Executive Summary of the MITP Scientific Program:
"Light-Cone Distribution Amplitudes of Hadrons in QCD and their Applications"

Vladimir Braun (Univ. Regensburg), Danny van Dyk (TU München), Sebastian Jäger (Univ. Sussex), Alexander Khodjamirian (Univ. Siegen).

13-24 January 2020

Goals of the Topical Scientific Program

To test the Standard Model of particle physics and to search for new phenomena beyond that theory, various processes with hadrons that are triggered through electroweak transitions of quarks are studied. A complete description of these processes is not possible without knowledge of their hadronic matrix elements. Calculating these matrix elements on the basis of Quantum Chromodynamics (QCD) poses an ongoing challenge. Light-cone distribution amplitudes (LCDAs) form a central and universal set of inputs used to describe the long-distance components of hadronic matrix elements in QCD. The recent years were marked by a significant progress in developing the theory of LCDAs. Their characteristics are currently being computed from first principles using the lattice QCD simulations. Furthermore, the knowledge of LCDAs is needed when calculating observables of multi-hadron matrix elements in the frameworks based on various QCD-based factorization methods. The goal of our scientific program was to bring together the experts from different subfields of QCD and flavour physics to exchange new results and to generate collaborative efforts concerning the theory, phenomenology and applications of LCDAs.

Scientific Highlights of the Topical Workshop/Scientific Program

The pion LCDA is the simplest one and is of the utmost importance for phenomenology, so that it is receiving considerable attention. In our program several talks were devoted, directly or indirectly, to the pion LCDA and we also have had a special discussion session. The most important new result that has appeared during the past year is the first lattice QCD calculation of the second moment with a full control over systematic errors (Gunnar Bali). When combined with the existing phenomenological information, most of which comes from studies of the $\gamma^*\gamma\pi$ form factor in the framework of QCD light-cone sum rules (LCSRs), this result indicates that the pion LCDA does not differ significantly from the asymptotic shape in the central region, but may have some enhancement close to the end points. Future perspectives to get more insight into this structure from the side of phenomenology were discussed in the talks by Kornelija Passek-Kumericki and Aleksey Rusov.

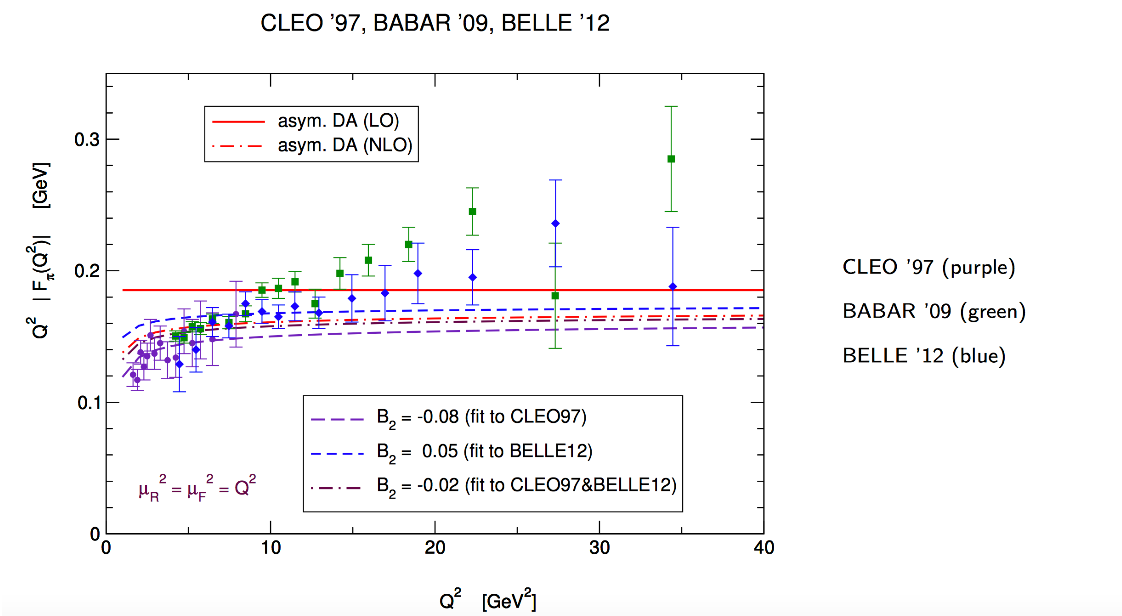

Figure 1: The twist-2 part of the $\gamma^*\gamma\pi$ form factor: predictions with various pion DAs and experiment (from the talk by K. Passek-Kumericki).

