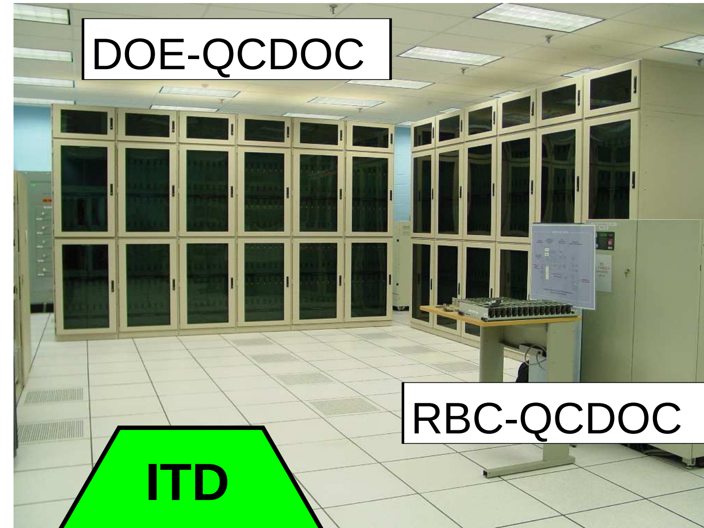
The Lattice Gauge Theory Group at BNL

2007 - 2009

- The LGT group and the BNL environment
- Research plan 2007 - 2009
- Update on research activities in 2006/07; ongoing and planned projects
- Budget situation

Lattice Gauge Theory @ BNL



RHIC

RIKEN **BNL**

ITD QCDOC

LGT
hot&dense QCD

NT
heavy ion phenomenology

HEP
LGT&particle physics

Collaborations

- **Columbia Univ.**
- **Bielefeld Univ.**
- **LGT Consortium**
- **LA, Tokyo, Wroclaw,..**

New Computing Resources

BlueGene/L

- **New York Blue @ NYCCS**
- **Livermore**
- **Argonne (BG/P)**

LGT group provides theoretical support for the experimental heavy ion program at BNL

The lattice group at BNL

group leader: Frithjof Karsch

2 Assistant Scientists:

Shinji Ejiri

Peter Petreczky (joint appointment with RIKEN/BNL)

4 Research Associates:

Christian Schmidt

Wolfgang Soeldner

Claudio Pica

Kay Hübner

1 PhD Student

Prasad Hedge (Stony Brook, with Jac Verbaarschoot)

