Status and plans of the NA65/DsTau Experiment

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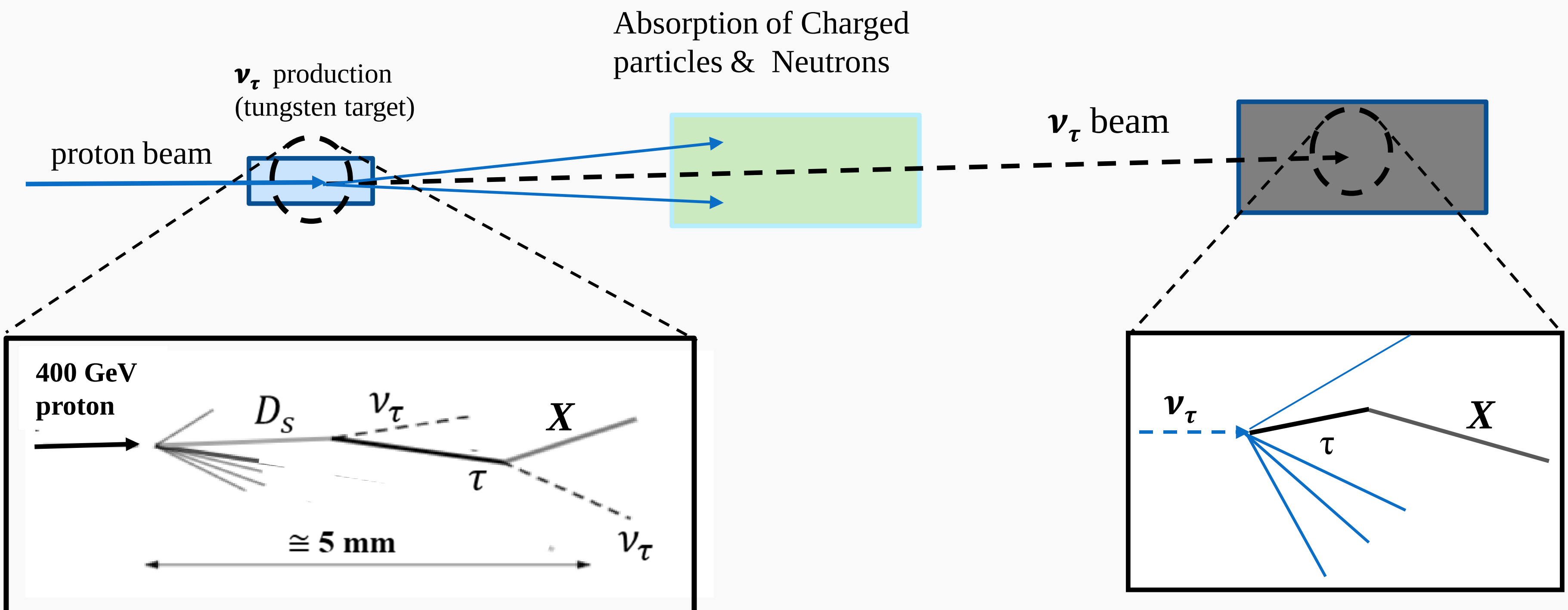
On behalf of the DsTau Collaboration

150th Meeting of the SPSC, CERN, 05.09.2023

DsTau: Physics Motivations

- Tau neutrino is the least studied particle of the Standard Model
  - $D_s \rightarrow \tau\nu_\tau$: DONuT (**9 ν_τ events**)
    - ν_τ CC DIS cross-section error > **50 %** due to systematic uncertainity in **ν_τ production**
  - $\nu_\mu \leftrightarrow \nu_\tau$: OPERA, Super-K, IceCube



ν_τ production: DsTau

ν_τ detection:
FASER , SND@LHC, SHiP …

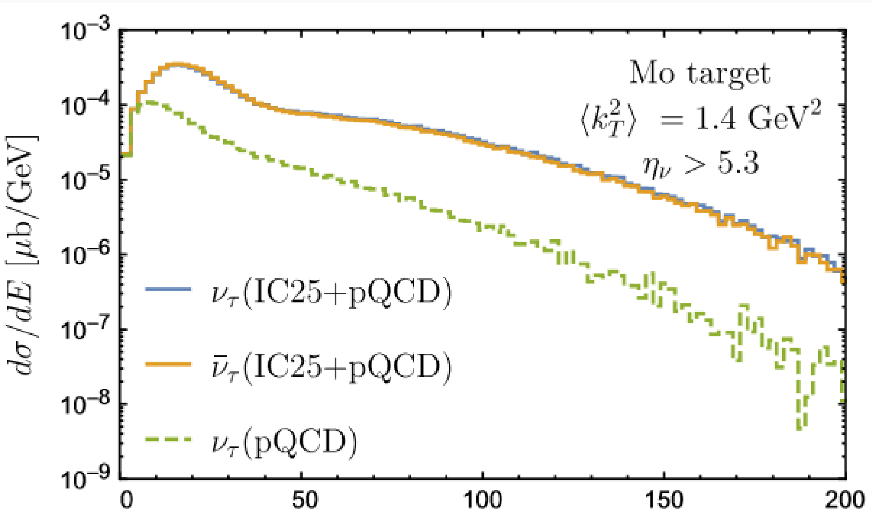
Reduce **ν_τ flux** uncertainty from **>50% to 10%**

Lepton Flavour Universality test in neutrino scattering

DsTau: Physics Motivations

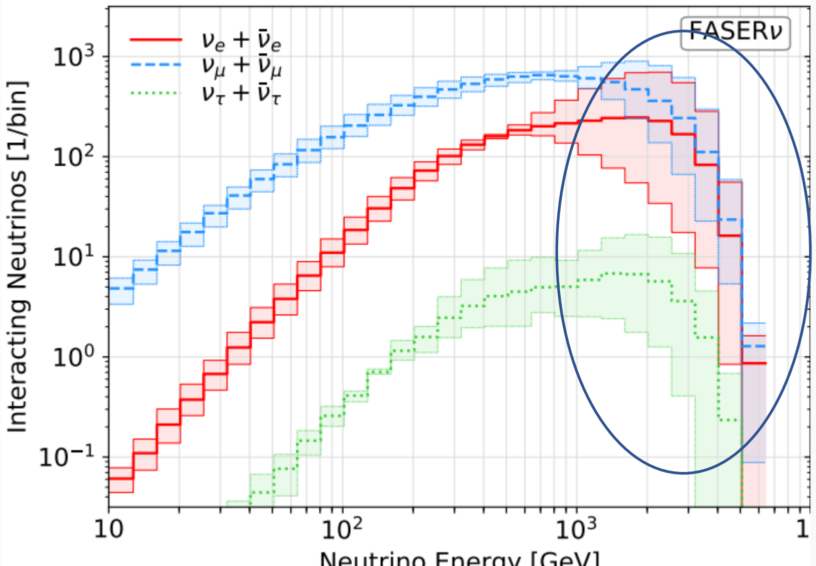
- Forward charm physics, intrinsic charm component in proton
  - Large theoretical uncertainity for forward charm production
    - Intrinsic charm content of proton can affect ν_τ flux.
    - **ν_τ flux** may change by a factor of ~**10**

SHiP case (400 GeV p-N) interaction



JHEP02(2019)077

FASER case (7-7 TeV)



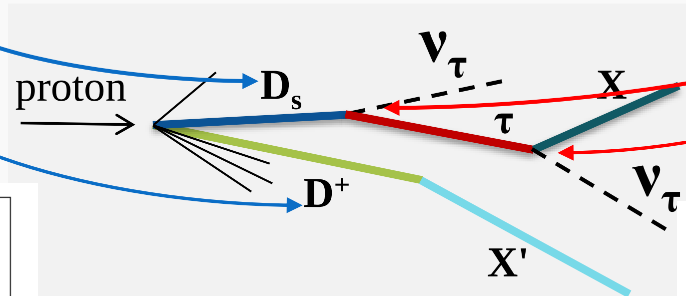
Phys. Rev. D104.113008 (2022)

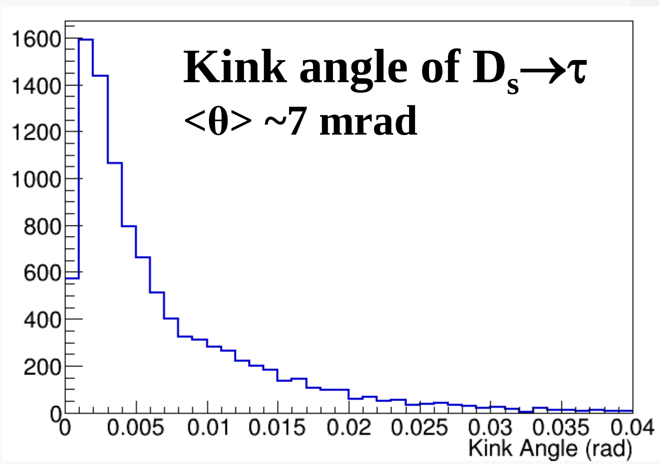
- Neutrino experiments need data on **forward charm** production in **p-A** interactions!
- DsTau: In **2.3x10^8** proton interactions, ~**10^5 charm pairs** & ~**10^3** $\boldsymbol{D_s \rightarrow \tau \rightarrow X}$ decays can be detected.

