



# Charm baryons at finite temperature on anisotropic lattices

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Lattice 2022: QCD at Non-zero Temperature  
August 10, 2022

# Motivation

- Charm hadrons are important probes of quark-gluon plasma
- More experimentally accessible than bottom hadrons
- Pheno. models and heavy-quark effective field theories are viable
- Few lattice studies on charm baryons at non-zero temperature
  - ▶ Extend our previous work on light baryons and hyperons

# What are we going to do?

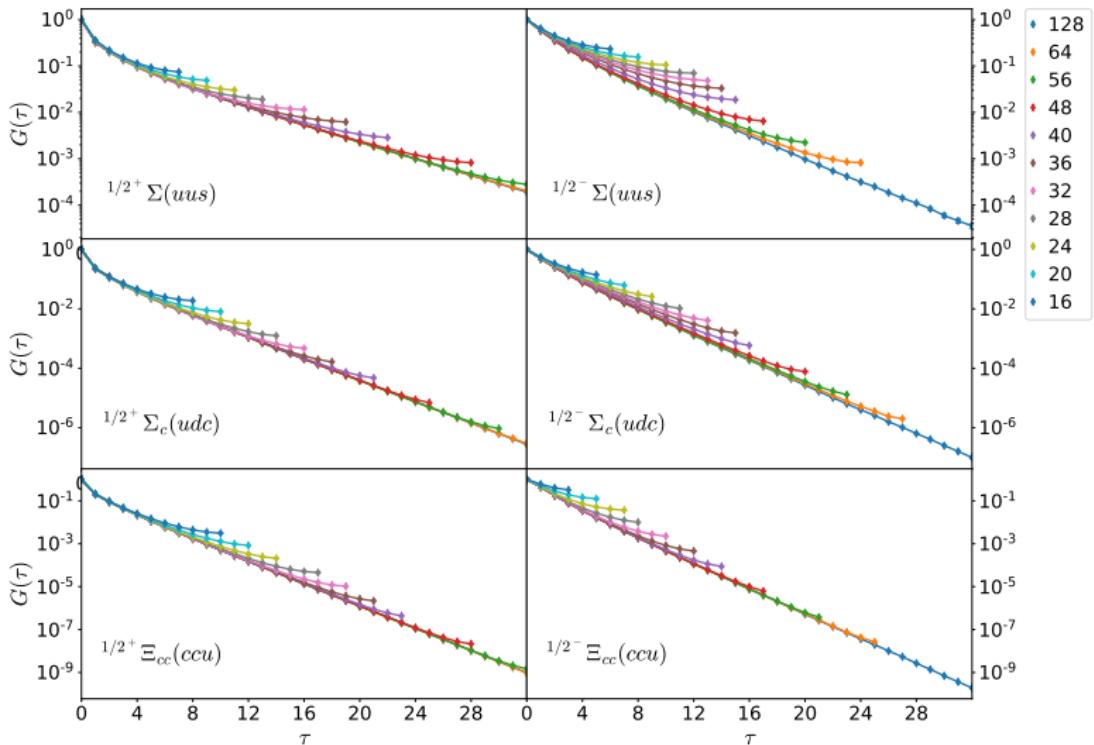
- Calculate charm baryon correlators at a range of temperatures
  - ▶ Mostly below  $T_c$
- Determine positive and negative parity masses for each channel as a function of temperature
- Examine the parity doubling effect
  - ▶ A signature of a quark-gluon plasma

# How

$N_\tau$	128	64	56	48	40	36	28
$T$ (MeV)	47	94	107	125	150	167	214
$T/T_c$	0.289	0.578	0.661	0.771	0.925	1.028	1.322

- FASTSUM Generation 2L  $N_f = 2 + 1$  anisotropic ensembles
  - ▶  $m_\pi \sim 230$  MeV,  $\xi \sim 3.5$ ,  $T_c \sim 165$  MeV,  $N_{\text{meas}} \sim 8000$
- Standard baryon operators  $[q \, C \, \gamma_5 \, q] \, q$  (mostly)
- Calculations performed using openQCD-FASTSUM
  - ▶ <https://gitlab.com/fastsum>
  - ▶ stout-link and source/sink smearing

