

Searches in (di)tau tails in ATLAS and CMS

Arne Reimers

LHC EFT WG meeting

21 November 2022

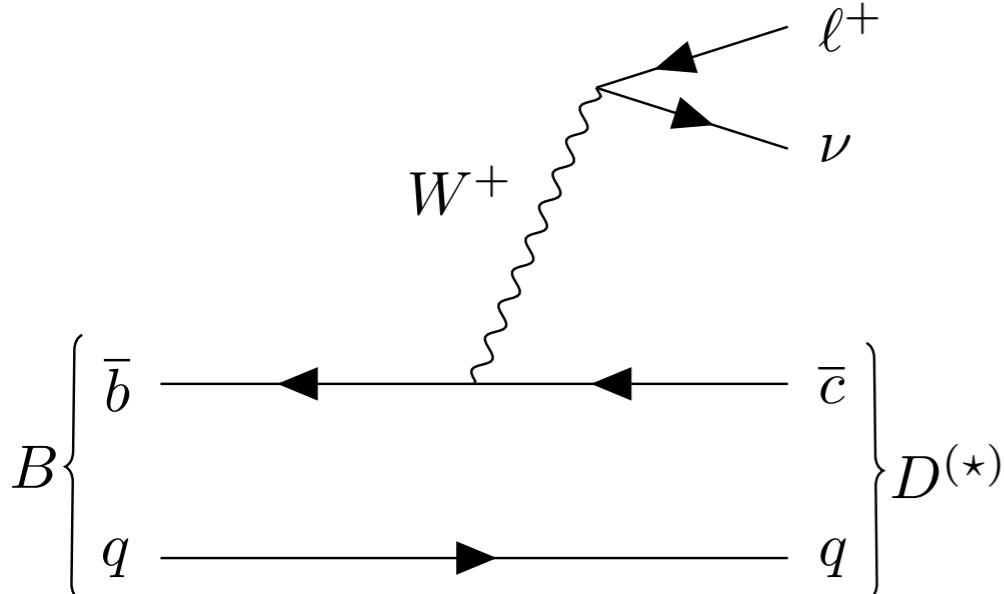


**Universität
Zürich^{UZH}**

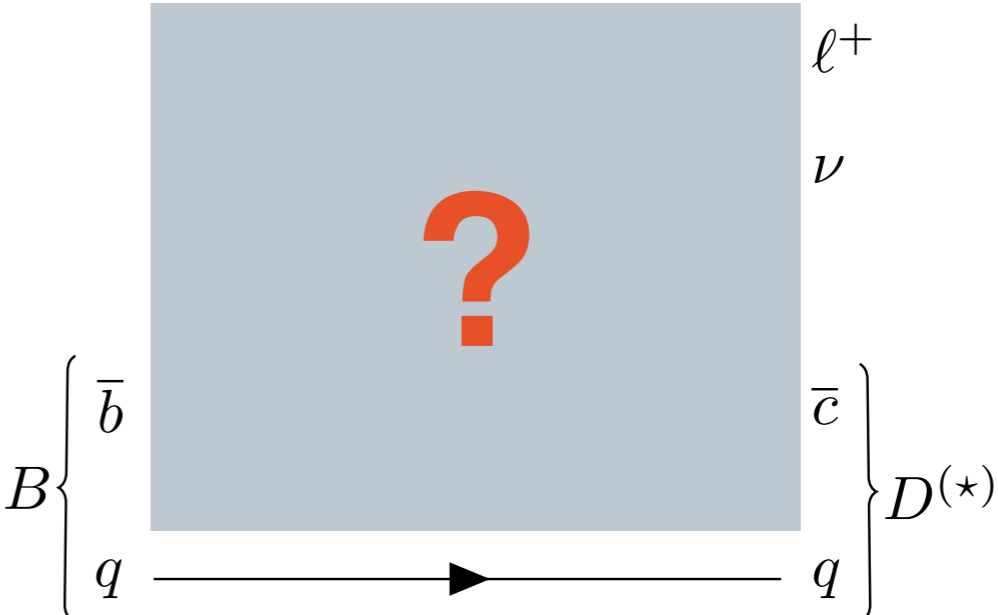
- For combined BSM explanations: flavor structure driven by anomalies
 - ▶ Tree-level in SM → Need strong effect for 3rd generation

$$R(D^{(\star)}) = \frac{\mathcal{B}(B \rightarrow D^{(\star)}\tau\nu)}{\mathcal{B}(B \rightarrow D^{(\star)}\ell\nu)}$$

SM



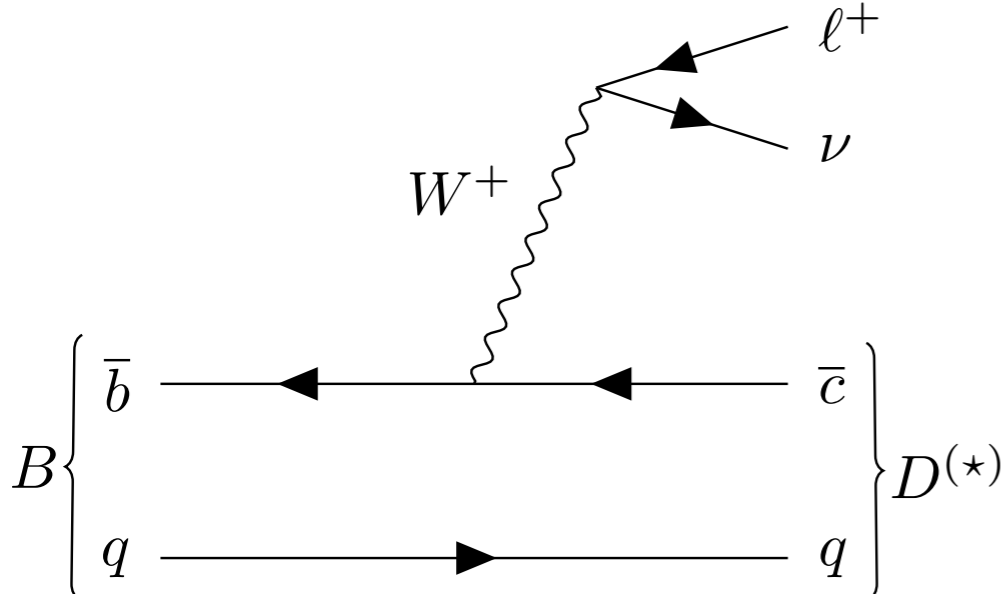
BSM



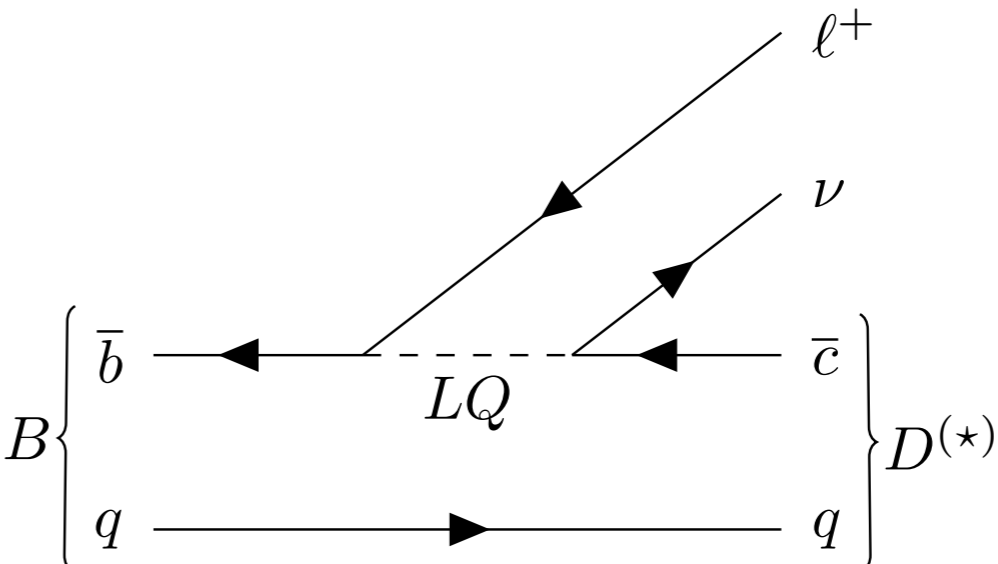
- For combined BSM explanations: flavor structure driven by anomalies
 - ▶ Tree-level in SM → Need strong effect for 3rd generation
 - ▶ Dominant couplings to 3rd generation

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SM

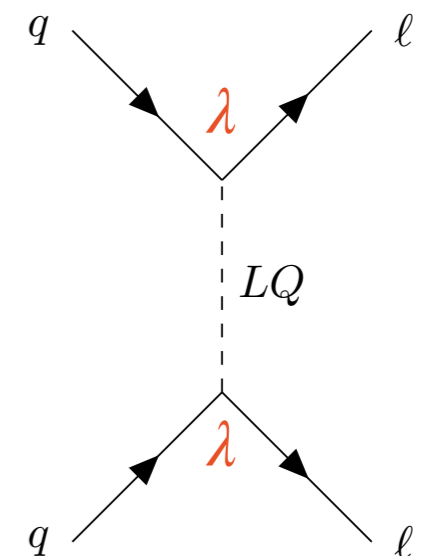
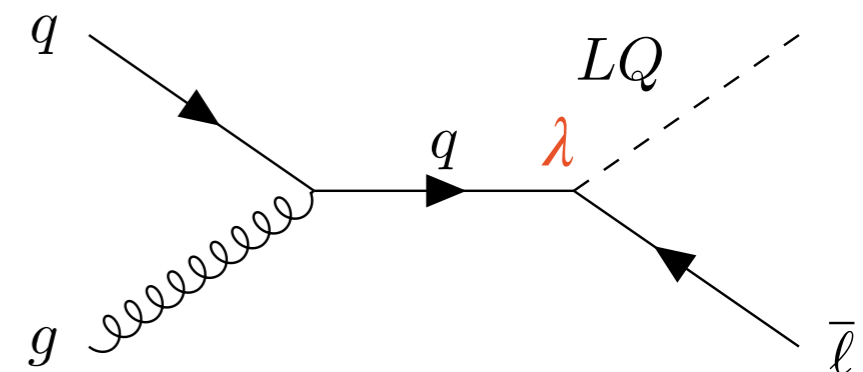
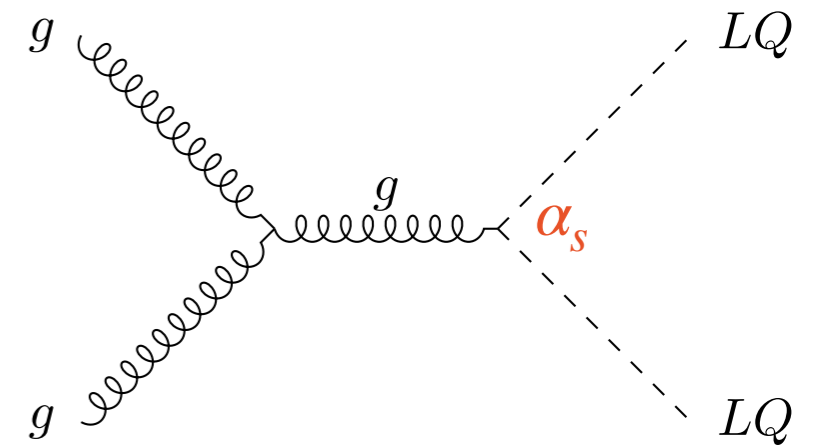


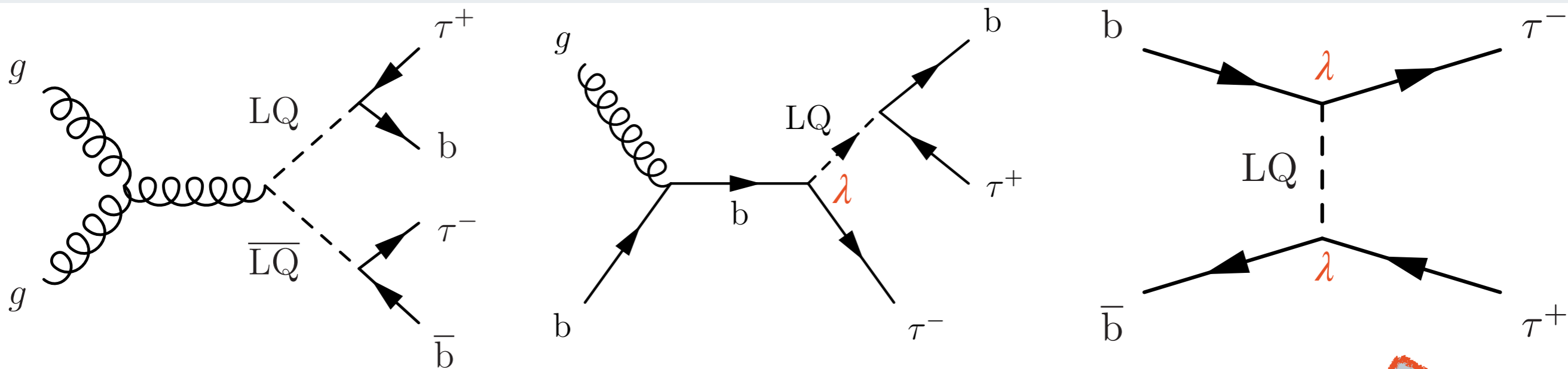
BSM



Leptoquarks at the LHC

- Pair production via QCD
 - ▶ Depends only on M_{LQ}
 - ▶ Model-independent
- Single production
 - ▶ Depends on M_{LQ}
 - ▶ Scales with λ^2
 - ▶ Sensitive to initial-state PDF
- LQ in the t-channel
 - ▶ non-resonant process
 - ▶ Much weaker dependence on M_{LQ}
 - ▶ Scales with λ^4

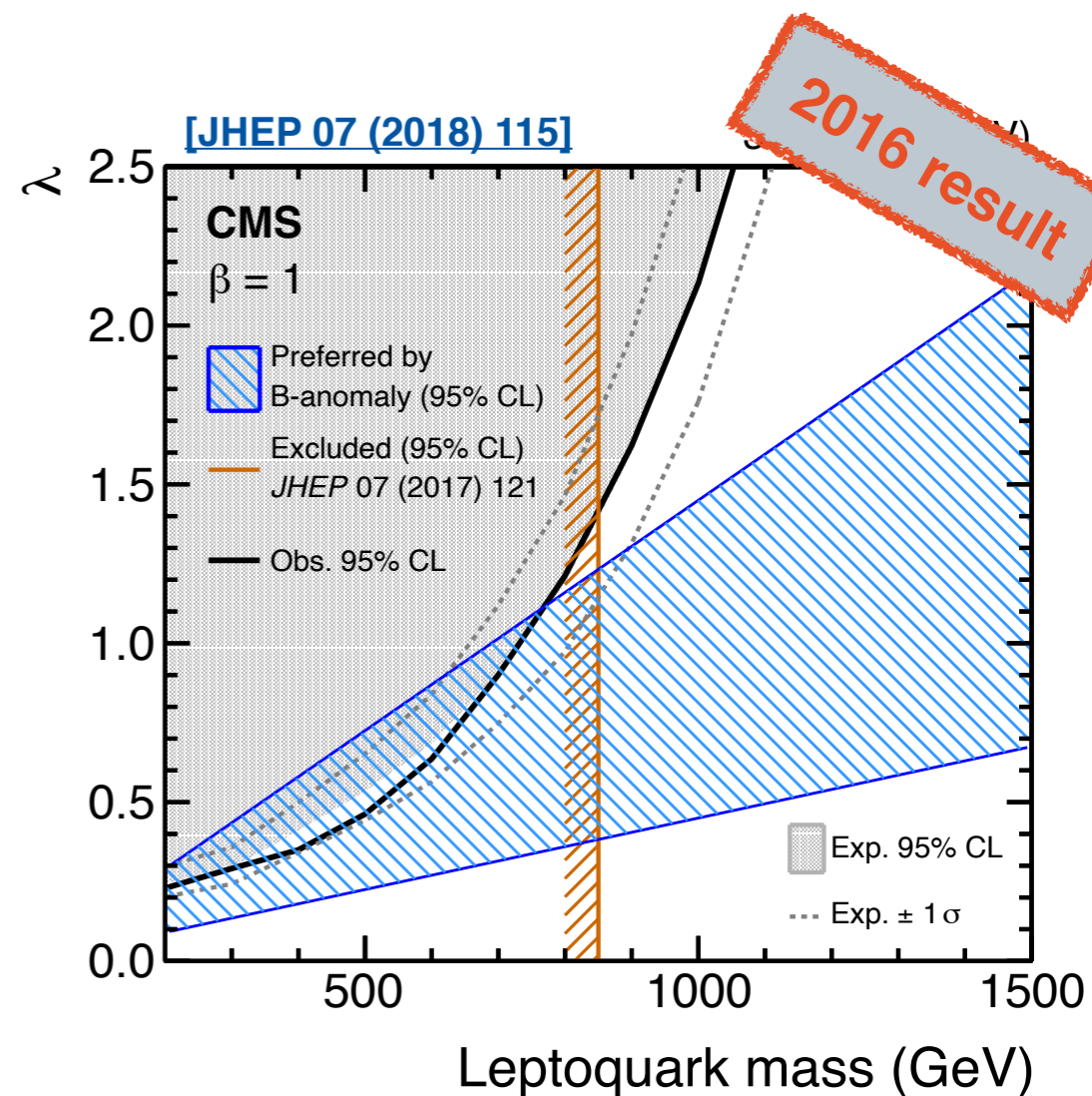




- Full Run-2 legacy analysis
- Targets all three processes
 - ▶ Sensitive to (flavor non-universal) coupling λ
- Assumes exclusive $b\tau$ couplings

