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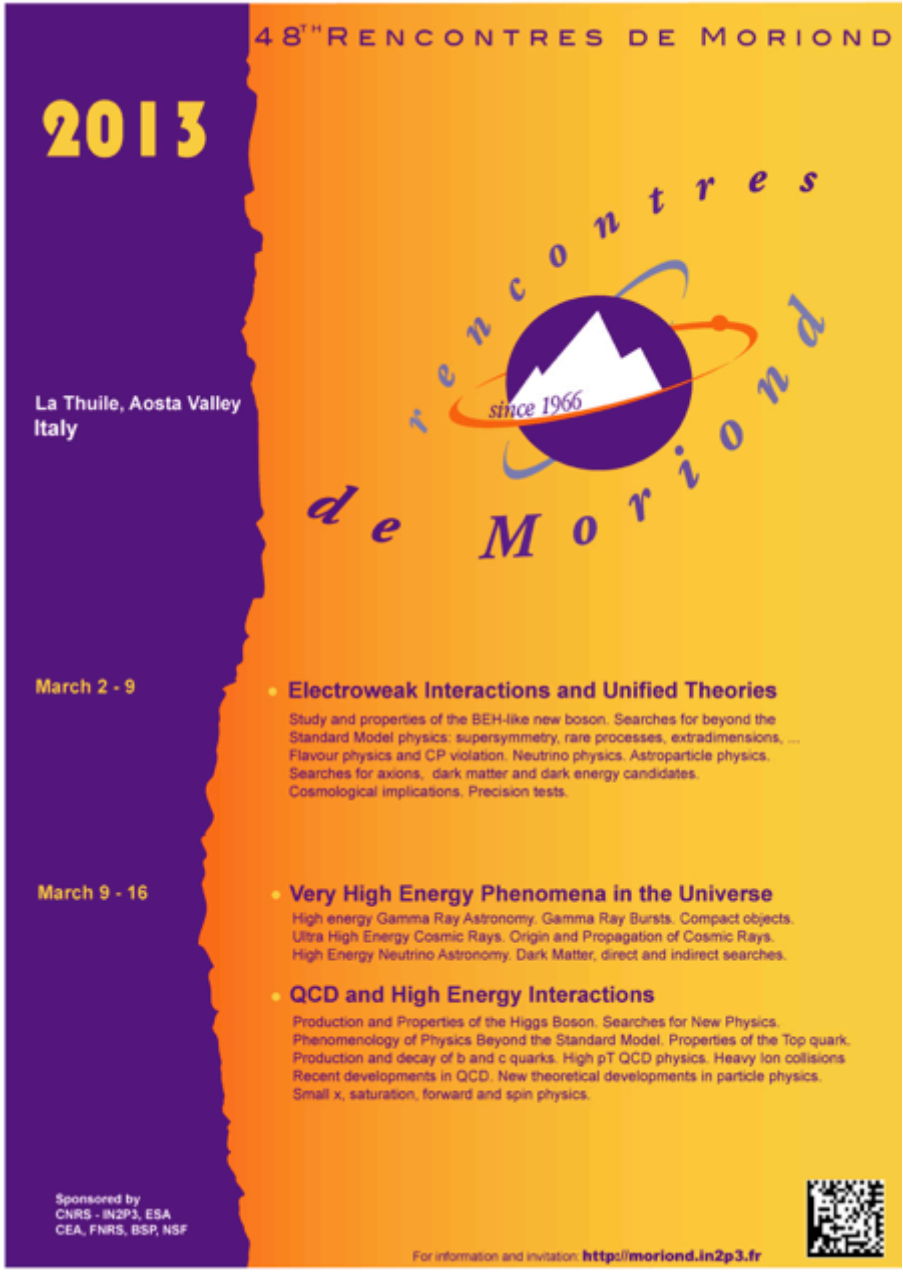
SUSY Highlights from Moriond

Christian Sander *(Hamburg University)*

DESY Seminar / LHC Forum – March 2013 – Hamburg / Zeuthen

Outline

- Introduction
- Inclusive searches
- Direct chargino/neutralino production
- 3rd generation
  - Light staus
  - **Light stops and sbottoms → "Natural" supersymmetry**
- *R* parity violating SUSY
- Conclusion



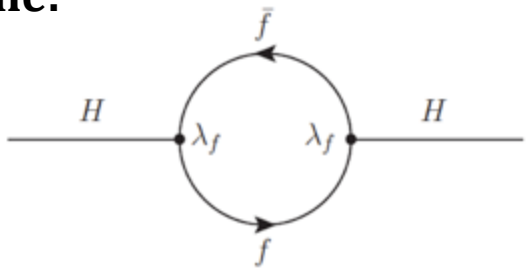
Physics Beyond the SM

New Physics expected at TeV scale:

- **"Fine tuning" problem:**

  $\Delta m^2_{H,f} \propto \Lambda^2_{\mathrm{UV}}$

→ SUSY / Technicolour …



- **Hierarchy problem**

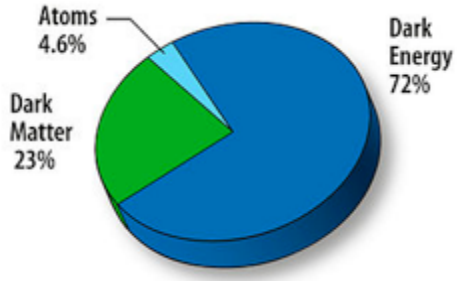
→ Large Extra Dimensions / SUSY …

- **Dark Matter**

→SUSY / Extra Dimensions …

- **Dark Energy**

→ ???

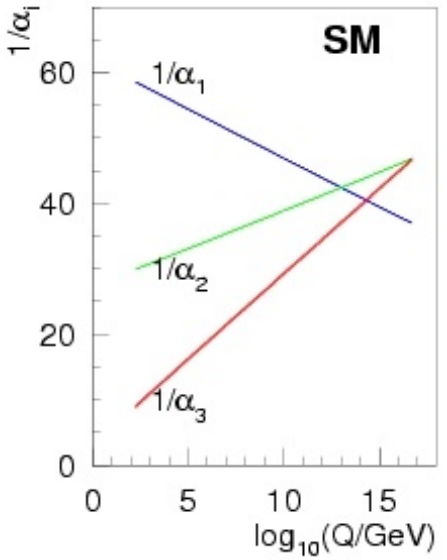


- **Unification of gauge couplings**

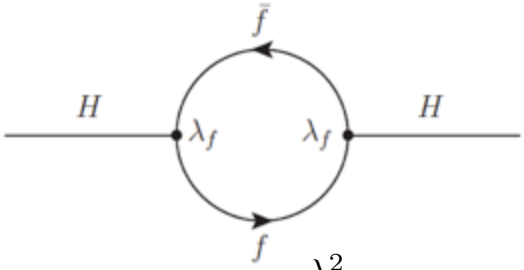
→ Supersymmetry / Leptoquarks …

- **…**

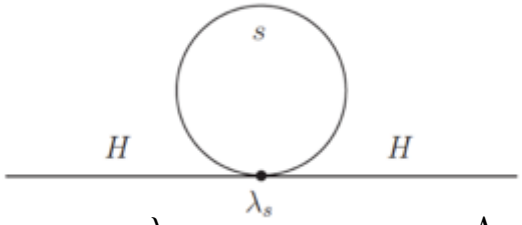
Best place to search for Physics Beyond the SM → LHC



Supersymmetry



$$\Delta m^2_{H,f} \approx -\frac{\lambda_f^2}{8\pi^2}\Lambda^2_{\mathrm{UV}}$$



$$\Delta m^2_{H,s} \approx \frac{\lambda_s}{16\pi^2}(\Lambda^2_{\mathrm{UV}} - 2m_s^2 \log\frac{\Lambda_{\mathrm{UV}}}{m_s})$$

Last possible extension of Poincare group:

Fermions ↔ Bosons

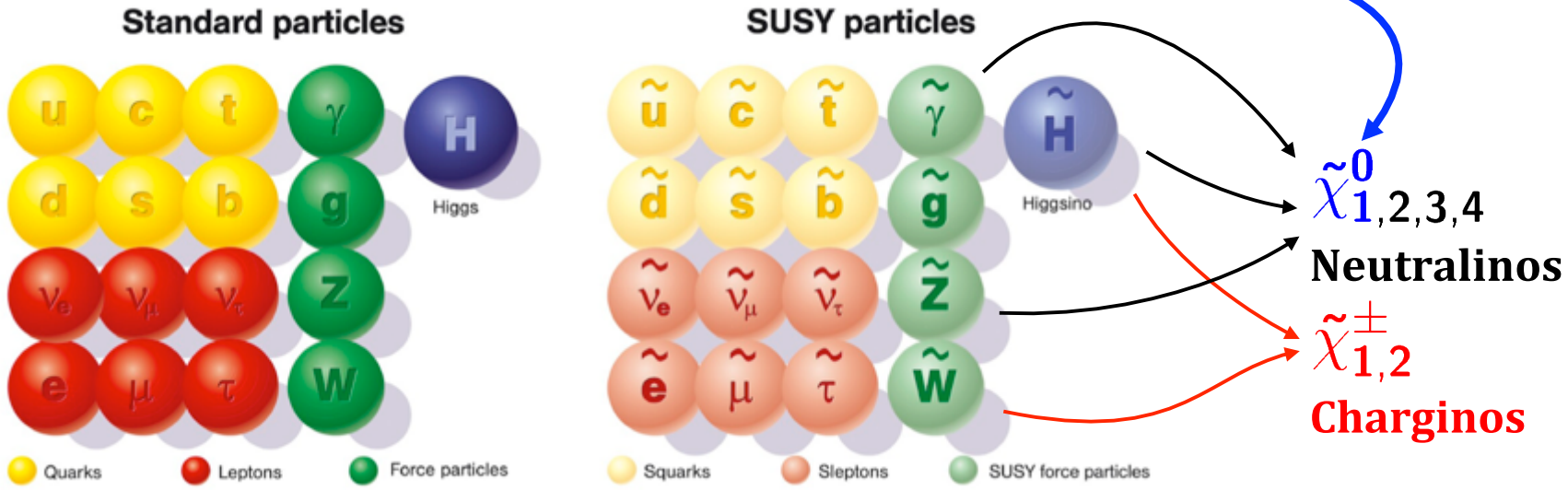
Solve "Fine Tuning" by SUSY opposite sign contributions:

$$\Delta m^2_{H,\mathrm{tot}} \approx \frac{\lambda_f^2}{4\pi^2}(m_s^2 - m_f^2)\log\frac{\Lambda_{\mathrm{UV}}}{m_s} \quad \text{for } \lambda_f^2 = \lambda_s$$

