The Fermilab Lattice Gauge Theory Project

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Additional material at:
http://lqcd.fnal.gov.

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Fermilab
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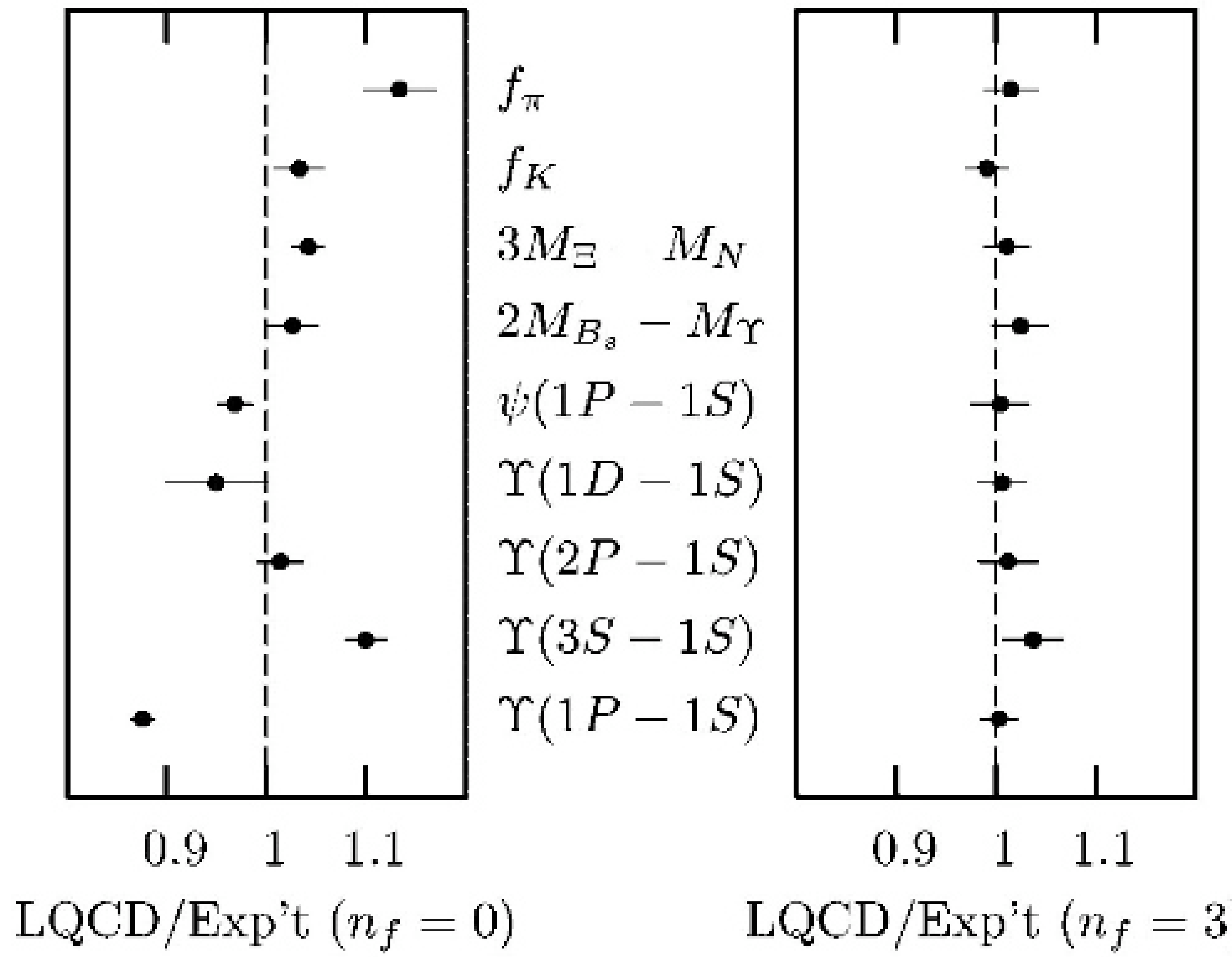
Recent big progress with unquenched improved staggered fermions.

Several groups compared their <u>simplest</u> calculations. 10% disagreement quenched → few per cent agreement unquenched.



C.T.H. Davies *et al.*, **Phys.Rev.Lett.92:022001,2004, hep-lat/0304004.**

What about slightly more complicated quantities?
Do other light quark methods agree?

The progress has been reported in nice articles in Physics Today and Nature.

arXiv:hep-lat/0304004 v1 7 Apr 2003

High-Precision Lattice QCD Confronts Experiment

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(Dated: 31 March 2003)

We argue that high-precision lattice QCD is now possible, for t... improved staggered quark discretization. We compare a wide variety... in QCD with experiment, and find agreement to within statistical an... We also present a new determination of $\alpha_{\overline{MS}}^{(5)}(M_Z)$; we obtain 0.121... of this breakthrough for phenomenology and, in particular, for hea...

