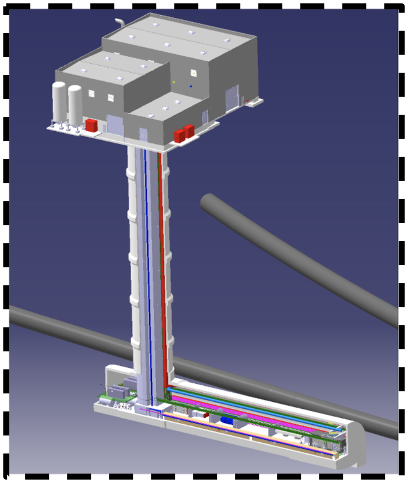
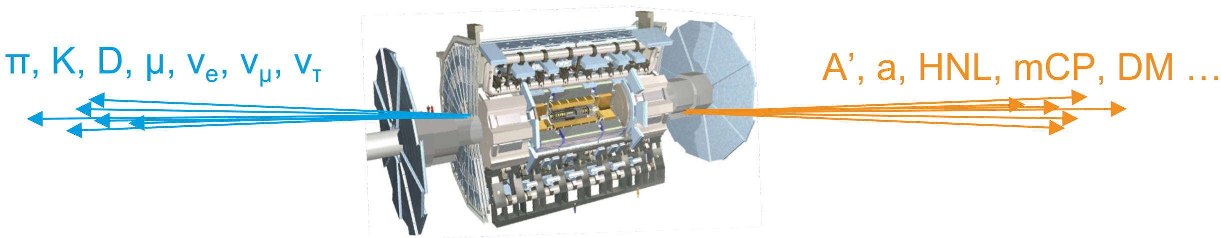
FPF Forward Physics Facility



Jamie Boyd (CERN)
5th Feb 2025

Motivation and Introduction

LHC collisions produce an enormous number of particles along the beam collision axis, which escape existing LHC detectors.



In recent years it became very clear that there is a broad program of SM and BSM physics associated to these particles.

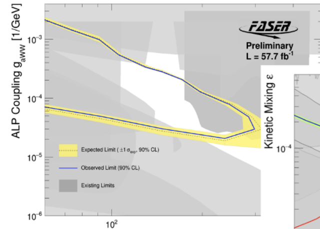
Without dedicated detectors in the far-forward direction, the LHC would be blind to this beautiful physics program.

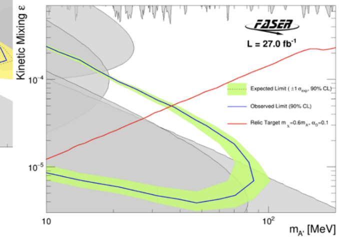
The FASER experiment has been operating in LHC Run 3 to take advantage of this – however, it has become clear that bigger and better detectors are needed to fully exploit the physics potential in the far forward region of the LHC collisions. This has led to the Forward Physics Facility proposal to maximise this physics, both in terms of neutrinos and searches for light, weakly coupled new particles.

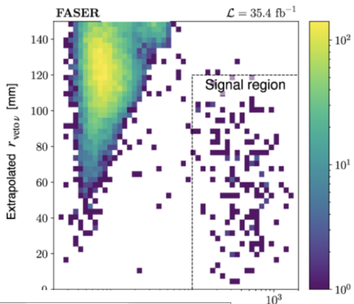
FASER Results

The FASER experiment, operating in Run 3 has already released several strong results, including the first observation of neutrinos from a collider!

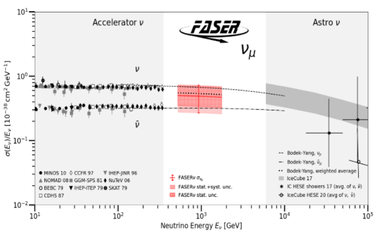
First search results on dark photons and ALPs
[FASER, 2308.05587] [FASER, 2204.03599]





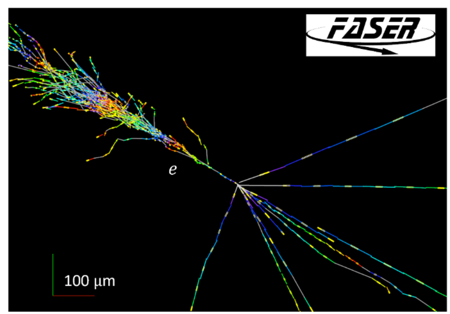


First observation of collider neutrinos:
153 events (FASER)
[FASER, 2303.14185]



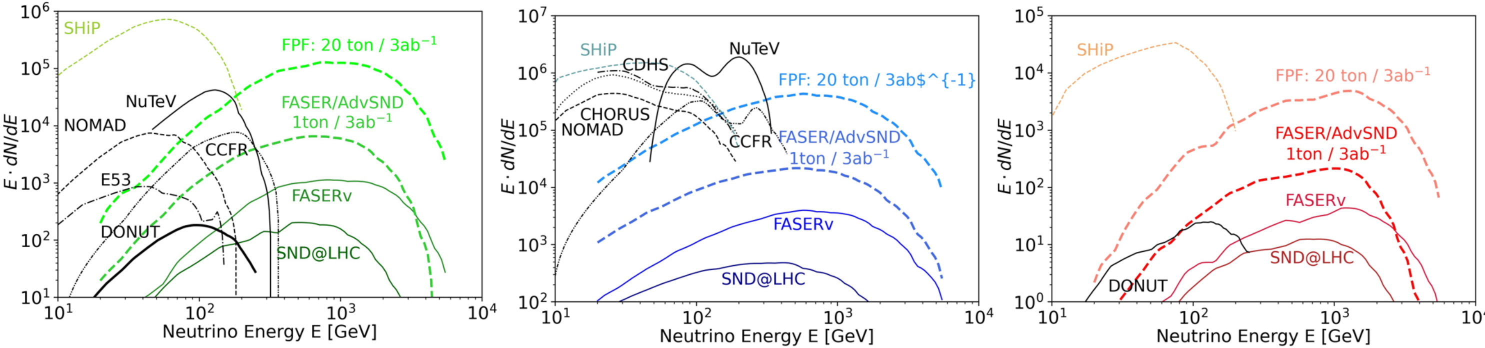
First measurement of TeV energy neutrino cross sections. [FASER, 2403.12520]

many more results to come:
analyzed just 1% of the
FASERnu data taken so far



Neutrino Physics Overview

LHC is source of most energetic human made neutrinos.

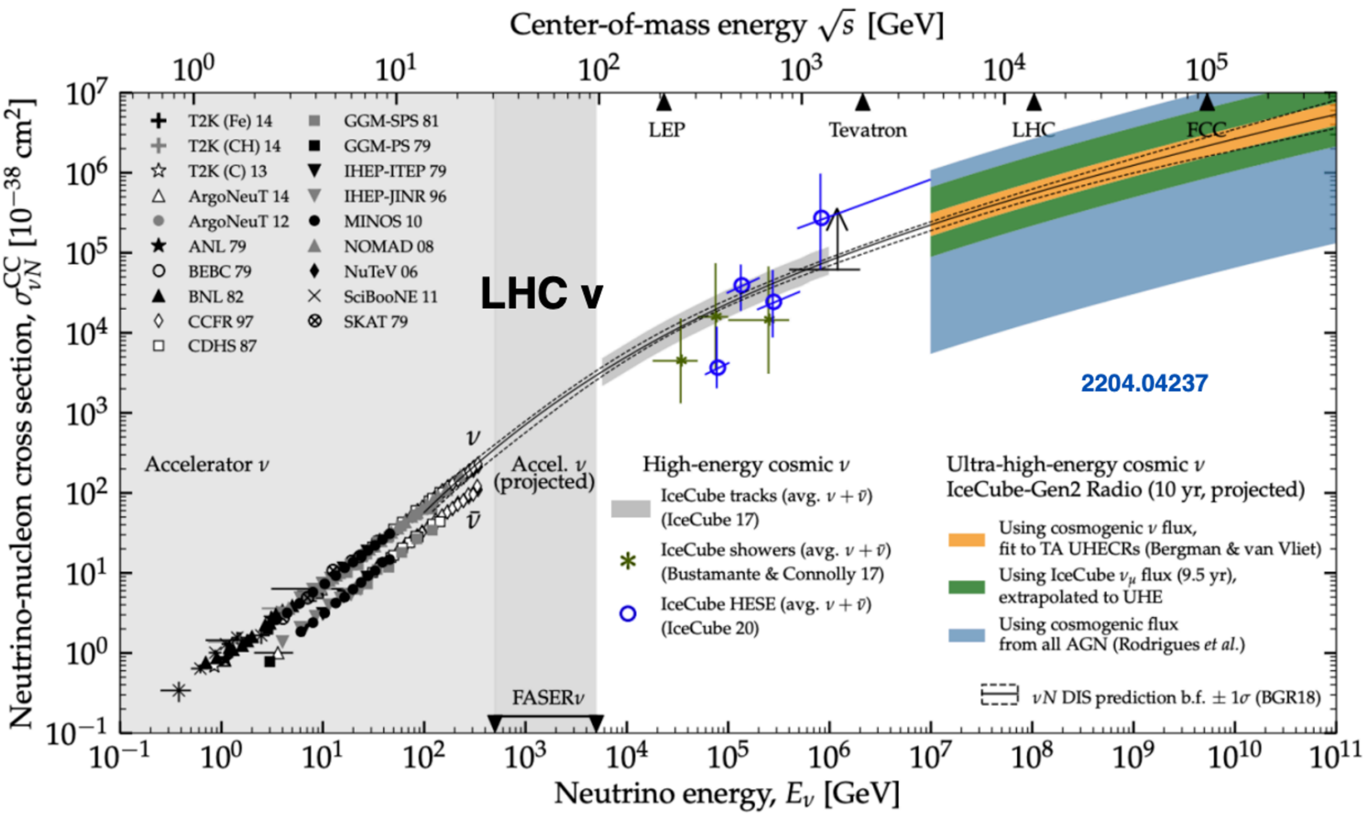


thousands of neutrino interactions in current detectors (FASER / SND@LHC)

