Quark number susceptibilities at high temperatures

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in collaboration with

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Lattice data collected : 2009-2013 with p4 and HISQ action

Quark number susceptibilities (QNS) are defined as:

$$\chi_{2n}^{q} = \frac{\partial^{2n}(p/T^4)}{\partial(\mu_q/T)^{2n}}|_{\mu_q=0}, \quad q = l, s, \; n = 1, 2$$

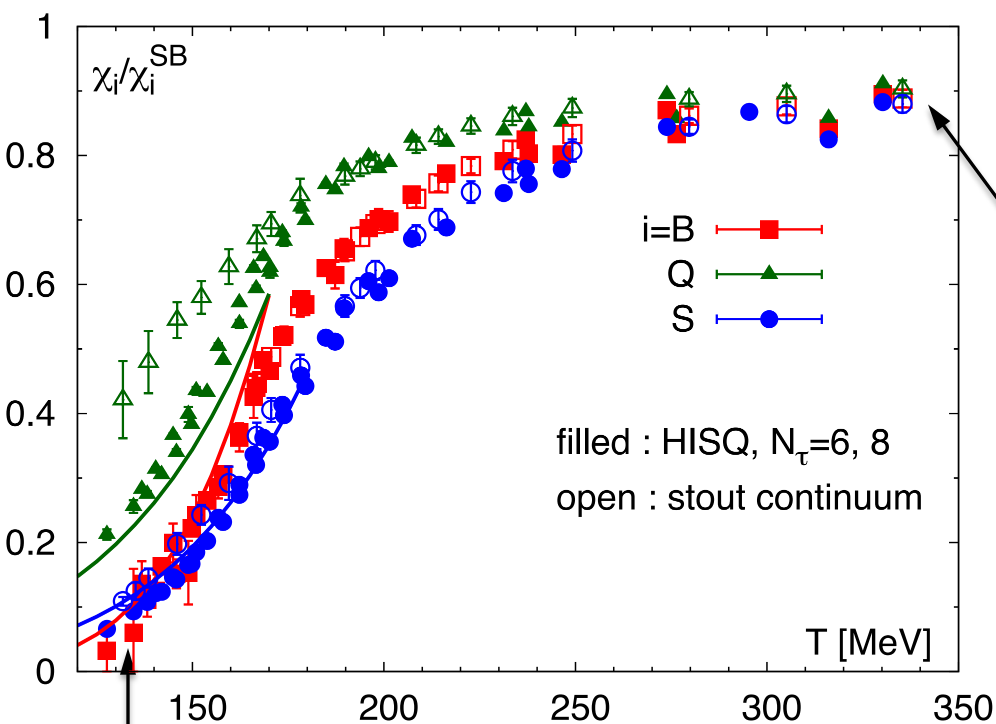
Lattice 2013, Mainz, July 29, 2013

Deconfinement : fluctuations of conserved charges

$$\chi_{\mathrm{B}}^{\mathrm{SB}} = \frac{1}{VT^3}(\langle B^2\rangle - \langle B\rangle^2)$$ baryon number

$$\chi_{\mathrm{Q}}^{\mathrm{SB}} = \frac{1}{VT^3}(\langle Q^2\rangle - \langle Q\rangle^2)$$ electric charge

$$\chi_{\mathrm{S}}^{\mathrm{SB}} = \frac{1}{VT^3}(\langle S^2\rangle - \langle S\rangle^2)$$ strangeness



conserved charges are carried by massive hadrons

Ideal gas of massless quarks :

