Research Final Report for NSC 96-2112-M-009-020-MY3

Chi-Jen David Lin

(Dated: January 2011)

Keywords: Lattice QCD, PC cluster, LHC-b, Λ_b baryons, electroweak symmetry breaking, walking technicolour

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 theories 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 October 2010 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 field 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 Japan, DESY Zeuthen, as well National Taiwan University.

A. Summary of Publications from June 2007 to October 2010

1. Etsuko Itou, Tatsumi Aoyama, Masafumi Kurachi, C.-J. David Lin, Hideo Matsufuru, Hiroshi Ohki, Tetsuya Onogi, Eigo Shintani, Takeshi Yamazaki,
   Search for the IR Fixed Point in the Twisted Polyakov Loop Scheme (II),
   PoS LATTICE2010:054, 2010.

2. Hiroshi Ohki, Tatsumi Aoyama, Etsuko Itou, Masafumi Kurachi, C.-J. David Lin, Hideo Matsufuru, Tetsuya Onogi, Eigo Shintani, Takeshi Yamazaki,
   Study of the Scaling Properties is SU(2) Gauge theories with Eight Flavours,
   PoS LATTICE2010:066, 2010.

3. Erek Bilgici, Antonino Flachi, Etsuko Itou, Masafumi Kurachi, C.-J. David Lin, Hideo Matsufuru, Hiroshi Ohki, Tetsuya Onogi, Eigo Shintani, Takeshi Yamazaki, *Search for the IR Fixed Point in the Twisted Polyakov Loop Scheme*, **PoS LATTICE2009:063, 2009**.

4. Stefan Meinel, William Detmold, C.-J. David Lin, Matthew Wingate, *Bottom Hadrons from Lattice QCD with Domain Wall and NRQCD Fermions*, **PoS LATTICE2009:105, 2009**.

5. Erek Bilgici, Antonino Flachi, Etsuko Itou, Masafumi Kurachi, C.-J. David Lin, Hideo Matsufuru, Hiroshi Ohki, Tetsuya Onogi, Takeshi Yamazaki, *A New scheme for the running coupling constant in gauge theories using Wilson loops.*, **Phys.Rev.D80:034507, 2009**.

6. William Detmold, C.-J. David Lin, Matthew Wingate, *Bottom hadron mass splittings in the static limit from 2+1 flavour lattice QCD*, **Nucl.Phys.B818:17-27, 2009**.

7. Erek Bilgici, Antonino Flachi, Etsuko Itou, Masafumi Kurachi, C.-J. David Lin, Hideo Matsufuru, Hiroshi Ohki, Tetsuya Onogi, Takeshi Yamazaki, *A New Method of Calculating the Running Coupling Constant*, **PoS LATTICE2008:247, 2008**.

8. William Detmold, C.-J. David Lin, *Chiral Behaviour of Matrix Elements of $\Delta B = 2$ and $\Delta C = 2$ Operators*, **PoS LATTICE2007:361, 2007**.

9. William Detmold, C.-J. David Lin, *Matrix Elements of the Complete Set of $\Delta B = 2$ and $\Delta C = 2$ Operators in Heavy Meson Chiral Perturbation Theory*, **Phys.Rev.D76:014501, 2007**.

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. We have finished this spectrum calculation and the result has been published in Nuclear Physics B.

With the support from this NSC grant and National Chiao-Tung University, I have set up 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

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

where $\mathcal{O}_{\Lambda_b}$ is the interpolating operator for the Λ_b baryon. At large Euclidean time, this correlator is dominated by the one-Λ_b contribution and will behave like

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

One can then look at the effective mass defined as

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

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 1, 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 finished this spectrum calculation and the results are summarised in Figure 2.

