PUBLISHABLE SUMMARY

Collisions of highly energetic hadrons play a crucial role throughout much of nuclear and particle physics. They offer insights into the inner structure of nucleons and nuclei, allow studies and tests of the strong interactions and their microscopic theory, Quantum Chromo Dynamics (QCD), and also serve as invaluable tools in the search for physics beyond our "Standard Model" of the interactions in nature.

The present project aims at providing improved theoretical predictions for cross-sections in high-energy hadronic scattering reactions. Specifically, the primary goal of the project is to further develop all-order QCD resummation techniques for specific observables, thereby providing state-of-the art theoretical predictions. Besides their inherent theoretical interest, the results are of much relevance for present-day experiments.

In this project, we have performed work on the following topics:

(1) Resummation for high-p_T photo-production processes at COMPASS and HERMES.

The HERMES collaboration at DESY and COMPASS at CERN use spin asymmetries in the photon-gluon fusion process in lepton scattering to explore the spin-dependent gluon distribution, Δg, in the nucleon. A key process that is being used is $\gamma d \to hX$, where h denotes a hadron produced at large transverse momentum p_T. Both experiments are fixed-target experiments, and kinematics are such that QCD threshold resummation effects can be significant. In collaboration with D. de Florian (Buenos Aires), M. Pfeuffer (graduate student, Regensburg), and A. Schäfer (Regensburg) we have derived the all-order resummation of threshold logarithms for this process. Figure 1 shows our results as published in D. de Florian *et al.*, Phys. Rev. D 88, 014024 (2013). It turns out that the resummation contributions that we have developed are indeed needed for a quantitative description of the experimental data.

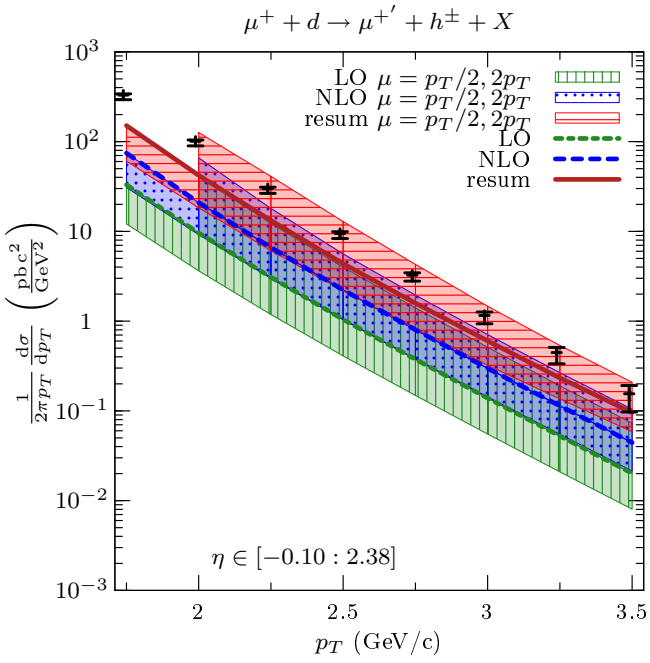

Figure 1: *Next-to-leading order and resummed calculations for the cross section for $\gamma d \to hX$, compared to the COMPASS data from C. Adolph et al. [COMPASS Collaboration], Phys. Rev. D 88, 091101 (2013). The shaded colored bands indicate the scale dependence of the results.*

(2) Threshold-resummed cross sections in $pp \to hX$, $pp \to \text{jet}X$, $pp \to h_1 h_2 X$.

For observables involving "pure-QCD" $2 \to 2$ scattering reactions, the resummation is known to become significantly more involved. We have carried out studies of various reactions of this type, with special attention to their phenomenology. In particular, we have investigated jet production at the LHC, where resummation calculations may be used to predict the size of higher-order terms in the perturbative series. Figure 2 shows an example from our publication D. de Florian *et al.*, Phys. Rev. Lett. 112, 082001 (2014).

