Scale setting and the light baryon spectrum on CLS ensembles

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Lattice 2021
The 38rd International Symposium on Lattice Field Theory
June 27th, 2021

Collaborators

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The work presented was carried out in collaboration with

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Many thanks also to our CLS colleagues!

Scale setting

High precision is needed for setting the scale

→ for dimensionful quantities error from scale setting comes on top of stats./systematic error of quantities computed from lattice

Setting the scale with Wilson Flow Parameter t_0

[Lüscher 2010, Narayanan, Neuberger 2006]

- properties: mild dependence on quark masses, high precision, easy to compute
  → but large autocorrelations
- t_0 can not be measured directly in experiments
  → connection to an experimental quantity is needed
- determinations from other groups:
  - BMW: $\sqrt{t_0} = 0.1465(25)$fm using m_Ω $(2+1f)$
  - Bruno *et al.*: $\sqrt{t_0} = 0.1467(16)$fm using f_π , f_K $(2+1f)$
  - RBC/UKQCD: $\sqrt{t_0} = 0.1439(8)$fm using m_Ω $(2+1f)$
  - Bornyakov *et al.*: $\sqrt{t_0} = 0.1511(24)$fm using average octet baryon mass $(2+1f)$
  - ...

Scale setting on $2+1$f CLS ensembles

Determination of t_0 on CLS ensembles

- value: $\sqrt{t_0} = 0.1467(16)$fm → determined by a subgroup of CLS members [Bruno *et al.* 2016]
- pseudoscalar decay constants have been employed to connect to "experimental values"
- a subset of currently available CLS ensembles have been used
  - → an update of this analysis is currently ongoing employing almost all available ensembles
  - → see parallel talk by Ben Strassberger on Friday

RQCD determination of t_0 on CLS ensembles

- complementary approach to obtain t_0
  → utilizing the light baryon spectrum using Ξ (and also Ω)
- no CKM matrix elements need and el. mag. corrections are less of an issue (compared to determinations using f_K,...)
- almost all available CLS ensembles plus some additional ensembles are utilized

⇒ Goal: confirm/improve on the value of t_0

Simulation Overview

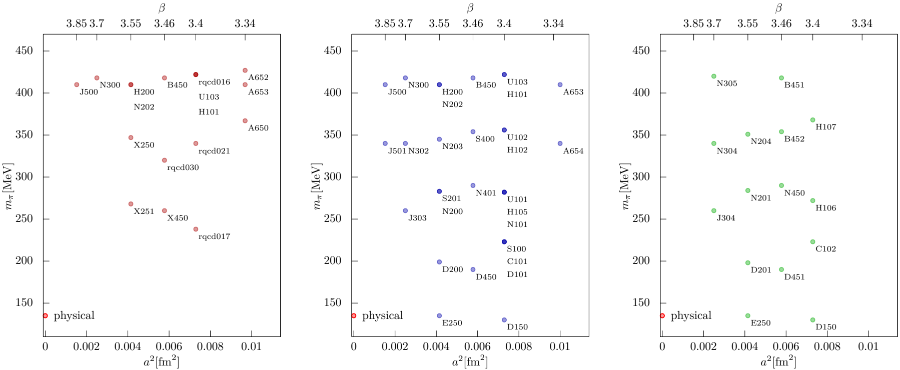
CLS $2+1$f simulation program

- CLS (Coordinated Lattice Simulations): HU Berlin, CERN, TC Dublin, Mainz, UA Madrid, Milano Bicocca, Münster, Odense/CP3-Origins, Regensburg, Roma I, Roma II, Wuppertal, DESY Zeuthen, Krakow
- lattice action and simulations
  - two degenerate light quarks and one strange quark
  - non-perturbatively improved Wilson action (clover)
  - tree-level improved Symanzik gauge action
- utilizing open boundaries (at small lattice spacings) → avoid topological freezing

Simulation details

- three different chrial trajectories
  - constant average quark mass: $\overline{m} = m_{\mathrm{symm}}$ $\leftarrow \mathrm{Tr}M = const.$
  - constant physical strange quark mass: $\widetilde{m}_s = \widetilde{m}_{s,\mathrm{ph}}$
  - symmetric line: $m_s = m_\ell$
- large number of sources with optimized smearing available
- high statistics with 1000 - 20000 MDUs

