USQCD's Hot-Dense Lattice QCD Programs

a brief overview

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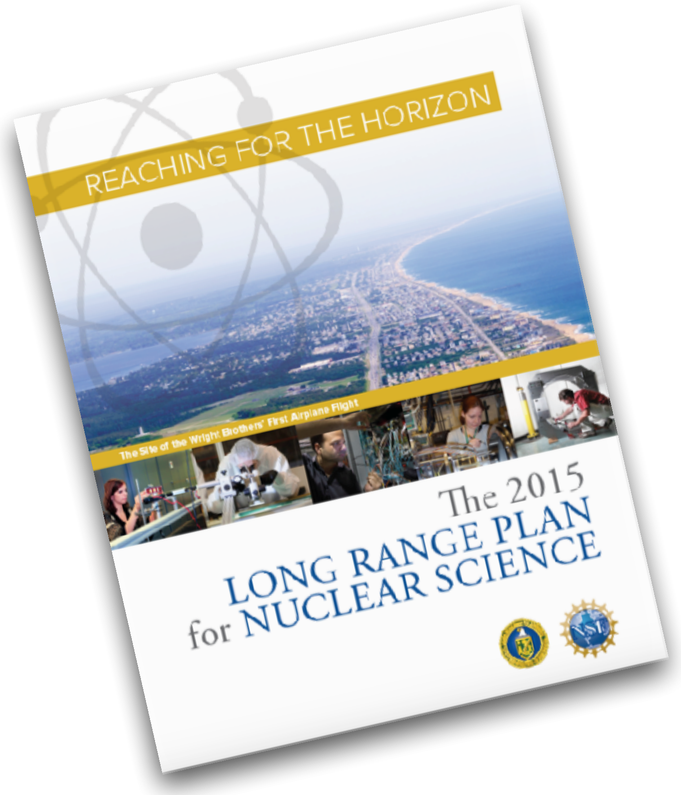
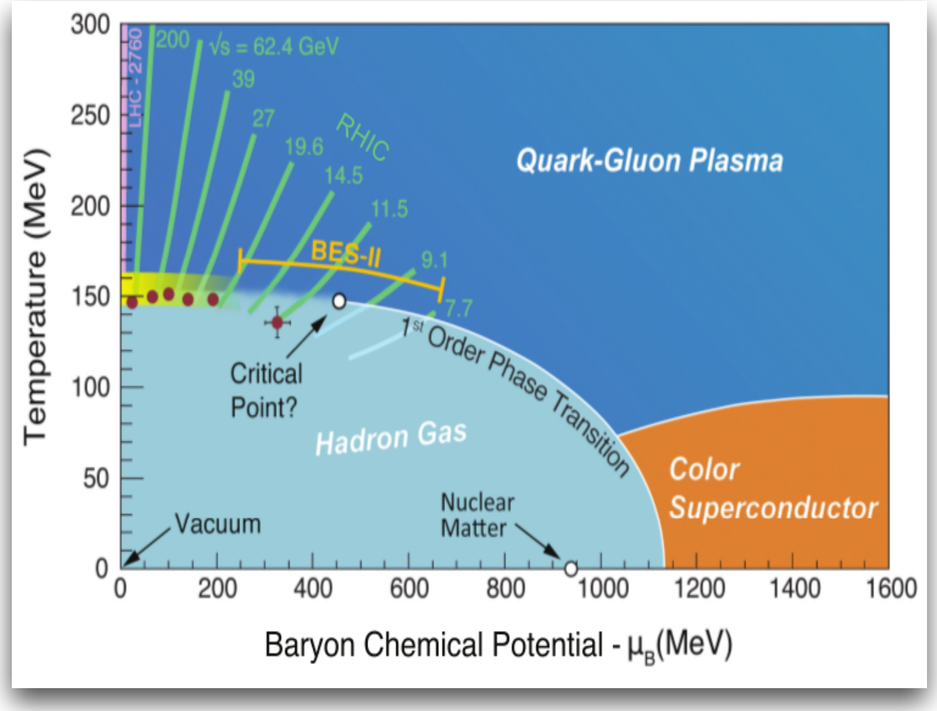
the big questions …



