# Status of NA65(DsTau) data taking and analysis

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On behalf of the DsTau Collaboration

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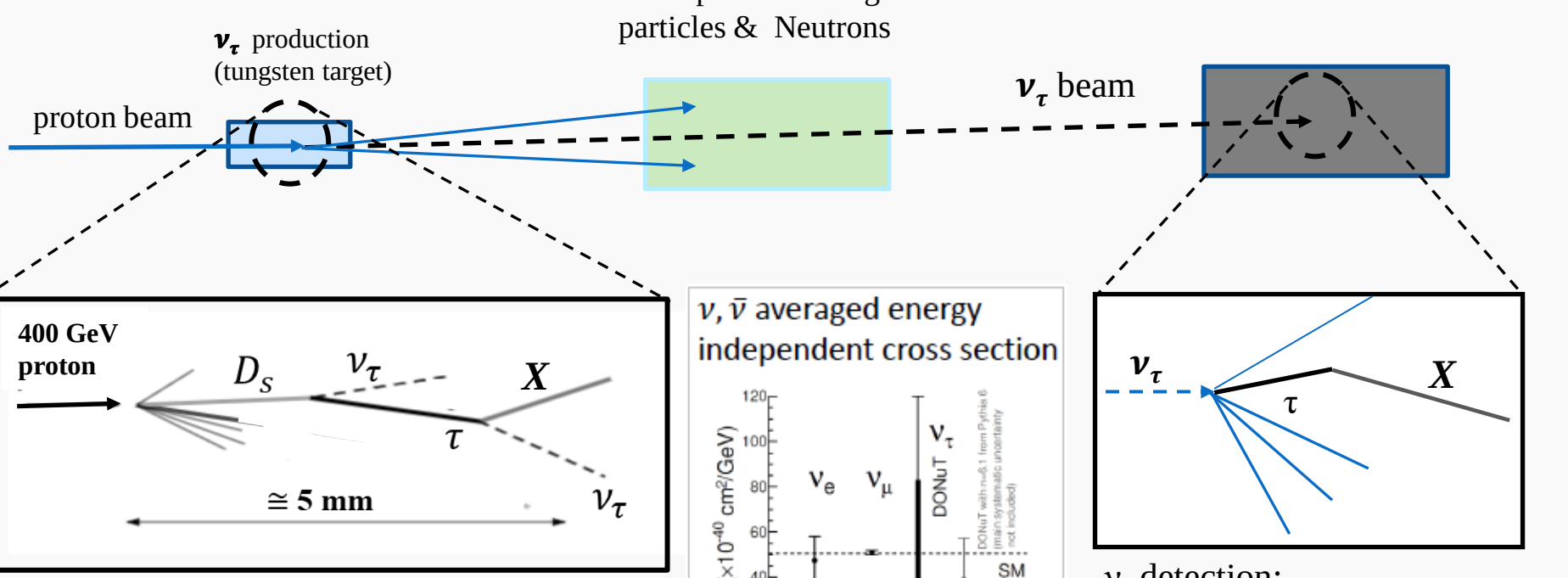
# DsTau: Physics Motivations

- Tau neutrino is the least studied particle of the Standard Model.
  - $\nu_\tau$ beam : DONuT (9 $\nu_\tau$ events )
  - oscillated $\nu_\tau$ : OPERA, Super-K, IceCube
  - $\nu_\tau$ cross section error >50% (DIS) due to systematic uncertainty in $\nu_\tau$ production

**$\nu_\tau$ source: $D_s \rightarrow \tau \rightarrow X$**



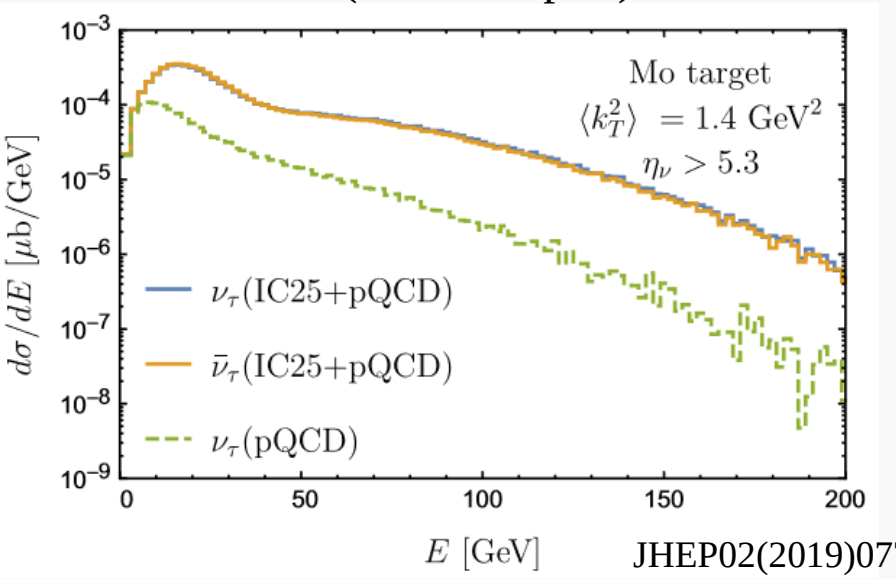

$\nu_\tau$ production study: DsTau

$\nu_\tau$ detection:
SND@LHC, FASER, SHiP etc.

# DsTau: Physics Motivations

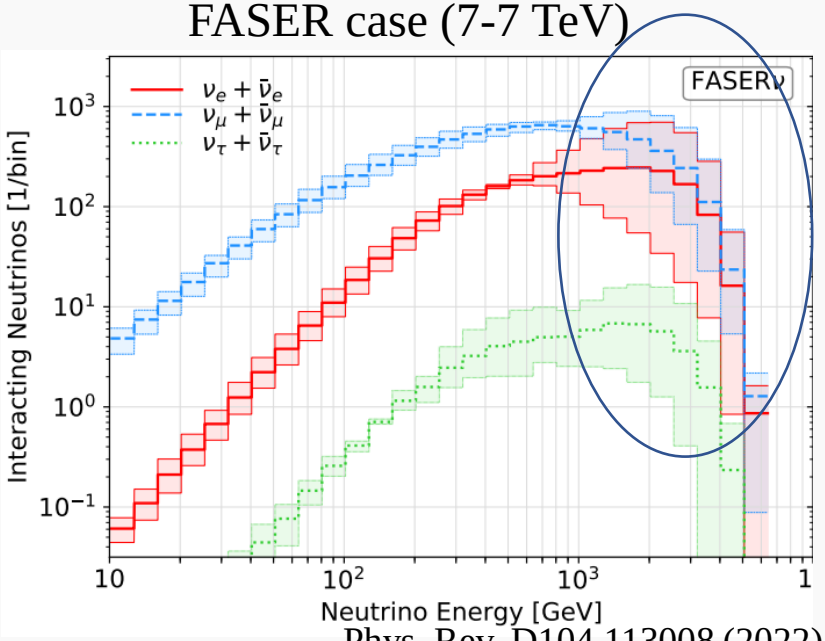
- First measurement of Ds differential production cross section
- Forward charm physics, intrinsic charm component in proton
  - Large theoretical uncertainity for forward charm production
    - Intrinsic charm content of proton can affect $\nu_\tau$ flux.
  - $\nu_\tau$ flux may change by a factor of ~10
  - Neutrino experiments needs data on forward charm production !
- Detailed understanding $\nu_\tau$ production allows measuring precise cross-section
  - Reduce uncertainty of $\nu_\tau$ flux from >50% to 10% <
  - Test of Lepton Universality in neutrino scattering

SHiP case (400 GeV p-N) interaction




JHEP02(2019)077

FASER case (7-7 TeV)



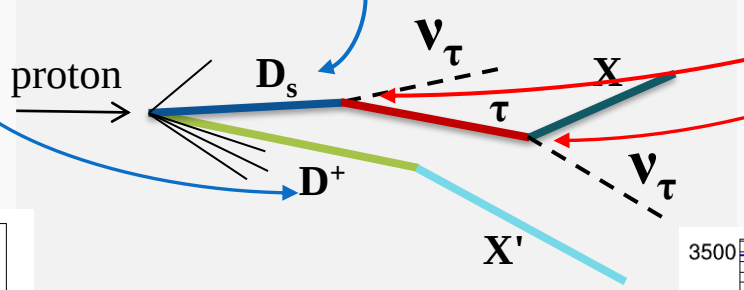

Phys. Rev. D104.113008 (2022)

