PROCEEDINGS OF SCIENCE

Study of tau-neutrino production at the CERN SPS (CERN-NA65)

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The tau neutrino is one of the least studied particle in the Standard Model. Current tau neutrino-nucleon cross section measurement suffer large $\sim 30\%$ statistical and $\sim 50\%$ systematic uncertainties. In near future statistical uncertainty will be reduced to a few % by the SHiP experiment, or by the experiments such as SHiP. DsTau (NA65) experiment at CERN aims to reduce the systematic uncertainty on tau neutrino-nucleon cross section through investigating a precise measurement on tau neutrino production, $Ds \to \tau + \nu_\tau$ differential production cross section with tungsten target. The uncertainty of the tau neutrino flux will be reduced to 10 % from 50%. Collaboration will collect 2.3×10^8 proton interactions with tungsten target and study about 10^5 charm associated interactions. A pilot run was performed in 2018 Aug and collecting about a tenth of final statistics to perform full analysis chain. Here the analysis stream and the analysis status of 2018 Aug pilot run will be described.

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1. Introduction

Neutrinos are belonging to neutral lepton group in Standard Model. While their properties are not well understood in comparison with charged leptons or quarks. This is due to their very weak interacting activity with materials and it is difficult to detect or study in detail. Historically it was introduced as a hypothetical neutral particle having very low interaction activities in 1930s. The first experimental detection was achieved in 1956 and now three neutrino generations, ν_e, ν_μ, ν_τ are known. Tau neutrinos confirmation was achieved recently because of experimental difficulty.

DONuT [1] experiment observed tau neutrino interactions with nuclear emulsion hybrid target in 2000. The tau neutrinos were produced at FNAL 800 GeV proton beam dump. They detected 578 neutrino interactions in nuclear emulsion target. Thanks to very fine spacial resolution of nuclear emulsion, short lived tau particle decay vertex is reconstructed in precisely. Finally 9 tau neutrino interaction candidates were reported with one background contamination.

Through the discoveries of neutrino oscillations, the mixing angles between neutrino generations and the existence of neutrino mass is established. While the δcp phase and the absolute mass values and its ordering are still unknown and one of biggest topics in elementary particle physics field. In order to reveal the problem, precision improvement on neutrino-nucleon cross sections is a key issue.

As the basic property, neutrino-nucleon interaction cross sections are measured and plenty of measurements on muon neutrinos and several on electron neutrinos and few of tau neutrinos exist. The neutrino-nucleon cross section measurement is performed by two steps, step1. neutrino production and step2. detection of the neutrinos. So the neutrino flux uncertainty come from these two steps. From step1. uncertainties due to observed statistics and detector performance uncertainties and from step2. uncertainties on production mechanism are dominant component. DONuT report also tau neutrino cross section in 2000.

2. DsTau experiment

Tau neutrinos emitting at Ds meson decays are used for the accelerator tau neutrino beam source. High energy proton exposed to beam dump target generates proton interactions having charm pair by 0.1% rate and a kind of charm meson Ds will decay to tau and tau neutrino (Ds$\rightarrow$ $\tau+\nu_\tau$) by 4.3% branching ratio and tau decay ($\tau \rightarrow X+\nu_\tau$) in cascade. This is the principle of tau neutrino production mechanism by the accelerator. Figure 1 is the schematic view of the tau neutrino production through Ds meson decays. DONuT case, 800 GeV proton beam were exposed to tungsten beam dump target. DONuT reported tau neutrino nucleon cross section using the 9 tau neutrino candidates with large statistical (33%) and the systematic uncertainty (50%). The statistical uncertainty can be reduced in future experiment like SHiP [2] aiming to collect 10,000 tau neutrino events. The large systemic uncertainty come from tau neutrino flux uncertainty should be reduced to measure tau neutrino-nucleon cross section in accurate.

The DsTau [3] experiment aims to measure Ds meson differential cross section to make tau neutrino flux uncertainty as bellow as 10%. The specific feature of $Ds \rightarrow \tau$ decay is the small angle difference (decay angle) between Ds meson and tau particle and larger angle difference at tau decay then this cascade decays trajectory looks like a double kinks within a few mm short distance.

The smallness of first kink angle (average $\sim$ 7 mrad) within a few mm distance request spacial resolution well better than μm. So DsTau experiment uses nuclear emulsion as the tracking device as like as DONuT experiment. We are aiming to collect 1000 $Ds \to \tau \to X$ decays to report its production cross section in detail for realizing tau neutrino flux uncertainty as below as 10%. This request a mother sample of 2.3×10^8 proton tungsten interaction.

