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Prospects of searches for excited neutrinos at the LHC

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The Baur, Spira, and Zerwas model of composite quarks and leptons predicts the excited neutrinos to be produced in proton-proton collisions via contact interactions. Subsequently, the excited neutrinos decay via gauge interaction or contact interaction. The final states always include missing transverse energy; there can also be zero to three charged leptons and/or jets. The present study scans the possible final state scenarios, depending on the model parameter values, to identify a search that can be reinterpreted as a search for excited tau neutrinos, focusing on excited tau neutrinos for demonstration purposes. The ATLAS monojet search appears to be a suitable candidate for such reinterpretation. The publicly available results of the ATLAS monojet search are used to derive rough limits on the excited tau neutrino mass and the contact interaction scale. The reinterpretation of the search can considerably improve the current 1.6 TeV mass limit and reach the 4 TeV region.

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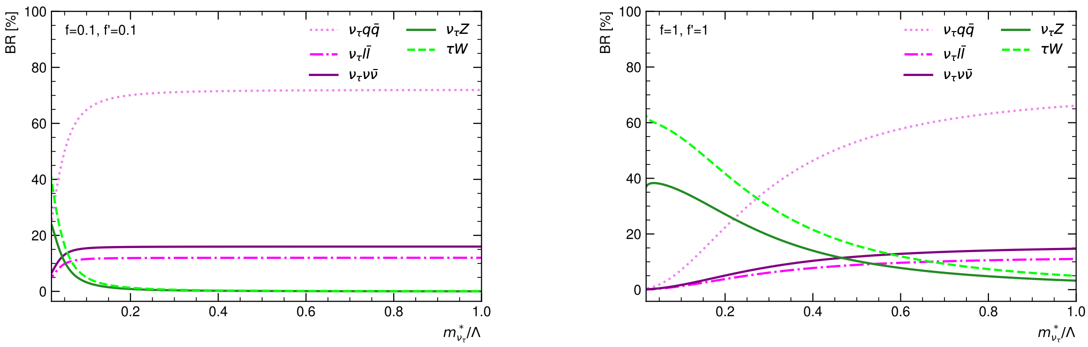
1. Introduction

The Baur, Spira, and Zerwas model [1] of composite quarks and leptons proposes the existence of excited neutrinos (ν^*), which are one of the possible manifestations of new physics beyond the Standard Model (SM). This model describes how ν^* can be produced in proton-proton collisions via contact interactions (CI) or gauge interactions (GI). Single production of ν^* occurs through the process $q\bar{q} \rightarrow \nu\nu^*$, while pair production follows $q\bar{q} \rightarrow \nu^*\nu^*$. The ν^* can decay via either CI ($\nu^* \rightarrow \nu f \bar{f}$) or GI ($\nu^* \rightarrow \nu Z$ or $\nu^* \rightarrow \nu W$). The final states in both cases typically include missing transverse energy ($E_{\mathrm{T}}^{\mathrm{miss}}$), jets, and charged leptons, depending on the interaction type.

The presented study aims to reinterpret the ATLAS Monojet search to improve the current limit on the mass of excited tau neutrinos (ν_τ^*). The current limit on the mass of ν_τ^* is set by a search conducted by the ATLAS Collaboration using 8 TeV data in 2012, which established a limit of 1.6 TeV [2].

Branching ratios (BR) for decays of ν_τ^* depend on the coupling constants f, f' from Eq. (2) in Ref. [1], describing the strength of the coupling to the electroweak gauge fields. The BRs also depend on the ratio of $m_{\nu_\tau^*}$ to the compositeness scale ($m_{\nu_\tau^*}/\Lambda$). Figure 1 illustrates the variation in BRs for different decay modes as functions of $m_{\nu_\tau^*}/\Lambda$ for different values of f and f'. These plots indicate that CI is dominant in the region where $m_{\nu_\tau^*}/\Lambda$ is high and the coupling constants are small. On the other hand, GI dominates for small $m_{\nu_\tau^*}/\Lambda$ and larger coupling constants.



