Study of tau-neutrino production at CERN SPS

Yury Gornushkin (JINR, Dubna, Russia) on behalf of DsTau Collaboration

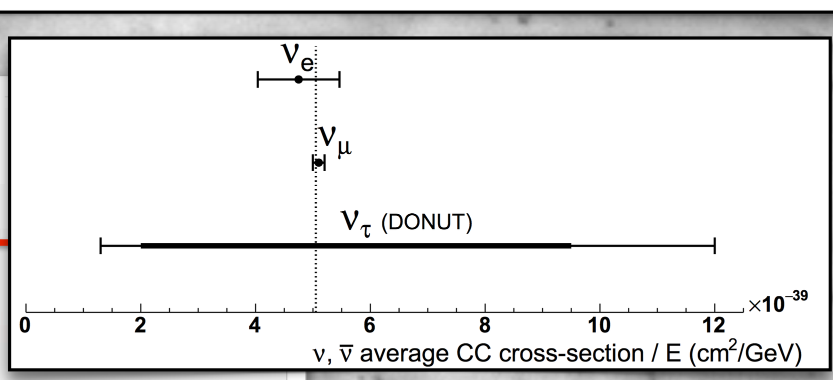
The DsTau project aims to study tau-neutrino production in high energy proton-nuclei interactions and to improve the ν_τ CC cross-section accuracy. The ν_τ cross section was only measured by DONUT experiment with a statistical error of 30% and large systematic error of ~50% due to uncertainty of ν_τ flux. Precise measurement of the ν_τ CC cross-section will allow testing of the Lepton Universality (LU) in tau neutrino scattering. A violation of LU would provide an evidence of new physics effect. Re-evaluation of ν_τ cross section is needed also for future ν experiments (SHIP, DUNE, HyperKamiokande).

Japan: Nagoya, Kyusyu, Aichi, Kobe
Switzerland: Bern
Romania: Bucharest
Russia: Dubna
Turkey: Ankara

Letter of Intent, Feb. 2016
Beam tests in Nov. 2016, May 2017
Proposal (SPSC-P-354), Aug. 2017

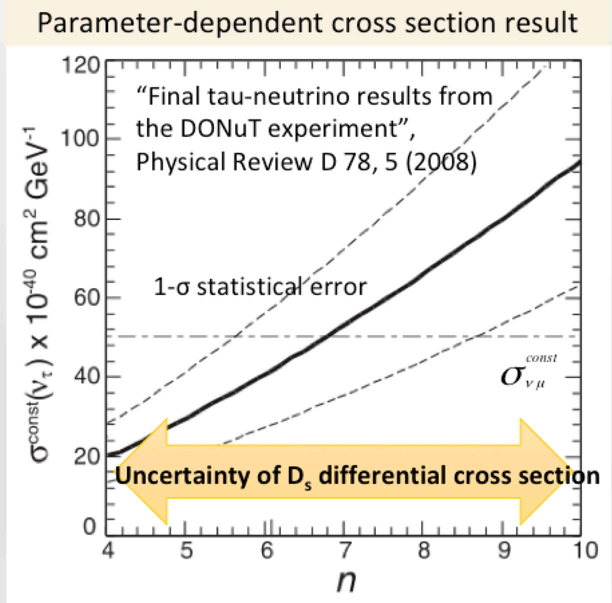
Project motivation

9 ν_τ CC events observed with an estimated background of 1.5 events



ν_τ CC cross section $\sigma_{\nu\tau}(E) = \sigma_{\nu\tau}^{const} \times E_{\nu\tau} \times K_\tau(E)$

Parameter-dependent cross section result



The largest uncertainty in DONuT: D_s differential cross section (used to calculate the ν_τ flux)

Parametrization used in DONUT

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

longitudinal dependence — transverse dependence

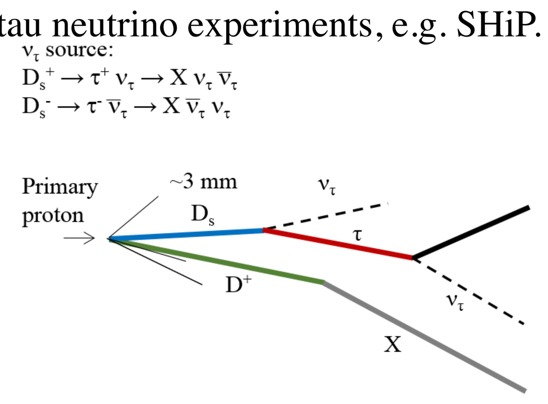
No experimental result effectively constraining the D_s differential cross section

