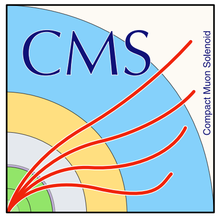
Searches for Leptoquarks with the CMS Detector at the LHC

ICHEP 2024

Arne Reimers on behalf of the CMS Collaboration

20 July 2024

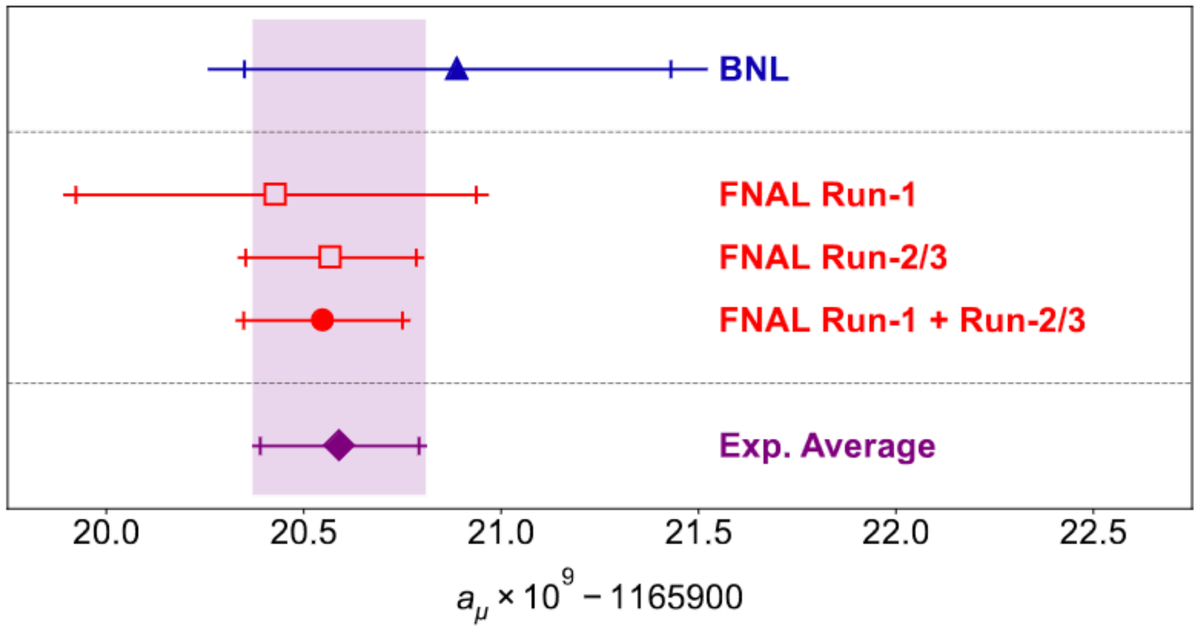


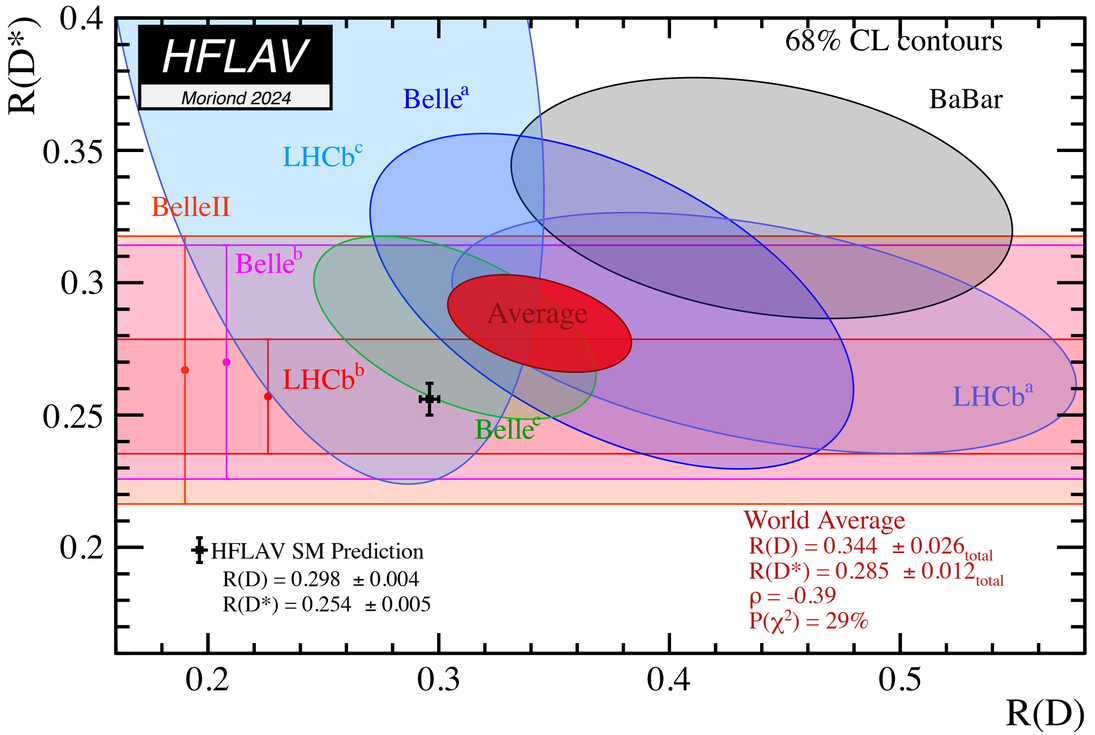
Universität Zürich[UZH]

Introduction

- Flavor anomalies in b→clν transitions and other observables
  - 3-σ-level tension with SM in $\mathscr{R}(D^{(\star)})$ for over a decade HFLAV
- Muon g-2 PRL 131, 161802 (2023)

$$R(\mathrm{D}^{(\star)}) = \frac{\mathscr{B}(\mathrm{B} \to \mathrm{D}^{(\star)}\tau\nu)}{\mathscr{B}(\mathrm{B} \to \mathrm{D}^{(\star)}\ell\nu)}$$





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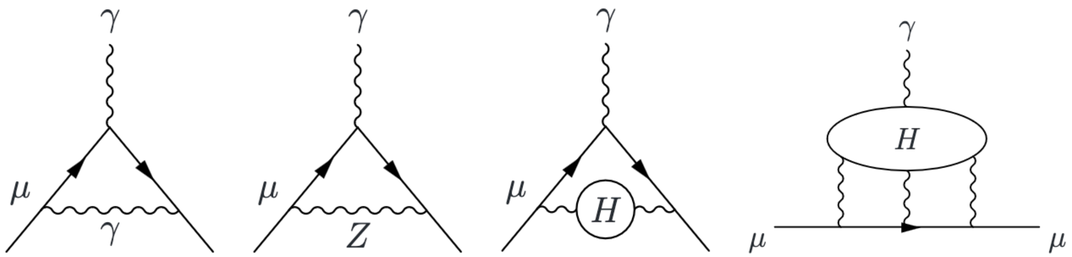

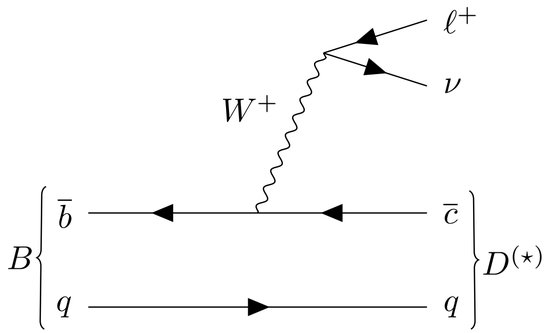

Introduction

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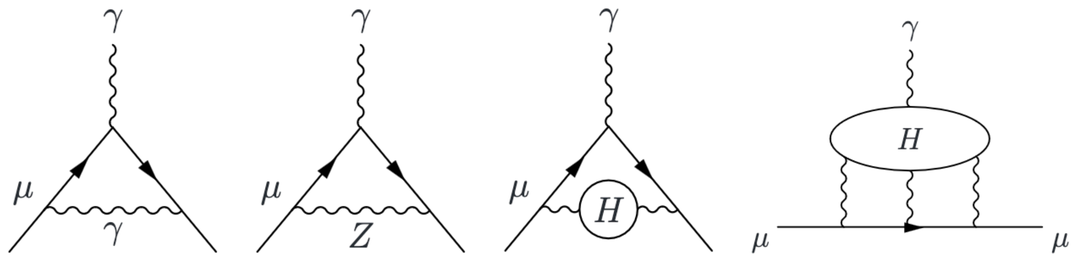
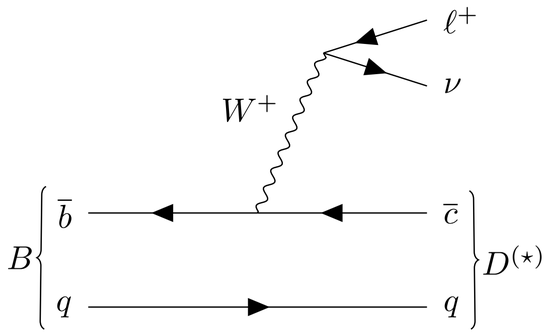
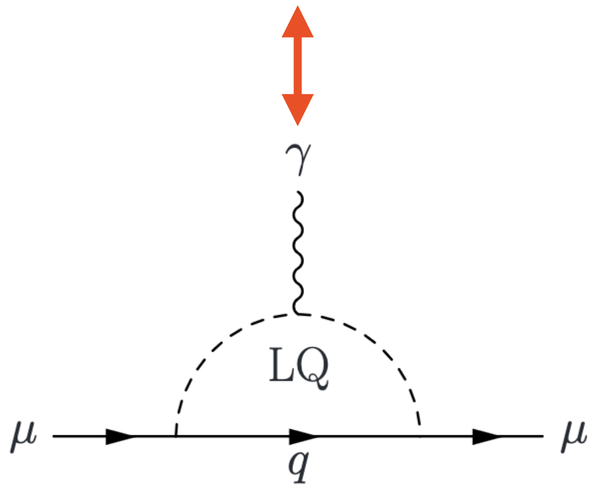
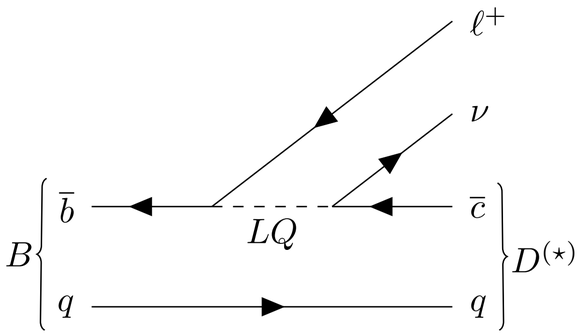




