Ab-initio computation of hot and dense strongly interacting matter

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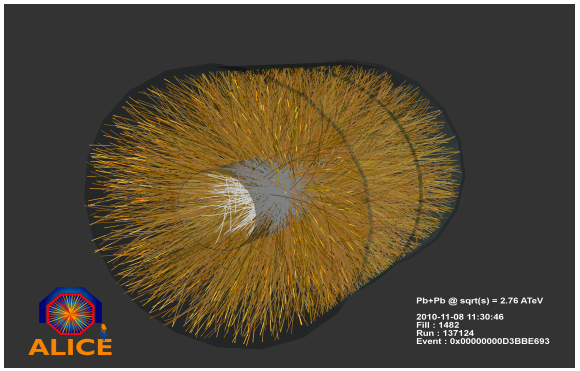
July 2012, Washington DC

Heavy ion collision experiments and Lattice QCD

HIC: RHIC, LHC

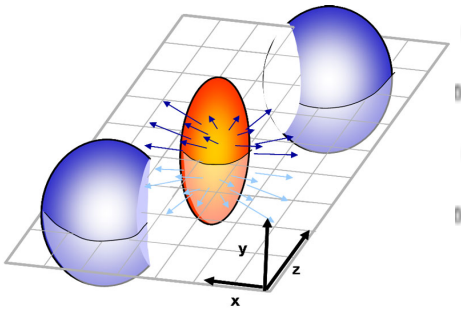
a new state of matter: QGP ?

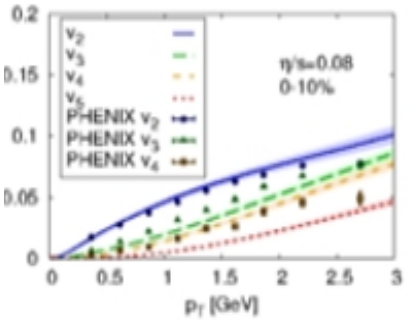


- transition temperature
- critical energy density
- nature of QCD transition

Hydrodynamic flow

QGP a perfect liquid ?

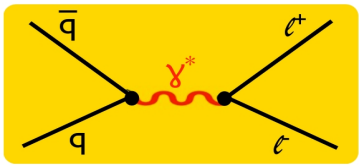


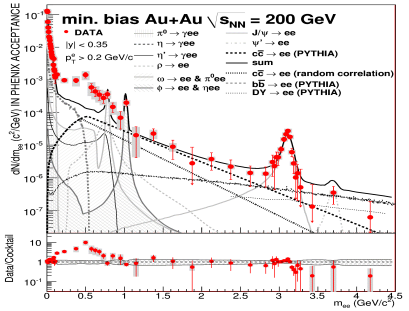


- equation of state
- shear, bulk viscosity

Electomagnetic probes

hotness of QGP ?

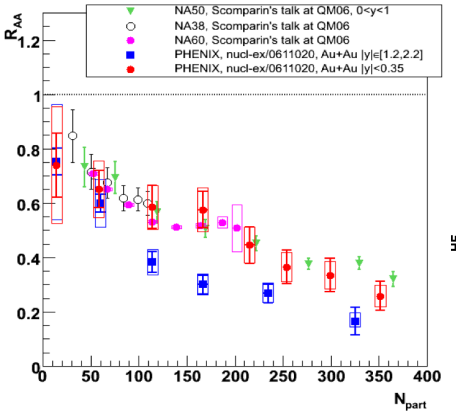


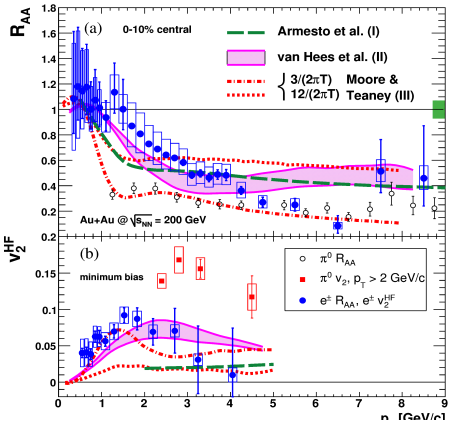


- photon, dilepton rate
- electrical conductivity

Heavy quark probes

QGP melts Quarkonia ?