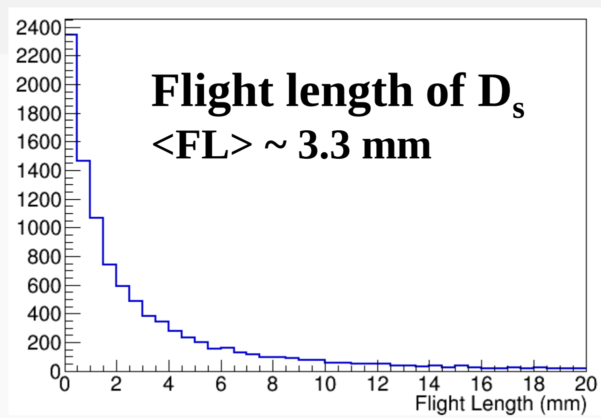
$D_s \rightarrow \nu_\tau \tau \rightarrow \nu_\tau X$ decay signature

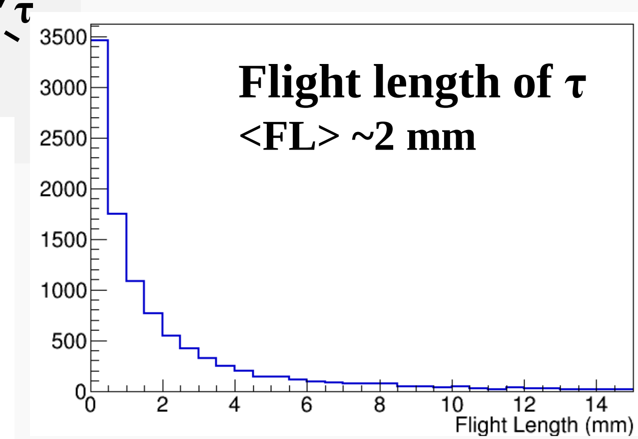
Double charm hadron production

Double kink topology



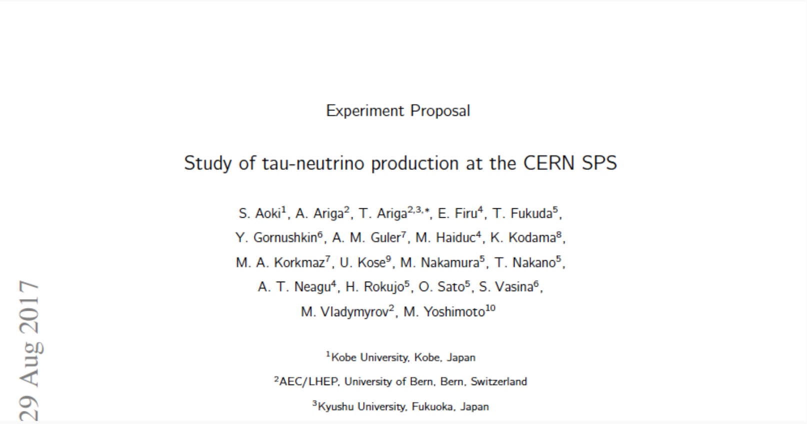






- **Among the available detector technologies only nuclear emulsion can provide required spatial and angular resolutions to detect Ds decays.**

DsTau: Timeline


29 Aug 2017

Experiment Proposal

Study of tau-neutrino production at the CERN SPS

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M. A. Korkmaz[7], U. Kose[9], M. Nakamura[5], T. Nakano[5],
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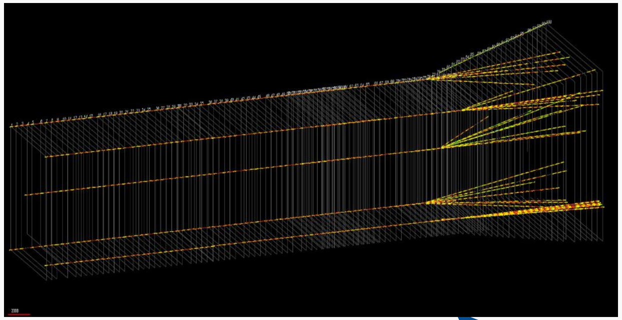


