

## Hadronic Probes of Fundamental Symmetries

Workshop at the ACFI, March 6-8, 2014

Report

The joint ACFI-Jefferson Lab workshop on hadronic probes of fundamental symmetries took place at the University of Massachusetts, Amherst, from March 6 to 8 2014. The workshop addressed the prospects of further study of fundamental symmetries with hadrons, with particular focus on rare decays of the  $\eta$  meson, precision theoretical study of the  $\eta \rightarrow 3\pi$  decays, and the open issues of light-by-light (LBL) scattering contributions to the muon's anomalous magnetic moment ( $(g-2)_\mu$ ). An important motivation for the workshop is the prospect of an experiment in Hall D at Jefferson Lab where a large sample of  $\eta$  mesons can be produced via the  $\eta$ -photoproduction with a 11 GeV tagged photon beam. Such an experiment, known as JEF (Jefferson Lab Eta Factory) could collect of the order of  $10^8$   $\eta$ s, which in addition to improving already measured decays, it can further constrain the bounds on rare processes within the Standard Model (SM) and also provide opportunities for observation of some specific processes requiring physics beyond the SM.

An overview of the JEF experiment was given by Liping Gan (University of North Carolina, Wilmington), where she presented the processes being considered and the various preliminary studies carried out for composing the proposal submitted to Jefferson Lab. The currently proposed focus of the JEF experiment is the study of the allowed decay  $\eta \rightarrow \pi^0\gamma\gamma$ , and the very rare decays  $\eta \rightarrow \pi^0\pi^0$  and  $\eta \rightarrow \gamma\gamma\gamma$ , both of which are unobservable unless new physics BSM drives them. As part of the experiment the measurement of the  $\eta \rightarrow \pi^0\pi^0\pi^0$  will be measured; at the workshop it was proposed that also the  $\eta \rightarrow \pi^0\pi^+\pi^-$  decay should be measured.

Experimental overviews of other programs were also presented. Marc Unverzagt (Mainz) gave a summary of present and future light meson physics with the Crystal Ball detector at MAMI (Mainz). He presented results on  $\eta \rightarrow 3\pi^0$ ,  $\eta \rightarrow \pi^0\gamma\gamma$  and  $\eta \rightarrow e^+e^-\gamma$ , as well as preliminary results on the decay  $\eta' \rightarrow \pi^0\pi^0\eta$ . Similarly, an overview which focused primarily on transition form factors of the  $\pi^0$  and  $\eta$  mesons from measurements at KLOE-KLOE2 @ DAFNE (Frascati) and at WASA @ COSY (Jülich) was given by Andrzej Kupsc (Uppsala). He also presented results from the recent measurements of the very important anomaly mediated decays  $\eta, \eta' \rightarrow \pi^+\pi^-\gamma$

at KLOE, WASA, BESIII, as well as for the current efforts to observe the decay  $\eta' \rightarrow \pi^0 \gamma \gamma$ .

These experimental talks provided a good summary of the current status of the facilities and measurements relevant to the main topics covered in the workshop.

An introductory theoretical/phenomenological overview on rare  $\eta$  decays was presented by Jose Goity (HU and JLab). Decays allowed in the SM and sensitive to the strong interaction dynamics were discussed, in particular the  $\eta \rightarrow \pi^0 \gamma \gamma$ , and also decays suppressed in the SM, namely  $\eta \rightarrow 2\pi$  and  $\eta \rightarrow 3\gamma$ , which as mentioned above if observed are immediate evidence for physics BSM. The particular decay  $\eta \rightarrow \pi^0 \gamma \gamma$  already measured at MAMI and to be studied by JEF was emphasized due to its peculiarities: it is the only known meson decay which proceeds via polarizability type mechanism, it is suppressed at the leading chiral order and gives profound insight on the dominance by excited mesonic states  $\rho$ ,  $\omega$ ,  $a_0$  and  $a_2$ .

The possible scenarios of physics BSM which could be manifested in  $\eta$  decays were discussed in talks by Sean Tulin (Michigan) and Michael Ramsey-Musolf (Amherst). A discussion was presented on the so called Gorchtein bound for  $\eta \rightarrow 2\pi$  derived from the current bound on the neutron's EDM, and possible ways in which physics BSM could evade that bound. The possible manifestation of a dark B-boson (or dark  $\omega$ ) coupling only to quarks in the decays  $\eta \rightarrow \pi^0 \gamma \gamma$  was presented by S. Tulin. M. Ramsey-Musolf discussed C violating processes in general and the theoretical tools that help carry analyses of effects from BSM physics. He also discussed a possible constrained scenario which connects to the physics to be studied at JEF, where the decay  $\eta \rightarrow 3\gamma$  could be significantly enhanced with respect to the very small rate predicted in the SM.

