Pheno 2019

# Constraining New Physics

## Using Drell-Yan Processes at the LHC

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UNIVERSITY OF NOTRE DAME

SB, A. Delgado, C. Kolda, M. Quiros, (PRD) [ArXiv:1810.11588]

SB, A. Delgado, C. Kolda, M. Quiros [in prep]

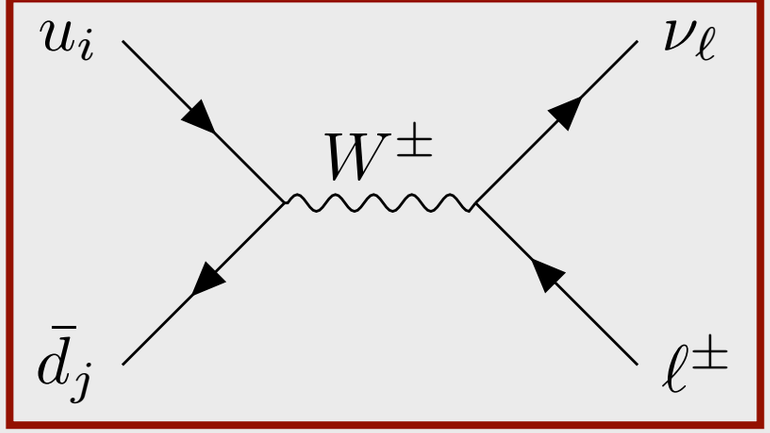
Related Work: SB, R. Capdevilla, A. Delgado, C. Kolda, A. Martin, N. Raj, (PRD) [arXiv:1806.02370]

# Drell-Yan Processes

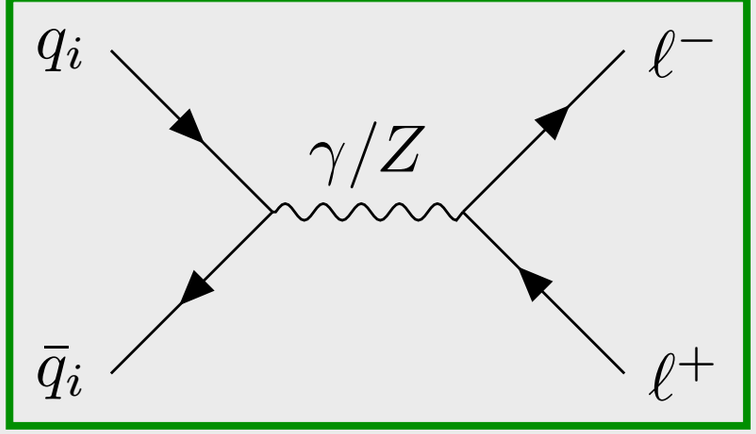
- Two categories of Drell-Yan processes:
  1. **Monolepton** $(q\bar{q}' \to \ell^{\pm}\nu)$
  2. **Dilepton** $(q\bar{q} \to \ell^{+}\ell^{-})$

**SM Tree Level**

**Monolepton**




**Dilepton**




**Ignoring negligible contribution from Higgs**

$\ell = e, \mu, \tau$

- Importance of Drell-Yan processes:
  1. Well-understood backgrounds
  2. Large statistics

# *R*-Parity Violating Supersymmetry

- Supersymmetry (SUSY) offers a natural extension to the SM.
- We have yet to find signatures of SUSY in the *expected* parameter space.
- Currents mass limits for sparticles range from 0.5 - 2 TeV.
- This has led physicists to consider modified versions to SUSY, including R-parity-violating (RPV) SUSY.
- R-parity is a multiplicative quantum number defined by,

$$R_P = (-1)^{3(B-L)+2S}$$

All SM particles are $R_P$ even,
New physics partners are $R_P$ odd.

- RPV Superpotential, Drell-Yan processes are sensitive to:

$$\mathscr{W}_{\not{R}_P} \supset \lambda'_{ijk} L_i Q_j D^c_k$$

- 27 different $\lambda'_{ijk}$, one for each value of *i, j, k* ∈ *{1,2,3}.*
- We examine Drell-Yan constraints on these couplings by assuming only one $\lambda'_{ijk}$ to be non-zero at a time.

- The Lagrangian for the λ’ term:

$$\mathscr{L} = \lambda'_{ijk}\Big[\Big(\bar{d}^c_j P_L \nu_i - \bar{u}^c_j P_L \ell_i\Big)\tilde{d}^c_k + \Big(\bar{d}_k P_L \nu_i \tilde{d}_j - \bar{d}_k P_L \ell_i \tilde{u}_j\Big) + \Big(\bar{d}_k P_L d_j \tilde{\nu}_i + \bar{d}_k P_L u_j \tilde{\ell}_i\Big)\Big]$$

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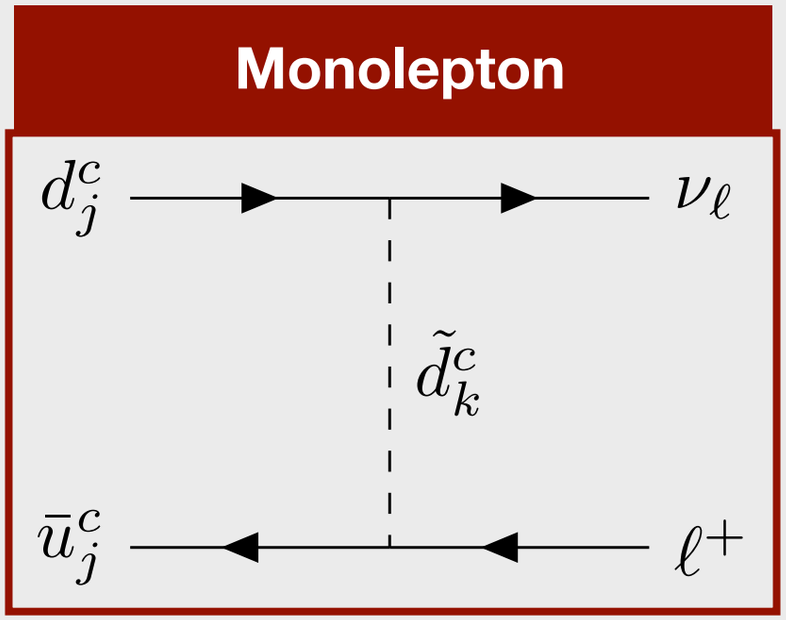

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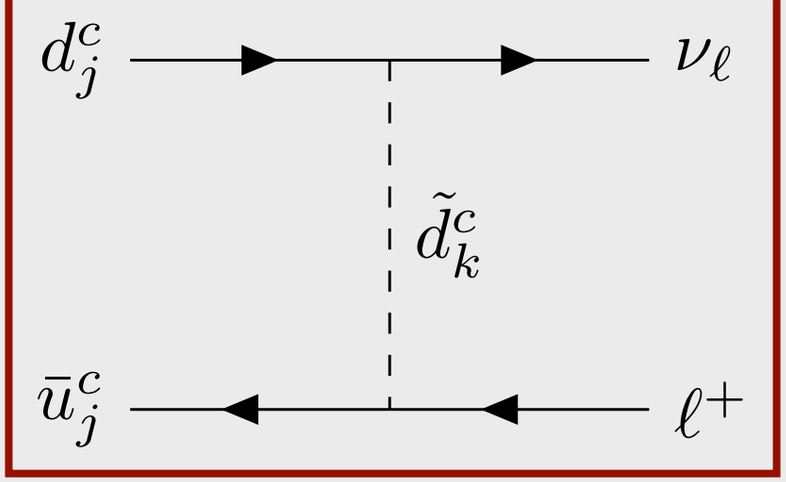


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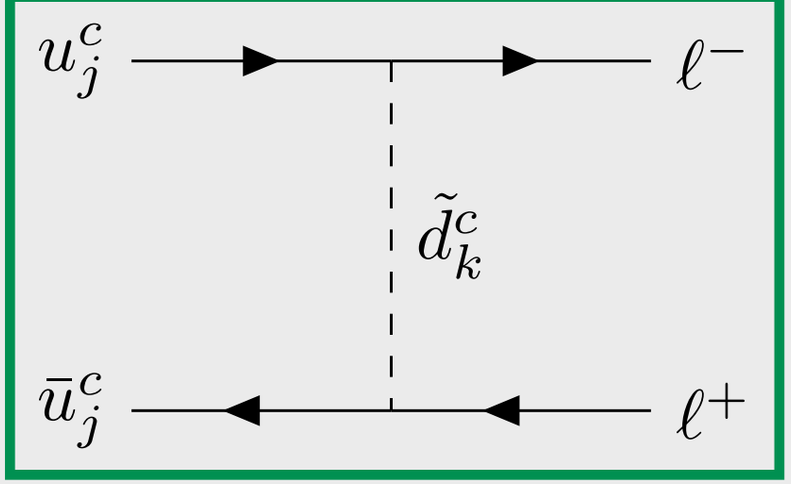

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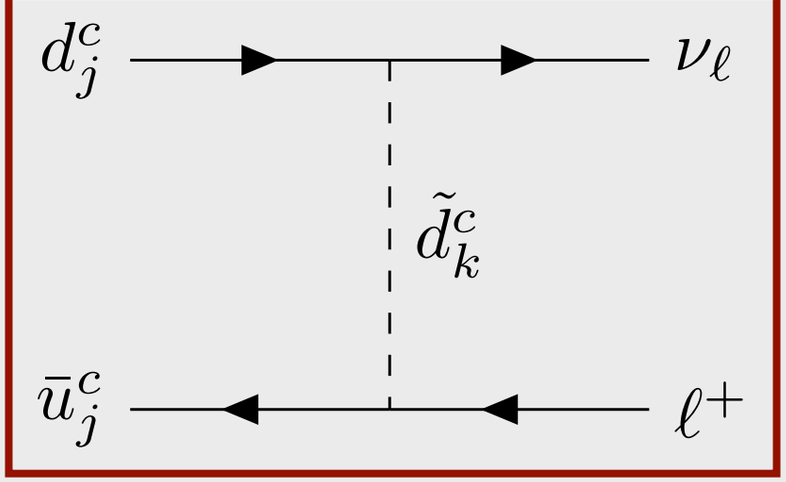


