Particle physics perspectives after LHC run 2

BSM
Model Building
High-p_T

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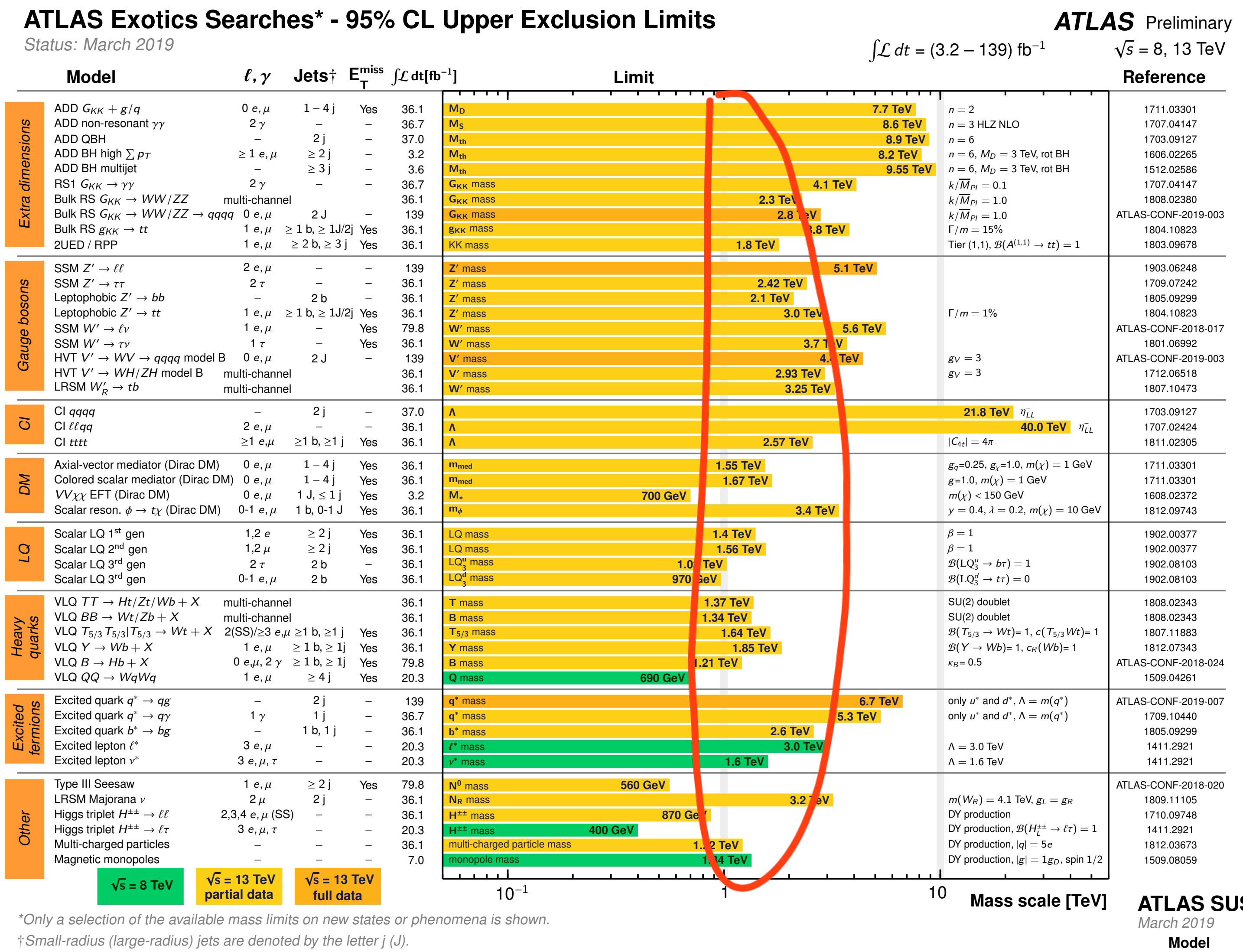
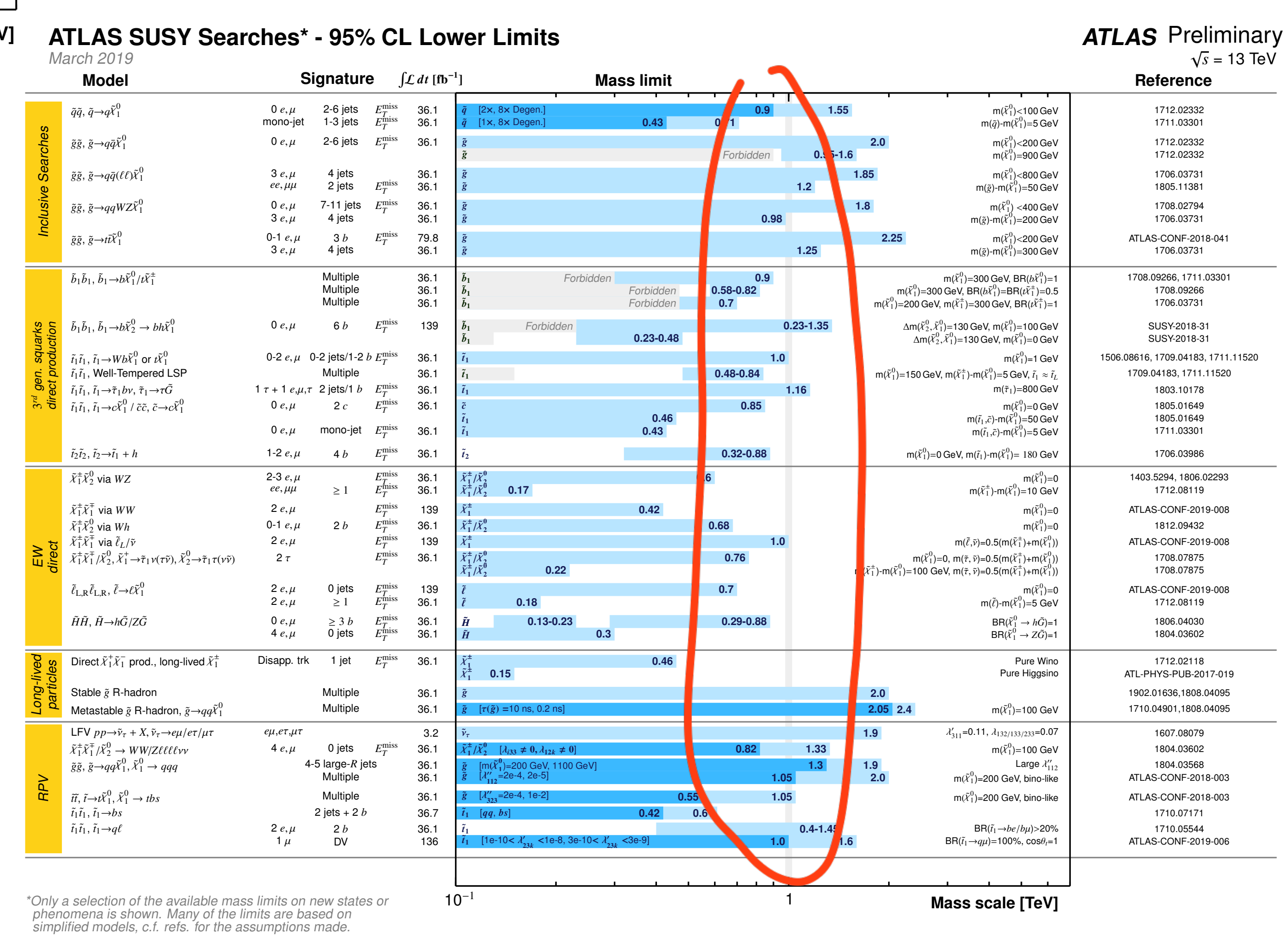
CAFPE. CENTRO ANDALUZ DE FISICA DE PARTICULAS ELEMENTALES


