Quark Number Susceptibilities & The Wróblewski Parameter

Rajiv V. Gavai *
T. I. F. R., Mumbai, India

* *In collaboration with Sourendu Gupta, TIFR, Mumbai*

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- Most signal considerations based on Simple Models.
  - $T_{QGP} > m_{strange}$
  - Energy Threshold for $(s\bar{s})$ in QGP $<$ in Hadron Gas.
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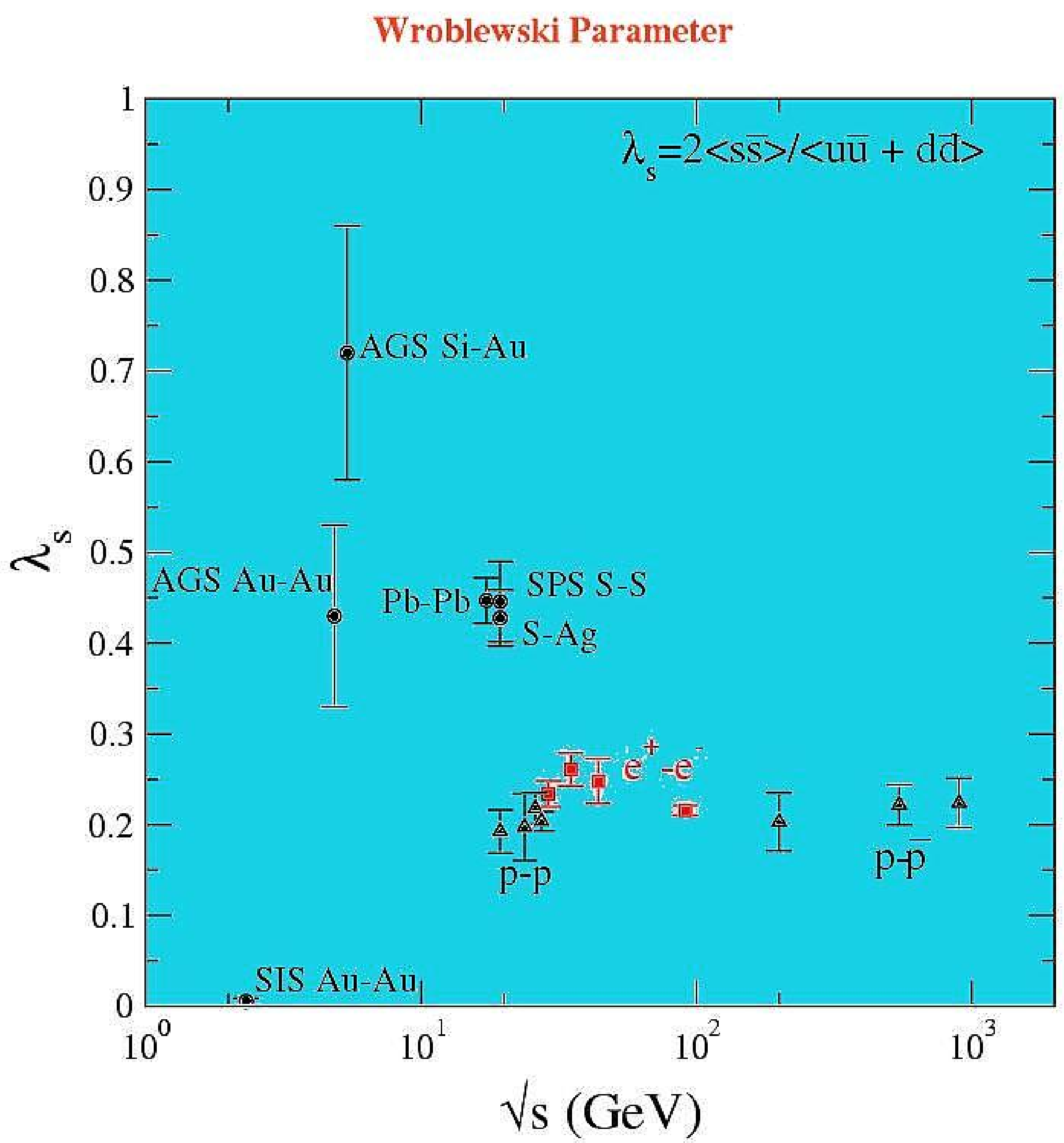

Ratio of newly created strange quarks to light quarks :

$$\lambda_s = \frac{2\langle s\bar{s}\rangle}{\langle u\bar{u} + d\bar{d}\rangle} \quad (1)$$

Figure from Becattini et al., Statistical Thermal Model fit, Phys. Rev. C 64, 024901 (2001).

Quark Number Susceptibility

Assuming three flavours, u, d, and s quarks, and denoting by μ_f the corresponding chemical potentials, the QCD partition function is

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Defining $\mu_0 = \mu_u + \mu_d + \mu_s$ and $\mu_3 = \mu_u - \mu_d$, baryon and isospin density/susceptibilities can be obtained as :
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$$n_i = \frac{T}{V}\frac{\partial \ln \mathcal{Z}}{\partial \mu_i}, \qquad \chi_{ij} = \frac{T}{V}\frac{\partial^2 \ln \mathcal{Z}}{\partial \mu_i \partial \mu_j}, \qquad i,j = 0, 3, u, d, s$$

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$$\chi_{fg\cdots} = \frac{T}{V} \frac{\partial^n \log Z}{\partial\mu_f \partial\mu_g \cdots} = \frac{\partial^n P}{\partial\mu_f \partial\mu_g \cdots} \ . \tag{3}$$

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Setting $\mu_i = 0$, n_i =0 but the diagonal χ_{ii}'s are nontrivial :

$$\chi_0 = \frac{T}{2V}[\langle \mathcal{O}_2(m_u) + \frac{1}{2}\mathcal{O}_{11}(m_u)\rangle] \tag{4}$$

$$\chi_3 = \frac{T}{2V} \ \langle \mathcal{O}_2(m_u)\rangle \tag{5}$$

$$\chi_s = \frac{T}{4V}[\langle \mathcal{O}_2(m_s) + \frac{1}{4}\mathcal{O}_{11}(m_s)\rangle] \tag{6}$$

Here $\mathcal{O}_2 = \mathrm{Tr}\ M_u^{-1} M_u'' - \mathrm{Tr}\ M_u^{-1} M_u' M_u^{-1} M_u'$, and $\mathcal{O}_{11}(m_u) = (\mathrm{Tr}\ M_u^{-1} M_u')^2$, and the traces are estimated by a stochastic method:

$\mathrm{Tr}\ A = \sum_{i=1}^{N_v} R_i^\dagger A R_i / 2N_v$, and $(\mathrm{Tr}\ A)^2 = 2 \sum_{i>j=1}^{L} (\mathrm{Tr}\ A)_i (\mathrm{Tr}\ A)_j / L(L-1)$, where R_i is a complex vector from a set of N_v subdivided in L independent sets.

