Executive Summary

MITP Scientific Program
"Composite Dynamics: from Lattice to the LHC Run II"

4-15 April 2016, Mainz Institute for Theoretical Physics, Johannes Gutenberg University

The main goal of this MITP program is to bring together experts from various communities under the flag of understanding the role of strongly interacting theories in particle physics and cosmology, with special focus on theories beyond the Standard Model (BSM). The expertise from the participants to the program ranged from Lattice calculations to collider phenomenology, from Dark Matter to field theory in the strong coupling regime, from model building of Composite Higgs to Cosmology. The great array of interests combined with the flexible schedule created a fertile environment for discussions and exchange of ideas. We organised one informal topical talk per day, in the morning, often co-chaired by two speakers presenting the subject in a critical and provocative way. In the afternoon, time was dedicated to collaborative work and discussion sessions, often organised by the participants themselves. A few afternoon talks were proposed by the participants. All in all, the program was a great success thanks to the many discussions we had during the two weeks.

Many topics were touched upon, a comprehensive description of which goes beyond a summary. The main physics questions that were raised during the workshop are listed below.

- *What can Lattice results add to our understanding of strongly interacting BSM models? What theories should be studied on the Lattice?*
- *What are the key ingredients for natural composite Higgs models? How can solid predictions be made for the LHC Run-II?*
- *Are there any hints for composite dynamics in the data? What did we learn from the (now gone) excesses in di-boson at 2 TeV and di-photon at 750 GeV?*
- *Are there new fundamental theories that have not been studied yet? Is asymptotic freedom a must?*

Lattice results

Enormous progress has been achieved in Lattice calculations aiming at BSM theories. However, many open questions still remain unanswered, as we do not know which underlying theory is most promising in describing a viable model. New Lattice results were presented during two topical talks by J.Kuty and C.Pica during the first week, and E.Pallante and L.del Debbio during the second. In particular,

there were heated discussions on how a conformal behaviour can be detected on the Lattice. This is a challenging issue as the Lattice itself, due to the discretisation of space-time, is not conformal invariant. Yet, conformality, i.e. the existence of a fixed point in the InfraRed, may play an important role in BSM composite dynamics, especially in relation to the flavour problem. The generalisation of QCD to many flavours already poses a challenge, as it is not clear if the conformal window starts at 8 or 12 Dirac flavours. Detecting signs of conformal behaviour relies on a precise understanding of Lattice effects and on the scaling properties of various quantities. For phenomenology, another important issue is the existence of a light composite scalar resonance that may be identified with the spontaneous breaking of scale invariance - growing evidence is appearing on the Lattice, however how to identify such an object remains unclear.

Underlying theories: model building

Composite Higgs models have been mainly studied at the level of effective Lagrangians. The issue on how to define underlying theories based on strongly interacting gauge-fermion models was presented by G.Ferretti and L.Vecchi. During the discussion, it became clear that the key ingredient is the origin of the top mass. Defining an underlying theory of gauge-fermion interactions is a very handy tool to study this issue. One mechanism which became popular recently is the so-called partial compositeness, where fermions become massive by mixing with heavy fermionic bound states. This mechanism is an alternative to the more traditional bilinear four-fermion interactions, where a bilinear of fermions couples to a bilinear of the condensing fermions. The former mechanism, thus, relies on the fact that the fermionic bound states have a larger anomalous dimension that the scalar bilinear, so that the former becomes a relevant operator at low energies before the scalar one does. During the workshop, the issue of anomalous dimensions has been explored in some detail. The concept of anomalous dimensions only makes sense at a fixed point where the theory is conformal, while theories of composite Higgs are, by necessity, not conformal. Also, preliminary calculations were presented by participants showing that it seems unlikely that the anomalous dimension of the fermionic operator is larger than the one of the scalar operator. This result has been achieved in the perturbative regime by means of higher loop computations. Results on the Lattice are ongoing for some of the models discussed during the workshop. This proves the usefulness of having workshops where these communities can meet and exchange ideas. Another key point that has been raised regards the prediction of the Higgs mass, which originates form the spurions related to the top mass. Lattice calculations can help predict some of the form factors that appear in the low energy Lagrangian.

Dark Matter and Cosmology

The issue of the presence of a Dark Sector in composite models has been touched upon in the presentation by M.T.Frandsen and O.Antipin. Many candidates exist in

generic composite scenarios, from fermionic bound states which may be protected by an analogue of the baryon number to additional pions. Some issues related to model building have been touched upon, pointing towards the fact that a systematic study of the presence of Dark Matter candidates is still lacking. K.Tuominen also presented results on the role of (elementary) scalars in Cosmology.

The 750 di-photon excess

In 2015, excitement has been spreading in the community following the announcement of significant excesses in bi-boson (WW, ZZ and WZ in the fully hadronic channel) at a mass of 2 TeV and di-photon at 750 GeV. The newest results announced at Moriond Conference, shortly before the MITP meeting, had confirmed the di-photon one, while disfavouring the 2 TeV di-boson. This situation has been discussed during the meeting, where N.Vignaroli presented general results on the role topological terms can play for the phenomenology of composite models. In fact, via topological anomalies, some of the pions naturally couple to pairs of gauge bosons, with coefficients that are sensitive to the details of the underlying theory, namely the dimension of the representation of the underlying fermion under the confining gauge interactions. Thus, composite pions offer a natural candidate for any resonance in a channel with two gauge bosons. Some explicit examples where discussed during the meeting. Due to the interest of the community, shorter presentations where organised by M.Bauer, A.Carmona and P.Ko who discussed how other models may fit the data. Models in extra dimensions as well as weakly interacting models were discussed. The general consensus has been that composite models seem to fit the excess more comfortably that extra dimensions or weakly coupled models. Even though the di-photon excess was not confirmed by further data in 2016, the exercise proved very useful in characterising and understanding the physics that may lie behind future signals in these channels. A more general overview of collider searches related to compositeness has also been given by A.Belyaev.

Summary and perspectives

In the view of the organisers, the program has been a great success, thanks to the participation of leading scientists from all over the world and belonging to various communities. The scientific program has been left light, with only one informal presentation per day. Often, the morning presentation merged with the discussion time, thus leading to interesting exchange of ideas. We believe, and hope, that the program initiated new collaborations between the participants.

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