# Correlator Temperature Dependence



# Fit Window Dependence

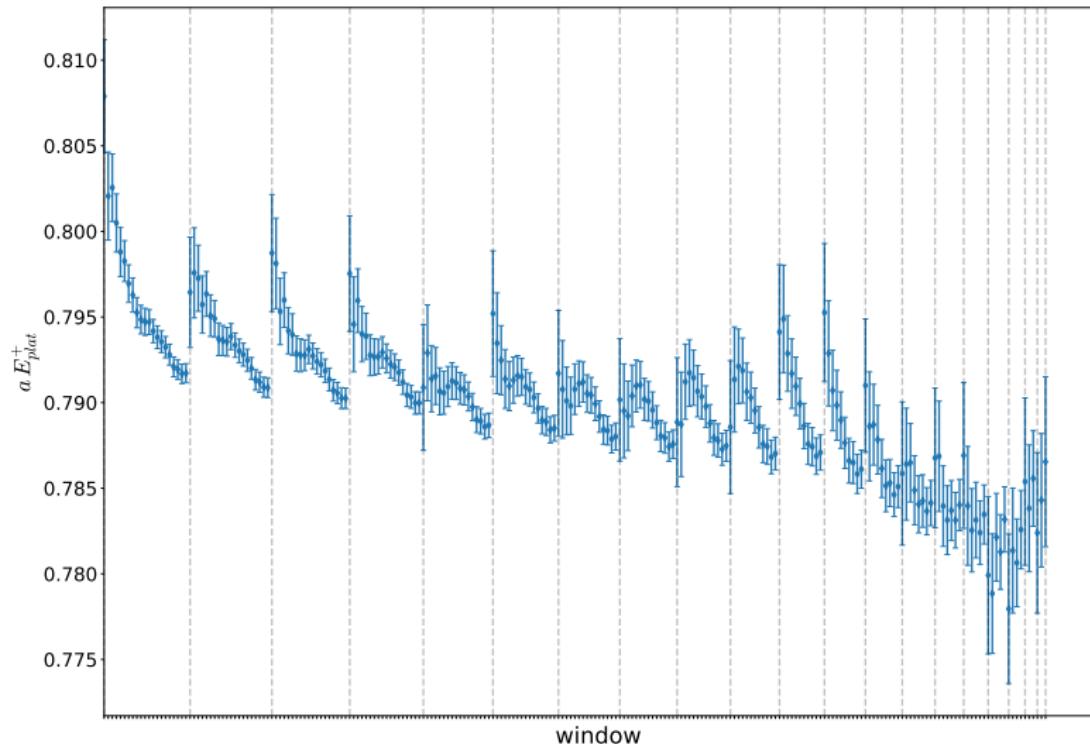


Figure: Constant plateau fits as a function of fit window

# Fit Window Dependence

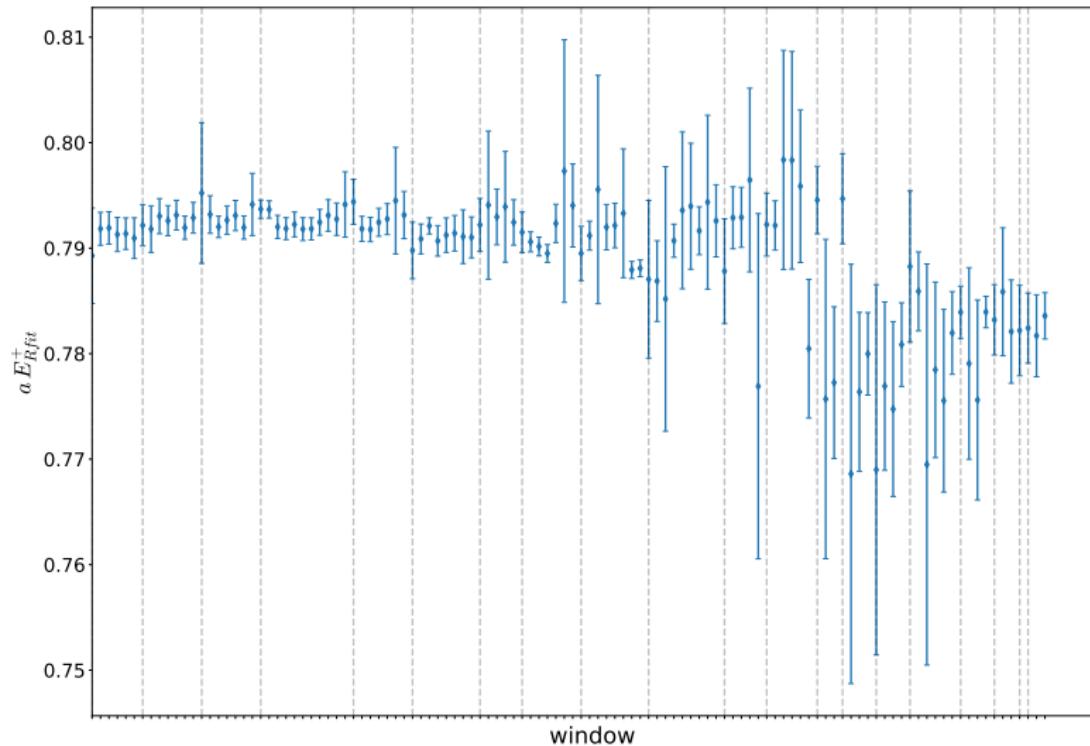


Figure: Multi-exponential fits as a function of fit window

# Model Averaging Methods

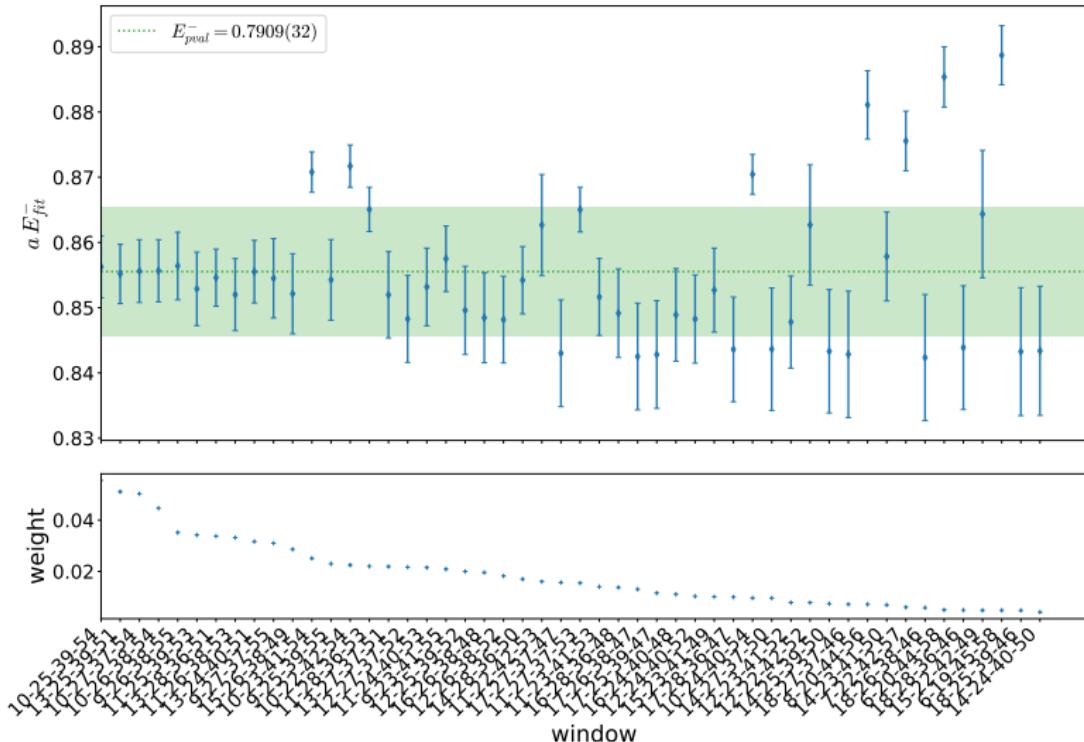
- Systematic approach to selection of “fit window”
- Weighted average over all possible fit windows
- Two different methods used to increase confidence in the result
  - ▶ First method uses modified Akaike information criterion  
W. Jay, E. Neil: **2008.01069**

$$\tilde{w}^f = pr(M_f|D) = \exp\left(-\frac{1}{2}\left(\chi_{\text{aug}}^2(E^f) + 2k + 2N_{\text{cut}}\right)\right),$$

