Our current theory of interactions between elementary particles is called the Standard Model. The agreement between its predictions and the data collected by several generations of particle accelerators is truly impressive. In particular, experiments at the most powerful accelerator constructed to date, the Large Hadron Collider (LHC), measured cross sections (which can be thought of as probabilities) for productions of various configurations of particles, whose values cover 14 orders of magnitudes. And they all agree with theoretical predictions of the Standard Model.

Yet, the agreement between theory and data can only be claimed within the accuracy of the two, and it may go away when this accuracy is improved. In fact, there is an overall consensus that the Standard Model will eventually need to be replaced by a more general theory, as it is incapable of addressing several important questions such as that about dark mater, dark energy, hierarchy problem, quantum gravity, and others. It is therefore of great importance to keep on improving the accuracy of theoretical predictions and experimental measurements in order to, on one hand, get better understating of the Standard Model, and, on the other hand, test its consistency and look for deviations that could point towards its extensions.

The data collected by the LHC up to now show no significant discrepancies when confronted with predictions from the Standard Model. Fortunately, many more years of LHC running, which are still ahead of us, including the high-luminosity period, will allow the experimentalists to increase the precision of the measurements by reducing the uncertainties, in many cases to a sub-percent level. And this has a chance to uncover new secrets about properties and interactions of elementary particles.

However, we will be able to address these questions only if we can compare the new, extremely precise measurements from the LHC with theoretical predictions of similar accuracy. And this is exactly what is missing, as the state-of-the-art theoretical results are in most cases less precise than what is expected to be delivered by the LHC in the coming years. Hence, the goal of this project is to move the accuracy of theoretical predictions for some of the key processes measured at the LHC to the next level. This will not only improve theoretical results but it will also lead to more precise data, as most experimental analyses use theory predictions as an input and large uncertainties of the latter are the main source of systematic uncertainties of measured quantities.

The proposed research focuses on processes which involve production of the Z and W bosons, the particles that mediate weak interactions, and the production of a pair of top quarks, the heavies quarks we know. These processes are used on regular basis to pin down many fundamental parameters of the Standard Model, such as particle masses, couplings, parton distribution functions. Improved precision of theoretical predictions will therefore have a direct and immediate impact on reducing the uncertainties with which the above fundamental parameters will be determined. And this will help establishing whether the Standard Model is a self-consistent theory or whether it exhibits tensions which can only be removed by some form of new physics.

Theoretical results are calculated as a series, with each consecutive term being smaller than the previous one. The more terms are included, the more precise the result. In turns out that in many cases convergence of the series is slow. On one hand, this is good, because the higher-order terms significantly increase the production rates. For theorists, however, this means that we need to calculate at least the first four terms in order to arrive at predictions which will be accurate enough to fully exploit the potential of the LHC measurements.

Calculation of the contribution from the fourth term in the series is the subject of this research project. And that will involve use of the most sophisticated concepts and methods of theoretical physics. It will also demand significant effort because of great complexity characteristic to the calculations at that high accuracy.

The endeavour is, however, worth taking, as, once the theoretical results of that precision are available, we will be much closer to knowing the answer to one of the most fundamental scientific questions of our times: is the Standard Model of particle physics all we need at the energies currently available at particle colliders, or perhaps, Nature has prepared some surprises for us, which are waiting to be discovered just behind the corner.