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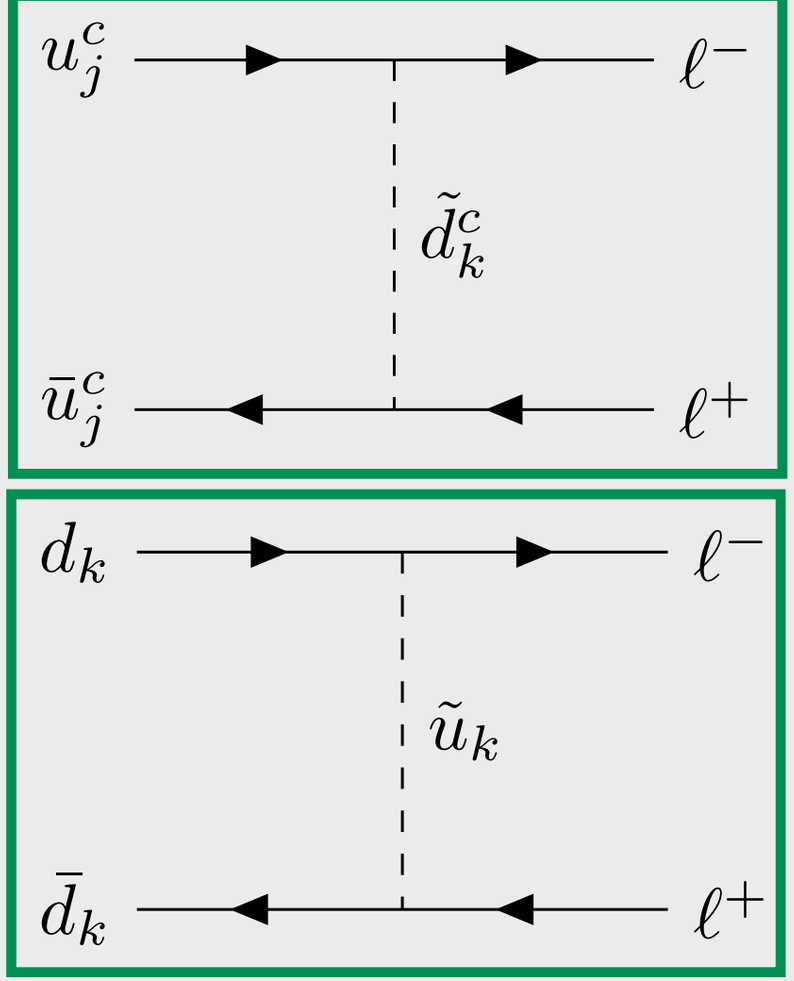

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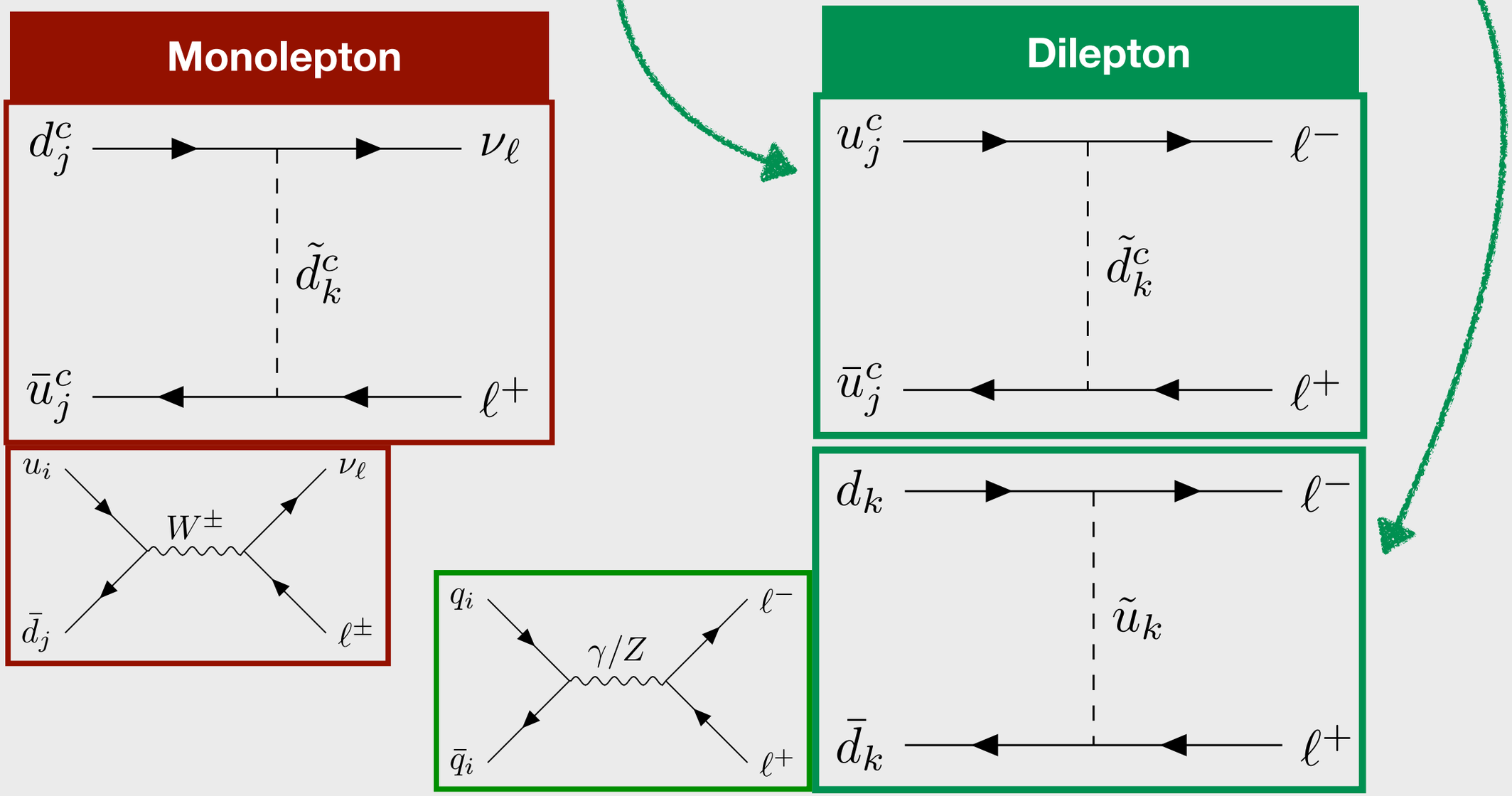



- All these contributions interfere destructively with the corresponding SM amplitudes.

# Drell-Yan Data

- The Drell-Yan data required for this kind of analysis are provided by both ATLAS and CMS collaborations.

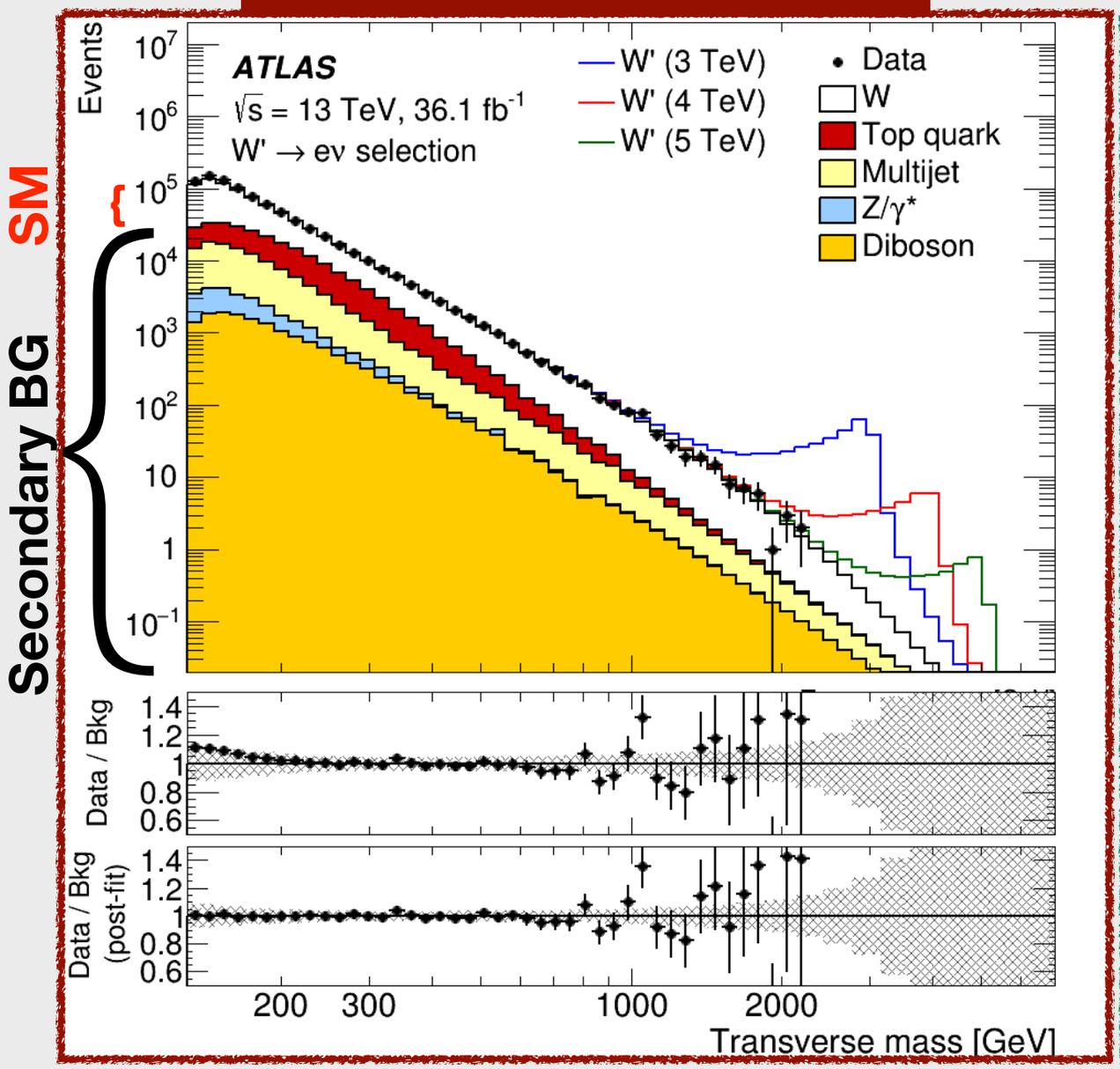
- For final state **electrons** or **muons**: Both ATLAS and CMS provide both mono- and di-lepton data at $\sqrt{s} = 13\ \text{TeV}$ with $36\ \text{fb}^{-1}$ of integrated luminosity.
  **ATLAS**: [arXiv:1706.04786], [arXiv:1707.02424] **CMS**: [arXiv:1803.11133], [arXiv:1803.06292]

