NA65 / DsTau experiment: Tau neutrino production study at the CERN SPS

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for the NA65 Collaboration

NA65/DsTau paper:
DOI:10.1007/JHEP01(2020)033
NA65/ DsTau web site:
https://na65.web.cern.ch/

NA65 (DsTau) experiment

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Goals:

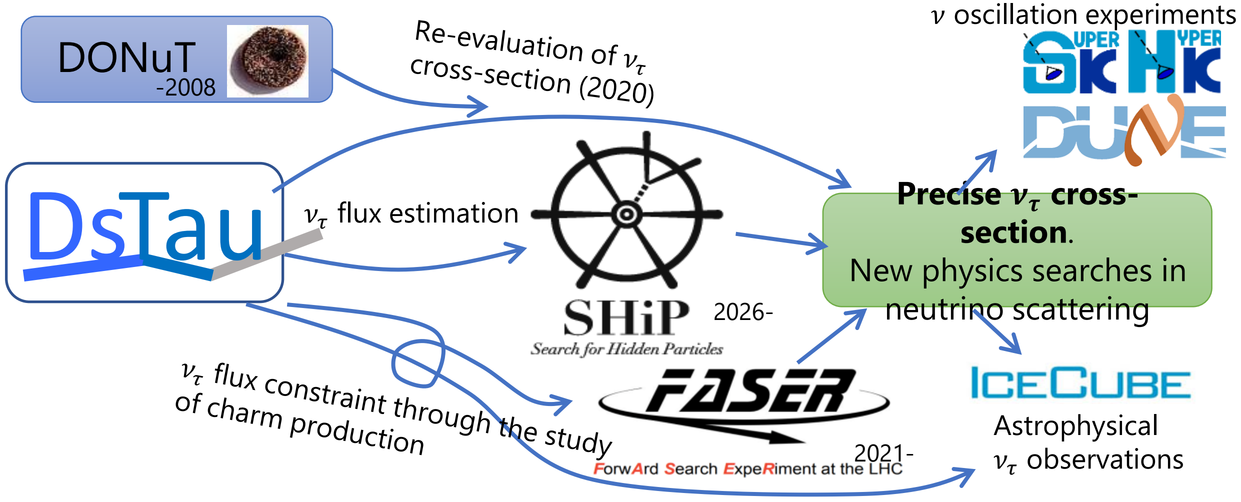
- Study of ν_τ production for future tau neutrino experiments.
  - First measurement of D_s **double differential production cross section**
  - Reduce uncertainty of ν_τ flux from >50% to 10%

    → Fundamental input for future ν_τ experiment: SHiP, and indirectly FASER
- Forward charm physics, intrinsic charm component in proton.

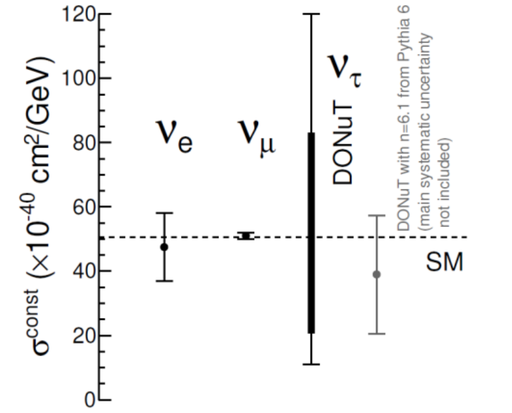
D_s differential production cross section

Phenomenological formula

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



$\nu, \bar{\nu}$ averaged energy independent cross section



NA65 (DsTau) experiment

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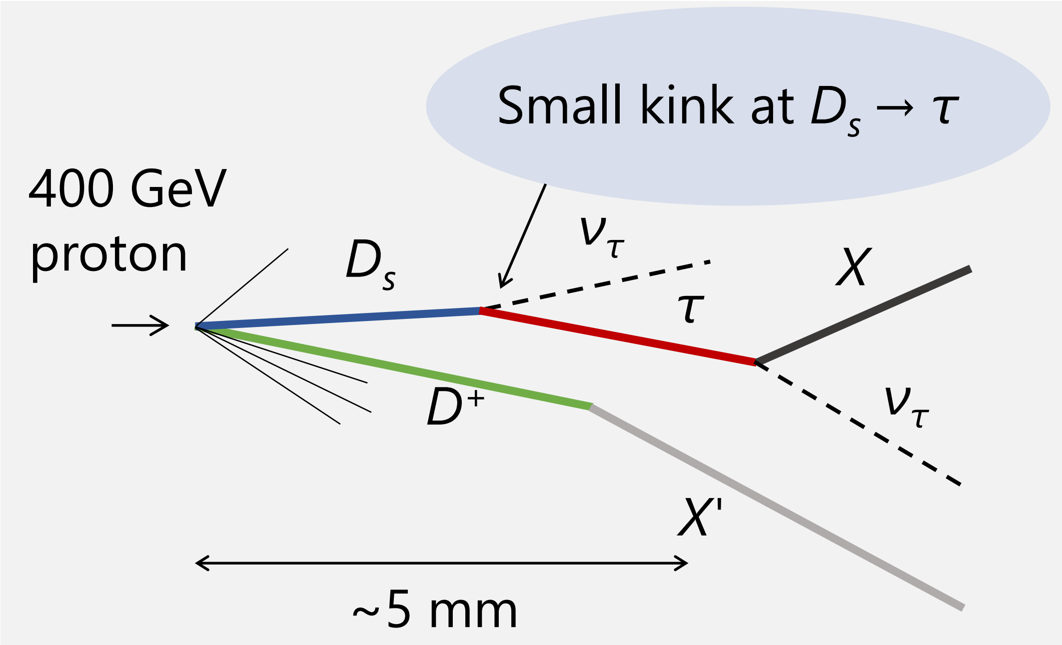
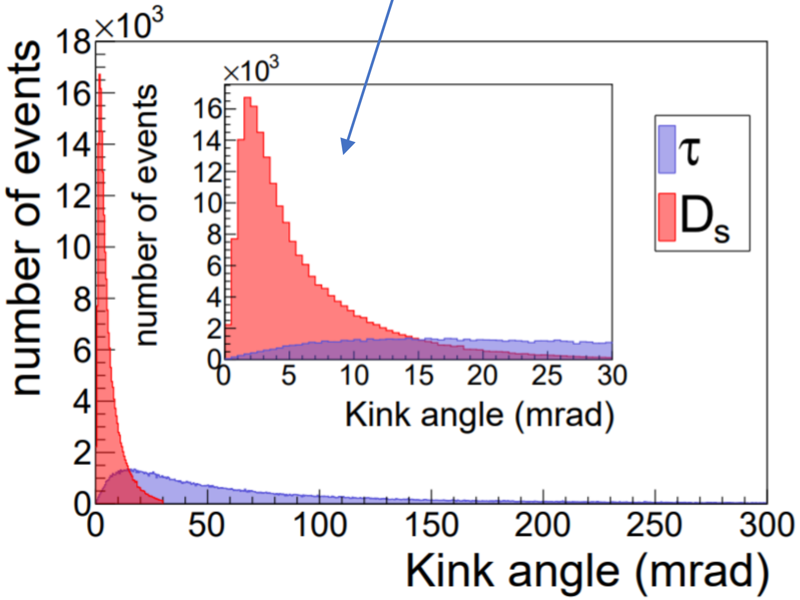
- **Principle of the experiment**
  - Detection of "**double-kink + charm decay**" topology within 10 mm.
  - 4.6×10^9 protons, $\mathbf{2.3 \times 10^8}$ proton interactions in target,
    10^5 charm pairs,
    $1000\ D_s \to \tau \to X$ detected events.



