DsTau (NA65) experiment:

study of tau neutrino production in proton-nucleus interactions at CERN-SPS

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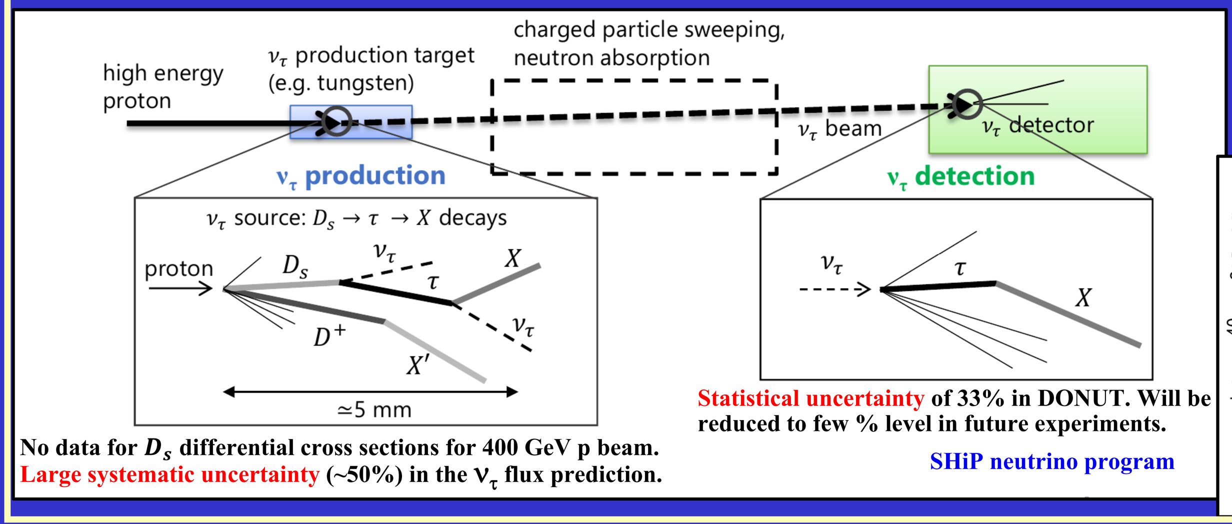
Physics motivation

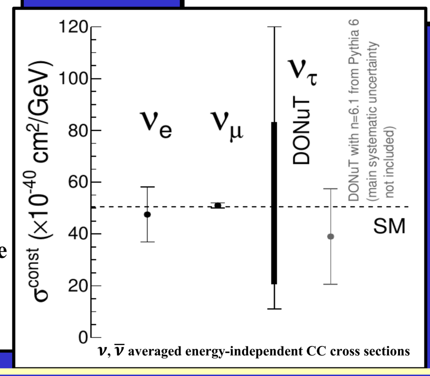
Tau neutrino is eventually the least studied elementary particle. Study of ν_τ production and detection is important for precise measurement of its cross section.



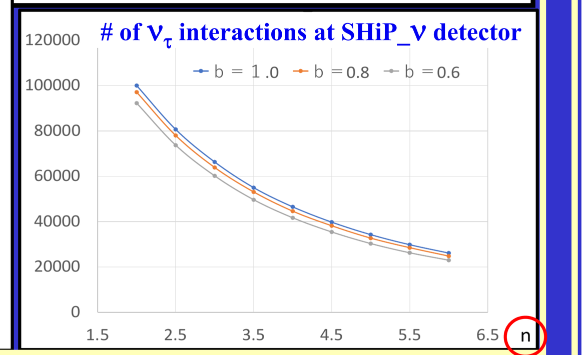
No data for D_s differential cross sections for 400 GeV p beam. Large systematic uncertainty (~50%) in the ν_τ flux prediction.

Parametrization used in DONuT for D_s differential production cross section

$$\frac{d^2\sigma}{dx_F dp_T^2} \propto \underbrace{(1-|x_F|)^n}_{\text{longitudinal dependence}} \underbrace{exp(-bp_T^2)}_{\text{transverse dependence}}$$



Statistical uncertainty of 33% in DONUT. Will be reduced to few % level in future experiments.



