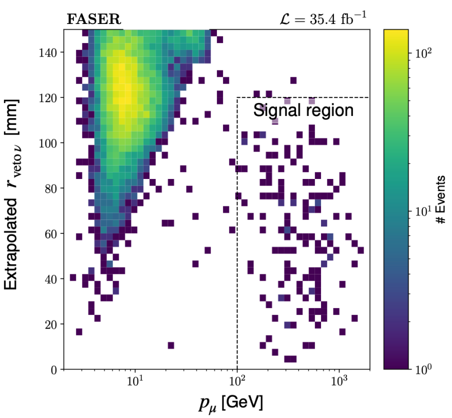
STATUS OF THE COLLABORATION AND PROSPECTS AFTER P5

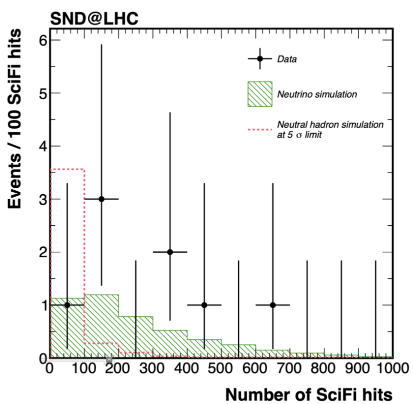
PBC Annual Meeting, CERN

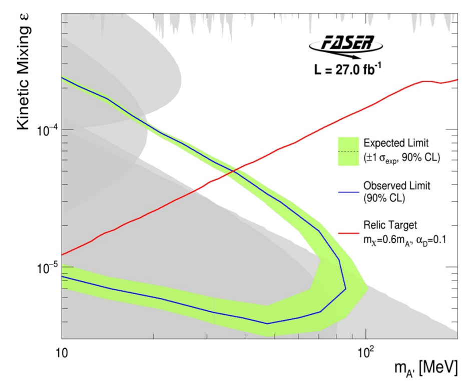
Jonathan Feng, UC Irvine, 25 March 2024

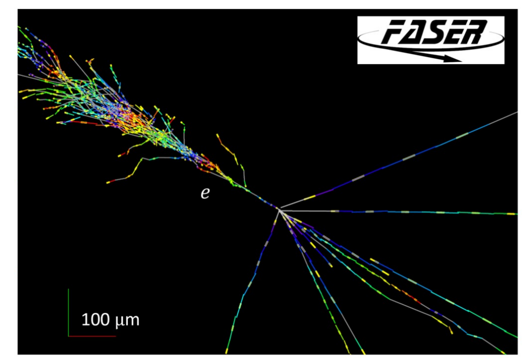
PROGRESS SINCE LAST PBC MEETING

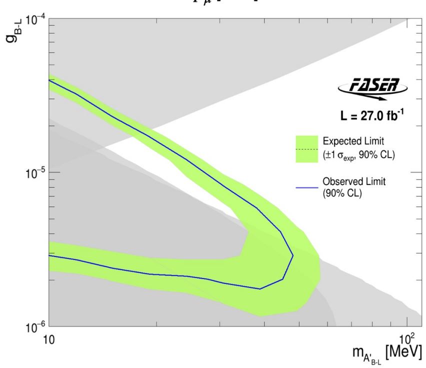
- An exciting year for FPF pathfinder experiments. Some highlights:
  - First Direct Observation of Collider Neutrinos with FASER at the LHC, PRL, 2303.14185
  - Observation of Collider Muon Neutrinos with SND@LHC, PRL, 2305.09383
  - Search for Dark Photons at FASER, CERN-FASER-CONF-2023-001, PLB, 2308.05587
  - Observation of High-Energy Electron Neutrinos with FASERν, CERN-FASER-CONF-2023-002
  - Search for U(1)B-L Gauge Bosons at FASER, PLB, 2308.05587
  - First Measurement of the ν_e and ν_μ Interaction Cross Sections at the LHC with FASERν, 2403.12520
  - Much more to come – see Aspen, Moriond EW, and Moriond QCD talks this week and next week.

