Search for 3rd Generation Scalar Leptoquarks Decaying to Top Quark - Tau Lepton Pairs

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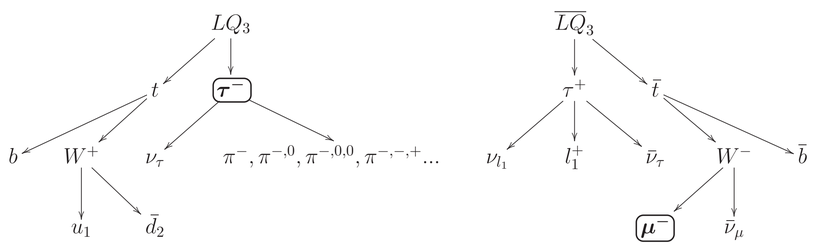
Leptoquarks: Model & Signature

- Pair-production cross-section depends only on the LQ mass and is independent of the unknown Yukawa coupling (ℓ-q-LQ).
- Assumptions:
  - $LQ_3 \to t\tau^-$ with unit branching fraction
  - $M_{LQ_3} > m_t$



- Final states of interest:
  - $\mu^\pm\tau^\pm_{had}\ell^\mp 2jb\bar{b}$ and $\mu^\pm\tau^\pm_{had}\ell^\mp\ell^\mp b\bar{b}$

Event Selection

- Require $N_{jet} \geq 2$ and a same-sign $\mu\tau_{had}$ pair.

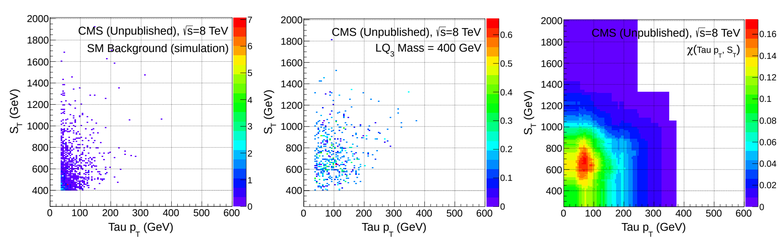
Tau	p_T>35 GeV	$\lvert\eta\rvert < 2.1$
Muon	p_T>25 GeV	$\lvert\eta\rvert < 2.1$
Jet	p_T>40 GeV	$\lvert\eta\rvert < 3.0$
Electron	p_T>15 GeV	$\lvert\eta\rvert < 2.5$

- Muon and tau objects are required to be isolated in the signal region.
- A combination of isolated and non-isolated single muon triggers are used.
- LQ_3 signal is in the central region of the detector:

$$\widetilde{|\eta|} = \Theta^{-1}\left(\frac{1}{N_\mu+N_\tau+N_e}\sum_\ell \Theta(|\eta_\ell|)\right)$$
$$\text{where } \Theta(\eta) = 2\ \tan^{-1}(e^{-\eta})$$

- The search is conducted in two channels: **Central** ($\widetilde{|\eta|} < 0.9$) / **Forward** ($\widetilde{|\eta|} \geq 0.9$)
- Selection optimization is done on a 2D plane of S_T (scalar sum of $e, \mu, \tau, jet, E_T^{miss}$ p_Ts) and tau p_T for each M_{LQ_3}, yielding progressively tighter cuts, where the Punzi figure of merit is maximized:

$$\chi(tau\ p_T, S_T) = \frac{\varepsilon(tau\ p_T, S_T)}{1+\sqrt{B(tau\ p_T, S_T)}}$$



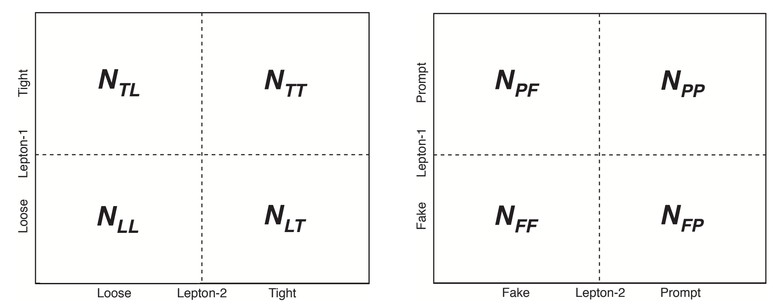
- Signal region is dominated by events **with fake taus**.
- There are also lesser contributions due to:
  - **same-sign**
  - **charge-mismeasured opposite-sign** dilepton events.

Prompt-Prompt Backgrounds

- Backgrounds due to lepton charge mismeasurements and irreducible processes with same-sign leptons are estimated directly from MC samples.