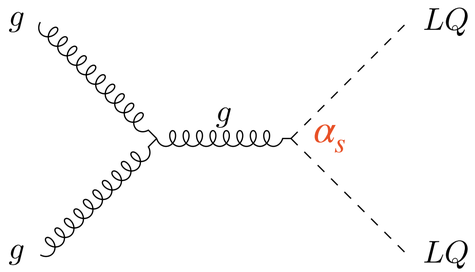




Leptoquarks at the LHC

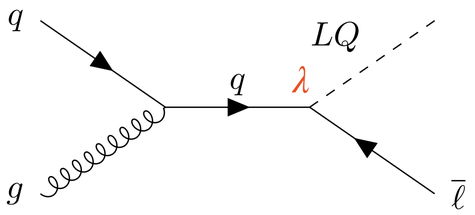
QCD pair production

- Depends on M_{LQ}
- Model-independent



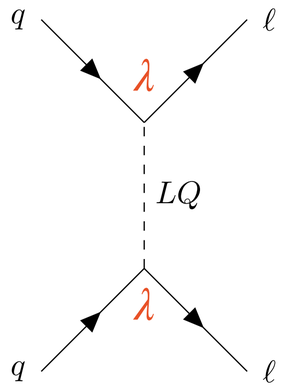
Single production

- Depends on M_{LQ} and λ^2
- Model-dependent



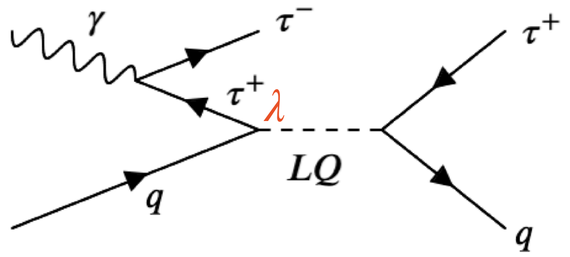
t-channel

- Depends on M_{LQ} and λ^4
- Model-dependent



Resonant s-channel

- Depends on M_{LQ} and λ^2
- $\gamma \rightarrow \tau\tau$ splitting

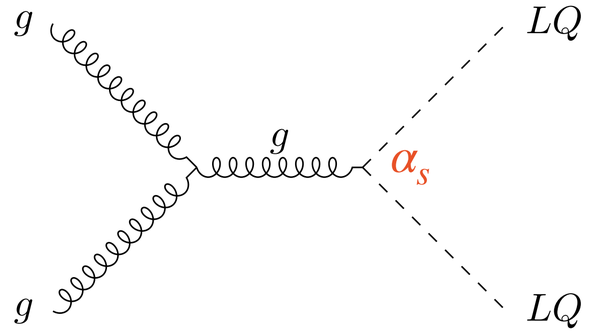


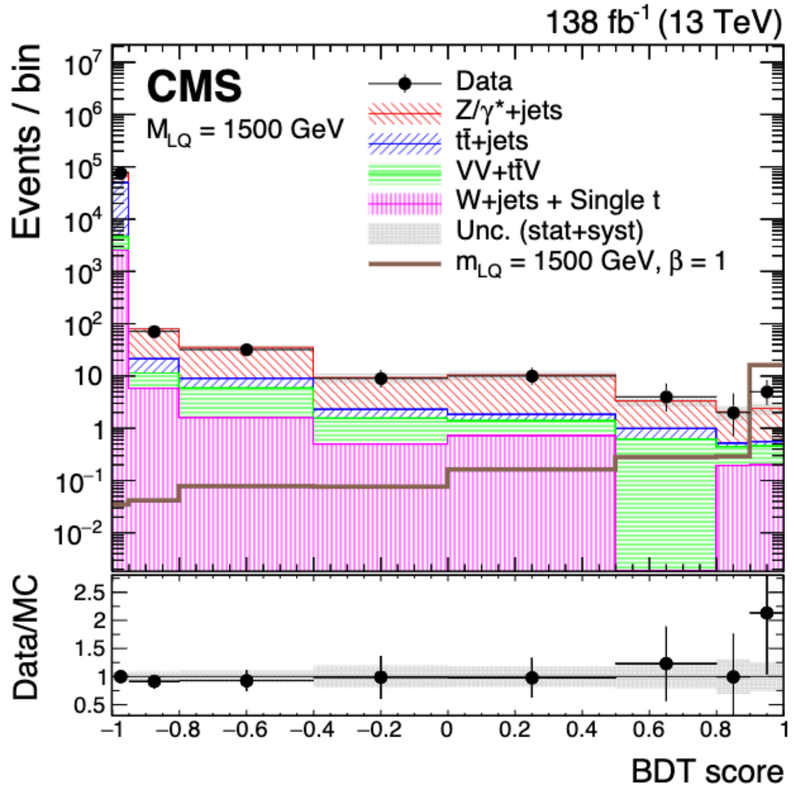
Search for LQ → bμ pair production

PRD 109 (2024) 112003

Strategy

- BDT trained for each LQ mass hypothesis
  - 11 high-level input variables with little correlation (e.g. invariant masses)
  - Cut on BDT score to maximize Punzi significance



