Limits from Simplified Models

for supersymmetry and same-spin models

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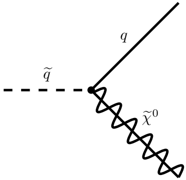
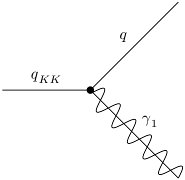
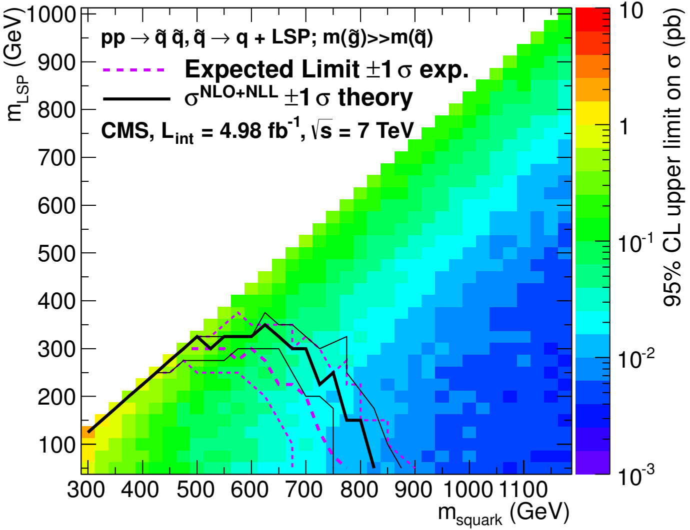
SUSY 2014, Manchester 2014-07-22





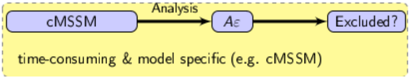


CMS SUS-11-022

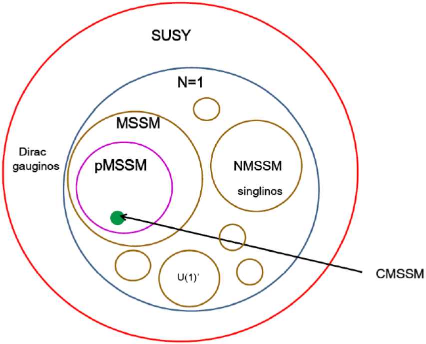
But: does it work?

Simplified Models: Why?

Usual (time-consuming) approach:

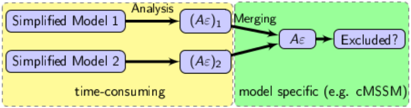


SUSY Theory phase space



T. Rizzo (SLAC Summer Institute, 01-Aug-12)

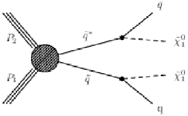
Or, use simplified modules:



model name	prod. mode	decay	visibility
T1	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0$	hadronic
T2	$\tilde{q}\,\tilde{q}^*$	$\tilde{q} \to q\tilde{\chi}^0$	hadronic
T5zz	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to q\bar{q}Z\tilde{\chi}^0$	hadronic di-leptons multi-leptons
T3w	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0$ $\tilde{g} \to q\bar{q}\tilde{\chi}^\pm$, $\tilde{\chi}^\pm \to W^\pm\tilde{\chi}^0$	single lepton
T5lnu	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^\pm$ $\tilde{\chi}^\pm \to \ell\nu\tilde{\chi}^0$	di-leptons
T3lh	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0$ $\tilde{g} \to q\bar{q}\ell^+\ell^-\tilde{\chi}^0$	di-leptons
T2bb	$\tilde{b}\,\tilde{b}^*$	$\tilde{b} \to b\,\tilde{\chi}^0$	hadronic
T2tt	$\tilde{t}\,\tilde{t}^*$	$\tilde{t} \to t\,\tilde{\chi}^0$	hadronic
T1bbbb	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to b\,\bar{b}\,\tilde{\chi}^0$	hadronic
T1tttt	$\tilde{g}\,\tilde{g}$	$\tilde{g} \to t\,\bar{t}\,\tilde{\chi}^0$	hadronic(b) single-leptons(b) di-leptons(b) inclusive(b)
TChiSlepSlep	$\tilde{\chi}^\pm\tilde{\chi}^0_2$	$\tilde{\chi}^0_2 \to \ell^\pm\tilde{\ell}^\mp$, $\tilde{\ell} \to \ell\tilde{\chi}^0$ $\tilde{\chi}^\pm \to \nu\tilde{\ell}$, $\tilde{\ell} \to \ell\tilde{\chi}^0$	multi-leptons
TChiwz	$\tilde{\chi}^\pm\tilde{\chi}^0_2$	$\tilde{\chi}^\pm \to W^\pm\tilde{\chi}^0$, $\tilde{\chi}^0_2 \to Z\tilde{\chi}^0$	multi-leptons
TChizz	$\tilde{\chi}^0_2\tilde{\chi}^0_3$	$\tilde{\chi}^0_2, \tilde{\chi}^0_3 \to Z\tilde{\chi}^0$	multi-leptons
T5gg	$\tilde{g}\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_2$, $\tilde{\chi}^0_2 \to \gamma\tilde{\chi}^0_1$	photons
T5Wg	$\tilde{g}\tilde{g}$	$\tilde{g} \to q\bar{q}\tilde{\chi}^0_2$, $\tilde{\chi}^0_2 \to \gamma\tilde{\chi}^0_1$ $\tilde{g} \to q\bar{q}\tilde{\chi}^\pm$, $\tilde{\chi}^\pm \to W^\pm\tilde{\chi}^0_1$	photons

