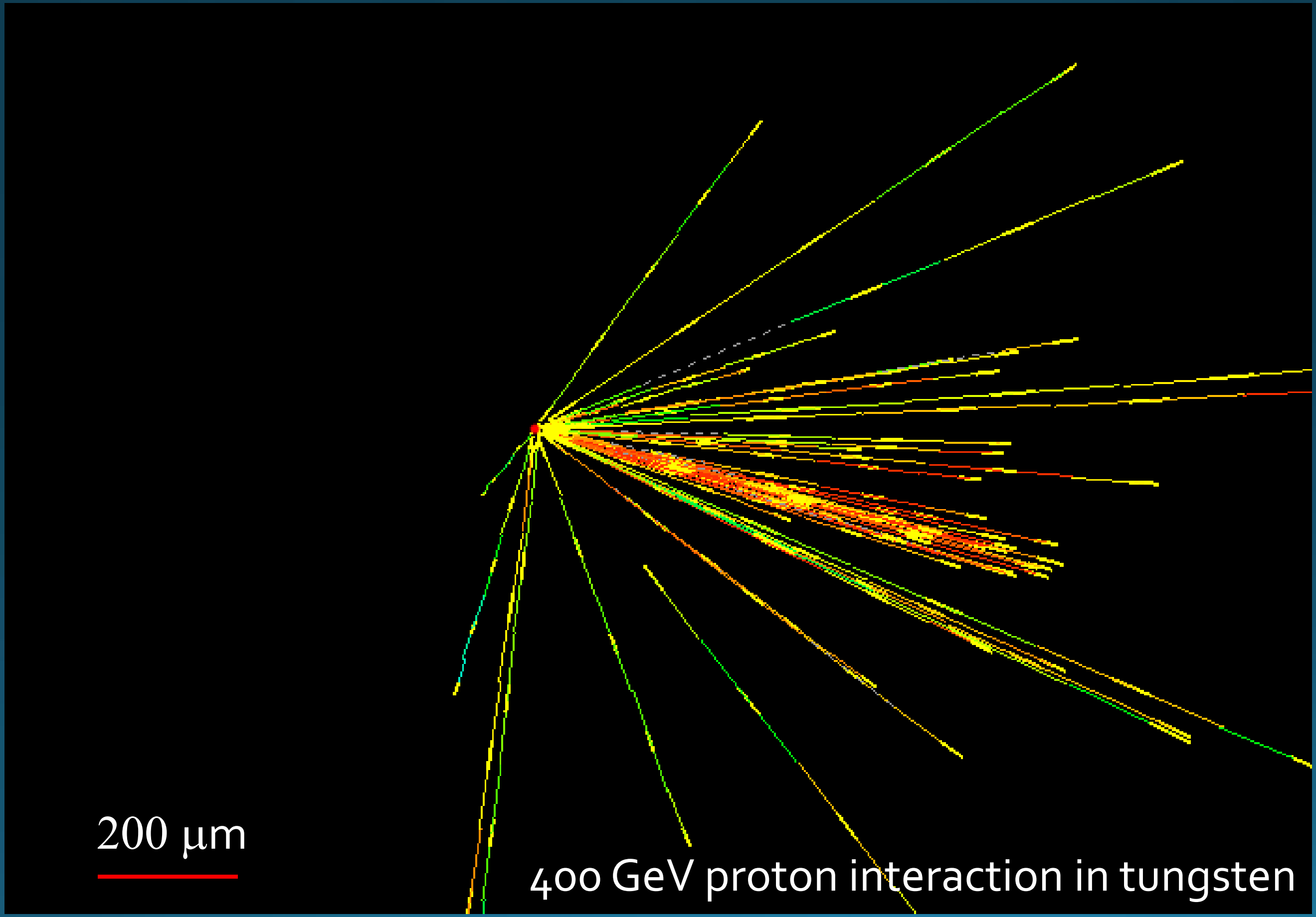
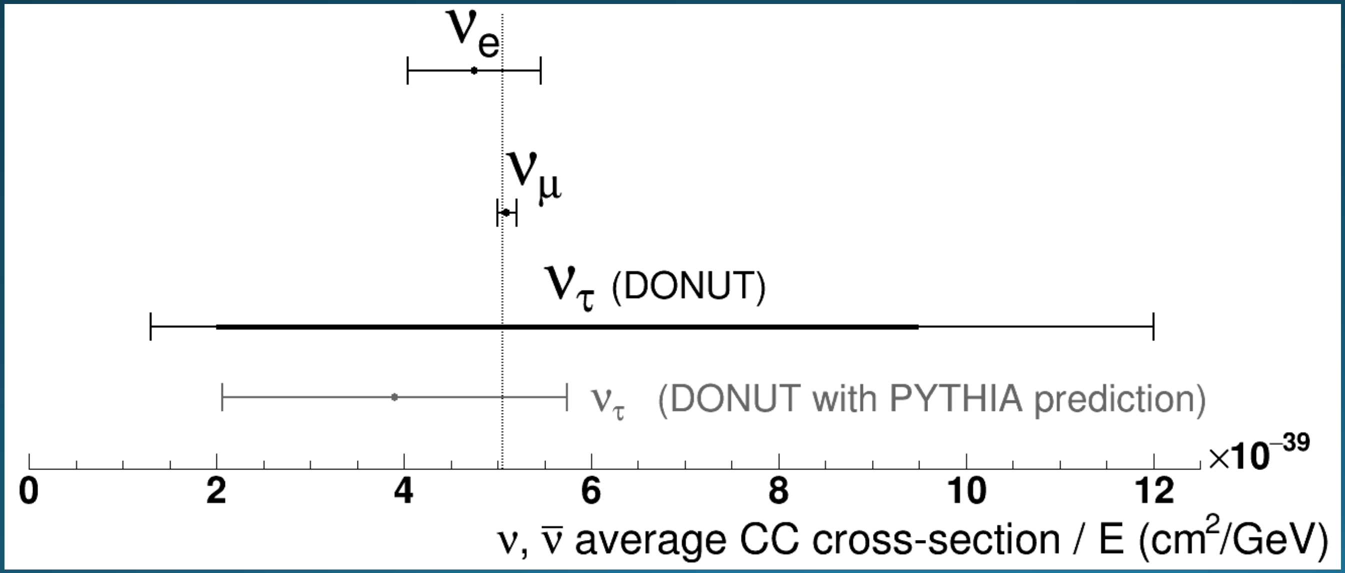
Direct measurement of tau neutrino production

A. Ariga University of Bern, for the DsTau Collaboration



Tau neutrino

- ν_τ is the least studied particle in the standard model. Only 15 events were observed so far.
- ν_τ cross-section measurement has a large uncertainty > 50%.
  - Main uncertainty due to the ν_τ production process.
- Precise measurement of it will be a test of lepton universality in neutrino scattering, violation of which implies a new physics.

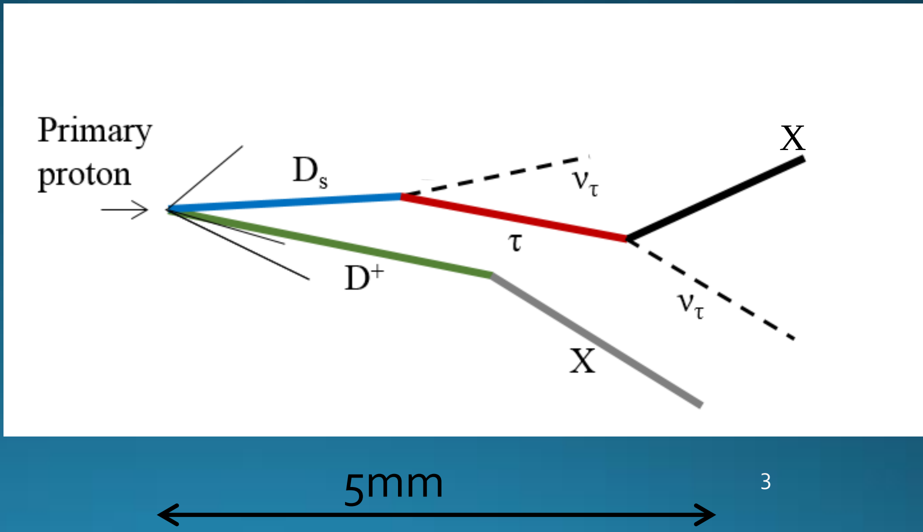


The DsTau project at the CERN SPS

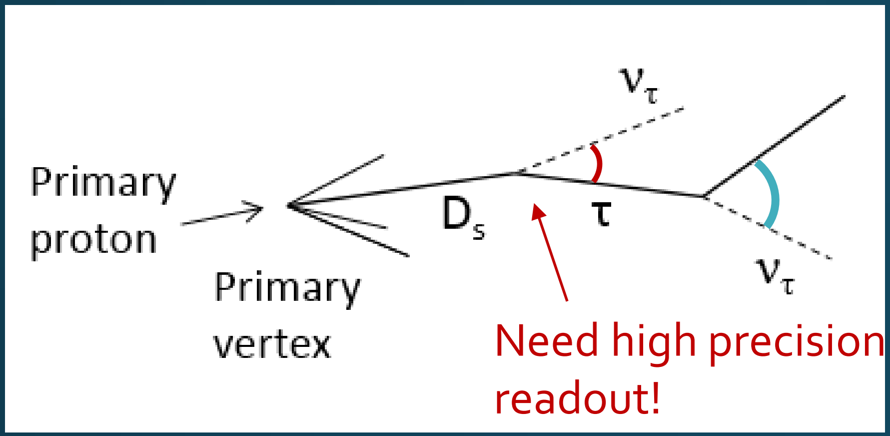
- **Global motivation: Test of lepton universality in neutrino CC interactions**
  - error source of ν_τ cross section is dominated by the systematic uncertainty from ν_τ production.
- **DsTau goal**:
  - Improve knowledge of tau-neutrino production: systematic uncertainty >50% → ~10%.
  - Re-evaluate ν_τ cross section of DONUT.
  - Provide essential data for future neutrino experiments, e.g. SHiP, DUNE, Hyper-K etc.
- **Method**: Direct measurement of tau-neutrino production in 400 GeV proton interactions.
  - Dominant source:

$$D_s \rightarrow \tau\, \nu_\tau \rightarrow X\, \nu_\tau\, \nu_\tau.$$

  - Detect the double-kink topology within a few mm by emulsion detector.
  - Small background by requesting charm-pair production.
  - Measure differential production cross-section of D_s mesons, ~1000 D_s for 10 % ν_τ flux uncertainty.

