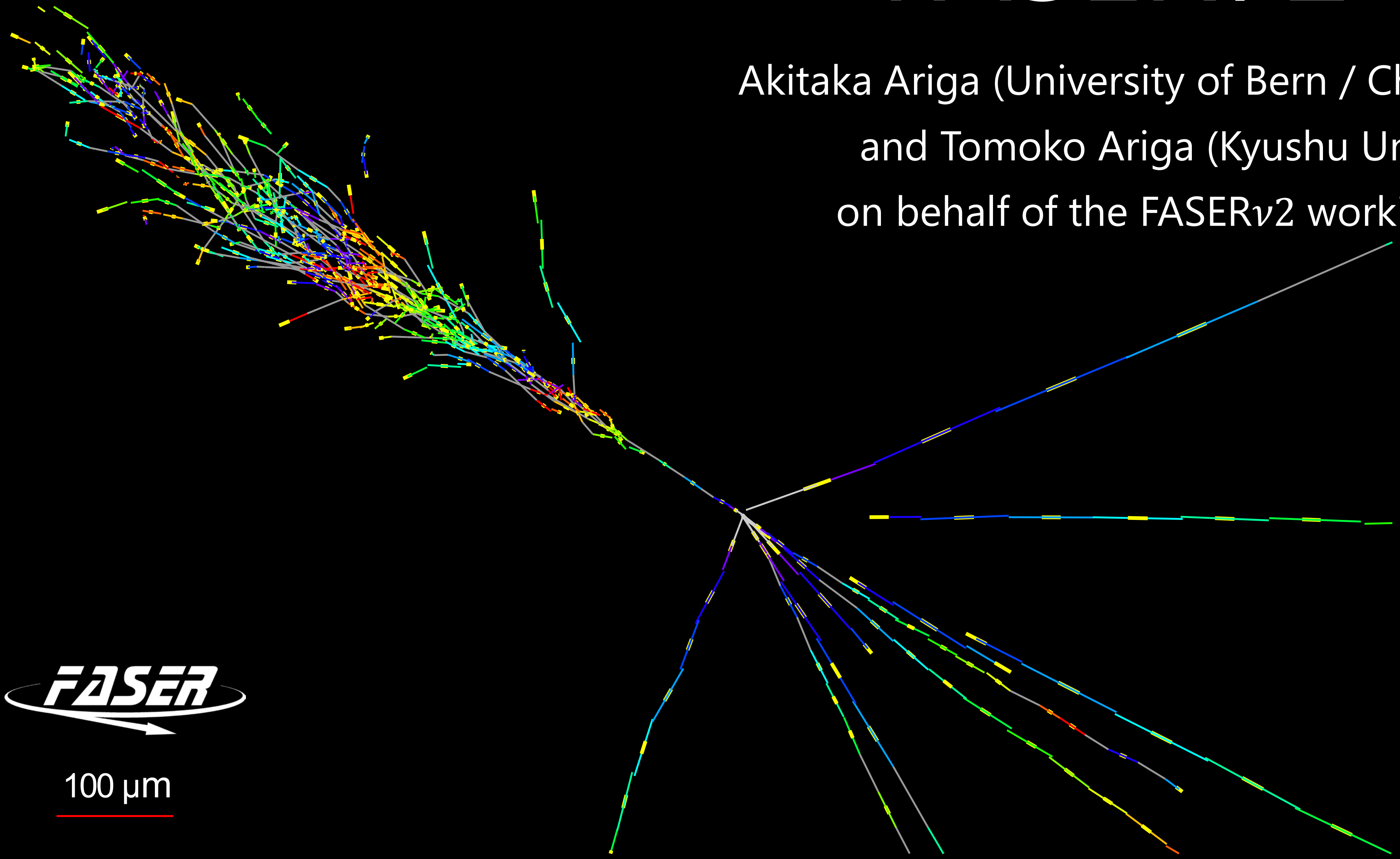
FASERν2

Akitaka Ariga (University of Bern / Chiba University)
and Tomoko Ariga (Kyushu University)
on behalf of the FASERν2 working group