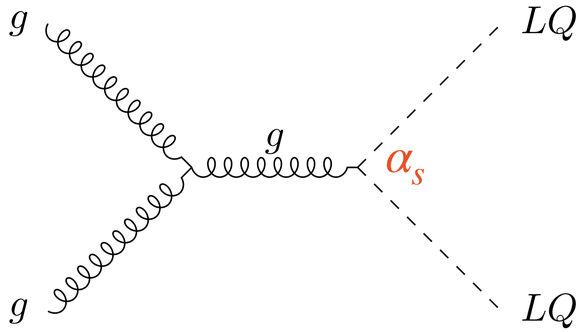


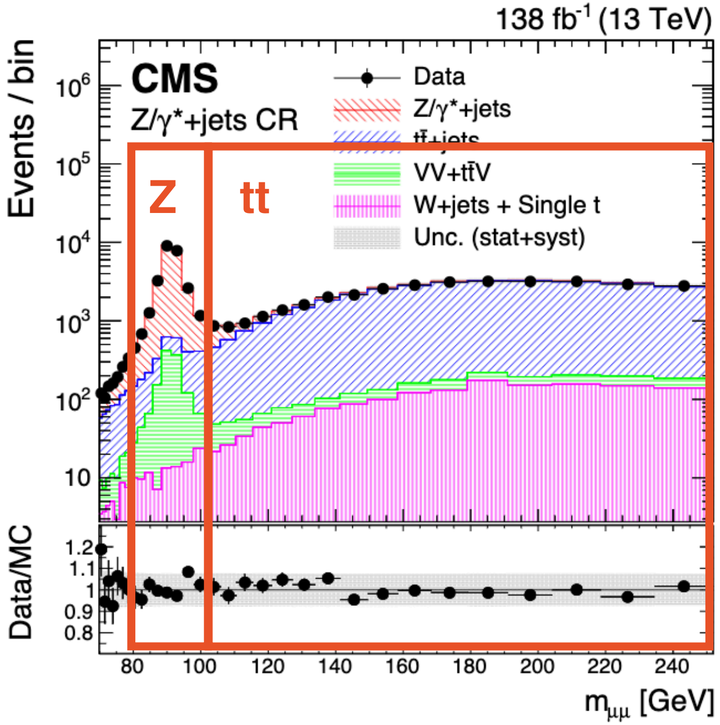
Search for LQ → bμ pair production

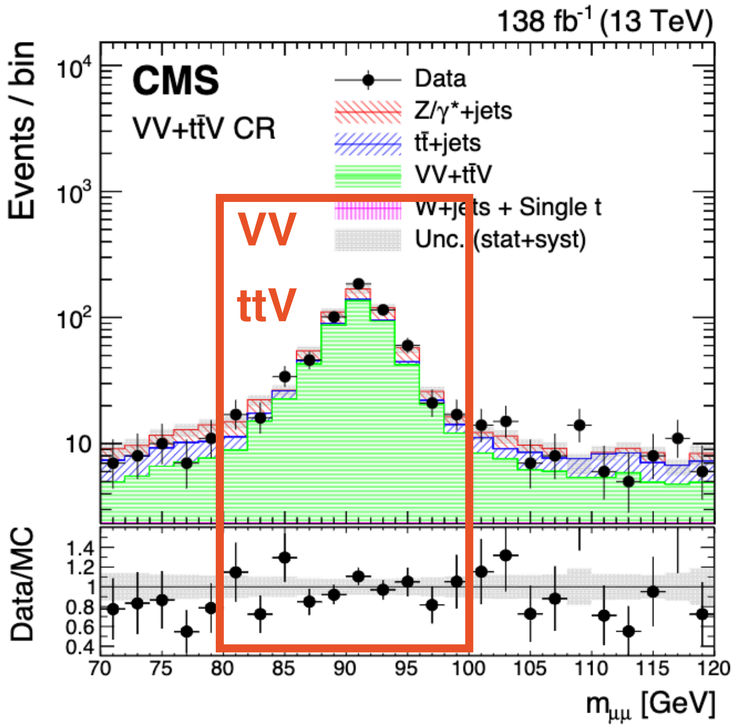
PRD 109 (2024) 112003

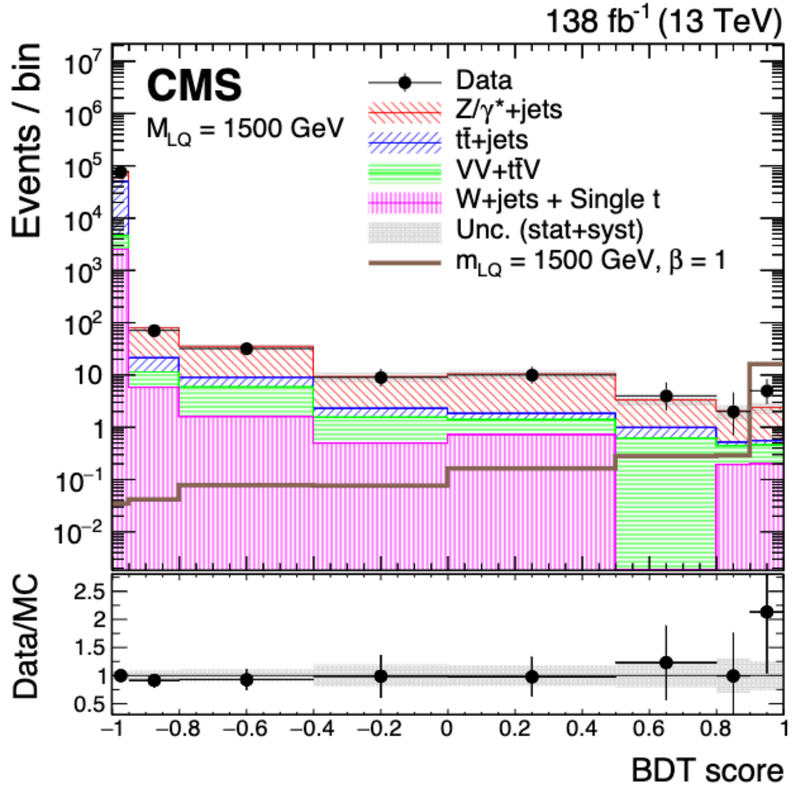
Strategy

- BDT trained for each LQ mass hypothesis
  - 11 high-level input variables with little correlation (e.g. invariant masses)
  - Cut on BDT score to maximize Punzi significance
- Yield of dominant backgrounds corrected using data in CRs







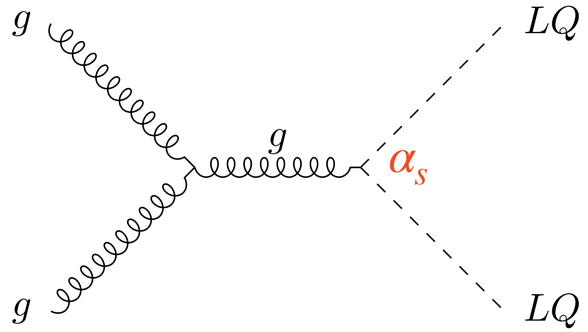


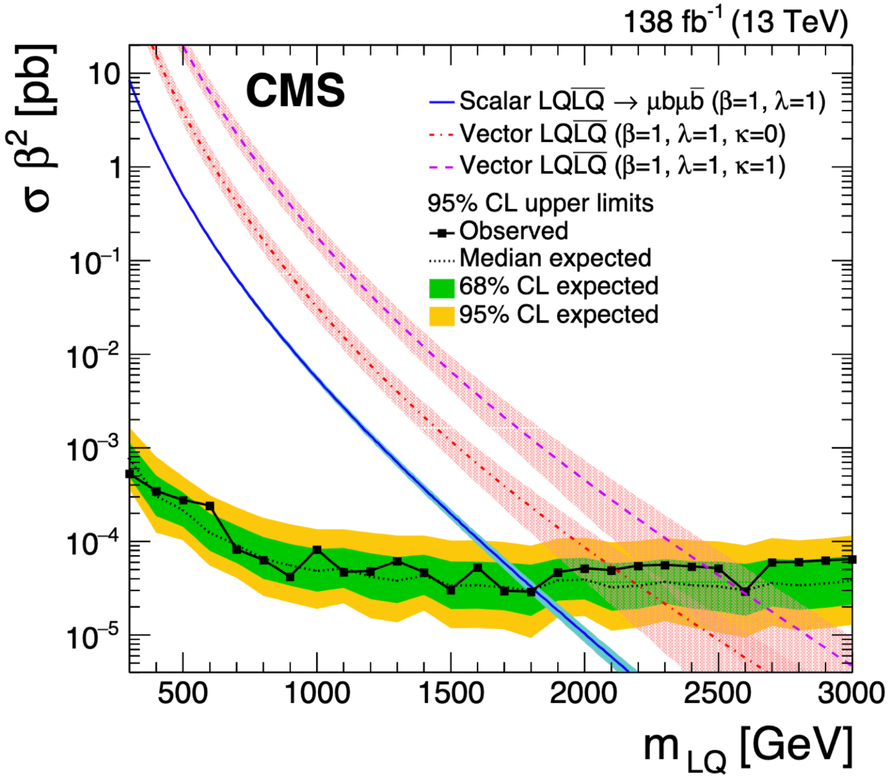
Search for LQ → bμ pair production

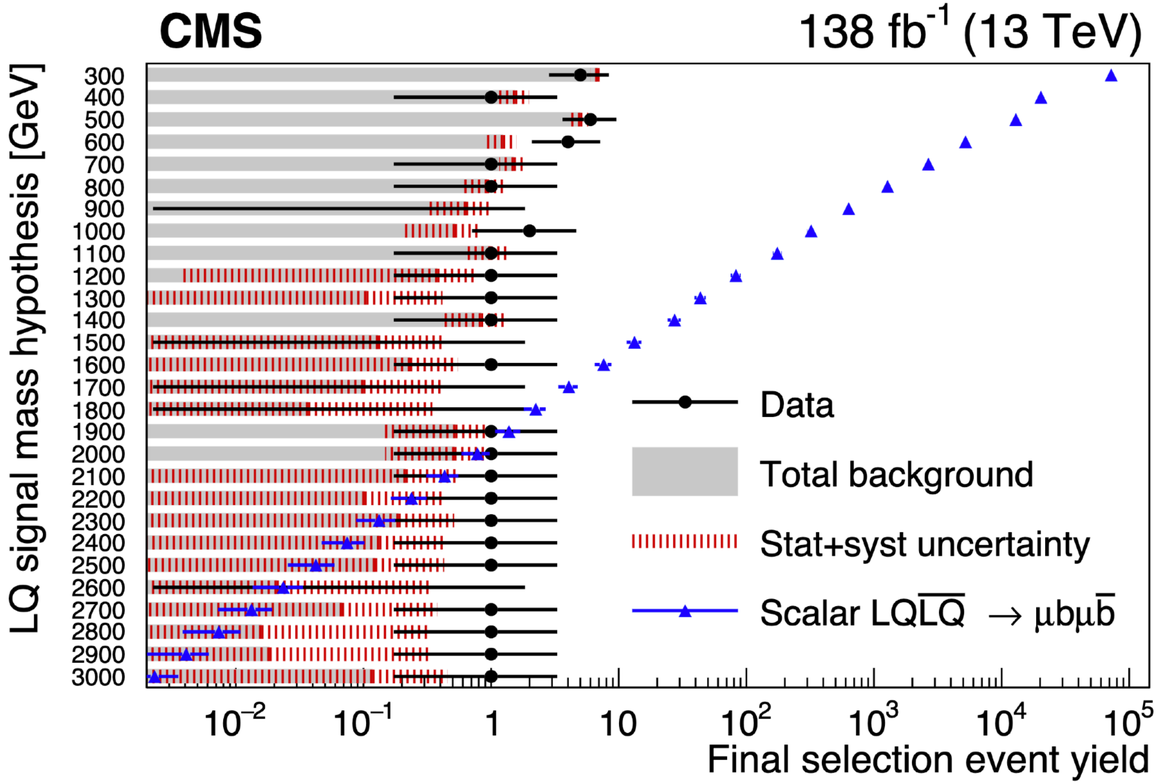
PRD 109 (2024) 112003

Results

- Cut-and-count for each LQ mass
- No excess observed
- LQ masses below 1.8 / 2.5 (scalar / vector [κ=1]) excluded





