The NA65/DsTau experiment, status and plans

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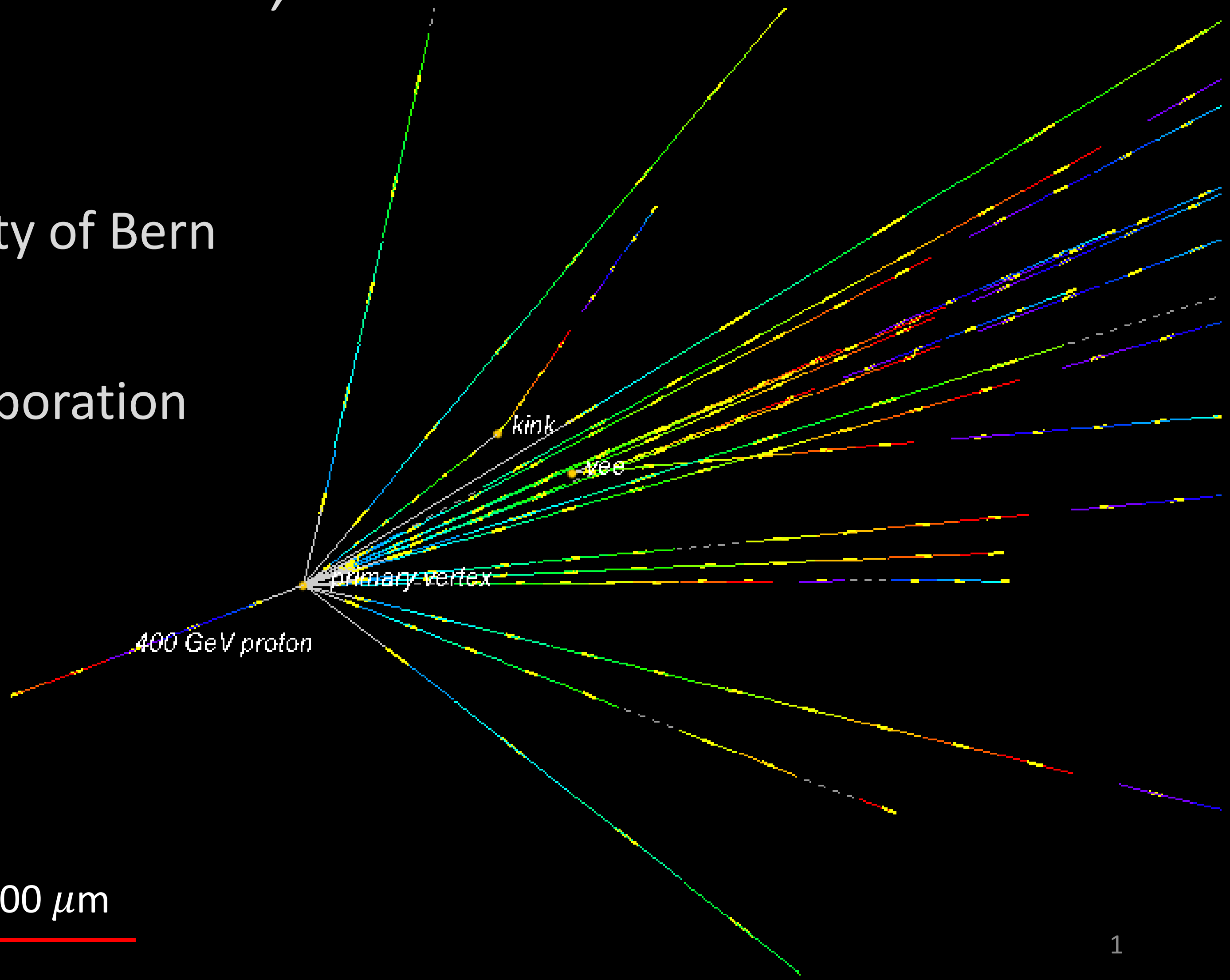
(Spokesperson)

On behalf of the DsTau Collaboration



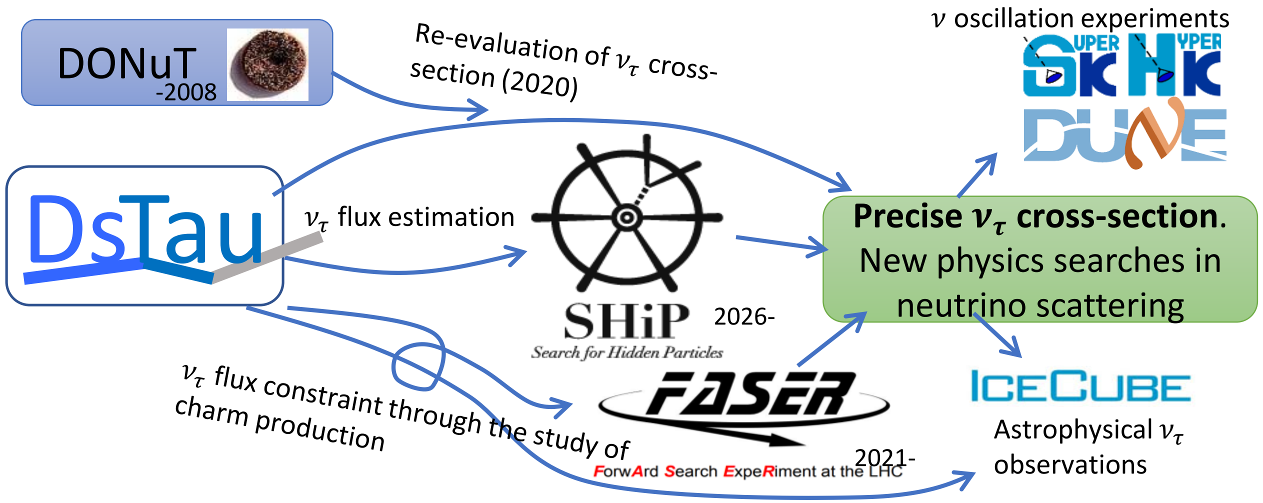
500 μm

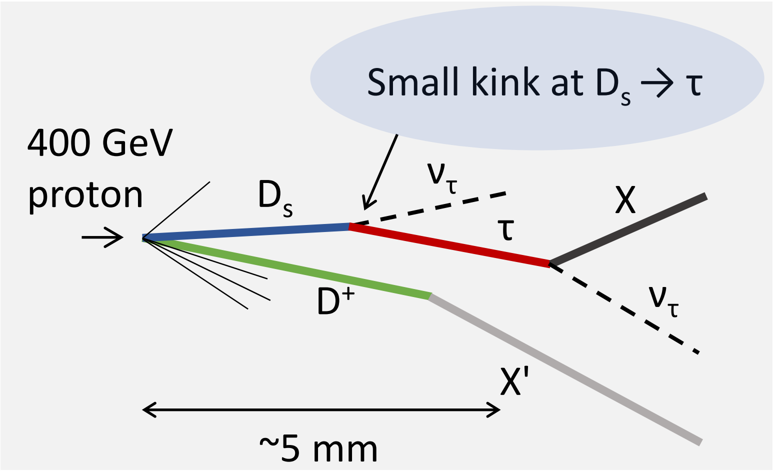
DsTau paper:
[10.1007/JHEP01(2020)033](https://doi.org/10.1007/JHEP01(2020)033)

DsTau web site:
https://na65.web.cern.ch/

The NA65/DsTau experiment at the CERN SPS

- Study of ν_τ production for future tau neutrino experiments.
  - First measurement of D_s **double differential production cross section**
  - Reduce uncertainty of ν_τ flux 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.

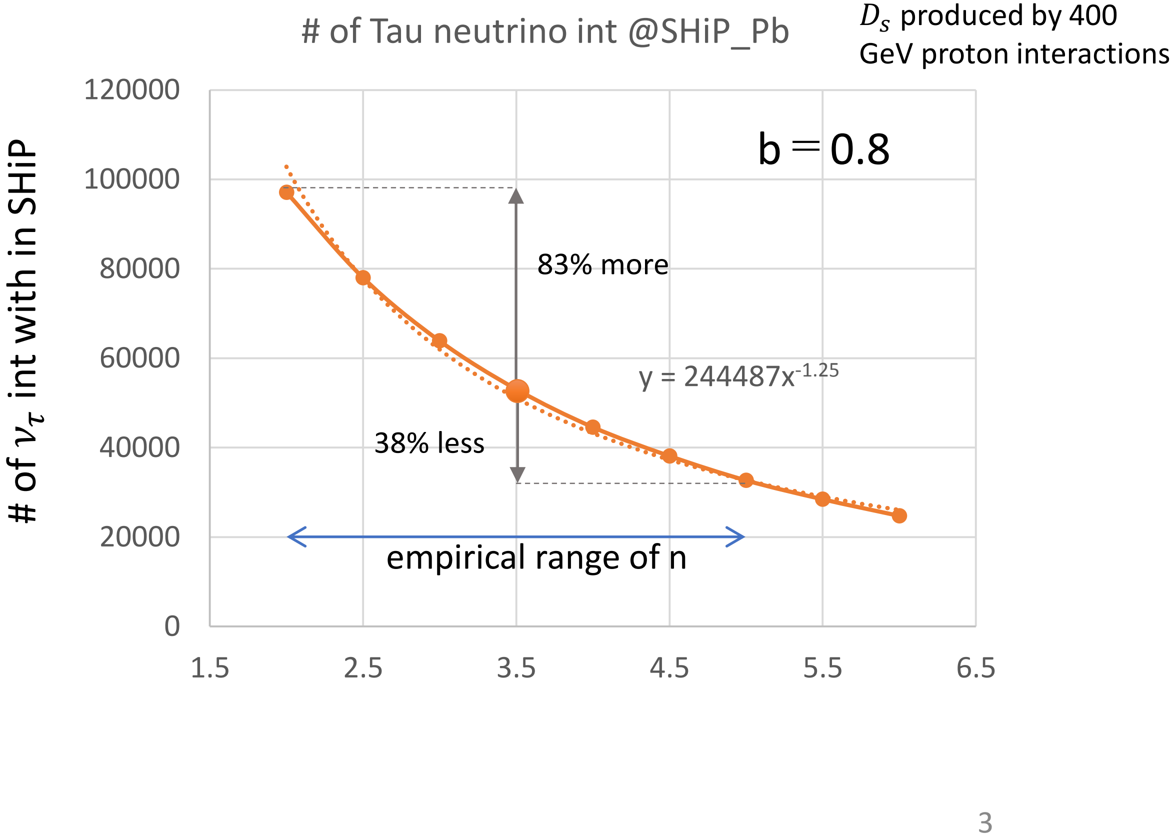
Impact of the ν_τ flux uncertainty to the SHiP ν_τ measurements

- There is neither data on D_s differential production xsec at 400 GeV p-N interactions → The same situation with DONUT

Phenomenological formula

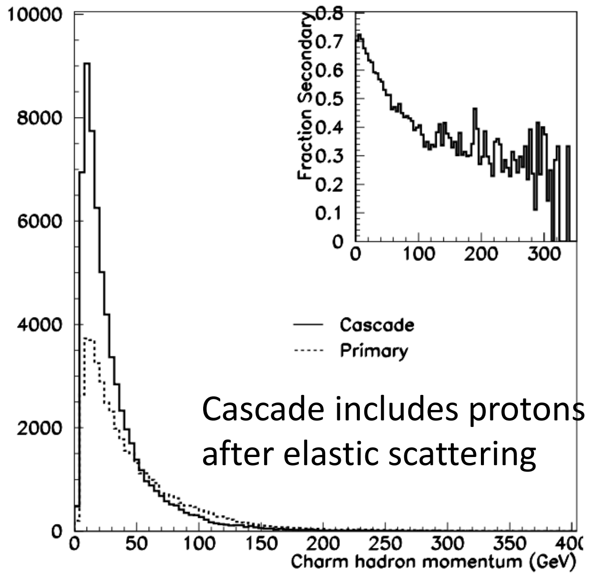
$$\frac{d^2\sigma}{dx_F\,dp_T^2} \propto \underbrace{(1-|x_F|)^n}_{\text{longitudinal dependence}} \underbrace{\exp(-bp_T^2)}_{\text{transverse dependence}}$$

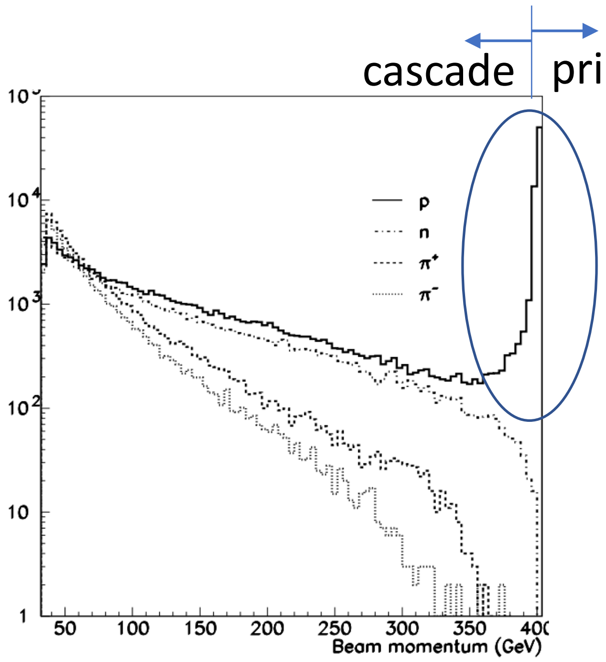
- No experimental data on n
- The expected number of ν_τ interactions strongly depends on n.
  - Empirical value of $n = 3.5 \pm 1.5$
  - Expected event rate varies +80% -40%
- Direct impact to ν_τ cross section measurement!



Charm production in the BDF/SHiP

SHiP-NOTE-2015-009





Parent momentum

Main contribution for the ν_τ interaction rate in SHiP

For neutrino interaction rates in SHiP detector one has to take into account also

- Detector acceptance, only forward emitted tau neutrinos intersect detector (~5% of produced ν_τ)
- Neutrino cross section, higher neutrino energy, higher cross section

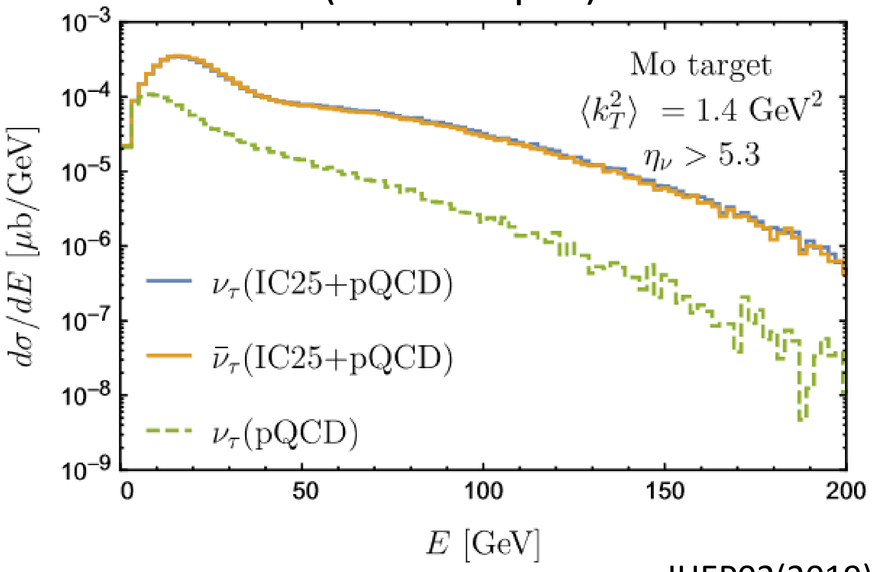
The contribution from cascade production (lower energy, wide spread) is limited.

A data at 400 GeV from DsTau would provide a good representation of charm production at the BDF

Theoretical uncertainty in forward charm production

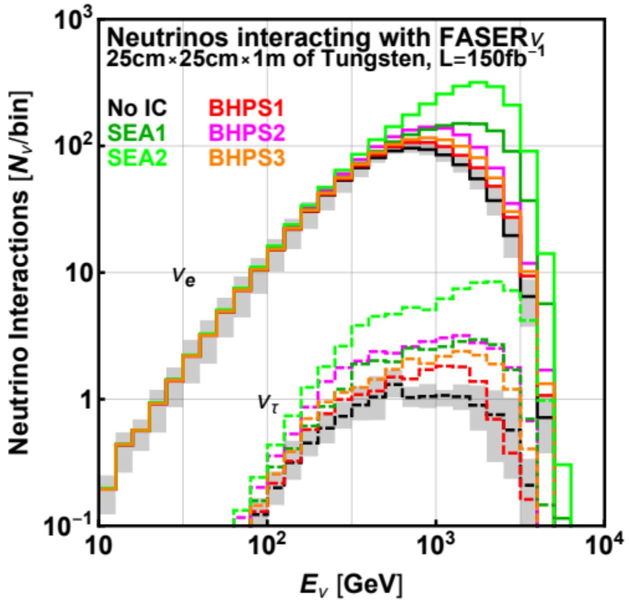
- Large theoretical uncertainty for forward charm production.
  - ex) “intrinsic charm” content of proton can affect ν_τ flux drastically, by enhancing charm meson production in forward direction
- ν_τ flux may change by a factor of 10

SHiP case (400 GeV p-N) interaction



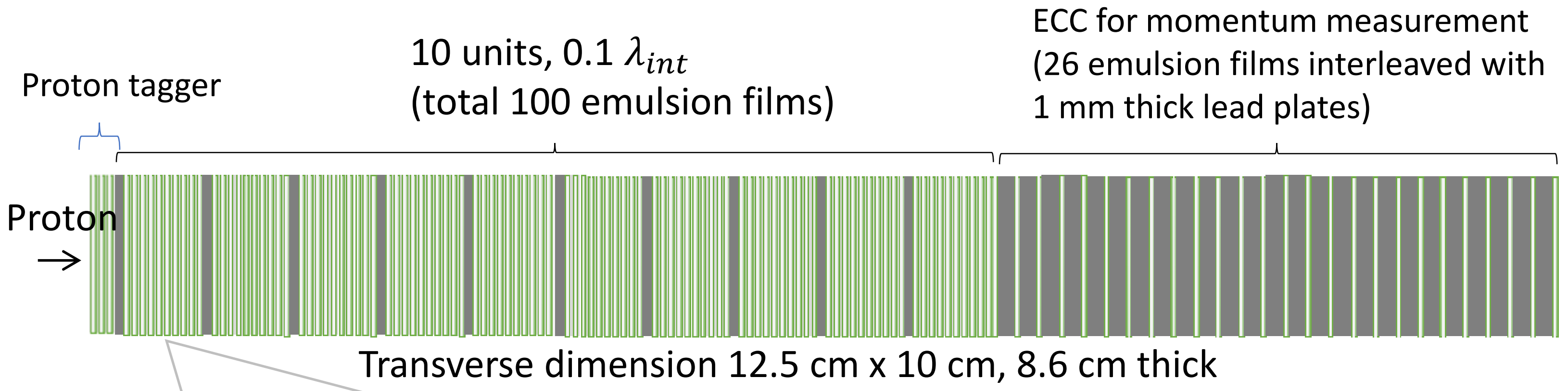
JHEP02(2019)077

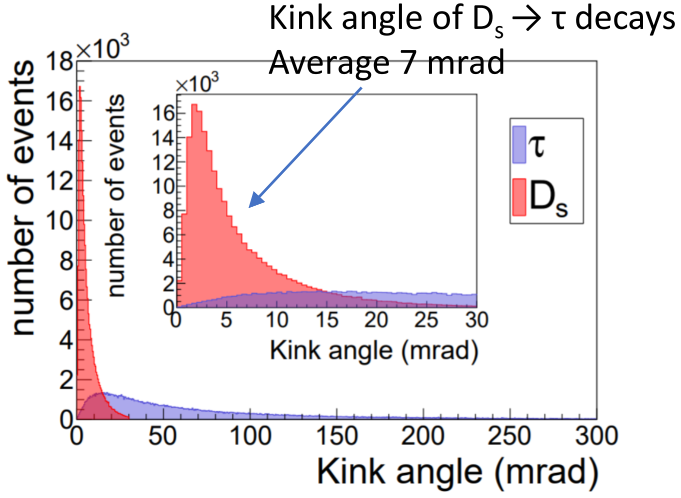
FASER case (7-7 TeV)

