Cluster of Excellence Precision Physics, Fundamental Interactions and Structure of Matter
PRISMA

Mainz Institute for Theoretical Physics

High Time for Higher Orders: From Amplitudes to Phenomenology

Organized by Fabrizio Caola (Durham University), Bernhard Mistlberger (CERN) and Giulia Zanderighi (CERN).

13-24 August 2018

A substantial part of the current research on QCD in collider physics focuses on the following closely interconnected topics: the formal calculation of amplitudes and integrals, their use in higher-order calculations and the merging of these fixed-order calculations to all order results, either analytic resummations or parton-shower simulations.

This scientific program brought together the world leading experts on these topics and addressed several key issues paramount to the future development of high-precision collider phenomenology such as
(i) the bridge between the formal computation of amplitudes or formal next-to-next-to leading (NNLO) subtraction schemes to practical realizations and actual phenomenology. In particular issues like advantages, performances, differences, shortcomings of the different subtraction and slicing methods for double real radiation were addressed.
(ii) Furthermore recent advances in the computation of virtual corrections: analytic versus numerical computation and their respective advantages, performance and shortcomings were analyzed.
(iii) Also the merging fixed order calculations to parton showers, building NNLO parton showers (NNLOPS) and a comparison between different current NNLOPS approaches were discussed.
(iv) Finally, improvements on shower algorithms were considered.

The Large Hadron Collider (LHC) in Geneva currently provides a flurry of measurements that allow the scientific community to explore fundamental forces in previously entirely inaccessible ways. Furthermore, the obtained results support the existing understanding of fundamental interactions at unprecedented levels of precision. It is crucial to the success of the physics exploration spearheaded by the rapid experimental advancement to develop our theoretical understanding of the processes observed in experiment. These theoretical developments were at the core of the scientific program. In particular, it focused on the most recent developments in our understanding of quantum field theory that allows us to derive the highest possible accuracy for the prediction of the outcome of scattering processes in the collision of particles. This area of research is coined by rapid mathematical and technological advancement and yet has to face a great variety of challenges in order to fully exploit the experimental results obtained at the LHC. The desire to predict and understand the outcome of highly energetic interaction as observed in experiment often goes hand in hand with a deepening of our fundamental understanding of quantum field theory.

A diverse group of world leading scientists exploring the above-mentioned topics participated in the scientific program. Recent developments in different areas of the field were discussed in one or two presentations each day. These talks managed to bring the participants up to date on recent scientific progress and led to ample discussions about future directions of research.

During the scientific program two leaders of the experimental community, Matthias Schott and Greg Landsberg, from the ATLAS and CMS collaboration respectively, presented their insights on the current interplay of theoretical and experimental challenges. They shed light on various aspects, in particular on the question where the boundaries between these fields need to be overcome. They also outlined key aspects of future experimental progress that will strongly demand further theoretical insight. The presentation of these two speakers served as a solid reference point revealing where the future research has to go. They pointed out opportunities for scientific exploration that are currently not entirely developed.

The past couple years have seen rapid progress of extending perturbative quantum field theory computations for a vast class of observables to second order in perturbation theory and beyond. The key to this success was the development of methods to handle infrared singularities in the computation of such observables. Methods to regulate and subtract singularities efficiently and with a high degree of automation are in progress and subject to ongoing research. Franz Herzog, Alexander Huss, Tom Melia, Raoul Roentsch and Paulo Torielli reported on their fascinating advances in this particular direction. To accomplish computations for higher order scattering cross sections it is crucial to have complicated scattering amplitudes readily available. The more complex the scattering process the more difficult the calculation becomes. Costas Papadopoulos reported on recent advances in his research of five particle scattering amplitudes at second perturbative order. The intricacies of this highly demanded functions extend the boundaries of our mathematical understanding of Feynman integrals. The exploration thereof has ties deep into the realms of pure mathematics. Claude Duhr and Lorenzo Tancredi shared some recent insights into so-called Elliptic Multiple-Polylogarithms with the participants. Furthermore, Huaxing Zhu showed how novel analytic techniques can be exploited to better understand otherwise familiar event-shape observables.

Describing real scattering processes requires us to think beyond purely strong interactions and to consider all difficulties of computation within the full Standard Model of particle physics. The presence of masses of particles and of electro-weak interactions makes such calculations very challenging. This is why Paulo Nason, Simon Plaetzer, Sebastian Sapeta and Christopher Wever illuminated several recent developments in the treatment of massive fermions in perturbative computation at high order. Valentin Hirschi also reported furthermore on recent developments to incorporate the full complexity of the standard model into automated computer codes at first perturbative order in a consistent manner. Some observables measured by the LHC are inaccessible to predictions by fixed-order perturbative quantum field theory. Therefore it is crucial to the advancement of our understanding of quantum field theory in general and for LHC phenomenology in particular to understand how one may resum part of the perturbative series and explore such regimes. Dingyu Shao shared his rsearch in the treatment of so-called non-global logarithms in resummation techniques.

Ian Moult and Jian Wang gave talks on how resummation frameworks can be extended even beyond the leading power of a kinematic limit. Finally, Keith Ellis sparked a discussion about the future of our field. He presented an out-look and insights about a new experimental machine yet to be built that will shatter the boundaries of what currently can be explored. The collaborative atmosphere and the interesting variety of cutting edge research topics discussed at our scientific program made it a great success. The stimulating discussions and ample exchange of new ideas certainly triggered a range of new research projects.