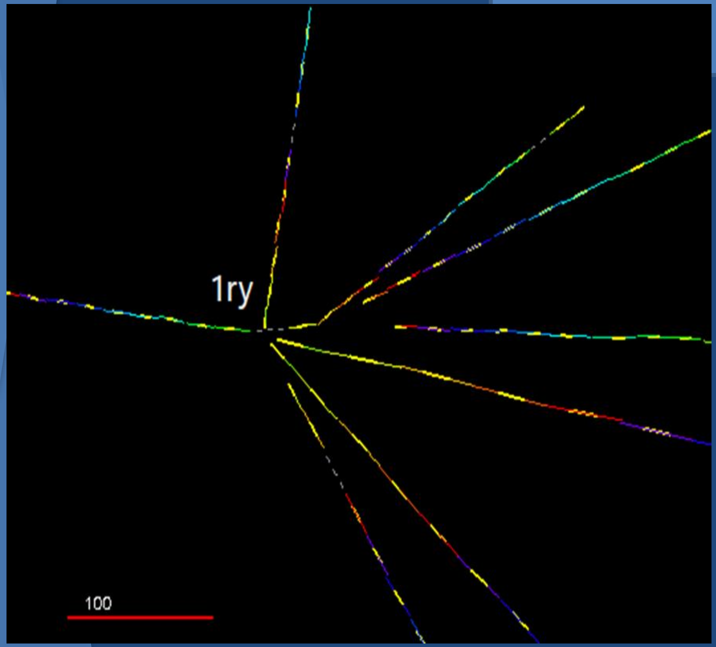
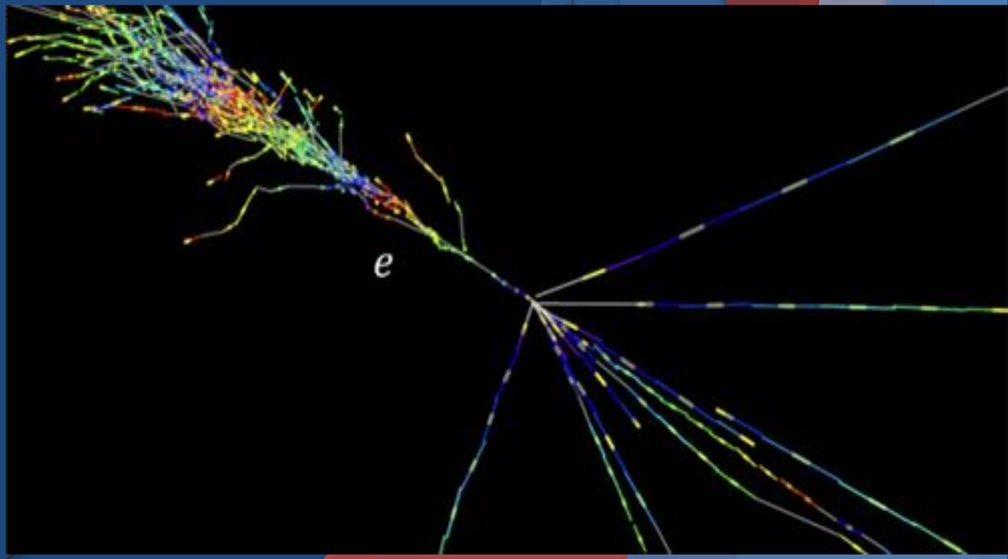
ISS @ DsTau (NA 65) and FASER Experiment:

Study of the 3 neutrino flavors in the DsTau and FASER experiments at CERN using nuclear emulsion detectors

Project SOFT2

Elena FIRU (team leader)





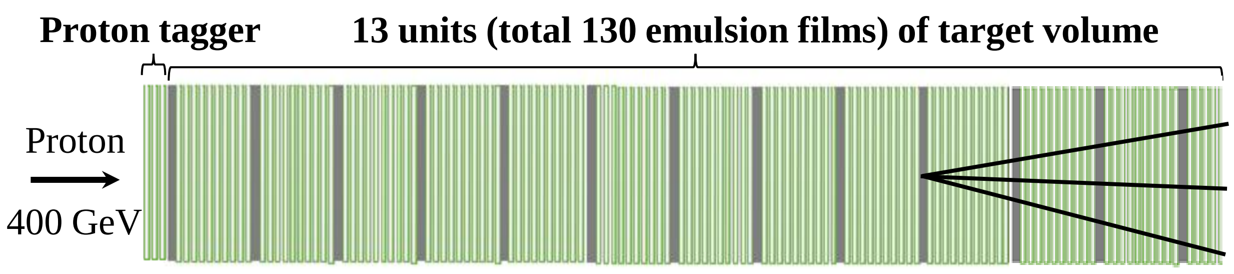
Outlines

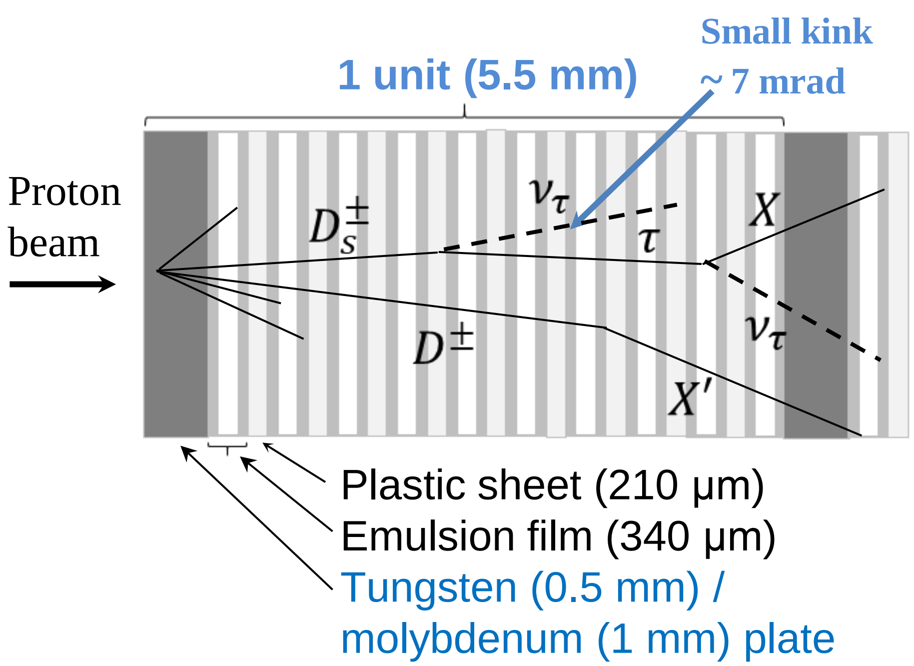
- 2025 ISS @DsTau in SOFT2
- 2025 ISS @FASER in SOFT2
- ISS future involvement in DsTau for SOFT 2
- ISS future involvement in FASER for SOFT 2

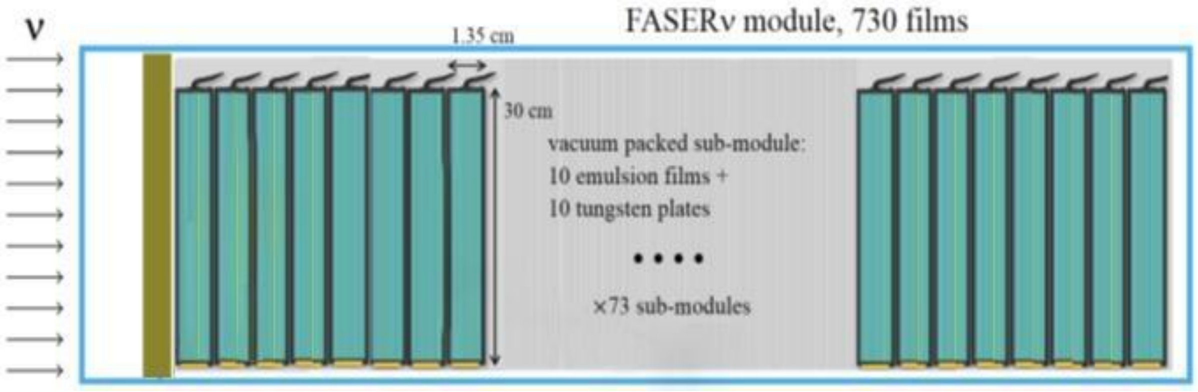
Nuclear emulsions in DsTau and FASERν

- ✓ high spatial resolution of Emulsion Cloud Chambers of DsTau and FASERnu for detecting the tau neutrinos production in DsTau and respectively the interaction with W of the neutrinos emerging from ATLAS detector

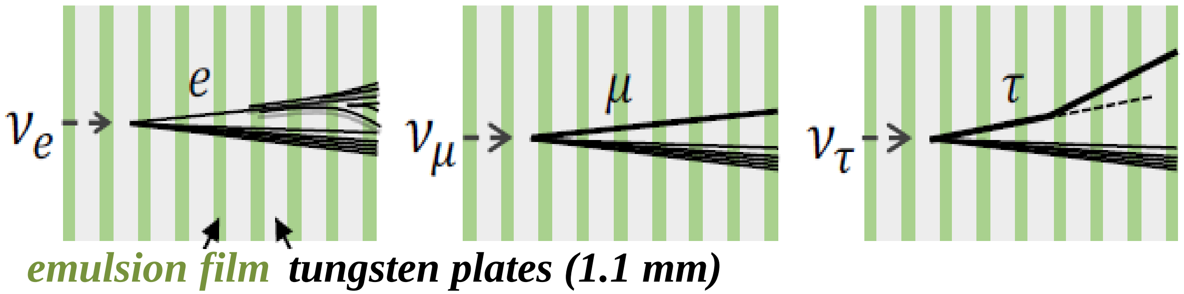
DsTau module







ν flavor tagging with topological information



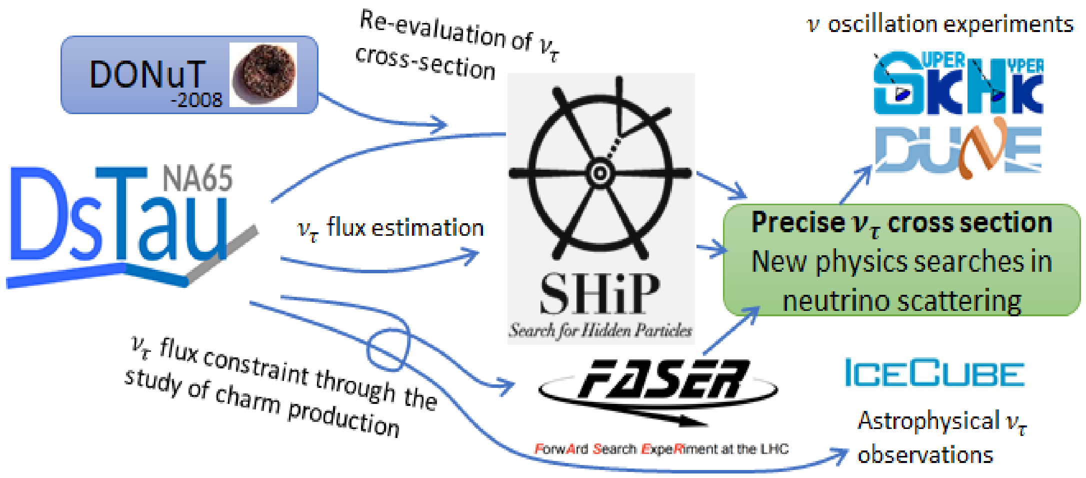
2025 ISS @DsTau (NA65) in SOFT2

The DsTau (NA65) experiment – physics goals

❑ DsTau goals

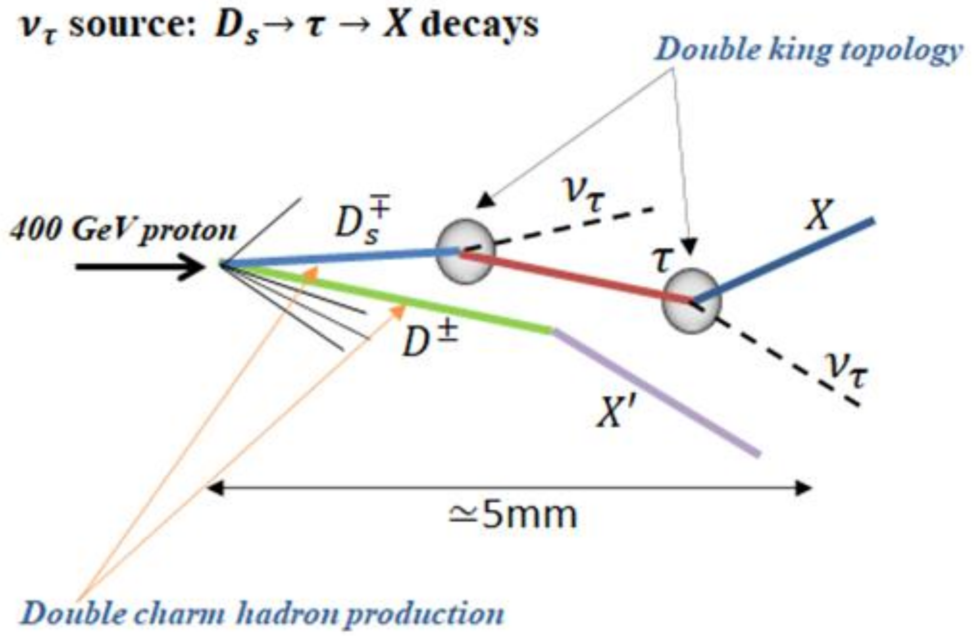
- study of the tau neutrino production by **D_s** decays
- reduce the systematic uncertainty of ν_τ flux production from

  50% to 10 %
- first measurement of 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:

- 4.6×10^9 protons, 2.3×10^8 proton interactions in tungsten/molybdenum
- detection of "**double-kink + charm decay**" topology within few mm

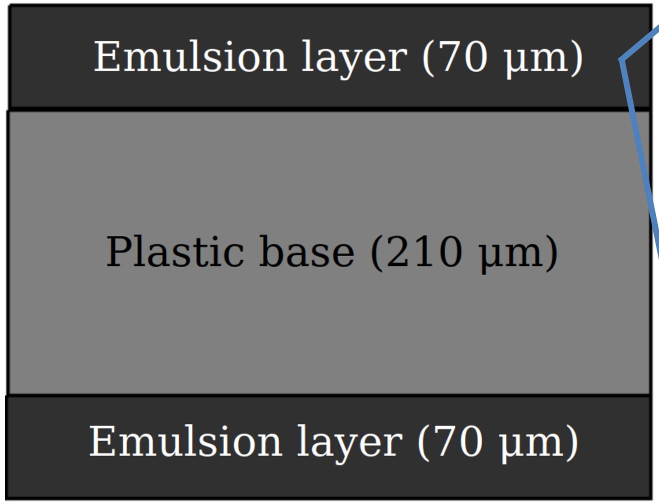
❑ Estimate:

1000 ⟶ $D_s \to \tau \to X$ *decays*

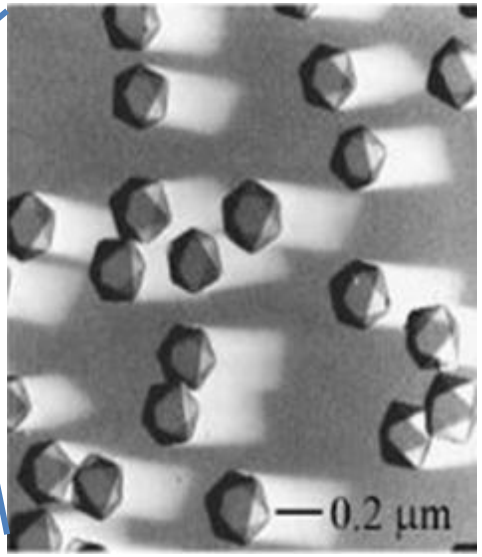
ν_τ production study: DsTau (NA65)

Nuclear emulsion detector

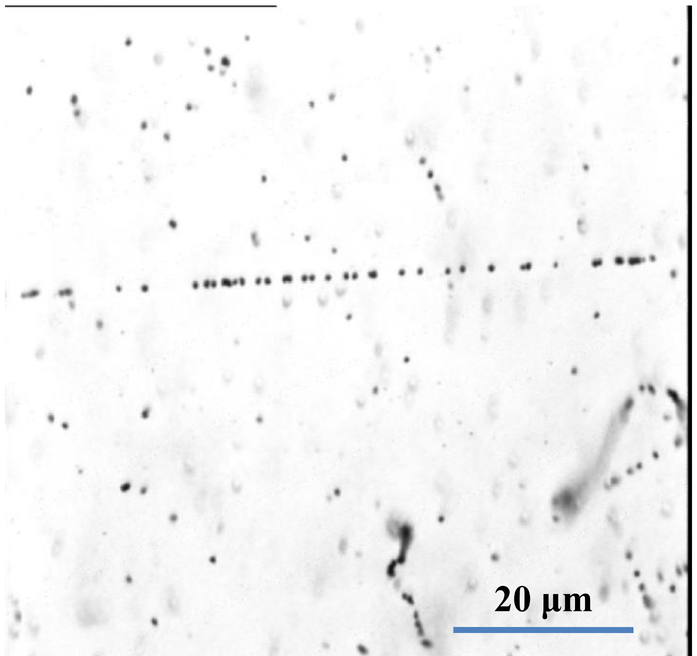
Emulsion films



cross-sectional view of an emulsion film



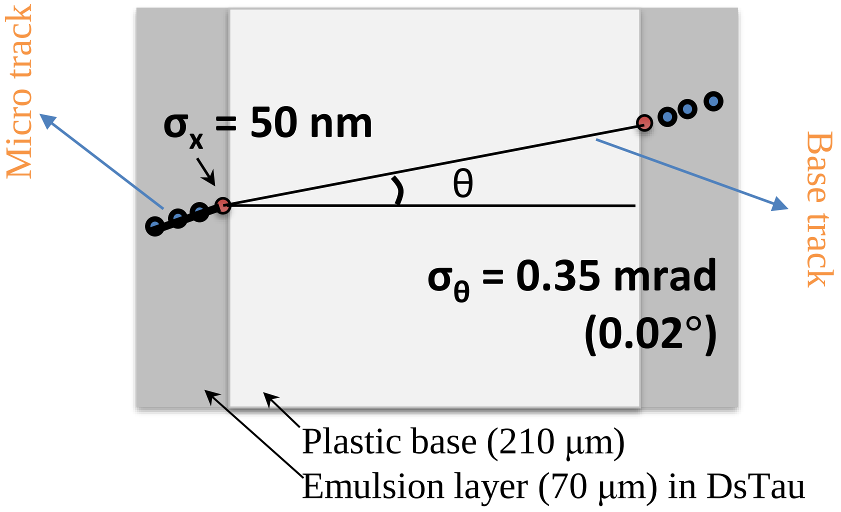
electron microscope picture of silver halide crystals

