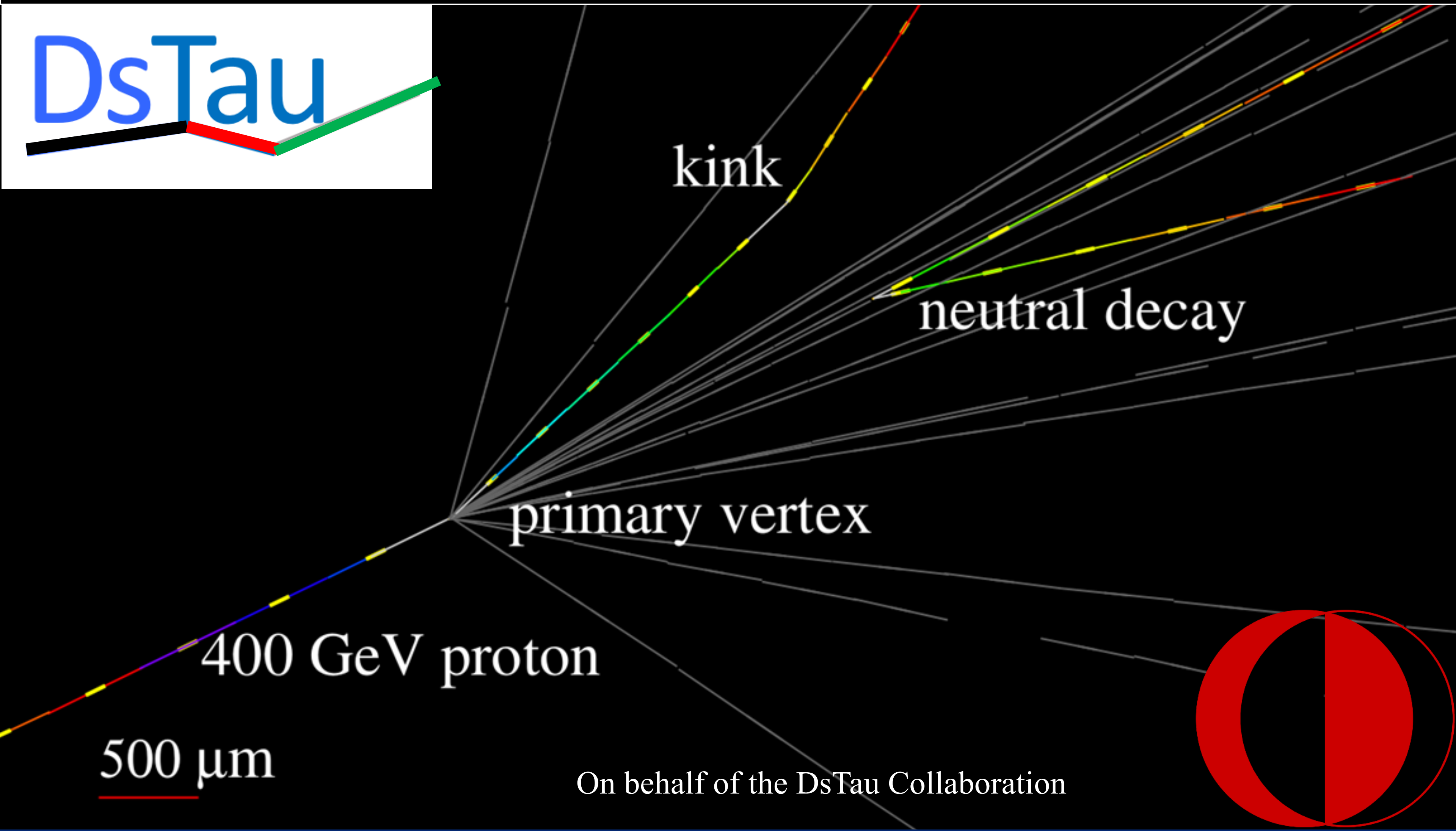
# Status of DsTau data taking and analysis

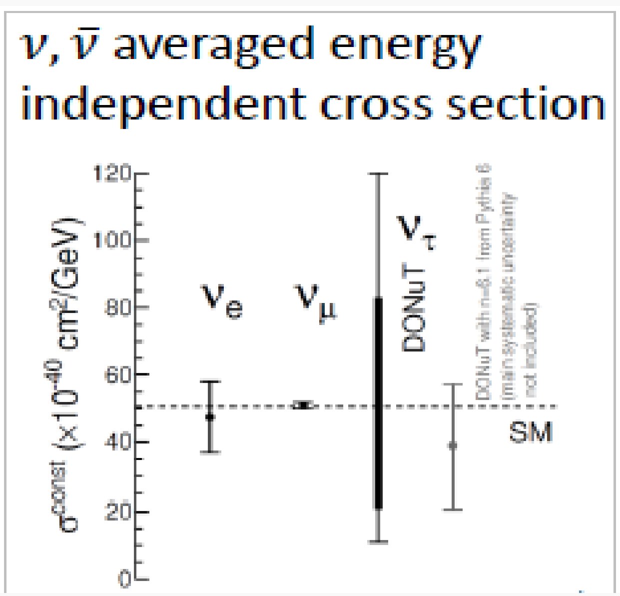



On behalf of the DsTau Collaboration

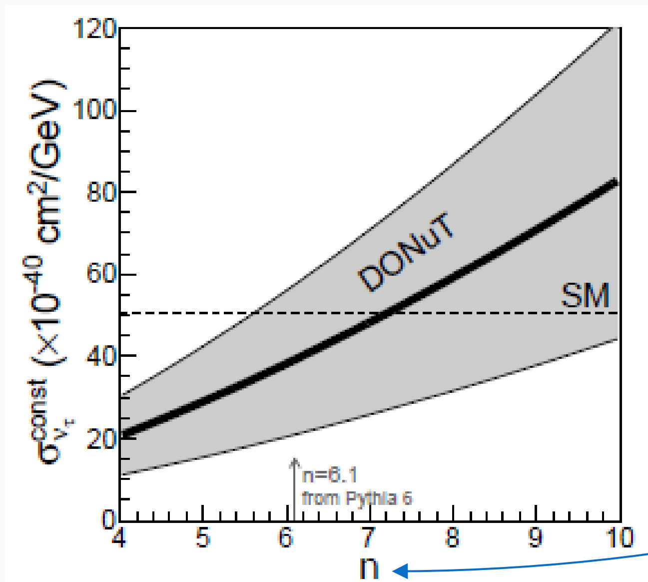
# DsTau: Physics motivations

- Tau neutrino is the least known particle of the Standard Model.
  - $\nu_\tau$ beam : DONuT
  - oscillated $\nu_\tau$ : OPERA, Super-K, IceCube
  - $\nu_\tau$ cross section error >50% (DIS) due to systematic uncertainty in $\nu_\tau$ production (DONuT)

- Measurement of $\nu_\tau$ production
  - Reduce uncertainty of $\nu_\tau$ flux from >50% to 10% <
  - Fundamental input for future $\nu_\tau$ experiments: SHiP, DUNE, Hyper-K




$$\sigma_{\nu\tau}^{const} = 7.5(0.335\,n^{1.52}) \times 10^{-40}\,cm^2 GeV^{-1}$$



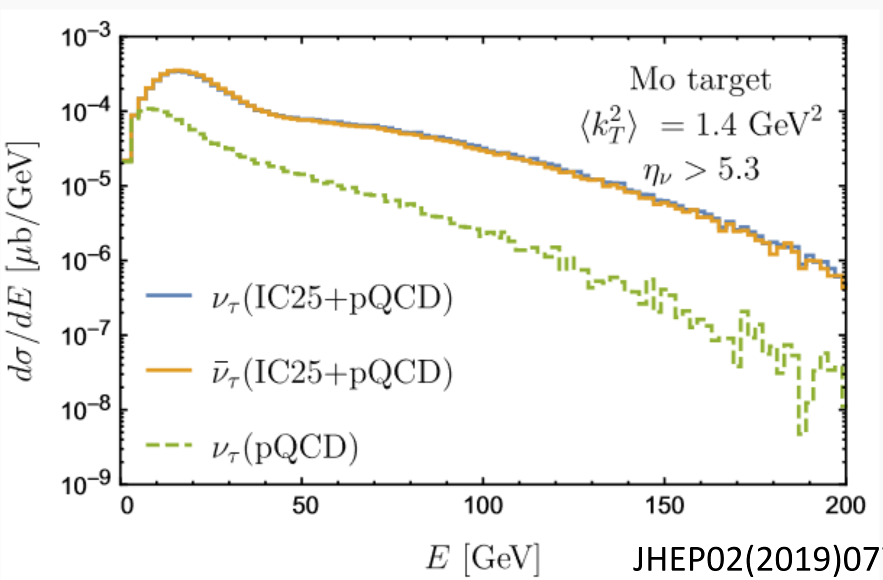

No experimental data giving $n$ for $D_s$

$$\frac{d^2\sigma}{dx_F\,dp_T^2} \propto (1-|x_F|)^n \exp(-bp_T^2)$$

# DsTau: Physics motivations

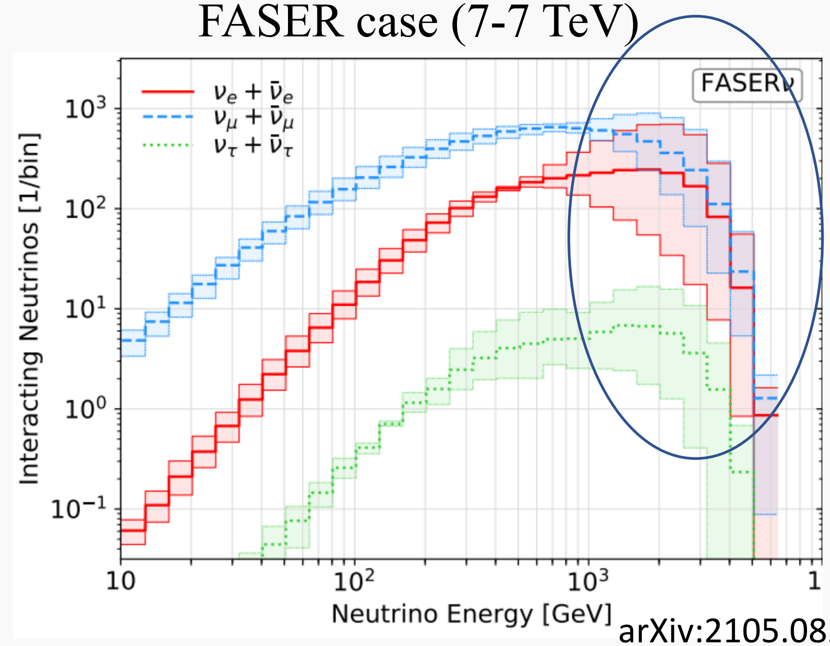
- First Measurement of Ds differential cross section
- Forward charm physics
  - Large theoretical uncertainity for forward charm production.
    - *Intrinsic charm* content of proton can effect $\nu_\tau$ flux drastically, by enhancing charm production in forward direction, $\nu_\tau$ flux may change by a factor of 10
  - Neutrino experiments  need data on the forward charm prduction

