SUSY and Naturalness

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Bonn University & Bethe Center for Theoretical Physics

Contents

Contents

Contents

Contents

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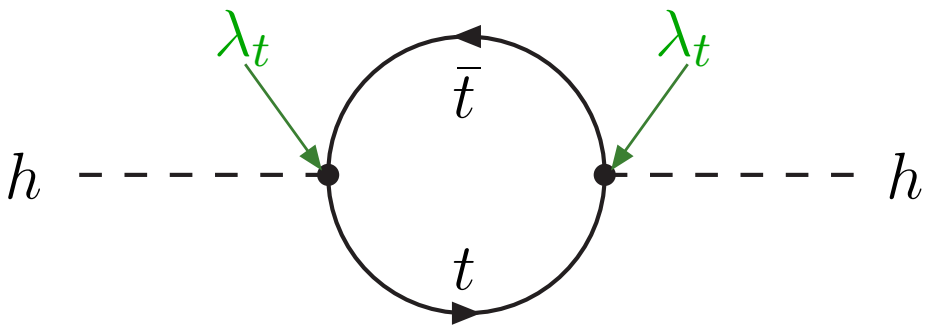
Introduction: Hierarchy Problem

Quantum corrections to Higgs mass diverge quadratically!



$$\delta m^2_{h,t} = \frac{3\lambda_t^2}{8\pi^2}\Lambda^2 + \mathcal{O}(\Lambda/m_h)$$

Λ: cut–off for momentum in loop.

Introduction: Hierarchy Problem

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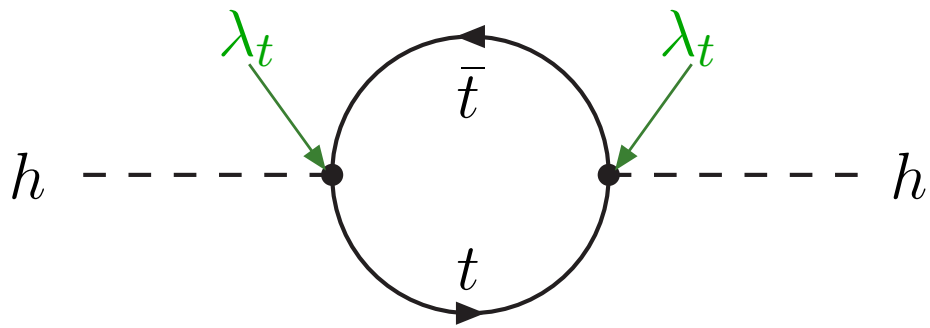

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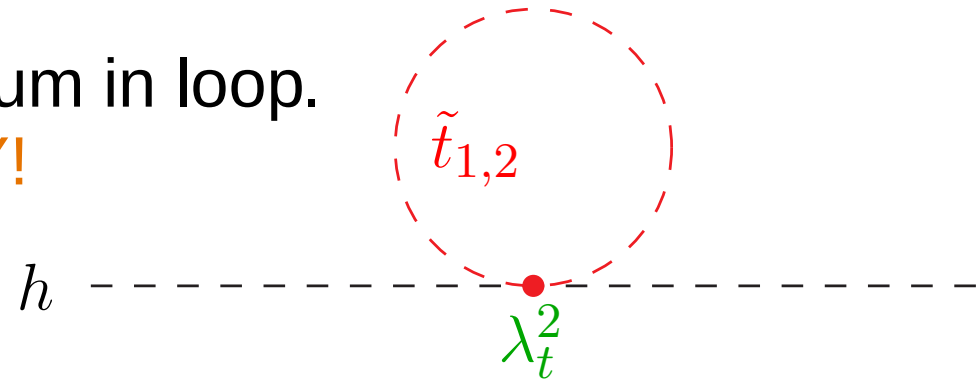
Are canceled in SUSY!



$\delta m^2_{h,\tilde{t}} = -\frac{3f_t^2}{8\pi^2}\Lambda^2 + \ldots$ Quadratic divergencies cancel exactly!

