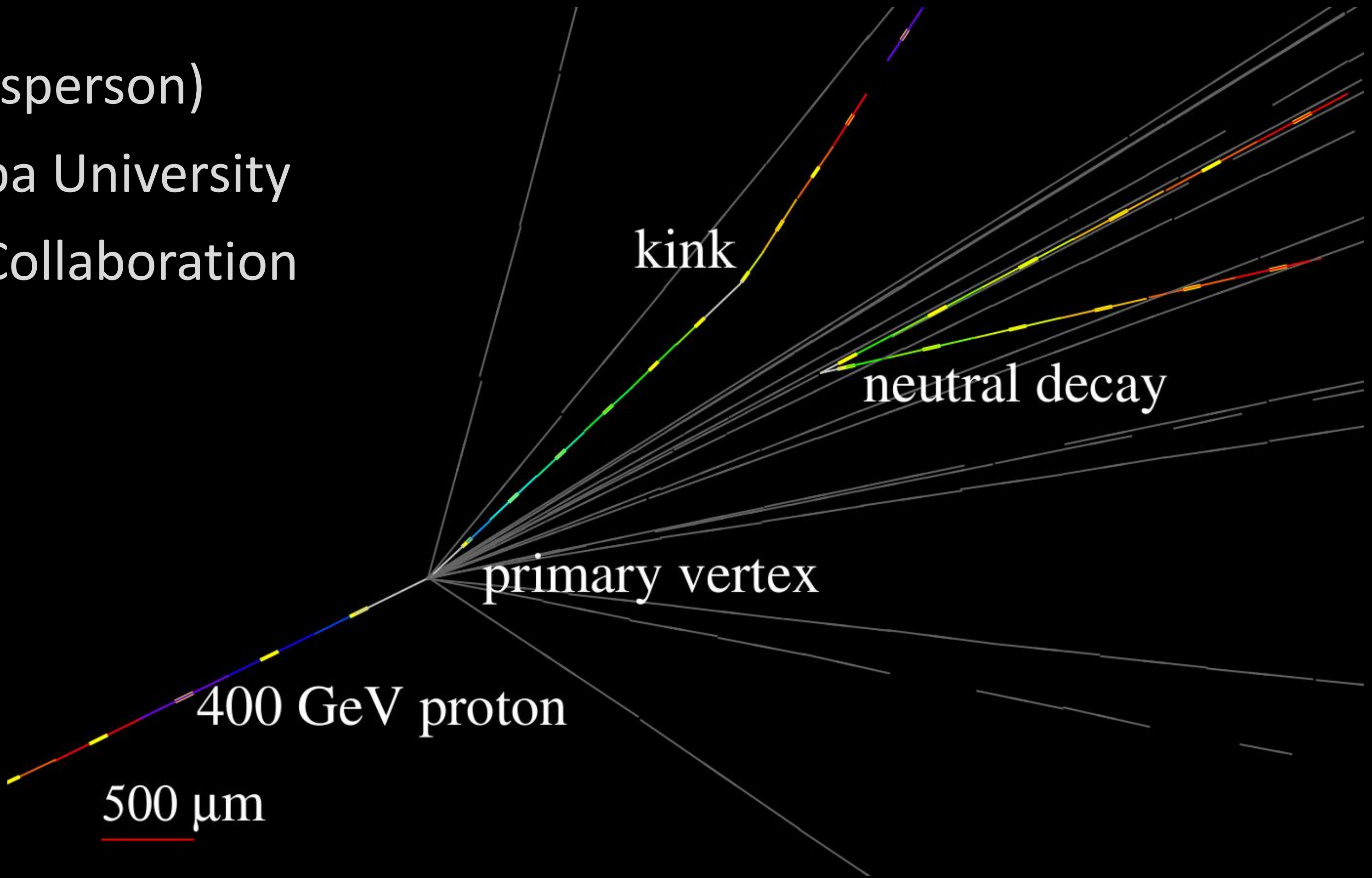
NA65/DsTau experiment, status and plans

Akitaka Ariga (Spokesperson)
University of Bern / Chiba University
On behalf of the DsTau Collaboration

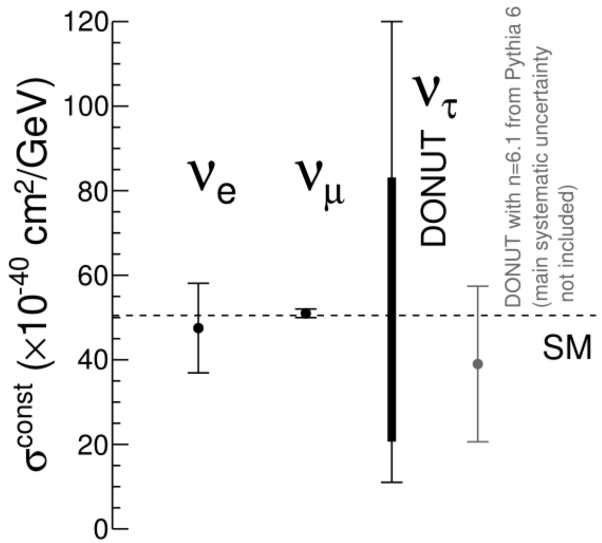
SPSC Open session June 2022



DsTau paper:
10.1007/JHEP01(2020)033
DsTau web site:
https://na65.web.cern.ch/

Motivation to tau neutrinos

- Tau neutrino is one of the least studied particles
  - Only a few measurements   Direct ν_τ beam: **DONUT** (DIS)
    Oscillated ν_τ: **OPERA** (DIS), **Super-K** (QE), **IceCube** (DIS).
  - DONUT's ν_τ cross section error >50% (DIS) due to systematic uncertainty in ν_τ production
- Lepton Universality test in neutrino scattering
  - Hints of LU violation from B decays, $\bar{B} \to \tau \nu_\tau D^{(*)}$. New physics in tau sector?
  - A precise measurement of ν_τ cross-section would provide a complementary information



Tau neutrino cross-section uncertainties in DONUT

- Tau neutrino **detection** statistics of 9 events, **33%** → SHiP, FASERν etc
- Tau neutrino **production**: Lack of D_s differential prod cross section data, **>50%**
- Tau neutrino **production** : Others, **33%**

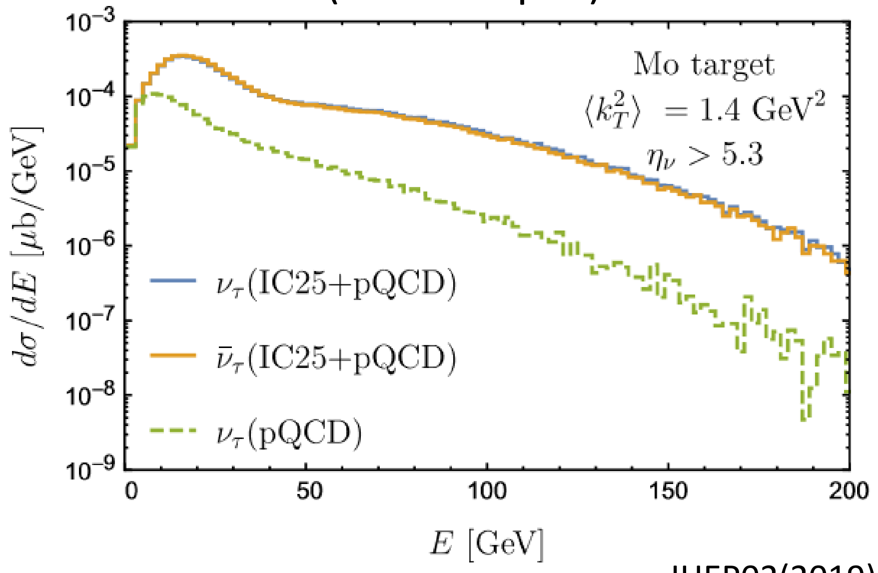
→ DsTau (production uncertainties)

Need to improve both ν_τ statistics and ν_τ production

Forward charm production

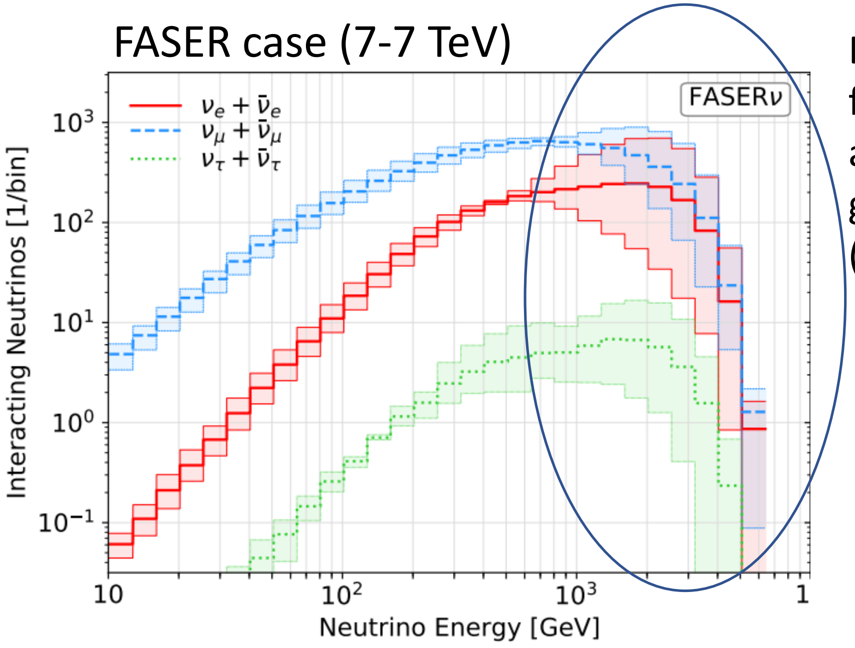
- Large theoretical uncertainty for forward charm production.
  - ex) "intrinsic charm" content of proton can affect ν_τ flux drastically, by enhancing charm meson production in forward direction
- ν_τ flux may change by a factor of 10
- Neutrino experiments needs data on forward charm production!