$$\chi_B^{SB} = \frac{1}{3} \qquad \chi_Q^{SB} = \frac{2}{3}$$

$$\chi_B^{SB} = 1$$

conserved charges carried by light quarks

HotQCD: PRD86 (2012) 034509

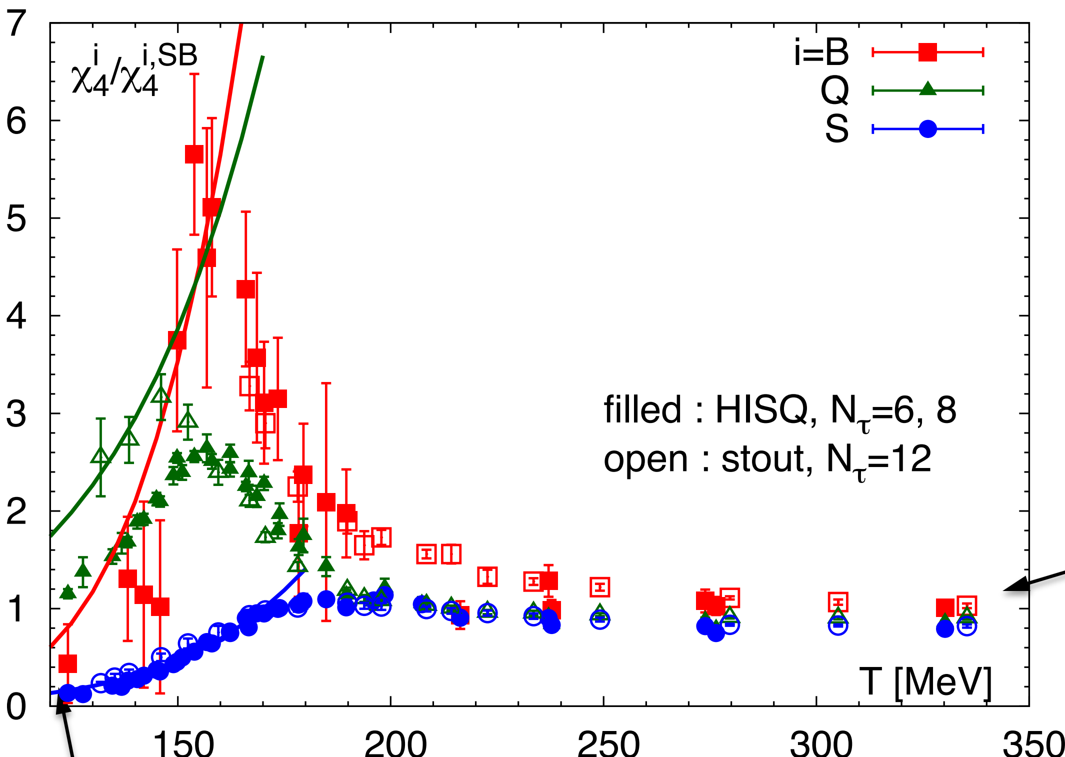
BW: JHEP 1201 (2012) 138,

Deconfinement : fluctuations of conserved charges

$$\chi_4^B = \frac{1}{VT^3}(\langle B^4\rangle - 3\langle B^2\rangle^2)$$ baryon number

$$\chi_4^Q = \frac{1}{VT^3}(\langle Q^4\rangle - 3\langle Q^2\rangle^2)$$ electric charge

$$\chi_4^S = \frac{1}{VT^3}(\langle S^4\rangle - 3\langle S^2\rangle^2)$$ strangeness



Ideal gas of massless quarks :

$$\chi_4^B{}_{\mathrm{SB}} = \frac{2}{9\pi^2} \qquad \chi_4^Q{}_{\mathrm{SB}} = \frac{4}{3\pi^2}$$

$$\chi_4^S{}_{\mathrm{SB}} = \frac{6}{\pi^2}$$

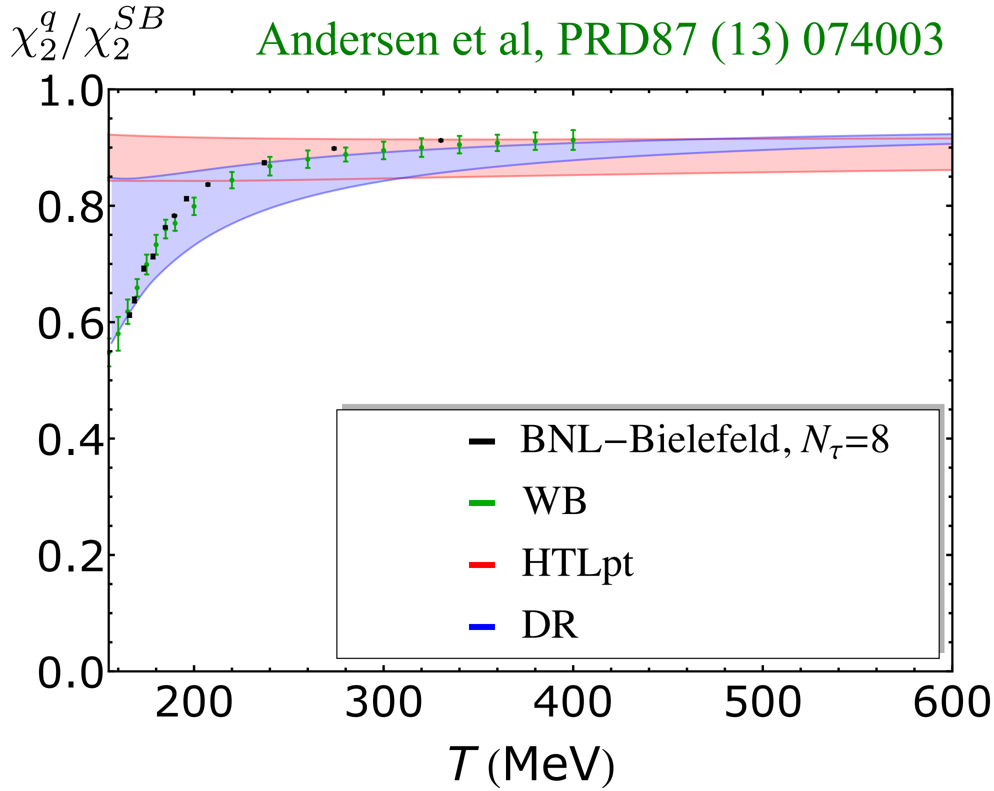
conserved charges carried by light quarks