Adding up

$$\delta m_h^2 \sim \frac{3\lambda_t^2}{8\pi^2}\left(m_{\tilde{t}_1}^2 + m_{\tilde{t}_2}^2 - 2m_t^2 + |A_t|^2\right)\ln\frac{\Lambda^2}{m_h^2} + \cdots$$

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$$m_{\tilde{g}} \ln\frac{\Lambda^2}{m_h^2} \leq 1200\ \mathrm{GeV}$$

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Should have seen stops and/or gluinos at the LHC??

Natural SUSY Scan

MD, J.S. Kim

Minimization of Higgs potential: $\frac{1}{2}M_Z^2 \simeq -|\mu|^2 - m_{H_u}^2$

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In our scan:
$|\mu| \leq 500$ GeV
$m_{\tilde{t}_i},\ m_{\tilde{g}}$ as small as possible
(implies $m_{\tilde{b}_1}$ is also "light")
All other sparticles, heavy Higgses out of LHC range.

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- Compare with LHC results using CheckMATE

  ATLAS: $0\,\ell + 2b$; $2\,\ell$ (direct stop); $\ell^\pm\ell^\pm$; $3\,\ell$; $1\,\ell + (b-)$jets (stop); Monojet or $c-$jet (stop); $1\,\ell + \geq 4$ jets; $0\,\ell + 2b + 4$ or more jets; $0\,\ell + 2$ to 6 jets; 0 or $1\,\ell + 3\,b$; 1 or $2\,\ell + 3$ to 6 jets; $2\,\ell$ (razor)

  CMS: $\alpha_T + b$; $\ell^\pm\ell^\mp + 3\,b$.

  All searches require some missing E_T.

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- Doesn't work for "smart" multivariate analyses