- For final state **taus**, only monolepton data is available. This data is provided by both ATLAS and CMS at $\sqrt{s} = 13\ \text{TeV}$ data with $36\ \text{fb}^{-1}$ of integrated luminosity.
  **ATLAS**: [arXiv:1801.06992] **CMS**: [arXiv:1807.11421]

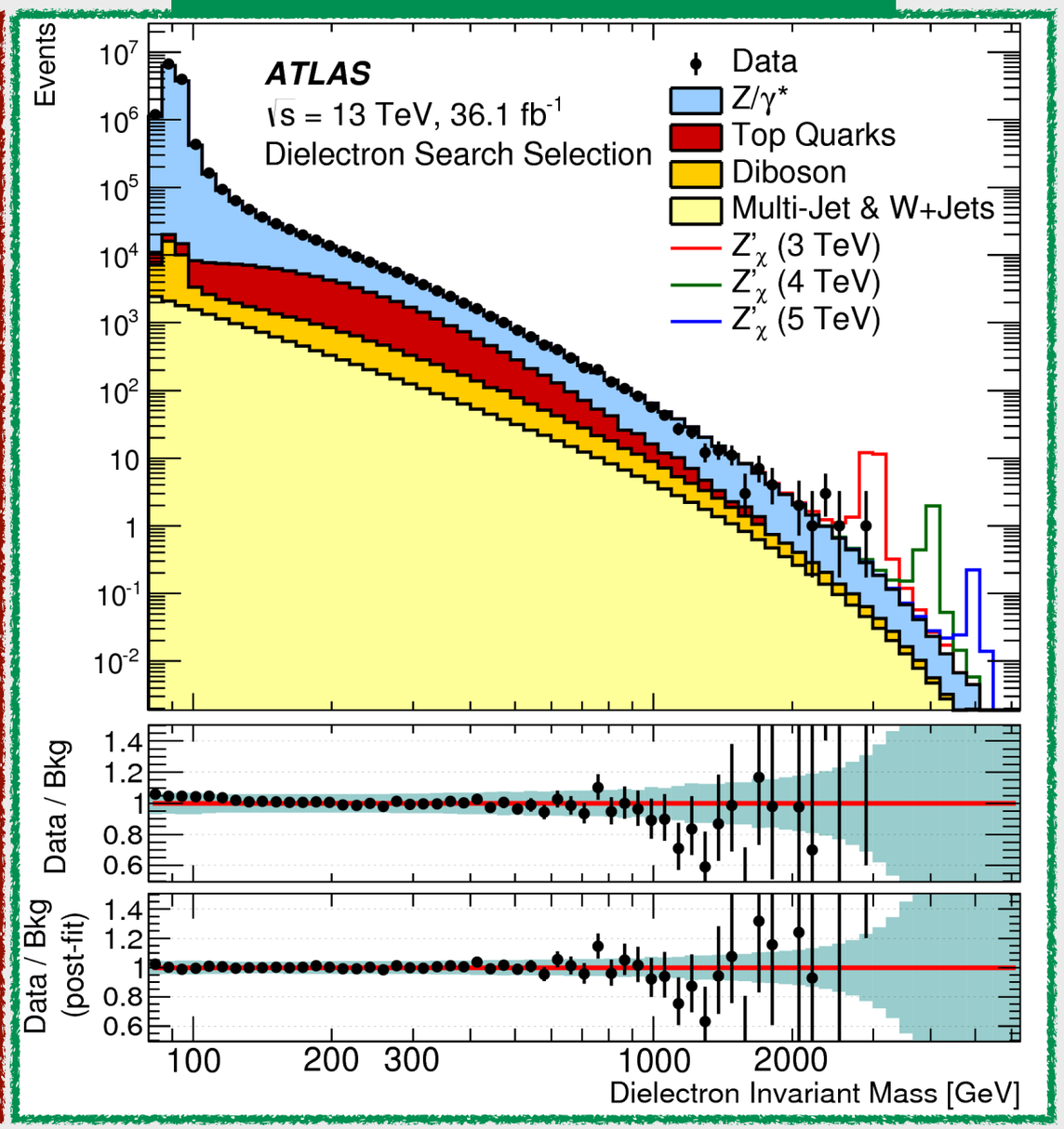
- In this work, we only use the ATLAS data to constrain R-parity violating supersymmetry.

# Data

## Monolepton: $pp \to e\nu$




## Dilepton: $pp \to e^+e^-$




Monolepton transverse mass:

$$M_T \equiv [2p_T^{\ell} \not{E}_T (1 - \cos\Delta\phi)]^{1/2}$$

transverse momentum of the charged lepton

missing transverse energy

Data available at hepdata.net

NOTE: Correlation matrices are NOT provided.

# Analysis

## Monolepton

- Start by analytically calculating the *transverse mass* distribution for both the SM and RPV (for one non-zero $\lambda'_{ijk}$): $\frac{d\sigma(pp \to \ell\nu)}{dM_T}$ ***Transverse Mass***
- Bin data and scale the number of events in each bin so that the calculated SM events match the SM background from ATLAS. This accounts for the higher order corrections and lepton reconstruction efficiency.
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- Add secondary background (from ATLAS data) to the RPV and SM scaled events to obtain the net signal and backgrounds.
- Compare with the no. of observed events to obtain constraints on RPV using a chi-square test.
- We obtain bounds at 95% C.L, which is defined at $\Delta\chi^2 \equiv \chi^2_{\text{RPV}} - \chi^2_{\text{SM}} = 5.99$

$$\chi^2_{\text{theory}} = \sum_i^{\text{bins}} \frac{(N_{\text{theory}_i} - N_{\text{data}_i})^2}{N_{\text{data}_i} + \delta^2_{\text{sys}}}$$

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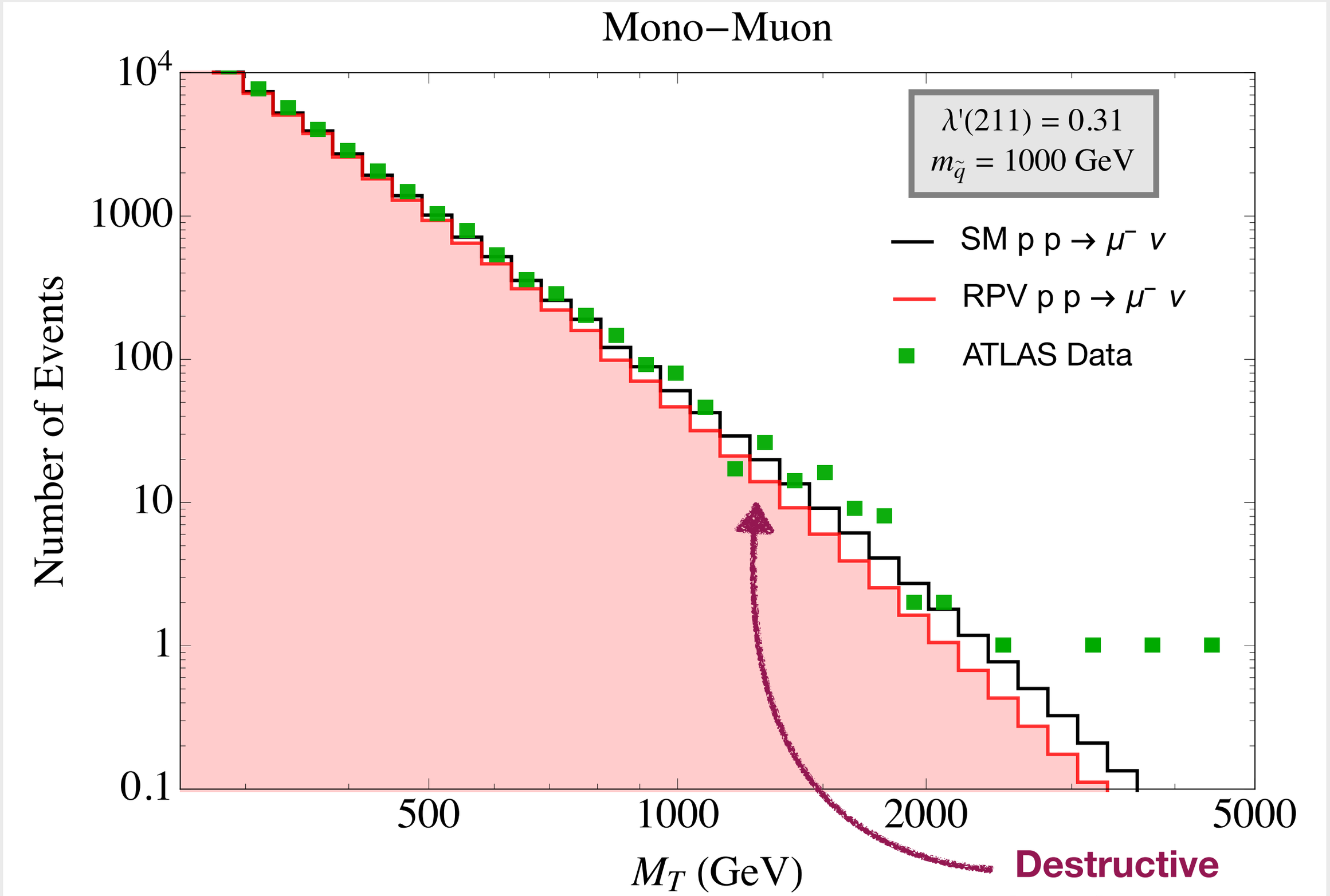
## Dilepton