A simplified model: T2

squark antisquark $\equiv$ CMS T2

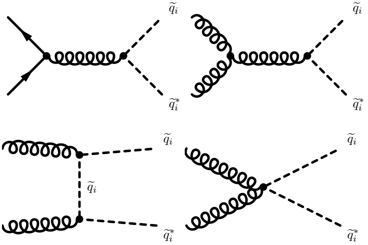


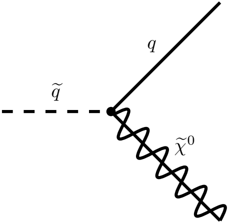
T2: $\tilde{u}_L$, $\tilde{d}_L$, $\tilde{c}_L$, $\tilde{s}_L$

$m_{\tilde{g}} = 10^5$ GeV (decoupled)

CMS SUS-11-016; arXiv:1301.2175 (CMS Simplified Models)

$\tilde{q}_L \tilde{q}_L^*$ production:



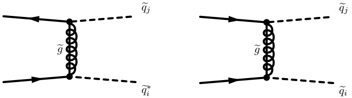


one decay

What T2 is not

Not included in T2:

- right-handed squarks $\widetilde{q}_R$
- gluinos, resulting in production:

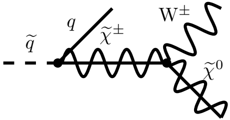


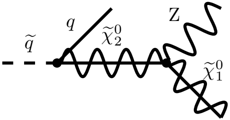
→ Effect on limits when including:

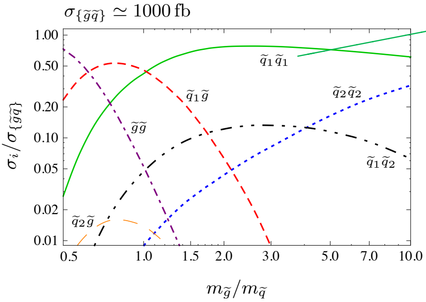
- production channels like $\widetilde{q}_L\widetilde{q}_L$, $\widetilde{q}_L\widetilde{q}_R$, $\widetilde{q}_L\widetilde{q}_R^*$;
- a non-decoupled gluino?

Not included in T2, **not** considered here:

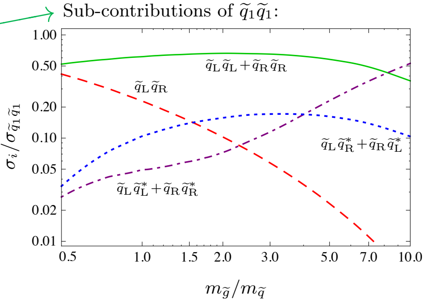
- decays such as







1st and 2nd generation



1st generation

Testing Closure: all-hadronic analyses in $\not{H}_T$ and α_T

Main cuts in $\not{H}_T$ **analysis**:
CMS SUS-13-012: arXiv:1402.4770

- $\not{H}_T = -\left|\sum_{\text{jets}} \vec{p}_T\right|,\ p_{T_j} > 30$ GeV
- $H_T = \sum_{i=1}^{n_{\text{jet}}} p_T^{j_i},\ p_{T_j} > 50$ GeV

Main cuts in α_T **analysis**:
CMS SUS-12-028: arXiv:1303.2985

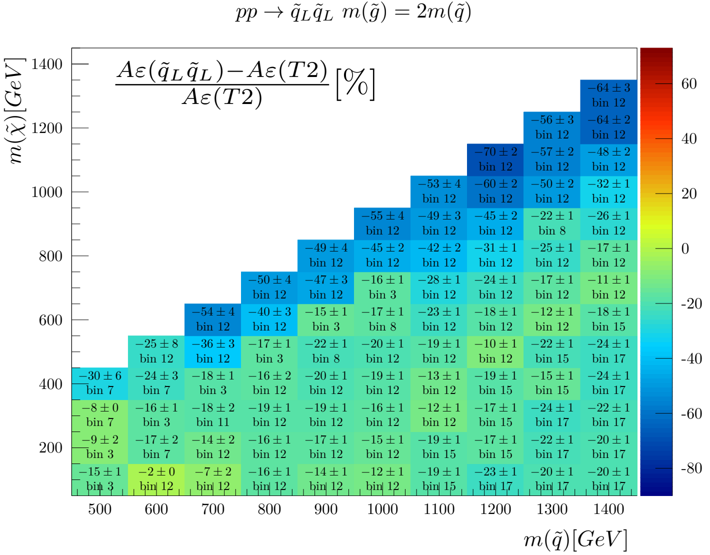
- $\alpha_T = \frac{E_T^{j_2}}{M_T}$ (dijet)

$\rightarrow A\varepsilon$: acceptance x efficiency
(% events after cuts)

