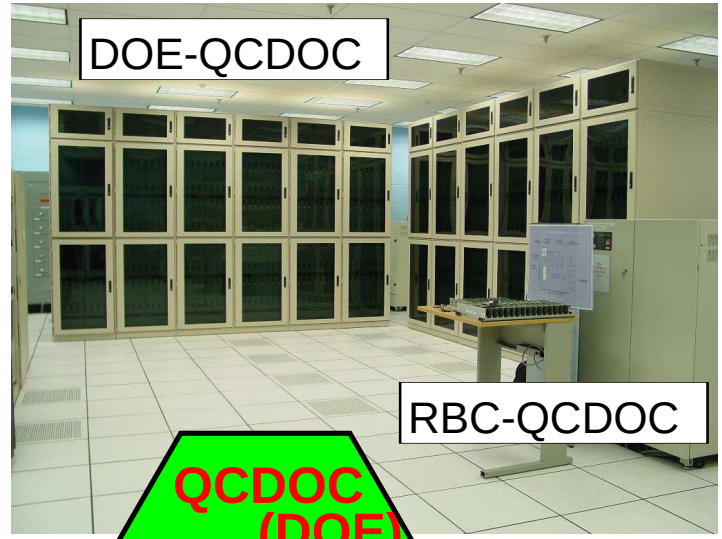
Lattice Gauge Theory at BNL

- The LGT group and the BNL environment
- BNL role in USQCD
- recent physics results
- LQCD-II proposal

Lattice Gauge Theory @ BNL

RHIC



RIKEN

BNL

QCDOC

QCDOC (DOE)

ITD (NY)

NYBlue

LGT

hot&dense QCD

NT

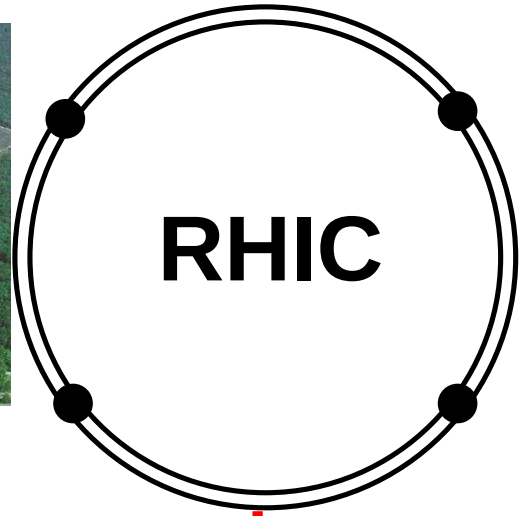
heavy ion phenomenology

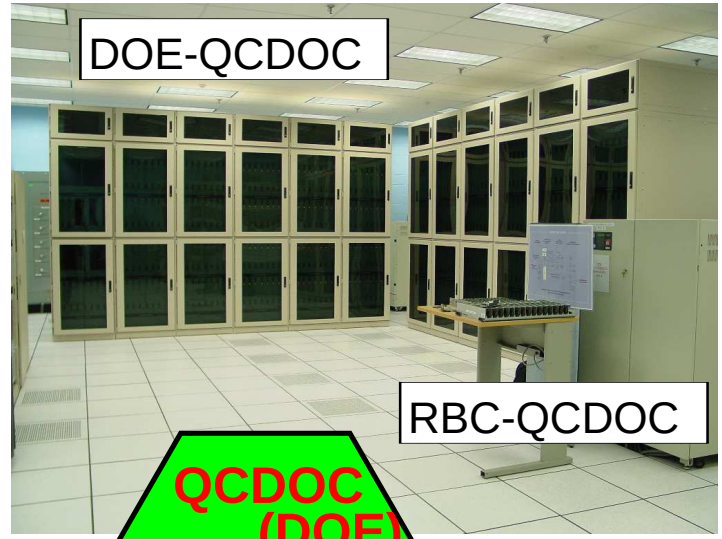
HEP

LGT&particle physics

LGT group provides theoretical support for the experimental heavy ion program at BNL

