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Phase-2 Tracking for ITk based on ACTS and Higgs self-coupling

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The reconstruction of trajectories of charged particles is one of the the most complex and CPU consuming stages of event reconstruction in particle physics experiments. At the High Luminosity Large Hadron Collider (HL-LHC), up to 200 proton-proton collisions happen during a single bunch crossing, which leads on average to tens of thousands of particles emerging from the interaction region. Reconstructing the trajectories of track particles is therefore a computational challenge at HL-LHC, motivating the development of more performant track reconstruction algorithms for the LHC experiments. A Common Tracking Software toolkit (ACTS) has been developed based on the track reconstruction algorithms of the ATLAS experiment. This contains a set of algorithms that are agnostic to the details of the detection technologies and magnetic field configuration, which makes it applicable to many different experiments, and are designed for modern computing architectures and multi-threaded event processing. The ATLAS Collaboration has therefore decided to migrate the reconstruction code to use ACTS and directly profit of thread-safety and high-performing software.
During my stay at CERN and the rest os my PhD, I will work within the international environment of the ATLAS collaboration on a first Phase-2 track reconstruction prototype based on the ACTS. I will write software using modern C++ standards and carry out R&D on state-of-the-art pattern recognition and track reconstruction algorithms. The proposed thesis also intends to increase our knowledge of the Higgs boson self- coupling and the shape of the Higgs potential, and search for new physics at the CERN Large Hadron Collider within the ATLAS experiment.
The Higgs boson became a prime tool to search for physics beyond the Standard Model (SM). At the current level of precision, the Higgs boson is compatible with SM expectations. A number of open questions indicate the existence of new physics that could be unveiled as we explore the LHC data. A wealth of experimental results from the ATLAS and CMS experiments, probe the region around the minimum of the Higgs potential, or vacuum. But the shape of this potential is not constrained experimentally.
This shape is intimately connected to the breaking of the electroweak gauge symmetry, which resulted in the fundamental forces we experience today. To experimentally constrain this shape we must measure the Higgs boson self-coupling, which is accessible at the LHC through the simultaneous production of two Higgs bosons. This is an extremely rare process that has not yet been observed, and has an expected production rate approximately 1000 times smaller than that for the production of a single Higgs boson. Possible production modes for Higgs boson pairs, HH, at the LHC are gluon- gluon fusion (ggF), vector boson fusion (VBF) and associated production with vector bosons or top quarks. Modifications of the EWSB potential are predicted by several beyond the SM (BSM) theories. Some BSM anomalies on the Higgs boson couplings and interactions could enhance the production rate of Higgs boson pairs by more than one order of magnitude.
The searches for Higgs boson pair production conducted by the ATLAS and CMS collaborations are usually divided into resonant and non-resonant searches. Resonant searches are conducted considering that a new massive intermediate particle is produced, which subsequently decays to pairs of Higgs bosons, creating a distinct peak in the Higgs boson pair invariant mass. For a new heavy particle to decay to a pair of Higgs bosons, it must be either a scalar (spin-0) itself or a massive spin-2 particle to preserve the total angular momentum along the decay axis. Several BSM models with extended Higgs sectors, e.g. MSSM and 2HDM, predict the existence of several Higgs bosons, some areneutral and can mix with the observed 125 GeV Higgs boson.
With this project, I also expect to contribute to enhancing our current knowledge in this important area, focusing on the search for di-Higgs production in VBF HH⟶4b, in both the resonant and non-resonant channels,

which will become one of the most important measurements of the HL-LHC and future colliders. The long-term goal is to measure fundamental properties of the Higgs boson, as a way to explore the SM at a deeper level. Due to a very low HH production cross section, properties such as the trilinear Higgs coupling and the quartic coupling between two Higgs and two weak vector bosons (VVHH) are very difficult to achieve experimentally, in SM-like scenarios.
On the other hand, it is crucial to prepare such measurements in all relevant channels, such as VBF HH. In addition, there are many BSM scenarios, such as the 2HDM model, in which a heavy resonance will result in HH production. So the for HH resonant production in the VBF channel will bring crucial benefits in the development of techniques and expertise needed for the understanding of fundamental properties of the Higgs boson.

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