Study of tau-neutrino production with emulsion particle detectors
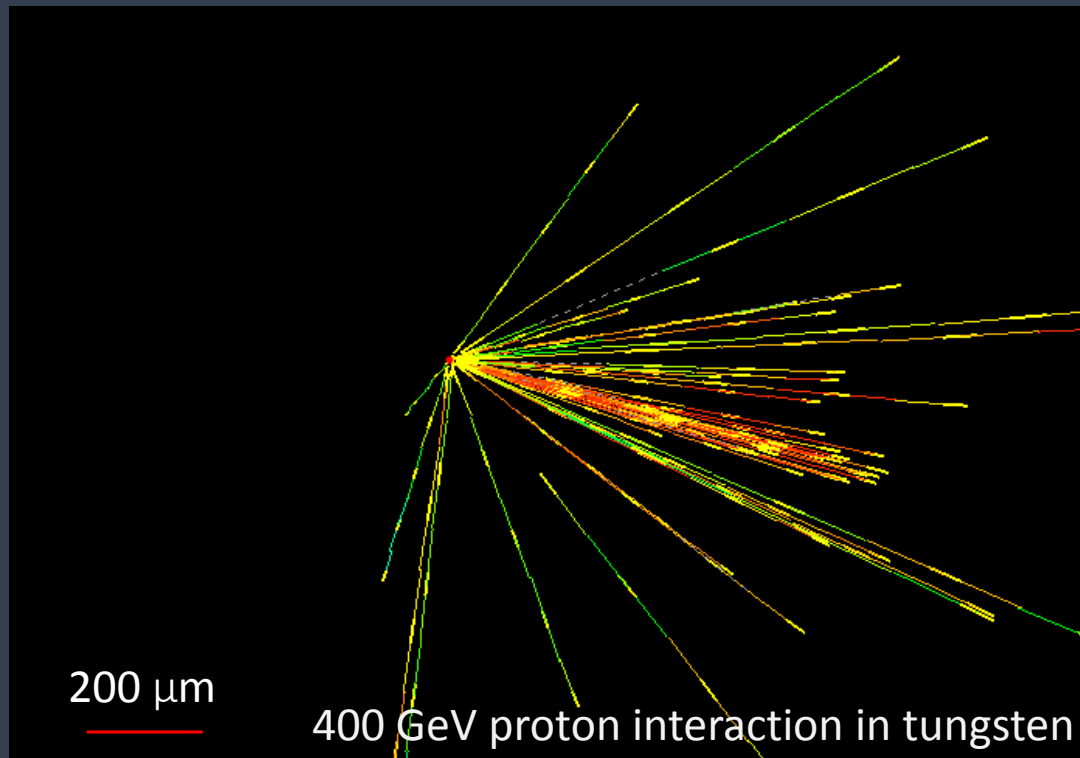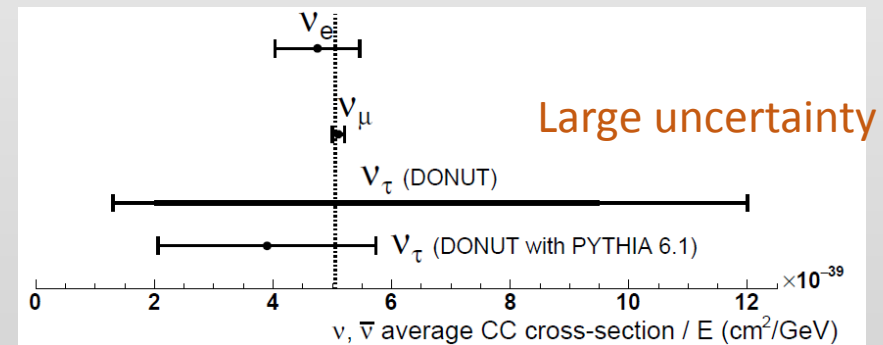
Tomoko Ariga for the DsTau collaboration

Kyushu University

200 μm

400 GeV proton interaction in tungsten

The DsTau project at the CERN SPS

- **Physics motivations**
  - Tau neutrinos are among the less known particles in the Standard Model
  - Large systematic uncertainty in the cross section measurement
  - Precision measurement of   CC cross section

    Test of lepton universality in   CC interactions
    (search for new physics effects)
   Also important for future neutrino experiments, e.g. DUNE, Hyper-K

$$\nu_e$$

Large uncertainty

$$\nu_\mu$$

ν_τ (DONUT)

ν_τ (DONUT with PYTHIA 6.1)

$\times 10^{-39}$

0   2   4   6   8   10   12

$\nu, \overline{\nu}$ average CC cross-section / E (cm^2/GeV)

- **DsTau goals**
  - Measurement of   production
    - Reduce systematic uncertainty ~50%   ~10%
    Re-evaluation of the cross section from DONUT
    Essential input for future   experiment, e.g. SHiP
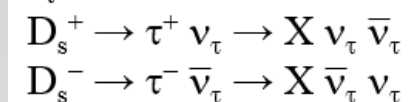
ν_τ source:
$$D_s^+ \to \tau^+ \nu_\tau \to X \nu_\tau \overline{\nu}_\tau$$
$$D_s^- \to \tau^- \overline{\nu}_\tau \to X \overline{\nu}_\tau \nu_\tau$$

