Results from the DsTau/NA65 experiment at CERN

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On behalf of the DsTau Coll.

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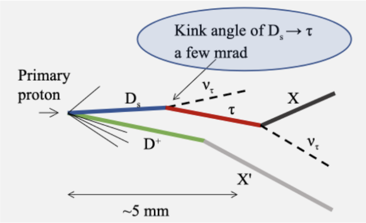
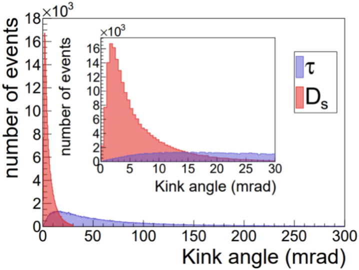
Introduction

- The tau neutrino is one of the least known particle in the Standard Model.
- A few measurements have reported the cross-section for charged current interactions of ν_τ with a limited statistics.
  - A significant systematic uncertainty in ν_τ flux ($>$50%) is due to forward charm production.
- The DsTau experiment was proposed to measure an inclusive differential cross-section of D_s production in p-A interactions.
- Precise measurement of ν_τ CC cross-section would be:
  - Search for new physics effect in ν_τ – nucleon interaction
  - Important for current and future neutrino experiments like **FASER**, **SND@LHC** and **SHiP** and astrophysical ν_τ observations.

The concept of measuring the production of ν_τ

- The main source of tau neutrinos is decay of D_s mesons to tau neutrino and tau lepton.
- Detect double kink topology of $D_s \to \nu_\tau \tau \to X$ & partner charm decay topology within a few mm.
- Technical challenge to a few mrad kink angle of $D_s \to \nu_\tau \tau$ decays.

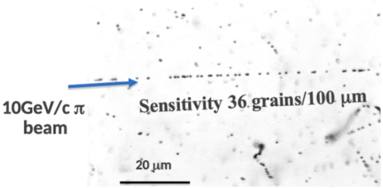




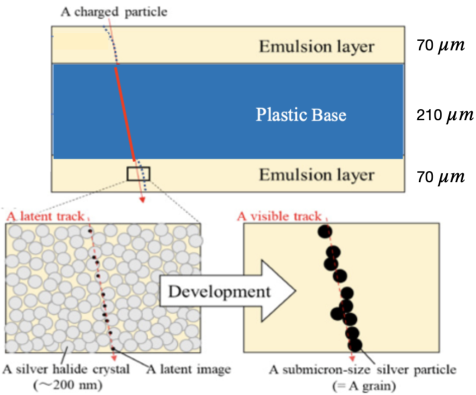
- Observing the decay topology of D_s into τ requires sub-micron spatial resolution and sub-mrad three-dimensional angular resolution.

Emulsion detector

- Nuclear emulsion can provide the required spatial and angular resolutions

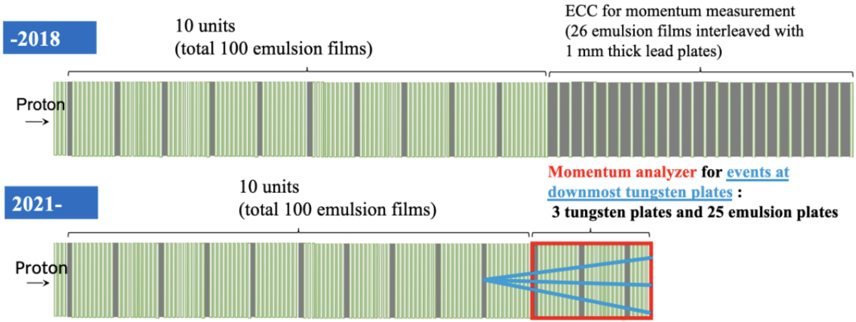


Cross-sectional view of emulsion plate



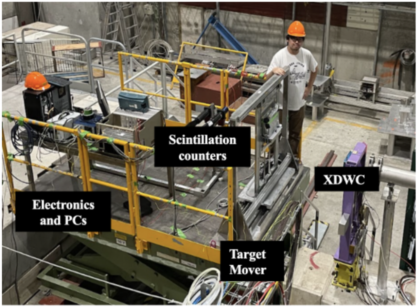
Experimental setup

- In each unit, there is a 500 μm tungsten plate followed by 10 nuclear emulsion films interleaved with 9 plastic spacers. This unit structure is repeated 10 times in a module.
- Original structure had more material → too high track density in ECC → Dedicated scanning is required.
- Reduce material, but sufficient performance
- Making data taking procedure simple