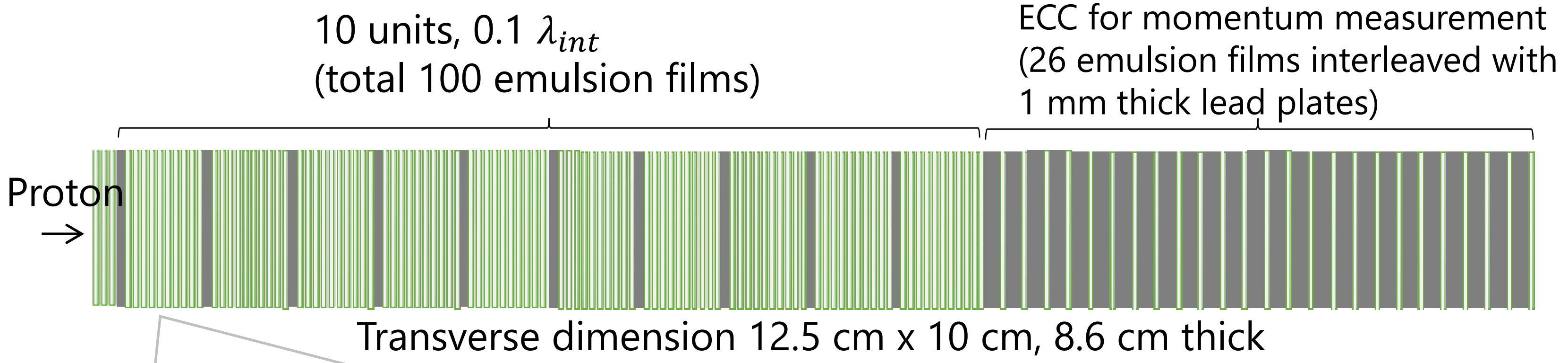
Kink angle of $D_s \to \tau$ decays
Average 7 mrad

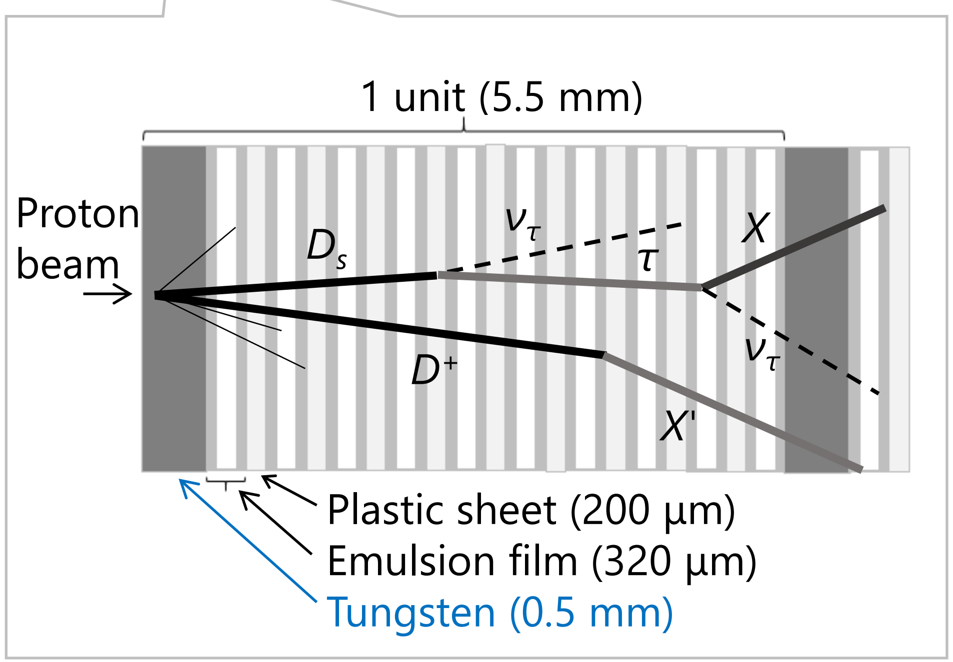


Emulsion based detector structure for $D_s \rightarrow \tau \rightarrow X$ measurement