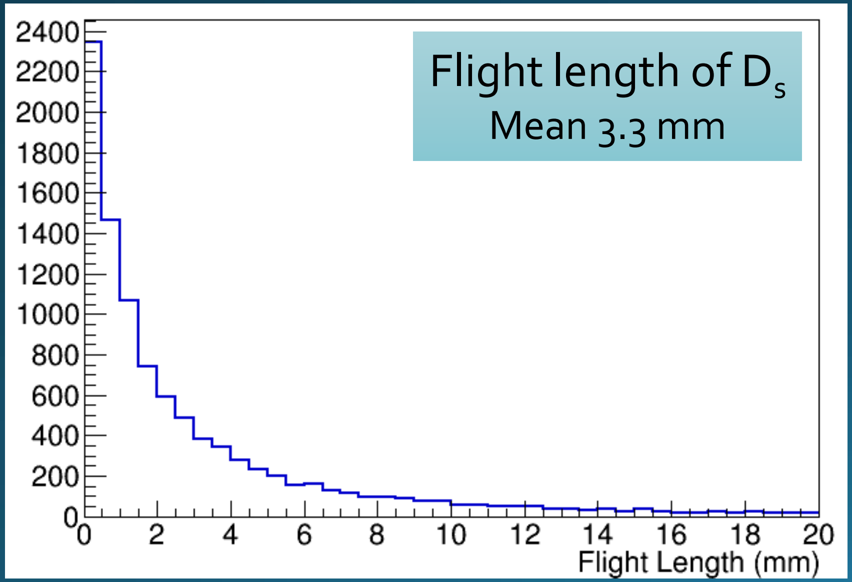


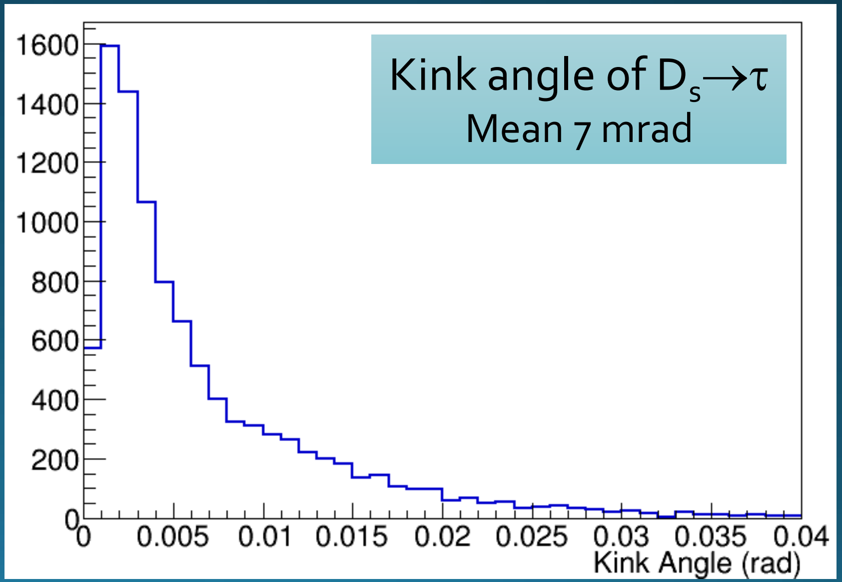
Detection of $D_s \longrightarrow \tau \longrightarrow X$ events (double-kink topology)



$Ds \rightarrow \tau$ decay has a very small kink angle ~7mrad. A high precision detector is required.
(τ decay kink angle ~100 mrad)

Emulsion detector with nano-precision readout.



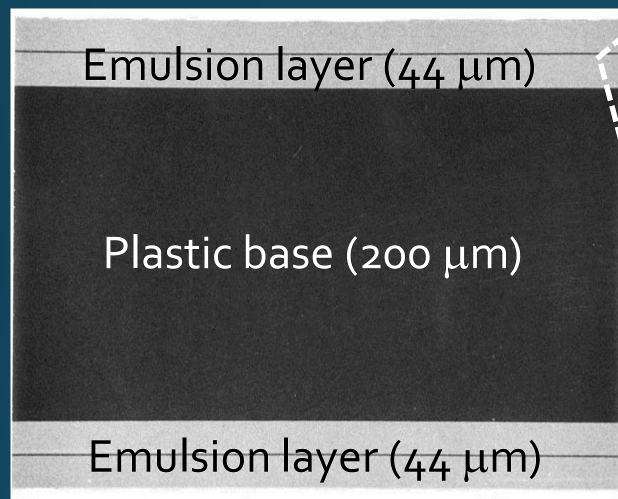


Towards detection of a few mrad kink topology

Emulsion detectors: 3D tracking device with 50nm precision

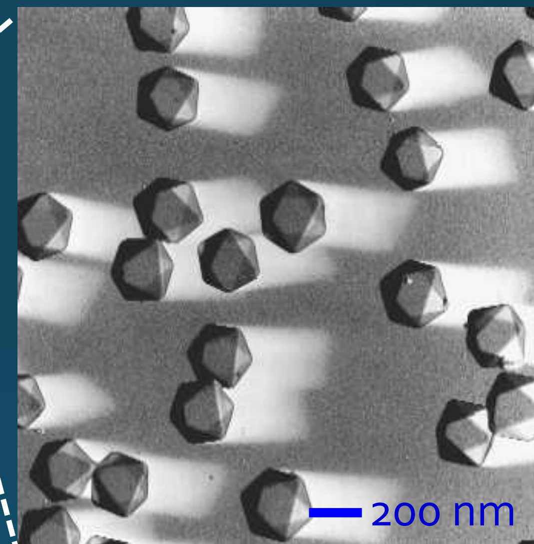
Emulsion film

Cross-sectional view

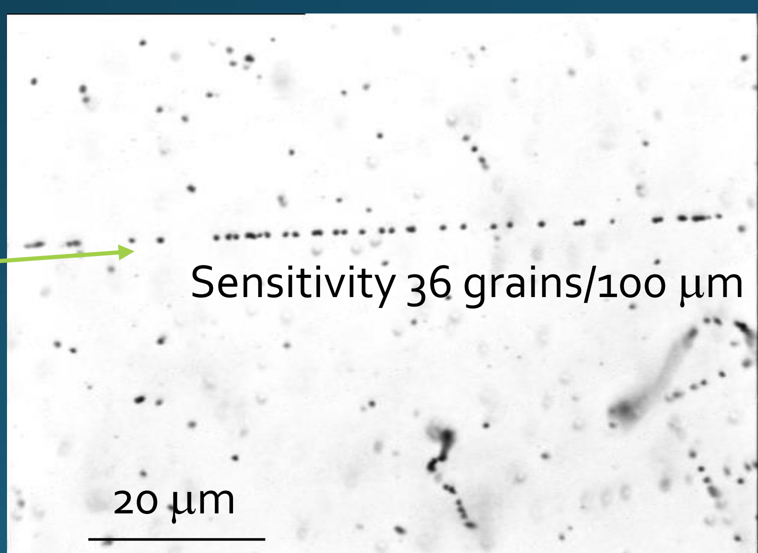


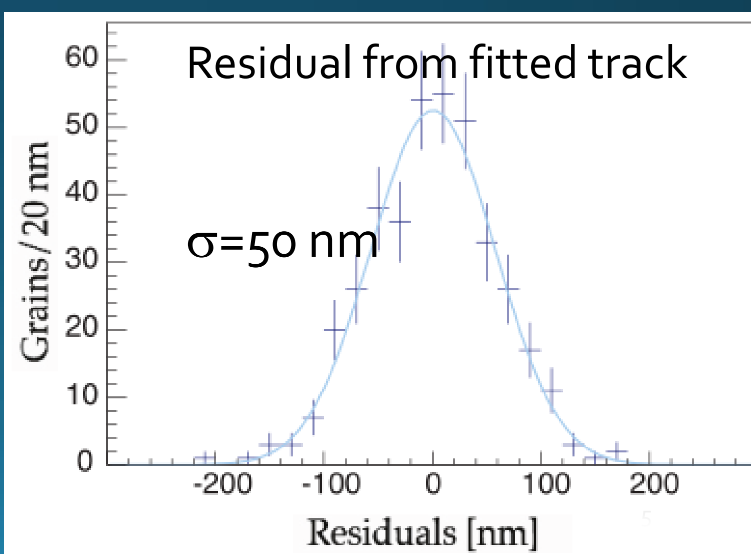
AgBr crystal

10^{14} crystals in a film



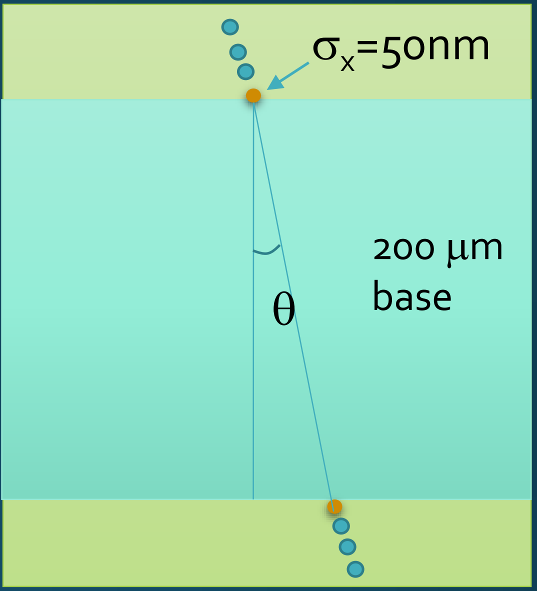
10GeV/c π beam

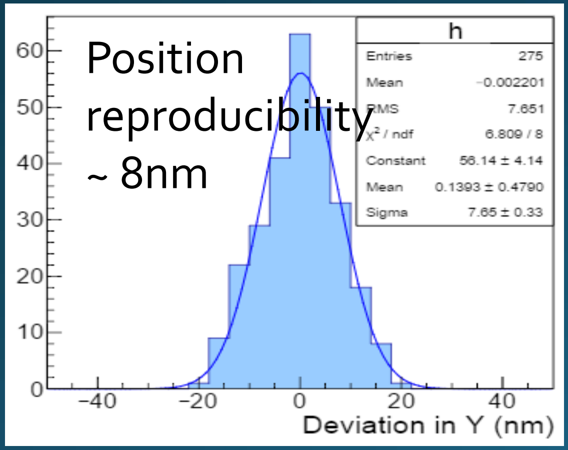


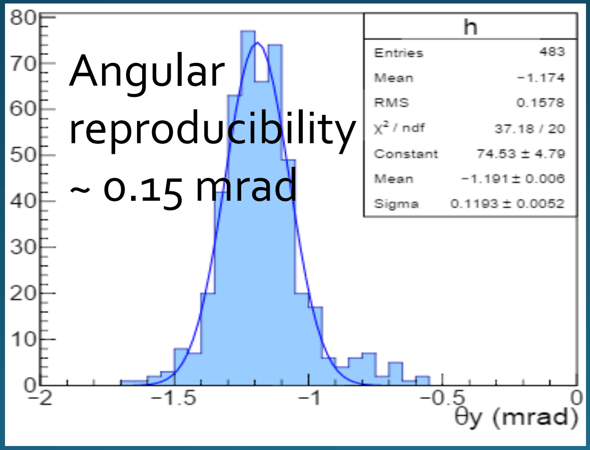


High precision measurement

- Intrinsic resolution of each grain = 50nm
  - Two grains on top and bottom of 200 µm base → 0.35 mrad
  - Discrimination of 2 mrad at 4 sigma level.
- Conventional systems spoil it due to mechanical vibration of Z axis (about 0.2µm, corresp. 1.5 mrad)
- → Need high precision Z-axis
- Piezo objective scanner for Z axis.
- Angular measurement reproducibility of 0.15 mrad was achieved.