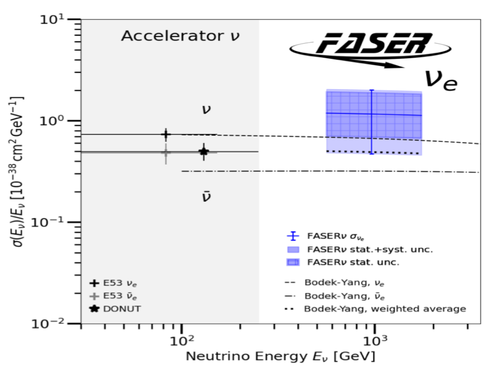


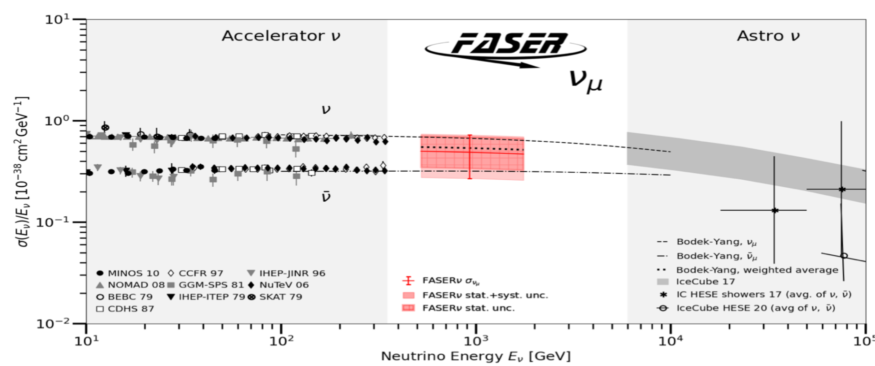










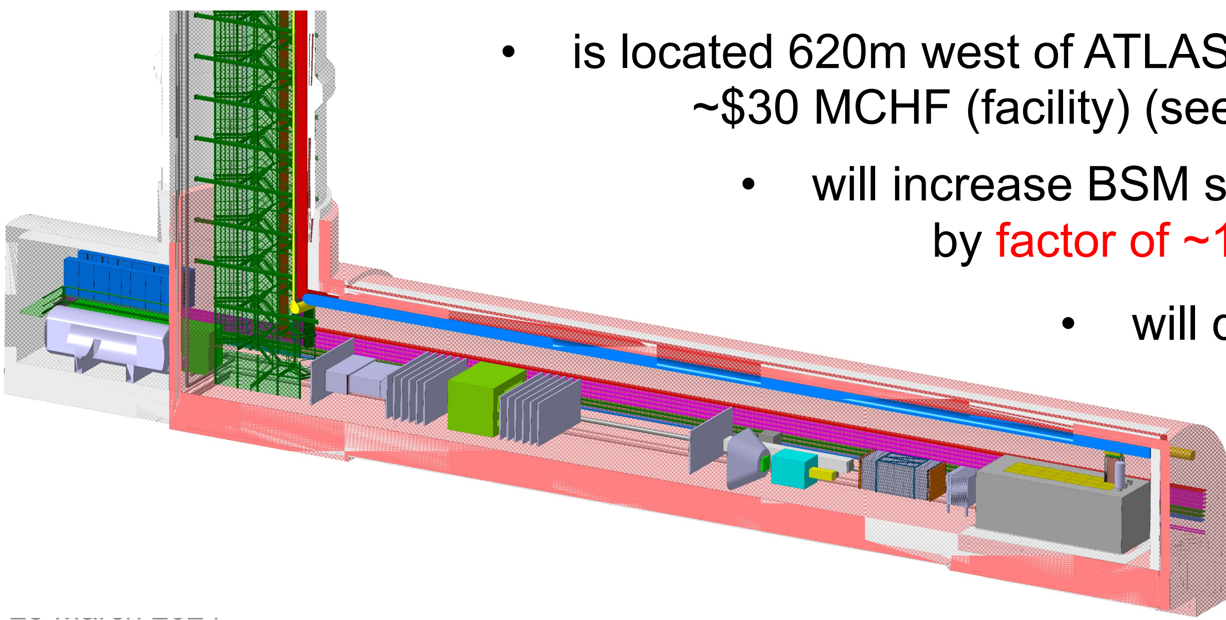


FORWARD PHYSICS FACILITY

- These experiments have demonstrated the ability to detect thousands of TeV neutrinos and carry out background-free BSM searches with tabletop-size far-forward experiments on time and on budget.
- They have opened a new window at the energy frontier.
- Similar to the discovery of cosmic neutrinos or gravitational waves, the appropriate question is not whether we should follow up on these discoveries, but how can we best exploit this new way of learning about the Universe.

