bottom and charm hadron spectroscopy from lattice QCD

\[ m_u \approx m_d < m_s \sim \Lambda_{\text{QCD}} < m_c < \frac{1}{a} < m_b \]

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Mass differences between these multiplets, eg. \( m(\Sigma^*) - m(\Sigma) \), vanish as \( m_b \to \infty \).
MDLW also have preliminary results for $bb$ and $b$ baryons (see LAT2009 proceedings).

ALSO:

They see a curious systematic dependence:
$O_5$ for $\Lambda_b, \Xi_b$ versus $O_{\mu}$ for $\Sigma_b, \Xi'_b, \Omega_b$. 
Fine lattice results produce systematically large splittings of $(\Lambda_b, \Xi_b)$ versus $(\Sigma_b, \Xi'_b, \Omega_b)$ relative to other lattice results and experiment.

The thesis suggests a possible cause: “we cannot separate $J^p = \frac{1}{2}^+$ and $\frac{3}{2}^+$ states using the spin projection operators” for $\mathcal{O}_\mu$. See the thesis for a thorough discussion.
ALSO:
Meinel, Detmold, Lin, Wingate LAT2009

( Preliminary. Systematic errors unavailable. )

Lewis, Woloshyn PRD, 2009

AUTHORS: u, d, s ACTION

LW: nonpert-tuned clover
NG: improved staggered
BHLLS: chirally improved
DLW: domain wall
LCMO: sea = impr. staggered
: valence = domain wall
MDLW: domain wall

ALSO:
contains valuable data for mass differences of b and bb baryons.
Meinel, Detmold, Lin, Wingate LAT2009

( Preliminary. Systematic errors unavailable. )

Lewis, Woloshyn PRD, 2009

Lewis, Woloshyn PRD, 2009

Burch, Hagan, Lang, Limmer, Schafer PRD, 2009

Detmold, Lin, Wingate NPB, 2009

Lin, Cohen, Mathur, Orginos PRD, 2009

CDF

D0

mass \ [ \text{GeV/c}^2 ]

( Preliminary. Systematic errors unavailable. )

**AUTHORS : LATTICE SPACING**

LW : 0.104 fm
NG : 0.15, 0.12, 0.09 fm
BHLLS : 0.11, 0.16 fm
DLW : 0.114 fm
LCMO : 0.124 fm
MDLW : 0.11 fm

**ALSO:**
Na (and Gottlieb) PhD thesis, 2008 contains valuable data for mass differences of \( b \) and \( \bar{b}b \) baryons.
Meinel, Detmold, Lin, Wingate LAT2009

( Preliminary. Systematic errors unavailable. )

Meinel, Detmold, Lin, Wingate LAT2009

Lewis, Woloshyn PRD, 2009

Lewis, Woloshyn PRD, 2009

Burch, Hagan, Lang, Limmer, Schafer PRD, 2009

Lin, Cohen, Mathur, Orginos PRD, 2009

CDF

D0

ALSO:

AUTHORS: LATTICE VOLUME

LW: (2.1 fm)$^3$

NG: (2.4 fm)$^3$

BHLLS: (1.35 fm)$^3$, (2.5 fm)$^3$

DLW: (2.7 fm)$^3$

LCMO: (2.5 fm)$^3$

MDLW: (2.7 fm)$^3$
AUTHORS: PION MASS

- LW: 4; minimum $\sim 600$ MeV
- NG: 2 or 3; min $\sim 290$ MeV
- BHLLS: 461 MeV and 525 MeV
- DLW: 3 sea + 6 valence; minimum $\sim 275$ MeV
- LCMO: 4; minimum $\sim 290$ MeV
- MDLW: 331 MeV

ALSO:
Na (and Gottlieb) PhD thesis, 2008 contains valuable data for mass differences of $b$ and $\bar{b}b$ baryons.
AUTHORS: s MASS

LW: 2; interpolate to physical
NG: \sim\text{physical}
BHLLS: s quark is absent
DLW: \mathcal{O}(10\%) > \text{physical}
LCMO: \sim\text{physical}
MDLW: \mathcal{O}(10\%) > \text{physical}

ALSO:
\begin{align*}
\text{mass [GeV/c}^2\text{]} & \begin{array}{c}
\Omega_{\text{bbb}}^* \\
\Omega_{\text{bb}} \\
\Xi_{\text{bb}} \\
\Xi_{\text{bb}}^* \\
\Omega_{\text{bb}}^* \\
\end{array} \\
\end{align*}

\text{AUTHORS : b MASS} \\
\text{LW} : 3; \text{interpolate to physical} \\
\text{NG} : 1; \sim \text{physical} \\
\text{BHLLS} : \infty \\
\text{DLW} : \infty \\
\text{LCMO} : \infty \\
\text{MDLW} : 1; \text{physical}

\text{ALSO:} \\
\text{Na (and Gottlieb) PhD thesis, 2008 contains valuable data for mass differences of b and bb baryons.}
charmed baryons in context

spin 1/2

spin 3/2
LLOW use Symanzik gauge, staggered sea, domain wall valence, Fermilab charm, $a = 0.125$ fm, volume = $(2.4 \text{ fm})^3$, $m_{\pi} \geq 290$ MeV.

NG study many mass differences, including $\Xi_{cc}^{*}$ and $\Omega_{cc}^{*}$.

Flynn+, Mathur+, and Chiu+ are quenched results, including spin 3/2.

This is figure 14 of Liu, Lin, Orginos, Walker-Loud arxiv:0909.3294.
As $m_b \to \infty$, heavy quark symmetry \( \Rightarrow m(B^-) = m(B^{*-}), \quad m(B^0) = m(B^{*0}), \quad m(B_s) = m(B_s^*) \).

These doublets are named $1S$. Excited doublets are named $1P_-, 1P_+, 1D_-, 1D_+, \ldots 2S, \ldots$
Status of the static-strange ($\sim B_s$) spectrum for $N_f = 2$ in 2007

This is figure 21 of Koponen Phys.Rev.D78:074509,2008.

Warning: Do not attempt continuum extrapolations with different actions.
spectrum of static-light mesons with $N_f = 2$

JMSW use tree-level Symanzik gauge, two twisted mass light quarks, static "b", $a = 0.0855$ fm, volume = $(2.05 \text{ fm})^3$, $m_\pi \geq 300$ MeV.

MSW is similar but $a = 0.051, 0.064, 0.080$ fm and a partially-quenched s quark.
spectrum of bottom mesons

HPQCD: tune parameters to $\Upsilon$, $\eta_c$, pion and kaon.
charmed mesons in context

pseudoscalars

vectors
Mass (MeV)

$D_s(0^-)$, $D_s^*(0^+)$, $D_{s1}(1^+)$, $D_{s1}(1^+)$, $D_{s1}^*(1^-)$

This is figure 5 of Dong, Alexandru, Draper, Liu, Li, Streuer, Zhang LAT2009.

Iwasaki gauge, domain wall sea, overlap valence, $a = 0.08$ fm, volume = $(2.7$ fm$)^3$, $m_\pi = 331$ MeV.
References mentioned on the preceding pages

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Burch, Chakrabarti, Hagen, Maurer, Schafer, Lang, Limmer (BGR) LAT2007 arxiv:0709.3708
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Meinel, Detmold, Lin, Wingate LAT2009 arxiv:0909.3837
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Gregory, Davies, Follana, Gamiz, Kendall, Lepage, Na, Shigemitsu, Wong LAT2009 arxiv:0911.2133
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