FASERν and FASERν2

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

0.01 tons × 12 fb^{-1}

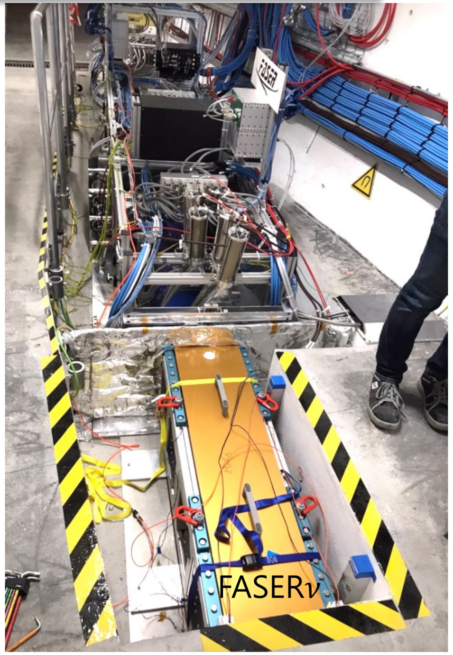
FASERν pilot run

First neutrino interaction candidates at the LHC

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

1.1 tons × 250 fb^{-1}

FASERν physics run



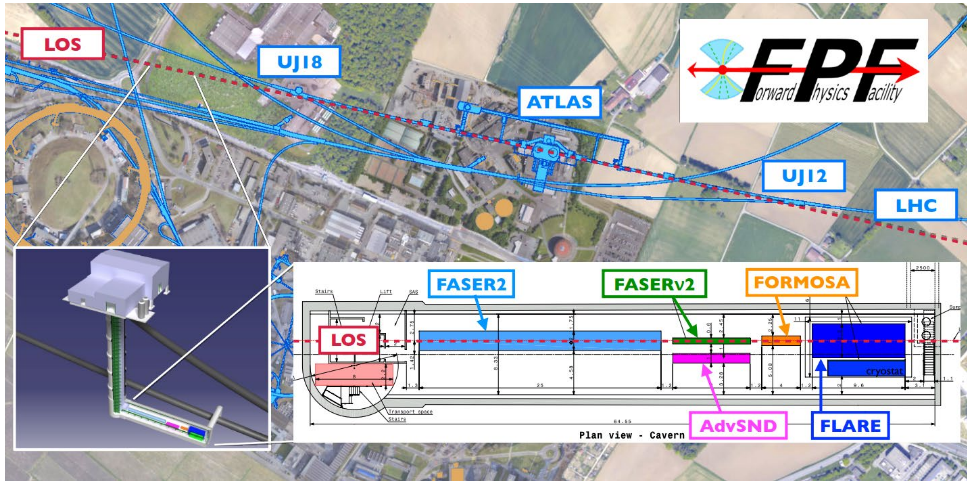
ν

Cross section measurements of different flavors at TeV energies

10-20 tons × 3000 fb^{-1}

FASERν2

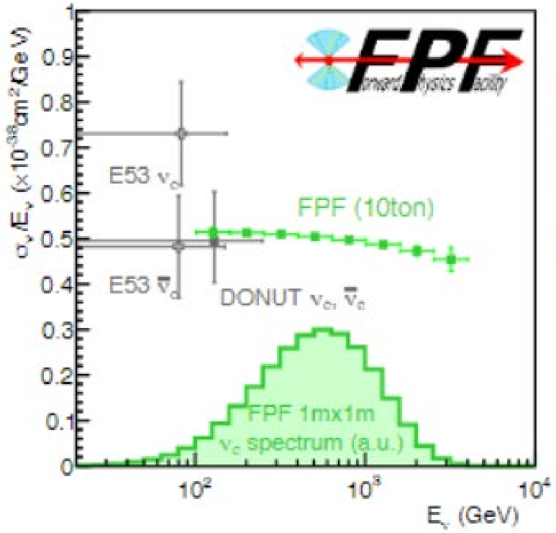
Precision ν_τ measurements and heavy flavor physics studies



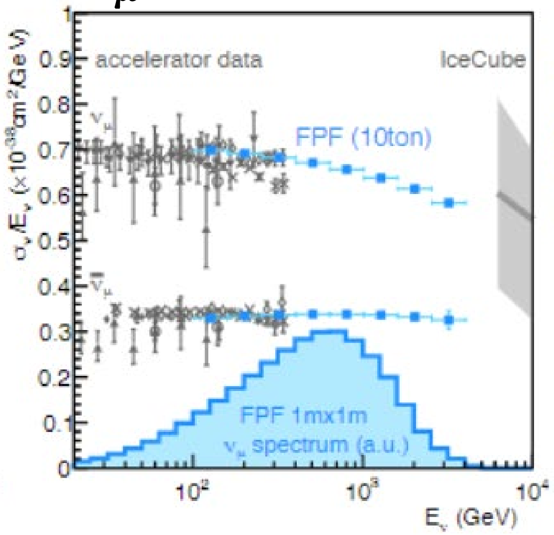
FASERν2: Neutrino physics

- FASERν @LHC-Run 3 (1.2 ton)
  - Unexplored TeV energy ~3000 ν_e, ~9000 ν_μ, ~50 ν_τ CC events
- FASERν2 @HL-LHC (~10 ton)
  - FASERν2: Beam ×15-20, ~10 tons mass → FASERν ×200
  - **$\sim 10^5\ \nu_e$, $\sim 10^6\ \nu_\mu$, $\sim 10^3\ \nu_\tau$ CC events**
- Tau neutrino physics, precise measurement of cross sections, rare process