Methodology

- Study   production by measuring the $D_s \to \tau$ decays following high-energy proton interactions
  - source: $D_s \to \tau \nu_\tau \to \nu_\tau \bar{\nu}_\tau X$
  - Detect double-kink + another decay topology within a few mm
  - Technical challenge to detect small kink angle of $D_s \to \tau$ decays
  - Measure the D_s differential production cross section and decay branching ratio to   inclusively   improve the   flux prediction
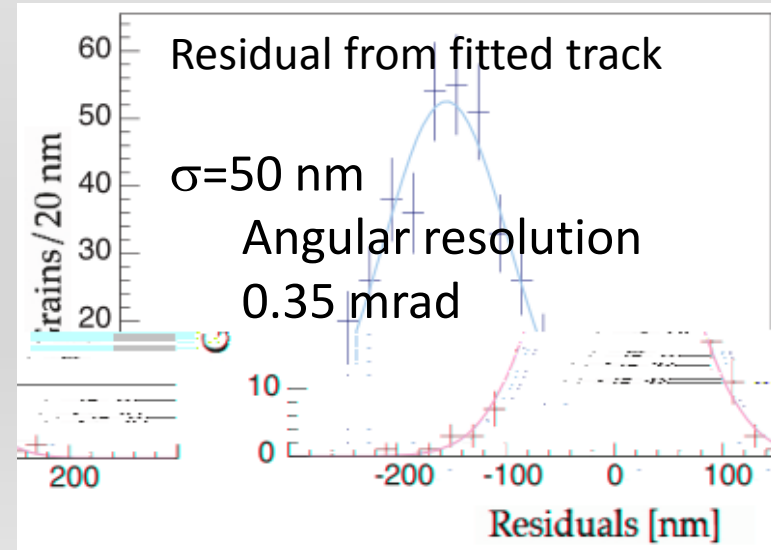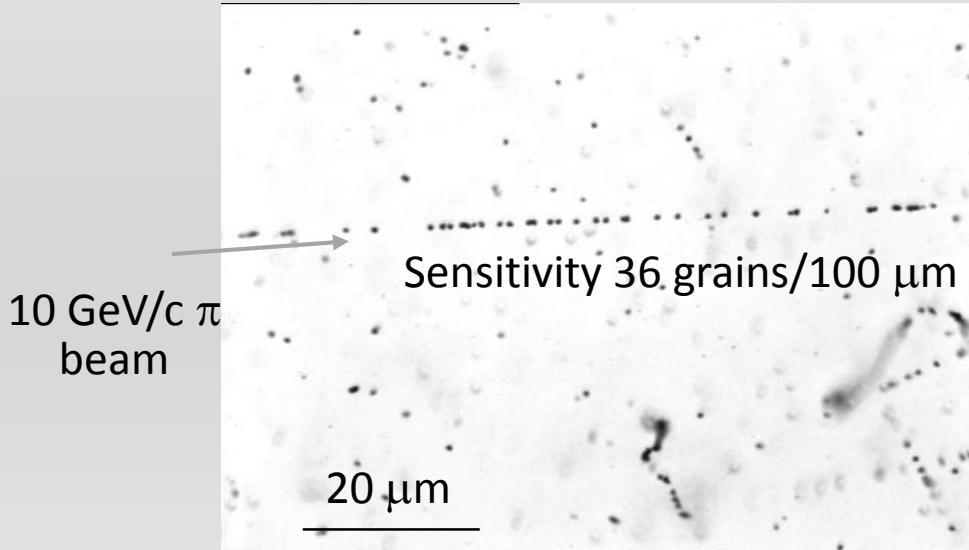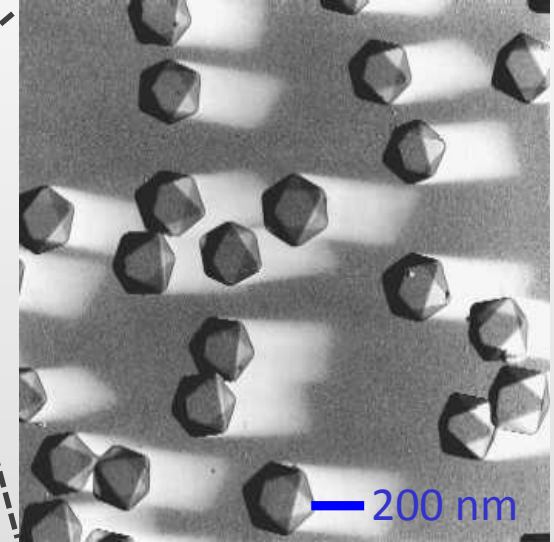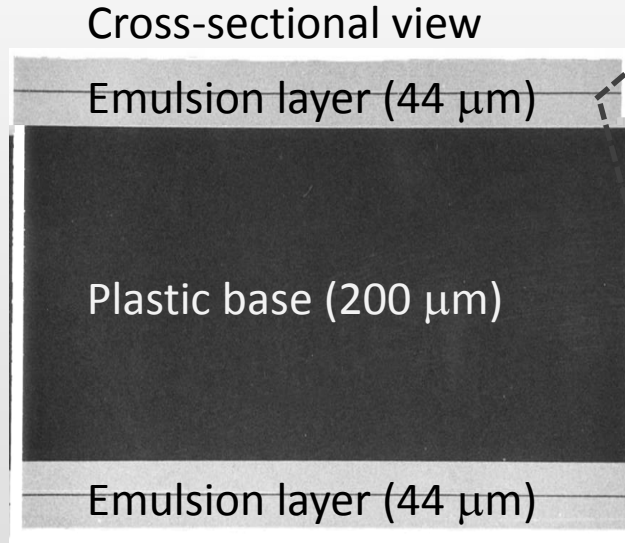

Kink angle of D_s a few mrad

Primary proton

D_s

D^+

X

X'

~5 mm
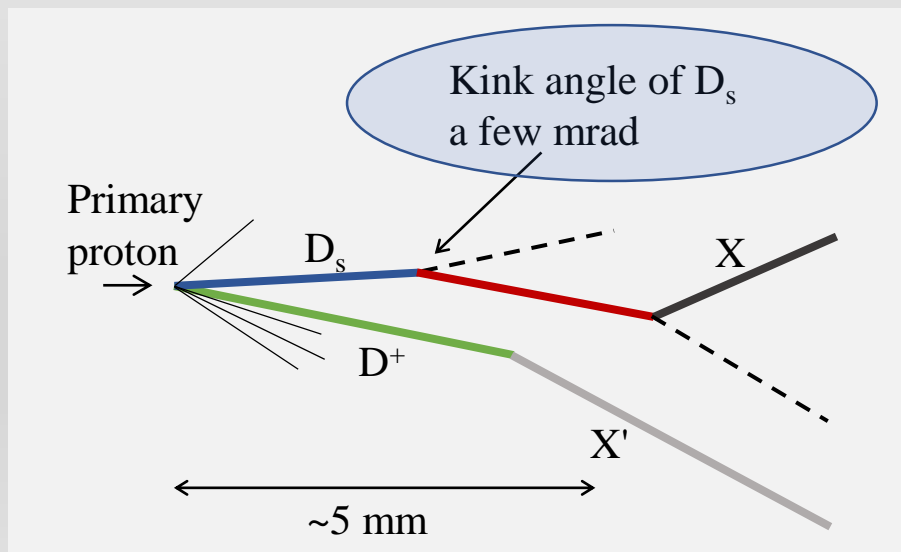
	$< FL >$	$< \theta_{kink} >$
D_s	3.3 mm	7 mrad
100 mrad τ	2.0 mm	

Emulsion detectors:
3D tracking device with 50 nm precision

AgBr crystal

10^{14} crystals in a film

Cross-sectional view

Emulsion film

Emulsion layer (44 μm)

Plastic base (200 μm)

Emulsion layer (44 μm)

