PROCEEDINGS OF SCIENCE

NA65(DsTau): study of tau neutrino production in p-A interactions

Emin Yuksel[a,*] **and Ali Murat Guler for the DsTau Collaboration**[a]

[a] *Physics Department, Middle East Technical University, Dumlupınar Bulvari, 06800 Ankara, Turkey*

E-mail: eyuksel@metu.edu.tr, amg@metu.edu.tr

The DsTau experiment at CERN-SPS has been proposed to measure an inclusive differential cross-section of a D_s production with a consecutive decay to tau lepton in p-A interactions. A precise measurement of the tau neutrino cross section would enable a search for new physics effects such as testing the Lepton Universality (LU) of the Standard Model in neutrino interactions. The detector is based on nuclear emulsion providing a sub-micron spatial resolution for the detection of short-length and small "kink" decays. Therefore, it is very suitable to search for peculiar decay topologies ("double kink") of $D_S \to \tau \to X$. In 2022, the second physics run of the experiment was performed successfully. In this talk, we discuss the physics potential of the experiment and present the analysis result of the pilot run data and the near-future plans.

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1. Introduction

The DsTau experiment [1] is proposed to measure the differential production cross-section of D_s mesons in proton-nucleus interactions at an energy level of 400 GeV. This initiative is driven by the understanding that one of the principal sources of Tau neutrino generation lies in the process of D_s decay. The characteristic event signature for $D_s \to \tau \to \nu_\tau$ transitions are characterized by a distinctive double kink pattern, coupled with the additional decay topology involving a pair of charm particles, both occurring within a short spatial range (Figure 1). Notably, the angular divergence (kink angle) in the $D_s \to \tau$ decay is remarkably small, approximately 7 milliradians. To facilitate the precise measurement of such decay topologies within this limited range, an emulsion detector boasting nanometric spatial resolution is employed.

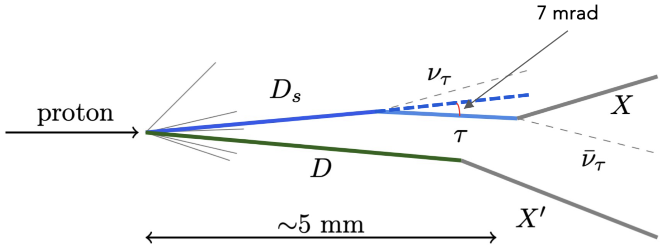

Figure 1: Decay topology of D_s meson decay.

Previously, the cross-section for Tau neutrinos has been measured, with a substantial degree of uncertainty, primarily through charged meson decay in the DONuT experiment [2]. The primary source of this uncertainty stems Tau neutrino production mechanism, contributing to a systematic error of approximately 50%, and the statistical error accounts for roughly 33% of the overall uncertainty. Moreover, only 9 ν_τ events are observed [3] in the DONuT experiment.

This pronounced level of uncertainty in the Tau neutrino cross-section measurements underscores the critical need to enhance the precision of D_s meson production cross-section measurements. Consequently, the DsTau experiment is designed to measure of uncertainty associated with D_s production. This will be achieved through the measurement of 10^3 D_s to Tau decay events, with tungsten and molybdenum as the experimental targets.

2. Experimental Setup and Data Taking

Nuclear emulsion contains silver halide crystals combined with gelatin as the binding medium. When charged particles pass through the emulsion, activates silver grains along the particle's path, and with the chemical development process grains inside the emulsion films are fixed. Then, the analysis of these emulsion tracks is carried out using automated optical microscopes.

The DsTau detector is constructed using emulsion films separated by plastic spacers, effectively functioning as a tracking apparatus. Tungsten and molybdenum serve as the proton target. Each unit of the detector comprises a target followed by 10 emulsion films and 9 plastic spacers. This unit is repeated 10 times. Additionally, there are 5 emulsion films situated in front of the detector, which aids in determining the characteristics of the incoming particle beam (Figure 2).

The DsTau experiment is conducted at the CERN-SPS/North Area. It is expected to have 4.9×10^9 400 GeV protons on target, resulting in 2.3×10^8 proton interactions on target. As of 2022, 50% of the data collection phase has been completed, and a physics run is scheduled for September 2023.

