Charm Hadron Interaction Cross Section Measurement in DsTau Experiment

O.Sato (Nagoya Univ.)

and DsTau Collaboration

Japan:
Nagoya
Kyusyu
Aichi
Kobe

Switzerland:
Bern

Romania:
Bucharest

Russia:
Dubna

Turkey:
Ankara

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.

$D_s \rightarrow \tau \rightarrow X$ 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	**0.03**
Decay branching ratio	0.23	
Target atomic mass effects (A dependence)	0.14	

Observable of the experiment

- D_s production x decay branching ratio

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

With collecting **1000** detected Ds→τ

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

→ Energy distribution → x_F dependence

LOI (SPSC-I-245), Experimental proposal (SPSC-P-354) submitted to CERN SPS
Beam exposure planning in 2018 and in 2021.

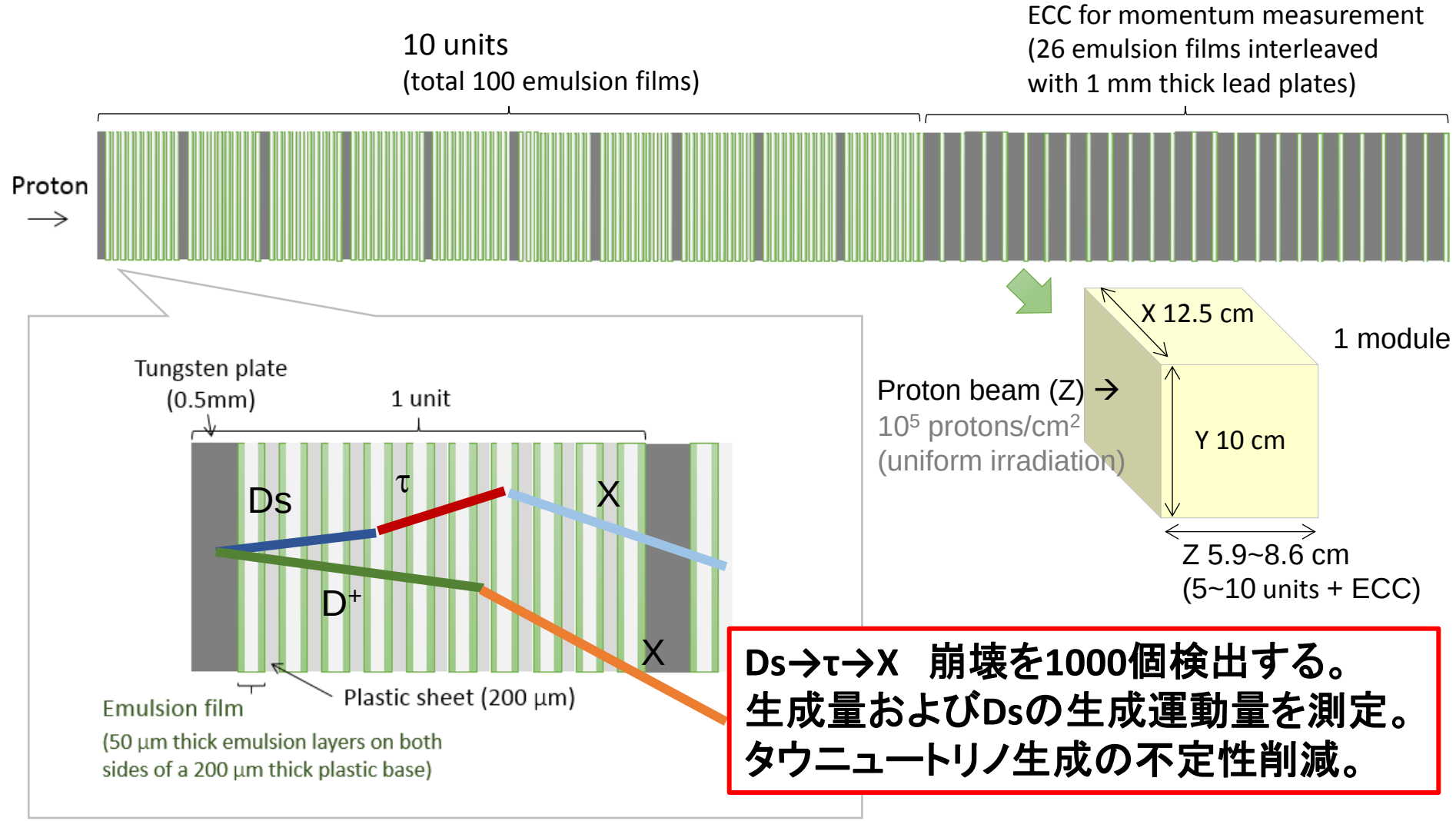
Nagoya, Kyushu, Kobe, Aichi, Bern, Bucharest, Ankara, Dubna

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

0.05 λ_{int} in 10 units tungsten → 4.6x10^9 pot needed to get 2.3x10^8 proton int.

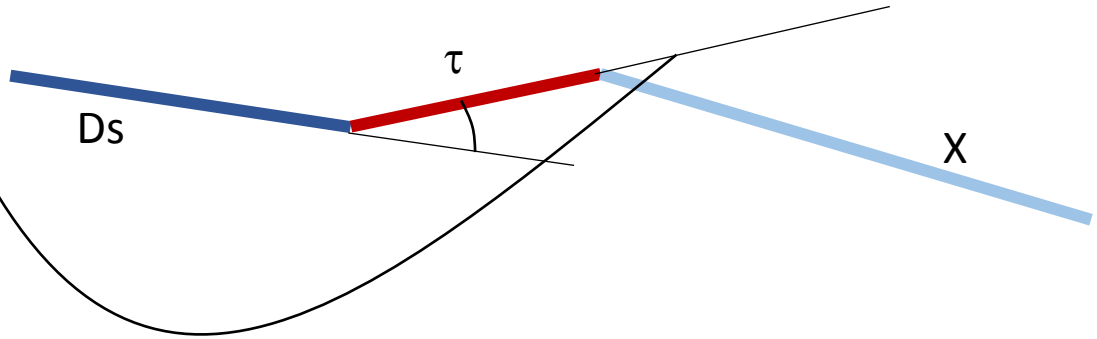
Track density in emulsion: **keep <10^5 tracks/cm^2** at the upstream side

To expose 4.6x10^9 pot → **detector surface 4.6x10^4 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。

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



November 2016 Pilot run

11 modules were exposed to 400GeV Proton beam, CERN H4
called D1 to D11
10 modules 10^5 /cm2 exposed full area
1 module 10^6 /cm2 exposed full area

11/400= about **1/40 scale** of final data of the project.
11/400*1000 = **27.5 detected Ds->tau in 11 modules** .

One module have 2.5 detected Ds->tau events.
One module have 500,000 interaction at tungsten targets.
One module have ~500 interaction with Charm pair

D2 and D5 is under analyzing

Physics motivations

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

2.5 detected Ds->tau events /ECC

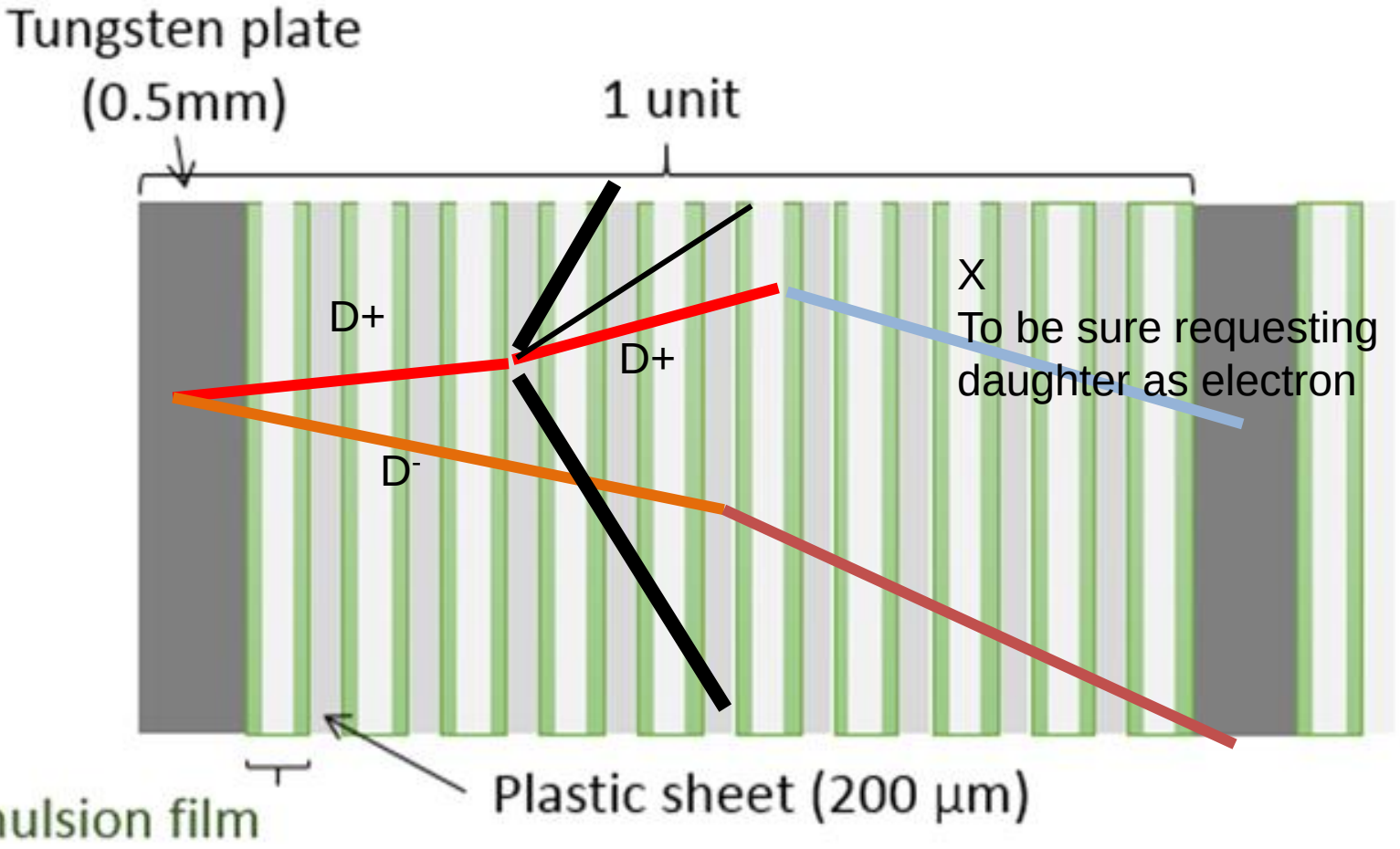
Charm hadron interaction length measurement.
500 ε Charm events /module
λw= 0.005 , λem=0.0055

2.8ε x 2 x η detected Charm interaction/ ECC

4 charms production/event rate in proton interaction
0.6±0.4μb/N Nakazawa Doctor thesis (1987) WA75 350GeV/c π^-
Phys.Lett.B Vol.187 Issues 1-2,19 March 1987, Pages 185-190
"The double associated production of charmed particles
by the interaction of 350 GeV/c π^- mesons with emulsion nuclei"

