Search for Higgs Bosons in SUSY Cascade Decays & Neutralino Dark Matter

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Outlines

1. Introduction:

- A less investigated Higgs production channel: Susy decay chains

2. Higgs production

- The branching ratios
- Neutralino dark matter
- Constraints coming from direct searches

3. Signals at the LHC

- 14 TeV LHC
- Early 7 TeV run LHC

4. Conclusions

Based on:

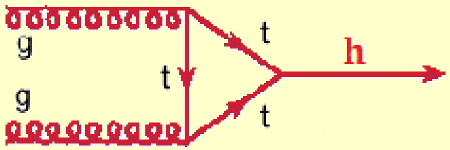
„Search for Higgs Bosons in SUSY Cascade Decays and Neutralino Dark Matter "

SG, P. Schwaller, C. E. M. Wagner

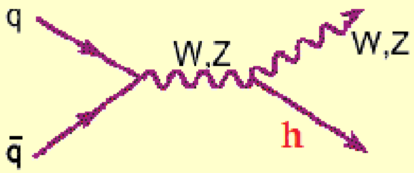
arXiv:1103.4138 [hep-ph]

Introduction

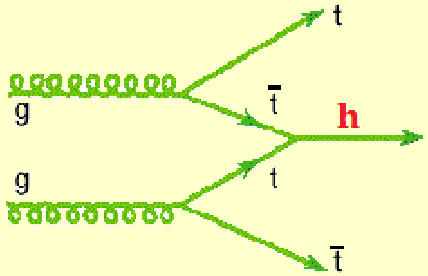
- Main production channels for the Higgs boson at the LHC



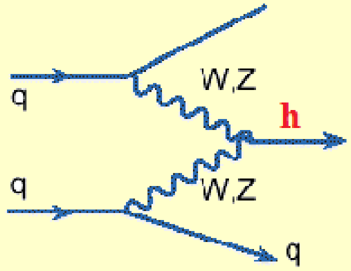
Gluon-gluon fusion



W-Z bremsstrahlung



t-t fusion



WW-ZZ fusion

and then, in the low mass range:

$$h \rightarrow bb\,,\ \gamma\gamma\,,\ \tau\tau$$

BUT

Due to the large QCD background, a light Higgs decaying into bb is very hidden at LHC!

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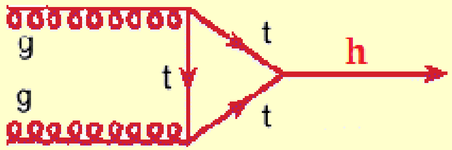

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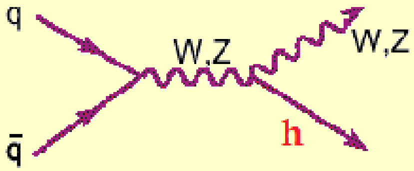

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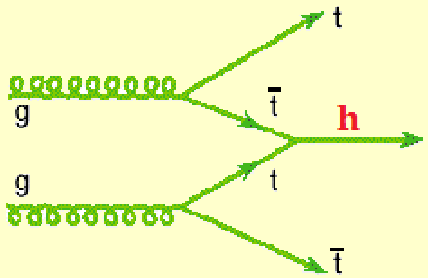

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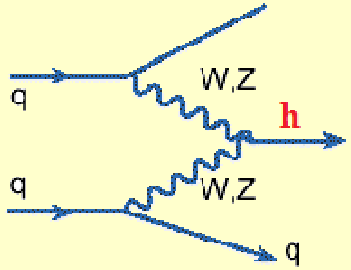

WW-ZZ fusion

and then, in the low mass range:

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BUT

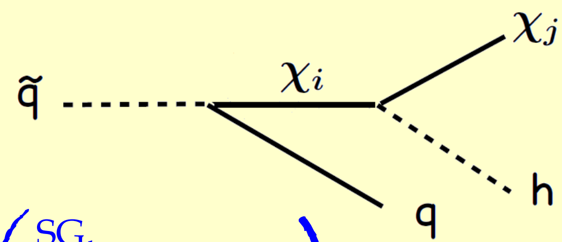
Due to the large QCD background, a light Higgs decaying into bb is very hidden at LHC!

HOWEVER the situation can be ameliorated by searching for

$$pp \to \tilde{g}\tilde{g}\,,\ \tilde{q}\tilde{q}\,,\ \tilde{q}\tilde{g} \to (\tilde{C}_2\,,\ \tilde{N}_i) + X \to (\tilde{C}_1\,,\ \tilde{N}_j) + h + X$$

(for a recent study see Kribs, Martin, Roy, Spannowsky (2010))

Boosted Higgs bosons can be detected easier (jet substructure algorithms)
Butterworth, Davison, Rubin, and Salam (2008)



- Large Higgs production branching ratios are a general feature of the MSSM?
- Can this be compatible with neutralino dark matter?

and finally

- What about the effective number of events expected at the LHC?

