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

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The DsTau (NA65) experiment at CERN was proposed to measure an inclusive differential cross-section of D_s production in p-A interactions. As this process is a main source of tau neutrino production, its study is necessary for a measurement of the tau neutrino interaction cross-section which, in turn, enables a search for new physics effects such as testing the Lepton Flavour Universality of the Standard Model in the neutrino interactions. The DsTau detector is based on the nuclear emulsion technique providing an excellent spatial resolution providing a very high spatial resolution for detecting short-lived particles like charmed hadrons. A high precision in vertex reconstruction allows one to measure charged particle multiplicities accurately in a high track density environment. In this paper, the preliminary results of the analysis of the pilot run data are presented.

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1. Introduction

The DsTau experiment [1] aims to measure tau neutrino production in p-A interactions at CERN-SPS. Study of tau neutrino interactions is an important probe in constraining the models beyond the Standard Model. For example, the universality of the weak interaction can be tested. In addition, accurate knowledge of tau neutrino flux in accelerator neutrino beams is essential for ongoing and future neutrino experiments. However, the data on tau neutrino interactions are scarce, in the past only a few experiments reported on their observations with low statistics. The first experiment directly observed the tau neutrino charged-current interactions is DONuT [2] at Fermilab in 2000. The DONuT experiment also made an estimation of the tau neutrino interaction cross-section though with a rather large uncertainty. The systematic error, dominated by the uncertainties in the neutrino production mechanism is about 50 %. The statistical error contributes with about 33 % as only 9 ν_τ events were observed. DsTau aims to reduce the systematic uncertainty in the tau neutrino production down to 10% level by detecting about 10^3 $D_s \to \tau$ decays in 2×10^8 proton interactions in the tungsten/molybdenum target. Moreover, the charmed hadrons production in p-A interactions can also be studied with a large statistics.

2. Experimental Setup and Data Taking

To observe a fully reconstructed decay topology of D_s mesons, a sub-micron spatial resolution, and a sub-mrad three-dimensional angular resolution are required. Among the available detector technologies, only nuclear emulsion can provide required spatial and angular resolutions. The DsTau detector, based on the nuclear emulsion technology, consists of tungsten/molybdenum plates interspaced with nuclear emulsion films and plastic spacers forming one unit. The tungsten/molybdenum plates act as a target for beam protons; emulsion films separated by plastic spacers act as high accuracy tracking devices. The nuclear emulsion films consist of 70-micron thick emulsion layers on both sides 210-micron thick plastic base. In one unit, a 500 μm tungsten plate is followed by interleaved 10 nuclear emulsion films and 9 plastic spacers. This unit structure is repeated 10 times in a module which is 12.5 cm wide, 10 cm high and 8.6 cm thick. In addition a module contains five emulsion films which are placed upstream to tag beam protons. The downstream part of a module is for secondary particles momentum measurement via multiple coulomb scattering measurement and consists of 26 emulsion films interleaved with 1 mm thick lead plates.

The CERN Proton Synchrotron provides a beam of protons with a momentum of 400 GeV/c ($\sqrt{s}$ = 27 GeV). The test beam studies in 2016 and 2017 were performed to test and characterise the detector concept. In 2018, a pilot run was conducted 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 beam-line. During the data taking each emulsion module was mounted on a motorized X-Y stage called target mover which provided the synchronized movement of the module with respect to the proton beamline [3]. So that the detector surface was uniformly irradiated at a density of 10^5 tracks/cm^2. The recorded data corresponds to 10 % of planned statistics of the experiment. The first phase of emulsion scanning of the pilot run films has been completed and analysis of the collected data is going on. For the present measurement, we report the analysis results of a sub data sample from the pilot run. To keep high efficiency and purity in track and vertex reconstruction, the data in the last two tungsten plates are not included.

