ISSN 0027-1349, Moscow University Physics Bulletin, 2022, Vol. 77, No. 2, pp. 415–417. © Allerton Press, Inc., 2022.

NEUTRINOS

The NP06/ENUBET Project: Towards a Monitored Neutrino Beam

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Received February 15, 2022

Abstract—The ENUBET experiment is developing a new narrow-band neutrino beam in which the flux and the flavor composition are known at 1% level, and the energy with O(10%) precision. Such a goal is accomplished monitoring the associated charged leptons produced in the decay region of the ENUBET facility: e^+ and μ^+ from kaons are measured by a segmented calorimeter instrumenting the walls of the decay tunnel, while muon stations after the hadron dump can monitor muons from pions. We report an update on the status of the project.

DOI: 10.3103/S0027134922020990

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1. THE ENUBET MONITORED NEUTRINO BEAM

ENUBET is aimed at developing the concept of monitored neutrino beams [1], i.e., beams where the production of neutrinos is monitored in a direct manner measuring the rate of leptons in the decay tunnel. ENUBET is an ERC project started in June 2016 that was recently extended up to June 2022. It was approved as a CERN Neutrino Platform experiment (NP06) in March 2019. The project is focused on the measurement of large angle positrons from the $K^+ \to e^+\pi^0\nu_e$ decay, which is directly linked to the flux of ν_e. It also considers the possibility of measuring muons both from the two body large angle decay of the kaons ($K^+ \to \mu^+\nu_\mu$) and, after the hadron dump, from the pion decays ($\pi^+ \to \mu^+\nu_\mu$). The physics goal of ENUBET is to use the monitoring technique to reduce the uncertainty on the flux of ν_e and ν_μ below 1%. Since this uncertainty is the main source of systematic error for the cross section measurements, ENUBET will allow a high-precision determination of ν cross sections at the energy of interest for DUNE and HyperK. It will, therefore, reduce the systematics of long-baseline experiments increasing the sensitivity to oscillation parameters and to CP violating phase. Assuming $\sim 10^{20}$ proton on target, ENUBET is able to provide a sample of about 10^4 ν_e CC and 10^6 ν_μ CC in a 500 t detector located 50 m after the hadron dump monitored with an expected precision of 1%. The other source of systematic uncertainty is the reconstruction of the ν energy, which is biased by the inaccurate reconstruction of the final state particles. ENUBET is a narrow band beam (5–10% momentum bite) and using the off-axis narrow band technique [2], it can provide a measurement of the neutrino energy at 10–20% level, just by locating the radial position of the interaction vertex and without relying on accurate final state particle reconstruction.

2. THE ENUBET BEAMLINE

ENUBET is a conventional beamline where the pions and kaons are produced by protons impinging on a fixed target. Focusing can be done either with a conventional horn or with a purely static system. The selected particles are transported to the decay tunnel that is located off the axis of the proton beam. Non-interacting protons are stopped in a proton dump. The 40 m long decay tunnel is instrumented along its walls to monitor the leptons. Not decayed particles (mostly pions) and leptons produced along the axis (mostly muons from pion decay) are stopped by a hadron dump at the end of the tunnel. The ENUBET beamline produces a narrow-band neutrino beam by selecting positively charged mesons with a central momentum of 8.5 GeV/c and a typical spread of 10%. The charge and momentum selection is performed by two normal conducting dipole magnets that introduce a large angle bending between the neutrinos and the target axis (14.8°). This displacement ensures that the GeV neutrinos produced in the first non-instrumented part of the beamline (decay of neutral hadrons, early decay-in-flight of charged particles) do not reach the neutrino detector.

3. TUNNEL INSTRUMENTATION

The ENUBET tunnel instrumentation is based on a calorimeter for e^+/π^+ separation and on an inner light-weight photon veto for e^+/π^0 separation. This last detector also provides the absolute timing of the events and is thus called the "t_0-layer". We carried out the detector R&D between 2016 and 2018, mostly at the CERN East Experimental Area [3]. The final choice is an iron-scintillator sampling calorimeter divided into modules (lateral readout compact module, LCM) of 10 cm length that samples the showers every 4.3 radiation lengths. The light is collected by WLS fibers running along the lateral edges of the five scintillator tiles of each module and bundled in groups of ten, and it is read out by SiPMs. The photon veto is based on plastic scintillators, whose light is transported by WLS fibers toward the upper part, beyond a 40 cm thick borated polyethylene shielding, where all the SiPMs are located. A detailed description of the performance of a small scale prototype based on this concept is given in [4]. The final ENUBET demonstrator is a 1.65 m long section of the instrumented decay tunnel that will be built and tested at CERN in 2022 [5].

4. PARTICLE RECONSTRUCTION IN THE DECAY TUNNEL

Positrons and muons in the calorimeter are identified with dedicated algorithms [6]. The event reconstruction starts with the identification of a seed, that corresponds to a hit in a LCM of the innermost layer. All LCM and t_0-layer deposits compatible in space and time with the seed are clustered together and constitute the candidate event. A set of variables describing the energy deposition in the calorimeter and the event topology are used as input for a neural network, based on the Root TMVA package [7], that identifies and classifies positrons and muons. The preliminary performance obtained for e^+ from K_{e3} show a selection efficiency ($\sim 50\%$), of about 22% dominated by the geometrical efficiency, and a S/N of $\sim$2.1, while μs from K^+ are reconstructed with an efficiency of about 34%, and a S/N of $\sim$6.0.

5. MUON NEUTRINO MONITORING FROM PION DECAYS

Low energy ν_μ from πs can be constrained by monitoring the associated μs produced in the decays. These μs are emitted at low angle and go through the decay tunnel impinging on the hadron dump. A measurement of relevant physics observables can be performed by instrumenting the hadron dump with detector layers installed at increasing depth and interleaved by absorbing material [8]. ENUBET is therefore potentially equipped with a tool to determine the flux of the ν_μ with a precision similar to that of the ν_e flux, enhancing remarkably the physics reach of the facility.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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