ENIGMASS
Postdoc Project Application

Project Title:	Effective Field Theories for Higgs and SM Physics
Laboratory of LABEX Involved:	LAPP
Research group:	ATLAS
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Work Package:	WP1 Origin of mass and search for new physics

Physics Case

The LHC at CERN is a unique machine for searches for physics beyond the Standard Model (BSM), operating at a center of mass energy that has risen from 7 TeV in 2011 to 13 TeV in 2018. This has led to a steady increase in the mass limits set in a wide range of BSM physics, which in many cases now attain the multi-TeV level [1]. No signal for new physics has however been detected so far, and the mass sensitivity of direct searches is expected to rise only slowly in the coming years: with the collision energy expected to reach its design value of 14 TeV in Run 3 of the LHC starting in 2021, further gains will be driven mainly by increased dataset size. Sensitivity to BSM physics can however come from a complementary approach, by searching for its impact on low-energy observables. This follows a similar strategy as that followed at LEP and SLC to set strong constraints on the mass of the top quark and the Higgs boson, before these states were discovered at higher-energy machines, and can provide sensitivity to states with masses potentially far above the collision energy of the LHC.

The SM effective field theory (SMEFT) framework [2] is designed to implement this program. It provides a setting to study deviations between measurements and SM predictions, within general assumptions such as invariance under the SM gauge group. The deviations are parameterized as effective operators appended to the SM Lagrangian. Constraints on these operators can then be used to set very general limits on BSM models at scales above those accessible at LHC. In the case where deviations are observed, their pattern could also provides indications as to the nature of the new physics. The SMEFT provides a unified framework in which measurements of SM observables can be interpreted. At LHC these include in particular measurements of the couplings of Higgs boson and weak gauge bosons, which provide sensitivity to SMEFT parameters that are both expected to be sensitive to new physics, and in many cases only weakly constrained by other measurements.

International status and proponent positioning

ATLAS is an international collaboration of about 3000 scientists from 38 countries. The project focuses on an important part of the ATLAS physics program, and aims at securing a leading role towards the publications of the results. The proponents of the project are well integrated in the ATLAS collaboration and have shown their ability to collaborate at several levels, fulfilling leading roles in all the relevant aspects of the experiment. In particular, the LAPP ATLAS group has been strongly involved in the areas discussed in the previous section.

In Higgs boson physics, the group has a longstanding involvement in the analysis of the $H \rightarrow \gamma\gamma$ decay process, which provides precise measurements of Higgs boson kinematics. It has also contributed to combined measurements of Higgs boson couplings [3], which provide the most complete inputs to SMEFT constraints. The group has recently put forward studies of techniques used for EFT interpretation [4] and has also contributed to the development of the Simplified template cross-section framework [5], which allows fine-grained measurements of Higgs boson processes. Finally, the group is contributing to the measurements of Higgs pair production processes, which is sensitive to SMEFT operators inaccessible to other measurements.

The group is also strongly involved in measurements of vector-boson scattering (VBS) processes, which are among the rarest processes observable at LHC and can be used to set constraints on SMEFT parameters related to vector boson couplings. The group has been involved in particular in the observation of VBS in the WZ final state [6] as well as establishing evidence for the $Z\gamma$ final state [7]. These searches make increasing use of machine learning (ML) techniques in order to increase measurement sensitivity. In both cases interpretations in terms of SMEFT constraints have already been introduced.

Project details

The project is intended to continue and extend the described efforts through the **recruitment of a postdoctoral researcher, starting in October 2020**. The postdoctoral candidate work will occur along several directions:

- A complete framework for SMEFT interpretations will be established, in which Higgs boson couplings, VBS and other measurements can be integrated. Specific tasks will involve the development of a general framework for SMEFT interpretations, to be used in arbitrary ATLAS analyses; the precise quantification of SMEFT effects on the measurements, in particular the interplay between signal and background effects; and developing tools to provide robust prediction of SMEFT effects, in close collaboration with the theory community.
- The program will also allow the inclusion of results from other sectors such as precision electroweak measurements and flavor physics, following an approach similar to [8]. This will allow to make full use of the SMEFT framework and set stronger constraints on BSM

effects. Unlike the a posteriori combination such as Ref. [8], this will use the full experimental information and lead to more sensitive and more robust results.

- The current Higgs couplings and VBS analyses are designed for SM measurements, and their sensitivity to SMEFT effects will be improved with dedicated optimizations. The work will be directed in particular towards the increased use of ML techniques specifically targeted towards SMEFT measurements. In particular, EFT-aware neural networks [9] have recently been shown to improve sensitivity to SMEFT parameters, and represent a promising direction of study that will be explored.
- The sensitivity of the $H\rightarrow\gamma\gamma$ and VBS analyses in Run 3 is strongly dependent on the performance of electrons, photons and jets. The task will therefore include contributions to the identification or calibration of these objects.

Work in each of these areas is currently ongoing or being initiated within ATLAS, with strong contributions from the LAPP group. This should make it possible for the candidate to get involved quickly into these efforts, and to contribute strongly to this emerging topic of research.

Bibliography

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