The QCD equation of state with 2+1 dynamical flavors

Sz. Borsanyi, G. Endrodi, Z. Fodor, S. D. Katz,
S. Krieg, K. Szabo, C. Ratti

Budapest-Wuppertal collaboration

- $n_f = 2 + 1$ physical quark masses
- four lattice spacings $N_t = 6, 8, 10, 12$
- two different volumes $N_s/N_t = 3, 6$
- temperatures upto 1000 MeV

Lattices

action= stout smeared one link staggered, Symanzik gauge

old results: $N_t = 4, 6$ Aoki, Fodor, Katz, Szabo '06

new results: $N_t = 8, 10, 12$

N_t	finite T	zero T	T values
6	$6 \times 18^3, 6 \times 36^3$	$18 \times 18^3, 36 \times 18^3$	100 . . . 1000 MeV
8	8×24^3	24×24^3	100 . . . 1000 MeV
10	10×32^3	$32 \times 32^3, 96 \times 32^3$	100 . . . 365 MeV
12	$12 \times 32^3, 12 \times 64^3$	$32 \times 32^3, 64 \times 64^3$	165, 220 MeV

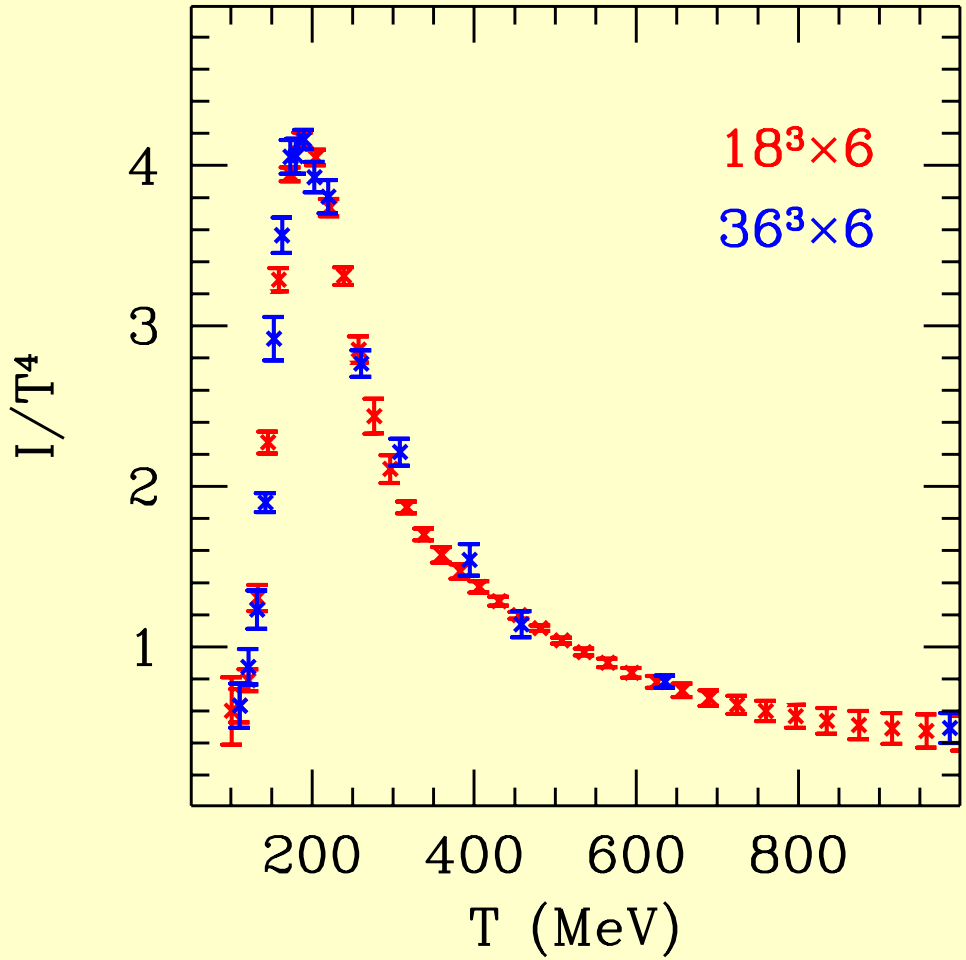
physical strange mass: m_s^{phys}