Lattice Gauge Theory @ BNL

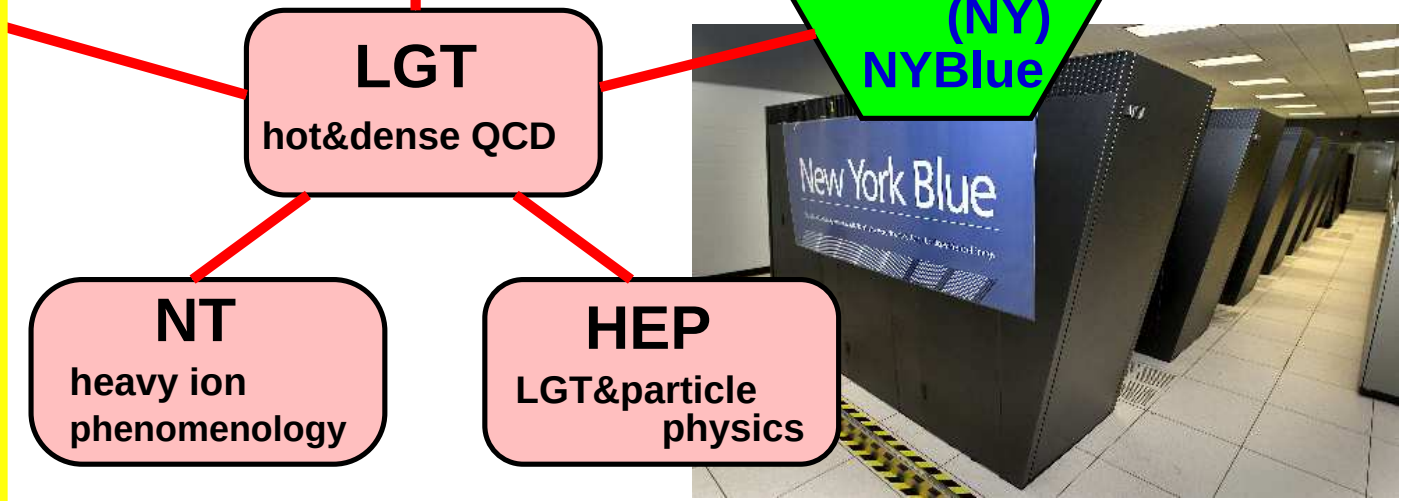




Collaborations &

Cooperations

- RBC-Bielefeld (uses QCDOC, NYBlue, apeNEXT)
- hotQCD (RBC-BI+LLNL +LANL; uses BGL@LLNL)
- USQCD (LQCD ⇒ LQCD-II)
- SciDAC-I and II



LGT group provides theoretical support for the experimental heavy ion program at BNL

The USQCD Collaboration

- The USQCD Collaboration consists of nearly all the high energy and nuclear physicists in the United States involved in the numerical study of QCD. It was formed nine years ago with the goal of developing the computational infrastructure needed for these studies

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- The USQCD Collaboration consists of nearly all the high energy and nuclear physicists in the United States involved in the numerical study of QCD. It was formed nine years ago with the goal of developing the computational infrastructure needed for these studies
- Membership in USQCD is open to all scientists in the United States; access to hardware is open to members on a peer reviewed basis; the software is publicly available
- USQCD software development is funded through SciDAC I grant (2001-2006) and SciDAC II grant (2006-2011);
- USQCD hardware development is currently funded through a DOE LQCD grant (2006-2009);
- USQCD builds infrastructure as a community, but does science in groups or as individuals

LQCD project: hardware

6n@JLAB

QCDOC@BNL

USQCD operators computer installations at BNL, FNAL and JLAB funded through the LQCD project;

