Muon *g*-2 vs LHC in SUSY models

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27th Aug. 2013
SUSY 2013 Conference @ ICTP Trieste, Italy

Reference)
M. Endo, K. Hamaguchi, S. Iwamoto, and T. Yoshinaga [1203.4256]

LHC

 **Higgs!!**

$\Longrightarrow$ Standard Model ✓

LHC

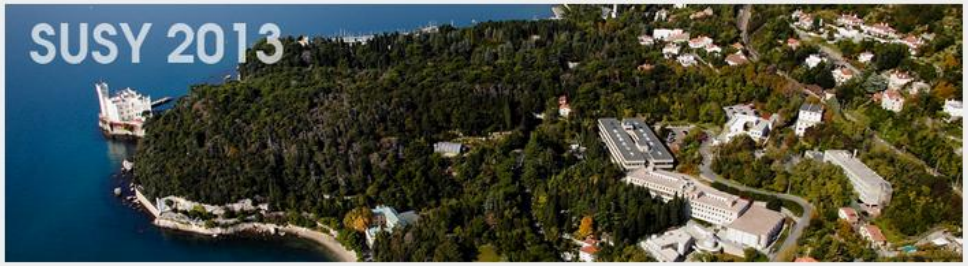
Higgs!!

$\Longrightarrow$ Standard Model ✓

- Hierarchy Problem

⇩

SUSY?



SUSY 2013

ICTP Trieste, Italy

26—31 August 2013

21st International Conference on Supersymmetry and Unification of Fundamental

C

$\Longrightarrow$ Standard Model ✓

- Hierarchy Problem

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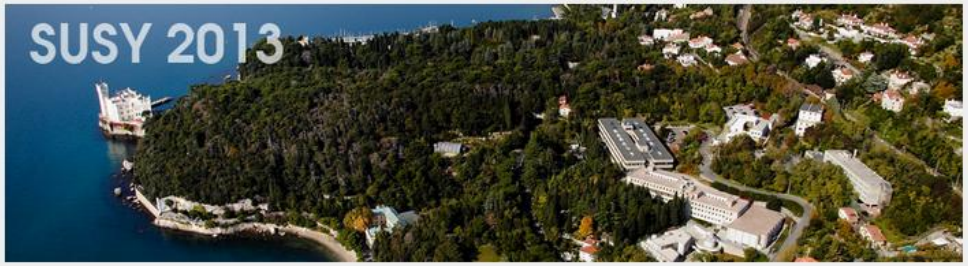
SUSY?



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$\Longrightarrow$ Standard Model ✓

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SUSY!!!

We  SUSY!

(Minimal SUSY Standard Model)

- **SUSY (MSSM)** can solve
  - Hierarchy problem
  - Dark matter problem
  - Muon $g-2$ anomaly

But Not Found yet…

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(Minimal SUSY Standard Model)

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  - Hierarchy problem
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But Not Found yet…

Where is SUSY??

(Minimal SUSY Standard Model)

- **SUSY (MSSM)** can solve
  - Hierarchy problem
  - Dark matter problem
  - Muon $g-2$ anomaly

- Not found yet. $\Rightarrow m(\tilde{q}, \tilde{g}) \gtrsim 1\,\text{TeV}$.
- $m_h = 126$ GeV
  - $\Rightarrow \Delta(m_h)^{\text{loop}}$: large
  - $\Rightarrow m_{\tilde{t}} = \text{O}(1\text{–}10)\,\text{TeV}$?
    (or extension?)

$$m_h^2[\text{MSSM}] \approx \underbrace{m_Z^2}_{\text{tree}} + \underbrace{\frac{3g_W^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\frac{m_{\tilde{t}}^2}{m_t^2} - \frac{(\alpha^2-6)^2}{12} + 3\right]}_{\Delta\left(m_h^2\right)^{\text{loop}}}$$

where $\alpha := A_t/m_{\tilde{t}}$.
(stop mixing parameter)

A Nightmare:

SUSY$\gg 1\,\text{TeV}$ & we cannot reach SUSY?

- Dark matter problem
- Muon $g-2$ anomaly

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A Nightmare:

SUSY$\gg 1\,\mathrm{TeV}$ & we cannot reach SUSY?

- Dark matter problem

The last(?) hope for detectable SUSY.

- Muon $g-2$ anomaly

$(g-2)_\mu$ ⇨ SUSY spectrum should be [ ] .

"$(g-2)_\mu$- motivated MSSM"

⇨ **The hopeful channels are**

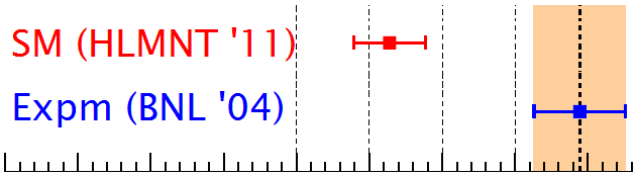
$pp \rightarrow$ [ ] , [ ] , [ ] .