In addition, Philipp Wein presented results of an exploratory study of the pion LCDA in lattice QCD using a novel approach based on the calculation of Euclidean correlation functions. The problem is complicated and it seems that a progress in medium term future can be expected from the measurements of the $\gamma^*\gamma\pi$ form factor at BELLE II and BESIII where a much higher precision can be achieved. It is important to make our experimental colleagues aware of the importance and topicality of such measurements.

More information can come from studies of the electromagnetic pion form factor, both in experiments (JLAB12) and on the lattice. In the exploratory calculations presented by Christine Davies and Sara Collins it was demonstrated that the lattice calculations can achieve a good statistical precision at least up to the momentum transfer $Q^2 \sim 9$ GeV^2 and that the next step will be to understand and control systematic errors.

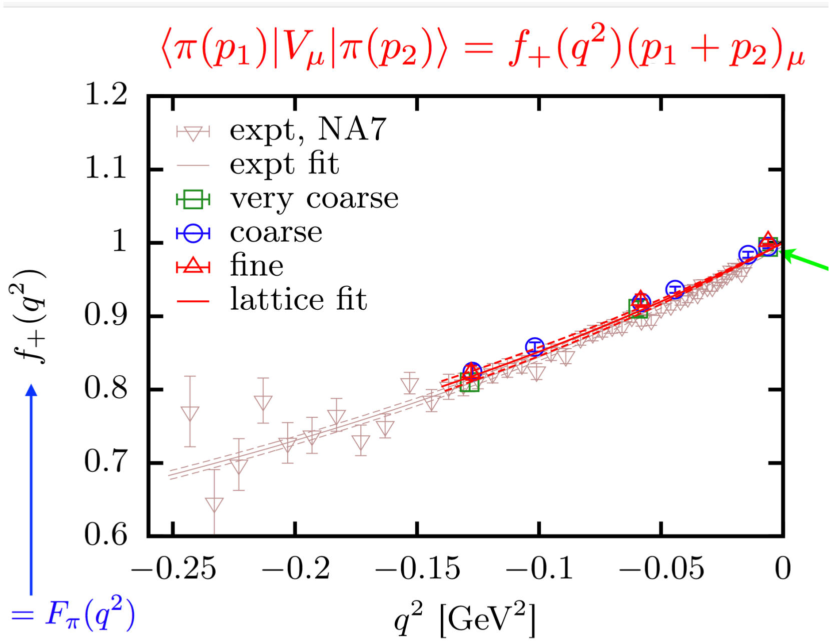

Figure 2: Pion electromagnetic form factor: lattice QCD calculation compared to the data (from the talk by Christine Davies).

The B-meson LCDA was another focus of attention by the participants. In last years there was a considerable progress in understanding its scale dependence and the structure of higher-twist LCDAs, including two-particle and three-particle ones (Yao Ji).

These results were used to estimate the structure of subleading power corrections to several processes that can yield –via LCSRs– additional information on the shape of the leading LCDA and the crucial inverse moment parameter (Yu-Ming Wang, Roman Zwicky). A possibility to assess the $SU(3)_{fl}$ violation in this parameter applying QCD sum rules and resulting in the phenomenologically important LCDA for the B_s -meson was presented (Rusa Mandal). Novel ideas on the role of QED effects in B meson DAs were presented (Robert Szafron). In addition, the matching of the effective theory LCDA relevant to B-decay to the full QCD LCDA relevant for B production in hard reactions was a topic of an exploratory discussion by several participants.

