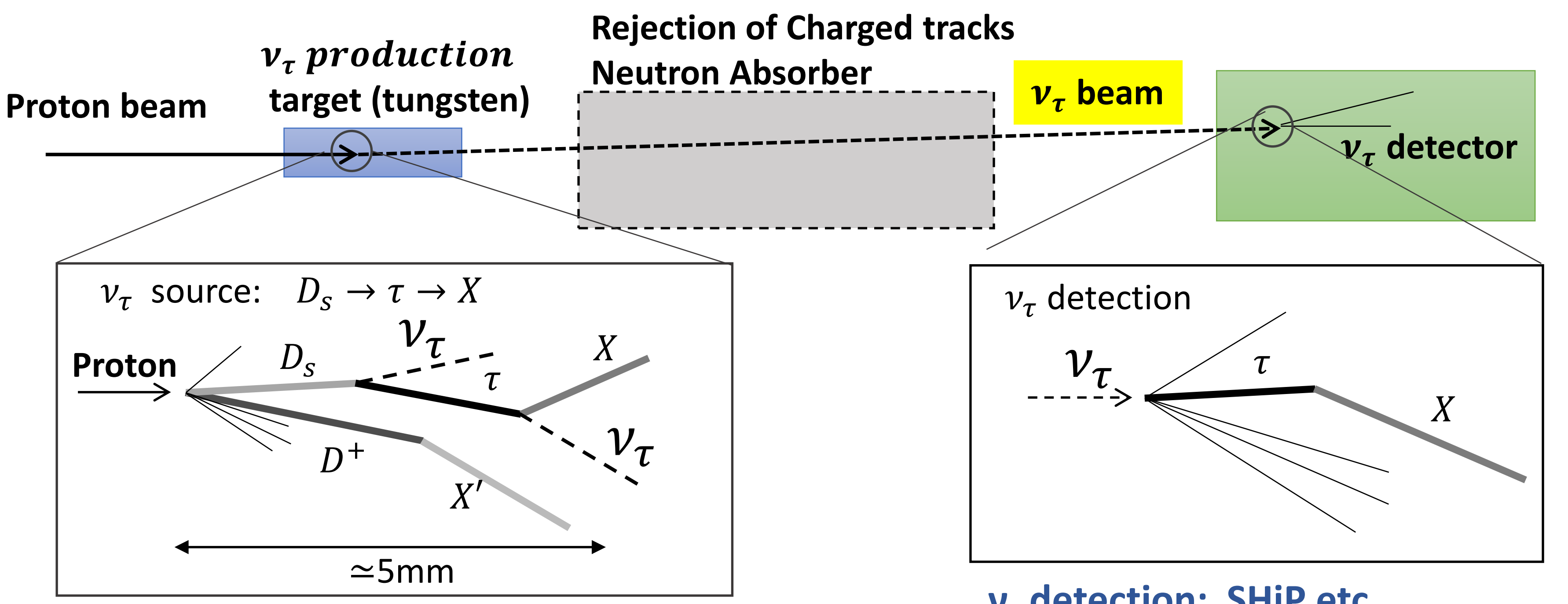
Proton interaction and its charm production study

2nd Dec 2023 O. Sato

For the DsTau Collaboration

Tau neutrino cross section measurement
- concept -



ν_τ production study: DsTau

- **No data of Ds differential production cross-section**
- **Larger ~50% uncertainty of ν_τ flux**

ν_τ detection: SHiP etc.

- 9 ν_τ detected by DONuT (bam ν_τ). 33% statistical error
- 10 ν_τ detected by OPERA (Oscillated ν_τ)
- SHiP ~ 10000 events a few % statistical error

DsTau Experiment (CERN NA65) Physic motivations

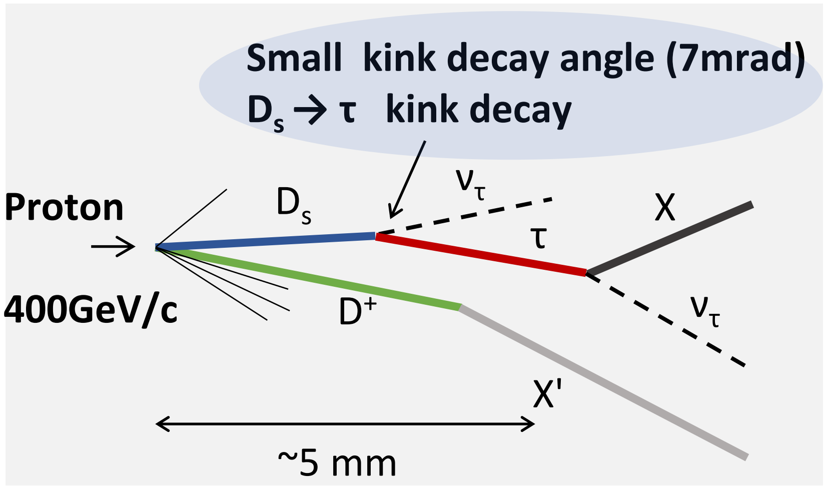
Precise understanding of ν_τ production flux

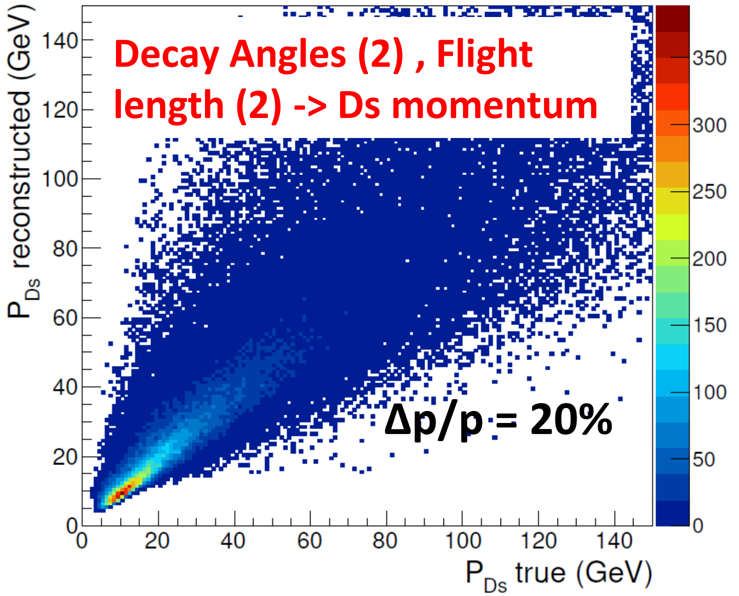
Measurement of differential production cross section of Ds .
Using a specific decay topology :: Ds->tau->X (double kink) decay .