— 200 nm

Residual from fitted track

σ=50 nm

Angular resolution
0.35 mrad

10 GeV/c π beam

Sensitivity 36 grains/100 μm

20 μm

grains / 20 nm

Residuals [nm]
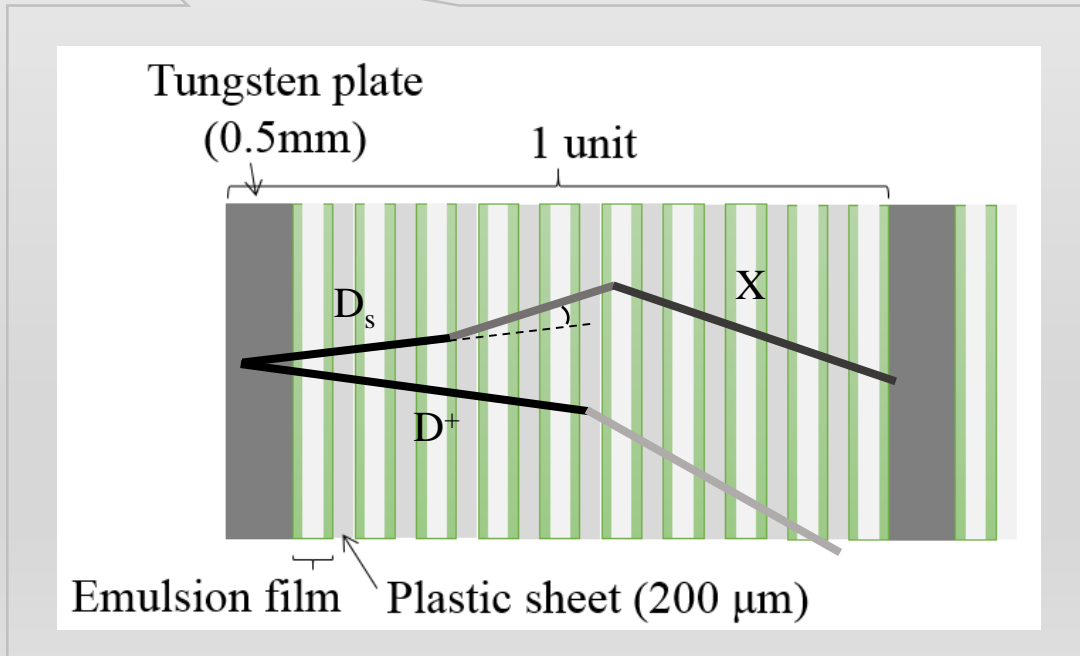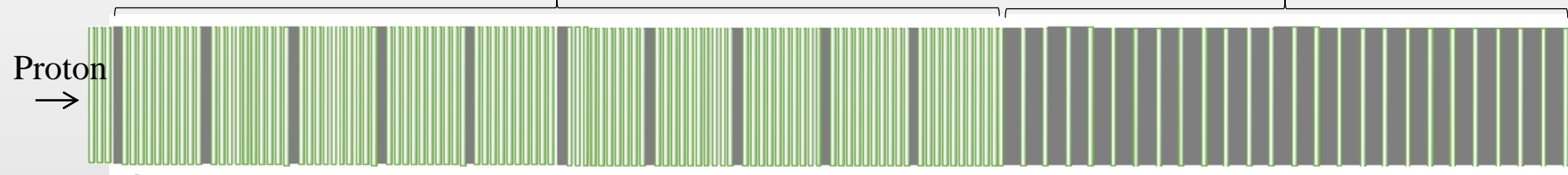
Module structure for $D_s \to \tau \to X$ measurement

10 units
(total 100 emulsion films)

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

Proton
→

Tungsten plate
(0.5mm)

1 unit

D_s

X

D^+

Emulsion film   Plastic sheet (200 μm)

1 module

X 12.5 cm

Proton beam
10^5 protons/cm^2
(uniform irradiation)

Y 10 cm
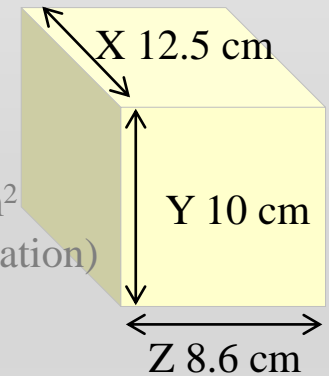
Z 8.6 cm
(10 units + ECC)

How many interactions to be analyzed?

To detect 1000 $D_s \to \tau$ events,

- **2.3×10^8 proton interactions to be analyzed**
  - Efficiency 20%
  - BR($D_s \to \tau$) = 5.54% (PDG2016)
  - D_s production cross section in tungsten target $\sim 4 \times 10^{-4}$ @400GeV

- 4.6×10^9 pot needed
  - 0.5 mm tungsten x 10 units = 0.05 λ_{int}

- To expose 4.6×10^9 pot with the density 10^5 tracks/cm^2 detector surface 4.6 m^2 (368 modules, film surface 593 m^2)

Signal

Kink angle of D_s a few mrad

Primary proton

D_s

D^+

X

X'

~ 5 mm
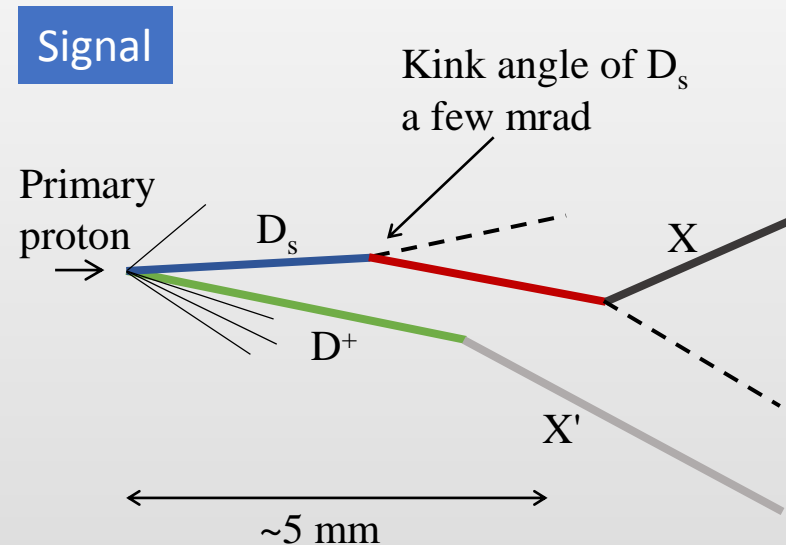
With the preliminary criteria,
Signal probability 5×10^{-6} /proton int.
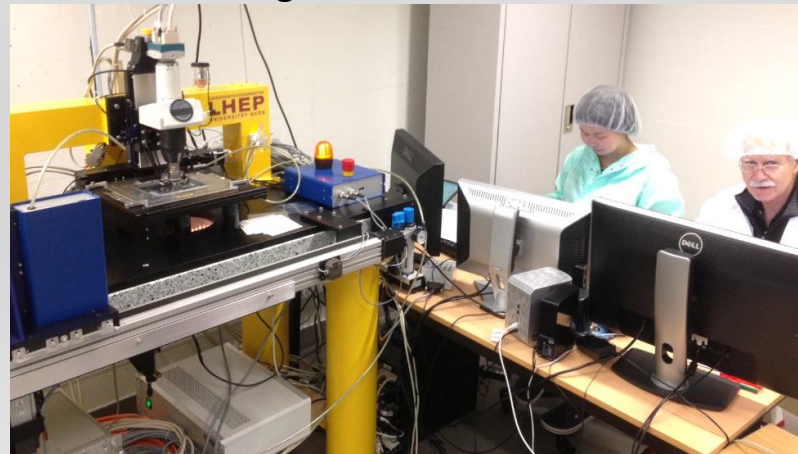Background 9×10^{-9} /proton int.