NA65/DsTau paper:
DOI:10.1007/JHEP01(2020)033

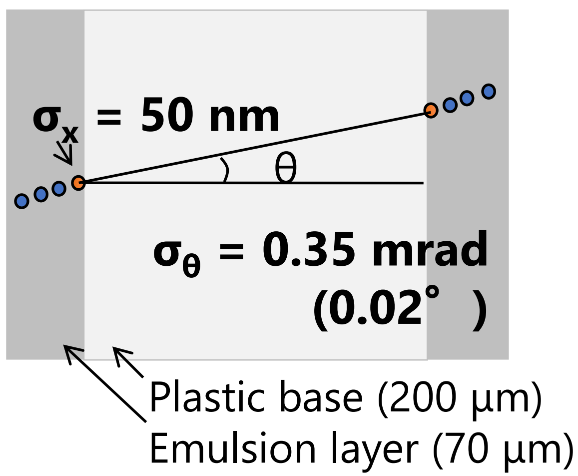
A total of 370 modules to be analyzed

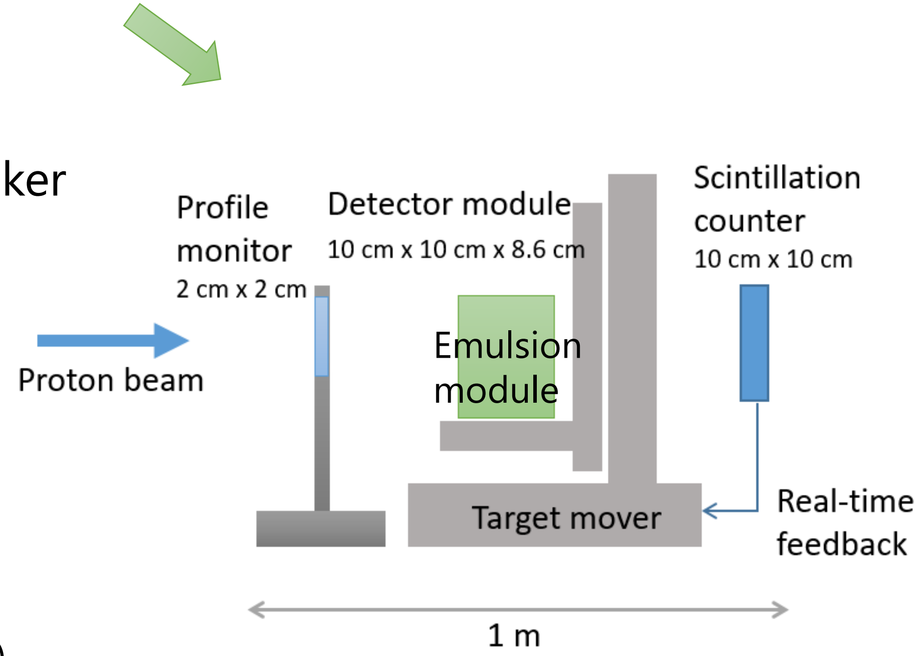




Single emulsion film

High angular resolution tracker





NA65 (DsTau) milestones

LoI in 2016

TP in 2017

Approved as NA65 in June 2019

Test beam 2016

- Test of detector structure

Test beam 2017

- Improved detector structure
- Refine exposure scheme

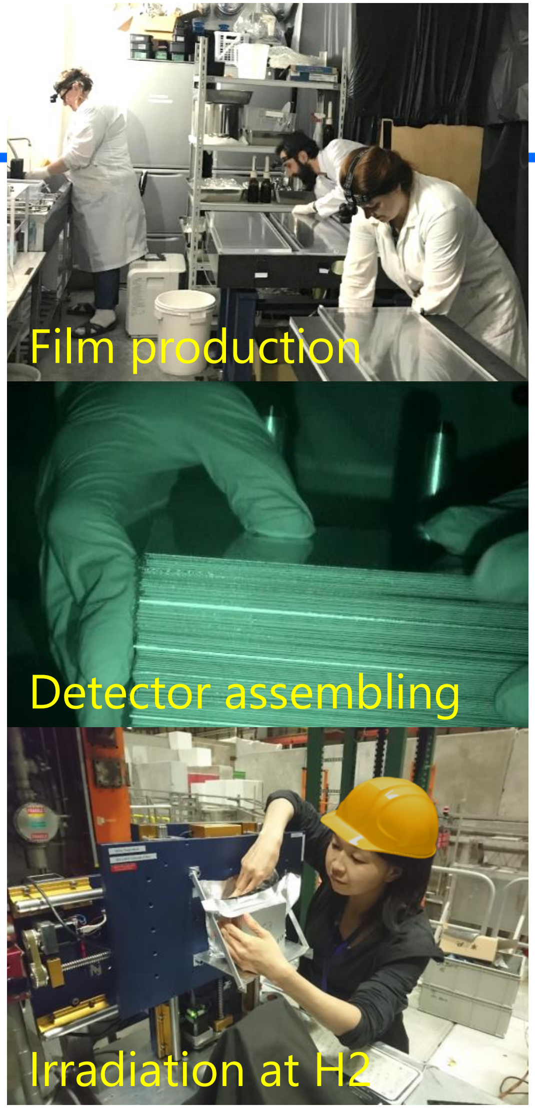
Pilot run 2018

- 1/10 of the full-scale experiment with tungsten target
- 30 % uncertainty on ν_τ flux
- Revise the DONUT result
- Charm physics

We are here

Physics run 2021-2022

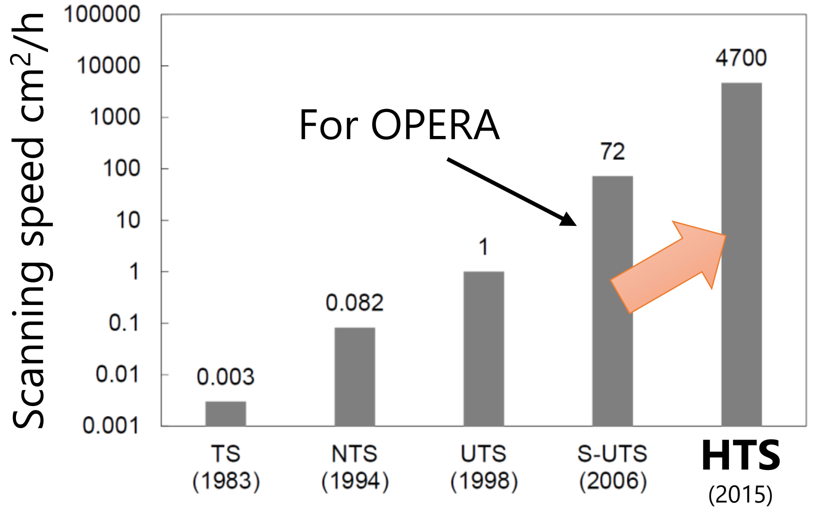
- Full scale experiment with tungsten and molybdenum targets
- Aiming at 1000 $D_s \rightarrow \tau \rightarrow X$ events
- 10 % uncertainty on ν_τ flux



