SPC perspective on USQCD thermodynamics

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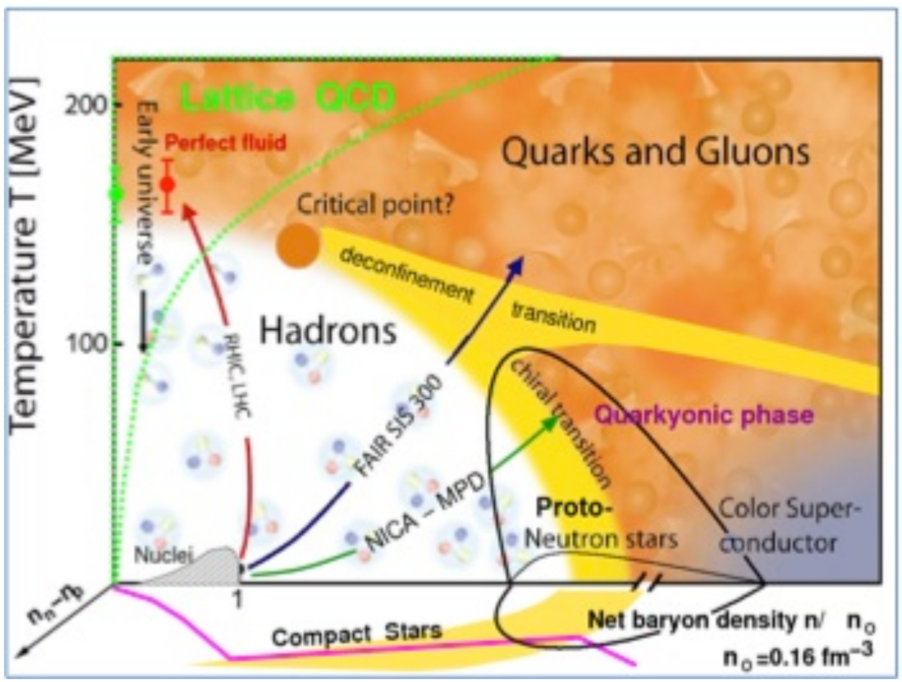
Tools : LQCD, Heavy ion experiments and phenomenology

LQCD results → models of dynamical evolution → RHIC experiments



Strategic goals outlined in 2013 White paper, "Computational Challenges in QCD Thermodynamics":

1) EoS at zero chemical potentials in the continuum limit
⇒ Hydro models in HIC at top energies

2) Thermodynamics at non-zero chemical potentials, fluctuations of conserved charges
⇒ Freezout condition in HIC, BES@RHIC

3) Universal properties of the chiral transition, $T_c(\mu)$
Freezout condition in HIC, BES@RHIC

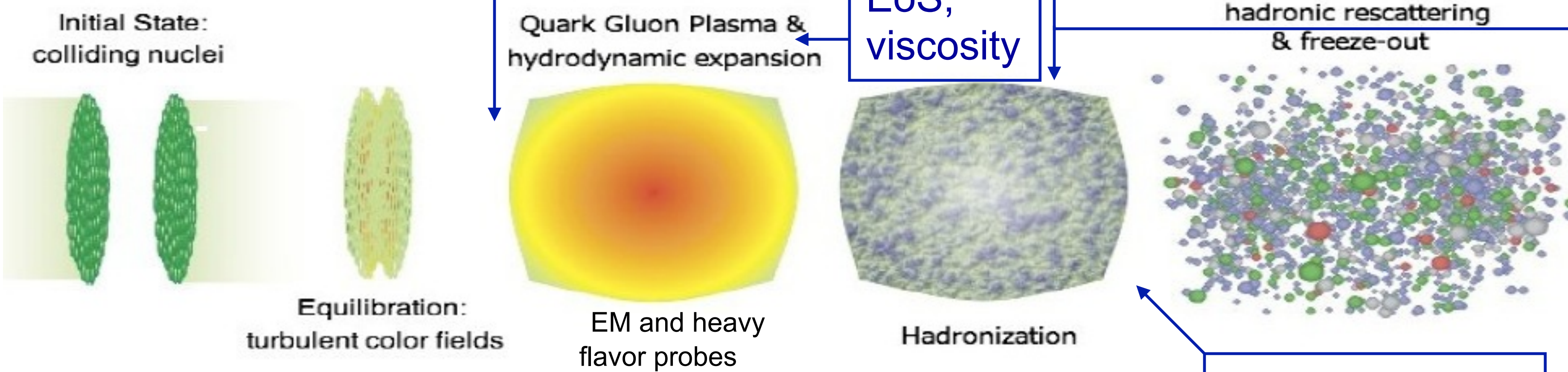
4) In-medium hadron properties
⇒ dileptons/quarkonia

