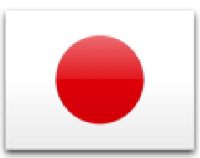
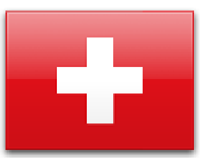
Study of tau neutrino production property with measuring open-Charms at 400 GeV proton beam dump

O.Sato (Nagoya University)

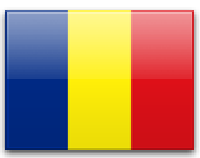
For DsTau Collaboration



Japan:
Nagoya
Kyusyu
Aichi
Kobe



Switzerland:
Bern



Romania:
Bucharest

Russia:
Dubna

Turkey:
Ankara

Current status on neutrino CC cross section measurements

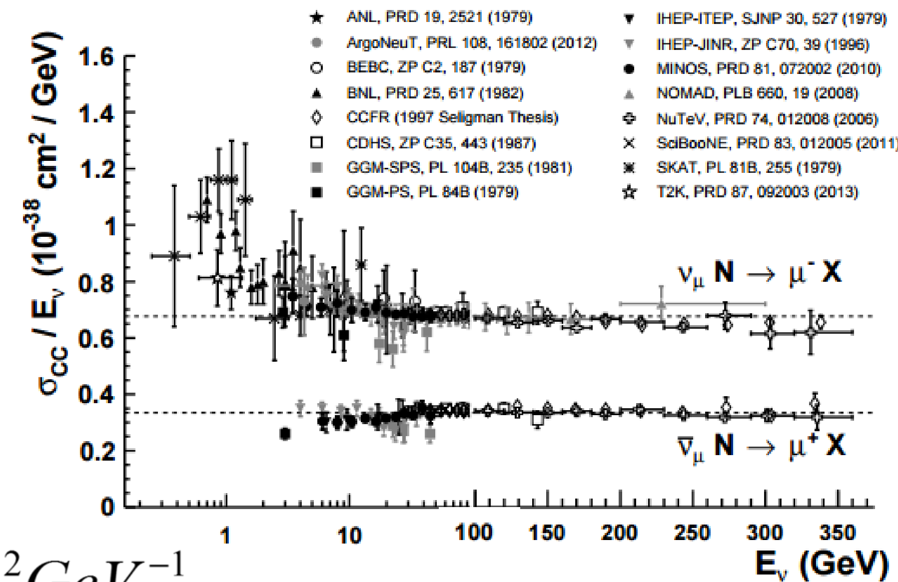
ν_μ : measured by many experiments

Average over 30 - 200 GeV

$$\sigma_{\nu\mu}^{const} = (0.51 \pm 0.01) \times 10^{-38} cm^2 GeV^{-1}$$

~2% error

Muon neutrino CC inclusive cross sections (PDG 2014)



ν_τ : **only the DONuT experiment**

Beam source : Ds → τ + ντ

τ → x + ντ

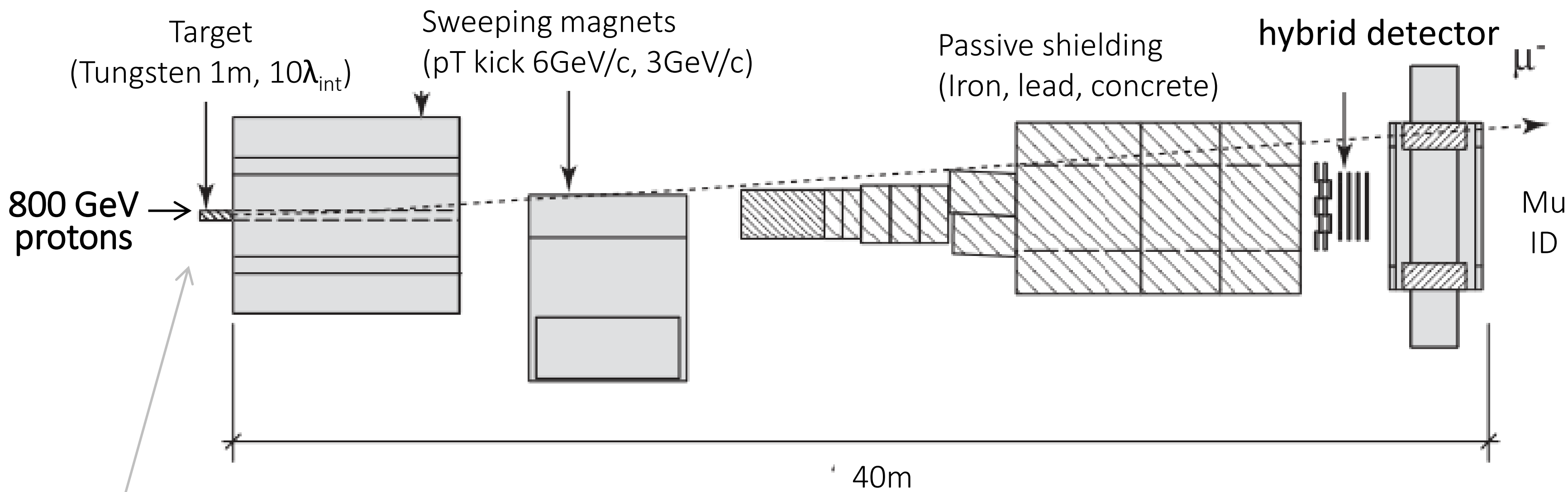
$$\sigma_{\nu\tau}^{const} = 7.5(0.335 n^{1.52}) \times 10^{-40} cm^2 GeV^{-1}$$

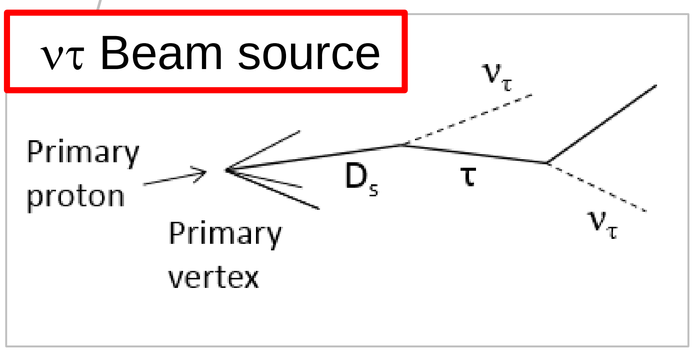
Measured as a function of a parameter n describing $d\sigma(D_s)/dx_F \sim (1-|x_F|)^n$

No experimental data giving n for Ds

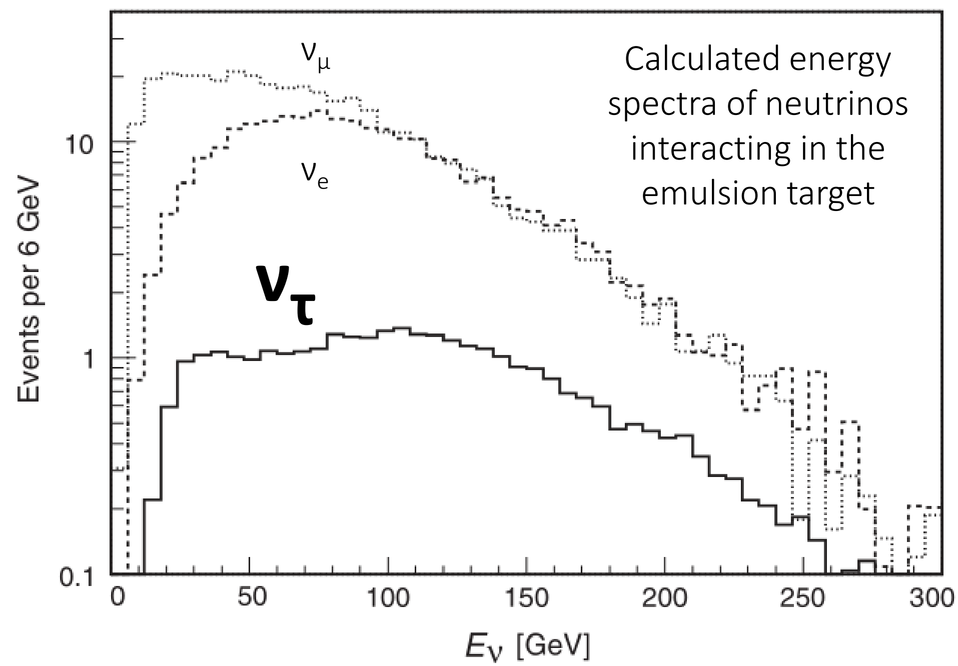
–> 50% systematic uncertainty

Neutrino beam line in DONuT



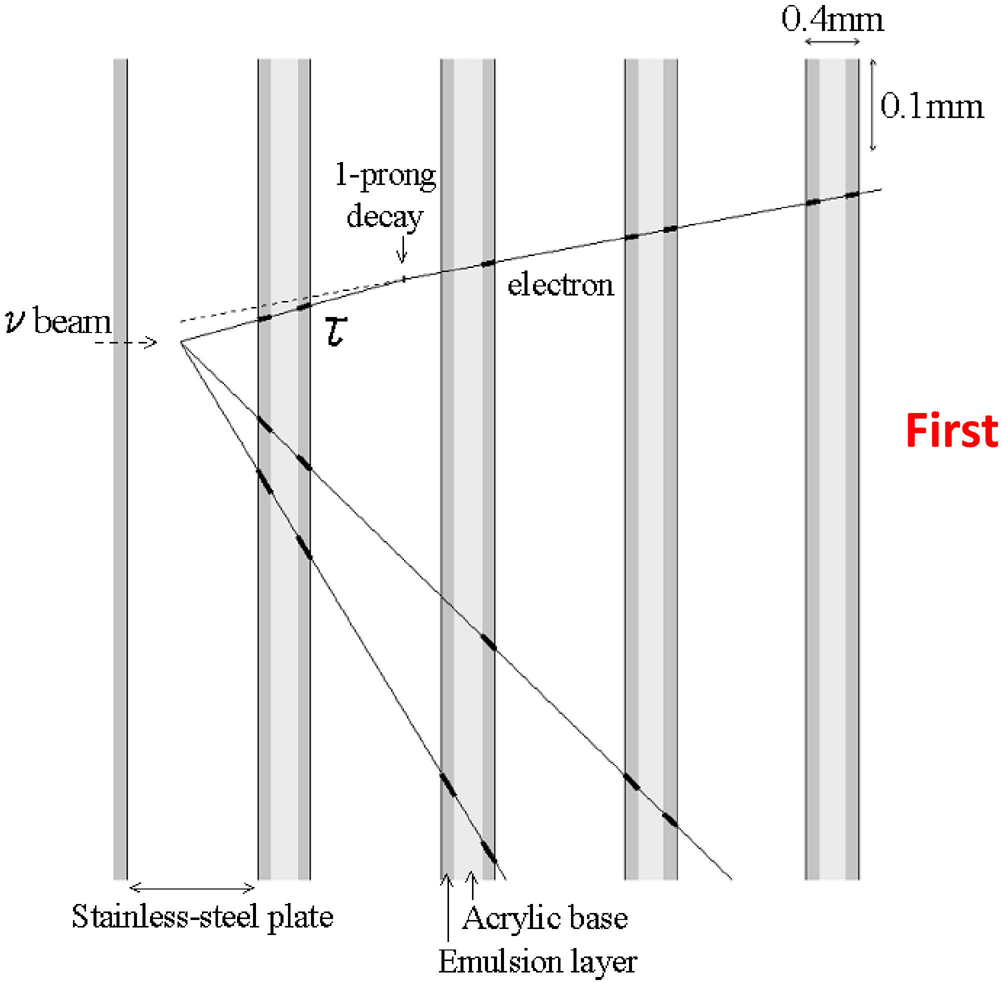


	Main source
ν_e	D^0, $D^{\pm}$, D_s, Λ_c
ν_μ	D^0, $D^{\pm}$, D_s, Λ_c, π, K
ν_τ	D_s



The DONuT experiment (Fermilab E872)

- Designed to observe ν_τ CC interactions by identifying τ
- **The first direct observation of ν_τ interactions (2000)**



Final result with total analyzed statistics (**578** neutrino interactions)

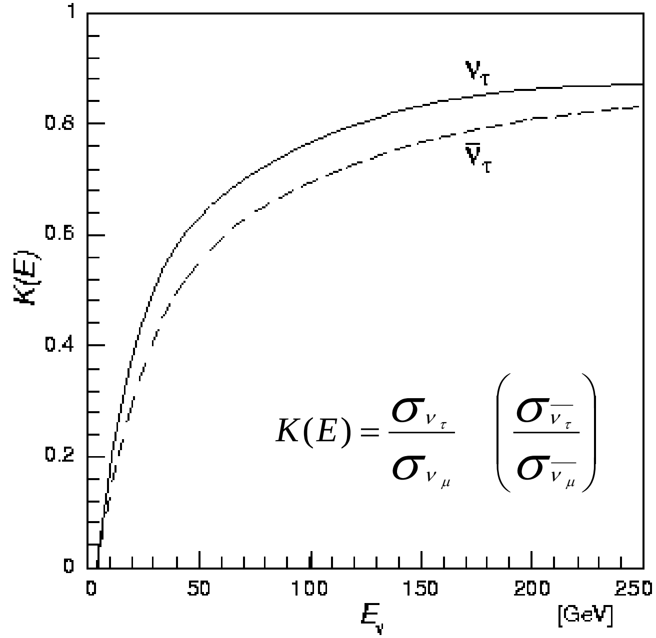
↓

9 ν_τ CC events observed

First measurement of ν_τ CC cross section

"Final tau-neutrino results from the DONuT experiment", Physical Review D 78, 5 (2008)

