This is a collaboration project between the particle and cosmology theory group at the Faculty of Physics, University of Warsaw and the experimental group at the Department of Physics and Technology, University of Bergen. The project is devoted to fundamental research aiming to contribute to ultimate construction of a deeper than the Standard Model (SM) theory of the elementary interactions that would allow to understand the history of the Early Universe.

There are two well known and highly publicized points about the present state-of-the-art in the physics of elementary interactions. One is the great success of the Standard Model, completed by the discovery of the Higgs-like particle, and its implications for the cosmological history of the Universe, starting with few parts in a million of a second after the Big Bang, confirmed by many astrophysical observations. The other is the fact that, nevertheless, the SM leaves several fundamental puzzles unexplained, in particular in the history of the very Early Universe. Moreover the theoretical structure of the SM itself, strongly points to the existence of a deeper theory. The two main puzzles of the Early Universe is the existence of Dark Matter, Dark Energy (with no candidates in the SM to explain it) and the matter-antimatter asymmetry. Any explanation of the latter also requires some extension of the SM, in particular new beyond the SM sources of the combined charge and parity symmetry (CP) violation. Baryogenesis at the electroweak (EW) phase transition at around 10^{-10} sec after the Big Bang, which is an attractive possibility, would also require the 1st order electroweak phase transition (it is 2nd order in the SM). On the SM side, the present understanding is plagued with several issues such as the question why the Higgs boson mass is so much smaller than the Planck scale (the energy scale where the gravitational interactions become of similar strength as the other elementary interactions), lack of the theory explaining fermion masses and mixing, the fate of certain symmetries in the SM like for instance the baryon number conservation (expected to be broken by gravitational interactions), to give few examples. It is very tempting to expect that unexplained observational puzzles in cosmology are linked to those of the Standard Model itself and both will find explanation in a framework of the same deeper theoretical structure. The existence of new symmetries (like supersymmetry), extra dimensions or new interactions and new particles would shed light on both kinds of the puzzling aspects.

The new element of the present state-of-the-art is that none of the proposed theoretical ideas for extending the SM have been so far experimentally supported. Even the most precise experimental measurements in the particle physics sector are so far in agreement with the SM. The reason for that can be that the energy (mass) scales characteristic for the deeper theory are beyond the reach of the Large Hadron Collider (LHC) and beyond the precision accessible in precision experiments. However, it may also well be that the new phenomena remain hidden for some other reasons. The analyses of experimental data are extremely complicated and it is is difficult (if not impossible) to look for beyond the Standard Model physics without some theory guiding. However, the theorists offer many different ideas and models. Their systematic experimental verification, model by model, is close to impossible, particularly in their full parameter ranges. A lack of experimental support for a particular model has only limited experimental implications for constructing an extension of the SM. Moreover, in spite of the multitude of theoretical models, none of them may be close enough to the actual pattern of nature.

In this project we focus on few experimental signatures that are generic for a broad spectrum of new physics models and, in fact, even for new phenomena with no concrete theoretical frameworks proposed yet. The guiding principle for our choice of signatures are the existing experimental/observational puzzles that SM is not able to explain, that is existence of Dark Matter, need for additional source of CP violation to explain the observed matter-anti matter asymmetry and, considering the electroweak baryogenesis to be an interesting option, the characteristic of the EW phase transition.

Our goal is to develop best strategies for observing such signatures in the experiments with the upgrades of the LHC, based on the guiding by a broad spectrum of the existing and new theoretical models. New data analysis techniques (Machine Learning) and new theoretical constructions will be investigated. Furthermore, theoretical interpretation of the potential new discoveries will be studied.