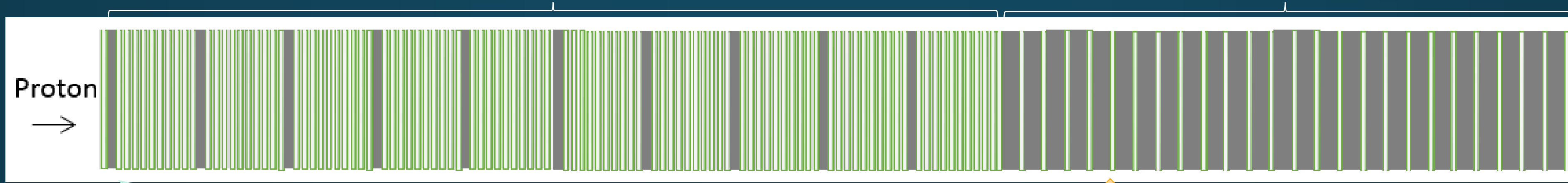


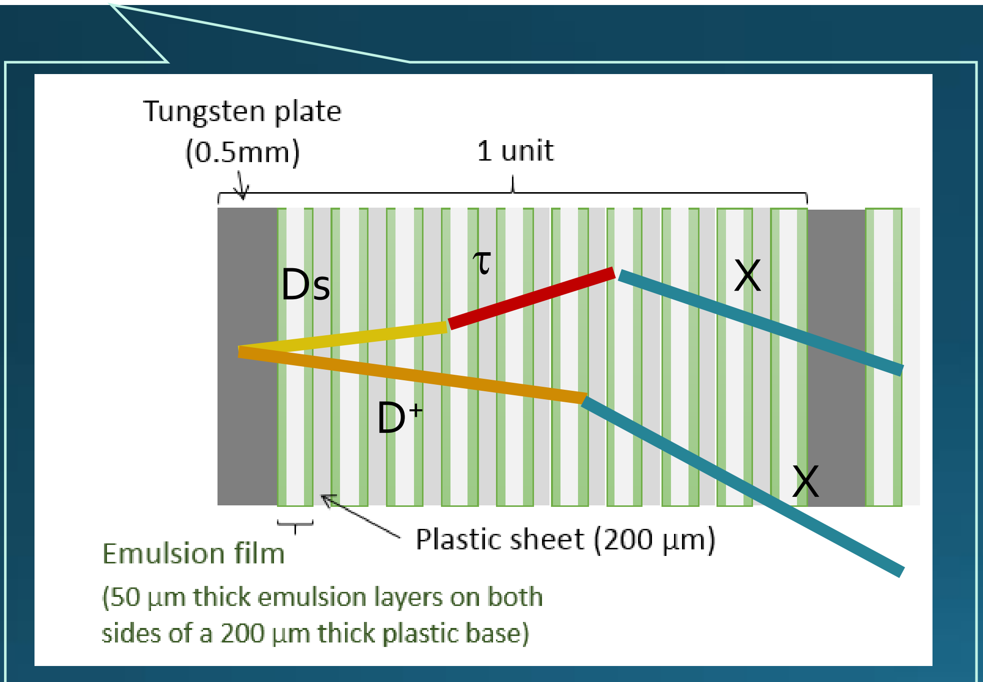


Piezo objective scanner

- Angular alignment between films to be done by using dense 400 GeV proton tracks

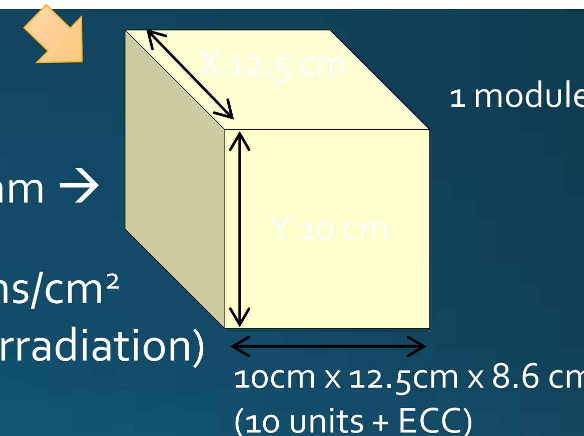
Module structure for $D_s \rightarrow \tau \rightarrow X$ measurement





Proton beam →

10^5 protons/cm²
(uniform irradiation)

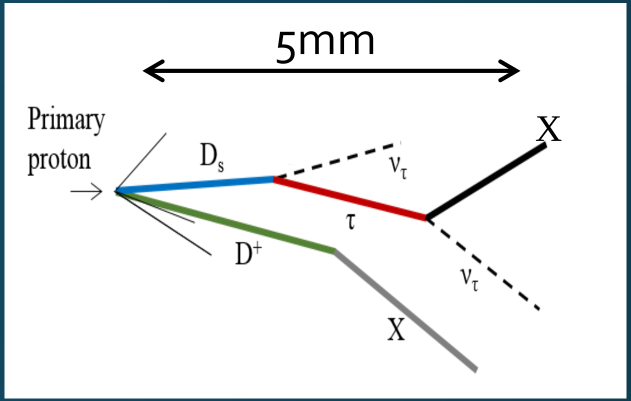


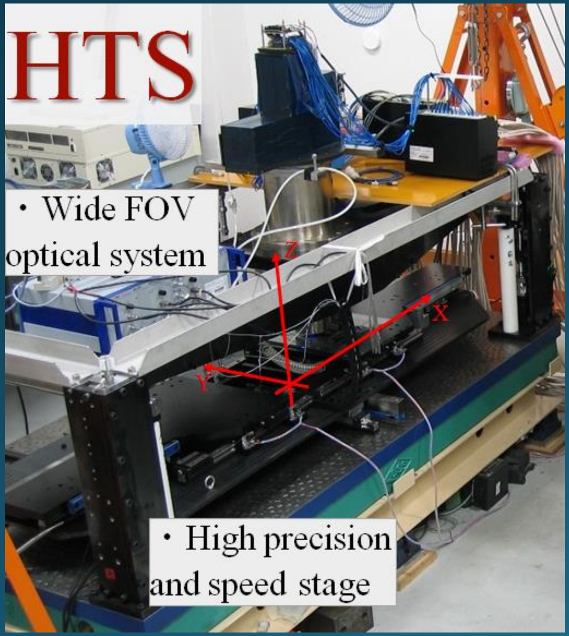
400 modules , -- a total film surface of 500 m² for 1000 D_s detection.

Efficiency estimation with preliminary selection (FL: flight length) :
1 film <FL(D_s)&FL(τ)< 5 mm & $\Delta\theta(D_s \rightarrow \tau)$> 2 mrad & $\Delta\theta(\tau)$> 15 mrad & partner-charm detection
→ Efficiency 20% (will be further optimized using more careful simulations)

Two step analysis for double kink search

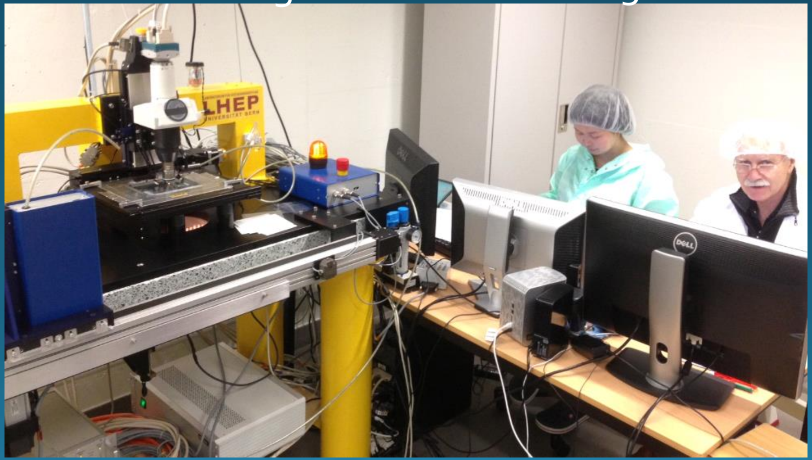
1. High speed scanning to select $\tau \rightarrow X$ + partner-charm decays (trigger)
2. Precision measurement to detect $D_s \rightarrow \tau$ decay.





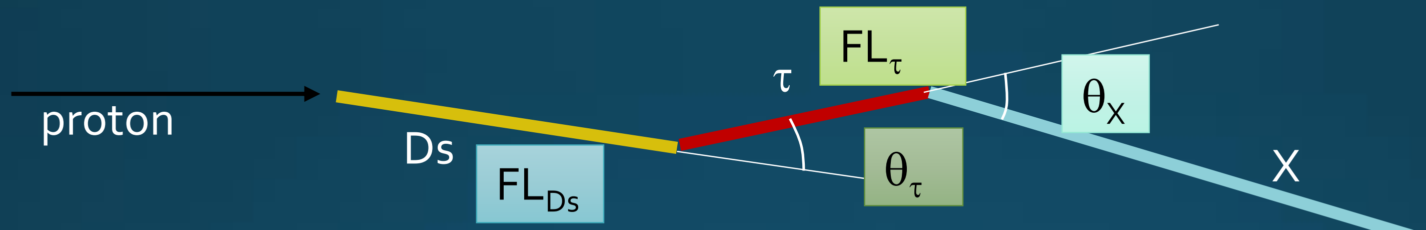
← A **Fast** scanning system being developed in Nagoya, aiming at the speed of 9000 cm^2/h (22 m^2/day). Angular resolution = 2mrad

A **nano-precision** measurements in Bern. Angular resolution = 0.3 mrad

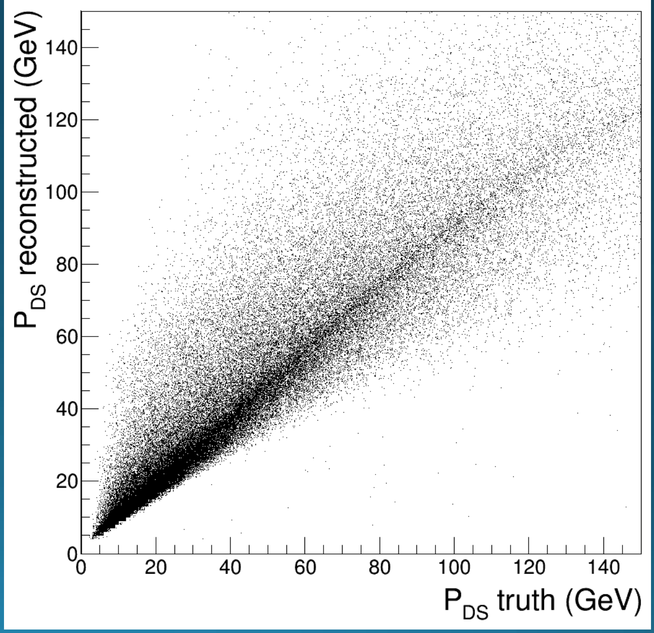


Ds momentum reconstruction

- The peculiar decay topology is rich in kinematical information.
- Ds momentum reconstruction only by topological variables