SHiP neutrino program

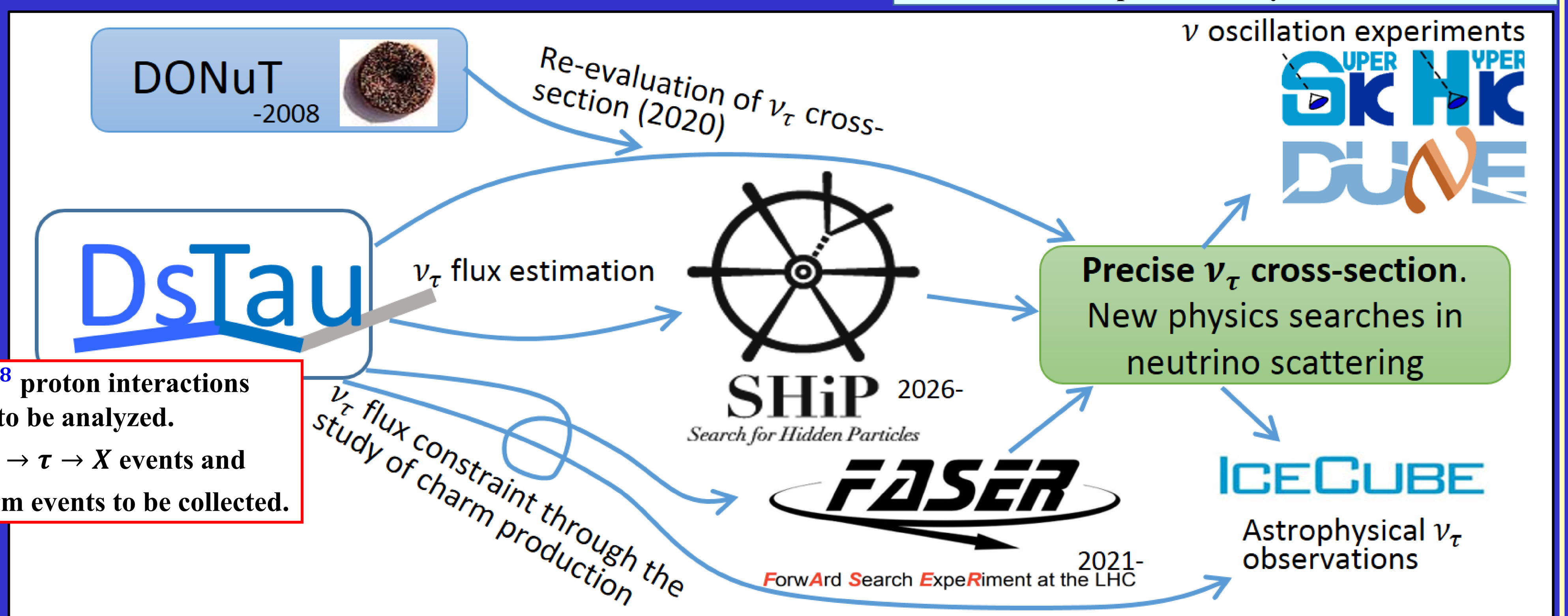
Physics goals and principles of the experiment

In the DsTau experiment an independent and direct way to measure ν_τ production following high-energy proton-nucleus interactions is proposed. This will allow:

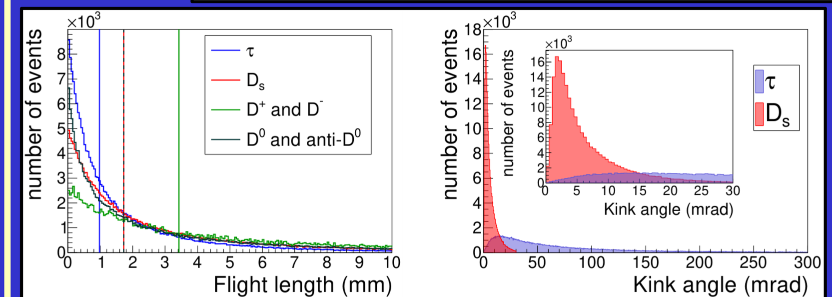
- the first measuring of D_s double-differential production cross section;
- reducing of systematic uncertainty of ν_τ flux prediction from ~50% to 10%.
  — a fundamental input for future ν_τ experiment at the SPS (SHiP).