Conserved *R* parity: $R = (-1)^{3(B-L)+2S}$

→ SUSY particles produced/annihilated in pairs

→ Lightest SUSY particle (LSP) stable → **DM candidate**



Supersymmetry – Search Strategy

Breaking scenarios: cMSSM, GMSB, AMSB … → Plethora of SUSY models

***R*-Parity conserved SUSY:**

- If $\tilde{q}$ and $\tilde{g}$ not much heavier than other sparticles → Strong production dominates
- (Long) decay chains down to LSP
- LSP stable → Missing transverse energy

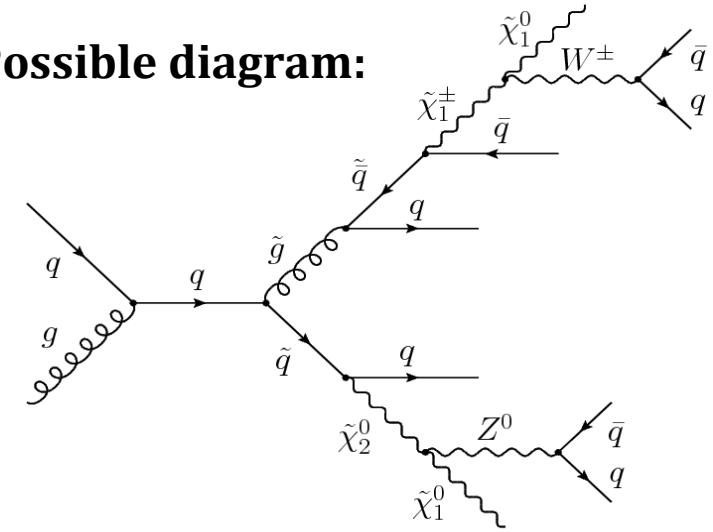
Realized final states very model dependent

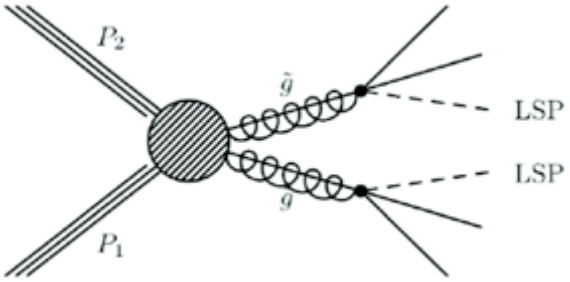
Past: Interpretation in specific SUSY breaking models

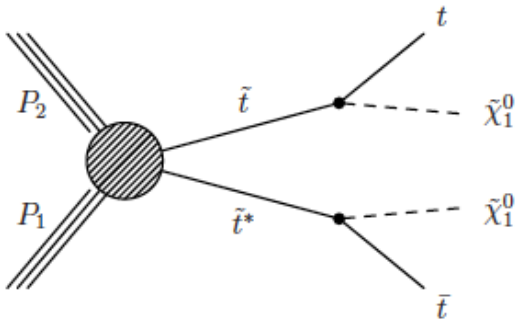
Present: Interpretation mostly in simplified models (decay topologies)

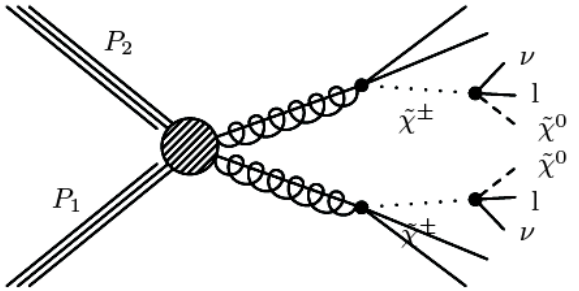
→ As model independent as possible

Possible diagram:









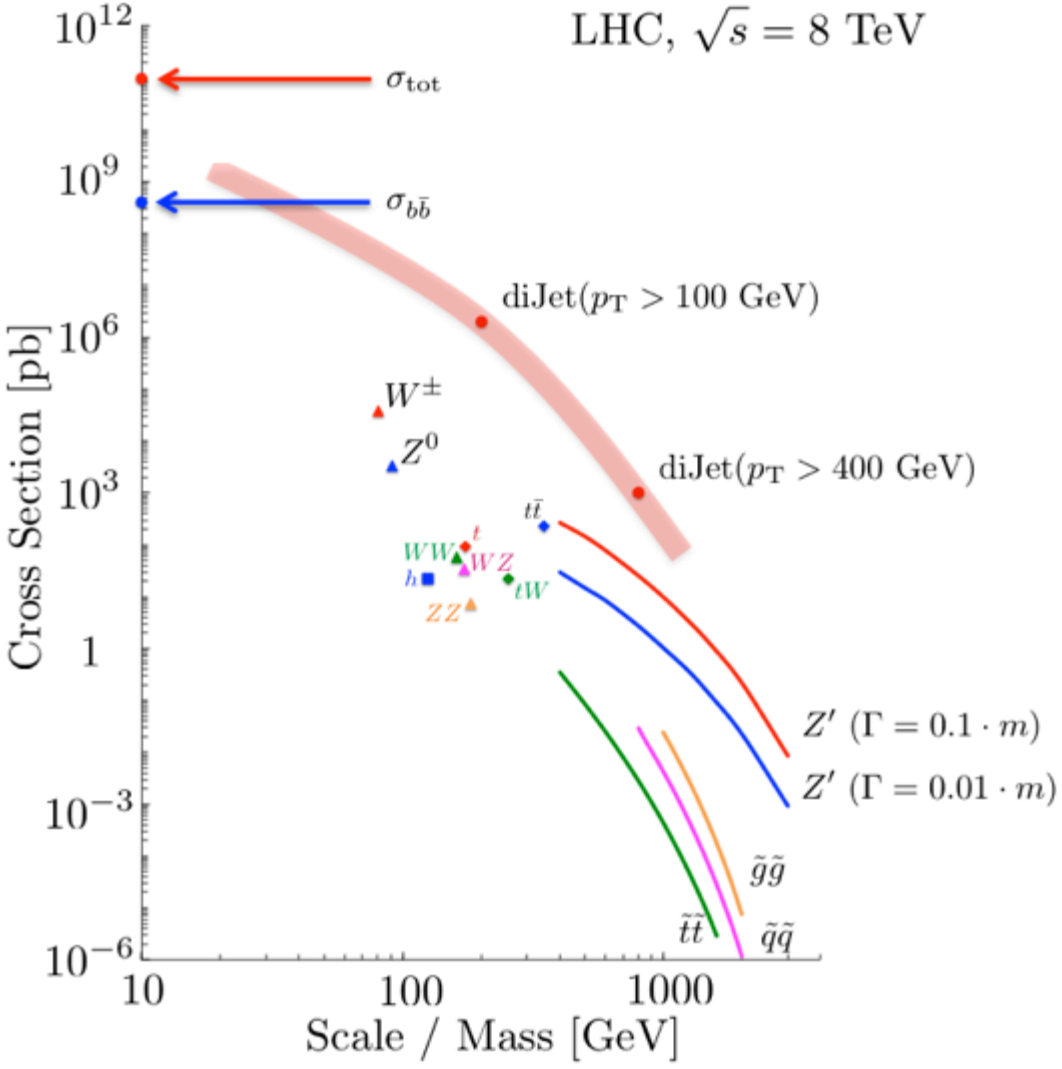
Standard Model Backgrounds

SM backgrounds have order of magnitudes larger cross sections than signal

Search in tails of distributions requires precise knowledge of

- SM processes
- detector effects

→ Use as much as possible data to estimate and validate background predictions



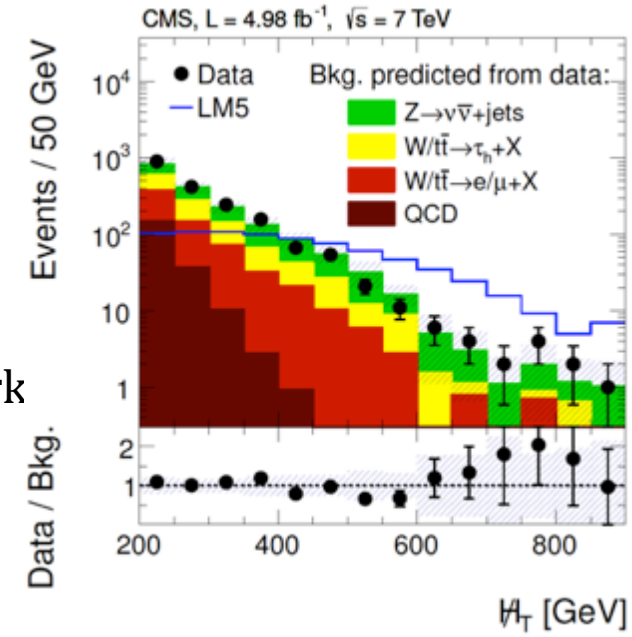
Example: Jets + MHT

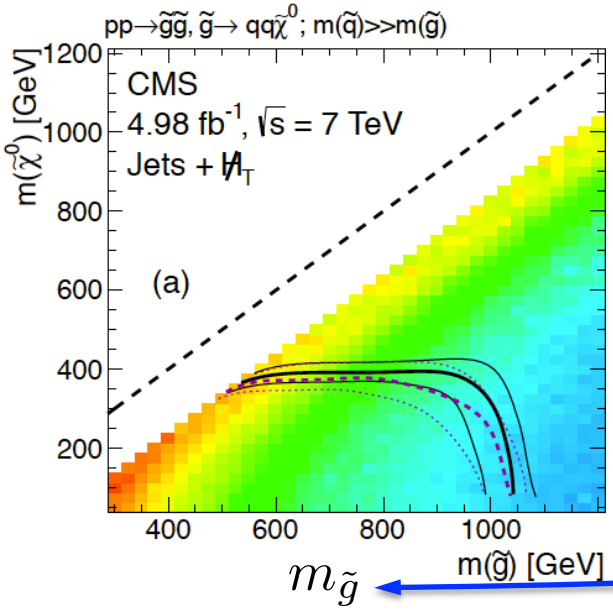
PRL 109, 171803 (2012)