Ensemble overview



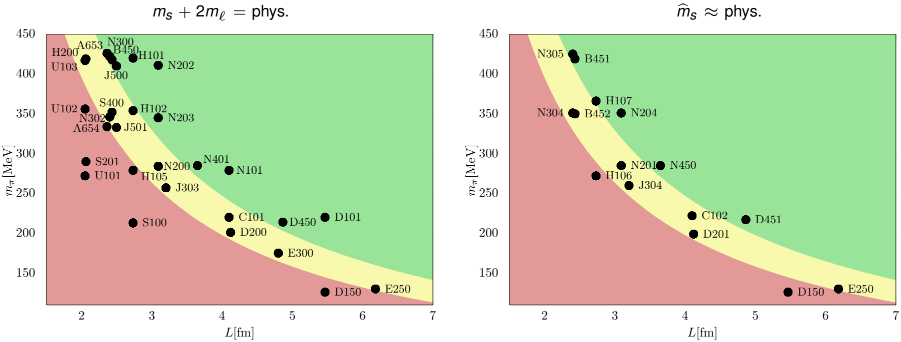
$m_s = m_\ell$

$m_s + 2m_\ell = \text{phys.}$

$\widehat{m}_s \approx \text{phys.}$

- 6 different lattice spacings ($a \approx 0.1 - 0.04$fm), 2 ensembles at the physical point
- note: symmetric ensembles very helpful for resolving $\overline{m}$ dependence

Finite volume effects



$m_s + 2m_\ell$ = phys.

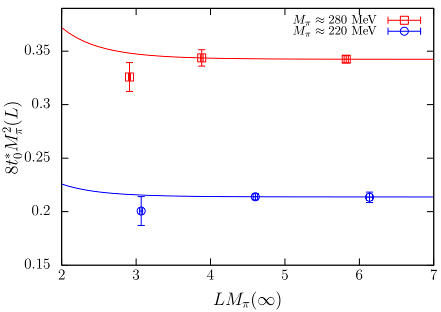
$\widehat{m}_s \approx$ phys.

Overview of ensembles: finite volume effects

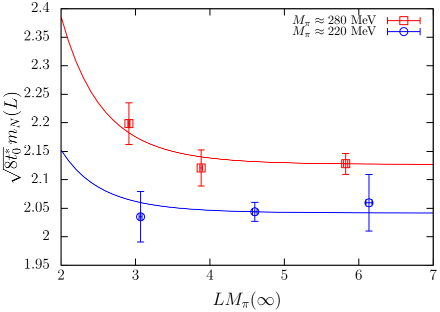
- red area: $m_\pi L \leq 4$
  yellow area: $4 < m_\pi L \leq 5$
  green area: $5 < m_\pi L$

$\Rightarrow$ almost all ensembles are within yellow or green area showing small finite volume effects (and also $L \gtrsim 2.3$fm)

Finite volume effects



pion mass



nucleon mass

Dedicated ensembles with small/large volumes

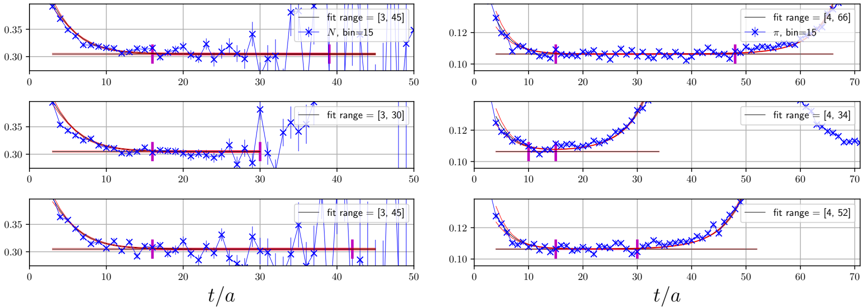
→ small finite volume effects for $m_\pi L > 4$

→ given the large number of ensembles, small effects may add up!

⇒ include finite volume effects for baryons for all ens.: $\chi^2/dof \sim 1.4 \rightarrow 1.2$ ← without additional parameters!

→ finite volume effects for mesons are also included in our analysis but they are negligible

Excited states

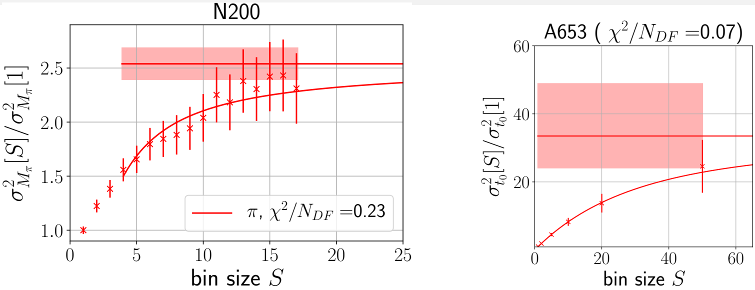


examples of effective masses of nucleon and pion

Effective mass

- determination of the fit range by means of a two-state fit
  - → time slices where contribution of excited state is negligible determines fit range
  - → similarly boundary effects from the open boundary condition are taken into account
  - → for baryons: stop fitting if noise becomes too large
- vertical red bands indicate the determined fit range for fitting the ground state mass

