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Study of tau neutrino production with nuclear emulsions at CERN-SPS

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The data on tau neutrino is very scarce, only a few experiments have detected its interactions. At FNAL, the beam dump experiment DONUT, the tau neutrino interaction cross-section was directly measured with large systematic (~50%) and statistical (~30%) errors. The main source of systematic errors is due to a poor knowledge of the tau neutrino flux. The effective way for the tau neutrino production is the decay of D_S mesons, produced in proton-nucleus interactions. The DsTau experiment at CERN-SPS has been proposed to measure an inclusive differential cross-section of the D_S production with a consecutive decay to tau lepton in p-A interactions. The goal for this experiment is to reduce the systematic uncertainty to 10% level. After successful pilot runs and data analysis, CERN approved the DsTau project as a new experiment NA65 in 2019. During the physics runs, 2.3×10^8 proton interactions will be collected in the tungsten target, and about 1000 $D_S \rightarrow \tau$ decays will be detected. In this talk, the results from the pilot run will be presented and the prospect for physics run in 2021-2022 will be given.

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[*] Speaker

1. Introduction

The tau neutrino was detected by the DONUT Collaboration in 2000. Using a dozen of tau neutrino events, the charged-current tau neutrino interaction cross-section was measured with a large systematic (~50%) and statistical (~30%) errors.

One source for tau neutrinos is the sequential decay of the D_S mesons ($D_S \rightarrow \tau\nu_\tau \rightarrow X\nu_\tau\overline{\nu_\tau}$). This decay is easily recognizable thanks to its double kink topology (double decay topology) (Figure 1).

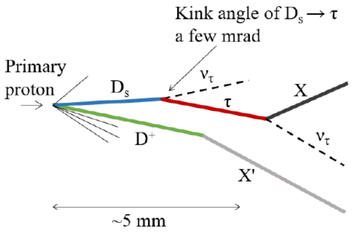

Figure 1: D_S decay topology [4]

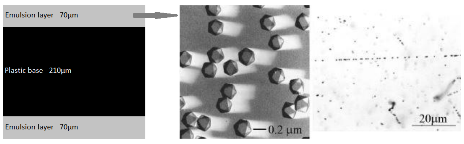

Figure 2: Emulsion film structure (left). Silver halide crystals (middle). Track inside emulsion (right) [2]

For the determination of tau neutrino flux it is essential to know the differential production cross section of the mesons, which can be approximated with the following formula :

$$\frac{d^2\sigma}{dx_F\, dp_T^2} \propto (1 - |x_F|)^n \cdot e^{-b \cdot p_T^2}$$

where x_F is the Feynman x ($x_F = \frac{2p_z^{CM}}{\sqrt{s}}$) and p_z, p_T are the longitudinal and transverse momenta. The longitudinal dependence of the D_S cross-section is controlled by the parameter "n" and the transverse dependence is controlled by the parameter "b". The uncertainties appeared due to the lack of measurements regarding the longitudinal dependence of the differential production cross section [3]. Both parameters can be measured experimentally. For the DONUT experiment, the value $n = 6.1$ was used for the estimation of the cross-section by using PYTHIA [5].

The DsTau experiment at CERN-SPS has been proposed to measure an inclusive differential cross-section of the D_S production with a consecutive decay to tau lepton in p-A interactions. The goal for this experiment is to reduce the systematic uncertainty to 10% level. A precise measurement of the tau neutrino cross-section would enable a search for new physics effects such as testing the Lepton Universality (LU) in neutrino interactions.

2. Experimental set-up

In the DsTau target, 2.4×10^8 proton interactions will be accumulated and about 1000 double decay topologies (D_S decays) are expected to be observed over a duration of 5 years (test beams from 2016 and 2017, pilot run from 2018 and physics runs from 2021 and 2022).

Although the decay topology of D_S is unique, its detection requires a precise tracking detector. Since the decay length and decay angle of D_S are very small, only nuclear emulsion technology, which can provide sub-micron resolution, can detect the decay of D_S directly. A nuclear emulsion film is made up of an emulsion gel poured on both sides of a plastic base. The emulsion gel comprises silver halide crystals dispersed in gelatin. When the emulsion is exposed to radiation, it modifies the silver halide grains and forms a latent image which is amplified by means of chemical treatment. The particle's path is recorded as silver grains along its trajectory after the film's development. The nuclear emulsion gel used for the DsTau experiment is 70 μm thick and it is poured on a 210 μm thick plastic base (Figure 2) [2].

