Update on Onium Masses with Three Flavors of Dynamical Quarks

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Outline

- What is New This Year
- Charmonium Results
- Bottomonium Results
- Outlook

What is New This Year

MILC has been generating three flavor configurations to allow control of these errors. Many configurations are available to others through NERSC Gauge Connection. Some new configurations generated via SciDAC program.

- Next table shows some "extra coarse" ($a \approx 0.18$ fm), "coarse" ($a \approx 0.12$ fm) and "fine" ($a \approx 0.09$ fm) ensembles.
- To better control continuum limit, we now have:
  - Medium coarse: $a \approx 0.15$ fm
  - Fine: $a \approx 0.09$ fm; **0.0031/0.031**, $40^3 \times 96$
  - Extra fine: $a \approx 0.06$ fm. This is a challenging project and will require more than a year to "complete." Currently, $m_l = 0.4 m_s$ running on BNL QCDOC. For $m_l = 0.2 m_s$ just finished equilibrating.
  - All bottom results are new.

Main 2+1 Flavor Ensembles Used

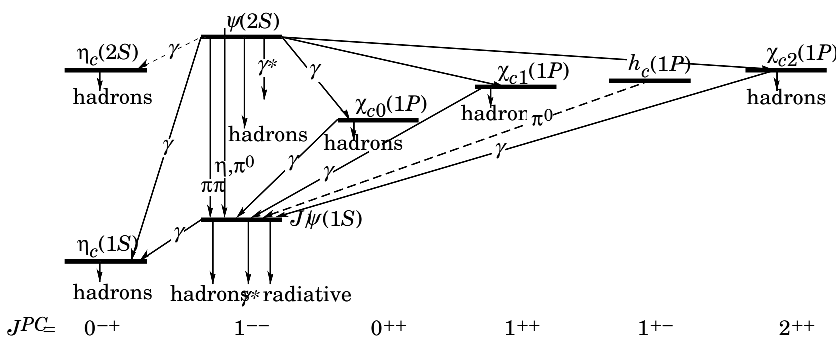
am_q / am_s	$10/g^2$	size	volume	config.
0.0492 / 0.082	6.503	$16^3 \times 48$	$(2.8\ \mathrm{fm})^3$	401 — 401
0.0328 / 0.082	6.485	$16^3 \times 48$	$(2.8\ \mathrm{fm})^3$	331 — 501
0.0164 / 0.082	6.467	$16^3 \times 48$	$(2.8\ \mathrm{fm})^3$	645 — 645
0.0082 / 0.082	6.458	$16^3 \times 48$	$(2.8\ \mathrm{fm})^3$	400 461 601
0.03 / 0.05	6.81	$20^3 \times 64$	$(2.4\ \mathrm{fm})^3$	549 210 564
0.02 / 0.05	6.79	$20^3 \times 64$	$(2.4\ \mathrm{fm})^3$	460 210 484
0.01 / 0.05	6.76	$20^3 \times 64$	$(2.4\ \mathrm{fm})^3$	593 210 658
0.007 / 0.05	6.76	$20^3 \times 64$	$(2.4\ \mathrm{fm})^3$	403 — 651
0.005 / 0.05	6.76	$24^3 \times 64$	$(2.9\ \mathrm{fm})^3$	136 — 500
0.0124 / 0.031	7.11	$28^3 \times 96$	$(2.4\ \mathrm{fm})^3$	261 210 527
0.0062 / 0.031	7.09	$28^3 \times 96$	$(2.4\ \mathrm{fm})^3$	472 159 592

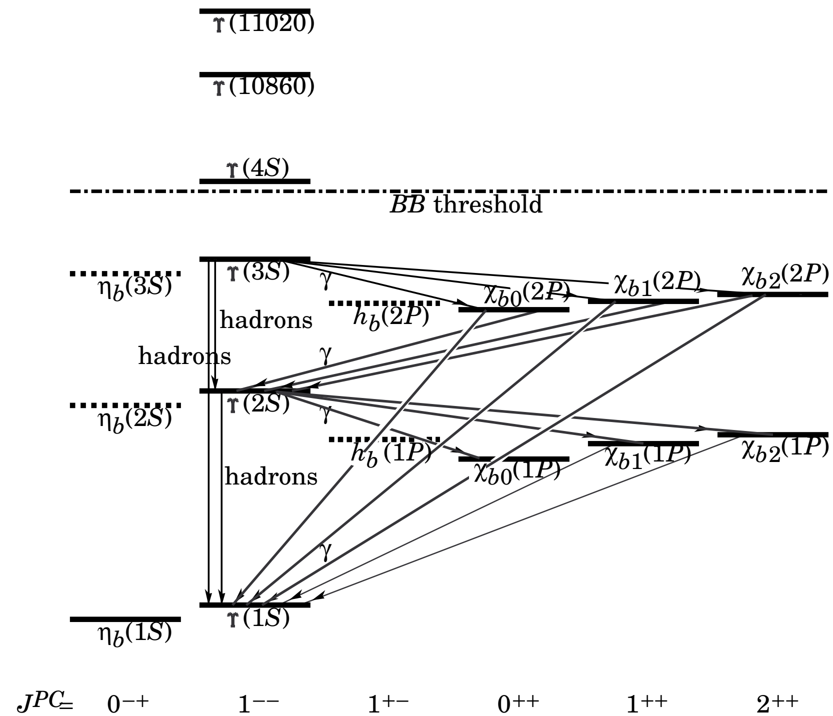
Blue corresponds to NRQCD analysis, red total available.

Heavy Quark Spectrum

- Best tests of LGT are states that require no chiral extrapolation, are stable to strong decay (and far from threshold).
  Examples: J/Ψ, Υ, D_s, B_s
- FNAL Lattice/MILC collaborations have used Clover quarks to study charmonium
  [PoS LAT2005: 203(2006); hep-lat/0510072]
- HPQCD/UKQCD collaborations have used NRQCD accurate to order v^4 to study bottomonium on MILC configurations [PRD 72, 09407 (2005); hep-lat/0507013]. We will compare with some of their results on the same ensembles.