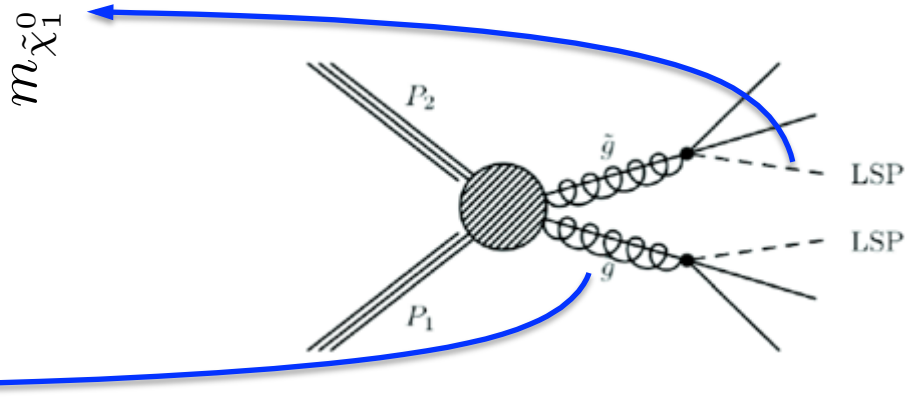
Jets + MHT:

- $N_{jet} \geq 3$ ($p_T > 50$ GeV, $|\eta| < 2.5$)
- $H_T > 500$ GeV (jet p_T scalar sum: $p_T > 50$ GeV, $|\eta| < 2.5$)
- MHT > 200 GeV (jet p_T vector sum: $p_T > 30$ GeV, $|\eta| < 5$)
- $\Delta\Phi$(MHT, jet$_{1,2,3}$)>(0.5,0.5,0.3)

No excess → Strong limits on 1st and 2nd generation squark gluinos in various simplified models, e. g.







Direct $\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$ Production

If $\tilde{q}$ and $\tilde{g}$ much heavier than $\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$

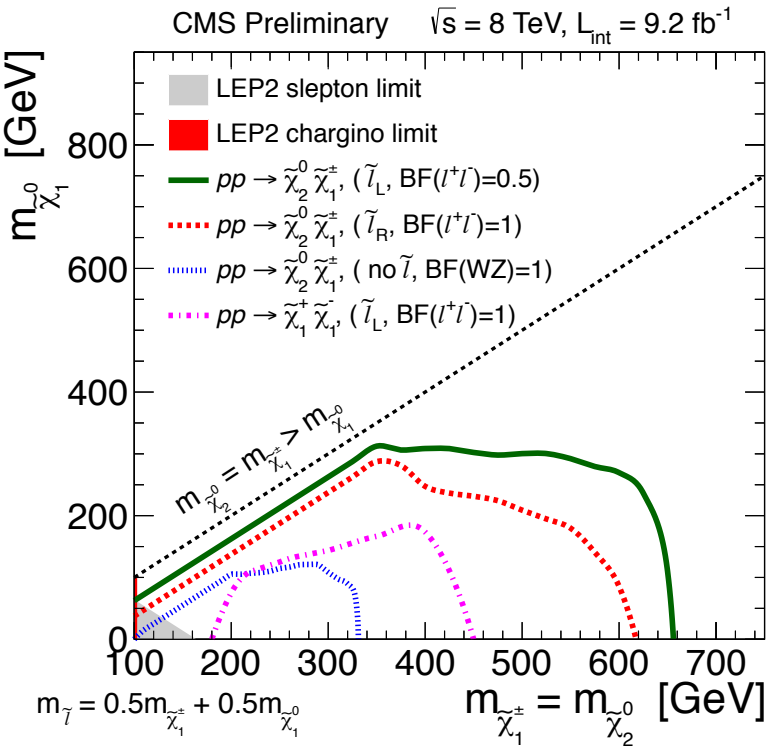
→ Direct chargino and/or neutralino production

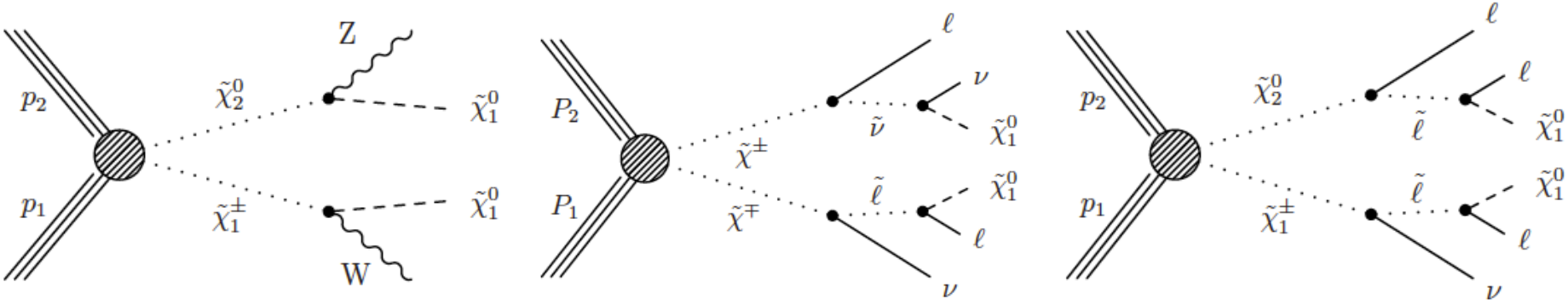
Leptonic decay modes provide clean signature:

- Many leptons (up to 4) + MET
- Possible opposite sign same flavour pairs with $m_{ll} = m_Z$
- Small jet activity

No excess → Limits

CMS SUS-12-022





Light Staus – EWK Production (≥2 τ_{had})

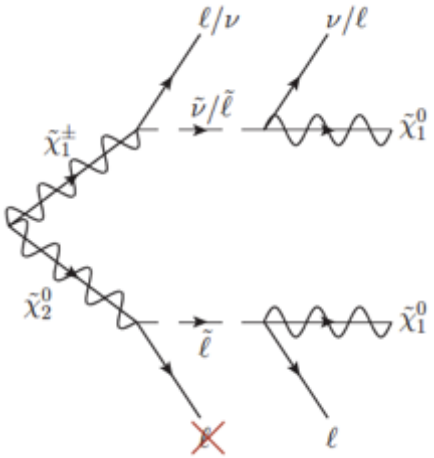
If staus significantly lighter than other sleptons

→ $\tilde{\chi}^0$, $\tilde{\chi}^{\pm}$ decay predominantly in $\tau^+\tau^-\tilde{\chi}_1^0$ / $\tau\nu_\tau\tilde{\chi}_1^0$

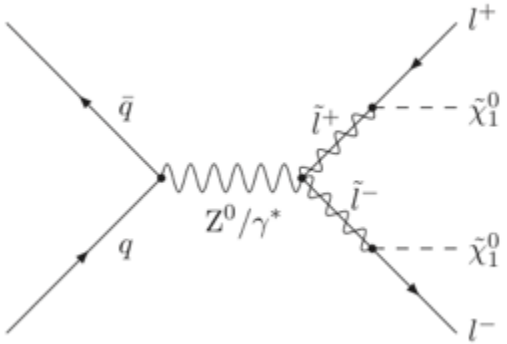
Search for taus, moderate MET, and large M_{T2}

$$M_{T2} = \min_{\not{p}_T^a + \not{p}_T^b = \not{p}_T} \{\max\{m_T(p^{\tau,a}, \not{p}_T^a), m_T(p^{\tau,b}, \not{p}_T^b)\}\}$$

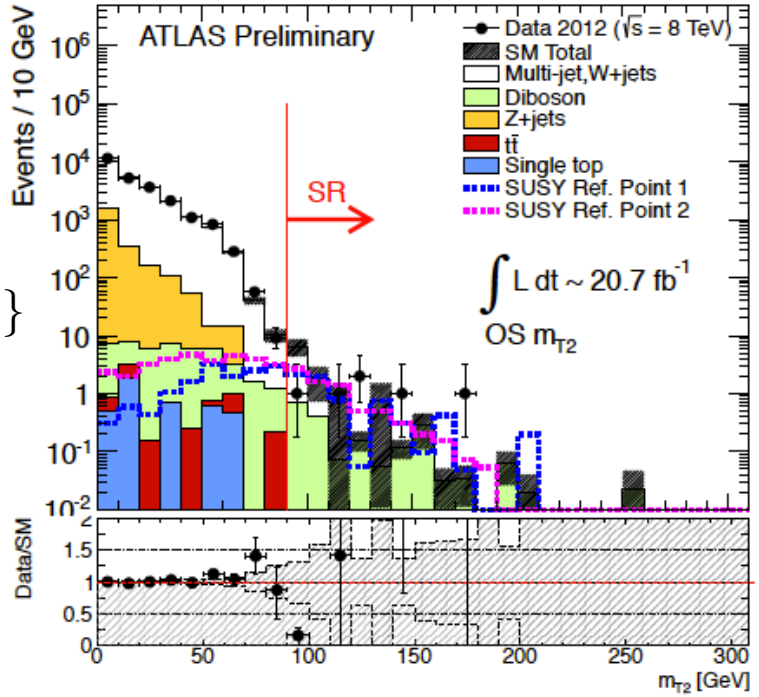
No excess: Interpretation in various models, e. g.

