A novel technique for the measurement of the electron neutrino cross section

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Abstract

Absolute neutrino cross section measurements are presently limited by uncertainties on ν fluxes. In this paper, we propose a technique that is based on the reconstruction of large angle positrons in the decay tunnel to identify three-body semileptonic K^+ decays. This tagging facility operated in positron counting mode ("single tag mode") can be employed to determine the absolute ν_e flux at the neutrino detector with $\mathcal{O}(1\%)$ precision. Facilities operated in "event by event tag mode" i.e. tagged neutrino beams that exploit the time coincidence of the positron at source and the ν_e interaction at the detector, are also discussed.

1 Introduction

A detailed knowledge of neutrino interaction cross sections plays a crucial role in the precision era of oscillation physics [1, 2]. In the last decade, a vigorous experimental programme has been pursued, employing both the near detectors of running long-baseline experiments [3, 4, 5] and dedicated experiments [6, 7, 8] with special targets and PID capabilities. The large statistics accumulated so far and the careful strategy implemented for systematic mitigation have improved our knowledge of total and differential cross sections for ν_μ and $\bar{\nu}_\mu$ in the range of interest (0.3-5 GeV) for future long-baseline and sterile neutrino experiments [9]. All these experiments are, however, designed to work in ν_e appearance mode and the direct measurement of ν_e interactions still relies on scarce data [10, 11]. Calculations [12] are thus based on extrapolation from ν_μ results. Despite lepton universality of weak interactions, the ratio between ν_μ and ν_e suffers from uncertainties due to nuclear effects that have to be constrained with data to reduce systematic errors in future long baseline ν_e appearance experiments. To cope with this challenge, novel experimental approaches have been proposed with the aim of producing pure, intense and well controlled sources of electron neutrinos [13, 14, 15, 16, 17]. The technique proposed in the following has a similar aim: electron neutrinos are produced by the three body decay of K^+ (K_{e3}, i.e. $K^+ \to e^+ \nu_e \pi^0$) in standard neutrino beams. The positrons are identified in the decay tunnel by purely calorimetric techniques and the beam-line is optimized to enhance the ν_e components from K_{e3} and suppress to a negligible level the ν_e contamination from muon decays. This approach has several advantages. It provides a source of electron neutrinos that can be used to study ν_e interactions in a direct manner, i.e. without relying on extrapolations from ν_μ. In addition, it delivers an observable (the positron rate) that can be directly linked to the rate of ν_e at the far detector through the three body kinematics of K_{e3}. The positron rate in the decay tunnel thus determines the flux with a precision significantly better than what is currently achieved with conventional untagged ν_μ beams ($\sim 10\%$). Finally, this facility paves the way for the realization of tagged neutrino beams [18, 19, 20, 21, 22] in the configuration proposed in Ref. [23], where the positron is associated to the corresponding ν_e interaction at the far detector on an event by event basis. In this mode, full kinematic reconstruction of the K_{e3} can be achieved measuring the photon pair from π^0 decay, thus retrieving information on the energy of ν_e for each tagged event.

The tagging concept and the rationale for the choice of the beam-line parameters, the tagging detector and the neutrino detector are introduced in Sec. **??**. The beam-line up to the decay tunnel is detailed in Sec. **??** together with the expected secondary flux (π and K) at CERN, Fermilab, JPARC and Protvino. The decay tunnel instrumented with positron taggers and the corresponding positron identification performance are summarized in Sec. **??**. This section also summarizes the rates and integrated doses expected at the tagger units. Background, systematics and rates at the far detector are presented in Sec. **??** and Sec. **??**. Finally, perspectives for the event by event tag mode upgrade are described in Sec. **??**.

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