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$$\lambda_s = \frac{2\chi_s}{\chi_u + \chi_d} . \tag{7}$$

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♠ Our improvement: Fixed m_q/T_c, Continuum limit...

Comparing Full and Quenched QCD

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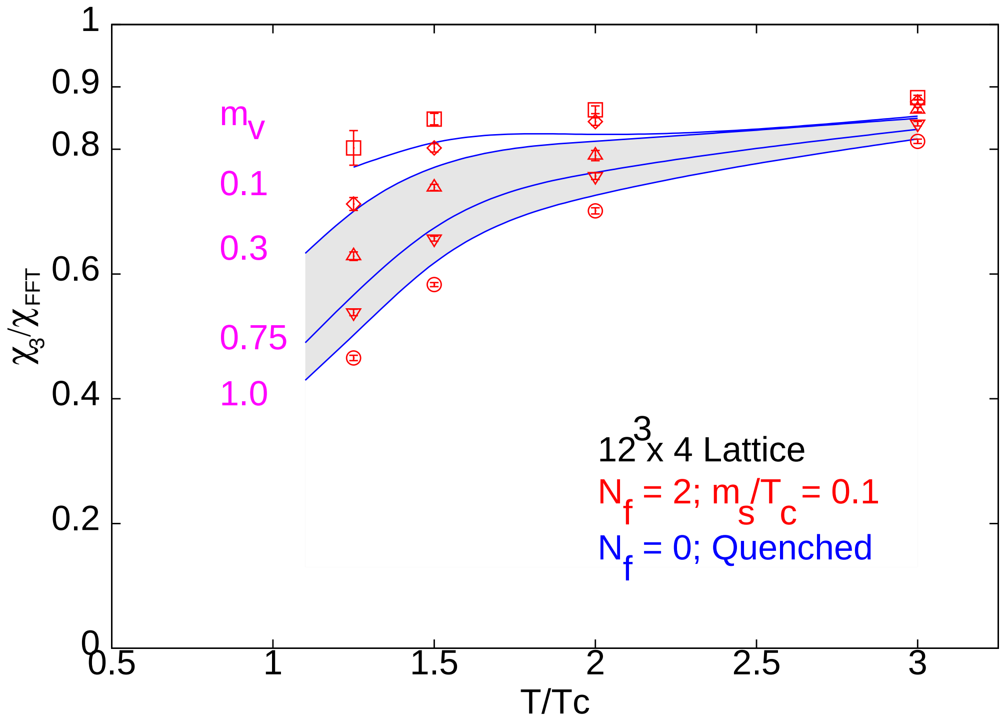

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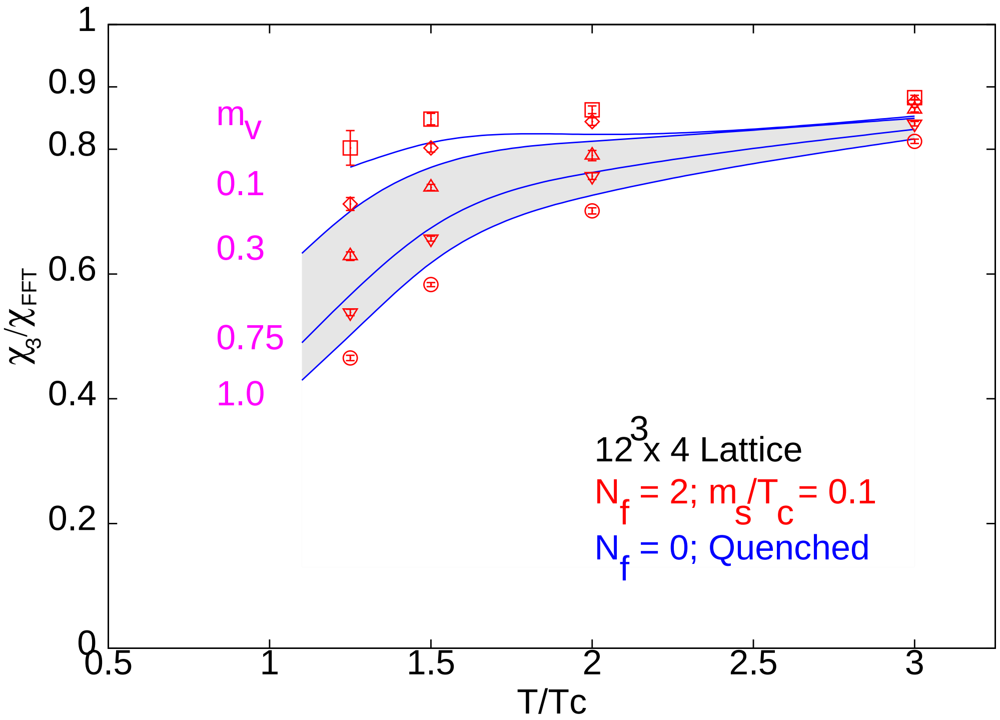

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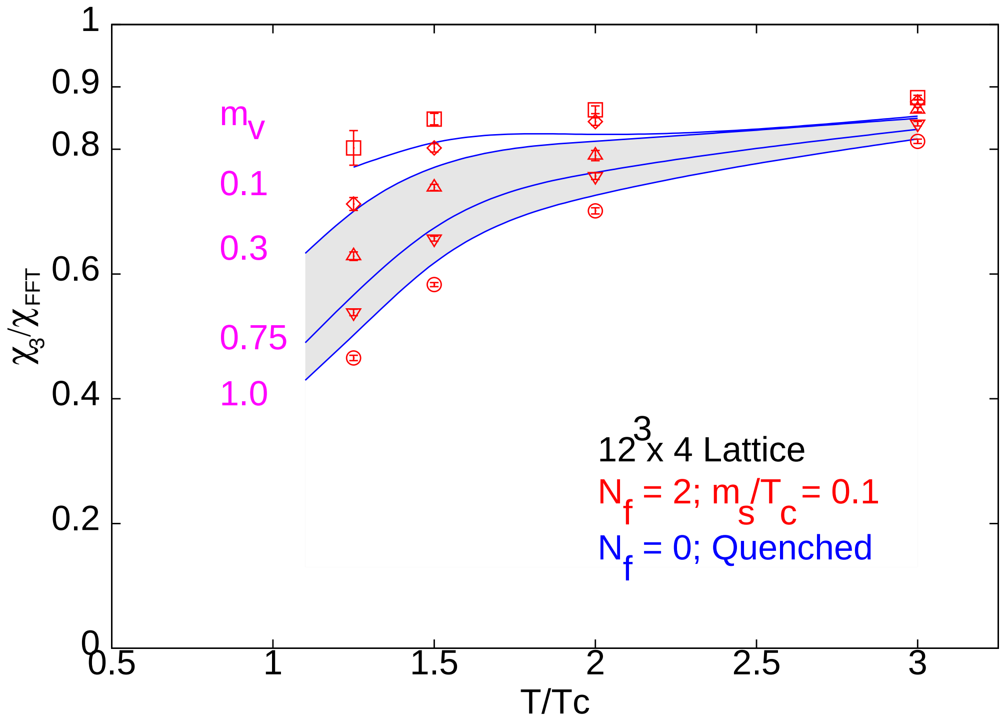