The decays  $\eta \rightarrow 3\pi$  were discussed from different approaches by Johan Bijnens (Lund), who presented the studies carried out at order  $p^6$  in ChPT, and by Emilie Passemar (Los Alamos) who presented the study in the framework of combined ChPT and dispersion theory and highlighted the present work in progress. These improved studies along with increasingly precise experimental determinations of the total rate and the Dalitz distributions are expected to increase the accuracy of the quark mass ratio  $Q^2 = (m_s^2 - \hat{m}^2)/(m_d^2 - m_u^2)$ , which is one fundamental ratio in the Standard Model. In the context of these decays, Susan Gardner (Kentucky) discussed the possibilities of testing for CP violation via asymmetries in the Dalitz distribution of  $\eta \rightarrow \pi^0 \pi^+ \pi^-$ .

The problem of LBL scattering contributions to  $(g - 2)_\mu$  was discussed in a dedicated session by Michael Ramsey-Musolf, Johan Bijnens, Gilberto Colangelo (Bern) and Bastian Kubis (Bonn). M. Ramsey-Musolf gave an overview of the status and open issues concerning hadronic contributions to  $(g - 2)_\mu$ , highlighting the LBL contributions by the  $\pi^0$  as well as the charged pion loop. J. Bijnens also gave a comprehensive theoretical overview on LBL scattering, with results from calculations based quark-loop models, VMD models and ChPT. B. Kubis presented a detailed analysis on the  $\pi^0$  form factor based on ChPT and dispersion theory, which is important to improving the calculations of the  $\pi^0$  contributions to LBL scattering with virtual photon(s). G. Colangelo presented a new analysis in progress of LBL scattering in the framework of dispersion theory which naturally encompasses a broader class of contributions, bringing the theoretical study of LBL to a new level of theoretical development.

During the workshop the participants engaged in fruitful and enlightening discussions, which served to focus on the outstanding issues and in devising strategies to address them. Here a brief summary of those discussions is provided.

The impact of the prospective JEF measurement of  $\eta \rightarrow 3\pi$  vis-à-vis the accurate determination of the ratio  $Q^2$  was discussed. From this discussion the recommendation was made to consider not only the already proposed measurement of  $\eta \rightarrow 3\pi^0$  but also the final state with charged pions. Improved accuracy of the measurement of the Dalitz distribution of the  $\eta \rightarrow \pi^0\pi^+\pi^-$  should be a future goal. In addition, concerning the total rate the bench mark set by  $\eta \rightarrow \gamma\gamma$  width in the Hall D already approved Primakov experiment should improve the absolute rate determination of the  $3\pi$  channels. This experimental progress along with the theoretical one will significantly improve the accuracy of the quark mass ratio  $Q$ .

A discussion followed on a more accurate measurement of the  $\eta \rightarrow \pi^0\gamma\gamma$  decay as a probe for hadronic physics, namely VMD and scalar meson contributions. Also the possible sensitivities of this channel to particular BSM physics was highlighted as a challenge to theorists to find scenarios new physics could show up in this. In addition the chiral anomaly driven decay  $\eta \rightarrow \pi^+\pi^-\gamma$  was discussed and considered as a prospective channel for JEF, which could potentially add to the recent results from other facilities mentioned earlier. The very suppressed in the SM  $\eta \rightarrow 3\gamma$  decay represents one of the most sensitive channels in  $\eta$  physics for new physics. Here also theorists

have been encouraged to find potential scenarios of BSM physics affecting this channel.

A possible discovery window was identified for a new dark B-boson search through  $\eta \rightarrow B\gamma \rightarrow \pi^0\gamma\gamma$  in the 140-550 MeV mass range, which has not been explored by any on-going search experiments in the World. The JEF experiment with two orders of magnitude background reduction in the multi-photon final states will be a niche to probe this unexplored parameter space in the dark sector.

The problem of measurements of the  $\pi^0$  form factors as well as measurements of the pion (generalized) polarizabilities at JLab and KLOE were discussed, as they are important for the improvement of the calculations of LBL scattering.

The coordination of experimental efforts at different facilities, namely MAMI, JLab, Frascati and other facilities was also a point of discussion, which is a topic to be further pursued. A continued discussion of the JEF capabilities, which is the only facility that could cover both  $\eta$  and  $\eta'$  physics with similar kinematics, was encouraged.

Theoretical efforts have been encouraged, with the formation of two working groups, one focusing on the chiral dynamics and the other on BSM physics aspects. It is hoped that these working groups will be integrated and active during the Summer of the current year.

Finally, strategies for going forward were discussed. Among them the editing of a white paper where the area of hadronic probes of fundamental symmetries is explored and proposals for experimental and theoretical efforts are identified. Additional efforts through working groups involving experts in the various areas of key importance was suggested. At present a follow up workshop is being planned for the Fall 2014 for the purpose of further advancing the studies addressed in this past first workshop.

### List of participants

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