(SG, P. Schwaller, C.E.M. Wagner)

The setup

Main setup:

- Gaugino mass universality at the GUT scale

⇒ at the EW scale $M_3 \approx 3M_2 \approx 6M_1$

- Heavy squarks and sleptons $m_{\tilde{q}} = m_{\tilde{\ell}} \equiv m_{\tilde{f}} = 1\,\text{TeV}$

- Trivial flavor structure in the squark mass matrices and trilinear terms

Light SM Higgs boson

$m_h \simeq 115\,\text{GeV}$

⇒ The free parameters of the model are

$$M_1,\ \mu,\ \tan\beta,\ M_A,\ m_{\tilde{f}}$$

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Variation of the main setup:

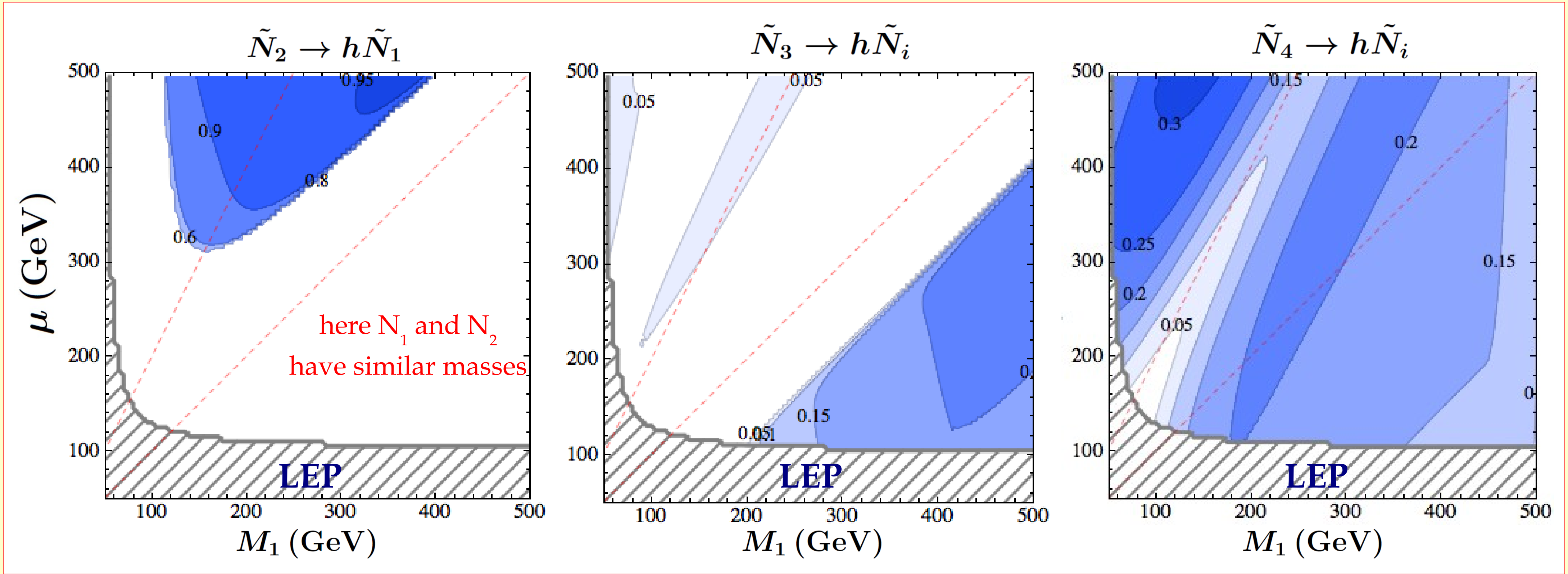
- What about lighter sleptons?
- What if the universal gaugino mass condition is relaxed?

  → Good prospects for the detection of the heavier Higgs bosons decaying into bb

see SG, P. Schwaller, C. E. M. Wagner **arXiv:1103.4138 [hep-ph]**

Considering only direct decays of neutralinos:

$M_A = 300\,\text{GeV},\ \tan\beta = 10$



The decay is kinematically open only if

$$M_2 - M_1 > m_h,\ \ \mu - M_1 > m_h$$

If open, it can reach **95%** of BR!

