Tau-neutrino production study at CERN SPS: Novel approach by the DsTau experiment

O. Sato (Nagoya University)
for the DsTau collaboration

26/Aug/2016 NuFact2016, ICISE, Quy Nhon

Current status on neutrino CC cross section measurements

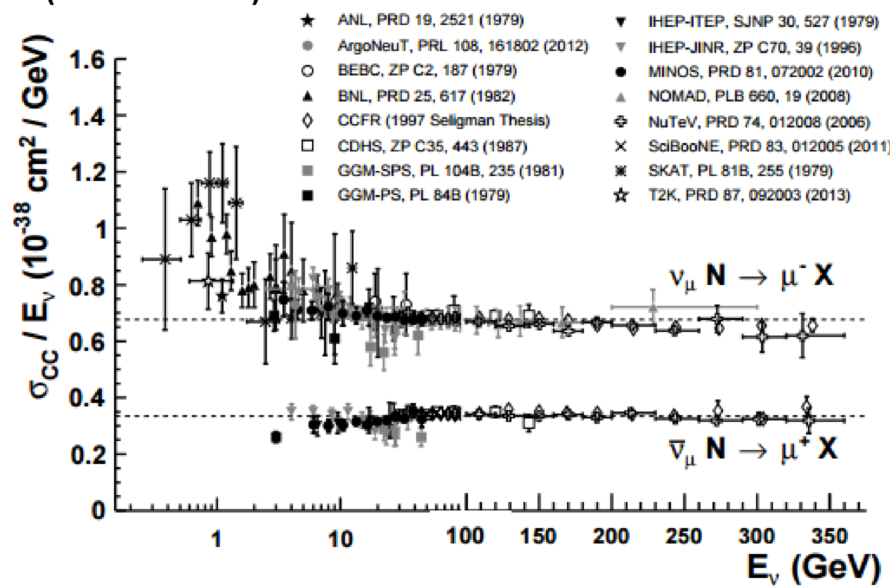
ν_μ : measured by many experiments

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

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

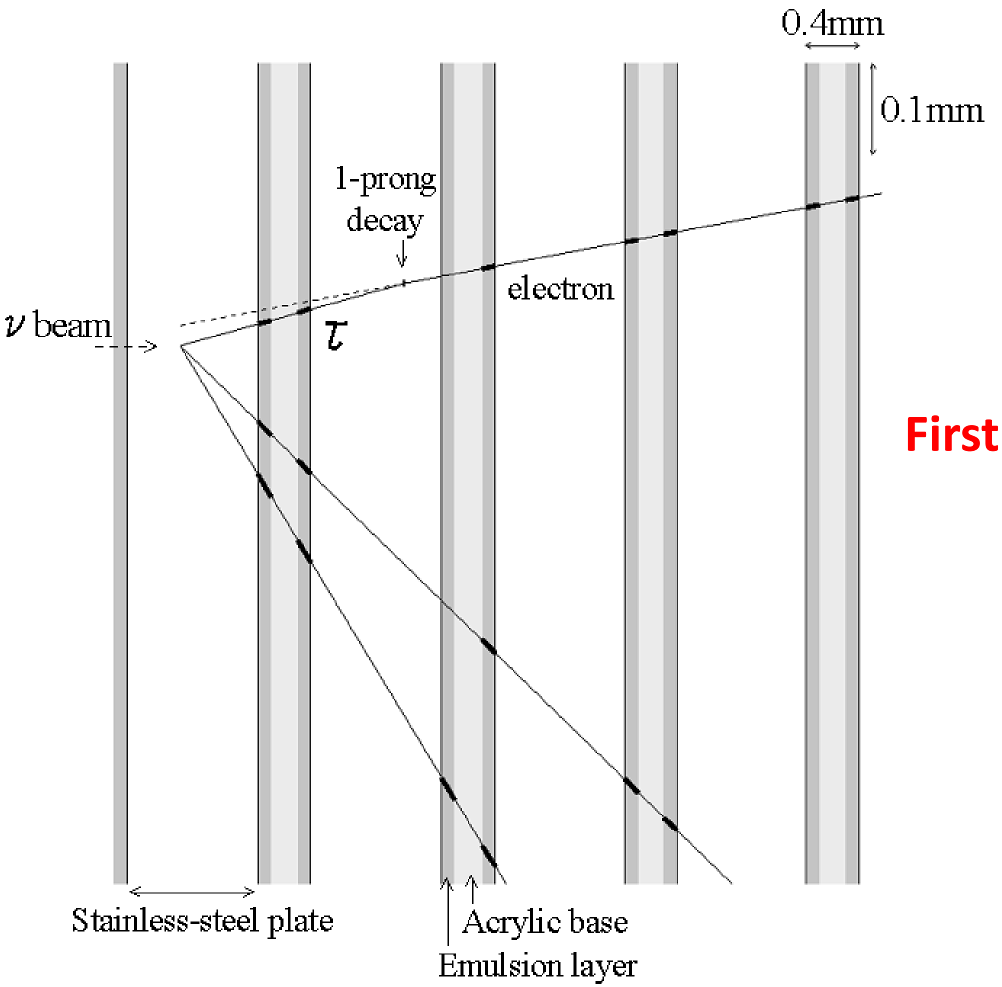
Measured as a function of a parameter n describing $d\sigma(D_s)/dx_F \sim (1-|x_F|)^n$

No experimental data giving n for Ds

–> **50% systematic uncertainty**

The DONuT experiment (Fermilab E872)

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



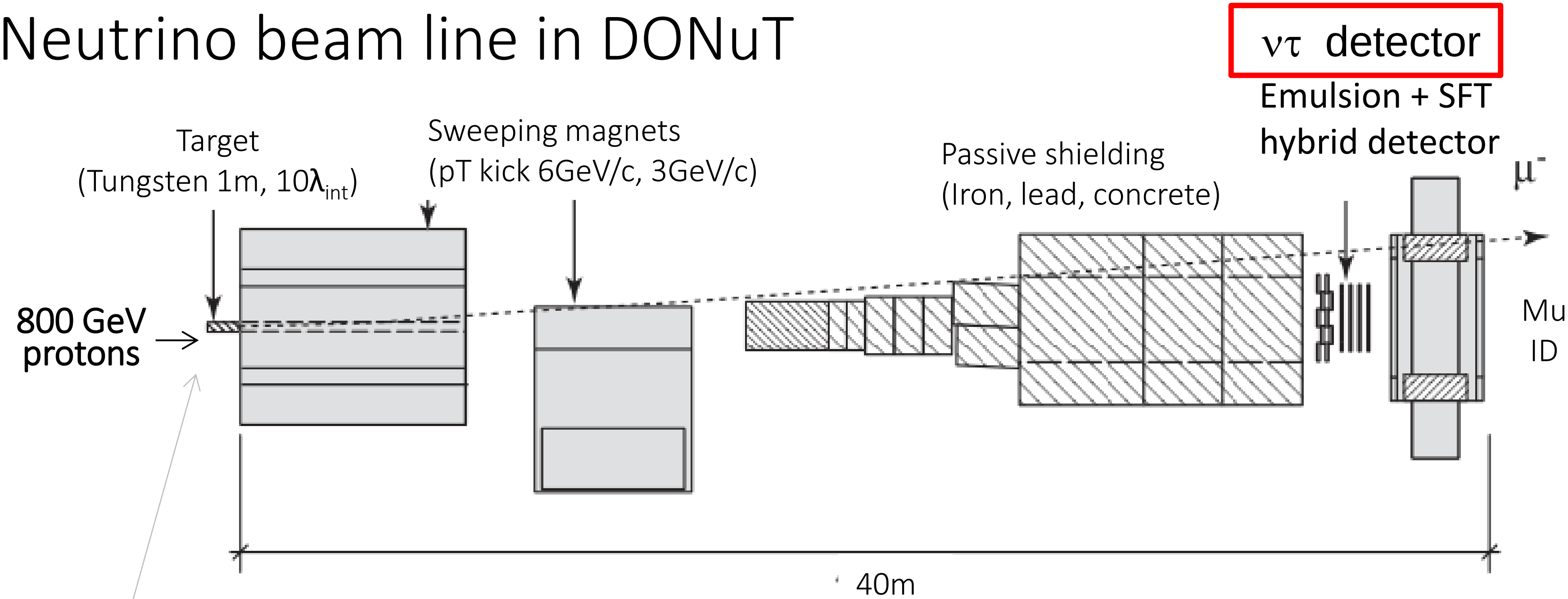
Final result with total analyzed statistics (**578** neutrino interactions)

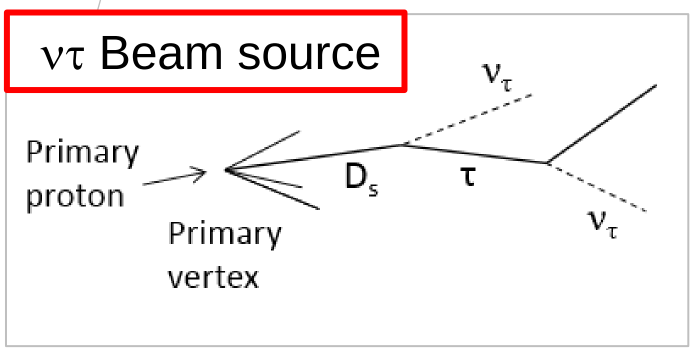
9 ν_τ CC events observed

First measurement of ν_τ CC cross section

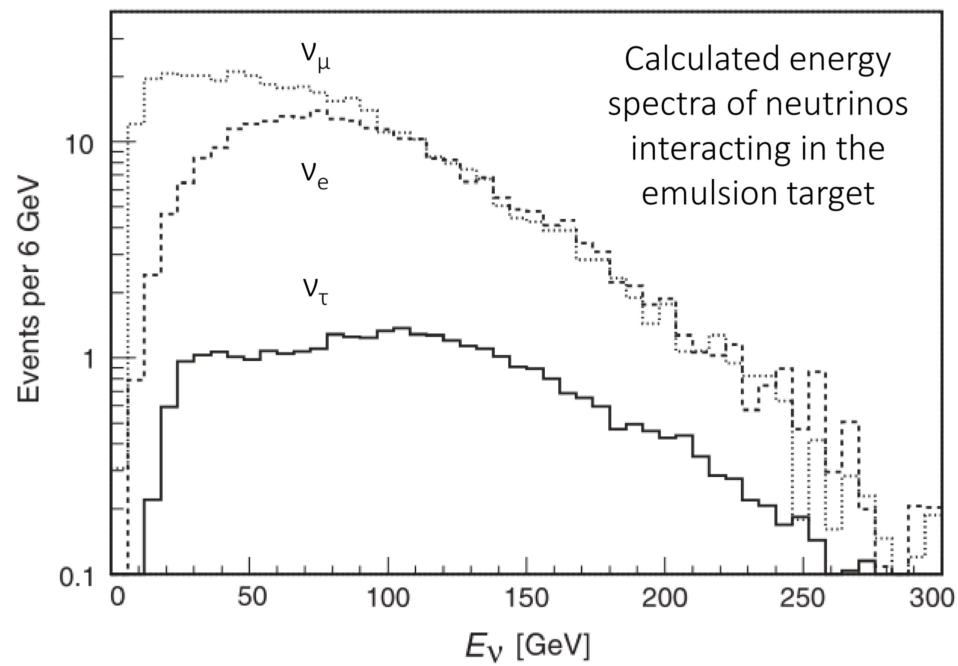
"Final tau-neutrino results from the DONuT experiment", Physical Review D 78, 5 (2008)

