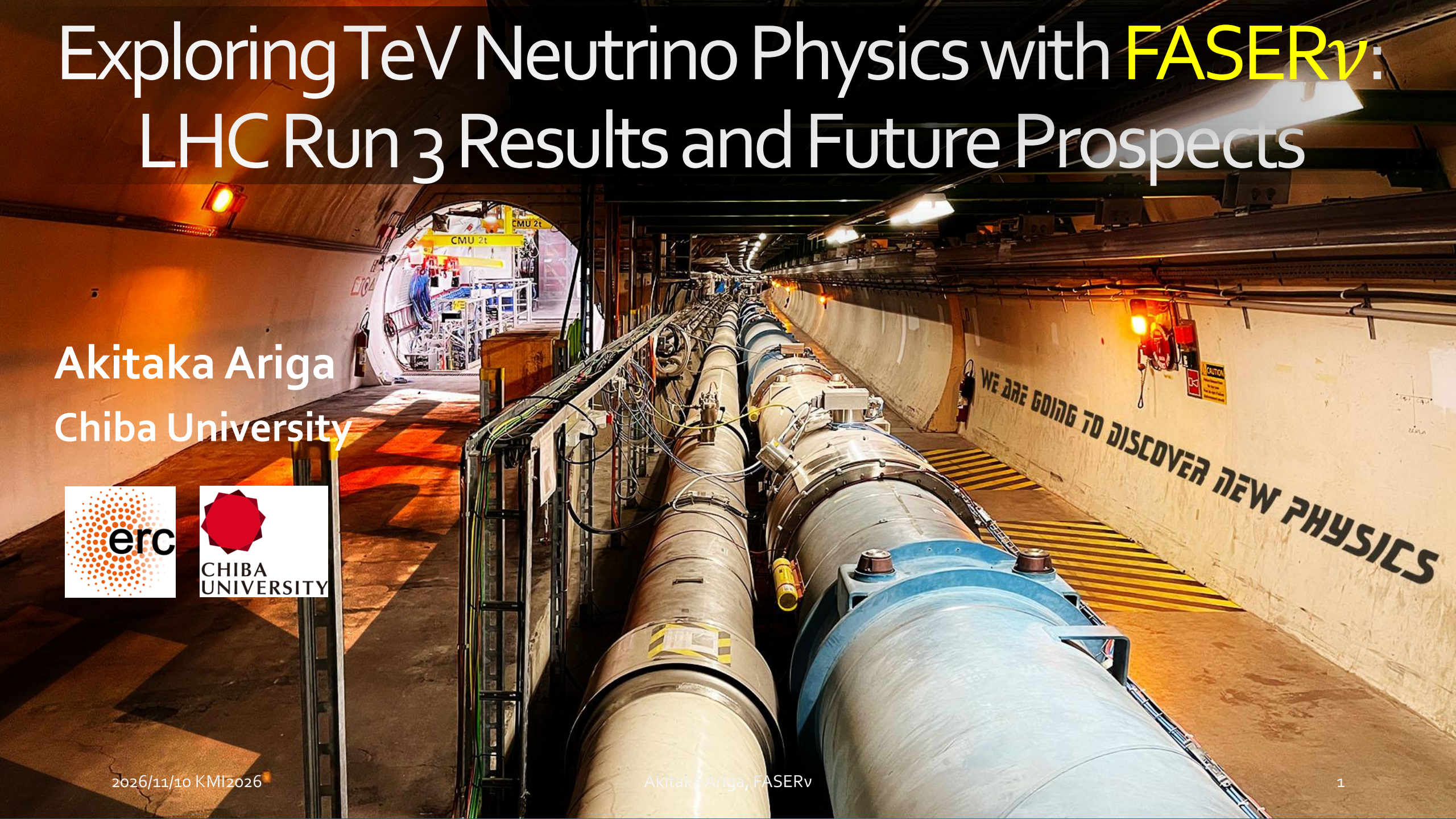
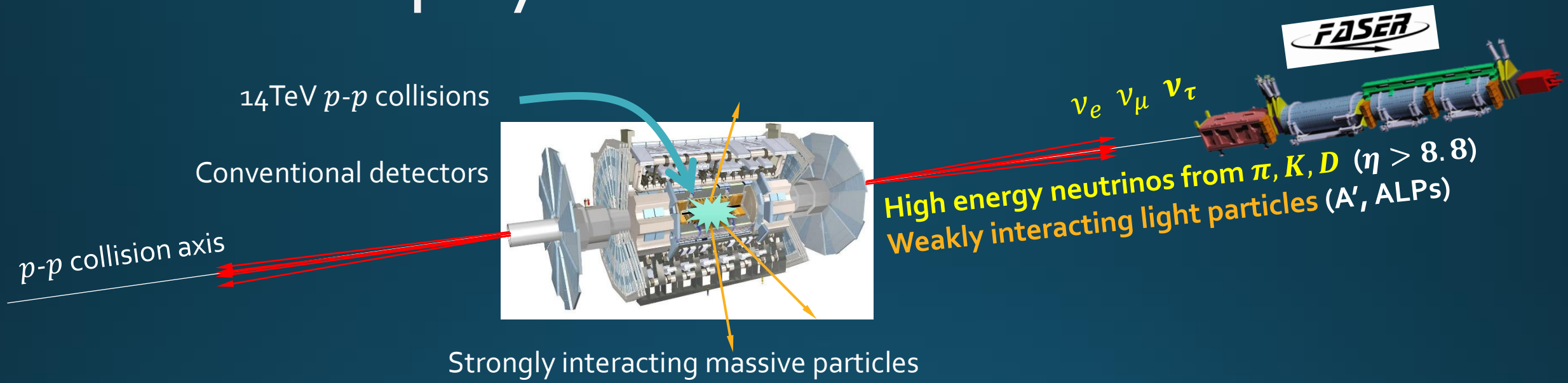
Exploring TeV Neutrino Physics with FASERν: LHC Run 3 Results and Future Prospects



Akitaka Ariga

Chiba University

Forward physics at colliders



- LHCf pioneered forward physics at the LHC through hadron production measurements.
- **FASER** brought a breakthrough: neutrinos and BSM particle searches.
- A paradigm shift: The forward region is now a frontier for both SM and BSM physics.
- Forward Physics Facility (FPF) will unlock the full potential of forward physics at the HL-LHC.

Pathfinder experiments

- *Proof of concepts*: collecting data and validating designs/DAQs through Run 3
  - **FASER (FASERν), SND@LHC, FORMOSA demonstrator**

SND@LHC



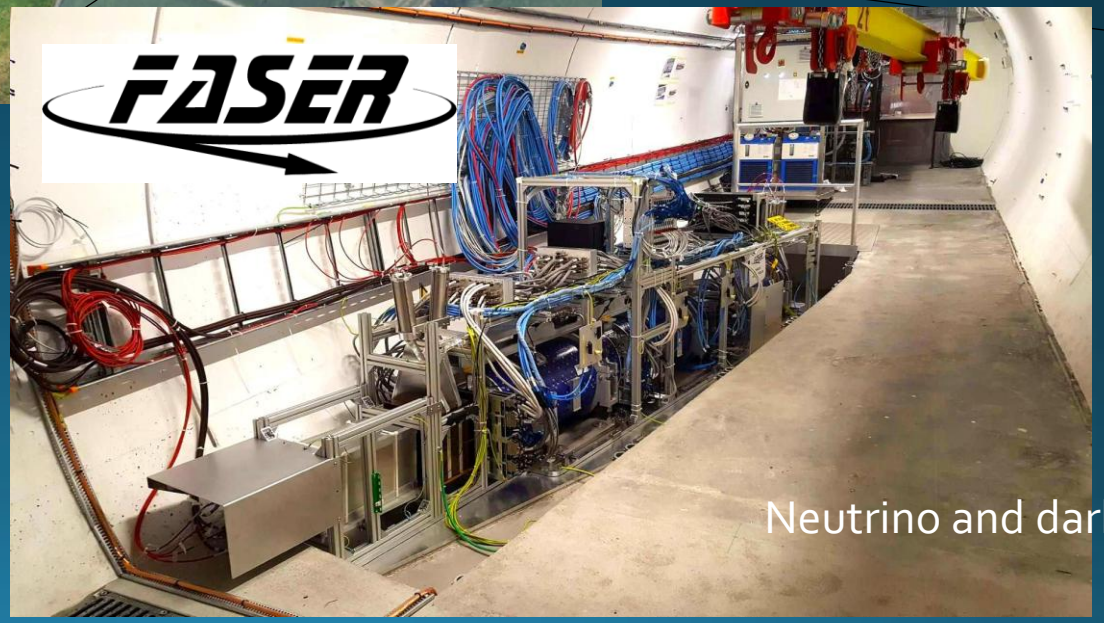


Milli charged particles

LHC
Scattering and Neutrino Detector
at the LHC



Neutrino



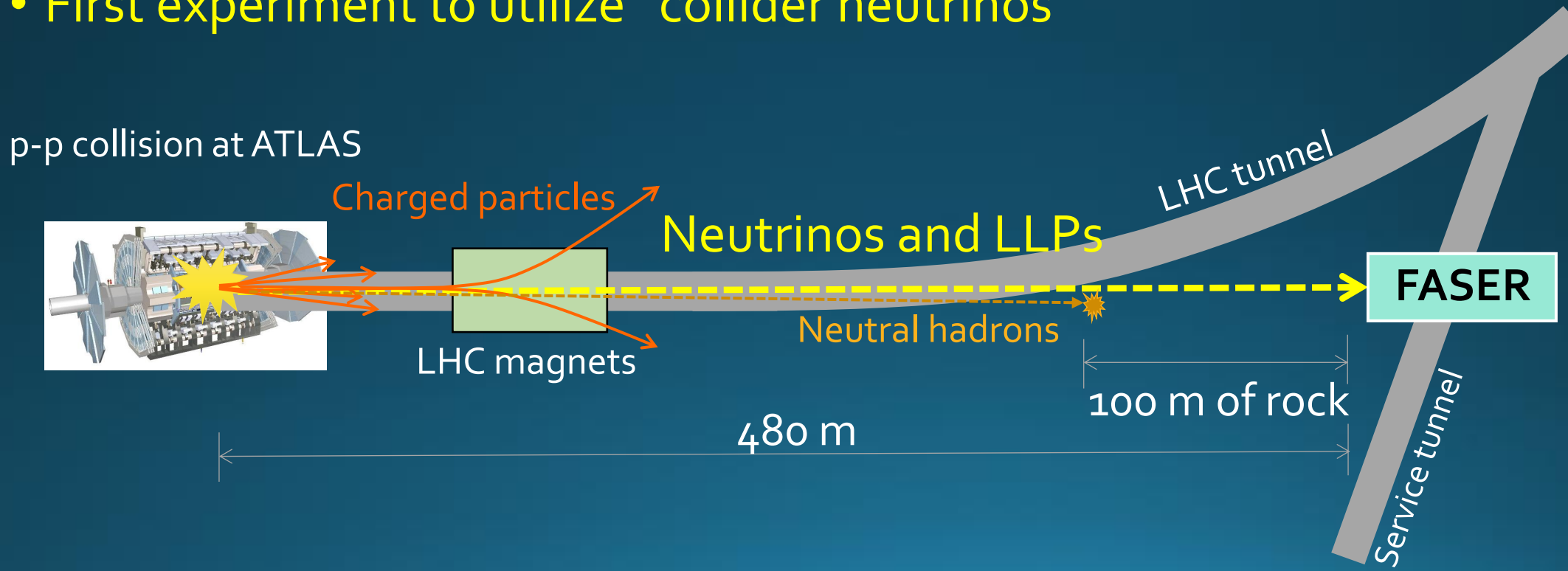
Neutrino and dark sector

The FASER experiment

FORWARD SEARCH EXPERIMENT AT THE LHC

FASER TP arXiv:1812.09139,
FASERν Eur. Phys. J. C (2020) **80**: 61
FASER web page: https://faser.web.cern.ch/