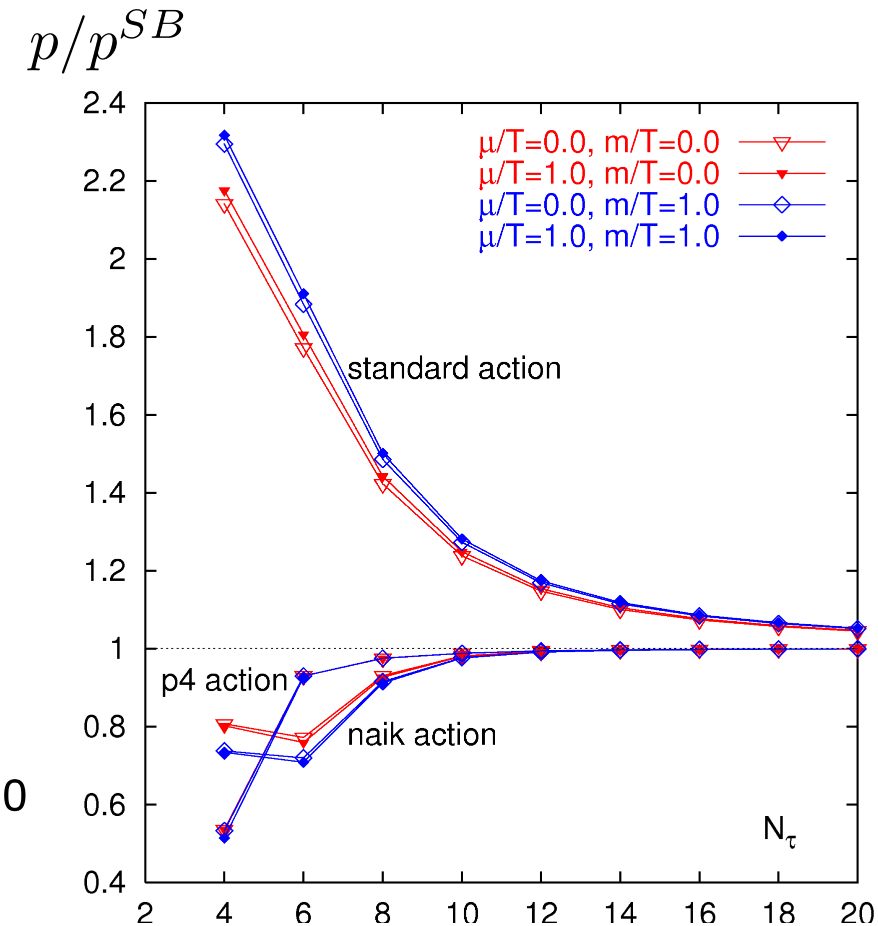
conserved charges are carried by massive hadrons

BNL-Bielefeld : talk by C. Schmidt
BW: talk by Borsanyi
@ Confinement X conference

Motivations

What are the degrees of freedom at high T? Do we understand cutoff effects at high T?