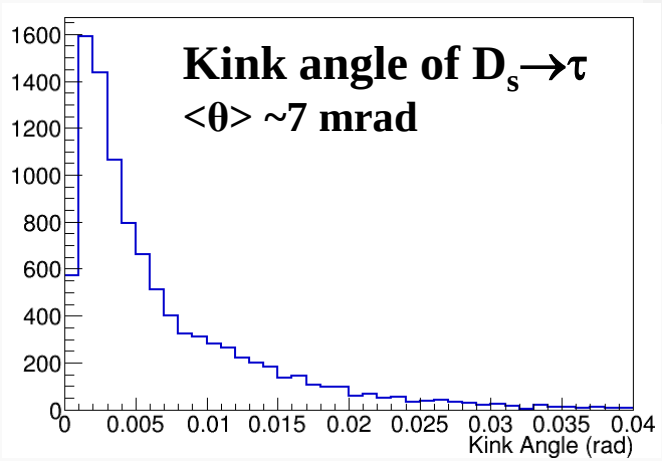
# DsTau: Unique Signature

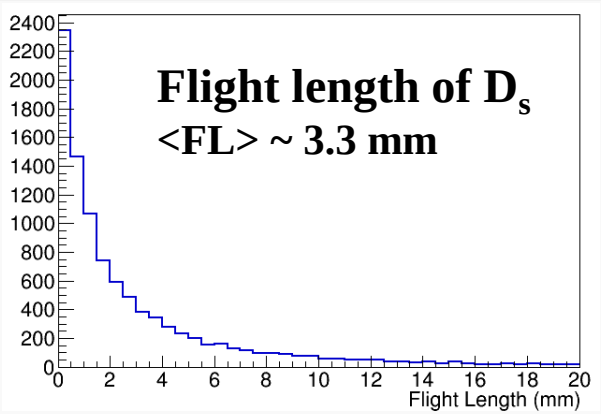
Double charm hadron production

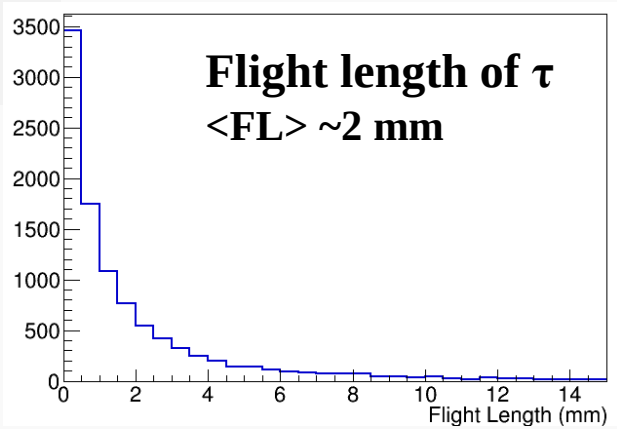
Double kink topology

Small kink @ $D_s \rightarrow \tau$



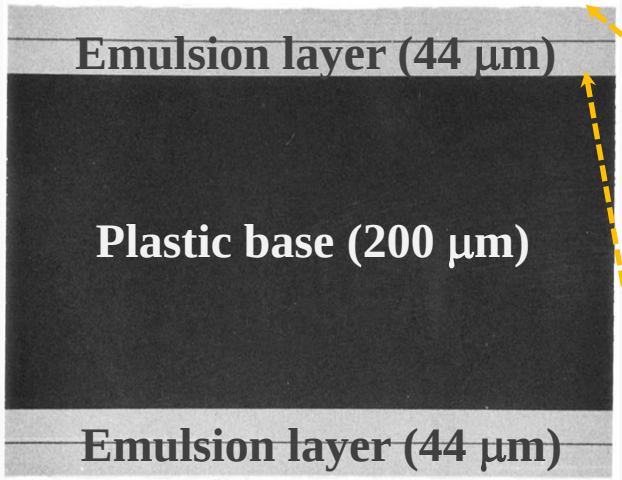

- 4.6 × $10^9$ protons, **$2.3 \times 10^8$** proton interactions in target (tungsten & molybdenum),
- **~$10^5$ charm pairs** & ~$10^3$ $D_s \rightarrow \tau \rightarrow X$ decays can be detected.

# Emulsion detector

- Among the available detector technologies, only nuclear emulsion can provide **a sub-micron three dimensional spatial resolution**, which gives us a sub mrad three-dimensional angular resolution

