Lattice QCD in the US:

Past, Present and Future

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Background

- Members of the U.S. Lattice Gauge Theory Community have been working together for the last seven years to create the computational infrastructure needed to study quantum chromodynamics (QCD).
- Nearly all high energy and nuclear physicists in the U.S. who work on lattice QCD are participating. The infrastructure will be available to all.
- Three DOE laboratories are playing critical roles:
  - Brookhaven National Laboratory
  - Fermi National Accelerator Center
  - Thomas Jefferson National Accelerator Facility

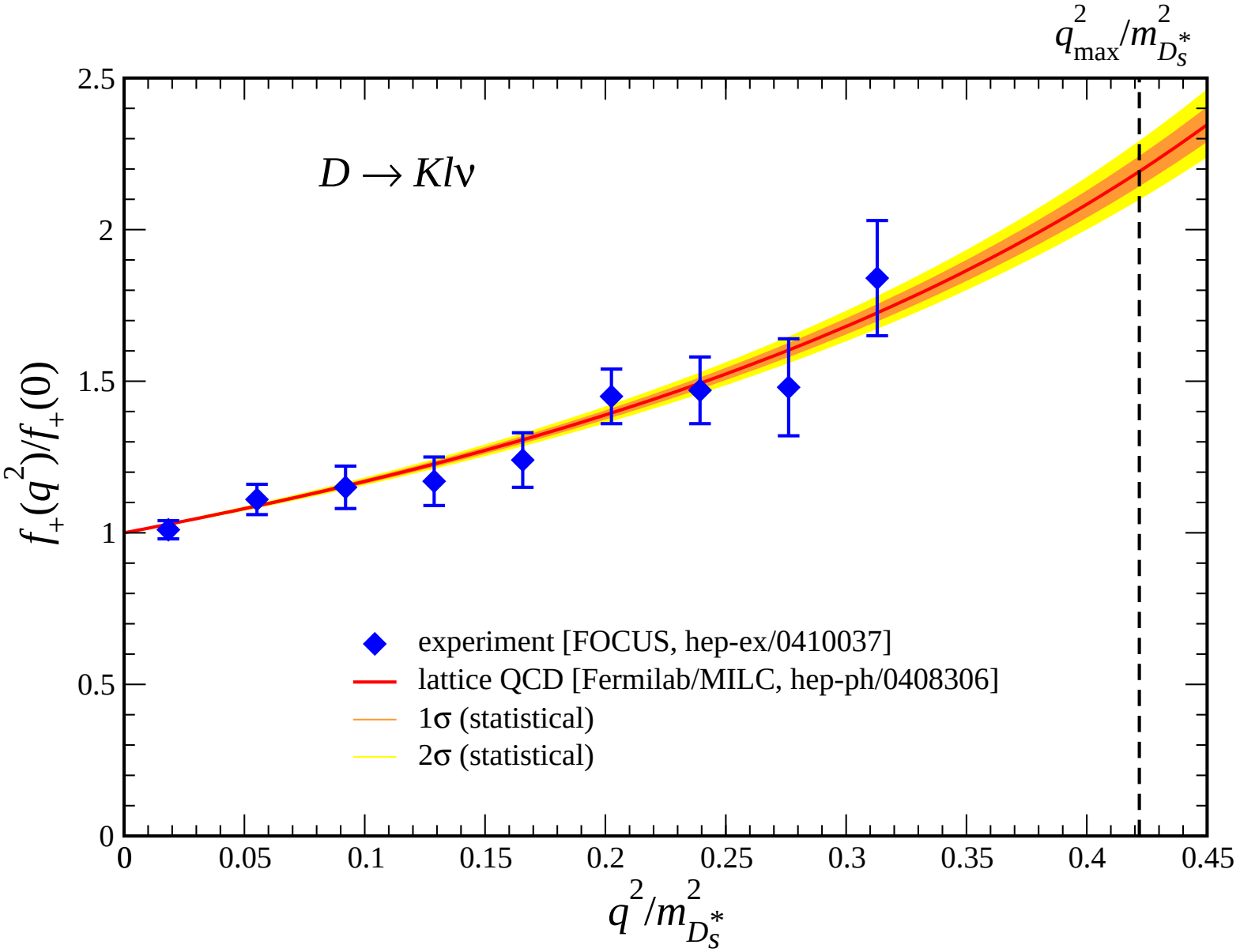
Lattice QCD Executive Committee

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. of Washington
Robert Sugar (Chair)	UC Santa Barbara