Physics of heavy ion collisions and LQCD

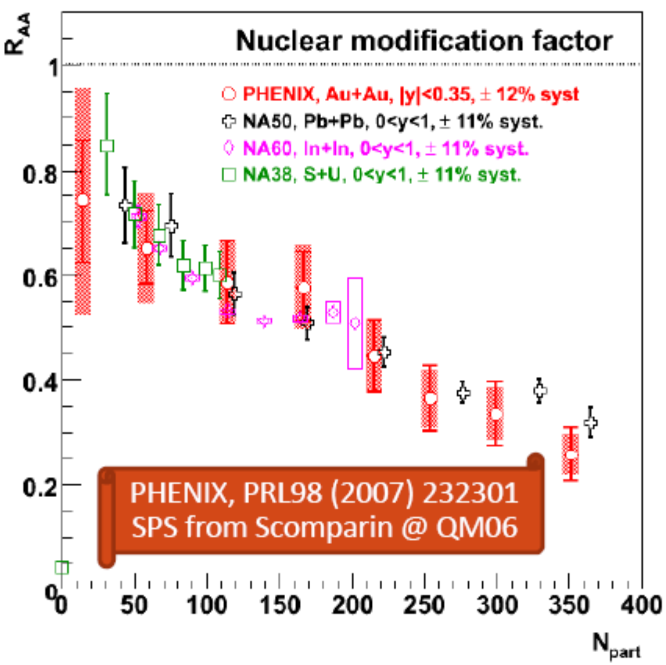
high temperature QCD
weak coupling ?