The DsTau detector consists of two parts. The first part is a sequence of 10 units, one unit consisting of a 500 μm thick tungsten plate followed by 10 emulsion films interleaved with 200 μ thick plastic separators. The second part is called the ECC (Emulsion Cloud Chamber), comprising 26 emulsion films interleaved with lead plates. The ECC is used to determine the momentum of charged particles using the Multiple Coulomb Scattering method. Before the first tungsten plate, 5 emulsion films are placed to tag the incoming protons [2]. After the modules are assembled, they are mounted on a target mover at the 400 GeV proton beam at SPS. A silicone pixel telescope is used to monitor the beam's profile. The beam's intensity is monitored by a scintillation counter. Each emulsion detector module is located on a motorized X-Y stage (target mover) whose motion is synchronized with respect to the proton beam to make the detector surface uniformly irradiated. The DsTau detector and experimental set-up are shown in Figure 3.

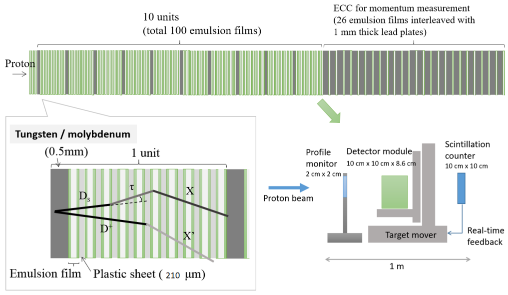

Figure 3: DsTau detector (top, bottom left). Experimental set-up (bottom right) [4]

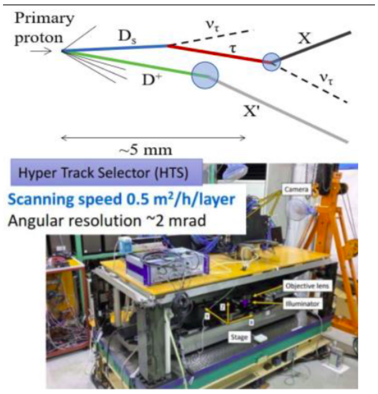

Figure 4: HTS from Nagoya University

After the data taking, the emulsion films undergo a full area scanning process using a high precision automatic readout system from Nagoya University: HTS (Hyper Track Selector) (Figure 4) which has a scanning speed of $\sim 0.5\ m^2/h$. This scanning is performed to detect the decays of τ and $D^\pm/D^0$. A new scanning system, HTS-2, is under development and it will be able to scan films with a speed of 2.5 m^2/h [6].

3. The data taking

Until now, two test beams (2016, 2017), the 2018 pilot run and the 2021 physics run were successfully performed. The acquired information from the 2018 pilot run is shown in Table 1. During the test beams from 2016 and 2017 and the pilot run from 2018 there were over 2×10^7 proton interactions, while for the physics run from 2021 and 2022 approximately 2.4×10^8 proton interactions in tungsten are expected.

Data	**Observed**	**Expected**	
Vertices in tungsten	147236	155135	
		Signal	**Background**
Double Decay Topology	115	80.1 ±19.2	12.7 ± 5.0

Table 1: Data from 2018 pilot run

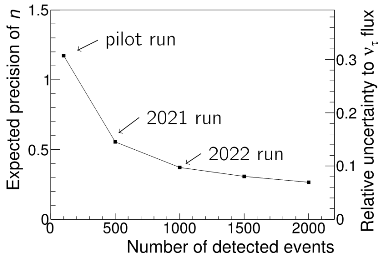

Figure 5: Expected precision of "n" [1]

For the test beams and pilot run, emulsion films were poured manually but for the physics run in 2021, emulsion films were produced by an automatic emulsion pouring system at Nagoya University.

The 2021 physics run took place this year in October, where 17 modules were exposed and developed. In this run a new detector configuration was used.

The next physics run (2022) aims to expose 50 modules. The analysis of the physics runs data will provide about 1000 D_S decays in 2.4×10^8 proton interactions. An independent ν_τ flux prediction for future neutrino beams can be done with an accuracy of 10% by measuring the parameter "n" with a precision of 0.4 (Figure 5).

Acknowledgment

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