0.5 secretariat: A. Aponte

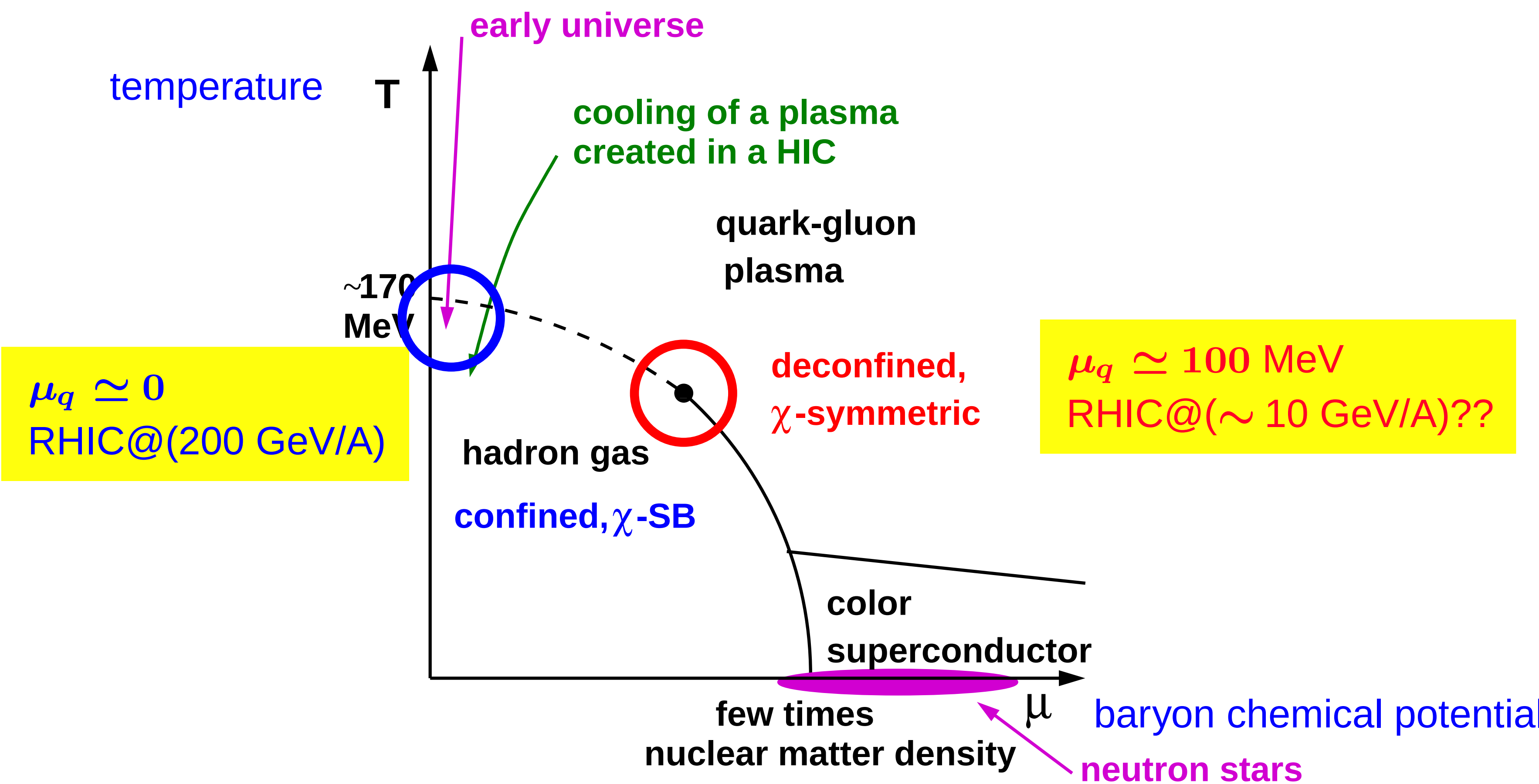
Research Plan 2007 - 2009

- QCD thermodynamics
  - equation of state and critical temperature
  - thermodynamics at non-zero baryon number density
  - Charge fluctuations and baryon number correlations
  - structure of the QCD phase diagram
- In-medium properties of hadrons
  - light quark sector: χSB and thermal dilepton rates
  - heavy quark sector: deconfinement and quarkonium
  - Hadrons at $T \neq 0$ and QCD with dynamical light quarks
- Software development and the next generation of computers for LGT

Phase diagram of
strongly interacting matter

RHIC and LHC $\Leftrightarrow$ LGT at zero chemical potential

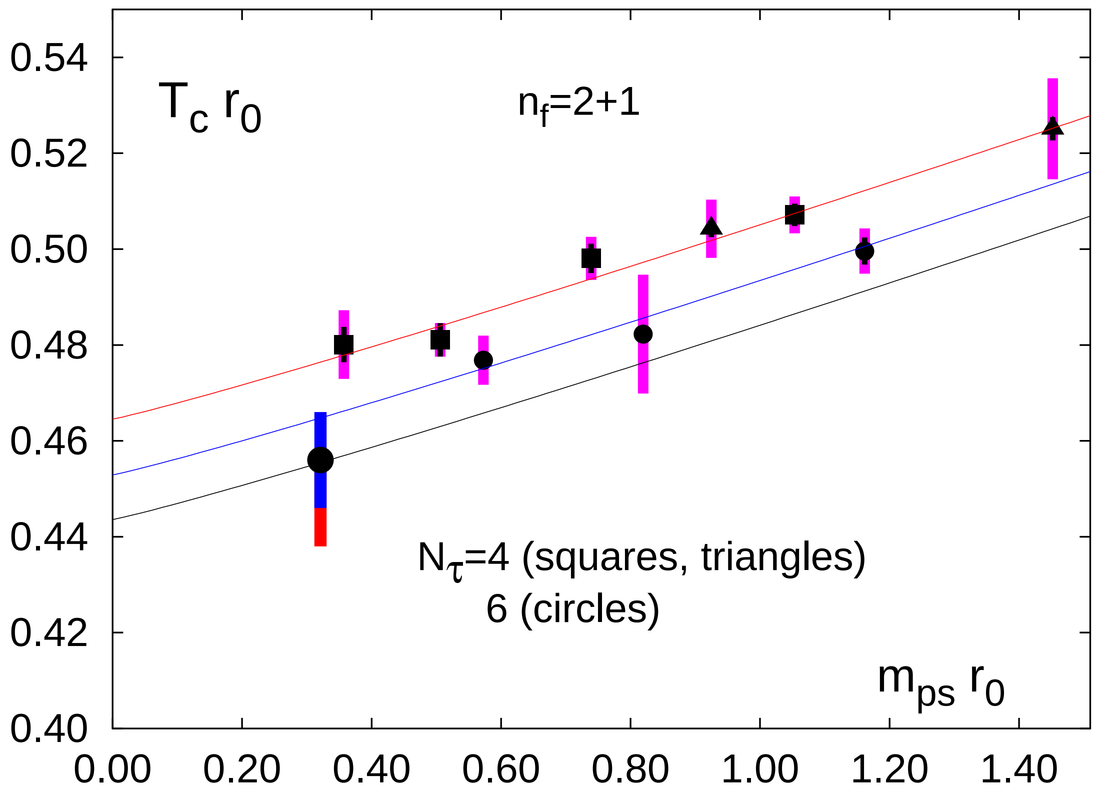
RHIC at low energy $\Leftrightarrow$ LGT at non zero chemical potential