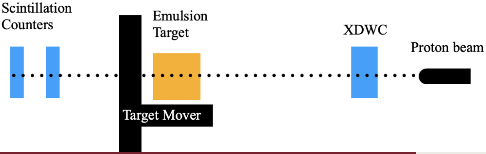
Experimental setup

Scintillation counters
Measure the beam intensity



XDWC
Measure the beam profile

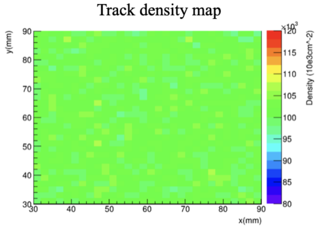
Target mover
Movable stage,
+ Real time speed control wrt beam intensity
→ Uniform irradiation with proton density of $10^5/cm^2$

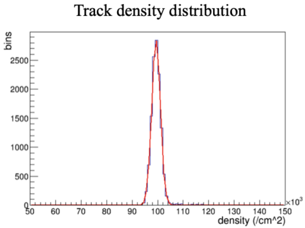


Data taking

- Data taking was completed in 2023.

	Emulsion films	Beam time
Pilot run	50 m^2	1 week
2021 run	110 m^2	2 weeks
2022 run	110 m^2	1 week
2023 run	260 m^2	2 weeks

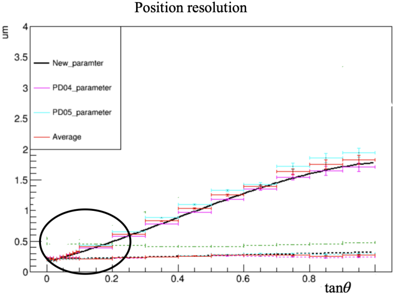


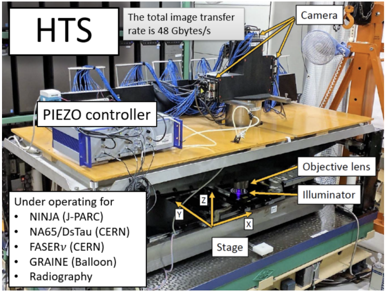


- We successfully collected the highest-quality data!

Emulsion scanning

- Emulsion scanning is performed by the HTS system
- A throughput rate of 10 Gbytes/sec
- It takes about 40 min per film (20 cm x 25 cm x 2 = 1000 cm^2)
- About 15% of emulsion films have been scanned.

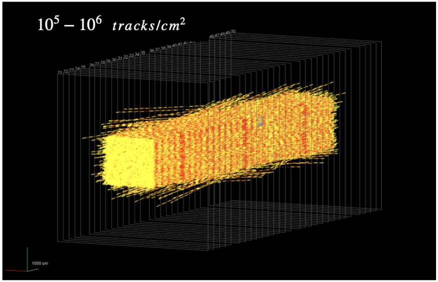


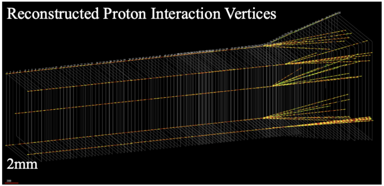


- 300 nm spatial resolution in the relevant angular range

Event reconstruction

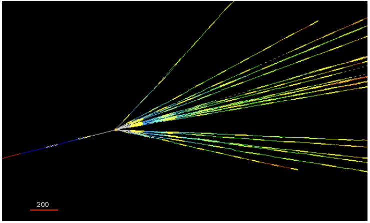
- Event reconstruction consists of several steps
  - After base-track reconstruction, film-to-film alignment is performed by applying base-track pattern matching.
  - Base-tracks are connected film by film according to angular and position acceptance to form so-called volume tracks.
  - After completing the track-reconstruction step, vertexing algorithms are applied to identify the proton interactions. Tracks containing at least four base tracks are used for vertexing.

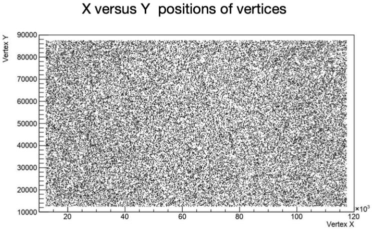




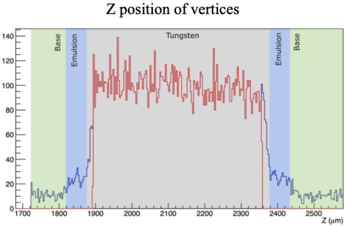
Analysis of proton-tungsten interactions

- A sample of about 100k proton interaction in the tungsten plates are analyzed from a single module of the pilot run data (paper submitted to EPJC, arXiv:2411.05452v1).