1.5x 10^{-5} of **σ**(pN)～40mb/N **→(7.5±5.0) ε'/ ECC**

Charmed hadron interaction
Cross section



Detector setup @ CERN H4 beam line

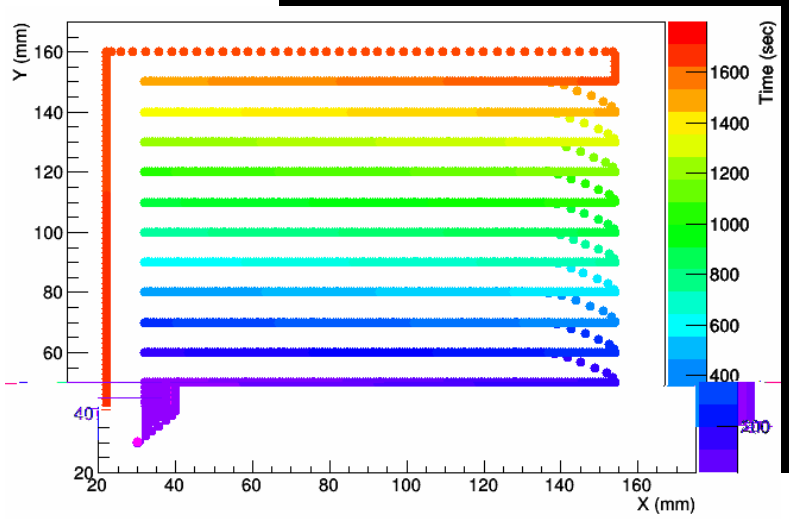
Target mover

ECC

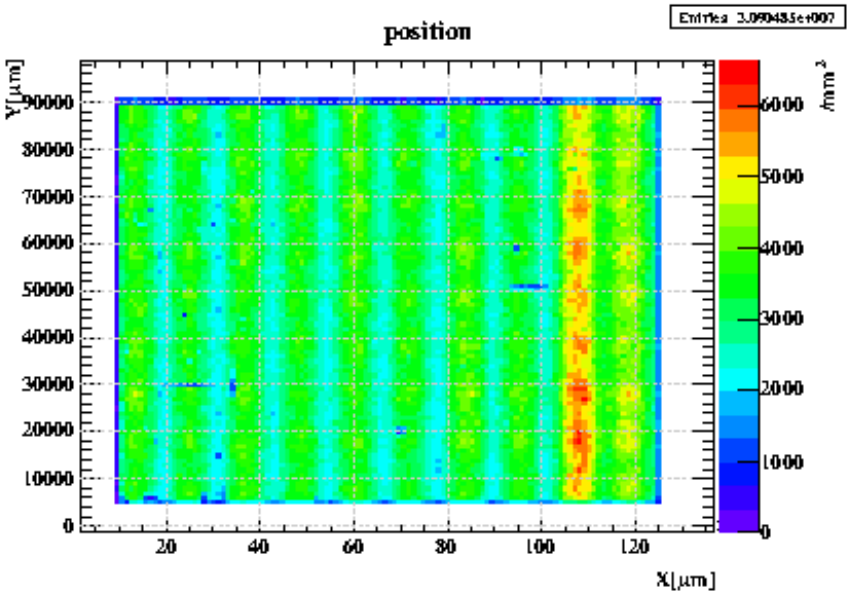
Stage controled
By each spill

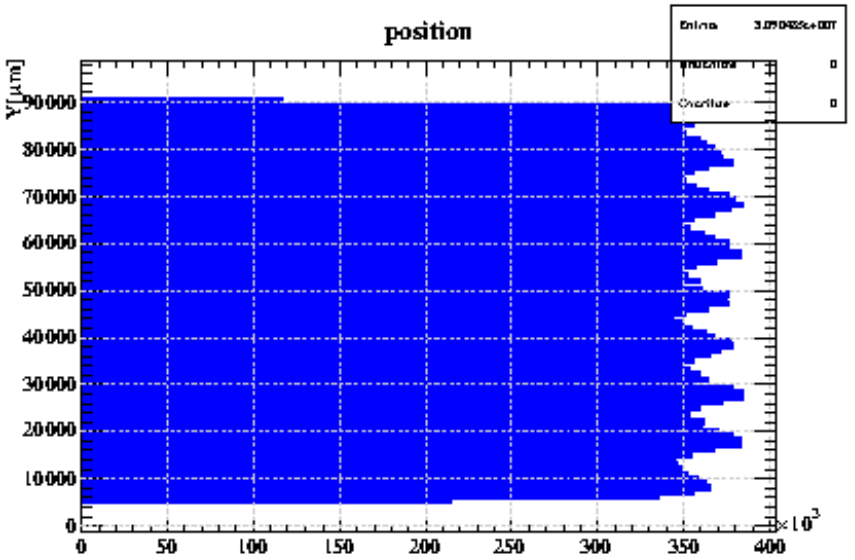
Proton

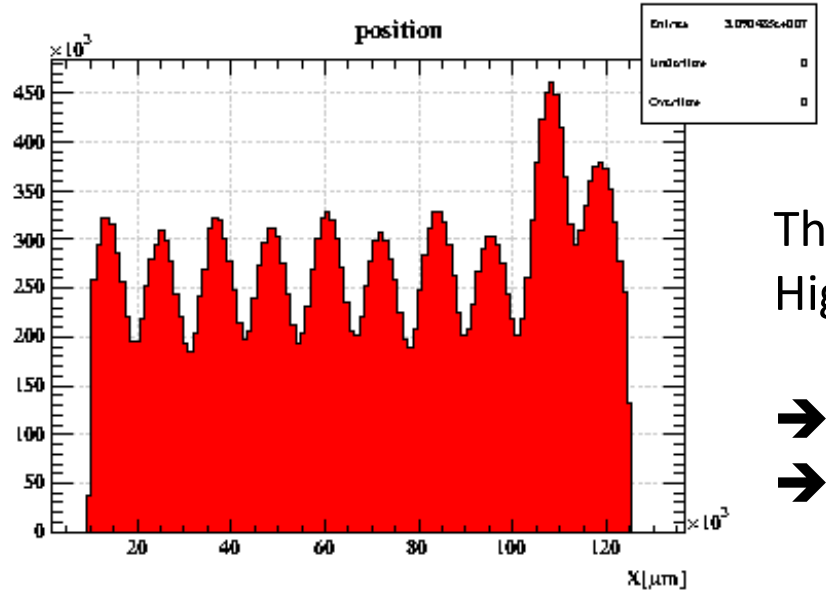
Silicon
detector



Track density distribution

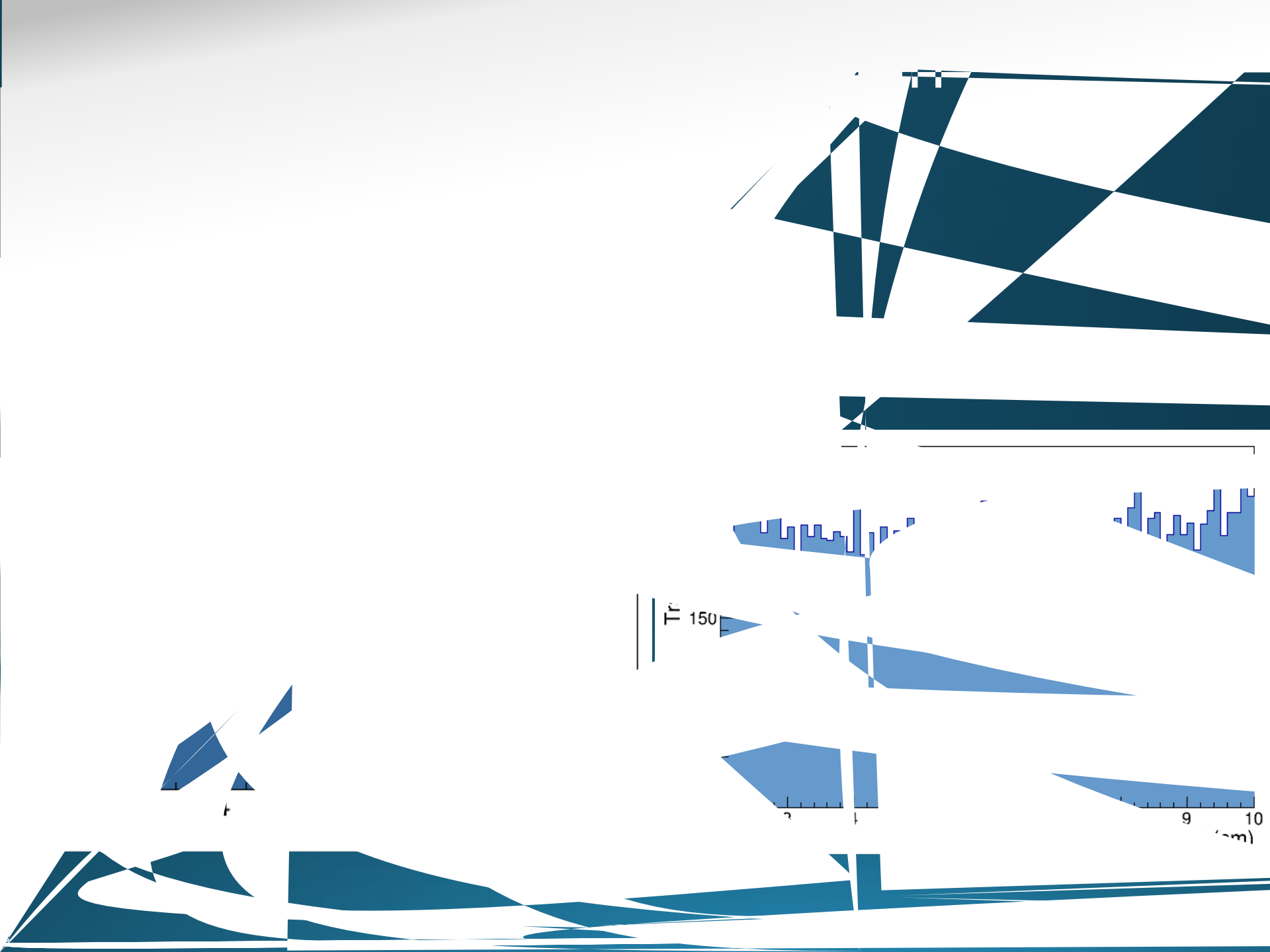




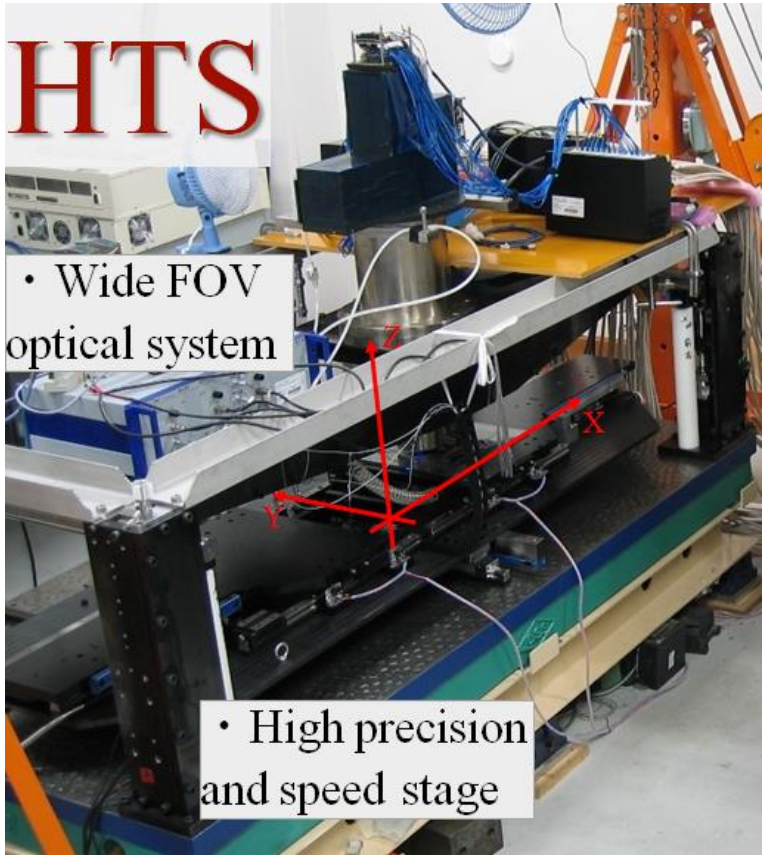


The track density stored in the Emulsion is cyclic
Higher track density make the event analysis dif

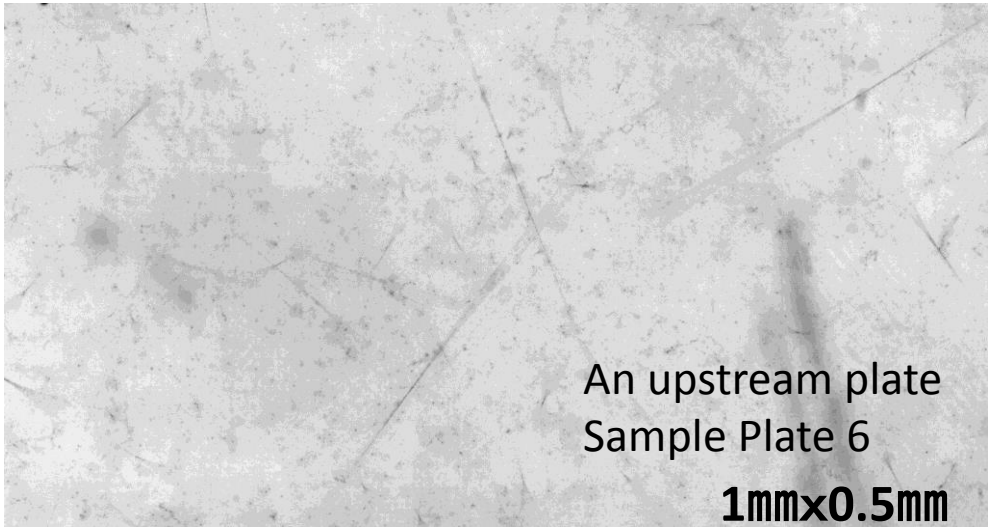
➔ Tried to uniform
➔ The problem was time profile of a spill.


