



# LHC SUSY searches after the Higgs discovery: respecting the muon g-2

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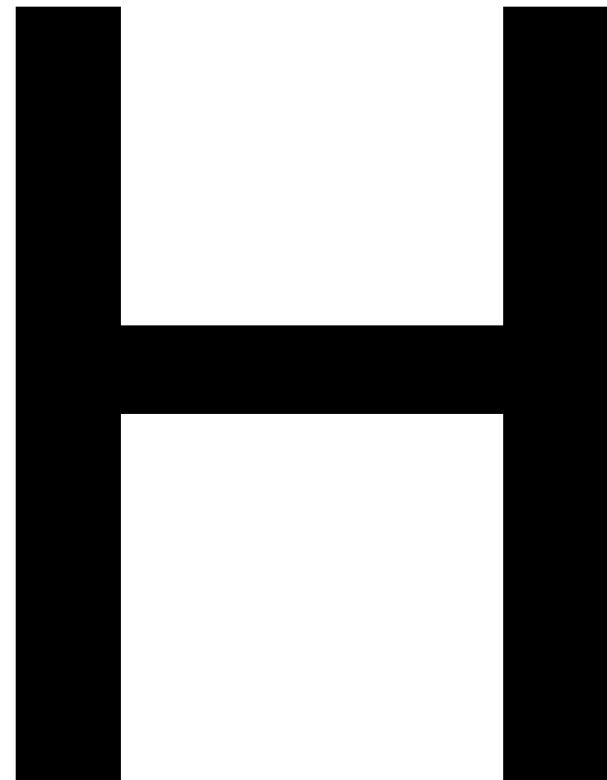
13<sup>th</sup> Feb. 2013

HPNP 2013 at University of Toyama

References)

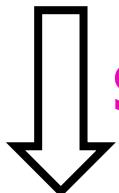
M. Endo, K. Hamaguchi, S. Iwamoto, and T. Yoshinaga [1302.xxxx]

2012



## **Standard Model** Now Completed!

- Problems
  - Hierarchy Problem, Dark Matter, muon  $g - 2$  anomaly, ...
- Anxiety towards ultimate theory



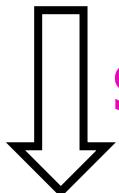
## **Supersymmetry (SUSY)**

### **MSSM** (Minimal SUSY Standard Model)

- solves Hierarchy problem.
- can provides Dark Matter candidate.
- can explain Muon  $g - 2$  anomaly.

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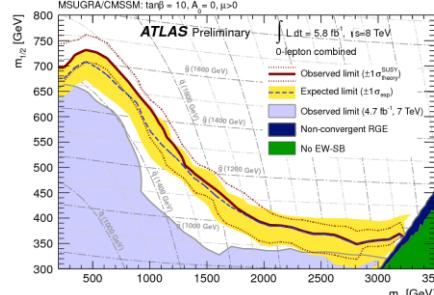
**But Not Found yet.**

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

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

↑ tree       $\Delta(m_h^2)^{\text{loop}}$

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



ATLAS 8 TeV,  $5.8 \text{ fb}^{-1}$   
[\[ATLAS-CONF-2012-109\]](#)

## A Nightmare: SUSY $>$ 1 TeV & we cannot reach SUSY?

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- ◎ can explain Muon  $g - 2$  anomaly.

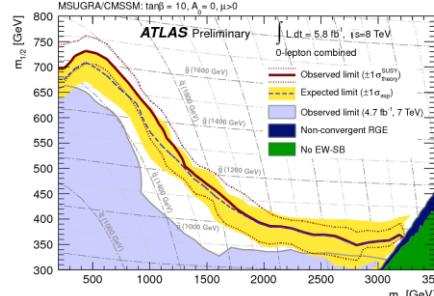
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## A Nightmare: SUSY $> 1 \text{ TeV}$ & we cannot reach SUSY?

◎ can provide Dark Matter candidate.

◎ can explain Muon  $g - 2$  anomaly.

**The last(?) hope for detectable SUSY.  
But Not Found yet.**

## What We Will see:

$(g - 2)_\mu \Rightarrow$  SUSY spectrum should be .

$\Rightarrow$   **$(g - 2)_\mu$ - motivated MSSM.**



How to search?

— current status & future prospects.

### 1. Introduction

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

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

- Current status
- Future prospects

### 4. Summary

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

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◎  $(g - 2)_\mu$  anomaly

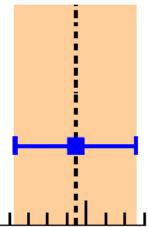
$$\left( a_\mu := \frac{g_\mu - 2}{2} \right)$$

SM (HLMNT '11)



$$a_\mu^{\text{SM}} = (116591828 \pm 49) \times 10^{-11}$$

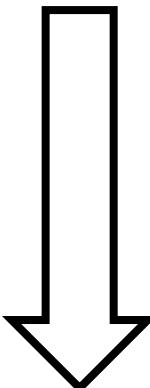
Expm (BNL '04)



$$a_\mu^{\text{exp}} = (116592089 \pm 63) \times 10^{-11}$$

Hagiwara, Liao, Martin, Nomura, Teubner [[1105.3149](#)]

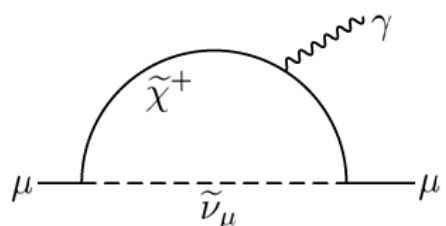
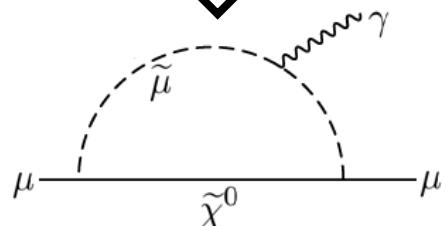
$3.3\sigma$  discrepancy



can be explained with MSSM

if  $\mu > 0$ ,  $\tan \beta \gtrsim 10$ ,

and  $m(\tilde{\chi}^0, \tilde{\chi}^\pm, \tilde{\mu}, \tilde{\nu}_\mu) \sim O(100) \text{ GeV}$ .



$$\Delta a_\mu (\tilde{\chi}^0, \tilde{\mu}) \approx \frac{\alpha_Y m_\mu^2}{m_{\text{soft}}^2} \text{sgn}(\mu M_1) \tan \beta + \dots,$$

$$\Delta a_\mu (\tilde{\chi}^\pm, \tilde{\nu}) \approx \frac{\alpha_2 m_\mu^2}{m_{\text{soft}}^2} \text{sgn}(\mu M_2) \tan \beta.$$