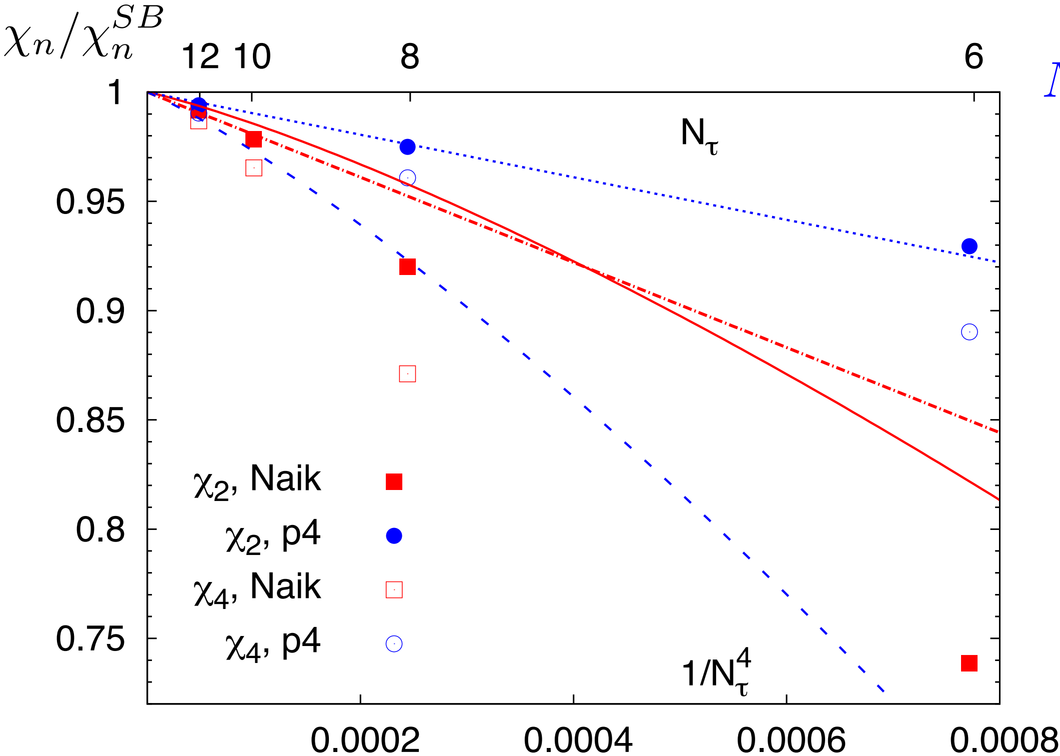


Resummed perturbative approach seems to agree with LQCD within large uncertainties
⇒ Extend to higher T, where the uncertainties are smaller

Cutoff effects are large for std. action

Cutoff effects in the free theory

Hegde et al, EPJC 55 (08) 423



N_τ – dependence up to $1/N_\tau^6$:

$$\chi_2 = 1 + a_{24}\frac{\pi^4}{N_\tau^4} + a_{26}\frac{\pi^6}{N_\tau^6},$$

$$\chi_4 = \frac{6}{\pi^2}\left(1 + a_{44}\frac{\pi^4}{N_\tau^4} + a_{46}\frac{\pi^6}{N_\tau^6}\right),$$

$$a_{24} = -\frac{93}{70},\ \ a_{44} = -\frac{21}{10},$$

$$a_{26} = -\frac{381}{70},\quad a_{46} = \frac{62}{945},\quad \text{Naik}$$

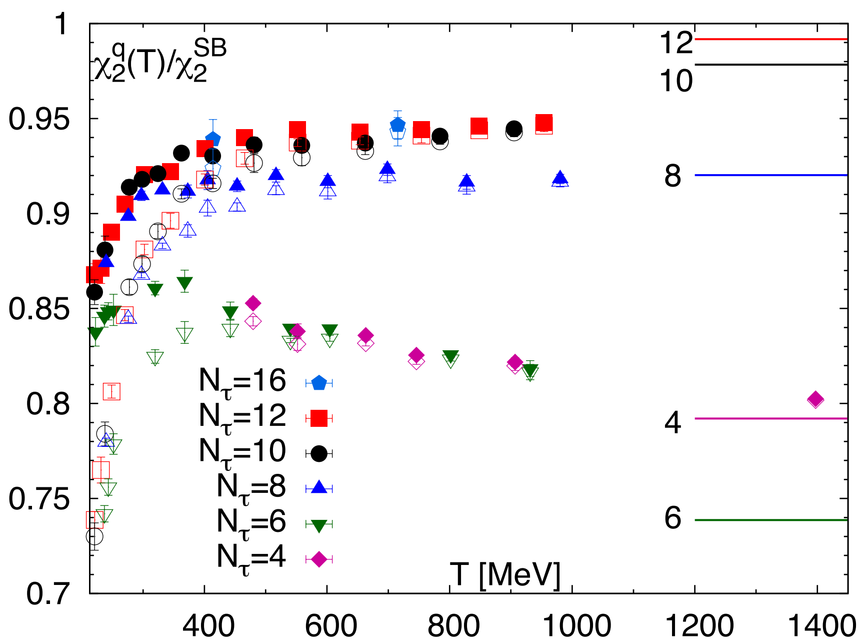
$$a_{26} = \frac{127}{3150},\quad a_{46} = -\frac{62}{7},\quad \text{p4}$$