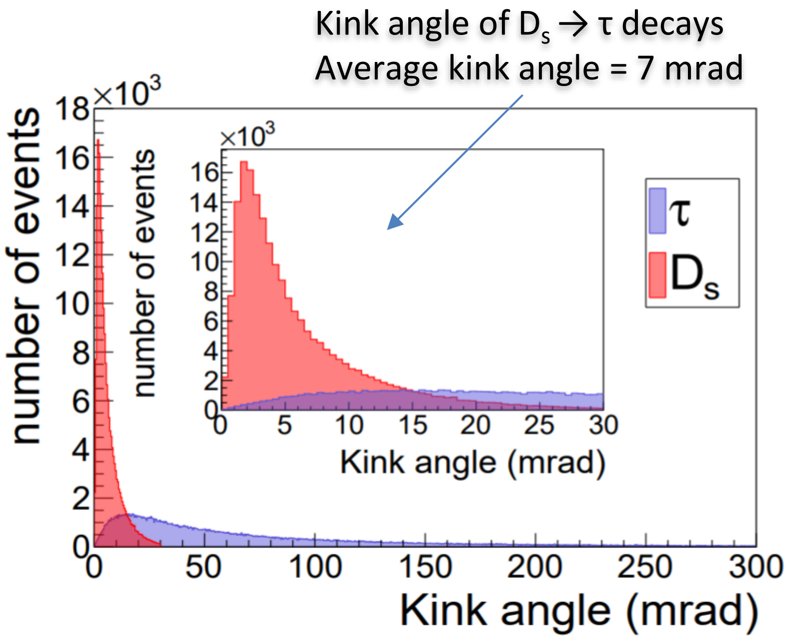


track of a relativistic particle (10 GeV/c π beam)

Single emulsion film

High angular resolution tracker

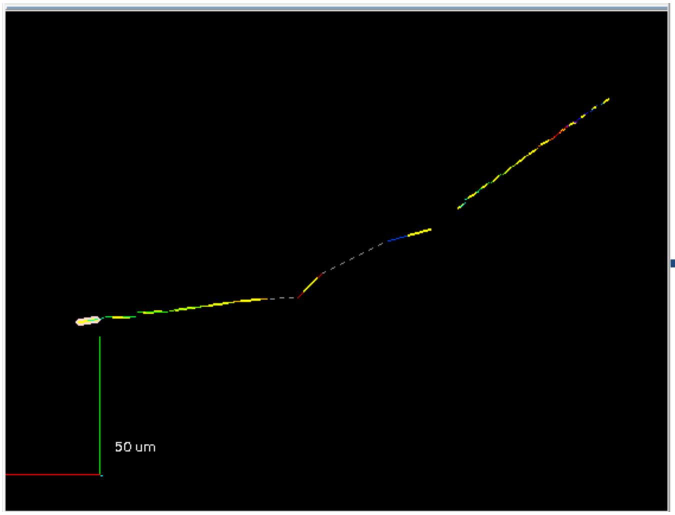


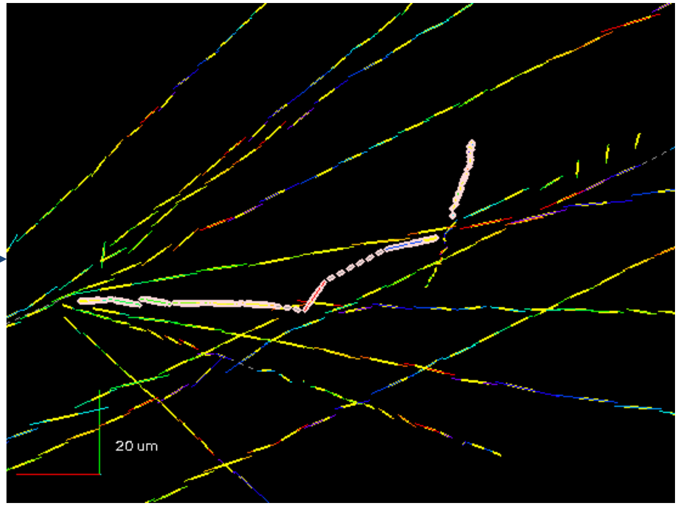


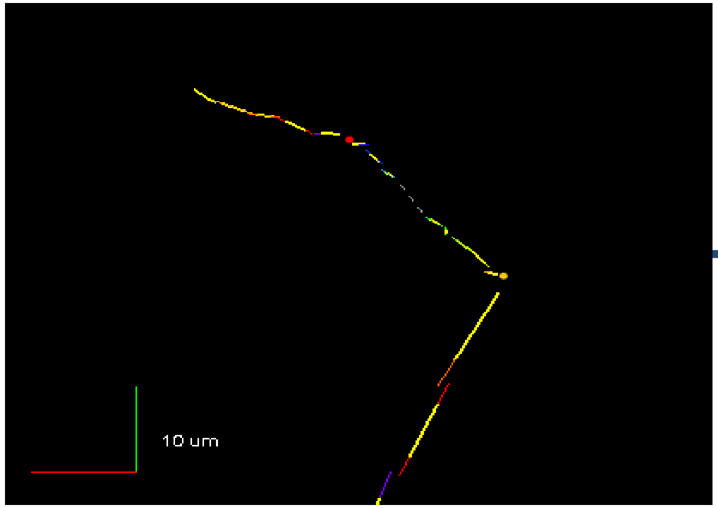
Study of tau neutrino events from $p+W \rightarrow D_s$, $Ds \rightarrow \tau + \nu_\tau$

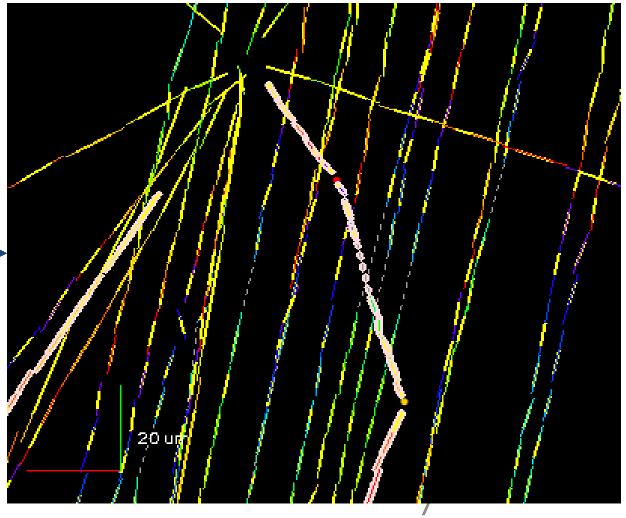
1. Analyzing of miss-connections between Ds and tau neutrino
2. Determining the particle momentum with the software developed in ISS

	Current status	When all is done
p-A interactions	1 863 286	1 863 286
Selected events	88	88
Check with event viewer	87	88
Confirmed events	33	34
Momentum measurement	21	34
P_T > 0.1 GeV & partner charm	5	7







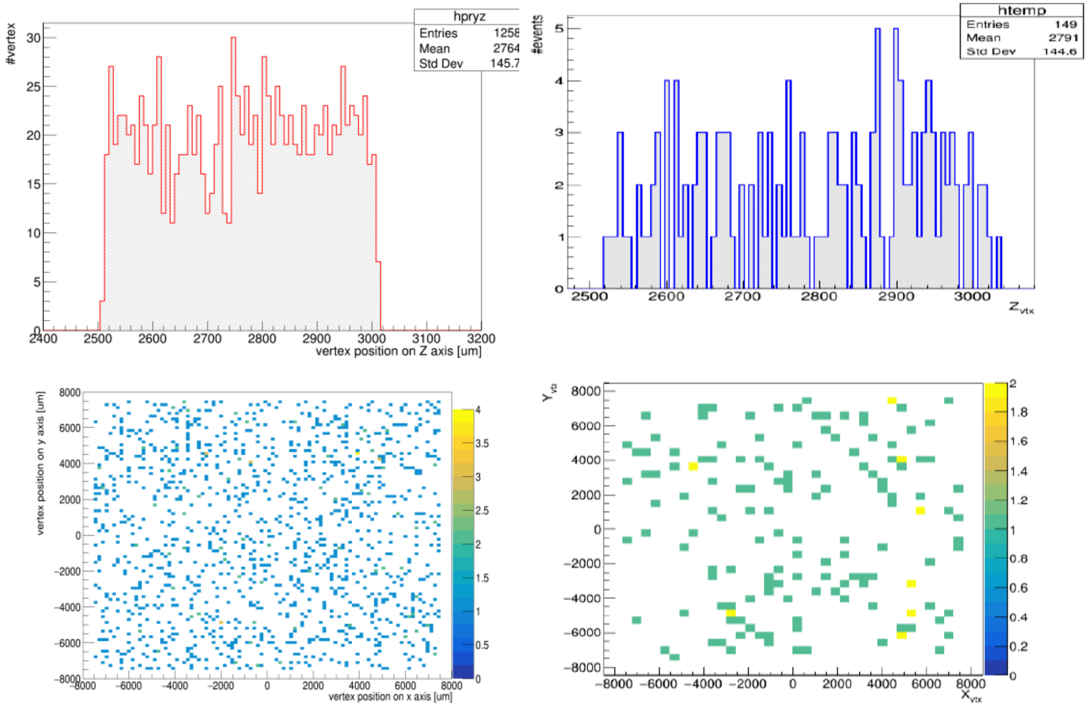


Analysis of 4 charms production using reconstructed Monte Carlo data

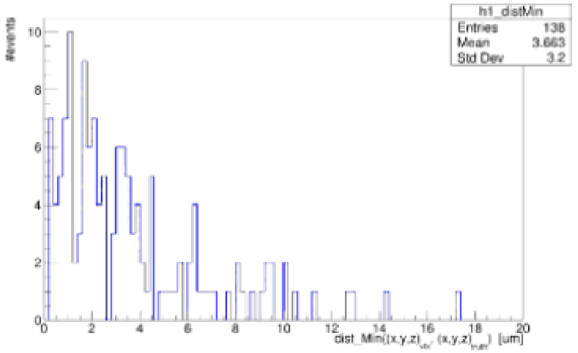
898 x 106 events were simulated → 0.00549% events with 4 charms per event

In the first W plate :
MC Truth: 1258 interaction vertices with 4 charms,
MC Reco: 149 interaction vertices with 4 charms were reconstructed
(c1, n2, c3, n4)

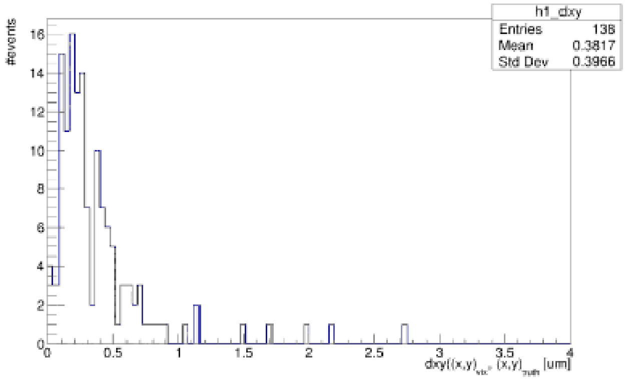
A match of a reconstructed event with an MC event occurs if the distance between the vertices is less than 15 μm, and the distance in the xOy plane is less than 5 μm



Distributions of Z and XY positions of primary vertices in the first W plate. Truth (left) and Reco (right)



Distribution of the (x,y, z) distance



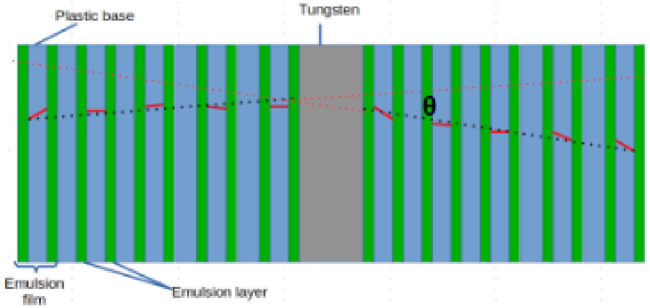
Distribution of the (x,y) distance

- matching algorithm needs to be improved to scan the entire MC data and find the minimum of the two distances
- as it currently terminates at the first MC event that meets the specified conditions for a reconstructed event

Momentum estimation in DsTau

Momentum estimation algorithm (3 C++/ROOT codes):

1. Follow down search - connecting track segments across emulsion films
2. Angle difference - calculated using 5 films before and 5 films after W plates

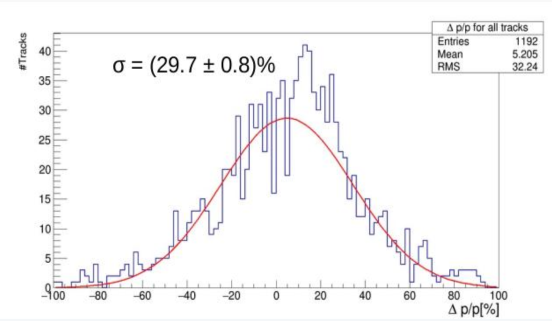


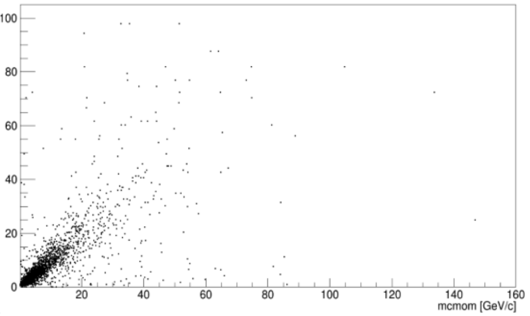
3. Momentum estimation - using the Highland formula

$$\theta_0 = \frac{13.6}{pc\beta} \cdot \sqrt{\frac{x}{X_0}} \cdot \left(1 + 0.038 \cdot \ln \frac{x}{X_0}\right)$$

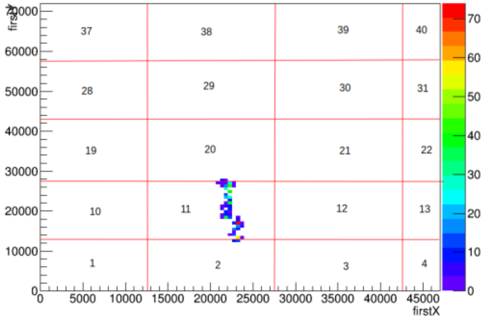
Algorithm was automated to reduce runtime

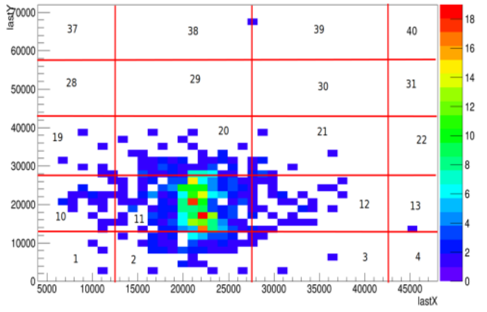
1. Tested with MC sample
   - Resolution of 30% for p < 30 GeV/c



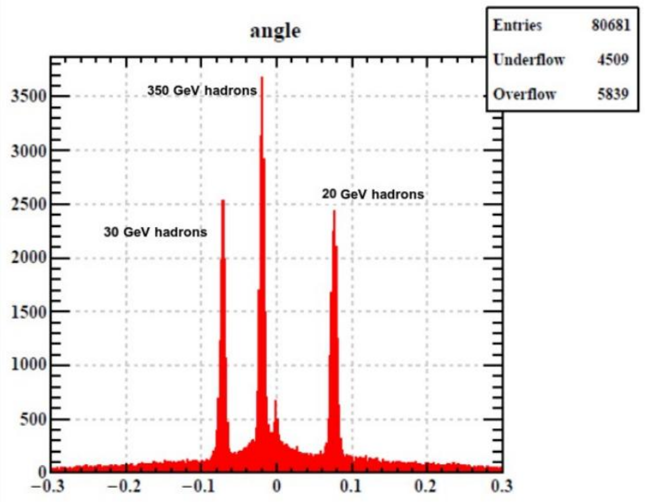


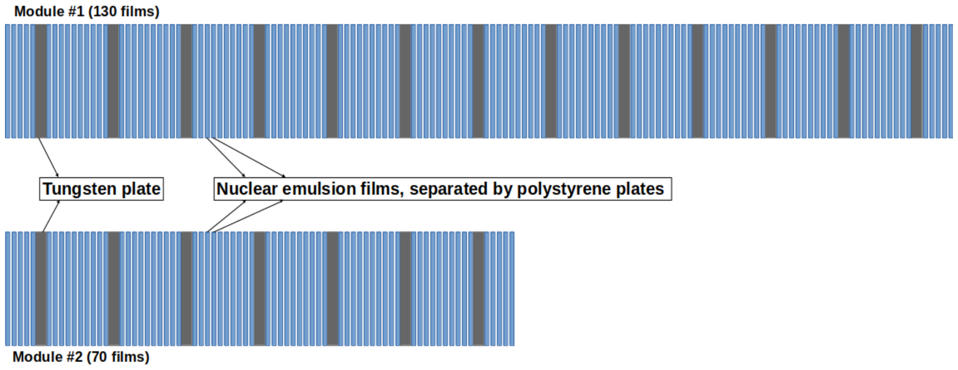
2. Tested with real data sample
   - Films divided into 63 sub-areas
   - Automated algorithm was modified