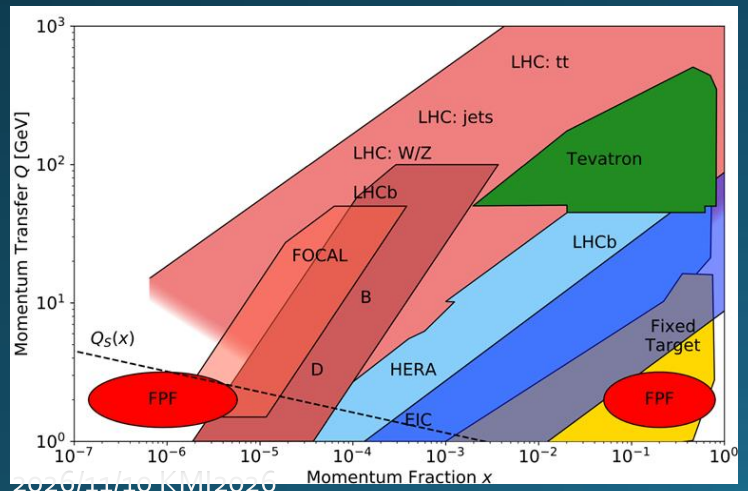
- Targets neutrinos (and μ) and long-lived BSM particles (e.g. A′, ALPs)
- First experiment to utilize "collider neutrinos"



What is special in LHC's forward beam?

Neutrino production

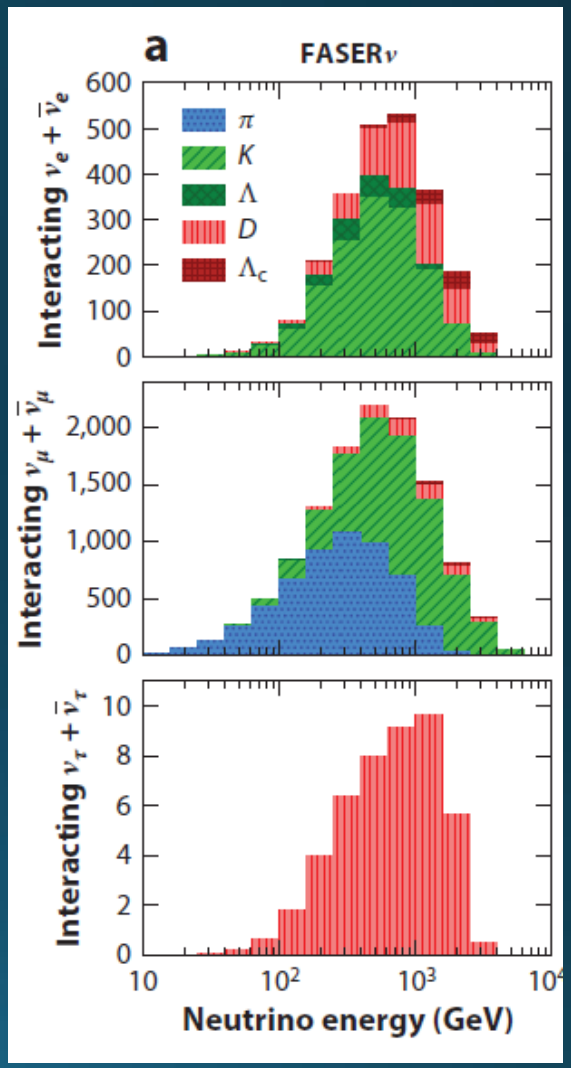
- Forward hadron production in p-p collisions at $\sqrt{s} = 13.6\,\mathrm{TeV}$
  - Equivalent to 100 PeV p fixed-target interactions
  - Neutrinos from π, K, D decays
- Asymmetric gluon-gluon interaction: small-x × large-x
  - Unexplored kinematical region



$x \sim 10^{-6}$

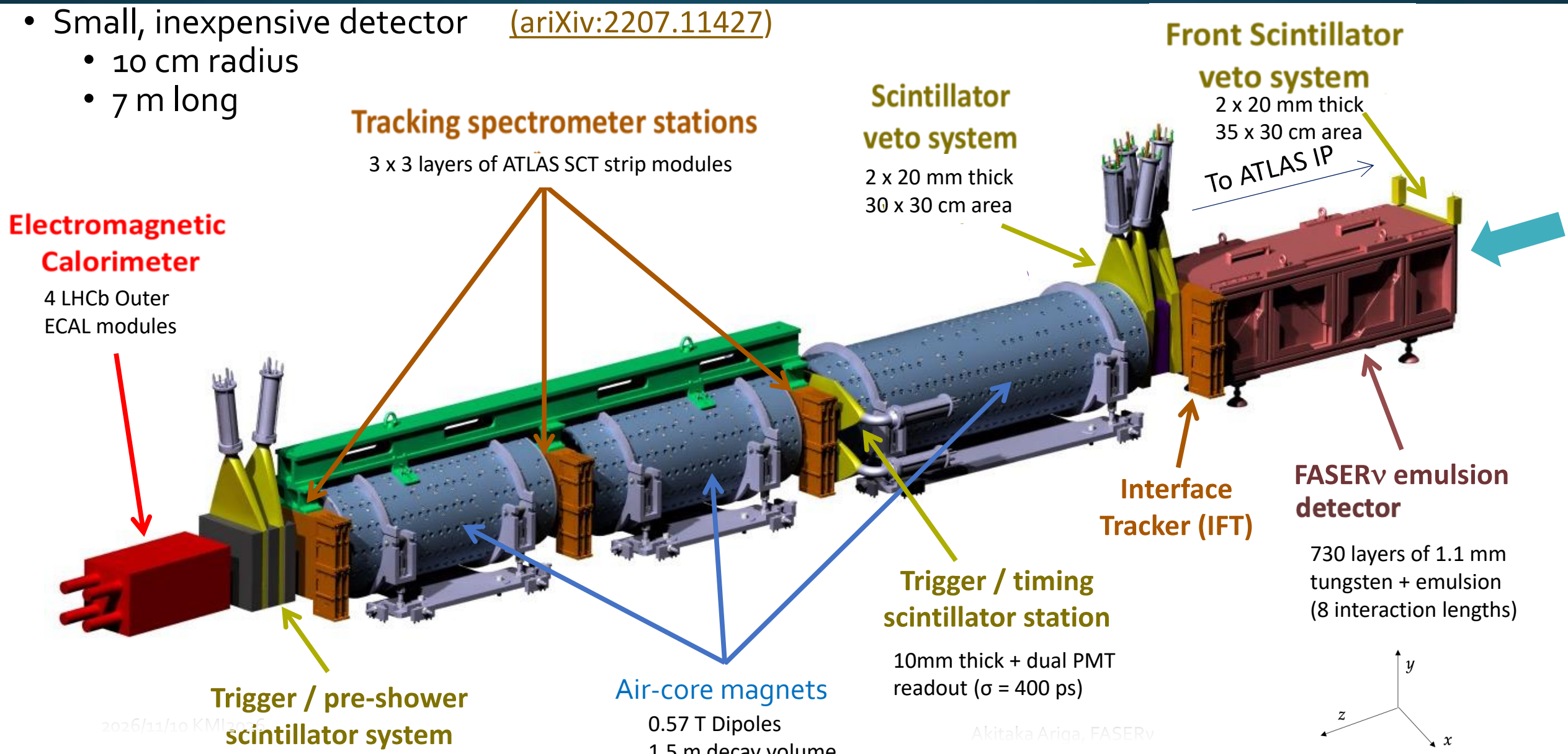
Neutrino beam

- 3 flavor neutrinos; ν_e, ν_μ, $\boldsymbol{\nu_\tau}$ and $\bar{\nu}_e$, $\bar{\nu}_\mu$, $\boldsymbol{\bar{\nu}_\tau}$
- TeV energies, dominated by DIS
- Access to heavy flavor particles, such as tau/charm/beauty, $\simeq 15\%$ charm production rate
- Collimated neutrino beam
  - $O(10)$ cm radius at 500 m



