Impact of the recent LHC results on supersymmetry

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(DESY)

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K. Takayama (Nagoya University)

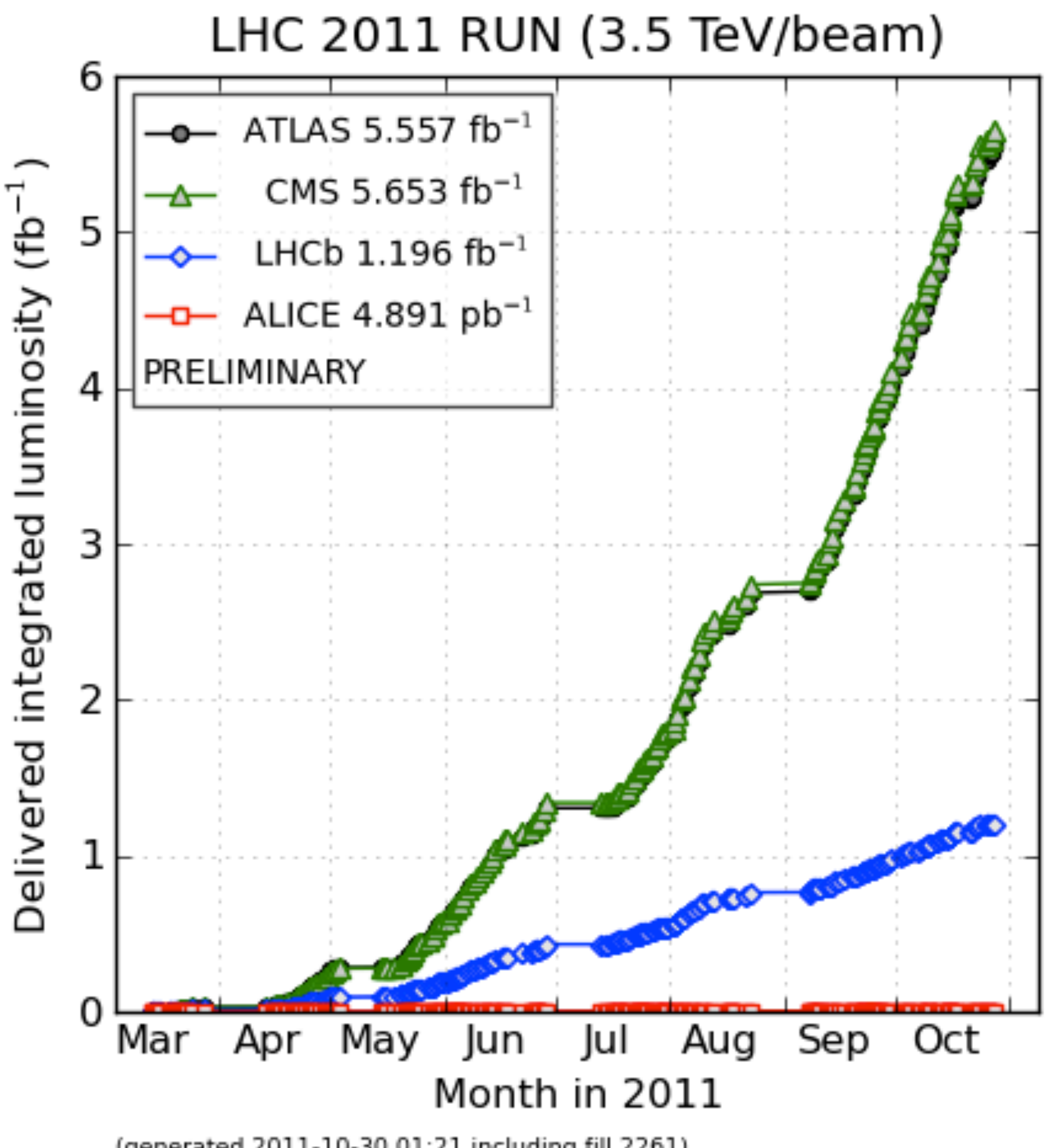
Based on:

arXiv:1106.3794 [hep-ph]

arXiv:1110.1119 [hep-ph]

31/10/2011 DESY

LHC status



> 5/fb of data has been accumulated in 2011.

LHC is working very well.

New physics searches

- No exotic signature, beyond the fluctuation, has been observed...

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LHC results put supersymmetry theory 'on the spot'

By Pallab Ghosh
Science correspondent, BBC News

Results from the Large Hadron Collider (LHC) have all but killed the simplest version of an enticing theory of sub-atomic physics.

Researchers failed to find evidence of so-called "supersymmetric" particles, which many physicists had

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Supersymmetry 'may be wrong'

Dr Tara Shears, spokesperson for experiment: "So far we've drawn
puts supersymmetry under a bit of a squeeze."

00.03

Results from the Large Hadron Collider (LHC) have all but killed one ver
supersymmetry, an enticing new theory of sub-atomic physics.

Science correspondent Pallab Ghosh explains how researchers have fail

New physics searches

- No exotic signature, beyond the fluctuation, has been observed...

What is the status of SUSY?

Contents

- A review of SUSY searches   (limit on the CMSSM)
- Constraint on the mAMSB
- Constraint on a light 3rd generation model
- Summary

Why Supersymmetry?

- gauge coupling unification

- dark matter

  -- R-parity makes LSP stable. LSP, in the majority of parameter space, is a neutral particle (neutralino in the MSSM, gravitino in the GMSB).

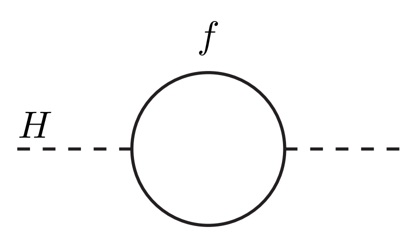
- naturalness

  -- providing a solution of the fine-tuning problem

$$V = -m_H^2 H^2 + \lambda H^4$$

$$\begin{aligned} 2\lambda v^2 &= m_H^2(v) \\ &= m_H^2(\Lambda) + \boxed{\Delta m_H^2} \\ &\qquad\qquad\qquad \sim \Lambda^2 \end{aligned}$$

SM



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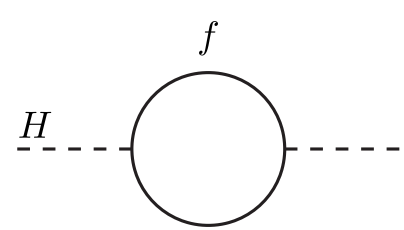

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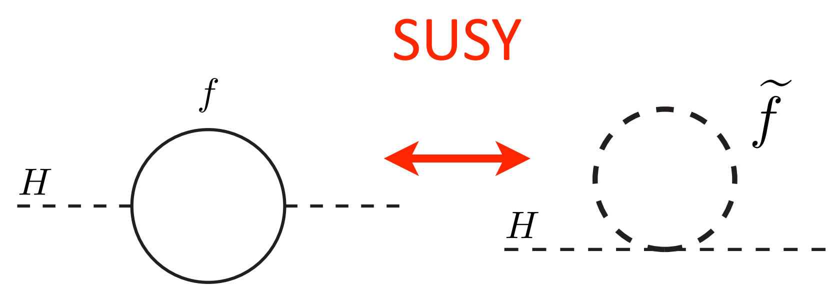

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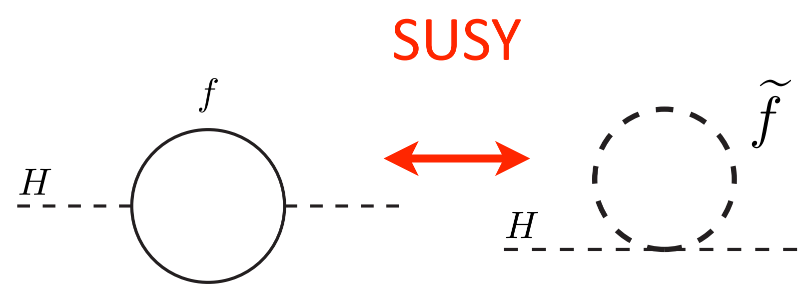
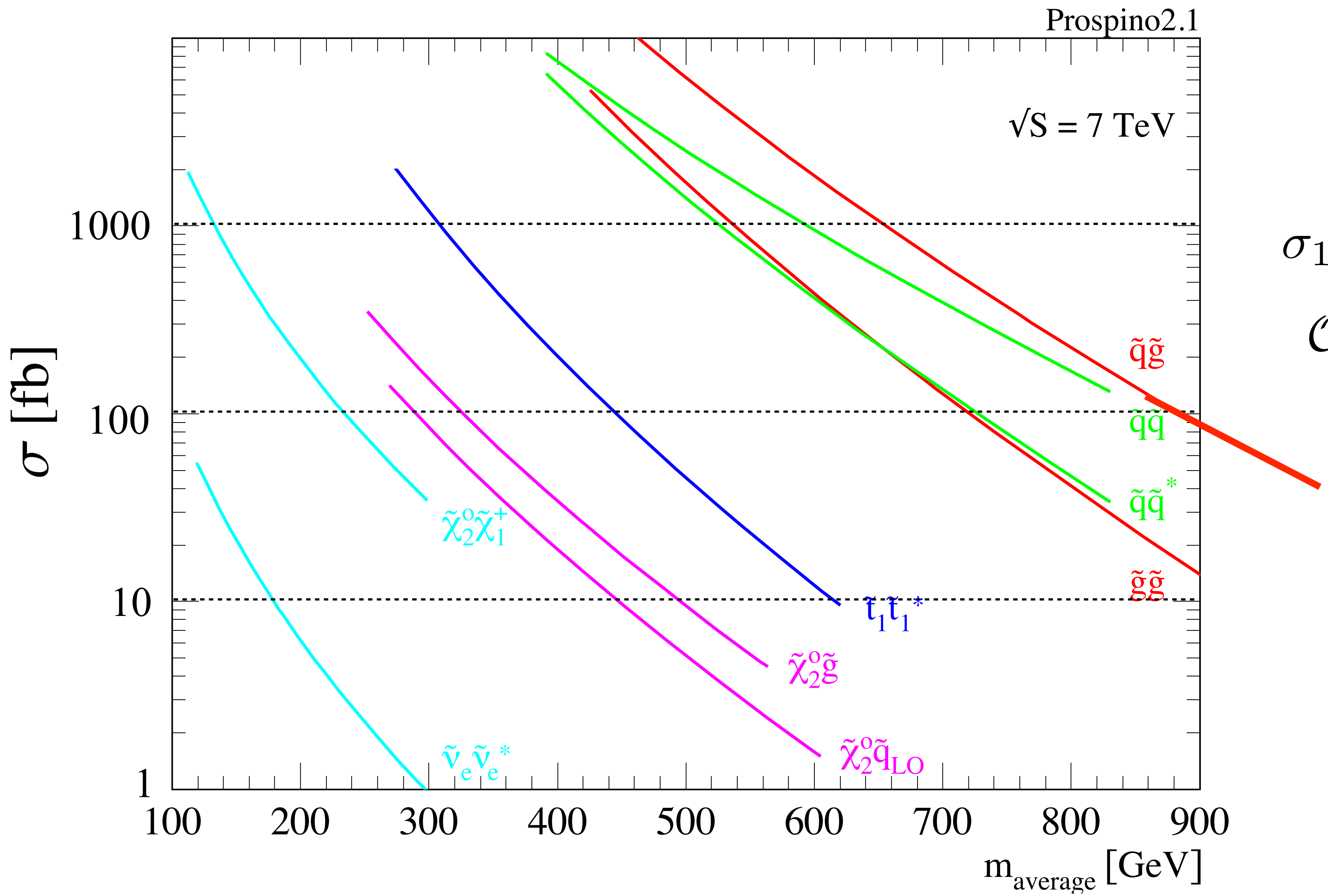


SUSY particles should be produced at the LHC

SUSY cross section @ 7 TeV LHC

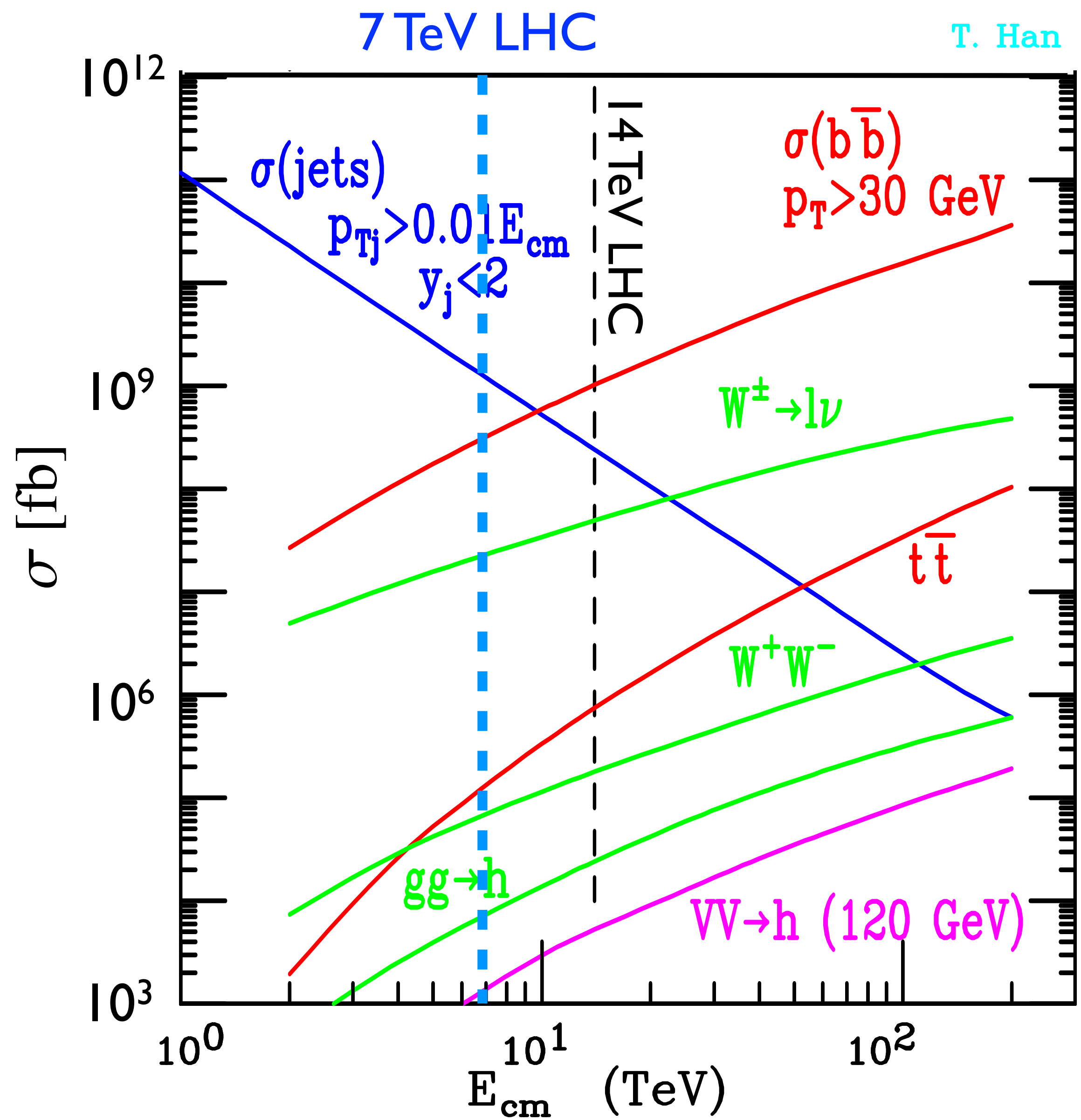


$\sigma_{14\text{TeV}} \sim$

$\mathcal{O}(10)\,\sigma_{7\text{TeV}}$

In $1\,\text{fb}^{-1}$ about 100 $\tilde{q}\tilde{g}$ pairs are produced if $m_{\tilde{q}} = m_{\tilde{q}} = 900\,\text{GeV}$.

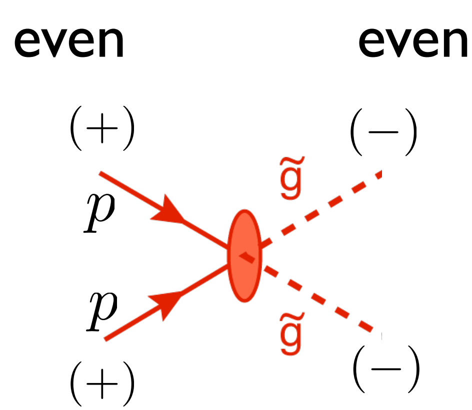
Background



$$\sigma_{BG} \sim (10^2 - 10^5) \times \sigma_{SUSY}$$

SUSY events

- Because of R-parity, SUSY particles have to be produced in pairs and decay to the LSP.



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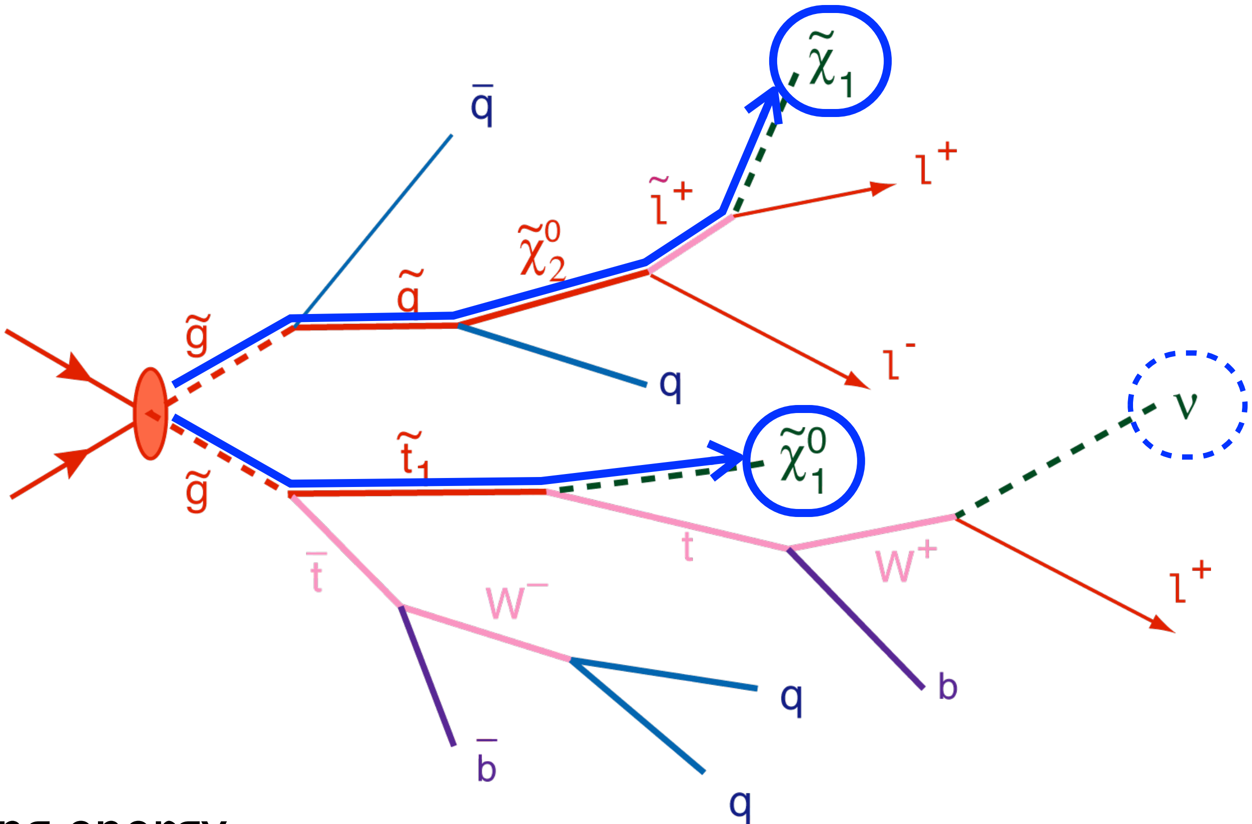

- large missing energy

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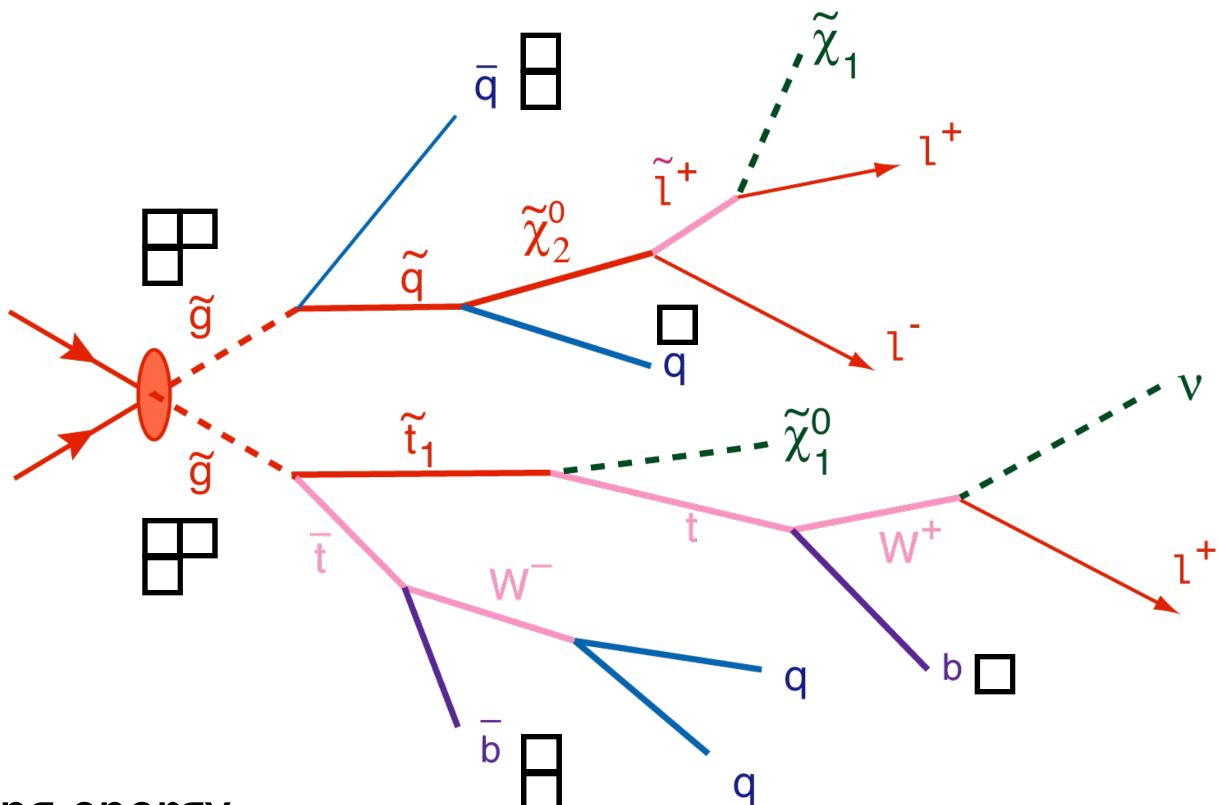

- large missing energy
- multiple high pT jets

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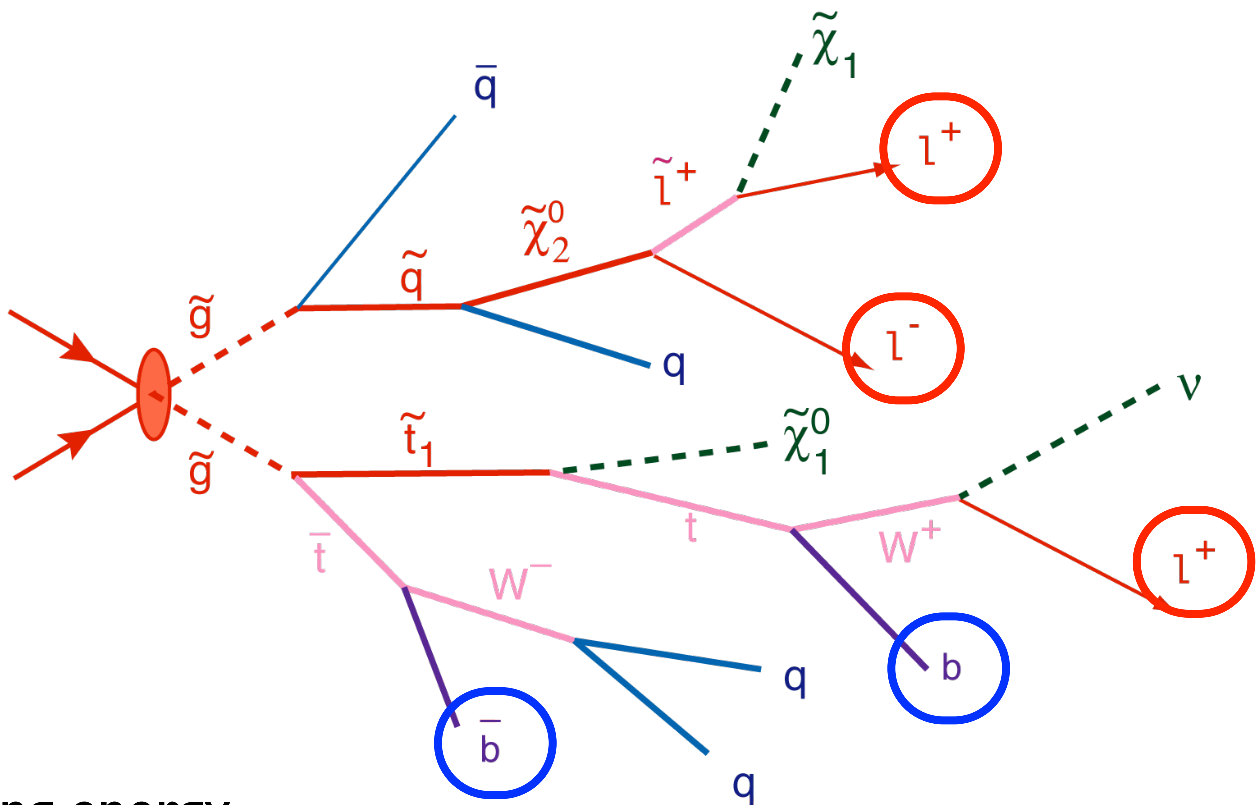


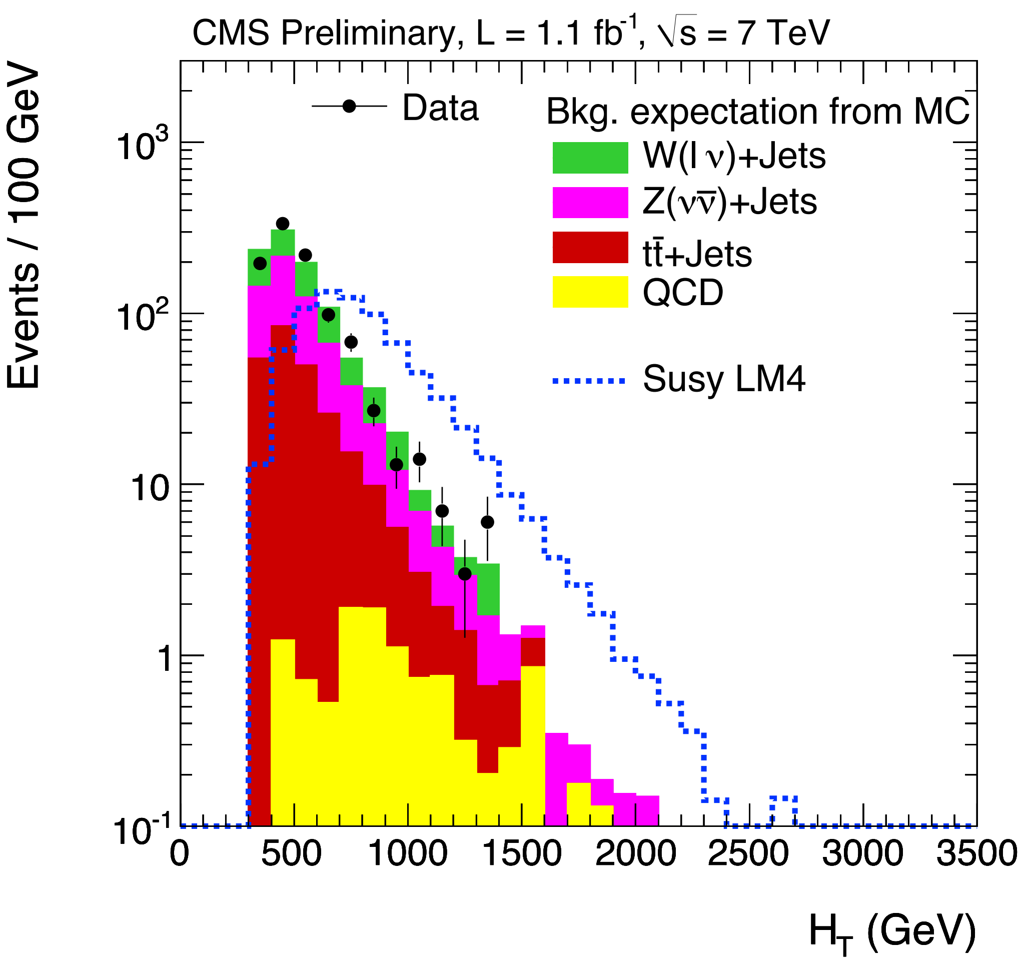
- large missing energy
- multiple high pT jets
- b-jets
- leptons