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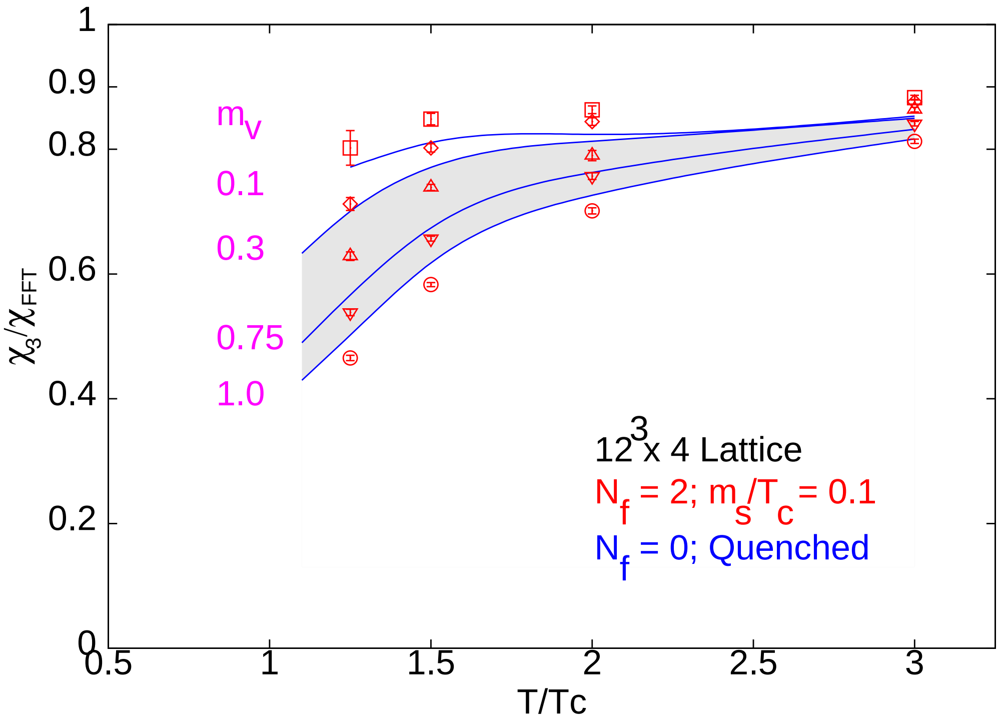

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3) PDG values for strange quark mass $\Longrightarrow m_v^{strange}/T_c$ $\simeq$ 0.3-0.7 (N_f=0); 0.45-1.0(N_f=2).

Perturbation Theory

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Weak coupling expansion gives:

$$\frac{\chi}{\chi_{FFT}} = 1 - 2\left(\frac{\alpha_s}{\pi}\right) + 8\sqrt{(1+0.167N_f)}\left(\frac{\alpha_s}{\pi}\right)^{\frac{3}{2}} - 6\left(\frac{\alpha_s}{\pi}\right)^2 \log\frac{1}{4\pi\alpha_s} + \mathcal{O}(\alpha_s^2)$$

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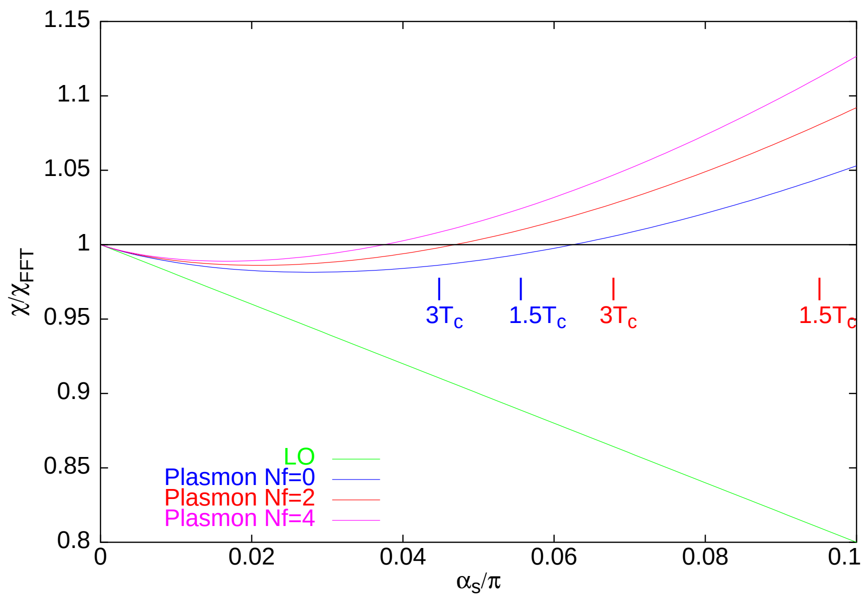

♣ Minm 0.981 (0.986) at 0.03 (0.02) for $N_f = 0$ (2).

♣ For $1.5 \leq T/T_c \leq 3$ pert. theory $\longrightarrow$ 0.99-0.98 (1.08=1.03) for $N_f = 0$ (2).