LOI in 2016

TP in 2017

Approved as NA65 in June 2019

Physics run in 2021

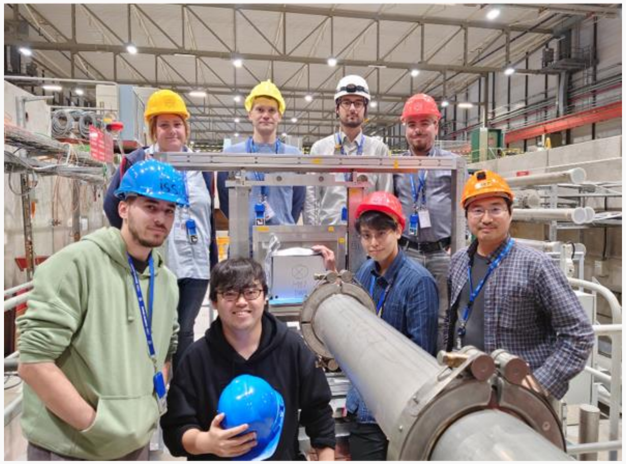
Physics run in 2022

Physics run in 2023

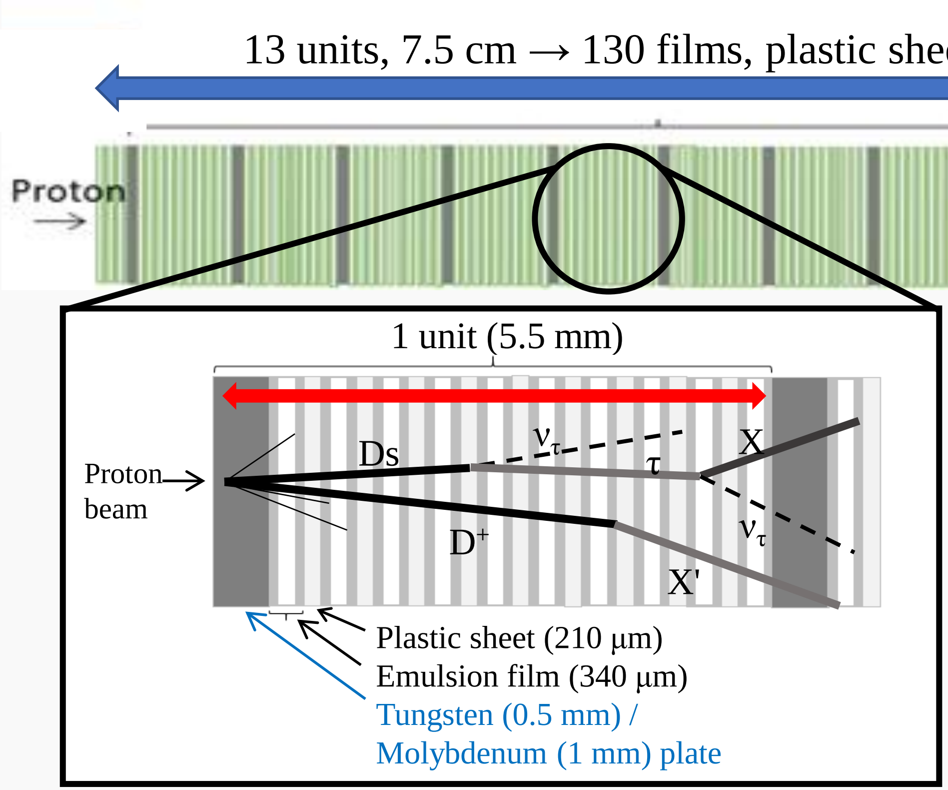
Test beam 2016

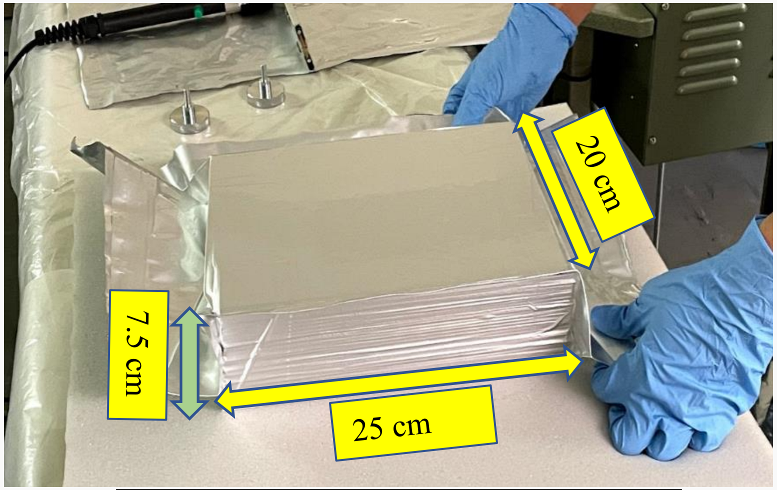
Test beam 2017

Pilot run 2018



The DsTau Detector

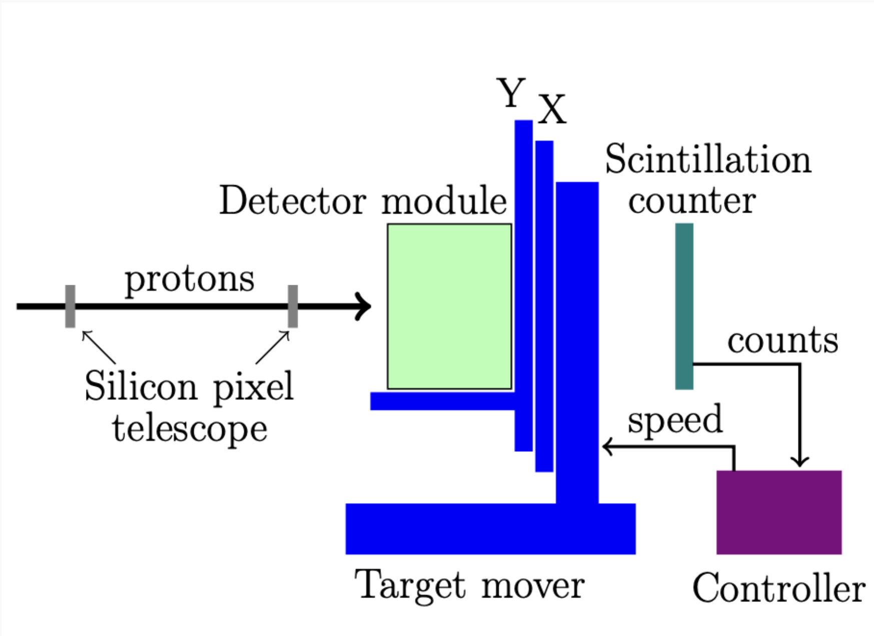


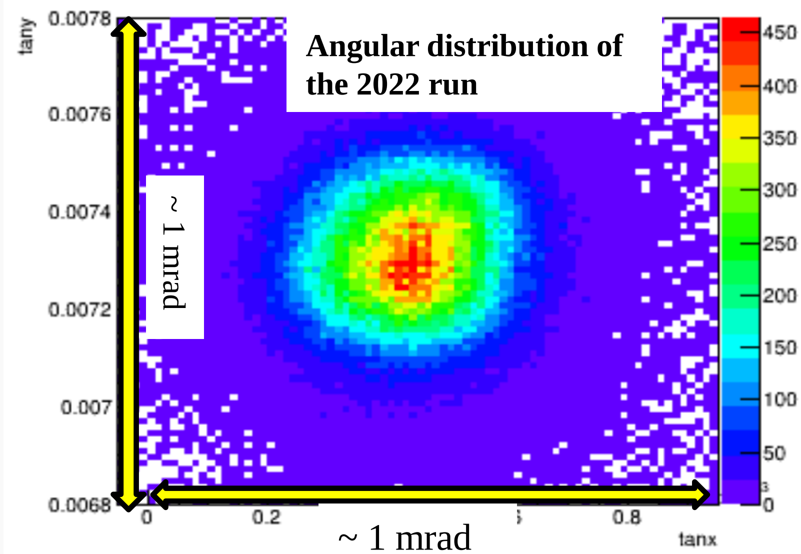


Size of module since 2021

- Original structure had more material (2018 pilot run) → too high track density in ECC
  - Dedicated scanning is required
- Reduce material (longer module, **10→13**, without ECC), but sufficient performance

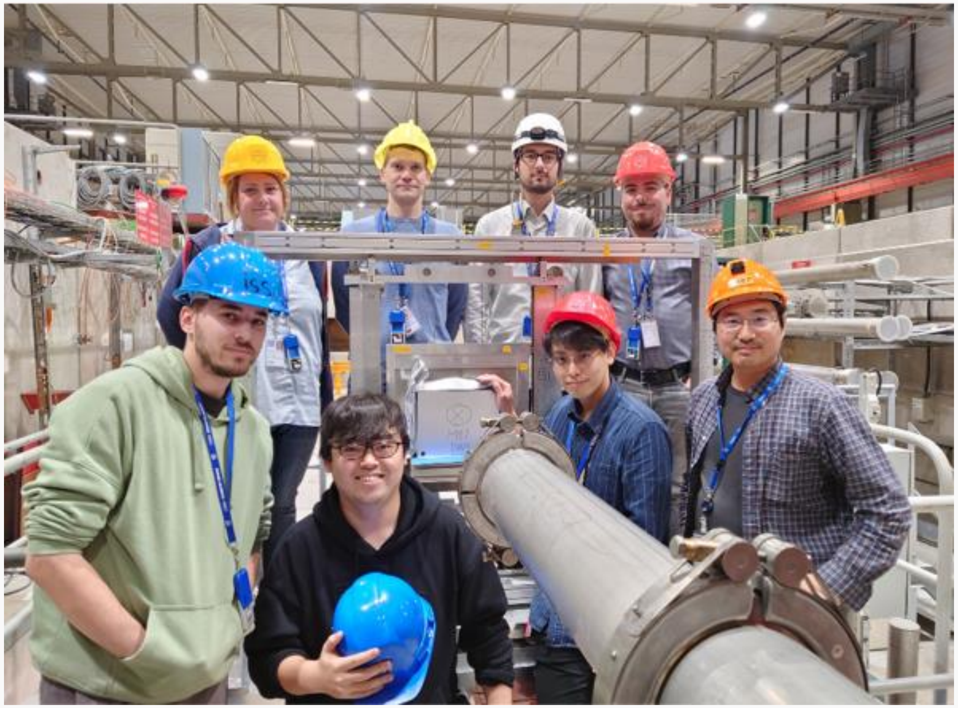
Data Taking 2022





- **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

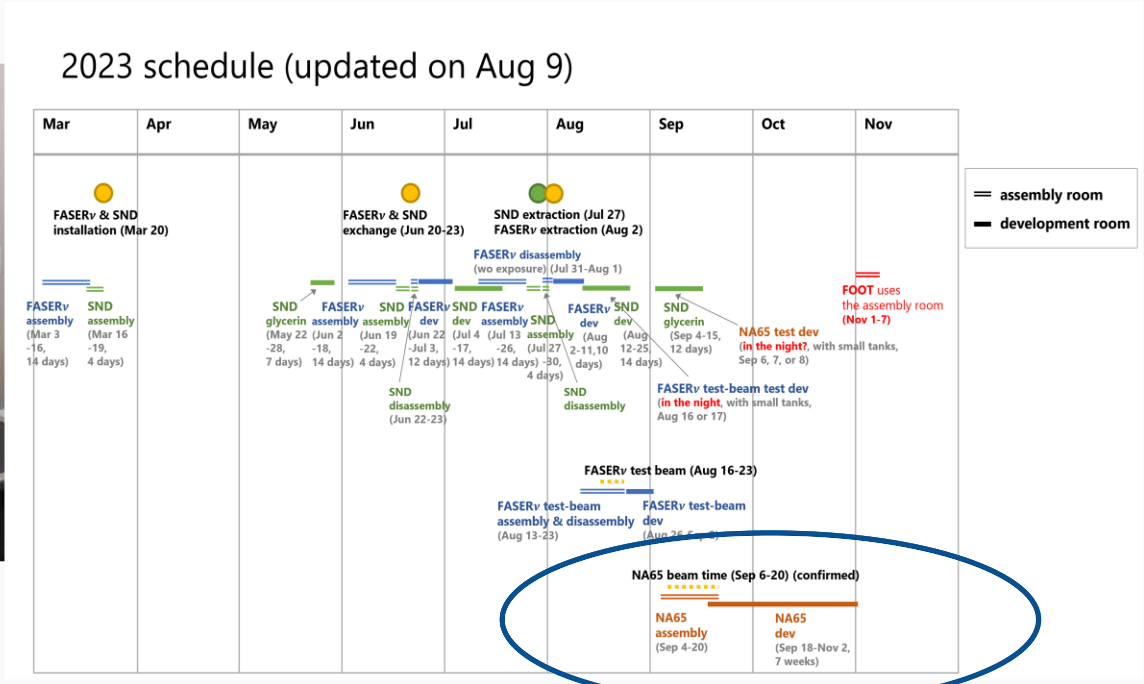
Data Taking 2023

- Beam time : **September 6-20** @ H2
- Emulsion film production for a large surface of **260 m^2** was completed
  - ≃ **40 modules** of size 25 cm x 20 cm
  - Dark room operation ↔ beam exposure simultaneously
  - Irradiate up to 3-7 modules per day
- This run would be the **final** data taking for DsTau
  - 50% of the total data

	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

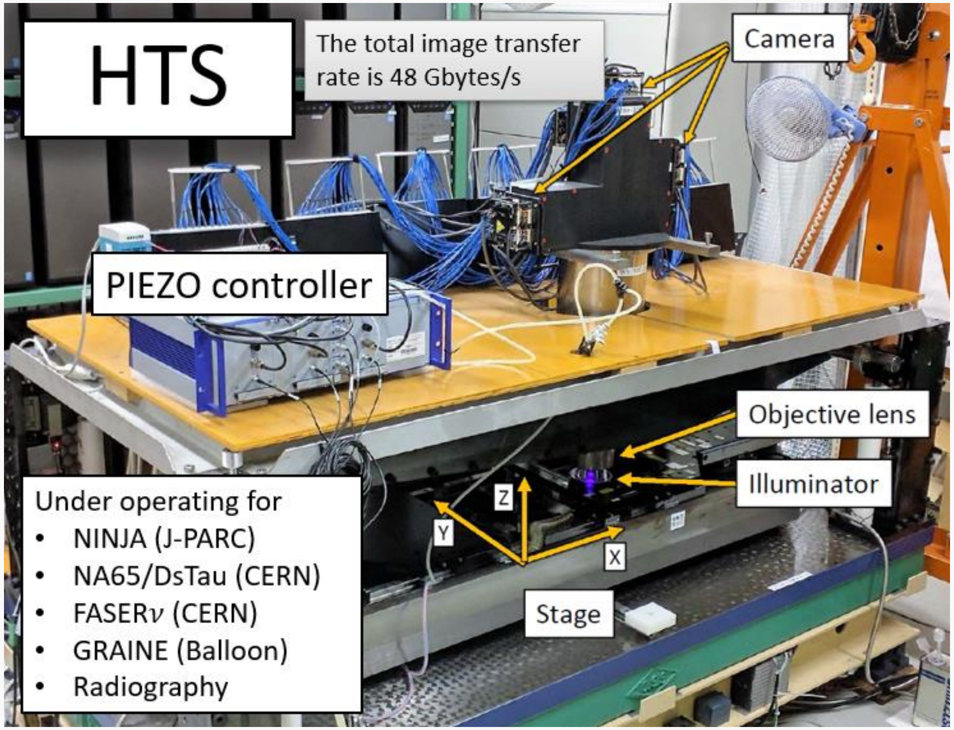
Emulsion Processing

- Emulsion facility at CERN was upgraded (2022)
- Capacity
  - ~5 modules/day assembling
  - ~300 films/day development
- NA65 development schedule in September-November period