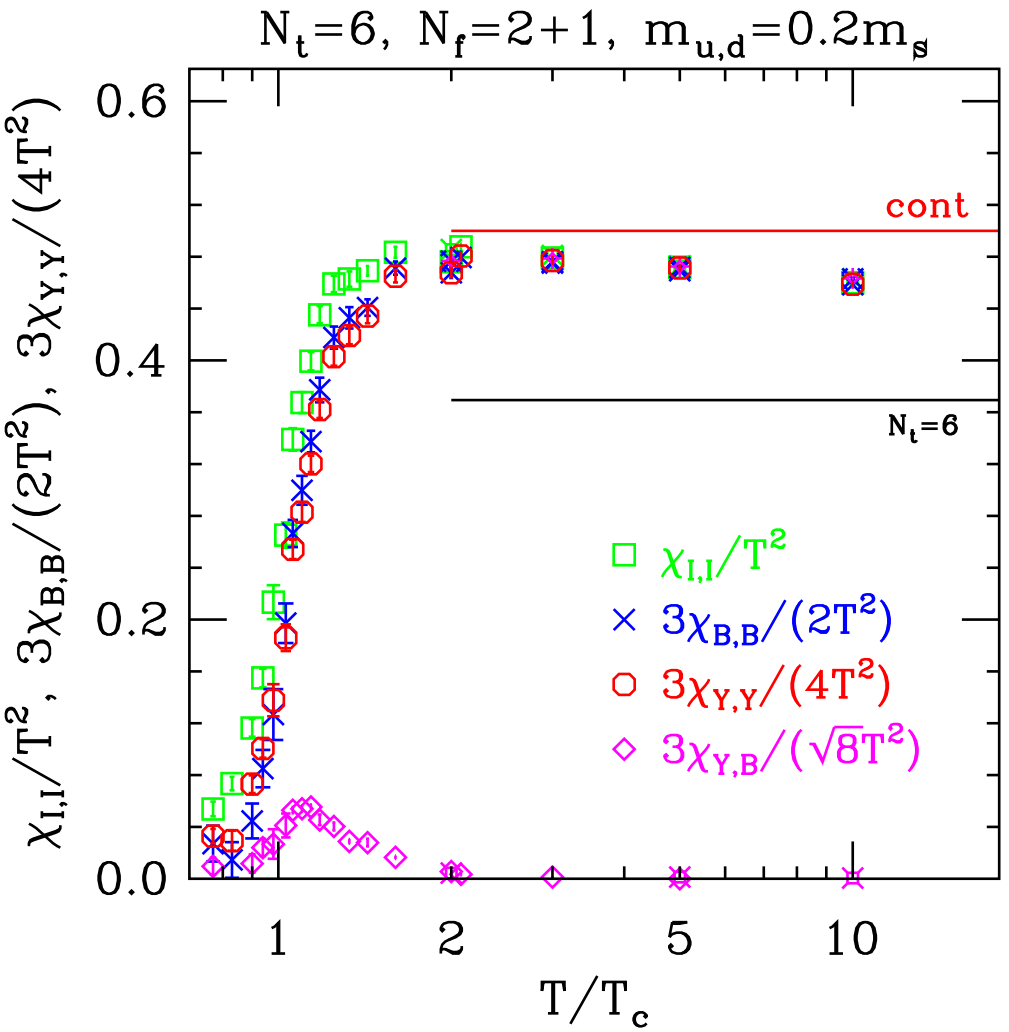
Opportunities for Major Scientific Advances