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

x_F : Longitudinal momentum (Pl) / Pl_max
Pt : Transverse momentum

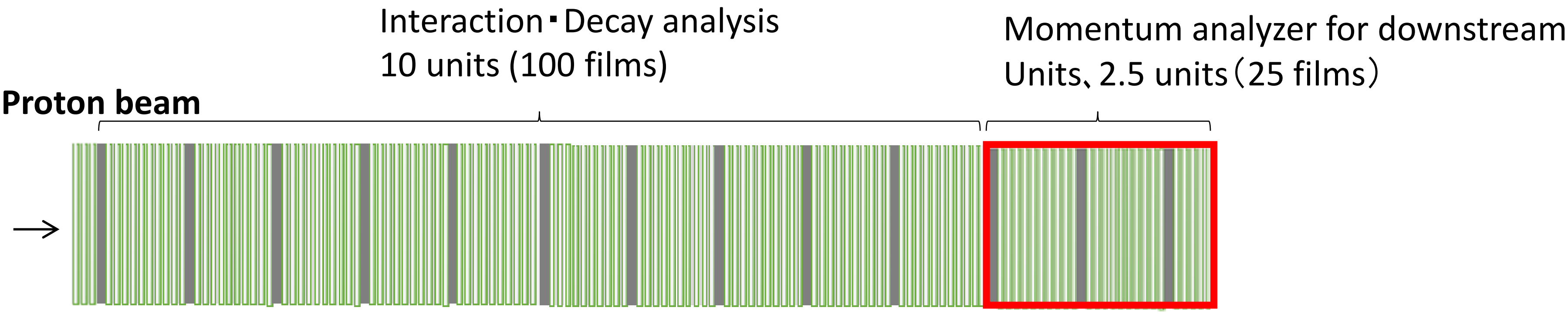
Ds->tau decay angle is small as average 7mrad in flight length a few mm .
Using Sub micron spatial resolution 3D tracker :: Nuclear emulsion tracker .

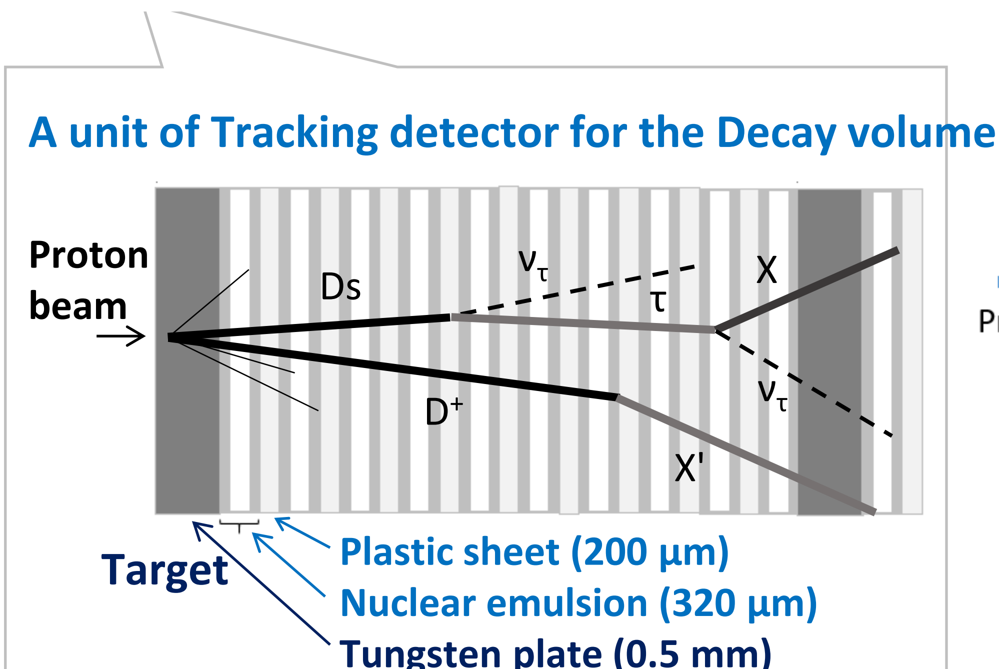




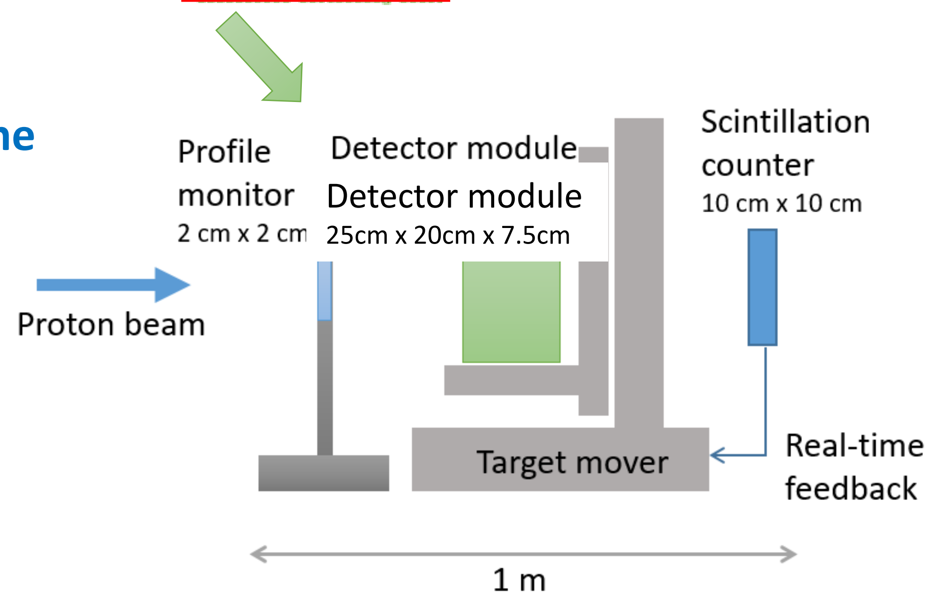
The detector structure (～74 modules)

2.0x10^8 Proton x tungsten (Molybdenum) interactions
(4.0x10^9 beam Proton)





1000 detected Ds → τ →X decay



Uniform irradiation on detector surface x,y

DsTau Experiment (CERN NA65) Physic motivations

1. Precise understanding of ν_τ production flux (cont.)

Reduction of $\nu\tau$ nucleon cross section uncertainty 50%→10% .

For re-evaluation with updated $\nu\tau$ flux for DONUT

For input for future experiment SHiP $\nu\tau$ program etc .

The detected 1000 Ds->tau->X events for the uncertainty reduction

A total of **$2x10^8$ proton interactions will be analyzed** to hand detected 1000 Ds->tau->X .

2. Understanding of charm production

Several 10^5 events having pair charms among proton interaction products.

The angle (θ, ϕ) correlation of the pair charm particles for event by event , etc .

X_F distribution for Charged and Neutral charm respectively.

Analysis about Charms produce into Forward direction :: intrinsic charms (valence quark like c) exist ?etc .

into “Backward direction (soft Charm production region) ”

3. Understanding of proton interaction

Plenty of proton interactions .

Interaction with several Materials (Tungsten, Molybdenum , Nuclear Emulsion, Plastic) .

Charged track’s angle (rapidity) and momentum distributions .

2021,2022,2023 Physics run(NA65) status

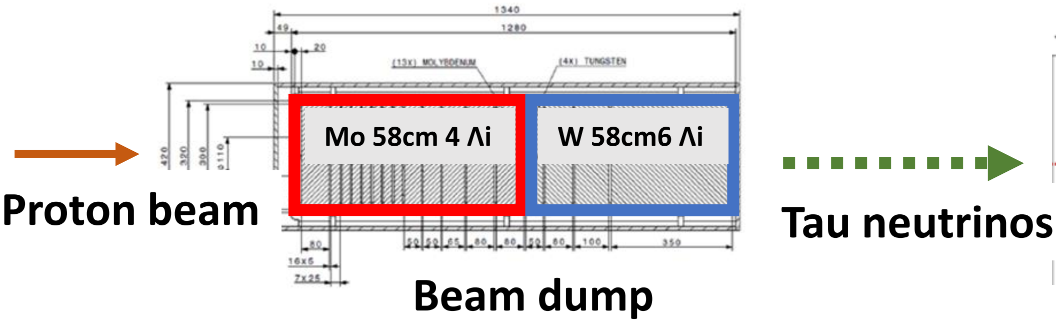
	# of Detector modules (Count as Physics run module size)	Nuclear emulsion film Total surface (m^2)	Integrated # of modules	Interactions in tungsten /Molybdenum target Integrated # of Int. (x 10^8 int)
Pilot run 2018	¼ x 30 = 7.5	49	7.5	0.19
Physics run 2021	**17**	**110**	**24.5**	**0.61**
Physics run 2022	**17**	**110**	**41.5**	**1.04**
Physics run 2023	**40**	**260**	**81.5**	**2.04**