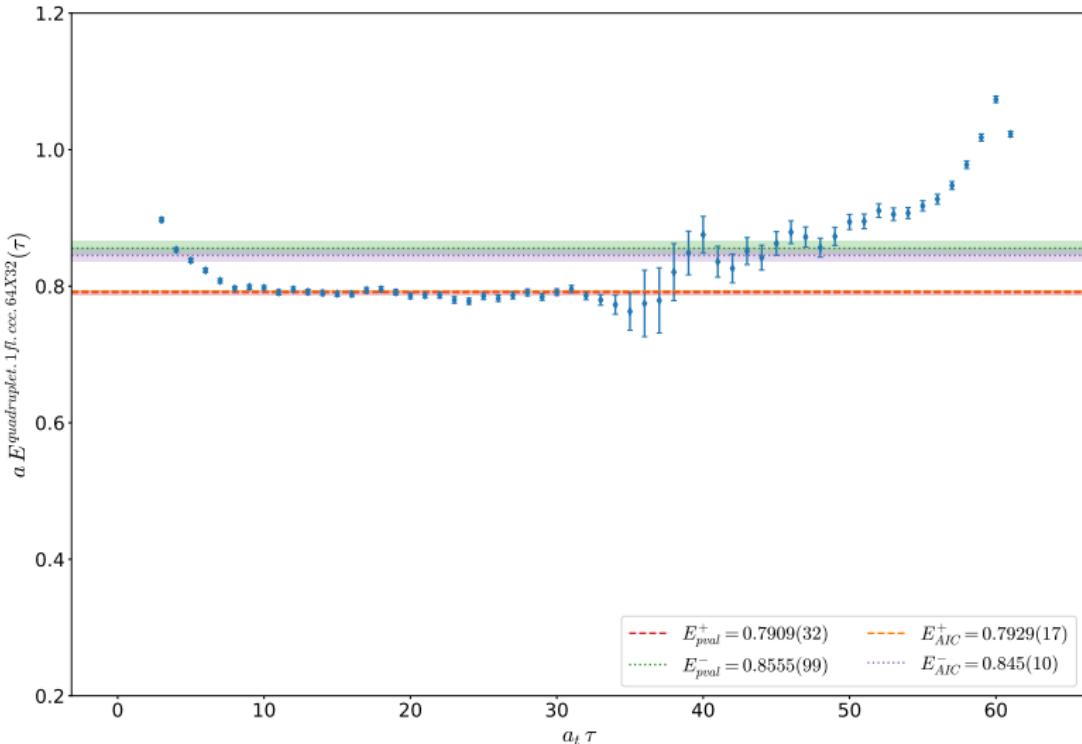
- ▶ Second method weights proportionally to statistical error and  $p$ -value E. Rinaldi, *et al.*: **1901.07519**

$$\tilde{w}^f = \frac{p_f (\delta E^f)^{-2}}{\sum_{f'=1}^N p_{f'} (\delta E^{f'})^{-2}},$$