(a) $f = f' = 0.1$ **(b)** $f = f' = 1$

Figure 1: Branching ratios for different decay modes as functions of $m_{\nu_\tau^*}/\Lambda$ for different values of f and f'

2. Simple Reinterpretation of the ATLAS Monojet Search

By analyzing potential final states based on model parameters, one can identify searches on LHC that can be reinterpreted as a search for ν_τ^*. One such search is the Monojet search by the ATLAS Collaboration [3]. This search, conducted at $\sqrt{s} = 13$ TeV, looks for events with energetic jets and high $E_{\mathrm{T}}^{\mathrm{miss}}$. The signal region includes up to four jets with the leading jet p_{T} greater than 150 GeV and $E_{\mathrm{T}}^{\mathrm{miss}}$ greater than 200 GeV.

To reinterpret the publicly available results, signal samples are replaced with samples for ν_τ^* generated by Pythia 8.3 [4] and Delphes 3 [5]. The uncertainty in the background estimate combines systematic and statistical uncertainties from the original search. Also, to be able to use Monojet search for reinterpretation, the used control regions (CR) ($W \rightarrow \mu\nu$, $W \rightarrow e\nu$, $Z \rightarrow \mu\mu$, $Z \rightarrow ee$, and Top) should not be contaminated with signal events. The signal contamination in CRs was studied with the signal-to-background ratios as a function of p_T^{recoil} (p_T of the system which recoils against the hadronic activity in the event). For $W \to \mu\nu$ region it is lower than 5% in each p_T^{recoil} bin with the signal being generated for different combinations of parameters f, f', and $m_{\nu_\tau^*}$ as shown in Figure 2. For other CRs, the maximal signal contamination is the following: 3% in $W \to e\nu$, 5% in $Z \to \mu\mu$, 3% in $Z \to ee$, and 6×10^{-3} in the Top region.

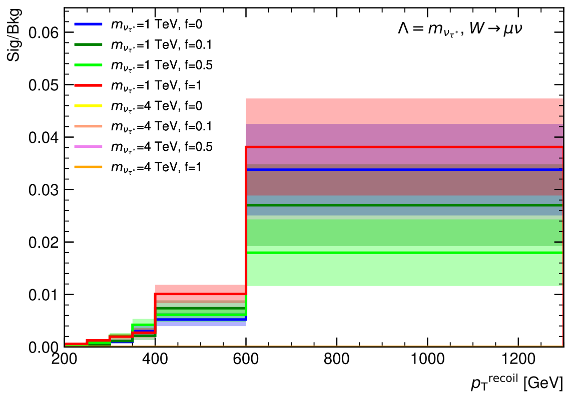


Figure 2: Signal/Background ratio in $W \to \mu\nu$ CR

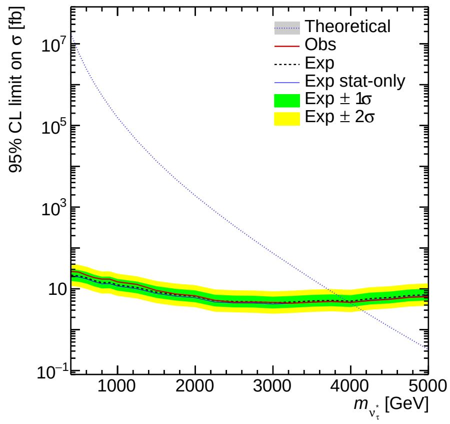


Figure 3: Upper 95 % CL limit on the ν_τ^* production cross-section

The upper limit on the $m_{\nu_\tau^*}$ has been estimated using a statistical test based on a profile likelihood ratio test statistic implemented in the HistFitter [6] package. Signal samples were generated for different values of $m_{\nu_\tau^*}$, assuming $\Lambda = m_{\nu_\tau^*}$ and setting the parameters $f = f' = 0$, corresponding to a CI-only scenario. The upper 95% confidence level (CL) limit on the production cross-section as a function of $m_{\nu_\tau^*}$ is presented in Figure 3. The analysis excludes ν_τ^* masses below 4 TeV at 95% CL, significantly improving the previous limit of 1.6 TeV established by the earlier ATLAS search [2].

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