Fast readout by the HTS

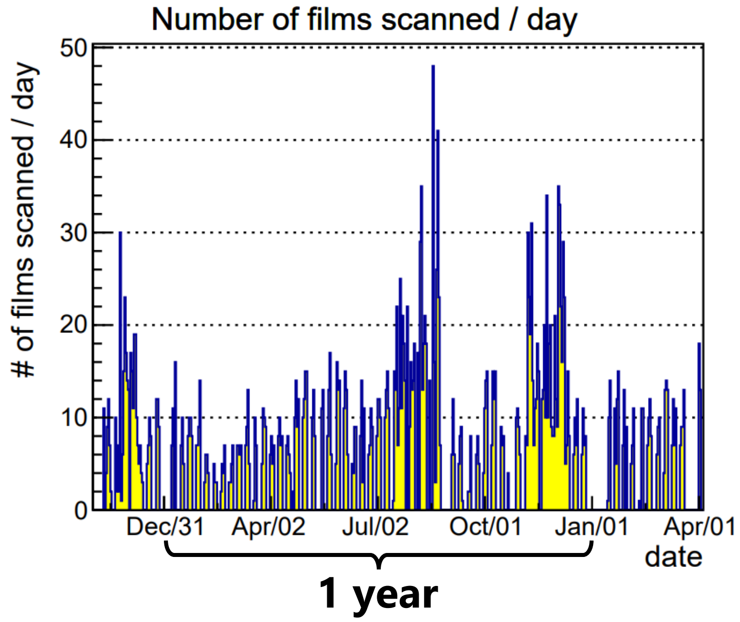
- HTS: 70x faster than the scanning system of OPERA
  - Area scanning speed of 0.5 m^2/h
  - Effective throughput 13 GB/s for microscope photo
- **All** pilot run films was already scanned.

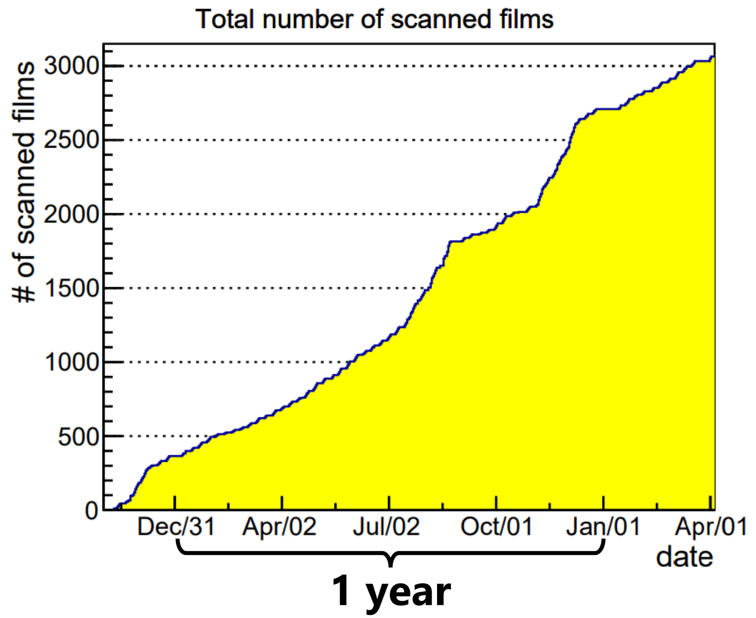
except for a trouble films



Readout system in Nagoya Univ.