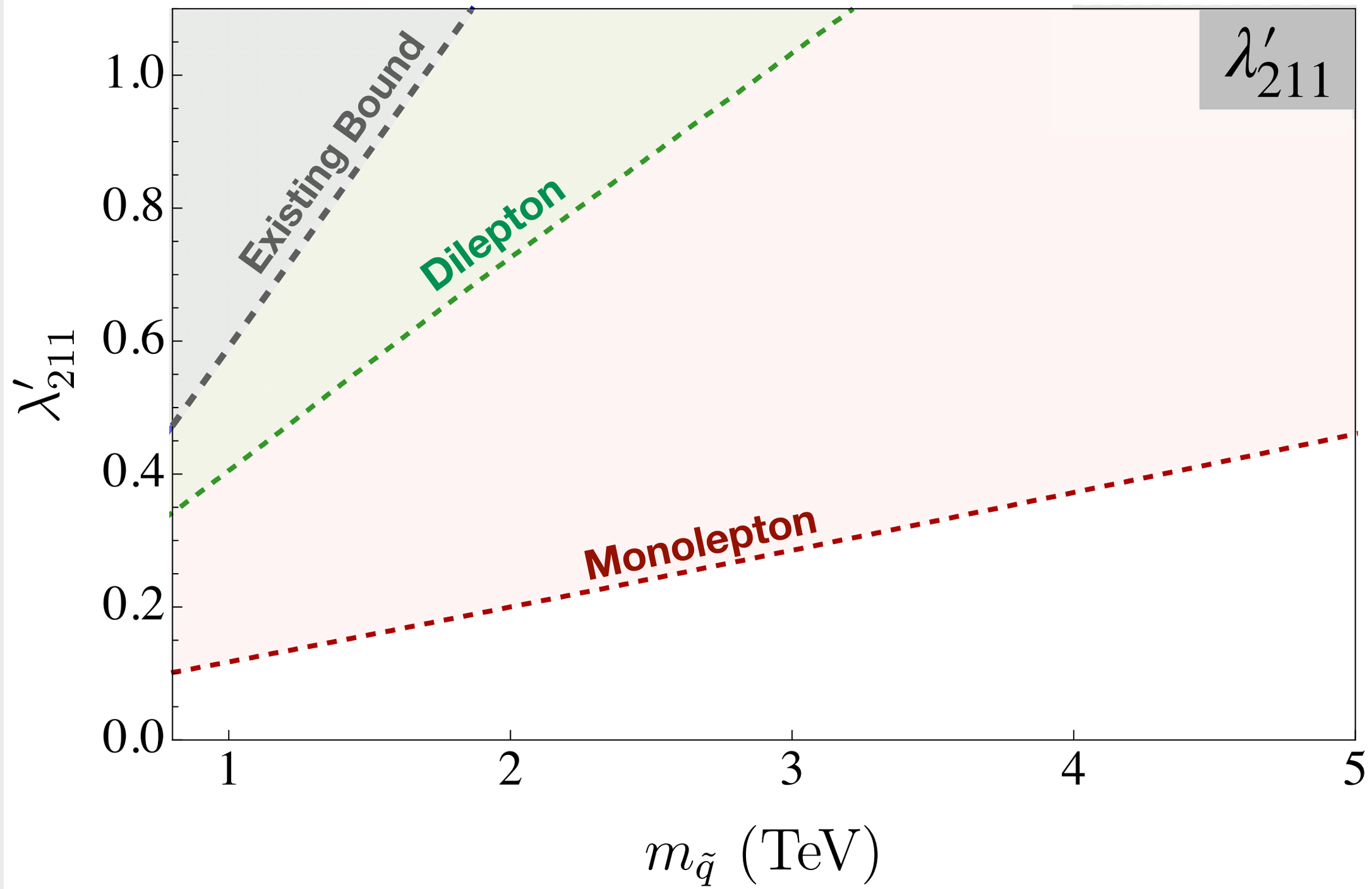
- Same procedure as above after replacing transverse mass by **invariant mass.**

# Example: Monolepton Distribution



# Results

$\lambda'_{ijk} L_i Q_j D^c_k$



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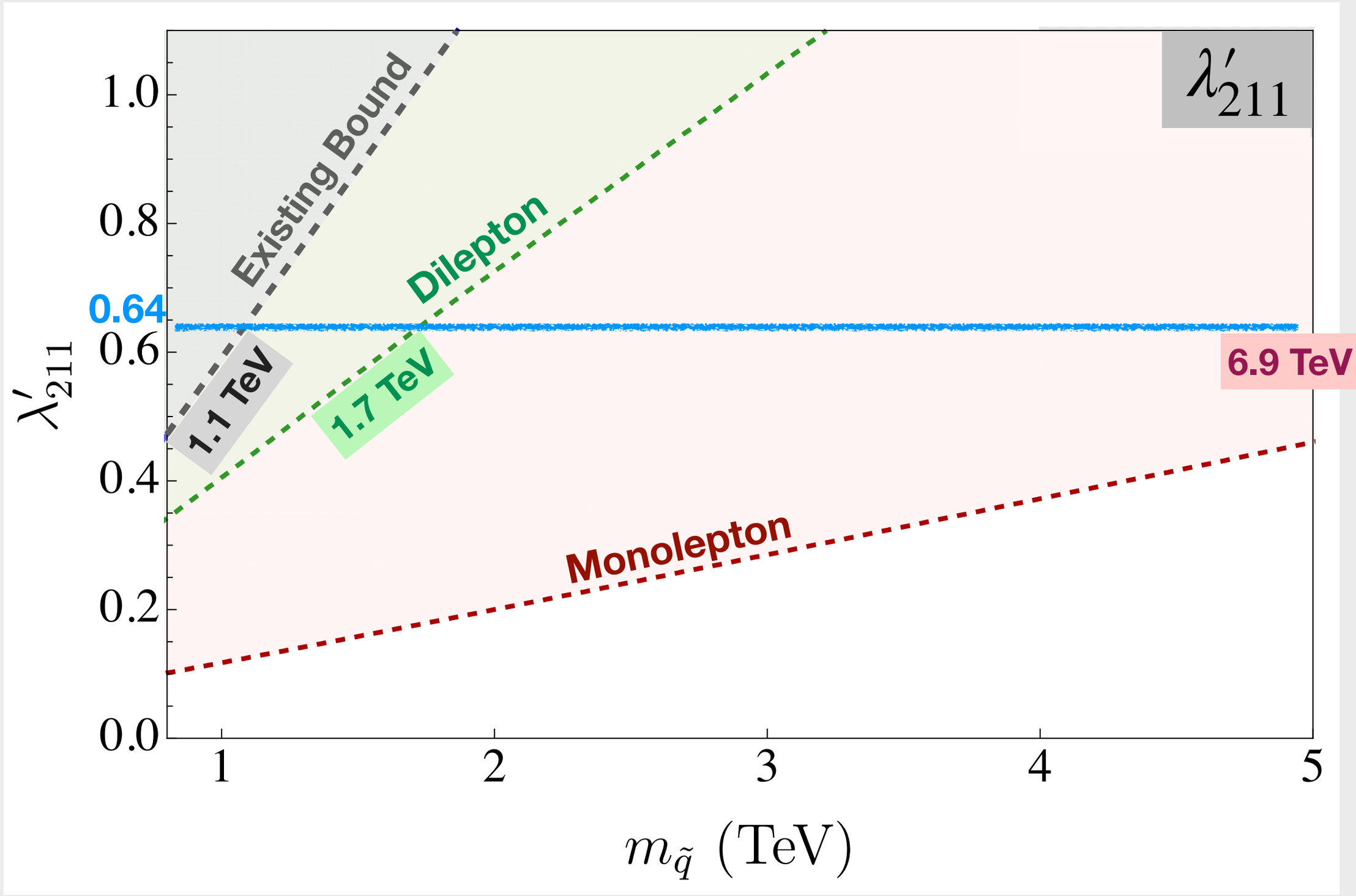