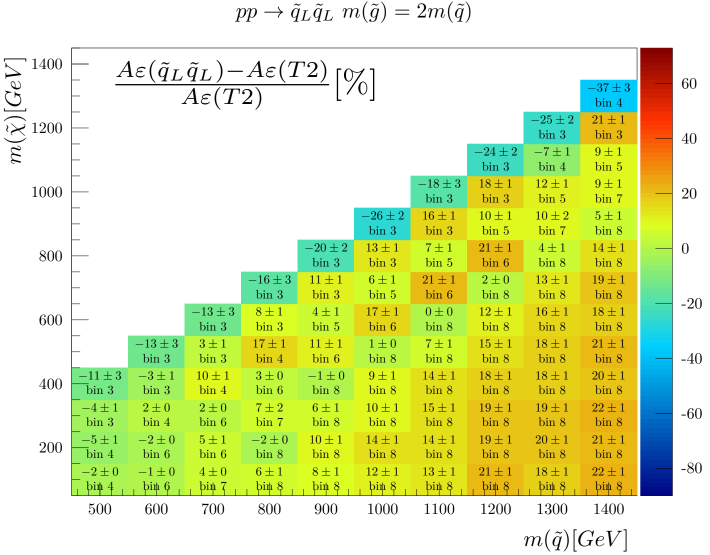
We find

- $A\varepsilon_{\tilde{q}_L\tilde{q}_L} < A\varepsilon_{\mathrm{T2}}$ for $\not{H}_T$
- $A\varepsilon_{\tilde{q}_L\tilde{q}_L} > A\varepsilon_{\mathrm{T2}}$ for α_T

$A\varepsilon$ differences: $\not{H}_T$



$A\varepsilon$ differences: α_T

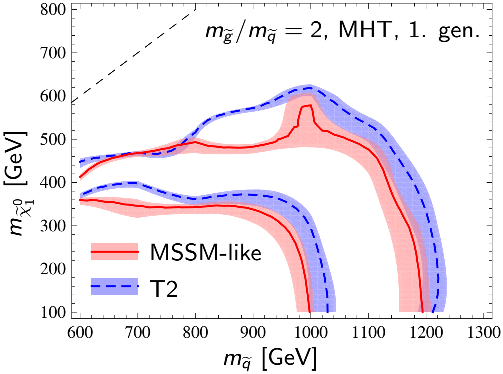


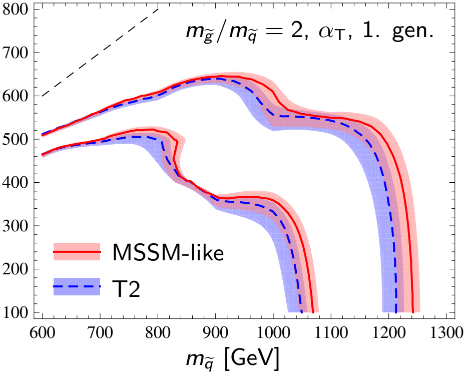
Limits for MSSM-like model

- MSSM-like: Limits using (correct) $A\varepsilon$ scaled with cross section:

$$2\tilde{q}_L\tilde{q}_L + 2\tilde{q}_L\tilde{q}_L^* + \tilde{q}_L\tilde{q}_R + 2\tilde{q}_L\tilde{q}_R^*$$

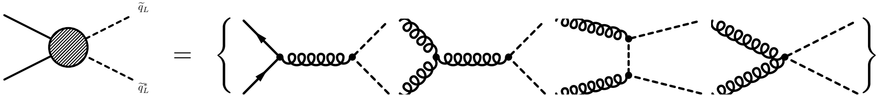
- T2: Limits using (incorrect) $A\varepsilon$ from T2



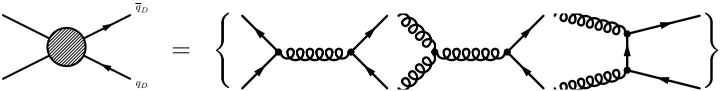


Same-spin models

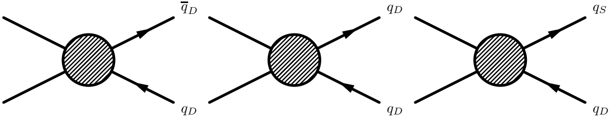
SUSY



Same-spin Model (as SM)



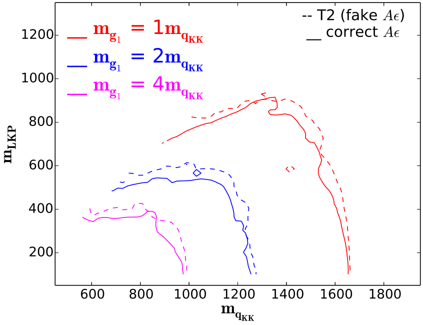
Same-spin production modes (UED):



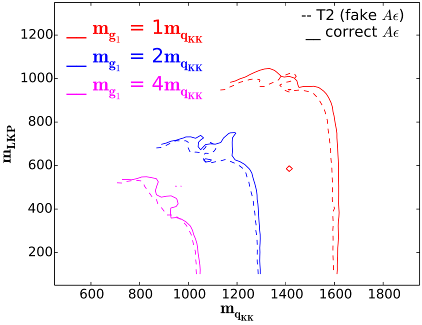
$$\text{UED combined} = 2q_D q_D + 2q_D \bar{q}_D + q_D q_S + 2q_S \bar{q}_D$$

$q_{D(S)}$: KK SU(2) doublet (singlet) quark

MHT



α_T



Summary and Future work

Simplified models have:

- underlying differences in individual production channels

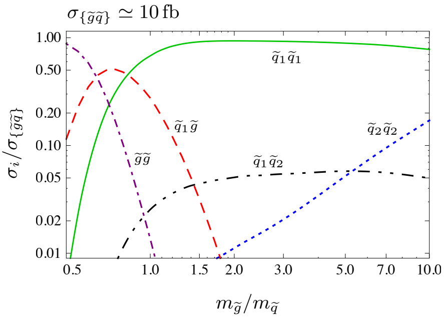
. . . but are also a good approximation

- in limit setting;
- for a model such as the MSSM;
- for same-spin models [in preparation].

