Heavy quark physics with NRQCD

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- heavyonium MILC super-coarse configs
- heavy-light on MILC super-coarse configs
- what next?

See also Kit Wong's talk later today on high order pert. renormln of NRQCD.

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MILC super-coarse ensemble

$16^3 \times 48$ lattices with $a \approx 0.17$ fm. Ensemble size $\approx$ 600.

Complement the coarse ($a = 0.12$ fm) and fine ($a = 0.09$ fm) ensembles.

sea quark masses: $am_s = 0.082$, $am_{u/d} = 0.0082$.

Advantage of super-coarse lattices: $am_c \approx 1.0 \rightarrow$ we can use NRQCD for the c quark here, and cover both b and c physics.

Disadvantage: lattices are rather coarse so disc. errors could be high. Need careful analysis of systematic errors.

N.B. current NRQCD action can be improved further to reduce all of these errors.

Analysis of systematic errors

For heavyonium states can estimate the systematic error from missing higher order relativistic and radiative terms in the NRQCD action by estimating e.g. $< p^4 >$ in a potential model.

Our NRQCD action is correct at tree-level (tad-imp) through v^4.

First rel. errors are $\alpha_s p^4/4m_Q^3$, $4\pi\alpha_s^2\Psi(0)^2/3m_Q^2$ etc.

First disc errors are $\alpha_s a p^4/8m_Q^2 n$ from NRQCD + disc. errors from gluon action.

Analysis of systematic errors

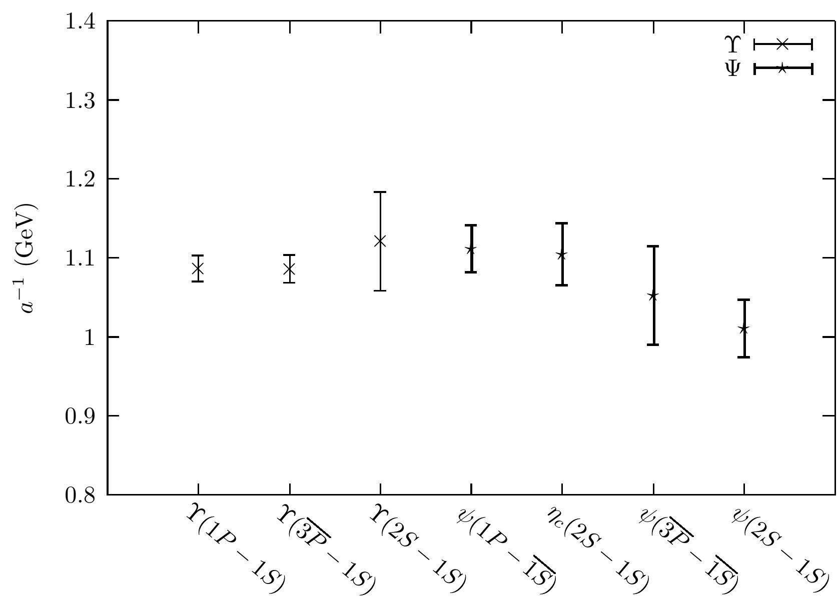
Percentage errors in splittings for Υ and ψ on super-coarse are:

error	$\Upsilon(2S-1S)$	$\Upsilon(1P-1S)$	$\psi(2S-1S)$	$\psi(1P-1S)$
rel/rad	1%	3%	2%	4%
disc	3%	11%	1%	2%

Not bad, except for possible Υ disc. and this is to be expected.

