PROCEEDINGS OF SCIENCE

Study of Tau Neutrinos Production using Nuclear Emulsions at CERN-SPS

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The DsTau (NA65) experiment aims to study $Ds \to \tau + \nu_\tau, \tau \to X + \nu_\tau$ differential production cross section using 400 GeV/c proton and tungsten target. The nuclear emulsion tracker is adopted to detect $Ds \to \tau + \nu_\tau$ small angle kinks and short flight lengths in the in mm scale. The analysis of 2.3×10^8 proton interactions in tungsten will produce about 1000 detected $Ds \to \tau + \nu_\tau, \tau \to X + \nu_\tau$ cascade decays and will reduce the uncertainty of ν_τ flux to 10%. In addition, about 10^5 charm pair associating events will be collected during the analysis. The charm production properties and correlations between two charm's angles or momenta or fragmentations will be analyzed. Not only interactions with tungsten but also interactions with plastic and emulsion are identified using the vertex position. Therefore, Z dependence analysis of target nucleus can be carried out for proton interactions. A pilot run was carried in 2018 and preliminary results on proton interactions and charm productions were obtained. About 22% of the pilot run data was processed and the systematic small kink decay search is scheduled to start soon. Physics run is scheduled for 2021 and 2022. The beam exposure in 2021 was successful and all emulsion films were developed and are ready for scanning and analysis.

**** The 22nd International Workshop on Neutrinos from Accelerators (NuFact2021) ****
**** 6–11 Sep 2021 ****
**** Cagliari, Italy ****

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https://pos.sissa.it/

PoS(NuFact2021)084

1. Introduction

Existence of three neutrino flavors is well known. Among them, study of muon neutrinos is advanced. There are several studies based on measurements of cross section with nucleon and electron neutrinos. However, measurements of the cross section with tau neutrinos and its properties are the least studied and only a few reports exist [1] etc. Hence the experimental check for neutrino flavor universality is not sufficient to exclude the effects beyond standard model physics. There are two major difficulties in conducting experiments with tau neutrinos. The first difficulty is making of tau neutrino beams and the other is the difficulty in detection and identification of the tau neutrino interaction vertex. Tau neutrinos are produced by the decay of Ds meson to tau and the tau cascade decays, $Ds \rightarrow \tau + \nu_\tau, \tau \rightarrow X + \nu_\tau$. Essentially the tau neutrino beam is produced at proton beam dump where Ds are created by proton-target nucleus interactions. The concept of tau neutrino cross section measurement is shown in Fig.1. The main inputs needed for the tau neutrino cross section measurement are tau neutrino flux and the number of tau neutrino interactions. DONuT tau neutrino cross section measurement [1] suffers a large statistical error of 33%, however, in the future experiments like SHiP [2] will reduce such errors.

Ds meson's tauonic decays rate at the beam dump would give the tau neutrino beam flux. Moreover, tau neutrino flux as a function of its energy can be calculated using the momentum distribution of Ds particles. The aim of this DsTau experiment is to study the Ds production differential cross section caused by 400GeV proton interactions and to reduce tau neutrino flux uncertainty from 50% to 10%.

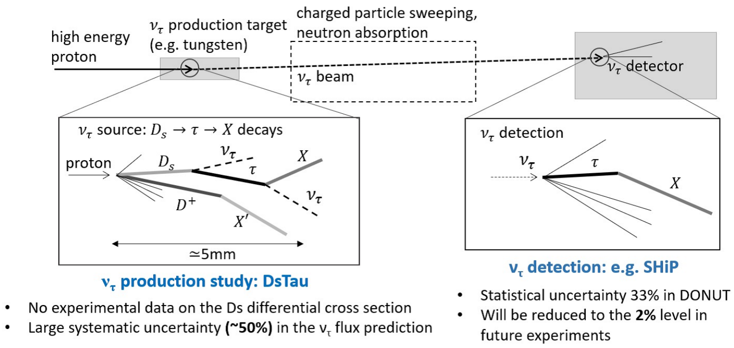

Figure 1: Schematic view of tau neutrinos production by accelerator.

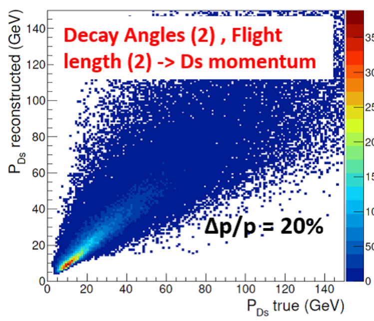

Figure 2: Ds momentum estimation by topological information.

