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Study of tau neutrino production property with measuring open-Charms at 400 GeV proton beam dump

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The property of tau neutrino is not well known, due to difficulty of its production and detection. The comparison of the neutrino-nucleon cross-section of tau neutrinos and other neutrino flavours is one of the interesting topics. The tau neutrino cross-section has been measured by the DONUT experiment, but with a large statistical error of $\sim 30\%$ and a systematical uncertainty of $\sim 50\%$. The statistics of detected tau neutrinos will be improved by a planned experiment such as SHiP experiment at CERN in near future. The DsTau collaboration aims to reduce the systematic uncertainty to 10% by measuring the mother particles(*Ds* mesons) of tau neutrinos at the beam source. *Ds* mesons are generated by proton interactions with the beam dump target, which decay in sequence $Ds \rightarrow \tau + \nu_\tau$ and $\tau \rightarrow \nu_\tau + X$. DsTau will collect 1000 $Ds \rightarrow \tau$ associated events in 2.3×10^8 proton interactions with the tungsten target using the 400 GeV/c proton beam at CERN SPS. The rate and x_F distribution of the *Ds* production will be measured and the reduction of uncertainty on the tau neutrinos production will be achieved as the result. Since *Ds* and tau mass difference is small, the kink angle($\sim 7mrad$) in the *Ds* to tau trajectory within a short distance of a few mm decay flight is difficult to detect. Emulsion Cloud Chambers, ECCs, dedicated structure with tungsten plates and nuclear emulsion plates are used to detect small angle kinks at *Ds* to tau decays. Since large number, 10^5 events, of associated charm production will be accumulated and analyzed in ECCs, physics of open-charm could be studied as a byproduct. The DsTau project introduction and results from small scale test exposure in 2016, 2017 are described.

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PoS(DIS2018)228

1. Tau neutrino cross-section

Neutrino cross-section with a nucleon is measured by several experiments and the uncertainty of that is about 2% for muon neutrinos and 14% for electron neutrino for higher energy than several tens of GeV. While tau neutrino cross-section with a nucleon is only measured by DONUT experiment [1] with large uncertainty both systematic and statistical errors. The difficulty of tau neutrino cross-section measurement can be categorized into two parts as shown in fig.1. The first part is to precise measurement of the tau neutrino production flux produced by D_s meson decays from proton interactions at tungsten target. The other is detection of the tau decays at tau neutrino interactions in a short distance. Nuclear emulsion have a sub-micron spatial resolution and used the tau detection by DONUT experiment.

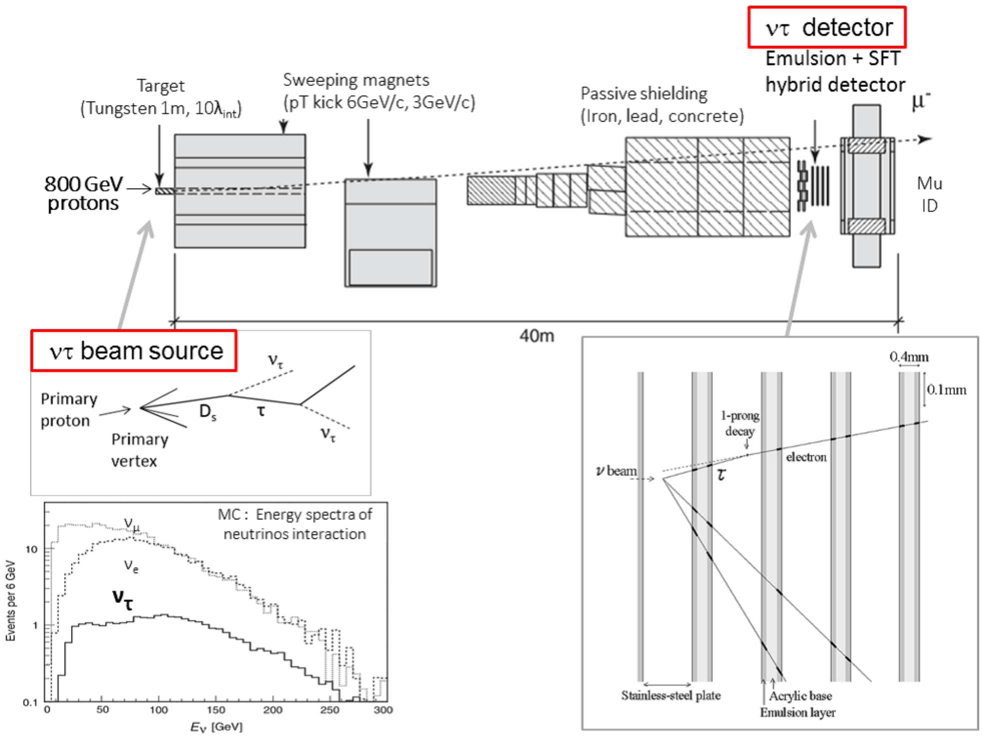

Figure 1: The schematic of the DONUT experiment.

