Mid Term Report 2009 (01.04.2009-30.03.2010)

Type of the project	**Helmholtz-(Hochschul-)Nachwuchsgruppen**
Support Number	HGF-VH-NG-401
Topic	Physics of gluons and heavy quarks from HERA to the LHC: Precision measurement of the gluon density at HERA and its application for cross section measurements at the LHC
Scientist in charge	Katerina Lipka
Helmholtz Center:	DESY
University Partner	Hamburg, Mainz, Wuppertal
Reference period	05/2008 untill 04/2013

The topics addressed in the project are the precision measurement of the charm contribution to the proton structure function at HERA, phenomenology of charm quark production in deep inelastic electron-proton scattering, and the measurement of the top quark production at the LHC. Correspondingly, the activities in the group are divided in 3 working packages. In the following, the progress of each of the working packages is summarised.

Progress on the working plan of the proposal

Precision measurement of the charm contribution F^c_2 to the inclusive proton structure function F_2.

The aim of this part of the project is to access the gluon density in the proton directly, via precision measurements of the cross section of events involving charm quarks, produced in the boson-gluon fusion process. Charm quarks can be tagged via charm- containing mesons. Precisely measured cross section of D* meson production in the deep inelastic scattering at H1 experiment are extrapolated using perturbative QCD calculations to obtain F^c_2. These measurements can be used in the QCD fits to the HERA data to determine the parton density functions (PDFs) of the proton.
Since the contribution of heavy quarks to the total DIS cross sections increases with Q^2 to up to 30% in case of charm, one of the key issues of the global analysis of the proton structure is the proper treatment of heavy quarks in the QCD fits. Different approaches available from different phenomenology groups can be tested using the heavy flavour production measurements.

- In Fixed Flavour Number Scheme (FFNS) massive charm quarks are assumed to be produced dynamically in boson-gluon fusion, the active flavours in the proton are u,d,s (the flavour number is fixed to N_f=3). This scheme gives a proper description of the charm threshold region but is expected to break down at scales (μ=Q) much higher than the charm mass. Currently FFNS has also a disadvantage that it can not incorporate the charged current data in the QCD analysis.

- In Zero Mass Variable Flavour Number Scheme (ZMVFNS) the flavour number is increasing with the scale crossing the mass thresholds, the charm is treated as an active flavour in the proton. At high scales $Q^2 >> m_c$ ZMVFNS is expected to describe the data best but is obviously wrong at a heavy quark thresholds.

- The Generalized Mass Variable Number Scheme (GMVFNS) is an attempt to match the best features from the both schemes above. Different methods of matching exist on the market. Prediction of differential distributions of the observed cross sections in GMVFNS is not yet available and is one of the tasks of the NG-401 group. Several phenomenology groups in UK and USA provide the GMVFNS schemes of the QCD analysis for the PDF fits to the inclusive DIS data and predictions of charm structure function F_2^c. The measurements of F_2^c allow direct tests of the available implementations of the GMVFNS.

As indicated in the proposal, this part will be the main focus of the group activities until 2011. In this context the following progress was made in this subject.

- The analysis of D*-production cross section and extraction of charm structure function F_2^c at high photon virtualities $Q^2>100$ GeV^2 with the H1 experiment is finalized and published [1]. This measurement provides a direct test of two main schemes of charm quark treatment in NLO QCD. At high Q^2 accessible at HERA for charm production, ZMVFNS does not agree with the data, while FFNS describes data very well. The F_2^c extracted using these data is compared to the FFNS and different implementations of GMVFNS. The precision of the data is good enough to distinguish between several phenomenological predictions.

- Studies of the hadronic final state and charm fragmentation into D* mesons are ongoing in a framework of a Ph.D thesis (2009-2012). In particular the dependence of the fragmentation function of charm quarks into D* mesons is studied as a function of the mass of the charm-anticharm system. Different methods to reconstruct this mass are under investigation.

- The feasibility study of the D* production using a backward silicon tracker (BST) of the H1 detector has shown very poor efficiency of track reconstruction in the BST. Therefore this topic is not further followed.