3. Efficiency Evaluation and Data-MC Comparisons

The vertex reconstruction and proton-linking efficiencies are evaluated with making a detailed simulation of the detector response using a program based on the GEANT4.11 toolkit. The simulated geometry set as for 2018 pilot run setup. A large number of proton interactions are generated using EPOS, PYTHIA8, QGSJET, DPMJET and GEANT4.11 generators by considering the realistic beam proton density in a module. Then, the generated output is transported through the module with GEANT4.11 and HTS [4] tracking algorithms are deployed. The data driven smearing in coordinates and direction of the base tracks has been applied to reproduce the effect of the measurement errors. Then, the reconstruction algorithm, the same as the one used for data, was applied on MC samples to reconstruct particle tracks and vertices. MC predictions are compared with the data in terms of multiplicity, impact parameter and particle slope as shown in Figure 1. The MC plots are normalized with the number of events in the data. Among other event generators, EPOS predictions in the multiplicity of charged particles and impact parameter distributions are in good agreement with data within 10%. However, in track slopes, there is some discrepancy between data and all MC generator predictions. This discrepancy is investigated further whether it is due to inefficiency in track reconstruction or due to underlying physics process in MC event generators. Figure 2 show average slope versus track multiplicity distribution in data and EPOS predictions (the other event generators show similar distributions). In both data and MC predictions, the secondary particle slope distribution shows a dependence on multiplicity.

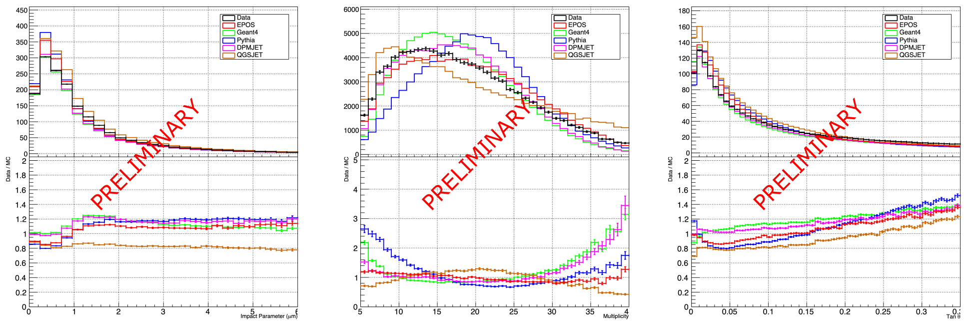

Figure 1: Data-MC comparisions of impact parameter, multiplicity and particle angle.

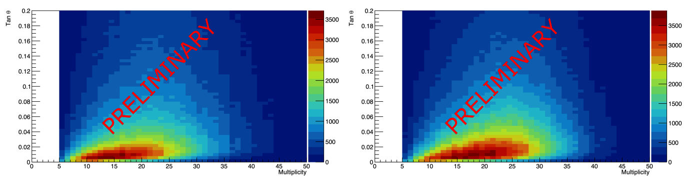

Figure 2: Particle slope vs multiplicity distribution; Data(left), EPOS (right).

As the multiplicity increases, the average angle of charged particles also increases. This can be explained by the constant P_T feature of hadron interactions. That is the average transverse momentum produced in the hadronisation of a jet is constant. Figure 3 shows the Data/MC comparisons of secondary particle angles for the vertices with multiplicity smaller(greater) than 10. The agreement between data and MC predictions in low multiplicity vertices is good for all event generators. However, in high multiplicity events, the agreement between Data/MC deteriorated but it satisfactory up to 200 mrad except for QGSJET. The angular dependence on multiplicity is stronger in the MC event generator predictions. This results in the observed discrepancy at high multiplicity events.

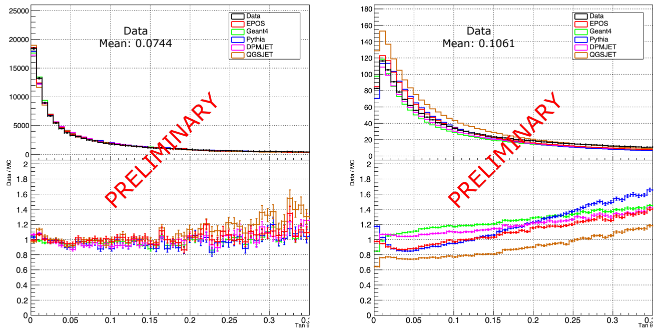

Figure 3: Data/MC comparison of particle angle for the multiplicity less than 10 (left) and greater than 9 (right).

4. Conclusion

The analysis results of pilot run shows that a precise tracking and vertexing can be performed in a high-track density environment. The performance of tracking, vertexing shown in this paper demonstrates that the basic performances necessary for charmed hadron detection, so that for the precise determination of the tau neutrino flux can be achieved. Using a sub-sample of the pilot run, we present the preliminary results on the multiplicity distribution. The secondary particle slope distribution shows a dependence on multiplicity in both data and MC. However, this dependence is stronger in MC predictions. This resolves the observed discrepancy in particle slopes of high multiplicity events in data.

References

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