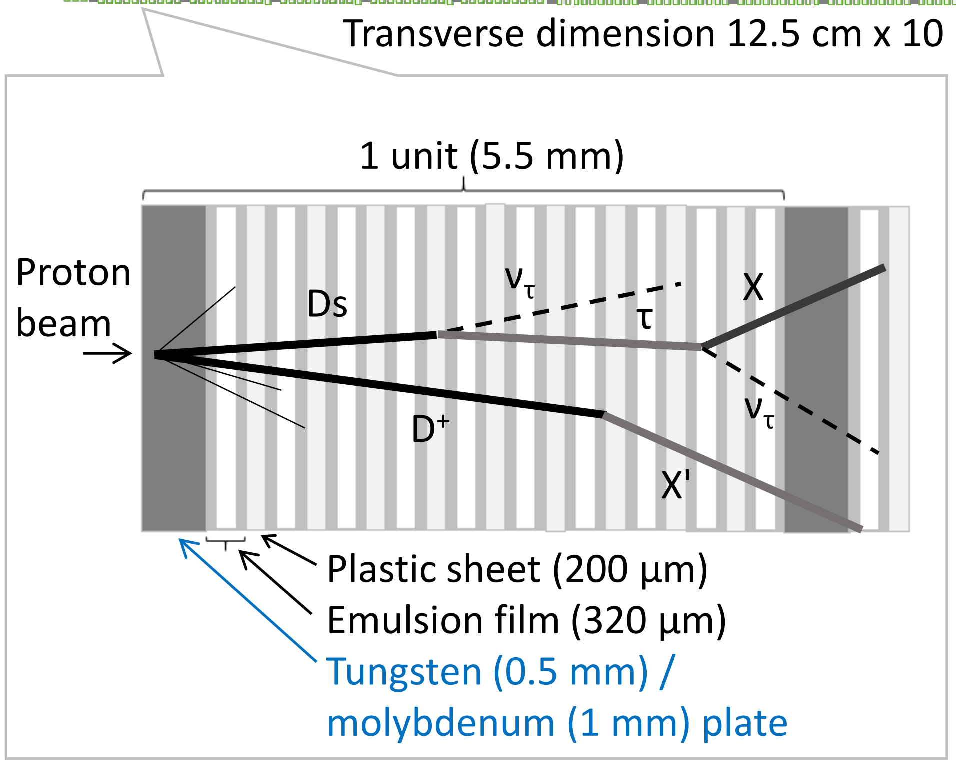


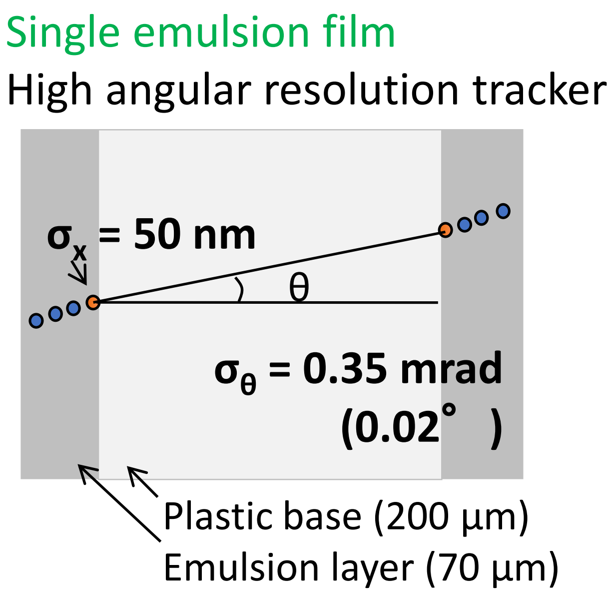
10.1140/epjc/s10052-020-7631-5

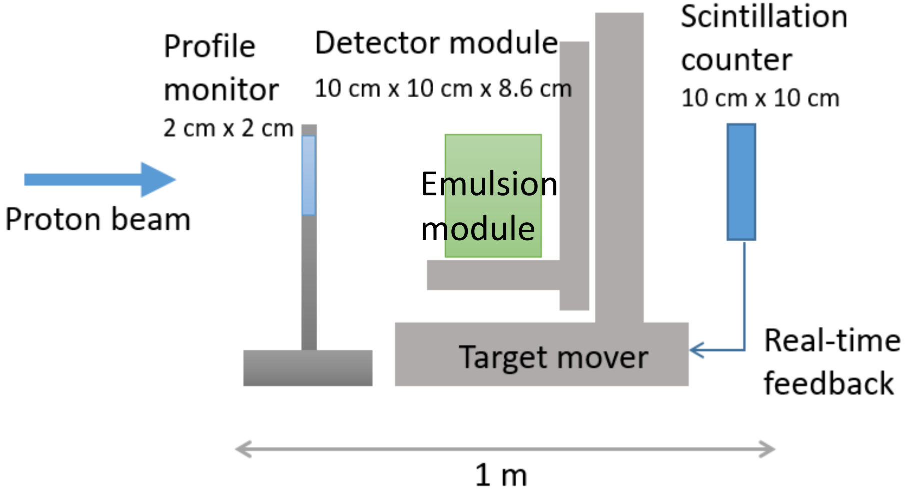
Emulsion based detector structure for $D_s \rightarrow \tau \rightarrow X$ measurement











A total of 370 modules to be analyzed

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 % uncertainty on ν_τ flux
- Revise the DONUT result
- Charm physics

We are here

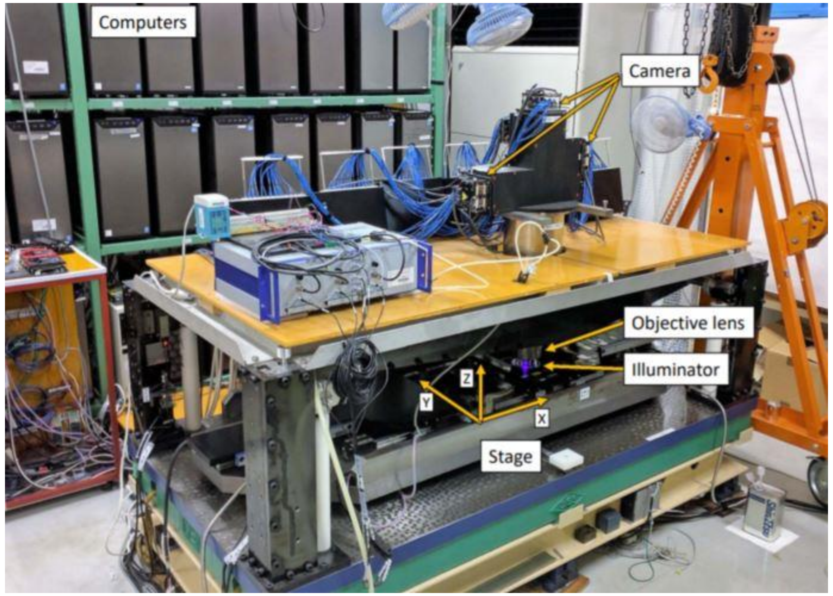
Physics run 2021-2022

- Full scale experiment with tungsten and molybdenum targets
- Aiming at 1000 $D_s \rightarrow \tau \rightarrow X$ events
- 10 % uncertainty on ν_τ flux

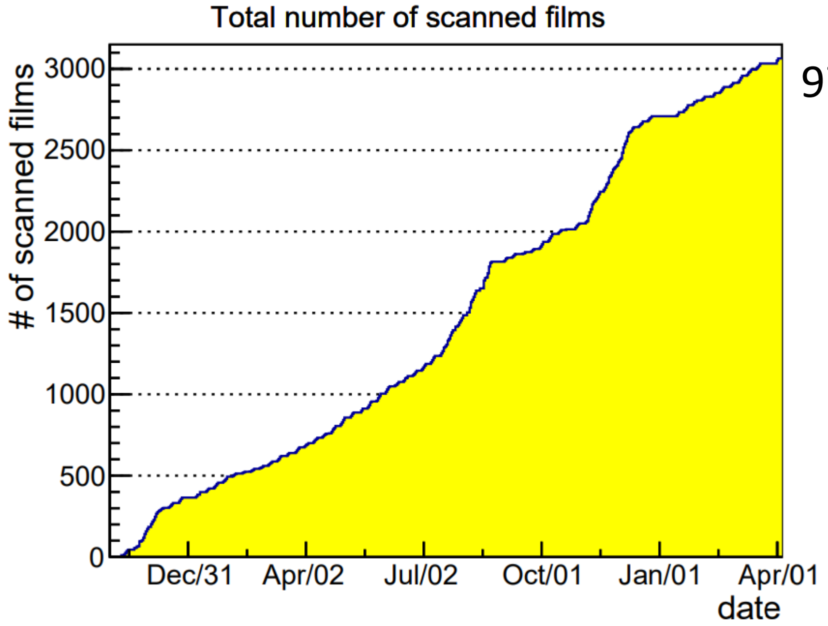
In total 30 modules were exposed

Fast readout by the HTS

- HTS: 100x faster than the scanning system of OPERA
  - Area scanning speed of 0.5 m^2/h
  - Effective throughput 13 GB/s
- **97%** of the pilot run films (3150 films) was already scanned



Scanning progress



97%

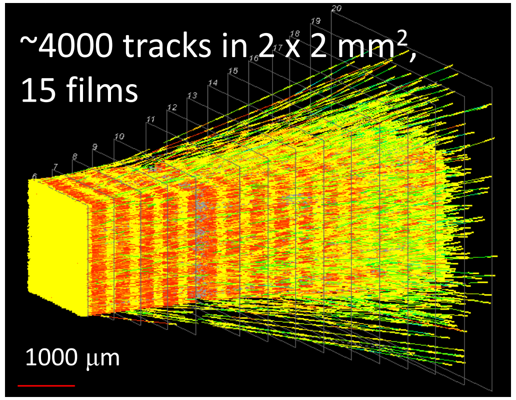
2018 Nov

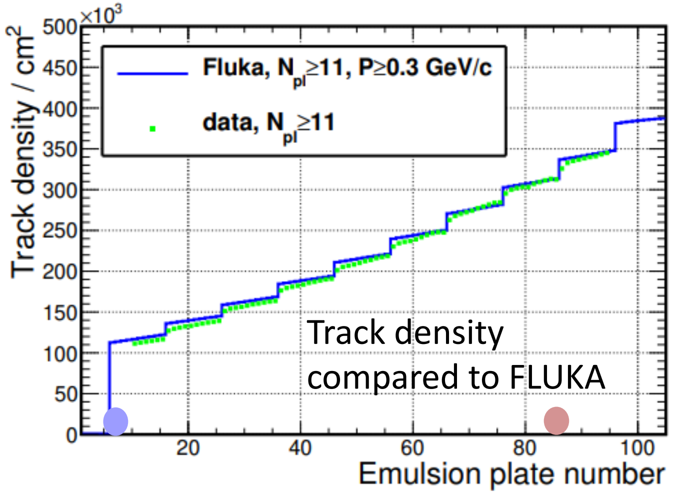
2020 May

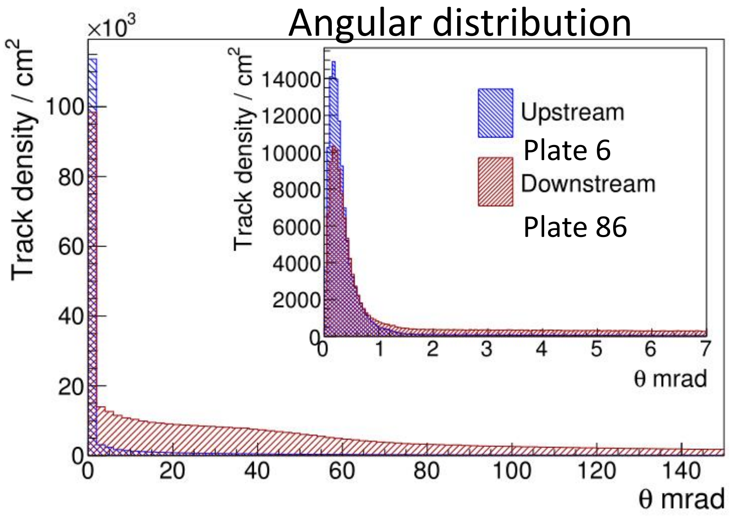
Reconstruction performance: Track reconstruction

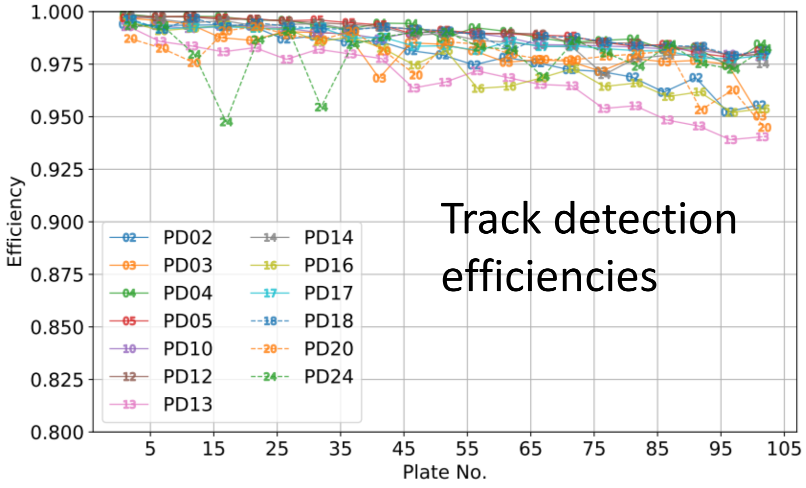
High track density (OPERA x 1000) → New tracking algorithm

Fine alignment with proton tracks, **0.4 μm** position accuracy → **0.1 mrad** angular resolution for long tracks (>7mm)



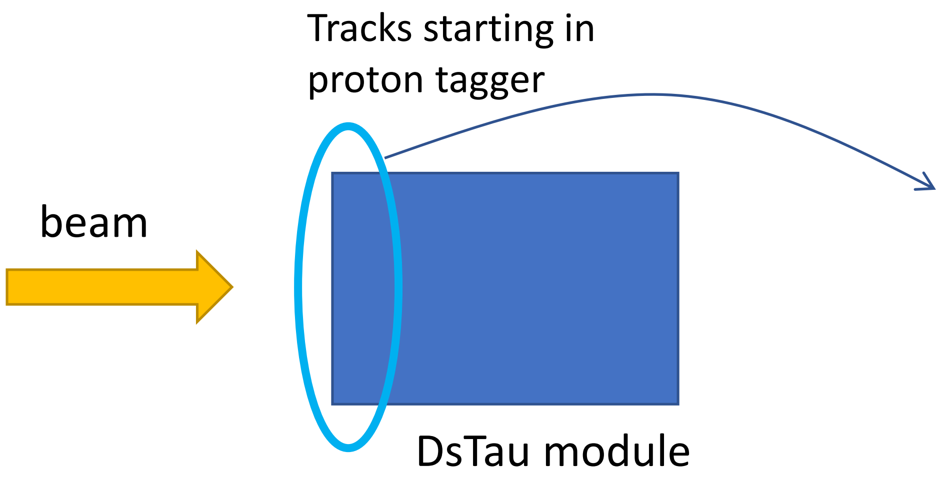


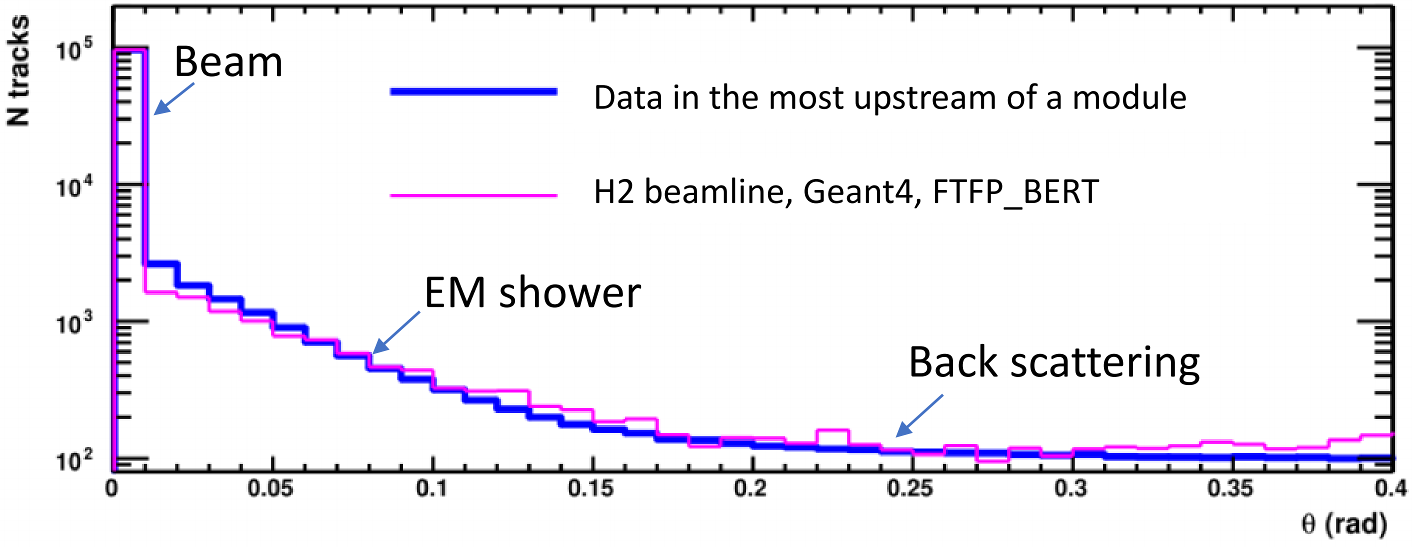




Beam purity estimation

- Reconstructed data was compared to the H2 beam line simulation with the exact magnet, collimator settings → Good agreement.
- From the simulation, the contamination is expected to be less than 2 % in the angle acceptance $\theta < 2\text{mrad}$.

