LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

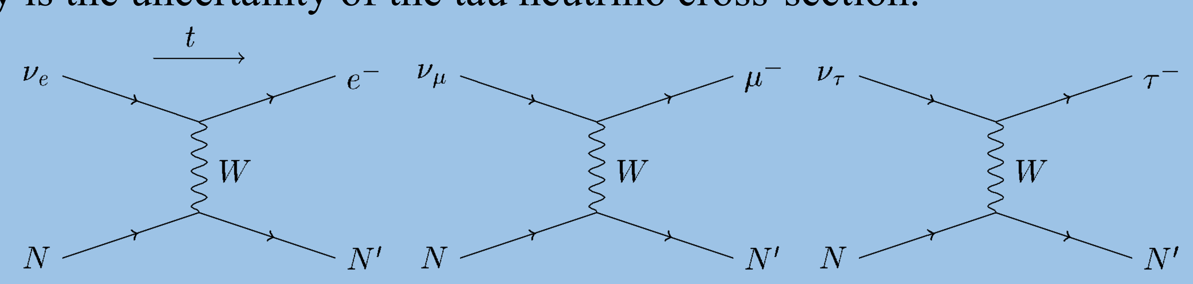
Novel measurement of tau-neutrino production by DsTau at the CERN SPS, T. Ariga (tomoko.ariga@lhep.unibe.ch), A. Ariga (University of Bern, Switzerland) for the DsTau collaboration

UNIVERSITÄT BERN
AEC ALBERT EINSTEIN CENTER FOR FUNDAMENTAL PHYSICS

Abstract: The tau-neutrino CC cross section has never been well measured. There has only been one measurement, by the DONuT experiment, with a systematic uncertainty larger than 50%, mainly due to uncertainties in the D_s differential production cross section in high energy proton interaction. The DsTau collaboration proposes to study tau-neutrino production and the energy distribution by analysing $D_s \rightarrow \tau$ events in 400 GeV proton interactions. By employing state-of-the-art emulsion particle detector technologies, we will analyse 10^8 proton interactions and detect the double kink topology of $D_s \rightarrow \tau \rightarrow X$ decays. Using this new measurement, we will re-evaluate the tau-neutrino cross section with the data from DONuT and test lepton universality in neutrino CC interactions. Furthermore, it will provide useful data for future tau-neutrino experiments. In this talk, we report an overview of the experiment and the planned prototype test in 2016.

Lepton universality and tau neutrino cross-section

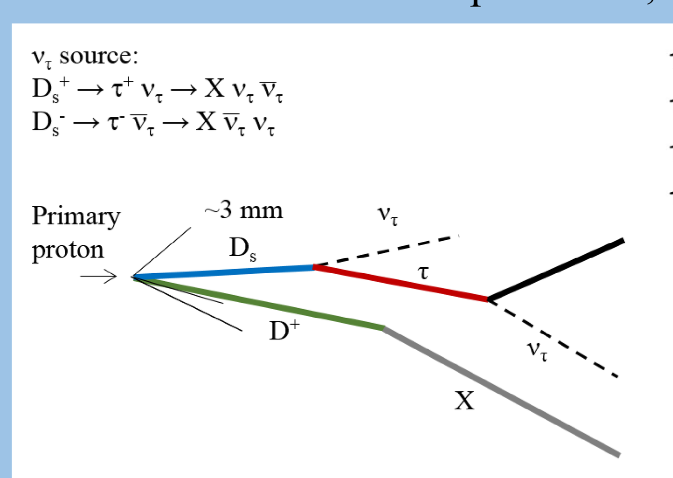
Lepton universality is one of the symetries which has been hypothesized in lepton sector. Under the condition, all generations of neutrinos (ν_e, ν_μ, ν_τ) should interact with weak bosons (W, Z) with a equal coupling constant. The univerality has been better tested in decay modes, e.g. $Z \rightarrow ll$, $\tau \rightarrow e,\mu$. However, it has never well tested in the neutrino charged current interaction, in which neutrinos interact with nuclei via W bosons. The main difficulty is the uncertainty of the tau neutrino cross-section.