light quark masses: $m_{ud} = m_{ud}^{\text{phys}} \ldots m_s^{\text{phys}}$

aspect ratio: $N_s/N_t = 3$

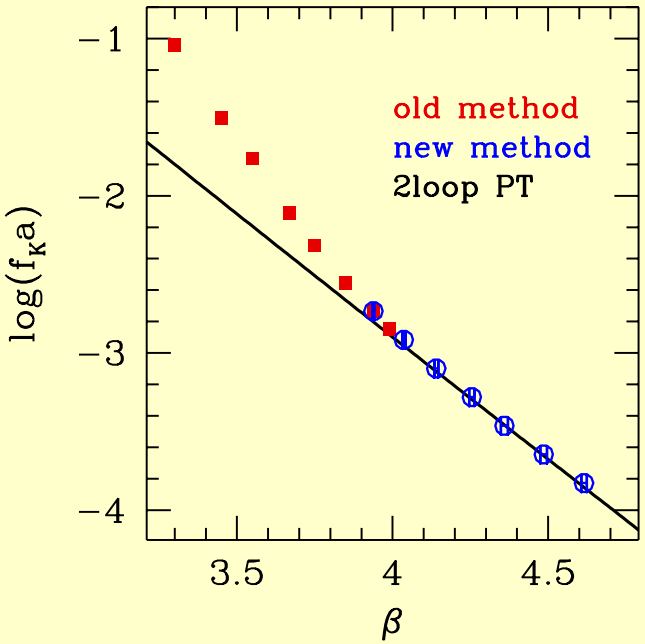
Finite volume effects

not significant, crossover



Lines of Constant Physics

old method: measure hadronic observables (m_π, m_K, f_K)
reference length scale = f_K^{-1} (or r_0, . . .)
m_π/f_K, m_K/f_K constant $\rightarrow$ tune parameters = LCP



problem: T=1000 MeV $\rightarrow$ a=0.025 fm $\rightarrow$ 180^4 lattice too large
new method: use box sizes « hadronic length scale Luscher et al '91
reference length scale = box size (L)
renormalized $g_R^2(L)$ is kept fixed $\rightarrow$ tune parameters = LCP

Bilgici et al '09

tested in 1. quenched 2. dynamical ($a = 0.07$ fm, 64^4)

Integral method Engels et al '90

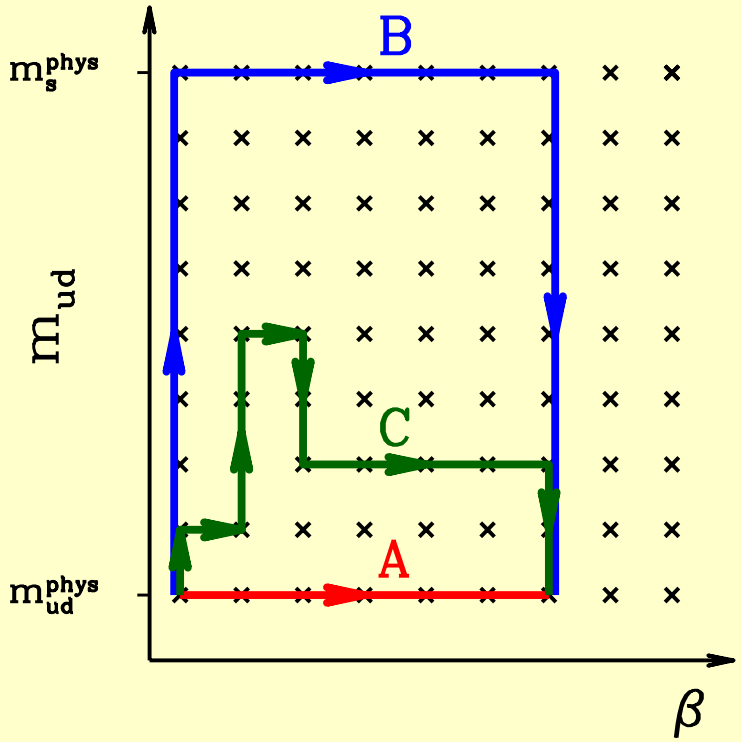
two parameters: β, $m_{ud} = m_{ud}^{\rm phys} \ldots m_s^{\rm phys}$