Results from DONuT



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

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

longitudinal dependence

transverse dependence

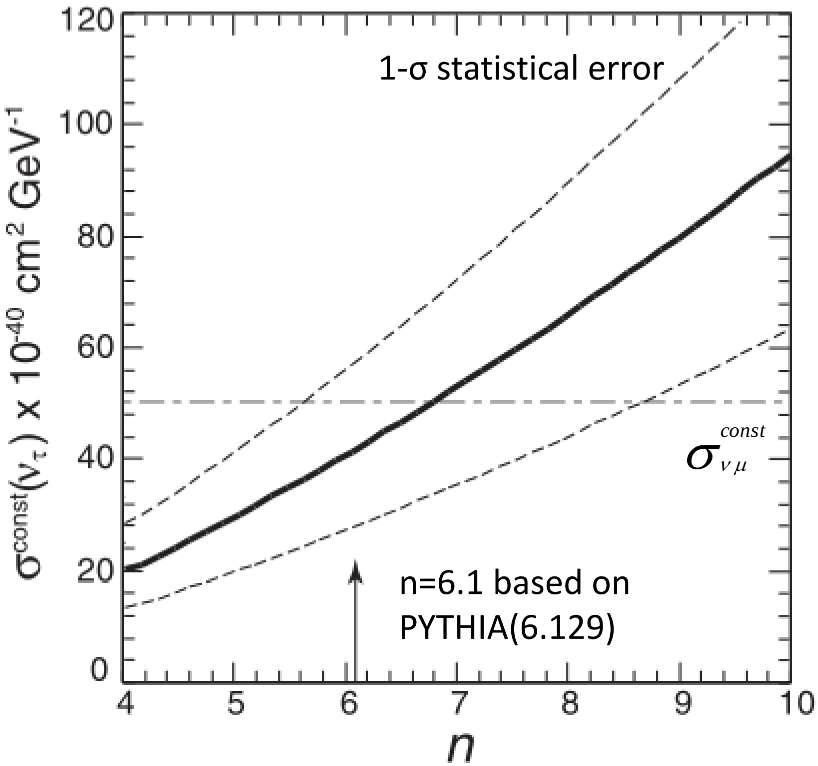
x_F is Feynman x

($x_F = 2p^{CM}_Z/\surd s$)

p_T is transverse momentum

Results from DONuT

ν_τ CC cross section as a function of the parameter n



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

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

Systematic uncertainties	
D_s differential cross section (x_F dependence)	**~0.5!?**
Charm production cross section	0.17
Decay branching ratio	0.23
Target atomic mass effects (A dependence)	0.14

The main uncertainty is ..
How (hard/soft) Ds($\nu\tau$ source) are produced !

DsTau project : New experiment to re-evaluate ν_τ cross section

- ν_τ cross section was measured by DONUT with large uncertainty(~50%) on ν_τ flux at beam source.
- The uncertainty reduction on ν_τ production cross section is important.
- $D_s \to \tau \to X$ precision measurement in high energy proton interactions

→ Re-evaluation of ν_τ cross section & useful results for future ν_τ experiments

Systematic uncertainties	DONUT	With DsTau
D_s differential cross section (x_F dependence)	**~0.5**	**0.1**
Charm production cross section	0.17	0.05 (combined)
Decay branching ratio	0.23	
Target atomic mass effects (A dependence)	0.14	

Observable of the experiment

- D_s production x decay branching ratio

$$\frac{N^{beam}_{\nu_\tau}}{N_{pot}} = \frac{2\times\sigma(pW\to D_s X)\times BR(D_s\to\nu_\tau\tau)}{\sigma(pW)}$$

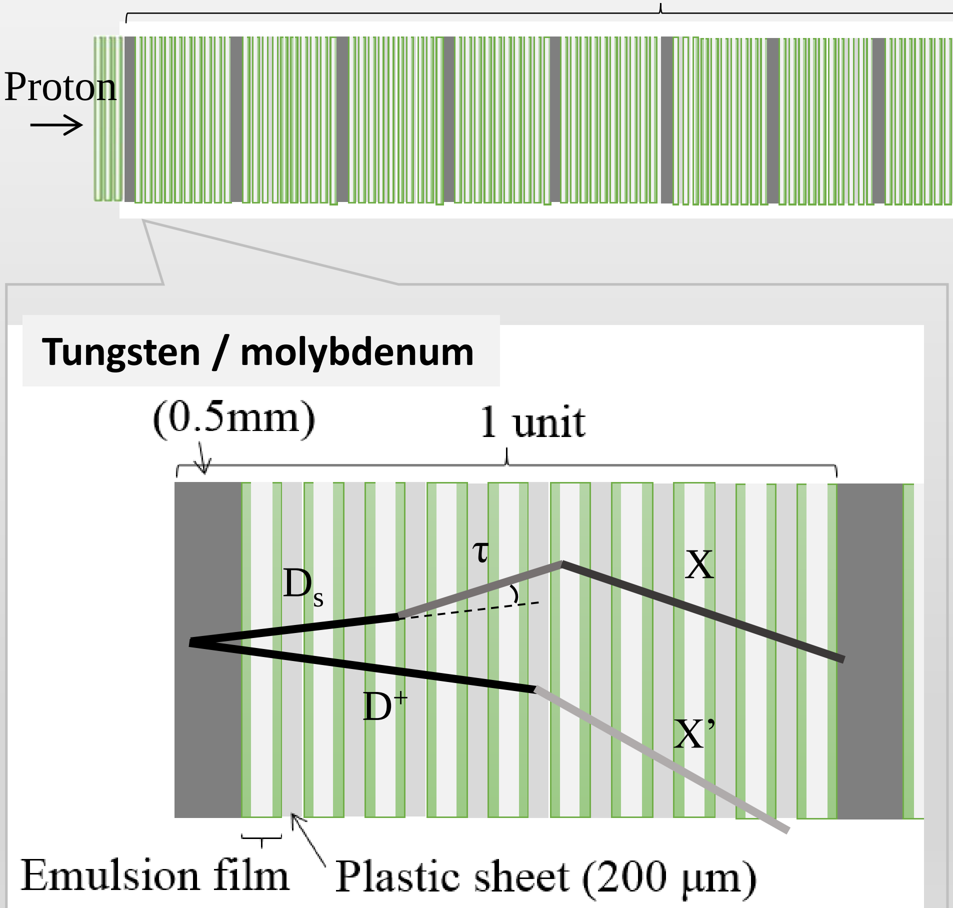
With collecting **1000** detected $Ds\to\tau$

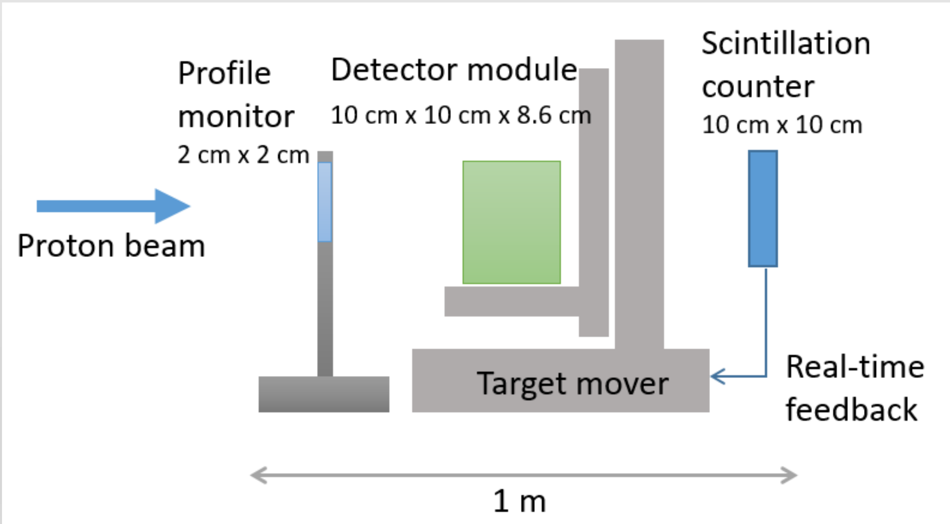
- Angular distribution of $D_s \to \tau$ events

→ Energy distribution → x_F dependence

$2.3\text{x}10^8$ proton W interactions stored in Emulsion Cloud Chambers

$D_s \to \tau \to X$ measurement detector (ECC)

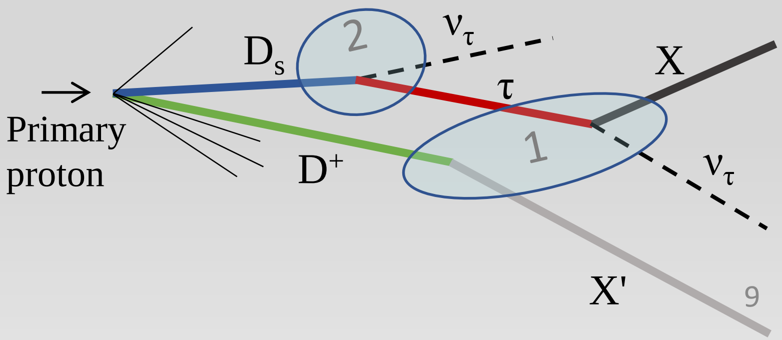




400 ECCs will be exposed to accumulate 2.3×10^8 int

Analysis plan

- Expectations
  - Detailed analysis in 2.3×10^8 proton interactions (4.6×10^9 pot)
    - 4×10^5 charm-pairs produced
    - 9×10^4 Ds produced
    - 5000 Ds → τ events produced
    - 1000 Ds → τ events detected
    - (Preliminary estimates: efficiency 20%, background 9×10^{-9} per proton interactions)
- Steps in Double-kink search
  1. High speed scanning of full area (scanning speed 0.5 m^2/h)
     - to select τ -> X + partner-charm decays (Δθ ~100 mrad)
  2. Precision measurement
     - to detect Ds -> τ decay (a few mrad)



Signal and background

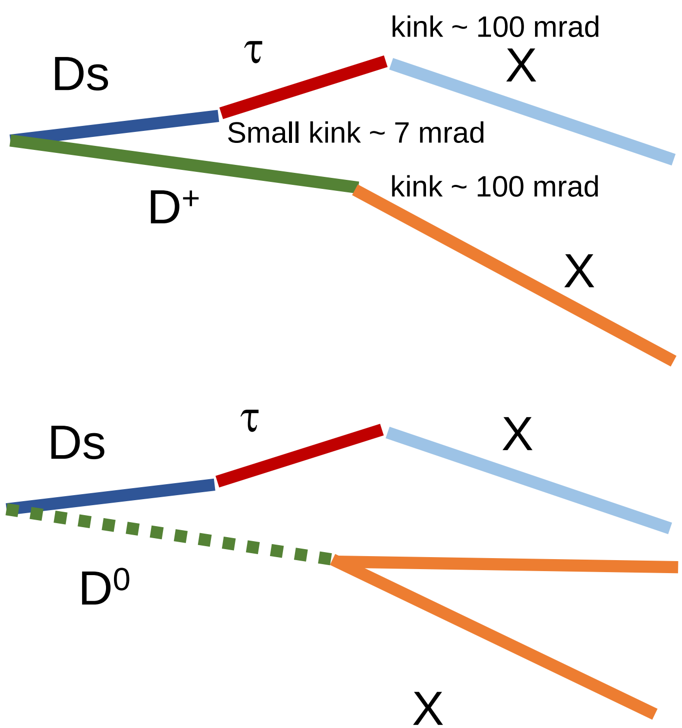
Very preliminary

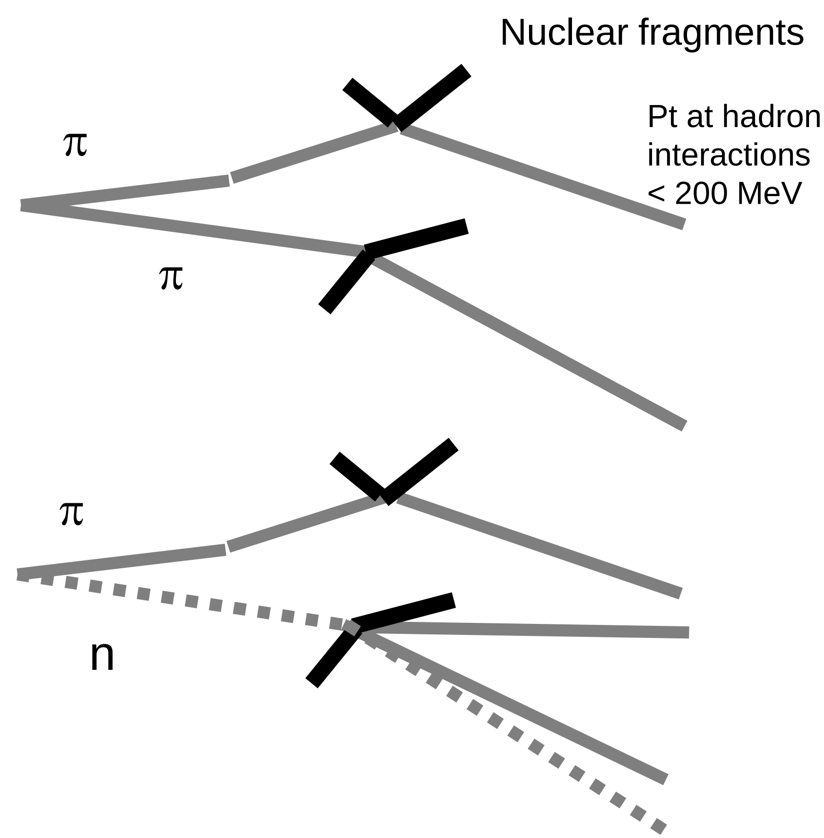
- Signal = a double kink + a charmed particle decay

