# The Scalar does not decay at finite temperatures

Lattice 2010, Villasimius

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# Motivation

- Nature and composition of quasiparticles in QGP plasma : subject of intense investigation for the past two decades [MILC collaboration, RBC-Bielefeld, ILGTI (Gavai-Gupta)]
- Above $\sim 2 - 3T_c$, weak coupling resummation schemes are known to agree with lattice results on Equation of state and susceptiblities. [Laine et al.]
- Around $\sim T_c$, only lattice methods reliable in making quantitative statements
- Distinguishing the hadronic phase from the plasma phase? Important for experiments! Screening masses offer useful ideas.
- Also important for estimating finite volume corrections for thermodynamics
- Chiral symmetry restoration in the medium

# Configuration details

- Configurations used for analysis are reported in Gavai, Gupta PRD 78, 114503 (2008)

- Main features for recap:
  - R-algorithm for hybrid molecular dynamics used : naive staggered fermions + Wilson gauge action
  - Scan in temperature from $0.89T_c$ to $1.92T_c$ on $N_\tau = 6$ lattices, keeping $m_\pi \simeq 230$ MeV
  - For screening mass study, $N_s = 24$
  - For finite volume study, $N_s = 8, 12, 18, 24, 30$

- Tolerance of the CG algorithm $\epsilon = 10^{-5}$ for calculating the quark propagator ▸ More details

- Point-point correlation function for local meson operators in the pseudo-scalar(PS), scalar(S), vector(V), axial-vector(AV) channels analyzed

# Analysis Details

Covariance matrix $\mathcal{C}_{zz'}$ was used to fit the correlation functions $C(z)$

$$\begin{aligned} C(z) &= A_1(\, e^{-m_1 z} + e^{-m_1(N_z - z)}\,) \\ &+ (-1)^z A_2(\, e^{-m_2 z} + e^{-m_2(N_z - z)}\,) \end{aligned}$$

$m_1$,$m_2$: screening masses of the lightest meson and its parity partner
$A_1$, $A_2$: the corresponding amplitudes

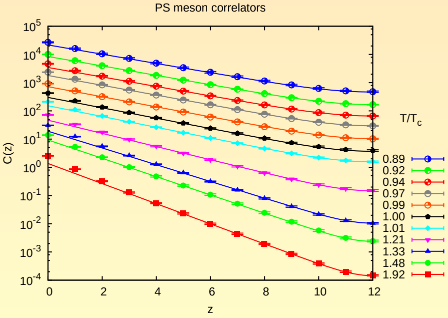
Goldstone pion is the non-oscillating pion with positive $A_1$
Convention same as in Mukherjee, PoS LAT2007:210

by minimizing the $\chi^2$:

$$\chi^2 = \sum_{zz'} \frac{C(z) - \langle C(z) \rangle}{\sigma(z)} \, \mathcal{C}^{-1}_{zz'} \, \frac{C(z') - \langle C(z') \rangle}{\sigma(z')}$$

# Fit details-1

- Inversions done with Mathematica routines
- Inversions much more accurate than statistical errors
- Pion correlators equally good at all temperatures; characterized by single mass fits very well
- Other correlators noisy at small T and large z



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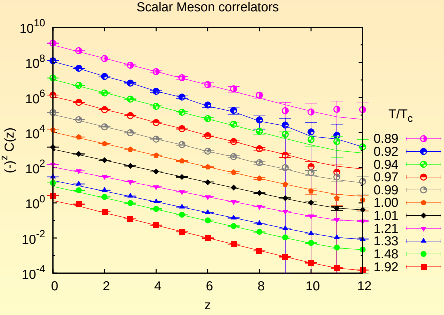
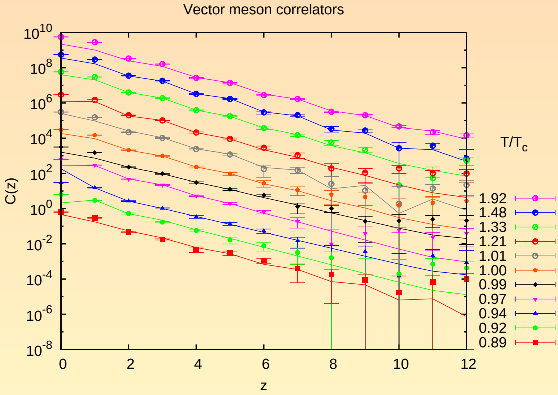


