PROCEEDINGS OF SCIENCE

NaNu — North Area NeUtrino experiment at the CERN SPS collider

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In recent times, numerous experiments have been proposed to investigate the properties of tau neutrinos. One noteworthy low-cost initiative in this direction is the North Area Neutrino (NaNu) experiment. Its primary objective is to explore the domain of muon and tau neutrinos within the 10 to 60 GeV energy range. NaNu aims for the first experimental observation of anti-tau neutrinos. Beyond this, NaNu's scientific scope extends to measuring inclusive and differential cross sections of muon neutrinos, as well as examining the production of charm quarks in muon neutrino scattering events. The statistical data gathered from tau neutrino interactions will allow for tests of lepton flavor universality within the neutrino sector. The experiment could be installed in the North Area of the SPS collider at CERN as integrated part of the future SHADOWS experiment. In this work, we present a comprehensive study on the expected muon background at the prospective NaNu experimental site, with a detailed analysis of muon rate and flux magnitude.

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1. Introduction

The neutrino sector remains the least comprehended aspect within the Standard Model of particle physics. Notably, recent experimental advancements, exemplified by initiatives like FASER [2] and SND@LHC [3], are striving to measure neutrino cross sections in novel energy ranges. Of particular significance are tau neutrino events, as only nine ν_τ occurrences have been recorded in DONUT [5], and ten in Opera [6]. Notably, there has been no experimental identification of anti-tau neutrinos so far.

NaNu is conceptualized as a beam dump experiment strategically positioned between the SHADOWS [7] and HIKE [8] experiments. This off-axis experiment is designed to capture data from a 400 GeV proton beam collison, amounting to 5×10^{19} protons on target over a span of 4 years. The objective of NaNu is to delve into the unexplored territory of tau neutrinos, contributing valuable insights in a domain where experimental observations have been notably scarce.

2. Detector Setup

The experimental configuration for NaNu is designed with a focus on cost-efficiency, employing established detection techniques for neutrino studies. The schematic representation of the experimental setup, depicted in Fig. 1, comprises four key components: the magnet system, emulsion target, active trigger system, and a muon spectrometer. The baseline NaNu detector can be classified into active and passive detection systems, both featuring dimensions of $45 \times 45 \times 100$ cm^3 and an effective length of 20 cm situated within a dipole magnet (1.4 T, 2400 A) for both the active and passive systems.

The passive detector utilizes emulsion detector technology, composed of 200 nm Silver Bromide crystals dispersed in a gelatin medium. Emulsion detector layers are interleaved with 1 mm thick tungsten absorber plates, facilitating charged current interactions. This detector boasts a spatial resolution ranging from 50 nm to 100 nm. Timing and angular information are obtained from an array of MM (MM) detectors with two-dimensional readout electronics.

The active detector component incorporates 0.9 cm thick plastic Scintillator detectors and Silicon Photomultiplier-based readout. Similar to the passive detector, the active detector is interleaved with 2.5 cm thick tungsten absorber plates and an array of MicroMegas(MM) detectors. Scintillators will be measuring hadronic shower energies, while MM detectors will provide the angle of traversing muons. Two planned variants of this experiment include: NaNu with a combination of emulsion + active detector systems and SuperNaNu with a fully passive emulsion detector.

Lastly, the muon spectrometer follows the active and passive detectors, consisting of four MM detectors placed 20 cm apart. The first out of three MM detector will be shielded with a 20 cm thick iron layer in order to suppress hadronic particles.

3. Neutrinos at NaNu location

Neutrino flux estimates have been computed using PYTHIA8 [9] and GENIE [10] programs, aligning with findings from studies conducted by SND of the SHiP [11, 12] experiment. The predominant source of tau neutrinos at the NaNu location arises from mesonic decay: $D_s \to \tau\nu_\tau$.

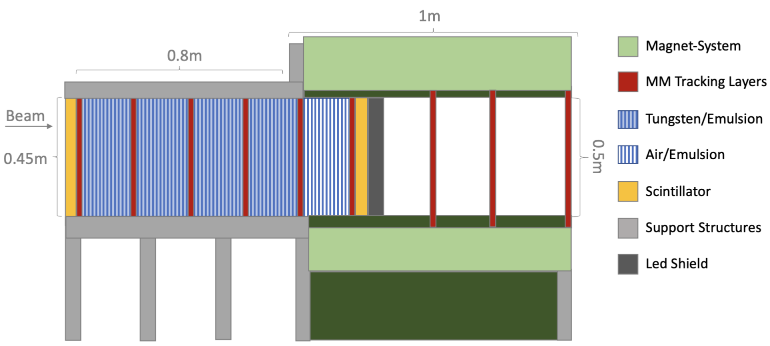

Figure 1: Side schematic of the NaNu with its four major components [1]