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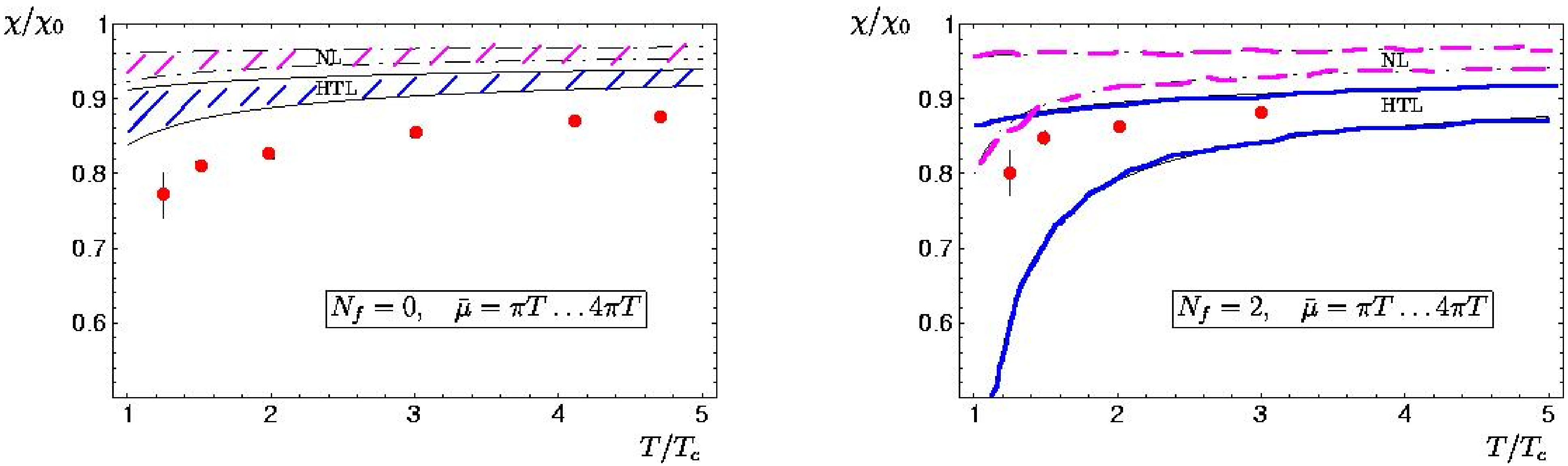

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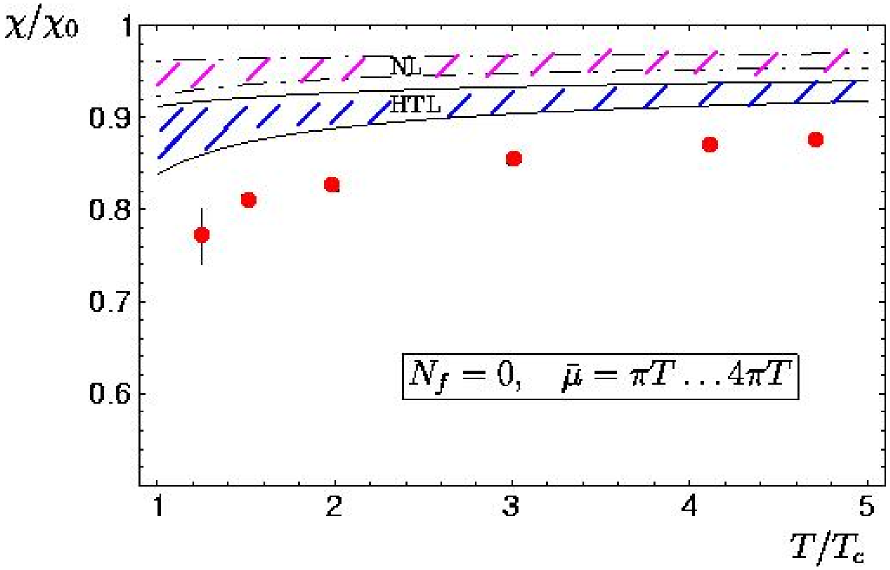

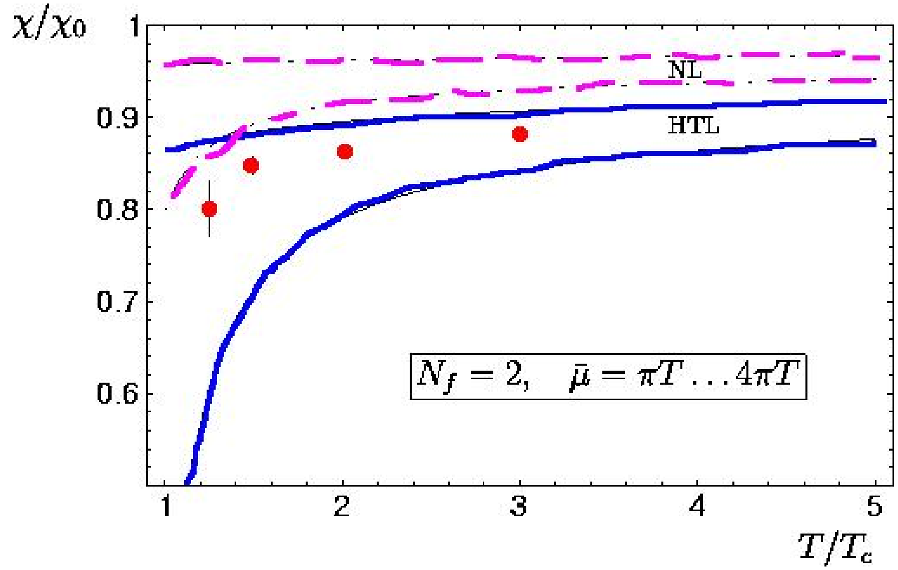

Our results for $N_t = 4 \rightsquigarrow$ Lattice artifacts ?
Check for larger N_t and improved actions.

Taking Continuum Limit

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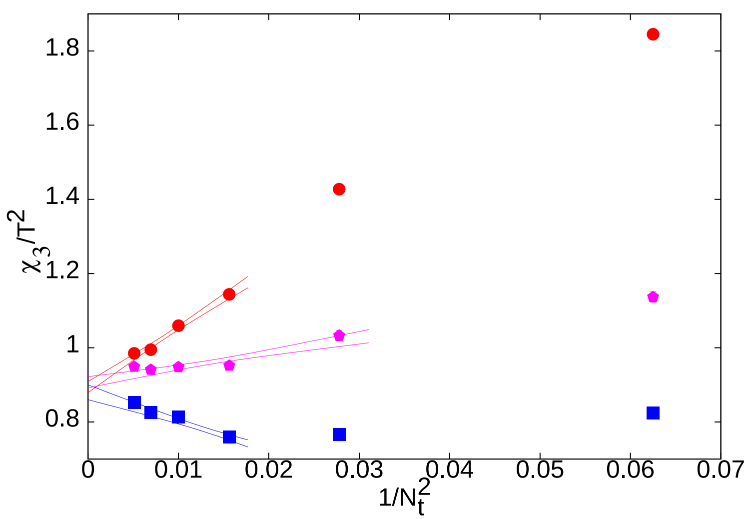