5×10^{-6} / proton interaction

- Background = hadron interactions

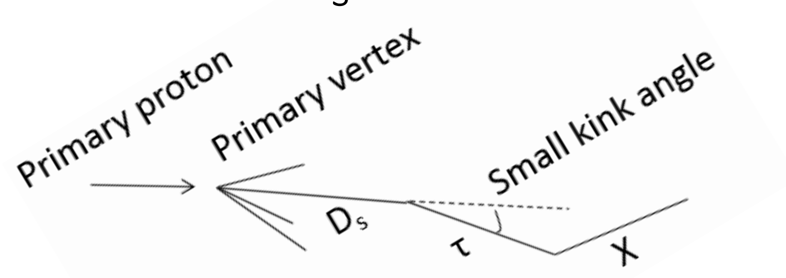
9×10^{-9} / proton interaction
White kink mean free path 11m is assumed





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

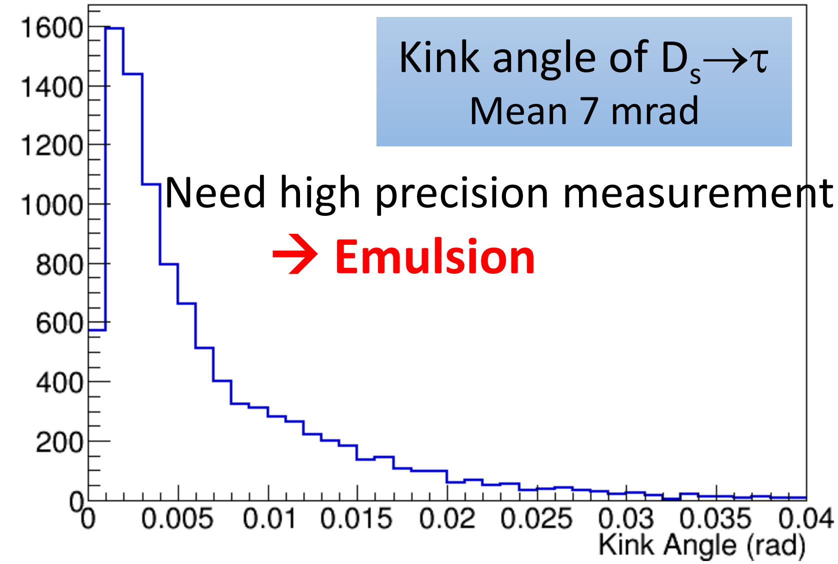
PYTHIA



The analysis chain:

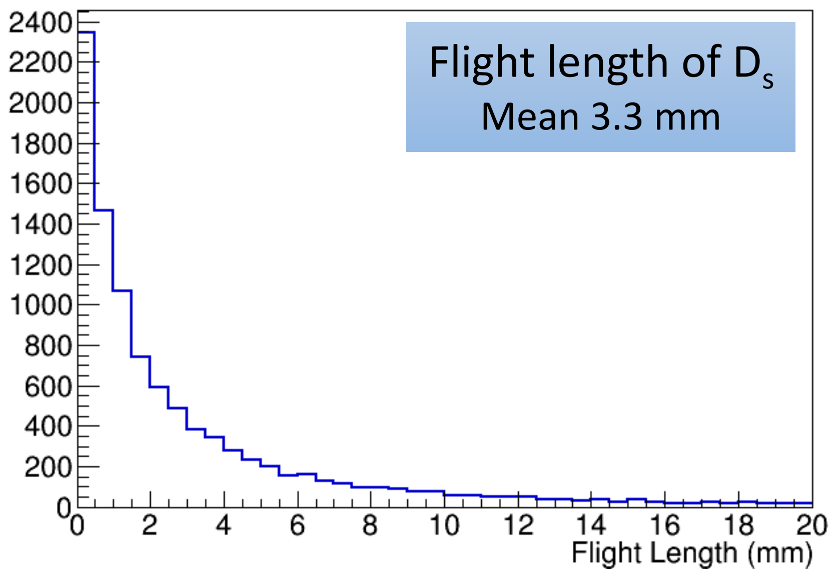
1) Tag $\tau \rightarrow X$ decay (mean ~100 mrad)

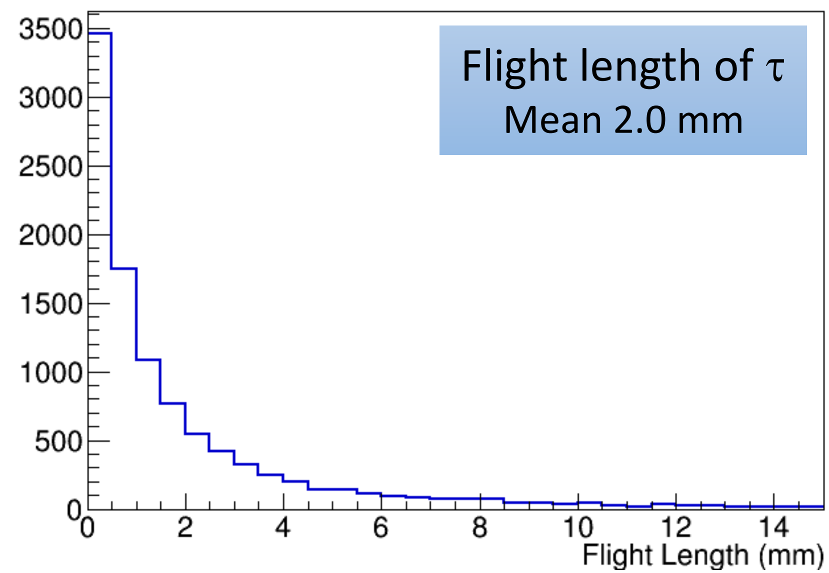
2) Perform high precision measurement to detect $D_s \rightarrow \tau$ decay



Need high precision measurement!

→ **Emulsion**





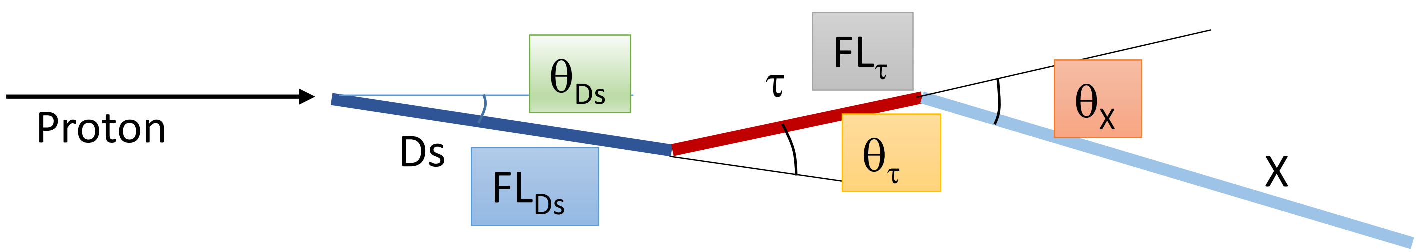
Preliminary selection :

1 film<FL(D_s)<5mm & $\Delta\theta(D_s \rightarrow \tau)$>2mrad & FL($\tau$)<5mm & $\Delta\theta(\tau)$>15mrad & pair charm detection

→ Efficiency **20%** (will be further optimized using more careful simulations)

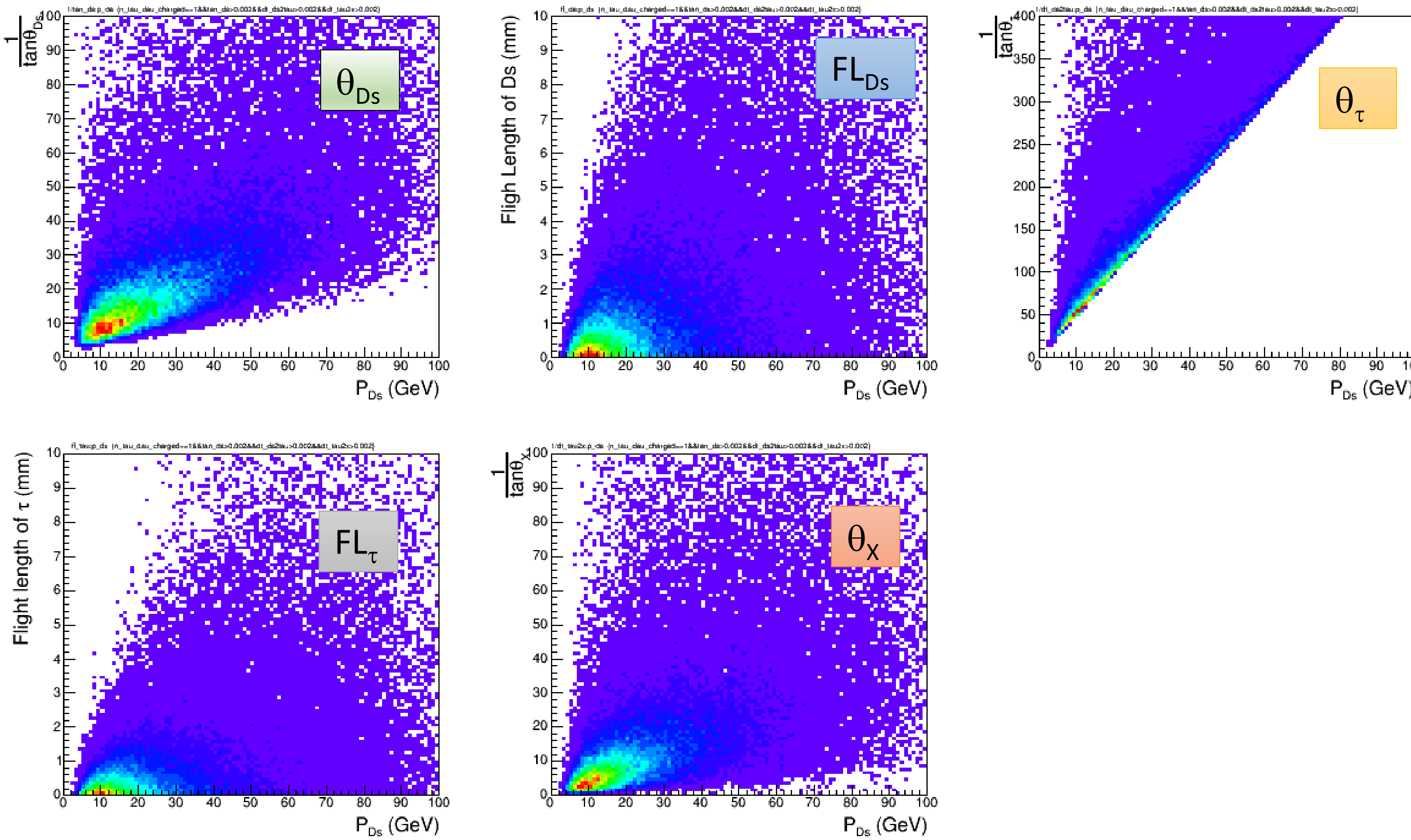
Key technique for Xf measurement : Ds momentum reconstruction from topological variables

- x_F is a longitudinal profile of Ds: $x_F = 2p_z^{CM}/\sqrt{s} = 2\gamma(p_{Ds}^{Lab}\cos\theta_{Ds} - \beta E_{Ds}^{Lab})/\sqrt{s}$
- Ds decays quickly, unable to measure P directly
- Need a method to estimate P_{Ds} from topological variables

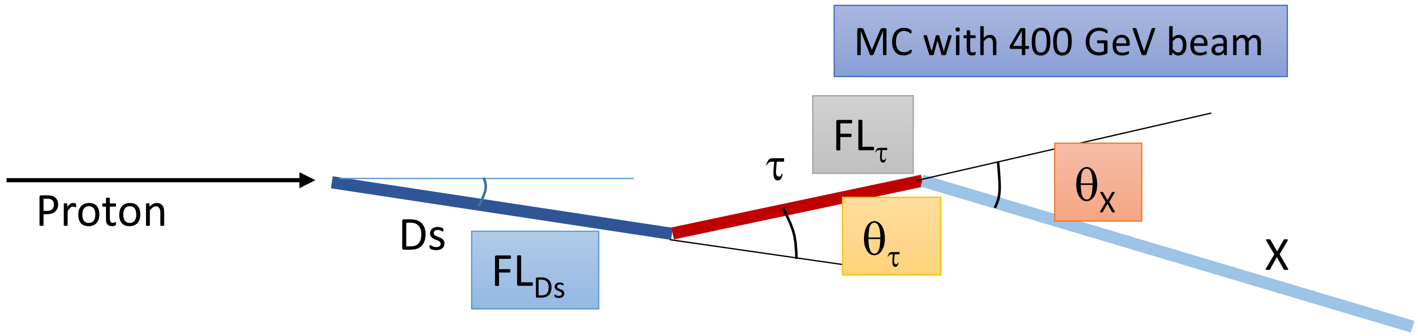


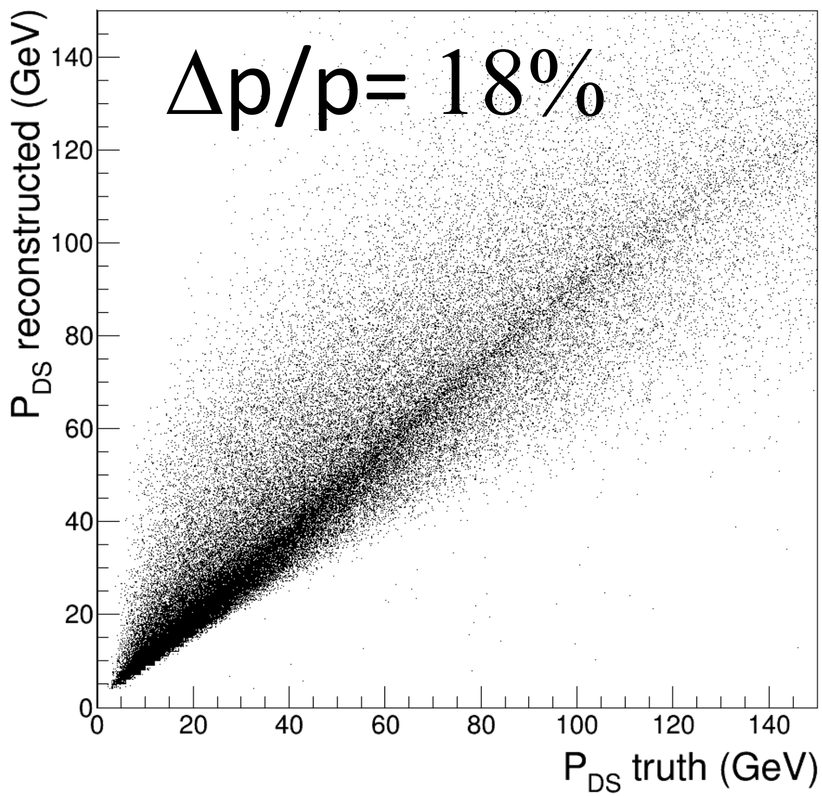
Topological variables: correlation with P_{Ds}