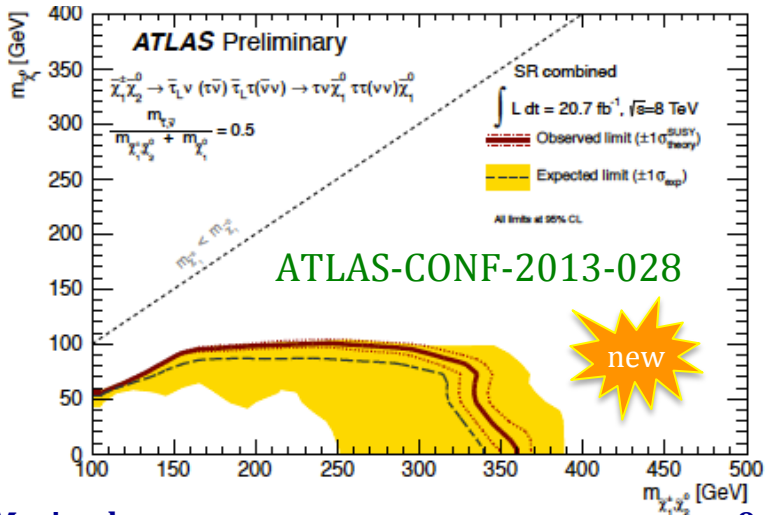


Chargino/neutralino production



Direct stau production





Light Staus – Jet+ MET + 1 or ≥2 τ_{had}

GMSB:

Gravitino is LSP (weak coupling to NLSP)

Signature depend on NLSP, e. g. $\tilde{\tau} \rightarrow \tau \tilde{G}$

cMSSM:

Fix A_0, tan β and μ such that $m_H \sim 125$ GeV

For some models NLSP = stau → τs in decay chain

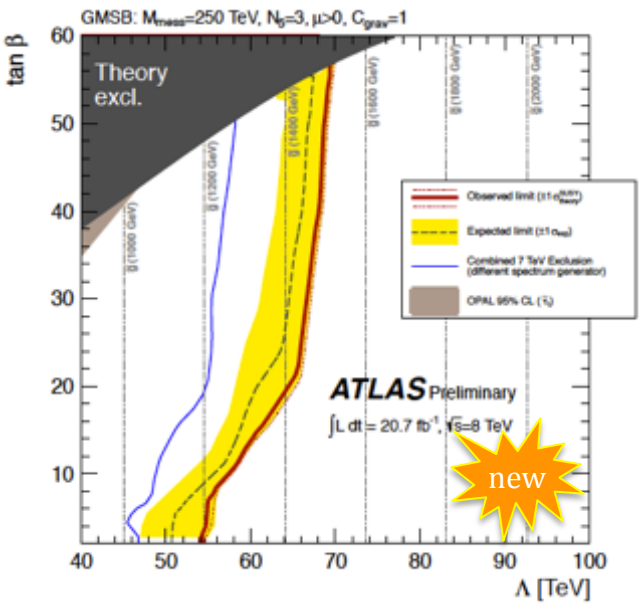
Natural GM:

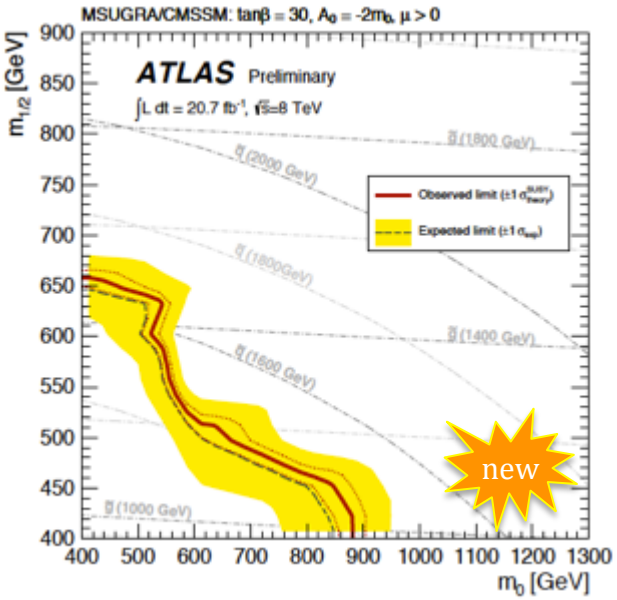
General Gauge Mediation + set weak scale parameters such to avoid fine tuning

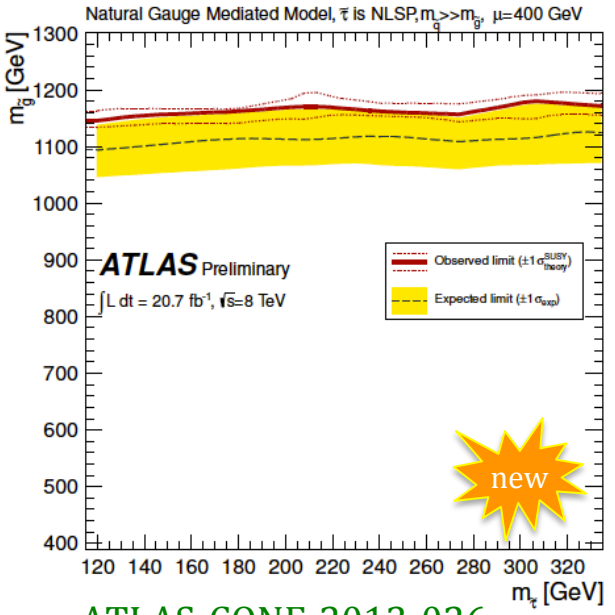
→ Light staus, accessible gluinos, other sparticles heavy

Common signature:

Strong production (squark & gluinos) dominates → jets; light staus → τs; LSPs → MET







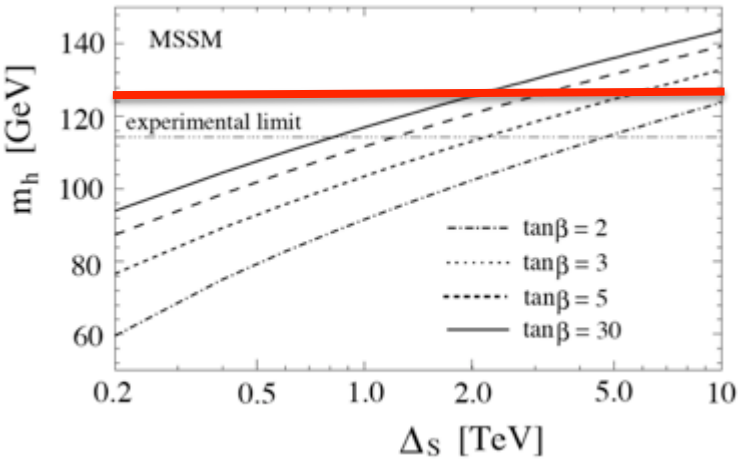
ATLAS-CONF-2013-026

Supersymmetry-Higgs Interplay

Implications of 125 GeV Higgs:

$$M_h^2 \leq M_Z^2 \cos^2 2\beta + \frac{3m_t^4}{\sqrt{4}\pi^2} \log \frac{\Delta_S^2}{m_t^2} \quad \text{with} \quad \Delta_S^2 = m_{\tilde{t}_1} m_{\tilde{t}_2}$$

Tobe, Wells
PRD 66 (2002) 013010



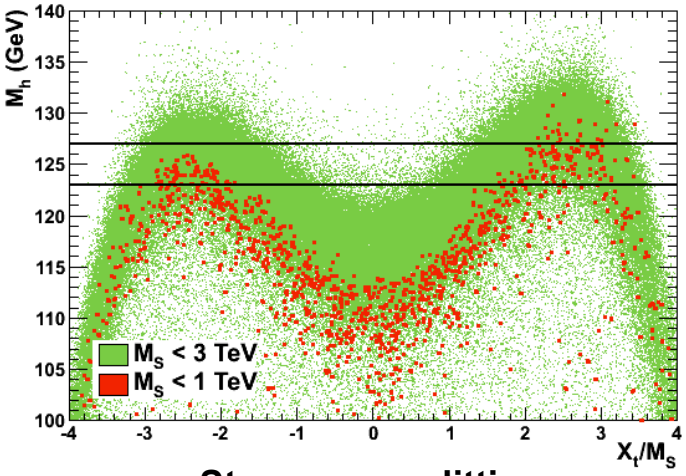
- Either stops are heavy (≫1 TeV) → Tension to "naturalness" (→ some amount of fine tuning)

$$\frac{M_Z^2}{2} = \frac{(m_{H_d}^2 + \Sigma_d) - (m_{H_u}^2 + \Sigma_u)\tan^2\beta}{\tan^2\beta - 1} - \mu^2$$

Radiative EWSB

- or large stop mass splitting ("Maximal mixing")

$$\mathcal{M}_{\tilde{t}} = \begin{pmatrix} \tilde{m}_{t_L}^2 & \overbrace{m_t(A_t - \mu\cot\beta)}^{X_t} \\ m_t(A_t - \mu\cot\beta) & \tilde{m}_{t_R}^2 \end{pmatrix}$$