150
9
10

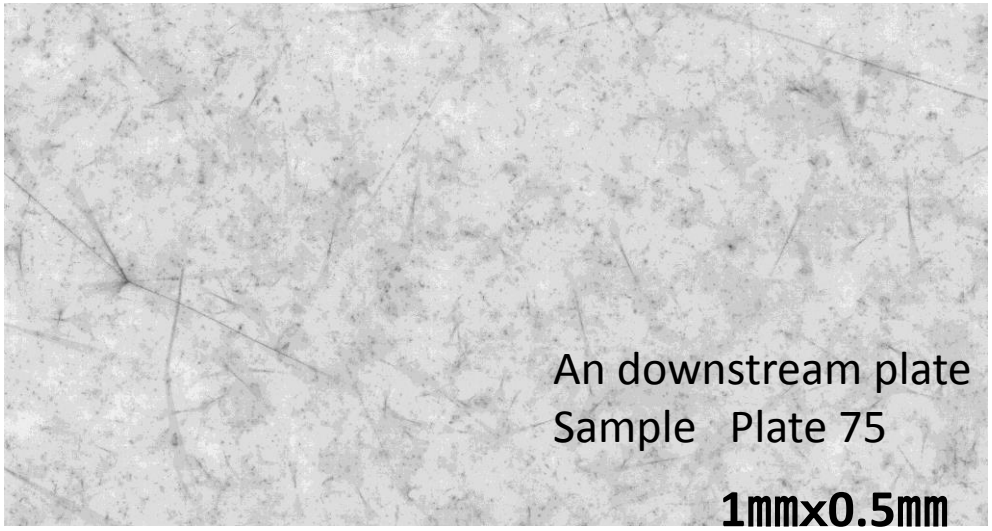
A microscope view data of the films



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



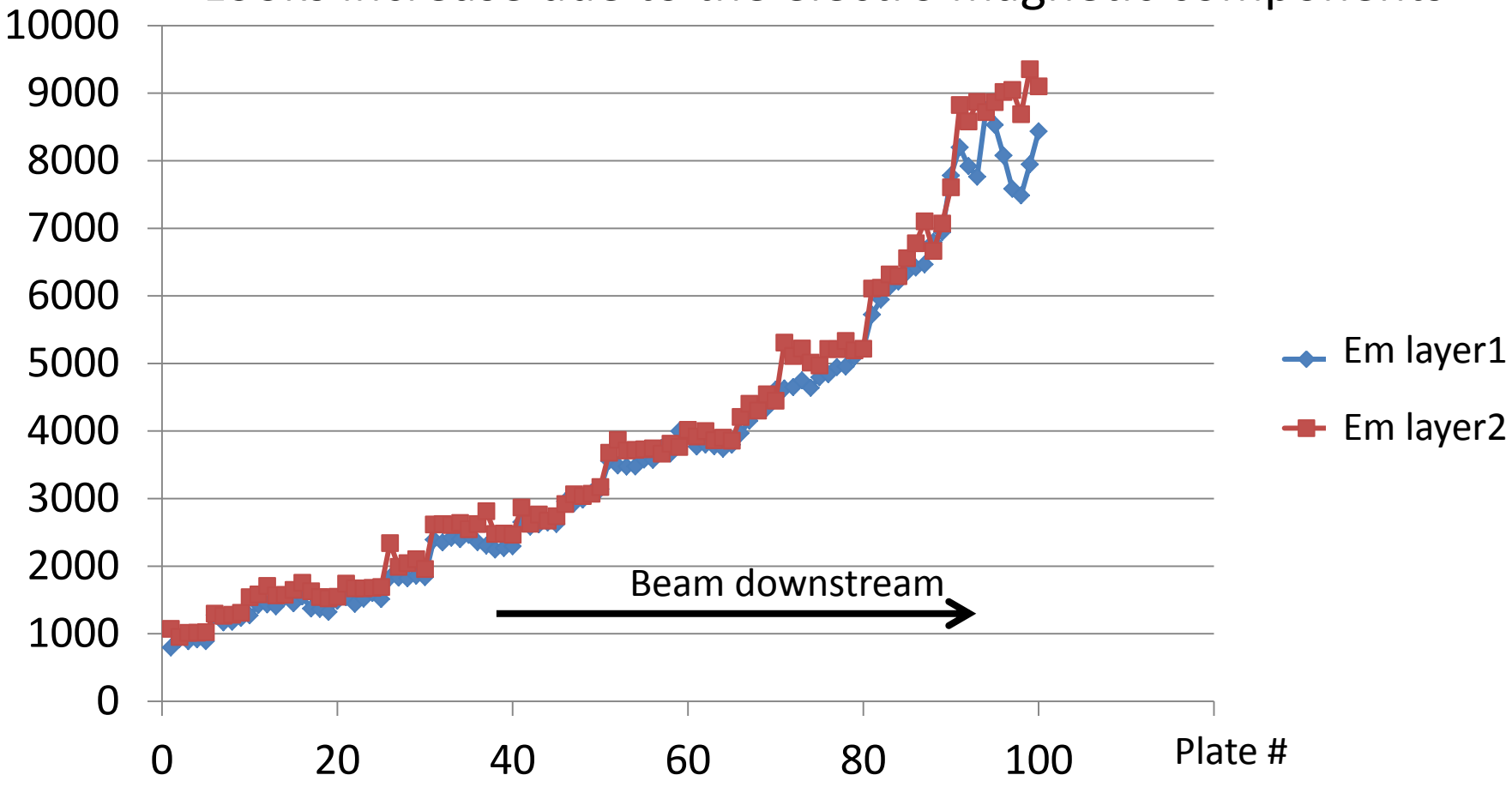
Getting dirty



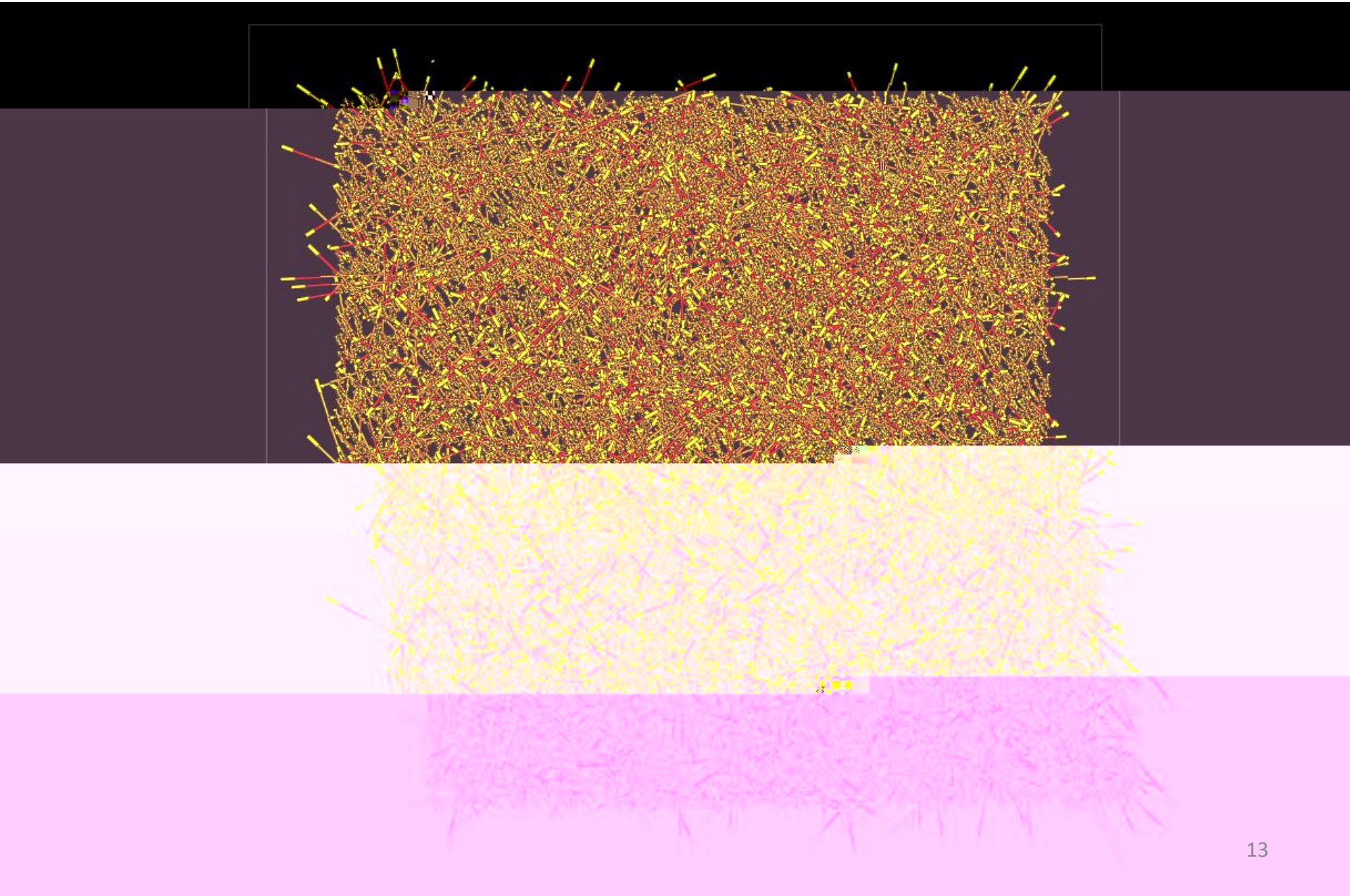
Track density per a view(raw data)

Material of 1ECC (100Pl) 0.124 λi 1.90 X_0

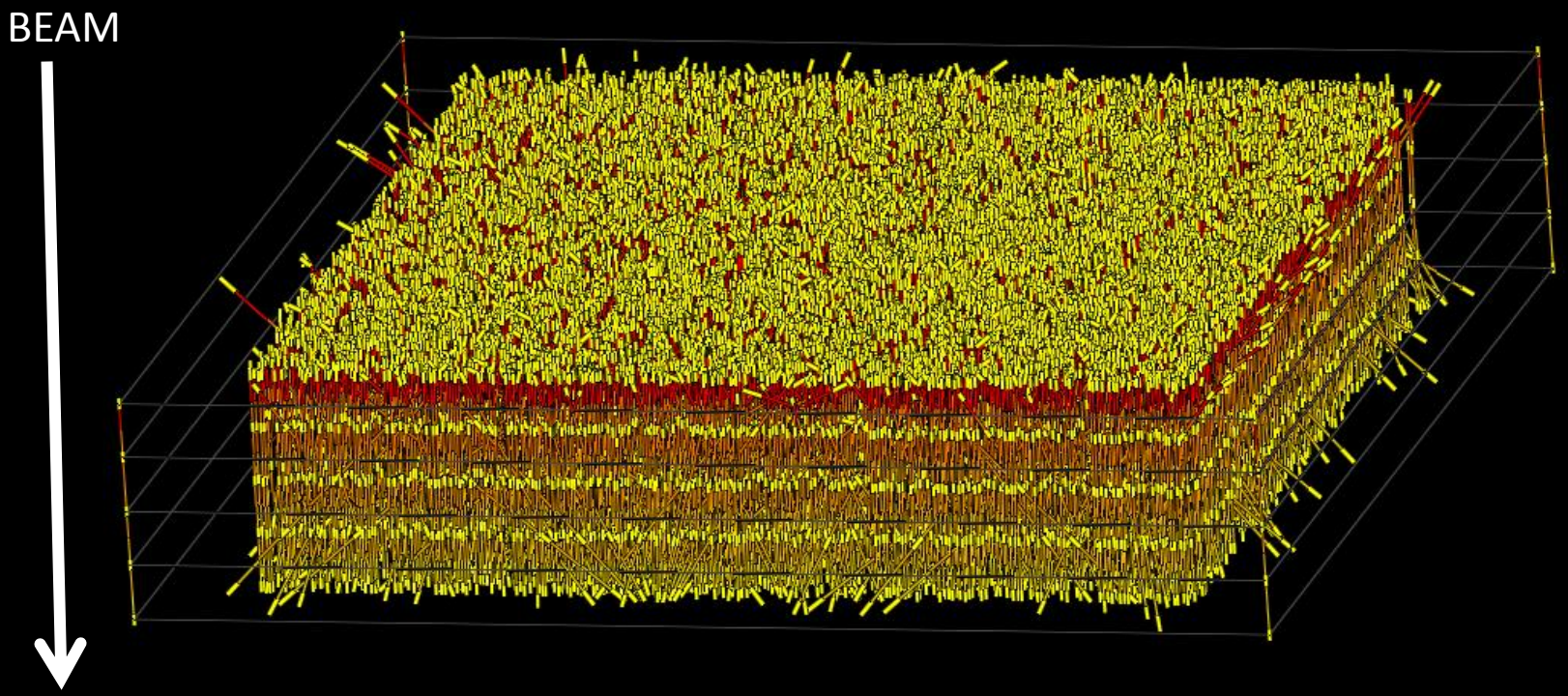
Looks increase due to the electro magnetic components



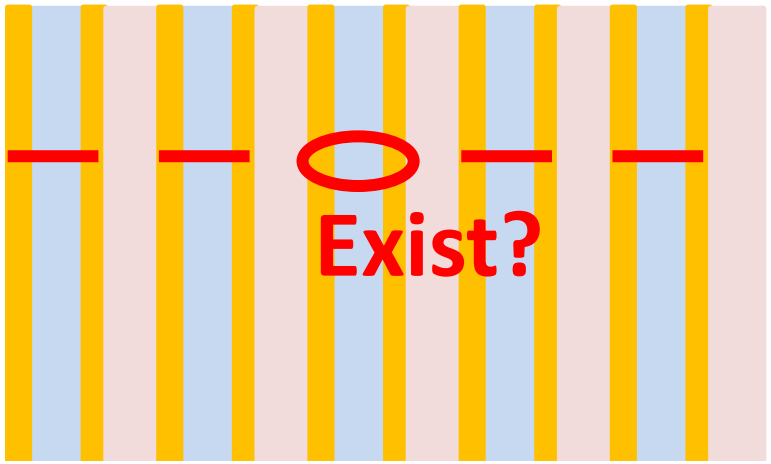
M-file 2.5mm x 2.5mm Z-view pl11-15



M-file 2.5mm x 2.5mm tilted view pl11-15

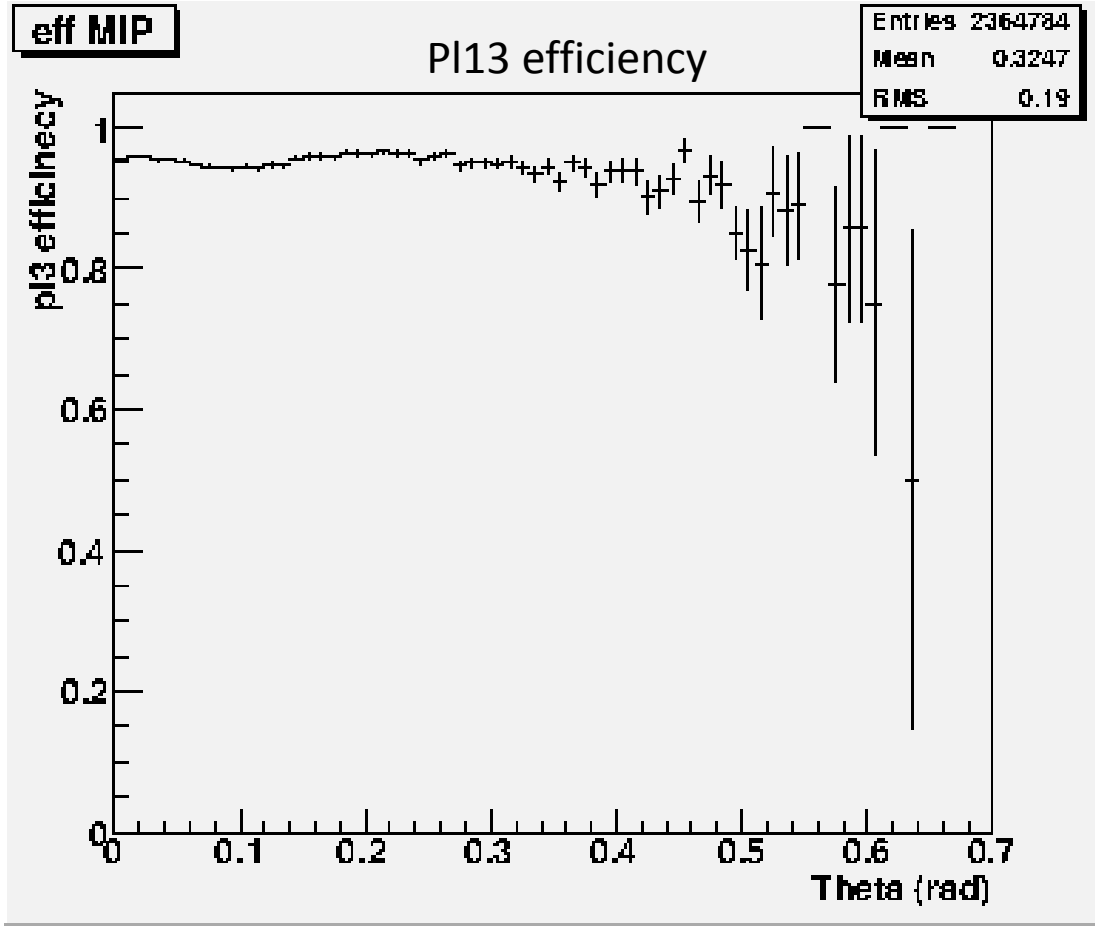


Base track efficiency evaluation using m-file

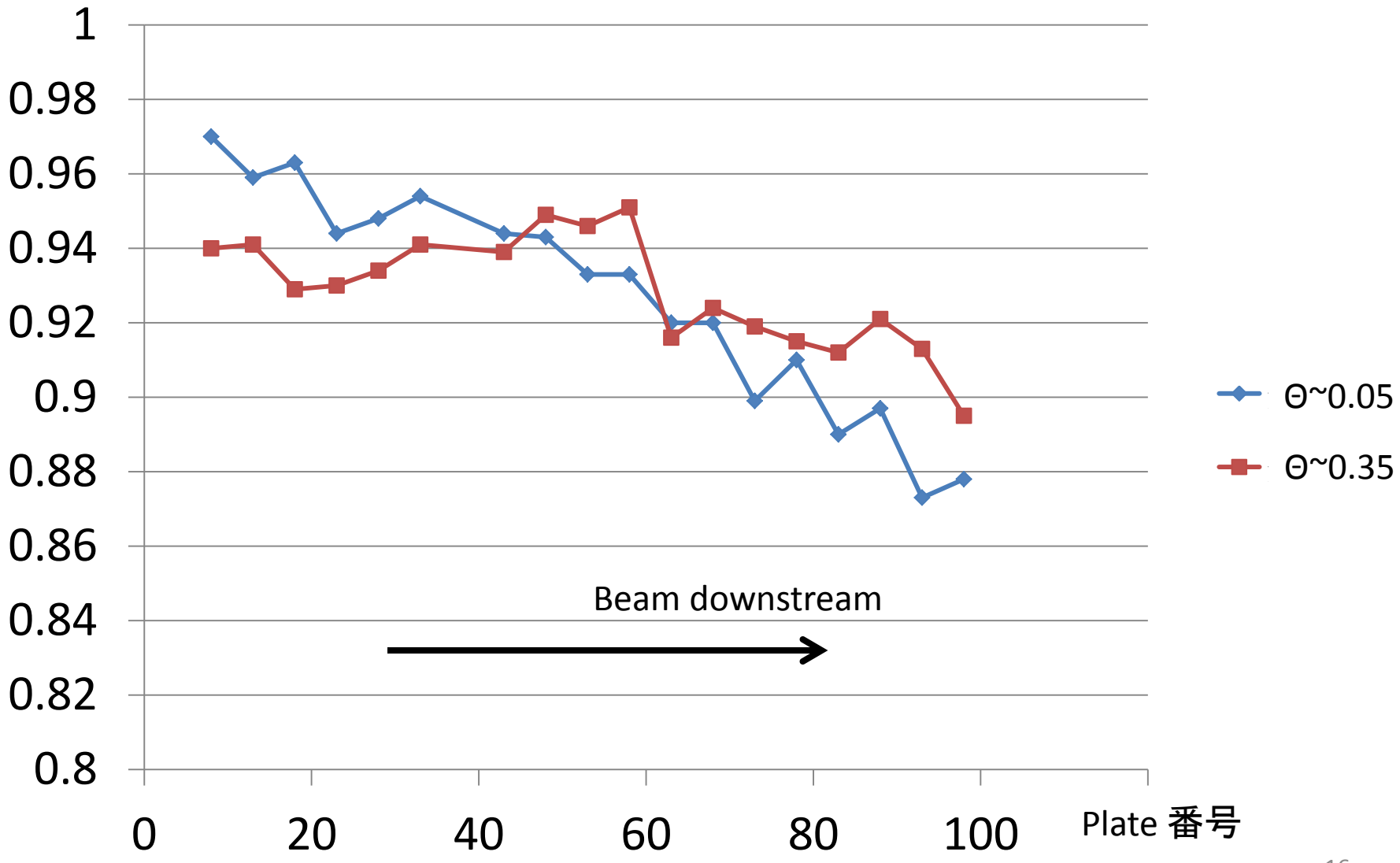


Test track were selected by
$\sqrt{rms\_ax^2+rms\_ay^2} < 3$ mrad
using 4 plates excluding test plate.