SHiP case (400 GeV p-N) interaction



JHEP02(2019)077

FASER case (7-7 TeV)

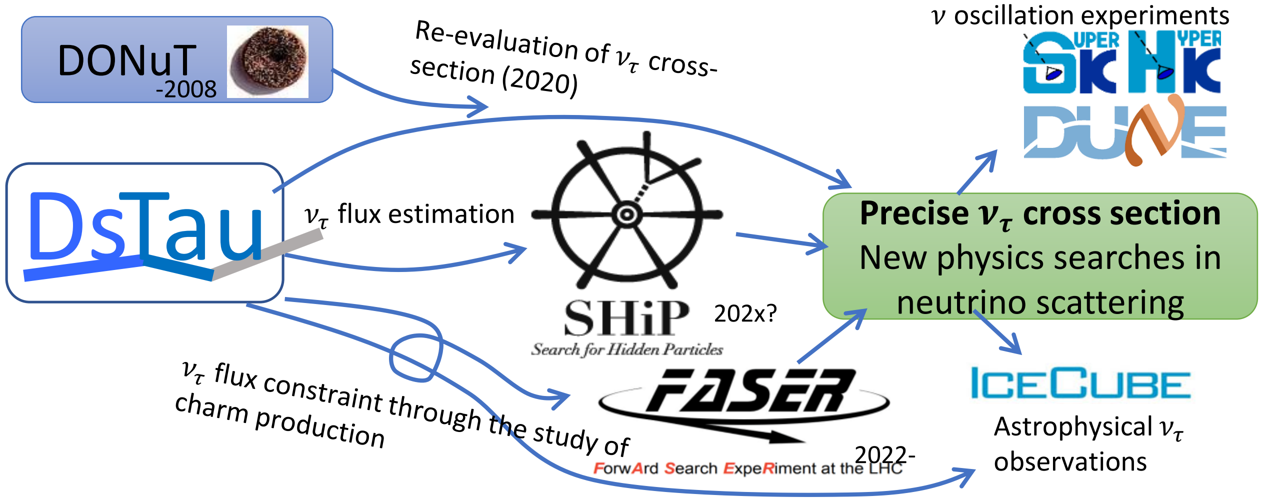


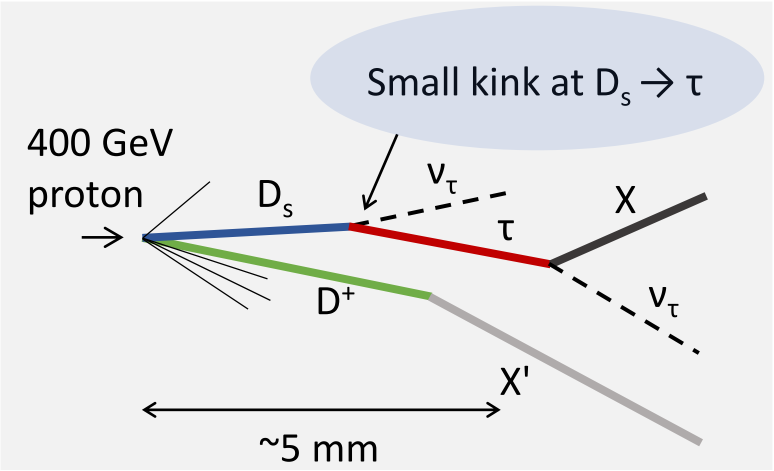
Due to large uncertainties of forward charm production among different hadron generators (Pythia, Sibyll, DPMJet)

arXiv:2105.08270

The NA65/DsTau experiment at the CERN SPS

- Study of ν_τ production for future tau neutrino experiments.
  - **D_s double differential production cross section** measurements
  - Reduce ν_τ flux uncertainty from >50% to 10% → Fundamental input for future ν_τ experiment: SHiP, and indirectly FASER
- Forward charm physics, charm/gluon PDF



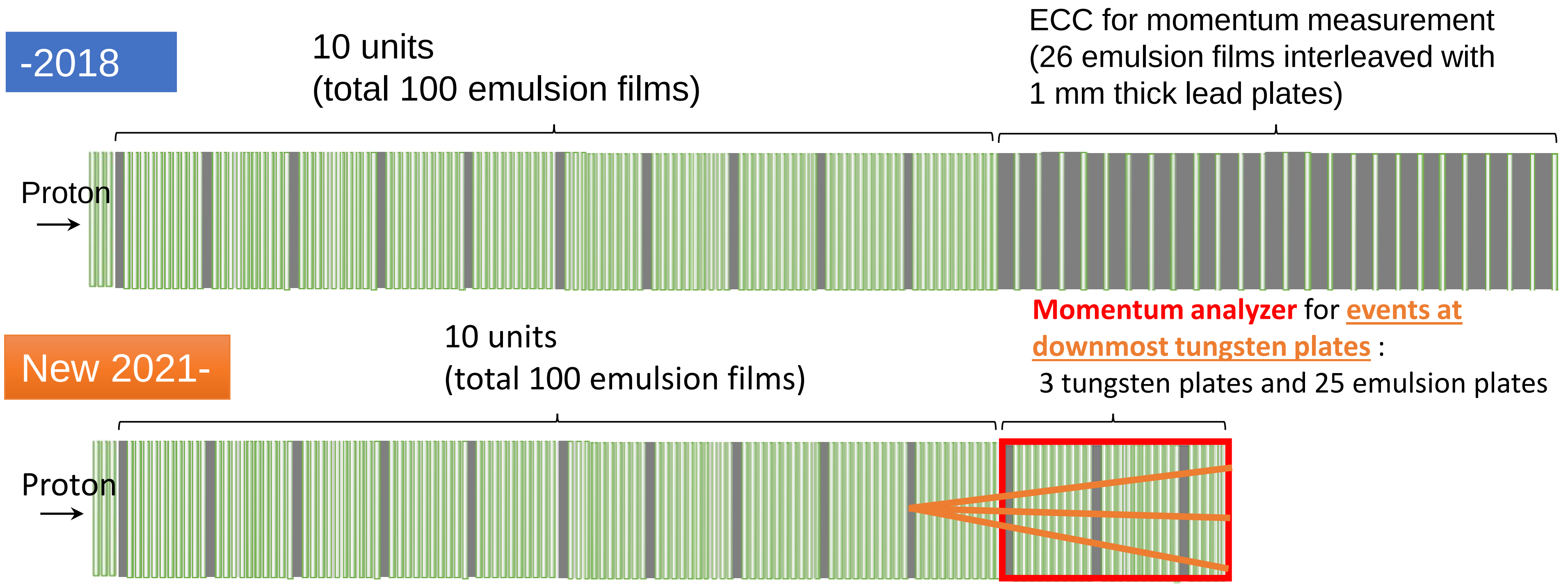


- Principle of the experiment
  - Detection of "**double-kink + charm decay**" topology within 10 mm.
  - 4.6×10^9 protons, $\mathbf{2.3 \times 10^8}$ proton interactions in target, 10^5 charm pairs, $1000\ D_s \to \tau \to X$ detected events.

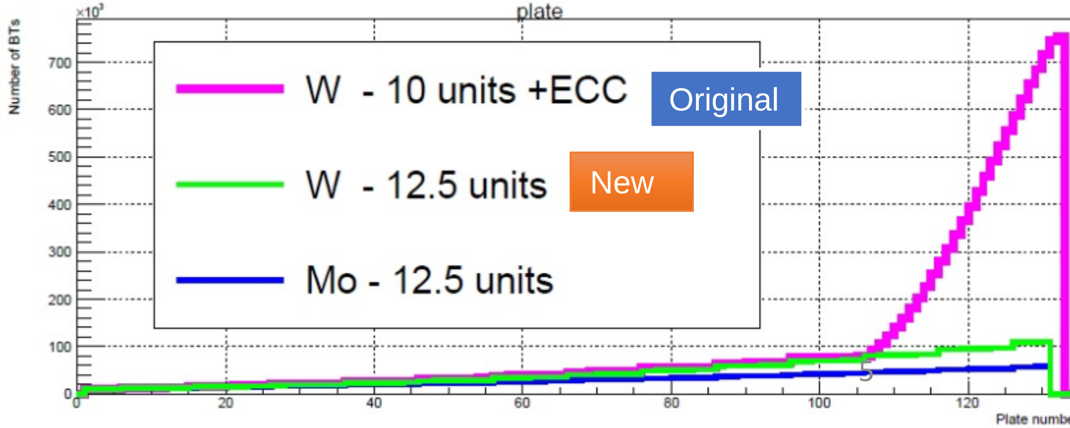
Change of structure for momentum measurement

Momentum measurement is relevant to reject low energy events (MCS mimicking $D_s \rightarrow \tau \rightarrow X$ events)

- Original structure had more material → too high track density
  - Dedicated scanning is required
- Reduce material, but sufficient performance
- Making data taking procedure simple