Update on the transition temperature in QCD

- calculation of transition temperature with almost physical quark masses and different lattice cut-off values

$\Rightarrow$ extrapolation to physical limit ($m_\pi = 135$ MeV) and continuum limit ($a \longrightarrow 0$)



$\sqrt{\sigma} \simeq 465$ MeV

$r_0 = 0.469(7)$ fm

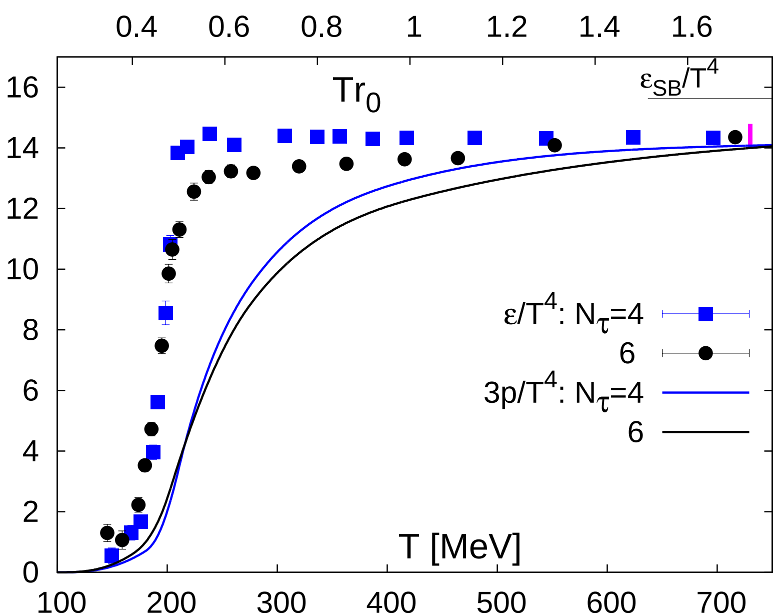
$\Downarrow$

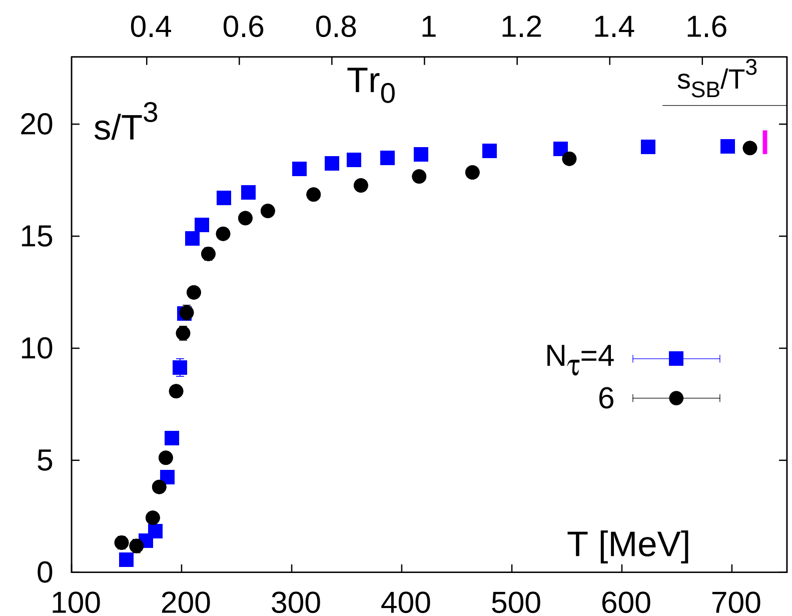
$T_0 \simeq 192(7)(4)$ MeV

RIKEN-BNL-Columbia-Bielefeld collaboration, Phys. Rev. D74, 054507 (2006) and Phys. Rev. D75, 034506 (2007) (45 citations)

QCD equation of state: $\mu_q = 0$

- p/T^4 from integration over $(\epsilon - 3p)/T^5$;
  systematic error arises from starting the integration at $T_0 = 100$ MeV with $p(T_0) = 0$;
  use hadron resonance gas to estimate systematic error: $[p(T_0)/T_0^4]_{HRG} \simeq 0.265$
- p/T^4 and ϵ/T^4 contain terms $\sim T^{-4}$ from vacuum normalization;
  these terms drop out in s/T^3



