The phase diagram of QCD

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TIFR Mumbai

20th CBM Collaboration Meeting
VECC Kolkata
September 26, 2012

1. Introduction
2. The nature of hot QCD
3. Improved and new lattice results
4. The energy scan and the search for the critical point
5. Summary

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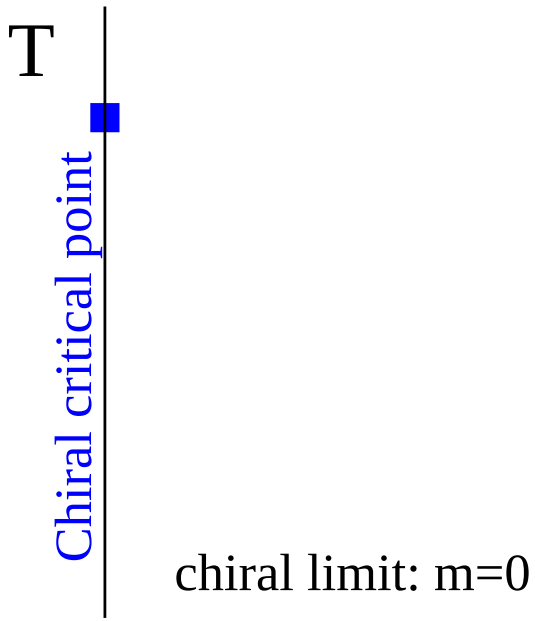

Pisarski, Wilczek, 10.1103/PhysRevD.29.338; Stephanov, Rajagopal,Shuryak, hep-ph/9903292, hep-ph/9806219

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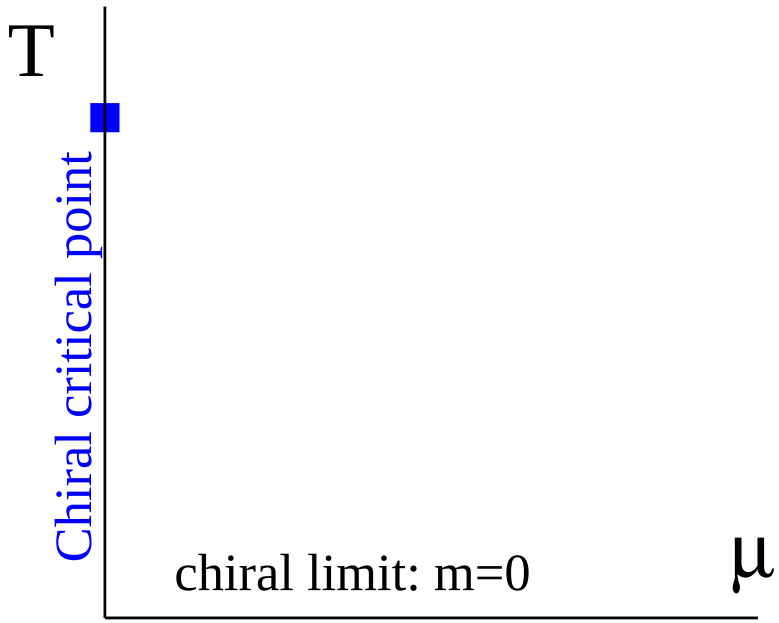

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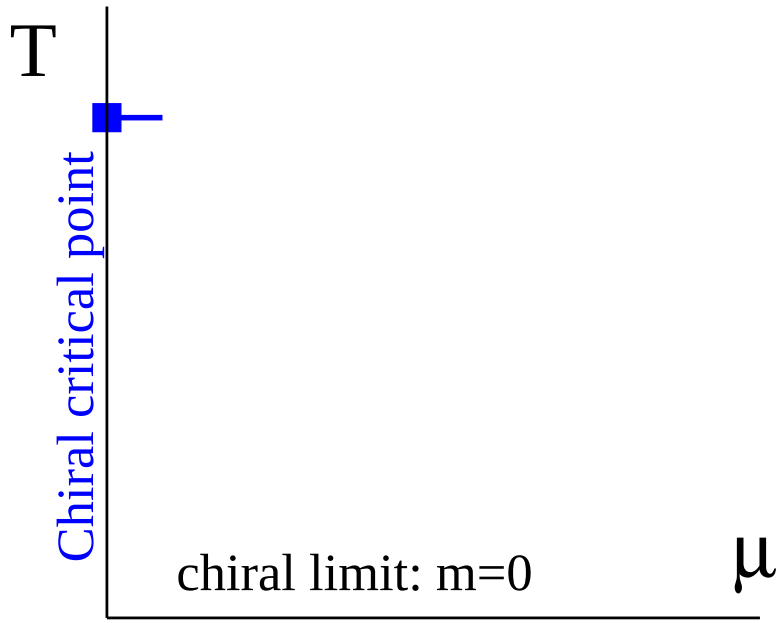

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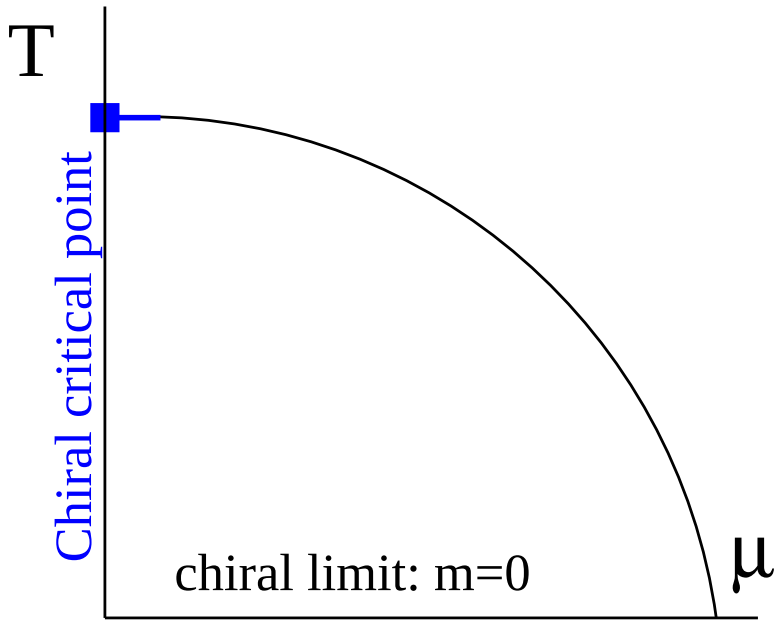

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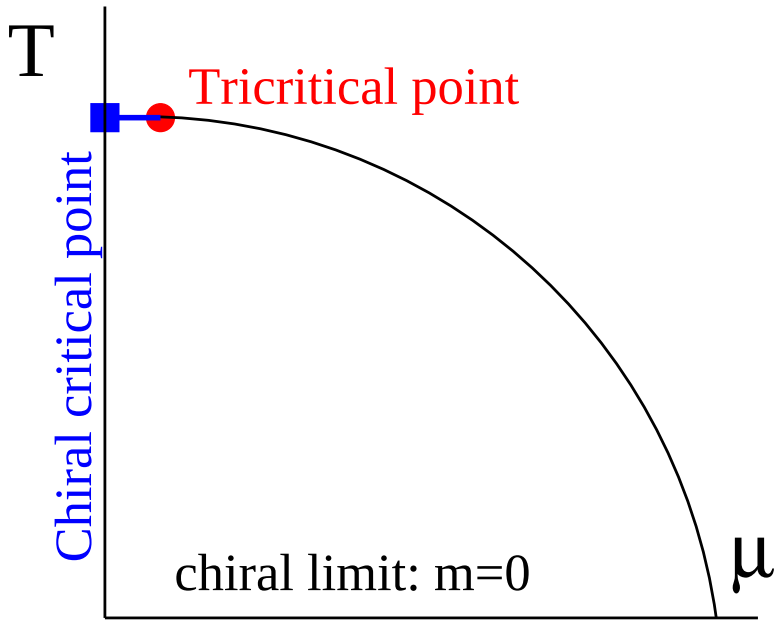

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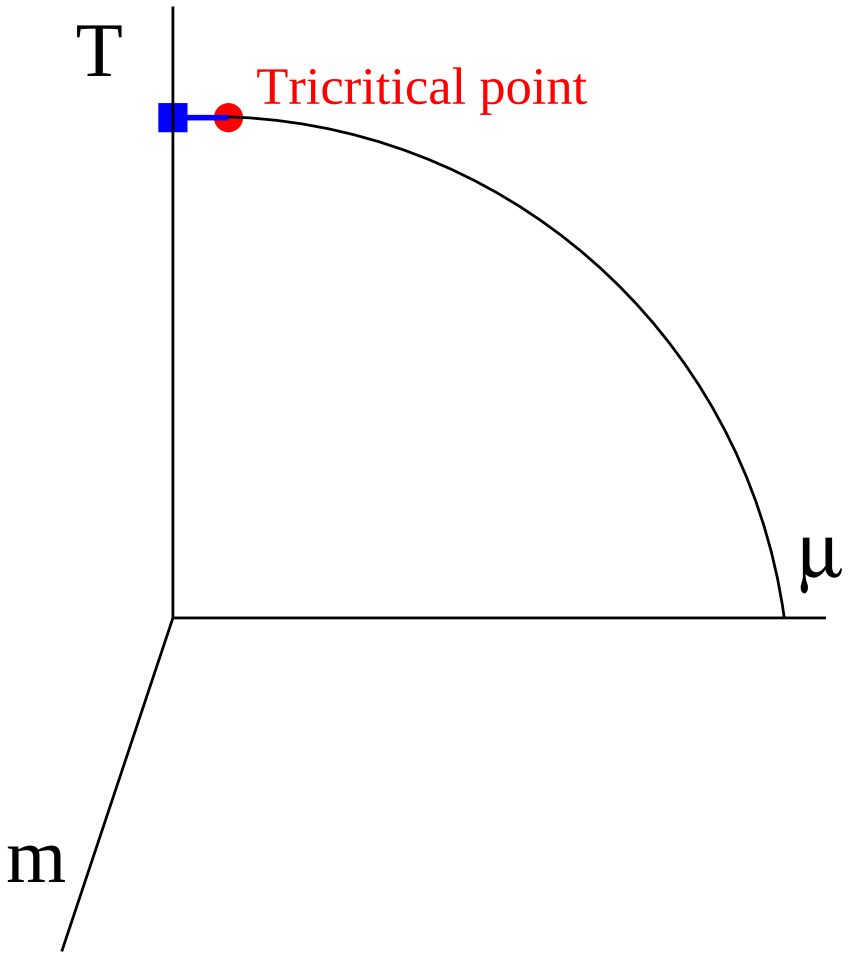

