Pure gauge glueball behavior at finite temperature.[1]

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[1] M.Caselle, R.Pellegrini

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Glueball masses.

- The zero temperature glueball masses are by now known with good precision [1].
- At finite temperature the standard approach is to compute a temporal correlator [2].
- The spectrum computed in this way is almost constant as the temperature increases, and insensitive to the deconfinement transition [2].

[1] Teper et al. 2004, Lucini et al. 2010, Lucini et al. 2012

[2] Ishii et al. 2002

The Isgur-Paton model

- The Isgur-Paton model is a very successful phenomenological model of glueballs [3].
- The glueballs are considered "closed flux tubes" kept together by the same string tension of the interquark potential.
- The model predicts glueball masses as adimensional ratios $\frac{m_i(0)}{\sqrt{\sigma(0)}}$.
- Substituting the zero temperature string tension with the finite temperature string tension we obtain

$$m_i(T) = \frac{m_i(0)}{\sqrt{\sigma(0)}}\sqrt{\sigma(T)}.$$

[3] N. Isgur and J. E. Paton 1985

QCD thermodynamics

- For $T < T_c$ the thermodynamics seems compatible with the one predicted by a free glueball gas [4].
- In the deconfined phase $T > T_c$ the thermodynamics is instead well described by a gas of free gluons[4].
- If the glueball spectrum was insensitive to the deconfining transition the glueball would be present also in this phase.
- This would give an extra contribution to the thermodynamics fully incompatible with lattice measurements.

[4] Meyer 2009, Panero 2009,Caselle et al. 2011,Caselle et al. 2012

- These observations suggest that with the standard approach one is probably measuring some finite size scale.
- The relation with the glueball spectrum is probably similar to the relation between the spatial string tension σ_s and the finite temperature string tension $\sigma(T)$.

A new observable

- We propose an alternative method to extract finite T glueball masses.
- To ensure the correct finite T behaviour our observable is built using exclusively Polyakov loops P.
- The simplest observable with the correct quantum numbers is a pair of nearby Polyakov loops

$$M(x) = P(x)P^{\dagger}(x + a)$$

.

- The glueball mass will be extracted by the large R behaviour of the correlator

$$G(R, T) = \langle M(0)M(R)\rangle - < M >^2 \propto_{R\to\infty} e^{-M_0(T)R}$$

.

The correlator

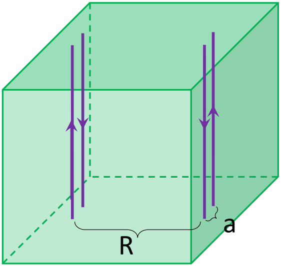

Figure: The glueball correlator discussed in the text.

A test in 3d gauge Ising model.

- The Ising model is a perfect model to test our observable.
- There exists very precise estimate of the zero temperature spectrum [5], that can be compared with our results in the low T regime, in particular

$$m_0 = 3.15(5)\sqrt{\sigma(0)}$$

- We can predict the behavior of the correlator $G(R,T)$ in the vicinity of T_c using dimensional reduction [6].
- In this limit our observable is equivalent to the energy-energy correlator G_ϵ of the 2d Ising model.

[5] Caselle et al. 1997
[6] Svetitsky Yaffe 1982

G(R,T) near T_c

- From the exact solution of the 2d Ising model we know that at temperature close enough to T_c a new mass scale should appear, which is known to be

$$m_s(T) = 2\frac{\sigma(T)}{T}$$

- To summarize; we expect two relevant scales: $m_0(T) \propto \sqrt{\sigma(T)}$ is the glueball mass dominant at low temperature, the other scale $m_s(T) = \frac{2\sigma(T)}{T}$ should appear at high temperature.

Simulation settings

- We performed three sets of simulation at different values of the gauge coupling.

β	$\frac{1}{T_c}$	L_s	N_t	R
0.743543	5.67 a	90	7,8,9	$6 \leq R \leq 20$
0.751805	8 a	90	9,10,11,12,13,14,20,56,64	$8 \leq R \leq 22$
0.756427	12 a	120	20	$12 \leq R \leq 33$

Table: For each of the three β values we report the corresponding critical temperature T_c and the values of L_s , N and R that we studied.