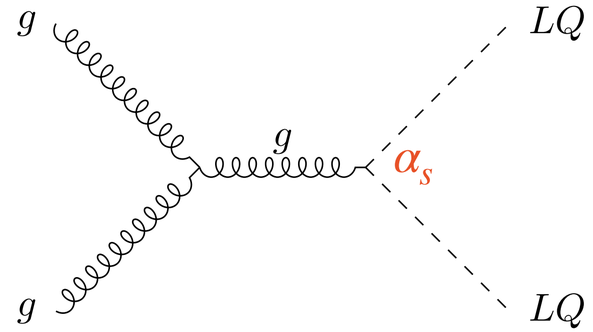


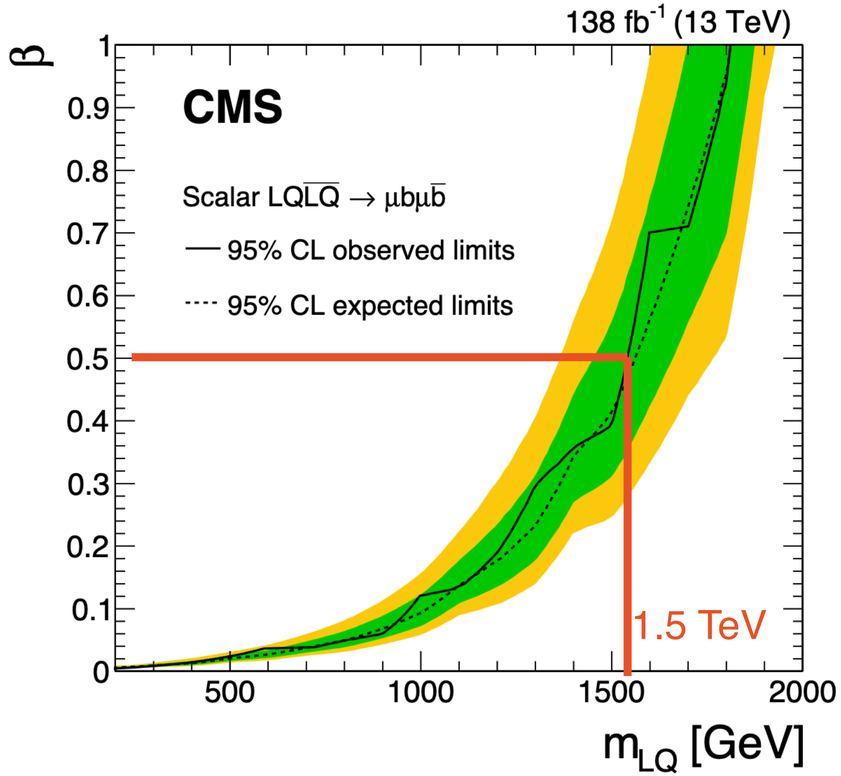
Search for LQ → bμ pair production

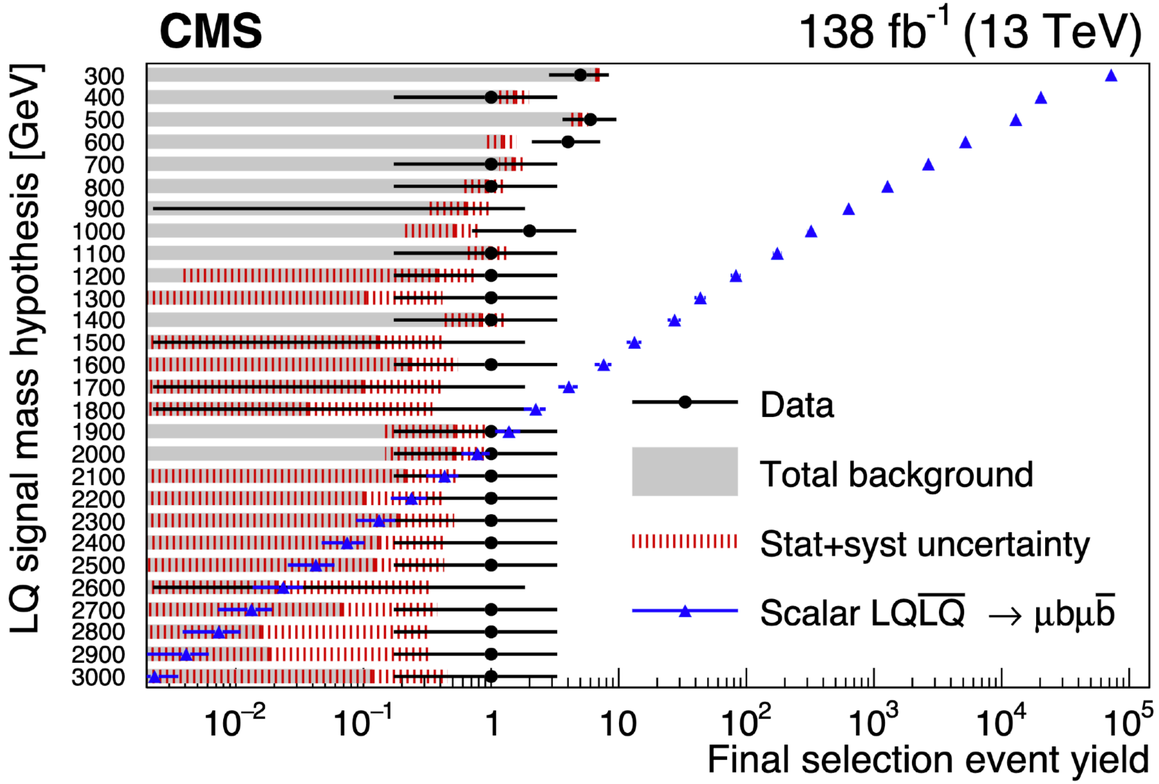
PRD 109 (2024) 112003

Results

- Cut-and-count for each LQ mass
- No excess observed
- LQ masses below 1.8 / 2.5 (scalar / vector [κ=1]) excluded
- Limits also placed vs. β = $\mathcal{B}$(LQ → bℓ): m_{LQ} > 1.5 TeV at β = 0.5

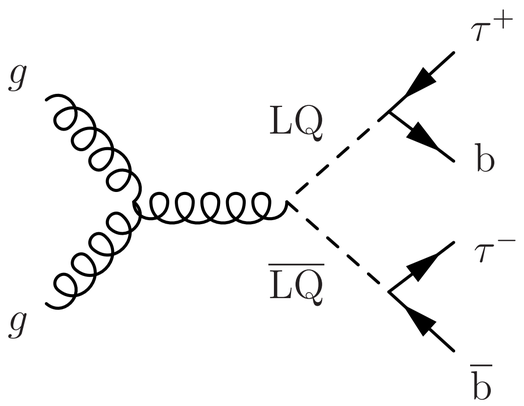


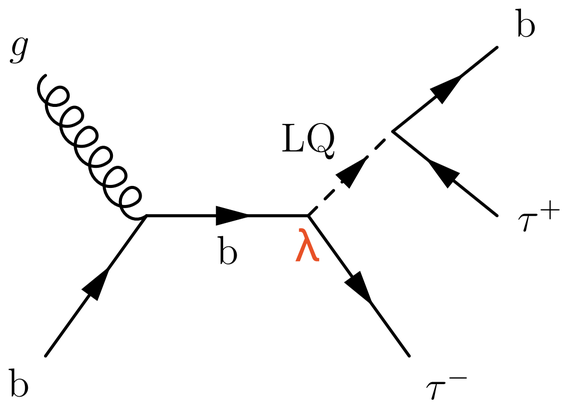


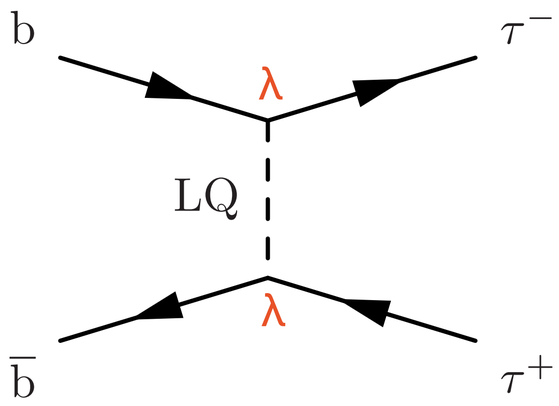


Search for LQ → bτ

JHEP 05 (2024) 311

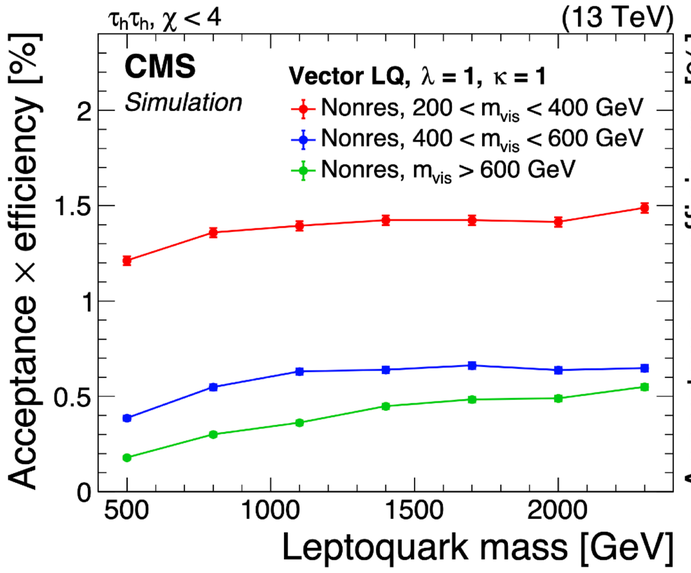


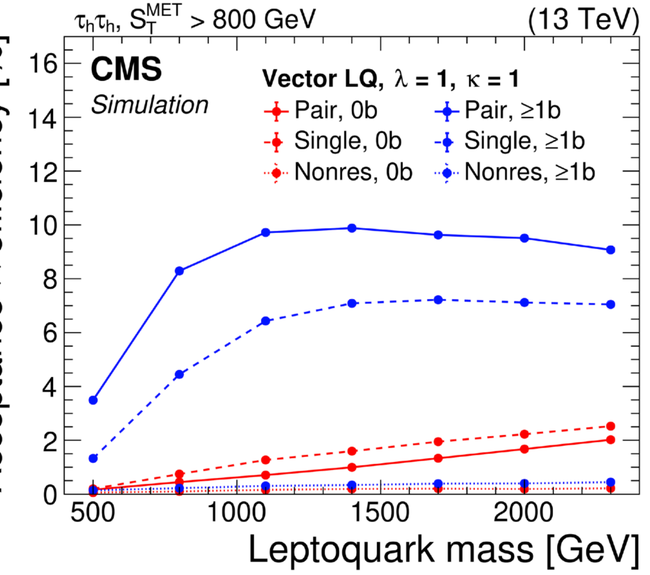




Strategy

- Assumes exclusive bτ couplings
- 2 hard τ leptons + varying number of hard (b-)jets
- **No hard jet:**
  - 3 categories in $m_{\tau\tau}$, fit $\chi = e^{\Delta\eta}$
  - Sensitive to t-channel process
- **≥ 1 hard jet:**
  - 2 categories in $N_{\text{b-jets}}$, fit $S_{\text{T}}^{\text{MET}} = \sum_i p_{\text{T,i}}$
  - Sensitive to all three processes