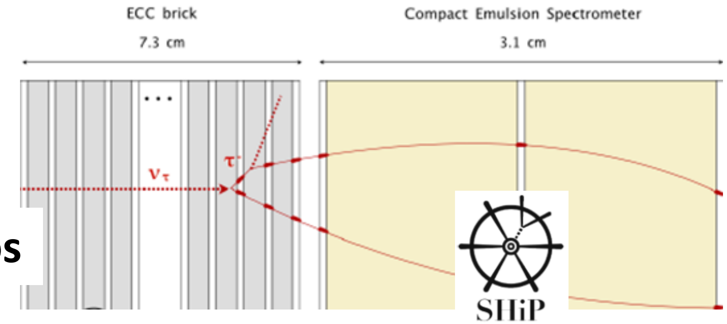
1-2 weeks beam exposure / year

- 2021 run : Beam exposure：22nd Sep ～6th Oct
- 2022 run : Beam exposure : 12th Oct ~ 19th Oct
- **2023年run Beam exposure: 6th Sep ~20th Sep**

Molybdenum($_{42}$Mo) Target

DONuT used tungsten **($_{74}$W)** as neutrino source beam dump.
On the other hand, SHiP will use molybdenum alloy **($_{42}$Mo:99% or more)** as first part then tungsten target as second part of the hybrid beam dump.
Tau neutrino flux produced by molybdenum interactions, need to be estimated / measured.





From 2021run
Molybdenum (1.0㎜) modules and Tungsten (0.5㎜) modules exposed about 1:1 .

Run	All	Molybdenum	Tungsten
2021	17	5	12
2022	17	8	9
2023	40	20	20
Total	74	33	41

2023 run exposure successfully finished.
A largest scale in DsTau runs !

Module Assembling & De-assembling on cite

- Assembling to exposure

  7th Sep to 15th Sep
  - 130 films ＋ 12 target plates vacuum packing.
  - ~1 h/module, Max: 7 module/day

- De-assembling for chemical development

  9th Sep to 17th Sep
  - ~40 min/module, Max: 8 module/day

- Assembling and de-assembling on parallel.

