Natural and Unnatural supersymmetry

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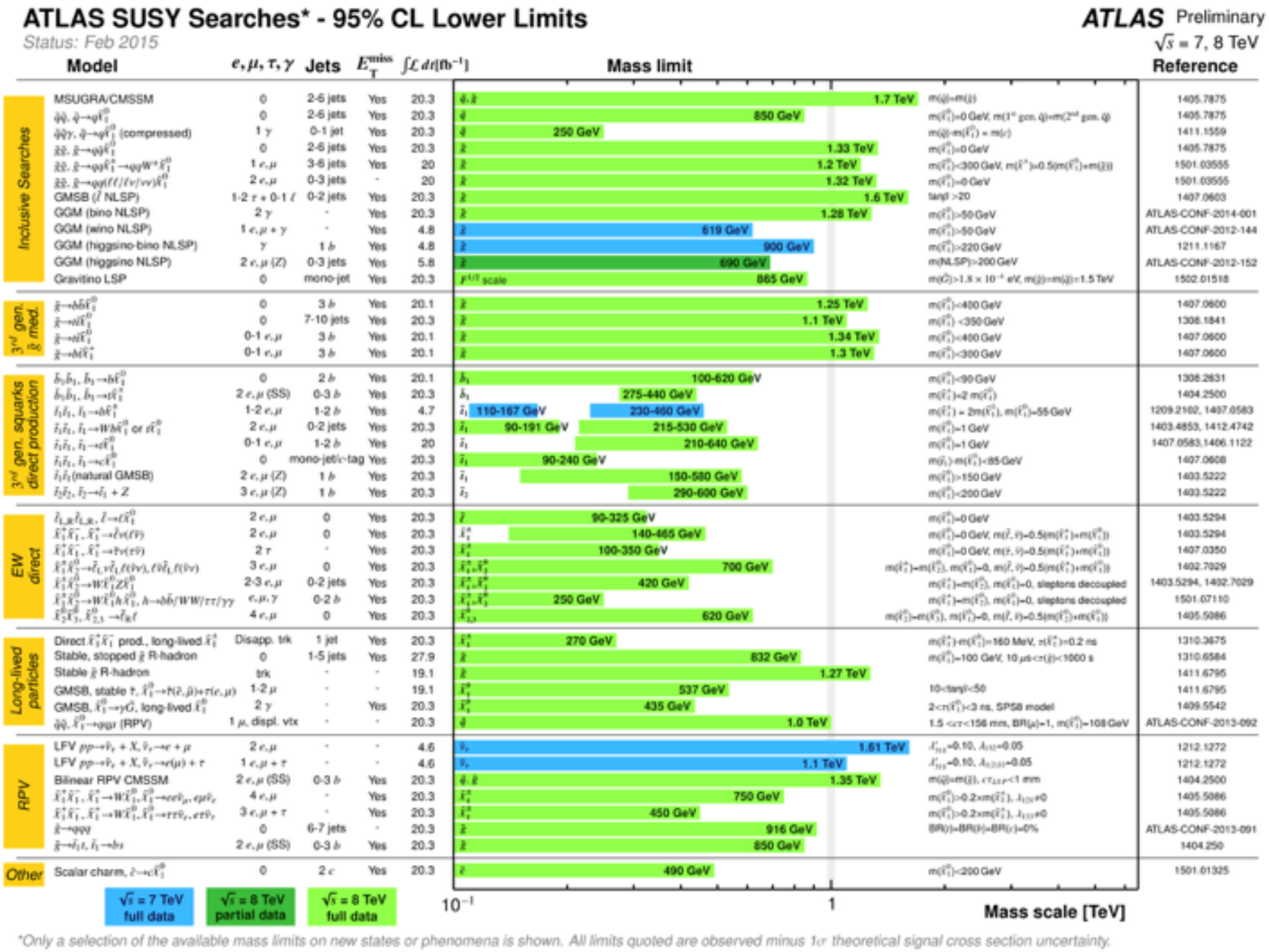
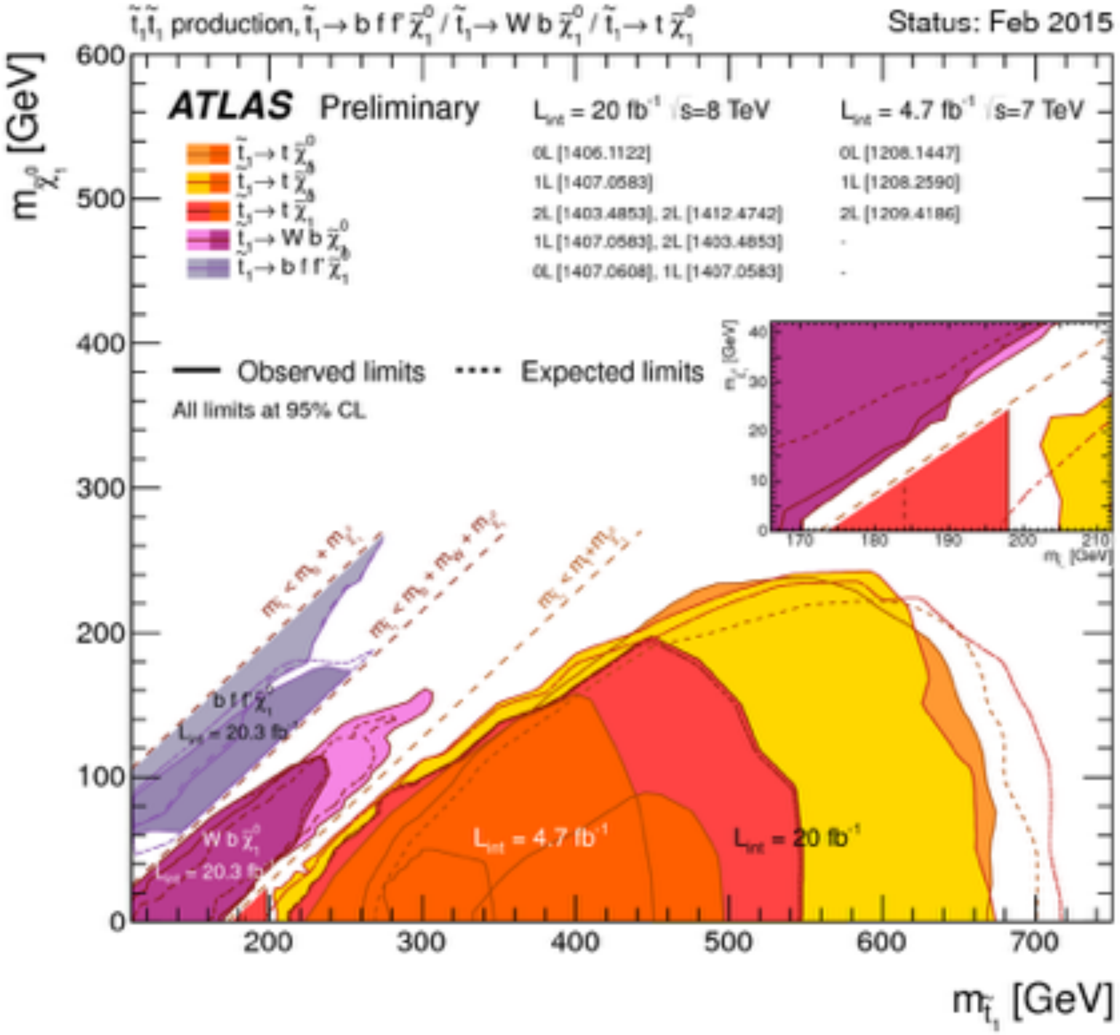
CAP congress 2015