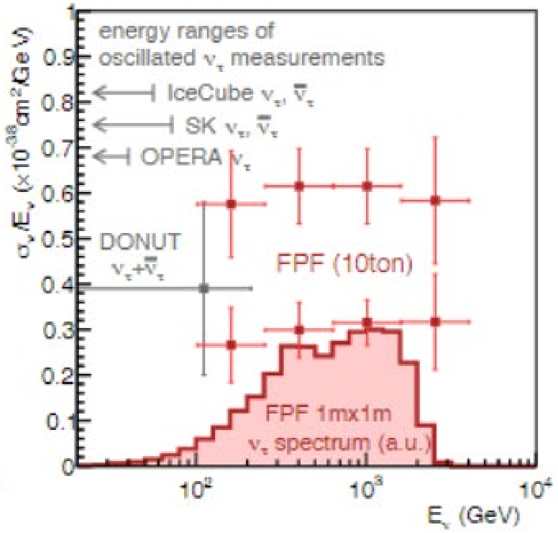
ν_e



ν_μ

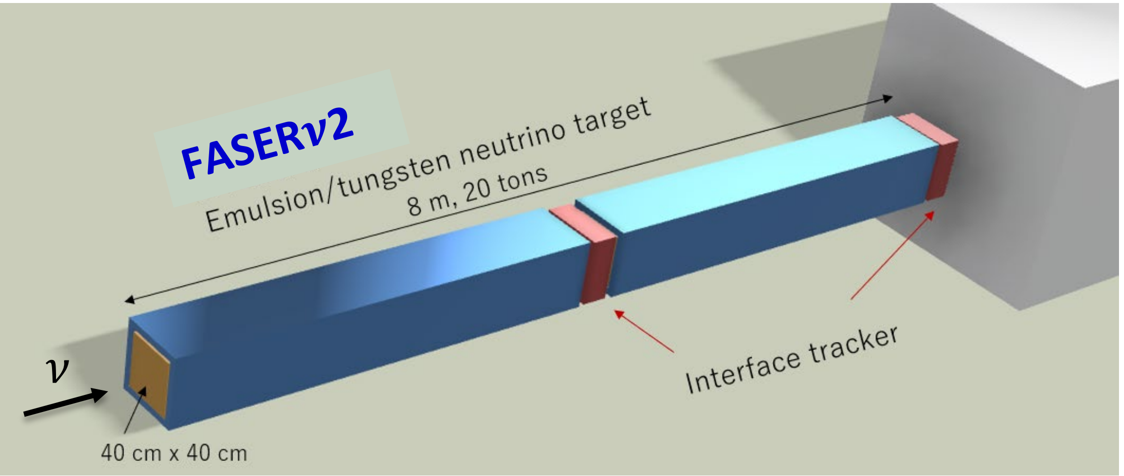


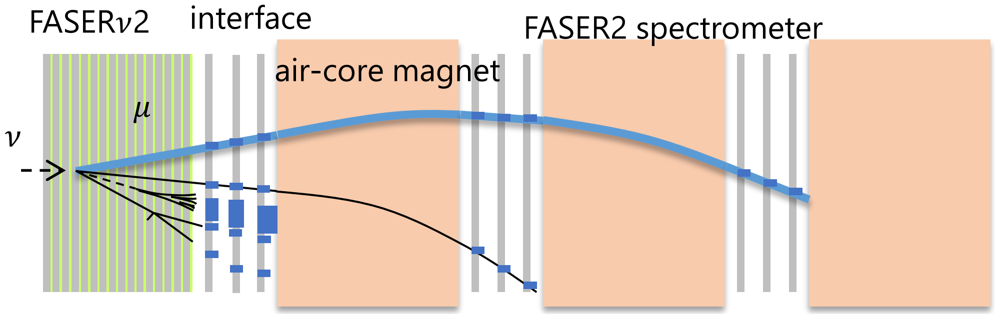
ν_τ

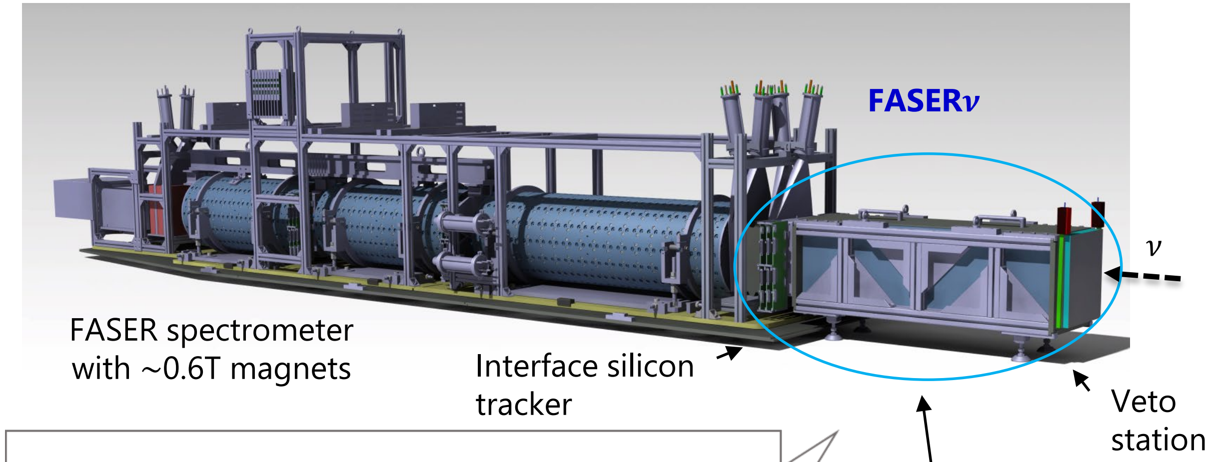


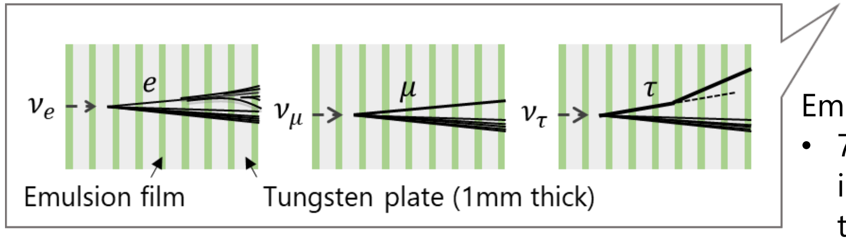
FASERν and FASERν2 detectors

- 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

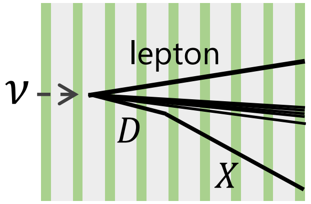
- The FASERν2 detector will be composed of 3300 emulsion layers interleaved with 2 mm-thick tungsten plates.
- It will also include a veto detector and interface detectors to the FASER2 spectrometer.
- The total volume of the tungsten target is 40 cm $\times$ 40 cm $\times$ 6.6 m, and the mass is 20 tons.
- The muon rate is to be reduced (with a sweeper magnet) to make the emulsion replacement only once per year.

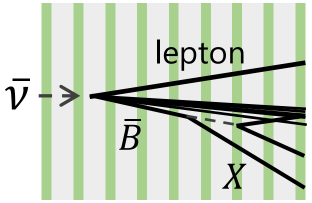
FASERν and FASERν2 expected number of events

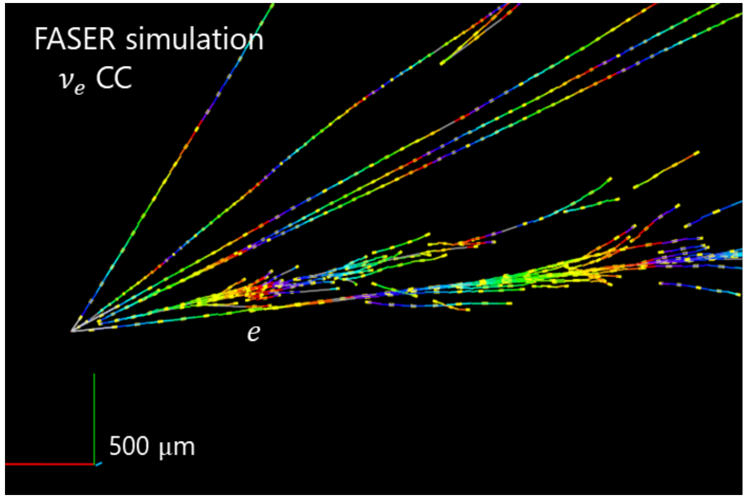
Based on "F. Kling and L.J. Nevay, Forward Neutrino Fluxes at the LHC, Phys. Rev. D 104, 113008"
and "J.L. Feng et al., The Forward Physics Facility at the High-Luminosity LHC, arxiv:2203.05090"

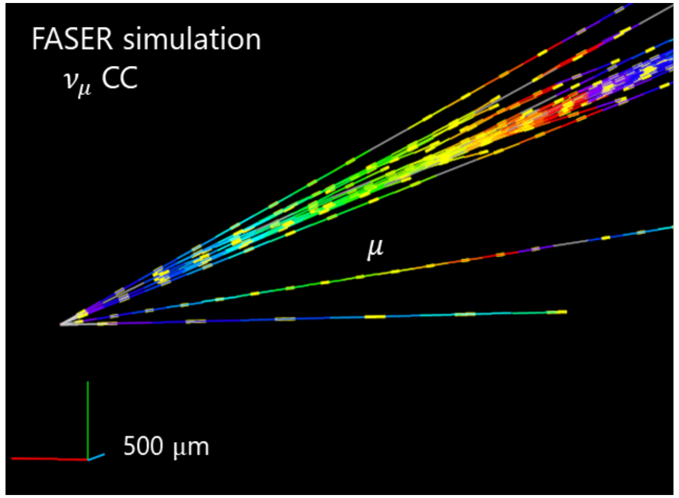
(ν int. rate estimated using **Sibyll 2.3d**) (**DPMJET 3.2017**)

