LATTICE GAUGE PLANS

Michael Creutz

Lattice gauge theory is a powerful tool

Successes

- Confinement   **Q**uark **C**onfining **D**ynamics
- Hadronic spectrum
- Verification of chiral symmetry breaking $m_\pi^2 << m_\rho^2$
- Deconfinement at high temperature $T_c \sim 150$ Mev
- Matrix elements to test standard model (K decays, etc.)

Future Potential

Experiments need lattice results for interpretation

- plasma at BNL; $g-2$
- structure functions at JLAB
- weak decays at FNAL, SLAC, BNL, CLEO

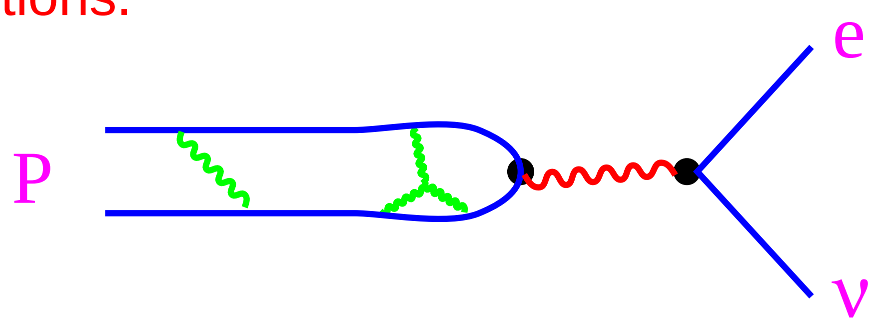
Theory errors often dominate

Remove quenched approximation

TERASCALE COMPUTING ESSENTIAL TO PROGRESS

Matrix elements

To test standard model predictions for weak decays, need strong interaction corrections.



G. Martinelli, Lattice 2001:

Table 2
Lattice results for $\Delta I = 1/2$ transitions using $K \to \pi$ matrix elements from RBC and CP-PACS. The experimental numbers are also given.

Reference	$Re\mathcal{A}_0$	$Re\mathcal{A}_2$	$Re\mathcal{A}_0/Re\mathcal{A}_2$	ϵ'/ϵ
CP-PACS [3]	$16 \div 21 \times 10^{-8}$	$1.3 \div 1.5 \times 10^{-8}$	$9 \div 12$	$-7 \div -2 \times 10^{-4}$
RBC [4]	$29 \div 13 \times 10^{-8}$	$1.1 \div 1.2 \times 10^{-8}$	$24 \div 27$	$-8 \div -4 \times 10^{-4}$
ps. [16–18] 2001	33.3×10^{-8}	1.5×10^{-8}	22.2	$17.2 \pm 1.8 \times 10^{-4}$

