Updates on FASERν and FASERν2

Tomoko Ariga (Kyushu University)
on behalf of the FASER Collaboration and FASERν2 WG

FASERν and FASERν2

2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Run 2				Run 3	Run 3	Run 3	Run 3				Run 4	Run 4	Run 4	Run 4			

11 kg

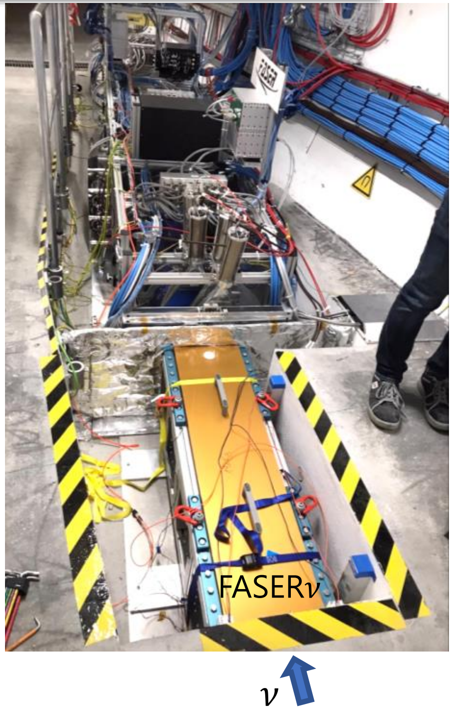
FASERν pilot run

First neutrino interaction candidates at the LHC

FASER Collaboration,
Phys. Rev. D 104, L091101 (2021)