pressure= integral of lattice observables ($\langle s_g \rangle$, $\langle \bar{\psi}\psi \rangle$, . . .)

standard path= A, alternative pathes= B, C

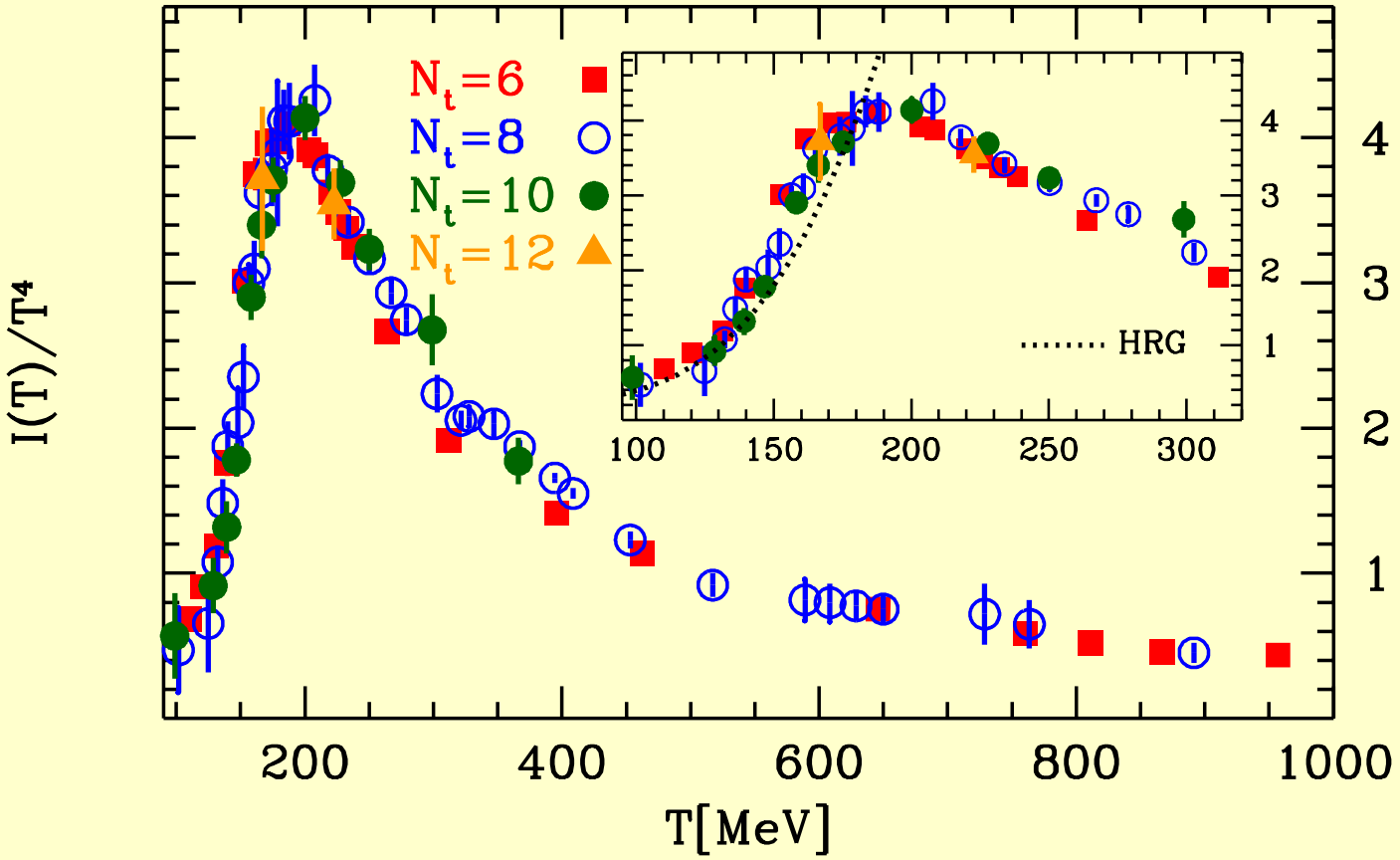
take into account all pathes:

1. parametrize pressure (2d spline with many fit parameters)
2. fit the derivatives to the measurements

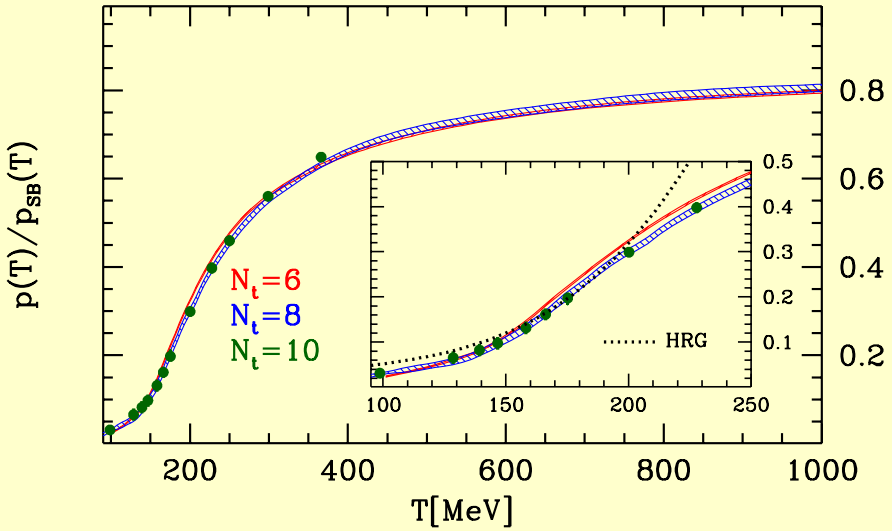


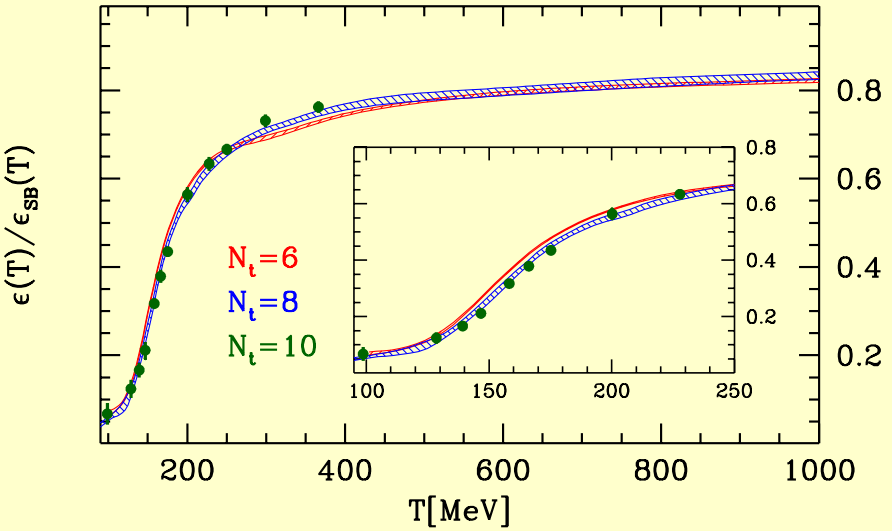
Trace anomaly

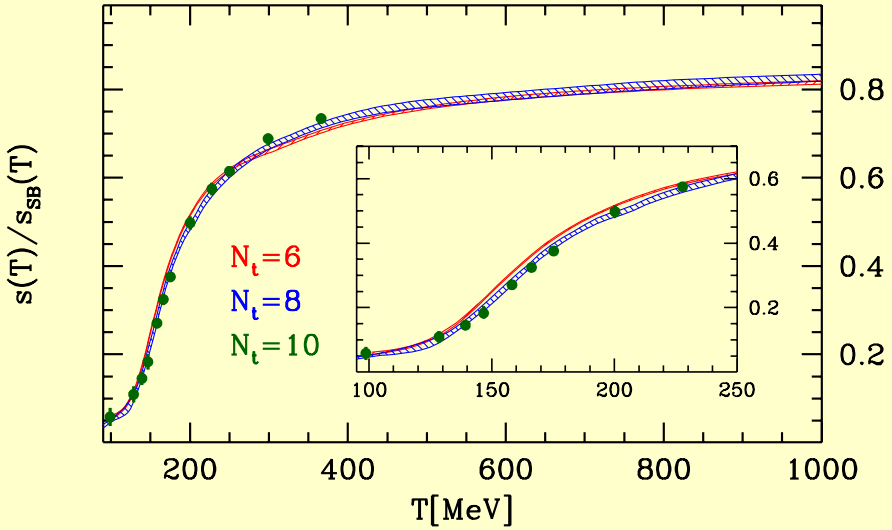
T_c: peak position 187(5) MeV, inflection point 154(4) MeV
maximum value of the peak: 4.1(1)