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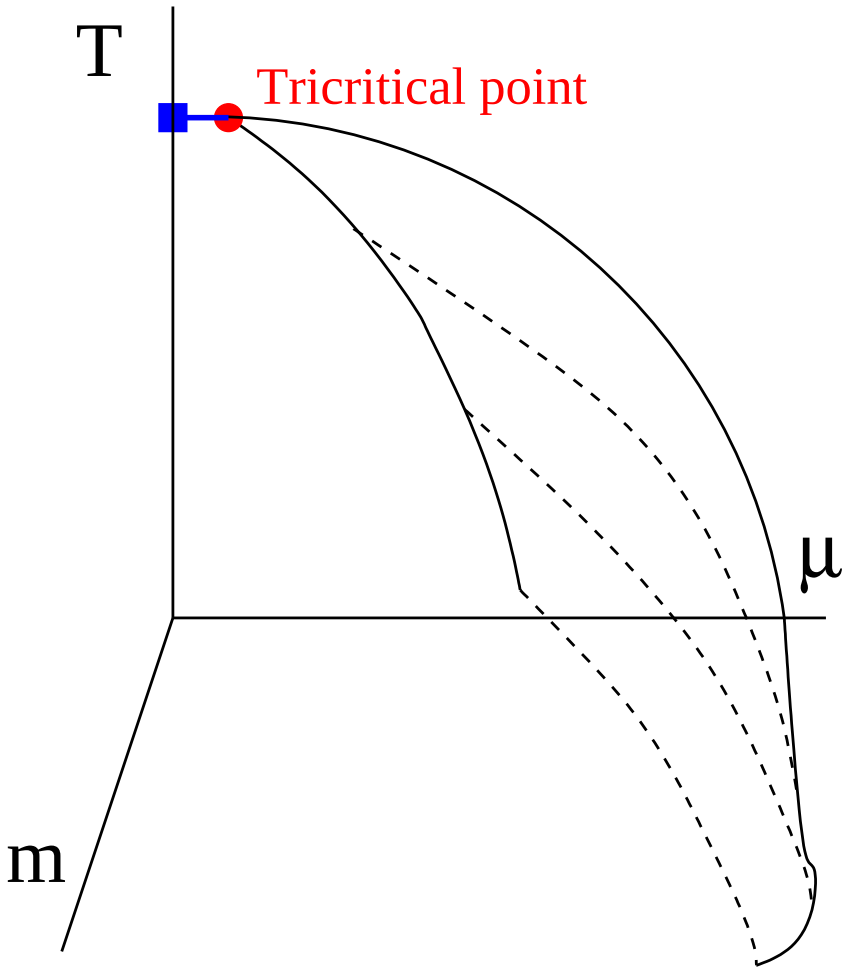

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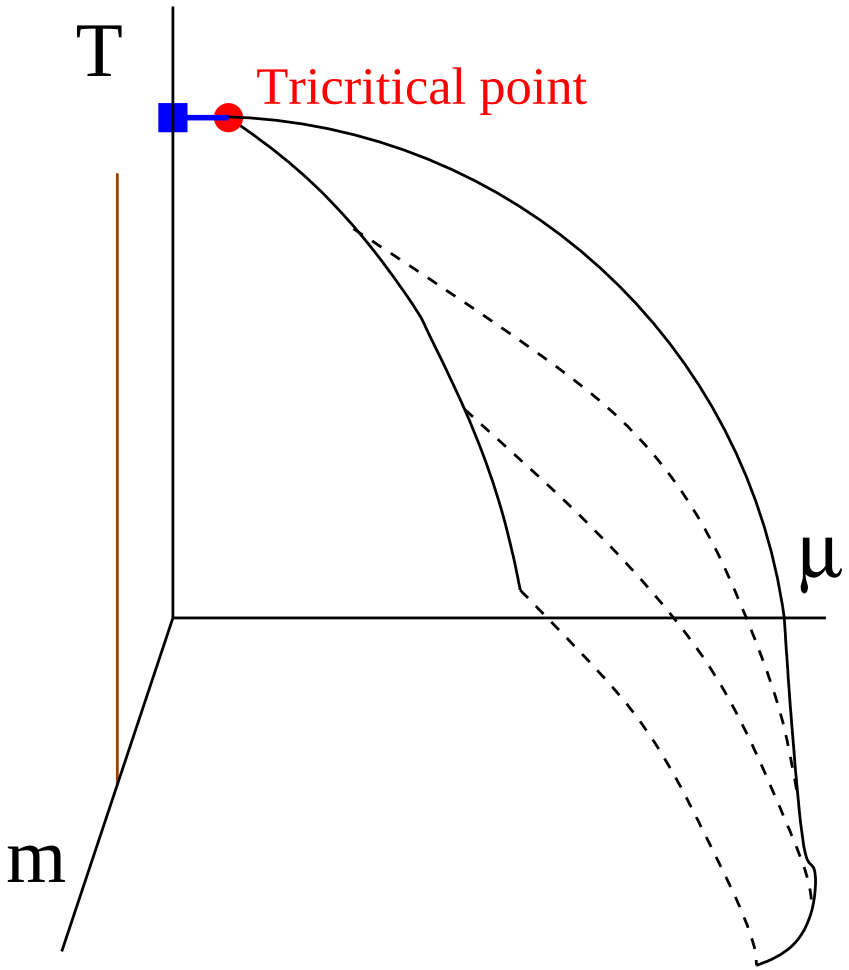

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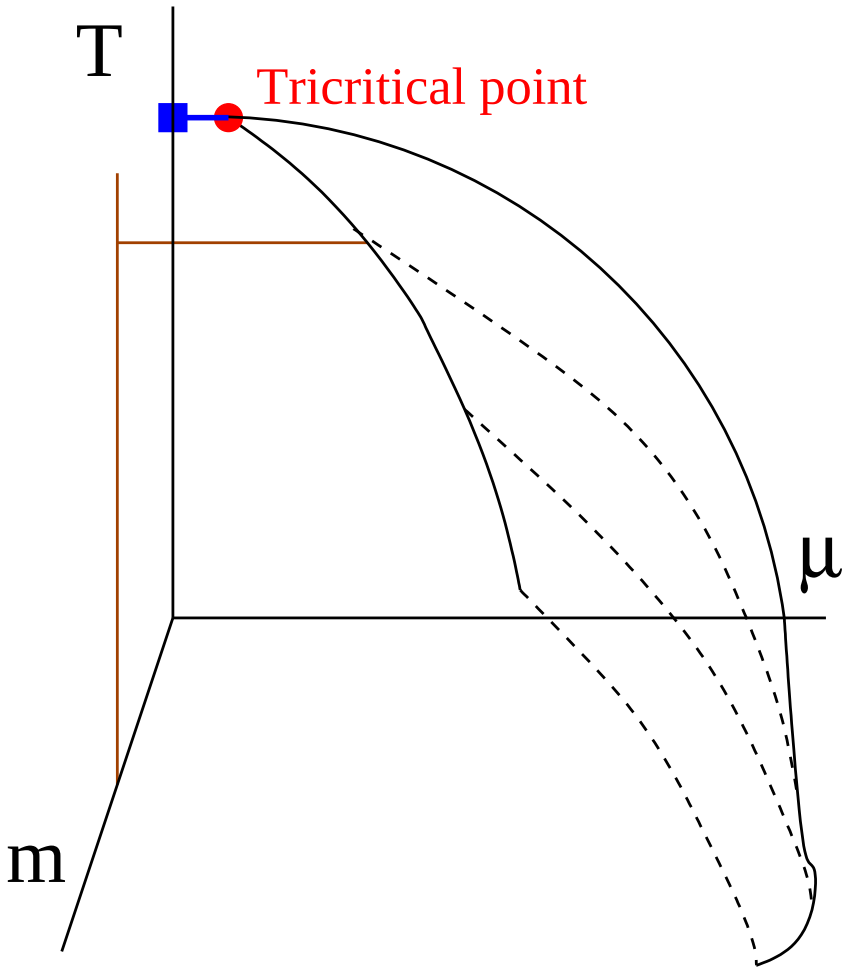

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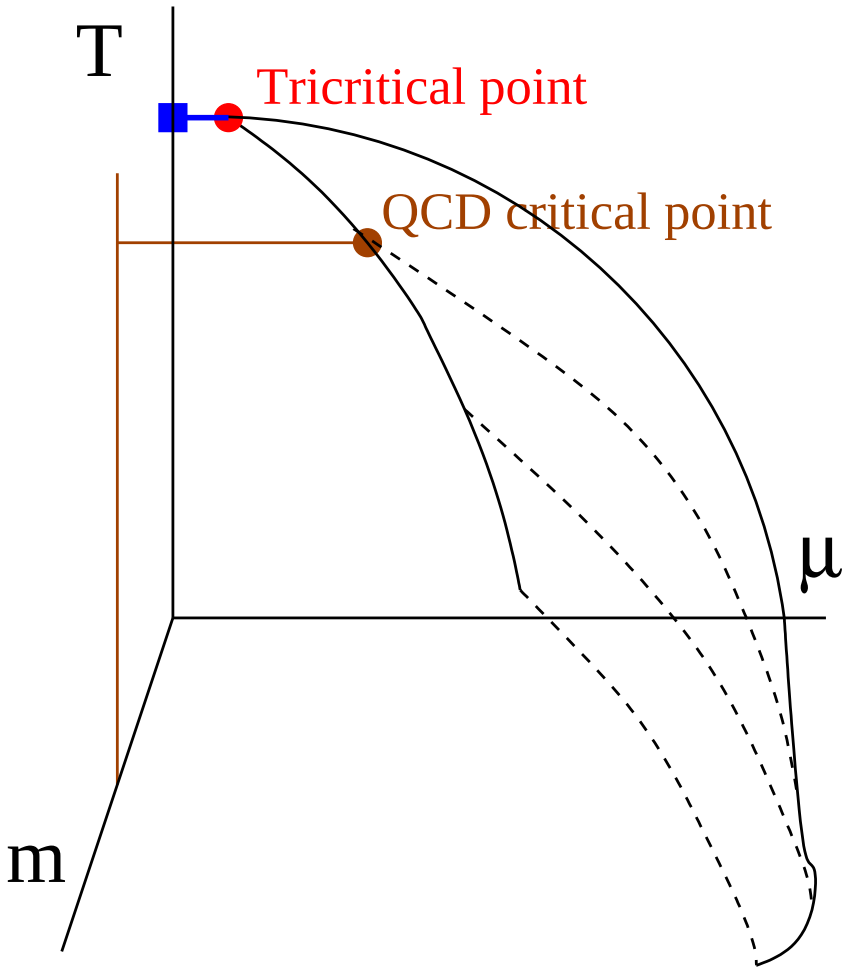

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What is special about chiral symmetry

Hadron and nuclear properties at $T = 0$ imply PCAC and approximate chiral symmetry: $m_\pi \ll m_\rho$. As a result, sum over intermediate hadron states in VEVs well approximated by sum over pion states.