1.1 tons

FASERν physics run

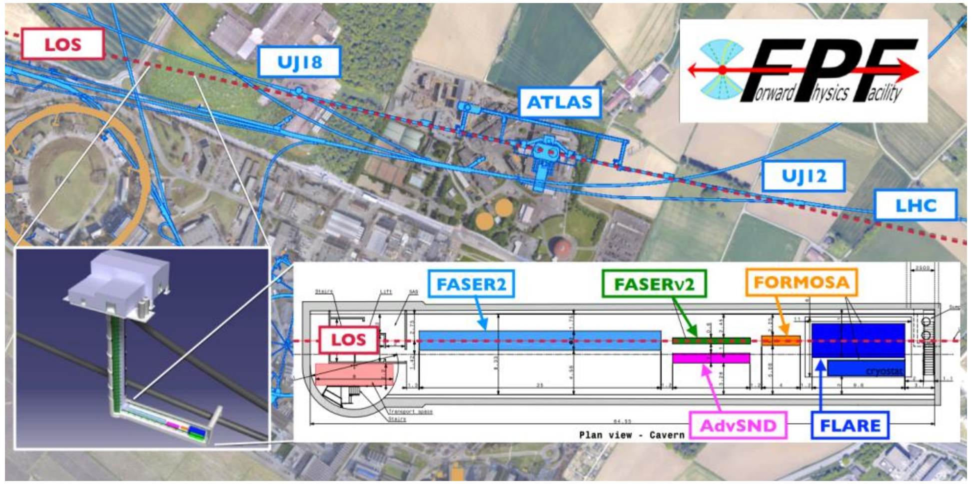


Cross section measurements of different flavors at TeV energies

20 tons

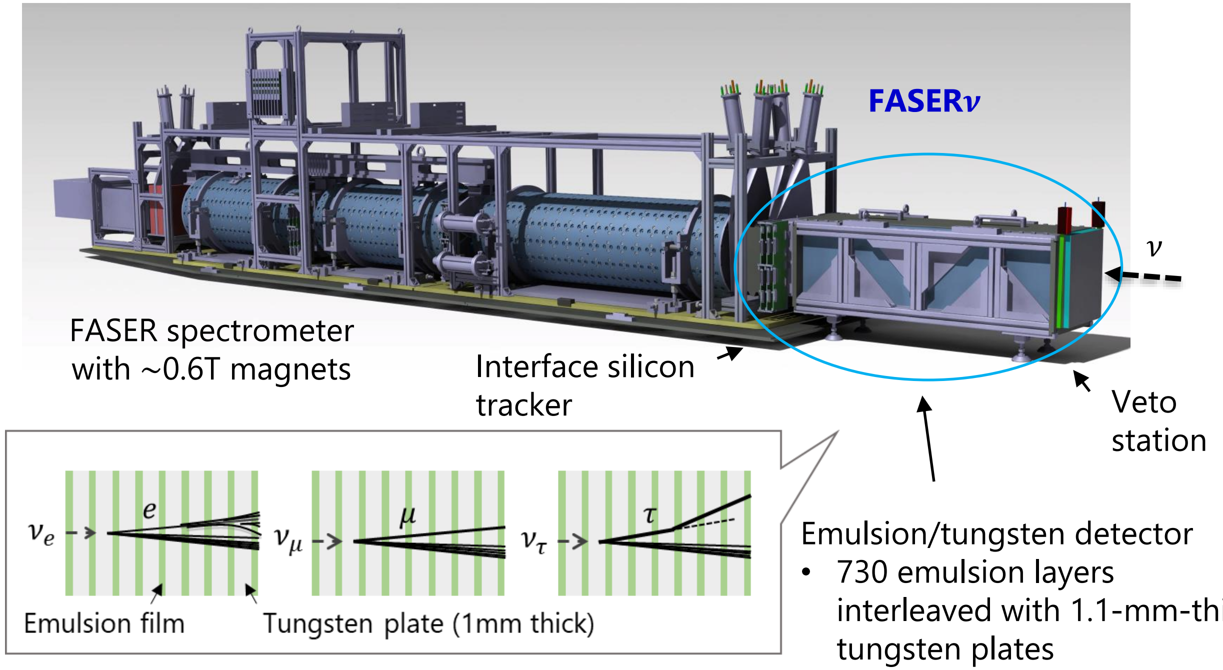
FASERν2

Precision ν_τ measurements and heavy flavor physics studies



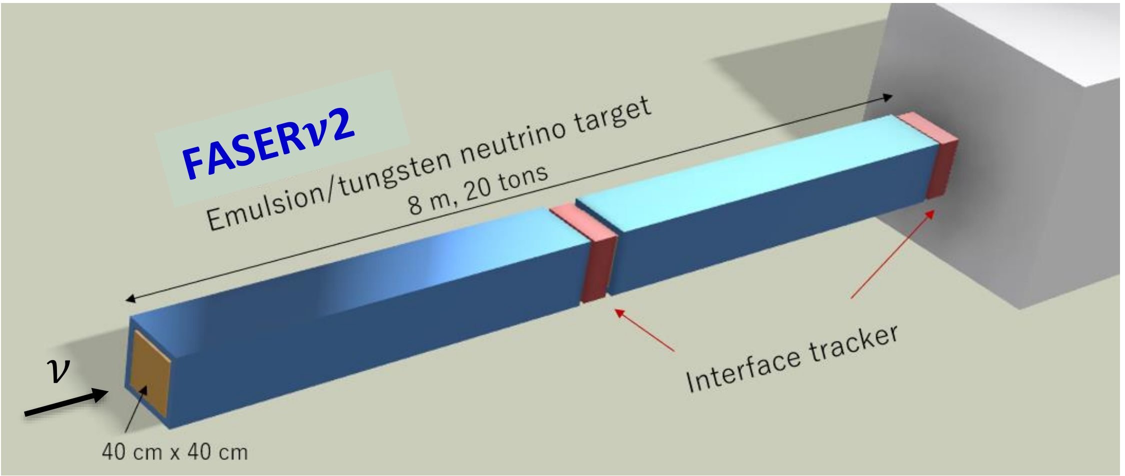
FASERν and FASERν2 detectors

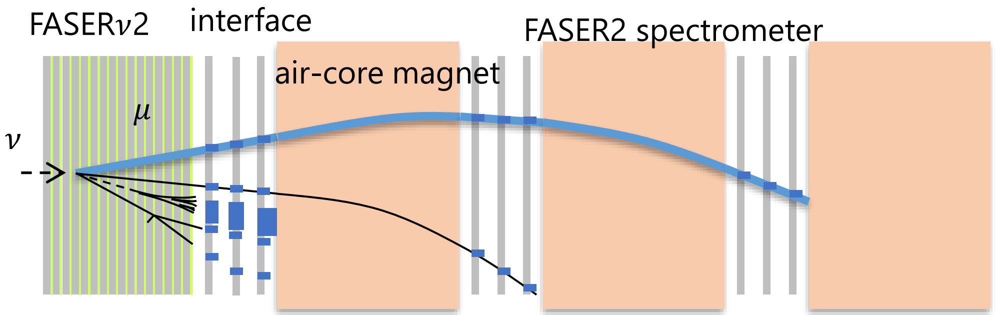
- On-axis
- Flavor sensitivity
- Charge ID for muons ($\nu_\mu/\overline{\nu_\mu}$ separation, $\nu_\tau/\overline{\nu_\tau}$ separation)



Emulsion/tungsten detector

- 730 emulsion layers interleaved with 1.1-mm-thick tungsten plates
- 25x30 cm^2, 1.1 m long, 1.1 tons



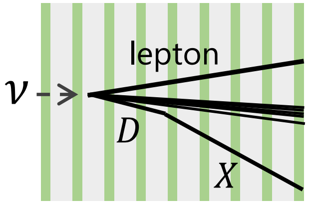


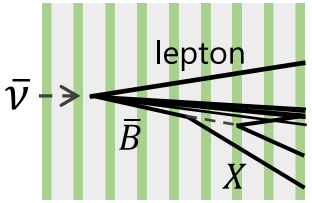
- The FASER**ν**2 detector will be composed of 3300 emulsion layers interleaved with 2 mm-thick tungsten plates.
- It will also include a veto detector and interface detectors to the FASER2 spectrometer.
- The total volume of the tungsten target is 40 cm × 40 cm × 6.6 m, and the mass is 20 tons.
- The muon rate is to be reduced with a sweeper magnet to make the emulsion replacement only once per year.