We also had a discussion session on the perspectives of a lattice calculation of the B-meson LCDA, where one recent attempt was presented (Christoph Lehner, Davide Giusti). Another discussion session was devoted to the search for a suitable ansatz for its shape that can be used in the future data analysis (Danny van Dyk, Bjorn Lange).

The possibilities and challenges of extending the concept of the LCDA to the

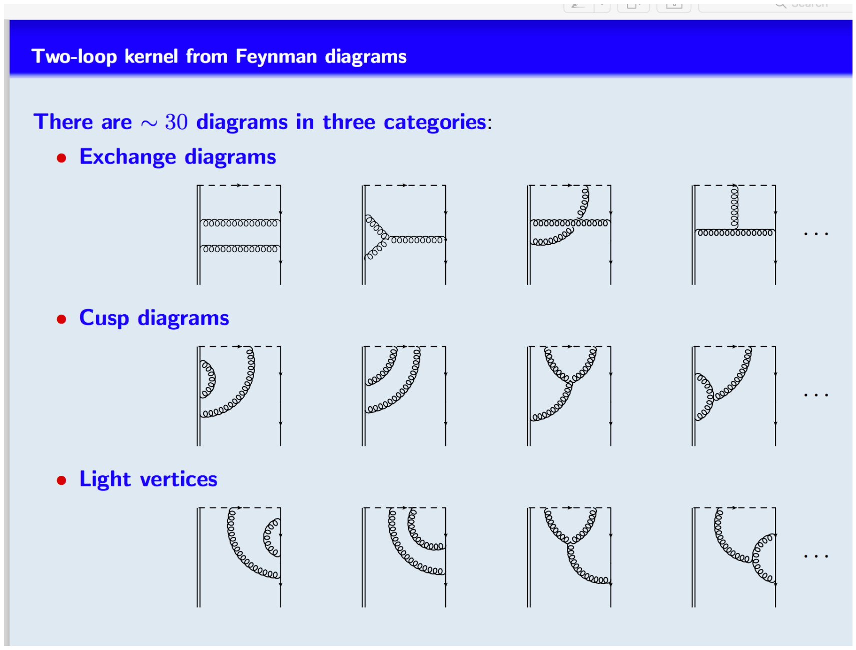

Figure 3: Feynman diagrams describing the evolution of the B-meson LCDAs (from the talk by Yao Ji).

dimeson hadronic system were discussed at a separate session (Alexander Khodjamirian) where also the recent application of these LCDAs in the factorization pattern of nonleptonic B-decays were presented (Keri Vos).

Some other topics included in the program concerned the baryon sector. In particular, the baryon LCDAs on the lattice (Gunnar Bali), their applications to the nucleon form factors (Goran Duplancic) and their connection to the light-front quantized wave functions (Edward Shuryak) were also discussed. It was emphasized that huge $SU(3)_{fl}$ violations in the LCDAs of the baryon octet found on the lattice need clarification and can have impact on phenomenology.

Open problems and Conclusions

Summarizing the current studies of LCDAs presented and discussed at the program, we can single out the following most important open problems:

- the pion LCDA close to the endpoints remains an enigma.
- there is no workable technique as yet to calculate the B -meson LCDA in the lattice QCD.

- with all the progress in the QCD factorization framework for B-decays in the leading power, we still are not in a position to perform a systematic and convergent calculation of the power suppressed terms.

- the issue of $SU(3)$-flavour symmetry violation in the baryon LCDAs should be clarified.

- the dimeson LCDAs should be extended from the currently explored twist-2 dipion amplitudes to include also higher twist components as well as the $K\pi$ and $K\bar{K}$ states.

Concluding, the program has succeeded in making a comprehensive and comparative assessment of the current status of LCDAs achieved by all existing methods: the lattice QCD, sum rules in QCD, hadron phenomenology and flavour physics. The level of synergy between lattice and continuum QCD communities in solving topical problems involving LCDAs has significantly increased. Discussions among participants played an important role in stimulating several projects in progress. It is therefore very desirable after some time to organize a topical workshop on the same theme.