Observed Spectrum



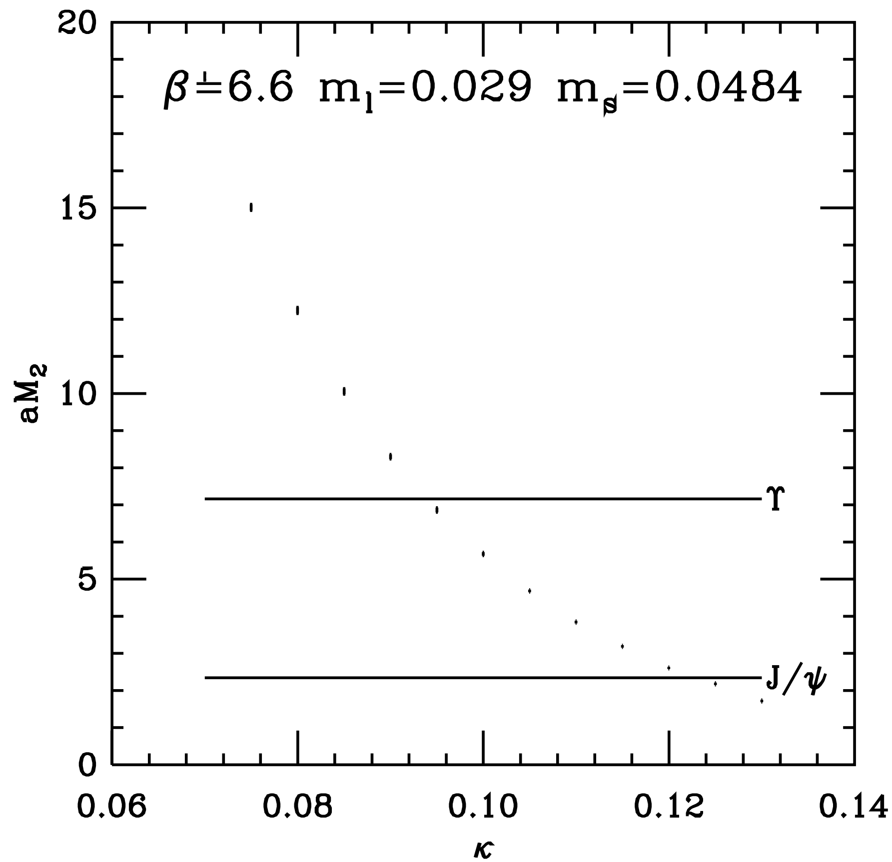


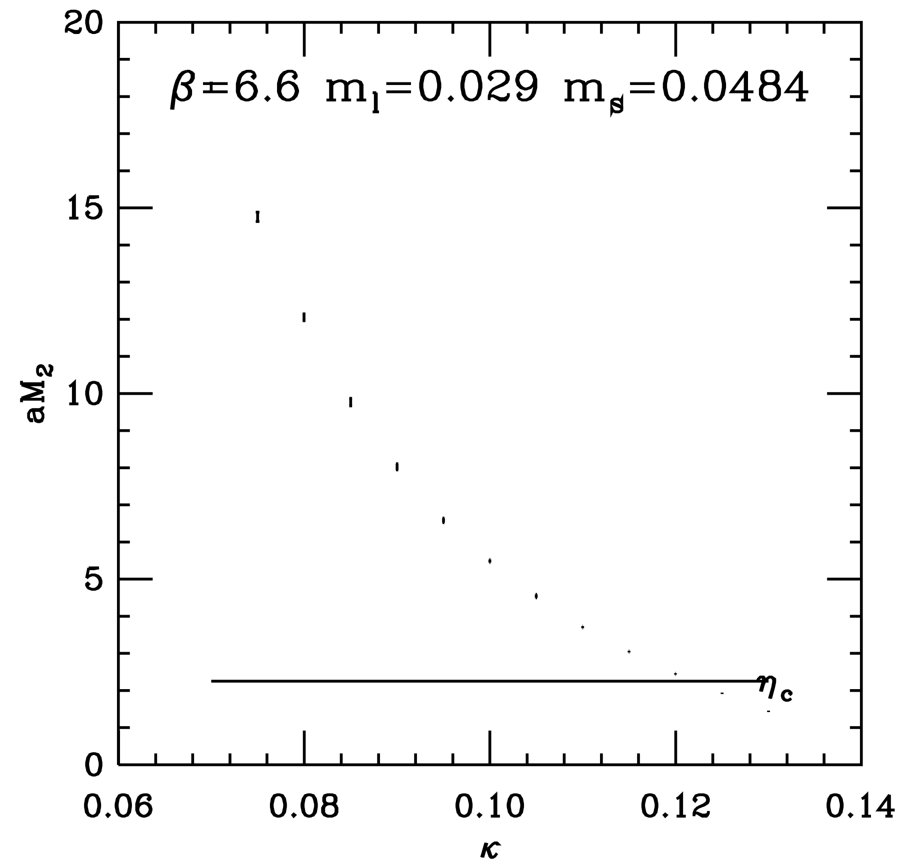
[S. Eidelman et al., PL B592, 1 (2004)]

Heavy Quark Formalism

- We use Clover quarks with the Fermilab interpretation for the heavy quark
- To find the appropriate κ for charm and bottom, we must study the kinetic mass for a range of κ
- Kinetic masses have larger errors than rest energies. Splittings are based on differences in rest energy.
- After looking at tuning on one ensemble, we consider various splittings for onium.