Status of Supersymmetry

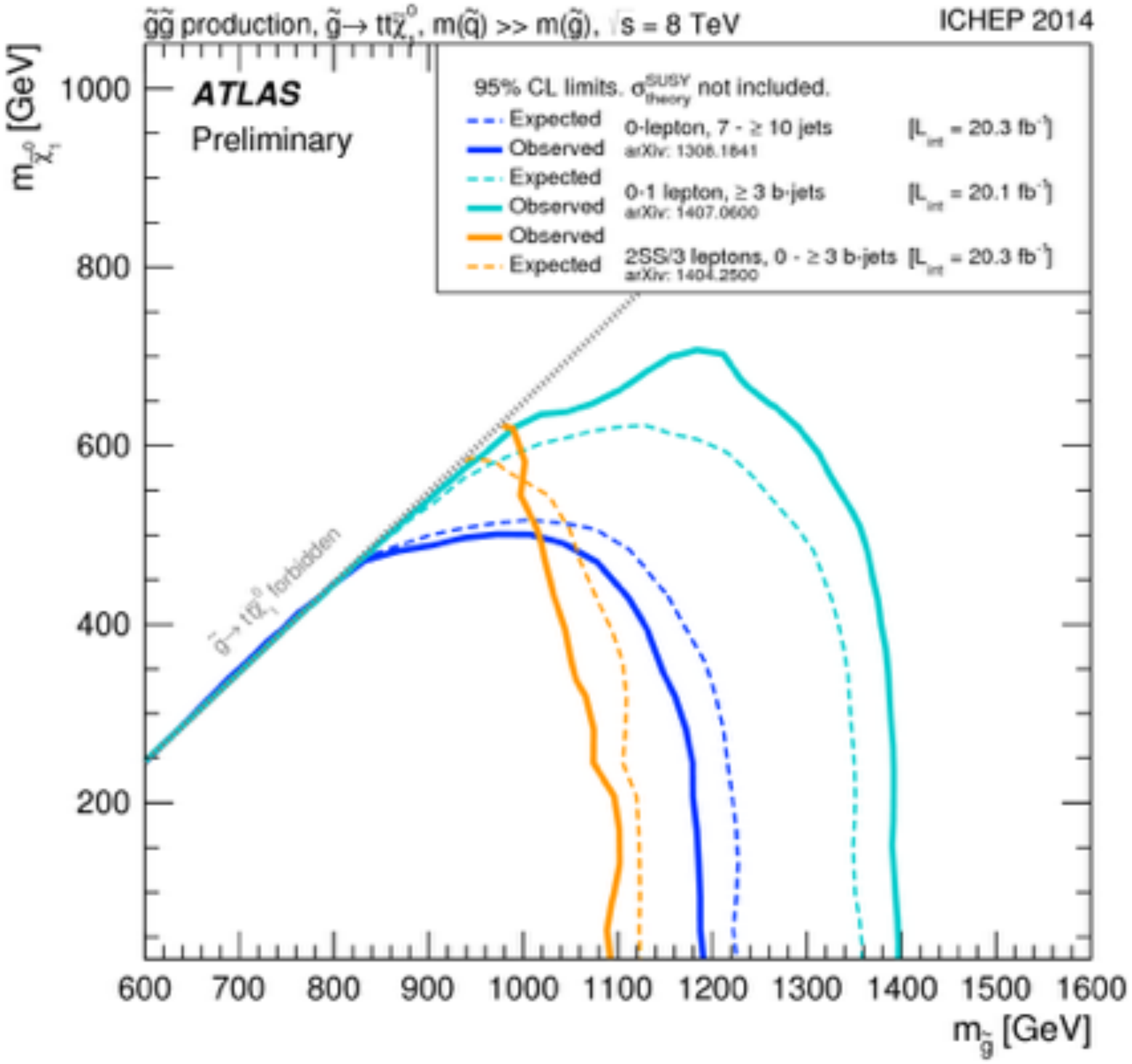


stop searches



$$m_{\tilde{t}} \gtrsim 700\text{GeV}$$

gluino searches



$$m_{\tilde{g}} \gtrsim 1.4\text{TeV}$$

What does it mean for naturalness?

‘natural SUSY’ (stop,gluino,higgsino)

Papucci, Ruderman,Weiler
‘11

stop

$$\delta m_h^2 = -\frac{3}{8\pi^2} y_t^2 \left(m_{Q_3}^2 + m_{u_3}^2 + |A_t|^2 \right) \log \left(\frac{\Lambda}{\mathrm{TeV}} \right)$$

$$\sqrt{m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2} \lesssim 600\mathrm{GeV} \left(\frac{\Delta^{-1}}{20\%} \right)^{-1/2}$$

gluino

$$\delta m_h^2 = -\frac{2}{\pi^2} y_t^2 \left(\frac{\alpha_s}{\pi} \right) M_3^2 \log^2 \left(\frac{\Lambda}{\mathrm{TeV}} \right)$$

$$M_3 \lesssim 900 \text{ GeV} \sin\beta \left(\frac{\Delta^{-1}}{20\%} \right)^{-1/2}$$

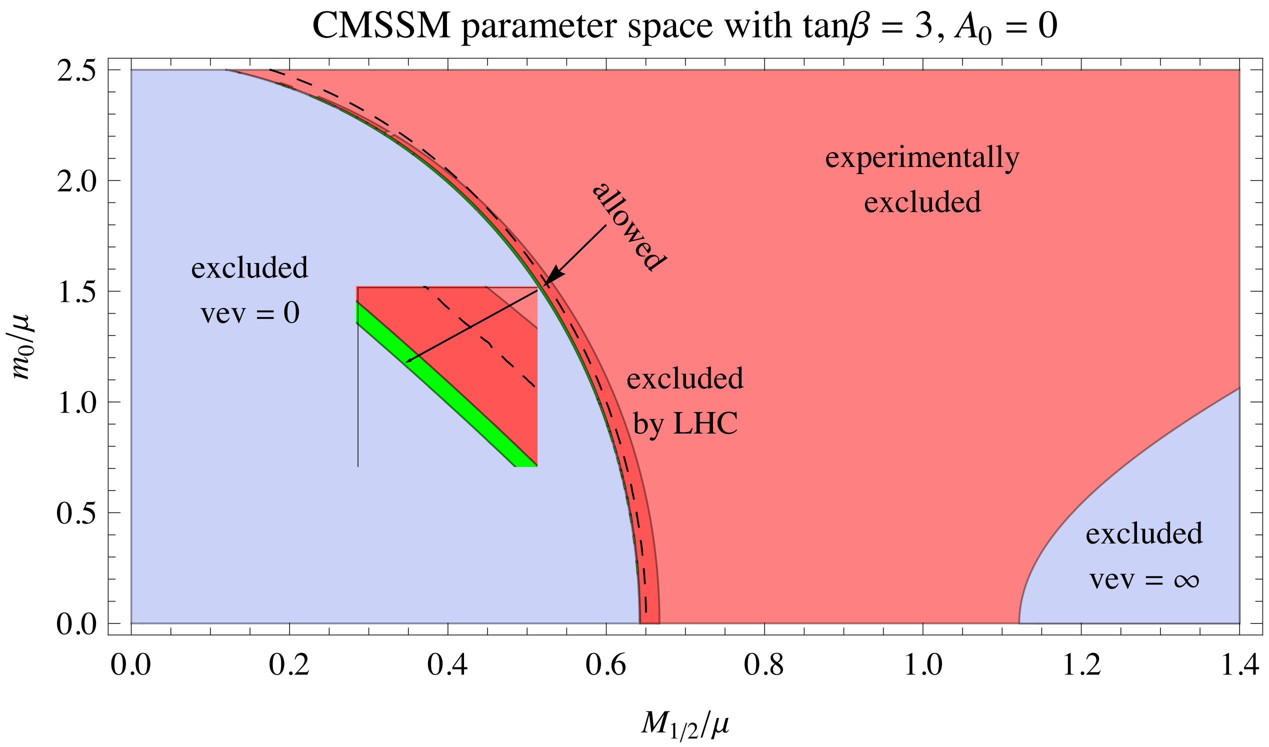
125 Gev Higgs : prefers heavy stops

$$\delta m_h^2 = \frac{3G_F}{\sqrt{2}\pi^2} m_t^4 \log\left(\frac{m_{\tilde{t}}^2}{m_t^2}\right)$$

~ 1-10 TeV stop depending on A-term

More complete models generally yield %-level fine-tuning

CMSSM



Strumia ‘11

NMSSM, split generation, low-scale mediation and even R-parity breaking are generically tuned.