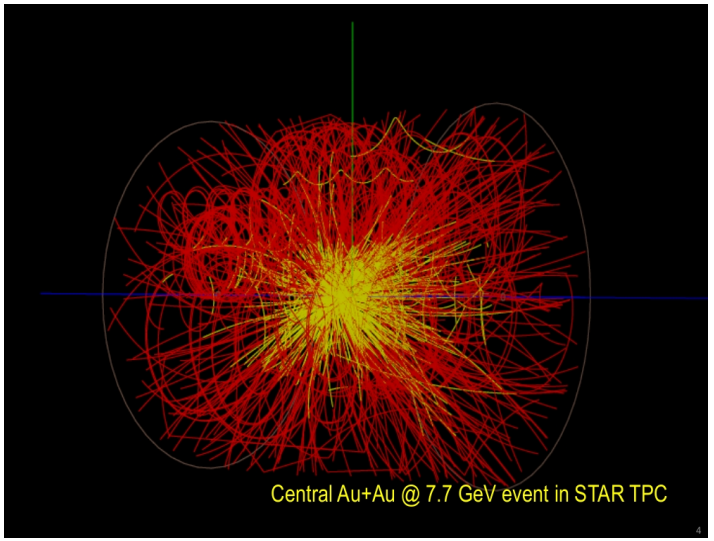




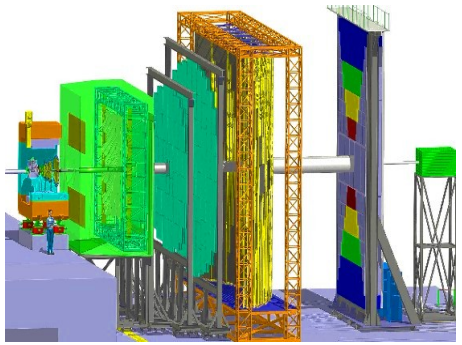
- quarkonia melting
- heavy quark diffusion

Heavy ion collision experiments and Lattice QCD

RHIC Beam Energy Scan

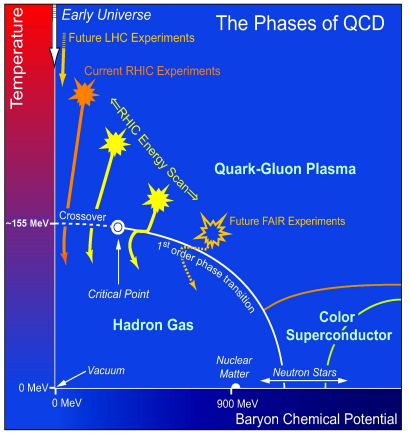


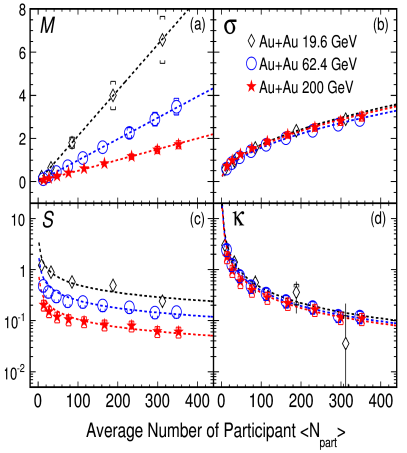
CBM@FAIR



Properties of dense QCD

QCD critical point ?

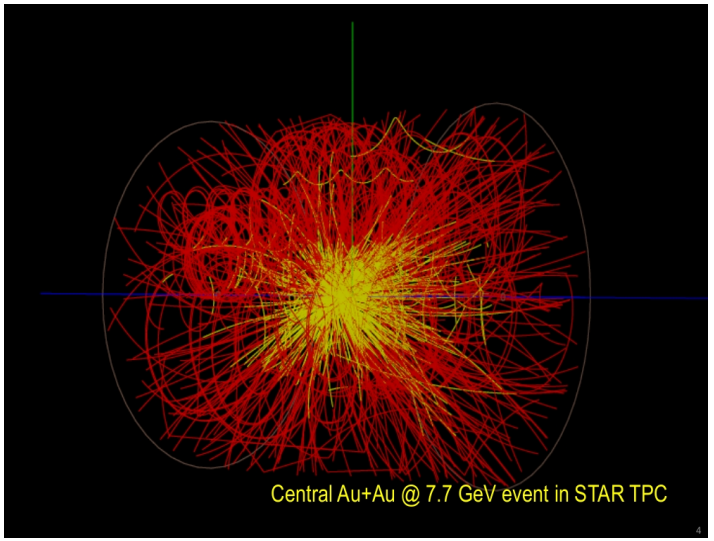




- transition temperature
- charge fluctuations & freeze-out condition
- equation of state
- (non-)existence of QCD critical point