millions of neutrino interactions expected at FPF detectors

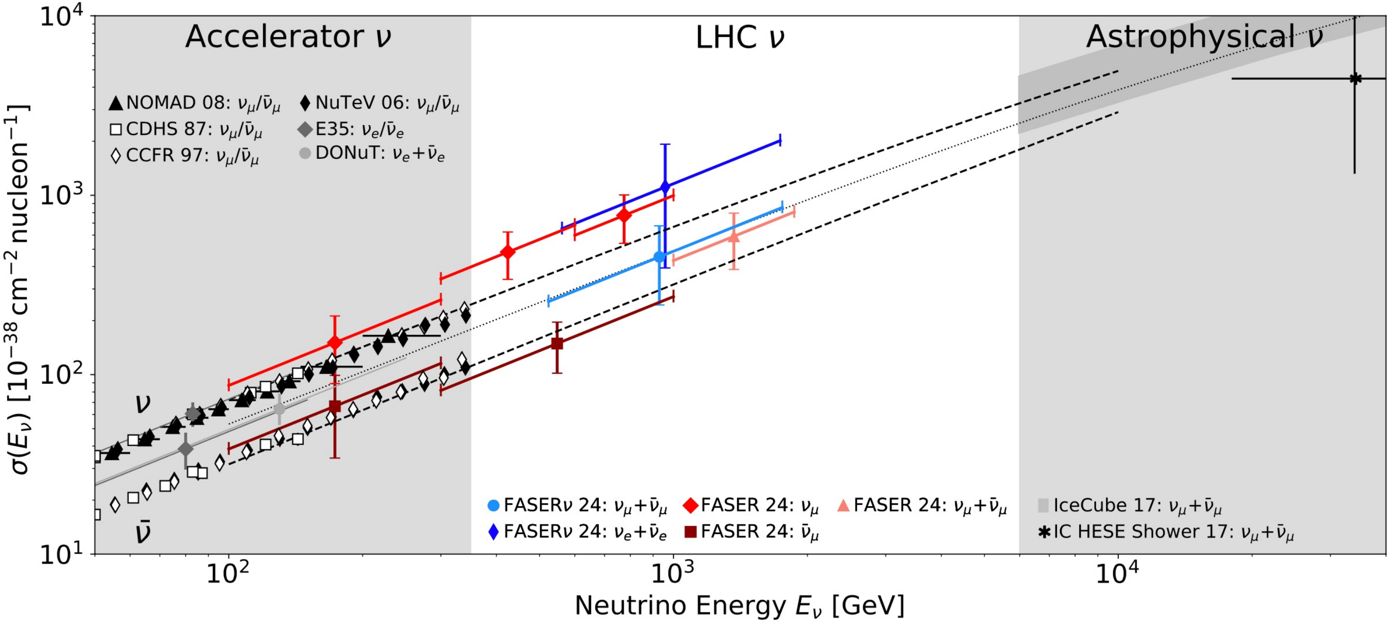
Neutrinos in the 1 TeV range: ~200-500 events/ 10 ton/day
Tau neutrino flux and associated heavy flavour physics: ~1-2 events/10 ton/day

Neutrino Physics Overview



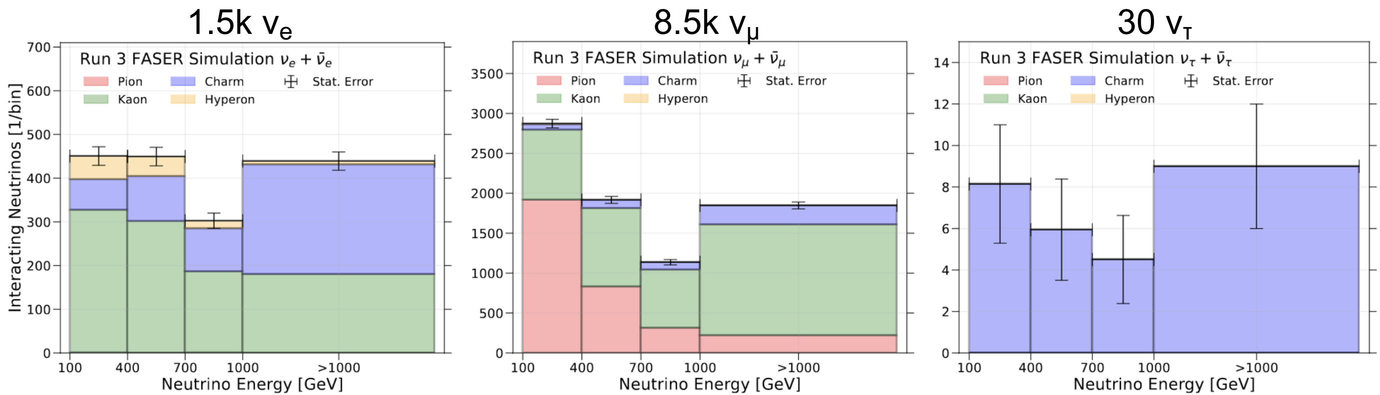
Neutrino Physics Overview

Zooming in around the TeV energy scale…. [FASER, 2403.12520, 2412.03186]



First measurements of the cross section in the LHC region by FASER.
But curently with very large uncertainties. The FPF would allow >100x more statistics (>10x target mass, >10x luminosity).

Collider Neutrino Origin



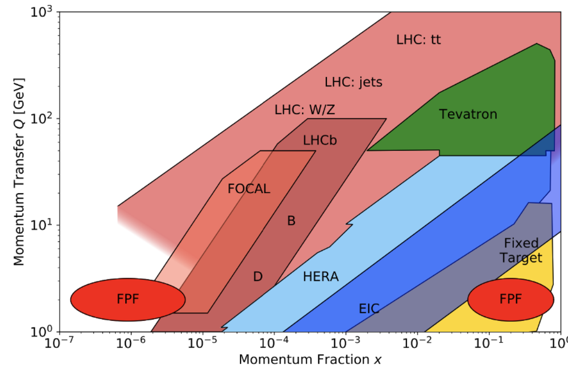
[FASER, 2402.13318]

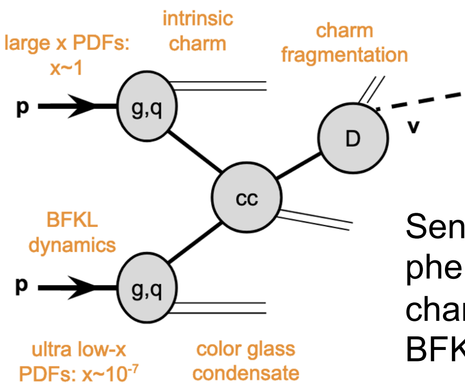
Collider neutrinos are a novel probe of forward particle production.

Laboratory for QCD

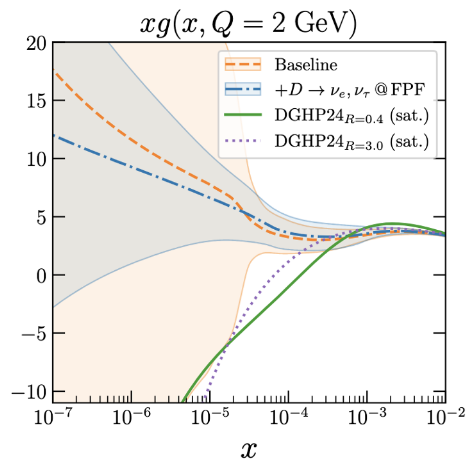
Neutrinos from forward charm production probe uncharted kinematic regimes in QCD.

[FPF 2203.05090]





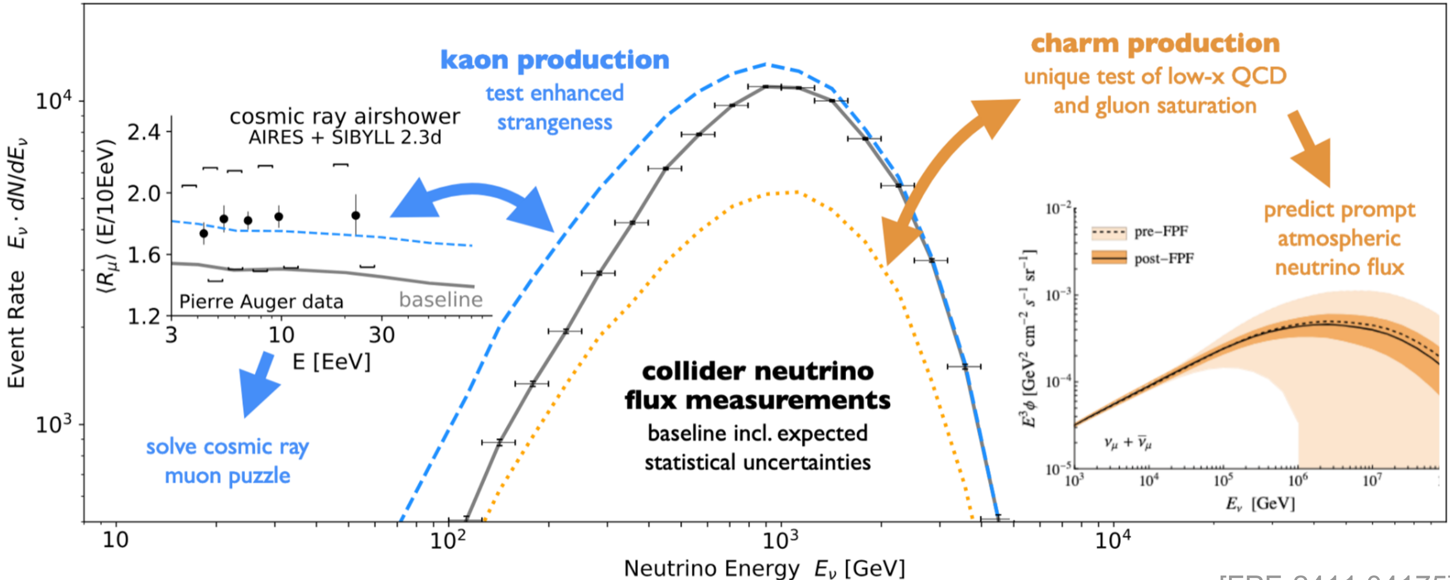
Sensitive to a variety of phenomena: intrinsic charm, gluon saturation, BFKL dynamics, …



Unique ability to constrain PDFs at x~10^-7

[FPF 2411.04175]

Input for Astroparticle Physics



[FPF 2411.04175]

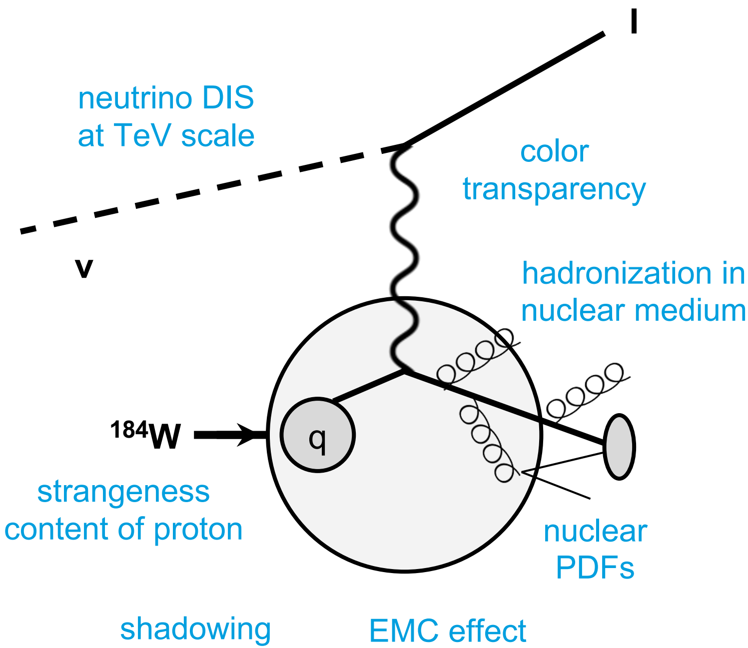
cosmic ray muon puzzle: observed 8σ excess of muons compared to predictions from hadronic interaction models

forward charm production at the LHC constraints on **prompt atmospheric neutrino flux** at IceCube

