STUDY OF PROTON-NUCLEUS INTERACTIONS IN THE DsTau(NA65) EXPERIMENT AT THE CERN-SPS

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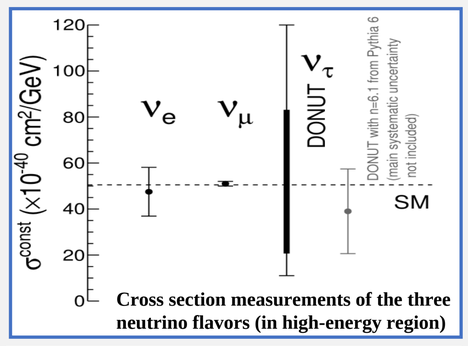
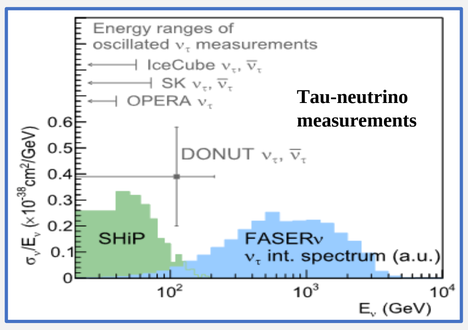
ABSTRACT: The DsTau (NA65) experiment at CERN was proposed to measure an inclusive differential cross-section of Ds production, and its decay branching ratios in p-A interactions. The DsTau detector is based on the nuclear emulsion technique providing an excellent spatial resolution for detecting short-lived particles like charmed hadrons. The first results of the analysis of the pilot-run data are presented. The accuracy of the proton interaction vertex reconstruction is reported. A high precision in vertex reconstruction allows one to measure the proton interaction length and charged particle multiplicities accurately in a high-track density environment. The measured data have been compared with several Monte Carlo event generators in terms of multiplicity and angular distribution of charged particles. The results presented in this study can be used to validate event generators of p-A interactions.

STUDY OF TAU NEUTRINOS

- **Tau neutrino is one of the least studied particles**
- only a few measurements:
  - **i.** Direct ν_τ beam: DONUT (DIS) - first direct evidence of tau-neutrino interaction
  - **ii.** Oscillated ν_τ: OPERA (DIS), Super-K (QE), IceCube (DIS)
- cross section error >50% (DIS) due to systematic uncertainty in ν_τ production
- **A new precise measurement of the ν_τ cross section**
  - test lepton universality
  - new physics effects in ν_τ CC interactions
- **Future ν_τ measurements**
  - SHiP: high statistics measurement at the SPS
  - reduce statistical uncertainty from 33% in DONuT
  - indirectly FASER



Cross section measurements of the three neutrino flavors (in high-energy region)