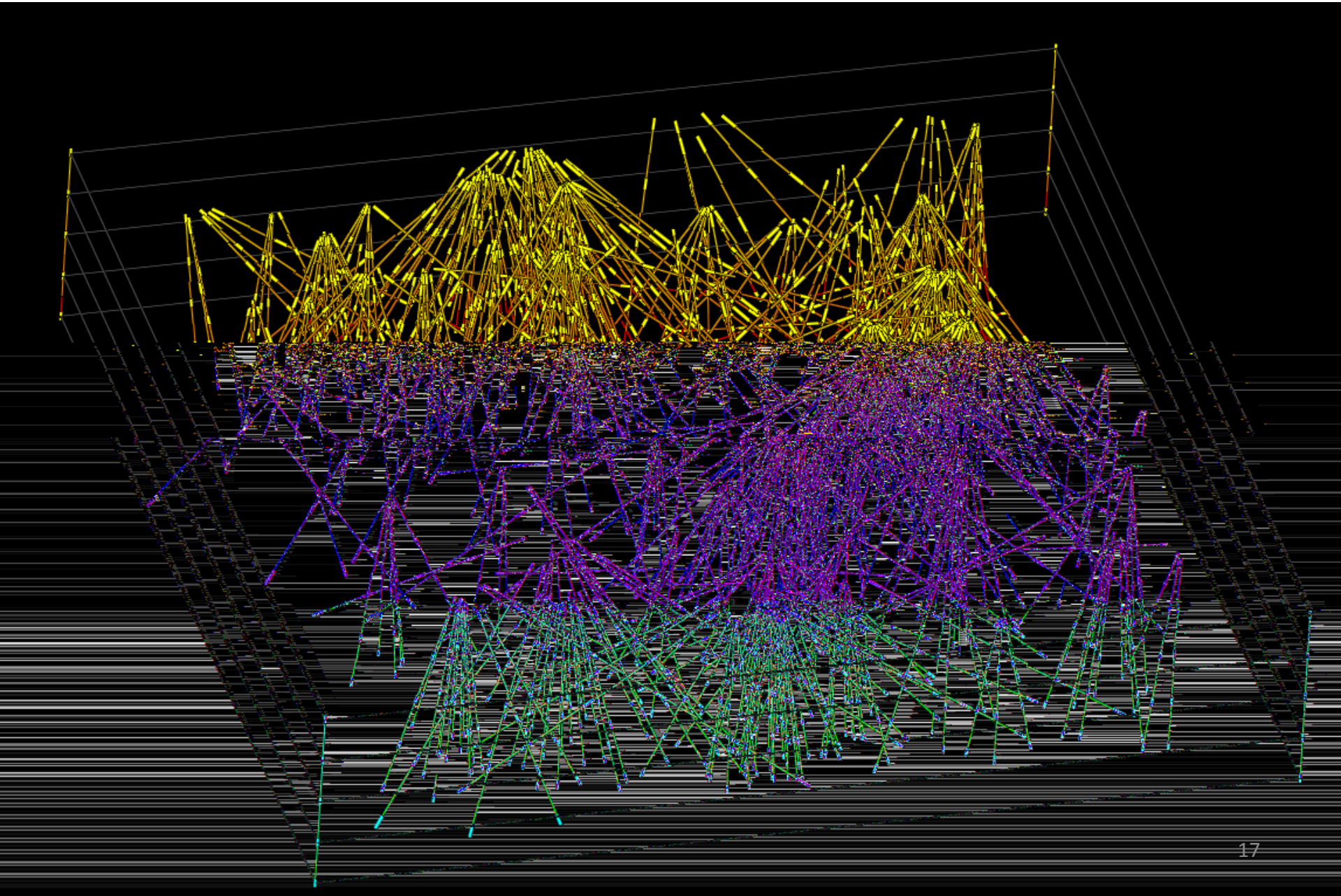
fiducial volume cut
2cm < x < 10cm && 2cm < y < 7cm



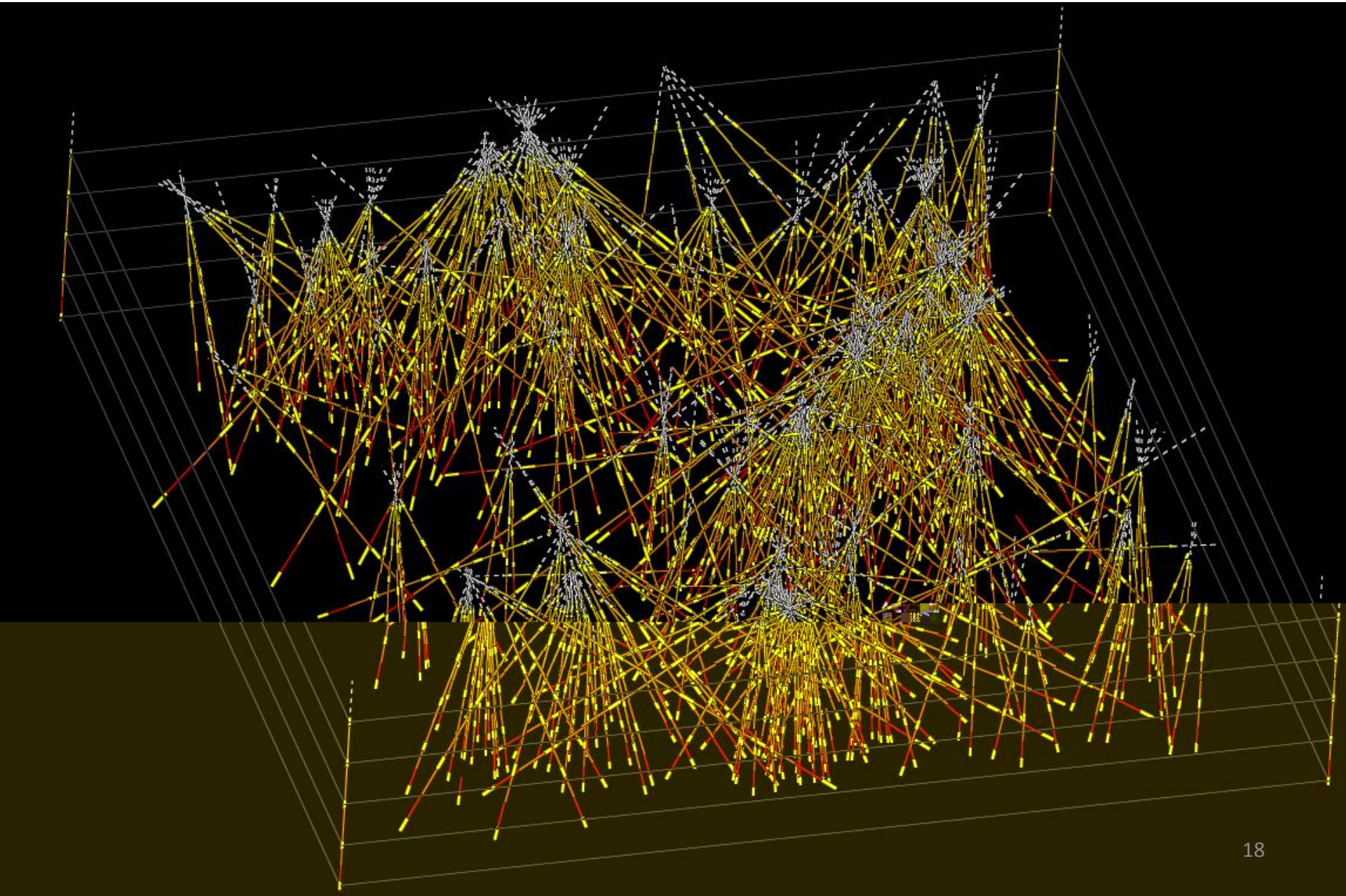
The efficiency in one plate



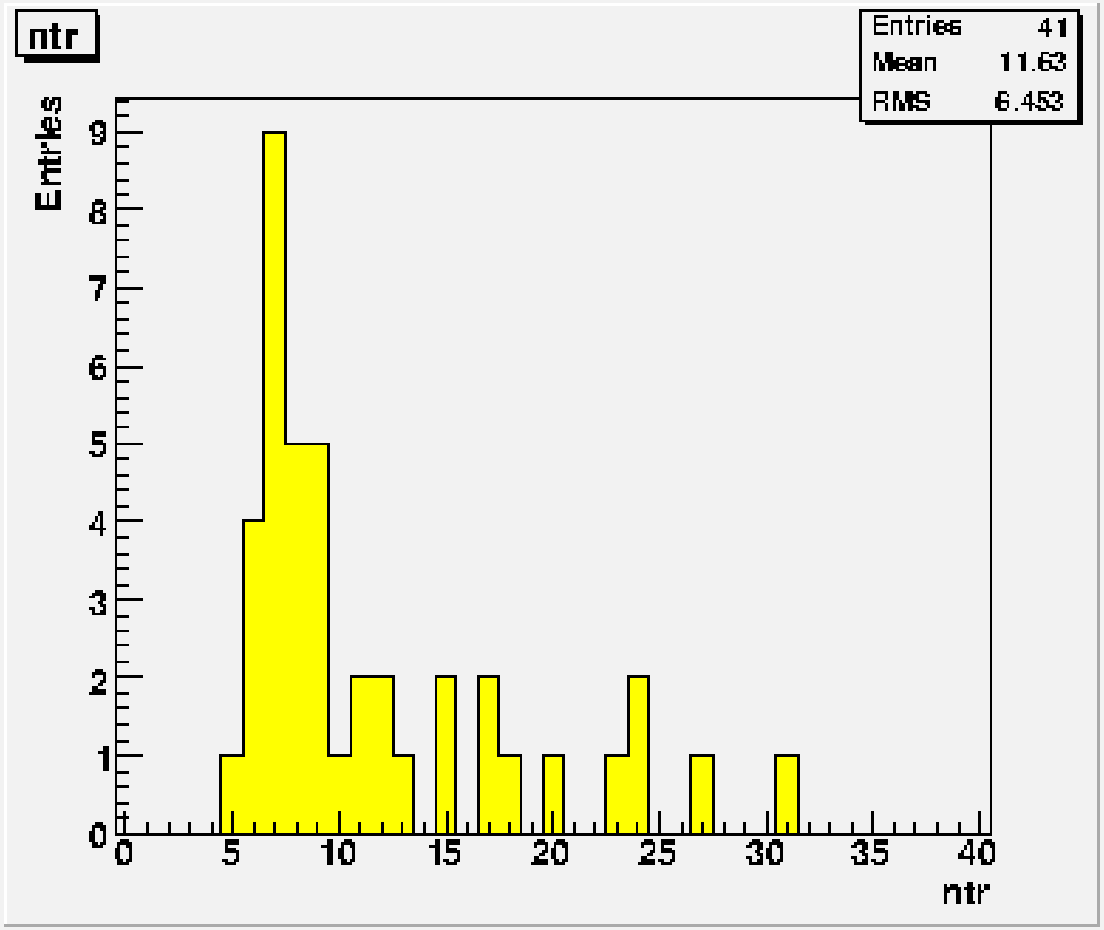
Vertices in 2.5mm x 2.5mm pl11-15



Vertices in 2.5mm x 2.5mm pl11-15



Track multiplicity



15plates data
Display eye check in a few mm² D

① Track produced in just after tungste
Penetrating 10 plates

（Start from Pl11 or pl12
to pl19 or pl20, Nseg>=8）

② no track segment in upstream than

Vertex track multiplictiy

Av. 11.63 track

Less than 5 was omitted

Summary

The goal of the DsTau project is the reduction of the uncertainty on tau neutrino production by precise measurement of the Ds->tau with 1,000 Ds->tau.

Accumulating large amount of charm pair associating events and it make possible to measure the hadronic interaction cross section with charmed particle.

About **1000xε events** of charmed interactions would be expected to detect,

As much as possible the beam density in the ECC for saving cost. While it make difficult to analyze with higher track density in the ECC.

Test beam exposure performed in 2016、2017

In 2016 a pilot run and improvement on uniformity of track density in 2017 test bem.

Now analyzing **ECCs exposed with $10^5/cm^2$ track density .**

The raw data amount increase by 8-9 times at most downstream films .

Currently **1＋1/ ECCs data taken have been finished.**

The tracking efficiency keep more than 90% even in most down stream films.

Fake track reduction is under study. **Charm pair events will be searched with the clean data.**

In 2018, 1st Physics run willl collect 3-4 times of events than pilot run done in 2016.