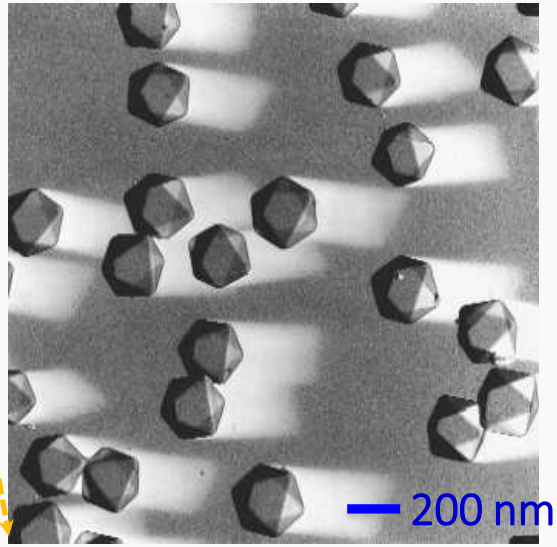
**Emulsion film**


**Cross-sectional view**



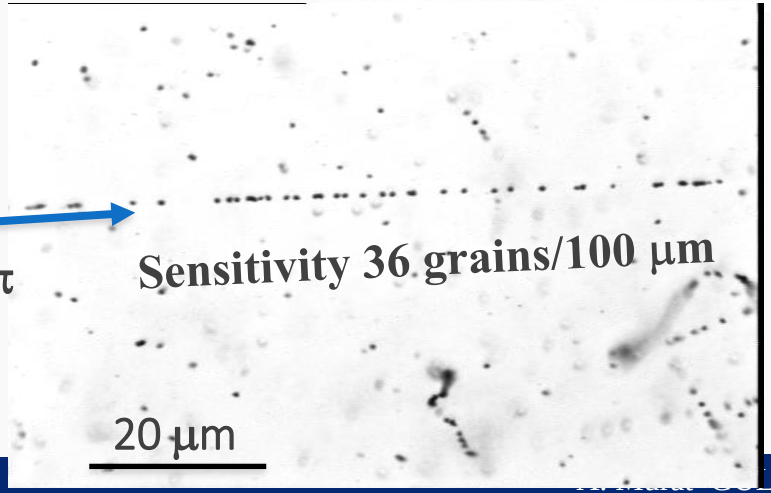

**AgBr crystal**

**$10^{14}$ crystals in a film**

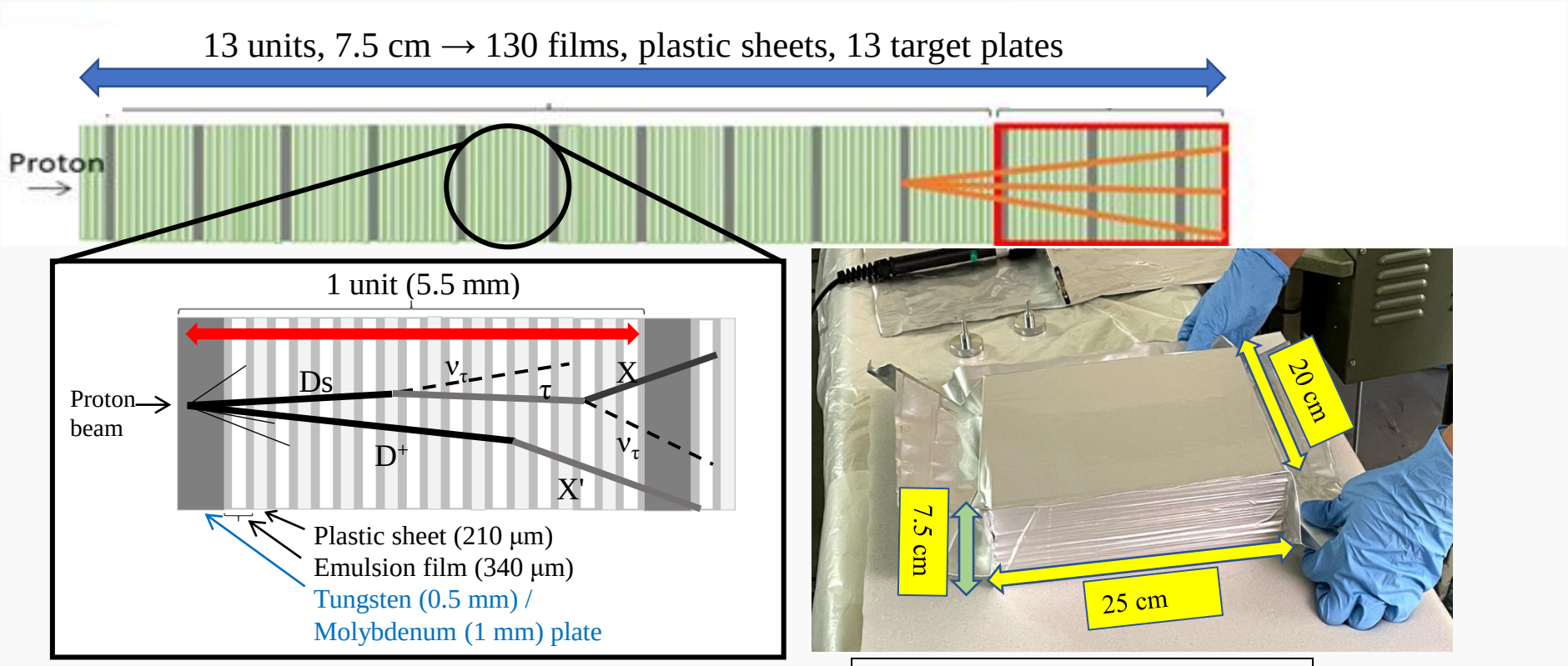



**3D tracking device**

**10 GeV/c π beam**



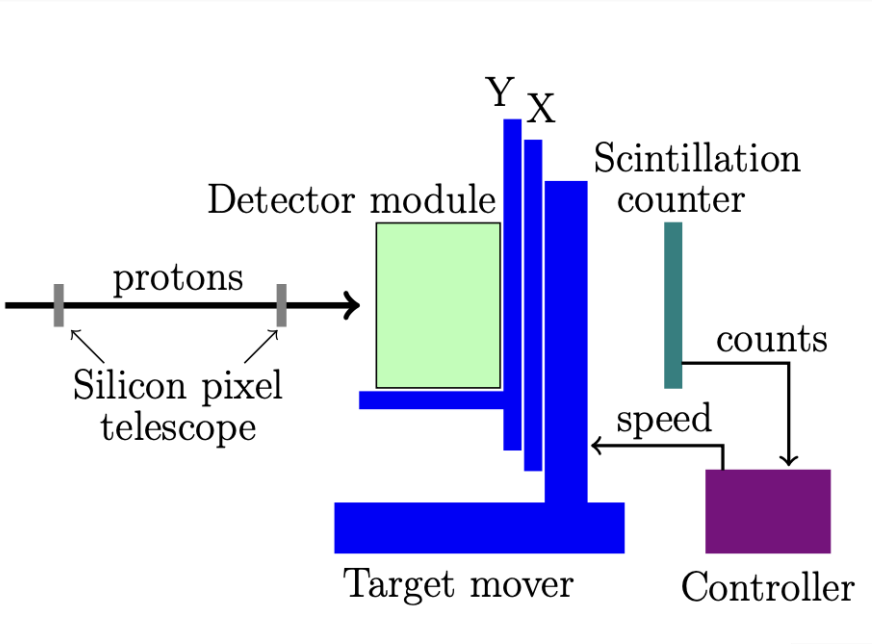
# The DsTau Detector



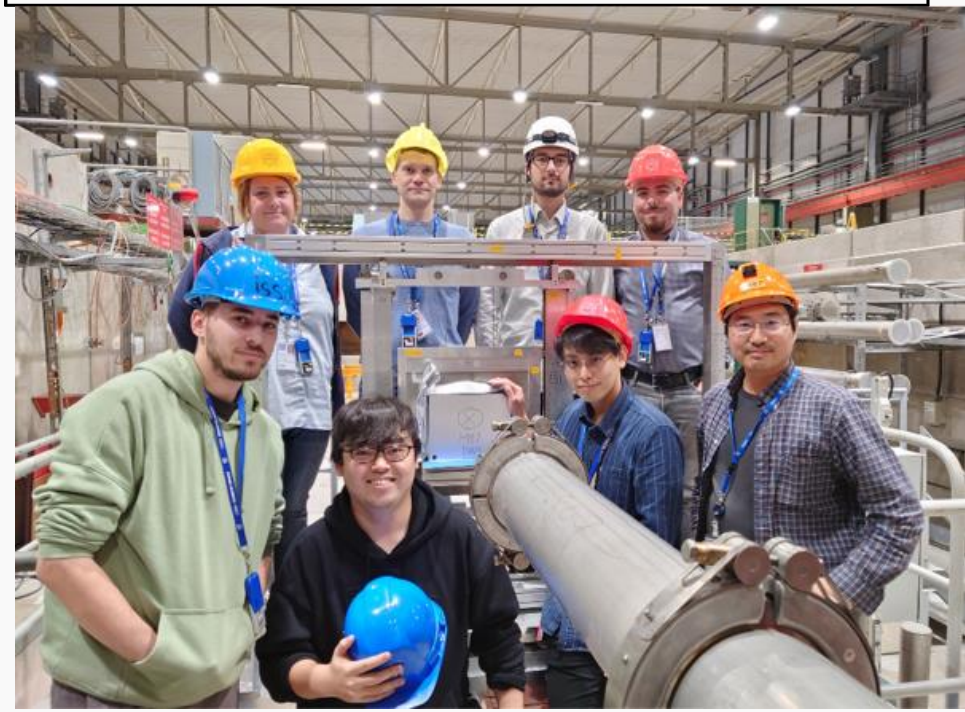

Size of module since 2021

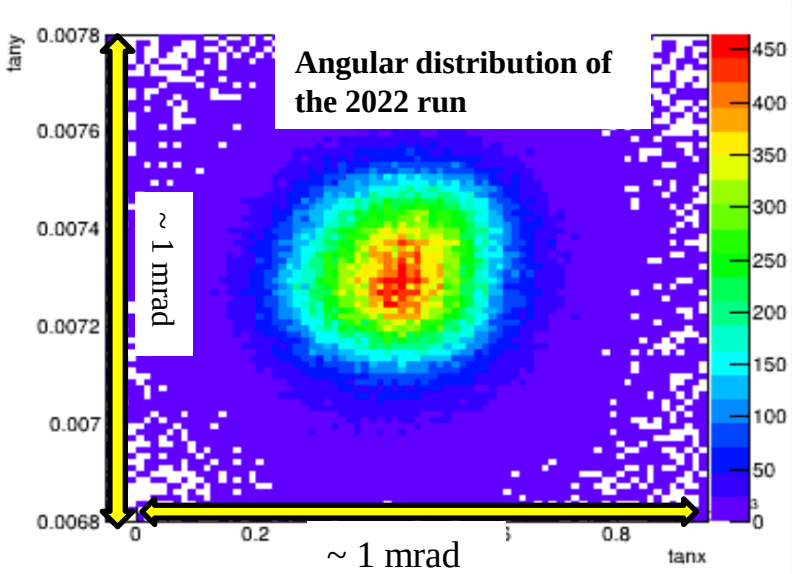
- Original structure had more material (2018 pilot run) → too high track density in ECC
  - Dedicated scanning is required
- Reduce material (without ECC), but sufficient performance
- Making data taking procedure simple

# Data Taking 2022




- **Beam condition**
  - Energy : 400 GeV proton
  - Size : $\sigma_x \approx 7.2$ mm, $\sigma_y \approx 10.0$ mm
- Intensity : $\approx 4.5 \times 10^5$ protons/spill
- Data taking rate $\approx$ 100 kHz






