

# Computational Infrastructure for Lattice Gauge Theory

## Lattice QCD Executive Committee

**Richard Brower**

**Norman Christ**

**Michael Creutz**

**Paul Mackenzie**

**John Negele**

**Claudio Rebbi**

**Stephen Sharpe**

**Robert Sugar (Chair)**

**Chip Watson**

**Boston U.**

**Columbia U.**

**BNL**

**FNAL**

**MIT**

**Boston U.**

**U. of Washington**

**UC Santa Barbara**

**JLab**

## **Scientific Objectives**

- **Understand the physical phenomena encompassed by quantum chromodynamics (QCD)**
- **Make precision calculations of the predictions of QCD**

**The next generation of Lattice QCD calculations will require computing facilities capable of sustaining tens of teraflops**

# Coupling with the Experimental Program

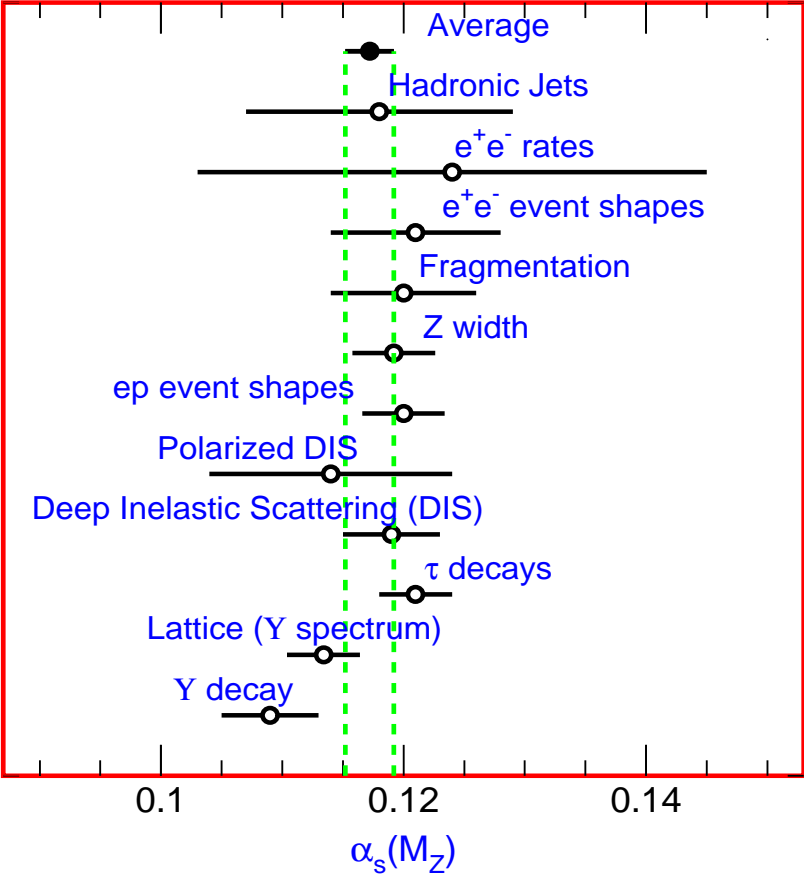
Lattice QCD is an integral part of research in high energy and nuclear physics, and is closely coupled to the DOE's experimental program in these fields.

- **Weak Decays of Strongly Interacting Particles**
  - **BaBar (SLAC)**
  - **Tevatron B-Meson Program (FNAL)**
  - **CLEO-c Program (Cornell-Proposed)**
  
- **Quark-Gluon Plasma**
  - **RHIC (BNL)**
  
- **Structure and Interactions of Hadrons**
  - **Bates BNL FNAL JLab SLAC**

## Status of Lattice Calculations

- **Some key quantities have been calculated to an accuracy of a few percent**
  - **The strong coupling constant**
  - **The masses of the  $b$  and  $c$  quarks**
- **We know the resources required for accurate determination of a broad range of fundamental quantities**
- **Important progress is anticipated over the next five years**
  - **Major improvements in algorithms**
  - **Major increases in computing power**

# Determination of the Strong Coupling Constant



Summary of the determinations of  $\alpha_s(M_Z)$  from the Particle Data Group. Lattice QCD calculations along with experimental data for the  $\Upsilon$  spectrum were used for the determination denoted *Lattice*. The combination of lattice calculations and experimental data is needed to determine a wide variety of fundamental quantities.