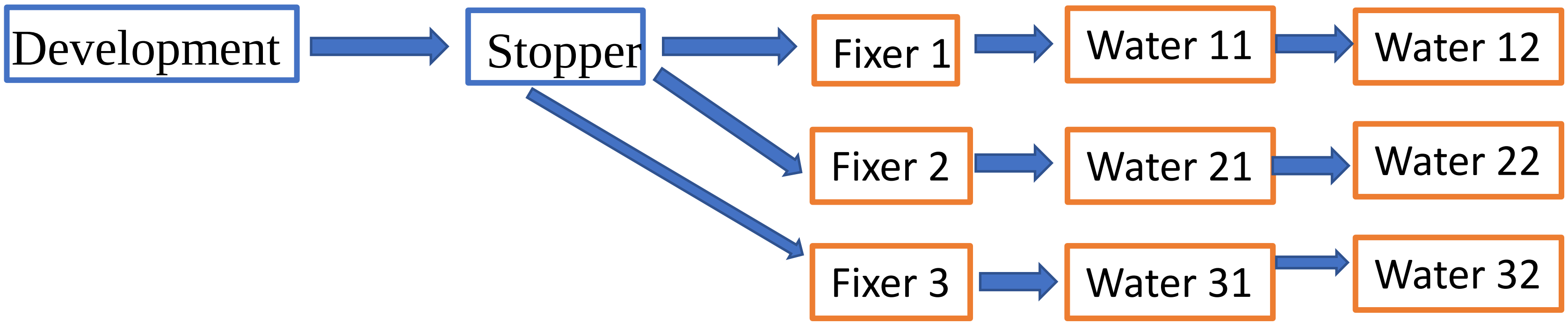
  7 modules de-assembling

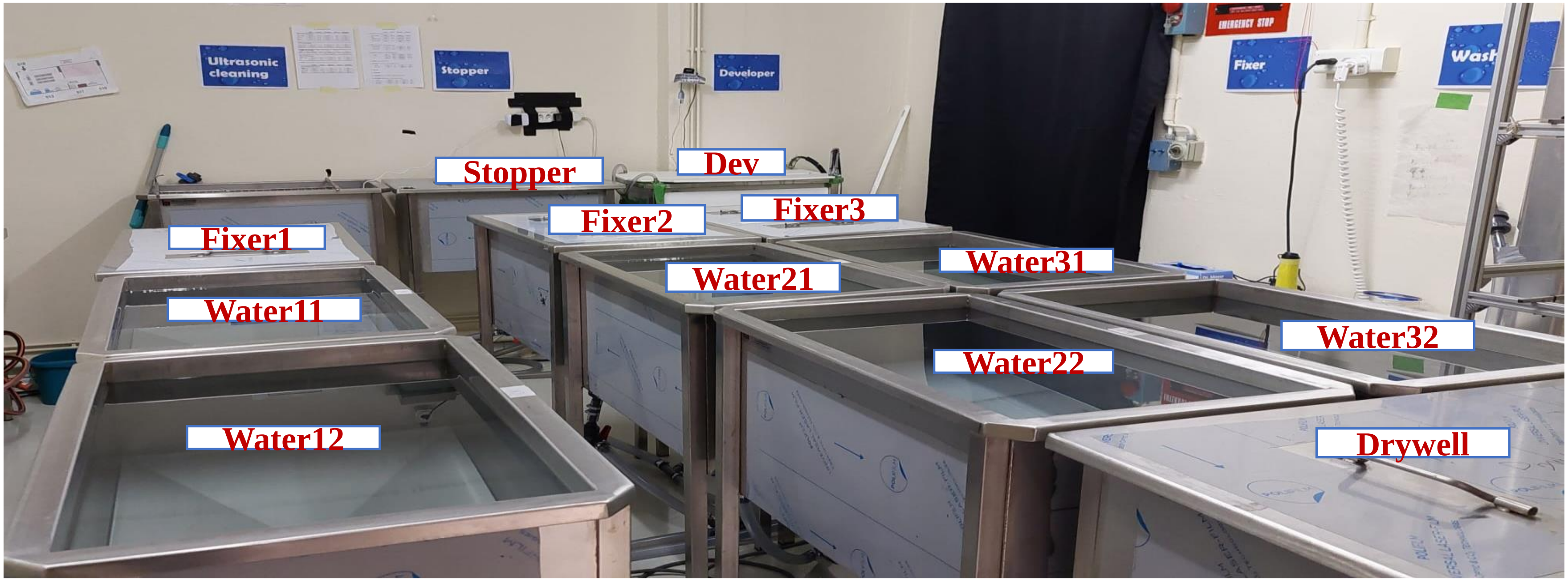
  and 7 modules assembling ～7 hours

- **<u>Without serious error</u>**

Development at CERN：19^{th} Sep to 1^{st} Nov : 7 weeks

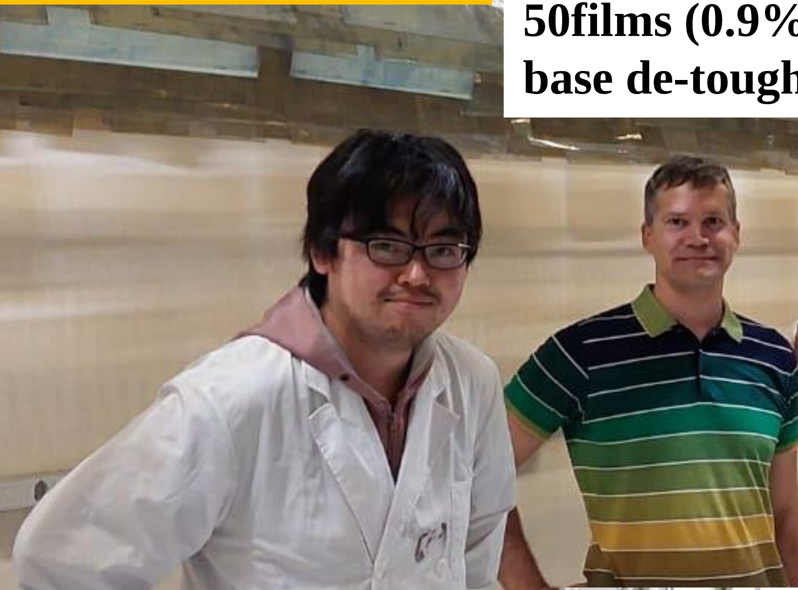
- 5200films (25cm x 20cm) + Momentum test beam 200 films (12.5cm x 5cm)
- 18 development cycles. 1cycle(2days) ＝ 25 films x 12 chains

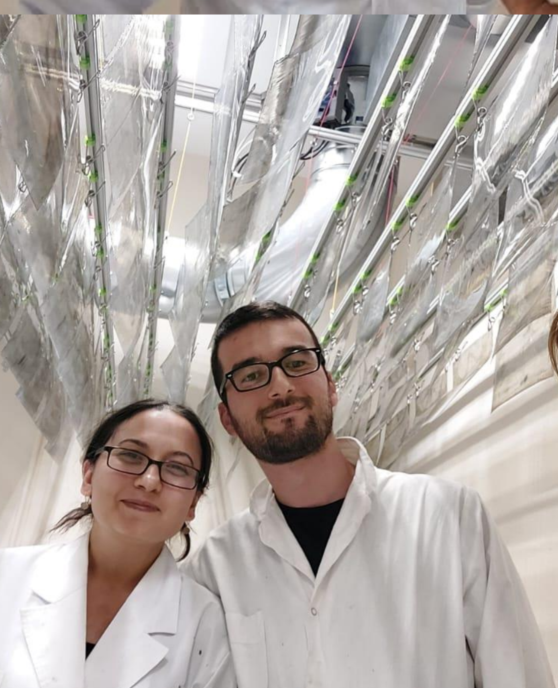


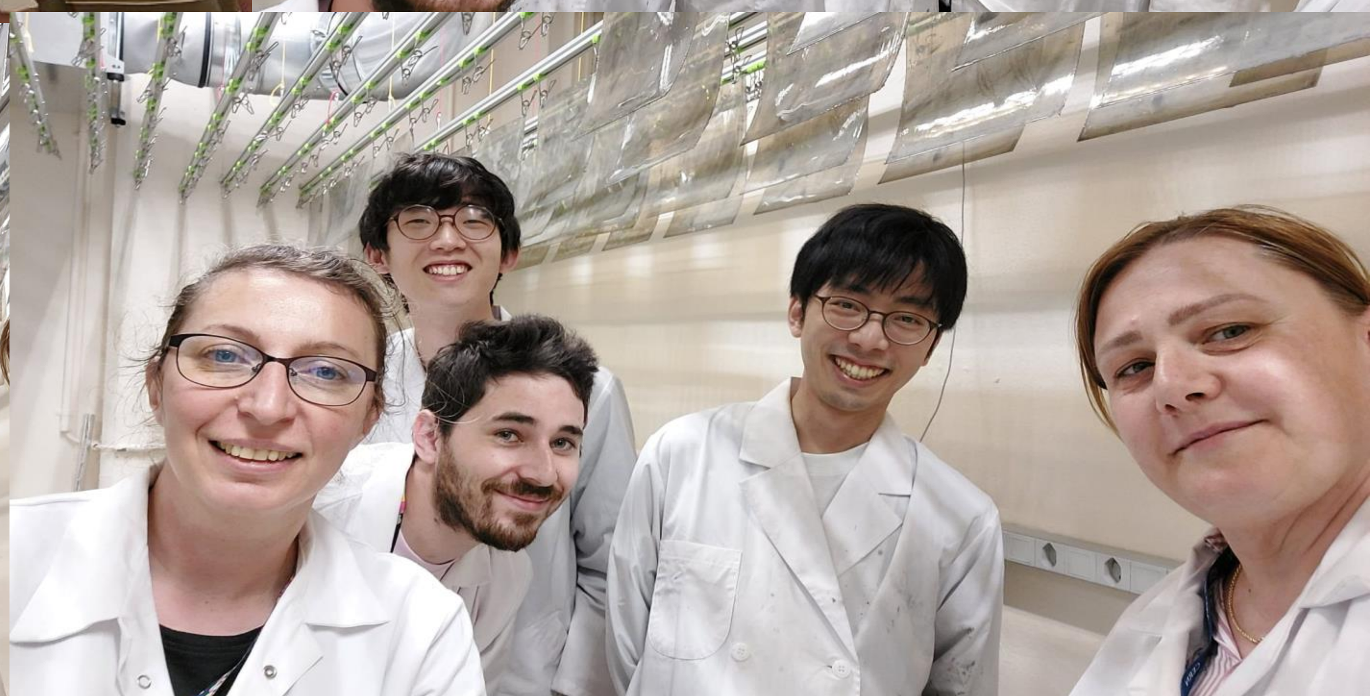


Development Team 10 people

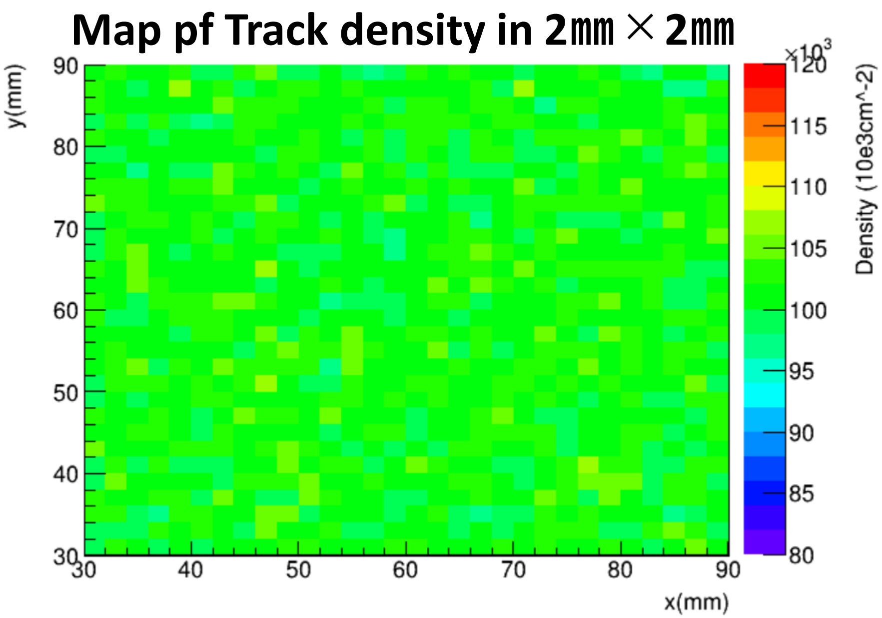
Almost no error films among 5200 developed films.
2 films : touch each other
50films (0.9%) emulsion / base de-toughed at edge part