The proposed Forward Physics Facility at the HL-LHC

- is located 620m west of ATLAS, 75m long, 12.5m wide, ~$30 MCHF (facility) (see J. Boyd's talk)
- will increase BSM sensitivity (decay vol * lumi) by factor of ~10,000 over FASER
- will detect ~1000 TeV-energy neutrinos *per day*



FPF PHYSICS PROGRAM

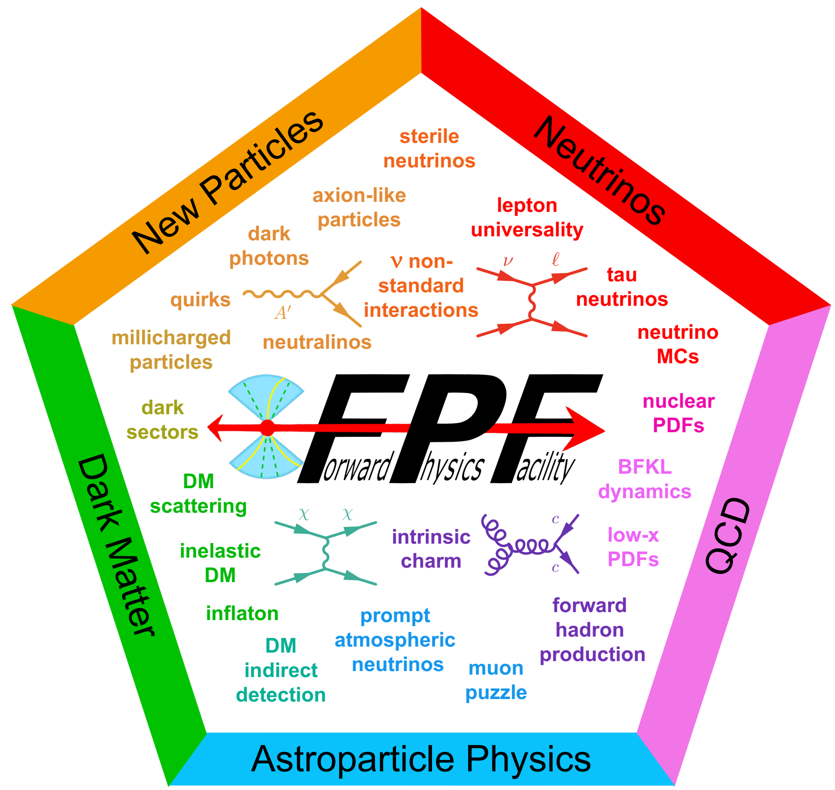
- The FPF physics program is extremely broad, impacting almost every area of particle and astroparticle physics.

- FPF experiments have discovery potential in every one of the PBC benchmark scenarios. These have been useful in comparing different experiments.

- But they do not span the full range of BSM possibilities, and they do not come close to capturing the breadth of the FPF physics program (cf. mSUGRA in SUSY).

- Below are a few generic examples (one PBC benchmark, two not) of the FPF physics potential that make essential use of LHC energies and demonstrate the complementarity to the rest of the worldwide program (e.g., fixed target experiments like SHiP).