## Precision Tests of The Standard Model

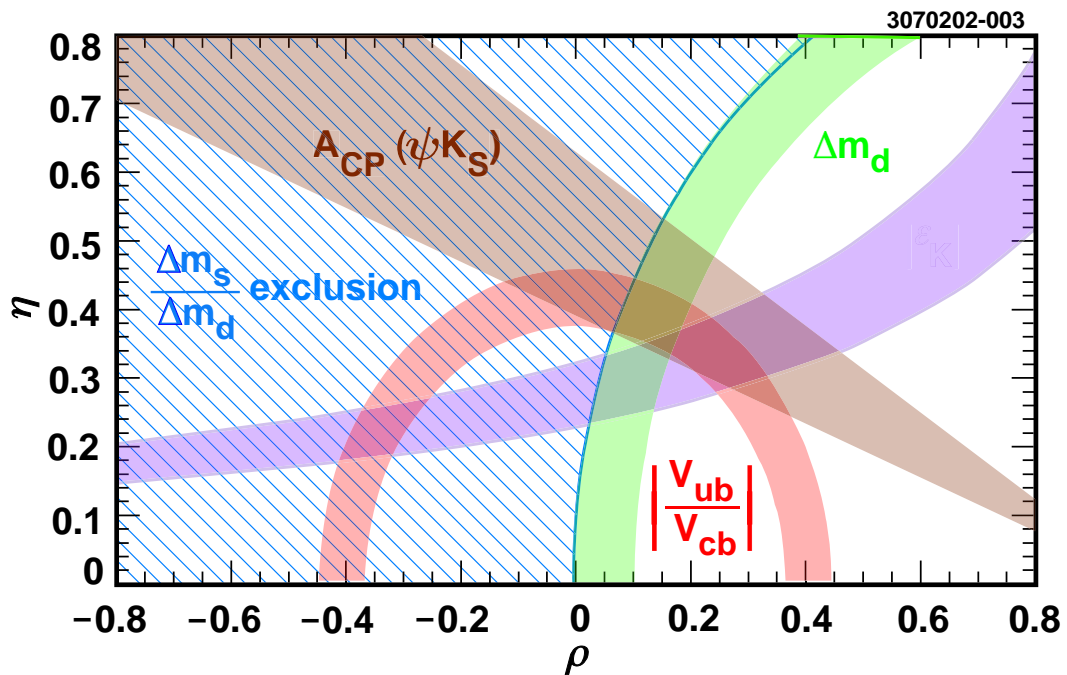
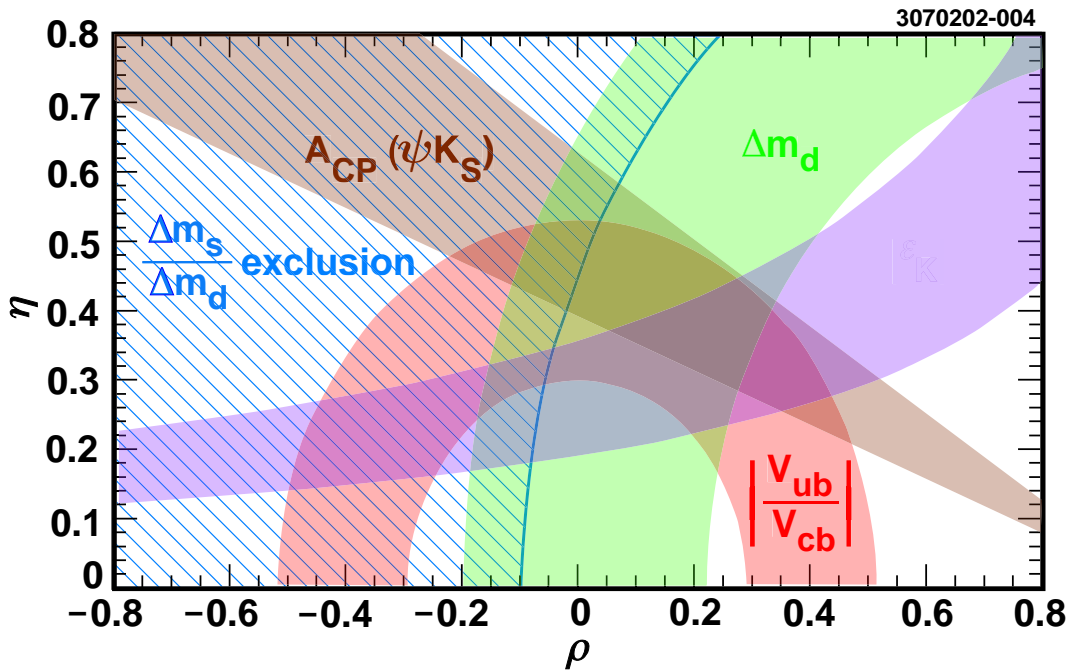
- Lattice calculations of weak matrix elements are needed to relate experimental results to underlying parameters of the Standard Model.
- Multiple measurements of the same Standard Model parameters in different experiments and calculations will lead to crucial consistency tests.
- In many cases the greatest challenge is to reduce the uncertainties in the lattice calculations.