They compete with the decays

$$\tilde{N}_3 \to \tilde{C}_1^{\pm} W^{\mp}$$

$$\tilde{N}_4 \to h\tilde{N}_{2,3}$$

kinematically forbidden at $\mu=2M_1$

(The Br of $\tilde{C}_2 \to h\tilde{C}_1$ is very similar to the one of the heaviest neutralino)

Decays of neutralino & chargino to the Higgs

Considering only direct decays of neutralinos:

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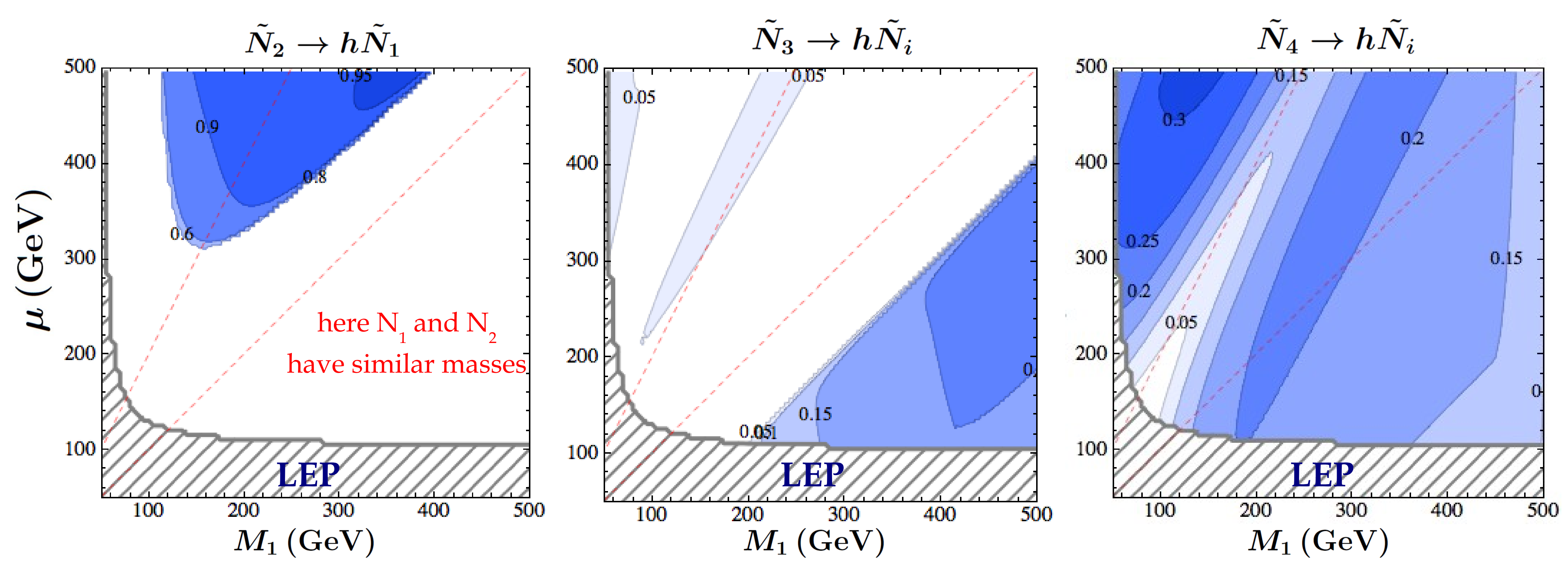


Note: sizable branching ratios are only possible for heavy sleptons

$$m_{\tilde{\ell}} > M_2 = 2M_1 > 2m_h$$

at least left-handed sleptons

Otherwise, the decays of **neutralinos/charginos to slepton-lepton pairs** would **deplete** largely the Higgs production

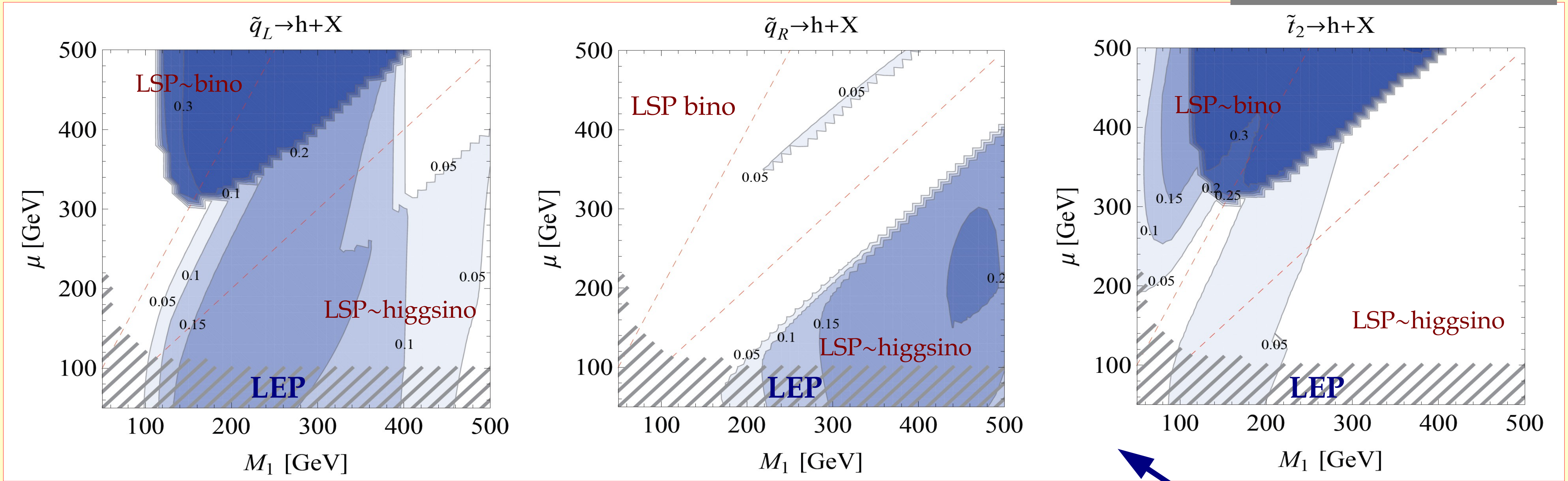
$\tilde{C}_2 \to \tilde{\ell}\nu,\ \ \tilde{N}_i \to \tilde{\ell}\ell$