Neutrino beam line in DONuT

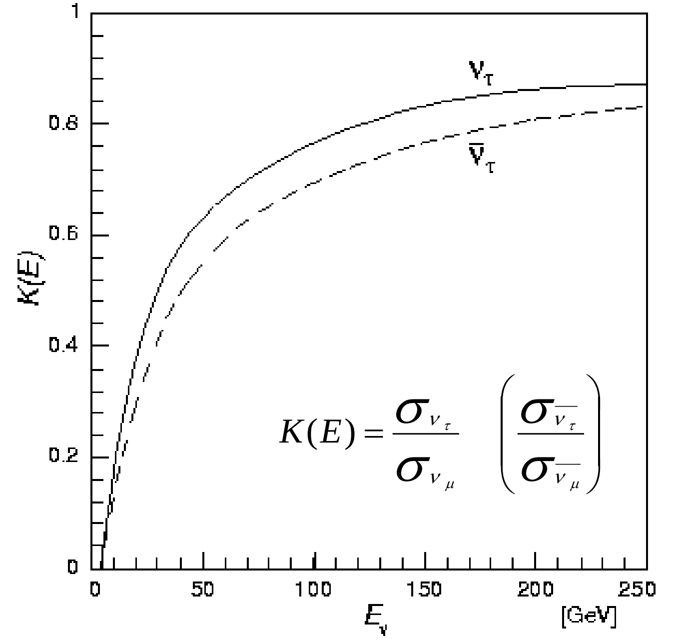




	Main source
ν_e	D^0 , $D^\pm$, D_s , Λ_c
ν_μ	D^0 , $D^\pm$, D_s , Λ_c , π, K
ν_τ	D_s



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

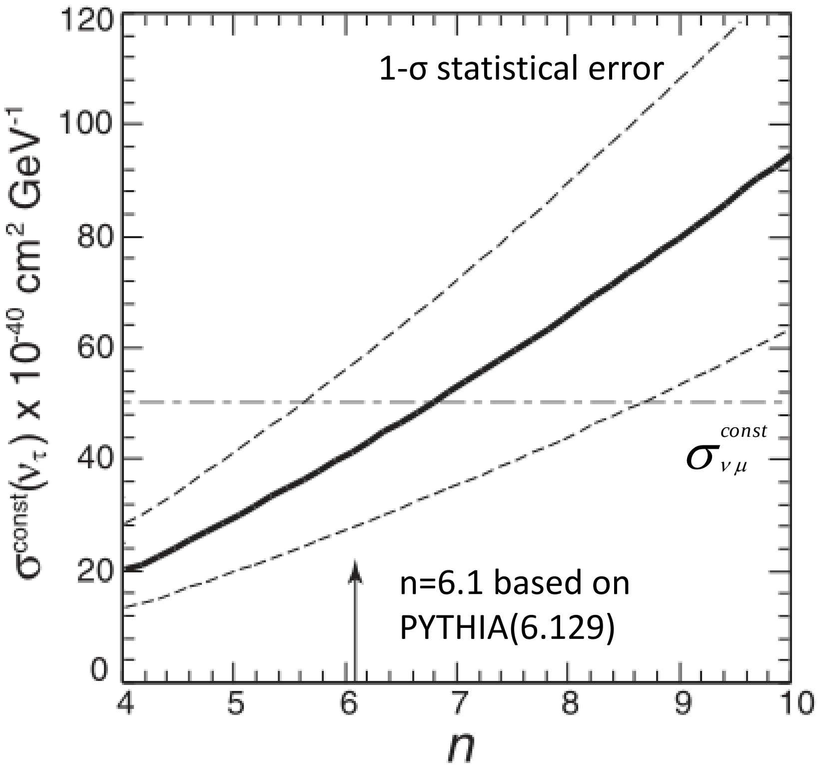
Phenomenological formula

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

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

Results from DONuT (2)

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 !

Motivation of DsTau project

ν_μ : measured by many experiments

Average over 30 - 200 GeV

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

~2% error

ν_τ : **only the DONuT experiment**

Beam source : Ds → τ+$\nu\tau$

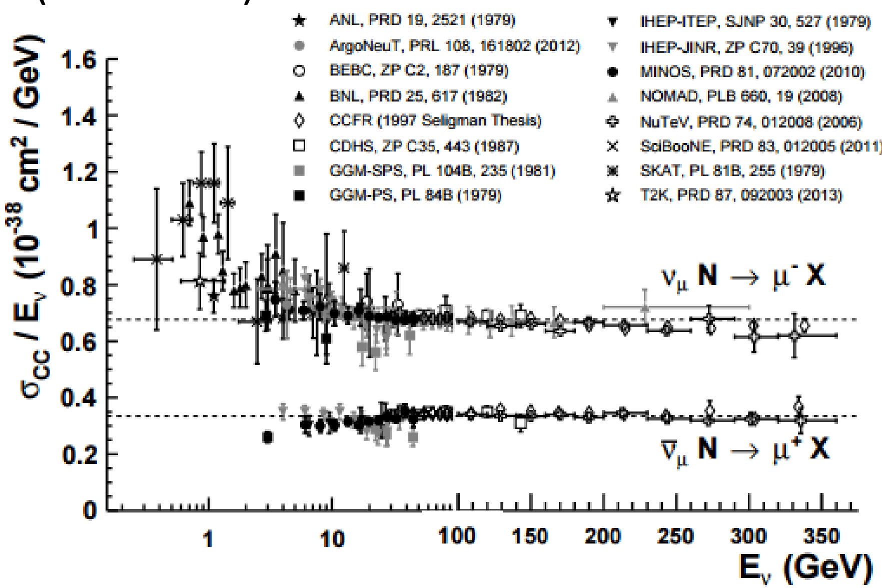
τ → x+ $\nu\tau$

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

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

Muon neutrino CC inclusive cross sections (PDG 2014)



New experiment, DsTau for precise ν_τ cross section measurement

$\nu\tau$ beam source Ds production feature should be measured in accurate.

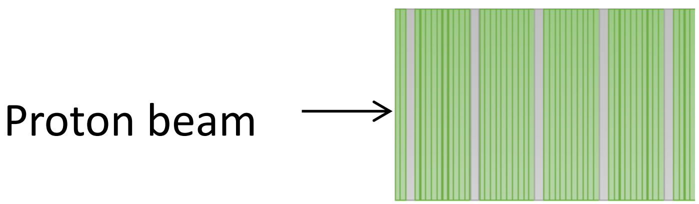
- **Essential input** for test **ν_μ - ν_τ universality** in CC interactions
- **Useful** results for experiments which are aiming **to detect ν_τ**
- Possibly **rich by-products**

New experiment to re-evaluate the cross section

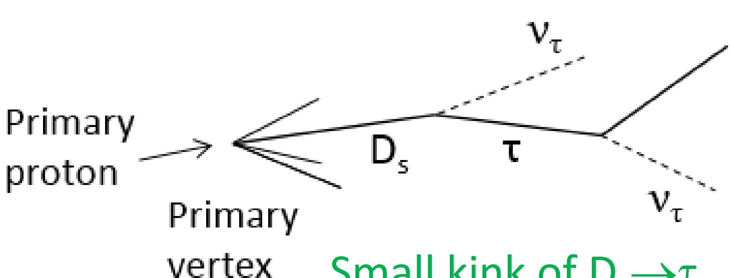
- $D_s \to \tau \to X$ precision measurement in high energy proton interactions

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

Proton target:
Tungsten foil + emulsion tracker



Detection of double-kink topology



Small kink of $D_s \to \tau$
Mean 7 mrad

Observable of the experiment

- D_s production x decay branching ratio

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

With collecting **1000** detected Ds→τ

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

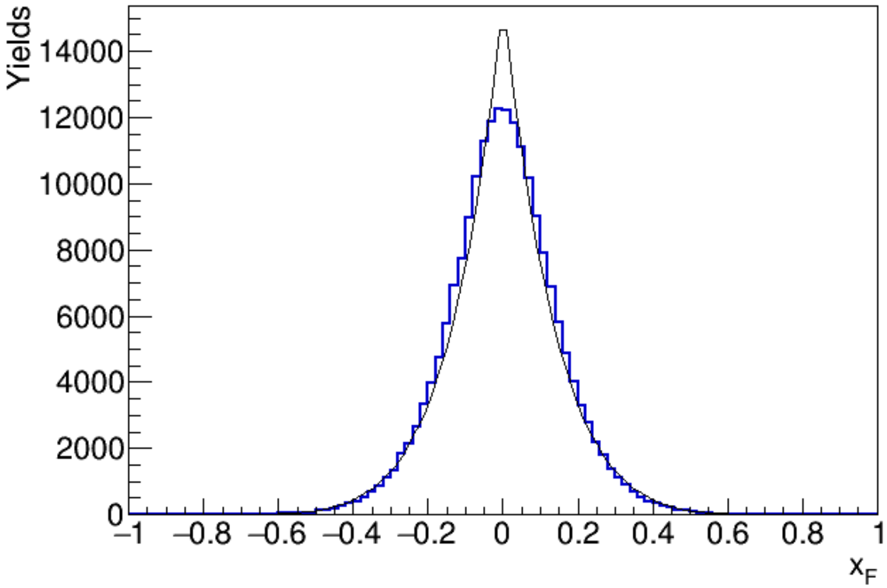
→ Energy distribution → x_F dependence

LOI submitted to the CERN SPSC (CERN-SPSC-2016-013; SPSC-I-245)