2. $(g-2)_\mu$-Motivated MSSM

Let’s consider “discover-able” SUSY!

$$\left(a_\mu := \frac{g_\mu - 2}{2}\right)$$

- $(g-2)_\mu$ anomaly



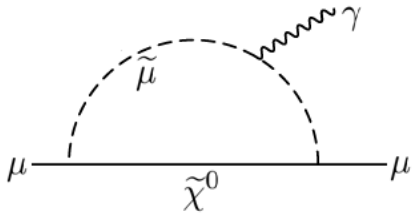
$$a_\mu^{\mathrm{SM}} = (116\,591\,828 \pm 49) \times 10^{-11}$$
$$a_\mu^{\mathrm{exp}} = (116\,592\,089 \pm 63) \times 10^{-11}$$

Hagiwara, Liao, Martin, Nomura, Teubner [1105.3149]

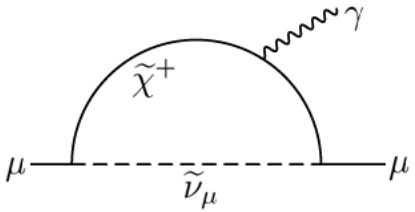
3.3σ discrepancy

can be explained with **MSSM**
if μ-term > 0, $\tan\beta \gtrsim 10$,
and $m\left(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{\mu}, \tilde{\nu}_\mu\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$.

Lopez, Nanopoulos, Wang [ph/9308336]
Chattopadhyay, Nath [ph/9507386]
Moroi [ph/9512396]



$$\Delta a_\mu\left(\tilde{\chi}^0, \tilde{\mu}\right) \approx \frac{g_Y^2}{(4\pi)^2}\frac{m_\mu^2}{m_{\mathrm{soft}}^2}\,\mathrm{sgn}(\mu)\tan\beta + \cdots,$$



$$\Delta a_\mu\left(\tilde{\chi}^\pm, \tilde{\nu}\right) \approx \frac{g_2^2}{(4\pi)^2}\frac{m_\mu^2}{m_{\mathrm{soft}}^2}\,\mathrm{sgn}(\mu)\tan\beta.$$

$W \ni \mu H_{\mathrm{u}} H_{\mathrm{d}}$ (Higgsino mass term), $\quad \tan\beta = \dfrac{\langle H_{\mathrm{u}}\rangle}{\langle H_{\mathrm{d}}\rangle}$,

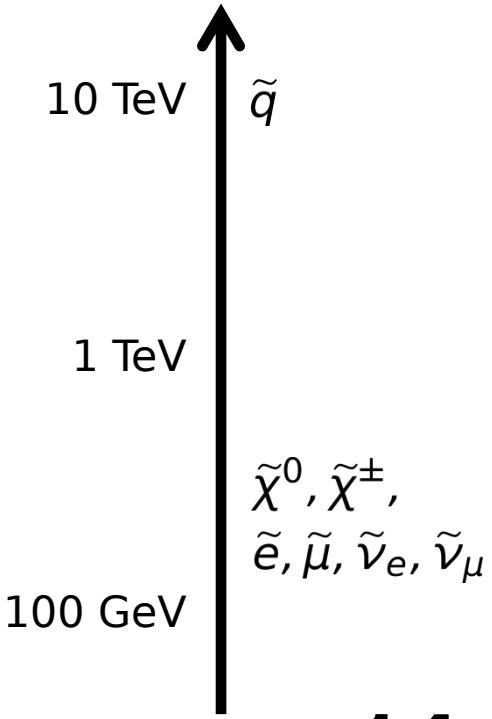
m_{soft} : SUSY-particle mass-scale, $\quad g_i$: Gauge couplings.

MSSM current status

- $m_h = 126\,\mathrm{GeV}$ ⟹ $m\left(\tilde{t}\right) \sim \mathrm{O}(1\text{–}10)\,\mathrm{TeV}$??
- LHC SUSY searches ⟹ $m(\tilde{g}, \tilde{q}) \gtrsim 1\,\mathrm{TeV}$
- $(g-2)_\mu$ anomaly ⟹ $m\left(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{\mu}, \tilde{\nu}_\mu\right) \sim \mathrm{O}(100)\,\mathrm{GeV}$ and large $\tan\beta$??

$(g-2)_\mu$-motivated MSSM

- squarks $\gg 1\,\mathrm{TeV}$.
- $\tilde{\chi}^0, \tilde{\chi}^\pm$ & slepton ~ O(100)GeV.



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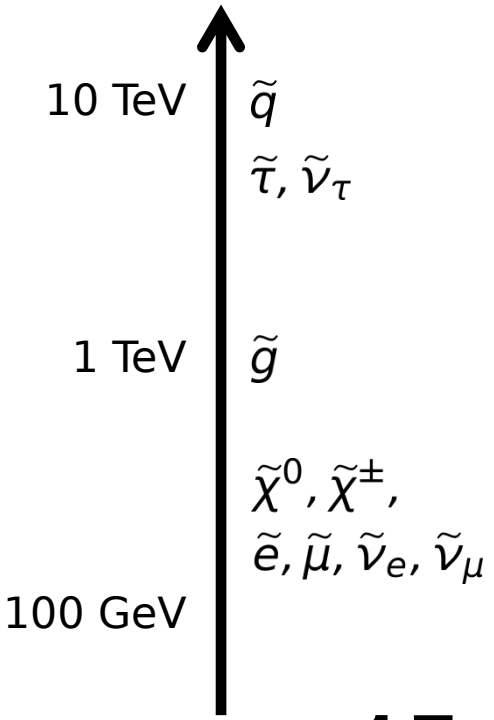
$(g-2)_\mu$-motivated MSSM

