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Status of DsTau(NA65) data taking and analysis

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The DsTau(NA65) experiment at CERN was proposed to study an inclusive differential cross-section of D_s production with a consecutive decay to tau lepton and tau neutrino in p-A interactions. A precise measurement of the tau neutrino cross-section allow us to search for new physics effects beyond Standard Model such as testing the Lepton Universality in neutrino interactions. The DsTau detector is based on nuclear emulsion providing a very high spatial resolution for the detection of short length and small "kink" decays. A high precision in vertex reconstruction allows to measure the proton interaction length and charged particle particle multiplicities in a high track density environment. The status of the experiment and results from the pilot run are presented.

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1. Introduction

The DsTau (NA65) collaboration aims to study the tau neutrino production in p-A interactions at the CERN-SPS. The data on tau neutrino interactions are very scarce; only a few experiments have reported its interactions with a low statistics. Therefore it is one of the least studied particle of the Standard Model. A first observation of tau neutrino interactions was achieved by the DONuT collaboration [1] at Fermilab. Later, tau neutrino interactions were also observed by OPERA[2], Super-K[3] and Icecube[4] experiments through the neutrino oscillations. Using the limited number of tau neutrino interactions in DONuT, the tau neutrino interaction cross section was measured with a large uncertainty which is mainly due to uncertainty in the ν_τ flux. Indeed, DONuT reported tau neutrino cross section measurement as a function of a parameter n, which acts on the longitudinal part of the D_s differential cross section:

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

where x_F Feynman x and p_T is transverse momentum. The central value of the cross-section depends on the n value which is derived from Monte Carlo (MC) event generators. Therefore, it contributes to the main uncertainty of the ν_τ cross-section measurements. In order to reduce the systematic uncertainty of the tau neutrino interaction cross-section to a few percent level, the parameter n must be obtained at a precision of ~ 0.4. The DsTau measurements can be used to reduce the systematic uncertainty in the tau neutrino cross section measurement to a few percent level. DsTau will detect about 10^3 $D_s \to \tau$ decays in 2×10^8 proton interactions in the tungsten/molybdenum target. In addition, the analysis of proton interactions in different target material leads to measurement of multiplicity and angular distribution of secondary particles. Such data are useful in tuning interaction models in MC generators.

2. Experimental Set up and Data Taking

In order to observe the fully reconstructed decay topology of D_s meson, a spatial resolution of a few micrometers is required. Since the mean decay angle of $D_s \to \tau$ decays is less than 10 mrad. Out of the available detector technologies, only nuclear emulsion can provide a sub-micron spatial resolution, which gives us a few mrad three-dimensional angular resolution. The basic unit of the DsTau detector consists of tungsten/molybdenum plate, nuclear emulsion films and plastic spacers. The tungsten plate acts as target for proton interactions; emulsion films act as high accuracy tracking devices with a sub-micron spatial resolution and plastic spacers provide a space for the decay. In one unit, a 500 μm tungsten/molybdenum plate is followed by 10 nuclear emulsion films, each 290 μm thick and interleaved with 9 plastic spacers each 200 μm thick. This unit structure is repeated 10 times to form a module which is 12.5 cm wide, 10 cm high and 8.6 cm thick. In addition, five emulsions films, placed most upstream of the module, act as veto planes for beam protons; a momentum detector (ECC) for the momentum measurement of charged daughters, located at downstream of the module, consists of 26 emulsion films interleaved with 1 mm thick lead plates. Multiple Coulomb Scattering (MCS) in the tungsten/lead plates along particle tracks is used to measure the momentum. For physics runs, the ECC part has changed since high mass density results in electromagnetic showers and high track density requires a dedicated scanning system. Instead of ECC, three tungsten plates followed by 25 emulsion films are used for momentum measurement. This new design shows similar performance to the ECC detector. In addition, the size of the emulsion film is changed to $25 \times 20\ cm^2$ in order to reduce dead time for plate change during the emulsion scanning. Based on this structure 4.6×10^9 protons on target are necessary to collect $2.3x10^8$ proton interactions in the tungsten/molybdenum plates. The CERN-SPS delivers spills with about 2×10^{11} protons at 400 GeV. The first test beam study to test and characterize the detector concept in 2016 and 2017. In 2018, a pilot experiment was performed to demonstrate proton interaction detection in a high track density environment. In the pilot run, 30 modules were exposed to the proton beam at the H4 beamline. The collected data corresponds to 10 % of the physics run. A schematic view of the detector setup is shown in Figure 1.