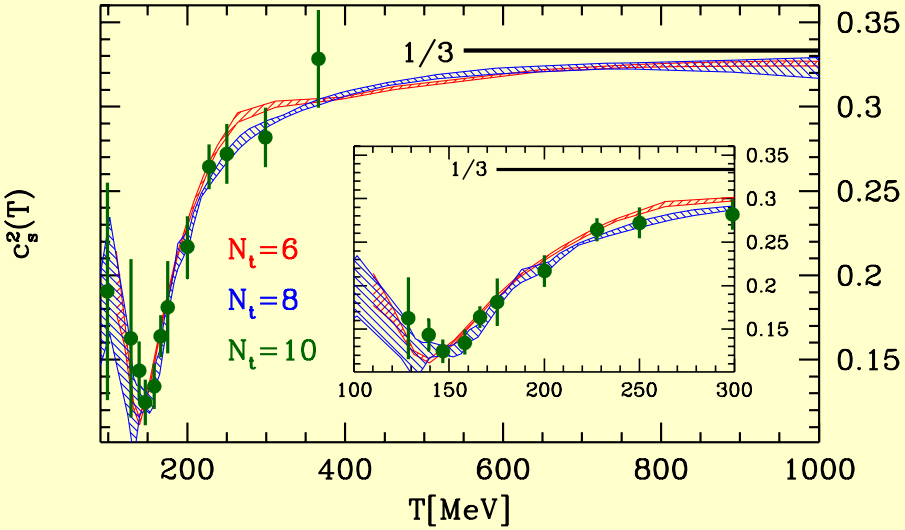


Pressure, energy, entropy, speed of sound



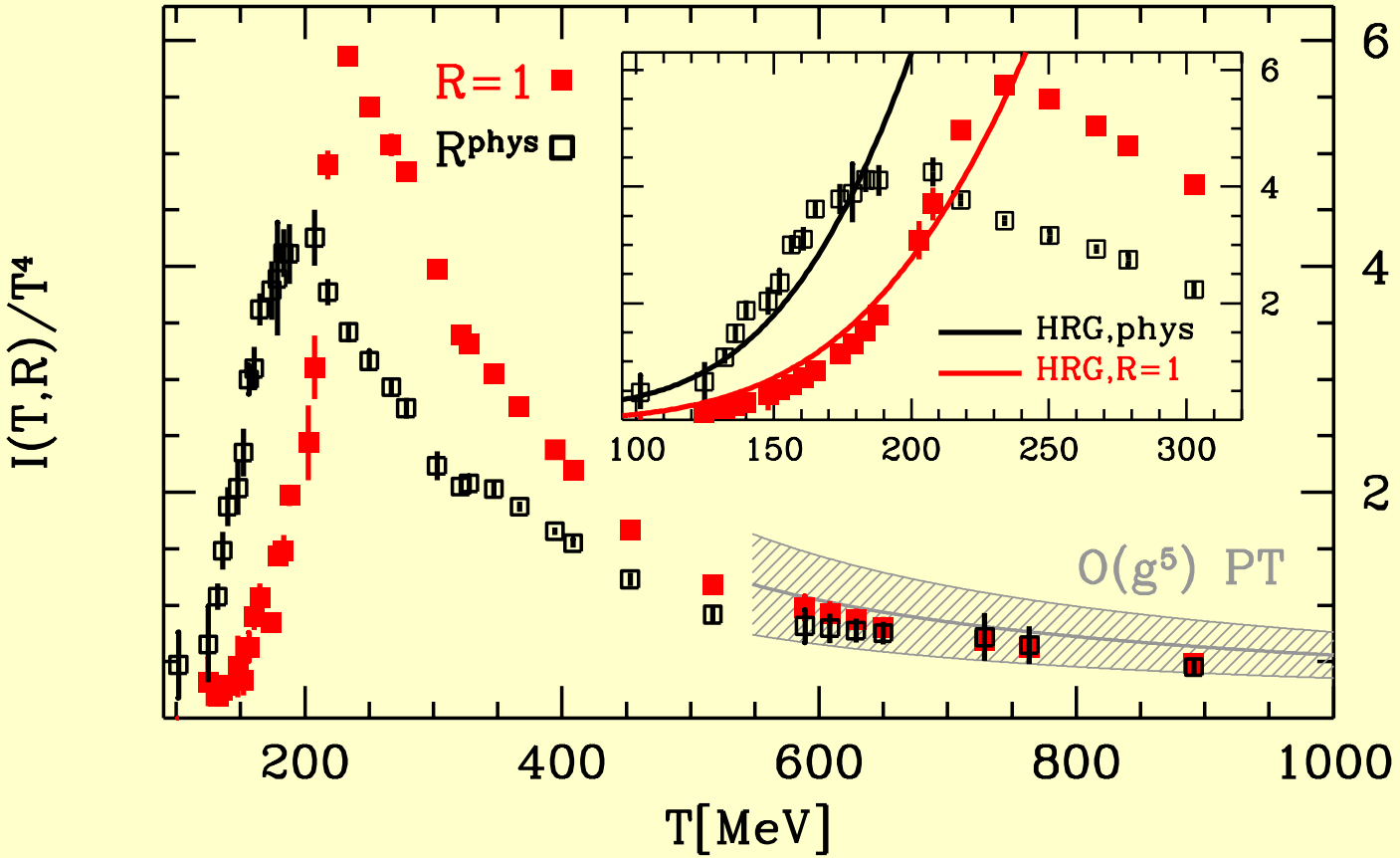