Arvanitaki, Baryakhtar,
Huang, Tiburg, Villadoro ‘13

More clever model building might save the day

Scherk-Schwartz SUSY breaking

Dimopoulos, March-Russell
‘14

Compressed spectrum

LeComte, Martin ‘11
Dimopoulos, March-Russell,
Scoville ‘14

Stealth supersymmetry

Fan, Reece,Ruderman ‘11

Twin Higgs

Chacko, Goh, Harnik ‘05

Craig, Howe ‘13

Dirac gauginos

In the MSSM gauginos are Majorana

$$M\lambda\lambda$$

$$\begin{tikzcd} F_X\theta^2 & \int d^2\theta\, \boxed{X} W_\alpha W^\alpha \arrow[l] \end{tikzcd}$$

Can be Dirac if new superfields are added

$$\begin{tikzcd} W^1_\alpha, W^2_\alpha, W^3_\alpha \arrow[dr] & & S, T, G \arrow[dl] \\ & M_D\lambda\Psi & \end{tikzcd}$$

N=2 supersymmetry

extra-dimension

Supersoft SUSY breaking

Fox, Nelson, Weiner ’02

D-term breaking

$$\int d^2\theta\, \overset{D'\theta_\alpha \nwarrow}{\boxed{W'_\alpha}} W_i^\alpha \Phi_i$$

Dirac gauginos do not feed into scalar masses through renormalization

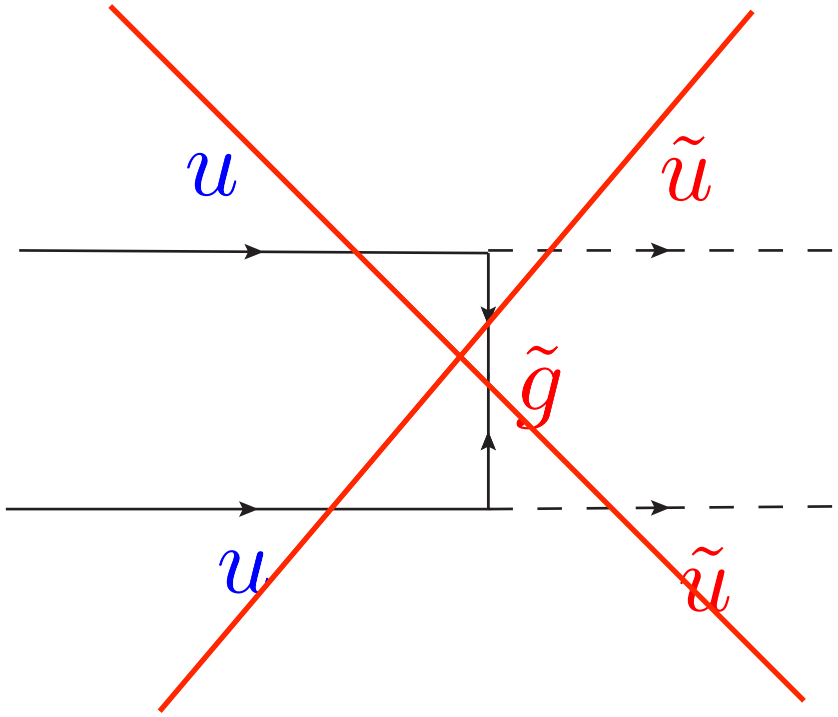
$$m^2 = \frac{C_i\left(r\right)\alpha_i m_i^2}{\pi}\log\left(\frac{\delta^2}{m_i^2}\right)$$

They can be naturally heavier than scalars

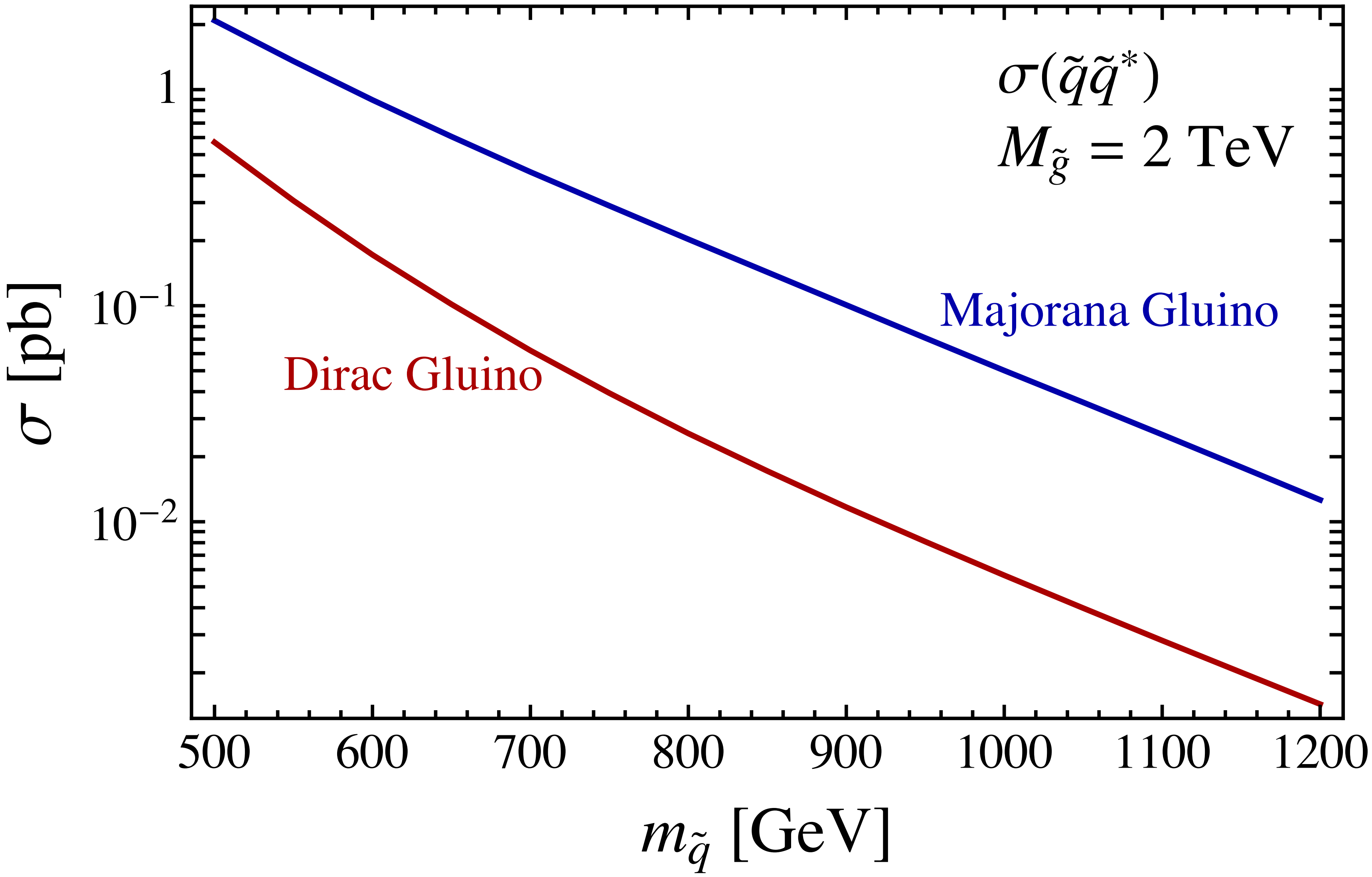
LHC will have a harder time seeing the gluino...