$Ds^{\pm}$ x_F distributions

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

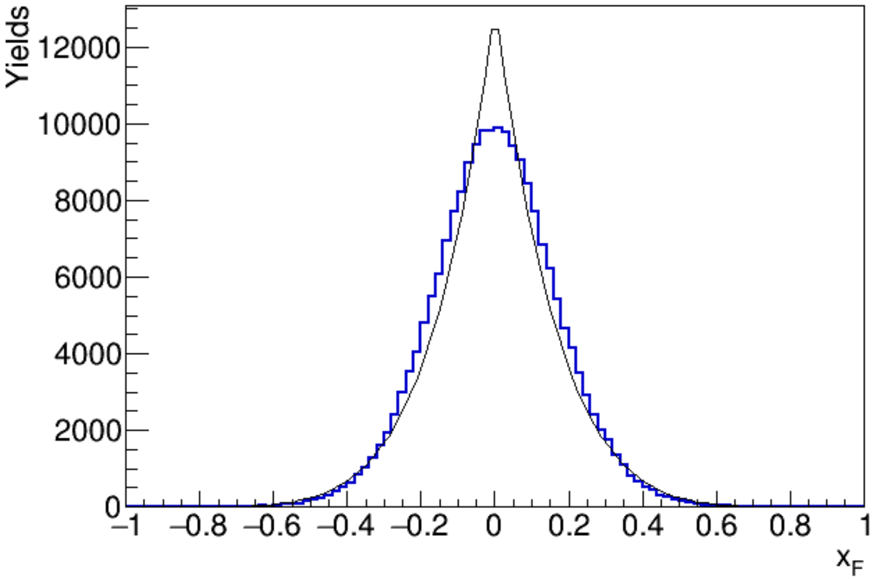
MC with 800 GeV beam



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

n = 6.9

MC with 400 GeV beam



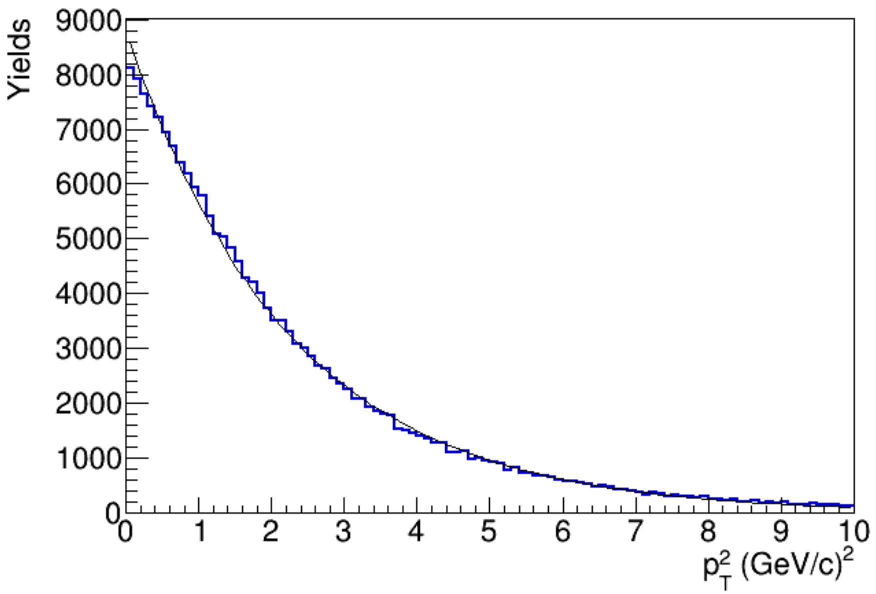
Fit of the yields to $(1-|x_F|)^n$

n = 5.8

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

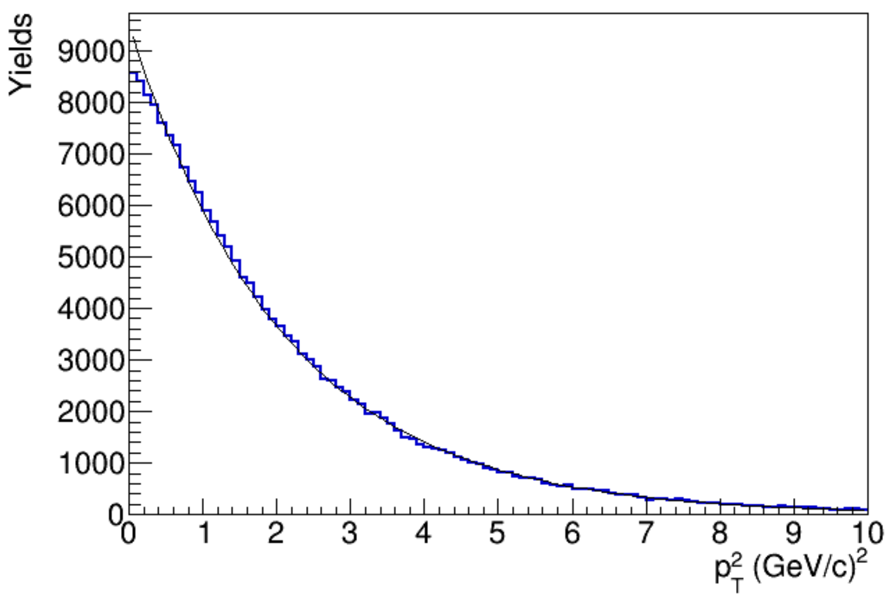
p_T distributions for $Ds^{\pm}$

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 !

Target systematic uncertainty for $\nu\tau$ cross section measurement

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

Systematic uncertainties	DONUT	With DsTau
D_s differential cross section (x_F dependence)	**~0.5!?**	**0.1**
Charm production cross section	0.17	**0.03**
Decay branching ratio	0.23	
Target atomic mass effects (A dependence)	0.14	

DsTau Project will provide Ds production information with detecting 1000 Ds→ τ →X !

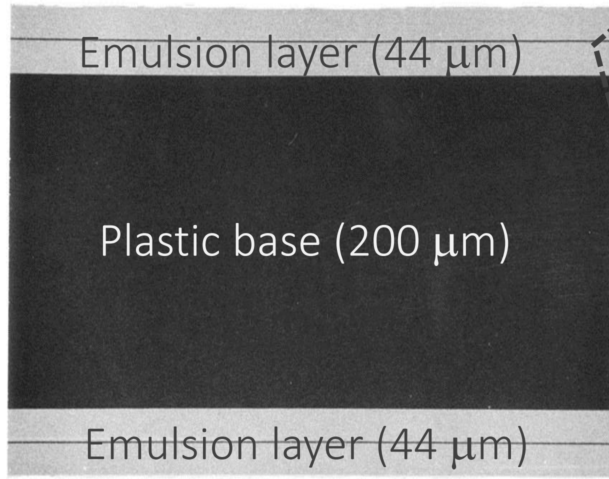
Emulsion detectors: highest position resolution

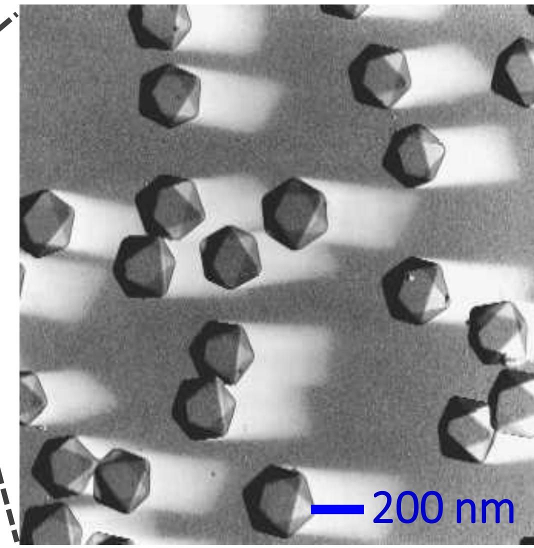
AgBr crystal

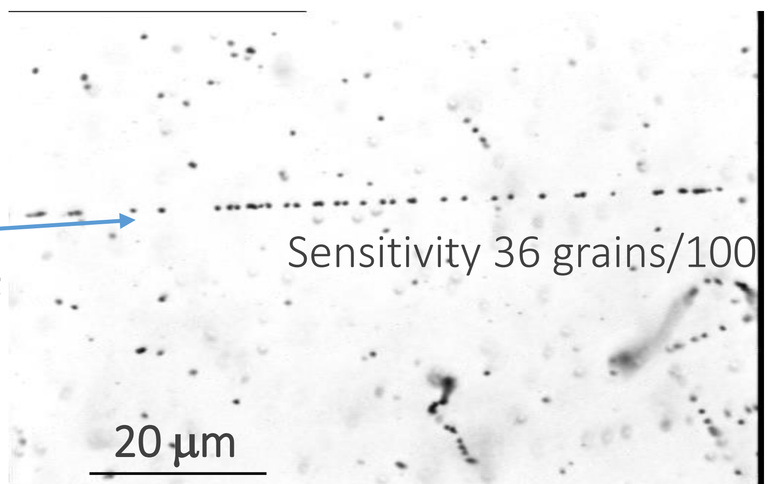
10^{14} crystals in a film

Emulsion film

Cross-sectional view







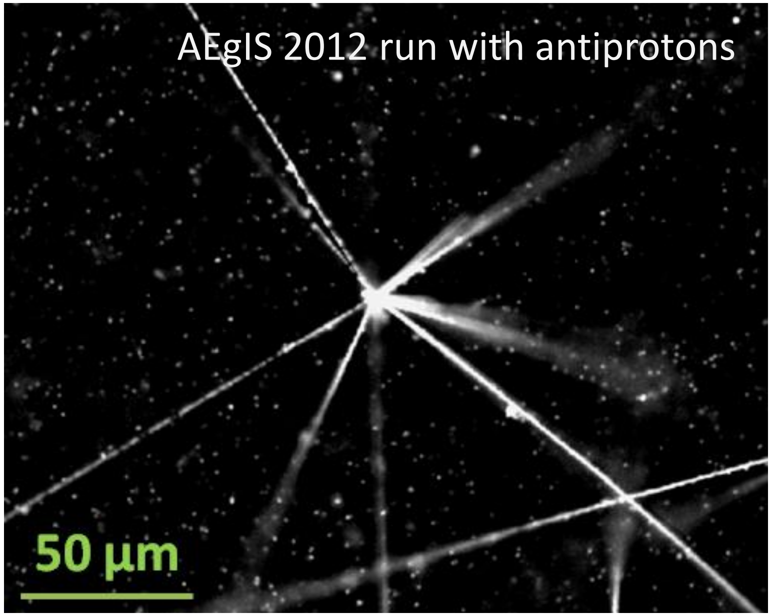
10GeV/c π beam

Sensitivity 36 grains/100 μm

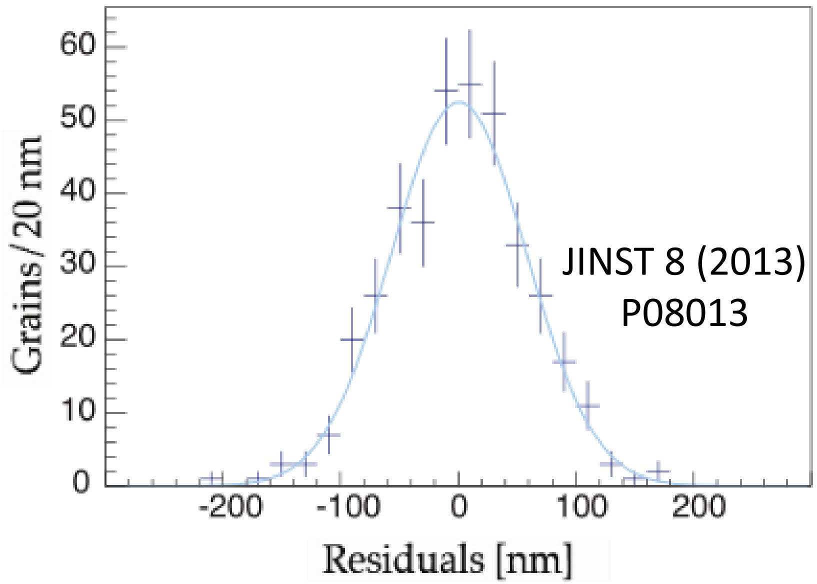
3D tracking device

Emulsion detectors: intrinsic resolution

Emulsion detector produced in Bern using high sensitivity emulsion gel produced in Nagoya University