SHiP case (400 GeV p-N) interaction




JHEP02(2019)077

FASER case (7-7 TeV)



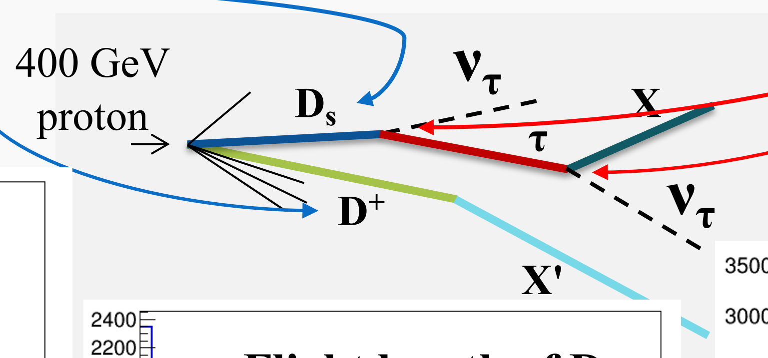

arXiv:2105.08270

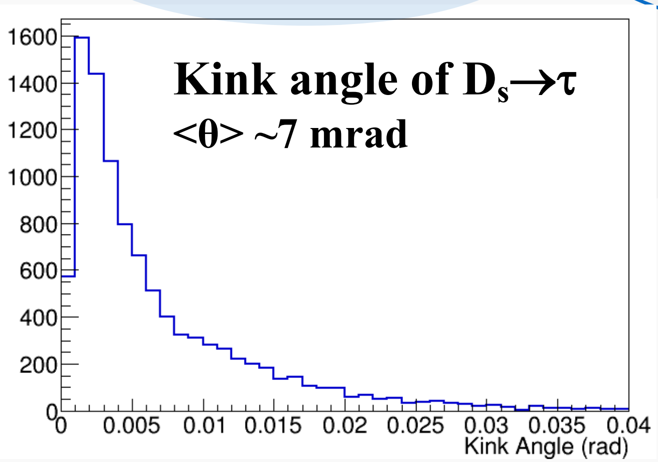
# DsTau: Unique signature

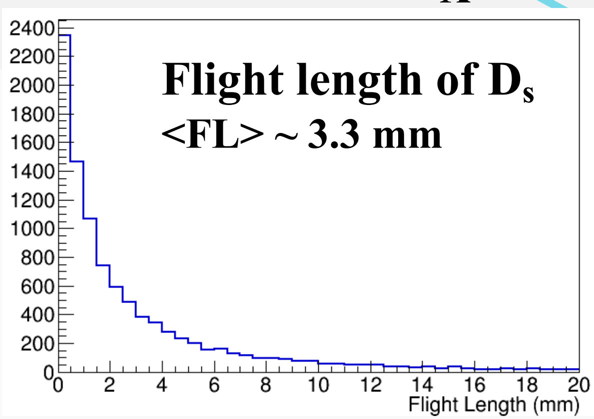
Double charm hadron production

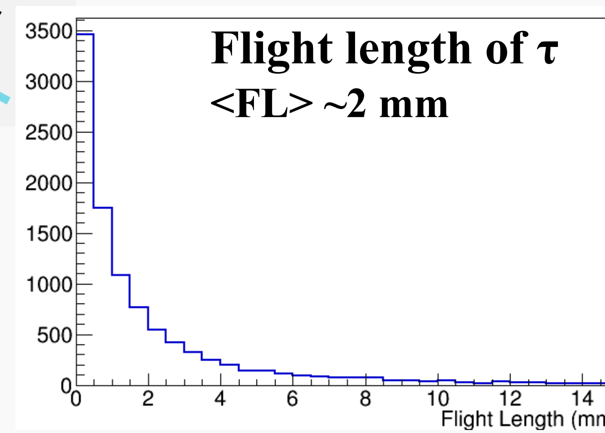
Double kink topology

Small kink @ $D_s \rightarrow \tau$



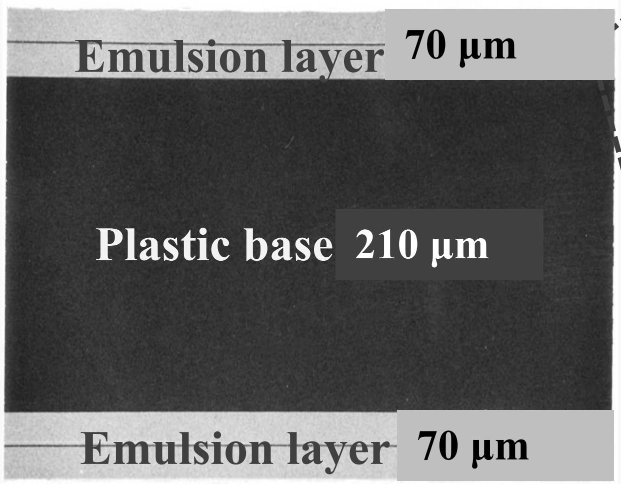



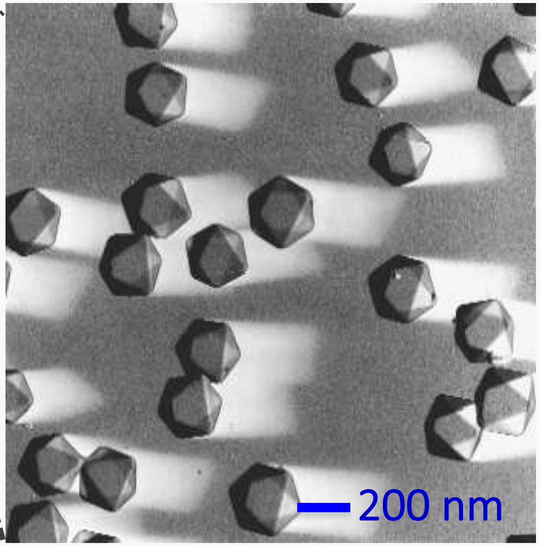



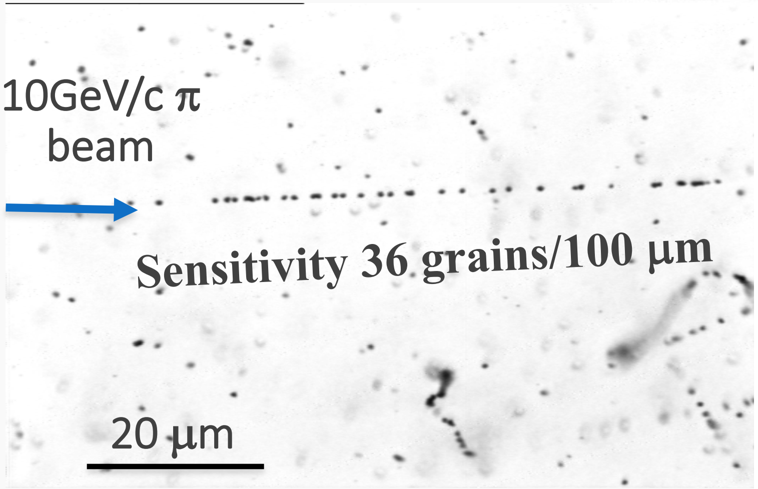

- $4.6 \times 10^9$ protons, $\mathbf{2.3 \times 10^8}$ proton interactions in target (tungsten & molybdenum),
- $\sim 10^5$ charm pairs & $\sim 10^3$ $D_s \rightarrow \tau \rightarrow X$ decays can be detected.