High(low) energy Ds meson produce high(low) energy tau neutrinos. So the momentum vector of Ds meson will be measure to know the produced tau neutrino energy. The one of the key technique of DsTau experiment is this Ds momentum measurement by geographic parameters in ranging around 5 to 30 GeV, where (>10GeV) usual momentum measurement by multiple coulomb scattering suffer larger uncertainty than 100%. The flight lengths and decay angles are input for the momentum estimation and reaching $\sim$18% momentum resolution (Figure 2).

We adapt Emulsion Cloud Chamber (ECC) detectors piling up of 10 basic unit with 500 μm thick tungsten foil for proton interaction target followed by 10 nuclear emulsion films together with plastic separators. One ECC detector is made by 10 basic unit followed by alternatively stack of 1mm thick lead plates and nuclear emulsion plates (see Figure 3). A total of about 400 ECC detector modules will be used to store 2.3×10^8 proton-tungsten interactions.

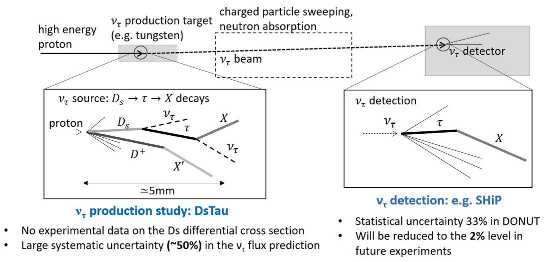

Figure 1: Schematic view of tau neutrino production by accelerator

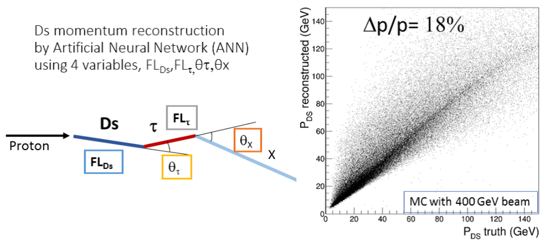

Figure 2: Ds momentum estimation

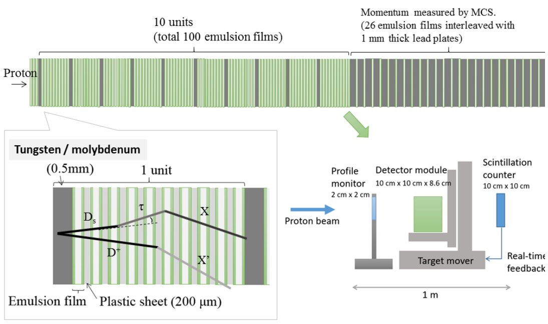

Figure 3: Schematic view of emulsion detector and target mover

3. Test runs and the pilot run 2018 Aug

Detector performance test with CERN SPS 400 GeV proton test beam were done in 2016 and 2017. By the performance test, we established or confirmed the method of the emulsion detector piling up in a CERN dark room and transportation to experimental site and beam exposure. The one of the key issue of the test beam is accumulating proton beam density uniformly for whole surface 12.5cm×10cm of emulsion module. Since the proton beam divergence is small as a few cm × a few cm at maximum expanding setting, the emulsion detector should be moved depending on the accumulated track density. In 2016 , a constant speed operation on X-axis is tested by a so-called target mover and as a result a cyclic, corresponding to spill by spill movement, track density in x axis was seen. This was due to proton track extraction spill have time structure in number of proton more at begging than ending. In 2017, target mover was controlled with feedback from scintillator counting penetrating proton at behind the emulsion detector. This movement control works very well and the cyclic track density deviation was disappeared and uniform accumulation method was established.

We have demonstrated a tenth of full scale event accumulation in Aug 2018. 30 emulsion detector modules, total ∼4000 emulsion films were used. After photo chemical development of emulsion films systematic scanning of films started from November 2018 together with tuning for scanning. An automated track selector HTS [4] readout all (tan(θ)<1.) recorded charged particle's trajectory (track) from full area of emulsion films. And alignment in emulsion films have been adjusted by connecting tracks between emulsion films and thanks to high energy 400 GeV penetrating protons, the alignment accuracy is well bellow sub μm. The track recoding efficiency by one emulsion films have been estimated as high as 90-95% by penetrating tracks. Observed number of proton interactions and charm pair candidates in subsample data is consistent with MC (Table1).