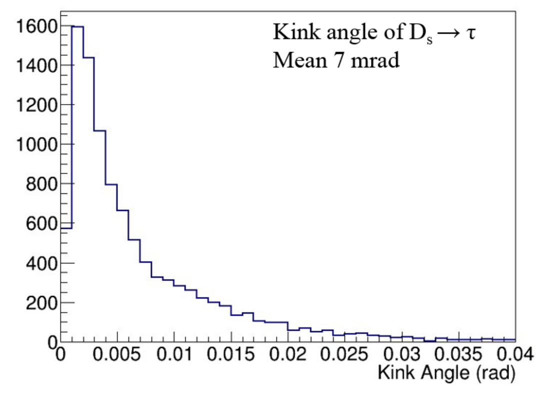
The energy-independent part was parameterized as

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

Goals

The DsTau project proposes to study tau neutrino production by measuring $D_s \to \tau$ events in 400 GeV proton-tungsten interactions, in view of testing Lepton University in neutrino charged-current interactions.
The $D_s \to \tau$ events have a very peculiar topology that features a double-kink of $D_s \to \tau \to X$ and an additional decay of a charmed particle, created by the pair production of charm quarks, in a millimetre scale. A measurement of this signature has an advantage wrt of study the Ds production cross-section and branching fraction of $D_s \to \tau$ separately. Our measurement will give an inclusive measurement of both, so some of 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 also prerequisite to carry out future tau neutrino experiments, e.g. SHiP.

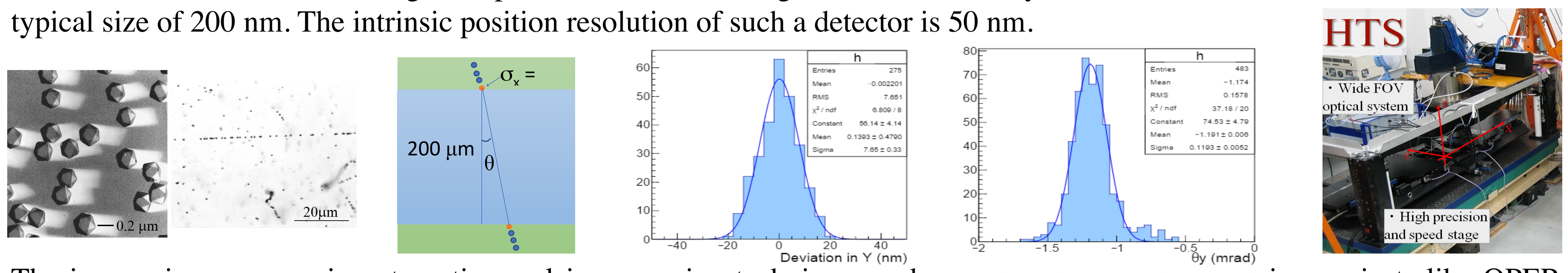




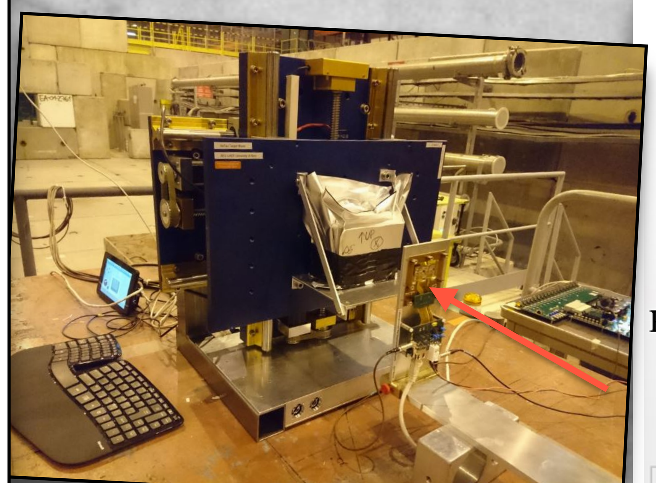
The difficulties in this measurement are the detection of decays in a few millimeter scale. Especially, the $D_s \to \tau$ decays express a small kink angle, 7 mrad on average. Note that, $c\tau(D_s)$=98 μm, $c\tau(\tau)$=87 μm, $P_\tau(D_s \to \tau)$=182 MeV, $\langle P(D_s)\rangle$>~50GeV. In order to secure a large acceptance, an angular resolution better than 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 m² would be needed to accomplish this statistics.