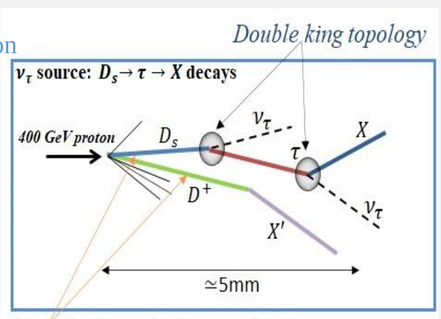


Tau-neutrino measurements

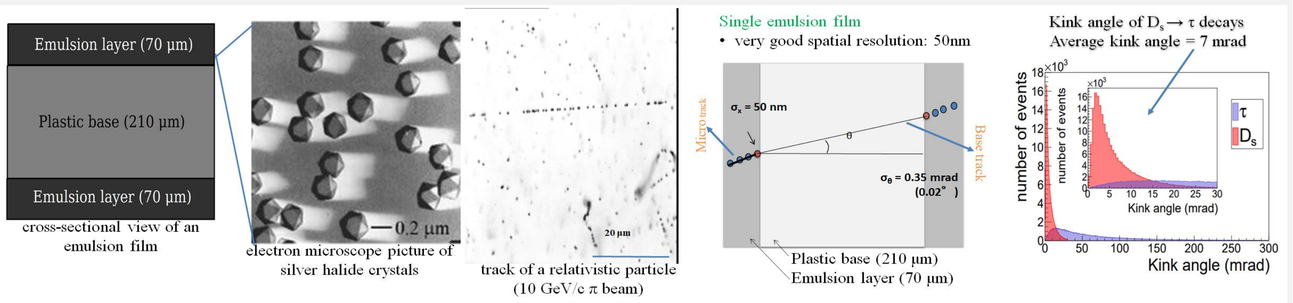
PHYSICS GOALS

- **DsTau goals**
  - study of the tau neutrino production by $\mathbf{D_s}$ decays
  - reduce the systematic uncertainty of ν_τ flux production from *50% to 10 %*
  - first measurement of $\boldsymbol{D_s}$ double differential production cross section
  - fundamental input for future ν_τ experiment *(like FASER, SHiP)*
- **By product: Study of open charm production**
  - in tungsten/molybdenum target: ~ 4.5 x 10^5 charm pairs produced
  - in other materials (emulsion/plastic): ~ 2.7 x 10^5 charm pairs produced
- **Principle of the experiment:**
  - detection of "**double-kink** + **charm decay**" topology within few mm
  - 4.6 × 10^9 protons, 2.3 × 10^8 proton interactions in tungsten

1000 $D_s \rightarrow \tau \rightarrow X$ decays

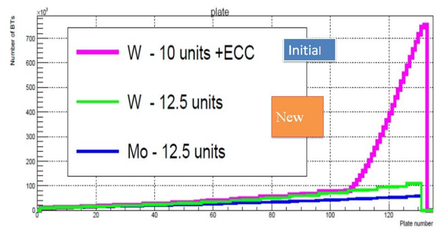


NUCLEAR EMULSION DETECTOR

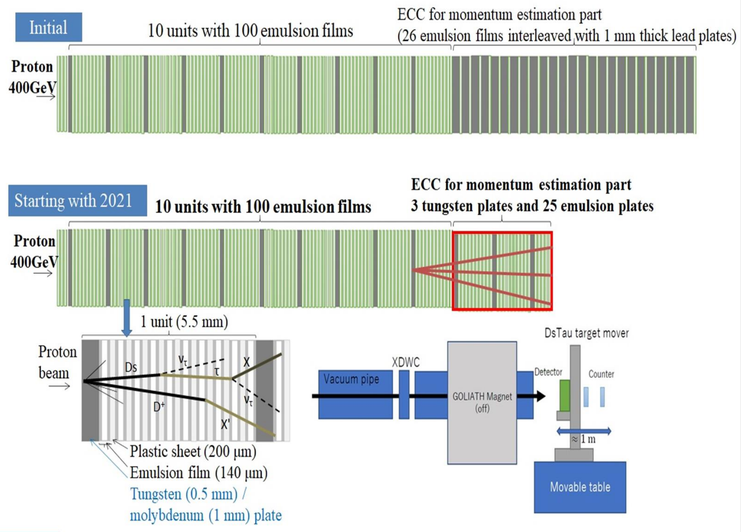


EXPERIMENTAL SET-UP

- **initial structure of ECC had more material → high track density → dedicated scanning is required**
- **new ECC:**
  - **reduces material budget, but with about same sufficient tracking performance**
  - **making data taking procedure simple**
- ***for the analysis part* in some modules (50%) 0.5 mm tungsten plates were replaced with 1mm molybdenum plates**



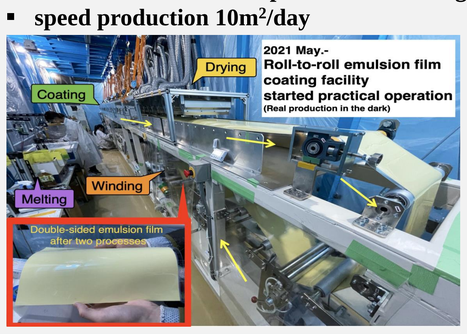
	Initial: lead emulsion ECC	*New:* additional tungsten units for ECC
Structure	25 – 1 mm lead, 26 emulsion plates	3 – 0.5 mm tungsten, 25 emulsion plates
Momentum resolution	15 – 40 % (upstream ev.) 35 – 45 % (downstream ev.)	15 – 40 % (upstream ev.) 35 – 45 % (downstream ev.)
Weight	15.0 kg	2.4 kg



