The spectrum of static-light baryons in twisted mass lQCD
Lattice 2010

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Abstract

- Compute the static-light baryon spectrum with $N_f = 2$ flavors of sea quarks using wilson tm lQCD.
- Unitary light quarks as well as partially quenched light quarks (mass of physical strange quark)
- Masses of states with isospin $I = 0$, $I = 1/2$ and $I = 1$, with light cloud angular momentum $j = 0$ and $j = 1$, and with parity $P = +$ and $P = -$.
- Preliminary extrapolation in the light u/d and in the heavy quark mass to the physical point and compare with available experimental results.

Introduction

- Static light baryon: a bound state of an infinite heavy quark and two light quarks
- Approximation of a B-baryon
- States are classified by: flavor, angular momentum, parity and isospin
- Many low-lying states accessible on the lattice
- Our goal: compute the masses of experimental known and unknown states

The form of baryon operators

We use operators of the form:

$$\mathcal{O}_\Gamma = \epsilon^{abc} Q^a \left((q^b)^T \mathcal{C} \Gamma q^c \right)$$

Where $\mathcal{C} = \gamma_0 \gamma_2$ and Γ a suitable combination of γ matrices yielding well-defined spin and parity
We require:

- gauge invariance
- well-defined spin (light quarks have relative angular momentum 0, i.e. are in a S wave)
- well-defined parity
- well-defined isospin

The heavy quark operator

Baryon creation operator:

$$\mathcal{O}_\Gamma = \epsilon^{abc} Q^a \left((q^b)^T \mathcal{C} \Gamma q^c \right)$$

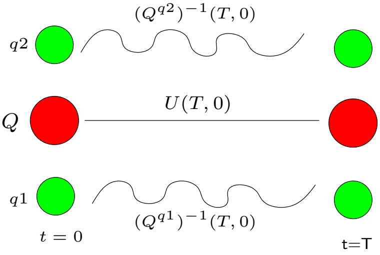
- In the operator, Q represents the bottom quark.
- We treat it in the static approximation. (legitimate because of its large mass)
- Choosing an infinite heavy quark implies that we can only compute mass differences to bottom particles (e.g. the B meson).
- Use HQET to write its propagator as:

$$\left(Q^B\right)^{-1}(x,y) \sim \delta^{(3)}(\mathbf{x}-\mathbf{y}) U(\mathbf{x}, x_0; \mathbf{y}, y_0)$$

The light quark operators

$$\mathcal{O}_\Gamma = \epsilon^{abc} Q^a \left((q^b)^T \mathcal{C} \Gamma q^c \right)$$

- q represents the light quarks; we studied up, down and partially quenched strange quarks.
- For two light quarks we use $qq \equiv$ uu, dd, ud+du, ud-du to obtain well-defined isospion.



List of baryon operators

$$\epsilon^{abc} Q^a \left((q^b)^T \mathcal{C} \Gamma q^c \right)$$

creation operator	$j^{\mathcal{P}}$	J	I	u/d	I	ud/s	I	s/s
$\Gamma = \gamma_5$	0^+	$1/2$	0	Λ_b	$1/2$	Ξ_b	—	—
$\Gamma = \gamma_0\gamma_5$	0^+	$1/2$	0	Λ_b	$1/2$	Ξ_b	—	—
$\Gamma = \mathbb{1}$	0^-	$1/2$	0	?	$1/2$	?	—	—
$\Gamma = \gamma_0$	0^-	$1/2$	1	?	$1/2$	?	0	?
$\Gamma = \gamma_j$	1^+	$1/2, 3/2$	1	Σ_b	$1/2$	(Ξ_b)?	0	Ω_b
$\Gamma = \gamma_0\gamma_j$	1^+	$1/2, 3/2$	1	Σ_b	$1/2$	(Ξ_b)?	0	Ω_b
$\Gamma = \gamma_j\gamma_5$	1^-	$1/2, 3/2$	0	?	$1/2$	?	—	—
$\Gamma = \gamma_0\gamma_j\gamma_5$	1^-	$1/2, 3/2$	1	?	$1/2$	?	0	?

the twisted mass fomalism

Computing was done using the twisted mass fermionic action
$S_F[\chi,\bar{\chi},U] = a^4 \sum_x \bar{\chi}\left(i\gamma^\mu \mathcal{D}_\mu - \frac{a}{2}\Box + m + i\mu\gamma_5\tau_3\right)\chi$
$\psi = \exp\left(i\omega\gamma_5\tau_3/2\right)\chi, \quad \bar{\psi} = \bar{\chi}\exp\left(i\omega\gamma_5\tau_3/2\right)$

- \+ $\mathcal{O}(a)$ improvement
- \+ Wilson formalism → fast
- − parity and flavor breaking
- − ⇒ different quantum numbers, correlation matrices

⇒ Choose the operators with well-defined twisted quantum numbers.

