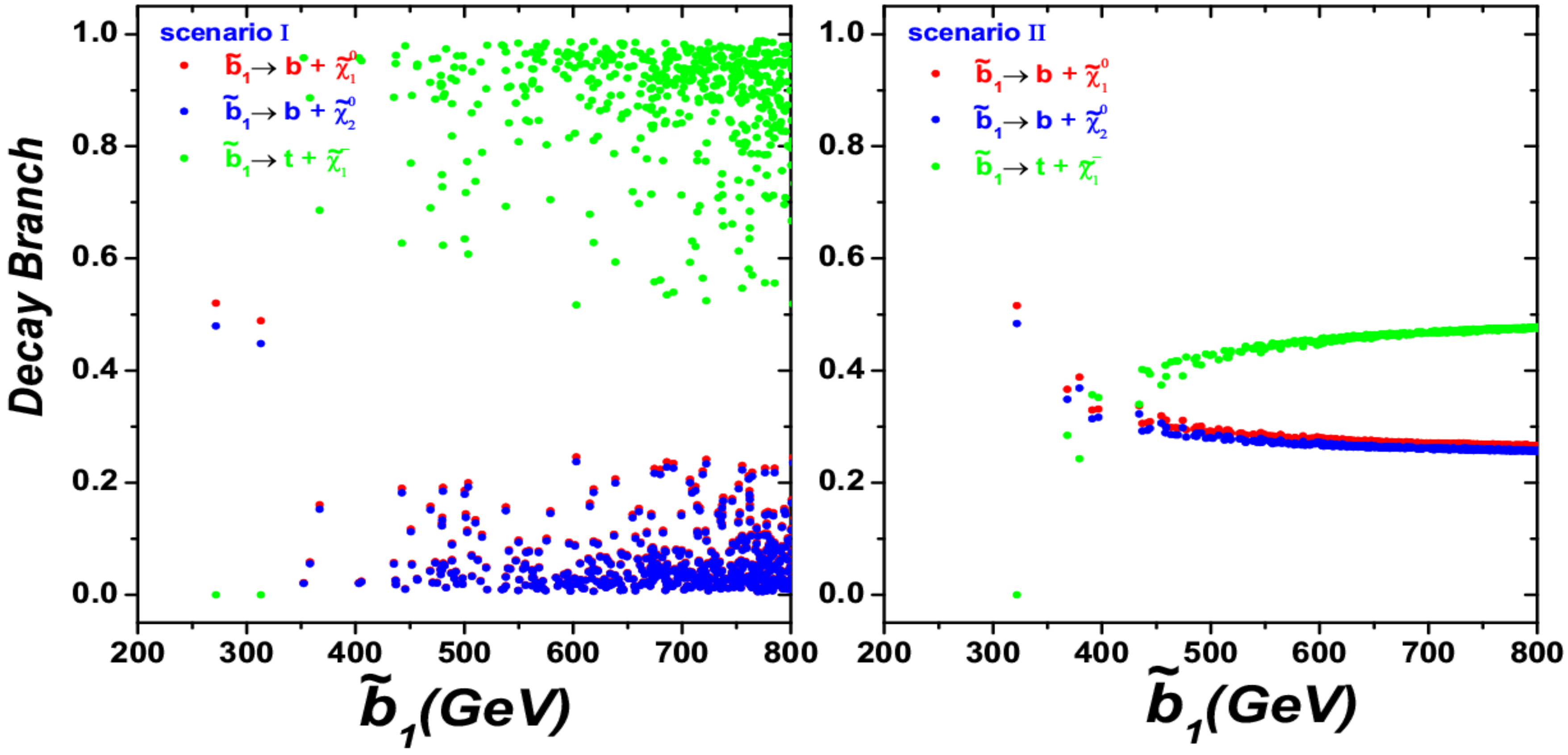


Stop decay



Decay Branch
scenario I
$\tilde{t}_1 \to t + \tilde{\chi}_1^0$
$\tilde{t}_1 \to t + \tilde{\chi}_2^0$
$\tilde{t}_1 \to b + \tilde{\chi}_1^+$
$\tilde{t}_1$(GeV)
scenario II
$\tilde{t}_1 \to t + \tilde{\chi}_1^0$
$\tilde{t}_1 \to t + \tilde{\chi}_2^0$
$\tilde{t}_1 \to b + \tilde{\chi}_1^+$
$\tilde{t}_1$(GeV)