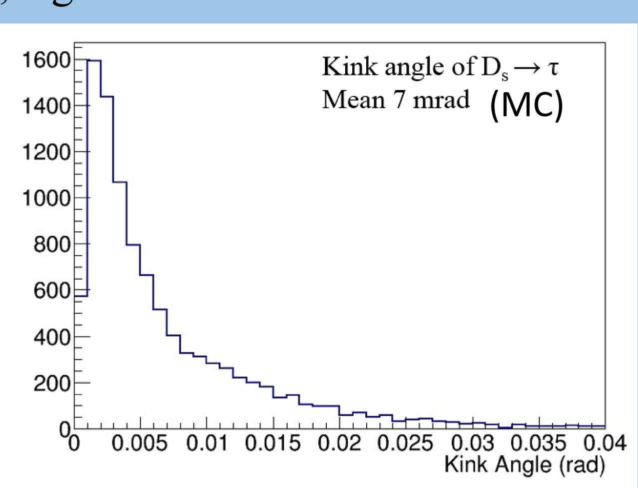


The universality predicts same cross-sections among three neutrinos after the correction concerning the charged lepton mass. A precision measurement of neutrino-nucleus interaction cross-sections will lead us to a test of the lepton universality.
Furthermore, the precise measurement of the tau neutrino cross-section is of interest for astrophysical observation and neutrino oscillation physics, e.g. in IceCube, Super-K, Hyper-K, Dune, as it is a fundamental input for the physics analyses.

DsTau: Direct measurement of tau neutrino flux

The DsTau project (LOI: CERN-SPSC-2016-013 / SPSC-I-245) proposes a study of tau neutrino production by measuring $D_s \rightarrow \tau$ events in 400 GeV proton-tungsten interactions, in view of testing lepton university in neutrino charged-current interactions.
The $D_s \rightarrow \tau$ events have a very peculier topology that features a double-kink of $D_s \rightarrow \tau \rightarrow X$ and an additional decay of a charmed particle, created by the pair production of charm quarks, in a millimeter scale. A measurement of this signature has an advantage rather than studying the Ds production cross-section and branching fraction of $D_s \rightarrow \tau$ separately. Our measurement will give an inclusive measurement of both, so that some of the systematic errors will be cancelled out. Therefore, we consider this measurement as a direct measurement of ν_τ flux. By detecting such events, DsTau is going to measure the differential production cross-section of the Ds mesons (σ_n<0.3). Such a measurement is prerequisite to carry out future tau neutrino experiments, e.g. SHiP.

