Hadronic spectrum calculations in the quark-gluon plasma

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July 27th 2018

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Talk overview

1. Introduction
2. Method
3. Results
4. Future work
5. openQCD-FASTSUM

Introduction

Baryons at finite temperature

Although mesons have been thoroughly studied at finite temperatures, baryons have not been given nearly the same attention

- They have definite parity: $P_{\pm}\mathcal{O}_B(x) = \mathcal{O}_B(x)$
- Experimentally accessible results
- Important for model builders
  - Quark models, e.g. hadron resonance gas
  - Verification of thermodynamic models

More broken symmetries...

In nature baryon parity is a broken symmetry

$$m_{\{uud\}^{1/2+}} \equiv m_N = 0.939 \text{ GeV}$$
$$m_{\{uud\}^{1/2-}} \equiv m_{N*} = 1.535 \text{ GeV}$$

Similar to other broken symmetries, what happens to this one as we increase temperature and enter the deconfined phase?

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Previous studies by FASTSUM:

1502.03603, 1703.09246, 1710.00566, ...

Open questions

- Does parity restoration happen at T_c?
- How does hadron content effect parity restoration?
- Is there a flavour hierarchy in the deconfinement transition?
- How does m_π affect parity restoration?

Method

Lattice setup - Gen2l ensembles

Results produced with the FASTSUM "Gen2l" ensembles (lattice parameters by the HadSpec collaboration)

- $N_f = 2 + 1$ dynamical quarks, Wilson-Clover action
- Anisotropic action: $a_s = 0.1227(8)\,\text{fm}, \; a_s/a_t = 3.5$
- $m_\pi =$ 236 MeV, $m_s = physical$

N_t	256	48	40	36	32	28	24	20	16
T/T_c	0.12	0.63	0.76	0.84	0.95	1.09	1.27	1.52	1.90
N_{cfg}	750	500	500	500	500	1000	1000	1000	1000

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Have to be checked, numbers from Gen2 ensembles

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Still generating (the N_t = 48, 40, 36, 32 ensembles)

Lattice setup - baryon correlation functions

Use the following baryon interpolation functions:

$$\chi_{N,\gamma} = \epsilon^{abc} u^a_\gamma (u^b_\alpha (C\gamma_5)_{\alpha\beta} d^c_\beta)$$
$$\chi_{\Delta^+,\gamma,\mu} = \epsilon^{abc} \left(2u^a_\gamma (u^b_\alpha (C\gamma_\mu)_{\alpha\beta} d^c_\beta) + d^a_\gamma (u^b_\alpha (C\gamma_\mu)_{\alpha\beta} u^c_\beta)\right)$$
$$\chi_{\Delta^{++},\gamma,\mu} = \epsilon^{abc} u^a_\gamma (u^b_\alpha (C\gamma_\mu)_{\alpha\beta} u^c_\beta)$$

for all baryons that can be constructed with from them having flavour content using $\{u, d, s, c\}$

- N, $\Delta_{s/c}$, $\Sigma_{s/c}$, $\Sigma^*_{s/c}$, $\Xi_{s/c}$, $\Omega_{s/c}$