# Fit details-2



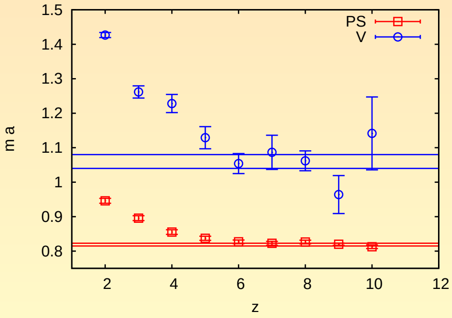

Large contribution from the parity partner for the vector.

- Results indicate considerable correlation entering through $\mathcal{C}_{zz'}$
- Noisy points excluded as much as possible
- Stability of fit checked by varying the fit range
- Most of the fits have $\chi^2/dof \sim 1$

# Local Masses

Due to oscillations, local masses using 2-z slices Gavai, Gupta, Majumdar(2002)

$$\frac{C(z+1)}{C(z-1)} = \frac{\cosh[-m(z)(z+1-N_z/2)]}{\cosh[-m(z)(z-1-N_z/2)]}$$

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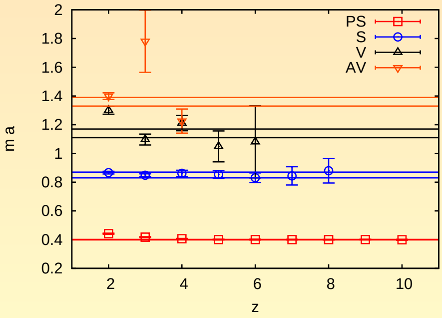
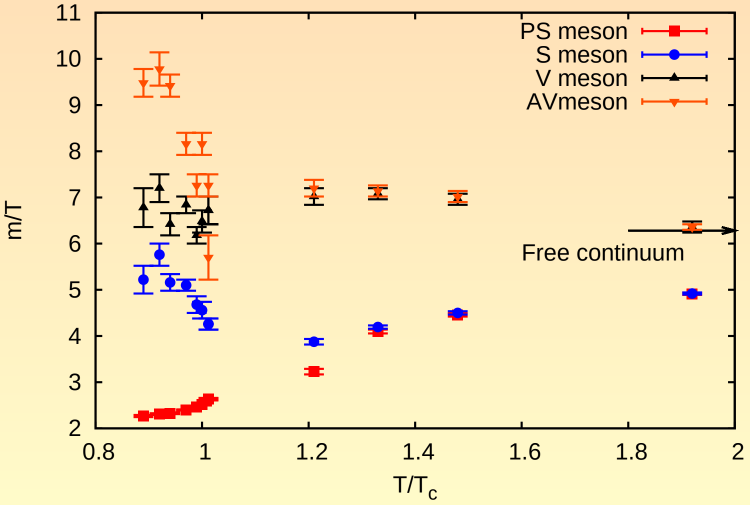



