Hadrons at high temperature: update from the FASTSUM collaboration

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Outline

Introduction, lattice setup

Light hadrons

Charm

Beauty

Towards new ensembles

Summary and outlook

Background



Background

- Quark–gluon plasma is created in heavy-ion collisions at RHIC and LHC
- No direct observation of QGP must infer from "fallout"
- Dynamical medium: expanding, cooling fireball
 - $\rightarrow\,$ transport coefficients are crucial in understanding
- In-medium mass and width modifications below T_c
 - \rightarrow relevance for hadron resonance gas models?
- Sequential suppression —> quarkonia as QGP thermometers?

Simulation parameters

[PRD 76 194513 (2007), HadSpec Collab, PRD 79 034502 (2009)]

Gen	N _f	ξ	a_s (fm)	$a_{ au}^{-1}$ (GeV)	m_{π} (MeV)	Ns	L_s (fm)
1	2	6.0	0.162	7.35	490	12	1.94
2	2+1	3.45	0.123	5.63	390	24	2.95
						32	3.94
2L	2+1	3.45	0.112	6.08	240	32	3.58
2P	2+1	3.45	*0.100	*6.80	140	48	4.80
3	2+1	7.0	*0.123	*11.66	*390	32	3.94

Simulation parameters: temperatures

	Gen 2			Gen 2L		
$N_{ au}$	T (MeV)	T/T_c	$N_{ au}$	T (MeV)	T/T_c	
128	44	0.24	128	47	0.42	
			64	95	0.59	
			56	109	0.67	
48	117	0.63	48	127	0.78	
40	141	0.76	40	152	0.94	
36	156	0.84	36	169	1.04	
32	176	0.95	32	190	1.17	
28	201	1.09	28	217	1.34	
24	235	1.27	24	253	1.56	
20	281	1.52	20	304	1.87	
16	352	1.90	16	380	2.34	
			12	507	3.12	
			8	760	4.69	

Susceptibilities and chiral transition [PRD105(2022)034504] Isospin, charge and baryon Renor

susceptibility

Renormalised chiral condensate



 T_c is shifted by \sim 20 MeV when m_π goes from 390 to 240 MeV

Light mesons

PRELIMINARY

- Exponential fits to smeared and point correlators
- Consistent results, only showing smeared
- Chiral partners A and V become degenerate at transition
- ► No degeneracy seen in PS-S
- ▶ Slight increase in m_{π}



Light baryons

[PRD92(2015)014503; JHEP1706034; PRD99(2019)074503; PRD105(2022)034504]

Positive and negative parity states encoded in same correlator



Forward propagating: + parity; Backward propagating: - parity Using smeared sources to enhance ground state overlaps

Baryon mass modifications [Gen2]



- Positive parity ground state masses unaffected by T up to T_c
- Negative parity masses decrease
- Parity restoration near T_c?

Parity restoration

Measure of parity restoration:

$$R(\tau) = \frac{G(\tau) - G\beta - \tau)}{G(\tau) + G(\beta + \tau)}$$
$$R = \frac{\sum_{n=0}^{\beta/2 - 1} R(\tau_n) / \sigma^2(\tau_n)}{\sum_{n=0}^{\beta/2 - 1} 1 / \sigma^2(\tau_n)}$$



J/ψ spectral functions [Gen2]



- BR method for thermal (solid lines) and reconstructed (dotted lines) correlators
- Similar results from MEM
- Consistent with no change below T_c
- Possible weakening or melting for $T \gtrsim 1.5 T_c$

Charmonium: Gen2L



BR on thermal correlators only

 Fits to smeared correlators suggest negative mass shift for T > 120MeV

D mesons: reconstructed correlators and fits



- Significant changes for $T \gtrsim T_c$
- Modifications below T_c
- Smaller for D_s



Open charm spectral functions



• Clear difference at $T \approx 1.9 T_c$

Charmed baryons



Parity doubling crossover is at same temperature for (singly) charmed as for light and strange baryons

Beauty: MEM analysis [Gen2]

S-waves



 Υ (2S) melts, but ground state remains robust

P-waves



P-waves dissociate close to T_c

MEM vs BR method



Known discrepancy: BR produces more peak structures

BR spectral functions — Gen2L



PRELIMINARY

- Negative mass shift at all T?
- No significant thermal broadening for T ≤ 250 MeV?
- Width and mass to be cross-checked with other methods — in progress
- ↑ (2S) not resolved
- Preliminary results for chi_{b1} suggest substantial broadening at 220 MeV

Towards new ensembles

Gen2P: physical pion mass

- Quark mass tuning in progress
- May need to retune anisotropies

Gen3: towards continuous time

- 4-parameter tuning: matching $\xi_g, \xi_q, a_s, m_\pi/m_\rho$
- Tuned to 3-flavour symmetric point matching Gen2:

$$\rightarrow \xi_g = \xi_q = 7.0$$

- $\rightarrow a_s = 0.129 \, \text{fm} (\text{target } 0.125)$
- $\rightarrow m_{PS}/m_V = 0.592$ (target 0.545)

▶ Anisotropy parameters to be fixed for tuning to 2+1 flavours

Gen3 tuning



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Summary

Light mesons:

- ightarrow chiral doubling $ho-a_1$ seen at T_c
- $ightarrow m_\pi$ increases with T

Baryons:

- $\rightarrow\,$ observed parity restoration
- $\rightarrow\,$ impact on hadron resonance gas
- $\rightarrow\,$ singly charmed baryons behave similarly to light

Open charm:

- $\rightarrow\,$ thermal modifications already below $\,{\cal T}_c$
- $\rightarrow\,$ indication of significant mass drop
- ightarrow no bound states above ${\mathcal T}_c$

Beautonium:

- ightarrow S wave survival up to $T>2T_c$, moderate mass shift
- $\rightarrow~\mbox{Quantitative}$ results for mass shift and width still elusive

Outlook

- Complete understanding of systematics
- Towards the physical limit with lighter quarks underway
- Repeat with smaller a_{τ} underway
- Open beauty

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