- Important experimental programs in high energy and nuclear physics require accurate lattice QCD calculations to reach their goals:
  - Precise tests of the Standard Model.
  - Determination of the properties of strongly interacting matter under extreme conditions.
  - Understanding the internal structure of nucleons and other strongly interacting particles.
- Major improvements in lattice calculations are possible because of:
  - Improved formulations of QCD on the lattice
  - Improved algorithms
  - Improvements in computer hardware

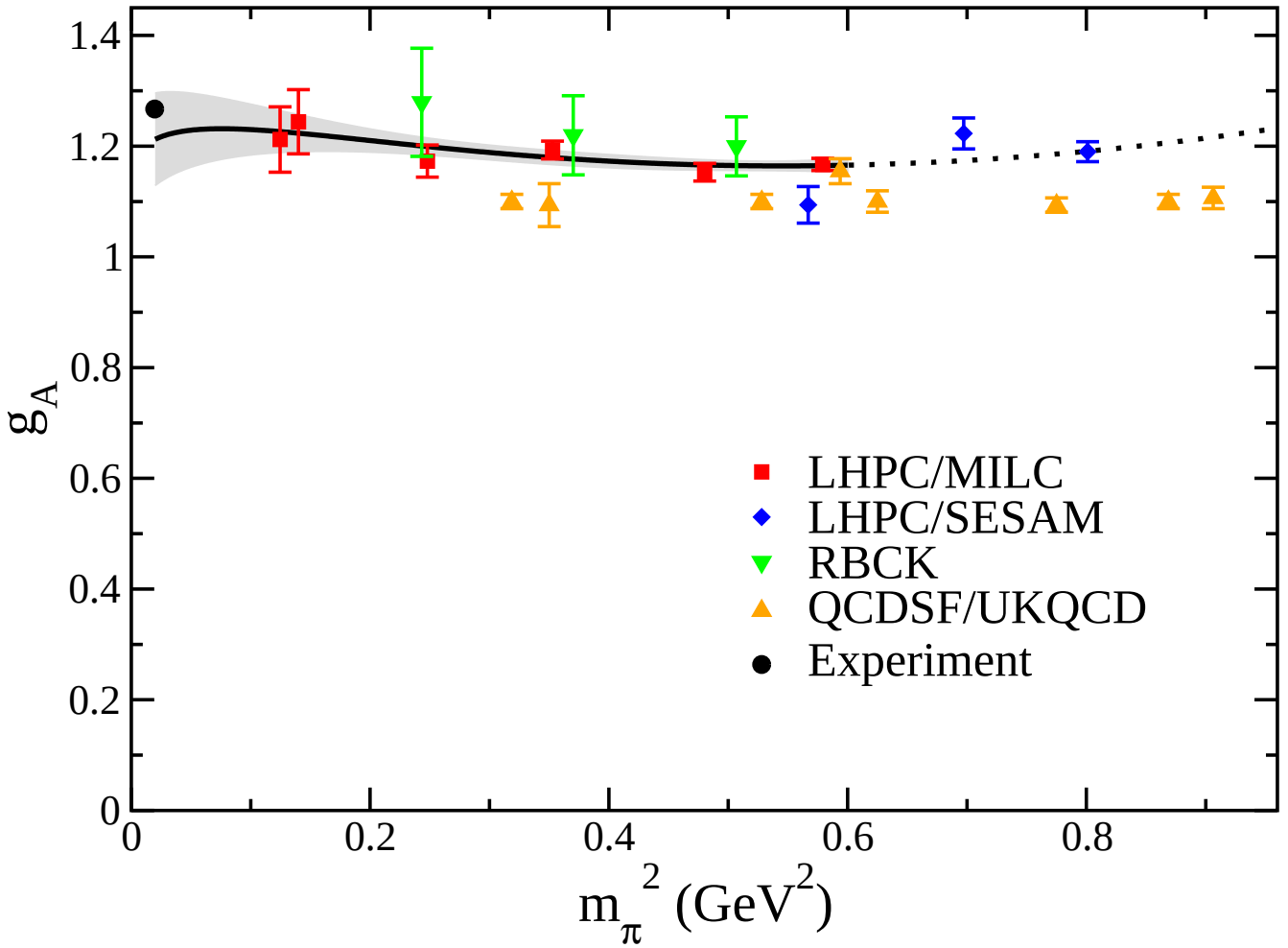
Semileptonic Decay of the D Meson



Quark Number Susceptibilities



Nucleon Axial Charge



The nucleon axial charge as a function of the square of the pion mass by the LHPC Collaboration. The solid line denotes the infinite volume chiral perturbation theory fit.

MILC Configuration Generation

a(fm)	$\mathbf{m_l/m_s}$	Lattice	Trajectories	TF-Years
0.12	0.4	$20^3 \times 64$	3,000	0.004
0.12	0.2	$20^3 \times 64$	3,000	0.01
0.12	0.1	$24^3 \times 64$	3,000	0.06
0.09	0.4	$28^3 \times 96$	3,000	0.04
0.09	0.2	$28^3 \times 96$	3,000	0.09
0.09	0.1	$40^3 \times 96$	3,000	0.54
0.09	0.05	$56^3 \times 96$	4,200	6.05
0.06	0.4	$48^3 \times 144$	3,000	0.45
0.06	0.2	$48^3 \times 144$	3,750	1.69
0.06	0.1	$60^3 \times 144$	4,500	7.98
0.06	0.05	$84^3 \times 144$	6,300	93.19

• DOE/NSF Centers; • QCDOC; • Next Generation Machines

Specialized Hardware for QCD

- Simplifying features of lattice QCD calculations make building specially designed computers more cost effective than buying commercial ones.
  - Uniform grids
  - Regular, predictable and short range communications
  - Low memory requirements
- Approach was pioneered at Columbia University
- Approach adopted world-wide
  - Europe (APE, commodity clusters)
  - United Kingdom (QCDOC)
  - Japan (CP-PACS,PACS-CS)

Two Hardware Tracks

- Fully customized computers (QCDOC)