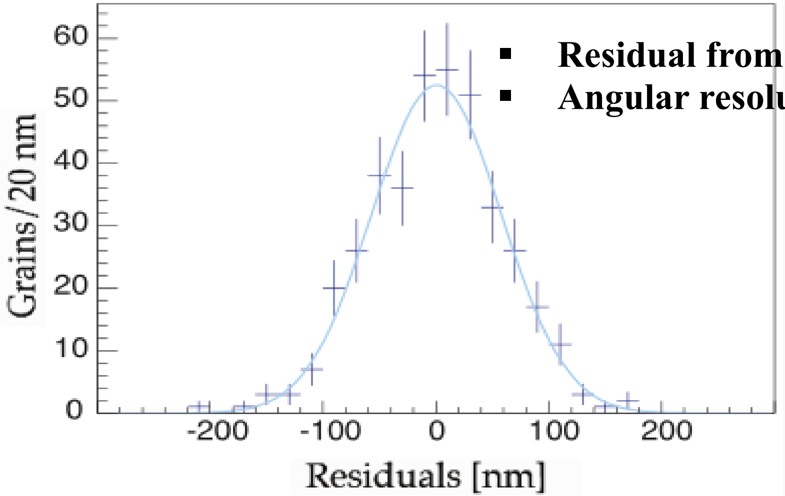
# Emulsion detectors

**3D tracking device with highest position resolution**

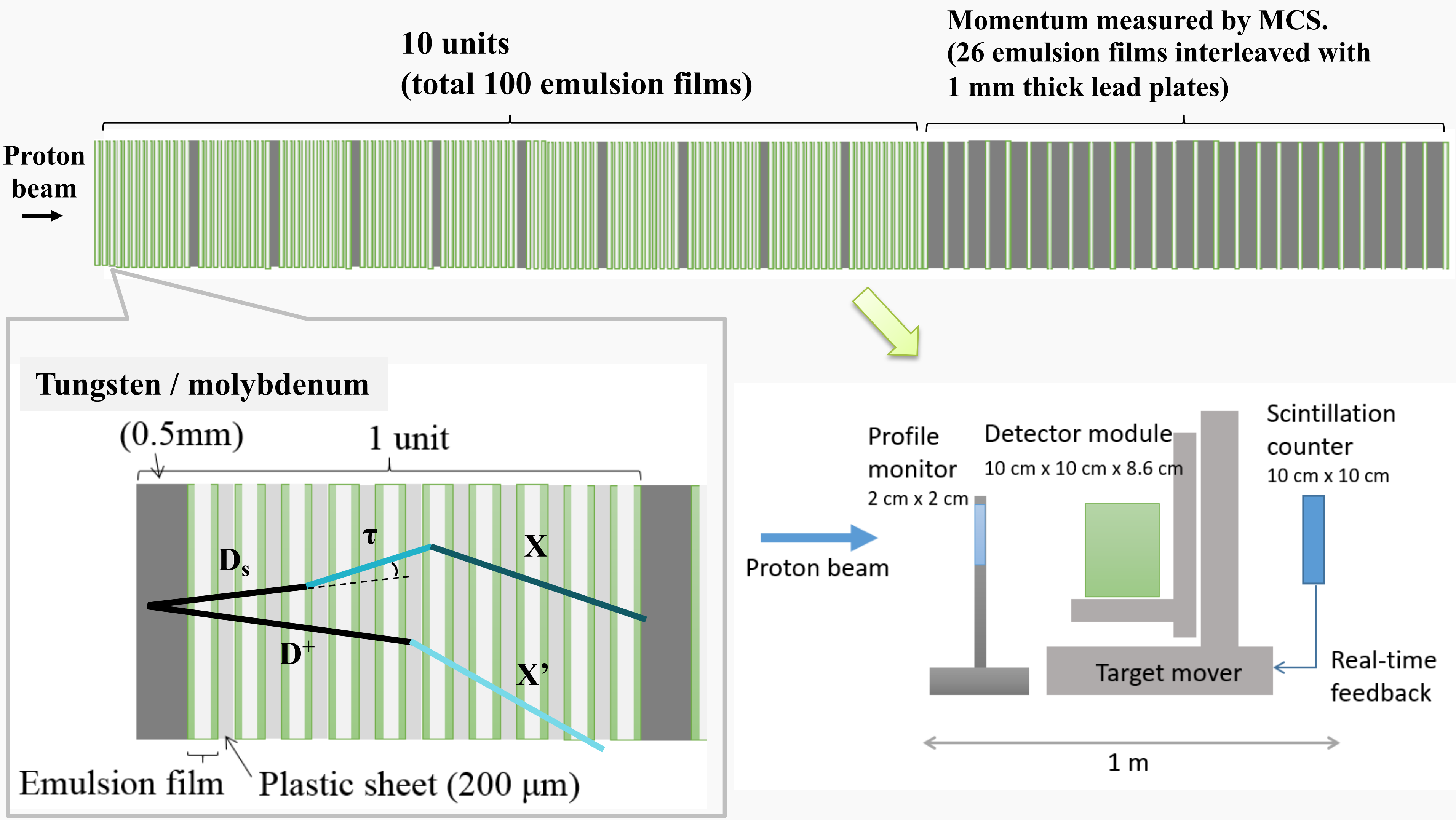




- **Residual from fitted track σ= 50 nm**
- **Angular resolution 0.35 mrad**

# Concept of $D_s \to \tau \to X$ detection

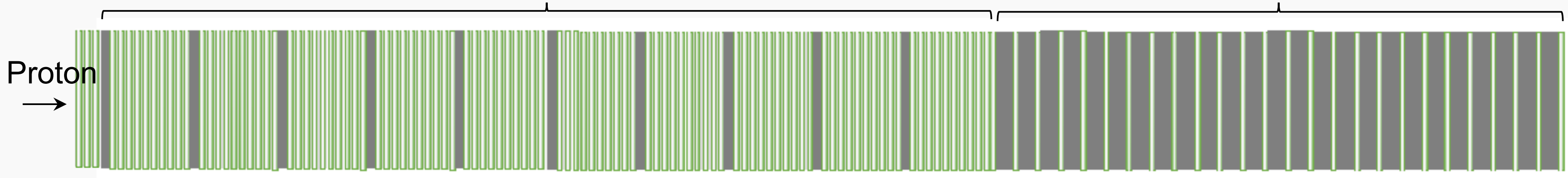


# Change of structure for momentum measurement

**-2018**

10 units
(total 100 emulsion films)

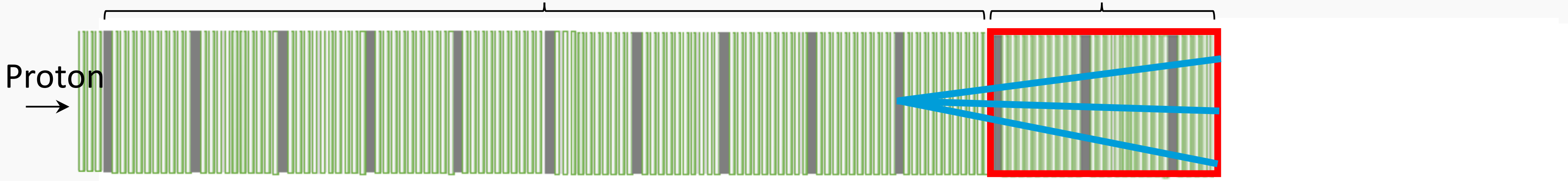
ECC for momentum measurement
(26 emulsion films interleaved with
1 mm thick lead plates)




**2021-**

10 units
(total 100 emulsion films)

**Momentum analyzer for events at downmost tungsten plates :**
**3 tungsten plates and 25 emulsion plates**



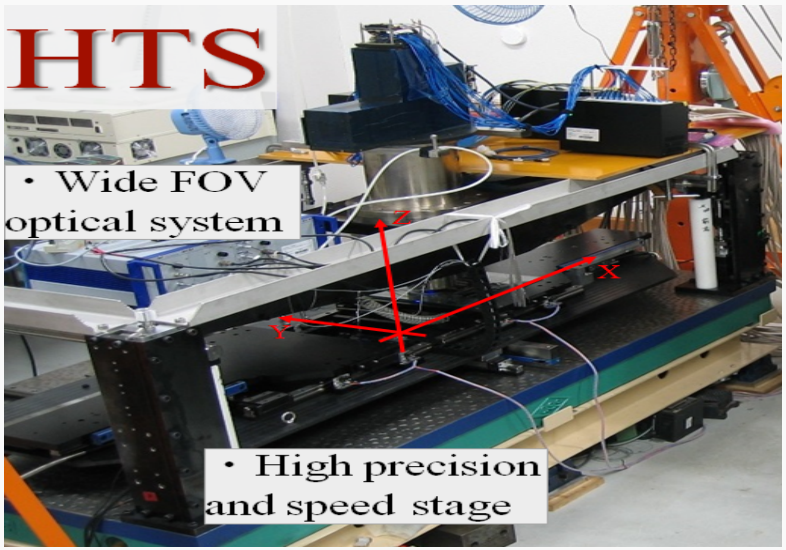

- Original structure had more material → too high track density in ECC
  - Dedicated scanning is required
- Reduce material, but sufficient performance
- Making data taking procedure simple

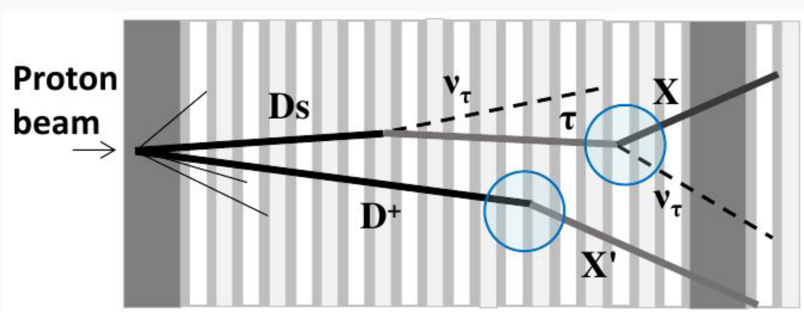
| | Original: lead emulsion ECC | New: additional tungsten units |
|---|---|---|
| Structure | 25 1mm lead, 26 emulsion plates | 3 0.5mm tungsten, 25 emulsion plates |
| Momentum resolution | 20 - 40% (upstream ev.)<br>20 - 40% (downstream ev.) | 15 - 40% (upstream ev.)<br>35 - 45% (downstream ev.) |
| Weight | 15.0 kg | 2.4 kg |