Search for LQ → bτ

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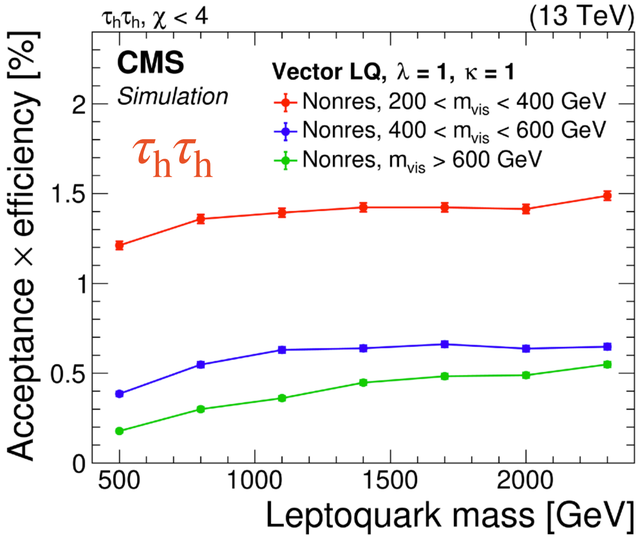
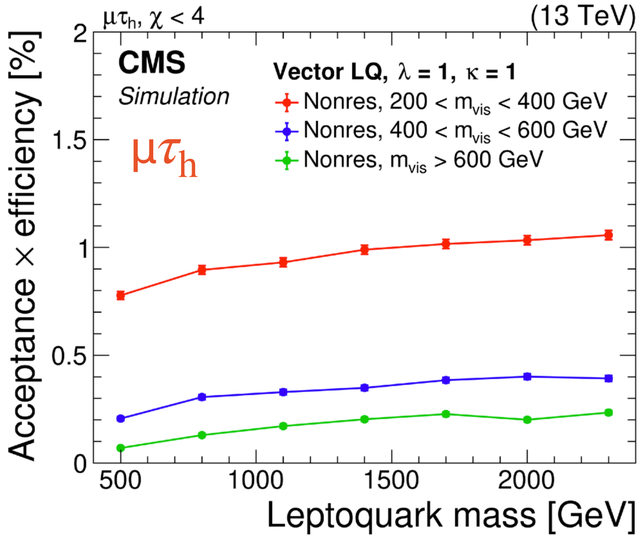
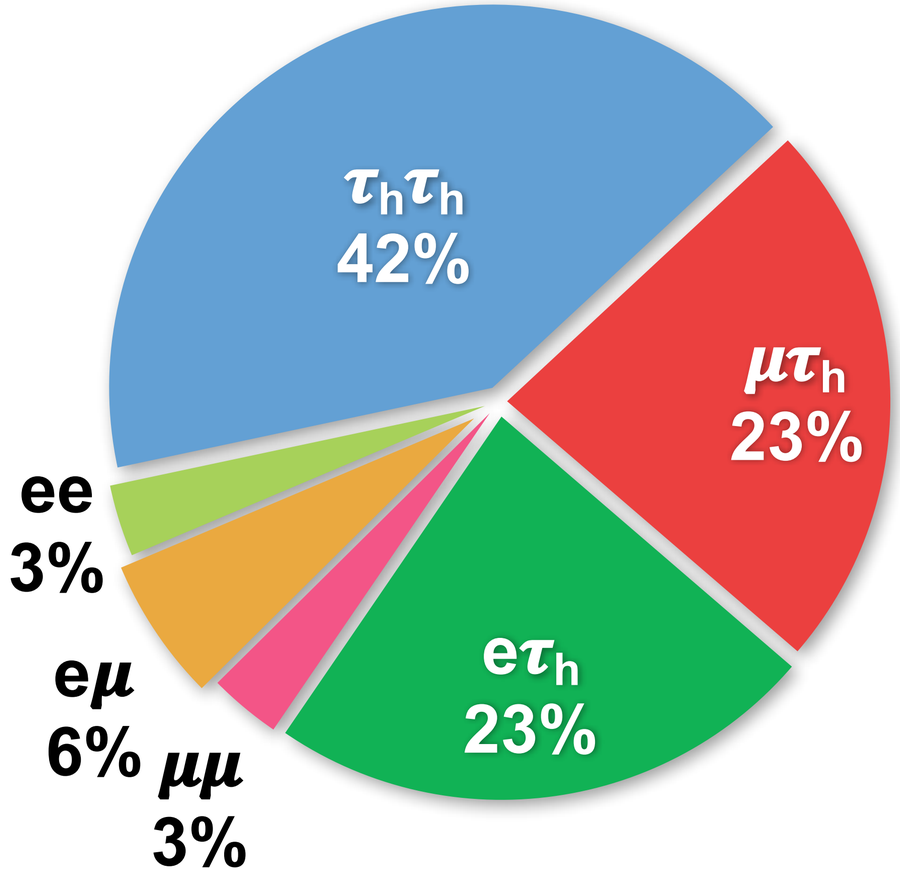
- Consider different τ decay modes
- Individual search channels based on lepton flavor
  - $\tau_h\tau_h$
  - $e\tau_h$
  - $\mu\tau_h$
  - $e\mu$
  - $\mu\mu$

Signal regions (88% branching fraction)

Signal-free: control regions for SM backgrounds







Search for LQ → bτ

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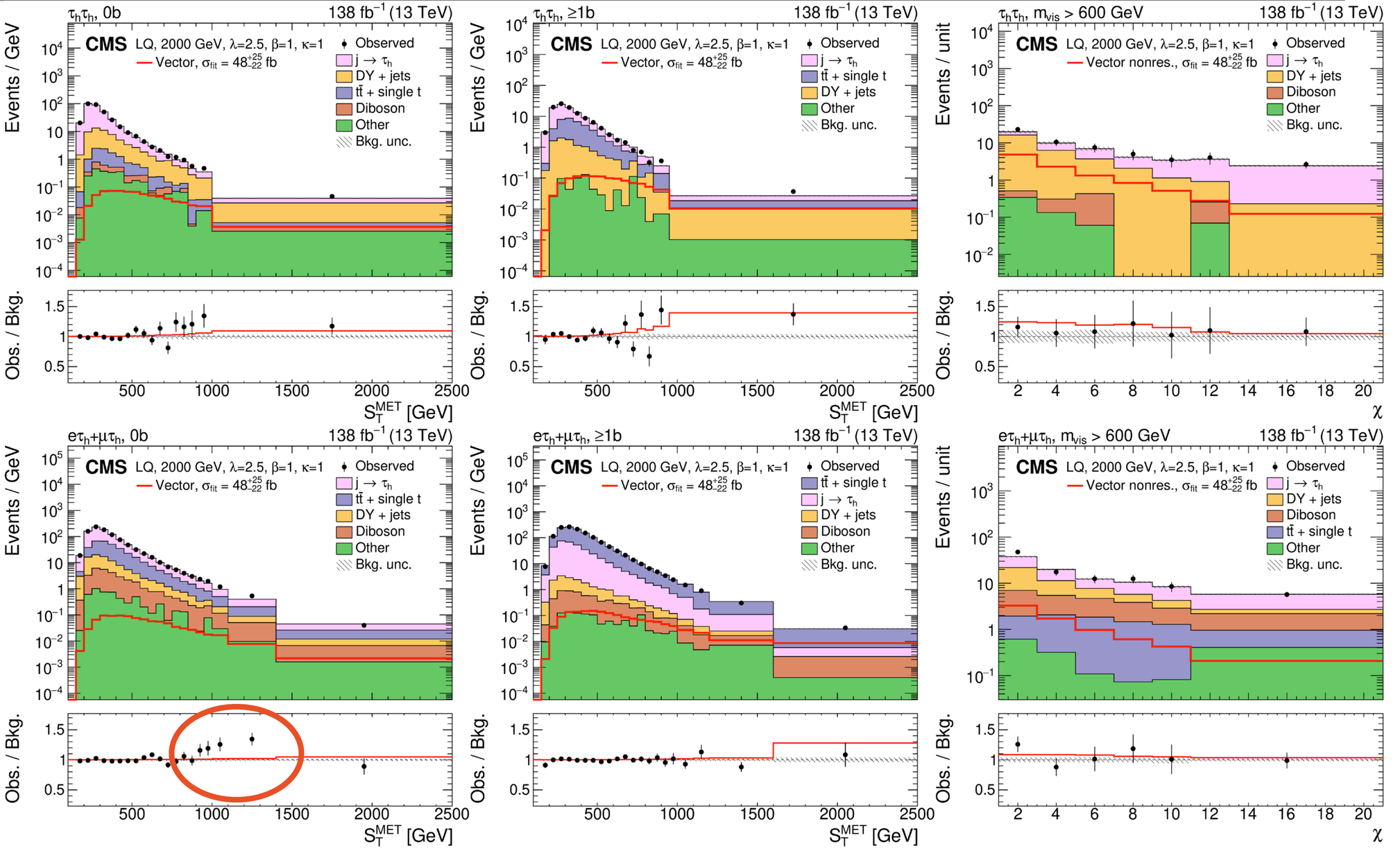
- Signal regions after combined fit
- Vector LQ signal:
  - 2 TeV
  - λ = 2.5
  - All 3 processes combined
- Local disagreement with SM
- Most significant:
  - $e\tau_h$ + $\mu\tau_h$, 0b
- Not explained by this LQ signal