Sinks and sources smeared with Gaussian smearing to extract ground states

Results

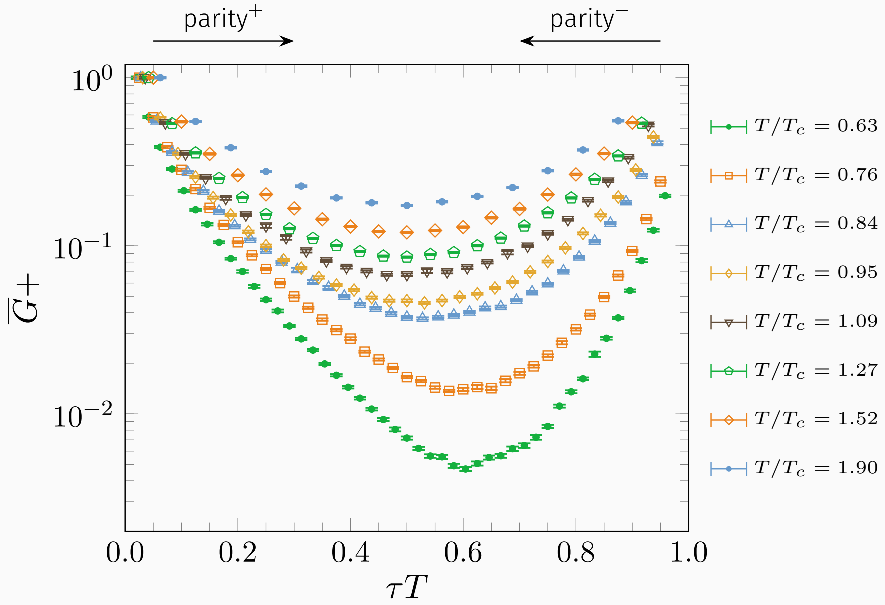
Parity and correlation functions

Due to charge conjugation symmetry (at $\mu = 0$)

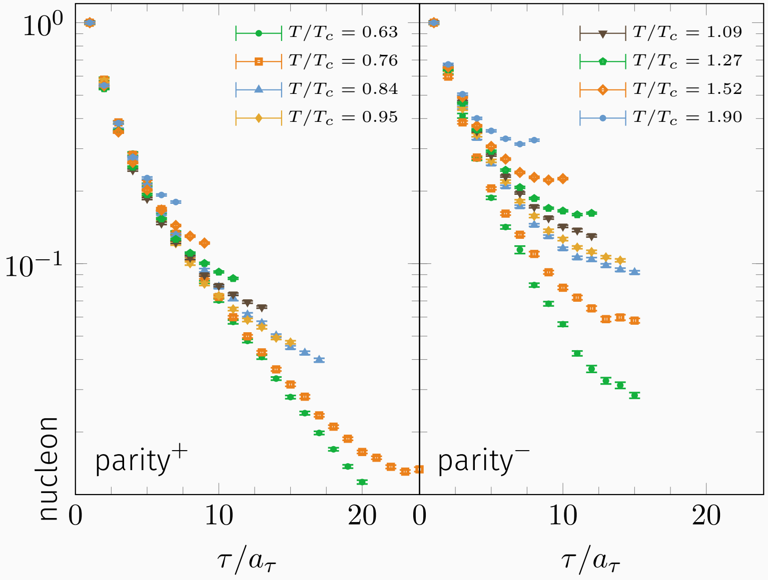
$$G_{\pm}(\tau, \mathbf{p}) = -G_{\mp}(1/T - \tau, \mathbf{p})$$

Thus the correlation function is a sum of forward moving parity^{+} states and backwards moving parity^{-} states