Strategy

- 2 hard τ leptons + varying number of hard (b-)jets
- Categorize events in $m_{\tau\tau}$ and $N_{b\text{-jets}}$
 - ▶ Each most sensitive to different processes
- Simultaneous final fit of all categories



0 jets

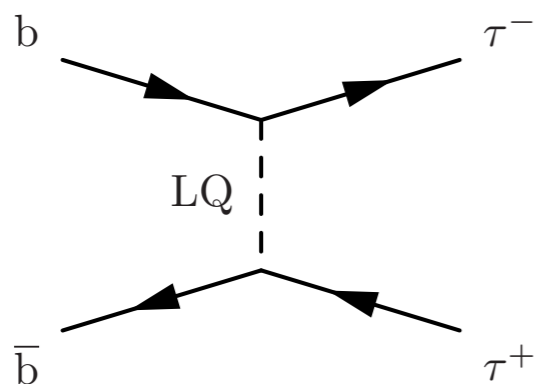
- Regions of dilepton invariant mass $m_{\tau\tau}$:

200-400

400-600

> 600

- Fitted observable: $\chi = e^{\Delta\eta}$
- Sensitive to t channel LQ



≥ 1 jet

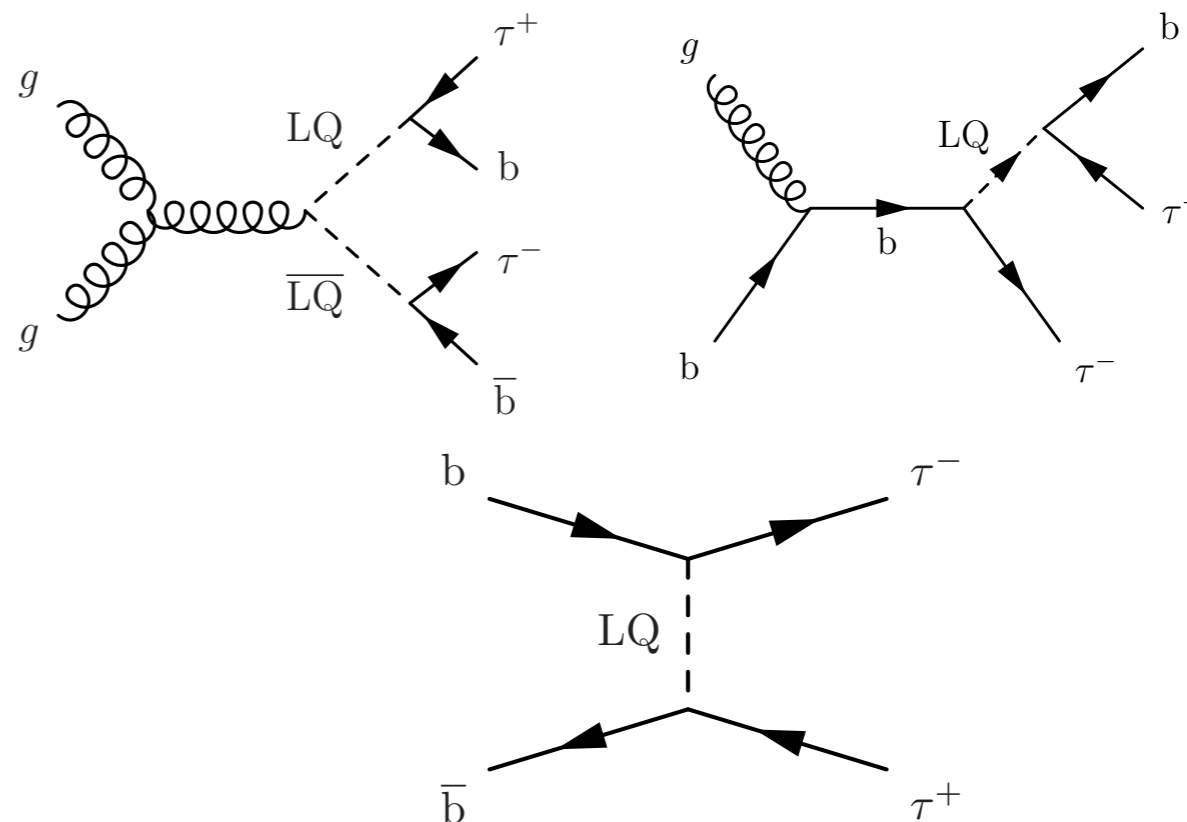
- number of b-tagged jets:

0 b-tags

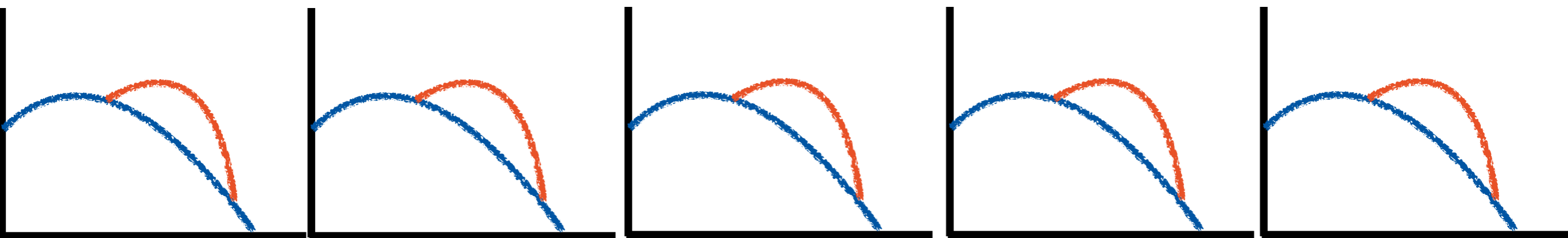
≥ 1 b-tag

- Fitted observable:

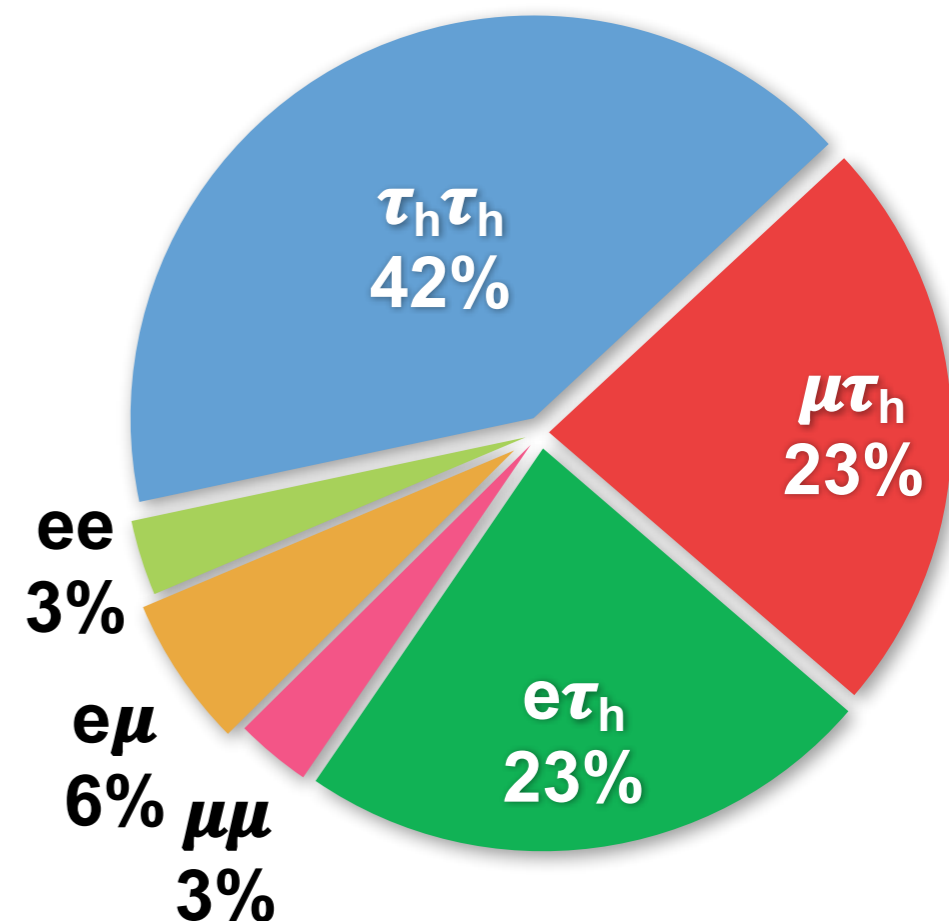
$$S_T^{\text{MET}} = p_T^{j1} + p_T^{\tau1} + p_T^{\tau2} + p_T^{\text{miss}}$$
- Sensitive to resonant & non-resonant LQ processes



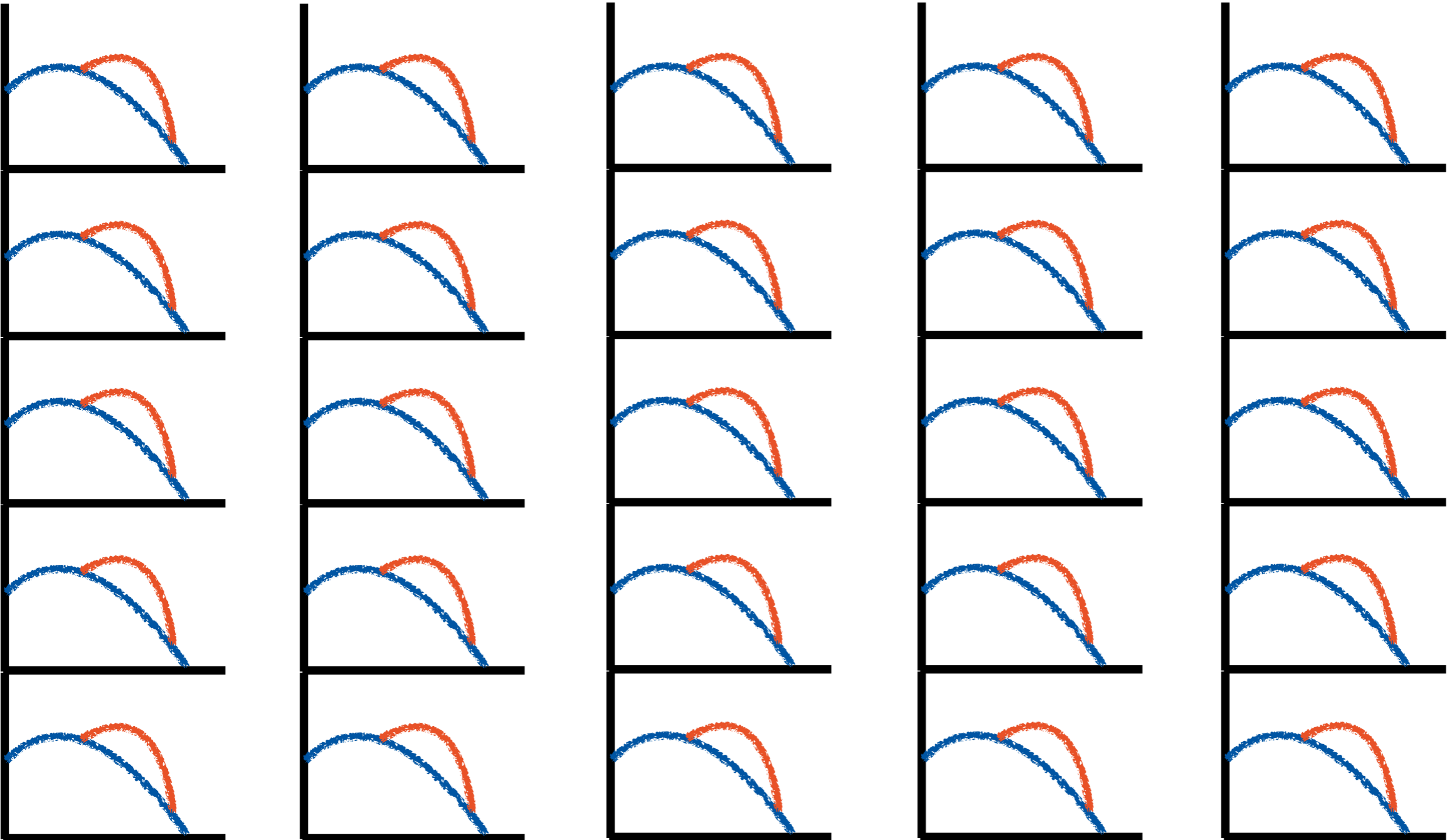
- 5 event categories ...