# Emulsion readout

1. High speed scanning of full area to select $\tau \rightarrow X$ + partner-charm decays ($\Delta\theta$ ~100 mrad)

**Angular resolution ~2 mrad**

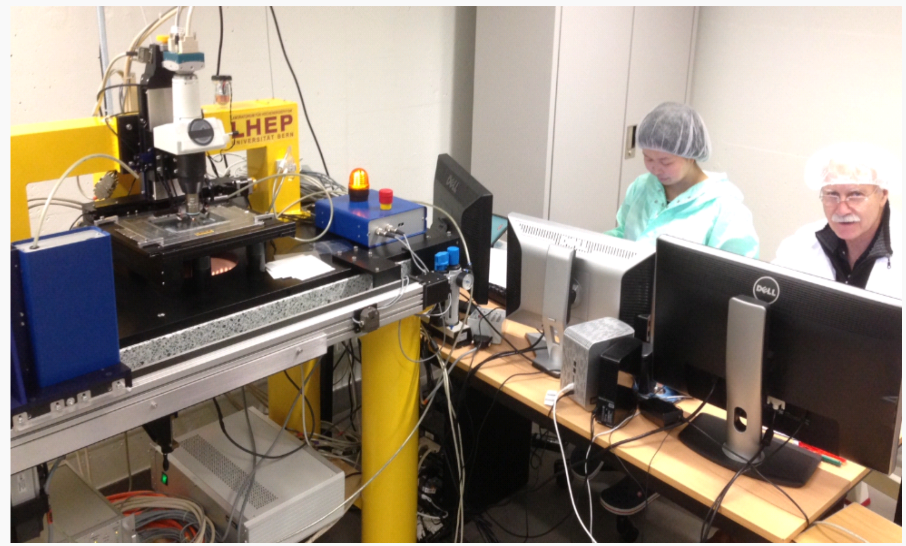


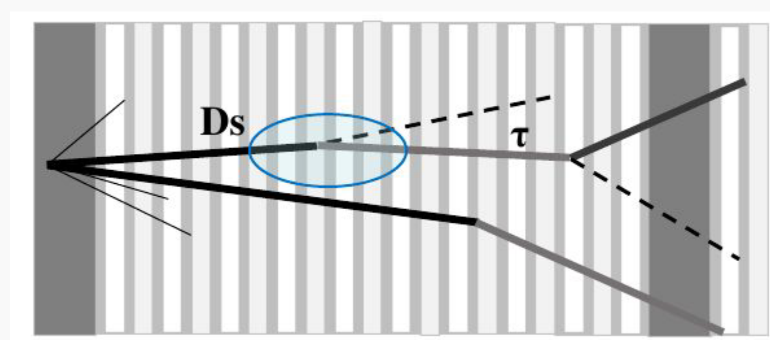




**Scanning speed of 9000 cm$^2$/h (22 m$^2$/day)**

2. Precision measurement to detect $D_s \rightarrow \tau$ decay (a few mrad)

**Angular resolution ~0.3 mrad**

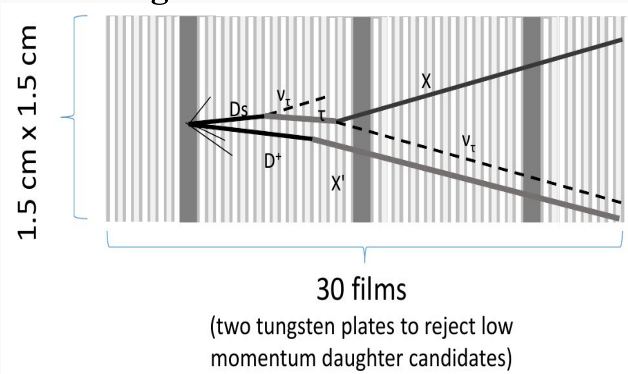


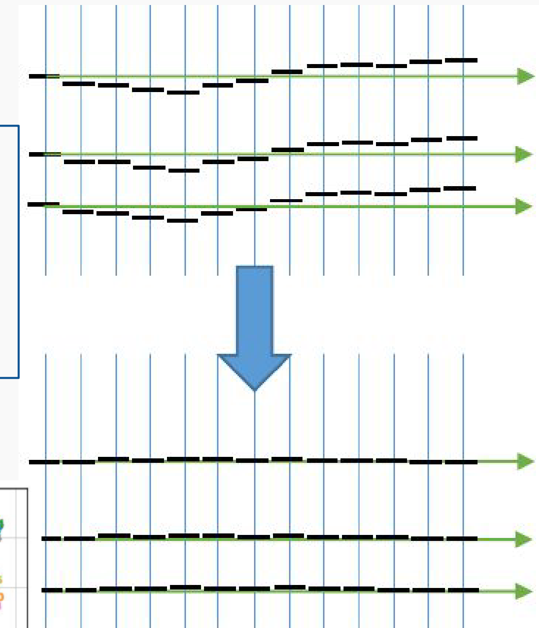
# Data reconstruction

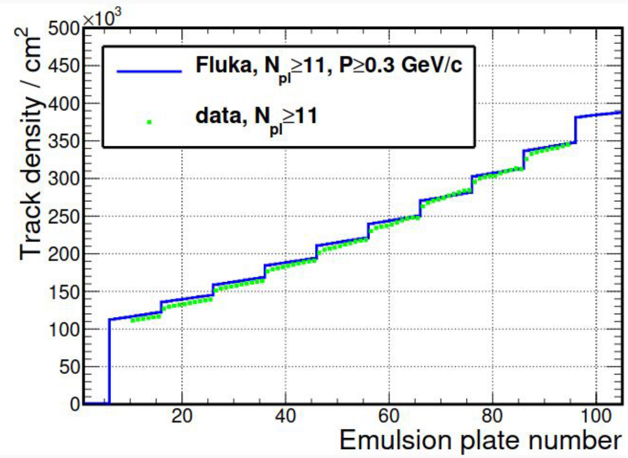
- The automatic scanning systems read out the track information accumulated in the emulsion film during the exposure, digitize it and transfer to the computers for the pattern recognition and tracking/vertexing.

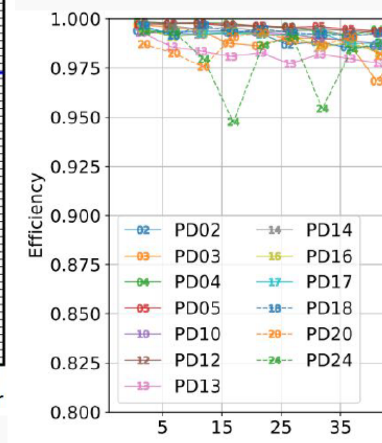
**Processing in subvolumes 1.5 cm x 1.5 cm x 30 plates**




- Alignment with proton beam tracks,100 tracks/mm$^2$.
- Residual of track segments to fitted line(RMS) $\simeq$ **0.4 µm**





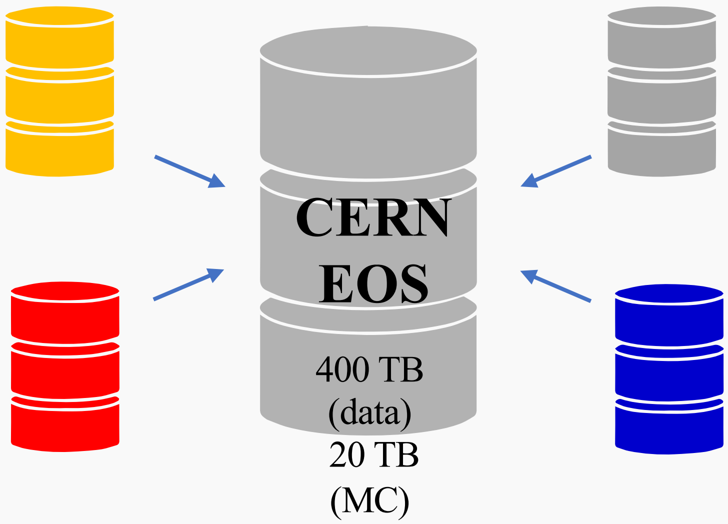

**Track finding efficiency in a single film 94%-98%**

# Data processing

- Film to film alignment and track reconstruction procedures require powerful processing servers with CPU/GPU and high memory (~128-256~GB of RAM) and disk space (~10~TB for each data module) resources.
- Distributed data processing is being done gradually. Up to now, 25 out of 30 modules in 2018 run have been fully processed (track reconstruction).

**Japan (Nagoya/Kyushu):**
2 processing servers
**CPU**, **GPU**, 256 GB of **RAM**
Storage capacity: ~150 TB
**(+2 in Chiba in near future)**