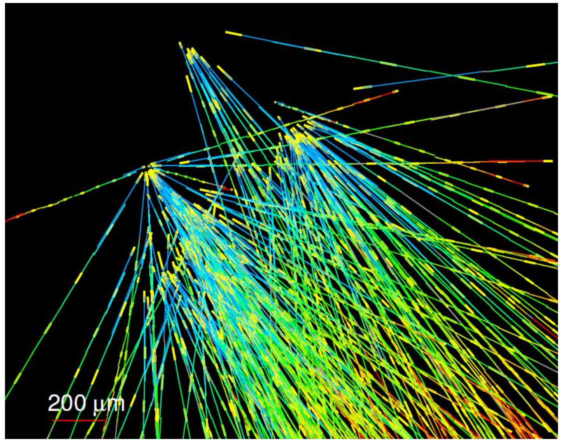




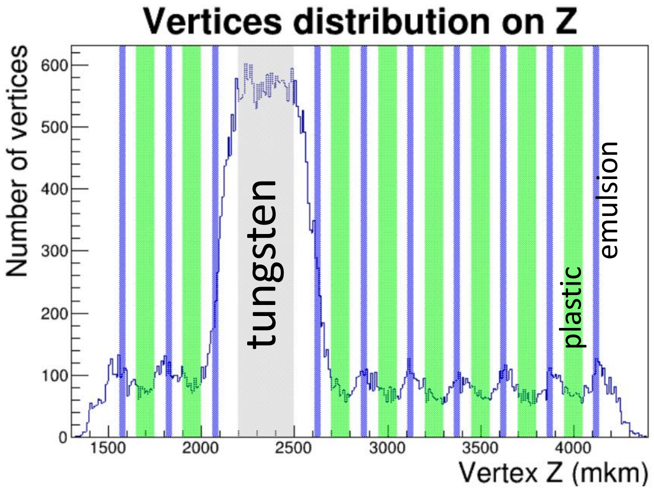
Track slope w.r.t. beam

Proton interaction analysis

Tracks emerging from tungsten target

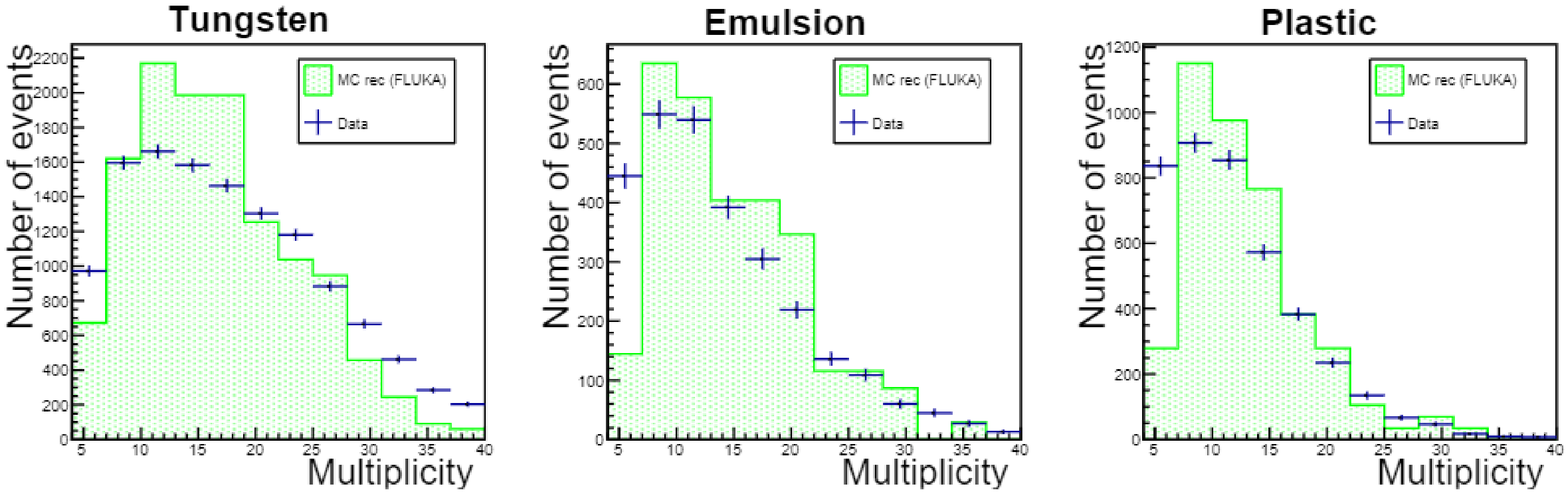


Vertex density ~500/cm²/ tungsten plate



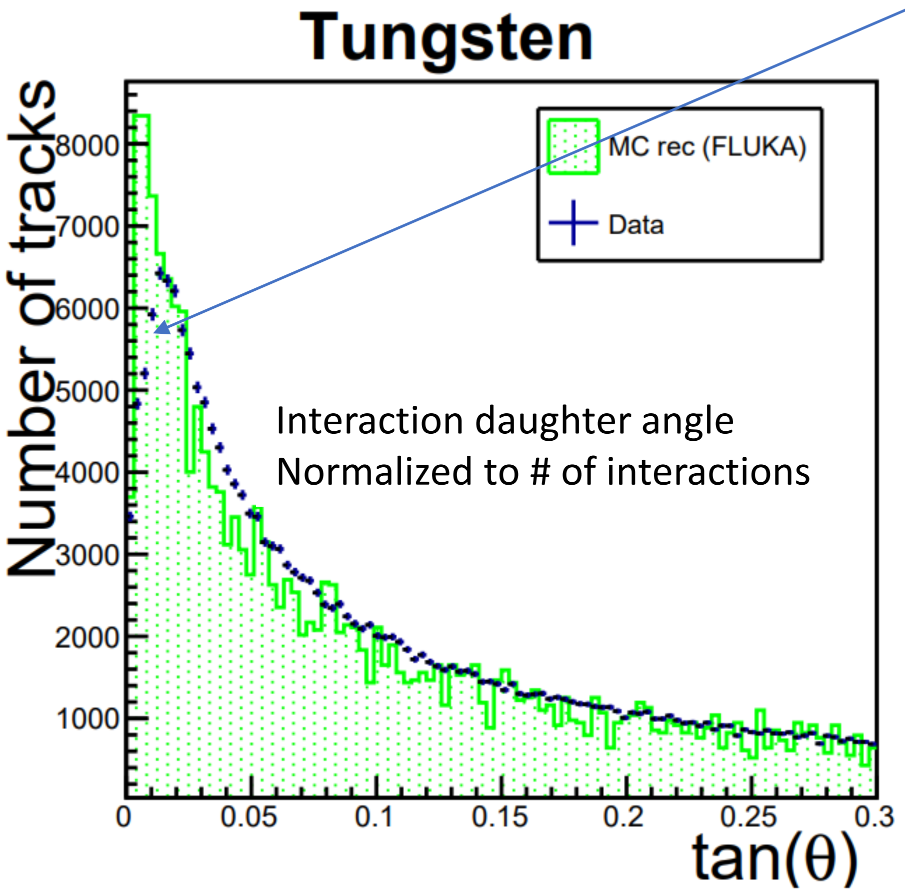
Fine detector structures are visible by reconstructed vertices.

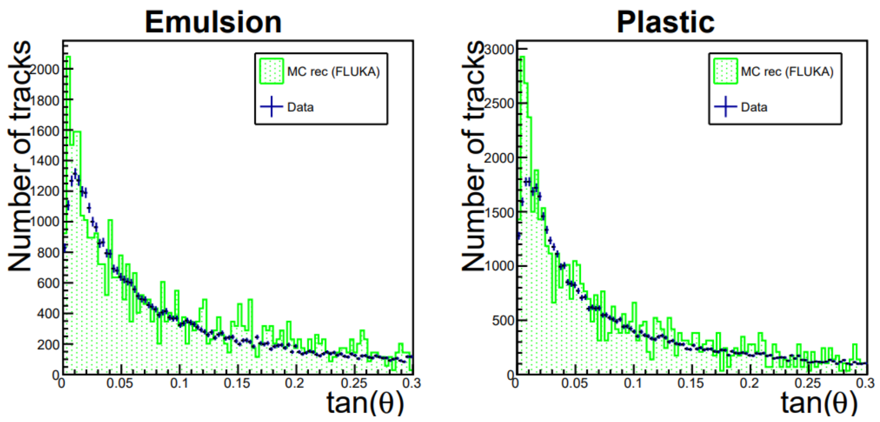
Charged particle multiplicity at the proton interaction vertices

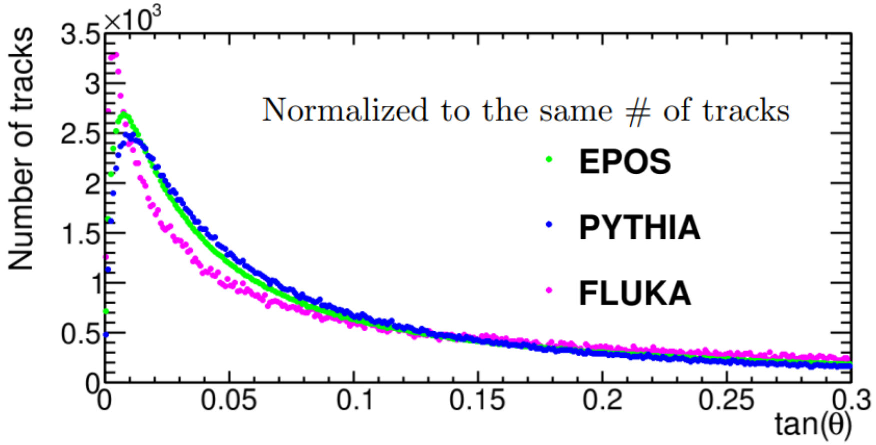


Angular distributions

- General distribution agrees with the FLUKA prediction.
- A deficit of forward angle (<20 mrad or $\eta > 4.6$) is observed.
- Comparisons between other generators are ongoing.

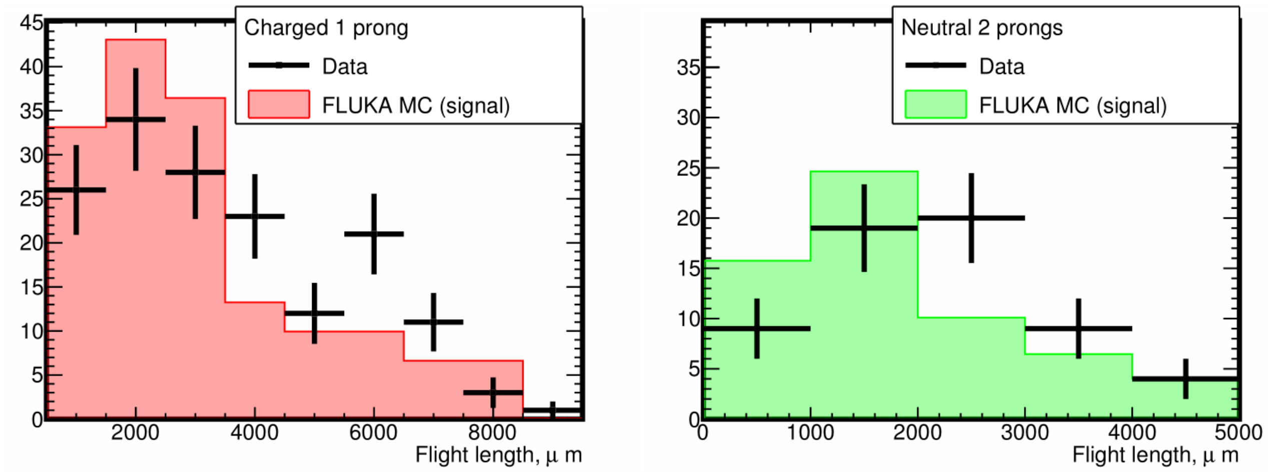






Charm candidate search, increasing statistics

- Search for double charm events
  - 34253301 protons analyzed (~2% of pilot run)
  - 272,120 proton interactions reconstructed (147,236 in tungsten)
  - 159 events (115 in tungsten) with double decay topology detected



	Observed	Expected	
Vertices in tungsten	147,236	155,135	
		Signal	Background
Double decay topology	115	80.1±19.2	12.7±5.0

- We will increase statistics x50
- High precision measurement to be done for selected events

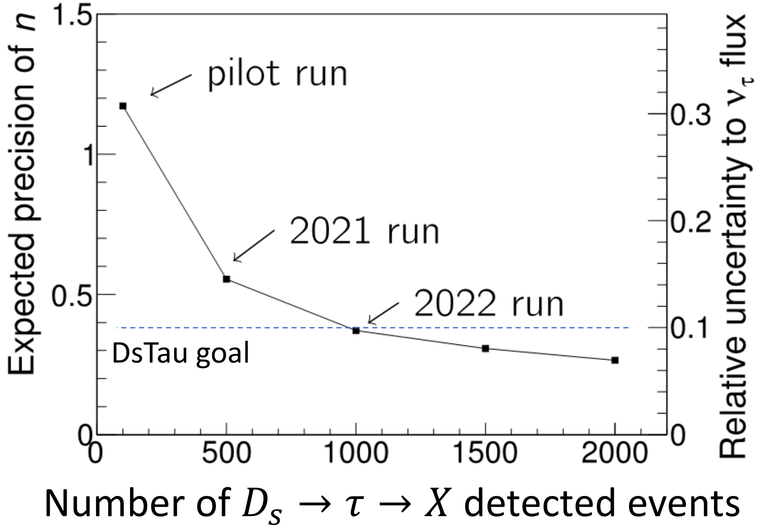
Plans

- Pilot run in 2018 (1/10 scale)
  - Emulsion readout of pilot run being completed (3150 films, 40m^2)
  - So far 2% of data is analyzed → to be completed.
  - Expect about 10,000 charm events, 80 $D_s \to \tau \to X$ events

	# of modules	emulsion films (m^2)
Pilot run 2018	30	49
Physics run 2021	**150 ***	**246**
Physics run 2022	**190 ***	**312**

* Change of film size is not accounted

- Physics run in 2021, 2022
  - 2+2 weeks of beam time at NA
  - Emulsion film 550 m^2
  - Expect 100,000 charm detected, 1000 $D_s \to \tau \to X$ detected events
  - ν_τ flux uncertainty to 10%



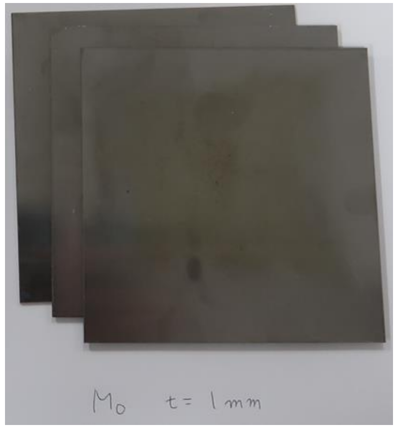
Target materials for the physics run

- Both Tungsten and Molybdenum will be employed as target by the BDF.
- In the DsTau's physics runs, we are going employ Tungsten and Molybdenum
  - 0.5-mm tungsten plates, 1.0-mm molybdenum plates
  - The same detector structure, equal number of modules for each target.
- Chemical compatibility tests has been done
  - No problem with a contact for a short period of time needed for the DsTau irradiation

target	# of stored proton int.	with charm pair	detected $D_s \to \tau \to X$
tungsten 0.5 mm	1.08×10^8	1.95×10^5	528
molybdenum 1.0 mm	1.41×10^8	2.10×10^5	498

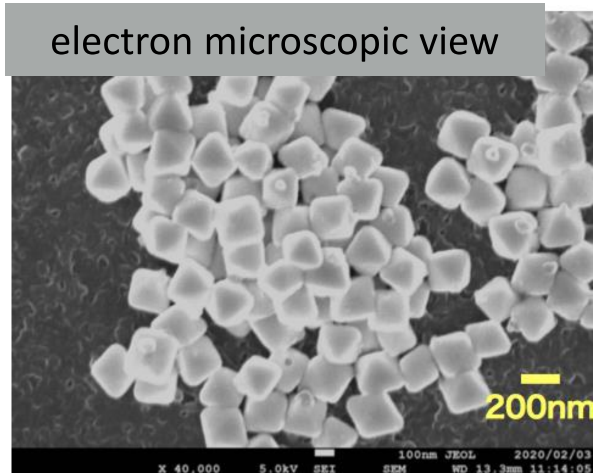
The total number of $D_s \to \tau \to X$ events will not change.