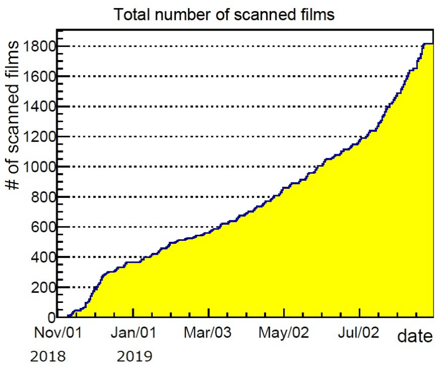

Figure 4: Scanning progress plot . 57.7% (87% at article editing time, end of 2019)) of pilot run films have been scanned.

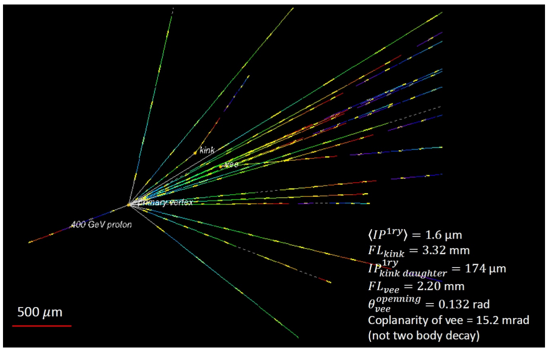

Figure 5: Event Display of a proton interaction with charmed particles decay.

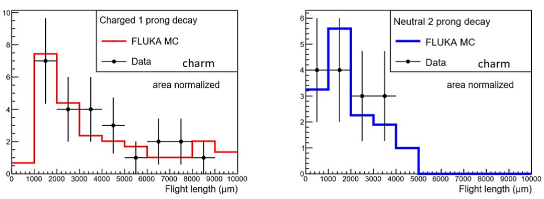

Figure 6: Flight length distribution of detected charm candidates. Charged charm decays into one prong in the left and neutral charm decays into two prongs in the right histogram.

Table 1: Data and MC consistency: vertices in tungsten and charm pair candidates in subsample data. Data and MC are normalized by number of penetrating protons in analysed volume.

subsample	2016 run		pilot run	
protons	3,712,959		3,355,967	
	Data	MC	Data	MC
Vertices	19008	18567	17001	16779
Charm pairs	10	9.1	10	8.2

4. Summary and prospect

DsTau project will accumulate 2.3 $\times 10^8$ proton interactions with tungsten by nuclear emulsion detector and analyse $\sim$1000 $Ds \to \tau \to$X to report its differential production rate. The collaboration performed detectability of charm particles in the realistic track density ($10^5/cm^2$) in physics run 2021 -2022. Basic experimental tools and performance checks were done through 2016 and 2017 test beam exposure with CERN SPS 400 GeV proton. A method of the uniform exposure in track density on full surface of emulsion was established by controlling target mover with feedback from scintillator track counter behind the emulsion detector. The pilot run, a tenth of full scale have been conducted in Aug 2018 and the full chain of the analysis, emulsion detector construction and its beam exposure and photo chemical development have been successfully done. Accumulating about 20 million proton -tungsten interactions in 30 emulsion modules and a systematic film scanning by automated microscope (HTS) started the data taking from Nov 2018 and expected to finish in end of 2019. By analysing subsample of data from test beam and pilot run, proton interactions in tungsten foils and events with associated charm pair have been analysed.

Toward physics run in 2021-2022, we are planning to improve emulsion scanning speed by using faster scanning system currently under construction and launching in middle of 2020. The expected scanning speed will be 5 times faster than current HTS and a size of 12.5cm$\times$10cm film can be scanned in one of two minutes. In order to reduce emulsion film setting time loss, a larger area (like 25cm$\times$25cm) emulsion detector should be designed and related tools should be prepared. Using the HTS-II , the total scanning time for all Physics run emulsion films will be one year. Currently the precise measurement for small angle kink study is developing and this procedure should be applied in for all collecting charm pair events.

Improvement on speed for event reconstruction and decay search analysis is on going using pilot run data to digest physics run data in time.

References

[1] Final tau-neutrino results from DONUT experiment., DONUT Collaboration (K.Kodama et al.), *Phys.Rev.***D78**:052002, 2008.

[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] Study of tau-neutrino production at the CERN SPS., S.Aoki et al., CERN-SPSC-2017-029, SPSC-P-354, *arXiv*:1708.08700

[4] Hyper-track selector nuclear emulsion readout system aimed at scanning an area of thousand square meters., M.Yoshimoto, T.Nakano et al., *PTEP* 2017(2017) no.10, 103H01