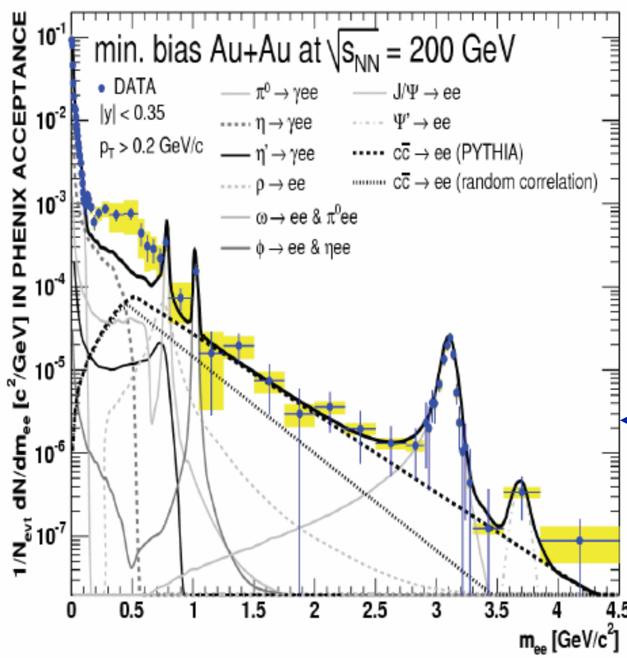
EoS,
viscosity

Chiral transition, T_c fluctu-
ations of conserved charges



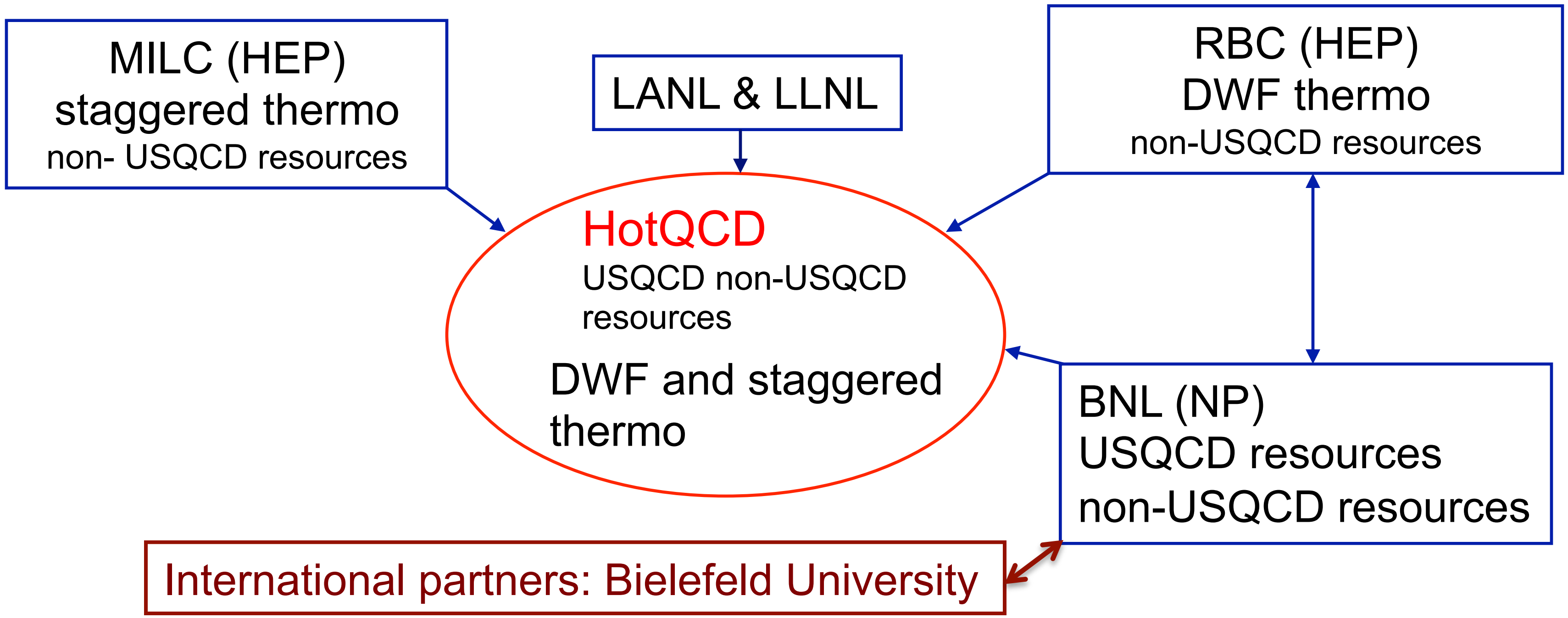
test of Hadron
Resonance Gas
(HRG)
using LQCD





quarkonium spectral
functions,
heavy quark diffusion,
thermal dileptons

Structure of thermo LQCD community and USQCD proposals



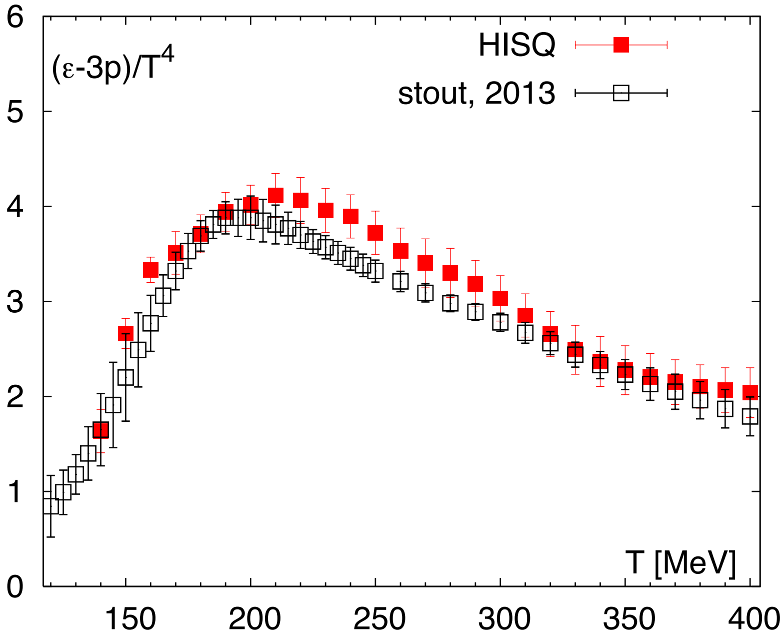
USQCD proposals in 2013 (time requested in M J/psi core h and GPU node h) :