Tau neutrino cross-section was reported in the expression as $\sigma_{\nu_\tau} = \sigma_{\nu_\tau}(const) \times E_{\nu_\tau} \times K_\tau(E_{\nu_\tau})$. Where K_τ is the kinematic correction factor. An the energy independent part was parameterized as $\sigma_{\nu_\tau}(const) = 7.5(0.335n^{1.52}) \times 10^{-40} cm^2 GeV^{-1}$. Where n is the parameter controlling the longitudinal part of the D_s production differential cross-section and this part have large uncertainty.

$$\frac{d^2\sigma}{dx_F d_{P_t^2}} \sim (1-|x_F|)^n exp(-bP_t^2). \tag{1.1}$$

$$x_F = \frac{2p_z^{CM}}{\sqrt{s}}$$

2. The DsTau experiment

The aim of the DsTau experiment[1] is the reduction of the uncertainty on tau neutrino production flux by measuring the D_s production differential cross-section in accurate with 1000 detected D_s mesons.

The first key point is identification of D_s meson with negligible background from other charm mesons or hadron interactions. The pure D_s identification will be done by detecting a "double kink" topology due to the cascade decay of $D_s \to \tau + \nu_\tau, \tau \to X + \nu_\tau$. The first decay, $Ds \to \tau$ make a small angle ($\sim 7mrad$) kink between the *Ds* track and the tau track and the second decay,$\tau \to X$, shows a relatively large kink angle ($\sim 100mrad$) topology. A tentative selection[2] efficiency for picking up the double kink events is estimated as $\sim 20\%$. And a negligible background events from other charm hadron ($\leq 1.$) or from hadron interaction ($\leq 1.$) is expected by carefully check of track multiplicity and validated by the absence of nuclear evaporation tracks at decay candidates.

The second key point is the ingredient for differential cross-section measurement is to know *Ds* momentum value. We use again topological informations for measuring the D_s momentum. As shown in fig.2 D_s meson momentum and the decay parameters have correlations. For example, the kink angle at $Ds \to \tau$ decay is smaller (larger) when *Ds* have larger (smaller) momentum. Four such correlated variables, *Ds* flight length, tau flight length, the first kink angle, the second kink angle, are used in *Ds* momentum estimation by Artificial Neural Network (ANN). The estimated *Ds* momentum from ANN shows momentum resolution $\sim 18\%$ shown as fig.3.

The big challenge in this project is a huge number of proton interactions, 2.3×10^8, is needed to be analyzed to accumulate a 1000 detected $Ds \to \tau$ events in the detector. This number is more than three order higher than that of maximum number of past experiments using nuclear emulsion. Setting a proton track density $\sim 10^5/cm^2$ in the module surface by controlled target mover, a total of 400 modules will be exposed to CERN SPS 400GeV/c proton.

2.1 Charm hadron interaction

About 10^5 charm pair associating proton interactions will be accumulated in the modules. So byproduct study could be considered using charm pair produced events. Charm hadron interaction length is not yet measured. So the measurement of charm hadron interaction length is one of such physics targets. As shown in fig.4, emission of nuclear fragments or inconsistent number of charged tracks as a decay at the vertex point when a charm hadron interact with a nuclear. Nuclear emulsion can easily distinguish nuclear fragments from shower tracks produced at the interaction vertex by the track darkness with large angular acceptance as $tan(\theta) \leq 3$. The detected number of charm hadron interaction will be about 1000 events assuming charm hadron have similar interaction length with a proton.