ATLAS Exotics Searches* - 95% CL Upper Exclusion Limits
Status: March 2019
ATLAS Preliminary
∫L dt = (3.2 – 139) fb⁻¹
√s = 8, 13 TeV
Model
ℓ, γ
Jets†
E_T^miss
∫L dt[fb⁻¹]
Limit
Reference
Extra dimensions
ADD G_KK + g/q 0 e,μ 1 – 4 j Yes 36.1 M_D 7.7 TeV n = 2 1711.03301
ADD non-resonant γγ 2 γ – – 36.7 M_S 8.6 TeV n = 3 HLZ NLO 1707.04147
ADD QBH – 2 j – 37.0 M_th 8.9 TeV n = 6 1703.09127
ADD BH high Σ p_T ≥ 1 e,μ ≥ 2 j – 3.2 M_th 8.2 TeV n = 6, M_D = 3 TeV, rot BH 1606.02265
ADD BH multijet – ≥ 3 j – 3.6 M_th 9.55 TeV n = 6, M_D = 3 TeV, rot BH 1512.02586
RS1 G_KK → γγ 2 γ – – 36.7 G_KK mass 4.1 TeV k/M̄_Pl = 0.1 1707.04147
Bulk RS G_KK → WW/ZZ multi-channel 36.1 G_KK mass 2.3 TeV k/M̄_Pl = 1.0 1808.02380
Bulk RS G_KK → WW/ZZ → qqqq 0 e,μ 2 J – 139 G_KK mass 2.8 TeV k/M̄_Pl = 1.0 ATLAS-CONF-2019-003
Bulk RS g_KK → tt 1 e,μ ≥ 1 b, ≥ 1J/2j Yes 36.1 g_KK mass 3.8 TeV Γ/m = 15% 1804.10823
2UED / RPP 1 e,μ ≥ 2 b, ≥ 3 j Yes 36.1 KK mass 1.8 TeV Tier (1,1), B(A^(1,1) → tt) = 1 1803.09678
Gauge bosons
SSM Z′ → ℓℓ 2 e,μ – – 139 Z′ mass 5.1 TeV 1903.06248
SSM Z′ → ττ 2 τ – – 36.1 Z′ mass 2.42 TeV 1709.07242
Leptophobic Z′ → bb – 2 b – 36.1 Z′ mass 2.1 TeV 1805.09299
Leptophobic Z′ → tt 1 e,μ ≥ 1 b, ≥ 1J/2j Yes 36.1 Z′ mass 3.0 TeV Γ/m = 1% 1804.10823
SSM W′ → ℓν 1 e,μ – Yes 79.8 W′ mass 5.6 TeV ATLAS-CONF-2018-017
SSM W′ → τν 1 τ – Yes 36.1 W′ mass 3.7 TeV 1801.06992
HVT V′ → WV → qqqq model B 0 e,μ 2 J – 139 V′ mass 4.3 TeV g_V = 3 ATLAS-CONF-2019-003
HVT V′ → WH/ZH model B multi-channel 36.1 V′ mass 2.93 TeV g_V = 3 1712.06518
LRSM W′_R → tb multi-channel 36.1 W′ mass 3.25 TeV 1807.10473
CI
CI qqqq – 2 j – 37.0 Λ 21.8 TeV η⁻_LL 1703.09127
CI ℓℓqq 2 e,μ – – 36.1 Λ 40.0 TeV η⁻_LL 1707.02424
CI tttt ≥1 e,μ ≥1 b, ≥1 j Yes 36.1 Λ 2.57 TeV |C_4t| = 4π 1811.02305
DM
Axial-vector mediator (Dirac DM) 0 e,μ 1 – 4 j Yes 36.1 m_med 1.55 TeV g_q=0.25, g_χ=1.0, m(χ) = 1 GeV 1711.03301
Colored scalar mediator (Dirac DM) 0 e,μ 1 – 4 j Yes 36.1 m_med 1.67 TeV g=1.0, m(χ) = 1 GeV 1711.03301
VVχχ EFT (Dirac DM) 0 e,μ 1 J, ≤ 1 j Yes 3.2 M_* 700 GeV m(χ) < 150 GeV 1608.02372