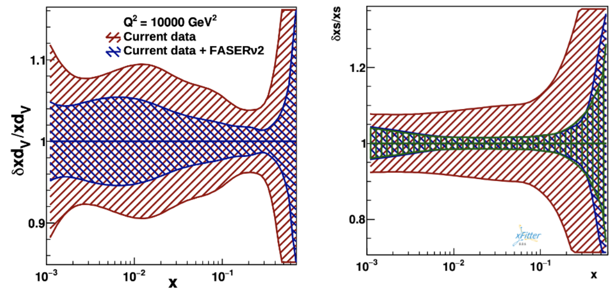
collider neutrino program is endorsed/supported by the astroparticle community

Collider Neutrino Interactions

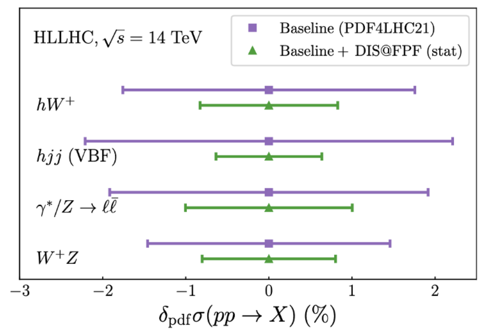
Collider Neutrino Experiments
are a Neutrino-Ion Collider
at EIC center of mass energies



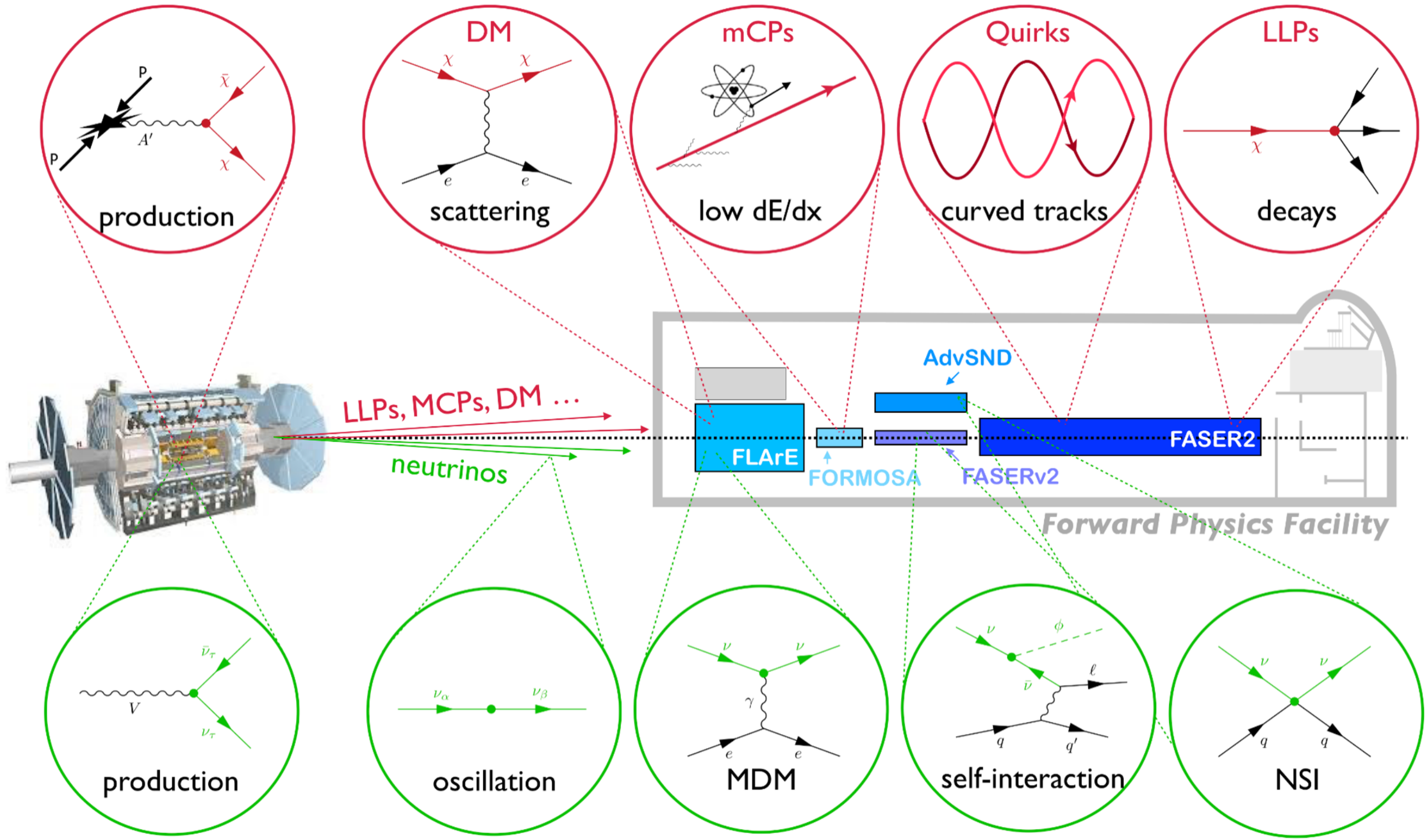
neutrino DIS data will improve PDFs
[Cruz-Martinez et al. 2309.09581]



reduced PDF uncertainties for
many LHC processes and breaks
PDF/BSM degeneracy [FPF 2411.04175]



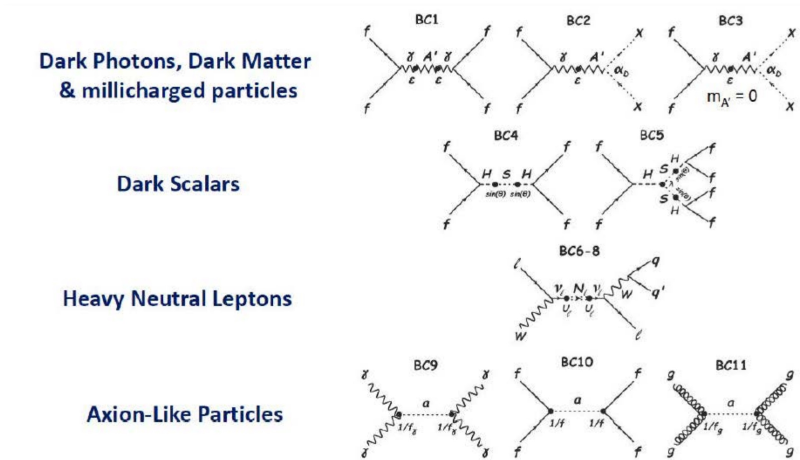
Searches for BSM Physics



[FPF 2203.05090]

BSM Searches

FPF experiments would have strong sensitivity in all proposed CERN PBC dark sector benchmark models.
Although not as sensitive as SHiP in many cases – there are other models where the energy of the LHC beams creates unparalleled sensitivity.

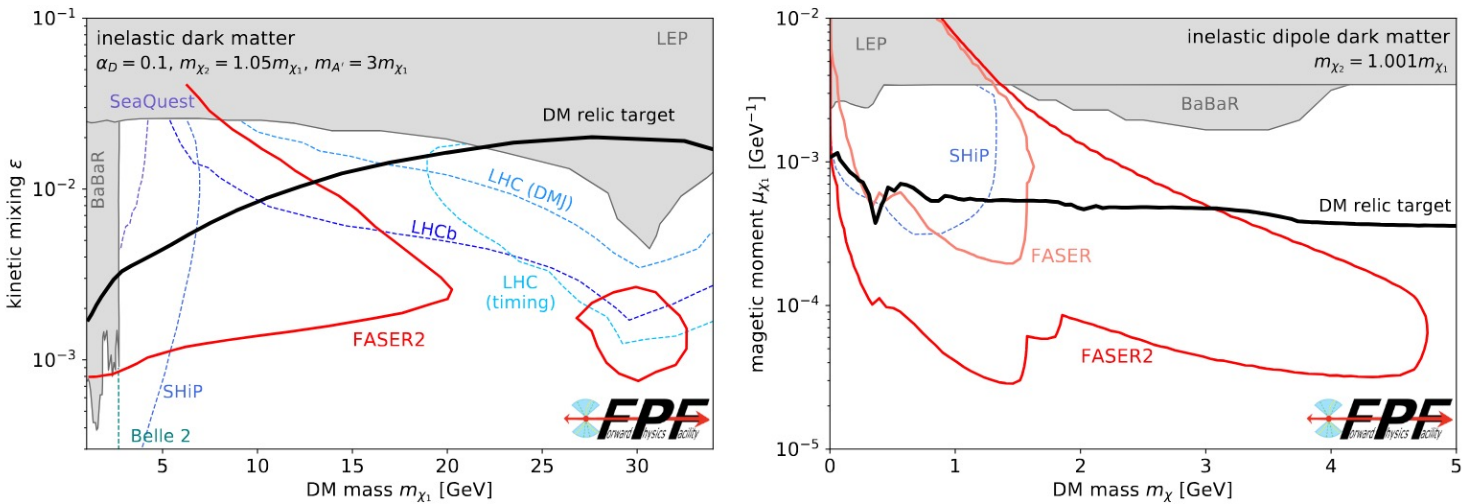


Benchmark Model	Underway	FPF
BC1: Dark Photon	FASER	FASER 2
BC1': $U(1)_{B-L}$ Gauge Boson	FASER	FASER 2
BC2: Dark Matter	–	FLArE
BC3: Milli-Charged Particle	–	FORMOSA
BC4: Dark Higgs Boson	–	FASER 2
BC5: Dark Higgs with hSS	–	FASER 2
BC6: HNL with e	–	FASER 2
BC7: HNL with μ	–	FASER 2
BC8: HNL with τ	FASER	FASER 2
BC9: ALP with photon	FASER	FASER 2
BC10: ALP with fermion	FASER	FASER 2
BC11: ALP with gluon	FASER	FASER 2

Examples of BSM Physics Reach

FPF experiments have unique sensitivity in many Dark sector models.
For example:

- **Inelastic dark matter:** where the boost of the particles in the forward region of the LHC can allow states with very small mass splittings to observed.

