ABC of RPV II:
Status of RPV UDD Couplings at the LHC

Rhitaja Sengupta

BCTP and Physikalisches Institut
Universität Bonn

Based on: arXiv:2503.03830, *JHEP* (2025)
with: Herbi Dreiner, Apoorva Shah, Martin Schürmann, Yong Sheng Koay, Michael Hank (ATLAS), Evelyn Thomson (ATLAS), Nadja Strobbe (CMS)

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28 May 2025

Most general MSSM superpotential

$$W_{\text{MSSM}} = W_{\text{RPC}} + W_{\text{RPV}}$$

$$R\text{-parity} = (-1)^{\overset{\text{Spin}}{2S}+\underset{\text{Baryon number}}{3B}+\overset{\text{Lepton number}}{L}} = \begin{cases} +1 \text{ for ordinary particles} \\ -1 \text{ for their superpartners} \end{cases}$$

$$W_{\text{RPV}} = \frac{1}{2}\lambda_{ijk}L_iL_j\bar{E}_k + \lambda'_{ijk}L_iQ_j\bar{D}_k + \kappa_i H_u L_i + \frac{1}{2}\lambda''_{ijk}\bar{U}_i\bar{D}_j\bar{D}_k$$

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Trilinear couplings: LLE, LQD, UDD ← **This talk**

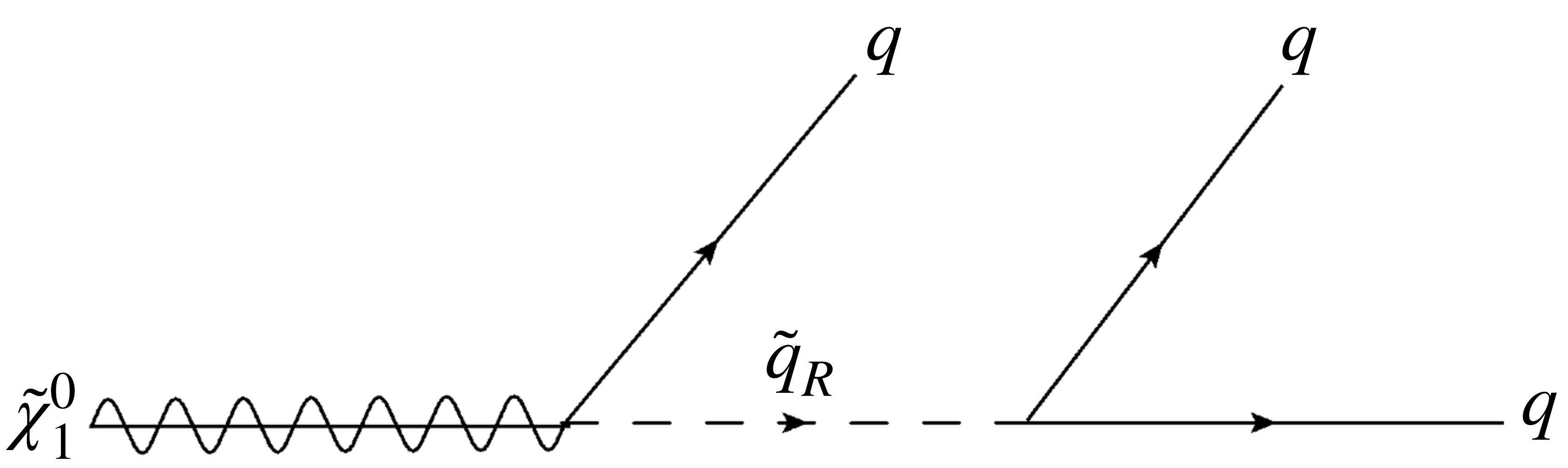
Bilinear couplings: severely constrained from neutrino mass data/ can be rotated away at fixed energy scales

Unique features with RPV couplings

Implications of allowing R-parity violation:

- LSP not stable anymore
  - LSP doesn't have to be electrically neutral and a colour singlet

    $\{\tilde{g}, \tilde{q}_{L/R}, \tilde{t}_1, \tilde{b}_1, \tilde{\chi}_1^0, \tilde{\chi}^{\pm}, \tilde{l}_{L/R}, \tilde{\tau}_1, \tilde{\nu}\}$
  - LSP cannot be a DM candidate



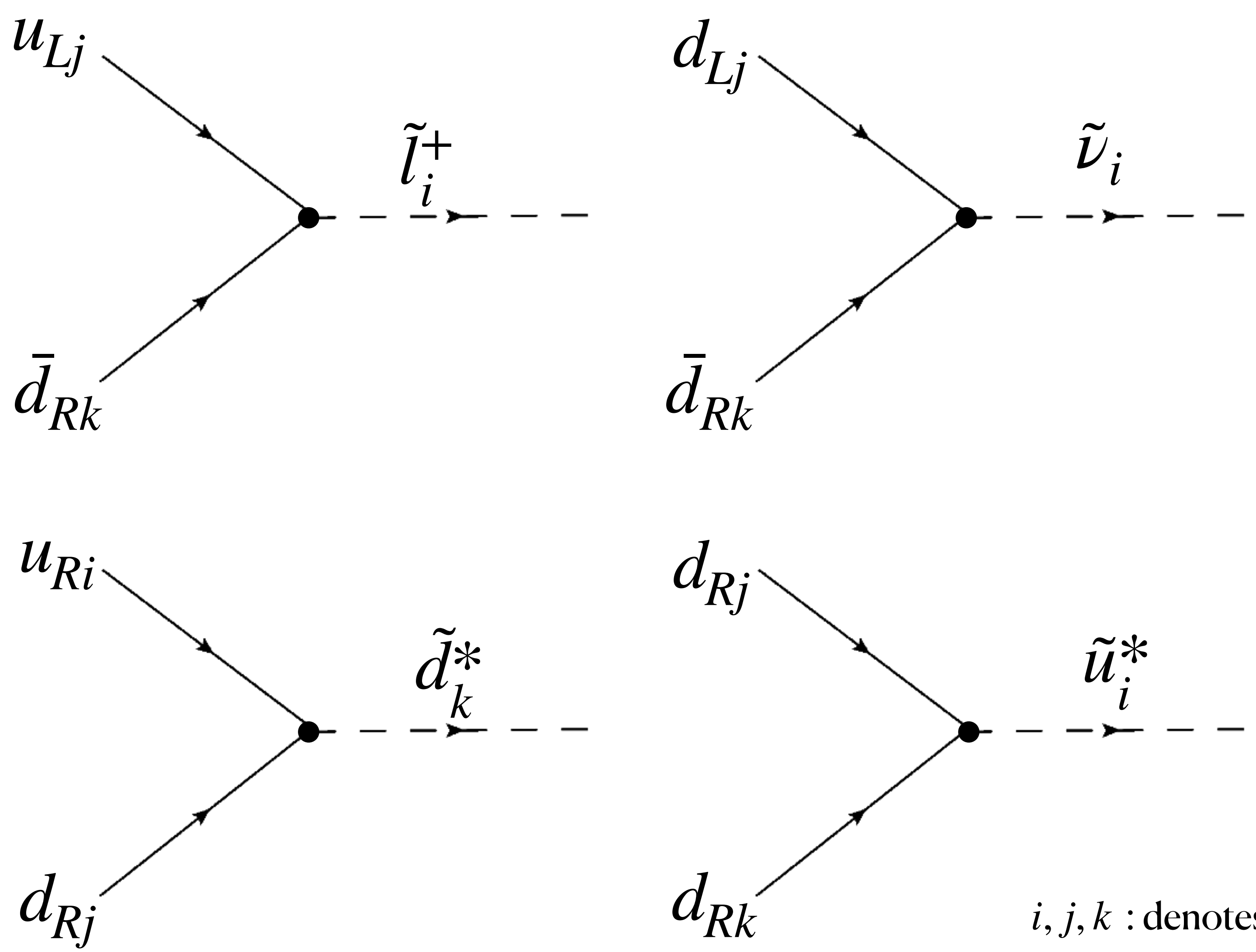
Unique features with RPV couplings

Implications of allowing R-parity violation:

- Sparticles can be singly-produced at colliders

LQD

UDD



i, j, k : denotes the generation

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Implications of allowing *R*-parity violation:

- Much richer collider phenomenology, depending on

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  1. the produced particle at the LHC and its cascade to the LSP
     (in case the produced particle is not the LSP)

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  2 the LSP: $\{\tilde{g}, \tilde{q}_{L/R}, \tilde{t}_1, \tilde{b}_1, \tilde{\chi}_1^0, \tilde{\chi}^{\pm}, \tilde{l}_{L/R}, \tilde{\tau}_1, \tilde{\nu}\}$

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3. the specific RPV coupling(s) present

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3. the specific RPV coupling(s) present
4. strength of the RPV coupling(s) present

Increasing strength of RPV coupling

Production: Gauge couplings
Displaced decay: RPV coupling

Production: Gauge couplings
Prompt decay: RPV coupling

Production: RPV couplings contribute
Prompt decay: RPV coupling

Unique features with RPV couplings

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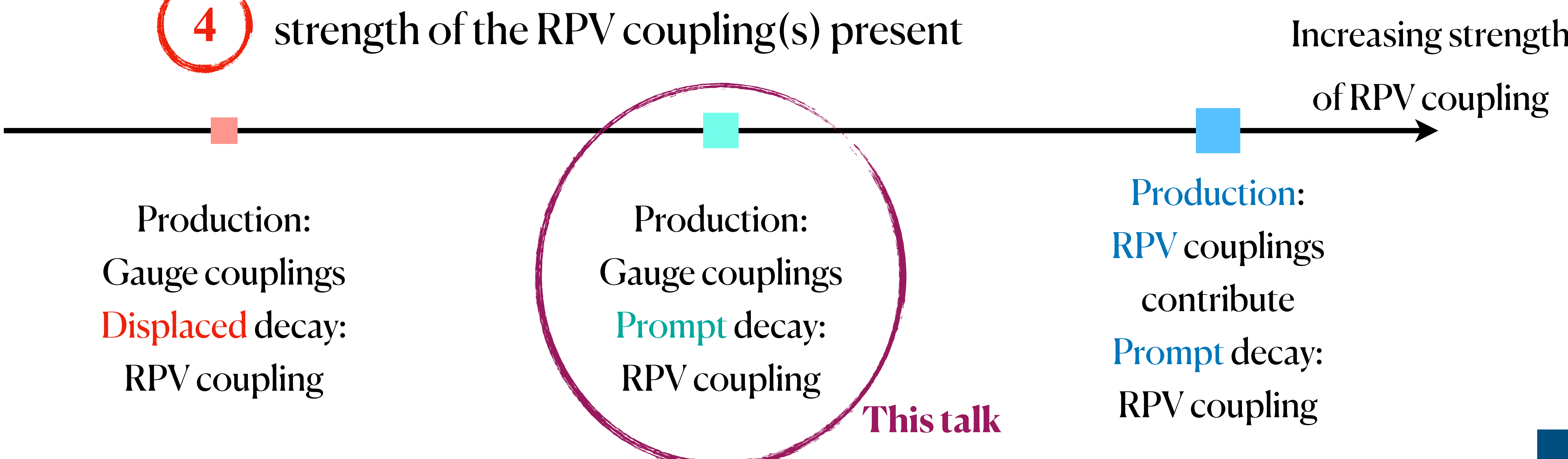

Systematic study of RPV signatures

Range of RPV couplings that we consider here: $\sqrt{\frac{(\beta\gamma)\ 10^{-12}\ \text{GeV}}{m_{\text{LSP}}}} \lesssim \lambda \ll g$

m_{LSP}: mass of the LSP

$\beta\gamma$: boost factor, $\frac{p}{m_{\text{LSP}}}$

λ: RPV coupling

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Pair production

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Production Channels

Possible LSPs

Pair production

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LSP Decay

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Have all these signatures been studied systematically?

Dercks, Dreiner, Krauss, Opferkuch, Reinert, EPJ. C77(2017)856

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Q: What is the minimal set of searches that would provide a complete coverage for RPV couplings?

Systematic study of RPV signatures

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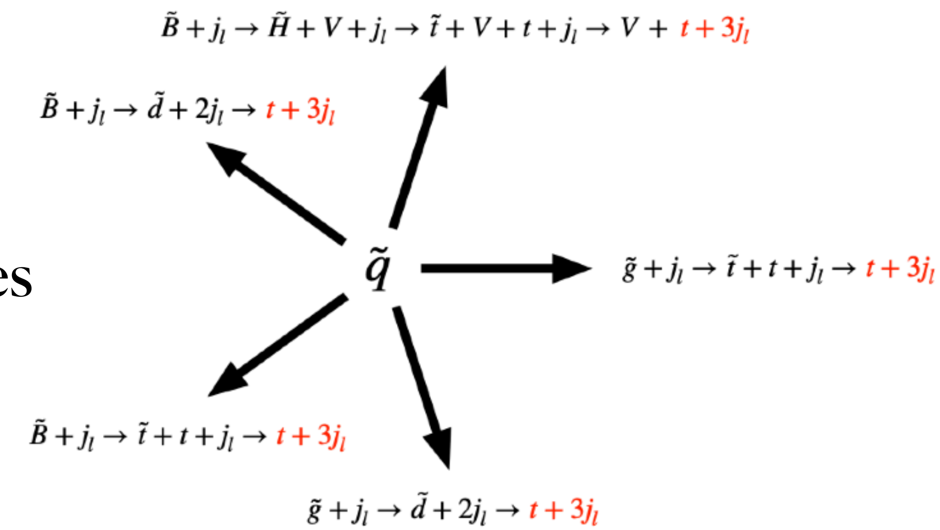
⇒ consider all LSPs, agnostic about the exact details of the rest of the spectrum

Example, $\tilde{q}$ -LSP decay via λ''_{312}

Can proceed via many intermediate states

Every path leads to $t + 3j_l + X$ final state



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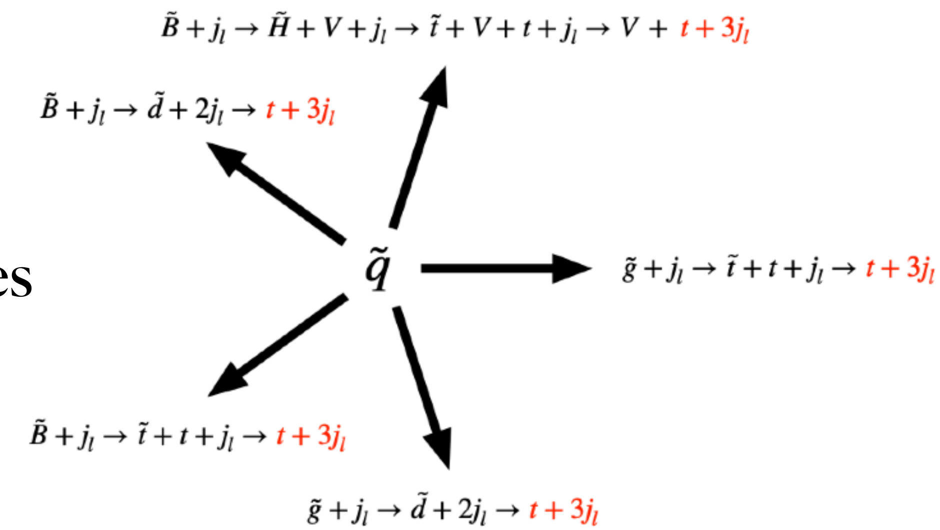