USQCD performs software development for its machines (funded through SciDAC); software packages are publicly available

software and hardware support at BNL:
Stratos Efstathiadis
Chulwoo Jung
Enno Scholz

kaon@FNAL

Research areas

- The determination of fundamental parameters of the Standard Model, and precision tests of the Standard Model (BNL High Energy group)
  - Experiments impacted: BaBar (SLAC), Bell (KEK), CLEO-c (Cornell), CDF and D0 (FNAL) and LHC (CERN).
- QCD at nonzero temperature and density (BNL Lattice Group)
  - Experiments impacted: RHIC (BNL), FAIR (GSI) and LHC (CERN)
- The spectrum, internal structure and interactions of hadrons
  - Experiments impacted: CEBAF (TJNAF), RHIC (BNL)
- Theories for Physics Beyond the Standard Model
  - Experiments impacted: LHC (CERN)

future plans outlined in four 2007 White papers:

http://www.usqcd.org/collaboration.html#2007Whitepapers

BNL members of writing committee: Michael Creutz, Frithjof Karsch

USQCD Committees

- LQCD Executive Committee

  Richard Brower (Boston U.), Norman Christ (Columbia U.), Michael Creutz (BNL), Paul Mackenzie (FNAL), John Negele (MIT), Claudio Rebbi (Boston U.), David Richards (JLab), Stephen Sharpe (U. Washington), Robert Sugar, (UCSB , Chair)

- Scientific Program Committee

  Thomas Blum (U. Connecticut), Christopher Dawson (U. of Virginia), Frithjof Karsch (BNL), Andreas Kronfeld (FNAL, Chair), Colin Morningstar (Carnegie Mellon U.), John Negele (MIT), Junko Shigemitsu (Ohio State U.)

BNL's role in USQCD and LQCD

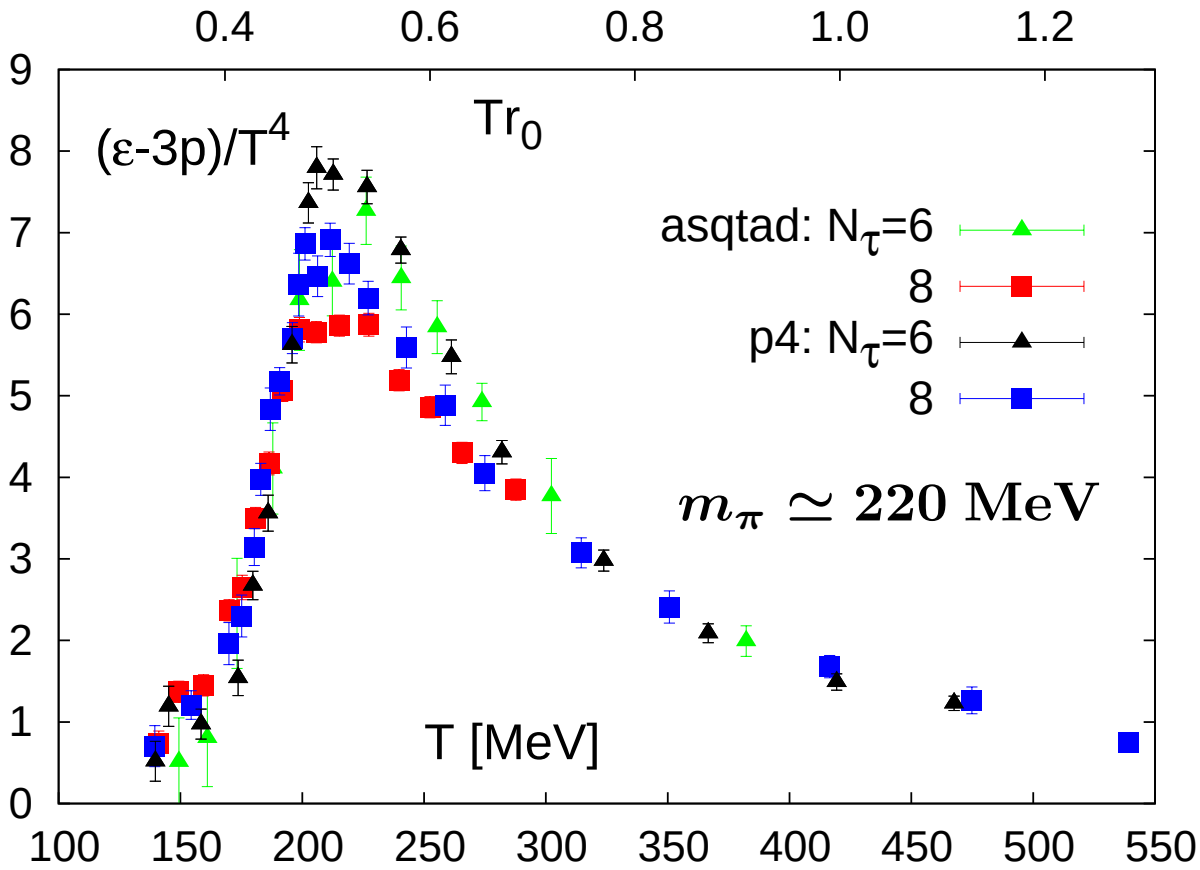
The 2007 LQCD Computing Project Review Report:

Contact with experiment is strong, partly because LQCD has computational and human resources spread over three national laboratories

- BNL has been the seed for the LQCD project; development of QCDOC as a joint RIKEN-BNL-Columbia-IBM project
- BNL operates the DOE-QCDOC; provides expertise on QCDOC and BlueGene software (partly supported through SciDAC grants)
- BNL provides space, electricity, air-conditioning etc.
- BNL provides networking infrastructure and computer security
- BNL's LGT group participates in all major US-based projects on QCD thermodynamics; stimulates contacts to experimental groups; serves the community through the organization of workshops

Thermodynamics of strongly interacting matter

- QCD thermodynamics close to the continuum limit
- input to the hydrodynamic modeling of heavy ion collisions



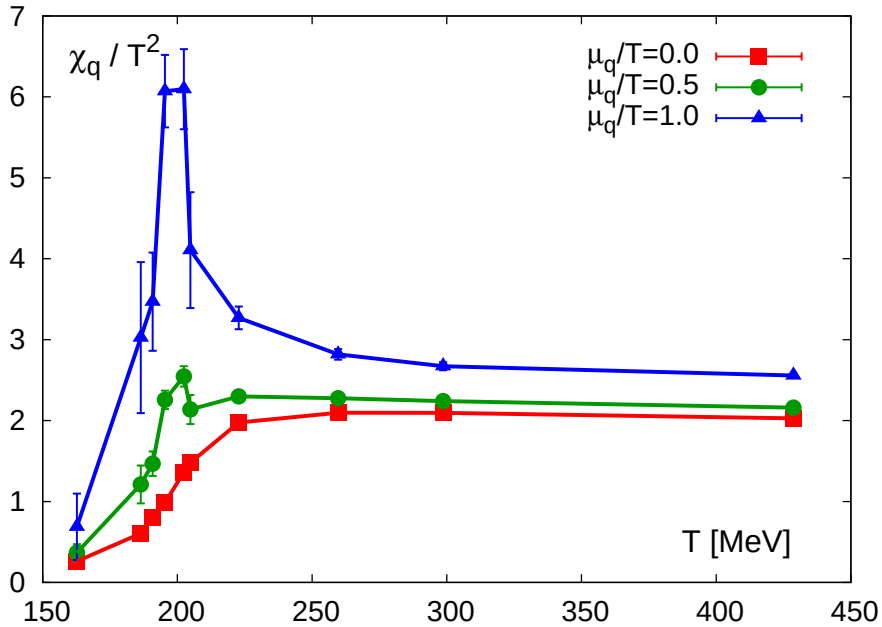
hotQCD Collaboration, preliminary

$\mu_q > 0$:QCD thermodynamics at non-zero baryon number density

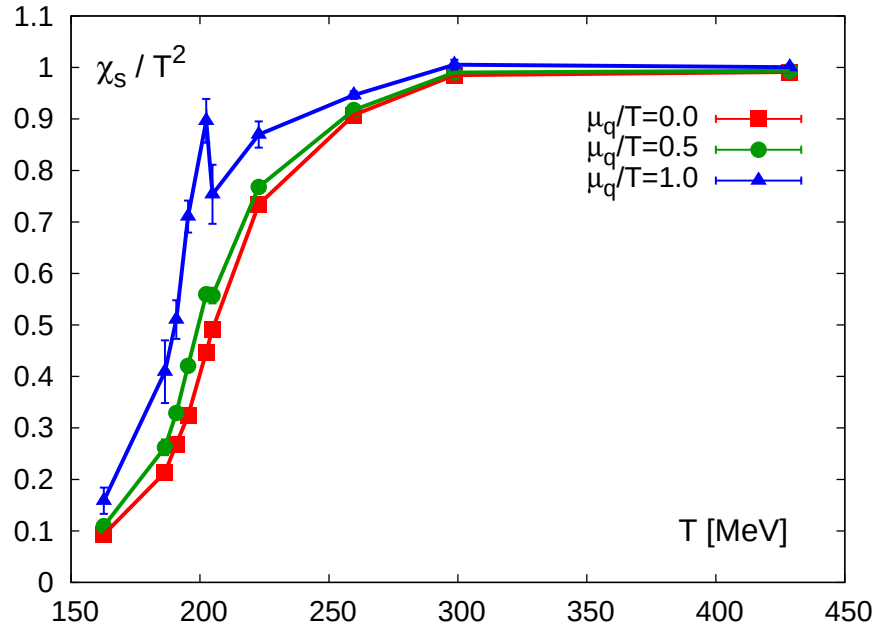
ongoing project of the RBC-Bielefeld collaboration

- fluctuations of baryon number and strangeness in (2+1)-flavor QCD
- input to RHIC low energy program and the search for a critical point

light quark number fluctuation



strangeness fluctuation



$\Rightarrow$ large quark number fluctuations