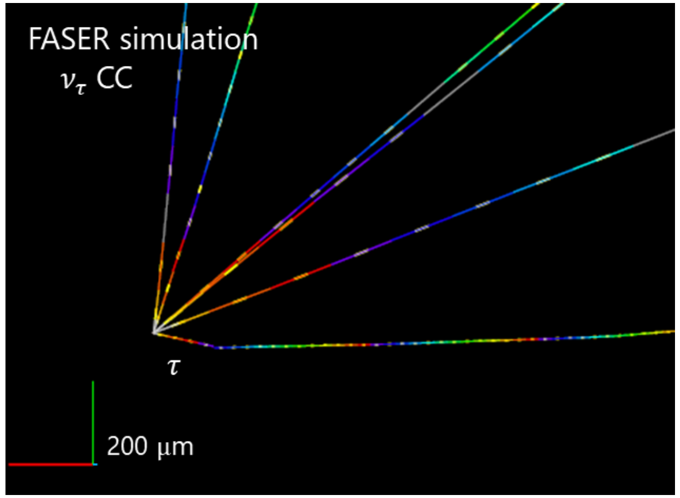
		Sibyll 2.3d: $\nu_e+\overline{\nu_e}$ CC	Sibyll 2.3d: $\nu_\mu+\overline{\nu_\mu}$ CC	Sibyll 2.3d: $\nu_\tau+\overline{\nu_\tau}$ CC	DPMJET 3.2017: $\nu_e+\overline{\nu_e}$ CC	DPMJET 3.2017: $\nu_\mu+\overline{\nu_\mu}$ CC	DPMJET 3.2017: $\nu_\tau+\overline{\nu_\tau}$ CC
FASERν (1.1 tons, 150 fb^{-1})	**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