Heavy ion collision experiments and Lattice QCD

RHIC Beam Energy Scan



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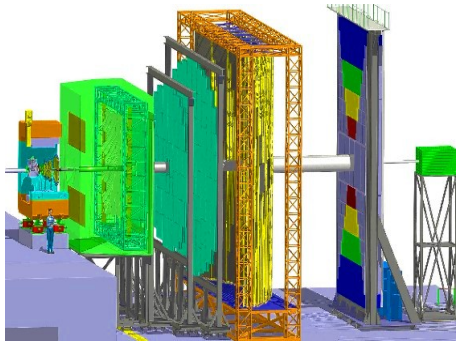
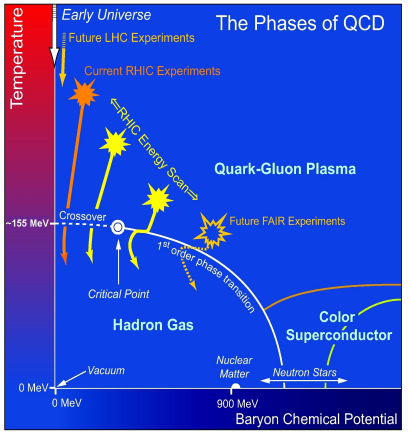
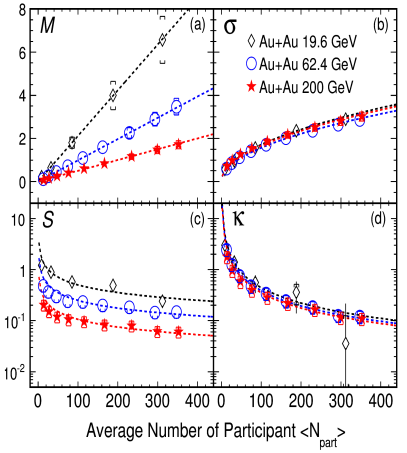


Properties of dense QCD

QCD critical point ?





- transition temperature
- charge fluctuations & freeze-out condition
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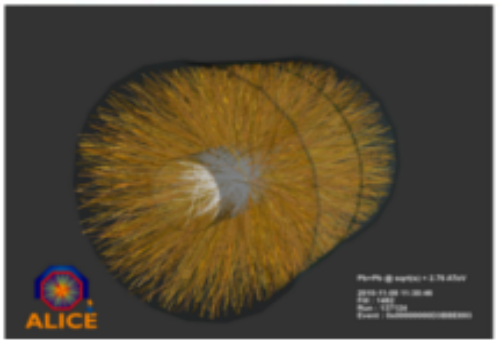
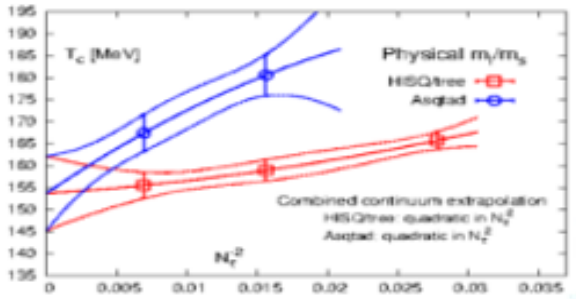
computational resources needed to address all these issues ?

Transition temperature and nature of QCD transition





$T_c = 154(9)$ MeV

nature of QCD transition using chiral fermions

QCD transition temperature from chiral fermions on coarser lattices

continuum value of QCD transition temperature from chiral fermions

continuum value of QCD trasition temperature from highly improved staggered fermions

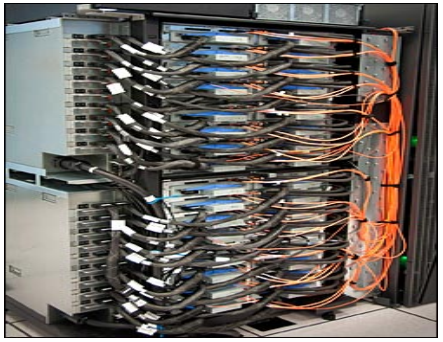
nature of QCD transition using highly improved staggered fermions