Scalar reson. φ → tχ (Dirac DM) 0-1 e,μ 1 b, 0-1 J Yes 36.1 m_φ 3.4 TeV y = 0.4, λ = 0.2, m(χ) = 10 GeV 1812.09743
LQ
Scalar LQ 1st gen 1,2 e ≥ 2 j Yes 36.1 LQ mass 1.4 TeV β = 1 1902.00377
Scalar LQ 2nd gen 1,2 μ ≥ 2 j Yes 36.1 LQ mass 1.56 TeV β = 1 1902.00377
Scalar LQ 3rd gen 2 τ 2 b – 36.1 LQ^u_3 mass 1.03 TeV B(LQ^u_3 → bτ) = 1 1902.08103
Scalar LQ 3rd gen 0-1 e,μ 2 b Yes 36.1 LQ^d_3 mass 970 GeV B(LQ^d_3 → tτ) = 0 1902.08103
Heavy quarks
VLQ TT → Ht/Zt/Wb + X multi-channel 36.1 T mass 1.37 TeV SU(2) doublet 1808.02343
VLQ BB → Wt/Zb + X multi-channel 36.1 B mass 1.34 TeV SU(2) doublet 1808.02343
VLQ T_5/3 T_5/3 | T_5/3 → Wt + X 2(SS)/≥3 e,μ ≥1 b, ≥1 j Yes 36.1 T_5/3 mass 1.64 TeV B(T_5/3 → Wt)= 1, c(T_5/3 Wt)= 1 1807.11883
VLQ Y → Wb + X 1 e,μ ≥ 1 b, ≥ 1j Yes 36.1 Y mass 1.85 TeV B(Y → Wb)= 1, c_R(Wb)= 1 1812.07343
VLQ B → Hb + X 0 e,μ, 2 γ ≥ 1 b, ≥ 1j Yes 79.8 B mass 1.21 TeV κ_B= 0.5 ATLAS-CONF-2018-024
VLQ QQ → WqWq 1 e,μ ≥ 4 j Yes 20.3 Q mass 690 GeV 1509.04261
Excited fermions
Excited quark q* → qg – 2 j – 139 q* mass 6.7 TeV only u* and d*, Λ = m(q*) ATLAS-CONF-2019-007
Excited quark q* → qγ 1 γ 1 j – 36.7 q* mass 5.3 TeV only u* and d*, Λ = m(q*) 1709.10440
Excited quark b* → bg – 1 b, 1 j – 36.1 b* mass 2.6 TeV 1805.09299
Excited lepton ℓ* 3 e,μ – – 20.3 ℓ* mass 3.0 TeV Λ = 3.0 TeV 1411.2921
Excited lepton ν* 3 e,μ,τ – – 20.3 ν* mass 1.6 TeV Λ = 1.6 TeV 1411.2921
Other
Type III Seesaw 1 e,μ ≥ 2 j Yes 79.8 N⁰ mass 560 GeV ATLAS-CONF-2018-020
LRSM Majorana ν 2 μ 2 j – 36.1 N_R mass 3.2 TeV m(W_R) = 4.1 TeV, g_L = g_R 1809.11105
Higgs triplet H^±± → ℓℓ 2,3,4 e,μ (SS) – – 36.1 H^±± mass 870 GeV DY production 1710.09748
Higgs triplet H^±± → ℓτ 3 e,μ,τ – – 20.3 H^±± mass 400 GeV DY production, B(H^±±_L → ℓτ) = 1 1411.2921
Multi-charged particles – – – 36.1 multi-charged particle mass 1.22 TeV DY production, |q| = 5e 1812.03673
Magnetic monopoles – – – 7.0 monopole mass 1.34 TeV DY production, |g| = 1g_D, spin 1/2 1509.08059
√s = 8 TeV
√s = 13 TeV partial data
√s = 13 TeV full data
10⁻¹
1
10
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown.
†Small-radius (large-radius) jets are denoted by the letter j (J).