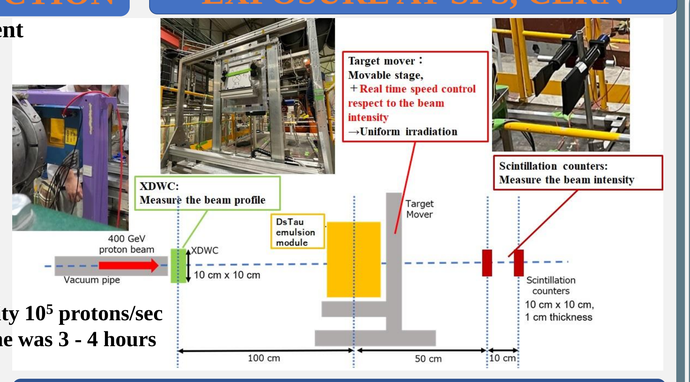
- **Nuclear emulsion (NE) films size: 25 cm x 20 cm = 4 x 2018 pilot run NE size – *to increase statistics***

NUCLEAR EMULSIONS FILMS PRODUCTION

- **automatic facility in Nagoya University, Japan for an efficient nuclear emulsion films production starting with Nov. 2020**
- **speed production 10m²/day**



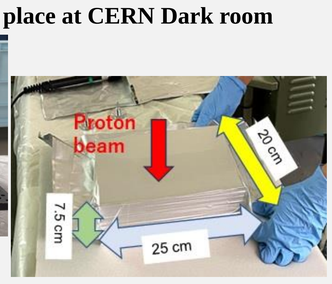
EXPOSURE AT SPS, CERN



- **beam intensity 10^5 protons/sec**
- **exposure time was 3 - 4 hours per module**

DETECTOR ASSEMBLY AT CERN

- **detector assembly take place at CERN Dark room**

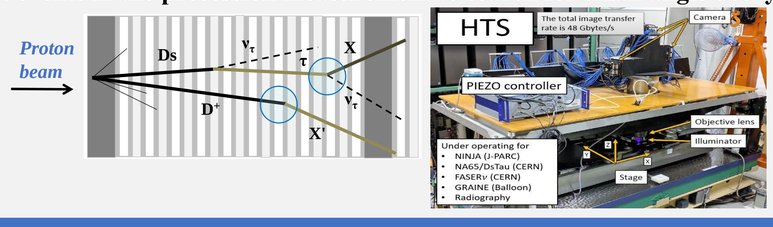


DEVELOPMENT AT CERN

- **take place at dark room of the CERN Emulsion Facility**

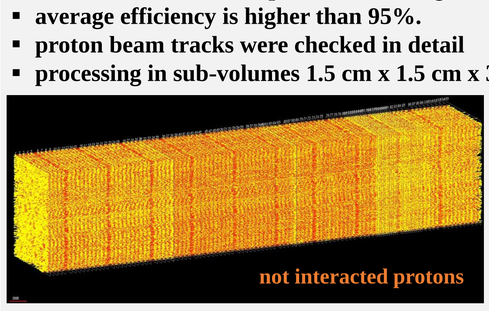
DATA PROCESSING

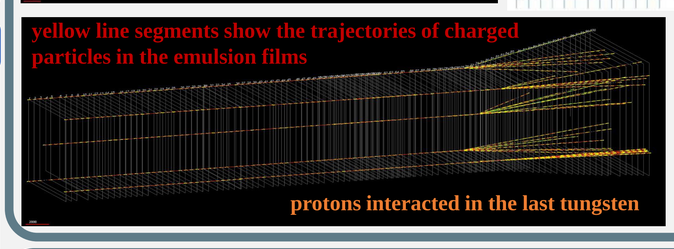
- **full surface scanning is done to accumulate all charged tracks segments by Hyper Track Selector (HTS)**
  - **HTS scans emulsion tracks with the speed of 5000 cm²/h**
- **Preselect events in the precession measurement to search for small angle decay of Ds→τ**