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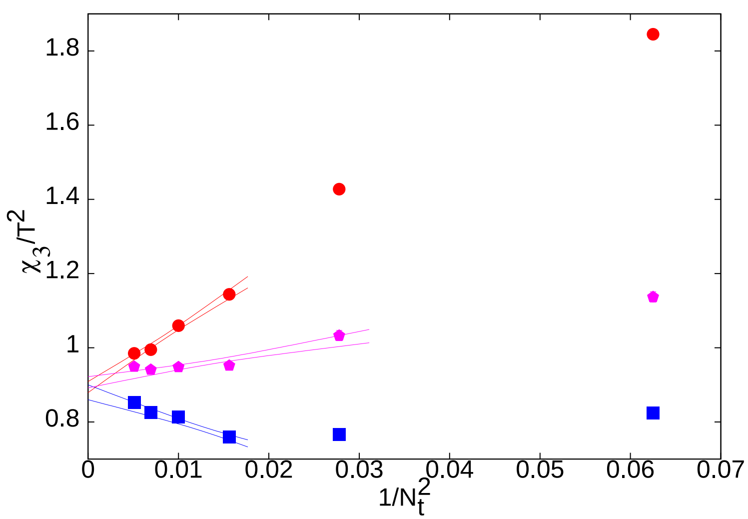

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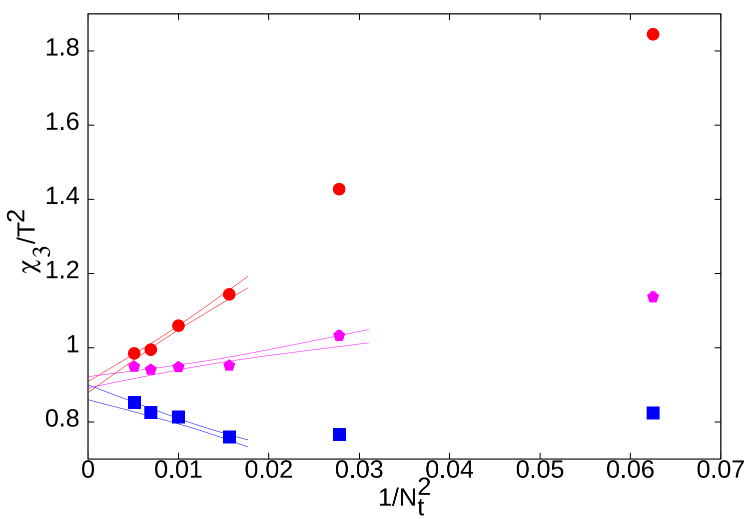

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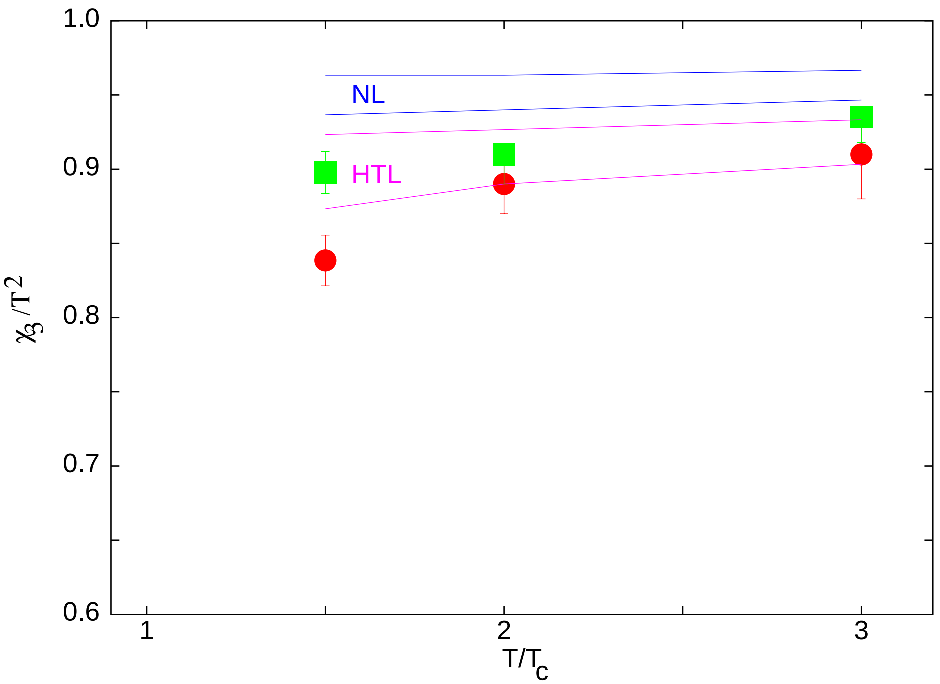

Naik action (Squares) and Staggered action (circles)

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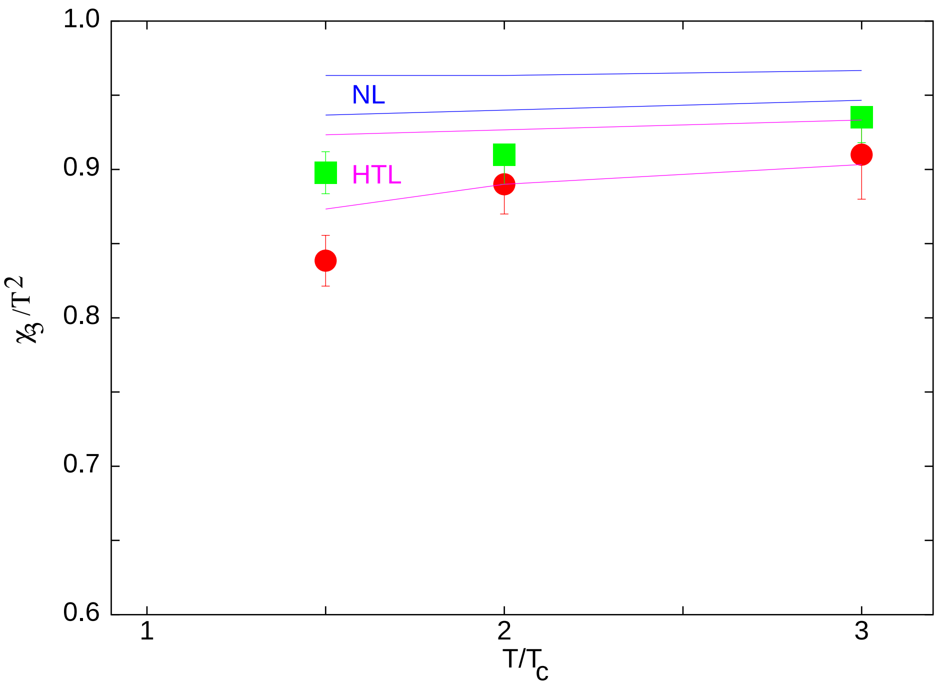

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♡ Also reproduced in dimensional reduction (1 free parameter). Vuorinen, PR D '03.