## 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
$\Delta M_{B_d}$ ( $\bar{B}B$ mixing)	$ V_{td} ^2$	$f_{B_d}^2 B_{B_d}$	4%	35%	18%	9%
$\Delta M_{B_s}/\Delta M_{B_d}$	$ V_{ts}/V_{td} ^2$	$f_{B_s}^2 B_{B_s}/f_{B_d}^2 B_{B_d}$	Not yet measured	10%	5%	3%
$\varepsilon$ ( $\bar{K}K$ mixing)	$\text{Im} V_{td}^2$	$B_K$	2%	20%	10%	5%
$B \rightarrow (\frac{\rho}{\pi}) l \nu$	$ V_{ub} ^2$	$\langle \frac{\rho}{\pi}   (V - A)_\mu   B \rangle$	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  $\rho$  and  $\eta$  (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.



## Hardware Plans

- Simplifying features of lattice QCD calculations make building specially designed computers far more cost effective than buying commercial ones.
  - Uniform grids
  - Regular, predictable communications
- Two hardware tracks:
  - QCD On a Chip (QCDOC)
  - Commodity Clusters
- Each track has its own strengths
- Each track may prove optimal for different aspects of our work
- The two track approach positions us to exploit future technological advances, and enables us to retain flexibility

## QCDOC

- The latest of the highly successful Columbia/Riken/BNL special purpose computers.
  - The Columbia group has pioneered the design and construction of special purpose computers for QCD.
  - The QCDSF won the Gordon Bell Prize in 1998 for price performance.
- The QCDOC combines processor, networking and memory on a single chip.
- Partnership with IBM provides access to its technology for chip design and fabrication.
- Targets a price–performance of \$1/Mflops for multi-teraflops machines as early as 2003.

# Commodity Clusters

- **Market forces are producing rapid gains in processor and memory performance**
  - **Moore's Law  $\Rightarrow$  60% growth in performance per year**
  - **Pentium 4 currently provides exceptional performance for QCD**
- **Market for interconnects is growing**
- **Open Source System Software**
  - **Flexible programming environment**
  - **SciDAC Scalable Systems Software**
- **Targeted price–performance**

	<b>FY 2003</b>	<b>FY 2004</b>	<b>FY 2005</b>	<b>FY 2006</b>
<b>\$/Mflops</b>	<b>2.0</b>	<b>1.2</b>	<b>0.9</b>	<b>0.7</b>

## Collaboration and Partnerships

- **Our collaboration includes nearly all senior lattice gauge theorists in the U.S.**
  - **Sixty–four senior scientists**
  - **Lattice gauge theorists, computer scientists, computer engineers**
- **Partnership with three DOE laboratories**
  - **Brookhaven**
  - **Fermilab**
  - **JLab**
- **Partnership with IBM**
- **Assistance from NSF PACI Centers**
  - **Pittsburgh Supercomputer Center**
  - **National Center for Supercomputer Applications**

## **We need to act now to deploy the infrastructure required for terascale simulations of QCD**

- **Major experiments which require terascale simulations for their interpretation have recently been completed, or will be completed within the next several years**
- **Theorists in Europe and Japan are moving rapidly to secure resources comparable to those we propose**
  - **The APE Collaboration will begin deploying multi-teraflops computers in 2003**
  - **UKQCD will acquire a 5.0 Tflops (sustained) QCDOC in 2003**
  - **DESY plans to acquire a 20.0 Tflops (peak) APE NEXT in 2004**

## Conclusion

Lattice gauge theory was invented in the U.S., and U.S. theorists have traditionally been leaders of this field. If U.S. lattice gauge theorists are to play a significant role in the major advances expected in this area over the next five years, we must act now.