- A Neural Network with 4 variables was trained with MC events.
- Momentum resolution for τ→1 prong decays
- $\Delta p/p = 18\%$



Status of the project

- LoI submitted to the CERN-SPSC in Feb. 2016 (SPSC-I-245)
  → positive feedback
  → proposal to be submitted including the test beam in 2016
- proton beam test in Nov. 2016, May 2017
- proposal submission by Autumn 2017

Study of ν_τ production by measuring $D_s \to \tau$ events in 400 GeV proton interactions:

Test of lepton universality in neutrino charged-current interactions

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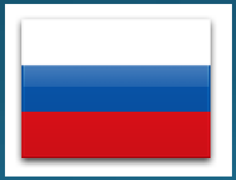
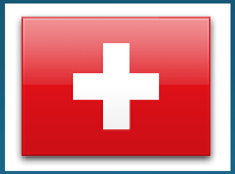
Collaboration

- Aichi University of Education, Japan
- Middle East Technical University, Turkey
- University of Bern, Switzerland
- Institute of Space Science, Romania
- Kobe University, Japan
- Kyushu University, Japan
- Joint Institute for Nuclear Research, Russia
- Nagoya University, Japan

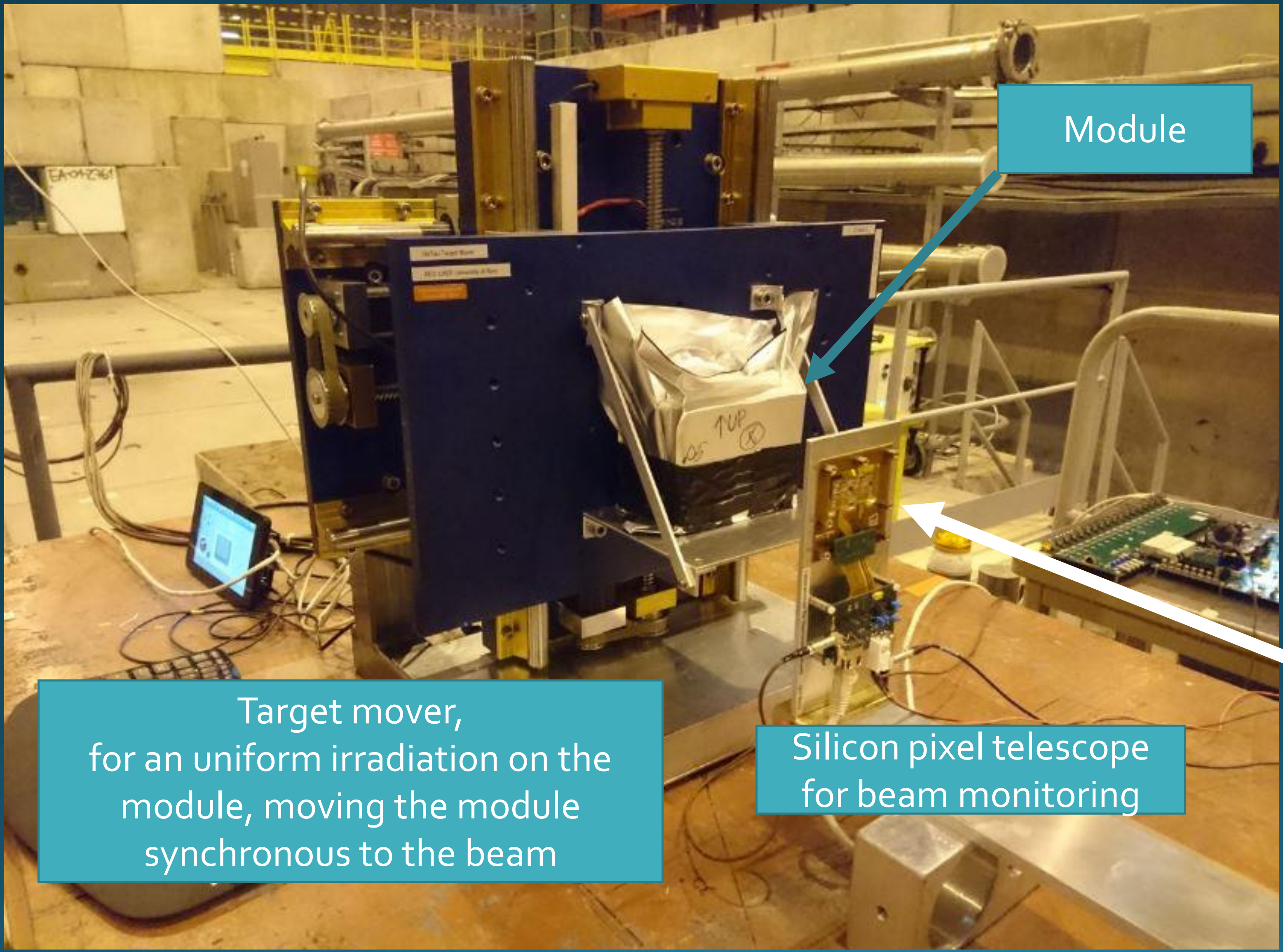
    

Test beam 2016. Detector assembling at the CERN dark room

Piling up of 200 components:
10 tungsten, 100 films, 90 plastic sheets.

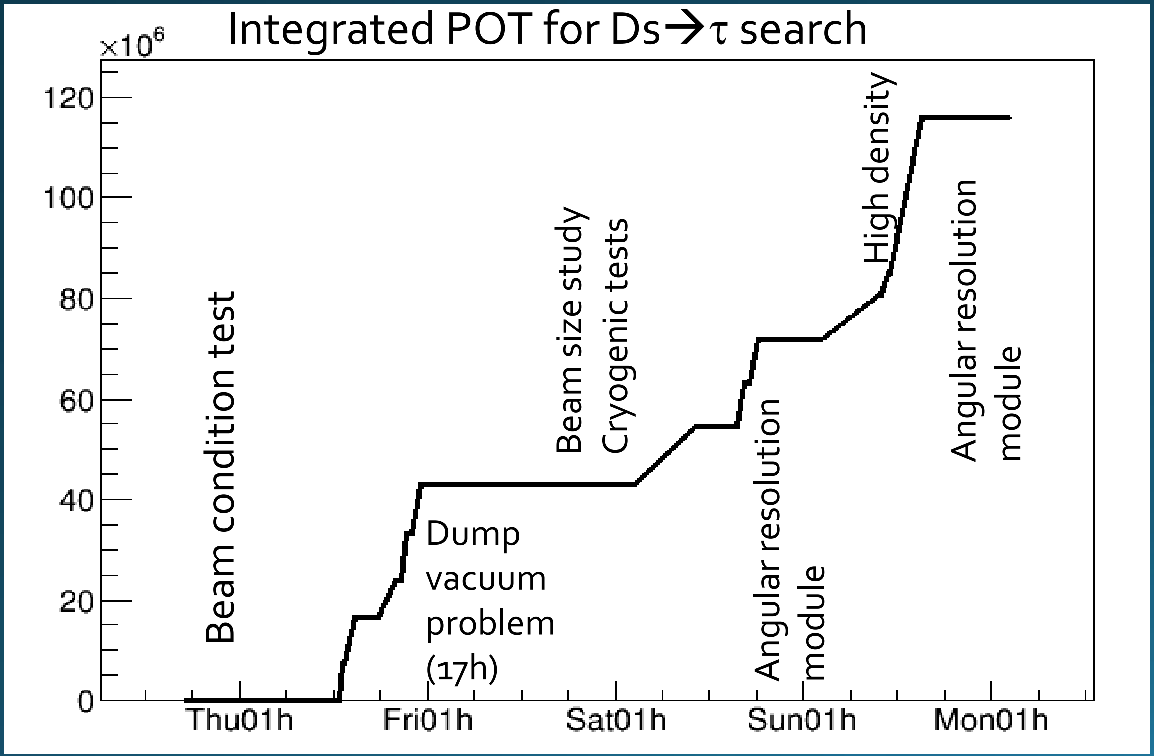
dedicated piling support

Detector setup at the H4 beamline



DsTau proton run summary, 2016

- About 10^7 protons per a detector module, 11 modules in total.
- $O(10^7)$ interactions, about 5×10^6 interactions expected in tungsten target



Nov 9th

Nov 14th

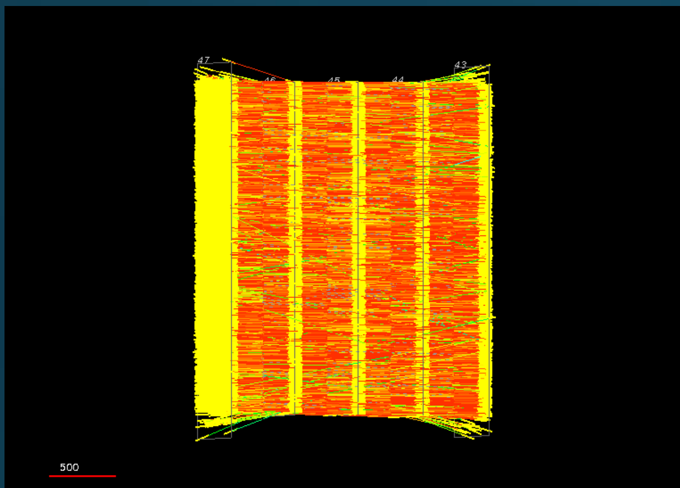
Expected recorded number of events

~5×10^6 proton interactions (in tungsten target)

~10^4 charm events (~2000 D_s, ~9500 D^0, …)