Scanning of the emulsion films is carried out using computer-operated optical microscopes, with a base reconstruction efficiency exceeding 95%. A full surface scan is performed to capture all segments of charged particle tracks by employing the Hyper Track Selector (HTS) [4]. Later, events are preselected in the precision measurement phase to search for small-angle decay processes such as $D_s \to \tau$.

The entire module is placed on a servo-driven motorized stage (Figure 2) that adjusts its position based on the beam intensity, ensuring more uniform irradiation of the emulsion films [5].

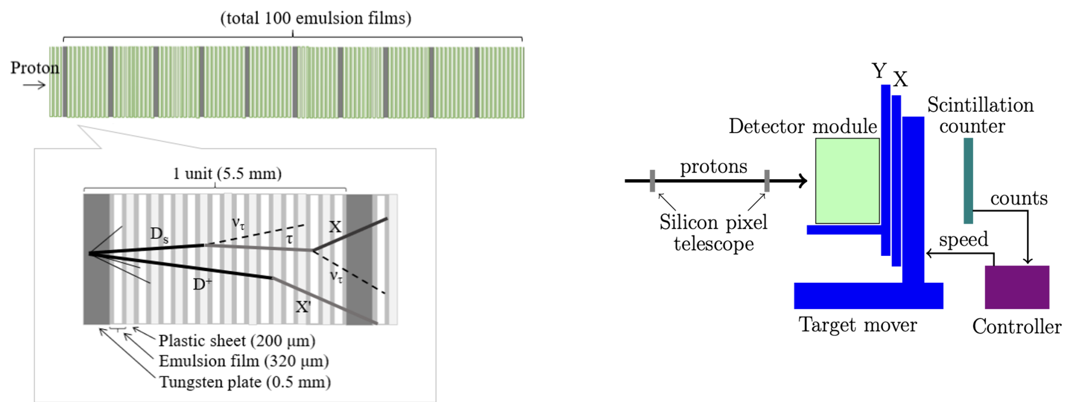

Figure 2: Left: schematics of the DsTau detector. Right: a drawing of the target mover.

3. Data Processing

The emulsion data undergoes processing using the DsTau software to accomplish the reconstruction of particle tracks and the identification of vertices. This process is initiated by the formation of base-tracks through the linkage of micro-tracks detected on both sides of the emulsion. To establish a global reference frame, a fine alignment procedure is applied on these base-tracks.

The base-tracks are systematically connected, plate by plate while adhering to specified criteria related to angular orientation and positional acceptance. This integration yields the creation of volume tracks, which include the paths traveled by the incident beam protons within the module. These beam protons are selected based on their track angles and followed down as they progress through the entirety of the module. Then, a vertexing algorithm is employed to reconstruct the locations of proton interactions and the points of charm particle decay.

4. Results from the Pilot Run

This section focuses on the analysis of proton interaction characteristics and the measurement of interaction length in tungsten, using a subset of data from the preliminary 2018 pilot run.

The proton interactions are simulated and generated through the utilization of the following event generators: Geant4[6], EPOS[7], Pythia[8], QGSJET[9], and DPMJET[10].

The generated output is then propagated through the module by Geant4. To mimic the effects of measurement, a data-driven smearing technique is implemented. The DsTau reconstruction algorithm is subsequently applied to Monte Carlo samples to enable the reconstruction of particle tracks and vertices. The evaluation of the reconstruction efficiency is achieved by comparing the true vertex positions with the positions reconstructed by the reconstruction algorithm.

To evaluate the consistency between the data and Monte Carlo simulations, a comparative analysis is conducted between the two sets of results (Figure 3). This analysis involves the analysis of three fundamental parameters: the impact parameter, the multiplicity of charged tracks, and the angle of the tracks. The figure illustrates that, when all three parameters are taken into account, the EPOS Monte Carlo simulation emerges as the most closely matching model to the observed data.