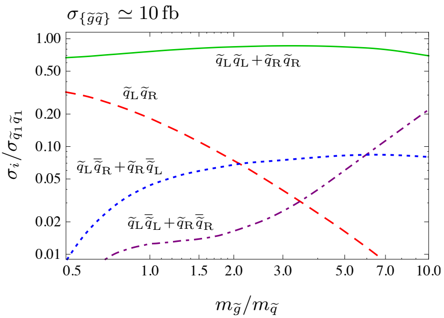
Future work:

- How can simplified models be used in global fits?

Backup



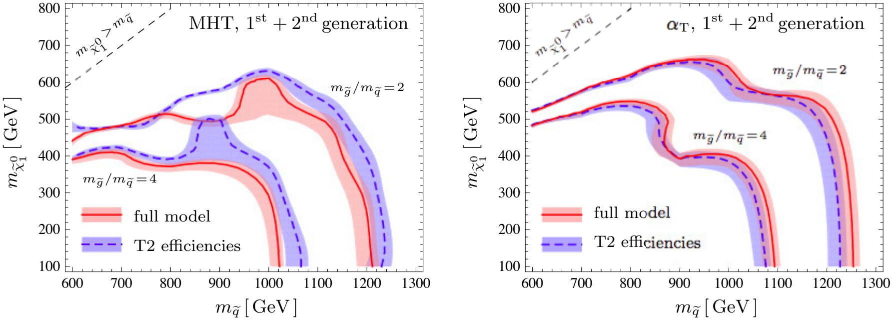
1st and 2nd generation



1st generation

Limits: MSSM-like vs T2

$$\text{MSSM-like} = 2\tilde{q}_L\tilde{q}_L + 2\tilde{q}_L\tilde{q}_L^* + \tilde{q}_L\tilde{q}_R + 2\tilde{q}_L\tilde{q}_R^*$$

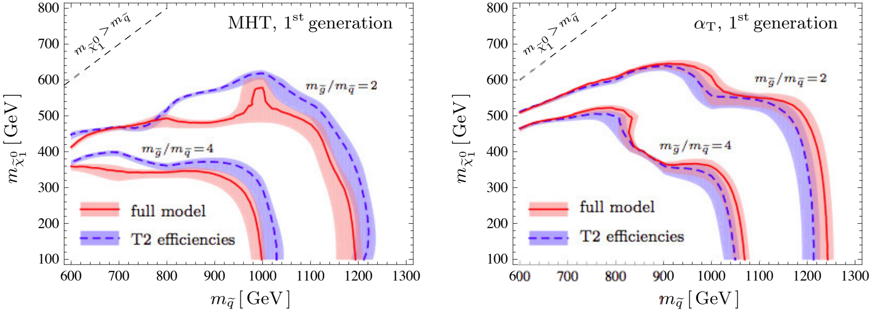


Band: scale variation

T2: 'wrong' $A\varepsilon$, correct cross section

MSSM-like: correct $A\varepsilon$, correct cross section

$$\text{MSSM-like} = 2\tilde{q}_L\tilde{q}_L + 2\tilde{q}_L\tilde{q}_L^* + \tilde{q}_L\tilde{q}_R + 2\tilde{q}_L\tilde{q}_R^*$$

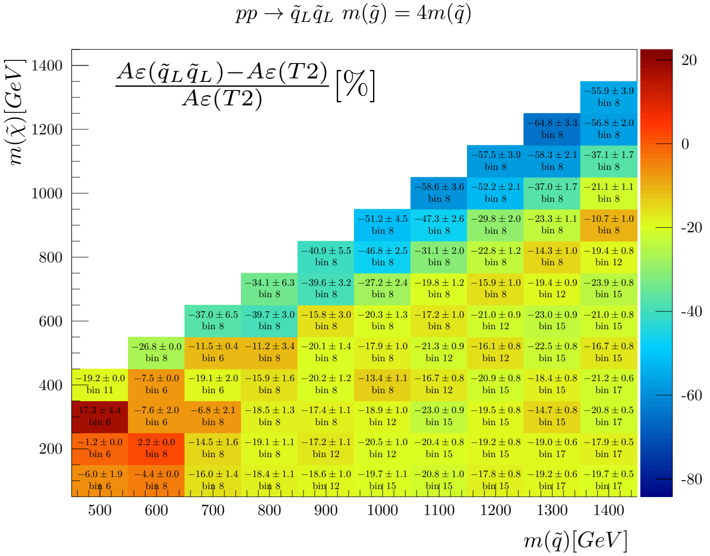


Band: scale variation

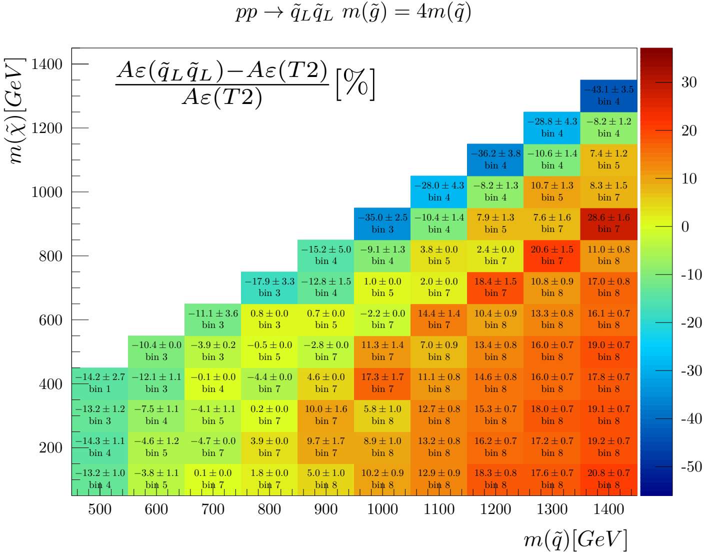
T2: 'wrong' $A\varepsilon$, correct cross section