Measured intrinsic resolution



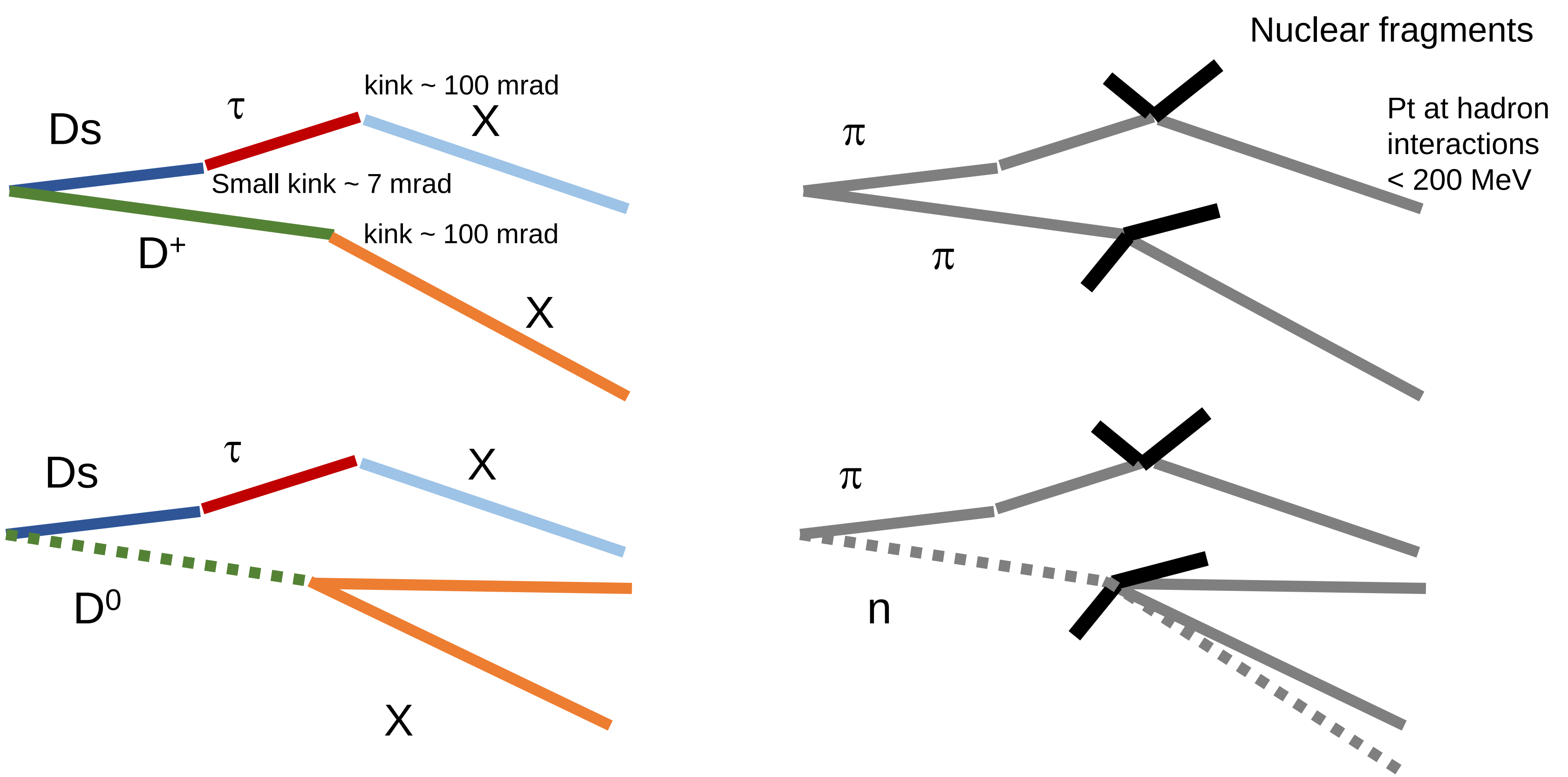
JINST 8 (2013) P08013

Intrinsic resolution 58 nm →

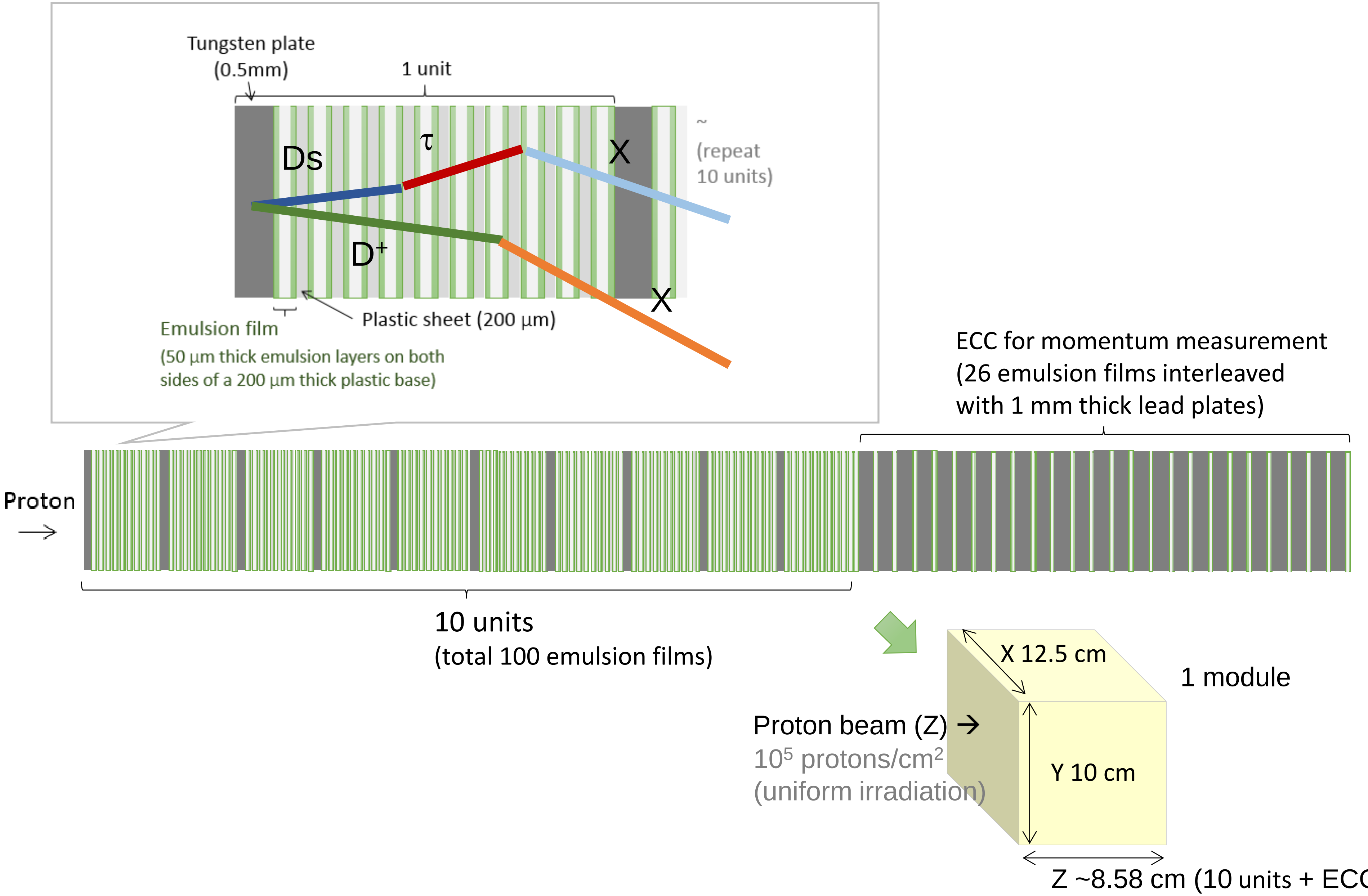
Angular resolution 0.05µm·√2/200µm = **0.35 mrad**

Signal and background

- Signal = a double kink + a charmed particle decay
- Background = hadron interactions

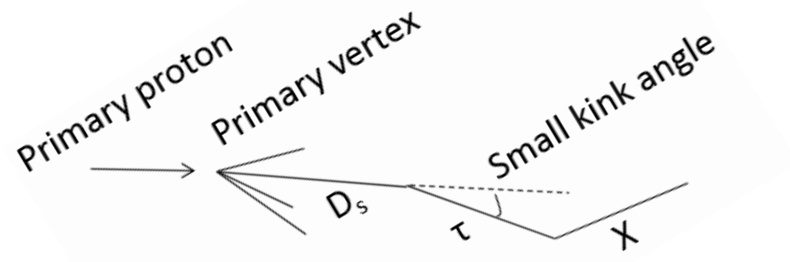


Module structure for $D_s \rightarrow \tau \rightarrow X$ measurement



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

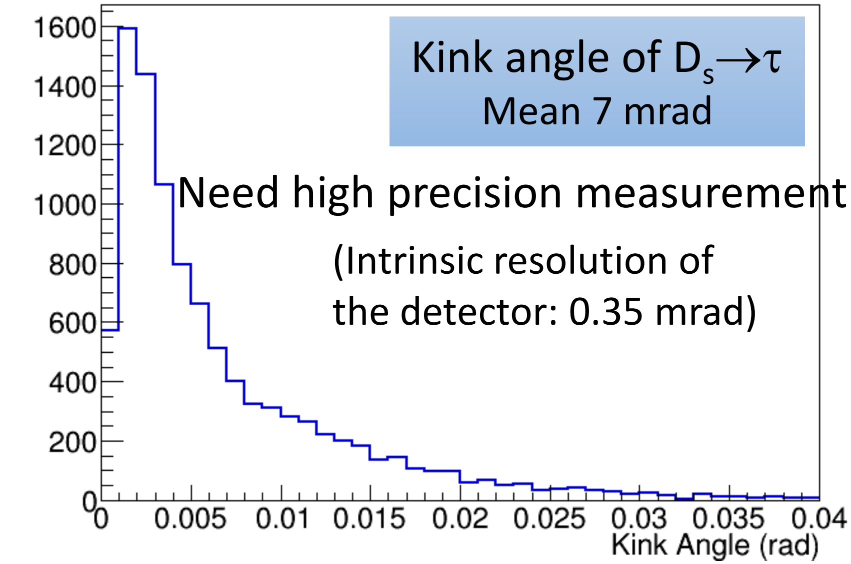
PYTHIA

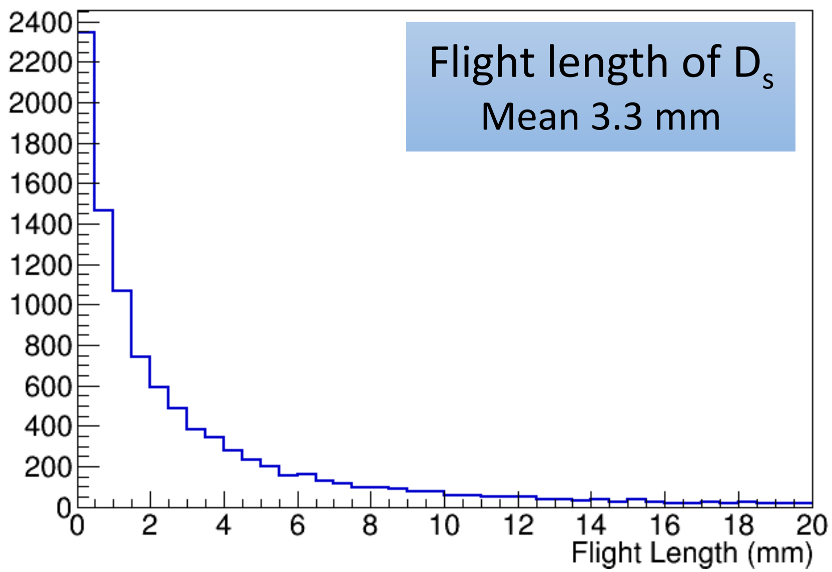


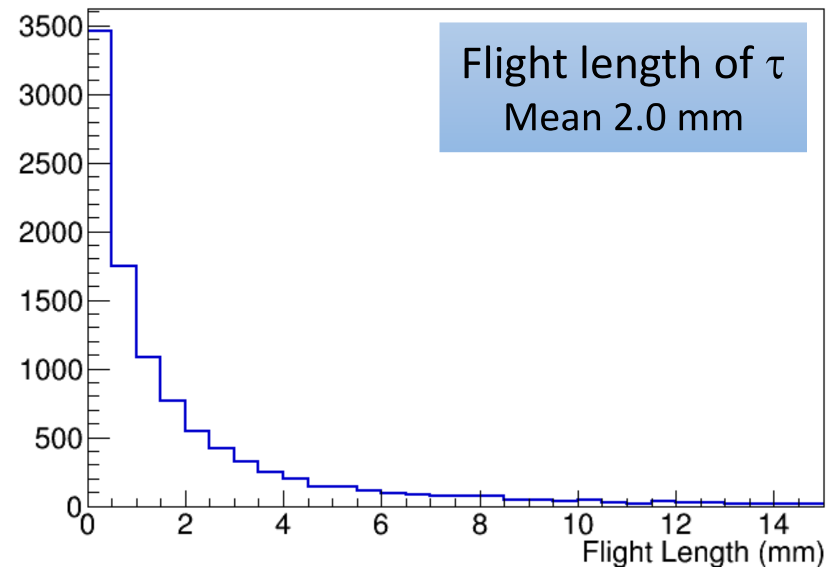
The analysis chain:

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

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







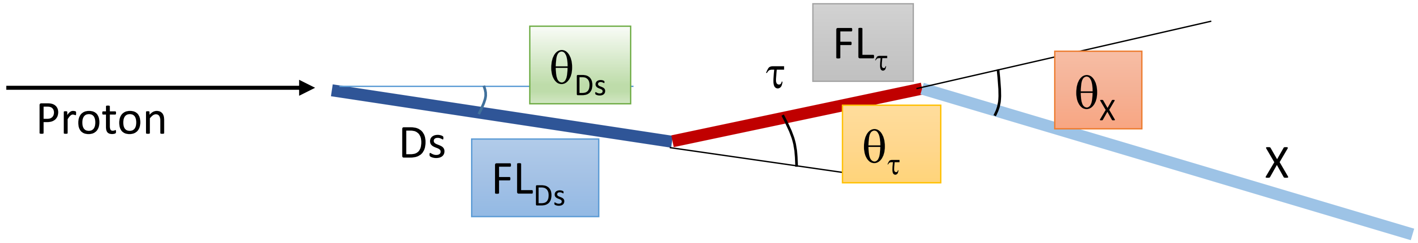
Preliminary selection :

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

→ Efficiency **22%** (will be further optimized using more careful simulations)

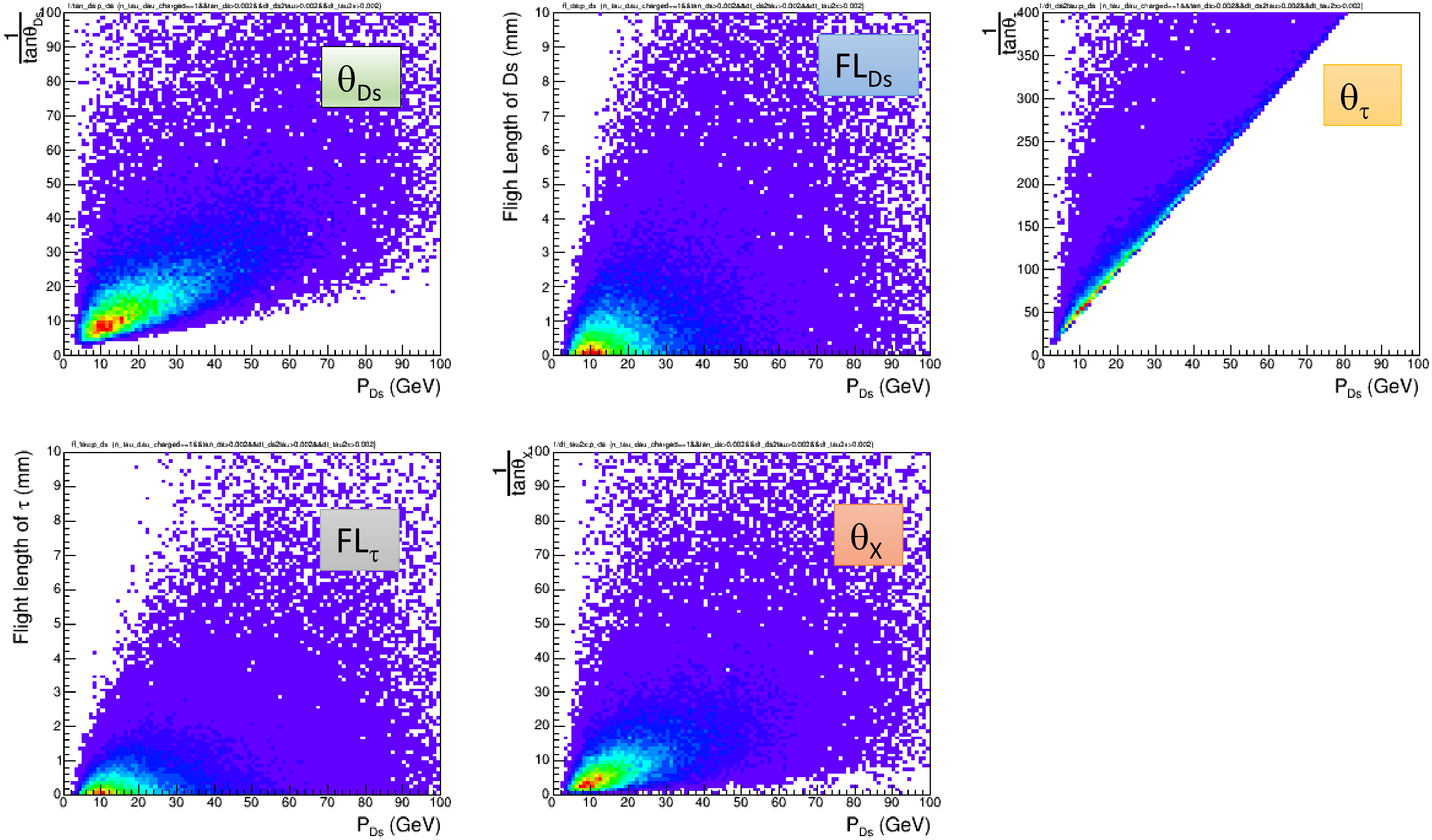
Key technique for Xf measurement : Ds momentum reconstruction from topological variables

- 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

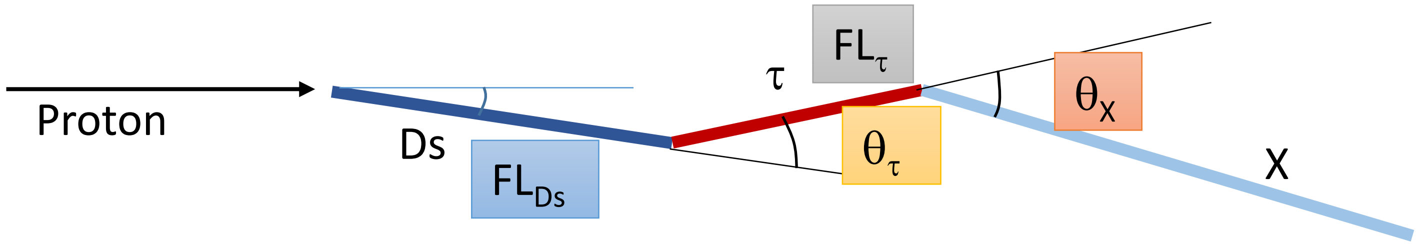


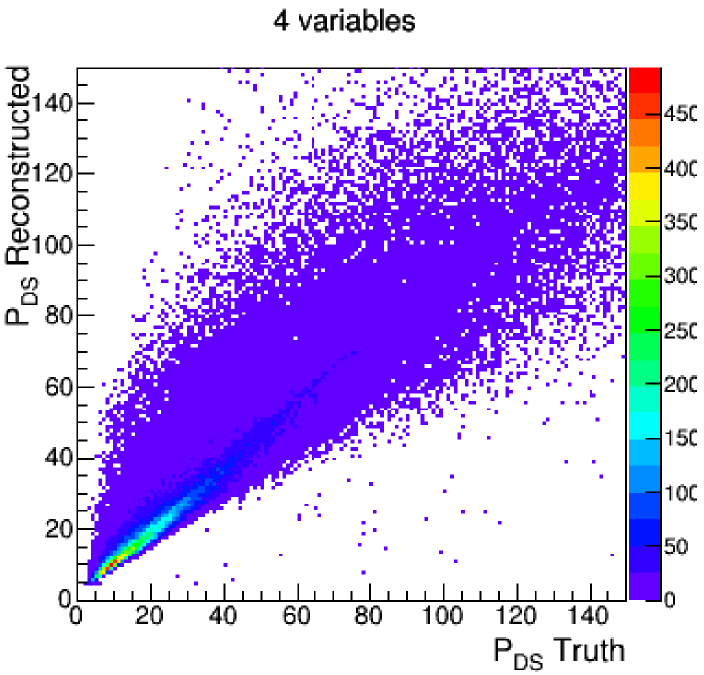
Topological variables: correlation with P_{Ds}

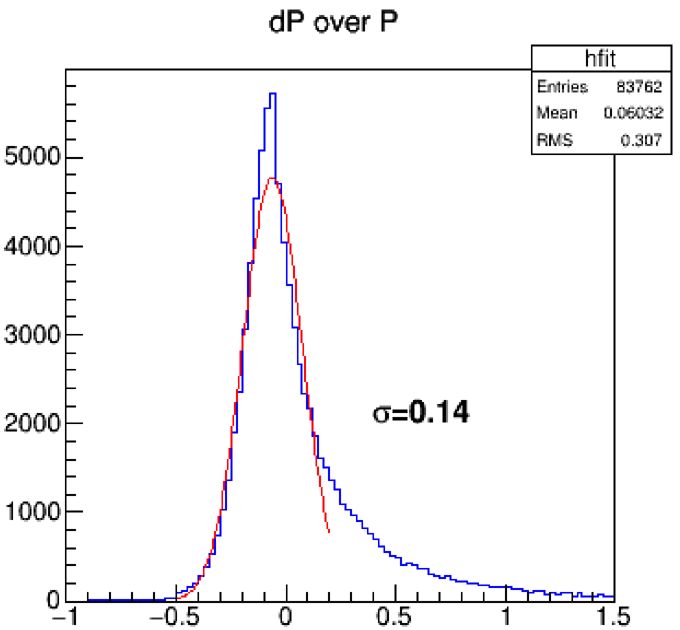
Sample: tau single prong decay



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





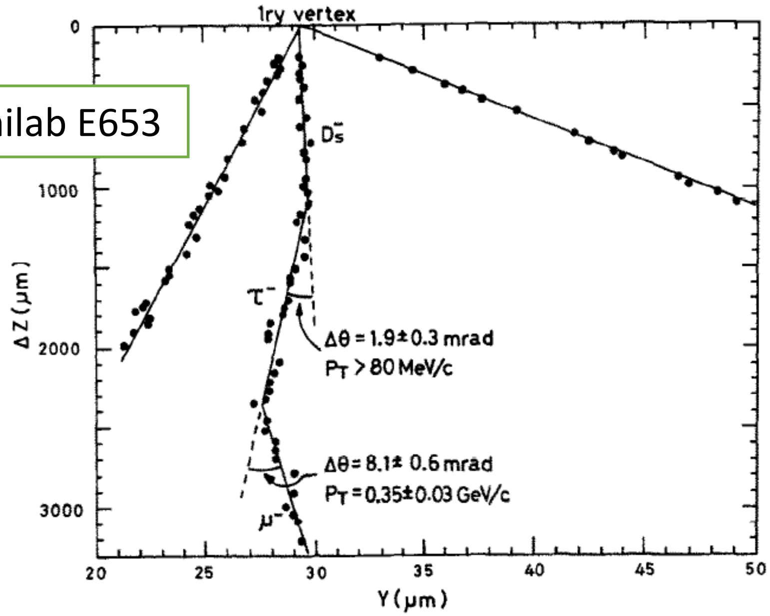


How many interactions to be analyzed?

