# Table of Contents

Welcome to the FASER Webpage ............................................................................................................................ 1
  FASER in a Nutshell........................................................................................................................................... 1
  Introduction..................................................................................................................................................... 1
  Location.......................................................................................................................................................... 2
  Signals, Detector Design and Backgrounds................................................................................................. 3
  Detailed Detector Design ............................................................................................................................. 3
  Discovery Prospects for FASER .................................................................................................................. 4
  Timeline and Detector Benchmarks .......................................................................................................... 6

Additional Resources ....................................................................................................................................... 6
  FASER Publications ................................................................................................................................. 6
  Papers about FASER ............................................................................................................................... 6
  Presentations about FASER .................................................................................................................... 6
  Press about FASER ............................................................................................................................... 6
  Meetings, Conferences, Workshops ....................................................................................................... 7
  Photos and Pictures ............................................................................................................................... 8

FASER Management ....................................................................................................................................... 8
  Contact ...................................................................................................................................................... 8
  FASER Web Utilities ............................................................................................................................... 9
FASER (ForwArd Search ExpeRiment at the LHC) is a proposed experiment to be situated 480m along the line-of-sight of the proton collisions in front of the ATLAS interaction point at the LHC. Preliminary studies show that a small experiment at this location has significant prospects for discovering a variety of light, weakly-coupled new particles, such as dark photons, dark Higgs bosons, heavy neutral leptons (sterile neutrinos), and axion-like particles, which could be produced in the decay of particles produced in the LHC collisions, or in the interaction of these particles with material. The FASER experiment is part of the CERN Physics Beyond Colliders study group.

The FASER Letter of Intent (sent to the LHCC in July 2018) is available on CDS and arxiv. (The LHCC minutes related to this document are available here.)

The FASER Technical Proposal (sent to the LHCC in November 2018) is available on CDS and arxiv. (The LHCC minutes related to this document are available here, and the minutes from the corresponding discussion at the CERN Research Board are here (section 3.7).)

FASER was approved by the CERN Research Board on March 5th 2019.

For the internal FASER site (protected), please follow this link: InternalFaserSite.

FASER in a Nutshell

Introduction

For decades, the leading examples of physics beyond the standard model were particles with TeV-scale masses and O(1) couplings to the standard model (SM). More recently, however, there is a growing and complementary interest in new particles that are much lighter and more weakly-coupled. Among their many motivations, such particles may yield dark matter with the correct thermal relic density and resolve outstanding discrepancies between theory and low-energy experiments. Perhaps most importantly, new particles that are light and weakly-coupled can be discovered by relatively inexpensive, small, and fast experiments with potentially revolutionary implications for particle physics and cosmology.

If new particles are light and very weakly coupled, the focus at the LHC on searches for new particles at high pT may be completely misguided. In contrast to TeV-scale particles, which are produced more or less isotropically, light particles with masses in the MeV-GeV range are dominantly produced at low pT. In addition, because the new particles are extremely weakly coupled, very large standard model event rates are required to discover the rare new physics events. These rates are not available at high pT, but they are available at low pT: at the 13 TeV LHC, the total inelastic pp scattering cross section is \( \sigma_{\text{inel}}(13 \text{ TeV}) \approx 75 \text{ mb} \), with most of it in the very forward direction. This implies inelastic pp scattering events for an integrated luminosity of 300 fb\(^{-1}\) at the LHC (3 ab\(^{-1}\) at the HL-LHC). Even extremely weakly-coupled new particles may therefore be produced in sufficient numbers in the very forward region. Due to their weak coupling to the SM, such particles are typically long-lived and travel a macroscopic distance before decaying back into SM particles. Moreover, such particles may be highly collimated. For example, new particles that are produced in pion or B-meson decays are typically produced within angles of...
\[ \frac{QCD}{E} \text{ or } \frac{m_B}{E} \text{ of the beam collision axis, where } E \text{ is the energy of the particle. For } E \sim \text{ TeV, this implies that even } \sim 500 \text{m downstream, such particles have only spread out } \sim 10 \text{ cm} - 1 \text{ m in the transverse plane. A small and inexpensive detector placed in the very forward region may therefore be capable of extremely sensitive searches, provided a suitable location can be found and the signal can be differentiated from the SM background.}

FASER, the ForwArd Search ExpeRiment, is an experiment designed to take advantage of this opportunity. It is a small detector, with volume \sim 1 \text{ m}^3, that will be placed along the beam collision axis, several hundreds of meters downstream from the ATLAS or CMS interaction point (IP).