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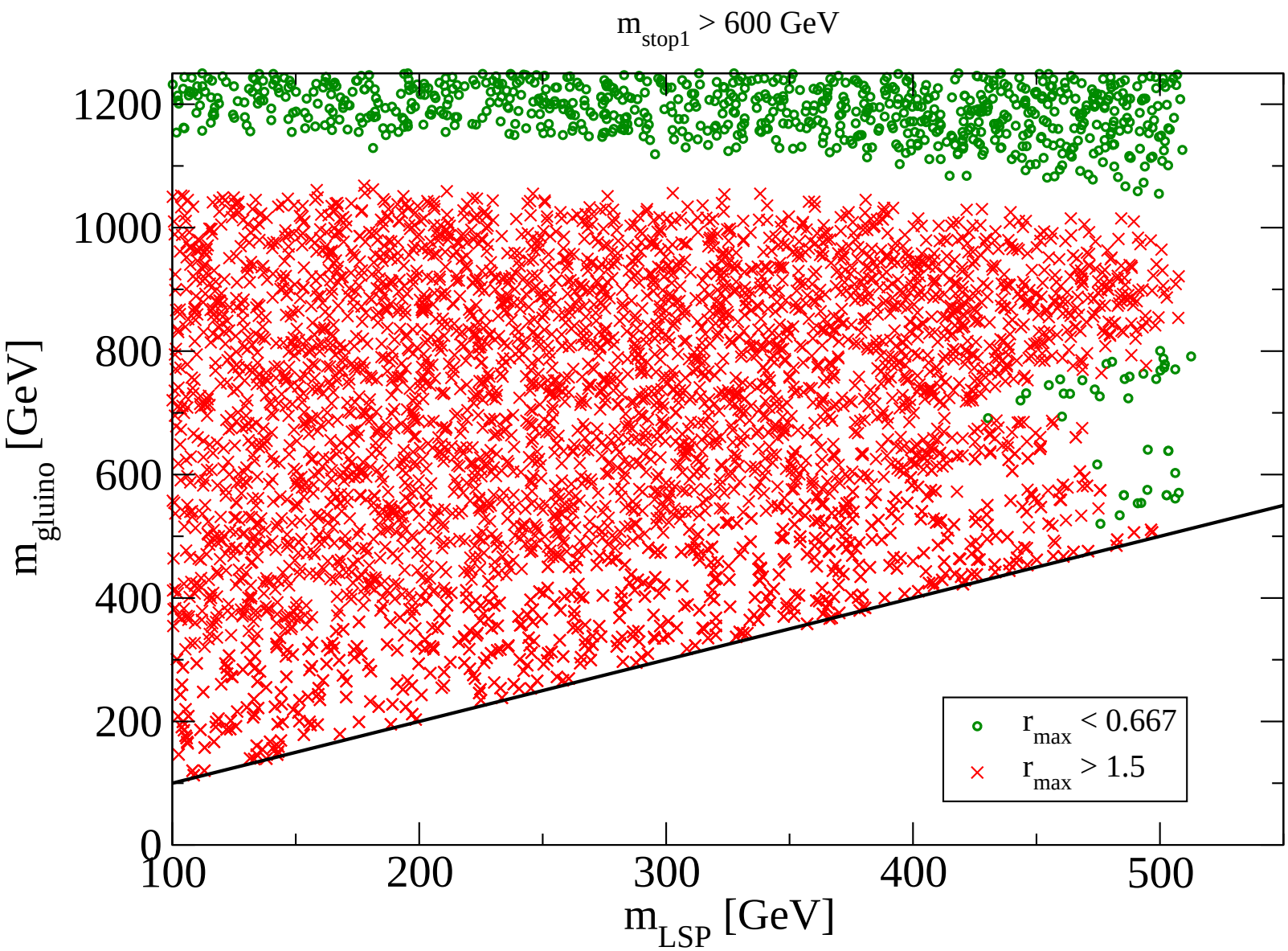
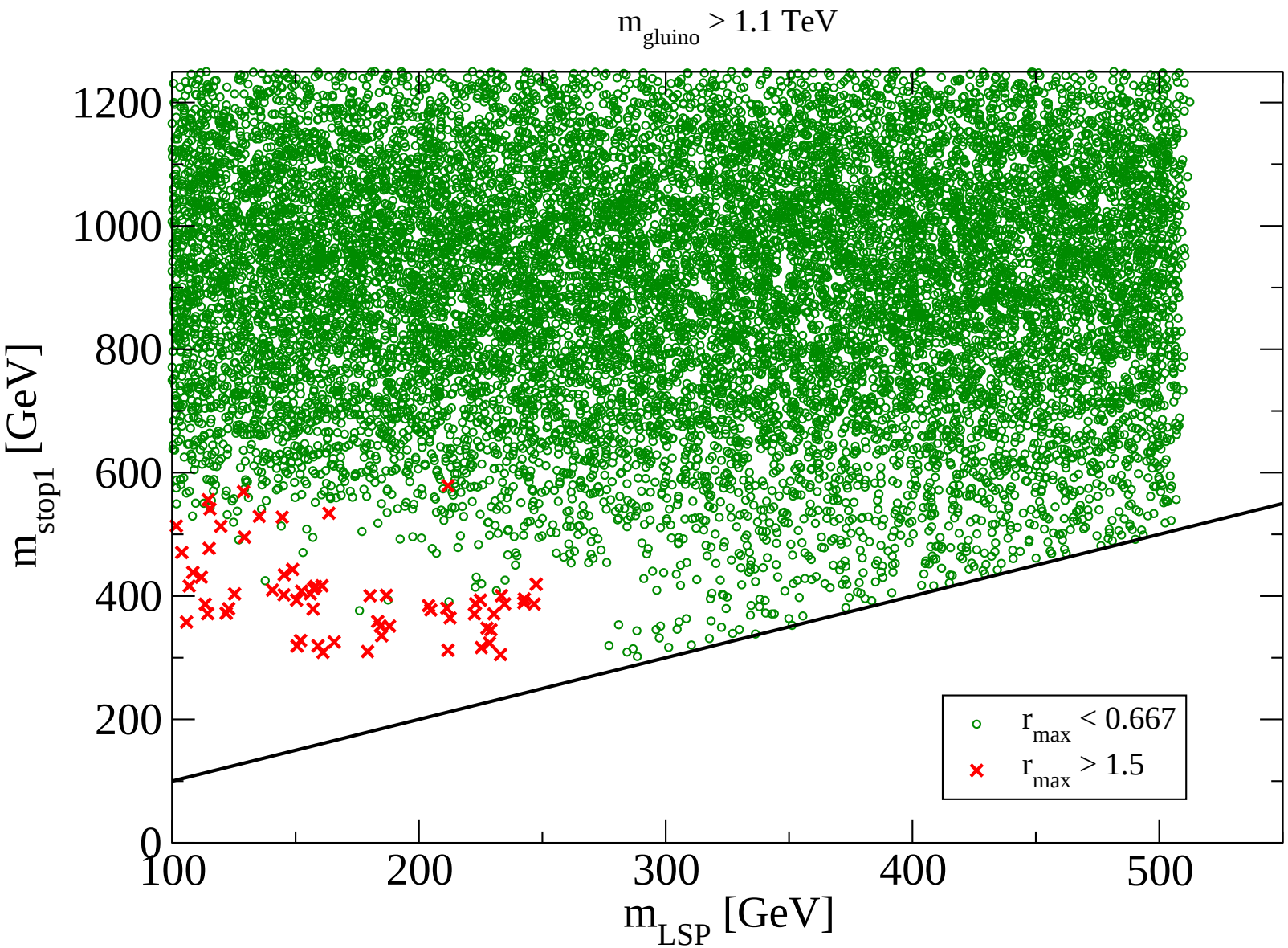