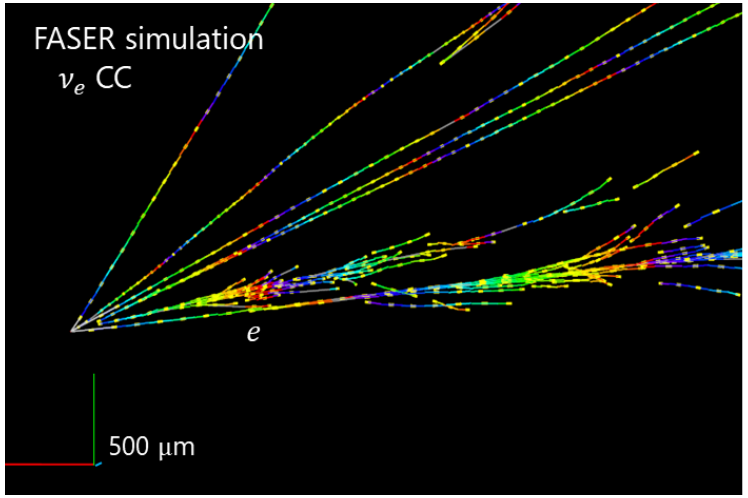
FASERν and FASERν2 expected number of events

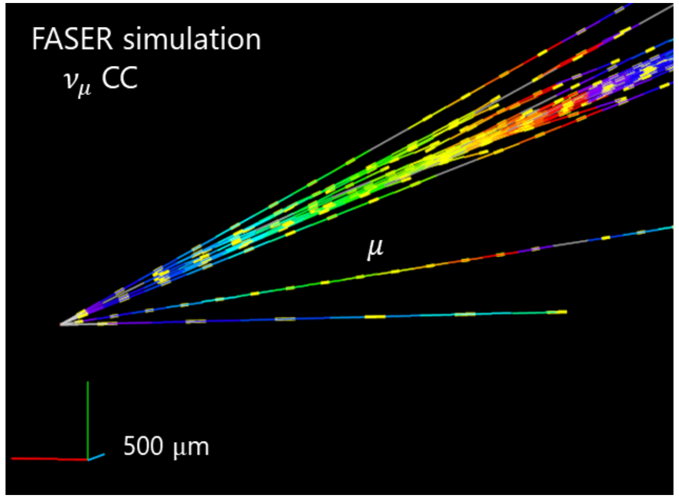
Based on "F. Kling and L.J. Nevay, Forward Neutrino Fluxes at the LHC, Phys. Rev. D 104, 113008"
and "J.L. Feng et al., The Forward Physics Facility at the High-Luminosity LHC, arxiv:2203.05090"

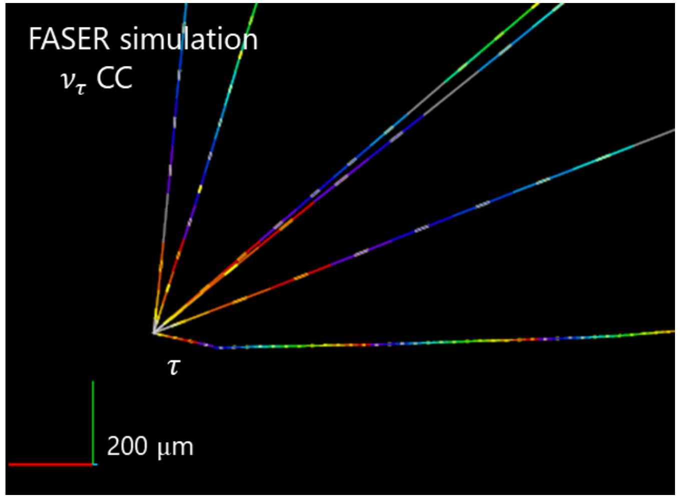
		(ν int. rate estimated using **Sibyll 2.3d**)			(**DPMJET 3.2017**)		
		$\nu_e+\overline{\nu_e}$ **CC**	$\nu_\mu+\overline{\nu_\mu}$ **CC**	$\nu_\tau+\overline{\nu_\tau}$ **CC**	$\nu_e+\overline{\nu_e}$ **CC**	$\nu_\mu+\overline{\nu_\mu}$ **CC**	$\nu_\tau+\overline{\nu_\tau}$ **CC**
FASERν (1.1 tons, 150 fb^{-1})	**ν int.**	**0.9k**	**4.8k**	**15**	**3.5k**	**7.1k**	**97**
	ν int. with charm	~0.1k	~0.5k	~2	~0.4k	~0.7k	~10
	ν int. with beauty	-	~0.05	-	-	~0.1	-
FASERν2 (20 tons, 3 ab^{-1})	**ν int.**	**178k**	**943k**	**2.3k**	**668k**	**1400k**	**20k**
	ν int. with charm	~20k	~90k	~0.2k	~70k	~100k	~2k
	ν int. with beauty	~2	~10	~0.02	~7	~10	~0.2