Modern nuclear emulsion technique

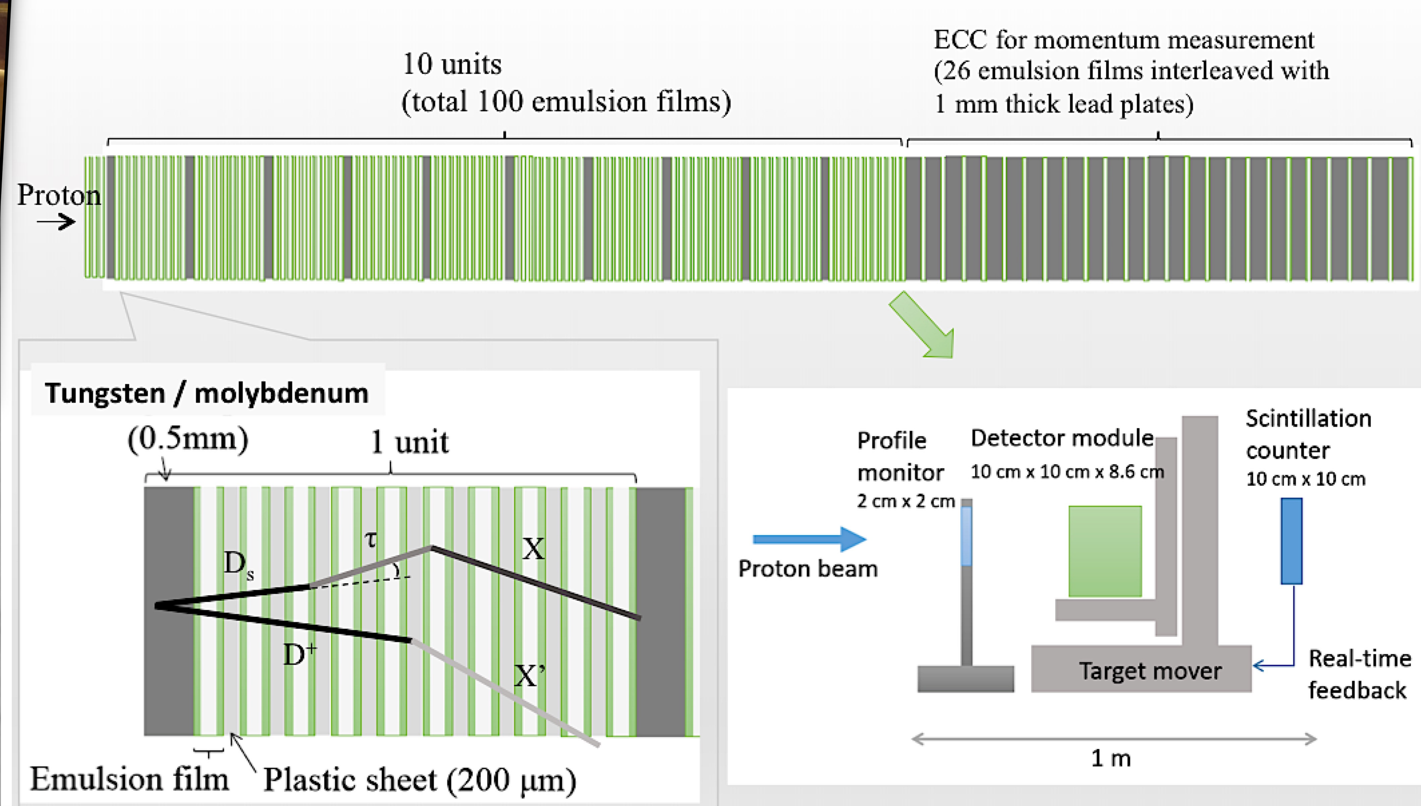
Emulsion detectors have the highest spatial resolution among all detectors. They are made of silver bromide cristals with a typical size of 200 nm. The intrinsic position resolution of such a detector is 50 nm.