10x tera | 100x tera | peta | 10x peta | 100x peta | exaflop year sustained

chiral fermion:
Domain Wall Fermions

suitable hardware type:
BlueGene/Q

Sequoia @ LLNL

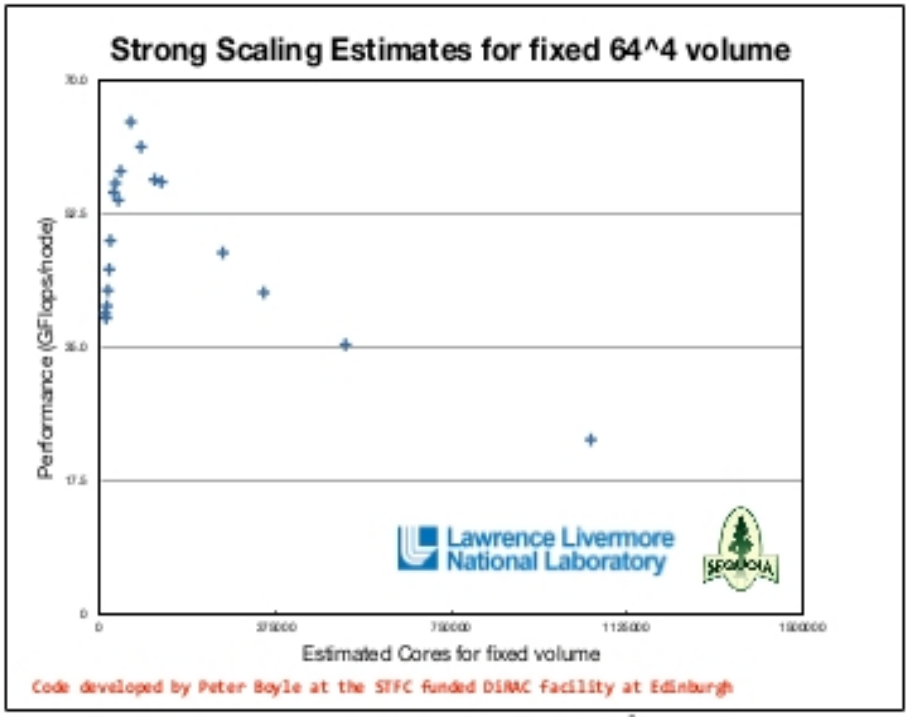


QCDCQ @ BNL

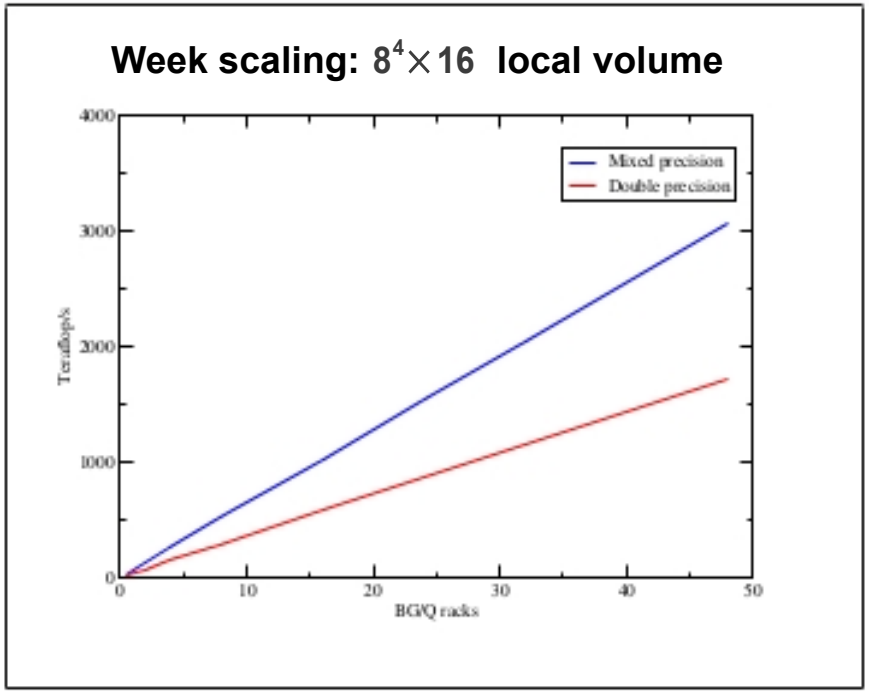
JuQeen @ Juelich

Mira @ ANL

Domain Wall Fermions on BlueGene/Q



532 Tflop/s, 8K nodes



3 Pflop/s sustained: 32% of peak

48 racks: 50% of machine

lattice size: $128^3 \times 96 \times 16$

early science time

hotQCD collaboration

Sequoia @ LLNL

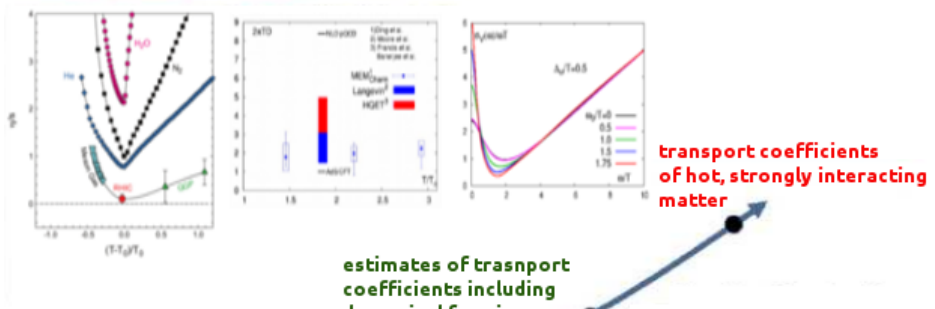
Courtesy: P. Boyle, Lattice 2012 & LGT group, LLNL

code development: C. Jung *et.al.*, SciDAC-2/3, USQCD

software suite: Columbia Physics System (CPS)

Transport coefficients, di-lepton rates, heavy quark, EOS ...