- squarks & stau-sector $(\tilde{\tau}, \tilde{\nu}_\tau) \gg 1\,\mathrm{TeV}$.
  (to simplify LHC analyses)
- $\tilde{\chi}^0, \tilde{\chi}^\pm$ & slepton $\sim$ O(100)GeV.
- Gaugino: $M_1 : M_2 : M_3 = 1 : 2 : 6$.
  (approximate GUT relation)



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$(g-2)_\mu$-motivated MSSM

- squarks & stau-sector ($\tilde{\tau}$, **The targets!**
  (to simplify LHC analyses)
- $\tilde{\chi}^0, \tilde{\chi}^\pm$ & slepton ~ O(100)GeV.
- Gaugino: $M_1 : M_2 : M_3 = 1 : 2 : 6$.
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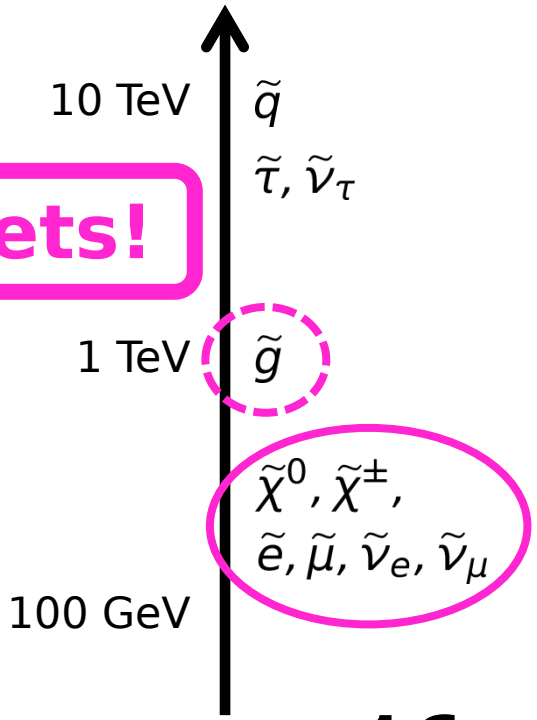
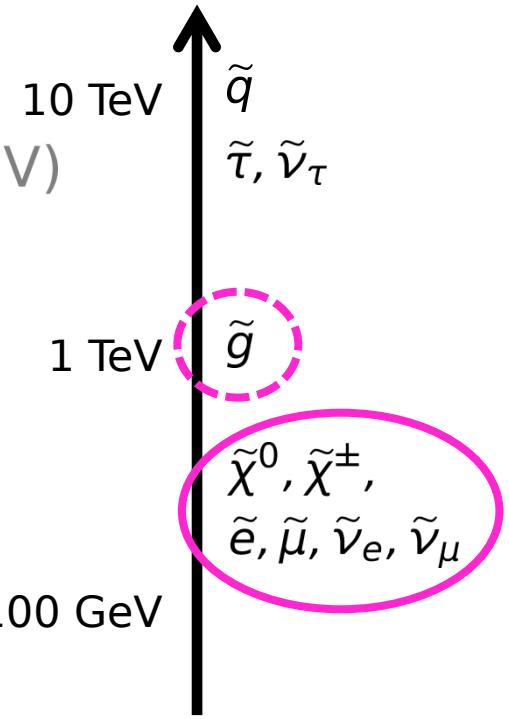


$(g-2)_\mu$-motivated MSSM

- squarks: $\tilde{q} \gg 1\,\mathrm{TeV}$. (so that $m_h = 126\,\mathrm{GeV}$)
- sleptons: $(\tilde{e}, \tilde{\nu}_e) = (\tilde{\mu}, \tilde{\nu}_\mu)$ $\left[\ll (\tilde{\tau}, \tilde{\nu}_\tau)\right]$
- gaugino: $M_1 : M_2 : M_3 = 1 : 2 : 6$.
  (approximate GUT relation)
- $\tan\beta =$ large $(= 40)$



- A-terms $= 0$
- $m_A = 1500\mathrm{GeV}$
- R-parity conserved.