M. Heikinheimo, M. Kellerstein, V. Sanz '12
Kribs, Martin '12

...and squarks



Squark production



Frugiuele, T.G., Kumar, Ponton

R-symmetry

With Dirac gaugino: possible to impose an U(1) R-symmetry

$$M_D \lambda \Psi$$

Kribs,Poppitz,Weiner ’02

- Bounds from FCNC are weaker: off diagonal m_{ij}

$$R[Q, U^c, D^c, L, E^c] = 1 \qquad R[H_u, H_d] = 0$$

$$\xcancel{\mu H_u H_d}$$

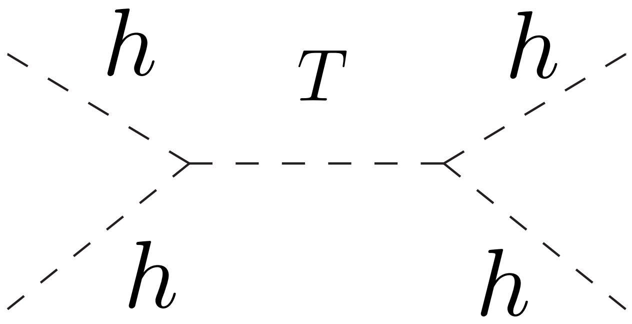
Higgs mass

Tree-level:

Reduced quartic, usual of Dirac gauginos

$$\int d^2\theta W'_\alpha W_i^\alpha \Phi_i \quad \Longrightarrow \quad D_2 = M_2 T^a + H_u^\dagger \sigma^a H_u + \ldots$$

When the scalar T is integrated out:



$$\boxed{\lambda \to 0}$$

Higgs quartic

If the mass of T is set by M_2 and $\lambda_T = 0$

No help (at tree-level) from

$$\lambda_T H_u T \boxed{R_d} + \lambda_S H_u S \boxed{R_d}$$

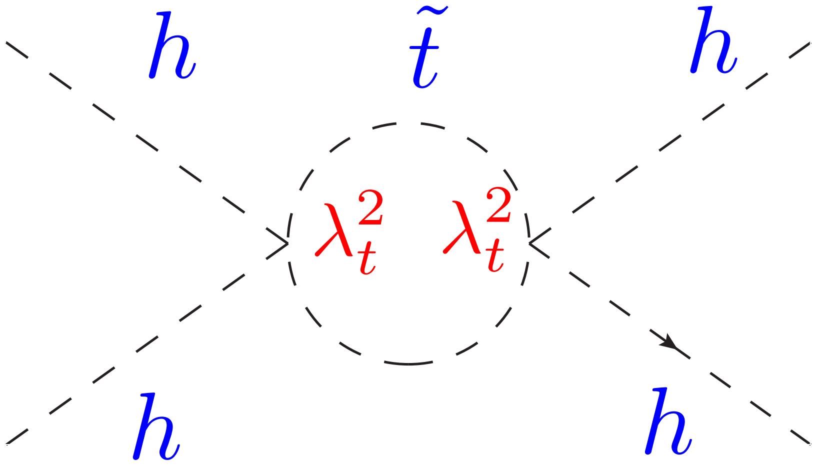
don’t get a vev (In the limit of exact R-symmetry)

But do help in models without an R-symmetry

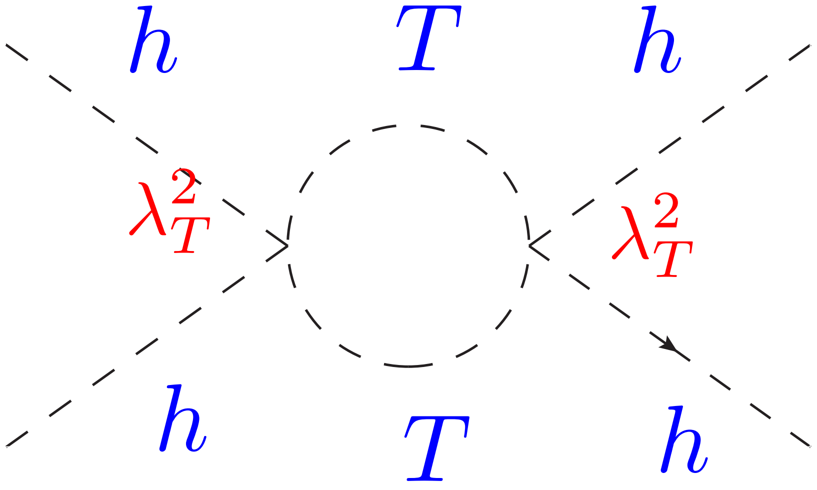
Benakli, Goodsell, Staub 1211.0552

Loop-level

Usual stop correction (but A-terms are 0)