MSSM-like: correct $A\varepsilon$, correct cross section

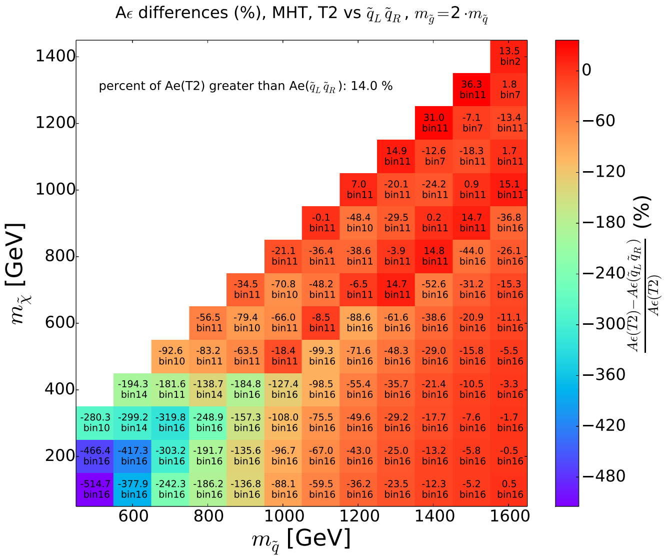
$A\varepsilon$ differences for T2 vs $\tilde{q}_L\tilde{q}_L$, $m_{\tilde{g}} = 4m_{\tilde{q}}$, $\not{H}_T$



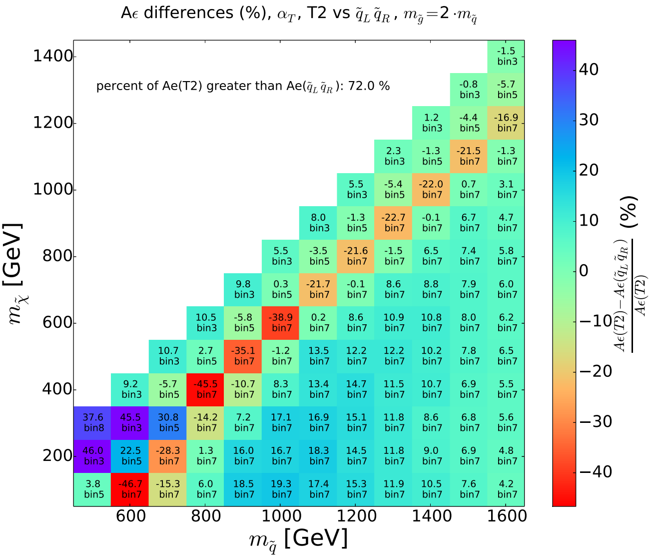
$A\varepsilon$ differences for T2 vs $\tilde{q}_L\tilde{q}_L$, $m_{\tilde{g}} = 4m_{\tilde{q}}$, α_T



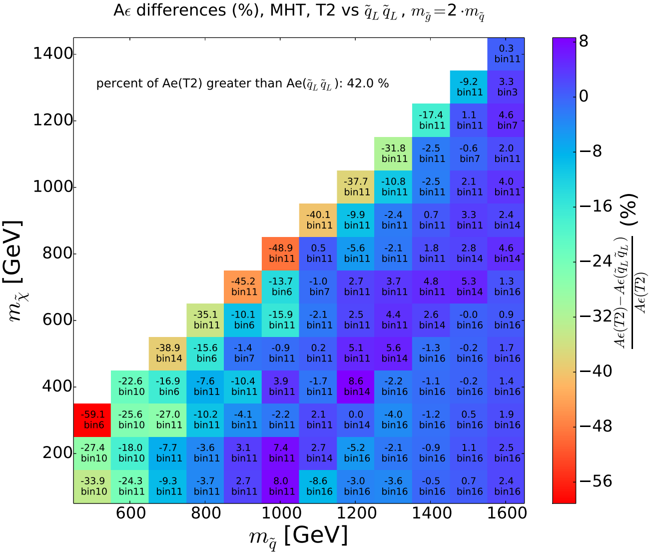
$A\varepsilon$ T2 vs $\tilde{q}_L\tilde{q}_R$, $\not{H}_T$