Two step analysis for double kink search

1. High speed scanning to select
   -> X + partner-charm decays
   (~100 mrad)

2. Precision measurement to detect
   D_s -> decay (a few mrad)
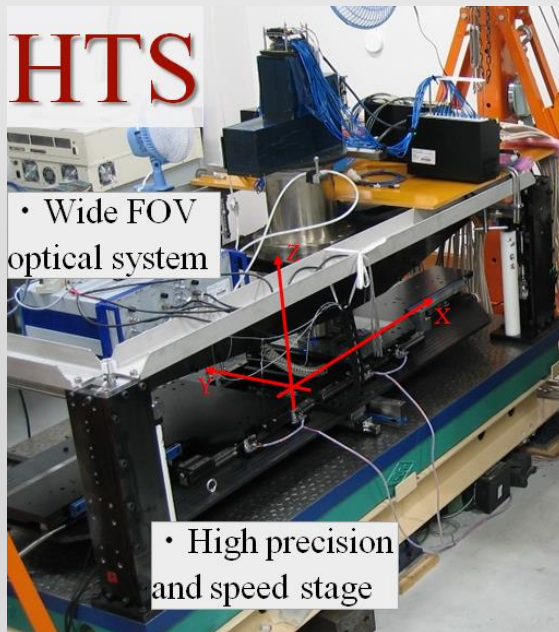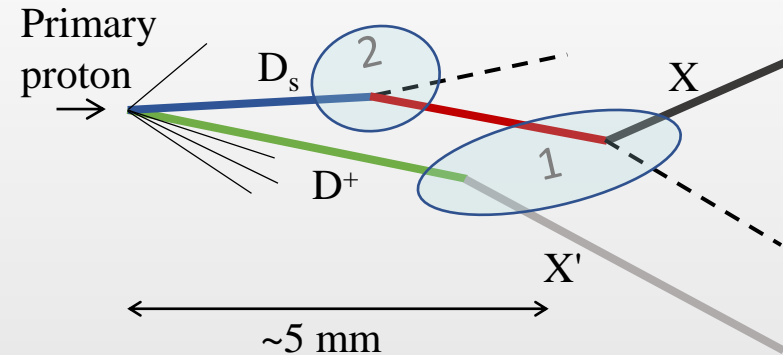
A **fast** scanning system in Nagoya:
Speed 0.5 m²/h/layer
Angular resolution ~2 mrad

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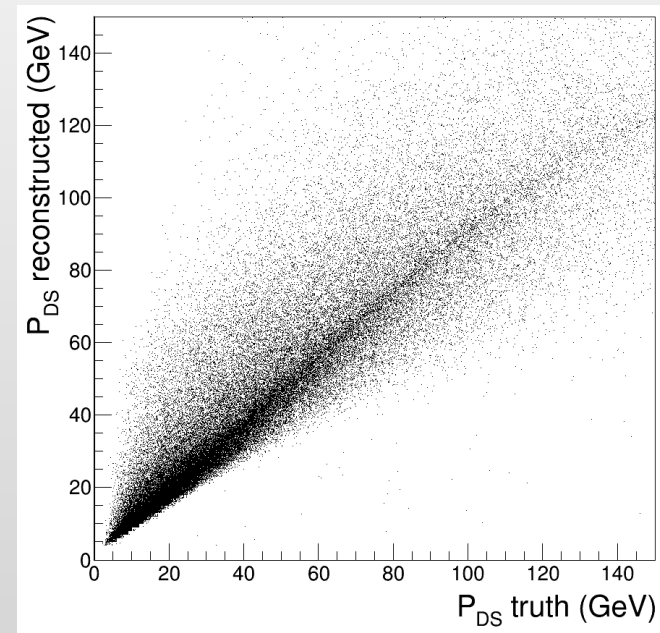Angular resolution ~0.3 mrad

7

D$_s$ momentum reconstruction

- The peculiar decay topology is rich in kinematical information
- D$_s$ momentum reconstruction only by topological variables

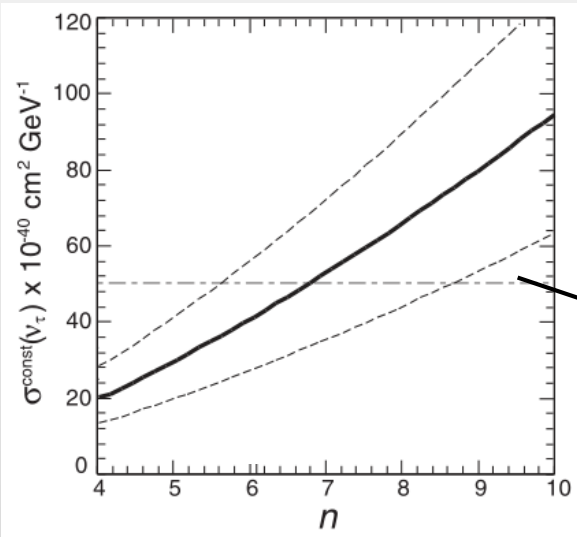

Primary proton →   D$_s$

FL$_{Ds}$ **FL**
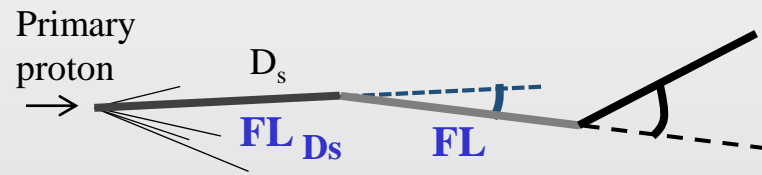
FL: flight length
    : kink angle