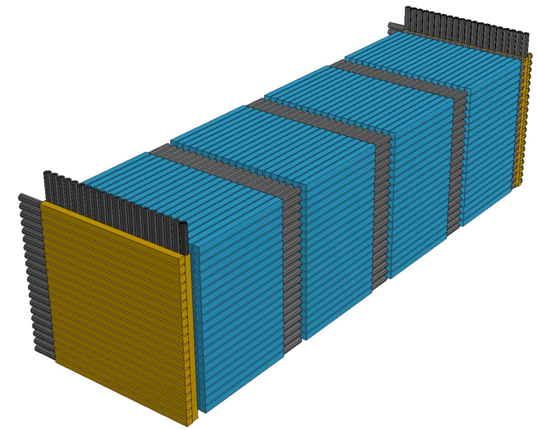
- For more, see J. Rojo's talk, and also the FPF White Paper.



MILLI-CHARGED PARTICLES

- The FPF accommodates a suite of experiments that can be optimized for various physics cases. This diversity is essential in probing a broad range of BSM physics possibilities.

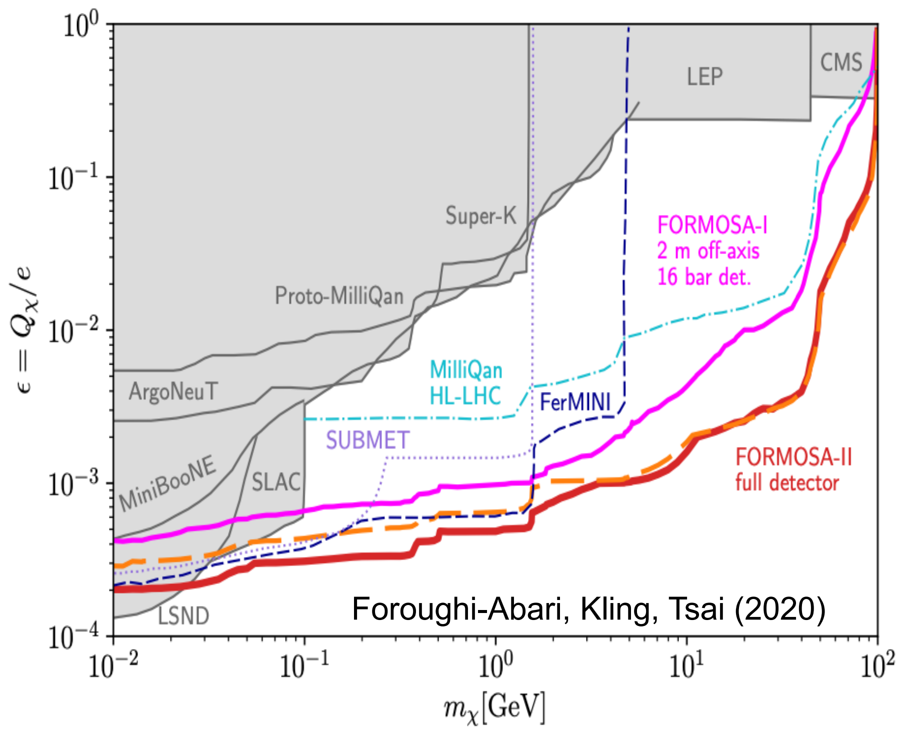
- For example: FORMOSA, targeting milli-charged particles.



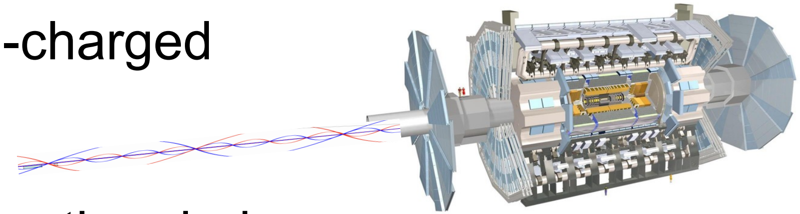
- Motivated by dark sectors with massless dark photons, but also new particles with magnetic or electric dipole moments, …

- World-leading sensitivity for masses from ~100 MeV to 100 GeV.