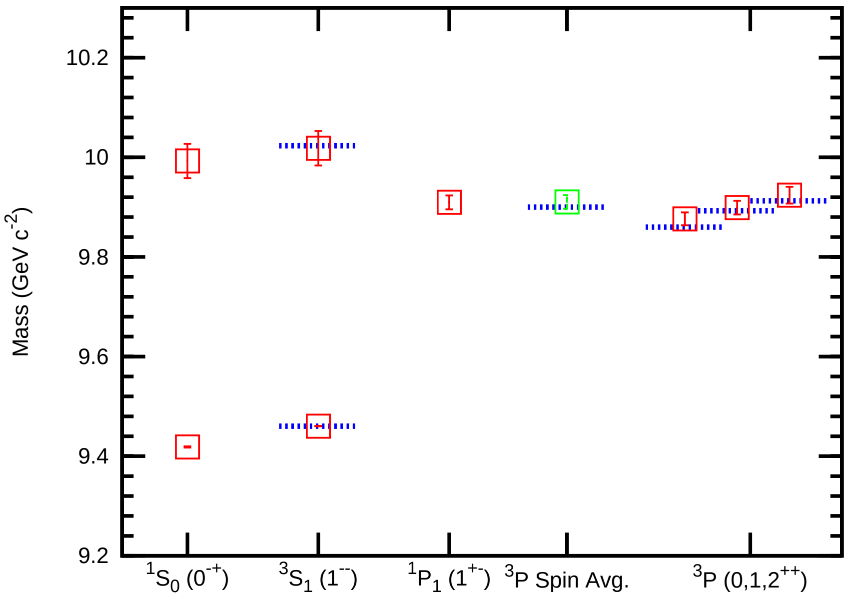
Coarse lattices had max error 4% and fine lattices max error 2% for Υ - see A. Gray et al (hep-lat/0507013).

Determination of the lattice spacing



Determinations of a^{-1} are very consistent, $\longrightarrow$ systematic errors are not a problem. Possibly low a^{-1} from $\psi(2S-1S)$, especially compared to $\eta_c(2S-1S)$. Sign of non-gold-platedness of ψ'?

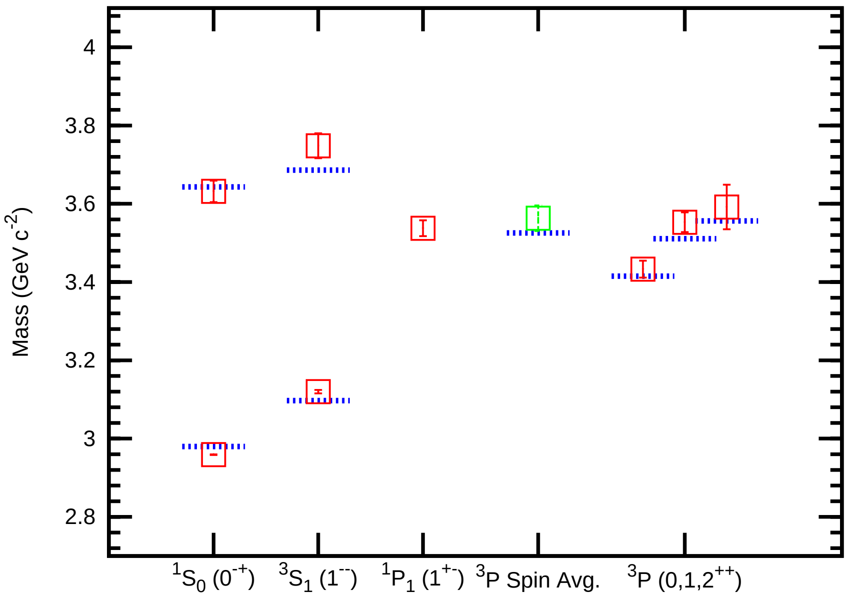
Υ spectrum



Using $\psi(1P - 1S)$ to fix scale, Υ spectrum looks good.

Fine structure e.g. hyperfine splitting has some disc. errors compared to coarse and fine (see hep-lat/0507013).

ψ spectrum



ψ spectrum also looks good except for ψ'?

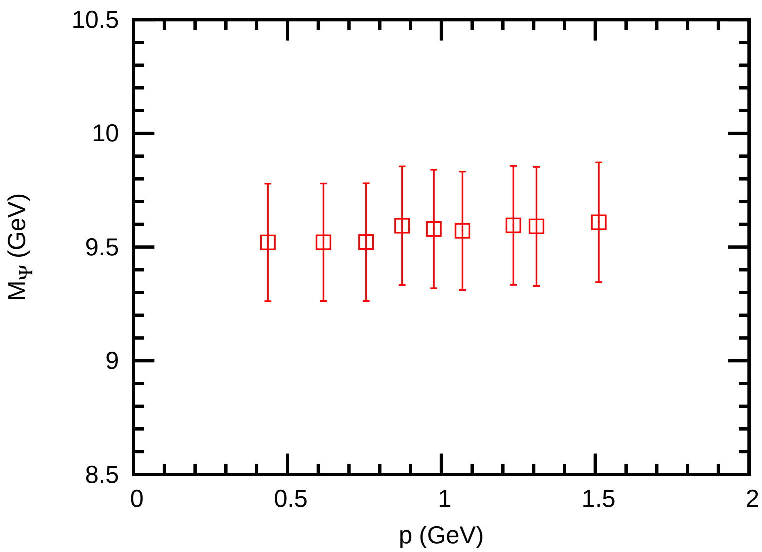
ψ' in real life only 50 MeV below $D\overline{D}$ threshold, so not gold-plated.

