Lattice Gauge Theory at BNL

Michael Creutz

Lattice gauge theory a major effort here

Many dramatic past successes

- Confinement — Quark Confining Dynamics
- Hadronic spectrum
  - Verification of chiral symmetry breaking $m_\pi^2 << m_\rho^2$
- Deconfinement at high temperature $T_c \sim 170$ Mev
- Matrix elements to test standard model (K decays, etc.)

Many experiments rely on non-perturbative results for interpretation

- plasma at BNL
- particle spectra
- $g - 2$
- structure functions
- weak decays

Lattice is the primary non-perturbative tool of the theorist

- Terascale computing essential to progress
  - theory errors often dominate
  - cheap compared to supported experiments

From "Fundamental parameters from future lattice calculations," Lattice QCD Executive Committee

Hadronic Matrix Element	Quenched Estimate in 2000	Lattice Result Current	UTA Result Current	Lattice Errors 10. TF-Yr	Lattice Errors 50. TF-Yr
$\widehat{B}_K$	0.87 ± 0.15	0.77 ± 0.08	0.75 ± 0.09	± 0.05	± 0.03
$f_{B_s}\sqrt{\widehat{B}_{B_s}}$	262 ± 40 MeV	282 ± 21 MeV	261 ± 6 MeV	± 16 MeV	± 9 MeV
ξ	1.14 ± 0.07	1.23 ± 0.06	1.24 ± 0.08	± 0.04	± 0.02

Table 1: History, status and future of lattice QCD calculations of three matrix elements which play a key role in the determination of CKM matrix elements. Quenched estimates from 2000 taken from Ref. [6], UTA values from Ref. [9, 10]. Present results are from Refs. [11, 12] (B_K), [13] ($f_{B_s}\sqrt{B_{B_s}}$), and [14] (ξ), and will be discussed further in sec. 4. Note that none of the present lattice results include fully controlled estimates of all errors.

B_K determines the CP violating part of the $K\overline{K}$ mixing ϵ_K

$f_{B_s}\sqrt{\hat{B}_{B_s}}$ controls the rate of $B_s\overline{B}_s$ mixing

ξ determines the relative size of $B_s\overline{B}_s$ and $B_d\overline{B}_d$ mixing

The QCD Equation of State with almost Physical Quark Masses

M. Cheng[a], N. H. Christ[a], S. Datta[b], J. van der Heide[c], C. Jung[b], F. Karsch[b,c], O. Kaczmarek[c], E. Laermann[c], R. D. Mawhinney[a], C. Miao[c], P. Petreczky[b,d], K. Petrov[e], C. Schmidt[b] and T. Umeda[b]

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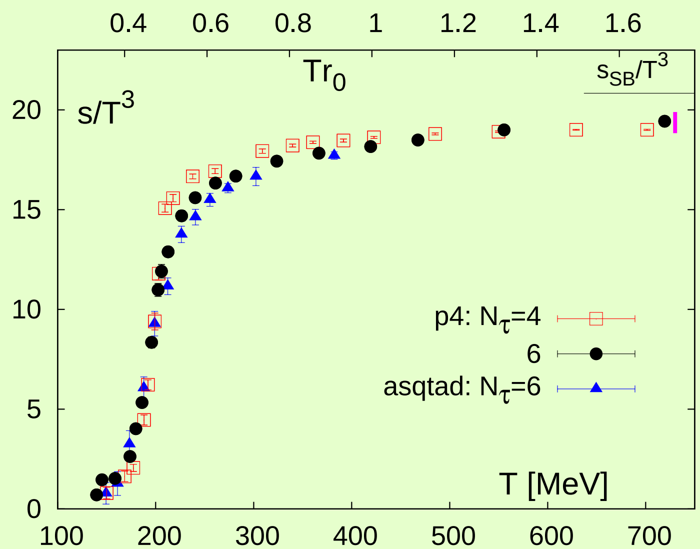


FIG. 10: Entropy density as function of the temperature obtained from calculations on lattices with temporal extent $N_\tau = 4$ and 6. Temperature and energy density scales have been obtained using the parametrization of r_0/a given in Eq. 22 and $r_0 = 0.469$ fm. The small vertical bar in the left hand figure at high temperatures shows the estimate of the systematic uncertainty on these numbers that arises from the normalization of the pressure at $T_0 = 100$ MeV.