Backup

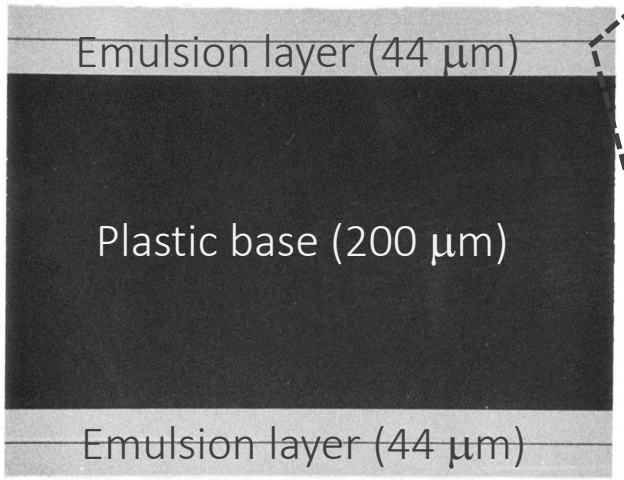
Emulsion detectors: highest position resolution

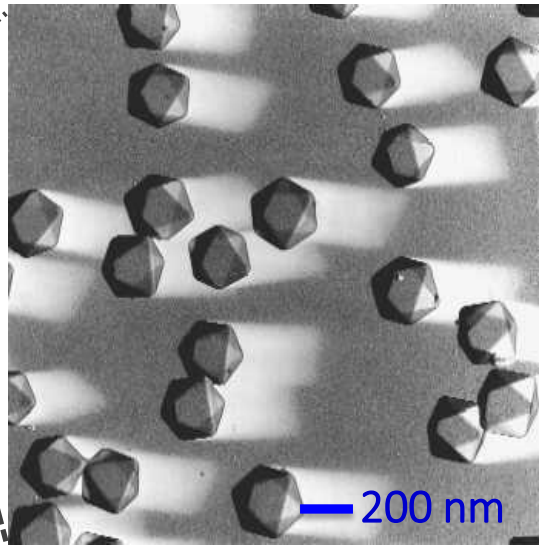
AgBr crystal

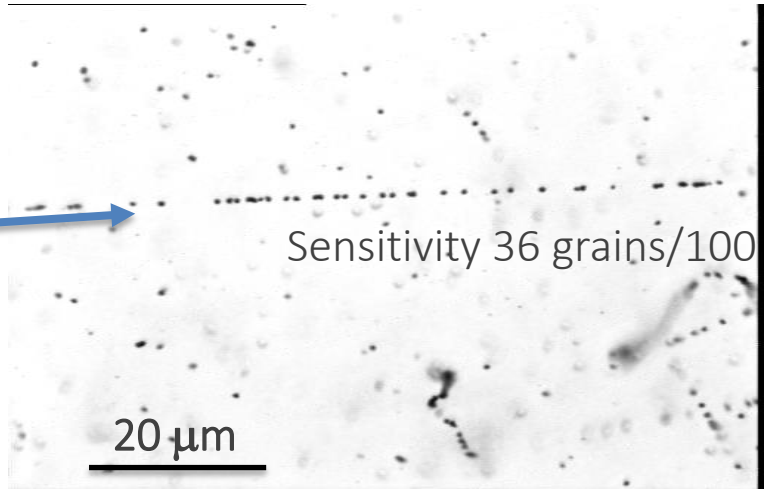
10^{14} crystals in a film

Emulsion film

Cross-sectional view





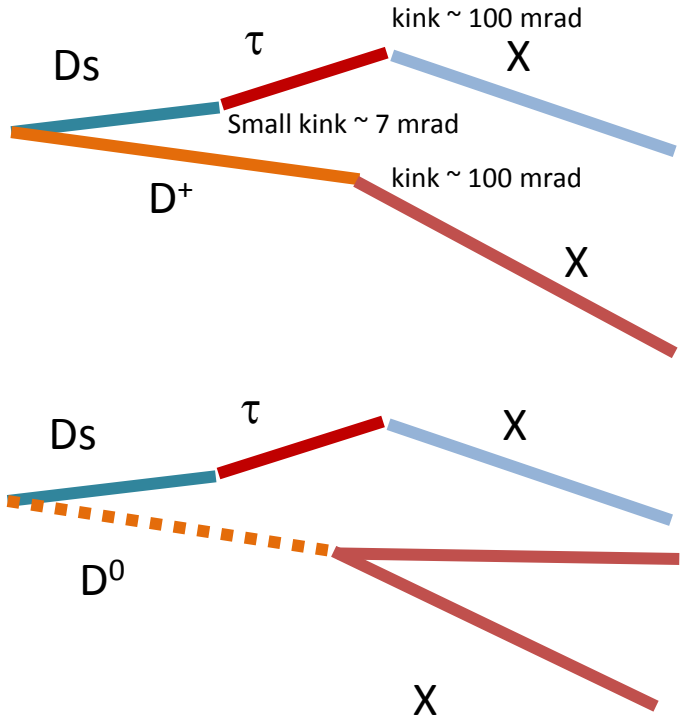


10GeV/c π beam

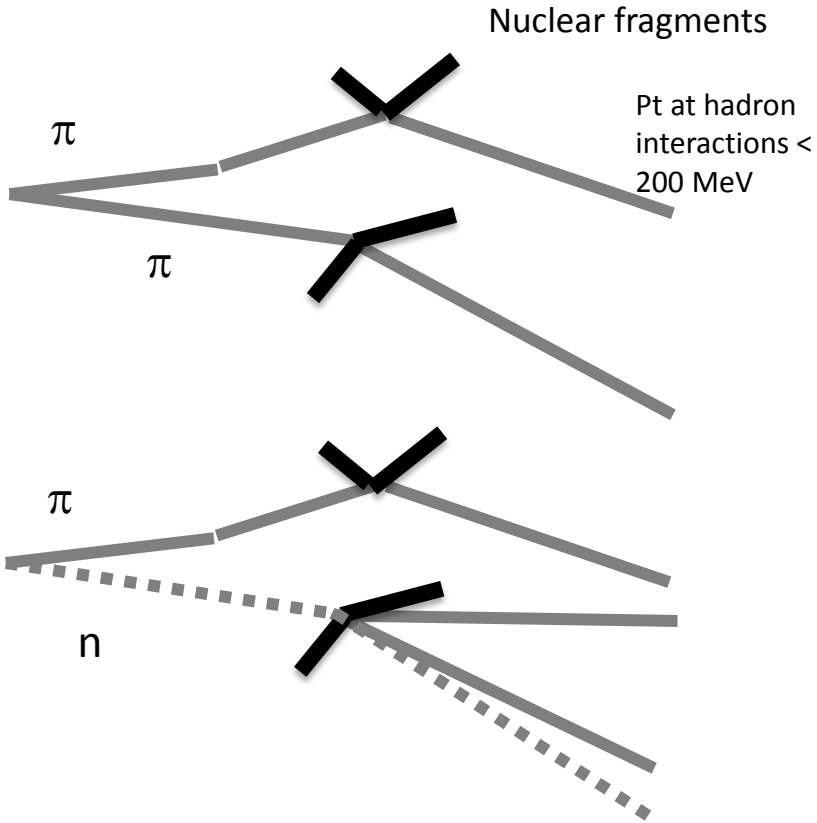
3D tracking device

Signal and background

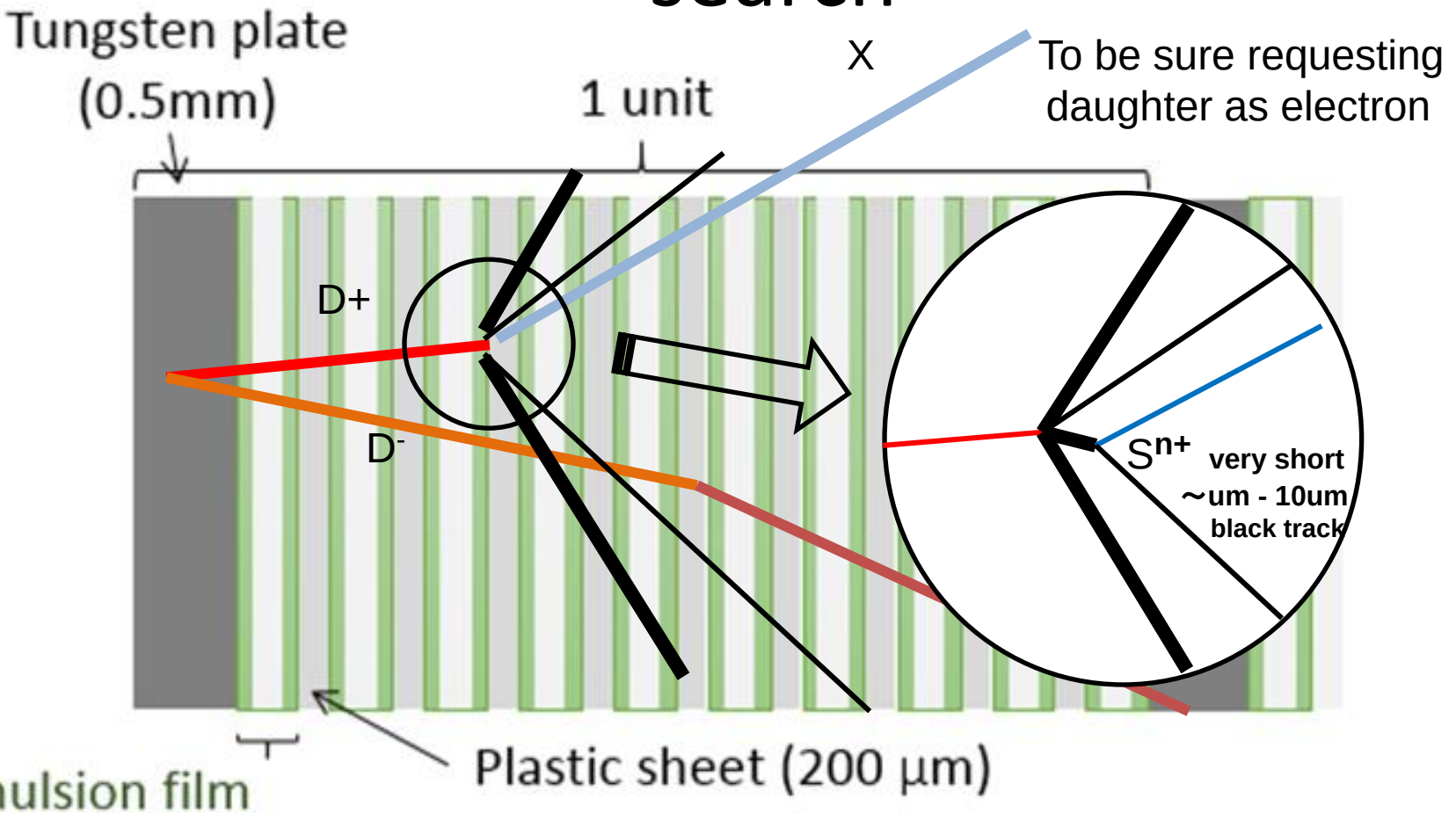
Signal = a double kink + a charmed particle decay



Background = hadron interactions



Charmed hadron interaction at emulsion Super fragment (charmed hyper nucleus) search



Magic momentum to produce Λ^+_c at rest

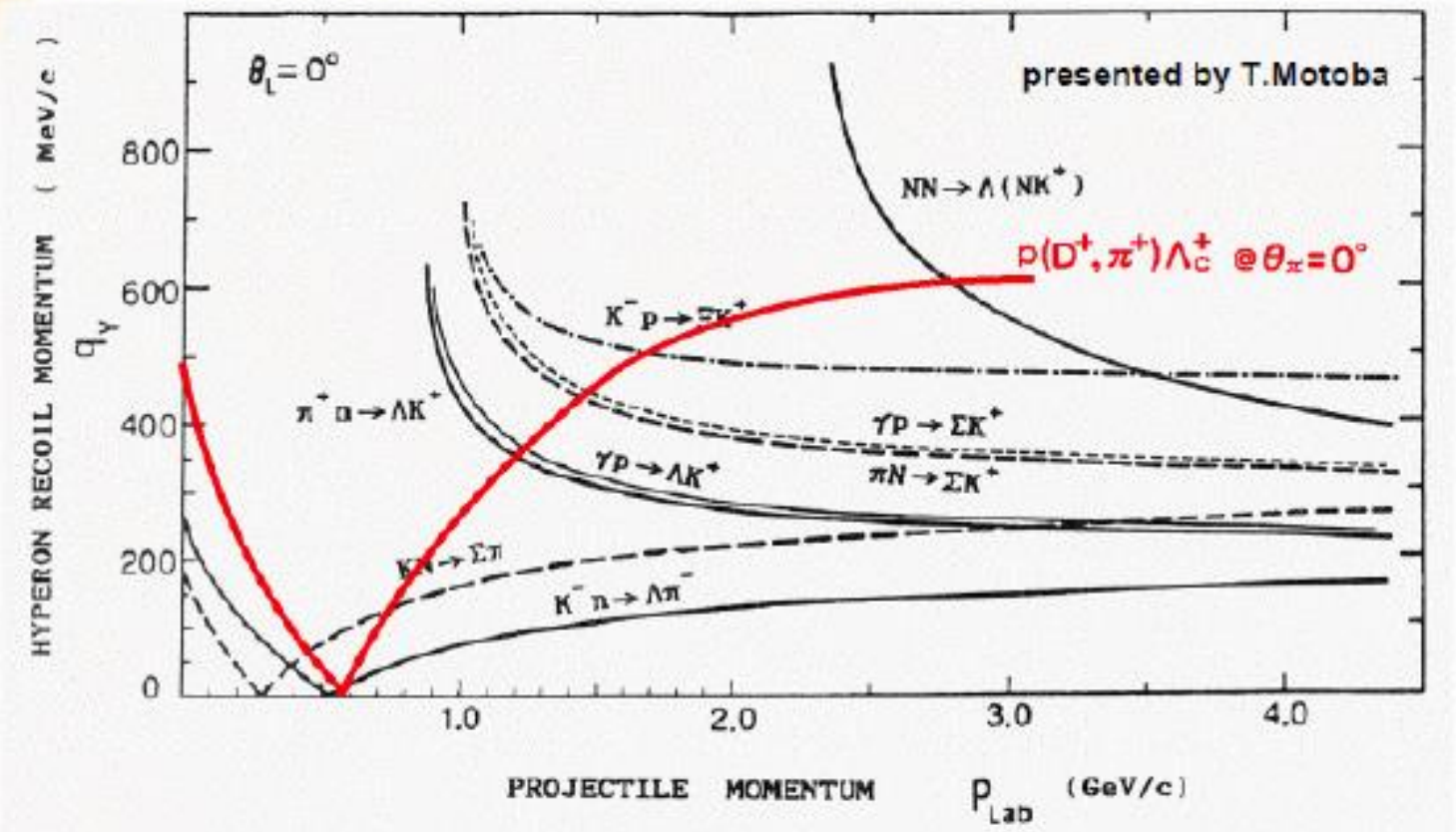


Fig. 2.3. The momentum q_Y transferred to the hyperon Y as a function of the projectile momentum $p_{proj} = p_a$ in the reaction $aN \to Yb$ at $\theta_{b,L} = 0°$.

Using ν_μ beam, measure $\sigma_{Int.}$ of $D^{+/-}$ to *p* & *n*.