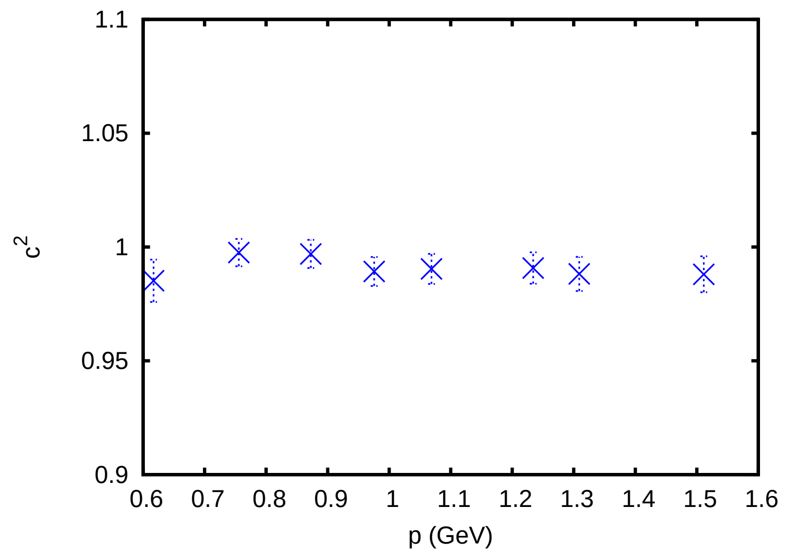
Lattice, even with light sea quarks, does not correctly include coupling to real/virtual decay modes.

Study volume dependence of ψ' mass?

(Note: consistent picture from FNAL ψ results on coarse MILC)

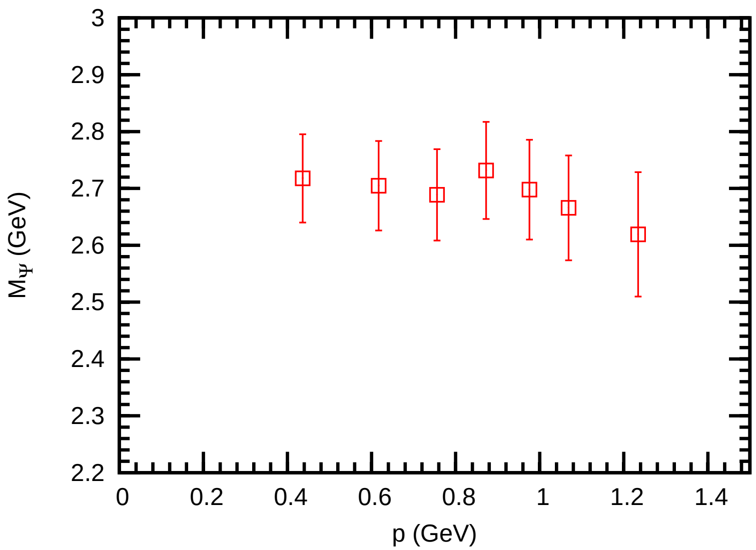
Kinetic masses and c^2 for Υ

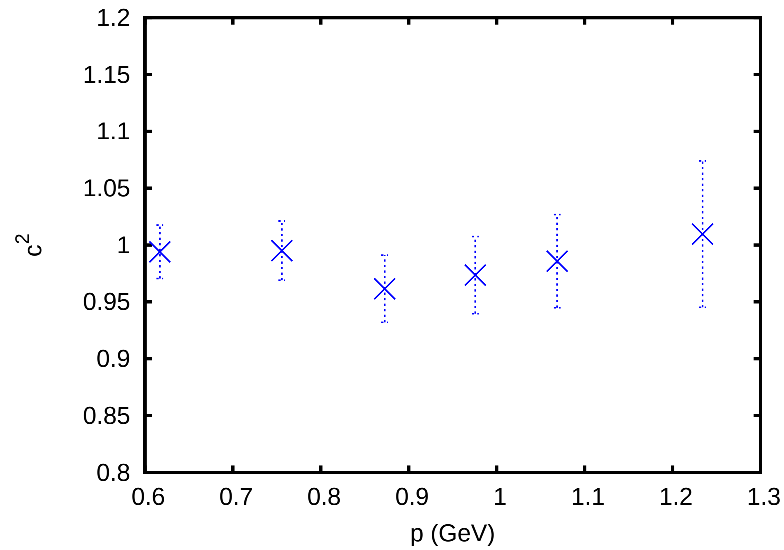




b mass is well-tuned ($m_b a = 4.0$). Note speed-of-light very close to 1. (compare other actions).