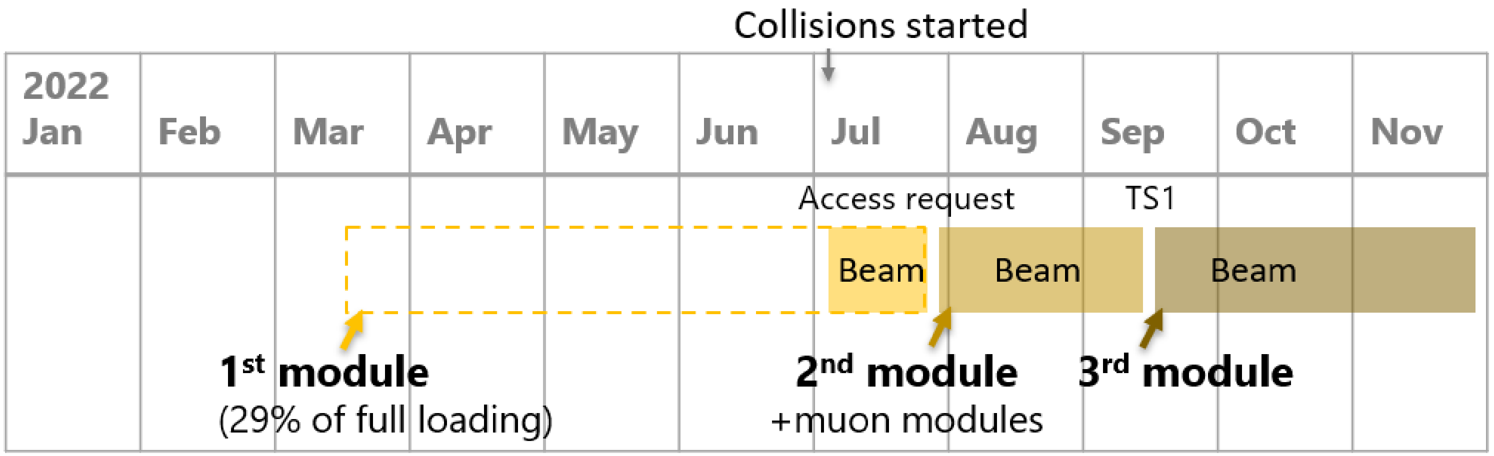








FASERν 2022 runs



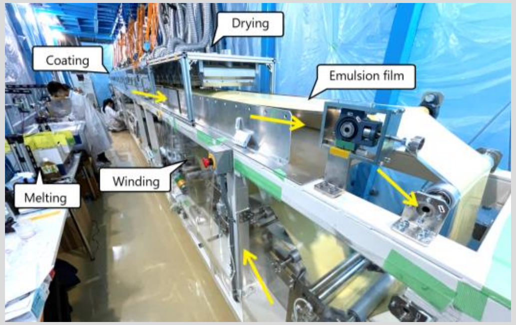
		Integrated luminosity per module (fb^{-1})	N ν int. expected
2022 1st module	Mar 15 – Jul 26	0.5	~7
2022 2nd module	Jul 26 – Sep 13	10.6	~530
2022 3rd module	Sep 13 – Nov 29	(~30)	(~1500)

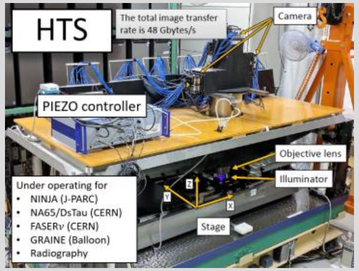
based on "F. Kling and L.J. Nevay, Forward Neutrino Fluxes at the LHC, Phys. Rev. D 104, 113008"

FASERν workflow (similar for FASERν2)