Another example: This final state would also be sensitive to

$\tilde{t}_{L/R}$ -LSP decay via λ''_{112}

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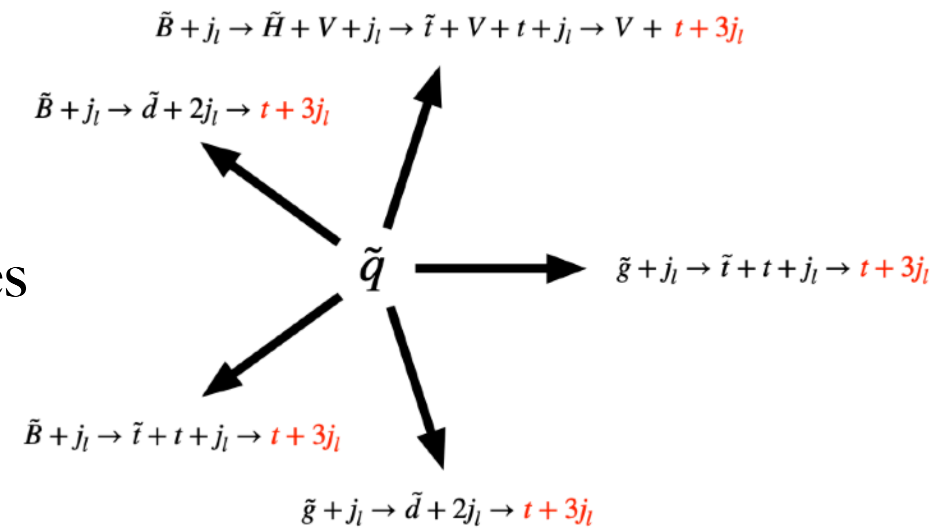

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Such broader classification of final states helps in

- identifying the relevant experimental searches for theorists
- deciding the target final state for experimentalists

The abc-rpv library

Provides a framework for analysing the collider signatures of the RPV-MSSM

Developed by Yong Sheng Koay available @

https://github.com/kys-sheng/abc-rpv.git

Based on the framework discussed in

arXiv:2306.07317, *JHEP* 07 (2023) 215

```
>>> import abcrpv as rpv
>>> x = rpv.ONE_LSP_RPV_DECAY_DICT["UDD"]
```

λ''_{312} coupling

$\tilde{u}_R$-LSP

```
>>> x[(x['Category']=='U_3 D D') & (x['LSP']=='u')]
    Category LSP decays via Signatures                                                    Chain  NV_cascade Signatures (ER)
203  U_3 D D   u          t       tjjj  [u -- (j) -- G -- (t) -- t -- [j,j], u -- (j) ...           2       3j_l + 1t
204  U_3 D D   u          d       tjjj  [u -- (j) -- G -- (j) -- d -- [t,j], u -- (j) ...           2       3j_l + 1t
```

Possible decay paths with different intermediate sparticles

Two-step cascade before the RPV decay

$t + 3j_l$ final state

This library is used to tabulate the possible final states for different LSPs decaying via different RPV operators

Systematic study of RPV signatures

UDD

	$\lambda''_{112}, \lambda''_{212}$	$\lambda''_{113}, \lambda''_{123}, \lambda''_{213}, \lambda''_{223}$	λ''_{312}	$\lambda''_{313}, \lambda''_{323}$
LSP	**UDD**	**UDD$_3$**	**U$_3$DD**	**U$_3$DD$_3$**
$\tilde{\ell}\,(\tilde{\nu})$				
$\tilde{e}$				
$\tilde{\tau}_L\,(\tilde{\nu}_\tau)$				
$\tilde{\tau}_R$				
$\tilde{g}$				
$\tilde{q}$				
$\tilde{u}$				
$\tilde{d}$				
$\tilde{t}_L(\tilde{b}_L)$				
$\tilde{t}_R$				
$\tilde{b}_R$				
$\tilde{B},\ \tilde{W},\ \tilde{H}$				

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$\tilde{\ell}\,(\tilde{\nu})$	$2\ell + 6j_l / \ell + 6j_l + E_T^{\text{miss}}$			
$\tilde{e}$	$2\ell + 6j_l$			
$\tilde{\tau}_L\,(\tilde{\nu}_\tau)$	$2\tau + 6j_l / \tau + 6j_l + E_T^{\text{miss}}$			
$\tilde{\tau}_R$	$2\tau + 6j_l$			
$\tilde{g}$	$6j_l$			
$\tilde{q}$	$8j_l$			
$\tilde{u}$	$4j_l$			
$\tilde{d}$	$4j_l$			
$\tilde{t}_L(\tilde{b}_L)$	$6j_l + 2j_3$			
$\tilde{t}_R$	$2t + 6j_l$			
$\tilde{b}_R$	$2b + 6j_l$			
$\tilde{B},\ \tilde{W},\ \tilde{H}$	$6j_l$			

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$\tilde{e}$	$2\ell + 6j_l$	$2\ell + 2b + 4j_l$	$2\ell + 4j_l + 2j_3$	$2\ell + 2b + 2j_l + 2j_3$
$\tilde{\tau}_L\,(\tilde{\nu}_\tau)$	$2\tau + 6j_l / \tau + 6j_l + E_T^{\rm miss}$	$2\tau + 2b + 4j_l / \tau + 2b + 4j_l + E_T^{\rm miss}$	$2\tau + 4j_l + 2j_3 / \tau + 4j_l + 2j_3 + E_T^{\rm miss}$	$2\tau + 2b + 2j_l + 2j_3 / \tau + 2b + 2j_l + 2j_3 + E_T^{\rm miss}$
$\tilde{\tau}_R$	$2\tau + 6j_l$	$2\tau + 2b + 4j_l$	$2\tau + 4j_l + 2j_3$	$2\tau + 2b + 2j_l + 2j_3$
$\tilde{g}$	$6j_l$	$2b + 4j_l$	$2t + 4j_l$	$2t + 2b + 2j_l$
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$\tilde{u}$	$4j_l$	$2b + 2j_l$	$2t + 6j_l$	$2t + 2b + 4j_l$
$\tilde{d}$	$4j_l$	$2b + 2j_l$	$2t + 2j_l$	$2t + 2b$
$\tilde{t}_L(\tilde{b}_L)$	$6j_l + 2j_3$	$2b + 4j_l + 2j_3$	$4j_l + 4j_3$	$2b + 2j_l + 4j_3$
$\tilde{t}_R$	$2t + 6j_l$	$2t + 2b + 4j_l$	$4j_l$	$2b + 2j_l$
$\tilde{b}_R$	$2b + 6j_l$	$4j_l$	$2t + 2b + 4j_l$	$2t + 2j_l$
$\tilde{B},\ \tilde{W},\ \tilde{H}$	$6j_l$	$2b + 4j_l$	$4j_l + 2j_3$	$2b + 2j_l + 2j_3$

Systematic study of RPV signatures

UDD

LSP	UDD ($\lambda''_{112}, \lambda''_{212}$)	UDD$_3$ ($\lambda''_{113}, \lambda''_{123}, \lambda''_{213}, \lambda''_{223}$)	U$_3$DD (λ''_{312})	U$_3$DD$_3$ ($\lambda''_{313}, \lambda''_{323}$)
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$\tilde{\tau}_R$	$2\tau + 6j_l$	$2\tau + 2b + 4j_l$	$2\tau + 4j_l + 2j_3$	$2\tau + 2b + 2j_l + 2j_3$
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$\tilde{q}$	$8j_l$	$2b + 6j_l$	$2t + 6j_l$	$2t + 2b + 4j_l$
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$\tilde{t}_L(\tilde{b}_L)$	$6j_l + 2j_3$	$2b + 4j_l + 2j_3$	$4j_l + 4j_3$	$2b + 2j_l + 4j_3$
$\tilde{t}_R$	$2t + 6j_l$	$2t + 2b + 4j_l$	$4j_l$	$2b + 2j_l$
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$\tilde{B},\ \tilde{W},\ \tilde{H}$	$6j_l$	$2b + 4j_l$	$4j_l + 2j_3$	$2b + 2j_l + 2j_3$

1. $4j$

$j : j_l, t, b$

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$\tilde{\ell}\,(\tilde{\nu})$	$2\ell + 6j_l / \ell + 6j_l + E_T^{\text{miss}}$	$2\ell + 2b + 4j_l / \ell + 2b + 4j_l + E_T^{\text{miss}}$	$2\ell + 4j_l + 2j_3 / \ell + 4j_l + 2j_3 + E_T^{\text{miss}}$	$2\ell + 2b + 2j_l + 2j_3 / \ell + 2b + 2j_l + 2j_3 + E_T^{\text{miss}}$
$\tilde{e}$	$2\ell + 6j_l$	$2\ell + 2b + 4j_l$	$2\ell + 4j_l + 2j_3$	$2\ell + 2b + 2j_l + 2j_3$
$\tilde{\tau}_L\,(\tilde{\nu}_\tau)$	$2\tau + 6j_l / \tau + 6j_l + E_T^{\text{miss}}$	$2\tau + 2b + 4j_l / \tau + 2b + 4j_l + E_T^{\text{miss}}$	$2\tau + 4j_l + 2j_3 / \tau + 4j_l + 2j_3 + E_T^{\text{miss}}$	$2\tau + 2b + 2j_l + 2j_3 / \tau + 2b + 2j_l + 2j_3 + E_T^{\text{miss}}$
$\tilde{\tau}_R$	$2\tau + 6j_l$	$2\tau + 2b + 4j_l$	$2\tau + 4j_l + 2j_3$	$2\tau + 2b + 2j_l + 2j_3$
$\tilde{g}$	$6j_l$	$2b + 4j_l$	$2t + 4j_l$	$2t + 2b + 2j_l$
$\tilde{q}$	$8j_l$	$2b + 6j_l$	$2t + 6j_l$	$2t + 2b + 4j_l$
$\tilde{u}$	$4j_l$	$2b + 2j_l$	$2t + 6j_l$	$2t + 2b + 4j_l$
$\tilde{d}$	$4j_l$	$2b + 2j_l$	$2t + 2j_l$	$2t + 2b$
$\tilde{t}_L(\tilde{b}_L)$	$6j_l + 2j_3$	$2b + 4j_l + 2j_3$	$4j_l + 4j_3$	$2b + 2j_l + 4j_3$
$\tilde{t}_R$	$2t + 6j_l$	$2t + 2b + 4j_l$	$4j_l$	$2b + 2j_l$
$\tilde{b}_R$	$2b + 6j_l$	$4j_l$	$2t + 2b + 4j_l$	$2t + 2j_l$
$\tilde{B},\ \tilde{W},\ \tilde{H}$	$6j_l$	$2b + 4j_l$	$4j_l + 2j_3$	$2b + 2j_l + 2j_3$

arXiv:2306.07317, *JHEP* 07 (2023) 215

1. $4j$
2. $2j_l + 4j$
3. $2j_l + 6j$
4. $1L + 2j_l + 4j + E_T^{\text{miss}}$
5. $2L + 2j_l + 4j$

$L : e, \mu, \tau$
$j_l : u, d, s, c$
$j : j_l, t, b$

The CheckMATE recasting framework

Q: What is the coverage of the existing searches on the RPV landscape?

The CheckMATE recasting framework

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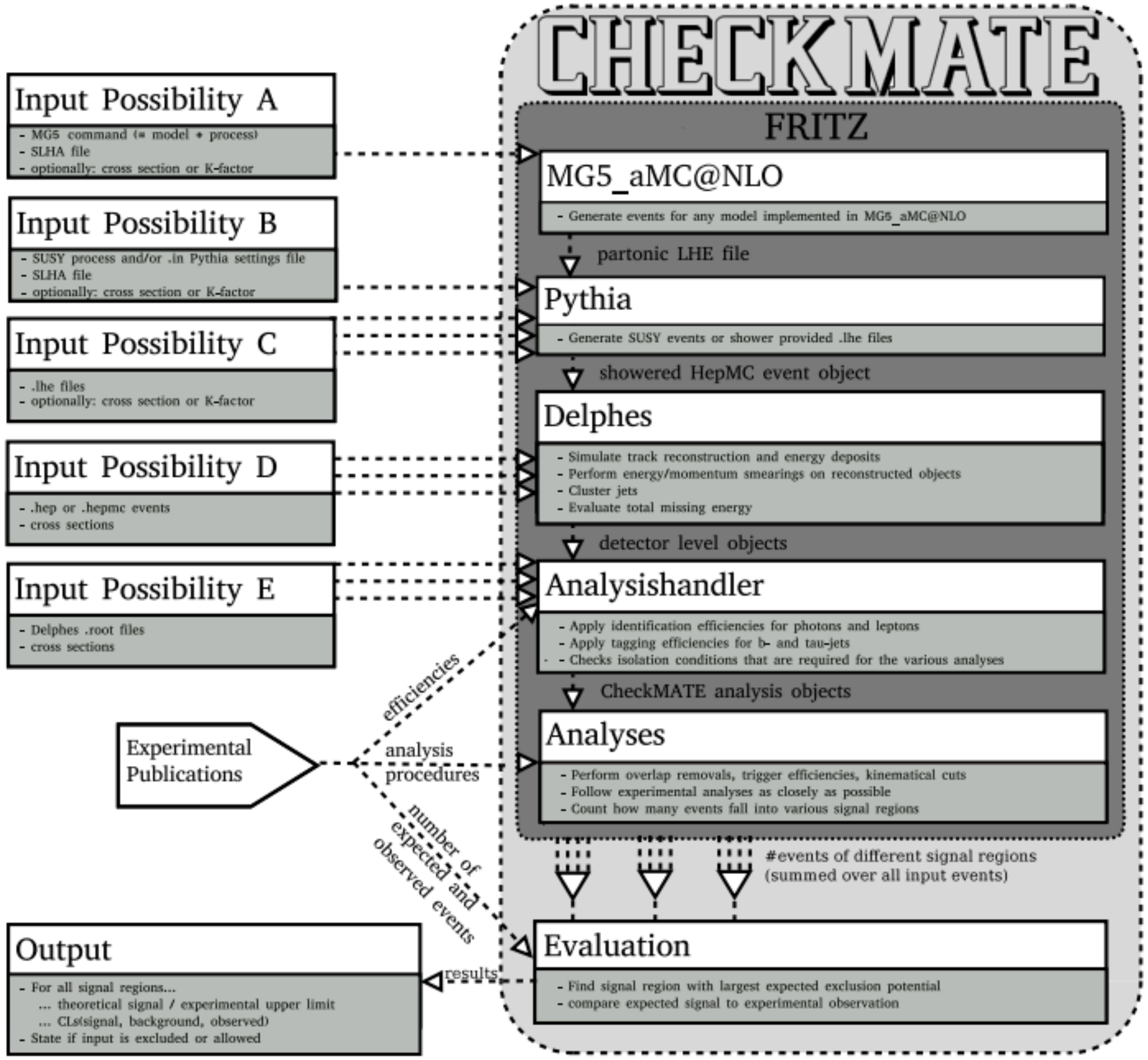