Search for LQ → bτ

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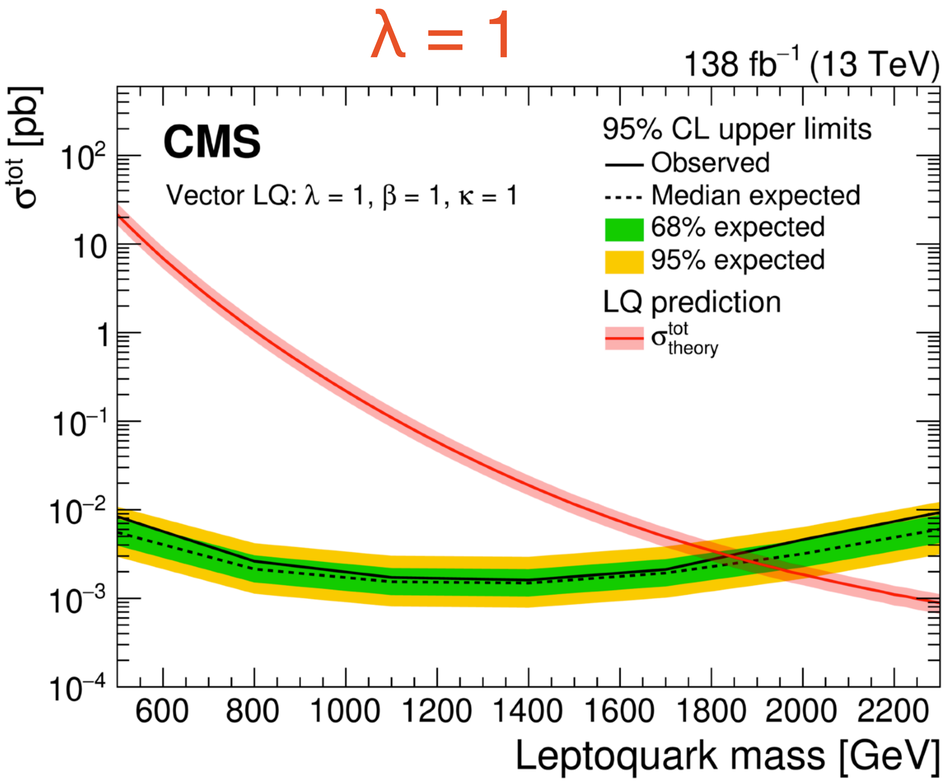
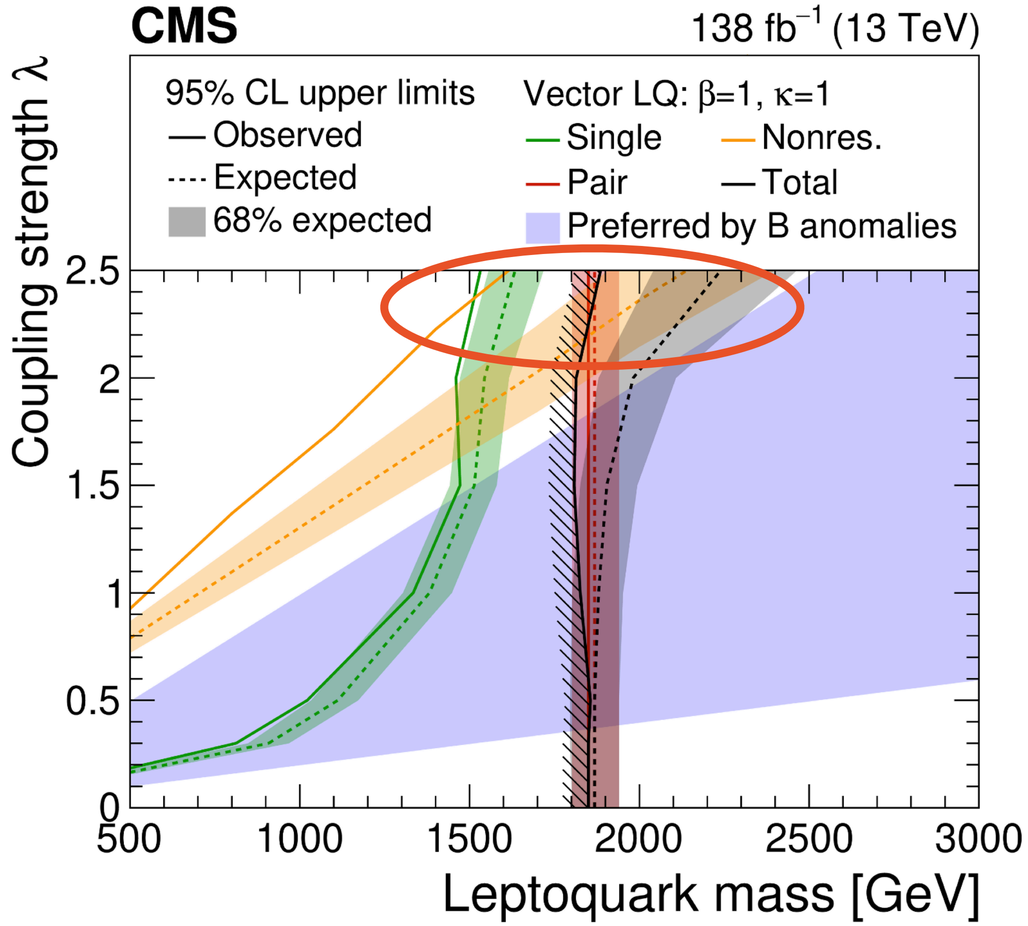
- Small couplings (λ = 1): signal dominated by pair production
  - Vector LQs excluded below 1.8 - 1.9 TeV
- Large couplings (λ = 2.5): high-mass signal dominated by nonresonant process
  - Local excess of 2.5 / 2.8σ (vector / scalar) at 2 TeV



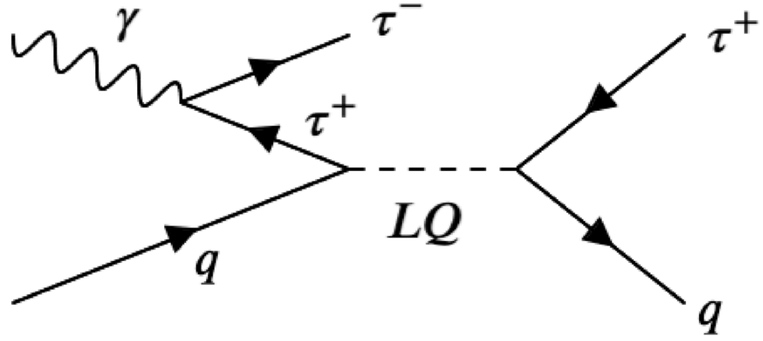


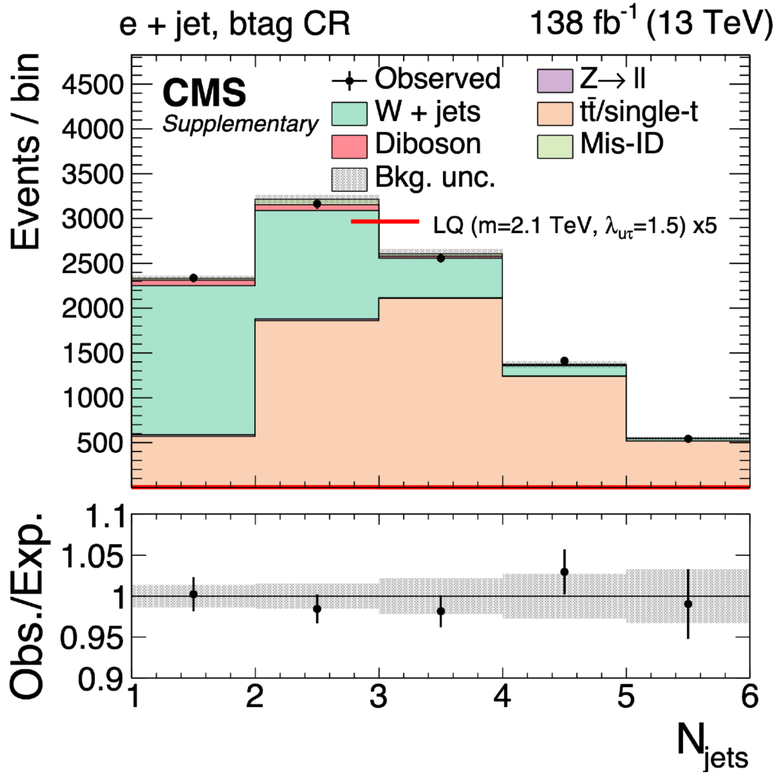
Search for qτ → LQ → qτ

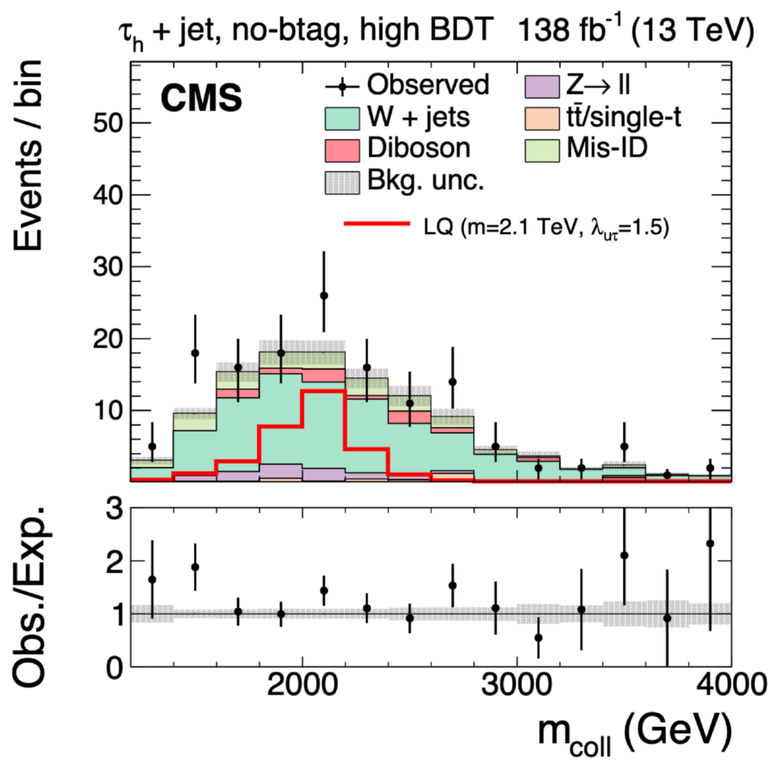
PRL 132 (2024) 061801

Strategy

- First search for τ lepton-induced LQ production
- Select high-p_T **τ (e, μ, had.)** and **jet (b-tagged or untagged)**
- Train BDTs to discriminate signal from W+jets and tt (e/μ channel) or jet→τ_h mis-ID (hadronic channel)
  - Define categories with different signal purity
- Fit collinear mass (p_T^{miss} assumed to come from τ decay)
- Normalization of W+b jet from CR data