$m_{\tilde{g}} > 1100$ **GeV**



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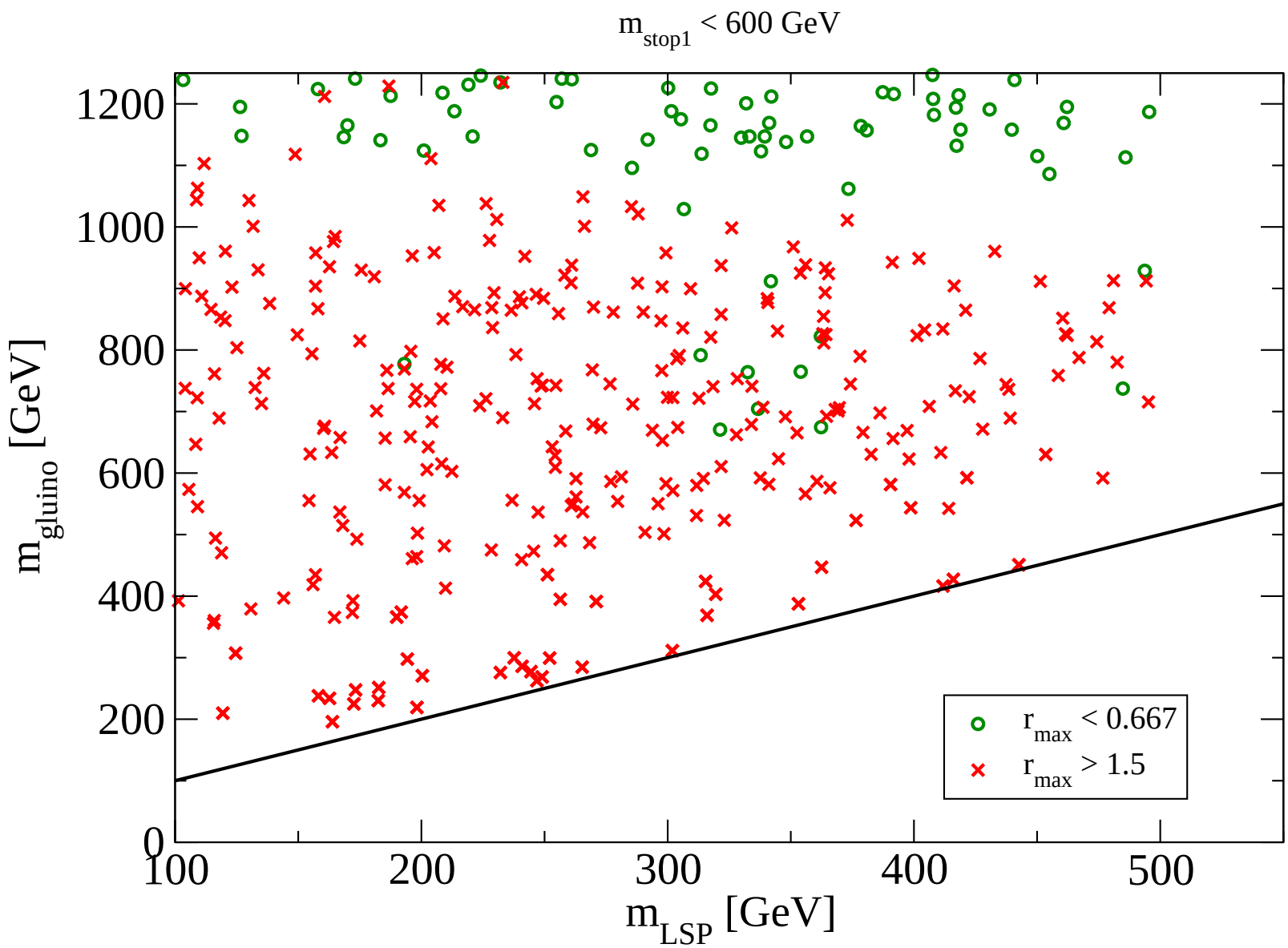