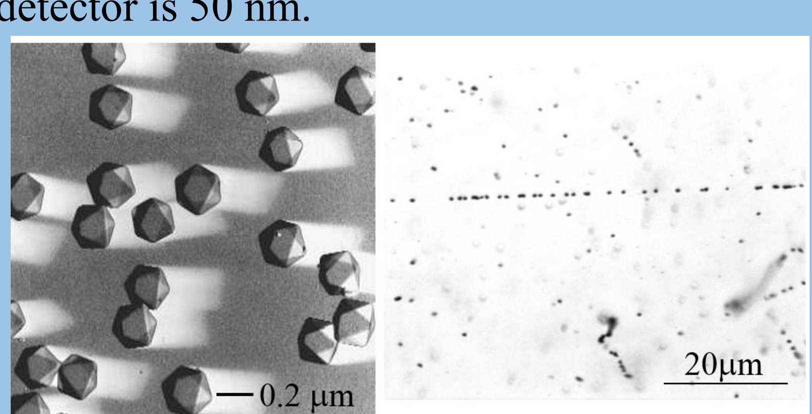


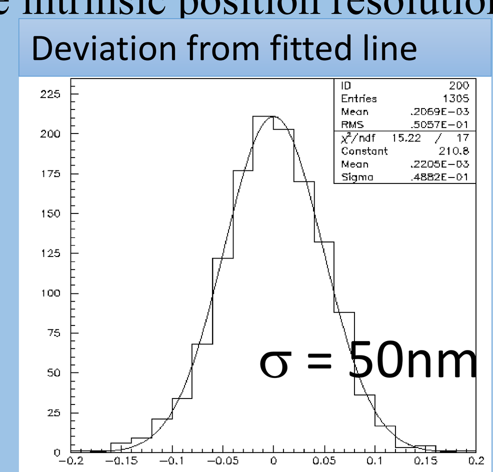


The difficulties in this measurement are the detection of decays in a few millimeter scale. Especially, the $D_s \rightarrow \tau$ decays express a small kink angle, 7 mrad on average. Note that, $c\tau(Ds)$=98 μm, $c\tau(\tau)$=87 μm, $P_T(D_s \rightarrow \tau)$=182 MeV, <P(Ds)>~50GeV. In order to secure a large acceptance, an angular resolution better han 0.5 mrad must be achieved. This is a big challenge in the detector technology. In order to realize the experiment, we employ the state-of-the-art emulsion detector technology.
2×10^8 proton interactions are to be analysed to collect 1000 D_s detected events. A total emulsion surface of 500 m^2 would be needed to accomplish this statistics.

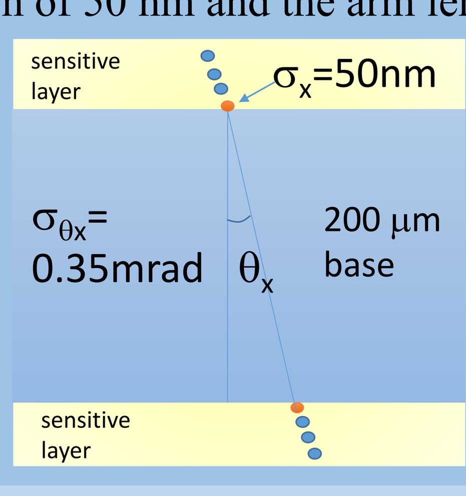
High precision measurement

Emulsion detectors have the highest position resolution among all detectors. They are made of silver bromide cristals with a typical size of 200 nm. The intrinsic position resolution of such a detector is 50 nm.





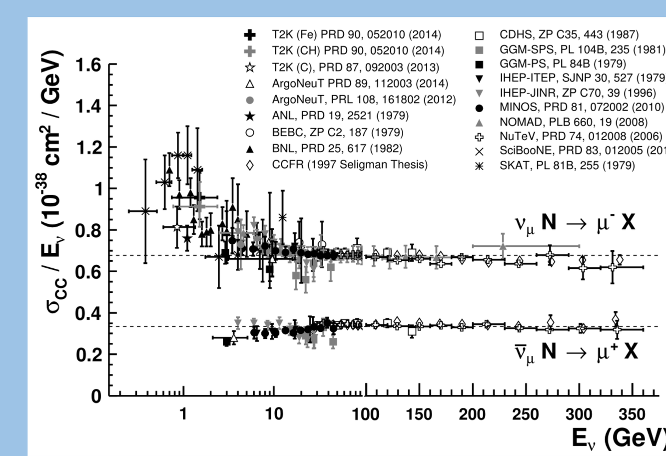
Recent microscope development for the emulsion detector readout have mostly been devoted for the „fast" readout. Therefore, the „precision" has not thoroughly been investigated, as the standard readout precision of track angle is 2-5 mrad. However, DsTau needs a four-sigma kink detection threshold of 2 mrad or smaller. In order to exploit the intrinsic precision of emulsion detectors, a high precision microscope is under development in Bern. Assuming the intrinsic resolution of 50 nm and the arm length of 200 μm between top and bottom sensitive layers, a precision of 350 μrad is expected. Moreover, by fitting a series of hits, 200 μrad resolution would be within our reach. The development is ongoing with the latest piezo technology, which makes a nanometric driving of objective lenses possible.