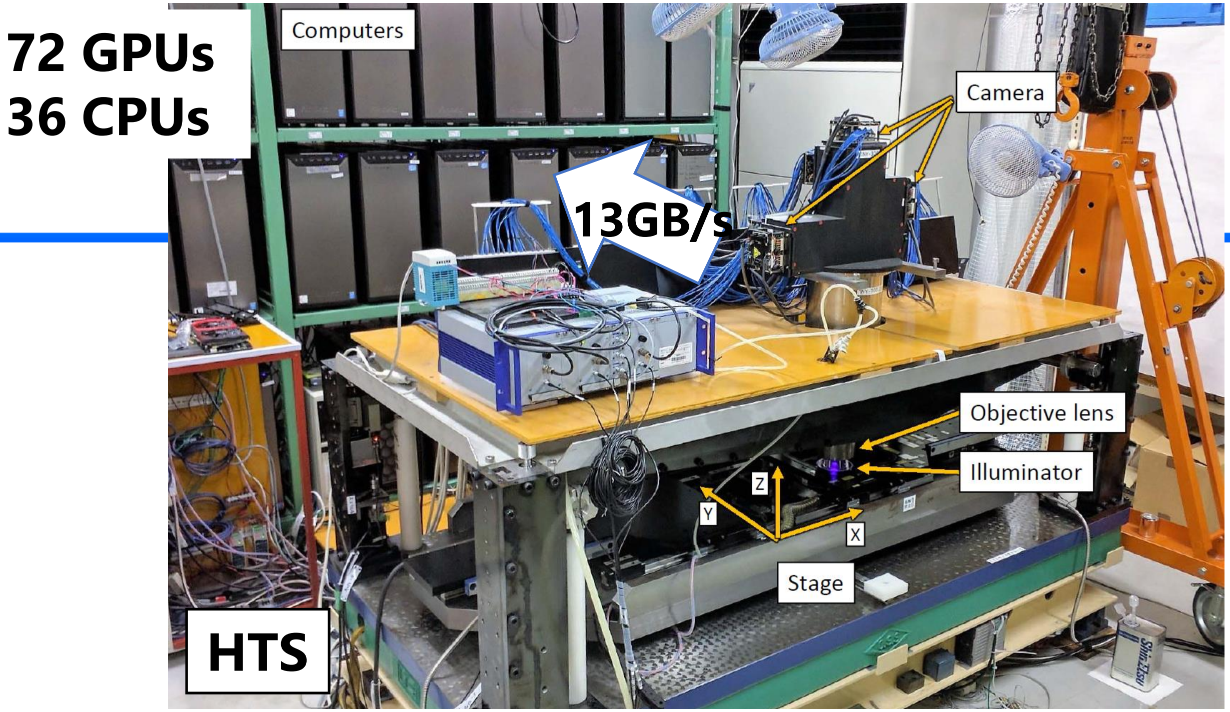
Scanning progress



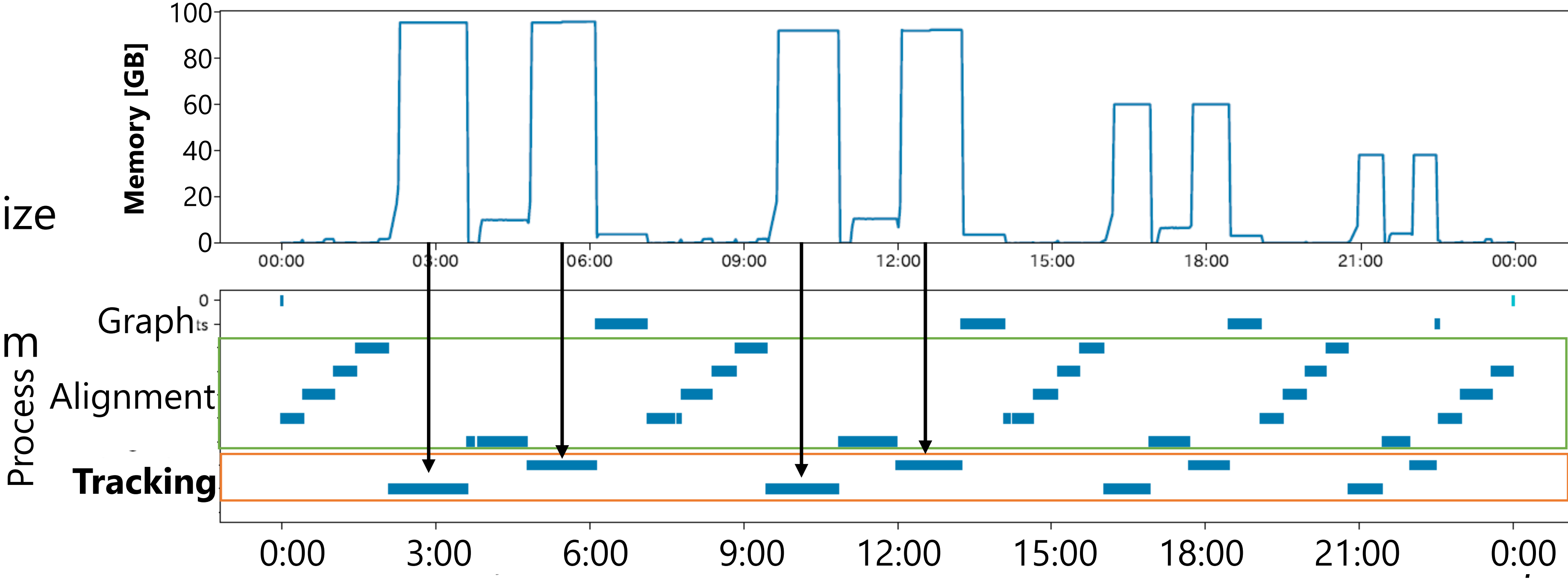


Data processing

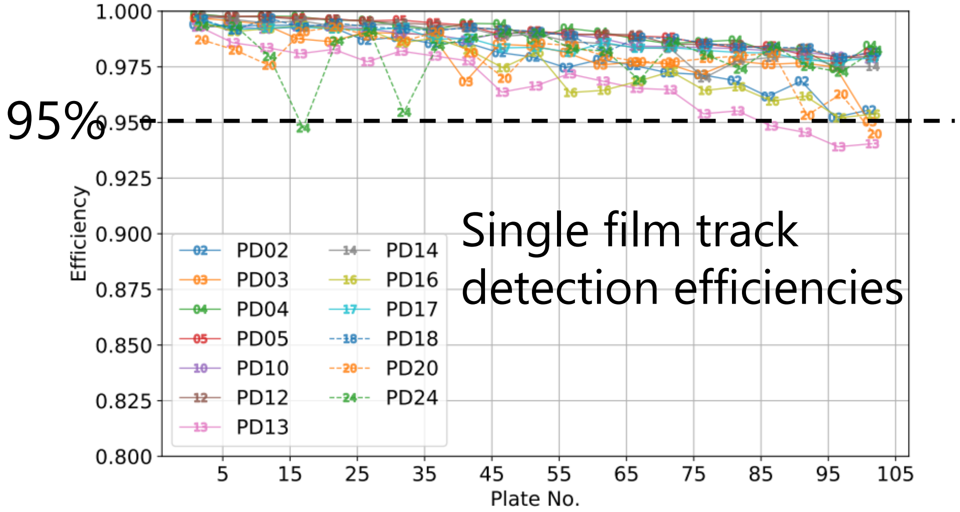
- Scanning of the emulsion films
  - Online process
  - ~10 PB microscope photo from HTS
  - →Single film track data (~10TB)



- Track reconstruction
  - Offline process
  - Need large memory size ≥128 GB
  - New tracking algorithm
  - →Linked track data

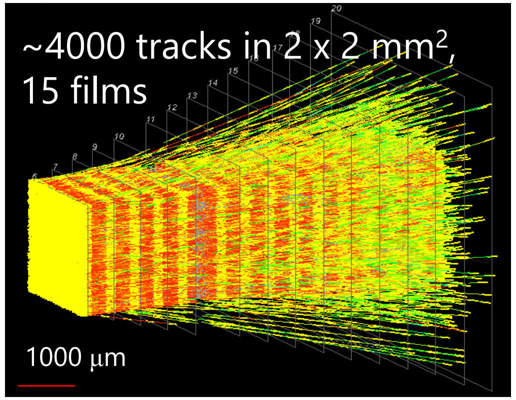


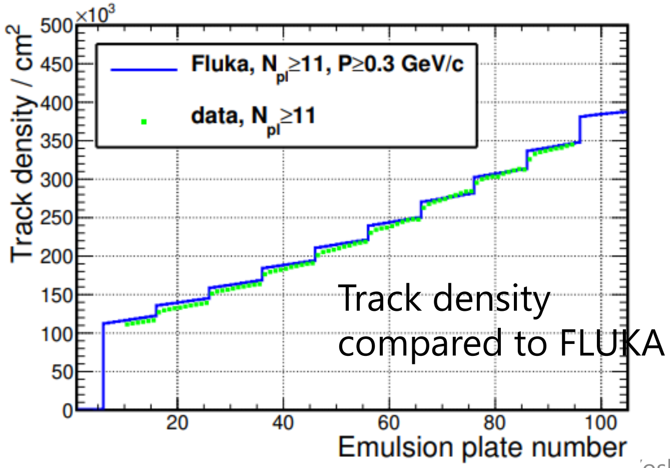
Reconstruction performance (1): Track reconstruction

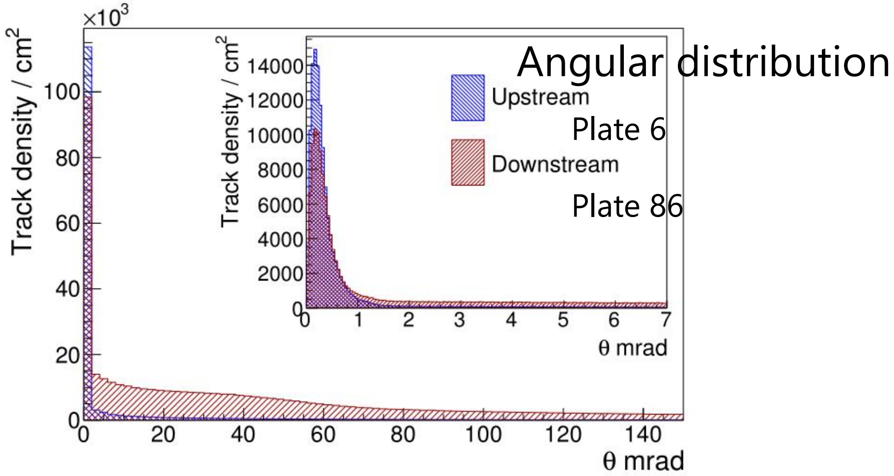


Single film track detection efficiency is >95% at high track density film (OPERA x 1000)