Transport coefficients



transport coefficients of hot, strongly interacting matter

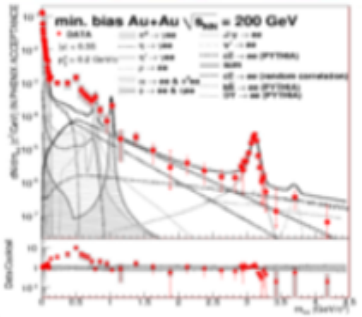
estimates of trasnport coefficients including dynamical fermions on coarse lattices

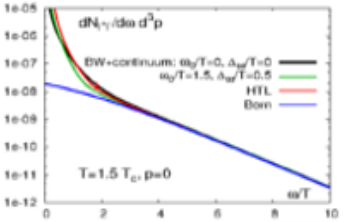
reliable estimates of trasport coefficients without dynamical fermions

viscosity
electrical conductivity
heavy quark diffusion

10x tera | 100x tera | peta | 10x peta | 100x peta | exaflop year sustained

Di-lepton/photon rate
Heavy quark melting

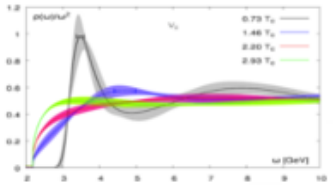


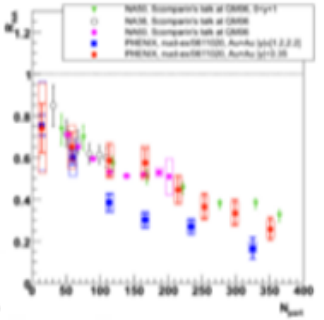


dilepton/photon rates & quarkonia melting temperatures in hot, strongly interacting matter

estimates of dilepton/photon rates & quarkonia melting temperatures including dynamical fermions on coarse lattices

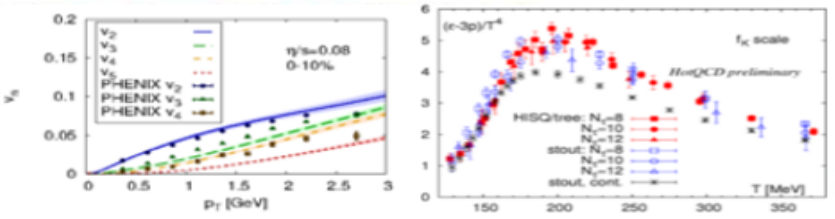
reliable estimaes of dilepton/photon rates & quarkonia melting temperatures without dynamical fermions





10x tera | 100x tera | peta | 10x peta | 100x peta | exaflop year sustained

Equation of state



precision computation of continuum extrapolated EOS with highly improved staggered fermions