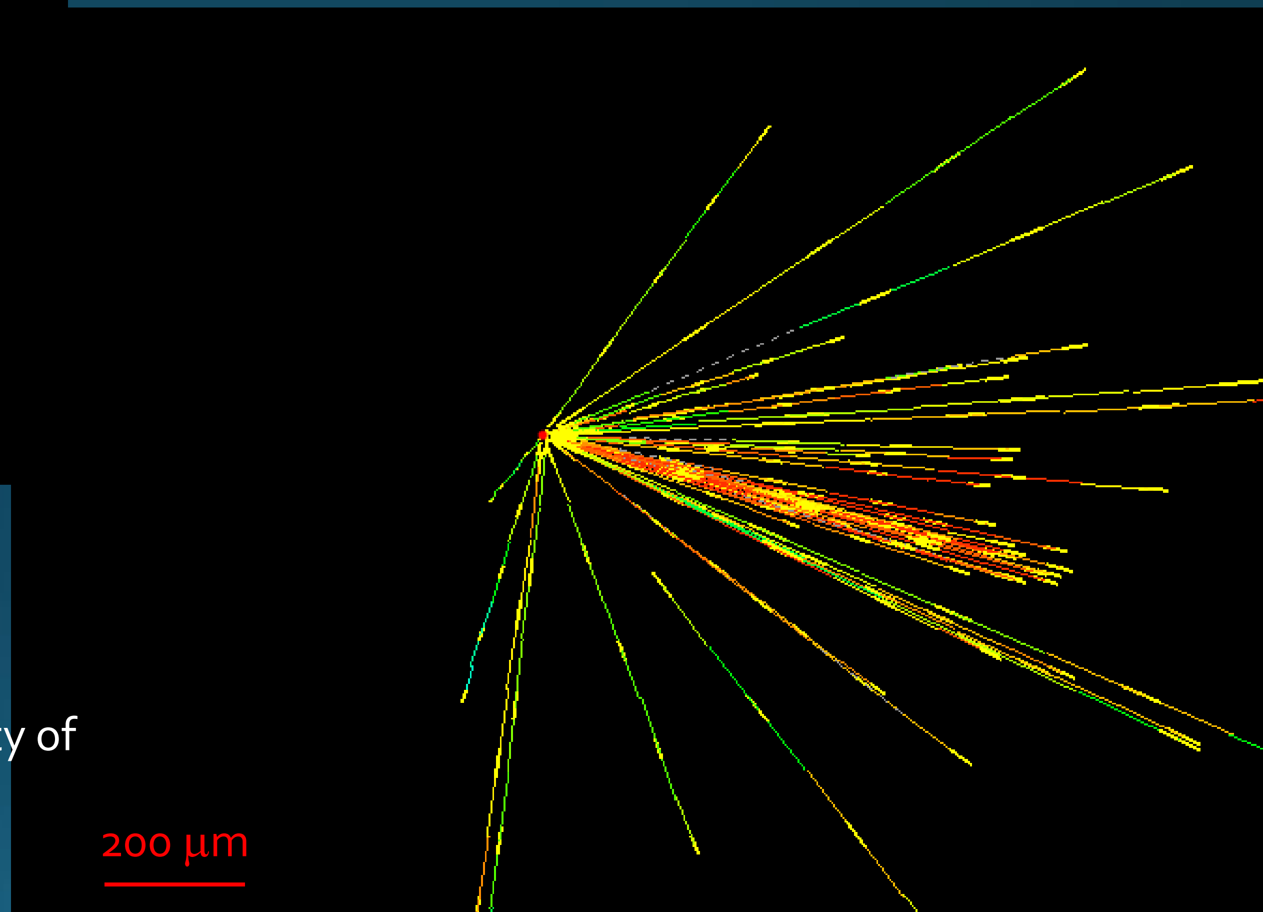
~100 D_s decaying to τ events

A glance at data from 2016 run



2mm x 2mm x 5 films
~15000 protons

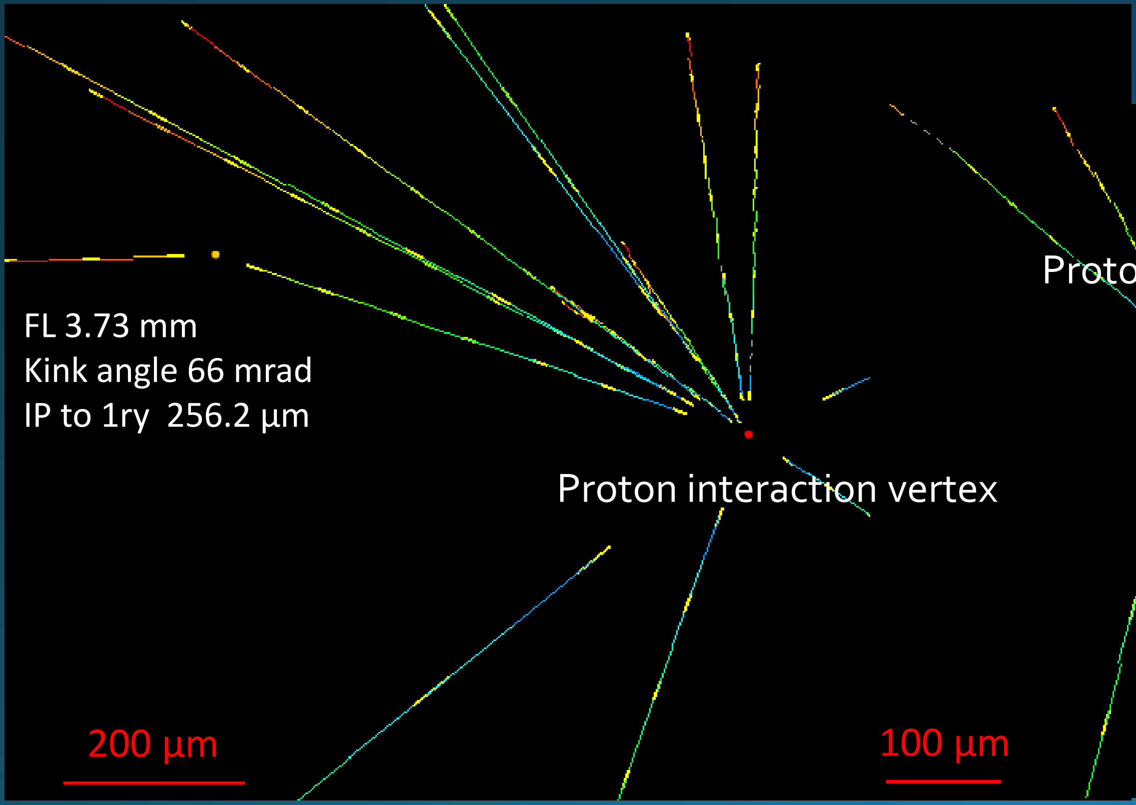
HTS data at the track density of
~$4x10^5/cm^2$



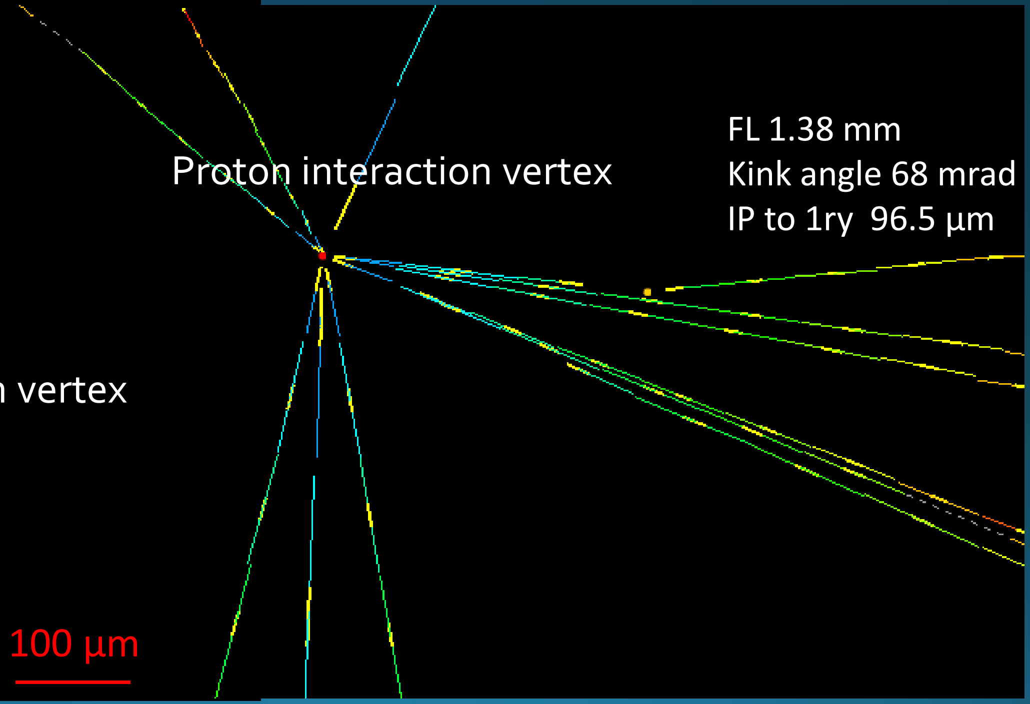
Data analysis is ongoing.

Decay topology search

A volume of 6 cm x 6 cm x 10 films was preliminary analyzed.
About 30,000 proton interactions.
150 events with possible decay topology (expected charm events ~ 30).



tilted views



Combination with NA61?

- Charge identification of Ds daughters as well as daughters of all other charmed particles.
- Total production cross-section of Ds and branching ration BR(Ds→τ), → Vcs measurement.

- Practical challenge:
  - Time stamping in emulsion
  - Interface detector (e.g. silicon pixel) between emulsion and TPC.

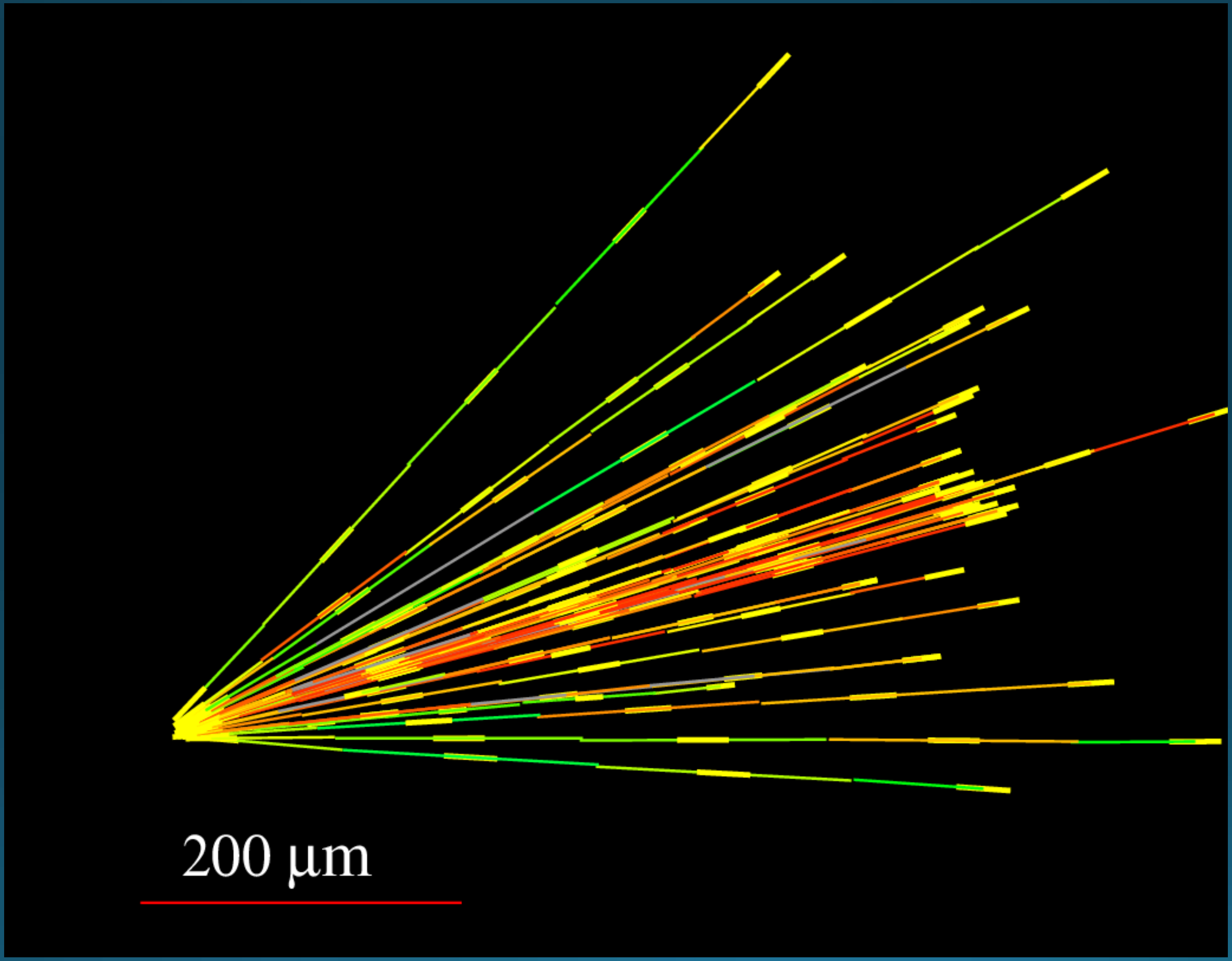
Summary and prospects

- $D_s \rightarrow \tau \rightarrow X$ precision measurement in proton interactions is essential input to precise evaluation of ν_τ cross section → DsTau
- Emulsion detectors with nano-precision readout
- Aiming to analyze ~2×10^8 proton interactions to detect 1000 $D_s \rightarrow \tau$ events (physics run in 2018 and 2021)
- Various by-product studies using the ~10^5 charmed-particles
    - e.g. Interaction cross-section of charmed particles, super-nuclei