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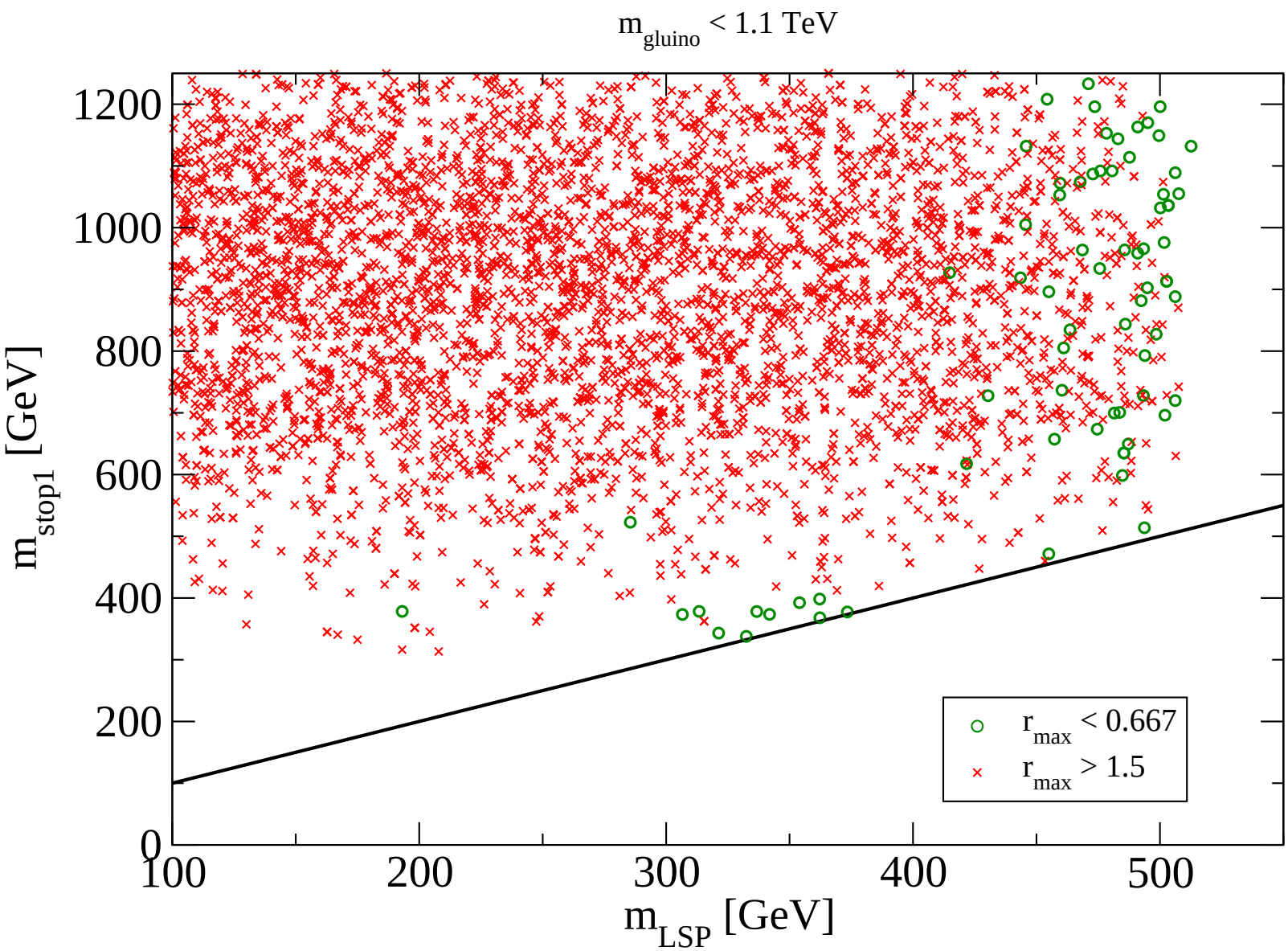