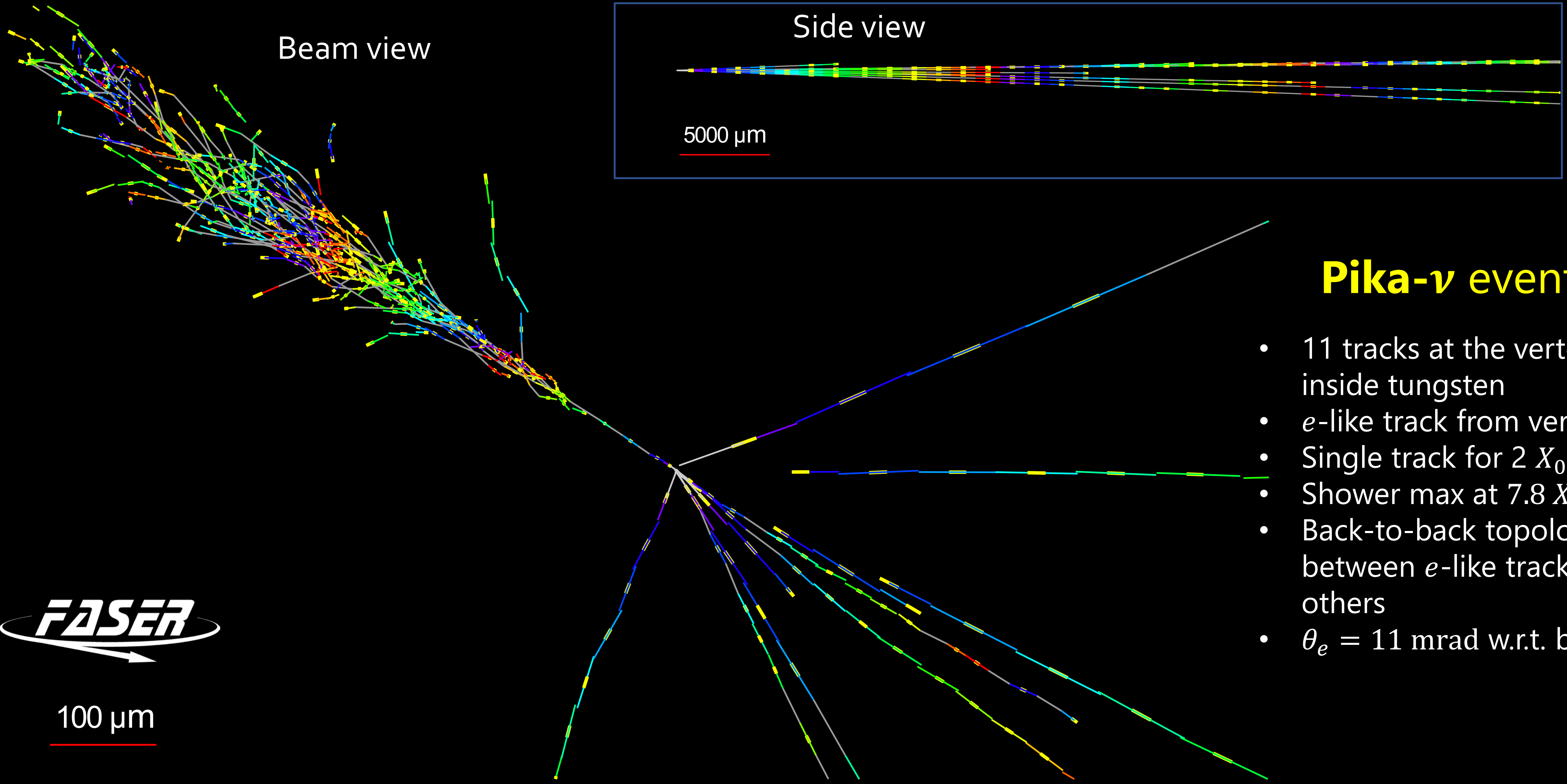








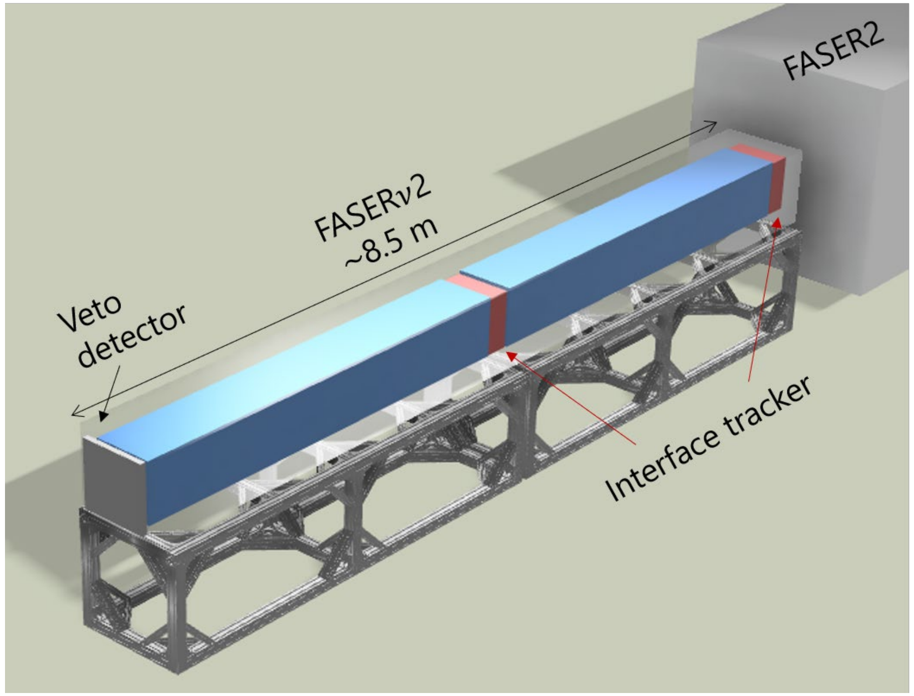
Observed ν_e candidate in FASERν



Pika-ν event

- 11 tracks at the vertex, 615 μm inside tungsten
- e-like track from vertex
- Single track for 2 X_0
- Shower max at 7.8 X_0
- Back-to-back topology, 175° between e-like track and others
- $\theta_e = 11$ mrad w.r.t. beam

FASERν2 main tasks



- **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)
  - Emulsion production facility in Nagoya University
  - Performance tests in realistic conditions (long-term performance)

- **Tungsten target**
  - 3300 2-mm-thick tungsten plates, 40×40 cm^2, purity>99.95%
  - Preliminary cost estimate from a Chinese company, 560 USD / plate
  - Will purchase sample plates and start testing them.

- **Mechanical structure, assembly method, cooling system**
  - Mechanical structure to hold 20-ton emulsion-tungsten target
  - Keep temperature as low as possible to prevent "fading"
  - Start working on each of them

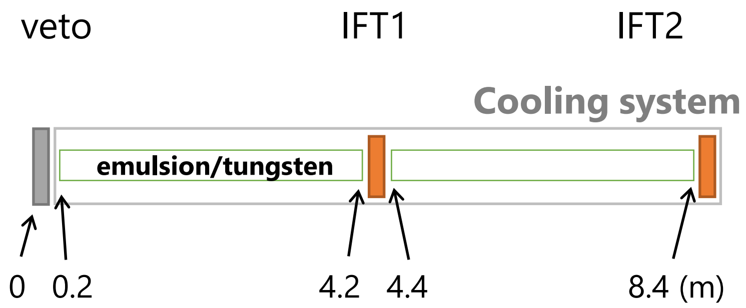
- **Emulsion facility**
  - Dark room for assembling and development

- **Emulsion readout system**
  - Development of HTS3 in Nagoya University
  - 2nd in Chiba University

- **Veto, interface tracker and charge ID**
  - Combined analysis with FASER2 → See the talk by Yosuke at FPF5

- **Performance, physics sensitivity studies**
  - Simulations

Setup for charge ID



Detector surface

- Emulsion: 40×40 cm^2
- Veto & IFT : 80×80 cm^2

FASER2

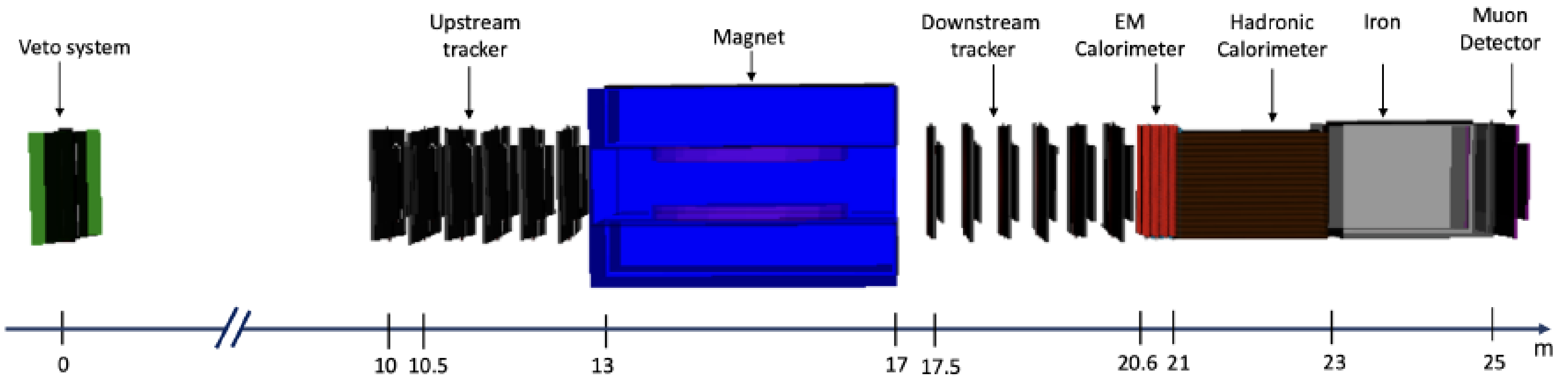
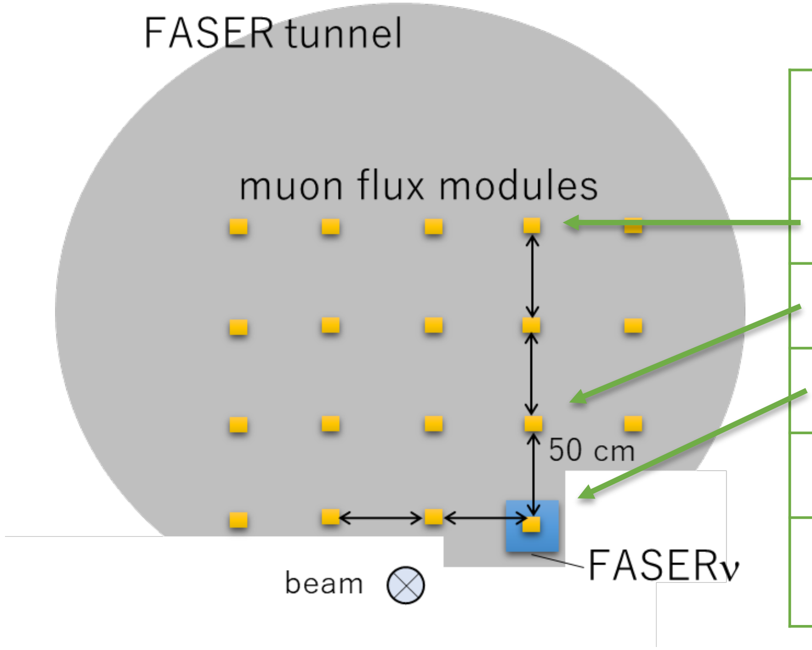