2. DsTau experiment

DsTau experiment uses CERN SPS 400 GeV proton beam to measure the Ds production differential cross section. The cascade decays, $Ds \rightarrow \tau + \nu_\tau, \tau \rightarrow X + \nu_\tau$ produce two kinks in the trajectories of charged particles. The decay angle at the first kink Ds→ τ is as small as ~ 7mrad. On the other hand, the decay angle at the second kink $\tau \rightarrow X$ is as large as several tens of mrad and easier to detect. To detect a kink topology, position resolution should be comparable or better than the expected impact parameter (IP) which given by the product of kink angle and flight length. For the first small angle kink, a dedicated tracking device with position resolution better than 7μm is required. The nuclear emulsion films that are selected as the tracking device have sub-micron position resolution and were also used in the E653 experiment in the first detection [3] of $Ds \to \tau + \nu_\tau, \tau \to X + \nu_\tau$ topology.

It is important to measure Ds momentum distribution to estimate tau neutrino flux as a function of energy. Topological information such as decay kink angle and flight length depend on mother Ds energy. If Ds energy becomes higher, the decay kink angle becomes smaller and flight length becomes longer. The Ds cascade decays have two kink angles and two flight lengths. These 4 variables from a dedicated Monte Carlo sample that can be used as CNN inputs to estimate mother Ds momentum. The CNN momentum estimation performance is shown in Fig.2 and the accuracy is evaluated at ~20% [4].

To achieve 10% uncertainty on tau neutrino flux, a sample of at least 1000 detected $Ds \to \tau + \nu_\tau, \tau \to X + \nu_\tau$ events is required. Approximately, 2.3 $\times 10^8$ of proton-tungsten interaction is needed for that. In addition to Ds search about 10^5 interactions with the charm pair will be detected during the analysis and charm production properties will be studied in detail. Not only charm study but the secondary particle's multiplicity distribution or angular distributions at proton interactions will be studied for several target materials.

3. Staus of data analysis

The DsTau detector structure is shown in Fig.3. A basic unit is a 500 μ m thick tungsten plate followed by interleaved 10 nuclear emulsion films and 9 plastic spacers. The tungsten plate acts as a target and emulsion films act as a tracking detector to locate the interaction and decay vertices. 10 units each adds some units to measure the charged particle's momentum at the end of a detector module. A motion-controlled target mover is used to uniformly irradiate proton beam onto our module. In 2018 a pilot run was performed to collect one tenth of the aimed total statistics.

The accumulated track density in the emulsion film is about 10^5 /cm^2 which originated mainly from the beam of protons and secondary particles. The track density increases toward detectors downstream due to the integration of secondary particles. The track density value is higher than that of typically used nuclear emulsions. There are both advantages and disadvantages of high accumulating track densities in emulsion trackers. The advantage being that precise alignment between emulsion films can be achieved which makes small angle kink detection rates higher and momentum estimation by Multiple Coulomb Scattering measurement between target plates more accurate. The disadvantage being that the possibility of miss track reconstruction rates would become higher by chance coincidence connected to wrong track segments. The rate of miss reconstruction depends on the tracking allowance, the reconstruction algorithm and the standard algorithm that makes miss track reconstructions. A dedicated algorithm [4] against high track density conditions is used to avoid miss reconstruction. As seen in Fig.4 the vertex reconstruction position accuracy in the beam direction is about 20 μm which is enough to identify the location of interaction in the target material, The secondary particle multiplicity by proton interactions is analyzed in each detector component material, Tungsten, Emulsion and Plastic (Fig.5). Also angle distribution of the secondary particles is studied in each of the materials. The nuclear emulsion records a charged track as a chain of silver grains by 3-dimentional coordinate (x,y,z) and hence the track angle is recorded as a 3-dimentional vector. In the case of x-projection and y-projection trackers, there is combination ambiguity but no such ambiguity happens in the case of nuclear emulsion tracker. The typical angular resolution of an emulsion film is a few mrad and 0.1mrad accuracy can be easily achieved by connecting two emulsion films. The detailed study on angular distribution compared with FLUKA Monte Carlo simulation shows a deficit in data of the forward angle region (<20mrad). A dedicated study on emulsion tracker's efficiency at the forward angle region and comparison with simulation data by MC generators is ongoing. A search for charm pair production in proton interactions at tungsten subsample is performed and 115 charm pair candidates are found from 147,236 proton interactions. The flight length distribution of detected charms agrees with the FLUKA MC sample. The data processing for event reconstruction is currently on going and 22.2 % of the data from 2018 run was processed and event selection has been applied. The selected sample will be checked using the event display. The processed data corresponds to 2,653,846 proton interactions. After collecting charm associated events, small angle kink $Ds \rightarrow \tau + \nu_\tau$ will be searched. We have already started the search for small kink in observed charm candidate events with preliminary selection cuts. The parent tracks making a large angle kink decay are examined for hidden kink.

As shown in Fig.6, several candidate events having small angle kink are selected and systematic search will be performed with tuned selection cuts.