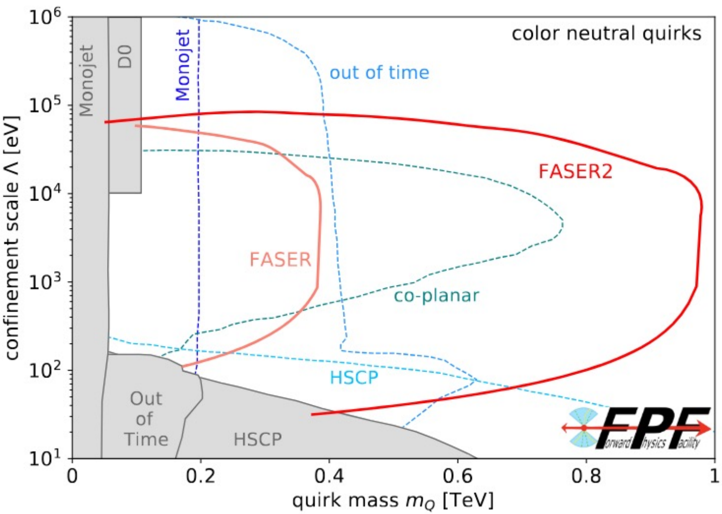


[FPF 2203.05090]

Examples of BSM Physics Reach

FPF experiments have unique sensitivity in many Dark sector models.
For example:

- **Heavy quirks:** where the high collision energy at the LHC is needed to produce them. (Note the quirks are heavy but the quirk pair system has very low p_T and since the quirks pair is coupled by a dark colour 'string' they go in the forward direction)

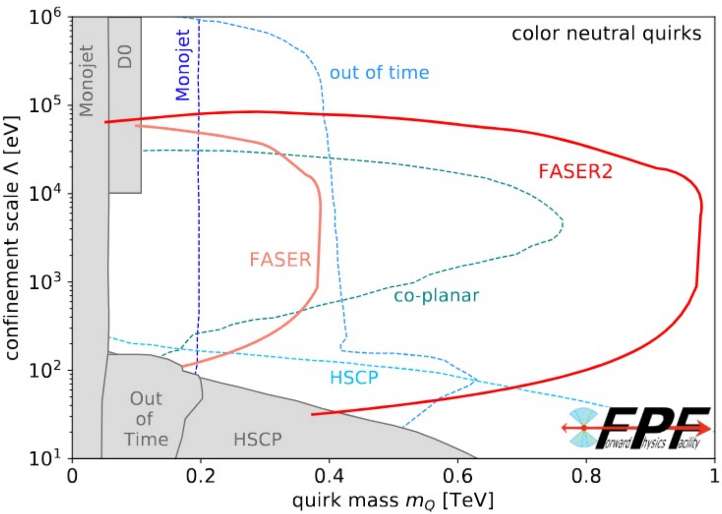


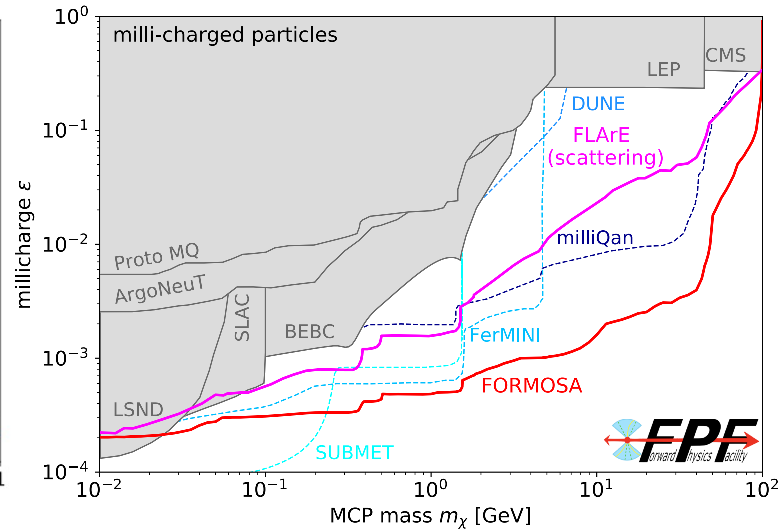
[FPF 2203.05090]

Examples of BSM Physics Reach

FPF experiments have unique sensitivity in many Dark sector models.
For example:

- **Milicharged particles:** The signal event rate can be >250x higher in the forward region of the collisions yielding the worlds best sensitivity across a broad range of masses/charges.

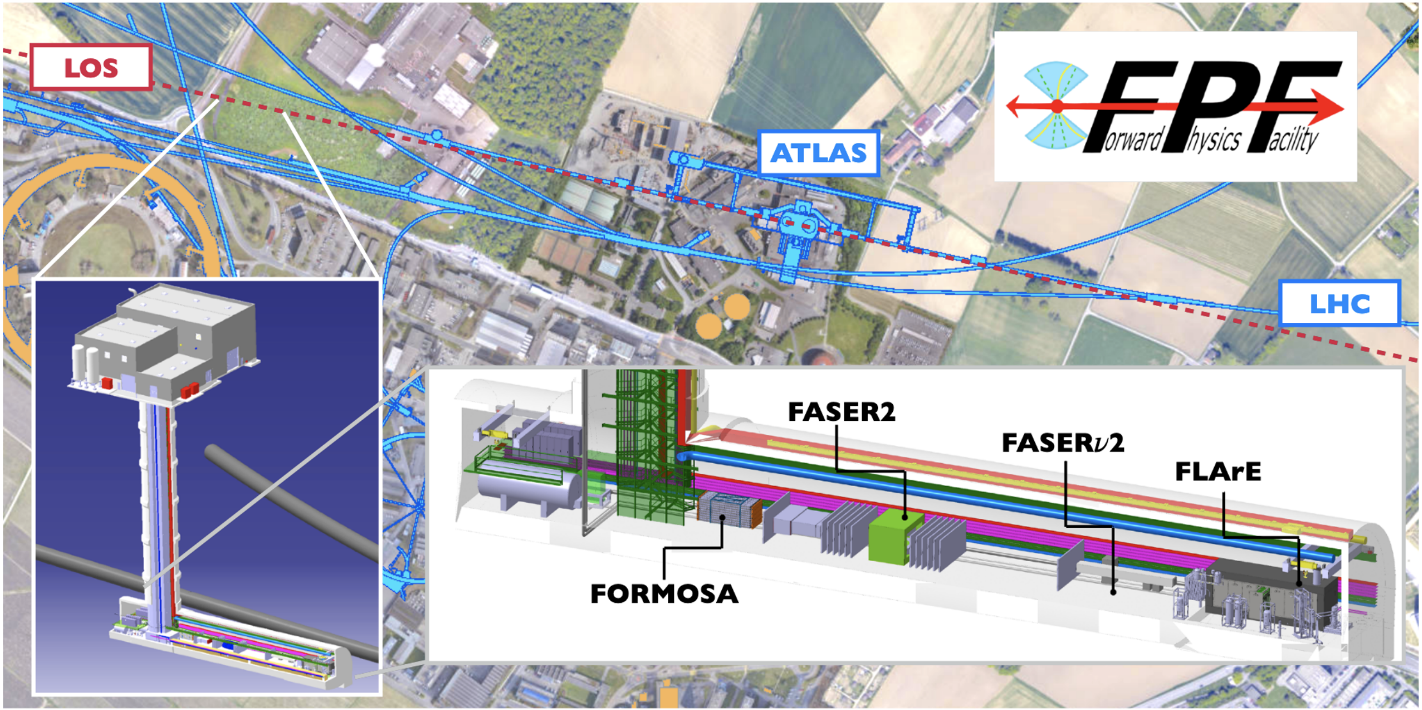




[FPF 2203.05090]

The Facility

Forward Physics Facility (FPF) will house a suite of dedicated forward experiments to exploit the physics potential in the forward direction.



Forward Physics Facility

The FPF status has been summarized recently in arXiv:2411.04175

SCIENCE AND PROJECT PLANNING FOR THE FORWARD PHYSICS FACILITY IN PREPARATION FOR THE 2024–2026 EUROPEAN PARTICLE PHYSICS STRATEGY UPDATE

Jyotismita Adhikary,[1] Luis A. Anchordoqui,[2] Akitaka Ariga,[3,4] Tomoko Ariga,[5] Alan J. Barr,[6] Brian Batell,[7] Jianming Bian,[8] Jamie Boyd,[9] Matthew Citron,[10] Albert De Roeck,[9] Milind V. Diwan,[11] Jonathan L. Feng,[8] Christopher S. Hill,[12] Yu Seon Jeong,[13] Felix Kling,[14] Steven Linden,[11] Toni Mäkelä,[8] Kostas Mavrokoridis,[15] Josh McFayden,[16] Hidetoshi Otono,[5] Juan Rojo,[17,18] Dennis Soldin,[19] Anna Stasto,[20] Sebastian Trojanowski,[1] Matteo Vicenzi,[11] and Wenjie Wu[8]

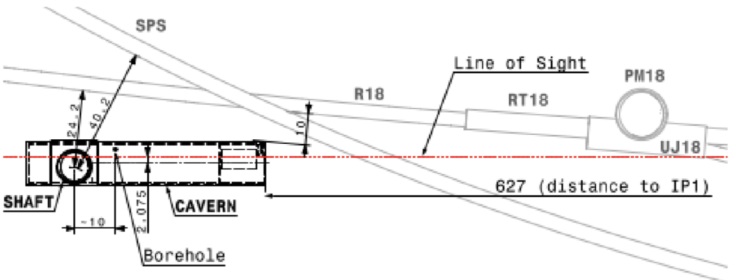
on behalf of the FPF Working Groups

The recent direct detection of neutrinos at the LHC has opened a new window on high-energy particle physics and highlighted the potential of forward physics for groundbreaking discoveries. In the last year, the physics case for forward physics has continued to grow, and there has been extensive work on defining the Forward Physics Facility and its experiments to realize this physics potential in a timely and cost-effective manner. Following a 2-page Executive Summary, we present the status of the FPF, beginning with the FPF's unique potential to shed light on dark matter, new particles, neutrino physics, QCD, and astroparticle physics. We summarize the current designs for the Facility and its experiments, FASER2, FASERν2, FORMOSA, and FLArE, and conclude by discussing international partnerships and organization, and the FPF's schedule, budget, and technical coordination.

FPF: Facility

Various studies performed by CERN teams:

- <u>location study</u>: preferred location 627 m west of the ATLAS IP, on CERN land (low background location: shielded by 200m of rock)
- <u>cavern design</u>: 75 m-long and 12 m-wide cavern, cover $\eta > 5.1$
- <u>vibration study</u>: excavation work possible during beam operation
- <u>radioprotection study</u>: cavern access possible during beam operation.
- <u>muon flux study</u>: background rates OK for experiments and physicists
- <u>site investigation and core drilling</u>: geological conditions OK
- <u>safety study</u>: one access point is sufficient
- <u>transport and installation study</u>: all large components can be transported into the facility



No technical show stoppers identified.
CERN has built many similar underground experimental areas - gives confidence in the cost/time estimates and the proposed technical choices.