Sbottom decay



We consider the following experiments

ATLAS stop/sbottom direct searches	natural MSSM stop/sbottom decays
$\ell + jets + \not{E}_T$	$\tilde{t} \to t\tilde{\chi}^0_{1,2}$, $\tilde{b} \to t\tilde{\chi}^-_1$
$t\bar{t}$(hadronic)+$\not{E}_T$	$\tilde{t} \to t\tilde{\chi}^0_{1,2}$, $\tilde{b} \to t\tilde{\chi}^-_1$
$2b + \not{E}_T$	$\tilde{b} \to b\tilde{\chi}^0_{1,2}$, $\tilde{t} \to b\tilde{\chi}^+_1$

and calculate the CL_s

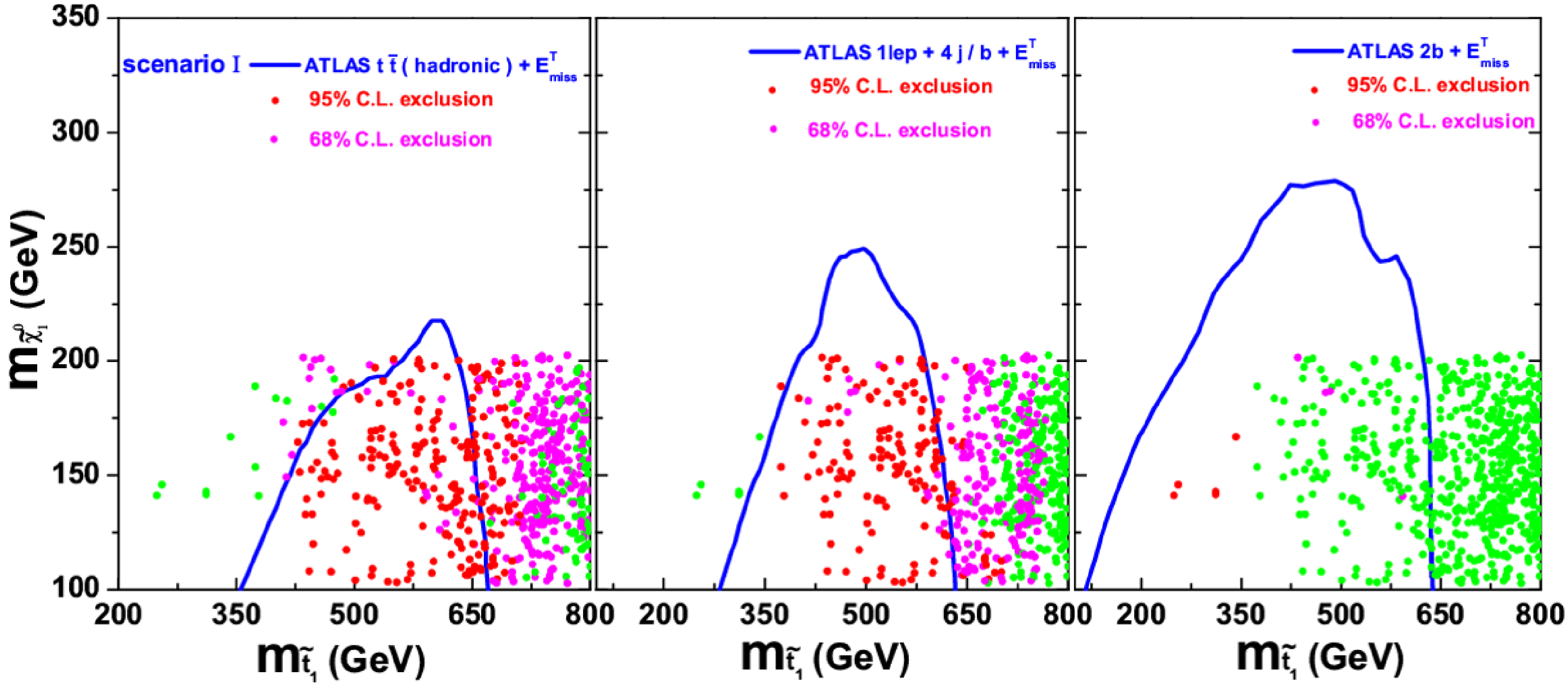
$$CL_s^i = \frac{Pois(n_i|b_i + s_i)}{Pois(n_i|b_i)}$$

considering the Gaussian distribution of background

$$Posi(n_i|b_i + s_i) \rightarrow \int \delta b_i \, Gaus\left(\delta b_i, f_i^b\right) Pois(n_i|b_i(1 + \delta b_i) + s_i)$$