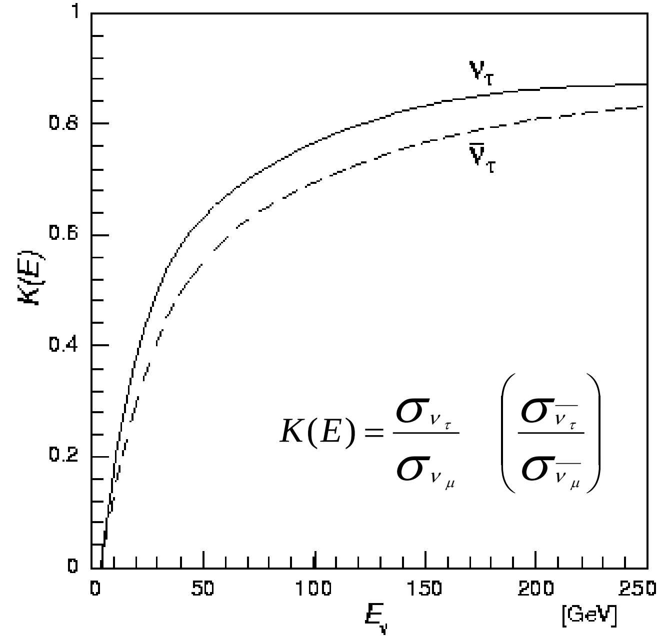
- Successful data taking in test beam in 2016, 2017
- Data analysis in progress

- Technical publications are under preparation
- Experimental proposal will be submitted soon
    - Physics run in 2018 and 2021.

Thanks!



Results from DONuT (1)



ν_τ CC cross section

$$\sigma_{\nu\tau}(E) = \sigma_{\nu\tau}^{const} \times E_{\nu\tau} \times K_\tau(E)$$

ν_τ CC cross section was calculated as a function of one parameter.
The energy-independent part was parameterized as

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

where **n** is the parameter controlling the longitudinal part of the D_s differential cross section

Phenomenological formula

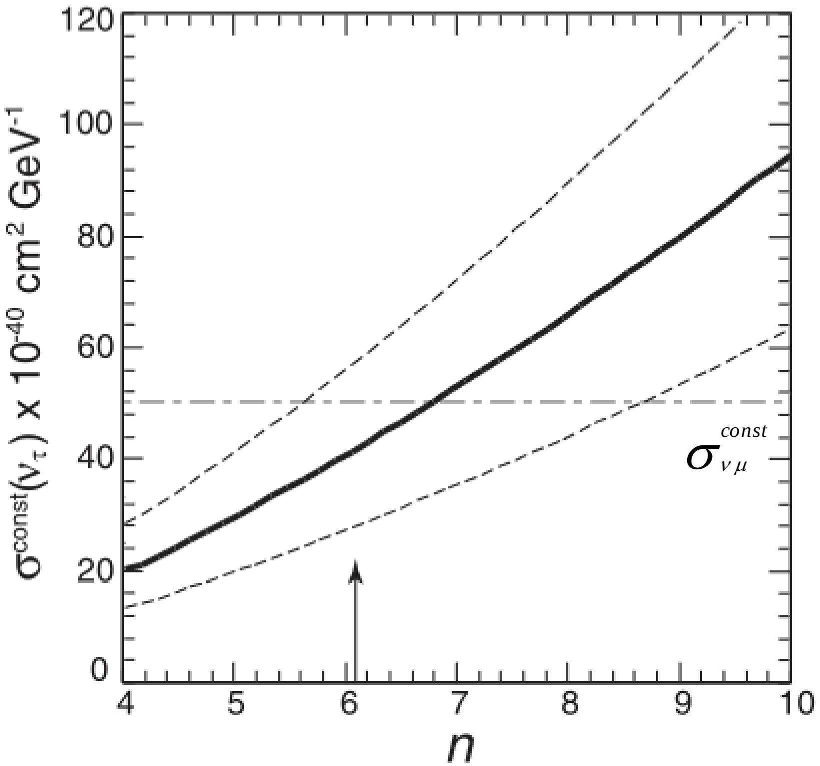
$$\frac{d^2\sigma}{dx_F\, dp_T^2} \propto (1 - |x_F|)^n \exp(-b p_T^2)$$

longitudinal dependence — transverse dependence

x_F is Feynman x ($x_F = 2p^{CM}_Z/\sqrt{s}$) and
p_T is transverse momentum

Results from DONuT

ν_τ CC cross section as a function of the parameter n



Using PYTHIA-derived value of n=6.1

$$\sigma^{const}_{\nu\tau} = (0.39 \pm 0.13 \pm 0.13) \times 10^{-38}\, cm^2 GeV^{-1}$$

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

No published data giving n for D_s produced by 800 GeV proton interactions

Systematic uncertainties	
D_s differential cross section (x_F dependence)	~0.50?
Charm production cross section	0.17
Decay branching ratio	0.23
Target atomic mass effects (A dependence)	0.14

How many interactions to be analyzed?

- To detect 1000 Ds→τ→X events
  - Efficiency ~20%, BR(Ds→ τ) = 5.55%
  - 8.2x104 Ds to be produced
  - Ds production cross section in Tungsten target ~4x10-4 @400GeV
- 2x108 proton interactions to be analyzed!
- 4x109 pot needed (0.5 mm tungsten x 10 units)

To expose $4x10^{9}$ pot with the density 10^{5} tracks/cm^{2}
→ detector surface $4x10^{4}$ cm^{2} (400 modules)

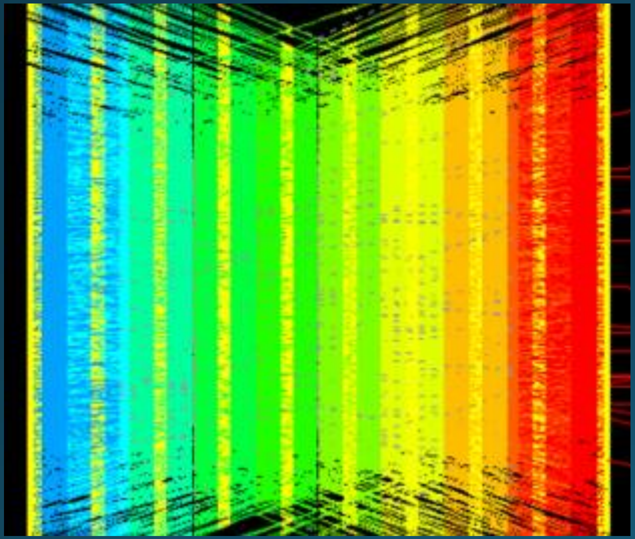
Detector production facility in Bern

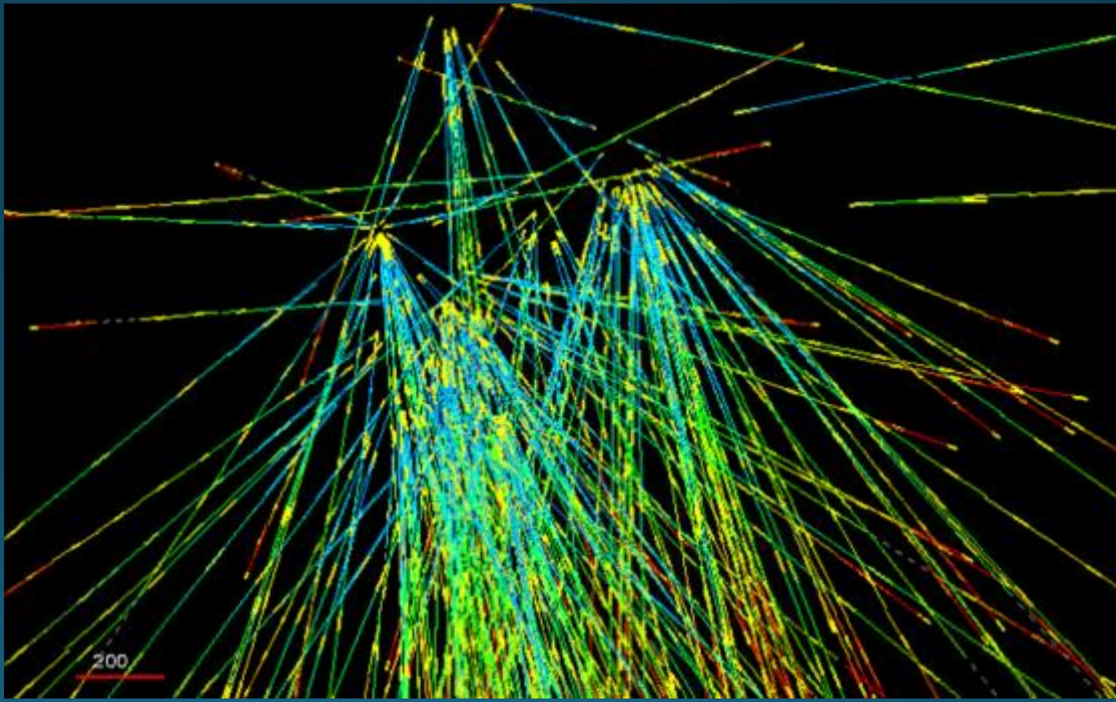
- General purpose film production facility
- 70 m.w.e. underground lab
  - low cosmic background
- 10 m^2/week production capability
- 9 pouring table with active-temperature control
- 1 large drying chamber with active humidity control

- To be upgraded for DsTau
  - production speed to be doubled
  - 500 m^2 → half year.