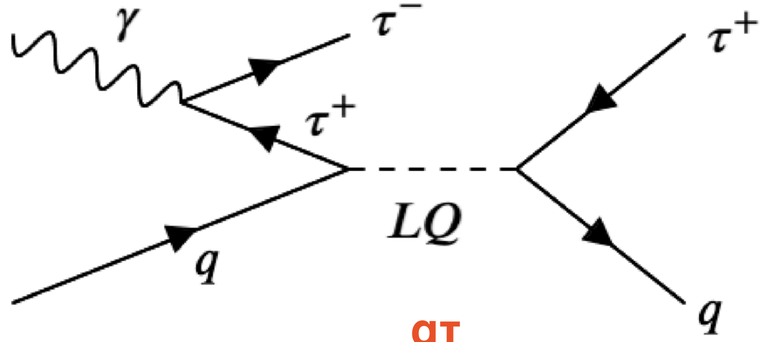


Search for qτ → LQ → qτ

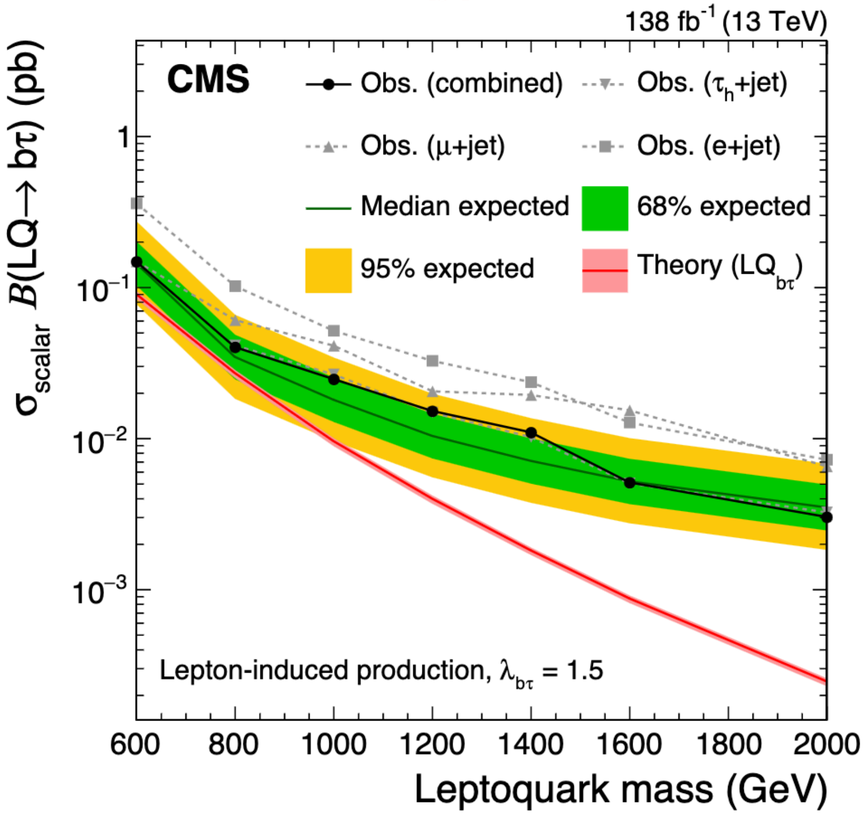
PRL 132 (2024) 061801

Results

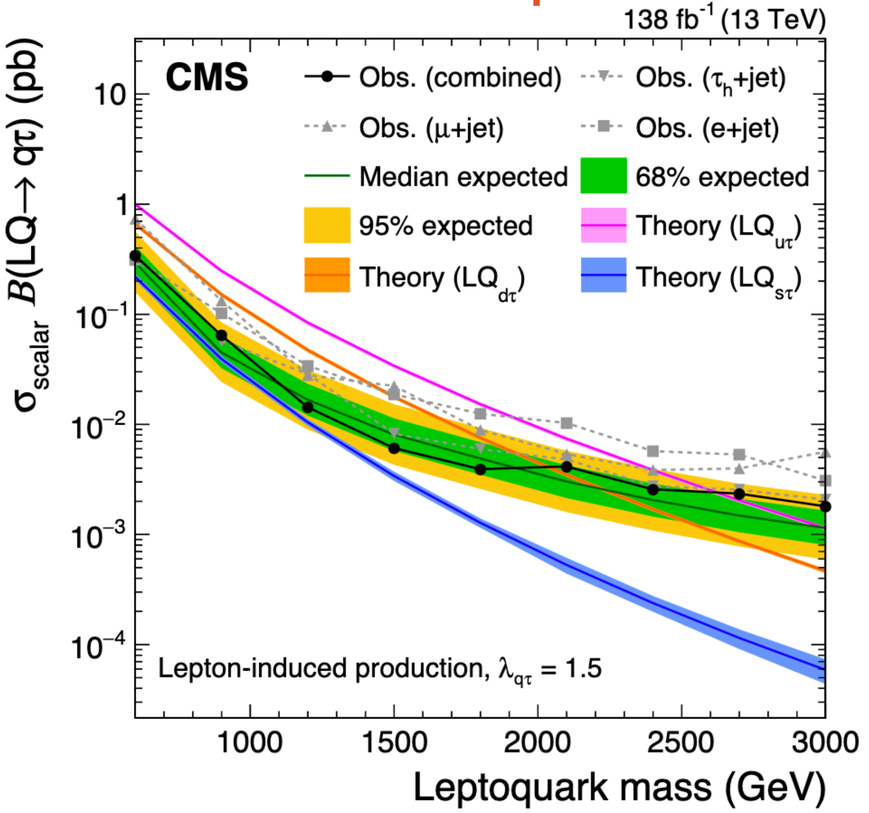
- No significant excess observed
- Limits for bτ and qτ couplings



bτ



qτ

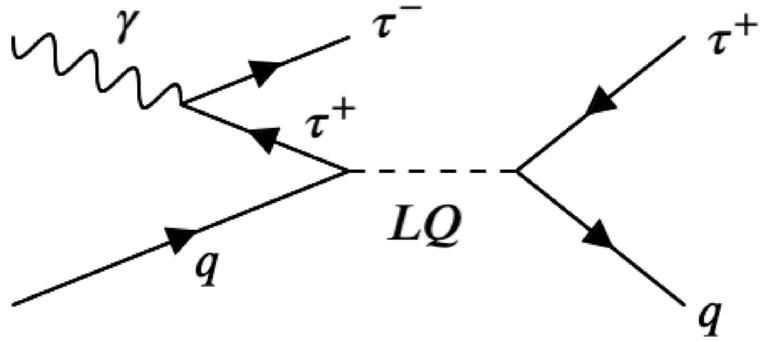


Search for qτ → LQ → qτ

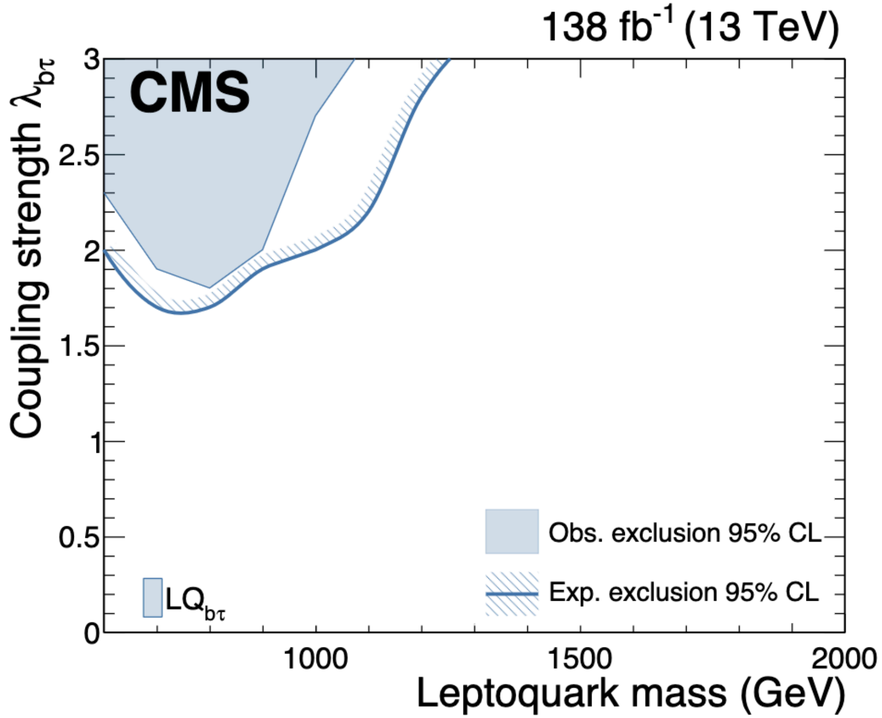
PRL 132 (2024) 061801

Results

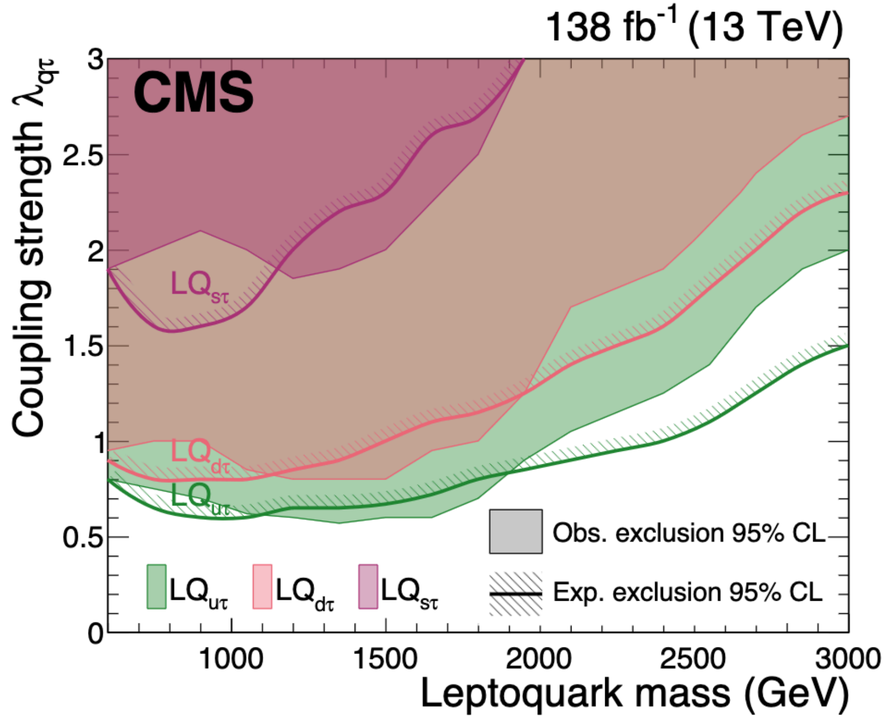
- No significant excess observed
- Limits for bτ and qτ couplings
- Sensitivity to λ: limits on M_{LQ} vs. λ
  - bτ cross section suppressed by b PDFs