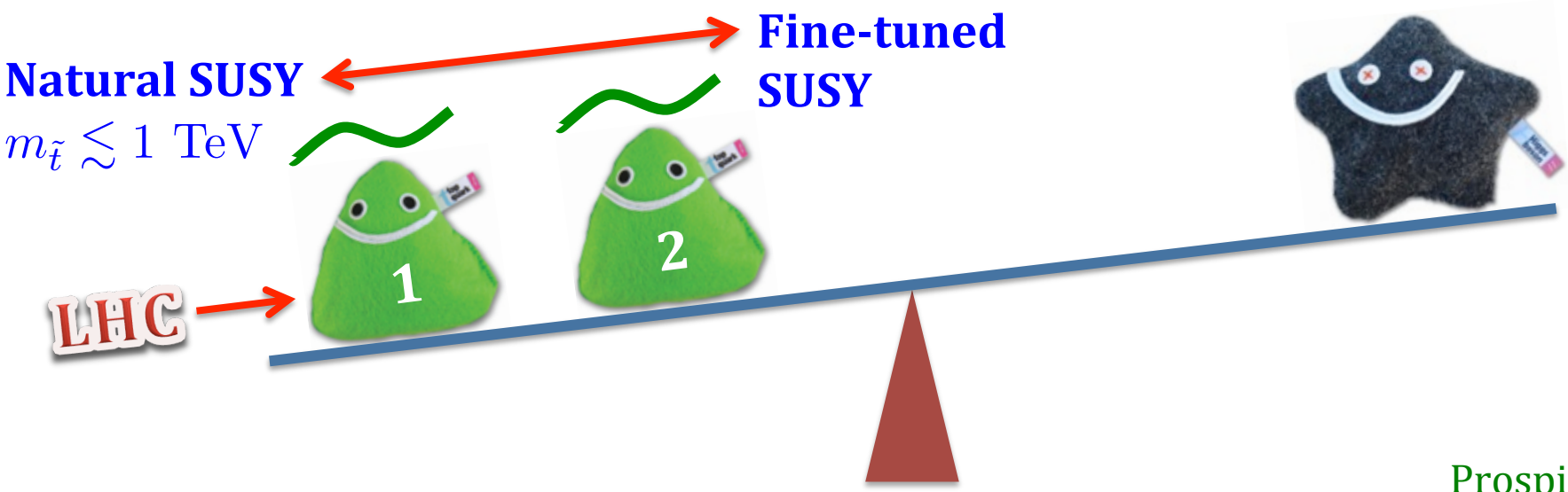


Stop mass splitting

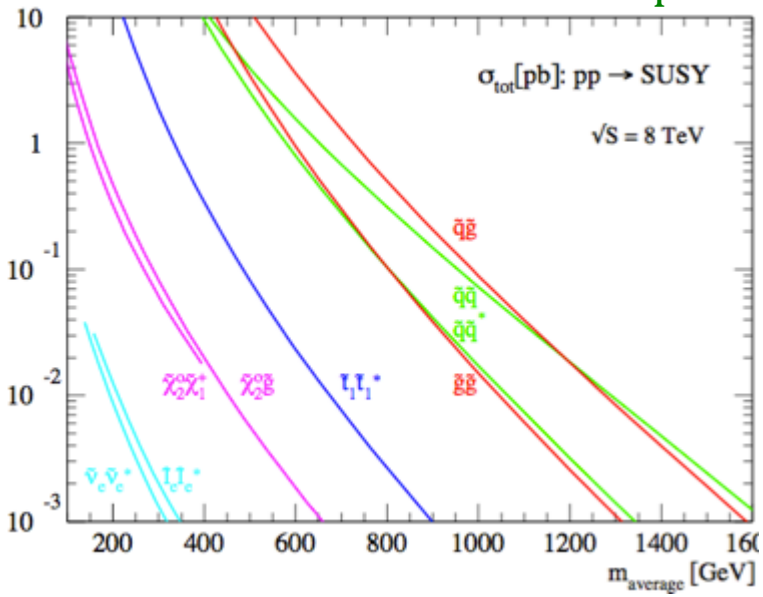
Arbey, Battaglia, Djouadi, Mahmoudi, Quevillon
arXiv:1112.3028

A Simplified Picture

$m_H \sim 125$ GeV



Prospino



Stop production cross section significantly smaller (compared to light squark production)

→ LHC limits on squarks masses only apply for 1st and 2nd generation

→ Stop quarks can be lighter than 1st and 2nd generation squarks!

Direct sTops Production

$m_{\tilde{t}} < m_{\tilde{g}}$ → Direct stop production

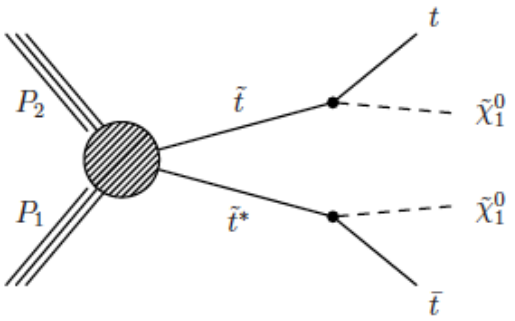
Signature: $t\bar{t}$ + MET

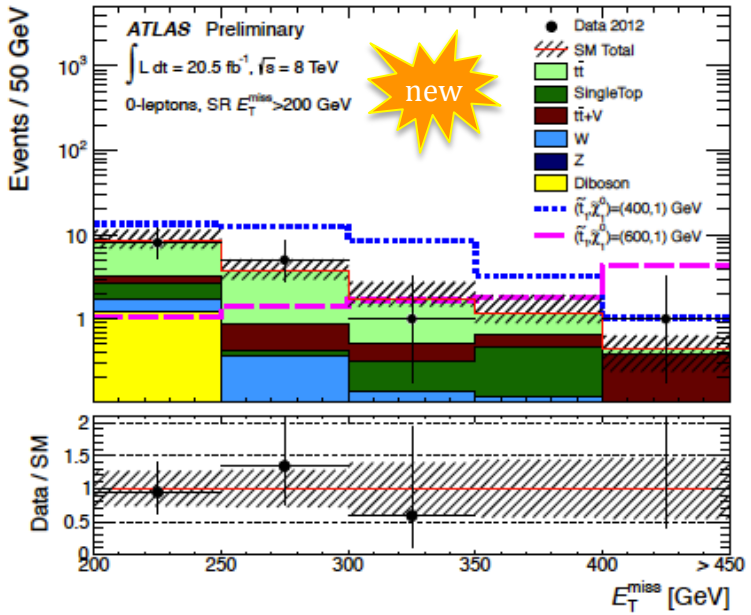
Challenge: dominant background ($t\bar{t}$) has also genuine MET

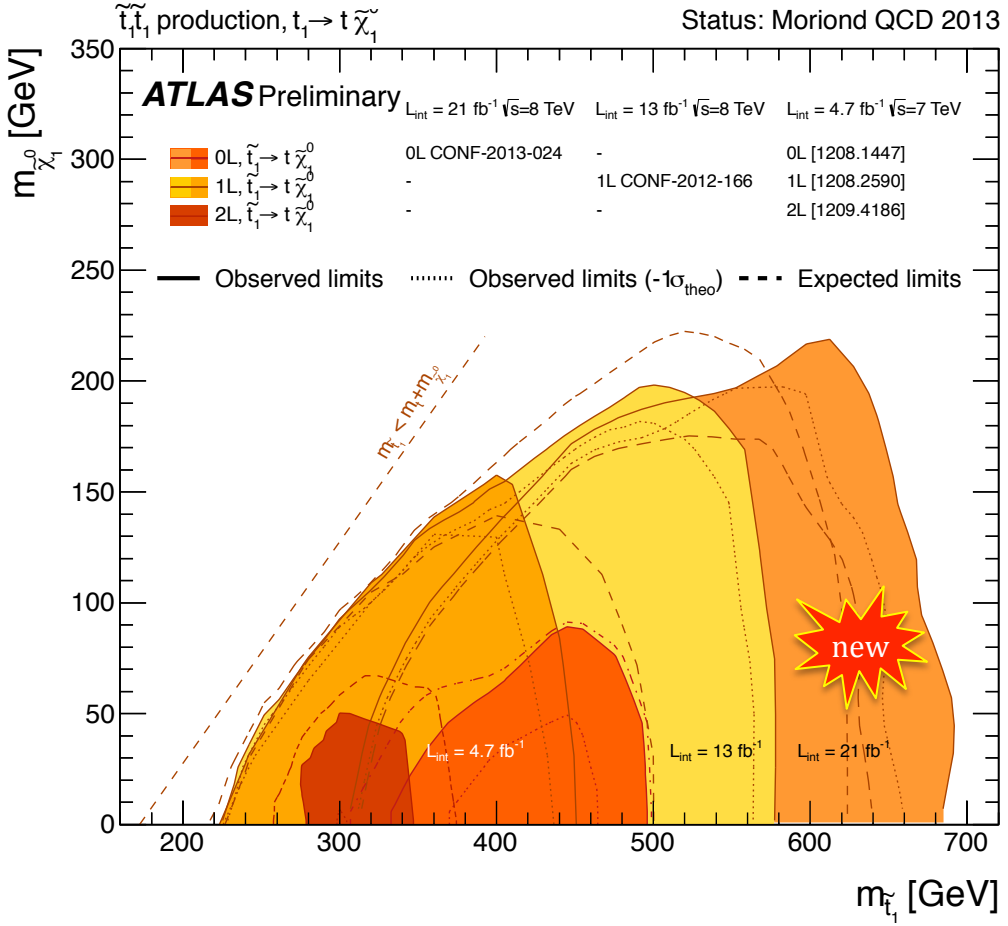
Leptonic and hadronic searches

No excess above SM expectation

$m_{\tilde{t}} < 680$ GeV (95% C.L., light LSP)