	Original: lead emulsion ECC	New: additional tungsten units
Structure	25 1mm lead, 26 emulsion plates	3 0.5mm tungsten, 25 emulsion plates
Momentum resolution	20 - 40% (upstream ev.) 20 - 40% (downstream ev.)	15 - 40% (upstream ev.) 35 - 45% (downstream ev.)
Weight	15.0 kg	2.4 kg



DsTau milestones

LOI in 2016

TP in 2017

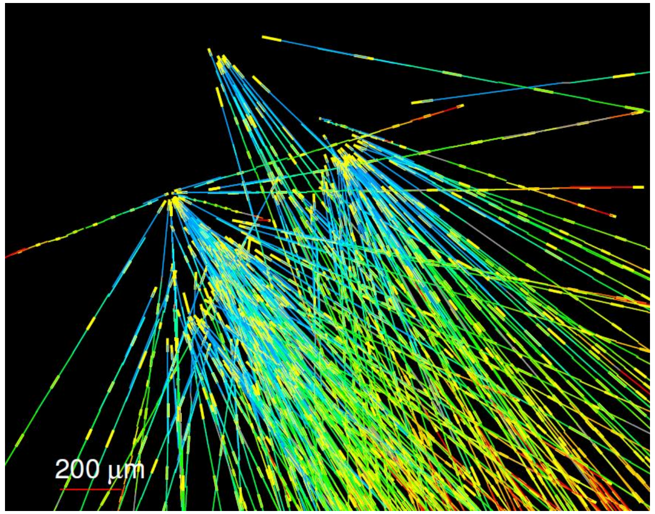
Approved as NA65 in June 2019

Test beam 2016
- Test of detector structure

Test beam 2017
- Improved detector structure
- Refine exposure scheme

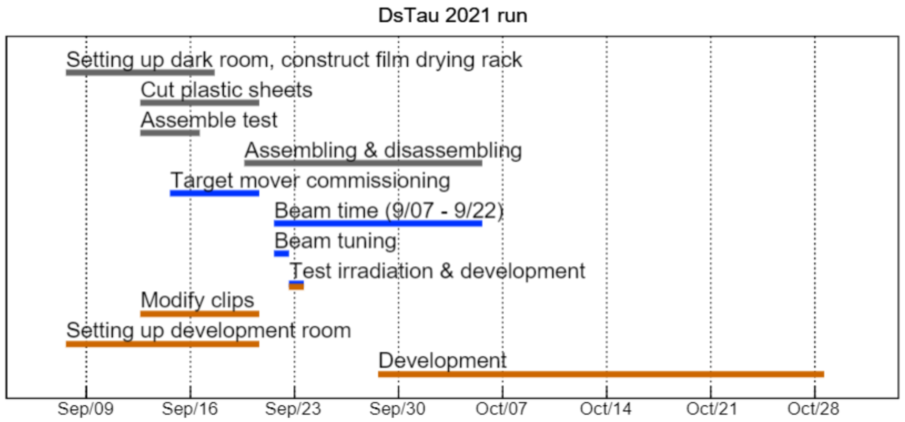
Pilot run 2018
- 1/10 of the full-scale experiment with tungsten target
- 30 modules, 50 m^2

Physics run 2021-2022 (2023)
- Full scale experiment with tungsten and molybdenum targets
- Aiming at 1000 $D_s \rightarrow \tau \rightarrow X$ events
- 10 % uncertainty on ν_τ flux



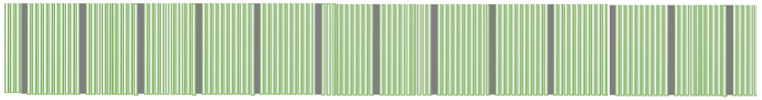
DsTau 2021 run

- Originally, we planned to use a total area of emulsion films of >200 m^2 → reduced to 110 m2 due to COVID19
- Several new:
  - Film size
  - Target mover
  - Development facility

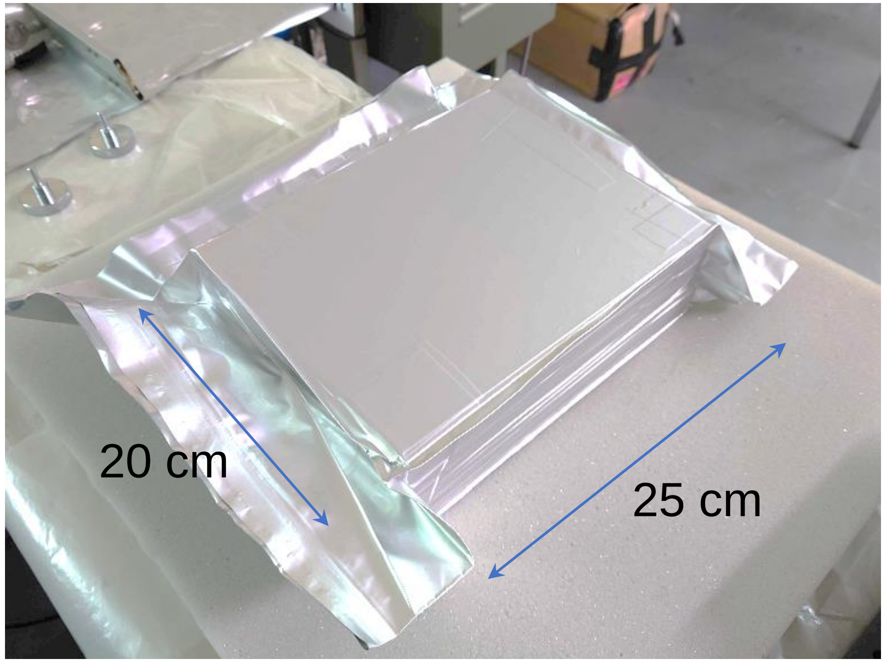


2021 run: Module assembling

- New assembling table
  - Films size from 12.5 cm x 10 cm → 25 cm x 20 cm
  - A total of 259 components/module