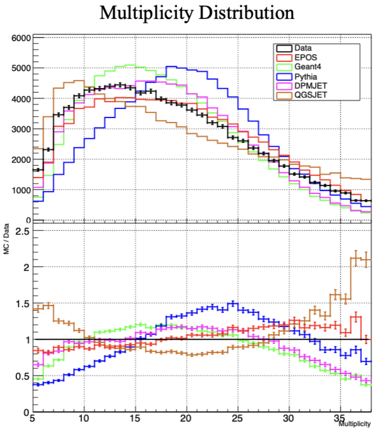


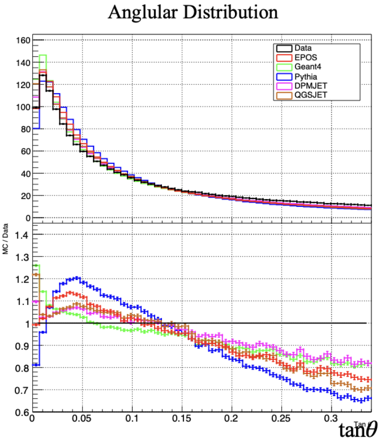
Tungsten Plate	N	N_0	$\frac{N}{N_0}$ (%)
1	13,586	3,310,658	0.41
2	13,390	3,292,677	0.41
3	12,653	3,256,746	0.39
4	12,256	3,214,141	0.38
5	11,745	3,157,020	0.37
6	11,264	3,082,105	0.36
7	10,645	2,996,099	0.35
8	9,775	2,892,348	0.34
Total	95,314	25,201,794	0.38



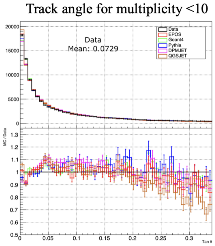
Analysis of proton-tungsten interactions

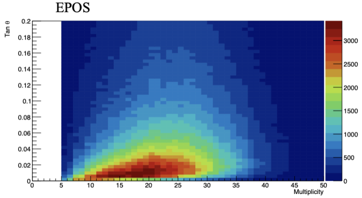
- None of the Monte Carlo models accurately describe proton-tungsten interactions, with a preference observed for EPOS.

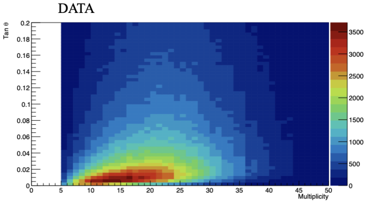


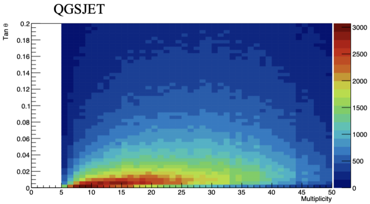


- There is a discrepancy between the data and MC predictions at high multiplicity.
  - Hadron production models in MC generators should be properly tuned.









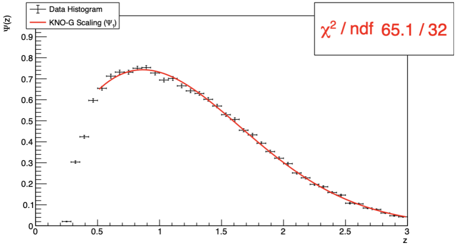
Analysis proton-tungsten interactions

- The first measurement of proton interaction length in tungsten.
- The multiplicity distribution is consistent with KNO-G scaling predictions.

Proton-tungsten interaction length

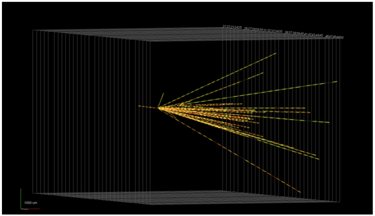
Sub-volume	Data(mm)	EPOS(mm)
1	91.0 ± 2.5	95.2 ± 2.7
2	90.8 ± 2.5	95.5 ± 2.8
3	93.7 ± 2.6	95.3 ± 2.8
4	93.9 ± 2.7	95.5 ± 2.8
5	94.5 ± 2.7	94.8 ± 2.8
6	94.4 ± 2.7	95.0 ± 2.8
7	94.7 ± 2.8	98.1 ± 3.1
8	96.8 ± 3.0	97.0 ± 3.1
Mean	93.7 ± 2.6	95.8 ± 2.8

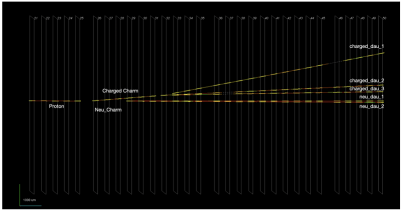
Test of KNO-G scaling

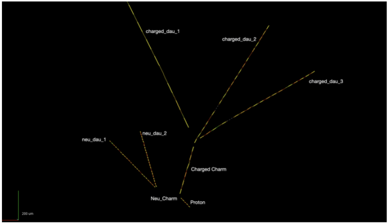


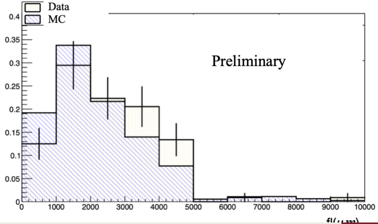
Charm production

- In $\sim$ 100k proton-tungsten interactions, 54 charm pairs (charged & charged or neutral charm) decaying into multi-prongs have been found, analysis of these events is going on.