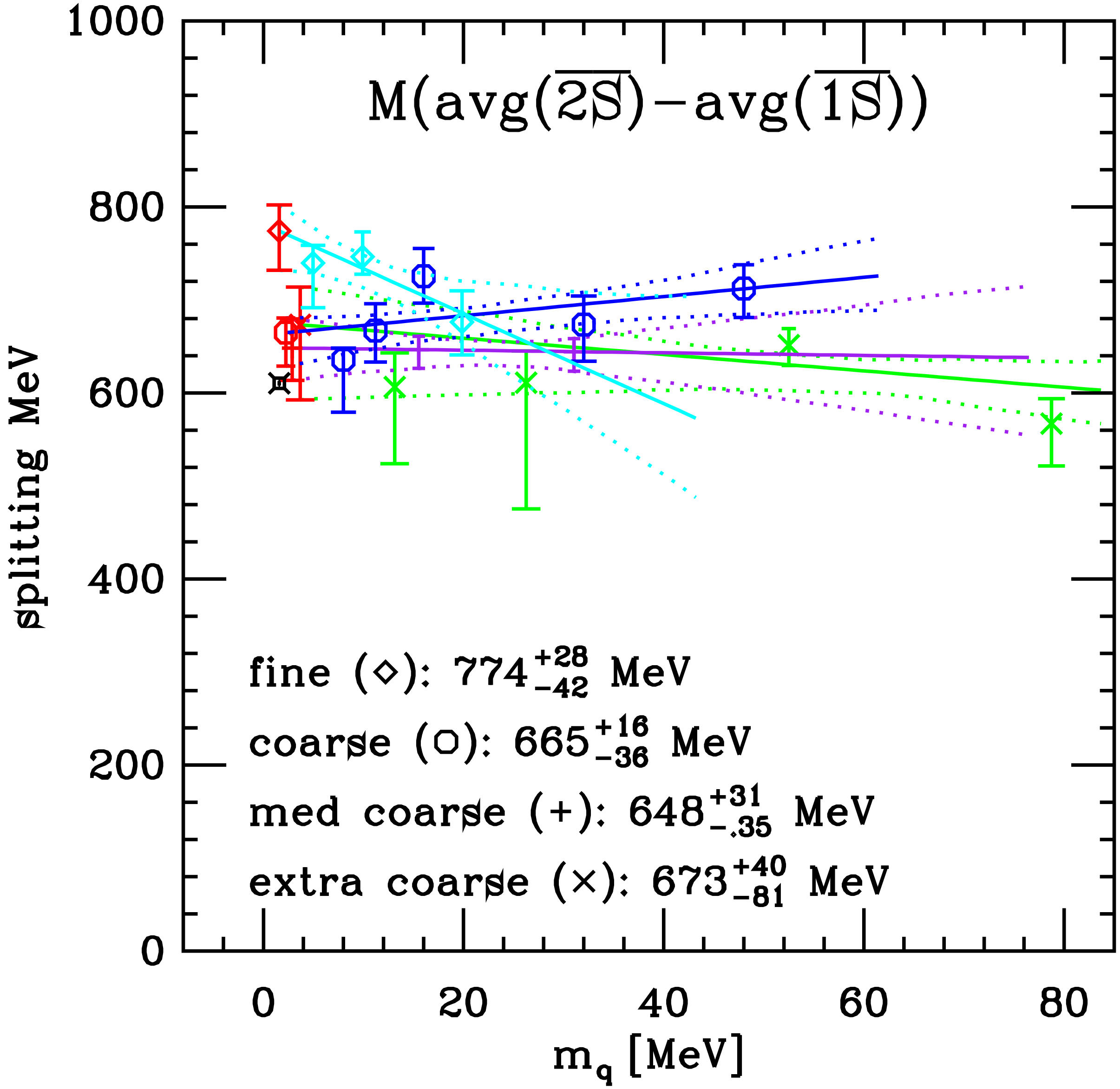
Tuning κ



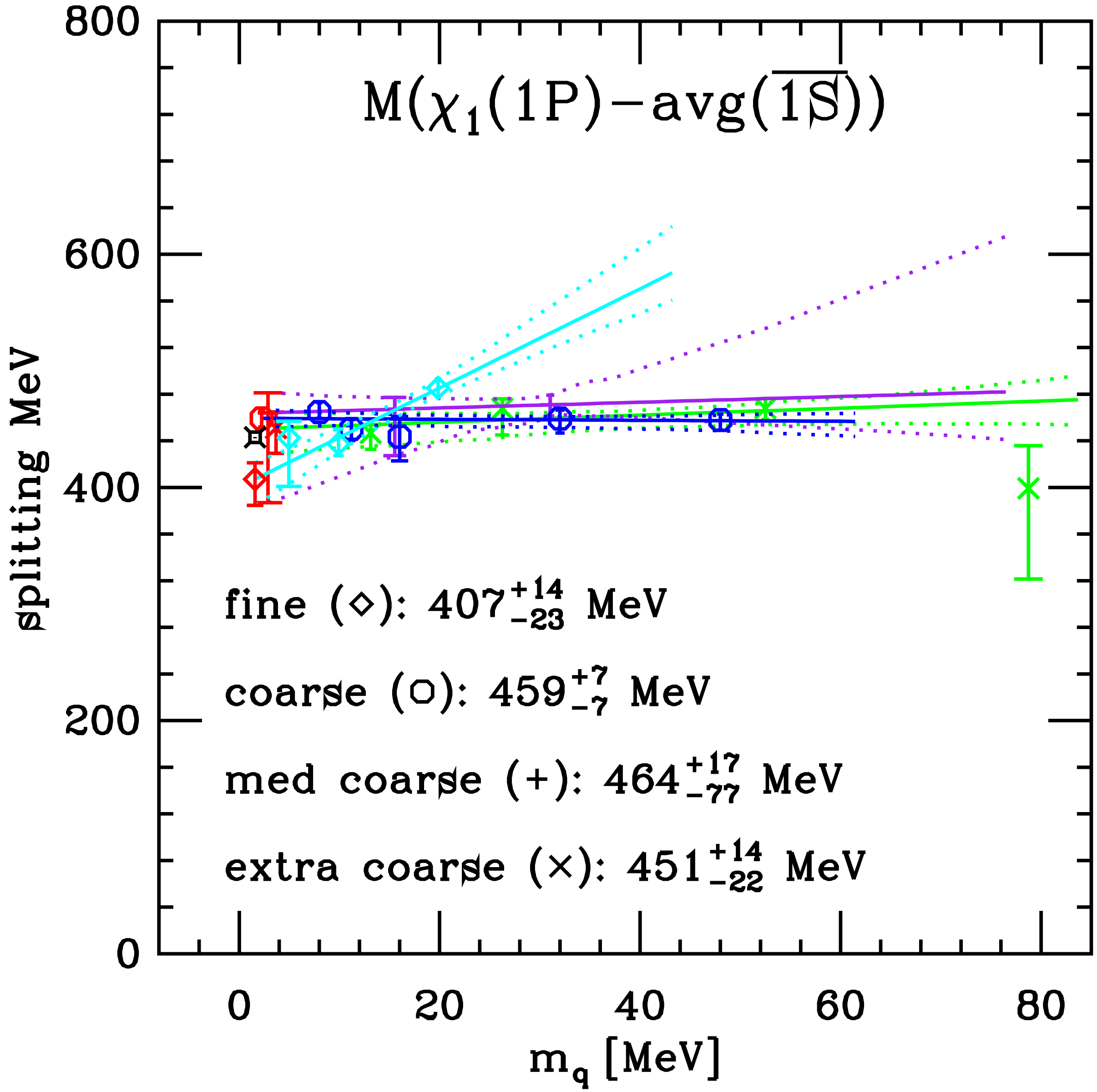


Tuning on medium coarse ensemble. Selected value was 0.122 for charm and 0.094 for bottom.