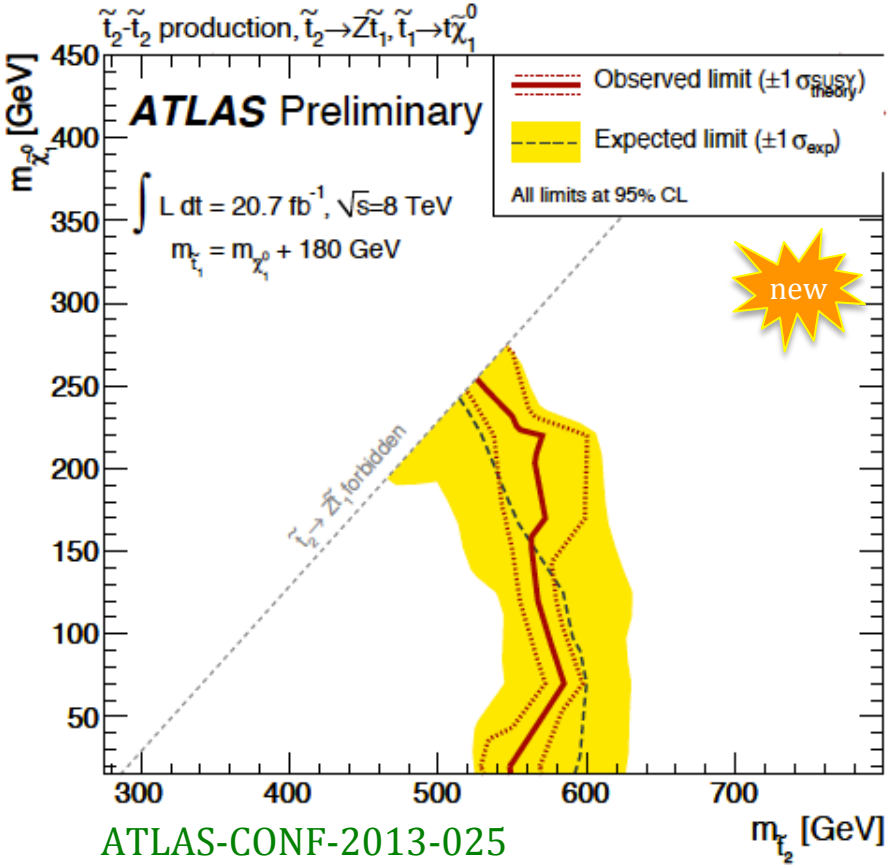


More Stop Searches

For $m_{\tilde{t}_1} \sim m_t + m_{\tilde{\chi}_1^0}$
similar kinematics of $\tilde{t}_1\bar{\tilde{t}}_1 \rightarrow t\bar{t}\tilde{\chi}_1^0\tilde{\chi}_1^0$ and $t\bar{t}$
If $m_{\tilde{t}_2} \gtrsim m_{\tilde{t}_1}$ → $\tilde{t}_2 \rightarrow \tilde{t}_1 + Z$

Similar topology in natural GMSB models
(NLSP: higgsino like $\tilde{\chi}_1^0$)

$\tilde{t}_1 \rightarrow t + \tilde{\chi}_1^0 \rightarrow t + Z\tilde{G}$



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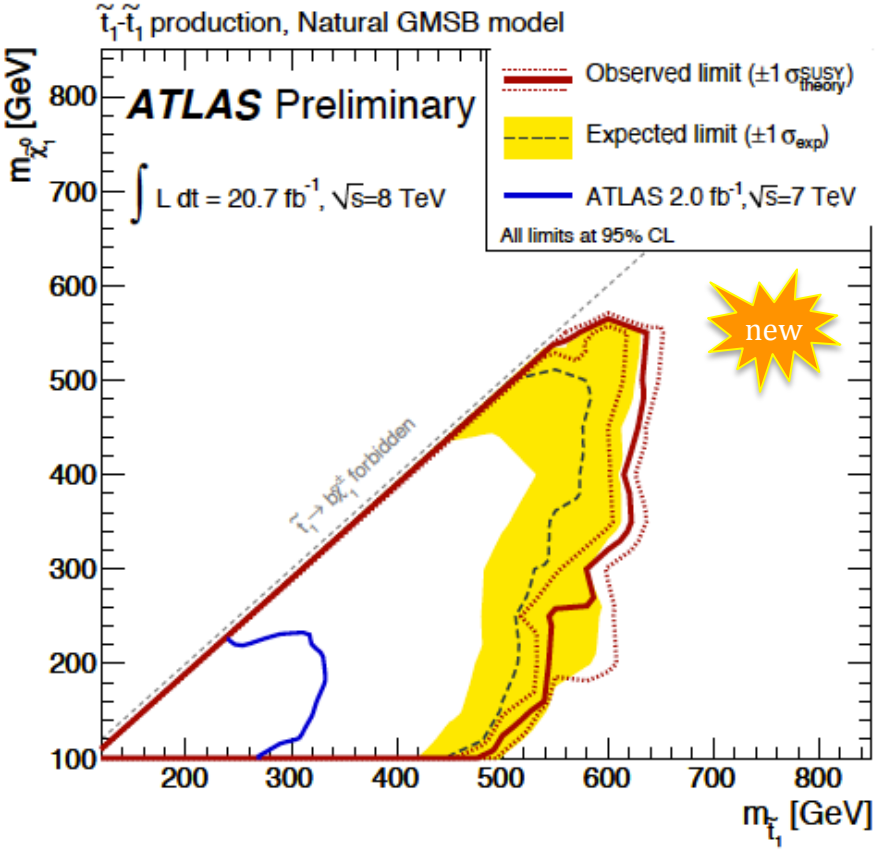
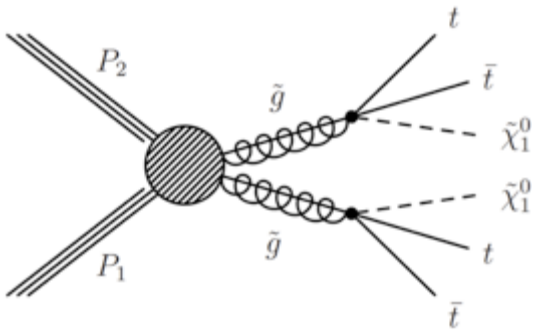


Light sTops



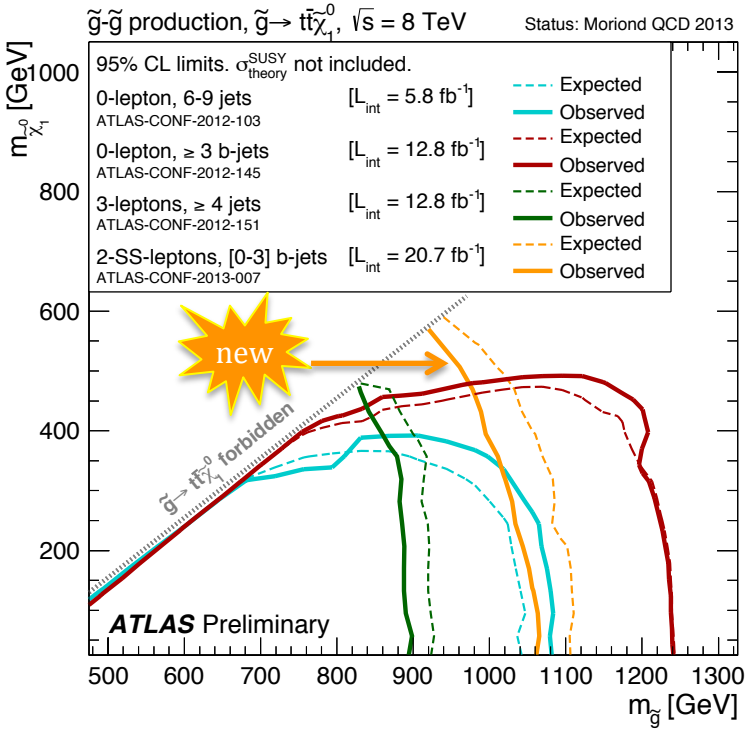
$m_{\tilde{t}} \sim m_{\tilde{g}}$ → "Gluino induced" production

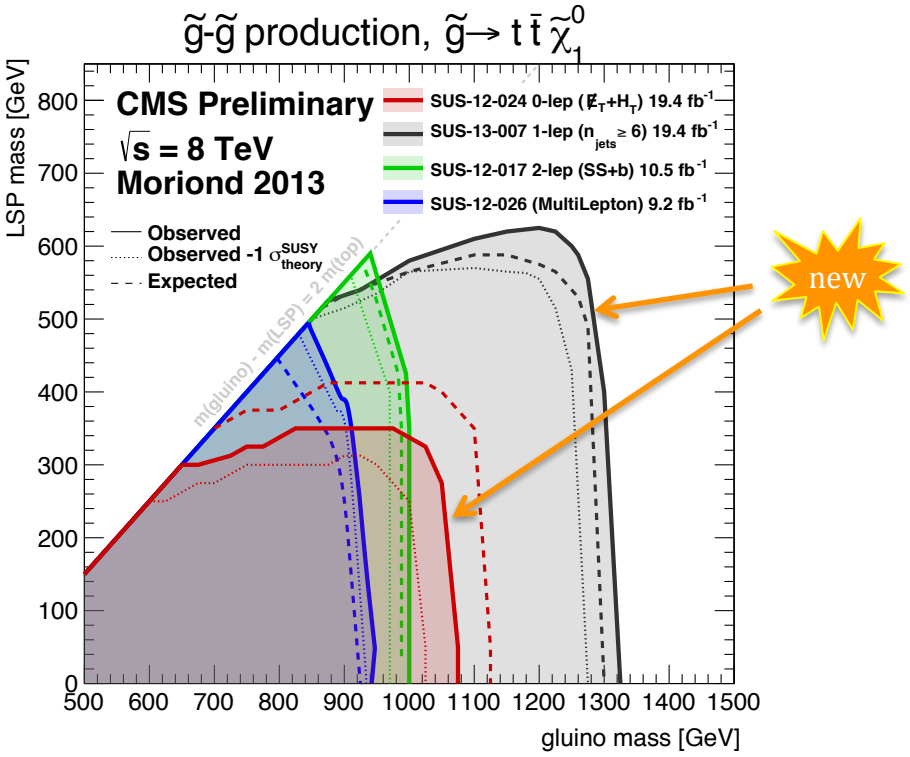
Signature: $t\bar{t}t\bar{t}$ + MET

→ Up to 12 jets; 4 *b*-tags; MET

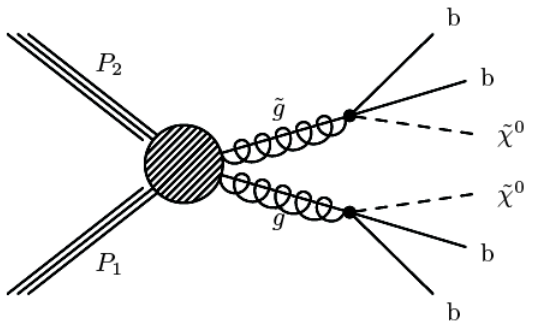
Small backgrounds: Searches have good sensitivity, e. g. lepton + 2 *b*-tags + >5 jets