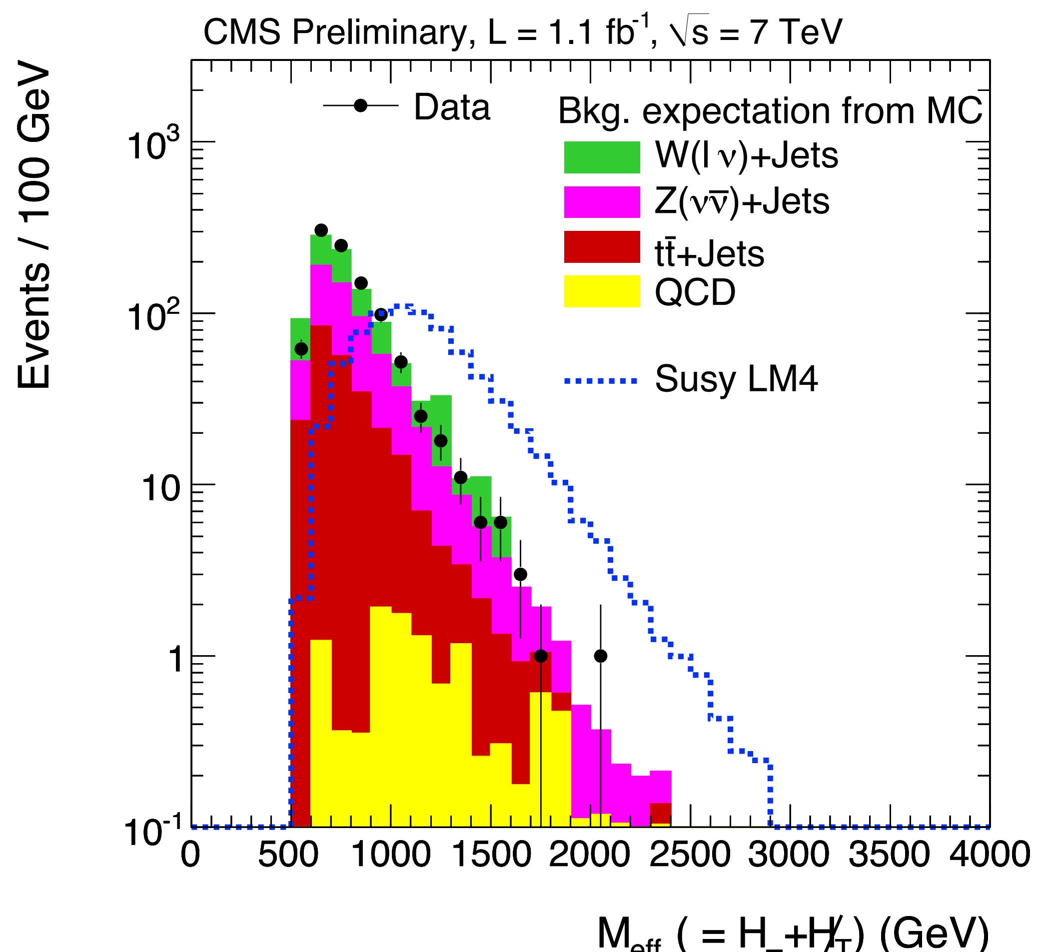
Variables for cut

$$p_T^{(1)} > p_T^{(2)} > p_T^{(3)}, \dots$$

$$H_T = \sum_i |p_T^{(i)}|$$

$$M_{\text{eff}} = H_T + E_T^{\text{miss}}$$





ATLAS 0-lepton analysis with 1/fb

ATLAS, 1109.6572

cuts:

Signal Region	$\geq$ 2-jet	$\geq$ 3-jet	$\geq$ 4-jet	High mass
E_T^{miss}	> 130	> 130	> 130	> 130
Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
Third jet p_T	–	> 40	> 40	> 80
Fourth jet p_T	–	–	> 40	> 80
$\Delta\phi(\text{jet}, \vec{P}_T^{miss})_{min}$	> 0.4	> 0.4	> 0.4	> 0.4
E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	$> 500/1000$	> 1100

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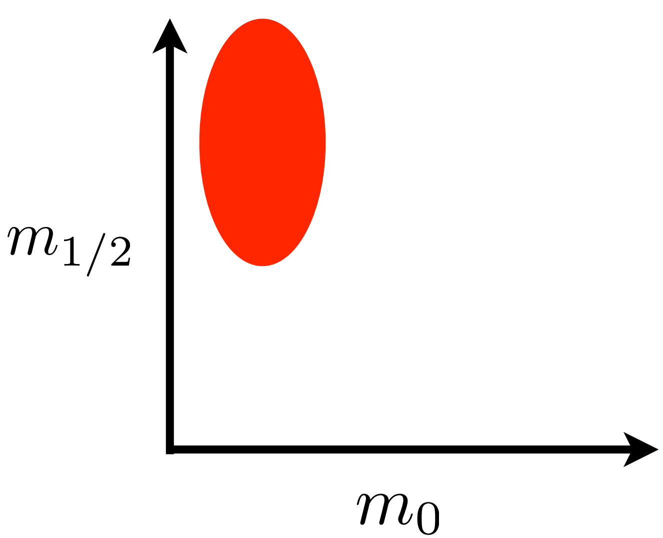
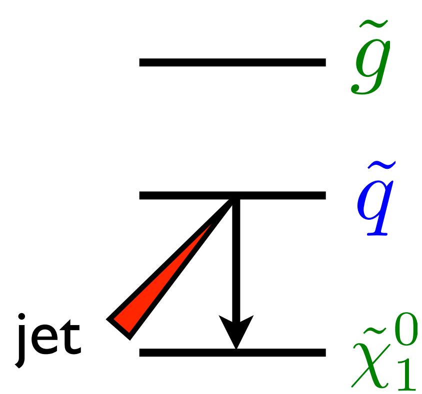
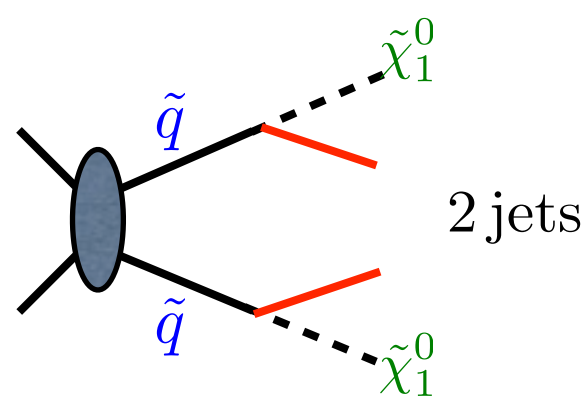
2-jet signal region:







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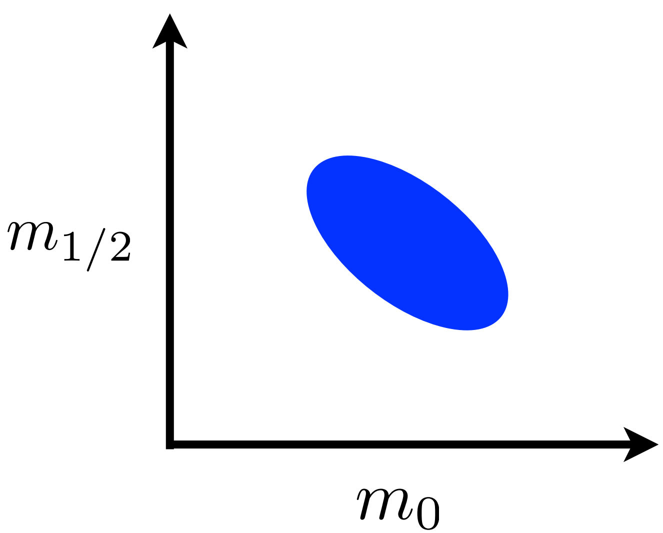
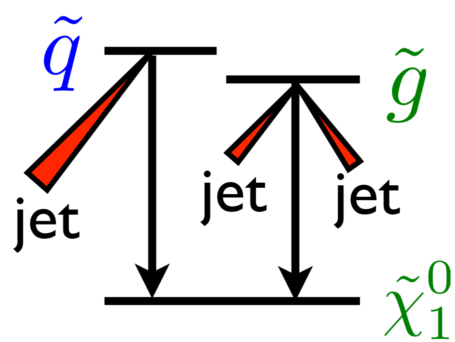
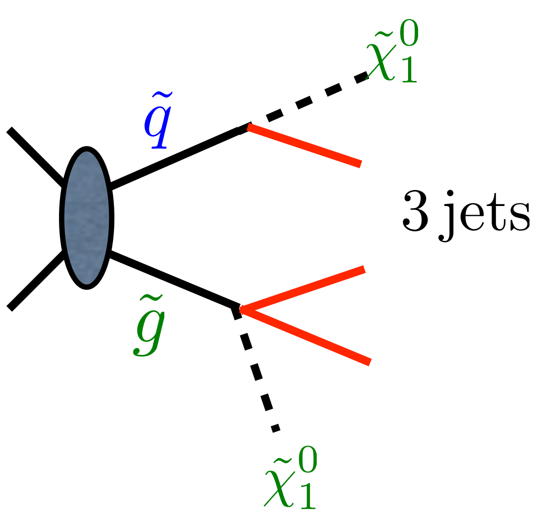
m_{eff}	> 1000	> 1000	$> 500/1000$	> 1100

3-jet signal region:







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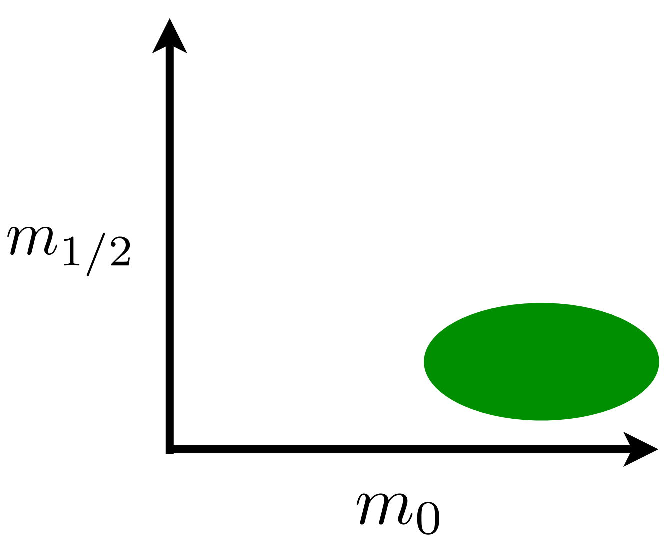
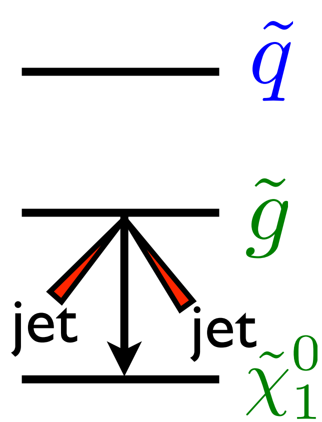
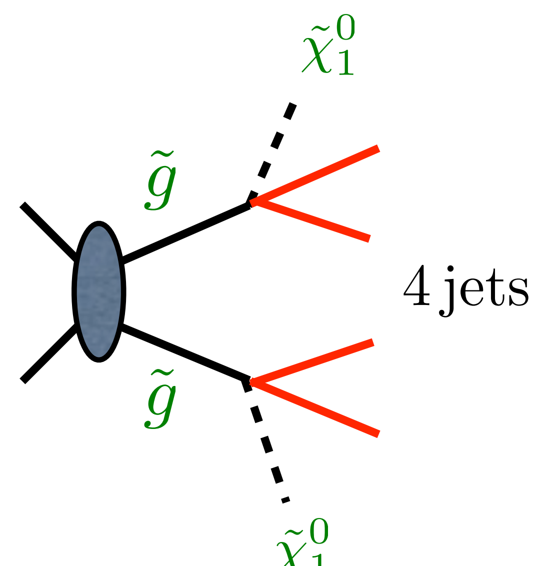
$E_{\mathrm{T}}^{\mathrm{miss}}$	> 130	> 130	> 130	> 130
Leading jet p_{T}	> 130	> 130	> 130	> 130
Second jet p_{T}	> 40	> 40	> 40	> 80
Third jet p_{T}	–	> 40	> 40	> 80
Fourth jet p_{T}	–	–	> 40	> 80
$\Delta\phi(\text{jet}, \vec{P}_{\mathrm{T}}^{\mathrm{miss}})_{\mathrm{min}}$	> 0.4	> 0.4	> 0.4	> 0.4
$E_{\mathrm{T}}^{\mathrm{miss}}/m_{\mathrm{eff}}$	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	$> 500/1000$	> 1100

4-jet signal region:







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Leading jet p_T	> 130	> 130	> 130	> 130
Second jet p_T	> 40	> 40	> 40	> 80
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E_T^{miss}/m_{eff}	> 0.3	> 0.25	> 0.25	> 0.2
m_{eff}	> 1000	> 1000	> 500/1000	> 1100

Process	Signal Region				
	≥ 2-jet	≥ 3-jet	≥ 4-jet, m_{eff} > 500 GeV	≥ 4-jet, m_{eff} > 1000 GeV	High mass
Z/γ+jets	32.3 ± 2.6 ± 6.9	25.5 ± 2.6 ± 4.9	209 ± 9 ± 38	16.2 ± 2.2 ± 3.7	3.3 ± 1.0 ± 1.3
W+jets	26.4 ± 4.0 ± 6.7	22.6 ± 3.5 ± 5.6	349 ± 30 ± 122	13.0 ± 2.2 ± 4.7	2.1 ± 0.8 ± 1.1
tt+ single top	3.4 ± 1.6 ± 1.6	5.9 ± 2.0 ± 2.2	425 ± 39 ± 84	4.0 ± 1.3 ± 2.0	5.7 ± 1.8 ± 1.9
QCD multi-jet	0.22 ± 0.06 ± 0.24	0.92 ± 0.12 ± 0.46	34 ± 2 ± 29	0.73 ± 0.14 ± 0.50	2.10 ± 0.37 ± 0.82
Total	62.4 ± 4.4 ± 9.3	54.9 ± 3.9 ± 7.1	1015 ± 41 ± 144	33.9 ± 2.9 ± 6.2	13.1 ± 1.9 ± 2.5
Data	58	59	1118	40	18

SM prediction →

observed →

How many SUSY events are allowed?

prediction for # of events after the cut:

$$\lambda = \lambda_{SM} + \lambda_{SUSY}$$

provability observing *n* events:

$$P(n) = \frac{e^{-\lambda}\lambda^n}{n!}$$

Incompatibility between model and data (p-value):

$$p_v = \sum_{n=0}^{n_{obs}} P(n)$$

The model is excluded at 95% CL, if $p_v < 0.05$.

- 95% CL upper bound on λ_{SUSY} in each signal region

signal region	$\geq 2\,\mathrm{jets}$	$\geq 3\,\mathrm{jets}$	$\geq 4\,\mathrm{jets}\,(a)$	$\geq 4\,\mathrm{jets}\,(b)$	High mass
upper bound	22	25	429	27	17

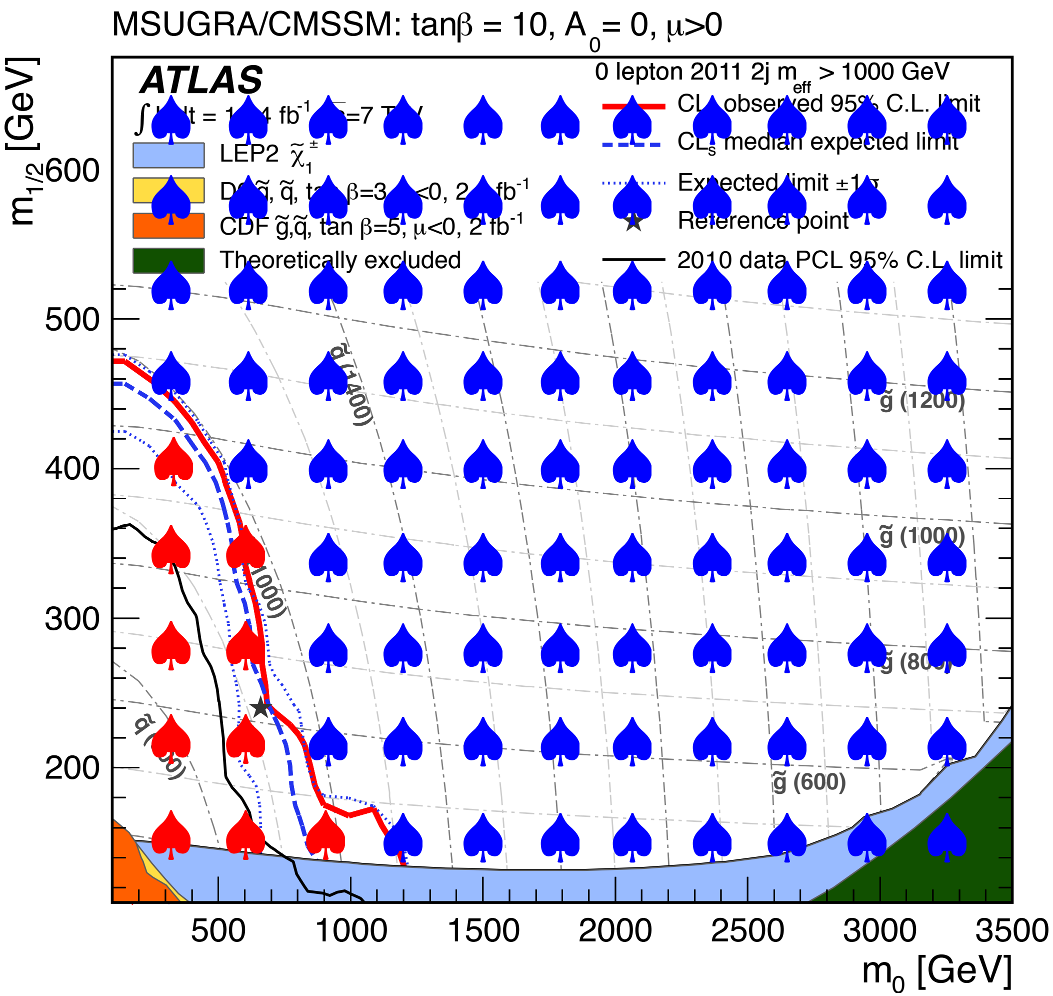
Constraint on the CMSSM

ATLAS, 1109.6572

- λ_{SUSY} can be estimated in each model point by the MC simulation.

  → One can make a judgement whether or not the model point is excluded.

2-jet signal region:



$\lambda_{\mathrm{SUSY}} \leq \lambda_{\mathrm{SUSY}}^{\mathrm{bound}}$ (allowed)

$\lambda_{\mathrm{SUSY}} > \lambda_{\mathrm{SUSY}}^{\mathrm{bound}}$ (excluded)

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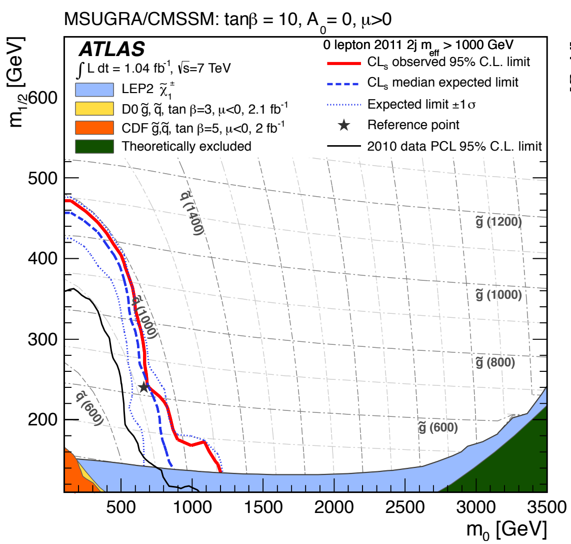
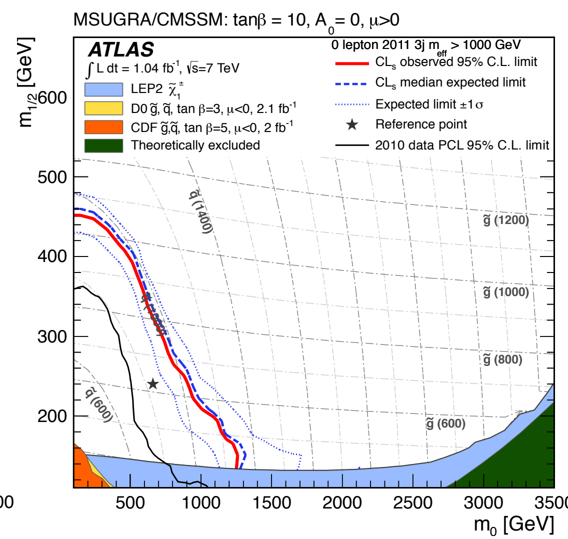
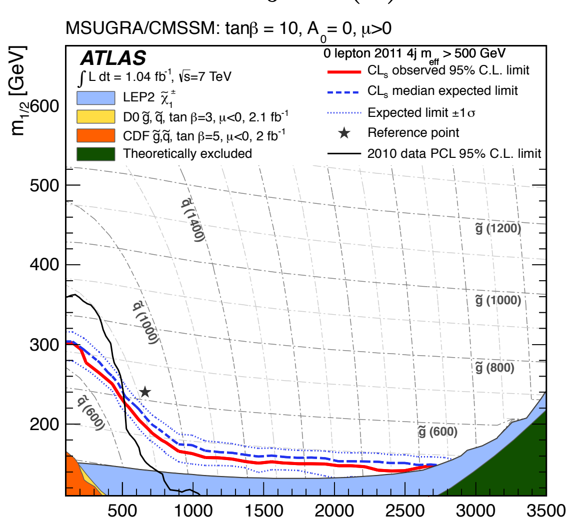
$\geq 2\,\mathrm{jets}$



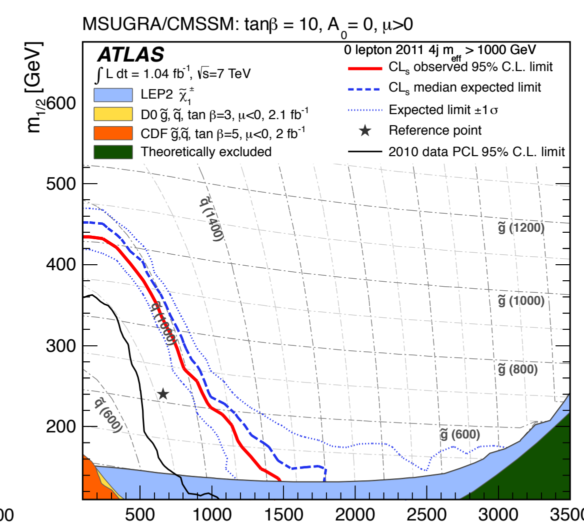
$\geq 3\,\mathrm{jets}$



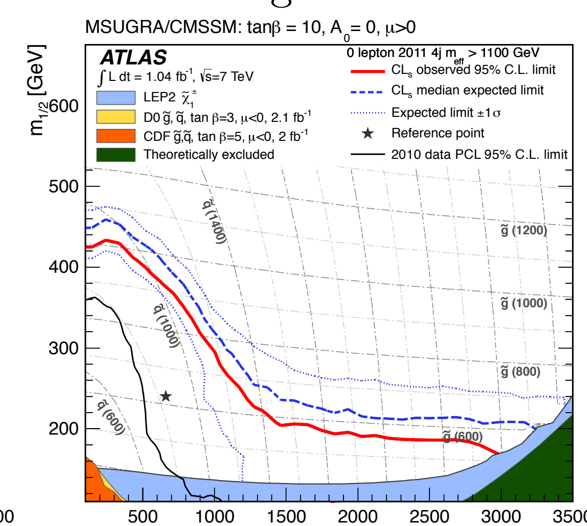
$\geq 4\,\mathrm{jets}\,(a)$



$\geq 4\,\mathrm{jets}\,(b)$



High mass



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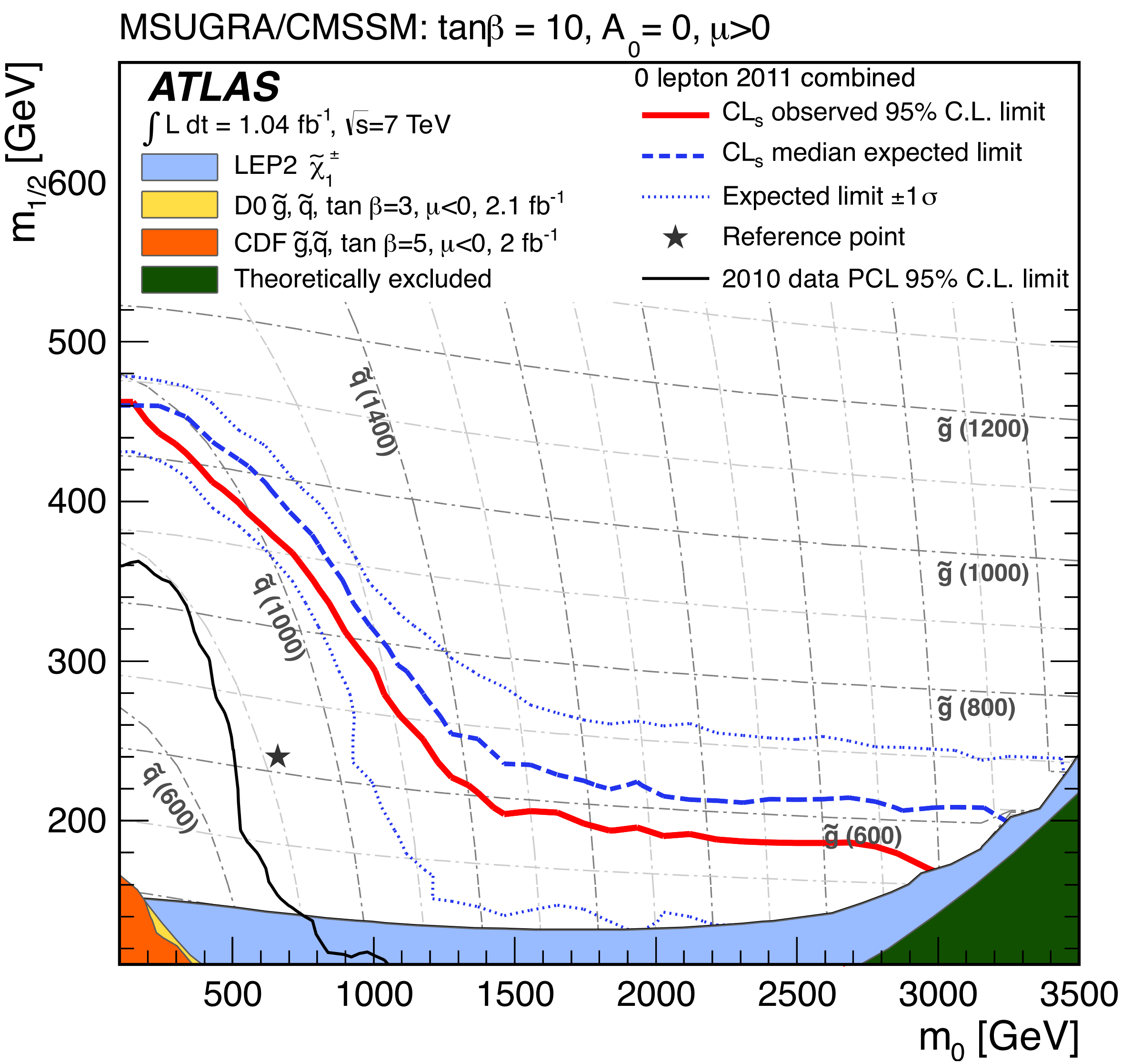