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

Expected performance

ν_τ CC cross section measured by DONUT as a function of the parameter n

Systematic uncertainties	DONUT	With DsTau
D_s differential cross section (x_F dependence)	~0.50	~0.10
Charm production cross section	0.17	
Decay branching ratio (0.04)	0.23	~0.03
Target atomic mass effects	0.14	

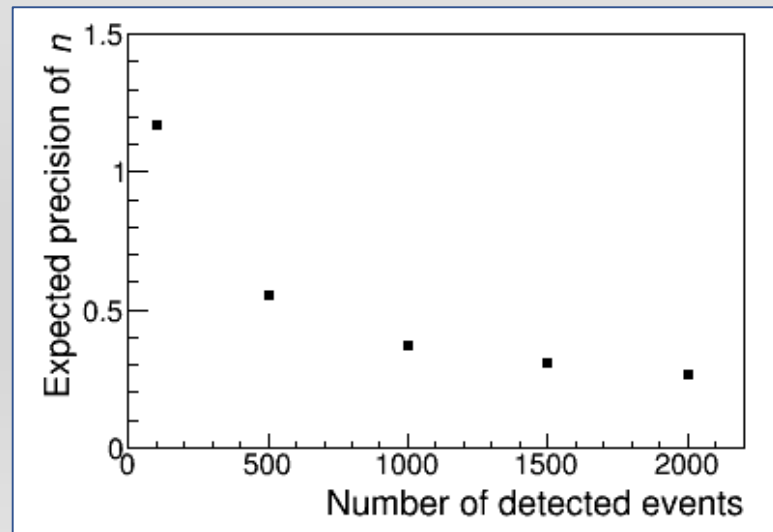To reach ~10% precision on the cross section, the parameter n has to be measured at a precision of ~0.4

Phenomenological formula conventionally used to describe charmed particles

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

Status of the project

- Letter of Intent submitted to the CERN-SPSC in Feb. 2016

- Test beam campaign in Nov. 2016, May 2017

- Proposal submitted in Aug. 2017
  - Physics run in 2018, 2021-2022

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

S. Aoki[1], A. Ariga[2], T. Ariga[2], K. Kodama[3], M. Nakamura[4], O. Sato[4]

[1]Kobe University
[2]AEC/LHEP, University of Bern
[3]Aichi University of Education
[4]F-lab, Nagoya University

CERN-SPSC-2016-013 / SPSC-I-245
05/07/2016

Experiment Proposal

Study of tau-neutrino production at the CERN SPS

S. Aoki[1], A. Ariga[2], T. Ariga[2,3,*], E. Firu[4], T. Fukuda[5],
Y. Gornushkin[6], A. M. Guler[7], M. Haiduc[4], K. Kodama[8],
M. A. Korkmaz[7], U. Kose[9], M. Nakamura[5], T. Nakano[5],
A. T. Neagu[4], H. Rokujo[5], O. Sato[5], S. Vasina[6],
M. Vladymyrov[2], M. Yoshimoto[10]