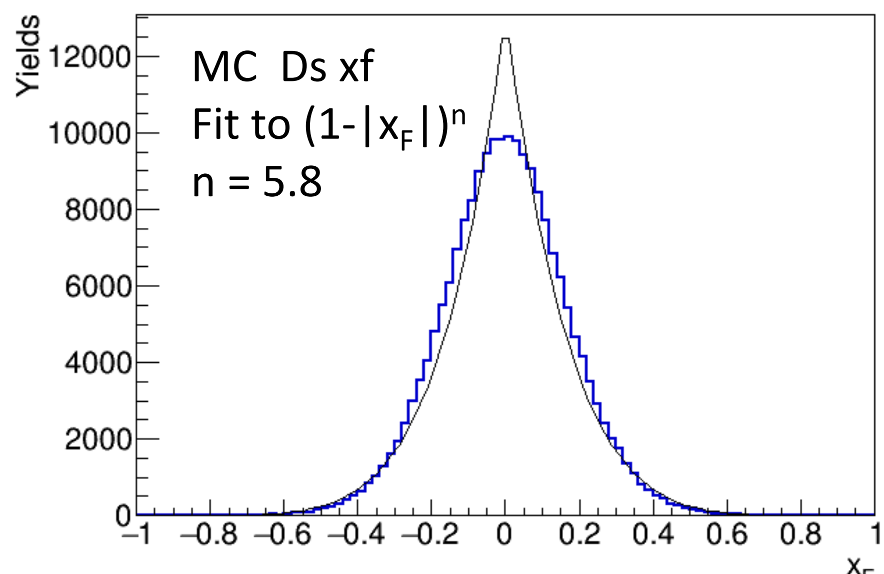
Sample: tau single prong decay



Ds momentum reconstruction
by Artificial Neural Network (ANN) using 4 variables







We will measure Ds xf distribution with 1000 detected Ds->tau events !

Proton beam exposure schedule

Run	Beam time	Emulsion surface	Goal
2016 test beam		(10 modules)	Test of the setup Proof of principle
2017 test beam		(~2 modules)	Improvement of exposure scheme
2018 pilot run (approved)	1 week	48 m^2 (30 modules)	Test of large data taking and analysis BG estimation with data Physics results (~80 $D_s \rightarrow \tau$ detected)
2021 physics run (recommended)	2 weeks	545 m^2 (338 modules)	Physics results (~1000 $D_s \rightarrow \tau$ detected)
2022 physics run	2 weeks		

Letter of Intent, Feb. 2016
Proposal (SPSC-P-354), Aug. 2017
The proposal has been reviewed during the SPSC meeting
→ **Positive feedback**

"The 2018 run has been approved and the Committee recommends that the beam time requested for 2021 will be granted."

Expected performance

Relative systematic uncertainty

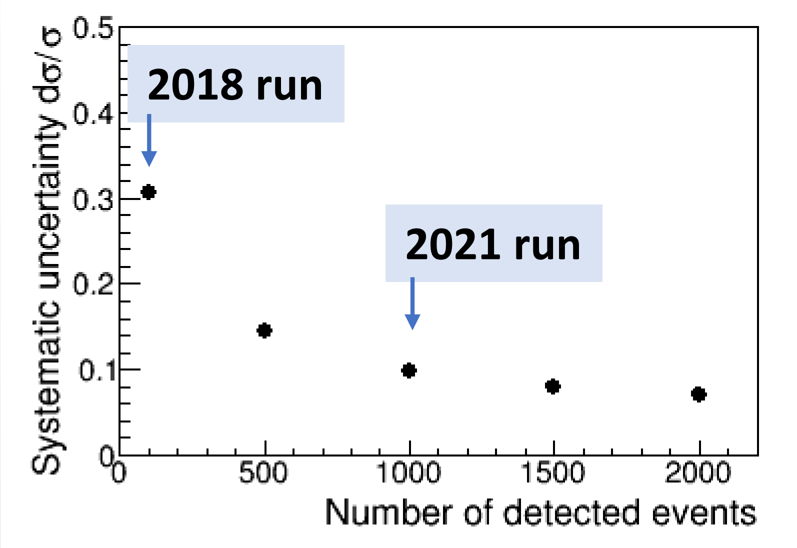
for cross section measurement:

~30% with 2018 run

→ Re-evaluation of the DONUT result

~10% with 2021-2022 run

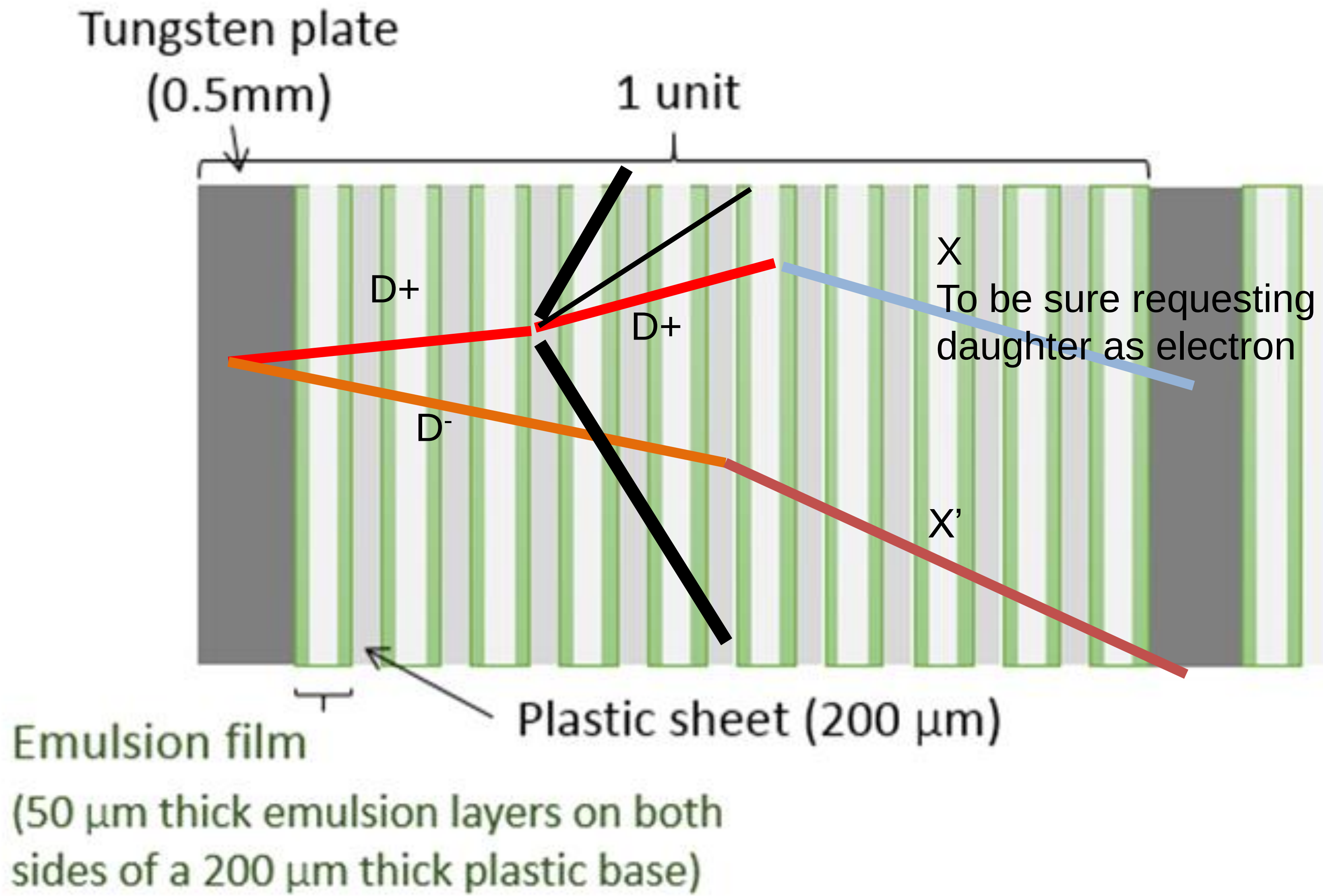
→ Input for future measurement



Uncertainties in cross section measurement	DONuT	Systematic uncertainty after DsTau outcome	Future ν_τ measurement with DsTau outcome
ν_τ statistics	0.33		0.02
D_s differential cross section (x_F dependence)	>0.50	0.10	0.10
Charm production cross section	0.17	0.05	0.05
Decay branching ratio ($D_s \to \tau$)	0.23 (0.04 at present)		
Target atomic mass effects	0.14		

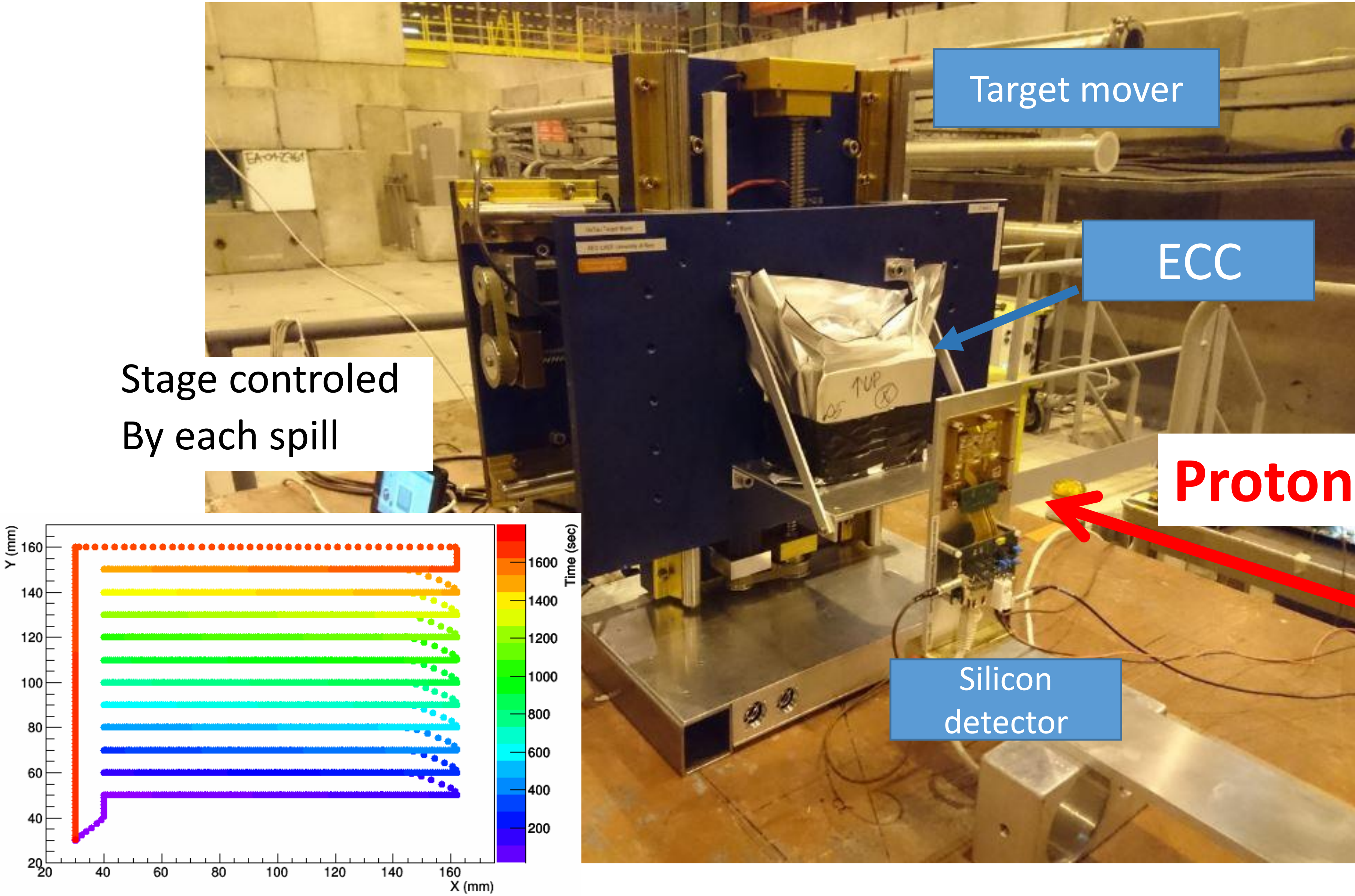
Aiming at 10% precision to look for new physics effects in ν_τ -nucleon CC interactions