3. Validating the algorithm (ongoing)

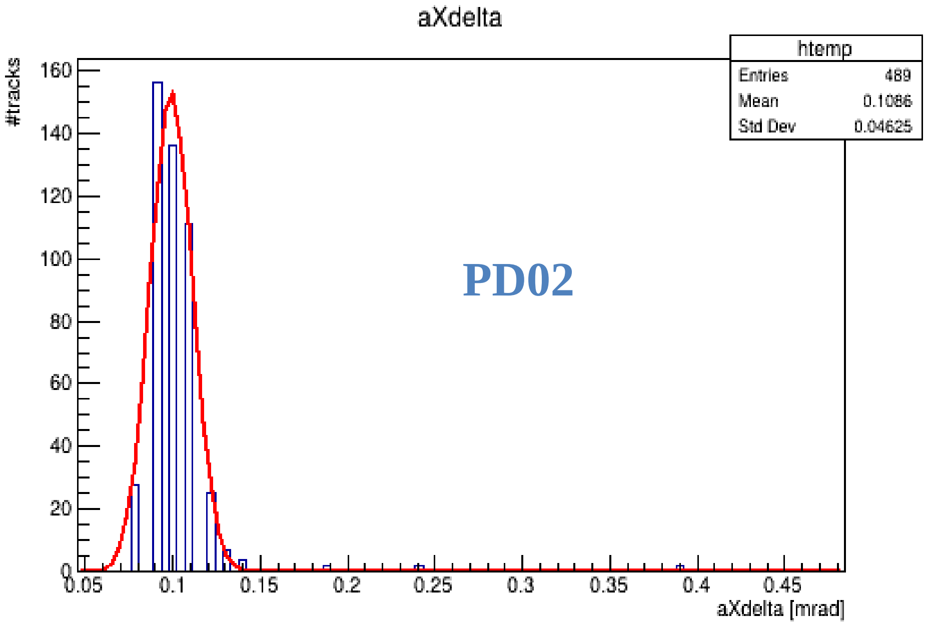




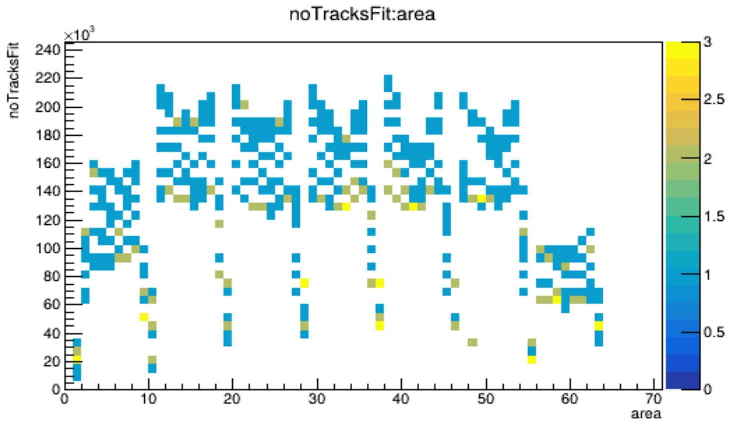
- the results obtained after validation will be published in a scientific paper

Development of the methodology for checking the quality of data for DsTau detector

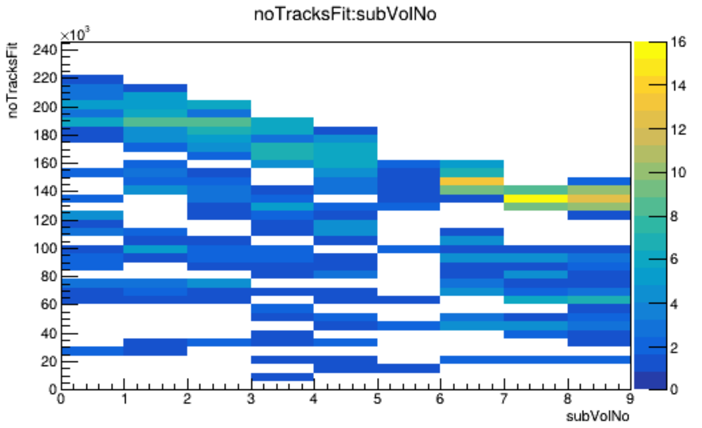
- ISS developed the method for selecting the values of Δa_x and Δa_y of the primary proton beam width for all 63 areas in 9 sub-volumes; a_x and a_y are slopes of a sample of beam tracks.
- we found the correspondence for maximum Δa_x and Δa_y and areas for all module detectors.



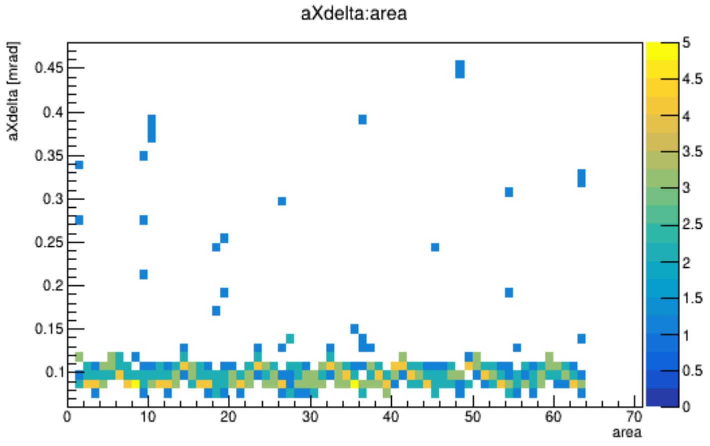
PD02 module



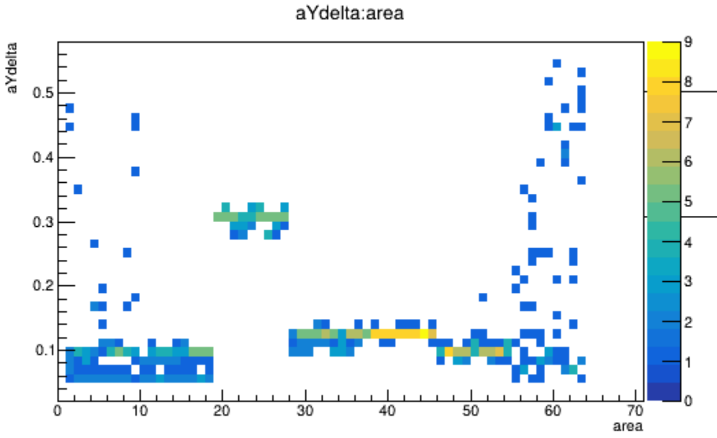
PD11 module



PD02



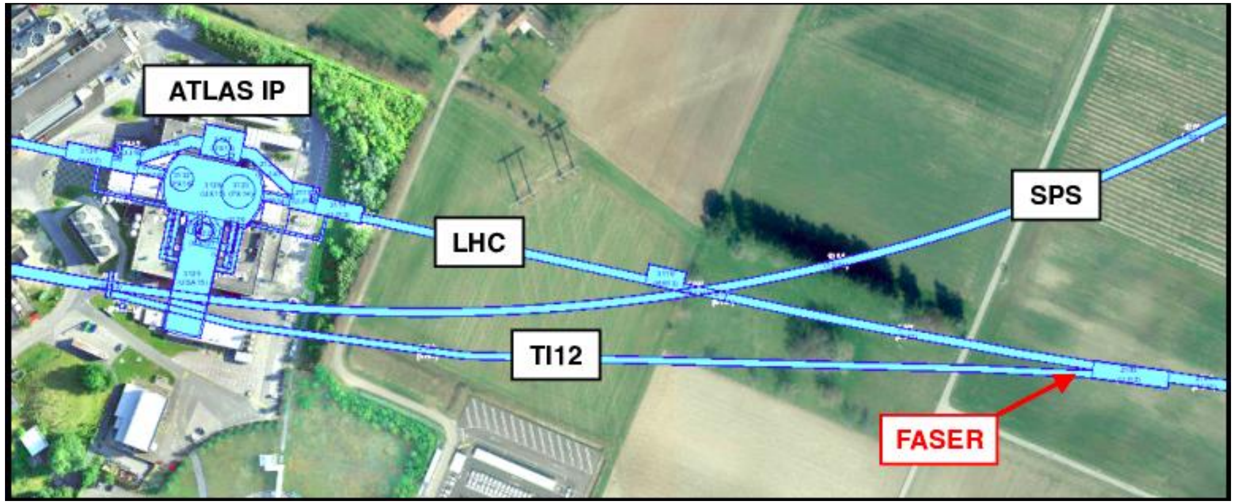
PD11



2025 ISS @FASER in SOFT2

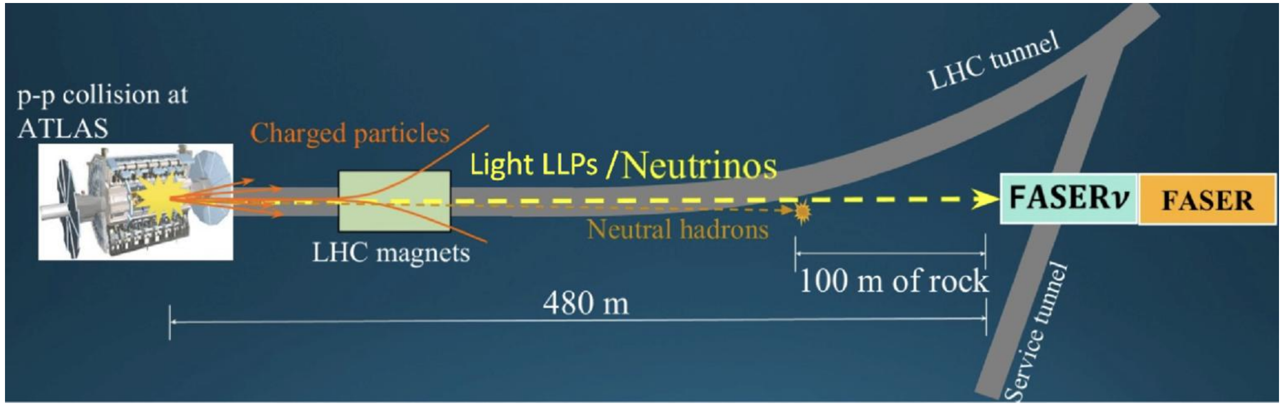
FASER experiment

- **ForwArd Search ExpeRiment** - faser.web.cern.ch
  - relatively new experiment at the LHC
  - small detector designed to search for new physics in the very forward region
  - complementary to existing LHC experiments
  - built between 2019 and 2021
  - 101 members, 27 institutes, 11 countries



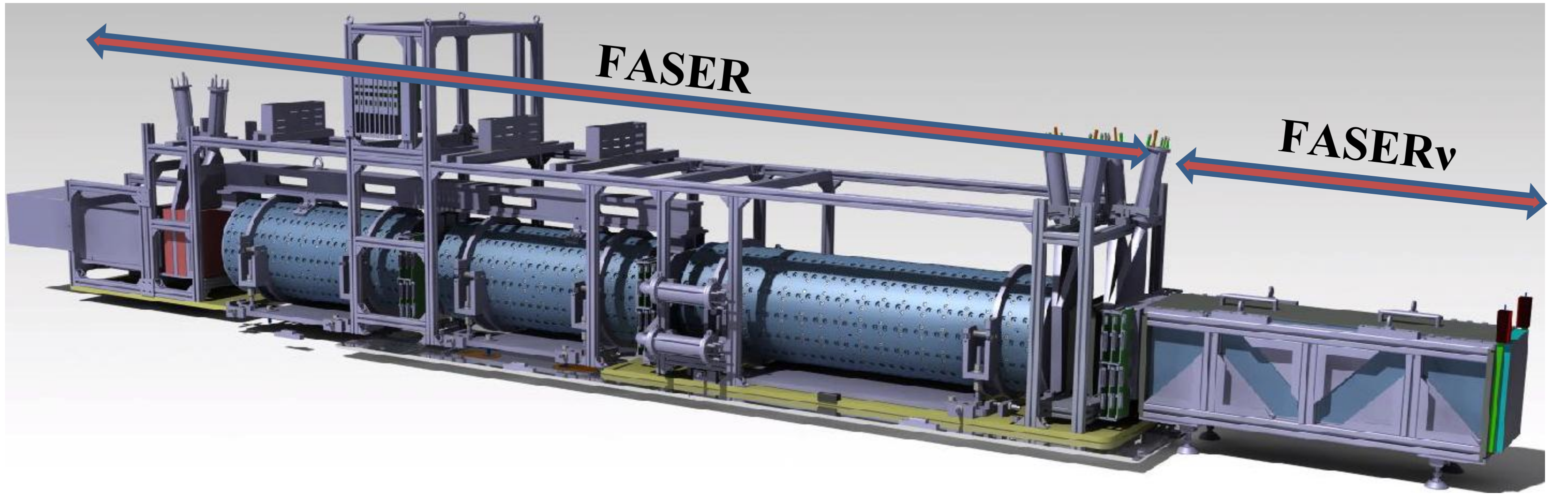
- **Located 480 m from ATLAS** p-p interaction point
  - aligned with ATLAS collision axis line-of-sight (LOS)
  - $\simeq$ 7 m length, 20 cm aperture (magnets)
  - FASERν has a transverse size of 25 x 30 cm^2
  - shielded by 100 m of rock

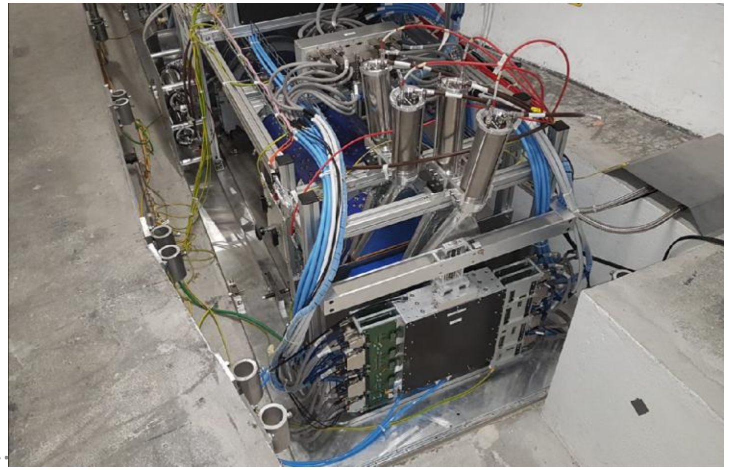
- **Physics data taking** since LHC Run 3 start