Additionally, a substantial influx of ν_μ and ν_e occurs as decay products of charmed hadrons, soft pions, and kaons. Strategically, the experimental setup is positioned at a distance from the beam axis to mitigate muon background. Simulation studies (refer to Fig. 2) illustrate the muon background for NaNu at 50 m from the beam dump in the transverse plane to the beam axis. The pivotal determinant for observing neutrino events lies in the precise location of the detector. Moreover, Pythia8 simulation studies were conducted to assess the kinematic distribution of neutrino flavors following the initial p-p interaction. The simulation reveals the distribution of tau neutrinos at a distance of 50 m from the beam dump (see Fig. 3). In its four-year operational span, NaNu aspires to accumulate data corresponding to 5×10^{19} POT.

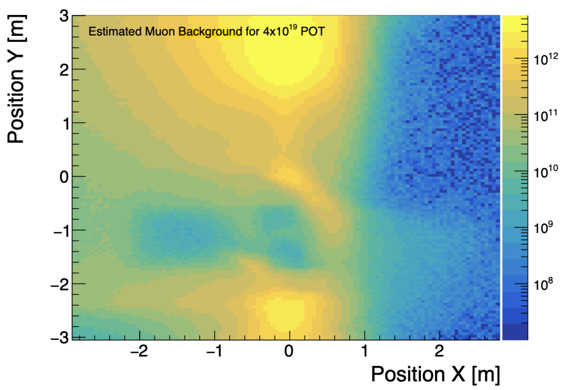

Figure 2: Estimated distribution of muon background in transverse plane, located 50m from the beam dump with 4×10^{19} POT [1]

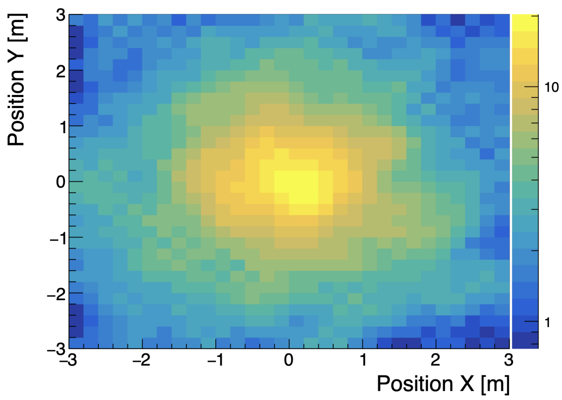

Figure 3: Distribution of τ neutrinos produced in 400GeV pp fixed target collision simulated with PYTHIA8 at 50m from beam dump [1]

4. Simulation Studies and Expected Detector Performance

The NaNu detector concept has been realized through implementation in the Geant4 simulation program, with neutrino interactions in the passive detector component simulated using the GENIE software, as illustrated in Figure 4. To identify neutrino interactions of all flavors, two tracks are required, each with at least 1 GeV, originating from a common vertex and an impact parameter less

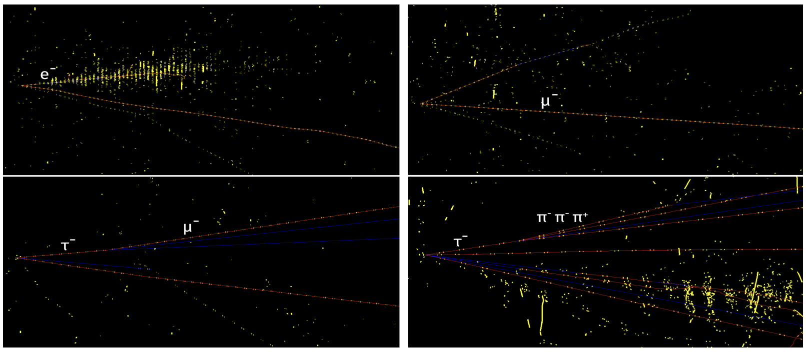

Figure 4: Event display of trajectories – electron neutrino (upper left) and muon neutrino (upper right) interactions with the NaNu Detector, tau neutrino interaction via muonic channel (left) and via hadronic channel (right) [1]

than 10 μm. One track corresponds to a lepton, and the other to nuclear recoil. Tracks with larger impact parameters serve as seed candidates for secondary vertices, identifiable by a sudden kink in trajectory and a displacement greater than 20 μm from the primary vertex. Muon interactions are identified by a primary vertex in the emulsion layer. Muon tracks are reconstructed using MM detectors, momentum information is provided by the Muon Spectrometer and the hadronic sandwich calorimeter enables vertexing of final state muons and the measurement of hadronic recoil energy. Tau neutrino interactions involve a tau lepton decaying into ν_e or ν_μ, generating a secondary vertex with a kink relative to the tau lepton track. Hadronic decay of tau leptons can be identified by short-lived decays and the number of charged hadrons in the final states – one pion or three pions[1].