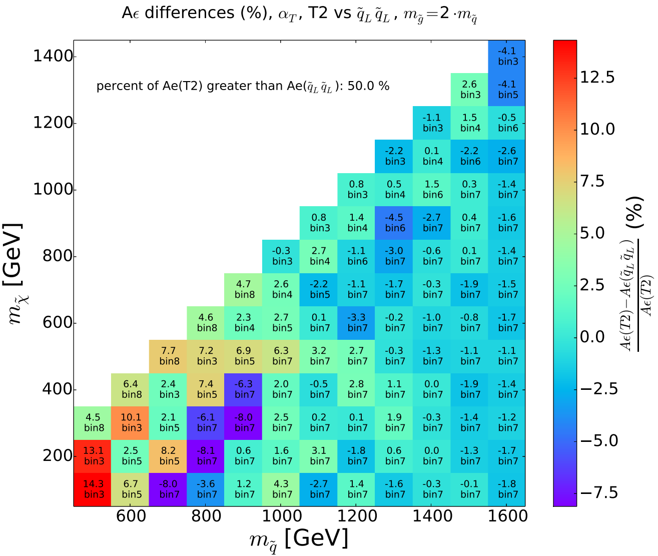
$A\varepsilon$ T2 vs $\tilde{q}_L\tilde{q}_R$, α_T

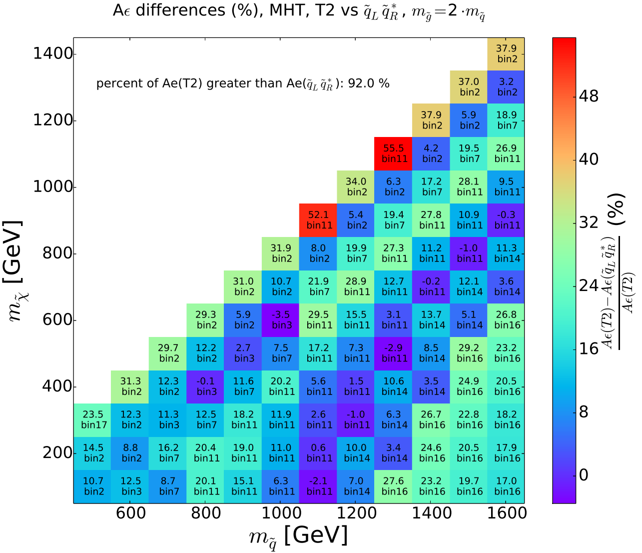


$A\varepsilon$ T2 vs $\tilde{q}_L\tilde{q}_L^*$, $\not{H}_T$



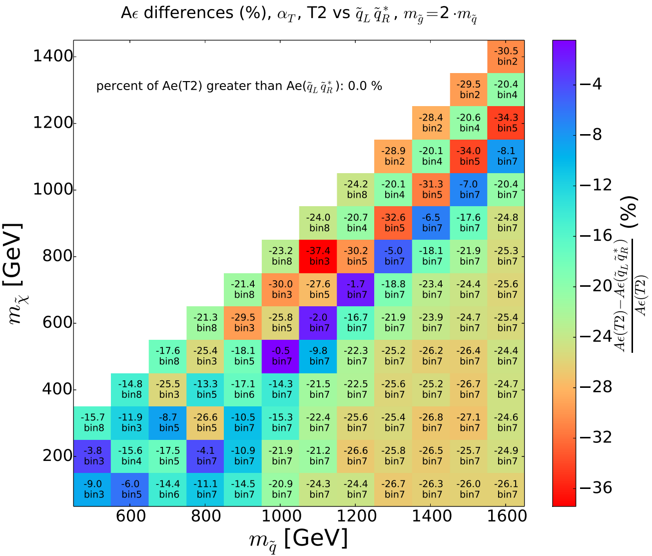
$A\varepsilon$ T2 vs $\tilde{q}_L\tilde{q}_L^*$, α_T





Aϵ differences (%), MHT, T2 vs $\tilde{q}_L \tilde{q}_R^*$, $m_{\tilde{g}} = 2 \cdot m_{\tilde{q}}$
percent of Ae(T2) greater than Ae($\tilde{q}_L \tilde{q}_R^*$): 92.0 %
$m_{\tilde{\chi}}$ [GeV]
$m_{\tilde{q}}$ [GeV]
$\frac{A\epsilon(T2) - A\epsilon(\tilde{q}_L \tilde{q}_R^*)}{A\epsilon(T2)}$ (%)
1400
1200
1000
800
600
400
200
600
800
1000
1200
1400
1600
48
40
32
24
16
8
0
37.9 bin2
37.0 bin2
3.2 bin2
37.9 bin2
5.9 bin2
18.9 bin7
55.5 bin11
4.2 bin2
19.5 bin7
26.9 bin11
34.0 bin2
6.3 bin2
17.2 bin7
28.1 bin11
9.5 bin11
52.1 bin11
5.4 bin2
19.4 bin7
27.8 bin11
10.9 bin11
-0.3 bin11
31.9 bin2
8.0 bin2
19.9 bin7
27.3 bin11
11.2 bin11
-1.0 bin11
11.3 bin14
31.0 bin2
10.7 bin2
21.9 bin7
28.9 bin11
12.7 bin11
-0.2 bin11
12.1 bin14
3.6 bin14
29.3 bin2
5.9 bin2
-3.5 bin3
29.5 bin11
15.5 bin11
3.1 bin11
13.7 bin14
5.1 bin14
26.8 bin16
29.7 bin2
12.2 bin2
2.7 bin3
7.5 bin7
17.2 bin11
7.3 bin11
-2.9 bin11
8.5 bin14
29.2 bin16
23.2 bin16
31.3 bin2
12.3 bin2
-0.1 bin3
11.6 bin7
20.2 bin11
5.6 bin11
1.5 bin11
10.6 bin14
3.5 bin14
24.9 bin16
20.5 bin16
23.5 bin17
12.3 bin2
11.3 bin3
12.5 bin7
18.2 bin11
11.9 bin11
2.6 bin11
-1.0 bin11
6.3 bin14
26.7 bin16
22.8 bin16
18.2 bin16
14.5 bin2
8.8 bin2
16.2 bin7
20.4 bin11
19.0 bin11
11.0 bin11
0.6 bin11
10.0 bin14
3.4 bin14
24.6 bin16
20.5 bin16
17.9 bin16
10.7 bin2
12.5 bin3
8.7 bin7
20.1 bin11
15.1 bin11
6.3 bin11
-2.1 bin11
7.0 bin14
27.6 bin16
23.2 bin16
19.7 bin16
17.0 bin16

