Hot-dense Lattice QCD: perspective & directions

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June 2016, Jefferson Lab

hot-dense LQCD component

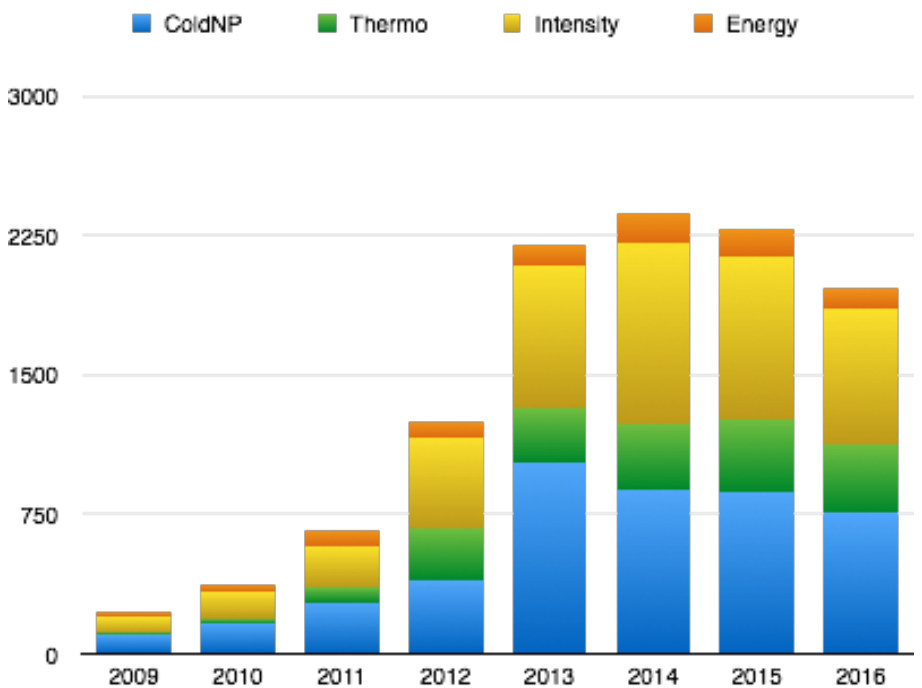
HotQCD collaboration

~10 institutions, 20+ members

BNL LGT (NP)