Dec.24,2004 Few Body 仲澤さんのファイルより

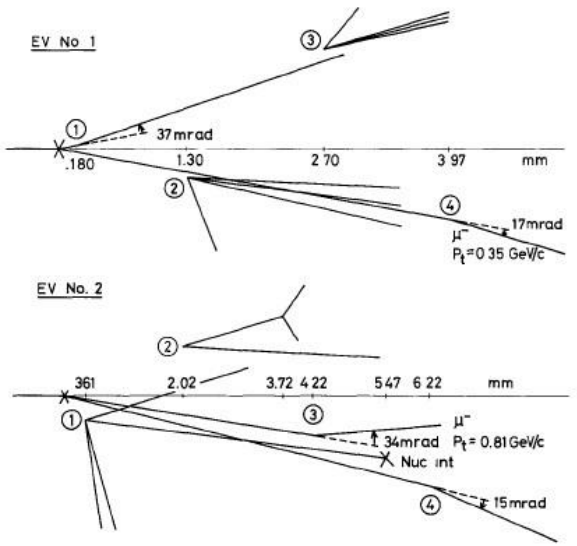


Fig. 1. Sketches of the events

Table 1
Geometrical and kinematical data of the four charmed particle events.

EV	(VT) [a]	Particle	Production [b]		L (mm)	Decay [b]		VD/R [c]	ID [d]	Notes [e]
			α (mr)	δ (mr)		α (mr)	δ (mr)			
1	(1)	$D^{\pm}$	22	11	0.180	16	47	0.3		$p\beta > 2.6$ GeV/c
	(2)	$D^0/\bar{D}^0$	−71	−28	1.30	81	−19	0.4		$p\beta = (1.5^{+1.9}_{-0.3})$ GeV/c
						−211	−7	–		$p\beta = (1.7^{+1.3}_{-0.4})$ GeV/c
						−163	−32	0.3		$p\beta = (2.0^{+3.2}_{-0.6})$ GeV/c
						−294	−400	–	π/μ	$p\beta = (0.12^{+0.4}_{-0.1})$ GeV/c
										$I/I_0 = 1.23^{+0.16}_{-0.14}$
	(3)	$D^0/\bar{D}^0$	12	50	2.70	43	39	0.3		$p\beta > 4.2$ GeV/c
						37	40	0.2		$p\beta > 4.7$ GeV/c
						101	152	0.8		$p\beta > 5.4$ GeV/c
						−40	39	1.5		$p\beta > 3.9$ GeV/c
	(4)	D^-	12	−24	3.97	24	−37	1.1	μ^-	$p = 20.5$ GeV/c
2	(1)	$D^0/\bar{D}^0$	−91	39	0.361	29	64	0.1		$p\beta > 2.6$ GeV/c
						−9	53	–		Nucl. int. at 5.11 mm
						−543	−73	–		$p\beta = (0.7^{+0.7}_{-0.3})$ GeV/c
						−335	34	–		$p\beta = (0.7^{+0.8}_{-0.4})$ GeV/c
	(2)	$D^0/\bar{D}^0$	34	−27	2.02	−4	−10	1.1		$p\beta > 6.3$ GeV/c
						27	−117	–	f)	$p\beta = (0.2^{+0.3}_{-0.1})$ GeV/c
	(3)	D^-	−12	−27	4.22	8	−55	0.3	μ^-	$p = 23.6$ GeV/c
	(4)	$D^{\pm}$	−20	−9	6.22	−34	−2	0.4		$p\beta > 4.6$ GeV/c

[a] VT: decay vertex number. See fig. 1.
[b] α,δ: projection angles with respect to the beam.
[c] VD/R: matching with VD track; $R = \Delta\theta/\sigma\theta$.
[d] ID: particle identification.
μ^-: measured in the spectrometer.
[e] $p\beta$: measured in emulsion (multiple scattering).
I/I_0: relative ionization in emulsion.
[f] Probable electron: gives rise to a knock-on electron after 1.70mm.

4 charms events at WA75 (2 Events)

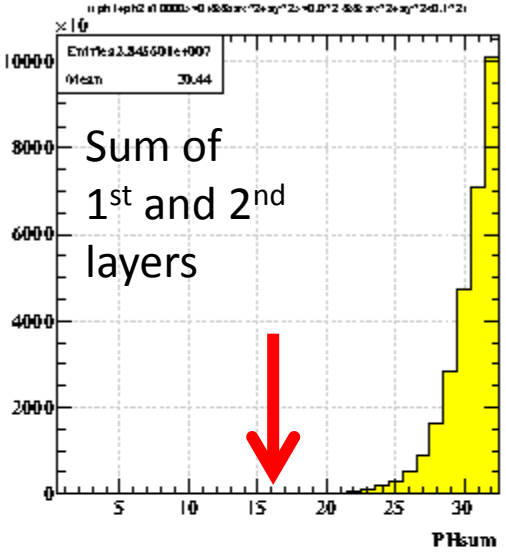
Phys.Lett.B Vol.187 Issues 1-2, 19 March 1987, Pages 185-190

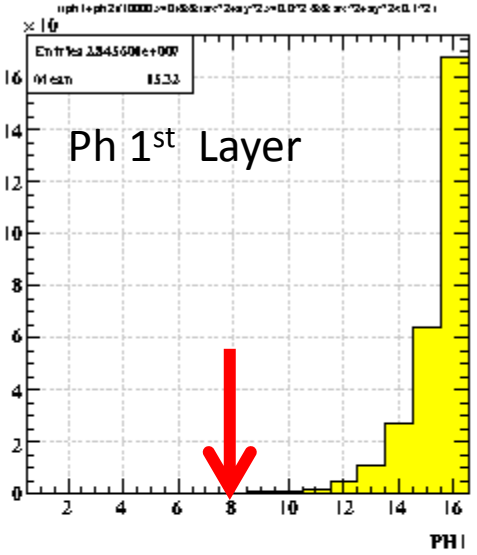
WA75
350 GeV/c π-

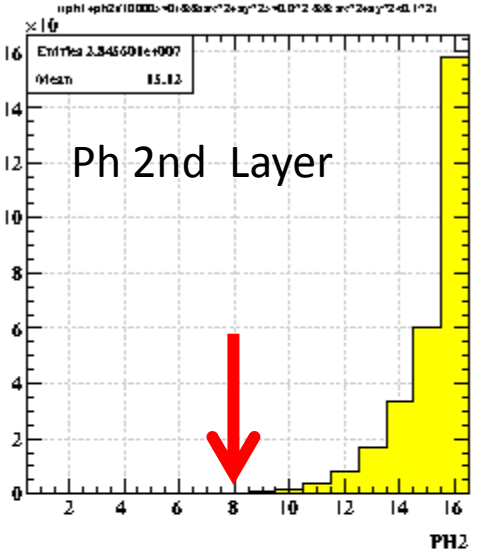
The beam energy is close to DsTau
400 GeV/c proton

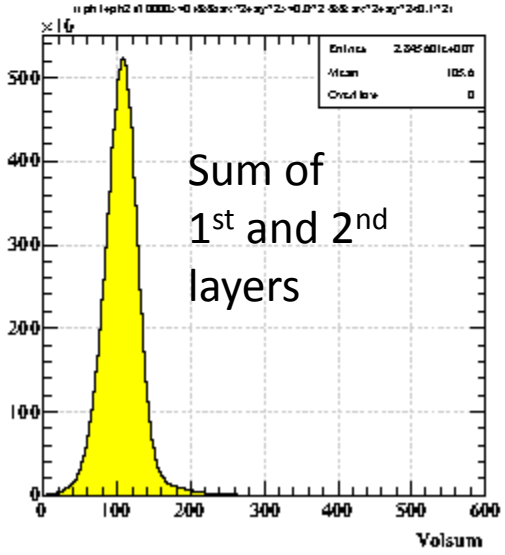
So the slopes and energy of charms and daughters should be similar.

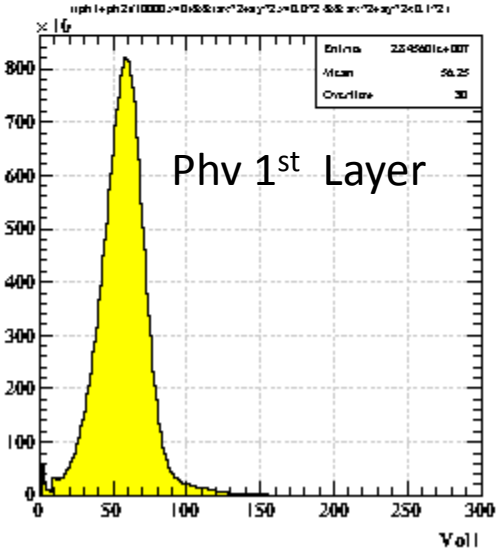
Pulse height angle in (0.0,0.1) **pl13**