The truncated expression works qualitatively
$\Rightarrow$ use it for continuum extrapolation

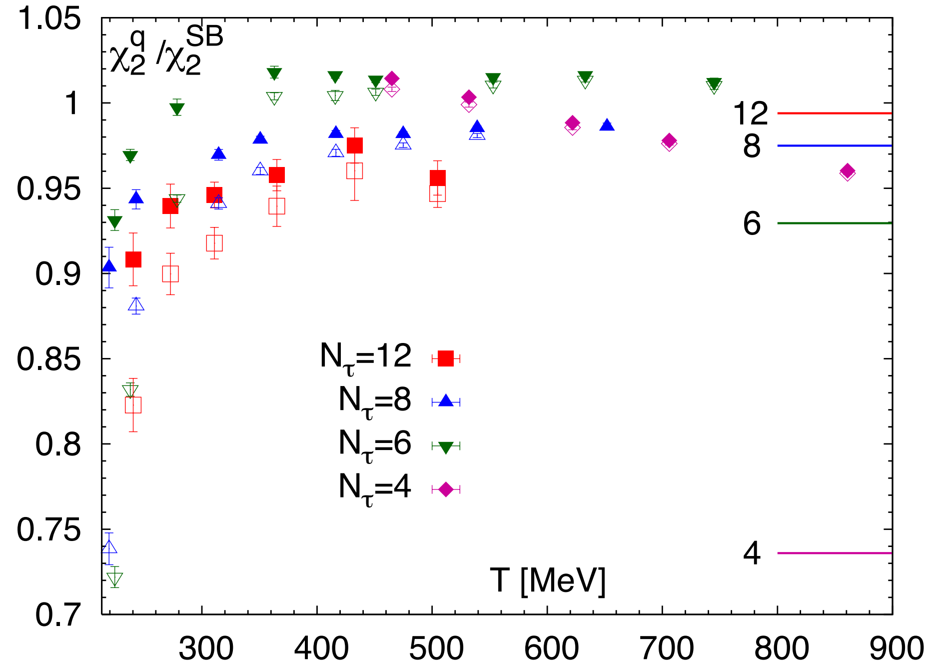
Beyond tree level cutoff effects should scalae as: $\alpha_s^n/N_\tau^2,\ n = 1, 2, ..$

Second order quark number susceptibility

HISQ



p4



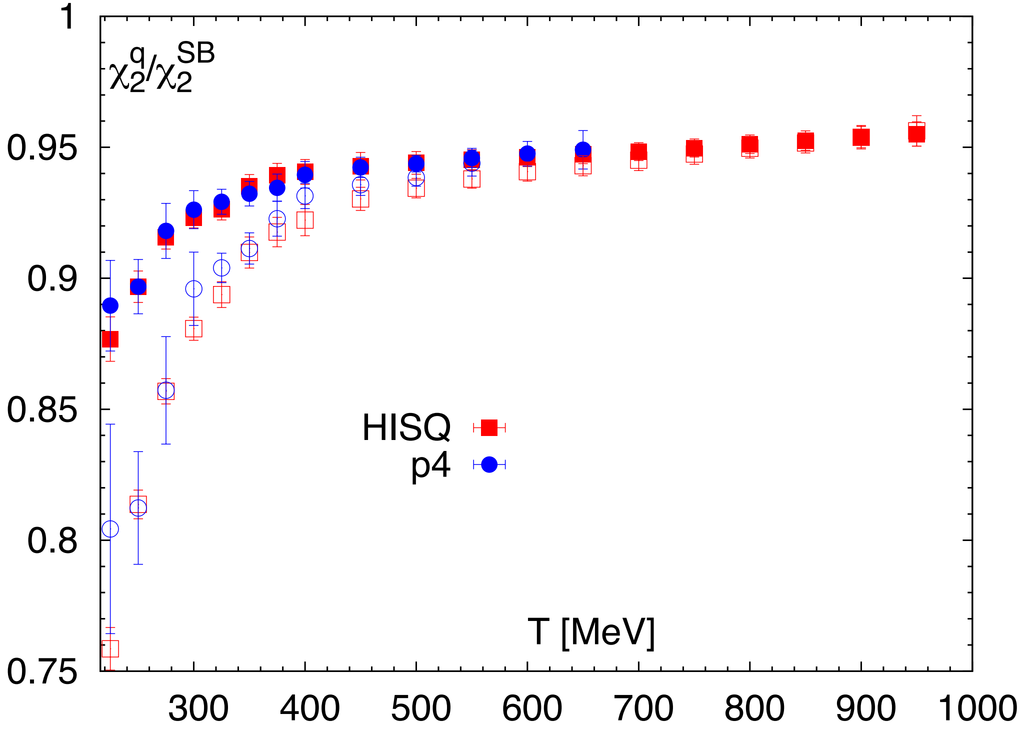
Cutoff effects for HISQ agree qualitatively with the free theory expectations but x2 smaller
In the studied T-range, possible accurate quantitatively at higher T