HotQCD & international partners

USQCD allocations by subfields

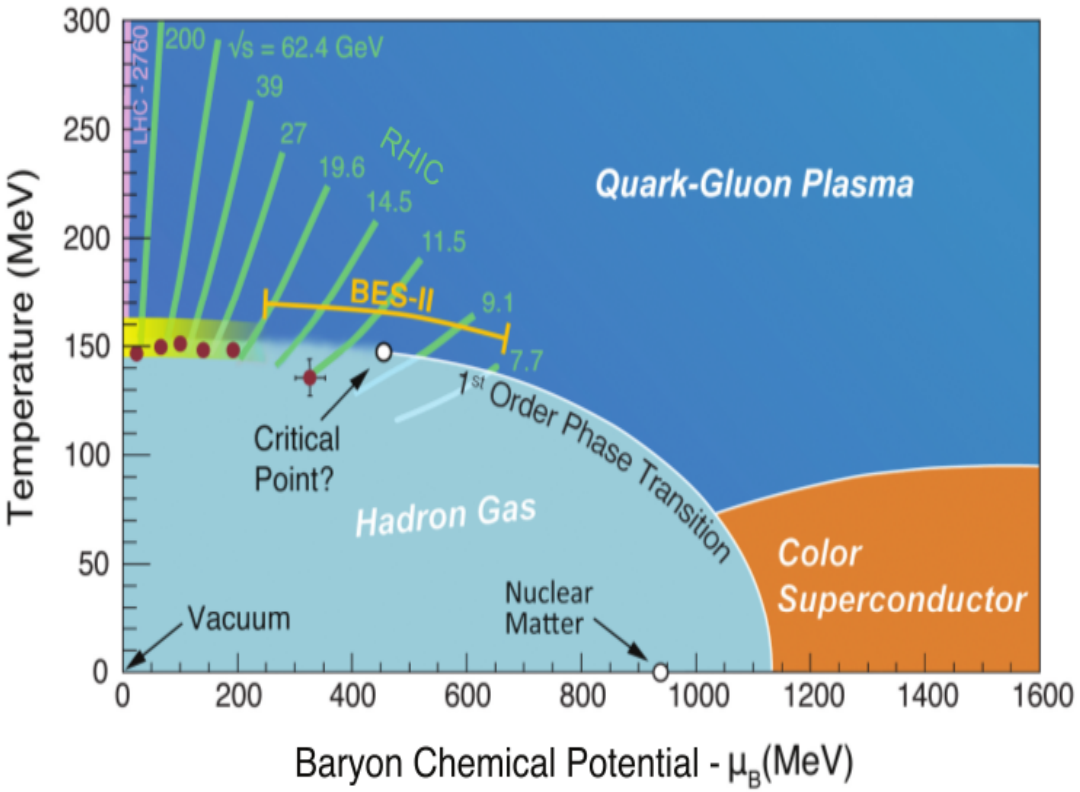


typically hot-dense LQCD
~15-18%

scientific & experimental drivers

phases & properties of QCD under extreme conditions

NSAC 2015 long range plan



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selected highlights

publications in refereed journals during 2015-16: 14

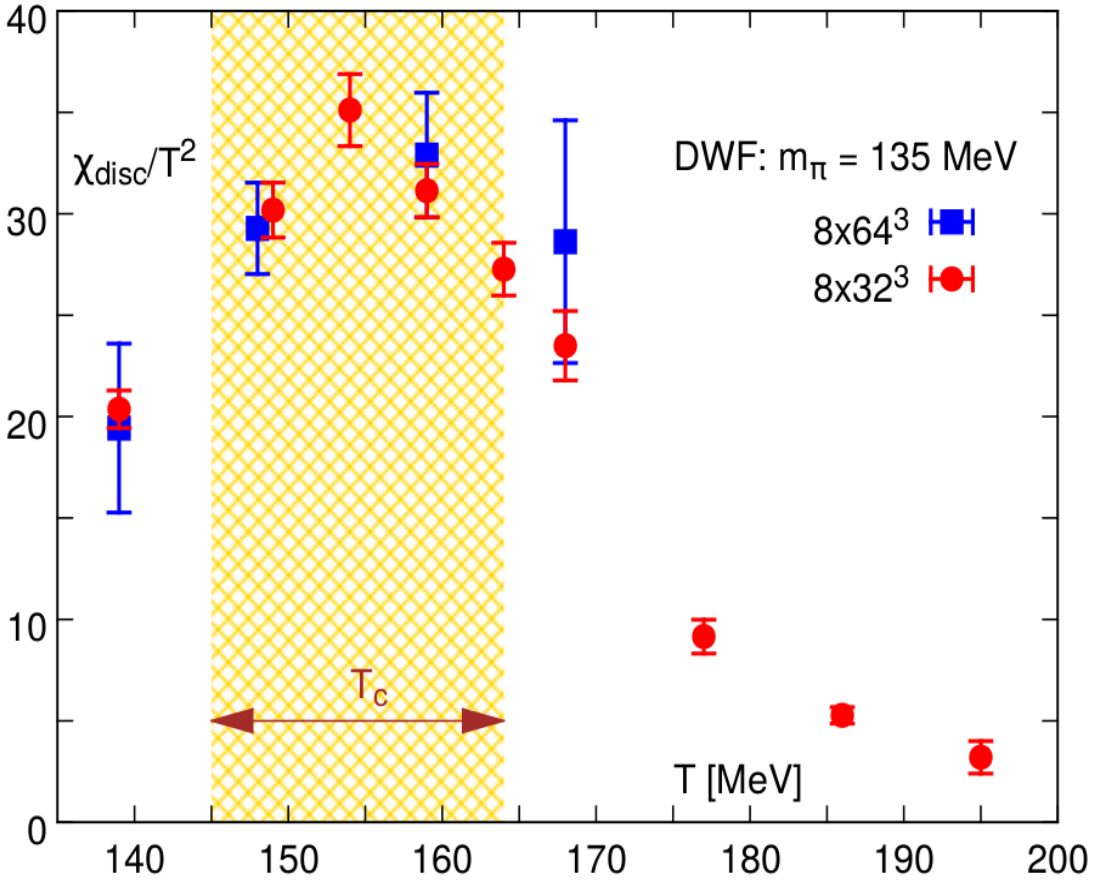
among 20 most cited hep-lat papers during 2015:

14 hot-dense LQCD, 5 USQCD hot-dense LQCD

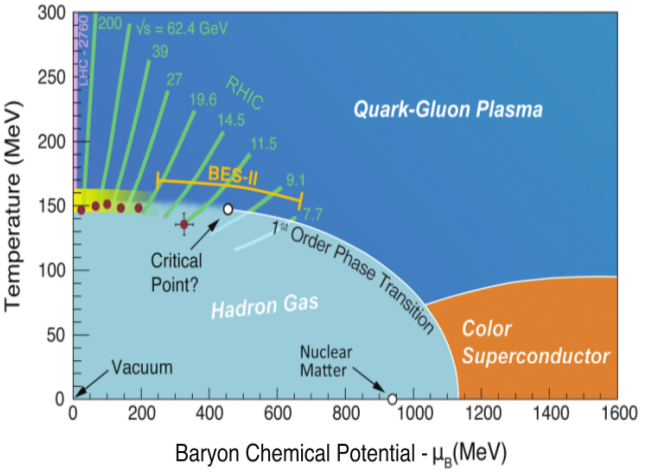
"lattice meets experiments" meetings during 2016: 2

- Indiana University, May 9-11, 2016: "Topical Workshop on Beam Energy Scan"
- BNL, June 7, 2016: "RHIC Annual Users' meeting: Beam Energy Scan Physics"