- FASERν: 3 modules per year
- FASERν2: 1 module per year

Successful operation in 2022 in the refurbished CERN emulsion facility

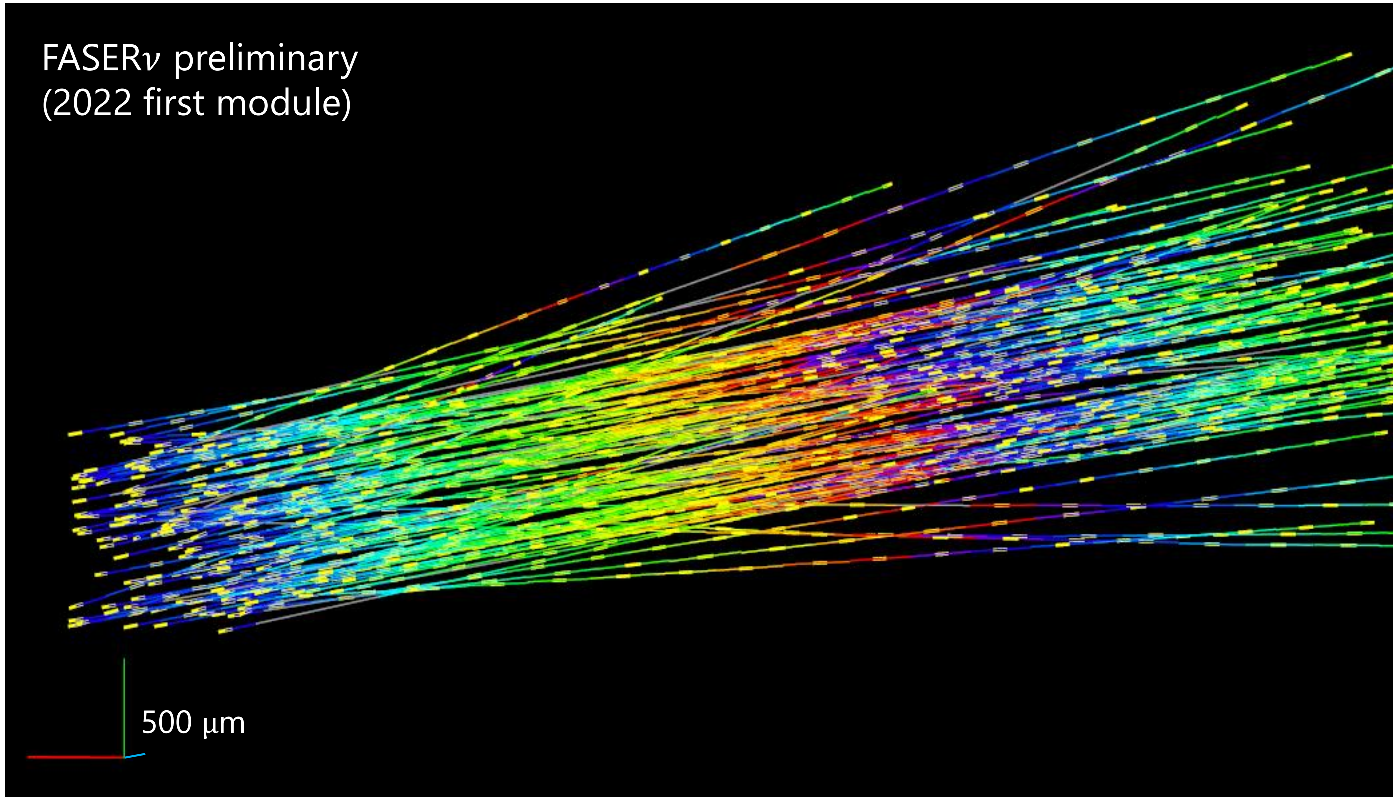




In Japan: **Emulsion film production** → **At CERN:** **Detector assembling** → **Exposure** → **Disassembling** → **Development** → **In Japan:** **Full area readout**

Off-line analysis: Alignment → Track reconstruction → Vertex reconstruction → μ / e ID → Search for tau/charm decays → Kinematical analysis / Charge ID

FASERν data from the 2022 first module

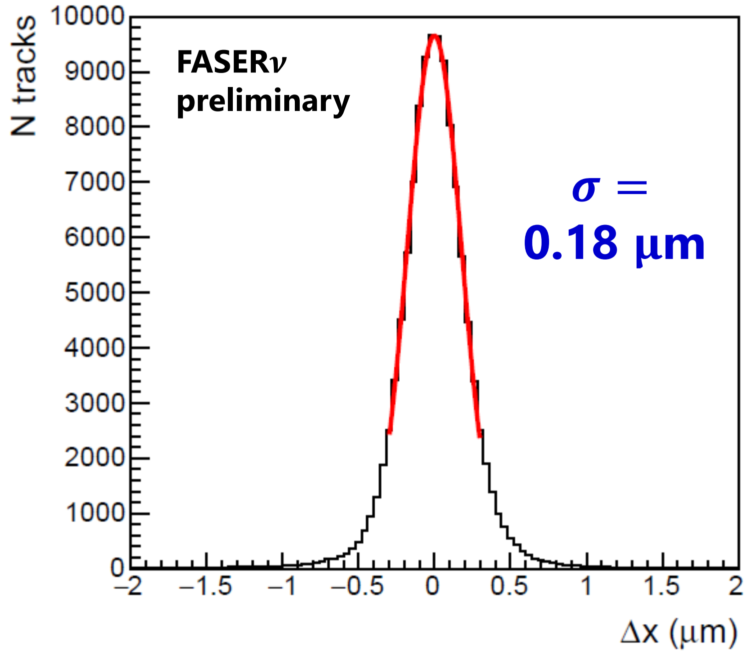


Reconstructed tracks (above ~1 GeV) in 1 mm × 1 mm × 20 emulsion films, which collected 0.5 fb^{-1} of data.

Track density:
1.2×10^4 tracks/cm^2/fb^{-1}
(within 10 mrad from the angular peak)

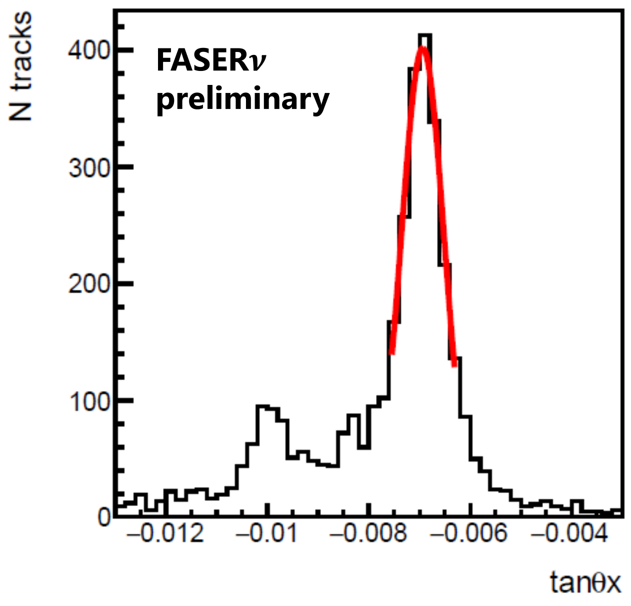
FASERν data from the 2022 first module

Position deviation between the track hits and the straight-line fits to reconstructed tracks



for the case dedicated alignment is applied to 10 emulsion films

Angular distributions



$\sigma \sim$ **0.4 mrad**

The angular spreads of the peaks are mainly due to the multiple Coulomb scattering through 100 m of rock.

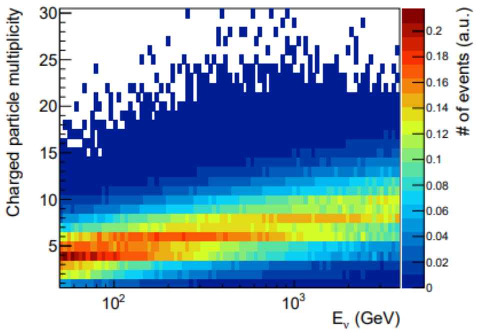
The angular resolution is ~0.1 mrad (using 1 cm thick).