Fake Lepton Backgrounds

- Fake lepton (mostly jets faking taus) contributions are estimated via the data-driven Loose-to-Tight-Extrapolation Method (LTEM).
- LTEM allows estimation of single and double fake contributions to the signal region from control regions with inverted isolation on the two lepton objects.



$$\begin{pmatrix} N_{FF} \\ N_{FP} \\ N_{PF} \\ N_{PP} \end{pmatrix} = J \cdot \begin{pmatrix} p_\mu \cdot p_\tau & -p_\mu \cdot \widehat{p_\tau} & -\widehat{p_\mu} \cdot p_\tau & \widehat{p_\mu} \cdot \widehat{p_\tau} \\ -p_\mu \cdot f_\tau & p_\mu \cdot \widehat{f_\tau} & \widehat{p_\mu} \cdot f_\tau & -\widehat{p_\mu} \cdot \widehat{f_\tau} \\ -f_\mu \cdot p_\tau & f_\mu \cdot \widehat{p_\tau} & \widehat{f_\mu} \cdot p_\tau & -\widehat{f_\mu} \cdot \widehat{p_\tau} \\ f_\mu \cdot f_\tau & -f_\mu \cdot \widehat{f_\tau} & -\widehat{f_\mu} \cdot f_\tau & \widehat{f_\mu} \cdot \widehat{f_\tau} \end{pmatrix} \begin{pmatrix} N_{LL} \\ N_{LT} \\ N_{TL} \\ N_{TT} \end{pmatrix}$$

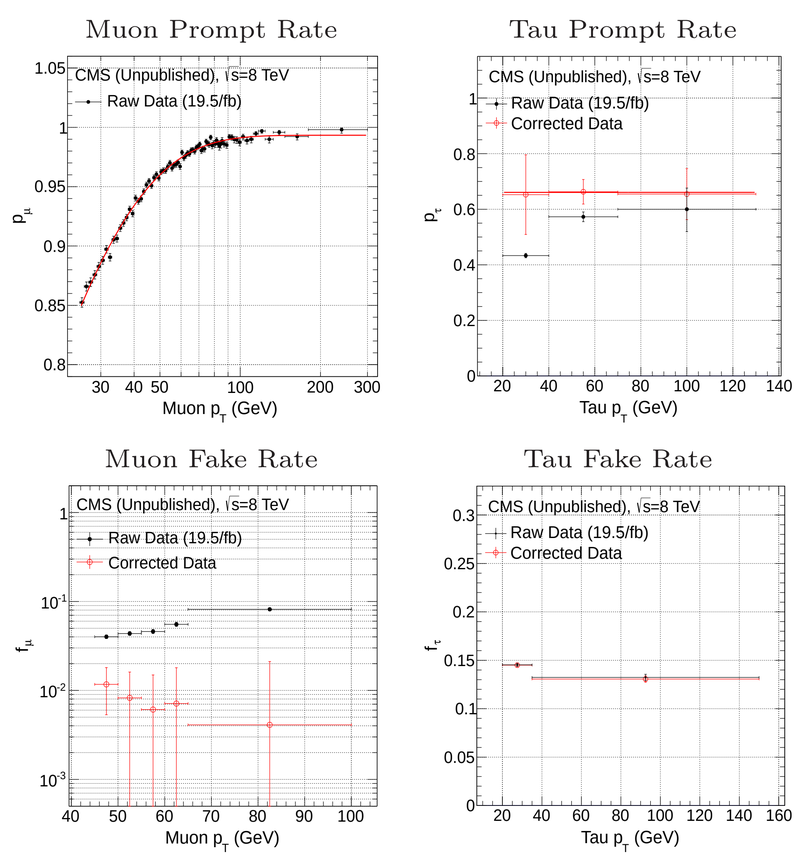
Where $J = \frac{1}{(p_\mu - f_\mu)(p_\tau - f_\tau)}$, $\widehat{p} = 1 - p$ and $\widehat{f} = 1 - f$.

$$N_{TT}^{Fake\ Bckg} = f_\mu\ f_\tau\ N_{FF} + f_\mu\ p_\tau\ N_{FP} + p_\mu\ f_\tau\ N_{PF}$$

- To reduce dependence on event topology, muon and tau prompt and fake rates are measured as a function of $|\eta|$, p_T and **the angular distance to the nearest jet:** $\Delta R(\ell, j)_{min}$.
- S_T-based corrections are applied for tau prompt and fake rates.
- Rate measurements are conducted in probe object enriched data and selected MC samples (W+$jets$, $t\bar{t}$+$jets$, LQ_3, QCD), where contributions of the undesired object type are subtracted using MC (i.e corrected rates).