crossover transition



$T_c = 154(9)$ MeV

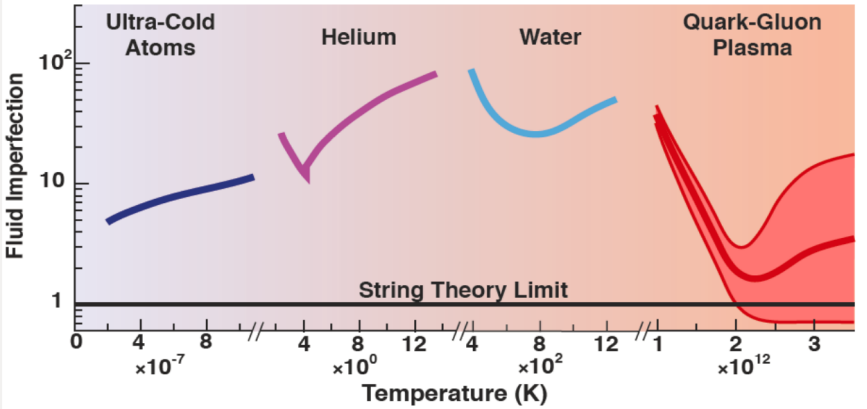


HotQCD:
Phys. Rev. Lett. 113, 082001 (2014)
APS Physics Viewpoint article

HotQCD:
Phys. Rev. D85, 054503 (2012)
2nd most cited hep-lat paper in '15

QGP a ‘nearly perfect fluid’:
strongly coupled

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



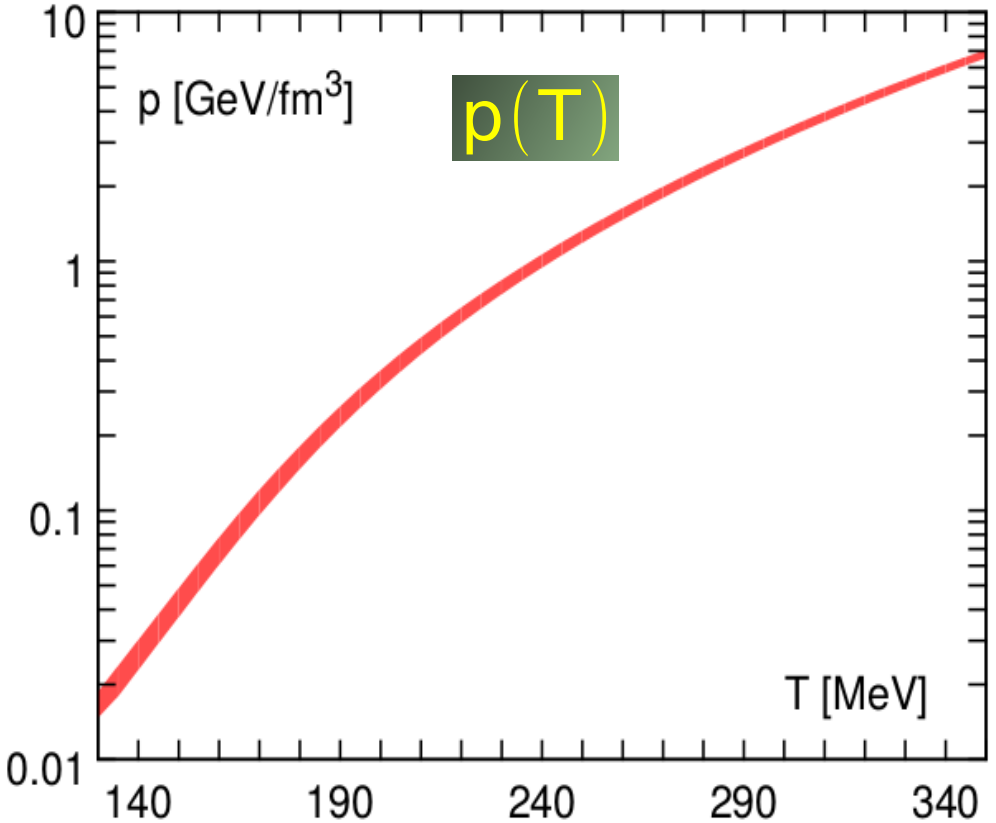
QCD equation of state

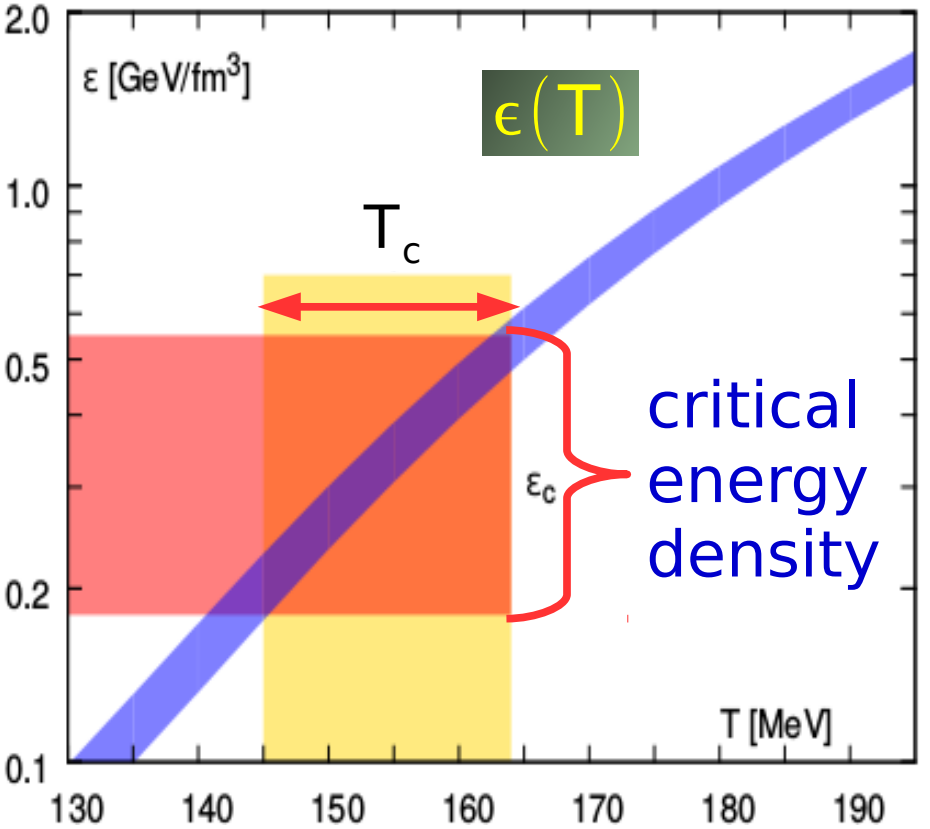
hot-dense LQCD

$\epsilon(T), p(T)$

hydrodynamic modeling → $\frac{4\pi T\eta}{\epsilon+p}$ ← experimental measurements