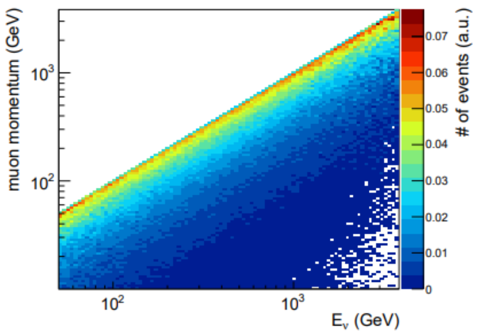
FASERν/FASERν2 energy reconstruction

- Neutrino energy will be reconstructed by combining topological and kinematical variables

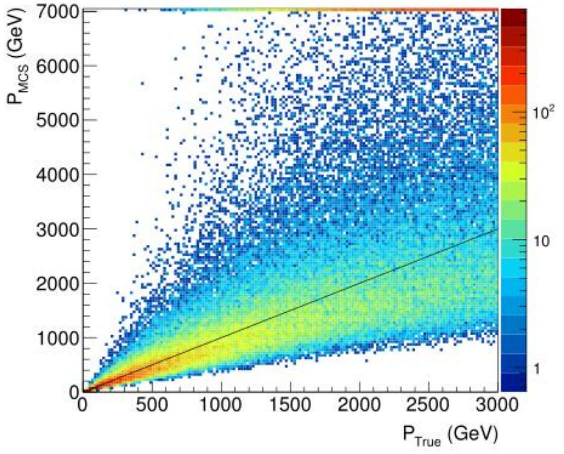
An ANN algorithm was built with
topological variables
- # of charged tracks → E_h
- # of γ showers → E_h
- inverse of lepton angle → E_l
- sum of inverse of hadron track angles → E_h
- inverse of median of all track angles → E_h, E_l

kinematical info (smeared)
- lepton momentum → E_l
- sum of charged hadron momenta → E_h
- sum of energy of γ showers → E_h



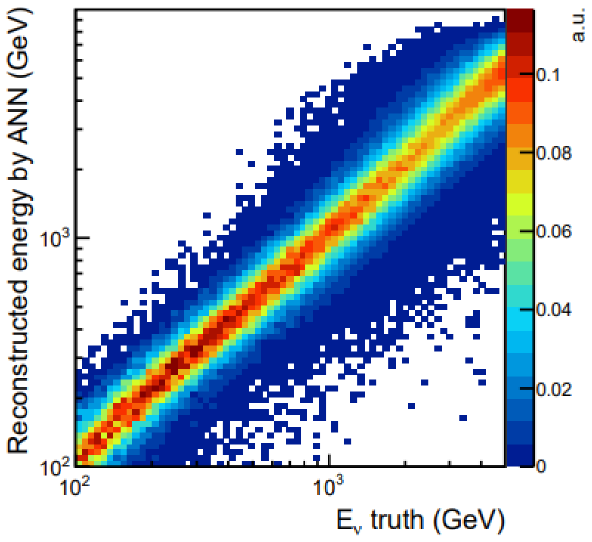


Momentum resolution
(using MCS in the emulsion detector)



Resolution of p_μ will be better using the **FASER2** spectrometer (→ to be studied)