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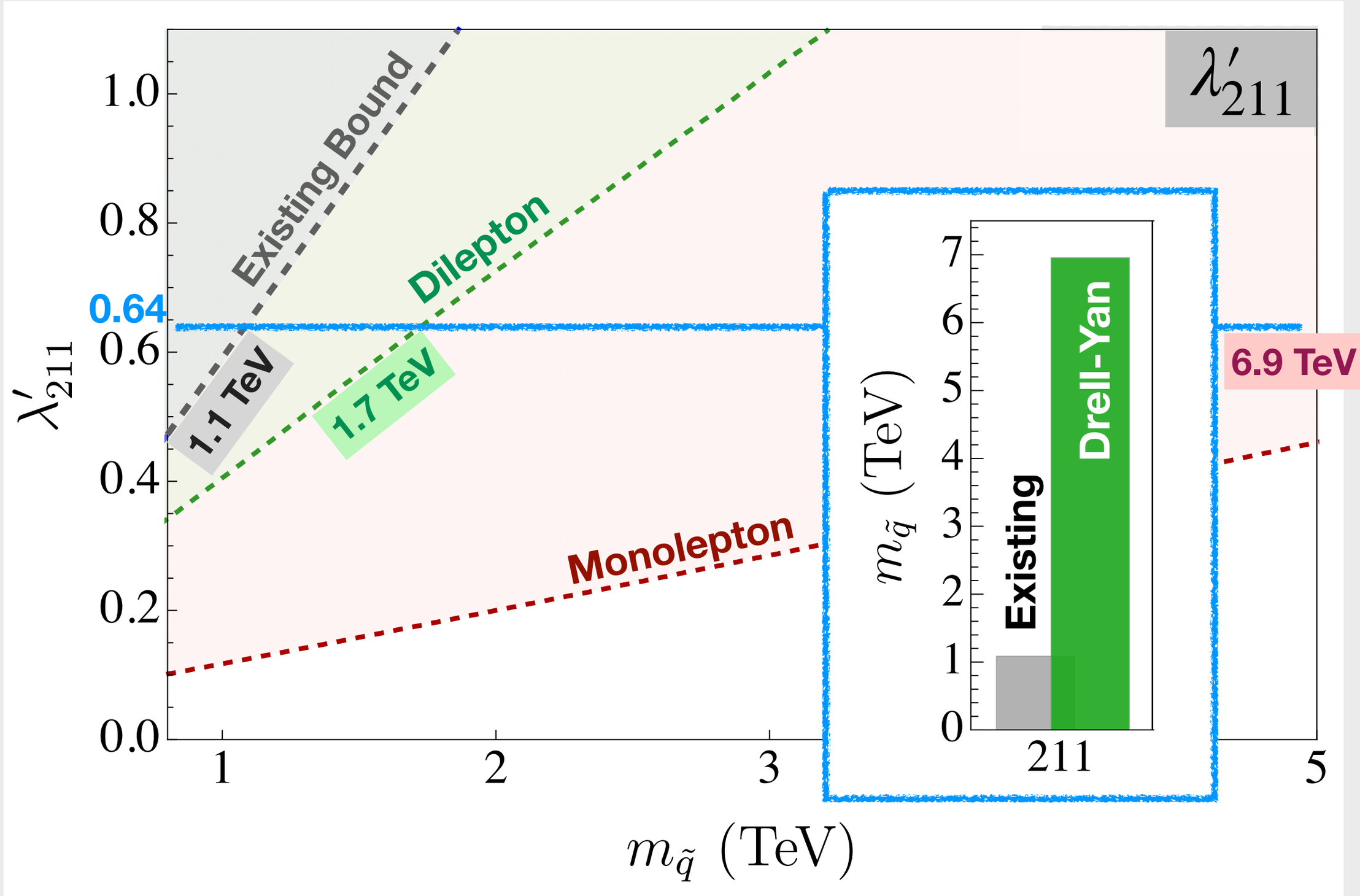
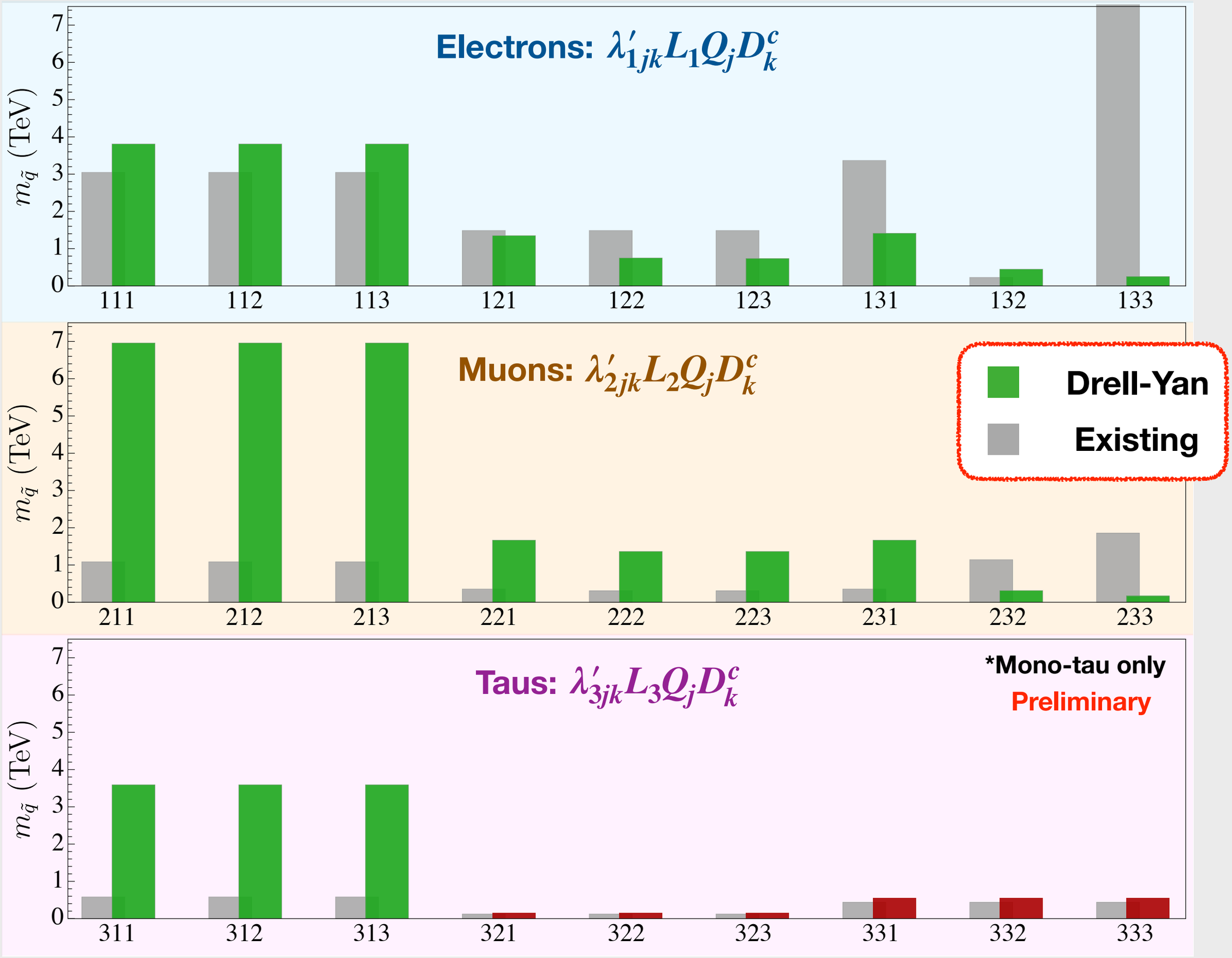


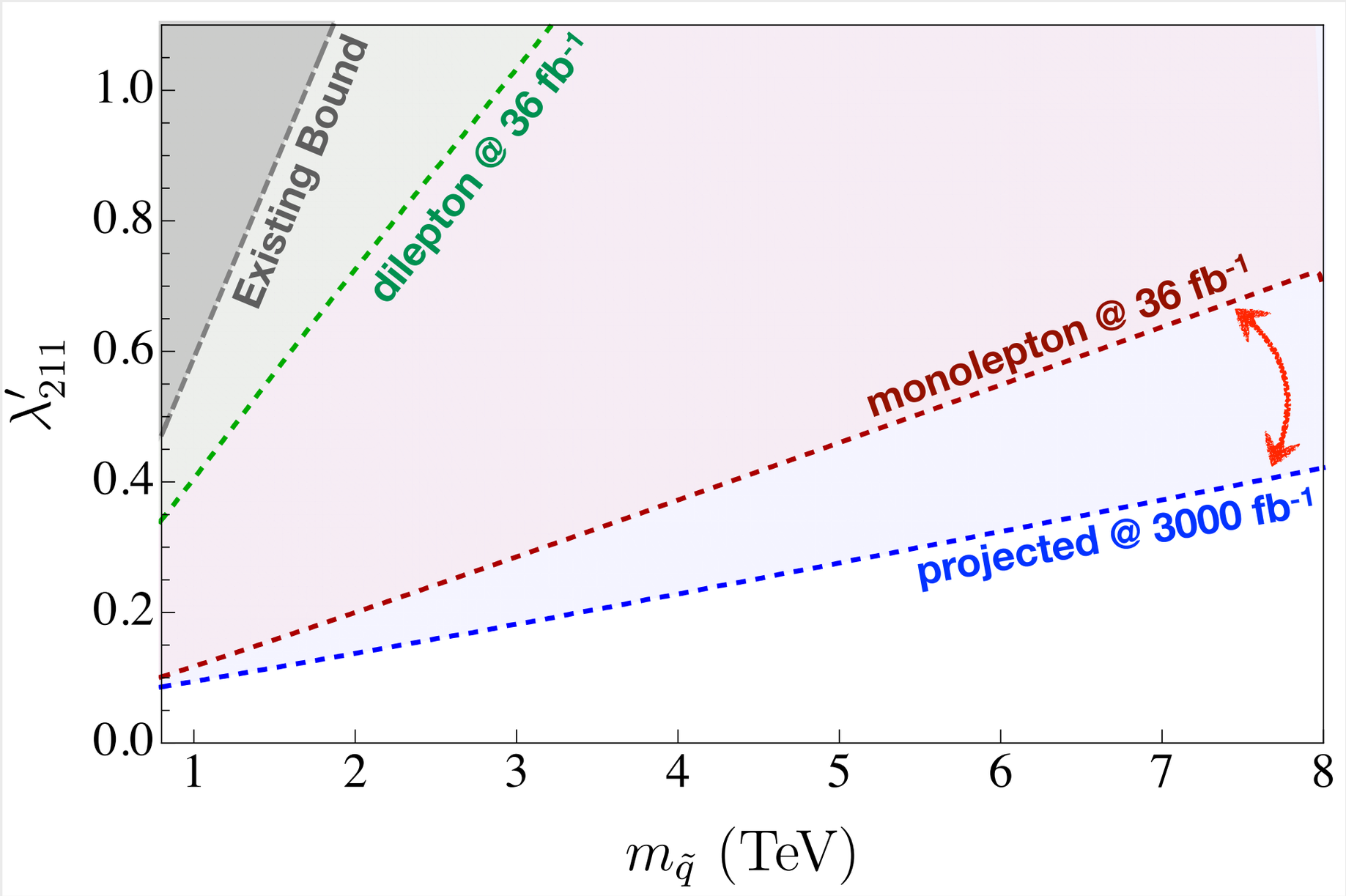
# Results continued…

$\lambda' = 0.64$



# Future

- These bounds become stronger with more integrated luminosity.
- We make a simple projection of the expected limits at the High Luminosity LHC with 3 $ab^{-1}$ of integrated luminosity.
- In this analysis, we combine the mono- and di-lepton contributions, and assume data matches the SM background.



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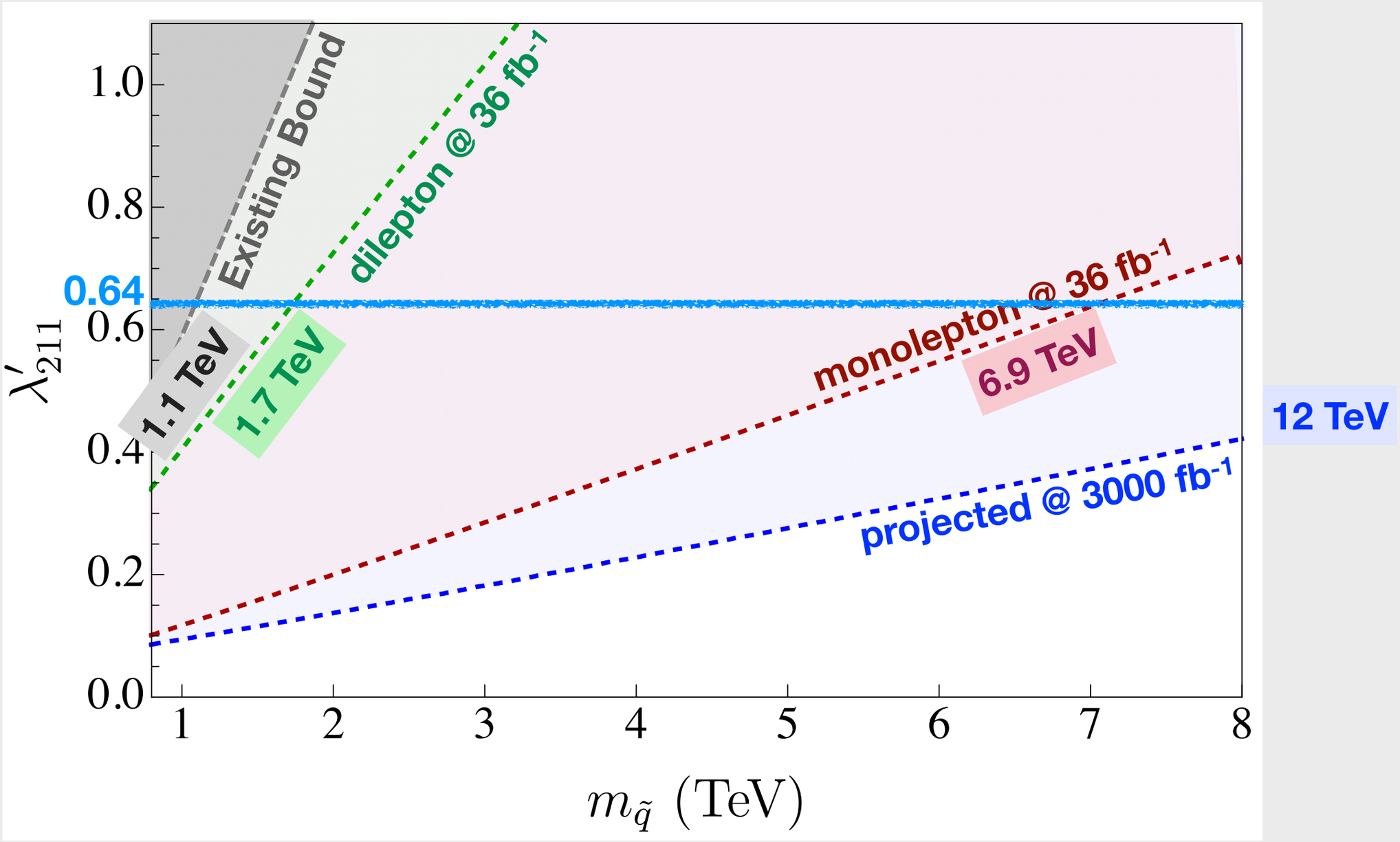