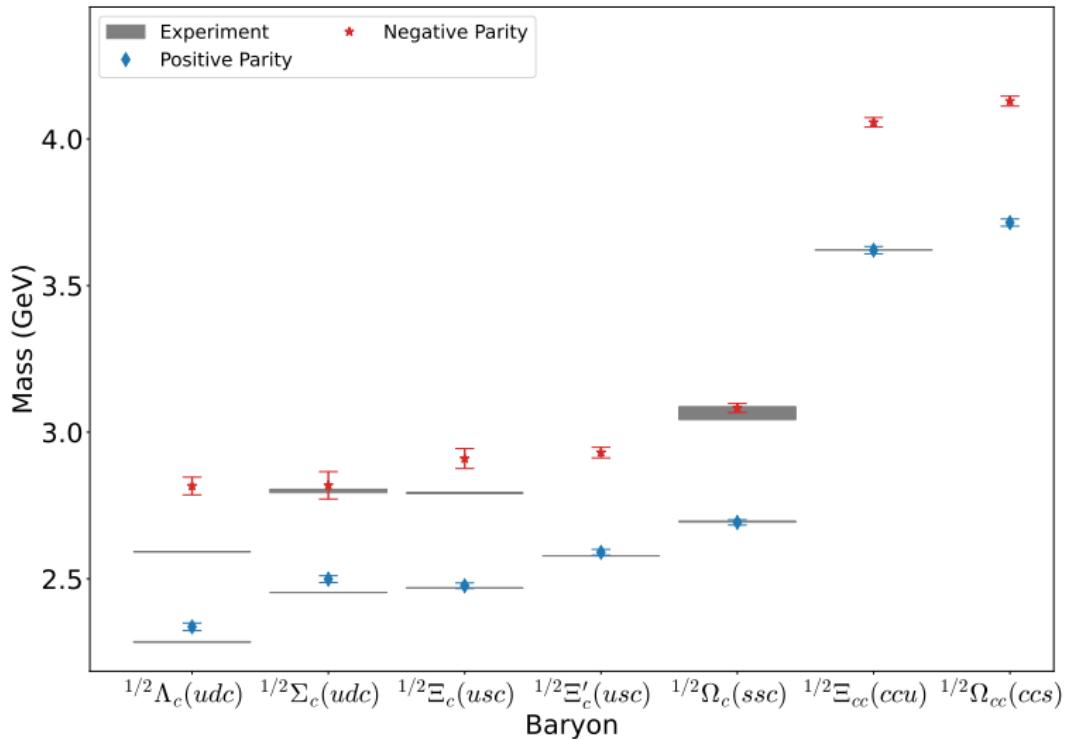
# Model Averaging Results



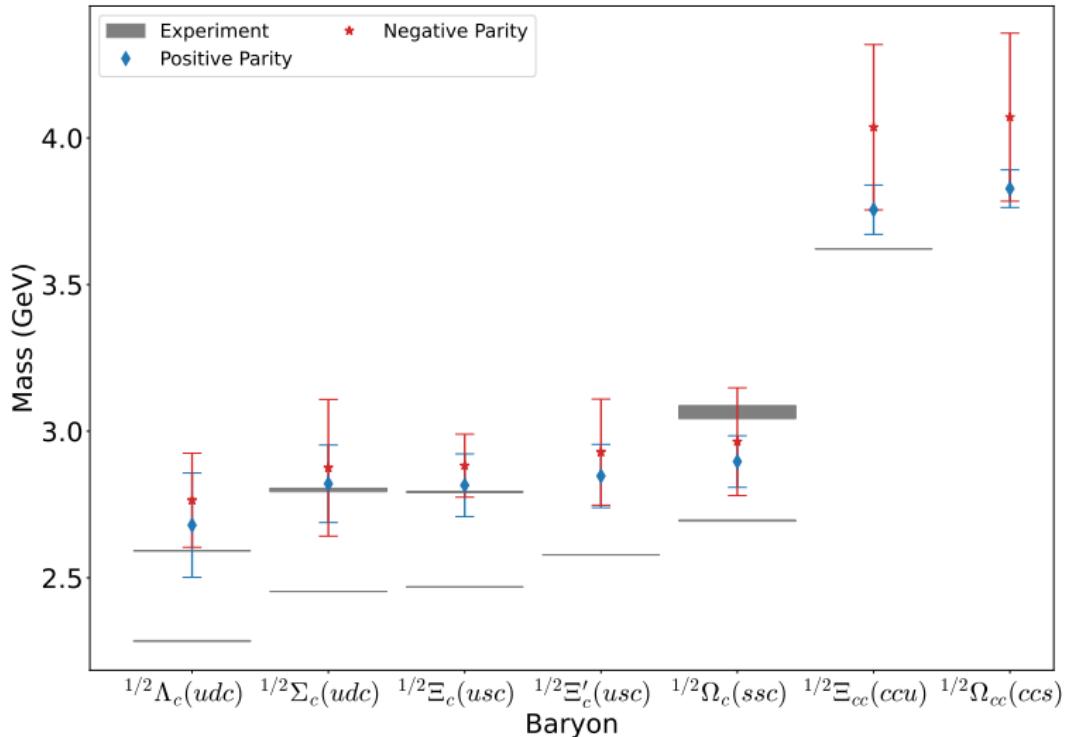
# Effective mass comparison



# Zero-temperature spectrum $J = 1/2$

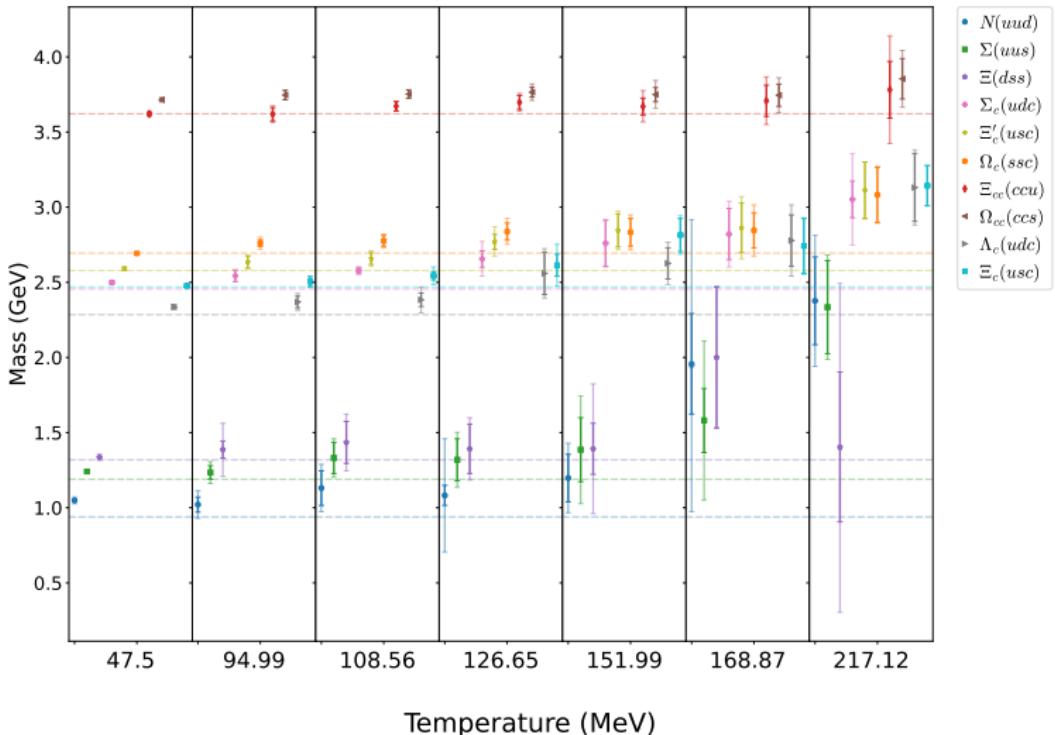


# 150 MeV spectrum $J = 1/2$



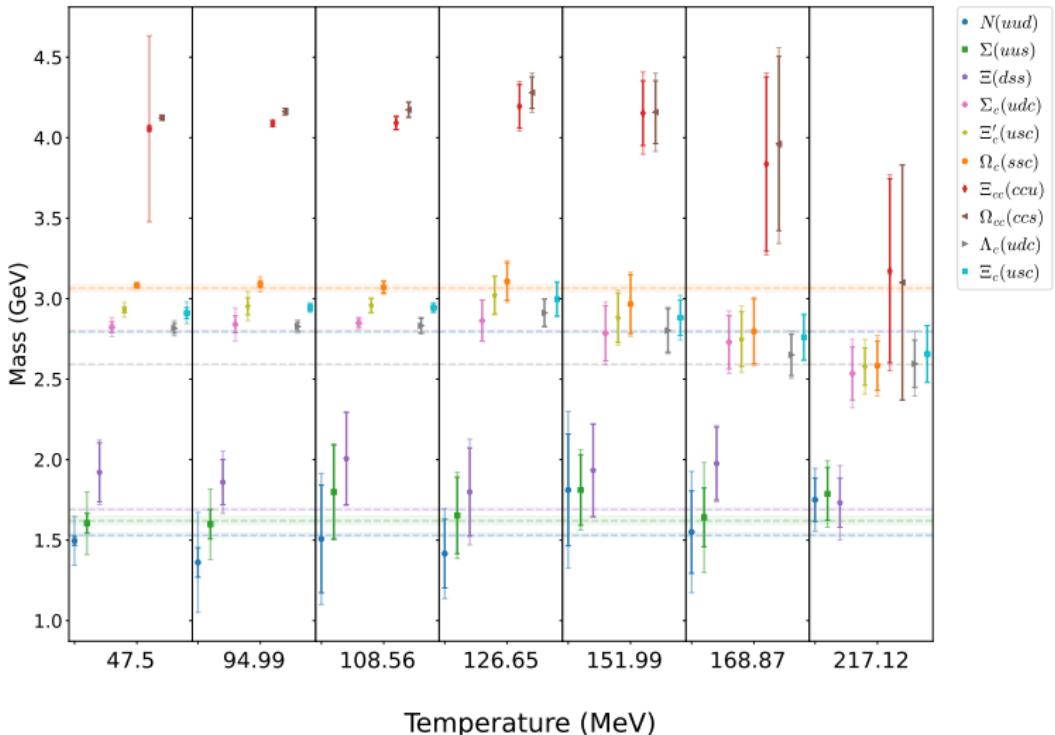
# All temperature Spectrum $J = 1/2$

## Positive Parity

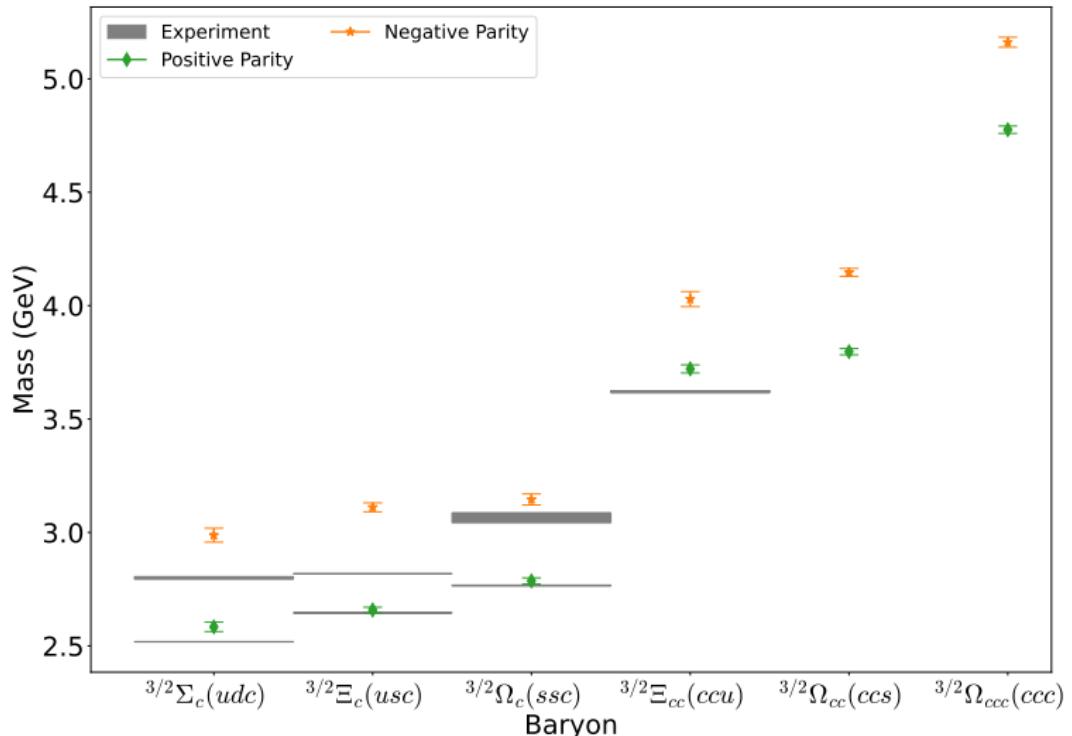