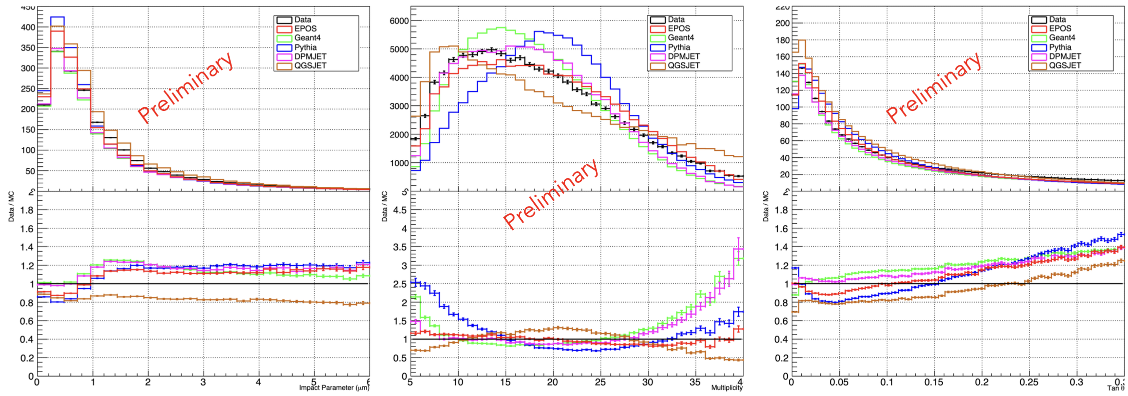

Figure 3: Data/MC comparison. Left: Impact parameter (μm). Middle: Multiplicity. Right: Track angle ($\tan\theta$)

A noticeable discrepancy becomes evident when the $\tan\theta$ exceeds 0.05. To understand this issue, an analysis is conducted, involving the track angles for each multiplicity (Figure 4) and it is seen that with multiplicities larger than 10 discrepancy becomes apparent. Subsequently, slope distributions are examined for two categories: multiplicities below 10 and those exceeding 10 (Figure 5). The outcomes of both analyses indicate that the data and Monte Carlo results generated by the EPOS model show consistency within the confines of lower multiplicity regions (i.e., those with values less than 10). However, a noticeable disparity becomes apparent within higher multiplicity regions (i.e., values exceeding 10). The underlying causes of this divergence remain under investigation within the framework of the DsTau collaboration.

Besides Data/MC comparison, the efficiency of the reconstruction process is also tested. The efficiency of vertex reconstruction is estimated to be approximately $84.2 \pm 0.2\%$, while the efficiency for proton linking reaches $91 \pm 0.2\%$. Furthermore, to examine the criteria used for proton selection, the proton purity of selection is measured and estimated to be around $96 \pm 0.2\%$.

In the concluding phase of our analysis, we perform the first measurement of the interaction length of protons in tungsten using empirical data (Table 1). These measurements are conducted separately for each tungsten sample. Remarkably, both the data and Monte Carlo results exhibit congruent distributions, signifying a high degree of consistency between the two datasets.

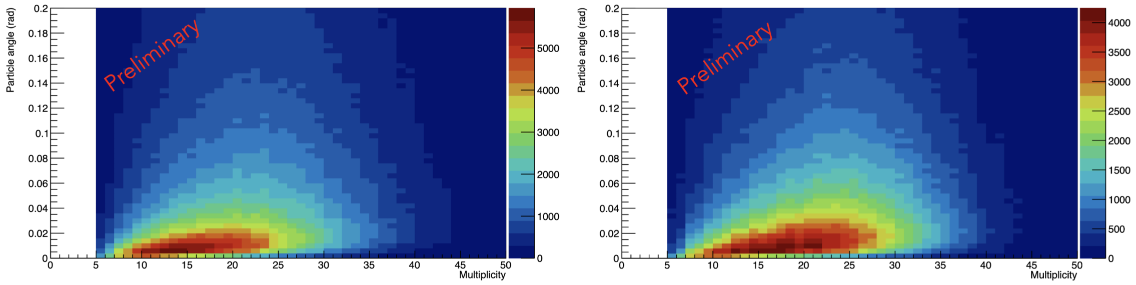

Figure 4: Track angle ($\tan\theta$) vs. multiplicity 2D histograms. Left: Data. Right: EPOS MC