FASER detector

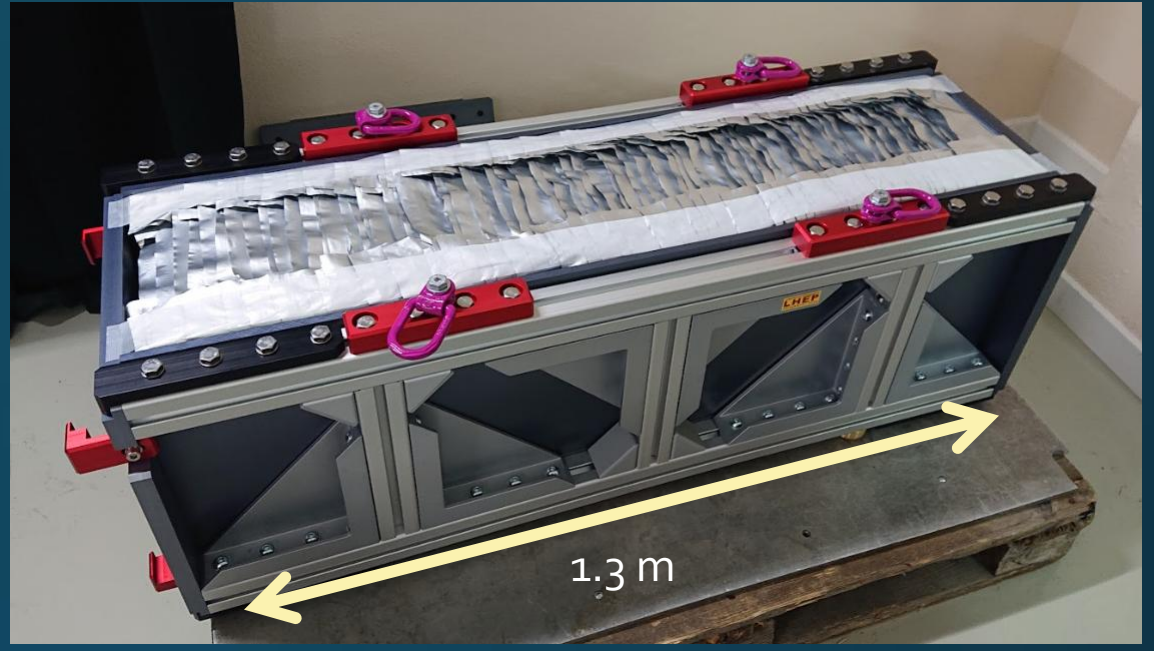
- Small, inexpensive detector (arXiv:2207.11427)
  - 10 cm radius
  - 7 m long

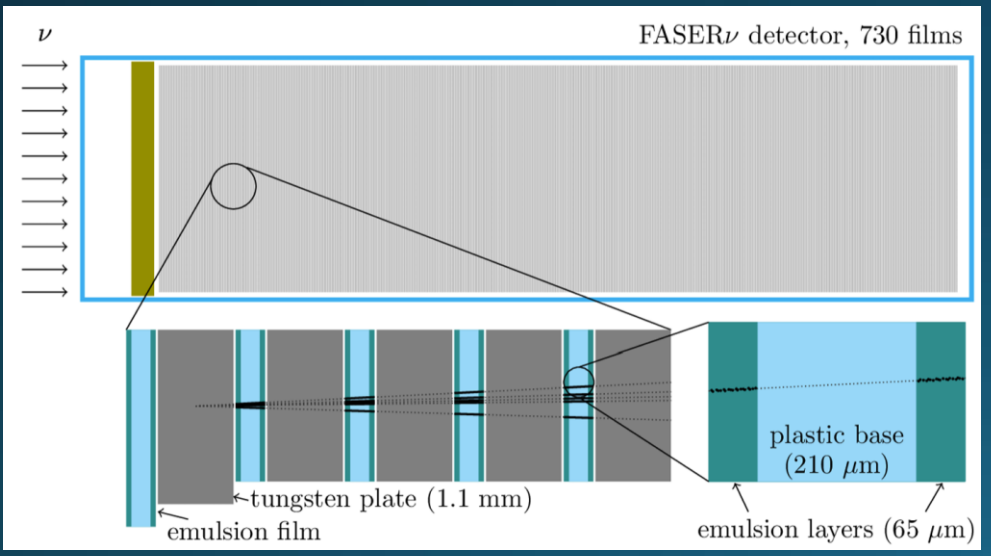


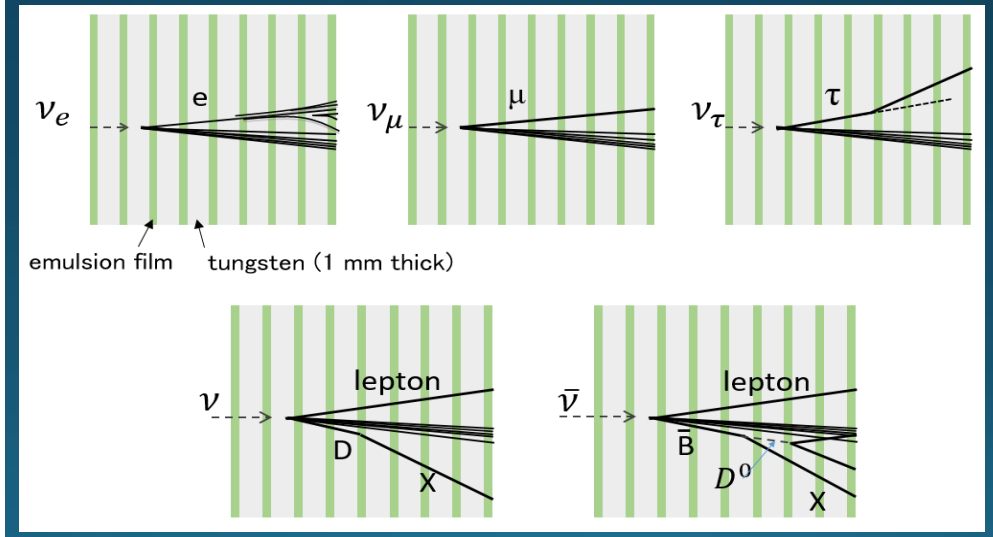

CMU 2t
2t
FASERν
IFT
Veto
Decay volume
Tracking spectrometer
Pre-shower
Calorimeter
FASERν installation
3 times / year

FASERν neutrino detector

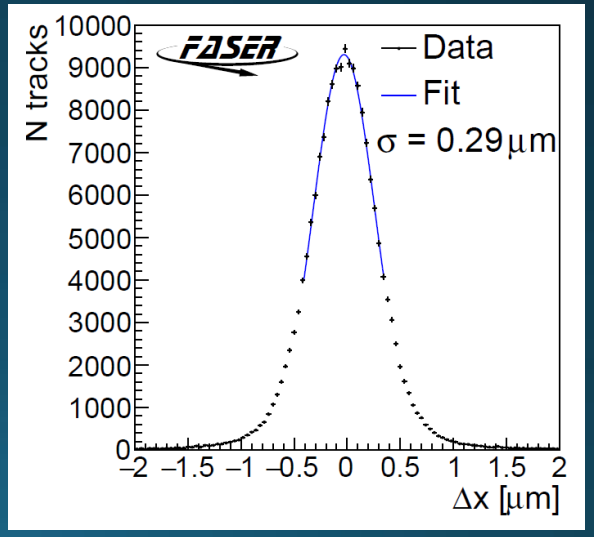
- Emulsion/tungsten neutrino detector
  - 730 emulsion films ~ an exa-channel detector
  - Target mass of 1.1 tons (8 λ_{int}, 220X_0)
- High position resolution, 300 nm
- Sensitivity to three neutrino flavors and heavy quarks



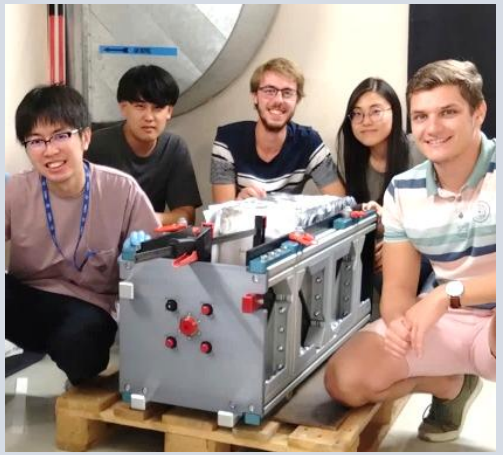


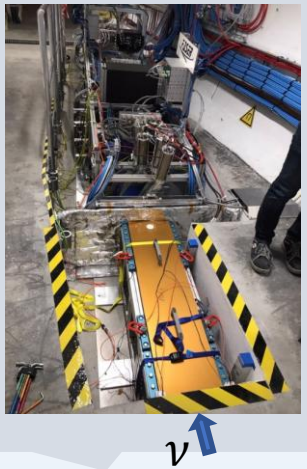


~300 nm resolution



FASERν workflow







Japan

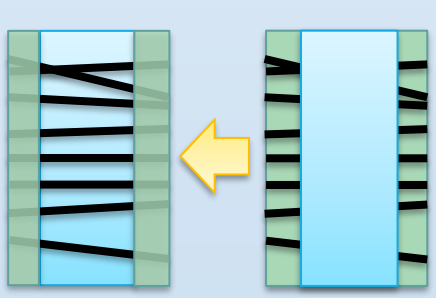
Emulsion film production

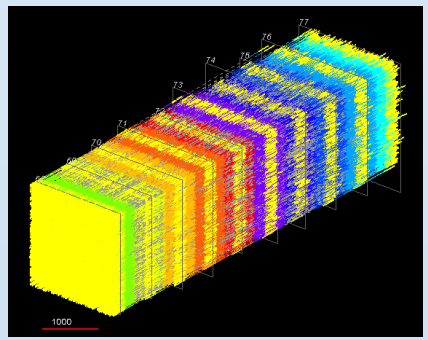
CERN

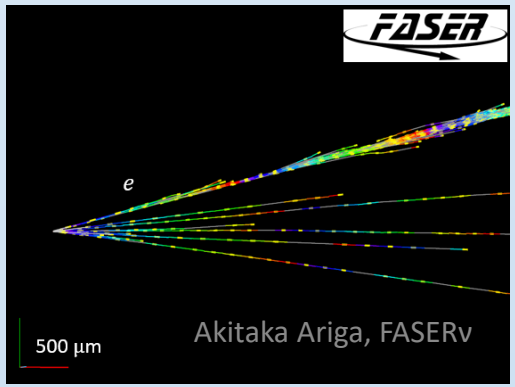
Detector assembly → **Exposure** → **Disassembly and development**

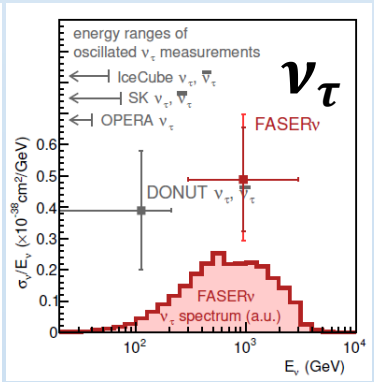
Japan

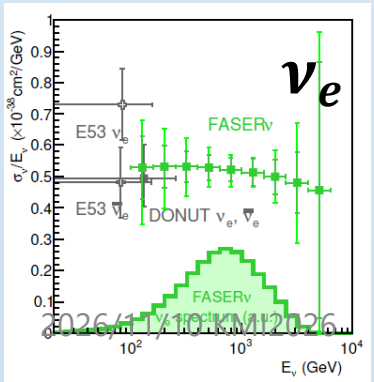
Readout → Alignment → Track reconstruction → Vertex reconstruction → μ / e ID → τ / charm decay search → Further analysis