# All temperature Spectrum $J = 1/2$

## Negative Parity

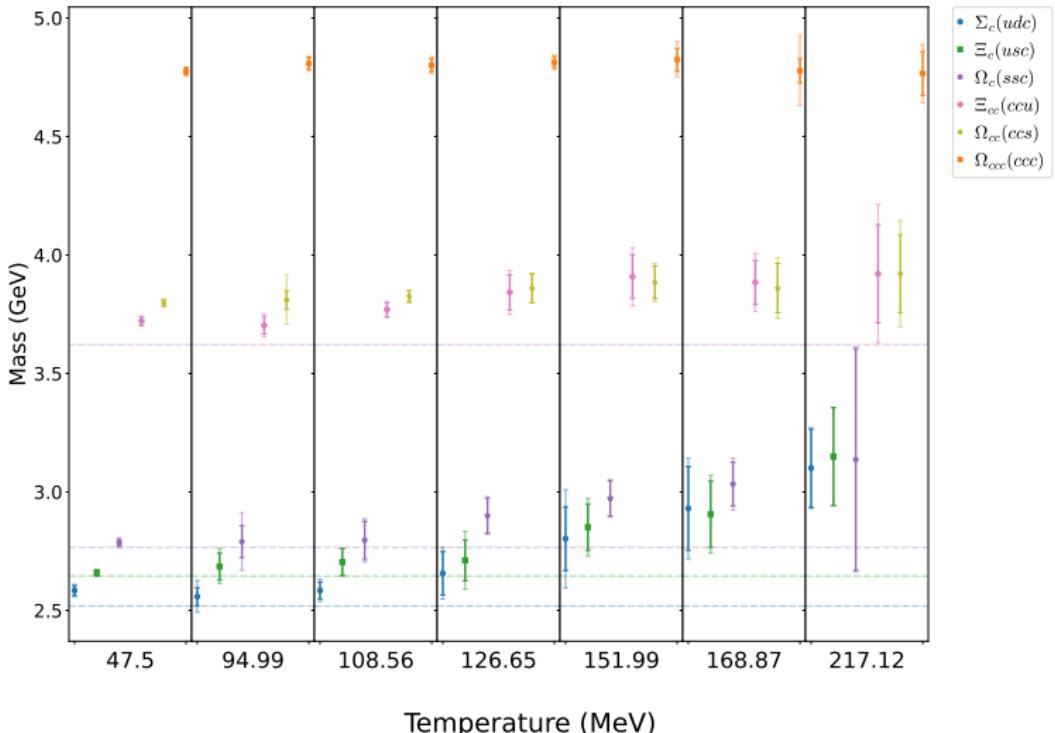


# Zero-temperature spectrum $J = 3/2$



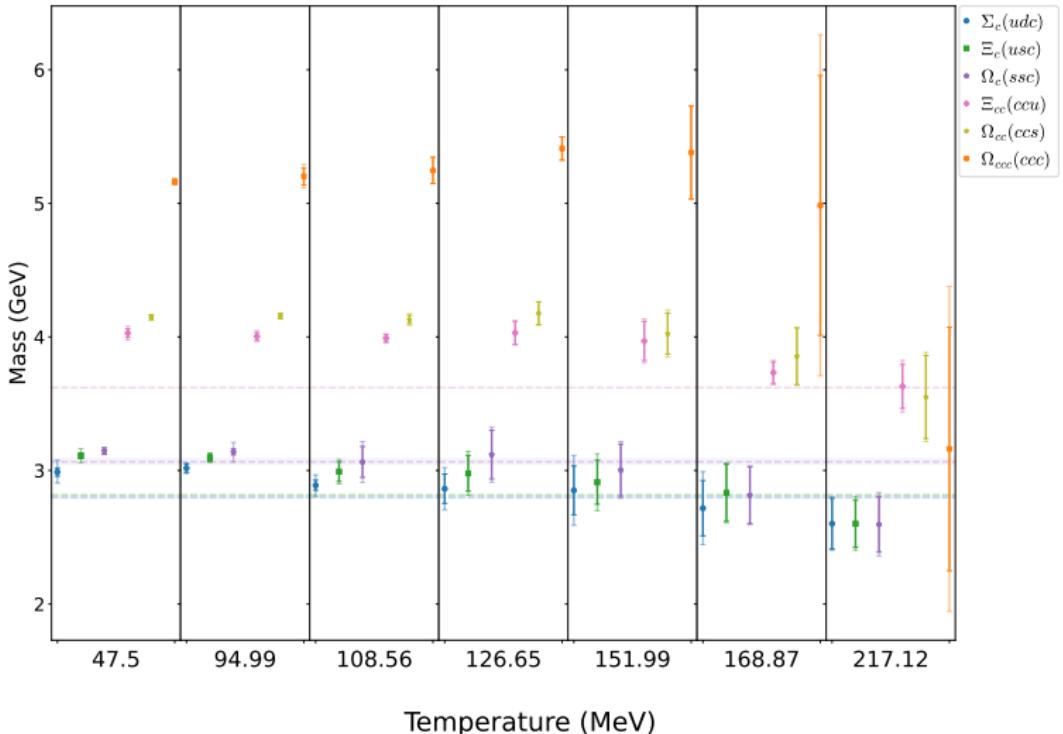
# All temperature Spectrum $J = 3/2$

## Positive Parity



# All temperature Spectrum $J = 3/2$

## Negative Parity



# Mass Summary

- Model averaging methods used to determine mass from correlator fits
  - ▶ of positive and negative parity states
  - ▶ at multiple temperatures