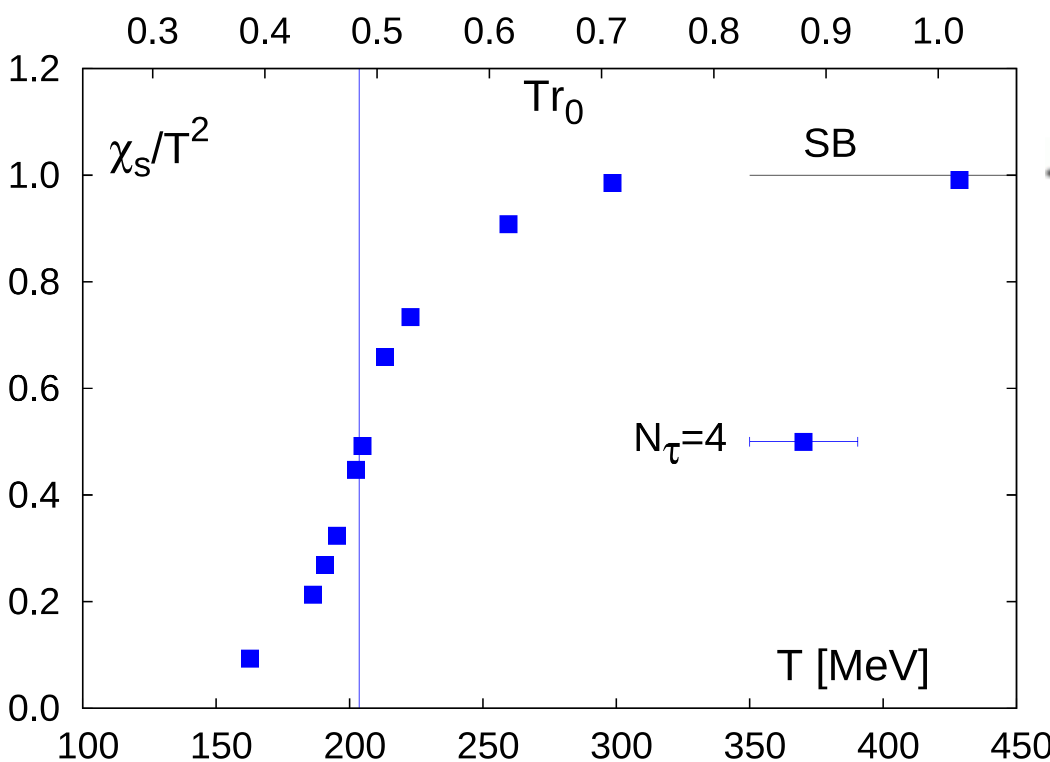


p4: RBC-Bielefeld, preliminary   to be presented at Lattice'07 (plenary talk)

Light and Strange Susceptibilities

- EoS for $\mu_q > 0$: quark number susceptibilities $\Leftrightarrow$ coefficients of the leading order correction to the pressure

$$\left(\frac{p}{T^4}\right)_\mu - \left(\frac{p}{T^4}\right)_0 = \frac{1}{2}\frac{\chi_l}{T^2}\left(\frac{\mu_l}{T}\right)^2 + \frac{1}{2}\frac{\chi_s}{T^2}\left(\frac{\mu_s}{T}\right)^2 + \frac{\chi_{ls}}{T^2}\frac{\mu_l}{T}\frac{\mu_s}{T} + \mathcal{O}(\mu^4)$$



p4: RBC-Bielefeld, preliminary

strange quark number susceptibility:

- $T \to \infty$, ideal gas limit:
  χ_l/T^2, $\chi_s/T^2 \quad \to \quad 1$

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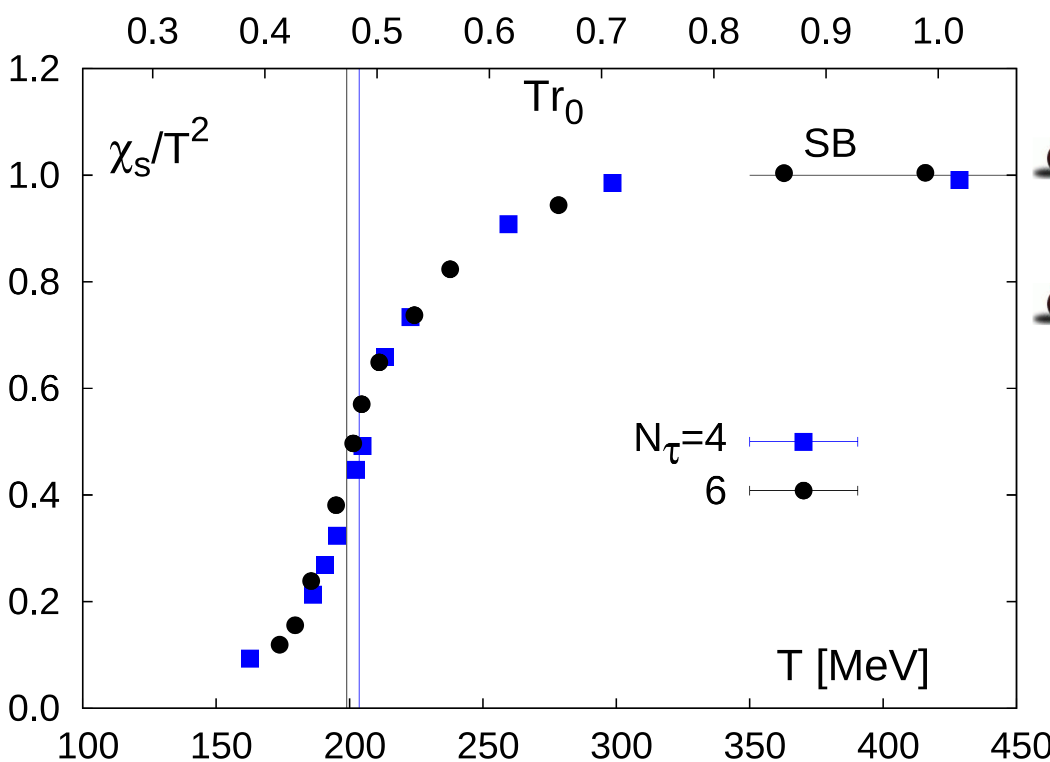

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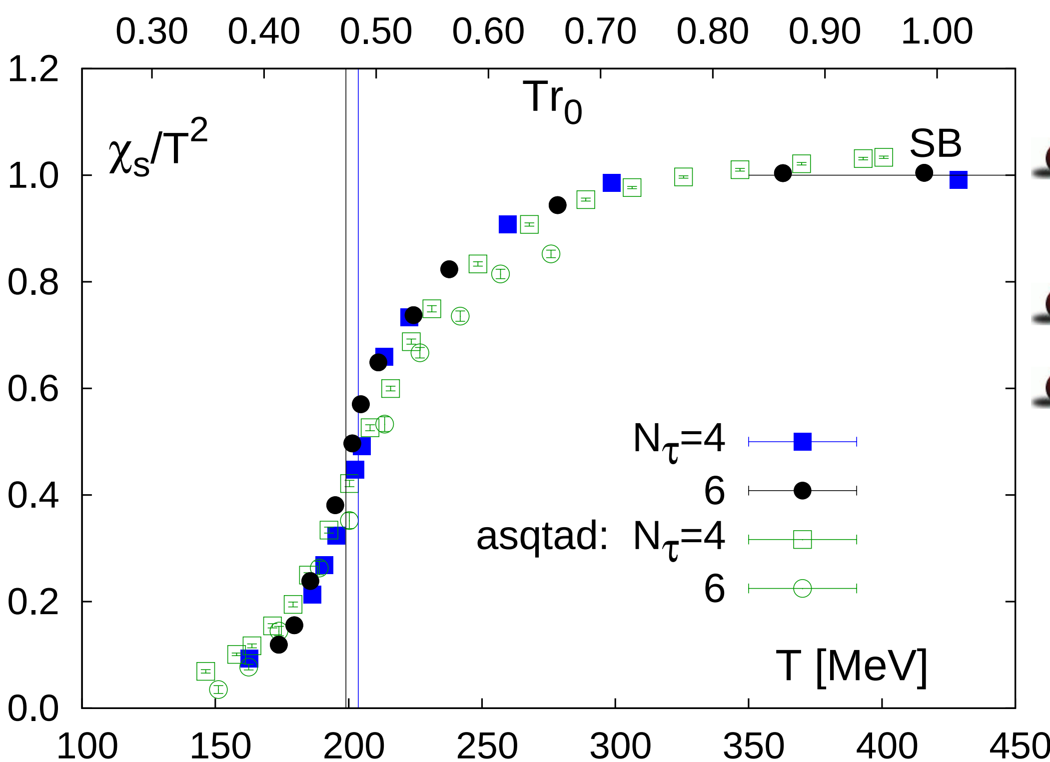


p4 versus asqtad

strange quark number susceptibility:

- $T \to \infty$, ideal gas limit: χ_l/T^2, $\chi_s/T^2 \quad \to \quad 1$
- small cut-off dependence
- good agreement with $\mathcal{O}(a^2)$ improved, asqtad fermion calculations

asqtad
C. Bernard et al (MILC), PRD71, 034504 (2005)

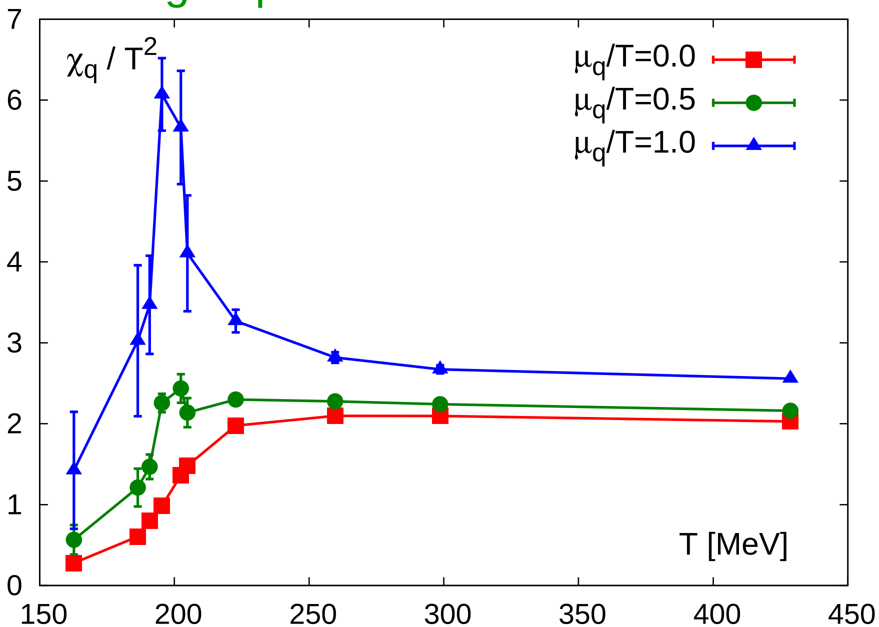
p4, $\mathcal{O}(a^2)$ improved
RBC-Bielefeld, preliminary

$\mu_q > 0$: Fluctuations of baryon number and strangeness in (2+1)-flavor QCD

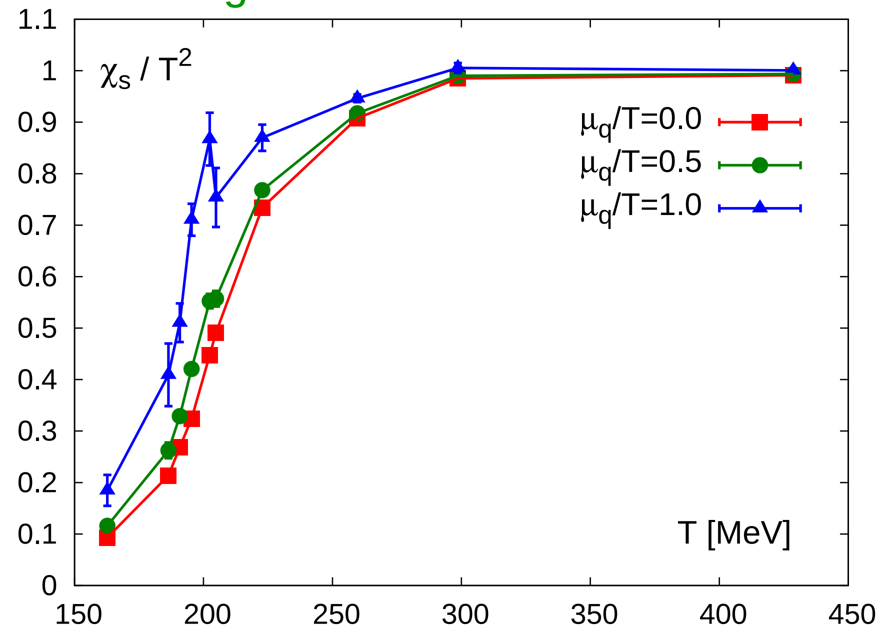
RBC-Bielefeld, preliminary

$$\chi_q/T^2 = 2c_2^q + 12c_4^q(\mu_q/T)^2 \qquad \chi_S/T^2 = 2c_2^s + 2c_{22}^{qs}(\mu_q/T)^2$$