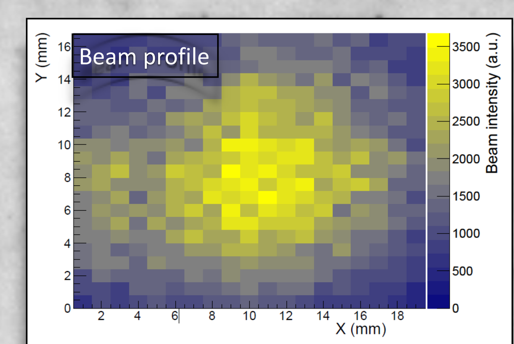


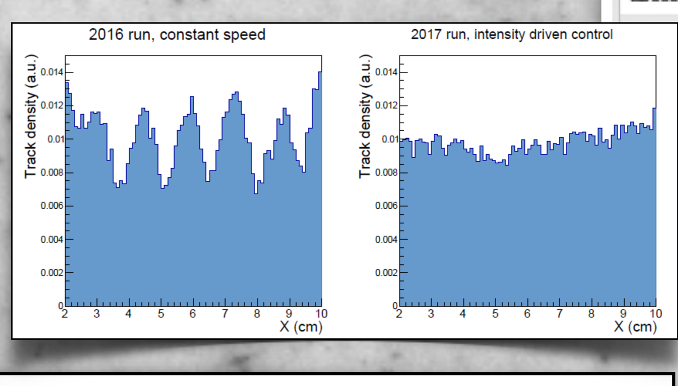
The impressive progress in automatic emulsion scanning technique made possible large scale emulsion projects like OPERA. HTS station can scan 0.5 m²/hour with standard readout precision of track angle about 2-5 mrad. However, DsTau needs a four-sigma kink detection threshold of 2 mrad or smaller. In order to exploit the intrinsic precision of emulsion detectors, a high precision microscope is under development. Assuming the intrinsic resolution of 50 nm and the arm length of 200 μm between top and bottom sensitive layers, 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.