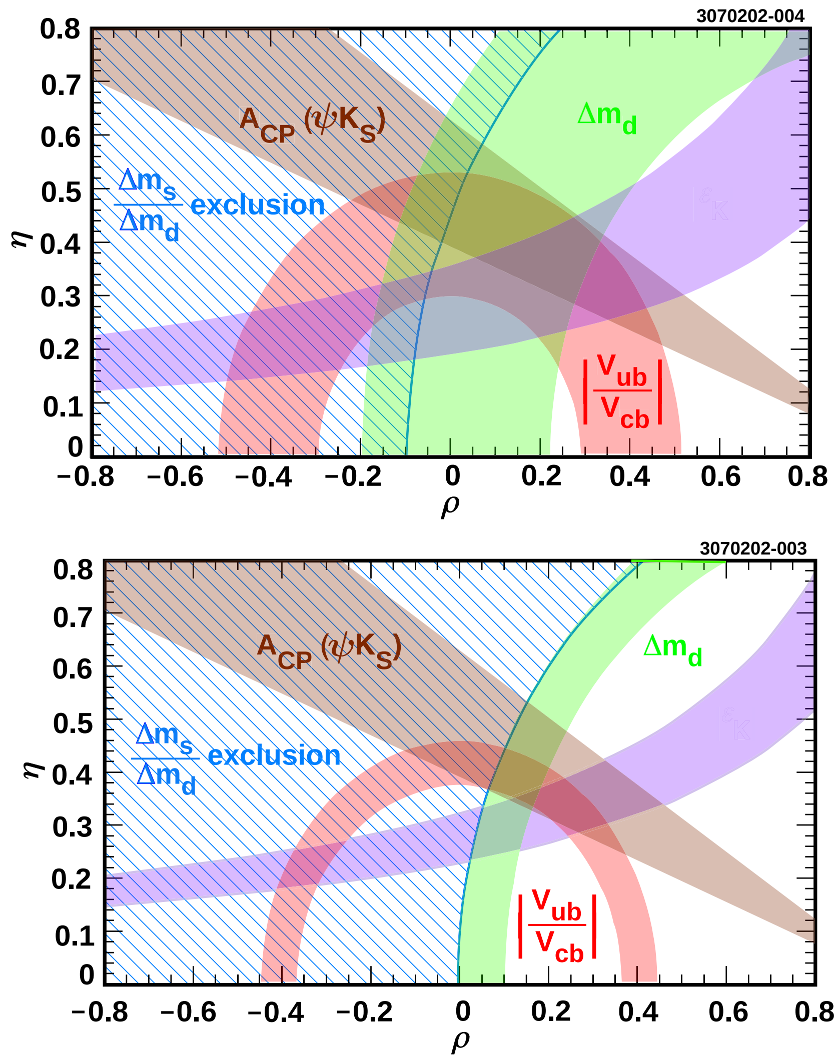
- $\Delta I = 1/2$ rule verified
- ϵ'/ϵ puzzling?
- systematic quenching errors under investigation
- heavy use of chiral perturbation theory

Impact of Lattice QCD on the Quark Mixing Matrix

Measurement	CKM Matrix Element	Hadronic Matrix Element	Expt. Error	Current Lattice Error	Lattice Error 0.5 TF-Yr	Lattice Error 10 TF-Yr
ΔM_{B_d} ($\bar{B}B$ mixing)	$\lvert V_{td}\rvert^2$	$f_{B_d}^2 B_{B_d}$	4%	35%	18%	9%
$\Delta M_{B_s}/\Delta M_{B_d}$	$\lvert V_{ts}/V_{td}\rvert^2$	$f_{B_s}^2 B_{B_s}/f_{B_d}^2 B_{B_d}$	Not yet measured	10%	5%	3%
ε ($\bar{K}K$ mixing)	$\mathrm{Im}\, V_{td}^2$	B_K	2%	20%	10%	5%
$B \to \binom{\rho}{\pi} l\nu$	$\lvert V_{ub}\rvert^2$	$\langle \binom{\rho}{\pi} \rvert (V-A)_\mu \lvert B\rangle$	25%	Calc. in progress	15%	5–10%

The first column of this table shows experimental measurements that can be used to determine elements of the quark mixing (CKM) matrix, which are fundamental parameters of the Standard Model of High Energy Physics. The second column indicates the CKM matrix element that can be determined from the experiment of the first column, and the third column shows the hadronic matrix element that must be calculated on the lattice to relate the experimental data to the CKM matrix element. The fourth and fifth columns show the current experimental and lattice uncertainties, respectively. The last two columns indicate the improvements in lattice errors that could be obtained with computers sustaining 0.5 and 10 Tflops for one year.

Constraints on the CKM Matrix



Constraints on the Standard Model parameters ρ and η (one sigma confidence level). For the Standard Model to be correct, they must be restricted to the region of overlap of the solidly colored bands. The figure on the top shows the constraints as they exist today. The figure on the bottom shows the constraints as they would exist with no improvement in the experimental errors, but with lattice gauge theory uncertainties reduced to 3%. R. Patterson, Cornell University.