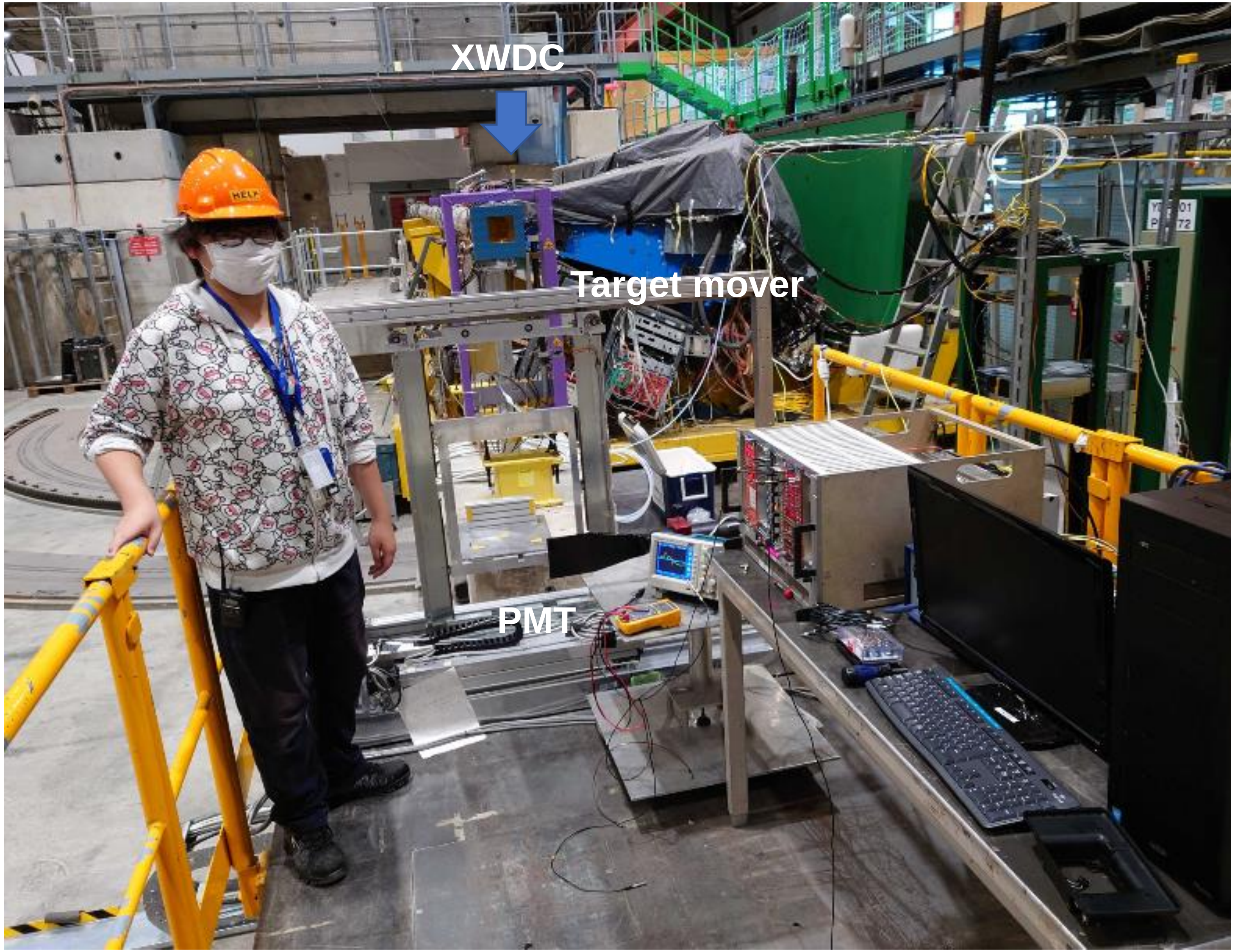


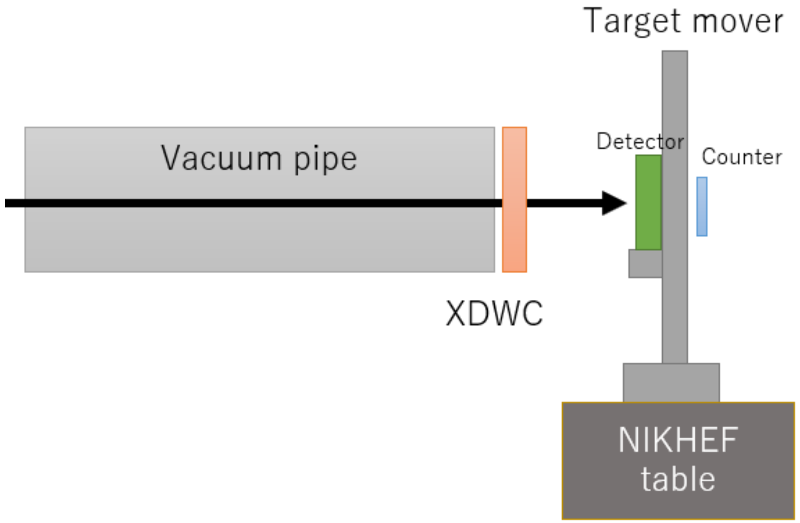
Vacuum packed to keep sub-micron alignment



A total of **17 modules** were produced

Setup in H2





- New target mover
- XDWC for beam profile monitor
- Scintillator(s) to feedback beam intensity in real-time

Exposure process

Set a module on the target mover → Exposure → Remove the exposed module

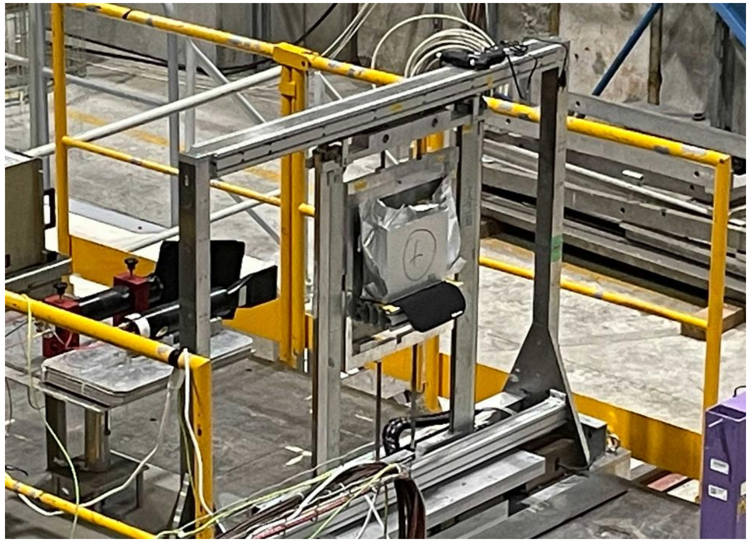
20 min

1 hour ~ 4 hours

Nighttime
2 spills/SC

Daytime
1 spills/SC

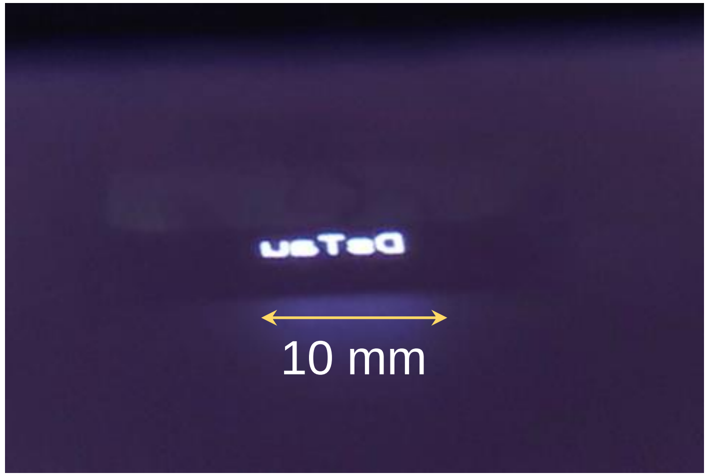
20 min



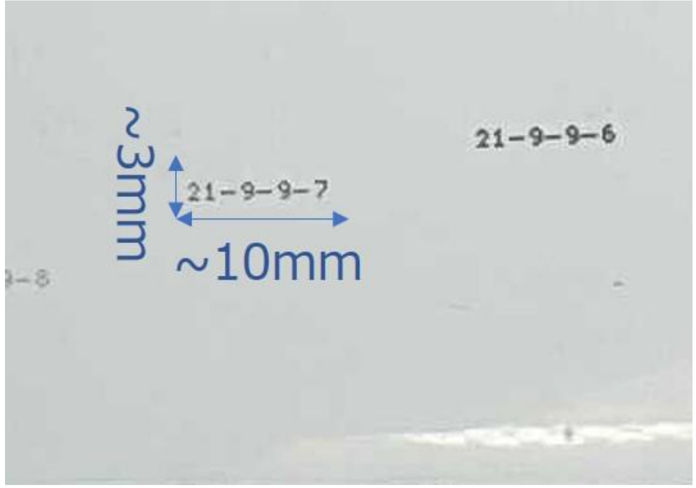
Film labeling

- Emulsion films are labeled by an optical label printer
- Raspberry pi -> LED dot matrix -> lens -> emulsion
- A trouble during operation (a fraction of films doesn’t have a readable pattern), but recoverable.

Light pattern on emulsion film



Labels after development



Development

the man with the clocks - didn't miss a second

preparation of fixer

putting clips

after development

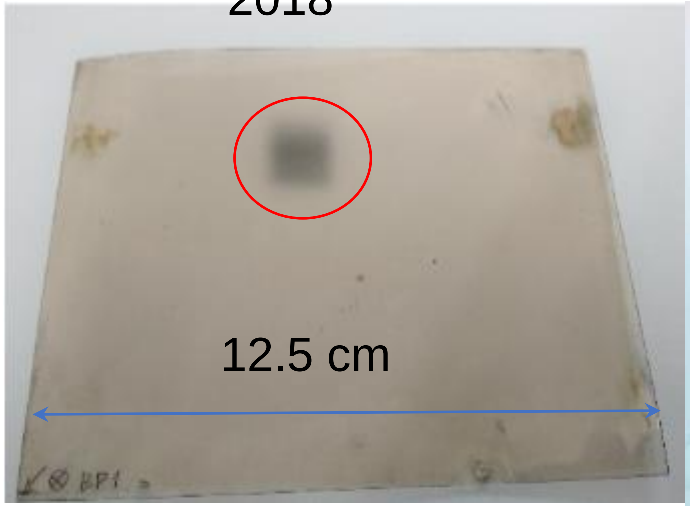
Drying films

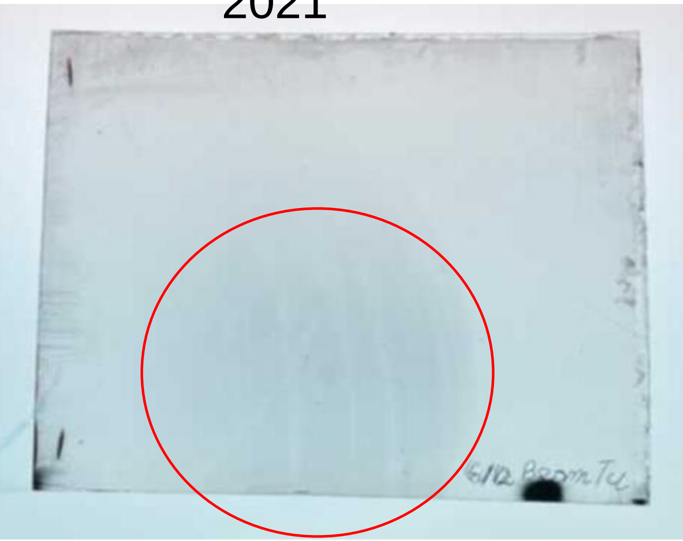
This was the first large scale development after CHORUS in 90s!
~2200 films were developed in 3 weeks