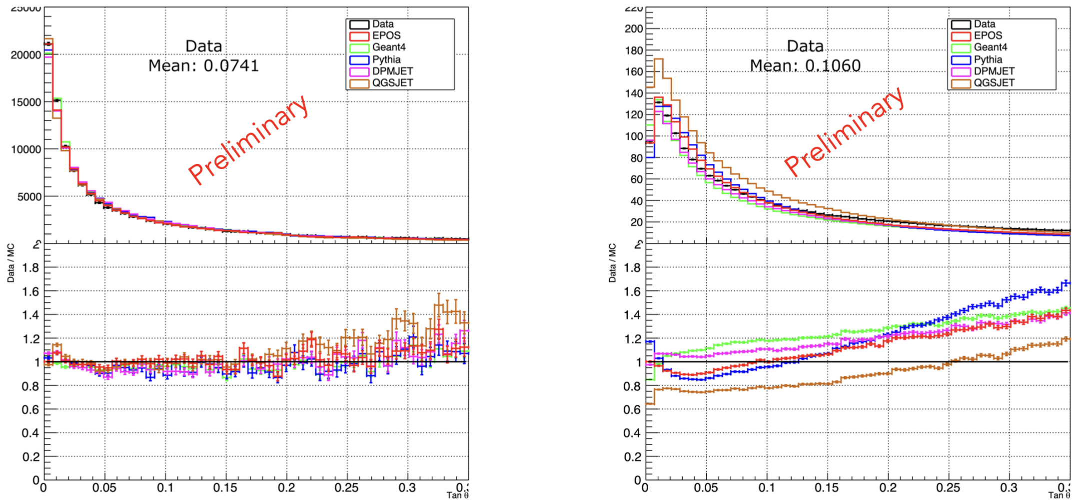

Figure 5: Data/MC comparison for track angle ($\tan\theta$). Left: Events with multiplicity < 10. Right: Events with multiplicity ≥ 10

Table 1: Estimated proton interaction length in tungsten target for Data and Geant4 MC

Sub-volume	Data	Monte Carlo
1	108.6±3.7	102.7±3.4
2	107.2±3.7	104.9±3.4
3	111.1±3.8	106.2±3.5
4	110.9±3.8	107.5±3.5
5	110.7±3.8	108.0±3.5
6	115.5±4.0	108.3±3.6
7	113.3±3.9	110.7±3.6
8	119.3±4.1	113.1±3.7
Mean	112.1±1.4	107.7±1.3

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References

[1] S. Aoki et al. [DsTau Collaboration], DsTau: study of tau neutrino production with 400 GeV protons from the CERN SPS, J. High Energ. Phys. 2020 (2020) 33

[2] K. Kodama et al. [DONuT Collaboration], Observation of tau neutrino interactions, Phys.Lett.B 504 (2001) 218-224.

[3] K. Kodama et al. [DONuT Collaboration], Final tau-neutrino results from the DONuT experiment, Phys. Rev. D 78 (2008) 052002, doi:10.1103/PhysRevD.78.052002.

[4] M. Yoshimoto, T. Nakano, R. Komatani, H. Kawahara, Hyper-track selector nuclear emulsion readout system aimed at scanning an area of one thousand square meters, PTEP 10 (2017) 103.

[5] S. Aoki et al. [DsTau Collaboration] (2023, June 30). Development of proton beam irradiation system for the NA65/dstau experiment. arXiv.org. https://arxiv.org/abs/2303.13070

[6] S. Agostinelli et.al., [GEANT4 Collaboration] GEANT4 a simulation toolkit, Nucl.Instrum.Meth.A 506 (2003) 250-303.

[7] S. Porteboeuf, T. Pierog, K. Werner, Producing Hard Processes Regarding the Complete Event: The EPOS Event Generator, https://doi.org/10.48550/arXiv.1006.2967.

[8] T. Sjöstrand et.al., An Introduction to PYTHIA 8.2, https://doi.org/10.48550/arXiv.1410.3012.

[9] S. Ostapchenko, Status of QGSJET, https://doi.org/10.48550/arXiv.0706.3784.

[10] J.Ranft, New features in DPMJET version II.5, https://doi.org/10.48550/arXiv.hep-ph/9911213.