Parameters: $(m_L^2, m_{\bar{E}}^2)$: slepton mass (soft mass)

(M_2, μ) : gaugino/Higgsino mass

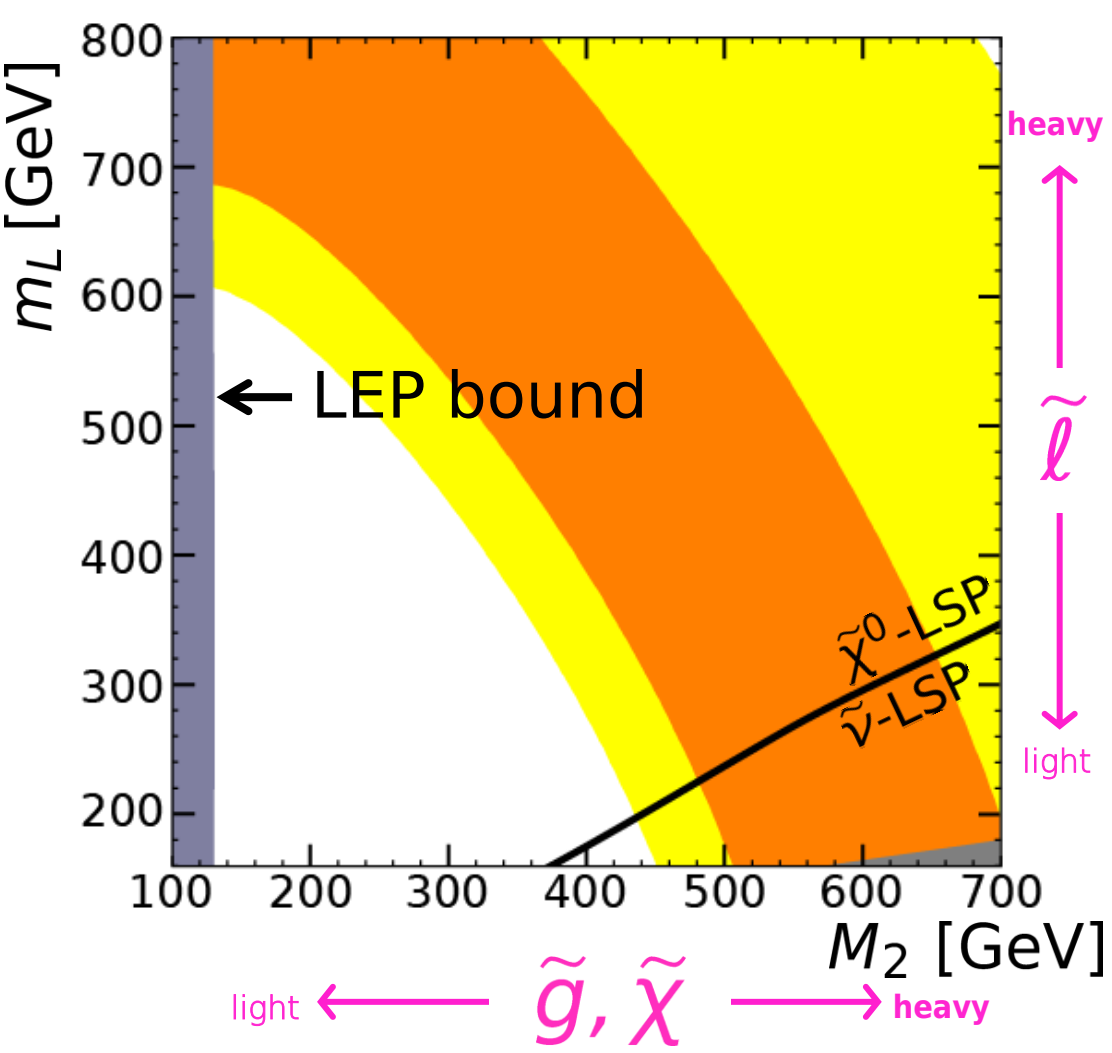
Today's Offer: $\mu = M_2, m_{\bar{E}}^2 = (3\,\mathrm{TeV})^2$

[out of 4 cases discussed in the paper.]

