Journal of Physics: Conference Series

Study of tau neutrino production at the CERN SPS

IOP Conf. Series: Journal of Physics: Conf. Series **1137** (2019) 012016 doi:10.1088/1742-6596/1137/1/012016

Study of tau neutrino production at the CERN SPS

Ali Murat Guler

Middle East Technical University, Ankara, Turkey

E-mail: ali.murat.guler@cern.ch

Abstract. At the CERN SPS, the DsTau project has been proposed to study tau-neutrino production aiming at providing important information for future ν_τ measurements. Precise measurement of the ν_τ cross section would enable a search for new physics effects in ν_τ charged current interactions. It also has practical implications for neutrino oscillation experiments. The dominant source of ν_τ is the sequential decay of D_s mesons produced by proton interactions, whose uncertainty dominates current uncertainty in the ν_τ cross section measurement. The project aims at reducing the systematic uncertainty from about 50% to 10% by measuring the D_s differential production cross section. For this purpose, emulsion detectors with a nanometre-precision readout will be used to detect small kinks of the $D_s \to \tau$ decay. An emulsion detector has a position resolution of 50 nm, allowing for the detection of $D_s \to \tau \to X$ double kinks in a few millimeter range.

1. Introduction

In proton beam dump neutrino experiments tau neutrinos are mostly produced through the decay of D_s meson. Therefore a precise knowledge of tau neutrino flux requires a precise measurement of D_s production rates. The DsTau experiment aims to measure D_s differential production cross section in proton interactions and therefore the tau neutrino production rate. Furthermore, the angular and energy spectra of charmed hadrons will be measured at high-energy proton beam for the first time. The experiment will use CERNS SPS proton beam to collect 4.6×10^8 protons on target(p.o.t.). The precise measurement of tau neutrino production rate in proton interactions will allow us to measure ν_τ charged current(CC) interactions precisely. Indeed, this measurement is required to test new physics effects like validity of lepton universality. However, the tau neutrino cross section is not known at sufficient precision unlike ν_μ and ν_e CC cross sections. The tau neutrino cross section was measured directly in DONuT[1] and OPERA[2] experiments with large uncertainty. The main systematic error in the DONut measurement comes from the ν_τ flux prediction that is an uncertainty in the differential production cross section of D_s meson. However, the data on D_s production cross section at the high-energy proton beam is scant. HERA-B has performed a measurement based on 11.4±4.0 D_s^+ events. The DsTau experiment proposes a new approach based on nuclear emulsion technology to detect about 10^3 $D_s \to \tau$ decays in 2.3×10^8 proton interactions in tungsten target. This allows us to reduce the uncertainty in ν_τ flux prediction below 10%.

2. Principle of Measurement

In proton beam-dump experiments, tau neutrino is mainly produced in D_s decays. In charm hadroproduction, charm quarks are produced in pairs. Therefore, in addition to D_s a second

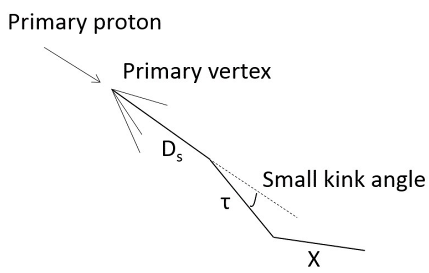

Figure 1. Decay topology of $D_s \to \tau \to X$.

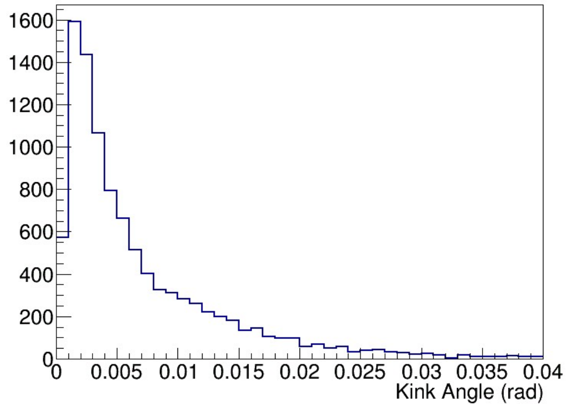

Figure 2. Kink angle distribution of $D_s \to \tau\nu_\tau$ decay.