Module structure for $D_s \to \tau \to X$ measurement

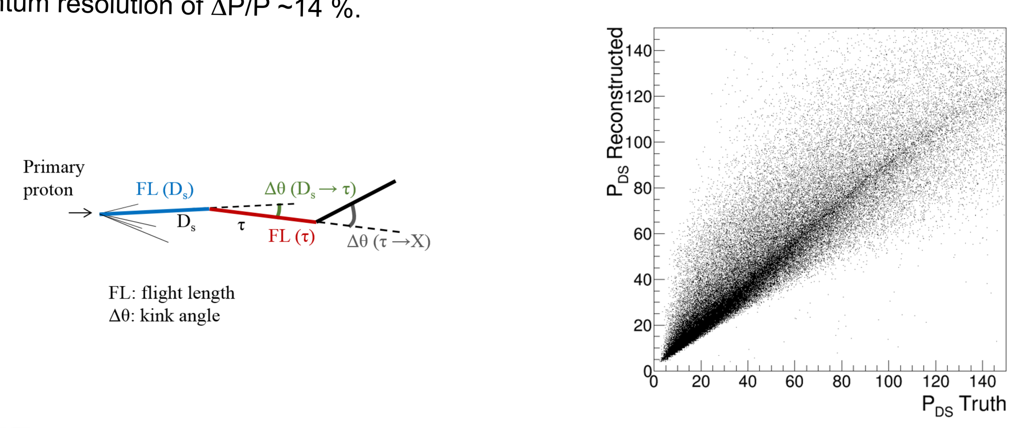






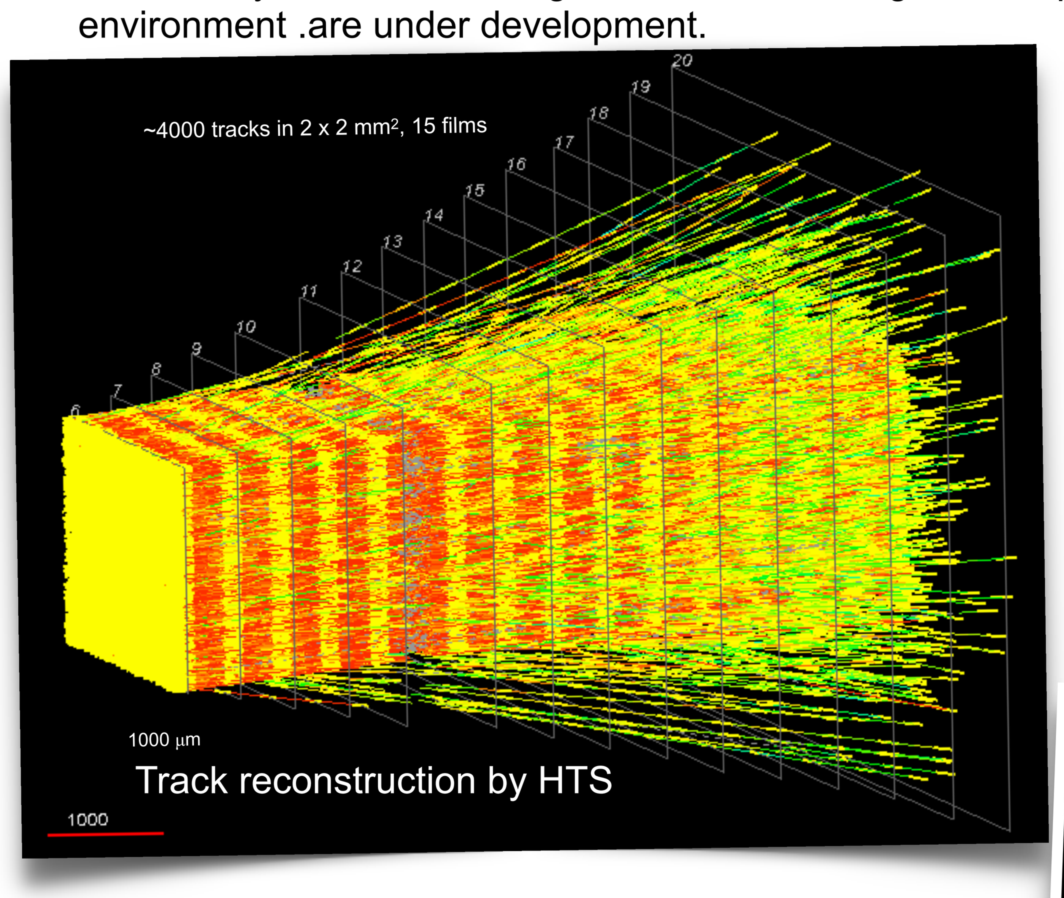
Momentum estimation

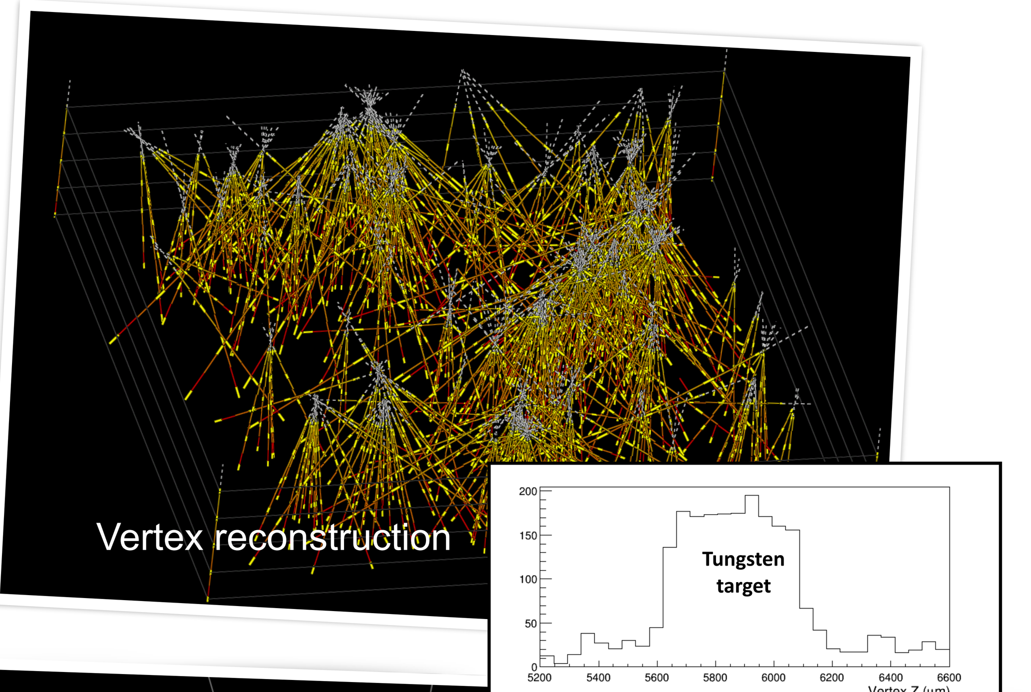
To estimate the parameter n in the D_s- cross-section parametrisation in the 400 GeV experiment, the measurement of D_s momentum is needed. In DsTau, it will be reconstructed using topological variables. The MC study shows that Artificial Neural Network using 4 