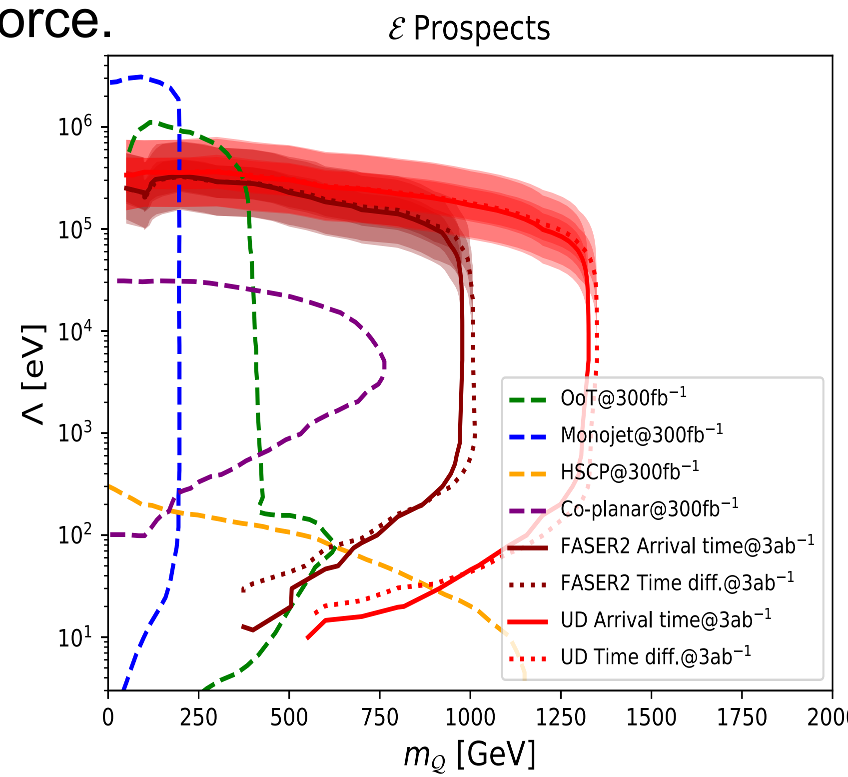
- Will not be probed by SHiP (and no fixed target experiment can produce particles with mass > 10-20 GeV).



STRONGLY-INTERACTING DARK SECTORS



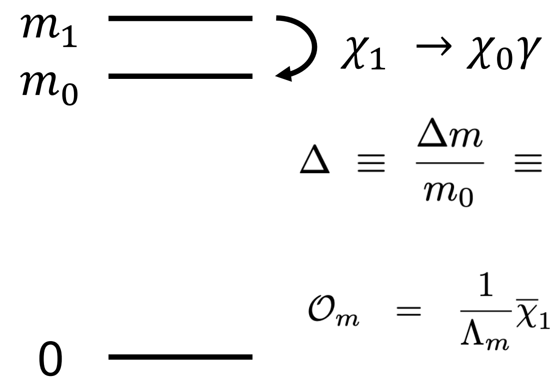
- U(1) dark force → dark photons, milli-charged particles.
- Any other dark force → strongly-interacting dark sector. Dark particles (“quirks”) can be pair-produced at the LHC, but then oscillate down the beampipe, bound together by the dark color force.
- FASER2 can discover quirks with masses up to ~TeV, as motivated by the gauge hierarchy problem (neutral naturalness).
- Requires LHC energies to produce new TeV particles, impossible to see at fixed target experiments.



Li, Pei, Ran, Zhang (2021); Li et al. (in progress)