**Location**

![FASER Location Map](image1)

Figure 1: Left panel: Map showing the proposed location of FASER in the TI12 tunnel. FASER's location is 480 m away from the ATLAS interaction point on the beam collision axis, after the LHC ring starts to curve. Right panel: A model of the FASER detector situated at the proposed location in the TI12 tunnel.

![FASER Schematic](image2)

Figure 2: A schematic drawing of the LHC and the very forward infrastructure downstream from the ATLAS interaction point.

As shown in Fig. 1, FASER will be placed along the beam collision axis, in the side tunnel TI12, 480m downstream from the ATLAS IP after the LHC tunnel starts to curve. (A symmetric location on the other side of ATLAS in tunnel TI18 has also been considered.) The TI12 tunnel was formerly used to connect the SPS to the LEP tunnel, but is currently empty and unused. As shown schematically in Fig. 2, the beam collision axis passes through TI12 close to where it merges with the main LHC tunnel. A more detailed study of the intersection between the beam collision axis and TI12 verifies that there exists space for FASER in the tunnel. Because of the geometry of the tunnel, the line-of-sight (LOS) is below the tunnel floor as it enters the tunnel, and then emerges from the floor. Measurements from the CERN survey team show that, with the allowed digging that can be done in Long Shutdown 2 (LS2), a roughly 5 m-long detector can be fit in TI12 (see Fig. 1 right).

In this location, FASER harnesses the enormous, previously "wasted," cross section for very forward physics (\sim 100 \text{ mb}), which implies that even very weakly-coupled new particles can be produced in large numbers.
at the LHC. In addition, the production of long-lived particles (LLPs) at high center-of-mass energy results in long propagation distances $d \sim O(100)$ m and decays that are far beyond the main LHC infrastructure in regions where the backgrounds are expected to be negligible.

**Signals, Detector Design and Backgrounds**

FASER will search for LLPs that are produced at or close to the IP, move along the beam collision axis, and decay within the volume of FASER into visible decay products.

LLPs produced in the very forward region of the beam collision axis typically have very high energies $E \sim \text{TeV}$. Although the identity of the LLP decay products depends on the mass of the LLP and the concrete new physics model, a characteristic signature is expected of two or more stable charged particles, such as electrons, muons or pions. This leads to a striking signature at FASER: two oppositely charged tracks with very high energy that emanate from a vertex inside the detector and which have a combined momentum that points back to the IP. A measurement of individual tracks with sufficient resolution and an identification of their charges is therefore imperative if the apparatus is to make use of kinematic features to distinguish signal from background. A tracking-based technology, supplemented by a magnet and possibly a calorimeter to allow for an energy measurement, will be the key components of FASER.

The FASER signals are two extremely energetic ($\sim \text{TeV}$) coincident tracks or photons that start at a common vertex and point back to the ATLAS IP. Muons and neutrinos are the only known particles that can transport such energies through 90 m of rock between the IP and FASER. Estimates based on detailed simulations and in-situ measurements show that muon-associated radiative processes and neutrino-induced backgrounds may be reduced to negligible levels.

FLUKA simulation study from the CERN Sources, Targets and Interactions group has been carried out to assess possible backgrounds and the radiation level in the FASER location. The study shows that no high energy (>100 GeV) particles are expected to enter FASER from proton showers in the dispersion suppressor or from beam-gas interactions. In addition, the radiation level expected at the FASER location is very low due to the dispersion function in the LHC cell closest to FASER.

To measure particle fluxes at FASER's location, emulsion detectors were placed in the TI12 tunnel, as well as in the symmetric tunnel TI18 on the other side of the ATLAS IP beginning from June 2018. The collected data correspond to the total integrated luminosity of about 10 fb$^{-1}$. The first analyses show that in situ measurements agree well with the FLUKA simulation given the uncertainties in the detection efficiency and uncertainty in the simulations. The results of the measurements will be further analyzed and will complement and validate the background estimates and inform future work, which includes refining background estimates, evaluating signal efficiencies, and optimizing the detector.

**Detailed Detector Design**

To be sensitive to the many possible forms of light, weakly-interacting particles, and to differentiate signal from background, the FASER detector has several major components. These components and the detector layout are shown in Fig. 5.
Figure 3: Layout of the FASER detector. LLPs enter from the left and the entire length of the detector is roughly 5 m. The detector components include scintillators (gray), dipole magnets (red), tracking stations (blue), a calorimeter (dark purple), and support structures (green).