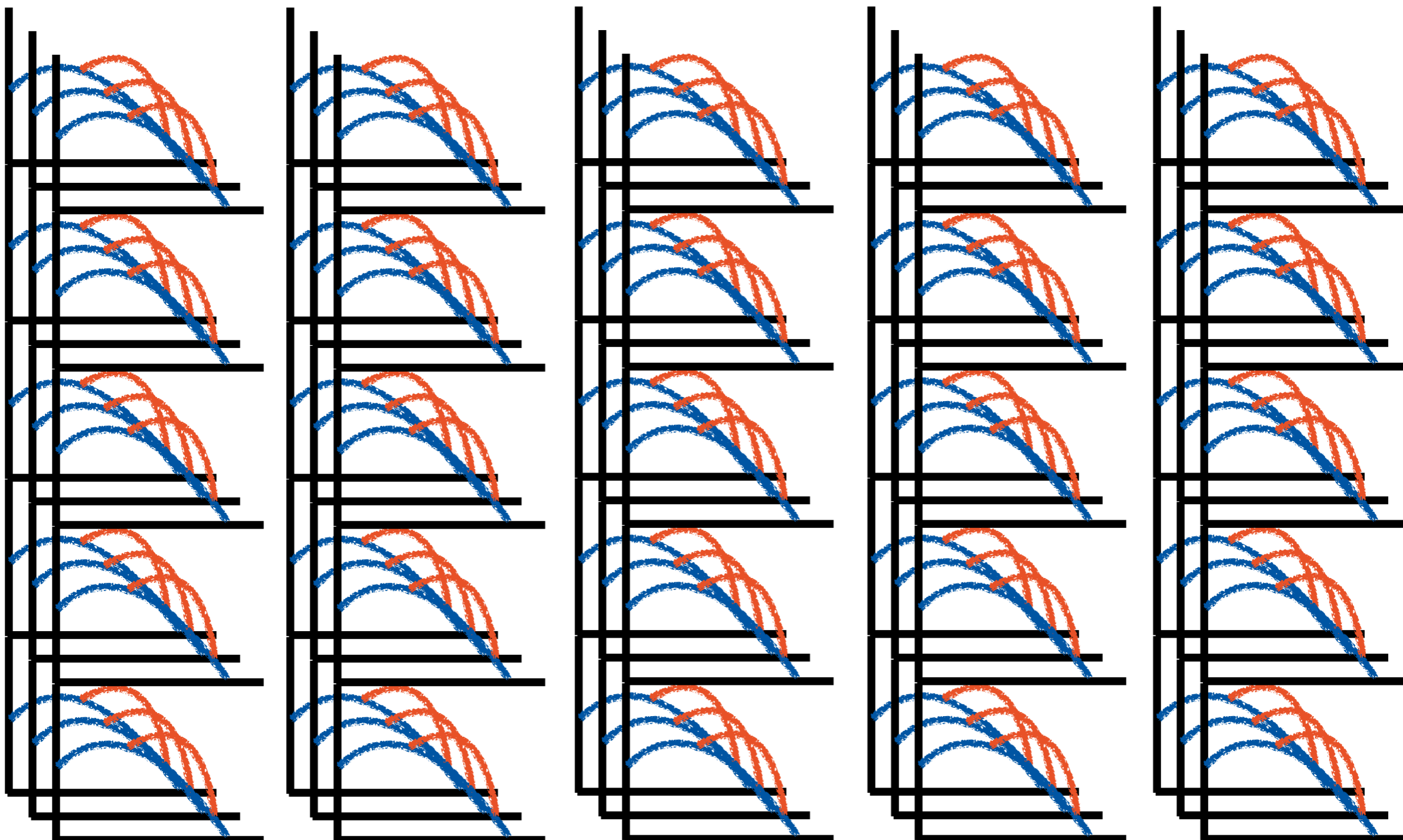
- Consider different τ decay modes
 - ▶ Individual search channels based on lepton flavor
 - ▶ $\tau_h\tau_h$
 - ▶ $e\tau_h$
 - ▶ $\mu\tau_h$
 - ▶ $e\mu$
 - ▶ $\mu\mu$
- Signal regions (88% branching fraction)
- Almost no signal: tt and DY control regions
- $\ell \rightarrow \tau_h$ fakes suppressed by DNN-based τ identification
 - $j \rightarrow \tau_h$ fakes estimated from data



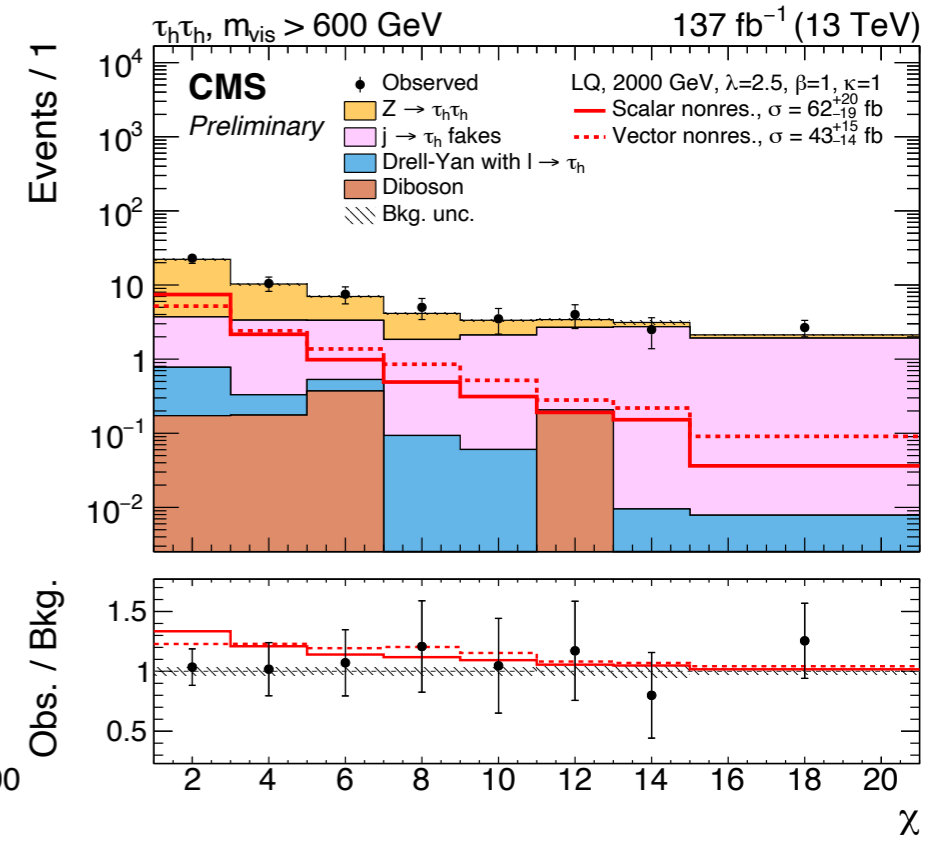
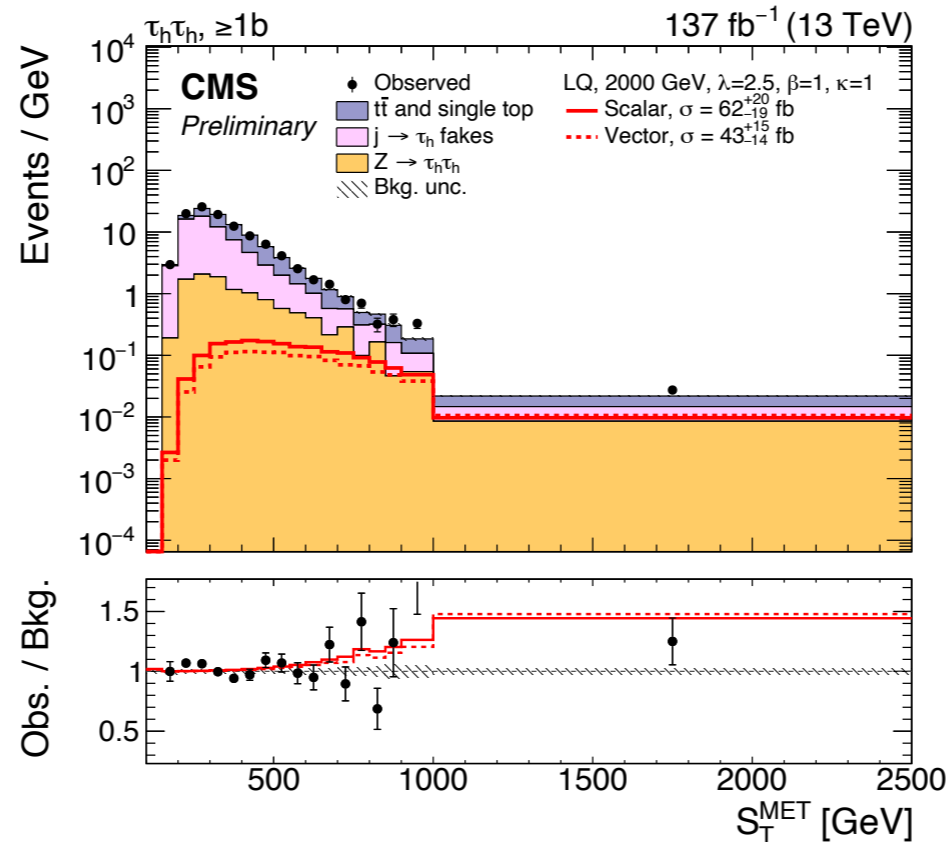
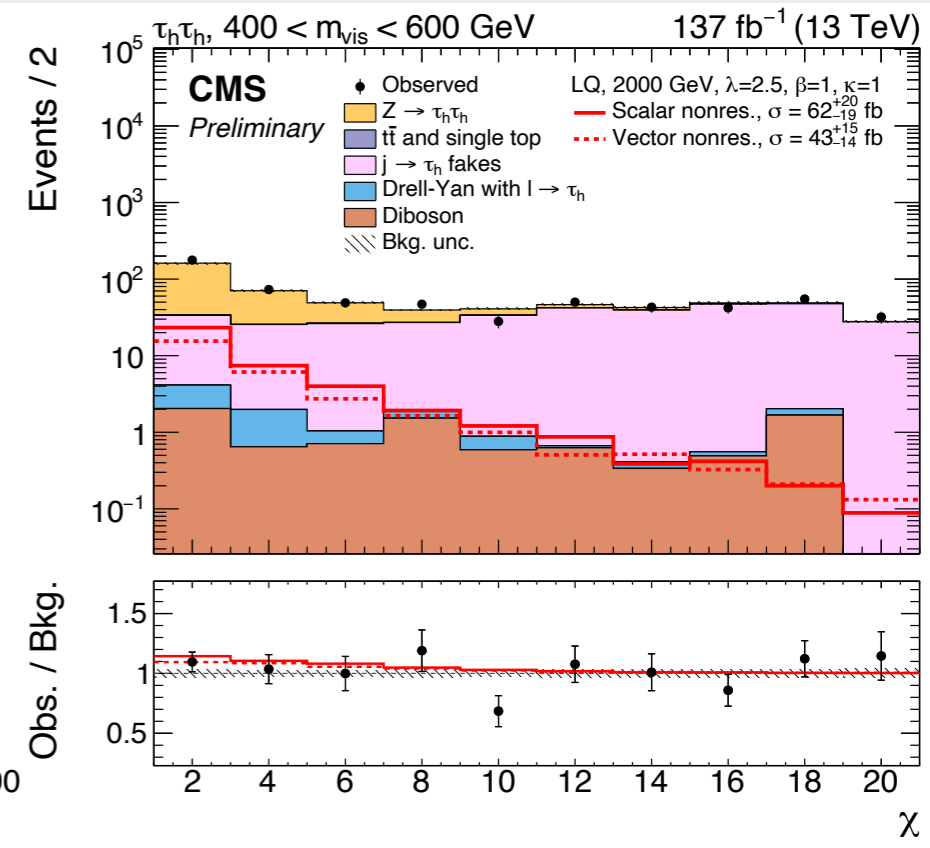
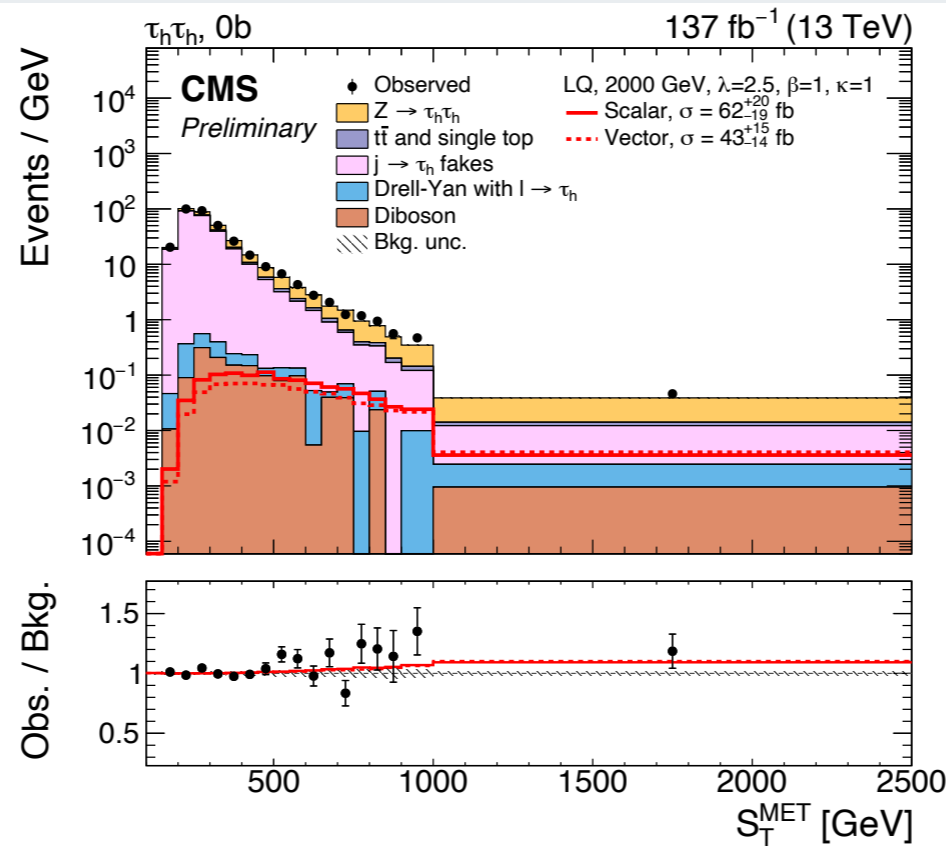
- 5 event categories x 5 $\tau\tau$ decay modes ...