LLPS FROM COMPRESSED SPECTRA

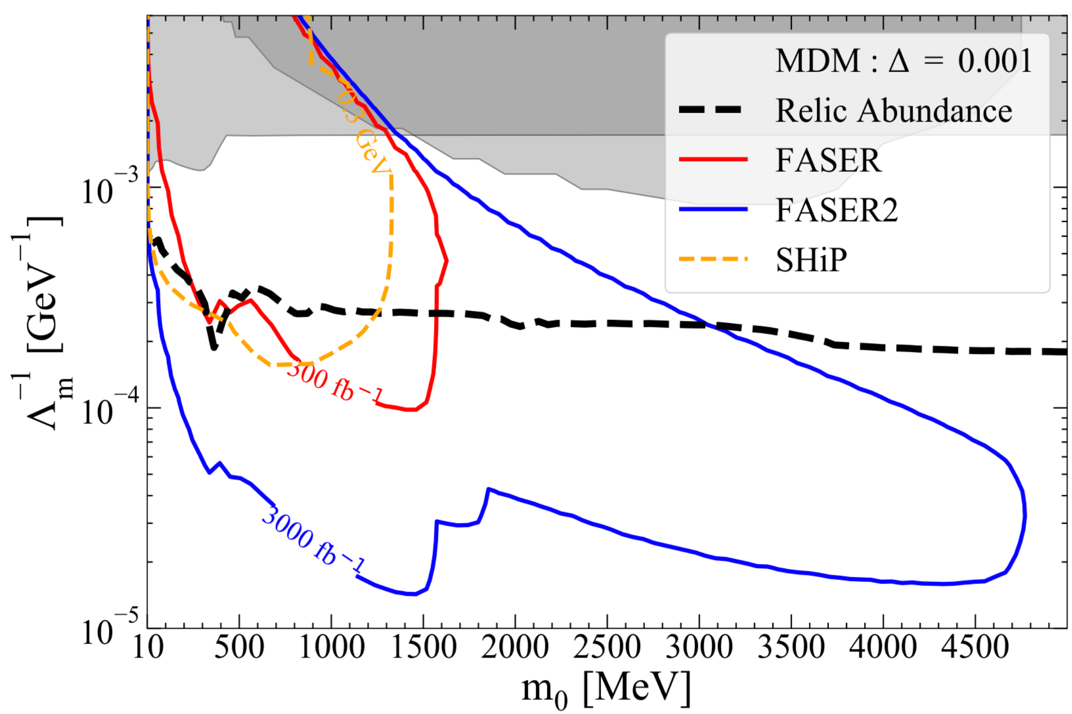
- LLPs can result from weak couplings.
- But they can also arise generically from compressed spectra (e.g., inelastic DM), where decays are phase-space suppressed by degeneracies.



$$\Delta \equiv \frac{\Delta m}{m_0} \equiv \frac{m_1 - m_0}{m_0}$$

$$\mathcal{O}_m = \frac{1}{\Lambda_m} \overline{\chi}_1 \sigma^{\mu\nu} \chi_0 F_{\mu\nu}$$

- In this case, decays $\chi_1 \to \chi_0 \gamma$ lead to very soft photons that can be difficult to detect.
- But these are boosted at the LHC by $\gamma \sim 1000$, FASER2 can detect GeV particles with even ~MeV mass splittings, thermal relic target.
- Difficult at SHiP (sensitivity contour assumes E_γ threshold of 300 MeV, 2 10^{20} POT).



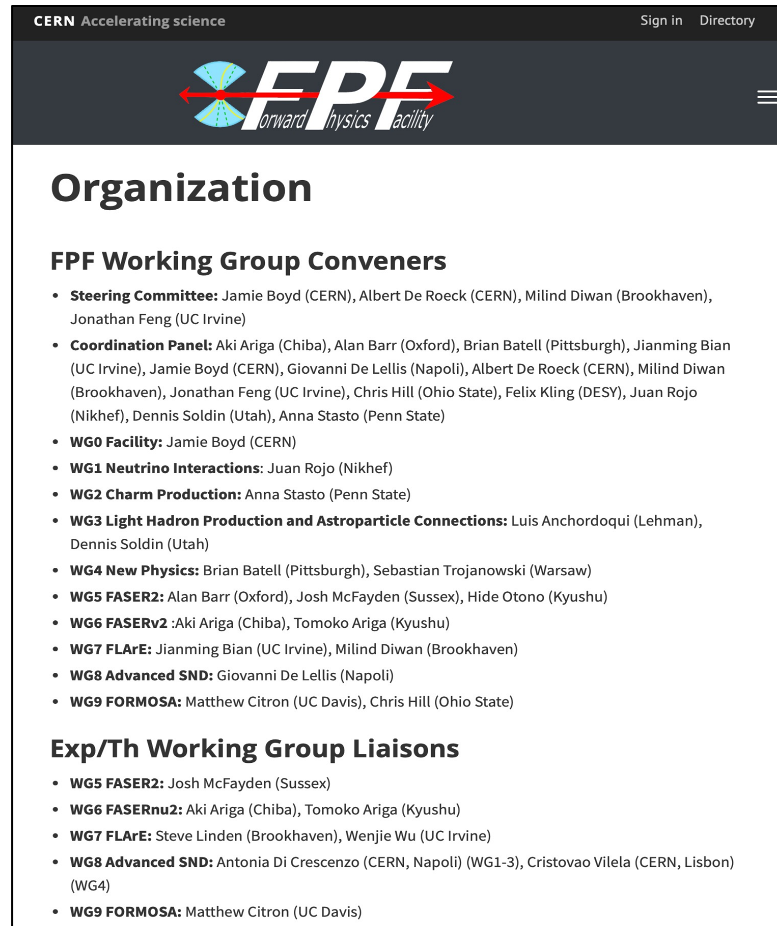
Dienes et al. (2023)