Particles produced at the ATLAS IP enter the detector from the left. At the entrance to the detector is a double layer of scintillators (gray) to veto charged particles coming through the cavern wall from the IP, primarily high-energy muons. Between the scintillation layers is a 20-radiation-lengths-thick layer of lead that converts photons produced in the wall into electromagnetic showers that can be efficiently vetoed by the scintillators.

The veto layer is followed by a $\Delta = 1.5$ m long, 0.6 T permanent dipole magnet (red) with a $R = 10$ cm aperture radius. Such permanent magnets take up relatively little space and, unlike electromagnets, do not require high voltage power and cooling. The cylindrical volume enclosed by this magnet serves as the decay volume for the light, weakly-interacting particles, with the magnet providing a horizontal kick to separate oppositely-charged particles to a detectable distance.

Next is a spectrometer consisting of two 1 m-long, 0.6 T dipole magnets with three tracking stations (blue), each composed of layers of precision silicon strip detectors located at either end and in between the magnets. The primary purpose of the spectrometer is to observe the characteristic signal of two oppositely charged particles pointing back towards the IP, measure their momenta, and sweep out low-momentum charged particles before they reach the back of the spectrometer. Scintillator planes (gray) for triggering and precision time measurements are located at the entrance and exit of the spectrometer.

The final component is an electromagnetic calorimeter (purple) to identify high energy electrons and photons and measure the total electromagnetic energy. As the primary signals are two close-by electrons or photons, these cannot be resolved by the calorimeter.

**Discovery Prospects for FASER**
In previous work, we studied FASER’s potential to detect several popular models for light long-lived particles with significant overlap with the benchmark models defined by the CERN Physics Beyond Colliders (PBC) study group. Combined, these studies established the significant potential for FASER to extend the LHC’s discovery reach. In particular, we have analyzed models with renormalizable portals: dark photons, dark Higgs bosons, heavy neutral leptons (HNLs), where the new physics couples to the SM through dimension-4 interactions:

\[ \mathcal{L} \supset \frac{g_{\phi}^2}{4} \phi^\dagger \phi \mathcal{O} \]

The physics reach at FASER for these models is shown in Fig. 4. Here we assume that backgrounds can be reduced to negligible levels. The gray-shaded regions of parameter space have already been excluded by previous experiments. For comparison we also show the projected reaches of other proposed experiments that search for long-lived particles.

Dark photons (left) are mainly produced in the decay of light mesons or via dark bremsstrahlung and are therefore very collimated around the beam collision axis. Already a very small detector with radius \( R = 10 \) cm and length \( \Delta = 1.5 \) m is able to probe large and unconstrained regions of parameter space, making dark photons an ideal short term goal for FASER. In contrast, dark Higgs bosons and HNLs define a good long term physics goal. They are both mainly produced in heavy meson decays, leading to a larger spread around the beam collision axis. A larger, but still relatively small, detector with \( R \sim 1 \) m is then required to exploit the full potential of FASER.

Note that FASER’s physics potential is not restricted to the models mentioned above. It has been shown that FASER can probe axion-like particles, flavor-specific scalar mediators, inelastic dark matter, neutralinos and \( U(1)_{B-L} \)-gauge bosons. Additionally, studies for FASER’s potential to discover strongly interacting massive particles are underway.

Importantly, FASER will start probing unexcluded region of the parameter space of popular models with light long-lived particles immediately after the beginning of the LHC Run 3. In particular, in Fig. 5 below we show the FASER sensitivity reach in searches for dark photons and axion-like particles with dominant diphoton coupling that correspond to only 10 fb\(^{-1}\) of the integrated luminosity and compare it with the expected sensitivity for 150 fb\(^{-1}\) obtained during Run 3 from 2021-23.
Timeline and Detector Benchmarks

The proposed timeline is for FASER to be installed in TI12 during Long Shutdown 2 (LS2), in time to collect data during Run 3 of the 14 TeV LHC from 2021-23. FASER's cylindrical active decay volume has a radius $R = 10$ cm and depth $D = 1.5$ m, and the detector's total length is under 5 m. FASER will run concurrently with the LHC and require no beam modifications. Its interactions with existing experiments are limited only to requiring bunch crossing timing and luminosity information from ATLAS.