light quark number fluctuation



strangeness fluctuation



$\Rightarrow$ large quark number fluctuations

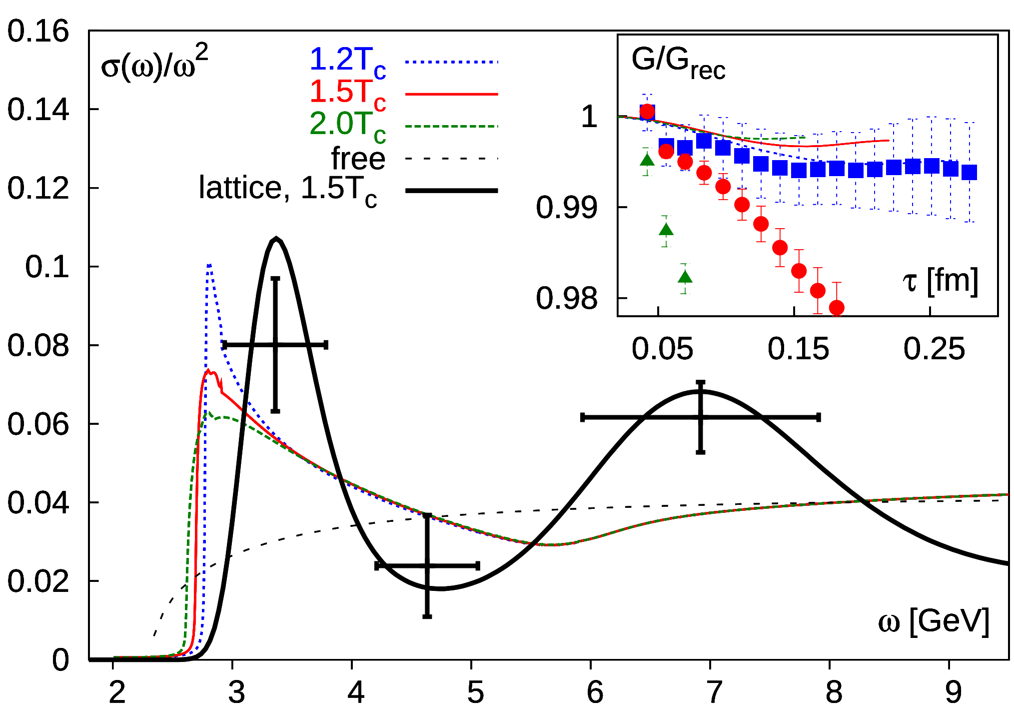
$\Rightarrow$ enhanced strangeness fluctuations (factor ~ 2)

Quarkonium at high temperature:
Potential models vs. Lattice results

A. Mocsy and P. Petreczky, Can quarkonia survive deconfinement?, arXiv:0705.2559

- a comparison of lattice results for the quarkonium correlation functions at high temperature with correlators constructed from potential model motivated spectral functions

$\Rightarrow$ melting of ALL $\bar{c}c$ bound states at or very close to T_c



lattice data from:

A. Jakovac, P. Petreczky, K. Petrov, A. Velytsky, Phys.Rev.D75 (2007) 014506

Projects on BlueGene/L

- Livermoore:
  - Modeling the QCD equation of state on BlueGene/L
    joint project with LANL, LLNL and MILC collaboration on the Livermore BlueGene/L (R. Gupta, R.Soltz (PIs))
    T_c, EoS on $N_\tau = 8$ lattices with light dynamical quarks:
    (2+1)-flavor QCD, close to physical m_π / m_K ratio;
    exploring the continuum limit: $N_\tau = 4,\ 6,\ 8$
    analyzing the thermodynamic limit: $V \simeq 500\ \mathrm{fm}^3$

    EoS on $32^3 \times 8$ lattices;   CPU-time: $\sim$ (20-40) TFlops-years

  - preliminary results will be presented in a plenary talk by FK at Lattice’07

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- New York Blue@NYCCS:
  - In-medium hadron properties, charmonium, dilepton/photon rates:
    quenched QCD on fine lattices ($a \simeq 0.02\ \mathrm{fm}$);
    analyzing light quark mesons with improved fermion formulations;
    exploring infra-red sensitivity of dilepton rates;
    analyzing charmonium spectra and colored bound state (sQCD fluid?);

    $\Rightarrow$ lattice sizes up to: $128^3 \times 16,\ 32$; CPU-time: $\sim$ 5 TFlops-years

