

**Zwischenbericht (Sachbericht)**

<b>Förderinstrument:</b>	<b>Sondermaßnahmen</b>
Impulsfonds-Förderkennzeichen	SO-072
Projekttitlel	Determination of the proton structure using deep inelastic scattering and proton-proton collisions
Federführende/r Wissenschaftler/in	Dr. Katerina Lipka
Helmholtz-Zentrum	DESY
Berichtszeitraum (=Kalenderjahr)	01/2013-12/2013

**1) Fortschritt des im Antrag beschriebenen Arbeitsprogramms**

*Berichten Sie kurz und allgemeinverständlich über die wesentlichen Ergebnisse. Waren Abweichungen vom Arbeitsprogramm notwendig?*

High-level scientific work is performed within the project, fully exploiting the developed synergies between the experimental analyses within large international collaborations and developments of theory calculations as well as of phenomenological tools.

The project follows the original working plan with several important extensions, initiated in 2012. Group members contribute significantly to the main Standard-Model (SM) analyses in both LHC collider experiments ATLAS and CMS, having strong impact on precise determination of the proton structure, and are involved the development of QCD analysis tools.

The group established its role as a driving force in determination of parton distribution functions (PDFs) at HERA and the LHC experiments. One group member contributes to the global QCD analysis within the international CTEQ collaboration through common activities of DESY and the Southern Methodist University (SMU) in Dallas, USA. The exchange program between DESY and the SMU is established.

The group represents the origin and the core of the international, multi-institute network "Proton Structure Analyses in Hadronic Collisions", an initiative between theoretical and experimental groups, aiming in enhancing of the LHC discovery potential through increased precision of the fundamental SM parameters. As a part of this activity, the group is contributing to the project "Inclusive and Semi-Inclusive Constraints on the Parton Distributions at the LHC and the Study of Hard Processes" within HGF Alliance "Physics at the Terascale", launched in 2013. This project receives contributions in theoretical and experimental physics from DESY and the universities of Freiburg, Hamburg, Karlsruhe, Mainz and Wuppertal.

The group members receive significant visibility in the large international collaborations through taking the following coordination responsibilities at the LHC experiments and HERA, PROSA and HERAFitter collaborations:

- Convening the CMS top-mass physics working group;
- Monte-Carlo generator production managing for the CMS top-quark group;
- Leadership in CMS and ATLAS PDF forums;
- ATLAS condition database coordination;
- Convening HERA proton structure group;
- HERAFitter coordination;
- Coordination and convening PROSA working packages.

In 2013 the group participated actively in the organisation of several national and international

workshops, schools and conferences. The group contributes significantly to the student supervision and takes over the institutional responsibilities like software coordination and various contributions to the institutional service commitments within the ATLAS and CMS collaborations.

In the following, detailed activities within the project are presented, separated into the experimental and the phenomenology/tool development parts.

- **Experiment-Related Analyses and Investigation of the Proton Structure**

The determination of the top-quark pole mass and of the strong coupling constant using the top quark-pair production cross section, measured with the CMS experiment at the centre of mass energy of 7 TeV, is updated and published. The novelty of this measurement is the usage of the full next-to-next-to-leading order (NNLO) QCD calculation, available since March 2013. The determination of the strong coupling using top-quark production is the world-first measurement. Its advantage with respect to other measurements of the strong coupling at hadron collider is the smallest theory uncertainty due to the use of the full NNLO prediction. The work on a simultaneous determination of the gluon distribution in the proton, the top quark mass and the strong coupling using differential cross sections of the top-pair production at the LHC is ongoing.

The group contributes to the CMS trigger validation with particular focus on di-muon high-level trigger in multi-jet environments. The results of these trigger studies are used across the CMS working groups on top quark and Higgs physics and searches for supersymmetry.