Kinetic masses and c^2 for ψ





c mass is about 10% low ($m_c a = 1.0$) ($\rightarrow$ hyperfine high). Note speed-of-light very close to 1. (compare other actions).

Mass of the B_c

Calculate mass of the B_c using splitting with ψ and Υ, now using entirely NRQCD calcs.

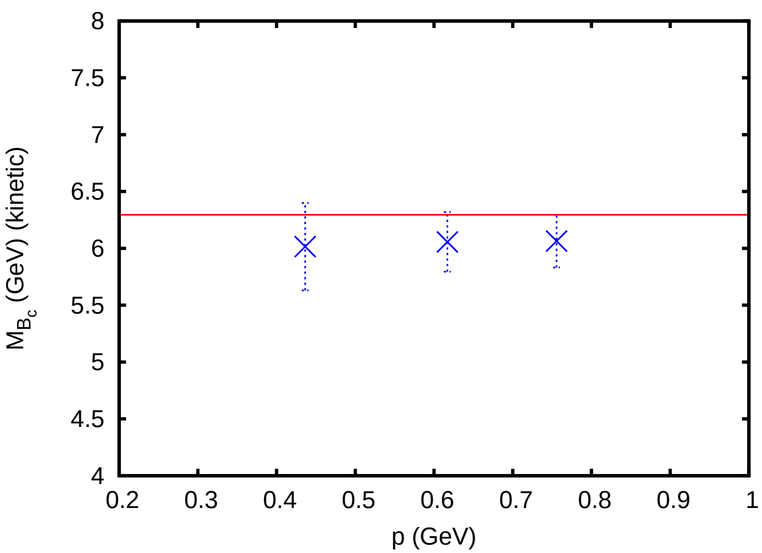
$$m_{B_c} = 0.5(m_\Upsilon + m_{\overline{\psi\eta_c}})_{expt} + \Delta$$

$$\Delta = E_{B_c} - 0.5(E_\Upsilon + E_{\overline{\psi\eta_c}})$$

Result: 6.274(1)(25)(10) GeV with errors stat, syst, si $+$ syst sd (not spin-averaging Υ and B_c.

Agrees with previous lattice prediction 6.304(22) GeV and expt (CDF) 6.287(5) GeV.