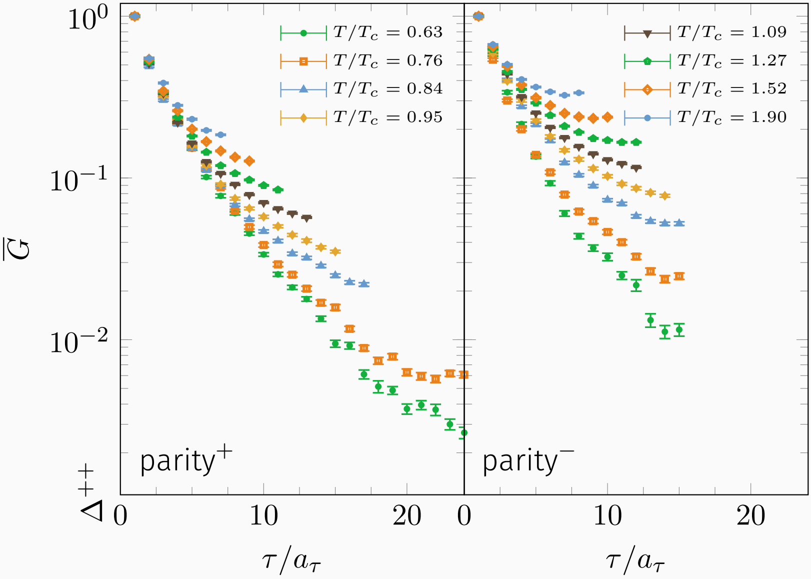
Correlation functions



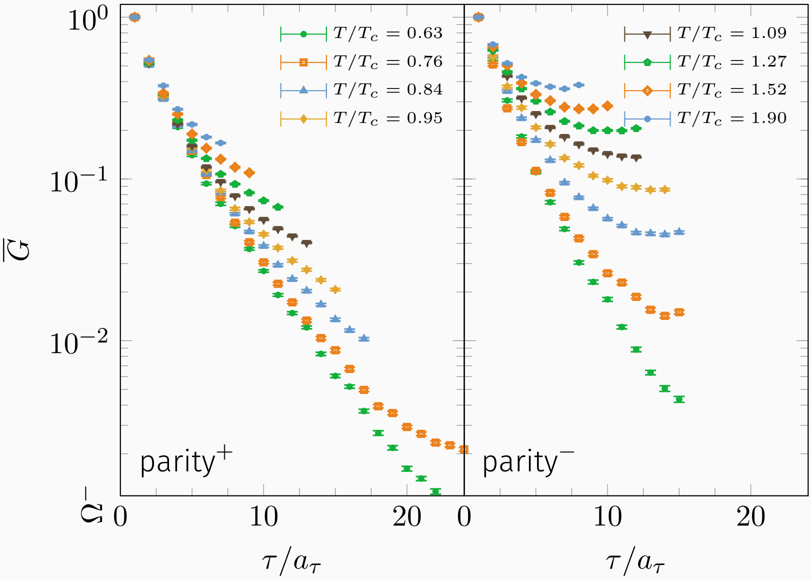
Parity channels - nucleon



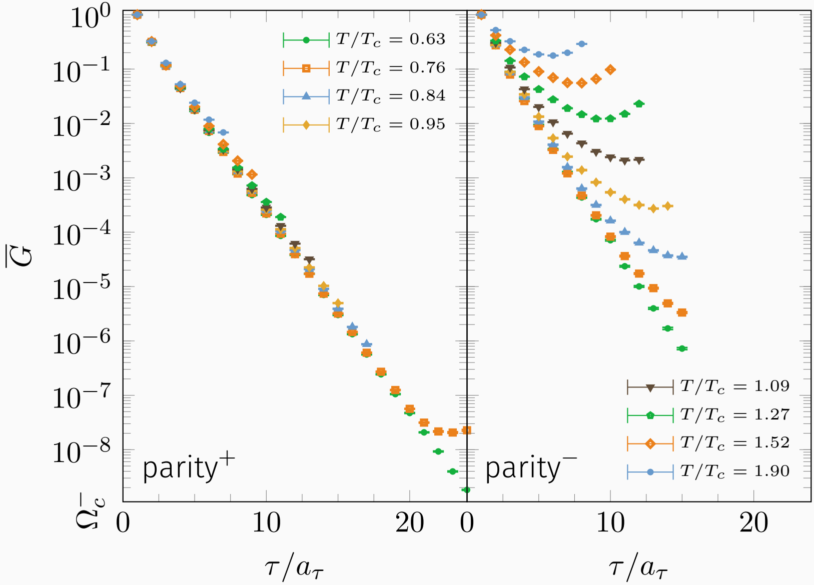
Parity channels - Δ^+ particle



Parity channels - Ω particle



Parity channels - Ω_c particle



Symmetry restoration parameter - the R parameter

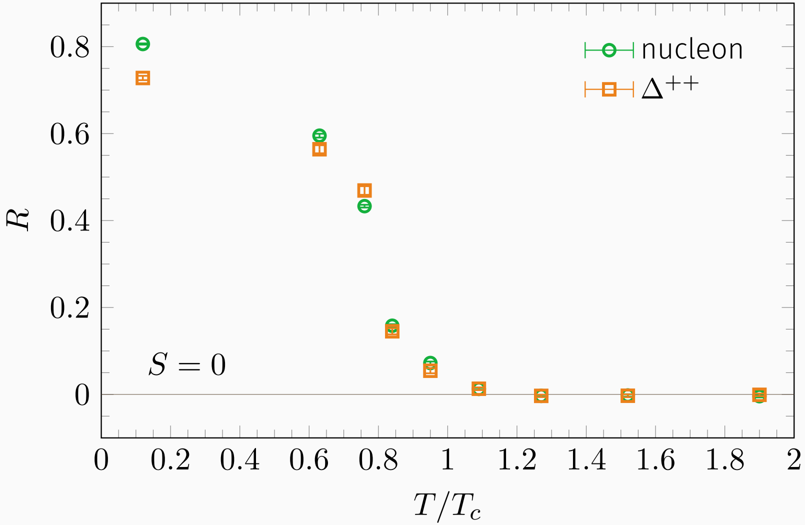
$$R(\tau) = \frac{G_+(\tau) - G_+(1/T - \tau)}{G_+(\tau) + G_+(1/T - \tau)}$$