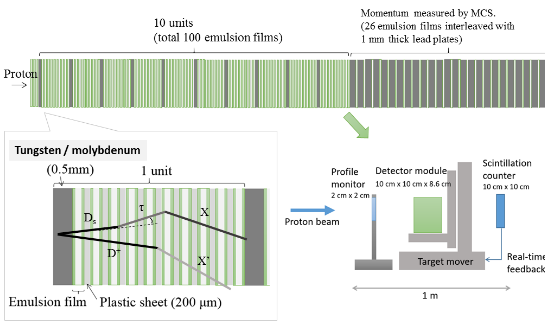

Figure 3: Schematic view of emulsion detector and target mover.

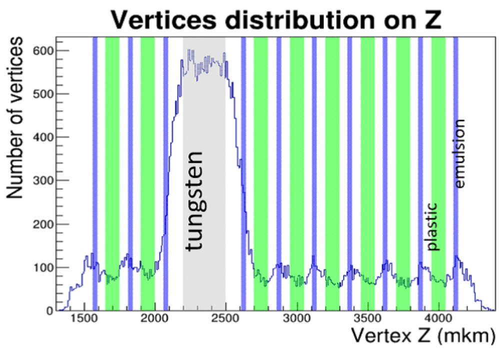

Figure 4: Vertex position distribution.

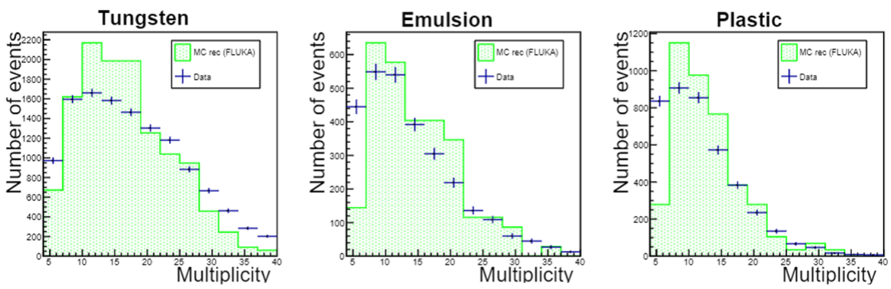

Figure 5: Track multiplicity distribution in target materials.

Two weeks of beam time in 2021 and 2022 is originally scheduled for Physics run. The beam time in 2021 was allocated to 22nd September to 6th October. Due to COVİD19 pandemic, the 2021 run was performed with a reduced target mass; 45% of the proposed target exposed to the proton beam. After the exposure, all the emulsion films were developed and are currently ready

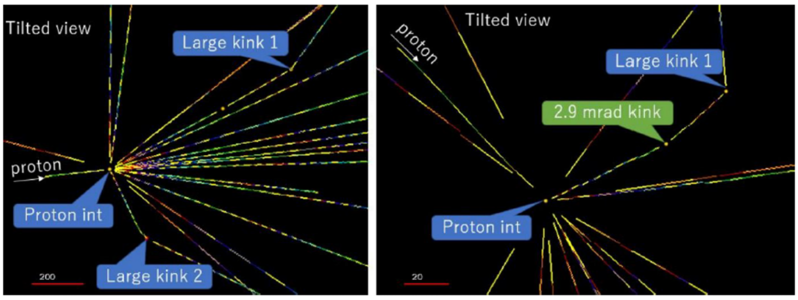

Figure 6: A candidate event with a small kink.

for scanning. The recovery of lack of exposure in 2021 will be done in 2022. Some molybdenum target modules are also exposed for the first time in DsTau. Molybdenum is a major component of the SHiP beam dump target. We are looking forward to seeing the differences in secondary track multiplicity distribution and charm production properties between tungsten and molybdenum targets.

4. Summary

The DsTau (NA65) experiment aims to study Ds differential production cross section using 400 GeV/c proton beam and tungsten target. Nuclear emulsion tracker is adopted to detect $Ds \rightarrow \tau + \nu_\tau$ small angle kinks in short flight lengths in the ~ mm scale. The analysis of a total of 2.3×10^8 proton tungsten interactions and detection of ~ 1000 $Ds \rightarrow \tau + \nu_\tau, \tau \rightarrow X + \nu_\tau$ will reduce the uncertainty of ν_τ flux to 10%. In addition to Ds production measurement, charm production properties will be studied with a large statistics of charm hadron pairs; about10^5 charms pairs are expected. The target material is not only tungsten but interactions also in plastic and emulsion can be identified with the vertex positions. Therefore, material dependence analysis on proton interaction and charm production will be performed. The 2018 pilot run data is analyzing and showing performance of event and charm detection. About 22% of the pilot run data has been processed so far and the systematic small angle kink decay search is scheduled to be performed soon. The beam exposure of 2021 run was successfully done even under the prevailing COVID19 situation and the preparations for 2022 run is going as per plans.

References

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[2] A Facility to Search for Hidden Particles (SHiP) at the CERN SPS, SHiP collaboration, CERN-SPSC-2015-016 (2015) [SPSC-P-350] arXiv:1504.04956

[3] New techniques for emulsion analysis in a hybrid experiment, K.Kodama et al. NIM B 93(1994) 340-354, Fig.15 (p.353)

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