Baryon spectrum

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ETM Collaboration

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Outline

- Twisted fermions
- Lattice setup
- Octet of $J = \frac{1}{2}^+$ Baryon
- Chiral extrapolation
- Isospin breaking effects
- $\Omega$ baryon
Simulations

♦ fermions: $N_f = 2$ maximally twisted mass QCD

→ fermionic action composed of a quark doublet.

→ formally equivalent to QCD in the continuum limit and infinite volume limit

→ automatic $O(a)$ improvement

→ But: explicit breaking of parity and isospin in the action
Lattice setup

- three lattice spacings: 0.066 – 0.10 fm
- $270 \lesssim m_{PS} \lesssim 600$ MeV
- $L > 2$ fm
- $m_\pi L > 3.2$
Decuplet and Octet

\[ s = 0 \]
\[ s = -1 \]
\[ s = -2 \]
\[ q = 1 \]
\[ q = 0 \]
\[ q = -1 \]
- Partially quenched study: Osterwalder-Seiler strange quark.
- Bare strange quark mass fixed for each value of the lattice spacing in the
  sector of mesons by V. Lubicz et al.
- Lattice spacing fixed using $f_\pi$.
  $\rightarrow$ no parameter fixed in the baryonic sector.
- Mass obtained by computing a 2-points function: i.e. $\langle J(x)J(0) \rangle$.
- Optimization of the interpolating field with smearing: Gaussian + APE.
- Error estimated using Jackknife.
Extraction of masses

Local-Local

\[ M_{\text{eff}} \approx 0.573 \pm 0.015 \quad \chi^2/\text{ndf} \approx 0.960 \]

\[ M_{\text{eff}} \approx 0.590 \pm 0.030 \quad \chi^2/\text{ndf} \approx 0.997 \]

\[ \alpha \sim 0.0855 \text{ fm} \quad m_\pi \sim 310 \text{ MeV} \]
Extraction of masses

Smeared-Smeared

\[ \lambda_{\text{data}} \]

\[ \text{time} \]

**Effective Mass**

\[ \text{data} \]

\[ \text{fit1} \]

\[ \text{fit2} \]

\[ M_1^{\text{eff}} = 0.580 \pm 0.007, \chi^2/\text{ndf} = 0.999 \]

\[ M_2^{\text{eff}} = 0.580 \pm 0.007, \chi^2/\text{ndf} = 0.999 \]

\[ \alpha \sim 0.0855 \text{ fm}, m_\pi \sim 310 \text{ MeV} \]

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*LPSC, Grenoble, V. Drach: Baryon spectrum in tmQCD*
Chiral extrapolation

- Assuming no finite volume and lattice discretization effects
- Polynomial fit of the form:
  \[ M_X = M_0 + aM_\pi^2 + bM_\pi^3 \]
- Nucleon case: \( HB_X pT \rightarrow b_N = \frac{3g_\pi^2}{32\pi f_\pi^2} \)
- Direct extraction of the mass difference between the members of the octet and the nucleon

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Lambda Mass (\(a=0.0855\) fm)

\[ \Delta M^\text{exp} = 0.157 \pm 0.010 \text{ GeV} \]
\[ \Delta M^\text{theo} = 0.176 \text{ GeV} \]

Sigma Mass (\(a=0.0855\) fm)

\[ \Delta M^\text{exp} = 0.225 \pm 0.008 \text{ GeV} \]
\[ \Delta M^\text{theo} = 0.251 \text{ GeV} \]
Chiral extrapolation

- **Linear behaviour**: $b_{octet} \sim b_N \rightarrow$ contradiction with $SU(3)$ prediction
- **Scale fixed in the pion sector**
Chiral extrapolation

- Extrapolation using the cubic term of the nucleon

Octet Extrapolation ($a = 0.0855 \text{ fm}$)

\[ \begin{align*}
M_\Xi &= 1.348 \pm 0.031 \text{ GeV} \\
M_\Sigma &= 1.235 \pm 0.036 \text{ GeV} \\
M_\Lambda &= 1.128 \pm 0.047 \text{ GeV}
\end{align*} \]

\[ \rightarrow \text{ Prediction depends on the value of cubic term} \]

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Baryon spectrum in tmQCD
Isospin Breaking

- Test of isospin breaking in the $\Sigma$ and $\Xi$ sector
- For small pion mass and small lattice spacing all the $\Sigma$ have to be degenerate

![Graph showing the spectrum of baryons in tmQCD](image)
Isospin Breaking

Idem for the $\Xi$

![Graph showing the baryon spectrum in tmQCD](image)

$\text{LPSC, Grenoble}$  $\text{V. Drach}$  $\text{Baryon spectrum in tmQCD}$
First attempt to show the decrease of isospin breaking effect for small lattice spacing.
Baryon spectrum in tmQCD

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Strange Mass Dependence $\beta = 3.9$ $\mu_{\text{sea}} = 0.004$

- $M_{\Omega} = 0.690 + 5.985\text{ ms}$
- $M_{\xi} = 0.512 + 6.101\text{ ms}$
- $M_{\lambda} = 0.530 + 2.372\text{ ms}$
Summary

- Rather important isospin breaking in the octet which vanish when the pion mass is light
- Chiral extrapolation are preliminary due to a cubic term not well known
- $m_s$ dependance is encouraging