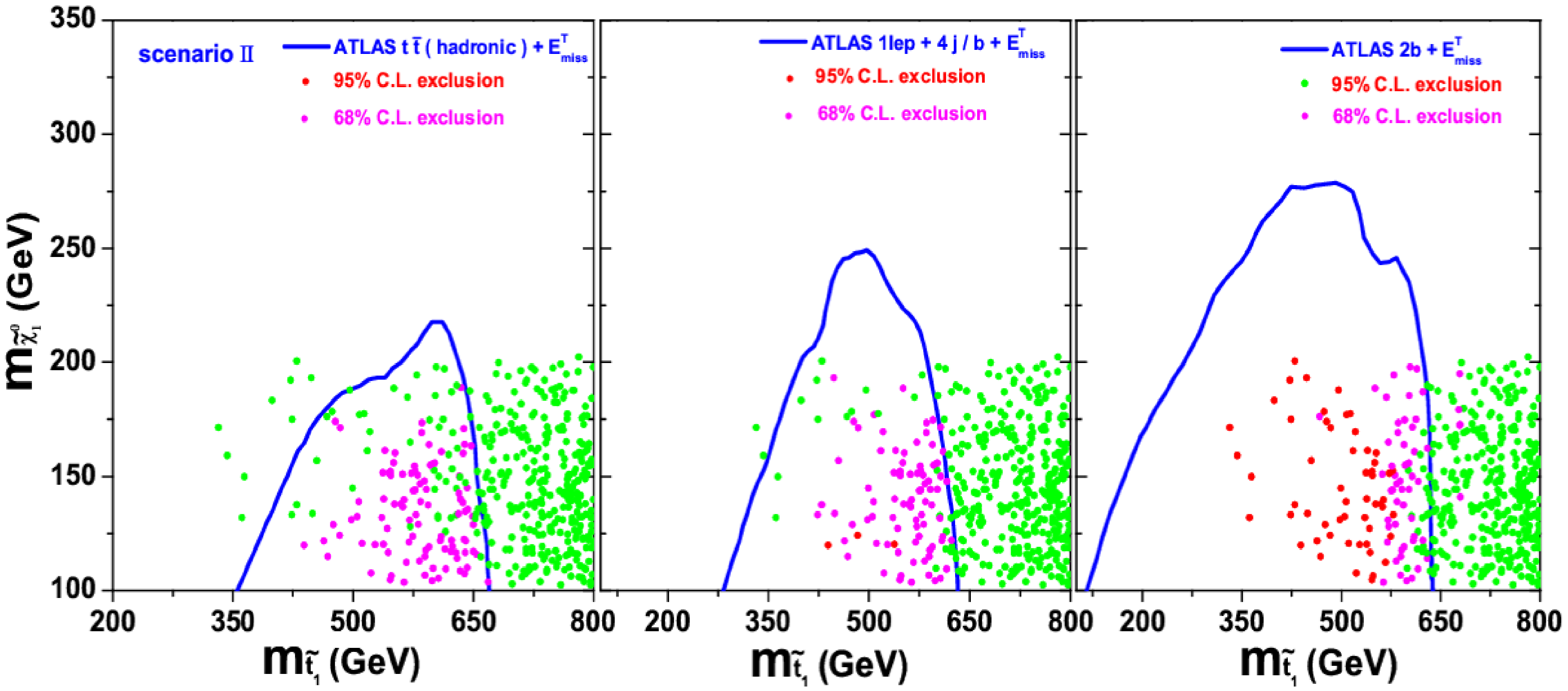
Scenario I

The effects on the parameter space from each channel

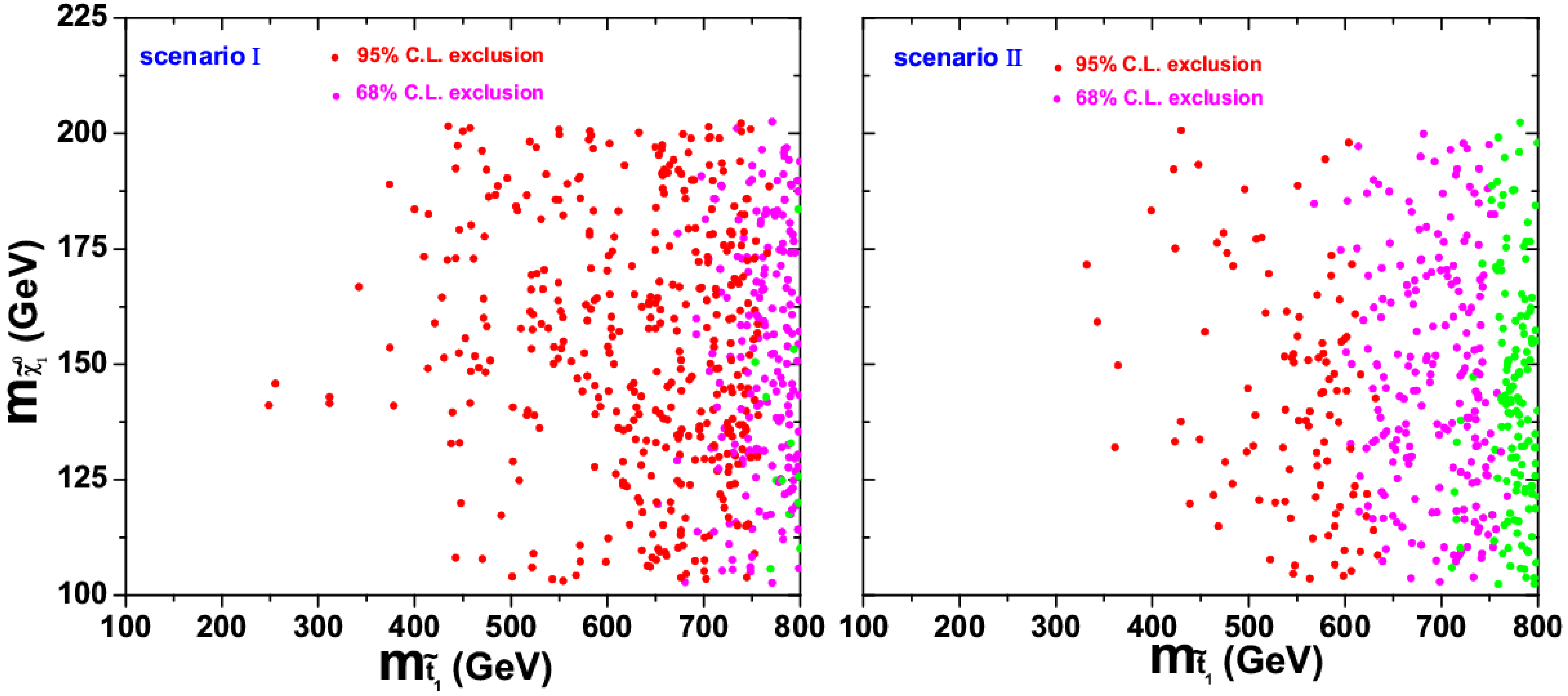