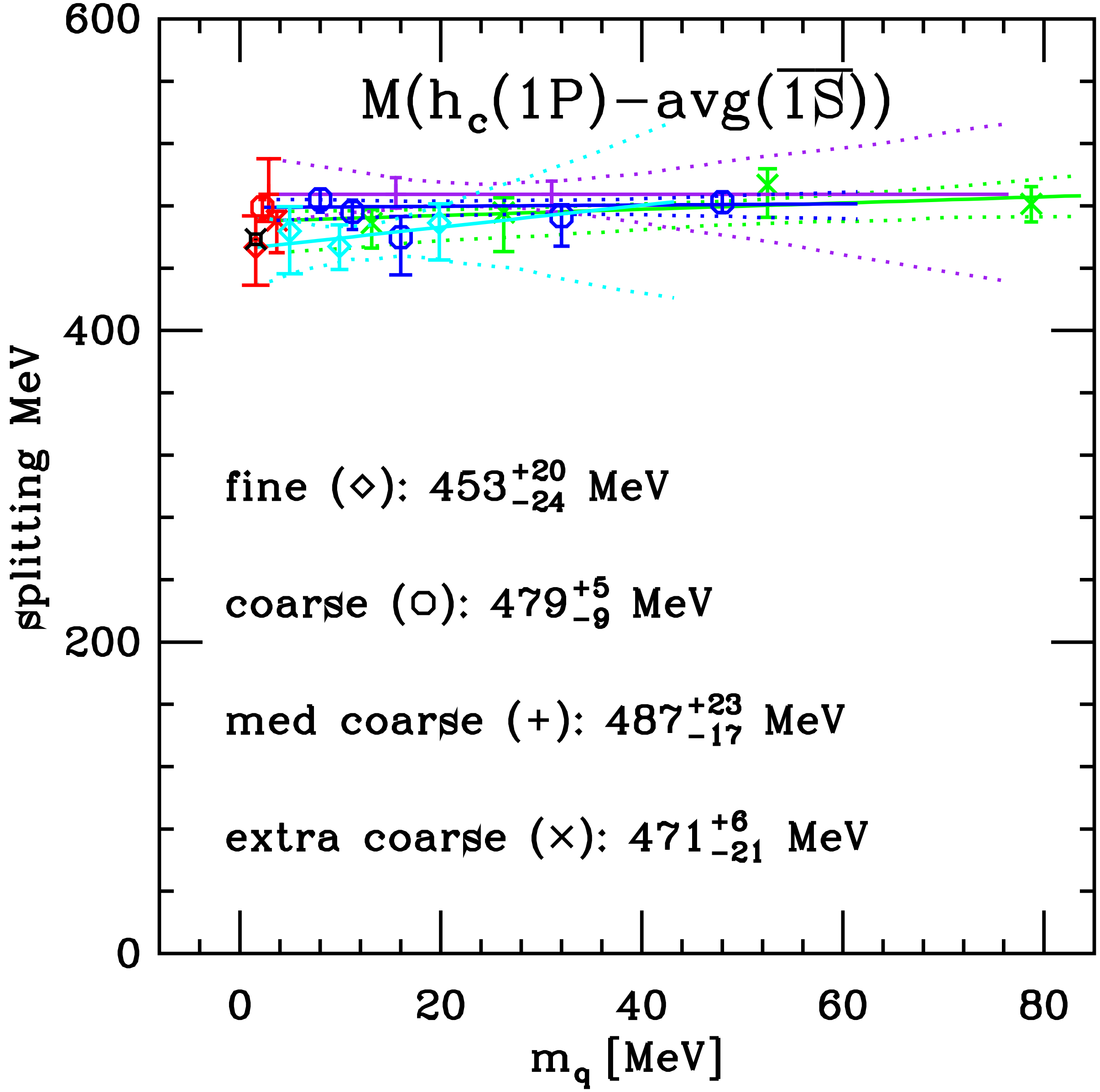
Charmonium 1S-2S Splitting



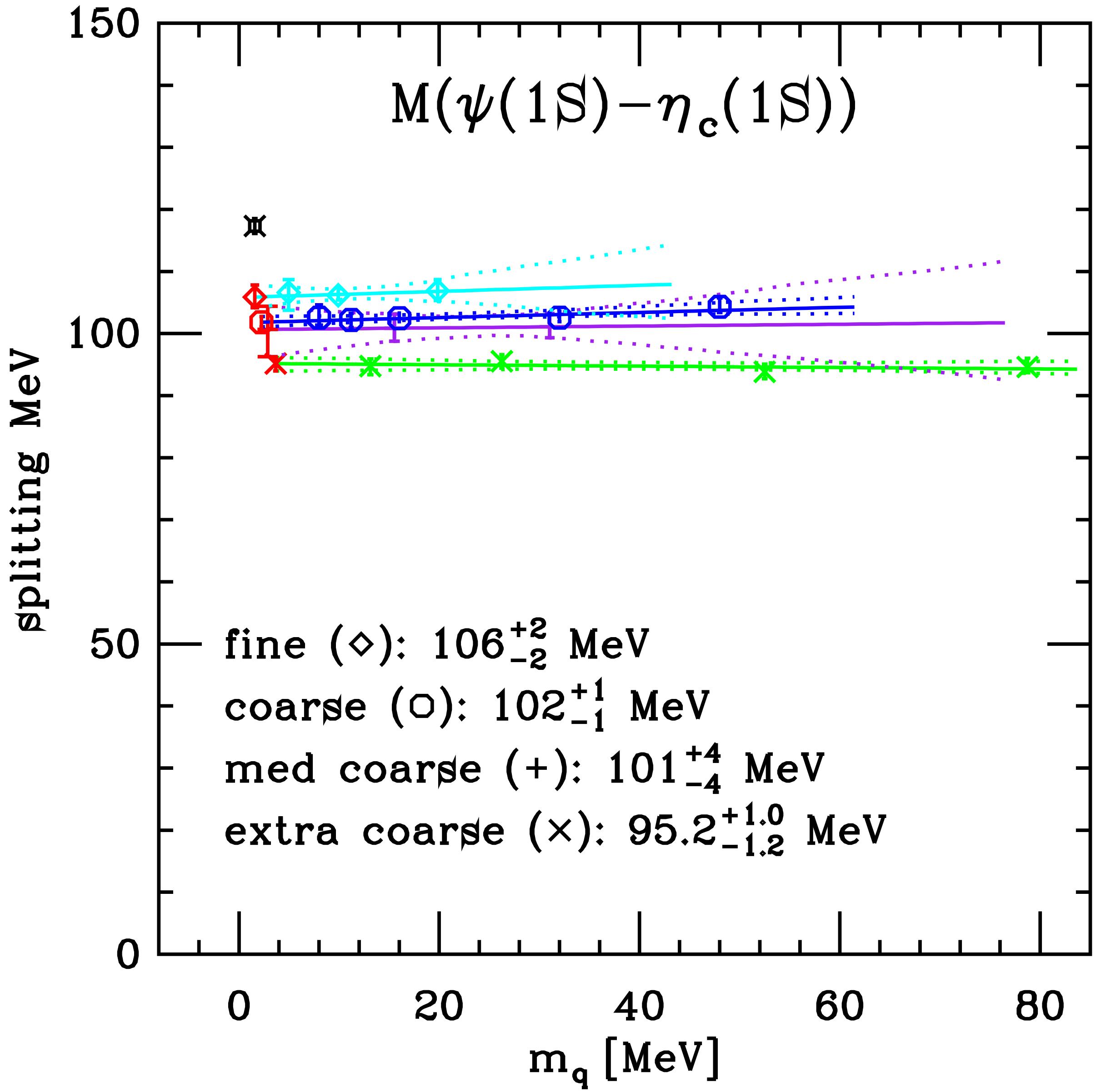
Charmonium Fine Structure I