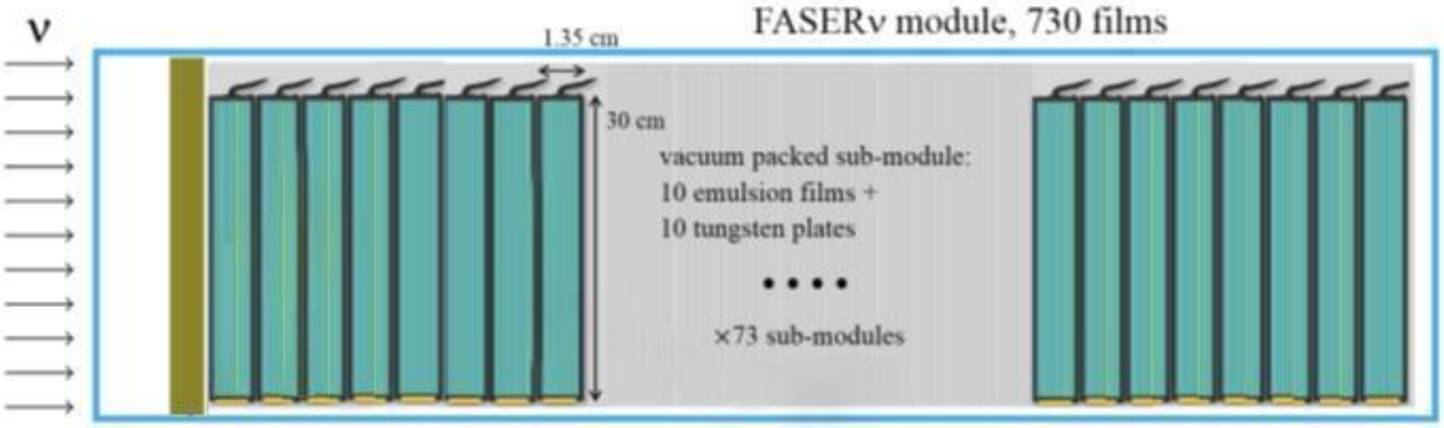


FASERν emulsion detector

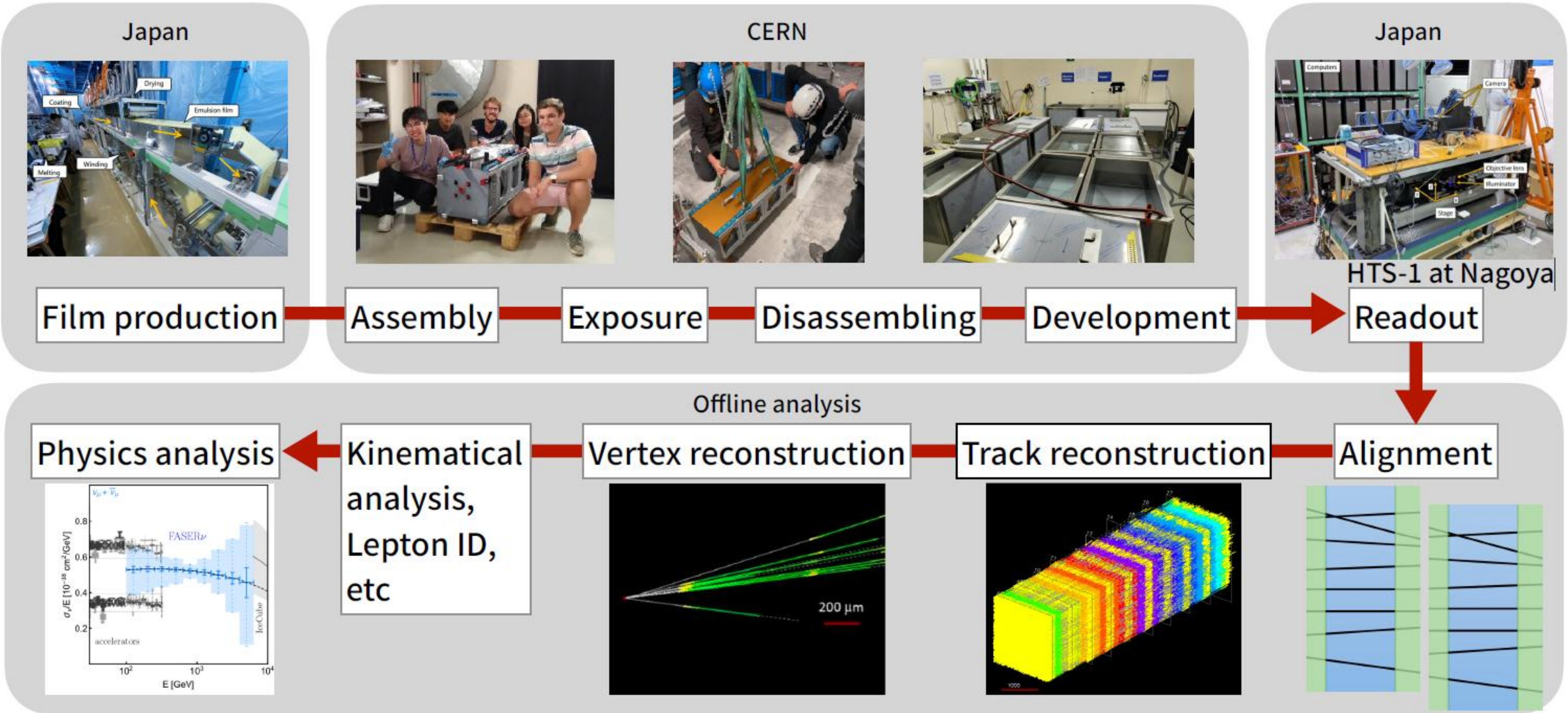
- 730 emulsion films interrelated with 1.1 mm thick tungsten plates
- 25 cm × 30 cm, 1 m long, 1.1 tons ($8\lambda_{int}$, $220X_0$)
- Track resolution in emulsion is 0.3 μm
- 3 - 4 detectors per years (install - exchange)







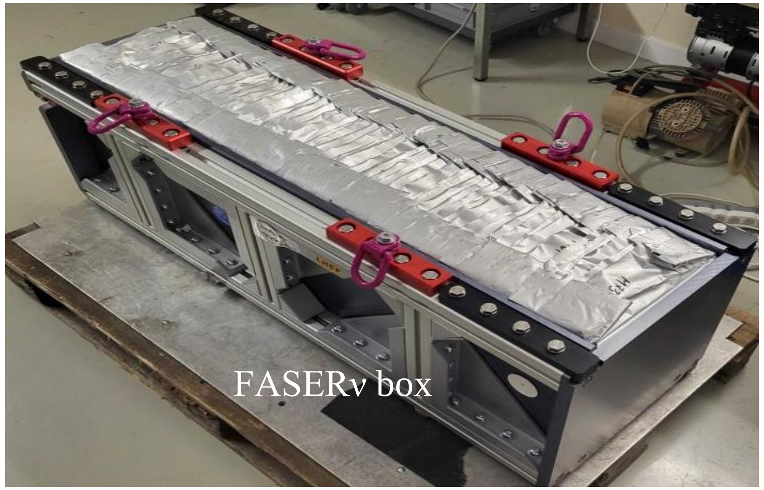
FASERν work flow



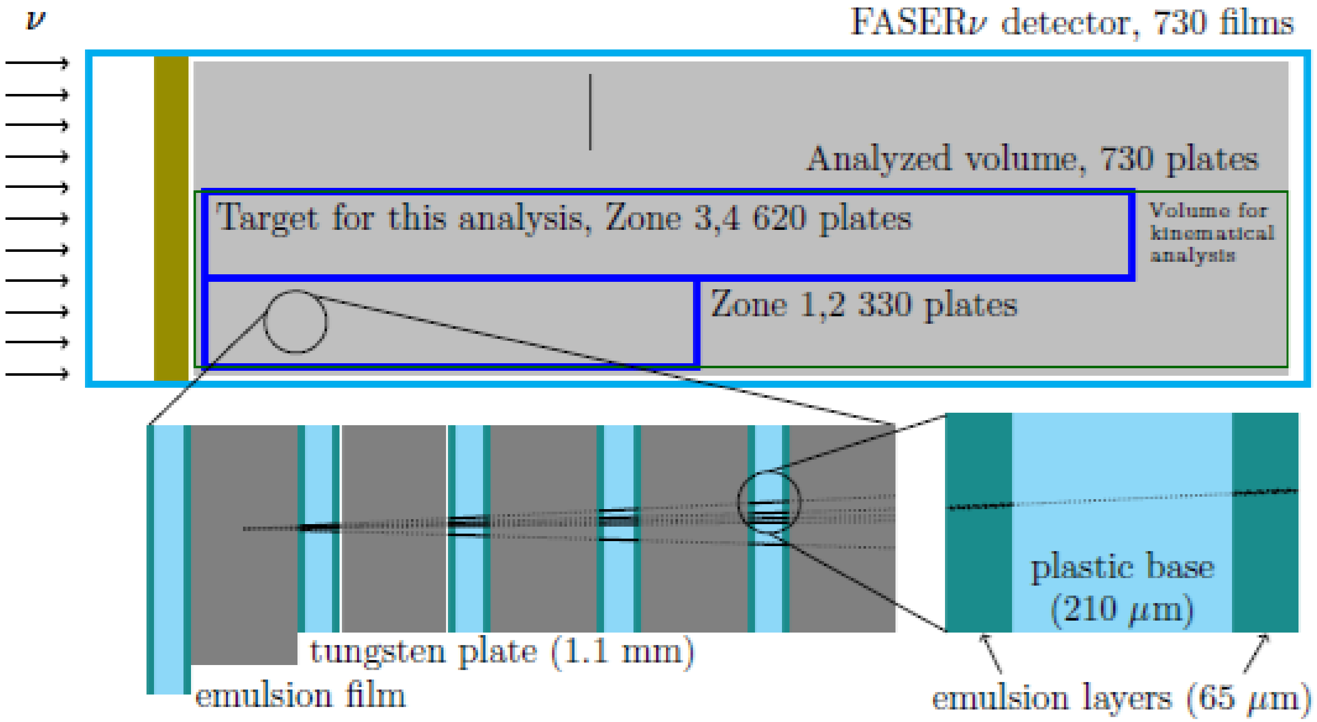
FASERν data analysis

❑ Data set analyzed:

- using 3nd module from 2022, 2024 (9.5 fb^{-1})
- target mass analyzed – 314.7 out of 1100 kg
- 3.7% of data collected



Selection criteria	
Vertex reconstruction	$N_{track} \geq 5$
	N_{track} ($\tan\theta \leq 0.1$) ≥ 3 (suppress the neutral-hadron background)
Lepton requirements	E_e or p_μ > 200 GeV
	$\tan\theta_e$ or $\tan\theta_\mu > 0.005$
Back to back topology	$\Delta\phi > 90°$



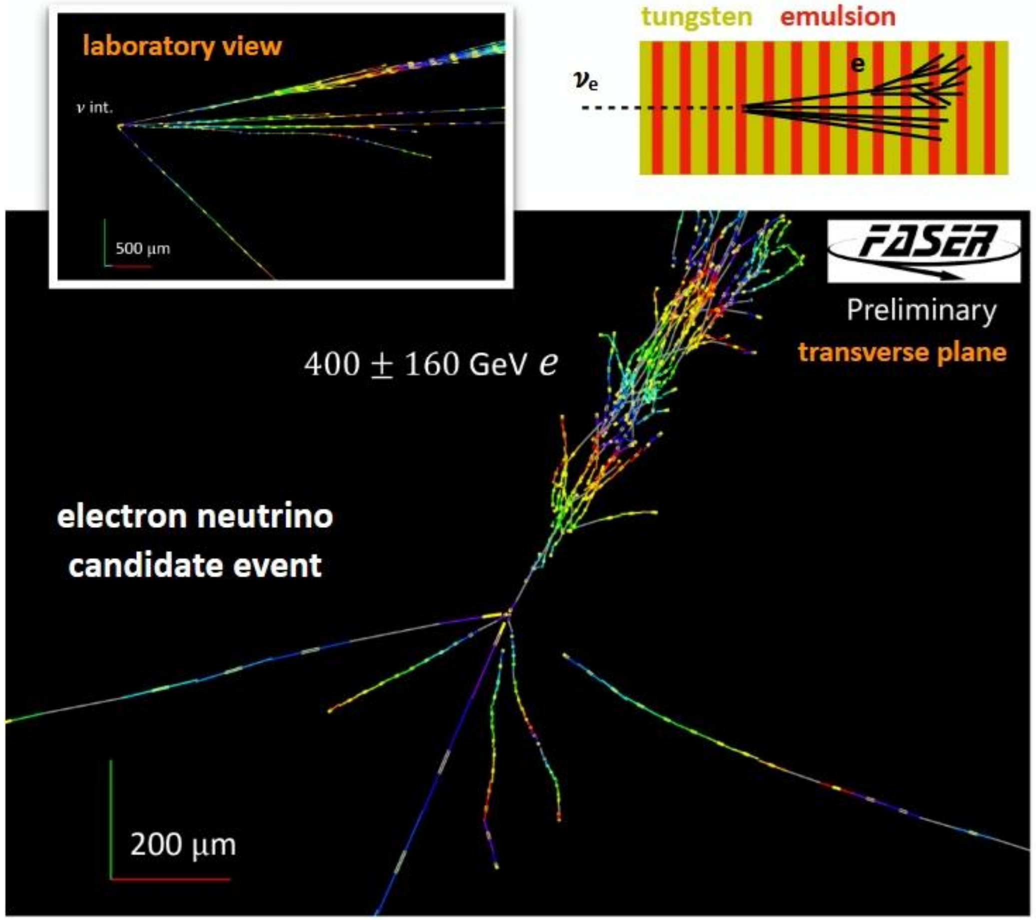
- neutrino interactions are searched inside the fiducial volume defined by the blue box

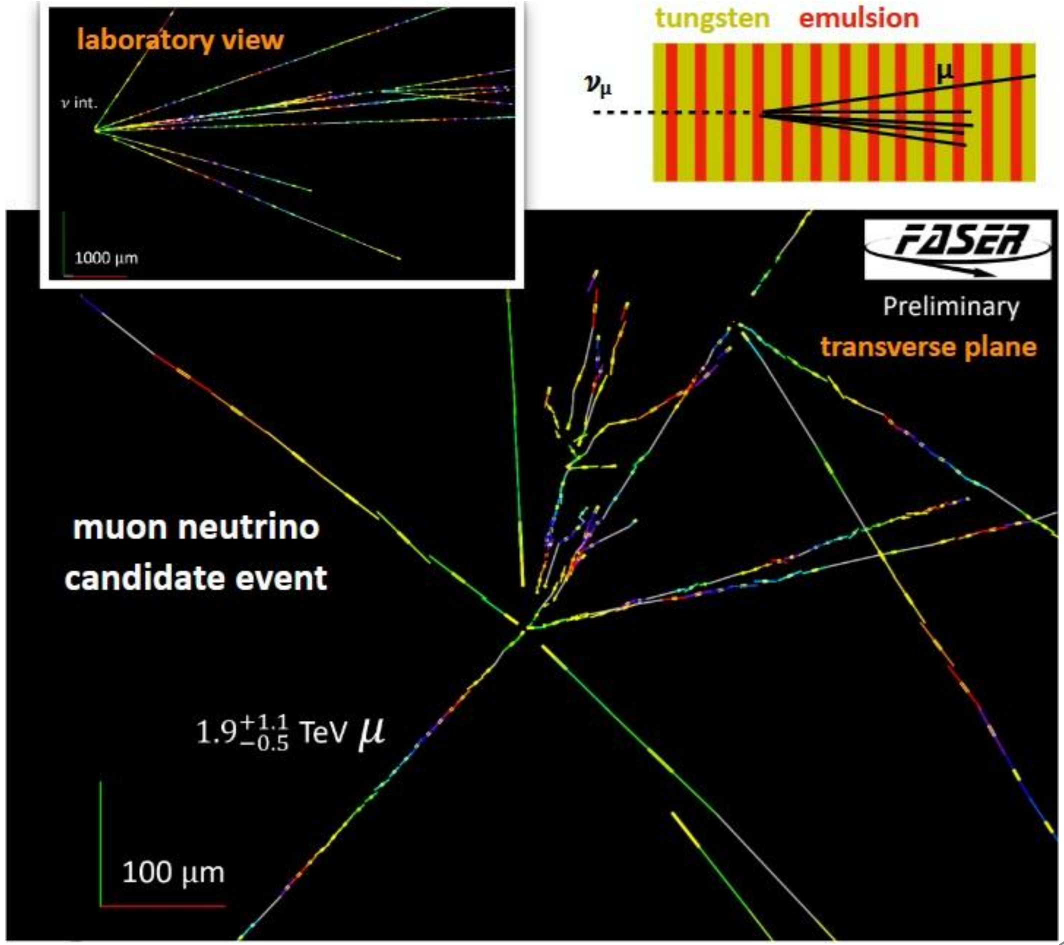
FASERν data analysis

Search of electron and muon neutrino - W interactions with FASERν

	ν_e CC	ν_μ CC
Expected signal	2.8 – 7.2	16.2 – 28.7
Expected background	$0.006^{+0.04}_{-0.02}$	$0.54^{+0.22}_{-0.17}$
Observed events	5	20

Summary of the selected events





FASERν data analysis

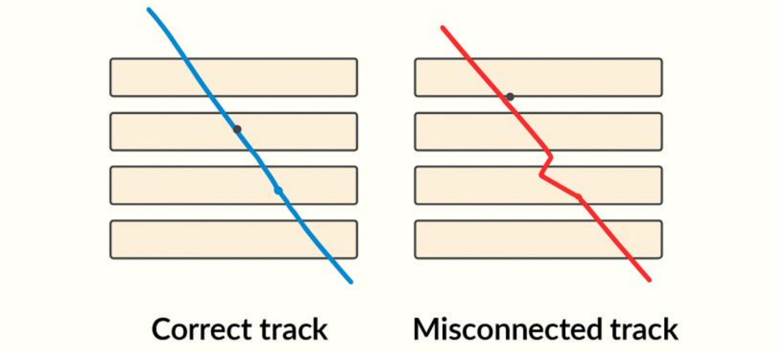
Study of misconnected tracks for the ν_μ-W interactions

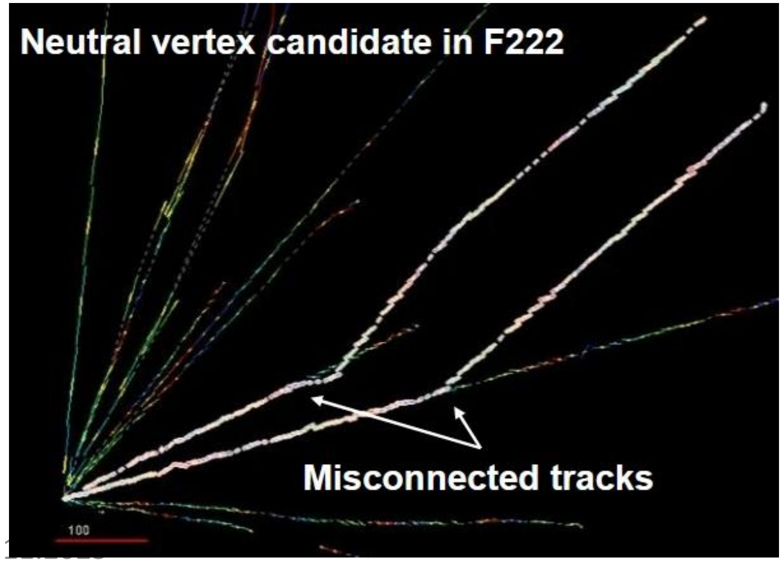
Causes of Misconnections:

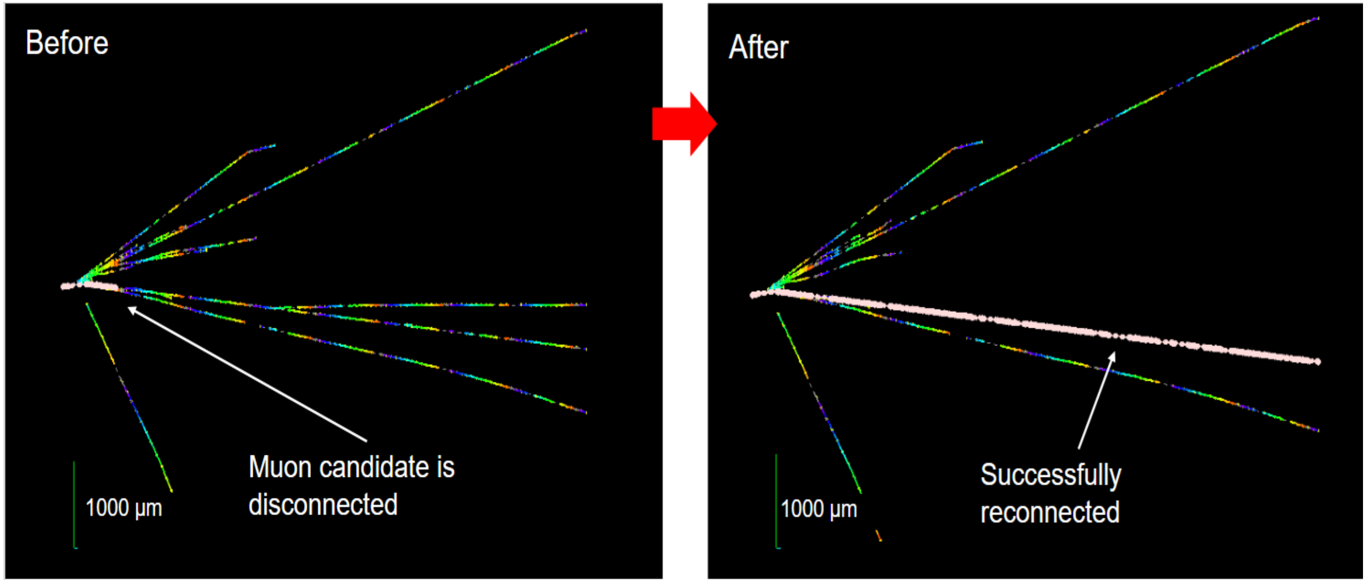
1. ***high track density*** *(especially near the interaction vertex),*
2. ***angular overlaps*** *of nearby tracks,*
3. ***noise hits*** *or* ***grain fog*** *in emulsion films,*
4. ***alignment errors*** *between films,*
5. ***multiple scattering*** *or* ***track fragmentation*** *(especially for low-energy particles).*

Impacts on FASERν Physics:

1. ***vertex reconstruction errors*** *- wrongly connected tracks may shift or fake a neutrino vertex.*
2. ***fake events*** *- could mimic neutrino interactions or decay topologies.*
3. ***efficiency loss*** *- true tracks may be lost or misidentified.*
4. ***systematic uncertainties*** *- affect measurements of neutrino cross sections and flavor identification.*







- the tracks are currently being reconnected manually with event display.
- higher statistics will be analyzed in the future therefore we need to correct these misconnections automatically.
- to address this issue, we started to create a dataset for evaluating track misconnections and also, we are developing an algorithm to automatically correct them.