**Russia (JINR):**
2 processing servers
**CPU**, **GPU**, 256 GB of **RAM**
Storage capacity : ~150 TB

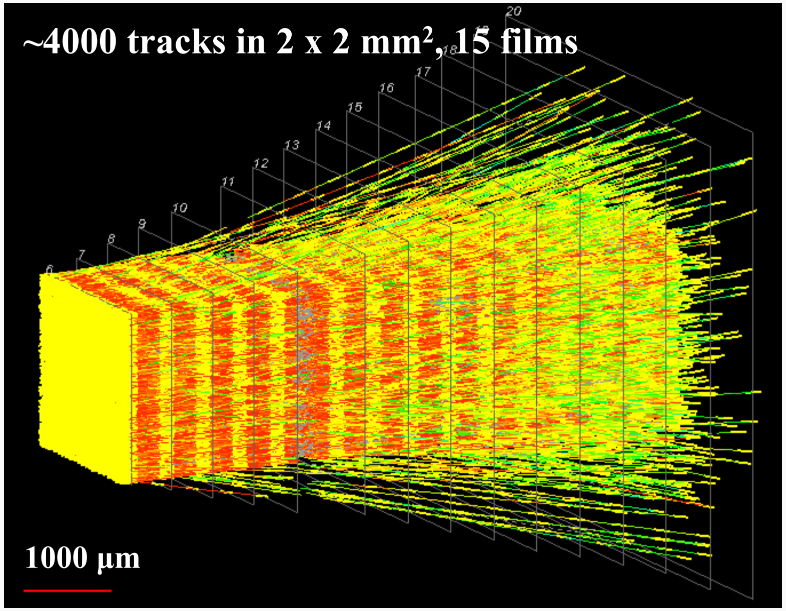


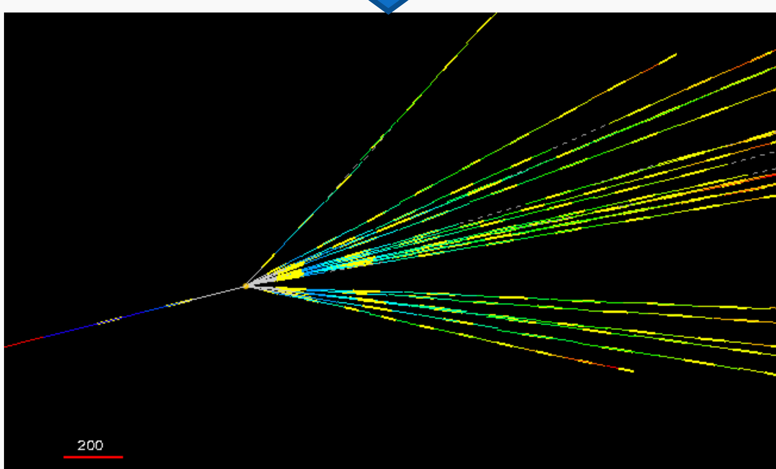

**Turkey (METU):**
**TRUBA** computing center resources
**CPU**, **GPU**, 128 GB of **RAM**
Storage capacity: 100+ TB

**Romania (ISS):**
1 processing server
**CPU**, **GPU**, 128 GB of **RAM**
Storage capacity : ~40 TB

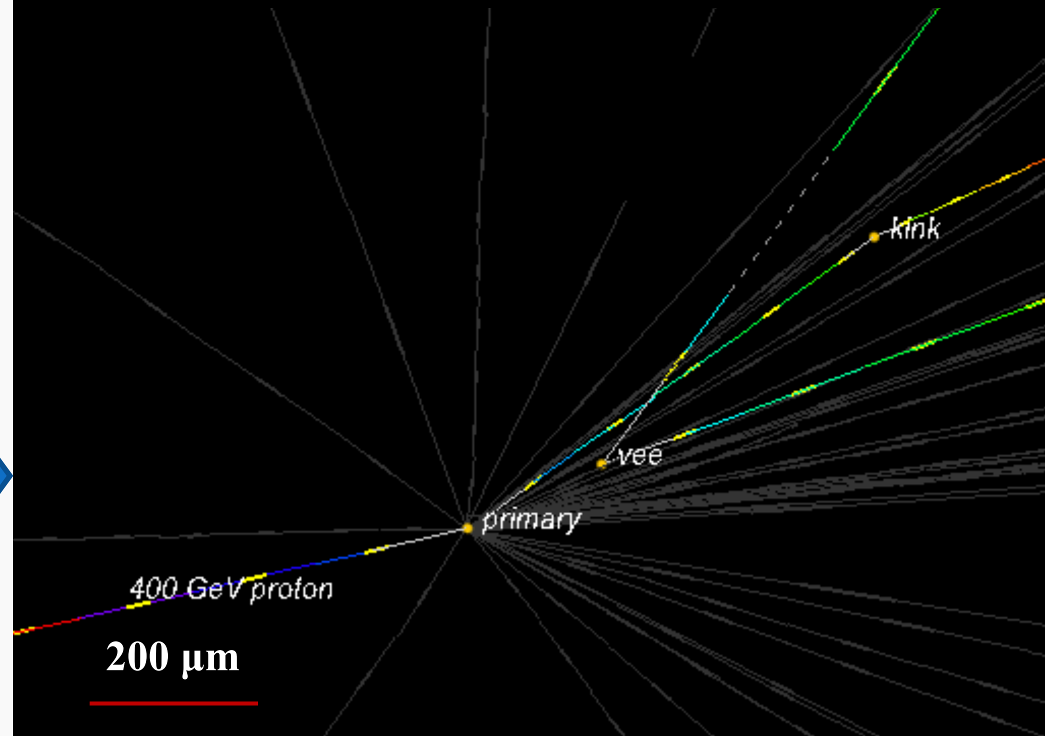
- Batch system of the CERN computing center is also going to be used to process the 2021 physics run data.

# Reconstructed double vertex



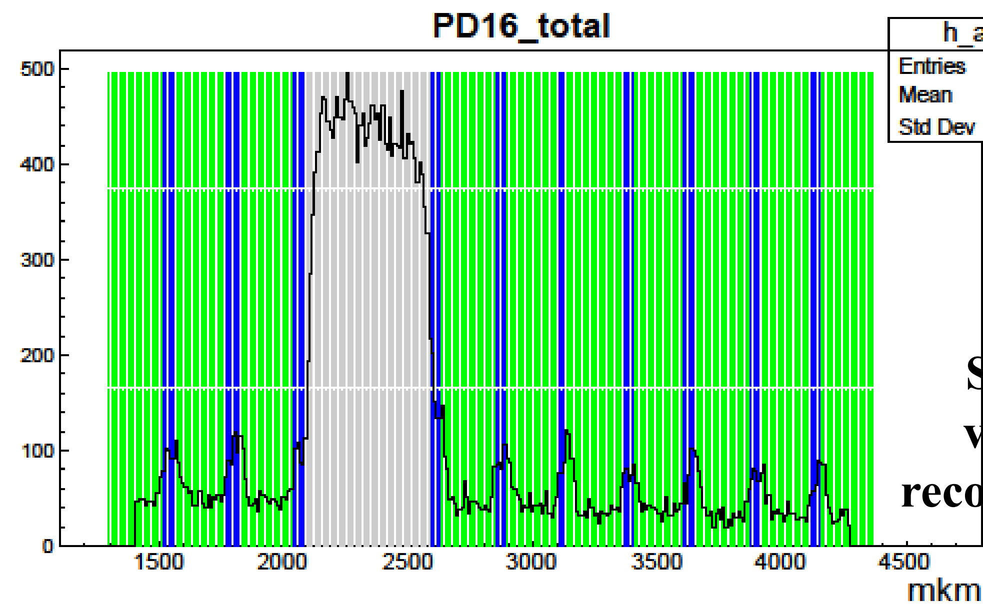




- Kink
  - IP of daughter 291.6 µm
  - FL 2536.6 µm
  - kink angle 118 mrad
- Vee
  - IP of daughters 20.9, 109.7 µm
  - FL 554.5 µm
  - Opening angle 242 mrad



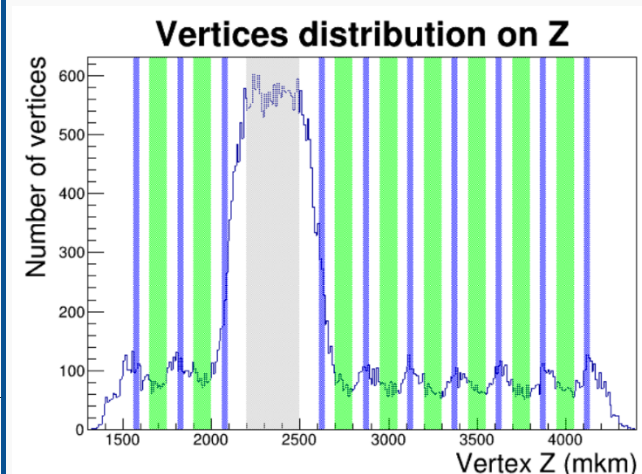
# Study of Proton interaction with tungsten

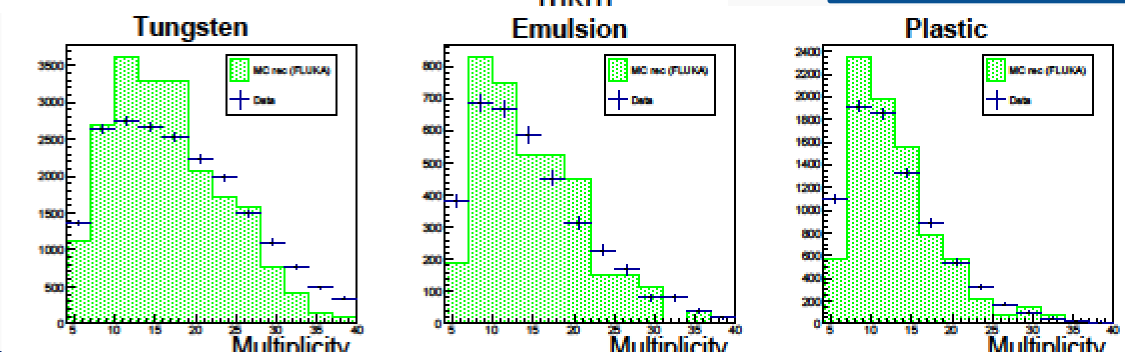
- Proton interaction vertices location by fine alignment on the material boundaries.
- Secondary tracks multiplicity distribution by each detector components.
- The results will be summarized into a paper soon.




Sharper vertex Z reconstruction

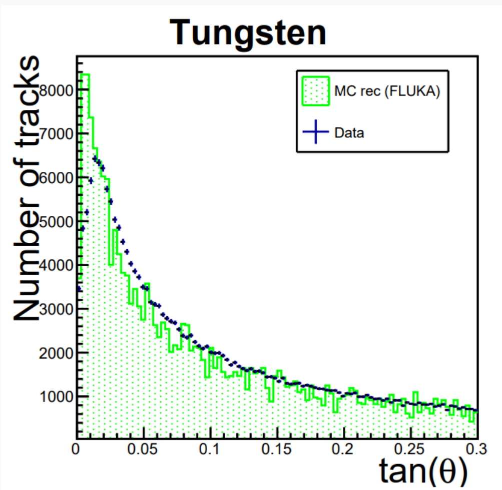
**Old reconstruction**

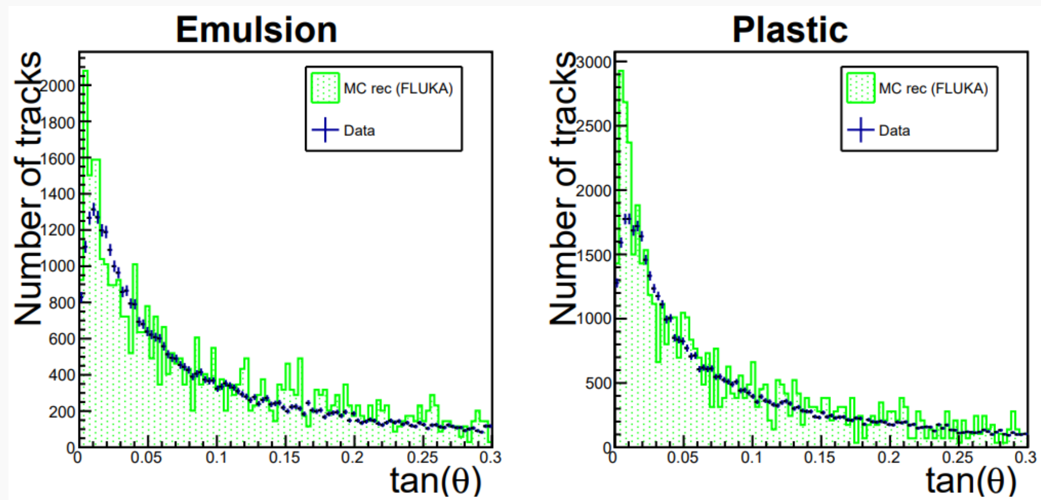


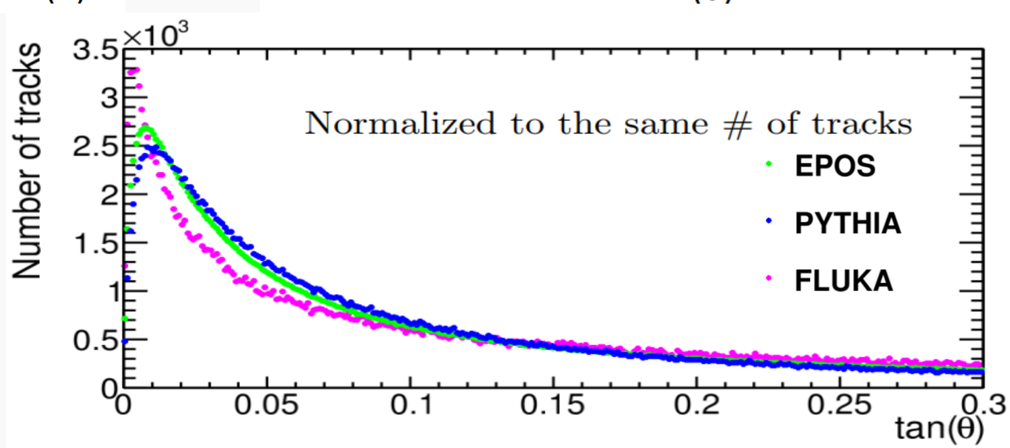



# Study of Proton interaction with tungsten

- General distribution agrees with the FLUKA prediction.
- A deficit of forward angle (<20 mrad or $\eta$>4.6) is observed.
- Comparisons between other generators are ongoing.