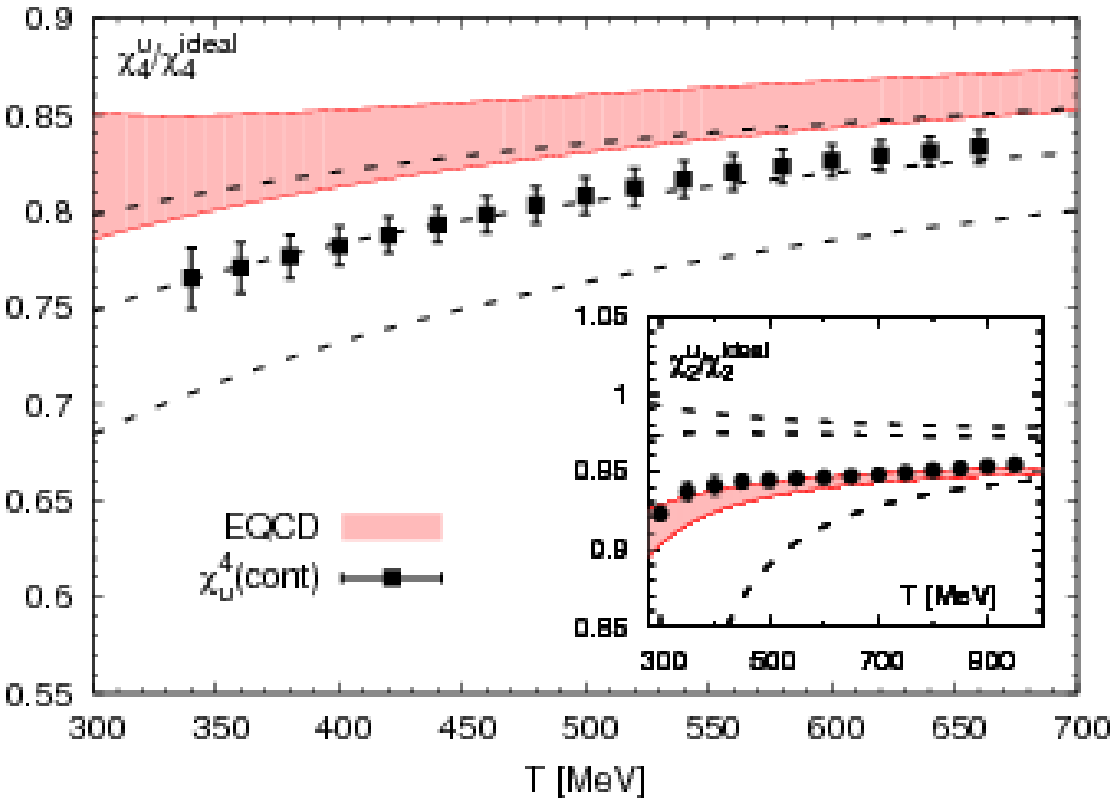
energy-momentum conservation





HotQCD:
Phys. Rev. D90, 094503 (2014)
5th most cited hep-lat paper in ‘15

passage to weakly interacting QGP

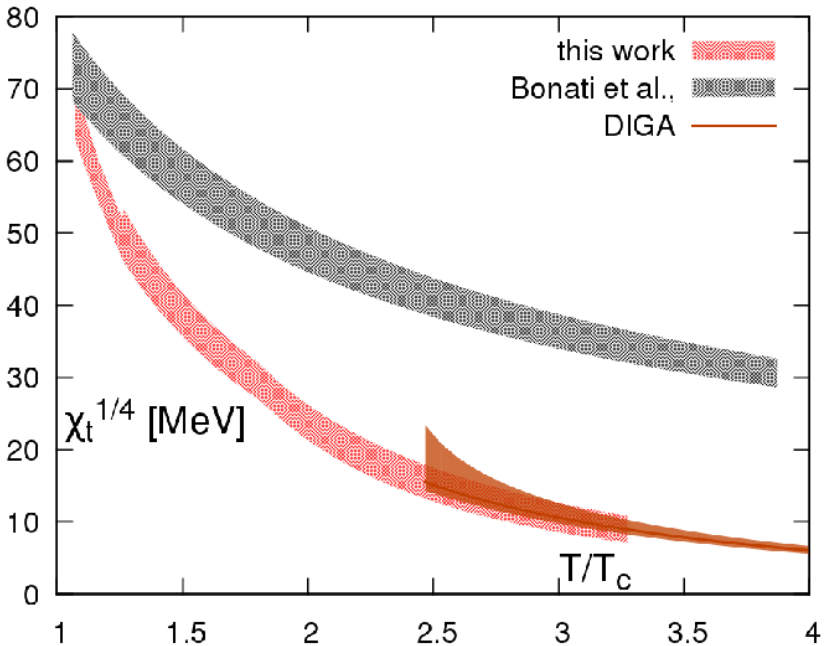


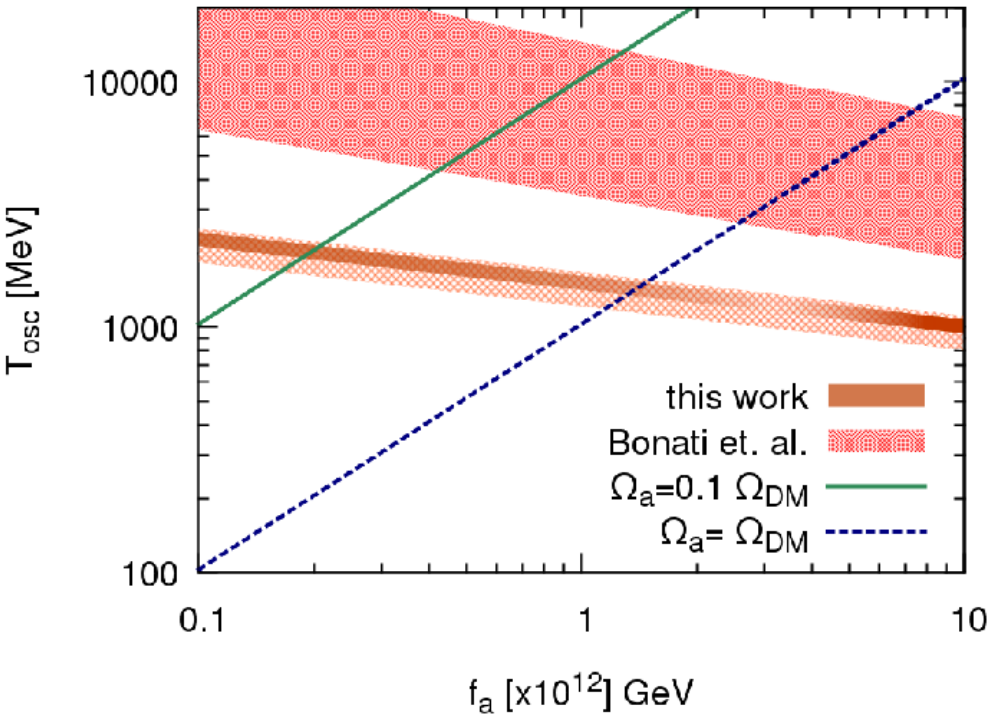
fermionic fluctuations agree with weak-coupling resummed perturbative (3-loop HTL) results for

$T \gtrsim 2\,T_c$