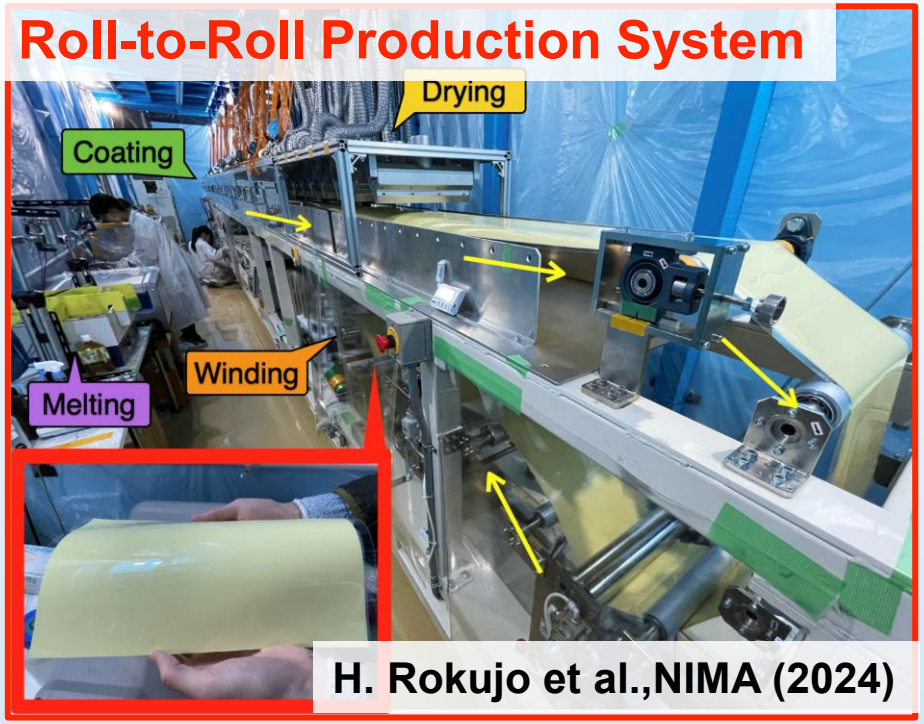




Nagoya's Technology enables FASERν Physics

Nagoya provides core infrastructure from emulsion-film production to precision track readout.

Roll-to-Roll Production System



H. Rokujo et al.,NIMA (2024)

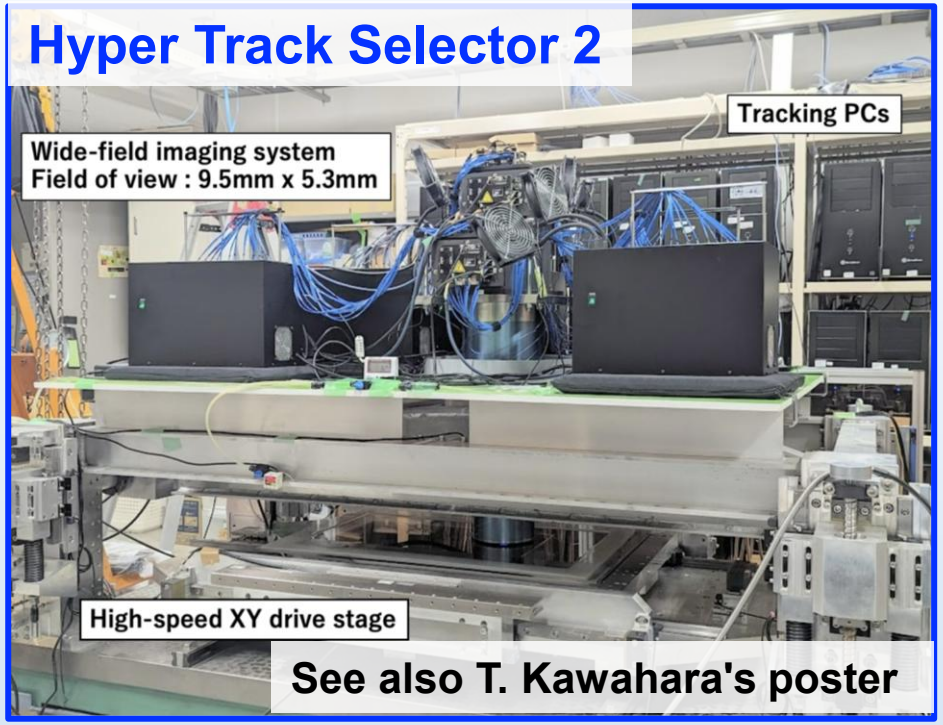
Film Production

Run 3 (2022–2025)
>9,000 films (~675 m²)
Stable supply to CERN

Scanning

Since 2022
Stable operation
Track Data processing & transfer

Hyper Track Selector 2



See also T. Kawahara's poster



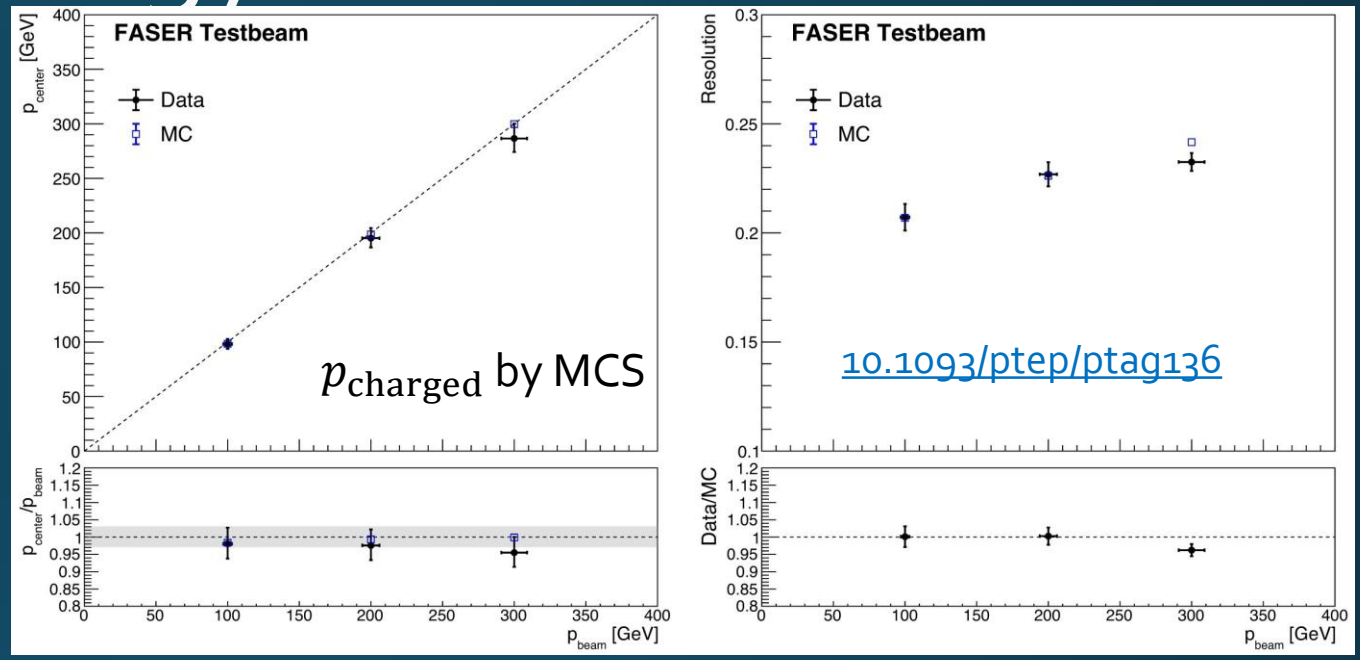
Nagoya University has hosted many FASERv collaborators for joint film production and scanning.

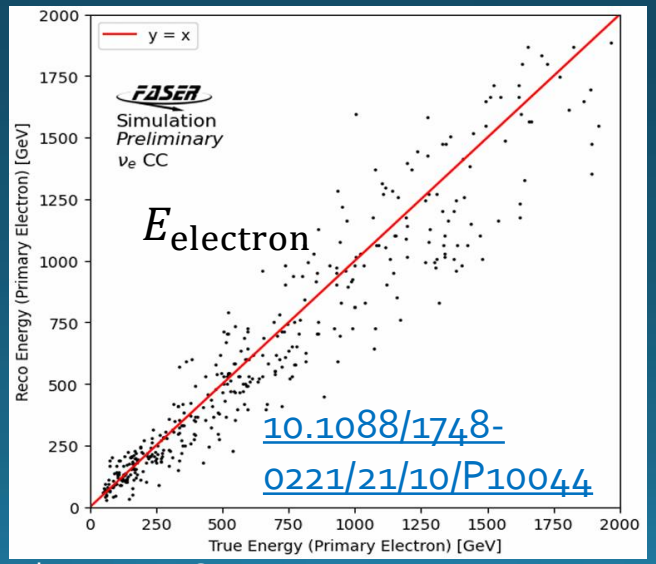
FASERν: Neutrino energy reconstruction

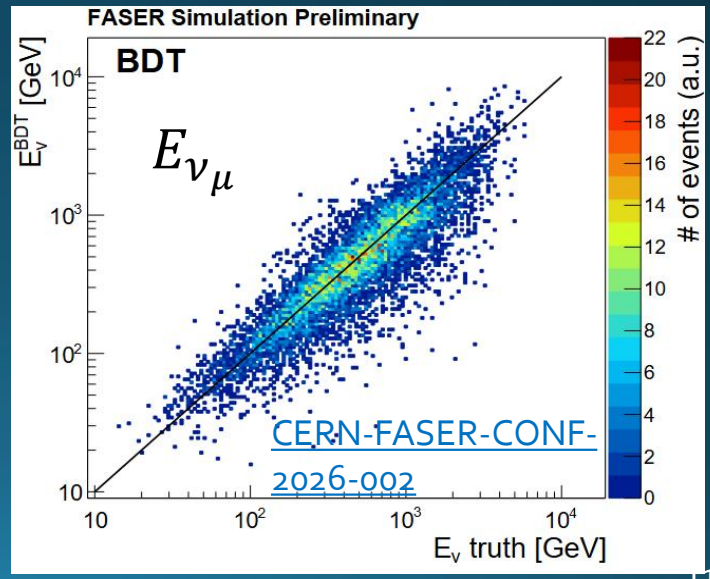
- Kinematical measurements
  - Momentum measurement with the Multiple Coulomb Scattering (MCS), 20-25%
  - EM shower measurement, 20-25%

- E_ν reconstruction
  - Reconstruct incident neutrino energy with Multi-variate analysis (MVA) Regression techniques
  - BDT with P_μ, $1/\tan\theta$, and $\Sigma P_{ch.had.}$ input variables → regression for E_ν.