3. The analysis status

The analysis stream starts with full area scanning of emulsion films by a high speed automatic

[1]Collboration of 19 people in 5 countries 8 institutes.
Japan (Nagoya, Kyusyu, Aichi, Kobe), Switzerland (Bern), Romania (Bucharest), Russia (Dubna), Turkey (Ankara)
[2]1 film<FL(Ds)<5mm & $\delta\theta(Ds \to \tau)$>2mrad & FL($\tau$) <5mm & $\delta\theta(\tau)$>15mrad & pair charm detection

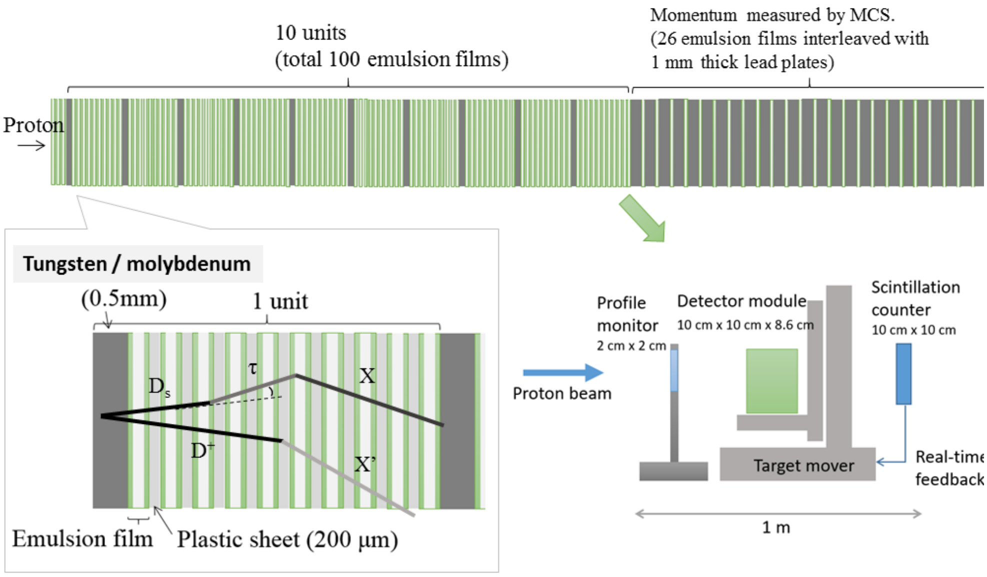

Figure 2: The module schematic view of the DsTau experiment.

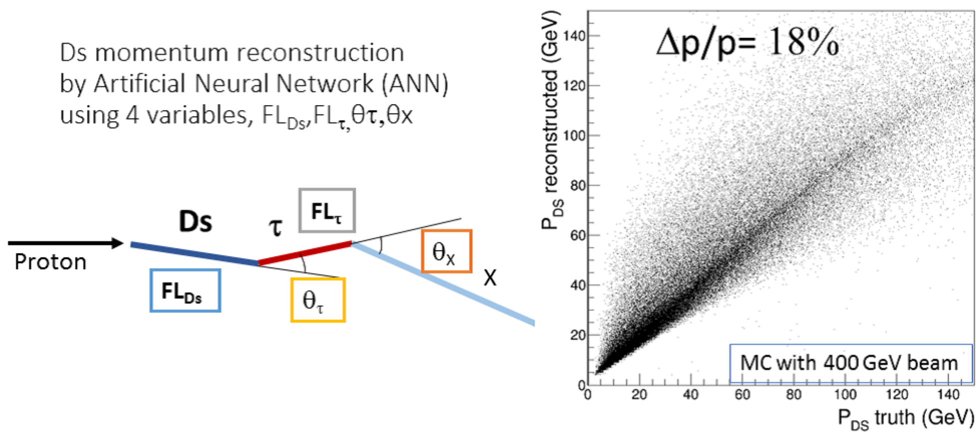

Figure 3: The *Ds* momentum estimation.

microscope stage, Hyper Track Selector [3] developed at Nagoya university. All tracks in a full surface, 12.5$cm \times 10cm$, of an emulsion film will be data taken in about 10min. A total of 100 films in a module will be scanned in 17 hours. A scanned track have x, y position and angle ax, ay information with the track darkness and tracking efficiency is above 95% per film for track slopes in subject. After alignment of stacked emulsion films with a sub-micron accuracy, tracks and vertices are reconstructed. A tau kink decay search will be performed for tracks from a proton interaction vertex occurred in tungsten plate. When a kink topology is detected the small angle kink search will be followed by high precision measurement [4] for the track trajectory from primary vertex to the tau kink decay candidate point. And partner charm decay search is performed for the primary