EOS using improved staggered fermions

high T limit of EOS with highly improved staggered fermions

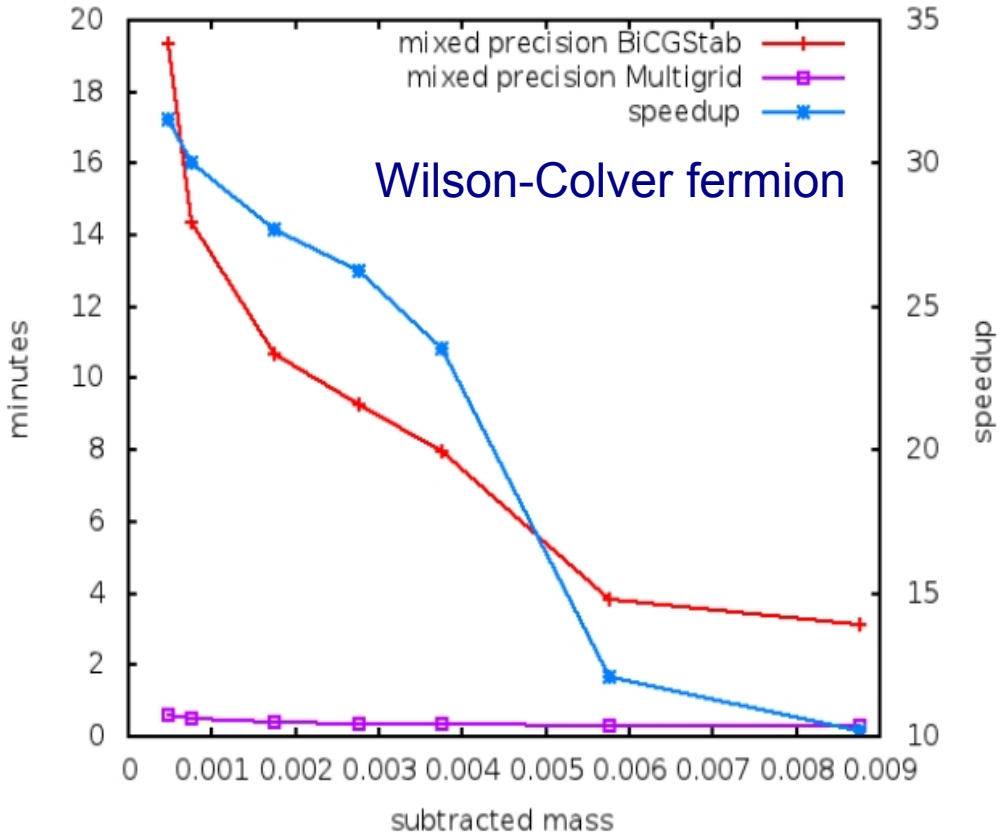
continuum extrapolated EOS with dynamical charm quarks using highly improved staggered fermions

10x tera | 100x tera | peta | 10x peta | 100x peta | exaflop year sustained

fermion type:
highly improved staggered
Wilson-Clover

suitable hardware type:
Blue Gene / Q

… on BlueGene/Q



25 times faster

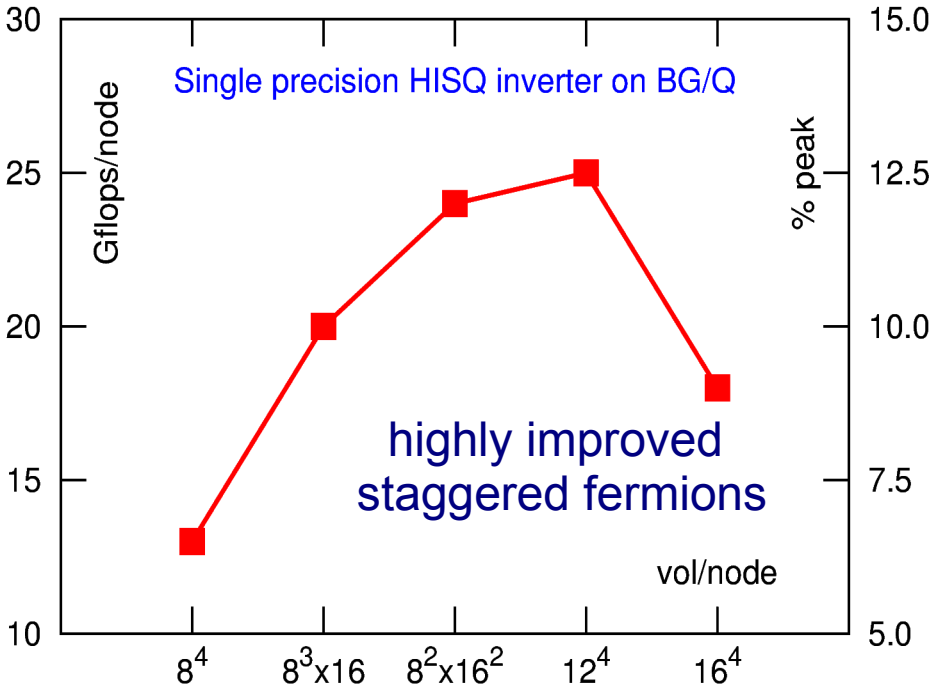
new algorithmic development
(multi-grid inverter)

code development: J. Osborn,
SciDAC-2/3, USQCD

software suites: MILC, Multi-Grid Inverter, ...