- **Performance: 30% - 40% E_ν resolution** between 200 GeV and 1.5 TeV.

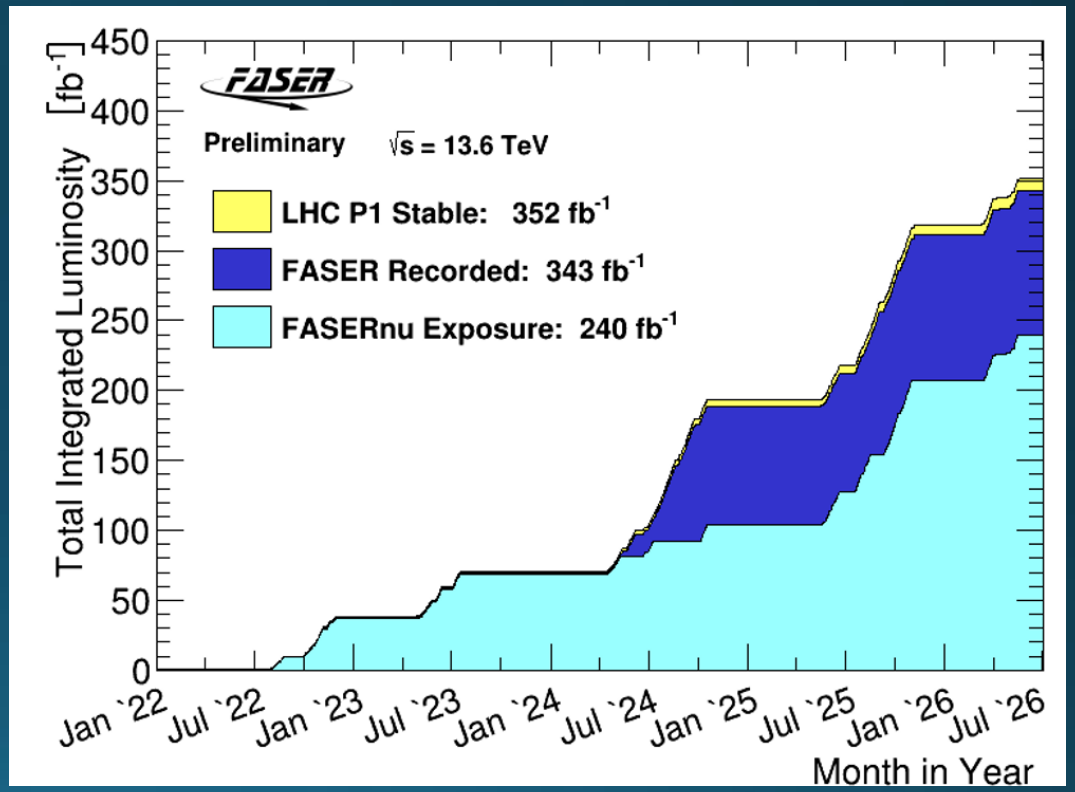






Data taking in LHC Run 3 completed

- FASER detector
  - >97% data taking efficiency
  - 343 fb^{-1} recorded
- FASERν detector
  - 240 fb^{-1} in emulsion (full target)
  - ~657 m^2 of emulsion in 12 modules exposed
  - Up to ~30 fb^{-1} per module before replacement



Results from the FASER experiment

SM

- Neutrino candidates with Run2 data
  - PhysRevD.104.L091101
- Neutrino detection with electronic detectors with 2022 data
  - PhysRevLett.131.031801
- First ν_e, ν_μ cross sections with emulsion detector
  - PhysRevLett.133.021802
- Differential $\nu_\mu, \bar{\nu}_\mu$ cross sections with electronic detectors with 2022-23 data
  - PhysRevLett.134.211801
- Further new results
  - CERN-FASER-CONF-2025-004 Forward hadron production
  - CERN-FASER-CONF-2026-002 Updated nue / numu results
  - CERN-FASER-CONF-2026-003 Neutrino-induced charm
  - CERN-FASER-CONF-2026-004 ν_e with calorimeter
  - CERN-FASER-CONF-2026-005 ν_μ double-differential measurement

2018
2019
2020
2021
2022
2023
2024
2025
2026

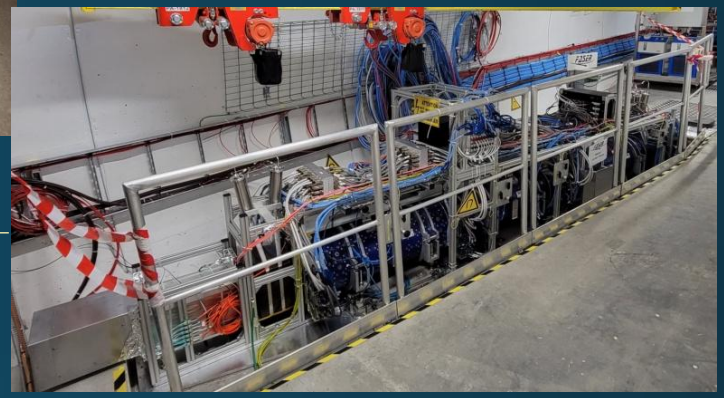
Run 2

Run 3



Pilot detector

Approved in 2019
Constructed by 2021



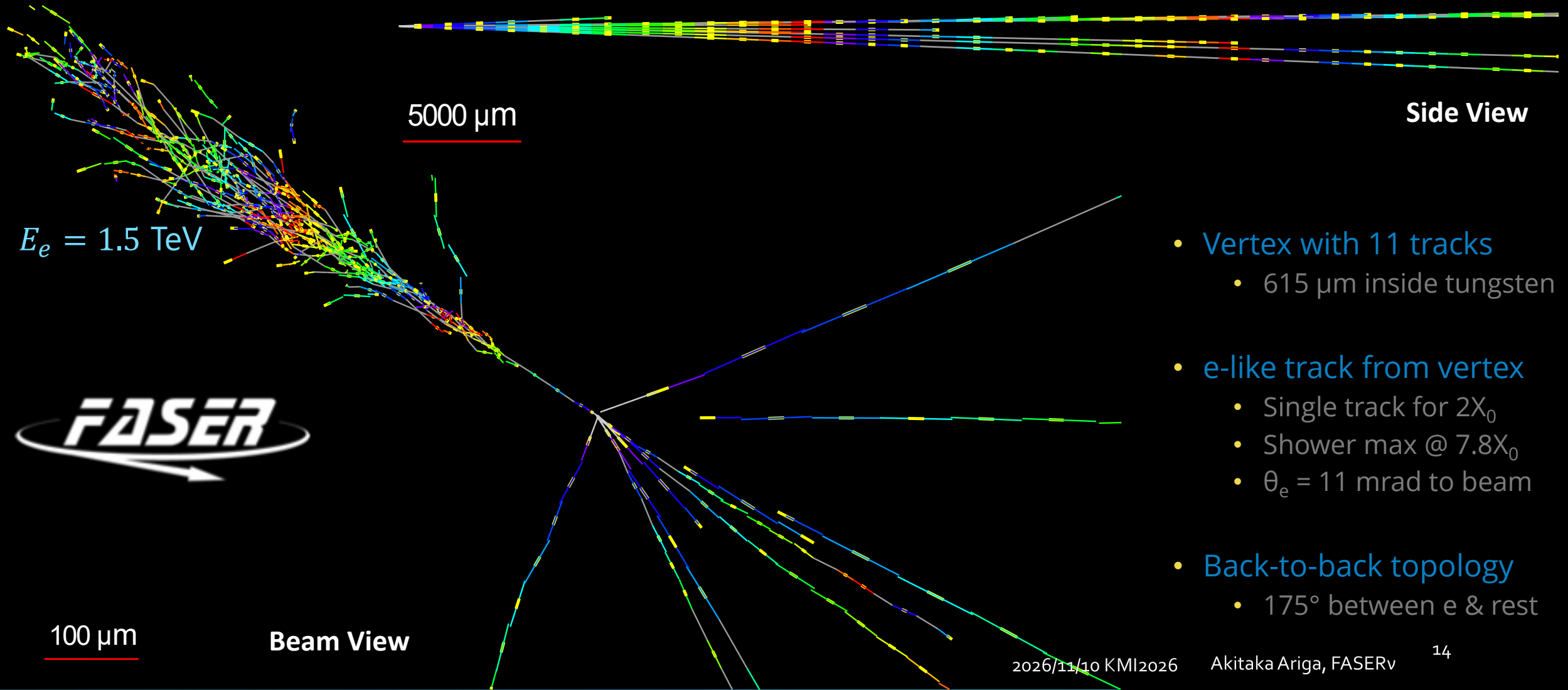
BSM

- Dark photon with 2022 data
  - 10.1016/j.physletb.2023.138378
- Axion-Like-Particles (ALPs) with 2022, 2023 data
  - 10.1007/JHEP01(2025)199
- Quirk with 22-24
  - 10.1103/z156-xk5y
- CERN-FASER-CONF-2026-001 Updated dark photon result

Electron neutrino observation in FASERν

ν_e CC event, "Pika-ν" event

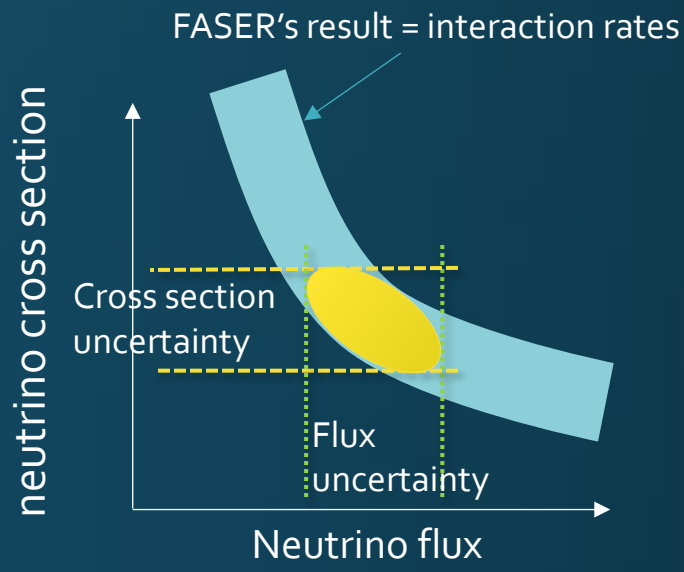
Enjoy an interactive 3D display here!