Comparing beam size with 2018 and 2021

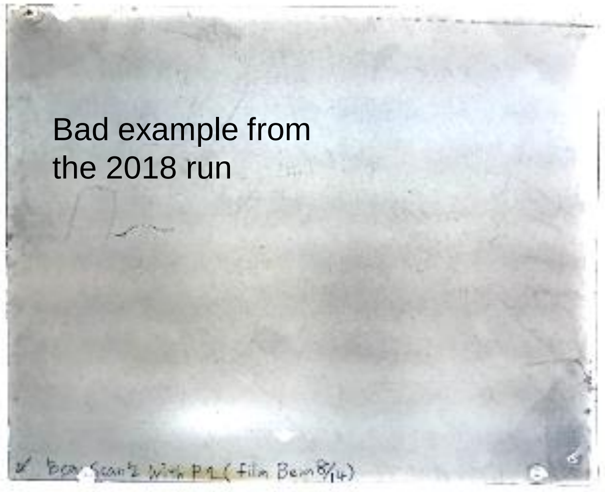
2018 | 2021

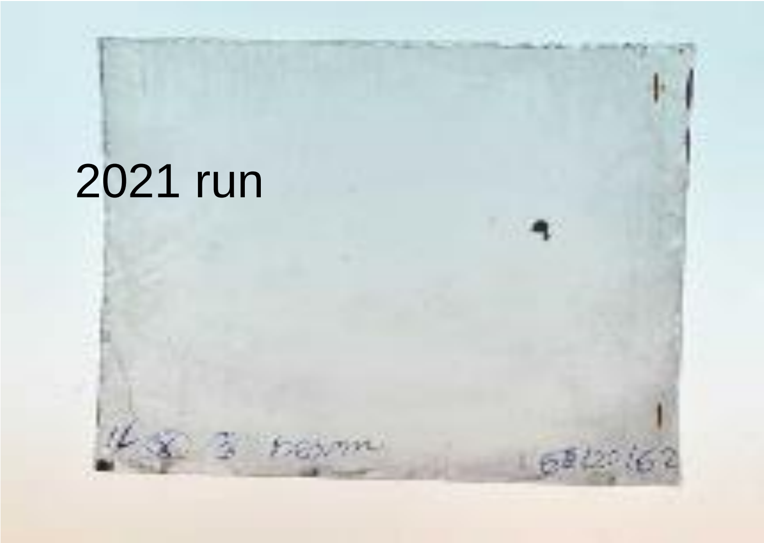
Single spot irradiation





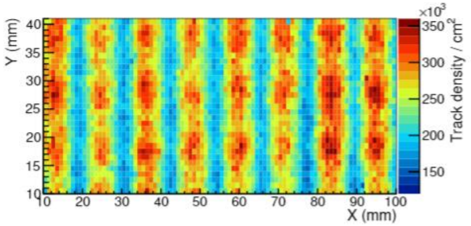
Irradiation with scanning by target mover



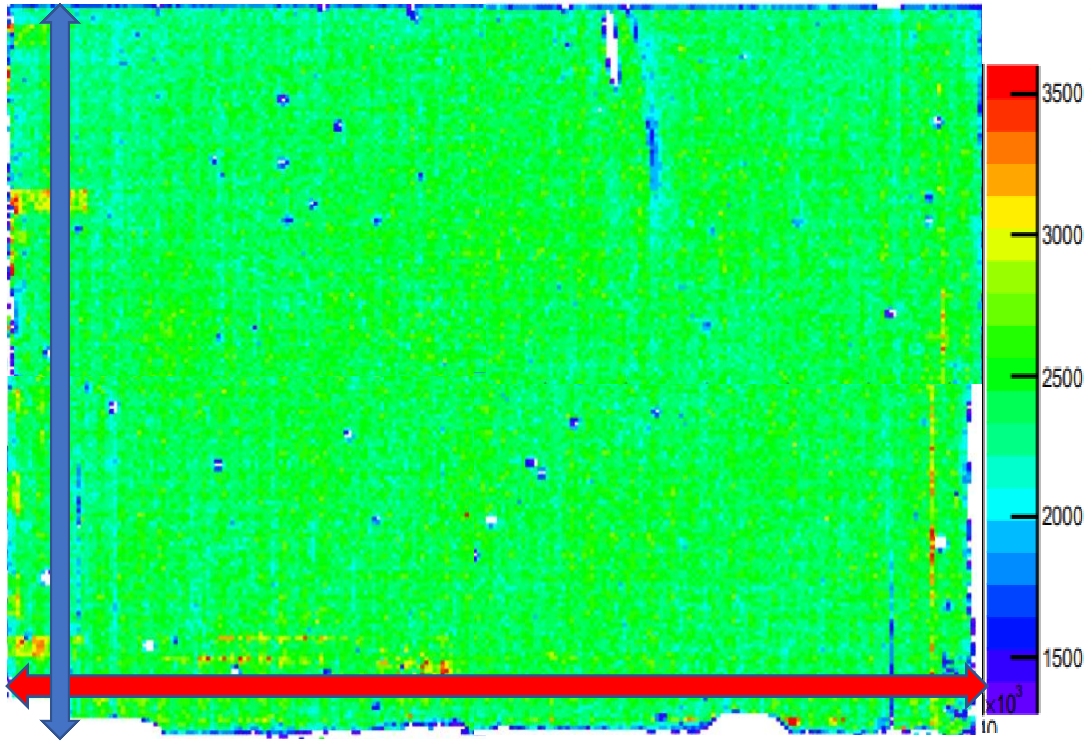


Evaluation of track density uniformity

2016 TB



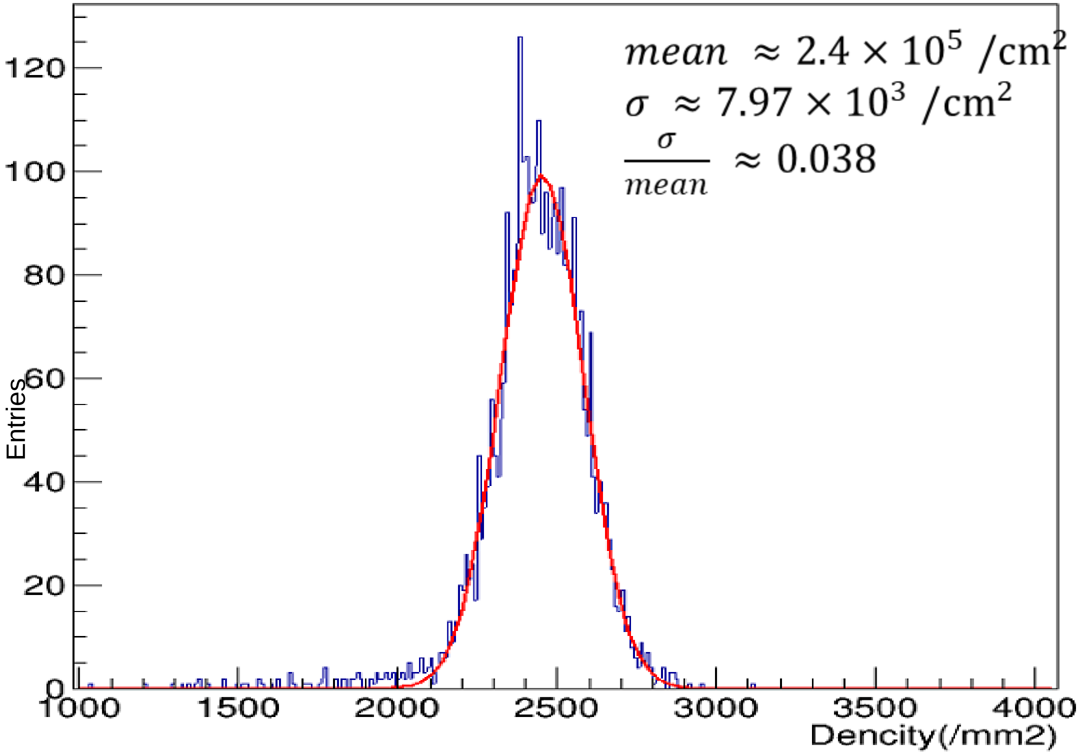
2021 run



20cm

25cm

Distribution of density, fitted by Gauss function

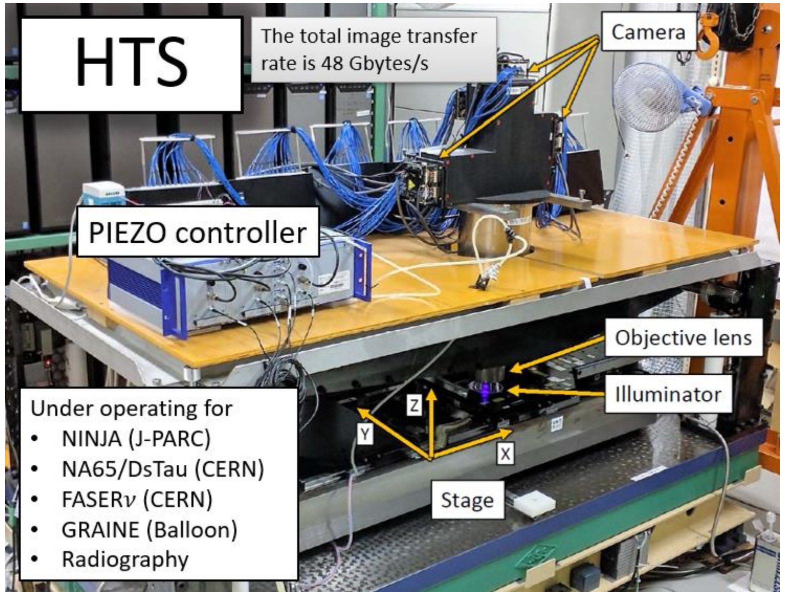


$3.8\% < 10\%(target)$

→enough uniformity is achieved by Target Mover

Summary the DsTau 2021 run

- 17 modules were exposed
  - 12 tungsten and 5 molybdenum targets
  - → about 30% of total (incl. 2018 run)
- All films were developed within 3 weeks
- Currently
  - Silver removal is being done
  - Swelling and scanning is ongoing



Emulsion facility at Meyrin (B169)

- DsTau, FASERν, SND@LHC + SHiP-charm need to share the same emulsion facility, but it was very old
- These experiments jointly requested a renovation → Accepted
- Renovation work is ongoing since 2021
- 4 bodies made an "Emulsion facility task force" to organize activities and schedule

Plan for 2022, 2023 runs

- Still, no foreign shifters can contribute to emulsion film production in Japan due to Covid.