topological variables (the flight lengths (FL) and kink angles of D_s and τ decays), provides a D_s momentum resolution of ΔP/P ~14 %.

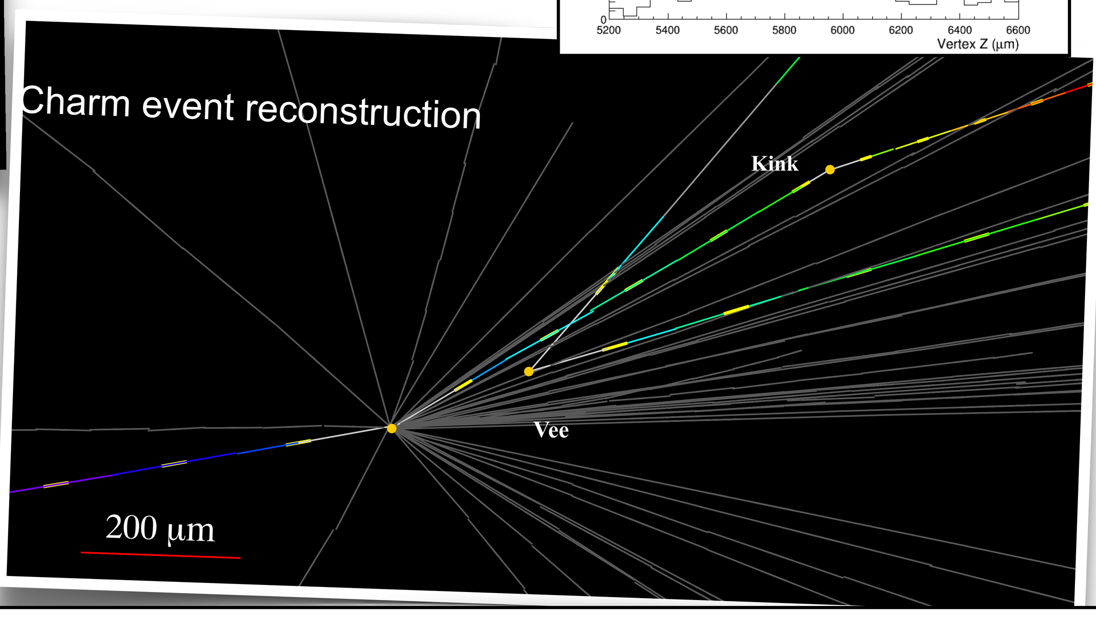


Status of the data analysis

The analysis of the data taken in 2016 and 2017 test beam runs is ongoing. So far ~50% of the emulsion films are scanned by the HTS. The algorithms of the background suppression and vertex reconstruction in high density tracks environment .are under development.