Current limitation: Systematic uncertainty on $\sigma_{\nu\tau}$

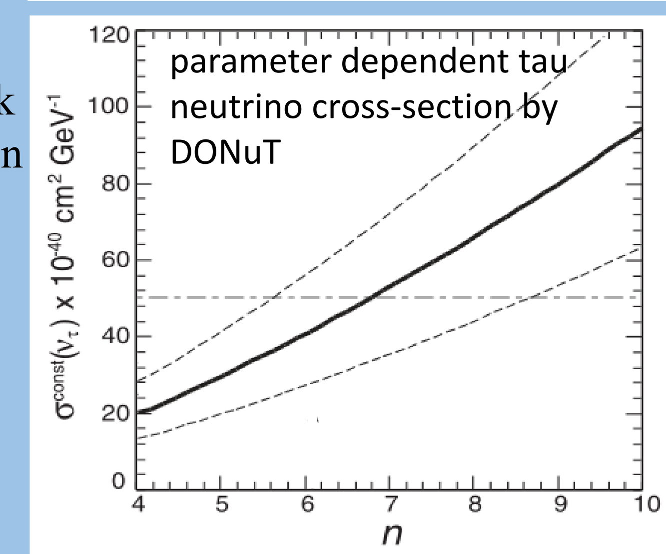
The energy independent cross-section of muon neutrino has been measured with about 2% error as an average over 30-200 GeV as,

$$\sigma^{const}_{\nu\mu} = (0.51 \pm 0.01) \times 10^{-38}\,\mathrm{cm}^2\mathrm{GeV}^{-1}.$$



However, there has been only one measurement on the tau neutrino cross-section, which was made by the DONuT exiperiment. The measurement was largely suffered from the systematic uncertainty of the tau neutrino flux produced in 800 GeV proton-tangsten interactions. The main source of tau neutrino (>95%) was due to the sequential decay of D_s meson (quarks=cs), $D_s \rightarrow \tau\,\nu_\tau \rightarrow X\,\nu_\tau\,\nu_\tau$. Lack of data on the D_s differential production cross-section resulted the parameter dependent tau neutrino cross-section,

$$\sigma^{const}_{\nu\tau} = 7.5(0.335 n^{1.52}) \times 10^{-40}\,\mathrm{cm}^2\mathrm{GeV}^{-1}.$$



Here, n is the parameter controlling the longitudinal part of Ds differential production cross-section as