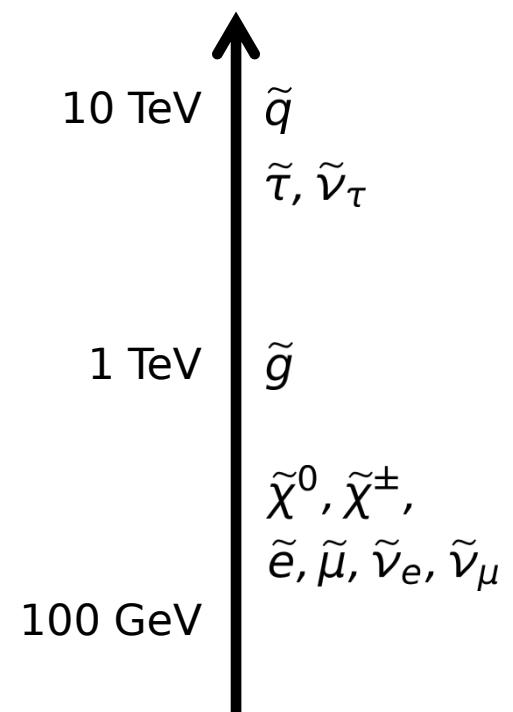
$$\left( \tan \beta = \frac{\langle H_u \rangle}{\langle H_d \rangle} \right)$$

MSSM current status

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

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

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



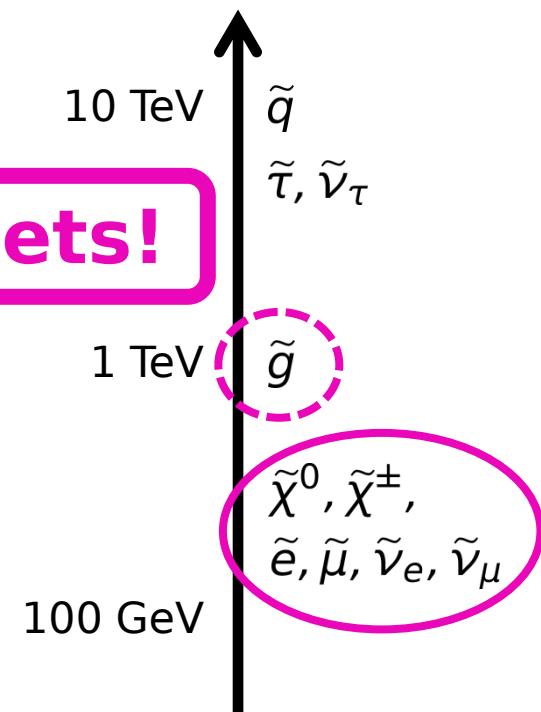
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**The targets!**

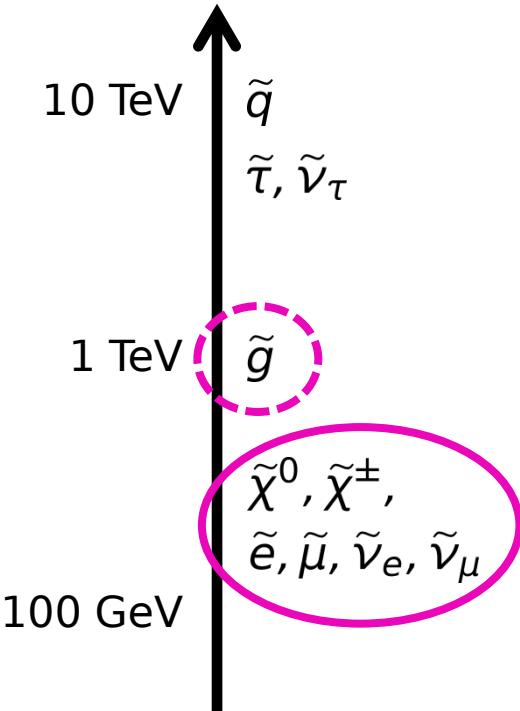


### **3. $(g - 2)_\mu$ -MSSM v.s. LHC**

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

- ◎ squarks:  $\tilde{q} \gg 1 \text{ TeV}$ .
- ◎ sleptons:  $(\tilde{e}, \tilde{\nu}_e) = (\tilde{\mu}, \tilde{\nu}_\mu) \ll (\tilde{\tau}, \tilde{\nu}_\tau)$
- ◎ gaugino:  $M_1 : M_2 : M_3 = 1 : 2 : 6$ .  
(approximate GUT relation)
  - $A$ -terms = 0
  - $\tan \beta = 40$
  - $m_A = 1500 \text{ GeV}$  (to avoid  $B_s \rightarrow \mu\mu$  constr.)
  - $m_h = 126 \text{ GeV}$  is assumed. ( $\because \tilde{q}$  are decoupled.)