FASERν data analysis

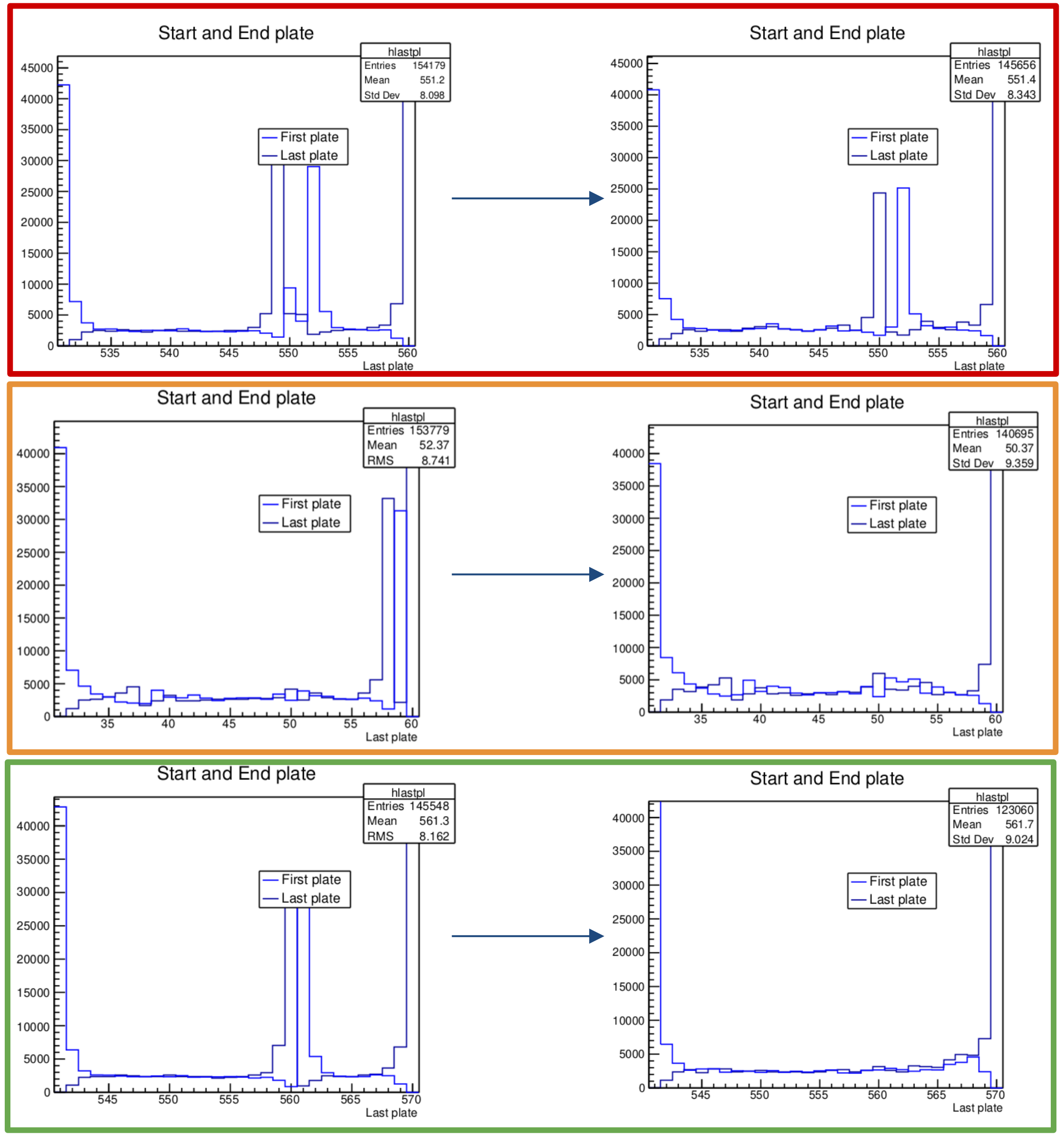
Development of the methodology for checking the quality of data for FASERν detector

- Due to alignment quality during reconstruction, tracks disconnected in some volumes

- No viable solution, but temporary solution was found
  - Search for sub-area with good alignment quality
  - Copy parameter files from good sub-area and use as initial value
  - Reprocess

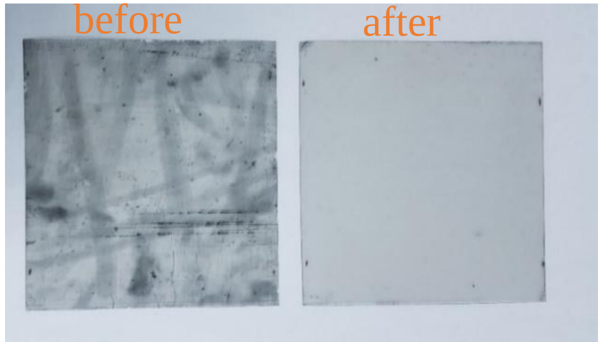
- List of bad sub-areas saved as csv file
  - List is sorted by priority (peak height and number of bad sub-areas in a volume

- After reprocessing:
  - worse/still bad results
  - better results
  - good results



ISS contribution to experimental part for DsTau and FASERν

ISS contributions – silver removal from nuclear emulsion films @ISS Dark Room



- ✓ **DsTau experiment:** From a total of 21 modules received by ISS from the 2023 physics run, 3 modules were cleaned in 2025. In total, 8 modules from 21 have been cleaned so far. (910 films out of 2730 films)
- ✓ **In 2025 ISS received 400 FASERν emulsion films** to do silver removal, 200 films from F251 module and 200 films from F242 module. 100 films from F251 module were cleaned and sent to the University of Nagoya for scanning at HTS2.
- ✓ the process is on-going and on schedule for others DsTau and FASERν modules
- ✓ ***ISS team leader is responsible for this process in both DsTau and FASERν experiments***

ISS contributions – computing infrastructure for reconstruction and alignment

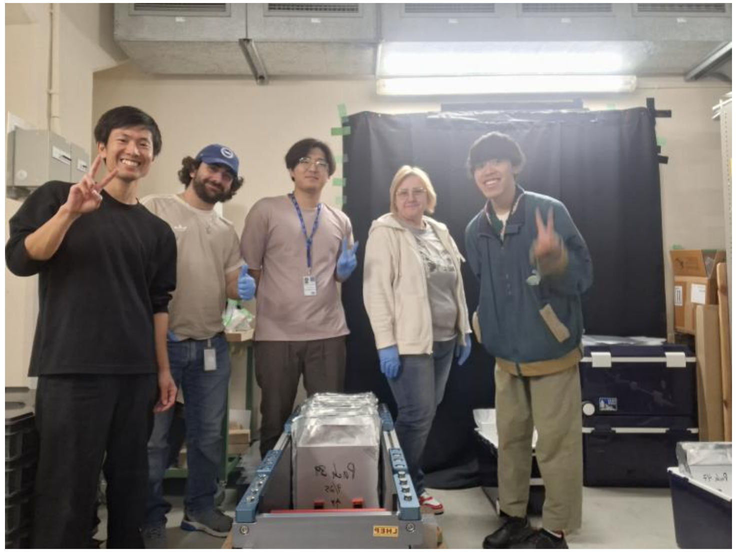
- ✓ 16 out of 30 modules were processed (pilot run) in ISS
- ✓ 6 reprocessed in ISS
- ✓ mass production of GEANT4 files
- ✓ reconstruction of Monte Carlo simulated data (DsTau)

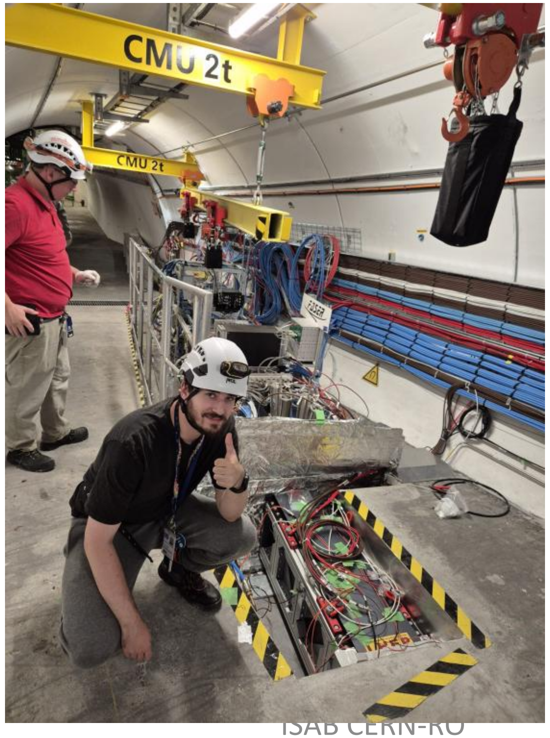
ISS contributions @FASERν detector activity at CERN

- **In 2025, FASERν had 4 irradiated modules - F251, F252, F253, F254**

  Activity 1: *assembly of the detector - 4 campaigns*
  Activity 2: *installation and replacement at LHC tunnel – 4 times*
  Activity 3: *disassembly of the modules and labeling of emulsion film after irradiation - 4 campaigns*
  Activity 4: *emulsion film development - 4 campaigns*

- *ISS group participated in all campaigns this year with one person for each activity:*
  - *expert for **activity 1, 2 and 3***
  - *leader for **activity 4***
  - *one time for **activity 3***





ISS contributions @FASERν detector activity

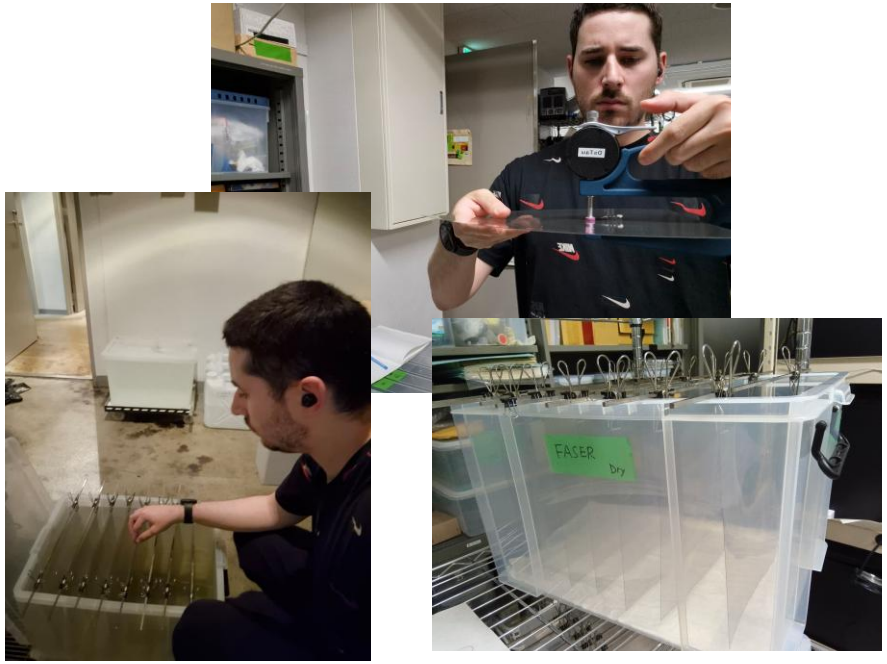
❑ ***The swelling process** in done before scanning and is conducted in 4 steps:*

1. 8-10 films are placed on a grid and then put in a box filled with water for at least one hour

2. after one hour the thickness of each film is measured (must be greater than 500 microns)

3. the films are moved in another box containing 50% water and 50% glycerine for 30-40 minutes

4. then they are put to dry for at least 24 hours, after can be scanned.



❑ ***Scanning process:***

- ✓ for *FASERν emulsion films*, the scanning is done for one shift (6-8 hours) in parallel at HTS1 and HTS2 - one week: 5 shifts
- ✓ for *DsTau shifts*, scanning is done in present at HTS1 (4 hours per shifts, 4 days per week). Now Nagoya University is testing if DsTau films can also be scanned at HTS2

❑ ***ISS participated with 2 persons for 2 months each***

Future plan

Experimental part

- ✓ participation at 2026 FASERν detector activity at CERN (assembly, installation - replacement and development)
- ✓ scanning shifts of the emulsion films for DsTau and FASERν module – 4 months is required at Nagoya University
- ✓ continue cleaning of emulsion films for both experiments @ISS Dark Room

Data analysis

- ✓ Continuation of the study of the events candidates for:
  - production of tau neutrinos in DsTau
  - interaction of electron and muon neutrinos in tungsten in FASERν
- ✓ improving the algorithm for matching Monte Carlo and MC reconstruction events for four charm analysis in the final state
- ✓ application of the momentum estimation software for a more complex kinematic analysis of the DsTau events
- ✓ applying the quality check methodology in DsTau and FASERν physics analysis

Geant4 simulation

- ✓ increase the MC charm production
- ✓ Geant4 software maintenance

Computing part

- ✓ software upgrade for the new requirements in finding interaction vertices with charm production in DsTau

ISS contributions - summary

2025 ISS@DsTau

- ❑ **study of tau neutrino events from $p+W \rightarrow D_s$, $D_s \rightarrow \tau + \nu_\tau$**
  - analyzing of miss-connections between Ds and tau neutrino
  - determining the particle momentum with the software developed in ISS
- ❑ **4 charms production analysis using reconstructed Monte Carlo data**
- ❑ **momentum estimation**
- ❑ **development of the methodology for checking the quality of data for DsTau detector**

2025 ISS@FASERν

- ❑ **search of electron and muon neutrino - W interactions**
- ❑ **study of misconnected tracks for the ν_μ-W interactions**
- ❑ **development of the methodology for checking the quality of data for FASERν detector**

- ➢ **computer and storage infrastructure for DsTau reconstruction and simulations**