The proton PDFs are investigated in a comprehensive QCD analysis using HERA inclusive DIS data and the recent CMS measurements of W-boson production at center-of-mass energy of 7 TeV. The latter encompass the measurement of W charge asymmetry and the measurement of the associated production of W-bosons and charm quarks. The NLO QCD analysis is performed using the HERAFitter program. Inclusion of the high-precision measurements of W lepton asymmetry results in a significant reduction of the uncertainties in the valence quark distributions. The associated W+c production probes the strange quark in the proton directly at leading order QCD. Using these CMS measurements, the strangeness distribution in the proton is determined. In comparison to the earlier analysis by the group members within the ATLAS collaboration, reported in 2012, this measurement is based on more precise data set and profits from the direct sensitivity of the used process to the strange quark in the proton. The advantage of determination of strange-quark distribution using the proton collision data is a clear proton environment, in contrast to the fixed nuclear target experiments used to determine strangeness up to now. The results obtained by the group are published within the CMS.

Drell-Yan production at the LHC is particularly sensitive to the light quark distributions in the proton. New measurements of inclusive cross sections for W- and Z-boson production with the ATLAS experiment are based on proton-proton collisions at a center-of-mass energy of 7 TeV, recorded in 2011. Results obtained using different boson decay channels are combined and compared to predictions computed at NNLO QCD for different NNLO sets of PDFs, integrated over transverse momentum. The combined measurements are used in a dedicated NNLO QCD analysis and constraints on PDFs are obtained. The group contributed to the ATLAS measurement of the differential cross-section for Drell-Yan production at the center-of-mass energy of 7 TeV at the LHC. The publication is in preparation and is expected in 2014. The group is involved in the measurements of the forward-backward asymmetry in Drell-Yan production at the LHC in the di-lepton rest-frame. These ATLAS measurements are used for determination of the effective weak-mixing angle. The publication expected in 2014.

The H1 and ZEUS collaborations are finalizing the last legacy publication on combination and

QCD analysis of the inclusive DIS measurements, performed in the HERA-II running period. These data correspond to the ultimate precision of the HERA inclusive measurements and represent the backbone for any global QCD analysis of the proton structure. The group members contribute significantly to the QCD analysis of the combined HERA data resulting in the PDF set HERAPDF2.0. The publication is expected in 2014.

- **Phenomenological Studies / Tool Development**

The work on the QCD calculation at approximate NNLO for predictions for the differential cross sections of the top-pair production in proton-(anti)proton scattering is accomplished. The calculation is making use of the threshold resummation formalism in QCD. This work is highly relevant for the interpretation of the recent and forthcoming LHC data on top-quark pair production and will have extensive applications in QCD analyses of the proton structure as well as in searches for physics beyond the standard model. The publication of the open-source program DiffTop, based on this calculation is planned for 2014.

The proton PDFs are obtained at NNLO in the framework of the CTEQ global QCD analysis. In this framework, the mass of the charm quark is determined by using generalized heavy-quark treatment ACOT-Chi at respective perturbation order.

The group contributes to the development of transverse-momentum resummation methods in essential collider processes, in particular W- and Z-boson production (program ResBos).

The group members play the leading role in the support and development of the open-source program HERAFitter, which is the unique QCD analysis tool. This program enables experimentalists to study of the impact of the different measurements on the fundamental QCD parameters and PDFs already at an early stage of data analysis. The stable release of HERAFitter is provided in 2013. The program is extensively used by the LHC experiments and the results are presented in many publications. The publication of HERAFitter is planned for 2014.

## 2) Meilensteine

*Welche wichtigen Meilensteine konnten im Berichtsjahr erreicht werden?*

- The stable release of the HERAFitter QCD analysis platform <http://herafitter.hepforge.org/> is available since October 2013.
- The determination of top quark pole mass and of the strong coupling constant using top-pair cross section at CMS is published.
- The QCD analysis of W-boson production at the CMS experiment and determination of strange quark distribution at CMS is performed and submitted to the journal.
- The program for the calculation of the differential cross sections of top-quark pair production in proton collisions at approximate NNLO QCD is accomplished.
- The exchange program between DESY and SMU Dallas is established.

## 3) Finanz-/Zeitplan

*Können Sie Finanz- und Zeitplan einhalten oder sind Anpassungen notwendig?*

As mentioned in the annual reports 2011/2012, the official start of the project and the related funding was shifted to 01.01.2012 and the end of the project is prolonged to 31.12.2014. Therefore, the funding obtained in 2011 is rebooked to the following years in accordance with the involved employments, planned till the end of the project.