  - Designed by a collaboration centered at Columbia University.
  - Built and operated by BNL
- Commodity clusters optimized for QCD
  - Designed and built at FNAL and JLab.

SciDAC-1 Grant

- July 15, 2001 to July 14, 2005
- Developed community software with the goals of enabling US lattice gauge theorists to:
  - Achieve high performance on the QCDOC, commodity clusters, and commercial supercomputers.
  - Quickly adapt codes to new architectures
  - Easily develop new applications
  - Preserve the large investment in existing codes
- Commodity cluster research and development
  - Myrinet
  - Infiniband
  - Gigabit Ethernet Mesh

Construction of the QCDOC

- 12,288 nodes QCDOC constructed in the spring and summer of 2005.
- Divided into several independent machines each dedicated to a specific research project. The largest sub-machine at present is 4,096 nodes
- Funded as a research project by the DOE's Advanced Scientific Computer Research, High Energy Physics and Nuclear Physics Programs from FY 2004 and 2005 funds.
- Has initiated a new era in the study of Lattice QCD.

Lattice QCD Computing Project

- October 1, 2005 to September 30, 2009
- Projected budget is $2.5M per year in FY 2006, 2007 and 2008. $1.7M in 2009.
- Construction or purchase of dedicated hardware
  - Large Infiniband cluster at FNAL in FY 2006
  - In each successive year we will build or purchase the hardware that best advances the physics.
- Operation of the QCDOC, SciDAC prototype clusters and hardware built or purchased under this project.

SciDAC-2 Proposal

- Software
  - Optimization of the code for new architectures
    - Infiniband
    - BlueGene/L and possibly other commerical machines
  - Additional support for physics codes
  - Uniform computing environment at the three laboratories
- Multiscale algorithms
- Hardware Research and Development
  - Investigation of cluster components
  - Research and development for a successor to the QCDOC