ISS contributions - summary

2025 ISS experimental part for DsTau and FASERν

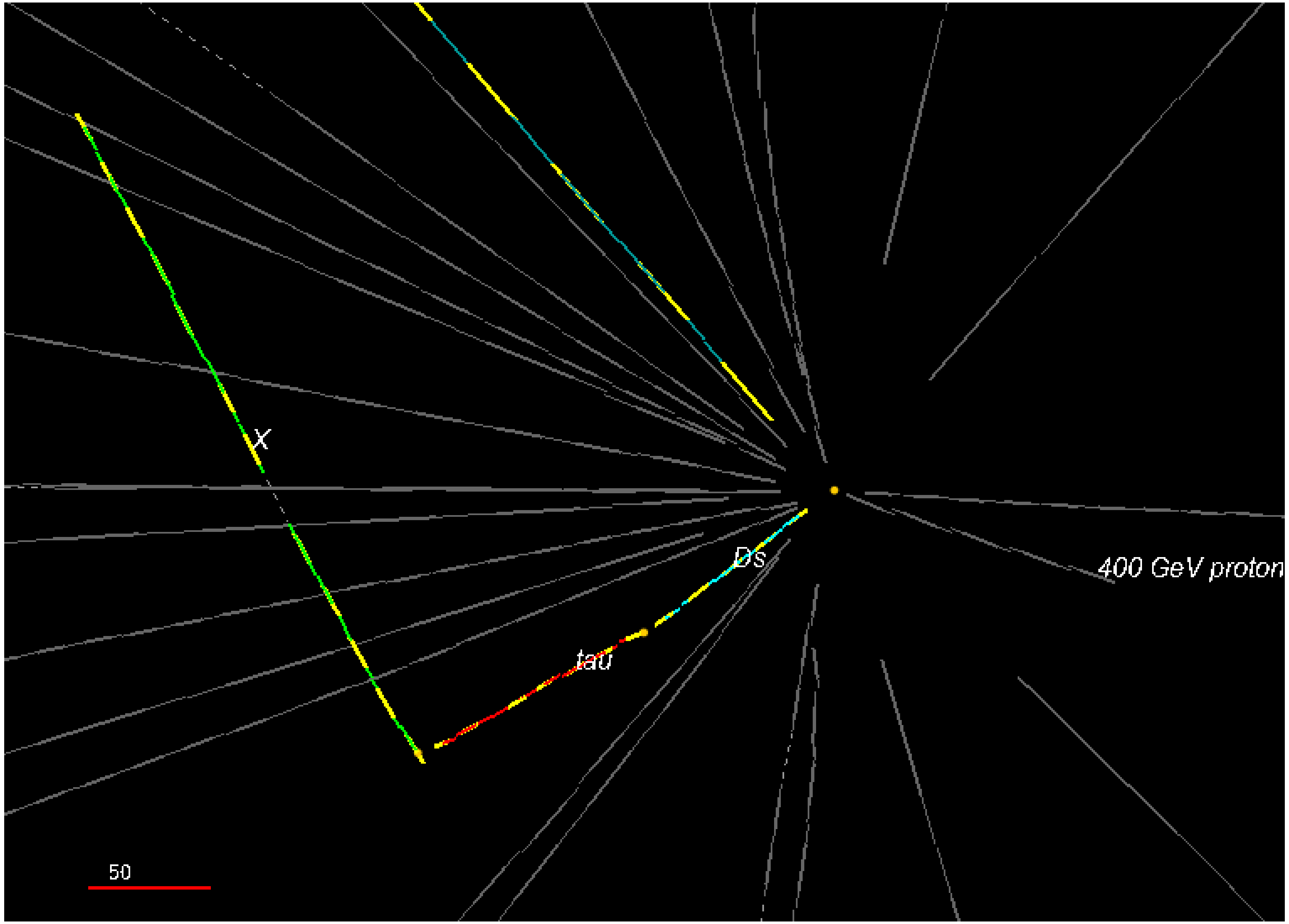
- **the silver removal process for DsTau and FASERν experiments @ISS Dark Room**

- **participation at the 2025 FASERν activities at CERN** (*4 irradiated modules - F251, F252, F253, F254 in 2025)*

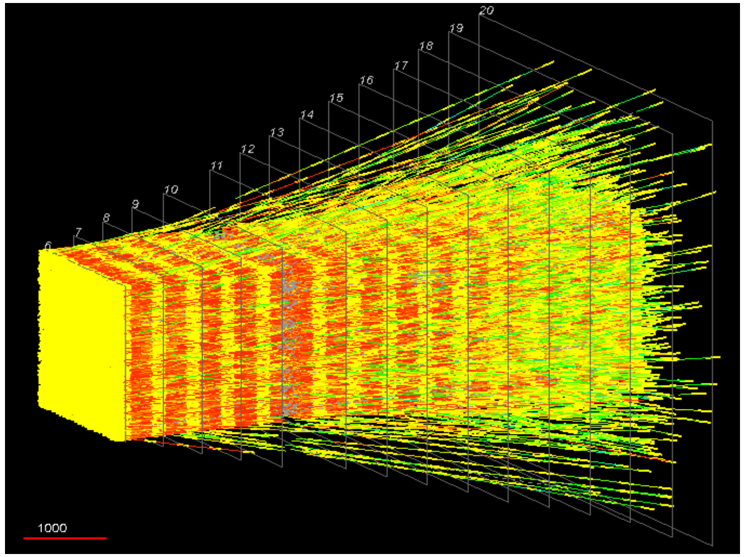
  *ISS participated in***:**
  - 4 campaigns of assembly of the detector – 4 campaigns as experts one person
  - 4 installation and replacement at LHC tunnel – 1 campaign as expert one person
  - 4 campaigns of disassembly of the modules and labeling of emulsion film after irradiation – 3 campaigns as experts one person and one as leader
  - 4 campaigns of emulsion films development – ***ISS led these campaigns***

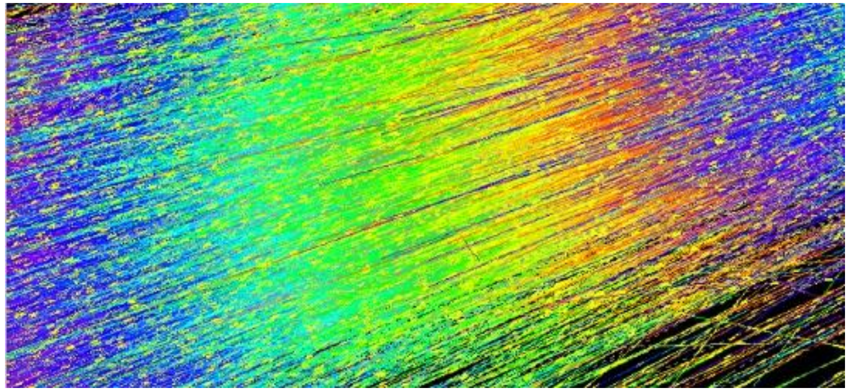
- **participation at the 2025 FASERν activities at Nagoya University (*swelling and scanning of emulsion films*):**
  - 2 persons for 2 mounts each

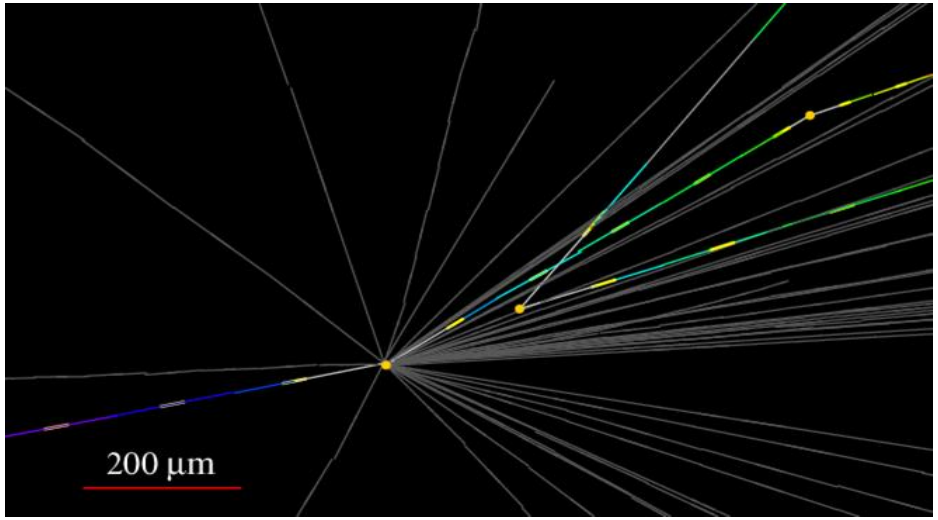
Event displays candidate

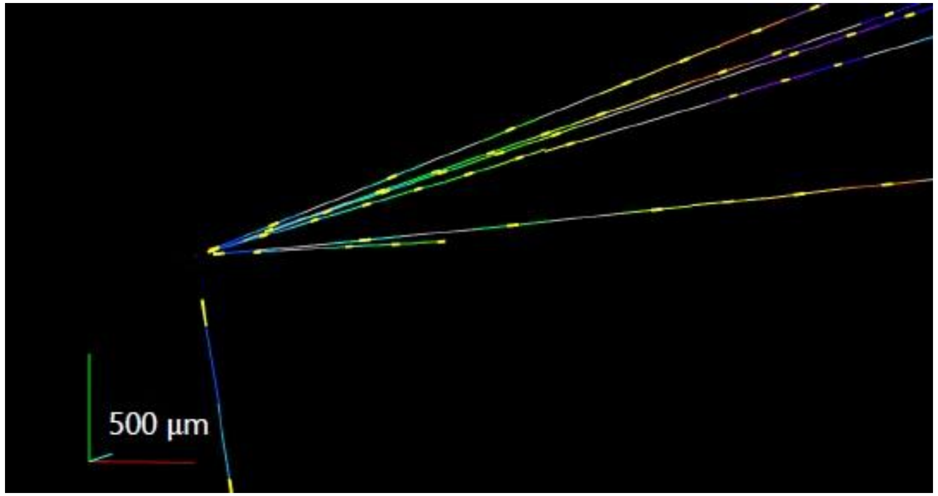


Thank you for your attention









BACKUP SLIDES

Articles, presentations, thesis

Thesis's

- ✓ A master's student (Radu Dobre) who made and defended his master's thesis on the topic of the DsTau experiment (Detection and study of tau lepton decays in neutrino experiments using nuclear emulsions), defended at Faculty of Physics, University of Bucharest, June 28, 2021
- ✓ Radu Dobre is PhD student beginning with September 2021 studying charm and top production in DsTau. He is currently member of DsTau collaboration and also employed in ISS
- ✓ ***Tudor-Andrei Diac*** - bachelor student at the Faculty of Physics, Computer Physics specialization. Defended at the Faculty of Physics, University of Bucharest his bachelor theses in July 2024 with the title "Study of charm mesons and tau neutrinos production in DsTau(NA65) experiment".
- ✓ ***Iulian Dănciulescu*** - bachelor student at the Faculty of Physics, Computer Physics specialization. Defended at the Faculty of Physics, University of Bucharest his bachelor theses in July 2024 with the title "Study of the production and interactions of particles with charm at the DsTau (NA65) experiment".

Outreach

- ✓ We were involved in education and outreach through two programs called "Different School" and "Green Week", where students of different ages came to visit the Nuclear Emulsion laboratory from the institute, and also the NA65/FASER exhibition room in the DUROCERN outreach center. During these visits, the students found out about the nuclear emulsion films, their working principle, their uses, along with the data taking steps in two CERN experiments: NA65 and FASER. They were also able to look at an interaction in a nuclear emulsion film under a microscope

Articles 2025	Papers presented at international and national conferences
1. Shining light on the dark sector: search for axion-like particles and other new physics in photonic final states with FASER, Roshan Mammen Abraham, Xiaocong Ai, ..., Dobre Radu, Firu Elena, Titi Preda, ..., JOURNAL OF HIGH ENERGY PHYSICS, 199, JAN 31 2025, DOI10.1007/JHEP01(2025)199 2. Study of proton-nucleus interactions in the DsTau/NA65 experiment at the CERN-SPS, Aoki S., ..., Dobre Radu, Firu Elena, Titi Preda, ..., EUROPEAN PHYSICAL JOURNAL C, 230, MAR 5 2025, DOI10.1140/epjc/s10052-025-13928-1 3. First Measurement of the Muon Neutrino Interaction Cross Section and Flux as a Function of Energy at the LHC with FASER, Roshan Mammen Abraham, Xiaocong Ai, ..., Dobre Radu, Firu Elena, Titi Preda, ..., PHYSICAL REVIEW LETTERS, 211801, MAY 27 2025, DOI10.1103/PhysRevLett.134.211801 ✓ There were also two round tables on 5 March and 30 September 2025 in which each members presented their activity in the last 6 months ✓ Also, participation to the meetings of the Emulsion Facility Task Force group, where the team leader who is responsible for the development part of the nuclear emulsion films for DsTau ✓ Presentation in DsTau, FASER GENERAL and FASERν meetings	***Presentation at international conferences in 2025:*** **1. FASERnu operation,** Elena Firu, on behalf of FASERnu team, FASER Collaboration Meeting #7, 1 -3 September, University of Liverpool. **2. DsTAU EXPERIMENT: STUDY OF TAU NEUTRINO PRODUCTION**, Alina-Tania NEAGU (on behalf of the DsTau (NA65) collaboration), International Balkan Workshop on Applied Physics and Materials Science - IBWAP, July 2025, Constanța, Romania, July 9–12, 2025 3. **Momentum estimation of charged particles registered in the DsTau (NA65) nuclear emulsion detector**, Radu DOBRE (on behalf of the DsTau (NA65) collaboration), International Balkan Workshop on Applied Physics and Materials Science - IBWAP, July 2025, Constanța, Romania, July 9–12, 2025 ***Presentation at national conferences in 2025:*** **1. Momentum estimation of charged particles registered in the DsTau (NA65) nuclear emulsion detector**, Radu DOBRE (on behalf of the DsTau (NA65) collaboration), Annual Conference of the Doctoral School of Physics, October 10-11 2025, Faculty of Physics, University of Bucharest

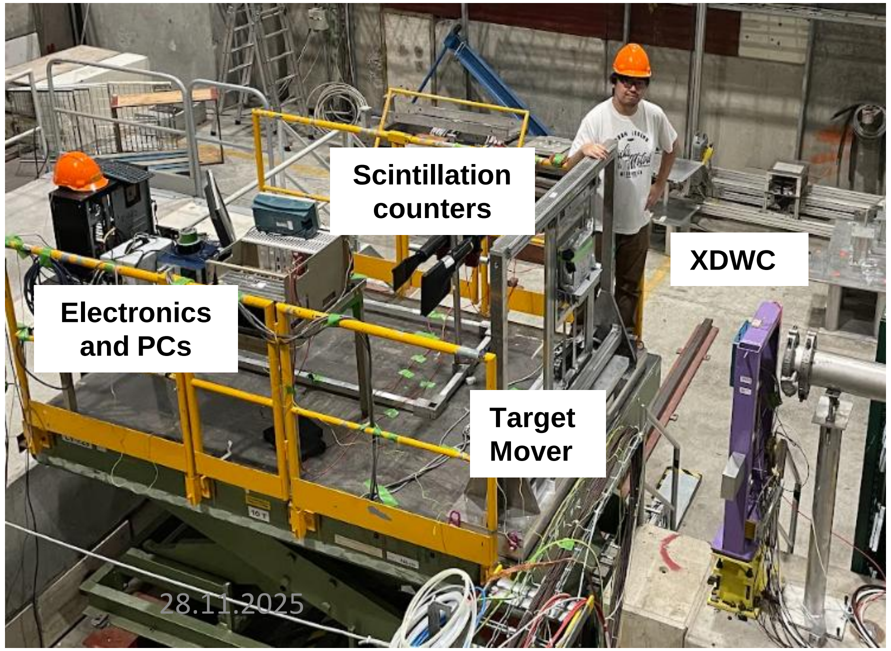
DsTau setup at SPS

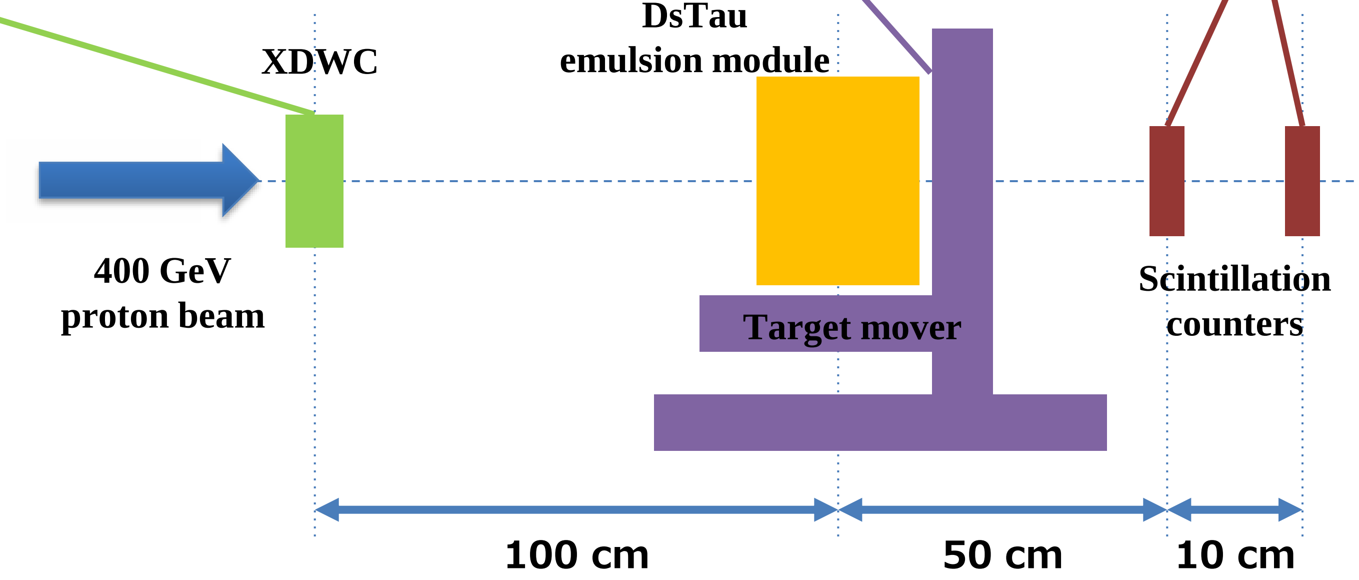
10.1088/1748-0221/18/10/P10008

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

Scintillation counters:
Measure the beam intensity

XDWC:
Measure the beam profile





DsTau: timeline

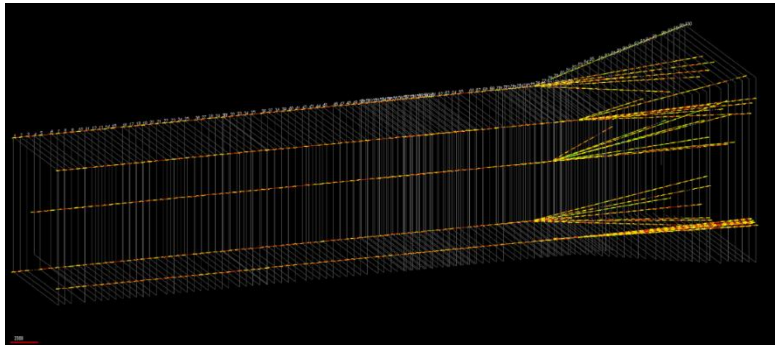
Experiment Proposal

Study of tau-neutrino production at the CERN SPS

S. Aoki[1], A. Ariga[2], T. Ariga[2,3,*], E. Firu[4], T. Fukuda[5], Y. Gornushkin[6], A. M. Guler[7], M. Haiduc[4], K. Kodama[8], M. A. Korkmaz[7], U. Kose[9], M. Nakamura[5], T. Nakano[5], A. T. Neagu[4], H. Rokujo[5], O. Sato[5], S. Vasina[6], M. Vladymyrov[2], M. Yoshimoto[10]