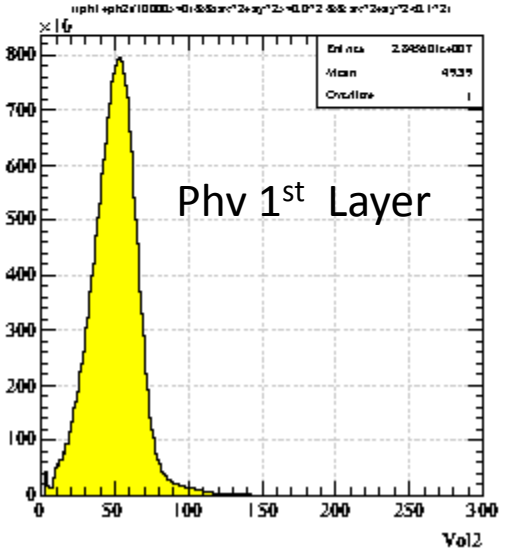




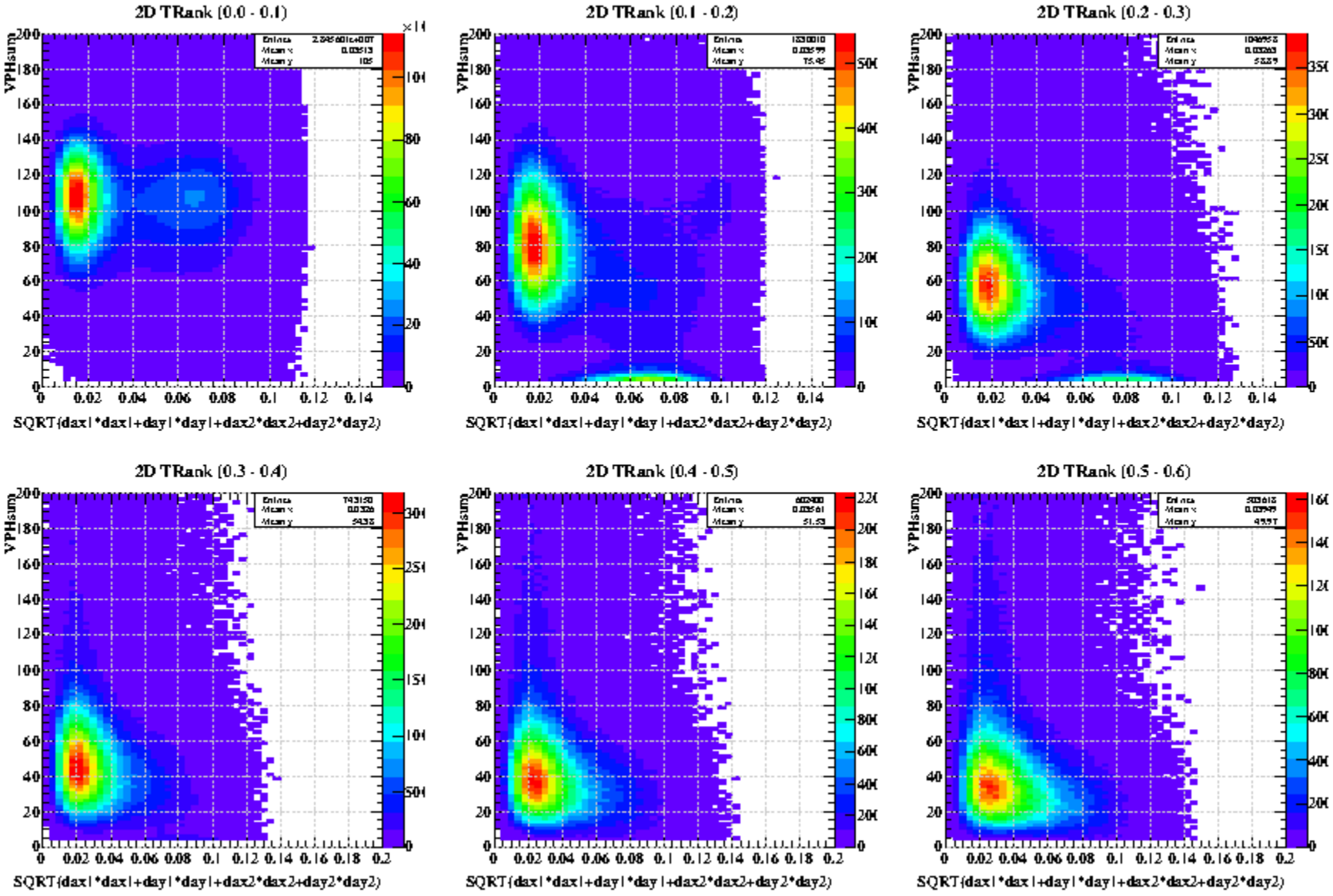




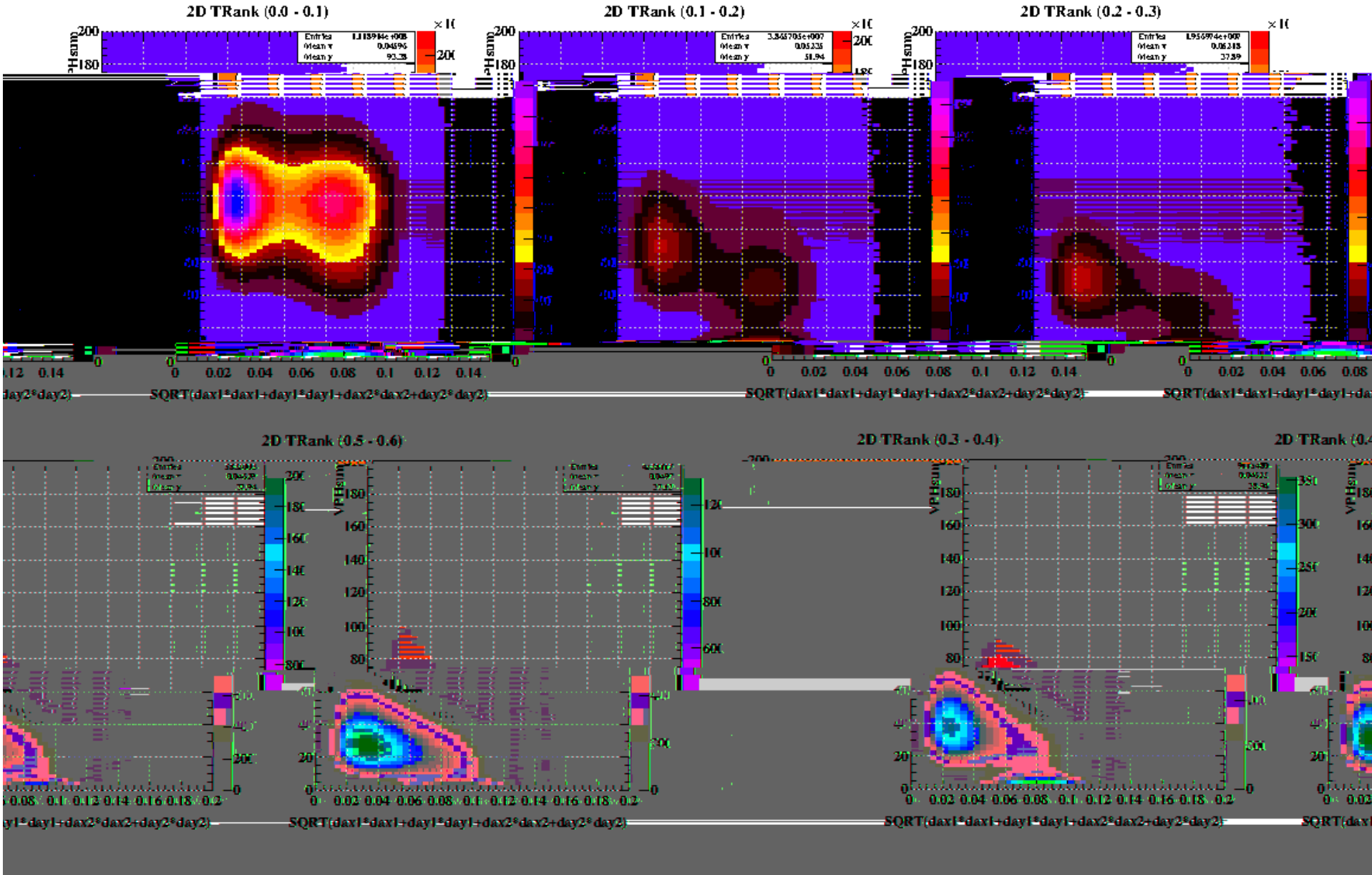




Angle difference vs. Pulse height Volume **pl13**



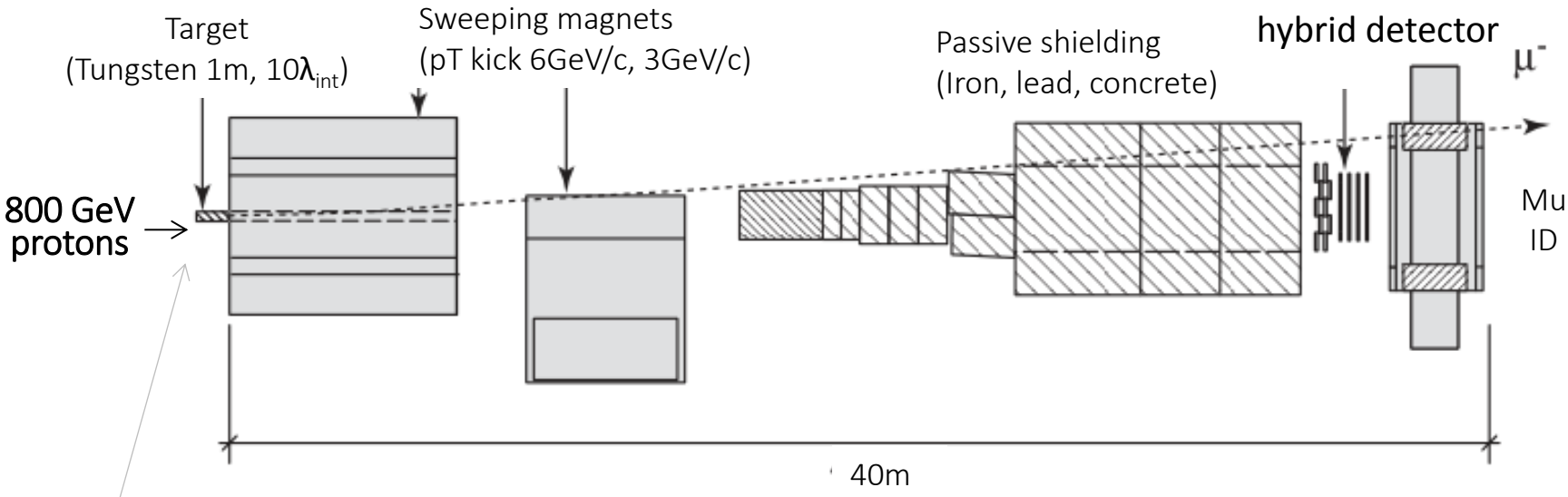
Angle difference vs. Pulse height Volume **pl97**



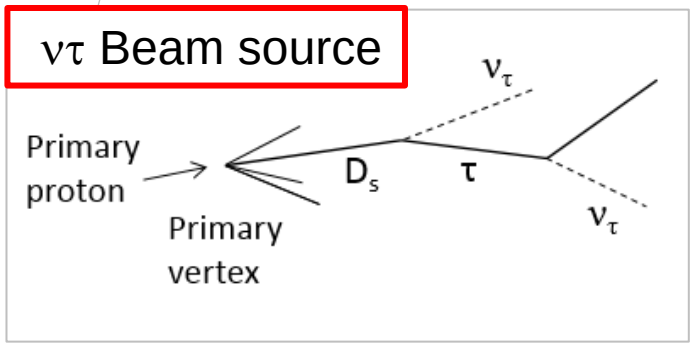
Neutrino beam line in DONuT

$\nu\tau$ detector

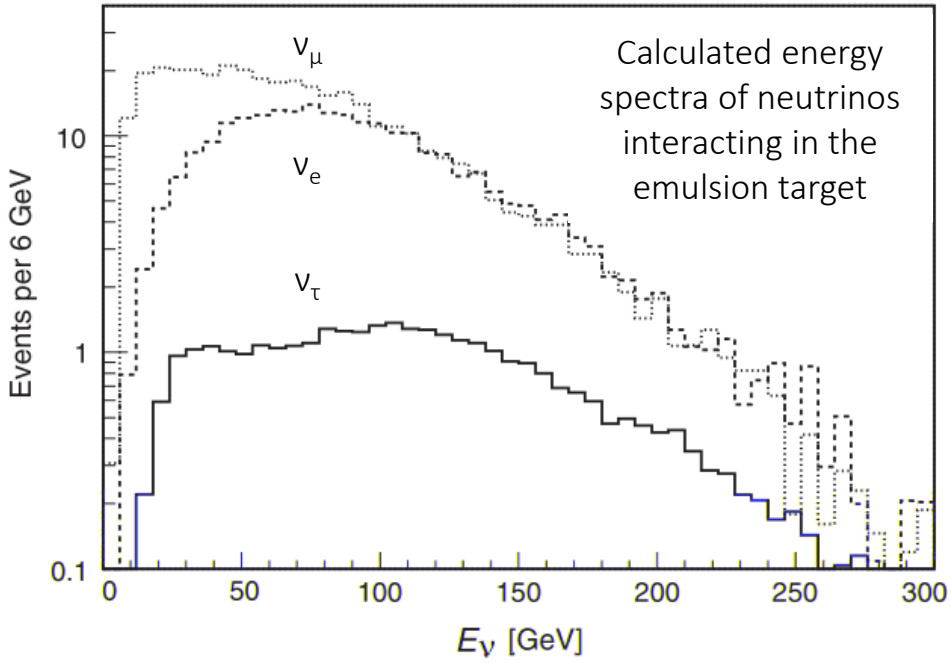
Emulsion + SFT
hybrid detector



$\nu\tau$ Beam source

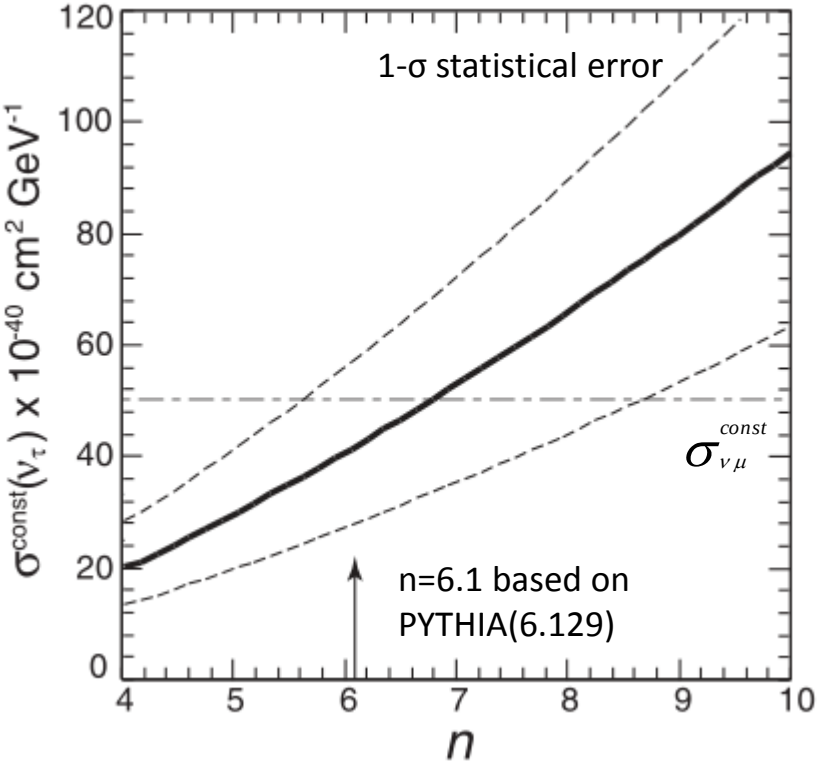


	Main source
ν_e	D^0 , $D^{\pm}$, D_s , Λ_c
ν_μ	D^0 , $D^{\pm}$, D_s , Λ_c , π, K
ν_τ	D_s



Results from DONuT (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 !

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

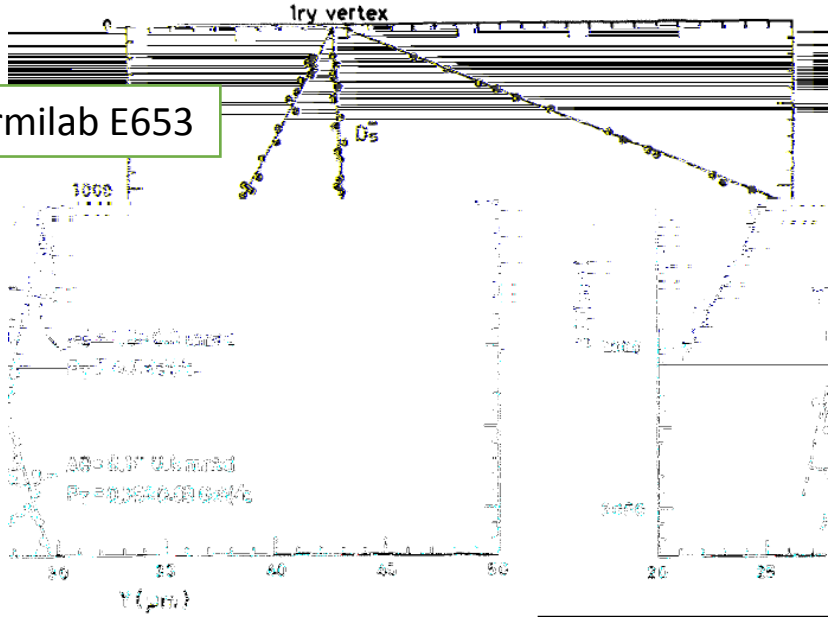
D_s production cross section in Tungsten target

~8.5×10^{-4} @800GeV → ~4×10^{-4} @400GeV

→ 2.3×10^8 proton interactions to be analyzed!

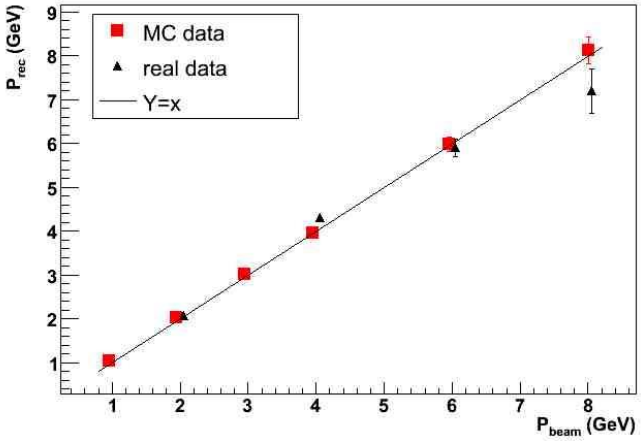
↔ only 10^5 proton interactions were analyzed in emulsions in E653 (previous exp.)

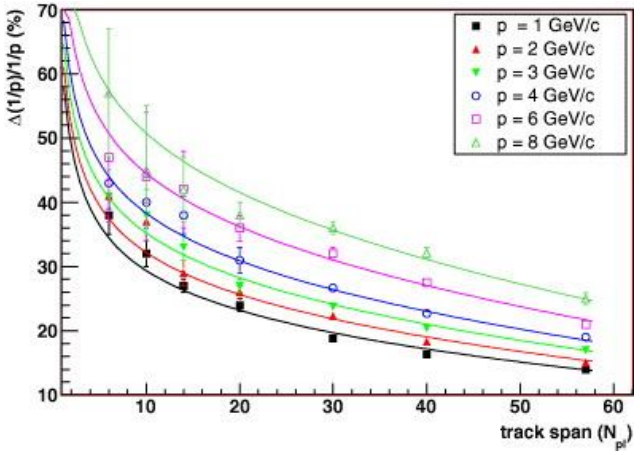
$D_s \rightarrow \tau \rightarrow \mu$ candidate found in Fermilab E653



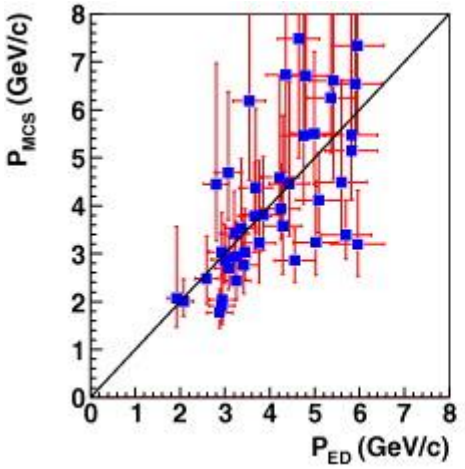
Momentum measurement through multiple Coulomb scattering

