Letter of Interest: Tau-neutrino Production at a multi-TeV Lepton Collider

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to be submitted to

the Accelerator Frontier (AF04), Energy Frontier (EF03), and Neutrino Frontier (NF06)

1 Motivations

Neutrino masses and leptonic mixing imply physics beyond the Standard Model, opening key questions about the new energy scale, particles and interactions necessary to explain their origin. In many models proposed to this aim, neutrinos have non-standard interactions at high energy leading to new observable signatures.

TeV-neutrino interactions in the laboratory are uncharted physics [1]: muon neutrinos have been studied up to about 350 GeV, electron neutrino measurements only exist at lower energies, and tau neutrinos are poorly studied. A few interactions of neutrinos of cosmic origin with energies beyond 6 TeV have recently been recorded [2].

τ neutrinos are of particular interest. Only a handful of ν_τ interactions have been directly observed so far in the DONUT [3] and OPERA [4] experiments. Hints at anomalies in the τ sector have accumulated:

- the precise LEP data measured an excess of the branching ratio $W \to \nu\tau$ with respect to the other leptons at the level of 2.8 sigmas [5], which persists;
- the Babar, Belle, LHCb experiments observe a τ excess ($>3\sigma$) in semileptonic decays of B in D, D^* [6].

2 Goals

Experiments being planned at LHC have the potential to fill in the energy gap between 350 GeV and a few TeV, and test different neutrino flavours [7–9]. Their detectors will intercept the flux of neutrinos from b and c decays, and those from pion and kaon decays. However the sample of observed tau-neutrino interactions in the LHC Run 3 (2022-2024) is expected to be marginal for precision measurements. Extension of those experiments in the High Luminosity LHC era beyond 2028 is unlikely, because the LHC environmental background will become prohibitive, ten times worse than at the LHC.

On the other hand, neutrinos will be abundant in a multi-TeV muon collider. They will arise in muon decays and will be produced promptly in many processes, in particular those involving production of W and Z, subsequently decaying leptonically.

We would like to propose a Snowmass activity on the opportunities for neutrino tau flavour studies at present and future colliders. More specifically, here we express our interest in investigating tau neutrino production in the process W^+W^- at future high-energy lepton colliders, such as a muon collider.

The t channel process is mediated by a neutrino exchange, and the W bosons are mainly forward produced. At a TeV lepton collider, these W bosons will experience a strong boost and their decay products will be collimated, resulting in fluxes of high-energy neutrinos and antineutrinos, of possibly different flavour, outgoing in opposite directions. About 33% of the leptonic W decays will be $W \to \nu\tau$.

Both charged lepton and neutrino can enter the detector acceptance, separated in azimuth, thus providing an unambiguous tag of the neutrino flavour. Our studies will address:

1. Angular distributions and energy spectra of neutrinos from leptonic decays of Ws produced in $\mu^+\mu^- \to W^+W^-$, separated by flavour;
2. Forward neutrino flux as function of collider luminosity;

3. Separation from the background of neutrinos from muon decays;
4. Optimisation of detector location and acceptance for observing tau-neutrinos and antineutrinos.

Physics simulations in 1. and 2. will use the usual chain MadGraph [10]/Pythia [11]. For 3. and 4., we plan for synergy with the Energy Frontier and Neutrino Frontier groups of Snowmass 2021, also in view of using shared simulation tools.

References

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