Quark mass dependence

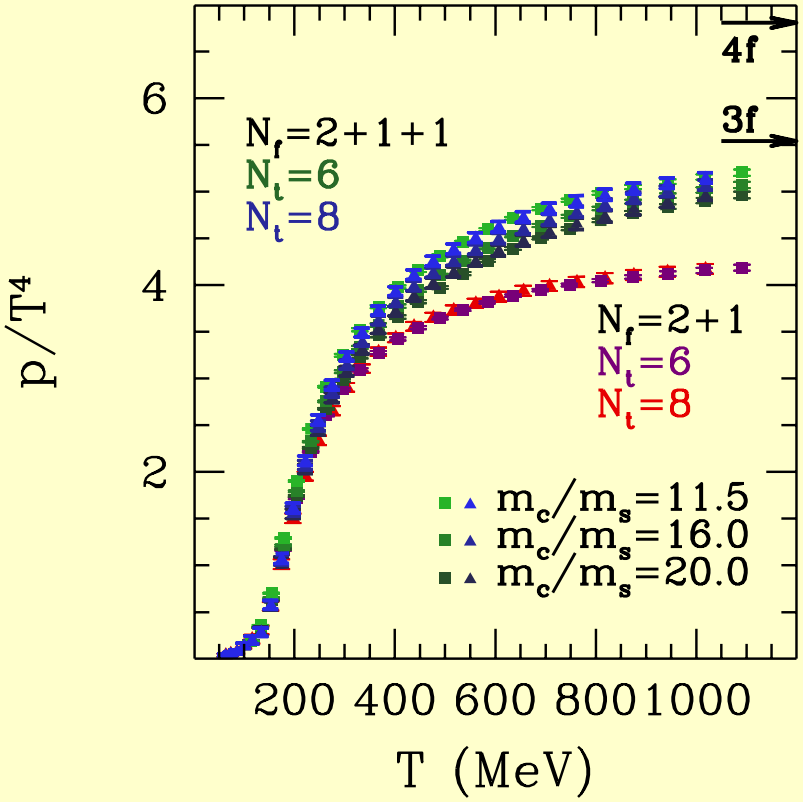
mass independent scale setting

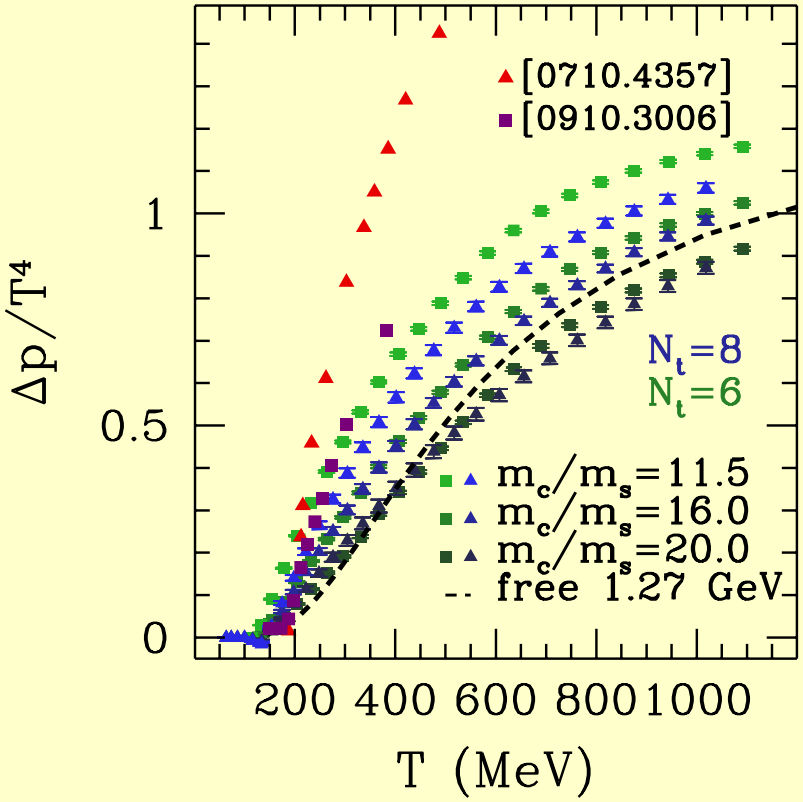


Charm quark contribution

partially quenched: measure $\langle \bar{\psi}_c \psi_c \rangle$ on $n_f = 2 + 1$ configs