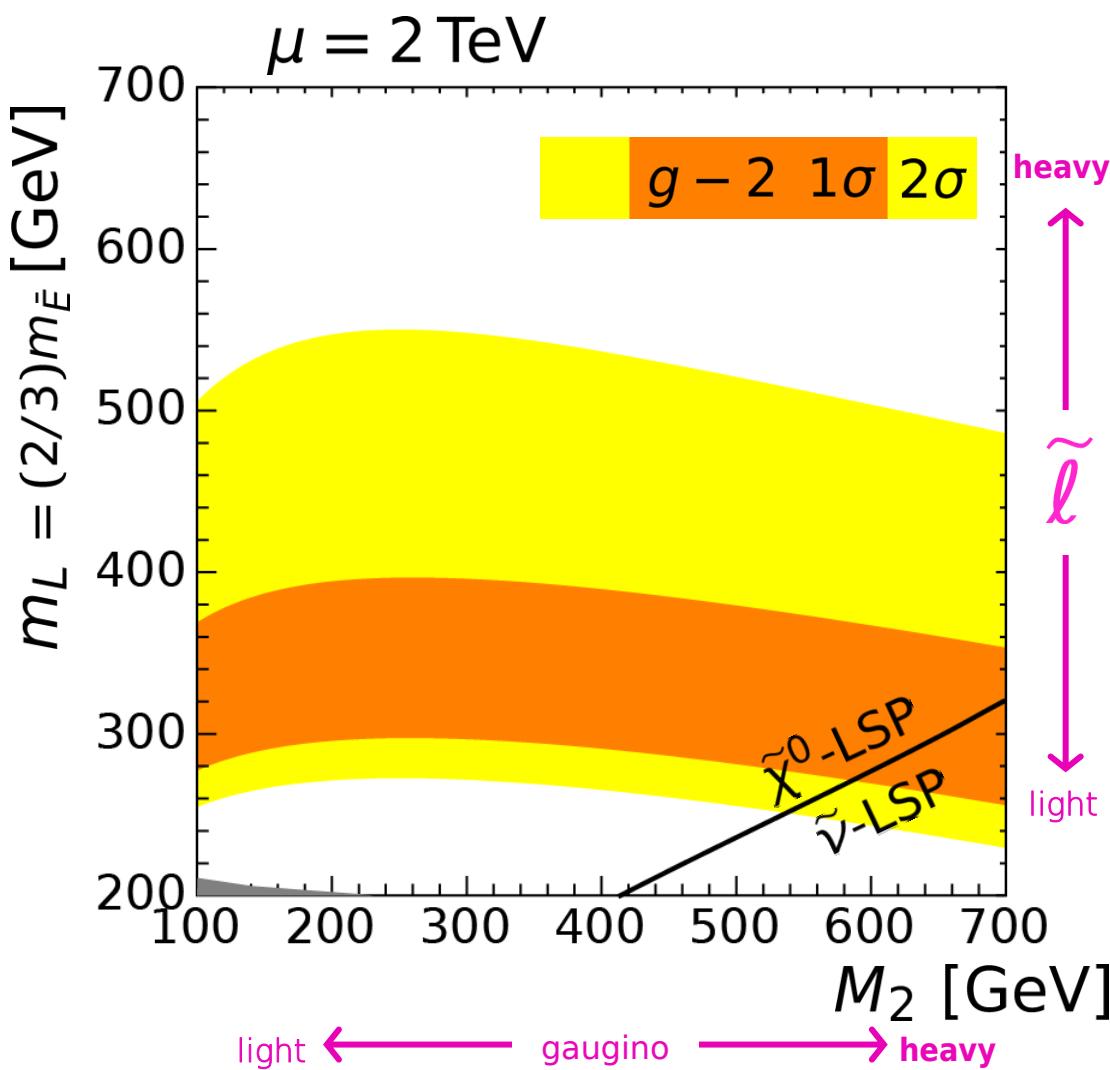


**Rest Params:**  $(m_L^2, m_E^2)$  : slepton soft-masses  
 $(M_2, \mu)$  : gaugino/Higgsino mass

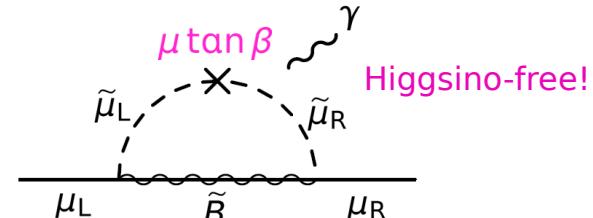
# RESULT

(an extreme case :  $\mu = 2 \text{ TeV}$ )

An extreme case:  $\mu = 2 \text{ TeV}$ ,  $m_L^2 : m_{\tilde{E}}^2 = 1 : (1.5)^2$



- $(g - 2)_\mu$  dominant source:



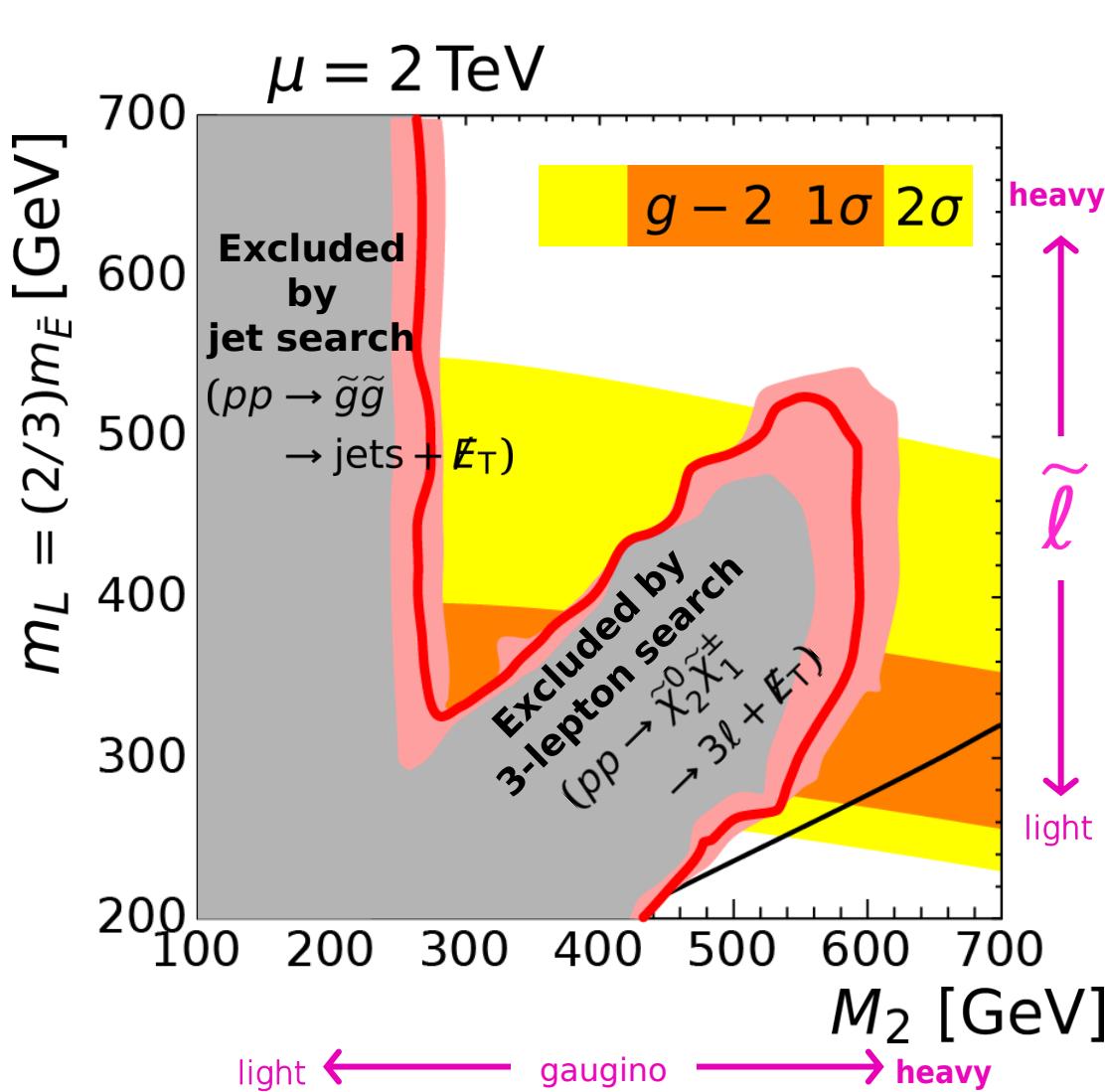
- Parameters:

- $M_1 : M_2 : M_3 = 1 : 2 : 6$
- $\mu = 2 \text{ TeV}$
- $m_L^2 : m_{\tilde{E}}^2 = 1 : (1.5)^2$
- $(\tan \beta, m_A) = (40, 1.5 \text{ TeV})$

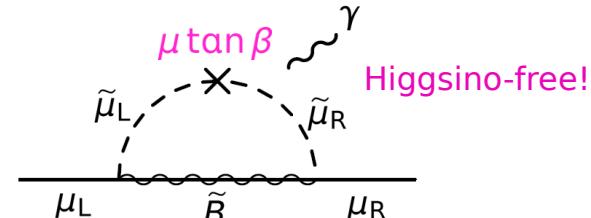
- Soft-params set @ 7 TeV ( $= m_{\tilde{t}}$ ).
- $R$ -parity conserved.
- LSP is long-lived.

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

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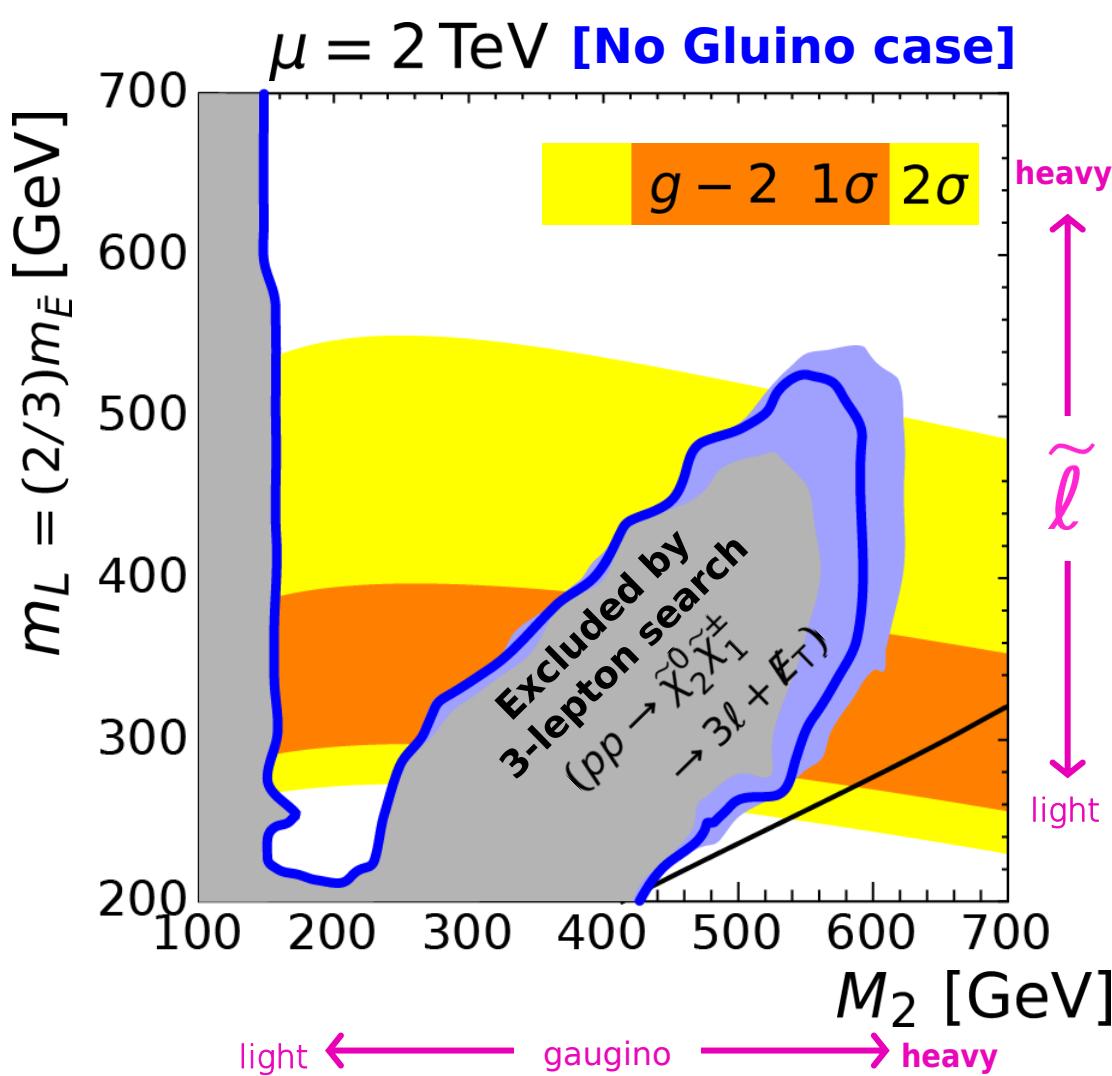
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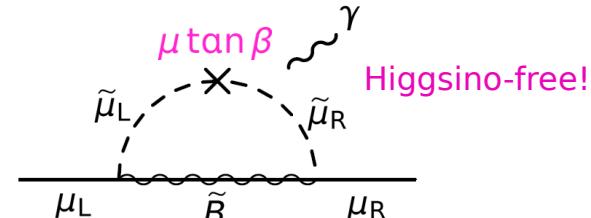
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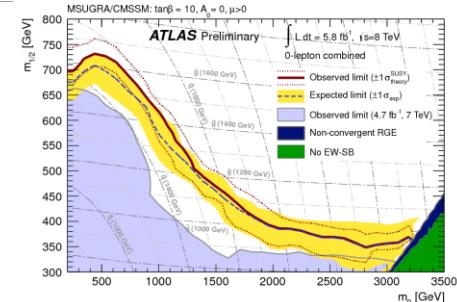
- $M_1 : M_2 : M_3 = 1 : 2 : 3$
- $\mu = 2 \text{ TeV}$
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### ○ jet search ( $pp \rightarrow \tilde{g}\tilde{g} \rightarrow \text{jets} + \cancel{E}_T$ )