$A\varepsilon$ T2 vs $\tilde{q}_L\tilde{q}_R^*$, α_T



α_T variable

2 jets

$$\alpha_T = \frac{E_T^{j_2}}{M_T}$$

$$M_T = \sqrt{\left(\sum_{i=1}^{2} E_T^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_x^{j_i}\right)^2 - \left(\sum_{i=1}^{2} p_y^{j_i}\right)^2}$$

$>$ 2 jets

Combination of jets into two pseudojets minimizing $|E_T|$ difference between pseudojets:

$$\alpha_T = \frac{1}{2} \times \frac{H_T - \Delta H_T}{\sqrt{H_T^2 - \not{H}_T^2}} = \frac{1}{2} \times \frac{1 - (\Delta H_T / H_T)}{\sqrt{1 - (\not{H}_T / H_T)^2}}$$

$$H_T = \sum_{i=1}^{n_{\mathrm{jet}}} E_T^{j_i}$$

$$\not{H}_T = |\sum_{i=1}^{N_{\mathrm{jet}}} \vec{p}_T^{j_i}|$$

The α_T analysis

CMS SUS-12-028: arXiv:1303.2985

- Jets are required to have $E_T > 50$ GeV $|\eta| < 3.0$;
- Events with electron or muon $p_T > 10$ GeV are vetoed;
- Events with photon $p_T > 25$ GeV are vetoed;
- The highest-E_T jet must have $|\eta| < 2.5$;
- The two highest-E_T jets must have $E_T > 100$ (73 and 87 GeV for bin 0 and bin 1, resp.);
- Events with any additional jet having $E_T > 50$ and $|\eta| > 3$ are vetoed;
- Events must have $H_T > 275$ GeV;
- It is required that $\not{H}_T / \not{E}_T < 1.25$;
- $\alpha_T < 0.55$;
- For focus on T2, events are required to have 0 b quarks and 2-3 jets.

8 bins in H_T:

- 2 bins of width 50 GeV in $275 < H_T < 375$ GeV;
- 5 bins of width 100 GeV in $375 < H_T < 875$ GeV.
- 1 bin with H_T ¿ 875 GeV.

The $\not{H}_T$ analysis

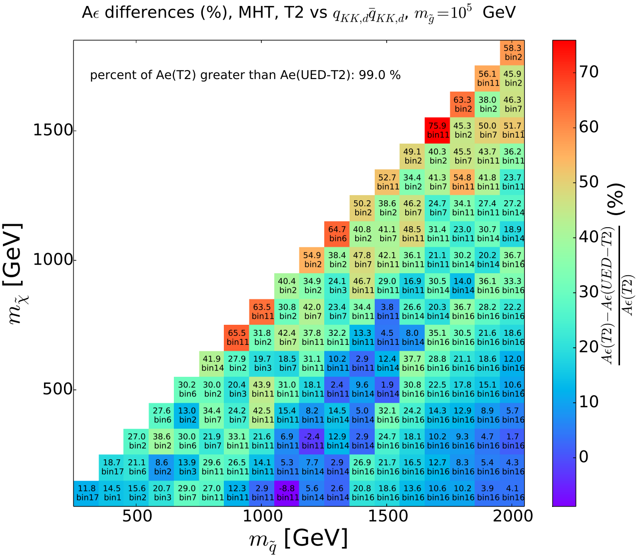
CMS SUS-13-012: arXiv:1402.4770

- Jets are required to have $p_{T,j} > 30$ GeV and $|\eta_j| < 5$;
- Events must contain 3 jets with $p_T > 50$ GeV and $|\eta| < 2.5$;
- An azimuthal angle difference between a jet axis and the $\vec{\not{H}}_T$ direction $|\Delta\phi(J_n, \vec{\not{H}}_T)| > 1.5$ rad, $n = 1, 2$ and $\Delta\varphi(J_3, \vec{\not{H}}_T)| > 0.3$ rad, with J_n the jet axis of jet n and n indicating the ranking of the jet in p_T from highest to lowest
- No isolated muons or electrons:
  - $p_T > 10$ GeV for muons and electrons;
  - $|\eta < 2.4$ for muons;
  - $|\eta| \leq 1.44$ or $1.57 \leq |\eta| < 2.5$ for electrons;
- $H_T > 500$ GeV;
- $\not{H}_T > 200$ GeV;
- Events should contain 3-5 jets.