[1]Kobe University, Kobe, Japan
[2]AEC/LHEP, University of Bern, Bern, Switzerland
[3]Kyushu University, Fukuoka, Japan
[4]Institute of Space Science, Bucharest, Romania
[5]Nagoya University, Nagoya, Japan

29 Aug 2017



	Amount of emulsion films	Number of emulsion films	Dimension of emulsion films	Number of modules	W/Mo target	Beam time
2018 pilot run	*50 m^2*	*3.900*	*12.5 x 10 cm*	*30*	*30 modules*	*1 week*
2021 run	*110 m^2*	*2.210*	*25 x 20 cm*	*17*	*12/5 modules*	*2 weeks*
2022 run	*110 m^2*	*2.210*	*25 x 20 cm*	*17*	*9/8 modules*	*1 week*
2023 run	*270 m^2*	*5.200*	*25 x 20 cm*	*40*	*20/20 modules*	*2 weeks*
		200	*12.5 x 5 cm*	*2 momentum modules*	*2/0 modules (used for validation of the particle momentum estimation method)*	

Test beam 2016
- test of detector structure

LOI in 2016

Test beam 2017
- improved detector structure
- refine exposure scheme

TP in 2017

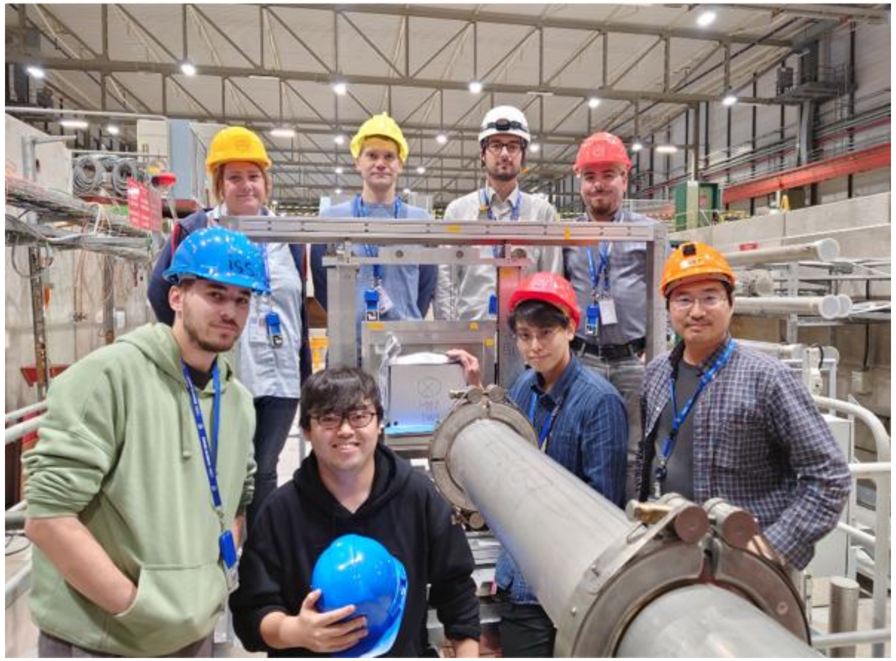
Pilot run 2018

Approved as NA65 in June 2019

Physics run in 2021

Physics run in 2022

Physics run in 2023



Detector module assembling of 2023 physics run

- Detector module is assembled just before the beam time
  - to avoid occupying background, ex. cosmic ray

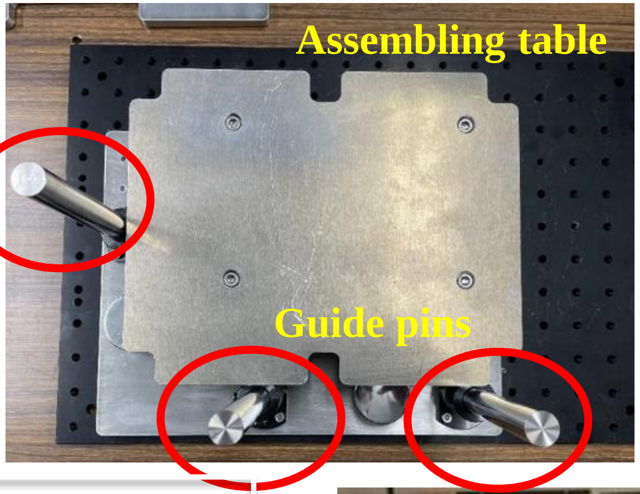
✓ the number of detector modules – ***40***
  - *20 modules with W target*
  - *20 modules with Mo target*

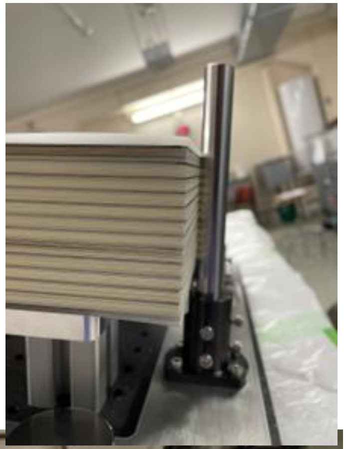
✓ total nuclear emulsion films area 270 m^2 ($\simeq$ 5200 films)

✓ 6 people participated, of which 2 from ISS all period

✓ Assembly time was 2 hours/module

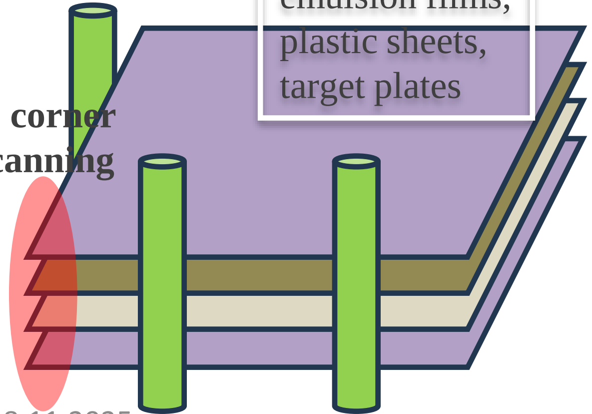
Step 1
Piling up films precisely with an assembling table





Components:
emulsion films,
plastic sheets,
target plates

Reference corner for film scanning



Guide pins

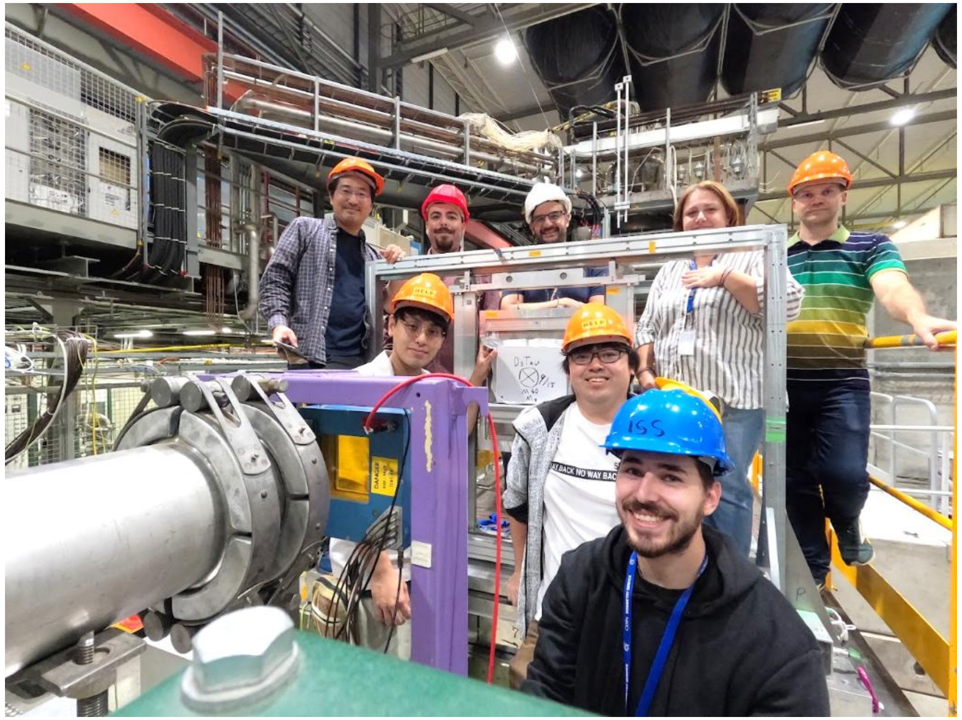
Step 2
Vacuum packing for fixing the relative position of the films

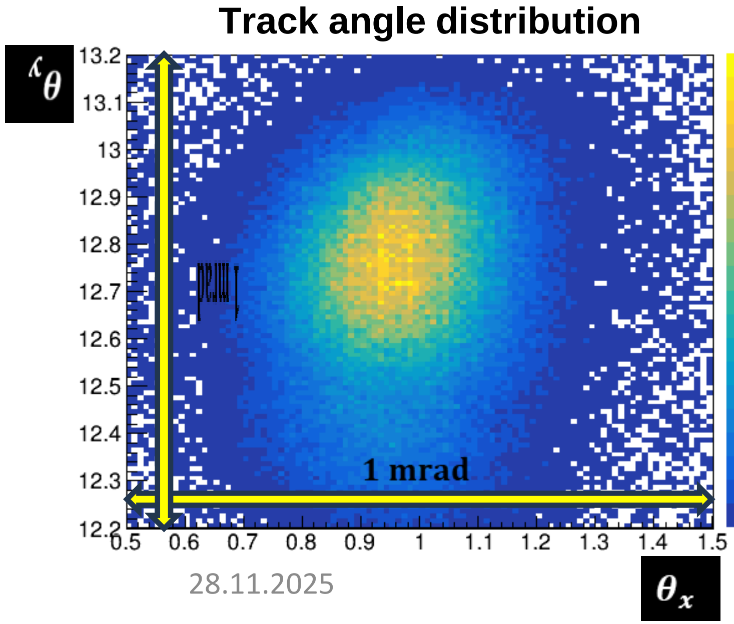
Data taking and performance of 2023 physics run

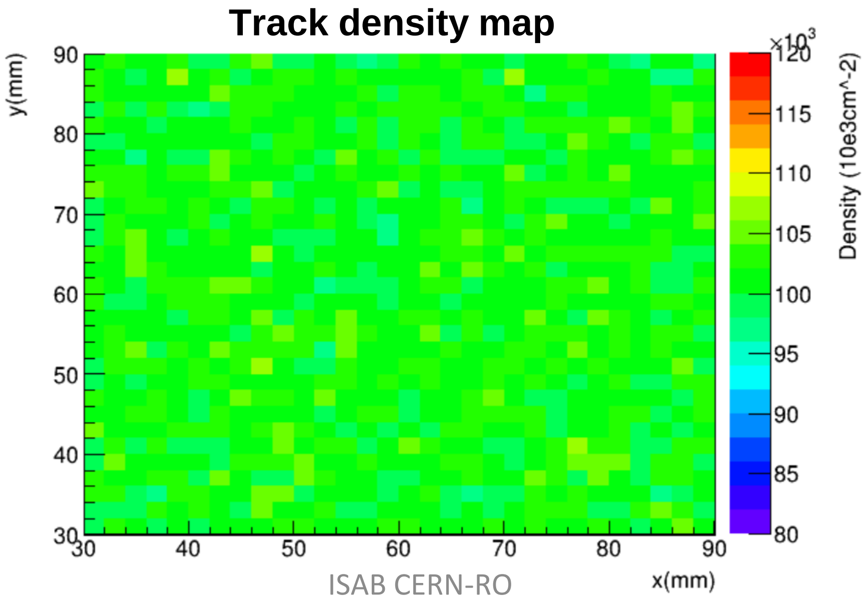
- ***Final physics data taking***
  - 2 weeks beam time in Sep 2023
  - 24-hour shift, 70% beam usage
  - 40 emulsion modules - 2×10^9 protons of target
  - data taking at 100 kHz
  - from ISS 2 people participated all period, one people 2 weeks

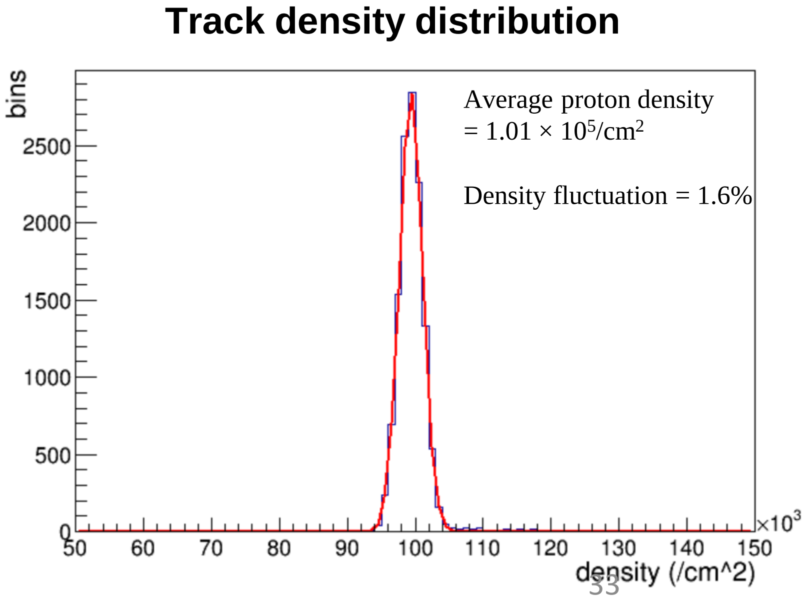
- ***We succeeded to take the best quality data!***

- ***Data taking is completed!***





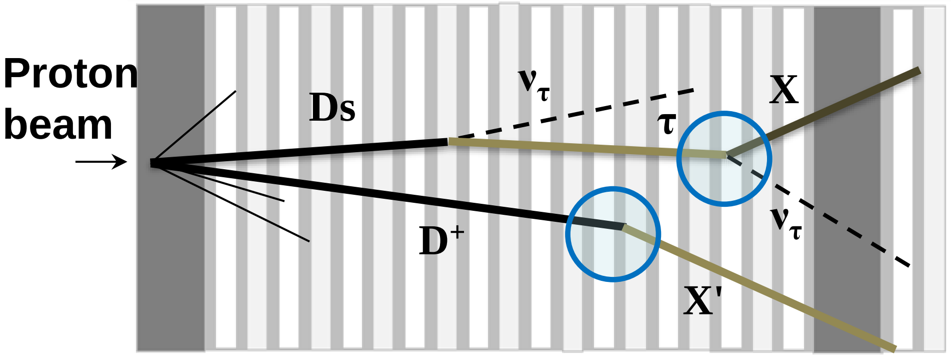




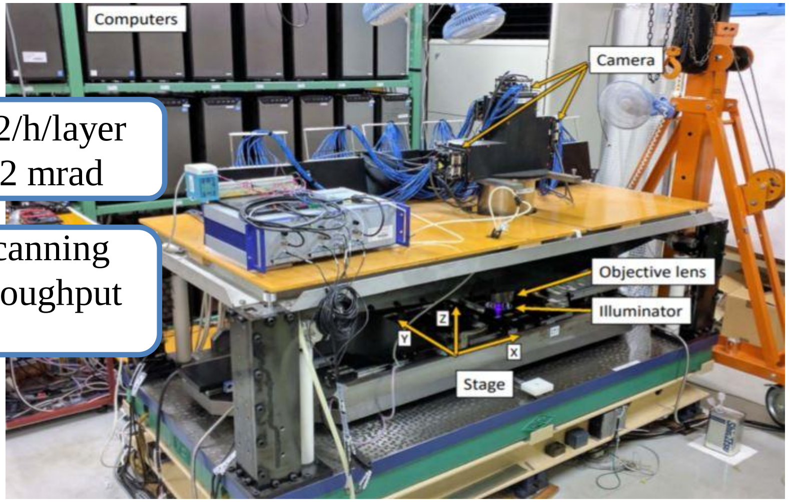
Dstau data acquisition

Step 1

- Full area scanning by a fast scanning system
- It selects decays with $\Delta\theta > 20$ mrad



Hyper Track Selector (HTS)

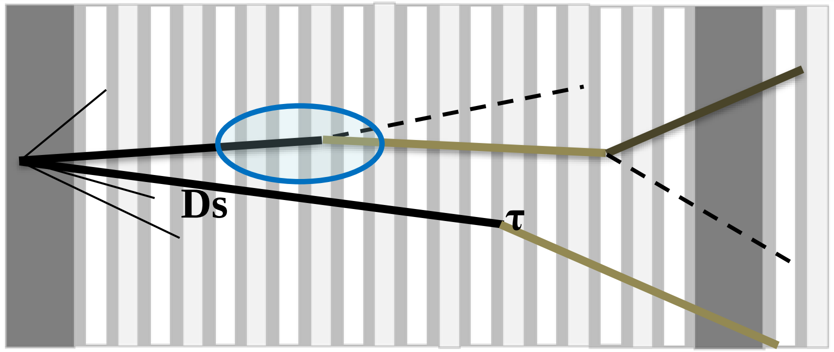


Scanning speed 0.5 m2/h/layer
Angular resolution ~2 mrad

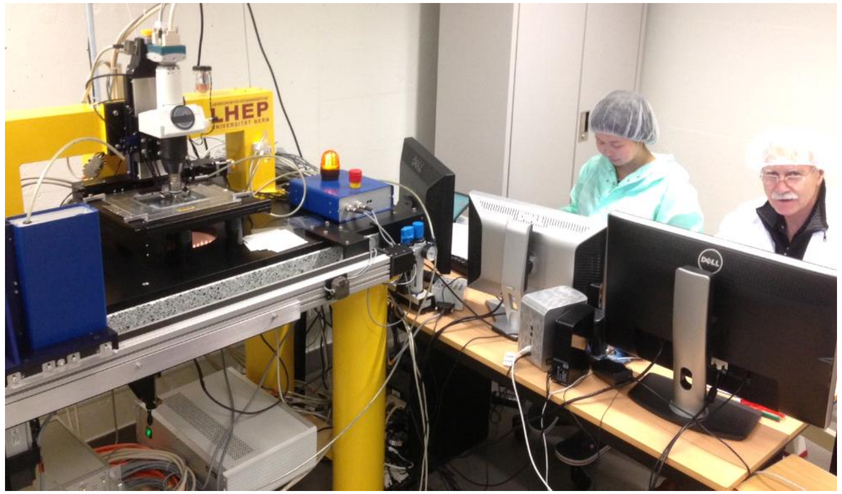
100x faster than the scanning system of OPERA (throughput 36 GB/s)