$\Rightarrow$ enhanced strangeness fluctuations (so far only $\mathcal{O}(\mu^4)$!!)

- $\mathcal{O}(\mu^6)$ and $\mathcal{O}(\mu^8)$ main project activity of the BNL Lattice Group on QCDOC

The current LQCD project: 2006-2009

- the mission is to acquire and operate dedicated hardware for the study of quantum chromodynamics (QCD)
- hardware is located at BNL, FNAL and JLab
- the project is funded jointly by DOE's offices of High Energy Physics and Nuclear Physics

Fiscal Year	2006	2007	2008	2009	Total
hardware	$1,850	$1,592	$1,630	$798	$5,870
operations	$650	$908	$870	$902	$3,330
Total	$2,500	$2,500	$2,500	$1,700	$9,200

Funding of the LQCD Computing Project in thousands of dollars

LQCD Computing Project Hardware

(2008/09 installation at FNAL: 6.2 teraflops/s)

Computer	Site	Nodes	Performance (teraflop/s)
QCD	FNAL	127	0.15
4g	JLab	384	0.36
Pion	FNAL	518	0.86
QCDOC	BNL	12,288	4.20
6n	JLab	256	0.62
Kaon	FNAL	600	2.56
7n	JLab	396	2.98

operated at BNL; software support at BNL

Computers operated by the LQCD Computing Project. The first three are SciDAC-1 clusters, and the last three are clusters obtained during the LQCD Computing Project.
Performance is measured as the average of that sustained by the sparse matrix inversion routines for Domain Wall and Improved Staggered quarks.
(peak performance: $\sim (4-5)$ times larger $\Rightarrow$ $\sim$ (80-100) teraflops/s peak)