Dercks, Desai, Kim, Rolbiecki, Tattersall, Weber, CPC 221 (2017) 383-418

CheckMATE: Confronting your Favourite New Physics Model with LHC Data

Drees, Dreiner, Kim, Schmeier, Tattersall, CPC 187 (2015) 227-265

The CheckMATE recasting framework

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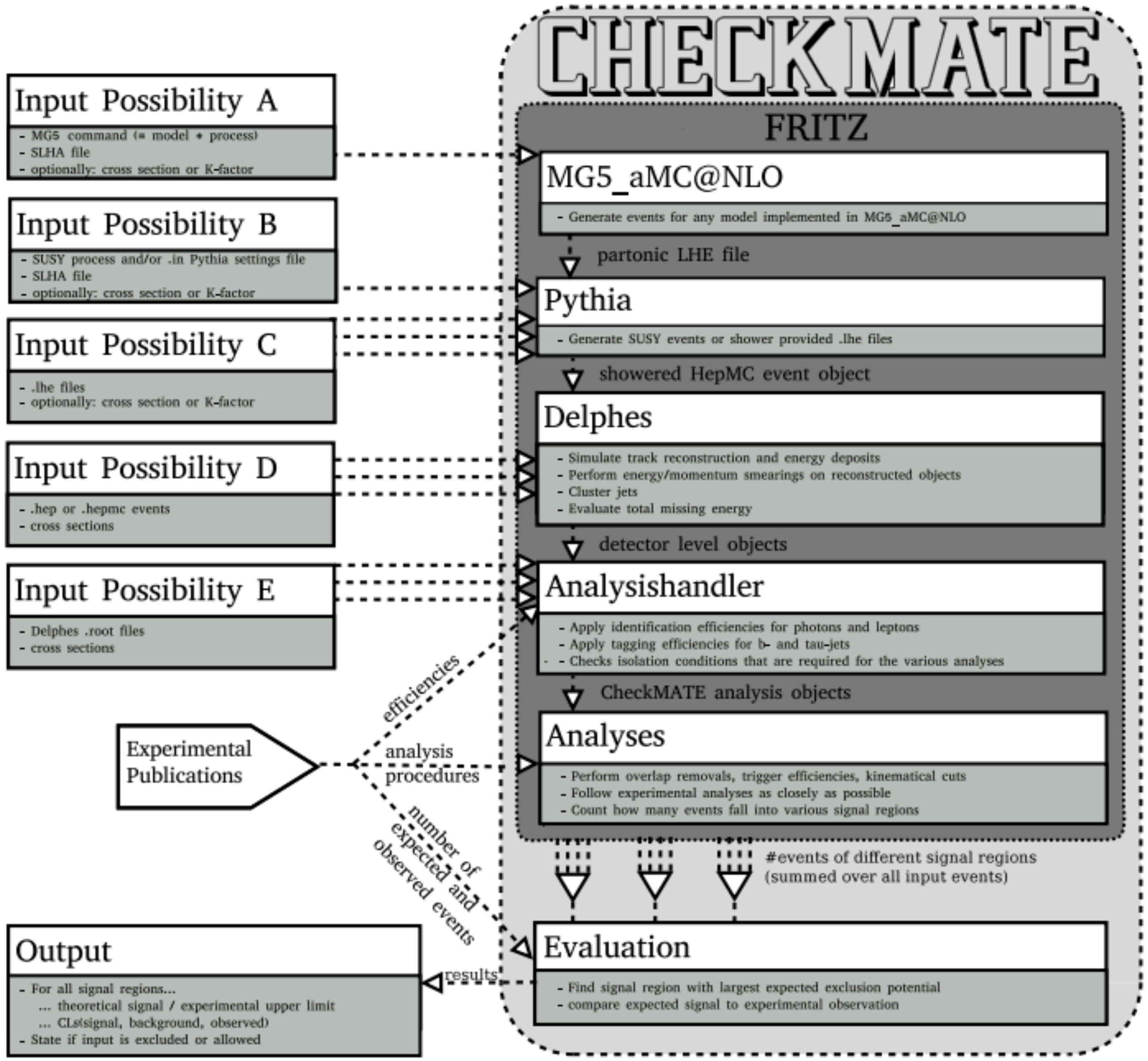


Dercks, Desai, Kim, Rolbiecki, Tattersall, Weber, CPC 221 (2017) 383-418

CheckMATE: Confronting your Favourite New Physics Model with LHC Data

Drees, Dreiner, Kim, Schmeier, Tattersall, CPC 187 (2015) 227-265

- Searches relevant for RPV

Implemented in CheckMATE?

Yes

No

Is the information available enough to implement it in CheckMATE?

- Are there some regions which still require experimental attention?

Status of RPV SUSY at the LHC: UDD

Searches relevant for UDD couplings

Broader class of final states:	Relevant experimental searches:	
1. $4j$	cms_2206_09997, atlas_2307_14944	
2. $2j_l + 4j$	atlas_2401_16333	
3. $2j_l + 6j$	atlas_2401_16333	
4. $1L + 2j_l + 4j + E_T^{\text{miss}}$	cms_1911_07558, atlas_2106_09609	Implemented in CheckMATE
5. $2L + 2j_l + 4j$	cms_1602_04334, cms_2001_10086, cms_2208_09700	

We have to implement new searches in CheckMATE to improve the coverage.

Status of RPV SUSY at the LHC: UDD

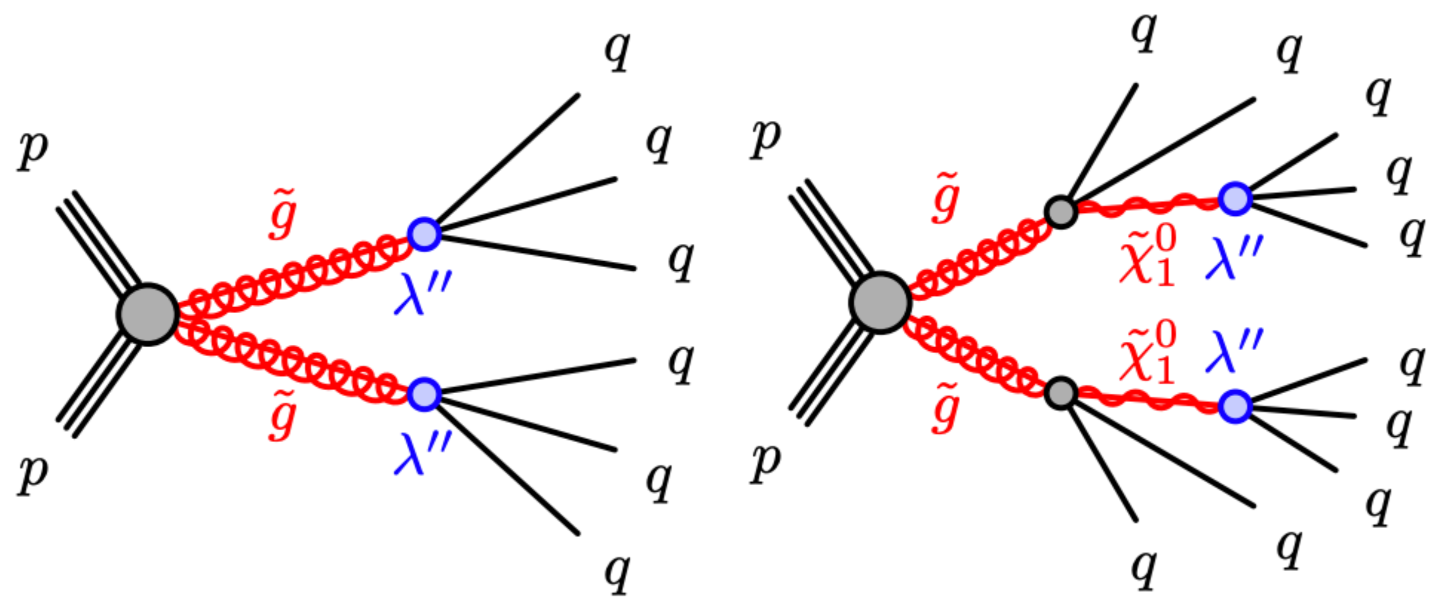
Searches relevant for UDD couplings

Broader class of final states:	Relevant experimental searches:	
1. $4j$	cms_2206_09997, atlas_2307_14944	Based on fitting the dijet resonance
2. $2j_l + 4j$	atlas_2401_16333	Multijet search
3. $2j_l + 6j$	atlas_2401_16333	
4. $1L + 2j_l + 4j + E_T^{\text{miss}}$	cms_1911_07558, atlas_2106_09609	
5. $2L + 2j_l + 4j$	cms_1602_04334, cms_2001_10086, cms_2208_09700	2 OS leptons + jets

We implement atlas_2401_16333 and cms_1602_04334 in CheckMATE for this study.

The analyses we implement in CheckMATE

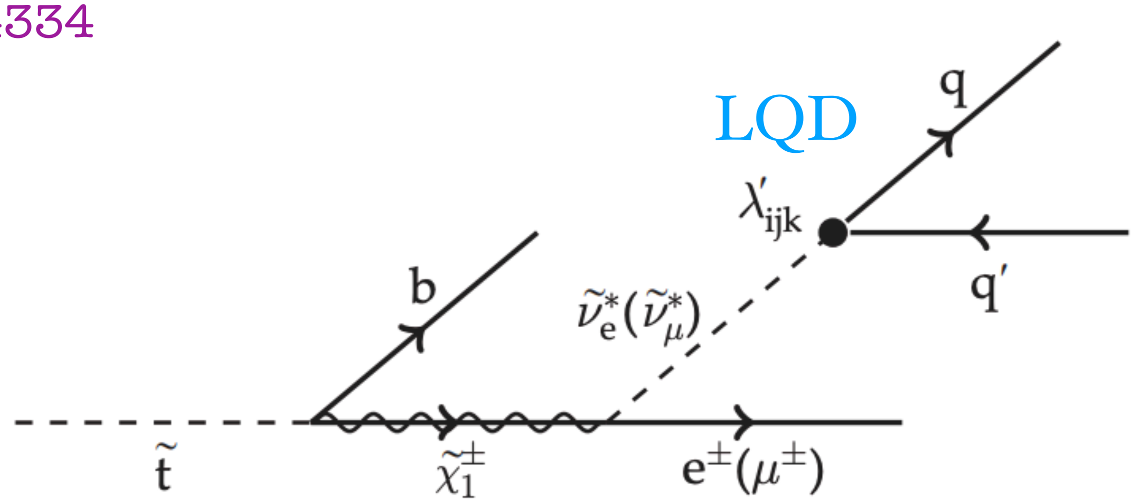
atlas_2401_16333



Multijet final state
Low MET
Event-shape variable, C
$C = 3(\lambda_1\lambda_2 + \lambda_2\lambda_3 + \lambda_1\lambda_3)$
$\lambda_{1,2,3}$: eigenvalues of Sphericity tensor

13 TeV search

cms_1602_04334



2 OS leptons + jets
Similar to the final state of slepton-LSPs decay via UDD

8 TeV search

Validations in the Backup

Status of RPV SUSY at the LHC: UDD

arXiv:2503.03830, *JHEP* (2025)

Direct production of the LSP:

rest of the spectrum decoupled

$pp \to \tilde{p}\tilde{p}$

$\tilde{p}$-LSP

Status of RPV SUSY at the LHC: UDD

Direct production of the LSP:

rest of the spectrum decoupled

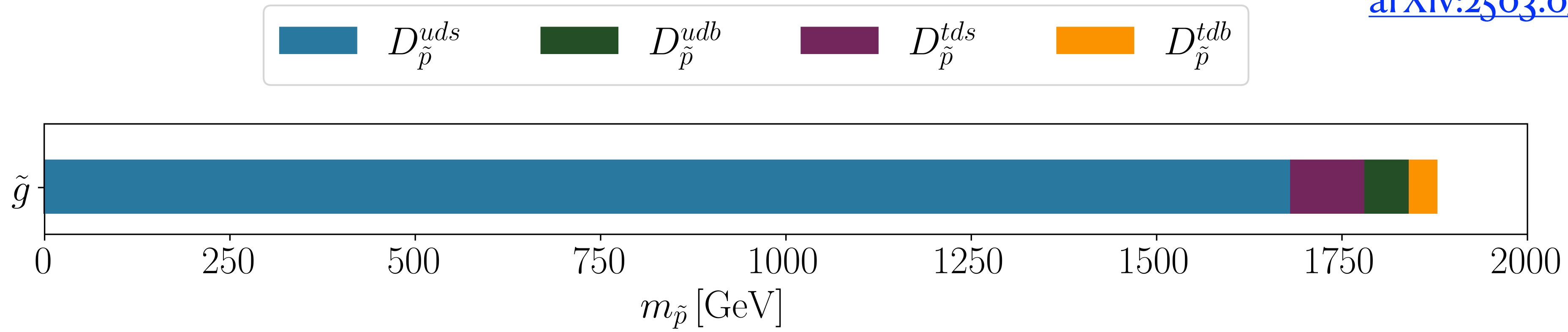
$pp \to \tilde{p}\tilde{p}$

$\tilde{p}$-LSP

LSP	Coupling	LSP Decay	Label
$\tilde{g}$	λ''_{112}	$3j_\ell$	$D^{uds}_{\tilde{g}}$
	λ''_{113}	$2j_\ell + 1b$	$D^{udb}_{\tilde{g}}$
	λ''_{312}	$2j_\ell + 1t$	$D^{tds}_{\tilde{g}}$
	λ''_{313}	$1j_\ell + 1b + 1t$	$D^{tdb}_{\tilde{g}}$

Other LSP tables in the Backup

arXiv:2503.03830, *JHEP* (2025)



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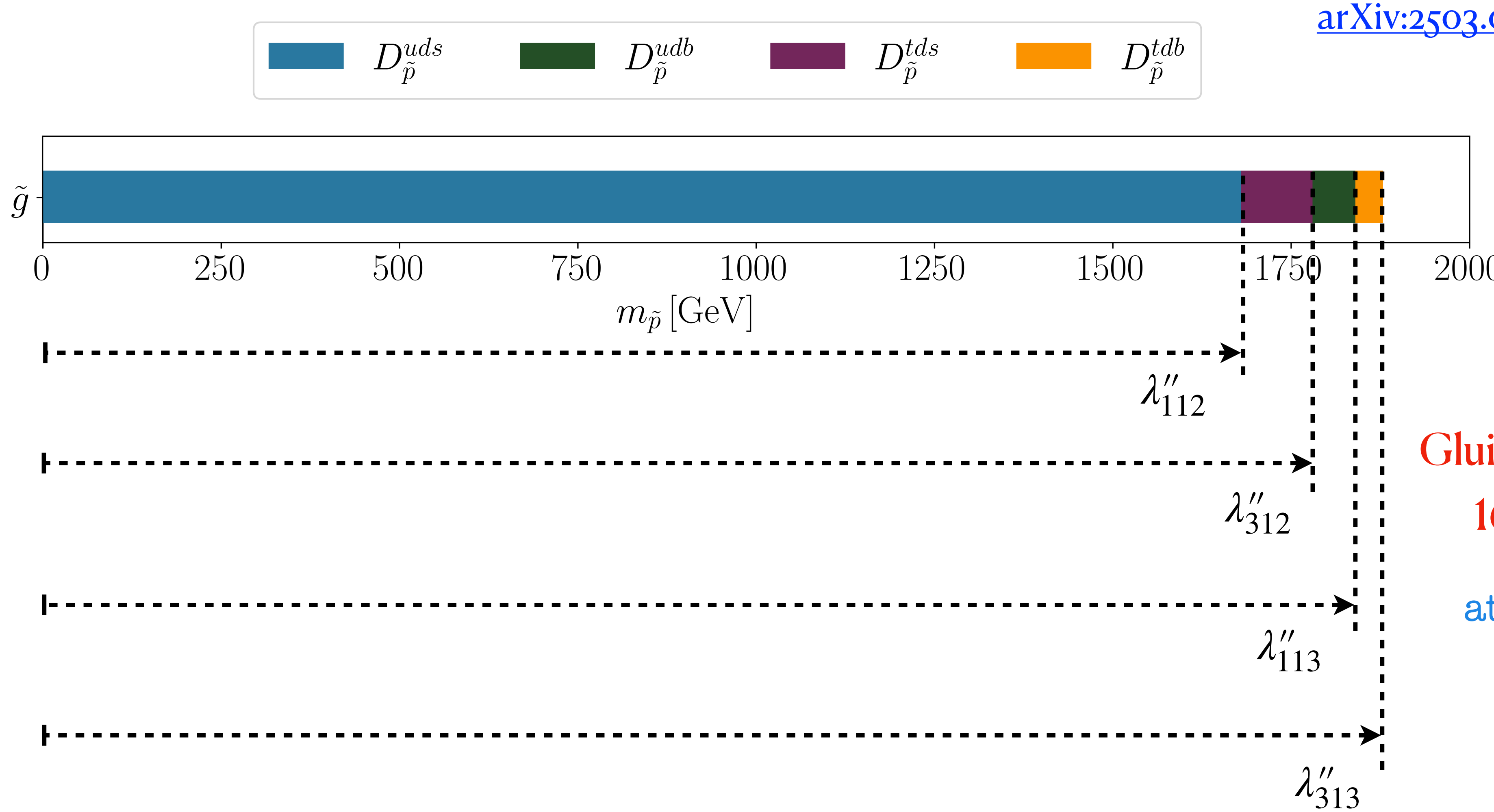