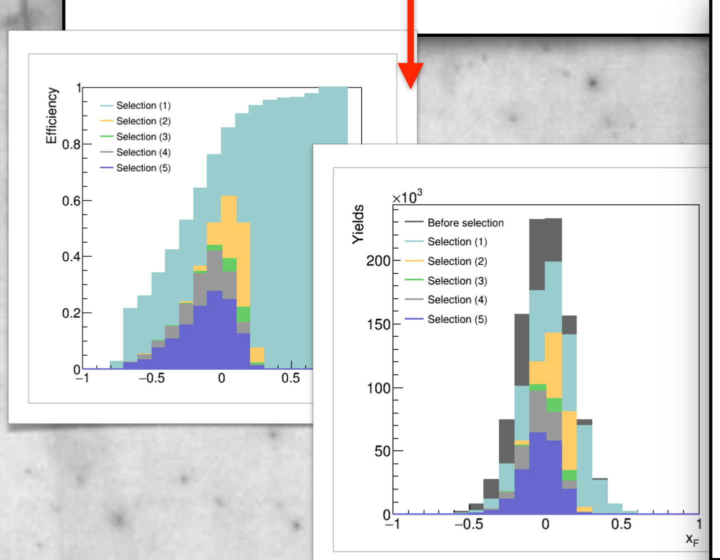






D_s events selection

Selection	Total efficiency (%)
(1) Flight length of D_s ≥ 2 emulsion layers	77
(2) Flight length of τ ≥ 2 layers & Δθ(D_s→τ) ≥ 2 mrad	43
(3) Flight length of D_s < 5 mm & flight length of τ < 5 mm	31
(4) Δθ(τ) ≥ 15mrad	28
(5) Pair charm: 0.1 mm < flight length < 5 mm (charged decays with Δθ > 15 mrad or neutral decays)	20



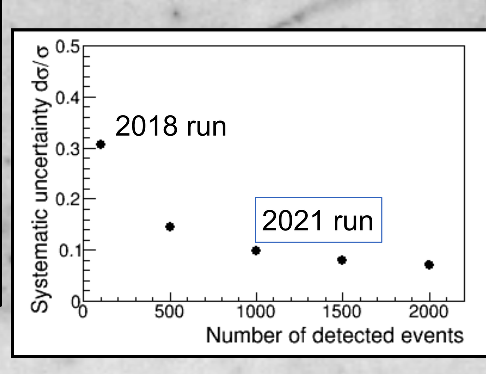
Project schedule

Run	Beam time	Emulsion surface	Goal
2016 test beam		(10 modules)	Test of the setup Proof of principle
2017 test beam		(~2 modules)	Improvement of exposure scheme
2018. pilot run (approved)	1 week	48 m² (30 modules)	Test of large data taking and analysis BG estimation with data Physics results (~80 $D_s \to \tau$ detected) Revision of ν_τ cross section of DONUT
2021 physics run (recommended)	2 weeks	545 m² (338 modules)	Physics results (~1000 $D_s \to \tau$ detected)
2022 physics run	2 weeks		

Prospects and plans

- Charm pair events will be searched systematically.
- In 2018, 1st Physics run will collect 3 times more events wrt 2016 test beam, reduction of the uncertainty on ν_τ production cross-section down to ~30% is expected.
- R&D on improvement of all the systems toward the 2nd Physics run in 2021-22 with X10 of 1st Physics run to reach the project goals .

	DONuT	Systematic uncertainty after DsTau outcome	Future ν_τ measurement with DsTau outcome
ν_τ statistics	0.33		0.02
D_s differential cross section (x_F dependence)	>0.50	0.10	0.10
Charm production cross section	0.17	0.05	0.05
Decay branching ratio ($D_s \to \tau$)	0.23 (0.04 at present)		
Target atomic mass effects	0.14		



Summary

- The goal of the DsTau project is to reduce the uncertainty on ν_τ cross-section down to 10% via precise measurement of the $D_s \to \tau$ with large statistics of ~10^3 events to allow Lepton Universality testing in tau neutrino scattering.
- Test beam exposure performed in 2016 and 2017
  - In 2016 there was a small scale test run.
  - Improvement of uniformity of track density in 2017 run.
- Track reconstruction is underway using HTS data: new tracking algorithm for high track density (10^5/cm²) developed.
- The 2018 beam exposure is under preparation.