A byproduct ::
Charmed hadron interaction Cross section measurement
(about 1000 charm interactions)

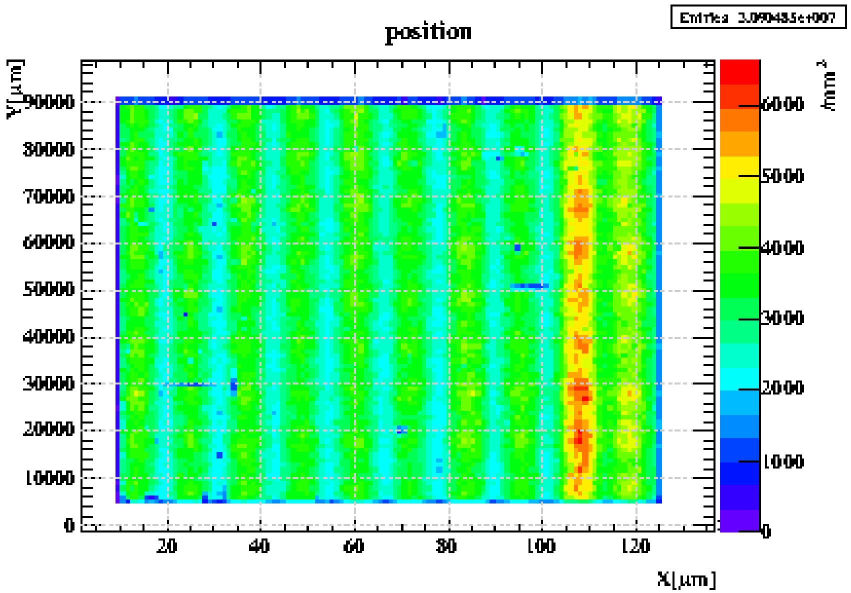


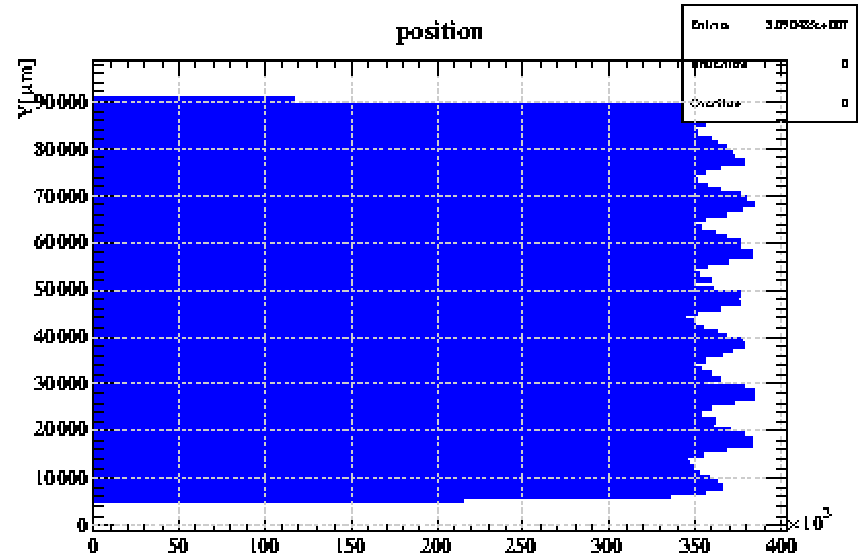
The analysis status

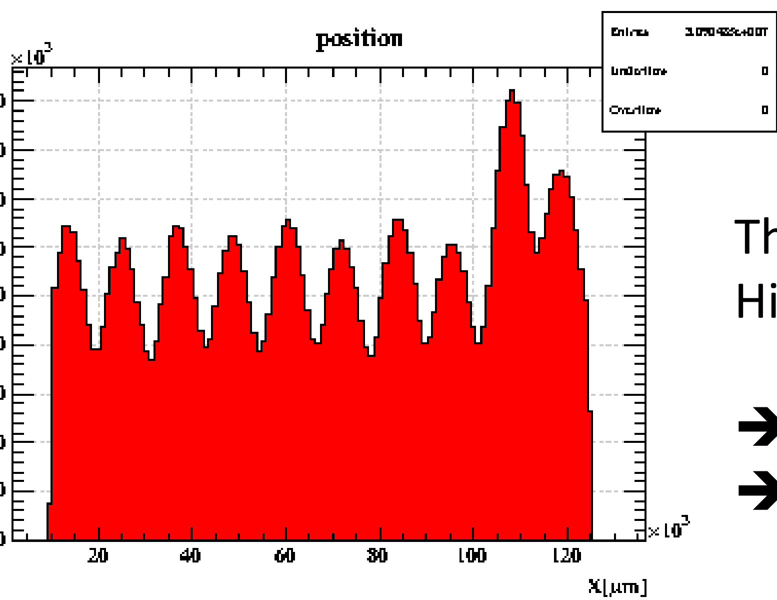
Detector setup @ CERN H4 beam line 2016 beam test



Track density distribution







The track density stored in the Emulsion is cyclic
Higher track density make the event analysis dif

➔ Tried to uniform

➔ The problem was time profile of a spill.

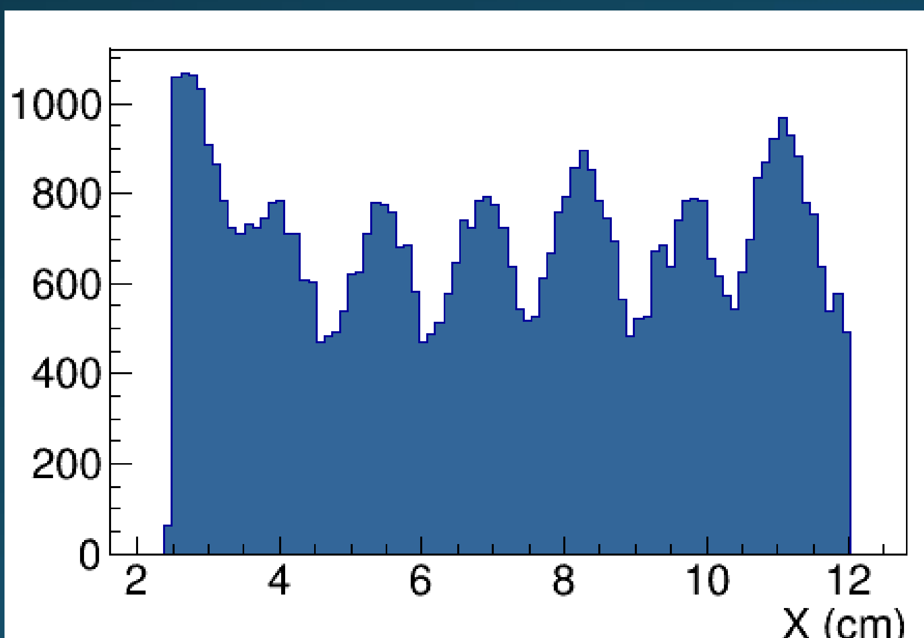
Improved @ 2017 test beam
Intensity driven stage control

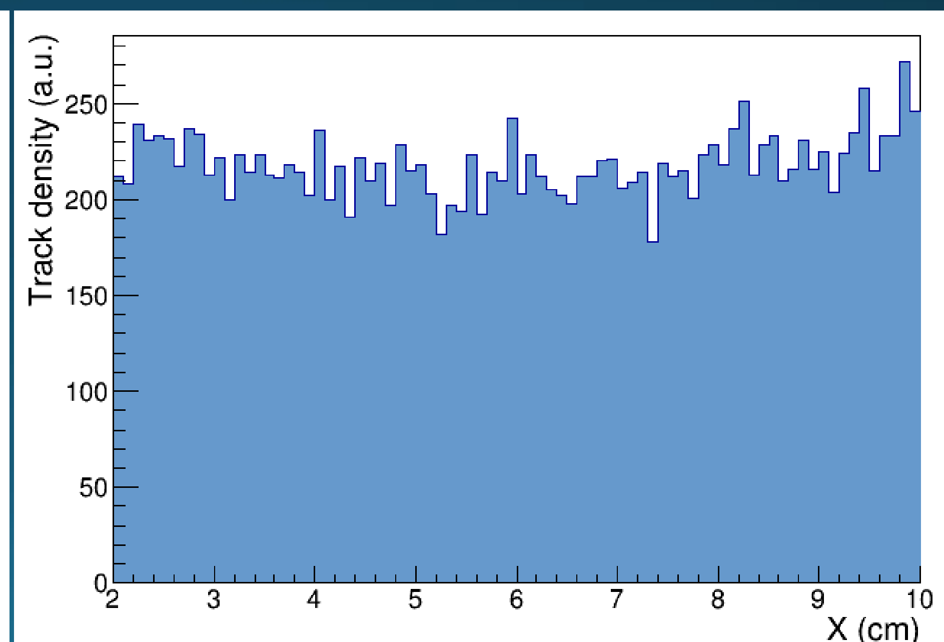
Module x,y position moved with

<u>Feedback from scintillator's track count by each 0.2 sec</u>

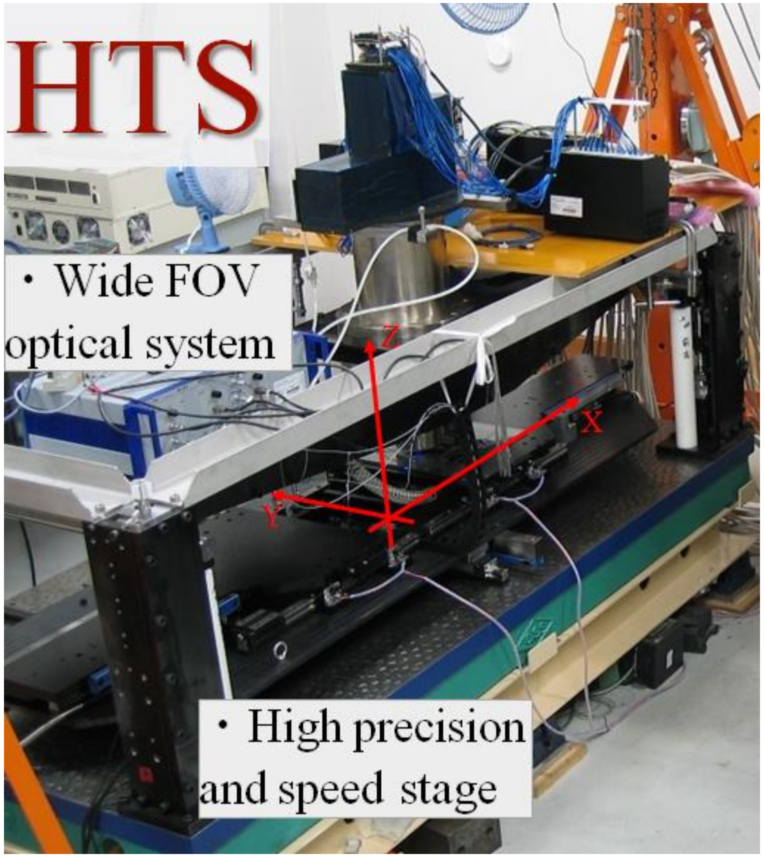
to realize uniform track density in whole module area

