Research Mid-term Report for NSC 96-2112-M-009-020-MY3

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Abstract: My main research interest is the effect of strongly-coupled gauge theories in electroweak physics at the era of Large Hadron Collider (LHC). This is reflected in two main research avenues that I am pursuing, namely the scenario of electroweak symmetry breaking via a strongly coupled gauge theory at TeV scale, and the physics of Λ_b baryons which is the main subject of the LHC-b project. The tool that I am using is large-scale numerical calculations with lattice gauge theory. In this article, I summarise the progress from June 2007 to May 2008 in this research direction, funded by the NSC through grant 96-2112-M-009-020-MY3.

I. BACKGROUNDS AND GOALS

There is strong evidence that physics beyond the Standard Model (SM) should start to reveal itself at the TeV scale. During the last two decades, particle physicists have relied on precision measurements in kaon and B-meson systems to try to investigate new physics. In this process, lattice gauge theory has played an important rôle in pinning down hadronic matrix elements. In the coming era of the LHC, part of this effort will carry on (*e.g.*, the LHC-b project). In addition, we can hopefully study the mechanism of the electroweak symmetry breaking with this powerful accelerator. My main goal is to apply lattice gauge theory to LHC-related research topics in these two directions. For the former, I am studying the physics of Λ_b baryons with colleagues in the USA and UK. As for the latter, I am setting up collaboration with physicists in Kyoto, Japan. Lattice calculations often take a long time to complete, especially I have just moved to the faculty job at Chiao-Tung University and have had to spend a long time setting up computer hardwares and codes. Nevertheless, we have started to produce promising results which will be discussed in the following sections.

A. Summary of Publications from 2007-7-1 to 2008-5-31

1. William Detmold and C.-J. David Lin, 2007 *Chiral behaviour of matrix elements of $\Delta B = 2$ and $\Delta C = 2$ operators*, PoS(LATTICE 2007), 361, **arXiv:0710.0413 [hep-lat]**, supported by NSC 96-2112-M-009-020-MY3.

II. SUMMARY OF RESEARCH PROGRESS AND RESULTS

A. Physics of the Λ_b baryon

The rare decay channels $\Lambda_b \to \Lambda\gamma$ and $\Lambda_b \to \Lambda l^+ l^-$ are sensitive to new physics effects involving the mixing of quarks via right-handed coupling structure that is absent in the Standard Model. This structure cannot be probed by existing experiments performed with the B mesons which do not carry spin. With William Detmold and Matthew Wingate, I have set up a programme to pin down the relevant matrix elements in the above decay channel as out final goal. In order to achieve this, many other preceding projects are needed, including the determination of the coupling constants amongst heavy-light-light baryons and pions. We are also working on some side projects, *e.g.*, the B hadron lifetime ratios. However, in order to study any of these, we have to investigate the spectrum of the heavy-light-light baryons on the lattice to confirm that we can indeed extract signals for these baryons.

During the last year, I have spent a lot of time to set up hardwares in Hsinchu for this long project. With the support from this NSC grant and National Chiao-Tung University, I have succeeded in acquiring a PC cluster with 24 nodes, each node contains two quad-core CPUs and 16 GB memory. Twenty out of these 24 nodes are connected by a 20-Gb infiniband network. Also, we have performed some spectrum study and the result is very encouraging, *i.e.*, we can extract signals for the heavy-light-light baryons!

In our project, we use the dynamical gauge configurations generated and kindly lent to us by the RBC Collaboration. The lattice size is 24×64 with lattice spacing around 0.1 fm. The 2+1 flavours of dynamical quarks in these RBC configurations are domain wall fermions. We also use the same fermions for our valence light quarks. For the heavy quark, we use the static approximation.

To study the Λ_b spectrum, one starts from the Euclidean correlator

$$C_{\Lambda_b}(\vec{p}, t) = \int d^3x \; \mathrm{e}^{i\vec{p}\cdot\vec{x}} \langle 0 | \mathcal{O}_{\Lambda_b}(\vec{x}, t) \mathcal{O}^\dagger_{\Lambda_b}(0) | 0 \rangle, \quad (1)$$

where $\mathcal{O}_{\Lambda_b}$ is the interpolating operator for the Λ_b baryon. Figure 1 shows a correlator of this kind on all the 176 configuration in our work. At large Euclidean time, this correlator is dominated by the one-Λ_b contribution and will behave like

$$C_{\Lambda_b}(\vec{p}, t) \sim \frac{\mathrm{e}^{-E_{\Lambda_b} t}}{2E_{\Lambda_b}}. \quad (2)$$

One can then look at the effective mass defined as

$$M(t) = \ln \left[\frac{C(\vec{0}, t)}{C(\vec{0}, t+1)} \right] \quad (3)$$

and identify the Λ_b state. Notice that the correlators for such baryons, especially that we are using the static heavy-quark action, tend to be very noisy. Therefore we have also performed the study of "smearing". From Figure 2, we can clearly see the difference between a "good" and a "bad" choice of the smearing parameters. From this figure, we can also conclude that we definitely can isolate a Λ_b state from the plateau around time slice 10.

We have also looked at the effective mass plots for Σ_b baryons and confirmed that we can extract signals for these baryons on our lattices.