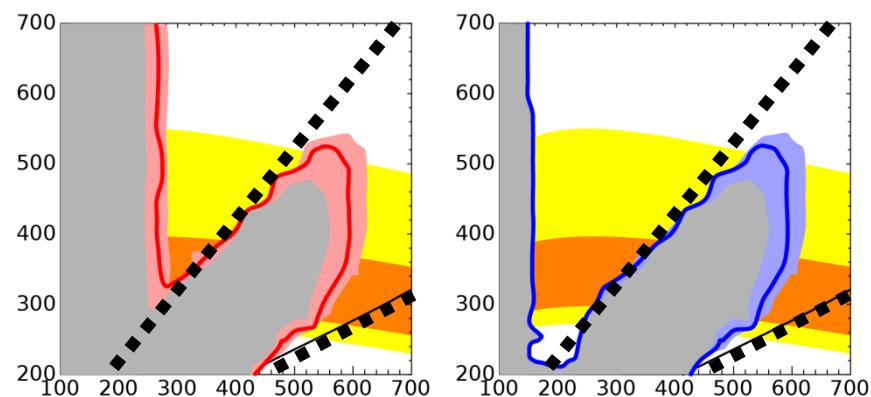
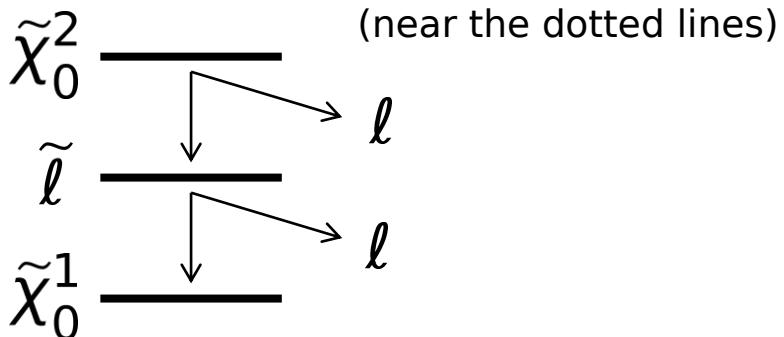
- ATLAS 8TeV  $5.8\text{fb}^{-1}$  [[ATLAS-CONF-2012-109](#)] →
- 2-6 hard jets + no lepton +  $\cancel{E}_T$
- Original bound :  $\tilde{g} \gtrsim 950\text{ GeV}$  (CMSSM,  $\tilde{q} \gg \tilde{g}$ )
 
$$\implies M_2 \gtrsim 300\text{ GeV} \text{ in our model}$$



### ○ 3-lepton search ( $pp \rightarrow \tilde{\chi}_2^0 \tilde{\chi}_1^\pm \rightarrow 3\ell + \cancel{E}_T$ )

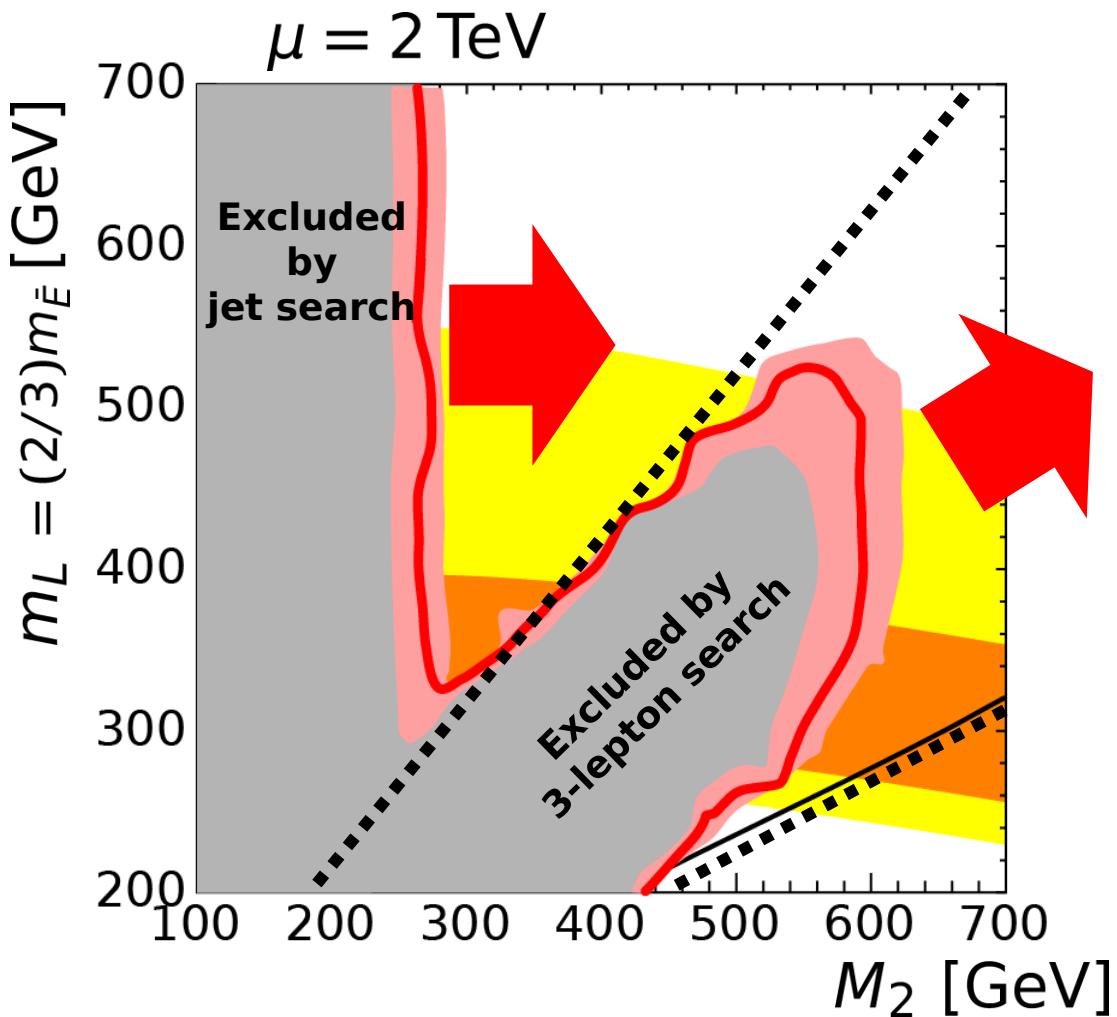
- ATLAS 8TeV  $13\text{fb}^{-1}$  [[ATLAS-CONF-2012-154](#)]
- Exact 3 leptons +  $\cancel{E}_T$  + SM-like signal vetoes  
 $(\text{no } b\text{-jets, no lepton pairs near } M_Z, \text{ etc...})$
- Degenerated regions

are not excluded.