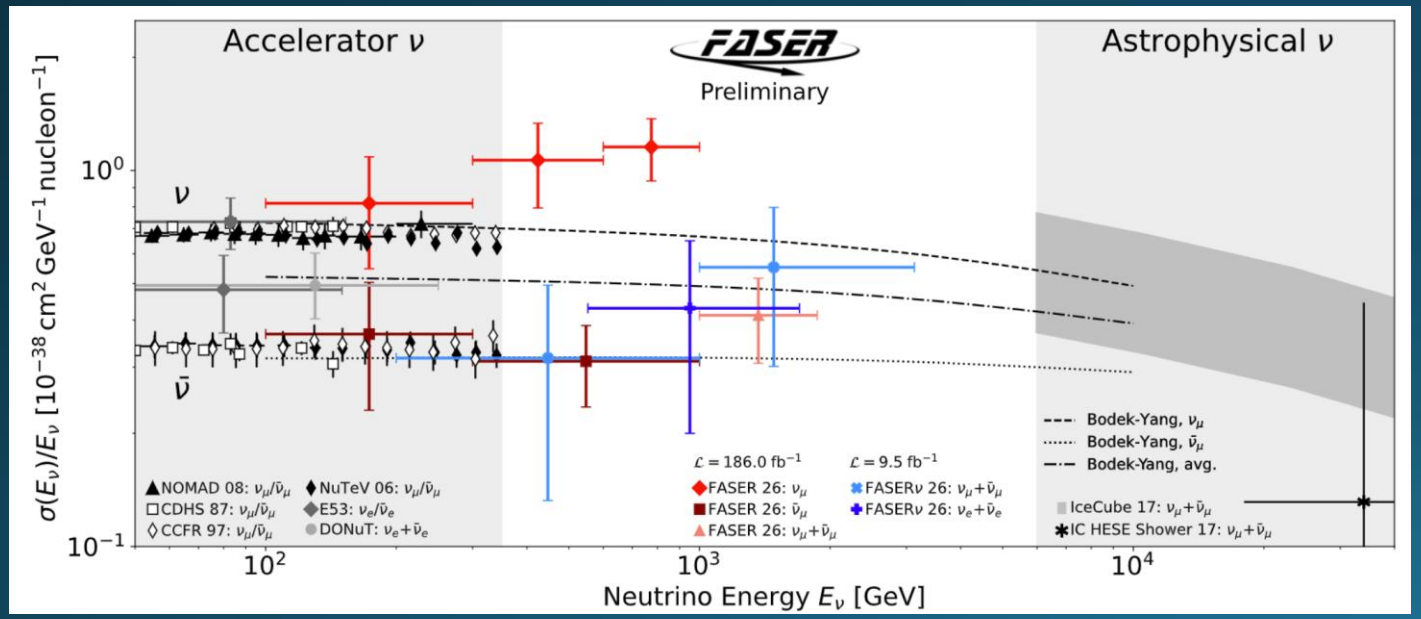


- Vertex with 11 tracks
  - 615 μm inside tungsten
- e-like track from vertex
  - Single track for $2X_0$
  - Shower max @ $7.8X_0$
  - θ_e = 11 mrad to beam
- Back-to-back topology
  - 175° between e & rest

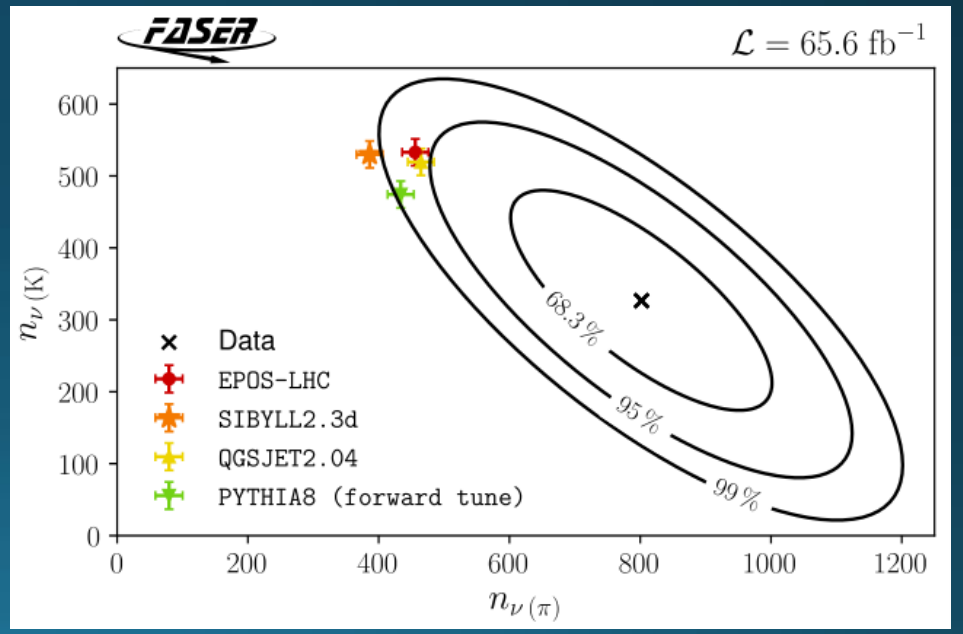
Interpretations of ν_μ interaction rate

- FASER's result can be interpreted in two ways
  - Neutrino cross sections
  - Flux measurement → hadron production model study





Neutrino cross sections



Analysis in π/K production ratio at p-p collisions

First search for neutrino-induced charm production with FASERν

CERN-FASER-CONF-2026-003

First search using the first FASERν Run-3 dataset (9.5 fb^{-1}, 2022 first module):

Motivations

- Lepton Universality tests in charm production
- First observation of ν_e-induced charm
- Access to strange PDFs and charm production

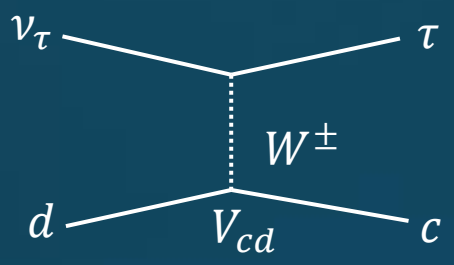
Analysis strategy

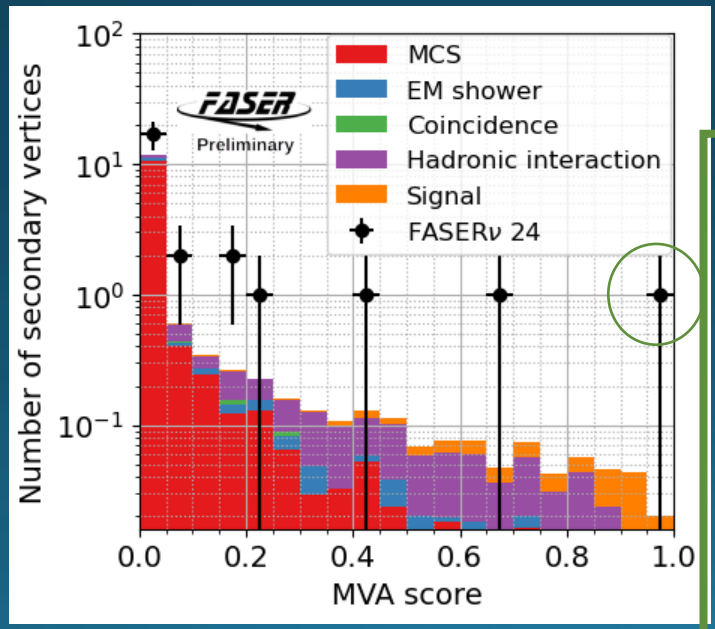
- Search for charged charm decays using secondary vertices in emulsion
- Kinematic selection followed by an interpretable ML classifier

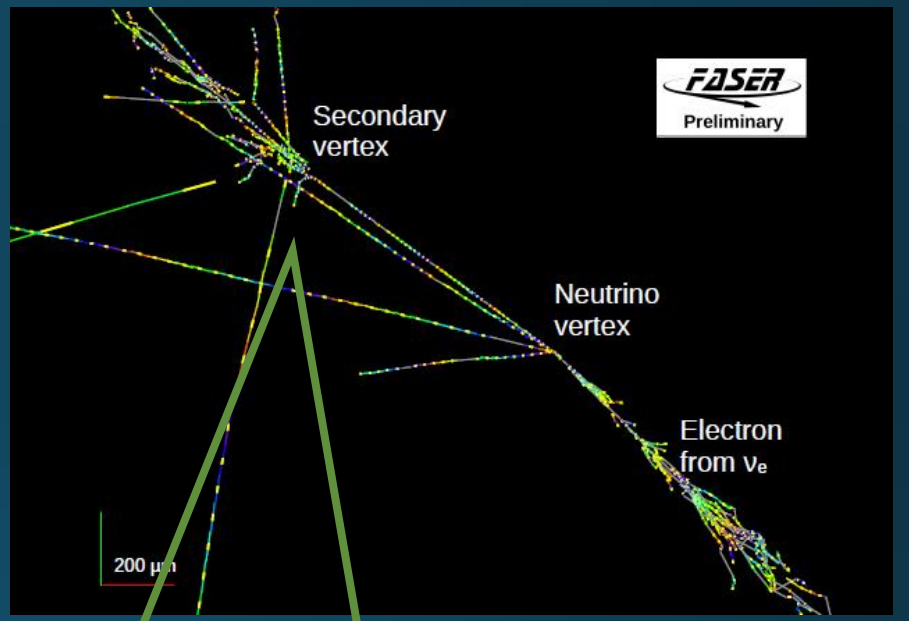
Status

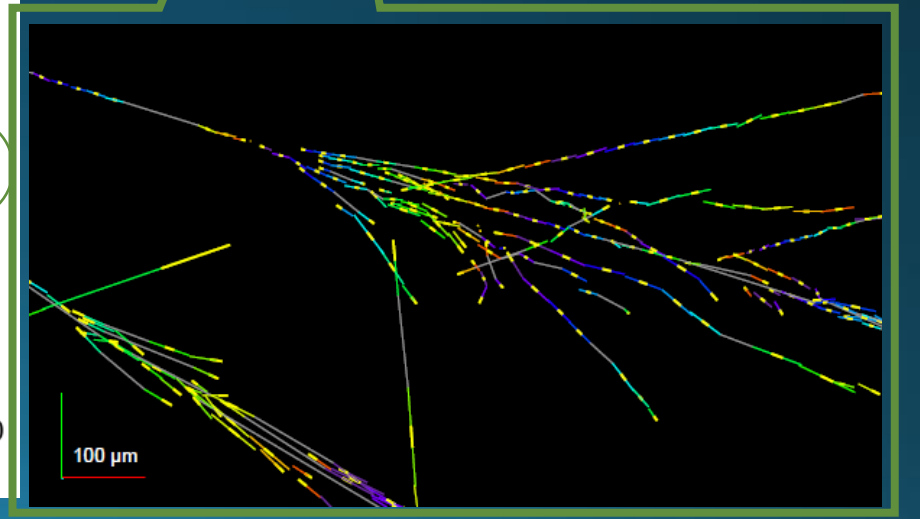
- 40 neutrino candidates analyzed
- Data and simulation broadly agree; selected charm candidates under investigation