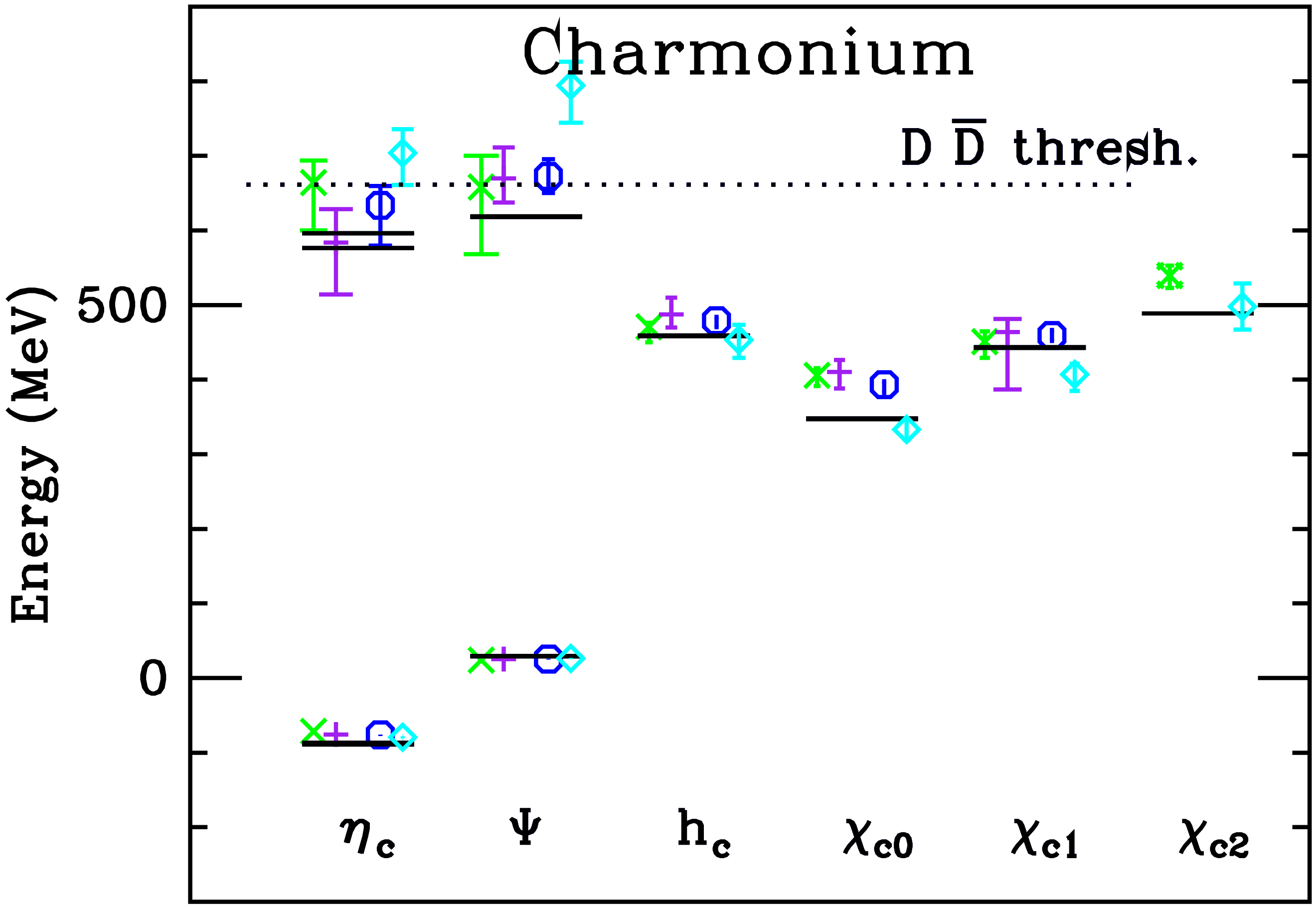
Charmonium Fine Structure II



1S Hyperfine Splitting

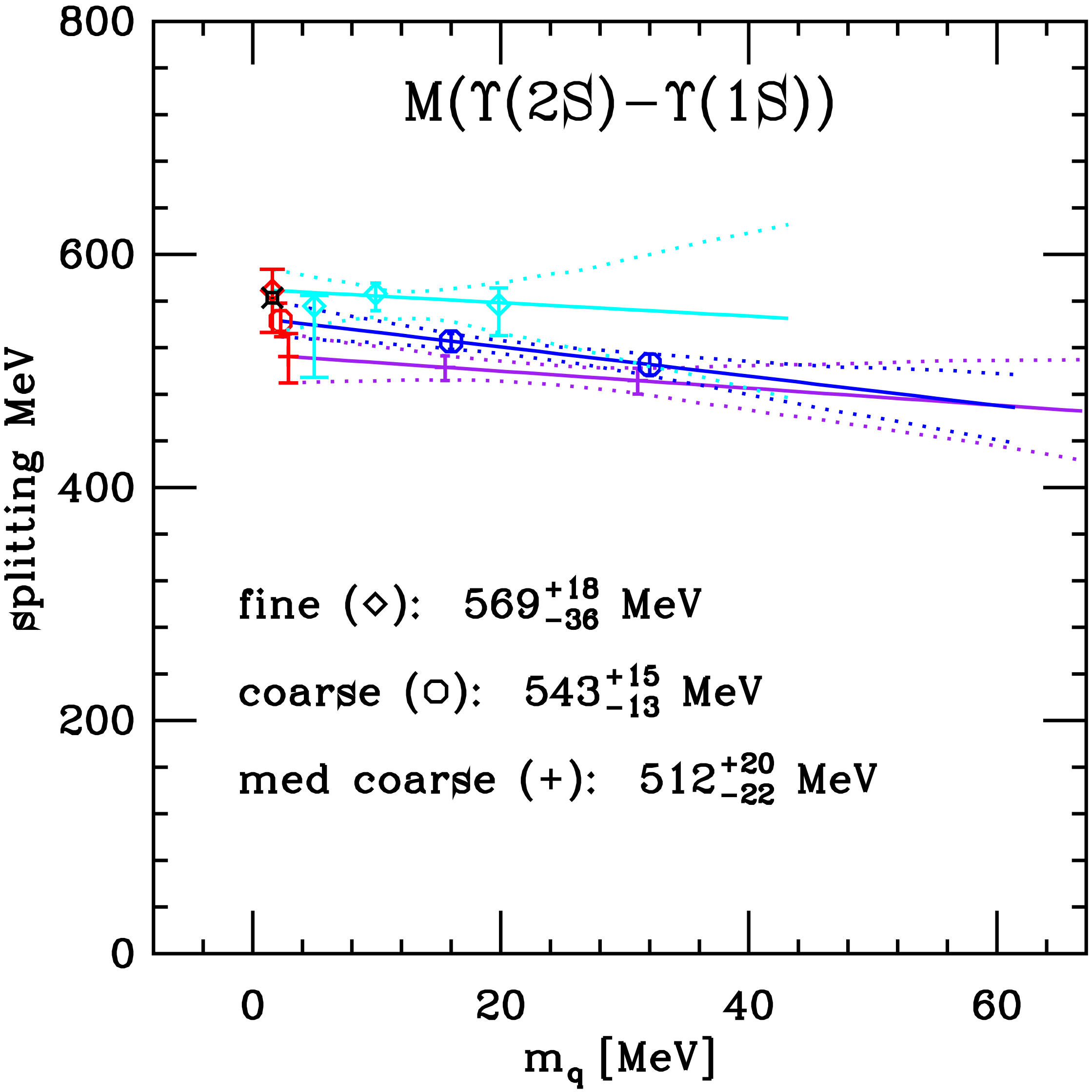


Summary of Charmonium Spectrum



Results for all four ensembles based on linear chiral extrapolation. χ_{c2} has only been studied on one extra coarse and one fine ensemble.