The Lattice SciDAC Project

66 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.), S. Sharpe (U. Washington), R. Sugar (UCSB) and W. Watson, III (JLab)

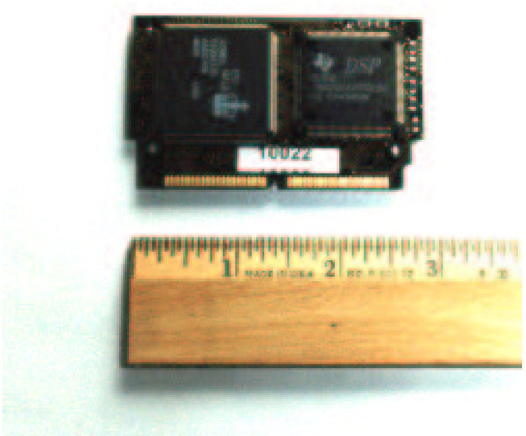
Two prong approach

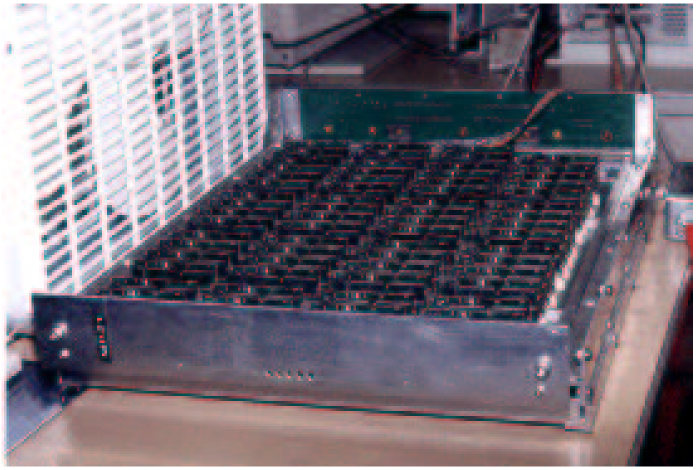
- QCDOC at BNL
- commodity clusters at Fermi Lab and Jefferson Lab
- $\sim 3 \times 10$ Teraflops distributed computing facility