Chiral symmetry ($m_u = m_d = 0$) implies $m_\pi = 0$. Then 20 pion states could be more important in sum over states in VEVs than a single pair $\rho^\pm$.

Corollary: sufficiently close to the chiral limit HRG can be replaced by a much simpler system: a pion gas.

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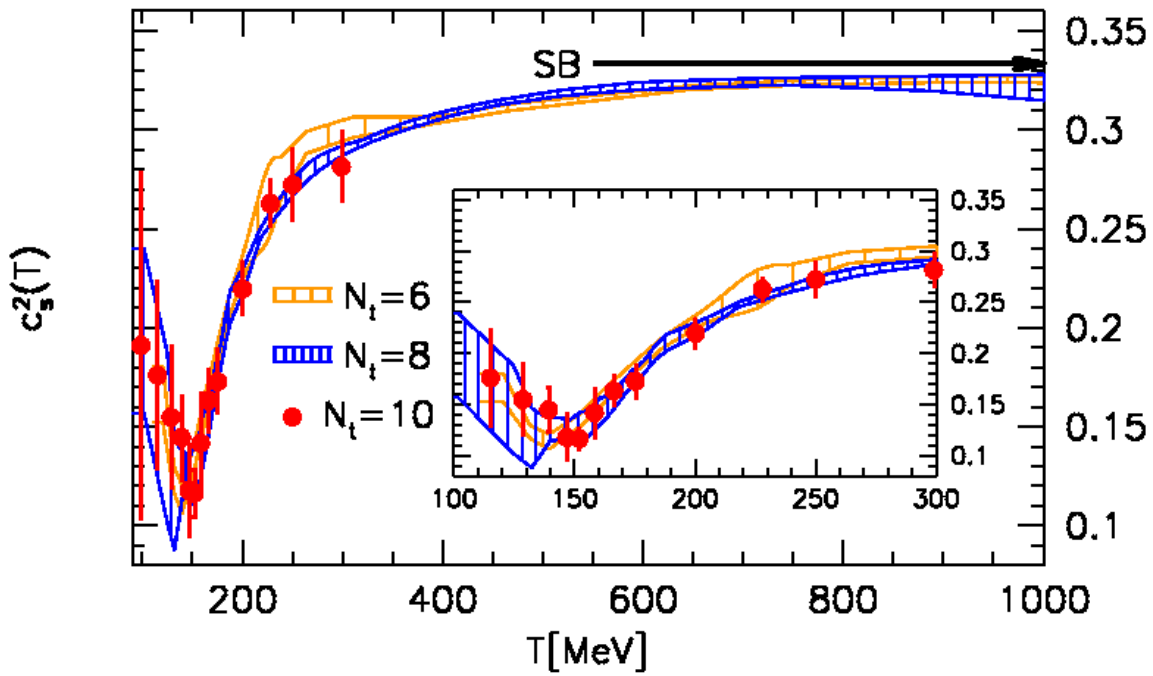
The QCD thermal cross-over

There is no phase transition in QCD at $\mu = 0$: gradual change from hadrons to quarks. Physically important: how fast does the fireball cool?



Endrodi et al, arxiv:1007.2580

Crucial question: what are the dof from 130 MeV$\leq T \leq$ 200 MeV?

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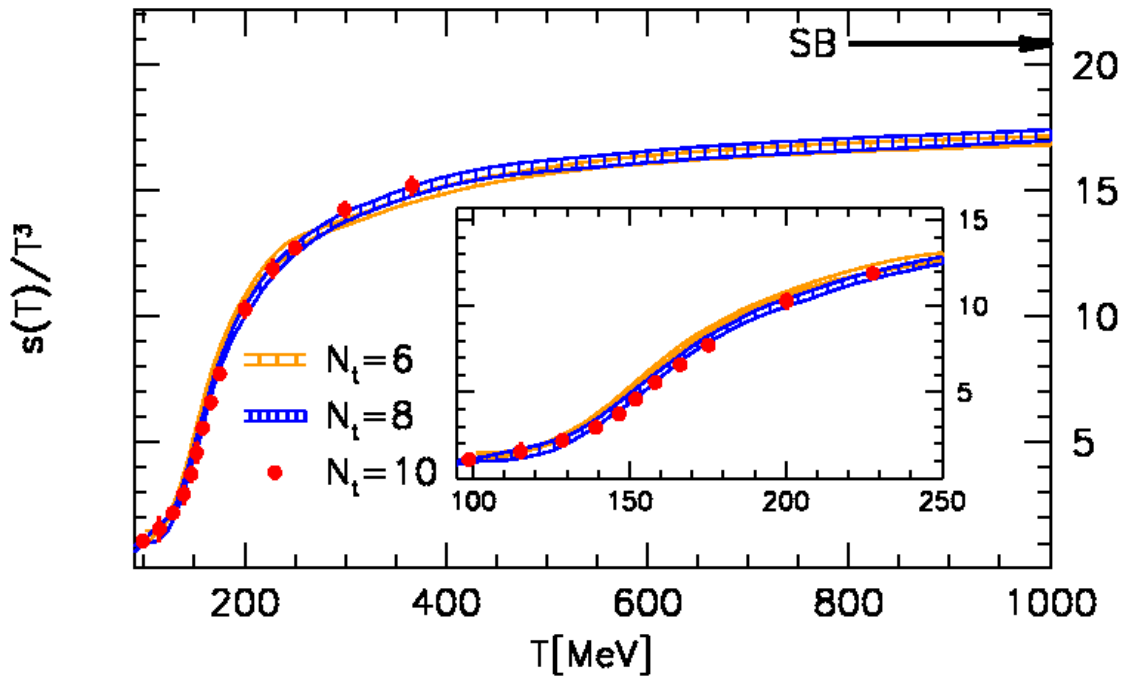

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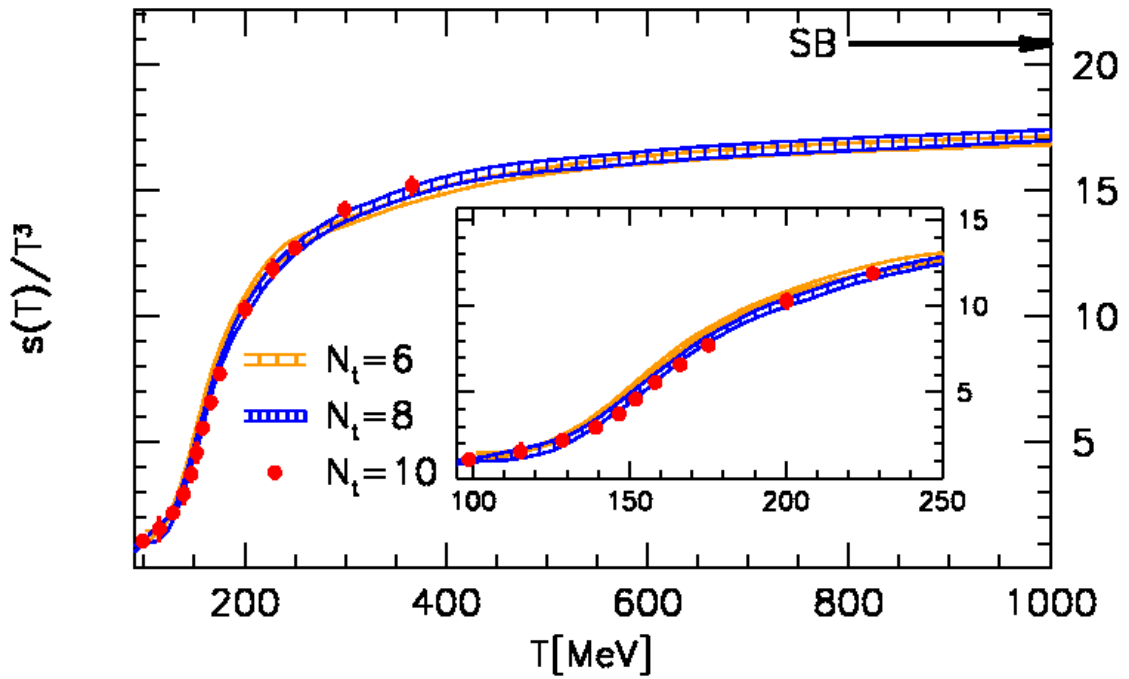

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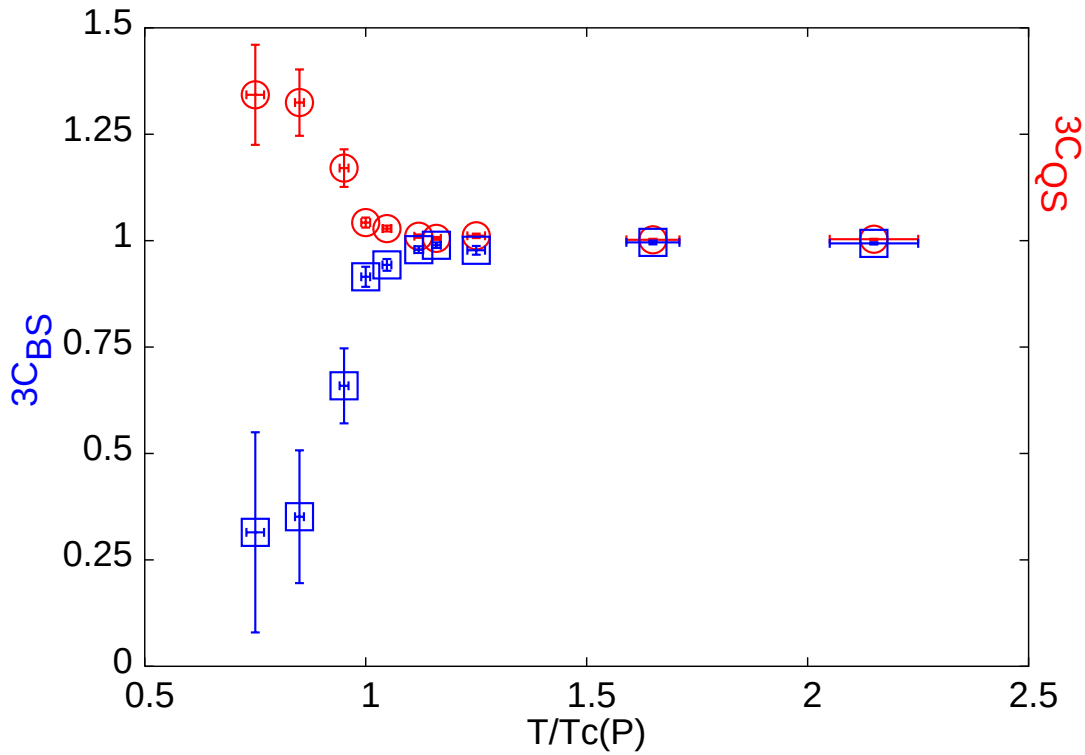
Quarks at high temperature: deconfinement



No linkage between S and B at $T = 0$; but perfect linkage for $T > T_c(P)$. Linkage between S and Q due to kaon at $T = 0$ but quarks at high T. **Koch, Majumder, Randrup, 10.1103/PhysRevLett.95.182301; Gavai, SG, 10.1103/PhysRevD.73.014004**

What about chiral symmetry?