Autocorrelations: error estimation of observables

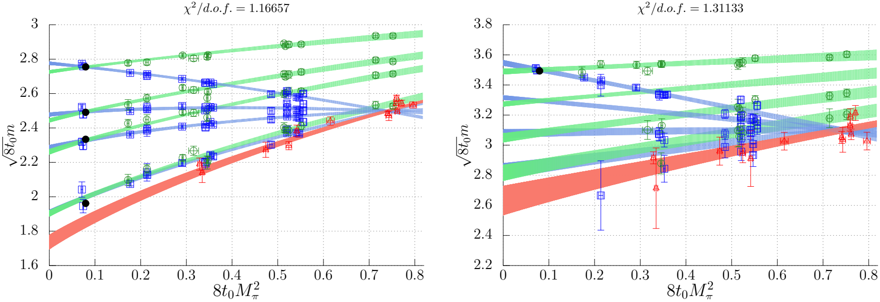


(normalized) variance σ^2 of pion mass M_π and Wilson flow parameter t_0

Autocorrelations

- extrapolation of bin size $S \rightarrow \infty$: extrapolated true error σ_{true}
- fit form for t_0: $\frac{\sigma^2(S)}{\sigma^2(1)} = 2\tau_{int}\left[1 - \frac{\tau_{int}}{S}\left(1 - \mathrm{e}^{-S/\tau_{int}}\right)\right]$ → ansatz works very well for all ensembles
  (note: fit form is exact for a coupling to only one mode)
- fit form for other observables: $\frac{\sigma^2(S)}{\sigma^2(1)} = 2\tau_{int}\left(1 - \frac{c}{S} + \frac{d}{S}\mathrm{e}^{-S/\tau_{int}}\right)$
- also covariances are extrapolated
  note: sign changes for the extrapolated covariances have been observed (depending on ensemble/observable)
- Uli Wolff method and bin size analysis give consistent results

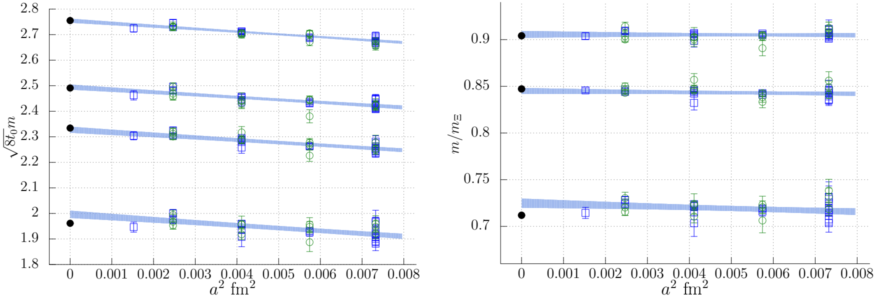
Chiral and continuum extrapolation baryon spectrum



(Prelim.) results for baryon octet (left), $m = N, \Lambda, \Sigma, \Xi$, and decuplet (right), $m = \Delta, \Sigma^*, \Xi^*, \Omega$

- masses rescaled with $\sqrt{8t_0}$
- combined chiral and continuum fit
- curves show the continuum part utilizing NNLO baryon chiral perturbation theory (BChiPT) → also other fits are investigated: NLO BChiPT, SSE, and GMO (Taylor expansion)
- data points are projected accordingly based on the fit, black points are physical values
- all three trajectories are utilized: $\widehat{m}_s \approx \widehat{m}_{s,\text{ph}}$ (green), $\mathrm{Tr}M = \text{const.}$ (blue), $m_s = m_\ell$ (red)
- data points for unstable decuplet baryons with respect to strong decays are not shown

Chiral and continuum extrapolation baryon spectrum



Cutoff effects for baryon octet masses

- data points are projected to the physical point according to the fit
- lines show the mild, but sizeable, linear cut-off effects in a^2 → no higher orders in *a* resolved

Conclusions and outlook

Systematics: chiral and continuum limit

- keep fit form fixed and vary data
  → apply cuts in average quark mass, lattice spacings
- keep data fixed and vary fit forms
  → different fit forms: NLO BChiPT, SSE, and GMO (Taylor expansion) ← w/o finite volume corrections

→ range of $\chi^2/dof \sim 0.7 - 1.5$

Compare to literature

- [Bruno *et al.* 2016]: 1.1 % total error on $\sqrt{t_0}$ ← based on CLS ensembles
- this analysis: $\sim$ 0.6 % statistical error (expectation based on our "best fits" with $\chi^2/dof \sim 1.1$)
  and in addition XXX % systematic error (also to be finalized)

Outlook

- ToDo: finalize systematic error based on given fits (currently ongoing)
- next steps:
  - → include few missing ensembles/configurations and update the analysis
  - → perform combined fits with light pseudoscalar decay constants
  - → extract low energy constants