- The work on the Preliminary HERA combination of H1 and ZEUS measurements of F_2^c was accomplished successfully [2]. The results based on D* cross sections and lifetime tag analysis at H1 in the full HERA running period, are combined with ZEUS measurements using D*, D^0, $D^{\pm}$ -meson cross sections as well from semi-leptonic decays of charm and beauty into muons in HERA-I and part of the HERA-II. This combination implies a sophisticated fit of the experimental data taking into account the correlations of the systematic uncertainties between the data points of a single measurement and systematic sources of different measurements of H1 and ZEUS experiments. The combined HERA F_2^c covers the range $2<Q^2<1000$ GeV^2 and $10^{-5}<x<10^{-1}$. The precision of combined F_2^c result varies between 5% and 10%. This precision allows the distinction between different implementations of GMVFNS in the PDF analysis and can be used to tune the models. Further precision improvement is expected from including the ZEUS results based on the full HERA-II data. The combination of current results is being finalized and the work on the publication of this is ongoing.

- The release of HERA F_2^c data triggered an intensive discussion on heavy quarks and in particular charm mass treatment in the HERA publication of combination of DIS cross sections and QCD analysis of HERA data [3]. As a result an additional uncertainty on the assumption of the charm mass in the HERAPDF1.0 was taken into account. The F_2^c data show preference for the higher charm mass, close to the experimentally measured pole mass of $m_c=1.65$ GeV, while the QCD fit to the inclusive data prefers the lower charm mass of $m_c=1.4$ GeV. The higher value of the

charm mass in the QCD fit results in a steeper gluon distribution and has also consequences for light quark distributions. At the PDF4LHC workshop at DESY in October 2009 the studies of the W and Z cross section production at the LHC at 10 TeV were presented, taking into account higher value of charm mass in the PDFs. The presented results showed a 3% rise in the W- and Z-cross section due to increasing the charm mass from 1.4 to 1.65 GeV. The largest assumed uncertainty on the prediction of the W and Z cross-sections is the error on the parton density distributions, which amount to 2% disregarding the uncertainty due to charm mass value. This observation is of particular importance since the precision of the $W^{\pm}$ cross section prediction due to PDF is a limiting factor for the luminosity measurements at the LHC experiments ATLAS and CMS.

- The first PDF fits to HERA inclusive and F_2^c data have been performed and preliminary results are in preparation to be shown on the International Workshop on Deep Inelastic Scattering in April 2010.

Phenomenology of charm production in DIS at HERA

In collaboration with the THEP group of the Johannes-Gutenberg University of Mainz, the group participates in the development of the theoretical models of charm production at HERA at next-to-leading order (NLO) of perturbative QCD in FFNS. Since March 2009 these activities are supported by the Forschungszentrum des Landes Rheinland-Pfalz “Elementarkräfte und Mathematische Grundlagen".

The development of a program for a single-particle inclusive production of heavy quarks in deep inelastic scattering in NLO QCD in GMVFNS is ongoing. The program HVQDIS (NLO QCD in FFNS) is being worked on. This package is used for the extrapolation of the D* cross sections to obtain F^c_2 in the full phase space. The charm quarks are produced in LO and NLO and are further fragmented independently via a phenomenological model into charmed hadrons. The aim of the work is to implement the GMVFNS prescriptions into HVQDIS so that evolved fragmentation functions can be used. Such, for the first time the predictions of differential cross sections of charm production would be possible in a scheme consistent with the QCD analysis of the proton structure.

The GMVFNS combines the low-scale massive calculation with the large-scale massless calculation. The number of active flavors in the initial state varies with the scale. The final-state heavy quarks are treated as massive so that the cross sections have the correct threshold behavior. The terms logarithmic in the quark masses are subtracted from the hard part and resummed in evolved PDFs and fragmentation functions. Therefore GMVFNS is valid in the full range of the scale.

The implementation of the GMVFNS is done by subtracting out the collinear divergences (the subtraction terms) from the FFNS hard scattering and folding the subtracted result with the evolved PDFs and fragmentation functions to obtain the hadronic cross section.
The subtraction terms are obtained either by comparing the ZMVFNS results to the vanishing heavy quark mass limit of the FFNS results, or are calculated using the mass factorization.