Cutoff effects for p4 action are different from the free theory expectation, continuum is approached from above

$$\text{p4} : c/N_\tau^2 \ \text{extrapolations}$$

$$\text{HISQ} : a/N_\tau^4 + b/N_\tau^6 \ \text{extrapolations}$$

Continuum limit for second order quark number susceptibility



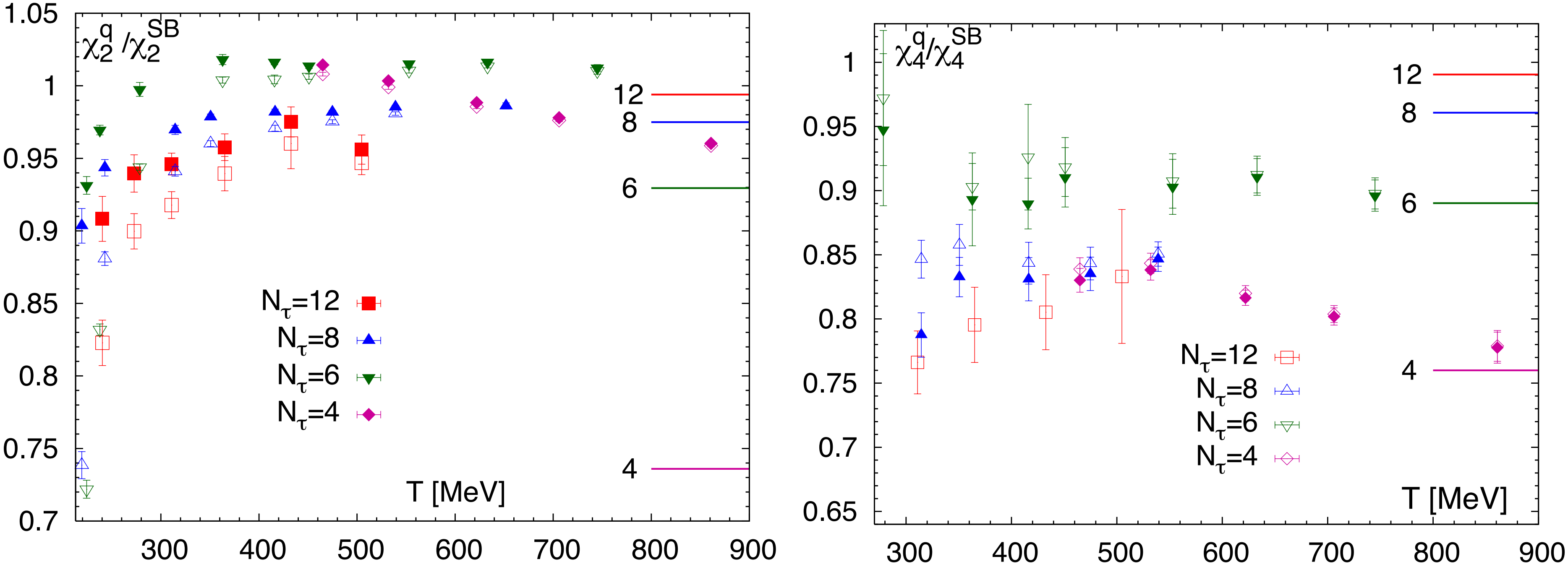
Continuum extrapolations for p4 and HISQ agree well

The difference between the light and strange QNS becomes small for *T>400* MeV and negligible for *T>600* MeV

For *T<400* MeV strange QNS agrees with the stout results within errors but the light QNS are larger by two standard deviations
Borsányi et al, JHEP 01 (2012) 138

