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Maths, Physics & Chemistry

Can we read the universe's book of secrets?

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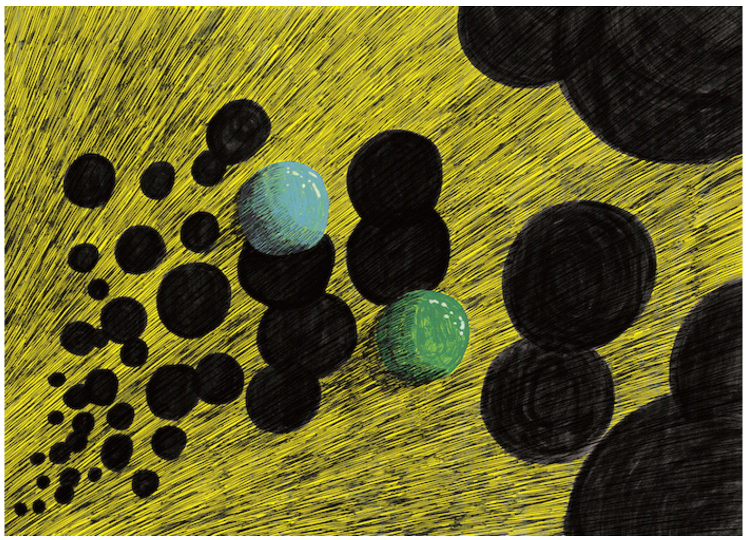
FASER, a small experiment at the CERN LHC, searches for new hypothetical particles proposed in theories that try to address some of the open questions of the Standard Model of particle physics. To enhance its discovery potential, an instrument using novel high-resolution silicon sensors was approved to be added to the experiment during the LHC Run-3, which has just started.



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The standard model of particle physics is one of the most successful theories out there. However, there are certain open questions that it fails to address. Some of them include the relative asymmetry in matter and antimatter, as well as the nature of dark matter, which we know very little about even though it makes 85

FASER will record its first data later this year and with its current design it is well equipped to capture the decay of LLPs into two electrons. On the other hand, there are many models that predict LLPs decaying into two photons. With the current design of FASER we are unable to detect these photons separately due to the miniscule distance between them. Hence, an upgrade is needed if we want FASER to be able to "see" these decays. One type of particles that are predicted to have these 2-photon decay signatures are called Axion-like particles (ALPs). To visualise what FASER intends to do, imagine the experiment being equipped with very powerful cameras that have high resolution allowing it to take photographs of these photons.

The part of FASER that identifies photons is called "the preshower". The preshower detector will record an image of the photons resulting from ALP decays along with photons coming from other standard model processes. The difficulty that arises when trying to detect the decay of ALPs is that the two photons are extremely high energetic and very closely spaced. Hence, a high-precision detector is required, which will hold the power to differentiate these photons efficiently. Therefore, the existing preshower detector needs an upgrade.

Taking advantage of the recent developments made by scientists at the nuclear and particle physics department (DPNC) at the University of Geneva in monolithic pixel detectors, the FASER collaboration intends to upgrade its preshower employing this in-house detector technology development. Monolithic detectors integrate sensor matrices and the readout electronics in one piece of

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silicon. These monolithic pixel detectors have significant advantages, like having very high resolution and being extremely thin. They have countless applications in other fields beyond high energy physics, like medical physics, imaging and industry.

Each pixel detector layer is made up of modules and the modules are made up of smaller electronic components, each of which is composed of 128 × 208 hexagonal pixels with sides of 65 . With the current design, each module will consist of 6 of these electronic components and each detector layer will have 12 of these modules. We currently envisage having 6 detector layers. Thanks to its 12 million channels, the preshower detector will be recording multi-layered high-resolution images of the photons resulting from ALP decays. High level imaging methods will be used for the analysis.

This preshower detector upgrade was approved by the CERN research board in March 2022. It will be constructed within the next two years. A passionate team of physicists and engineers are currently working vigorously to (1) finalize the design optimisations, (2) develop the algorithms necessary for utilizing the data that the detector will acquire and (3) prepare for the construction activities. The first two aspects are treated with software. Detector simulation is set up that will allow us to represent with software the detector behavior and performance. Algorithms, also employing machine learning methods, are developed to turn the detector signals into objects that we can associate with the particles of interest. The detector construction requires collaborative work in the DPNC laboratories at the University of Geneva along with other institutes in Switzerland and abroad.

To prepare for construction, the module mechanics, electronics, thermal properties, and various other fundamental aspects are studied in detail. Then comes the assembly into layers, the surface commissioning, and the installation of the preshower upgrade in 2023. The detector is expected to become operational in 2024. Which leads us finally onto the most exciting stages: data-taking and data-analysis!

So, what holds for the future of physics and this step forward with this new research opportunity? Will it guide us to some of the answers to the questions that we dwell upon? Will FASER lead us to the very book of secrets of the universe?

All details on the FASER preshower upgrade can be found at the Technical Proposal presented at the LHC Experiments Committee and approved by the CERN Research Board in March 2022: https://cds.cern.ch/record/2803084