contribution is non-zero from $T > 150$ MeV

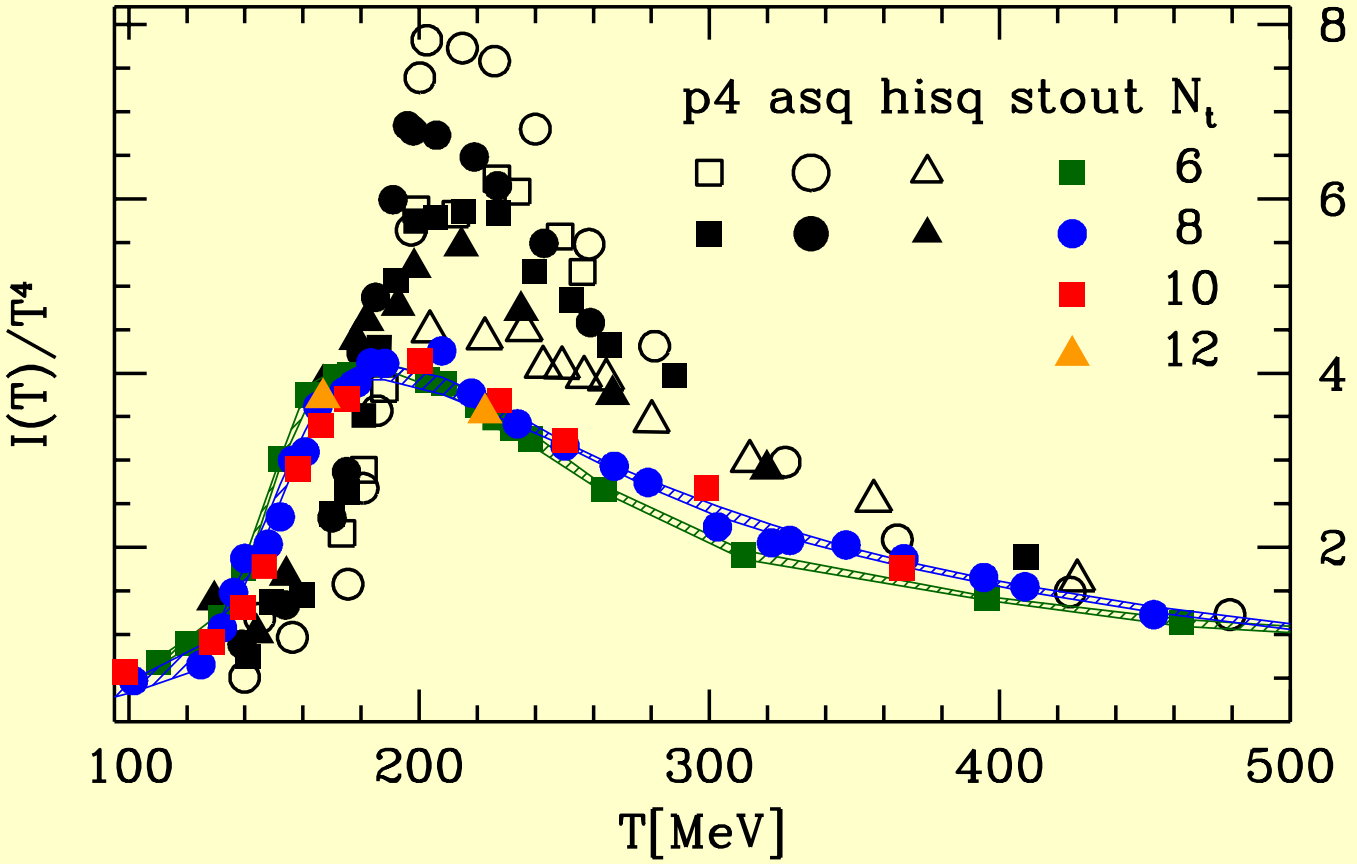




Comparison

hotQCD: Cheng et al '08, Bazavov et al '09, Cheng et al '10, Bazavov, Petreczky '10

shift in $T_c \rightarrow$ larger peak



Conclusion

QCD equation of state:

- $n_f = 2 + 1$ physical quark masses
- four lattice spacings $N_t = 6, 8, 10, 12$
- two different volumes $N_s/N_t = 3, 6$
- temperatures upto 1000 MeV

estimate effects of charm quark

contradicting hotQCD: smaller T_c, smaller peak in the trace anomaly