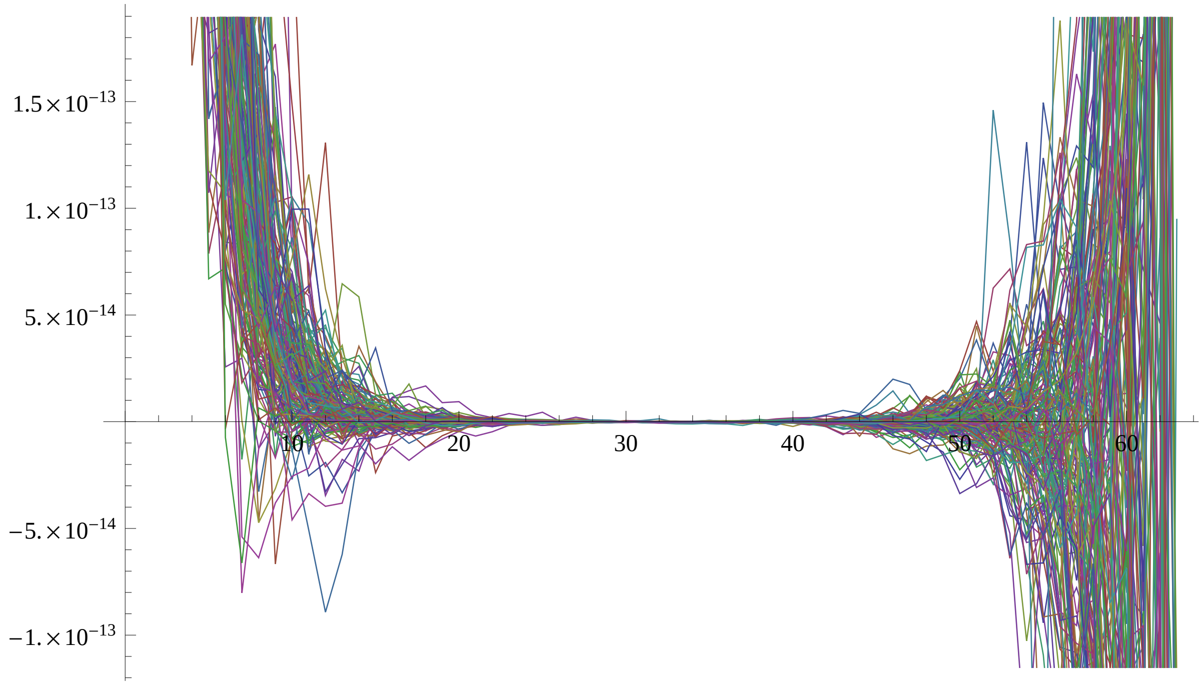

FIG. 1: The correlator $C_{\Lambda_b}(\vec{0}, t)$ in Eq. (1) configuration by configuration in our calculation with both sea quark mass and valence quark mass set to 0.01 in lattice units.

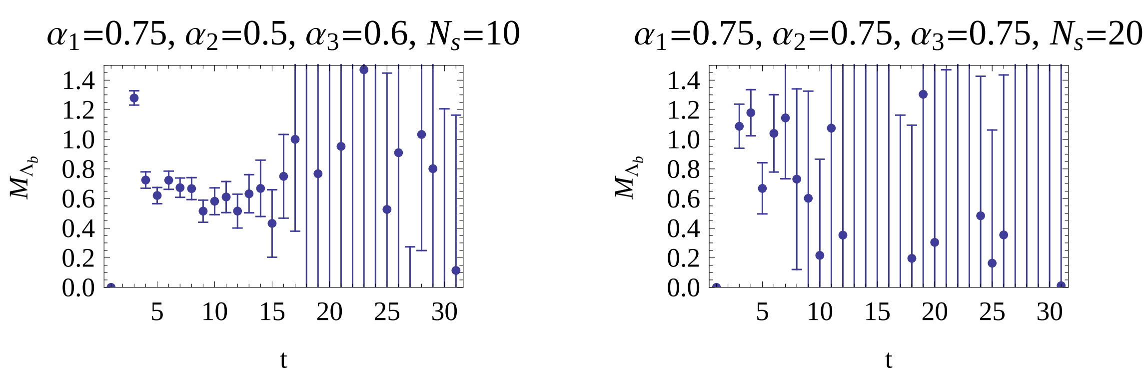

FIG. 2: The effective mass in lattice units for the Λ_b state in our calculation. The plot on the left is from a "good" choice for smearing parameters α_i and N_s, while the one on the right is from a "bad" choice.

B. Walking technicolour on the lattice

Walking technicolour is one of the candidates that solve the electroweak symmetry breaking at TeV scale without the need for the Higgs particles. It is a strongly-coupled gauge theory, hence lattice gauge theory can play an important rôle in this research avenue. At the moment, I have formed a collaboration with physicists at the Yukawa Institute at the University of Kyoto. We are studying the running of the coupling constant in gauge theories which may have stable infra-red fixed points. Exploratory result in the Schroedinger functional scheme using the step-scaling method was reported by Appelquist and collaborators recently. We will perform similar calculations in the twisted-Polyakov-line scheme and the Creutz-ratio scheme.

At the moment, we have resolved all the theoretical issues and numerical results should appear soon.

In the future, we will also try to compute the running of the condensate in these theories. This is the most crucial point in hunting for a walking technicolour theory.

III. TRAVEL GRANT

I used the NSC travel grant to visit University of Cambridge for around three weeks in January/February 2008. During the visit, I set up the runs for generating valence quark propagators for the Λ_b project on PC clusters with Matthew Wingate. I also discussed a side project on the D^* meson mass with Ron Horgan.