Gluinos excluded upto 1600-1850 GeV

atlas_2401_16333

Status of RPV SUSY at the LHC: UDD

Direct production of the LSP:

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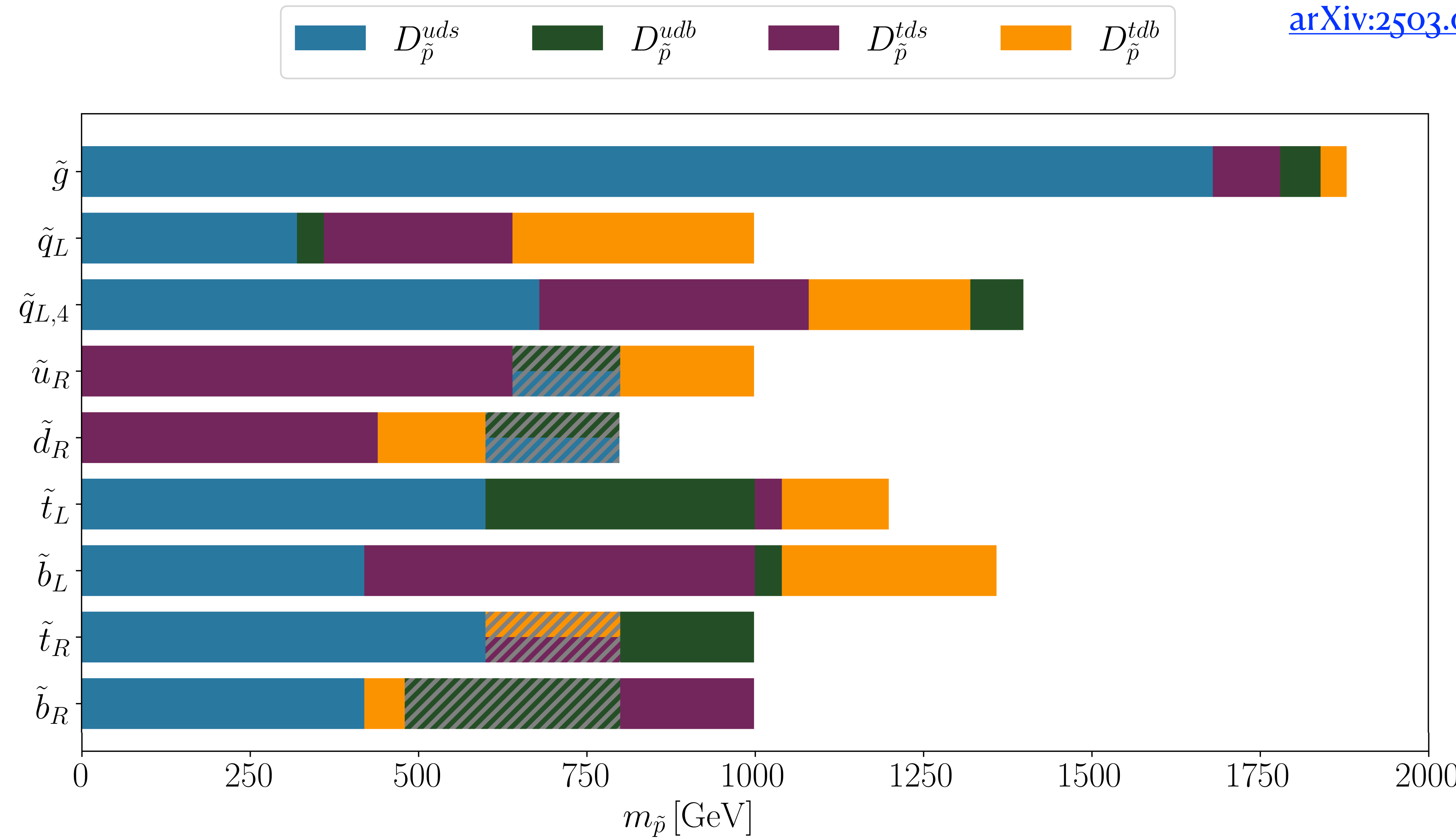
	λ''_{313}	$1j_\ell + 1b + 1t$	$D^{tdb}_{\tilde{g}}$

Other LSP tables in the Backup

arXiv:2503.03830, *JHEP* (2025)



Status of RPV SUSY at the LHC: UDD

Direct production of the LSP:

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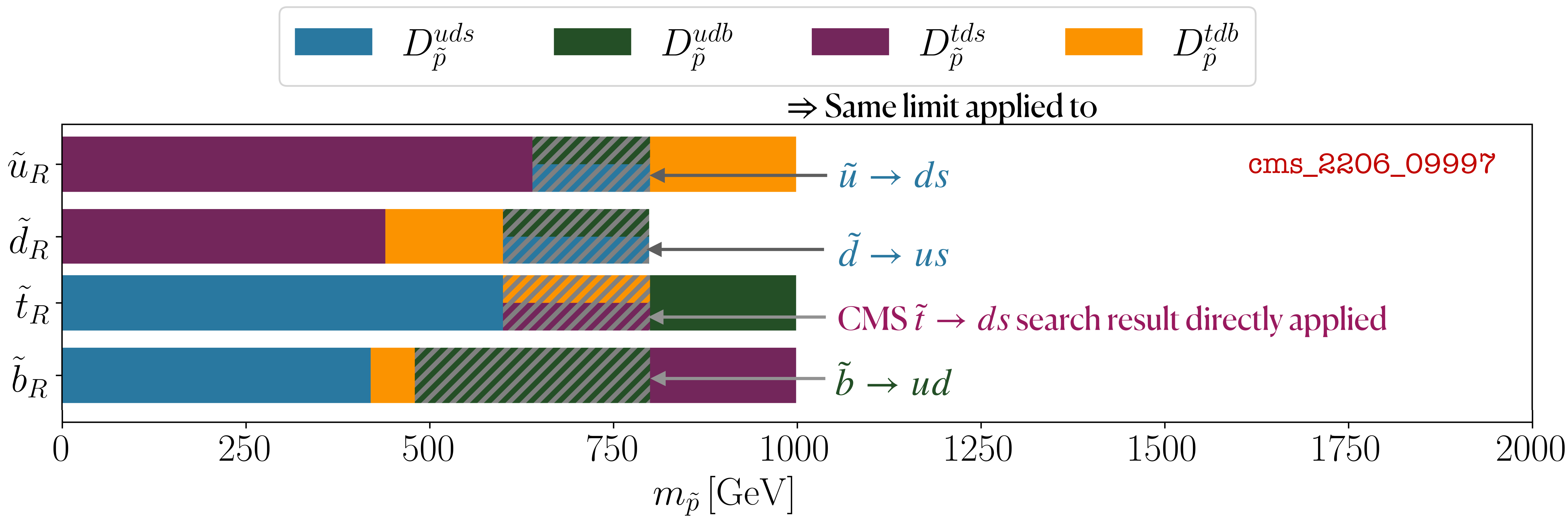
Other LSP tables in the Backup



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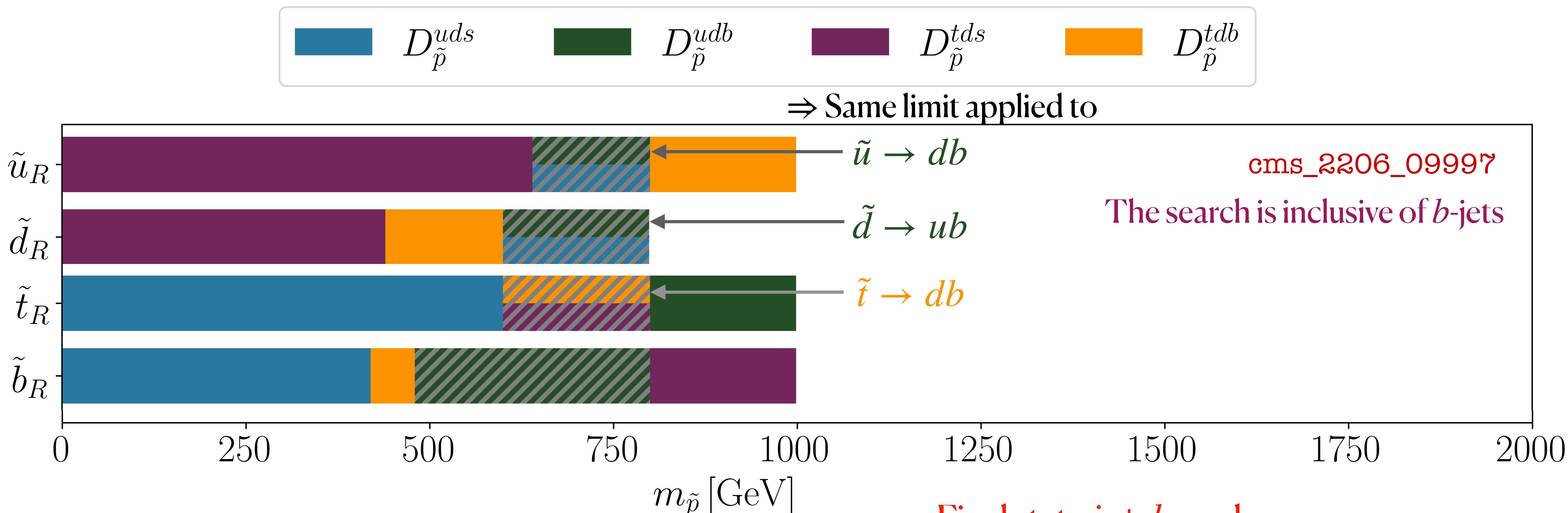
	λ''_{313}	$1j_\ell + 1b + 1t$	$D^{tdb}_{\tilde{g}}$

Other LSP tables in the Backup



arXiv:2503.03830, *JHEP* (2025)

Final state $j_l + b$ can be improved using b-tagging

Status of RPV SUSY at the LHC: UDD

Direct production of the LSP:

rest of the spectrum decoupled

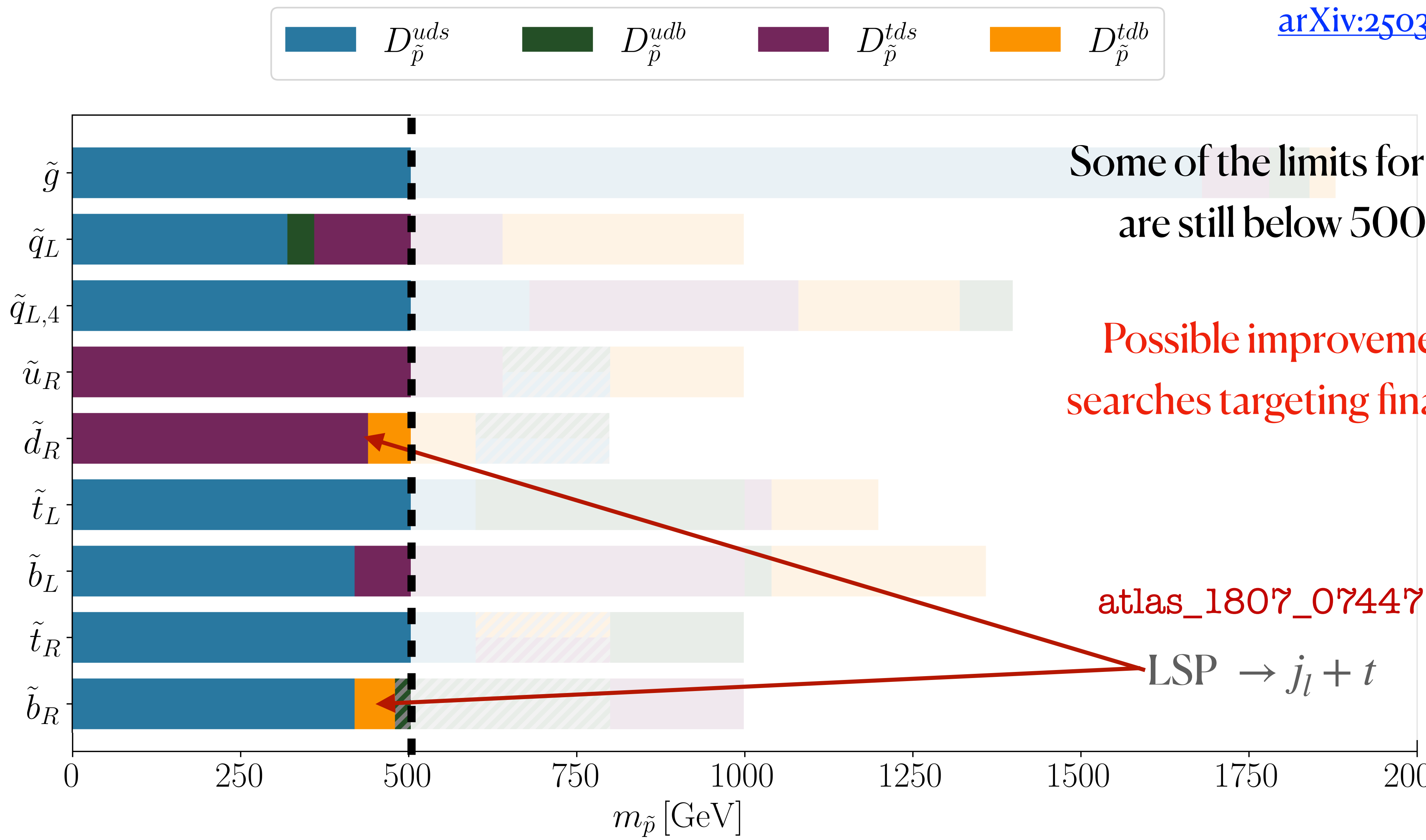
$pp \to \tilde{p}\tilde{p}$

$\tilde{p}$-LSP

LSP	Coupling	LSP Decay	Label
$\tilde{g}$	λ''_{112}	$3j_\ell$	$D_{\tilde{g}}^{uds}$
	λ''_{113}	$2j_\ell + 1b$	$D_{\tilde{g}}^{udb}$
	λ''_{312}	$2j_\ell + 1t$	$D_{\tilde{g}}^{tds}$
	λ''_{313}	$1j_\ell + 1b + 1t$	$D_{\tilde{g}}^{tdb}$

Other LSP tables in the Backup

arXiv:2503.03830, *JHEP* (2025)