- Uncertainty increases as temperature does
  - ▶ Likely signifies increasingly incorrect fit ansatz
- Masses of positive/negative parity states generally begin to converge within uncertainty

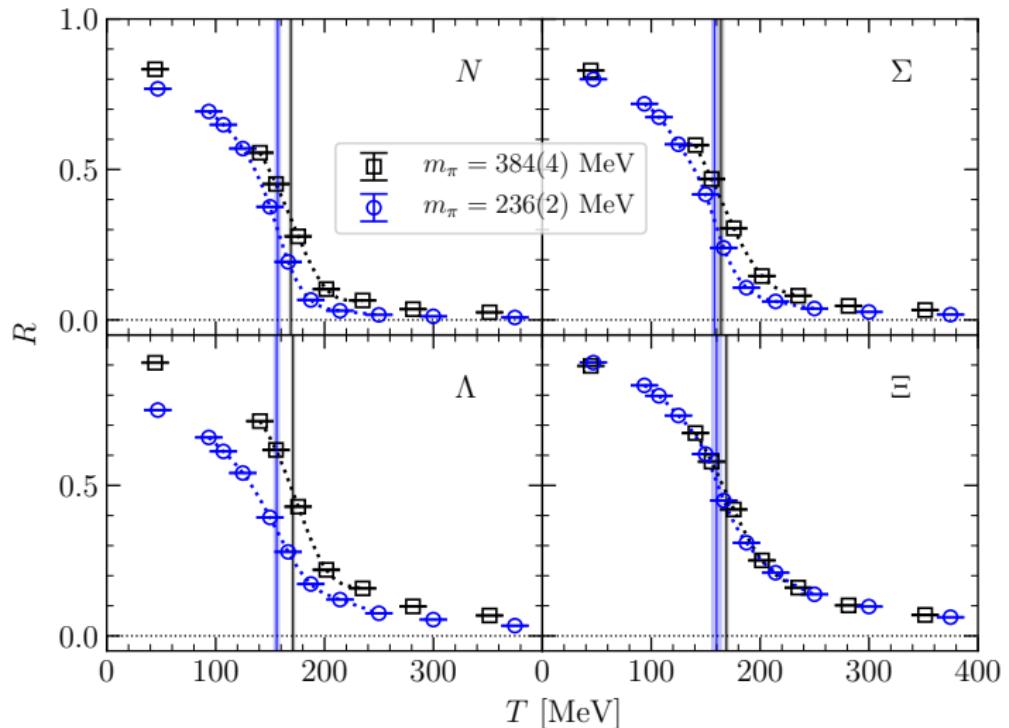
# Parity Doubling

- Examine emergence of parity doubling in baryonic correlators
  - ▶ Signal of chiral symmetry restoration
- Construct from positive ( $G^+(\tau)$ ) and negative ( $G^+(1/T - \tau)$ ) correlators