QCDOC

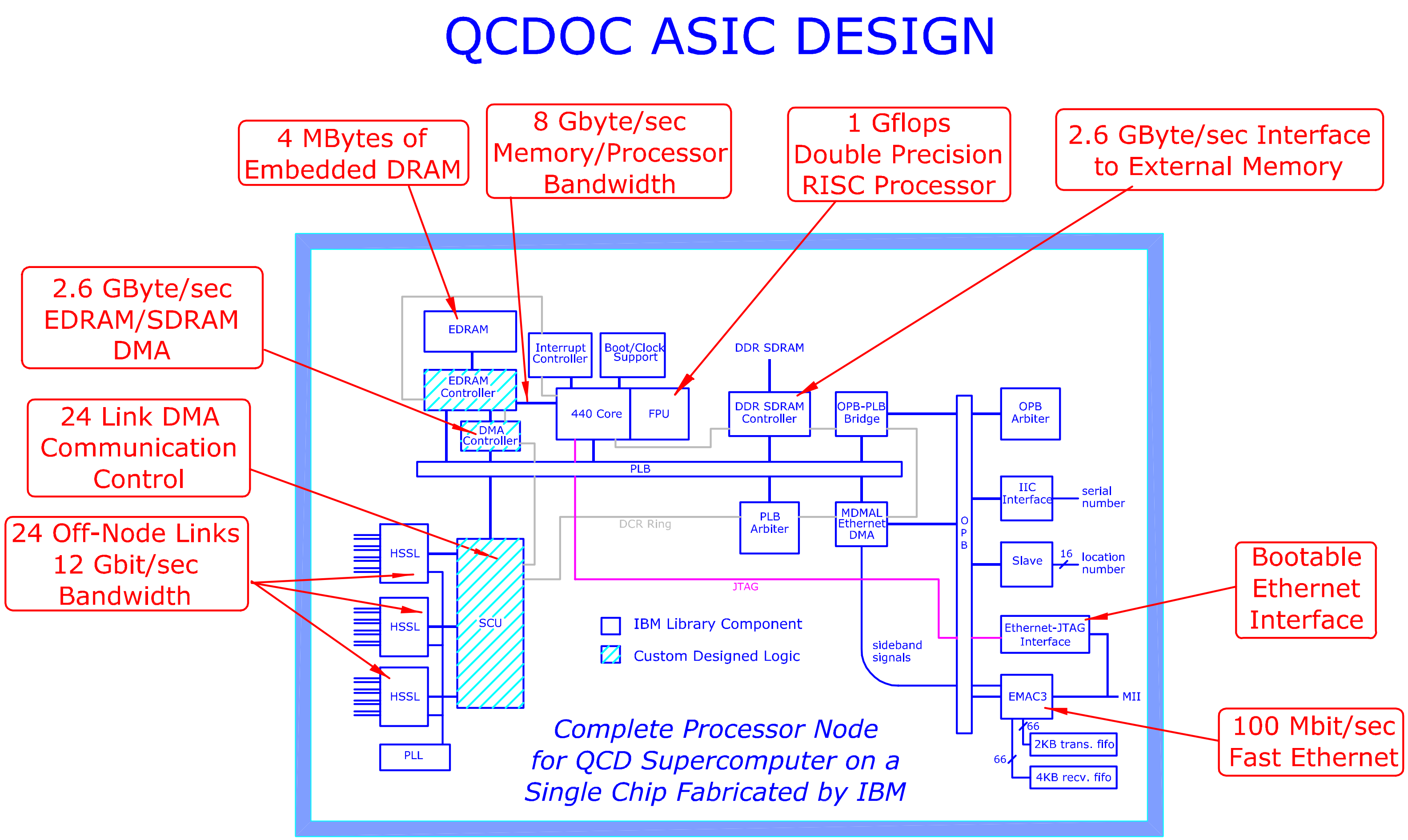
- next generation after QCDSP
- designed by Columbia University with IBM
- on design path to IBM Blue Gene
- Power PC nodes connected in a 6 dimensional torus
- processor/memory/communication on a single chip