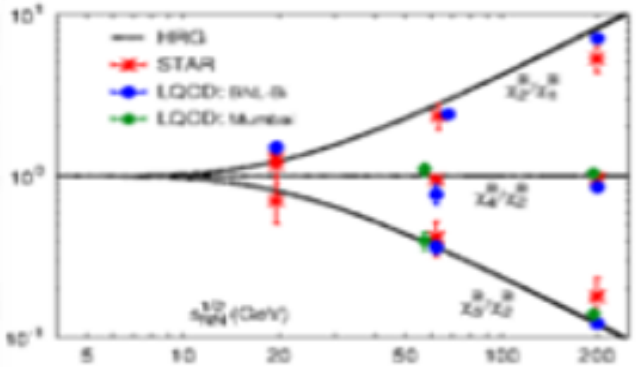
Mira @ ANL

Courtesy: J. Osborn, ANL



13% of peak

Properties of dense QCD



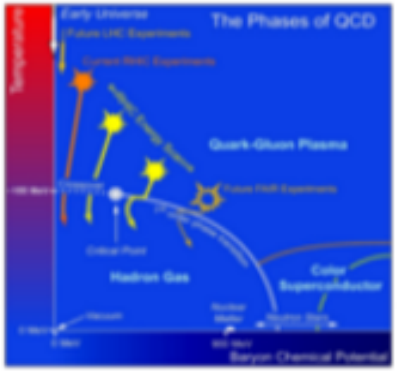
fermion type:
highly improved staggered

suitable hardware type:
GPU-based

transition temperature & EOS at non-zero density, (non)exsistance of the QCD critical end point

higher moments of charge fluctuations using highly improved staggered fermions on coarse lattices

freeze-out conditions of HIC from lattice QCD

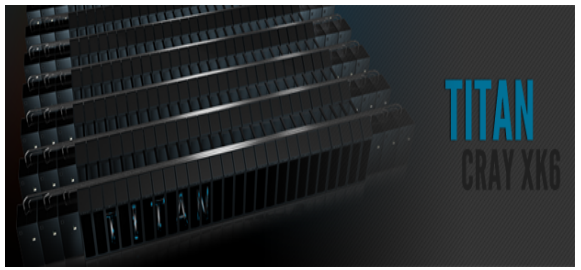


transition temperature at non-zero density using improved staggered fermions

transition temperature at non-zero density using highly improved staggered fermions on coarse lattices

10x tera | 100x tera | peta | 10x peta | 100x peta | exaflop year sustained

10g @ Jlab

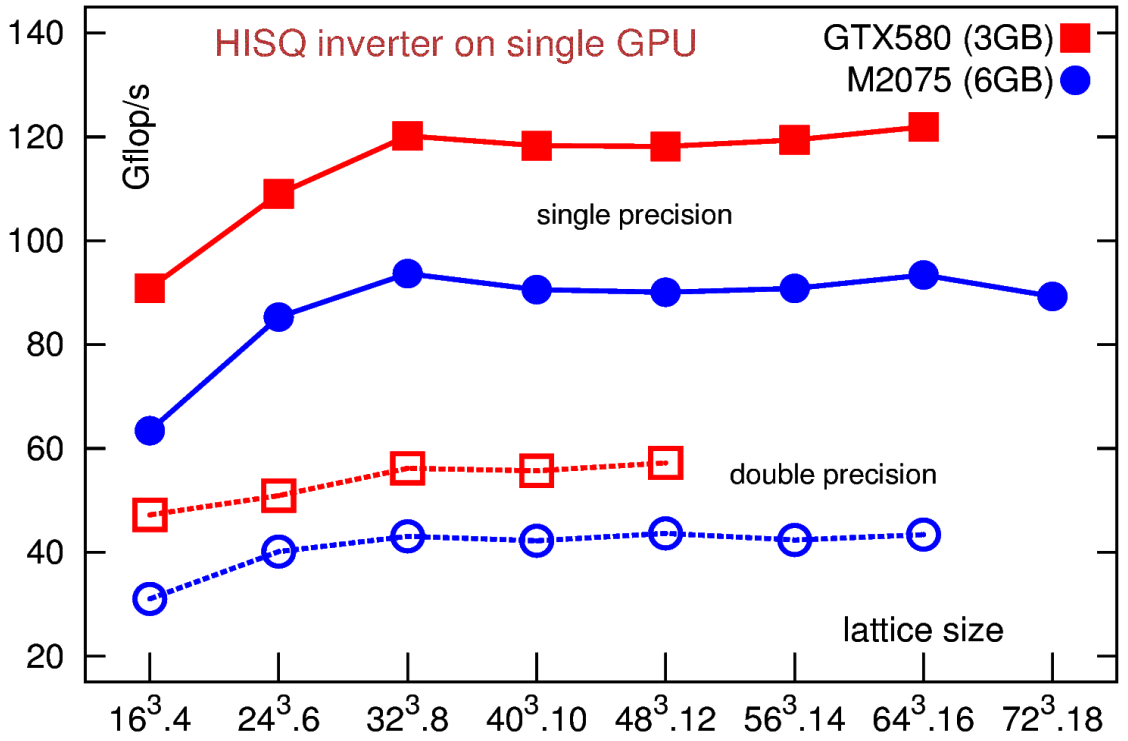


Titan @ ORNL

Edge @ LLNL

GPU-cluster @ Bielefeld

Dense QCD on graphics cards



125 Gflops/GPU

massive parallelizations possible
without sacrificing performance

GPU-cluster @ Bielefeld

thermodynamics is among the top 3
GPU users of US LQCD community

Courtesy: LGT group, Bielefeld

- computations completely dominated by fermion matrix inversions
- even the ultra-fine lattices fit into single GPU
- requires ~15K inversions on each gauge field configuration
- ideally suited for large scale GPU based architectures