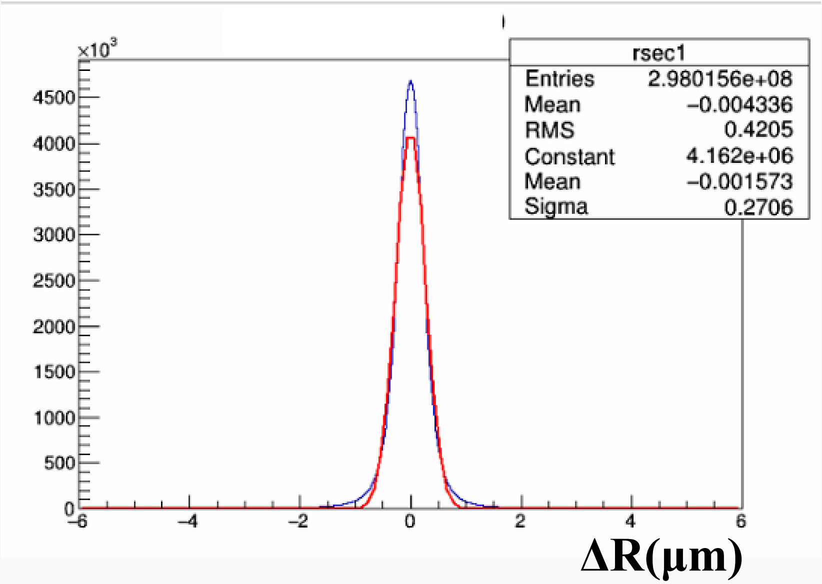


Emulsion Readout

- High speed readout by **HTS** system in Nagoya University
  - **40~50** min per film (20 cm x 25 cm x 2 = 1000 cm^2)

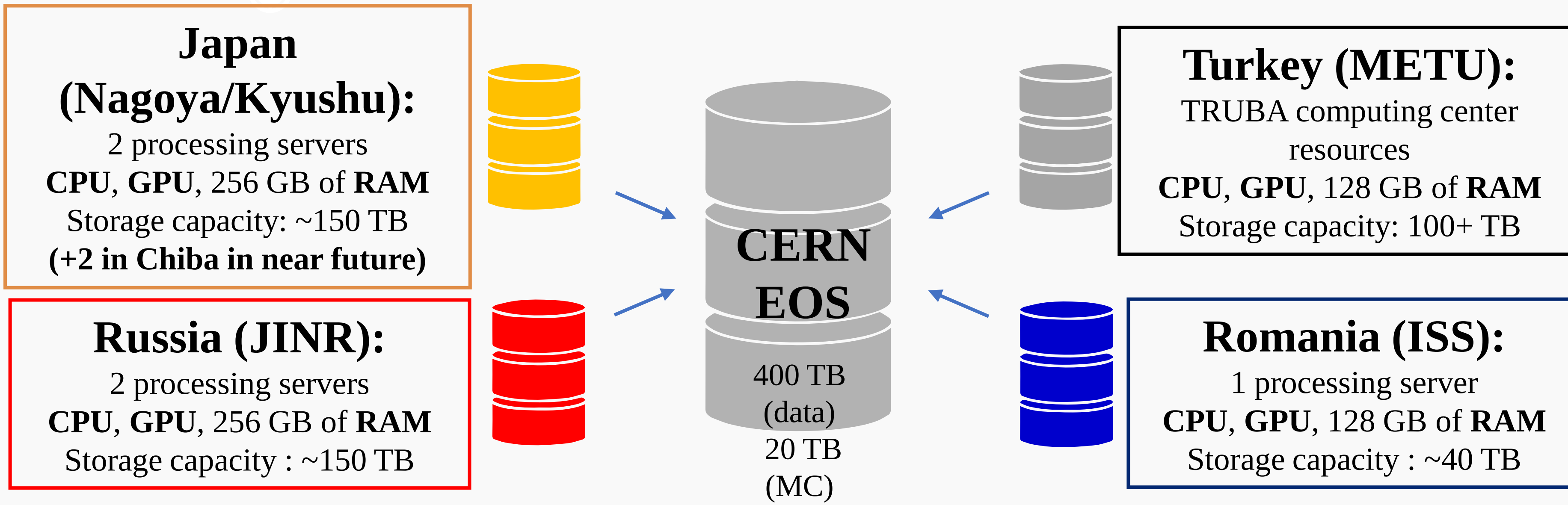


Position accuracy ~ 0.3 μm



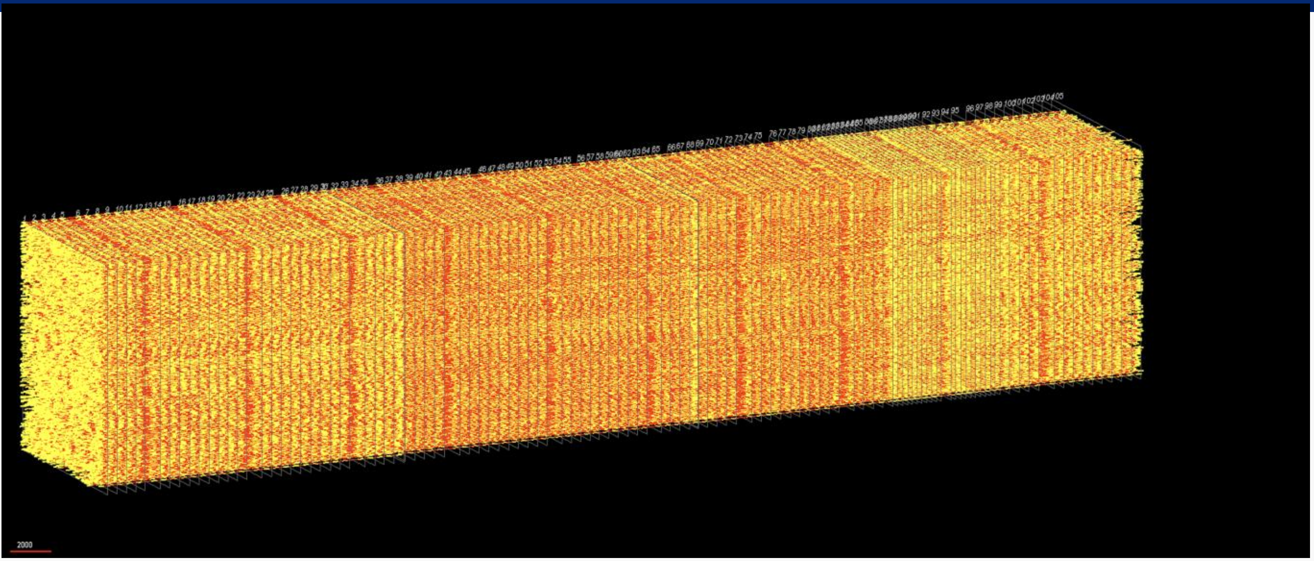
Data processing

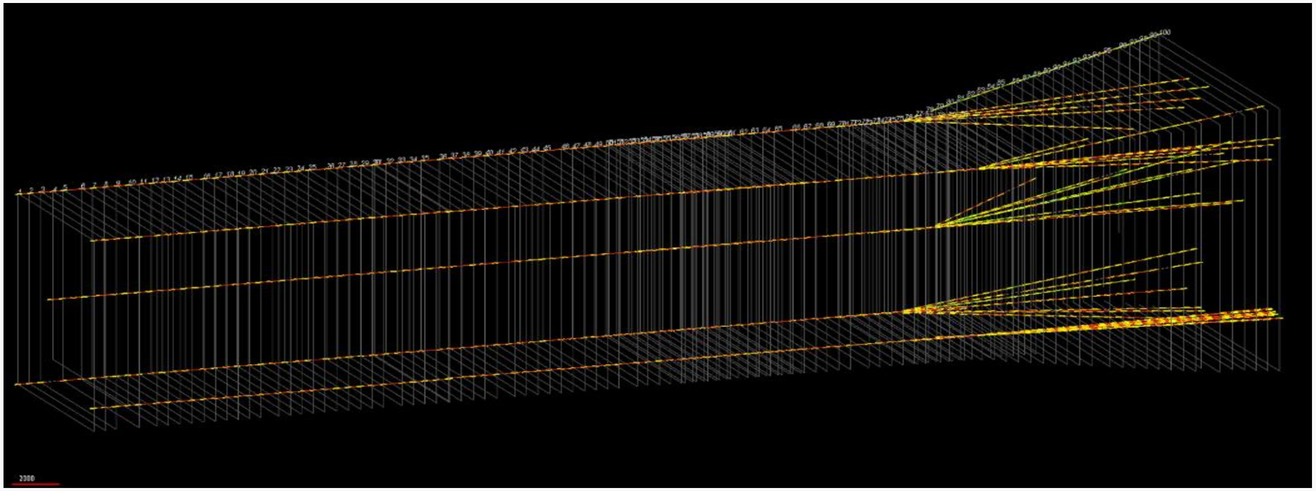
- Reconstruction procedures require powerful processing servers with high CPU/GPU and high memory (~128-256 GB of RAM) and disk space (~10 TB for each data module) resources.
- Data processing is distributed and being done gradually. All modules of 2018 run have been fully processed.