- 17 modules exposed
  1~4 hours / module

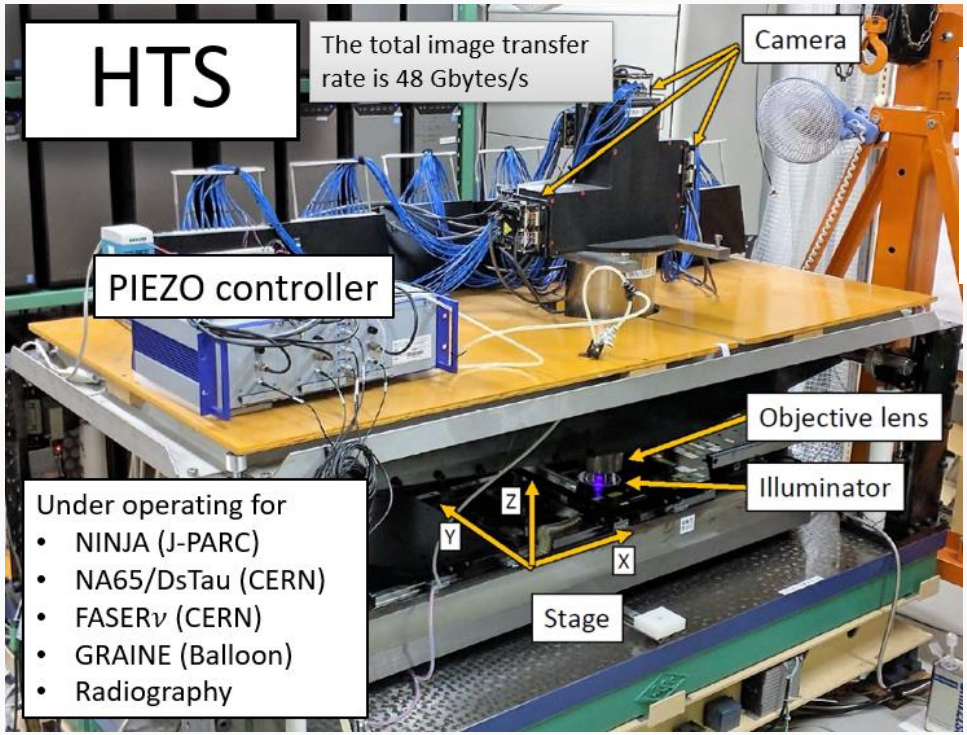
# Emulsion Processing

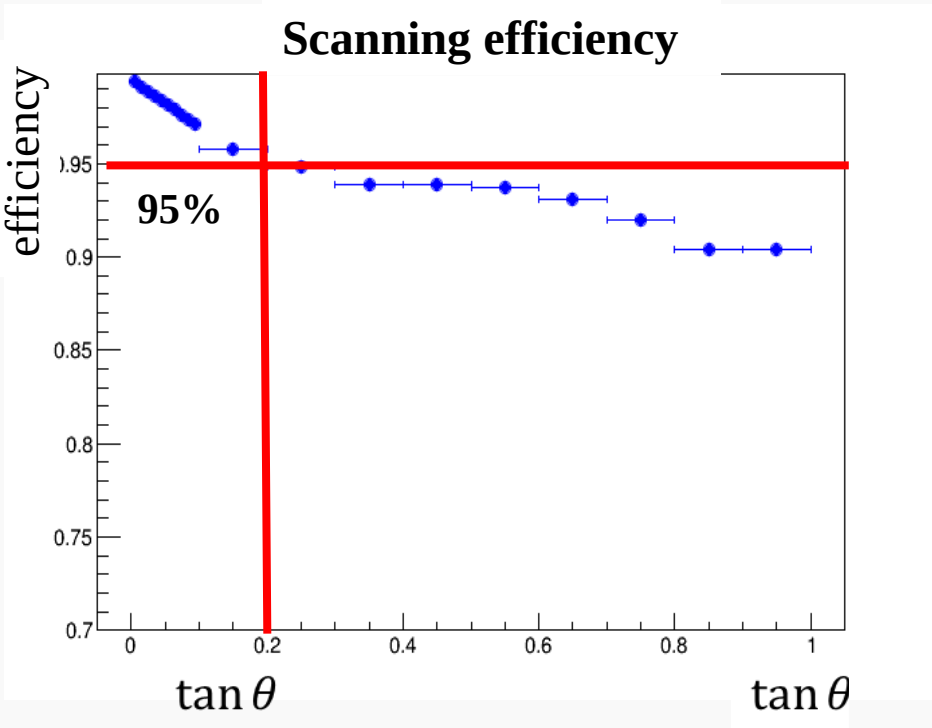
- Emulsion facility at CERN was upgraded (2022)
- 150~300 films per day

# Emulsion Readout

- **High speed readout by the Hyper Track Selector (HTS) in Nagoya University**
  **40~50 min per 1 film** ($20\ \mathrm{cm} \times 25\ \mathrm{cm} \times 2\ (both\ sides) = 1000\ \mathrm{cm}^2$)
  >