- 2016
- 2017



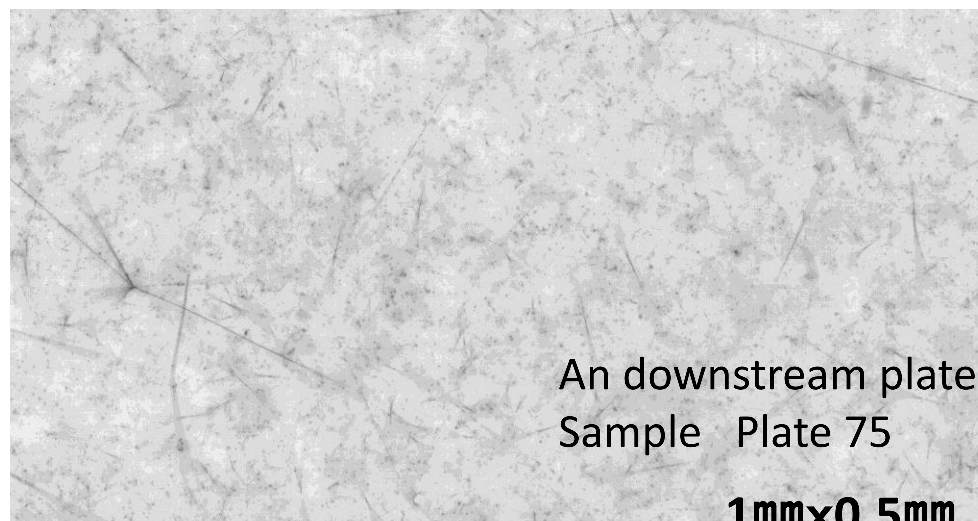


A microscope view data of the films



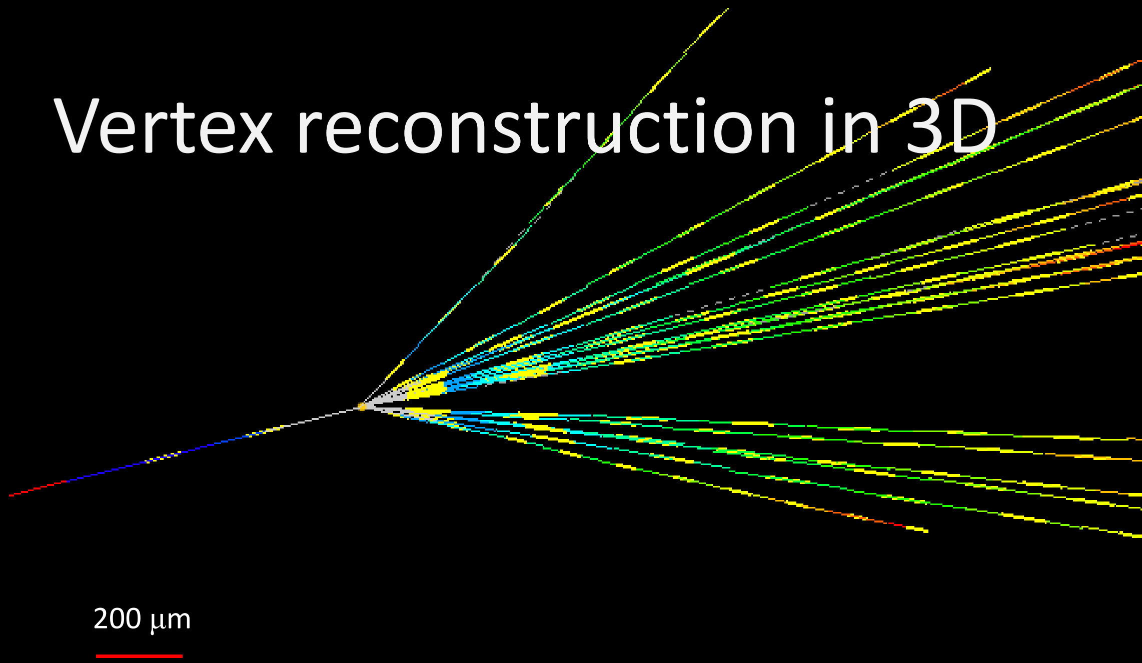
Scanning system working at Nagoya Univ,
scanning speed of 9000 cm^2/h (22 m^2/day)

Getting dirty



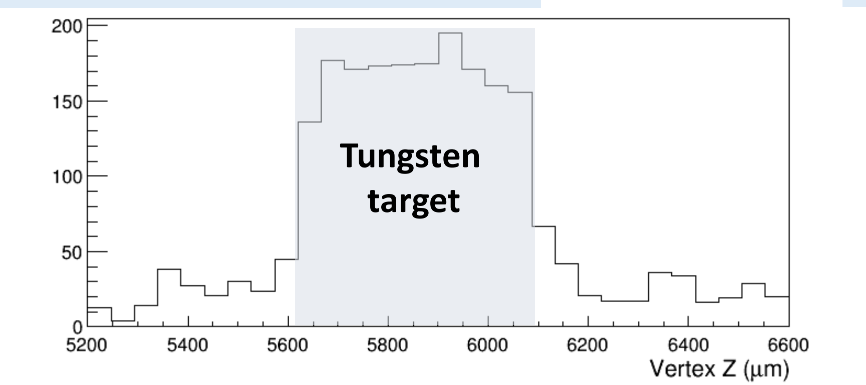
Data from the beam tests

Vertex reconstruction in 3D



Measured proton beam density in the analyzed region: 4.36×10^5 beam tracks/3.61 cm^2

Z distribution of observed vertices

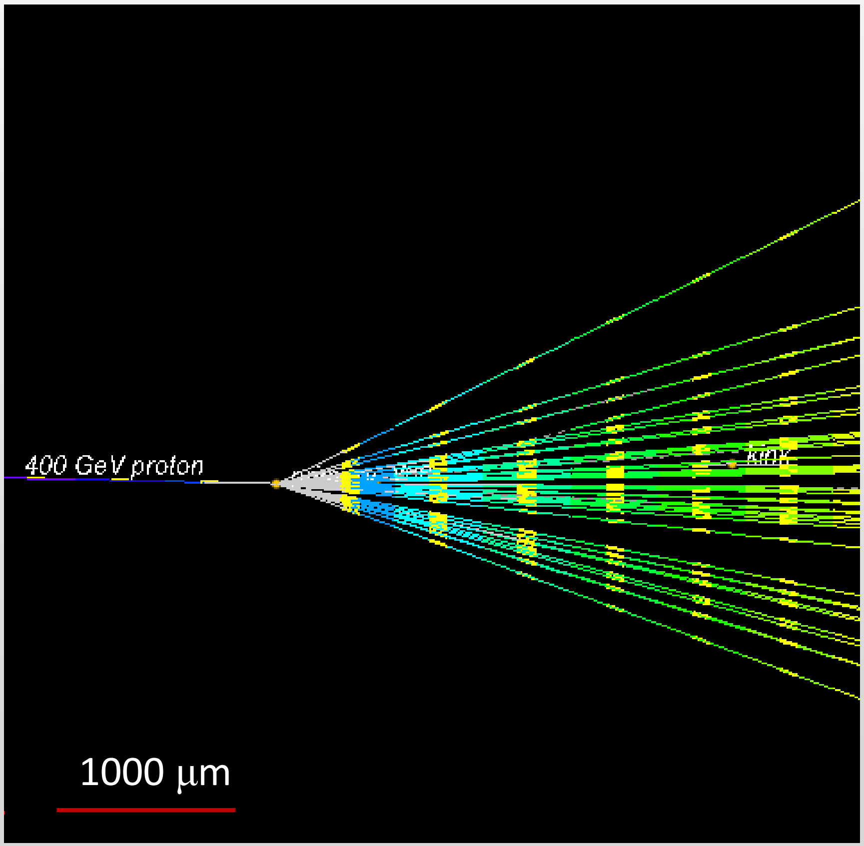


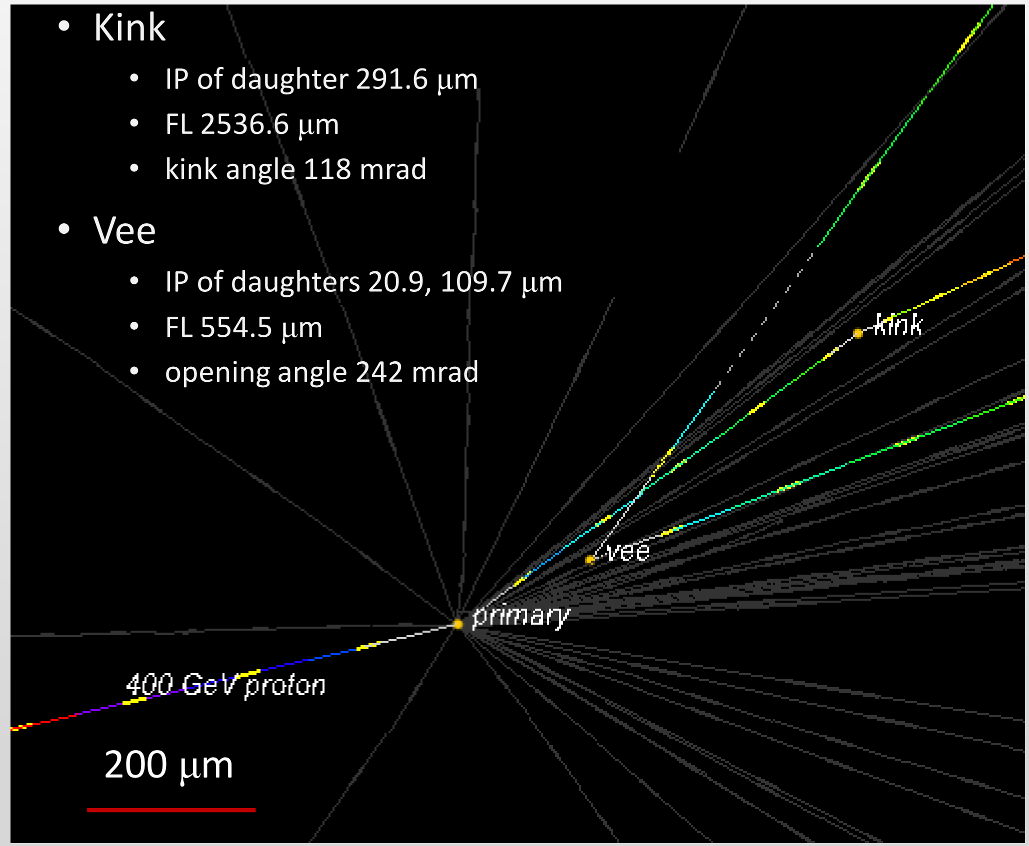
Interactions in a tungsten plate

	N vertices
Expected	1860
Observed	With parent 1832
	Without parent 130

- Consistent with the expectation
- Uncertainty due to reconstruction will be reduced by further study

Hunting of
Double-decay topology event (open charm)
Just started.





Summary

- The goal of the DsTau project is
  the reduction of tau neutrino production uncertainty
  by precise measurement of **1,000 Ds->tau->X**.
- **Measurement of Charmed hadron interaction length** (byproduct)

- **Test beam exposure performed in 2016 and 2017**
  In 2016 a small scale of physics run.
  Improvement on uniformity of track density in 2017 test beam.
- Analyzing **ECCs exposed with $10^5/cm^2$ track density .**
- **5.5 ECCs data taken have been finished.**
- The **tracking efficiency** is kept as more than **95%** / emulsion film.

- **Systematical search for Charm pair events being started.**
- **In 2018, 1st Physics run collects 3 times events of 2016 test beam.**
- **R&D is on going toward the 2nd Physics run, 10 times of 1st Physics run.**
- **2.3×10^8 proton + W interactions will be analyzed in total**

Backup

Charm production cross section results

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

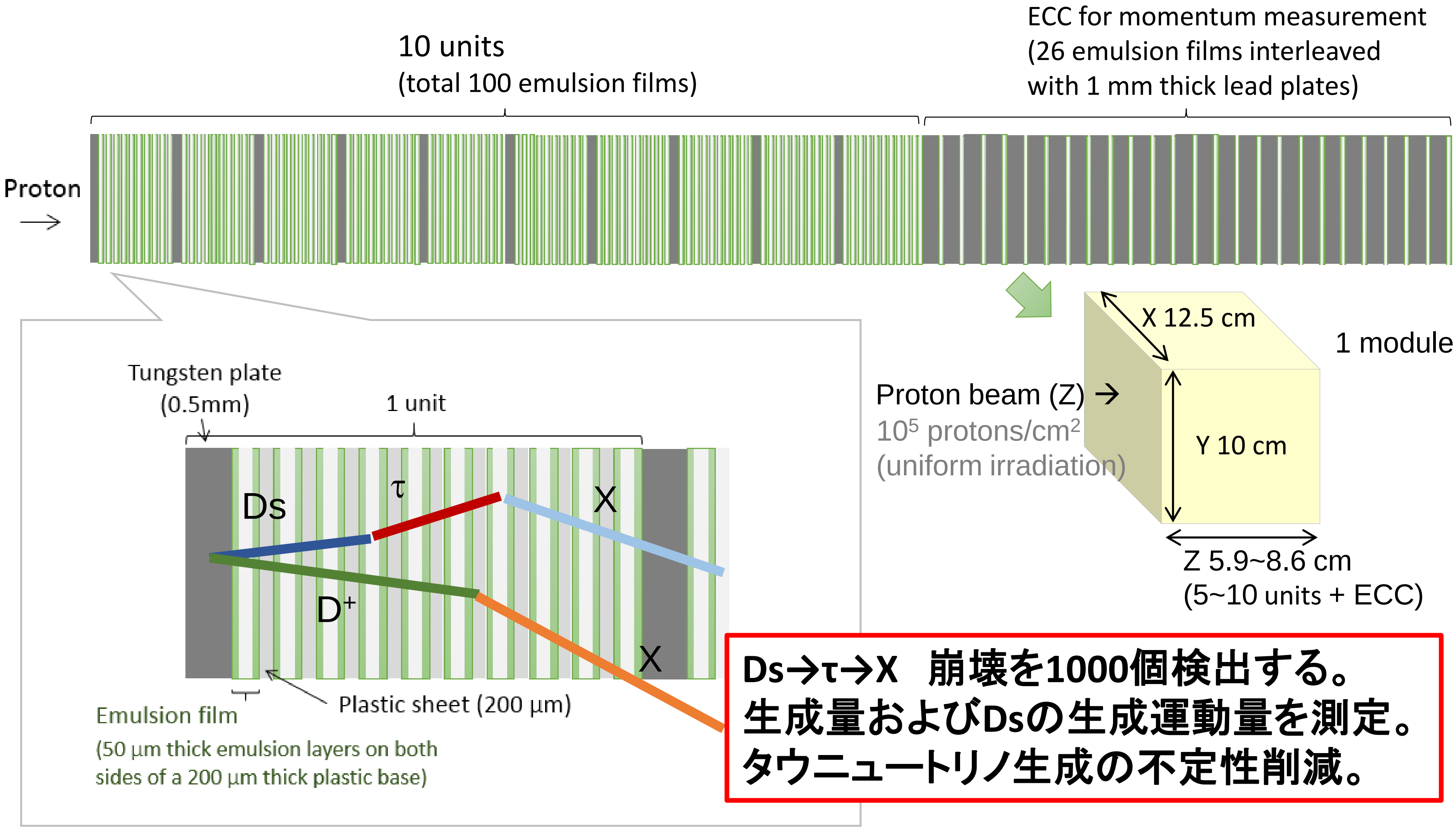
Experiment	Beam type / energy (GeV)	$\sigma(D_s)$ (μb/nucl)	$\sigma(D^\pm)$ (μb/nucl)	$\sigma(D^0)$ (μb/nucl)	$\sigma(\Lambda_c)$ (μb/nucl)	x_F and p_T dependence: *n* and *b* $(GeV/c)^{-2}$
HERA-B	p / 920	18.5 ± 7.6 (~11 events)	20.2 ± 3.7	48.7 ± 8.1	-	$n(D^0, D^+) = 7.5 \pm 3.2$
E653	p / 800	-	38 ± 17	38 ± 13		$n(D^0, D^+) = 6.9^{+1.9}_{-1.8}$ $b(D^0, D^+) = 0.84^{+0.10}_{-0.08}$
E743 (LEBC-MPS)	p / 800	-	26 ± 8	22 ± 11		$n(D) = 8.6 \pm 2.0$ $b(D) = 0.8 \pm 0.2$
E781 (SELEX)	Σ^- (sdd) / 600					~350 D_s^- events, ~130 D_s^+ events ($x_F > 0.15$) $n(D_s^-) = 4.1 \pm 0.3$ (leading effect) $n(D_s^+) = 7.4 \pm 1.0$
NA27	p / 400		12 ± 2	18 ± 3		
NA16	p / 360		5 ± 2	10 ± 6		
WA92	π / 350	1.3 ± 0.4		8 ± 1		
E769	p / 250	1.6 ± 0.8	3 ± 1	6 ± 2		320 ± 26 events ($D^\pm, D^0, D_s^\pm$) $n(D^\pm, D^0, D_s^\pm) = 6.1 \pm 0.7$ $b(D^\pm, D^0, D_s^\pm) = 1.08 \pm 0.09$
E769	$\pi^\pm$ / 250	2.1 ± 0.4		9 ± 1		1665 ± 54 events ($D^\pm, D^0, D_s^\pm$) $n(D^\pm, D^0, D_s^\pm) = 4.03 \pm 0.18$ $b(D^\pm, D^0, D_s^\pm) = 1.08 \pm 0.05$
NA32	π / 230	1.5 ± 0.5		7 ± 1		