Results

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- Smallest allowed masses in scan: $m_{\tilde{g},\rm min} = 520$ GeV, $m_{\tilde{t}_1,\rm min} = 300$ GeV

Improving Naturalness

MD, M. Asano

MSSM: $m_h < M_Z$ at tree–level

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Can be improved by increasing tree–level value of m_h!

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Cannot maximize both contributions to m_h^2 simultaneously!

TMSSM

Espinosa, Quirós (1992); Pérez, Spinner (2012); Kang, Liu, Ning (2013)

Introduces two Higgs triplets $T_1,\ T_2$ with

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$m_h^2 \sim M_Z^2 \cos^2(2\beta) + v^2\left(\lambda_1^2 \sin^4\beta + \lambda_2^4 \cos^4\beta\right)$:
both terms are large if $\tan^2\beta \gg 1$!

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Possible problem:
Need $v_T^2 = \langle T_1^0\rangle^2 + \langle T_2^0\rangle^2 \ll v^2$: new source of finetuning?

Triplet VEV

Assume $\tan^2\beta \gg 1$ for simplicity (not important):

$$v_T = \frac{v^2}{\sqrt{2}} \frac{\lambda_1 \mu_T \sin\beta_T - \mu \sin(2\beta)(\lambda_1 \cos\beta_T + \lambda_2 \sin\beta_T) - \lambda_1 A_1 \cos\beta_T}{m_{T_2}^2 \sin^2\beta_T - m_{T_1}^2 \cos^2\beta_T - \mu_T^2 \cos(2\beta_T)}$$

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Small v_T *not* unnatural if $m_{T_{1,2}}^2 \gg |\lambda_1 A_1| v,\ |\lambda_1 \mu_T| v,\ |\mu| v$!

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But: T_1 couples to H_u

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Performed *quantitative* analysis to compare finetuning in MSSM and TMSSM

Finetuning Measure

- $\Delta_{P_i}^{M_Z^2} = \left| \frac{P_i}{M_Z^2} \frac{\partial M_Z^2}{\partial P_i} \right|$ (P_i: some dimensionful free parameter of the theory, at input scale Q_0)

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  $\Delta^{M_Z^2} = \max_i \Delta_{P_i}^{M_Z^2}, \ \Delta^{v_T/v^2} = \max_j \Delta_{P_j}^{v_T/v^2}$
- Grand total: $\Delta = \Delta^{M_Z^2} \cdot \max\{\Delta^{v_t/v^2}, 1\}$
- Scan a few million points in parameter space, look for scenario with smallest Δ

Results

Take $m_{\tilde{g}} = 1.1$ TeV, 122.5 GeV $\leq m_h \leq$ 128.5 GeV, $\left|\frac{g_{hVV}}{g_{hVV,\mathrm{SM}}} - 1\right| \leq 0.1$

- For $\ln \frac{Q_0}{Q_{\mathrm{EW}}} = 5$: $\Delta < 7$ possible! $m_{T_1}^2 \sim m_{T_2}^2 > \mu_T^2 \sim 1$ TeV, $\lambda_1 \sim 0.3$; $\Delta^{v_T/v^2} < 1$ easy