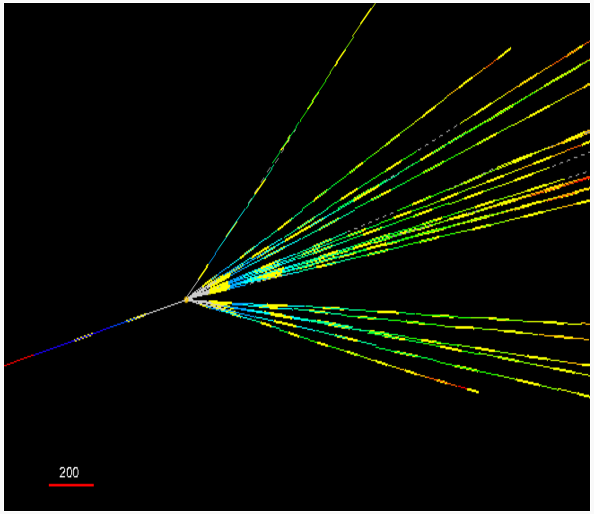


- Batch system of the CERN computing center is also used to process physics run data.

Reconstructed Proton Interactions





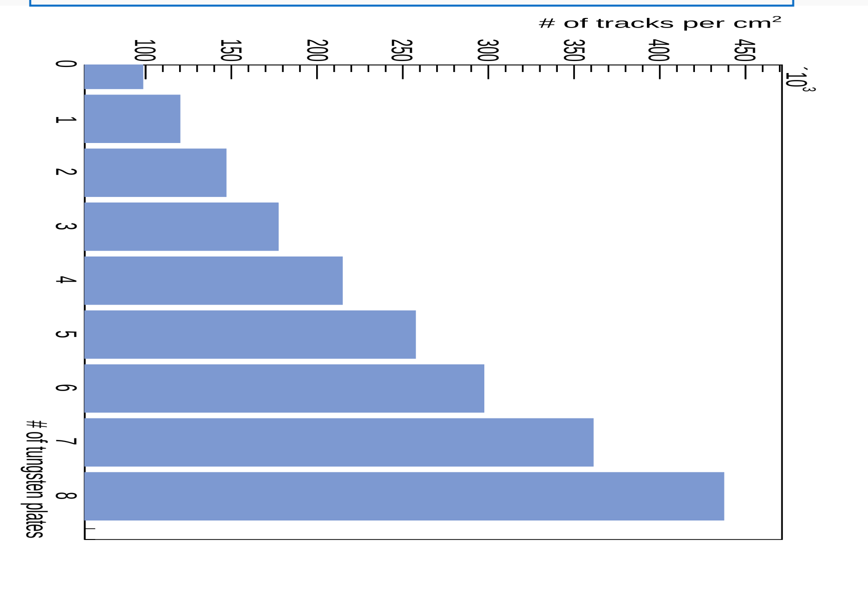


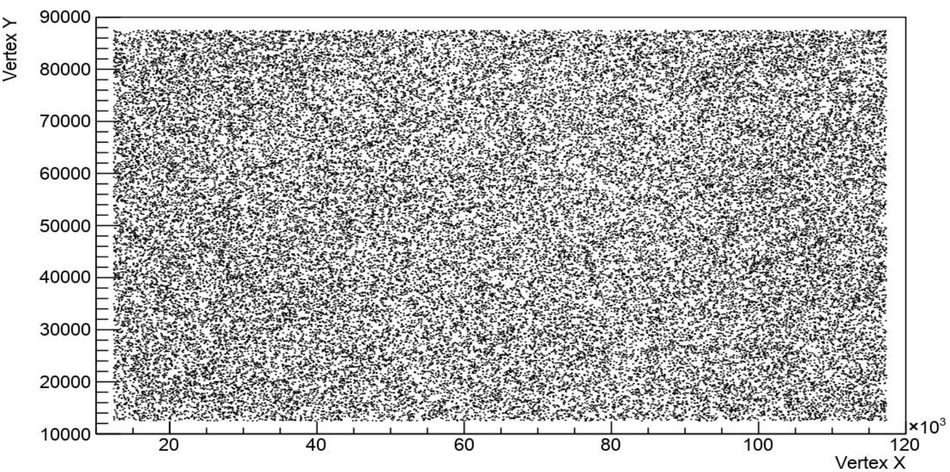
Study of Proton interaction in tungsten

- 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

Density of the reconstructed tracks in a module

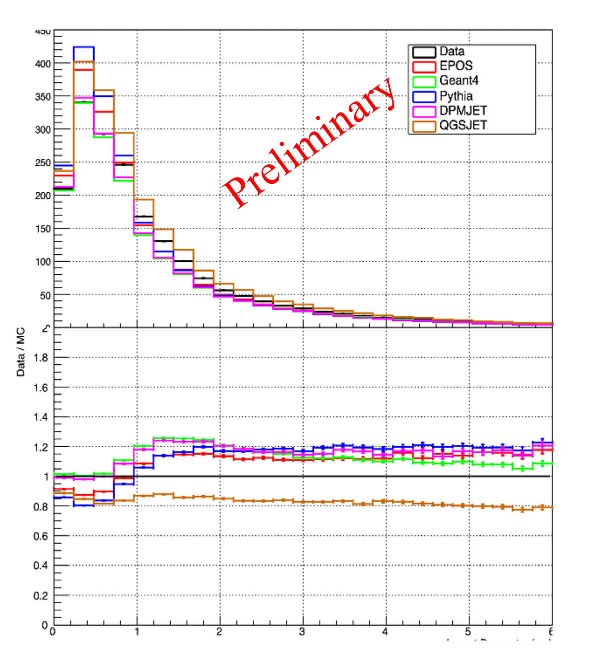




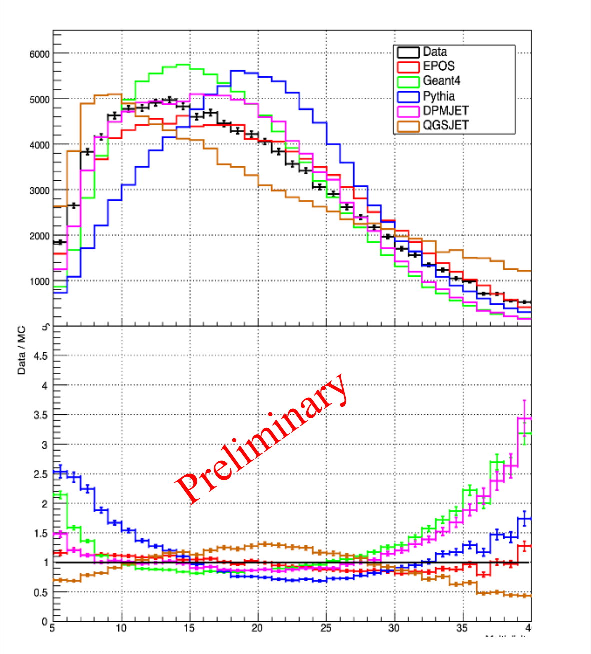
Study of Proton interaction in tungsten

- 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.

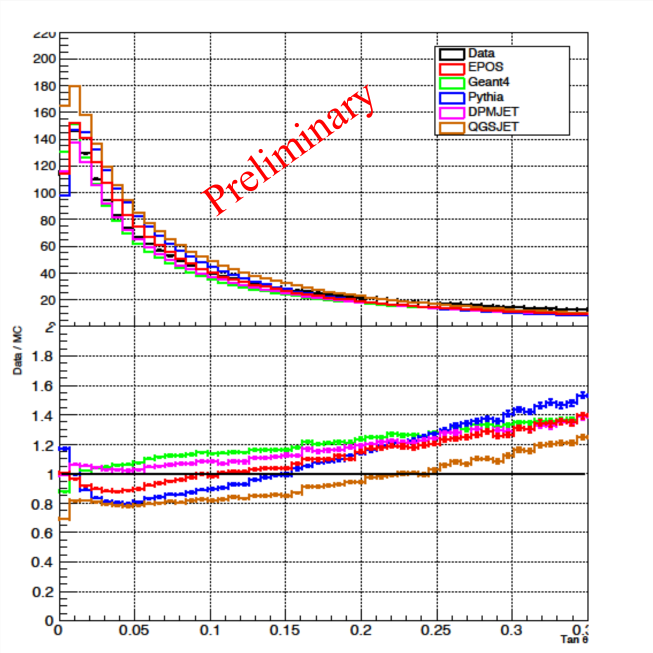
- A large number of proton interactions are generated using **EPOS**, **PYTHIA8**, **QGSJET**, **DPMJET**, and **GEANT4.11** generators by considering the realistic beam proton density in a module.