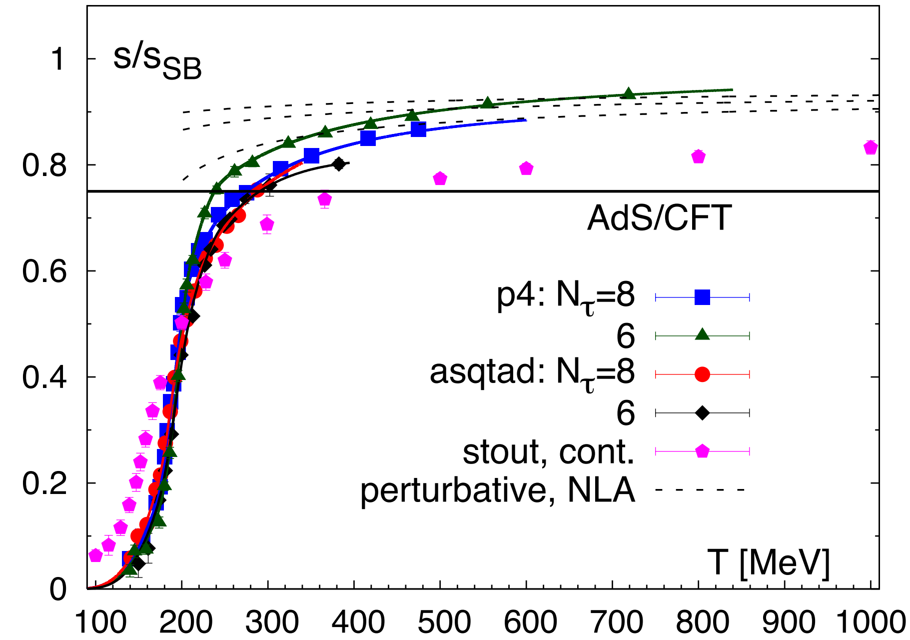
HotQCD (PI Karsch) Charge fluctuations : BG/Q, 25M; Titan, 44.5M (INCITE)

BNL (PI H. Ohno) Universal Behavior of the chiral transition : USQCD clusters, 37.4M

BNL (PI S. Mukherjee) Taylor Expansion : GPUs 2.4M GPU hours

Status of the EoS calculations





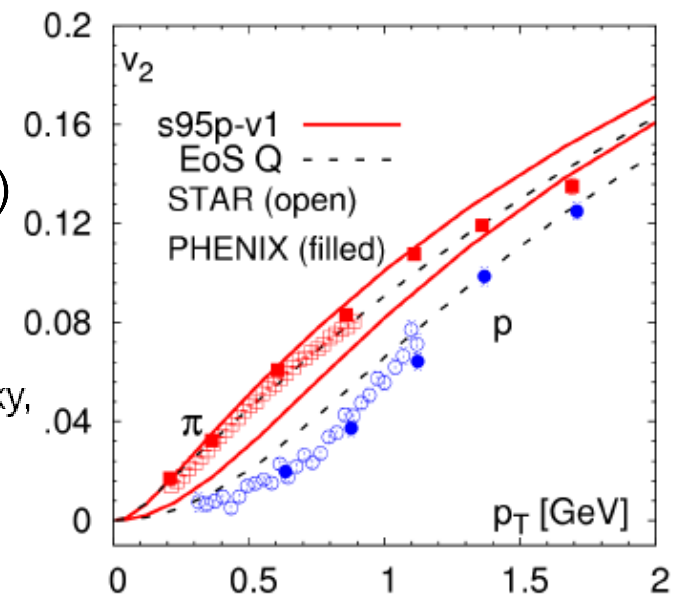
Running is finished analyzing data for the final publication

2013 White paper:

1) What is the nature of the QGP at *T>300* MeV ? (LHC)
2) What is the speed of sound ? (RHIC and LHC)

LQCD based parametrization of the EoS
Used in most of hydro models for HIC

P. Huovinen, P. Petreczky, NP A837, 26 (2010)



Future: include the effect of charm quark
(see 2013 White paper)

QCD thermodynamics at non-zero chemical potential

Taylor expansion :

$$\frac{p(T,\mu_B,\mu_Q,\mu_S)}{T^4} = \sum_{i,j,k} \frac{1}{i!j!k!l!} \chi_{ijk}^{BQS} \cdot \left(\frac{\mu_B}{T}\right)^i \cdot \left(\frac{\mu_Q}{T}\right)^j \cdot \left(\frac{\mu_Q}{T}\right)^k$$

Taylor expansion coefficients give the fluctuations and correlations of conserved charges, e.g.