ATLAS SUSY Searches* - 95% CL Lower Limits
March 2019
ATLAS Preliminary
√s = 13 TeV
Model
Signature
∫L dt [fb⁻¹]
Mass limit
Reference
Inclusive Searches
3rd gen. squarks direct production
EW direct
Long-lived particles
RPV
Forbidden
10⁻¹
1
Mass scale [TeV]
*Only a selection of the available mass limits on new states or phenomena is shown. Many of the limits are based on simplified models, c.f. refs. for the assumptions made.

- Large number of analyses trying to cover all corners of model and parameter space

- Very stringent bounds banning new physics beyond the TeV frontier.

- Is it over? NO!

    - Take the gap seriously: EFTs

    - Critically assess reach of experimental analyses

NP gap: EFT

- If there is a mass gap there won't be impressive 5σ signals but small (consistent) deviations
- In this case effective field theory is the way to go
- Global fits will be crucial to achieve a consistent picture
- Top-down approach (matching to specific models) needed to characterize the new physics

Why Global Fits (+ top-down)

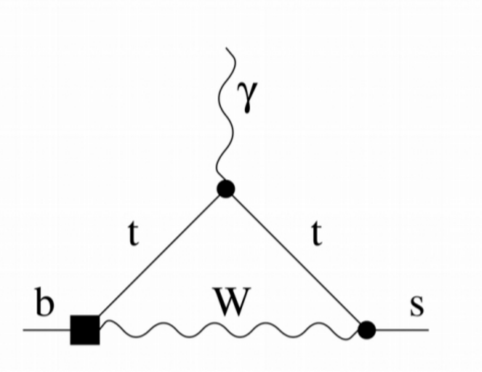
- Example: top anomalous couplings and $b \to s\gamma$

$$R_{b\to s\gamma} \equiv \frac{B(b\to s\gamma)}{B(b\to s\gamma)_{SM}} - 1 = -2.45\,\Delta C_7 - 0.58\,\Delta C_8$$

Grzadkowski, Misiak ('08)

$$= -2.51\,\delta v_L + 131\,v_R - 256\,g_L + 0.58\,g_R - 2.45\,C_7^{(p)} - 0.58\,C_8^{(p)}$$

$$\frac{-ig_w}{\sqrt{2}}[\gamma_\mu(v_L P_L + v_R P_R) + \frac{i\sigma_{\mu\nu}q^\nu}{M_W}(g_L P_L + g_R P_R)]$$



$$\mathcal{O}_7 = \frac{em_b}{16\pi^2}\bar{s}_L\sigma^{\mu\nu}b_R F_{\mu\nu},$$
$$\mathcal{O}_8 = \frac{g_s m_b}{16\pi^2}\bar{s}_L\sigma^{\mu\nu}T^A b_R G^A_{\mu\nu},$$

One-by-one limits

bound	δv_L	v_R	g_L	g_R	$C_7^{(p)}$	$C_8^{(p)}$
upper	0.03	0.0025	0.0004	0.57	0.04	0.15
lower	−0.13	−0.0007	−0.0013	−0.15	−0.14	−0.56

But contributions are rarely one by one

Why Global Fits (+ top-down)

- Example: top anomalous couplings and $b \to s\gamma$

$$\Delta\mathcal{L} = \bar{Q}(\mathrm{i}\not{D} - M_Q)Q - \left[\lambda_{Qt}\bar{Q}_L\tilde{\phi}t_R + \lambda_{Qb}\bar{Q}_L\phi b_R + \mathrm{h.c.}\right]$$

$Q_{L,R} \sim (3,2)_{1/6}$

$$R_{b\to s\gamma} = 131\, v_R - 2.45\, C_7^{(p)} - 0.58\, C_8^{(p)} \approx 171\, v_R$$

$$\Delta\mathcal{L}' = \bar{B}(\mathrm{i}\not{D} - M_B)B - \left[\lambda_{q_2B}\bar{q}_{2\,L}\phi B_R + \tilde{\lambda}\bar{Q}_R\phi B_L + \mathrm{h.c.}\right]$$