Some of the limits for squarks are still below 500 GeV

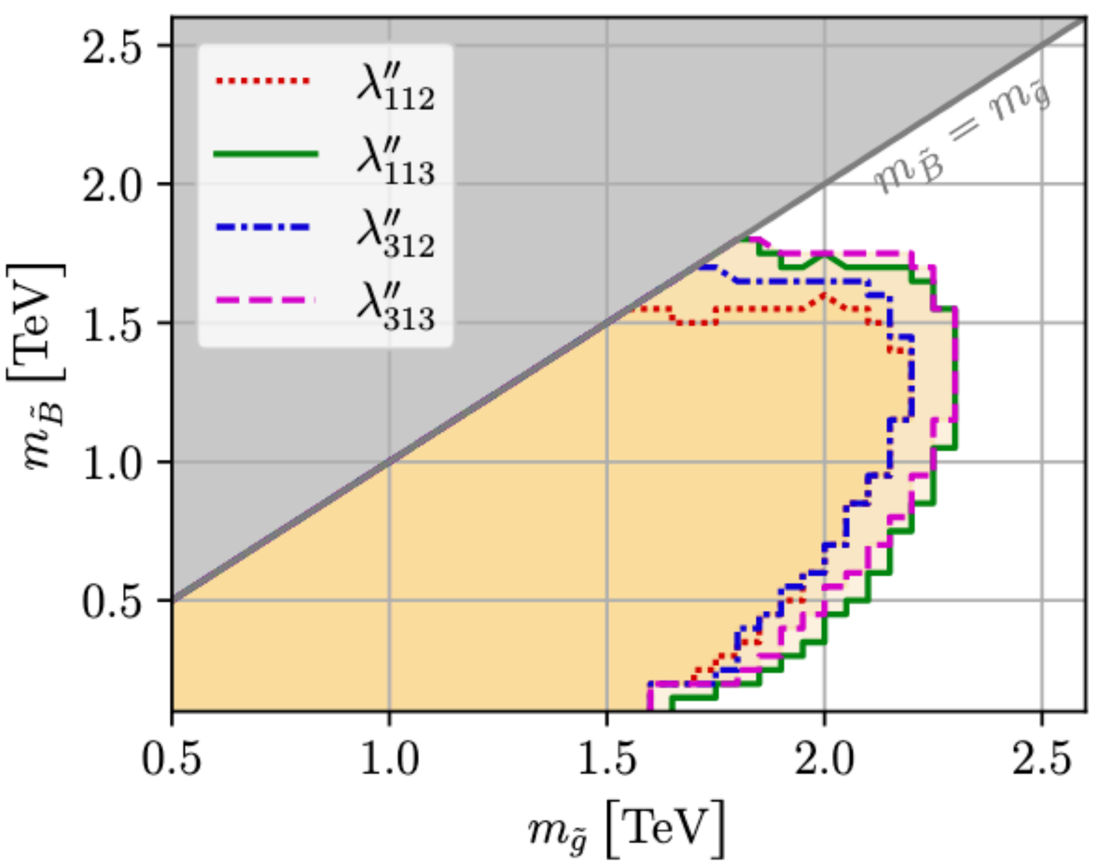
Possible improvements in searches targeting final states:

Status of RPV SUSY at the LHC: UDD

Bino LSP - from gluino cascade decay

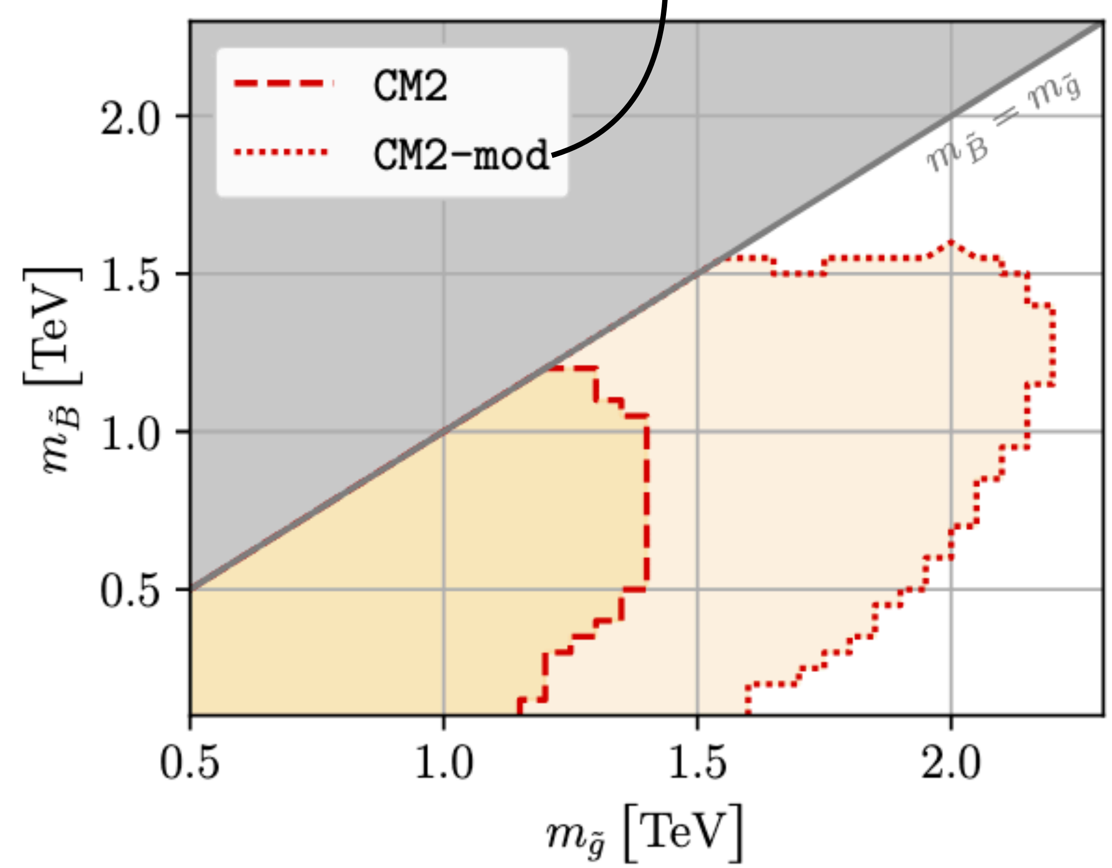
[arXiv:2503.03830](https://arxiv.org/abs/2503.03830), *JHEP* (2025)

$$pp \to \tilde{g}\tilde{g},$$
$$\tilde{g} \to jj\tilde{\chi}_1^0,\ \ \tilde{\chi}_1^0 \to jjj$$



Strong exclusion in the gluino-bino mass plane for all the four benchmark UDD couplings

CheckMATE with searches implemented by us



The ATLAS multijet search improves sensitivity significantly

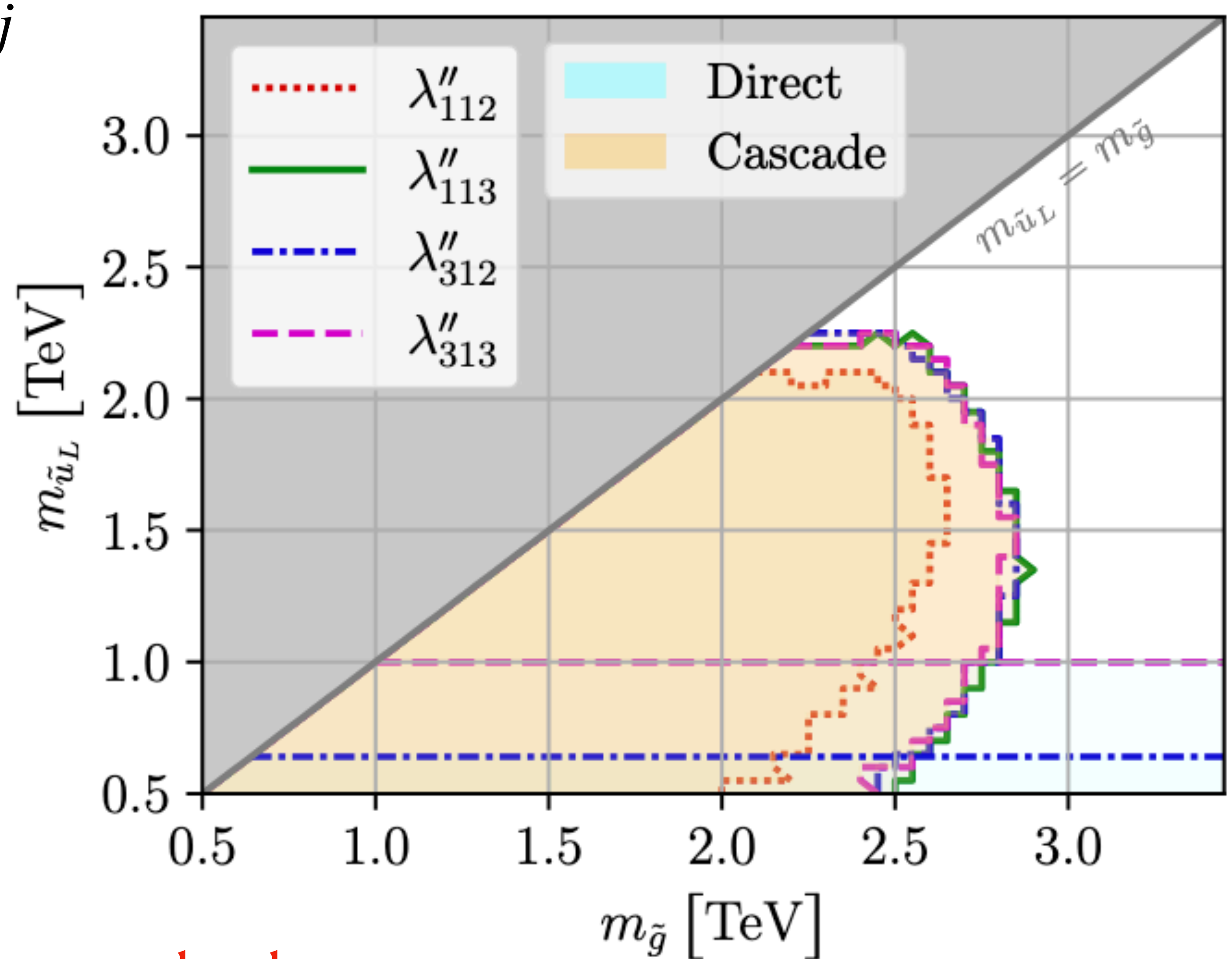
Status of RPV SUSY at the LHC: UDD

Squark LSP - from gluino cascade decay

arXiv:2503.03830, *JHEP* (2025)

$$pp \to \tilde{g}\tilde{g}/\tilde{g}\tilde{u}_L,$$

$$\tilde{g} \to j\tilde{u}_L, \;\; \tilde{u}_L \to jjjj$$

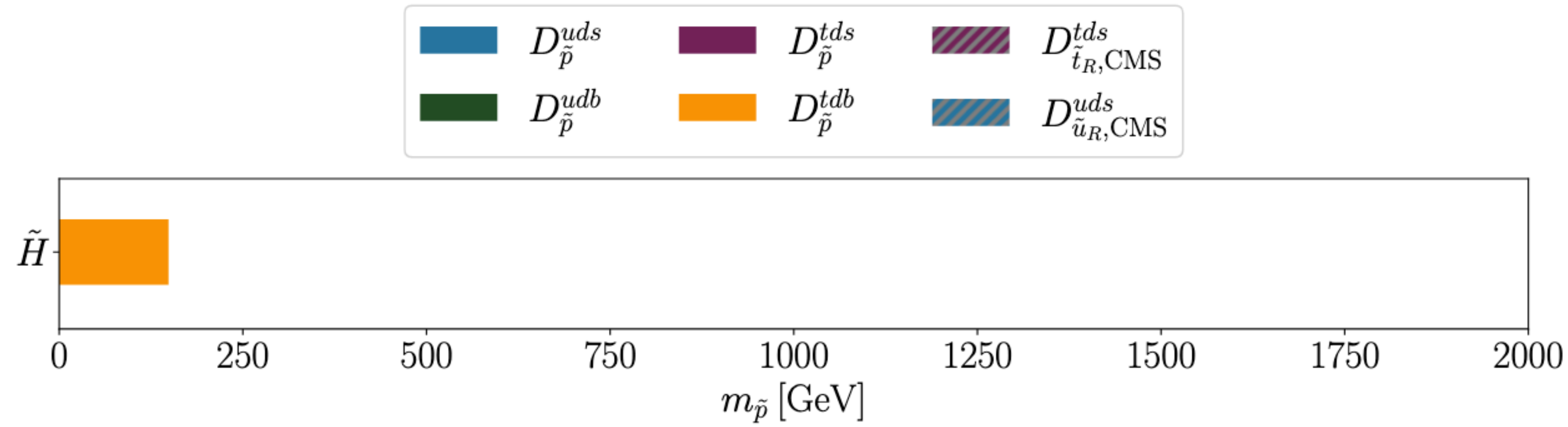


Better results as compared to the direct production results

Status of RPV SUSY at the LHC: UDD

Slepton LSPs and electroweakinos

arXiv:2503.03830, *JHEP* (2025)



Very weak sensitivity for $\tilde{H}$ LSP decay via λ''_{313} couplings, ~ 150 GeV

No sensitivity for $\tilde{e}$, $\tilde{\mu}$, $\tilde{\tau}$, $\tilde{\nu}$, $\tilde{W}$ LSPs

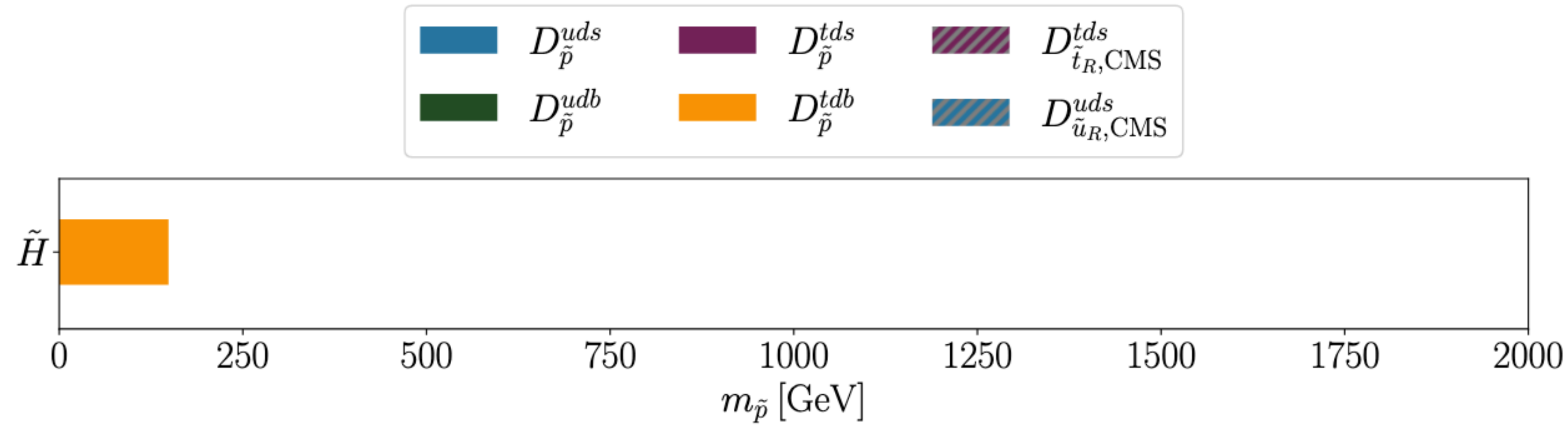
The best sensitivity still comes from the CMS 8 TeV search that we implement in CheckMATE

cms_1602_04334

Status of RPV SUSY at the LHC: UDD

Slepton LSPs and electroweakinos

arXiv:2503.03830, *JHEP* (2025)