Forward charm production is important also for high-energy neutrino studies:

- key input for ν production via charm decays.
  — for ν-telescopes, knowledge of prompt neutrinos is important to observe astrophysical νs.
  — FASERν at the LHC also targets neutrinos from charm particle decays.



2.3×10^8 proton interactions in target to be analyzed.
~1000 $D_s \to \tau \to X$ events and
~10^5 charm events to be collected.



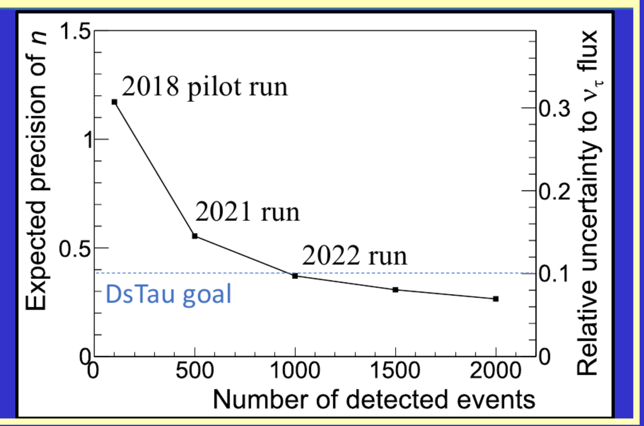
$D_s \to \tau \to X$ events can be recognized by their peculiar "double-kink + charm decay" topology. However, to register the events is a challenge: all the decays take place at a millimeter scale, moreover, the kink angle of $D_s \to \tau$ is very small, 6.2 mrad on average. We'll use state-of-the-art nuclear emulsion detectors with nanometric spatial accuracy to efficiently recognize the events.

Event statistics expected in the physics run, assuming an equal # of modules with W and Mo target

target	# of stored proton int.	with charm pair	detected $D_s \to \tau \to X$
tungsten 0.5 mm	1.08×10^8	1.95×10^5	528
molybdenum 1.0 mm	1.41×10^8	2.10×10^5	498

The project schedule

Run	Beam time	Emulsion exposure	Goals
Test beam 2016		10 modules	Test of the setup Proof of principle
Test beam 2017		2 modules	Improvement of exposure scheme
Pilot run 2018	1 week	30 modules (48 m^2)	Collection of ~10% of the whole data sample Test of large data taking and analysis Background estimation with data Revision of ν_τ cross section of DONuT
Physics runs 2021-2022	4 weeks	338 modules (545 m^2)	Collection of the whole data sample Obtaining final physics results



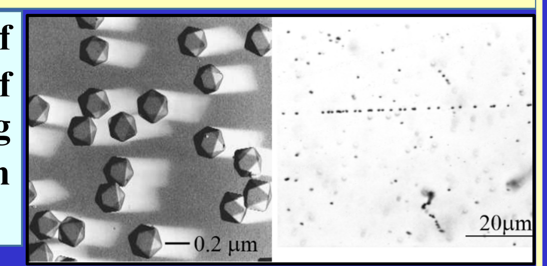
References

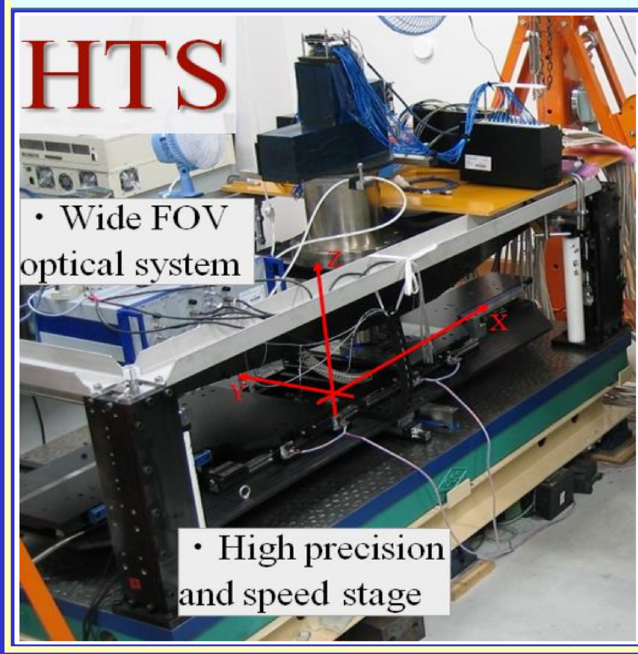
S. Aoki et al. (DsTau Collaboration), DsTau: study of tau neutrino production with 400 GeV protons from the CERN-SPS, JHEP01 (2020) 033