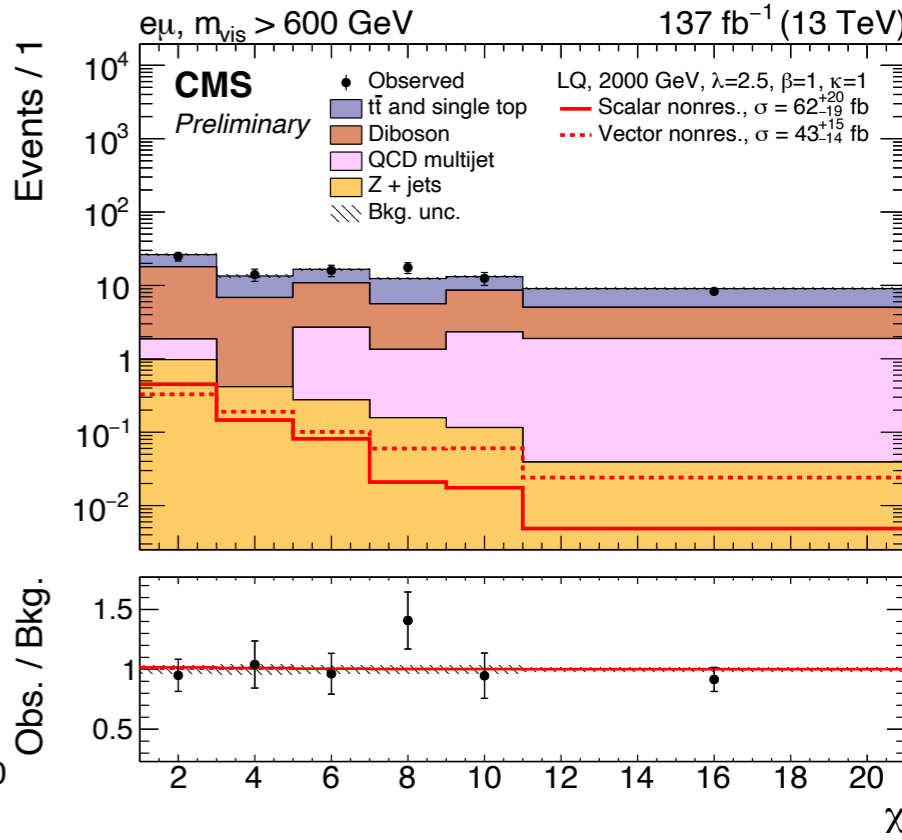
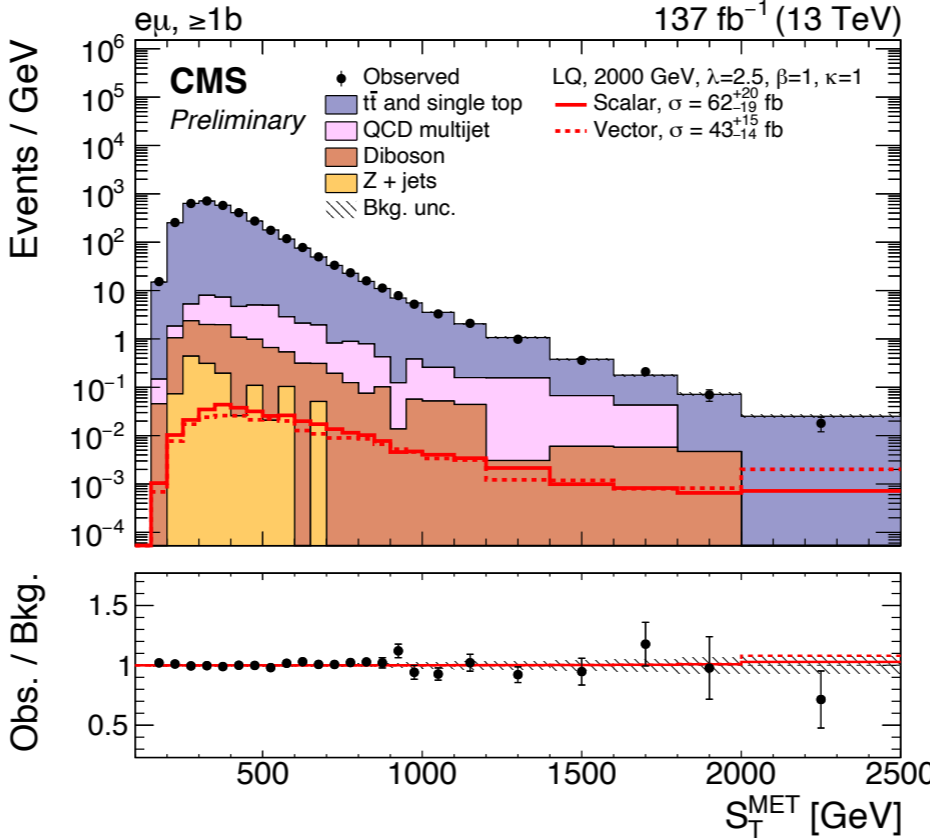
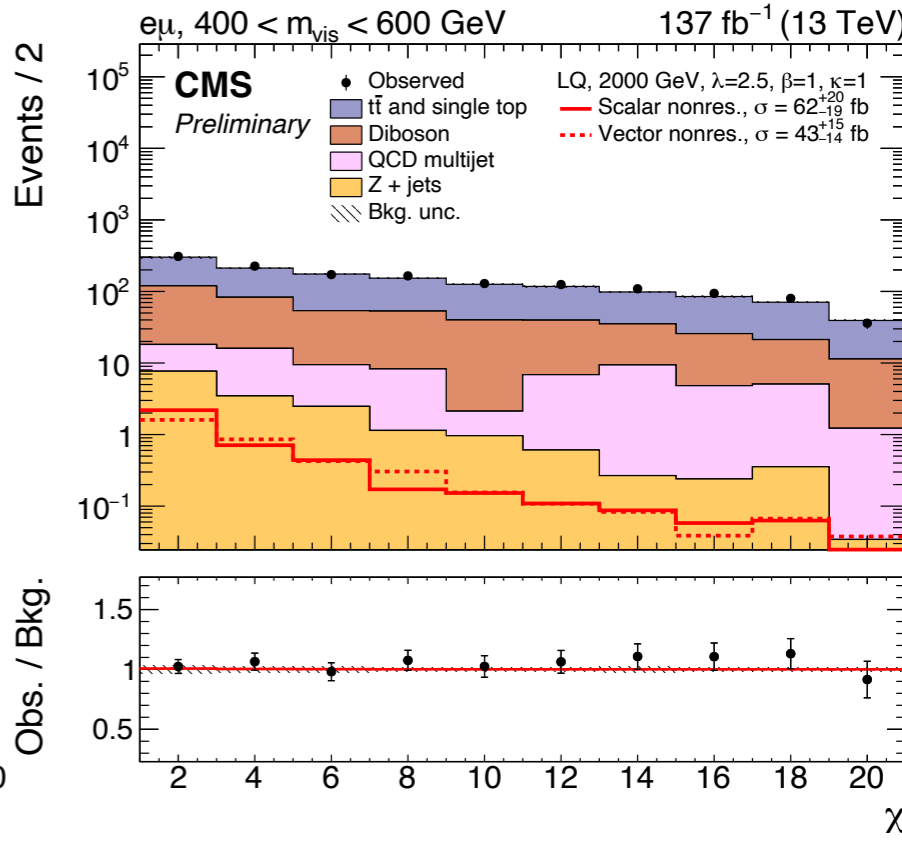
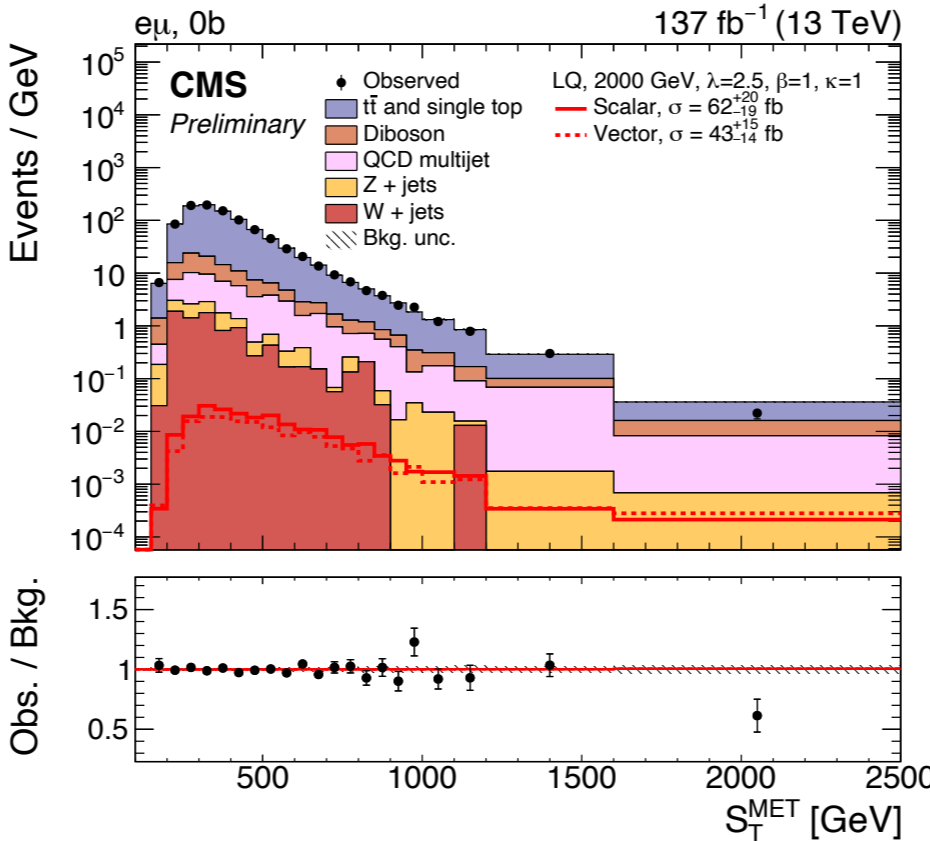
- 5 event categories x 5 $\tau\tau$ decay modes x 3 years of data taking
 - ▶ 75 distributions combined in simultaneous fit to data



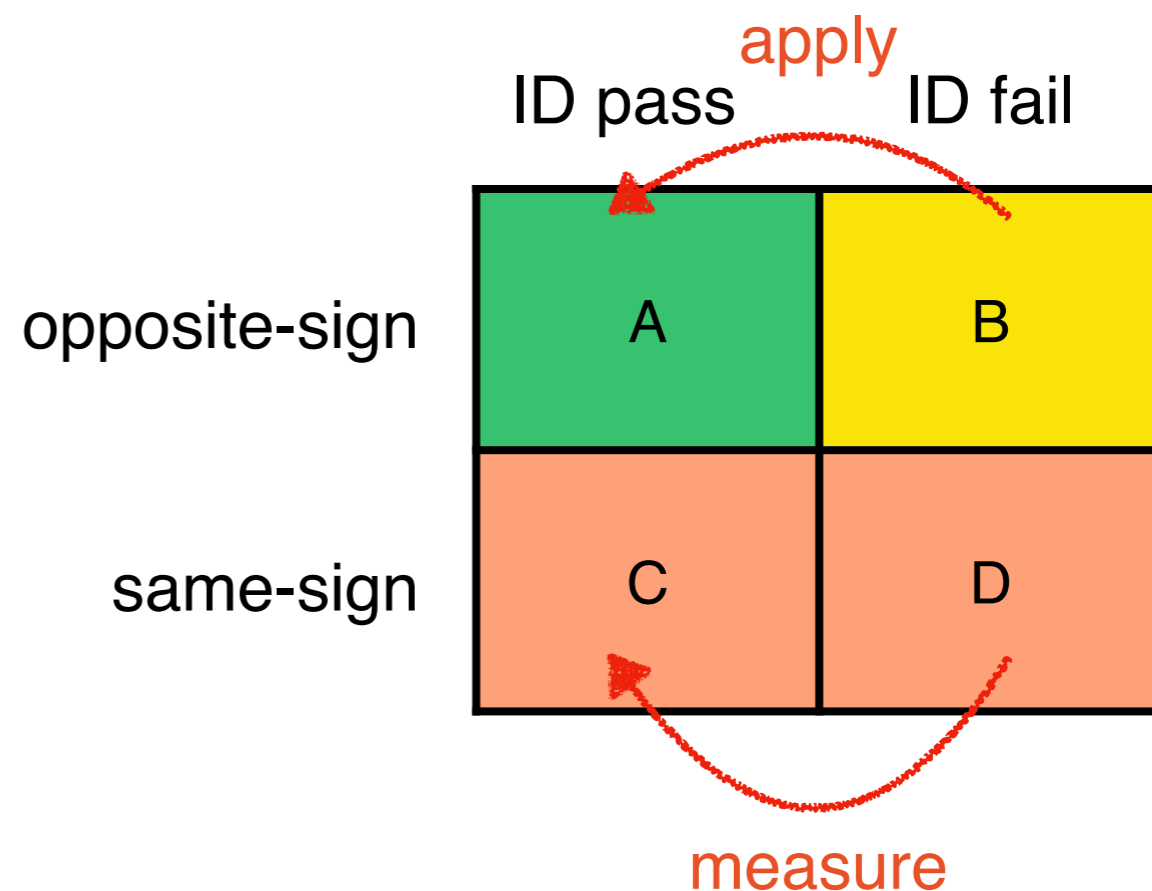
- Post-fit distributions in $\tau_h\tau_h$ channel
- Whole Run-2 dataset
- Vector LQ: 2 TeV, $\lambda = 2.5$
 - ▶ all 3 processes combined
- Disagreement with SM
 - ▶ $t\bar{t}$
 - ▶ DY ($\tau\tau$)
 - ▶ $j \rightarrow \tau$ fakes
- Dominant backgrounds:
 - ▶ $t\bar{t}$
 - ▶ DY ($\tau\tau$)
 - ▶ $j \rightarrow \tau$ fakes



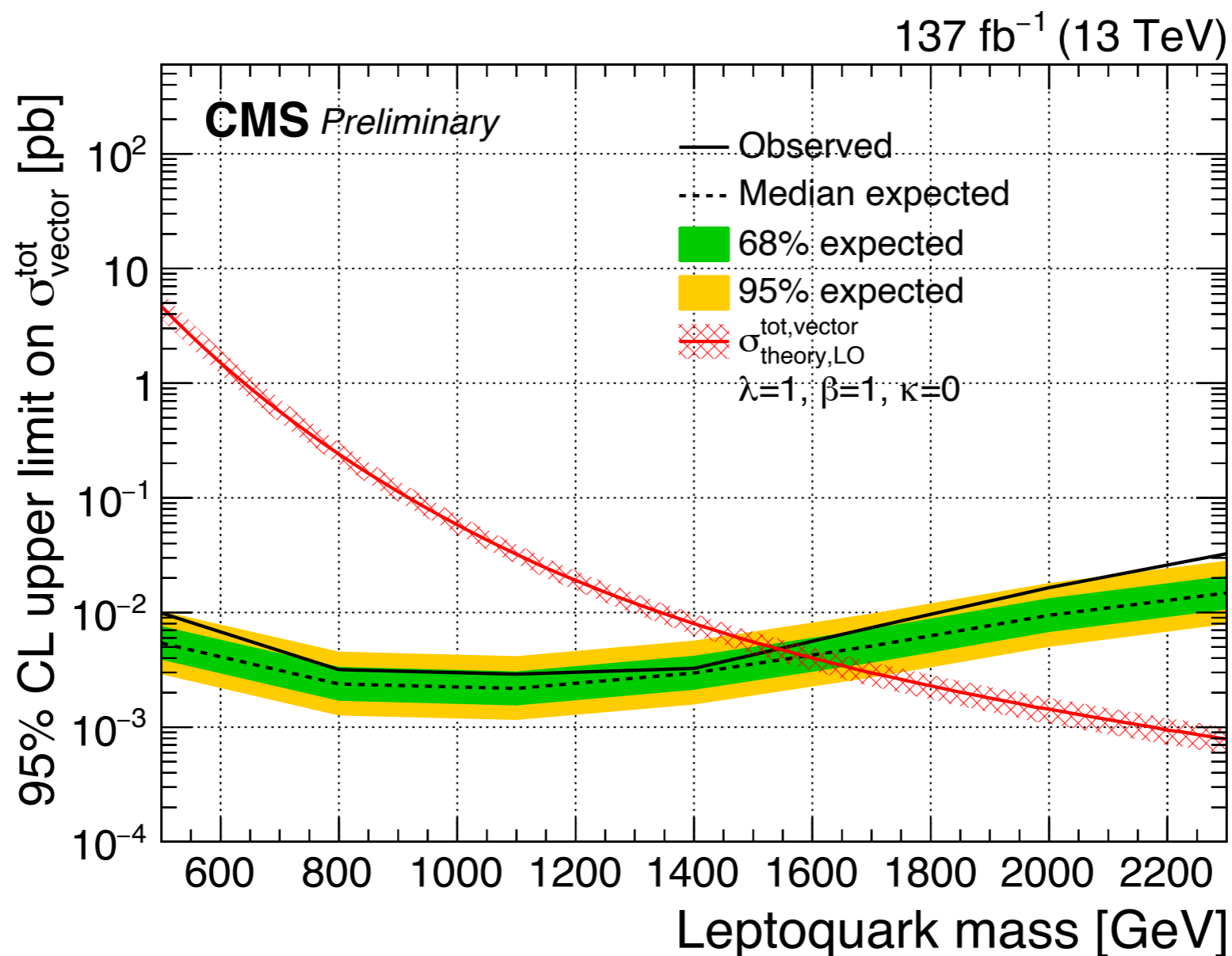
- Backgrounds with genuine τ_h constrained via fit in signal-depleted regions
 - ▶ $t\bar{t}$ in $e\mu$ region
 - ▶ DY in $\mu\mu$ region
- Useful for both experimental and theoretical uncertainties
- Excellent agreement with SM found