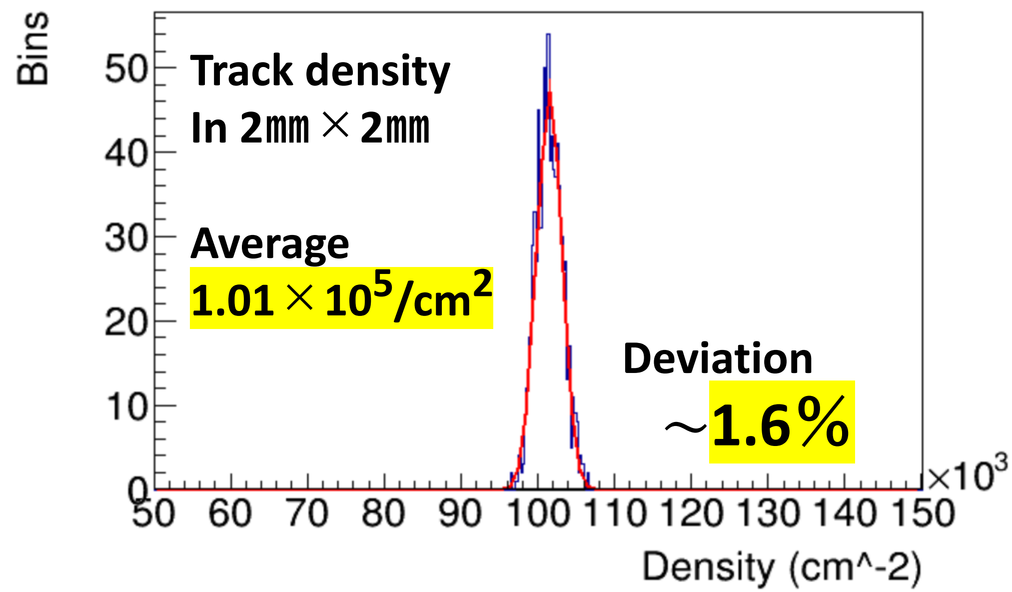


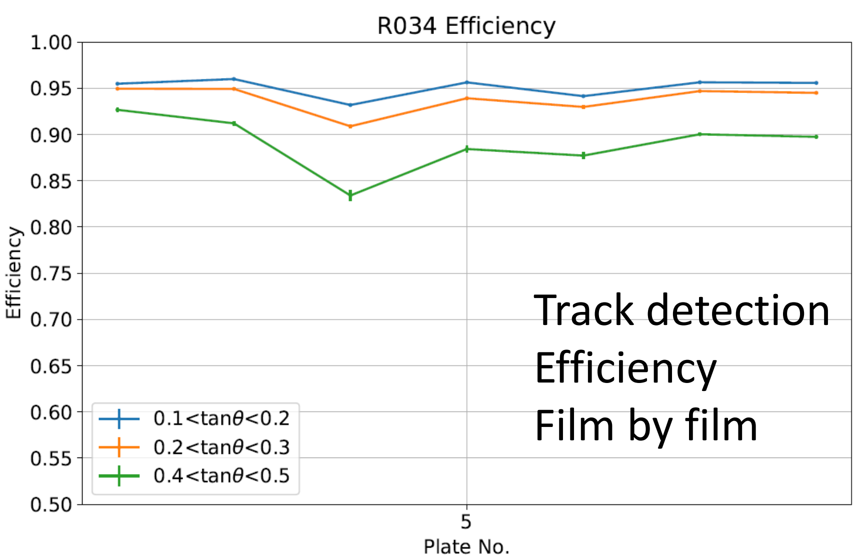




Quality check on 2023run films







Exposed as uniform track density in full area
As aimed value of $10^5/cm^2$
(2021 run deviation was 1.9％)

Track detection efficiency is about 95%.
Similar quality to other run films
Will be scanned / analyzed soon.

Tracks readout from Nuclear emulsion & Analysis .

Nuclear emulsion prior treatment for scanning .

Surface cleaning, Thickness control.

① Full surface scanning

~1 film / 1hour

~2018 run films were fully scanned by Apr 2020 . 1 year and 5 months.

② Ds -> τ search

Precise measurement for Small angle kink (~ 7 mrad)

Hyper Track Selector (HTS)

Track readout speed 0.5 m²/h/面

Angle resolution ~2 mrad

Track recognition efficiency >95%

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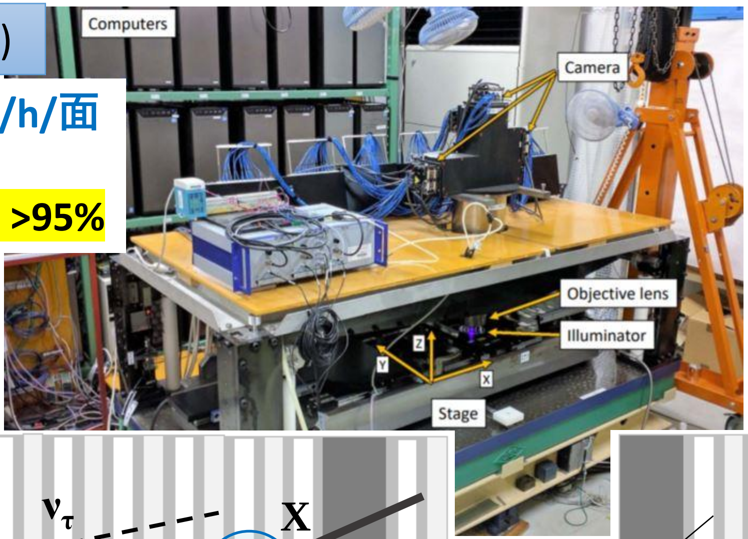
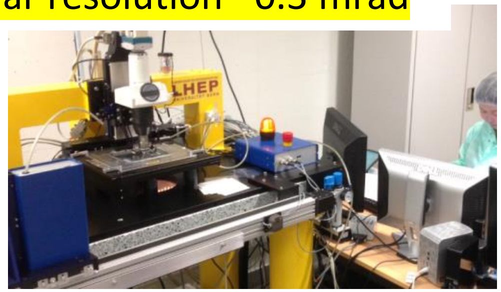
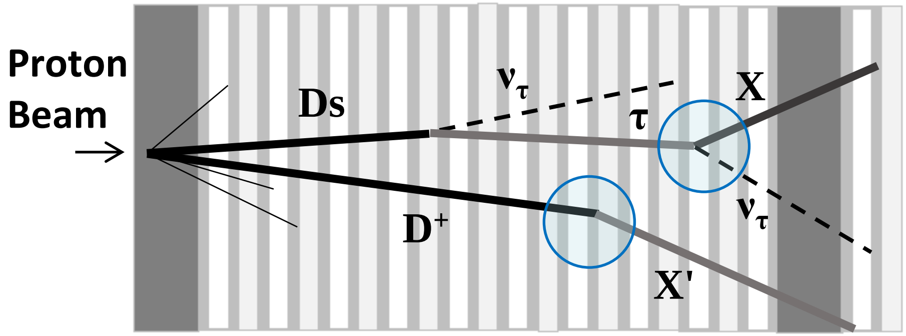
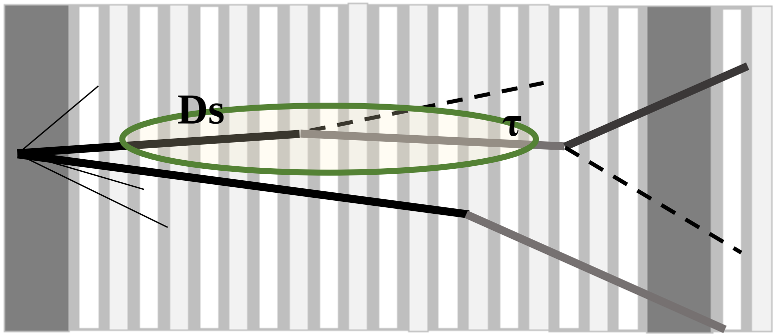