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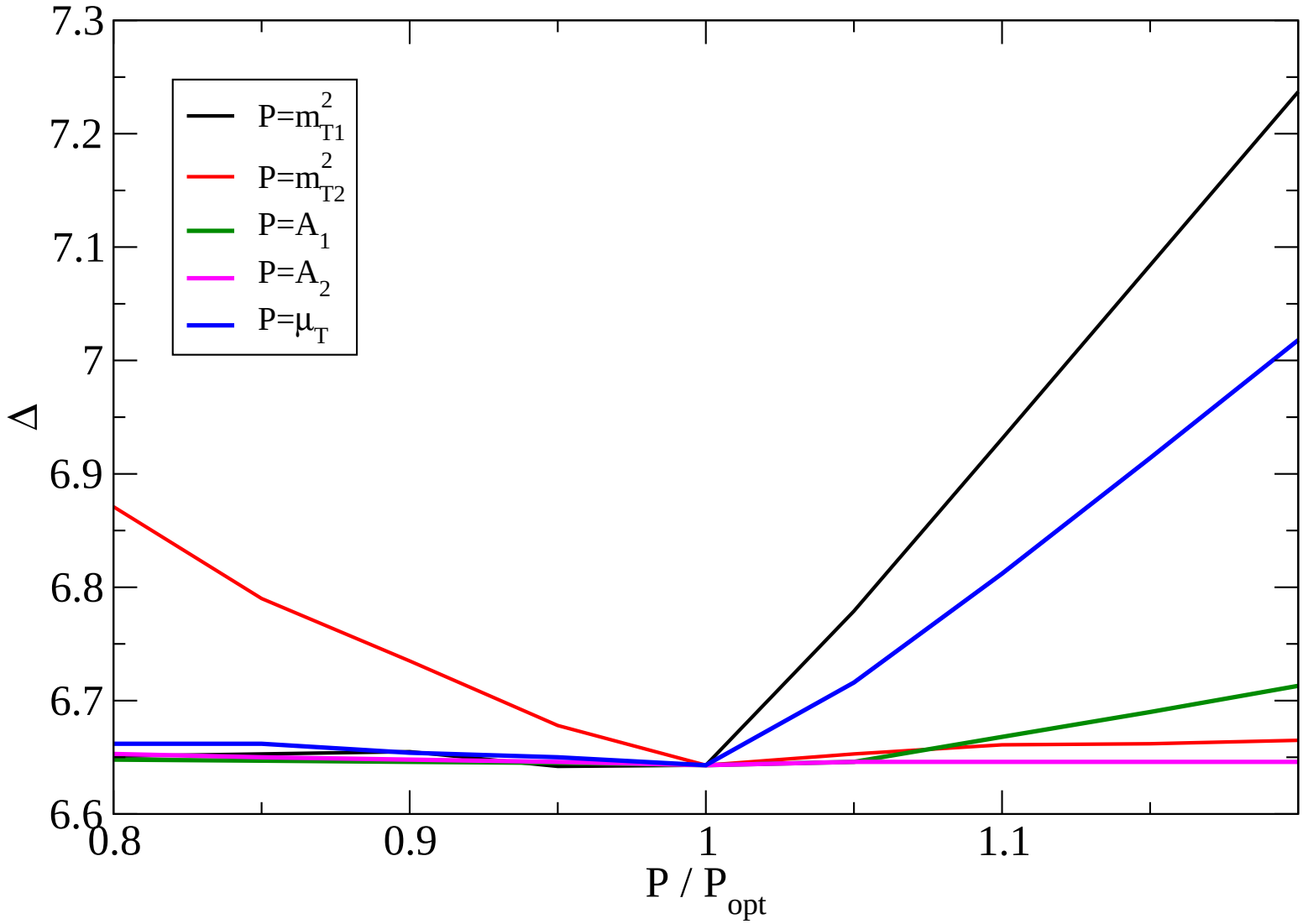
- All triplets can have mass > 1 TeV: *no* LHC signal!

Variation of triplet parameters



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Do not seriously expect 124, or even 18, "uncorrelated" parameters!?

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- No finetuning if all dimensionful parameters are correlated!