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 (t→q-LQ).
- Assumptions:
  - $LQ \rightarrow t\tau^-$ with unit branching fraction
  - $M_{LQ} > m_t$
- Final states of interest:
  - $\mu^+\mu^- (\tau^-\tau^-) b\bar{b}$ and $\mu^+\mu^- (\tau^-\tau^-) \ell\nu$

Event Selection
- Require $N_{had} \geq 2$ and a same-sign $\mu^+\mu^-$ pair.
  - Tau: $p_T > 35 \text{ GeV}$, $|\eta| < 0.9$
  - Muon: $p_T > 25 \text{ GeV}$, $|\eta| < 0.9$
  - Electron: $p_T > 15 \text{ GeV}$, $|\eta| < 0.9$
- 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:
  $$\eta = \Theta^{-1}\left(\frac{1}{\cos\Theta} \sum \Theta(\eta_i)\right)$$
  where $\Theta(\eta) = 2 tan^{-1}(e^{-\eta})$
- The search is conducted in two channels: Central ($|\eta| < 0.9$) / Forward ($|\eta| \geq 0.9$)
- Selection optimization is done on a 2D plane of $\Delta R (\ell, J)$ (scalar sum of e, $\mu$, $\tau$, jet, $E_T^{miss}$ pT's) and tau $p_T$ for each $M_{LQ}$, yielding progressively tighter cuts, where the Punzi figure of merit is maximized:
  $$\chi^2 = \frac{1}{2} \left(\frac{1}{1+\sqrt{2}(tau p_T, \Delta R)}\right)^2$$
- 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 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.
- To reduce dependence on event topology, muon and tau prompt and fake rates are measured as a function of $|\eta|$, $p_T$, and $\Delta R (\ell, J)$.
- Rate measurements are conducted in probe object enriched data and selected MC samples (W+jets, tt+jets, $LQ_3$, QCD), where contributions of the undesired object type are subtracted using MC (i.e. corrected rates).

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 reweighting and luminosity uncertainties.

Results & Conclusions
- $S_{T\tau}$, tau $p_T$ and $\tau\tau$ distributions corresponding to the lowest set of cuts ($M_{LQ} = 200 \text{ GeV}$) are provided below, where the $M_{LQ} = 400 \text{ GeV}$ signal distributions are superimposed for comparison.
- A limit is set on the pair-production cross-section of $LQ_3$ using the $CL_{s}$ 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.