Data reconstruction

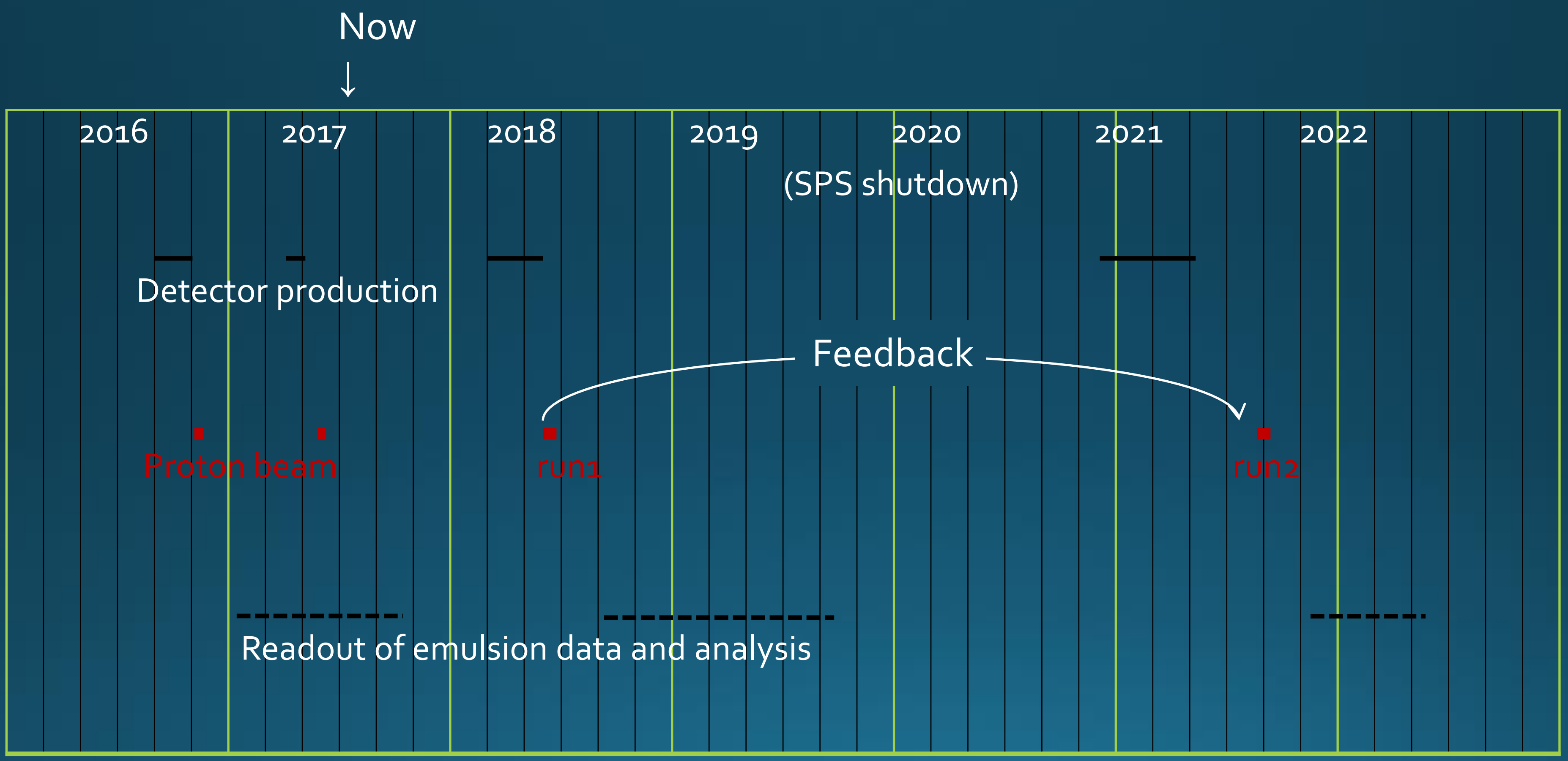
1 mm x 1 mm x 10 films





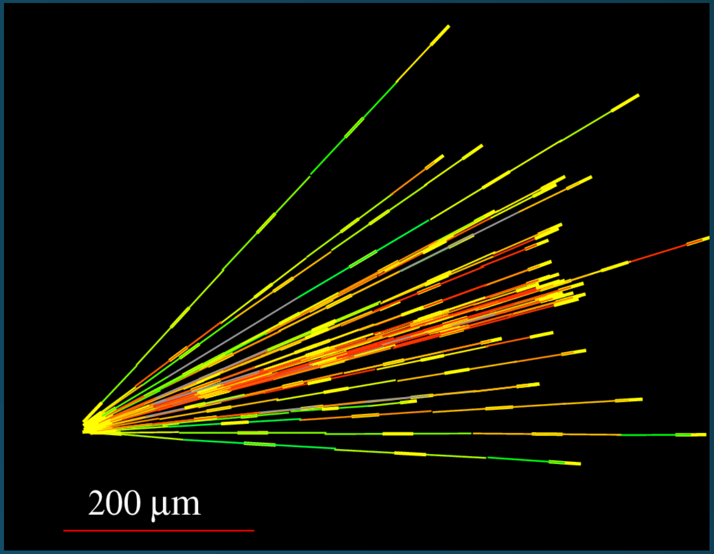
Interactions in the tungsten target

Timetable of the project



DsTau beam test 2017

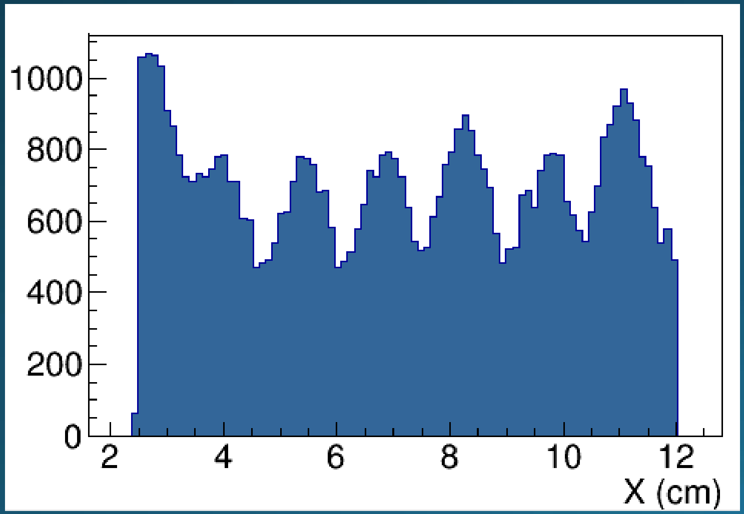
- Physics goal: Study tau neutrino production by proton beam → ultimately, to test lepton universality
  - Precision measurement of Ds differential production cross-section ($Ds \rightarrow \tau\nu_\tau$)
- Successful beam test in 2016 for the proof of principle
  - 1/40 scale of DsTau full design. The analysis is ongoing.



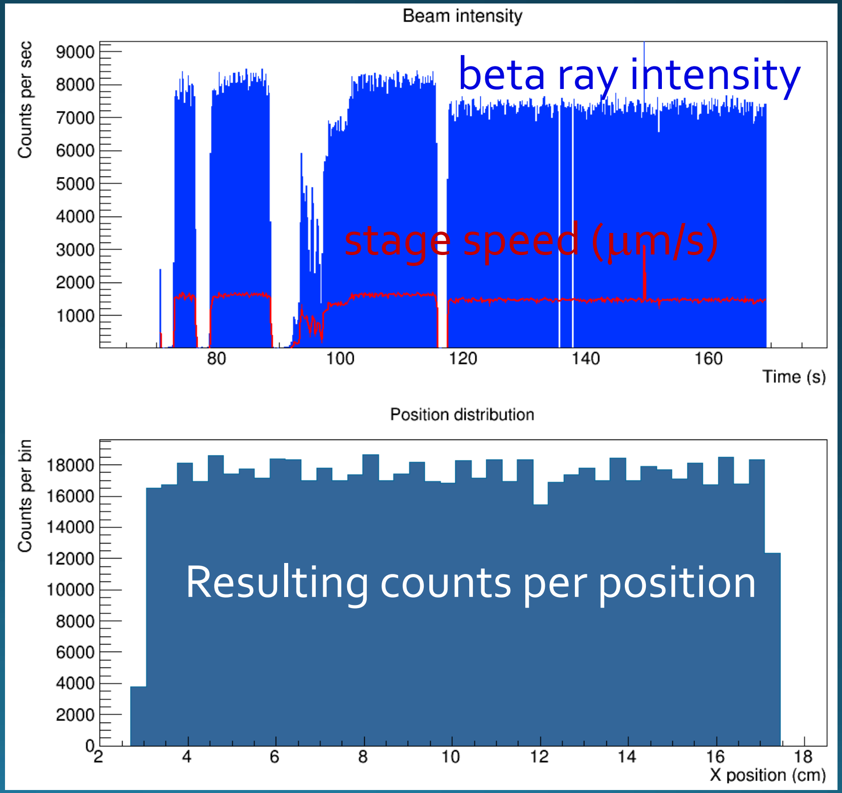
- This year,
  - Test an updated detector design, especially film design to improve angular resolution
  - Test lower intensity to fully reconstruct the kinematical information (Momentum measurement in ECC)
  - To improve exposure sequence (Intensity driven synchronization between beam intensity and target mover)