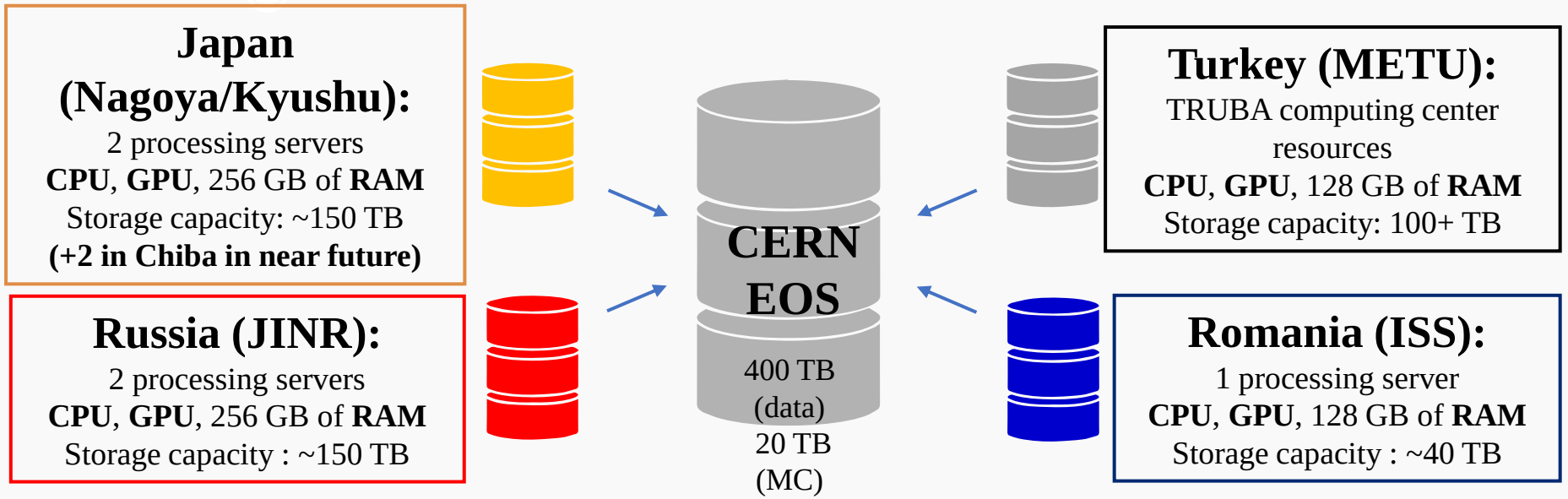
**Angular resolution ~2 mrad**



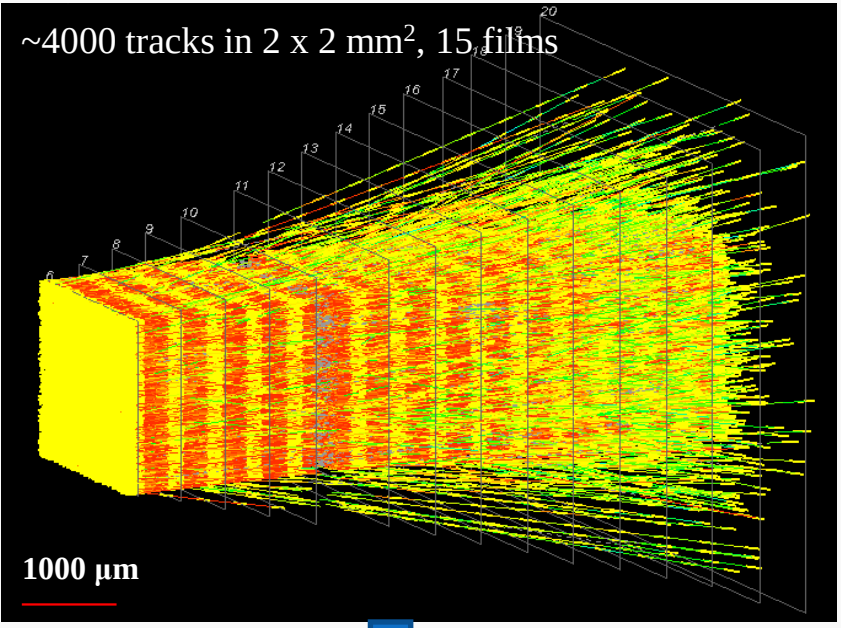
# Data processing

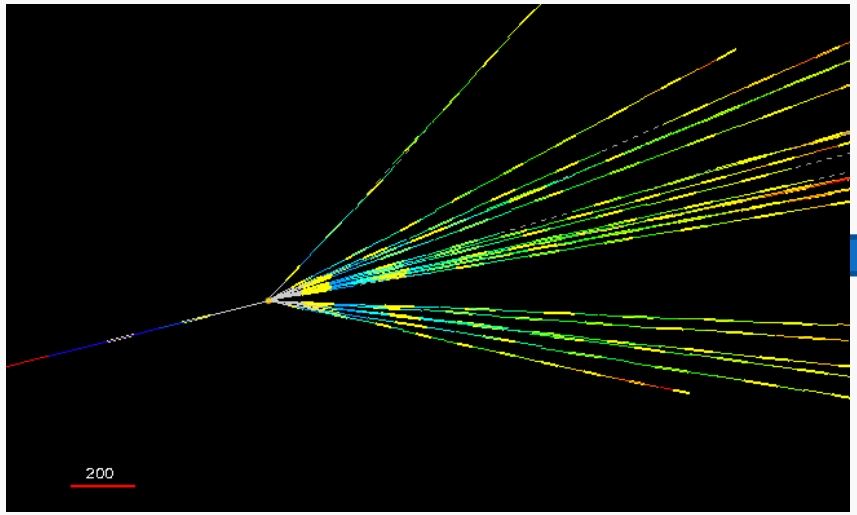
- Reconstruction procedures require powerful processing servers with CPU/GPU and high memory (~128-256~GB of RAM) and disk space (~10~TB for each data module) resources.
- Distributed data processing is being done gradually. All modules of 2018 run have been fully processed.



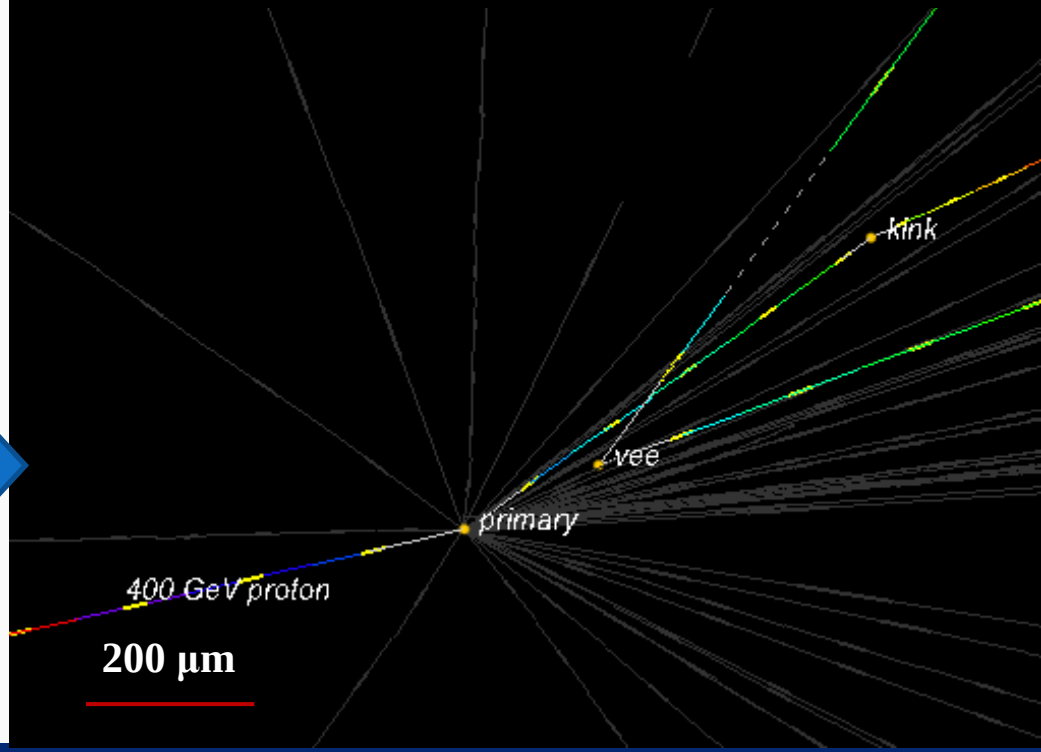

- Batch system of the CERN computing center is also used to process physics run data.

# Reconstructed Double Decay vertices



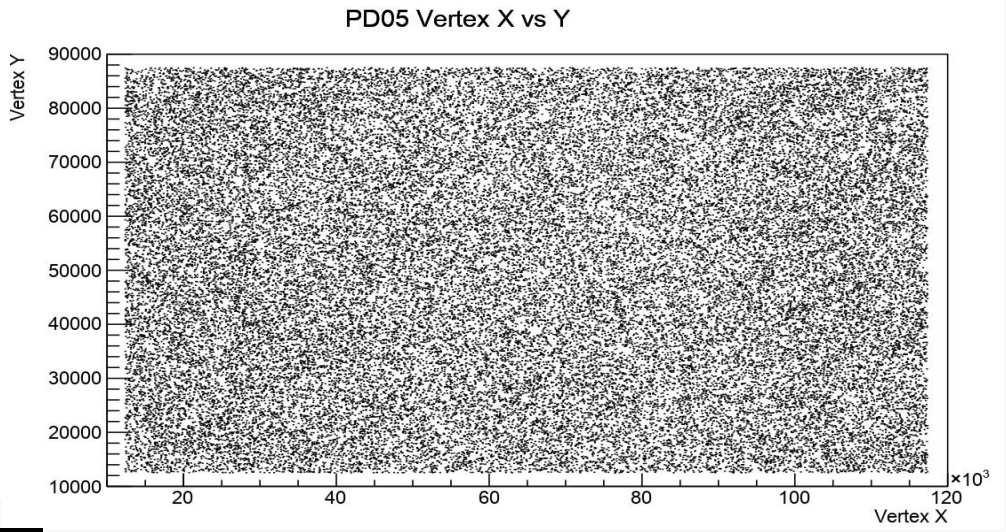

- Kink
  - IP of daughter 291.6 µm
  - FL 2536.6 µm
  - kink angle 118 mrad
- Vee
  - IP of daughters 20.9, 109.7 µm
  - FL 554.5 µm
  - Opening angle 242 mrad

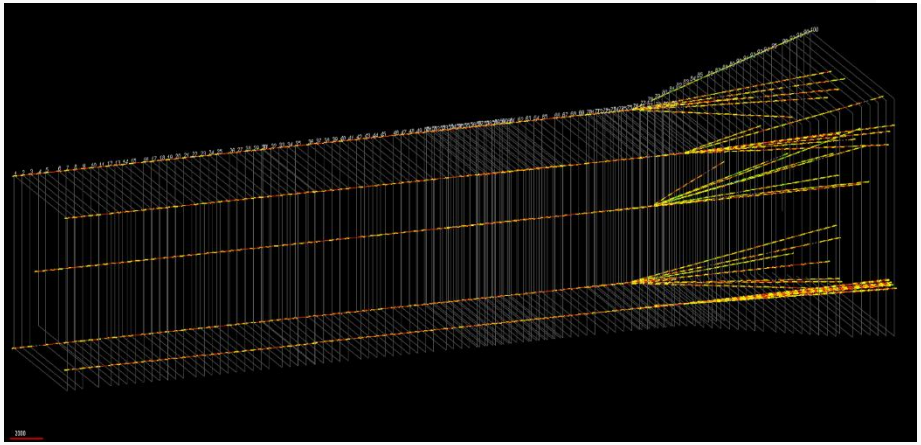


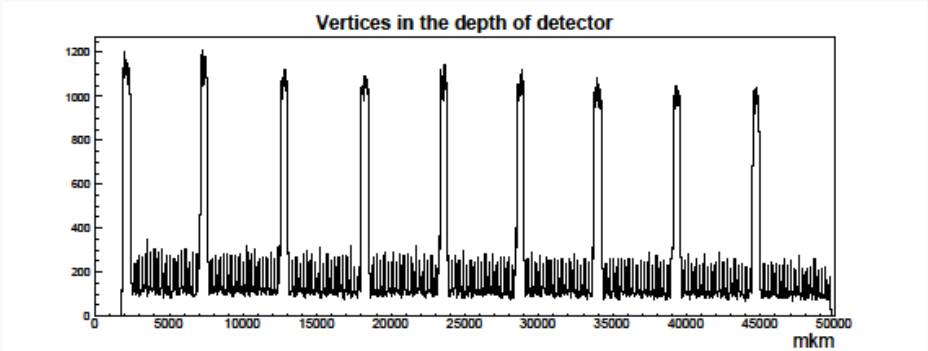
# Study of Proton interaction in tungsten