- To detect 1000 $D_s \rightarrow \tau \rightarrow X$ events
  - Efficiency ~22%, BR($D_s \rightarrow \tau$) = 5.55%
  - 8.2×10^4 D_s to be produced
- D_s production cross section in Tungsten target
  - ~8.5×10^{-4} @800GeV → ~4×10^{-4} @400GeV
- → 2×10^8 proton interactions to be analyzed!

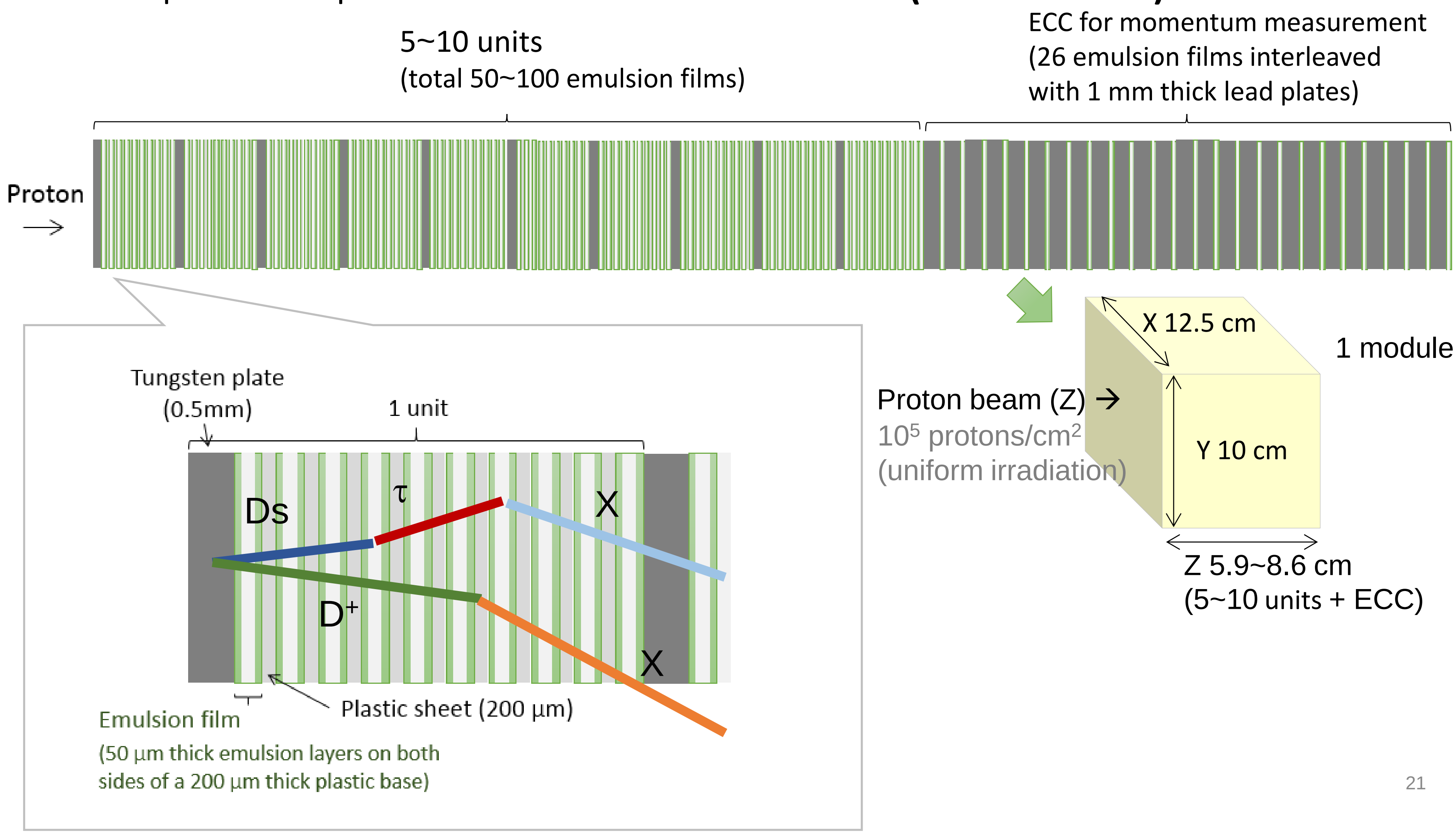
↔ only 10^5 proton interactions were analyzed in emulsions in E653 (previous exp.)

$D_s \rightarrow \tau \rightarrow \mu$ candidate found in Fermilab E653

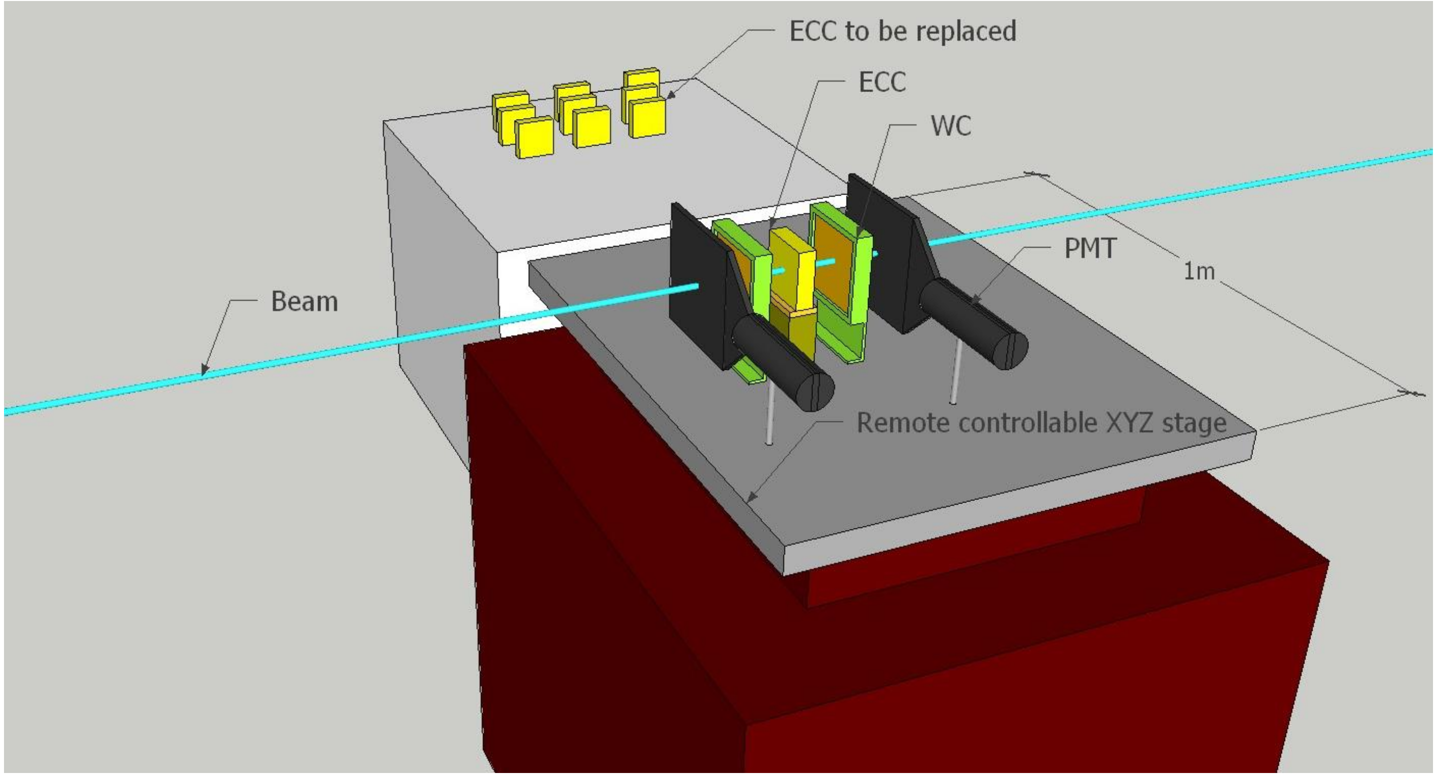


Module structure for $D_s \rightarrow \tau \rightarrow X$ measurement (current baseline)

- In case of 5 units → 0.025 λ_{int} in tungsten → 8x10^9 pot needed to get 2x10^8 proton int.
- Track density in emulsion: **keep <10^5 tracks/cm^2** at the upstream side
- To expose 8x10^9 pot → **detector surface 8x10^4 cm^2 (800 modules)**



The expected setup of the experiment



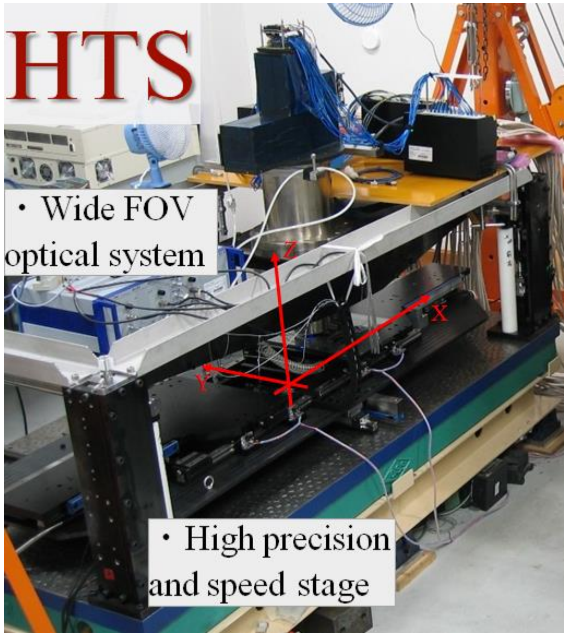
Needed beam time

- Assuming 10^5 protons/spill and the beam spot 1 cm^2,

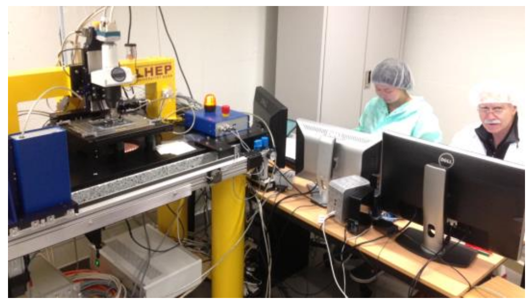
detector surface 8 x 10^4 (cm^2) x 30 (sec/cm^2) = ~4 weeks.

- Module exchange time: 10 min x 800 modules = ~ 1 week.