BNL-CCNU: Phys. Rev. D92 no.7, 074043 (2015)

axion dark matter & cosmology





topological susceptibility
at high temperature

bounds on axion
mass / decay constant

BNL: arXiv:1606.03145

future: scientific & experimental drivers

immediate & urgent:

RHIC Beam Energy Scan (BES) II – 2020

phases & properties of baryon-rich QGP

NSAC 2015 long range plan

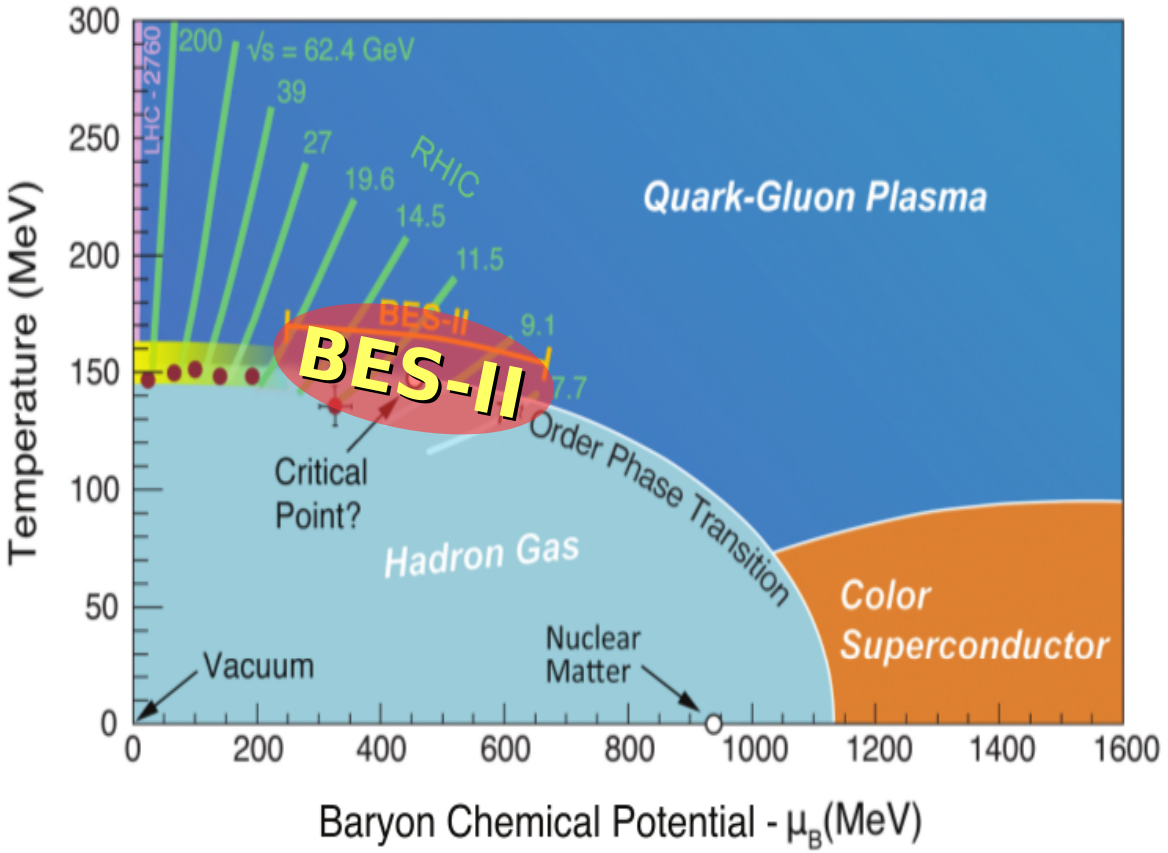
& beyond ...