$$\frac{d^2\sigma}{dx_F\,dp_T^2} \propto (1-|x_F|)^n \exp(-bp_T^2).$$

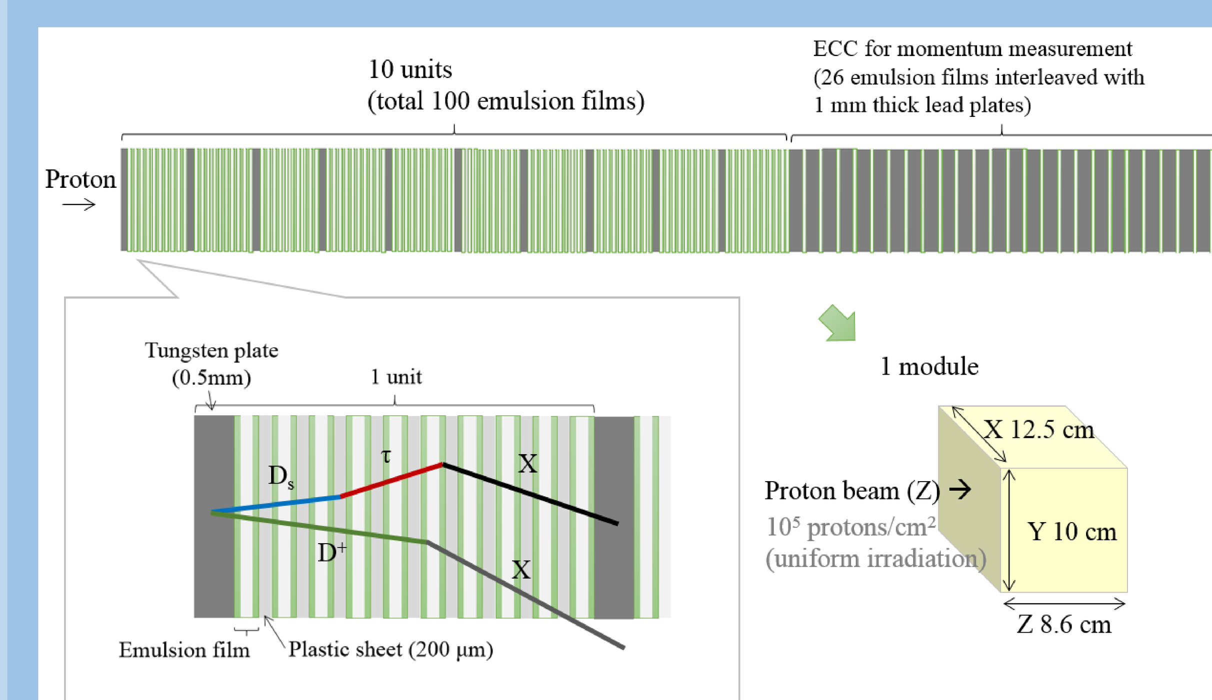
longitudinal dependence, transverse dependence

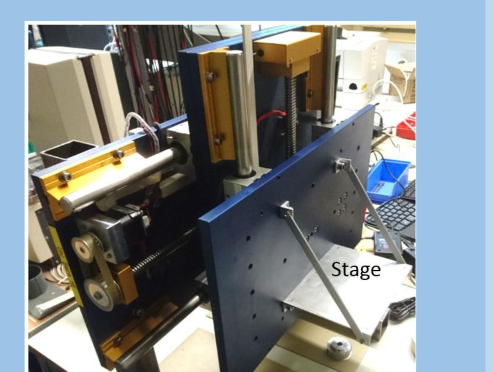
10.1103/PhysRevD.78.052002

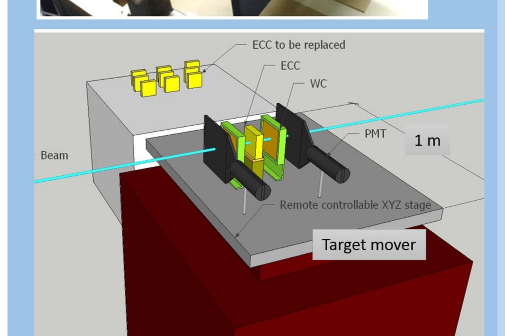
Therefore, the systematic uncertainty on tau neutrino cross-section in DONuT was bigger than 50%, which makes the insight of the lepton universality limitted. In order to reduce the systematic uncertainty to 10% level, the uncertainty of n should be below 0.3. There is no existing data to reach this precision.