IP(µm)

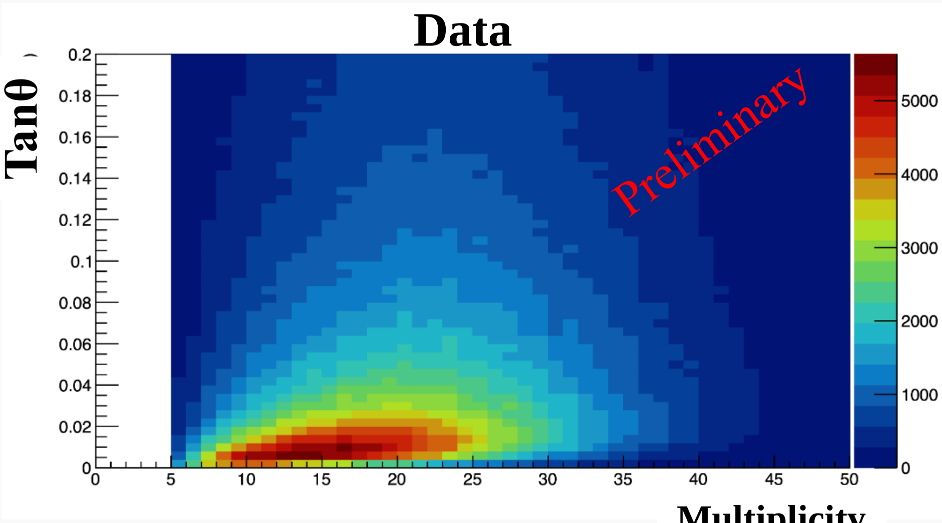


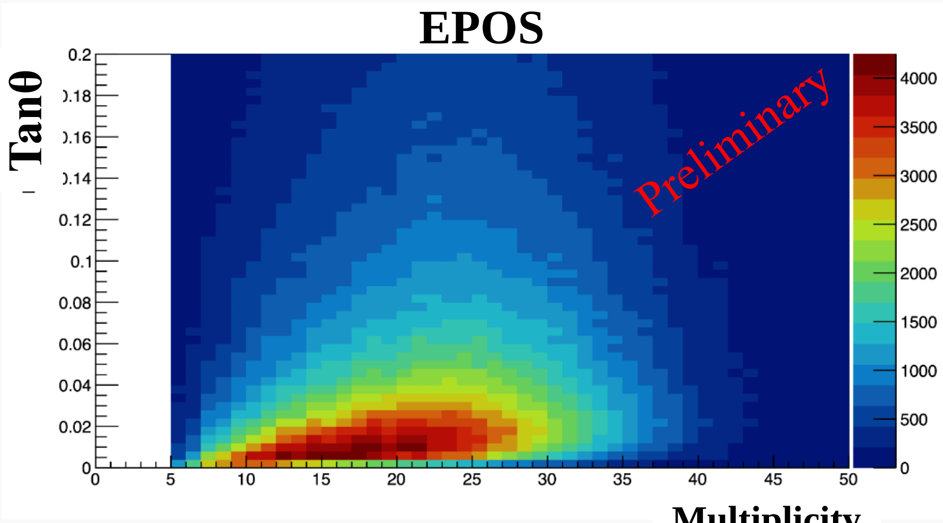
Multiplicity



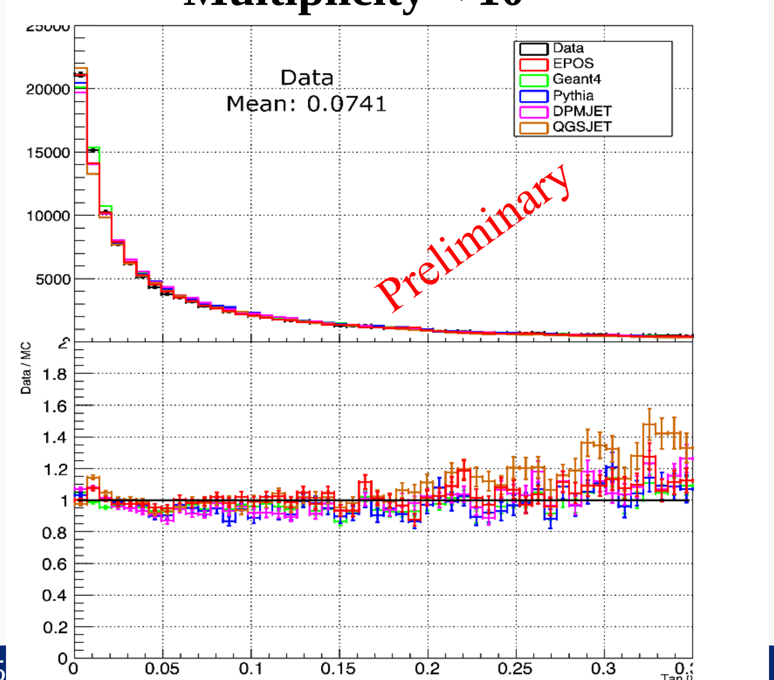
Tanθ

Angle dependence on multiplicity

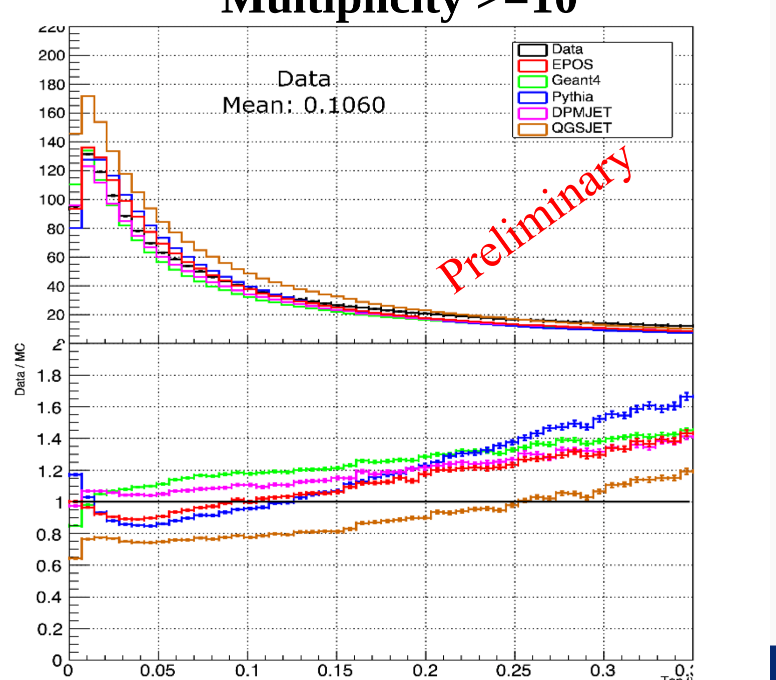




Multiplicity < 10



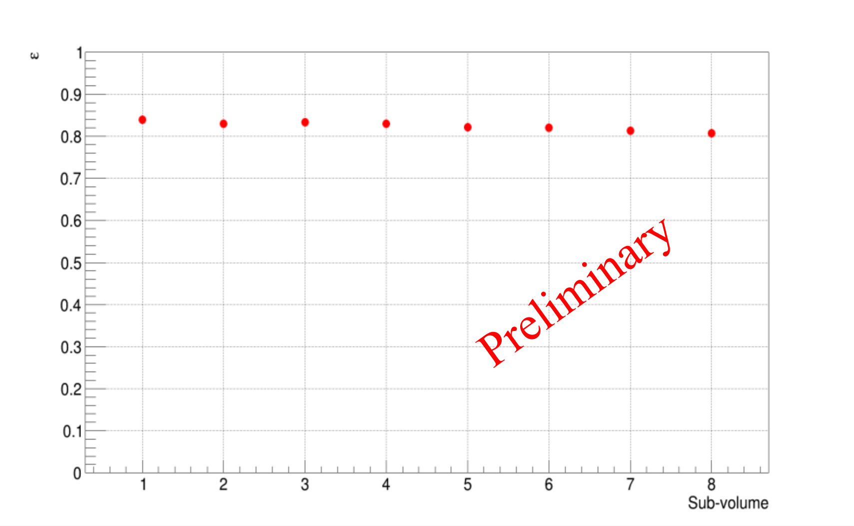
Multiplicity >=10



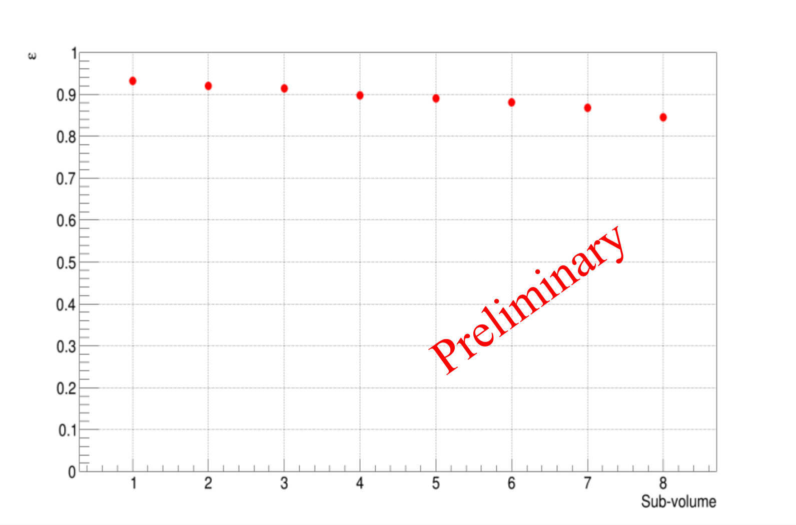
Efficiency Estimation

- EPOS predictions are in good agreement with data
- Efficiencies of vertex reconstruction and proton-linking are estimated using EPOS
- Proton purity for proton selection >96 %