CERN-SPSC-2017-029 / SPSC-P-354
29/08/2017

Beam tests in 2016, 2017

- Nov. 2016 H4 beamline
  - Optimization of the exposure scheme and the setup
  - Proof of principle (1/40 scale of the full design)
- May 2017 H2 beamline
  - Updated exposure sequence (intensity driven synchronization between beam intensity and target mover)
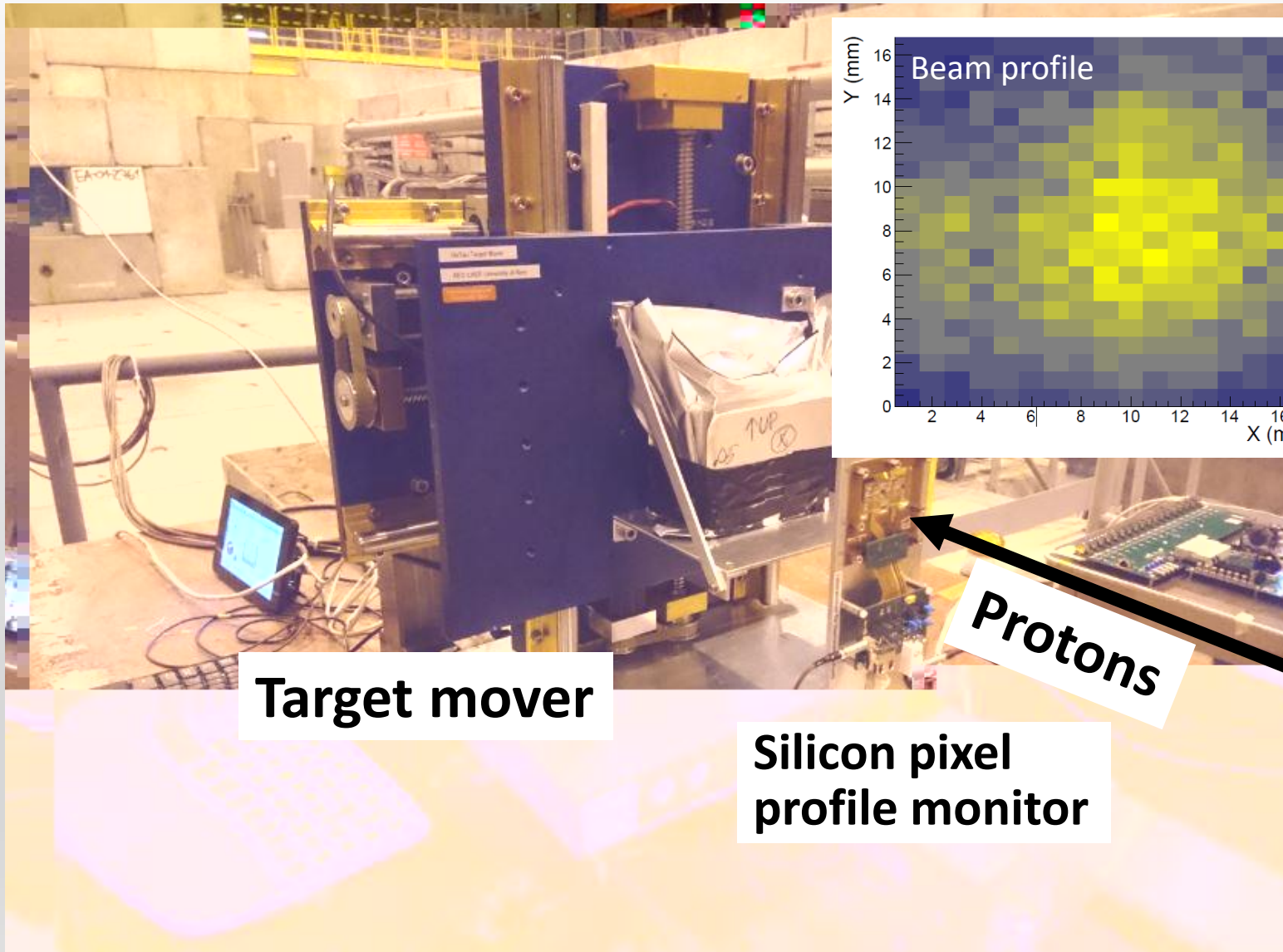 - Tests to improve angular resolution
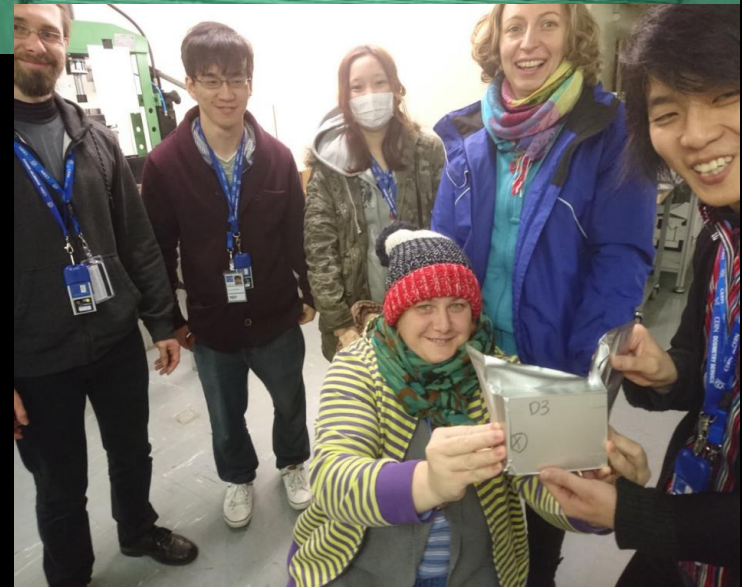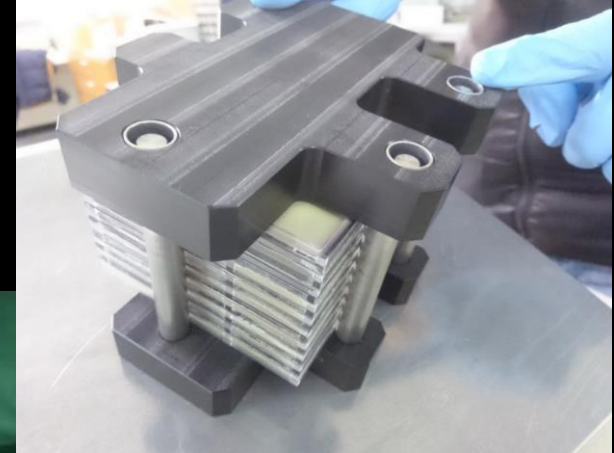
Detector setup at the H4 beamline
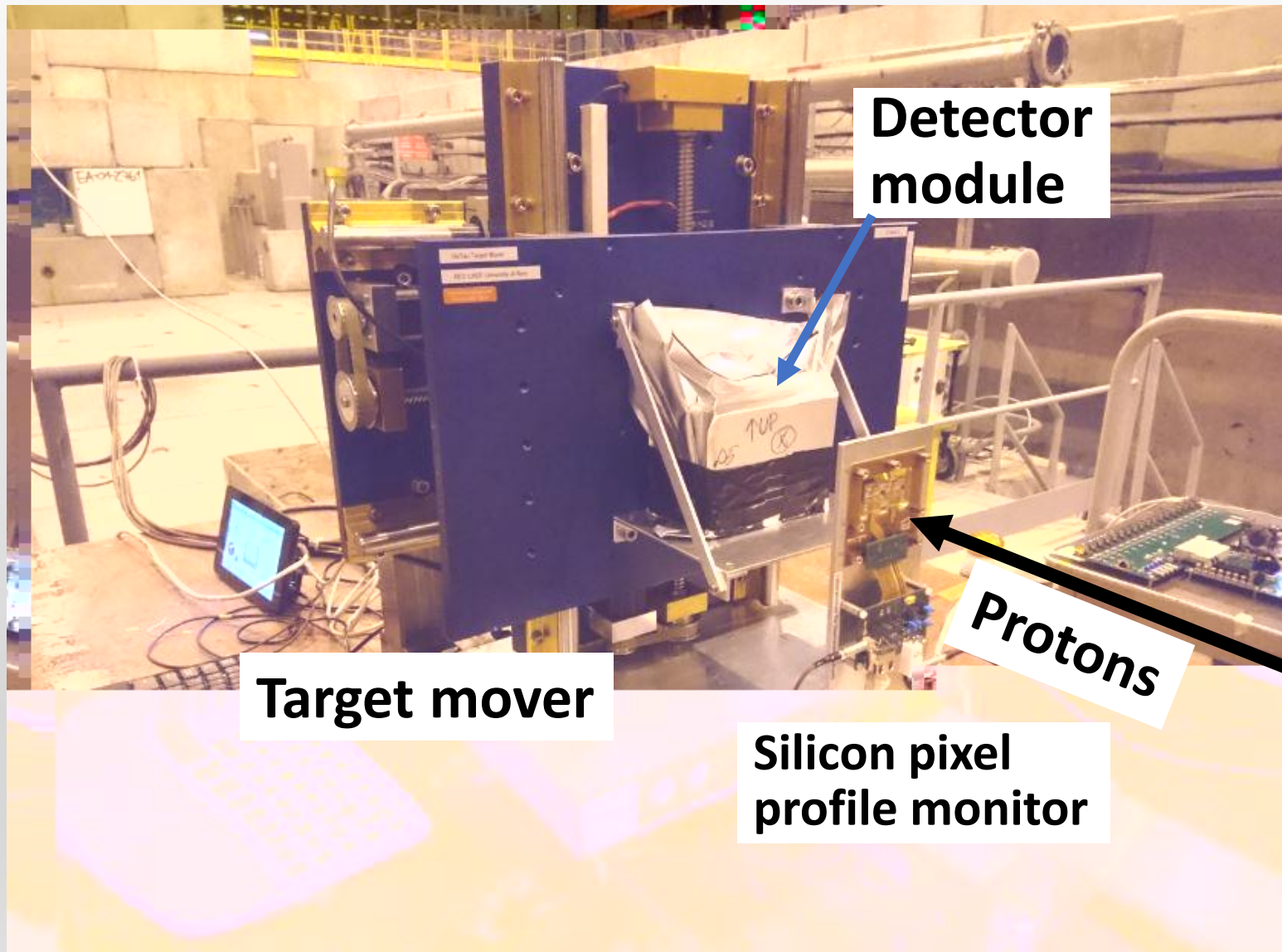
Detector setup at the H4 beamline
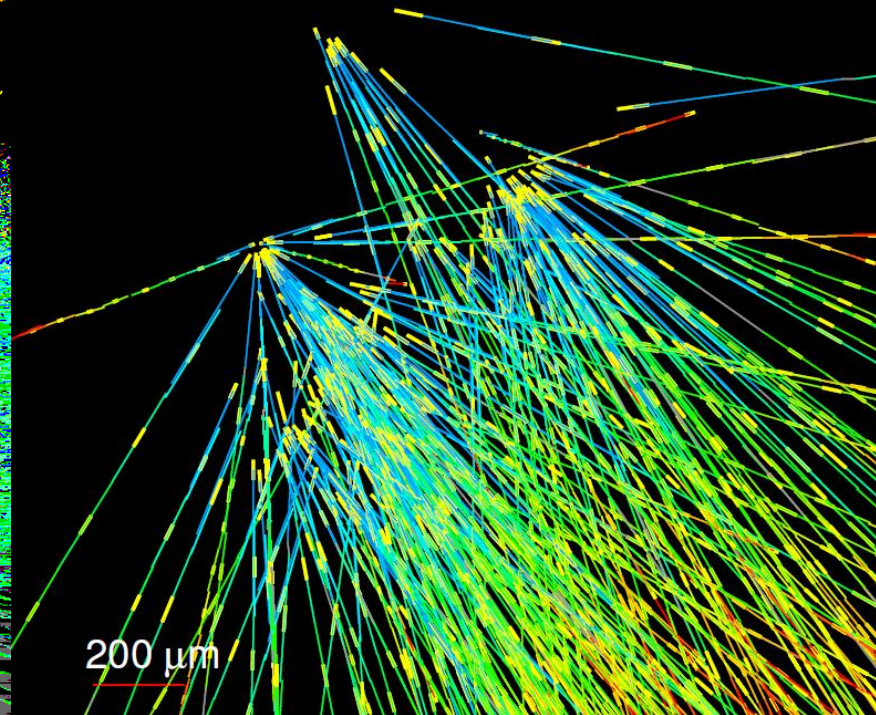
Vertex reconstruction in 3D