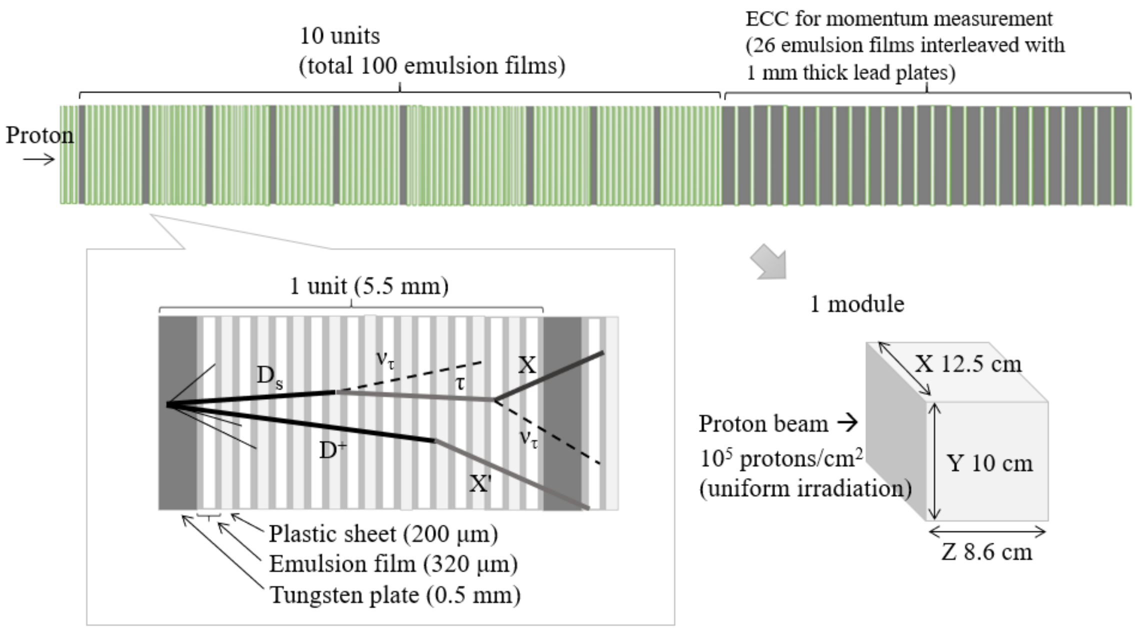

Figure 1: Schematic view of the emulsion detector

The physics runs were successfully performed in 2021 and 2022. During the data taking each emulsion module was mounted on a motorized X-Y stage called target mover which provides the synchronized movement of the module with respect to the proton spill. So that the detector surface can be uniformly irradiated at a density of 10^5 tracks/cm^2.

3. Data Analysis

The emulsion based experiments requires a second phase of DAQ which is performed by the automated microscope, equipped with a computer-controlled motorized stage, a CCD camera and a dedicated optical system. When a charged particle passes through emulsion it activates silver bromide crystals along its path; these are converted to metallic silver by a chemical development process. The developed grains are visible by means of optical microscope which takes topographic images at equally spaced depths of emulsion layer. These images are digitized, then an image processor recognizes the grains as clusters. Thus, the track in the emulsion layer (usually referred to as microtrack) is obtained connecting clusters belonging to different level. Two aligned micro-tracks in the two emulsion layers form base-tracks. Therefore, the emulsion readout is the essential part of the experiment. The latest scanning system called the Hyper Track Selector (HTS) [6] scans one layer of the emulsion film at a speed of 5000 cm^2/h. The efficiency of the base-track reconstruction is measured to be >95% for tracks with an angle of less than 400 mrad with respect to the beam direction. The efficiency slowly decreases towards the downstream part of the detector as the track density increases but it is kept high enough.

The emulsion readout is performed in two steps: the first one involves the scanning of the full surface of emulsion films to detect a decay topology by the HTS system; the second phase of scanning is the precision measurement to search for small-angle decay of D_s to τ. The resolution of precision measurement is sufficient for D_s kink detection. After the scanning, the data is processed with the DsTau reconstruction software. Tracks are reconstructed using the base-tracks. Then, those originated inside the module are used to reconstruct the proton interaction vertex. The passing through proton tracks are used for plate by plate alignment of the module with a high precision. An example of the reconstructed tracks in the detector is shown in Figure 2 where about 4000 tracks are reconstructed in a volume of 2×2 mm^2 $\times$ 15 films. Among these tracks a proton interaction is reconstructed at a high accuracy. Figure 3 shows a reconstructed proton interaction with a double charm decay topology. Figures 4 and 5 show impact parameter distribution of all charged-particles attached to the primary vertex. The multiplicty distributions of charged particles in p-A interactions are shown in Figures 6 and 7.