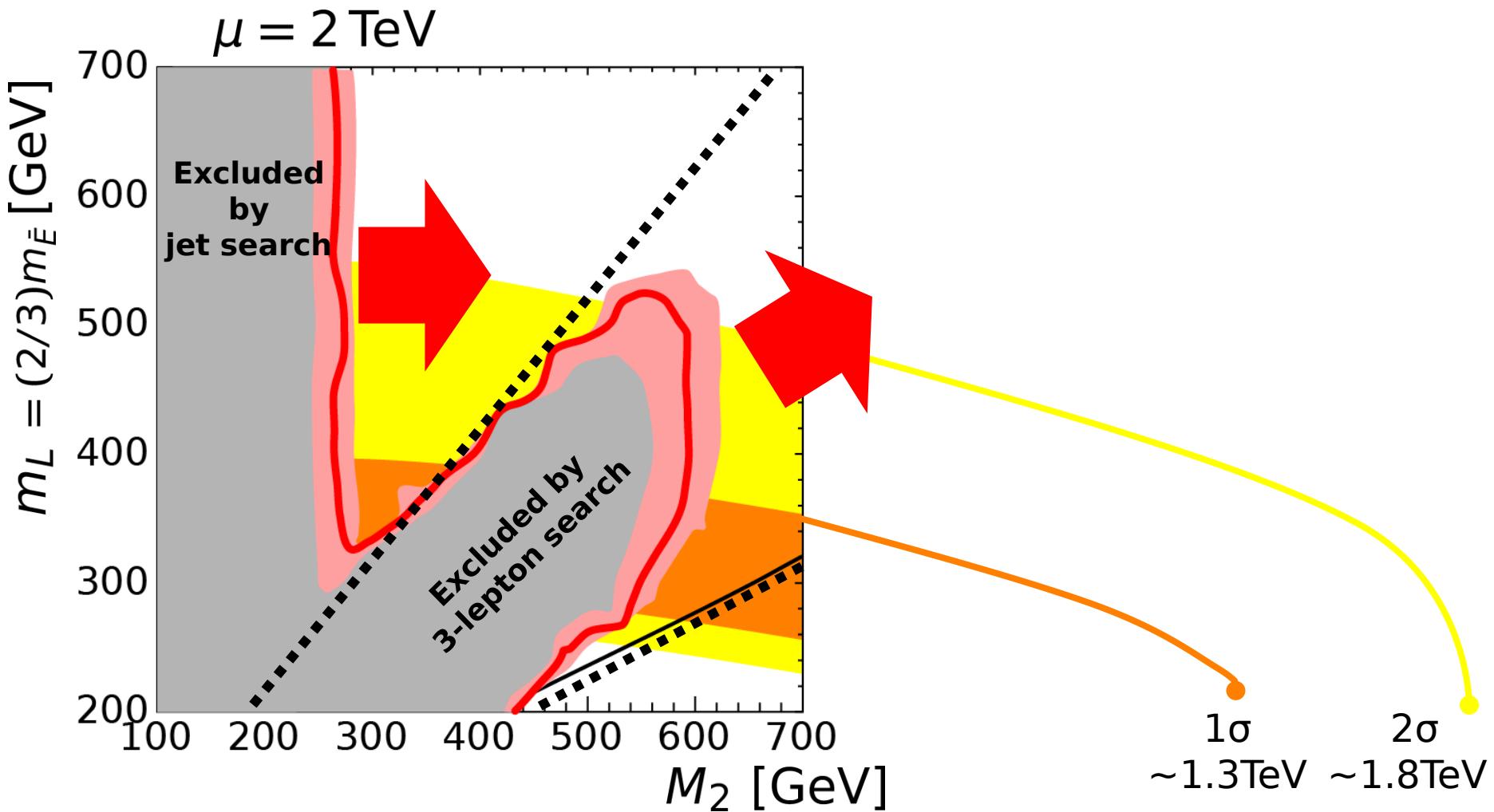


# Prospects

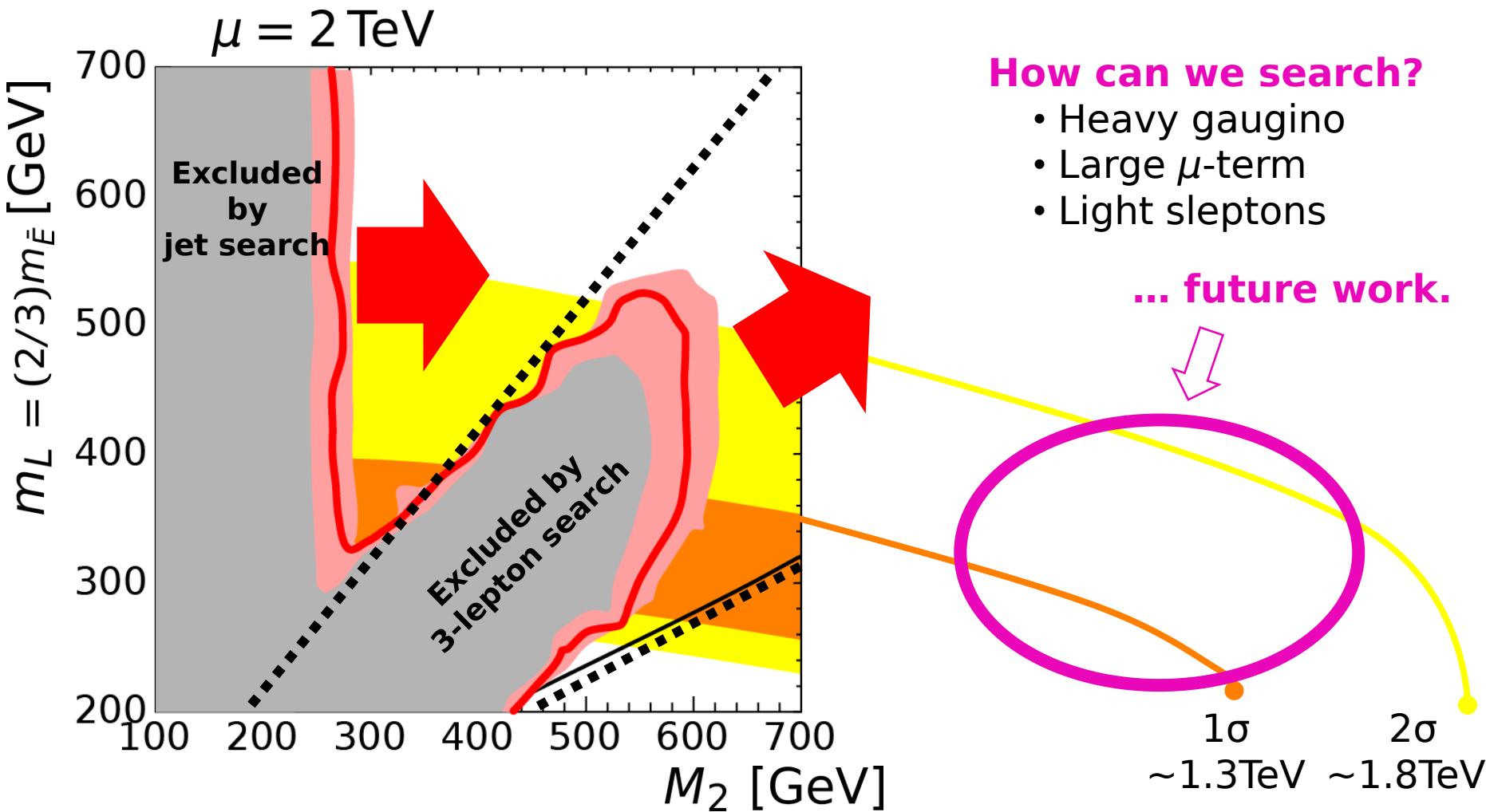
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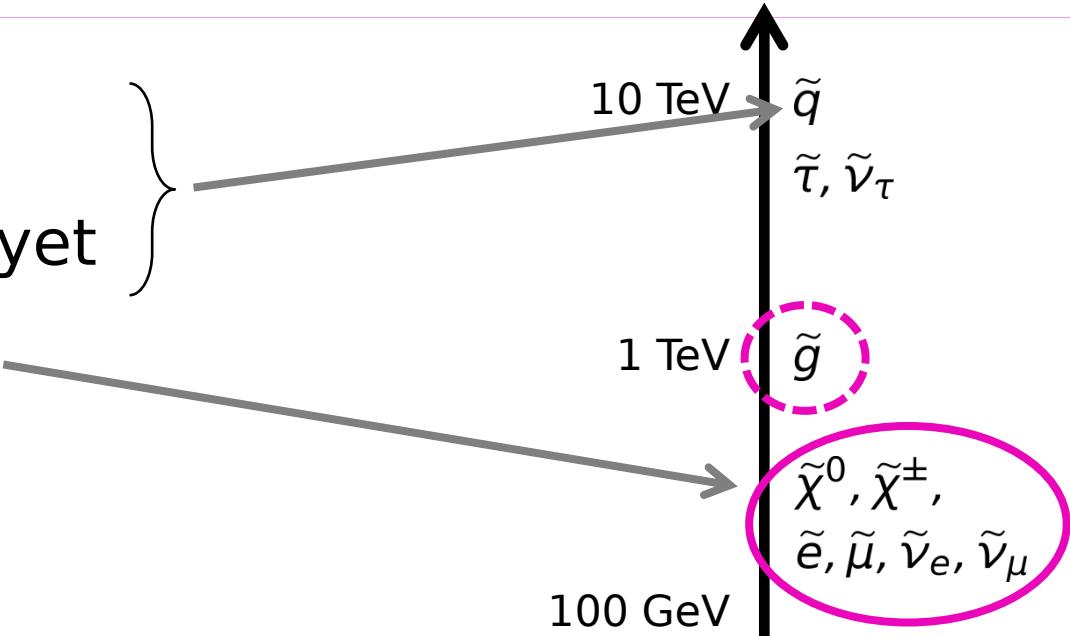