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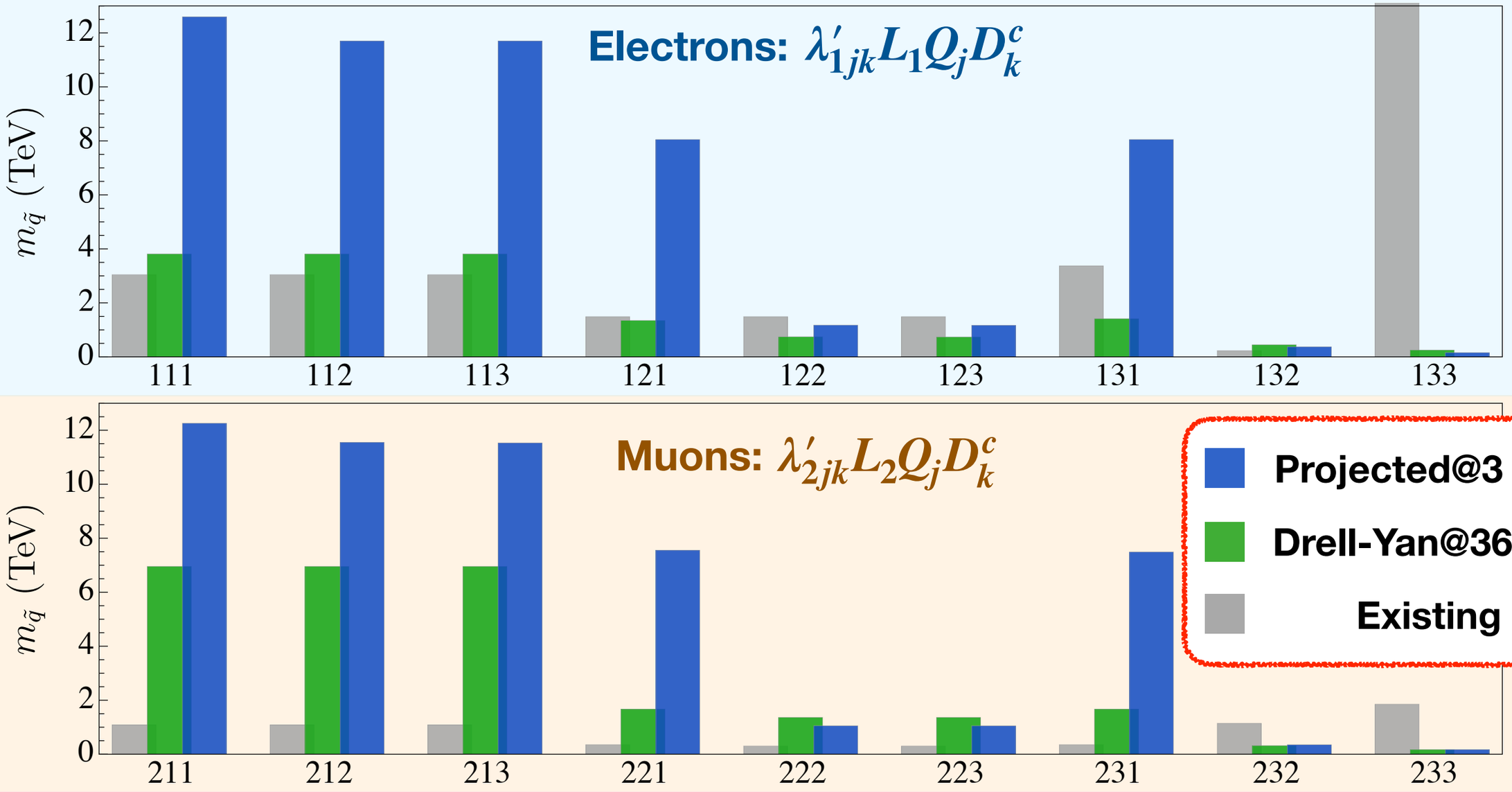


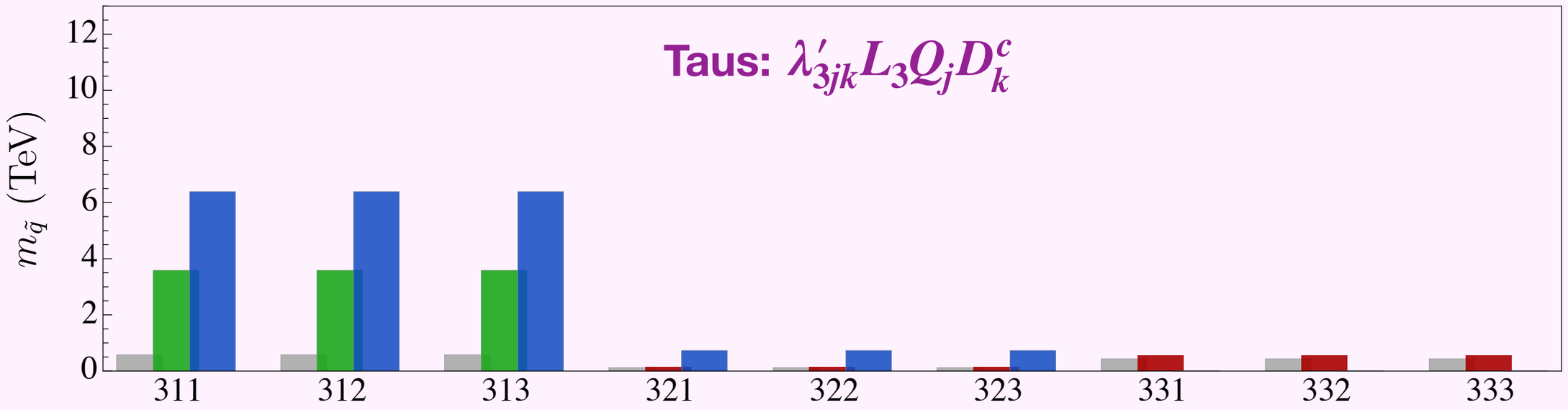




Projected@3 ab$^{-1}$

Drell-Yan@36 fb$^{-1}$

Existing



# Conclusions

- Drell-Yan processes at the LHC can strongly constrain the parameter space of LQd couplings of RPV SUSY.
- This analysis can be used to derive bounds on most of the LQd couplings that are stronger than the existing bounds.
- Because these constraints are all statistics limited, they will improve with additional luminosity.
- The 3000 $fb^{-1}$ bounds on squark masses for $\lambda'=1$ are in the 20 TeV range.
- The same analysis can be used for any model that leads to leptoquark-like couplings. [arXiv:1806.02370]
- We therefore strongly encourage the LHC collaborations to reanalyze their DY data in the context of RPV supersymmetry in order to obtain the best possible bounds.