FIG. 10. Schematic diagram of the full FASER2 detector, showing the veto system, un-instrumented 10 m decay volume, tracker, magnet, electromagnetic calorimeter, hadronic calorimeter, iron absorber, and muon detector.

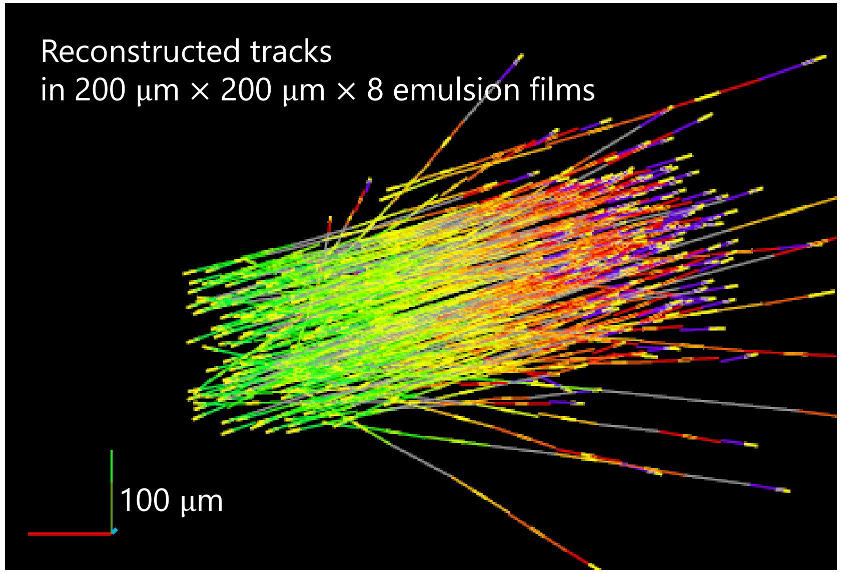
FASERν muon measurements

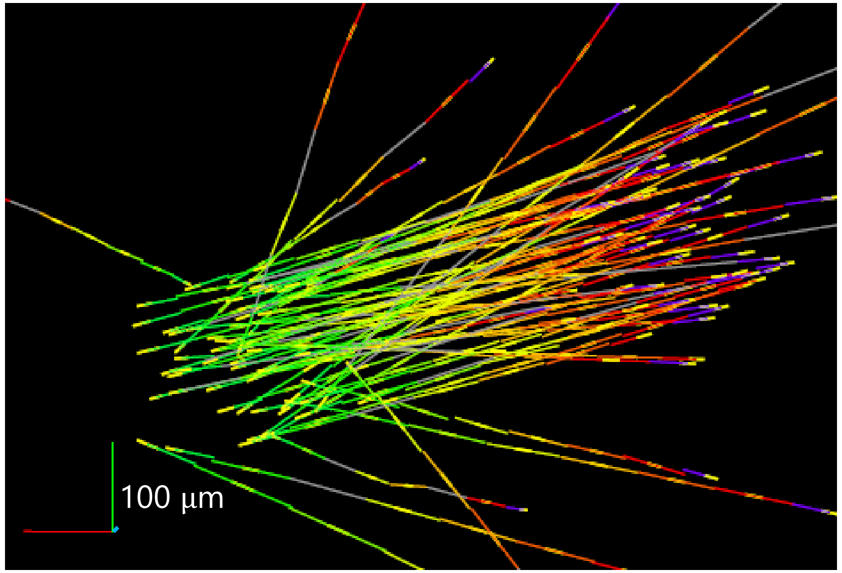
In order to validate the FLUKA/BDSIM simulations of the muon background, 19 small emulsion detectors were installed in July 2022 in the region ~2 m from the LOS to measure the muon flux. They were extracted in September 2022, collecting 10.6 fb^{-1}.



FASERν preliminary

	track density ($/cm^2/fb^{-1}$) (within 10 mrad from the peak)
height=150 cm	3.6×10^4
height=50 cm	1.3×10^4
height=0 cm	0.9×10^4
FASERν 1st module	1.2×10^4