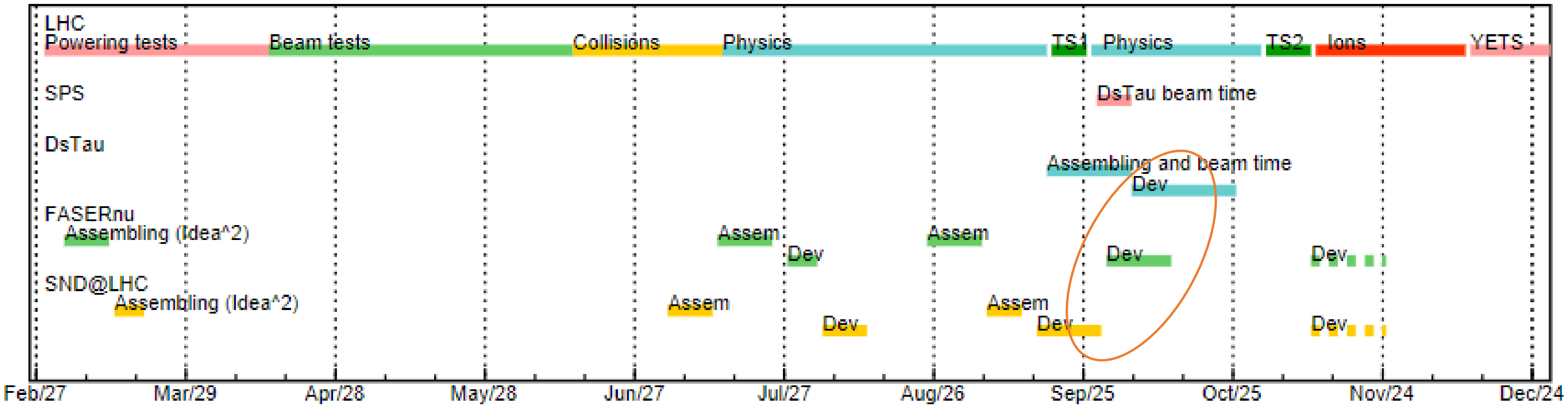
  → Limited amount of emulsion, ~100 m2

  - Shortened beam time (1 week) was requested

	Plan 2021	Updated plan 2022
Pilot run	50 m^2	50 m^2 (1w)
2021 run	100 m^2	110 m^2 (2w)
2022 run	450 m^2	110 m^2 (1w)
2023 run	0 m^2	330 m^2 (3w)

- Need an additional data taking in 2023
- 2022 run is scheduled 28 Sep – 5 Oct, for now
  - Crash with other LHC experiments (FASER, SND@LHC) in the use of emulsion facility. Hoping to delay the beam time ~2 weeks later.

Emulsion facility schedule



Data processing

• Film to film alignment and track reconstruction procedures require powerful processing servers with CPU/GPU and high memory (~128-256~GB of RAM) and disk space (~10~TB for each data module) resources.

• Distributed data processing is being done gradually. Up to now, 25 out of 30 modules in 2018 run have been fully processed (track reconstruction).

Japan (Nagoya/Kyushu):

(Nagoya/Kyushu):

2 processing servers

CPU, **GPU**, 256 GB of **RAM**

Storage capacity: ~150 TB

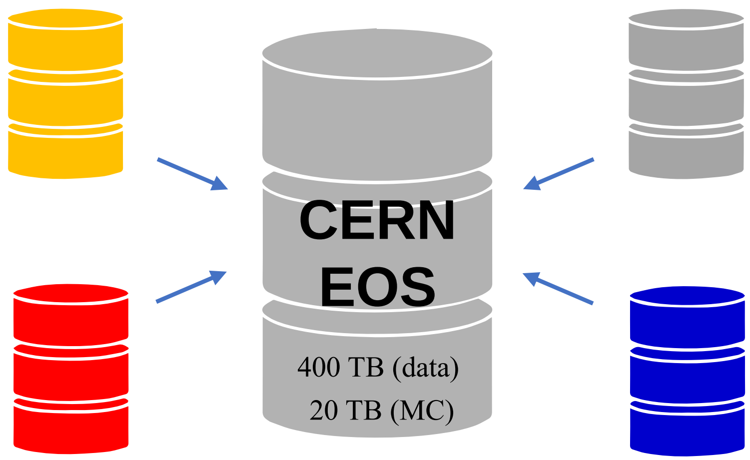
(+2 in Chiba in near future)

Russia (JINR):

2 processing servers

CPU, **GPU**, 256 GB of **RAM**

Storage capacity : ~150 TB



Turkey (METU):

TRUBA computing center resources

CPU, **GPU**, 128 GB of **RAM**

Storage capacity: 100+ TB

Romania (ISS):

1 processing server

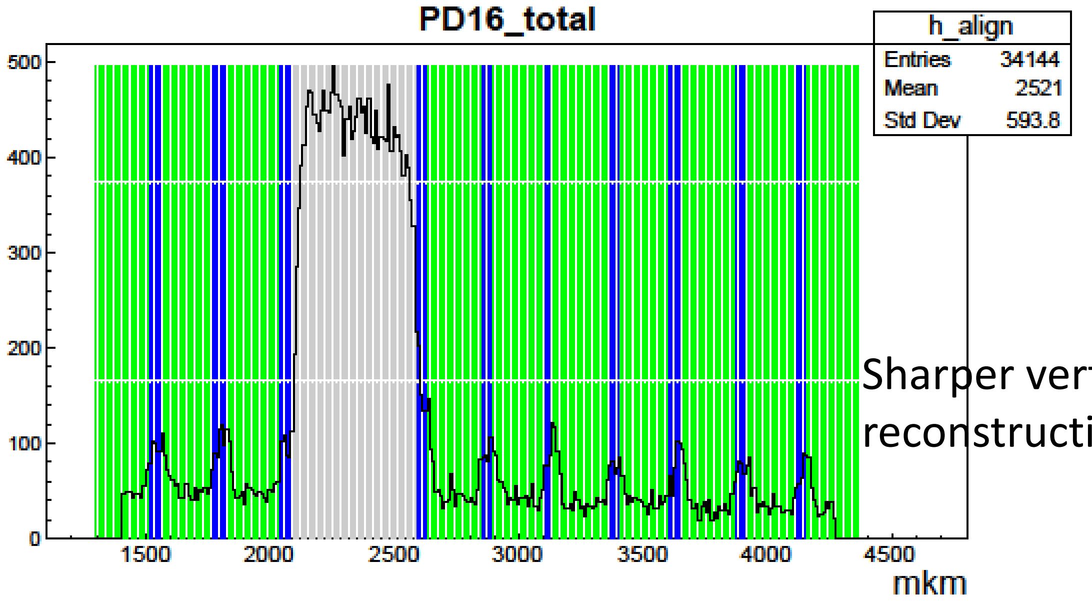
CPU, **GPU**, 128 GB of **RAM**

Storage capacity : ~40 TB

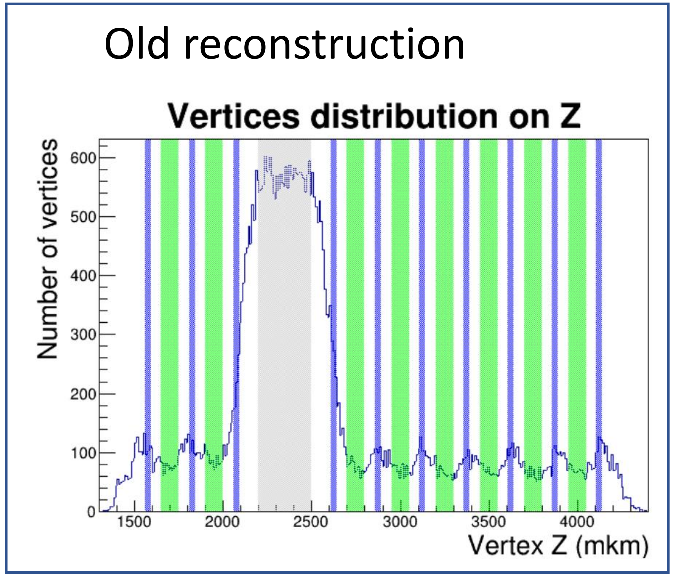
Batch system of the CERN computing center is also going to be used to process the 2021 physics run data.

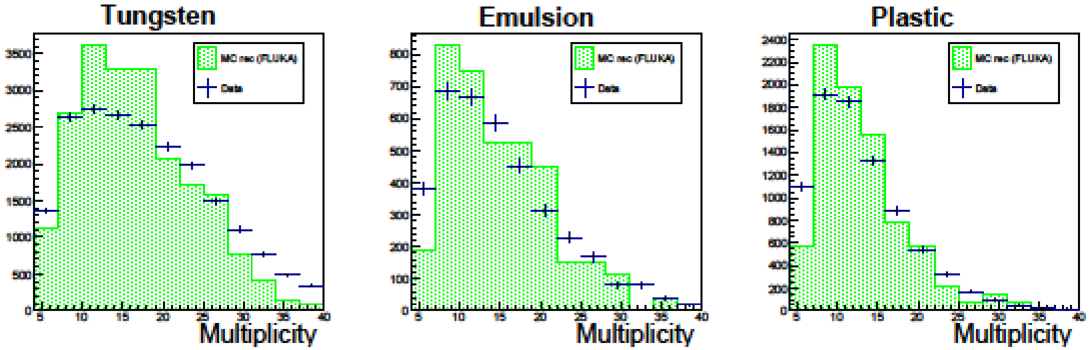
Study of Proton interaction with tungsten

- Proton interaction vertices location by fine alinement on the material boundaries.
- Secondary tracks multiplicity distribution by each detector components.
- The results will be summarized into a paper soon.