Chiral symmetric critical line near $\mu = 0$ gives universal "magnetic equation of state". Free parameter is $T_c(\chi)$. Lattice predicts $T_c(\chi) \simeq 155$ MeV. Then chiral symmetry predicts negative $[B^6]/[B^2]$ at $\mu = 0$.

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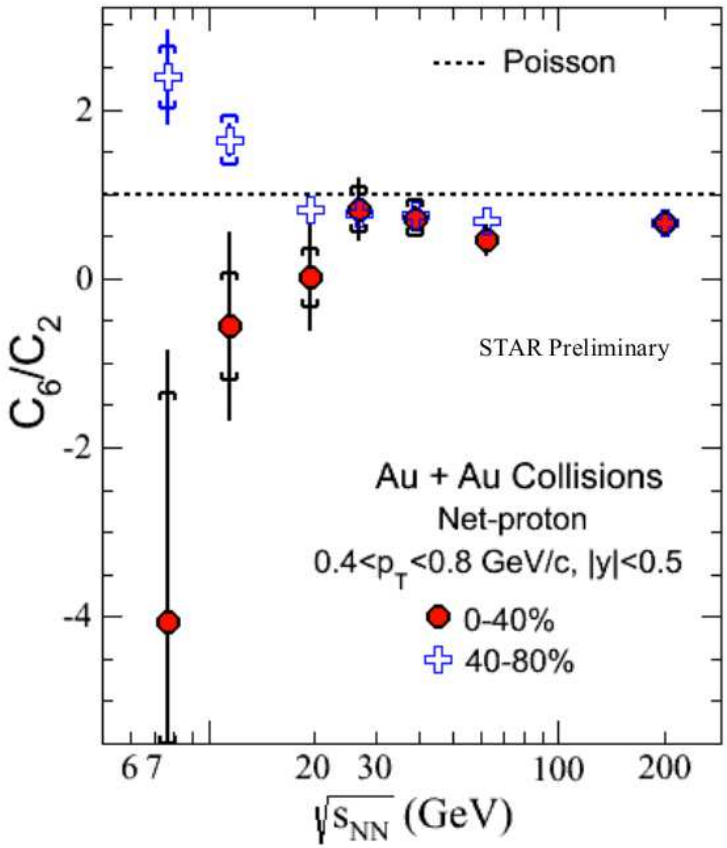

Lizhu Chen for STAR Collaboration, QM 2012

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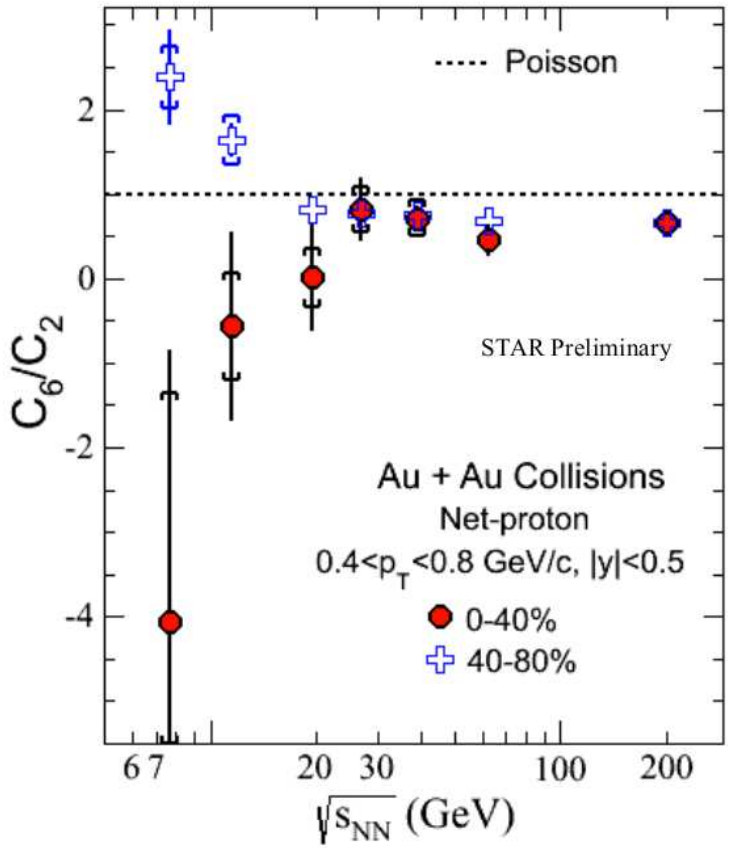
Opposite limit is HRG, where all hadrons important. In HRG $[B^6]/[B^2]$ is the positive Poisson value $+1$. Why does the observation lie between these two limits?



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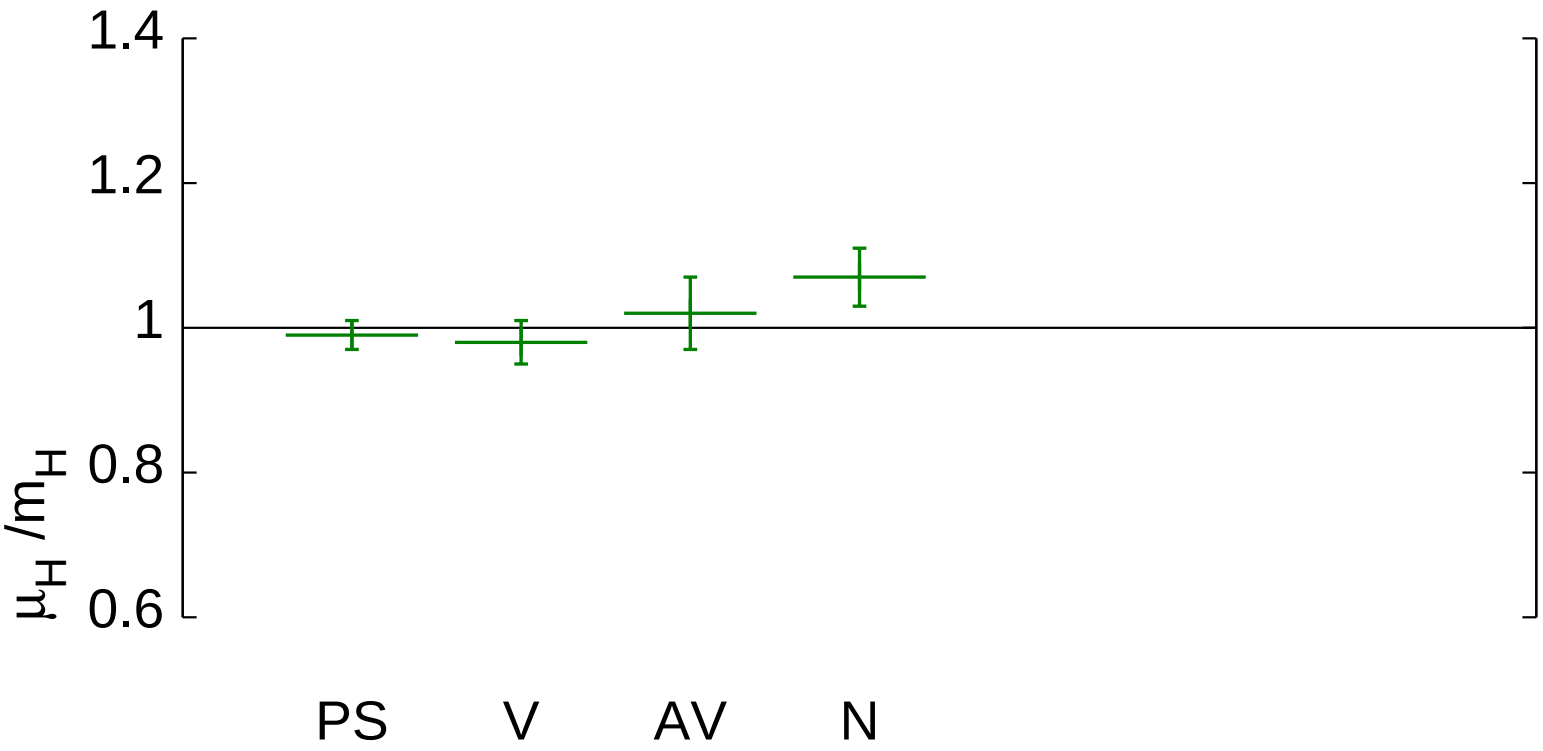
Unsuspected expression of chiral symmetry: CBM physics?



Padmanath, Datta, SG, Mathur, 2012: quenched QCD

Improved Wilson quarks with heavy pion ($m_\pi \simeq 2T_c$).