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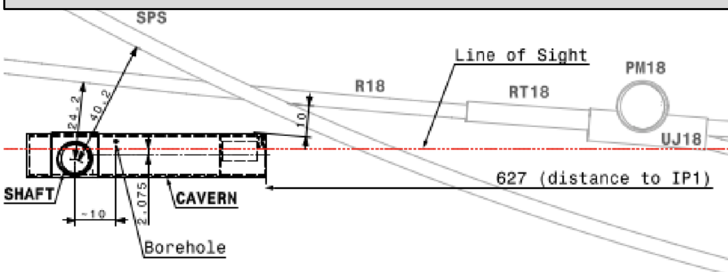
- vibration study: excavation work possible during beam operation
- radioprotection study: cavern access possible during beam operation

Technical studies on the FPF facility (CE, integration, muon background, vibration studies, safety etc..) documented in these PBC notes:
https://cds.cern.ch/record/2904086?ln=en
https://cds.cern.ch/record/2901520?ln=en
https://cds.cern.ch/record/2851822?ln=en



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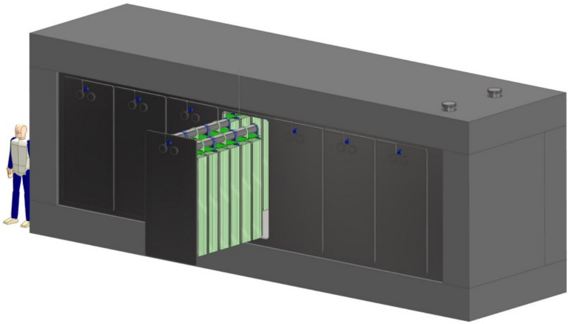
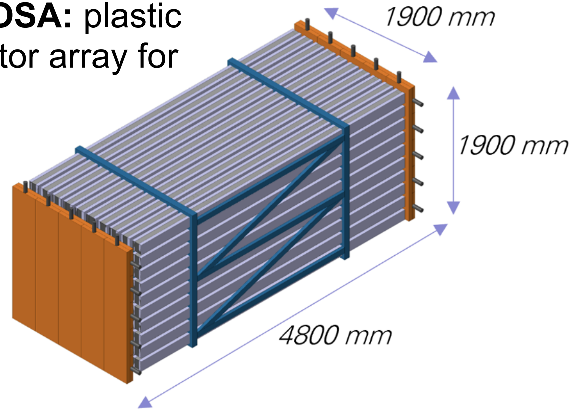
FPF: Experiments

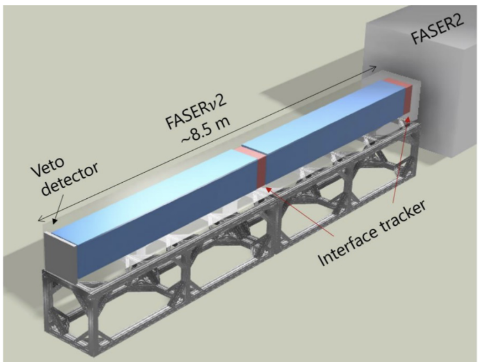
FLArE: 10 ton LAr TPC for neutrino detection



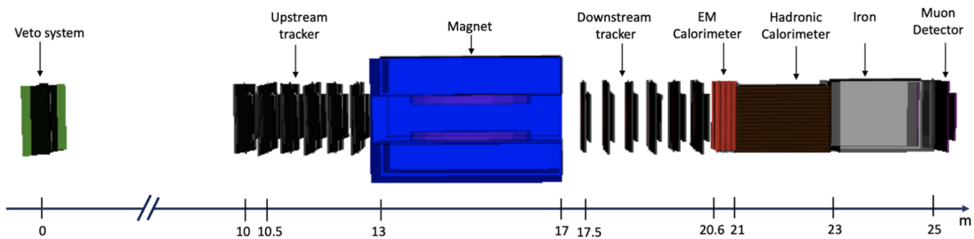
FORMOSA: plastic scintillator array for MCPs



FASERv2: 20 ton tungsten/emulsion detector for neutrinos



FASER2: tracking spectrometer for LLP searches and muon charge ID



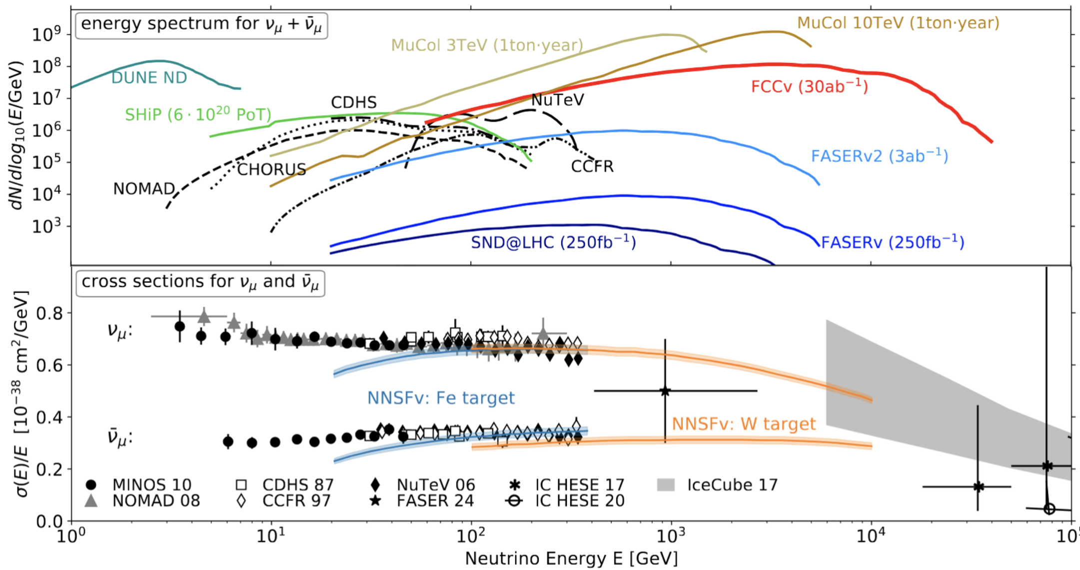
FPF: Cost

Component	Approximate Cost	Comments
Facility Costs		
FPF civil construction	35.3 MCHF	Construction of shaft and cavern
FPF outfitting costs	10.0 MCHF	Electrical, safety, and integration
Cryogenic infrastructure	3.8 MCHF	Cryogen storage and cooling systems
Total	**49.1 MCHF**	Includes integration for infrastructure
Experiment Costs		Core costs only
FASER2	11.6 MCHF	3+3 tracker layers, SAMURAI-style magnet, dual-readout calorimeter
FASERν2	15.9 MCHF	Tungsten target, scanning system, emulsion films (10 replacements), interface detector
FLArE	10.8 MCHF	Cryostat, proximity cryogenics, detectors
FORMOSA	2.3 MCHF	Plastic scintillator, PMTs, readout
Total	**40.6 MCHF**	Core cost experimental program

TABLE I. Cost for components of the FPF and the experimental program. Costs of the infrastructure at CERN are Class 4 estimates according to international standards; they have a range from −30% to +50%. The costs for experimental components are estimated as core costs, which consist of direct costs of materials and contracts only. Each core cost was computed with conservative technical choices; as new ideas and designs are considered, the costs are expected to change.

Future Colliders

Great potential for forward neutrino measurements and searches also muon collider [IMCC, 2407.12450] and FCC-hh [Abraham et al, 2409.02163]



1B neutrinos will allow many precision studies:
PDFs at x~10^{-9}, polarized PDFs, nuclear PDFs, neutrinos from heavy ions

Summary

A novel forward physics program has emerged to fully exploit potential of the LHC.

Physics:

- Guaranteed unique results for TeV energy collider neutrino measurements to probe uncharted regions of QCD and provide crucial input for astroparticle physics.
- Additionally, BSM searches for a broad range feebly interacting particles

Detectors:

- Four complementary detectors to fully exploit the available physics.
- Based on existing pathfinder experiments (FASER, miliQan) or well studied technologies (LAr TPCs for DUNE).

Sustainability:

- Collider neutrino experiments do not require use energy (in addition to HL-LHC operations) to produce the beam.

Time Scale:

- Mid-scale projects that can be realized on short and flexible timescales, offers scientific and leadership opportunities. Important contributions from construction to data analysis possible in a single graduate student lifetime.

Acknowledgements

Many thanks to the CERN Physics Beyond Colliders group for their support in studying the FPF feasiblity.

Many thanks to the FPF coordination group for their input.
Particular thanks to Felix Kling for many of the slides presented.

Backup…

CERNCOURIER | Reporting on international high-energy physics

Physics ▾ | Technology ▾ | Community ▾ | In focus | Magazine

SEARCHES FOR NEW PHYSICS | MEETING REPORT

Looking forward at the LHC

1 September 2023

The Forward Physics Facility (FPF) is a proposed new facility to operate concurrently with the High-Luminosity LHC, housing several new experiments on the ATLAS collision axis. The FPF offers a broad, far-reaching physics programme ranging from neutrino, QCD and hadron-structure studies to beyond-the-Standard Model (BSM) searches. The project, which is being studied within the Physics Beyond Colliders initiative, would exploit the pre-existing HL-LHC beams and thus have minimal energy-consumption requirements.

New territory 3D rendering of the proposed Forward Physics Facility and its experiments. Credit: A Navascues Cornago

On 8 and 9 June, the 6th workshop on the Forward Physics Facility was held at CERN and online. Attracting about 160 participants, the workshop was organised in sessions focusing on the facility design, the proposed experiments and physics studies, leaving plenty of time for discussion about the next steps.

FPF Collaboration

FPF studied by groups in:
UK, Germany, Switzerland, Netherlands, Serbia, Romania, US, Japan
Room for additional contributions – let me know if you are interested to get involved!

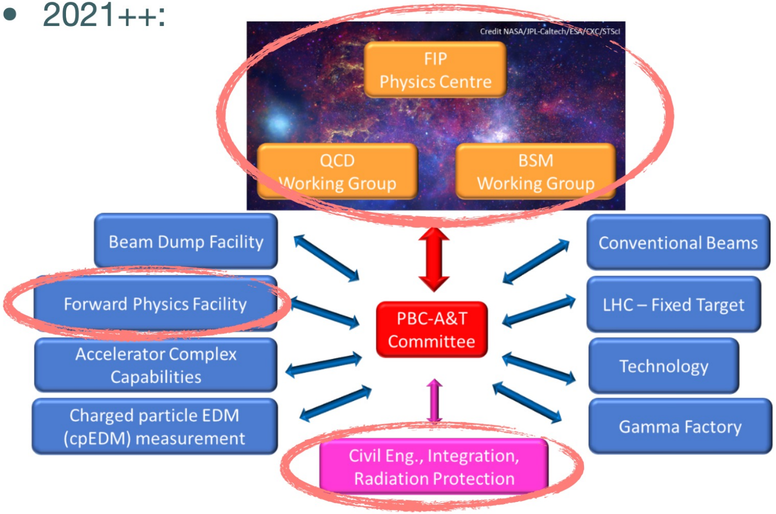
Steering Committee:
Jamie Boyd (CERN), Albert De Roeck (CERN), Felix Kling (DESY), Milind Diwan (BNL), Jonathan Feng (UCI)

Detector/Physics WG conveners:
Alan Bar (Oxford), Aki Ariga (Chiba), Tomoko Ariga (Kyushu), Steve Linden (BNL), Jianming Bian (UCI), Matthew Citron (UCSB), Juan Rojo (Nikhef), Anna Stasto (PennState), Luis Anchordoqui (Lehman), Dennis Soldin (Utah), Brian Batell (Pittsburgh), Sebastian Trojanowski (Warsaw)

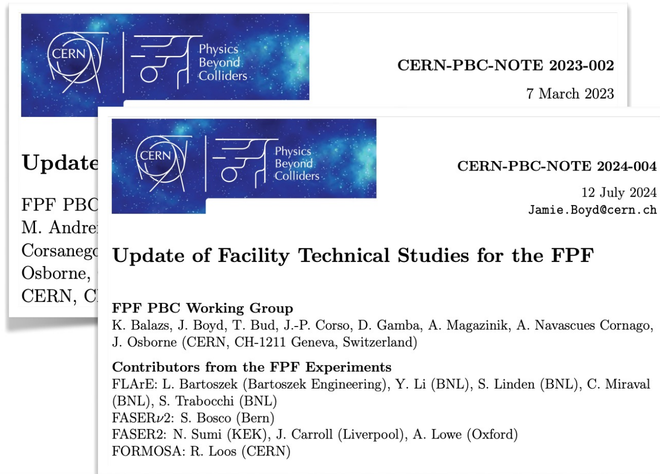
Physics Beyond Colliders

FPF & PBC

- 2021++:



- PBC contributions:
  - Dedicated FPF working group (WG)
  - Interaction with physics WGs
  - Civil Engineering studies etc.