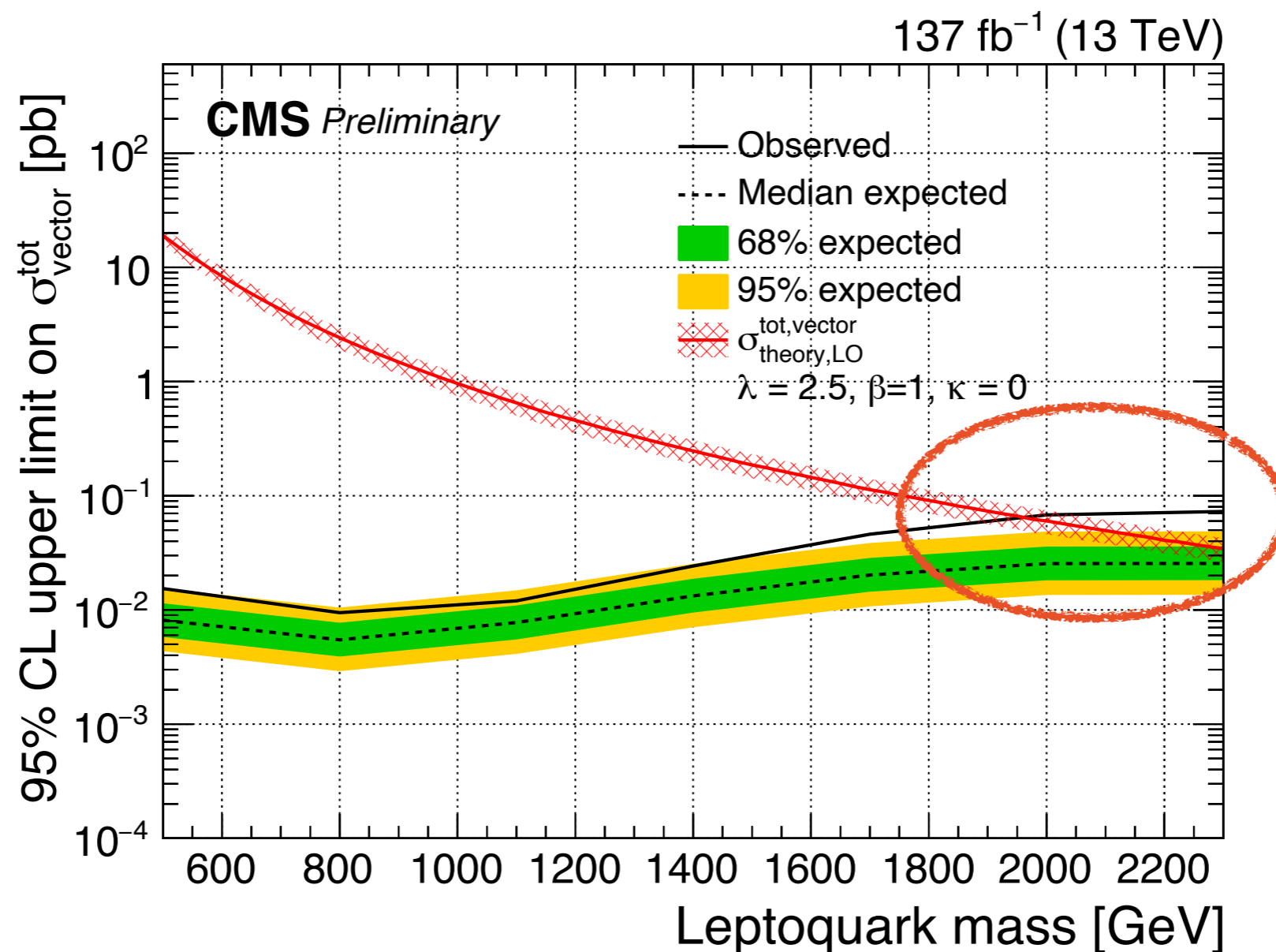
- Background with $j \rightarrow \tau_h$ fakes derived directly from data
- Separately for different processes
 - ▶ $t\bar{t}$
 - ▶ W+jets
 - ▶ QCD
- Invert τ_h identification \Rightarrow rich in fake τ_h
- Fake rate measured in same-sign $\tau\tau$ events
- applied to opposite-sign data



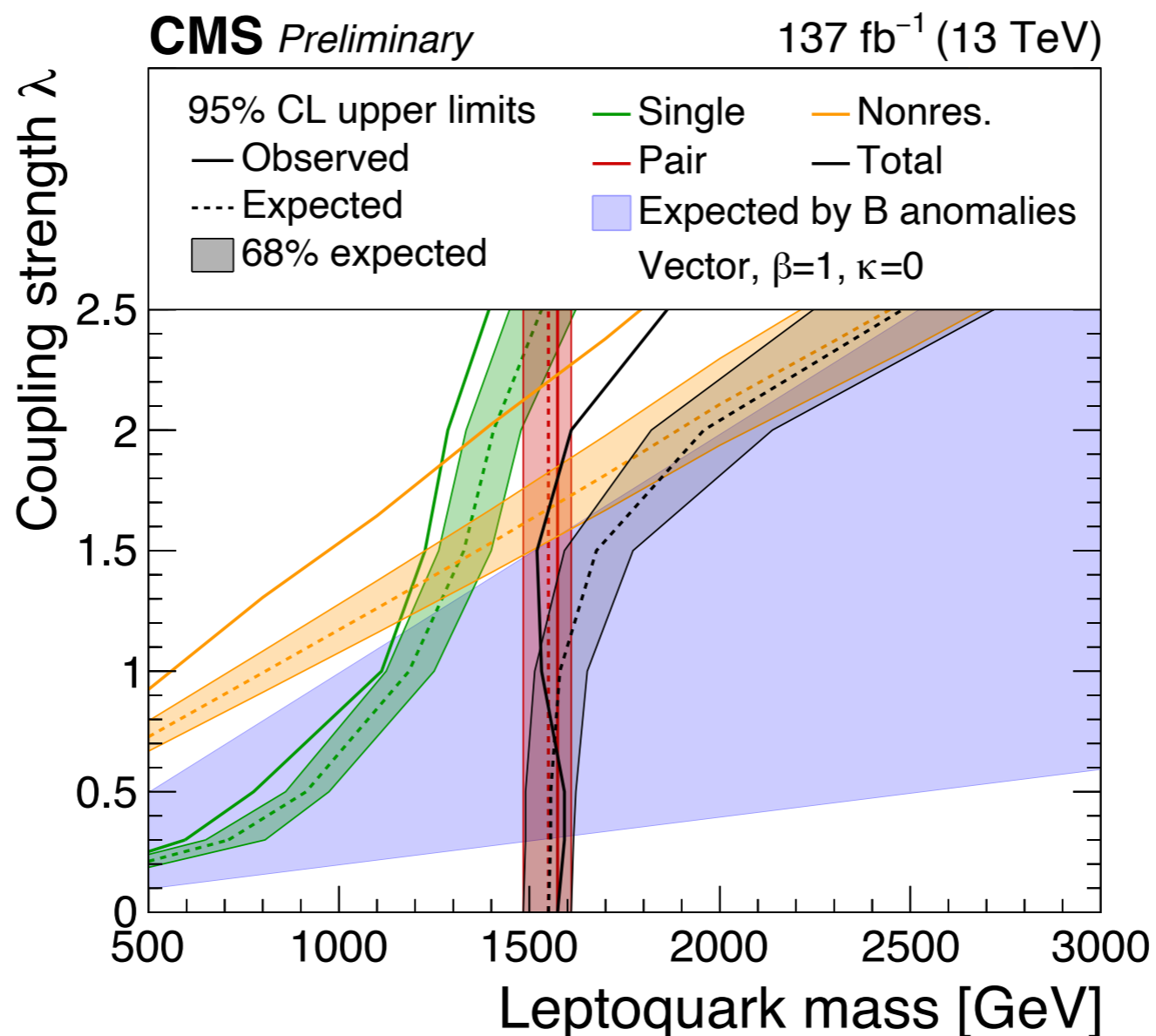
- Simultaneous fit of all 75 distributions
- Signal combined according to relative cross sections of each signal process
- Vector LQs excluded below 1.8-1.9 TeV assuming $\lambda = 1 \rightarrow$ LQ pair production



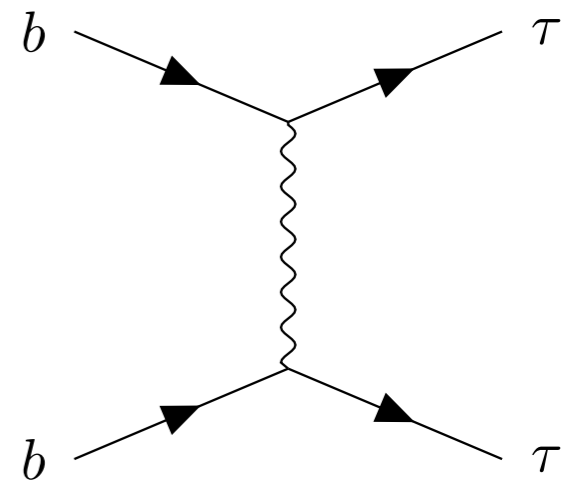
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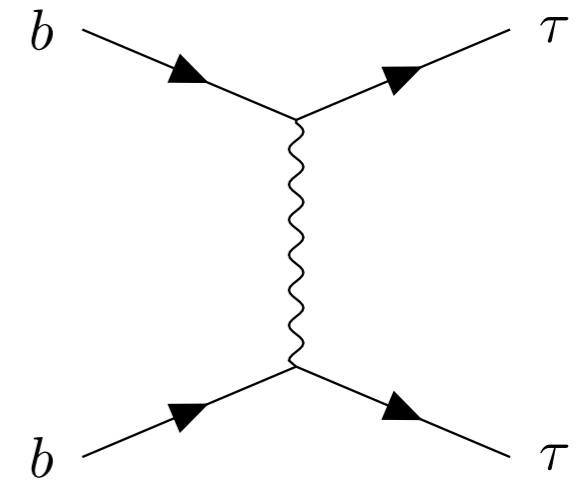
- Typical signature of searches for heavy $H \rightarrow \tau\tau$
 - ▶ Search in distribution of transverse mass
 - ▶ Sensitive to LQ t -channel signal, allow LQ $\rightarrow s\tau, b\tau$
 - ▶ Couplings predicted to fit anomalies [\[JHEP 08 \(2021\) 050\]](https://arxiv.org/abs/2108.050)



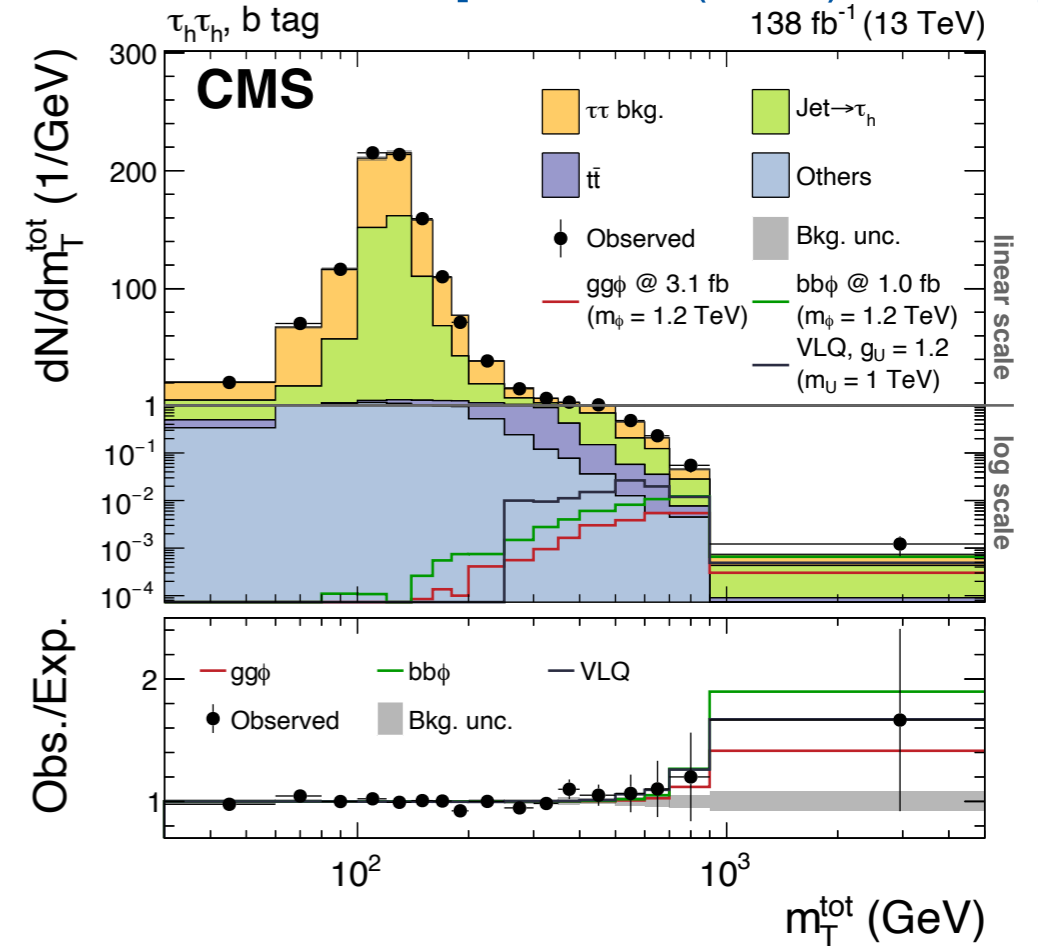
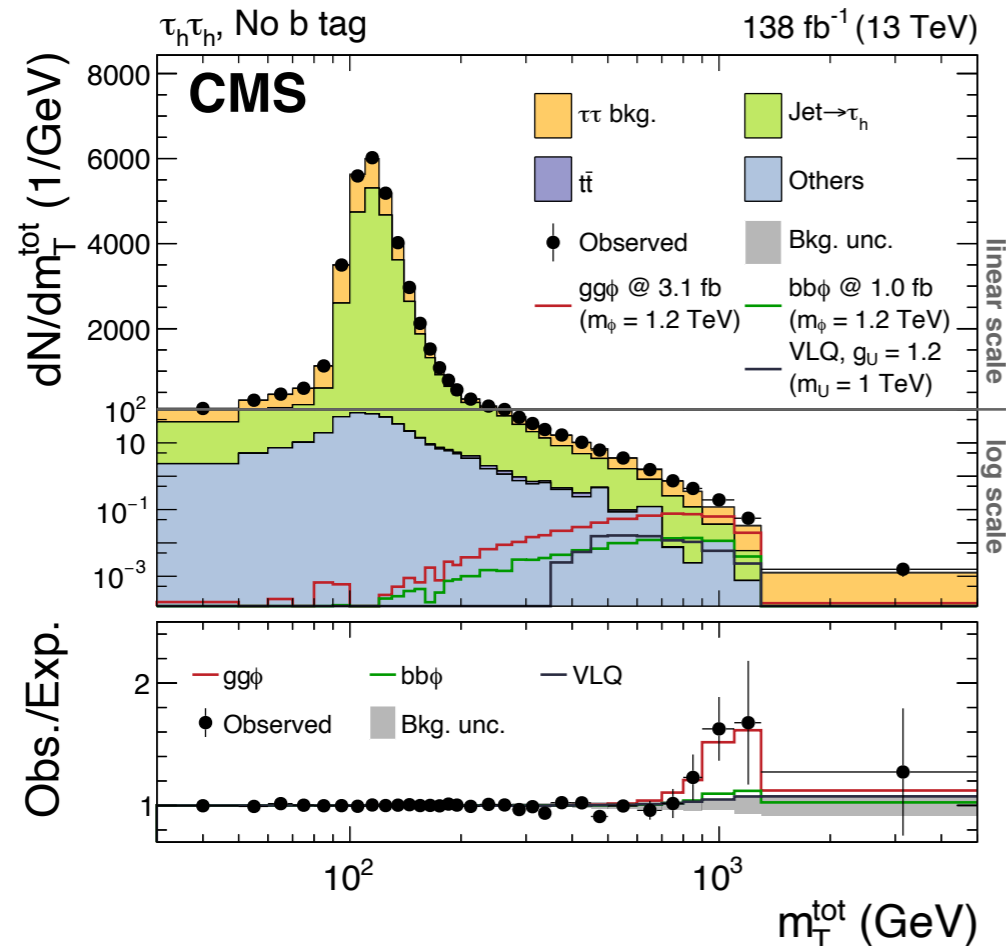
$$\beta_L = \begin{pmatrix} 0 & 0 & \cancel{\beta_L^{b\tau}} \\ 0 & \cancel{\beta_L^{s\mu}} & \beta_L^{s\tau} \\ 0 & \cancel{\beta_L^{b\mu}} & \beta_L^{b\tau} \end{pmatrix}$$