Agree with the fitted values

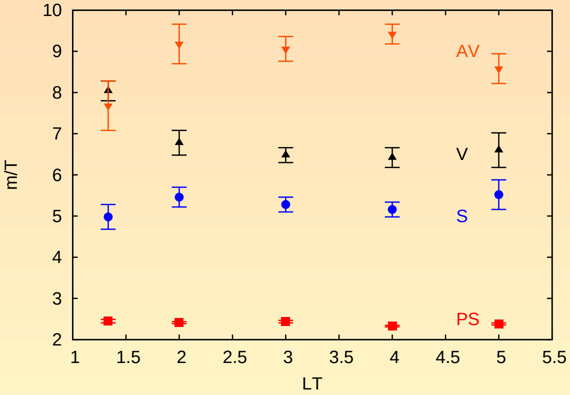
# Results - Screening Masses



# Screening Masses – observations

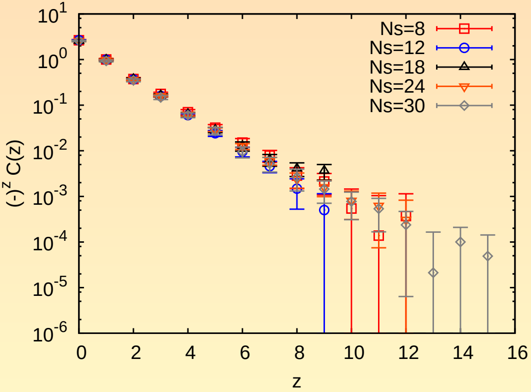
- PS and S non-degenerate at $T \sim T_c$
- Chiral symmetry seems restored slowly. Fully restored at about $T \sim 1.33T_c$
- V and AV degenerate even at $T \sim T_c$; and nearly equal to the free theory value
- PS and S differ considerably $\sim 15-20\%$ from the free theory values even at highest temperatures $T \sim 2T_c$
- Similar trends with results of RBC-Bielefeld collaboration for 2+1 flavour QCD with p4fat3 fermion action: Agreement for spin-1 mesons $\sim 5\%$ and spin-0 meson $\sim 10\%$ more figs
- Larger difference with the free theory for spin-0 mesons also seen in a quenched calculation with overlap quarks Gavai, Gupta, Lacaze (2007) more figs

# Finite Volume Results



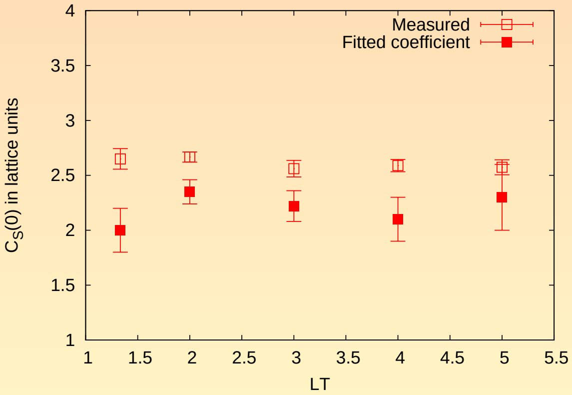

- $N_\tau = 6$; $N_s = 8, 12, 18, 24, 30$
- No volume dependence at $T = 0.94 T_c$!
- Same as critical end-point temperature (but $\mu = 0$) Gavai, Gupta (2008)
- Interesting region for experiments!

# No decay for scalars!




Correlation function of the scalar does not show any distinct volume dependence at $0.94T_c$

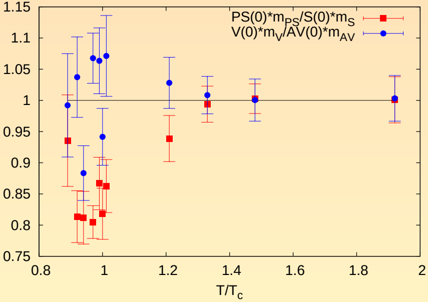
# No decay for scalars!

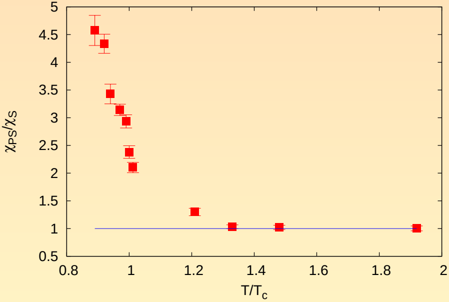



- Measured and fitted normalization also support our conclusion
- Possible reason for stability is that at finite temperatures, due to excess of pions in the heat bath their recombination is also possible
- Interesting to check at what temperature the threshold is reached
- A possible experimental signature!