Dominant SM process









Phase of experiments

$1\ \mathrm{fb}^{-1} \leftrightarrow 10^{14}$ pp interactions

Run 3 (2022-2026, 1 ton × 250 fb^{-1})

- Proof of principle

Run 4 (2030-2034, 1 ton × 780 fb^{-1})

- Physics-driven expansion in HL-LHC

Forward Physics Facility Run 4/5 (2033-, 20 tons × 2000 fb^{-1})

- High statistics measurements & precision physics

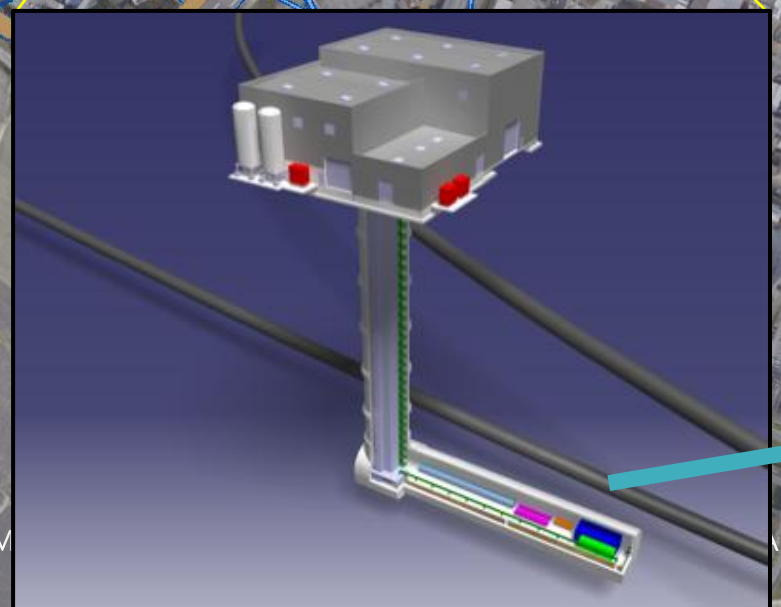
Forward Physics Facility at the HL-LHC

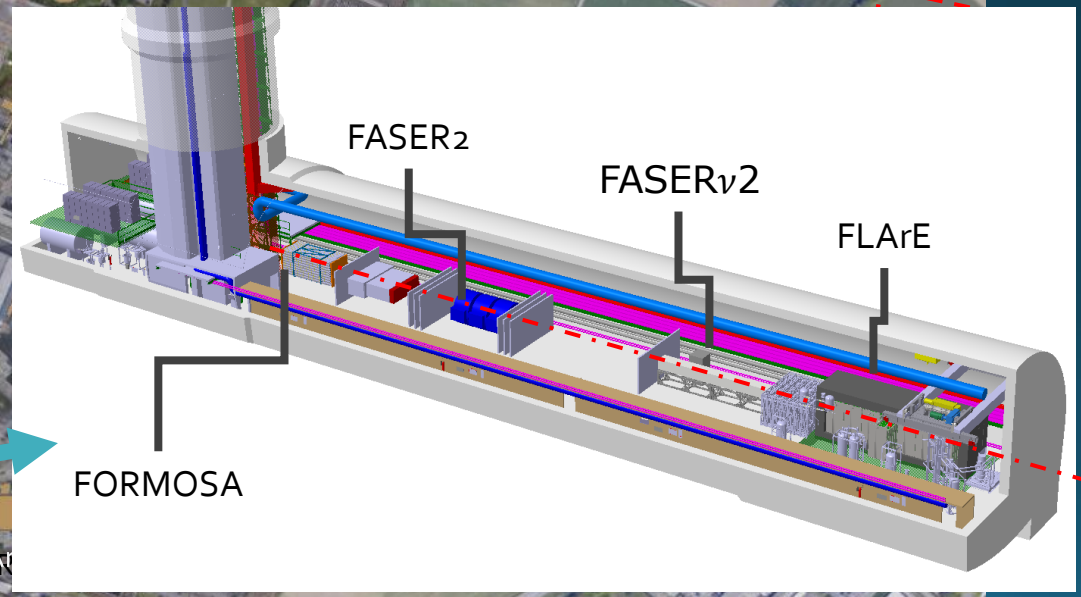
HL-LHC provides x20 proton collisions

Extending sensitivities for new particle searches and neutrino physics by **2 to 4 orders of magnitude**



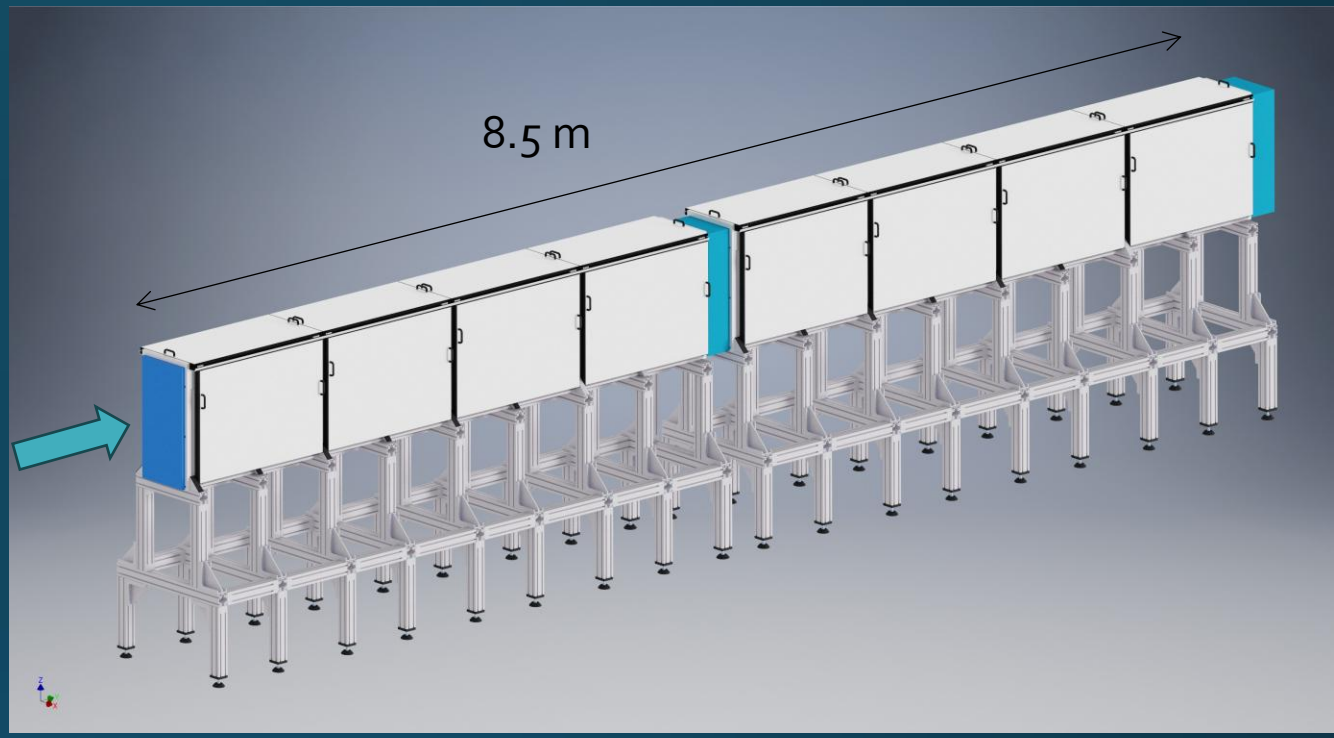
New shaft and hall

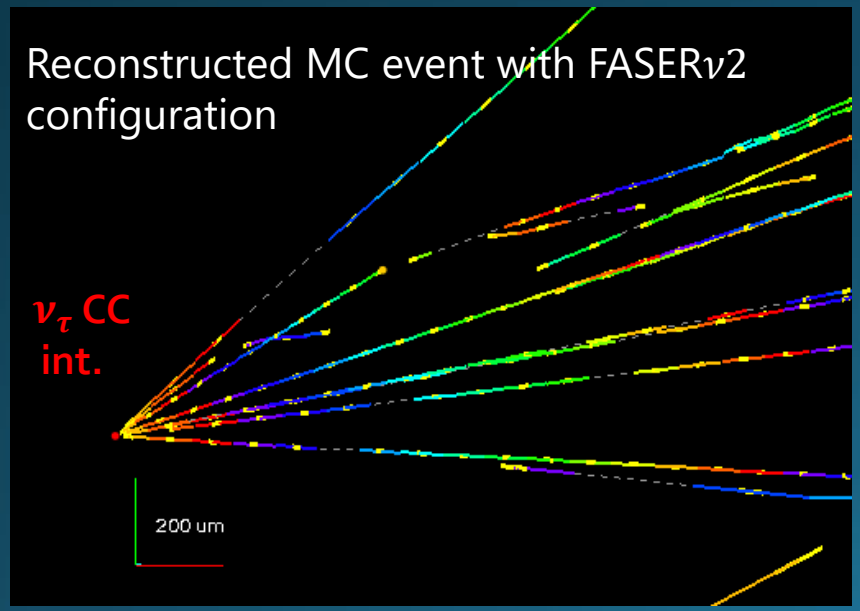




FASERν2

- 20-ton tungsten-emulsion detector
  - Tungsten target: 64 cm x 25 cm x **2 mm** X 3300 plates
  - Sensitivity to ν_e, ν_μ, ν_τ
  - $\mu^{\pm}$ charge ID with FASER2
- Performance proven by FASERν
- High statistics ν_τ studies and test lepton flavor universality