Similar loop from the triplet

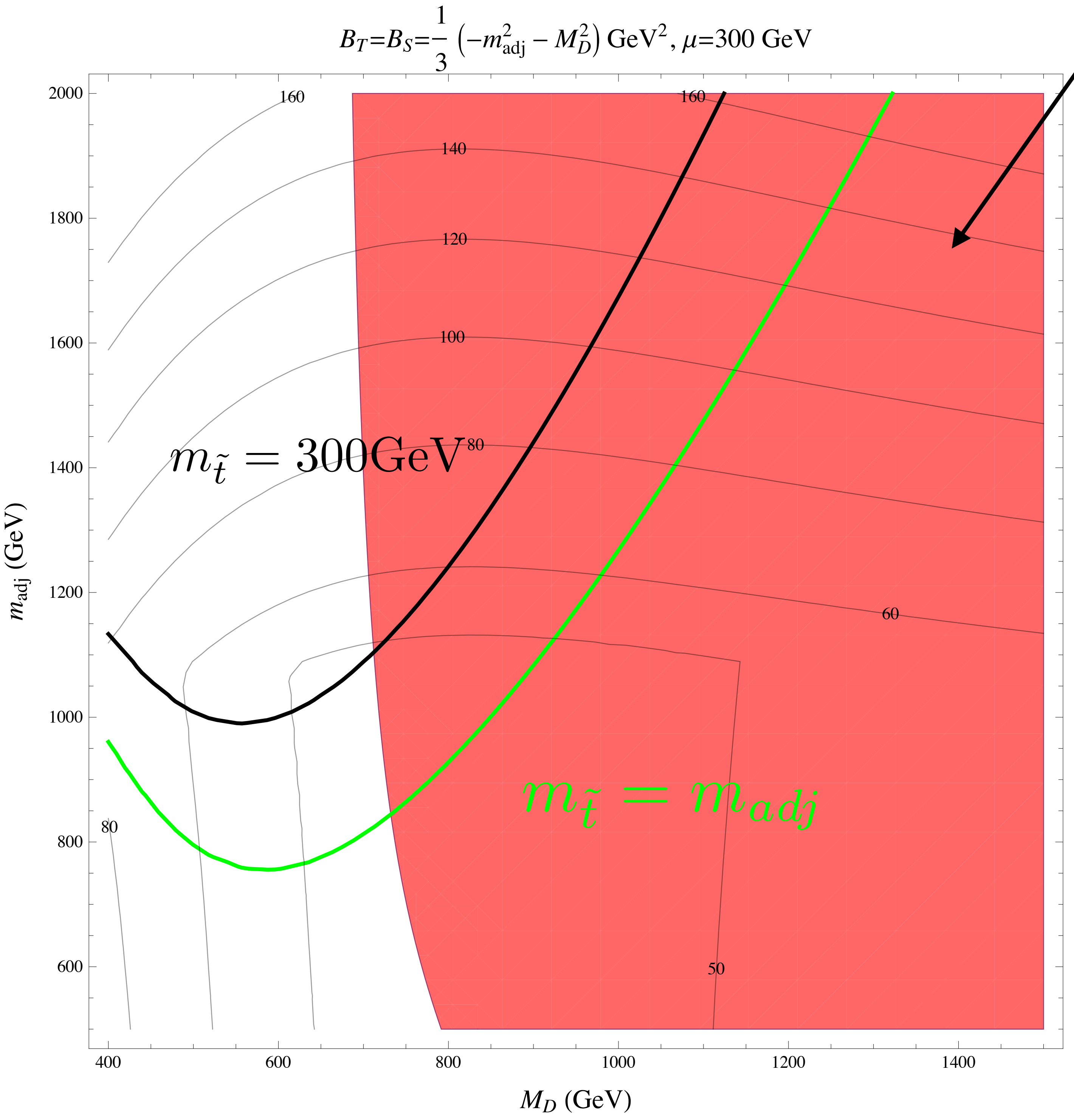


$$V_{\mathrm{CW}} \sim \frac{1}{16\pi^2}\left(5\enclose{circle}{\lambda_T^4}\log\frac{m_T^2}{M_2^2} + 3\lambda_t^4\log\frac{m_{\tilde{t}}^2}{m_t^2}\right)$$

↓

Very sensitive to λ_T

….but so are electroweak precision measurements allowed by EWPT



Bertuzzo, Frugiuele, T.G., Ponton

Arkani-Hamed, Dimopoulos
'05

Split Supersymmetry

Naturalness might not be a good guide

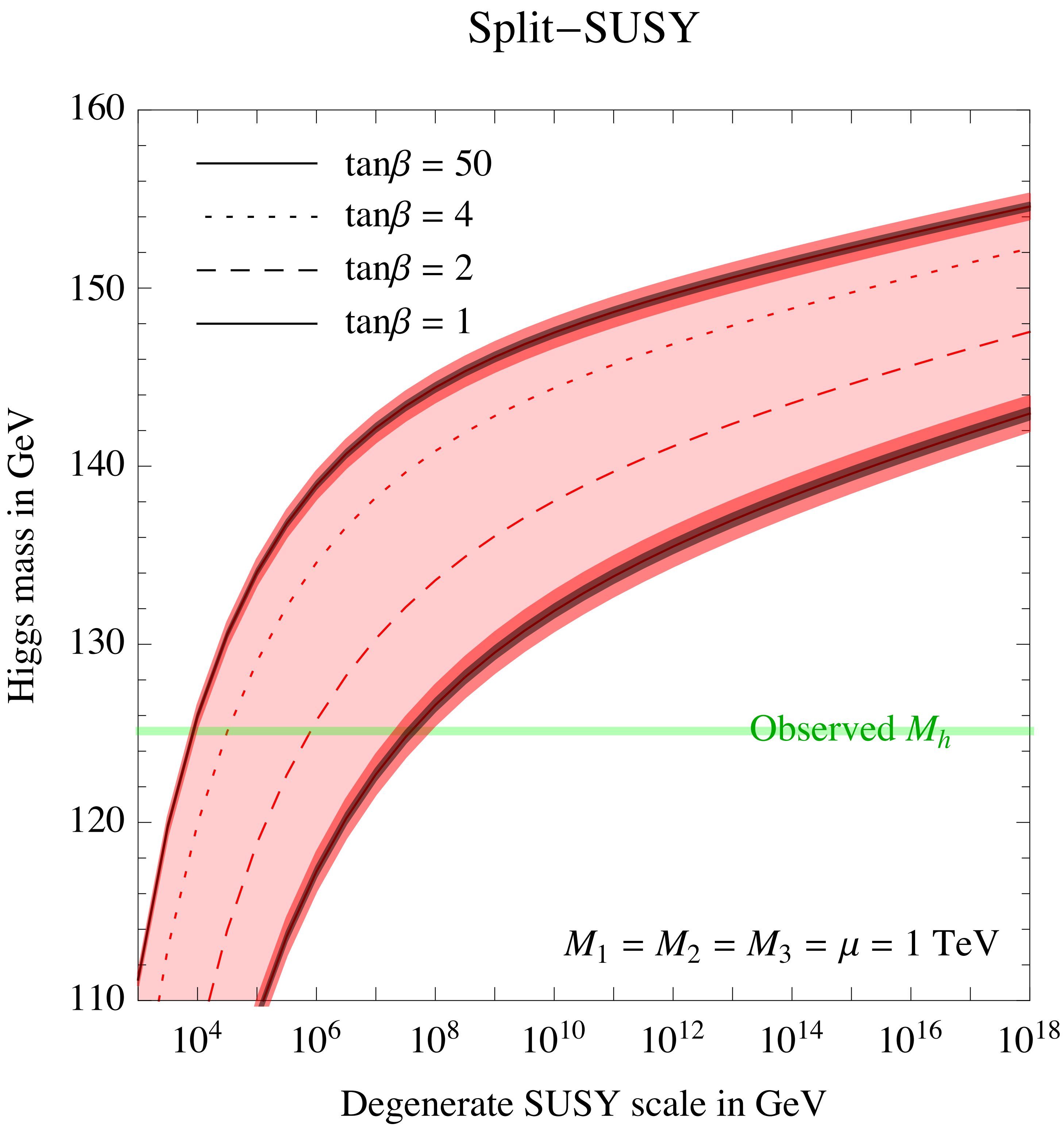
SUSY might still be relevant

- Dark matter
- Gauge coupling unification
- 'UV' reasons

Gauginos and scalars might not be at the same mass scale

natural in for example anomaly mediation

Prediction for the Higgs mass



Bagnaschi,
Giudice,Slavich,Strumia
'14

Arvanitaki, Craig, Dimopoulos
‘12

Mini-split in anomaly mediation

gaugino masses (AMSB):

$$M_i = \frac{b_i}{16\pi^2} g_i^2 m_{3/2}$$

scalar masses (gravity mediation):

