PROCEEDINGS OF SCIENCE

Design and commissioning of the FASER trigger and data acquisition system

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The FASER experiment is a new small and inexpensive experiment that is located 480 meters downstream of the ATLAS experiment at the CERN LHC. The experiment will shed light on currently unexplored phenomena, having the potential to make a revolutionary discovery. FASER is designed to capture decays of exotic particles, produced in the very forward region, beyond the ATLAS detector acceptance. The experiment installation was completed at the end of March 2021 and the experiment is now getting ready for the LHC Run 3 data-taking. This presentation will focus mostly on the trigger and data acquisition (TDAQ) system of the experiment. The TDAQ system is going to combine information from the tracker, scintillators, and calorimeter and will send them to the PC that is going to be located on the ground at the expected physics trigger rate of 650 Hz. The presentation will include information about the commissioning of the system on the ground and in the LHC tunnel as well as it will be presenting various tests performed during the commissioning phase including first test runs using cosmic particles.

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1. Introduction

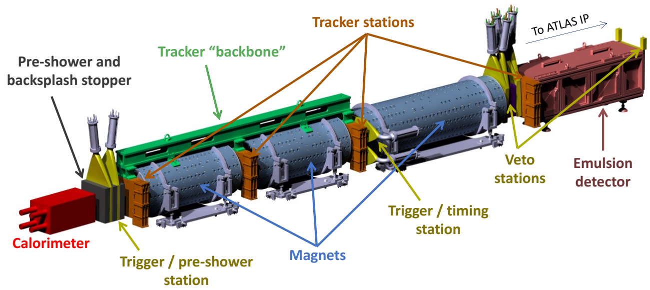

Figure 1: Model of the FASER experiment. Various sub-sytems are highlighted by different colours.

The Large Hadron Collider (LHC) at CERN is unique infrastructure that pushes the frontiers of particle physics. This is possible because of the mutual effort of many physicists participating in experiments using the accelerator, the largest of which are ATLAS and CMS. Despite the fact that these experiments are designed to be able to probe a large spectrum of physics phenomena, there are areas for which they are not well suited. This is the motivation for building complementary new smaller experiments.

Several physics theories propose the existence of new particles in order to explain some beyond the Standard Model (BSM) phenomena, such as the existence of dark matter. These particles are often assumed to be light, long-lived, and weakly interacting, which makes it challenging to detect them in experiments like ATLAS. A large number of light particles with very low p_T is being produced in pp collisions and can escape ATLAS if their direction is close to the accelerator's beam pipe without being detected. Exotic light particles weakly coupled to Standard Model (SM) with such properties would be missed by the large LHC experiments. Such particles, which will be long-lived, and because of the large boost factors, can decay far away from the ATLAS interaction point.

FASER is a small new experiment looking for decays of exotic weakly interacting particles and TeV neutrinos produced in pp collisions at ATLAS in the very forward region, out of the ATLAS detector acceptance. It is placed 480 m downstream of the ATLAS interaction point in so-far unused service tunnel TI12. Detailed discussion about physics theories relevant for FASER can be found in [1].

2. Detector design

The FASER experiment consists of several subsystems that are briefly described in the following paragraphs and depicted in figure 1.

Looking from the front of the detector in the direction of incoming particles from the ATLAS interaction point, the first sub-detector in the experiment is FASERν. The sub-detector is designed to detect collider neutrinos for the first time. It is composed of a repeated structure of emulsion films interleaved with 1-mm-thick tungsten plates. There are going to be 770 emulsions in total.

The FASER detector's length is dominated by three permanent magnets with a magnetic field of 0.55 T. These magnets are used to separate pairs of oppositely charged, high-energy SM particles, originating from decays of new physics particles. The first of the three magnets is longer than the remaining two with a total length of 1.5 m. This magnet is used as a decay volume whereas two other magnets serve as a spectrometer.

Apart from magnets, FASER has a tracker system to record paths of charged particles. The tracker system consists of three tracking stations that are going to be used to detect two oppositely charged tracks originating from the common vertex and one interface tracking station connecting FASERν and the main FASER detector. Each station consists of three tracking layers of eight pairs of single-sided silicon micro-strip sensors. Spare ATLAS semiconductor strip modules were used for this purpose.