Step 2

- Precision measurement to detect $D_s \to \tau$ decay (a few mrad)



Dedicated high-precision systems

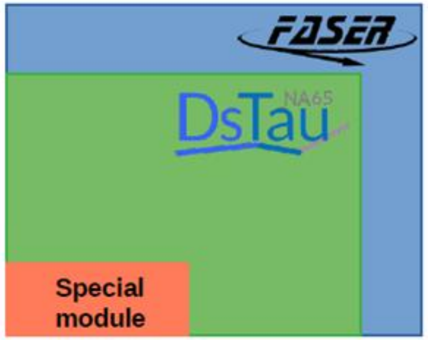


Angular resolution ~0.3 mrad

Validating the momentum estimation algorithm

ISS was responsible for preparing special modules during the DsTau 2023 physics run, which are used to validate the particle momentum estimation algorithm

1. **Film cutting**
- Nuclear emulsion films provided by DsTau/FASERnu experiments were cut for the special modules (12.5 cm x 5 cm)



2. **Module assembly**
- Same structure as for DsTau modules
- 2 modules:
  - #1: 130 emulsion films, 13 tungsten plates
  - #2: 70 emulsion films: 7 tungsten plates

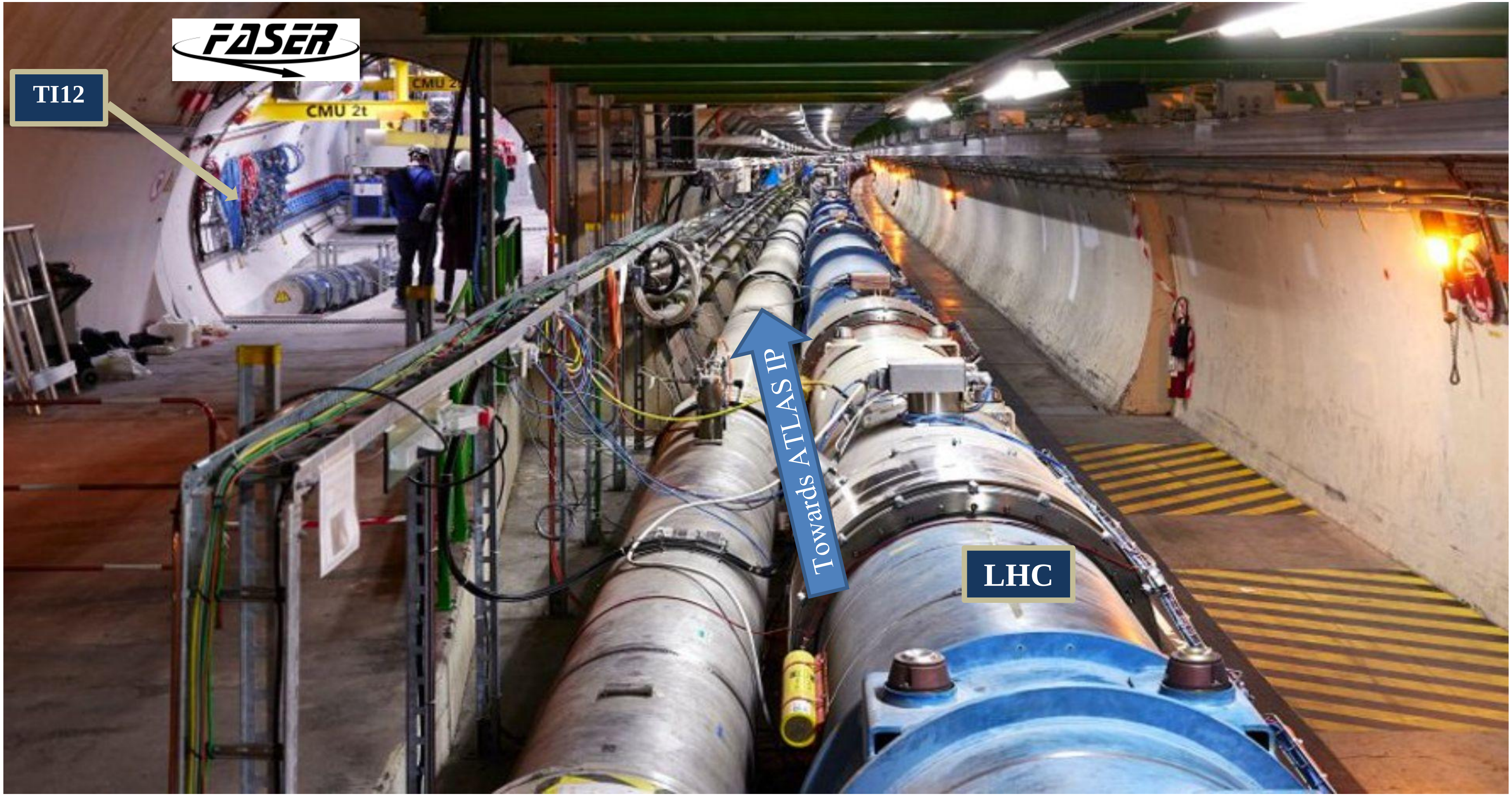

3. **Module exposure**
- Modules exposed with muon and hadron beams of different energies
- #1: 50 & 300 GeV muons și 20 & 30 GeV hadrons
- #2: 20, 30 & 350 GeV hadrons



4. **Film development**
- Films were developed during the DsTau development campaign
- 200 films developed in a day

5. **Scanning and reconstruction**
- The film scanning was done at Nagoya University
- The track data was reconstrcuted and preliminary analysis was conducted

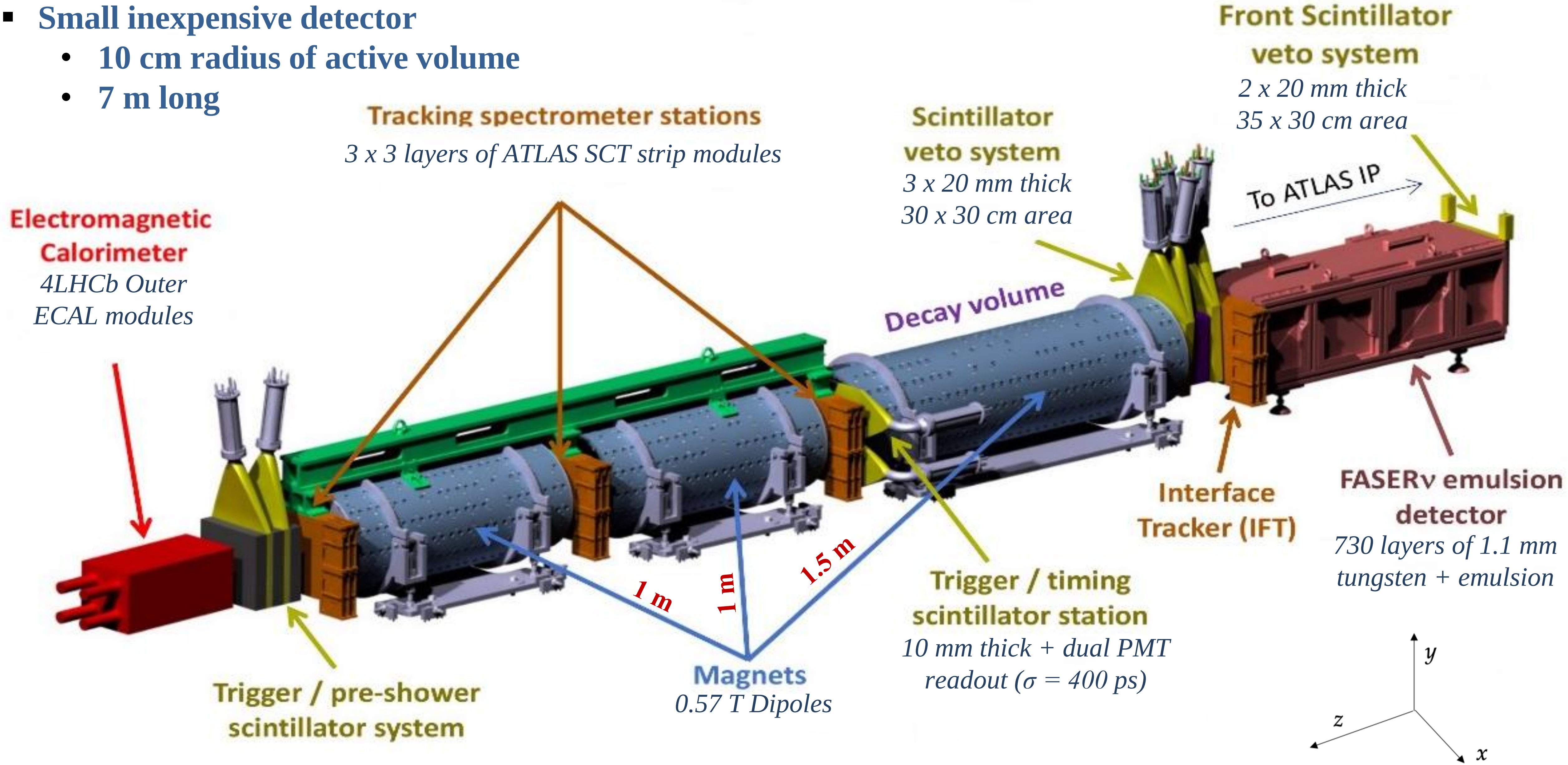
FASER experiment



FASER detector

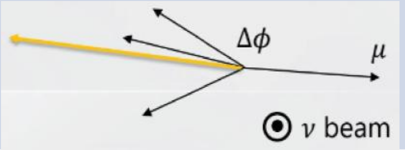
JINST 19 (2024) P05066

- **Small inexpensive detector**
  - **10 cm radius of active volume**
  - **7 m long**

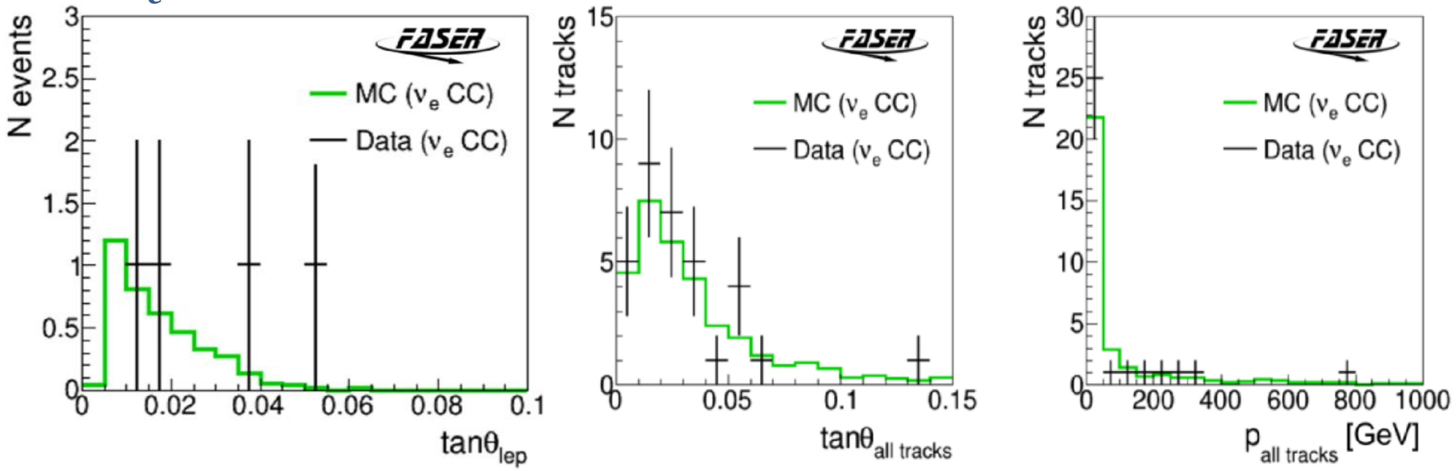


First detection of ν_e and ν_μ with FASERν emulsion detector

Phys. Rev. Lett. 133, 021802

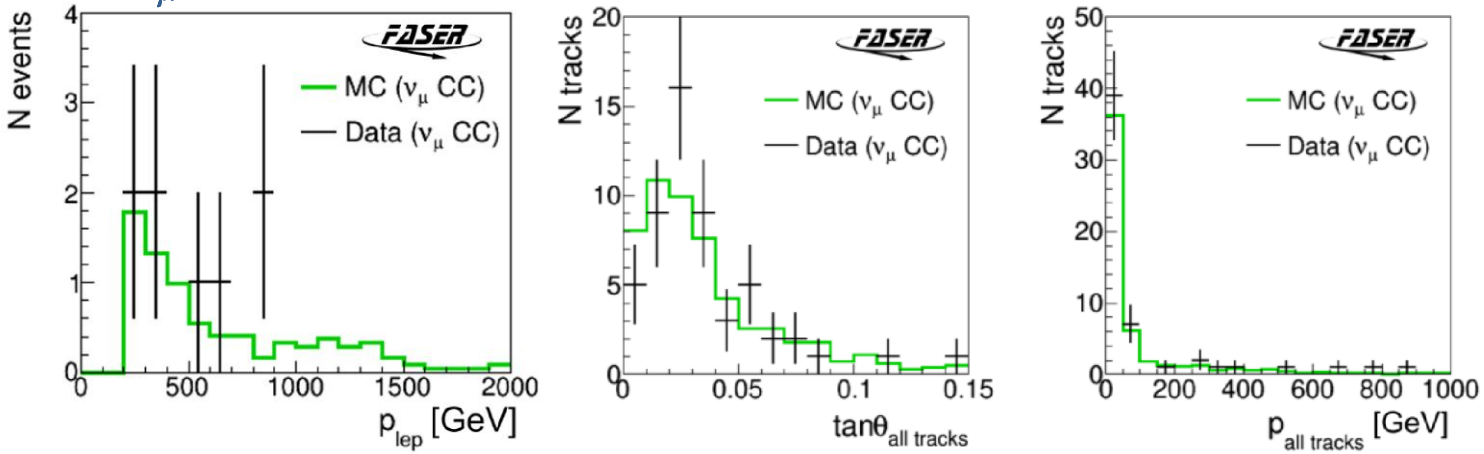
Selection criteria	
Vertex reconstruction	$N_{track} \geq 5$
	N_{track} ($\tan\theta \leq 0.1$) ≥ 3 (suppress the neutral-hadron background)
Lepton requirements	E_e or p_μ > 200 GeV
	$\tan\theta_e$ or $\tan\theta_\mu$ > 0.005
Back to back topology	$\Delta\phi$>90° 

ν_e

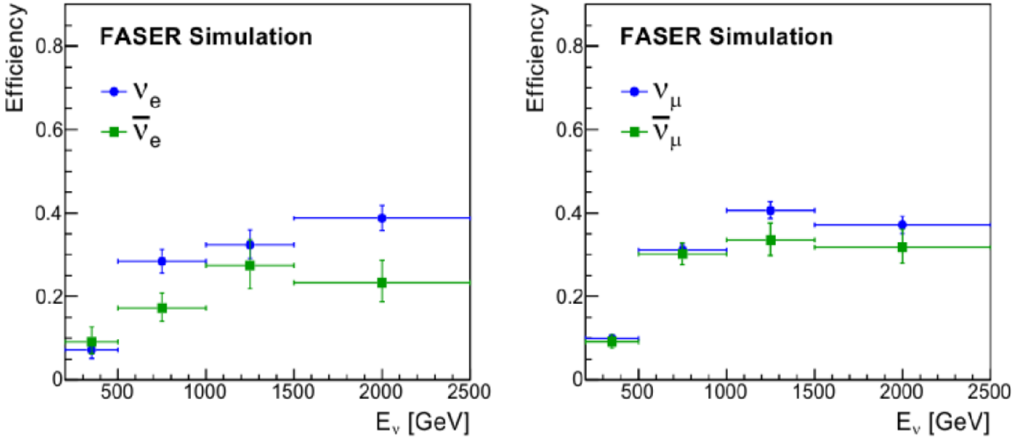


MC normalized to number of observed events

ν_μ



- **the efficiency of $\bar{\nu}$ events that pass the vertex selection is slightly lower than ν events**



- *E_e – from counting track segments at EM shower maximum (resolution: ~25% at 200 GeV) - associated high-energy EM shower*
- *p_μ – from track spread due to multiple Coulomb scattering (resolution: ~30% at 200 GeV/c, validated with test beam)*

- **kinematics of observed ν interactions are in good agreement with MC**
- **ν interactions at TeV range**

ν_e and ν_μ cross section measurements at TeV energies

Phys. Rev. Lett. 133, 021802

- **First observation of ν_e at the LHC**
- **First neutrino cross section measurement in the TeV range**
- Large uncertainty from neutrino flux

		1.1 – 3.3	**4**	5.2 σ
		6.5 – 12.4	**8**	5.7 σ