The subtraction terms as calculated by (Kniehl, Kramer, Pisano, Schienbein, Smith, Spiesberger, publication in preparation) are used and implemented in HVQDIS. The evolved fragmentation functions are implemented. The preliminary results using subtraction terms and proper fragmentation are available for the internal use and first comparison with the

data. The release of the improved version of the code and the publication are planed for summer 2010.

B-tagging and Top quark physics at CMS:

One of the aims of the project is the precision measurement of the top quark mass with the CMS detector at the LHC. The mass of the top quark will be identified in di-leptonic decays via the long lifetime of B-hadrons. The measurement relies on the precise spatial information provided by the silicon tracker and the efficient identification of the b-quarks.

The crucial issue for the analysis is the reconstruction of the secondary vertices. The group has overtaken the responsibility, within the CMS b-tagging Physics Objects Group, for the development of secondary vertex validation tool.
Within the b-tag Physics Objects Group (POG) and in collaboration with University of Illinois at Chicago, the group has developed a tool to classify and analyze secondary vertices in order to evaluate secondary vertex reconstruction, secondary vertex-based b-tag algorithms and verify the CMS software releases. Additional necessary software was also developed and successfully integrated in the CMS software framework, becoming the official secondary vertex validation tool for the experiment. It has also been implemented in the Offline Data Quality Monitoring validation package.

- The group is participating in developing data-driven procedures to validate secondary vertices with the first data delivered by the LHC. This activity is being carried out within the joint tracking and b-tagging POG effort to ensure the quality of the fundamental observables used for b-tagging, such as tracks or vertices. The data is compared to the simulation to illustrate the performance of the different b-tagging algorithms.

- The group has overtaken the responsibility of performing physics simulation studies of the pixel detector upgrade project, foreseen for 2011. The goal of the analysis is the evaluation of the b-tagging performance of the new detector geometry for top-quark analyses.

- The development of the analysis framework for the total cross-section measurement of top-quarks in the di-leptonic decay channel with early LHC data has started.

- The group has played a crucial role in the update of the measurement of the cosmic muon charge ratio [4], measured for the first time in CMS using the data collected at the MTCC ("Magnet Test and Cosmic Challenge", 2006). The update was necessary for its combination with the two new measurements of the charge ratio performed with CRAFT08 ("Cosmic Run At Four Tesla", 2008) data [5].

Achieved milestones:

- Publication of the D* production cross section and determination of the charm structure function F2c at high Q2 in deep inelastic scattetring at H1 experiment
- H1+ZEUS combination of the charm tagging methods to obtain the most precise measurement of F^c_2 at HERA
- First PDF fits using combined HERA F_2^c data
- Implementation of evolved fragmentation and subtraction terms into HVQDIS
- Analysis of the first CMS data
- Finalizing the analysis of the cosmic muon charge ratio by the CMS and preparation for the publication

Responsibilities of the group

K. Lipka, H1:
- H1 coordinator of HERA Combination Group
- H1 contact person for HERA Heavy Flavour Combination Subgroup

M. Aldaya, CMS:
- DESY CMS offline coordinator
- DESY/University of Hamburg CMS top-quark group convener

Adherence to the time and financial plans:

Physics:

The physics plan of the group is in the excellent agreement with the project even taken into account the additional responsibilities taken over by the group members. The group is playing the leading role in H1 and H1+ZEUS heavy flavour activities and a major role in HERA combination activities and QCD analysis at DESY.

Personnel: the group consists of the group leader and the following members

Post-Docs:
- Dr. Maria Aldaya Martin (started 01.10.2008)
- Dr. Kadeer Alimuijang (started 01.06.2008)
- Dr. Ringaile Placakyte (guest scientist February-March 2010)
- Dr. Kzrystof Nowak (started 15.03.2010)

Ph.D. Students:
- Ms. Monica Dobre (started 01.06.2009)
- Mr. Martin Brinkmann (started 01.02.2007)

Personnel changes:

Due to personal reasons, Mr. Boris Pokorny has cancelled his contract with University of Hamburg to 01.04.2009 . The position was filled by Ms. Monica Dobre.
Ms. Ewelina Kosior cancelled her contract with DESY to 09.10.2009 due to family reasons.
Mr. Martin Brinkmann was employed by the group for the finalization of the publication and accompletion of the Ph.D. thesis [6].