If FASER is successful, a larger version, FASER 2, with an active decay volume with $R = 1$ m and $D = 5$ m, could be installed during LS3 and take data in the 14 TeV HL-LHC era. FASER 2 would require extending TI12 or widening the adjacent staging area UJ12.

If you are interested in studying FASER's physics potential, please consider the following two benchmark geometries for FASER's decay volume:

Please also contact a FASER theorist - we are happy to assist and answer your questions.

Additional Resources

FASTER Publications

- Letter of Intent, arxiv:1811.10243
- Technical Proposal, arxiv:1812.09139
- FASER's Physics Reach for Long-Lived Particles, arxiv:1811.12522
- Input to the European Strategy for Particle Physics Update, arxiv:1901.04468

Papers about FASER

- Dark Higgs Bosons at FASER, arxiv:1710.09387, Jonathan L. Feng, Iftah Galon, Felix Kling, Sebastian Trojanowski
- Flavor-Specific Scalar Mediators, arxiv:1712.10022, Brian Batell, Ayres Freitas, Ahmed Ismail, David McKeen
- Heavy Neutral Leptons at FASER, arxiv:1801.08947, Felix Kling, Sebastian Trojanowski
- Heavy Neutral Fermions at the High-Luminosity LHC, arxiv:1803.02212, Juan Carlos Helo, Martin Hirsch, Zeren Simon Wang
- Hunting All the Hidden Photons, arxiv:1803.05466, Martin Bauer, Patrick Foldenauer, Joerg Jaeckel
- ALPs at FASER: The LHC as a Photon Beam Dump, arxiv:1806.02348, Jonathan L. Feng, Iftah Galon, Felix Kling, Sebastian Trojanowski
- R-parity Violation and Light Neutralinos at CODEX-b, FASER, and MATHUSLA, arxiv:1810.03617, Daniel Dercks, Jordy de Vries, Herbi K. Dreiner, Zeren Simon Wang

Presentations about FASER

- FASER: ForwArd Search ExpeRiment at the LHC, Felix Kling, Second Workshop of The LHC LPP community, Trieste, October 19th 2017
FASER: ForwArd Search ExpeRiment at the LHC, Felix Kling, SLAC EPP Theory Seminar, 16 February 2018

FASER and Other Outposts on the Lifetime Frontier, Jonathan Feng, KITP, Santa Barbara, 9 April 2018

Exploring dark sectors at FASER: ForwArd Search ExpeRiment at the LHC, Iftah Galon, APS Meeting, 14 April 2018

FASER: ForwArd Search ExpeRiment at the LHC, Felix Kling, Pheno 2018, 8 May 2018

FASER, Jamie Boyd, LPCC LLP workshop, CERN, 18 May 2018

FASER, Jamie Boyd, Accelerator session, Physics Beyond Colliders Workshop, 13 June 2018

FASER, Jonathan Feng, BSM session, Physics Beyond Colliders Workshop, 14 June 2018

FASER, Sebastian Trojanowski, workshop: New Physics with Displaced Vertices, Hsinchu, Taiwan, 21 June 2018

FASER-COSMO-18, Sebastian Trojanowski, COSMO-18 conference, Daejeon, 29 August 2018

FASER, Shih-Chieh Hsu, Searching for long-lived particles at the LHC: Fourth workshop of the LHC LLP Community, Amsterdam, 24 October 2018

FASER Proposal (video at 3:03), Jamie Boyd, 136th LHCC Open session, 28 November 2018

FASER: ForwArd Search ExpeRiment at the LHC, Felix Kling, High Energy Theory Seminar, Brookhaven National Lab, 28 November 2018

Looking forward to new physics with FASER: ForwArd Search ExpeRiment at the LHC, Sebastian Trojanowski, workshop of the LHC Working Group on Forward Physics and Diffraction, CERN, 18 December 2018

FASER presentation, Felix Kling, BSM session of PBC workshop, CERN, 16 January 2019

FASER presentation, Jamie Boyd, accelerator session of PBC workshop, CERN, 17 January 2019

DPNC Seminar, Jamie Boyd, University of Geneva, 27 February 2019

LHCC Poster Session - The FASER Experiment, Friedemann Neuhaus, CERN, 27 February 2019

FASER, Sebastian Trojanowski, DMUK meeting, King's College London, 11 April 2019

Press about FASER

FASER: CERN approves new experiment to look for long-lived, exotic particles, CERN, 5 March 2019

CERN approves UCI-initiated hunt for new particles at the Large Hadron Collider, UC Irvine, 5 March 2019