Susy decay chains to the light Higgs boson

Main decay chains: $$\mathrm{P}(\tilde{q} \to h + X) = \sum_{\chi_i} \mathrm{BR}(\tilde{q} \to \chi_i + q) \times \mathrm{BR}(\chi_i \to h + \chi_j)$$

Additionally, one has also to consider relevant indirect decays, such as $\tilde{N}_3 \to \tilde{N}_2 X \to h \tilde{N}_1 X$

$M_A = 300\,\mathrm{GeV},\ \tan\beta = 10$



To understand the structure of the plots:

- left-handed squarks decay mainly into winos (+ quarks),
- right-handed squarks decay mainly into binos (+ quarks),
- Stops decay also to higgsinos (+ quarks)

Largely independent on M_A and tanβ

Branching ratios can reach the 30% level

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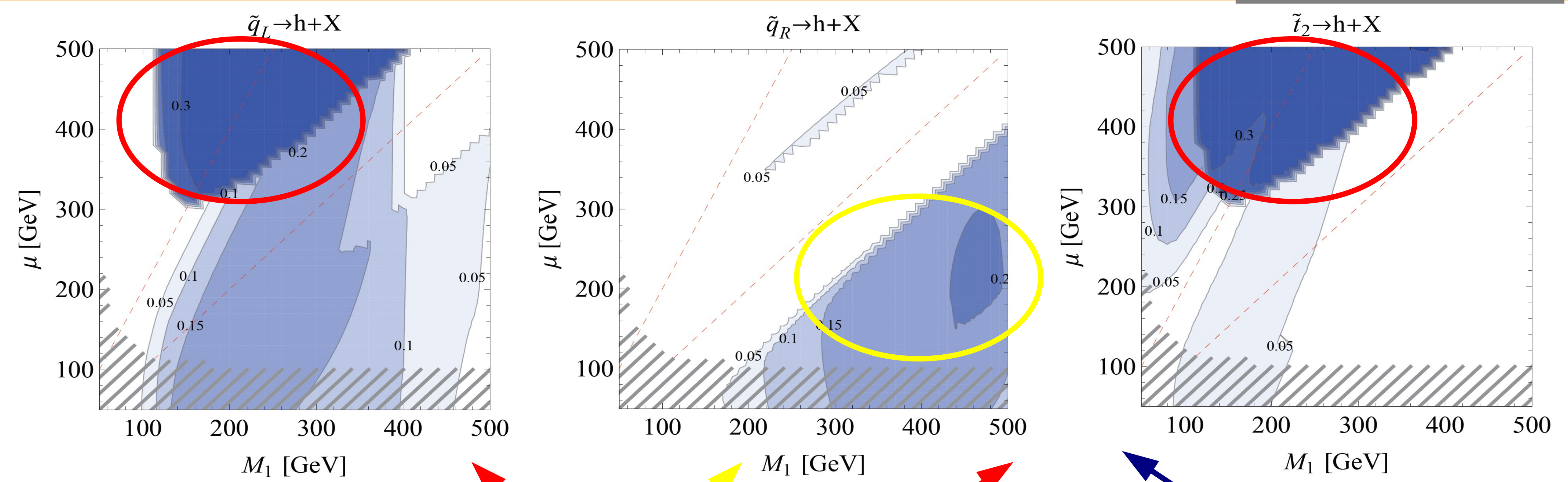


Two regions where one could have sizable branching ratios

Largely independent on M_A and tanβ

Is one of them favored by neutralino Dark Matter?

Branching ratios can reach the 30% level

Neutralino dark matter

The relic abundance of neutralinos depends inversely on the thermally averaged annihilation cross-section

- We are assuming gaugino mass universality

⇨ Lightest neutralino is in general a **mixture of higgsino and bino**.