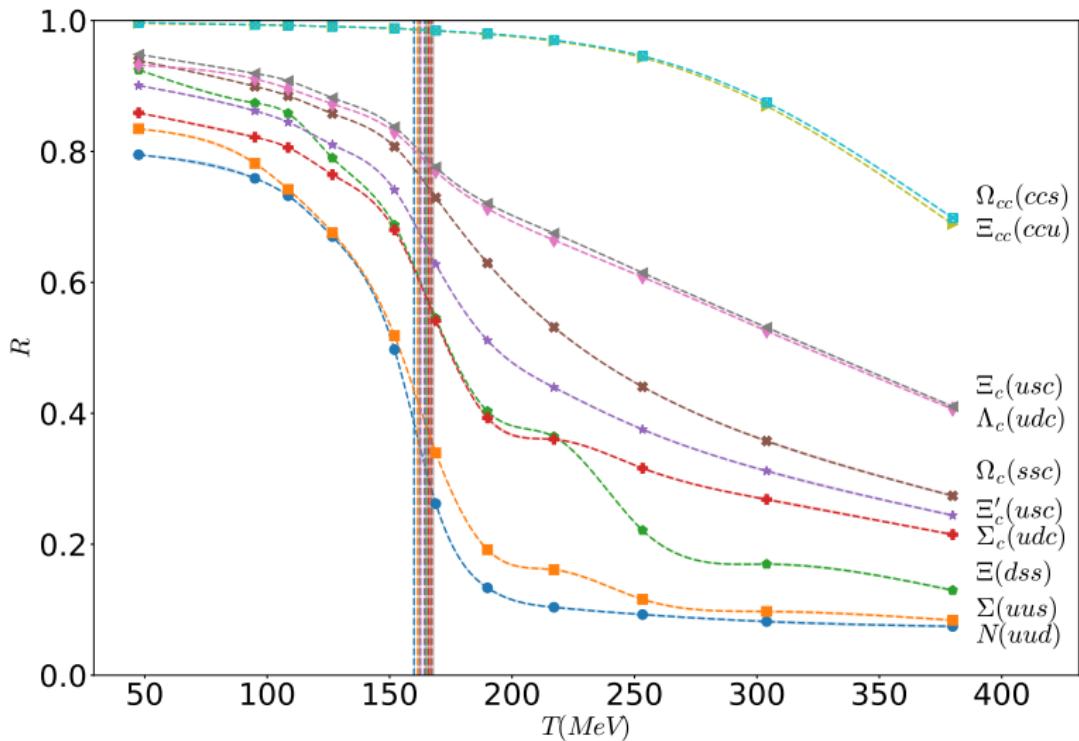
$$\mathcal{R}(\tau) = \frac{G^+(\tau) - G^-(\tau)}{G^+(\tau) + G^-(\tau)},$$
$$R(\tau_n) = \frac{\sum_n^{\frac{1}{2}N_\tau-1} \mathcal{R}(\tau_n)/\sigma_{\mathcal{R}}^2(\tau_n)}{\sum_n^{\frac{1}{2}N_\tau-1} 1/\sigma_{\mathcal{R}}^2(\tau_n)}.$$