In this researhc programme, right now we are computing the coupling constants that appear in Heavy-Hadron Chiral Lagrangian. It is important to compute these couplings to high precision, since they appear in the formulae for extrapolating heavy-hadron matrix elements to physical quark masses. To calcualte these couplings, we insert appropriate currents in the correlator in Eq. (1). We have enough lattice data to constrain them to a few percent. These computations will be finished by the summer of 2011 and will be published soon after that.

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 in Japan to work on this topic. We

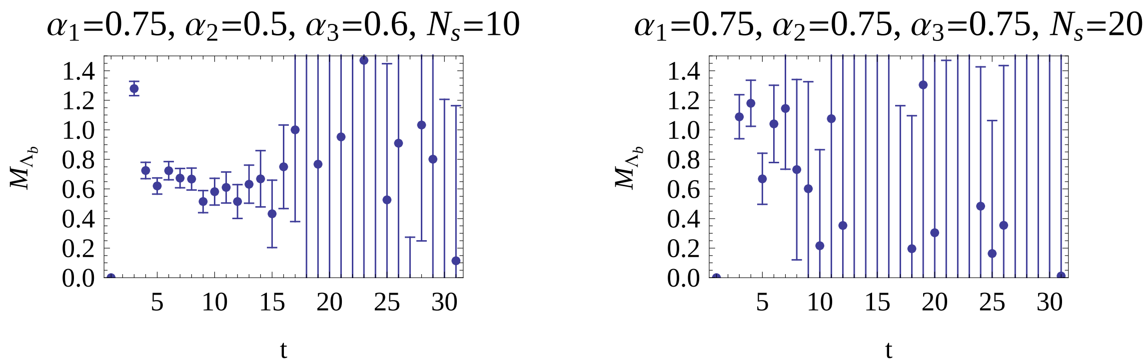

FIG. 1: The effective mass in lattice units for the Λ_b state in our calculation. The plot on the left is from a "good" choice for smearing parameters α_i and N_s, while the one on the right is from a "bad" choice.