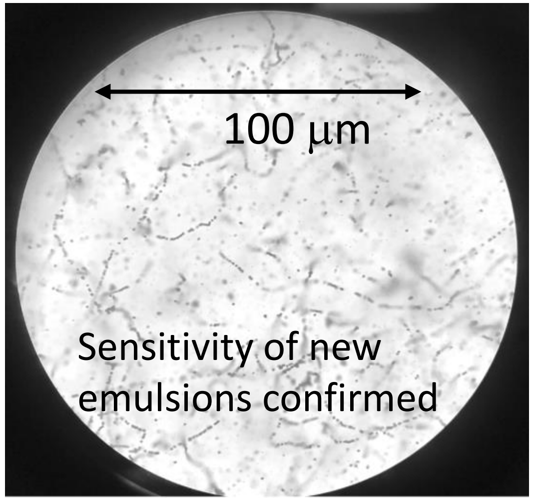
Molybdenum target



Preparation for physics run in 2021, 2022

New gel production facility setup



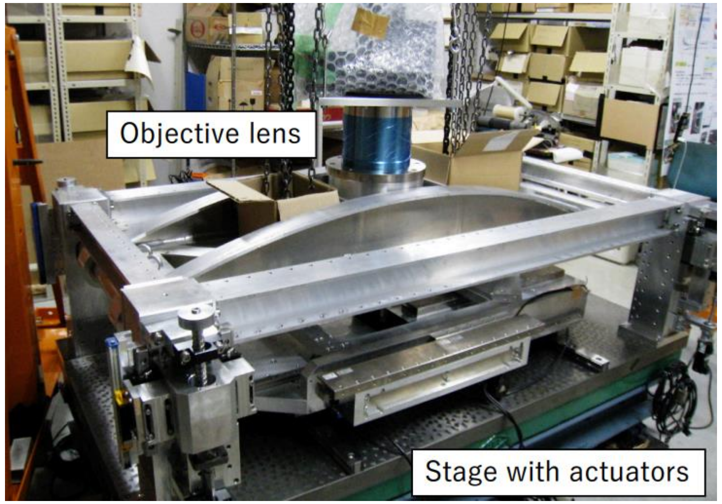


Larger film size

10x12.5 → 25 cm x 20 cm

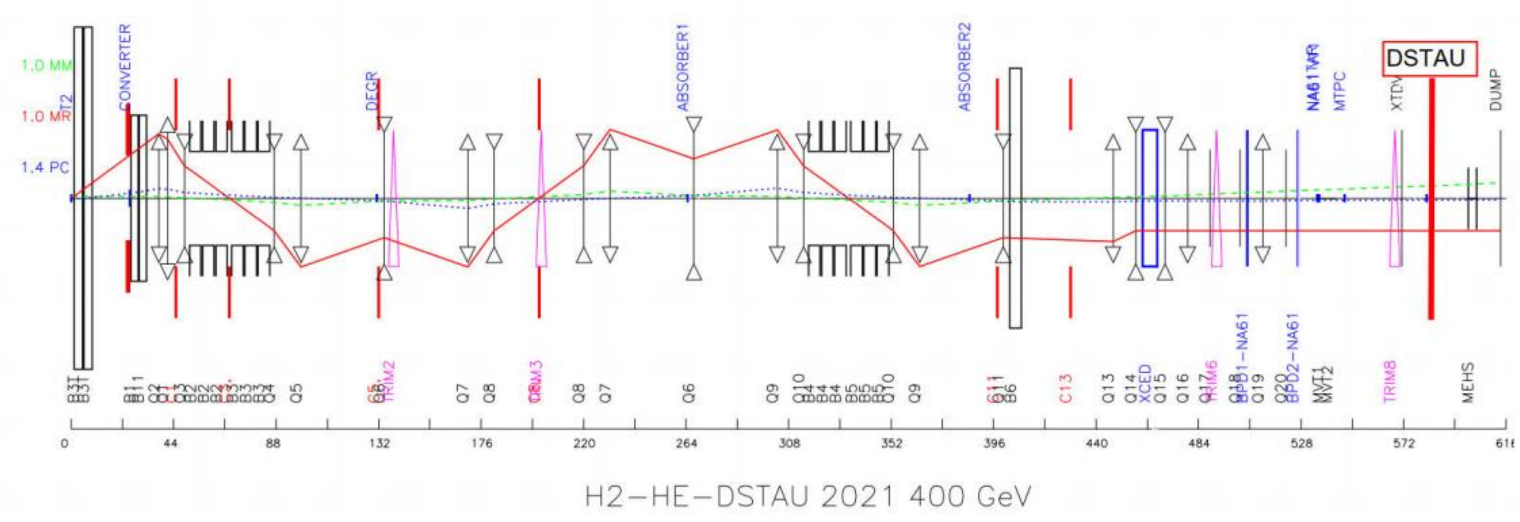
Film production facility

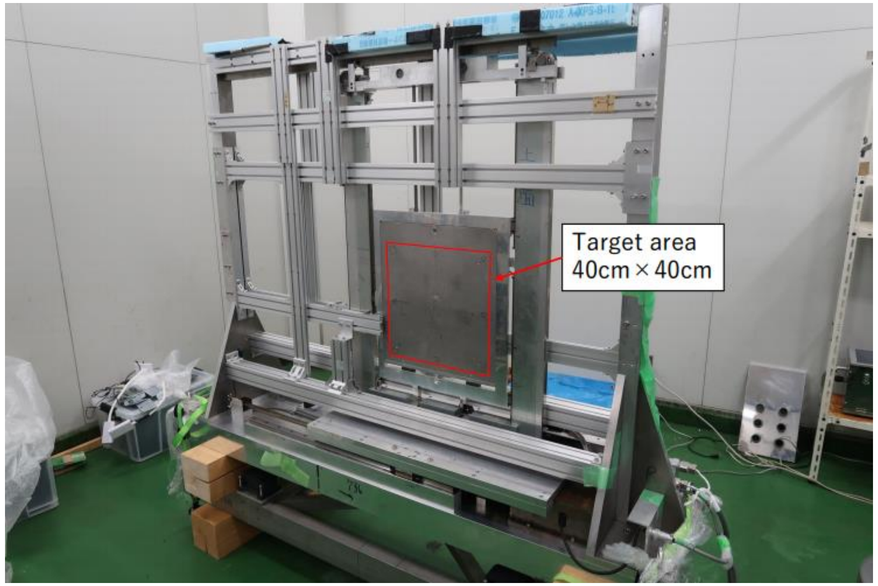
HTS (0.5 m^2/h) → HTS II (2.5 m^2/h)



Preparation for physics run in 2021, 2022

- A beamline optics study has been done to achieve a wide beam
- A larger target mover from J-PARC E07 experiment





Data processing

- Currently the bottleneck is the data processing. Pilot run experience:
  - $\simeq$2 months/module with a dedicated machine (CPU+1 GPU, 256 GB RAM)
  - Necessary data storage $\simeq$3.2 TB/module → pilot run data of 100 TB (1 PB for physics run)
- Optimizing algorithms and available resources
  - Use of computing clusters in the collaborating institutes
  - Investigating possibilities to use the HTS scanning system as a GPU cluster (72 GPUs) during its downtime
- We would like to ask supports from CERN for the data storage/distribution, and computing.

Summary

- The last one year was devoted to the 2018 run analysis and preparation for the physics run
- 2018 run analysis
  - 97% of films were scanned
  - 159 charm pair candidate events, increasing statistics
- Major publication
  - DsTau: Study of tau neutrino production with 400 GeV protons from the CERN-SPS 10.1007/JHEP01(2020)033
- Preparation for physics run
  - Target: Tungsten and Molybdenum
  - Emulsion films, target material, target mover, beam optics tuning
- Physics run in 2021-2022, 2 weeks in each year

Thank you for your attention!

The DsTau team in the pilot run in 2018

The DsTau Collaboration

Japan: Aichi U. Edu., Gifu U., Kobe U., Kyushu U, Nagoya U, Tohoku U

Romania: Institute of Space Science

Russia: JINR

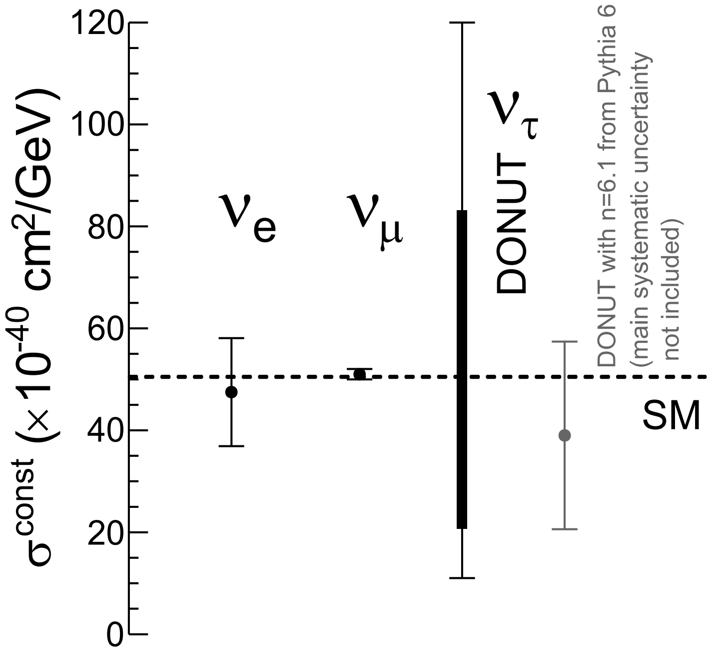
Switzerland: U. Bern, CERN

Turkey: METU

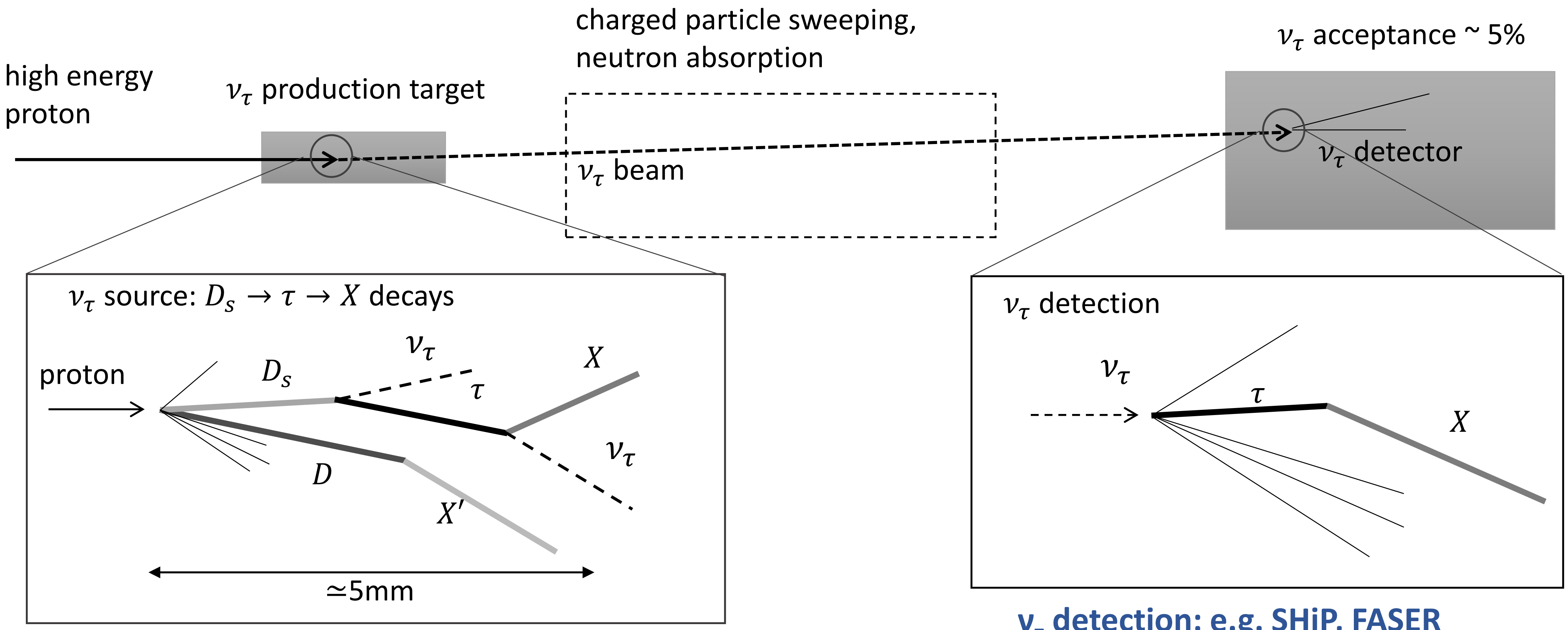
Backup

Tau neutrinos & lepton universality test

- 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).
- Lepton Universality test in neutrino scattering
  - Hints of LU violation in heavy meson decays, e.g. $\bar{B} \rightarrow \tau\nu_\tau D^{(*)}$. New physics in tau sector?
  - A precise measurement of ν_τ cross-section would provide a complementary information
  - Currently cross section error >50% (DIS) due to systematic uncertainty in ν_τ production



Concept of ν_τ cross section measurement (accelerator based)



ν_τ production study: DsTau

ν_τ detection: e.g. SHiP, FASER

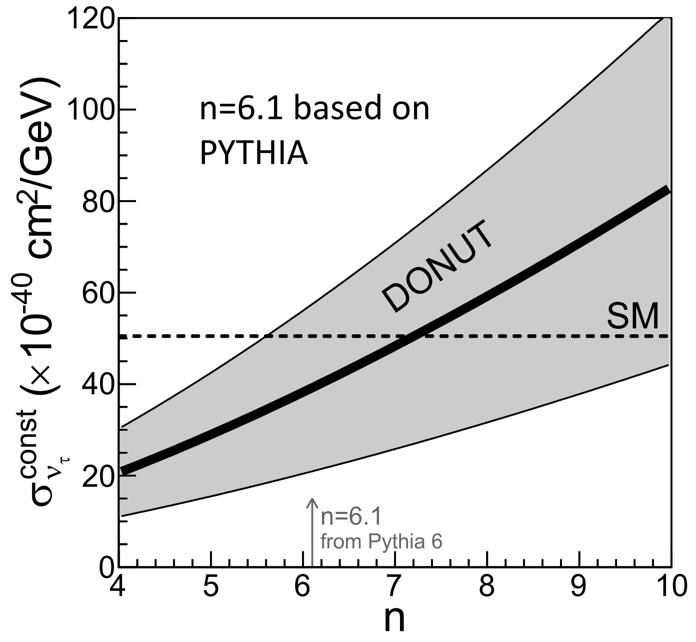
- Crucial to understand D_s differential production cross-section
- Need to know how many D_s mesons are emitted in which direction and which energy.

- Statistic of ν_τ detection

Uncertainty in ν_τ xsec measurements in DONUT

- DONUT's result is a function of a parameter controlling D_s differential production cross section

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



Using PYTHIA-derived value of n=6.1

$$\sigma_{\nu\tau}^{const} = (0.39 \pm 0.13 \pm 0.13)\times 10^{-38}\,cm^2 GeV^{-1}$$

D_s differential production cross section

Phenomenological formula

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

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

Tau neutrino cross-section uncertainties in DONUT	
Tau neutrino **detection** statistics of 9 events, **33%**	SHiP / FASERν etc → 2%
Tau neutrino **production**: Lack of D_s differential prod cross section data, **>50%**	DsTau
Tau neutrino **production** : Others, **33%**	DsTau

Need to improve both ν_τ statistics and ν_τ production

DsTau milestones

LOI in 2016

Test beam 2016

- Test of detector structure

TP in 2017

Test beam 2017

- Improved detector structure
- Refine exposure scheme

Approved as NA65 in June 2019

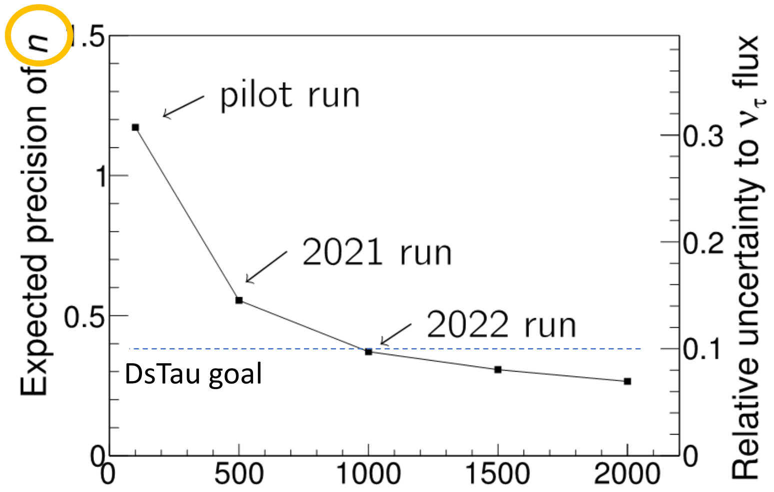
Pilot run 2018

- 1/10 of the full-scale experiment with tungsten target
- 30 % uncertainty on ν_τ flux
- Revise the DONUT result
- Charm physics

We are here

Physics run 2021-2022

- Full scale experiment with tungsten and molybdenum targets
- Aiming at 1000 $D_s \to \tau \to X$ events
- 10 % uncertainty on ν_τ flux



Number of $D_s \to \tau \to X$ detected events

Phenomenological formula for D_s production

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

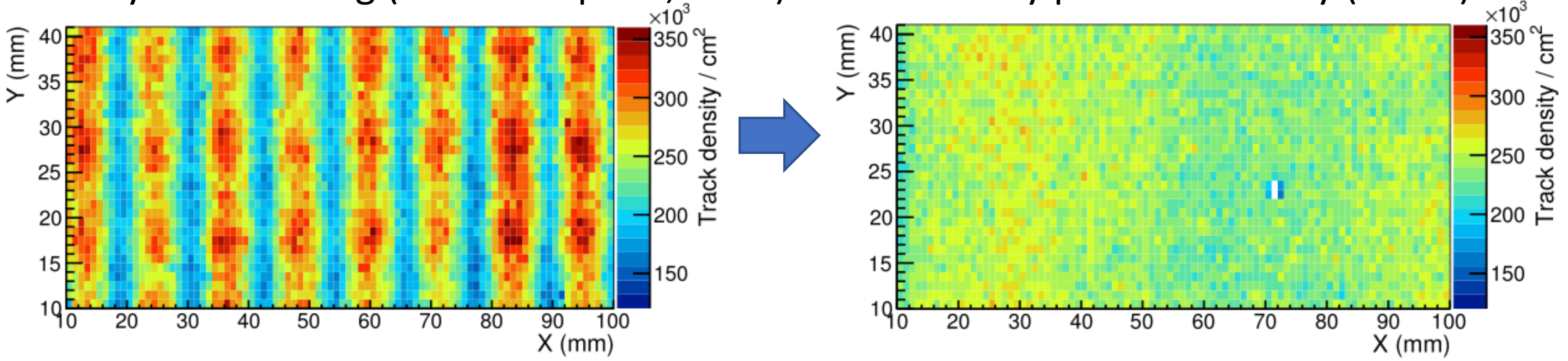
x_F is Feynman x ($x_F = 2p^{CM}_z/\sqrt{s}$)
and p_T is transverse momentum

Proton beam exposure at the SPS-H2 beamline

- Emulsion detector on target mover (scanning on X)

Proton beam position profile

Driven by beam timing (constant speed, 2016) | Driven by proton intensity (2017-)



Pilot run in 2018

- 30 modules were exposed
- 2-3 $\times 10^5$ protons/spill
- 10^5 protons/cm^2 → 1.25×10^7/module

  ↑ Factor 10 higher density than SHiP charm
- c.a. 18 million proton interactions in tungsten