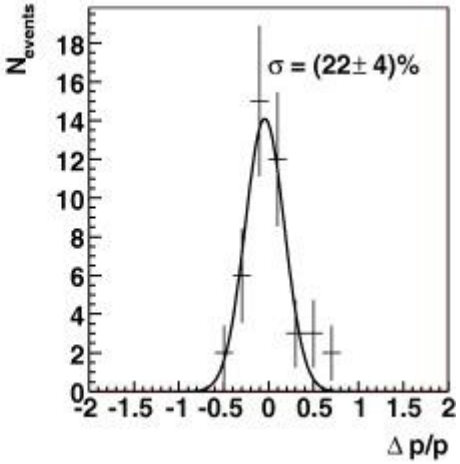
π test beam





Muon momenta measured by MCS in OPERA

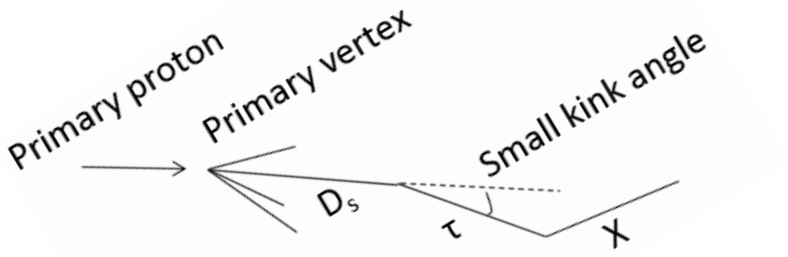




New Journal of Physics
14 (2012) 013026

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

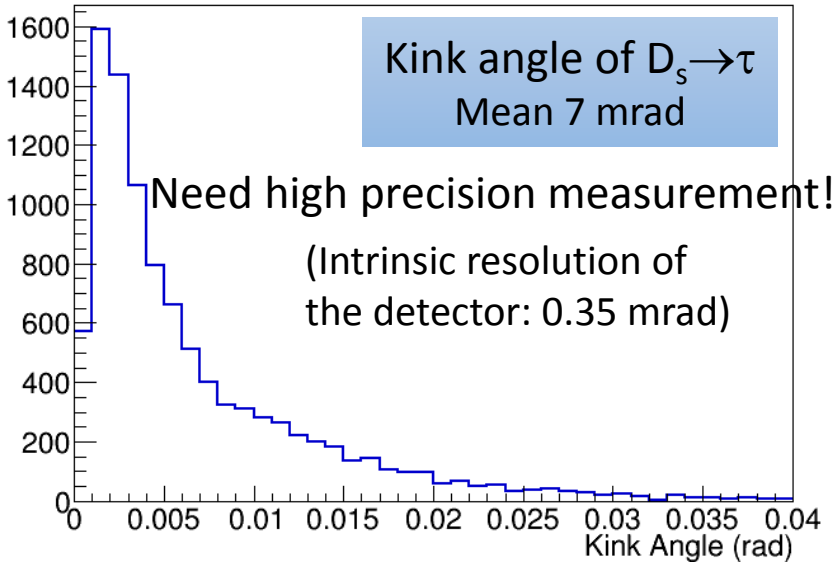
PYTHIA

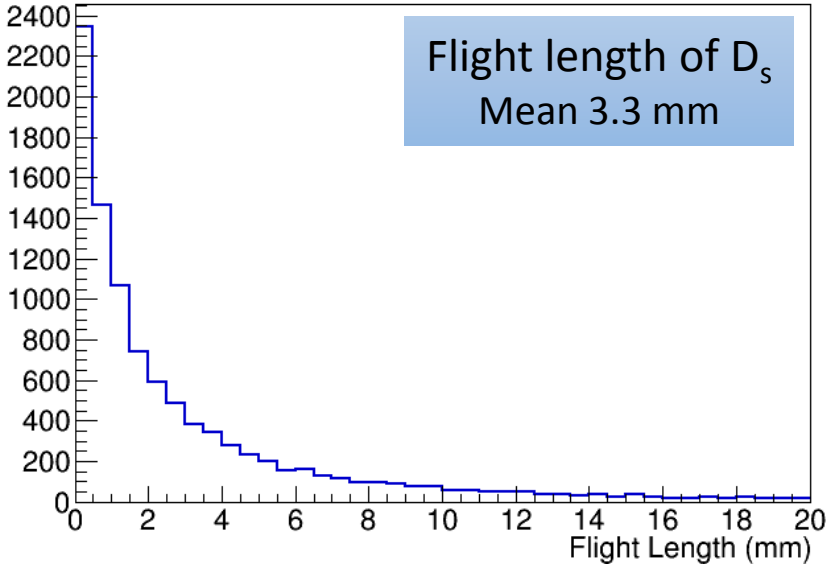


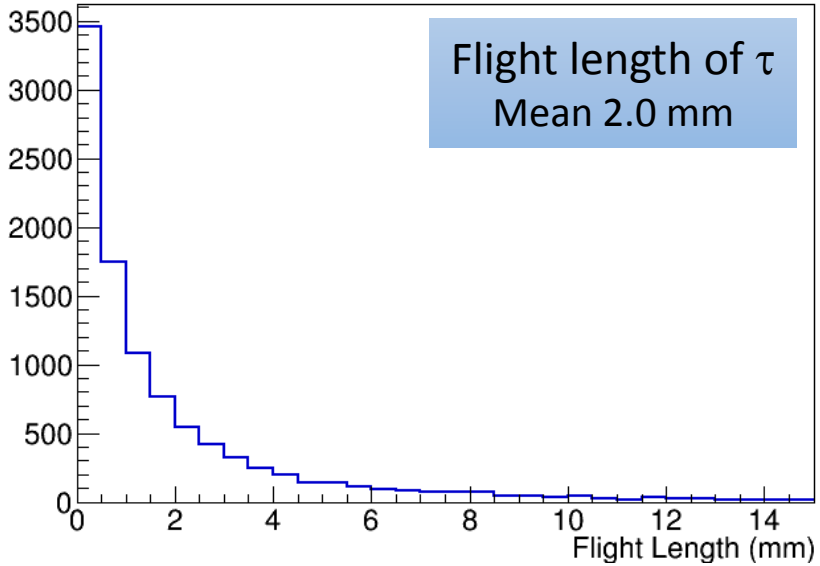
The analysis chain:

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

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







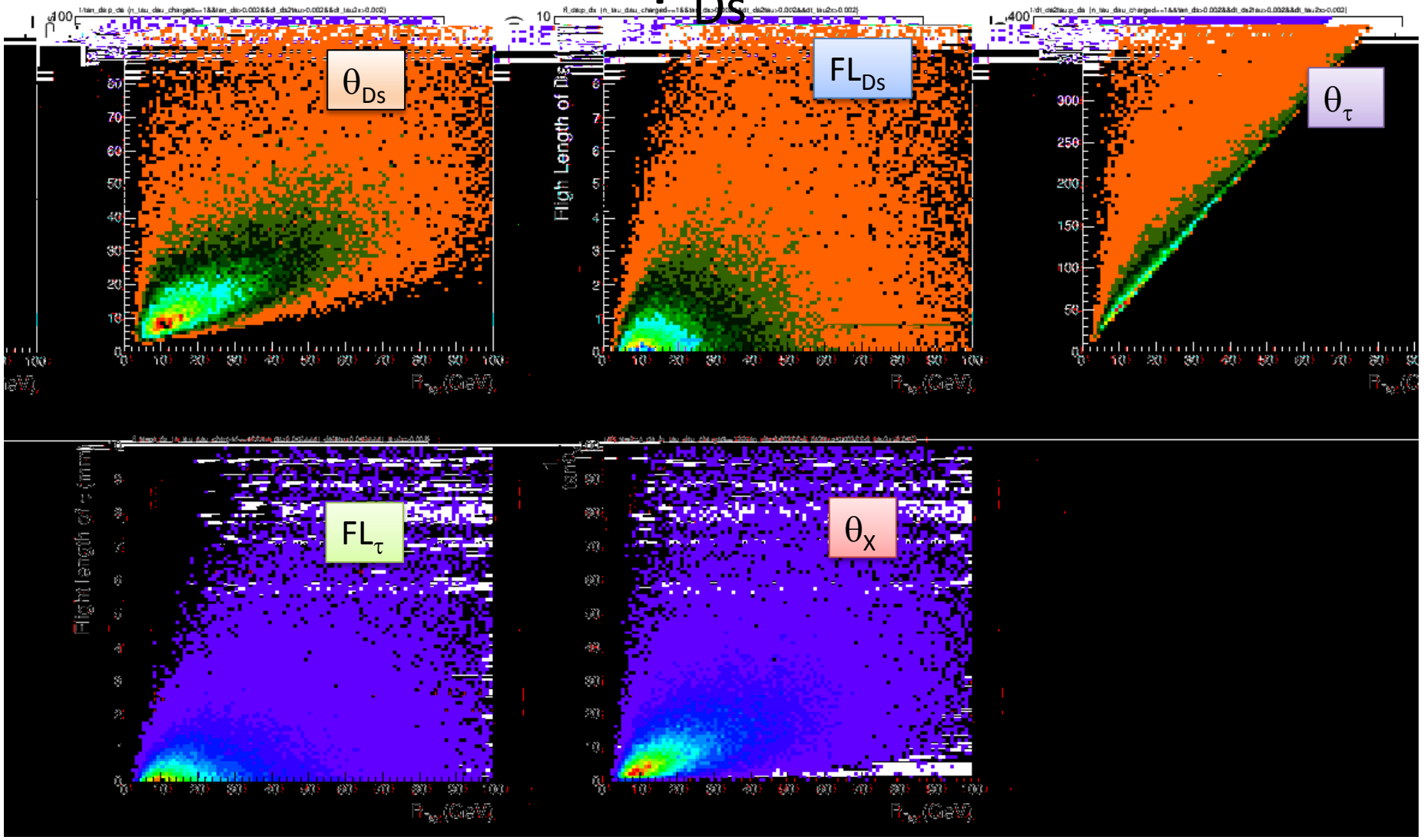
Preliminary selection :

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)

Topological variables: correlation with P_{Ds}

Sample: tau single prong decay

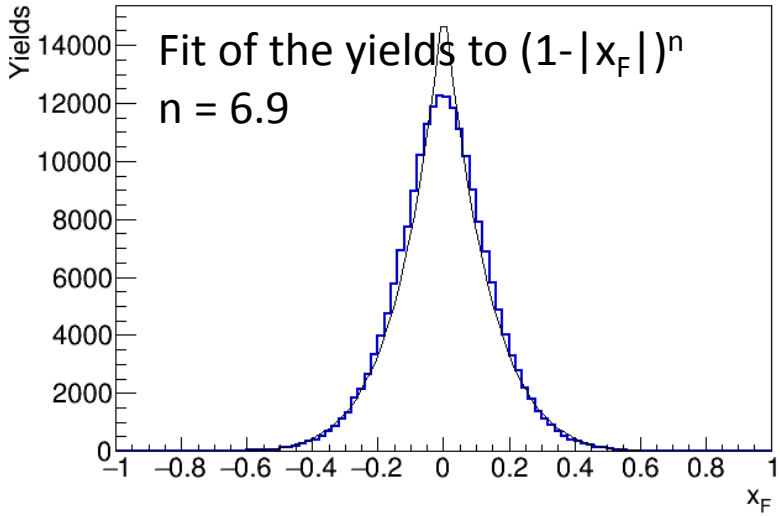


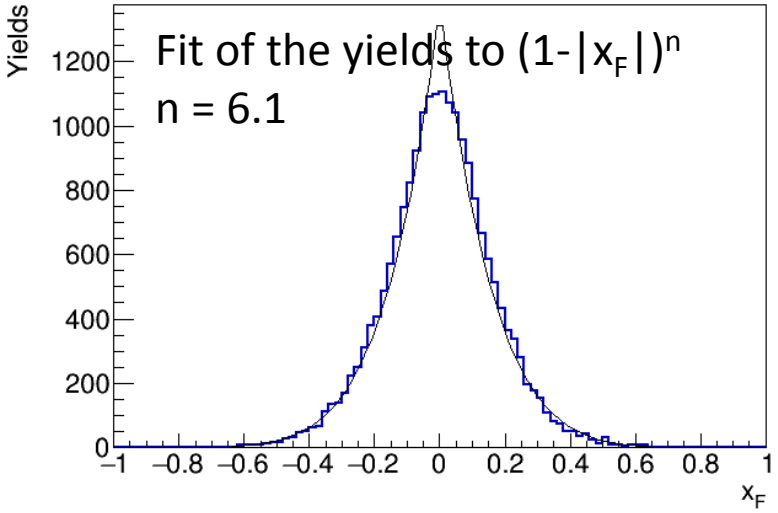
Difference due to pythia versions?

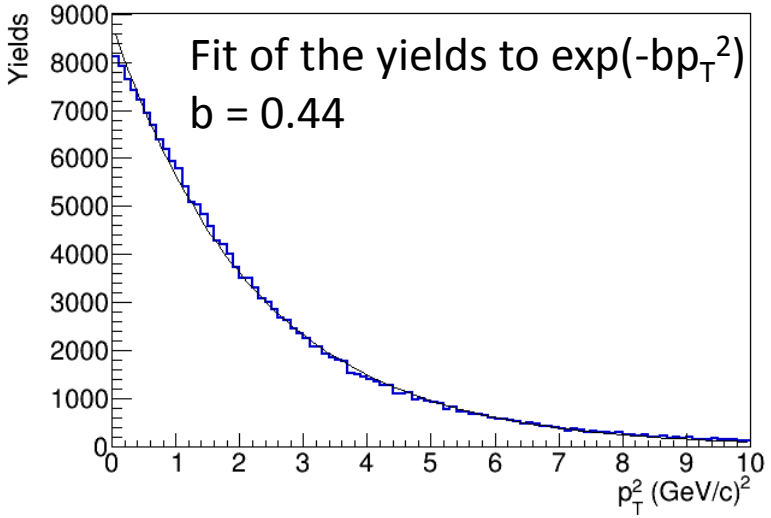
Both for 800 GeV beam

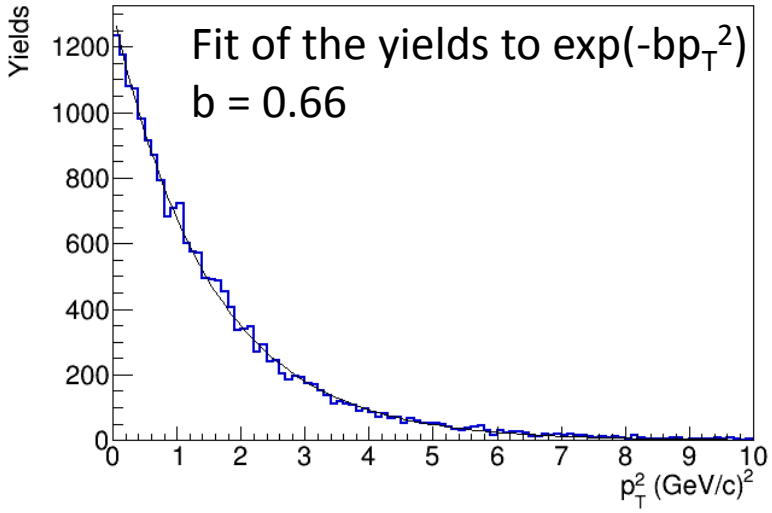
pythia8185

Using the files from Komatsu
(probably old version)









Production
Particle slope
With 400 GeV
proton beam