Detector setup

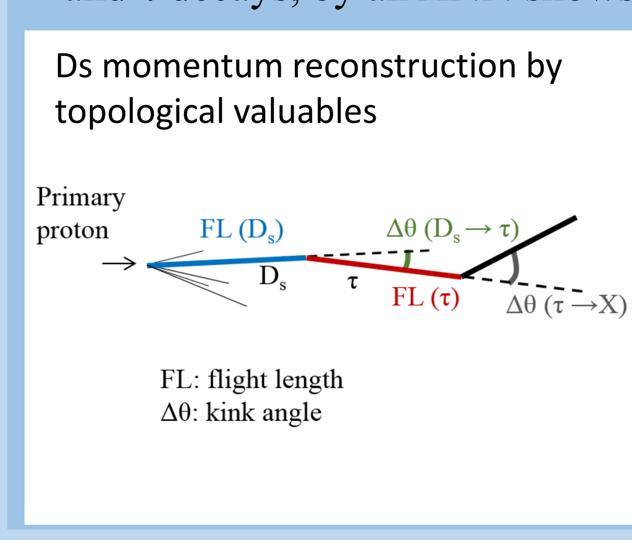
The DsTau setup is made of tungsten targets and emulsion trackers, and a silicon pixel detectors as the profile monitor. A 0.5-mm-thick tungsten target is followed by 5-mm decay volume for short-lived particles and trackers (emulsion films + plastic sheets).

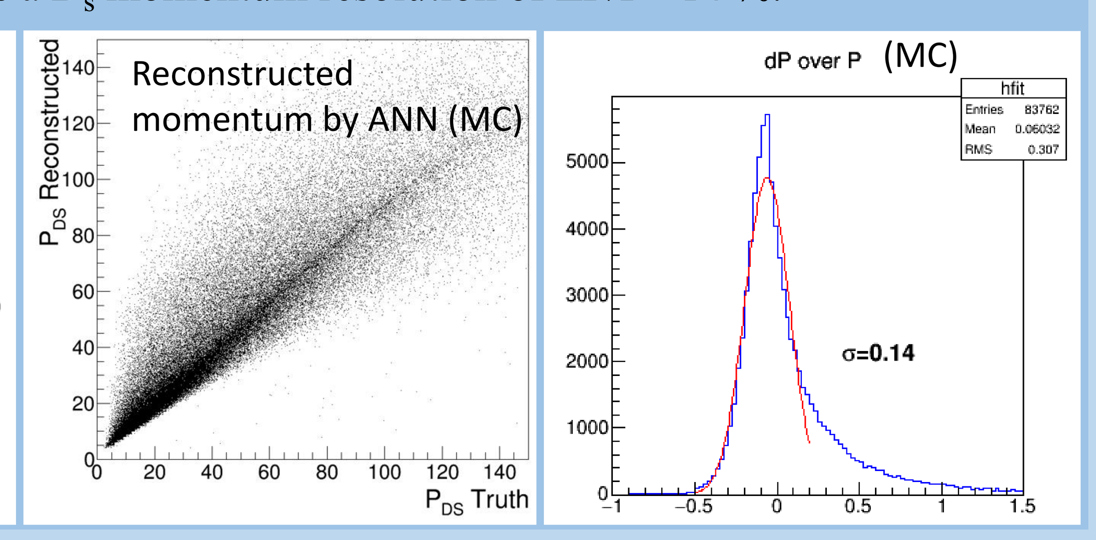






Due to the short flight length, magnetic spectrometers are not applicable to measure D_s momentum. In DsTau, it will be reconstructed by using topological valuables. Our MC study by combining 4 topological valuables, the flight lengths (FL) and kink angles of D_s and τ decays, by an ANN shows a D_s momentum resolution of $\Delta P/P$ =14 %.





Prototype experiment in 2016 and prospect

The letter of intent of the DsTau project was submitted to CERN (CERN-SPSC-2016-013 / SPSC-I-245) and under evaluation.
We are preparing the prototype experiment in Nov 2016 at CERN SPS. The primary goal is to show the proof of principle of the double kink topology detection, and naturally the improvement of the angular resolution.
The prototype test will be peformed with a total emulsion detector surface of 20 m^2. A dedicated emulsion detector production facility has been established in Bern, which can produce 10 m^2 per week. Currently a joint detector production with the Eiger-μ GT project (Eiger glacier tomography by means of muons) is ongoing and a total of 40 m^2 will be produced in next weeks.
Including the result of the prototype experiment, we will submit the proposal to CERN early next year.


Detector production facility in Bern