Important components for triggering are scintillators and the calorimeter. FASER has three scintillator stations that are used for triggering, veto, and inducing preshowers. There is also going to be one scintillator before FASERν. Calorimeter uses four spare LHCb outer ECAL modules that are placed at the very back of the experiment. This electromagnetic calorimeter is designed to stop highly energetic photons and electrons, identify them and measure their energies.

Finally there is a trigger and data acquisition system (TDAQ) details of which are discussed in section 3.

3. Trigger and data acquisition system

The TDAQ of the experiment is designed to be reliable and robust. These requirements are enhanced by the fact that the experiment is planned to be operated remotely, without shifters populating the control room. This is achieved by using simple architecture which is schematically illustrated in figure 2. It aims at minimizing the number of cables and equipment in the tunnel. The experiment will be triggering on high-energy particles traversing the detection volume for which the signal from scintillators and calorimeter will be used. While the threshold for triggering for photomultipliers (PMT) in scintillators is set below the energy deposit of minimum ionizing particle, the threshold in the calorimeter is going to be 20 GeV.

The expected trigger rate at an instantaneous luminosity of $2 \cdot 10^{34}\,\mathrm{cm}^{-2}\,\mathrm{s}^{-1}$ is going to be $500 - 1000$ Hz and will be dominated by muons coming from the ATLAS interaction point (IP), an estimate based on simulations and in-situ measurements. About 5 Hz of energetic signatures is going to be deposited in the calorimeter.

The TDAQ system relies on the following three hardware boards. They are the digitizer board, the Trigger Readout Board (TRB), and the Trigger Logic Board (TLB), and they are used to read out the data from the experiment, combine them together, and use this data for trigger decision. Schema pf the TDAQ system is illustrated in figure 2.

The TLB could be called the brain of the whole experiment since all the triggering logic is happening there. It is also responsible for producing a global trigger accept signal (L1A) when trigger-specific criteria are met. It is processing signals from digitizer and clock board and is sending data through the fiber from the TI12 up on the ground where data is saved to the storage. The digitizer digitizes analog signals from the scintillators and the calorimeter, the clock board provides precise LHC clock signal and the TRB is responsible for reading the data out of the tracker (one TRB per one tracking layer).

The core of the TDAQ software is written in C++ and is based on DAQling [2] which is a modular framework for the design of TDAQ systems for small and medium-sized experiments.

3.1 Monitoring

Since FASER will not have any control room it is necessary to have robust run control and monitoring system such that the control of the experiment can be done remotely. This monitoring is mostly based on the InfluxDB database and the Grafana monitoring tool that is used for plotting time series from the InfluxDB. Figure 3 is showing an example of a monitoring dashboard from Grafana.

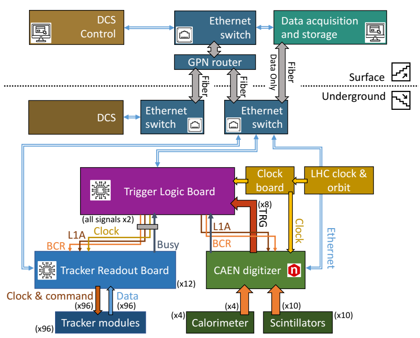

Figure 2: A simple schema of TDAQ architecture.

Figure 3: Part of Grafana monitoring dashboard.

4. Commissioning

The commissioning of different subsystems started in 2019, can be split into three parts. The first part consisted of testing individual components (scintillators, calorimeter modules, and tracker stations) as well as the commissioning of standalone TDAQ components.

The second part was on-surface commissioning in which various detector pieces were tested together with the assembly of the whole experiment. Most of these tests were carried out in a dedicated area at CERN in Prevessin, at the experimental hall EHN1. Very useful was also the FASER testbeam that was ongoing during the EPS-HEP conference 2021.

The last stage of commissioning tests was done in tunnel TI12 at the place where the experiment will be located during the actual data taking. Tests were done in the full detector setup and they were mainly focused on testing of reliability and robustness of the whole system. This was possible with help of the shifters from the FASER collaboration all around the world who were monitoring the experiment for a period of several weeks. Cosmic muons were used for triggering during this stage.

References

[1] Akitaka Ariga et al. (FASER Collaboration), *FASER's physics reach for long-lived particles*, *Phys. Rev. D* **Vol. 99**(9) May 2019, [hep-ph/1811.12522]

[2] Boretto Marco et al., *DAQling: an open-source data acquisition framework*, *EPJ Web of Conferences* **245**, 01026 (2020)