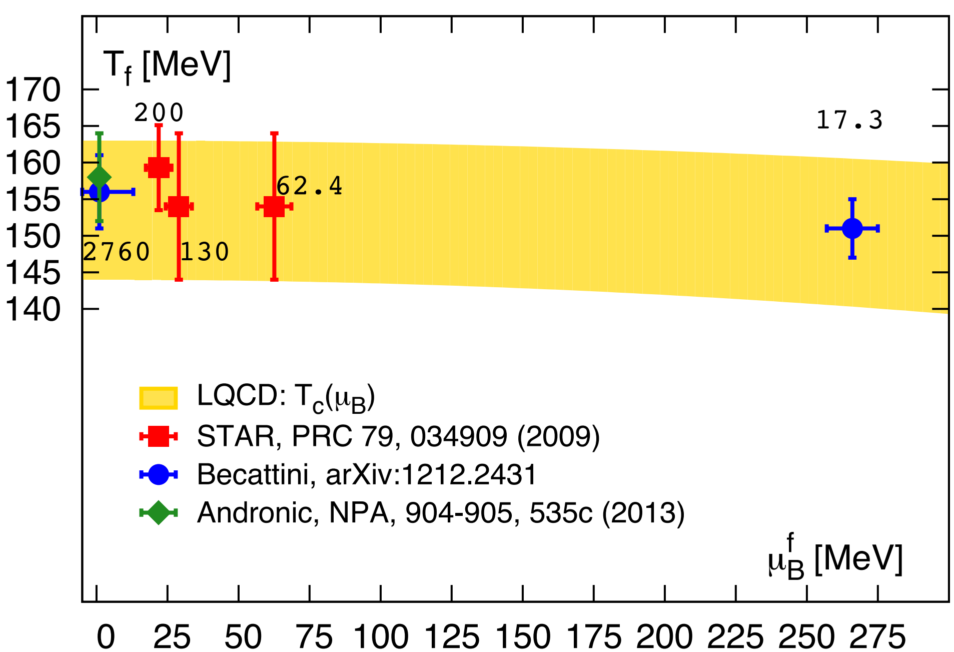
$$R_{nm} = \chi_n^Q / \chi_m^Q$$

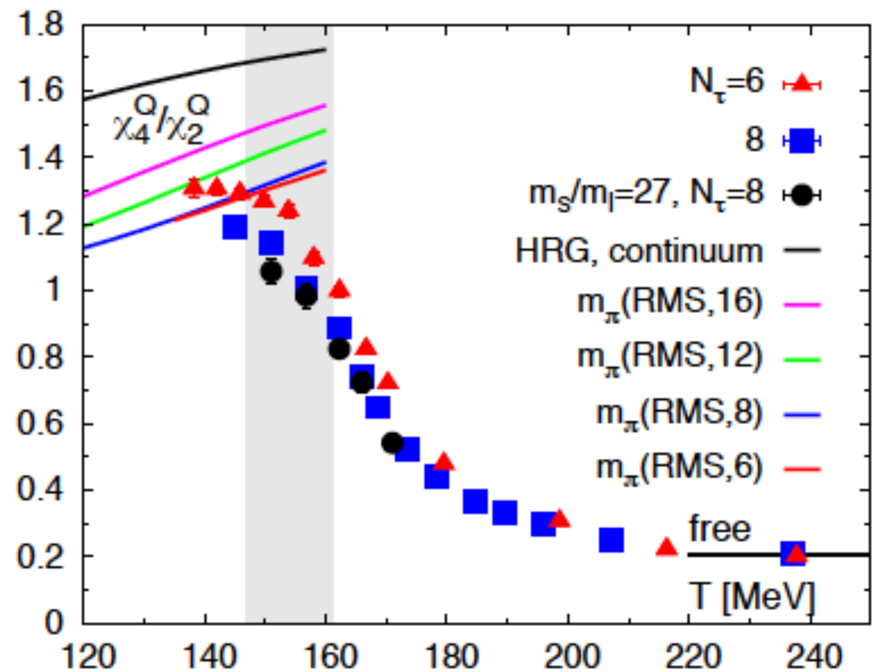
$$\frac{\chi_2^X}{T^2} = \frac{\chi_X}{T^2} = \frac{1}{VT^3}(\langle X^2 \rangle - \langle X \rangle^2) \qquad \frac{\chi_{11}^{XY}}{T^2} = \frac{1}{VT^3}(\langle XY \rangle - \langle X \rangle \langle Y \rangle)$$