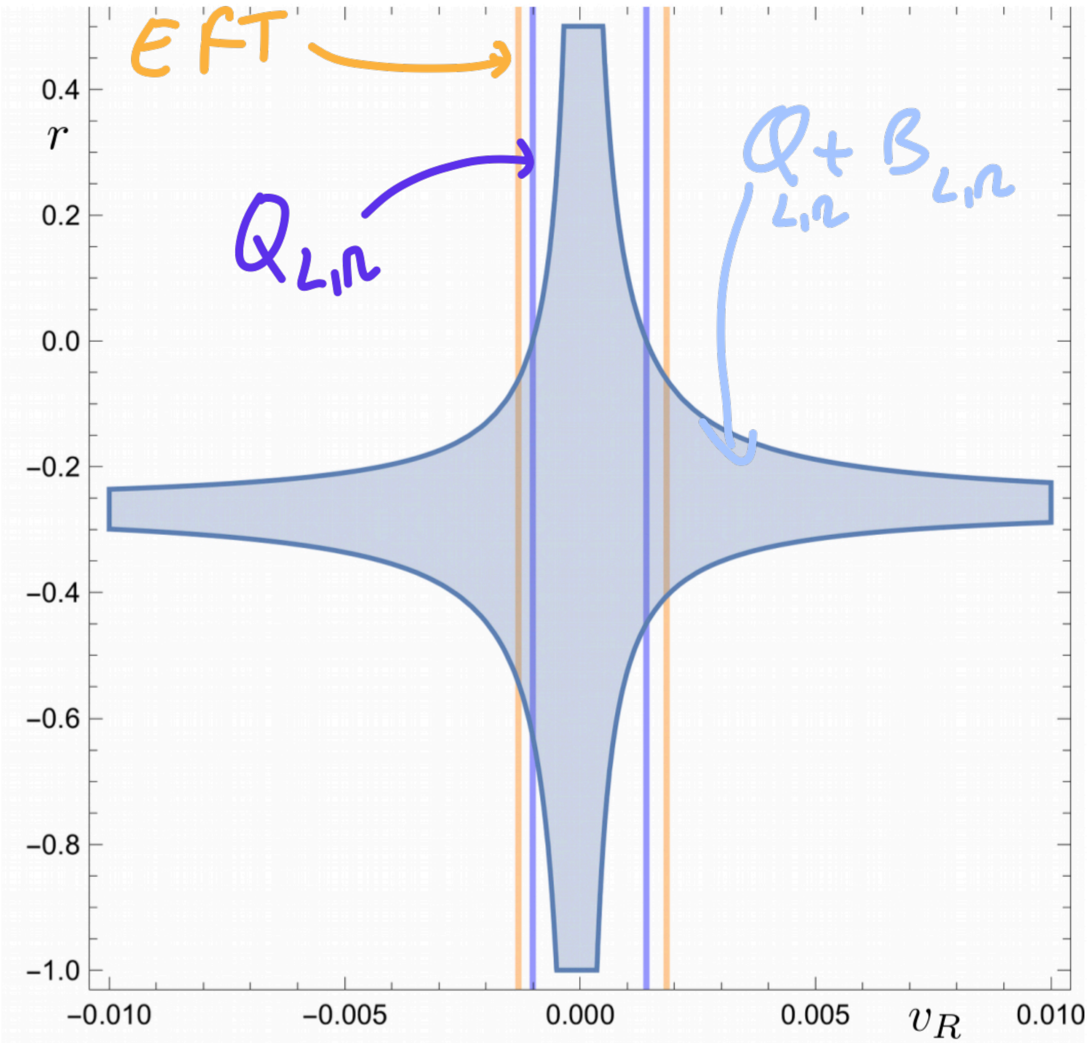
$B_{L,R} \sim (3,1)_{-1/3}$

$$R_{b\to s\gamma} = 131\, v_R - 2.45\, C_7^{(p)} - 0.58\, C_8^{(p)} \approx 171\, v_R \left(1 + 3.82\frac{\lambda_{q_2B}\tilde{\lambda}}{\lambda_{Qt}^*}\frac{M_Q}{M_B}\right)$$

Matching done with MatchMaker: C. Anastasiou, A. Carmona, A. Lazopoulos, J.S.

Why Global Fits (+ top-down)

$$R_{b\to s\gamma} = 131\, v_R - 2.45\, C_7^{(p)} - 0.58\, C_8^{(p)} \approx 171\, v_R \left(1 + \underbrace{3.82 \frac{\lambda_{q_2 B}\tilde{\lambda}}{\lambda^*_{Qt}} \frac{M_Q}{M_B}}_{r}\right)$$



$$\mathrm{Br}^{\mathrm{exp}}[b\to s\gamma] = (3.43 \pm 0.21 \pm 0.07)\times 10^{-4}\,,$$
$$\mathrm{Br}^{\mathrm{SM}}[b\to s\gamma] = (3.36 \pm 0.23)\times 10^{-4}\,.$$