S. Aoki et al. (DsTau Collaboration), Study of tau neutrino production at the CERN SPS, CERN-SPSC-2017-029 (SPSC-P-354), arXiv:1708.08700

Nuclear emulsion detector

Emulsion detectors have the highest spatial resolution among all detectors. They comprise a countless number of silver halide crystals with a typical size of 200 nm dispersed in the gelatin media. A trajectory of a charged particle passed the emulsion can be observed under an optical microscope. The modern use of the emulsion detection technology is based on the remarkable evolution of the high-speed and high-precision automatic readout of emulsions developed during the last two decades and available today. The latest scanning system (HTS-1) allows reading of the emulsion films at the speed of ~0.5 m²/hour per emulsion layer. A new scanning system (HTS-2) is under development now in order to increase the reading speed by factor of 5 by 2021.



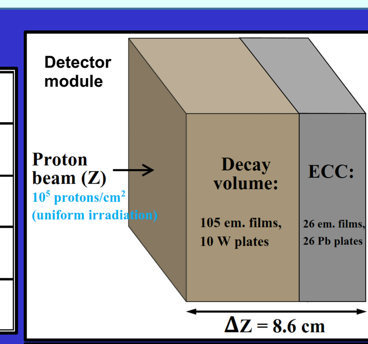


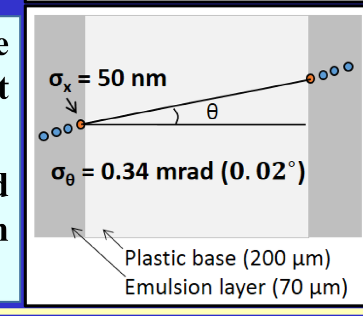
Main specifications of the HTS-1 and HTS-2

	S-UTS (OPERA)	HTS-1	HTS-2
Readout speed [cm²/h/layer]	72	4700	25000
Field of view [mm²]	0.052	25	50
Readable area [m²]	0.0125	0.0125	0.1
Drive mode	Continuous	Step by step	Continuous

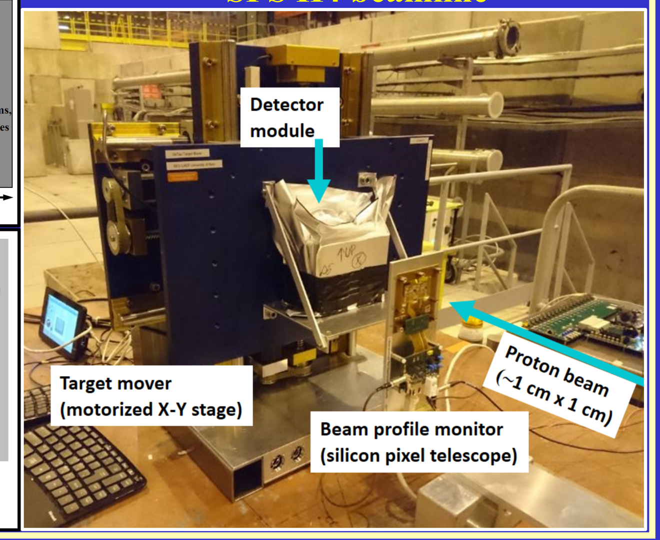
A DsTau detector module includes 131 emulsion films and consists of two parts. The upstream part acts as a decay volume for short-lived particles, while the downstream part (ECC) is used for momentum measurement of the daughter particles.

For the pilot (2018) run all emulsion films were manufactured by hand. Now an automated film production is being implemented at Nagoya University. Emulsion gel and film production facilities are scheduled to be constructed and to start operation from July-August 2020.