→ BES @ RHIC and freezout conditions

can be done very efficiently on GPUs

HotQCD proposal (PI: Karsch)

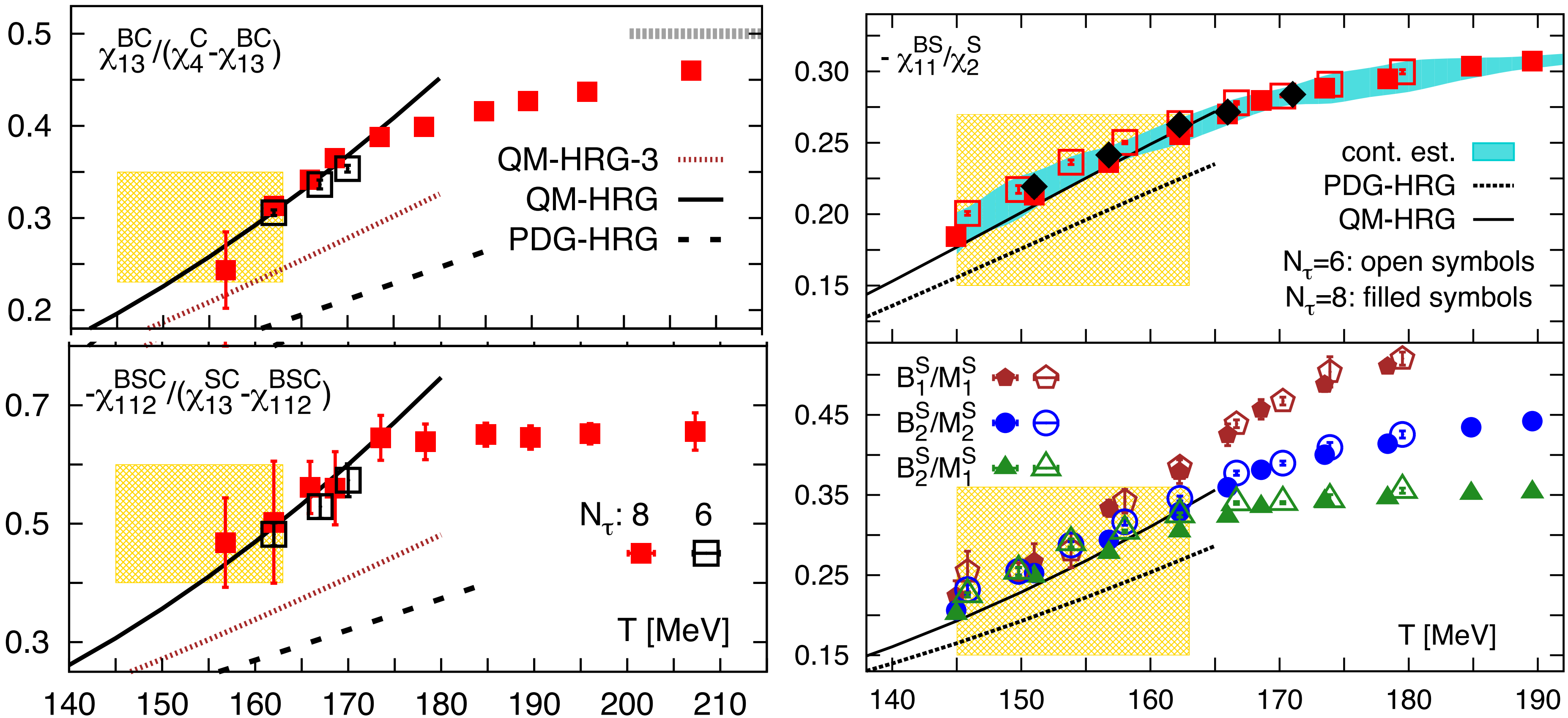




Charge and strangeness fluctuations and missing hadrons

Bazavov et al, arXiv:1404.4043v1

N_τ=6,8, m_π = 160 MeV



Experimental knowledge of strange and charm hadron spectrum is rathe incomplete !