Reconstructed tracks in 1 mm x 1 mm
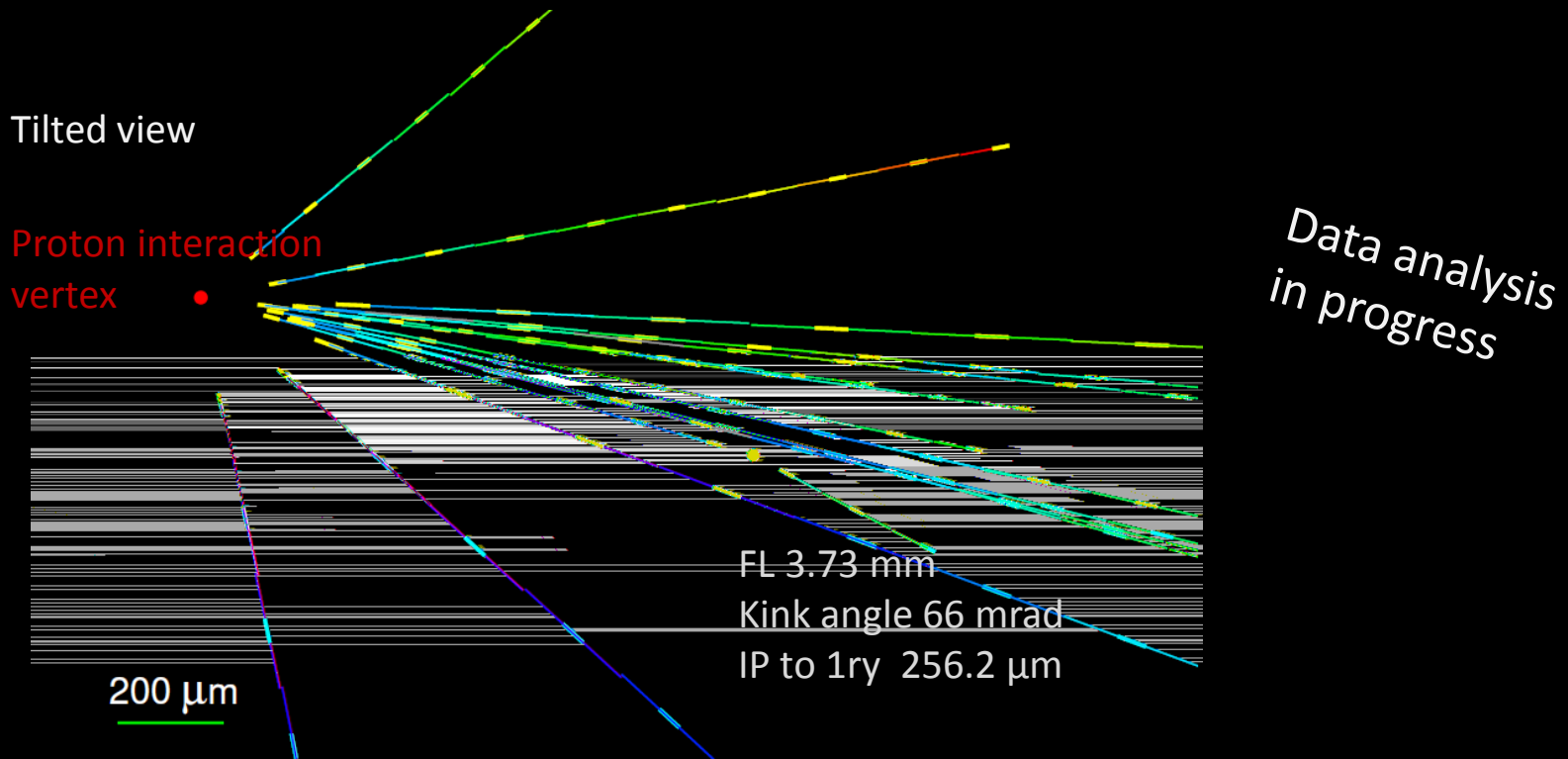(track density ~4×10^5 /cm^2)
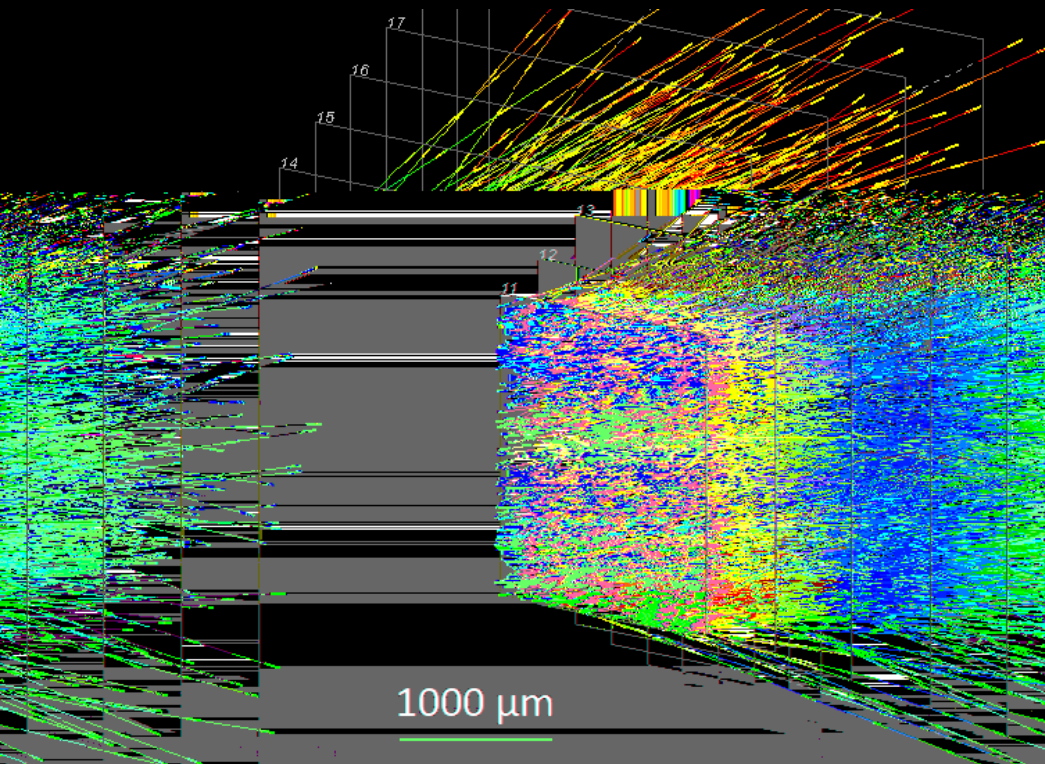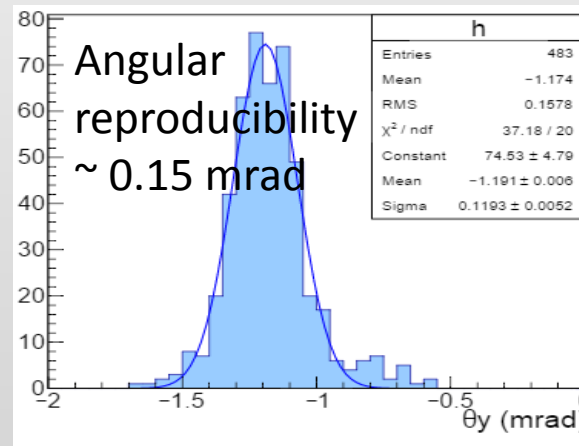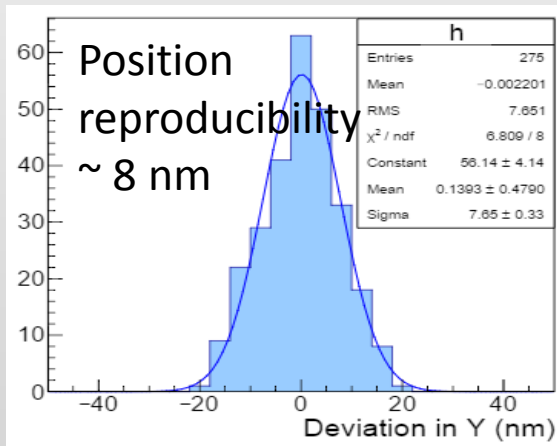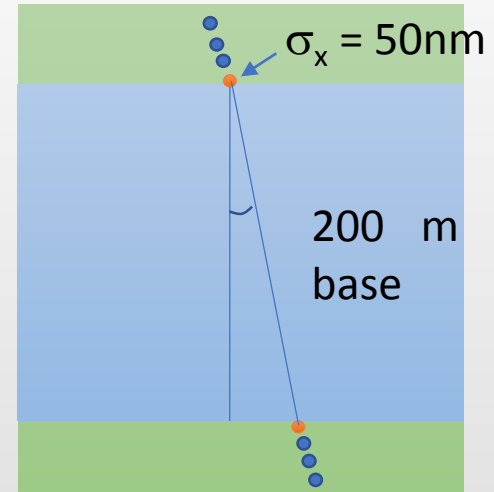
Proton interactions in tungsten