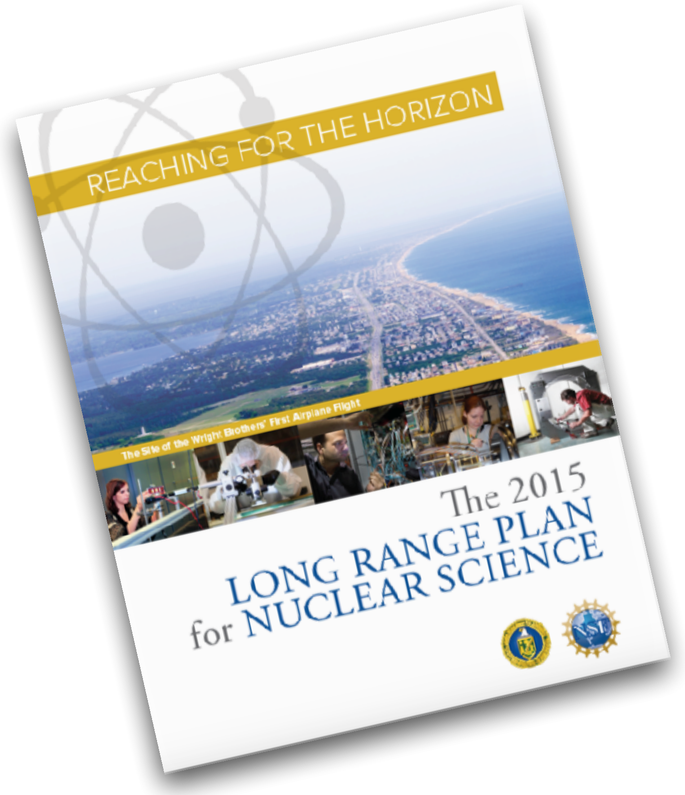
phases of strongly interacting matter

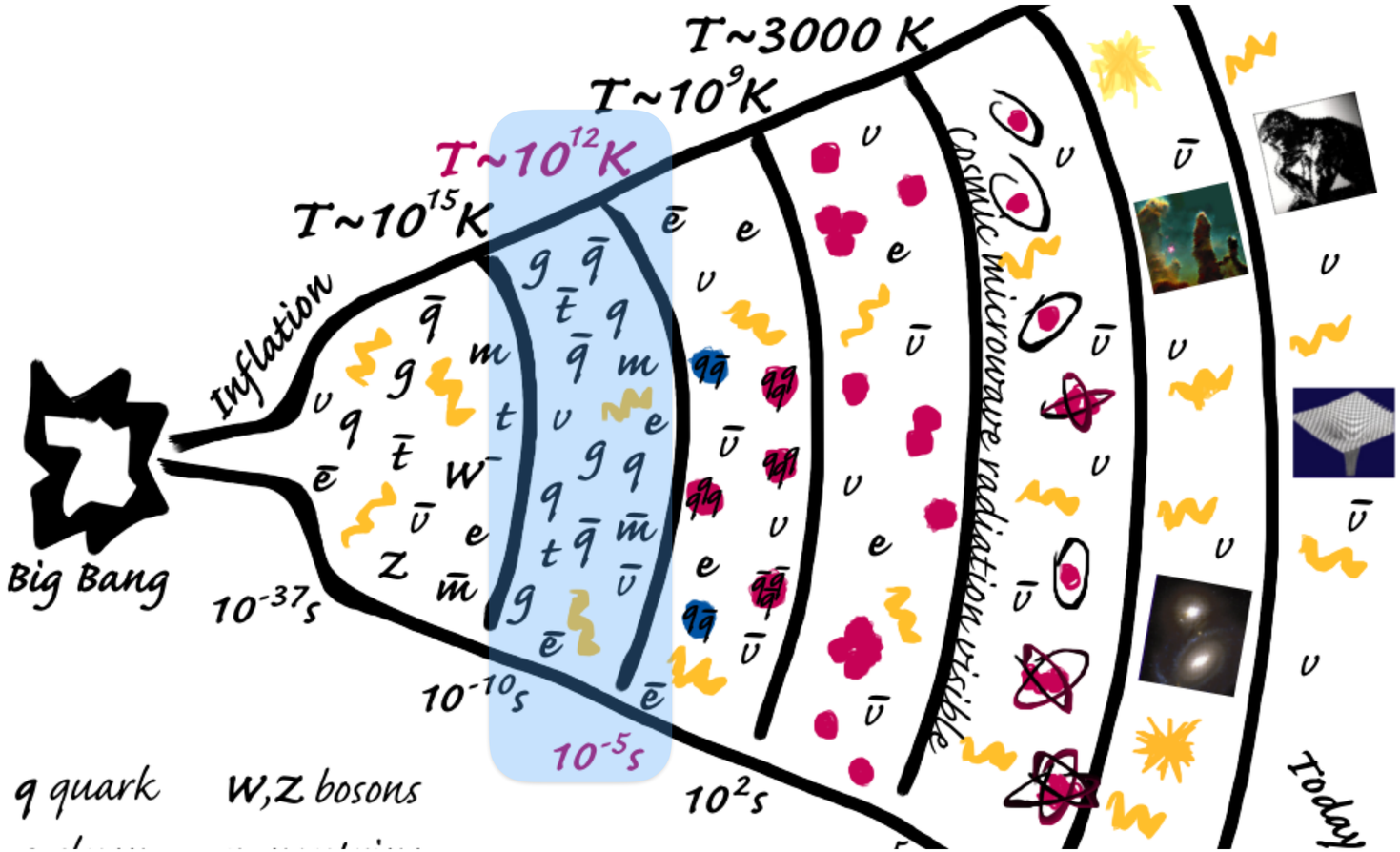


- high temperature
- non-zero baryon densities
- varying quark masses
- high magnetic field
- chiral-imbalanced matter …

properties of quark gluon plasma (QGP)

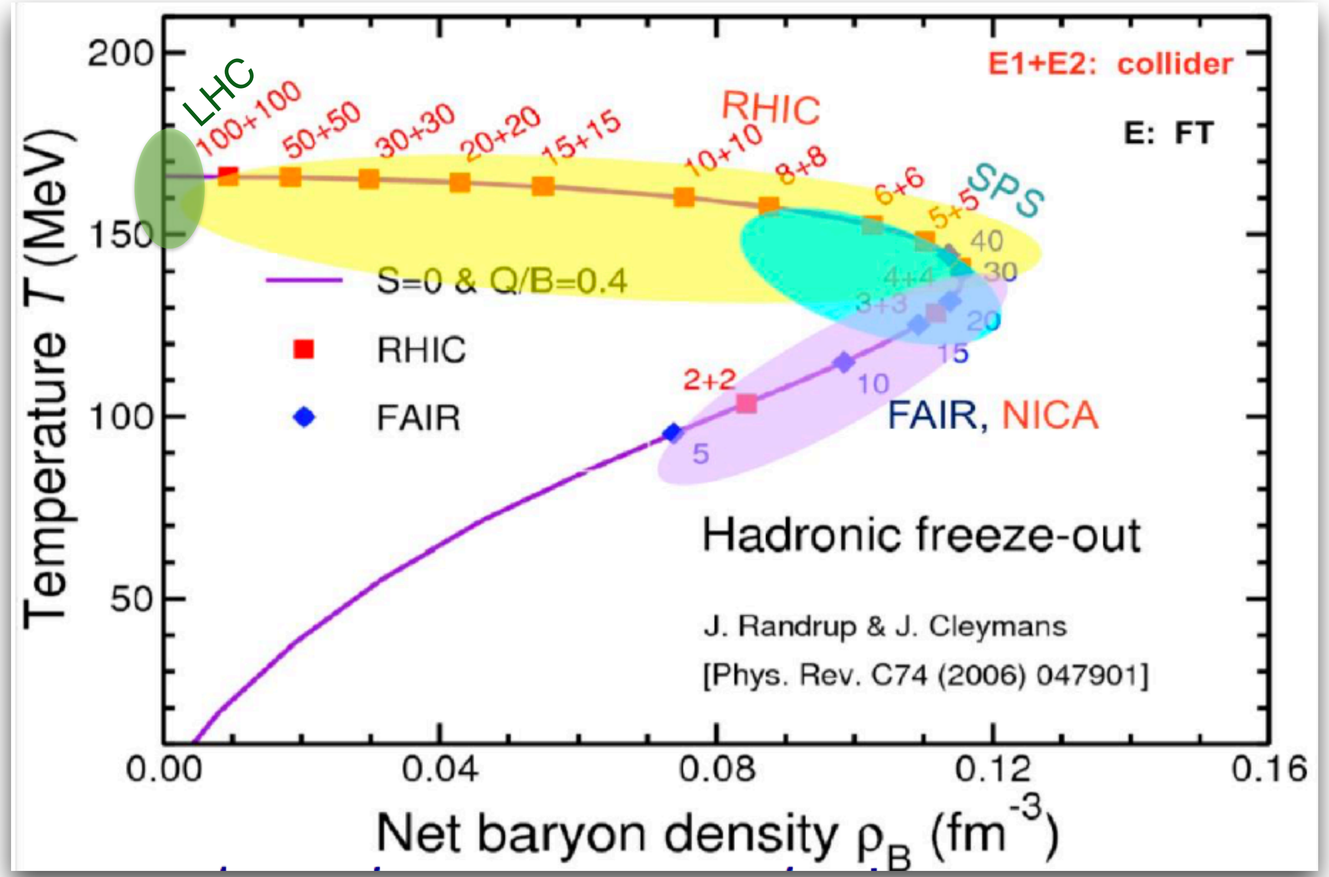
the big questions …





characterize the matter that existed
~ micro-seconds after the Big Bang

heavy-ion collision experiments …



STAR

PHENIX

CMS

ATLAS EXPERIMENT

ALICE

SHINE

HADES

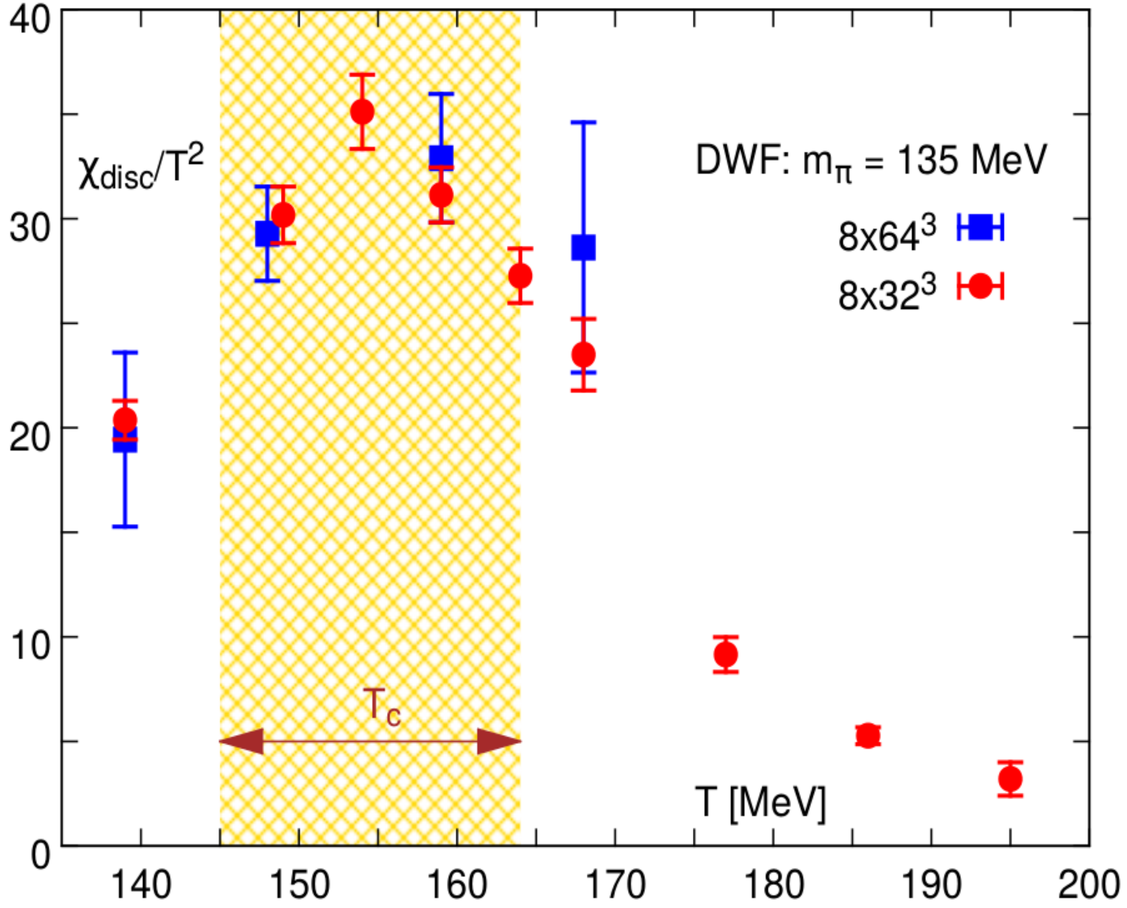
FAIR Facility for Antiproton and Ion Research in Europe GmbH