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**Thanks!**

# BACK UP

# Constraints - Muons

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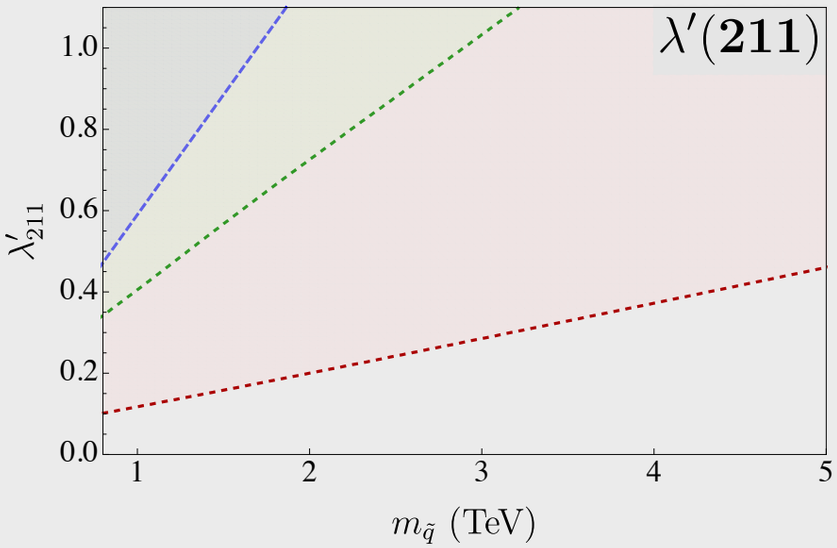
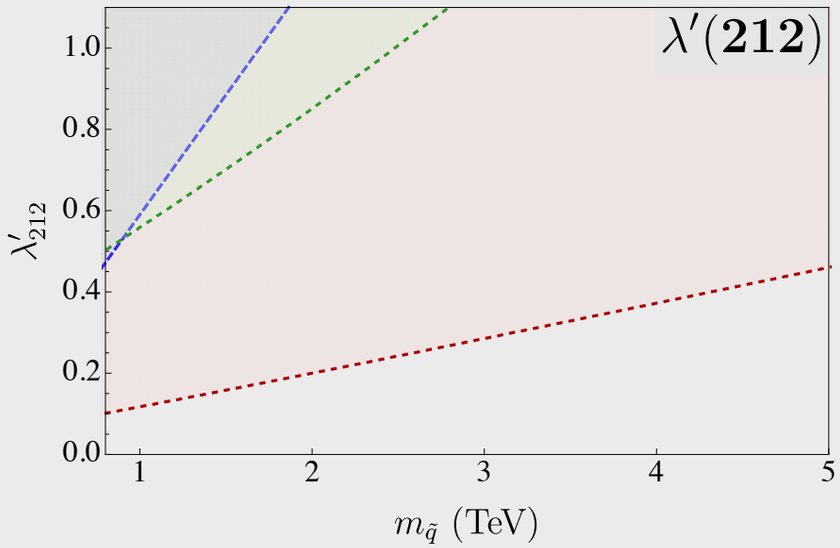
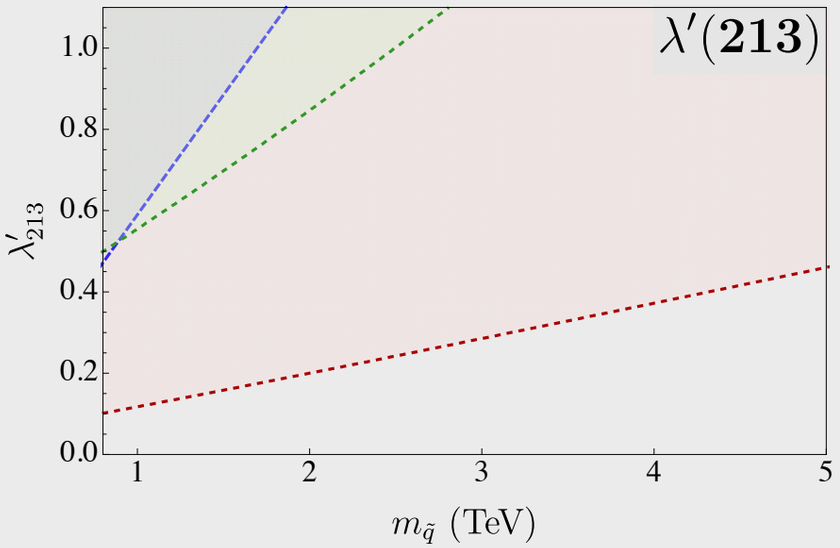
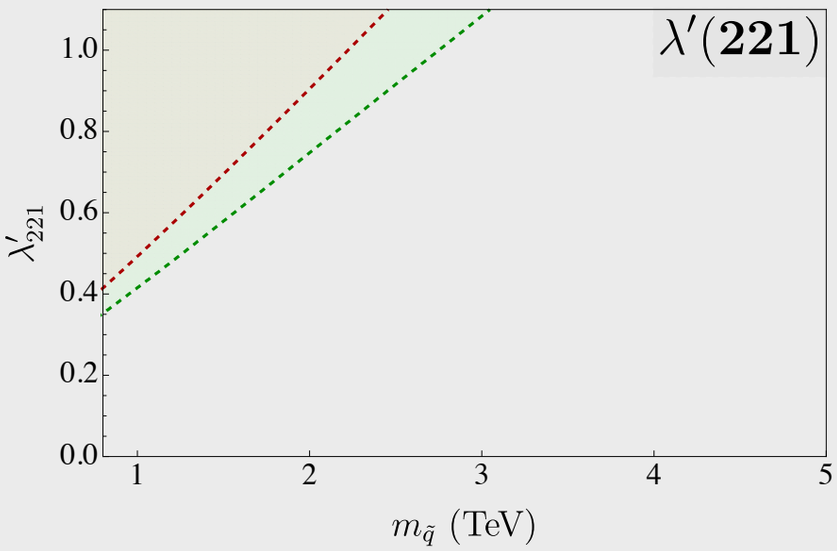
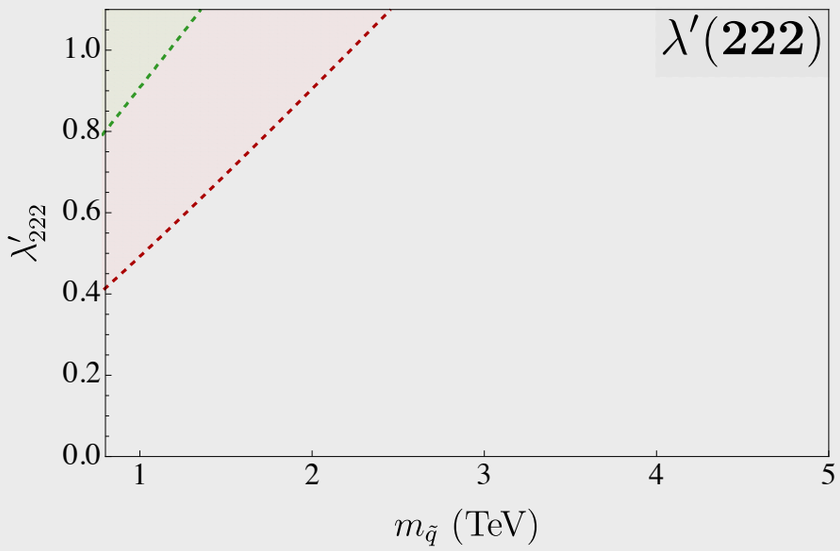
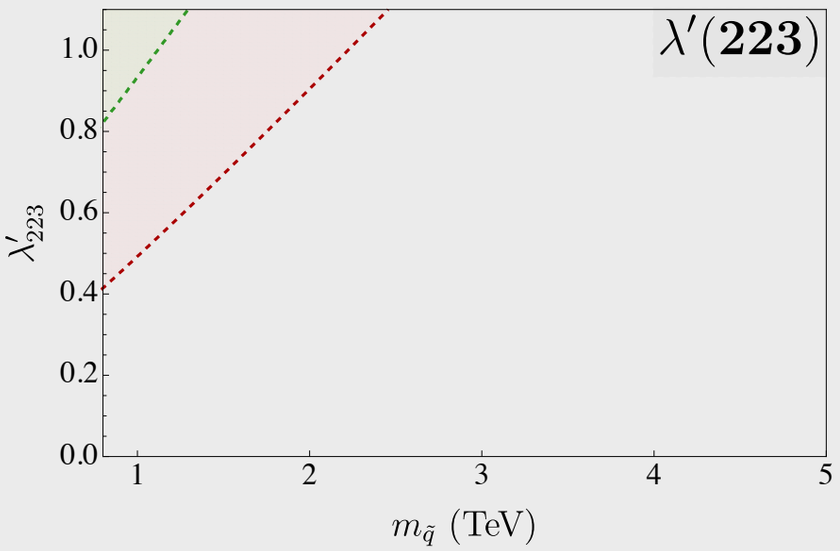