Numerical lattice gauge theory pioneered at BNL

Major effort of the high energy theory group since late 1970’s

Current HET group members concentrating on the lattice

- Michael Creutz
- Amarjit Soni

Plus two supported by SciDAC (I’m the BNL PI)

- Chulwoo Jung
- Enno Scholz

Shrinking HET group compensated by major growth of other groups

New lattice gauge group associated with nuclear theory

Frithjof Karsch (group leader)
Shinji Ejiri
Kay Huebner
Peter Petreczky
Claudio Pica
Christian Schmidt
Wolfgang Soeldner

RIKEN Brookhaven Research Center and affiliates

Sinya Aoki
Yasumichi Aoki
Tom Blum
Zhihua Dong
Tomomi Ishikawa
Taku Izubuchi
Adam Lichtl
Shigemi Ohta

Close collaboration with Columbia

Norman Christ
Robert Mawhinney
many students

APS

Urs Heller

Strengthening collaboration with UKQCD (Edinburgh)

BNL is a world class place for lattice people!

BNL effort concentrated in three areas

- hadronic corrections weak matrix elements
  - Riken-Brookhaven-Columbia collaboration (RBC)
  - using domain wall fermions for good chiral symmetry
  - lattices generated have many other uses
- QCD in extreme conditions (Karsch et. al)
  - mainly finite temperature $T_c \sim$ 170 MeV; J/ψ dissolution
  - exploratory probes of finite density critical endpoint
- algorithmic issues (MC)
  - staggered fermions involve an uncontrolled approximation
  - no known lattice formulation for weak interactions

Contentious fermion algorithm issues

- Staggered fermions
  - very fast to simulate but proven wrong in continuum limit
  - dominate the US effort outside RBC
- Wilson and improved Wilson fermions
  - still reasonably fast but tuning issues for chiral symmetry
  - twisted mass variation looks quite promising
  - primarily pursued in Europe
- Domain wall
  - 10-100 times slower but much better chiral symmetry
  - basic thrust of RBC collaboration
- Overlap operator
  - exact chiral limit of domain wall but another 10-100 slower
  - some heroic efforts in Japan

The US Lattice QCD Project

Part of SciDAC: Scientific Discovery through Advanced Computation

Goal: provide needed infrastructure for large lattice projects

- both hardware and software components

85 US lattice theorists; 9 member executive committee:

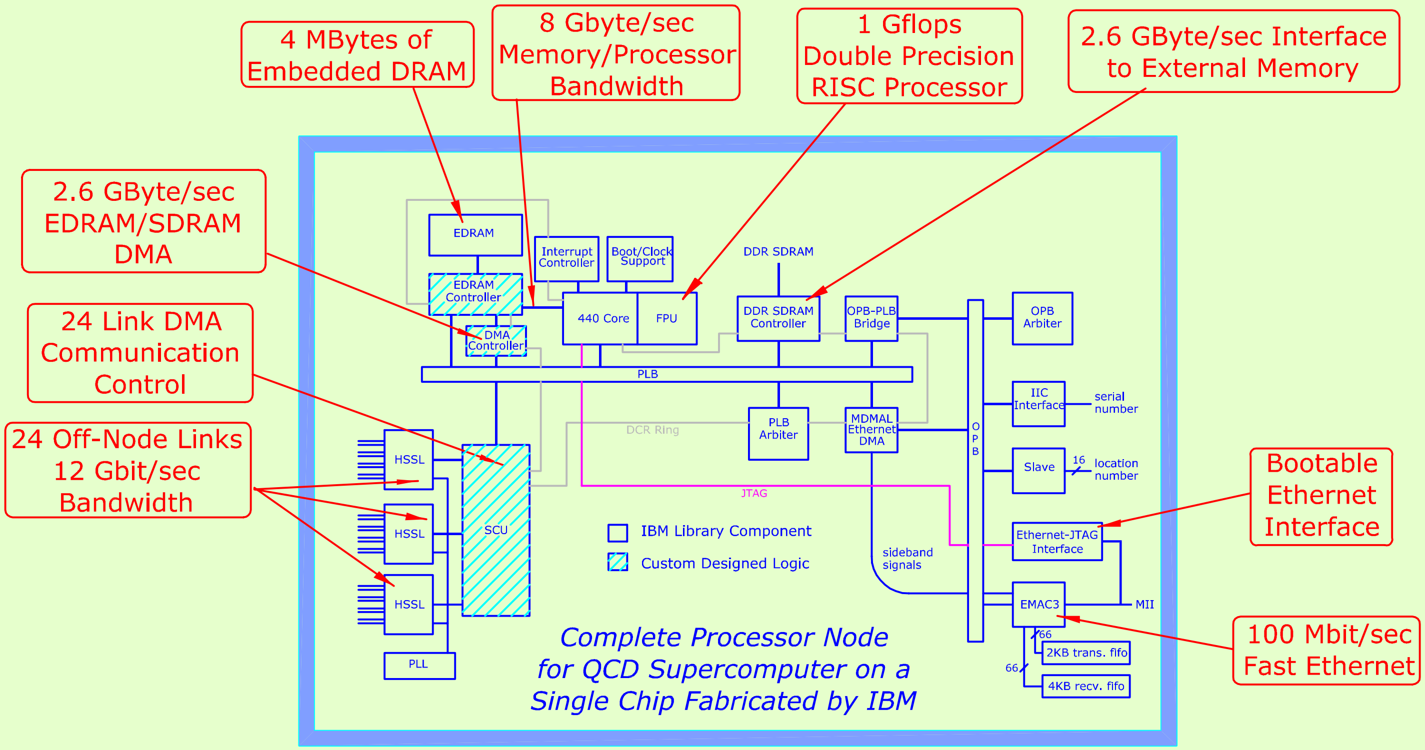
R. Brower, (Boston U.) N. Christ (Columbia U.), M. Creutz (BNL), P. Mackenzie (Fermilab), J. Negele (MIT), C. Rebbi (Boston U.), D. Richards (JLAB), S. Sharpe (U. Washington), R. Sugar (UCSB) (chair)