⇒ Interpret physical content of states by means of eigenvector components from GEP and rotating them back to the pseudo physical basis

Correlation matrices

Considering correlation matrices

$$C_{\Gamma_j,\Gamma_k}(t) = \langle\Omega|\mathcal{O}_{\Gamma_j}(t)\mathcal{O}_{\Gamma_k}(0)^\dagger|\Omega\rangle$$

for each sector corresponding to twisted quantum numbers ($\mathcal{P}^{(tm)}$, I_z, j), we get:

$$C_{\Gamma_j,\Gamma_k}(t) = \epsilon^{abc}\epsilon^{def}$$

$$\left\langle U^{ad}(t,0)\mathrm{Tr}_{\mathsf{spin}}\left(\Gamma_1\left[\left(Q^{\chi^{q_1}}\right)^{-1}\right]^{cf}(t,0)\;\Gamma_2\left[\left(Q^{\chi^{q_2}}\right)^{-1}\right]^{be}(t,0)\right)\right\rangle$$

Many matrix elements are related by the twisted mass symmetries. (γ_5 hermiticity, time reversal, parity, charge conjugation, cubic rotations) ⇒ we can compute the averages.

Simulation setup

We used the following setup:

Gauge configurations:

β = 3.9 ($a \approx 0.08$ fm), L/a = 24 (1.922 fm), T/a = 48 (3.8448 fm)

in the following preliminary results obtained with 270 gauge confs: 200 (m_π = 336 MeV) + 40 (m_π = 417 MeV) + 30 (m_π = 517 MeV)

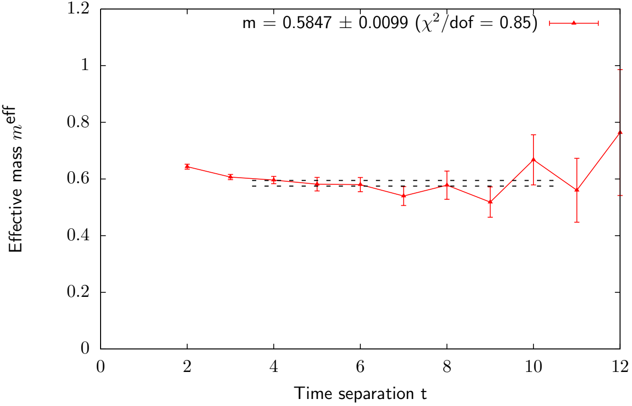
Inversions:

2x12 timediluted stochastic sources for each gauge conf, μ = 0.0040, 0.0064, 0.0100 (m_π = 336 MeV, 417 MeV, 517 MeV) for ud-quarks, μ = 0.0220 for partially quenched s-quarks

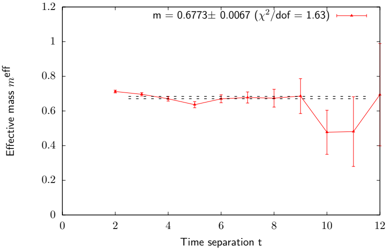
Smearing:

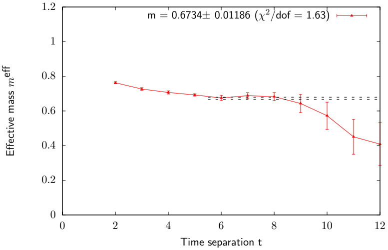
quark fields: Gaussian smearing (3 different smearing levels)
Spatial links: APE smearing (1 smearing level)
Temporal links: HYP2 static action

- $\Lambda_b \rightarrow$ QCD quantum numbers $I = 0$, $j^{\mathcal{P}} = 0^+$
- 3 x 3 correlation matrix, u/d quark, $\mu = 0.0040$
- experiment $m(\Lambda_b) - m(B) = 339.2(1.4)$MeV
- $m - m(B) = 461(24)$MeV

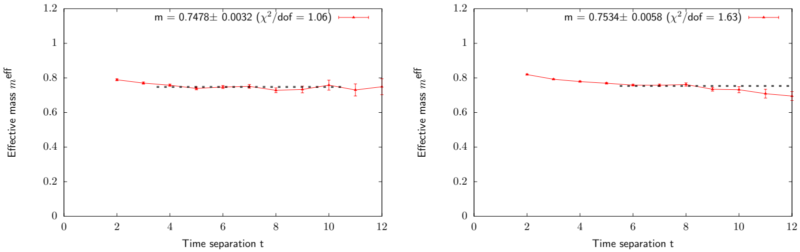


- $\Sigma_b \rightarrow$ QCD quantum numbers $I = 1$, $j^{\mathcal{P}} = 1^+$
- 3 x 3 correlation matrix, (u/d), (u/u, d/d) quarks
- experiment $m(\Sigma_b) - m(B) = 525 \ldots 560$ MeV
- $m - m(B) = 689(7)$ MeV, $m - m(B) = 680(15)$ MeV