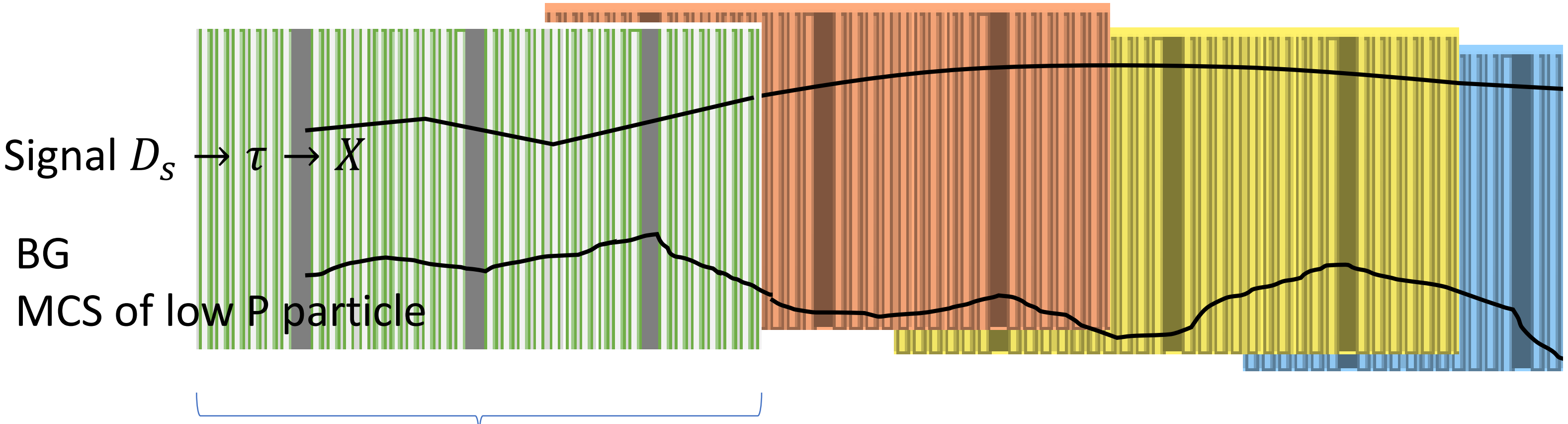
Sharper vertex Z reconstruction



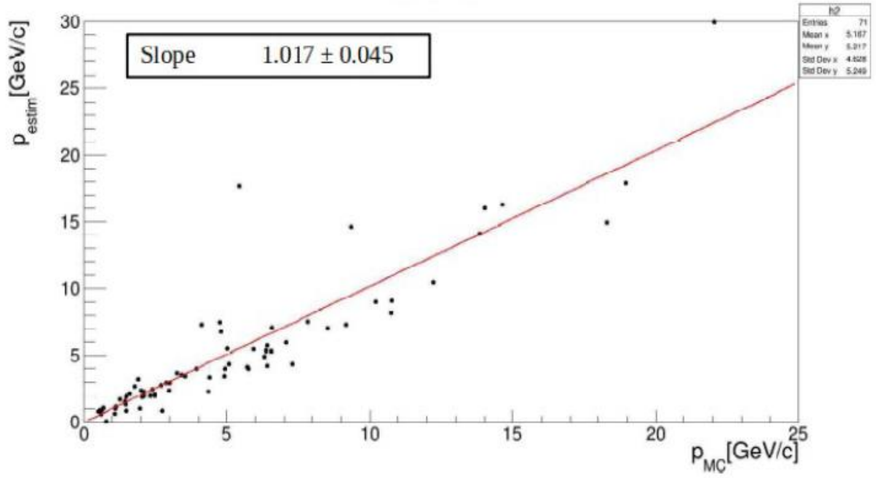


Momentum reconstruction

- Charm decay? or Coulomb scattering?
  - Kinematical information (= momentum, decay Pt) is important to discriminate charm decays from BG
- Algorithm has been implemented and tested
- Systematic application still needs a reorganization of data access over different data sets and alignment between them → Work in progress

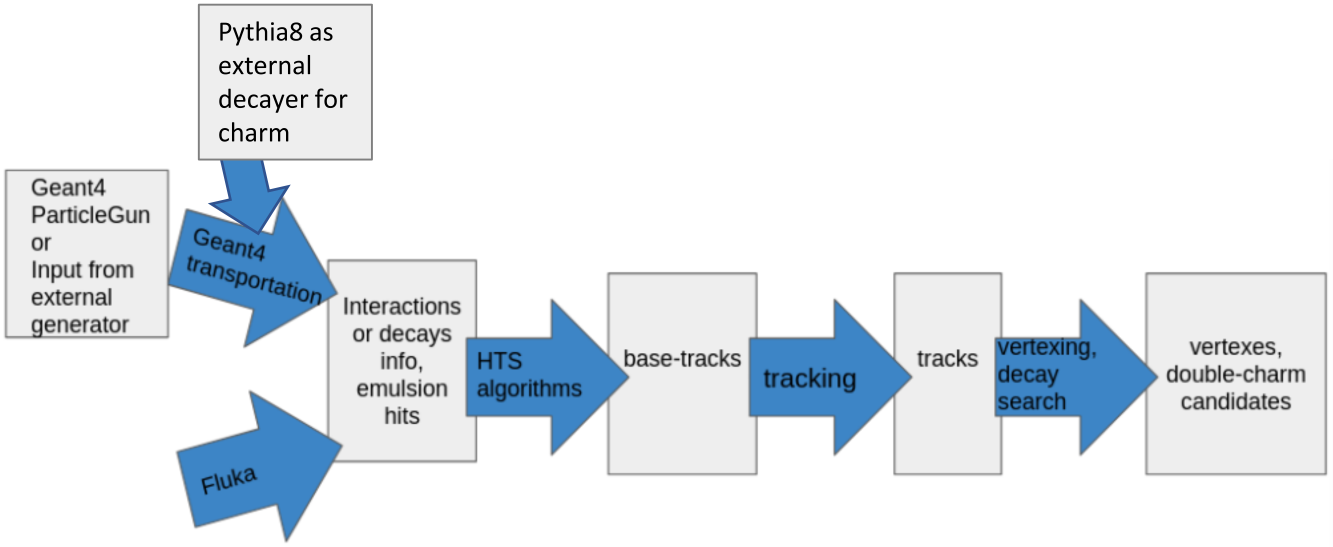


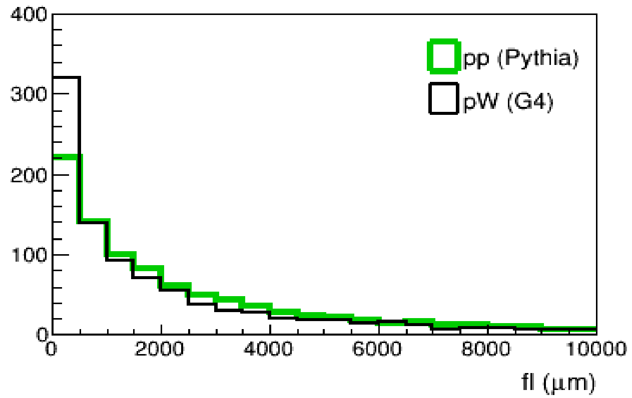
Alignment and tracking are closed in a data set of 30 films

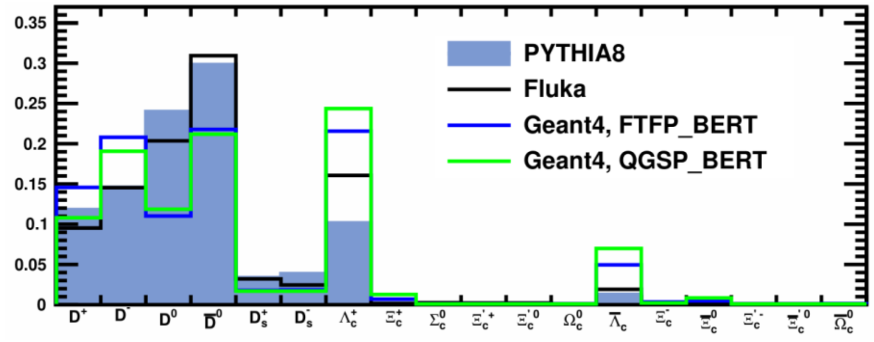


MC studies with different generators

- Now FLUKA/G4 frameworks are available
- Different hadron interaction generators (G4, Pythia, EPOS) can be tested.
- Pythia8 as an external decayer for charm.
- Comprehensive study is still to be done.