Rate	Data Selection	
Prompt Muon	$Z \to \mu\mu$	
Fake Muon	QCD	(jet$\to\mu$)
Prompt Tau	$Z \to \tau\tau \to \mu\tau$	
Fake Tau	$W \to \mu\nu$+$jets$	(jet$\to\tau$)

- Selected prompt and fake rate measurements as conducted in data are provided below:

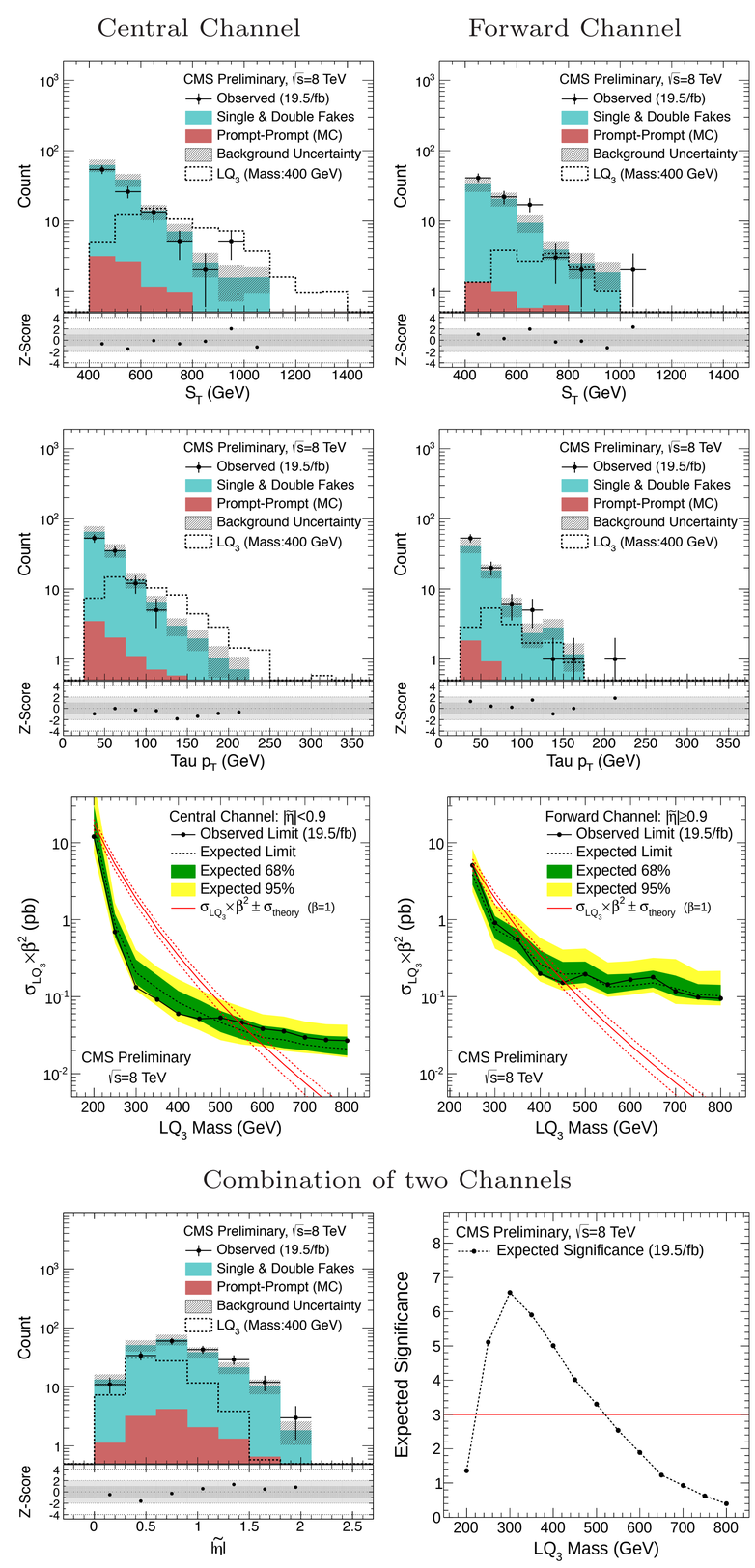


Systematic Uncertainties

- The LTEM systematic uncertainty, calculated via propagation of prompt and fake rate uncertainties, is the dominant uncertainty on the background estimate.
- For prompt-prompt backgrounds estimated using MC, the object energy and resolution uncertainties are considered for muons, taus, electron, and jets, as well as the muon and tau reco/ID/isolation efficiency, pileup reweighing and luminosity uncertainties.

Results & Conclusions

- S_T, tau p_T and $\widetilde{|\eta|}$ distributions corresponding to the loosest set of cuts (M_{LQ_3}=200 GeV) are provided below, where the M_{LQ_3}=400 GeV signal distributions are superimposed for comparison.
- A limit is set on the pair-production cross-section of LQ_3s using the CLs modified frequentist approach at 95% CL, where the counting experiment method is adopted for the statistical analysis.
- The pair-production of charge $-1/3$ third generation scalar leptoquarks is excluded for masses up to 550 GeV.



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The work presented here is documented in **CMS PAS-EXO-12-030**