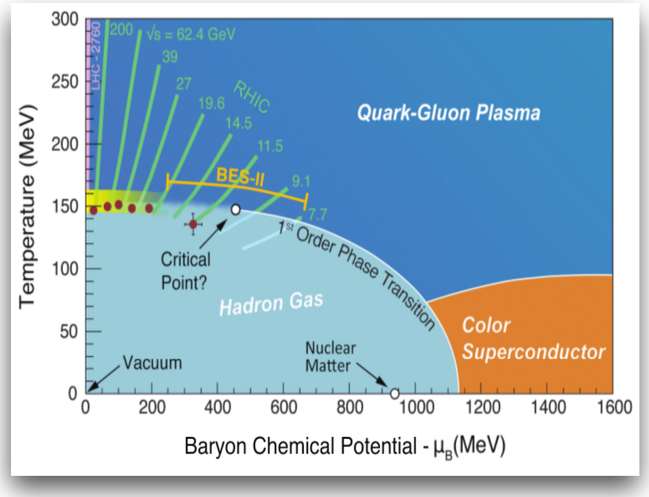
NICA

J-PARC

where do we stand …

$$@\ \mu_B = 0$$



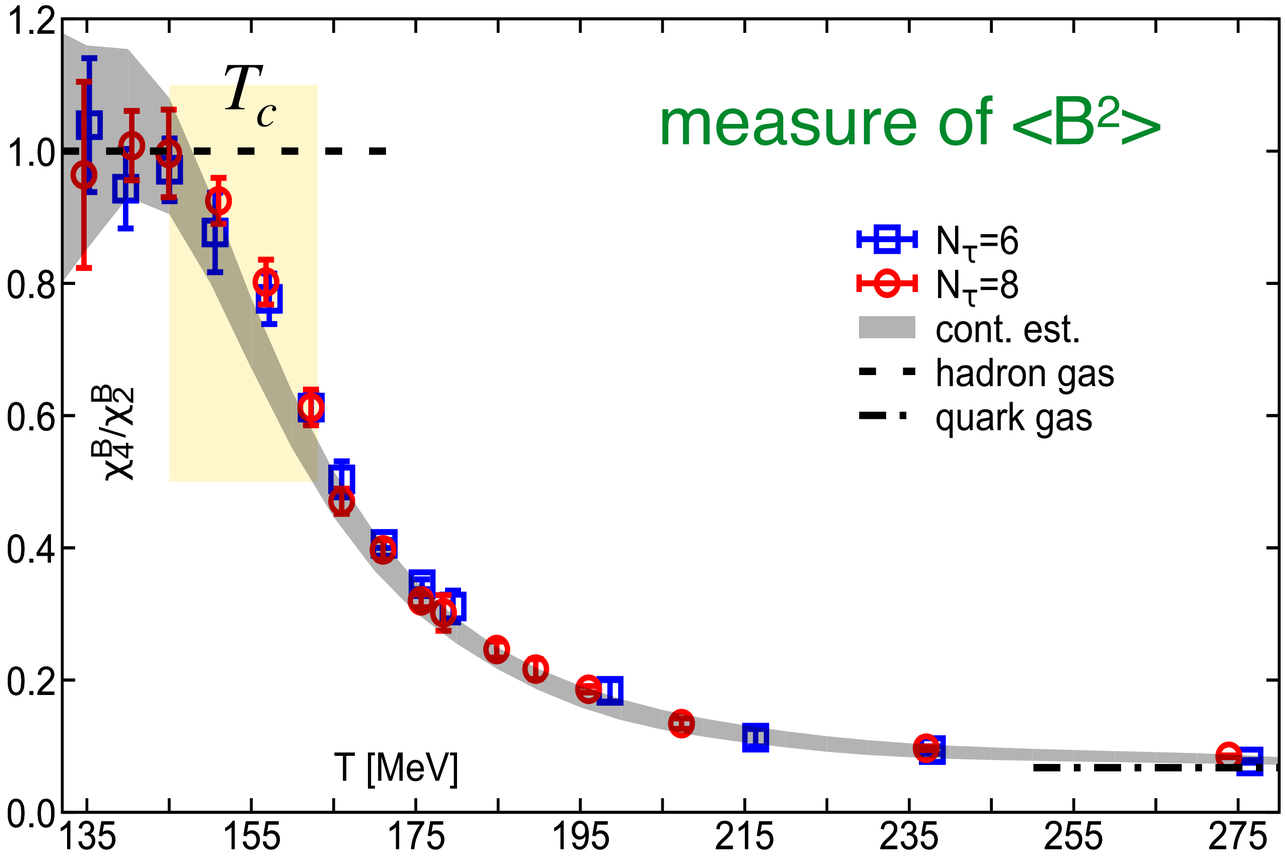


chiral crossover

— remnant of a 2nd order phase transition in the chiral limit

$$T_c = 154(9)\ MeV$$

HotQCD:
Phys. Rev. Lett. 113, 082001 (2014)
Phys. Rev. D85, 054503 (2012)