From WMAP:

$$\Omega h^2 = 0.1123 \pm 0.0035$$

Jarosik et al., arXiv:1001.4744

- Correct relic density obtained for

Bino state ⇨ too weak annihilation

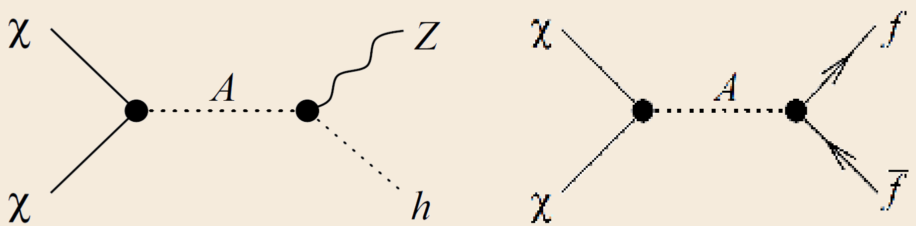
Higgsino state ⇨ too strong annihilation

1. **Heavily mixed** bino-higgsino state

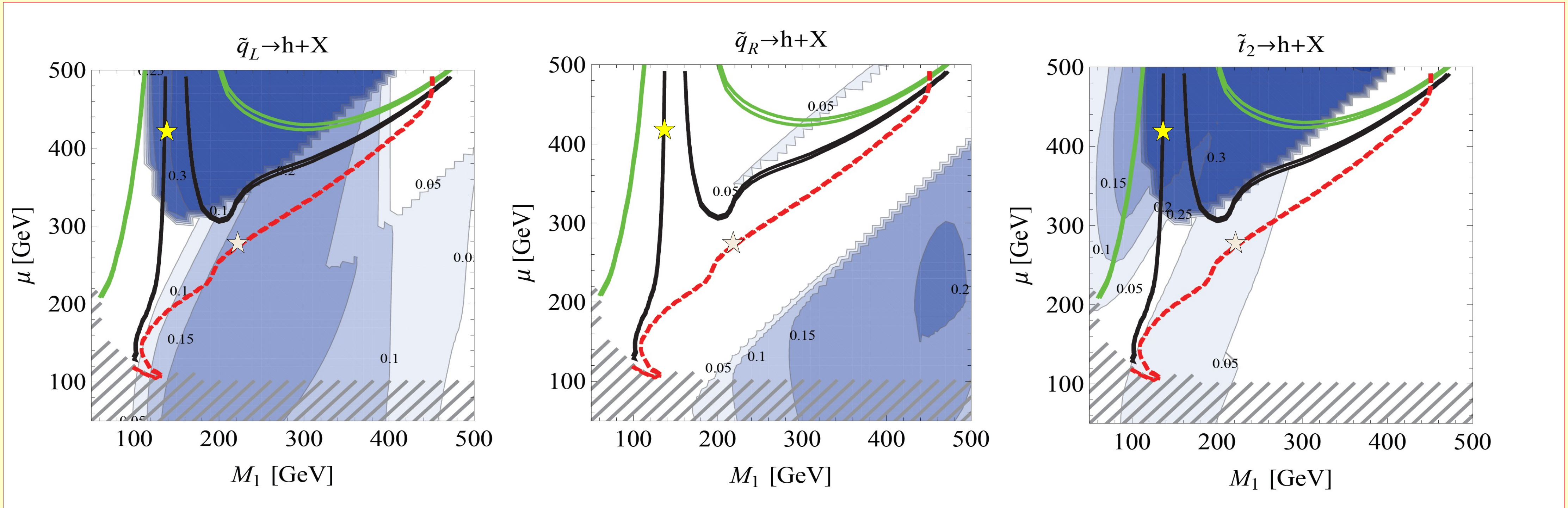
OR

2. **Bino** state BUT enhancement of the annihilation cross section thanks to the **resonant pseudoscalar A**

Ex.



Higgs in Susy chains & neutralino dark matter



= relic density for M_A=1000 GeV, tanβ=10

⇨ Main contribution to Higgs production from **left-handed quarks**, for **$M_1 \sim \mu$**

The brainching ratios do not change significantly, changing M_A and tanβ

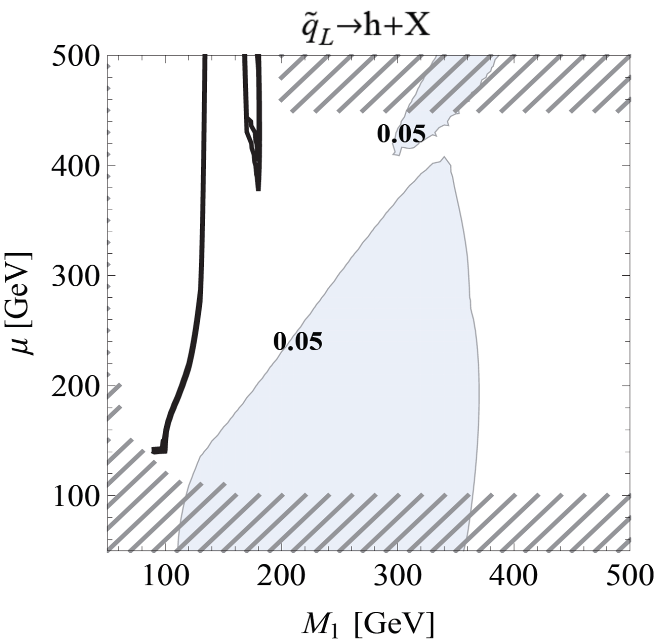
Disfavored (see later) — = relic density for M_A= 300 GeV, tanβ=50