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- Using our continuum QNS, ratio χ_s/χ_u can be obtained.

We use $m/T_c = 0.03$ for u, d and $m/T_c = 1$ for s quark;
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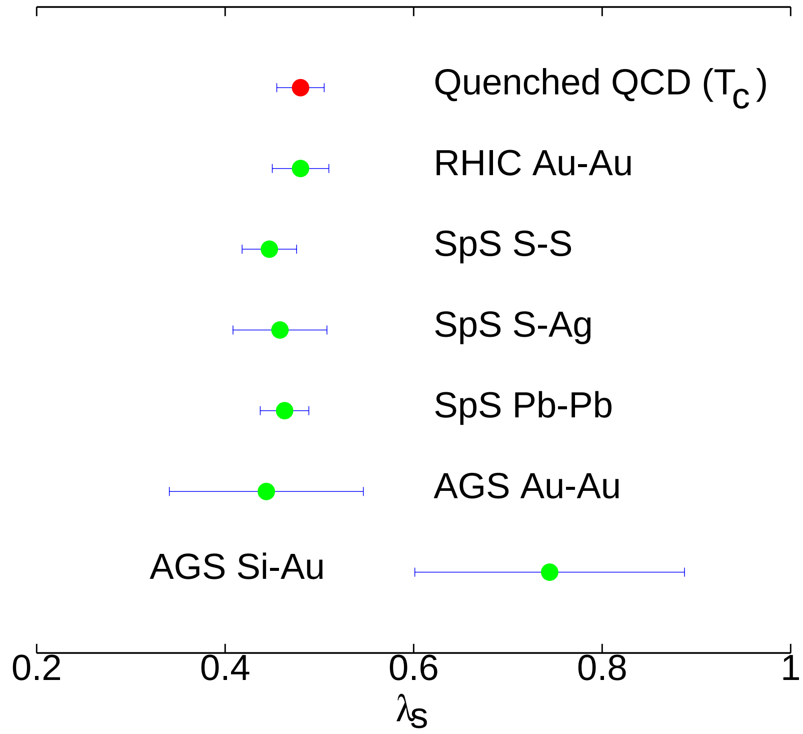

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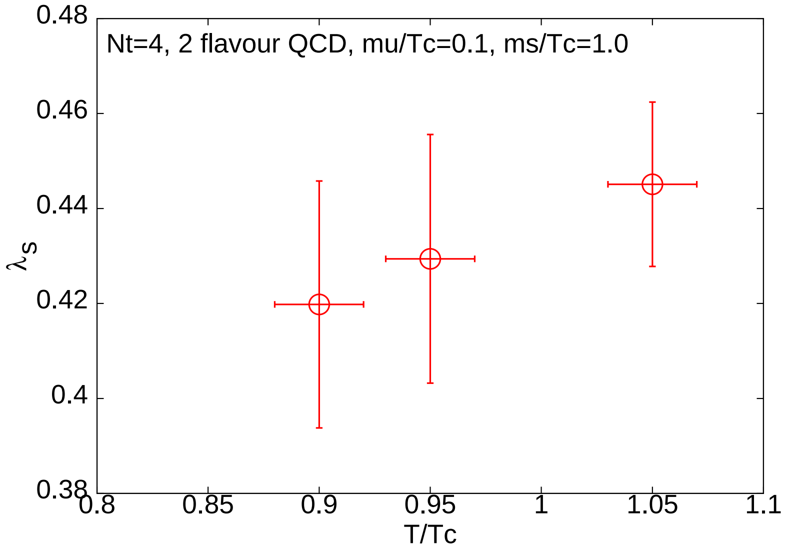

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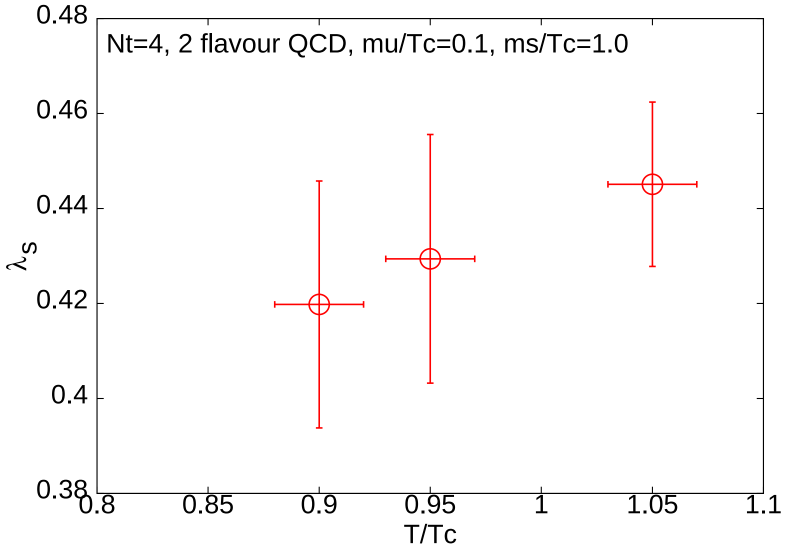

♣ Large finite volume effects below T_c
♣ Up to 12^3 Lattices used.
—Being extended to 24^3 Lattices.
♣ Strong dependence on m_s expected.
♣ Large finite a effects.