Scenario II

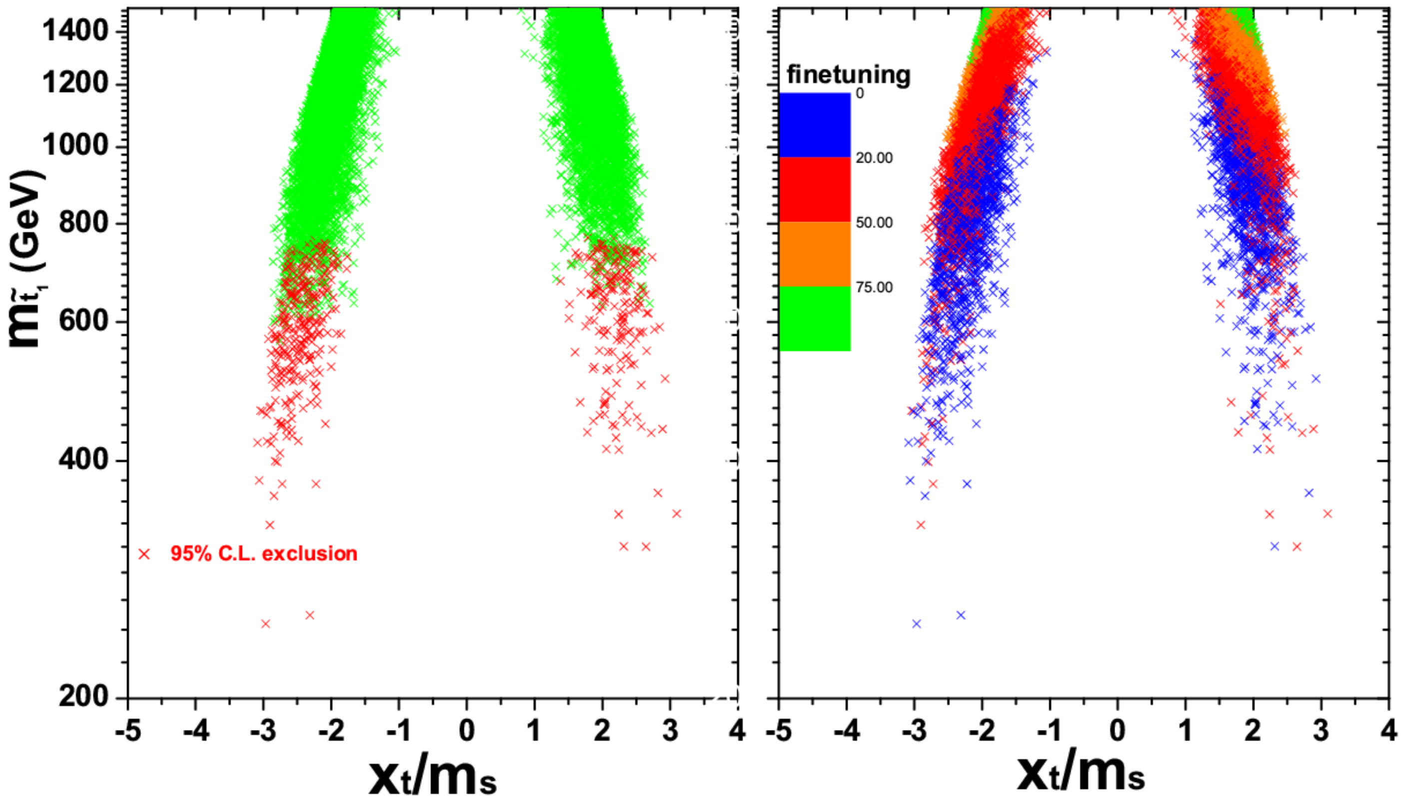
The effects on the parameter space from each channel