# Interaction strength

Seems to be a change in the nature of the interactions with the rise in temperature




- First defn (left fig):

$$r = \frac{C_{PS}(0) m_{PS}}{C_S(0) m_S}$$

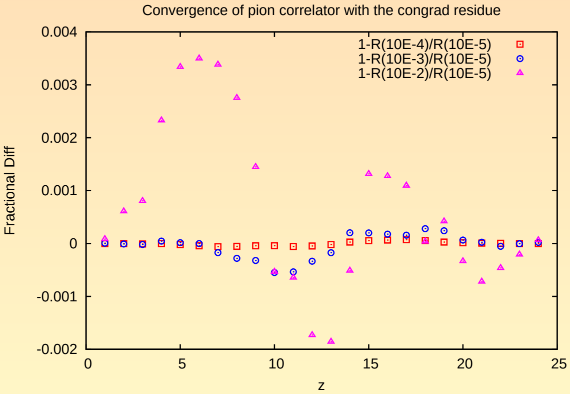
- Second defn (right fig): Ratio of susceptibilities

$$\chi_{PS} = \sum_z C_{PS}(z); \quad \chi_S = \sum_z (-1)^z C_S(z)$$

# Summary

- Calculated the screening masses in 2-flavour QCD with naive staggered fermions and Wilson gauge action
- Temperature range scanned in our study $0.89 - 1.92T_c$ on $N_\tau = 6$ lattices spanning both the hadronic and the QGP phase
- Pion seems to be a good eigenstate even for temperatures above $T_c$
- Chiral symmetry seems restored only at $T \sim 1.33T_c$ in spin-0 channel
- Scalar meson, known to decay at $T = 0$ is stable at $T = 0.94T_c$

# More analysis details

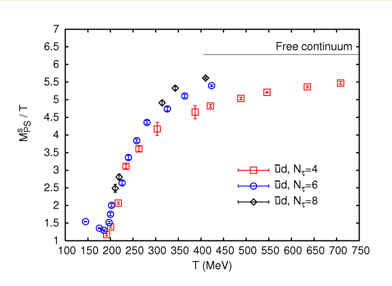


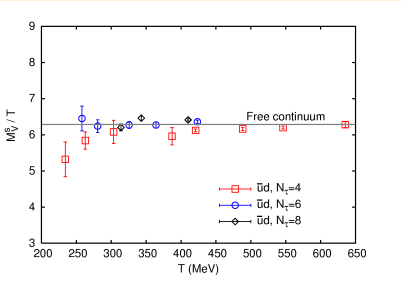

- $\beta = 5.42$
- $T = 0.94 T_c$
- $am_q = 0.0167$
- valence and sea quark mass identical

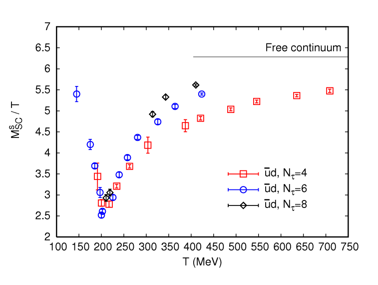
Tolerance of the CG algorithm $\epsilon = 10^{-5}$

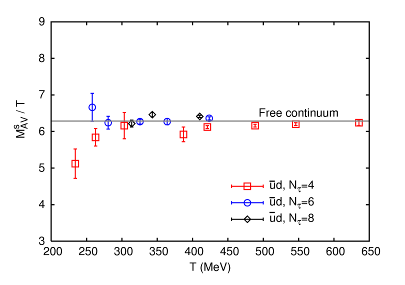
Increasing the tolerance by an order of magnitude required $\sim 250$ more iterations of the CG routine back

# RBC-Bielefeld Results

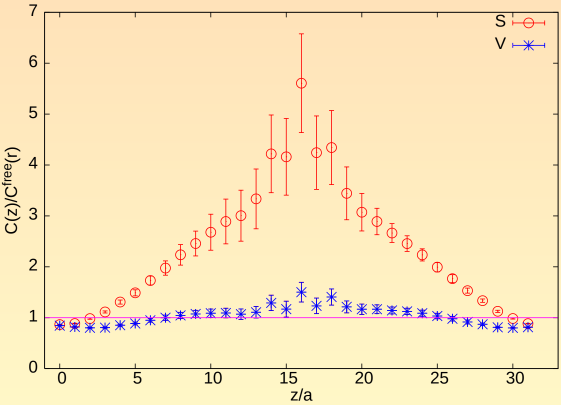


# ILGTI Results

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