- $R(\tau) \neq 0 \Leftrightarrow$ no parity doubling
- $R(\tau) = 0 \Leftrightarrow$ parity doubling

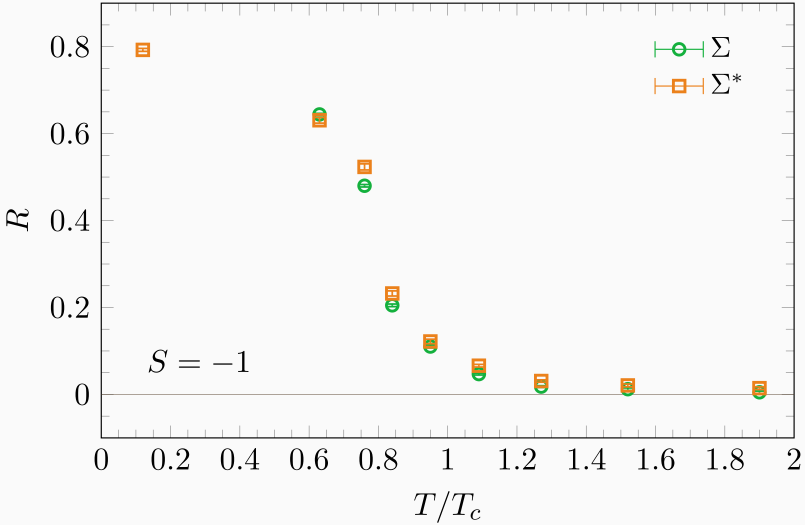
The summed ratio is a quasi-order parameter (as we will see)