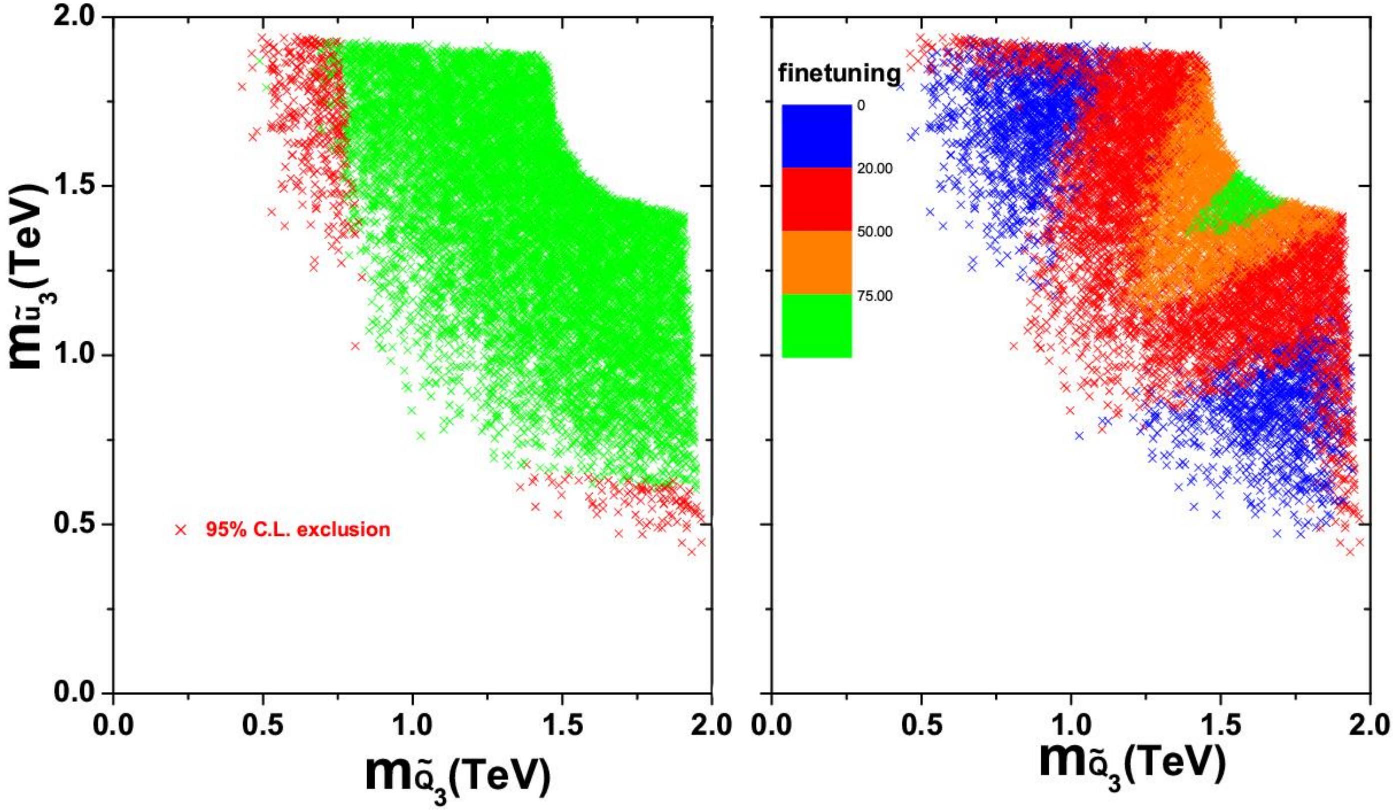
CL_s combination of the three channels

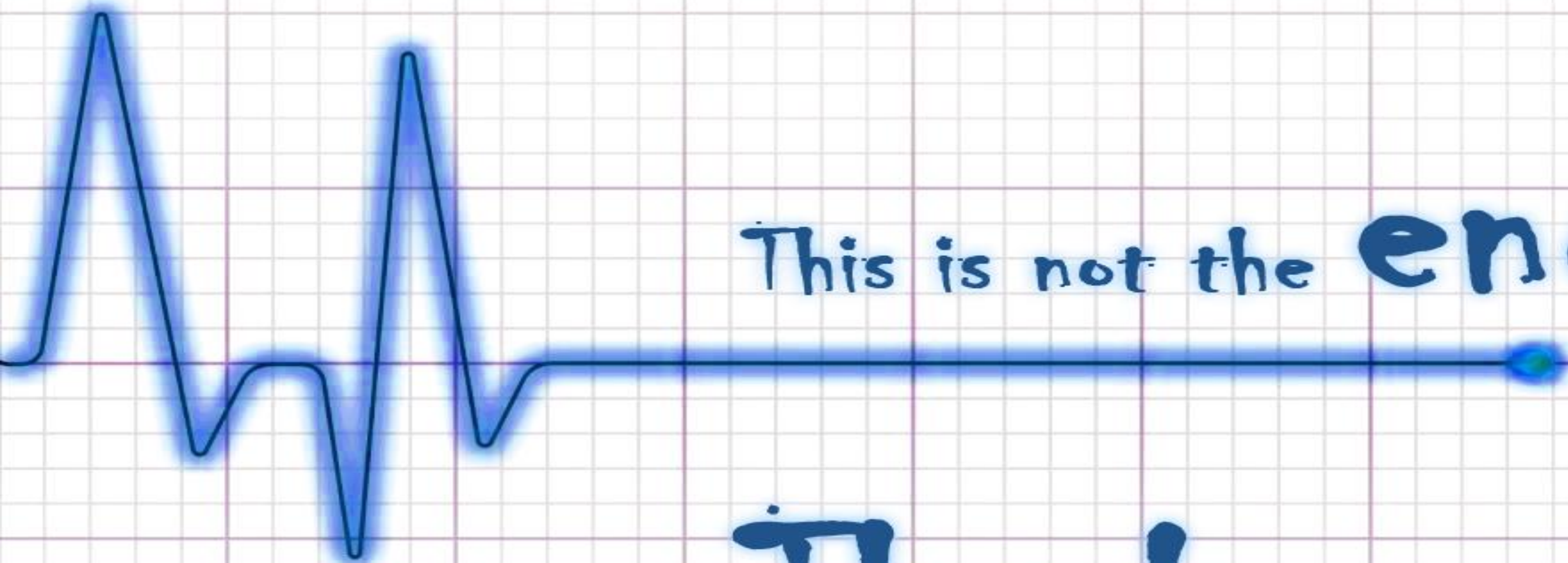


The final parameter space and the fine-tuning



The final parameter space and the fine-tuning





This is not the end

Thank you!