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First neutrino interaction candidates at Large Hadron Collider

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The FASERν pilot detector observed the first neutrino interaction candidates at the Large Hadron Collider (LHC), opening a new avenue for studying neutrinos from current and future high-energy colliders.

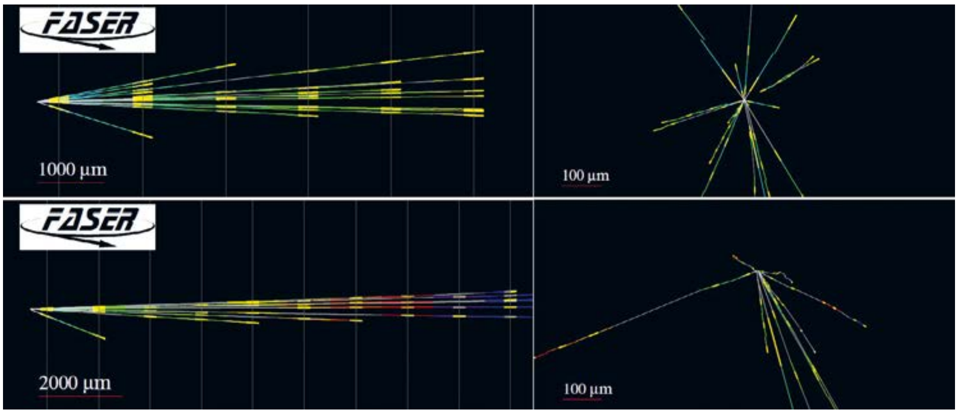
▲ FIG. 1: FASER detector installed inside tunnel shown in upper-left part of photograph.

FASERν

There has been a longstanding interest in studying neutrinos produced at the Large Hadron Collider (LHC), although collider neutrinos have not been directly detected. In Run 3 of the LHC starting from 2022, proton-proton collisions at a center-of-mass energy of 13.6 TeV and with an expected integrated luminosity of 150 fb^{-1} will produce a high-intensity beam of $O(10^{12})$ neutrinos in the far-forward direction with a mean interaction energy of about ~1 TeV. In the ForwArd Search ExpeRiment (FASER) [1], a neutrino detector, called FASERν, was designed to detect these neutrinos and examine their properties [2]. In 2021, the main FASER detector was installed 480 m downstream of the ATLAS interaction point inside tunnel TI12 (Figs. 1 and 2). The FASERν detector, consisting of an emulsion/tungsten detector, a veto detector and an interface silicon detector, is being installed in front of it. Beam exposure and data collection will be conducted from 2022. FASERν is located on the beam collision axis to maximise the interaction rate of the neutrinos of all three flavors, namely ν_e, ν_μ, and ν_τ. This deployment allows FASERν to measure the charged-current interaction cross-sections in the TeV energy range, which is currently unexplored. The FASERν measurements can probe the gap between accelerator measurements (E_ν<360 GeV) [3] and the IceCube data (E_ν>6.3 TeV) [4] for muon neutrinos. For electron and tau neutrinos, the existing cross-section measurements can be extended to significantly higher energy values. In addition to the charged-current interactions, neutral-current interactions can be measured. Such measurements can provide a new limit on the nonstandard interactions of neutrinos to complement existing limits [5]. Furthermore, forward hadron production, which is poorly constrained by other LHC experiments, can be investigated using FASERν. Currently, the uncertainty in forward charm production limits the clarification of the atmospheric neutrino background to astrophysical neutrino observations using neutrino telescopes. FASERν measurements of high-energy electron neutrinos, which mainly originate from charm decays, can provide the first data on high-energy and large-rapidity charm production, providing vital data in a controlled environment for astrophysical neutrino observations.

First neutrino interaction candidates

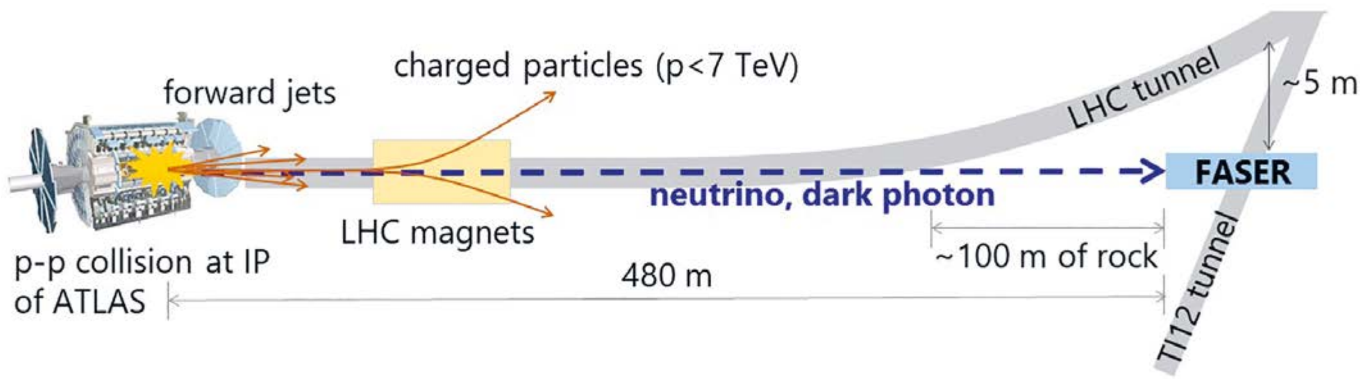
In 2018 during LHC Run 2, a pilot run was performed in the TI18 tunnel of the LHC beamline to demonstrate neutrino detection at the LHC for the first time. The data obtained from the pilot detector were used to prove the feasibility of high-energy neutrino measurements in this experimental environment. The pilot detector was incapable of identifying muons because its depth was only 0.6λ_{int}, significantly shorter than the 8λ_{int} of the full FASERν detector for LHC Run 3. We searched for neutrino interactions by analysing the data corresponding to 11 kg of the target mass. We observed the first candidate events consistent with neutrino interactions, owing to neutrinos from the LHC [6]. Fig. 3 shows two candidate events. A 2.7σ excess of neutrino-like signals over the muon-induced background was measured. These results demonstrate the ability of FASERν to detect neutrinos at the LHC, thus paving the way for future collider neutrino experiments.



▲ FIG. 3: Event displays of two neutrino interaction candidate vertices [6] in y–z projection longitudinal to beam direction (left) and in view transverse to beam direction (right).

Prospects

The preparation of the FASERν detector for obtaining data in LHC Run 3 is underway. With a deeper detector and lepton identification capability, FASERν will perform better than the 2018 pilot detector. In 2022-2024, we expect to record about ~10,000 flavour-tagged charged-current neutrino interactions during LHC Run 3, along with neutral-current interactions. Furthermore, toward the high-luminosity LHC era, we are studying the possibility to conduct the more sensitive experiment (FASERν2) at a proposed facility known as the Forward Physics Facility [7]. ■



▼ FIG. 2: Location of FASER detector.

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