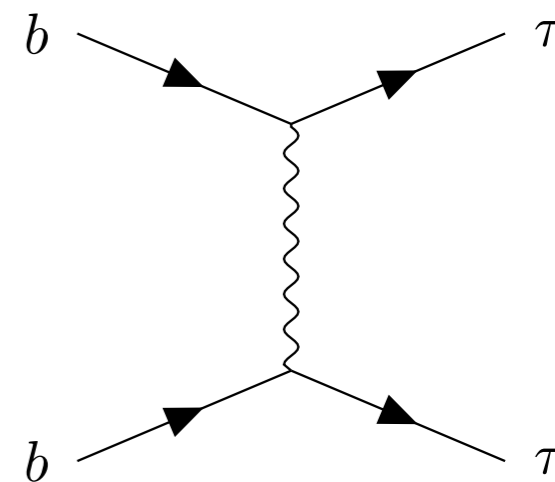
$$\beta_R = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & \beta_R^{b\tau} \end{pmatrix}$$

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- Similar event selection & categorization, **but not identical**
- Independent background estimation, different discriminant

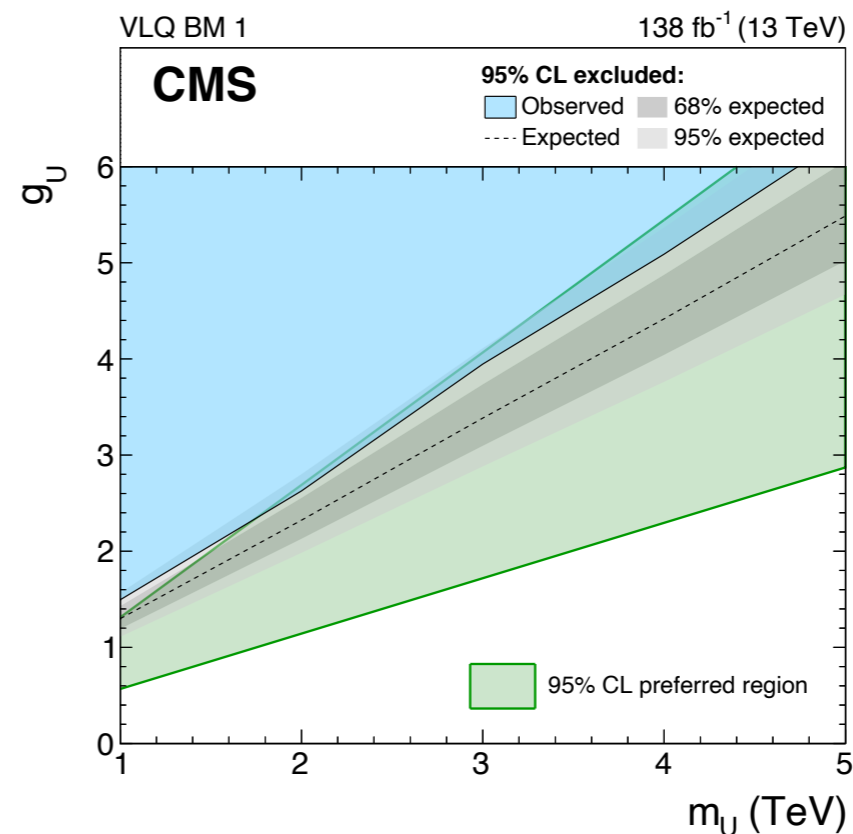
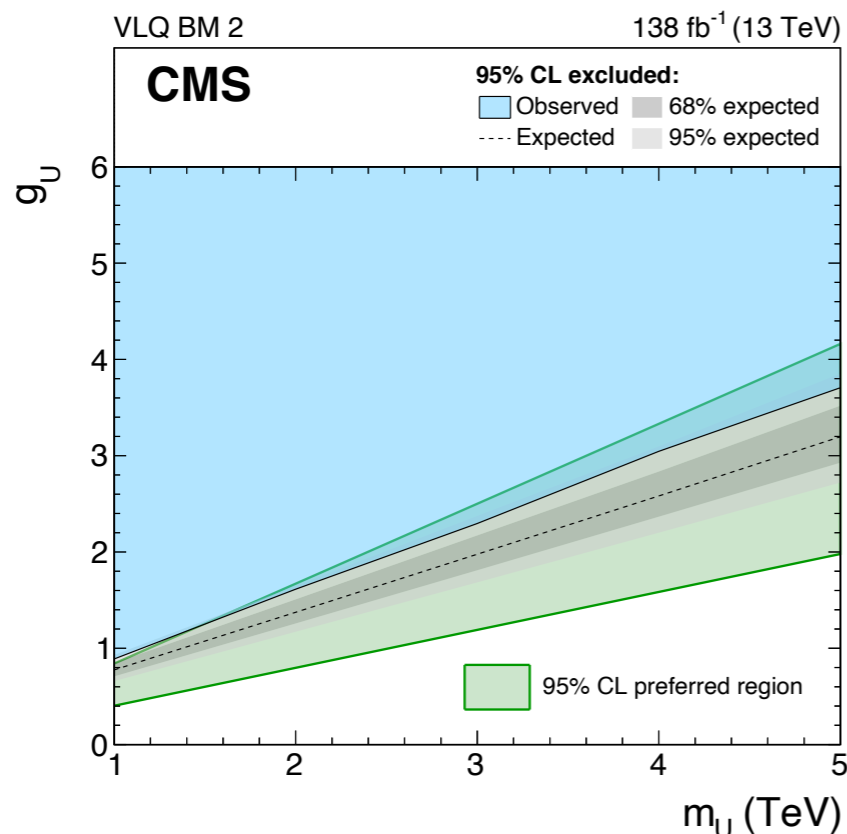


ATLAS: agreement with SM [\[PRL 125 \(2020\) 051801\]](#)

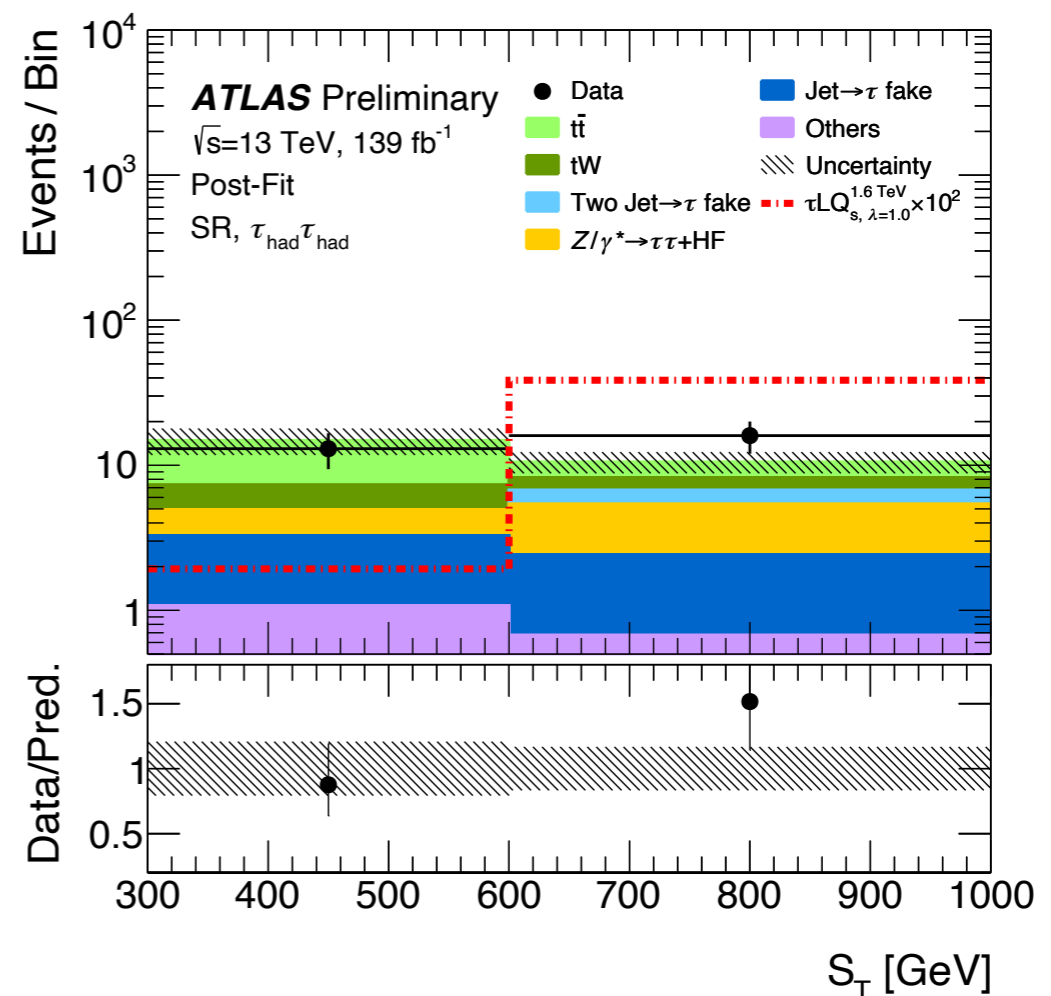
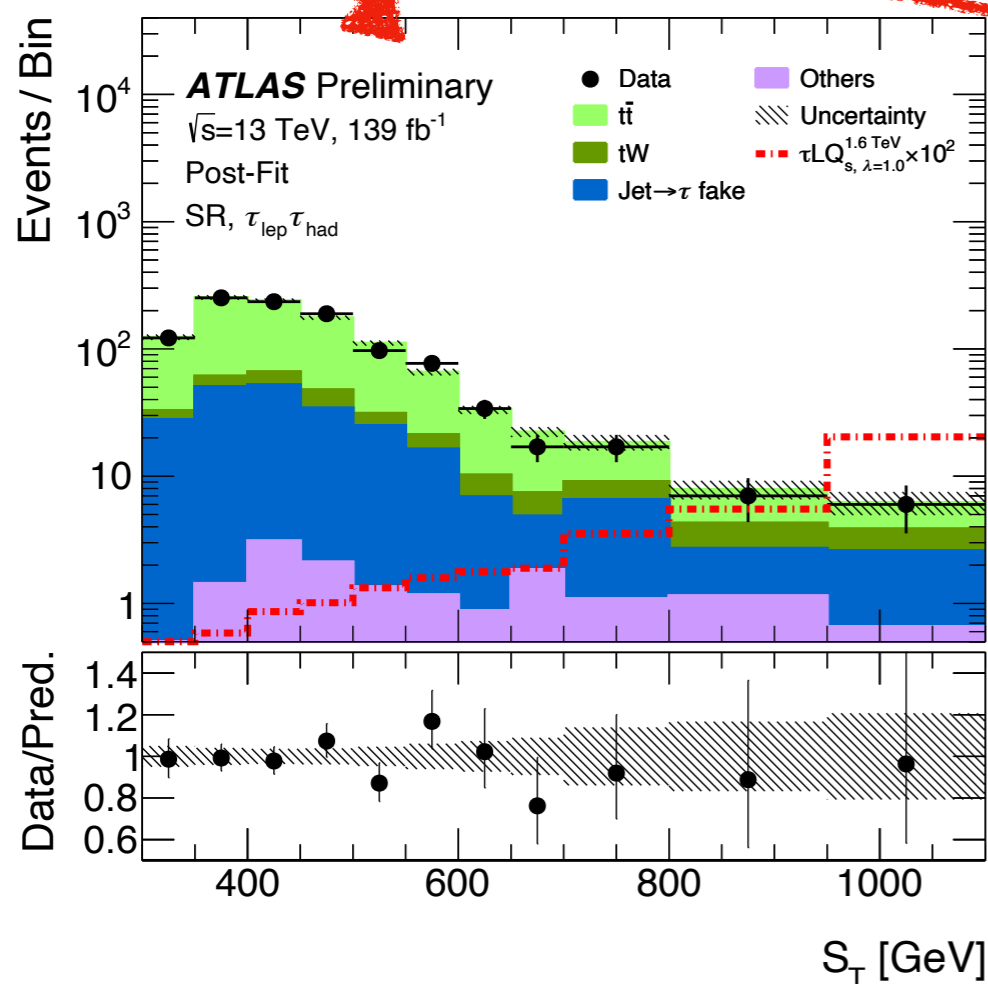
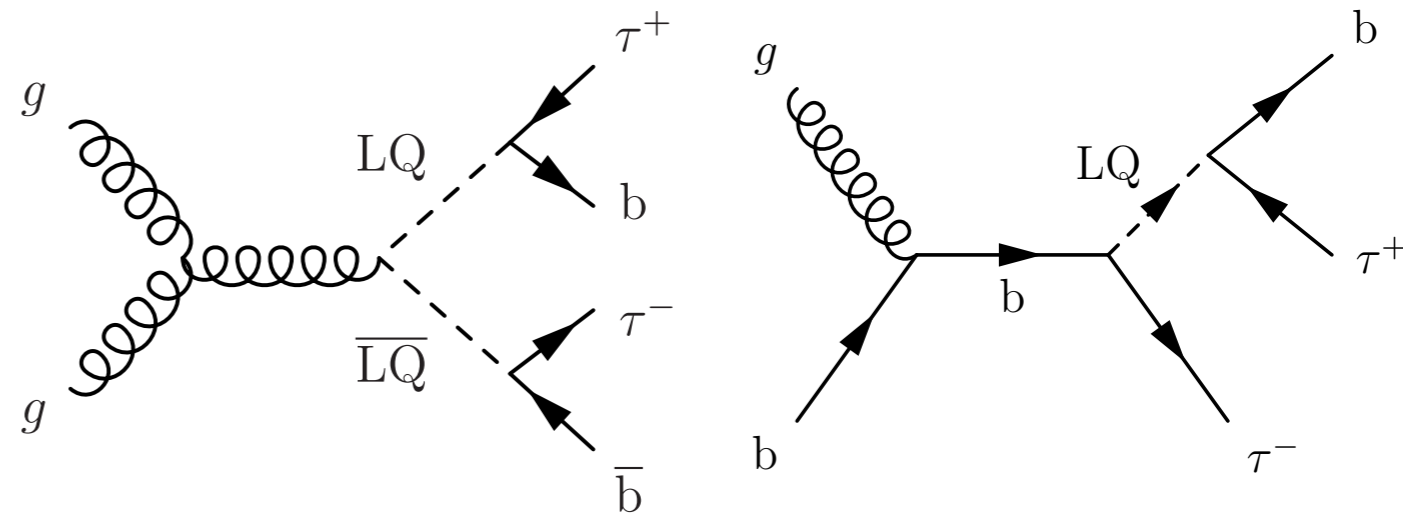