CERN-PBC-NOTE 2023-002

7 March 2023

Update

FPF PBC
M. Andre
Corsaneg
Osborne,
CERN, C

CERN-PBC-NOTE 2024-004

12 July 2024

Jamie.Boyd@cern.ch

Update of Facility Technical Studies for the FPF

FPF PBC Working Group
K. Balazs, J. Boyd, T. Bud, J.-P. Corso, D. Gamba, A. Magazinik, A. Navascues Cornago, J. Osborne (CERN, CH-1211 Geneva, Switzerland)

Contributors from the FPF Experiments
FLArE: L. Bartoszek (Bartoszek Engineering), Y. Li (BNL), S. Linden (BNL), C. Miraval (BNL), S. Trabocchi (BNL)
FASERν2: S. Bosco (Bern)
FASER2: N. Sumi (KEK), J. Carroll (Liverpool), A. Lowe (Oxford)
FORMOSA: R. Loos (CERN)

Site Investigation Works
Results and Recommendations

Results	Recommendations
Ground found mostly competent for tunnelling purposes.	N/A
Signs of hydrocarbons were found in the soft sandstone at depths between 84 and 90 m.	1) Excavation material contaminated with liquid hydrocarbons will require specific spoil management. 2) Underground tunnels and works in contact with soils contaminated with hydrocarbons will require specialised waterproofing membrane.
Foundations of the surface buildings will sit within competent moraine.	N/A
No water table has been identified. Overall the ground is not very permeable.	N/A
Vertical swelling test carried out showed a high swelling potential.	Swelling pressures to be considered during the design of the final lining.
Slight elevation of fluoride levels shown in the existing backfill material.	Existing backfill material will need to be disposed of at appropriate facilities.

SUMMARY

- The results of the site investigation were broadly positive
- Favourable ground conditions noted and no water table identified.
- Correct management of hydrocarbons, fluoride, and swelling potential still needed
- can be addressed during the design phase.

Civil Engineering Costing

Civil Engineering Cost Estimate

Ref.	Work Package	Cost [CHF]	Percentage of the CE Works
1.	Underground Works	12,392,344.00	35%
1.1	Preliminary activities	1,845,000.00	5.2%
1.2	Access shaft	4,424,143.00	12.5%
1.3	Experimental Cavern	6,123,201.00	17.3%
2.	Surface Works	6,727,231.00	19%
2.1	General items	720,776.00	2.0%
2.2	Topsoil and earthworks	702,227.00	2.0%
2.3	Roads and network	796,122.00	2.3%
2.4	Buildings	4,508,106.00	12.8%
2.4.1	Access building	2,224,786.00	6.3%
2.4.2	Cooling and ventilation building	1,497,350.00	4.2%
2.4.3	Electrical Building	563,689.00	1.6%
2.4.5	External platforms	222,281.00	0.6%
3.	General items	11,815,899.00	33.4%
4.	Miscellaneous	4,397,504.00	12.4%
	TOTAL CE WORKS	35,332,978.00	100.0%

Assumptions

1. Services not included
2. Technical galleries not included
3. Cranes not included
4. Access building as a conventional steel portal frame structure with cladding, only one floor
5. CV Building as a reinforced concrete building, only one floor
6. Finished floor level at 450m ASL
7. Sectional doors not included
8. Unit costs are based on a combination of Hi-Lumi (2018), Faser (2018), SPS Tunnel eye enlargement
9. Inflation figures have been taken dating from 2017-T4, with 2021 as the benchmark year

- Latest cost estimate from September 2024 following enlargement of cavern by 10m and 1m radius
- Previous costs were reviewed by external consultants, and adjusted according to advice
- Findings from site investigation has been incorporated
- Inflation since last (2021) estimate
- Previous declared cost estimate was 27.5MCHF

Estimation class 4

Expected accuracy range: L: -10% to -20%
H: +20% to +30%

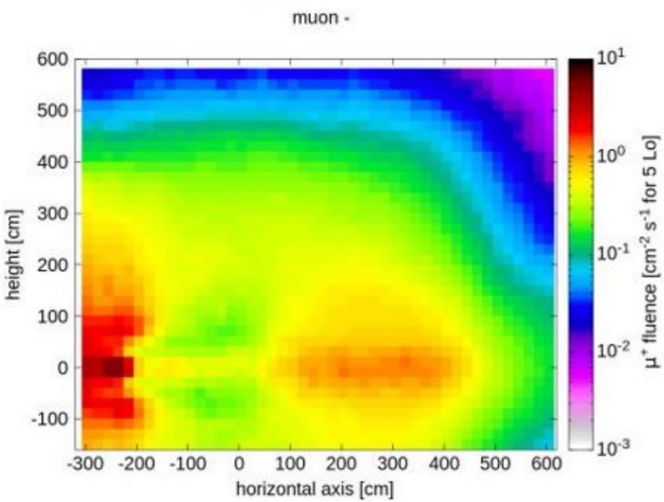
FPF: Timeline

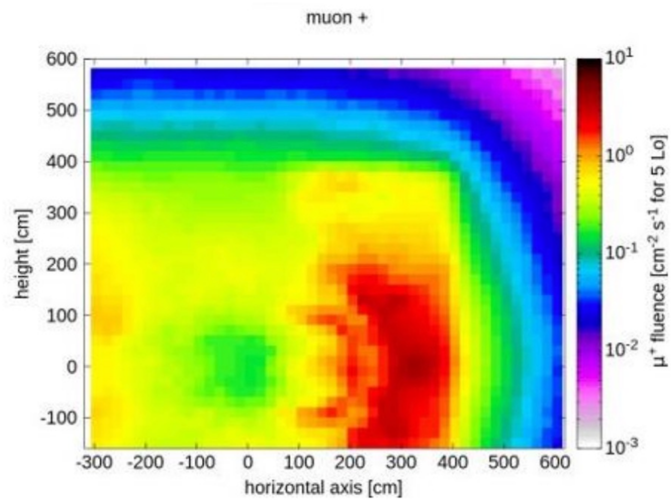
Year	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033
(HL-)LHC Nominal Schedule	Run 3	Run 3	Run 3 / LS 3	LS 3	LS 3	LS 3	LS 3 / Run 4	Run 4	Run 4	Run 4
FPF Milestones	Pre-CDR and physics proposal	R&D and prototype detectors	CDR, long lead items, magnet	Start of civil construction, TDR for detectors	Detector construction start	Major equipment acq.	End of civil construction, Install services	Detector install	Detector commissioning, physics start	Physics running all detectors
Experiment Core Costs (kCHF)		154	1275	3473	7257	11220	9503	6978	741	

TABLE II. Proposed funding profile for the FPF experimental program using the core cost numbers from Table I. The infrastructure cost profile is being developed. The approval and cost rules will be different for the different sponsors who are proposed to contribute to this overall profile. Nevertheless, for the purpose of this illustration, the profile is shown in as-spent funds in a single currency.

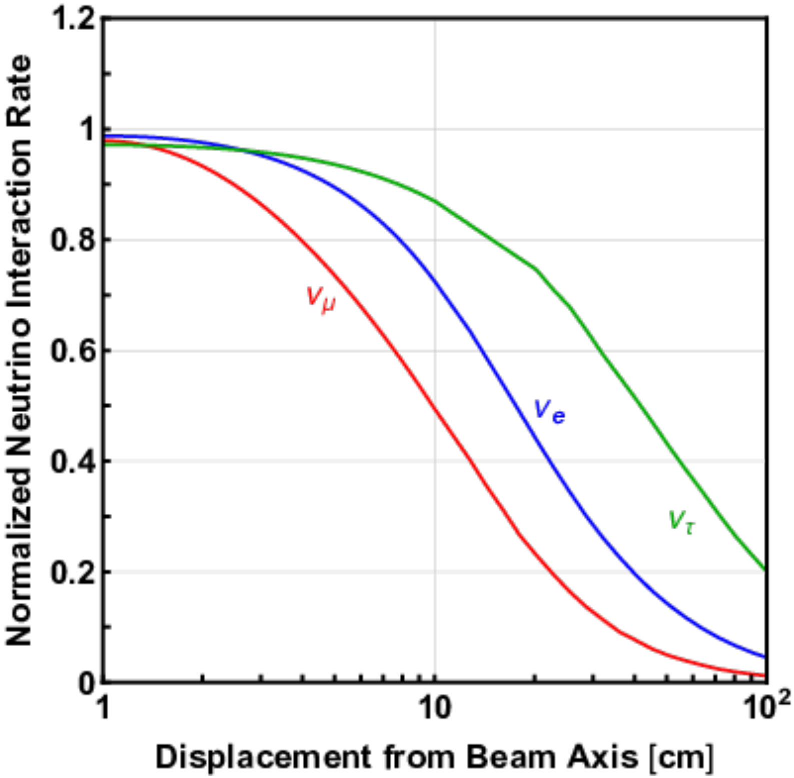
Experimental Details: Muon Background

Muon background in FPF studied with detailed FLUKA simulations.
Includes realsitic description of LHC infratsructure between IP and FPF (magnets, abosorbers, collimators etc…). Simulation validated with FASER and SND@LHC data.
Flux ~0.5Hz/cm^{-2} along collision axis line of sight (LOS).
Rises by an order of magnitude when going ~2m from LOS in horizontal direction (opposite direction for mu+ and mu-)





Transverse size of neutrino beam



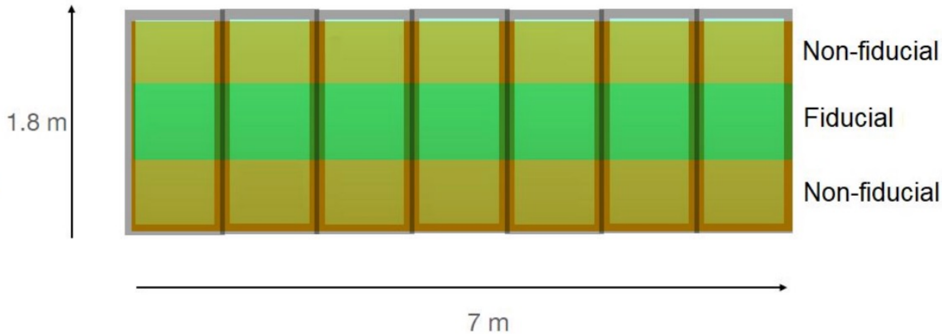
The neutrino beam is very collimated.
The flux falls off by about 50% at:

- 10cm for nu_mu
- 20cm for nu_e
- 50cm for nu_tau

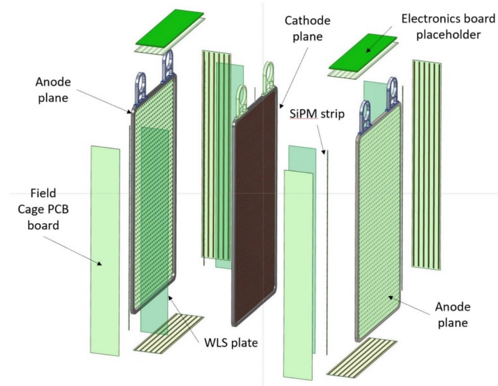
The production process also varies with rapidity, and mapping out in energy/rapidity will provide important information on forward hadron production.