Fourth order quark number susceptibility

p4

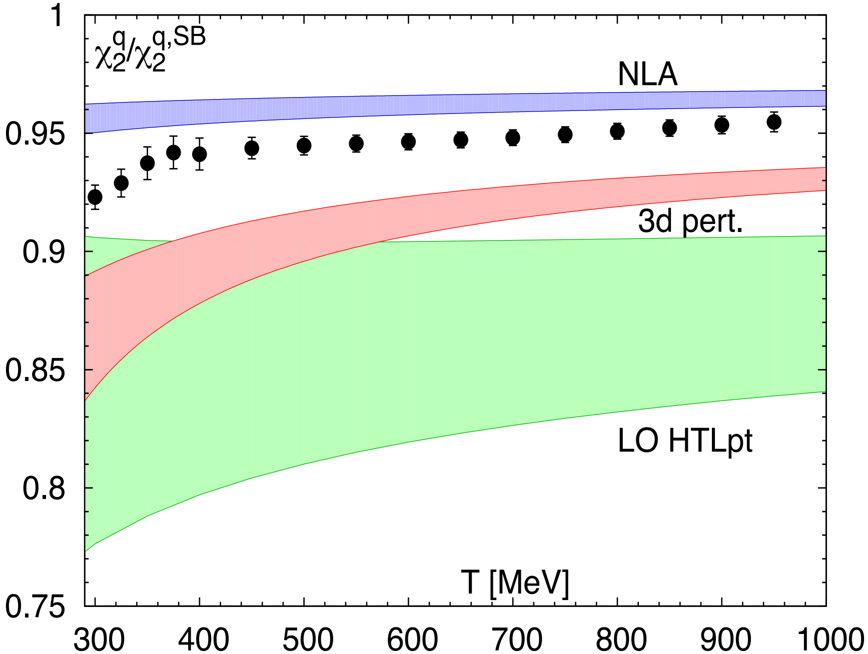


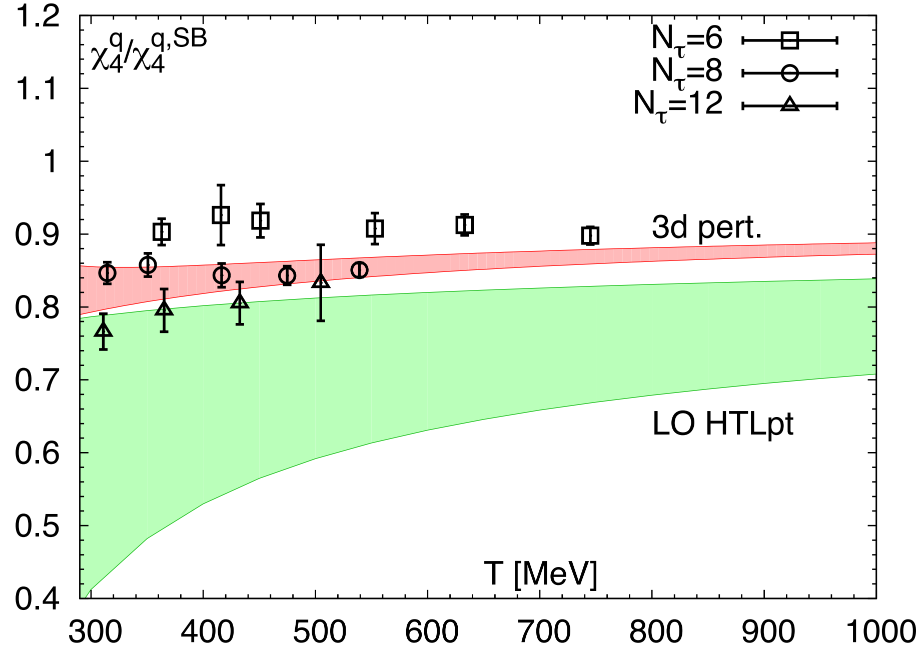
Cutoff effects in the 4th order QNS are similar to the cutoff effects in the 2nd order QNS, the continuum limit is approached from above

The deviations from the ideal gas limit appear to be larger

Comparison with resummed perturbative calculations

HTLpt : Haque, arXiv:1302.3228
Resummation in 3d effective theory: Andersen et al, PRD87 (13) 074003
Next-to-leading log resummation: Rebhan, hep-ph/0301130 (only 2[nd] order susceptibility)





Except for NLA resummed perturbative calculations are too low for 2[nd] order susceptibility

Resummed 3d result agrees within error but maybe high for the continuum lattice data
⇒ Need HISQ data and higher temperatures