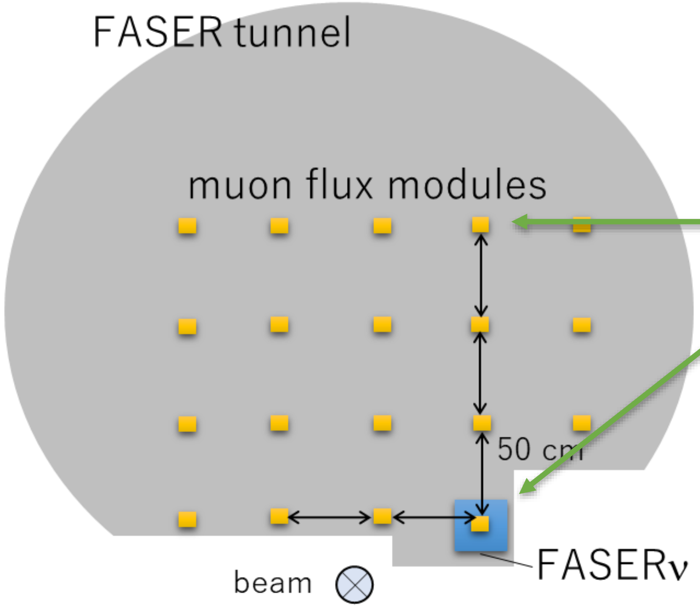
$E_\nu - E_{ANN}$



$$\frac{\Delta E_\nu}{E_\nu} \sim 30\%$$

FASERν muon measurements

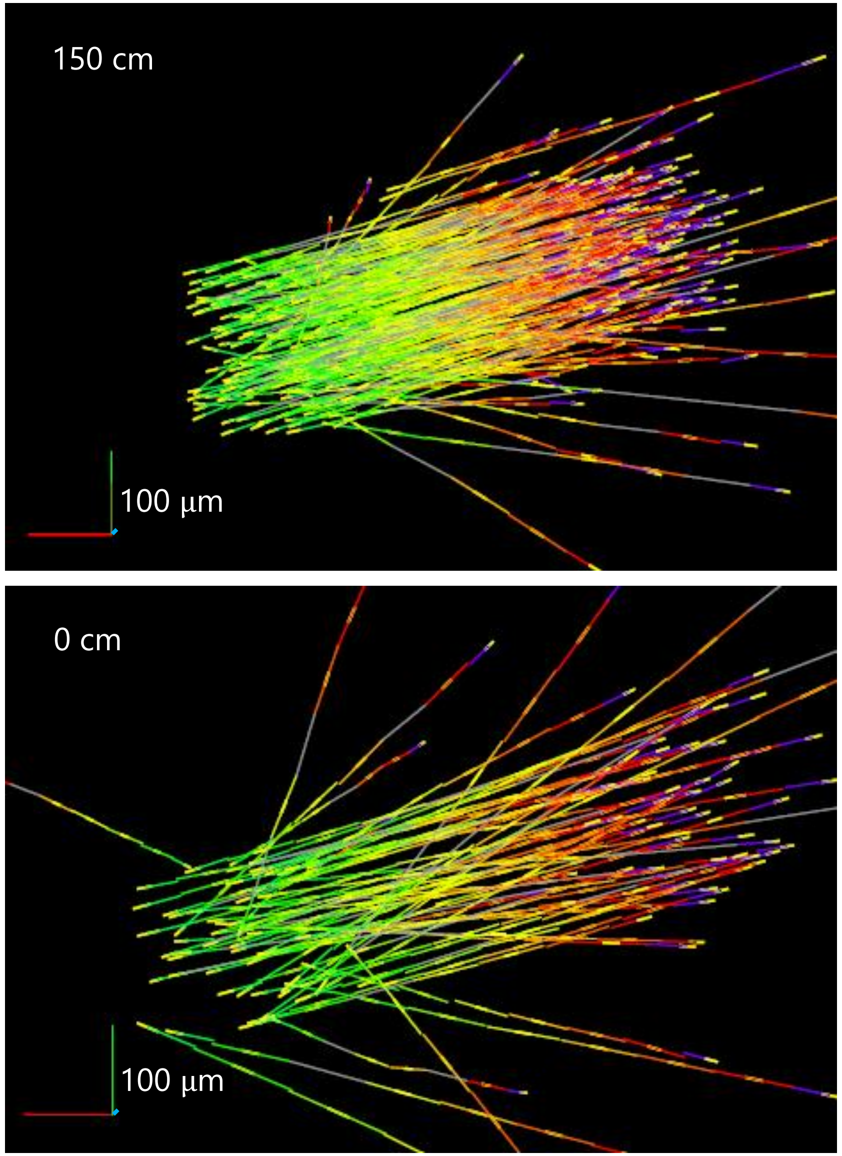
In order to validate the FLUKA/BDSIM simulations of the muon background, 19 small emulsion detectors were installed in July 2022 in the region ~2 m from the LOS to measure the muon flux. They were extracted in September 2022, collecting 10.6 fb-1.



FASERν preliminary
(before efficiency correction)

	track density (/cm^2/fb^{-1}) (within 10 mrad from the peak)
height 150 cm	3.6×10^4
height 0 cm	0.9×10^4
FASERν 1st module	1.2×10^4

Reconstructed tracks in 200 μm × 200 μm × 8 emulsion films from the muon modules



FASERν2 main components

- **Emulsion films**
  - The amount of emulsion films per year: 40×40 cm^2×3300 films or 20×40 cm^2×6600 films (total ~550 m^2)
  - → See the following talk by Hiroki Rokujo.

- **Tungsten target**
  - 3300 2-mm-thick tungsten plates, 40×40 cm^2, purity>99.95%
  - Preliminary cost estimate from a Chinese company (thanks to Zhen and Tomohiro for contacting the company)
    - 560 USD / plate
  - We will purchase sample plates and start testing them.

- **Emulsion readout system**
  - We are considering how to make a new scanning system like the HTS dedicated to FASERν2.

- **Interface tracker and charge ID**
  - → See the following talk by Yosuke Takubo.

FASERν2 cost estimate

~6M CHF (Run 4)
~9M CHF (after Run 4)

year
before 2031
2031
2032
...

year	main components	cost (CHF)
before year-1	tungsten (2-mm thick, 40×40 cm^2) 3300 plates +10%	~2M
	emulsion readout system "HTS"	~1.7M
	expert of the readout system	~0.5M
	interface detectors	~0.1M?
	support structure (& installation)	~0.2M?
	cooling system	~0.1M?
year-1	emulsion (40×40 cm^2) 3300 films	~1M (per year) (if the experiment provides no shift)
	chemicals for development	~0.05M (per year)
	personnel for scanning	~0.05M (per year)
year-2	...	~1.1M (if the experiment provides no shift)
year-3	...	~1.1M
year-4	...	~1.1M
year-5	...	~1.1M
year-6	...	~1.1M
year-7	...	~1.1M
year-8	...	~1.1M
year-9	...	~1.1M
year-10	...	~1.1M