2018 Pilot run: detector production

- 55 m^2 (4400 films) produced

Film production facility in Bern

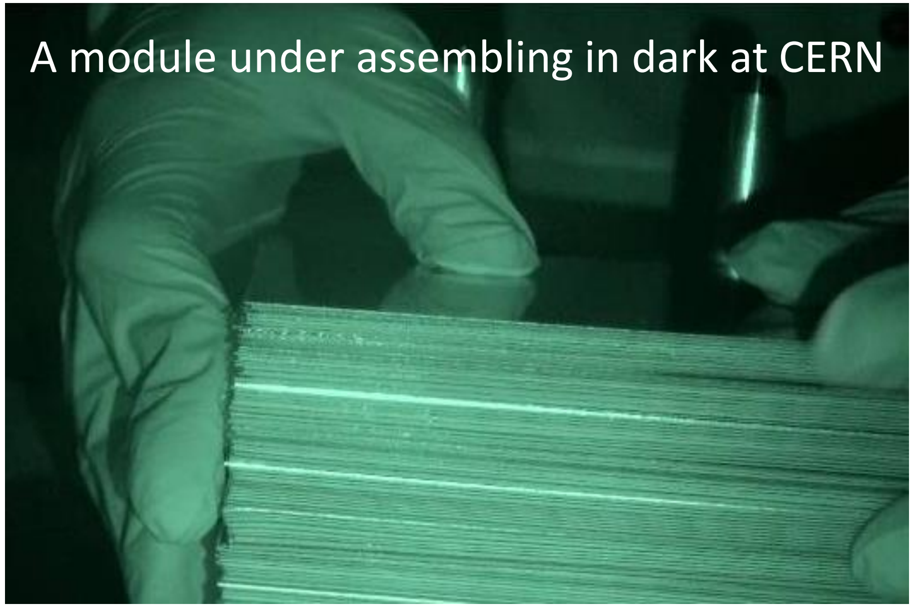
↑ Film production facility in Nagoya

Emulsion

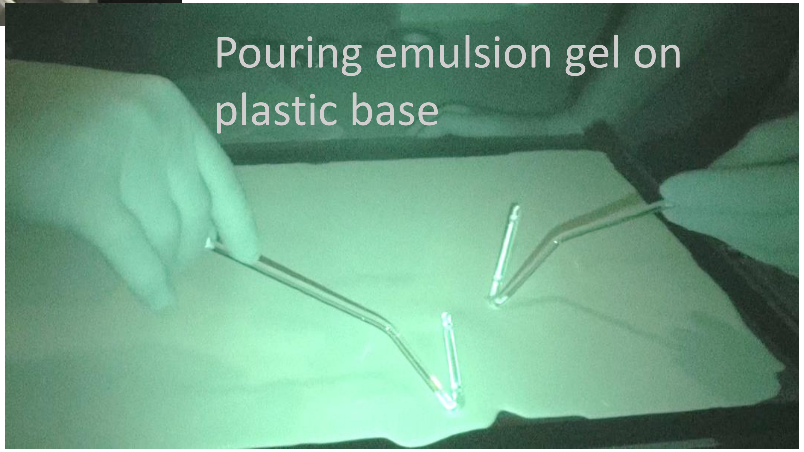
Base

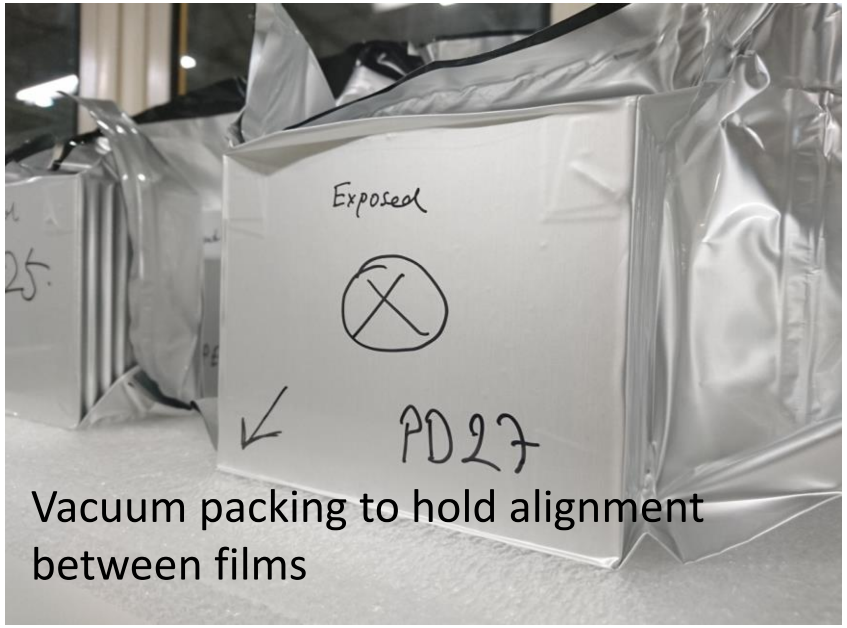
Emulsion

A module under assembling in dark at CERN



Pouring emulsion gel on plastic base

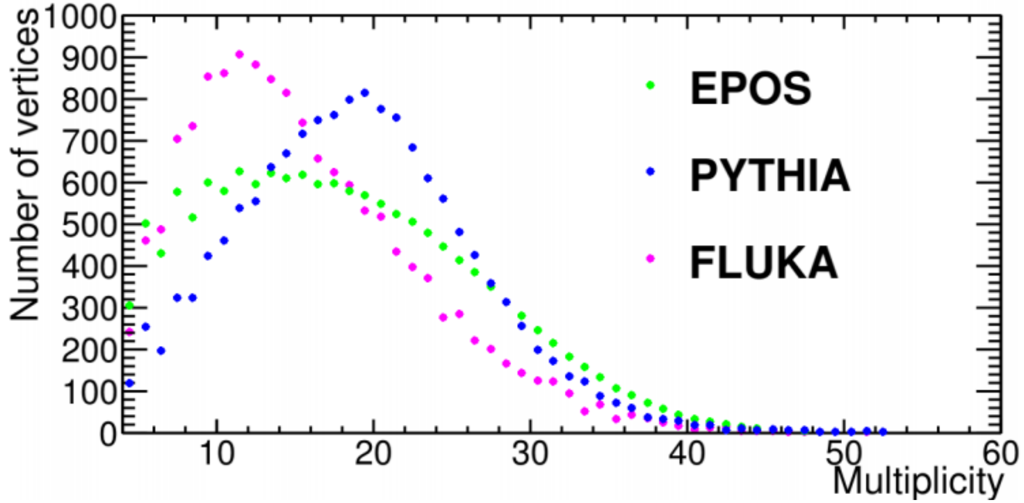


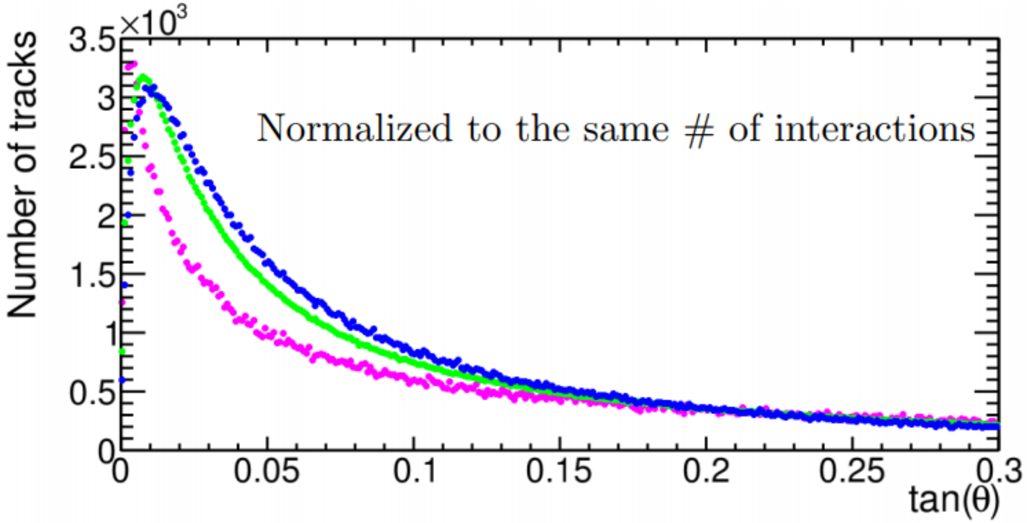


Vacuum packing to hold alignment between films

Comparison among different generators

- Implementing different hadron production generators in analysis. Their predictions are quite a bit different.
- Further investigation is required.

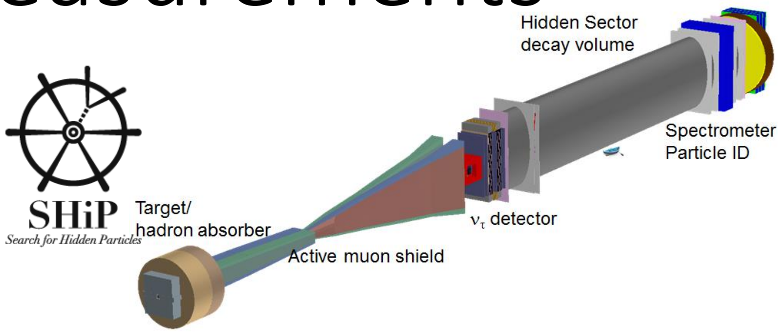


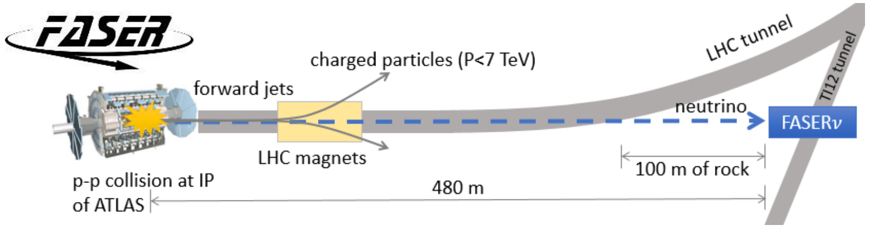


Future tau neutrino measurements

Opportunities to measure ν_τ cross section

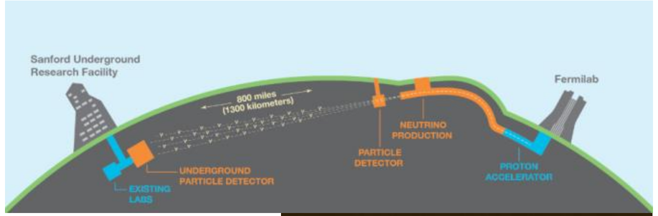
- **SHiP**: high statistics ν_τ measurement at the SPS beam dump facility
- **FASER**: high energy ν_τ measurements at the LHC.

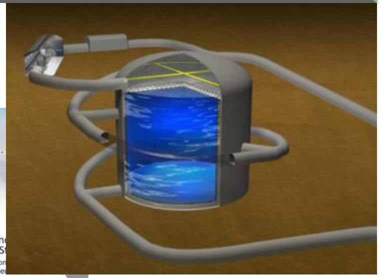


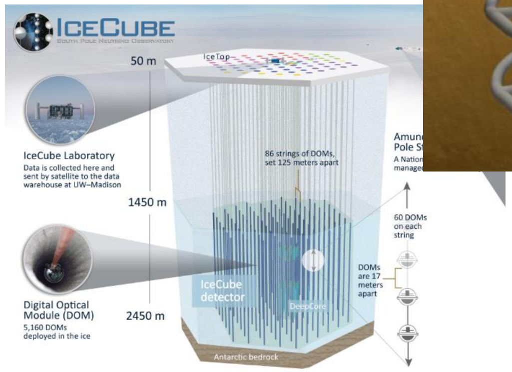


ν_τ cross section has influence to

- Long baseline neutrino oscillation experiments
  - **DUNE**, **Hyper-K**, **SK**
  - ν_τ is background to ν_e, due to $\tau \to e$
- **IceCube**
  - Astrophysical ν_τ measurement

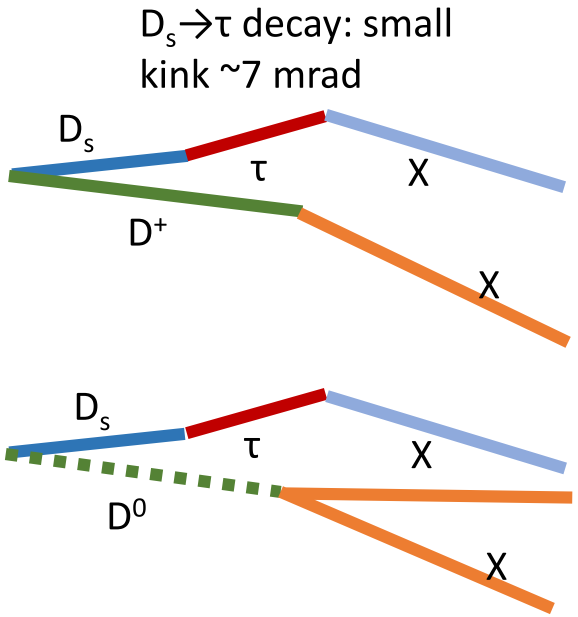






Signal and background

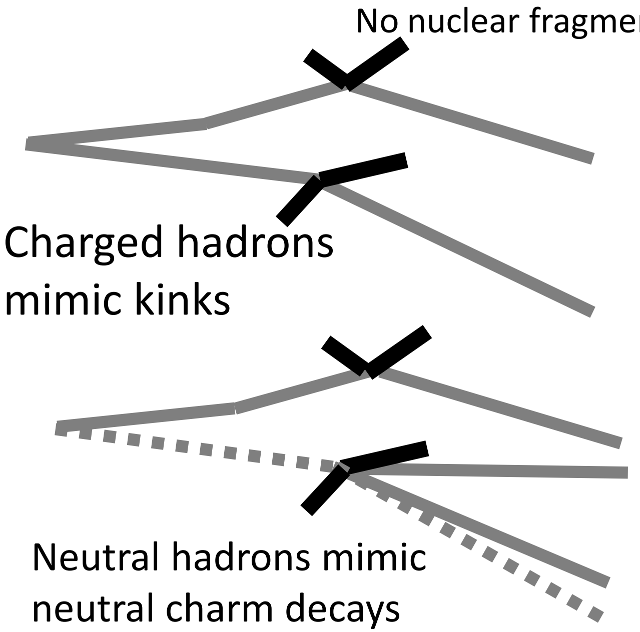
- Signal



Detection efficiency = 20%,
estimated with Pythia 8.
Signal probability 2.2x10^{-7} /proton

Signal in DsTau : 1000

- Main background: Hadron interactions of daughters of proton interactions



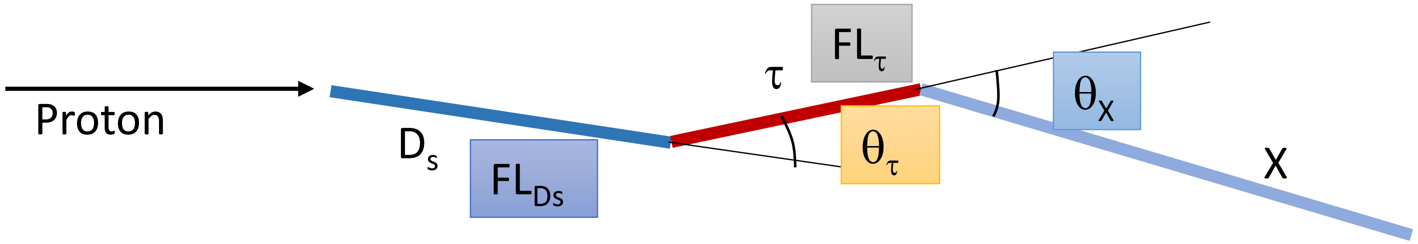
Background probability estimated by FLUKA.

$$P_{BG}^{charged} = 1.3 \pm 0.4 \times 10^{-9} / \text{ proton}$$
$$P_{BG}^{neutral} = 2.7 \pm 0.8 \times 10^{-9} / \text{ proton}$$

BG in DsTau : 18

New method for Ds momentum reconstruction

by Artificial Neural Network using topological variables

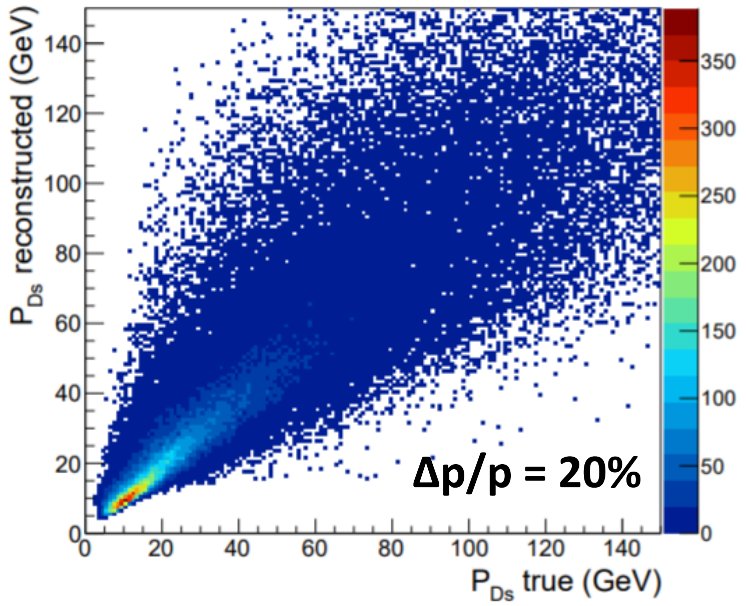


FL: flight length

- Difficult to measure Ds momentum directly due to short lifetime

→ Ds momentum reconstruction by topological variables

- A Neural Network with 4 variables was trained with MC events
- Momentum resolution for $\tau \rightarrow 1$ prong decays $\Delta p/p = 20\%$

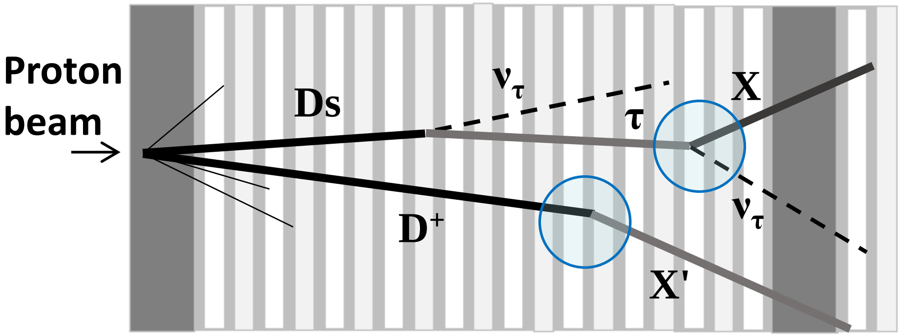


True P_{Ds} (GeV)

Analysis scheme for double-kink search

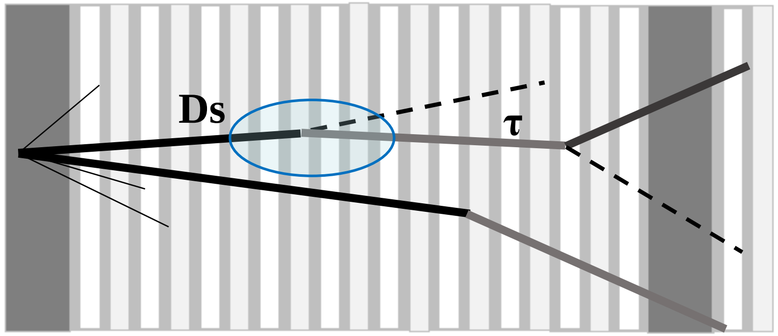
Step 1

- Full area scanning by the fast scanning system
- Select decays with Δθ > 20 mrad