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cms_1602_04334

Status of RPV SUSY at the LHC: UDD

[arXiv:2503.03830](https://arxiv.org/abs/2503.03830), *JHEP* (2025)

Slepton LSPs and electroweakinos

Black: 1-step cascade

Purple: 2-step cascade

Brown: 3-step cascade

Final states

2 OS leptons + jets

LSP	Coupling	LSP Decay	Label
$\tilde{e}/\tilde{\mu}/\tilde{\tau}$	λ''_{112}	$3j_l + 1e/\mu/\tau$	$D^{uds}_{\tilde{e}}$
	λ''_{113}	$2j_l + 1b + 1e/\mu/\tau$	$D^{udb}_{\tilde{e}}$
	λ''_{312}	$2j_l + 1t + 1e/\mu/\tau$	$D^{tds}_{\tilde{e}}$
	λ''_{313}	$1j_l + 1b + 1t + 1e/\mu/\tau$	$D^{tdb}_{\tilde{e}}$
$\tilde{\nu}_e/\tilde{\nu}_\mu/\tilde{\nu}_\tau$	λ''_{112}	$3j_l$+MET	$D^{uds}_{\tilde{\nu}}$
	λ''_{113}	$2j_l + 1b$+MET	$D^{udb}_{\tilde{\nu}}$
	λ''_{312}	$2j_l + 1t$+MET	$D^{tds}_{\tilde{\nu}}$
	λ''_{313}	$1j_l + 1b + 1t$+MET	$D^{tdb}_{\tilde{\nu}}$

LSP	Coupling	LSP Decay	Label
$\tilde{H}^0$	λ''_{112}	$3j_l + 1V$	$D^{uds}_{\tilde{H}}$
	λ''_{113}	$2j_l + 1b$, $2j_l + 1b + 1V$	$D^{udb}_{\tilde{H}}$
	λ''_{312}	$2j_l + 1t$, $2j_l + 1t + 1V$	$D^{tds}_{\tilde{H}}$
	λ''_{313}	$1j_l + 1b + 1t$, $1j_l + 1b + 1t + 1V$	$D^{tdb}_{\tilde{H}}$
$\tilde{H}^\pm$	λ''_{112}	$3j_l + 1V$	$D^{uds}_{\tilde{H}}$
	λ''_{113}	$2j_l + 1t$, $2j_l + 1b + 1V$	$D^{udb}_{\tilde{H}}$
	λ''_{312}	$2j_l + 1b$, $2j_l + 1t + 1V$	$D^{tds}_{\tilde{H}}$
	λ''_{313}	$1j_l + 2b$, $1j_l + 2t$, $1j_l + 1b + 1t + 1V$	$D^{tdb}_{\tilde{H}}$

LSP	Coupling	LSP Decay	Label
$\tilde{W}^0$	λ''_{112}	$3j_l$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{uds}_{\tilde{W}}$
	λ''_{113}	$2j_l + 1b + 1V$, $2j_l + 1t + 1V$, $2j_l + 1b$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{udb}_{\tilde{W}}$
	λ''_{312}	$2j_l + 1t + 1V$, $2j_l + 1b + 1V$, $2j_l + 1t$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{tds}_{\tilde{W}}$
	λ''_{313}	$1j_l + 1t + 1b + 1V$, $1j_l + 2b + 1V$, $1j_l + 2t + 1V$, $1j_l + 1t + 1b$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{tdb}_{\tilde{W}}$
$\tilde{W}^\pm$	λ''_{112}	$3j_l$+ $(2j_l/2V)$, $3j_l + 1t + 1b$, $3j_l + 1L$+MET	$D^{uds}_{\tilde{W}}$
	λ''_{113}	$2j_l + 1t + 1V$, $2j_l + 1b + 1V$, $2j_l + 1t + 2b$, $2j_l + 1b$+ $(2j_l/2V)$, $2j_l + 1b + 1L$+MET	$D^{udb}_{\tilde{W}}$
	λ''_{312}	$2j_l + 1b + 1V$, $2j_l + 1t + 1V$, $2j_l + 2t + 1b$, $2j_l + 1t$+ $(2j_l/2V)$, $2j_l + 1t + 1L$+MET	$D^{tds}_{\tilde{W}}$
	λ''_{313}	$1j_l + 1t + 1b + 1V$, $1j_l + 2b + 1V$, $1j_l + 2t + 1V$, $1j_l + 1t + 1b$+ $(2j_l/2V)$, $1j_l + 2t + 2b$, $1j_l + 1t + 1b + 1L$+MET	$D^{tdb}_{\tilde{W}}$

Status of RPV SUSY at the LHC: UDD

arXiv:2503.03830, *JHEP* (2025)

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Black: 1-step cascade

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Final states

2 OS leptons + jets

LSP	Coupling	LSP Decay	Label
$\tilde{e}/\tilde{\mu}/\tilde{\tau}$	λ''_{112}	$3j_l + 1e/\mu/\tau$	$D^{uds}_{\tilde{e}}$
	λ''_{113}	$2j_l + 1b + 1e/\mu/\tau$	$D^{udb}_{\tilde{e}}$
	λ''_{312}	$2j_l + 1t + 1e/\mu/\tau$	$D^{tds}_{\tilde{e}}$
	λ''_{313}	$1j_l + 1b + 1t + 1e/\mu/\tau$	$D^{tdb}_{\tilde{e}}$
$\tilde{\nu}_e/\tilde{\nu}_\mu/\tilde{\nu}_\tau$	λ''_{112}	$3j_l$+MET	$D^{uds}_{\tilde{\nu}}$
	λ''_{113}	$2j_l + 1b$+MET	$D^{udb}_{\tilde{\nu}}$
	λ''_{312}	$2j_l + 1t$+MET	$D^{tds}_{\tilde{\nu}}$
	λ''_{313}	$1j_l + 1b + 1t$+MET	$D^{tdb}_{\tilde{\nu}}$

LSP	Coupling	LSP Decay	Label
$\tilde{H}^0$	λ''_{112}	$3j_l + 1V$	$D^{uds}_{\tilde{H}}$
	λ''_{113}	$2j_l + 1b$ $\quad$ $2j_l + 1b + 1V$	$D^{udb}_{\tilde{H}}$
	λ''_{312}	$2j_l + 1t$ $\quad$ $2j_l + 1t + 1V$	$D^{tds}_{\tilde{H}}$
	λ''_{313}	$1j_l + 1b + 1t$ $\quad$ $1j_l + 1b + 1t + 1V$	$D^{tdb}_{\tilde{H}}$
$\tilde{H}^\pm$	λ''_{112}	$3j_l + 1V$	$D^{uds}_{\tilde{H}}$
	λ''_{113}	$2j_l + 1t$ $\quad$ $2j_l + 1b + 1V$	$D^{udb}_{\tilde{H}}$
	λ''_{312}	$2j_l + 1b$ $\quad$ $2j_l + 1t + 1V$	$D^{tds}_{\tilde{H}}$
	λ''_{313}	$1j_l + 2b$ $\quad$ $1j_l + 2t$ $\quad$ $1j_l + 1b + 1t + 1V$	$D^{tdb}_{\tilde{H}}$

$2V(W/Z/H)$+ jets

LSP	Coupling	LSP Decay	Label
$\tilde{W}^0$	λ''_{112}	$3j_l$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{uds}_{\tilde{W}}$
	λ''_{113}	$2j_l + 1b + 1V$ $\quad$ $2j_l + 1t + 1V$ $\quad$ $2j_l + 1b$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{udb}_{\tilde{W}}$
	λ''_{312}	$2j_l + 1t + 1V$ $\quad$ $2j_l + 1b + 1V$ $\quad$ $2j_l + 1t$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{tds}_{\tilde{W}}$
	λ''_{313}	$1j_l + 1t + 1b + 1V$ $\quad$ $1j_l + 2b + 1V$ $\quad$ $1j_l + 2t + 1V$ $\quad$ $1j_l + 1t + 1b$+ $(2j_l/2b/2t/2L/2V/\text{MET})$	$D^{tdb}_{\tilde{W}}$
$\tilde{W}^\pm$	λ''_{112}	$3j_l$+ $(2j_l/2V)$ $\quad$ $3j_l + 1t + 1b$ $\quad$ $3j_l + 1L$+MET	$D^{uds}_{\tilde{W}}$
	λ''_{113}	$2j_l + 1t + 1V$ $\quad$ $2j_l + 1b + 1V$ $\quad$ $2j_l + 1t + 2b$ $\quad$ $2j_l + 1b$+ $(2j_l/2V)$ $\quad$ $2j_l + 1b + 1L$+MET	$D^{udb}_{\tilde{W}}$
	λ''_{312}	$2j_l + 1b + 1V$ $\quad$ $2j_l + 1t + 1V$ $\quad$ $2j_l + 2t + 1b$ $\quad$ $2j_l + 1t$+ $(2j_l/2V)$ $\quad$ $2j_l + 1t + 1L$+MET	$D^{tds}_{\tilde{W}}$
	λ''_{313}	$1j_l + 1t + 1b + 1V$ $\quad$ $1j_l + 2b + 1V$ $\quad$ $1j_l + 2t + 1V$	$D^{tdb}_{\tilde{W}}$
		$1j_l + 1t + 1b$+ $(2j_l/2V)$ $\quad$ $1j_l + 2t + 2b$ $\quad$ $1j_l + 1t + 1b + 1L$+MET	

Conclusion

- A framework for a broader classification of final states for all the possible LSPs decaying via different RPV operators is presented — useful to identify potential gaps in the coverage
- Two-fold gap:
  - a relevant experimental search is present, but not properly recasted for applying it to the various RPV scenarios
  - very weak sensitivity to specific final states, which must be targeted in the future

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- The UDD colored sector is well-covered, with possible improvements for
  - $\tilde{u}_R \to db$
  - $\tilde{b}_R \to td$
- We find a gap in the coverage of UDD sleptons, winos, and higgsinos, where in some cases 8 TeV searches still provide the strongest sensitivity
  - 2 OS leptons + jets
  - $2V(W/Z/H)$ + jets

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  - $2V(W/Z/H)$ + jets
- LLE: comprehensive coverage arXiv:2306.07317, *JHEP* 07 (2023) 215
- LQD: future study

Thank you for your attention!

Backup

Systematic study of RPV signatures

UDD : 9 couplings
LLE : 9 couplings
LQD : 27 couplings

$L : e, \mu, \tau$
$j_l : u, d, s, c$
$j : j_l, t, b$

UDD	LLE	LQD
1. $4j$	1. $2L + E_T^{\text{miss}}$	1. $4j$
2. $2j_l + 4j$	2. $3L + E_T^{\text{miss}}$	2. $2b + 2j + E_T^{\text{miss}}$
3. $2j_l + 6j$	3. $4L$	3. $1L + (2-6)j + E_T^{\text{miss}}$
4. $1L + 2j_l + 4j + E_T^{\text{miss}}$	4. $4L + (0-4)j + E_T^{\text{miss}}$	4. $2L + (2-6)j + (E_T^{\text{miss}})$
5. $2L + 2j_l + 4j$	5. $5L + E_T^{\text{miss}}$	5. $3L + 4j + E_T^{\text{miss}}$
	6. $6L + E_T^{\text{miss}}$	6. $4L + 4j$

Benchmark scenarios: UDD

LSP	Coupling	LSP Decay	Label
$\tilde{q}_L$	λ''_{112}	$4j_l$	$D^{uds}_{\tilde{q}}$
$\tilde{u}_R/\tilde{d}_R$	λ''_{112}	$2j_l$	$D^{uds}_{\tilde{u}/\tilde{d}}$
$\tilde{q}_L$	λ''_{113}	$3j_l + 1b$	$D^{udb}_{\tilde{q}}$
$\tilde{u}_R/\tilde{d}_R$	λ''_{113}	$1j_l + 1b$	$D^{udb}_{\tilde{u}/\tilde{d}}$
$\tilde{q}_L/\tilde{u}_R$	λ''_{312}	$3j_l + 1t$	$D^{tds}_{\tilde{q}/\tilde{u}}$
$\tilde{d}_R$	λ''_{312}	$1j_l + 1t$	$D^{tds}_{\tilde{d}}$
$\tilde{q}_L/\tilde{u}_R$	λ''_{313}	$2j_l + 1t + 1b$	$D^{tdb}_{\tilde{q}/\tilde{u}}$
$\tilde{d}_R$	λ''_{313}	$1t + 1b$	$D^{tdb}_{\tilde{d}}$
$\tilde{t}_L/\tilde{t}_R$	λ''_{112}	$3j_l + 1t$	$D^{uds}_{\tilde{t}}$
$\tilde{b}_L/\tilde{b}_R$	λ''_{112}	$3j_l + 1b$	$D^{uds}_{\tilde{b}}$
$\tilde{t}_L/\tilde{t}_R$	λ''_{113}	$2j_l + 1t + 1b$	$D^{udb}_{\tilde{t}}$
$\tilde{b}_L$	λ''_{113}	$2j_l + 2b$	$D^{udb}_{\tilde{b}_L}$
		$2j_l + 2t$	
$\tilde{b}_R$	λ''_{113}	$2j_l$	$D^{udb}_{\tilde{b}_R}$
$\tilde{t}_L$	λ''_{312}	$2j_l + 2t$	$D^{tds}_{\tilde{t}_L}$
		$2j_l + 2b$	
$\tilde{t}_R$	λ''_{312}	$2j_l$	$D^{tds}_{\tilde{t}_R}$
$\tilde{b}_L/\tilde{b}_R$	λ''_{312}	$2j_l + 1t + 1b$	$D^{tds}_{\tilde{b}}$
$\tilde{t}_L$	λ''_{313}	$1j_l + 2t + 1b$	$D^{tdb}_{\tilde{t}_L}$
		$1j_l + 3b$	$D^{tdb}_{\tilde{t}_L}$
$\tilde{t}_R$	λ''_{313}	$1j_l + 1b$	$D^{tdb}_{\tilde{t}_R}$
$\tilde{b}_L$	λ''_{313}	$1j_l + 1t + 2b$	$D^{tdb}_{\tilde{b}_L}$
		$1j_l + 3t$	
$\tilde{b}_R$	λ''_{313}	$1j_l + 1t$	$D^{tdb}_{\tilde{b}_R}$

LSP	Coupling	LSP Decay	Label
$\tilde{B}$	λ''_{112}	$3j_l$	$D^{uds}_{\tilde{B}}$
	λ''_{113}	$2j_l + 1b$	$D^{udb}_{\tilde{B}}$
	λ''_{312}	$2j_l + 1t$	$D^{tds}_{\tilde{B}}$
	λ''_{313}	$1j_l + 1b + 1t$	$D^{tdb}_{\tilde{B}}$

LSP	Coupling	LSP Decay	Label
$\tilde{e}_L/\tilde{\mu}_L/\tilde{\tau}_L/$ $\tilde{\nu}_e/\tilde{\nu}_\mu/\tilde{\nu}_\tau$	λ''_{113}, λ''_{312}	$2j_l + 1t + 1V +$ $(e/\mu/\tau/\text{MET})$ $2j_l + 1b + 1V +$ $(e/\mu/\tau/\text{MET})$	$D^{udb}_{\tilde{e}}$, $D^{tds}_{\tilde{e}}$
	λ''_{313}	$1j_l + 1b + 1t + 1V +$ $(e/\mu/\tau/\text{MET})$ $1j_l + 2b + 1V +$ $(e/\mu/\tau/\text{MET})$ $1j_l + 2t + 1V +$ $(e/\mu/\tau/\text{MET})$	$D^{tdb}_{\tilde{e}}$

The CheckMATE checklist

Kim, Schmeier, Tattersall, Rolbiecki, CPC 196 (2015) 535-562

- Details of isolation requirements and tagging efficiencies

  Objects considered for isolation - track / call objects?
  Minimum p_T of a surrounding object to be used for isolation?
  ΔR of the cone used for isolation?
  Maximum p_T ratio used for isolation?
  } e, μ, γ

  b-tagging efficiency?
  τ-tagging efficiency?