Intensity driven stage control

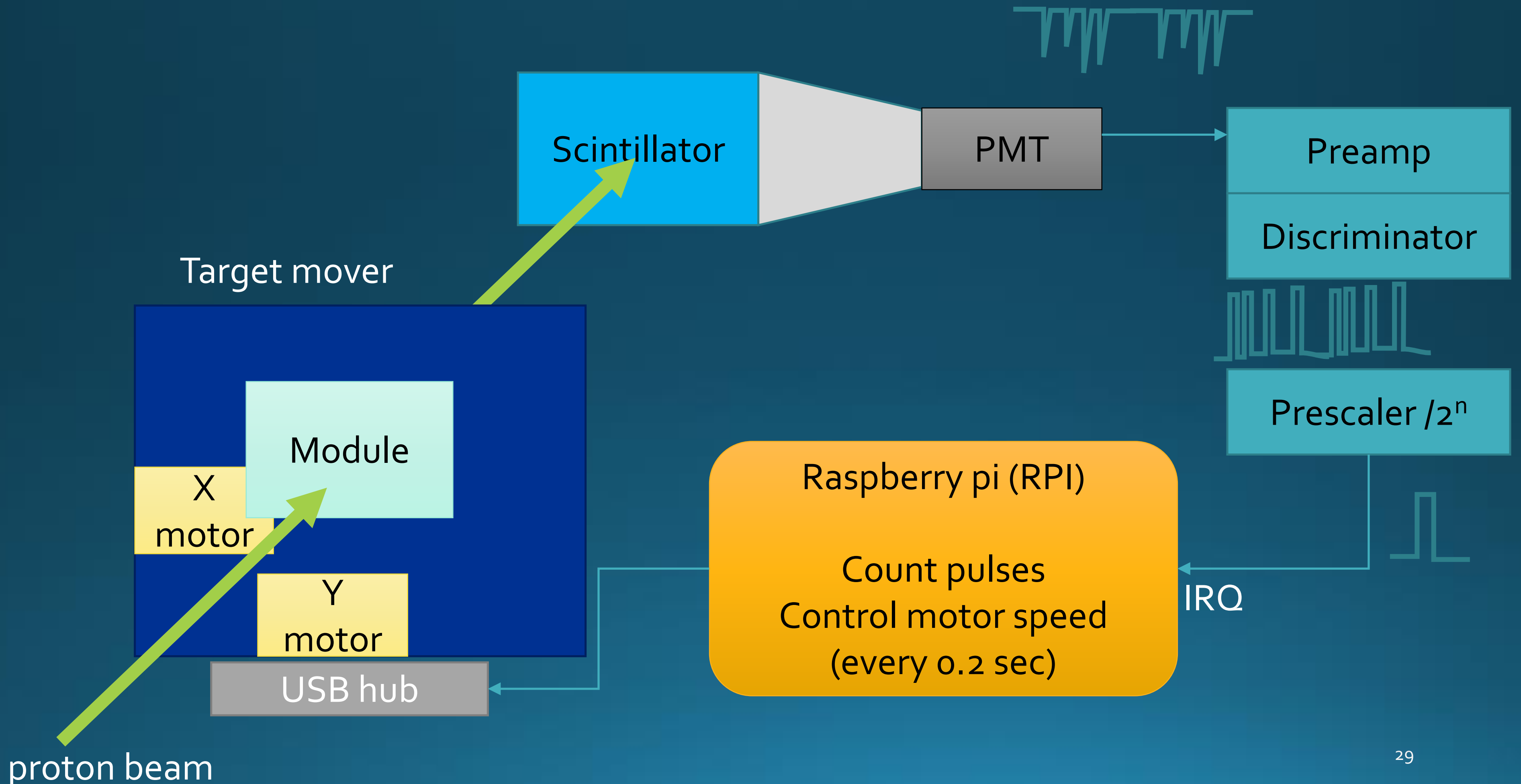
- Flat top was not flat!
- Last year, the target mover moved with a constant speed during FT, which made no uniformity of proton density.



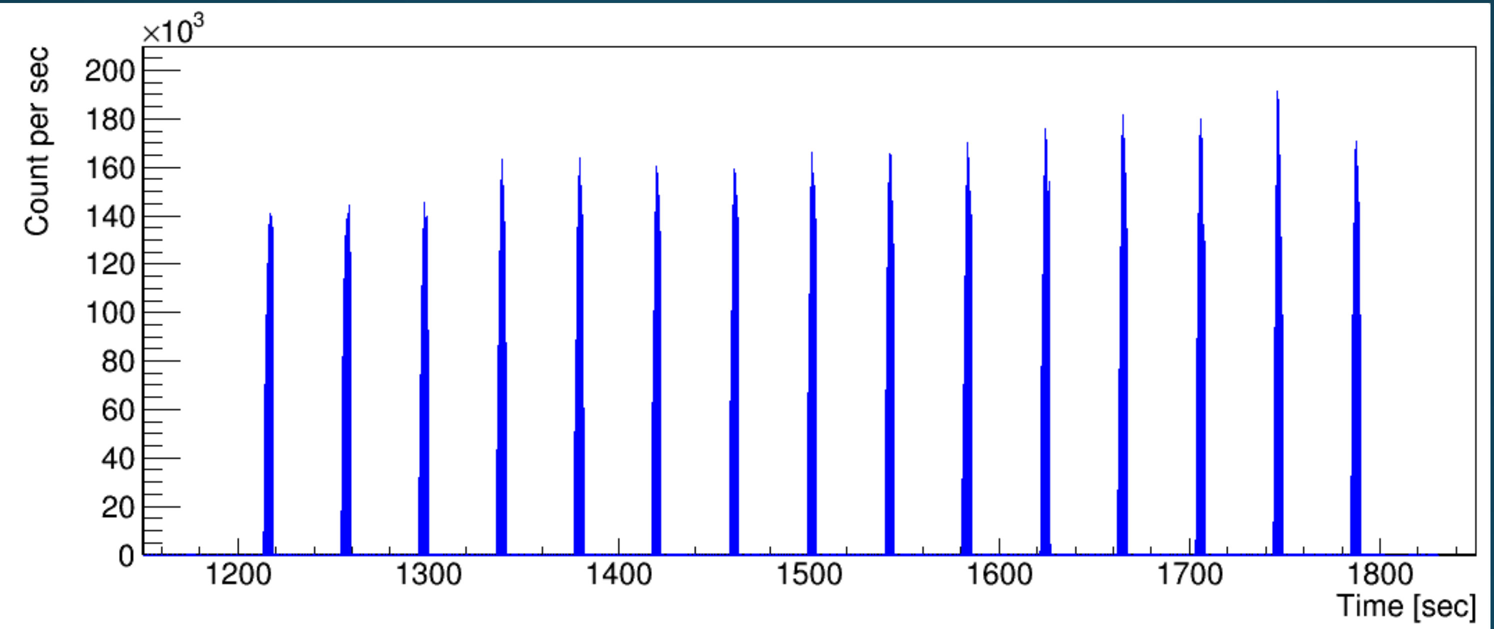
- This year, control speed depending on the beam intensity.

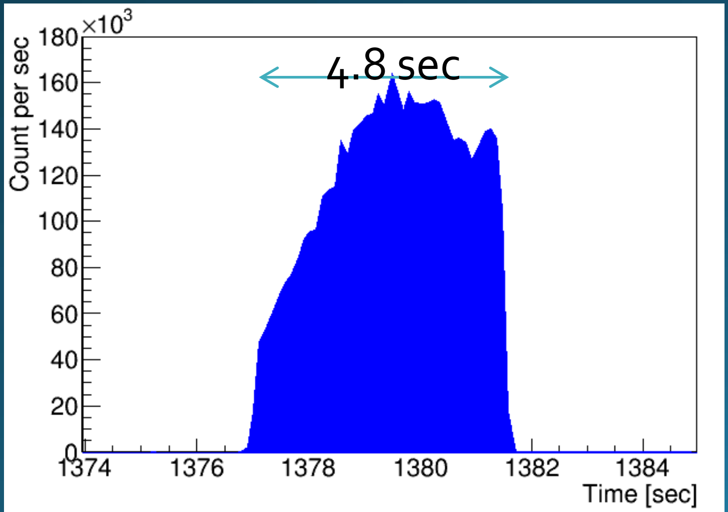


Intensity driven stage control schematic



Time structure of beam

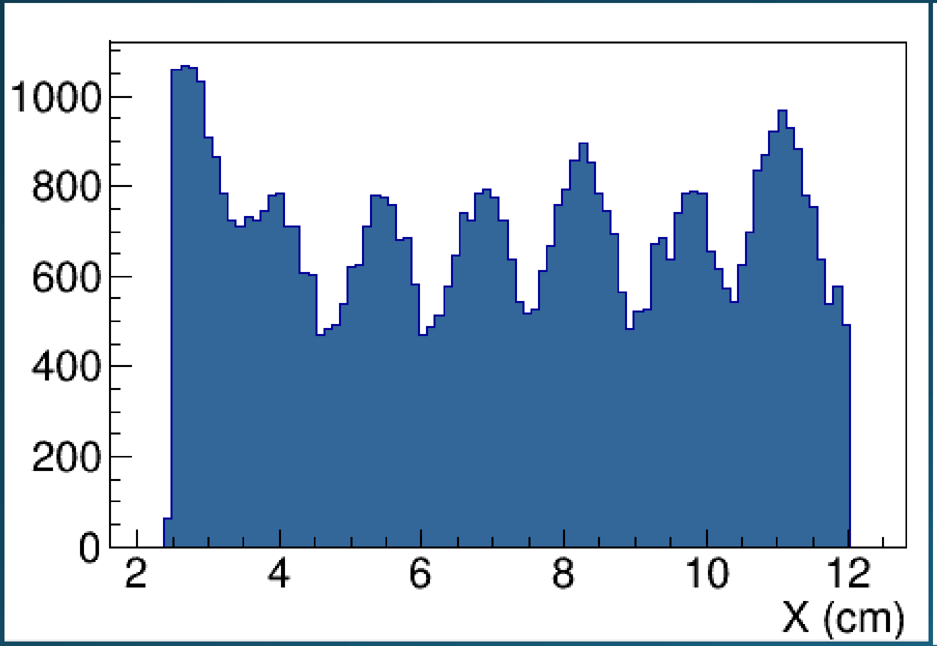




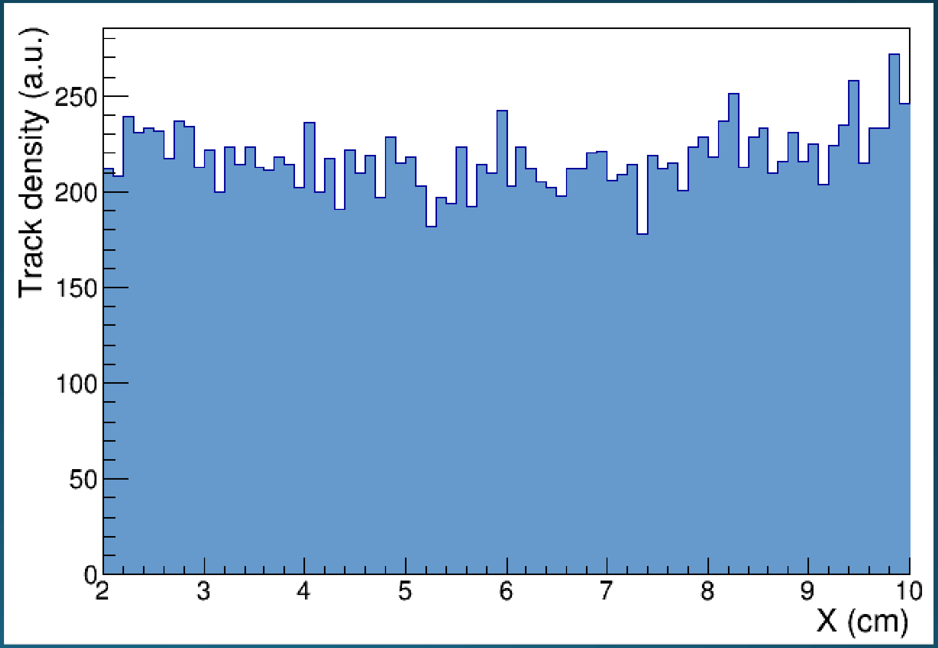
- The beam gradually increase and drop at the end.
- Intensity is measure about every 0.2 sec.

Comparison

- 2016



- 2017



Significant improvement!!

Stage movement test (BM3)

- To check the stage movement, single line exposure was done.
- $10^5/cm^2$ with $2.8x10^5$/spill ~2.8cm/spill
- A very flat distribution was observed in emulsion