= relic density for M_A= 300 GeV, tanβ=10

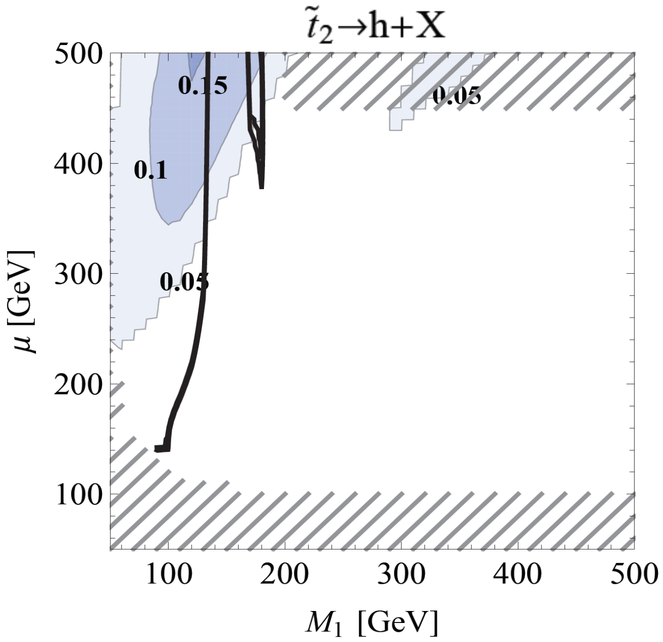
} Main contribution to Higgs production from **left-handed quarks and stops**, for **$M_1 > \mu$**

Due to the resonant behavior at smaller M_A

What if the sleptons are light?



N_2 decays mainly to slepton-lepton pair



N_4 has still sizable BRs to Higgs

$m_{\tilde{\ell}} = 200$ GeV, $m_{\tilde{q}} = 1000$ GeV

$M_A = 300$ GeV, $\tan\beta = 10$

Only loose lower bounds on the slepton masses are coming from the experiments

If sleptons are light, new decay modes for neutralinos and heaviest chargino are open

$$\tilde{C}_2 \to \tilde{\ell}\nu, \;\; \tilde{N}_i \to \tilde{\ell}\ell$$

The brainching ratios do not change significantly, changing M_A and tanβ

Higgs production branching ratios will be depleted!

Very difficult to observe Higgs at LHC in this light slepton scenario

Constraints (1)

- In the assumption of universal squark masses and trilinear terms, mild constraints are coming from **flavor physics**
  - $\mu>0$, to avoid negative NP contributions to $(g\text{-}2)_{\text{muon}}$
  - A_t negative and large in absolute value so to have in general smaller NP contributions to $b\to s\gamma$

$$A_t = -1000\,\text{GeV}$$

- **LEP** lower **bounds** on the mass of neutralinos and charginos ⇒ Lower bounds on M_1 and μ

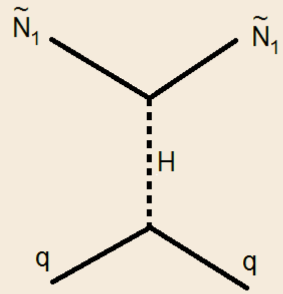
- **Dark Matter direct detection**

See also CDMS-II ArXiv:0912.3592

Xenon100 exclusion at the 90% level

$$m_{\tilde{N}_1} > 50\,\text{GeV}, \quad \sigma^{\text{SI}} > 7.0\cdot 10^{-45}\text{cm}^2$$

arXiv:1104.2549



  - Spin independent neutralino-nucleon scattering mediated by CP-even Higgs bosons