- Definitions of various signal regions

- The corresponding (obs, bkg, bkg_err) values

  To calculate the 95% upper limit on the signal yield, S95

- Description of the analysis procedures with the cuts defining the signal regions

  Electron identification - loose, medium, tight working points?
  Phase space cuts?
  Variables used to define signal regions?

- The trained model file (xml), if neural network based analysis is performed

  cms_2208_09700

The CheckMATE checklist

atlas_2401_16333

☑ Details of isolation requirements and tagging efficiencies

Uses b-tagging efficiency of 77%

☑ Definitions of various signal regions

Seven signal regions, based on number of jets, number of b-tagged jets, minimum transverse momenta of jets, and the event shape variable C

☑ The corresponding (obs,bkg,bkg_err) values

(obs, bkg, bkg_err) values not available, but the 95% upper limit on the signal yield, S95, is available

Directly compared with the signal yields obtained from CheckMATE

☑ Description of the analysis procedures with the cuts defining the signal regions

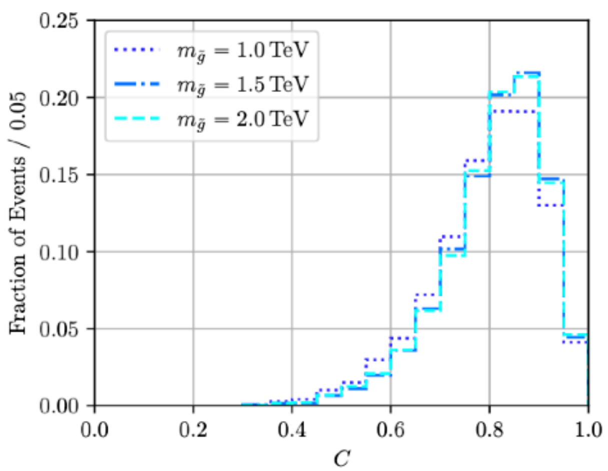
Vetoes electrons (Loose) and muons (Medium)

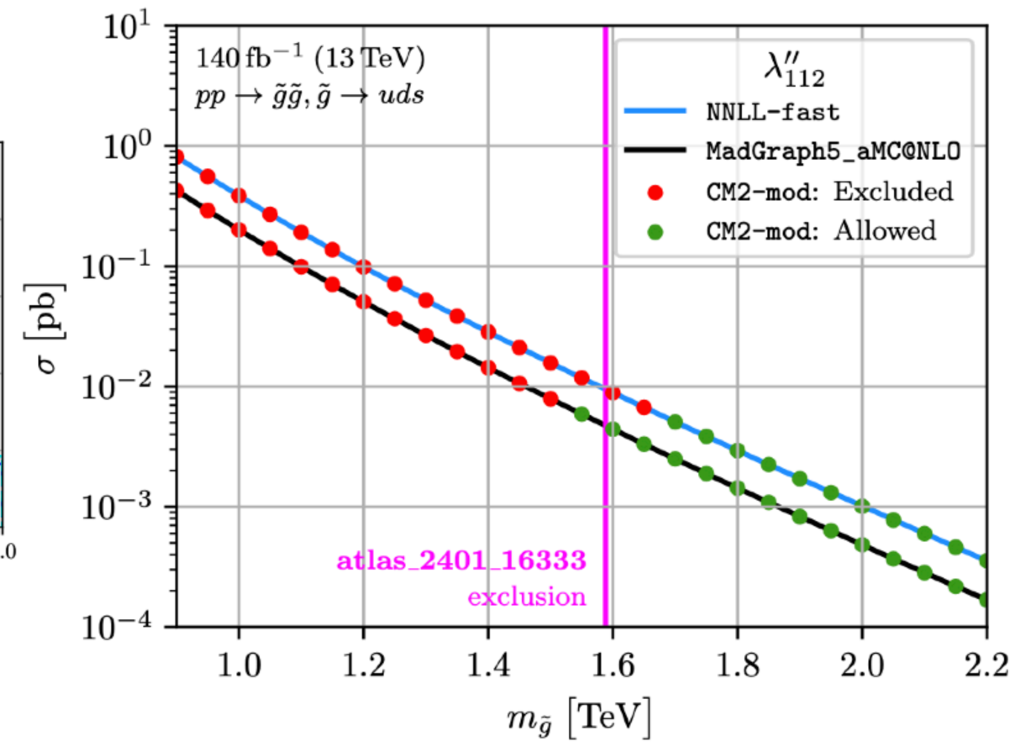
	n_{jets}	$p_{\text{T}}(j)$ [GeV]	C	$n_{b-\text{jets}}$
SR1	≥ 7	≥ 180	≥ 0.90	–
SR2	≥ 7	≥ 220	≥ 0.90	–
SR3	≥ 7	≥ 240	≥ 0.90	–
SR4	≥ 8	≥ 180	≥ 0.85	–
SR5	≥ 8	≥ 210	≥ 0.85	–
SR1bj	≥ 7	≥ 180	≥ 0.85	≥ 2
SR2bj	≥ 8	≥ 180	≥ 0.85	≥ 2

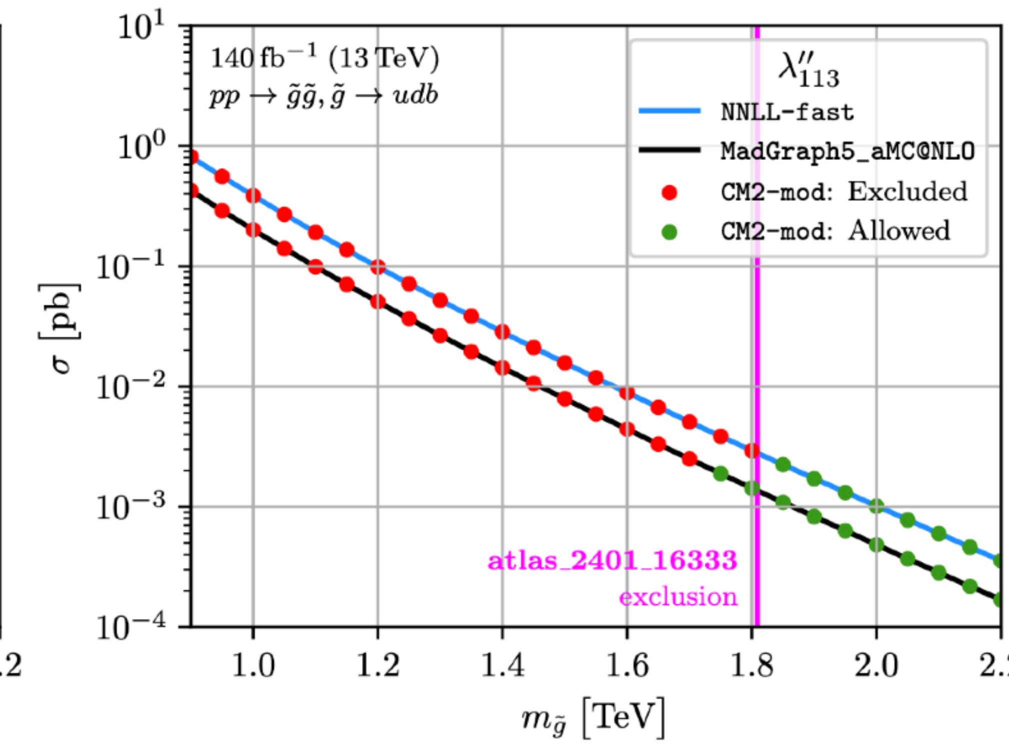
☐ The trained model file (xml), if neural network based analysis is performed

Validation of the searches implemented in CheckMATE

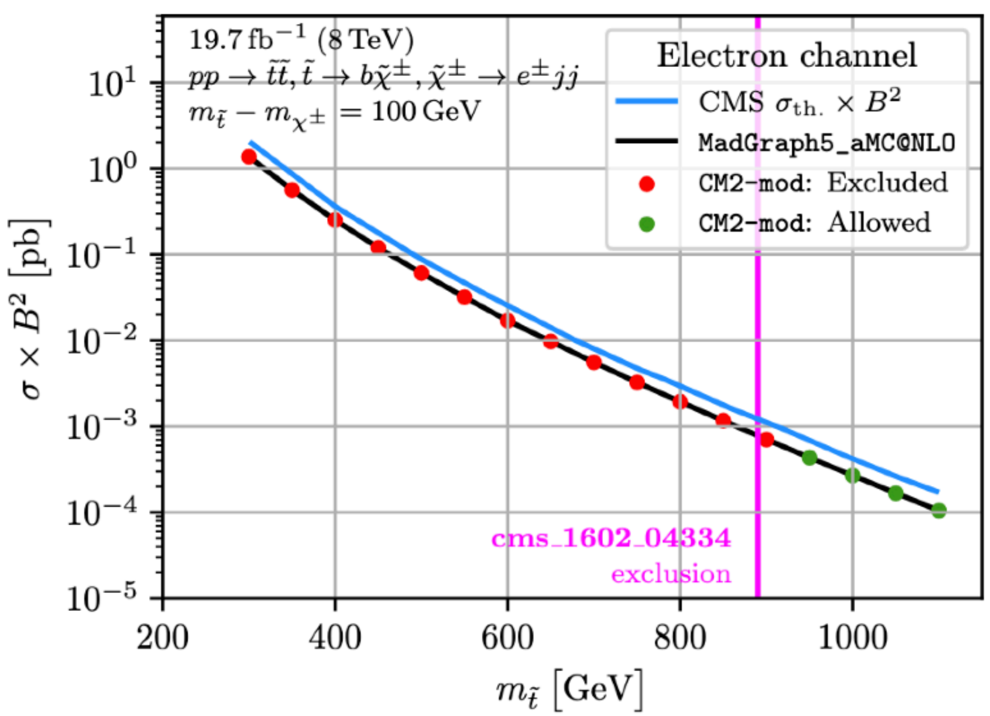
atlas_2401_16333

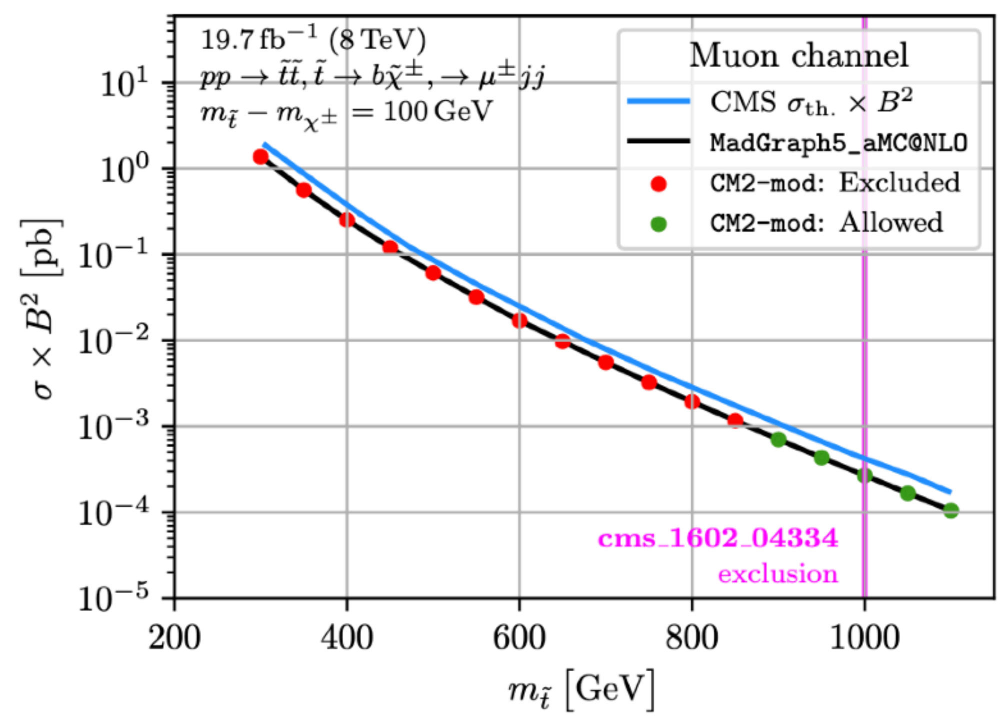






cms_1602_04334





Sensitive analyses for direct production of LSPs: UDD

LSP	Coupling	Sensitive Search	Signal Region	Mass Exclusion (GeV)
$\tilde{q}_L$	112	**atlas_1807_07447** [124]	**7j**	320
$\tilde{q}_L$	113	**atlas_1807_07447** [124]	**2b5j**	360
$\tilde{q}_L/\tilde{u}_R$	312	**atlas_2106_09609** [102]	**SR16/SR14**	640
$\tilde{q}_L/\tilde{u}_R$	313	**atlas_2106_09609** [102]	**SR4**	1000
$\tilde{q}_{L,4}$	112	**atlas_1807_07447** [124]	**9j**	680
$\tilde{u}_R/\tilde{d}_R$	112	**cms_exo_21_010**[4] [99]	-	800
$\tilde{u}_R/\tilde{d}_R$	113	**atlas_1807_07447** [124]	**2b2j**	380
$\tilde{d}_R$	312	**atlas_1807_07447** [124]	**MET1b5j**	440
$\tilde{d}_R$	313	**atlas_1807_07447** [124]	**4b2j**	600
$\tilde{e}$	112/113	**cms_exo_14_014** [125]	**SR_ee_150**	180
$\tilde{H}$	313	**atlas_1807_07447** [124]	**MET2b1j**	150

LSP	Coupling	Sensitive Search	Signal Region	Mass Exclusion (GeV)
$\tilde{b}_L/\tilde{b}_R$	112	**atlas_1807_07447** [124]	**2b6j**	420
$\tilde{b}_L$	113	**atlas_2106_09609** [102]	**SR4**	1040
$\tilde{b}_L/\tilde{b}_R$	312	**atlas_2106_09609** [102]	**SR4**	1000
$\tilde{b}_L$	313	**atlas_2106_09609** [102]	**SR4**	1360
$\tilde{b}_R$	113	**atlas_1807_07447** [124]	**4j**	220
$\tilde{b}_R$	313	**atlas_1706_03731** [126]	**Rpv2L1bS**	480
$\tilde{t}_L/\tilde{t}_R$	112	**atlas_2004_10894** [127]	**Cat2**	600
$\tilde{t}_L/\tilde{t}_R$	113	**atlas_2106_09609** [102]	**SR10**	1000
$\tilde{t}_L$	312	**atlas_2106_09609** [102]	**SR4**	1040
$\tilde{t}_L$	313	**atlas_2106_09609** [102]	**SR10**	1200
$\tilde{t}_R$	312	**atlas_1807_07447** [124]	**MET5j**	280
$\tilde{t}_R$	312	**cms_exo_21_010**[5] [99]	-	800
$\tilde{t}_R$	313	**atlas_1807_07447** [124]	**2b2j**	400