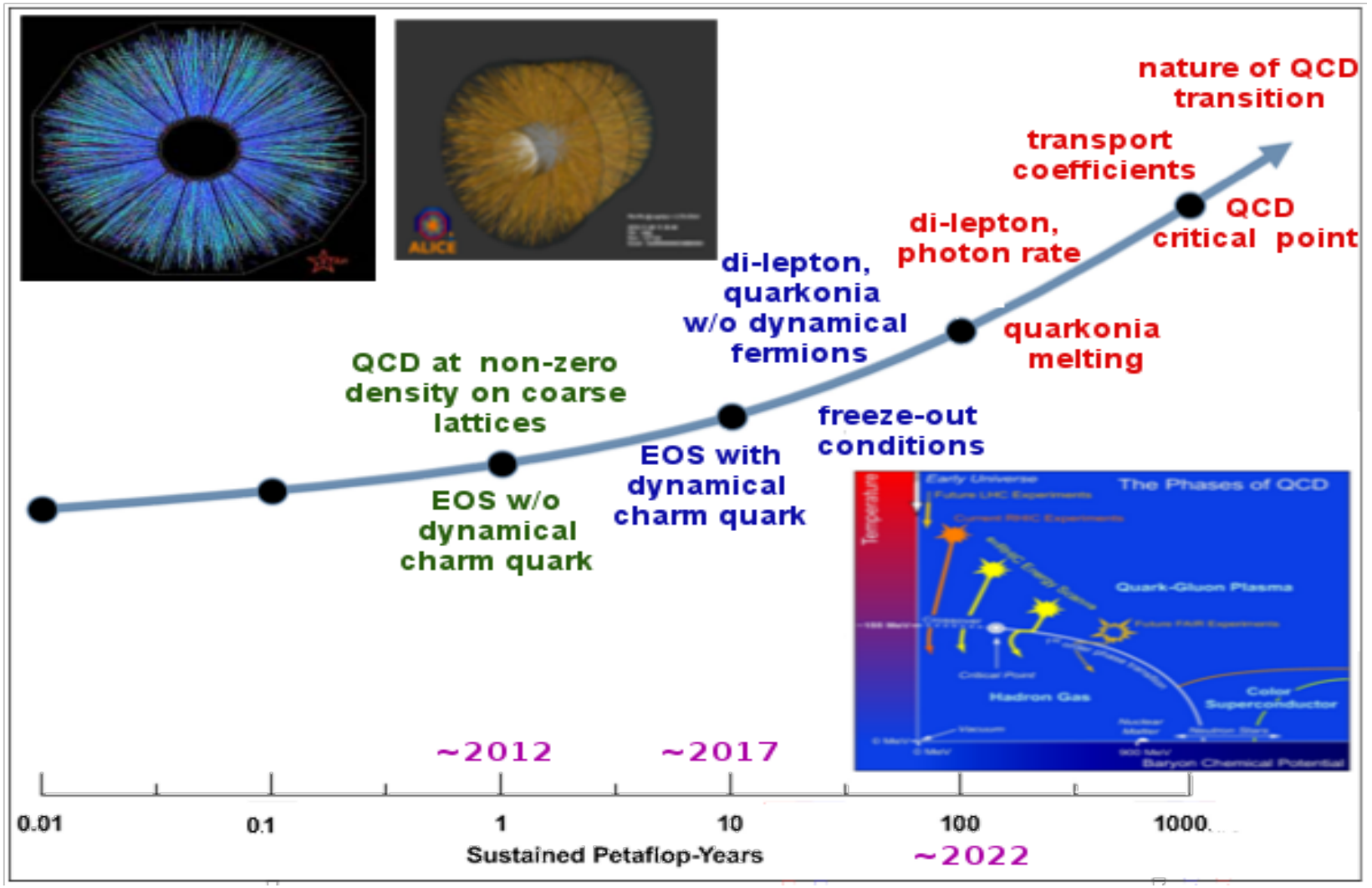
code development: M. Wagner & C. Schmidt, Bielefeld

software suite: Bielefeld code

Summary

require both BlueGene/Q type and GPU based machines

based on our present performances we can achieve ...



… if we continue to get adequate support

assuming computing increases x10 each 5 year