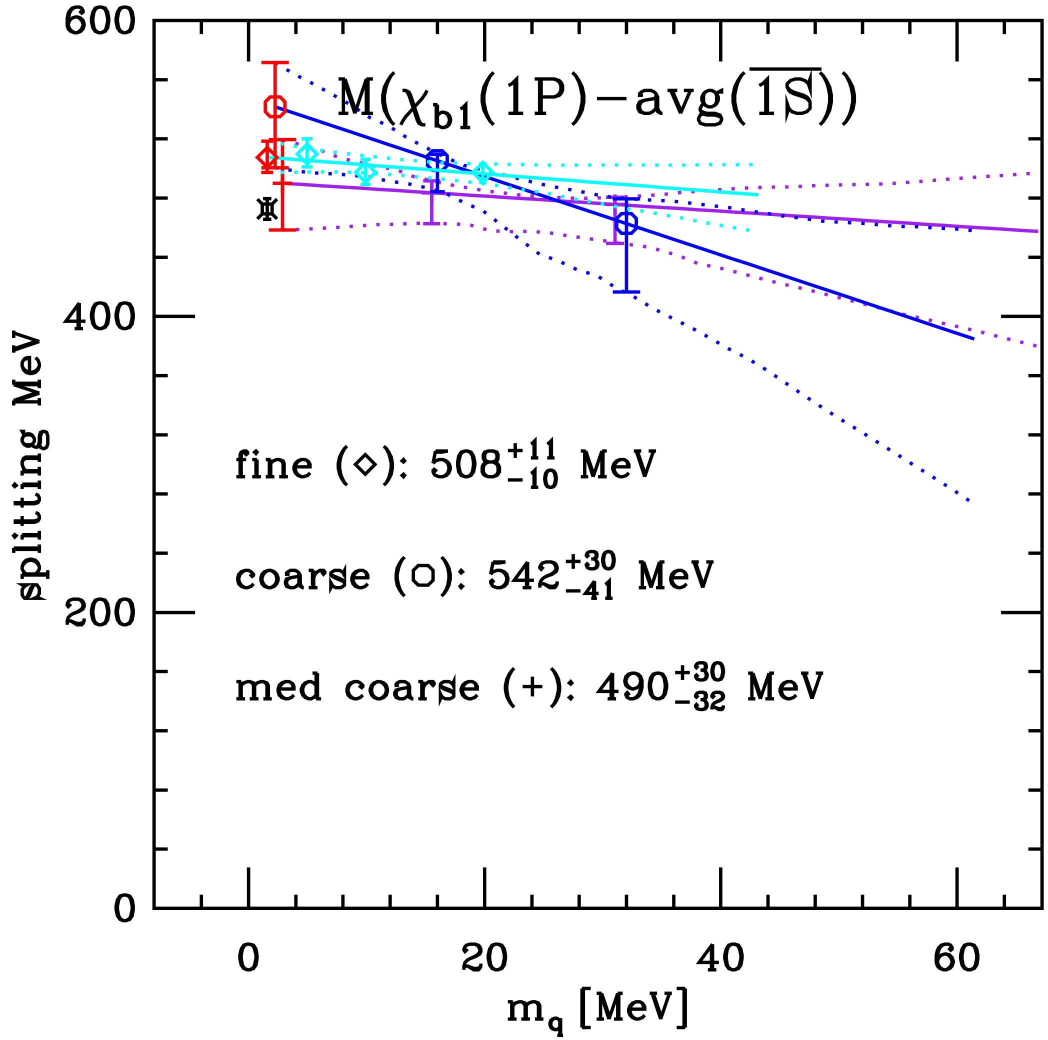
Bottom 2S-1S splitting



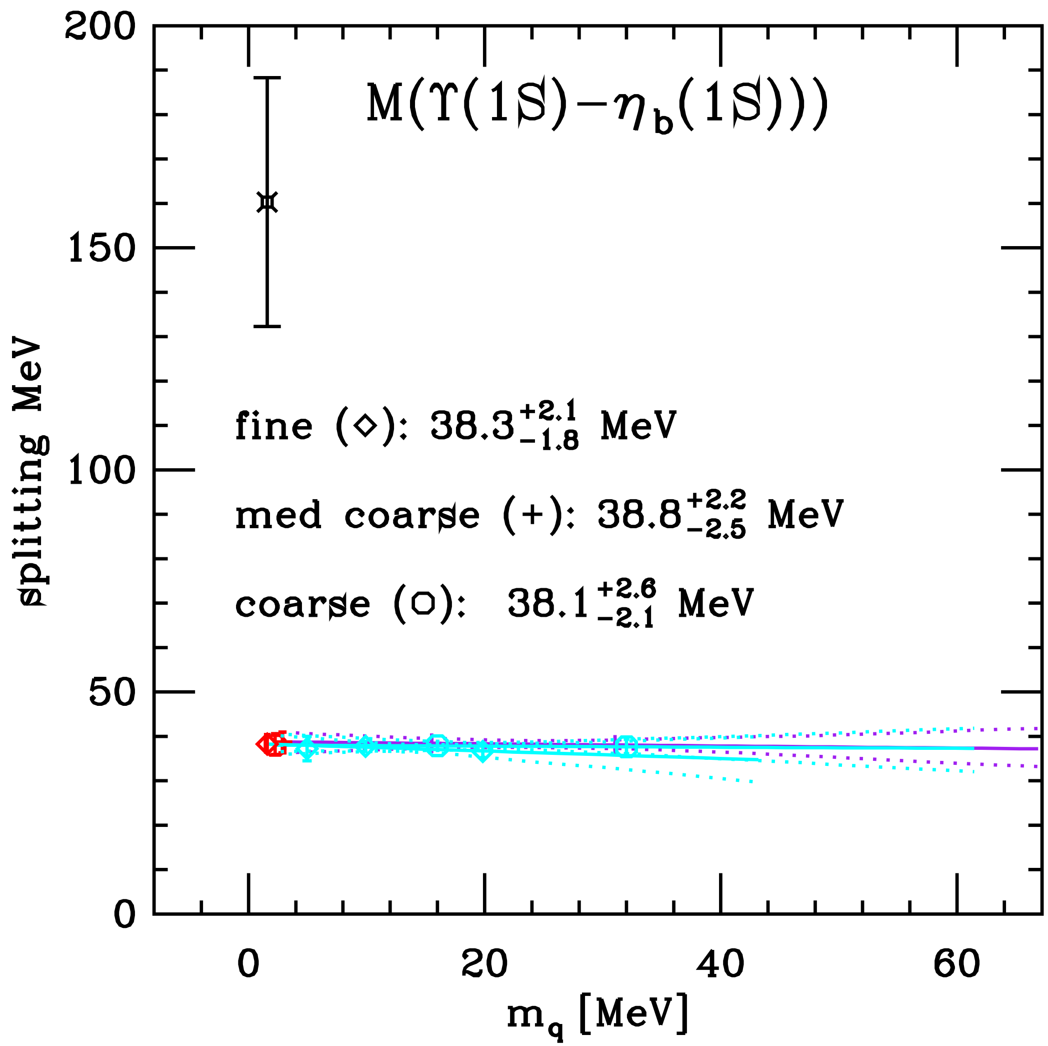
The mass of the $\eta_b(1S)$ is uncertain and the $\eta_b(2S)$ has not been observed, so here we just look at $\Upsilon(2S)$-$\Upsilon(1S)$ splitting.

Bottomonium Fine Structure

The h_b has not been observed and we have no results for χ_{b2}, so we consider the χ_{b1}, the middle of the three ^3P_J states.