Two prong hardware approach

- QCDOC at BNL
- commodity clusters at Fermi Lab and Jefferson Lab
- $\sim 3 \times 10$ Teraflops distributed computing facility

QCDOC places entire compute node on a single custom chip

QCDOC ASIC DESIGN



Misson-critical, custom logic (hatched) for high-performance memory access and fast, low-latency off-node communications is combined with standards-based, highly integrated commercial library components.

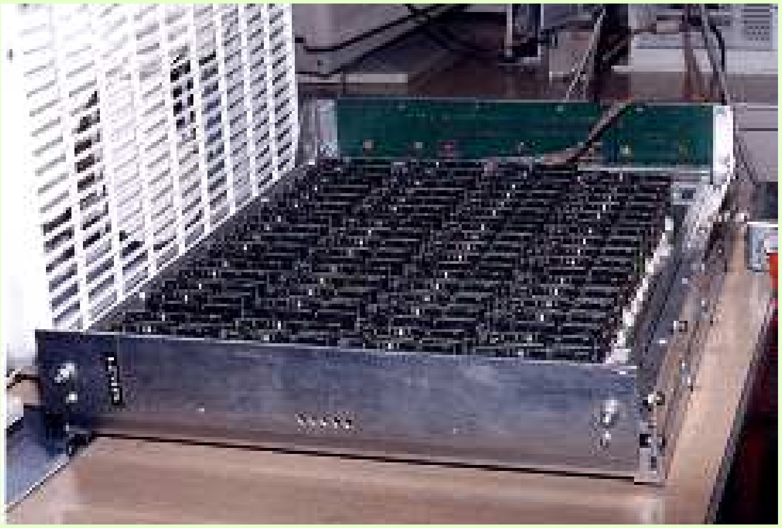
QCDOC

- next generation after QCDSP
- designed by Columbia University with IBM
- on design path to IBM Blue Gene
- Power PC nodes connected in a 6 dimensional torus
- processor/memory/communication on a single chip

UKQCD, RIKEN, DOE machines all running production

- 12K+ processors each
- Columbia Physics System Dirac inverter $\sim 40\%$ of peak
- MILC code $\sim 20\%$ of peak


DB 2



New resources

- NY State Blue Gene at BNL
- substantial resources expected at Argonne and Oak Ridge
  - through SciDAC
- some use of LLNL machines behind the fence
  - for QCD thermo
  - Karsch, via Rajan Gupta

Selective Sequence Electronic Calculator (IBM) - 1948

Where next?

- followup to QCDOC?
  - RBRC supporting development with Columbia and IBM
  - little public information, maybe a factor of 20-50
  - should DOE also get involved via SciDAC?
- Blue Gene or other traditional supercomputers?
- use resources at other labs for gauge computing resources
  - are commodity clusters too limited?

Time to think about the future