Status of RPV SUSY at the LHC: UDD

Direct production of the LSP:

rest of the spectrum decoupled

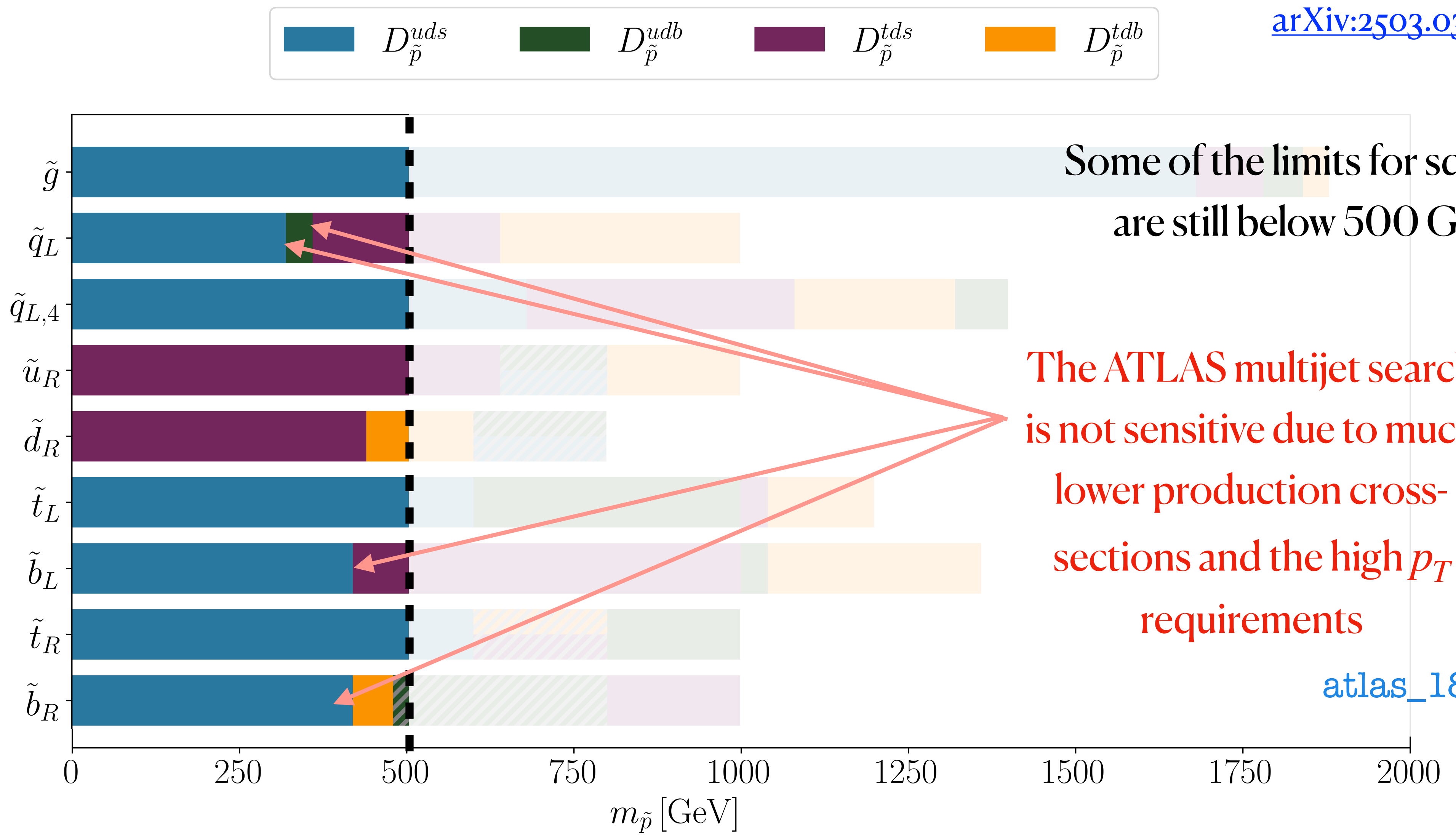
$pp \to \tilde{p}\tilde{p}$

$\tilde{p}$-LSP

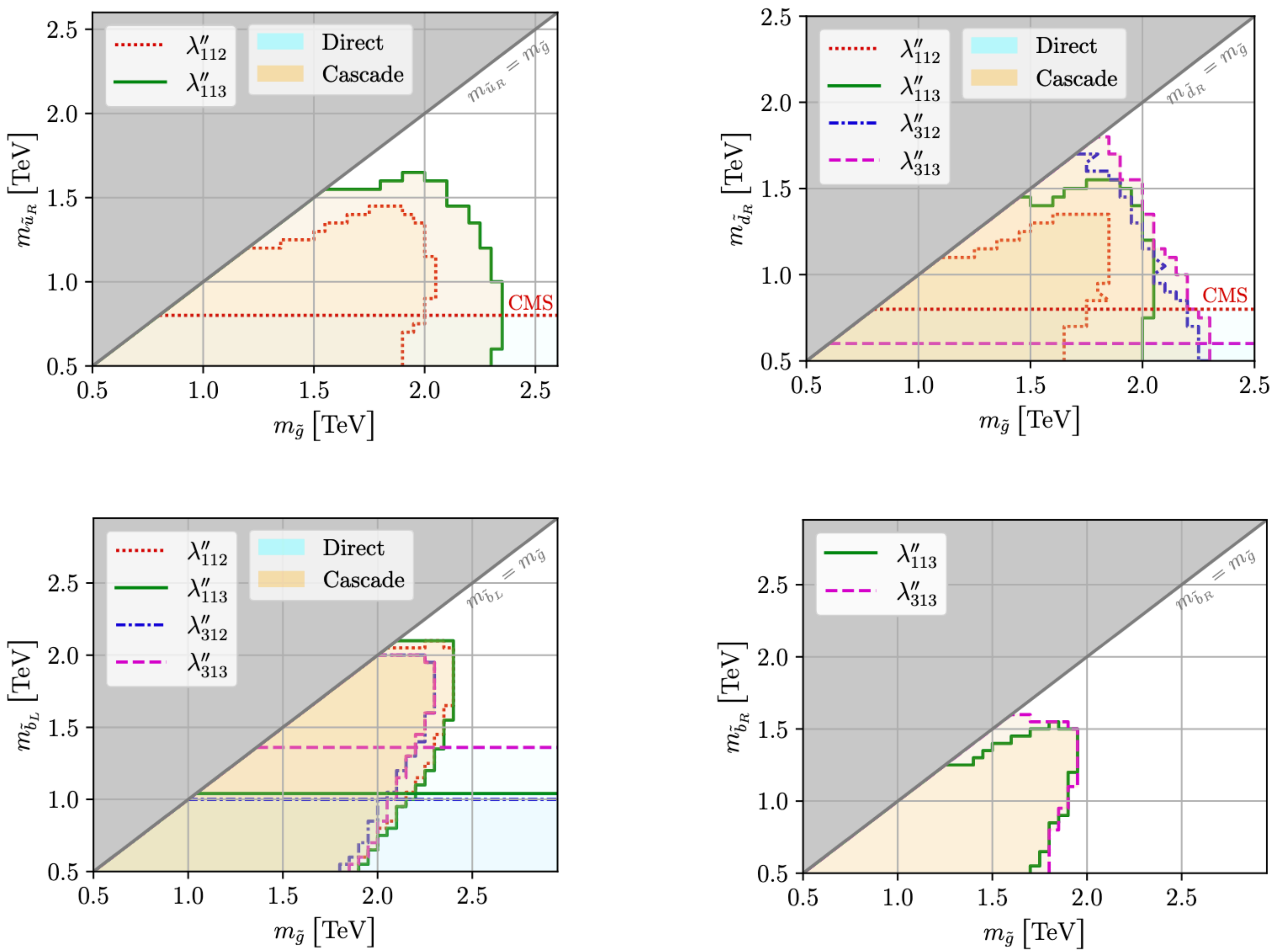
LSP	Coupling	LSP Decay	Label
$\tilde{g}$	λ''_{112}	$3j_\ell$	$D^{uds}_{\tilde{g}}$
	λ''_{113}	$2j_\ell + 1b$	$D^{udb}_{\tilde{g}}$
	λ''_{312}	$2j_\ell + 1t$	$D^{tds}_{\tilde{g}}$
	λ''_{313}	$1j_\ell + 1b + 1t$	$D^{tdb}_{\tilde{g}}$

Other LSP tables in the Backup

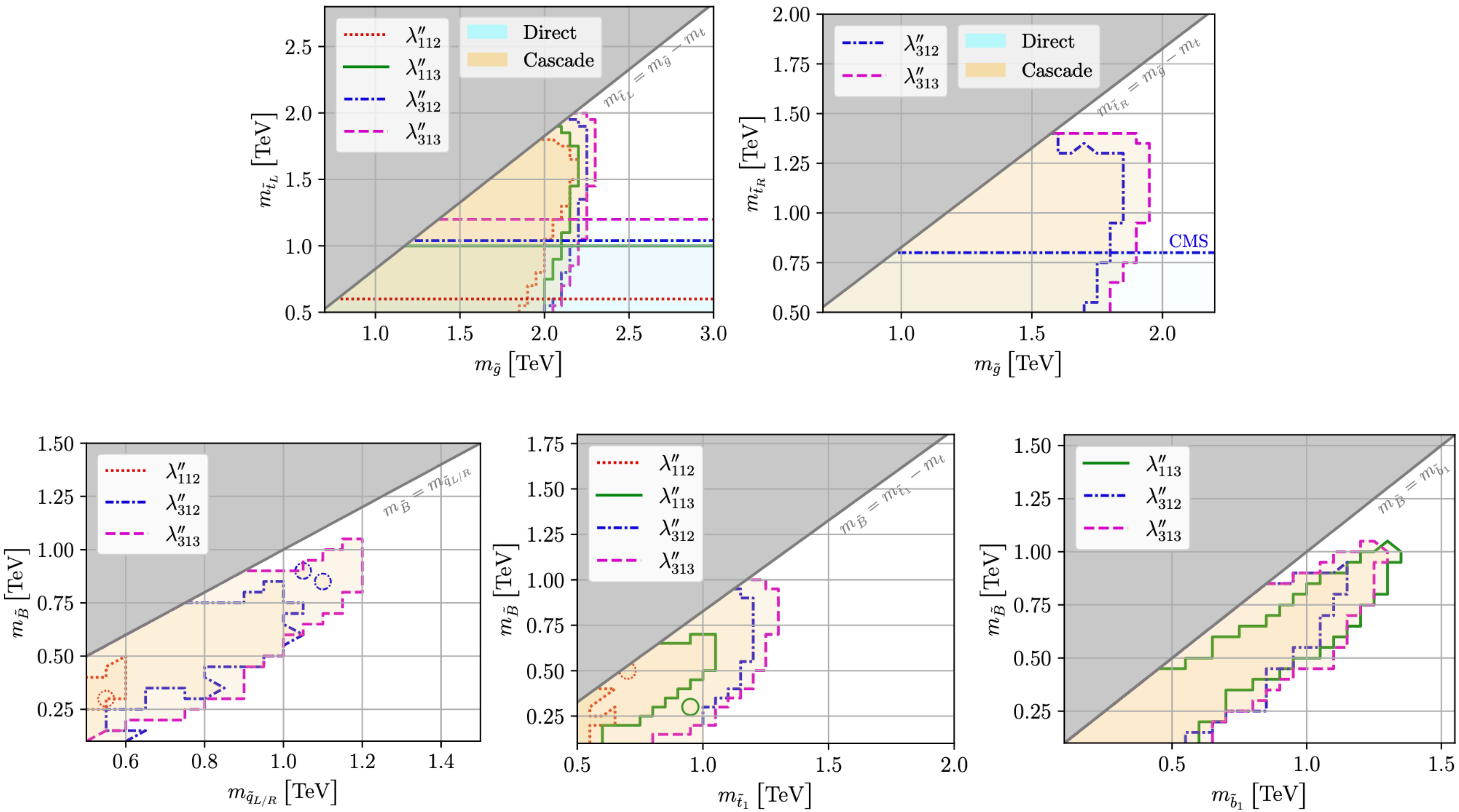
arXiv:2503.03830, *JHEP* (2025)



Cascade results: UDD



Cascade results: UDD



Summary of sensitive searches: UDD

arXiv:2503.03830, *JHEP* (2025)

Search	Energy, Luminosity	Final state	Signal regions
atlas_1706_03731	13 TeV, 36.1 fb^{-1}	SS $ll/\geq 3l$, $\geq$ 3-6j, 0b to $\geq 2b$, E_T^{miss}, m_{eff}	**Rpv2L1bS**
atlas_1807_07447	13 TeV, 3.2 fb^{-1}	Model-independent multiple SRs with $e, \mu, \gamma, j, b, E_T^{\text{miss}}$	**4j, 7j, 9j, 2b2j, 2b5j, 2b6j, 4b2j, MET5j, MET1b5j, MET2b1j**
atlas_1909_08457	13 TeV, 139 fb^{-1}	SS $ll/\geq 3l$, $\geq 6j$, 0b to $\geq 2j$, E_T^{miss}, m_{eff}	**Rpv2L**
atlas_2004_10894	13 TeV, 139 fb^{-1}	2γ(Higgs), $0l/\geq 1l$, $\geq 2j/< 2j$, E_T^{miss}	**Cat2**
atlas_2101_01629	13 TeV, 139 fb^{-1}	$1l$, $\geq$ 2-6j, $0b/\geq 1b$, E_T^{miss}, m_{eff}	**6J_btag_2800**
atlas_2106_09609	13 TeV, 139 fb^{-1}	$1l$/SS ll, $\geq$ 4-15j, 0b to $\geq 4b$	**SR4, SR9, SR10, SR14, SR16**
atlas_2401_16333	13 TeV, 140 fb^{-1}	$\geq$ 7-8j, $0e/\mu$, 0-2b	All SRs
cms_1602_04334	8 TeV, 19.7 fb^{-1}	OS $ee/\mu\mu$, $\geq 5j$, $\geq 1b$	All SRs
cms_2206_09997	13 TeV, 138 fb^{-1}	$\geq 4j$	Pairs of dijet resonances

Summary of sensitive searches: UDD

arXiv:2503.03830, *JHEP* (2025)

Search	Energy, Luminosity	Final state	Signal regions
atlas_1706_03731	13 TeV, 36.1 fb^{-1}	SS $ll/\geq 3l$, $\geq$ 3-6j, 0b to $\geq 2b$, E_T^{miss}, m_{eff}	Rpv2L1bS
atlas_1807_07447	13 TeV, 3.2 fb^{-1}	Model-independent multiple SRs with $e, \mu, \gamma, j, b, E_T^{\mathrm{miss}}$	**4j, 7j, 9j, 2b2j, 2b5j, 2b6j, 4b2j, MET5j, MET1b5j, MET2b1j**
atlas_1909_08457	13 TeV, 139 fb^{-1}	SS $ll/\geq 3l$, $\geq 6j$, 0b to $\geq 2j$, E_T^{miss}, m_{eff}	Rpv2L
atlas_2004_10894	13 TeV, 139 fb^{-1}	2γ(Higgs), $0l/\geq 1l$, $\geq 2j/\leq 3j$, E_T^{miss}	Cat2
atlas_2101_01629	13 TeV, 139 fb^{-1}	$1l$, $\geq$ 2-6j, 0$b/\geq 1b$, E_T^{miss}, m_{eff}	6J_btag_2800
atlas_2106_09609	13 TeV, 139 fb^{-1}	$1l$/SS ll, $\geq$ 4-15j, 0b to $\geq 4b$	SR4, SR9, SR10, SR14, SR16
atlas_2401_16333	13 TeV, 140 fb^{-1}	$\geq$ 7-8j, 0e/μ, 0-2b	All SRs
cms_1602_04334	8 TeV, 19.7 fb^{-1}	OS $ee/\mu\mu$, $\geq 5j$, $\geq 1b$	All SRs
cms_2206_09997	13 TeV, 138 fb^{-1}	$\geq 4j$	Pairs of dijet resonances

This kind of search is sensitive over a large range of RPV final states