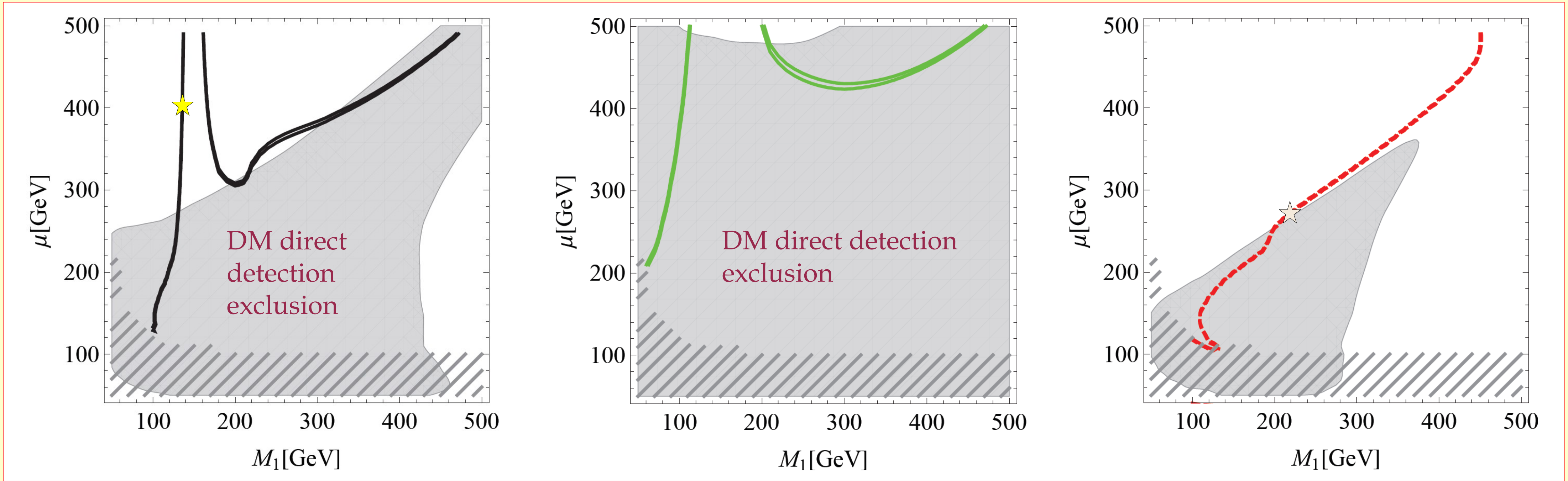
$$\sigma^{SI} \sim \frac{\tan^2\beta}{M_A^2}\cdot f_s^2$$

strange quark fom factor: main source of uncertainty

Recent lattice studies:

$$f_s = 0.020 \text{ with } f_s < 0.08 \text{ at } 1\sigma$$

ArXiv:0806.4744, ArXiv:0910.3271



$M_A = 300\,\text{GeV},\ \tan\beta = 10$ | $M_A = 300\,\text{GeV},\ \tan\beta = 50$ | $M_A = 1000\,\text{GeV},\ \tan\beta = 10$

The regions of our interest are not excluded!

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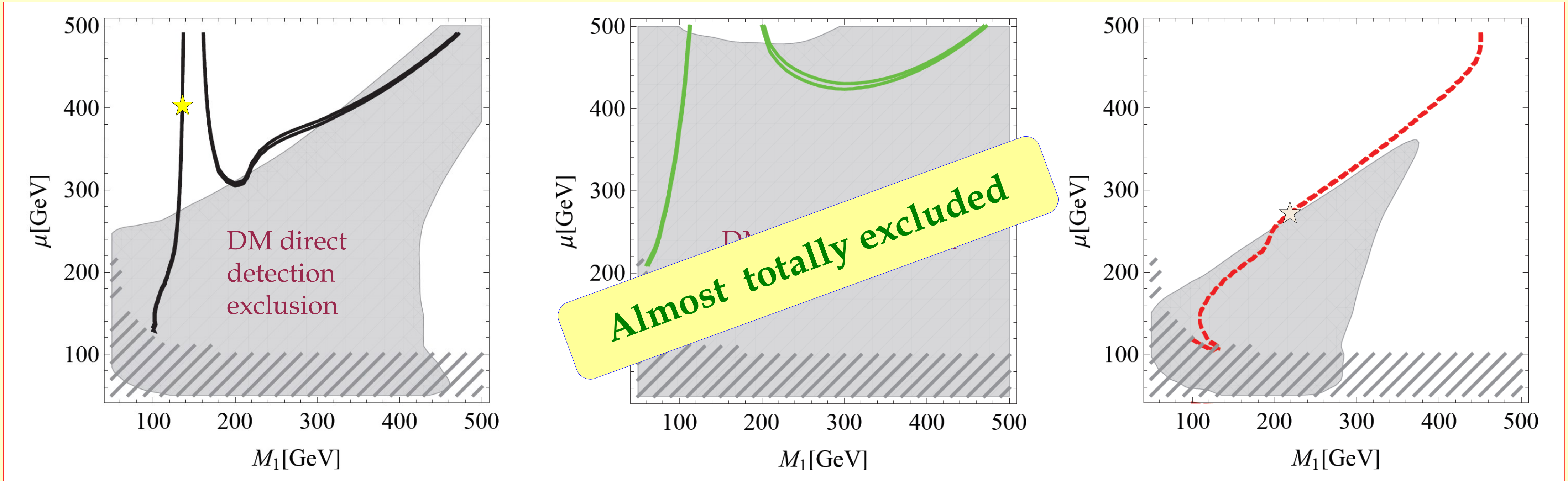
Constraints (2)



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Higgs signals at the 14 TeV LHC