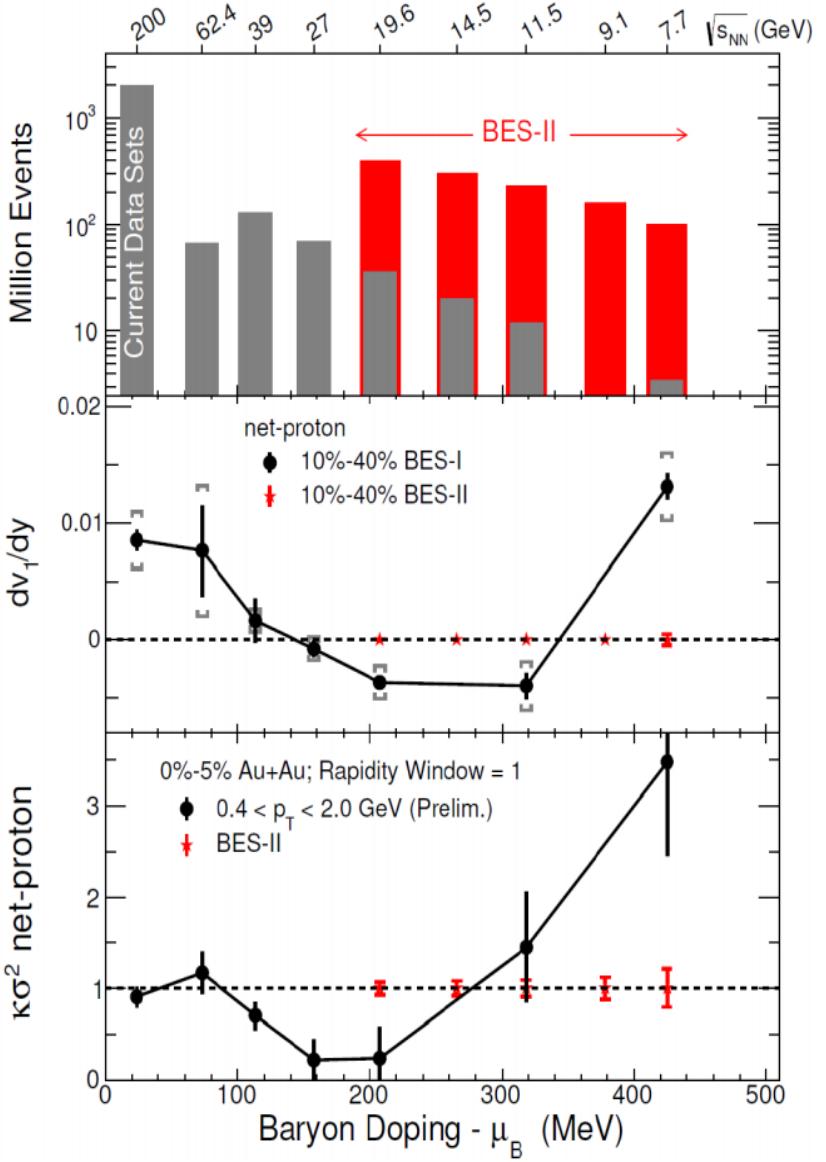
sPHENIX & ALICE upgrades

heavy flavor physics

tracers in QGP: probing shorter length scales

BES II: $\mu_B^f/T^f \approx 1.3-3$





USQCD hot-dense LQCD goals (~2020)

provide urgently needed QCD inputs & baselines
essential for dynamical modeling of BES energies

bulk thermodynamics @ $\mu_B>0$

- equation of state
- QCD phase boundary
- equilibrium baseline for higher cumulants
- freeze-out conditions
- ...