$$m^2 = m_{3/2}^2$$

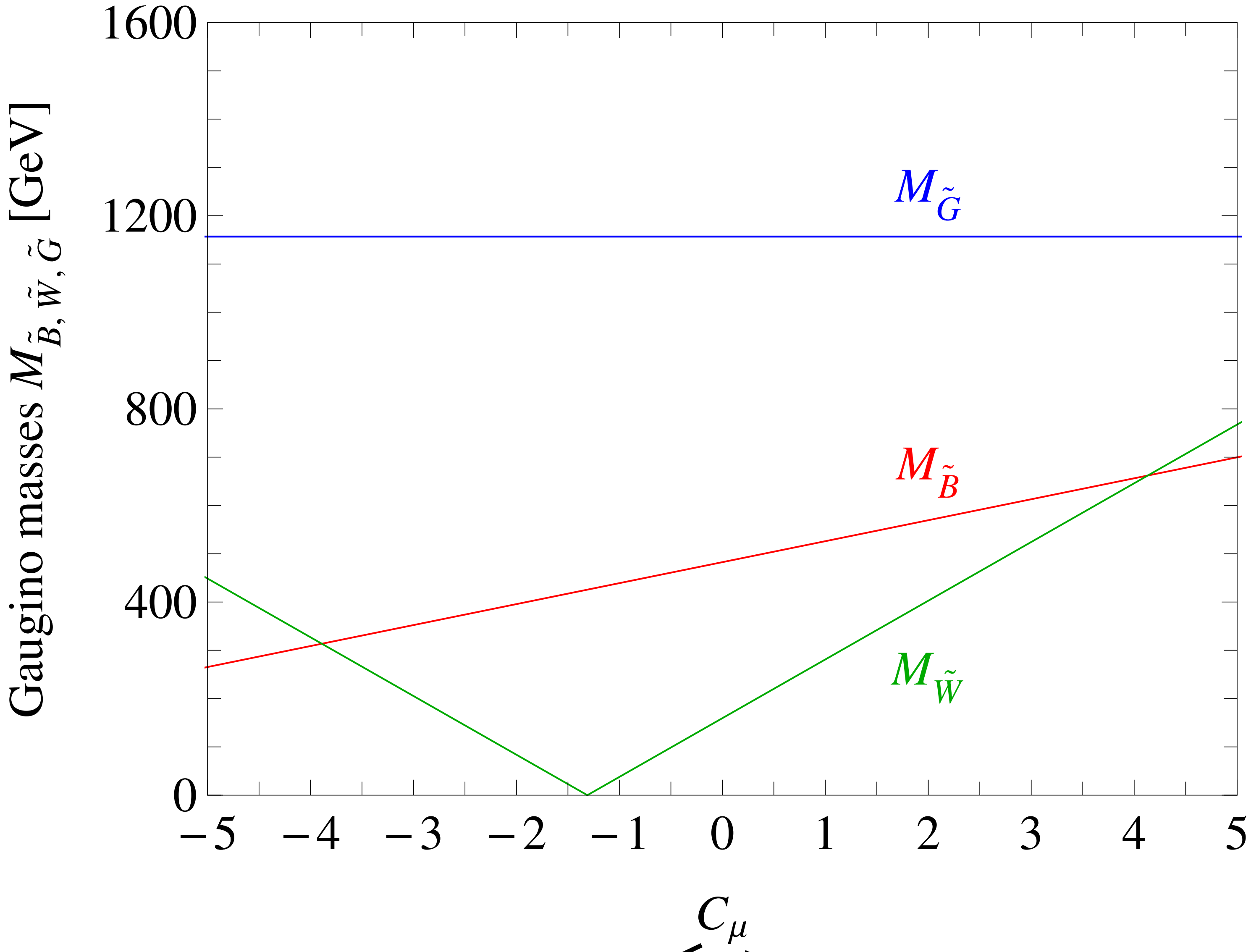
loop factor

Higgsino (mu term): chosen
to be at $m_{3/2}$

Similar possibility in gauge mediation

Gaugino spectrum

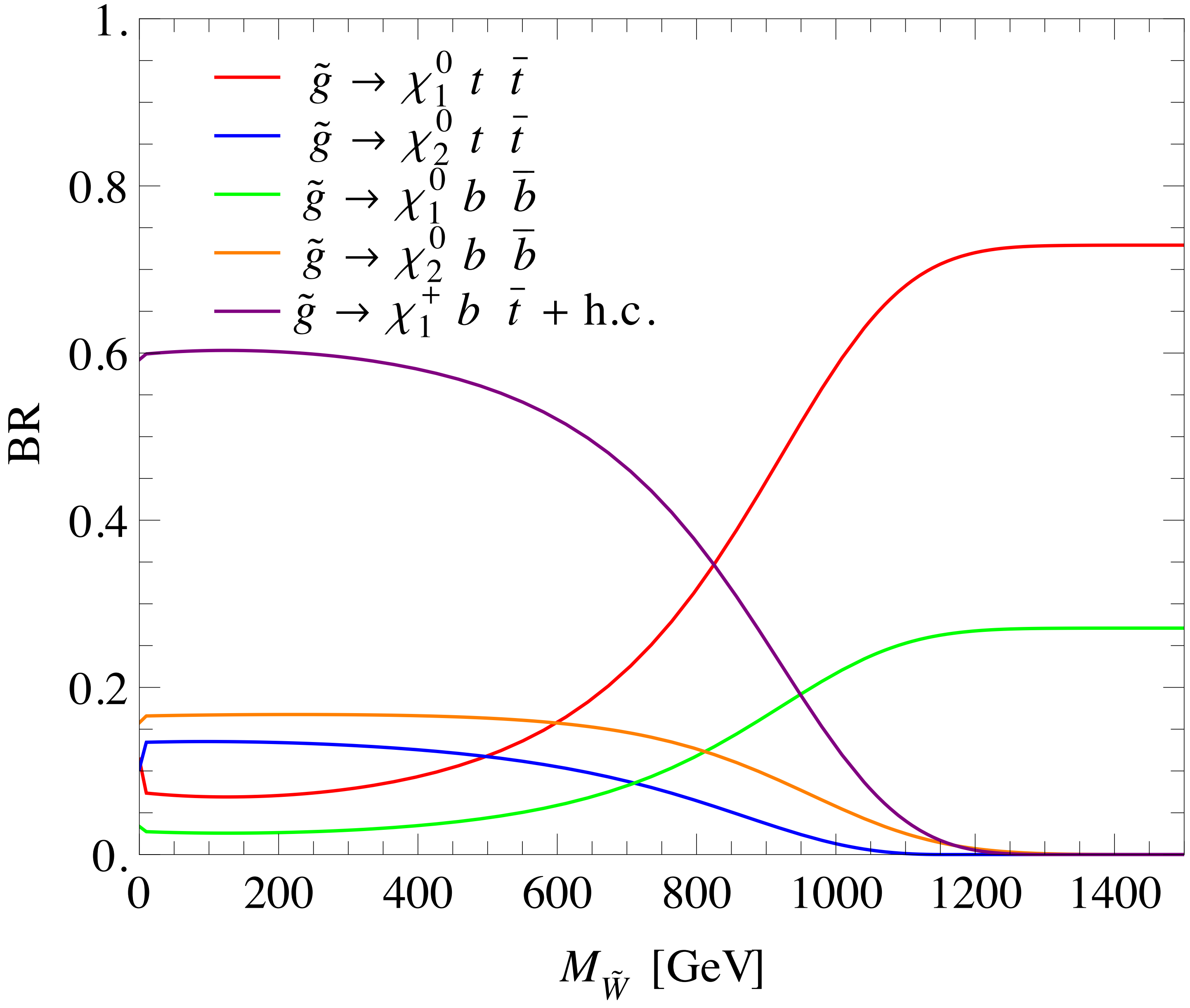
Beauchesne, Earl, T.G. ‘15



$$C_\mu = \frac{\mu}{m_{3/2}} \frac{m_A^2 \sin^2\beta}{m_A^2 - \mu^2} \ln\frac{m_A^2}{\mu^2}$$

Parametrize deflection from AMSB spectrum

Gluino decay (through 3rd generation)