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

Tilted view

Proton interaction
vertex ●

Data analysis
in progress

FL 3.73 mm
Kink angle 66 mrad
IP to 1ry 256.2 μm

200 μm

High precision measurement

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

σ_x = 50nm

200 m base

Position reproducibility ~ 8 nm

h	
Entries	275
Mean	−0.002201
RMS	7.651
χ^2 / ndf	6.809 / 8
Constant	56.14 ± 4.14
Mean	0.1393 ± 0.4790
Sigma	7.65 ± 0.33

Deviation in Y (nm)

Angular reproducibility ~ 0.15 mrad

h	
Entries	483
Mean	−1.174
RMS	0.1578
χ^2 / ndf	37.18 / 20
Constant	74.53 ± 4.79
Mean	−1.191 ± 0.006
Sigma	0.1193 ± 0.0052

θy (mrad)

Piezo objective scanner

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

Summary and prospects

- The DsTau project proposes to study tau-neutrino production in 400 GeV proton interactions
    - Prerequisite for measuring the v_τ charged-current cross section   test of lepton universality in v_τ scattering
    - Experiment proposal submitted to the CERN SPSC in Aug. 2017 (SPSC-P-354)
- Aims to detect 1,000 $D_s \to \tau$ decays in **2.3**   **10^8** proton interactions in tungsten target
    - Emulsion detectors with nano-precision readout
    - ~10^5 charm production as by-products