5. Expected Physics Reach

For muon neutrinos at the baseline NaNu, an anticipated 25,000 interactions for ν_μ and 5,000 for $\overline{\nu}_\mu$ are expected, with a minimum muon momentum exceeding 5 GeV. The experiment aims to measure the differential cross-section versus Bjorken x in the range of 0.1 to 0.8 and momentum transfer Q^2 in the range of 10 to 50 GeV. Charm production in neutrino scattering events can be identified either in the emulsion target or through the full reconstruction of the muonic decay channel using the active detector components. According to predictions from the GENIE program, a 4%-5% charm production is anticipated in neutrino deep inelastic scattering events, with a 3-6 times increment with identification from the emulsion target.

A first milestone is anticipated with the first experimental observation of $\overline{\nu_\tau}$. Inclusive and differential cross-section measurements of ν_τ and $\overline{\nu_\tau}$ interactions are expected, with a statistical uncertainty of 10 % with NaNu and 5% with SuperNaNu. The cross-section measurements of ν_τ and $\overline{\nu_\tau}$ can also provide constraints on the F4 and F5 structure functions for the first time due to the higher mass of tau leptons [13]. Cross section is influenced by 30% for ν_τ by F_4 and F_5 at E_ν = 20 GeV, where the maximal effect is expected [1].

6. Muon Background Measurements at the NaNu detector location

Muon background measurements were conducted within the NA62 experimental cavern at the SPS collider in CERN. To execute this test, the K12 beam line was operated in beam dump mode. The detector setup utilized for this measurement comprised an array of three MM detectors with a window size of 10 cm × 10 cm each, operating with an Ar/CO2 gas mixture in a 93:7 ratio (refer to Fig. 5). The readout electronics employed were the APV25 chips, each with 240 channels, connected to a scalable readout system and read via the MMDAQ software. The trigger for the MM detectors was derived from coincidences in two pairs of scintillators symmetrically placed at the front and back of the MM detector array. Coincidence between all four scintillators was established using standard NIM electronics.

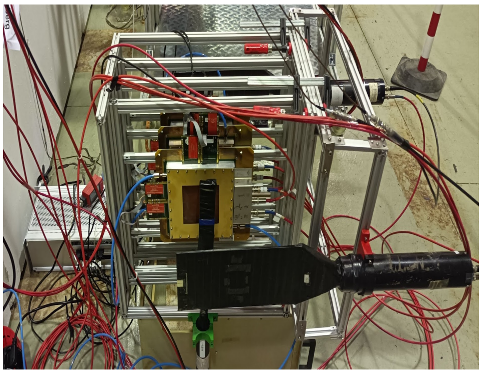

Figure 5: MM and Scintillator based setup for muon background measurement

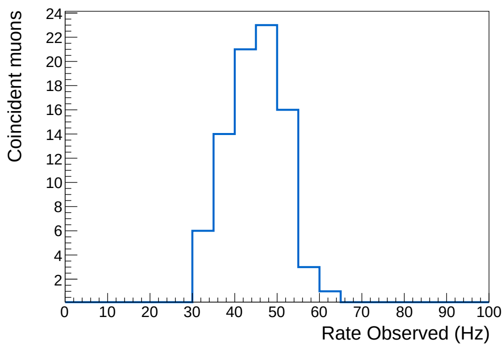

Figure 6: Rate of muons passing through scintillators and MM detector in coincidence

During the flux measurement, the beam intensity was increased to 3×10^{12} per spill, the detector setup was placed 69.91 m away from T-10 target and 3.12 m from beam line. Figure (6) shows the rate of coincident muons observed at the detector location. Due to the location of detector setup w.r.t. the T10 target and the span of trigger system in z, the low magnitude of geometrical acceptance was taken into account. The avergae muon flux observed was 37±6 cm^{-2} s^{-1} with 49 cm^{-2} s^{-1} being the highest with 256 coincidences in one spill.

7. Conclusion

In this proposed experiment, the focus is on probing the neutrino sector within the 10 GeV to 60 GeV energy range. The experiment comprises active and passive detectors for NaNu, while SuperNaNu employs a solely passive emulsion detector, with the primary goal of discovering tau neutrinos. A comprehensive study using a combination of a scintillator-based trigger system and MM detectors indicates a muon flux of 37±6 Hz/cm^2 with 3×10^{12} POT close to NaNu detector location.

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