$$R = \frac{\sum_n R(\tau_n)/\sigma^2(\tau_n)}{\sum_n 1/\sigma^2(\tau_n)}$$

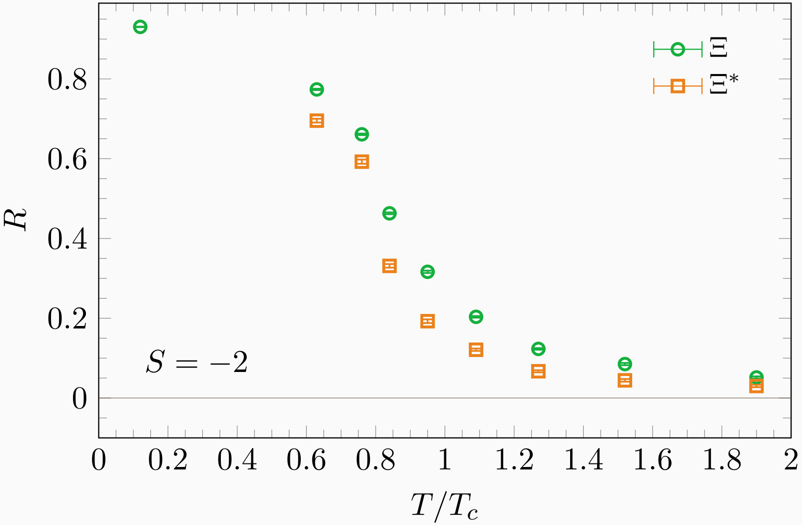
The R-factor - $S = 0$



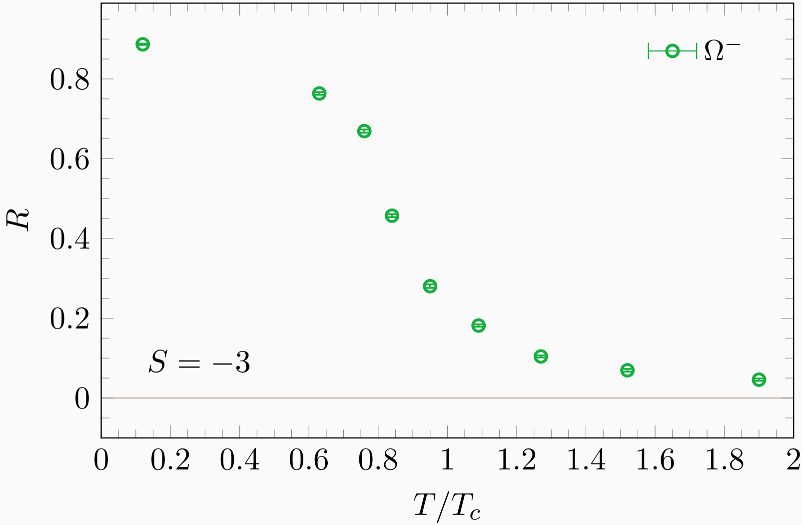
The R-factor - $S = -1$



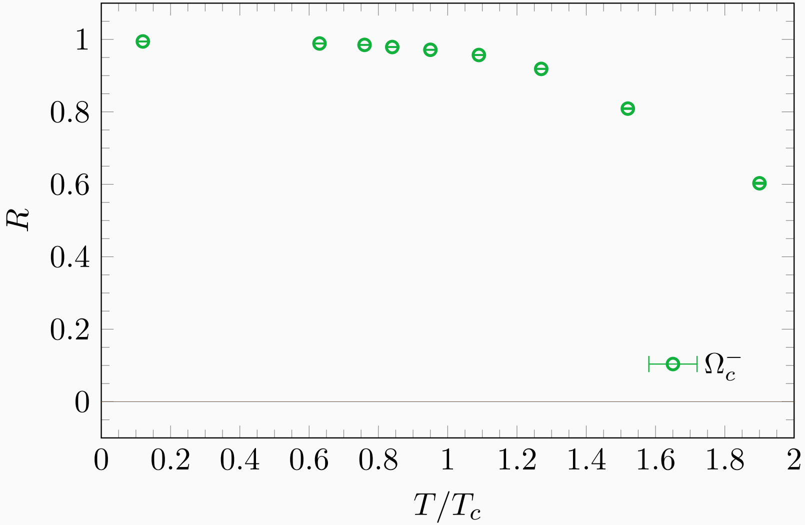
The R-factor - $S = -2$



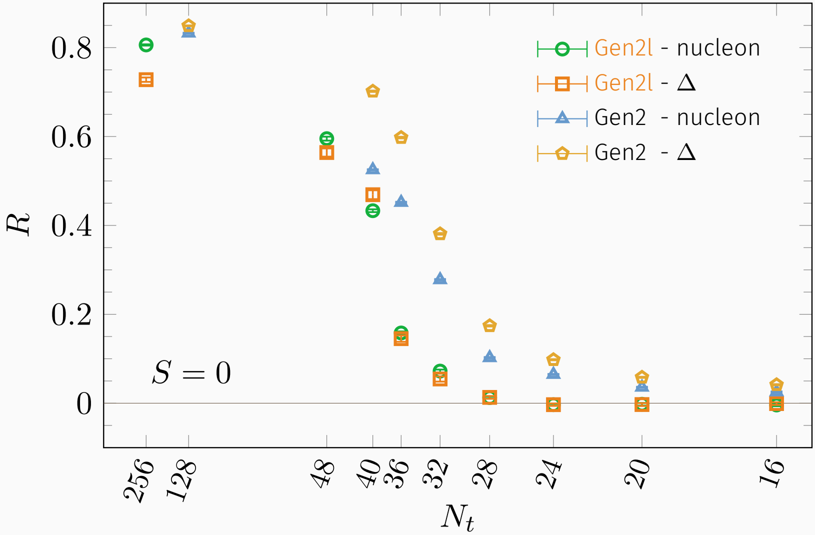
The R-factor - $S = -3$



The R-factor - Ω_c particle



The R-factor - comparison with previous ensemble



Future work

Still a lot more to be done

Study just getting started

- More thorough look at the masses and correlators
- Spectral reconstruction analysis
- Susceptibility calculations

Planned future ensembles

- Generation 2P
- Generation 3

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- Generation 2P (physical quark masses)
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Study just getting started

- More thorough look at the masses and correlators
- Spectral reconstruction analysis
- Susceptibility calculations

Planned future ensembles

- Generation 2P (physical quark masses)
- Generation 3 (higher anisotropy)

openQCD-FASTSUM

Two major features

- Anisotropic lattice actions
- Stout link smearing

+ AVX512 optimisations courtesy of the SA2C

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Future development plans

- Library/back-end interface
- Unit testing and CI

`https://fastsum.gitlab.io`

Questions?