## **4. Summary**

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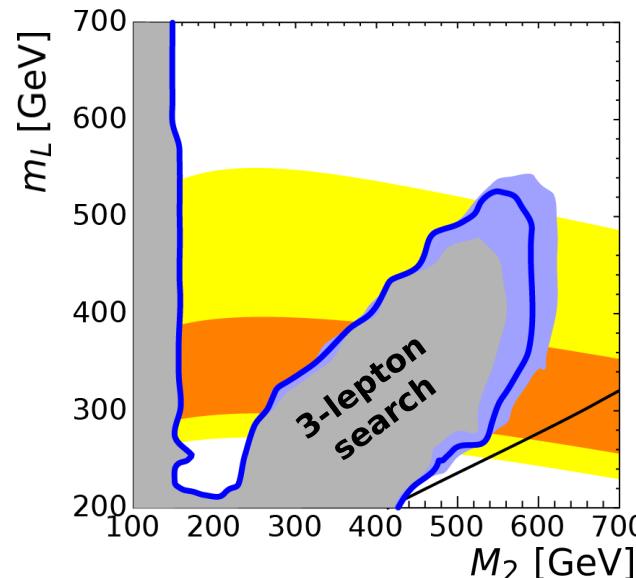
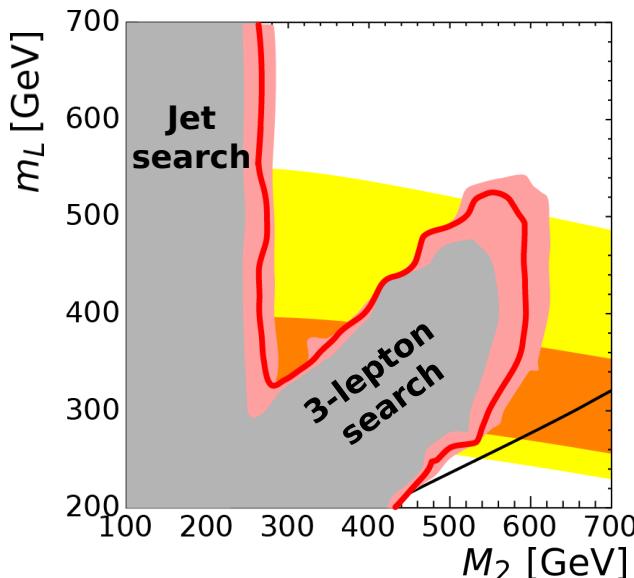
## Summary of this talk