Fine alignment with proton tracks, **0.4 μm** position accuracy
→ **0.1 mrad** angular resolution for long tracks (>7mm)

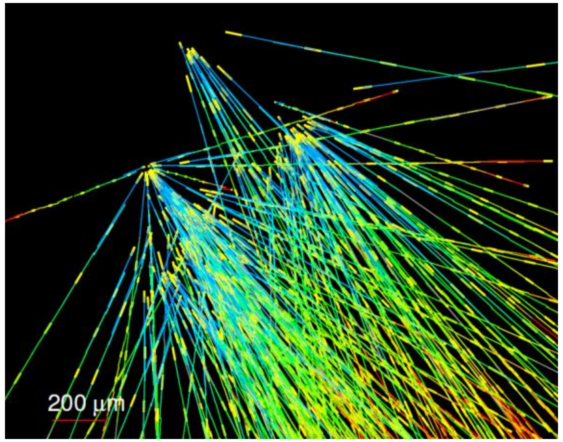




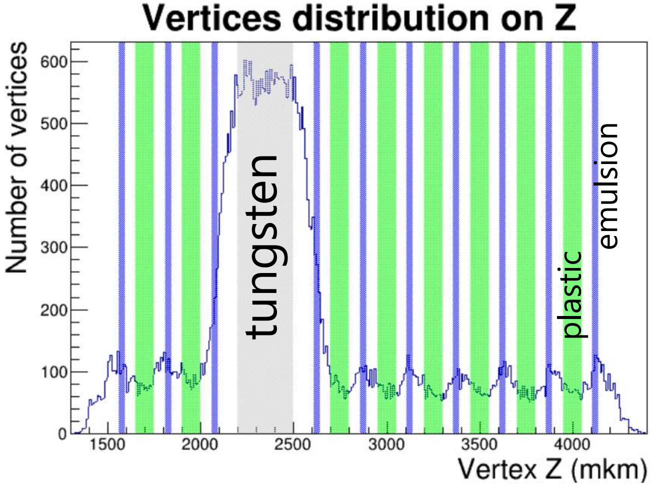


Reconstruction performance (2): Vertexing

Tracks emerging from tungsten target

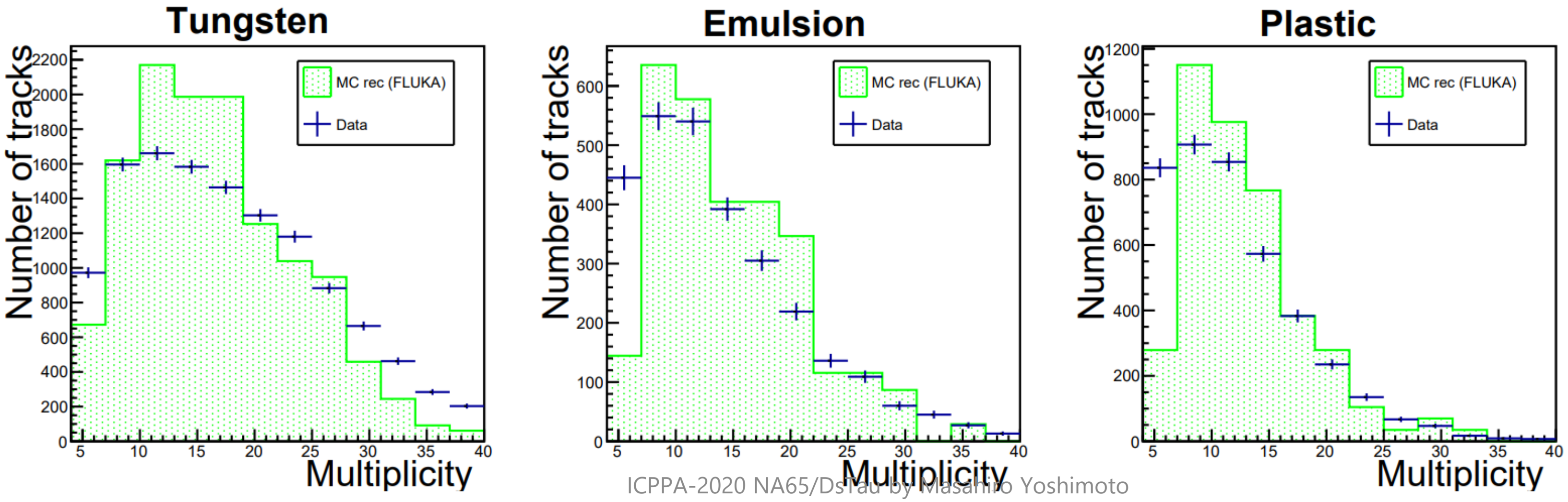


Vertex density ~500/cm^2/ tungsten plate



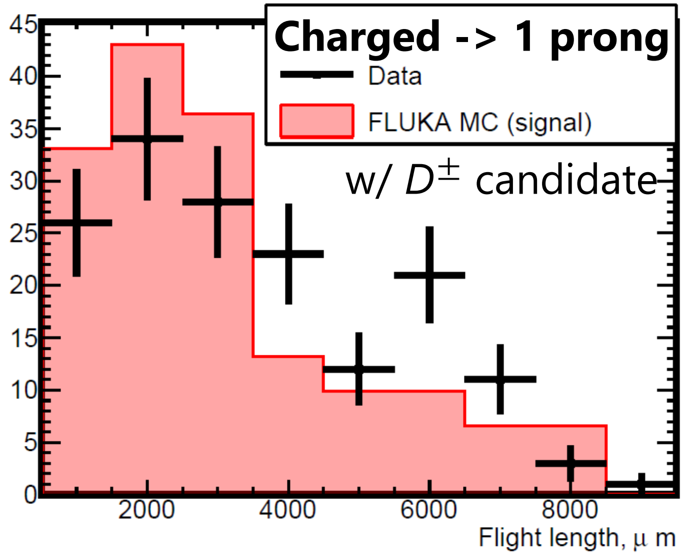
Fine detector structures are visible by reconstructed vertices.