HRG that includes hadron states predicted by by quark model (also LQCD) agrees better with lattice results that HRG with PDG states only !

⇒ Extend the calculations to physical pion mass and close to the continuum limit

proposal by Mukherjee

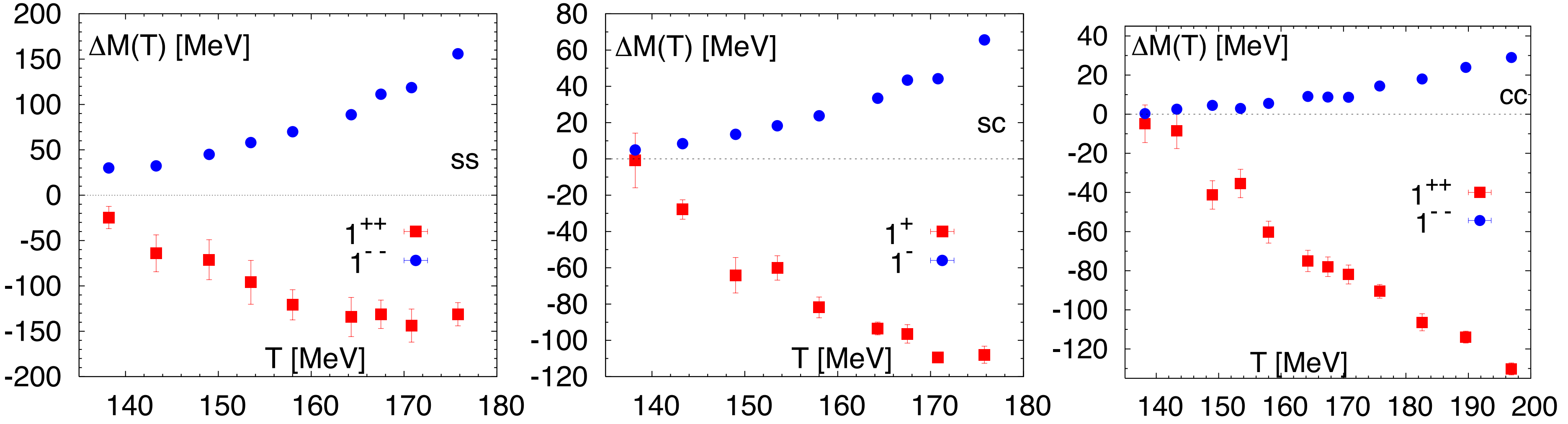
Meson correlators and spectral functions

No new proposals have been submitted, last year B-type proposal by Maezawa: calculations of spatial meson correlators which are related to the spectral functions

$$G(z,T) = \int_{-\infty}^{\infty} e^{ipz} \int_0^{\infty} d\omega \frac{\sigma(\omega,p,T)}{\omega}$$

$G(z,T) \sim exp(-M_{scr}\, z)$

Significant change in the meson screening masses $\Delta M = M_{scr}(T) - M_{T=0}$ close to T_c except for J/Ψ



However, T>0 HISQ configuration are being used for related analysis:
1) Calculations of the static potential at T>0. arXiv:1303.5500, arXiv:1404.4267
2) Calculation of bottomonium correlators using NRQCD at T>0, arXiv:1310.6461

What is the transition temperature ?

T_c determination requires the study of the chiral transition as function of the quark mass (now HISQ, later DWF):

$$M_b = \frac{m_s \langle \bar{\psi}\psi \rangle_l}{T^4} = h^{1/\delta} f_G(t/h^{1/\beta\delta}) + f_{M,reg}(T,H)$$