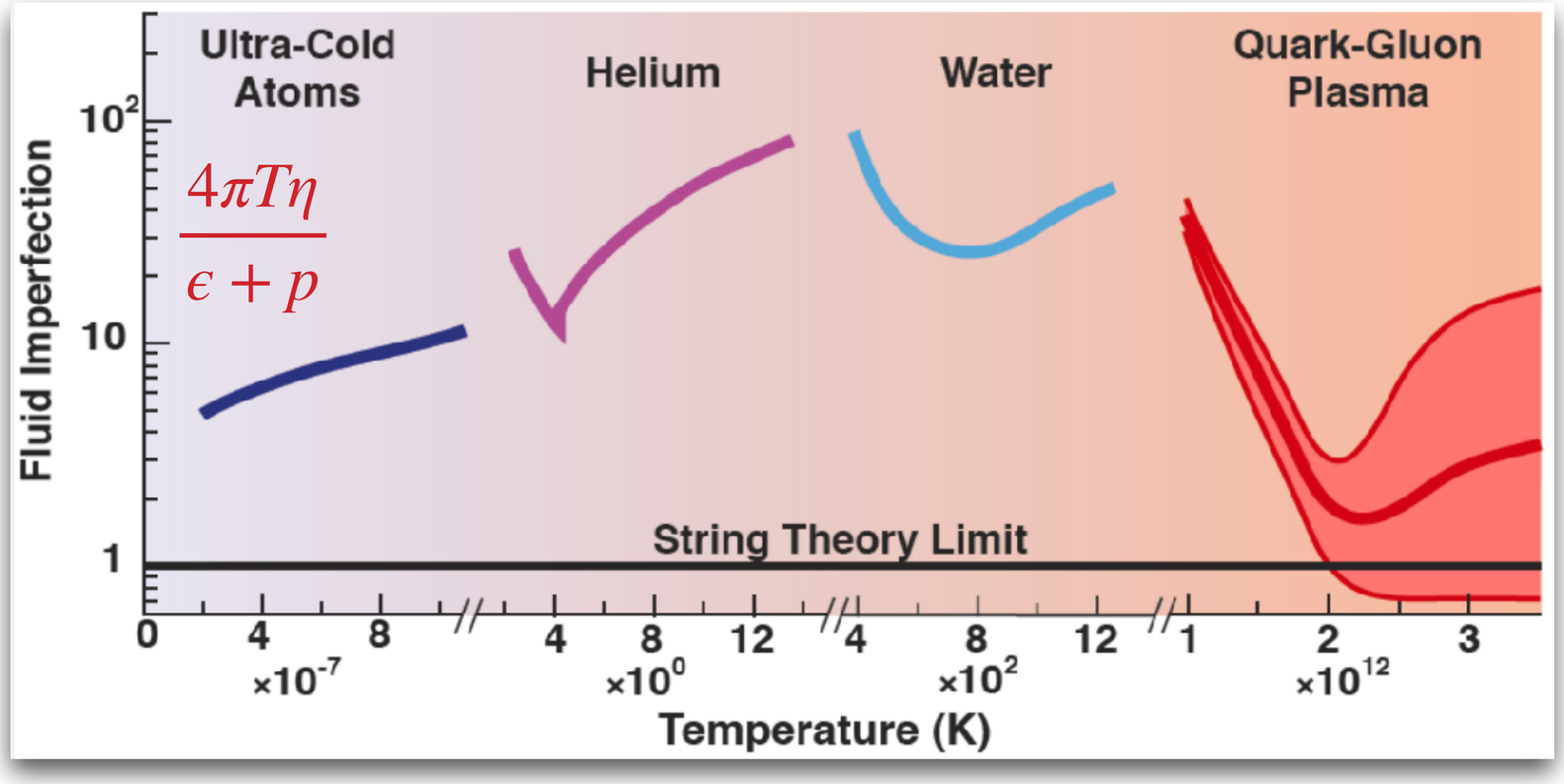
onset of deconfinement

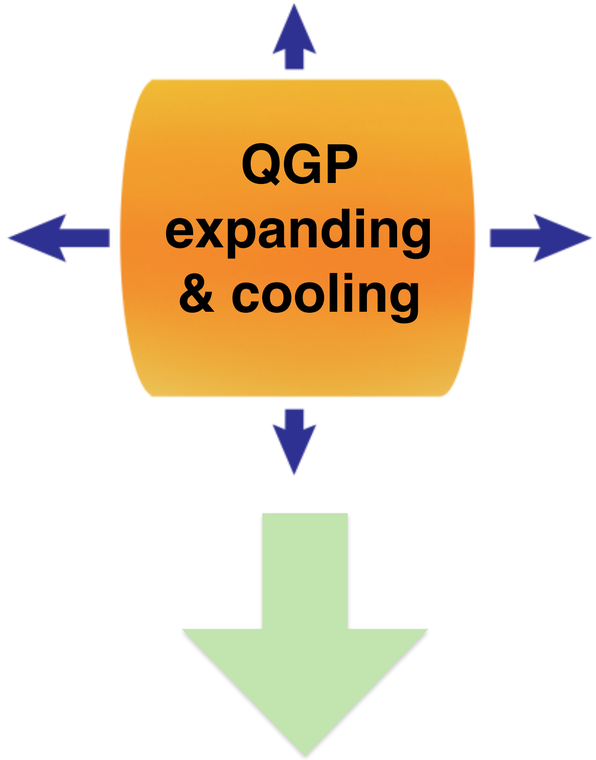
$$T_c = 154(9)\ MeV$$

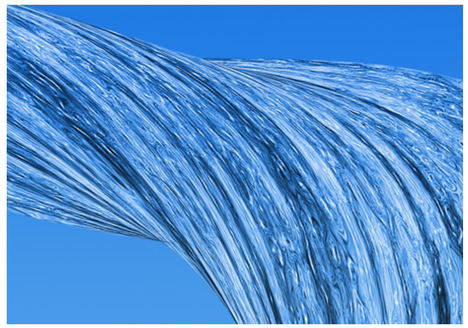
BNL-Bielefeld:
Phys. Rev. Lett. 111, 082301 (2013)
Phys. Lett. B737, 210 (2014)

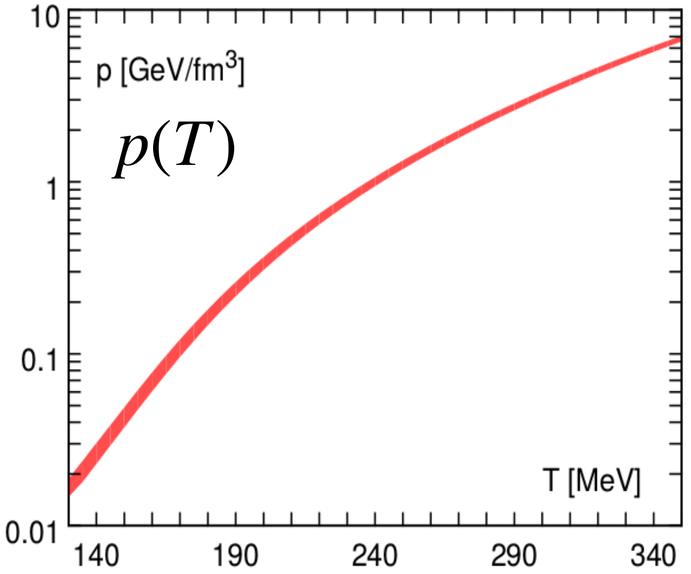
QGP @ large length scales …

flowing QGP: a nearly perfect fluid



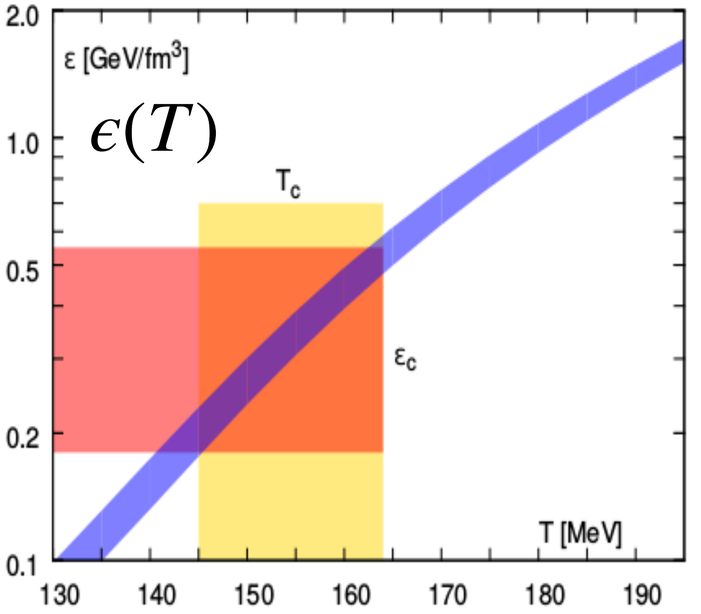






QGP properties

LQCD: equation of state



HotQCD:
Phys. Rev. D90, 094503 (2014)