Readout of emulsion data



← New scanning system being developed in Nagoya, aiming at the speed of 9000 cm^2/h (22 m^2/day)

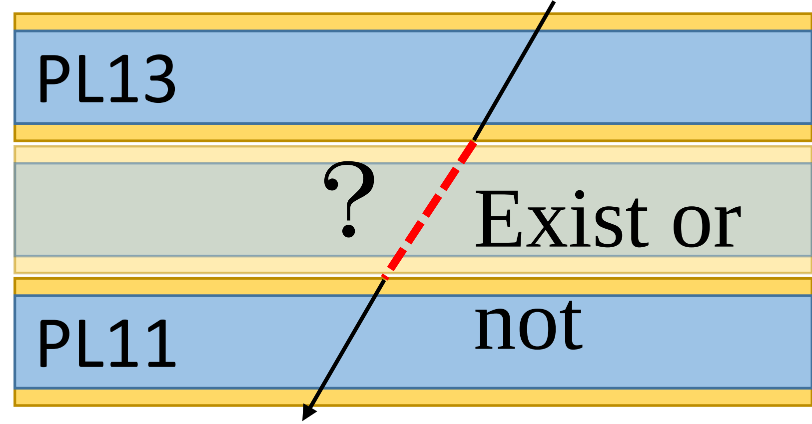


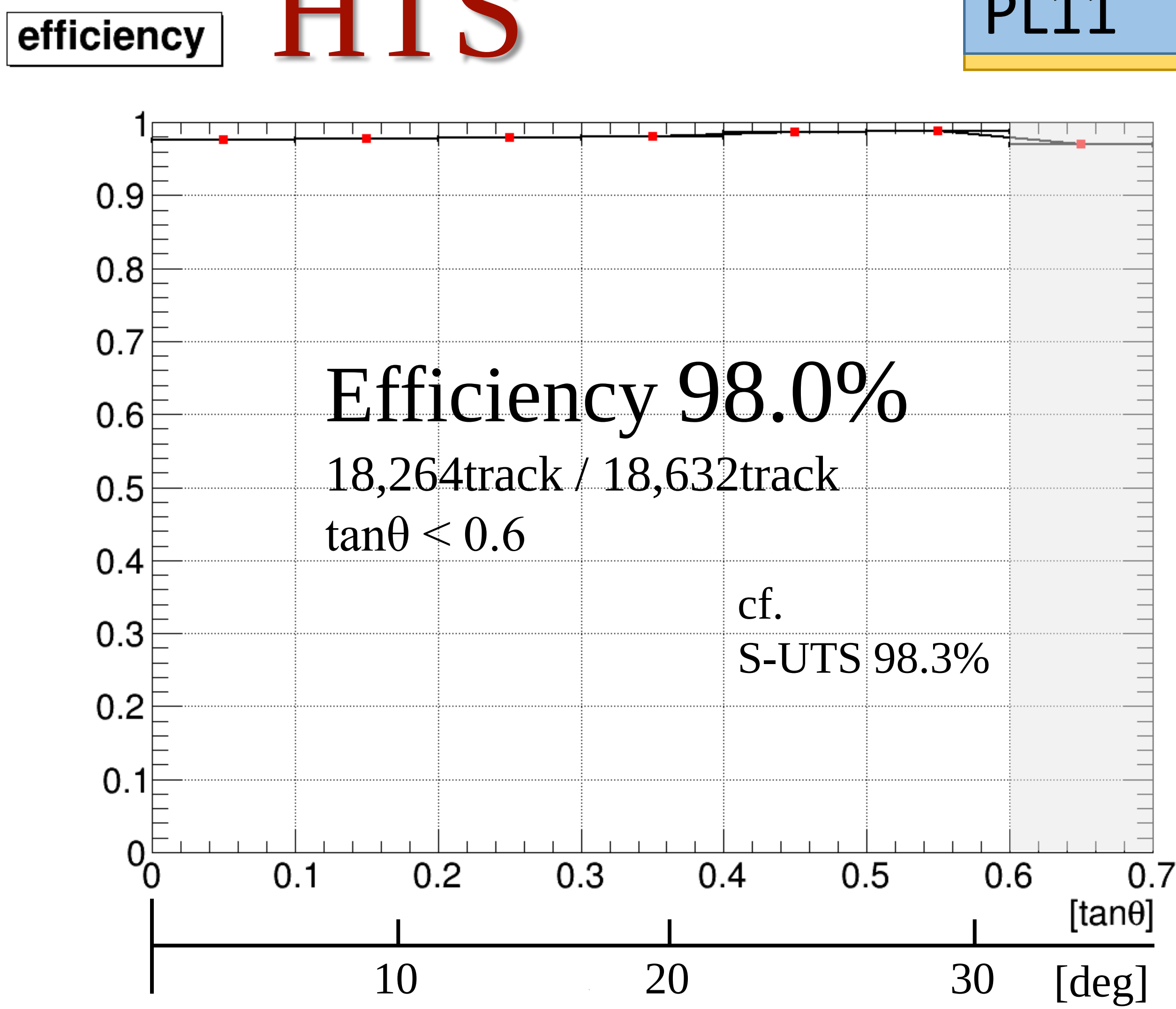
Another system dedicated to high precision measurements based on GPU technology in Bern, aiming at the speed of 100 cm^2/h

	New experiment
Emulsion surface	~400 m^2 (x2sides)
Readout time	Standard scan ~4 Months to 1 Year
	High precision scan ~3 months

New Emulsion Film

HTS





Efficiency 98.0%

18,264track / 18,632track

$\tan\theta < 0.6$

cf.

S-UTS 98.3%

Prototype test experiment in 2016

- 400 GeV Proton beam test in Nov. 2016
  - 5 days of beam time at the H4 beam line
  - 20 m^2 emulsion surface (1:40 of the final setup)

- Aim
  - Test of tuning the beam size
  - Optimization of the setup
  - Proof of principle experiment,
    Xf evaluation by about25 detected Ds->τ events

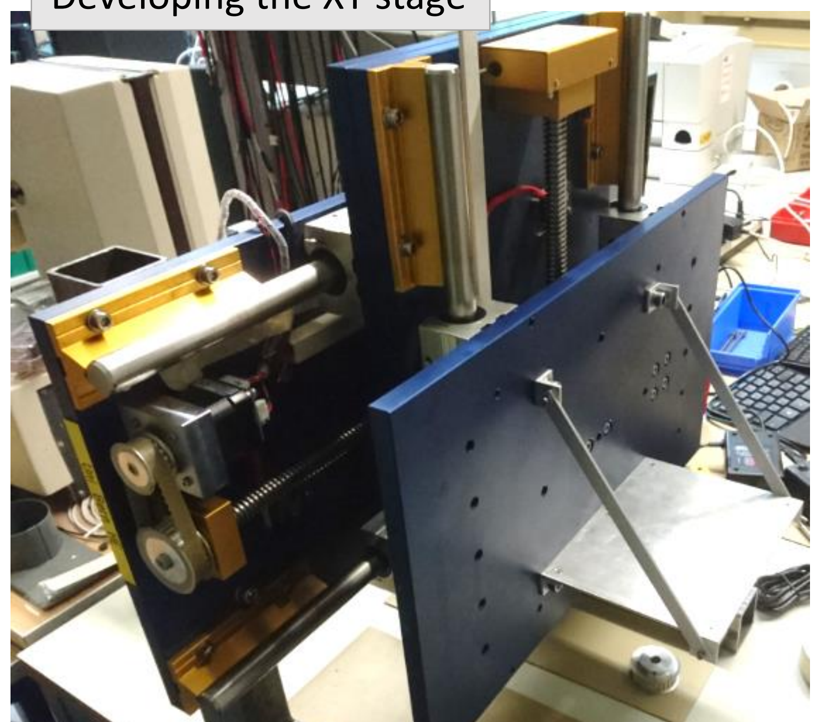
- Track density study
  - 10^4 / cm2 x a few bricks
  - 10^5 / cm2 x 10-20 bricks
  - 10^6 / cm2 x a few bricks
- Longitudinal thickness
  - 5, 10, 20 units (50, 100, 200 films)

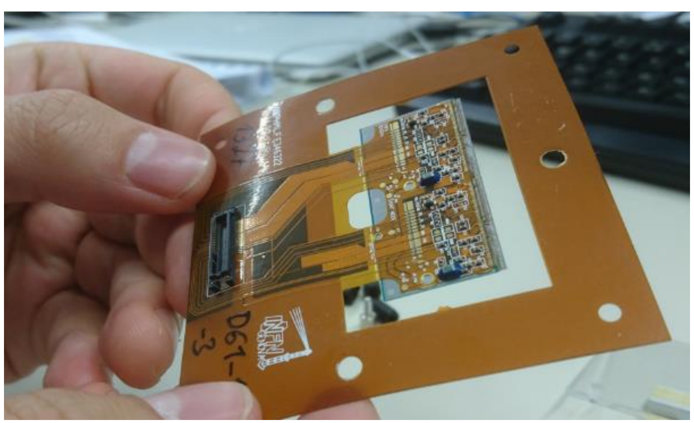
Preparation in progress

- Emulsion film production in Bern using the gel from Japan
- XY stage and control
- Beam profile monitor with silicon pixel sensors

Establishing the film production facility equipped with 9 gel pouring tables

Developing the XY stage





Summary and prospects

- $\nu\tau$ CC cross section measurement could be a check of lepton flavor universality.
- While $\nu\tau$ cross section measurement have been reported by only DONUT.
- The error on DONUT result suffer large systematic error (50%), not only statistical (9ev detected $\nu\tau$) error (30%).
- The main systematic error is how Ds were produced at beam source.

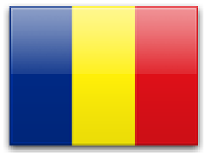
DsTau project aim

- $D_s \rightarrow \tau \rightarrow X$ precision measurement in high energy proton interactions is essential input toward precise evaluation of ν_τ cross section.
- **$2x10^8$** proton interactions are to be obtained and analyzed **1000 $D_s \rightarrow \tau \rightarrow X$ events .**

- Prototype test experiment in Nov. 2016
- Aiming to realize the experiment hopefully in **2018** before the SPS shutdown

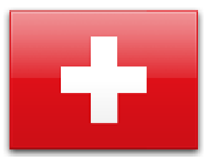
The collaboration

Japan:
Aichi
Kobe
Nagoya



Romania:
Bucharest

Russia:
Dubna



Switzerland:
Bern

Turkey:
Ankara

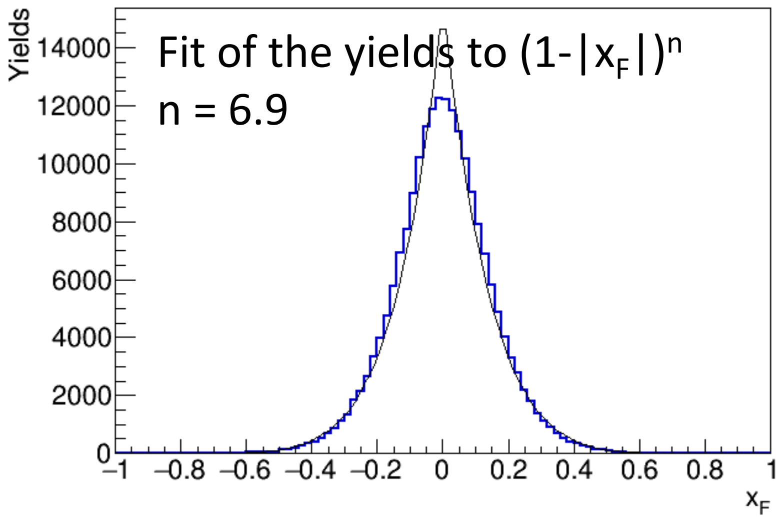
Backup

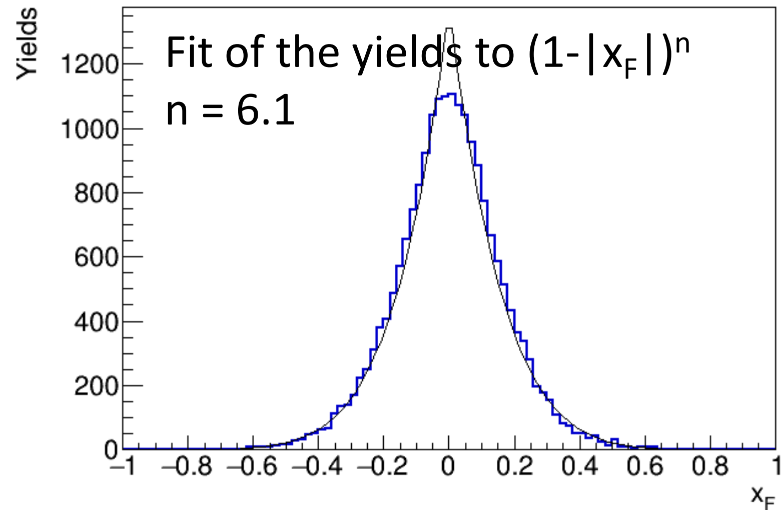
Difference due to pythia versions?