integral part of

Topical Collaboration
in nuclear theory
2016-2020
DOE, NP

bulk thermodynamics @ $\mu_B>0$

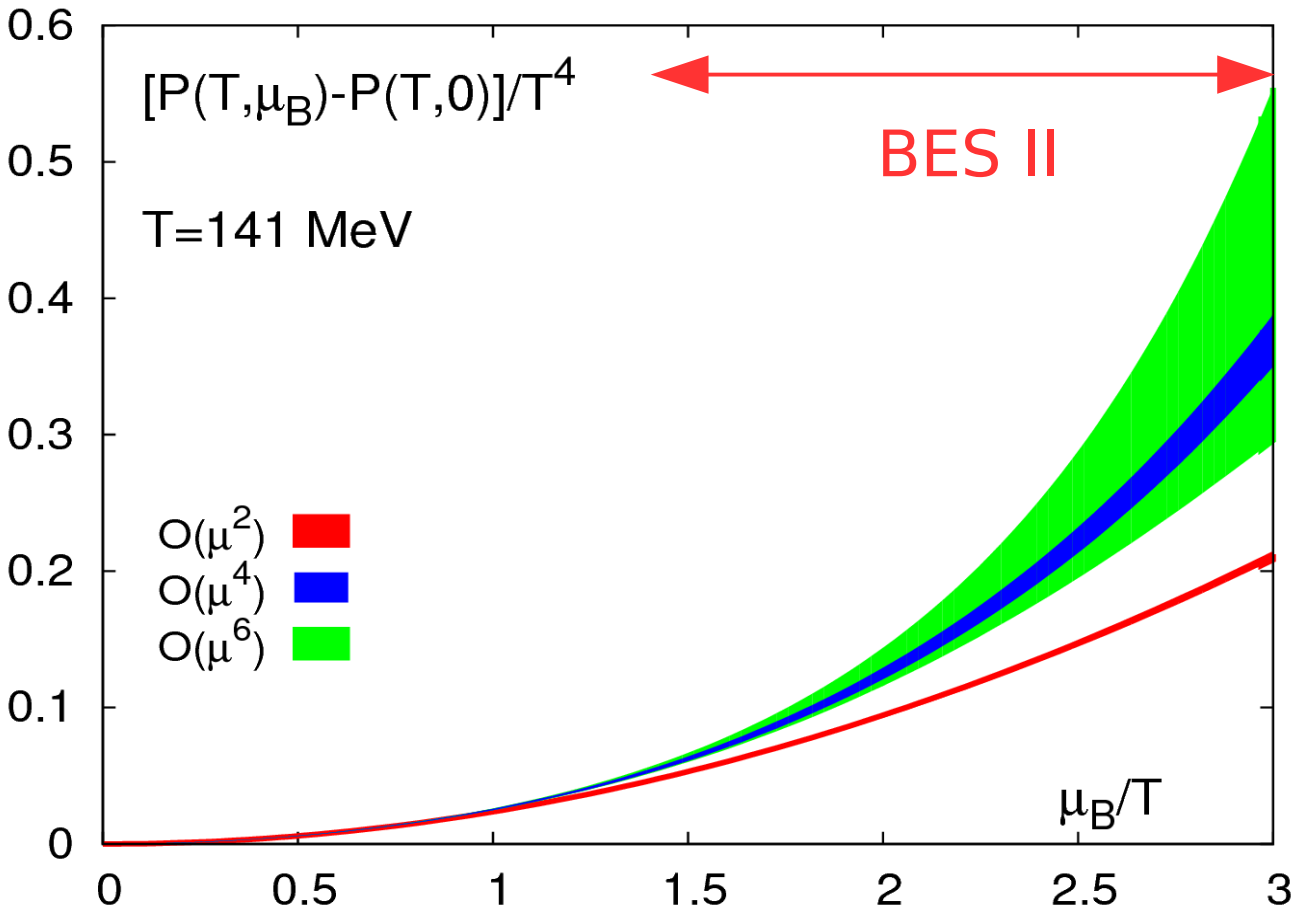
Taylor expansion method

$$\frac{p(\mu_B,T)}{T^4} = \sum_n \frac{1}{n!}\chi_n^B(T)\left(\frac{\mu_B}{T}\right)^n$$

CP–invariance → n=even

presently the only viable method for physical quark masses, close to thermodynamic & continuum limit