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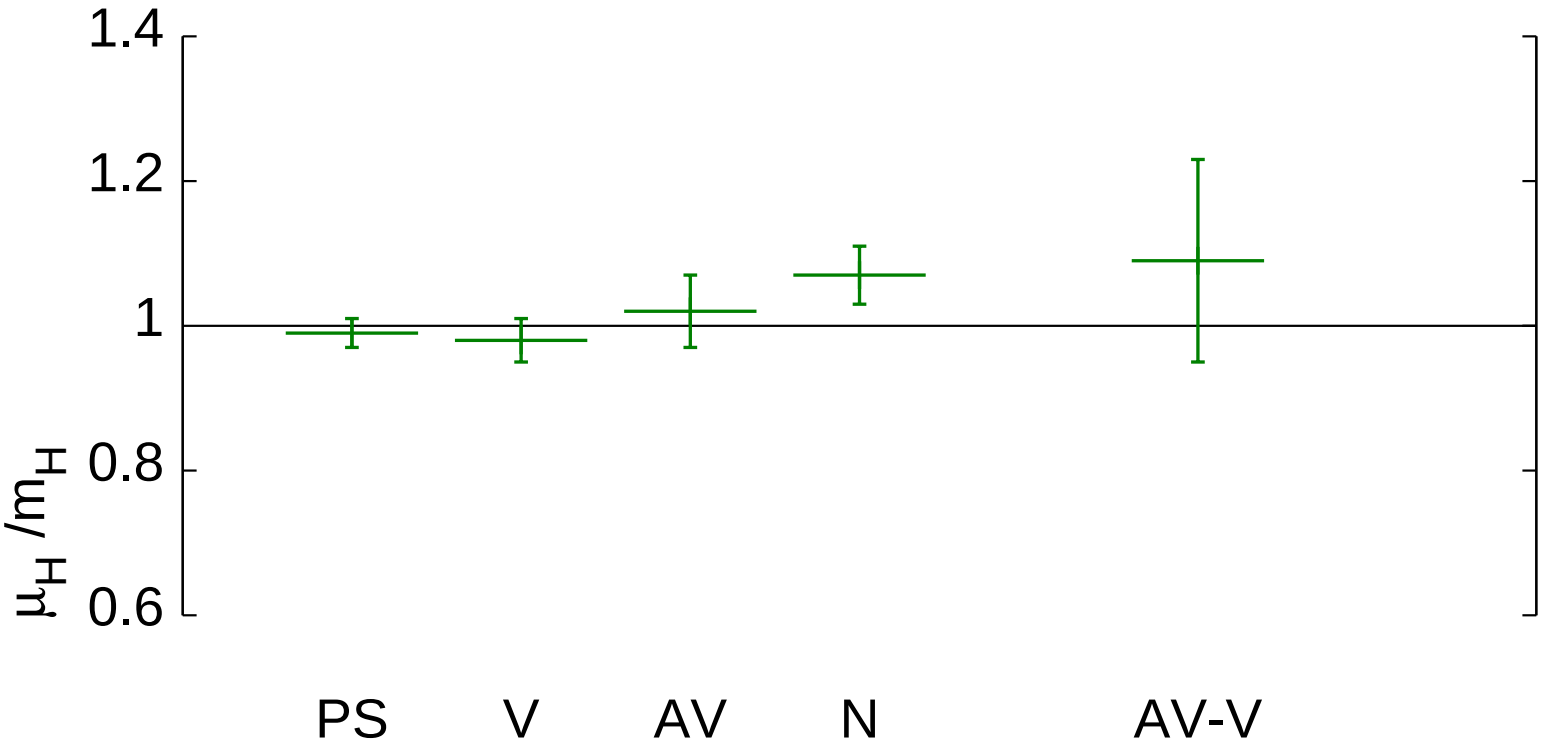

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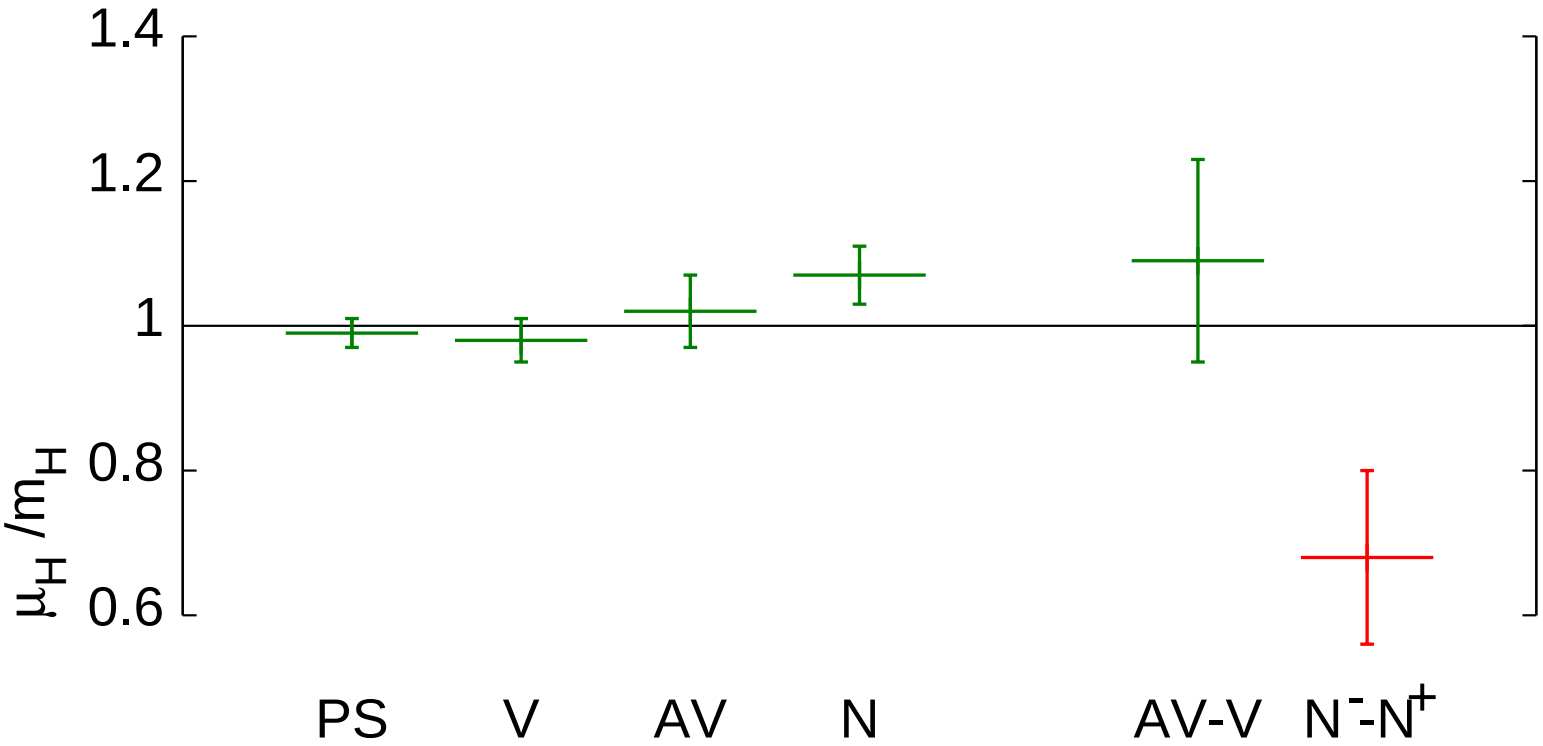

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Improved Wilson quarks with heavy pion ($m_\pi \simeq 2T_c$). Shift in nucleon sector mass splitting persists when pion mass is changed

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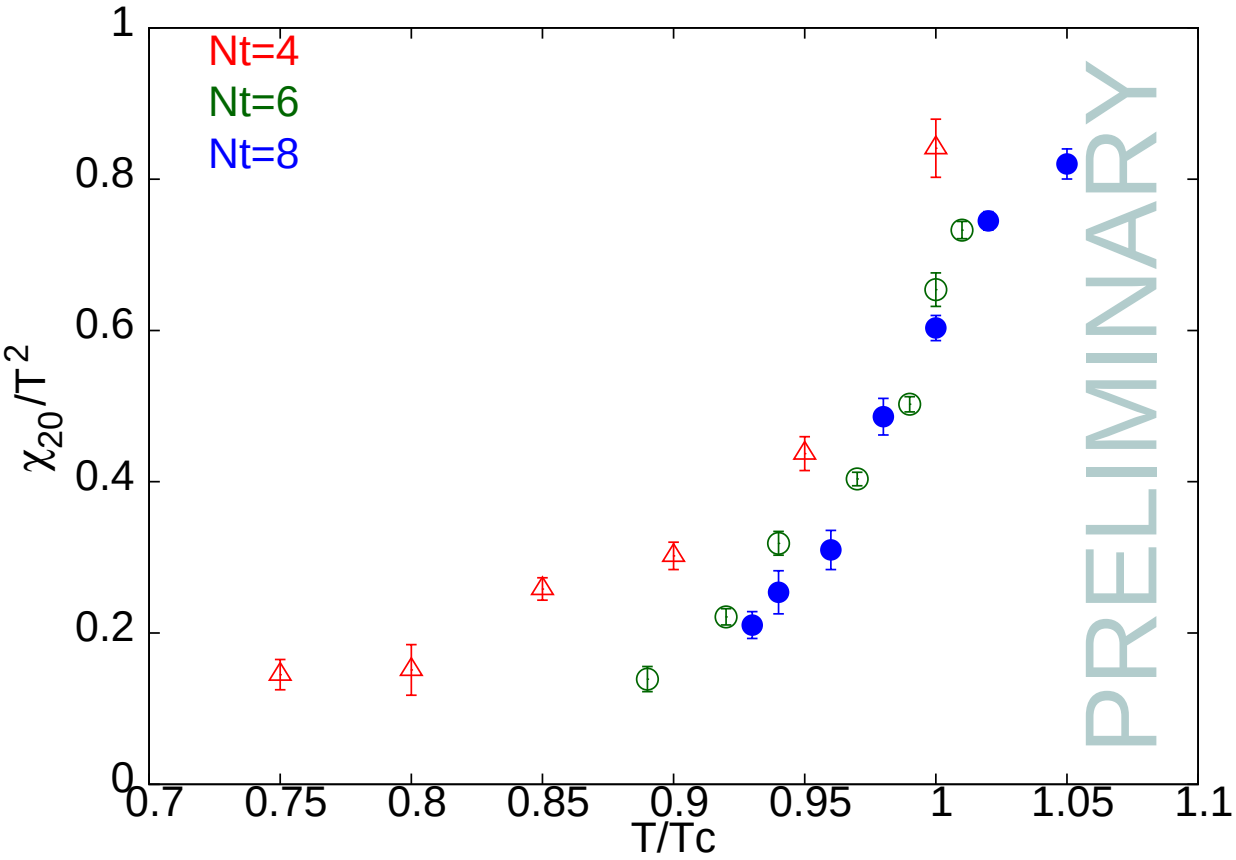
New lattice results



Lattice cutoff has now gone from 700 MeV ($Nt = 4$) to 990 MeV ($Nt = 6$) to 1300 MeV ($Nt = 8$).