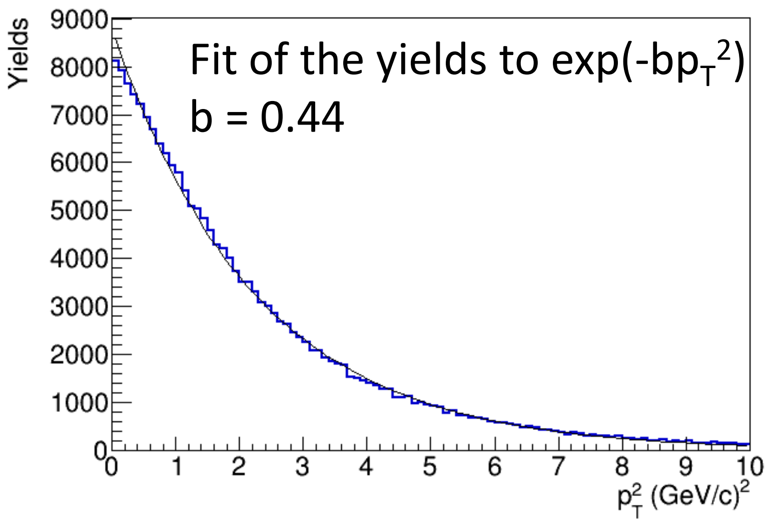
Both for 800 GeV beam

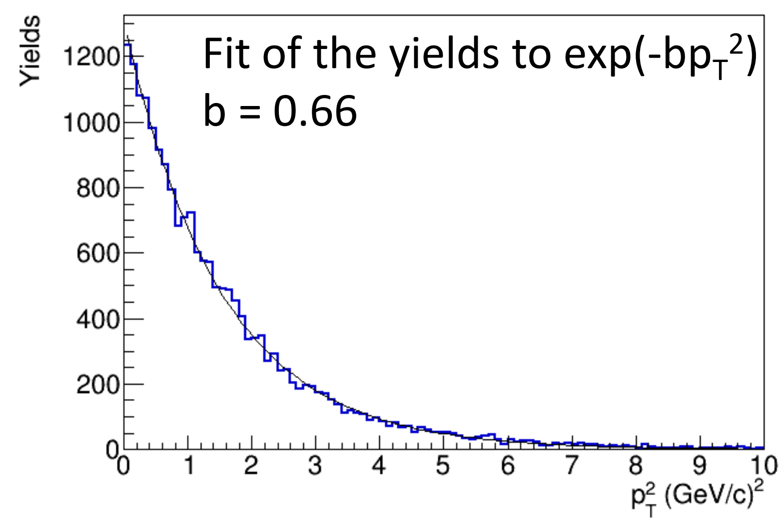
pythia8185

Using the files from Komatsu (probably old version)



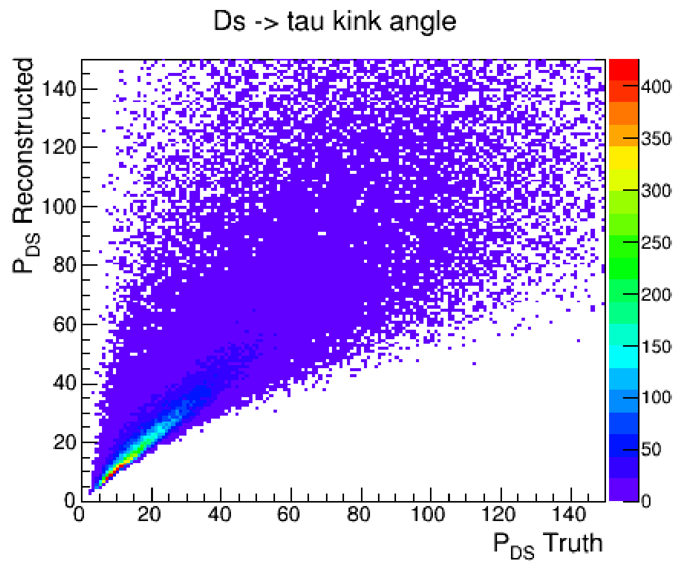


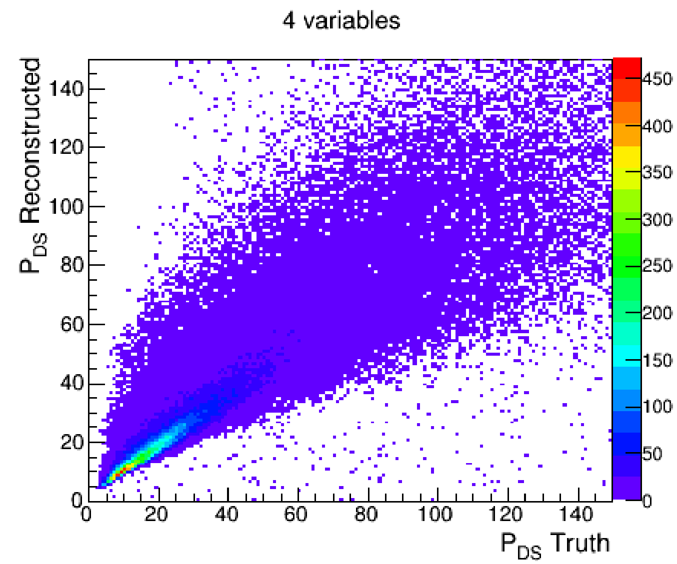


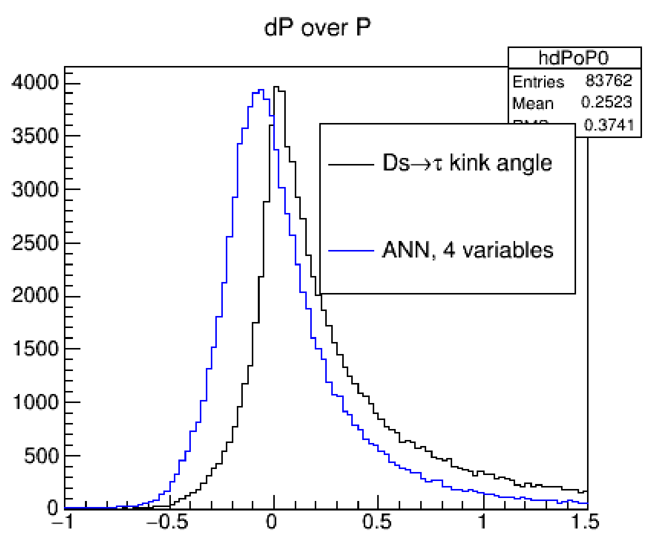


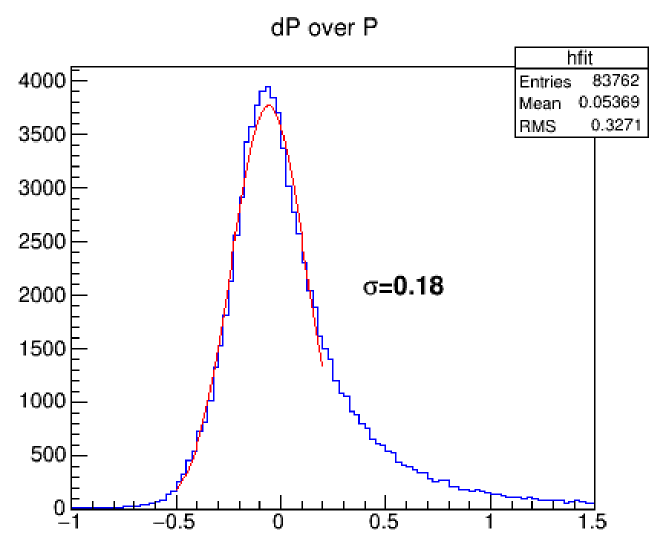
Including an angular resolution

- 0.35 mrad in each projection
- → 0.7 mrad for kink angle



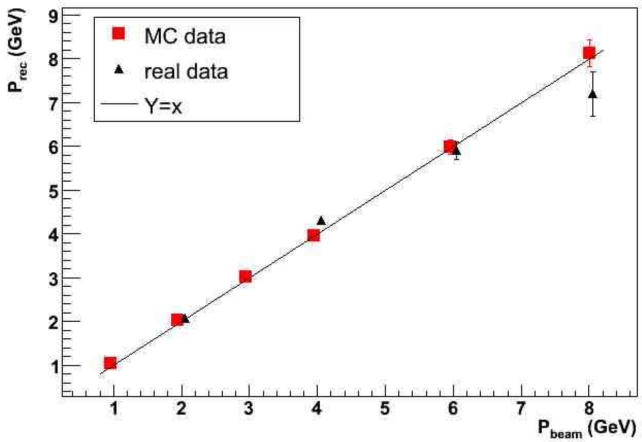


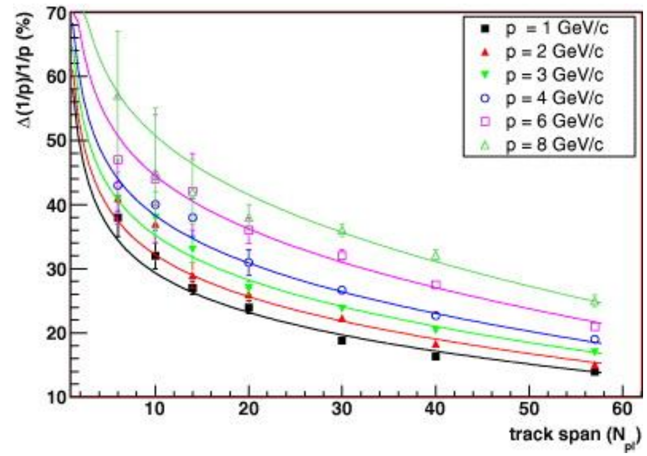




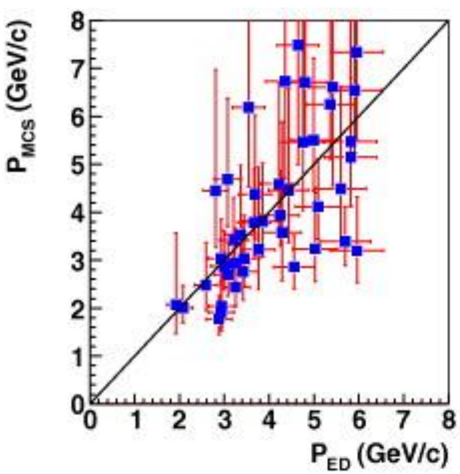
Momentum measurement through multiple Coulomb scattering

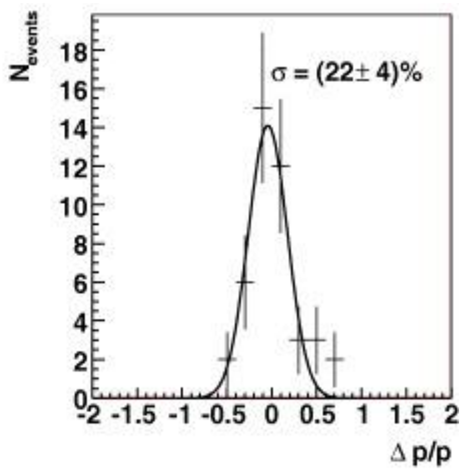
π test beam





Muon momenta measured by MCS in OPERA





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Production
Particle slope
With 400 GeV
proton beam