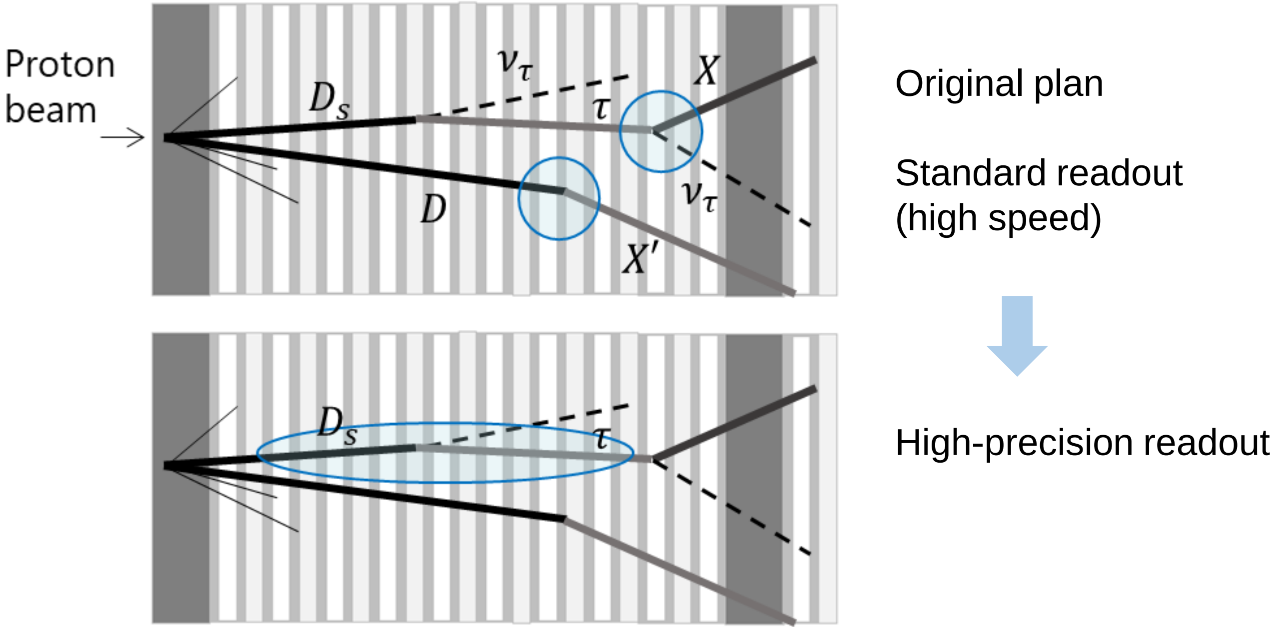




Study for detecting $D_s \to \tau \to X$ decays

MC simulation study with G4 pW interations

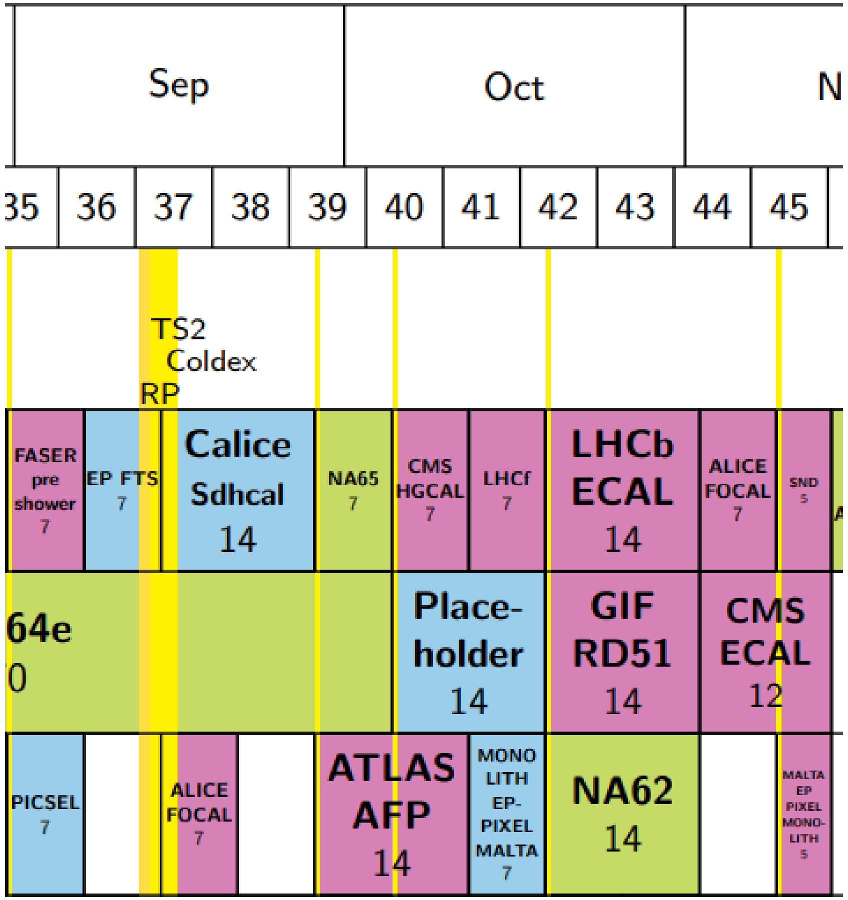
	detected / reconstructed 1ry vertex
$D_s \to X$ reconstructed ((D_s short decay not counted)	19%
$D_s \to \tau \to X$ reconstructed (assuming **only the standard readout**)	5%



- Efficiencies are floating due to
  1. Difference in generator: Since G4's charm flight length distributions are shorter than Pythia, efficiencies will be higher for events from the other simulations. (Can be fitted with DsTau data).
  2. Analysis strategy: Efficiency will be increased by applying the high-precision readout.
  3. Reconstruction effects: Position resolutions implemented in the simulations seem larger than that of the data. MC reconstruction might be revised.

Summary

- DsTau 2021 data taking campaign was successfully finished
  - 30% of planned exposure was done
- We are progressing in data readout, reconstruction and analysis
- MC studies are under revisited
- 2022 run will be again rescaled due to COVID19
  - Consequently we need 2023 run
  - Hoping to optimize the beam time


Sep
Oct
N
35 36 37 38 39 40 41 42 43 44 45
TS2
Coldex
RP
FASER pre shower 7
EP FTS 7
Calice Sdhcal 14
NA65 7
CMS HGCAL 7
LHCf 7
LHCb ECAL 14
ALICE FOCAL 7
SND 5
64e
0
Place-holder 14
GIF RD51 14
CMS ECAL 12
PICSEL 7
ALICE FOCAL 7
ATLAS AFP 14
MONO LITH EP-PIXEL MALTA 7
NA62 14
MALTA EP PIXEL MONO-LITH 5

Tracking improvement

- Miss reconstruction study

Since the track density is bit high than other emulsion experiment application, sometimes tracks are connected to different track at track-reconstruction process.

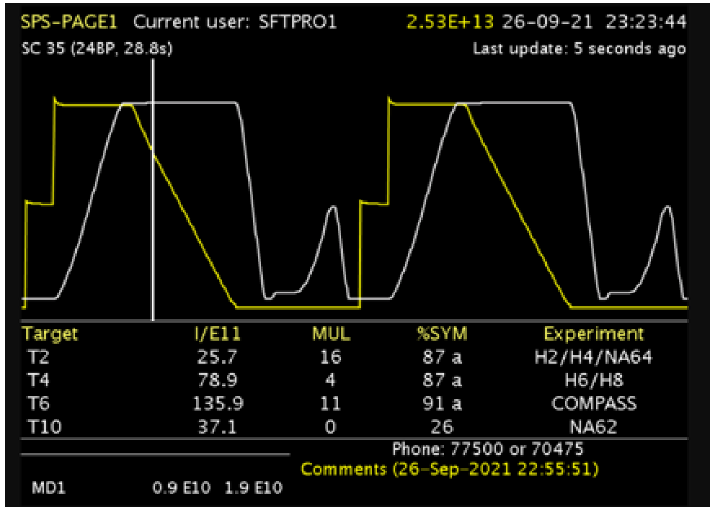
The track miss-reconstruction spoil decay hunting efficiency and MCS momentum measurement accuracy

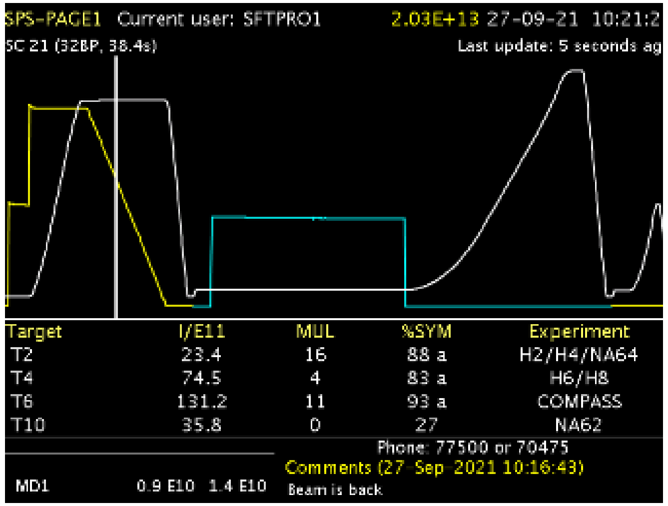
- MC study

A set of MC data were used to estimate wrongly connecting miss-reconstruction rate ~4%.

Estimated exposure time

- Usually (intensity: 5.0e05, daytime of weekday) it takes about 3 ~ 4 hours to finish exposing 1 module.
- On weekends or night (maybe after 7:00 p.m.) it takes shorter (about 1 ~ 2 hours).





↑ CERN Visters SPS Page1, weekday night (left) and daytime (right).

QCD with accelerators