3. $(g-2)_\mu$-MSSM v.s. LHC

Current Status

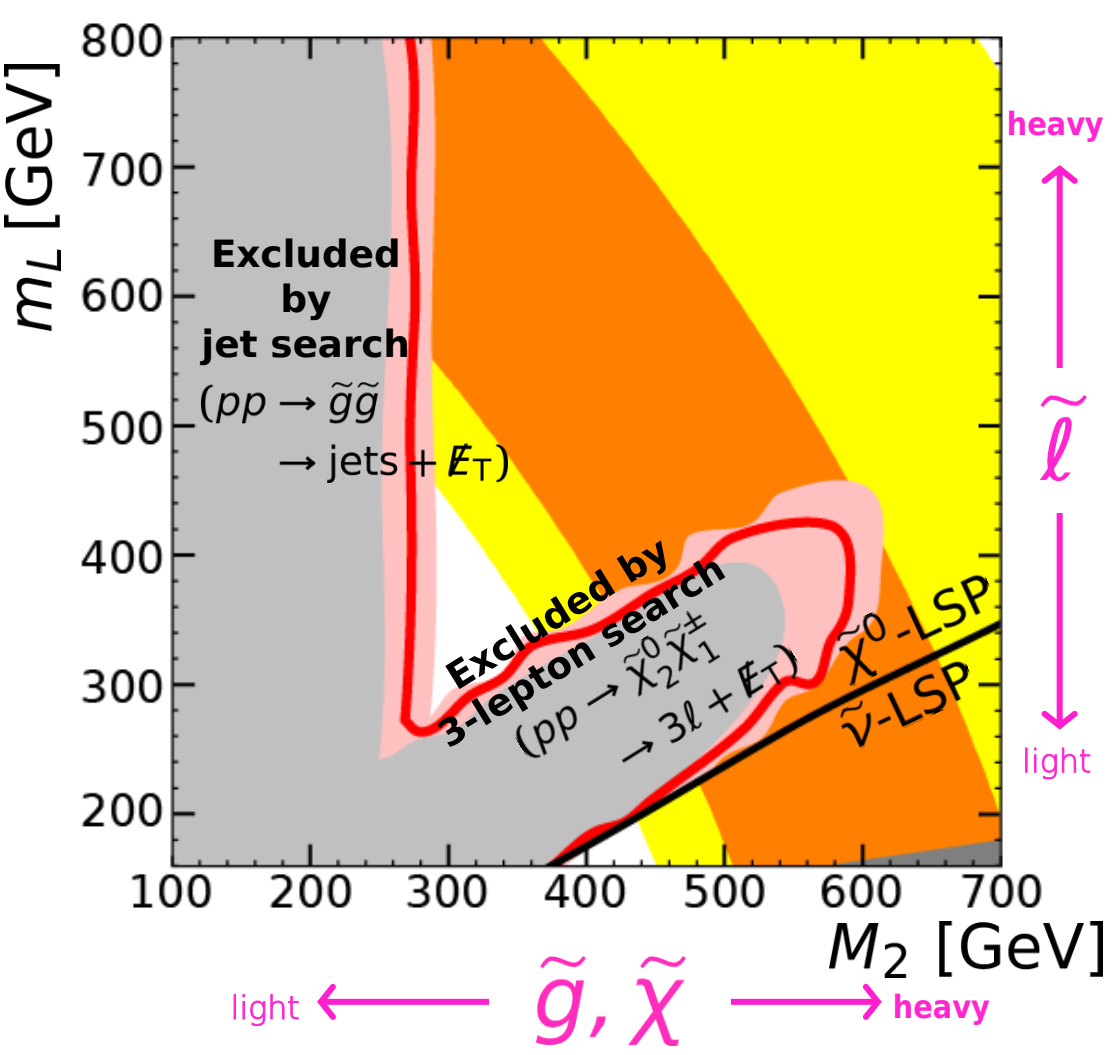
The case with $\mu = M_2$, $m_{\tilde{E}}^2 = (3\,\mathrm{TeV})^2$



- Other parameters:
  - $M_1 : M_2 : M_3 = 1 : 2 : 6$
  - $(\tan\beta, m_A) = (40, 1.5\,\mathrm{TeV})$
- R-parity conserved.
- LSP is long-lived.

- squark/stau decoupled.
- slepton 1st-gen = 2nd-gen.
- A-terms = 0.

The case with $\mu = M_2$, $m_{\tilde{E}}^2 = (3\,\mathrm{TeV})^2$



$g-2$ 1σ 2σ

Jet search : ATLAS-CONF-2012-109
(8TeV, 5.8/fb)

3-lep search : ATL-CONF-2012-154
(8TeV, 13.0/fb)

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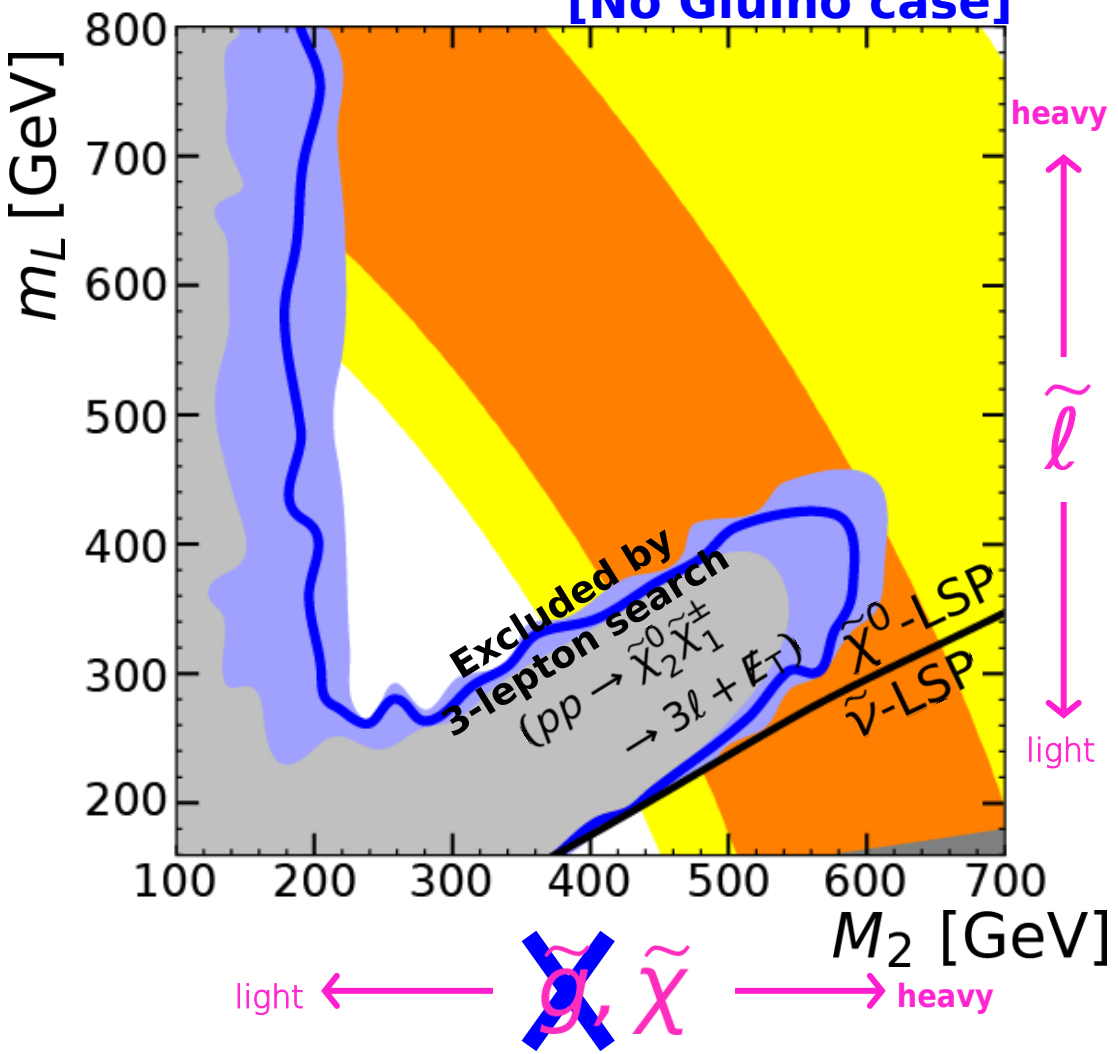
The case with $\mu = M_2$, $m_{\tilde{E}}^2 = (3\,\mathrm{TeV})^2$