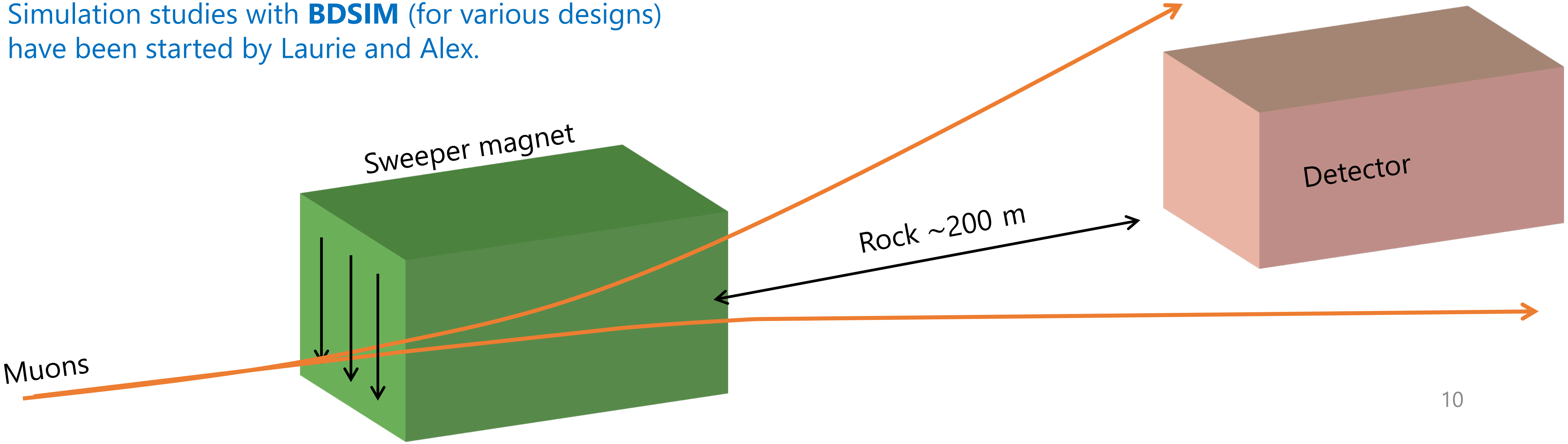




Reducing the background muon rate with a sweeper magnet

- To increase the duration of data taking with a FASERν2 detector, a reduction of muon rate is vital.
- Maximum track density in emulsion should be kept below ~5x10^5 tracks/cm^2 → 2 months without muon reduction
- A sweeping magnet equivalent to ~7 Tm may be installed in this location.
  - This would bend 100 GeV (1 TeV) muons on the LOS by 4.2 m (40 cm) from the LOS.

Simulation studies with **BDSIM** (for various designs) have been started by Laurie and Alex.



Cost estimate

Item	Cost (kCHF)	How many years	Sub-total	Comments
Fixed costs				
Tungsten	2000		2000	2-mm-thick 40x40 cm^2, 3300 plates +10%
Emulsion readout	1700		1700	
Expert of the readout system	500		500	
Veto / interface detectors	200		200	
Support structure	400		400	
Cooling system	100		100	
Annual cost				
Emulsion	1000	10	10000	40x40 cm^2, 3300 films
Chemicals for development	50	10	500	
Personnel for scanning	50	10	500	
Total			15900	

Schedule

	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
	Run 3	Run 3	Run 3				Run 4	Run 4	Run 4 Year-1	Run 4 Year-2	
MC studies and documentation		pre-CDR		TDR							
Detector support and cooling system		R&D			Construction						
Tungsten plates		Tests			Purchase and tests						
Readout system (HTS3?)		Development of HTS3			Dedicated system for Fnu2: production and tests						
Emulsion films		Stability study						Production	Production		
CERN darkroom facility for the assembly and development											
Construct the interface detector						Construction	Installation				
Construct the veto detector											
Cost					Tungsten ~2M Readout ~2.2M Support ~0.4M Cooling ~0.1M IFT+veto ~0.2M			Emulsion 1.1M (for 2031)	1.1M (for 2032)		1.1M/year during Run

To do

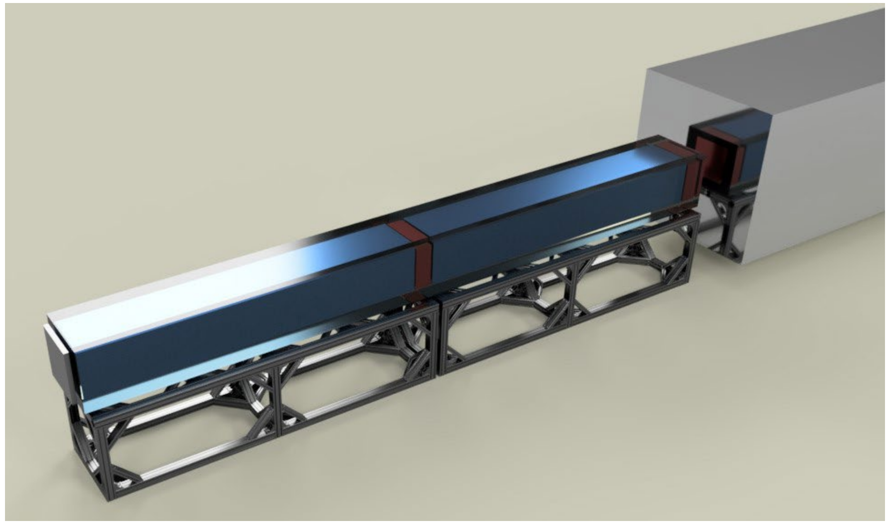
- Establish a firm FASERν2 team.
- Define the tasks and responsibilities and follow the development in regular WG meetings.
  - We plan monthly meetings.
  - You are welcomed to join!
- Define the timeline and more realistic cost estimate.

subjects	**people working or interested in joining** (no particular order)
overall design	Aki, Tomoko
emulsion film production, stability study (1 year scale), film size	Rokujo, Sato, [illegible]aki, …
tungsten target	Zhen, Tomoko, …
interface detector, SCT or SciFi? (# of stations), integration to FASER2	Yosuke, Hide, Tomohiro, …
veto detector, integration to FASER2	Brian, …
installation method, CAD design	need responsible with engineering team
detector support / assembly method	Chiba / Bern
cooling system (10 or 5 ℃)	Dubna?
emulsion development	Elena, …
readout system (HTS1/3?) (larger grain size?)	Nakano, Sato
readout system (HTS1/3 for FASERnu2?)	Aki, …
simulation (muon + sweeper magnet)	Laurie, Alex, Daiki, …
simulation (geometry, reco)	Umut, …
simulation (matching, charge ID, …)	Yosuke, Tomohiro, …
physics performances	with the theoretical WGs (contact persons: Tomoko, Aki)

Work in progress

Summary

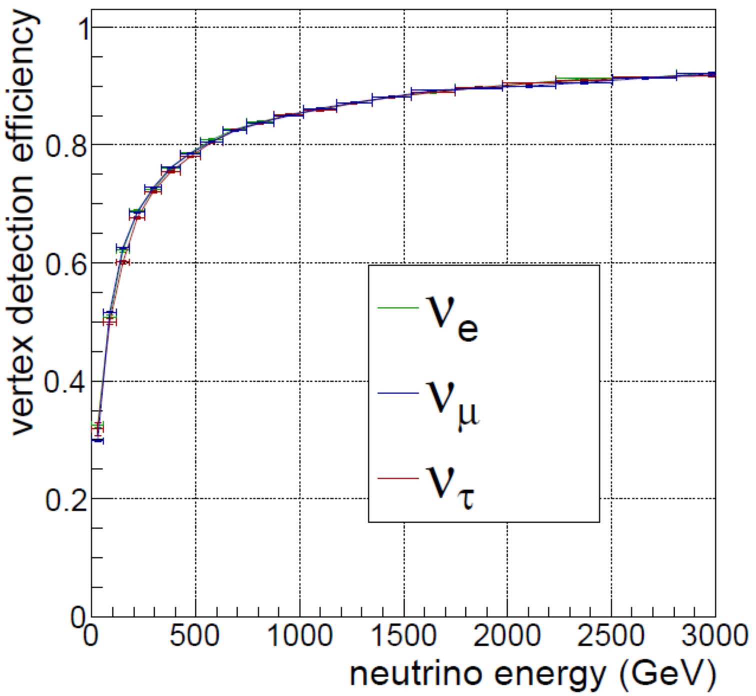
- FASERν2 aims $\sim O(100) \times$ FASERν in interaction statistics.
- People are busy with ongoing FASERν analyses.
  - FASERν is demonstrating the FASERν2 concepts.
- Accelerating to form FASERν2 working group.
  - Monthly meetings will be held.
- Time scale: pre-CDR 2024, TDR 2026, funding 2027/28, construction 28-, data taking 2031-