FASER detector at the Large Hadron Collider to seek clues about hidden matter in the universe, University of Washington, 5 March 2019

A tiny new experiment at the LHC, Symmetry Magazine, 5 March 2019

Heising-Simons Foundation press release, 6 March 2019

Simons Foundation press release, 6 March 2019

A small detector could strike big in the search for dark matter, Physics Today, 20 March 2019

Meetings, Conferences, Workshops

Searching for Long-Lived Particles at the LHC: Third Workshop of the LHC LLP Community, CERN, 16-18 May 2018

Physics Beyond Colliders Working Group Meeting, CERN, 13-14 June 2018

Workshop: New Physics with Displaced Vertices, Hsinchu, Taiwan, 20-22 June 2018

Workshop on Long-Lived Particle Searches at Various Energy Scales, Tokyo, 18 September 2018

Searching for Long-Lived Particles at the LHC: Fourth Workshop of the LHC LLP Community, Amsterdam, 23-25 October 2018

136th LHCC Meeting, CERN, 28-29 November 2018

Workshop of the LHC Working Group on Forward Physics and Diffraction, CERN, 18-19 December 2018

Physics Beyond Colliders Working Group Meeting, CERN, 16-17 January 2019
Photos and Pictures

• Photos

![Photos](image1.png)

• Line of Sight Maps

![Line of Sight Maps](image2.png)

• Schematics of the Detector

![Schematics of the Detector](image3.png)

FASER Management

• Spokespersons: Jonathan Feng (UC Irvine), Jamie Boyd (CERN)
• Collaboration Board Chair: Peppe Iacobucci (Geneva)

Contact

FASER Active members:

• Claire Antel (Geneva, experimentalist)
• Akitaka Ariga (Bern, experimentalist)
• Tomoko Ariga (Kyushu/Bern, experimentalist)
• Jamie Boyd (CERN, experimentalist) (contact with PBC accelerator group)
• Dave Casper (UC Irvine, experimentalist)
• Franck Cadoux (Geneva, experimentalist)
• Xin Chen (Tsinghua, experimentalist)
• Andrea Coccaro (INFN, experimentalist)
• Canan Dozen (Tsinghua, experimentalist)
• Yannick Favre (Geneva, experimentalist)
• Jonathan Feng (UC Irvine, theorist) (contact with PBC BSM group)
• Didier Ferrere (Geneva, experimentalist)
• Ifah Galon (Rutgers, theorist)
• Sergio Gonzalez-Sevilla (Geneva, experimentalist)
• Shih-Chieh Hsu (Washington, experimentalist)
• Zhen Hu (Tsinghua, experimentalist)
• Peppe Iacobucci (Geneva, experimentalist)
• Sune Jakobsen (CERN, experimentalist)
• Roland Jansky (Geneva, experimentalist)
• Enrique Kajomovitz (Technion, experimentalist)
• Felix Kling (UC Irvine, theorist)
• Susanne Kuehn (CERN, experimentalist)
• Lorne Levinson (Weizmann, experimentalist)
• Josh McFayden (CERN, experimentalist)
• Friedemann Neuhaus (Mainz, experimentalist)
• Hidetoshi Otono (Kyushu, experimentalist)
• Lorenzo Paolozzi (Geneva, experimentalist)
• Brian Petersen (CERN, experimentalist)
• Osamu Sato (Nagoya, experimentalist)
• Matthias Schott (Mainz, experimentalist)
• Anna Sfyrla (Geneva, experimentalist)
• Savannah Shively (UC Irvine, experimentalist)
• Jordan Smolinsky (UC Irvine, theorist)
• Aaron Soffa (UC Irvine, experimentalist)
• Yosuke Takubo (KEK, experimentalist)
• Eric Torrence (Oregon, experimentalist)
• Sebastian Trojanowski (Sheffield/Warsaw, theorist)
• Gang Zhang (Tsinghua, experimentalist)

Administrative support is provided by Veronique Wedlake from the CERN, EP Secretariat.

**FASER Web Utilities**

- advanced search
- WebTopicList - all topics in alphabetical order
- WebChanges - recent topic changes in this web
- WebNotify - subscribe to an e-mail alert sent when topics change
- WebRss, WebAtom - RSS and ATOM news feeds of topic changes
- WebStatistics - listing popular topics and top contributors
- WebPreferences - preferences of this web

This topic: FASER > WebHome
Topic revision: r77 - 2019-04-14 - SebastianTrojanowskiExternal1