- For the present analysis, a sample of ~100k proton interaction in the tungsten plates are used from a single module of the pilot run data.

| Tungsten | N | $N_0$ | $N/N_0$ (%) |
|---|---|---|---|
| 1 | 14,883 | 4,063,335 | 0.37 |
| 2 | 14,680 | 4,004,765 | 0.37 |
| 3 | 13,951 | 3,922,567 | 0.36 |
| 4 | 13,601 | 3,833,913 | 0.35 |
| 5 | 13,132 | 3,732,000 | 0.35 |
| 6 | 12,174 | 3,615,423 | 0.34 |
| 7 | 11,859 | 3,485,434 | 0.34 |
| 8 | 10,702 | 3,335,090 | 0.32 |



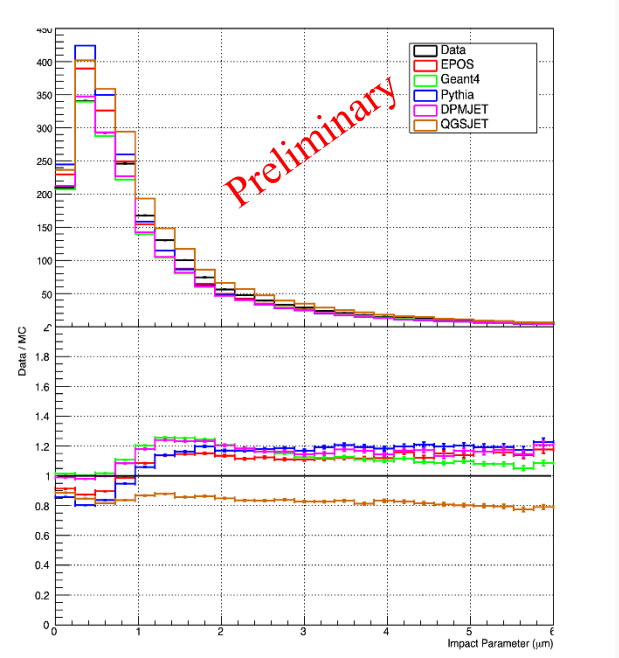



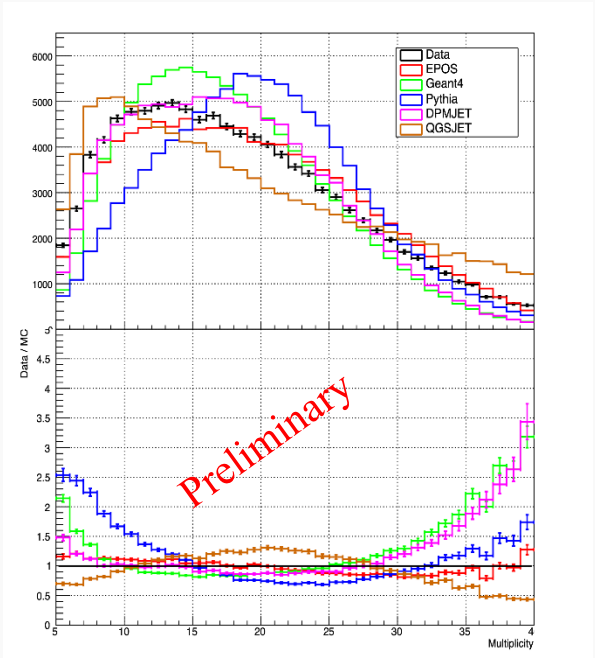


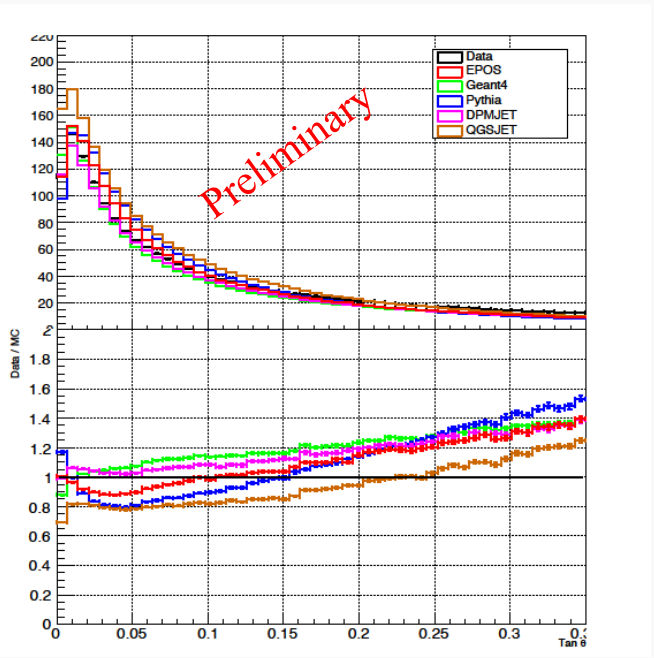
# Study of Proton interaction in tungsten

- The proton track and vertex reconstruction efficiencies are evaluated with making a detailed simulation of the detector response using GEANT4. The simulated geometry set as for 2018 pilot run setup.

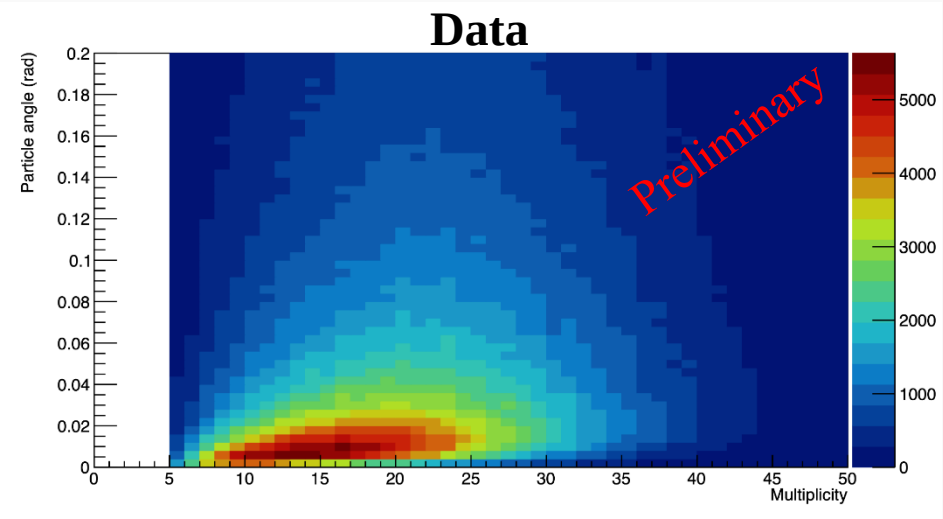
- A large number of proton interactions are generated using **EPOS**, **PYTHIA8**, **QGSJET**, **DPMJET**, and **GEANT4.11** generators by considering the realistic beam proton density in a module.