(Results from LHCb at $\sqrt{s}$ = 7, 8 or 13 TeV are not included since the energies differ too much)

No experimental result effectively constraining the D_s differential cross section at the desired level or consequently the ν_τ production

Module structure for $D_s \rightarrow \tau \rightarrow X$ measurement (current baseline)

- 0.05 λ_{int} in 10 units tungsten → 4.6×10^9 pot needed to get 2.3×10^8 proton int.
- Track density in emulsion: **keep <10^5 tracks/cm^2** at the upstream side
- To expose 4.6×10^9 pot → **detector surface 4.6×10^4 cm^2 (368 modules)**



Ds→τ→X　崩壊を1000個検出する。
生成量およびDsの生成運動量を測定。
タウニュートリノ生成の不定性削減。

Event rates of interesting events

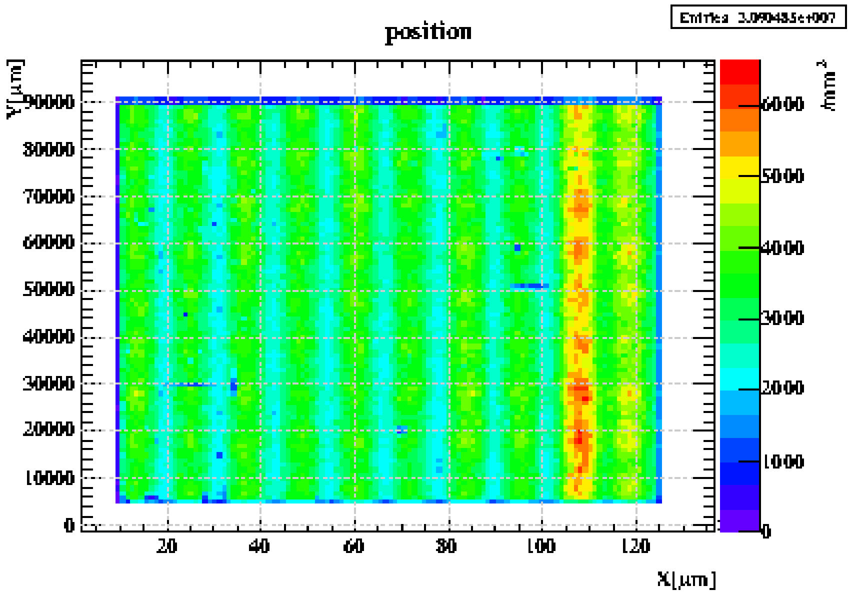
- **Ds->tau exclusive production*decay rate**
  for reducing uncertainty on tau neutrino flux.

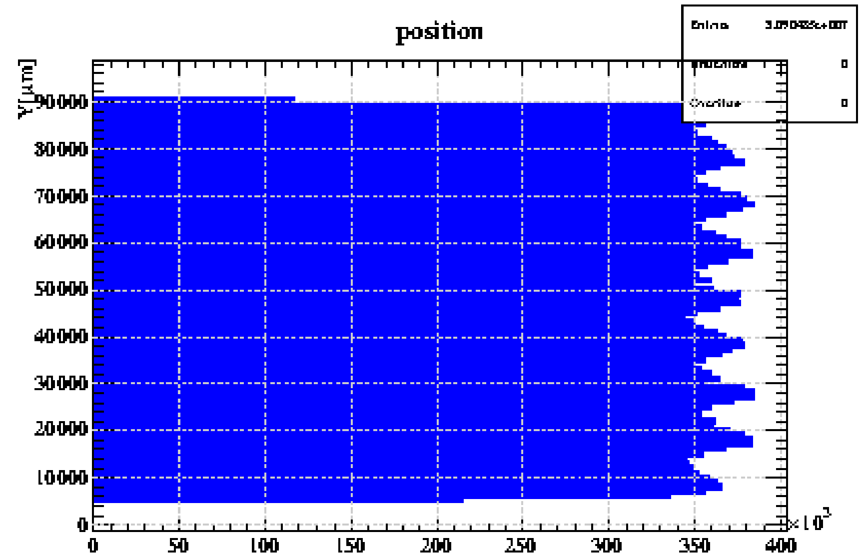
2.5 detected Ds->tau events /ECC

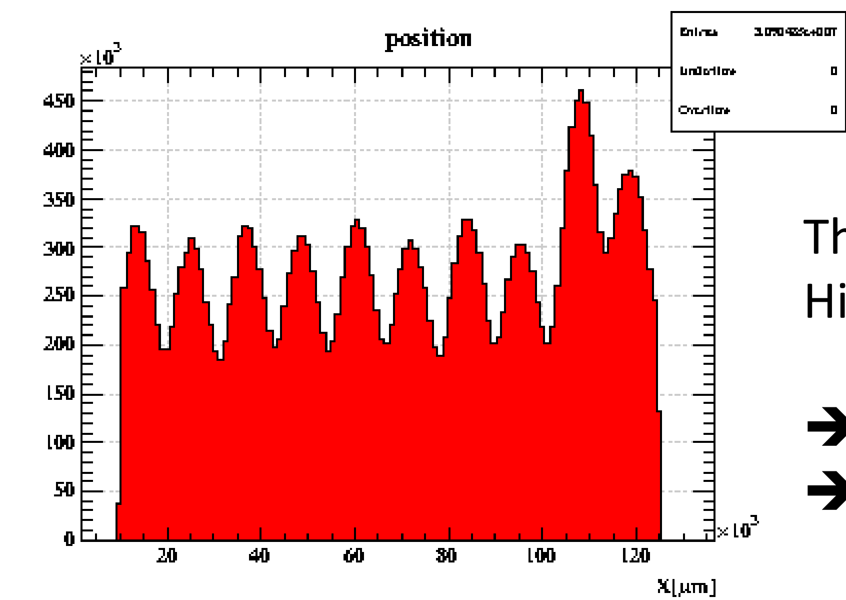
- **Charm hadron interaction length measurement.**
  500 ε Charm events /module
  λ_w= 0.005 , λ_{em}=0.0055

2.8ε x 2 x η detected Charm interaction/ ECC

Track density distribution







The track density stored in the Emulsion is cycli
Higher track density make the event analysis dif

➔ Tried to uniform
➔ The problem was time profile of a spill.

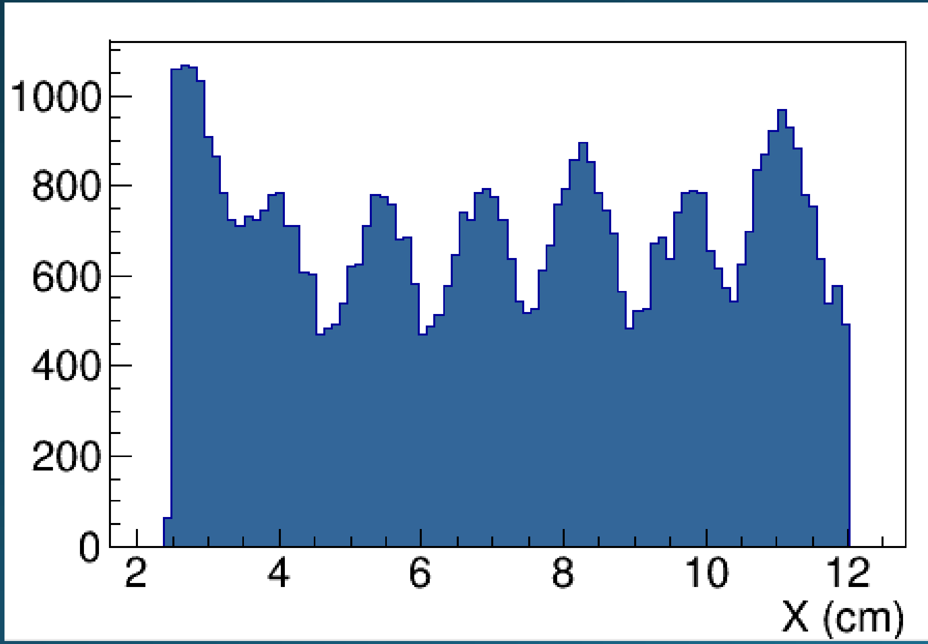
Improved @ 2017 test beam
Intensity driven stage control