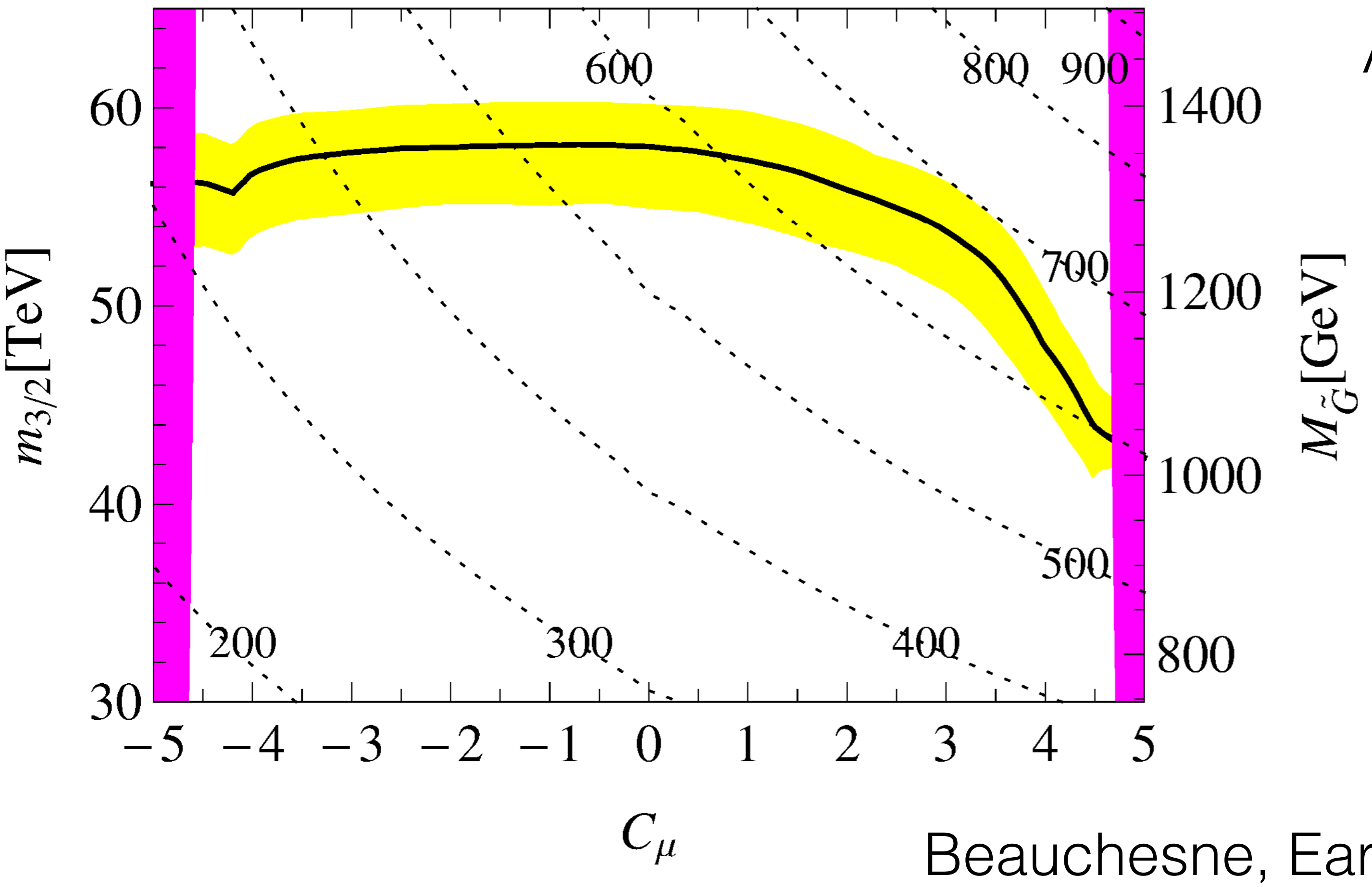


$m_{\tilde{G}} = 1.5$ TeV $\quad m_{\tilde{B}} = 0$ GeV

LHC limits

Gaugino spectrum and branching ratios are obtained as a function of $m_{3/2}$ and C_μ. The correct Higgs mass is obtained by fixing $\tan\beta$

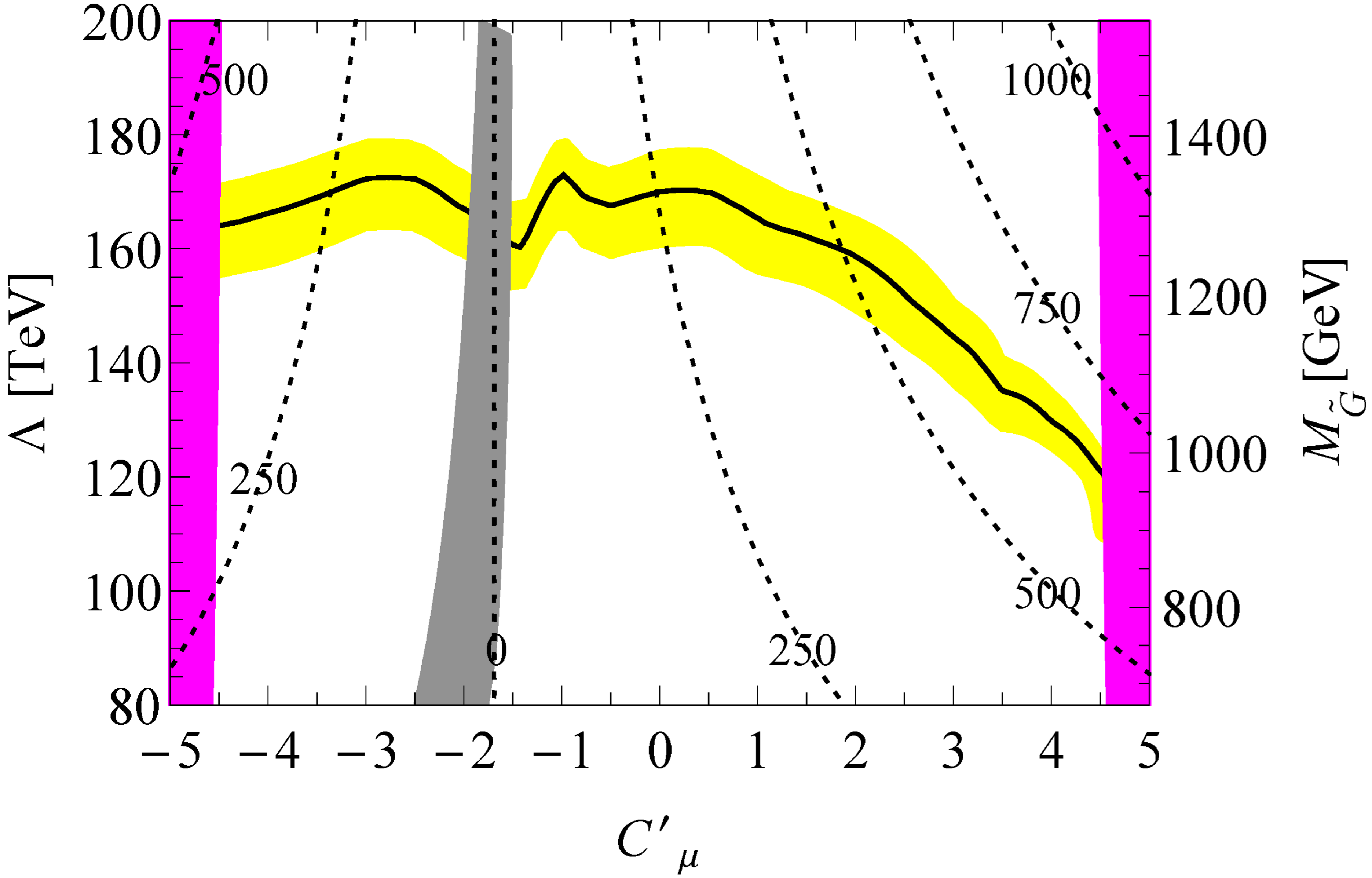
Recast LHC searches



ATLAS multi-leptons+b-jets
ATLAS 0-1 lepton+b-jets
CMS high jets multiplicity
CMS 2 OS leptons+jets