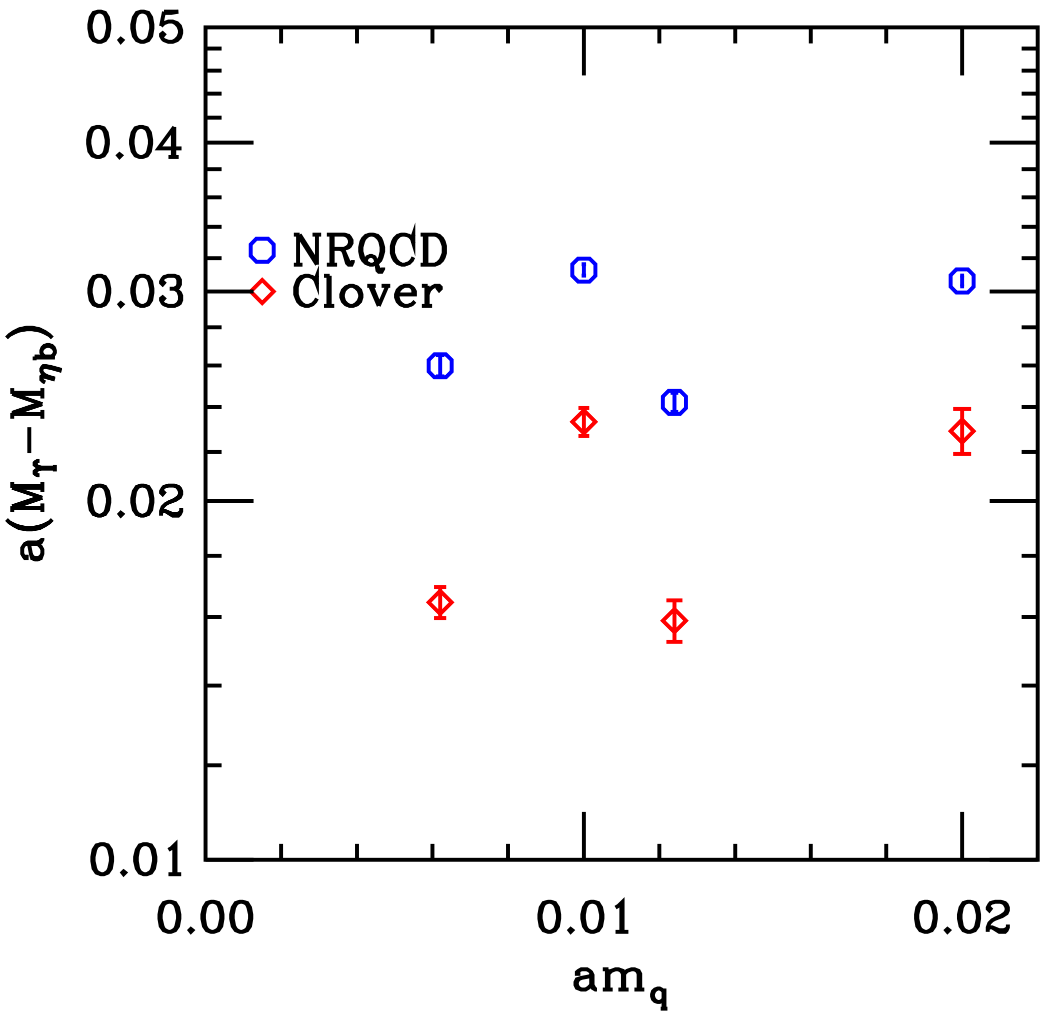
Bottomonium Hyperfine Structure I



Experimental splitting comes from single event of η_b (noted in PDG tables). Preliminary CDF result had a splitting of only 15 MeV.

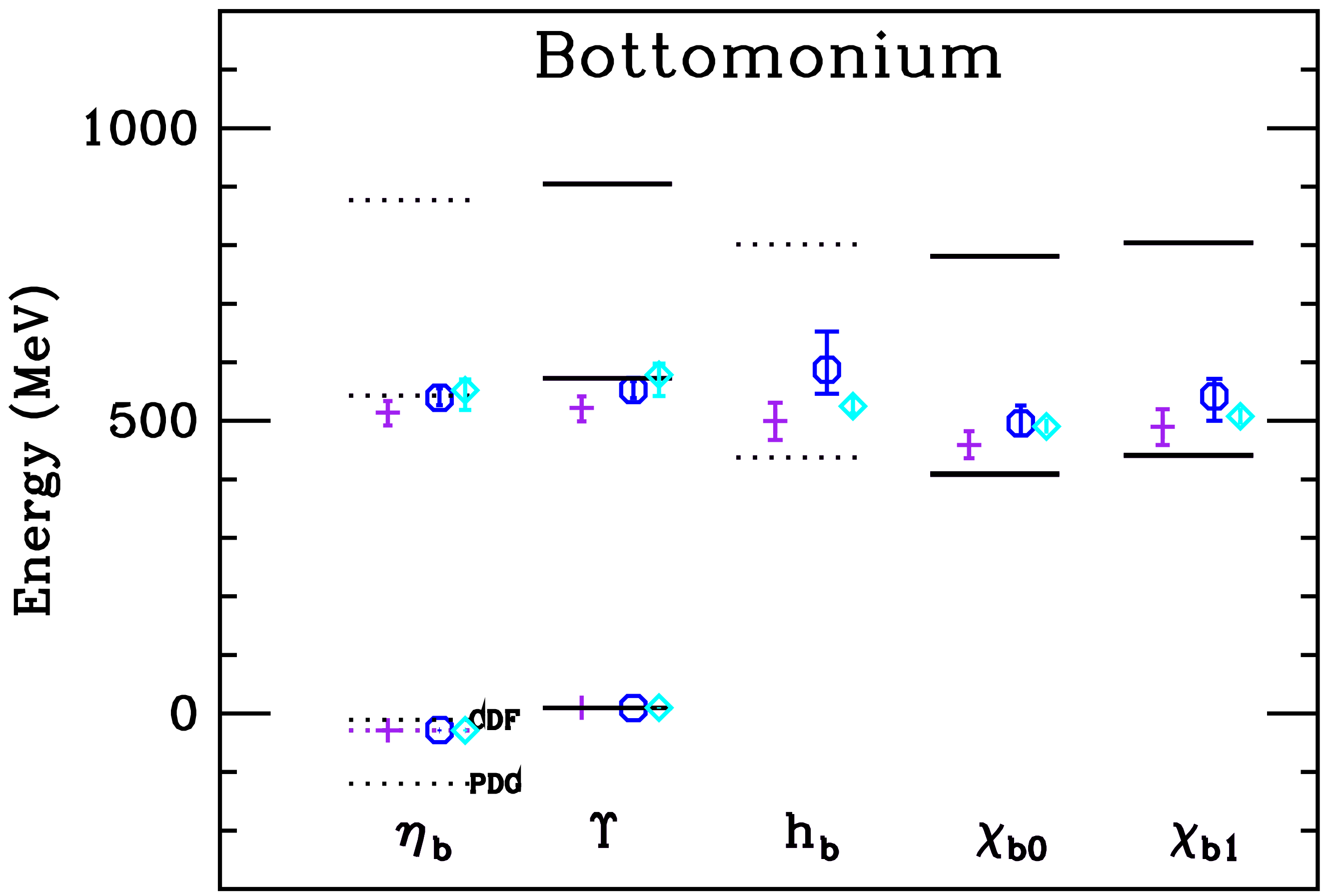
Bottomonium Hyperfine Structure II

We can directly compare with HPQCD results using NRQCD on several ensembles.



Our splitting is systematically smaller. Fractional effect larger on fine ensembles.

Summary of Bottomonium Spectrum



Results for ensembles with $a \approx 0.15$, 0.12 and 0.09 after chiral extrapolation

Conclusions

- For charmonium:
  - h_c and χ_{c1} look quite good.
  - Splittings between 1P states may be too small.
  - Hyperfine splitting is too small but improves at smaller lattice spacing.
  - 2S splitting seems too large, but 2S is close to threshold.
- For bottomonium:
  - 1P states seem too high.
  - 2S splitting looks good, and 2S is not near threshold.
  - Hyperfine splitting is smaller than with NRQCD. Experiment provides no guidance. No a dependence seen.

Outlook

- More statistics: not all of the available configurations have been analyzed. We are trying to catch up.
- New ensembles: We are generating configurations for a lattice spacing 0.06 fm. We have future plans to reduce the lattice spacing to 0.045 fm. We may also create ensembles with 0.105 fm. This would give us 7 lattice spacings with $a_{\mathrm{max}}/a_{\mathrm{min}} \approx 4$.
- Currently using an automatic criteria for picking best fit. Need to consider alternative.
- The bottom spectrum does not seem to be reproduced that well. Our quarks have larger errors for heavier quarks, unlike NRQCD, so this may not be surprising. Kronfeld and Oktay have been developing a highly improved clover quark action, that may be used in the future.

2005 Charmonium Spectrum