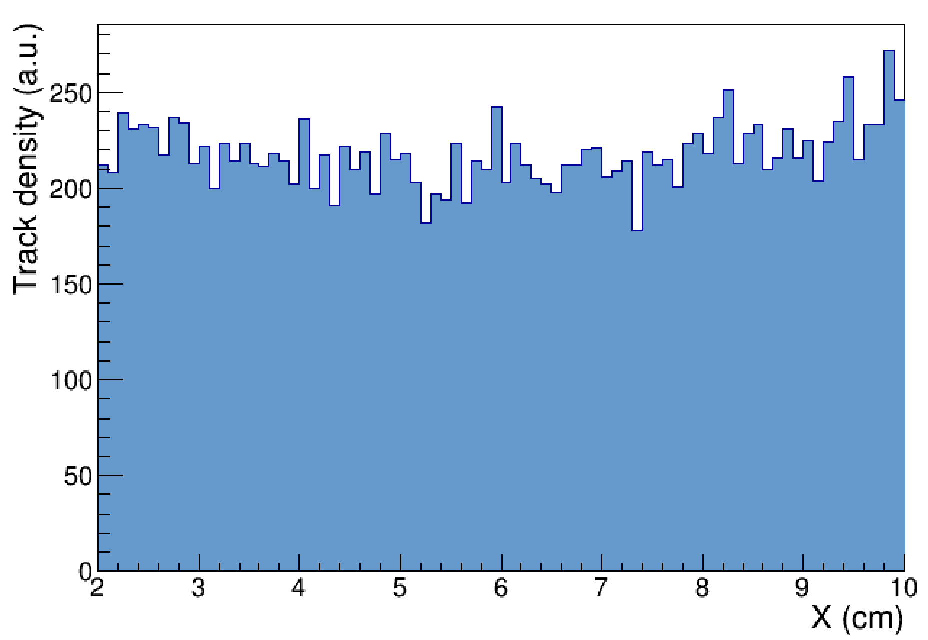
Module x,y position moved with

<u>Feedback from scintillator's track count by each 0.2 sec</u>

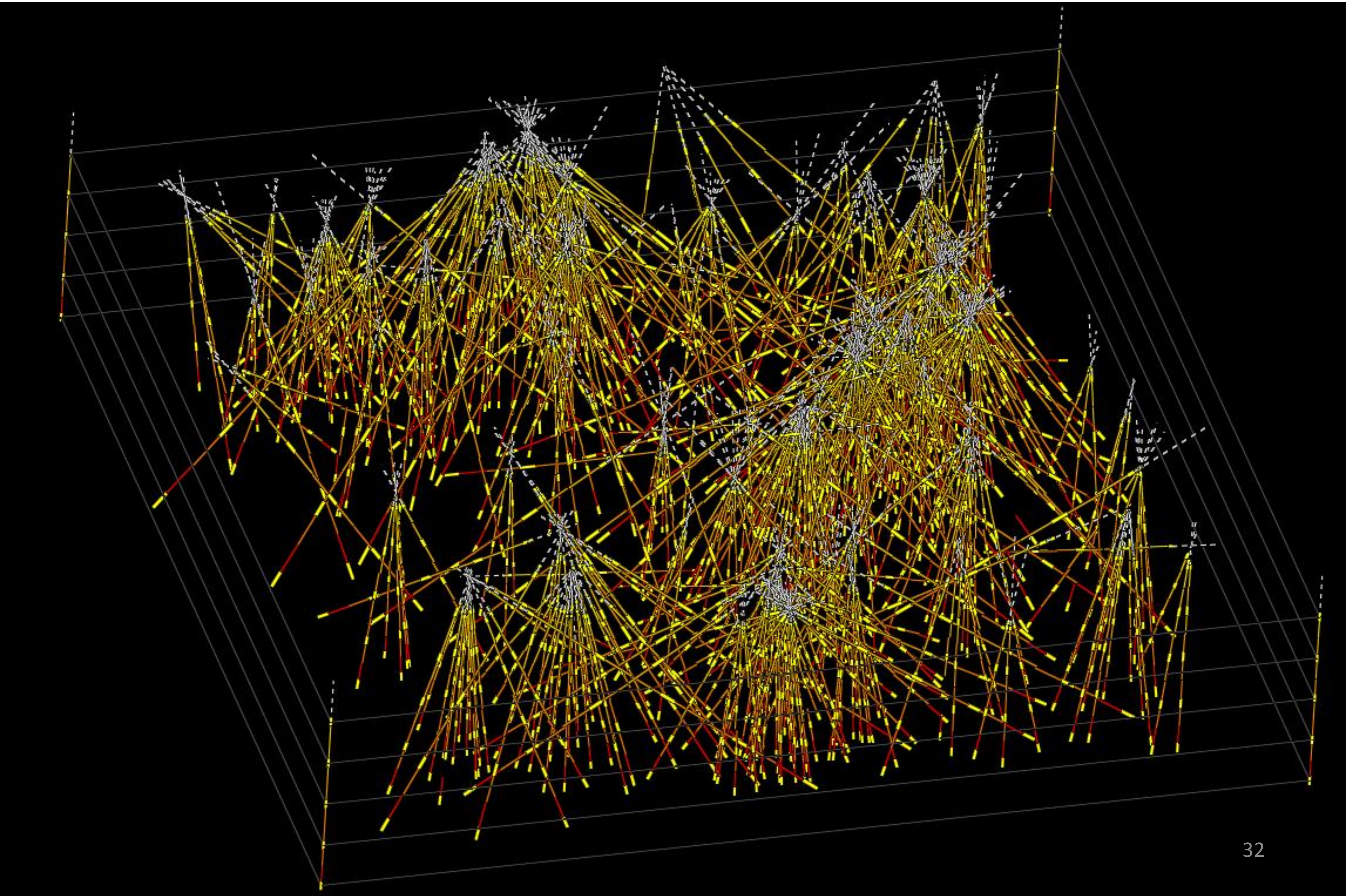
to realize uniform track density in whole module area

- 2016
- 2017



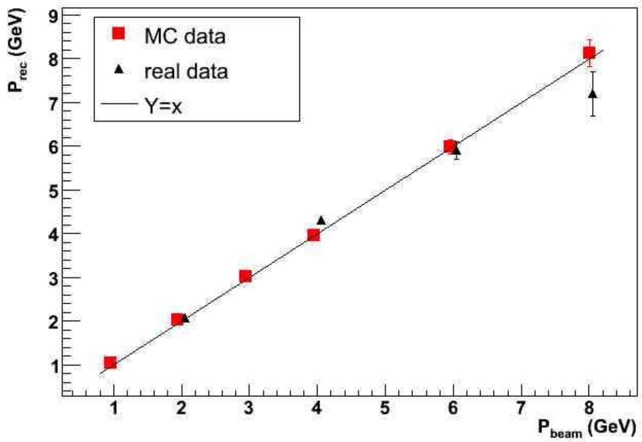


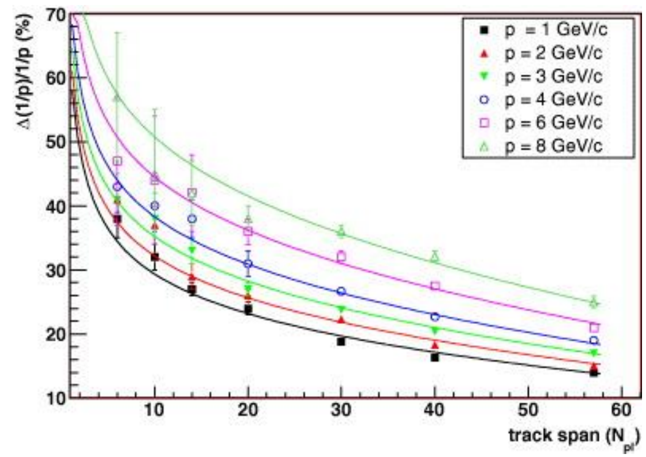
Vertices in 2.5mm x 2.5mm pl11-15



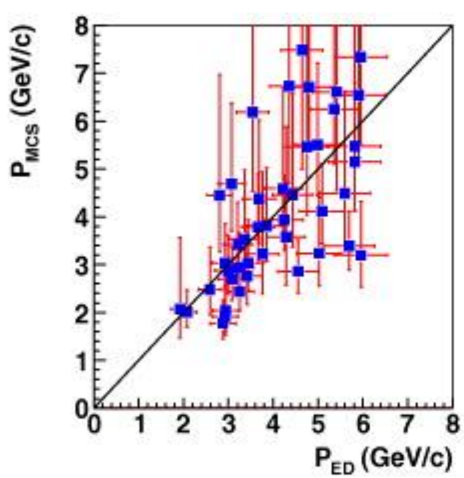
Momentum measurement through multiple Coulomb scattering

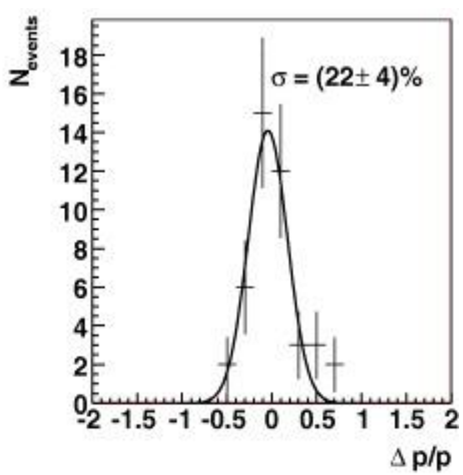
π test beam





Muon momenta measured by MCS in OPERA



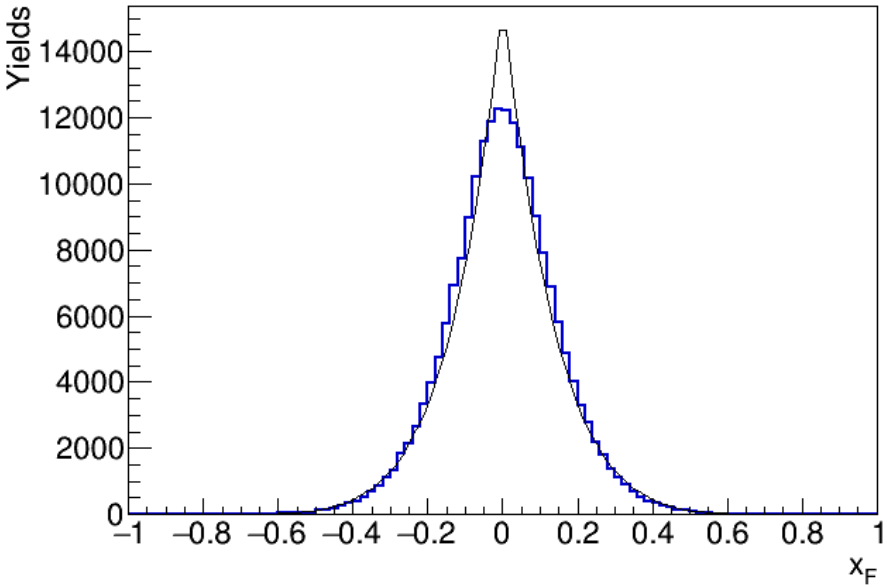


New Journal of Physics
14 (2012) 013026

$Ds^{\pm}$ x_F distributions

generated from pythia8185 for $Ds^{\pm}$ production in proton-nucleon interactions

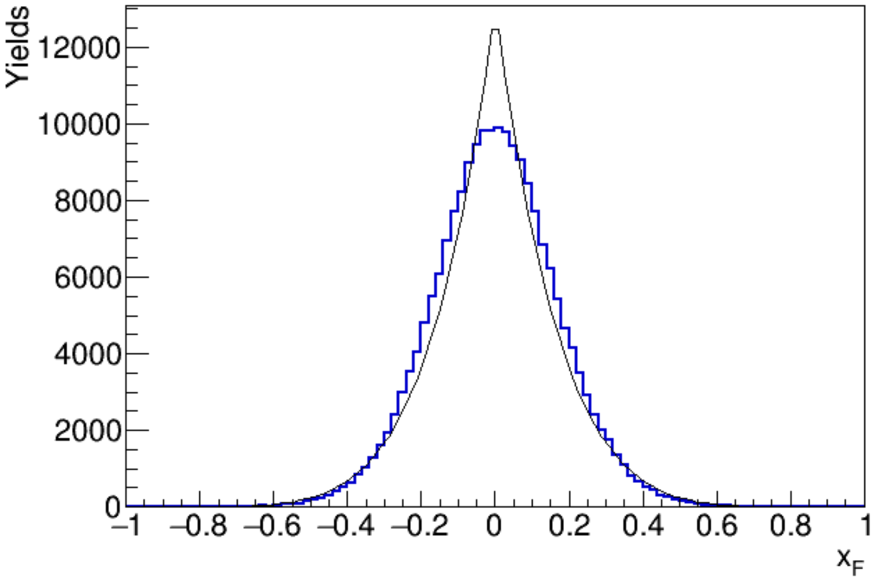
MC with 800 GeV beam



Fit of the yields to $(1-|x_F|)^n$

n = 6.9

MC with 400 GeV beam



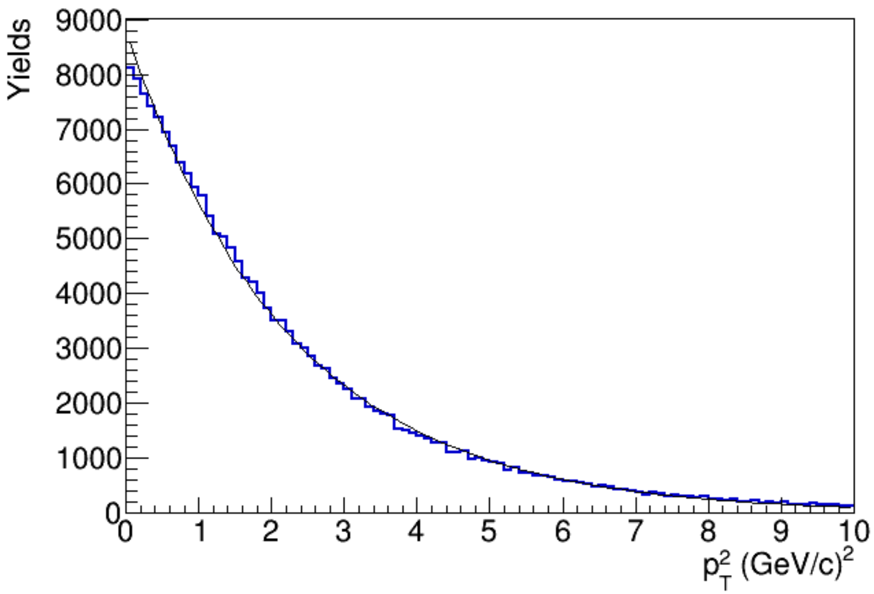
Fit of the yields to $(1-|x_F|)^n$

n = 5.8

We will measure this Xf distribution with 1000 detected Ds->tau events !

p_T distributions for $Ds^{\pm}$

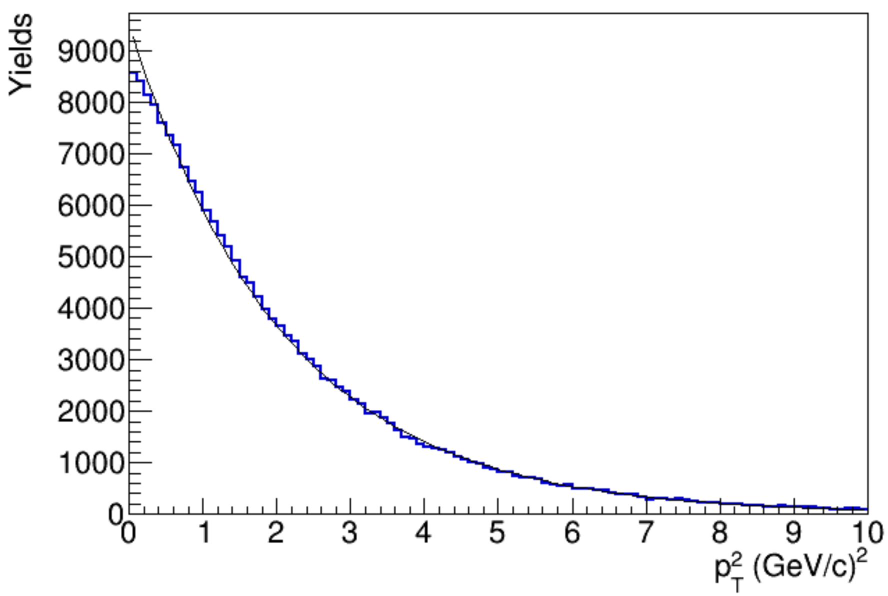
MC with 800 GeV beam



Fit of the yields to $\exp(-bp_T^2)$

b = 0.44

MC with 400 GeV beam



Fit of the yields to $\exp(-bp_T^2)$

b = 0.48

We will measure this Pt distribution with 1000 detected Ds->tau events !