Gluino masses excluded up to ~1.3 TeV (95% C.L.) for light LSPs





Light Sbottoms



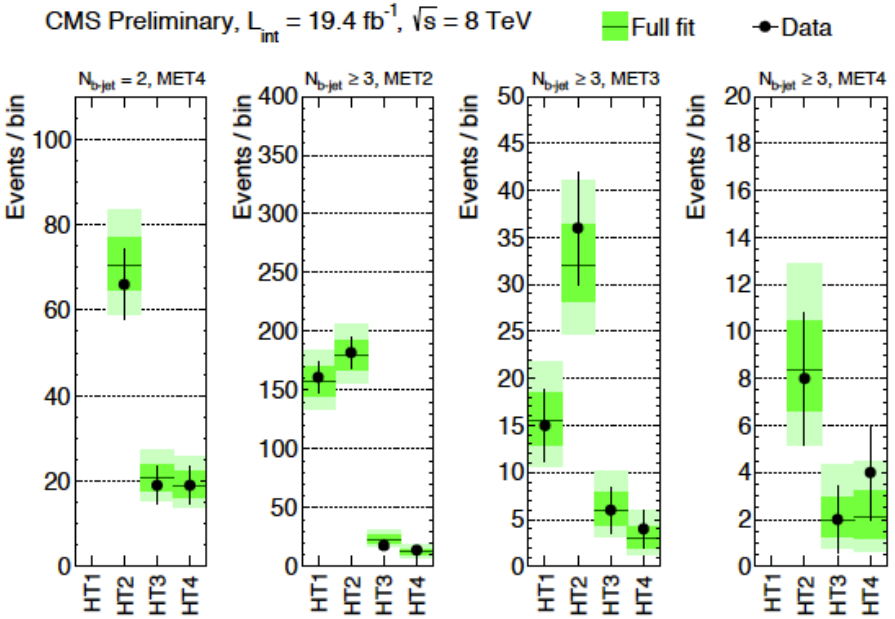
In case of light 3rd generation squarks and dominant gluino production

→ Large number of *b* jets in final state

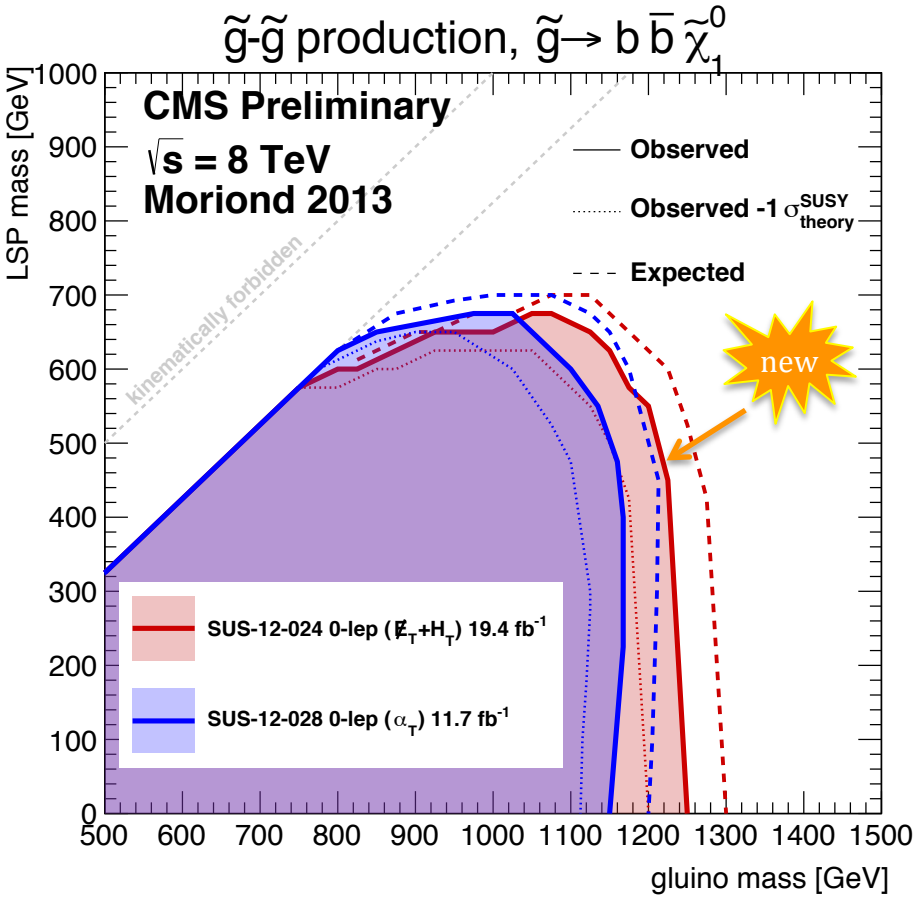
→ Even final state with only *b* jets possible

e. g. H_T (scalar some of jet p_T) + *b* jets + MET

Exclude gluino masses up to 1.25 TeV for light LSP mass



CMS SUS-12-024

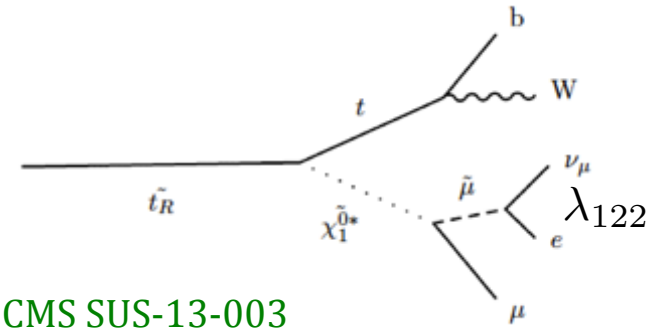


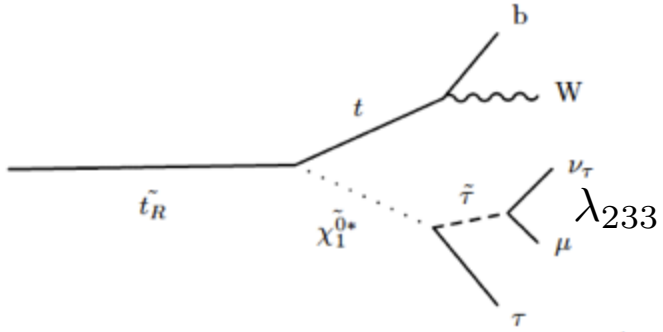
R-Parity Violating SUSY

R parity violation not in contradiction to long proton lifetime

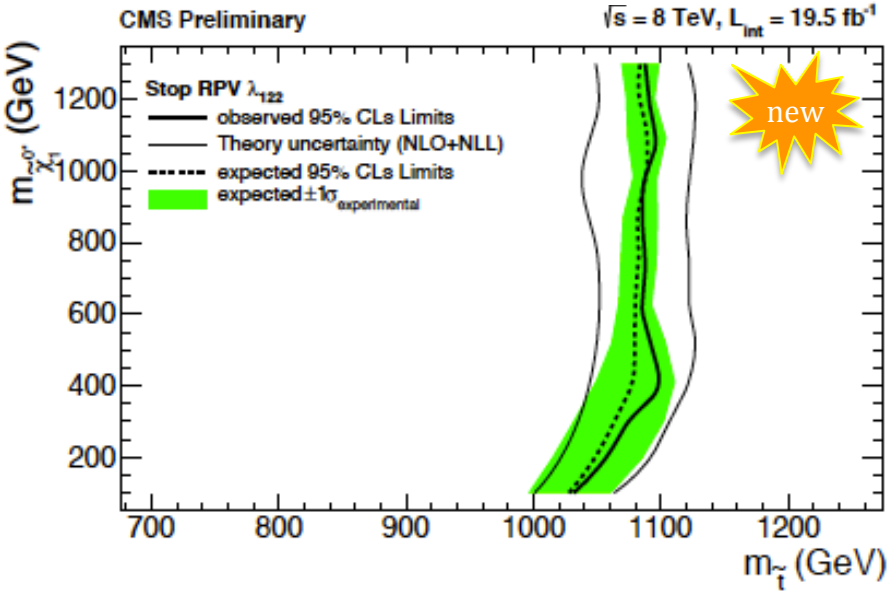
LSP not stable → Use S_T (scalar sum of all p_T) instead of MET

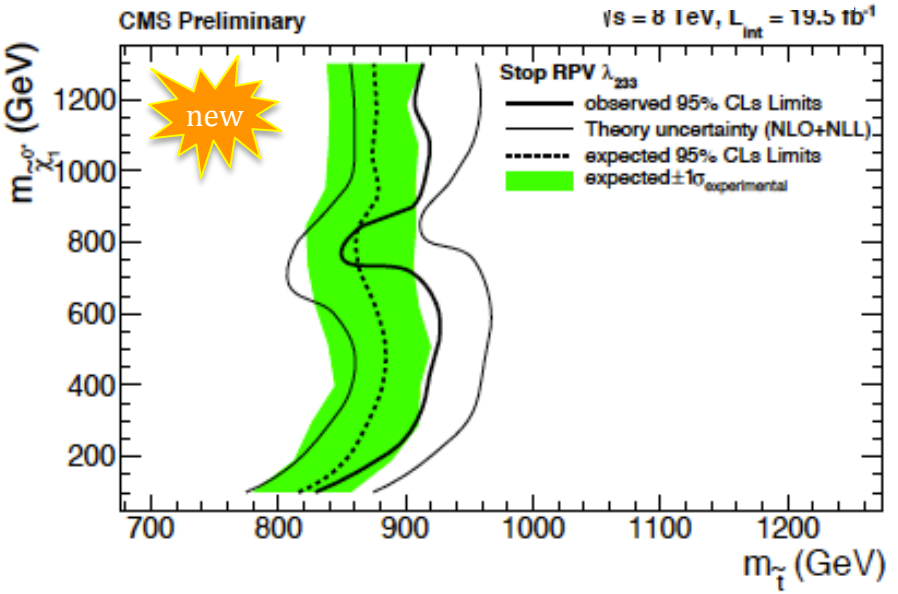
Natural Supersymmetry requires light stops → Search for RPV stop decays, e. g.