- $m_{\tilde{g}} \simeq m_{\tilde{q}} > 950\,\mathrm{GeV}$
- $m_{1/2} \gtrsim 200\,\mathrm{GeV}$

  independently on m_0

- $m_{1/2} \gtrsim 300\,\mathrm{GeV}$

  if $m_0 <$ 1TeV

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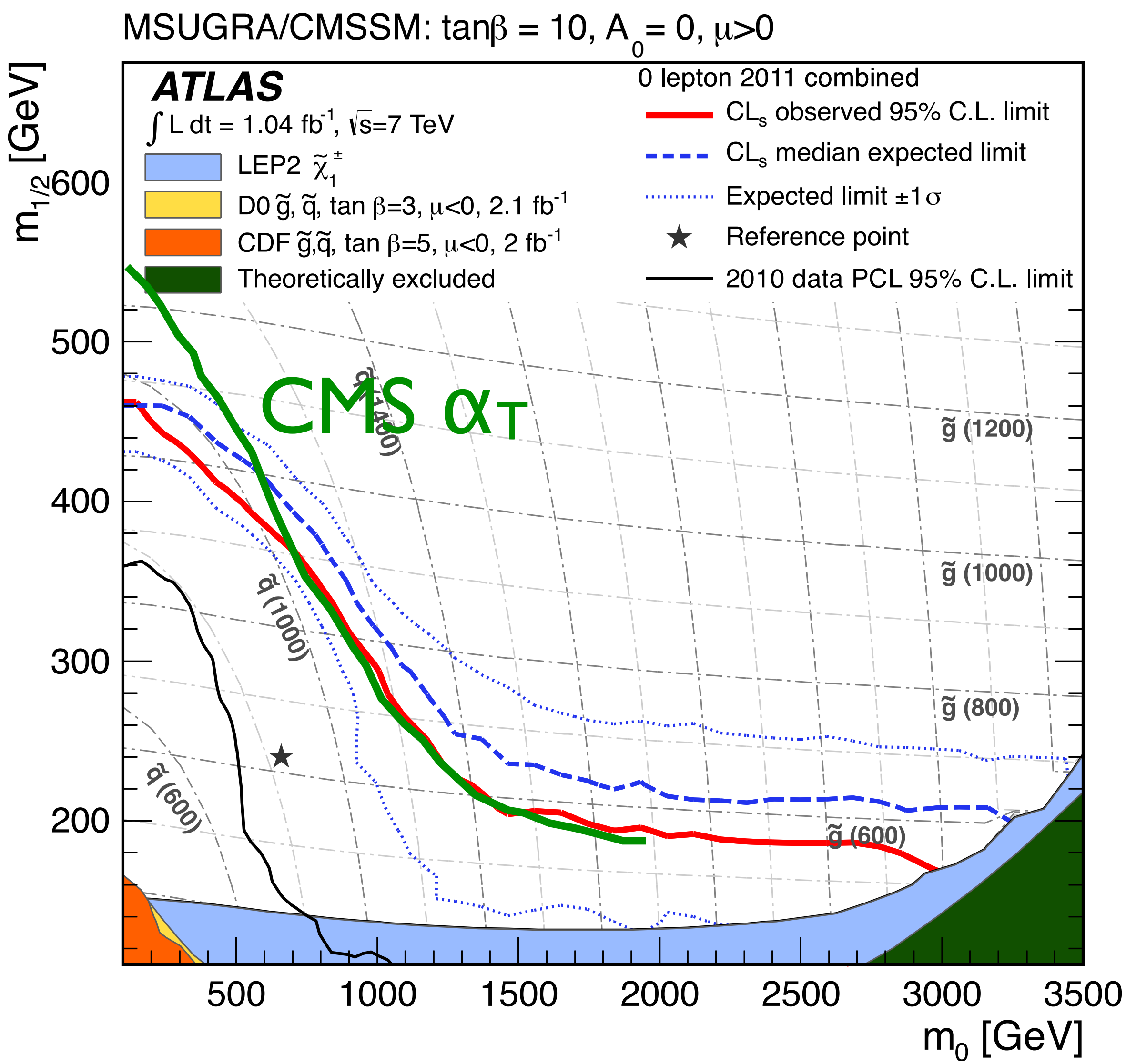

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independently on m_0

- $m_{1/2} \gtrsim 300\,\mathrm{GeV}$

if $m_0 <$ 1TeV

- CMS α_T analysis puts more stringent limit in small m_0, large $m_{1/2}$ region

Pushing up the exclusion contour

0-lepton 1000/pb

Signal region	2-jet	4-jet
pT	> 40	> 80
E_{Tmiss}	> 130	> 130
meff	> 1000	> 1100
stat. error (obs. events)	13% (58)	28% (18)
sys. SM, sys. SUSY	8%, ~30%	24%, ~30%

- How to get more stringent exclusion limit?

Pushing up the exclusion contour

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- How to get more stringent exclusion limit?
- Accumulate more data?

Pushing up the exclusion contour

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Statistical error and Systematic error
are the same order

- How to get more stringent exclusion limit?
- Accumulate more data?
- Improvement only on the statistical error doesn't help much.

Pushing up the exclusion contour

Signal region	0-lepton 1000/pb 2-jet	0-lepton 1000/pb 4-jet	0-lepton 165/pb 2-jet	0-lepton 165/pb 4-jet	0-lepton 35/pb 2-jet	0-lepton 35/pb 4-jet
pT	> 40	> 80	> 40	> 40	> 40	-
E_{Tmiss}	> 130	> 130	> 130	> 130	> 100	-
meff	> 1000	> 1100	> 1000	> 1000	> 500	-
stat. error (obs. events)	13% (58)	28% (18)	29% (10)	37% (7)	9% (87)	-
sys. SM, sys. SUSY	8%, ~30%	24%, ~30%	13%, ~30%	17%, ~30%	34%, ~30%	-

- How to get more stringent exclusion limit?
- Accumulate more data?
- Improvement only on the statistical error doesn't help much.
- Imposing more stringent cuts is important. (stat. and sys. can be balanced)

Pushing up the exclusion contour

	0-lepton 1000/pb		0-lepton 165/pb		0-lepton 35/pb	
Signal region	2-jet	4-jet	2-jet	4-jet	2-jet	4-jet
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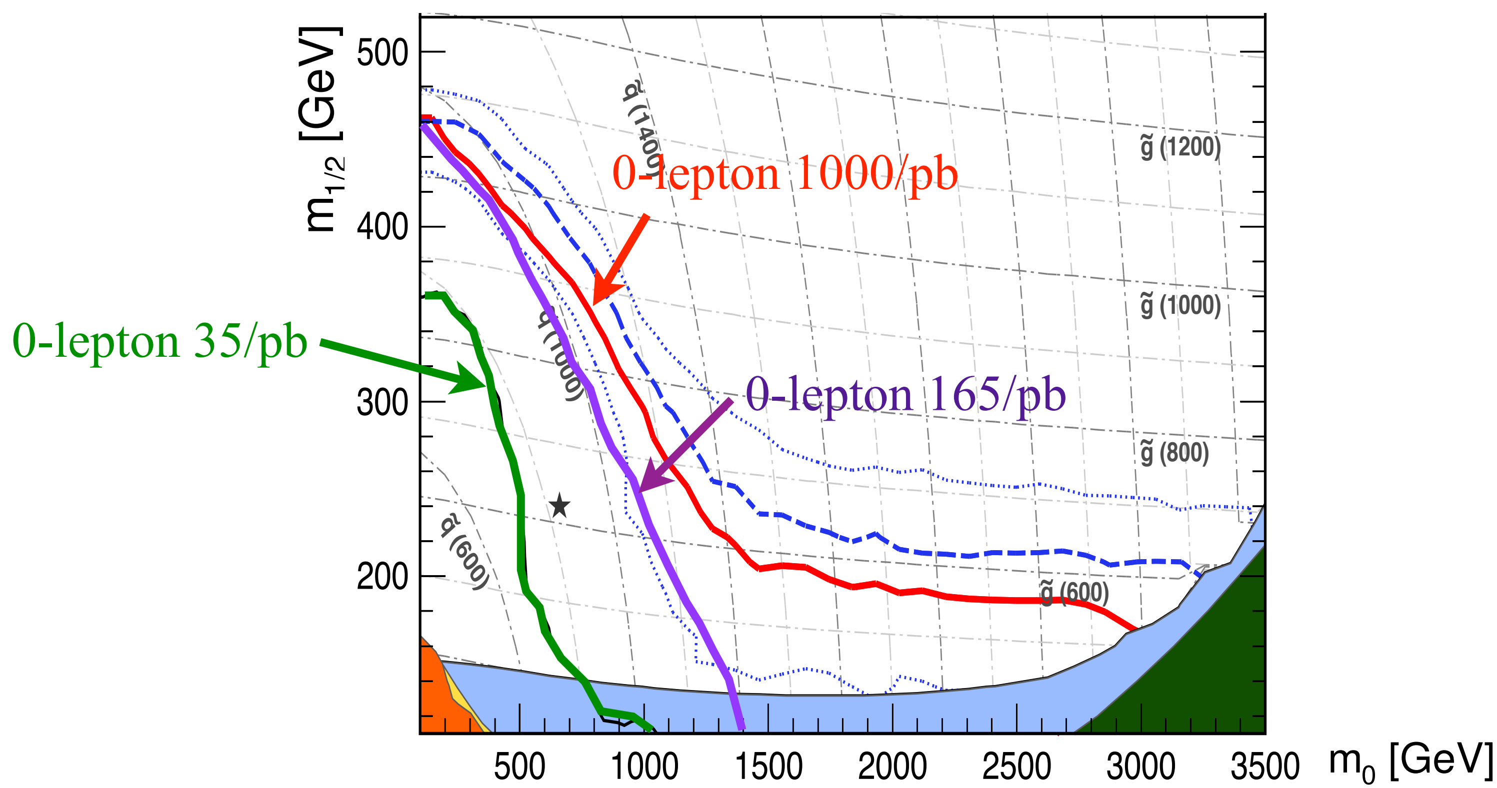
stat. error (obs. events)	13% (58)	28% (18)	29% (10)	37% (7)	9% (87)	-
sys. SM, sys. SUSY	8%, ~30%	24%, ~30%	13%, ~30%	17%, ~30%	34%, ~30%	-



Constraint on mAMSB

- Observed gluino and squark mass bounds can only be applied to the CMSSM.
- One should also look at constraints on the other SUSY models (CMSSM ≠ SUSY).
- We study the constraints on the mAMSB model points.

Softsusy: calculation of low energy spactrum

Susyhit: calculation of decay branching ratios

Prospino2: NLO cross section

Herwig++: event generation, parton shower, hadronisation

Delphes: detector simulation

minimal Anomaly Mediated SUSY Breaking (mAMSB)

- AMSB: assumed that a spontaneous SUSY breaking in hidden sector is mediated to the MSSM sector by anomalous violation of a conformal symmetry.

L. Randall, R. Sundrum
9810155[hep-th]

$$M_a = \frac{\beta_{g_a}}{g_a} m_{3/2} \qquad m_{ij}^2 = -\frac{1}{4}\left(\frac{\partial \gamma_{ij}}{\partial g}\beta_g + \frac{\partial \gamma_{ij}}{\partial y}\beta_y\right) m_{3/2}^2 \qquad A_{ijk} = -\frac{\beta_y}{y} m_{3/2}$$

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• Flavour and CP violations are safely suppressed, but sleptons become tachyonic, breaking EM symmetry.

$$m_{\tilde{e}_R}^2 = -\frac{m_{3/2}^2}{(16\pi^2)^2}\frac{198}{25} g_1^4$$

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• Add an additional soft mass m_0 to all the scalar masses at low energy to make slepton masses positive.

T. Gherghetta, G. F. Giudice, J. D. Wells
9904378[hep-ph]

⇨ minimal AMSB

$$m_{3/2}, \ m_0 \ \tan\beta, \ \mathrm{sign}(\mu)$$

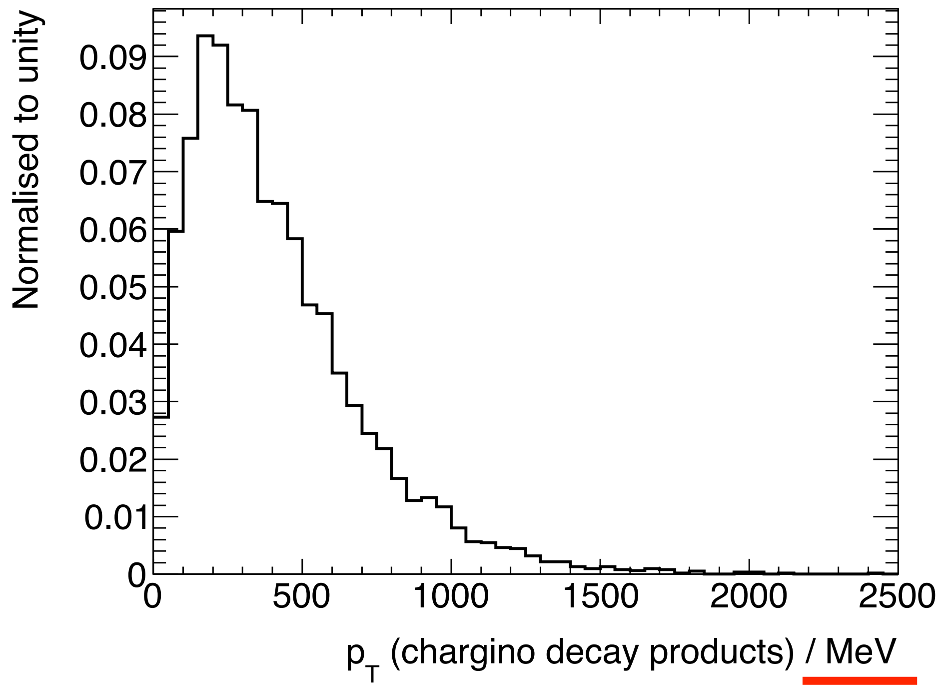
Mass spectrum

$\tan\beta = 10, \mu > 0$

gaugino mass: $M_a = \frac{\beta_{g_a}}{g_a} m_{3/2} \longrightarrow |M_3| \gg |M_1| \gg \underline{|M_2|}$

wino LSP $\quad m_{\tilde{\chi}^\pm} \gtrsim m_{\tilde{\chi}^0}$

- $\tilde{\chi}_1^\pm \to \pi^\pm \chi_1^0$, but $\pi^\pm$ is extremely soft.
- $\tilde{\chi}_1^\pm$ and χ_1^0 are experimantaly indistinguishable.



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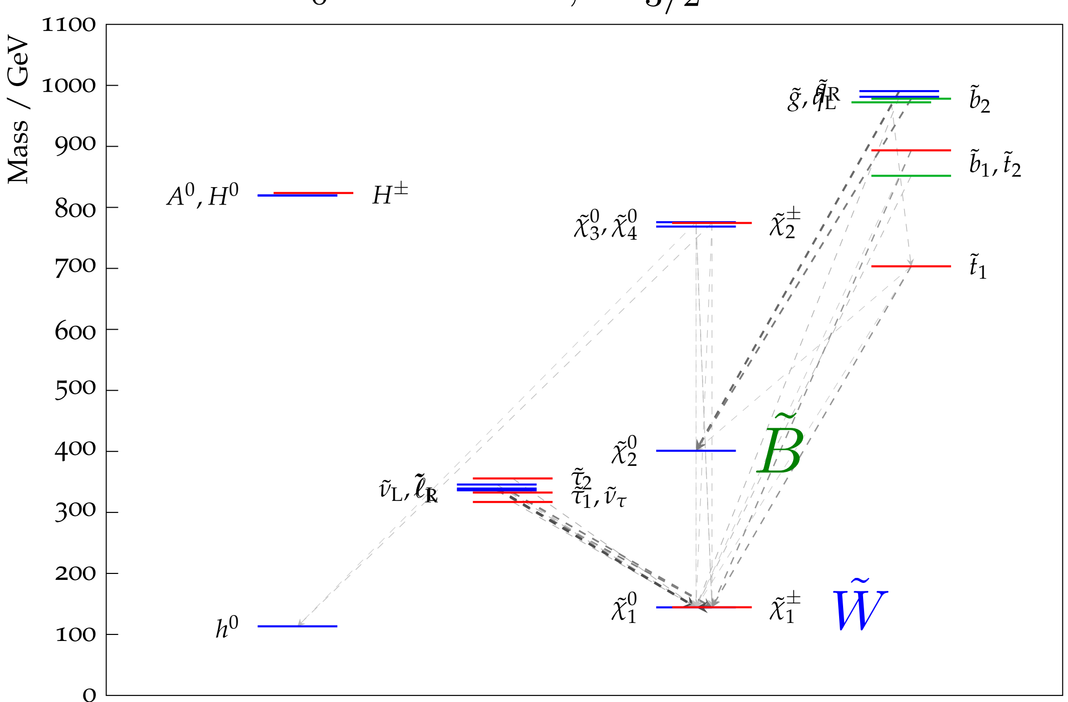
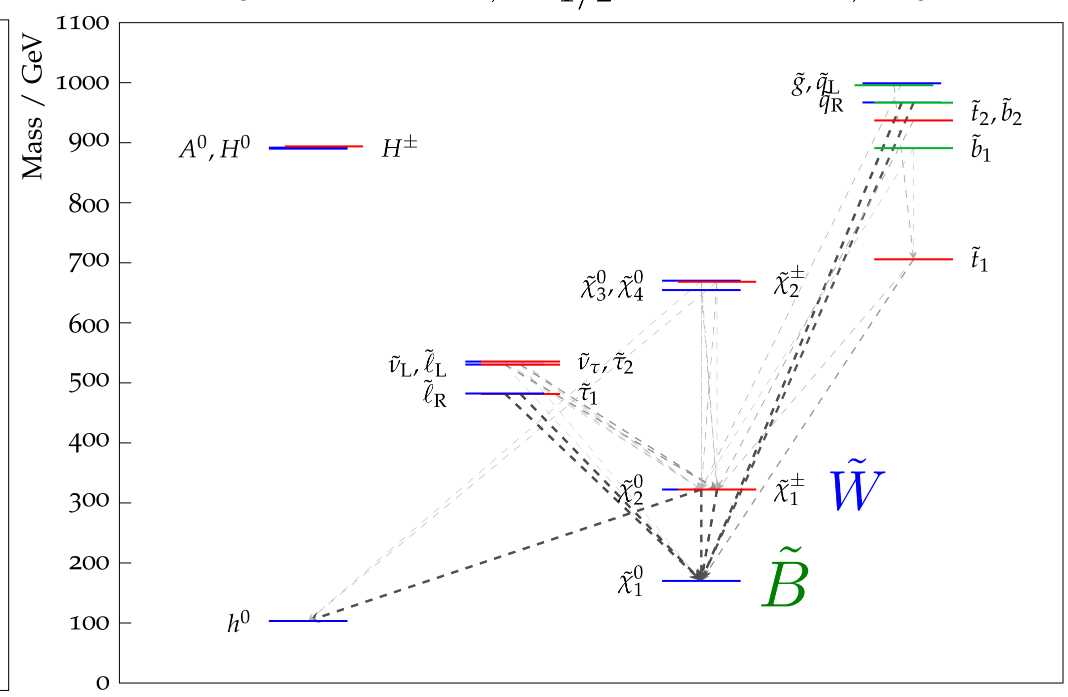
mAMSB:

$m_0 = 384\,\mathrm{GeV},\ m_{3/2} = 44\,\mathrm{TeV}$



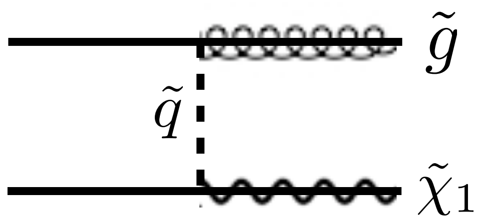
CMSSM:

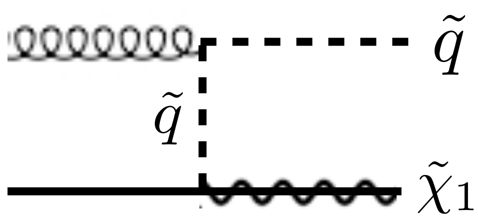
$m_0 = 455\,\mathrm{GeV},\ m_{1/2} = 420\,\mathrm{GeV},\ A_0 = 0$



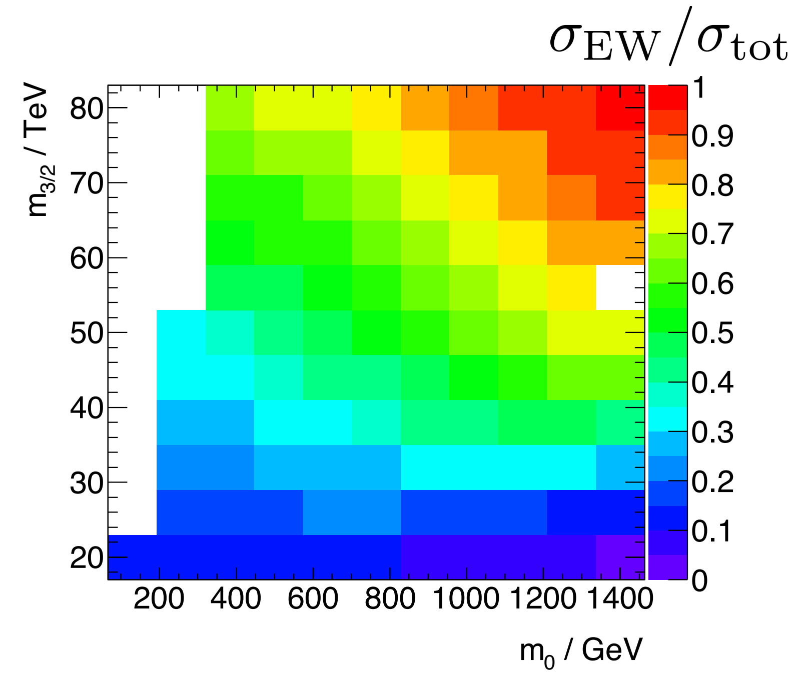
Associated wino production

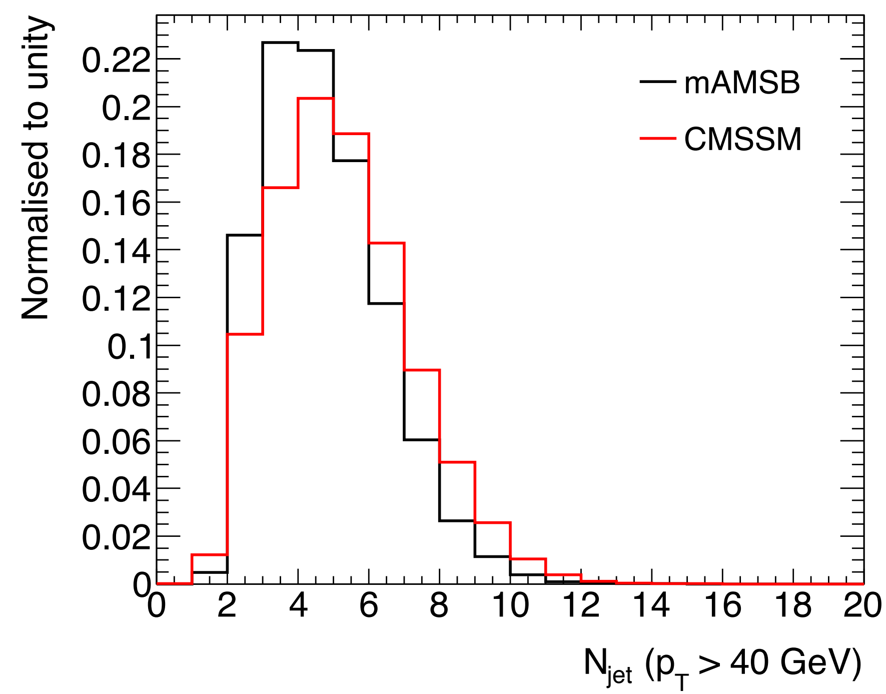
- Because of a larger hierarchy between gluino and LSP and larger wino gauge coupling, associated wino production is not negligible.





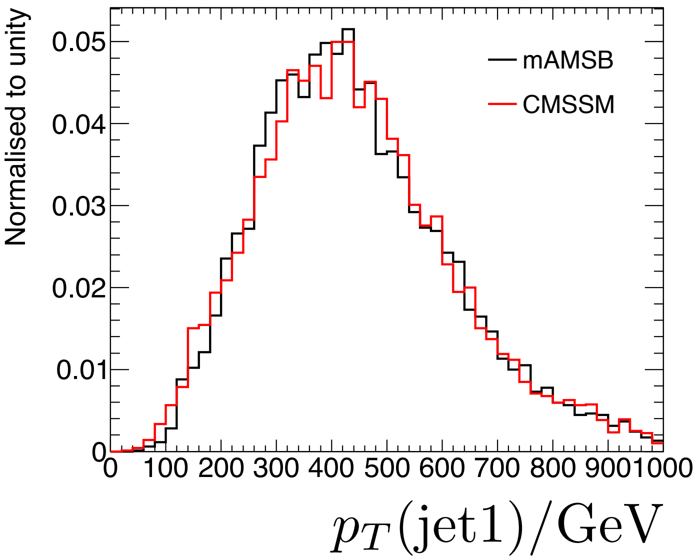
- It slightly enhances 2, 3-jet events.

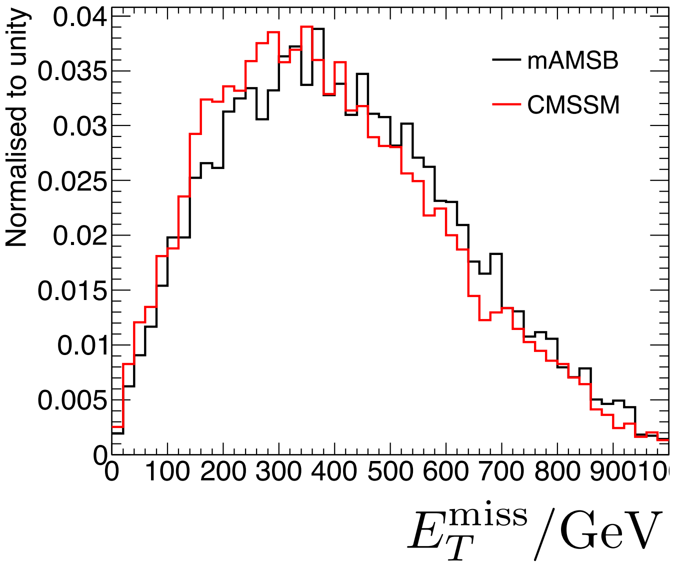


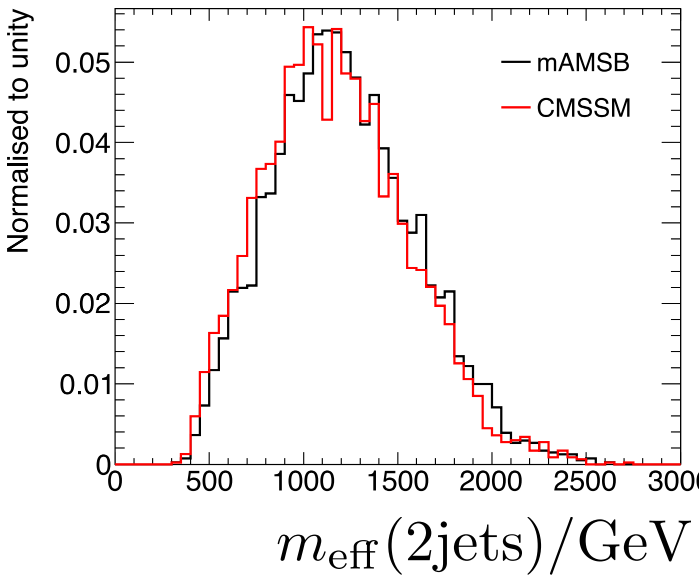


jet p_T, E_{Tmiss}, m_{eff}

- Distributions of jet P_T, ETmiss, meff are similar to ones in the CMSSM.