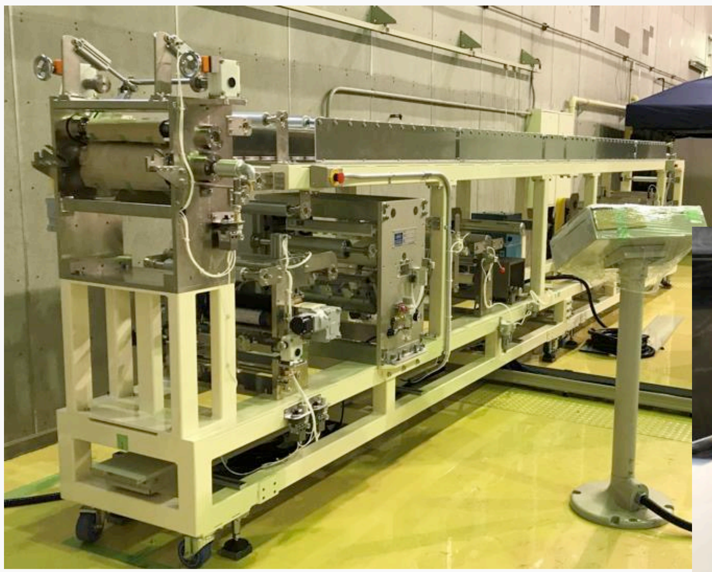


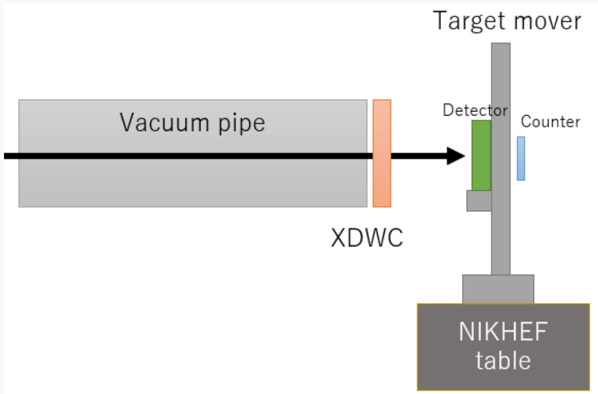
# DsTau 2021 run

- Originally, It was planned to use >200 $m^2$ emulsion but due to Covid19, the emulsion production is slowed down in Japan. The number of detector modules is reduced to 110 $m^2$ ($\simeq$2200 films)
- Updates
  - Films size was changed from 12.5 cm x 10 cm → 25 cm x 20 cm



# DsTau 2021 run

- New target mover



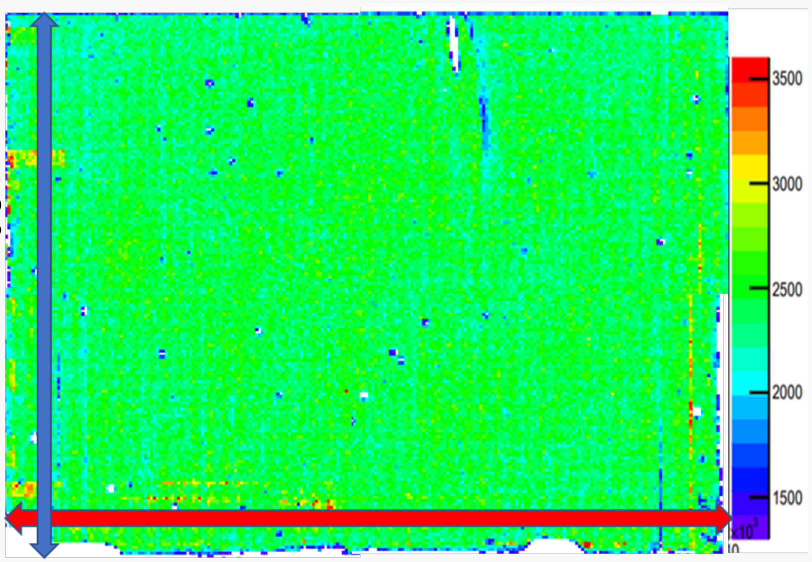

- XDWC for beam profile monitor
- Scintillator(s) to feedback beam intensity in real-time

- Development facility, a full renovation by CERN is underway


# DsTau 2021 run

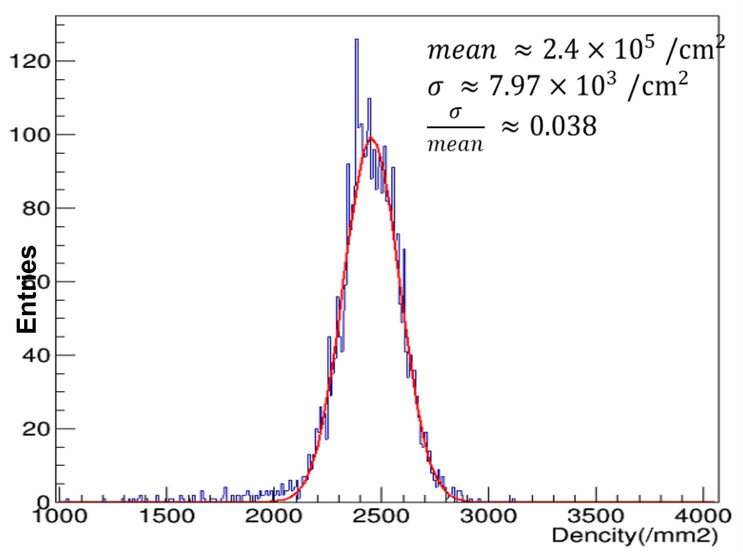
- 17 modules were exposed
  - 12 tungsten and 5 molybdenum targets
  - → about 30% of total (including 2018 run)
- All films were developed & scanning started

20cm




25cm

track density uniformity



# Plan for 2022, 2023 runs

- Emulsion film production

  → Limited amount of emulsion, ~100 $m^2$

  - Shortened beam time (1 week) was requested

| | Plan 2021 | Updated plan 2022 |
|---|---|---|
| Pilot run | 50 $m^2$ | 50 $m^2$ (1w) |
| 2021 run | 100 $m^2$ | 110 $m^2$ (2w) |
| 2022 run | 450 $m^2$ | 110 $m^2$ (1w) |
| 2023 run | 0 $m^2$ | 330 $m^2$ (3w) |

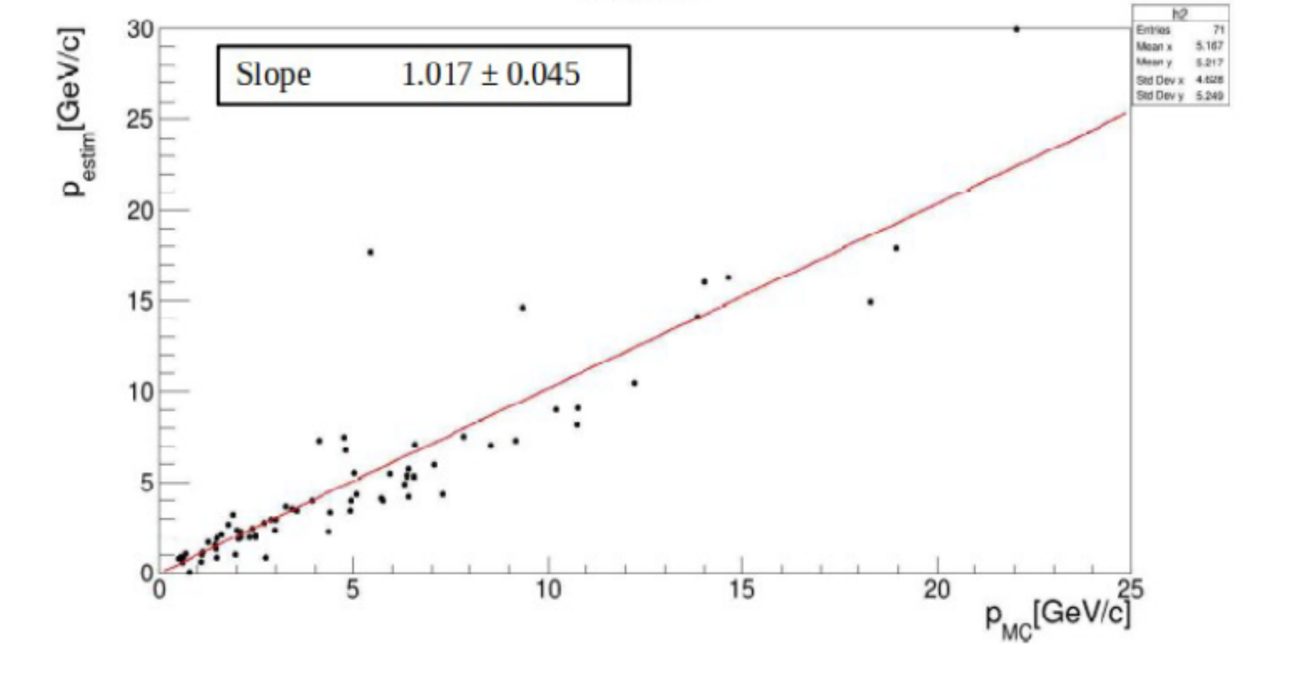
- Need of an additional data taking in 2023 for 3 weeks
- 2022 run is scheduled between 12– 19 October @ H4

# Summary

- DsTau 2021 data taking campaign was successfully finished
    - 30% of planned exposure was done
- Emulsion data readout, reconstruction and analysis are going on smoothly.
- The first physics results will be published soon.
- 2022 run is rescaled due to COVID19
    - Data taking extended one year.