# Parity doubling ratio $R$ $J = 1/2$

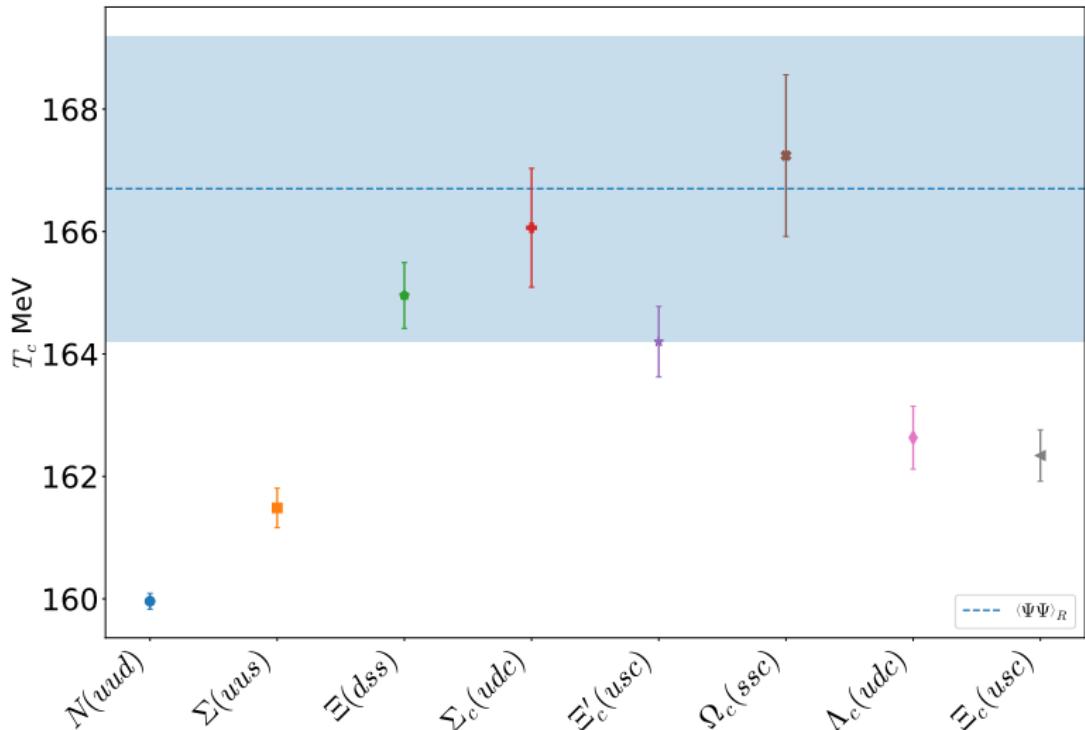
## Previous studies



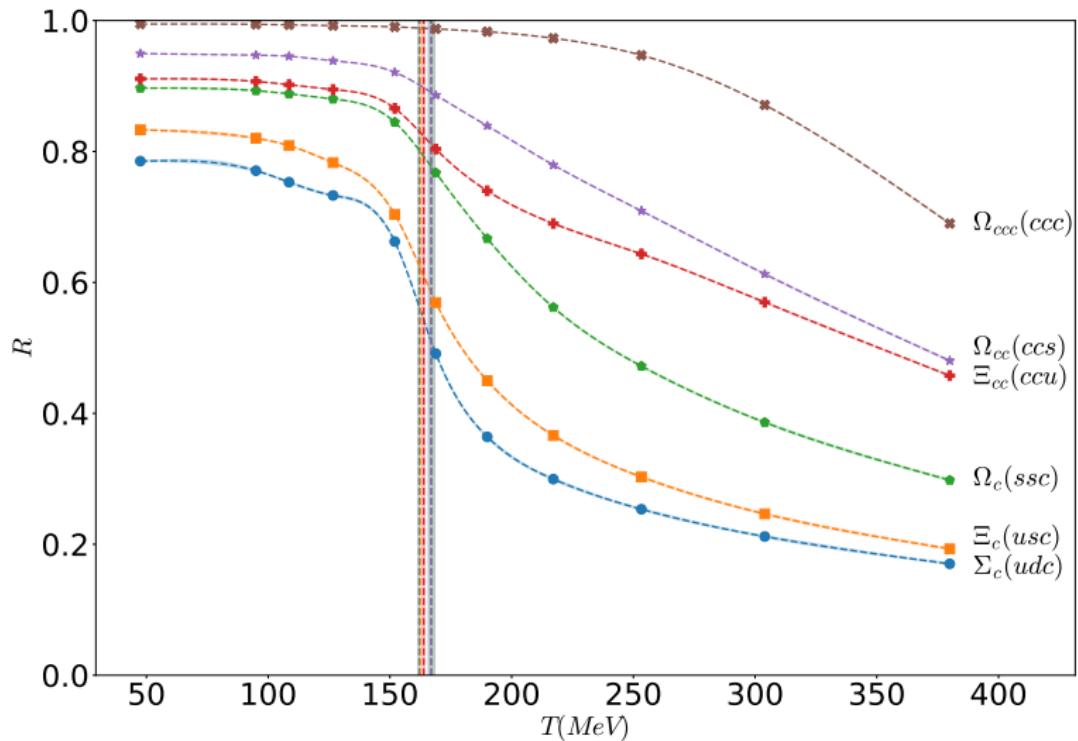
# Parity doubling ratio $R$ $J = 1/2$



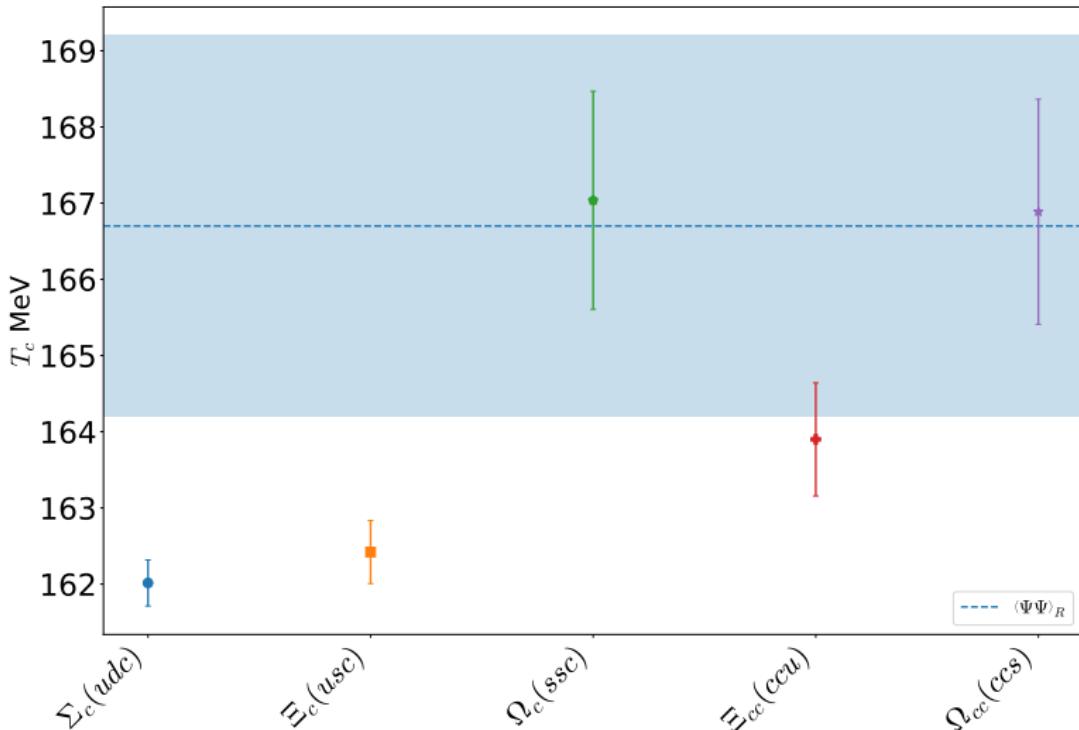
# Parity doubling ratio $T_c J = 1/2$



# Parity doubling ratio $R$ $J = 3/2$



# Parity doubling ratio $T_c J = 3/2$



# Summary

- Parity doubling effect decreases as quark mass increases
  - ▶ Quark mass explicitly breaks chiral symmetry
  - ▶ As does Wilson-Clover action
- Can still find inflection points for most baryons here
  - ▶ Even where parity doubling is not very evident!
  - ▶ Inflection points are close to  $T_c$  from the renormalised chiral condensate
- Exponential mass fits grow unreliable at higher temperatures
- Model averaging methods aids mass determination from many fits