bτ

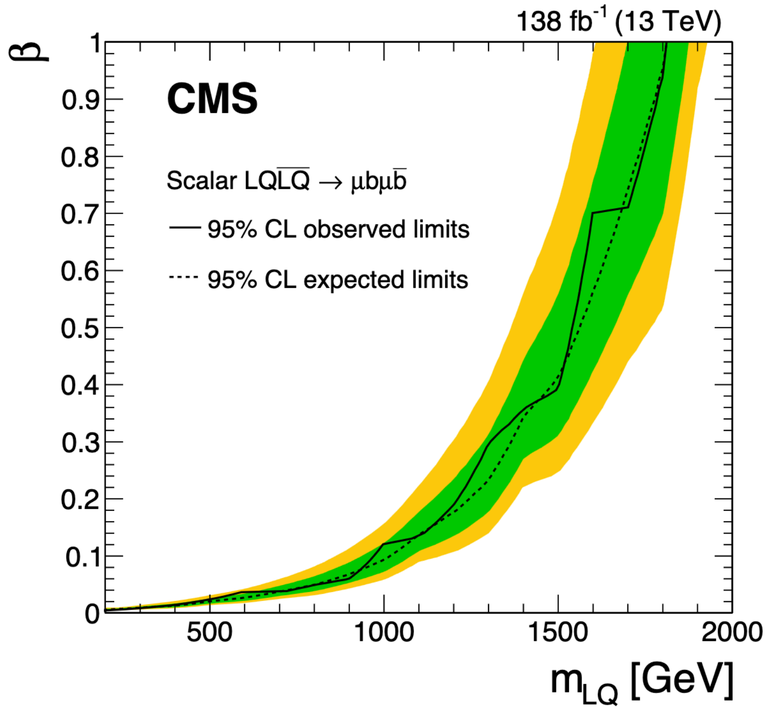


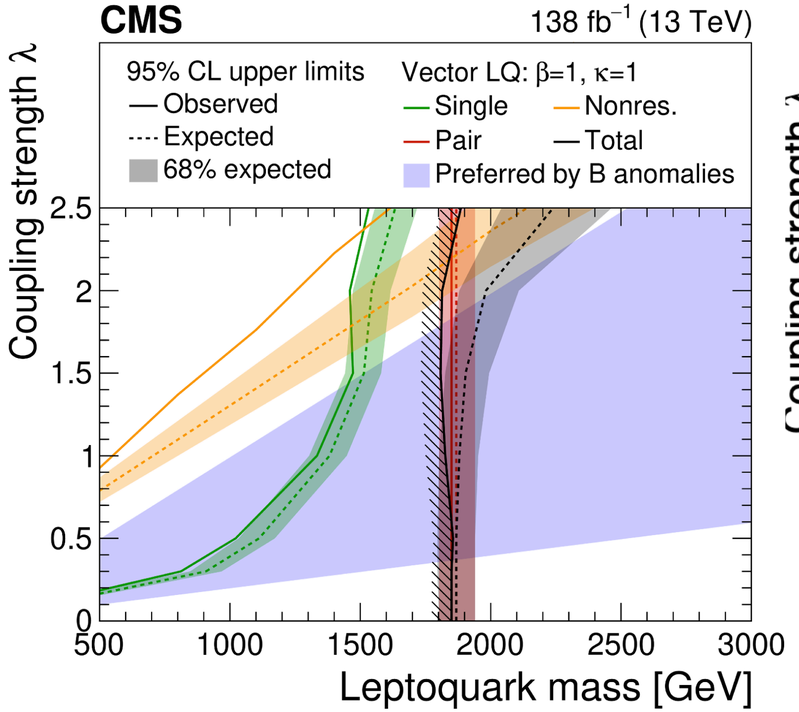
qτ

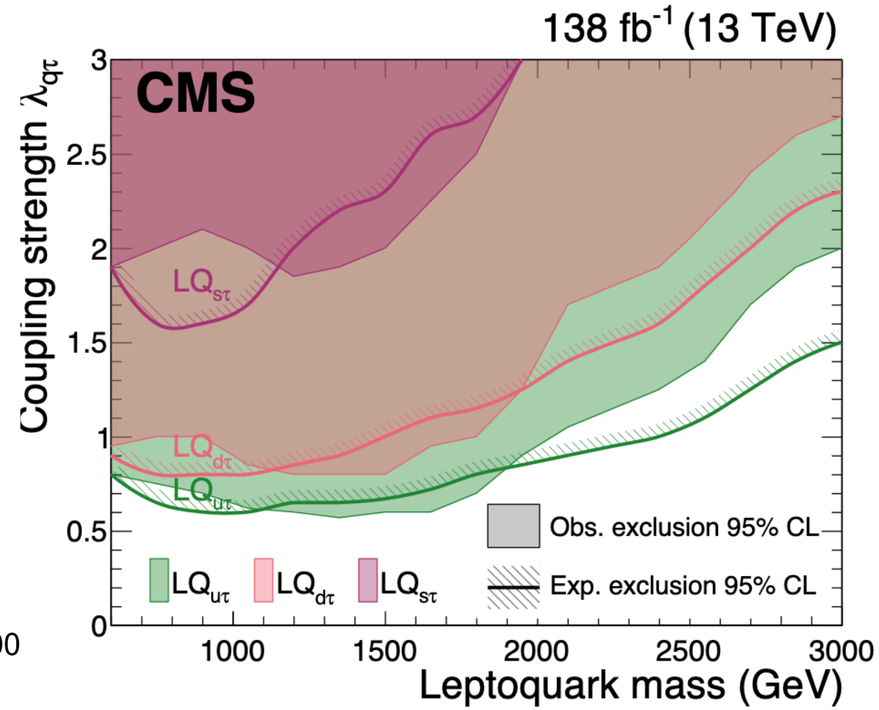


Conclusion

- Leptoquarks could explain B anomalies and muon g-2
- Search for LQ → bμ pair production: strongest limits on LQ → bμ to date
- Search for LQ → bτ: excess in $\ell\tau_h$ events with un-tagged jets
- Search for qτ → LQ → qτ: first search for τ lepton-induced LQ production





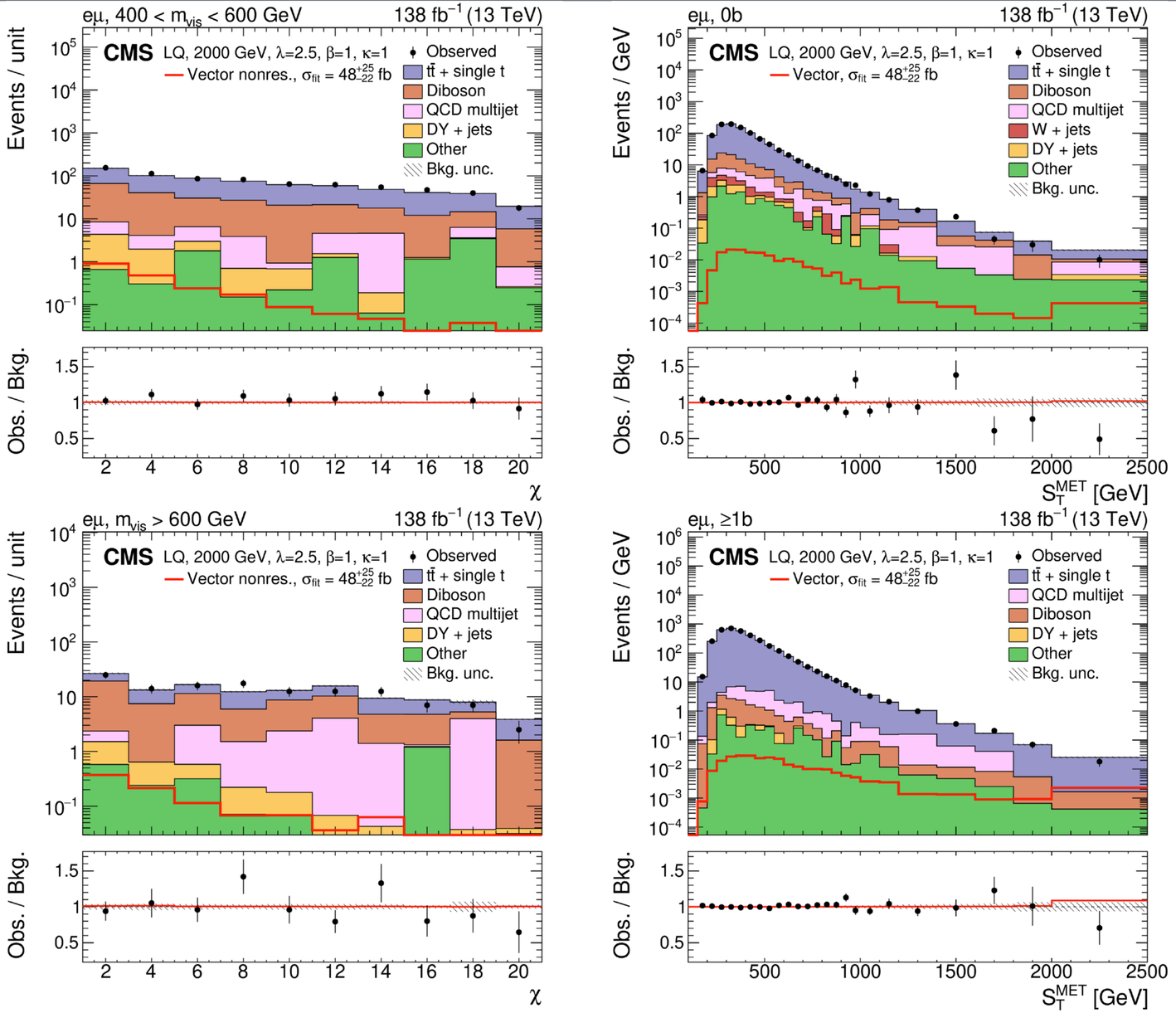


Additional material

Search for LQ → bτ

arXiv:2308.07826 (acc. by JHEP)

- Dominant SM backgrounds:
  - $e\tau_h$ & $\mu\tau_h$: **tt**
  - $\tau_h\tau_h$: **DY → ττ**
- Constrained by including control regions in simultaneous fit
  - **tt** in eμ region
  - **DY → ττ** in μμ region
- Useful for both experimental and theoretical uncertainties
- Excellent agreement after fit



Search for LQ → bτ

arXiv:2308.07826 (acc. by JHEP)

- Jets likely to be misidentified as τ_h
- Background with j → τ_h fakes derived from data

- Invert τ_h identification: enriched in mis-IDed τ_h
- Transfer factor (TF) measured in dedicated control regions C&D vs. $\tau_h\, p_T$

- j → τ_h probability depends on jet flavor
- Separate TFs measured for dominant processes:
  - tt
  - W + jets
  - QCD
- Application as weighted average