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NA65 (DsTau) experiment: Tau neutrino production study at the CERN SPS

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NA65 (DsTau) experiment: Tau neutrino production study at the CERN SPS

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Abstract. The NA65/DsTau experiment is an approved CERN experiment with the scope to investigate the tau neutrino production using nuclear emulsion. The production process of tau neutrino is important in the precise measurement of the cross-section of tau neutrinos, which has a positive impact on other experiments. A pilot run was conducted in 2018 and the analysis is underway. Preparations are also ongoing for physics runs in 2021 and 2022.

1. Introduction

The detection of tau neutrinos is very difficult due to the short lifetime of tau lepton which decays into tau neutrino. The direct detection of ν_τ is possible with tracking detectors with high spatial resolution, such as nuclear emulsion. The DONUT experiment observed nine ν_τ interactions directly at last [1]. The OPERA experiment was conducted to search for neutrino oscillation through ν_μ to ν_τ oscillations in an appearance mode. Ten ν_τ charged-current interactions were observed, and the result then contributed to the proof of neutrino oscillation [2].

The 19 ν_τ interactions were observed so far, but the number is much smaller than that of the other neutrino flavors. Therefore, the measurement error of the ν_τ cross-section is very large and the detailed properties of the ν_τ remain unknown. If the measurement error become small, it is possible to test symmetry of the cross-section among three neutrino flavors. Furthermore, the ν_τ cross-section is important to understand the systematic errors of research on neutrino oscillations and cosmic ν_τ.

A main origin of the systematic error in the ν_τ cross-section is uncertainty of the ν_τ beam flux. The uncertainty is due to lack of information on the production cross-section of D_s meson decaying to ν_τ. Therefore, we have been promoting the NA65/ DsTau experiment at CERN SPS for the precise measurements of the D_s production cross-section. The NA65/DsTau experiment was approved by CERN SPSC in 2019. The D_s mesons are produced by the proton-nucleus interaction and the differential production cross-section is measured with D_s mesons detected at 400 GeV/c proton beam. This production cross-section obtained by 1000 D_s mesons can make the ν_τ beam flux reduced from $> 50\%$ to 10%. This result will be an important input for future experiments on ν_τ interaction, such as SHiP [3] and indirectly FASER [4] experiments.

As a byproduct, the intrinsic charm component will be studied. The hypothesis of presence of the intrinsic charm component in nucleons is poorly studied experimentally. The ν_τ flux can be affected by the intrinsic charm component emitted forward by a factor of ten due to the enhancement of the charm meson production.

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2. The Experiment

The main detector in the NA65/DsTau experiment is nuclear emulsion and the target material is tungsten. Protons at 400 GeV/c interact with mainly the tungsten nucleus. D_s meson from a proton-nucleus interaction can be identified, when a double-kink topology where D_s candidate decay to tau lepton and the tau lepton decay to other particles, and the partner charm meson ($D^{\pm}/D^0$) are detected. The kink angle of the D_s to τ decay is very small, with the average angle of 7 mrad, so it is essential to analyze the emulsion with high angular resolution, which is close to a technical limit of the emulsion and the dedicated microscope.

Figure 1 shows the structure (one unit) of the emulsion detector which consists of 10 emulsion films stacked and a tungsten plate on the 10 films. The ten units stacked are one chamber, which has 0.1 interaction length. A set of emulsions and lead layers is installed downstream of the chamber to measure momentum of the long lived particles via multiple Coulomb scattering. The emulsion chamber is moved by the target mover at a speed proportional to the beam intensity to be irradiated uniformly with the proton beam with a diameter of about 10 mm. The number of protons on target (POT) is planned to be 4.6×10^9 and the number of proton interaction will reach 2.3×10^8.

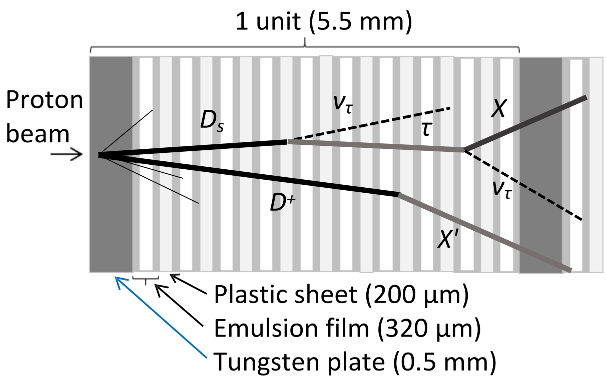

Figure 1. Tau neutrino production process ($D_s \to \tau \to X$) and the detector structure of the NA65/DsTau experiment. The emulsion film has two emulsion layers of 60 μm on both sides of the plastic base of 200 μm.

3. Analysis

All the charged particles recorded in the emulsion are read out using an automated microscope, HTS [5]. The HTS was developed for various emulsion experiments. The readout speed is about 100 times faster than that of the OPERA experiment and the throughput in readout microscope photo is 13 GB/s. About 10 PB photo data was readout for the NA65/DsTau pilot run in 2018. Tracks are detected by GPUs from the photos and the data size of the tracks was compressed with the ratios of around 0.1% of the original photo size. The track data size was $\sim$10TB for the pilot run, which is equivalent to $\sim10^{11}$ tracks.