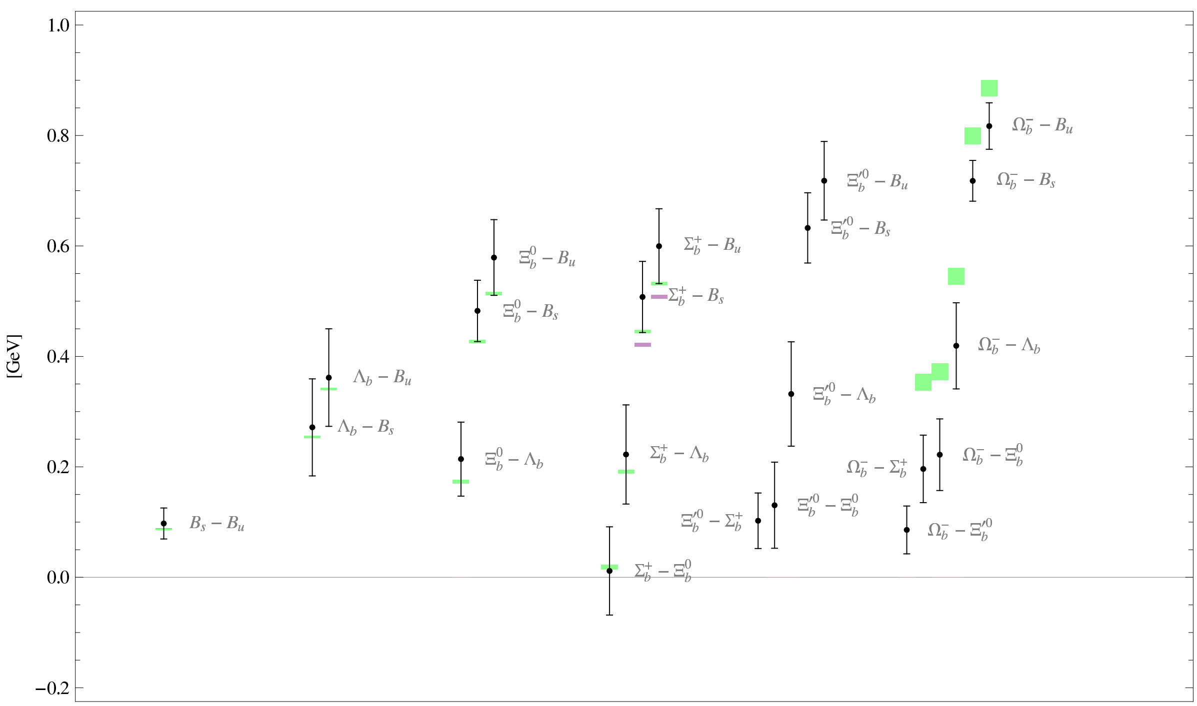

FIG. 2: The spectrum of b hadrons.

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.

The Creutz-ratio scheme is our new proposal for defining the coupling constant non-

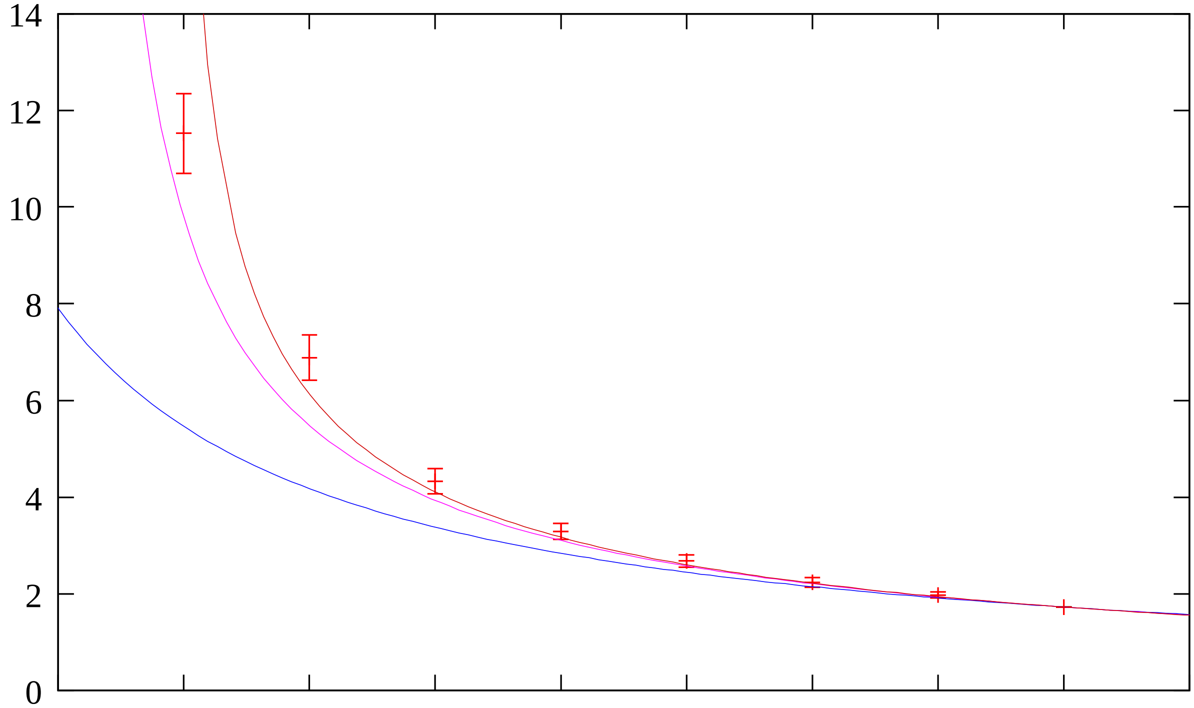

FIG. 3: The running coupling constant calculated in the Creutz-ratio scheme. The $x-$axis is momentum scale and the $y-$axis is the coupling constant. The curves are one-, two- and three-loop perturbative results.

perturbatively. Therefore we had to perform a numerical feasibility study. We have finished this task using the pure Yang-Mills theory and the result was published in Phys. Rev. D. Figure 3 is the result of this calculation, and it is evident that the scheme is valid.