Step 2

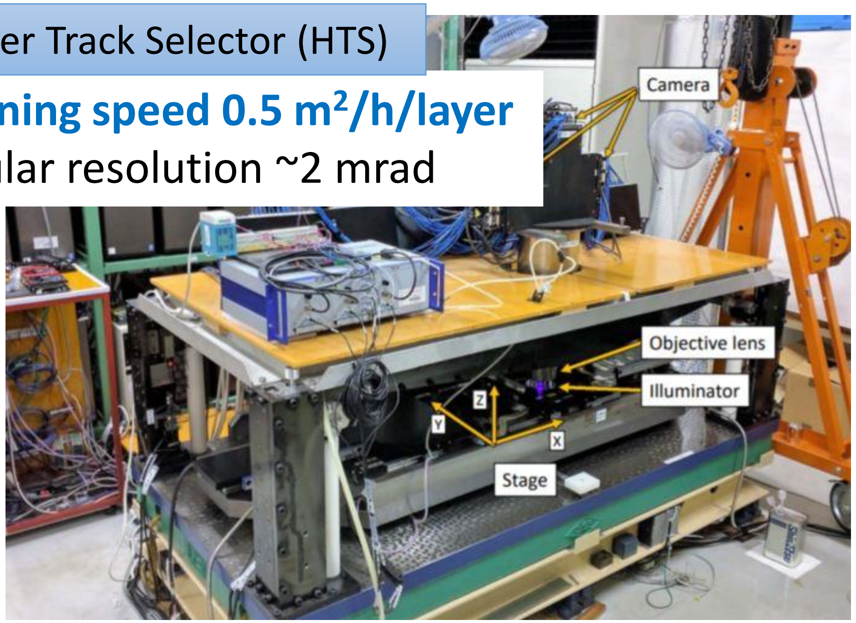
- Precision measurement to detect Ds -> τ decay (a few mrad)



Hyper Track Selector (HTS)

Scanning speed 0.5 m^2/h/layer

Angular resolution ~2 mrad



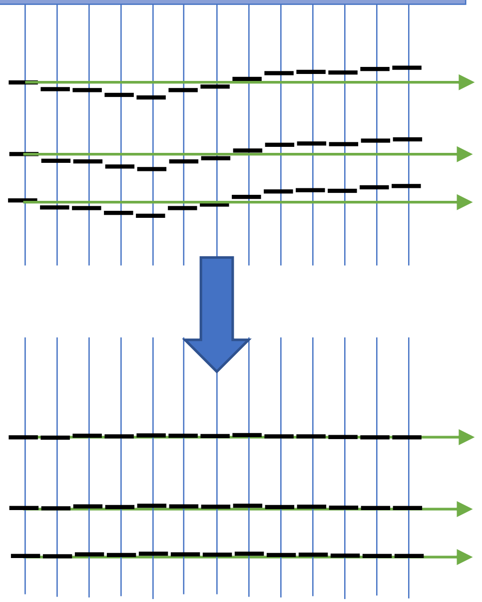
Nano-precision systems

Angular resolution ~0.3 mrad

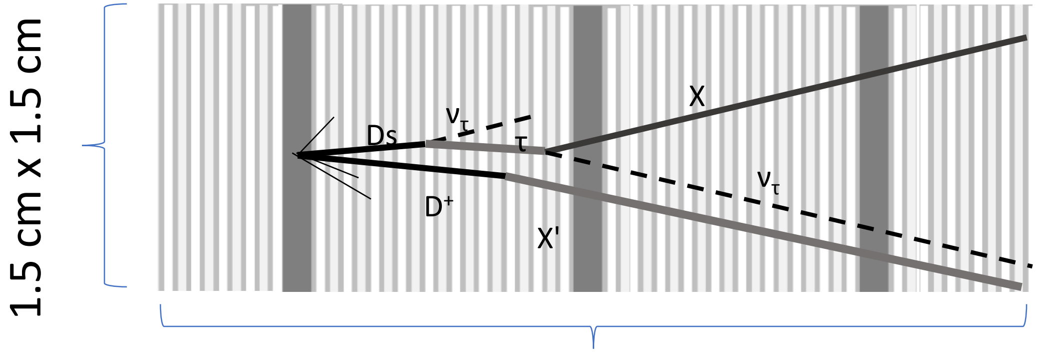
Reconstruction performance (1): alignment

- Processing in sub-volumes
  - e.g. 1.5 cm x 1.5 cm x 30 films
- Alignment with proton beam tracks
  - Alignment accuracy better than **0.4 μm**

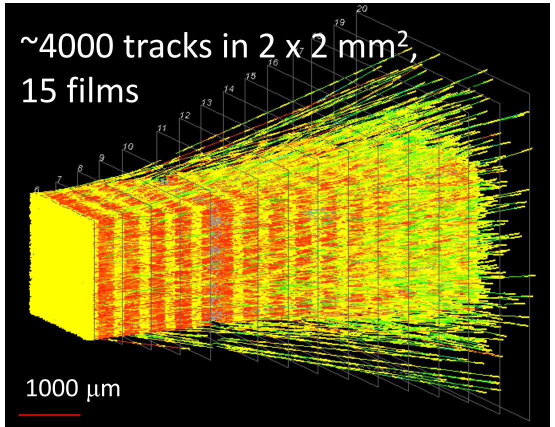
Align films with proton tracks, 100 tracks/mm²



Residual of track segments to fitted line (RMS) $\simeq$**0.4 μm**



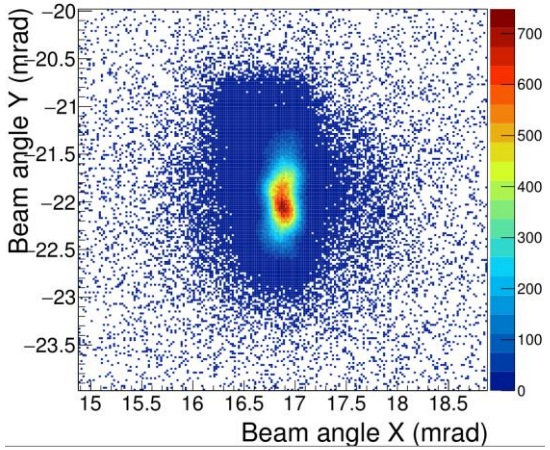
30 films
(two tungsten plates to reject low momentum daughter candidates)

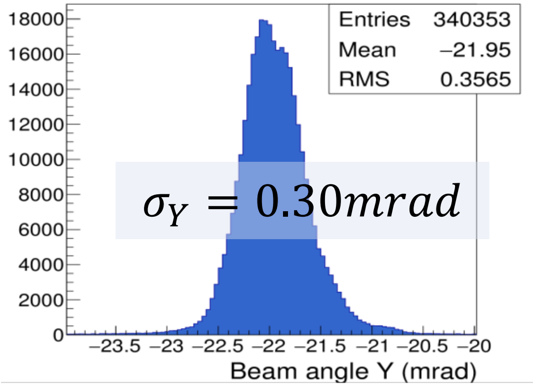


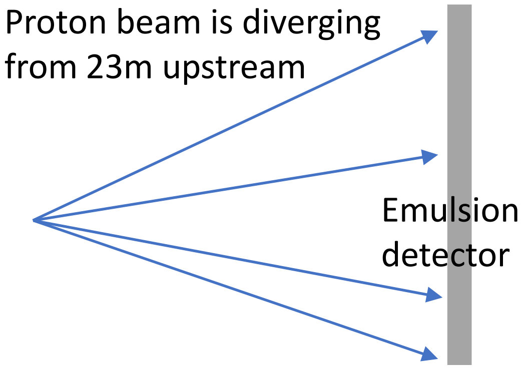
Reconstructed tracks

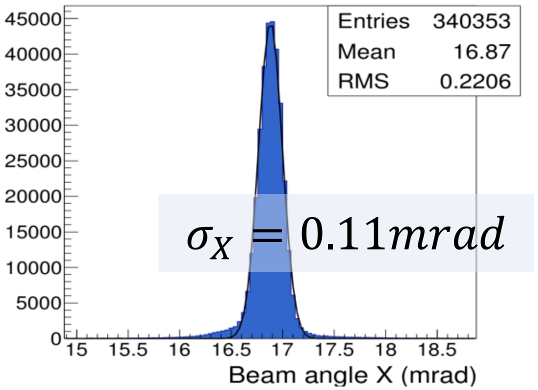
Reconstruction performance (2): Proton beam angle structure

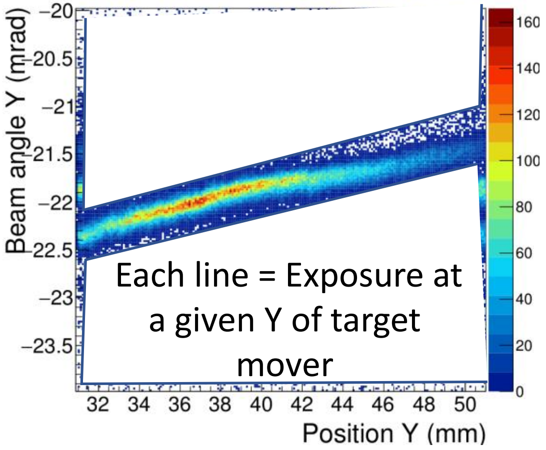
- Proton beam tracks were checked in detail
  - Tracks reconstructed in 20 emulsion films, thickness of 1.1 cm

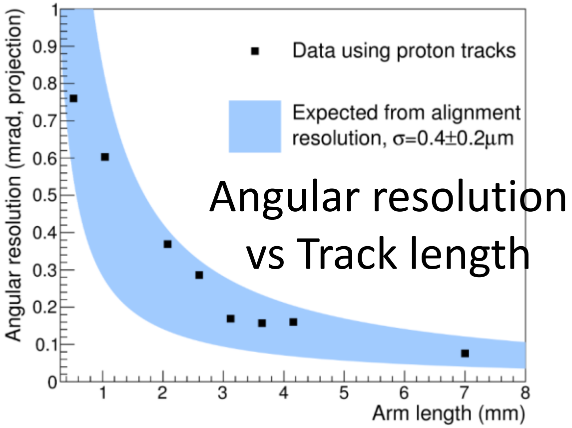












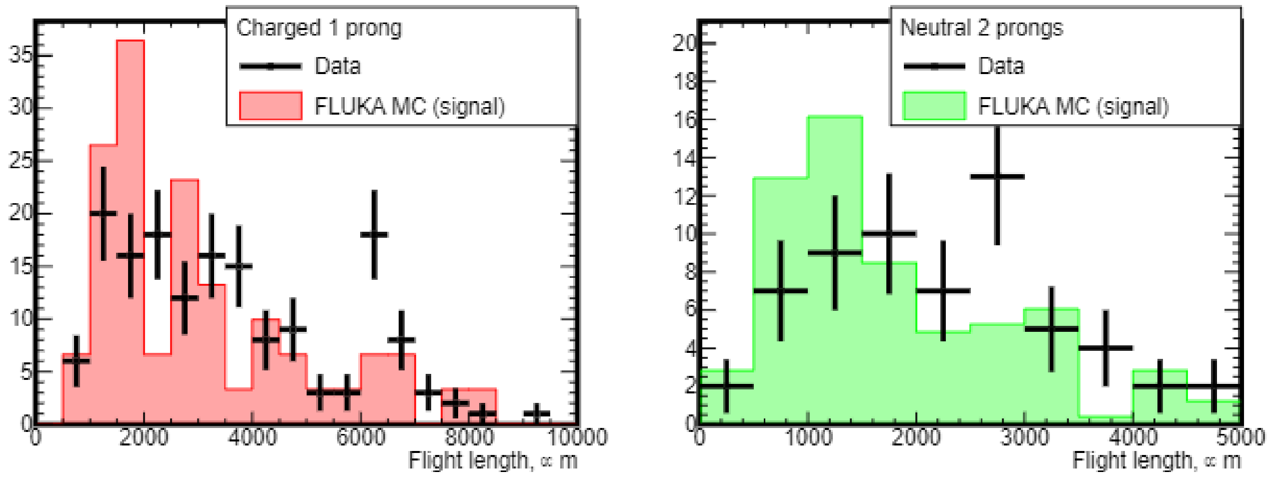


Figure 12: Distribution of the flight length for charged 1-prong topology (left) and for neutral 2-prong topology (right).

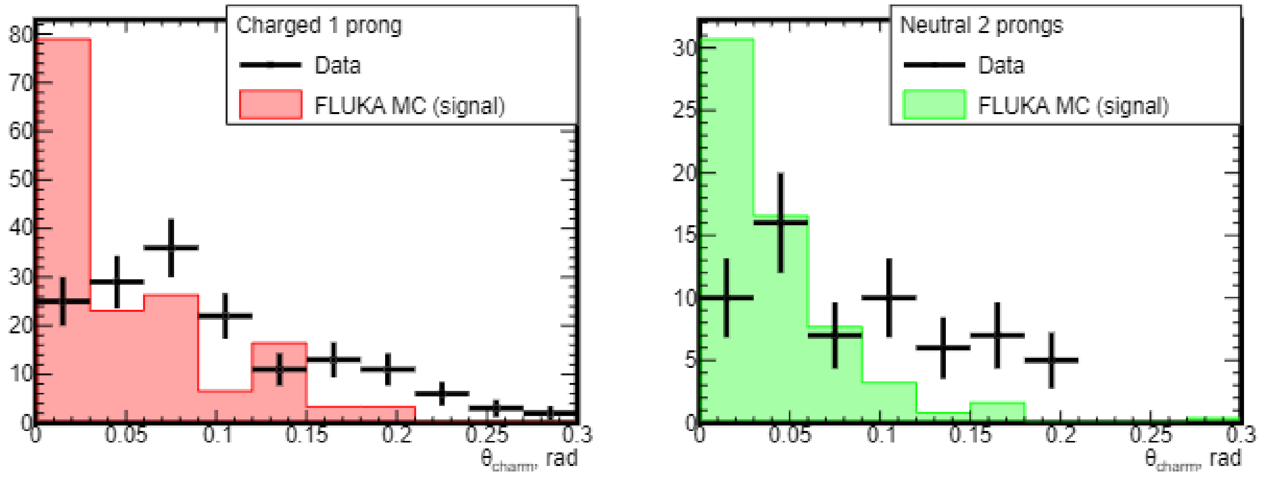


Figure 13: Distribution of the emission angle for charged 1-prong topology (left) and for neutral 2-prong topology (right).

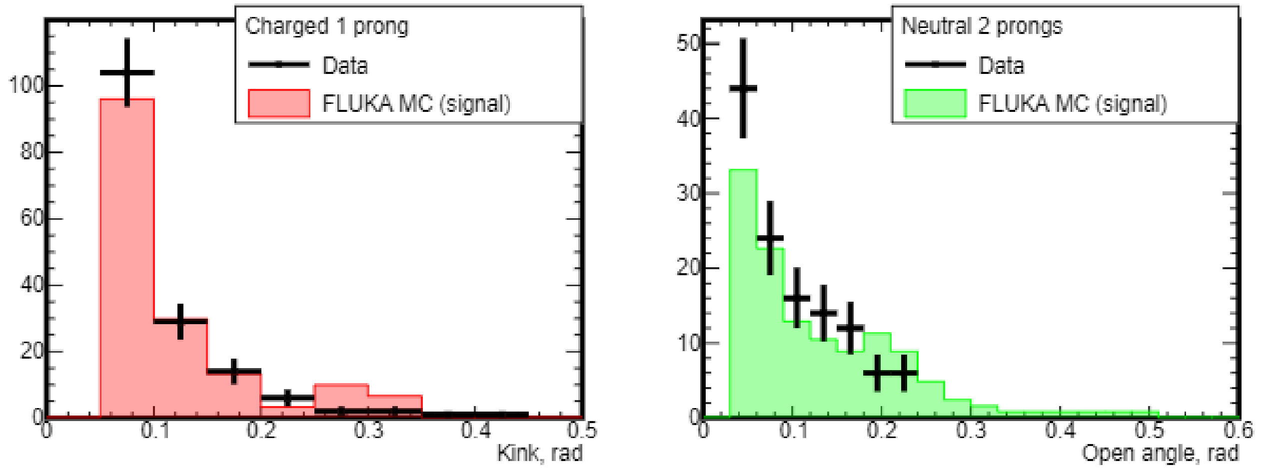


Figure 14: Distribution of the kink angle for charged 1-prong topology (left) and the opening angle for neutral 2-prong topology (right).

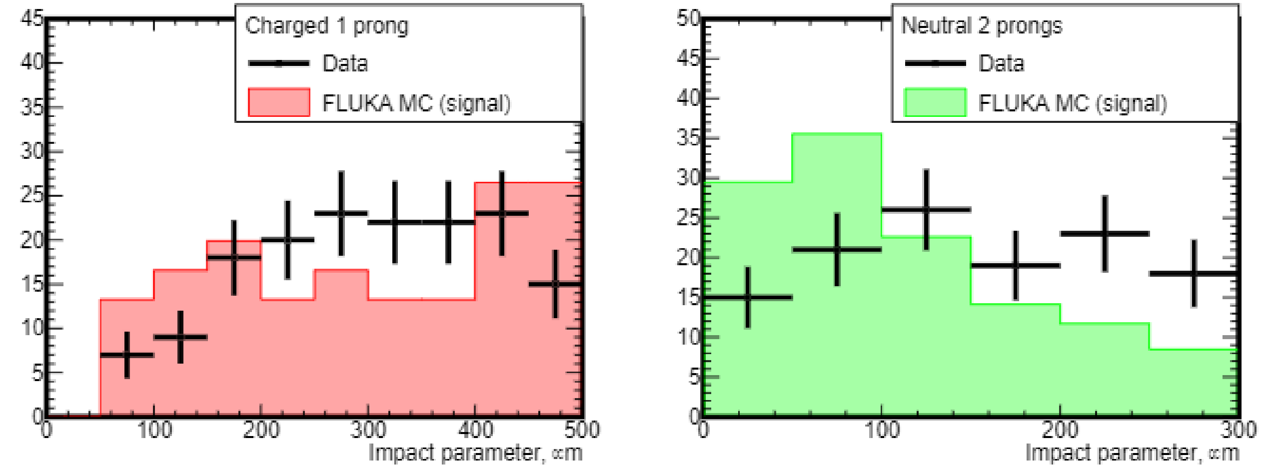


Figure 15: Distribution of impact parameter of daughter tracks to the primary vertex for charged 1-prong topology (left) and for neutral 2-prong topology (right).