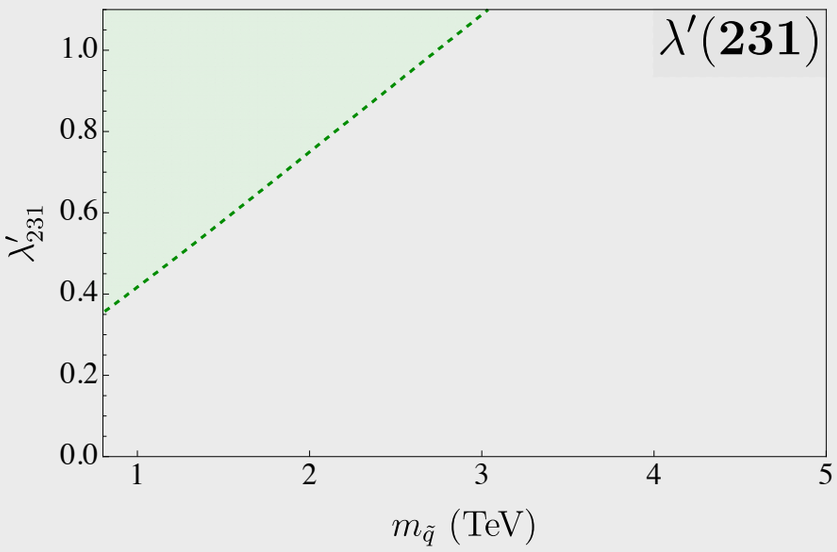



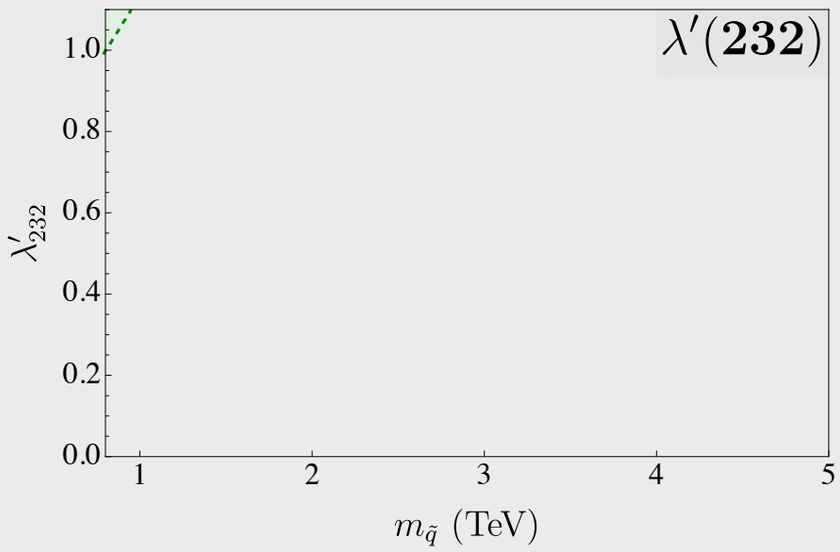



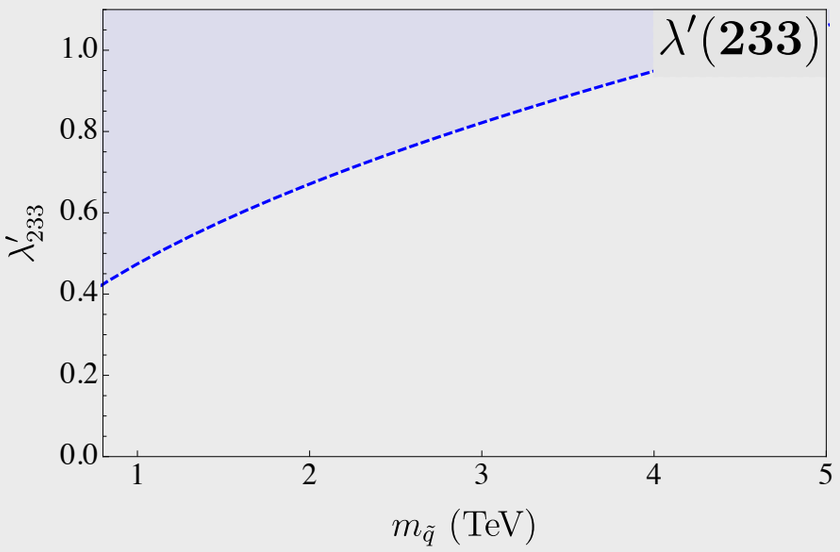



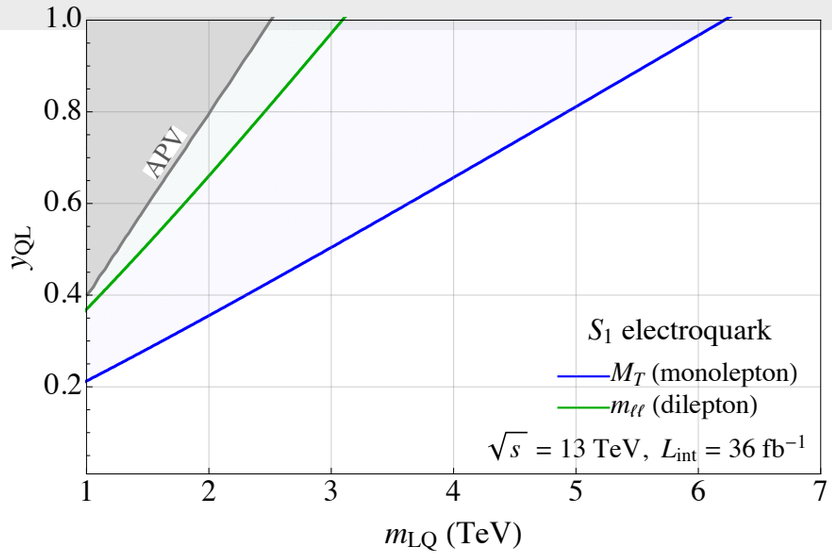



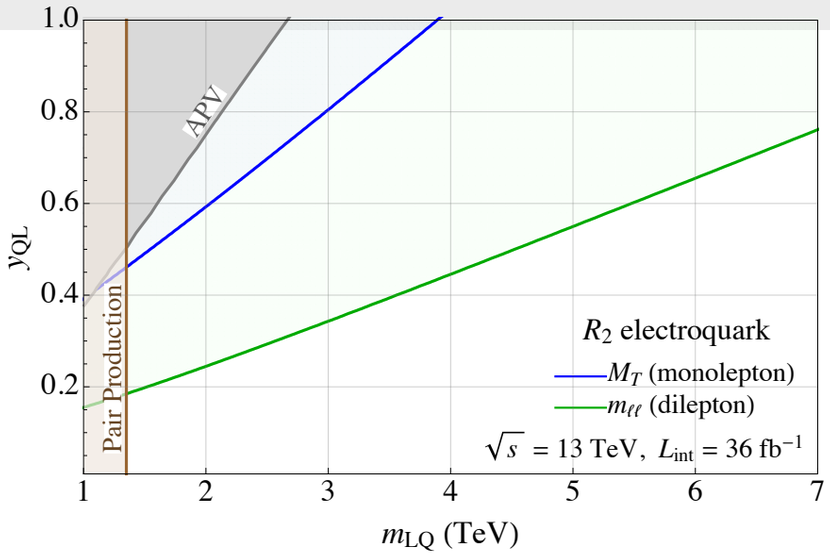

Monolepton  Dilepton  Other processes

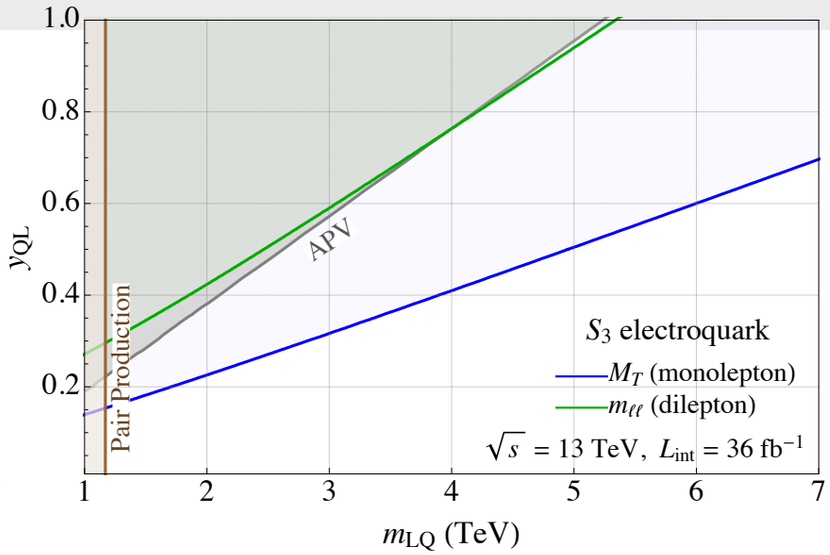
# Constraints - Leptoquarks

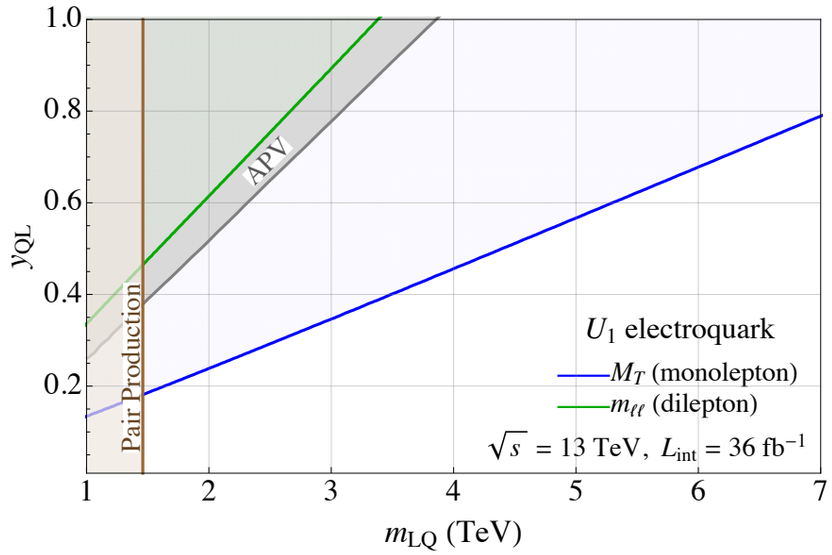
- Similar analysis was earlier used to constrain the parameter space of leptoquarks.

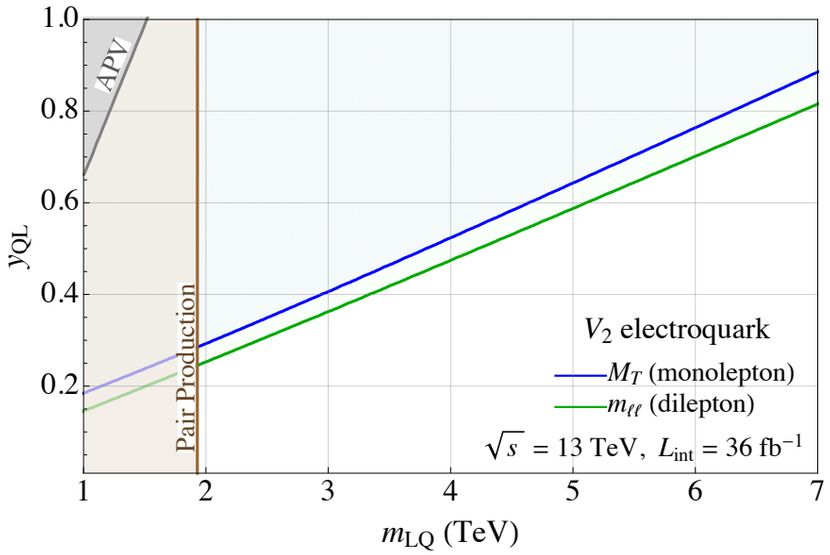
| | | | | | | |
|---|---|---|---|---|---|---|
| **Scalar** | $S_1$ | $(\bar{3}, 1, 1/3)$ | $S_3$ | $(\bar{3}, 3, 1/3)$ | $R_2$ | $(3, 2, 7/6)$ |
| **Vector** | $U_1$ | $(3, 1, 2/3)$ | $U_3$ | $(3, 3, 2/3)$ | $V_2$ | $(\bar{3}, 2, 5/6)$ |

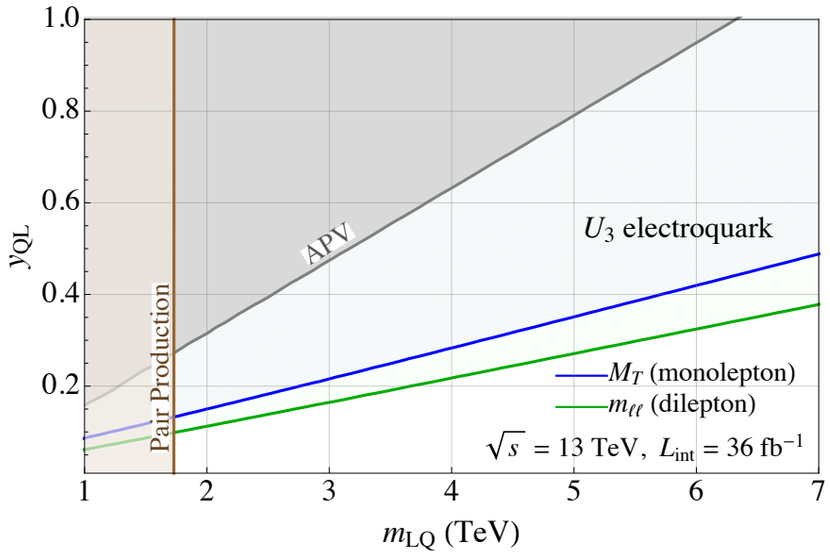
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