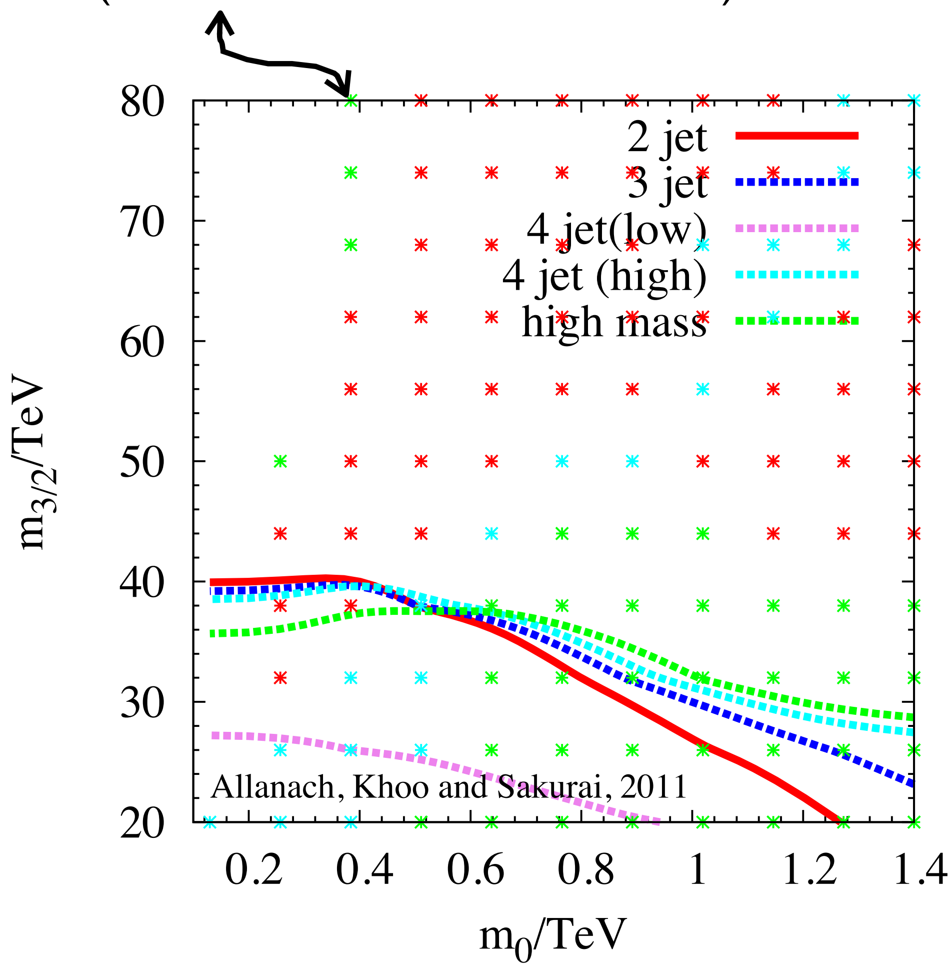




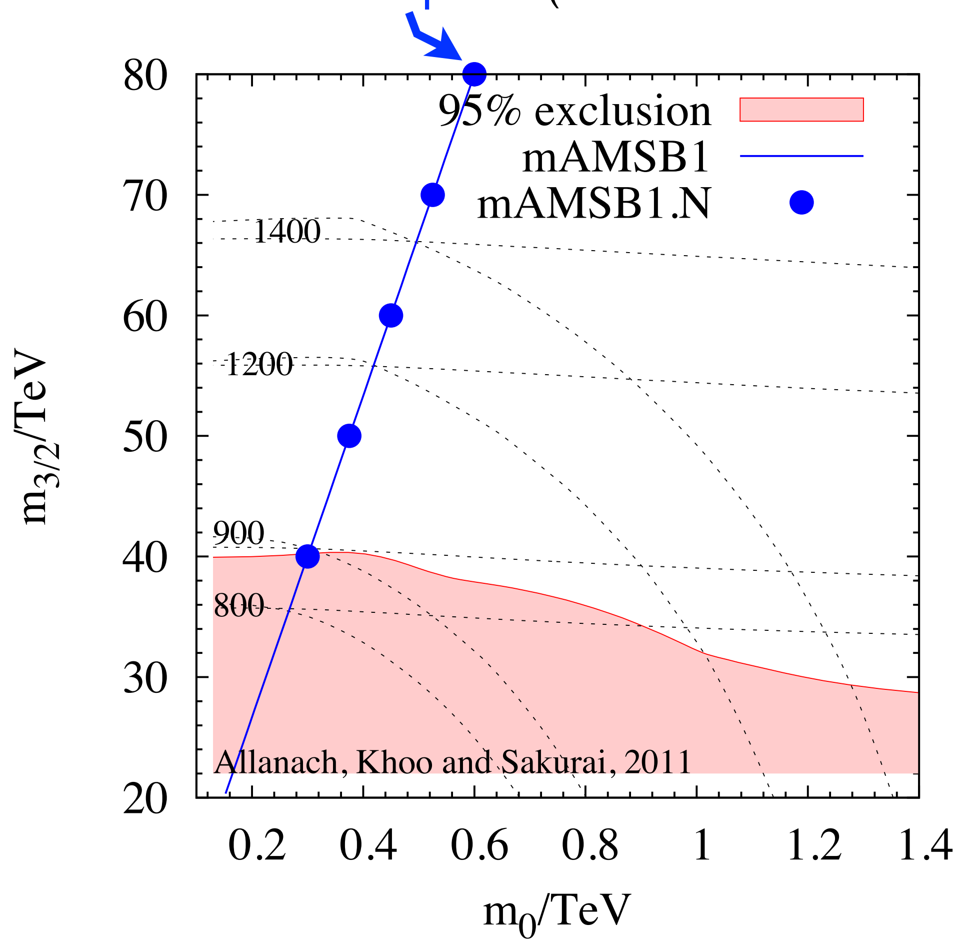


Constraint on mAMSB

(* * * *: most sensitive cuts)



Bench mark points (S. S. AbdusSalam et.al. 1109.3859)



- $m_{\tilde{g}} \simeq m_{\tilde{q}} > 900\,\mathrm{GeV}$
- $m_{3/2} > 30\,\mathrm{TeV}$ if $m_0 < 1.3\,\mathrm{TeV}$
- $m_{3/2} > 40\,\mathrm{TeV}$ if $m_0 < 500\,\mathrm{GeV}$

B.C.Allanach, T.J.Khoo, KS 1110.1119

CMSSM "on the spot"?

- Naturalness

O((10²GeV)²) $$2\lambda v^2 = m_H^2(v)$$

$$= m_H^2(\Lambda) + \boxed{\Delta m_H^2}$$

$$\sim m_{SUSY}^2$$

O((10²eV)²)

CMSSM “on the spot”?

- Naturalness

$$\lambda = \frac{g^2 + g'^2}{8}$$

$$-m_H^2 \simeq |\mu|^2 + m_{H_u}^2$$

O((10²GeV)²)

$$\begin{aligned} 2\lambda v^2 &= m_H^2(v) \\ &= m_H^2(\Lambda) + \boxed{\Delta m_H^2} \\ &\qquad\qquad \sim m_{SUSY}^2 \end{aligned}$$

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$$\begin{aligned}\frac{m_Z^2}{2} &= m_H^2(v) \\ &= m_H^2(\Lambda) + \underbrace{\boxed{\Delta m_H^2}}_{\sim m_{SUSY}^2}\end{aligned}$$

O((10^{2}eV)^2)

CMSSM "on the spot"?

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$$\lambda = \frac{g^2 + g'^2}{8}$$

$$\frac{m_Z^2}{2} \simeq -(|\mu|^2 + m_{H_u}^2(\Lambda) + \Delta m_{H_u}^2)$$

$$-m_H^2 \simeq |\mu|^2 + m_{H_u}^2$$

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$$\frac{m_Z^2}{2} \simeq -(|\mu|^2 + m_{H_u}^2(\Lambda) + \Delta m_{H_u}^2) \qquad -m_H^2 \simeq |\mu|^2 + m_{H_u}^2$$

$$\simeq -|\mu|^2 - 0.6 m_{H_u}^2(\Lambda) + 3.0 M_3^2(\Lambda) + 0.8 m_{\tilde{t}}^2(\Lambda) - 0.4 A_t(\Lambda) M_3(\Lambda) + \cdots$$

R. Dermisek, H. D. Kim 0601036[hep-ph]

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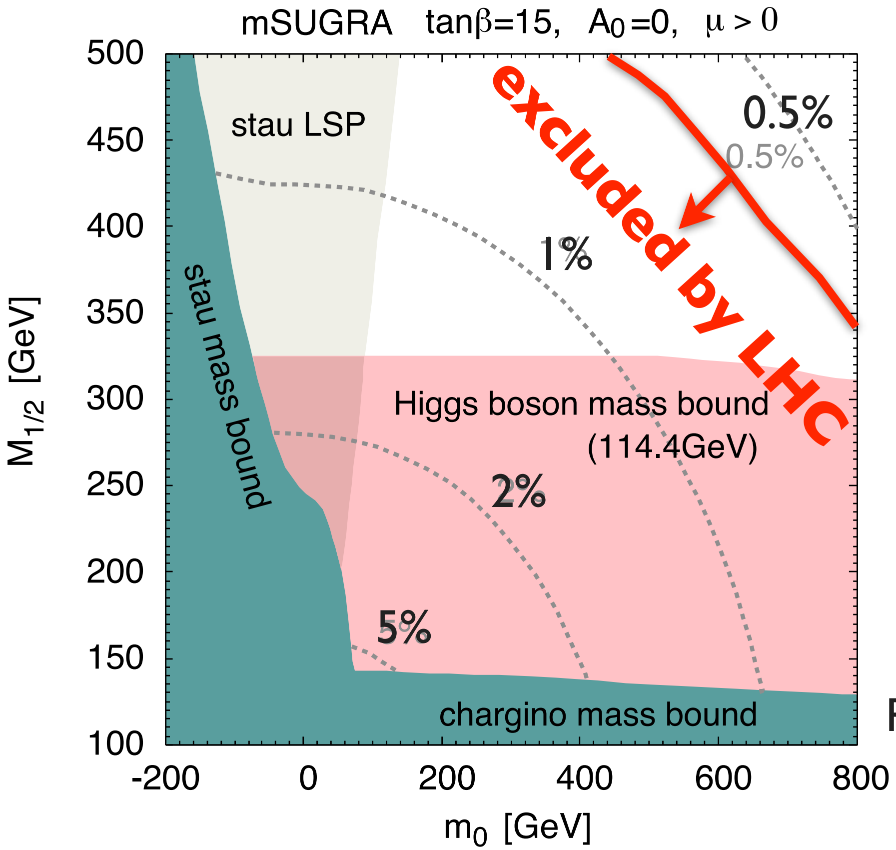
R. Dermisek, H. D. Kim 0601036[hep-ph]



R.Kitano, Y.Nomura 0602096[hep-ph]

Existence of the CMSSM is quite unnatural.

$$\lesssim 0.7 - 0.6\%$$

Natural SUSY model

- Naturalness

$$\frac{m_Z^2}{2} \simeq -(|\mu|^2 + m_{H_u}^2(\Lambda) + \Delta m_{H_u}^2)$$

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- $M_3,\ m_{\tilde{t}},\ m_{H_u}$ should be $\mathcal{O}(100)$ GeV.

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$\xrightarrow{\text{GUT}}$ $m_{1/2},\ m_{\mathbf{10}_3},\ m_{H_u}$ should be $\mathcal{O}(100)$ GeV.

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- a phenomenological model

$$m_0 \equiv m_{\mathbf{10}_{1,2}} = m_{\bar{\mathbf{5}}_{1,2,3}}$$

$$m_3 \equiv m_{\mathbf{10}_3} = m_{H_u} = m_{H_d} \qquad A_0,\ \tan\beta,\ \mathrm{sign}(\mu)$$

$$m_{1/2}$$

Natural SUSY model

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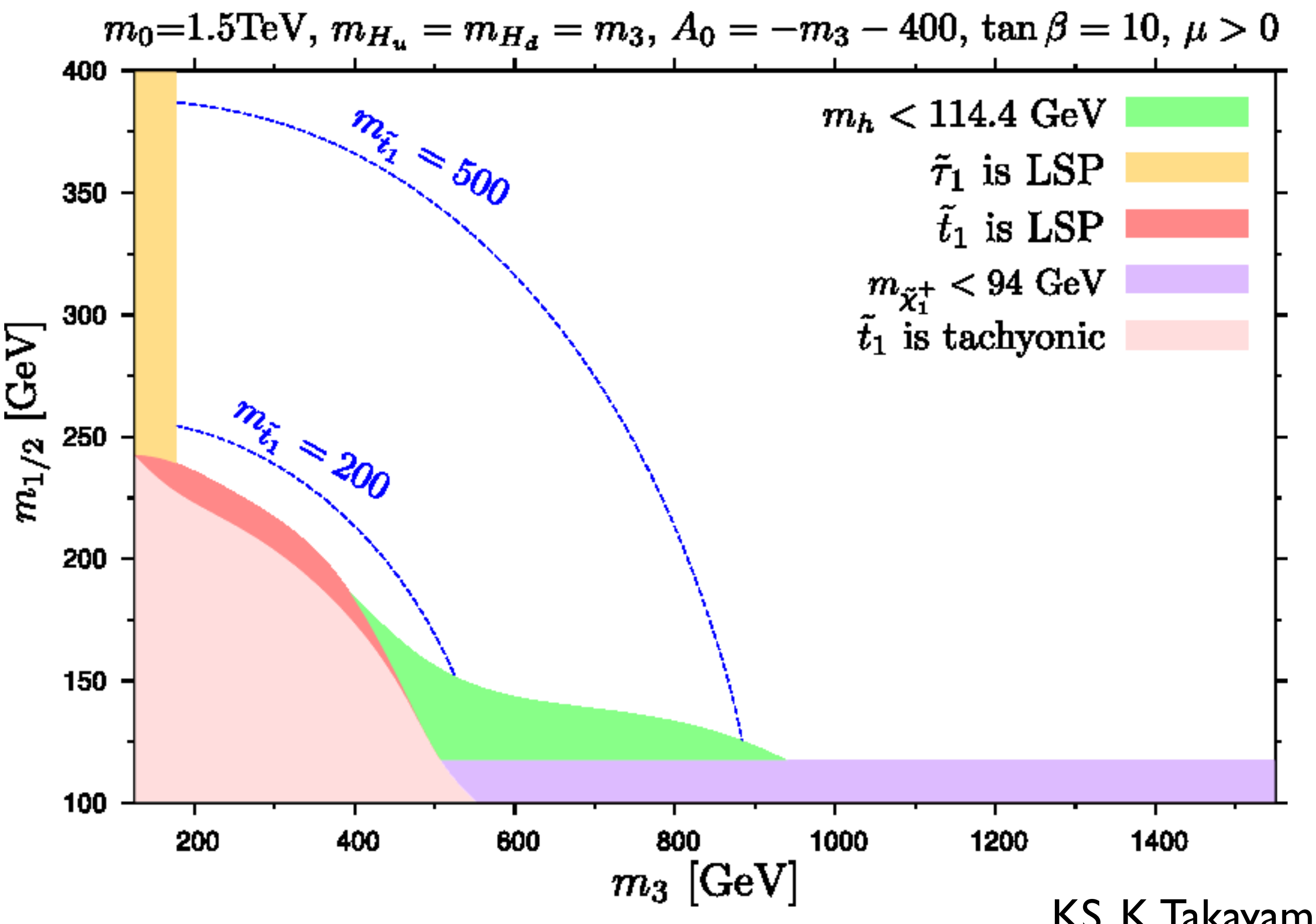
$\xrightarrow{\text{GUT}}$ $m_{1/2},\ m_{\mathbf{10}_3},\ m_{H_u}$ should be $\mathcal{O}(100)$ GeV.

- a phenomenological model

less sensitive to naturalness	$m_0 \equiv m_{\mathbf{10}_{1,2}} = m_{\bar{\mathbf{5}}_{1,2,3}}$	$\simeq 1.5$ TeV
		$A_0,\ \tan\beta,\ \mathrm{sign}(\mu)$
sensitive to naturalness	$m_3 \equiv m_{\mathbf{10}_3} = m_{H_u} = m_{H_d}$ $m_{1/2}$	$\simeq \mathcal{O}(100)$ GeV

Viable parameter region

- Softsusy is used.
- Small stop masses are reconciled with the Higgs mass bound by large A_0 .



KS, K.Takayama 1106.3794

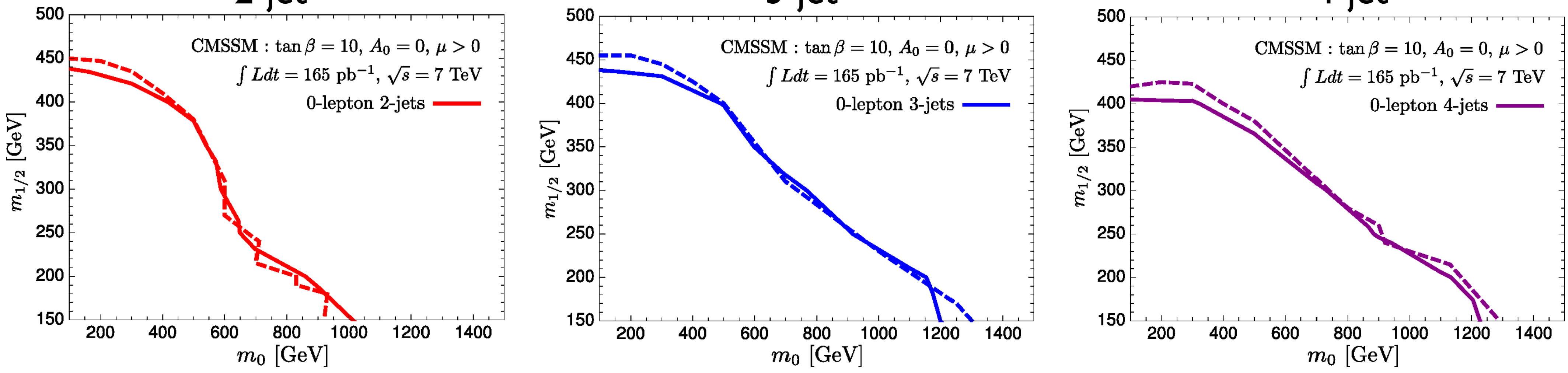
ATLAS 0-lepton analysis 165/pb

ATLAS-CONF-2011-086

Signal Region	≥ 2 jets	≥ 3 jets	≥ 4 jets
E_T^{miss} [GeV]	> 130	> 130	> 130
Leading jet p_T [GeV]	> 130	> 130	> 130
Second jet p_T [GeV]	> 40	> 40	> 40
Third jet p_T [GeV]	-	> 40	> 40
Fourth jet p_T [GeV]	-	-	> 40
$\Delta\phi(\text{jet}, E_T^{\text{miss}})_{\text{min}}$	> 0.4	> 0.4	> 0.4
$E_T^{\text{miss}}/m_{\text{eff}}$	> 0.3	> 0.25	> 0.25
m_{eff} [GeV]	> 1000	> 1000	> 1000
SM Background	12.1 ± 2.8	10.1 ± 2.3	7.3 ± 1.7
Observed Events	10	8	7

- CMSSM limits for validation (solid: our calculation, dashed: ATLAS)