[No Gluino case]



$g-2$ 1σ 2σ

~~**Jet search** : ATLAS-CONF-2012-109 (8TeV, 5.8/fb)~~

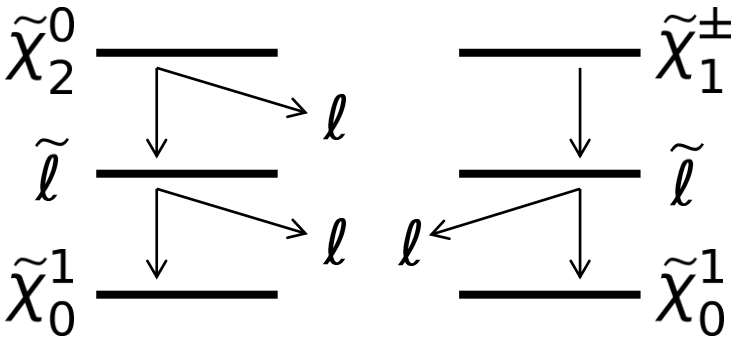
3-lep search : ATL-CONF-2012-154 (8TeV, 13.0/fb)

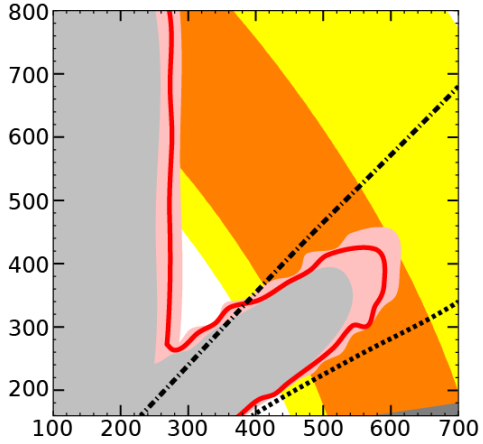
- Other parameters:
  - $M_1 : M_2 : M_3 = 1 : 2 :$ ~~5~~
  - $(\tan\beta, m_A) = (40, 1.5\,\mathrm{TeV})$
- R-parity conserved.
- LSP is long-lived.

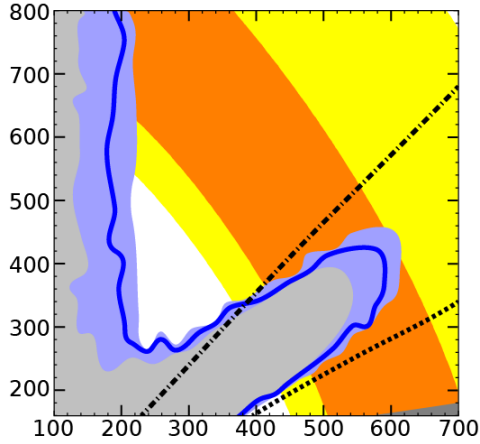
- squark/stau decoupled.
- slepton 1st-gen = 2nd-gen.
- A-terms = 0.

