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Multilayer SND (Scattering & Neutrino Detector) optimization for statistical analysis of tau-neutrino events using detector response

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The SHiP (Search for Hidden Particles) experiment is a new fixed-target experiment to be installed at the CERN SPS ring with a 400 GeV proton beam energy. The primary goal of the experiment is to detect signals from the Hidden Sector particles, introduced to describe dark matter, baryon asymmetry, and small neutrino masses. To suppress background, an iron magnetized hadron absorber and a muon shield are utilized, along with several veto systems, aiming to reduce the experiment's overall background to zero over 5 years of operation.

SND (Scattering and Neutrino Detector) is the SHiP detector project designed to detect neutrinos of all flavors and direct signals from Light Dark Matter (LDM) interactions. An updated design for SND@SHiP includes a high-granularity hadron calorimeter achieved using scintillating fibers (SciFi) and scintillator layers (Scint).

A key focus of this work is the classification of tau-neutrino events in the SND. This includes distinguishing tau-neutrino interactions via charged current (CC) deep inelastic scattering (DIS) followed by tau lepton decay in both leptonic and hadronic channels, from the background of muon-neutrino interactions via CC and neutral current (NC) DIS. Specifically, the classification is focused on:

- Signal from inelastic interaction of tau-neutrinos via charged current on nuclei followed by tau lepton decay in the leptonic channel (CC DIS $\nu_\tau N \rightarrow \tau + X \rightarrow \mu\nu_\tau\nu_\mu + X$) against the background of signal from inelastic interaction of muon neutrinos via charged current on nuclei (CC DIS $\nu_\mu N \rightarrow \mu + X$).
- Signal from inelastic interaction of tau-neutrinos via charged current on nuclei followed by tau lepton decay in the hadronic channel (CC DIS $\nu_\tau N \rightarrow \tau + X \rightarrow hadrons + X$) against the background of signal from inelastic interaction of muon neutrinos via neutral current on nuclei (NC DIS $\nu_\mu N \rightarrow \nu_\mu + X$).

The search for tau-neutrino signal was performed using reconstructed kinematics of secondary particles and detector response. Inelastic neutrino interaction events from the SHiP experiment spectrum on nuclei were simulated using the GENIE package, and secondary particles were passed through the detector using the GEANT4 package. Simulations show that the average error in muon momentum determination is about 12%, while vertex reconstruction accuracy is ∼1.5 cm. The energy resolution for pions ranges from $\sim 50\%/\sqrt{E}$ for energies between 1 and 100 GeV. A classifier was developed using machine learning methods trained on both kinematic and detector response variables, capable of accurately classifying event types.

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