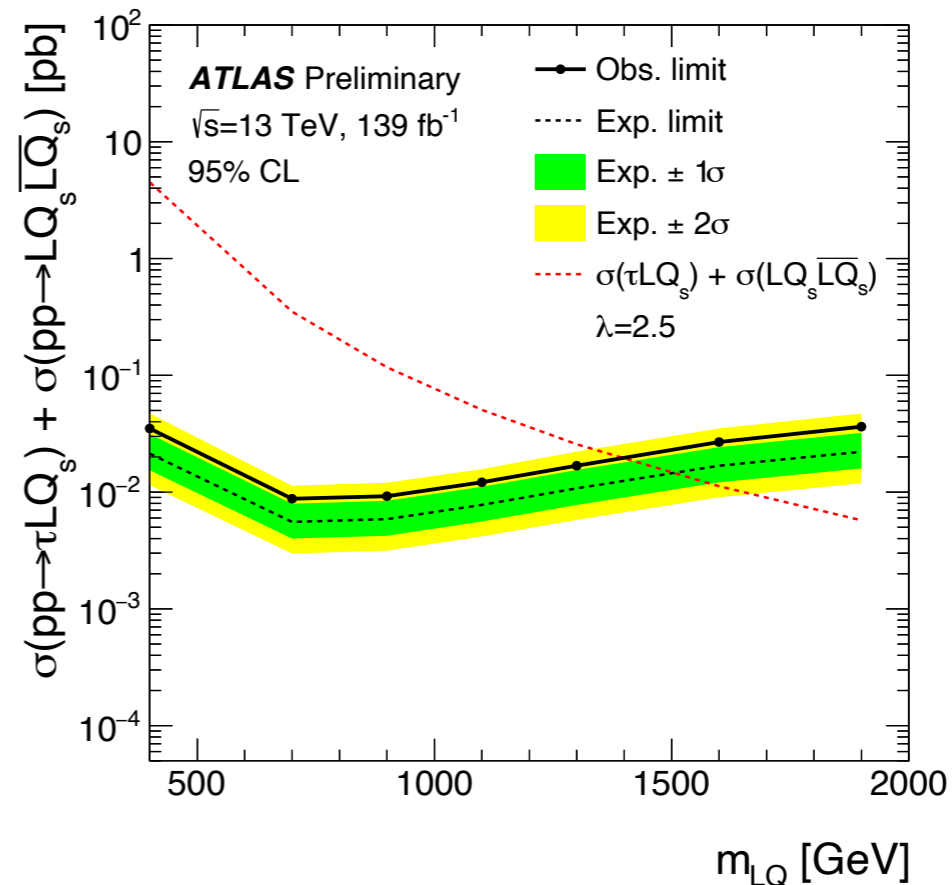
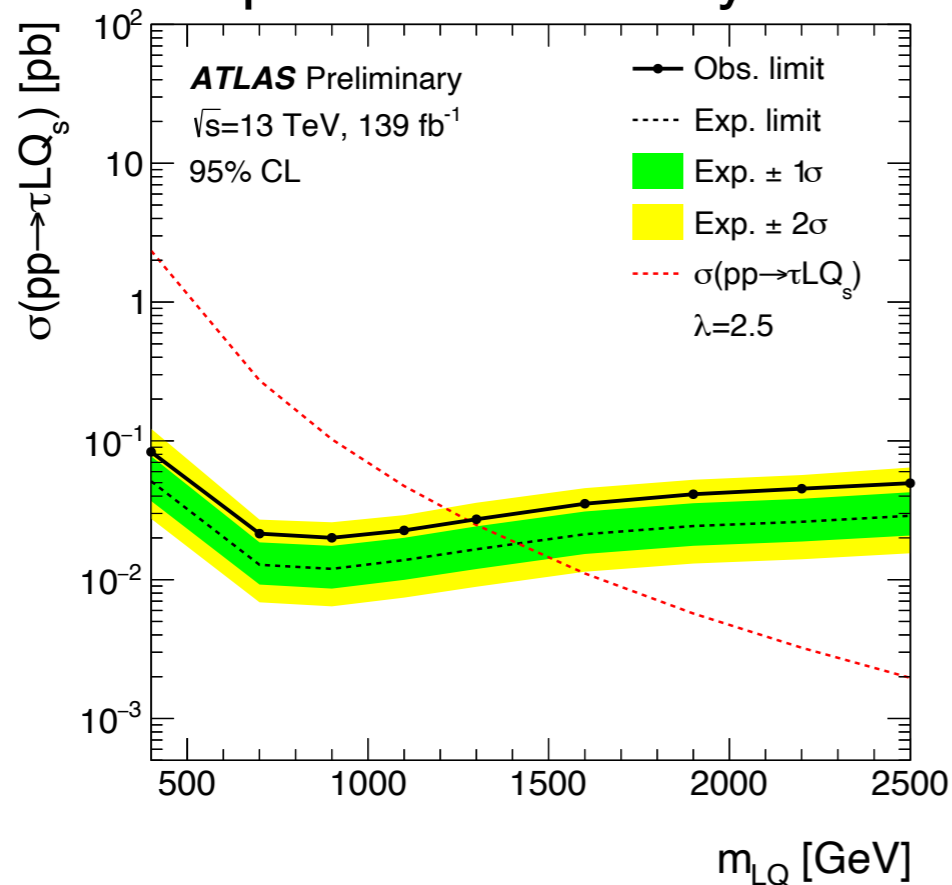
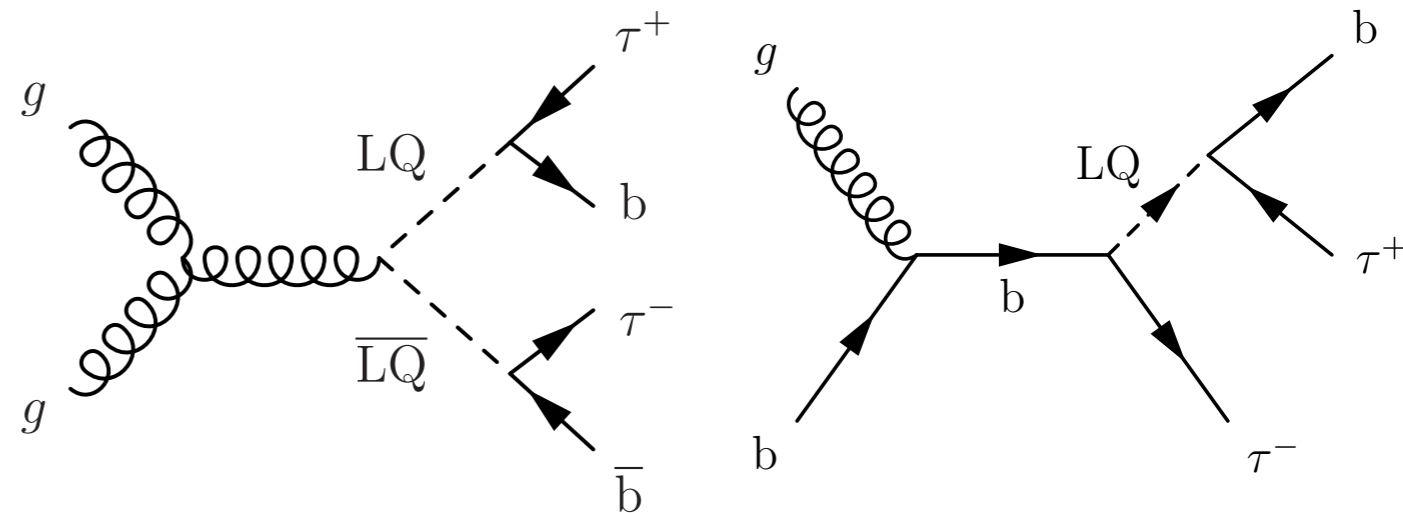
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- Similar event selection & categorization, **but not identical**
- Independent background estimation, different discriminant
- 1-2 σ discrepancy between expected and observed limit



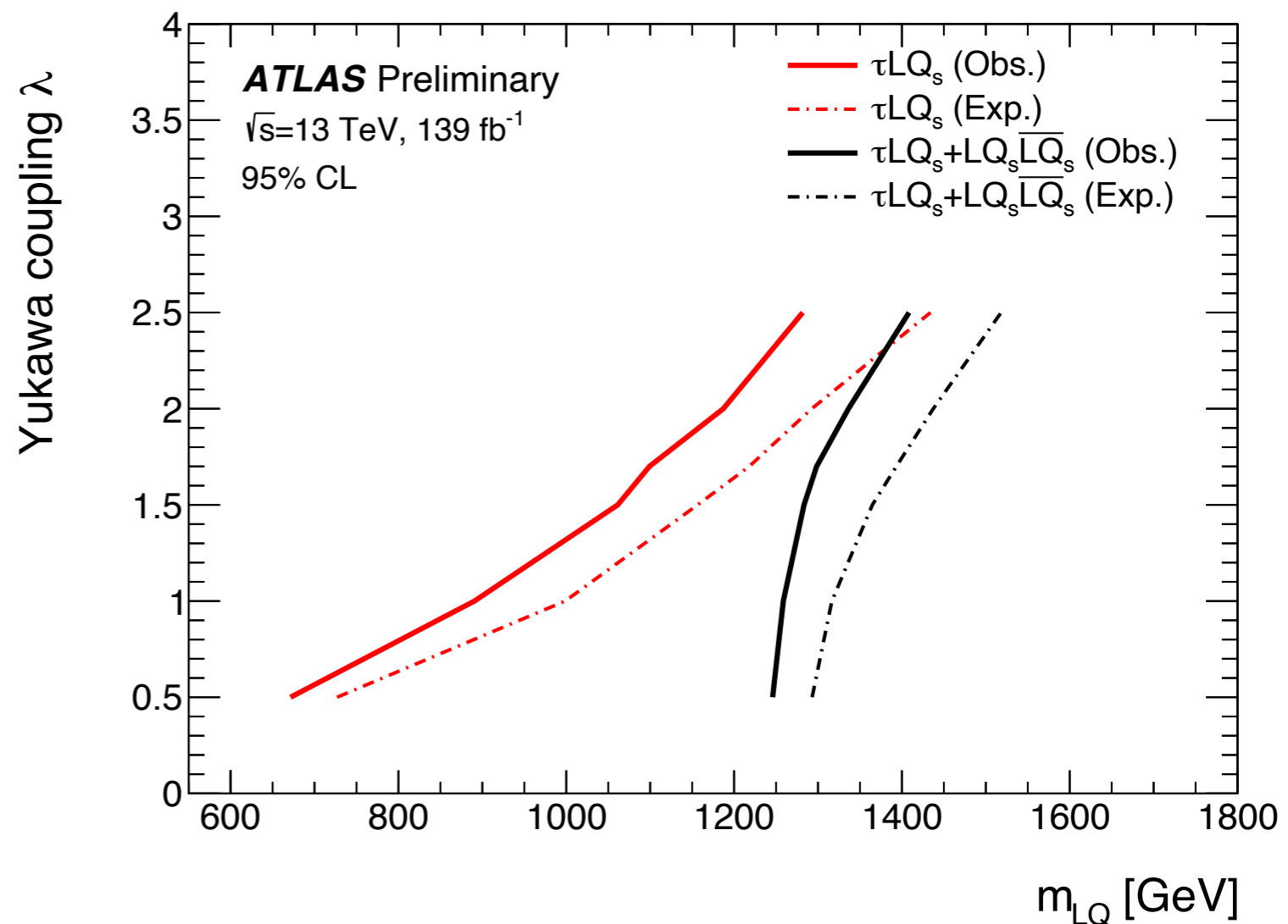
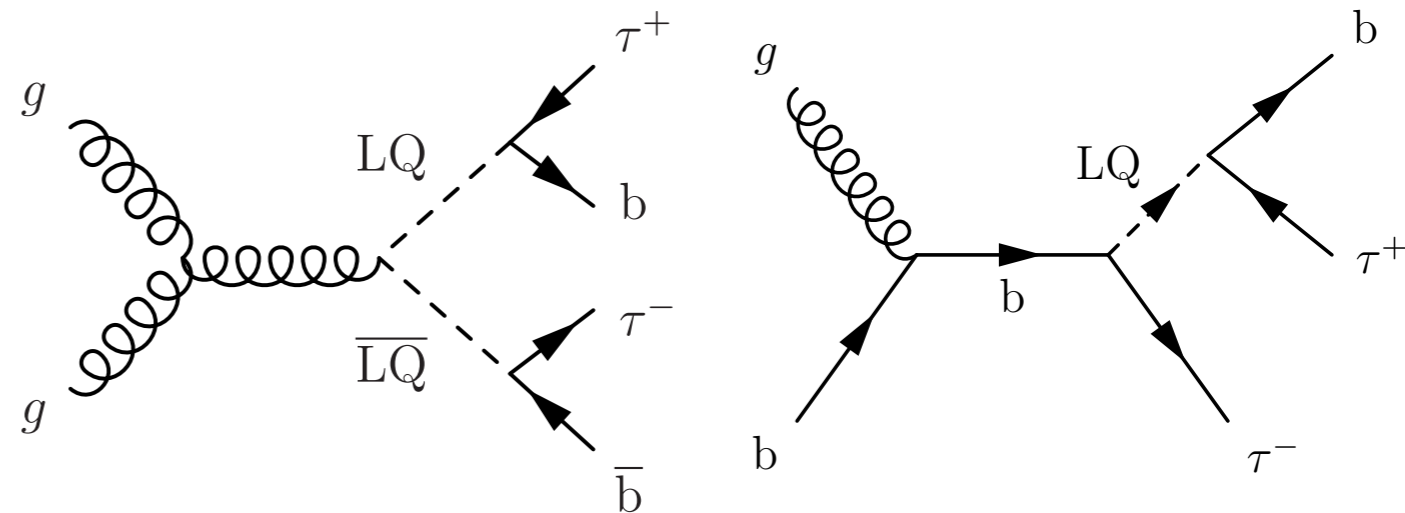
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- Several data-driven corrections to backgrounds
- Simultaneous fit of distributions of S_T in $\ell\tau_h$ and $\tau_h\tau_h$ channels



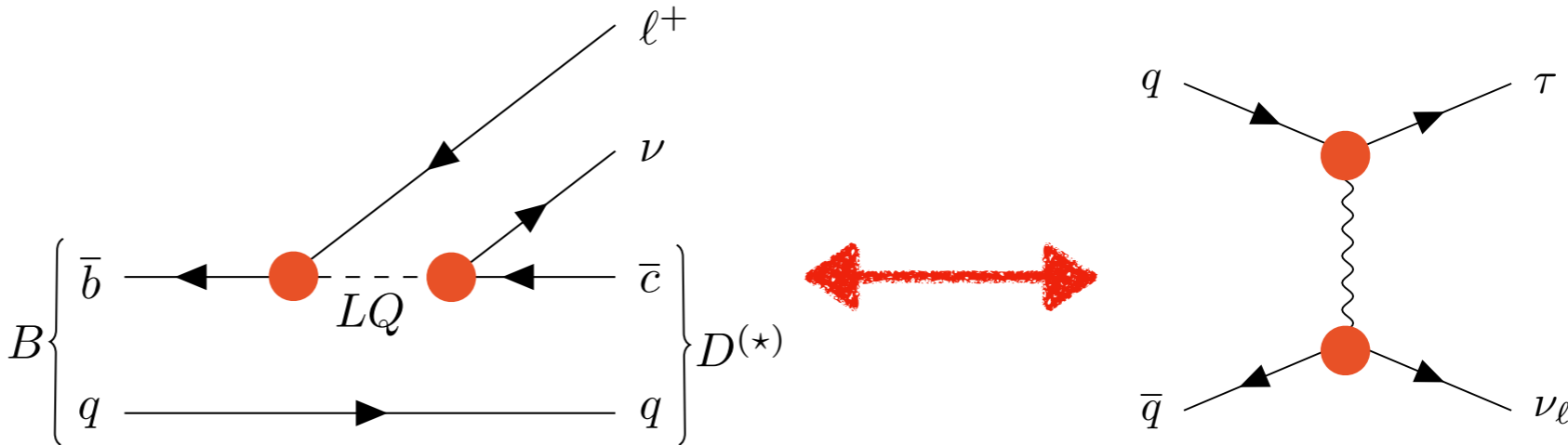
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- Combination of single & pair production improves sensitivity
- Limits on coupling λ vs. m_{LQ}