Next projects on QCDOC and apeNEXT

Exploring the QCD phase diagram as function of (non-degenerate) quark masses and chemical potential;

joint project with RIKEN-BNL-Columbia and Bielefeld

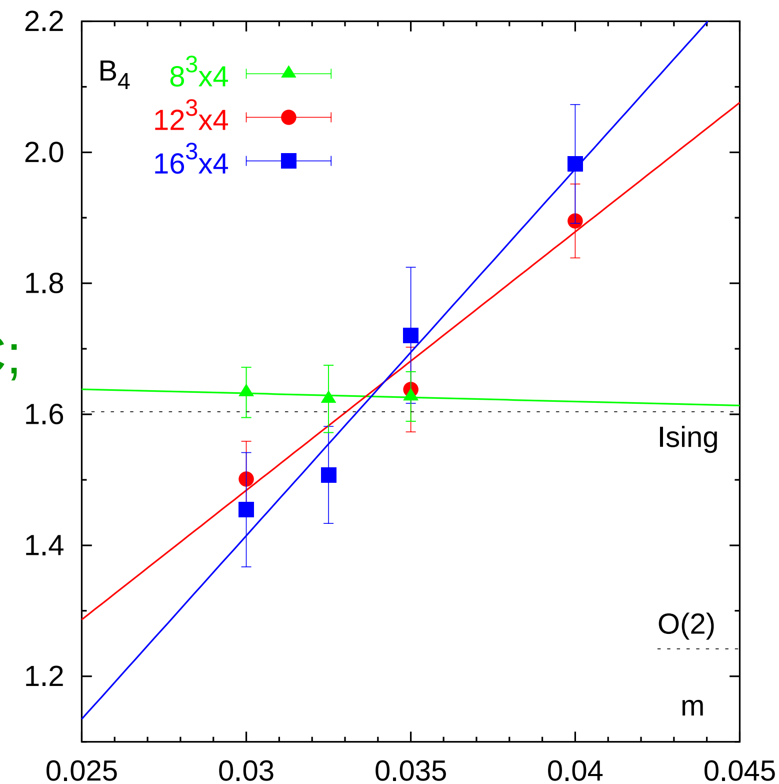
- Does the critical point in the QCD phase diagram exist?

  doubts have been raised (Philipsen and de Forcrand)

  question can be addressed using Taylor expansion techniques

- CPU-time: $\sim$ 7 TFlops-years

  (1.6 TFlops on DOE funded QCDOC; approved by USQCD Collaboration)



Towards petaflops computing

- co-authored white paper on
  Opportunities for Lattice QCD Thermodynamics with Petaflops Resources

project	lattice	# T	# m_q	trajecs	TF-y
EoS: $\mu = 0$, $T < 0.95T_c$	$48^3 \times 12$	7	2	100,000	35
EoS: $\mu = 0$, $T < 0.95T_c$	48^4	7	2	25,000	50
EoS: $\mu = 0$, $0.95T_c < T < 1.05T_c$	$48^3 \times 10$	6	2	100,000	10
EoS: $\mu = 0$, $0.95T_c < T < 1.05T_c$	48^4	6	2	25,000	20
EoS: $\mu = 0$, $2T_c < T < 4T_c$	$64^3 \times 10$	4	2	50,000	5
EoS: $\mu = 0$, $2T_c < T < 4T_c$	64^4	4	2	20,000	30
EoS DWF: $\mu = 0$, $0.95T_c < T < 1.05T_c$	$48^3 \times 10 \times 32$	4	1	50,000	100
EoS: $\mu > 0$ $T < 0.95T_c$ 8th order	$32^3 \times 8$	4	1	50,000	150
EoS: $\mu > 0$ $T < 0.95T_c$ 10th order	$32^3 \times 8$	1	1	50,000	340
phase boundary, $\mu = 0$	$32^3 \times 6$	4	10	10,000	200
phase boundary, $\mu = 0$, DWF	$48^3 \times 10 \times 32$	4	4	10,000	40
phase boundary $\mu > 0$	$32^3 \times 6$	4	4	10,000	100
spectral function, quenched	$128^3 \times N_\tau$	7	1	10,000	15
spectral function, dynamical	$48^3 \times N_\tau$	7	1	10,000	100

Summary of simulation parameters and cost estimates.

- RIKEN-BNL-Columbia petaflop initiative; joint project with IBM

Scientific Impact

- last years papers on T_c determination got cited already more than 45 times
- the ongoing work of the hotQCD collaboration on the QCD EoS receives much attention
  plenary talk on QCD thermodynamics at Lattice'07;
  2 parallel talks by hotQCD collaboration;
  6 parallel talks by RBC-Bielefeld collaboration
- invited talks at major conferences and workshops on QCD thermodynamics
  (QM'06, YKIS2006, APS April meeting, LHC prediction workshop, CPOD@GSI, SQM'07, Lattice'07,...)
- CPOD will be held at BNL in 2009

Budget of the LGT group

- the group is funded by the Lab
- a request for support of the group has been submitted to DOE
- all LDRD projects of the group end in 2008

A man without money
is no man at all
(Chinese proverb)