Requirements for batch data processing @CERN

Japan data processing machine characteristics:

CPU: Intel(R) Xeon(R) Gold 5218 CPU @ 2.30GHz

GPU: GeForse RTX 2080 SUPER

RAM: 128 GB

Rough estimation of processing time and storage resources (for 1 DsTau test data module):

Total processing time (**1 CPU + 1 GPU**): **~2 months**

- which includes **GPU**-using time: **~12.5 days (~21%)**

Estimated total processing time with **1 CPU** only: **~550-700 days**

Size of the processed data: **~6.4 TB.** To be stored at **CERN EOS: ~3.2 TB (?)**

Processing of **300 DsTau modules** (with the data quality similar to the **test module** and using the current version of the software) within **2 years** requires:

~25 computing nodes with **CPU** and **GPU**

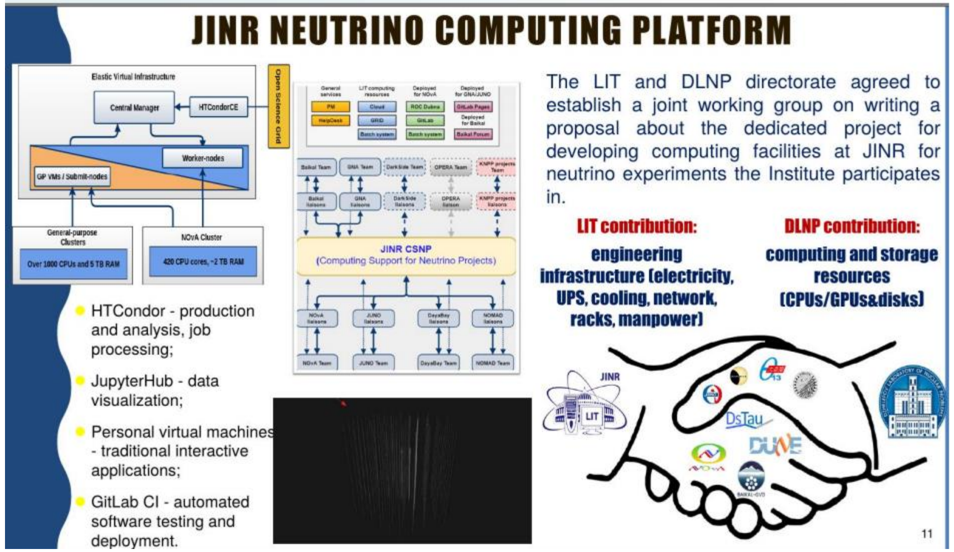
or **~225-290 computing nodes** with **CPU** only.

Required **CERN EOS** storage resources: **~1 PB (**we have **100 TB** at the moment**).**

The full processing time estimation doesn't take into account data copying (from **EOS** to the computing nodes and back), possible network connection delays, interruptions of the processing, etc.

Checking availability of computing resources

- JINR, ISS and Bern have multipurpose computing clusters
- Investigating possibilities to use HTS as a GPU cluster (72 GPUs), when it is not used for data readout.



Plan for physics runs in 2021, 2022

Test beam 2016
- Test of detector structure

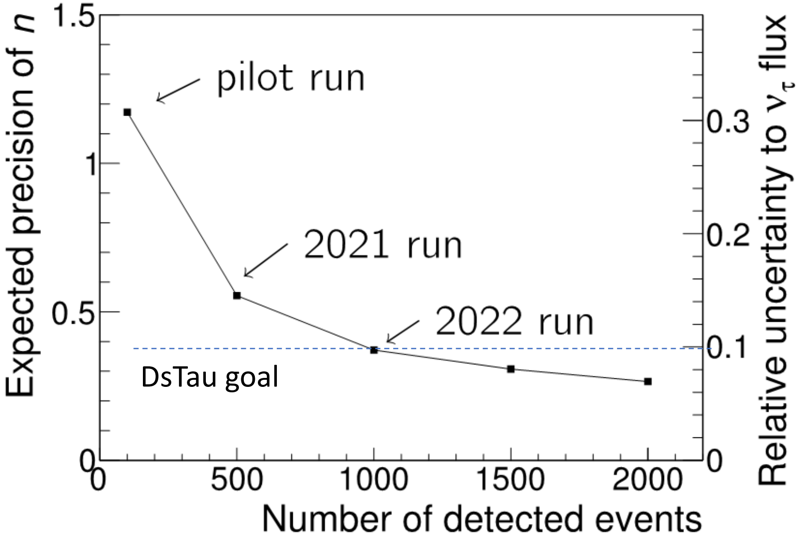
Test beam 2017
- Improved detector structure
- Refine exposure scheme

Pilot run 2018
- 1/10 of the full scale experiment
- 30 % uncertainty
- Revise the DONUT result
- Charm physics

Physics run 2021-2022
- Full scale experiment
- Aiming at collecting 1000 $D_s \to \tau \to X$ events
- 10 % uncertainty

	# of modules	emulsion films (m^2)
Pilot run 2018	30	49
Physics run 2021	**150**	**246**
Physics run 2022	**190**	**312**

- 2 weeks each
- The exposure speed achieved in the pilot run is quick enough



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)**	**σ(D_s) (μb/nucl)**	**σ($D^\pm$) (μb/nucl)**	**σ(D^0) (μb/nucl)**	**σ(Λ_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	-	$n(D^0, D^+)_{inclusive} = 7.5 \pm 3.2$
E653	p / 800	-	38 ± 17	38 ± 13		$n(D^0, D^+)_{inclusive} = 6.9^{+1.9}_{-1.8}$ $b(D^0, D^+)_{inclusive} = 0.84^{+0.10}_{-0.08}$
E743 (LEBC-MPS)	p / 800	-	26 ± 8	22 ± 11		n(D) = 8.6 ± 2.0 b(D) = 0.8 ± 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 $(D^\pm, D^0, D_s^\pm)_{inclusive}$ $n(D^\pm, D^0, D_s^\pm)_{inclusive} = 6.1 \pm 0.7$ $b(D^\pm, D^0, D_s^\pm)_{inclusive} = 1.08 \pm 0.09$
E769	$\pi^\pm$ / 250	2.1 ± 0.4		9 ± 1		1665 ± 54 events $(D^\pm, D^0, D_s^\pm)_{inclusive}$ $n(D^\pm, D^0, D_s^\pm)_{inclusive} = 4.03 \pm 0.18$ $b(D^\pm, D^0, D_s^\pm)_{inclusive} = 1.08 \pm 0.05$
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

Status of the DsTau project

- Letter of Intent, Feb. 2016
  - Beam tests in Nov. 2016, May 2017
- **Proposal (SPSC-P-354), Aug. 2017**

- Presentation at the 128th Meeting of the SPSC (open session):
- Reviewed during the SPSC meeting, Jan. 2018

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

CERN-SPSC-2017-029 / SPSC-P-354
29/08/2017

Experiment Proposal

Study of tau-neutrino production at the CERN SPS

S. Aoki[1], A. Ariga[2], T. Ariga[2,3,*], E. Firu[4], T. Fukuda[5], Y. Gornushkin[6], A. M. Guler[7], M. Haiduc[4], K. Kodama[8], M. A. Korkmaz[7], U. Kose[9], M. Nakamura[5], T. Nakano[5], A. T. Neagu[4], H. Rokujo[5], O. Sato[5], S. Vasina[6], M. Vladymyrov[2], M. Yoshimoto[10]

Collaboration

Japan:
- Aichi University of Education
- Kobe University
- Kyushu University
- Nagoya University

Romania:
- Institute of Space Science

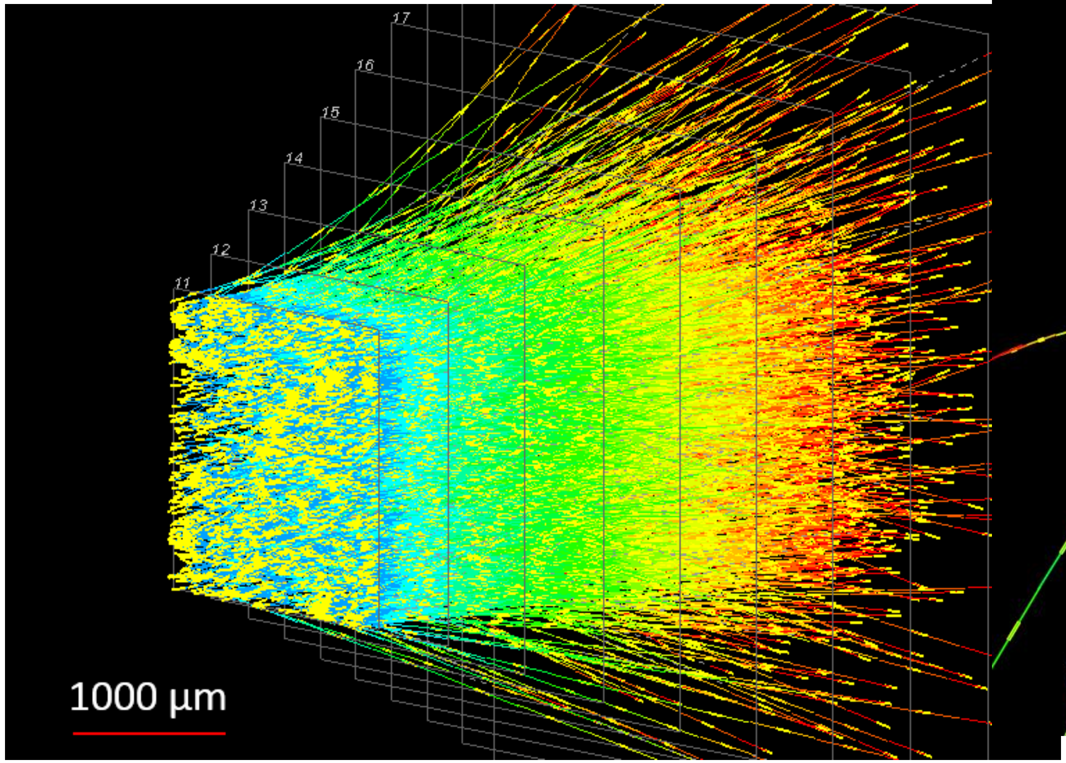
Russia:
- JINR-Joint Institute for Nuclear Research

Switzerland:
- University of Bern

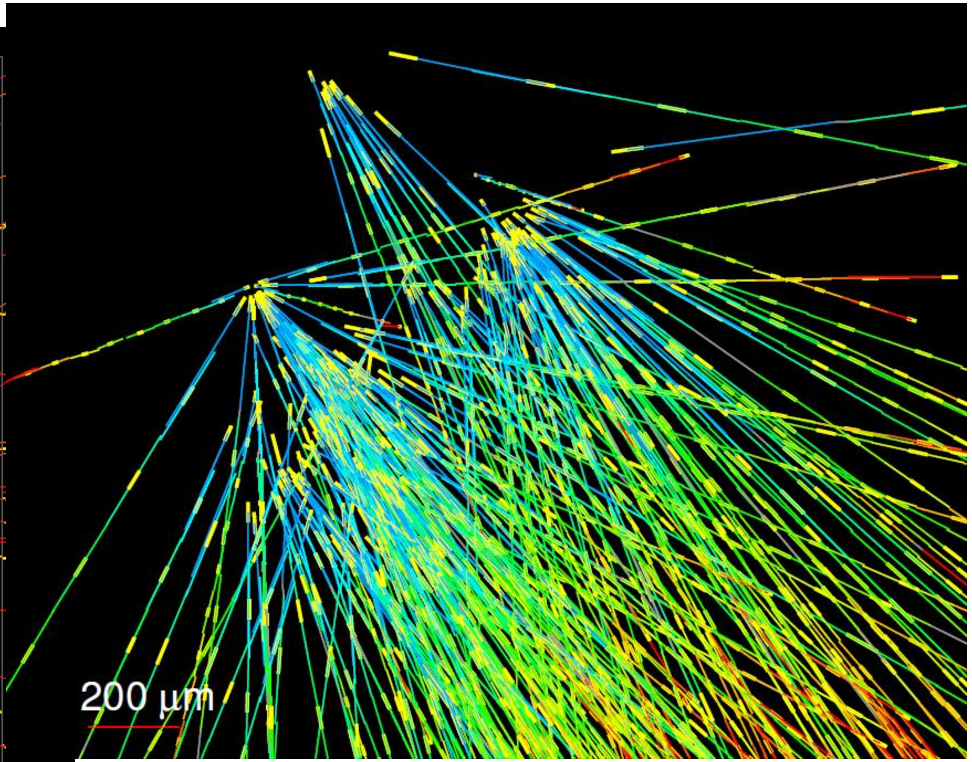
Turkey:
- METU-Middle East Technical University

A piece of data

Tracks 1 mm x 1 mm

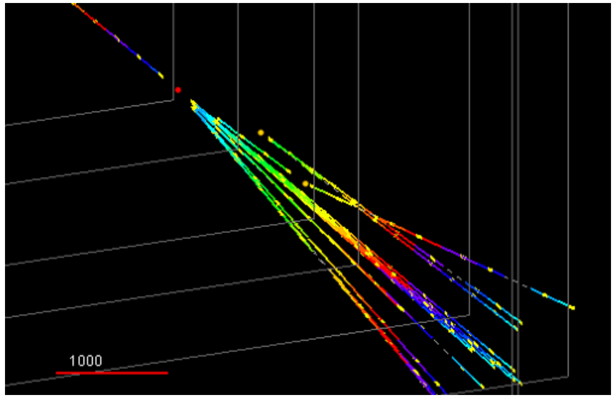


Tracks emerging from tungsten target

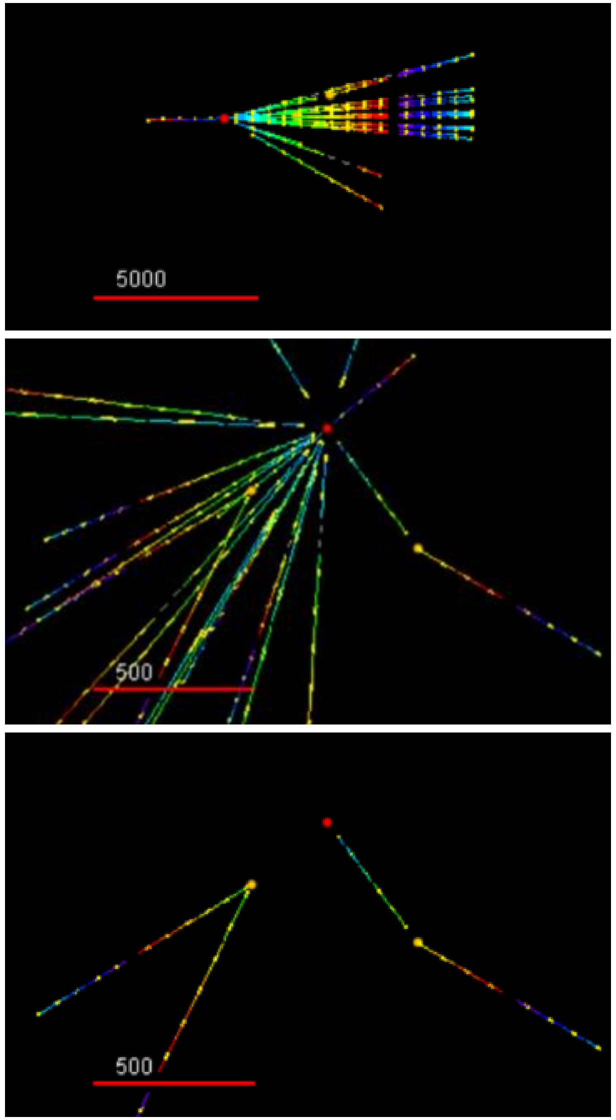


Event displays

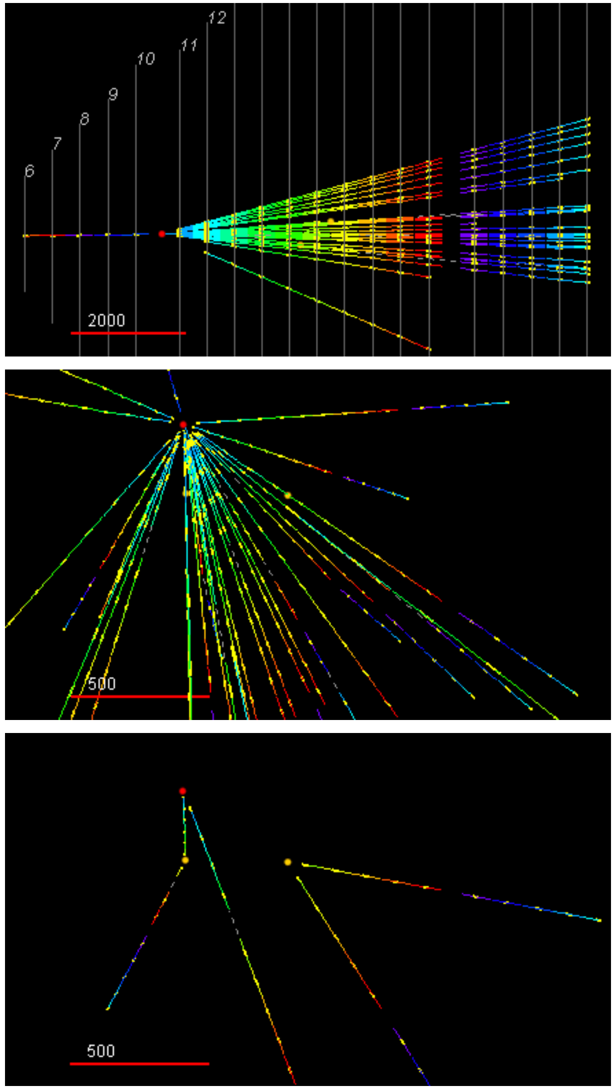
cand_20190117_p11_71651.2_33380.6
C1+N2 candidate