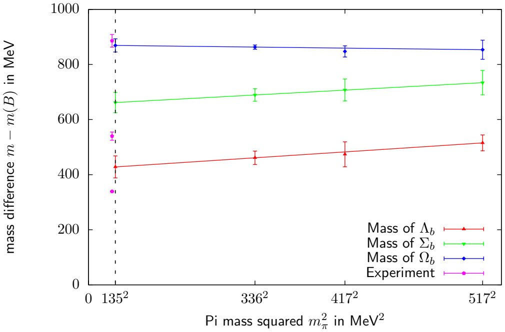




- $\Omega_b \rightarrow$ QCD quantum numbers $j^{\mathcal{P}} = 1^+$
- 3 x 3 correlation matrix, (s+/s-), (s+/s+, s-/s-) quarks
- experiment $m(\Omega_b) - m(B) = 886(23)$MeV (775(7) MeV CDF-Data)
- $m - m(B) = 863(8)$ MeV, $m - m(B) = 876(7)$ MeV



Extrapolation in the light quark mass



- $\Lambda_b : 428(40)$ MeV (experiment: 341(1) MeV)
- $\Sigma_b : 661(37)$ MeV (experiment: 525 ... 560 MeV)
- $\Omega_b : 869(25)$ MeV (experiment: 886(23) MeV (775(7) MeV CDF-Data))

Problems

- $\Rightarrow$ Masses for baryons with light quarks are to high (≈ 100 MeV)
- Possible reasons
  - Is linear fit appropriate in the physical u/d quark region?
  - Dependence on the heavy quark mass
  - Scale setting (from light mesons) corresponds to $r_0 = 0.42$ fm

- Comparison with other results ($r_0 = 0.49$ fm)
- $m(\Lambda_b)r_0 = 0.91(9)$ $(0.89(14)^\dagger)$
- $m(\Sigma_b)r_0 = 1.41(8)$ $(1.38(14)^\dagger)$

† [T. Burch et al., Phys. Rev. D **79**, 014504 (2009) [arXiv:0809.1103 [hep-lat]]]

Results compared to experimental results

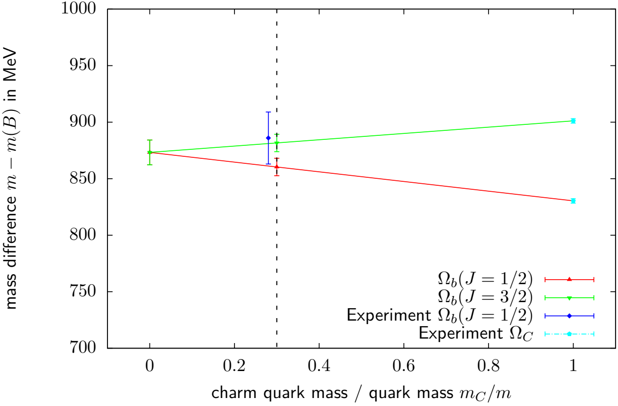
baryon	$j^{\mathcal{P}}$	I	$m - m(B)$ our result [MeV]	$m - m(B)$ experiment [MeV]
Λ_b	0^+	0	$428(42)$	$339, 2(1.4)$
$\Sigma_b(ud)$	1^+	1	$661(37)$	$525 \ldots 560$
$\Sigma_b(uu)$	1^+	1	$653(33)$	$525 \ldots 560$
$\Xi_b(s^- u)$	0^+	$1/2$	$622(32)$	$513(3)$
$\Xi_b(s^+ u)$	0^+	$1/2$	$668(24)$	$513(3)$
$\Omega_b(s^+ s^-)$	1^+	–	$869(25)$	$886(23)$ $(775(7))$
$\Omega_b(s^+ s^+)$	1^+	–	$891(23)$	$886(23)$ $(775(7))$

Results without experimental results

baryon	$j^{\mathcal{P}}$	I	$m - m(B)$ our result [MeV]	$m - m(B)$ experiment [MeV]
$(\Xi_b)?(s^-u)$	1^+	$1/2$	$778(32)$	$??$
$(\Xi_b)?(s^+u)$	1^+	$1/2$	$787(37)$	$??$
$??(ud)$	1^-	1	$994(82)$	$??$
$??(ud)$	1^-	1	$999(68)$	$??$
$??(s^+u)$	0^-	$1/2$	$1184(76)$	$??$
$??(s^-u)$	0^-	$1/2$	$1244(59)$	$??$
$??(s^-u)$	1^-	$1/2$	$1216(59)$	$??$
$??(s^+u)$	1^-	$1/2$	$1267(48)$	$??$
$??(s^+s^-)$	1^-	$-$	$1280(57)$	$??$
$??(s^+s^+)$	1^-	$-$	$1297(59)$	$??$
$??(ud)$	0^-	0	$1370(98)$	$??$
..	..	..	..	..

Interpolation in the heavy quark mass

We used experimental results for charmed baryons to perform an interpolation in the heavy quark mass and observe spin splitting.



Conclusion & Future plans

Achievements

- So far we computed the masses of 10 QCD states (4 are experimentally known); due to tm isospin and parity breaking these 10 states correspond to 18 tm states
- We considered 3 light quark masses and did an extrapolation to the physical point.
- Problem: Several masses we extracted are too high.

Future plans

- Increase statistics, find excited states
- Consider other light quark masses for extrapolation
- Continuum limit

Ideas for the future

- Use $N_f = 2 + 1 + 1$ configurations for calculation of static-strange quarks