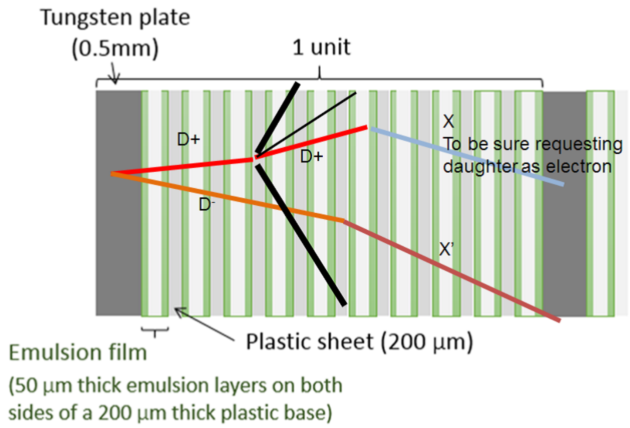

Figure 4: Charm hadron interaction.

vertex.

The beam tests were performed with CERN SPS 400 GeV/c proton beam in 2016 at H4, and 2017 at H2 beam line. 10 modules were exposed in 2016 and check the analysis principle and 4 modules were exposed in 2017 with improved target mover system for achieving the uniform track exposure density. Preliminary analysis for reconstructing proton interaction vertices and decay search have been just started with developing tools and softwares. The number of proton interaction was compared with Monte Carlo simulation in a subsample data of 2016 beam test and showing a good agreement. The number of proton penetrating a tungsten plate in analyzed area $3.61 cm^2$ was 4.36×10^5 and observed interaction in the tungsten plate was 1832 with MC expectation of 1860. The decay search procedure at high track density $\sim 10^5/cm^2$ is underdevelopment and several charm pair event candidates have been found.

In parallel, development for precision measurement system being developed at BERN University[4]. Using piezo actuator for microscope z-axis driver, a readout reproducibility accuracy of 0.15mrad is achieved.

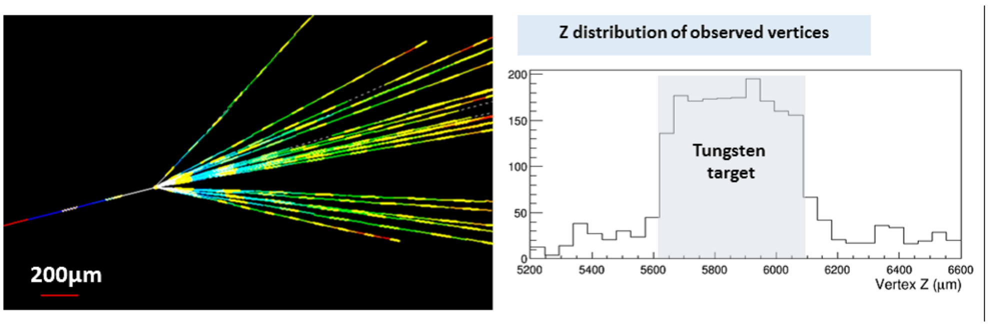

Figure 5: Reconstructed vertex. Left picture is a typical proton tungsten interaction. Incident proton come from left side. 10-20 tracks are produced at interacted vertex. Right histogram is the reconstructed vertex position distribution in beam direction. The vertex is well reconstructed in the target tungsten plate with the resolution and tail part is due to interaction with plastic plates and emulsion plates.

4. Summary

Tau neutrino property is not well studied. DsTau project aims to estimate the tau neutrino production flux in accurate at proton beam dump, the source of tau neutrino. The origin of tau neutrino production is *Ds* meson decay to tau and the cascade decay of the tau, $Ds \to \tau, \tau \to X$. While the production differential cross-section is not directly measured in fix target experiments. DsTau experiment will collect about 1000 detected $Ds \to \tau$ events analyzing 2.3×10^8 proton interaction in tungsten target plates followed by nuclear emulsion tracker films. Thanks to excellent spatial resolution, the peculiar topology "double kink" of the cascade decay, $Ds \to \tau, \tau \to X$, will be detected in a short (several mm) distance. Especially the first kink angle is small as 7mrad in average. The *Ds* momentum for differential cross-section measurement will be estimated by the "double kink" topological values, flight lengths and kink angles of the decaying particles. The number of analyzed events will be 2.3×10^8, three order larger than that of past experiments using nuclear emulsion. Among the 2.3×10^8 proton interactions, about 10^5 interactions have associating a charm particles pair. The byproduct physics using charm particles are considered. One of such study is measurement of interaction length of charmed particle with nuclei, or in other word a size measurement of charmed particle.

The DsTau pilot run will be performed in Aug 2018 and physics run is planned in 2021.

References

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PoS(DIS2018)228