- For all these values we extracted the correlator $G(R, T)$.
- In order to build adimensional ratios $\frac{m_i(T)}{\sqrt{(\sigma(T))}}$ we also computed the finite temperature string tension $\sigma(T)$ from Polyakov loops in a separate simulation.

Results

- We found two different behaviours.
- For low values of the temperature $\frac{T}{T_c} \lesssim 0.6$ the data were perfectly fitted by

$$G(R,T) = a_0(T)\frac{e^{-m_0(T)R}}{\sqrt{R}}$$

- At higher values of the temperature $\frac{T}{T_c} \gtrsim 0.6$

$$G(R,T) = a_s(T)\frac{e^{-m_s(T)R}}{R^2} + a_0(T)\frac{e^{-m_0(T)R}}{\sqrt{R}}$$

Results

β	$\frac{T}{T_c}$	$\sigma(T)$	$\frac{m_s(T)T}{\sigma(T)}$	$\frac{m_s(T)}{\sqrt{\sigma(T)}}$	$\frac{m_0(T)}{\sqrt{\sigma(T)}}$
0.743543	0.8	0.00961	2.03(4)	1.39(3)	3.1(2)
0.743543	0.7	0.01315	1.89(5)	1.73(5)	3.1(1)
0.743543	0.62	0.01542	1.98(5)	2.21(6)	3.14(8)
0.751805	0.89	0.00268	2.2(2)	1.02(8)	3.0(3)
0.751805	0.8	0.00444	1.97(5)	1.31(3)	2.9(3)
0.751805	0.73	0.00566	1.86(8)	1.54(7)	2.9(1)
0.751805	0.67	0.00654			3.3(1)
0.751805	0.62	0.00720			3.23(3)
0.751805	0.57	0.00771			3.29(5)
0.751805	0.4	0.00922			3.25(4)
0.751805	0.14	0.01037			3.14(3)
0.751805	0.125	0.01040			3.21(2)
0.756427	0.6	0.00326			3.29(6)

Table: Values of $\sigma(T)$, $\frac{m_s(T)}{\sigma(T)}$, $\frac{m_s(T)}{\sqrt{\sigma(T)}}$ and $\frac{m_0(T)}{\sqrt{\sigma(T)}}$.

Results

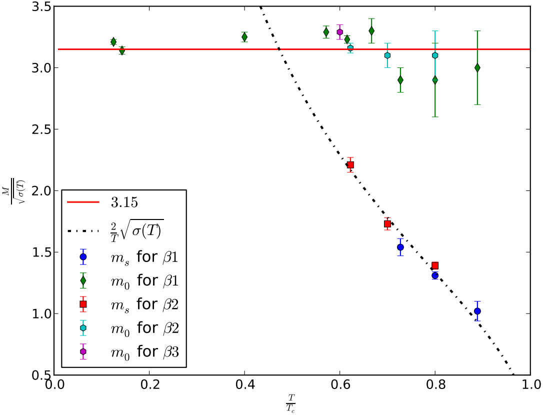

Figure: $\frac{m_0}{\sqrt{\sigma(T)}}$ and $\frac{m_s}{\sqrt{\sigma(T)}}$ plotted as a function of $\frac{T}{T_c}$ for $\beta_1 = 0.743543$, $\beta_2 = 0.751805$ and $\beta_3 = 0.756427$. The two curves correspond to the two expected scaling behaviours: $m_0(T) \sim 3.15\sqrt{\sigma(T)}$ and $m_s(T) = 2\sigma(T)/T$.

Conclusion

- The most importart message of our analysis is that the effective thermal mass of the lightest glueball is a function of the temperature.

$$m_0(T) \propto \sqrt{\sigma(T)}$$

- It vanishes as the critical temperature is approached $T \to T_c$.
- The previous results suggest that the Isgur-Paton model is also valid at finite temperature.

Conclusion

- The scaling behaviour predicted by the Isgur-Paton $\sqrt{\sigma(T)}$ model can also be riconciliated with the different Svetitsky-Yaffe behaviour $\frac{\sigma(T)}{T}$ thanks to the appearance of a new mass scale m_s.
- This new scale m_s should measure the interaction between a quark and an antiquark belonging to different mesons.
- This agrees with the intuitive picture of the melting of mesons into individual quarks approaching the deconfinement transition from below.