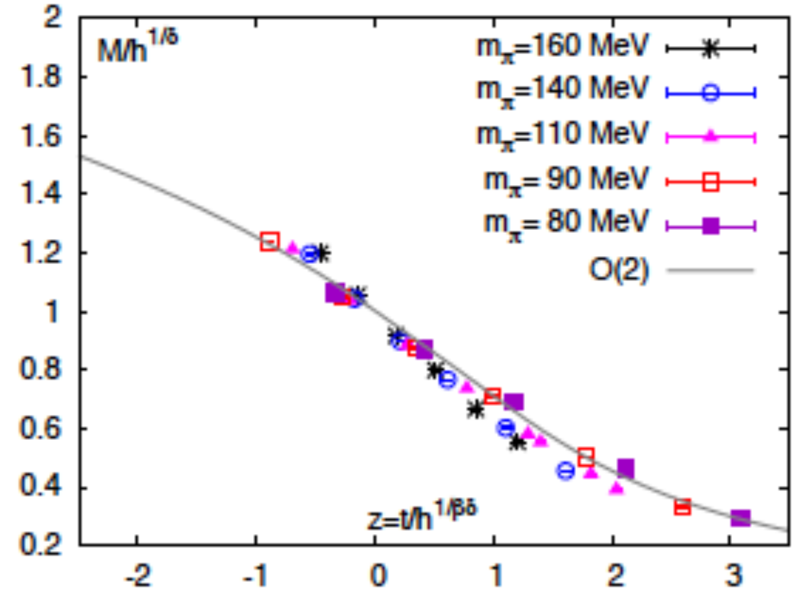
$$H = m_l/m_s, \quad h = H/h_0, t = (T - T_c^0)/(T_c^0 t_0)$$

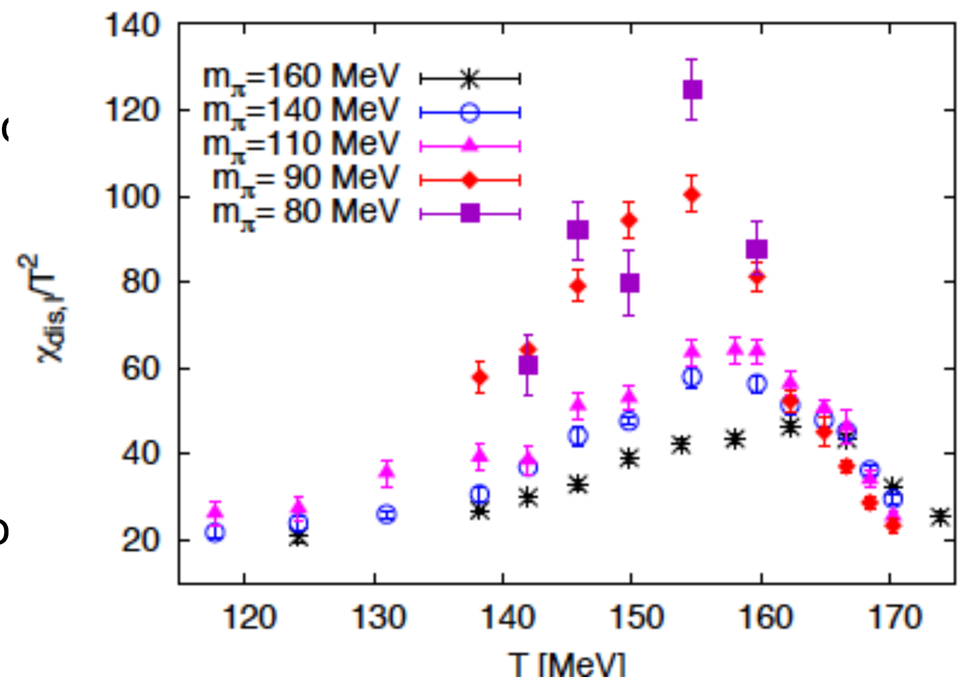
Zero net baryon density, HotQCD:
Bazavov et al, Phys. Rev. D85 (2012) 054503

$$T_c = (154 \pm 8 \pm 1(scale))\text{MeV}$$

How well is the regular part under control, what is the nature of the transiti
In the chiral limit, what is the role of the axial anomaly ?

Need more smallest m_l :
USQCD Proposal by H. Ohno:
down to $m_l=m_s/100$ ($m_\pi=80$ MeV)
⇒ crucial for understanding the transitio at non-vanishing baryon density, $T_c(\mu)$





Conclusions

Lattice QCD starts to provide quantitative results that provide important input for interpreting the experimental results from HIC

T_c, EoS, fluctuation of conserved charges, spectral functions

How sensitive is the QCD transition at physical quark masses to the universal properties in the chiral limit ?

How the transition is modified by baryon chemical potential ?

How the hadronic spectral functions are modified when T is increased ?

Use improved staggered fermions to achieve sufficiently small lattice spacing and large N_T *(now)*

Use chiral fermions to control the symmetries of QCD *(future)*