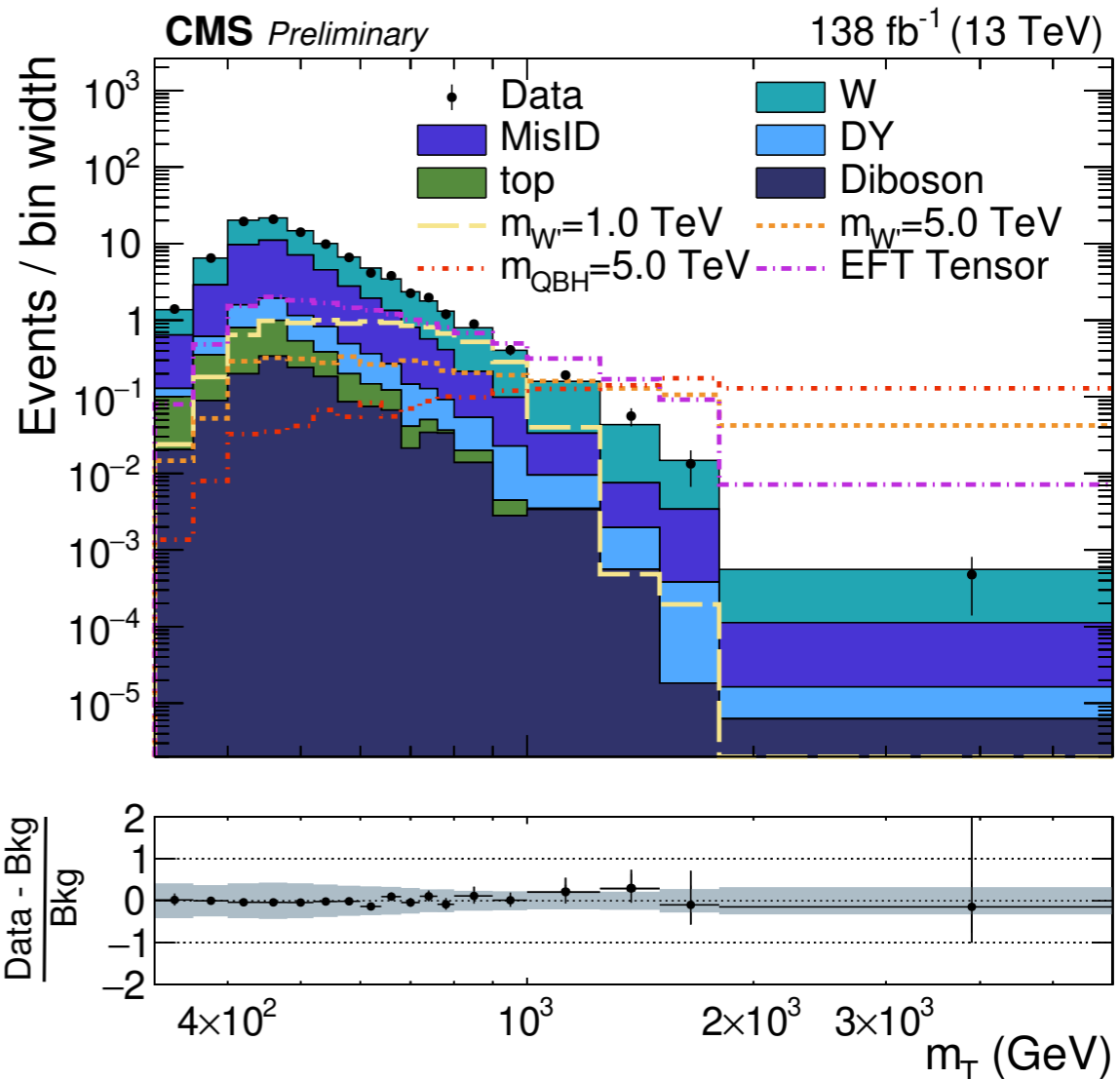


- Consider $b \rightarrow c\tau\nu$
- LQ t channel $\rightarrow \tau\nu$

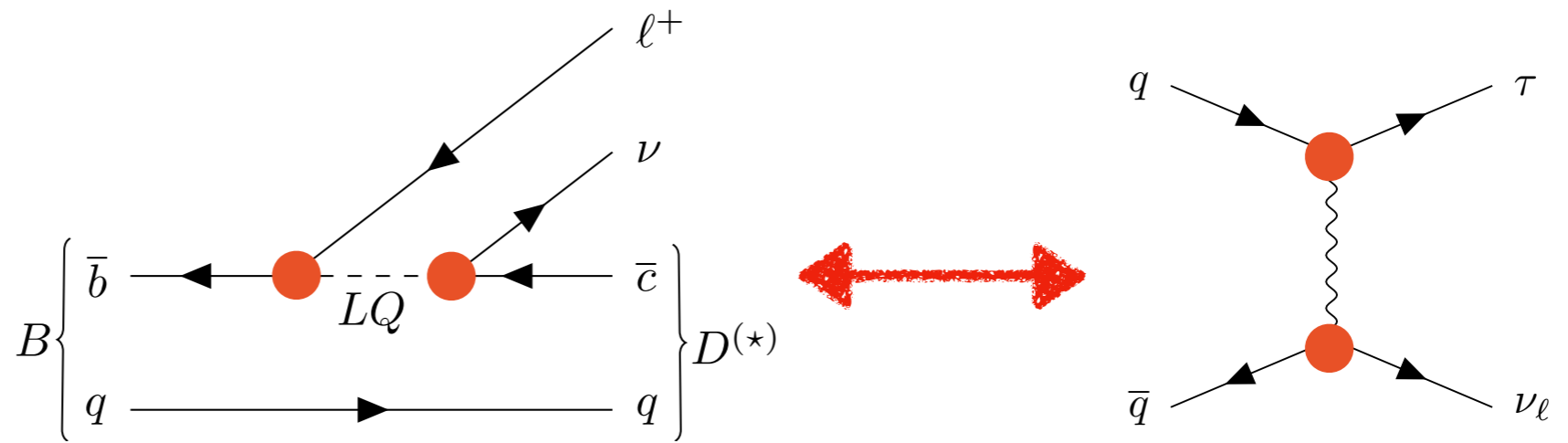


- Search for NP in $\tau + p_T^{\text{miss}}$ final state
 - ▶ Transverse mass final discriminant
 - ▶ Allow **all** couplings predicted to fit anomalies [\[JHEP 08 \(2021\) 050\]](#)

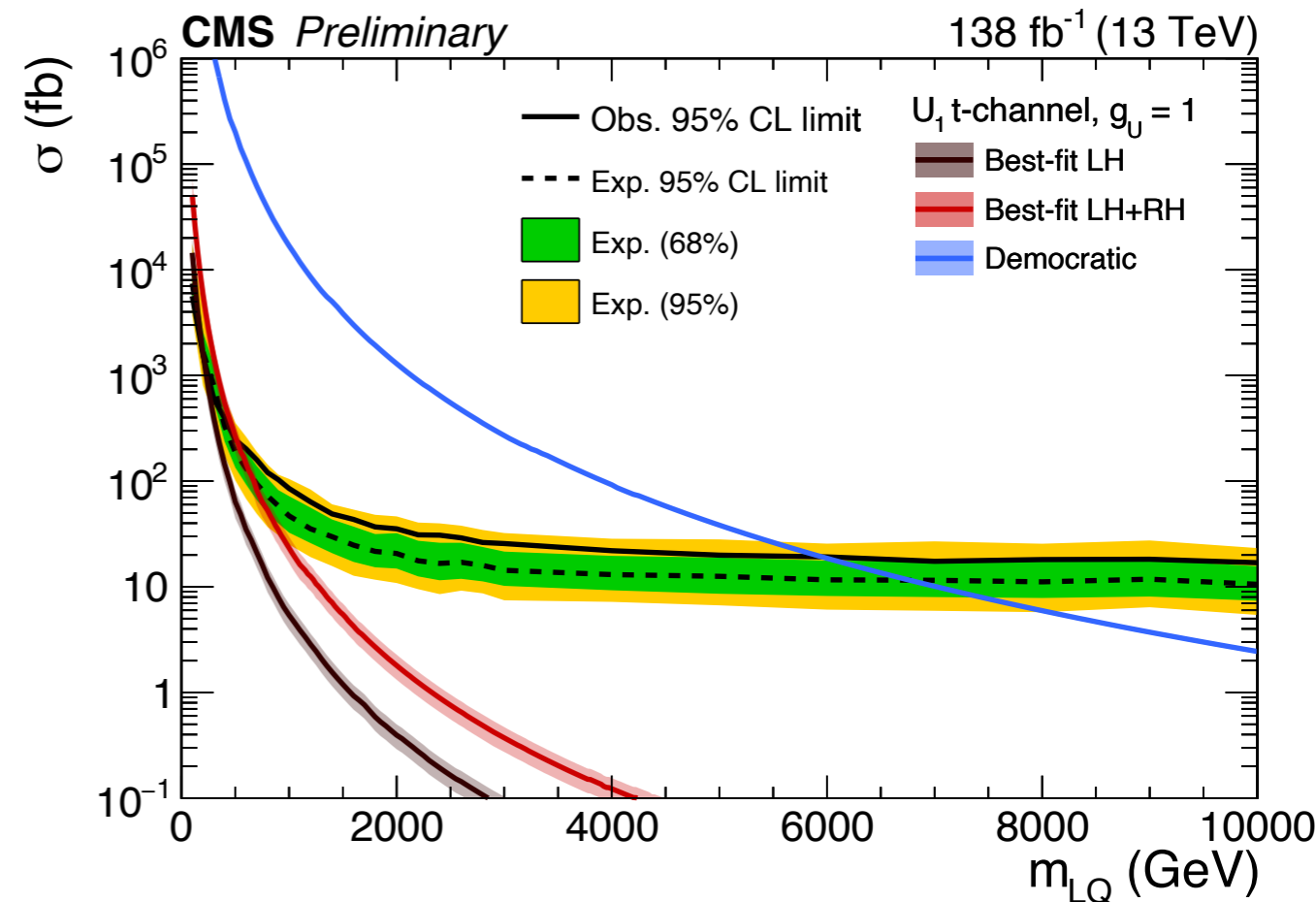
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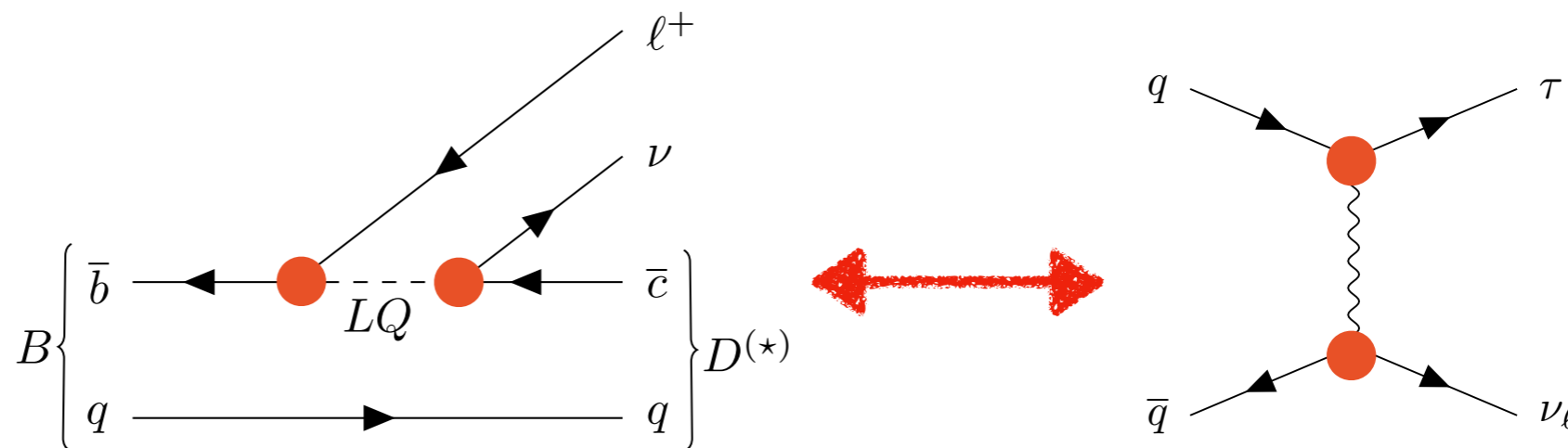
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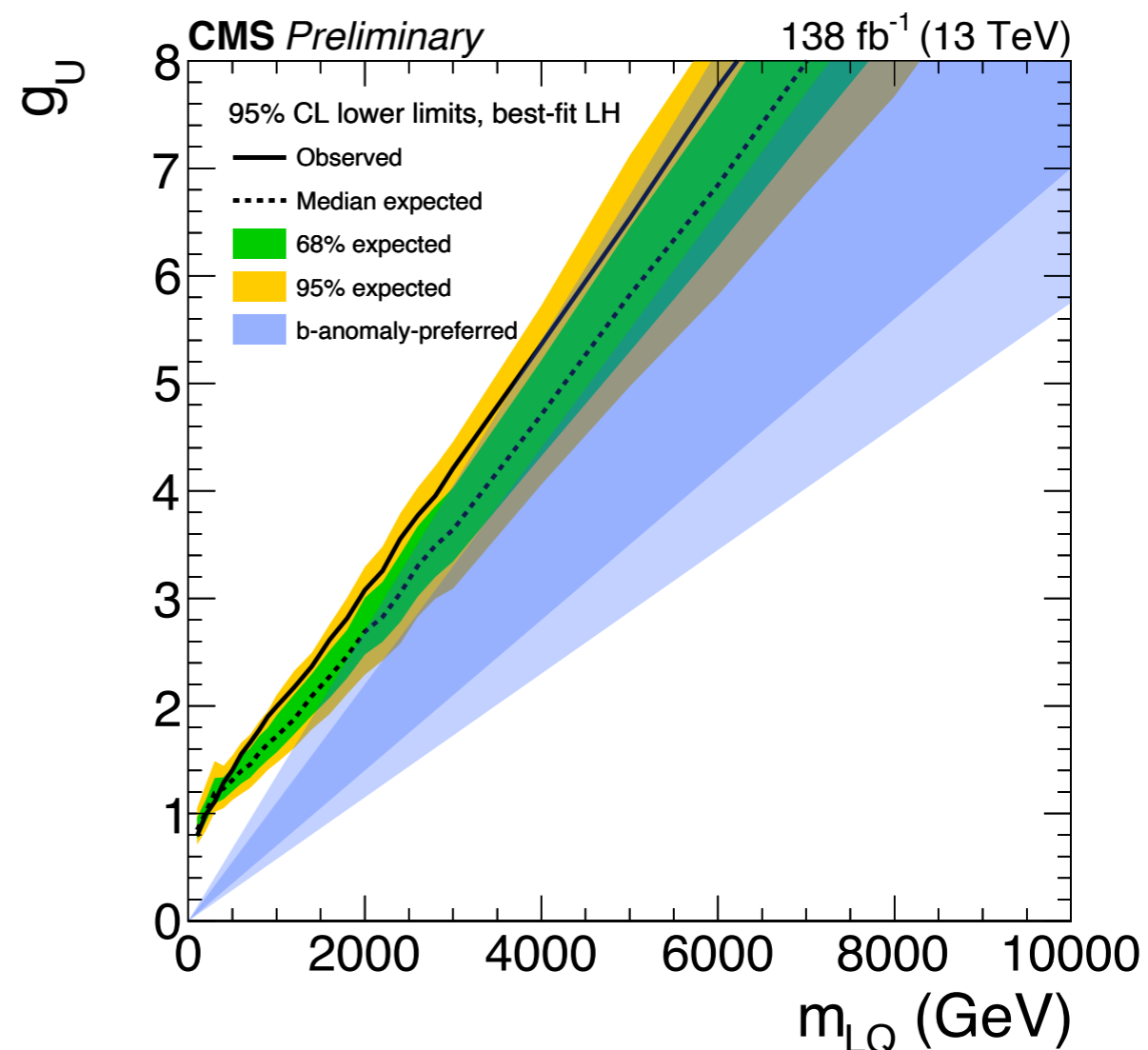
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 - ▶ Consider 3 LQ coupling benchmarks
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 - ▶ Transverse mass final discriminant
 - ▶ Allow all couplings predicted to fit anomalies [\[JHEP 08 \(2021\) 050\]](#)
 - ▶ Consider 3 LQ coupling benchmarks
 - ▶ First result in this channel
 - ▶ Limits on coupling vs. mass
 - ▶ Complementary to $\tau\tau$ searches, similar sensitivity
 - ▶ Observed limit $\sim 1 \sigma$ above expectation



Conclusion

- Leptoquarks strongly motivated as possible explanation for B anomalies
- Many recent search results for non-resonant signatures of t -channel LQs
- CMS search for LQ $\rightarrow b\tau$ covers all 3 LQ processes
 - ▶ Intriguing 3σ excess where sensitive to LQ in t channel ($\tau\tau$ final state)
 - ▶ Similar result from independent CMS search in same final state
- First search for t -channel LQ in $\tau\nu$ final state