Dedicated microscopes

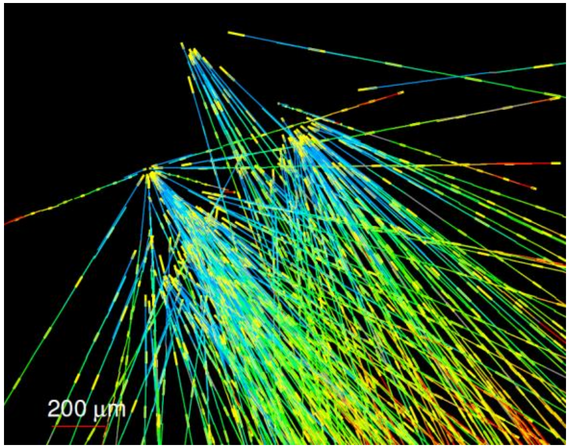
Angular resolution ~0.3 mrad



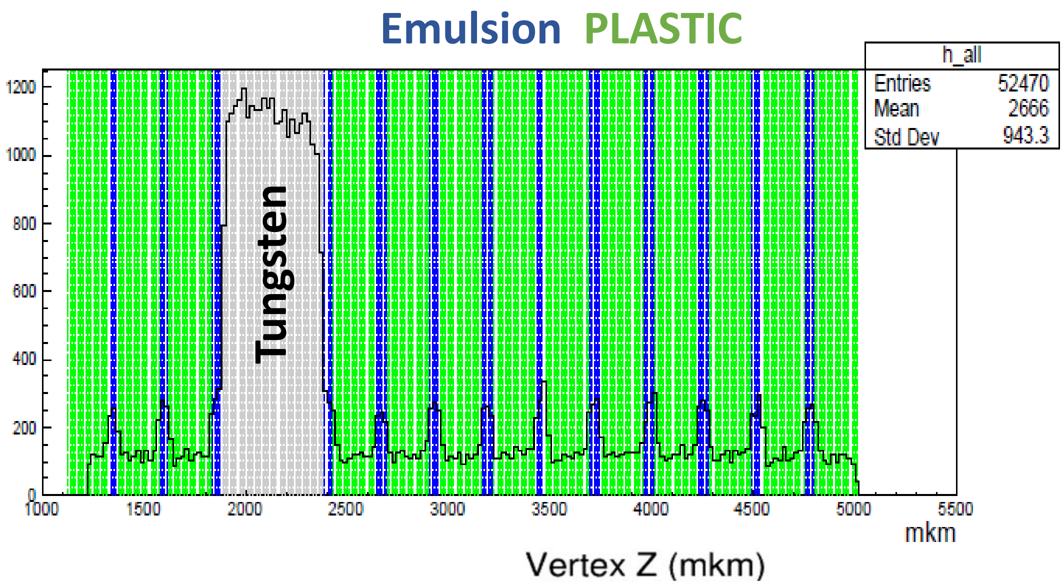


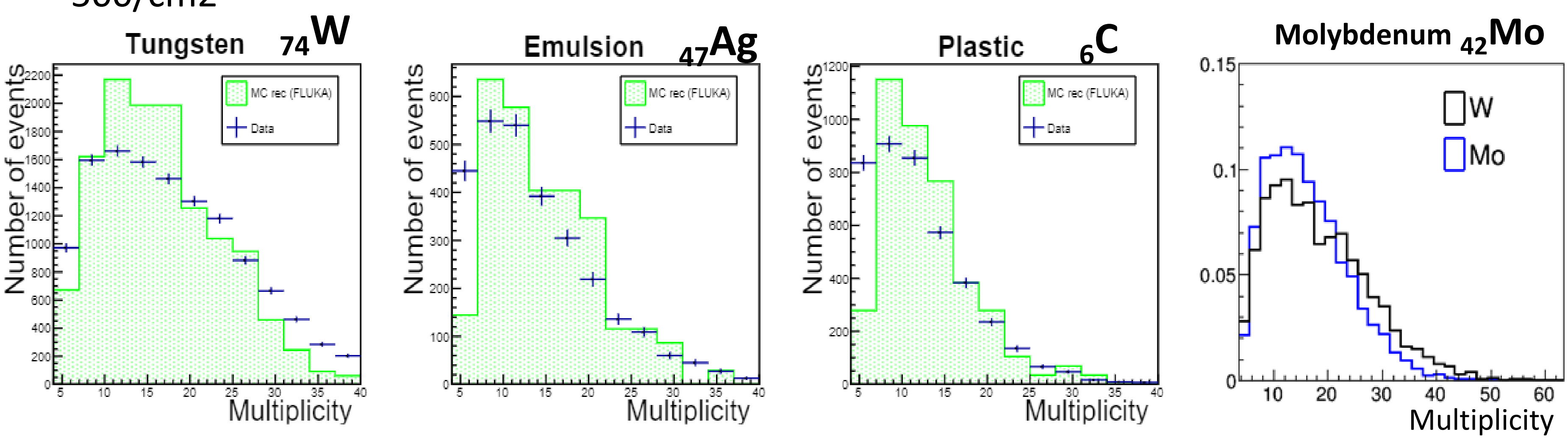


Proton-Target nucleus interactions



Interaction density at tungsten plate
～500/cm2

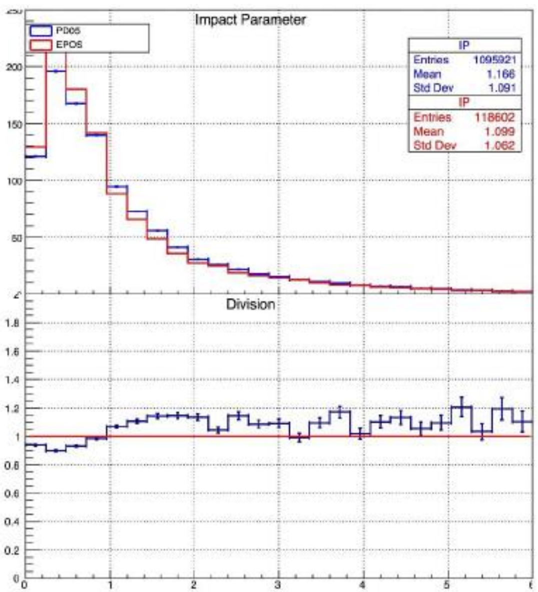




Charged track multiplicity distribution for several target nucleus.

A Data/MC comparison of tungsten interactions.