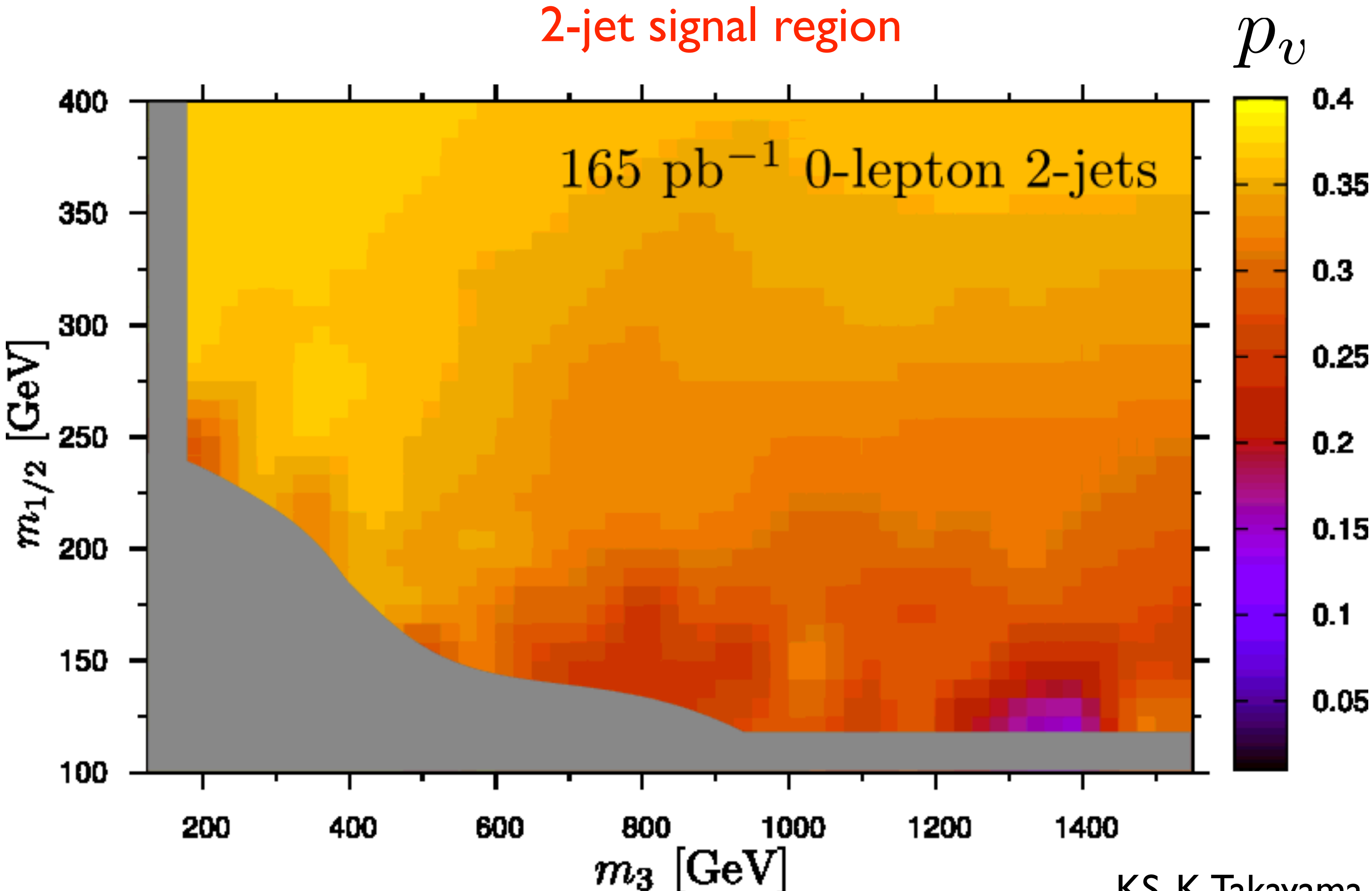
2-jet 3-jet 4-jet



Exclusion p-value

- No 95% exclusion region

2-jet signal region

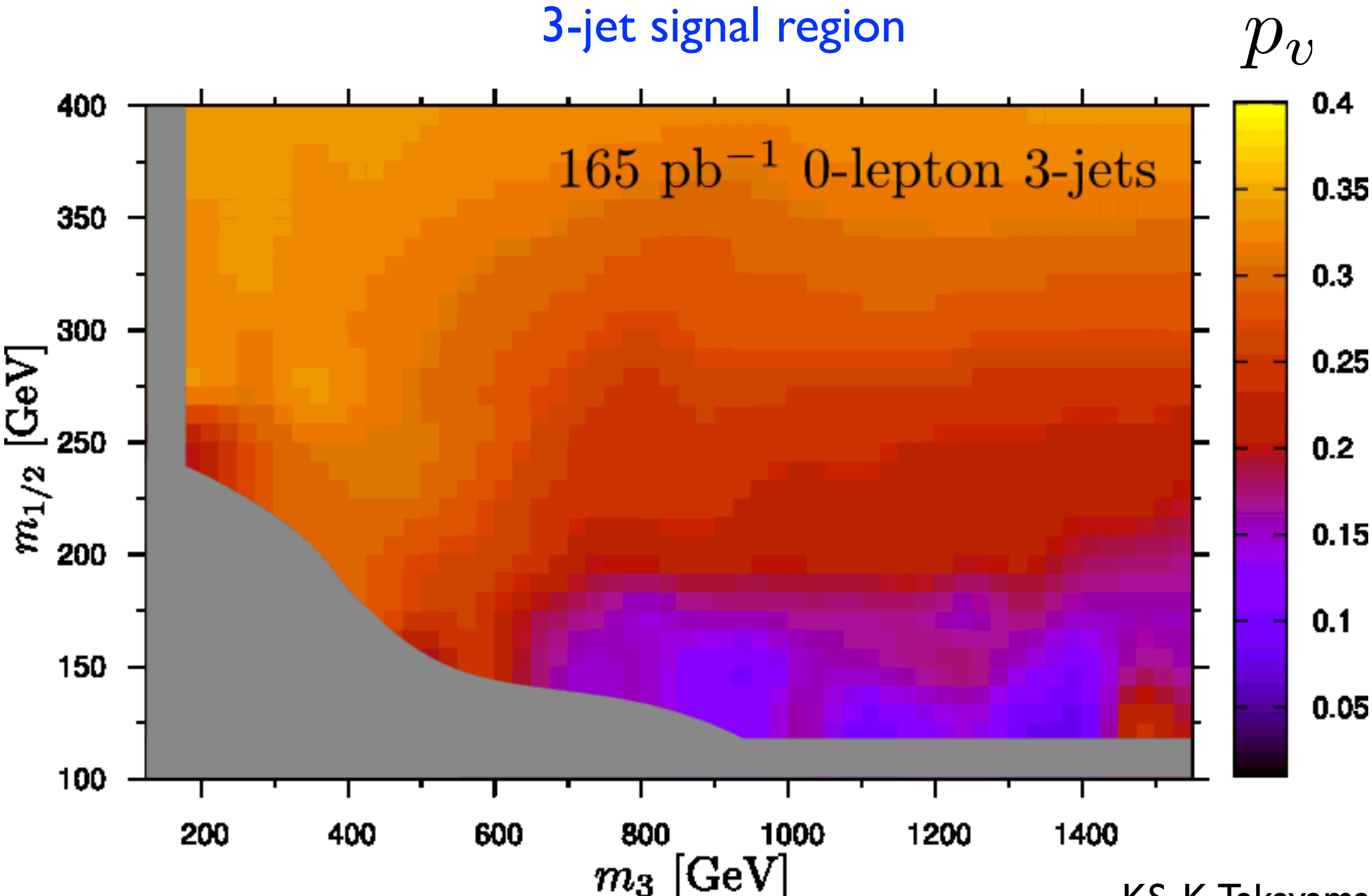


KS, K.Takayama 1106.3794

Exclusion p-value

- No 95% exclusion region

3-jet signal region

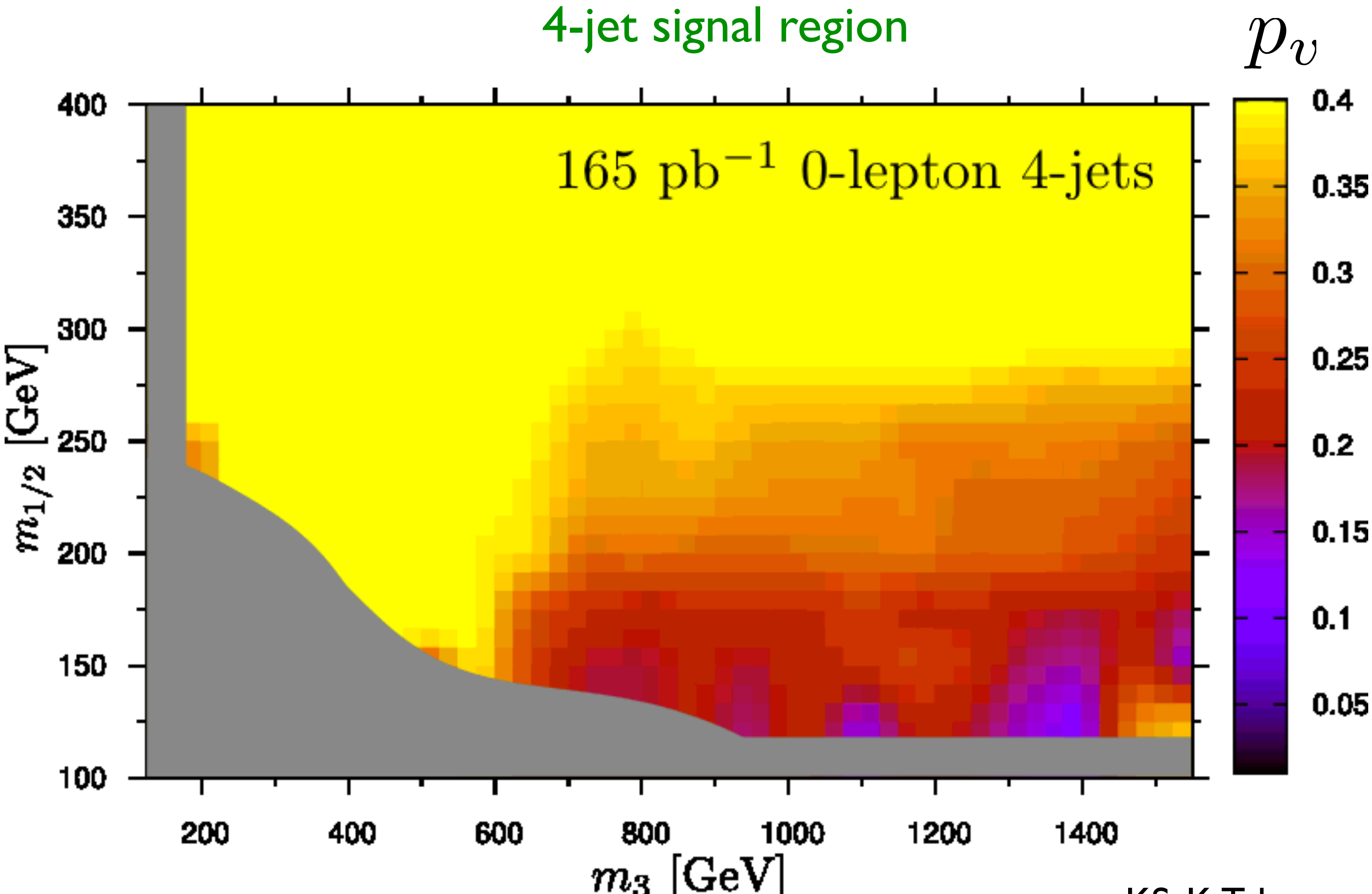


KS, K. Takayama 1106.3794

Exclusion p-value

- No 95% exclusion region

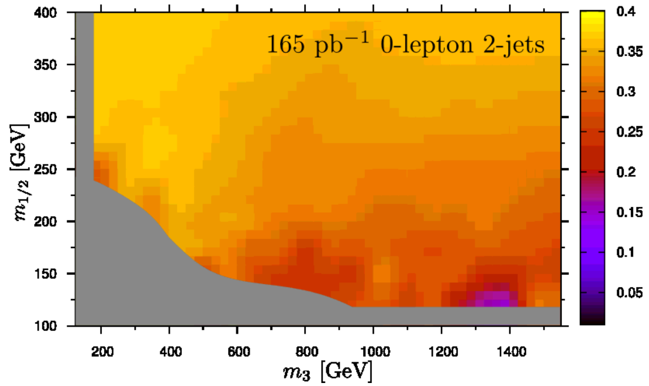
4-jet signal region



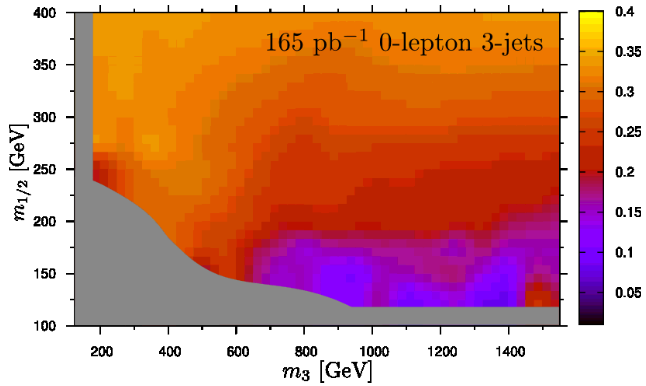
KS, K. Takayama 1106.3794

ATLAS 0-lepton 165/pb result

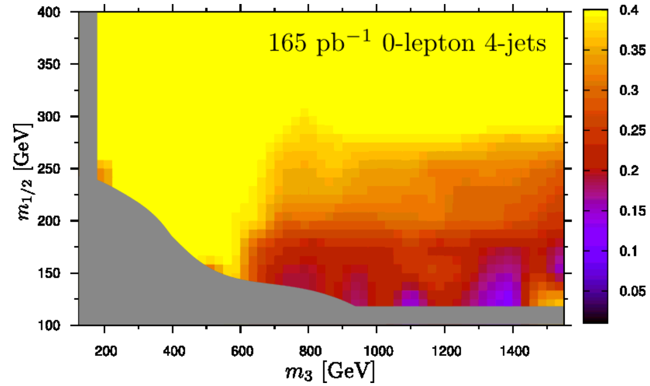
2-jets



3-jets



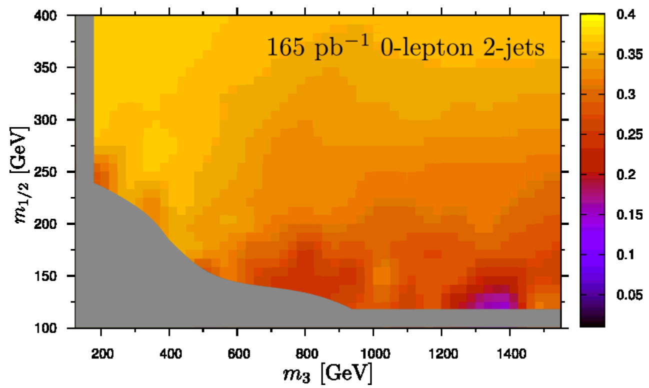
4-jets



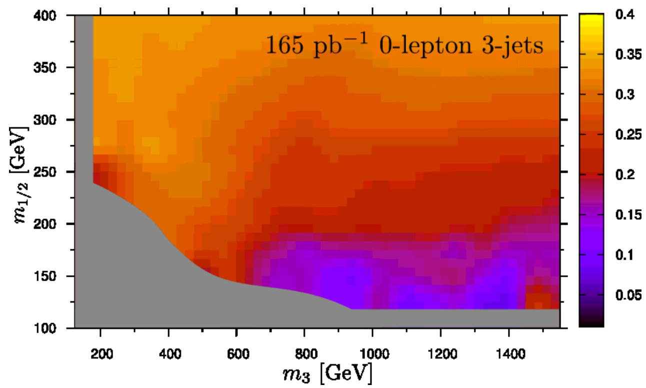
- The constraint from the 0-lepton analysis is very weak.

ATLAS 0-lepton 165/pb result

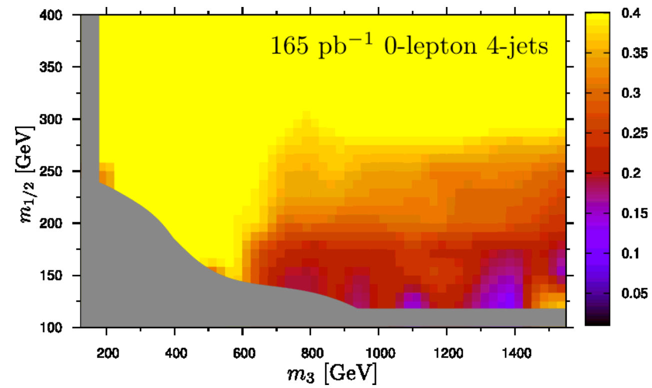
2-jets



3-jets



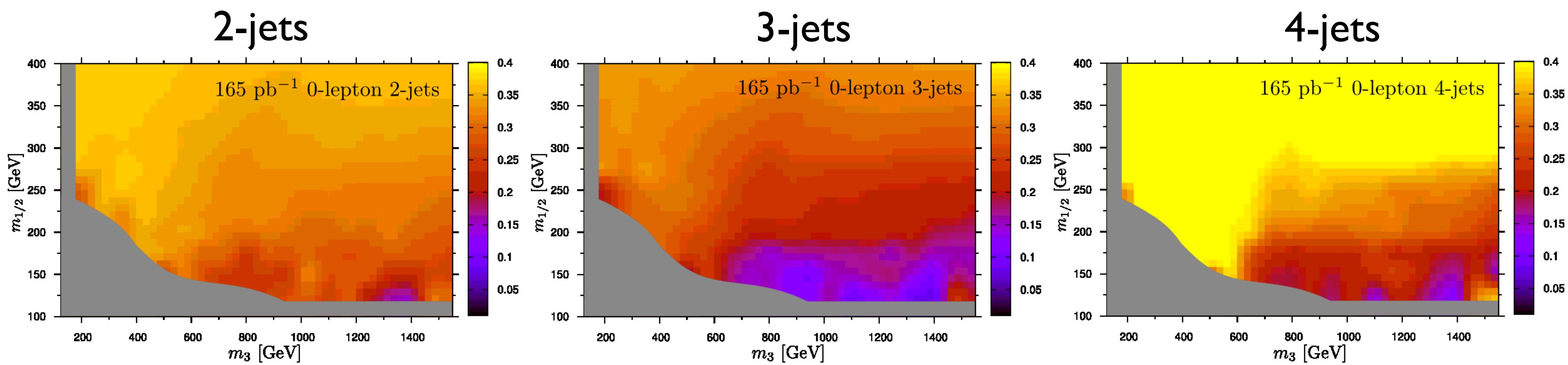
4-jets



- The constraint from the 0-lepton analysis is very weak.

- Small cross section compared to the CMSSM. σ(sq-sq), σ(sq-gl) are suppressed by the heavy squark mass. σ(gl-gl) cannot be large at 7 TeV because of small gluon, anti-quark components in PDF with large energy fraction.

ATLAS 0-lepton 165/pb result



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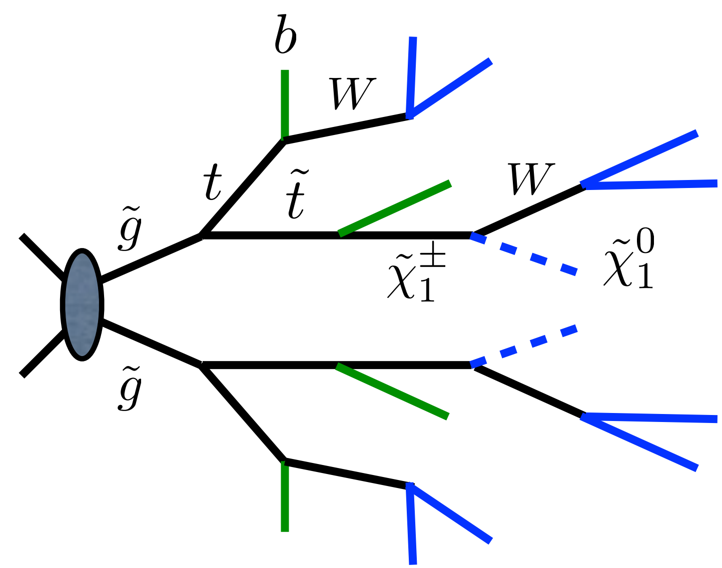
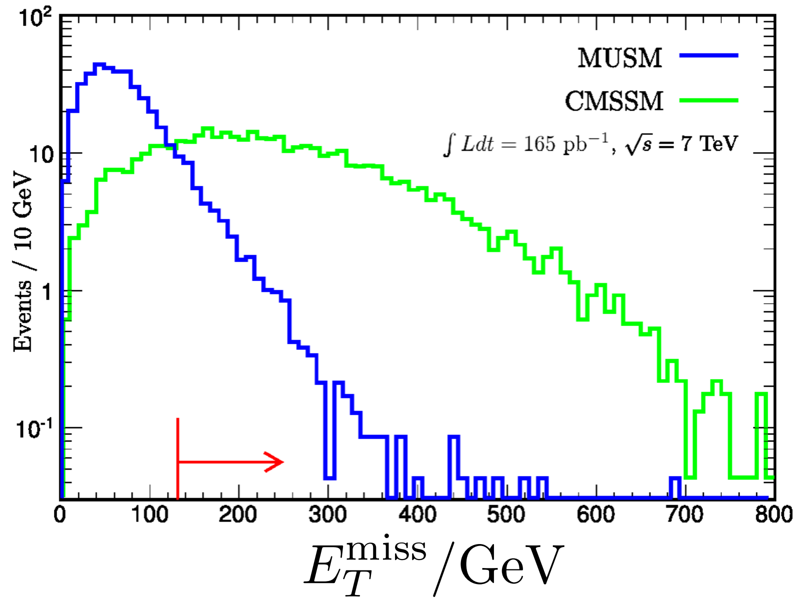
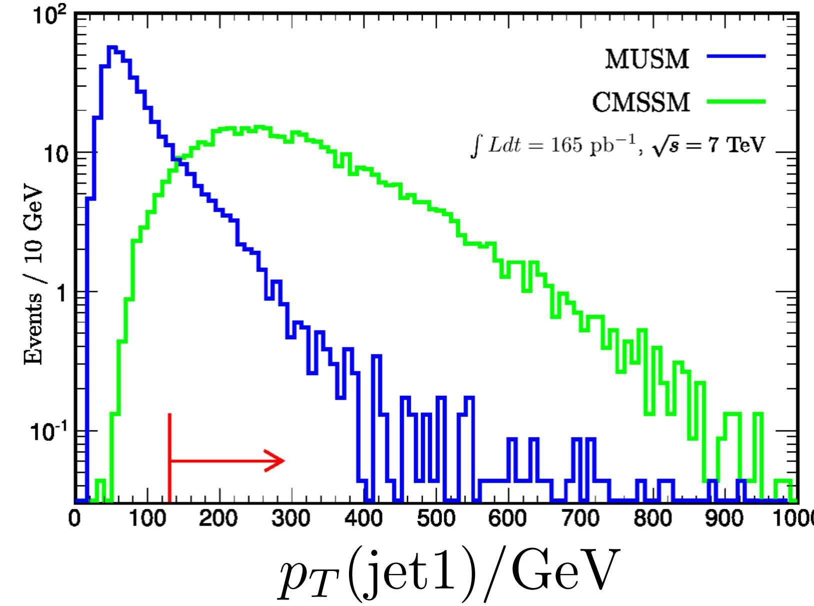
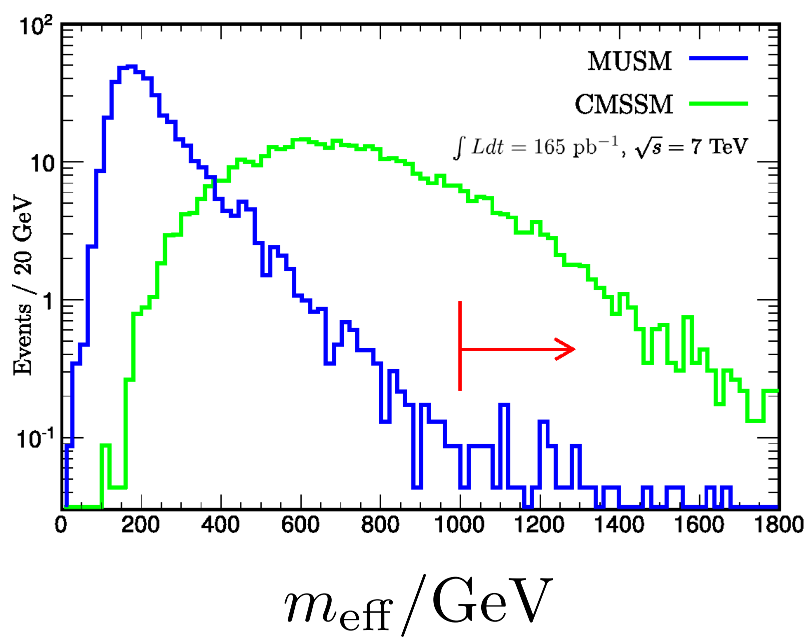
• Gluino typically decays to 7 particles. The gluino mass energy is divided by 7 particles and each jet cannot be hard. → fail to pass the high pT cut



E_{Tmiss}, highest p_T, m_{eff}





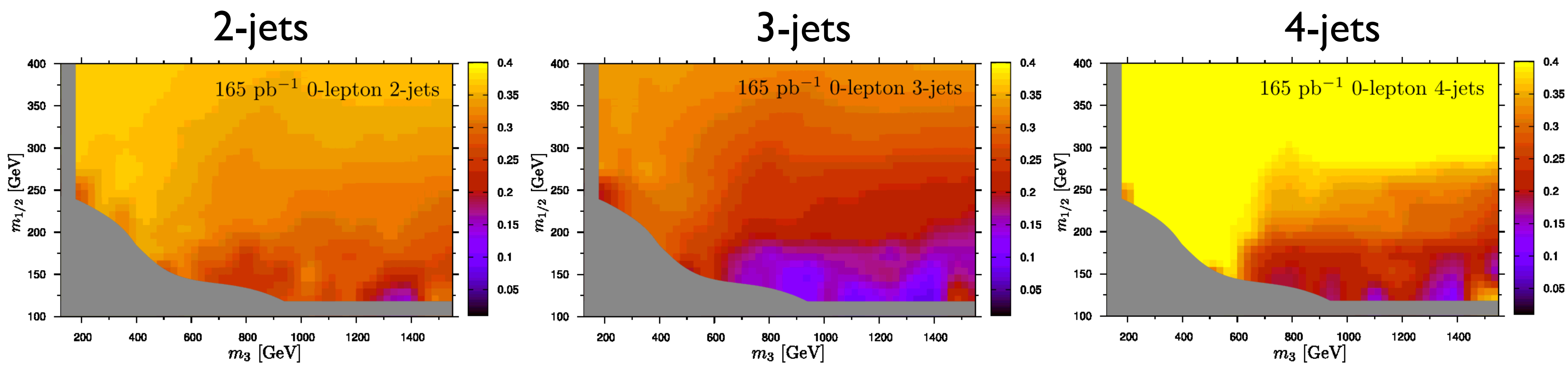


- Most of the SUSY events fail to pass the selection cuts.

$m_0 = 350\,\mathrm{GeV}$, $m_{1/2} = 250\,\mathrm{GeV}$ for the CMSSM

$m_3 = 350\,\mathrm{GeV}$, $m_{1/2} = 250\,\mathrm{GeV}$ for the light 3rd gen.

ATLAS 0-lepton 165/pb result



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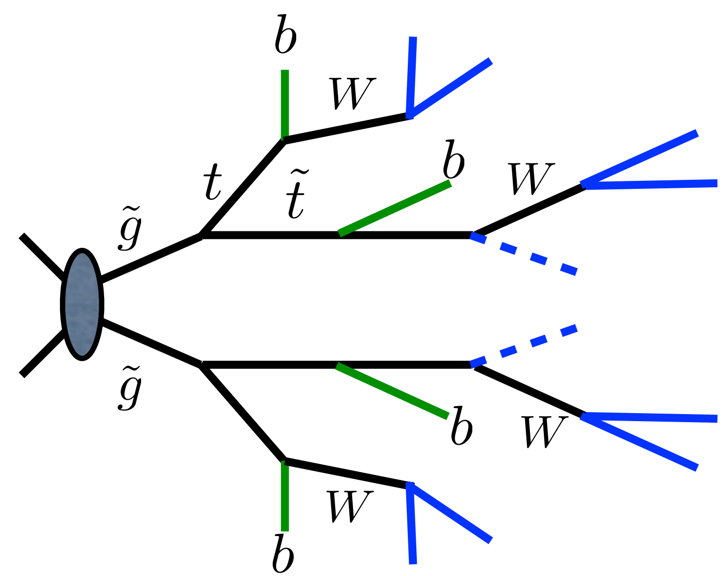
- Typically gluino decays to 7 particles in the final state. The gluino mass energy is divided by 7 particles and each jet cannot be hard. → fail to pass the high pT cut

- Large p_T, E_T^{miss}, meff cuts are not good strategies to exclude/discover this scenario.



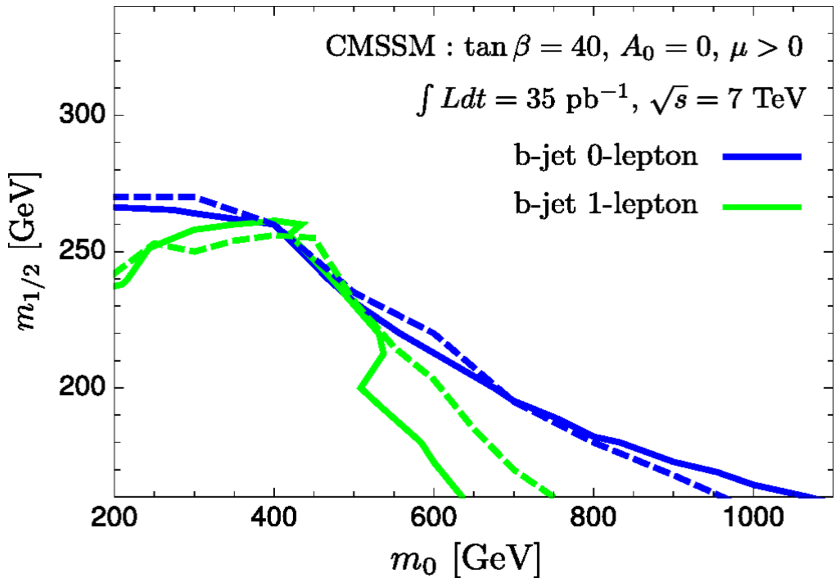
ATLAS b-jet analysis 35/pb

ATLAS 1103.4344

- 0-lepton: designed for $\tilde{g} \to b\tilde{b}_1^*$
- 1-lepton: designed for $\tilde{g} \to t\tilde{t}_1^*$

Signal Region	0-lepton	1-lepton
number of b-jets	≥ 1	≥ 1
$E_T^{\rm miss}$ [GeV]	> 100	> 80
Leading jet p_T [GeV]	> 120	> 60
Second jet p_T [GeV]	> 30	> 30
Third jet p_T [GeV]	> 30	-
$\Delta\phi(\text{jet}, E_T^{\rm miss})_{\rm min}$	> 0.4	> 0.4
$E_T^{\rm miss}/m_{\rm eff}$	> 0.2	-
$m_{\rm eff}$ [GeV]	> 600	> 500
m_T [GeV]	-	> 100
SM Background	19.6 ± 6.9	14.7 ± 3.7
Observed Events	15	9