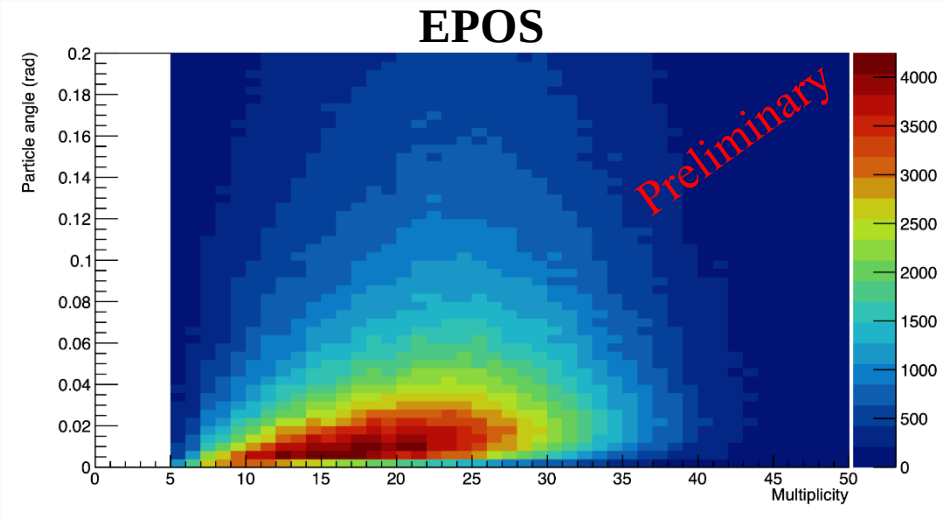


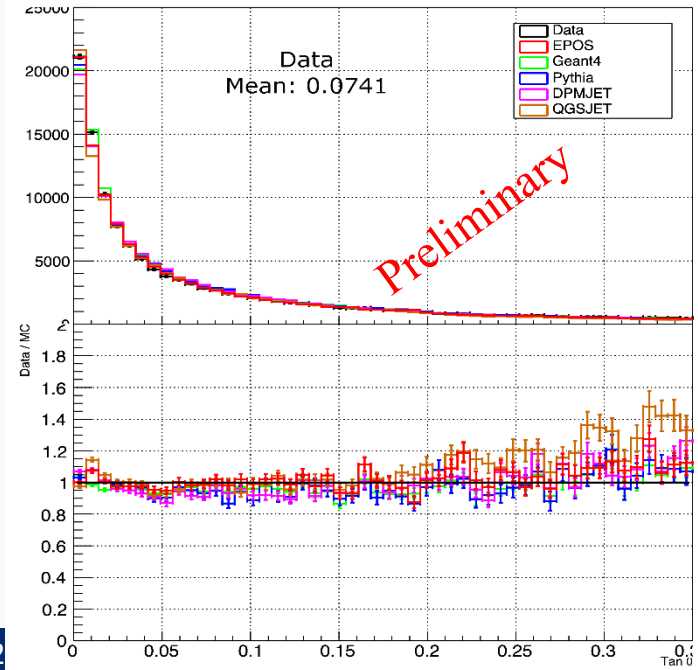



# Average angle dependence on multiplicity

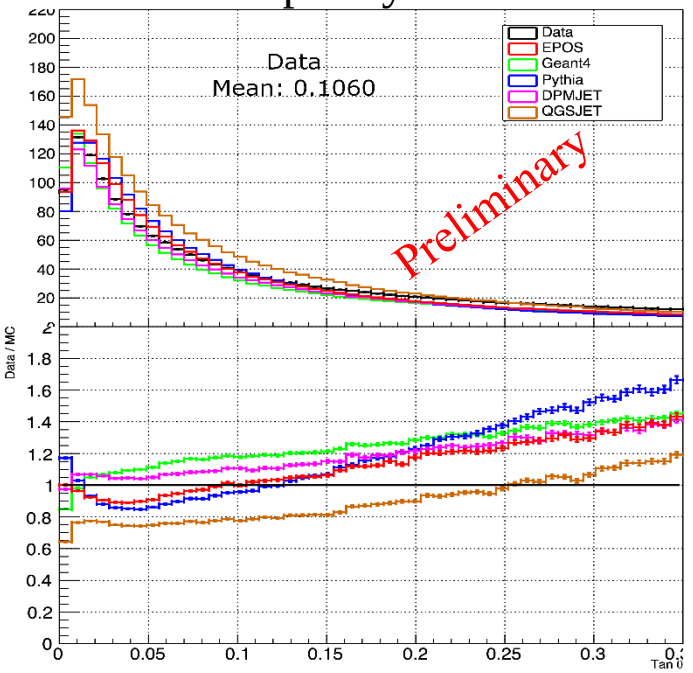



Multiplicity < 10



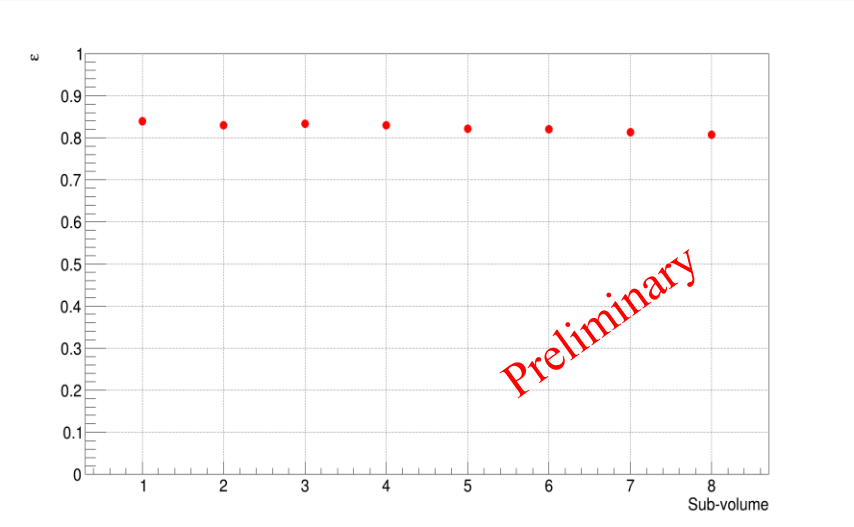

Multiplicity >=10



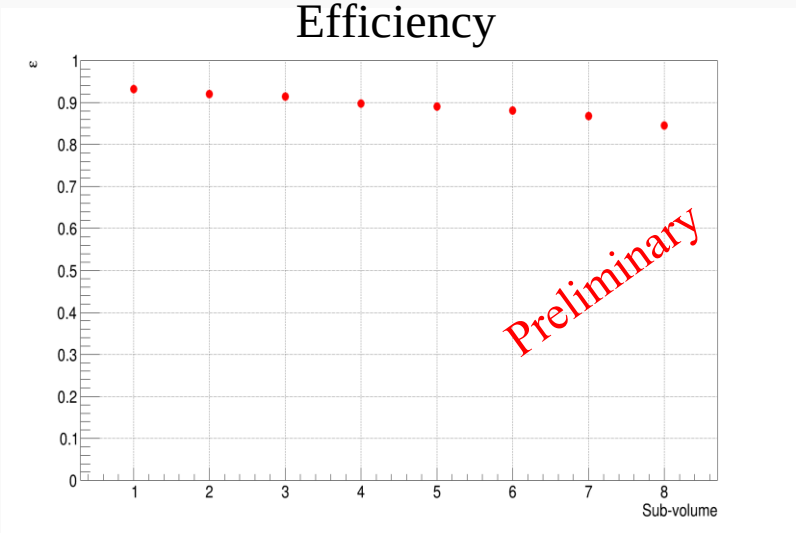
# Efficiency Estimation

- Among event generators, EPOS predictions are in good agreement with data within 10 %.
- Efficiencies of vertex reconstruction and proton-linking are estimated using EPOS
- Proton purity for proton selection measured as 96 ± 0.2%

Vertex reconstruction Efficiency

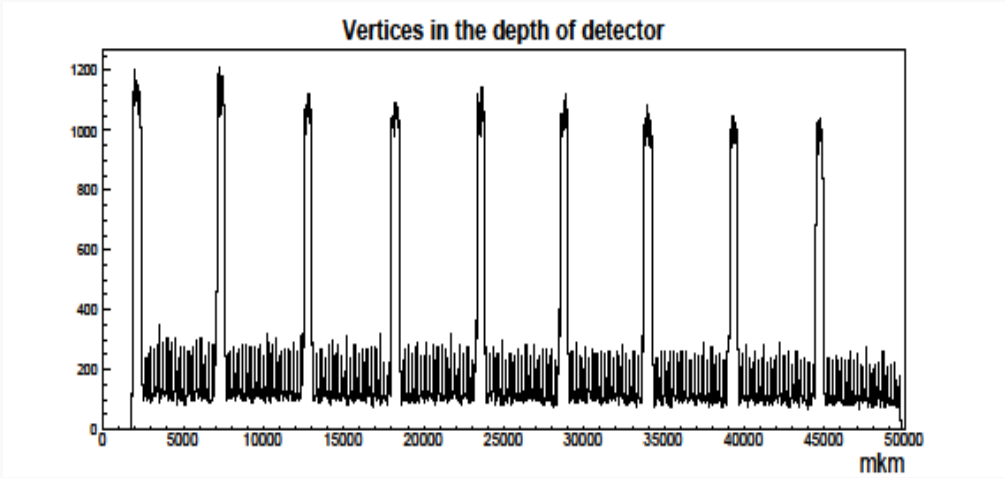



Proton track reconstruction Efficiency



# Proton Interaction Length in Tungsten/Polystyrene

- The ratio of proton interactions in Tungsten and Polystyrene is obtained by a fit to the measured vertex position in beam direction with a function which is a convolution of Gaussian and box functions.