- **jet search** ($pp \to \tilde{g}\tilde{g} \to \text{jets} + \not{E}_T$) : ATLAS 8TeV 5.8/fb
  [CONF-2012-109]
  - 2-6 hard jets + no lepton + $\not{E}_T$
  - Original bound : $\tilde{g} \gtrsim 950\,\text{GeV}$ (CMSSM, $\tilde{q} \gg \tilde{g}$)
    $\Longrightarrow M_2 \gtrsim 300\,\text{GeV}$ in our model

- **3-lep search** ($pp \to \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \to 3\ell + \not{E}_T$) : ATLAS 8TeV 13.0/fb
  [CONF-2012-154]
  - Exact 3 leptons + $\not{E}_T$ + SM-like signal vetoes
    (no b-jets, no lepton pairs near M_Z, etc…)
  - Degenerated regions are not excluded.
    (near the dotted lines)

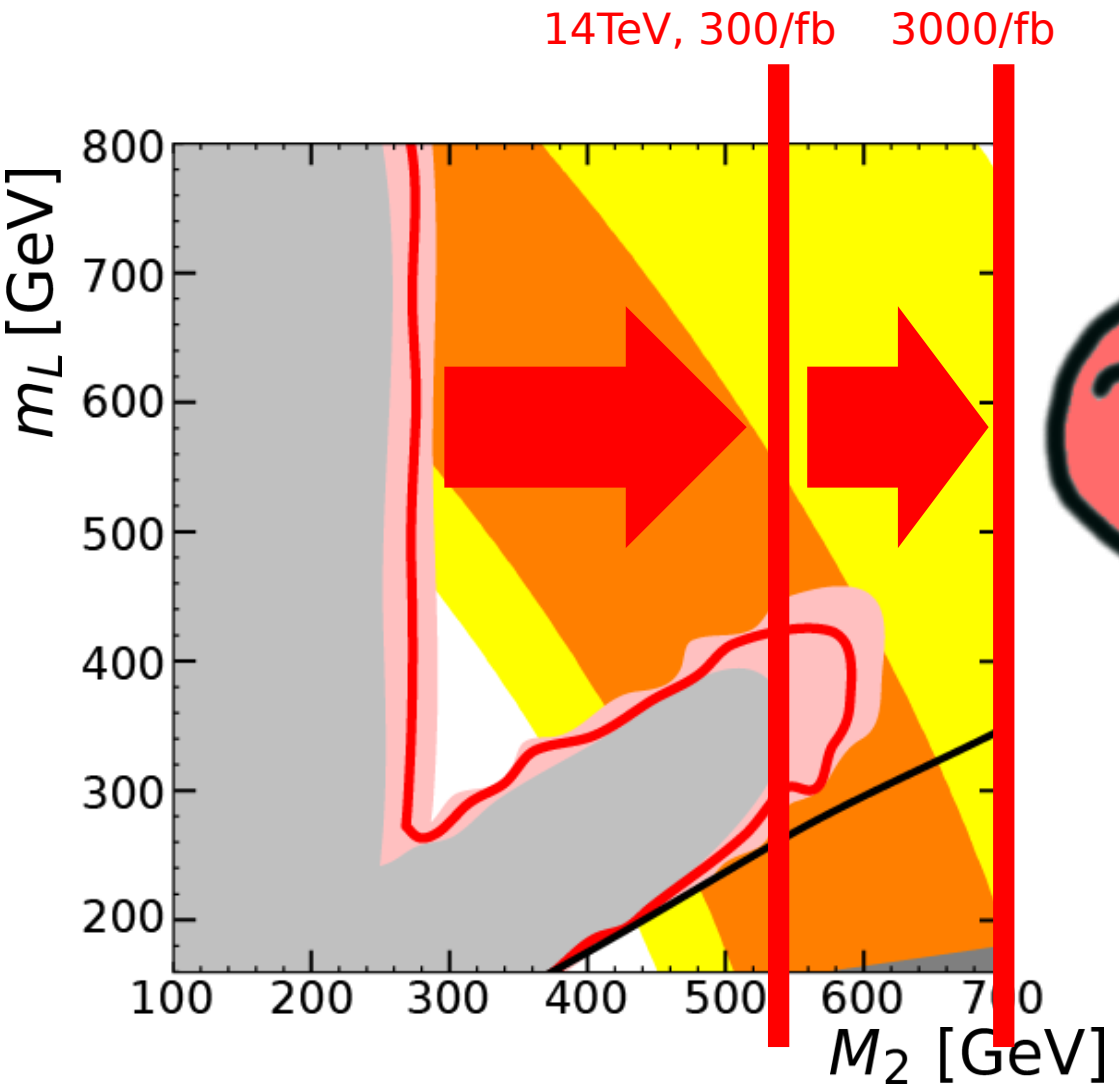






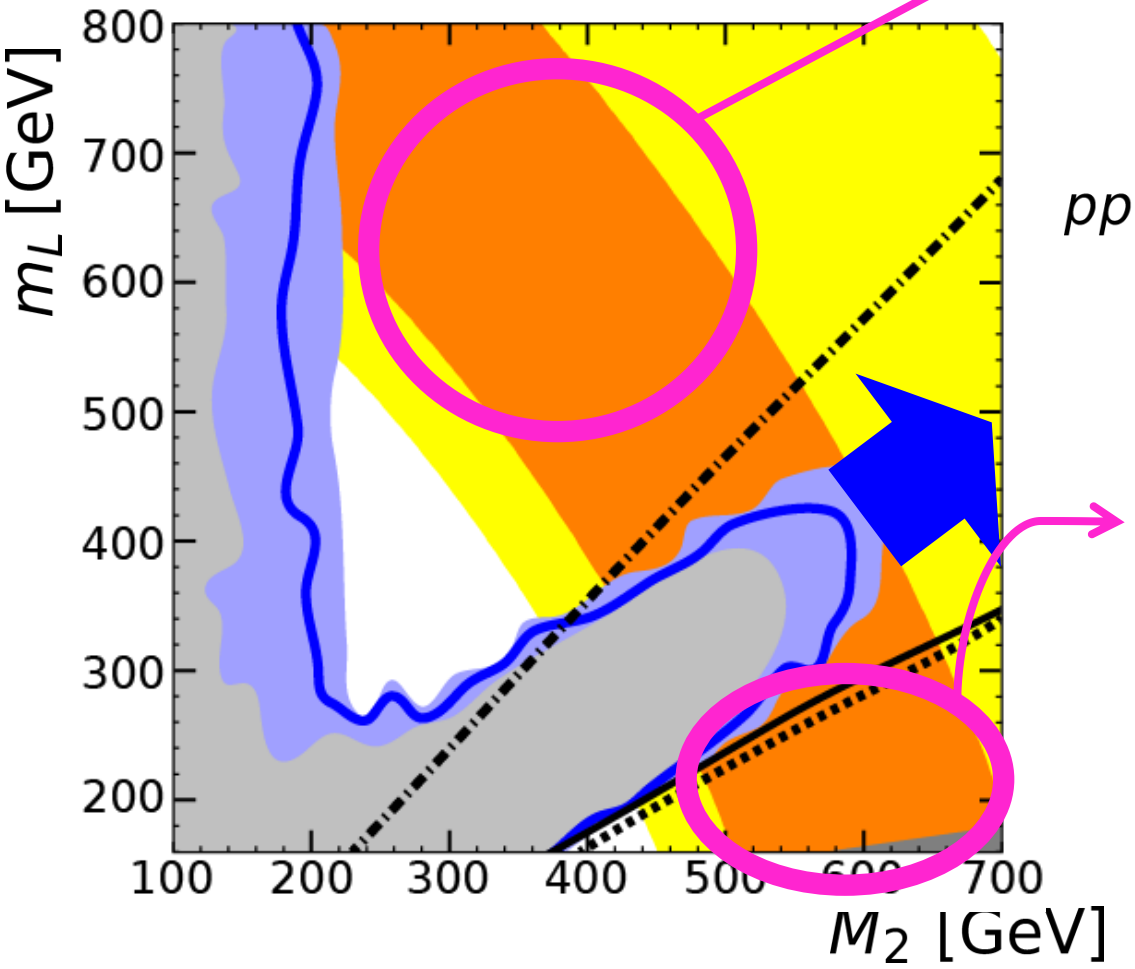
Prospects

The case with $\mu = M_2$, $m_{\bar{E}}^2 = (3\,\mathrm{TeV})^2$



But here