Backup

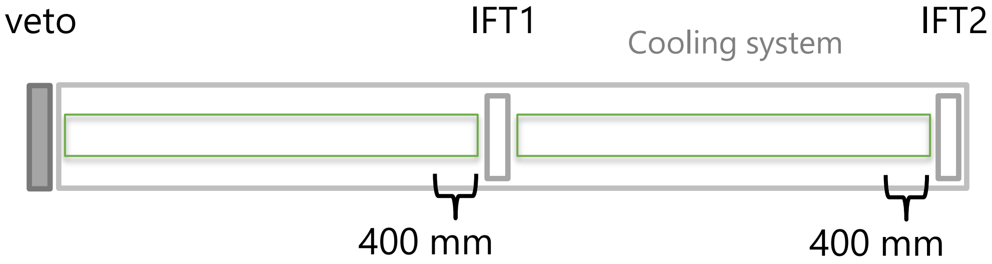
ν detection and acceptance

- **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

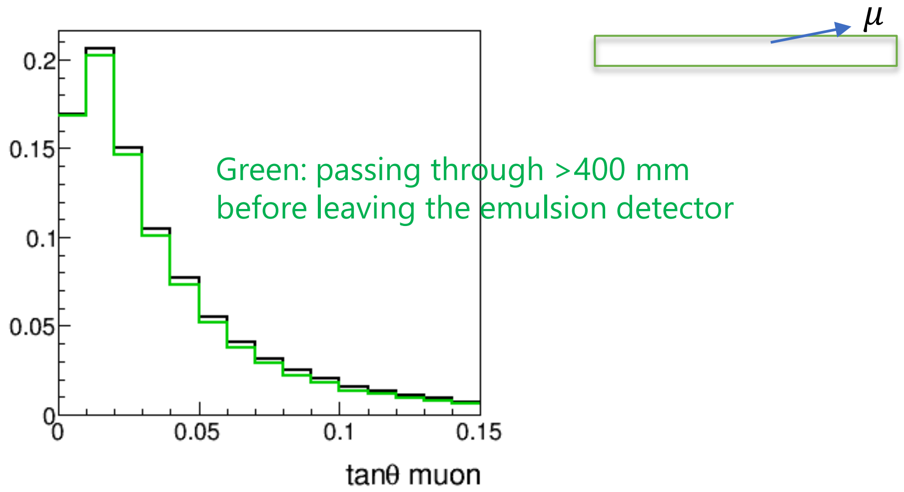


- **Additional inefficiencies for ν_μ**

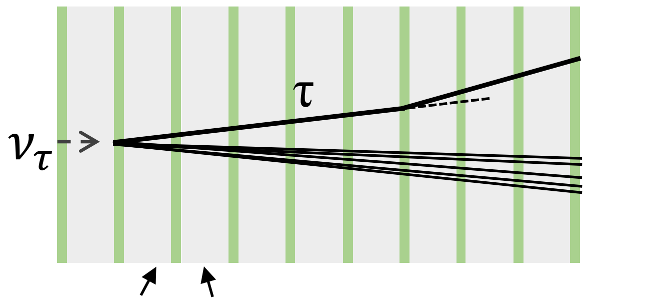
1. 400 mm tungsten from the most downstream layer would be used for μ ID (400 mm/3300 mm = 12%).



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

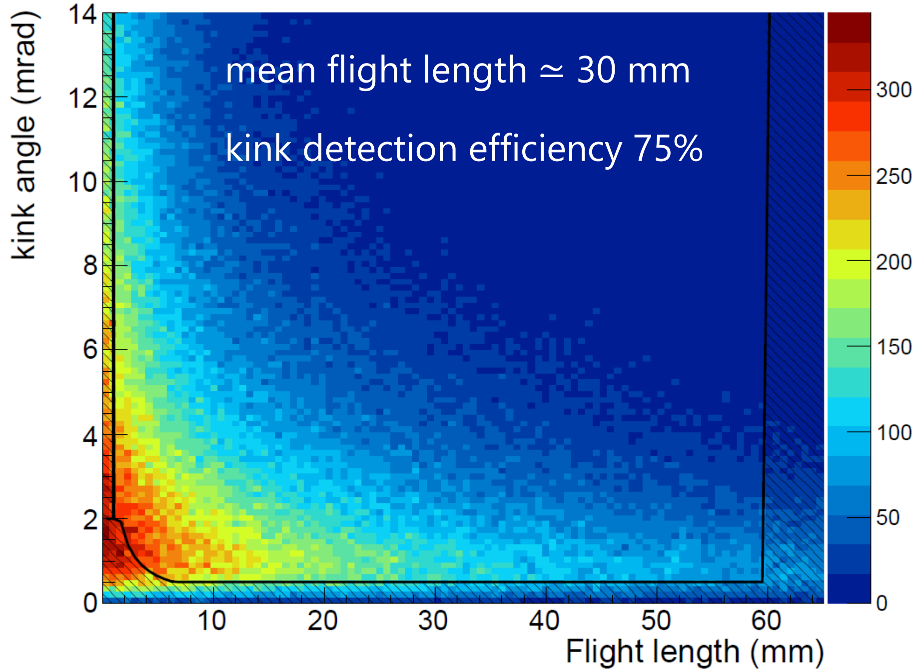


- Special resolution of hits in the emulsion
  - 0.5 μm (measured in the FASERν pilot run data)

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

flight length / kink angle



Emulsion readout systems

- Total emulsion film surface in FASERν2: ~530 m^2/year
  - ~2400 h/year with HTS
  - or ~420 h/year with HTS2

	Field of view (mm^2)	Readout speed (m^2/h/layer)
S-UTS	0.04	0.0072
HTS-1	**25**	**0.45**
HTS-2	**50**	**2.5**
HTS-3	**?**	**?**