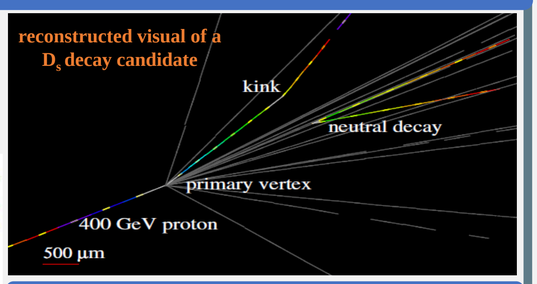


ALIGMENT AND TRACK RECONSTRUCTION

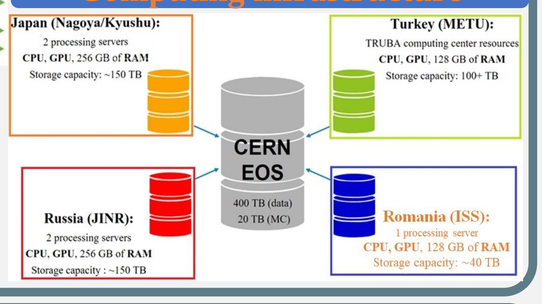
- **alignment algorithm - very precise - sub micron**
- **track reconstruction - positions and angular correspondences**
- **average efficiency is higher than 95%.**
- **proton beam tracks were checked in detail**
- **processing in sub-volumes 1.5 cm x 1.5 cm x 30 plates**







Computing infrastructure



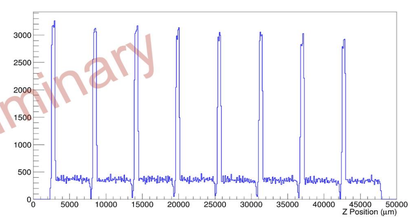
DsTau PHYSICS RUNS

Physics Runs	Amount of emulsion films	Number of nuclear emulsion films	Number of modules	W/Mo target
2021 run	*110 m²*	*2.210*	*17 modules*	*12/5 modules*
2022 run	*110 m²*	*2.210*	*17 modules*	*9/8 modules*
2023 run	*270 m²*	*5.200*	*40 modules*	*20/20 modules*
		200 (12.5 x 5 cm)	*2 momentum modules*	*2/0 modules (used for validation of the particle momentum estimation method)*

DATA ANALYSIS

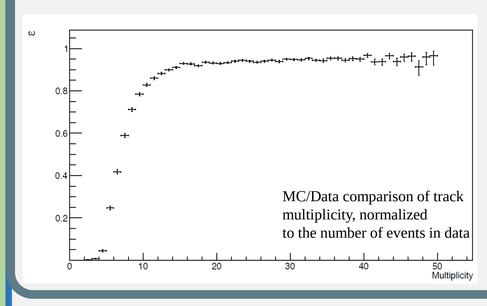
- **a sample from 2018 pilot run data is used for proton interaction characterization**
- **measurement of interaction length in tungsten in presented**

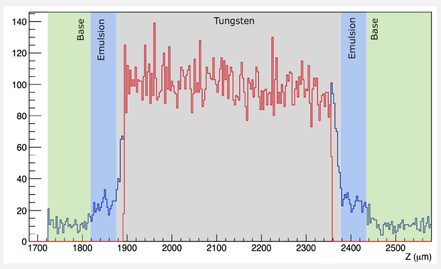
Tungsten	N	N_0	N/N_0 (%)
1	13,151	3,252,245	0.404
2	12,396	3,235,881	0.383
3	11,327	3,201,667	0.354
4	11,452	3,160,738	0.362
5	11,374	3,105,441	0.366
6	10,566	3,032,429	0.348
7	10,039	2,948,504	0.340
8	8,887	2,847,002	0.312



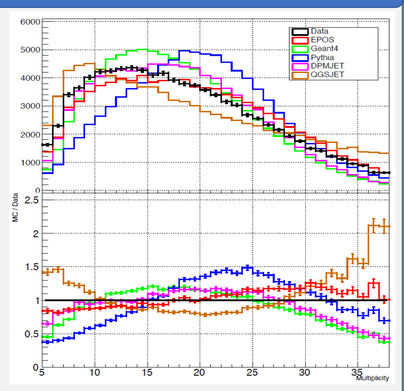
PRIMARY VERTEX RECONSTRUCTED

- **for estimation of vertex reconstruction efficiency, the true vertex position is compared with the reconstructed Monte Carlo**
- **efficiencies of vertex reconstruction and proton linking are estimated using EPOS**
  - **vertex efficiency = 81.0 ± 0.9%**