Current RIKEN QCDSP machine

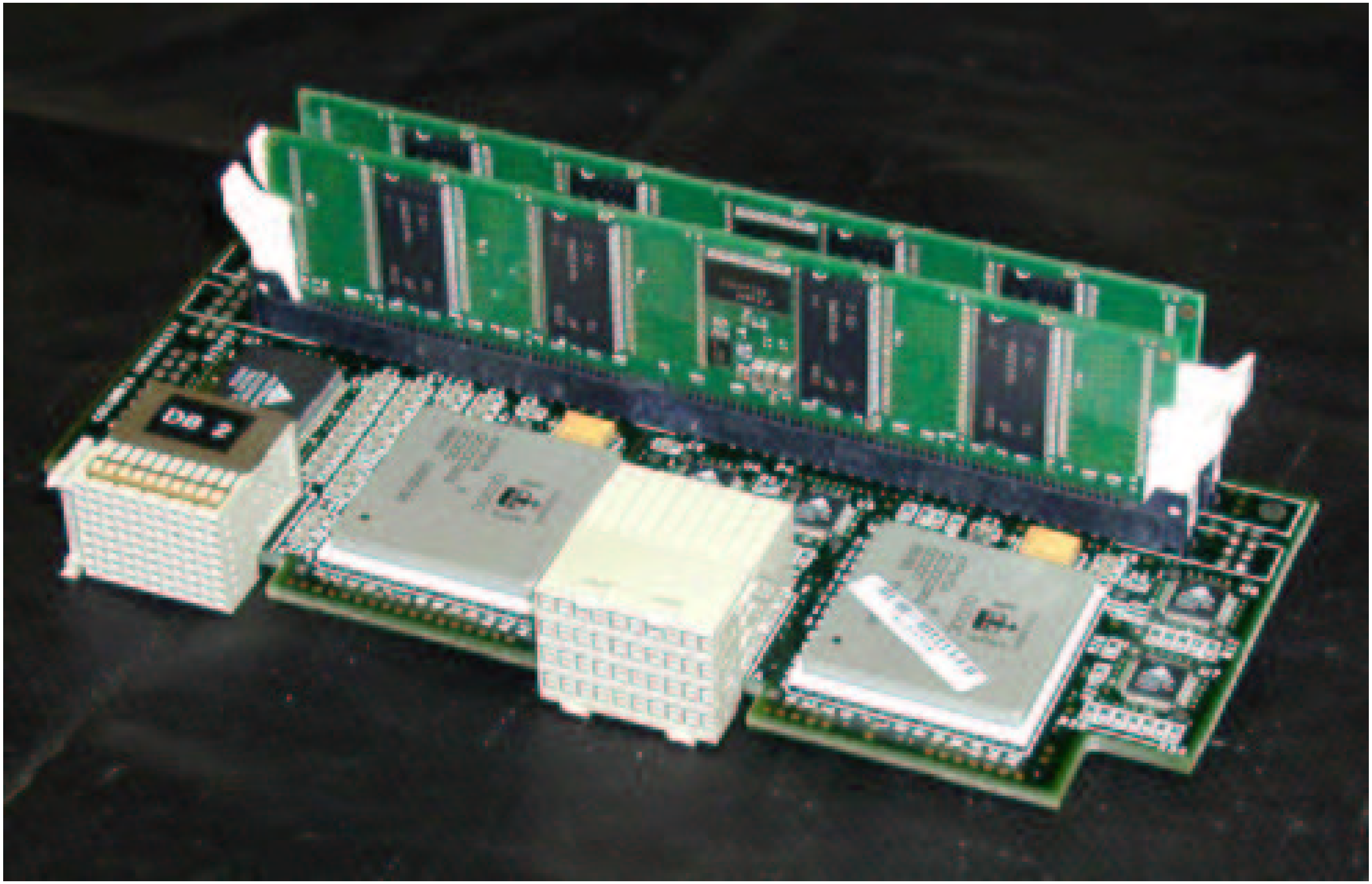




QCDOC places entire node on a single custom chip



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.



Schedule

- chip design: done --- first chips delivered beginning of June
- successful demonstration of Wilson Dirac operator
- 128 node prototype at Columbia: early fall
- 5 teraflop sustained RIKEN and UKQCD machines, 2004
- 1.5 teraflop development machine, at Columbia -- 2003 funding?
- 10 teraflop sustained community machine: 2004
- 5-8 teraflop clusters at JLAB and FNAL: end of 2005

DOE panel review, Feb. 2003

Frank Wilczek (MIT) - chair

Roy Briere (CMU)

David Ceperley (NCSA-UIUC)

Candy Culhane (NSA)

Lynn Kissel (LLNL)

Michael Ogilvie (Washington Univ)

Robert Swendsen (CMU)

Peter Varman (NSF)

‘‘In short, we feel the scientific merit of suggested program is very clearly outstanding.’’

BNL: a renowned Center for Lattice Gauge Theory

Outstanding existing lattice strength

- BNL High Energy Theory MC, Soni, Berruto
- BNL Nuclear Theory Petreczky
- SciDAC Jung, Petrov
- RBRC Aoki, Blum, Dawson, Nemoto, Noaki, Ohta, Orginos, Sugihara, Wettig
- Columbia Christ, Mawhinney, postdocs, many students
- APS Heller

RBRC QCDSP

- 600 GFlops peak, dominates current US resources

Potential strong interactions with

- RHIC and Atlas Computing
- DOE Grid Computing (PPDG)
- BNL Center for Data Intensive Computing
- Biology (see http://www.bnl.gov/CompBio/)

Scientific base for a BNL Topical Computing Facility