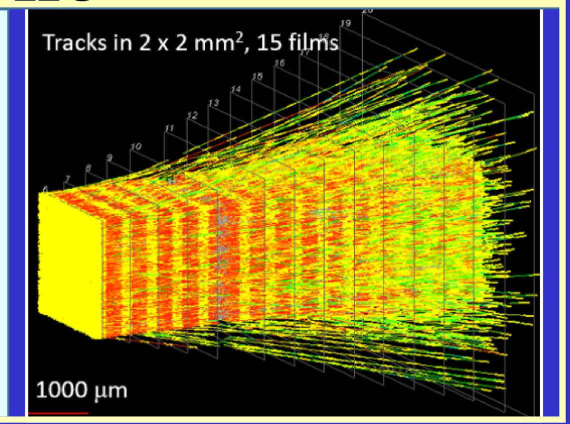


Setup at the CERN SPS H4 beamline



Track reconstruction in high track density environment

Another challenge for the DsTau analysis is to implement fast and efficient approach for tracking and film alignment in the environment of a high track density ($\sim 10^5 - 10^6/cm^2$) and narrow angular range. The conventional reconstruction tools used in previous emulsion experiments (e.g., OPERA) were tuned to a typical track density of $\sim 10^2 - 10^3/cm^2$ in large angular space. They are often not appropriate in our case. New (more advanced) algorithms have been developed and applied to DsTau data collected during beam tests and the pilot (2018) run at SPS. At the moment it takes ~60 days per module to process the data using a 256 GB RAM PC with CPU- and GPU-based software. Size of the processed data to be stored for further analysis is ~4 TB/module. The software is supposed to be further optimized in order to possibly reduce large memory consumption, CPU/GPU load, and the data processing time. For the processing of the physics runs 2021-2022 data (~300 modules) it is planned to exploit disk storage (in total of ~1 PB) and cluster computing power resources of CERN and the Collaboration institutes.



Status of the data analysis

Data processing/analysis scheme

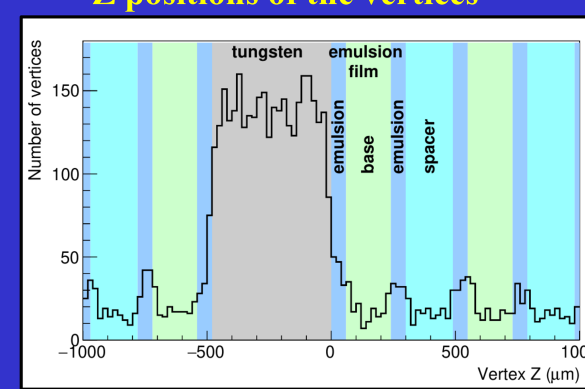
- A raw and fast scanning with the HTS scanning station allowing reconstruction of the track segments in each emulsion film.
- Reconstruction of the tracks in the whole detector via matching of the track segments in a series of the films. This step includes a thorough alignment of the films.
- Reconstruction of the vertices of proton interactions and "a decay search" – recognition of the secondary decay vertices and short-lived particles.
- Fine analysis of the events with a decay topology with help of the precise scanning stations and a search for the sequential "double kink" topology, namely $D_s \to \tau \to X$.

The processing of the data taken in the pilot (2018) run is ongoing. Scanning of the emulsion films by the HTS is close to finish. Analysis of proton interactions and charm production is in progress.

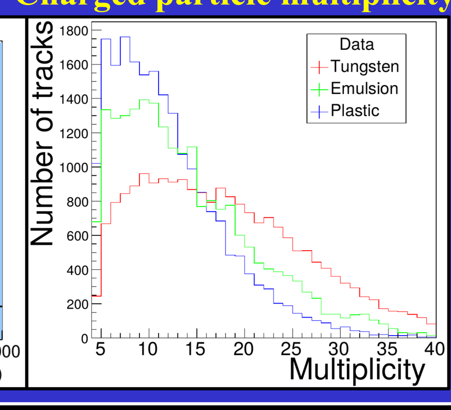
Current statistics of events with primary vertices in tungsten

	Observed	Expected	
Vertices in tungsten	147,236	155,135	
		Signal	Background
Double decay topology	115	80.1±19.2	12.7±5.0