D_s decay search

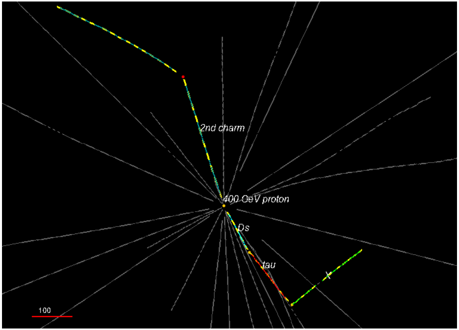
- A total of $\sim 2 \times 10^6$ proton-tungsten interactions from 10 out of 30 pilot run modules were analyzed.
- A preliminary selection is applied to the sample to enrich $D_s \to \tau \to X$ signal events.

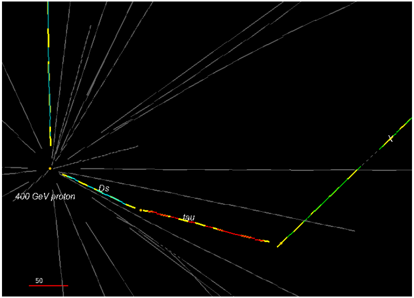
	Current status	If all is done
p-A interactions	1,863,286	1,863,286
Selected events	88	88
Check with event viewer	86	88
Confirmed events	22	22.5
Momentum measurement	12	22.5
$P_T > 0.1$ GeV & partner charm	5	9.4

  - A total of 1.7 signal events are expected based on the selection efficiency (preliminary!)

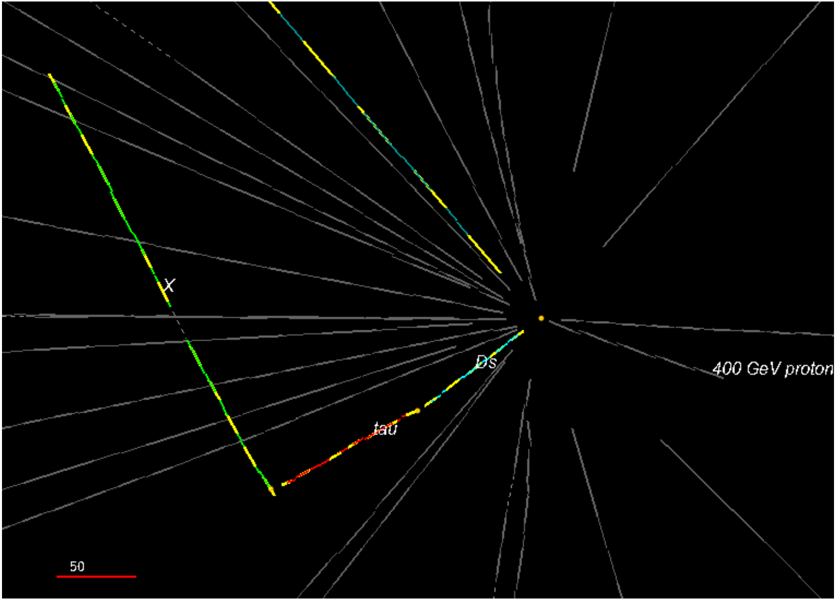
D_s decay search

- An automated search of small kinks & momentum measurement have been implemented.





D_s decay search



Conclusion

- DsTau studies are crucial for current and future neutrino experiments such as FASER, SND@LHC and SHiP.
- Physics run from 2021 to 2023 successfully completed.
- Emulsion data acquisition is going on.
- Excellent detector performance, nuclear emulsion provides 300 nm spatial resolution.
- The first measurement of proton interaction length in tungsten.
- An automated search of small kinks & momentum measurement have been implemented.
- More charm results will come in this year.
- The DsTau results can assist in refining proton-nucleus interaction models used in MC event generators.

Back up

Back up

Selection	Efficiency (%)
D_s angle < 50 mrad	69.3
D_s and τ decay length $>$1 plate 2^{nd} kink within 18 plates	31.4
1^{st} kink angle in (2 mrad, 10 mrad)	47.3
IP of 1^{st} kink in (8 μm, 30 μm)	70
2^{nd} kink angle and IP sel.	88.2
Partner Charm	79.3
$P_T > 0.1$ GeV	87.1
Total	4.4