charmed hadron is also produced. But topology of $D_s \to \tau \to X$ decay chain is quite unique (a schematic view is shown in figure 1), it decays into τ lepton after traversing about 3 mm. Then τ decay follows the D_s decay with mean flight length of 2 mm. Although this decay topology is very peculiar, it is very difficult to detect both decays at high efficiency. Since both decays occur at a scale of a few millimeters and decay angle of $D_s \to \tau$ is very small as shown in figure 2. The detection of this decay requires a sub-milliradians resolution in angle measurement. This obstacle can be overcome by using nuclear emulsion technology. Advances in nuclear emulsion technology and the automated readout system allow us to reach the required high resolution.

The basic unit of the emulsion detector consists of a tungsten target, nuclear emulsion films and plastic sheets, as shown in figure 3. The tungsten target is followed by 10 emulsion films, each 300 μm thick, interleaved with 200 μm plastic sheets acting as a decay volume. This structure is repeated 10 times forming a module. In order to measure momentum of the charged particles through Multiple Coulomb Scattering, Emulsion Cloud Chamber (ECC) consisting of 26 emulsion films interleaved with 1-mm thick lead plates is placed after the module. Moreover, three emulsion films will be located upstream of the emulsion module to tag protons. The number of module required to collect p.o.t. is estimated by considering the maximum number of track density that the automatic emulsion readout system can operate at high efficiency and purity. The readout system can handle about 10^6 tracks/cm^2. The corresponding emulsion film area to accumulate 4.6×10^9 p.o.t. is 593 m^2. The emulsion production will be done at the University of Bern, Switzerland and Nagoya University, Japan. Assuming 10 m^2/week production speed, it will take about 8 months to complete all emulsion film production.

The emulsion readout will be performed at two stages; the first stage will be done by using fast automatic microscopes at Nagoya University. The readout system, called Hyper Track Selector (HTS) [4], can reach the scanning speed of 0.5 $m^2/hour * layer$. Therefore all emulsion films, 368 modules, can be scanned in a half year. The second stage of the emulsion readout is the precise measurement of events localized by HTS systems and will be performed at the University of Bern. The readout system using a piezo-based Z-axis can provide nanometric position resolution. The precise alignment of emulsion films will be done by using high-energy proton tracks traversing the detector volume.

3. Physics Performance

A fast Monte Carlo (MC) simulation has been performed to estimate detection efficiency of $D_s \to \tau \to X$ decay topology. The charm hadroproduction process is generated by

IOP Conf. Series: Journal of Physics: Conf. Series **1137** (2019) 012016 doi:10.1088/1742-6596/1137/1/012016

PYTHIA8.1[5]. The following event selection criteria are applied:

- parent particles, D_s and τ, must penetrate at least one emulsion film and at most 5 mm before decaying
- kink angle of D_s and τ decays must be greater than 2 mrad and 15 mrad, respectively,
- pair charmed hadron must be detected within 0.1 mm in transverse direction and 5 mm in longitudinal direction

Based on these selection criteria, the detection efficiency is estimated to be 20%. The detection efficiency can be improved by loosening kink angle thresholds which depend on the readout resolution.

The main background for kink decay topologies is the hadronic secondary interactions. This background can be suppressed further by identifying nuclear fragments. A preliminary estimation of this background is done based on ref.[6]. The expected background is about 9×10^{-9}/proton int. which is smaller than signal probability (5×10^{-6}/proton int.). A more accurate background estimation is being performed with FLUKA[7].