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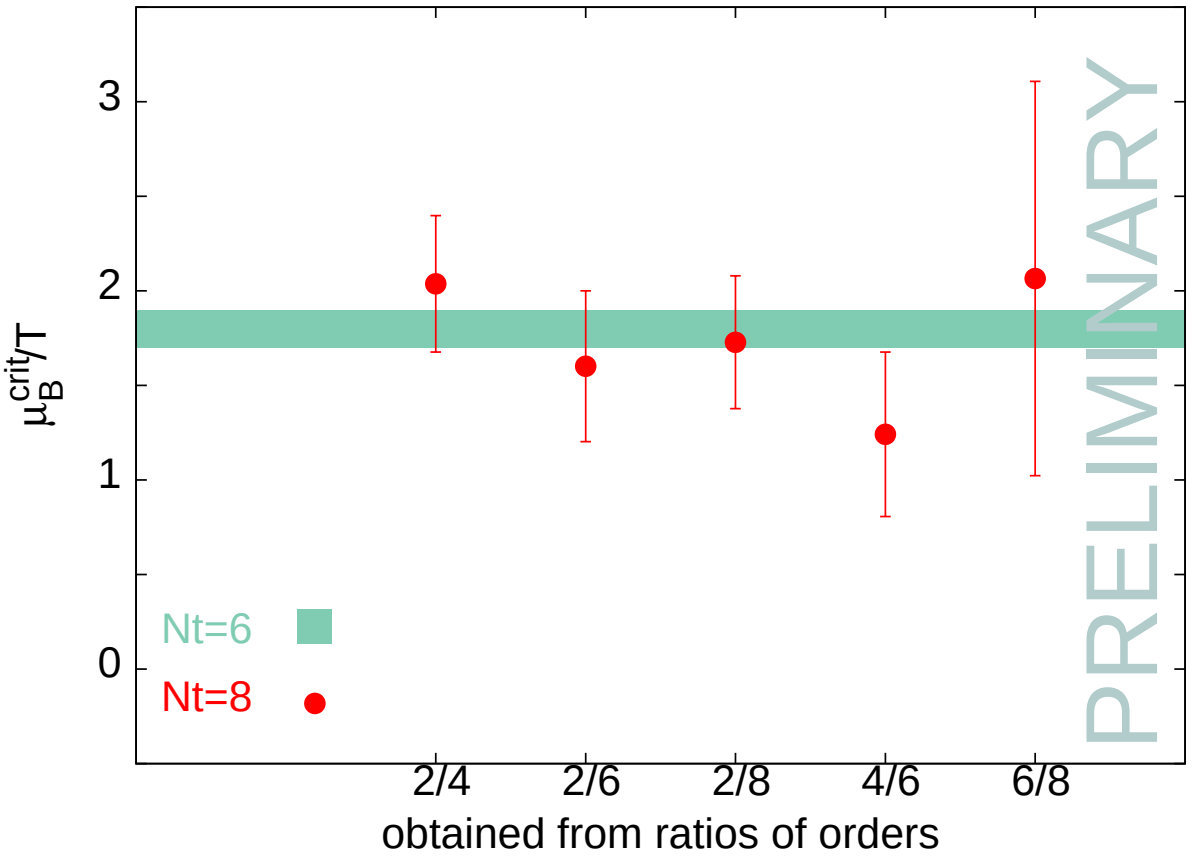

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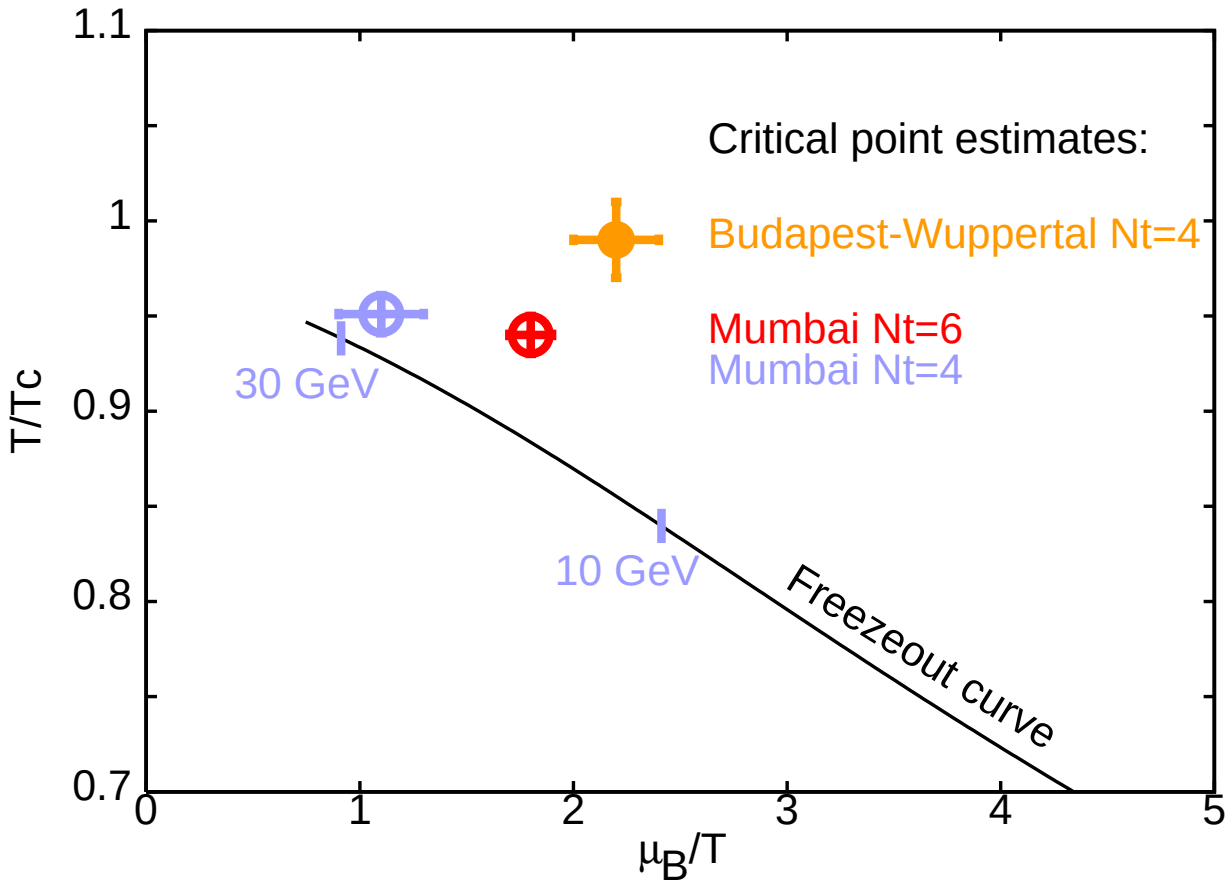
Summary of all lattice predictions



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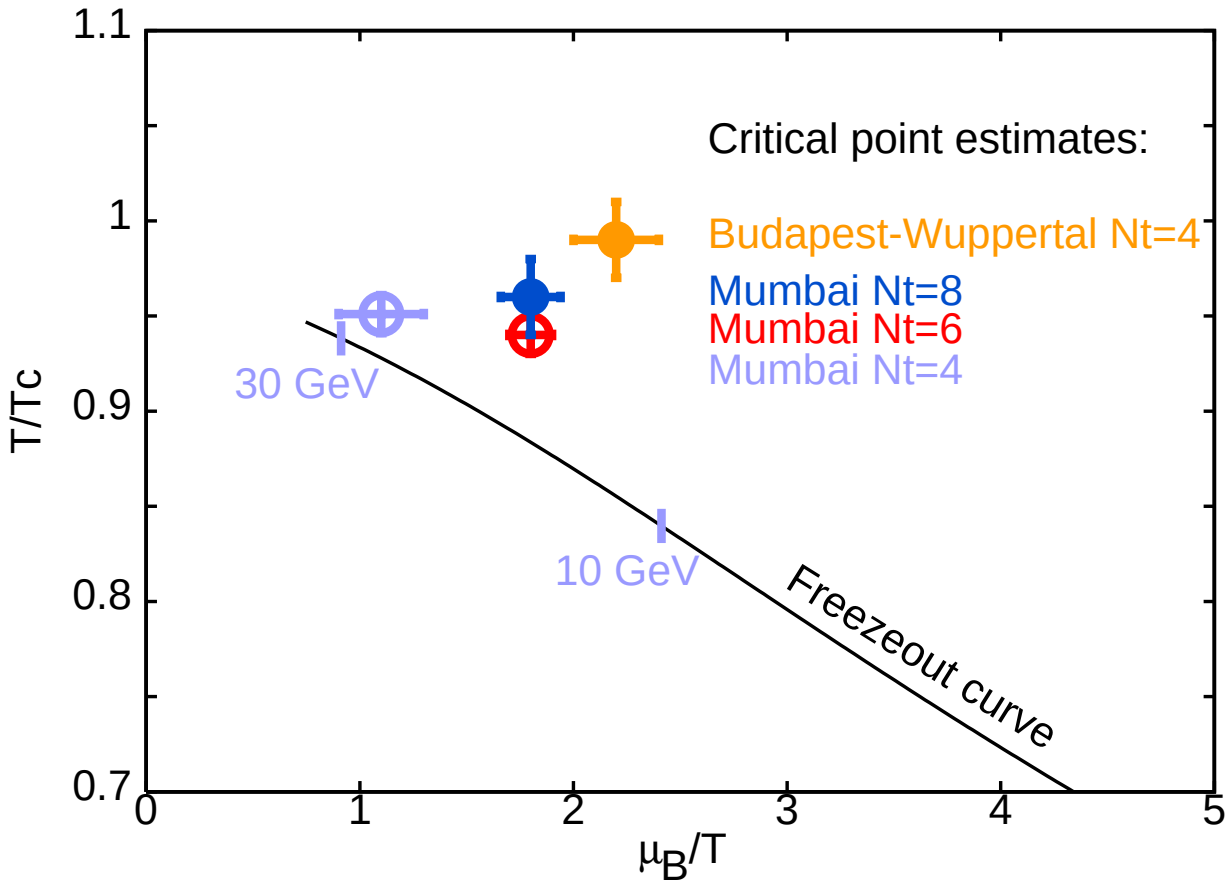