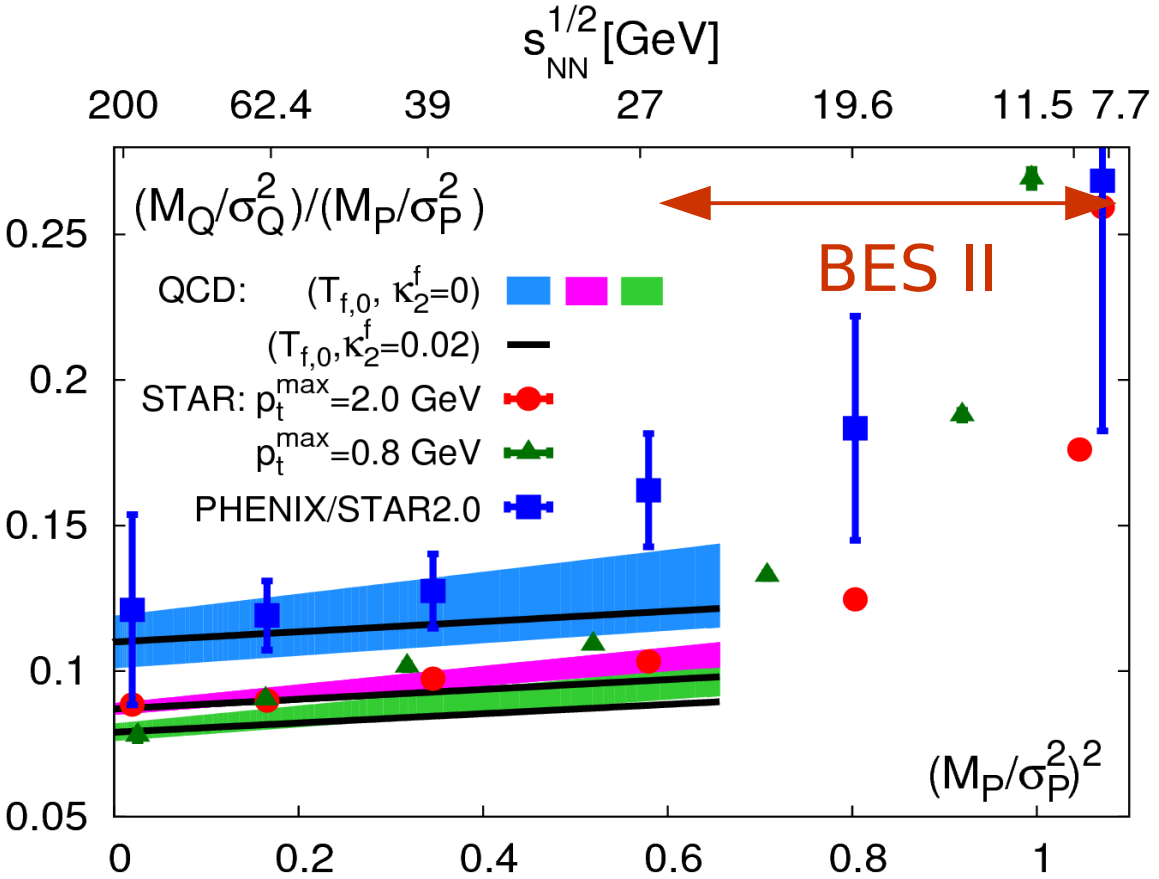
equation of state @ $\mu_B>0$



BNL-Bi-CCNU:
in preparation

goals: ~2x more precise → improved 6th order correction,
estimate truncation error → 8th order

equilibrium baseline for cumulants: LQCD vs. experiments

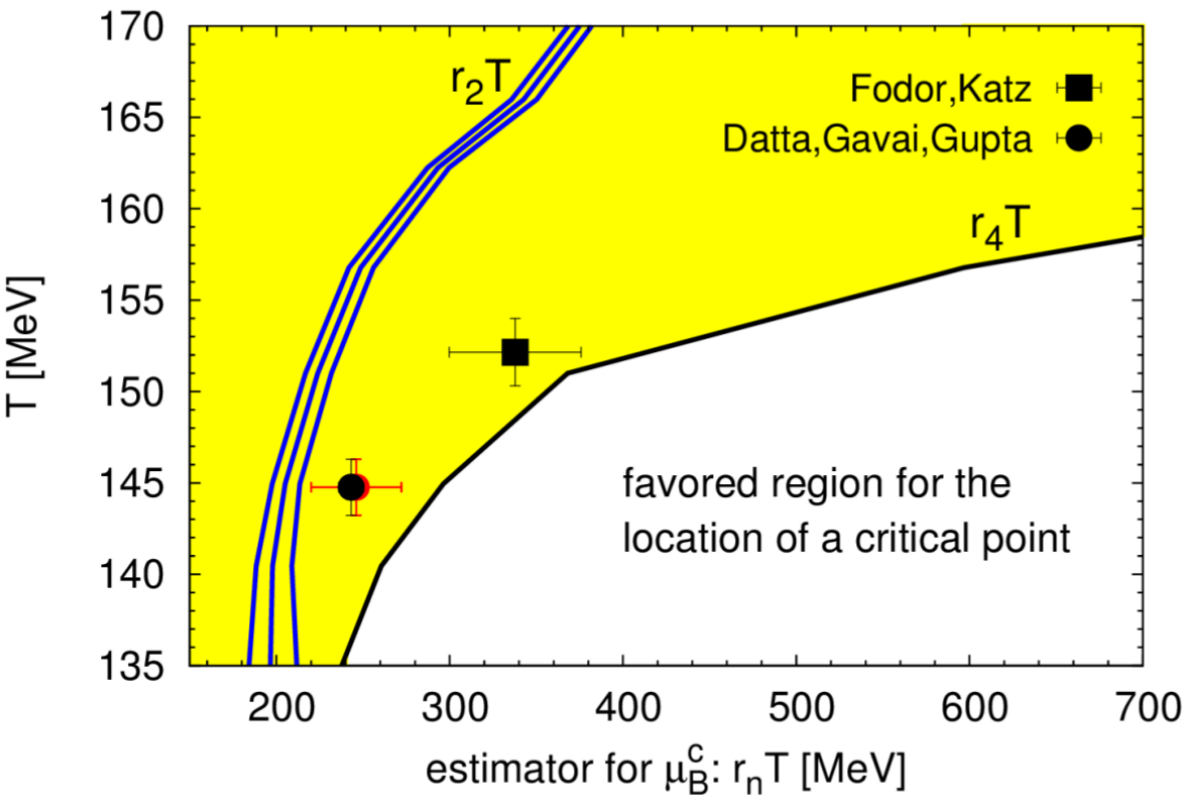


comparisons suggest freeze-out temperatures ~150 MeV for $\sqrt{s} \gtrsim 27$ GeV

goal:
extend to BES-II region

BNL-Bi-CCNU: Phys. Rev. D 93, no. 1, 014512 (2016)

constraining phase structure



by estimating convergence radius of the series

$$\frac{p(\mu_B, T)}{T^4} = \sum_n \frac{1}{n!} \chi_n^B(T) \left(\frac{\mu_B}{T}\right)^n$$

current estimate suggests radius of convergence:

$\mu_B \gtrsim 2\,T$

goals: higher order terms

USQCD hot-dense LQCD

well-aligned with DOE NP long term goals

programmatic

continues to deliver high-impact science

essential component for the success of RHIC BES-II program –

USQCD hardware critical