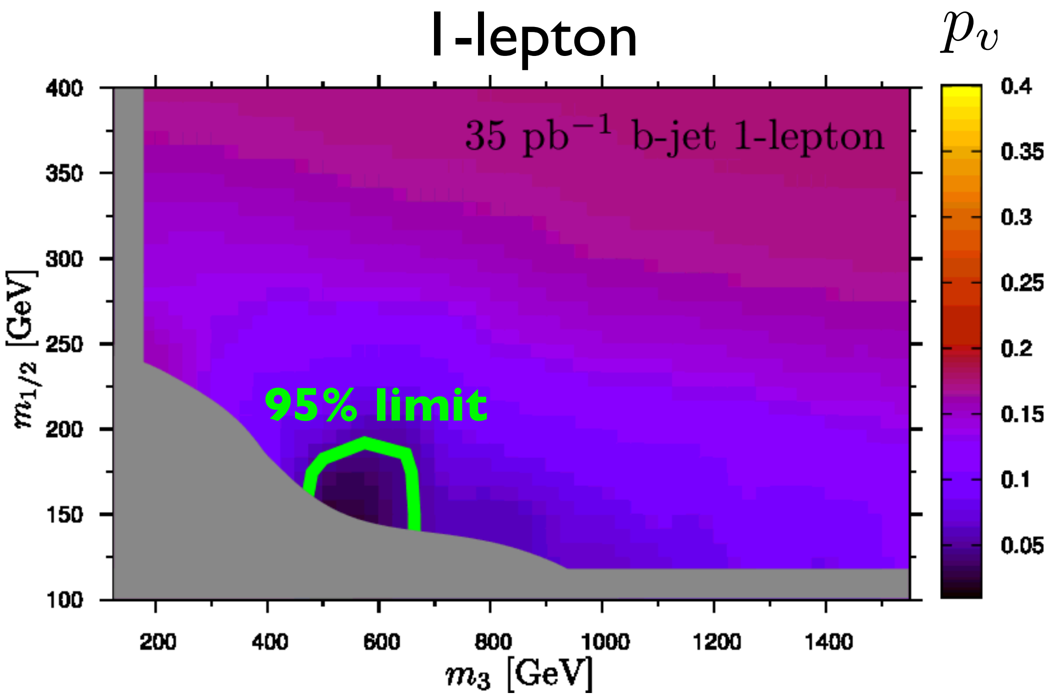
- CMSSM limits for validation



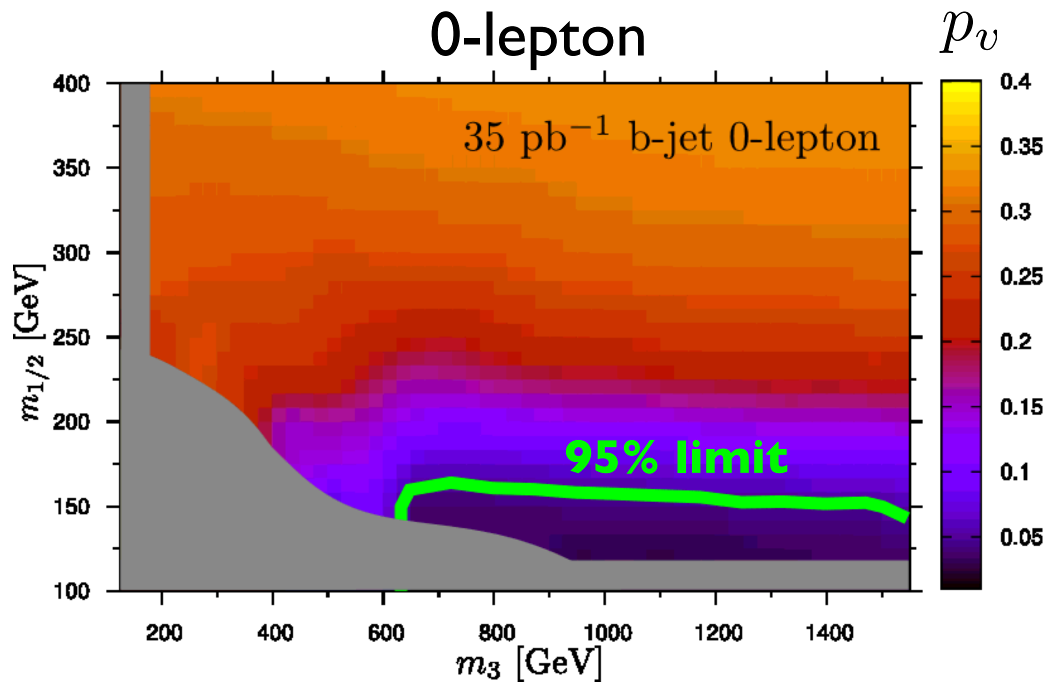
solid: our calculation, dashed: ATLAS

ATLAS b-jet 35/pb result

1-lepton



0-lepton



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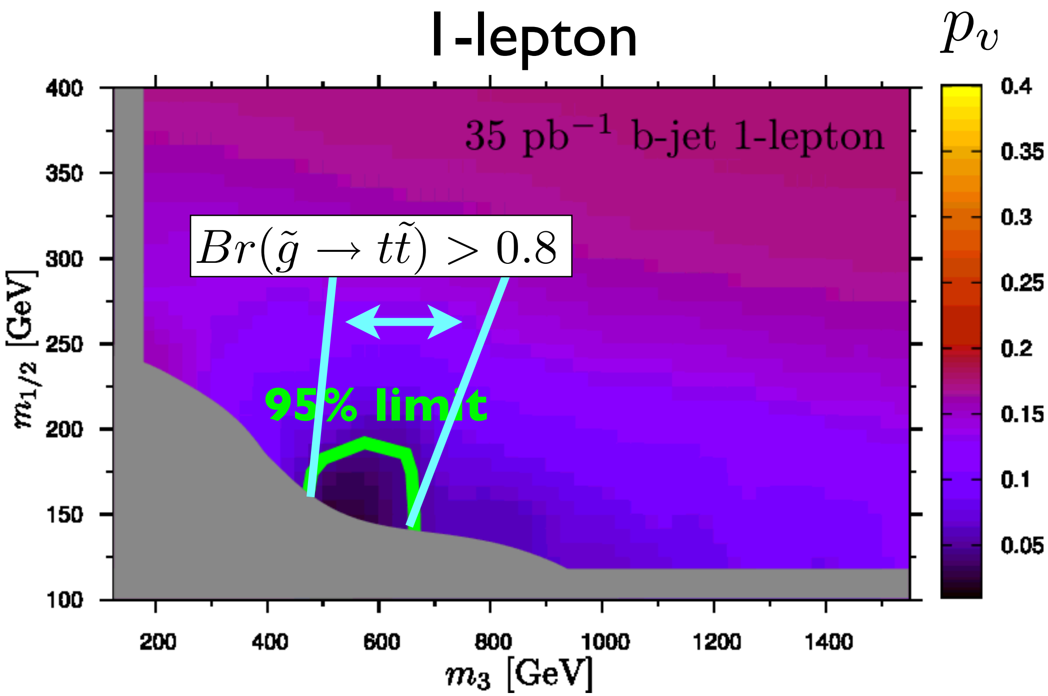
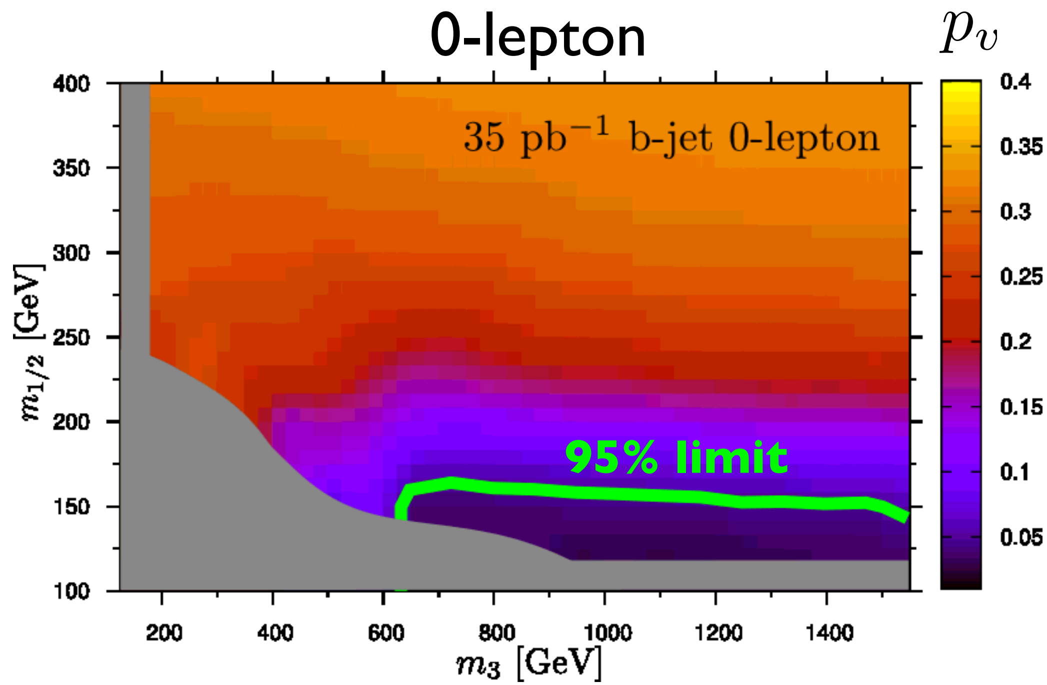
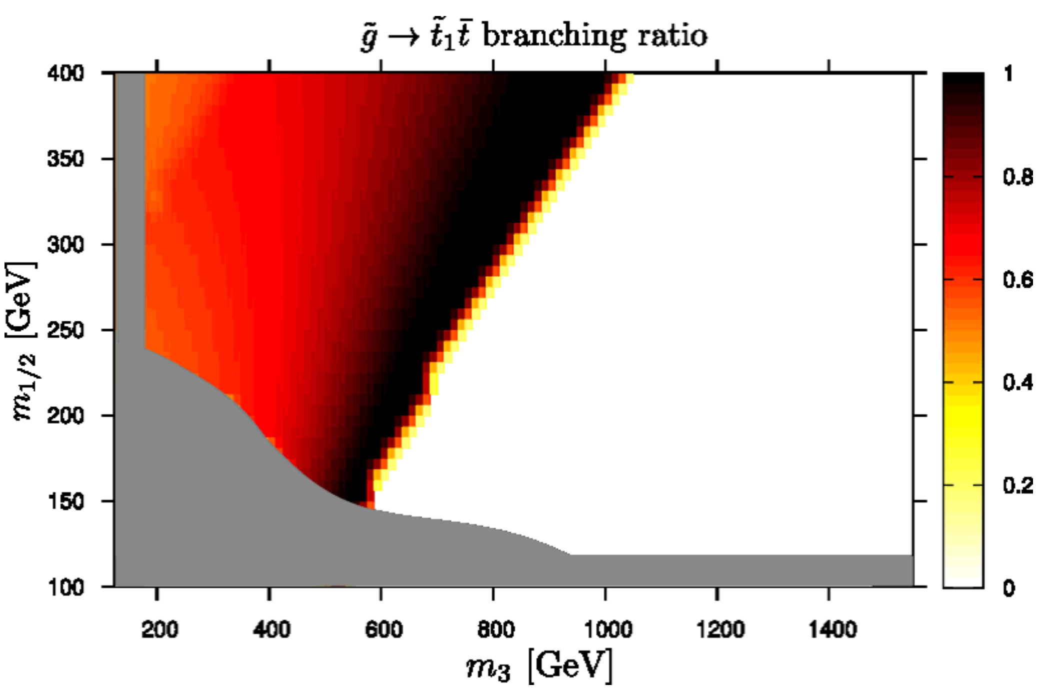
ATLAS b-jet 35/pb result







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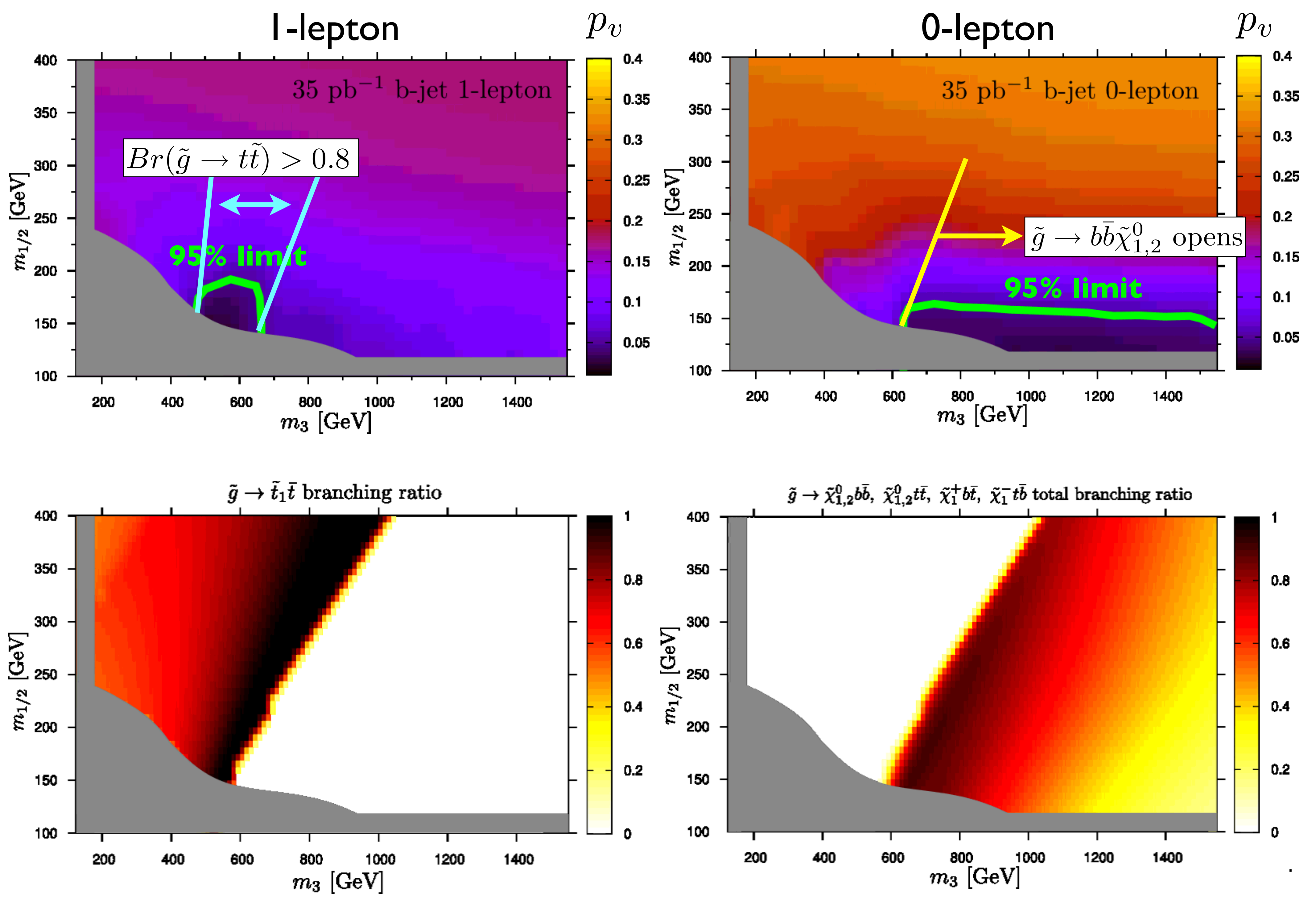
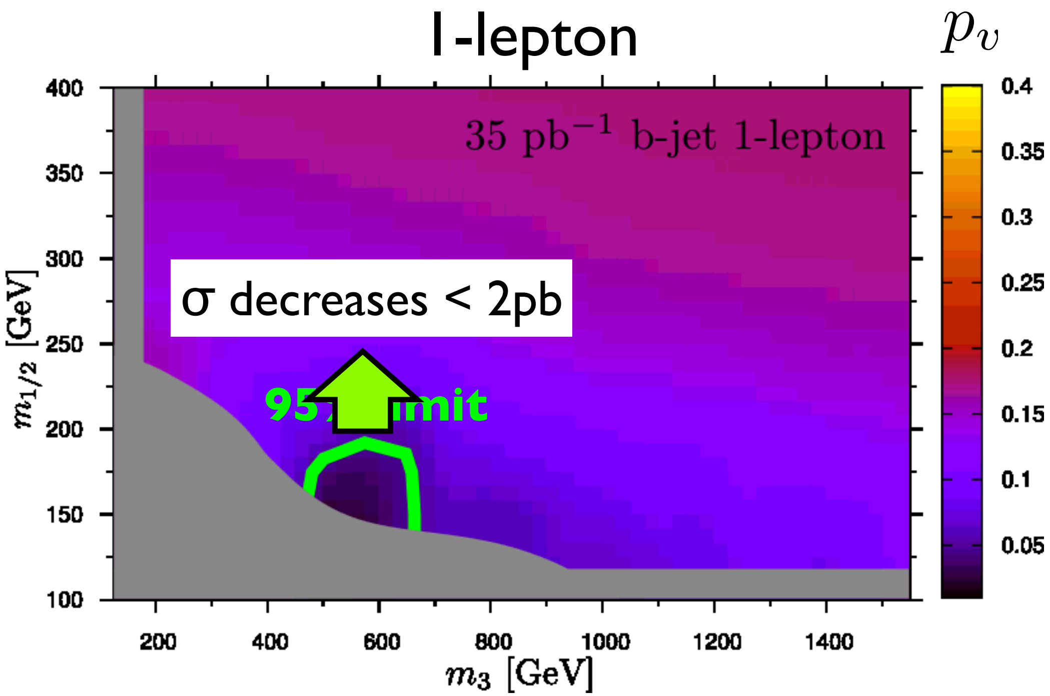
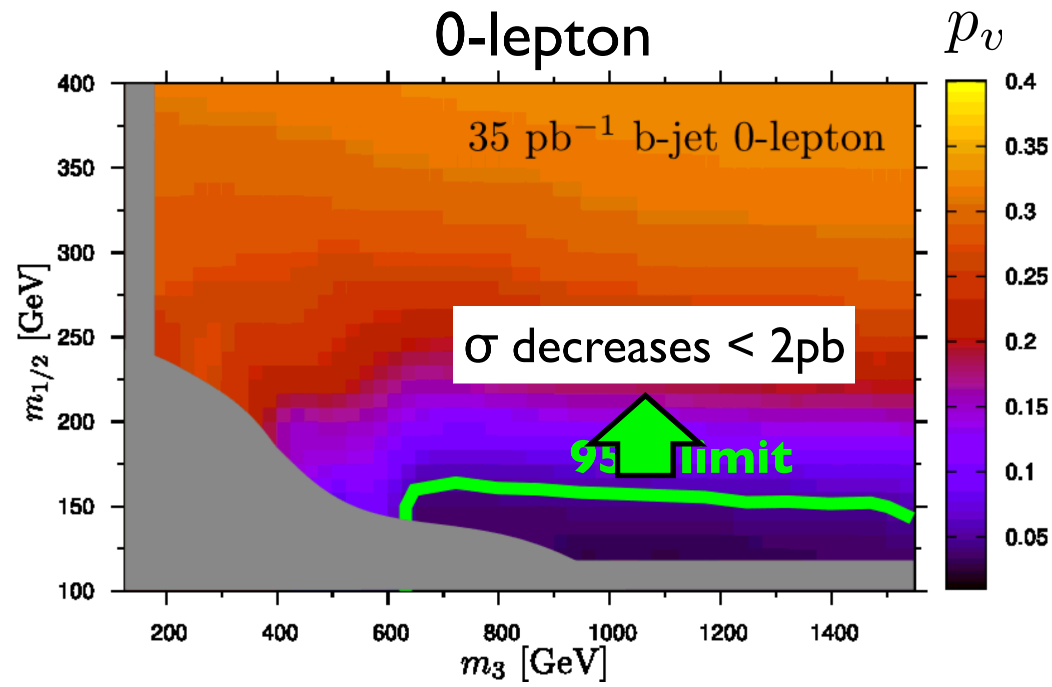
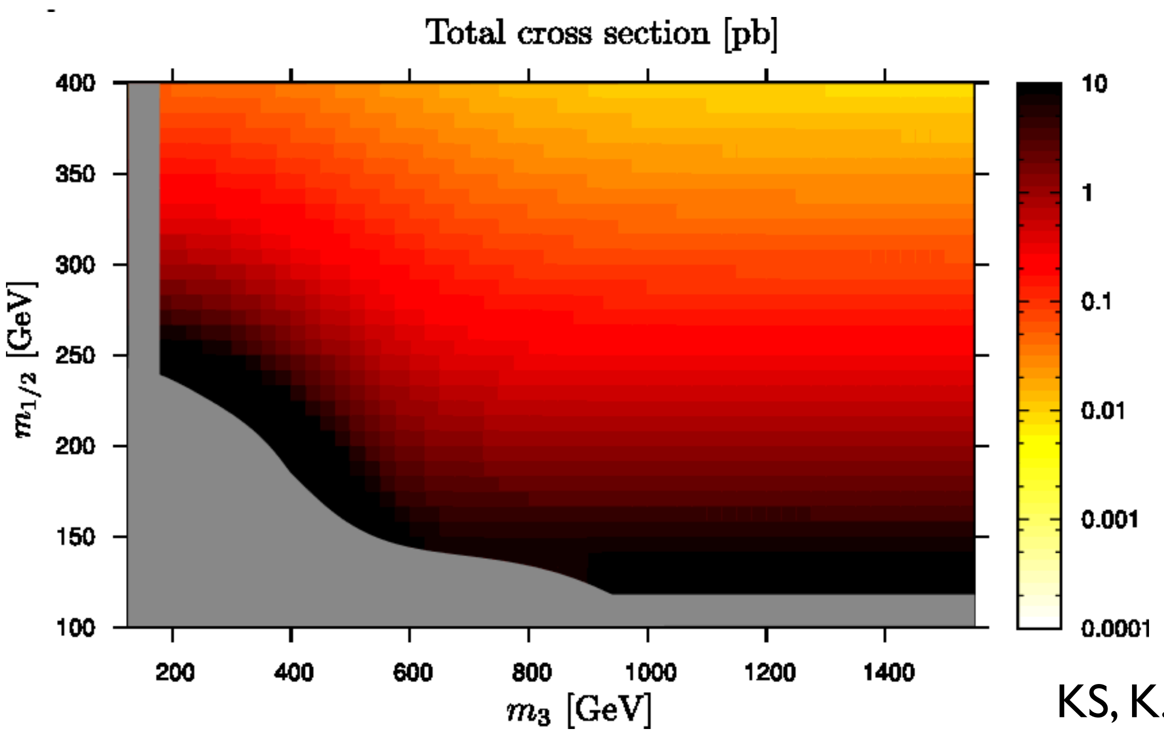
ATLAS b-jet 35/pb result



ATLAS b-jet 35/pb result







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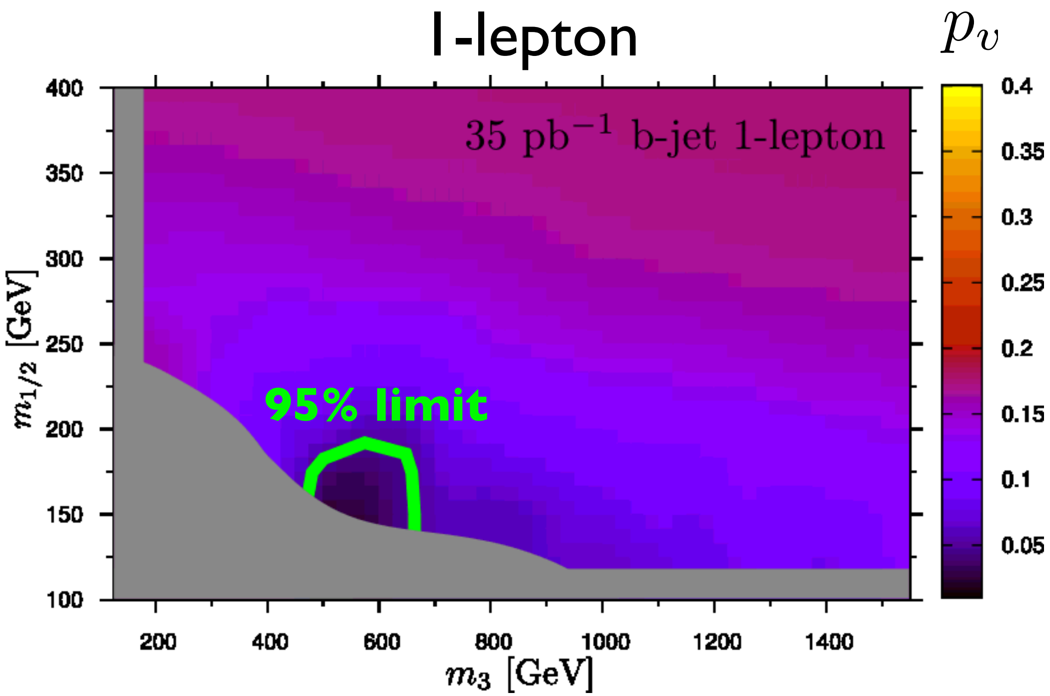
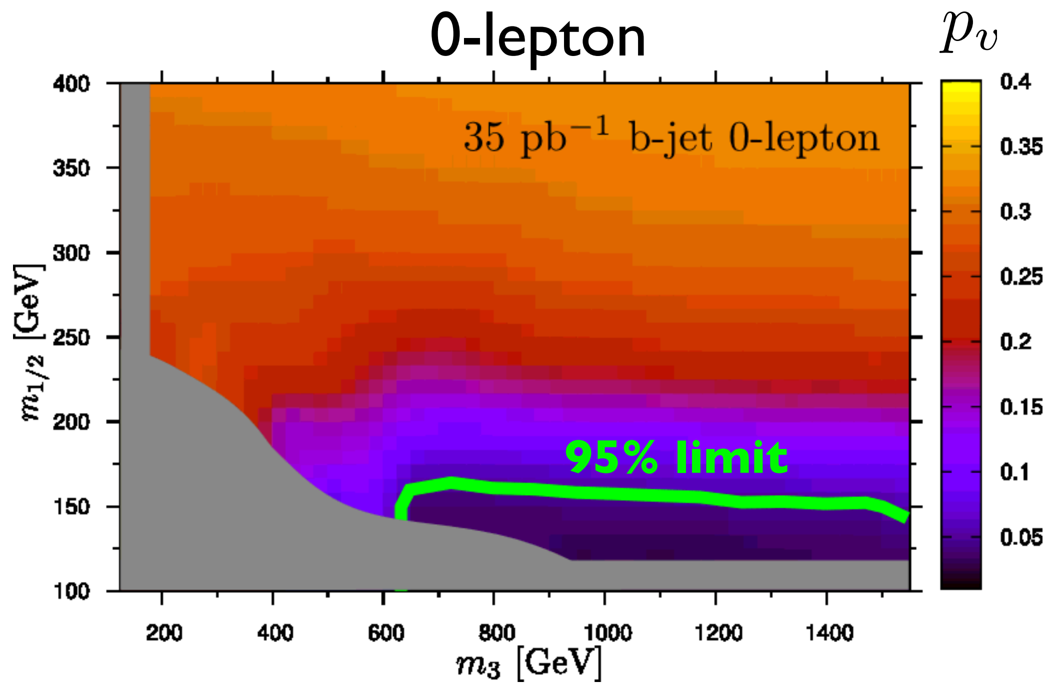
ATLAS b-jet 35/pb result





- Constraints are weak.

- There exists allowed region where m1/2 < 200GeV and m3 < 400GeV.

- In the light 3rd generation scenario, naturalness can be realised under the recent LHC constraints.

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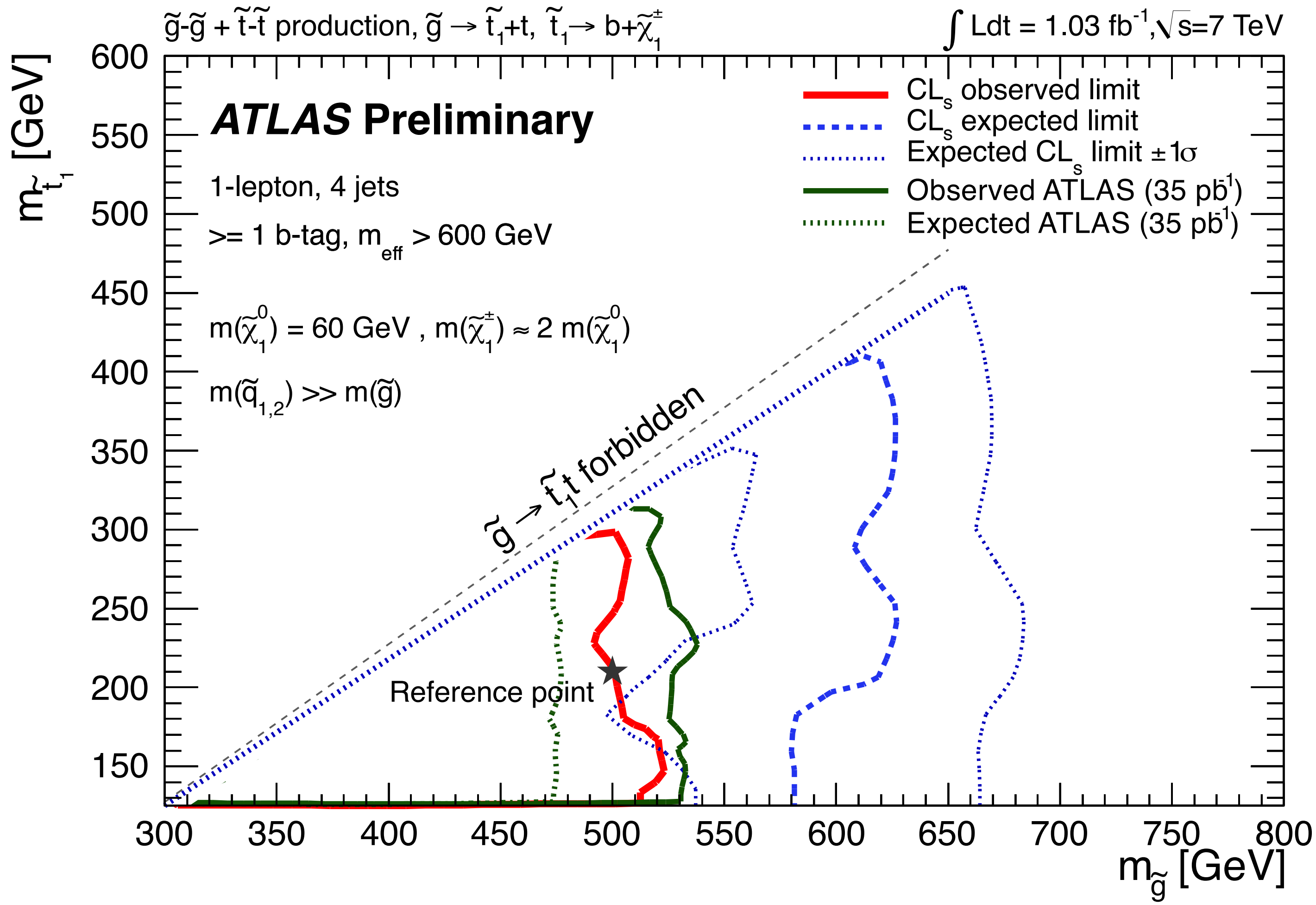
ATLAS b-jet 1-lepton 1/fb

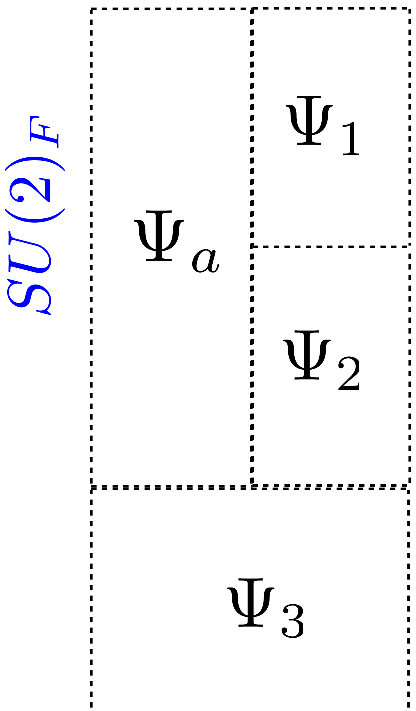


ATLAS-CONF-2011-130

E_6 with SU(2) flavour model

- Why $m_3 \neq m_0$?

$$\mathbf{27} = \mathbf{16}[\mathbf{10} + \overline{\mathbf{5}} + \mathbf{1}] + \mathbf{10}[\mathbf{5} + \overline{\mathbf{5}}'] + \mathbf{1}'$$



E_6 with SU(2) flavour model

N. Maekawa
0212141[hep-ph]

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$SU(2)_F$

Ψ_a	Ψ_1	$\mathbf{10}_1$	$\bar{\mathbf{5}}'_1$ $\bar{\mathbf{5}}_1$	$\mathbf{5}_1$
	Ψ_2	$\mathbf{10}_2$	$\bar{\mathbf{5}}'_2$ $\bar{\mathbf{5}}_2$	$\mathbf{5}_2$
Ψ_3		$\mathbf{10}_3$	$\bar{\mathbf{5}}'_3$ $\bar{\mathbf{5}}_3$	$\mathbf{5}_3$