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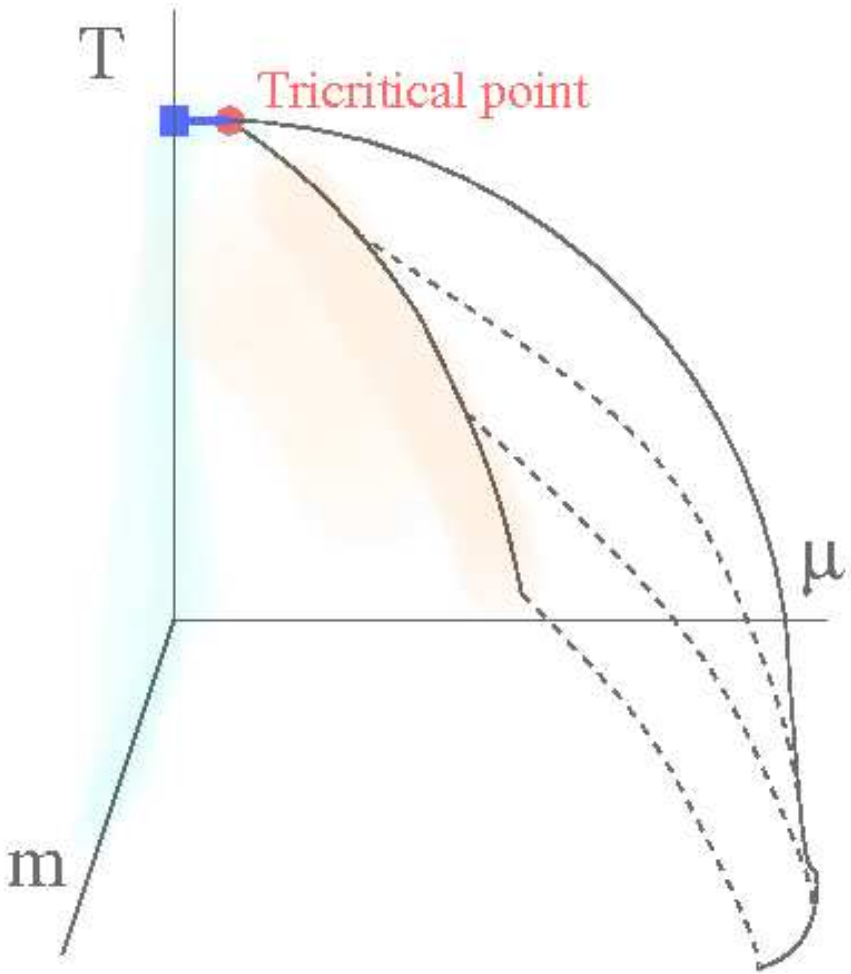

Using STAR Collaboration, 2012

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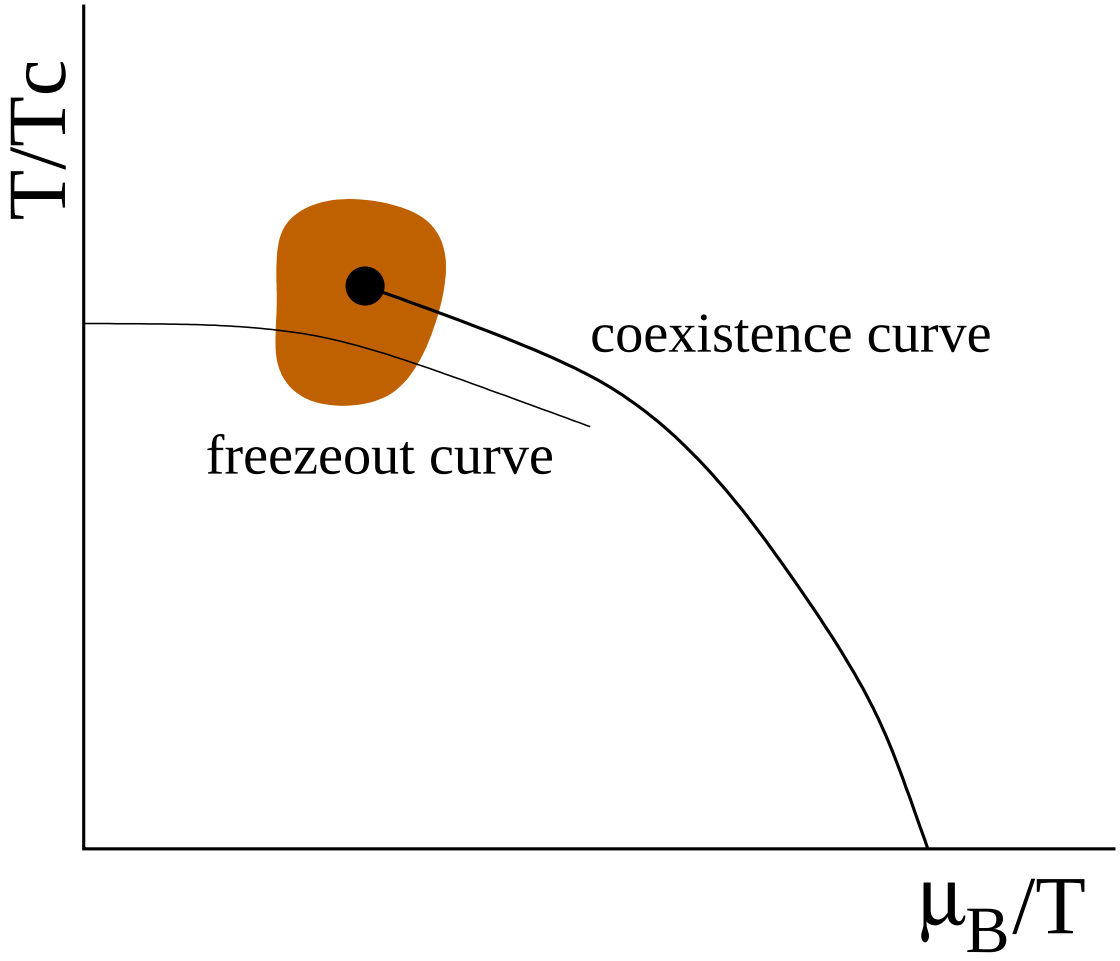

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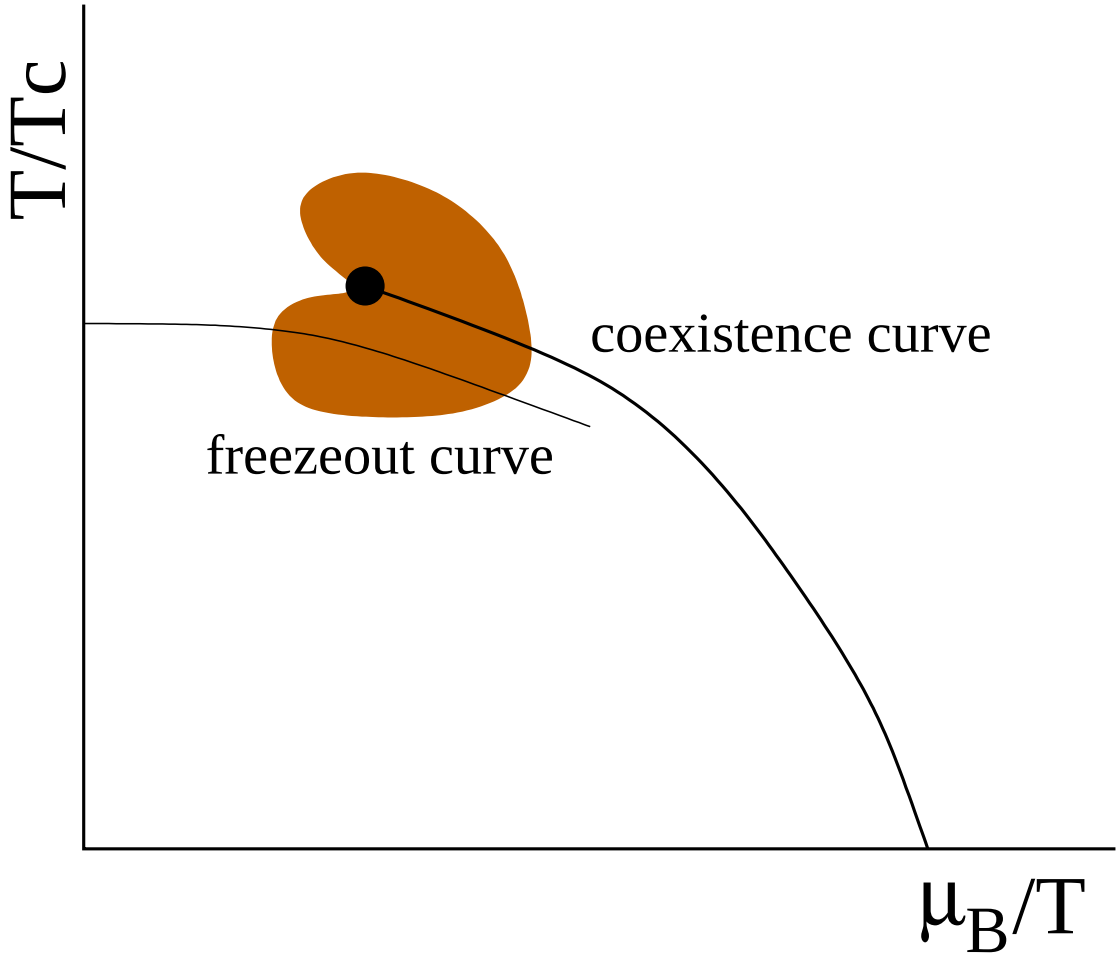