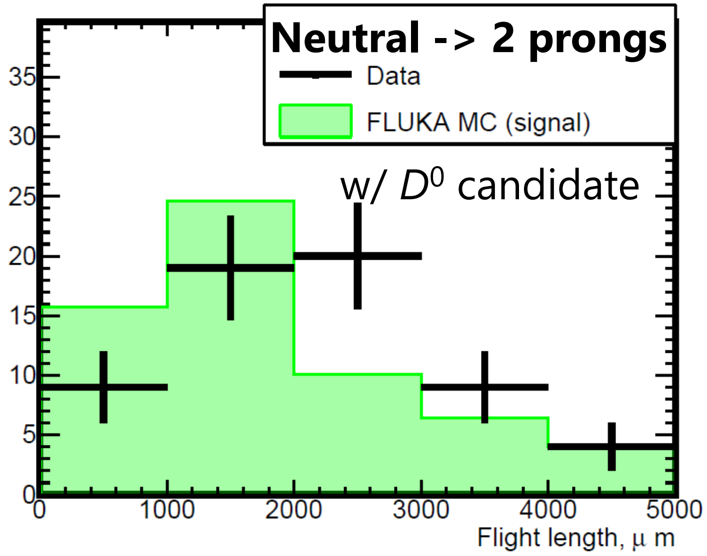
Charged particle multiplicity at the proton interaction vertices



Charm candidate search, increasing statistics

- Search for double charm events
  - 34,253,301 protons analyzed (~2% of pilot run)
  - 272,120 proton interactions reconstructed (**147,236 in tungsten**)
  - 159 events (**115 in tungsten**) with double decay topology detected





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

- We will increase statistics x50
- High precision measurement to be done for selected events

Plans

- Pilot run in 2018 (1/10 scale)
  - Emulsion readout of pilot run being completed (3150 films, 40m^2)
  - So far 2% of data is fully analyzed → to be completed.
  - Expect about 10,000 charm events, 80 $D_s \to \tau \to X$ events

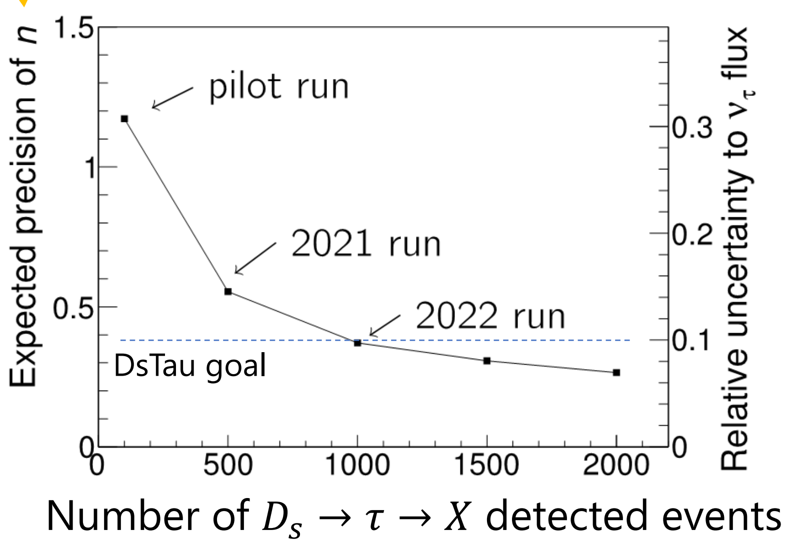
- Physics run in 2021, 2022
  - 2+2 weeks of beam time at NA
  - Emulsion film 550 m^2
  - Tungsten and molybdenum targets
  - Expect 100,000 charm detected,

    1000 $D_s \to \tau \to X$ detected events
  - ν_τ flux uncertainty to 10%
  - The plan is probably on schedule so far.

D_s differential production cross section

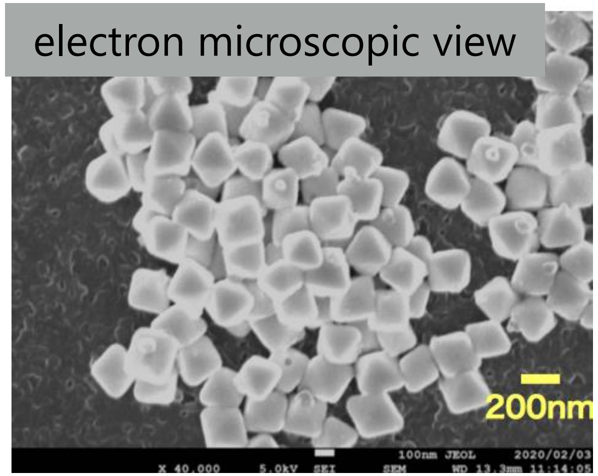
Phenomenological formula

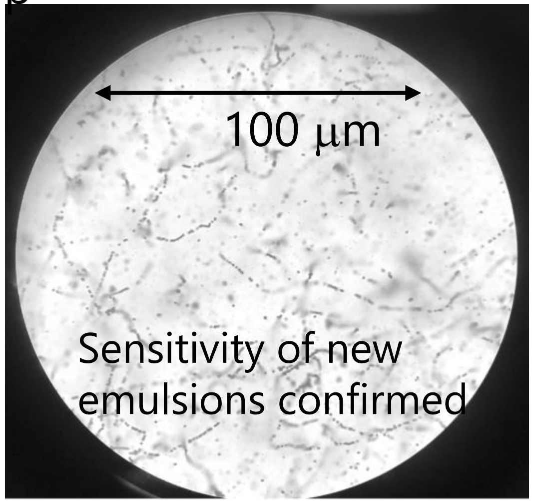
$$\frac{d^2\sigma}{dx_F dp_T^2} \propto \underbrace{(1-|x_F|)^n}_{\text{longitudinal dependence}} \underbrace{\exp(-bp_T^2)}_{\text{transverse dependence}}$$