All the emulsion films were completed to readout, except for problematic films caused by the emulsion handling. Figure 2 shows the detection efficiency which is more than 95% for the downstream part of the module where the track density is high due to secondary interactions. The spatial resolution of 0.4 μm was achieved for tracks perpendicular to the emulsions. The number of tracks for each plate was found to be in good agreement with that for MC based on FLUKA [6, 7] as shown in figure 3.

Since the tracks in emulsion are not time-stamped, the interactions are reconstructed using only the track position and angle.

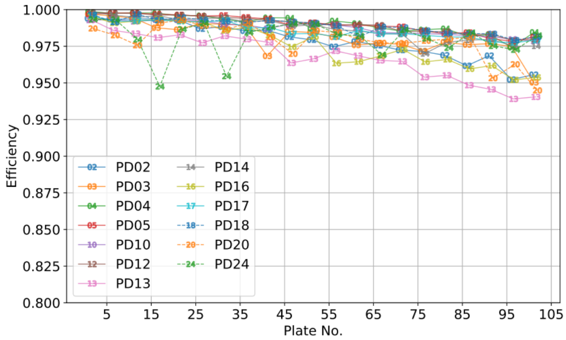

Figure 2. Base track detection efficiency averaged every 5 plates with angle of $\tan\theta < 0.1$. Plate no.1 is the most upstream.

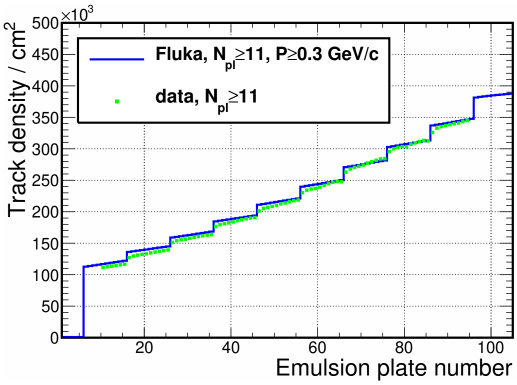

Figure 3. The evolution of track density as a function of depth in a module, compared with the FLUKA simulation [8].

All nearby tracks were combined and the interaction points emitting multiple tracks were found. The number of interactions in tungsten was the largest and that in plastics was the second largest; this tendency is consistent with MC. The number of charged particles emitted from interactions in tungsten at small angle (below 20 mrad) and found in emulsion is less than predicted by FLUKA simulation. We are then investigating the readout efficiency, track reconstruction, and the MC model in detail.

We have searched for the double charm event in the 3.4×10^7 protons. The number of proton interactions is 2.7×10^5 in all materials and 1.5×10^5 in tungsten. In a sub-sample of these interactions, 159 events in total and 115 events in tungsten were detected as having a charm pair topology. Since only 2% of the pilot run data have been analyzed, 50 times more events from the pilot run will be obtained. In order to search for small angle kinks of the D_s to τ decay, a precise measurement of track angles will be done with a special microscope.

4. Issues of physics run

The 2021-2022 physics runs use 10 times the amount of emulsion used in the pilot run. The data size of microscope photo is expected to be ∼100 PB, and the data size of tracks is expected to be 100 TB. To handle the amount of data, a new readout system, HTS-2 is being developed. It will have a low-magnification objective lens which will reduce the data size by half. By increasing throughput by 2.5 times, the readout speed is expected to be five times faster than HTS. Although it may sound like a no-barrier, it is difficult to process 48 GB/s (390 Gbps) of photo data in real time. This data processing will be accomplished by fully utilizing technologies such as parallel processing, high-speed network communication for exchanging data between PCs, and GPGPU for high-speed image processing. The pilot run took one year to read out with HTS, so the physics run will take two years if the new readout system can be used.

The track reconstruction is also difficult because the process needs large amount of working memory $\sim$100 GB. Four computers with $\geq$128 GB RAM are used for pilot run data analysis, however, preparing forty computers for physics run is not realistic to handle 10 times the amount of track data. The software will be improved to increase the processing speed. If it is still not enough, many computers will be installed in many institutes and share the workload for the data analysis.

The target mover for physics runs with wider aperture is almost ready, which is used in the E07 experiment at J-PARC. The drive tests are undergoing. The films were made by hand for pilot run, but it would take too long time for physics run in the same way. To reduce the time, new equipment for mass-production of emulsions was installed and an automatic application system is being constructed.

5. Conclusion and prospects

The NA65/DsTau experiment is a study conducted at the CERN SPS beamline to elucidate the differential production cross-sections of D_s mesons and the nature of intrinsic charm production. In the 2018 pilot run analysis, 100% of the films were readout and 159 candidates of charm pairs were found from 2% of the films, so far. The physics results of the pilot run will be available soon.

Despite the effects of COVID-19, physics runs are scheduled in 2021 and 2022 at CERN SPS. Emulsion readout system, data analysis, the target mover, and production of emulsion films are being prepared for the physics run.

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