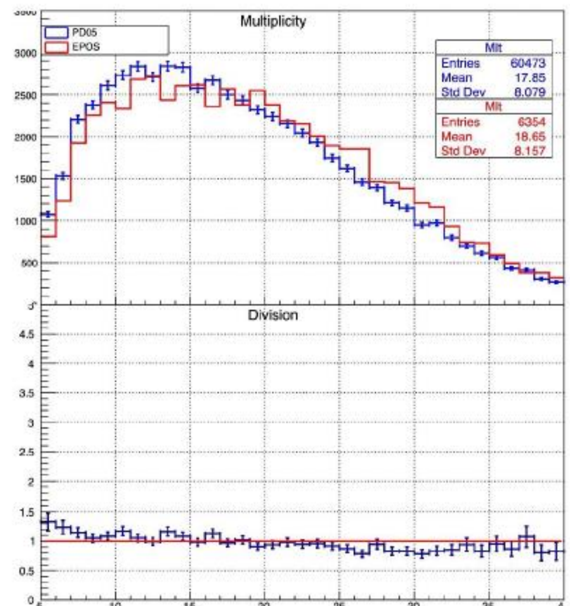
IP



IP (um)

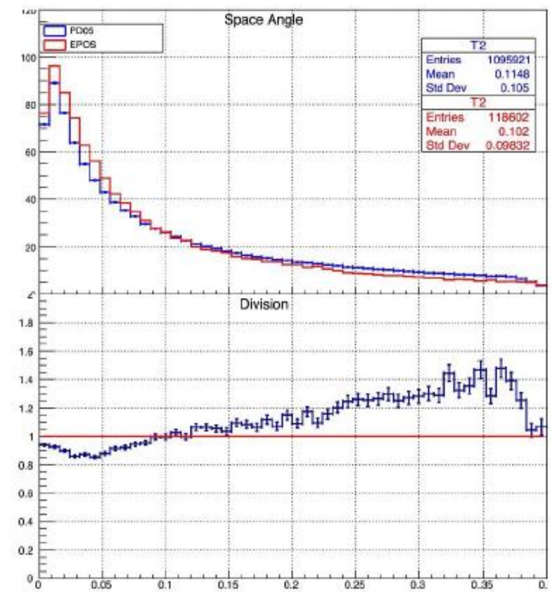
PD05: data of 15 sub-areas

Multiplicity



Multiplicity (本)

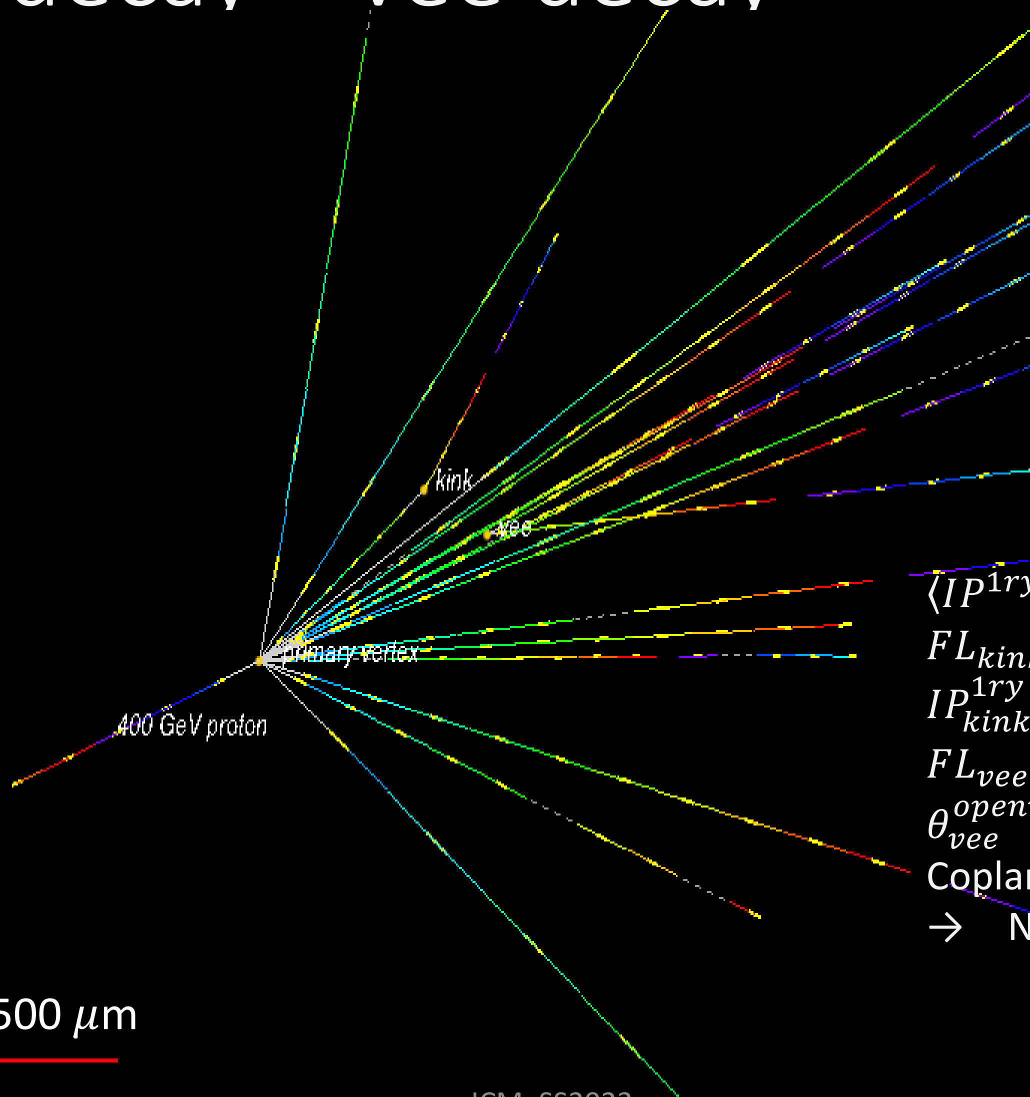
Space angle



angle (rad)

EPOS MC looks well agree with data.

A double charm candidate kink decay + vee decay



$\langle IP^{1ry} \rangle$ = 1.6 μm
FL_{kink} = 3.32 mm
$IP^{1ry}_{kink\ daughter}$ = 174 μm
FL_{vee} = 2.20 mm
$\theta^{openning}_{vee}$ = 0.132 rad
Coplanarity of vee = 15.2 mrad
→ Not a two body decay

500 μm

Cleaning by kinematical information for charm decay candidates.

Rejection of backgrounds

- Charged Charms (D+-,Ds+- ..)

  1） Hadronic interaction background

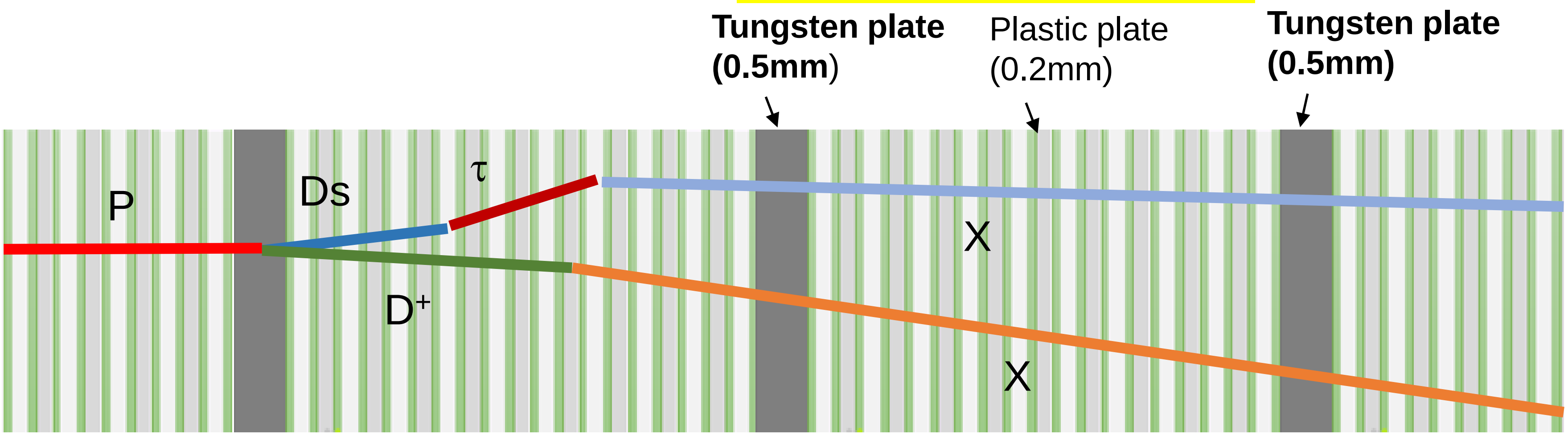
- Neutral charms (D^0)

  1） K^0 ,Λ^0 decay 2） neutral hadron （K^0,Λ^0,n） interaction backgrounds

Pt or **momentum** selection for charm candidates.