Funding for Dr. Kadeer Alimuijang is taken over by the Partner University of Mainz in period from 01.03.2009-01.03.2011.

Released funding from IVF is sufficient for further Post.Doc employment. As agreed with the scientific host at DESY the following employment are made:

-Dr. K. Nowak is employed by the group for 2 years to work on the QCD analysis at HERA including final state data like jet production at H1 and ZEUS experiments. Dr. Nowak will contribute significantly to the combination of H1 and ZEUS jet data in particular using the jet data of both experiments together with inclusive DIS cross sections and F_2^c to determine PDFs in the proton and the strong coupling constant, α_s. It is planed further that Dr. Nowak will join the top quark analysis at CMS.
- Dr. R. Placakyte is employed by the group for 1 month and is working on QCD analysis of HERA inclusive data including preliminary F_2^c data.

The status of the personal expences follows the original financial plan of the proposal with corrections for the changes of the personnel.

Investments
Investmets of the group is in accordance to the proposal, including the computing equipement of the group with the laptops for 2 group members.

Additional (travel) expenses
Additional expenses include travel expenses of the group members and the invited scientist for the organized workshop, as well as the CMS operation fee for Dr. Aldaya. These expenses correspond to the financial plan with corrections for unforeseen changes in the personnel.

Relevant Publications and Public Results
[1] [H1 Collaboration] Phys. Lett. B 686, 91 (2010) (corr. authors M. Brinkmann, K. Lipka)
Measurement of the D Meson Production Cross Section and F_2^c at High Q^2 in ep Scattering at HERA*
[2] [HERA Heavy Flavour Combination Group] (corr. author K. Lipka)
Combination of F_2^c from DIS measurements at HERA H1prelim-09-171/ZEUS-prel-09-015
[3] [H1+ZEUS Collaborations] JHEP 1001:109 (2010)
Combined Measurement and QCD Analysis of the Inclusive ep Neutral and Charged Current Scattering Cross-Sections at HERA
[4] M. Aldaya, P. Garcia-Abia, M. Mulders, CMS AN-2010/011
Updated measurement of the charge ratio of cosmic muons using MTCC data
[5] M. Aldaya et al.,CMS AN-2010/033
Measurement of the charge asymmetry of atmospheric muons with the CMS detector
[6] M. Brinkmann, “Measurement of cross sections of D* -meson production and extraction of F_2^c at high Q^2 at the H1 experiment”. Ph.D. Thesis, University of Hamburg, 2010

Public Presentations
- M. Aldaya and H. Geenen, "Top Physics in CMS-D", plenary talk, FSP-CMS Annual Workshop, DESY-Hamburg, 23 - 35 September 2009
- K. Alimujiang “General mass variable flavour number scheme in deep inelastic scattering”, EMG Klausurtagung, 21.10.2009, Mainz
- M. Brinkmann, “D* production at high Q2 at H1 Experiment”, , XVII International Workshop on Deep-Inelastic Scattering and Related Subjects DIS 2009, 26-30 April 2009, Madrid
- K.Lipka,“Combination of F2c using vertex detector and D* method at H1” (together with P. Thompson) , XVII International Workshop on Deep-Inelastic Scattering and Related Subjects DIS 2009, 26-30 April 2009, Madrid
- K. Lipka, "Charm and beauty of HERA" (for H1 and ZEUS), XXIèmes Rencontres de Blois “Windows on the Universe“, June 2009
- K. Lipka, "Measurement of F2cc and F2bb at H1", The 2009 Europhysics Conference on High Energy Physics 16-22 July 2009 Krakow, Poland
- K. Lipka, "Die Frage nach dem Leben, dem Universum und den ganzen Rest" , eingeladener Vortrag, Tagung der Helmholtz-Gemeinschaft zur Chancengleichheit November 2009, Leipzig
- K. Lipka, "Combined Measurement of F_2^c at HERA" at PDF4LHC Workshop October 2009
- K. Lipka, “Physics of gluons and heavy quarks fro HERA to the LHC”, eingeladener Vortrag, Frühjahrstagung der DPG, März 2010.