	σ [pb]	$\sigma_{\rm cut}$ [pb]	σ_h [fb]	$\sigma_{\rm boosted}$ [fb]
(I) $M_A = 1000$ GeV	1.11	0.52	78	31
(II) $M_A = 300$ GeV	2.59	0.90	360	135

- Heavy gluino: $m_{\tilde{g}} = 1300$ GeV
- Rather light gluino: $m_{\tilde{g}} = 800$ GeV

Cuts imposed: $\not{E}_T > 200$ GeV
$p_{T_{j1}} > 300$ GeV, $p_{T_{j2}} > 200$ GeV

Production of a Higgs boson

(I) difficult to find at LHC
(around 800 events with 10 fb^{-1})
(II) possible to find at LHC
(around 3500 events with 10 fb^{-1})

with conventional cut analysis
Huitu et. al., 0808.3094

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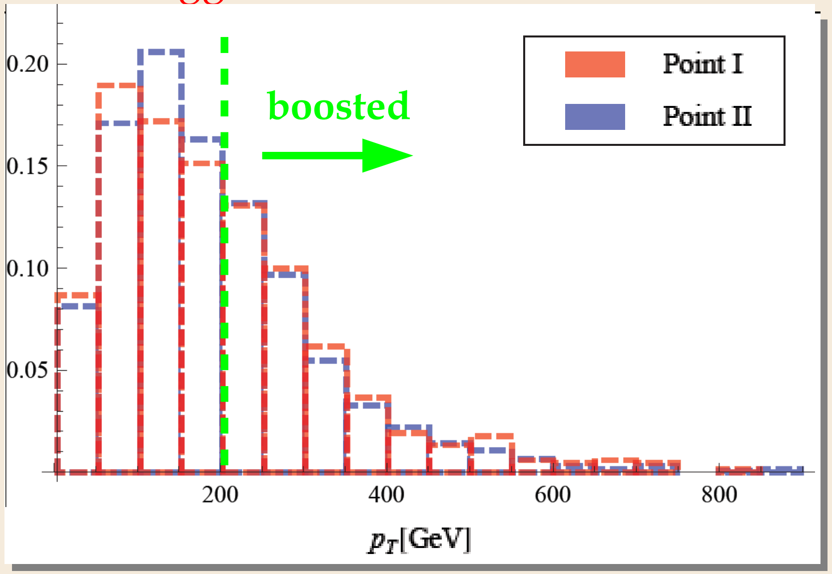
All the scenarios can be discovered at the LHC, using jet substructure algorithm for boosted Higgs bosons

Kribs et. al. 1006.1656



Large fraction of Higgs bosons is boosted,
even in parameter points compatible with a neutralino dark matter

Sufficiently common feature in the MSSM

Prospects for Higgs signals at the 7 TeV LHC

	σ [pb]	σ_{cut} [pb]	σ_h [fb]	$\sigma_{boosted}$ [fb]
(I) $M_A = 1000\,\mathrm{GeV}$	0.092	0.019	2.7	1.1
(II) $M_A = 300\,\mathrm{GeV}$	0.113	0.030	10	3.6

Large squark and gluino masses inhibit large cross sections

BUT, with lighter squarks...

	σ [pb]	σ_{cut} [pb]	σ_h [fb]	$\sigma_{boosted}$ [fb]
(I) $M_A = 1000\,\mathrm{GeV}$	0.23	0.086	11	3.0
(II) $M_A = 300\,\mathrm{GeV}$	0.31	0.142	36	11

$m_{\tilde{q}} = 800\,\mathrm{GeV}$

(Still allowed by the experiments)
ATLAS: ArXiv: 1103.6214
CMS: ArXiv: 1101.1628

Different cuts are performed: $\not{E}_T > 200\,\mathrm{GeV},\ p_{T_{j1}} > 200\,\mathrm{GeV},\ p_{T_{j2}} > 150\,\mathrm{GeV}$

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In general less boosted Higgs bosons

Some hopes!

Point (II) is less sensitive,
since the boost comes from the mass difference between the lightest and the heavier neutralino (that is not affected by the reduces squark mass)

Conclusions

- Large branching ratios of (heavy) squark decay chains to the SM Higgs boson can be possible

compatible with:

- Direct searches of sparticles
- Flavor constraints
- **Xenon100 direct searches of dark matter**

- **Neutralino dark matter**

A requirement: rather heavy sleptons: $m_{\tilde{\ell}} > M_2 = 2M_1 > 2m_h$

- **At 14 TeV LHC**

- Cross section for Higgs production can be rather high ⇒ prospects for discovery using conventional cut analysis
- Cross sections for **boosted Higgs production** are also large ⇒ prospects for discovery using jet substructure algorithms for boosted Higgs

- **At 7 TeV LHC**

- Hopes are for the discovery of boosted Higgs in the case of lighter squarks (800 GeV)

Soon LHC will tell us something about this regime