**4) Strategischer Mehrwert**

*Welchen strategischen Mehrwert für die Helmholtz-Gemeinschaft hat das Vorhaben bisher erreicht oder inwieweit ist er absehbar?*

The project gains its added value in the daily close collaboration of both LHC collider experiments, ATLAS and CMS, theory experts and inherits the expertise of HERA. This construction is unique among German LHC groups and could only exist in the environment provided by Helmholtz association. Due to expertise collected in the group, the level of the scientific results obtained in the project is remarkable. Most of the performed work is pioneering, which is acknowledged by the LHC experiments and clearly beneficial for the Helmholtz association.

**5) Nachhaltigkeit**

*Inwieweit ist Nachhaltigkeit des Vorhabens bereits abzusehen oder eine Weiterführung nach Auslaufen der Förderung geplant?*

The results of the project are of high importance for the high energy and high-luminosity upgrade of the LHC. The precision of the LHC measurements is expected to increase. For efficient data interpretation, the precision of the standard model predictions should follow the precision of the measurements. However with increasing LHC energy, there will be almost no change of the kinematics domain accessed, implying similar uncertainties on all gluon-induced processes as observed at 7 and 8 TeV. The limiting factors of the standard model predictions, e.g. for the Higgs-boson cross section at NNLO or relevant predictions for searches for new phenomena remain unchanged. The aim of the current project is the significant reduction of these limiting factors using the present and future LHC data. The prospects for achieving this goal go far beyond the termination of the SO-072 project. Without strong support necessary to keep the key experts in the project on their positions, there is a danger of losing the benefits of efforts going into many LHC measurements, which are limited by the precision of the QCD parameters.

**6) Drittmittel**

*Wurden Drittmittel eingeworben? Wenn ja, von wem und in welcher Höhe?*

Through the exchange program with the SMU Dallas in USA, the project profits from the travel costs (lodging costs) for the project members, invited to visit SMU on longer term. Currently it is SMU which is interested in inviting the project members for the knowledge transfer.

**7) Patentanmeldungen**

*Wurden Patente angemeldet bzw. erteilter? Ggf. wie viele?*

The work in the project encompasses fundamental investigations, targeted at open-source publications and code developments open for public use. No patent registration is expected.

**8) Publikationen**

*Im Zwischenbericht bitte nur die wichtigsten bzw. Anzahl aufführen (peer reviewed, andere)*

Journal publications:

-CMS Collaboration, *Determination of the top-quark pole mass and strong coupling constant from the  $t\bar{t}$  production cross section in  $pp$  collisions at  $\sqrt{s} = 7$  TeV*, Phys.Lett. B728 (2014) 496-517

- CMS Collaboration, *Measurement of the muon charge asymmetry in inclusive  $pp$  to  $W + X$  production at  $\sqrt{s}=7$  TeV and an improved determination of light parton distribution functions* CMS Collaboration, submitted to Phys. Rev. D, arXiv:1312.6283

- M. Guzzi et al. *Nonperturbative contributions to a resummed leptonic angular distribution in inclusive neutral vector boson production*, submitted to Phys. Rev.D, arXiv:1309.1393;

- J. Gao, M. Guzzi, P. Nadolsky, *Charm quark mass dependence in a global QCD analysis*, Eur.Phys.J. C73 (2013) 2541 SMU-HEP-13-09; DOI: 10.1140/epjc/s10052-013-2541-4 e-Print: arXiv:1304.3494 [hep-ph]

- J. Gao, M. Guzzi et al, *The CT10 NNLO Global Analysis of QCD*, Phys.Rev. D89 (2014) 033009, arXiv:1302.6246 [hep-ph];

- V. Guzey, M. Guzzi et al, *Massive neutral gauge boson production as a probe of nuclear modifications of parton distributions at the LHC*, Eur.Phys.J. A49 (2013) 35

Other public results with contributions from the group members:

- "Study of the underlying event, b-quark fragmentation and hadronization properties in ttbar events", CMS-PAS-TOP-13-007, September 2013

- "Projected improvement of the accuracy of top-quark mass measurements at the upgraded LHC", CMS-PAS-FTR-13-017, October 2013

In 2013 the group reported different results of the project in 23 public presentations, lectures at international conferences and invited seminars all over the world.