gluino is required.

The case with $\mu = M_2$, $m_{\tilde{E}}^2 = (3\,\mathrm{TeV})^2$



$pp \to \chi^0\chi^+ \to WZ + \mathrm{LSP}$

... No constraint yet.

(large SM BKG)

$pp \to \chi^0\chi^+ \to WH + \mathrm{LSP}$

is hopeful.

(**less** SM BKG)

$pp \to \tilde{\ell}\tilde{\ell}$ only

... We need

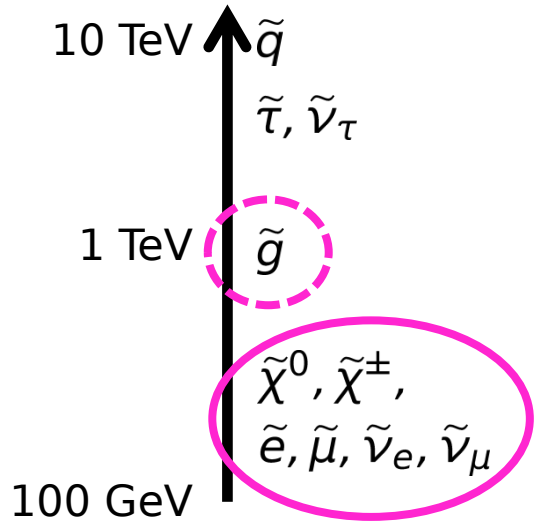
Linear Collider?

4. Summary

Endo, Hamaguchi, SI, Yoshinaga [1203.4256]

- We ❤ **detectable** SUSY.
- $(g-2)_\mu$: a guideline

"$(g-2)_\mu$- motivated MSSM"



- Important channels:
  - ($pp \to \tilde{g}\tilde{g}$)
  - $pp \to \tilde{\chi}^\pm \tilde{\chi}^0 \to 3\ell + \not{E}_T$
  - $pp \to \tilde{\chi}^\pm \tilde{\chi}^0 \to WZ + \not{E}_T$
  - $pp \to \tilde{\chi}^\pm \tilde{\chi}^0 \to WH + \not{E}_T$
  - $pp \to \tilde{\ell}\tilde{\ell}$ ⋯ possible? or ILC/CLIC?

@14 TeV