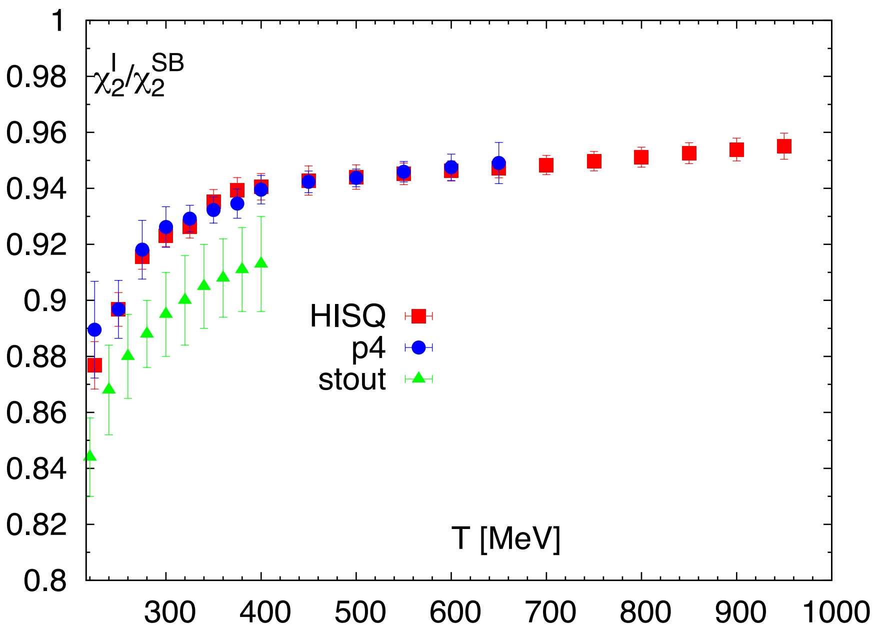
Summary and conclusions

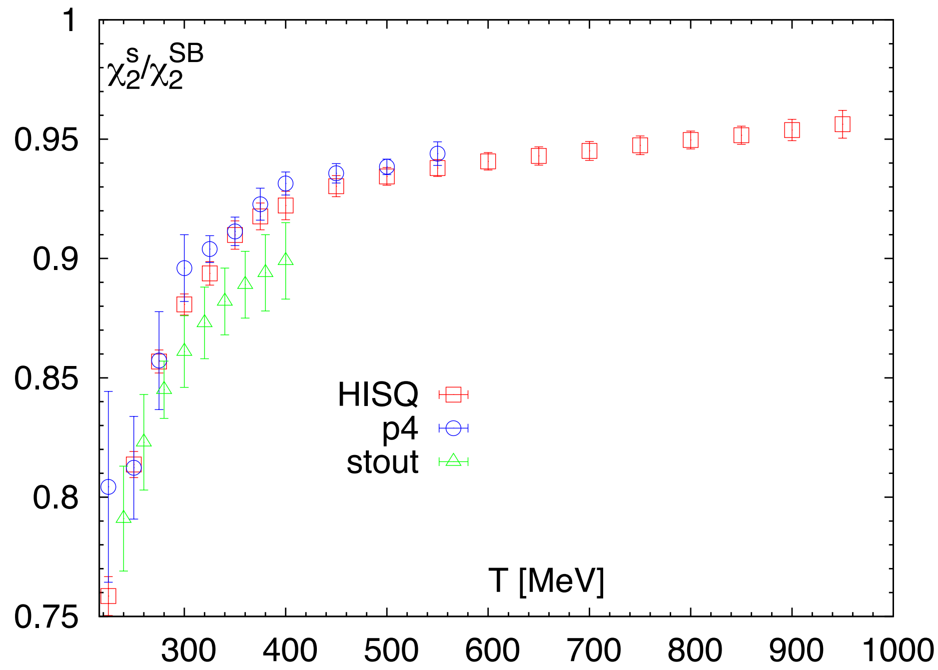
Second order quark number susceptibilities have been calculated in the continuum limit for *200* MeV < T < *950* MeV and p4 and HISQ results agree

At the highest temperatures deviations from the ideal gas limit is only 5% for the second order quark number susceptibilities and about 20% for the fourth order quark number susceptibilities
⇒ difficulties for resummed perturbative calculations

Cutoff effects at high temperatures are qualitatively described by the free theory result but (40-60)% smaller
⇒ lessons for continuum extrapolations for EoS

BACKUP:


χ_2^l/χ_2^{SB}
1
0.98
0.96
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
300
400
500
600
700
800
900
1000
HISQ
p4
stout
T [MeV]


χ_2^s/χ_2^{SB}
1
0.95
0.9
0.85
0.8
0.75
300
400
500
600
700
800
900
1000
HISQ
p4
stout
T [MeV]