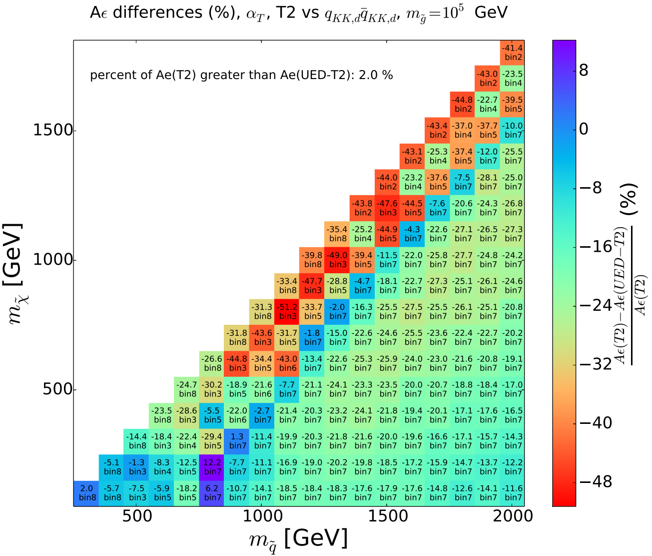
17 bins in H_T and $\not{H}_T$ and 3-5 jets:

- 500-800, 800-1000, and 1000-1250 GeV in H_T, and 200-300, 300-450, 450-600, and > 600 GeV for $\not{H}_T$ (bins 0-11, resp.);
- 1250-1500 GeV in H_T with $\not{H}_T$ binned into 200-300, 300-450, and > 450 GeV (bins 12-14, resp);
- > 1500 GeV in H_T with $\not{H}_T$ binned into 200-300 and > 300 GeV (bins 15-16, resp.).

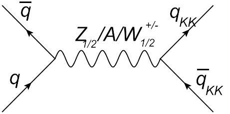
[in preparation] $A\varepsilon$ for UED-T2 and SUSY-T2, $\not{H}_T$

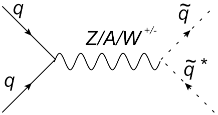


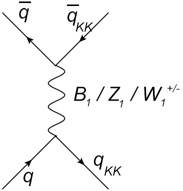
[in preparation] $A\varepsilon$ for UED-T2 and SUSY-T2, α_T

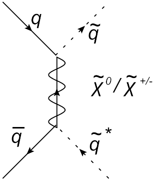


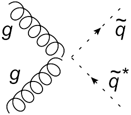
KK and SUSY quark-antiquark suppressed production modes



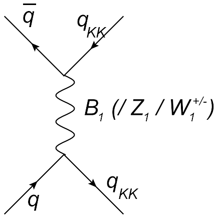


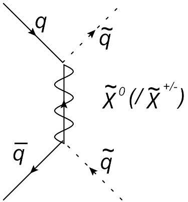




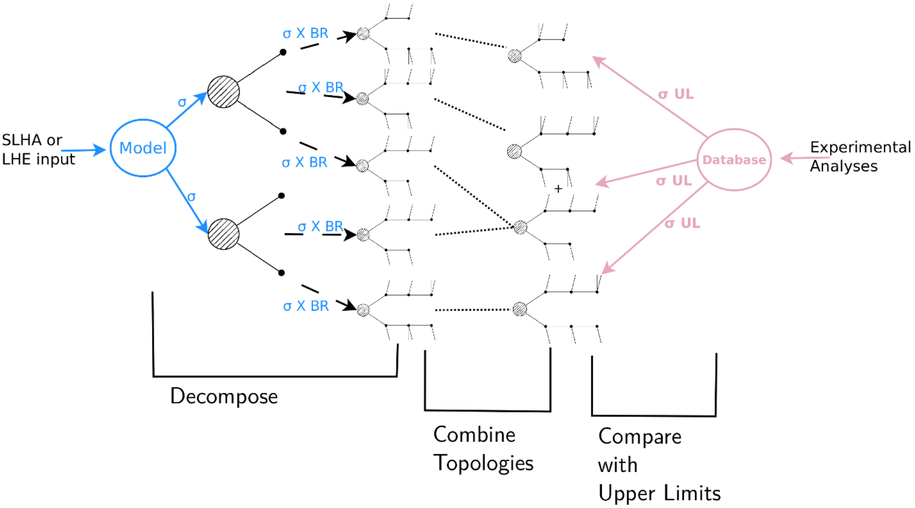


KK and SUSY quark pair suppressed production modes





SModelS


SLHA or
LHE input
Model
σ
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σ X BR
σ X BR
σ X BR
σ X BR
σ X BR
+
σ UL
σ UL
σ UL
Database
Experimental
Analyses
Decompose
Combine
Topologies
Compare
with
Upper Limits

UED

- Use orbifolding to solve problem of γ matrices in 5 dimensions;
- New dimension $x^4 = y$ that defines a circle of radius r, $y \equiv y + 2\pi$;
- Periodic scalar field $\varphi(x^m, y)$ can be expanded in Fourier modes:

$$\varphi(x^m, y) = \sum_{n=-\infty}^{\infty} \varphi_n(x^\mu) \exp\left(\frac{iny}{r}\right). \quad (1)$$

- Equations of motion $\partial^M \partial_M \varphi = 0$ have the solutions;

$$\left(\partial^\mu \partial_\mu - \frac{n^2}{r^2}\right) \varphi_n(x^\mu) = 0. \quad (2)$$

- Each mode n (KK mode) has in 4D a particle with mass $m_n^2 = \frac{n^2}{r^2}$
- UED is an effective theory with a cutoff Λ, $\Lambda R \sim 20$ for 1 ED