Vertex reconstruction Efficiency
>80 %

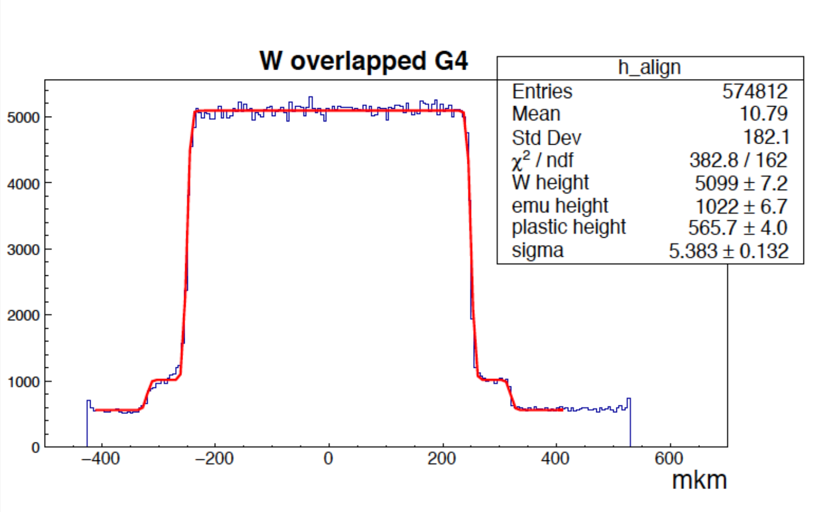


Proton track reconstruction
Efficiency
>85 %



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.



$$\lambda = -\frac{L}{ln(1 - \frac{N}{N_0})}$$

$$\frac{N_W}{N_{pl}} = 9,13 \pm 0,07$$

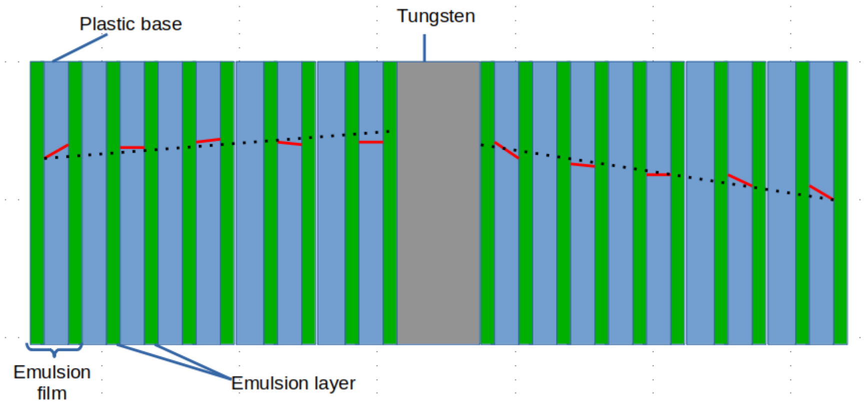
Preliminary

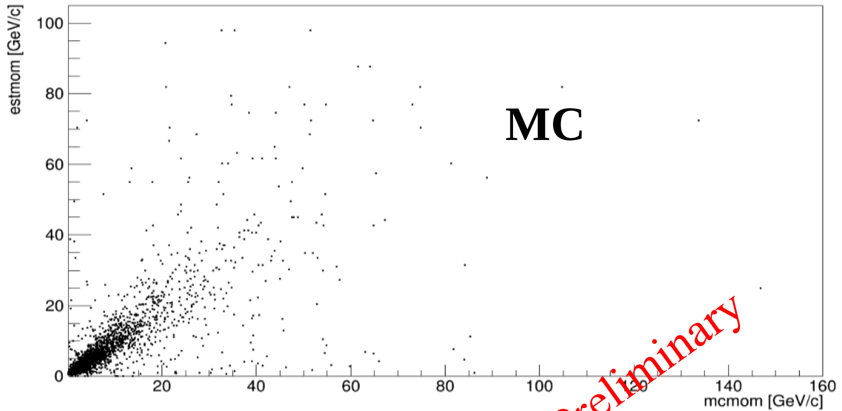
Proton interaction length

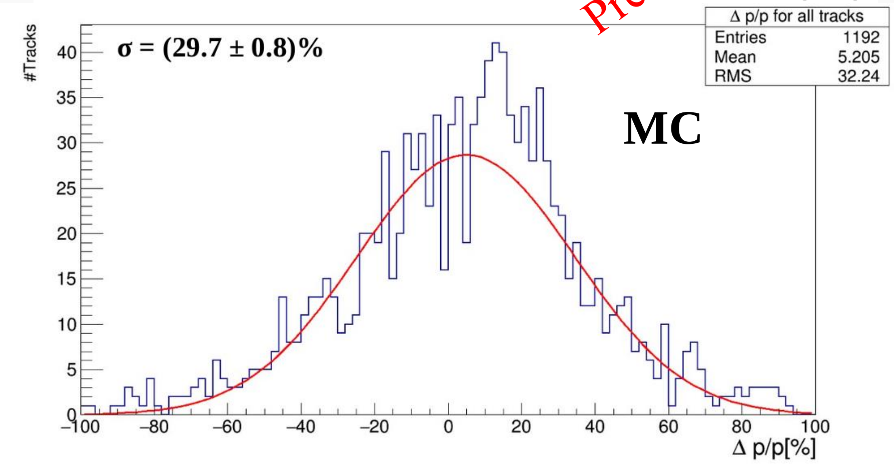
Material	Data	MC
Tungsten	112,1±1,4 mm	107,7±1.3 mm
Polystyrene	842,2±10,3 mm	809,9±9,4 mm

Momentum measurement by MCS

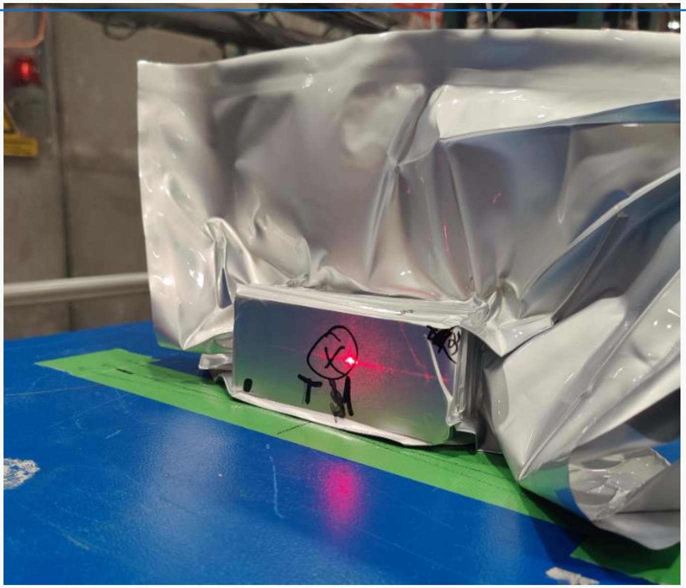
- Long range reconstruction has been established
- Scattering “angle”→ momentum
- Will also try “coordinate” method for higher momentum







- **Test beam with 50 GeV was performed in August 2023**
  - Same structure with DsTau
  - Will be analyzed as soon as scanning is done



Summary

- The proton interaction analysis led to a good and quantitive understanding of our data, which will be the base of future analysis.

- Proton interaction length in tungsten is measured for the first time.
  - will be submitted for a publication

- The analysis of physics run data is going on.

- 2023 physics run was scheduled in September.

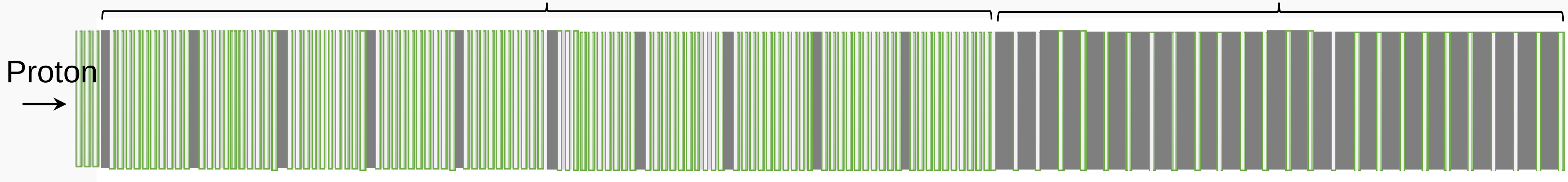
Backup

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

-2018

10 units
(total 100 emulsion films)

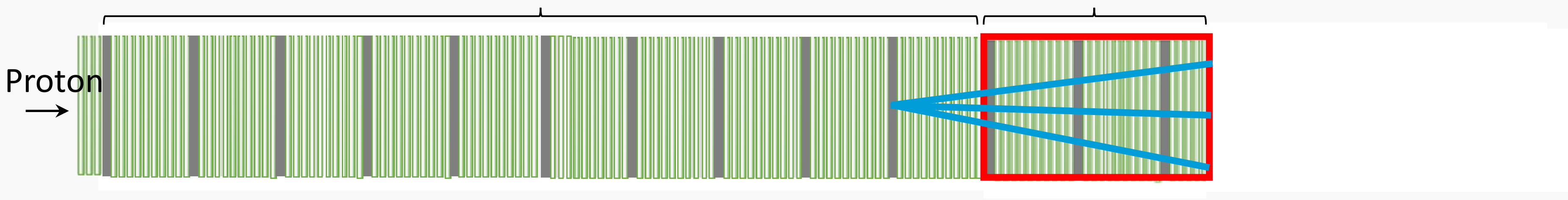
ECC for momentum measurement
(26 emulsion films interleaved with
1 mm thick lead plates)