➔ Multiple coulomb scattering by target plate (tungsten/molybdenum 12 plates)

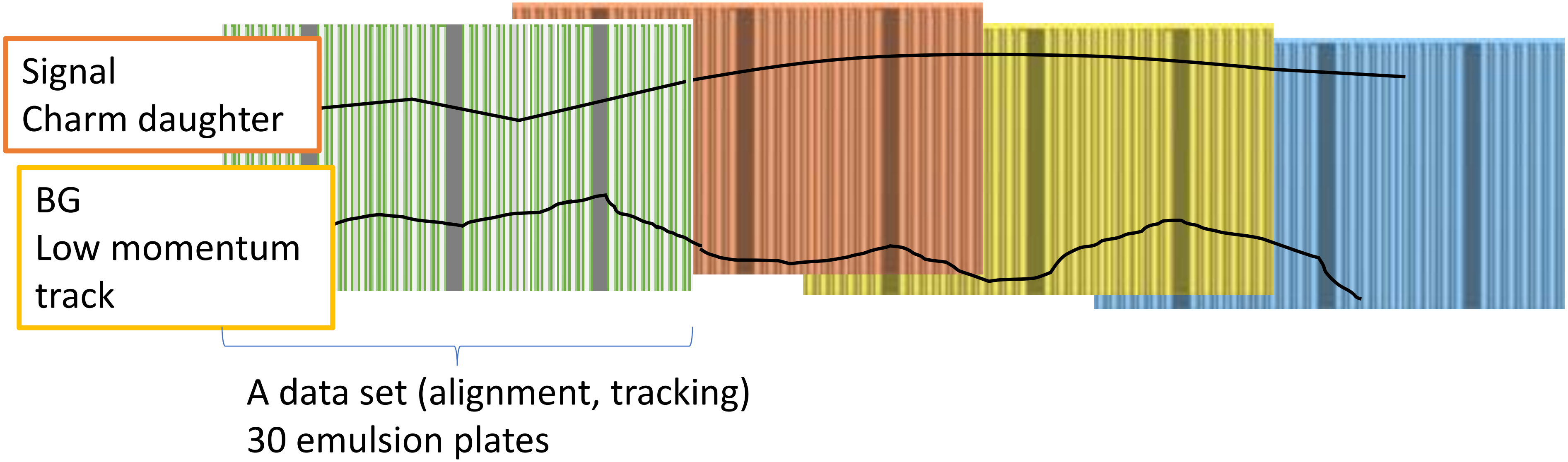
➔ Momentum of decay daughter （dP/P ~ 30% up to **30GeV/c** ）



Momentum estimation by multiple coulomb scattering

- Want to measure momentum of all (~Millions) interesting tracks.

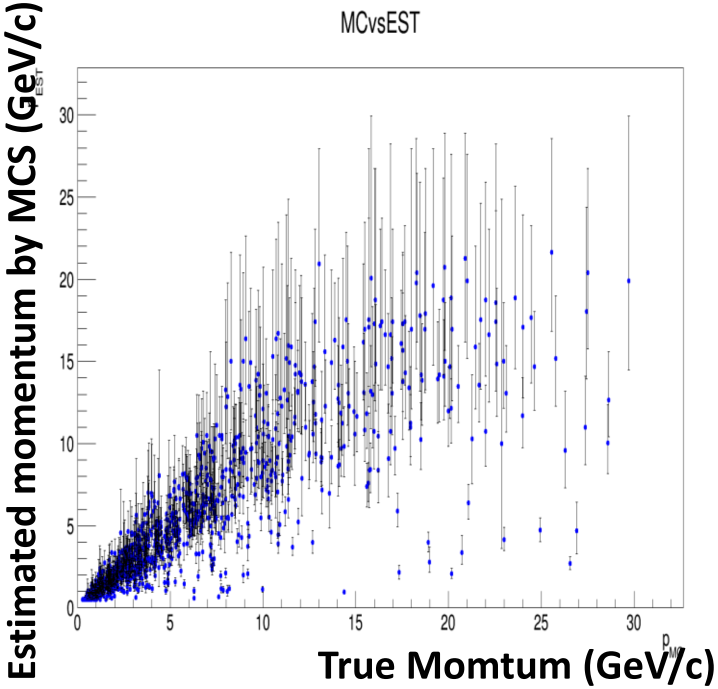
- Tracks are reconstructed by all films after interaction(decay) maximum 125 films.
- A data is aligned by 30 films sets with 10 films overlapping.
- Using 10 overlapping films tracks will be connected to the most downstream.
- Angle difference between tungsten/molybdenum plates.
  → Evaluate MCS scattering angle（δθ）
  →Then momentum of track（$p\beta = \frac{k\sqrt{x/X0}}{\delta\theta}$, k ~ 13.6MeV/c) will be estimated.



Speed up of momentum estimation algorithm.

- Study by MC with DsTau module structure (Geant4
  400GeV proton tungsten interactions
  charm daughter (~1200tracks) momentum
  were estimated as same way as data.

  ＭＣ truth and estimated momentum are compared.



- Up to ~20GeV/c, Estimated momentum is linear relation to momentum truth .
- It almost cover momentum region of secondary particles in proton ・tungsten interactions.
- Accuracy of the momentum estimation is about 30%.

It took two weeks by manually processed by a man for about 1000 tracks .
Now it took two days after automatization of management of track connecting information.
Real data to be processed for charm candidate daughter momentum estimation to clean up.

Summary

Motivation： DsTau(NA65) aims to study tau neutrino production by nuclear emulsion.

- Among 400 GeV proton-tungsten/molybdenum **2.0×10^8** interactions, **1000** in. with **Ds → τ →X decays** will be detected/ analyzed and measure the **Ds meson differential production cross section**.
- Uncertainty of ν_τ production will decrease from **50% to 10%. Contribute for neutrino study in future.**
- Bi Product: **10^5 Charm associating interactions, proton interaction, target nucleus dependence.**
- **POSTER presentation by M. Miura- san A1-P-14 Development of charm analysis in NA65/DsTau experiment.**

Status：

- **2018 pilot run（１０％ statistics of all)**

  All films were scanned, data are processed.

  double charm selection were done and wait for momentum analysis.（Fiducial Volume 40%）

- **2021-2023 Physics runs（９０％ statistics of all)**

  2021, 2022run moules：scanning and analysis on going.

  2023 run beam exposure completed and all films were developped.

  A largest scale in DsTau , 40 modules, 5200 films corresponding to 260m²

  Data quality of a module was checked and it was good as same as 2021, 2022 runs one.

Plan：Comparison in target nuclei（molybdenum, tungsten）interaction, charm production.

Charm candidates cleaning by MCS momentum estimation.

Small kink detection for Ds to tau decay search.