In order to measure the differential production cross section of D_s its momentum must be measured. However, the flight length of D_s is too short to measure its momentum directly. On the other hand, $D_s \rightarrow \tau \rightarrow X$ decay topology provides several topological observables, therefore an estimator can be developed by using two kink angles and two flight lengths. A machine learning algorithm was developed to estimate D_s momentum based on these variables. The achieved momentum resolution is about 18%. The phenomenological formula for the D_s differential production cross section is

$$\frac{d^2\sigma}{dx_F dp_T^2} \propto (1- \mid x \mid)^n e^{(-bp_T^2)} \tag{1}$$

DONuT ν_τ deep inelastic CC cross section measurement is given in terms of parameter n, $\sigma_{\nu_\tau} = 2.51 n^{1.52}(1 \pm 0.33(stat.) \pm 0.33(syst.)) \times 10^{-40} cm^2 GeV^{-1}$. In order to reach 10% precision in ν_τ CC cross section measurement, n must be determined at the level of several percent precision. The DsTau can reach this precision with 10^3 D_s events. Once the n parameter is determined, DONuT result can be re-evaluated.

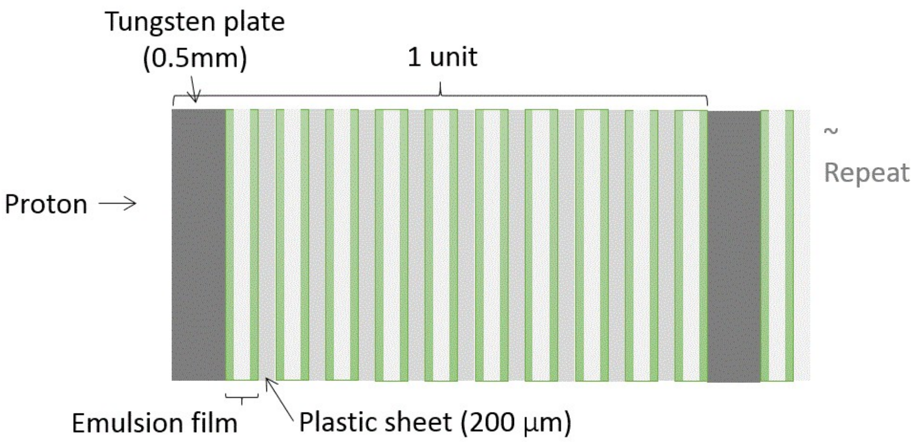

Figure 3. Schematic view of a module.

4. Test Beam Studies and Prospects

In order to demonstrate the decay search procedure and measure the angular resolution, test beam exposures were carried out in 2016 at H4 beamline and in 2017 at H2 beamline. The emulsion module is placed on a motorised stage that can move in X-Y plane that will allow a uniform irradiation of the proton beam on the emulsion module. In total, ten modules were exposed to the proton beam and these modules were readout by HTS. The number of located proton interactions is about 3.0×10^4 and among these 150 events have the consistent decay topology. This analysis is ongoing.

In order to reach our physics goal 16 days of beam time are required. Due to Long Shutdown2 (LS2) over whole CERN accelerator facilities, this period will split into three runs; first one in 2018 and other two runs will be after LS2 based on the schedule of CERN accelelator facilities. During LS2 period, the analysis of data collected in 2018, about 10% of total p.o.t., will be peformed to produce our first physics results. As the readout system and analysis methodology are developed during this period the analysis of second and third runs will take less time. The first pilot run was successfully completed between 23-28 August, 2018.

References

[1] Kodama K *et al.* [DONuT Collaboration] 2000 *Phys. Rev.* D **78** 052002
[2] Agafonova A *et al.* [OPERA Collaboration] 2015 *Phys. Rev. Lett.* **115** 121802
[3] Abt I *et al.* [HERA-B Collaboration] 2007 *Eur. Phys. J.* C **52** 531
[4] Yoshimoto M, Nakano T, Komatani R, Kawahara H 2017 *Prog. Theor. Exp. Phys.* **10** 103H01
[5] Sjostrand T *et al.* 2008 *Comput. Phys. Commun.* **178** 852
[6] Bulte A *et al.* 2002 *Nucl. Instrum. Meth.* A **485** 426
[7] Ferrari, Sala P R, Fasso A, Ranft 2005 *CERN 2005-10*