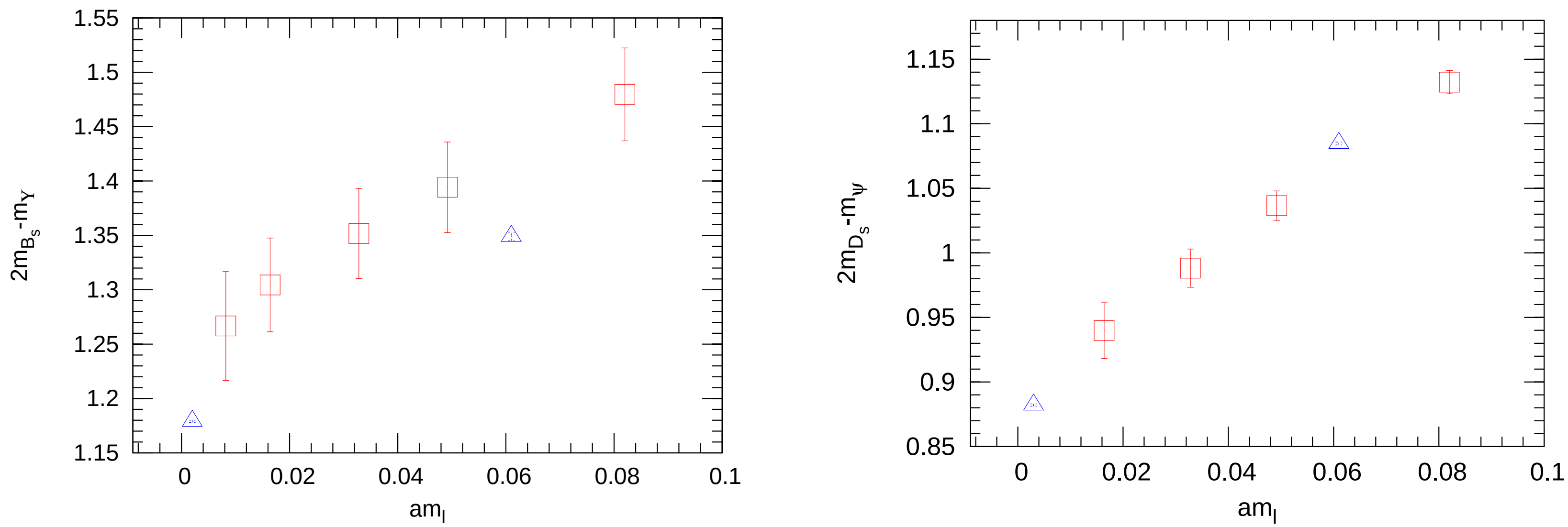
Kinetic mass of the B_c



Advantage of using NRQCD-NRQCD is that kinetic mass of B_c is also correct.
(Note: c mass is low so B_c kinetic mass will be $\approx$ 150 MeV low.)

Heavy-light physics

Use asqtad light propagators made by FNAL/MILC. Can now do $B/B_s/D/D_s$.



Good agreement with expt. Expect ≈ 70 MeV syst error in b case (from disc. in Υ), 50 MeV in c (from rel. errors on ψ).

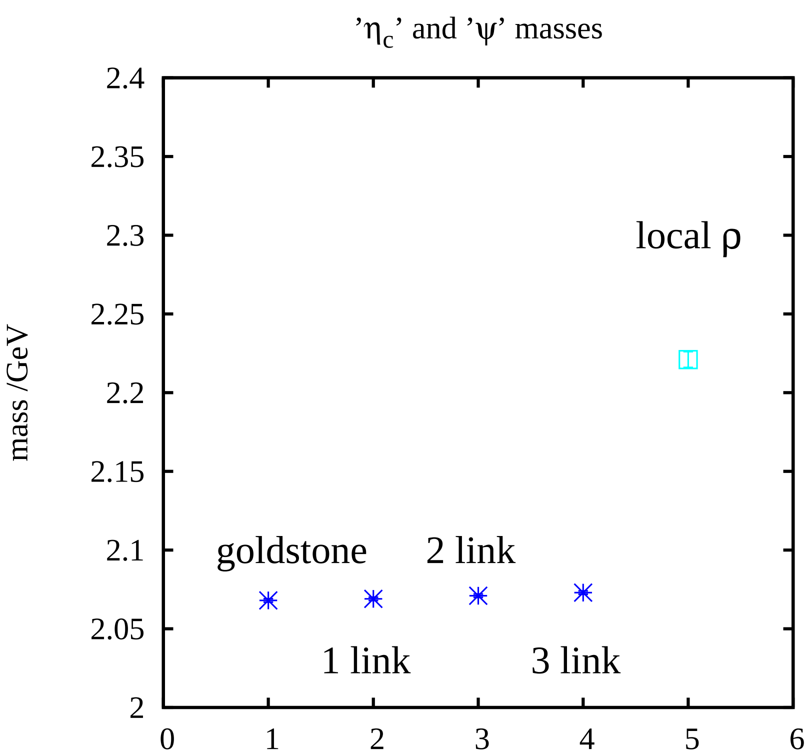
What next?

Amplitudes in progress for HH and HL, for leptonic widths and f_{D_s}/f_D. Watch this space!

What next?

Use a highly improved relativistic action for c quarks instead. HISQ staggered quarks are also fast.

PRELIMINARY results for $m_c a$=0.5 on MILC fine configs.



HISQ has much improved taste-splittings over asqtad. Find splitting between different η_c of 5 MeV. i.e. NOT a problem.

In fact m_c incorrect here, so need to rerun.

Conclusions

- Super-coarse MILC configs give good results with understood systematic errors for b AND c physics using NRQCD. New determination of B_c mass. ψ' worth further study as non-gold-plated but stable particle?
- On fine (and finer ...) MILC lattices HISQ for c will work well. Disc. errors are smaller than for other actions ($\alpha_s m_c a^2$) and χal symmetry means renorm. constants very close to 1 for e.g. f_D. In progress.