cand_20181205_p11_47291.8_32047.5
C1+N2 candidate

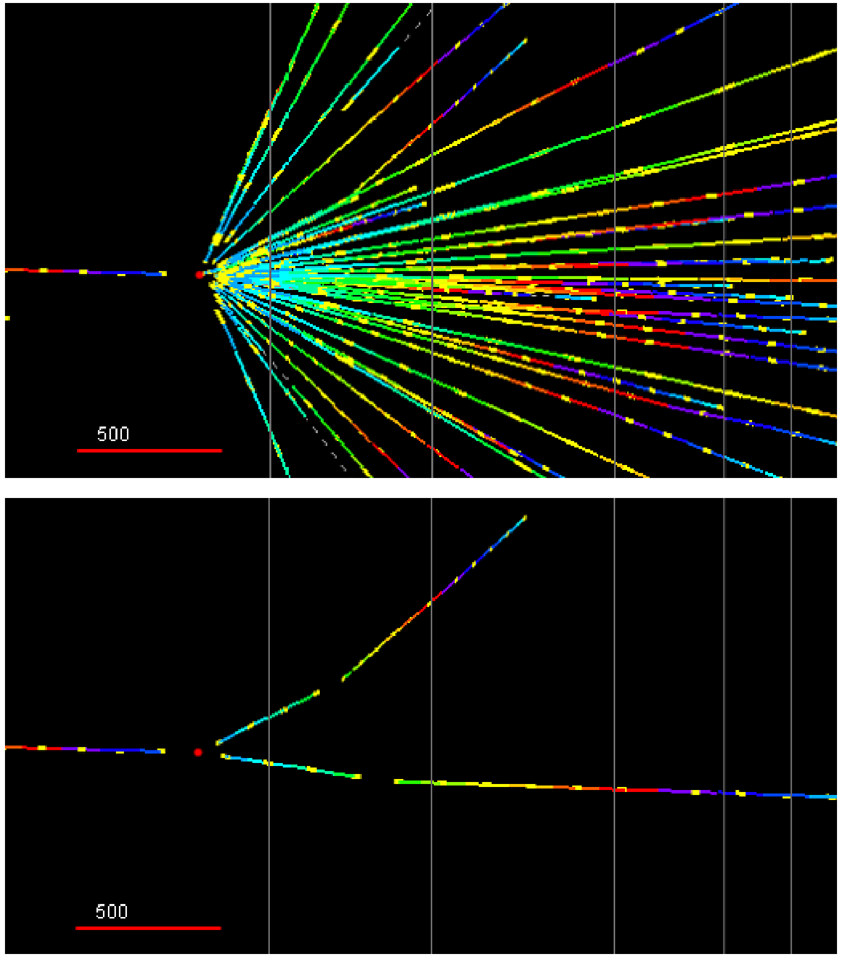


cand_20181205_p11_72182.0_63924.7
C1+N2 candidate

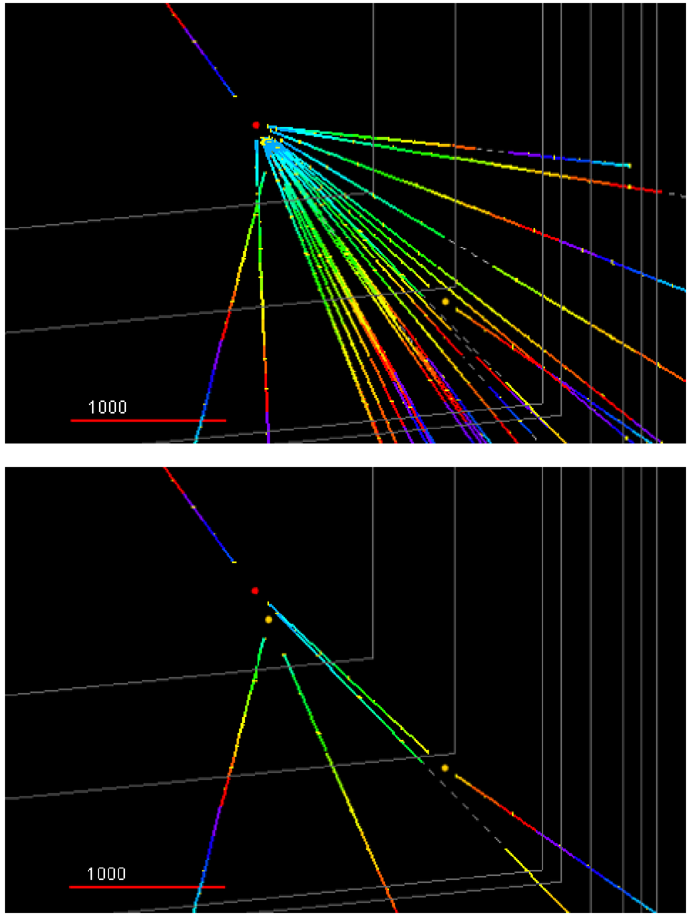


Event displays

cand_20190117_p11_61598.3_47632.7
C1+C1 candidate



cand_20190117_p11_61427.6_56633.2
C1+N2 candidate



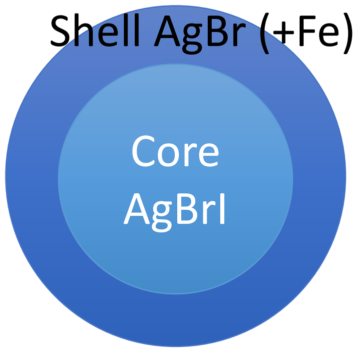
Emulsion detector

A minimal detector:

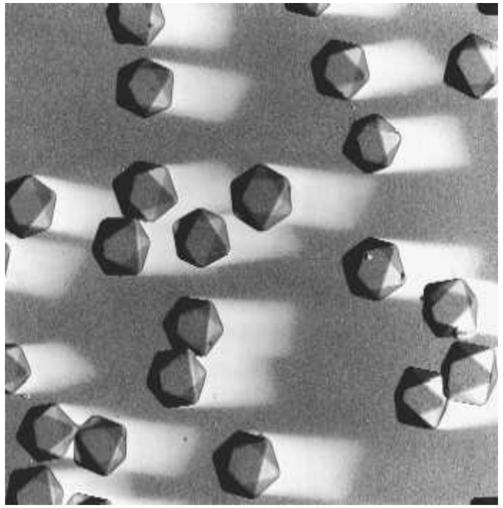
Silverbromide (AgBr) Cristal

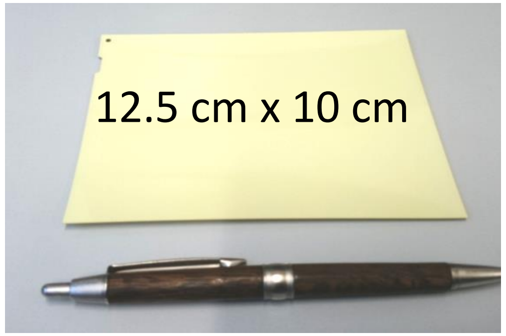
- diameter = 200 nm
- core-shell structure
- detection eff. = 0.16/crystal
- noise rate = 0.5×10^{-4}/crystal
- volume occupancy = 30%

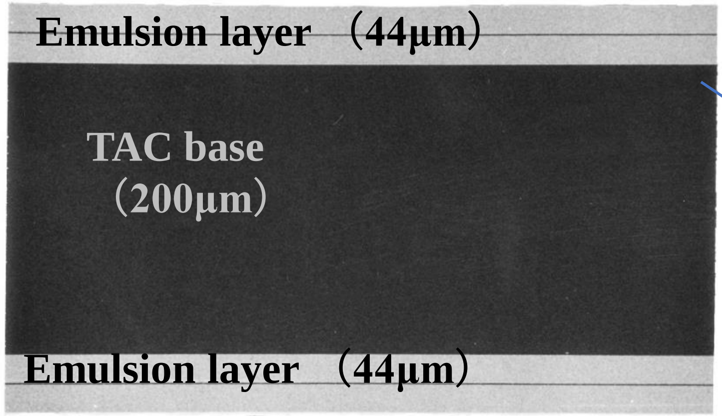
10^{14} crystals in a film



Core-shell structure

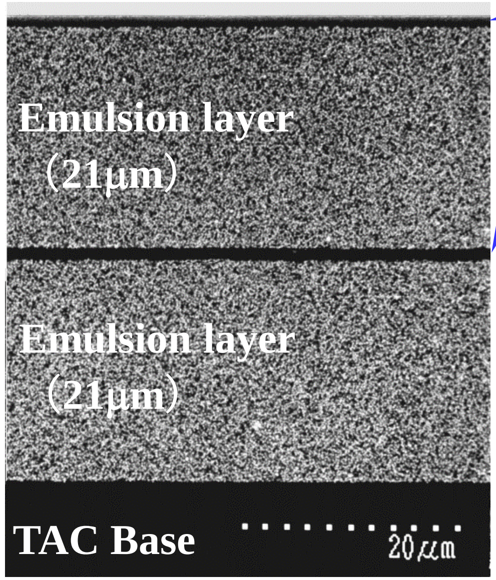




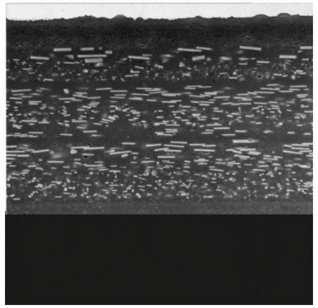


Zoom

Protection Coat
(1μm)



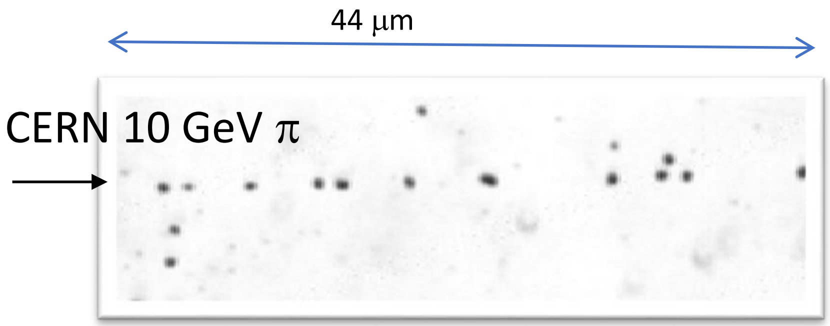
Color negative film

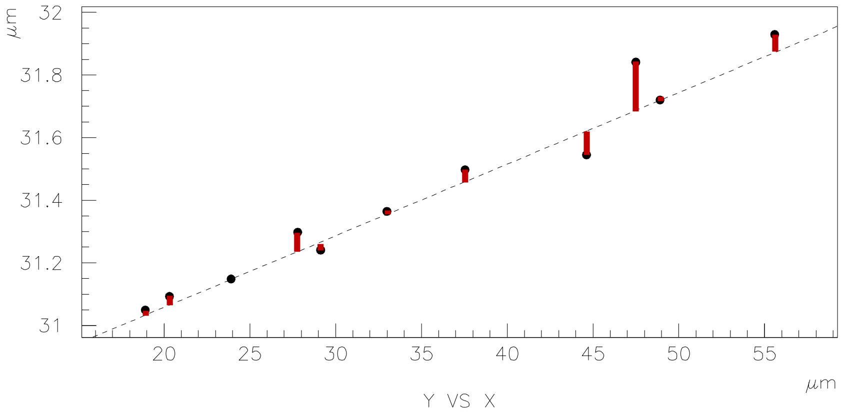


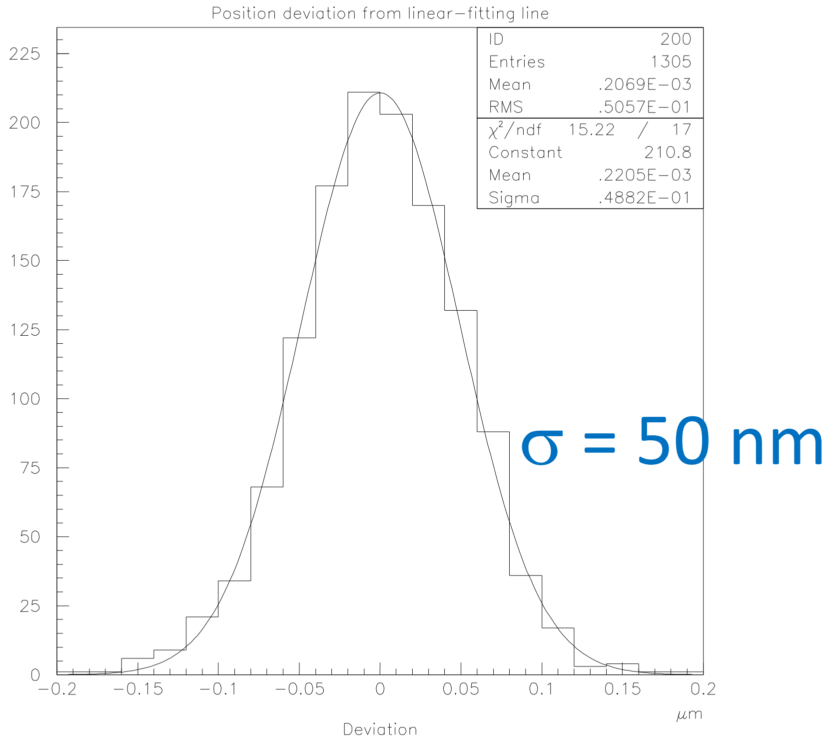
Nucl. Instrum. Methods A 556 80 (2006)

Intrinsic resolution of emulsion detector

- Precision measurement of hits (5nm)
- Deviation of grains from a fit line
- Resolution was found to be 50 nm
  - 0.35 mrad angular resolution

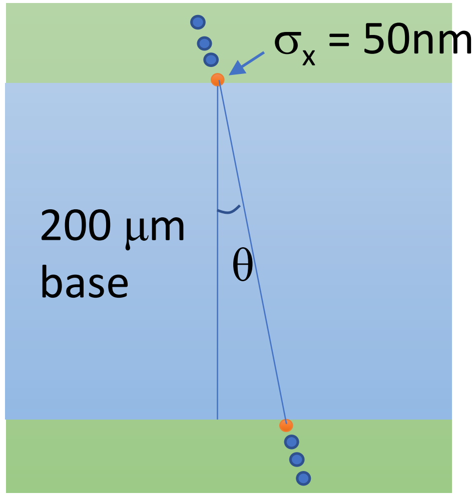


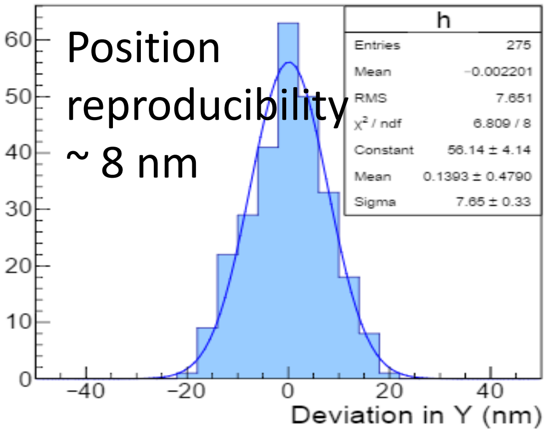


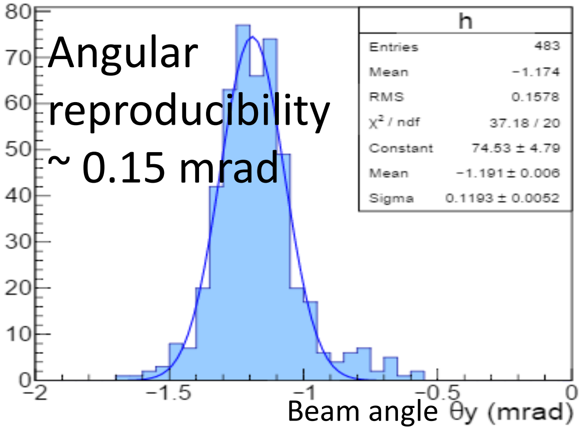


High precision measurement of track angles

- Intrinsic resolution of each grain = 50 nm
  - Two grains on top and bottom of 200 μm base → 0.35 mrad
  - Discrimination of 2 mrad at 4σ level
- A high precision system with a Piezo-based Z axis developmented



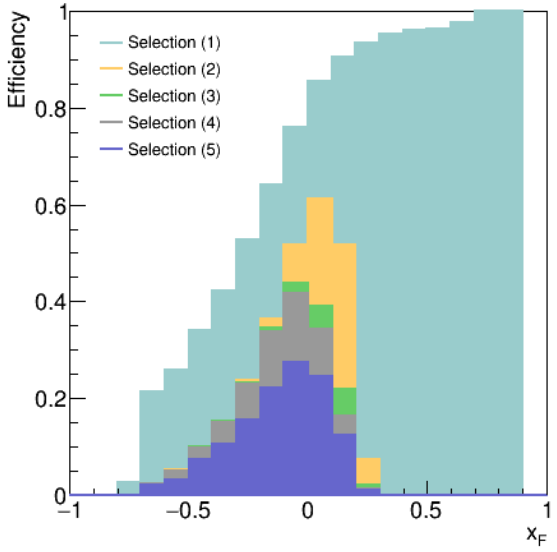


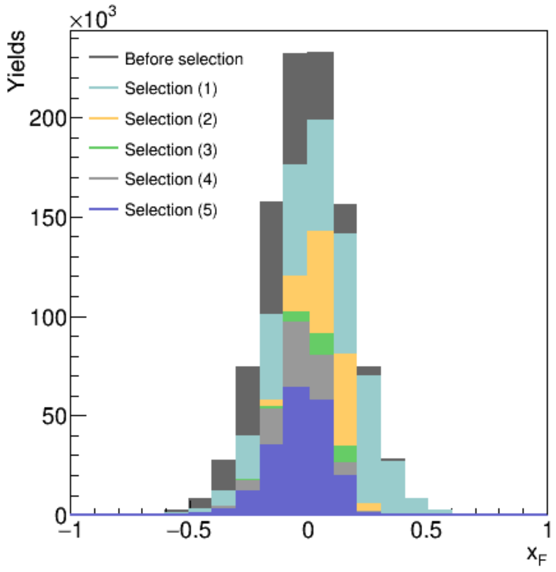


Piezo objective scanner

Efficiency of $D_s \to \tau \to X$ detection

Selection	Total efficiency (%)
(1) Flight length of D_s ≥ 2 emulsion layers	77
(2) Flight length of τ ≥ 2 layers & $\Delta\theta(D_s \to \tau)$ ≥ 2 mrad	43
(3) Flight length of D_s < 5 mm & flight length of τ < 5 mm	31
(4) $\Delta\theta(\tau)$ ≥ 15mrad	28
(5) Pair charm: 0.1 mm < flight length < 5 mm (charged decays with $\Delta\theta$ > 15 mrad or neutral decays)	20





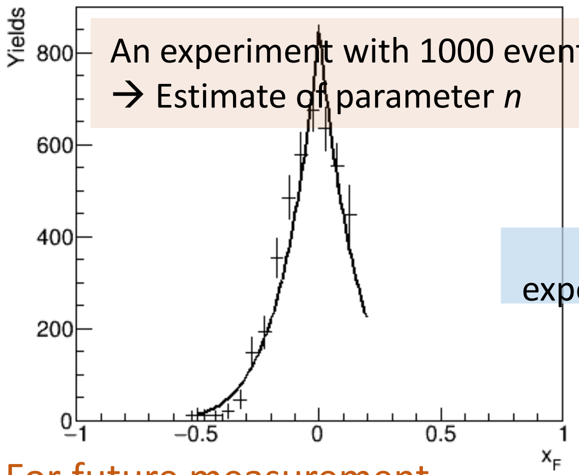
Estimation of parameter *n* for DONUT re-evaluation

Ds differential cross section

Parametrization used in DONUT

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

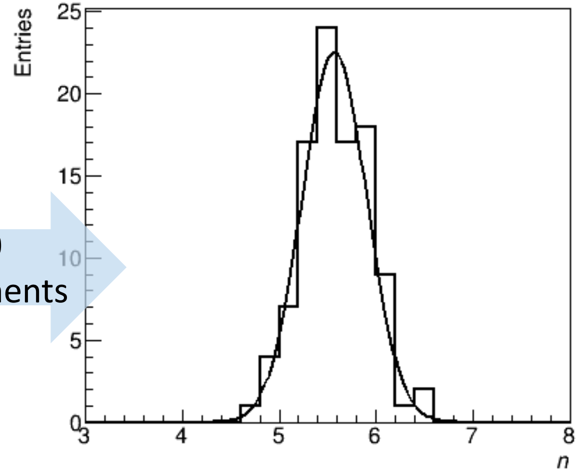
Reconstructed x_F
(corrected by the efficiency)



An experiment with 1000 events
→ Estimate of parameter *n*

100 experiments

Estimated parameter *n*



For future measurement,
a more appropriate parametrization will be used

Unfolding of the reconstruction xF distribution to be applied (method will be investigated)