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Yukawa couplings

$$W = Y_{33}\Psi_3\Psi_3\Psi_H$$

E_6 with SU(2) flavour model

N. Maekawa
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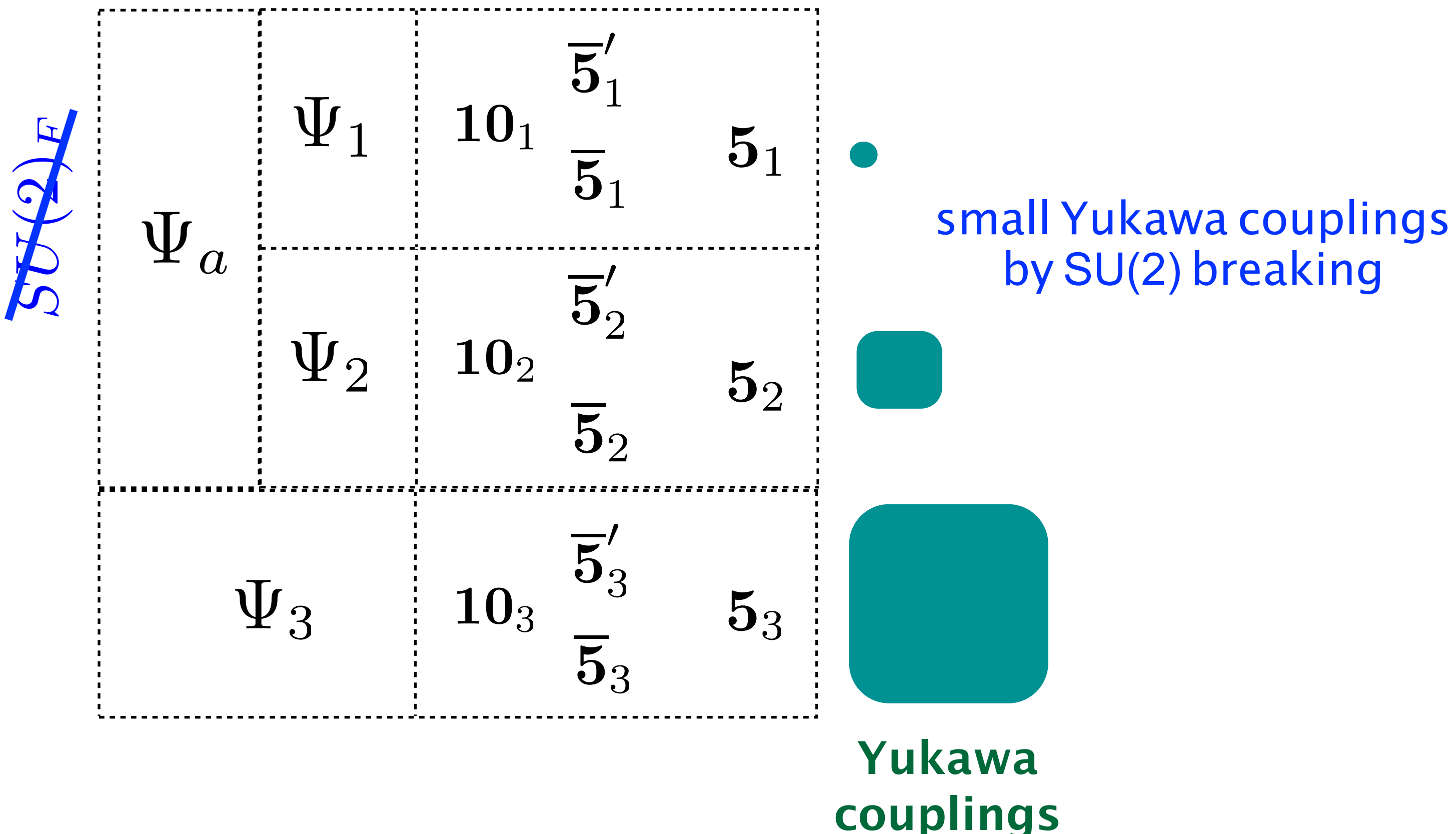

$$Y_{33} > Y_{32} > Y_{22} \cdots$$

$$W = Y_{33}\Psi_3\Psi_3\Psi_H + Y_{ab}\Psi_a\Psi_b\Psi_H$$

E_6 with SU(2) flavour model

N. Maekawa
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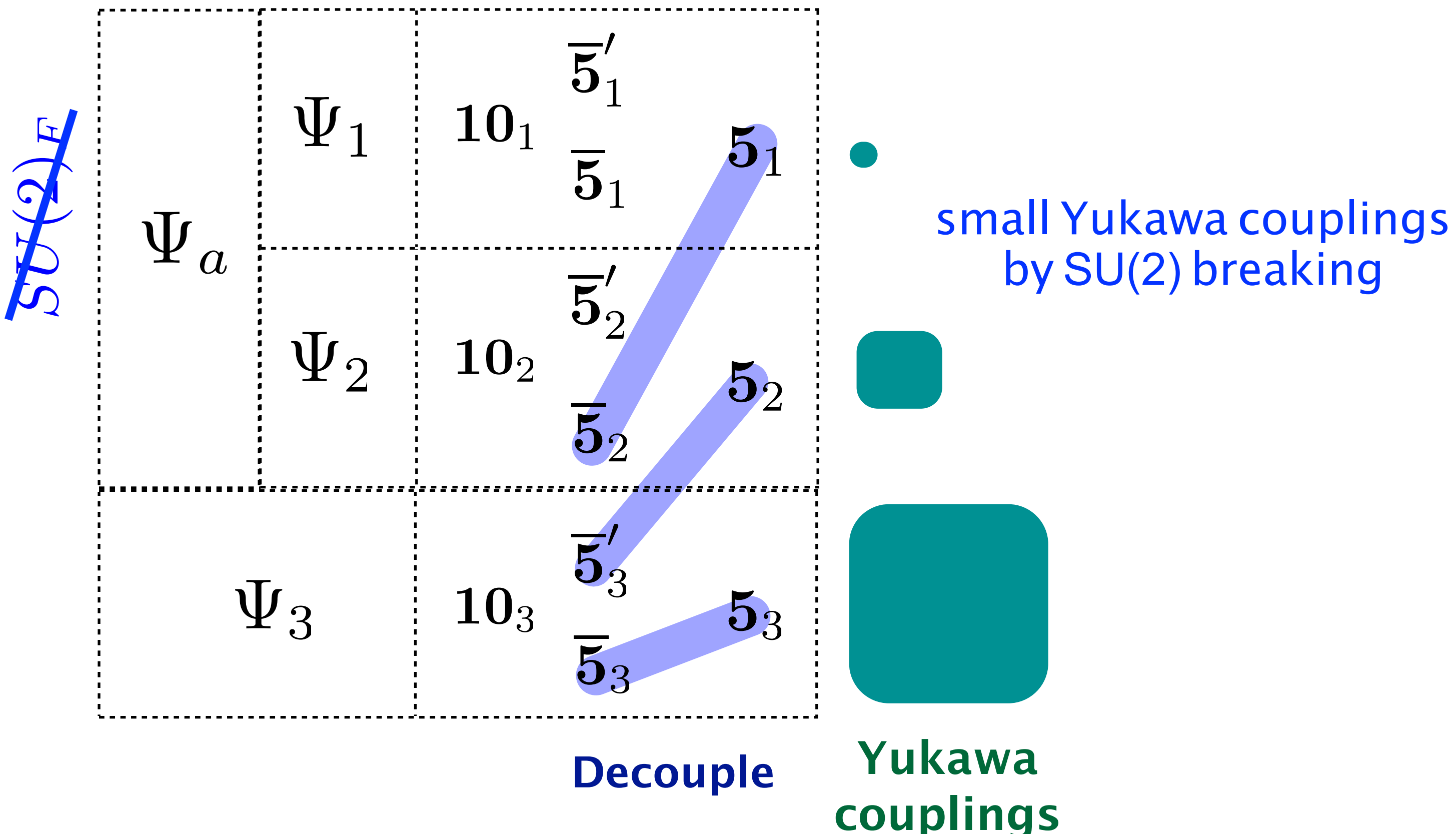

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$$= Y_{ij}\mathbf{5}_i\bar{\mathbf{5}}_j\langle\mathbf{1}_H\rangle + Y_{ij}\mathbf{5}_i\bar{\mathbf{5}}'{}_j\langle\mathbf{1}'{}_H\rangle$$

E_6 with SU(2) flavour model

N. Maekawa
0212141[hep-ph]

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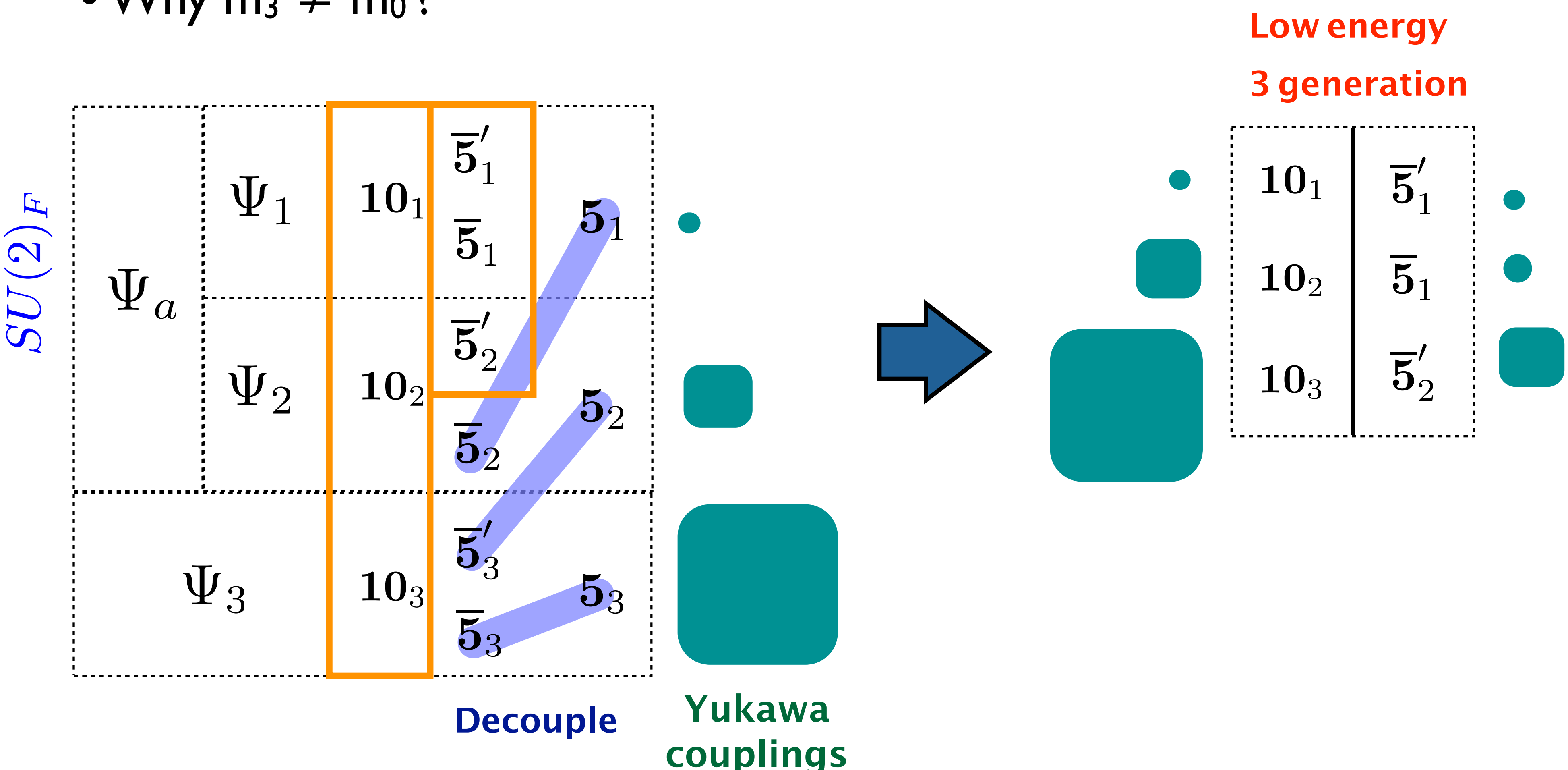

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0212141[hep-ph]

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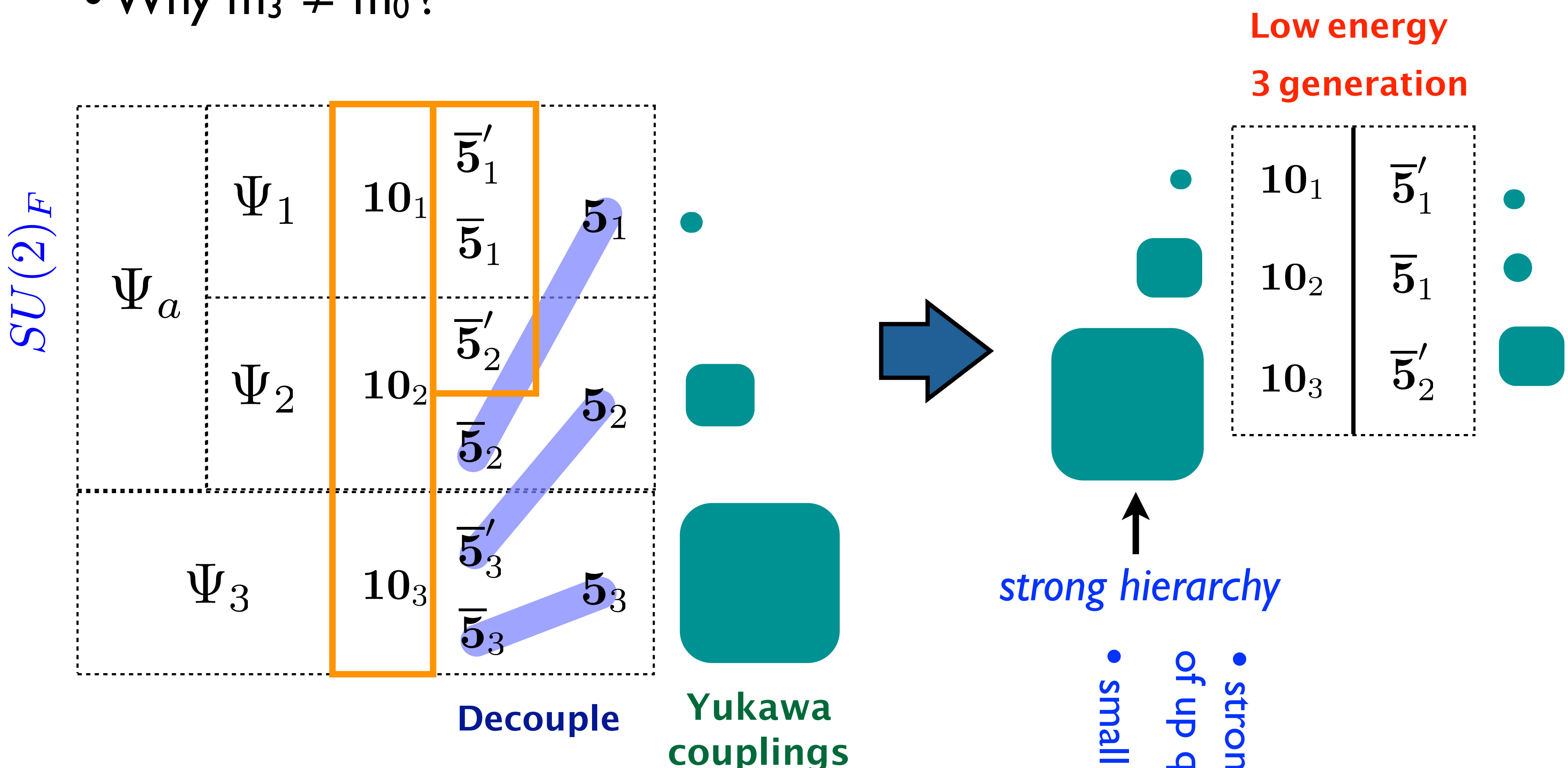

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$$= Y_{ij}\mathbf{5}_i\bar{\mathbf{5}}_j\langle\mathbf{1}_H\rangle + Y_{ij}\mathbf{5}_i\bar{\mathbf{5}}'_j\langle\mathbf{1}'_H\rangle$$

- strong mass hierarchy of up quark sector
- small CKM mixing

E_6 with SU(2) flavour model

N. Maekawa
0212141[hep-ph]

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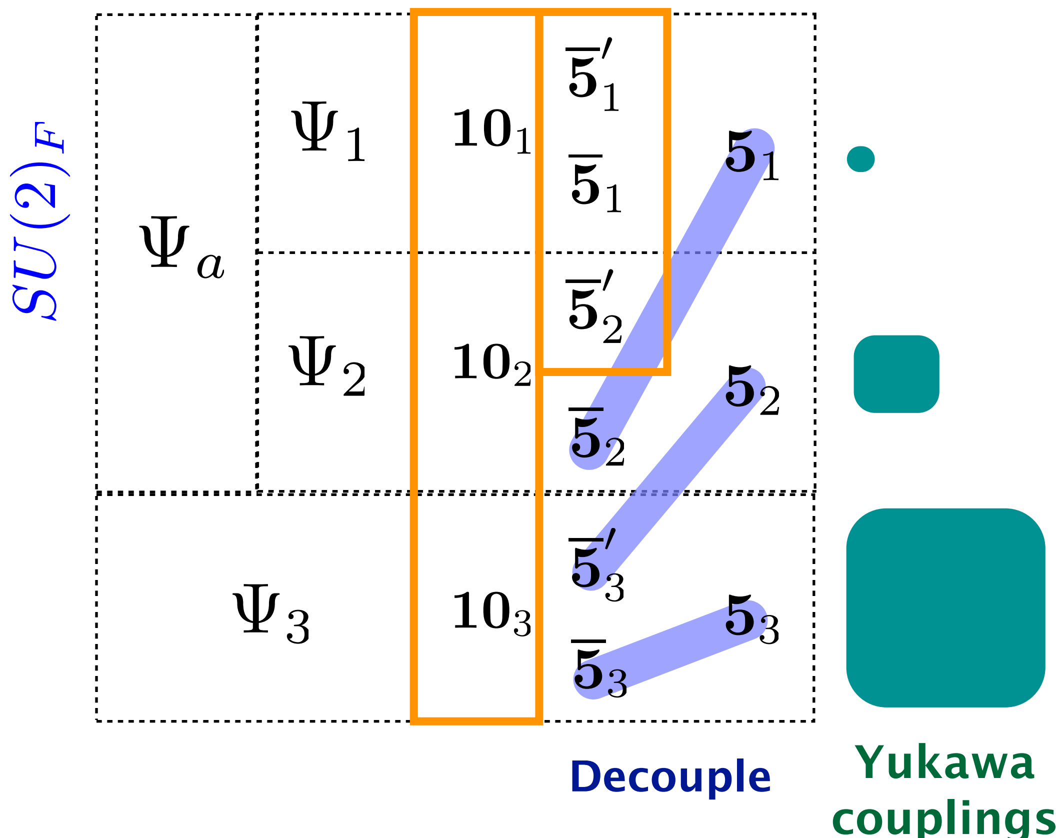

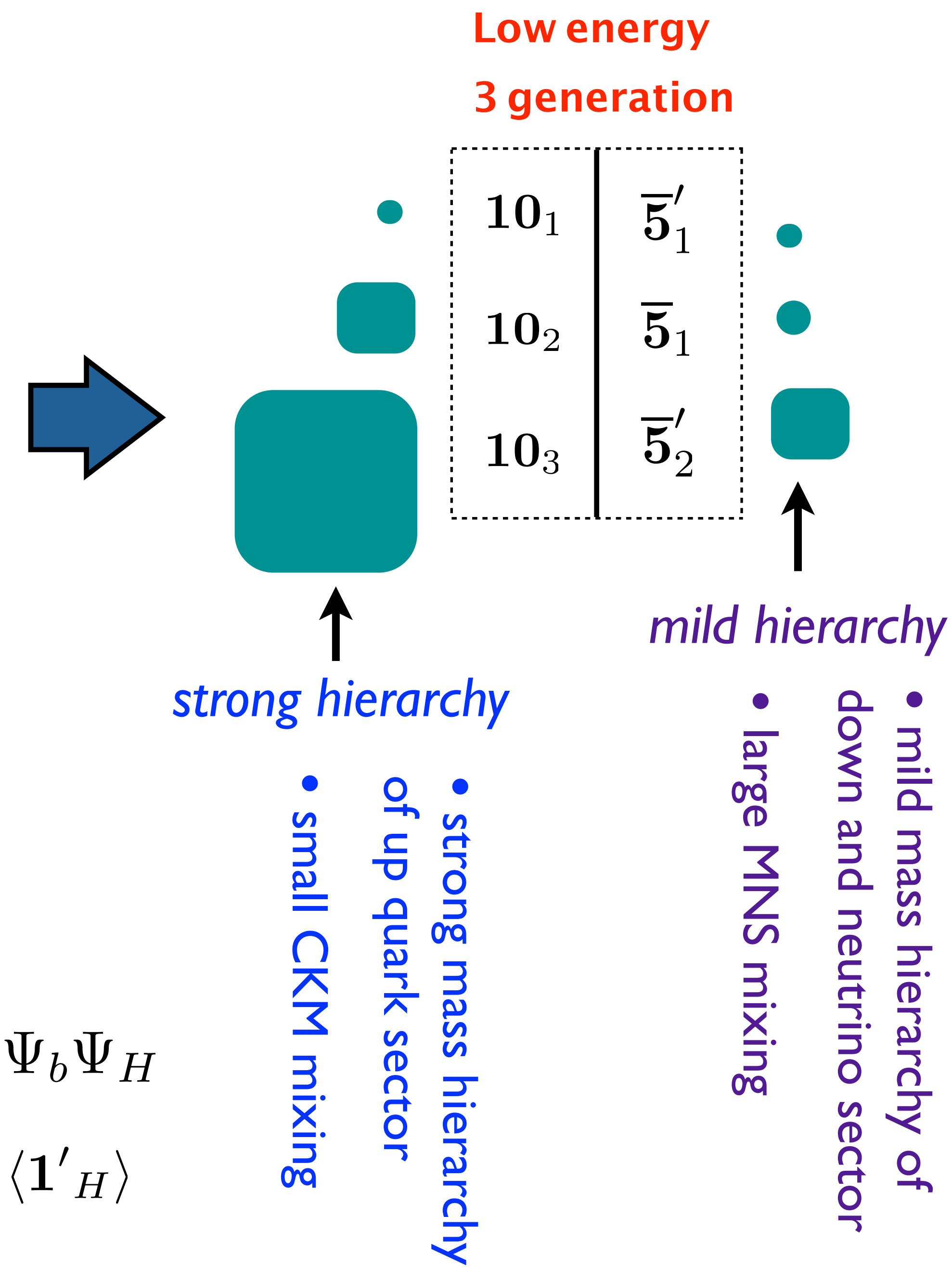

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E_6 with SU(2) flavour model

N. Maekawa
0212141[hep-ph]

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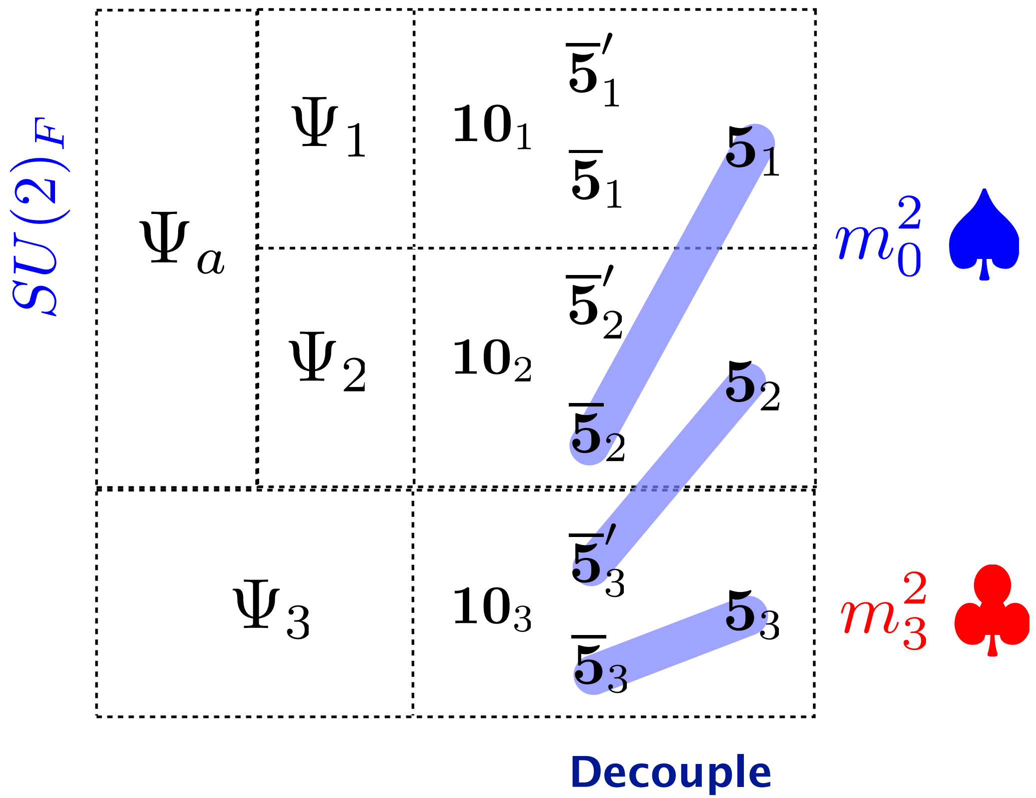

- soft scalar mass

$$V = m_0^2 \widetilde{\Psi}_a^\dagger \widetilde{\Psi}_a + m_3^2 \widetilde{\Psi}_3^\dagger \widetilde{\Psi}_3$$

E_6 with $SU(2)$ flavour model

N. Maekawa
0212141[hep-ph]

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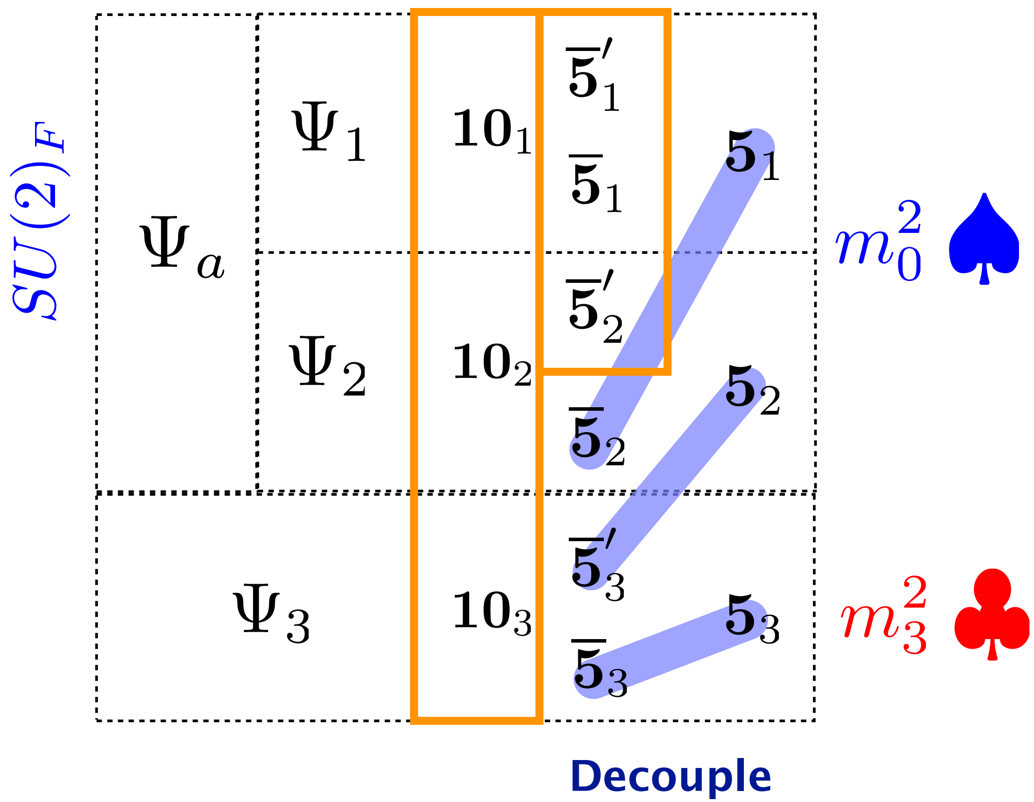
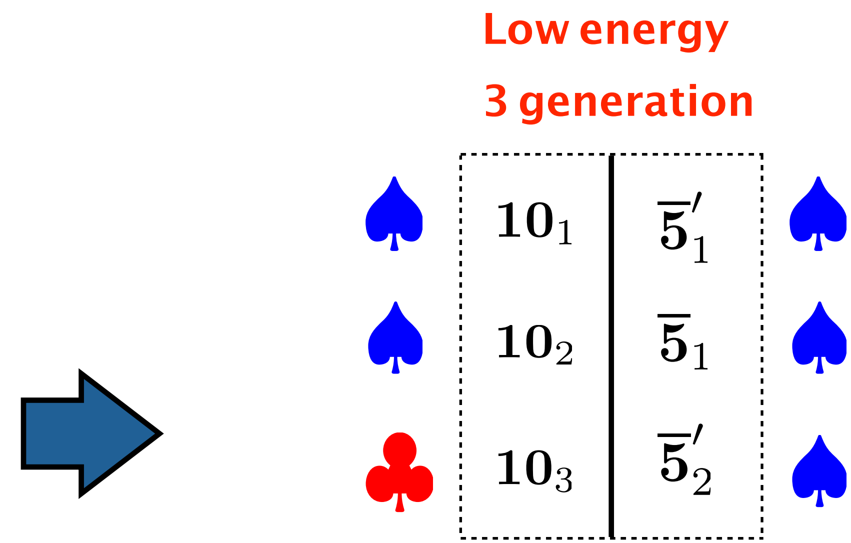




- $m_{\mathbf{10}_3} \neq m_{\text{others}}$ is realised

- soft scalar mass

$$V = m_0^2 \widetilde{\Psi}_a^\dagger \widetilde{\Psi}_a + m_3^2 \widetilde{\Psi}_3^\dagger \widetilde{\Psi}_3$$

Summary

- ATLAS and CMS are extending the exclusion limits on the CMSSM.