hydrodynamic modeling

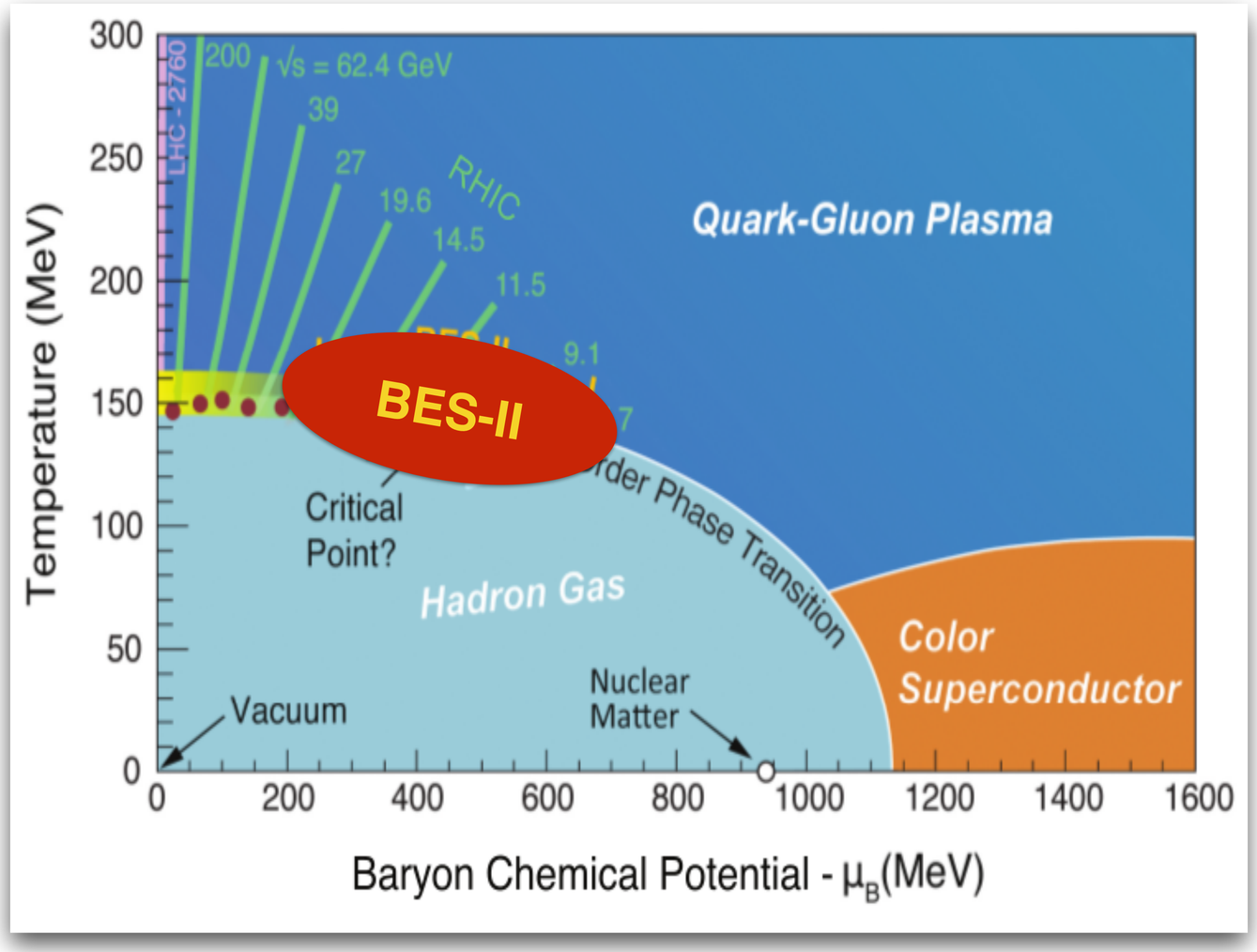
$$\frac{4\pi T\eta}{\epsilon + p}$$

experimental measurements

energy-momentum conservation

where are we going …

QGP @ $\mu_B > 0$, phase diagram, QCD critical point …



BES-II @ RHIC

2019-2021

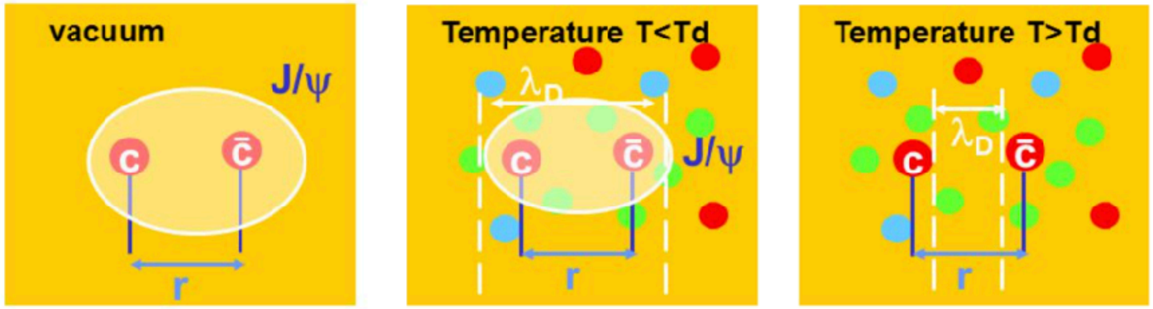
QGP @ shorter length scales

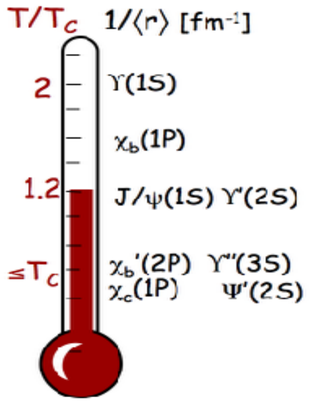
tracers in QGP: heavy quark probes

2021 - …

ultimate test of deconfinement

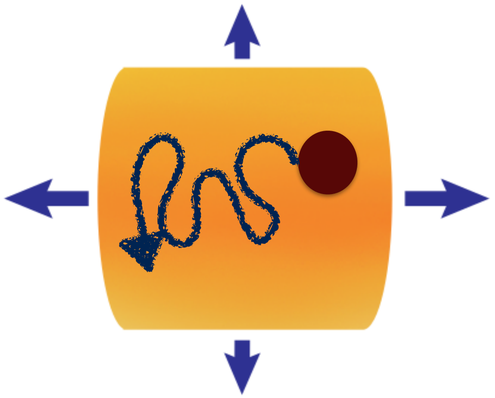
quarkonia melting





heavy quark diffusion in QGP

— energy loss, thermalization, flow



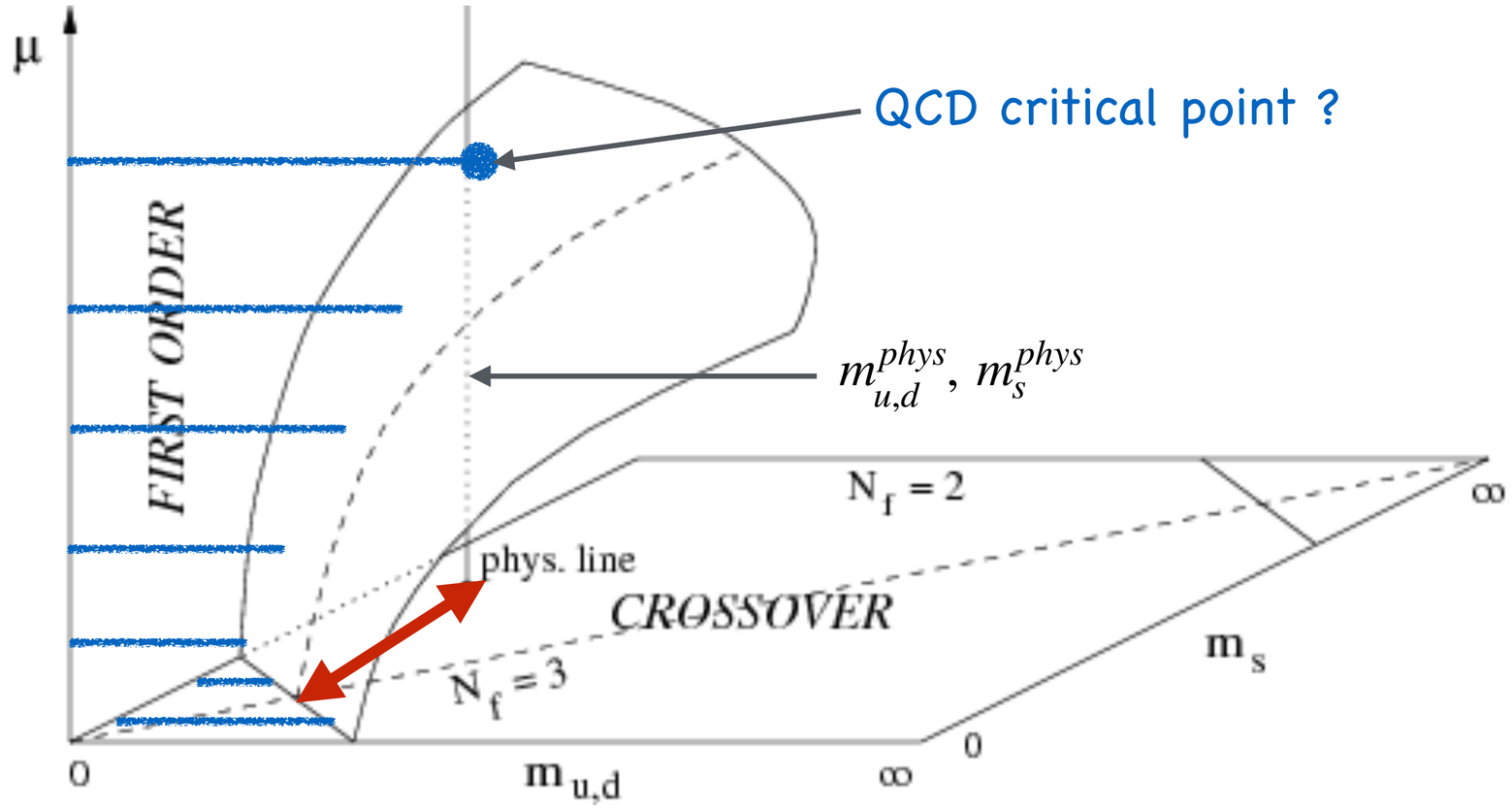
QGP at even higher T:

approach to perturbative properties …

last year …

$N_f = 3$: search for 1st order chiral transition @ $\mu_B = 0$

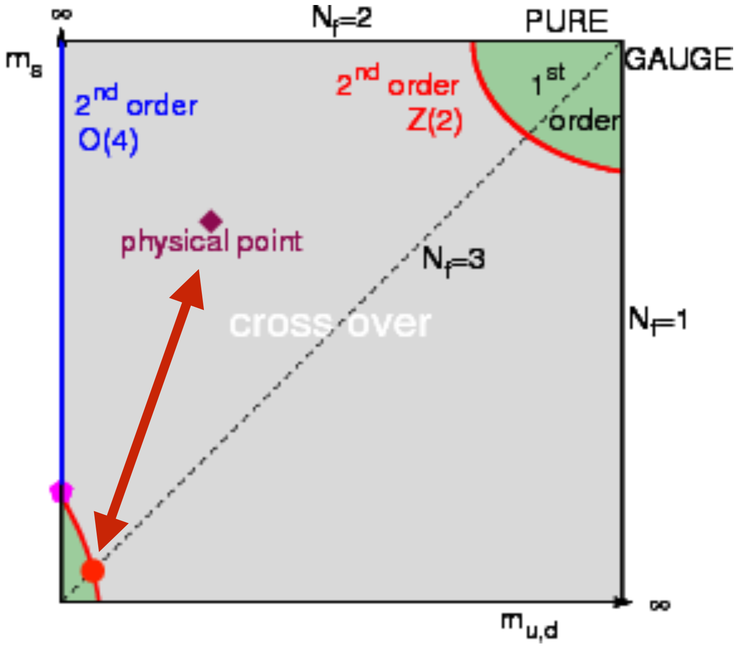
BNL-Bielefeld: Phys. Rev. D95, no.7, 074505 (2017)

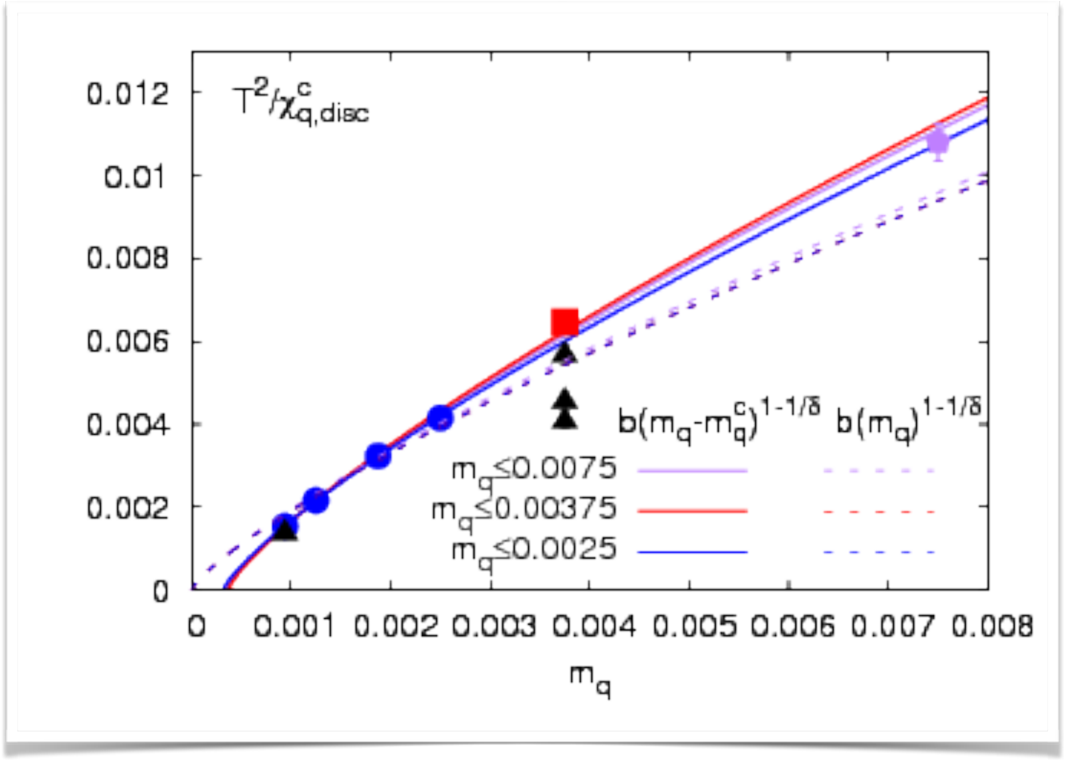


— no direct evidence of 1st order chiral transition order down to $m_\pi = 80$ MeV

— estimated upper bound: $m_\pi^c \lesssim 50$ MeV

- from 3d Ising scaling of chiral observables
- vanishing critical quark mass not favored





BNL-Bielefeld: Phys. Rev. D95, no.7, 074505 (2017)

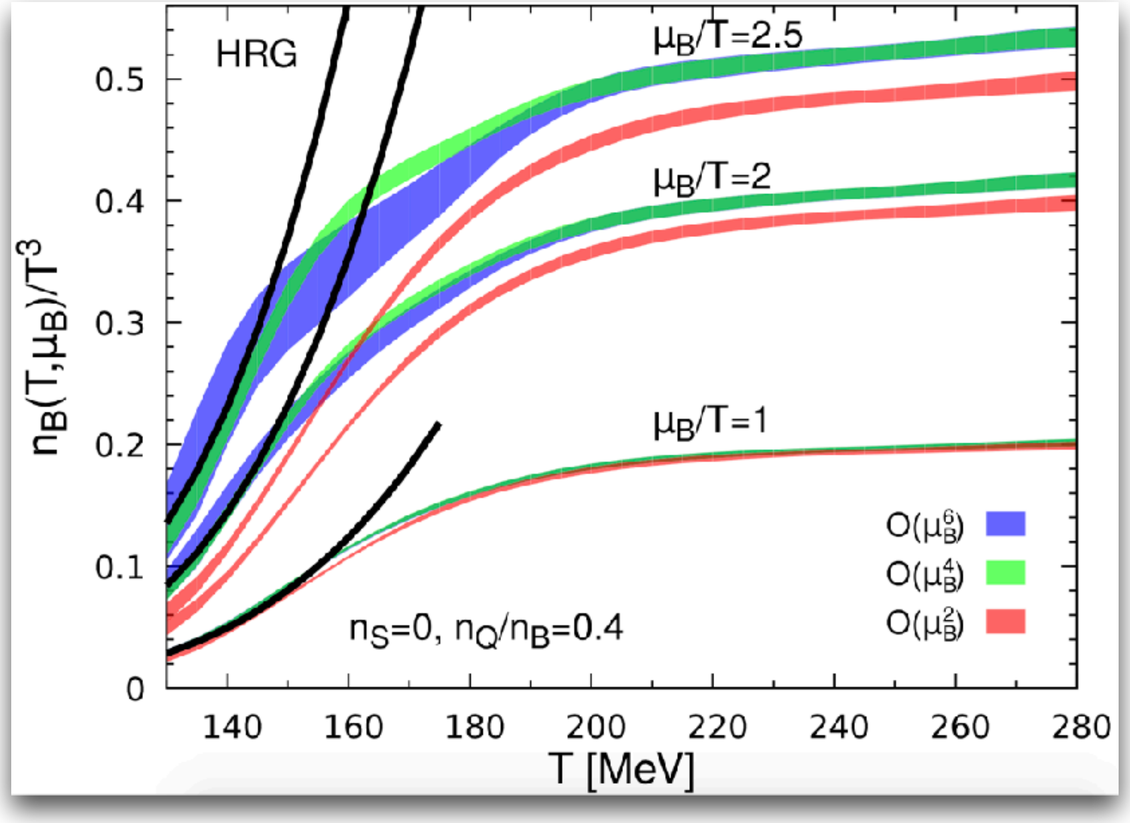
Nf=3 1st order chiral transition might have little influence on physical QCD phase diagram