Beauchesne, Earl, T.G. ‘15

Gauge mediation



Prospect for a 100 TeV collider

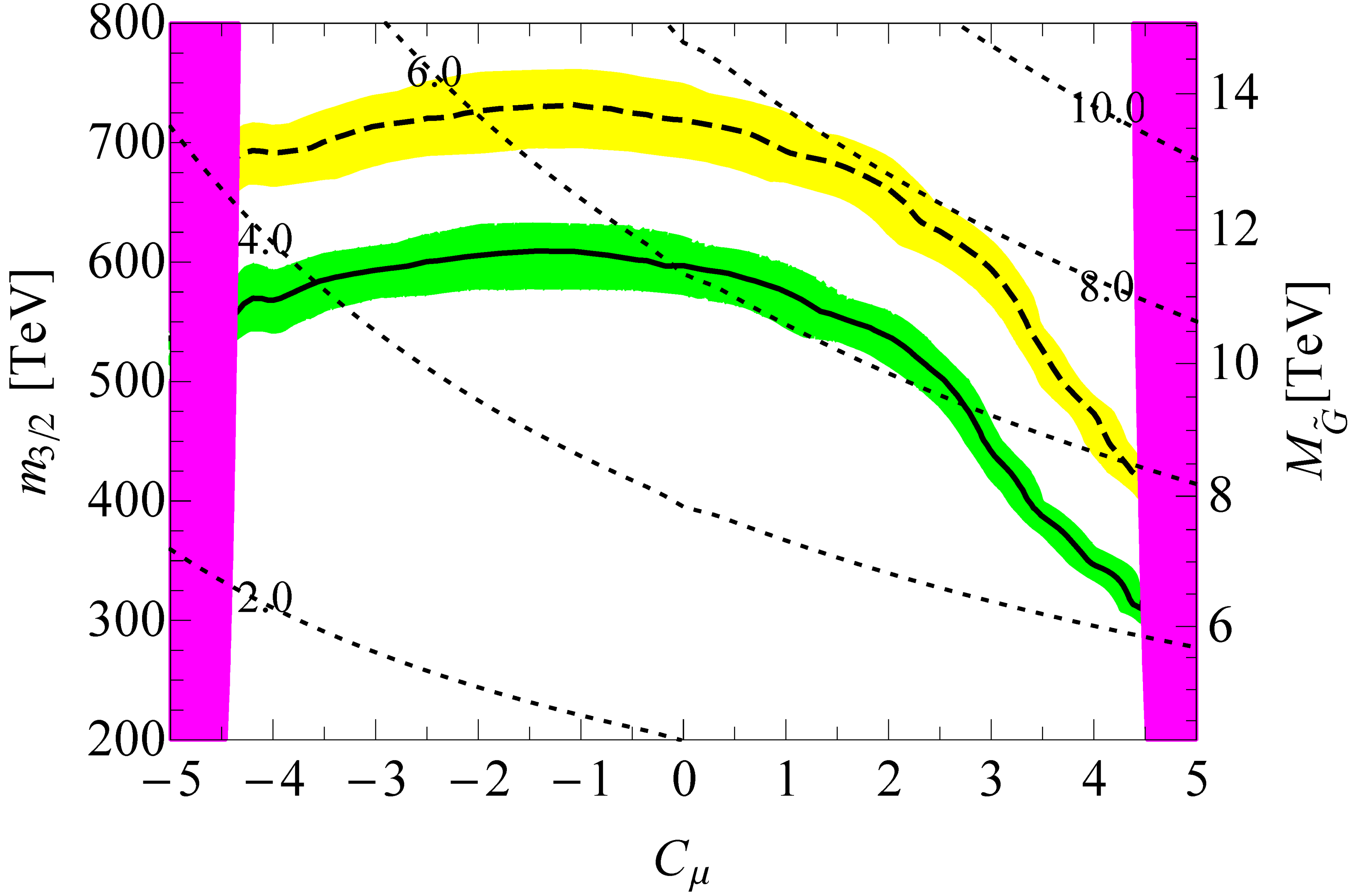
0-lepton + jets +MET analysis

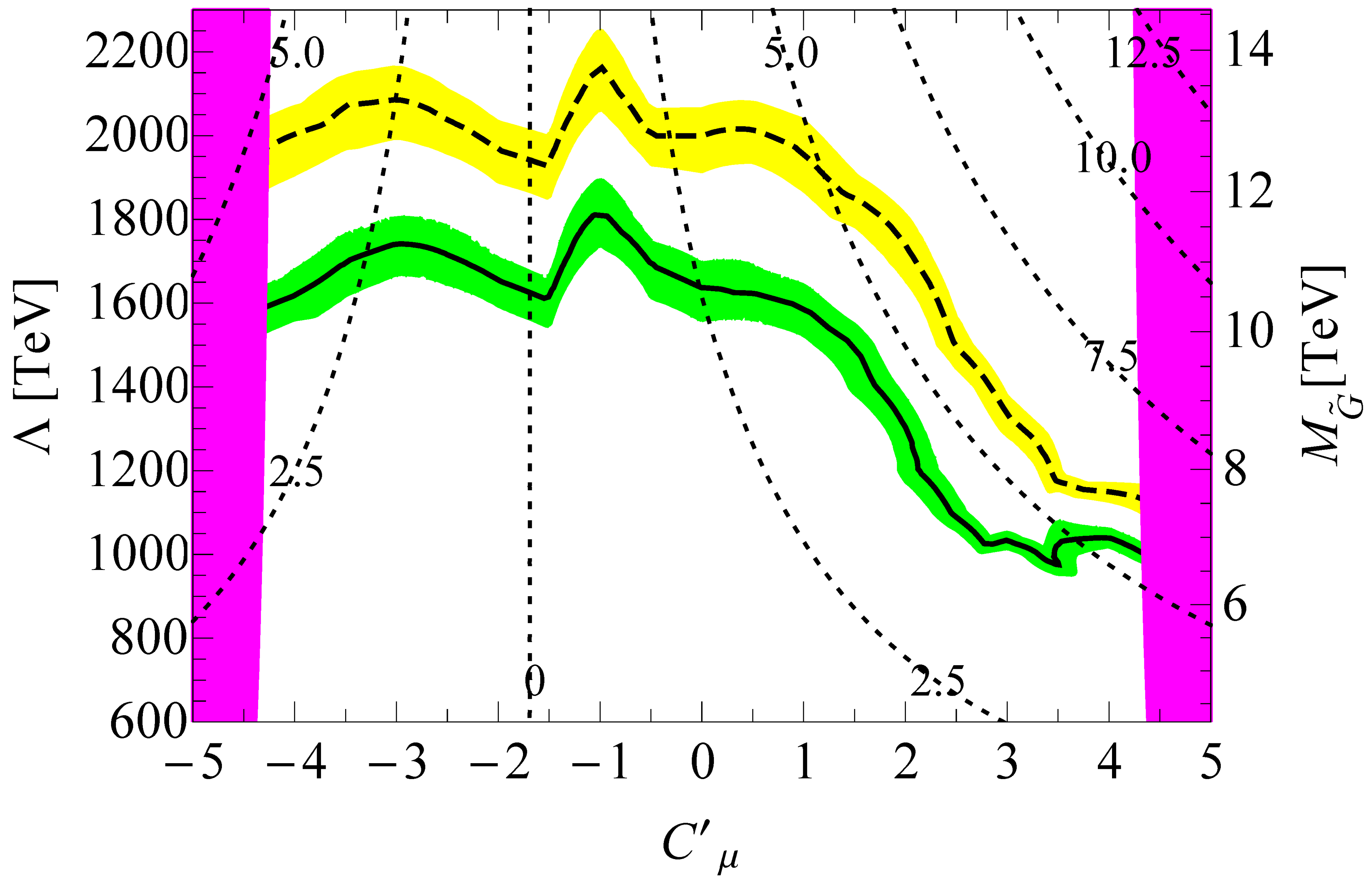
Jung, Wells '13

2 SS lepton analysis

Cohen et al. '14

AMSB





GMSB

Λ [TeV]
2200
2000
1800
1600
1400
1200
1000
800
600
$M_{\tilde{G}}$ [TeV]
14
12
10
8
6
−5
−4
−3
−2
−1
0
1
2
3
4
5
C'_{μ}
5.0
2.5
0
5.0
2.5
12.5
10.0
7.5