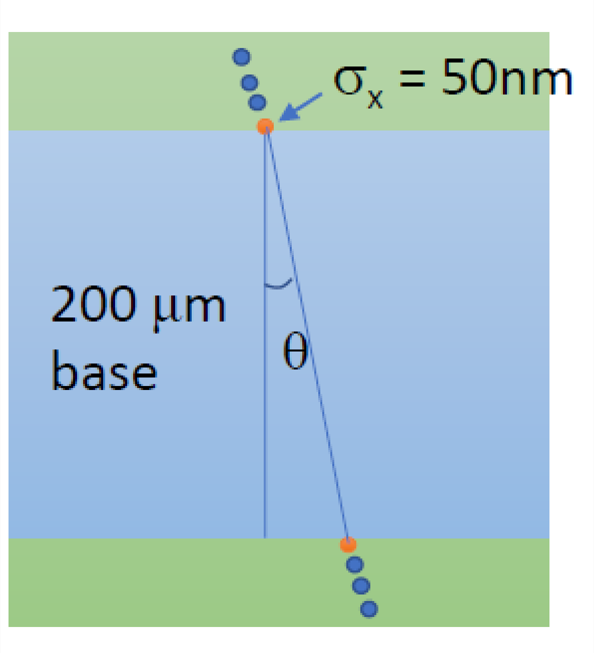
# Momentum reconstruction

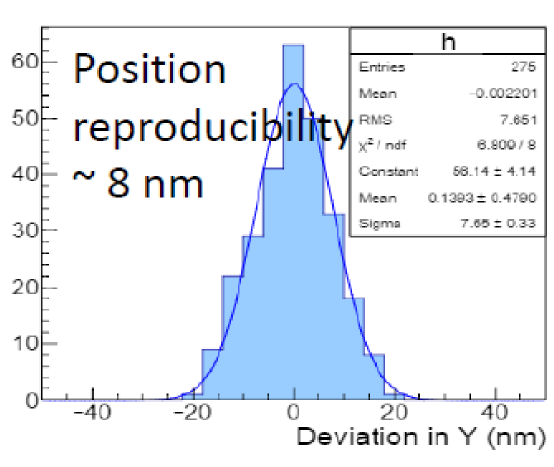
- Momentum measurement is important to discriminate charm decays from background.
- Algorithm has been implemented and tested
- Systematic application still needs a reorganization of data access over different data sets and alignment between them → Work in progress

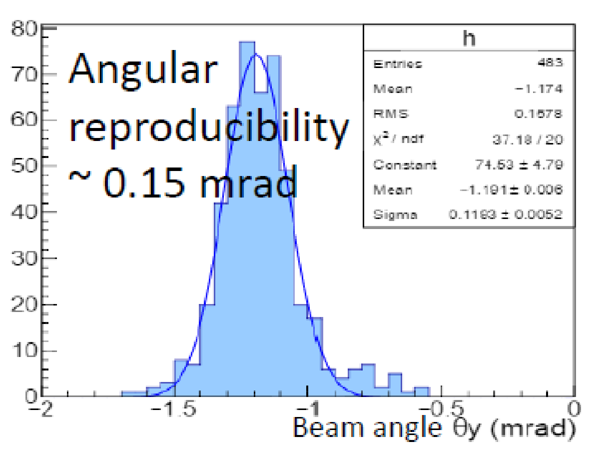


# High precision measurement of track angles

- Intrinsic resolution of each grain = 50 nm
- Two grains on top and bottom of 200 mm base → 0.35 mrad
- Discrimination of 2 mrad at 4σ level
- A new system with piezo-based Z axis under development
- Angular measurement reproducibility of 0.15 mrad was achieved

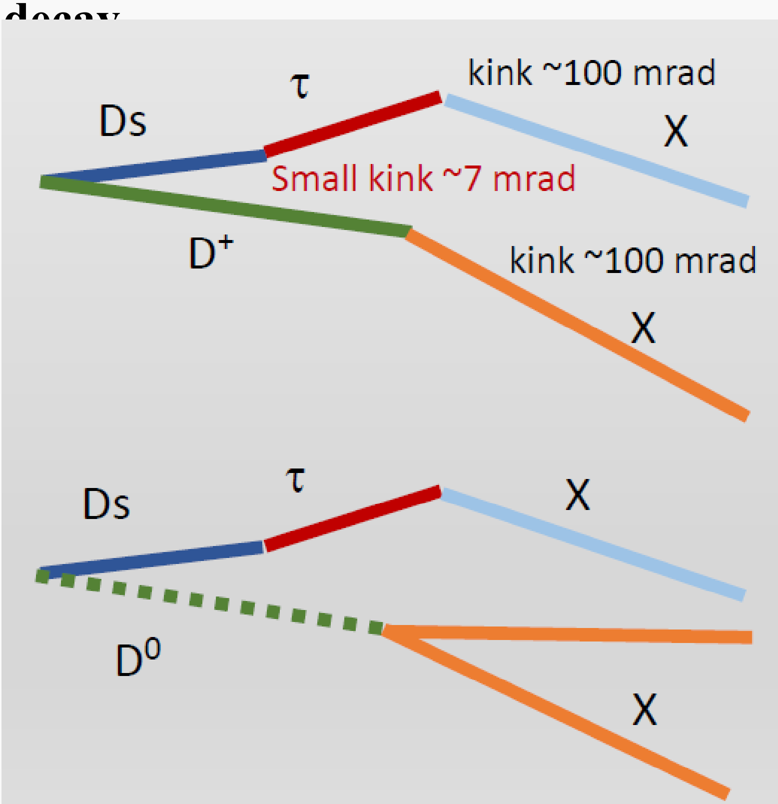


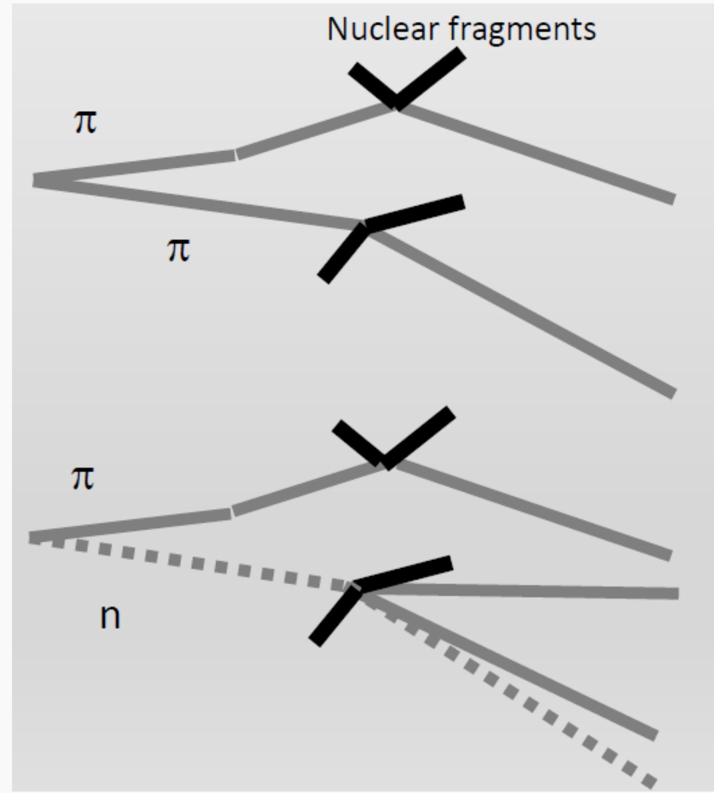



# Signal / Background

**Signal: a double kink + a charmed particle decay**




**Main background: hadron interactions**



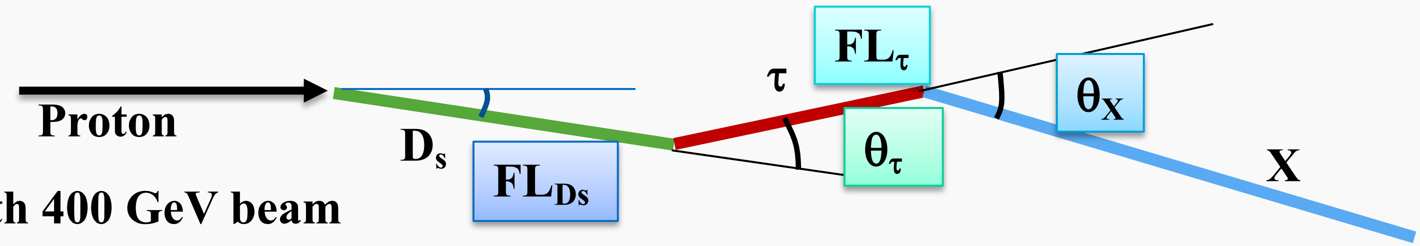

- Signal rate: 2.2x10$^{-7}$/proton int

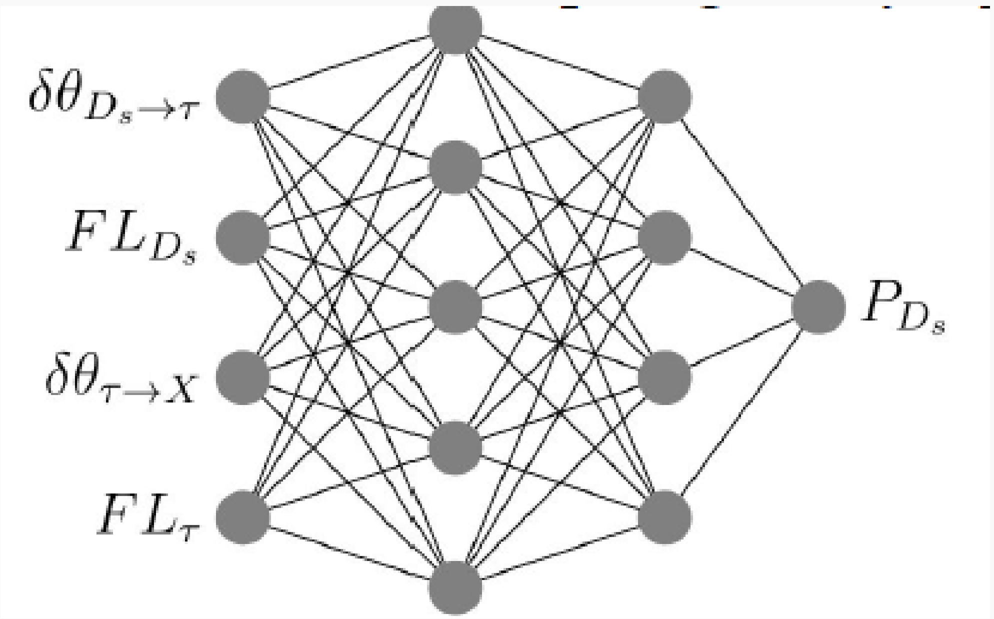
$$P_{BG}^{charged} = 1.3 \pm 0.4 \times 10^{-9} / \text{proton}$$
$$P_{BG}^{neutral} = 2.7 \pm 0.8 \times 10^{-9} / \text{proton}$$