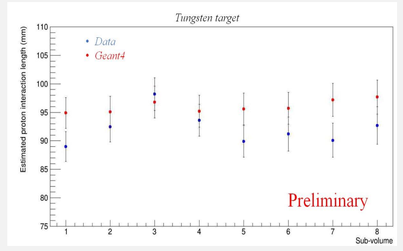
the measured vertex position in the first sub-volume in the beam direction(blue), vertices within 4-sigma of vertex position resolution(red)

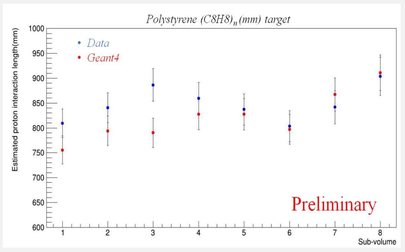


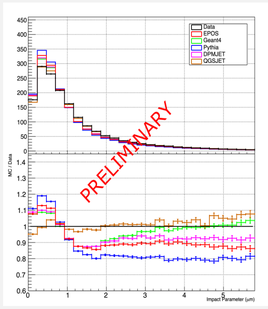
vertex reconstruction efficiency as a function of the multiplicity of charged tracks at the vertex, obtained with EPOS MC

MONTE CARLO AND DATA COMPARATION

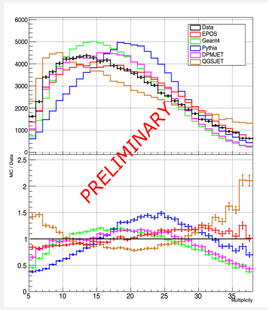
- **proton interactions are generated with the following event generator:**
  - **Geant4**
  - **Pythia**
  - **EPOS**
  - **QGSJET**
  - **DPMJET**
- **average measured interaction lengths in tungsten and plastic are 106.8±1.1 mm and 882.6±12.2 mm, the increase along the beam direction is due to an increase in the track density and variation of the alignment precision**
- **DsTau reconstruction algorithm is processed to Monte Carlo samples to reconstruct tracks and vertices**



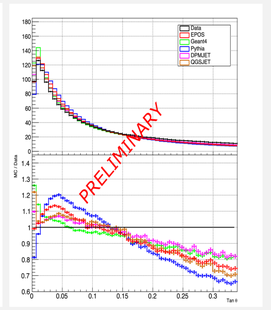




impact parameter of particle tracks to interaction vertex, normalized to number of tracks in data

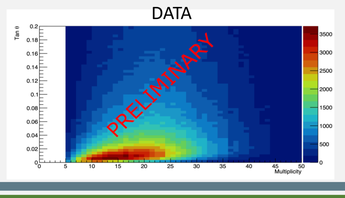


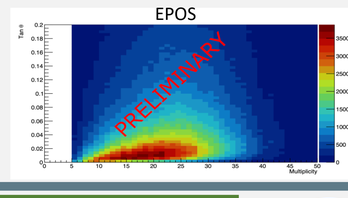
track multiplicity, normalized to the number of events in data



angular distribution of interaction daughters, normalized to the number of tracks in data

- **for understand discrepancy in track slope in MC/Data comparison, distribution between track slope vs multiplicity has been studied**
- **average track angle of EPOS increases more with multiplicity**





Summary:

- *DsTau(NA65) experiment aims to study tau neutrino production by D_s decays*
- *2018 pilot run data sample is analyzed to study proton interactions in tungsten*
- *proton interaction length in tungsten is measured for the first time, results will be submitted for publication*
- *data analysis of physics runs data is going on*

References:

1. *Aoki S, Ariga A., Ariga T., all, Development of proton beam irradiation system for the NA65/DsTau experiment, Journal of Instrumentation, Volume 18, October 2023*
2. *Ariga, A. Status and plans of the DsTau Experiment, SPSC Open session June 2021*
3. *A. M. Guler, NA65(DsTau): study of tau neutrino production in p-A interactions, PoS TAUP2023 (2024) 157*
4. *Ariga, A. DsTau status report 2023 (https://cds.cern.ch/record/2868526/files/SPSC-SR-334.pdf)*
5. *E. Yüksel, NA65/DsTau: Study of Tau Neutrino Production in p-A interactions, 31st International Workshop on Deep Inelastic Scattering, April 2024, Grenoble, France*

NEUTRINO 2024

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