FPF ORGANIZATION

- The FPF activities are organized into 10 WGs consisting of ~300 experimentalists on pathfinder experiments, ~200 theorists, and multiple CERN technical teams, with active exp/th interactions and optimization between experiments. For more, see fpf.web.cern.ch.

- FPF Meetings
  - FPF Kickoff Meeting, 9-10 Nov 2020
  - FPF2 Meeting, 27-28 May 2021
  - FPF3 Meeting, 25-26 Oct 2021
  - FPF4 Meeting, 31 Jan-1 Feb 2022
  - FPF5 Meeting, 15-16 Nov 2022
  - FPF6 Meeting, 8-9 Jun 2023
  - FPF Theory Workshop, 19-20 Sep 2023
  - FPF7 Meeting, 29 Feb-1 Mar 2024

- FPF Papers
  - FPF "Short" Paper: 75 pages, 80 authors, Phys. Rept. 968, 1 (2022), 2109.10905.
  - FPF White Paper: 429 pp, 392 authors + endorsers representing over 200 institutes, J. Phys. G 3, 030501 (2023), 2203.05090.


CERN Accelerating science   Sign in   Directory

Forward Physics Facility

Organization

FPF Working Group Conveners

- **Steering Committee:** Jamie Boyd (CERN), Albert De Roeck (CERN), Milind Diwan (Brookhaven), Jonathan Feng (UC Irvine)
- **Coordination Panel:** Aki Ariga (Chiba), Alan Barr (Oxford), Brian Batell (Pittsburgh), Jianming Bian (UC Irvine), Jamie Boyd (CERN), Giovanni De Lellis (Napoli), Albert De Roeck (CERN), Milind Diwan (Brookhaven), Jonathan Feng (UC Irvine), Chris Hill (Ohio State), Felix Kling (DESY), Juan Rojo (Nikhef), Dennis Soldin (Utah), Anna Stasto (Penn State)
- **WG0 Facility:** Jamie Boyd (CERN)
- **WG1 Neutrino Interactions**: Juan Rojo (Nikhef)
- **WG2 Charm Production:** Anna Stasto (Penn State)
- **WG3 Light Hadron Production and Astroparticle Connections:** Luis Anchordoqui (Lehman), Dennis Soldin (Utah)
- **WG4 New Physics:** Brian Batell (Pittsburgh), Sebastian Trojanowski (Warsaw)
- **WG5 FASER2:** Alan Barr (Oxford), Josh McFayden (Sussex), Hide Otono (Kyushu)
- **WG6 FASERv2** :Aki Ariga (Chiba), Tomoko Ariga (Kyushu)
- **WG7 FLArE:** Jianming Bian (UC Irvine), Milind Diwan (Brookhaven)
- **WG8 Advanced SND:** Giovanni De Lellis (Napoli)
- **WG9 FORMOSA:** Matthew Citron (UC Davis), Chris Hill (Ohio State)

Exp/Th Working Group Liaisons

- **WG5 FASER2:** Josh McFayden (Sussex)
- **WG6 FASERnu2:** Aki Ariga (Chiba), Tomoko Ariga (Kyushu)
- **WG7 FLArE:** Steve Linden (Brookhaven), Wenjie Wu (UC Irvine)
- **WG8 Advanced SND:** Antonia Di Crescenzo (CERN, Napoli) (WG1-3), Cristovao Vilela (CERN, Lisbon) (WG4)
- **WG9 FORMOSA:** Matthew Citron (UC Davis)

SNOWMASS AND P5 PROCESS

- In the US, particle physics priorities are established in a two-step process, most recently consisting of Snowmass from 2020-22 and P5 from 2022-23.