At the moment, we are performing dynamical simulation in the Polyakov scheme for SU(3) gauge theoy with 12 flavours of fermions in the fundamental representation. Our prelimenary results show that the running of the coupling constant in this theory does slow down in the IR. Figure 4 shows our current results. In this plot, u is the coupling constant at a certain scale, and σ is the corresponding coupling constant after enlarging the length scale by a factor of 1.5. On the other hand, it requires further investigation to conclude whether or not there exists an IR fixed point. Right now we are performing more simulations on large lattices in order to resolve this issue. We have reported the progress of this study at sevel conferences and will publish a journal paper on this project in 2011.

We are also studying the SU(2) gauge theory with eight flavours of fermions in the fundamental representation. The status of this computation is similar to that of the SU(3), 12-flavour calculation.

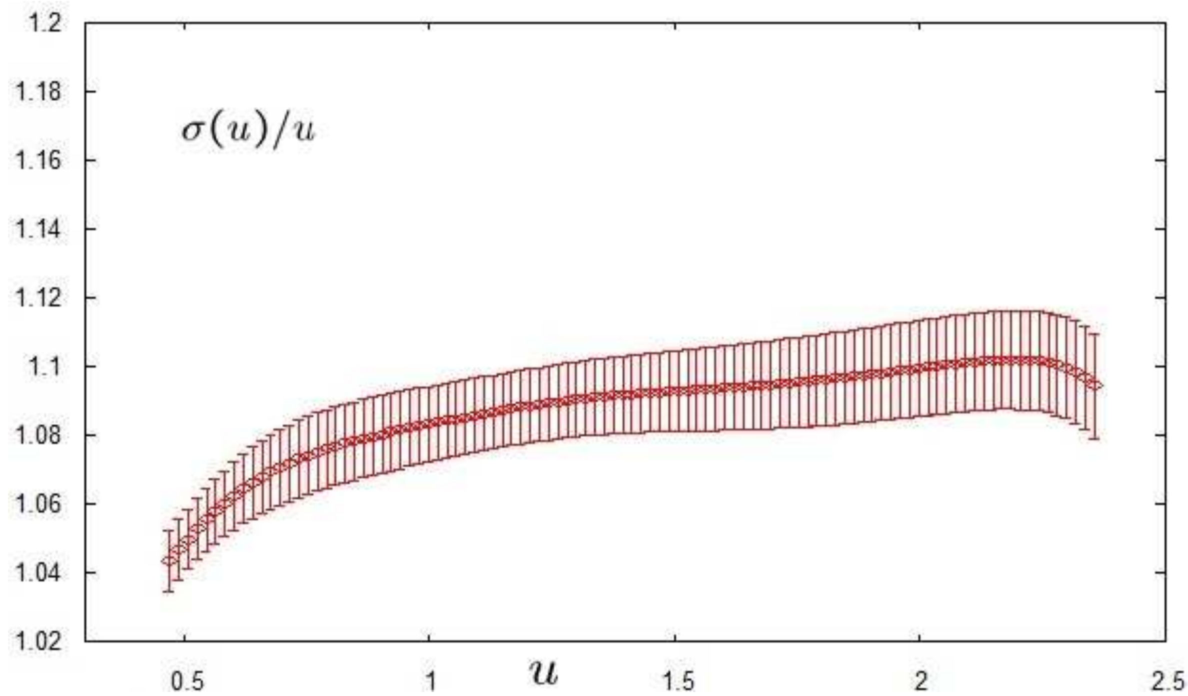

FIG. 4: In this plot, u is the coupling constant at a certain scale, and σ is the corresponding coupling constant after enlarging the length scale by a factor of 1.5.