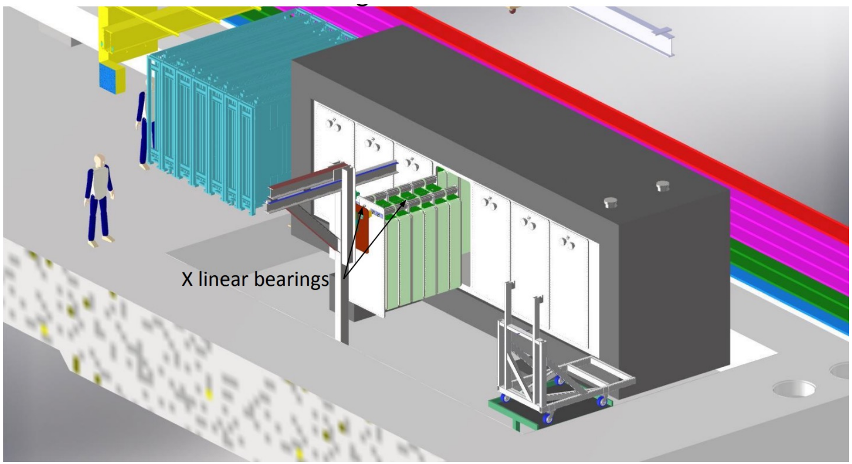
Experimental Details: FLArE TPC

FLArE made up of 21 TPC modules.
10tn fiducial mass.



Exploded CAD view of a TPC module





Installation sequence of TPCs into cryostat studied. Horizontal insertion solution favoured.

Experimental Details: FLArE TPC

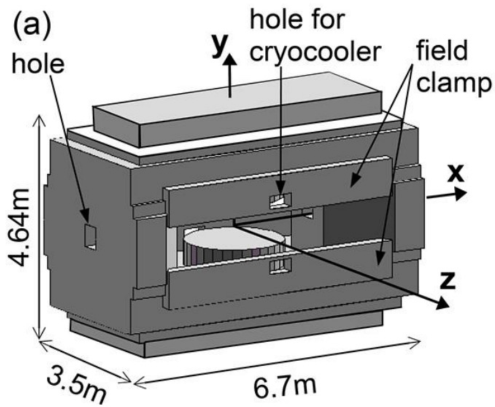
TPC requirements similar to DUNE Near Detector. Benefit from ND R&D.

Parameter	Value	comment
TPC liquid fill	LAr	radiation length 14 cm
Modules	3 (Wide) x 7 (Length)	21 modules
Module dimension	60 cm (W)x 100 cm (L) x 180 cm (H)	approximate
Gap length	30 cm	Cathode in center
Drift field	500 V/cm	
Max voltage	15000 V	
Anode pixel size	4 mm x 4 mm	5 mm spacing
Charge channels/anode	72000	two anodes per mod
Photon system	WLS plate with TPB	
SiPM channels/anode	50	

Table 8: Preliminary parameters for the FLARE TPC.

Experimental Details: FASER2 Magnet

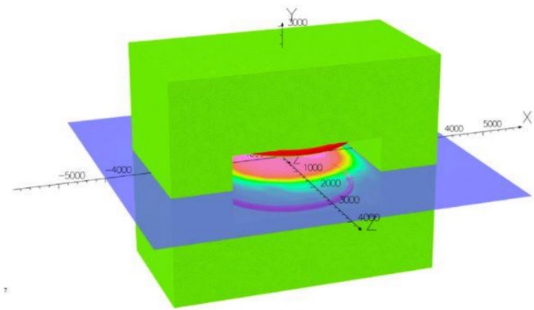
Made by Toshiba for RIKEN



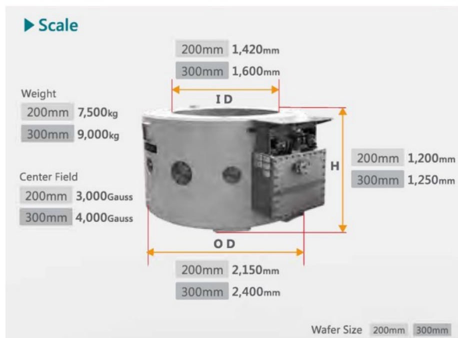
Key component of FASER2 is a large area, air core superconducting dipole magnet.
Transverse size: 3m x 1m (gap)
Bending power: 2Tm
Two solutions identified:

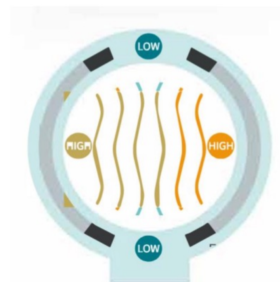
- Custom made by Toshiba (similar to SAMURAI experiment magnet)
- Multiple off-the-shelf “crystal puller” magnets (Toshiba or TESLA electroncis)

Discussions with companies show both fulfill requirements and are affordbale (<5MCHF)



Toshiba





Large uniform field area.

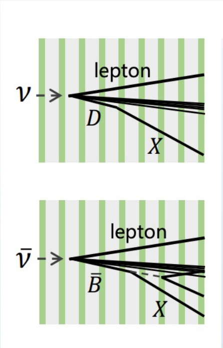
Experimental Details: FASERnu2

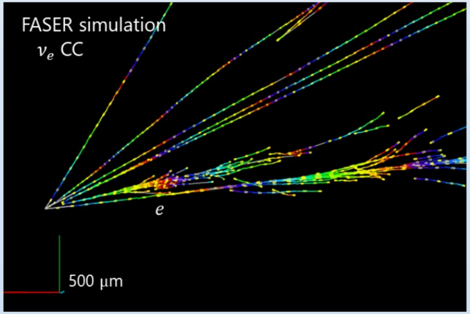
Expected number of events

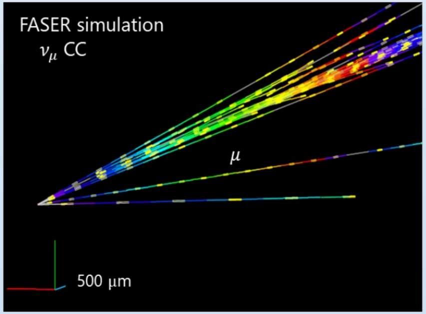
Based on "F. Kling and L.J. Nevay, Forward Neutrino Fluxes at the LHC, Phys. Rev. D 104, 113008" and "J.L. Feng et al., The Forward Physics Facility at the High-Luminosity LHC, arxiv:2203.05090"

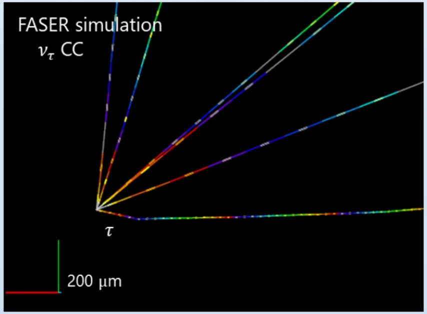
ν int. rate estimated using **Sibyll 2.3d** / **DPMJET 3.2017**

		Sibyll 2.3d $\nu_e+\bar{\nu}_e$ CC	Sibyll 2.3d $\nu_\mu+\bar{\nu}_\mu$ CC	Sibyll 2.3d $\nu_\tau+\bar{\nu}_\tau$ CC	DPMJET 3.2017 $\nu_e+\bar{\nu}_e$ CC	DPMJET 3.2017 $\nu_\mu+\bar{\nu}_\mu$ CC	DPMJET 3.2017 $\nu_\tau+\bar{\nu}_\tau$ 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









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The Dawn of Collider Neutrino Physics

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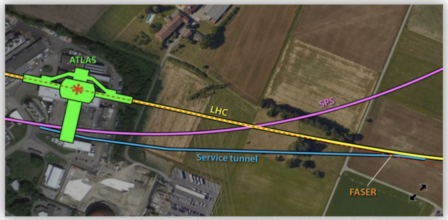
VIEWPOINT

The Dawn of Collider Neutrino Physics

Elizabeth Worcester
Brookhaven National Laboratory, Upton, New York, US

July 19, 2023 • *Physics* 16, 113

The first observation of neutrinos produced at a particle collider opens a new field of study and offers ways to test the limits of the standard model.



Google Earth, imagery (c)2023 Maxar Technologies, map data (c)2023; CERN; adapted by APS/Alan Stonebraker

Figure 1: The Forward Search Experiment (FASER) is installed in a service tunnel that connects the Large Hadron Collider (LHC) and the Super Proton Synchrotron (SPS). Proton collisions at the ATLAS experiment's interaction point (red star) generate beams of neutrinos (dashed red lines) that escape along a tangent to the LHC.

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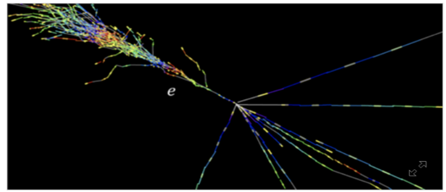
SYNOPSIS

First Direct Detection of Electron Neutrinos at a Particle Collider

July 11, 2024 • *Physics* 17, s80

Electron neutrinos produced by proton–proton collisions at the LHC have been experimentally observed.