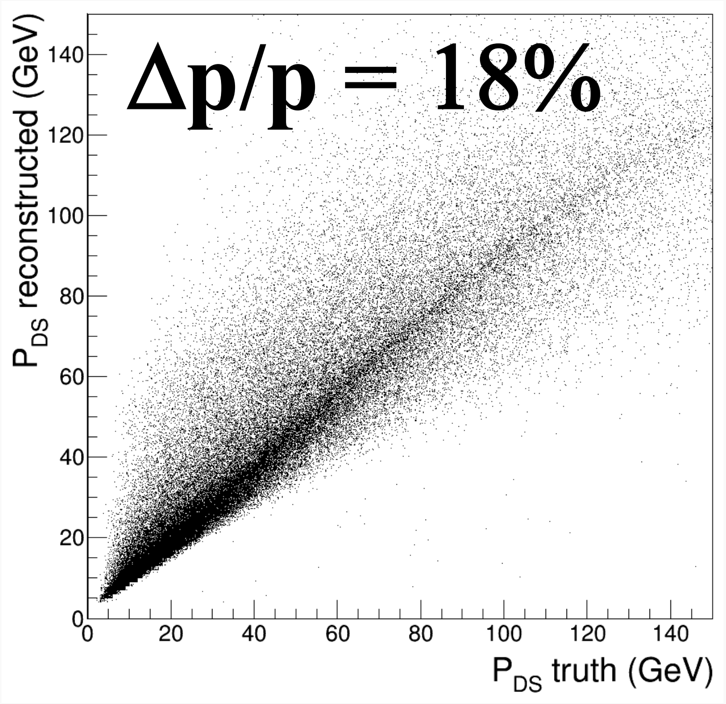
# $D_s$ momentum reconstruction

- **Difficult to measure $D_s$ momentum directly due to short lifetime**
- **Reconstruct the momentum using Artificial Neural Network (ANN) with 4 variables**

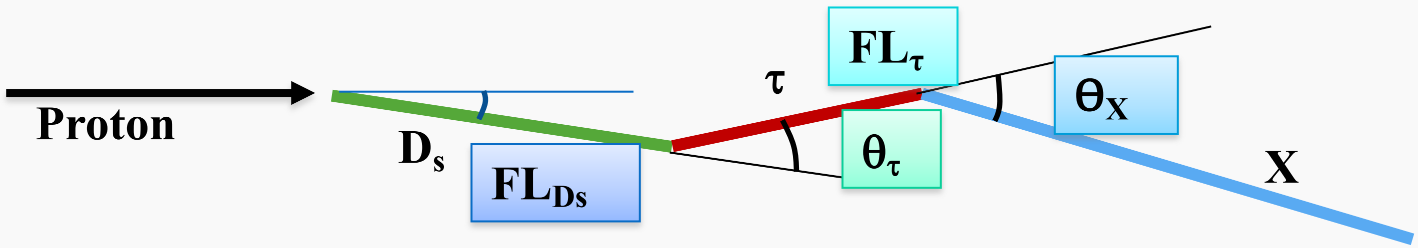
**MC with 400 GeV beam**



# Efficiency of $D_s$ detection



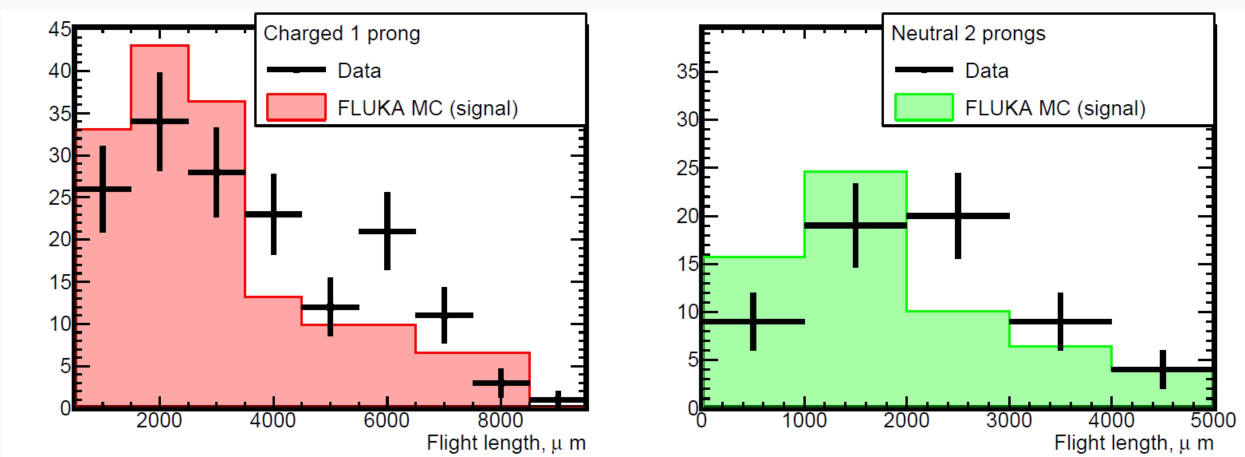

| Selection Criteria | Efficiency (%) |
|---|---|
| (1) Flight length of $D_s \geq 2$ emulsion layers | 77 |
| (2) Flight length of $\tau \geq 2$ layers & $\Delta\theta(D_s \rightarrow \tau) \geq 2$ mrad | 43 |
| (3) Flight length of $D_s < 5$ mm & flight length of $\tau < 5$ mm | 31 |
| (4) $\Delta\theta(\tau) \geq 15$mrad | 28 |
| (5) Pair charm: 0.1 mm < flight length < 5 mm<br>(charged decays with $\Delta\theta > 15$ mrad or neutral decays) | 20 |

# Data Analysis: Pilot Run (2018)

## Search for double charm events in pilot data

- Emulsion readout was completed & data reconstruction is going on.
- 3.4253301 x $10^7$ injected protons (2% of Pilot run) were analyzed
- 2.72120 x $10^5$ proton interactions (1.47236 x $10^5$ tungsten int) detected
- 159 (115 tungsten int) events with charm pair

| | Observed | Expected | |
|---|---|---|---|
| | | Signal | Background |
| Double Decay Topology | 115 | 80.1±19.2 | 12.7±5.0 |




*JHEP* **01 (2020) 033**

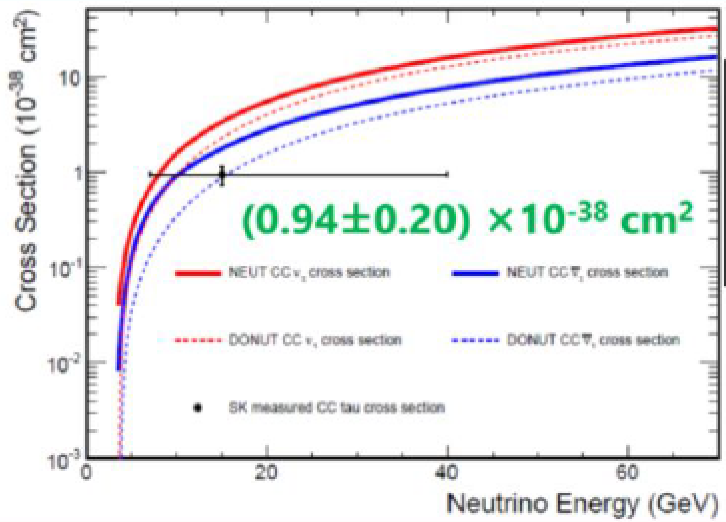
# $\nu_\tau$ cross section measurement by oscillated neutrinos

## SK

Atmospheric

$\nu_\mu \rightarrow \nu_\tau$ & $\overline{\nu}_\mu \rightarrow \overline{\nu}_\tau$

$\sigma_{meas}=(1.47 \pm 0.32)\ \sigma_{theory}$




arXiv:1711.09436

Presented 1st day by Guillaume Pronost

## OPERA

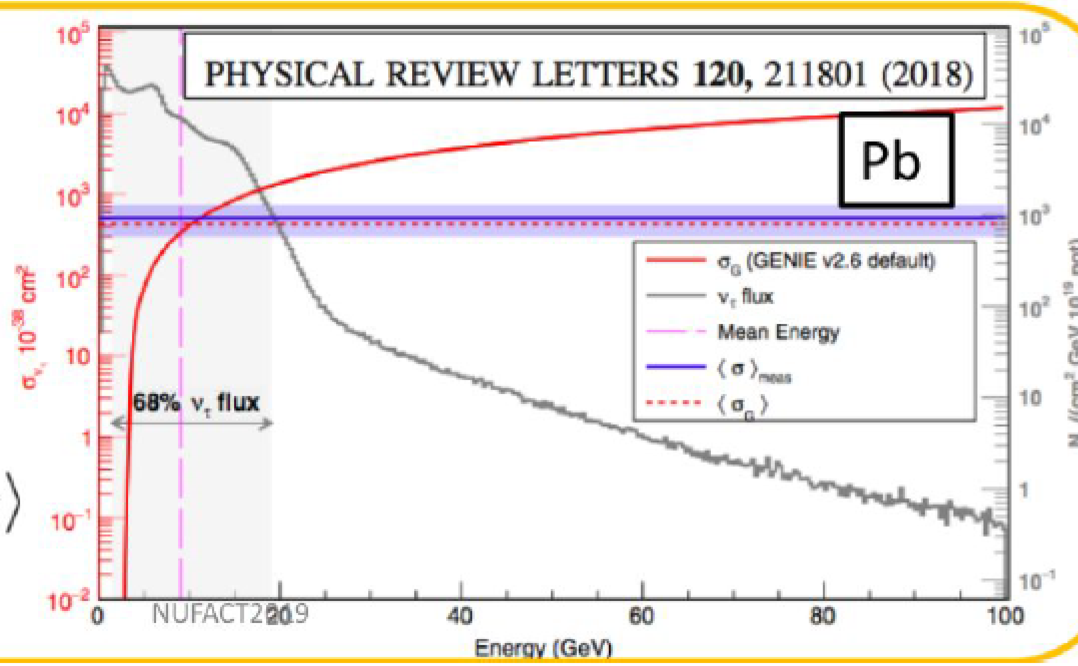
CNGS $\nu_\mu$ beam

$\nu_\mu \rightarrow \nu_\tau$

$\sigma$ with a Pb nucleus

$\langle\sigma\rangle_{\rm meas} = (5.1^{+2.4}_{-2.0}) \times 10^{-36}\ {\rm cm}^2.$

$$\langle\sigma\rangle_{meas} = (1.2^{+0.6}_{-0.5})\ \langle\sigma_G\rangle$$

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