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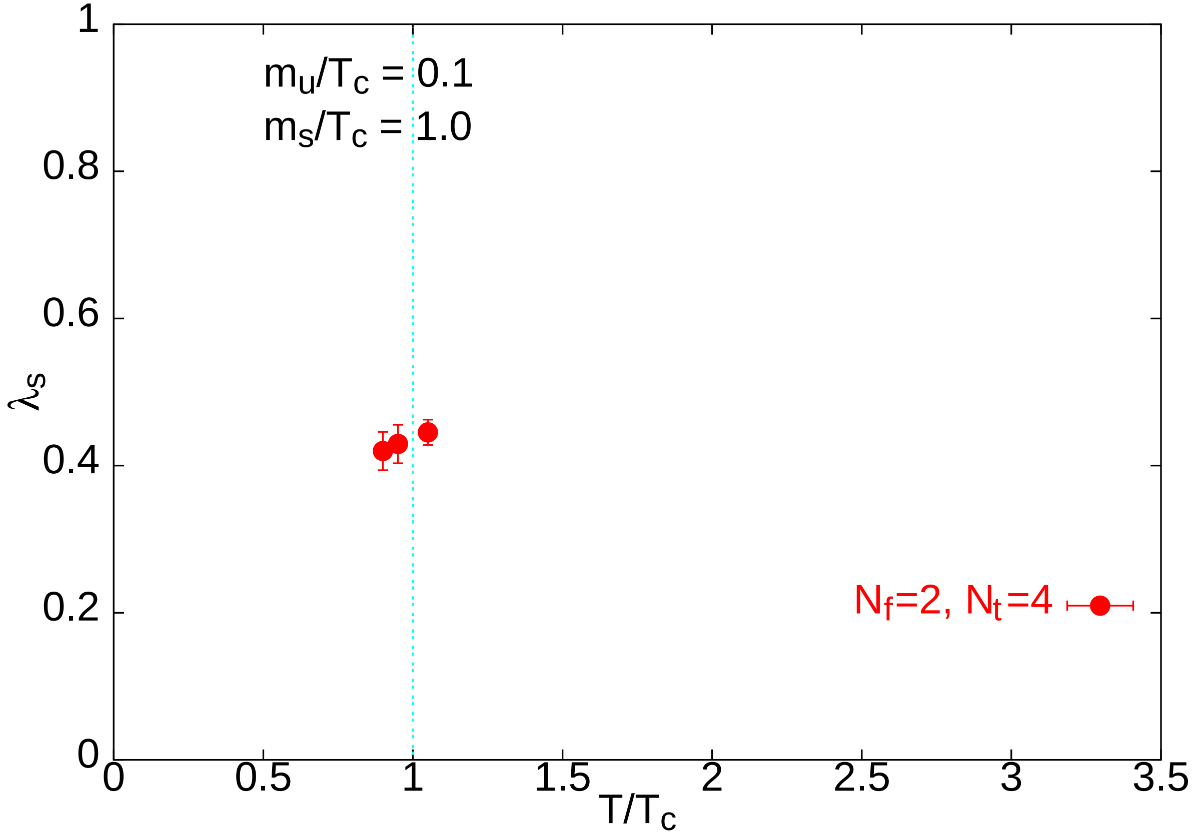
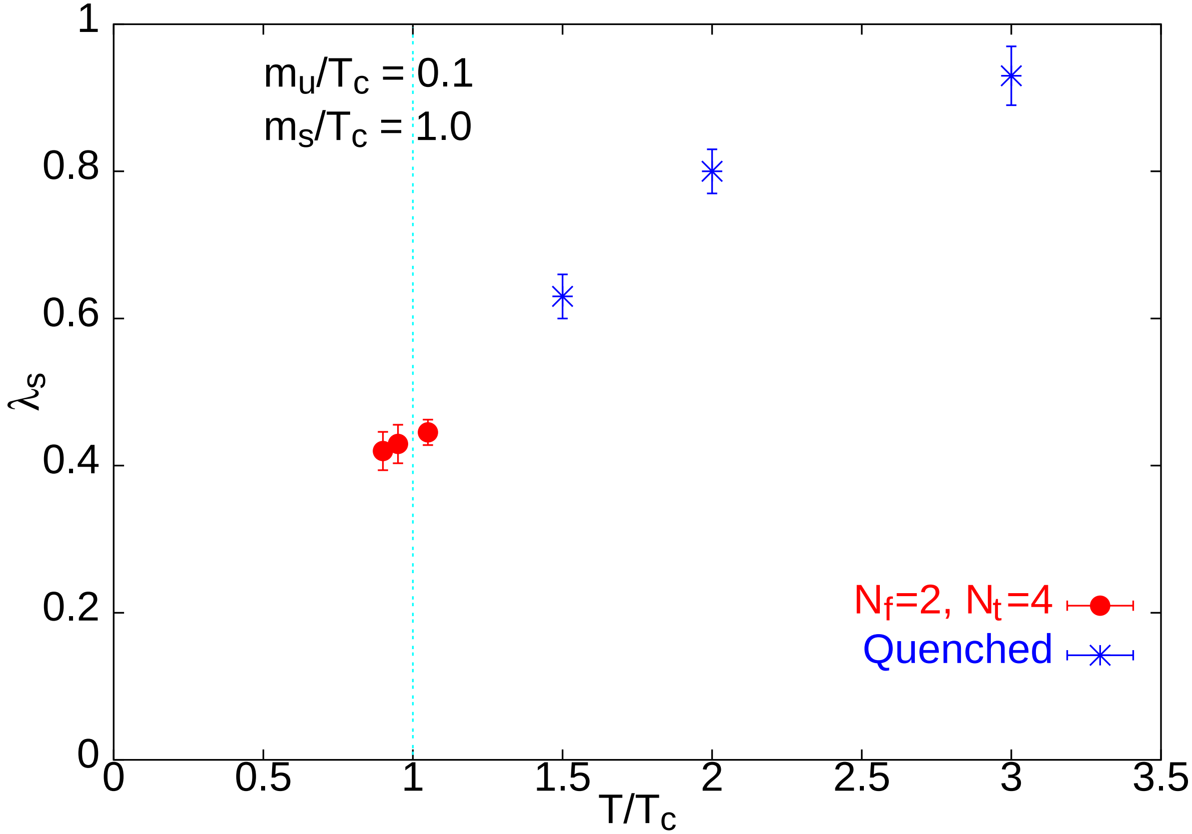
  - Theoretically, Screening mass- Susceptibility correlation and μ-dependence results of QCD-TARO on screening masses too suggest such an insensitivity.
  - Needs to be checked explicitly.
- Assumed : characteristic time scale of plasma are far from the energy scales of strange or light quark production.
  - Observation of spikes in photon production may falsify this.
- Assumed : Chemical equilibration in the plasma.