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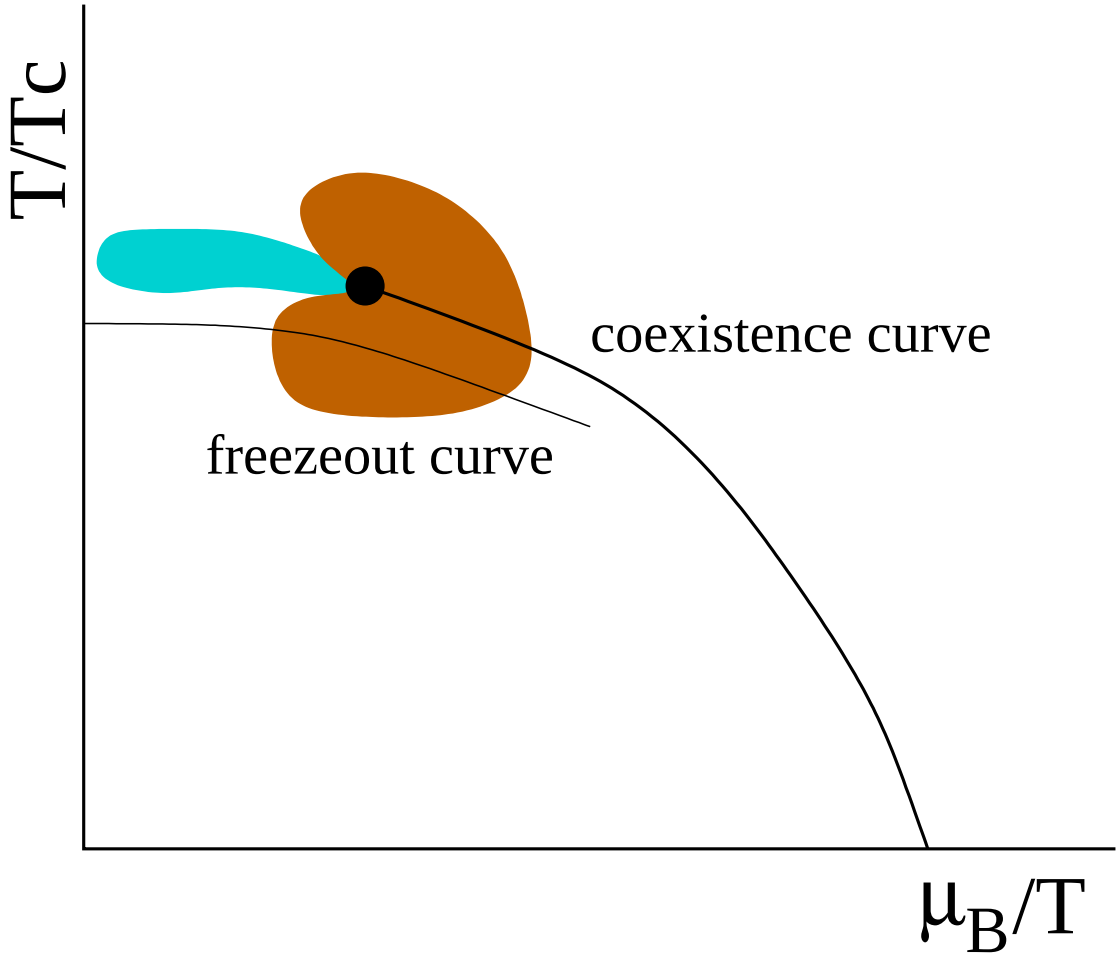
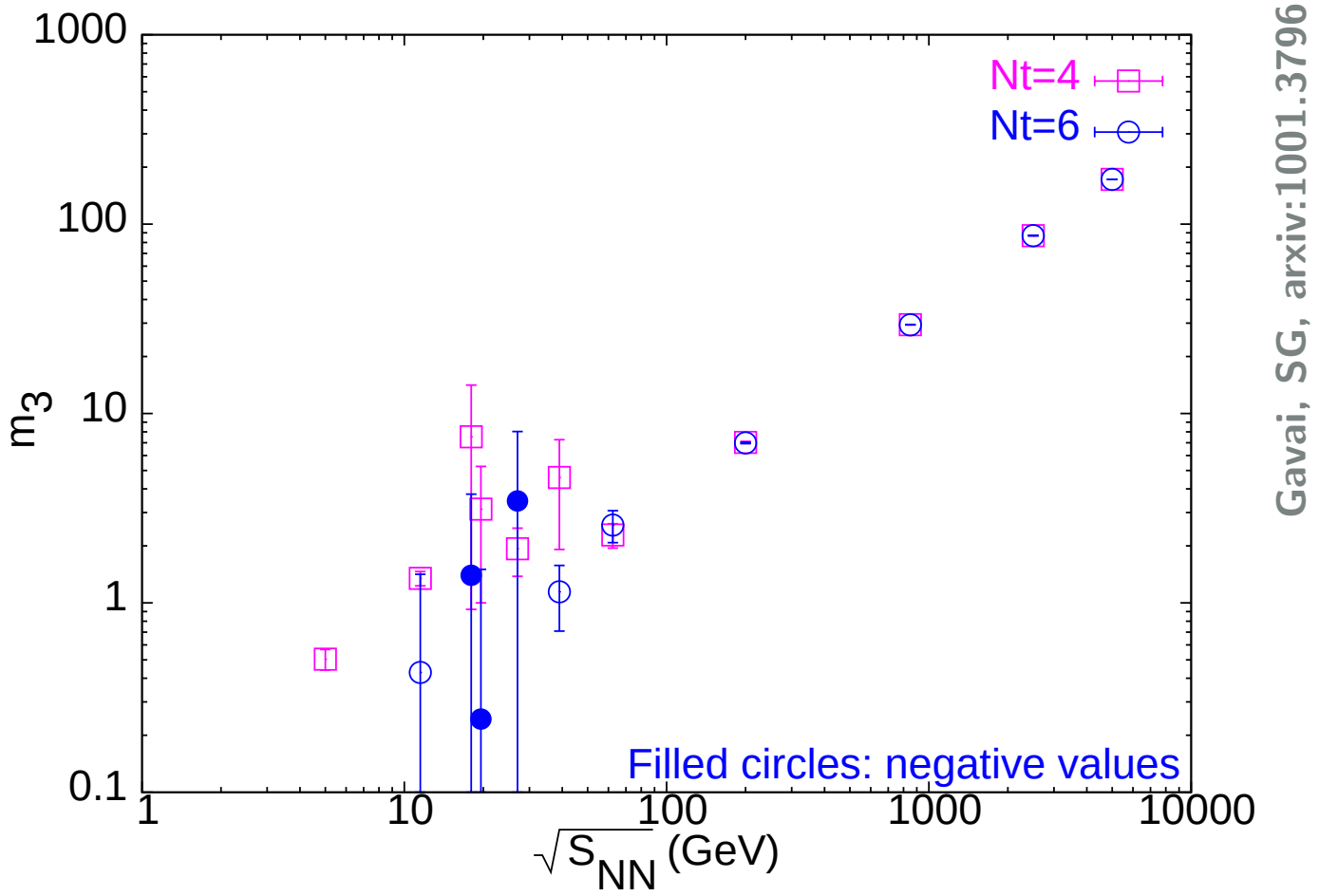


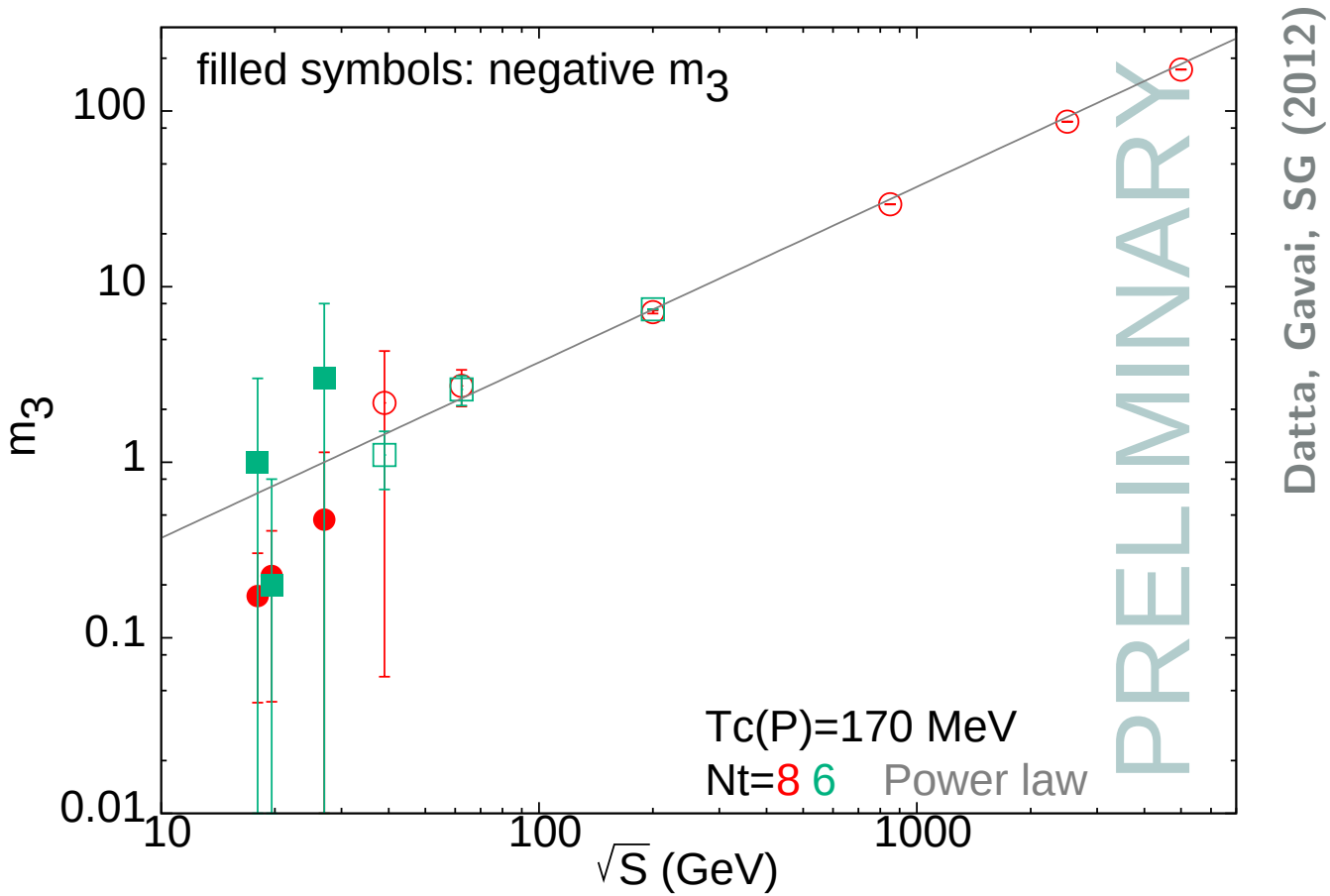
Not using STAR Collaboration, 2012

Fluctuations along the freezeout curve



Lattice predictions along the freezeout curve of HRG models using $T_c = 170$ MeV.

Smaller lattice spacing



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A short summary

1. The definition of a cross over temperature is a matter of convention. Choose one and stick to it. For deconfinement properties $T_c \simeq 175$ MeV, for chiral properties $T_c \simeq 155$ MeV.
2. Interesting demonstration from STAR that the "magnetic equation of state" based on chiral symmetry does not describe the fluctuation data. Await confirmation from the LHC.
3. Lattice results beginning to stabilize to the continuum: preliminary results from Mumbai.
4. Beam energy scan on track for QCD critical point search. Await first results. Look forward to CBM study of hadron states in dense and warm matter, and possible new physics.