- 126 GeV Higgs
- SUSY Not Found yet
- $(g - 2)_\mu$  anomaly



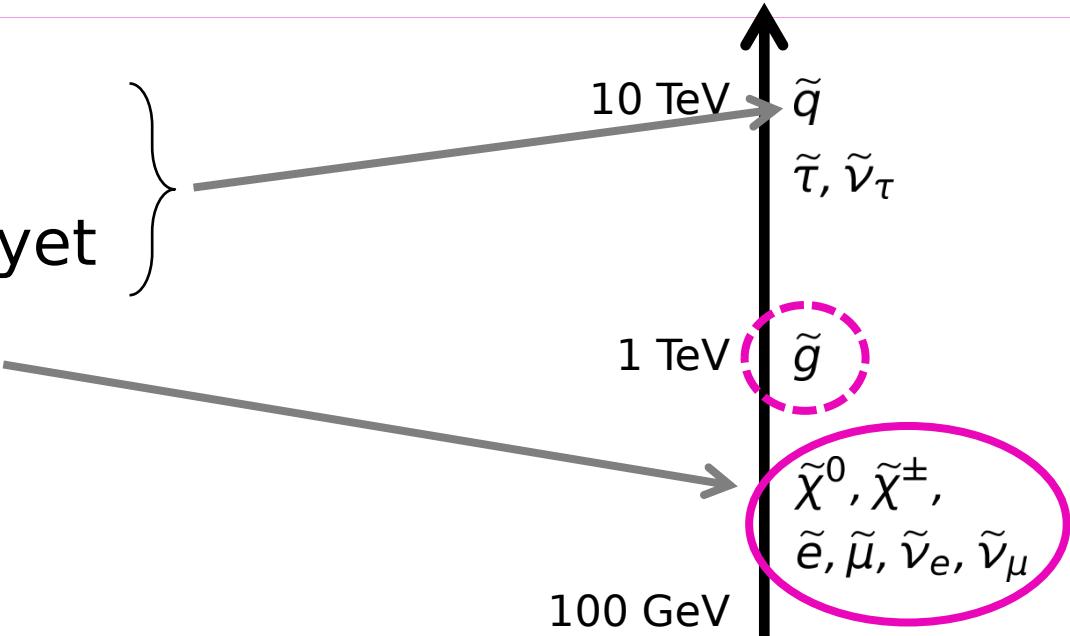
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Jet: [ATLAS-CONF-2012-109](#)  
3L: [ATLAS-CONF-2012-154](#)



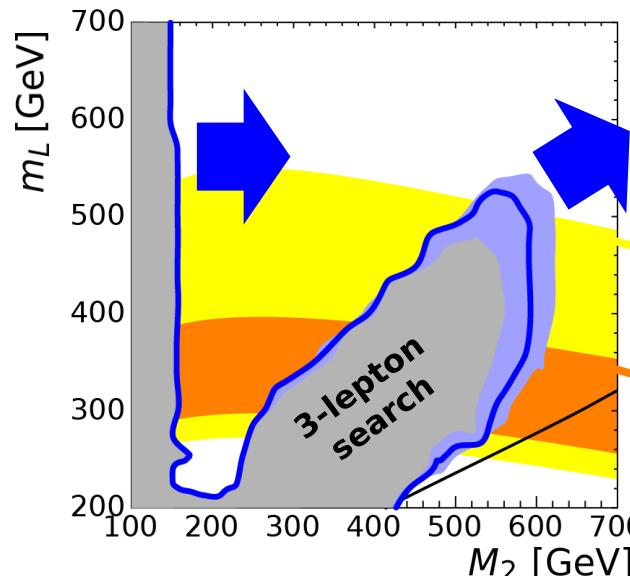
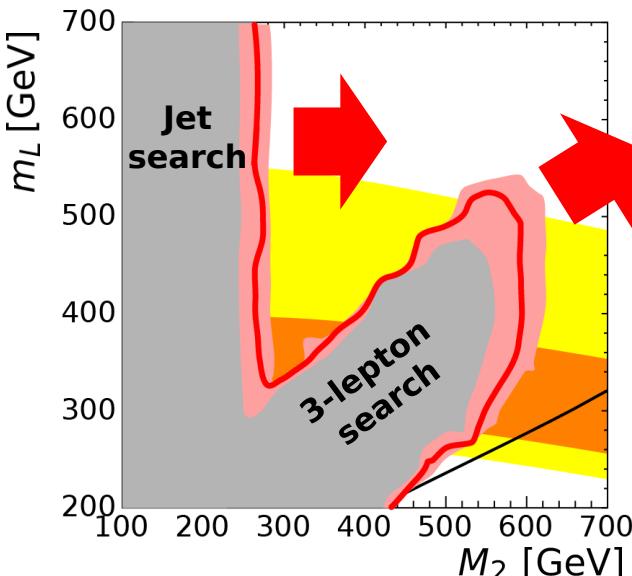
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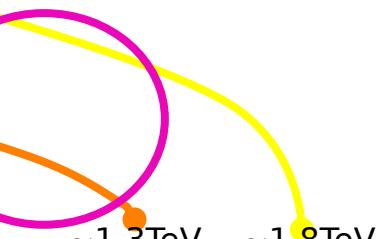
Jet: [ATLAS-CONF-2012-109](#)  
3L: [ATLAS-CONF-2012-154](#)



**How can we search?**

- Heavy gaugino
- Large  $\mu$ -term
- Light sleptons

**... future work.**



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# arXiv:NEW on Twitter everyday!

@hep\_ex  
@hep\_lat  
@hep\_ph  
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The screenshot shows the Twitter profile page for the account @hep\_ph. The header bar indicates the account is 'arXiv hep-ph (hep\_ph) on Twitter'. The profile picture is a blue square with a white egg icon. The bio reads: 'arXiv new submissions on hep-ph. Feedbacks to @Misho are welcome. [README] http://bit.ly/arxiv\_twitter [See also] @hep\_ex @hep\_lat @hep\_th'. Below the bio, there is a link: 'http://en.misho-web.com/phys/hep\_tools.html#arxiv\_speaker'. The stats section shows 3,360 tweets, 0 following, and 90 followers. A 'Following' button is present. The 'Tweets' section displays two recent posts from the arXiv hep-ph account:

- [1302.2894] Chiang, Nomura, Tandean : Effects of Family Nonuniversal Z' Boson on Leptonic Decays of Higgs and We... [arxiv.org/abs/1302.2894](http://arxiv.org/abs/1302.2894) 51m
- [1302.2888] S. Wallon : Hard exclusive processes [arxiv.org/abs/1302.2888](http://arxiv.org/abs/1302.2888) 51m