Summary



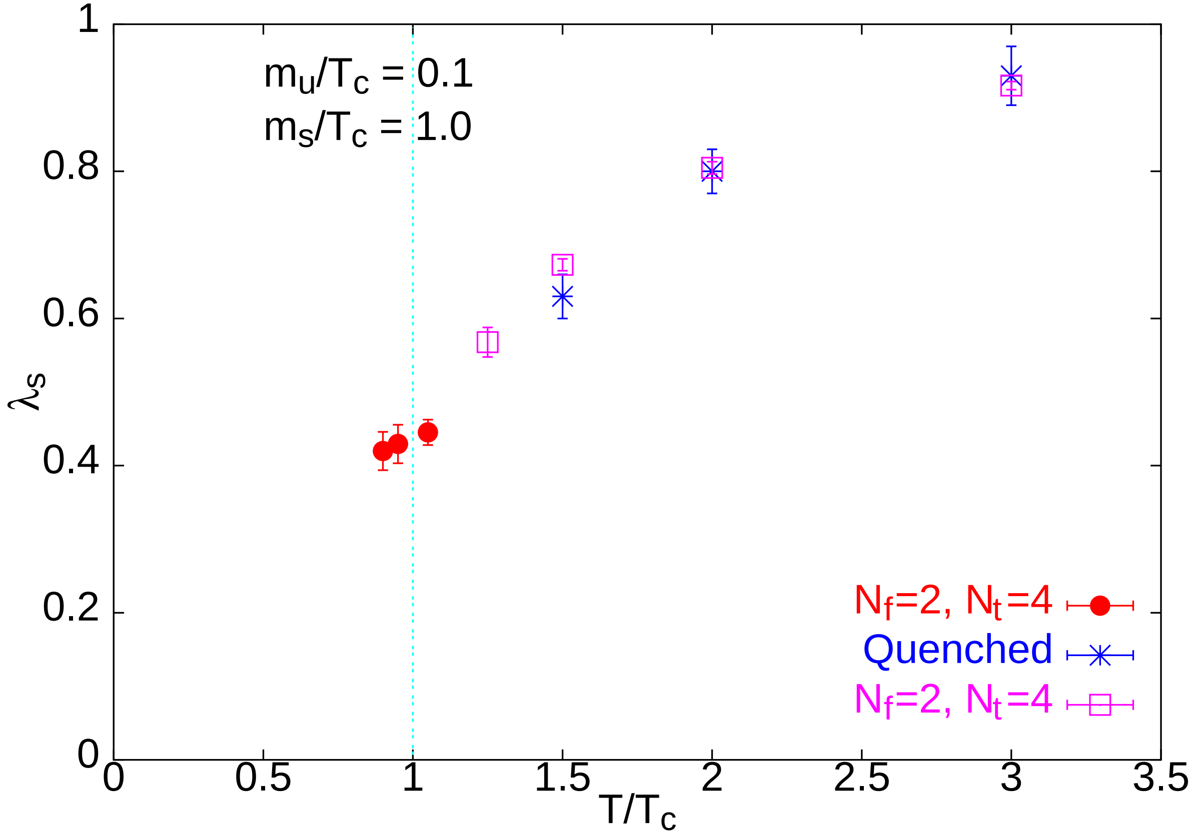
$m_u/T_c = 0.1$
$m_s/T_c = 1.0$
N_f=2, N_t=4
λ_S
T/T_c
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5

Summary



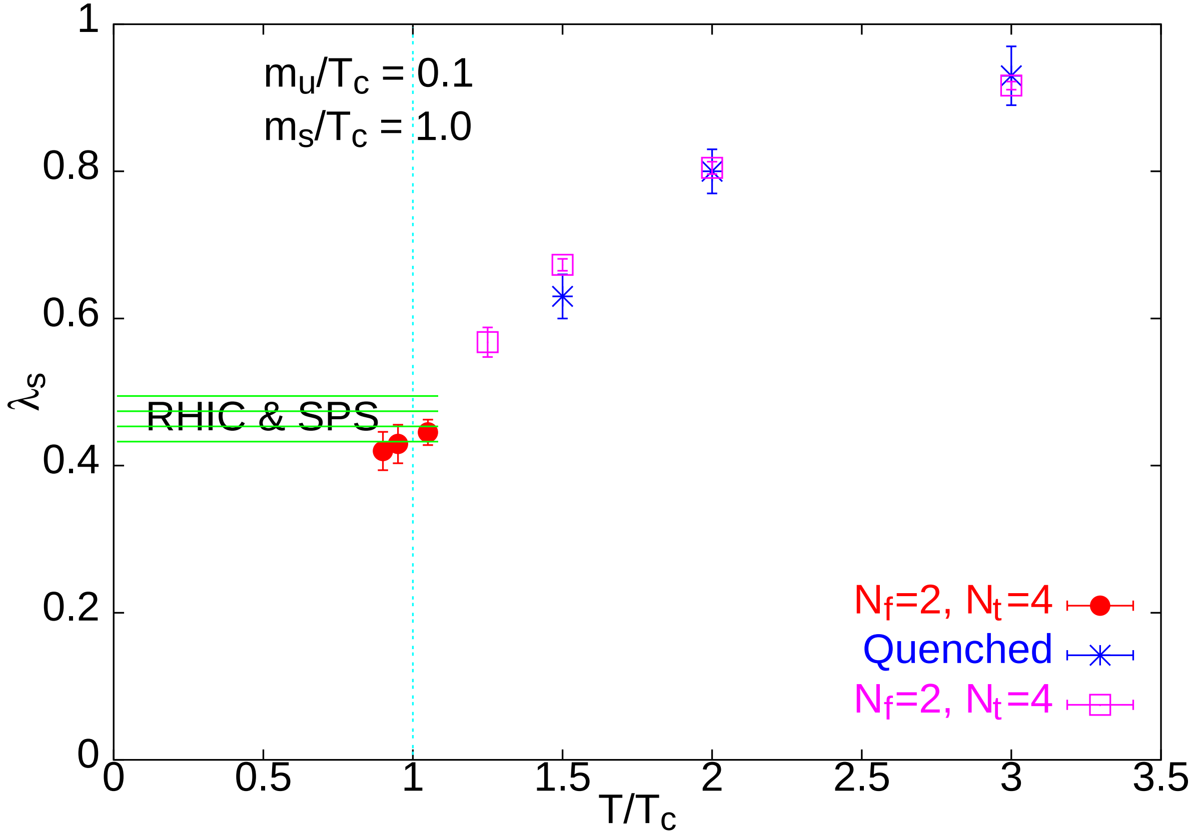
1
0.8
0.6
0.4
0.2
0
λS
0
0.5
1
1.5
2
2.5
3
3.5
T/Tc
mu/Tc = 0.1
ms/Tc = 1.0
Nf=2, Nt=4
Quenched

Summary



$m_u/T_c = 0.1$
$m_s/T_c = 1.0$
1
0.8
0.6
0.4
0.2
0
λ_S
0
0.5
1
1.5
2
2.5
3
3.5
T/T_c
N_f=2, N_t=4
Quenched
N_f=2, N_t=4

Summary



m_u/T_c = 0.1
m_s/T_c = 1.0
RHIC & SPS
λ_s
T/T_c
N_f=2, N_t=4
Quenched
N_f=2, N_t=4
0
0.2
0.4
0.6
0.8
1
0
0.5
1
1.5
2
2.5
3
3.5

Summary

- Quark number susceptibilities $\longrightarrow$ RHIC signal physics.
- They offer an independent check on resummed perturbation theory which seems to do well.

Summary

- Quark number susceptibilities $\longrightarrow$ RHIC signal physics.
- They offer an independent check on resummed perturbation theory which seems to do well.
- Continuum limit of χ_{uu} yields λ_s in agreement with RHIC and SPS results after extrapolation to T_c. First full QCD investigations show interesting trend.
- Higher susceptibilities up to 8th order computed. Interesting results on the QCD phase diagram soon.