| Sub-volume | $N_W/N_{pl}$ |
|---|---|
| 1 | 9.07±0.01 |
| 2 | 9.07±0.01 |
| 3 | 9.01±0.01 |
| 4 | 9.16±0.01 |
| 5 | 9.29±0.01 |
| 6 | 8.79±0.01 |
| 7 | 9.32±0.01 |
| 8 | 9.73±0.01 |
| Mean | 9.18±0.01 |

# Proton Interaction Length in Tungsten

**Data**

| Sub-volume | Tungsten (mm) | Polystyrene (mm) |
|---|---|---|
| 1 | 108.6±3.7 | 789.6±27.1 |
| 2 | 107.2±3.7 | 799.2±27.4 |
| 3 | 111.1±3.8 | 813.8±28.0 |
| 4 | 110.9±3.8 | 842.6±29.0 |
| 5 | 110.7±3.8 | 836.7±28.8 |
| 6 | 115.5±4.0 | 839.8±28.9 |
| 7 | 113.3±3.9 | 871.8±30.0 |
| 8 | 119.3±4.1 | 950.3±32.8 |

Preliminary

**Geant4 based MC**

| Sub-volume | Tungsten (mm) | Polystyrene (mm) |
|---|---|---|
| 1 | 102.7±3.4 | 746.8±24.4 |
| 2 | 104.9±3.4 | 780.2±25.5 |
| 3 | 106.2±3.5 | 778.1±25.4 |
| 4 | 107.5±3.5 | 816.5±26.7 |
| 5 | 108.0±3.5 | 816.4±26.7 |
| 6 | 108.3±3.6 | 787.5±25.8 |
| 7 | 110.7±3.6 | 852.2±27.9 |
| 8 | 113.1±3.7 | 901.1±29.5 |

Preliminary

# Summary

- The DsTau experiment aims to decrease $\nu_\tau$ production uncertainty.
- A sub sample of the pilot run data is analysed to study the proton interactions in Tungsten.
- Proton interaction length in tungsten is measured for the first time.
  - The results will be submitted for a publication
- The analysis of physics run data is going on.
- 2023 physics run was scheduled in September.

# DsTau Collaboration

**Japan**:
Aichi
Chiba
Kobe
Kyushu
Nagoya

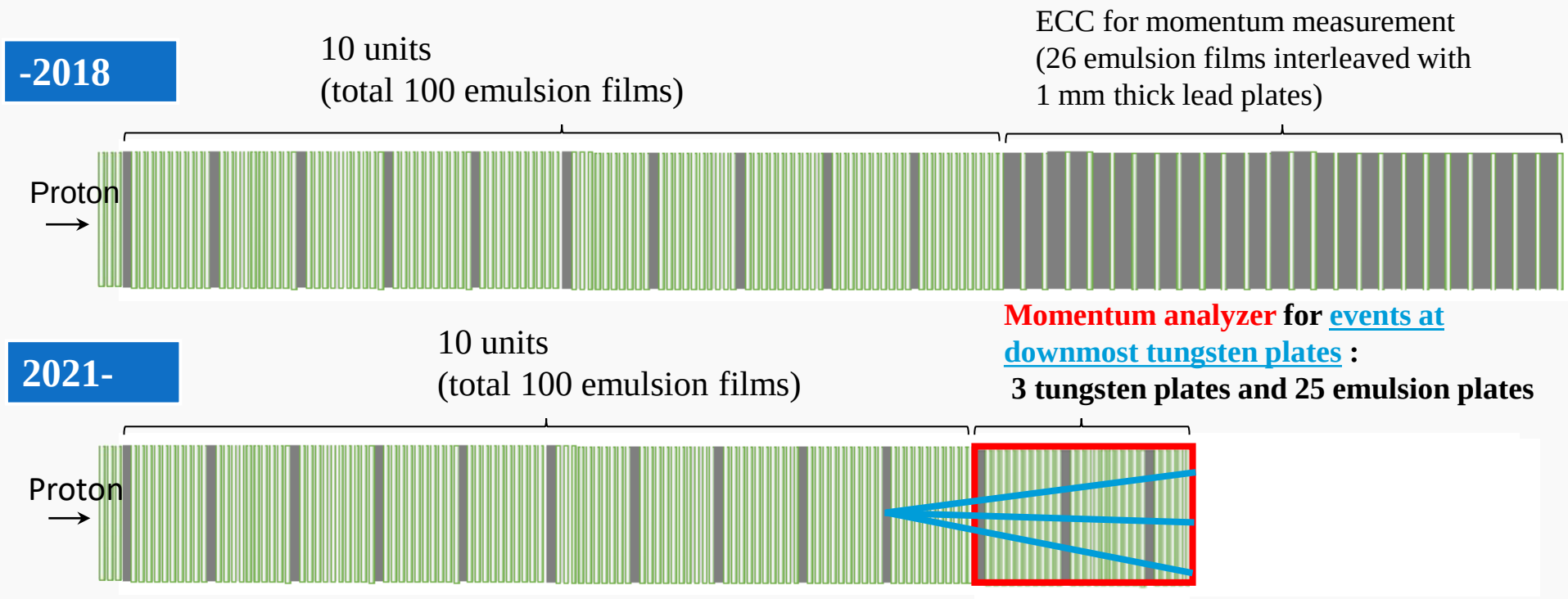
**Switzerland**:
Bern

**Romania**:
Bucharest

**Russia:**
Dubna

**Turkey:**
METU

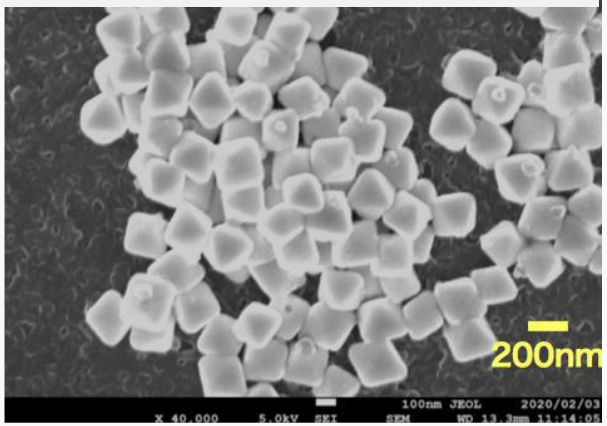
# Concept of $D_s \rightarrow \tau \rightarrow X$ Detection



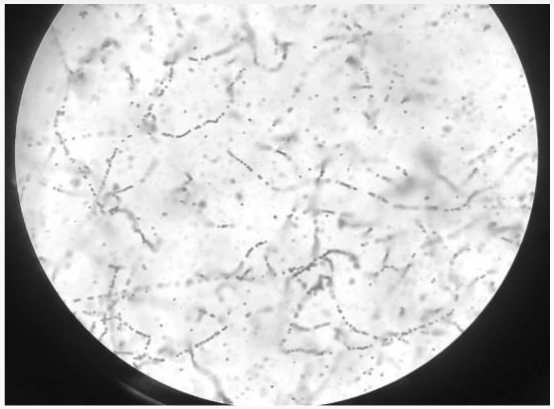

- Original structure had more material → too high track density in ECC
  - Dedicated scanning is required
- Reduce material, but sufficient performance
- Making data taking procedure simple

# Emulsion Production

Electron microscop view




Sensitivity of new emulsions confirmed



25cm x 20cm

Film production facility

# Tracking & Vertexing

- The first step of the reconstruction is to form base-tracks by linking the micro-tracks found on the both sides of emulsion films.
- Film to film alignment is performed by applying the base-tracks pattern matching.
- Base-tracks are connected film by film according to angular and position acceptance to form volume tracks.
- Tracks containing a set of at least four connecting base-tracks are used for the vertexing
- In order to have a purity in the vertex reconstruction, a vertex with more than four tracks are in use for further analysis.
- Beam protons are followed down to have a full module reconstruction.
- Decay search has been applied