QCD equation of state: $\mu_B/T \lesssim 2$

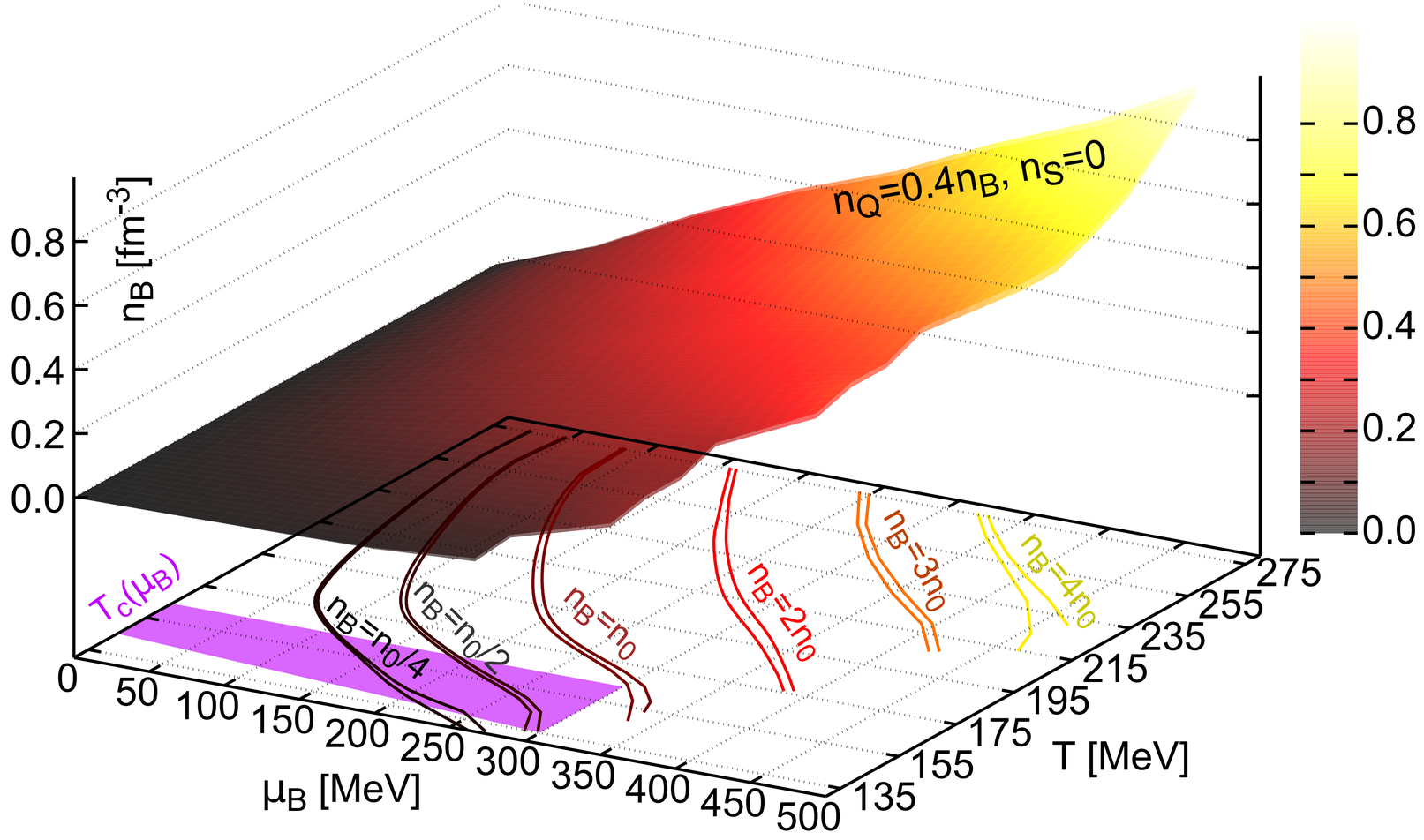
BNL-Bielefeld: Phys. Rev. D95, no.5, 054504 (2017)

Taylor expansion up to $\mathcal{O}\left(\mu_B^6\right)$

- controlled up to $\mu_B/T \lesssim 2$



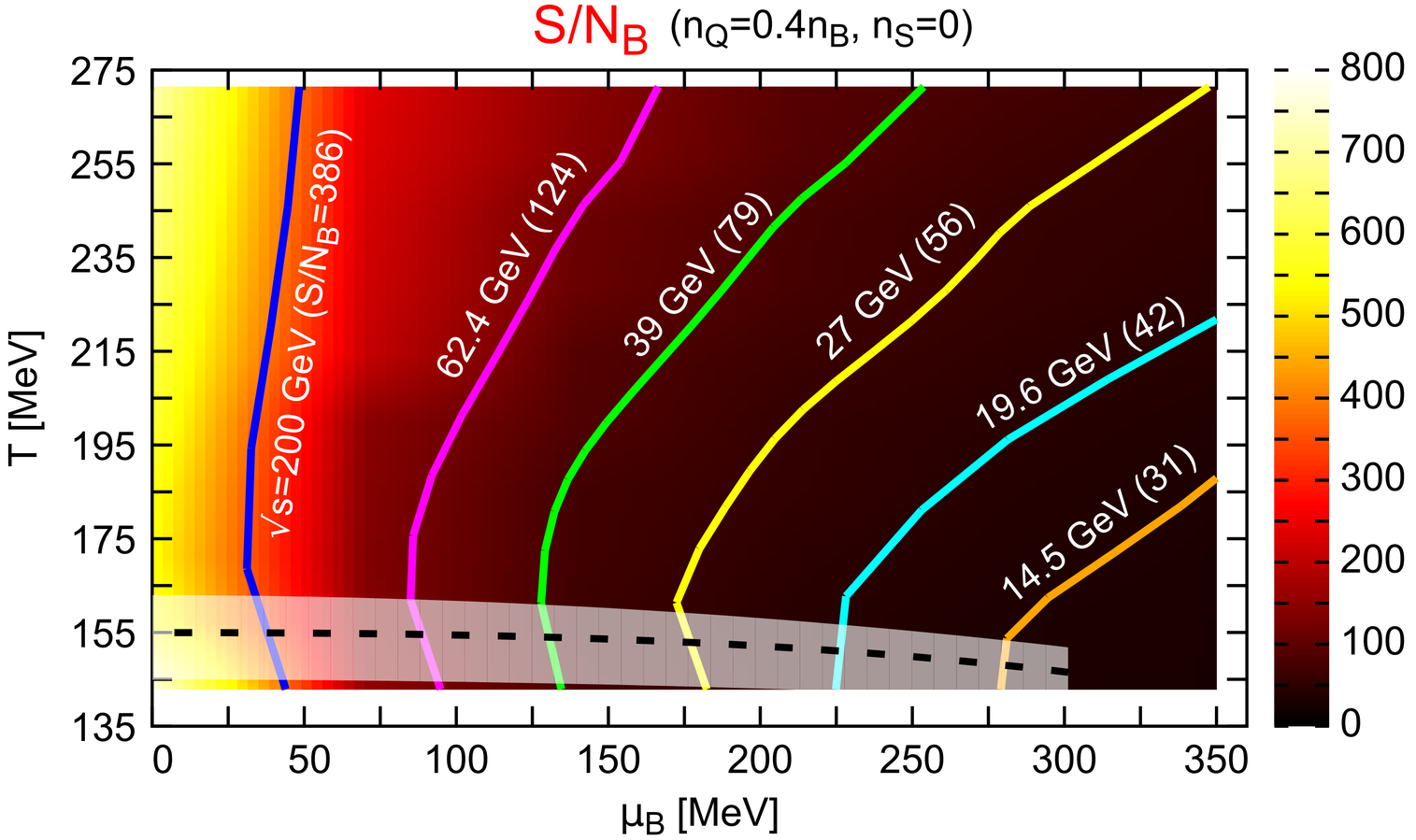
baryon density ~ up to 4 x nuclear matter density