- Finding constraint on the other SUSY scenario is non-trivial and important task.

- There arises a tension between naturalness and CMSSM.

- A light third generation scenario is interesting because it can accommodate naturalness and the resent LHC results.

- Considering a dedicated set of cuts for the light third generation scenario is important to discover/exclude the scenario.

2-loop RGE

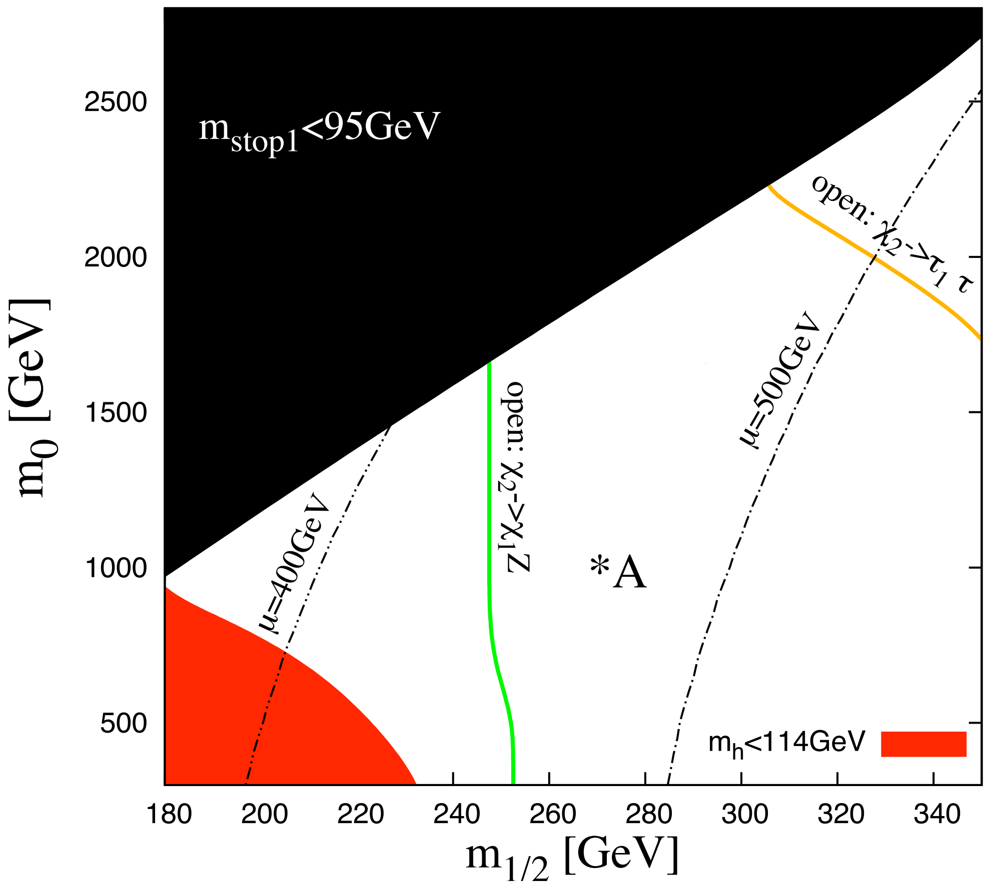
Arkani-Hamed, Murayama '97

As long as m_3 and $m_{1/2}$ are weak scale, m_0 cannot be arbitrarily large.

$$\frac{d}{dt} m^2_{\tilde{q}_3} \sim -\frac{16}{3}\alpha_3 M_3^2 + \alpha_b m^2_{\tilde{b}_R} + \frac{16}{3}\frac{\alpha_3^2}{4\pi}\mathrm{Tr}[m^2_{\tilde{q}} + m^2_{\tilde{d}_R} + m^2_{\tilde{u}_R}]$$

cannot take large $\tan\beta$

make $m_{\tilde{f}_3}$ tachyonic at low evergy



other parameters:

$m_{30} = m_{H_u}(\Lambda) = m_{H_d}(\Lambda) = 300\,\mathrm{GeV},$

$A_0 = -600\,\mathrm{GeV}, \quad \tan\beta = 10$

- $m_0 < 1$ - 2.5 TeV depending on m_3, $m_{1/2}$ and A_0.

How many SUSY events are allowed?

systematic errors

prediction for # of events after the cut: $\lambda = \lambda_{SM} + \lambda_{SUSY}$ → $\lambda = \lambda_{SM}(1 + \delta_{SM}\sigma_{SM}) + \lambda_{SUSY}(1 + \delta_{SUSY}\sigma_{SUSY})$

provability observing *n* events: $P(n) = \frac{e^{-\lambda}\lambda^n}{n!}$ → $P(n) = \frac{1}{N}\int d\delta_{SM} d\delta_{SUSY} \frac{e^{-\lambda}\lambda^n}{n!} e^{-\frac{1}{2}(\delta_{SM}^2 + \delta_{SUSY}^2)}$

Incompatibility (p-value): $p_v = \sum_{n=0}^{n_{obs}} P(n)$

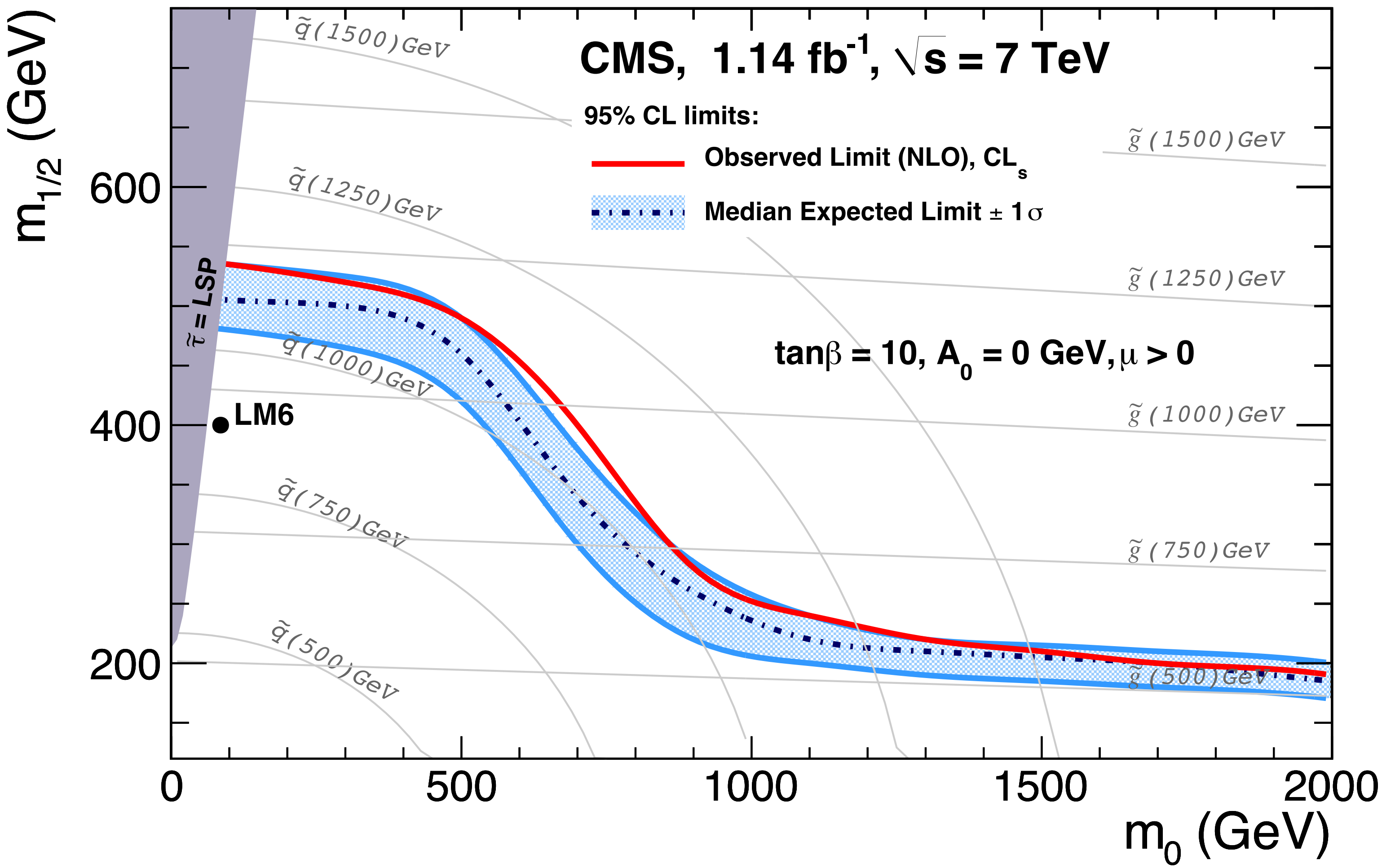
$$N = \int d\delta_{SM} d\delta_{SUSY} e^{-\frac{1}{2}(\delta_{SM}^2 + \delta_{SUSY}^2)}$$

conservative p-value: $\mathrm{CL_s} = \frac{p_v(\mathrm{Signal} + \mathrm{BG} : [0, n_{obs}])}{p_v(\mathrm{BG} : [0, (n_{obs} - 1)])}$ (PDG)

- The model is excluded at 95% CL, if it gives CLs < 0.05.

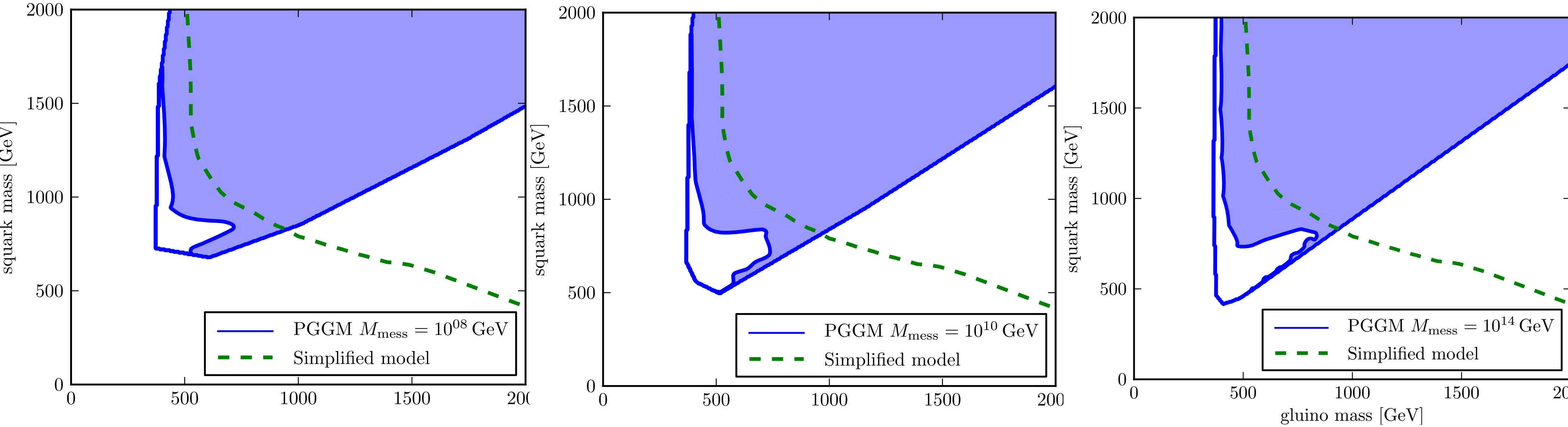
	≥ 2 jets	≥ 3 jets	≥ 4 jets (a)	≥ 4 jets (b)	High mass
95% upper bound on λ_{SUSY}	22	25	429	27	17

CMS α_T 1/fb



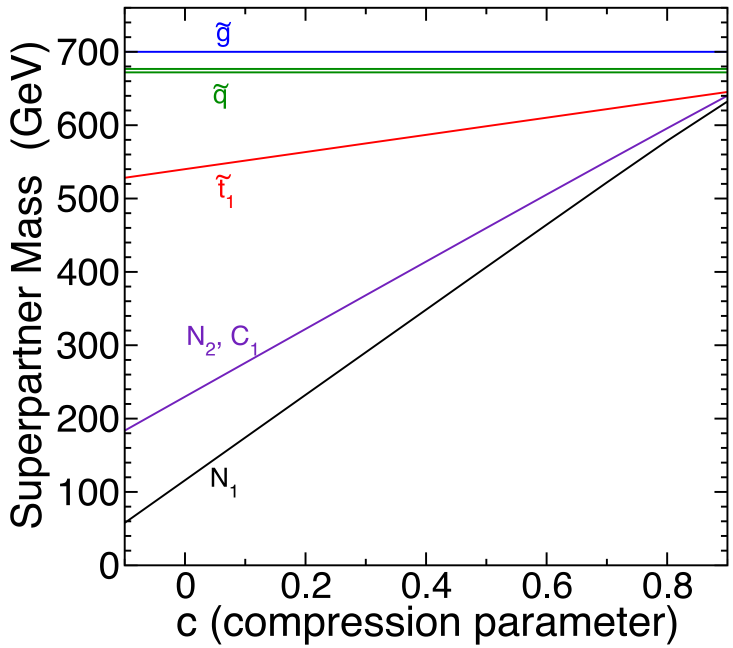
Limit on gauge mediation

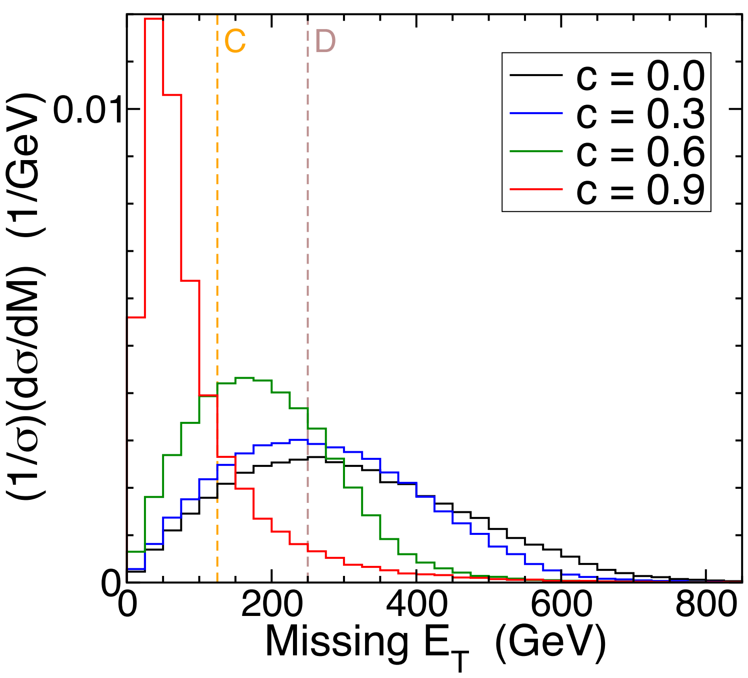
M.J.Dolan, D.Grellscheid, J.Jaeckel, V.V.Khoze, P.Richardson 1104.0585

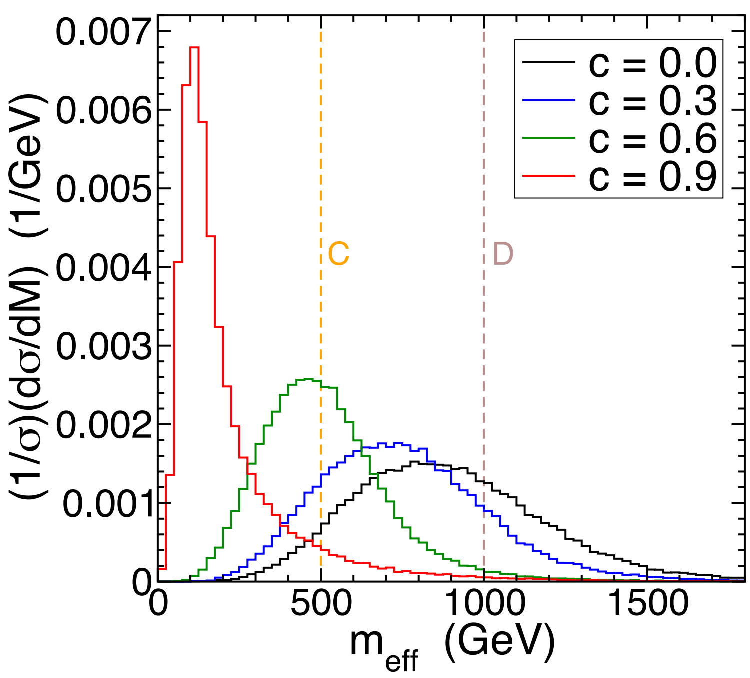


Compressed spectrum

T.J.LeCompte, S.P.Martin 1105.4304







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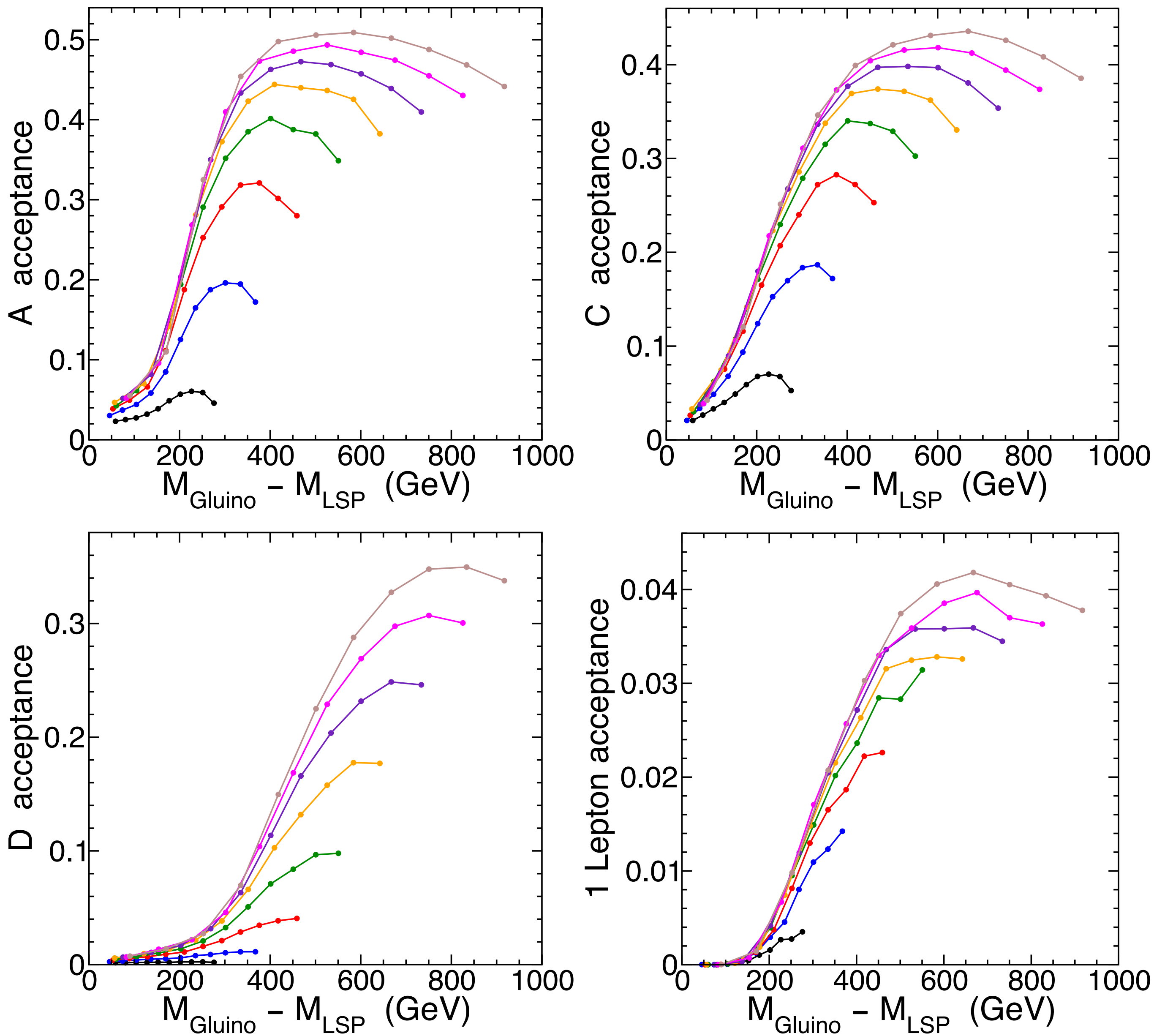
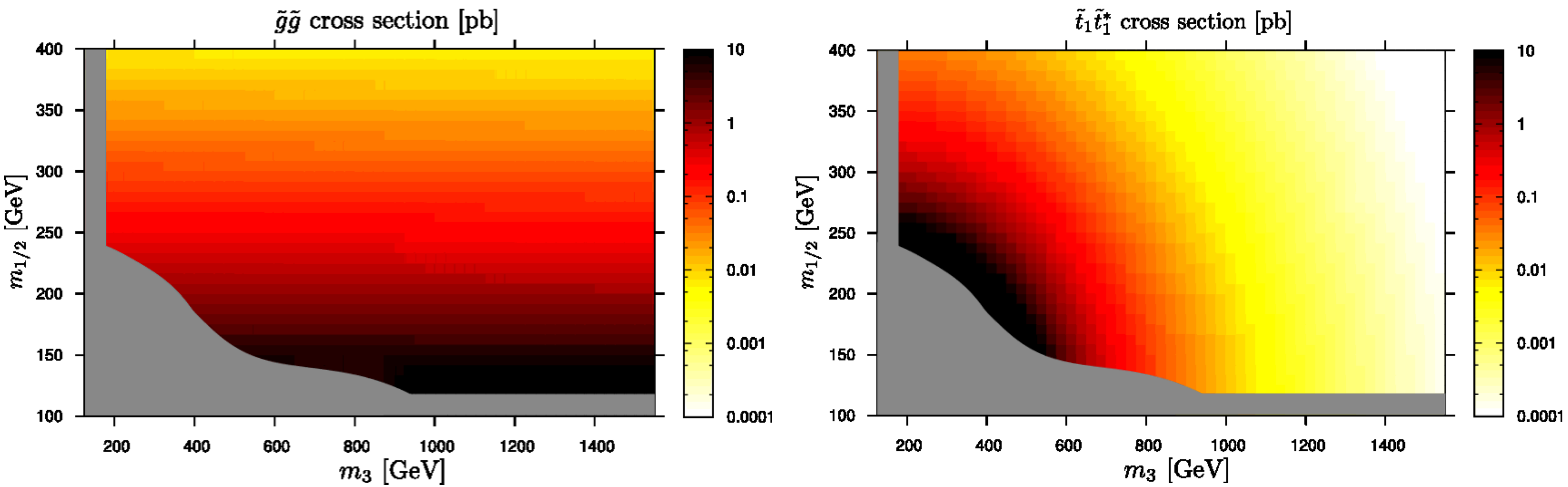


Lines: m_{gluino} = 300,400,...,1000GeV

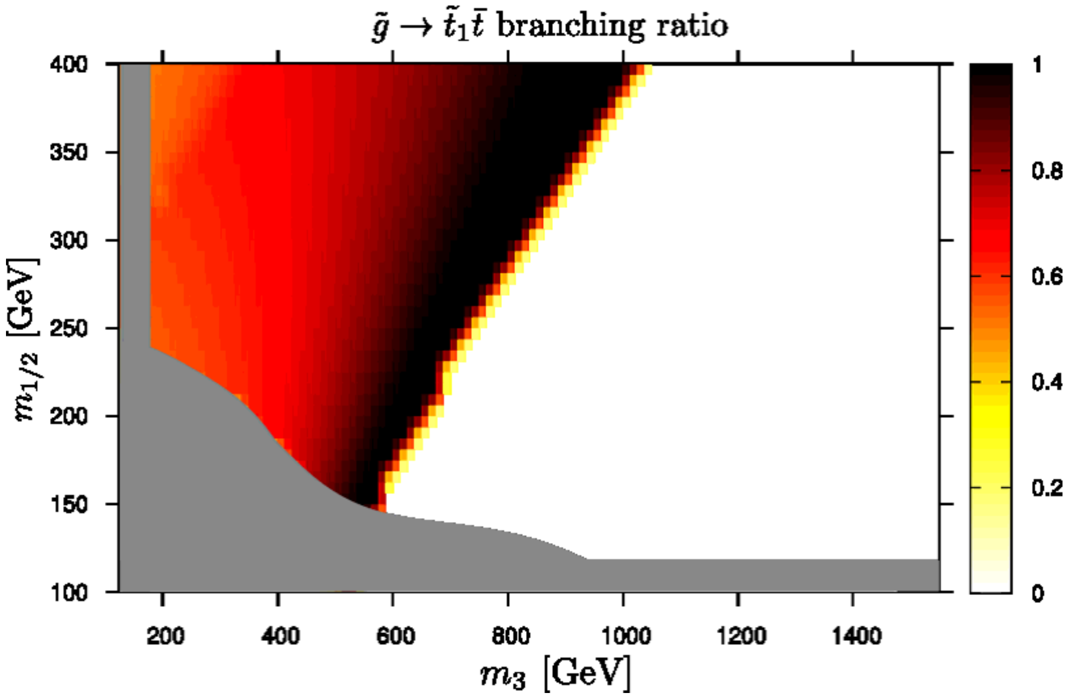
Cross section

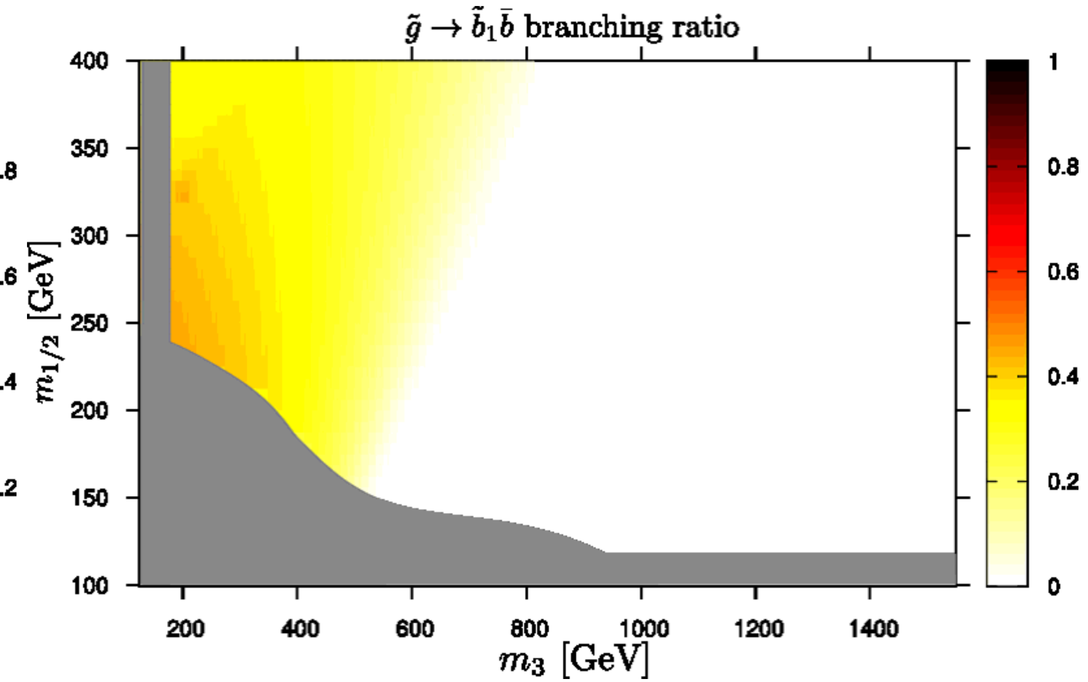


- σgg > 1pb, in small $m_{1/2}$ region
- $\sigma stst$ > 1pb, in small $m_{1/2}$ and m_3 region

KS, K.Takayama 1106.3794

Gluino decay modes





- $\tilde{g} \to t\tilde{t}_1^*$ is dominant

  in less fine-tuned region.

- $\tilde{t}_1 \to b\tilde{\chi}_1^{\pm} \to bW\tilde{\chi}_1^0$

  $(\to t\chi_1^0)$