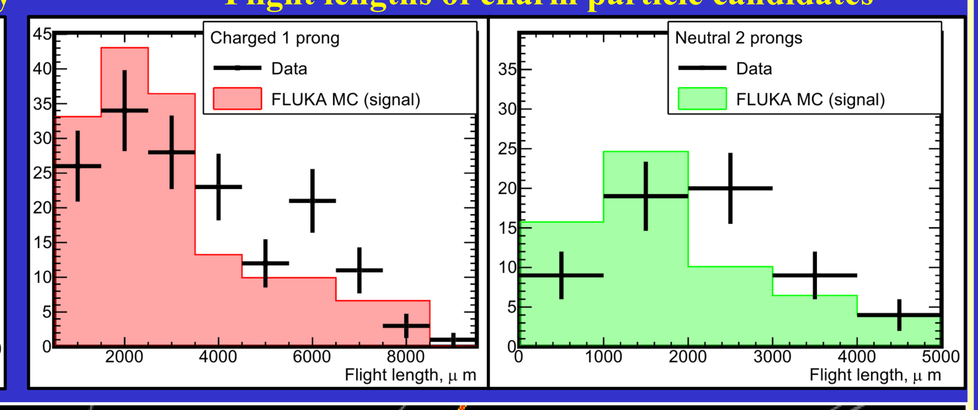
Z positions of the vertices



Charged particle multiplicity



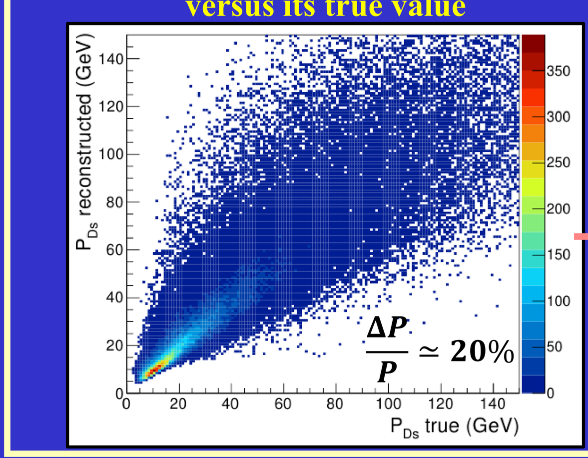
Flight lengths of charm particle candidates



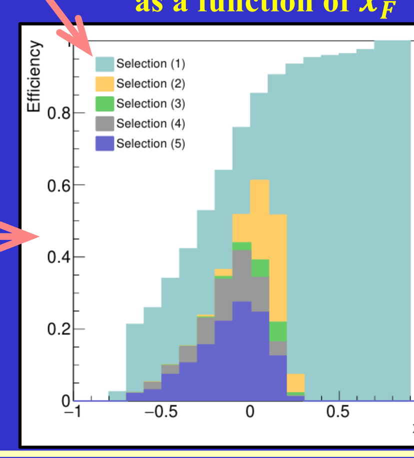
$D_s \to \tau \to$ 1-prong events selection

Selection	Efficiency (%)
(1) Flight length of $D_s \geq 2$ emulsion layers	77
(2) Flight length of $\tau \geq 2$ emulsion layers and $\Delta\theta_{D_s \to \tau} \geq 2$ mrad	43
(3) Flight length of $D_s < 5$ mm and flight length of $\tau < 5$ mm	31
(4) $\Delta\theta_{\tau \to X} \geq 15$ mrad	28
(5) Pair charm: 0.1 mm $\leq$ flight length < 5 mm (charged decays with $\Delta\theta \geq 15$ mrad or neutral decays)	20

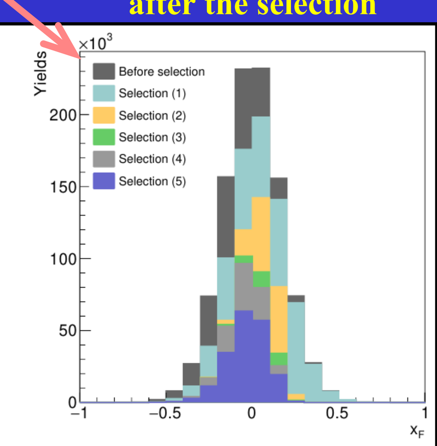
Reconstructed D_s momentum versus its true value



Detection efficiency as a function of x_F



The x_F distributions after the selection



An example of a double charm event candidate