2021-

10 units
(total 100 emulsion films)

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

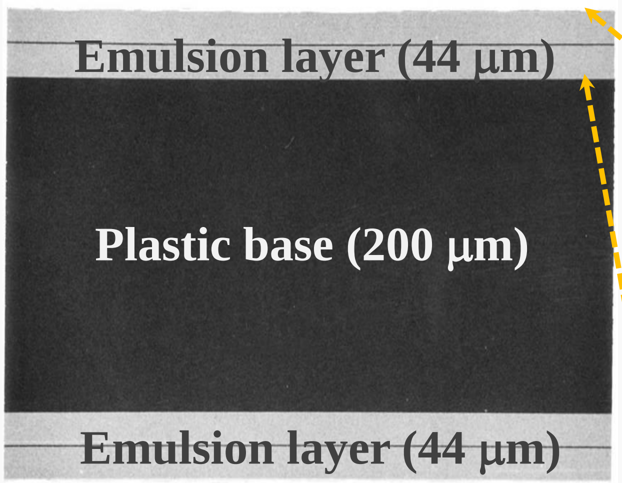


Emulsion detector

- 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

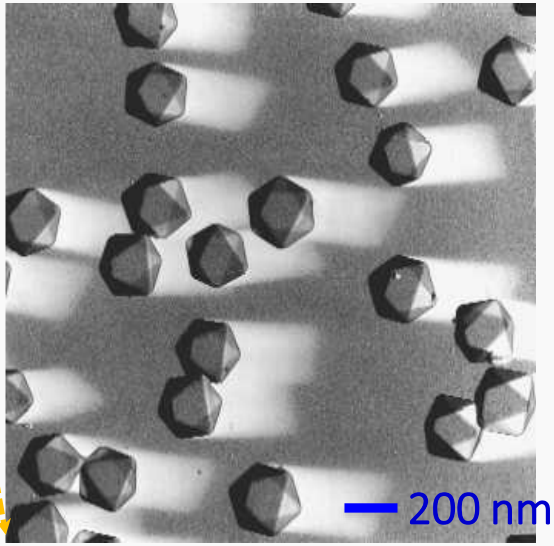
Emulsion film

Cross-sectional view



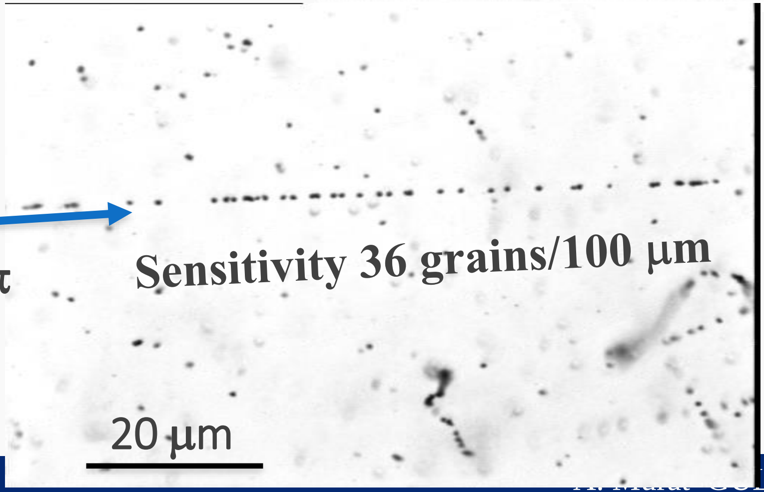
AgBr crystal

10^{14} crystals in a film



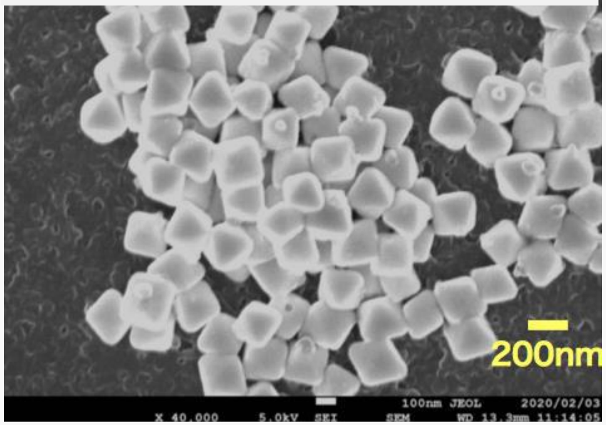
3D tracking device

10 GeV/c π beam

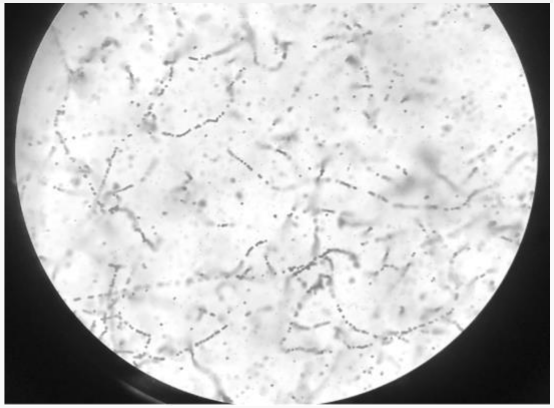


Emulsion Production

Electron microscop view



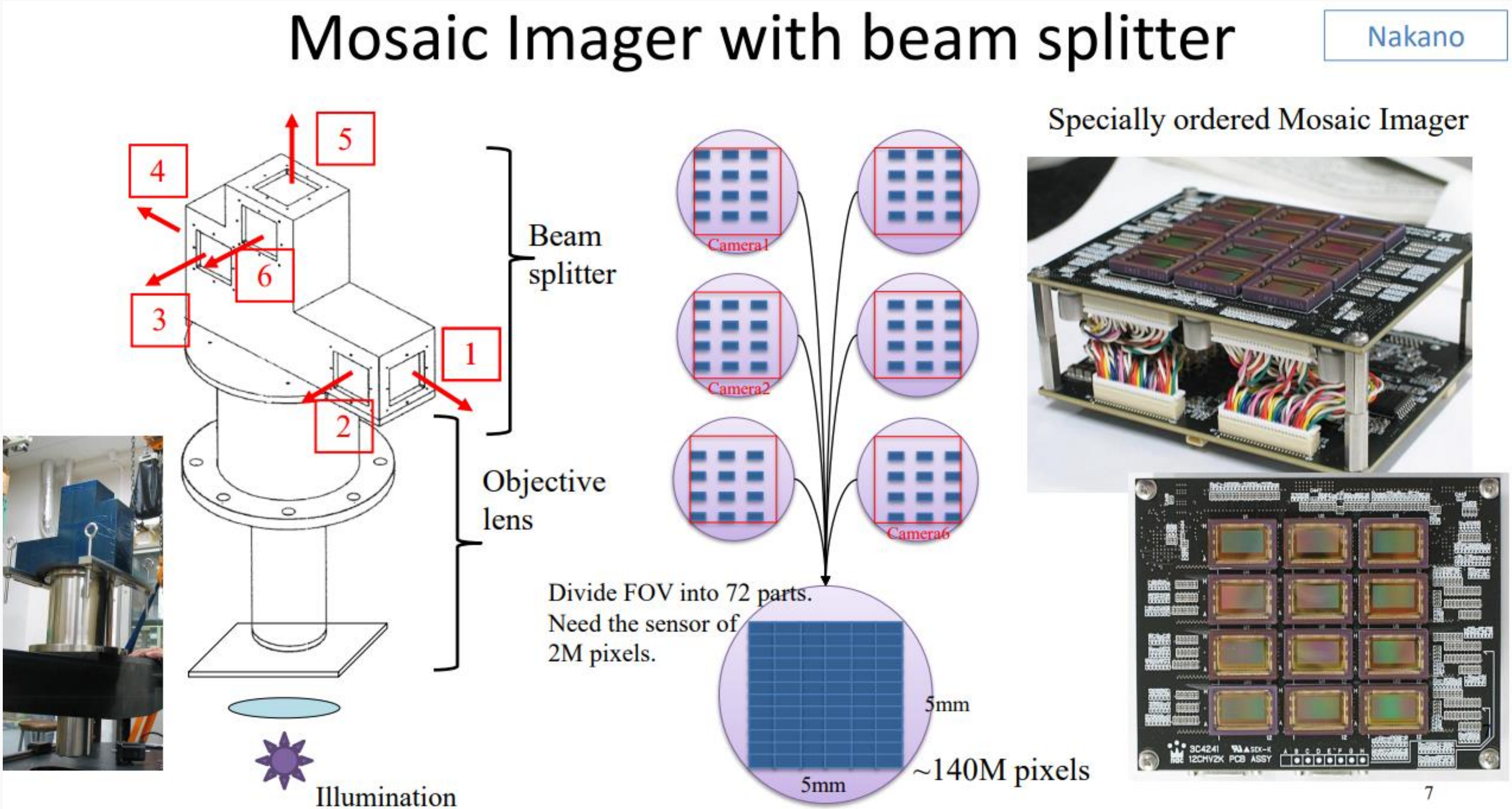
Sensitivity of new emulsions confirmed



25cm x 20cm

Film production facility

HTS



Mosaic Imager with beam splitter
Nakano
Specially ordered Mosaic Imager
Beam splitter
Objective lens
Illumination
1
2
3
4
5
6
Camera1
Camera2
Camera6
Divide FOV into 72 parts.
Need the sensor of 2M pixels.
5mm
5mm
~140M pixels
7