$$-0.17 \le R_{b\to s\gamma} \le 0.24$$

$-0.0013 \le v_R \le 0.0018$

$-0.0010 \le v_R \le 0.0014$

v_R unconstrained for $r \approx -0.26$

- But B contributes to other observables $\delta Z_{sL}, V_{is}, Y_{sb}, \ldots$

Critically assess exp. analyses

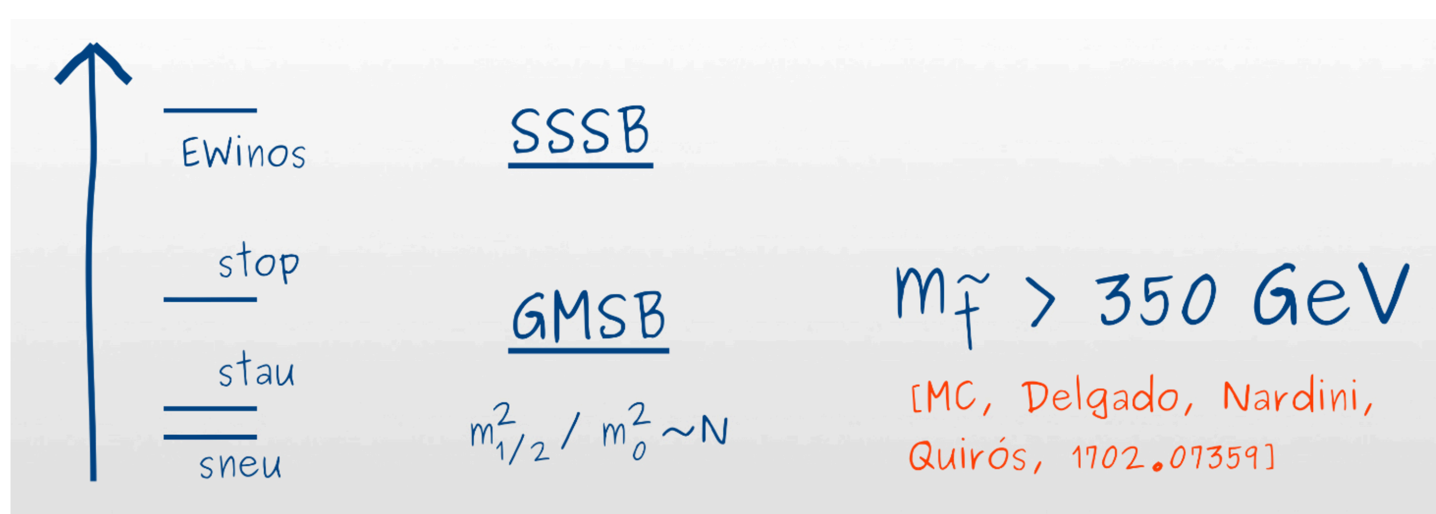
- Experimental analyses largely inspired by minimal/ simplified models
- Most models are not minimal and their signatures can be vastly different from the ones we are searching for.
  - R-parity violating SUSY
  - VL quarks with non-standard decays

Critically assess exp. analyses

- R-parity violating SUSY
  - Most analyses assume R-parity with lightest neutralino as DM candidate

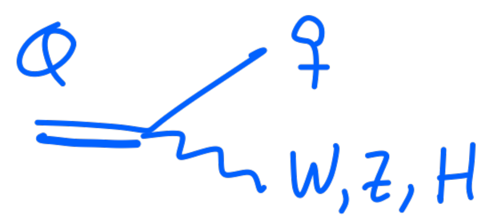
  - Things change if R-parity violated and different spectrum

Borrowed from M. Chala



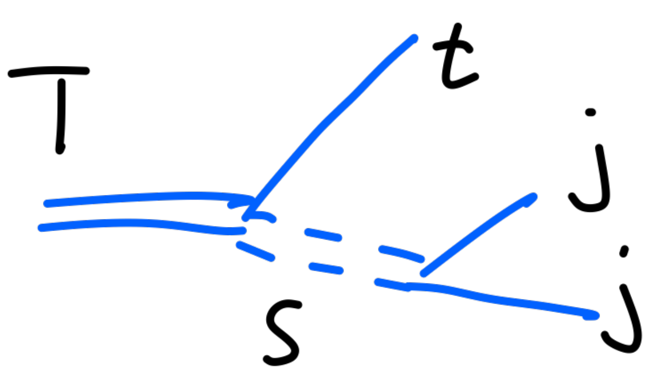
Critically assess exp. analyses

- VL quarks with non standard decays
  - Searches for VL quarks assume SM decays



$m_Q \gtrsim 1.3\text{-}1.6$ TeV

  - Things change if there are new light particles. Very common in non-minimal models.



swamped by $t\bar{t}$+jets

nMCHM $m_Q \gtrsim 600$ GeV [MC. 1705.03013]

Critically assess exp. analyses

- Experimental analyses largely inspired by minimal/simplified models result in very stringent bounds on new physics
- Realistic, natural models are usually far from minimal
- Non-optimized searches result in much milder bounds, leaving plenty of room for new physics to show up in future LHC runs and other experiments.