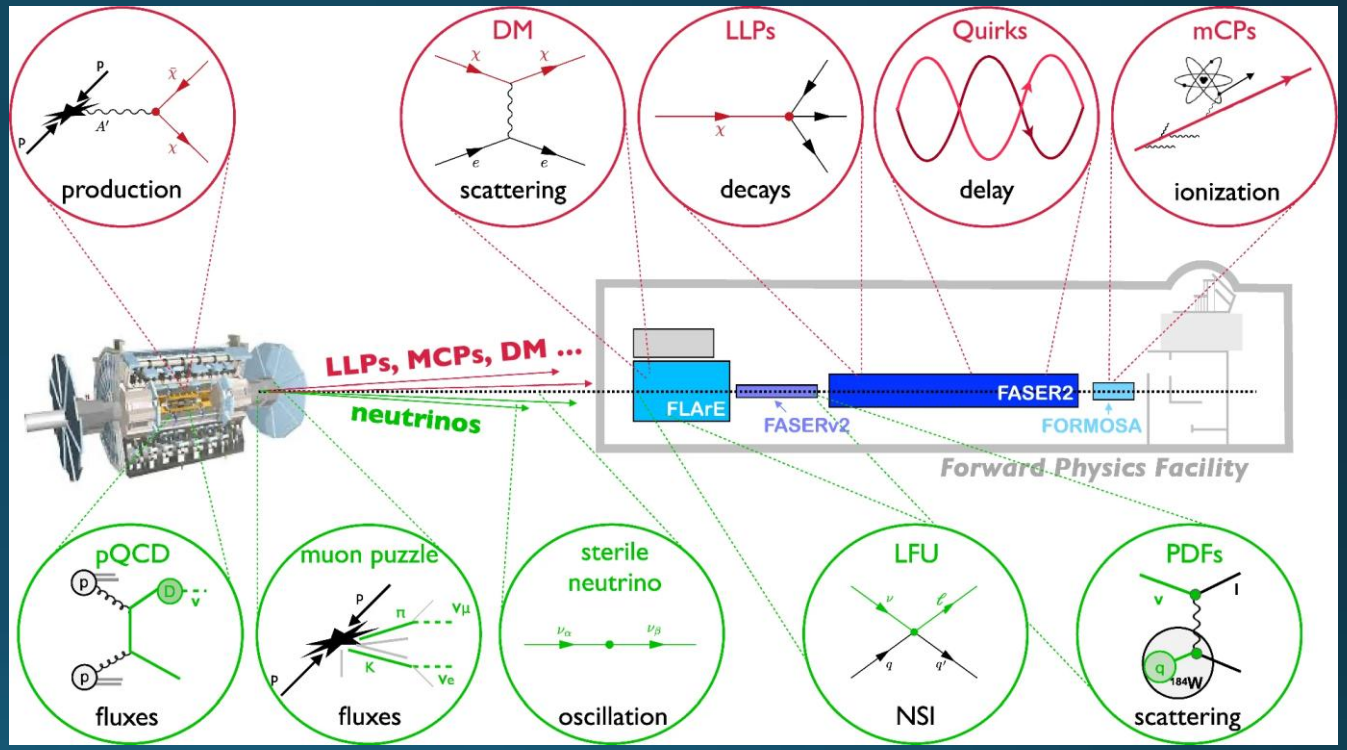


ν int. rate estimated based on **Sibyll 2.3d**

Detector				CC Interactions		
Name	Mass	Luminosity	Rapidity	$\nu_e+\bar{\nu}_e$	$\nu_\mu+\bar{\nu}_\mu$	$\nu_\tau+\bar{\nu}_\tau$
FASERν at Run 3	1.1 t	350 fb^{-1}	$\eta > 8.8$	2.3k	12k	40
SND@LHC at Run 3	0.8 t	350 fb^{-1}	$7.2 < \eta < 8.4$	300	1.5k	12
FASER at HL-LHC	1.1 t	3 ab^{-1}	$\eta > 8.8$	19k	102k	360
SND@HL-LHC	1.3 t	3 ab^{-1}	$6.9 < \eta < 7.6$	2.9k	15k	143
FASERν2 at FPF	20 t	2 ab^{-1}	$\eta > 8.5$	127k	647k	2.3k
FLArE at FPF	10 t	2 ab^{-1}	$\eta > 7.5$	34.7k	167k	1.0k
FLArE HCAL at FPF	41 t	2 ab^{-1}	$\eta > 6.5$	34.0k	180k	1.5k
FASER2 veto at FPF	0.9 t	2 ab^{-1}	$\eta > 6.7$	1.6k	6.8k	54

Physics objectives and experiments

- Neutrino physics at TeV energies
- Neutrino precision physics
- FPF as neutrino-ion collider
- Unique probe of small-x QCD
- Impact for Astroparticle Physics
- Dark matter and mediators
- Millicharged particles
- Other opportunities for new particle searches
- See the Letter of Intent submitted to CERN!



FPF documentation

- **FPF workshop series:**

- FPF1, FPF2, FPF3, FPF4, FPF5, FPF6, FPF7, FPF theory day, FPF8, FPF9

- **FPF paper:**
  - 2109.10905
- ~75 pages, ~80 authors

- **Snowmass Whitepaper:**
  - 2203.05090
- ~450 pages, ~250 authors

- **Recent Summary:**
  - FPF Update

- **Technical Documents:**
- Facility Technical Study
  - Muon Flux Study
  - Vibration Study
- Geotechnical Report

ESPPU scientific program:
doi.org/10.1140/epjc/s10052-025-14048-6

~25 pages, ~26 authors

LoI submitted to CERN

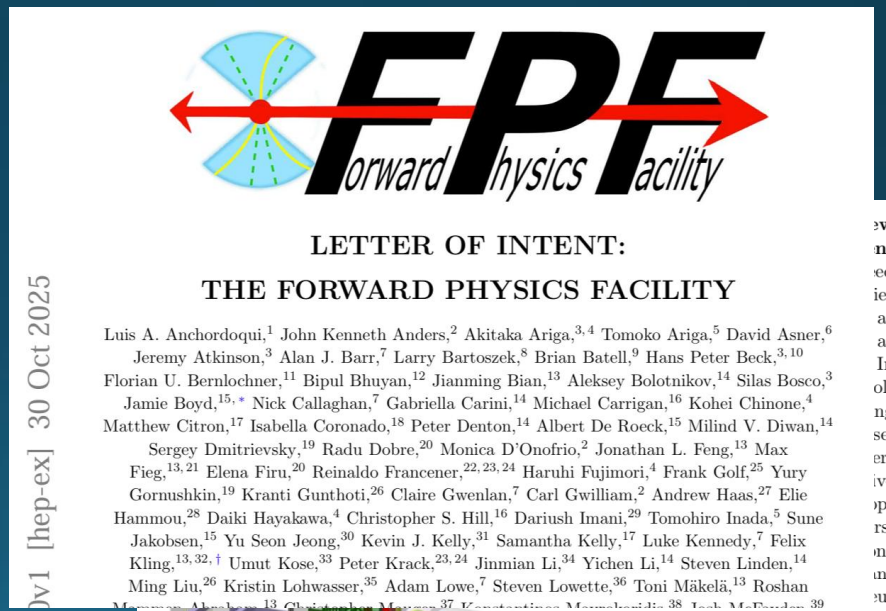
10.1016/j.nuclphysb.2026.117398

Oct 2025

73 pages, 114 authors



Photo at FPF9 workshop


Forward Physics Facility

LETTER OF INTENT:

THE FORWARD PHYSICS FACILITY

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trinos at colliders are ideal messengers of the inner structure of protons and nuclei. The FPF neutrino program will refine our understanding of forward hadron production, uniquely probe QCD in uncharted re-

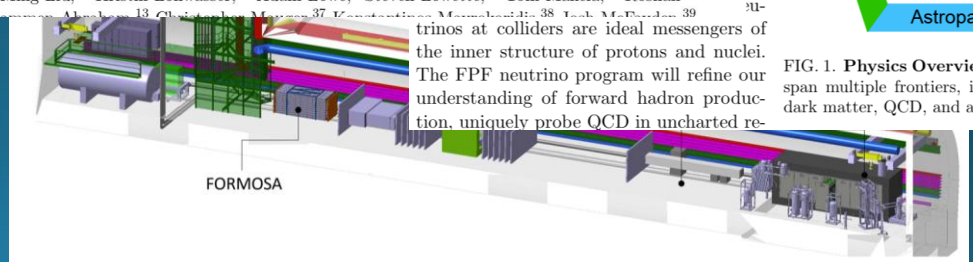

FIG. 24. **FPF Cavern Design.** The baseline layout of the FPF facility, showing the four proposed experiments and the large infrastructure.

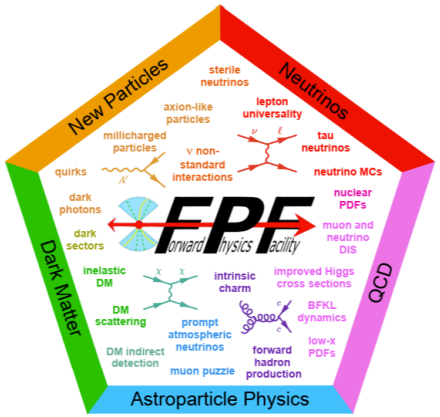

FIG. 1. **Physics Overview.** The FPF will probe topics that span multiple frontiers, including new particles, neutrinos, dark matter, QCD, and astroparticle physics.

Summary

- Forward physics at the LHC has proven to be a rich playground for exciting physics
  - FASER has opened a new window with neutrinos
- FASERν emulsion detector was realized thanks to Nagoya's expertise
- Data taking in LHC-Run 3 completed
- First neutrino ν_e, ν_μ cross sections at the TeV energies, BSM searches
- More results are coming

- FASER is going to take data in HL-LHC (Run 4)
- Forward Physics Facility (FPF) has been proposed to fully exploit the potential of the HL-LHC
  - 4 complementary experiments; FASER2, FASERν2, FLArE, FORMOSA