BNL-Bielefeld: Phys. Rev. D95, no.5, 054504 (2017)

present reach: beam energies $\sqrt{s} \sim 14.5\ GeV$

approximate trajectories in heavy-ion collisions

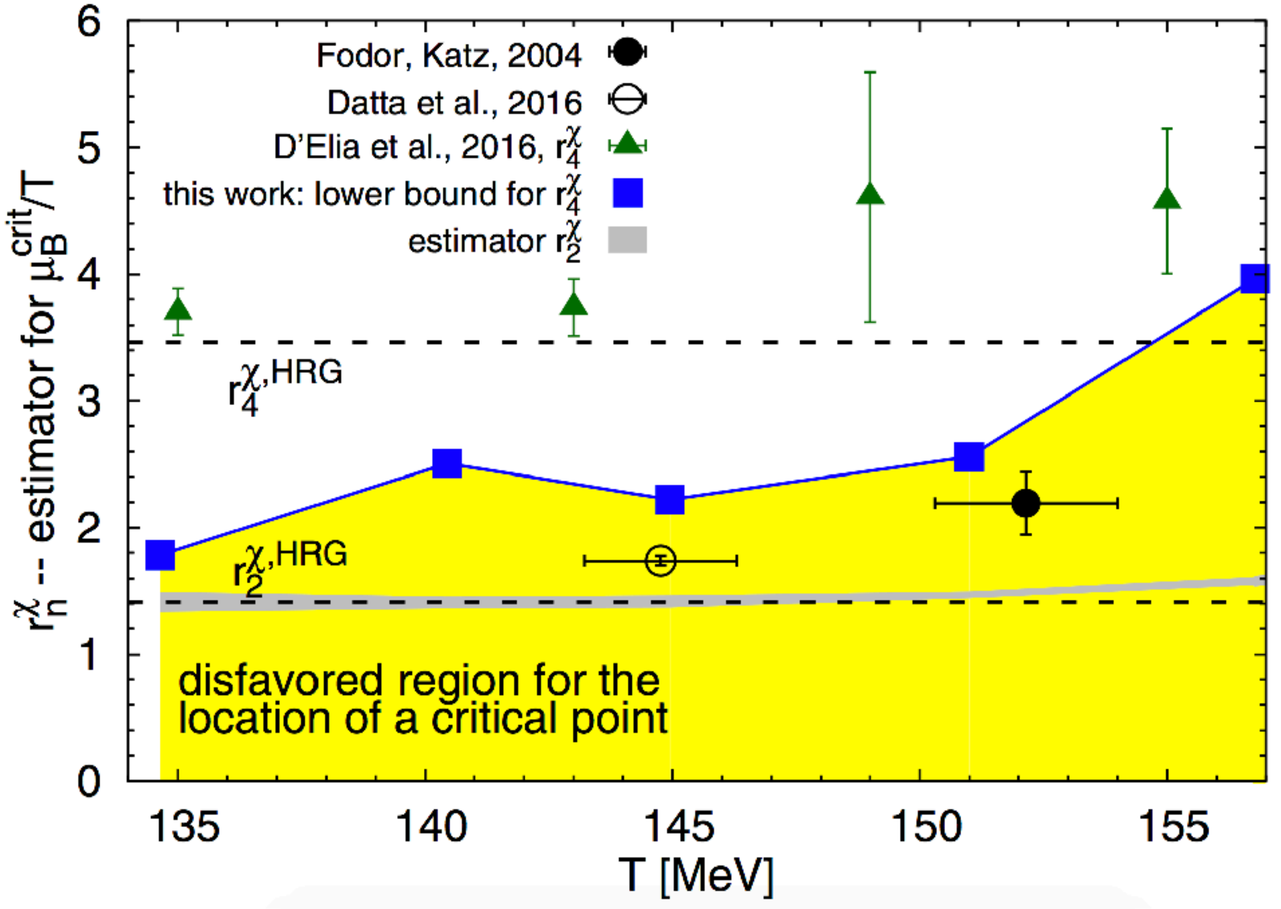


extend to: $\sqrt{s} \sim 7\ GeV,\ \mu_B/T \sim 3$

location of critical point:

$\mu_B/T \lesssim 2$ presently disfavored

- analyzing radius of convergence



BNL-Bielefeld: Phys. Rev. D95, no.5, 054504 (2017)

charm quark diffusion constant

new stochastic method (SAI) for spectral function reconstructions

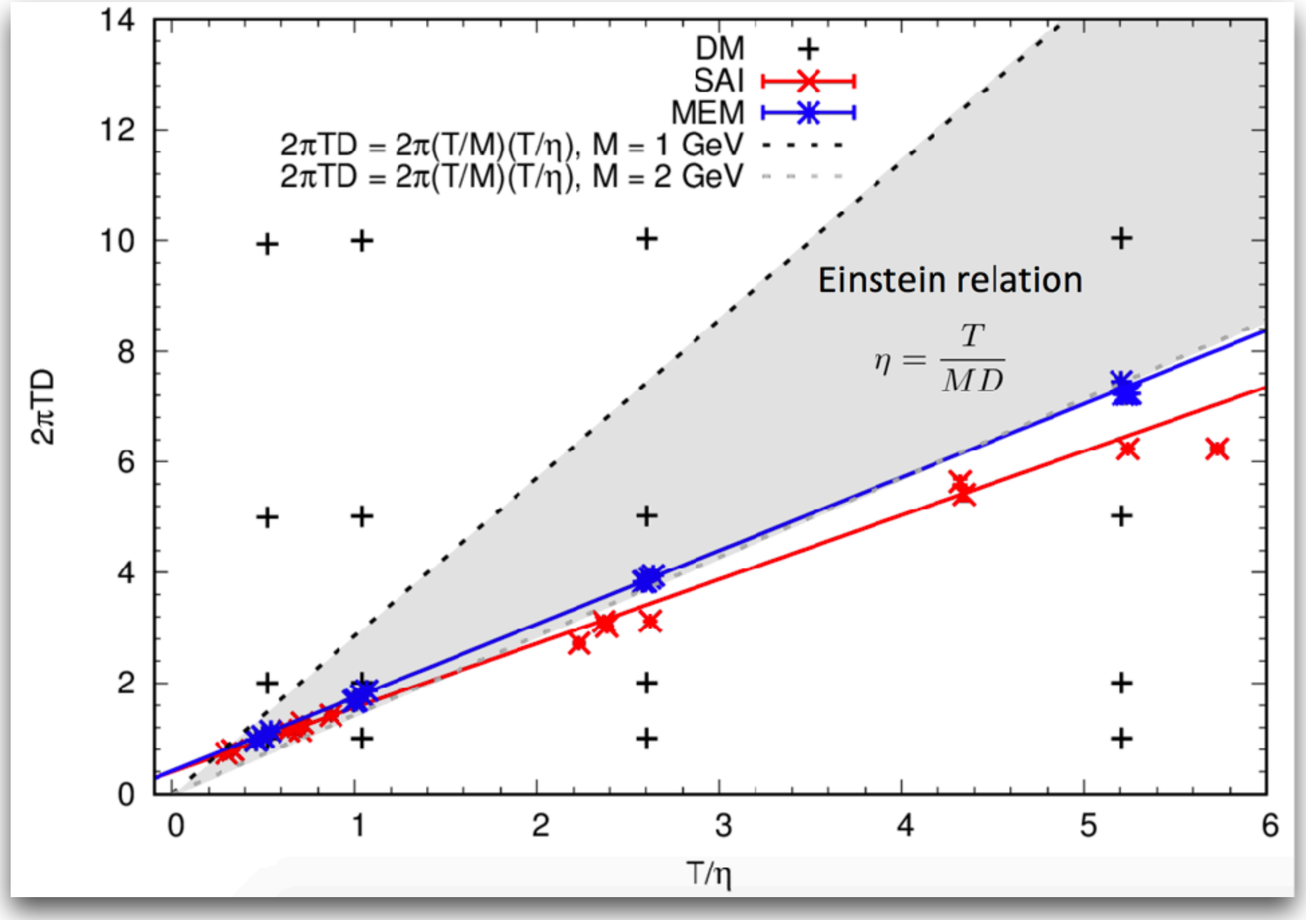
- tests on large quenched lattices

$$2\pi TD = 1.6 - 6.2 \ \ldots \ SAI$$

$$2\pi TD = 1.8 - 7.0 \ \ldots \ MEM$$

$$\ldots \ for \ T/\eta = 1 - 5$$

η: thermal width of charm quark



extend to: dynamical quarks

- need very large lattices

Hiroshi Ohno: Quark Matter 2017

proposals this year …

3 proposals along 3 directions

Karsch *et. al.*: QCD @ $\mu_B > 0$

— closer to continuum (finer lattices), extending μ_B-range

— 67 M KNL & 1.6 M GPU

Petreczky *et. al.*: quarkonia @ high T

— NRQCD on dynamical 2+1 HISQ configurations

— 8 M Jpsi CPU

Bazavov: equation of state @ high T, effects of dynamical charm

— 2+1+1 HISQ

— 18 M Jpsi CPU