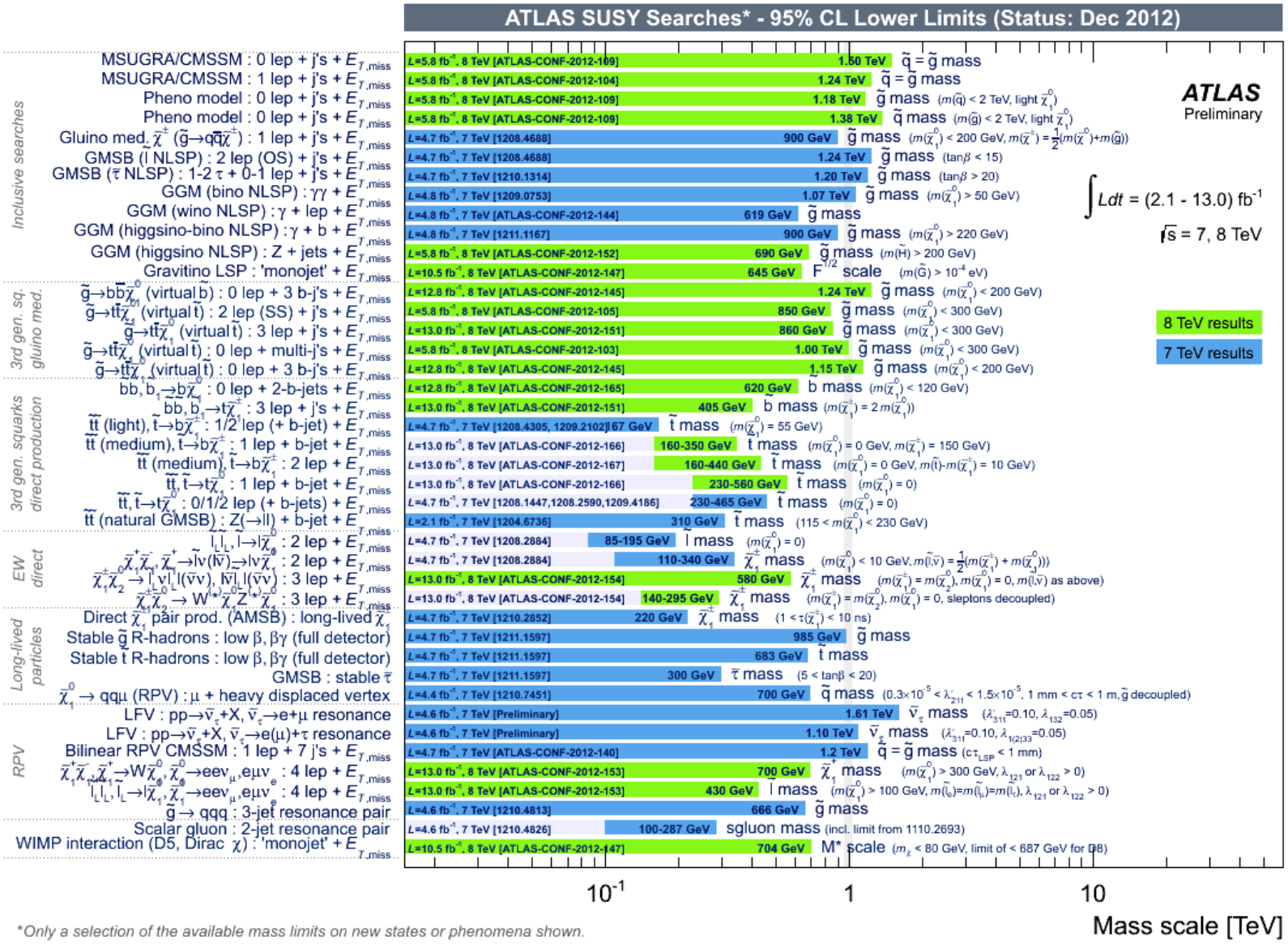


CMS SUS-13-003



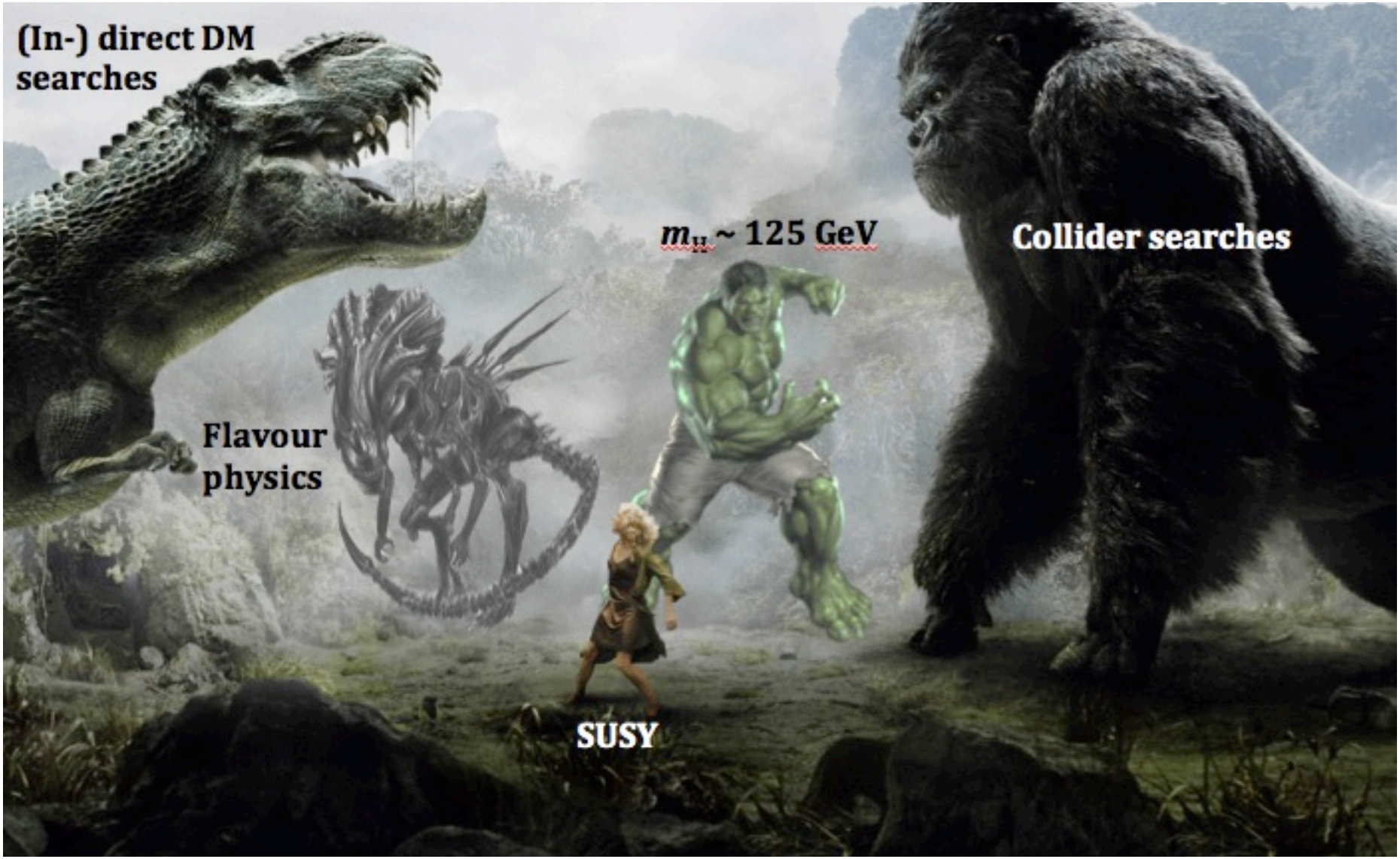


Supersymmetry – Summary



*Only a selection of the available mass limits on new states or phenomena shown.
All limits quoted are observed minus 1σ theoretical signal cross section uncertainty.

Natural SUSY under Pressure



Conclusion

- Search for physics beyond the Standard Model is one of the main motivations for the LHC experiments
- So far, no significant deviation from SM observed → Worlds best limits on almost all New Physics models
- Many more ATLAS, CMS, and LHCb results available and more to come from Run 1 dataset → Visit the public result pages
  - https://twiki.cern.ch/twiki/bin/view/AtlasPublic
  - https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResults
- LHC has entered first long shutdown … to be continued at 13/14 TeV

The End

... to be continued