Summary

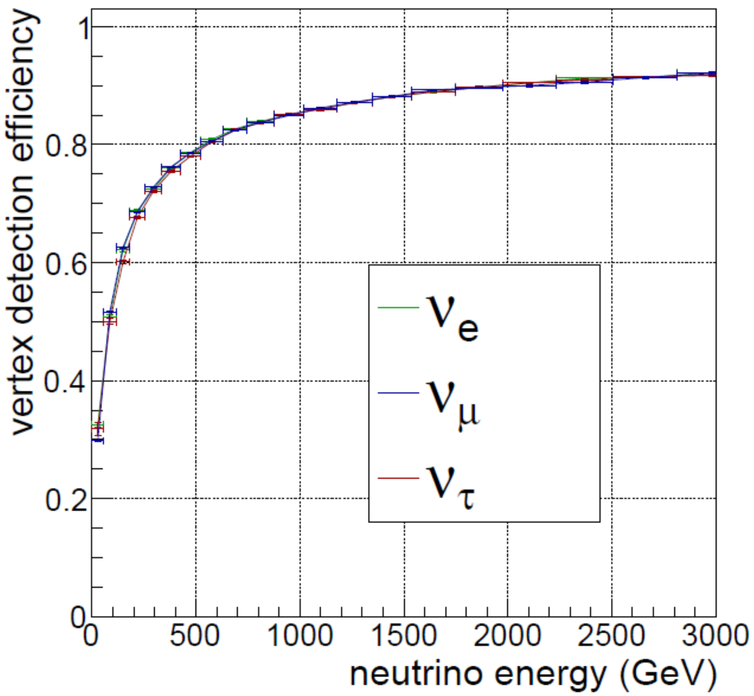
- FASERν
  - It is taking data in Run 3, and the emulsion films were successfully replaced twice. Emulsion development of the 1st and 2nd modules was also successfully performed, and the emulsion readout has started.
  - The data from the first module shows excellent performance. Further analysis of the first and second modules is in progress toward the first physics results.

- FASERν2
  - Work is in progress to decide the detector design and each component of the experiment.
  - The Initial cost estimate has been shown.
    - ~6M CHF (Run 4)
    - ~9M CHF (after Run 4)
  - The next speakers will discuss more details on the emulsion detector and the interface detector.

Backup

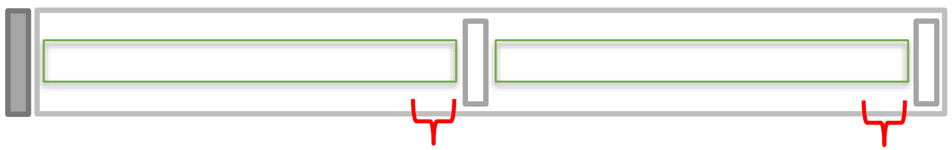
ν detection and acceptance

- **Vertex detection efficiency** after requiring at least 5 charged particles
  - Using charged tracks and γ rays with p > 0.3 GeV and $\tan\theta$ < 1 (relative to the neutrino direction)
  - → may change to p > 1 GeV and $\tan\theta$ < 0.5

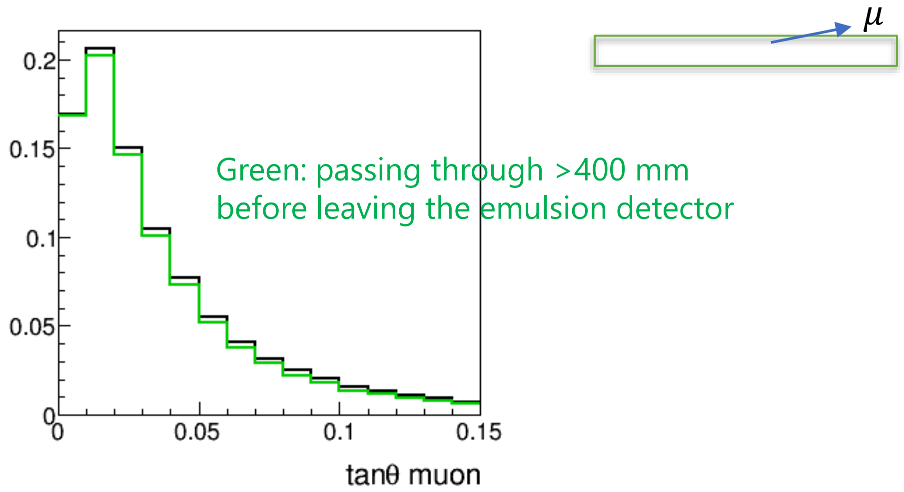


- **Additional inefficiencies for ν_μ**

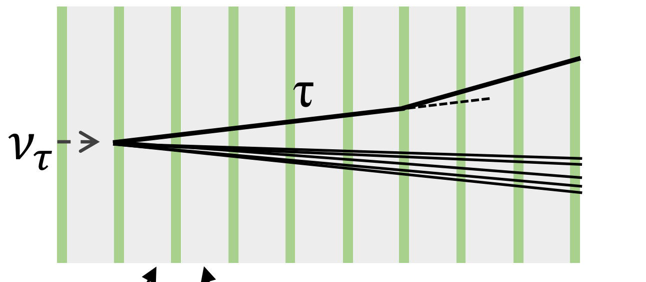
1. 400 mm tungsten from the most downstream layer would be used for μ ID (400 mm/3300 mm = 12%).



2. In addition, ~5.4% of μ^- (~3.5% of μ^+) will go side out before passing through enough material for the muon ID.



Detection of tau decays



- Special resolution of hits in the emulsion
  - 0.5 μm (measured in the FASERν pilot run data)

- → Angular resolution with the arm length of 10 mm = $0.5\times\sqrt{2}/10000$ = ~0.1 mrad

- To detect a kink,
  - tau should cross at least one emulsion layer,
  - kink angle should be larger than four times the angular resolution and more than 0.5 mrad
  - → reasonable efficiency for τ decays (75% for 1-prong decays)