- "Our highest immediate priority accelerator and project is the HL-LHC, …including the construction of auxiliary experiments that extend the reach of HL-LHC in kinematic regions uncovered by the detector upgrades." – 2022 Snowmass Energy Frontier Report

- P5 was then convened to prioritize medium-scale ($50-250M) and large-scale (>$250M) projects. Small-scale projects are not discussed individually and not explicitly recommended by P5.

- The FPF proposal to P5 was for a medium-scale project supporting FASER2 (1/2), FORMOSA, and FLArE, under the assumption that CERN would build the facility as host lab, and other nations/regions would fund FASER2 (1/2), FASERnu2, and AdvSND.

P5 REPORT

- P5 decided that they could not recommend funding given that CERN has approved the Facility.
- The “FPF trio” was given N#’s, where # indicates that “can be considered as part of ASTAE with reduced scope.”
- ASTAE is a new small projects portfolio recommended to be funded at $35M/year.
- FASER2 and FORMOSA fit as is; FLArE will benefit from international partners to reduce the US cost.
- P5’s Summary (20-year Vision): “The program described in this section consists of a combination of large and small projects and holds great promise for discovery. By the end of this 20-year period we will have ultimate LHC results from the general purpose experiments and a constellation of agile auxiliary experiments.”

Figure 2 – Construction in Various Budget Scenarios

Index: Y: Yes N: No R&D: Recommend R&D only C: Conditional yes based on review P: Primary S: Secondary

Delayed: Recommend construction but delayed to the next decade

† Recommend infrastructure support to enable international contributions

Can be considered as part of ASTAE with reduced scope

US Construction Cost	Scenarios: Less	Baseline	More	Science Drivers: Neutrinos	Higgs Boson	Dark Matter	Cosmic Evolution	Direct Evidence	Quantum Imprints	Astronomy & Astrophysics
>$3B										
onshore Higgs factory	N	N	N		P	S		P	P	
$1–3B										
offshore Higgs factory	Delayed	Y	Y		P	S		P	P	
ACE-BR	R&D	R&D	C	P				P	P	
$400–1000M										
CMB-S4	Y	Y	Y	S		S	P			P
Spec-S5	R&D	R&D	Y	S		S	P			P
$100–400M										
IceCube-Gen2	Y	Y	Y	P		S				P
G3 Dark Matter 1	Y	Y	Y	S		P				
DUNE FD3	Y	Y	Y	P				S	S	S
test facilities & demonstrator(s)	C	C	C		P	P		P	P	
ACE-MIRT	R&D	Y	Y	P						
DUNE FD4	R&D	R&D	Y	P				S	S	S
G3 Dark Matter 2	N	N	Y	S		P				
Mu2e-II	R&D	R&D	R&D						P	
srEDM	N	N	N						P	
$60–100M										
SURF expansion	N	Y	Y	P		P				
DUNE MCND	N†	Y	Y	P				S	S	
MATHUSLA	N#	N#	N#			P		P		
FPF trio	N#	N#	N#	P		P		P		

FPF TIMELINE

- In June 2023, CERN management and the LHCC and PBC conveners agreed on a review timeline for the FPF.

- August 2023 – Early 2024
  - Core study results.
  - A document summarizing the core study results, additional facilities updates, revised estimate for CERN host lab costs.
  - A unified plan for size and placement of experiments in the cavern.
  - Completion of “flagship” physics studies that emphasize core strengths and also complementarity with the rest of the world-wide program.

- June 2024: Document on the Facility (CE and Integration) to be submitted to the PBC.

- Early 2025: LOI to be submitted to the LHCC.

- With this timeline, and with successful following reviews and approval, aim for construction in time for physics in Run 4.