Preparation for physics run in 2021, 2022

New gel production facility setup

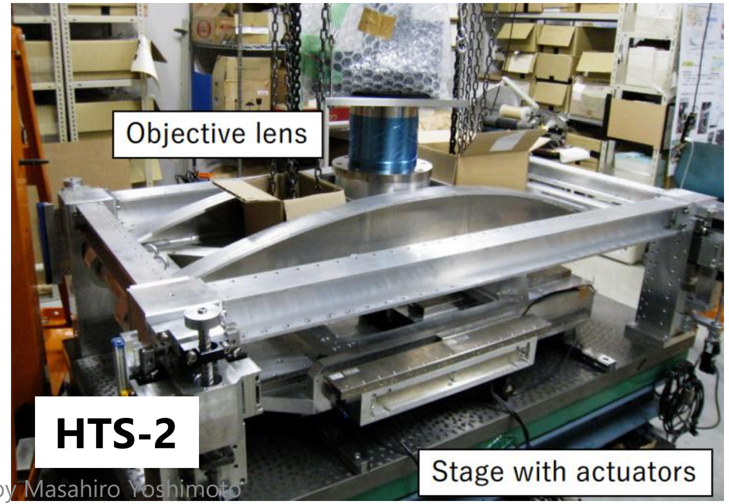




Larger film size
10x12.5 → 25 cm x 20 cm

Computers for track reconstruction

Film production facility



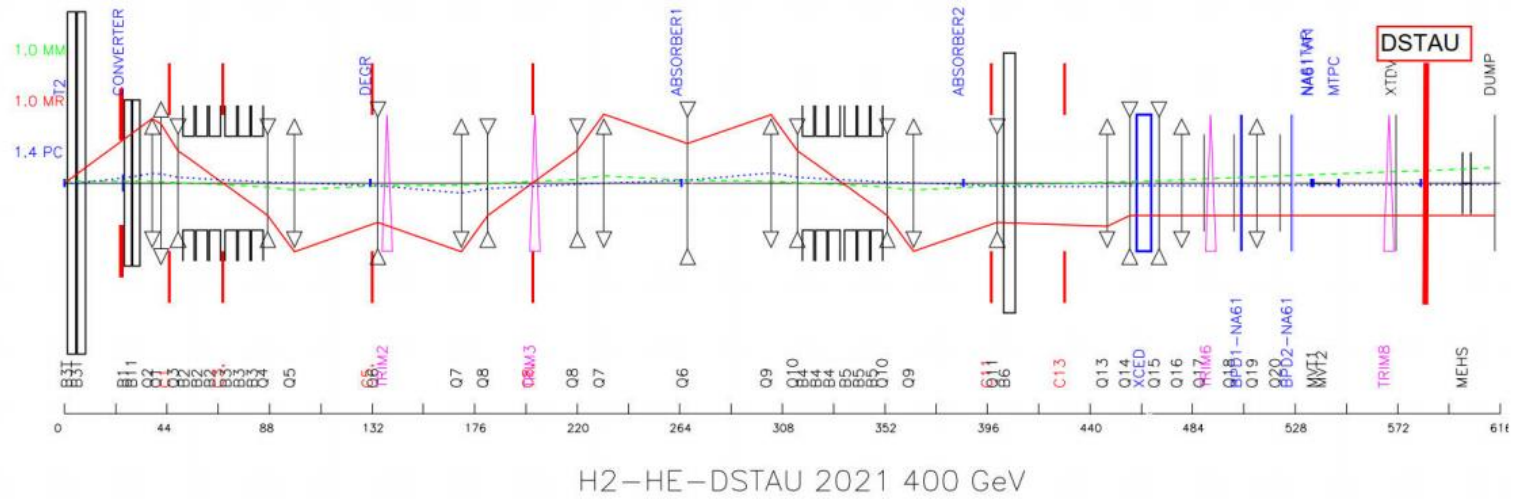
Readout system

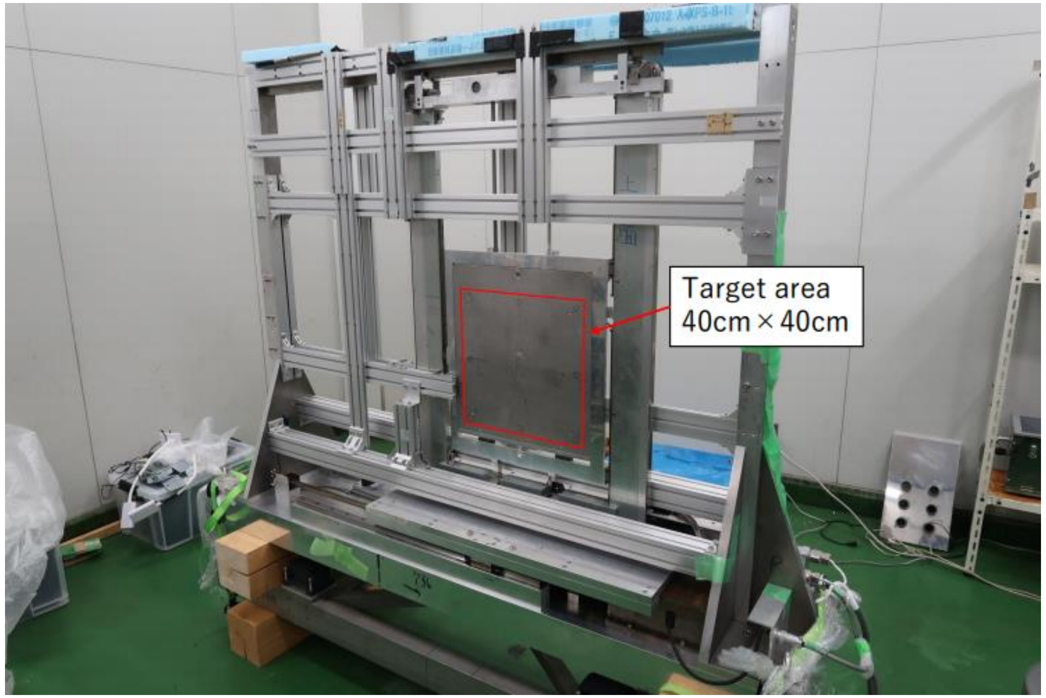
HTS (0.5 m^2/h)
13 GB/s

HTS-2 (2.5 m^2/h)
48 GB/s

Preparation for physics run in 2021, 2022

- A beamline optics study has been done to achieve a wide beam
- A larger target mover from J-PARC E07 experiment





Summary

- **NA65 / DsTau** experiment is aiming at the first measurement of $D_s \rightarrow \tau \rightarrow X$ **differential production cross section**.
- 2018 pilot run analysis
  - All films were scanned
  - 159 **charm pair candidate** (**115 in tungsten**) events, increasing statistics
- Preparation for physics run
  - Emulsion readout system, data analysis, target mover, and production of emulsion films
- Major publication
  - DsTau: Study of tau neutrino production with 400 GeV protons from the CERN-SPS
    DOI:10.1007/JHEP01(2020)033
- **Physics run in 2021-2022**