LQCD-II proposal (2010-2014)

The 2007 LQCD Computing Project Review Report:

The resources provided through the LQCD project are crucial for the US lattice QCD community to stay internationally competitive. This will remain true beyond the final year of the LQCD project, 2009, and the committee believes that an increase in computational resources beyond 2009 should be strongly encouraged, building on the success of of the 2006-2009 LQCD project

- The goal of LQCD II is to achieve the Office of Science's FY 2009 strategic milestone to

  Use computer simulations to calculate strong interactions between particles so precisely that theoretical uncertainties no longer limit our understanding of these interactions

Thermodynamics projects on future machines

...LQCD-II thermodynamics projects (2010 - 2014)

(extension of (exploratory) studies on current Teraflops computers)

Project	Lattice	Temp. values	Quark Masses	MC traj.	TFlop Years†
EoS: $\mu = 0, T < 2T_c$	$48^3 \times 12$	10	2	100,000	100
EoS: $\mu = 0, T < 2T_c$	48^4	10	2	25,000	
EoS DWF: $\mu = 0, T \simeq T_c$	$48^3 \times 10 \times 96$	4	1	50,000	80
EoS: $\mu > 0, T < 0.95T_c$	$32^3 \times 8$	3-4	1	50,000	80
phase boundary $\mu \geq 0$	$32^3 \times 6$	4	5	10,000	100
spectral function, quenched	$128^3 \times N_\tau$	7	1	10,000	20
transport, dynamical	$48^3 \times N_\tau$	7	1	10,000	100

† TFlop Years $\equiv$ sustained TFlop Years $\simeq$ 1/5 peak TFlop Years

Projects and CPU requirements (2007 White Paper)

50% of the resources needed should be funded through LQCD-II

LQCD-II: Hardware Goals

LQCD-II proposal requests funding for Dedicated Hardware only

Fiscal Year	Dedicated Hardware (Tflop-Years)*	Leadership Class Computers (Tflop-Years)*
2010	30	30
2011	60	50
2012	100	80
2013	160	130
2014	255	210
Totals	610	500

Computing resources from the use of dedicated hardware (column 2) and leadership class computers (column 3) needed to carry out the scientific program by fiscal year

* Computing resources are given in Tflop-Years calculated in USQCD units

(peak performance about a factor 4 larger)

LQCD-II: Budget request

Fiscal Year	Hardware Budget	Operations Budget	Total Budget
2010	3.00	1.45	4.45
2011	3.00	1.50	4.50
2012	3.00	1.60	4.60
2013	3.00	1.65	4.65
2014	3.00	1.70	4.70
Totals	15.00	7.90	22.90

LQCD-II budget request in millions of dollars.

- about 1/3 of this budget would go into installation and operation of hardware at BNL
- according to this plan QCDOC would operate at BNL until 2010; new hardware would be installed in 2011

Impact of LQCD-II on research at BNL

The 2008 LQCD-II Computing Project Review Report:

Lattice calculations are influencing the experimental physics plans at RHIC and JLAB. The lower energy runs planned at RHIC are the result of investigations in lattice simulations of QCD at non-zero temperature and baryon number.....

The review committee advocates full funding for LQCD II at the level described in their proposal. The scenario in which the funding for LQCD II would be flat with LQCD would cause the project to miss opportunities...

- a large fraction of QCD thermodynamics effort within USQCD is based on work done at BNL
- the LQCD-II proposal assumes that QCD thermodynamics projects would run mainly on dedicated hardware; 40% of time on dedicated hardware shall be used for QCD thermodynamics calculations!!
- Lattice studies of QCD thermodynamics would profit tremendously from a continuation of the LQCD project.