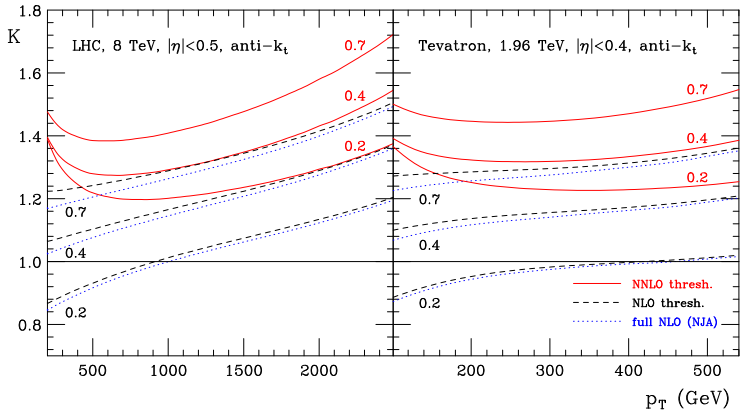

Figure 2: *Left: K-factors for jet production in pp-collisions at the LHC at $\sqrt{S} = 8$ TeV for various jet sizes R, as predicted by QCD resummation. Right: Same for $p\bar{p}$ collisions at the Tevatron at $\sqrt{S} = 1.96$ TeV.*

(3) Studies of spin-dependent parton distributions.

Thanks to the advent of new experimental data, exciting information on the partonic spin structure of the nucleon has emerged. Using our experience gained on the theory and phenomenology of hadronic scattering, we have performed a new "global" analysis of helicity parton distributions. A main feature is that, for the first time, evidence for polarization of gluons inside a proton is found; see Fig. 3. Our results have been published in D. de Florian *et al.*, Phys. Rev. Lett. **113**, 012001 (2014).

(4) Studies of transverse-momentum dependent distributions and angular dependences.

Here the focus has been primarily on the role of gluons. A particularly important result has been published in W. J. den Dunnen *et al.*, Phys. Rev. Lett. 112, 212001 (2014), where the angular dependences of various transverse-momentum distributions at the LHC were determined. These provide unique insights into gluon dynamics inside a proton.

Impact of our results:

Our results have significant impact on the fields of nuclear and particle physics. Overall, our studies lead to a better understanding and control of the theoretical predictions for many cross sections in high-energy nuclear particle physics, ranging from the fixed-target regime to high-energy colliders. This is of much importance for ongoing and planned experiments around the world, for instance COMPASS (CERN), HERMES (DESY), RHIC (Brookhaven). A central goal of each of these experiments is to provide new information on the inner structure of the nucleon. This can only be achieved by comparison with theoretical predictions that are adequate for the relevant kinematics of the experiments. This is what the present work on this project has provided. We hence consider our proposed work to be vital for the key experiments in high-

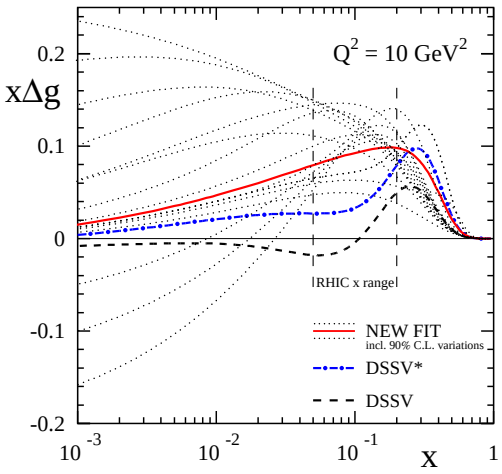

Figure 3: *Gluon helicity distribution at* $Q^2 = 10\,\mathrm{GeV}^2$ *obtained in our analysis. The dotted lines present the gluon densities for alternative fits that are within the* 90% *C.L. limit.*

energy nuclear and particle physics to reach their full potential. On the theoretical side, our resummation studies have provided new insights into the structure of QCD at high orders in perturbation theory and thereby enhance our understanding of the strong interactions.

It is also worth pointing out that through the support by this IRG the principal investigator has been fully re-integrated in the european scientific community and has been able to build his own group. Young scientists have been involved in this project and have been trained in its course.