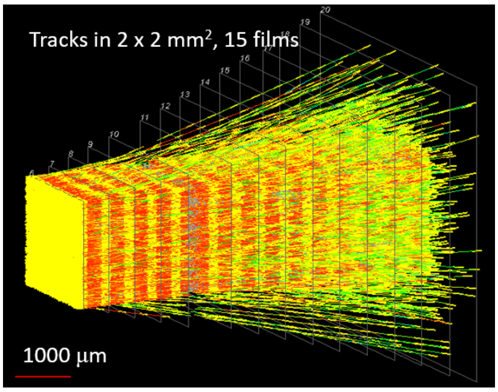

Figure 2: Reconstructed tracks in a fiducal volume of 2×2 mm^2 $\times$ 15 films.

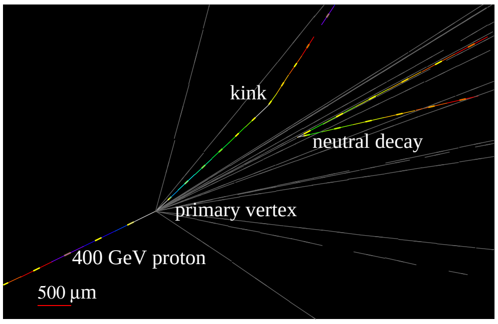

Figure 3: Proton interaction with a double charm topology.

4. Conclusion

The DsTau experiment aims at measuring tau neutrino production in p-A interactions by means of the CERN-SPS proton beam and nuclear emulsion technique. After the test beam studies and the pilot run, physics runs were launched in 2021. The physics run in 2022 was successfully carried out. The analysis of the pilot run data demonstrate that events having a small kink angle are reconstructed in a high track density environment. In the physics runs, 2.3×10^8 proton interactions will be collected in the tungsten/molybdenum target, and about 10^3 D_s decays will be detected. Due

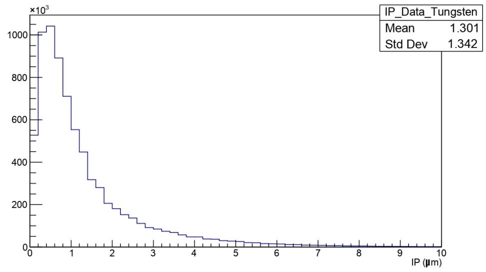

Figure 4: Impact parameter distribution of tracks from primary interaction vertex in tungsten target.

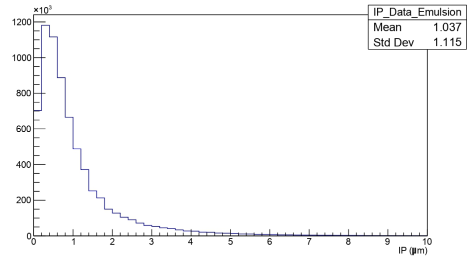

Figure 5: Impact parameter distribution of tracks from primary interaction vertex in emulsion.

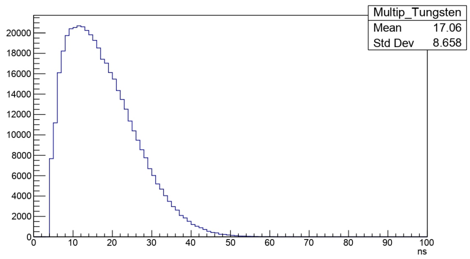

Figure 6: Multiplicity distribution of charged particles produced from proton interactions in tungsten target.

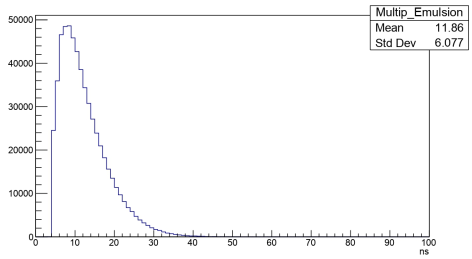

Figure 7: Multiplicity distribution of charged particles produced from proton interactions in emulsion.

to the pandemic conditions, nuclear emulsion production at Nagoya University in Japan was slowed down and only a limited amount of films were produced for 2022 run. Therefore, an additional one year run is scheduled in 2023.

Acknowledgment

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