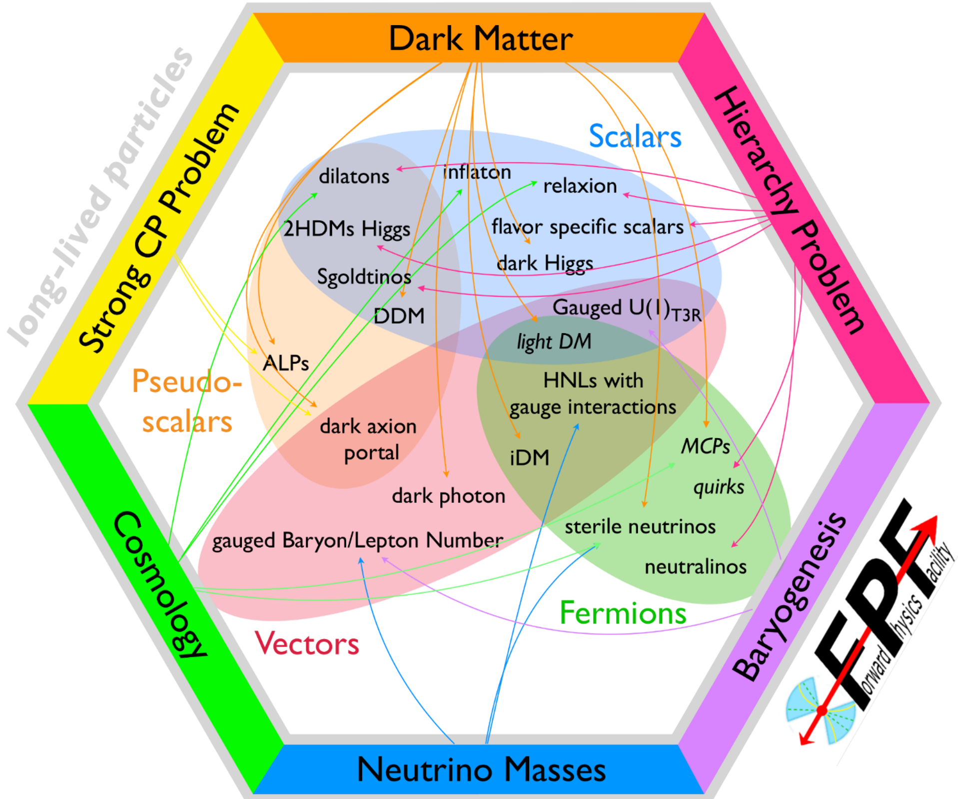
R. M. Abraham *et al.* (FASER Collaboration) [1]

The three flavors of neutrinos—electron, muon, and tau—are notoriously elusive, as they interact with ordinary matter only via the weak force. Notwithstanding this difficulty, neutrinos originating from astrophysical sources like the Sun and supernovae and from nuclear reactors and fixed-target experiments have been previously detected. In 2023, muon neutrinos produced by proton–proton collisions at a particle collider were directly detected by the Forward Search Experiment (FASER) at the Large Hadron Collider (LHC) at CERN in Switzerland (see **Viewpoint: The Dawn of Collider Neutrino Physics**). Now the FASER Collaboration has reported the first direct detection of another flavor—the electron neutrino [1].

Searches for BSM Physics

Discovery prospects for LLPs at FASER/FPF have been analyzed for a huge number of models.

Many of them related to various outstanding fundamental questions in particle and astro-particle physics.



[FPF 2203.05090]

Strongly Reviewed in Snowmass

Executive Summary (10 pages)

LHC

The Energy Frontier (Science Drivers 1 – 3 & 5): The Energy Frontier currently has a top-notch program with the Large Hadron Collider (LHC) and its planned High Luminosity upgrade (HL-LHC) at CERN, which sets the basis for the Energy Frontier vision. The fundamental lessons learned from the LHC thus far are that a Higgs-like particle exists at 125 GeV and there is no obvious and unambiguous signal of BSM physics. This implies that new physics either occurs at scales higher than we have probed, must be weakly coupled to the SM, or is hidden in backgrounds at the LHC. The immediate goal for the Energy Frontier is to continue to take and analyze the data from LHC Run 3, which will go on for about three more years, and carry out the 2014 P5 recommendations to complete the HL-LHC Upgrade and execute its physics program. The HL-LHC will measure the properties of the Higgs Boson more precisely, probe the boundaries of the SM further, and possibly observe new physics or point us in a particular direction for discovery.

A new aspect of the proposed LHC program is the emergence of a variety of auxiliary experiments that can use the interactions already occurring in the existing collision regions during the normal LHC and HL-LHC running of the ATLAS, CMS, LHCb, and ALICE experiments to explore regions of discovery space that are not currently accessible. These typically involve observing particles in the far forward direction or long-lived particles produced at larger angles but decaying far outside the existing detectors. These are mid-scale detectors in their own right and provide room for additional innovation and leadership opportunities for younger physicists at the LHC. The EF supports continued strong U.S. participation in the success of the LHC, and the HL-LHC construction, operations, and physics programs, including auxiliary experiments.

future collider

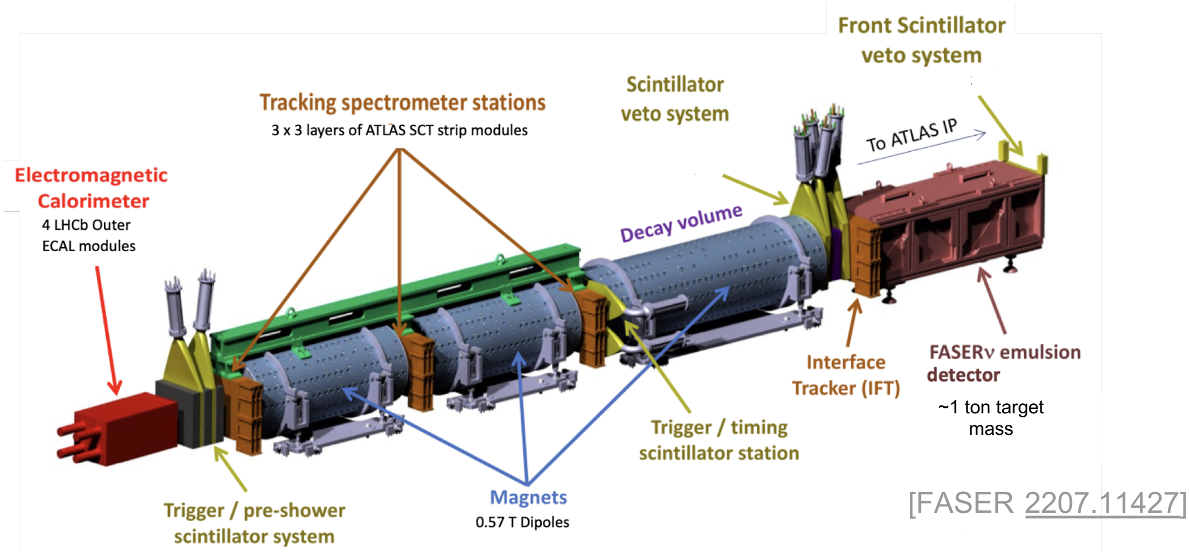
New colliders are the ultimate tools to extend the EF program into the next two decades thanks to the broad and complementary set of measurements and searches they enable. With a combined strategy of precision measurements and high-energy exploration, future lepton colliders starting at energies as low as the Z-pole up to a few TeV can shed substantial light on some of these key questions. It will be crucial to find a way to carry out experiments at higher energy scales, directly probing new physics at the 10 TeV energy scale and beyond. The EF supports a fast start for the construction of an e^+e^- Higgs Factory (linear or circular), and a significant R&D program for multi-TeV colliders (hadron and muon). The realization of a Higgs Factory will require an immediate, vigorous, and targeted accelerator and detector R&D program, while the study towards multi-TeV colliders will need significant and long-term investments in a broad spectrum of R&D programs for accelerators and detectors.

Finally, the U.S. EF community has expressed renewed interest and ambition to develop options for an energy-frontier collider that could be sited in the U.S., while maintaining its international collaborative partnerships and obligations with, for example, CERN.

A new aspect of the proposed LHC program is the emergence of a variety of auxiliary experiments that can use the interactions already occurring in the existing collision … to explore regions of discovery space that are not currently accessible. These typically involve observing particles in the far forward direction or long-lived particles … decaying far outside the existing detectors. These are mid-scale detectors in their own right and provide room for additional innovation and leadership opportunities for younger physicists at the LHC. The EF supports continued strong U.S. participation … including auxiliary experiments.

[Snowmass ExecutiveSummary]

FASER Experiment



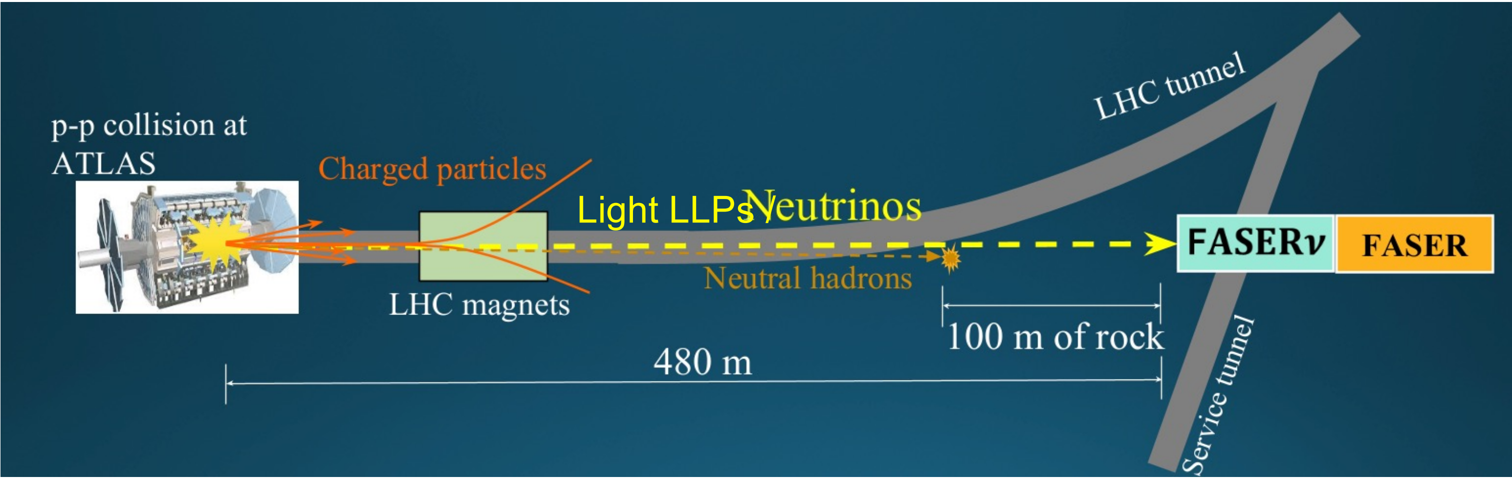
1 ton **FASERν tungsten emulsion detector** for neutrino measurements. Also target for electronic measurements using muon appearance.

decay volume, tracking spectrometer and calorimeter system primarily designed for new physics search

centered on beam collison axis where flux is largest: η>8.8

operation during LHC Run 3

FASER Location



The FASER experiment started operation in 2022 to take advantage of this and to search for new, light, long-lived particles (LLPs), and study high energy neutrinos in the far forward region of the LHC collisions. The experiment has a 1.1tn neutrino target, and a 1.5m-long,20cm diameter decay volume, it is situated ~500m from the ATLAS collision point, on the beam collision axis line-of-sight (LOS).

FPF/FASER Locations