PACS numbers: 11.15.Ha,12.38.Aw,12.38.Gc

For almost thirty years precise numerical studies of nonperturbative QCD, formulated on a space-time lattice, have been stymied by our inability to include the effects of realistic quark vacuum polarization. In this paper we present detailed evidence of a breakthrough that may now permit a wide variety of nonperturbative QCD calculations including, for example, high-precision B and D meson decay constants, mixing amplitudes, and semi-leptonic form factors — all quantities of great importance in current experimental work on heavy-quark physics. The breakthrough comes from a new discretization for light quarks: Symanzik-improved staggered quarks [1, 2, 3, 4, 5, 6, 7, 8].

Quark vacuum polarization is by far the most expensive ingredient in a QCD simulation. It is particularly difficult to simulate with small quark masses, such as u and d masses. Consequently, most lattice QCD (LQCD) simulations in the past have either omitted quark vacuum polarization ("quenched QCD"), or they have included effects for only u and d quarks, with masses 10–20 times larger than the correct values. This results in uncon...

trolled systema... Symanzik-imp... the most accur... more efficient... comparable ac... are possible no... exact chiral sy... simulations wi... d masses we u... are now small... a reliable tool...

In this pape... with this new ... perturbative re... cent. We do th... imental measu... restrict oursel... sured (< 1% e... with existing t... unstable hadr... leptonic decay...

Lattice Quantum Chromodynamics Comes of Age

Quantum chromodynamics is the elegant but notoriously intractable theory of the strong interactions. Recent advances in numerical computer simulation are beginning to reveal, in impressive detail, what the theory predicts.

Carleton DeTar and Steven Gottlieb

The strength of the electron–photon interaction is characterized by the fine-structure constant α ≈ 1/137.036. Because α is small, quantum electrodynamics (QED), the theory of interacting electrons and photons, can be solved to very good approximation with the traditional technology of pencil and paper. By contrast, quantum chromodynamics (QCD), the generally accepted theory of strongly interacting quarks and gluons, has proven to be remarkably resistant to that approach. But in recent years, advances in computer technology and algorithms have brought the ab initio numerical simulation of QCD to a level of credibility that will have a significant impact on scientific discovery.

Lattice QCD

In formulation, QCD and QED are strikingly similar. Both are gauge-invariant quantum field theories. ...

High-precision calculations

...

Carleton DeTar is a professor of physics at the University of Utah in Salt Lake City. Steven Gottlieb is a professor of physics at Indiana University in Bloomington.

Lattice window on strong force

Ian Shipsey

A long-awaited breakthrough has been made in lattice quantum chromodynamics — a means of calculating the effect of the strong force between sub-atomic particles that could, ultimately, unveil new physics.

The fundamental particles called quarks exist in atom-like bound states, such ...

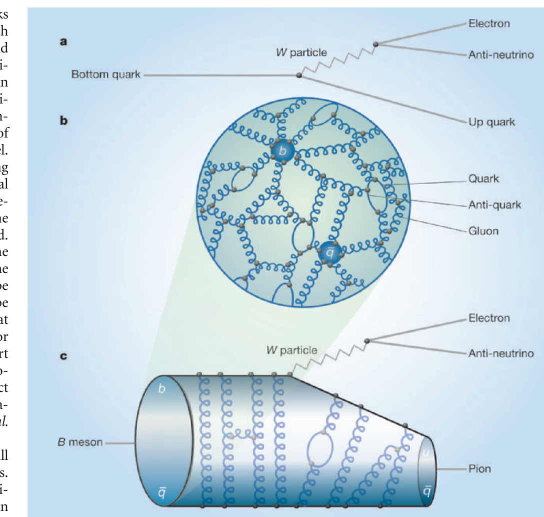


Figure 1 Bottom's up. a, An idealized representation of the decay of a free bottom quark into an up quark. In the standard model of particle physics, the process occurs through the weak force, mediated by a W particle, and also produces an electron and an anti-neutrino. b, In the real world, however, there is no such thing as a free quark. Instead, a bottom quark exists in a bound state with other quarks — such as in a B meson, bound by the exchange of gluons to an anti-quark. Gluons and quark pairs are constantly emitted then reabsorbed; only a fraction of this 'sea' of particles is shown here. c, So the realistic picture of the decay of a bottom quark is complex. The B meson — a bottom quark and anti-quark pair — becomes a pion (an up quark and an anti-quark), but the route is obscured by the mass of gluons and quarks (of which, again, only a fraction are shown). Calculating the details of the process is fiendishly complicated. But new advances in lattice quantum chromodynamics mean that precise theoretical correction factors can be worked out, and the problem effectively reduced to the simple process shown in a.

would be no matter in the Universe today. So how did that asymmetry arise?

If heavy particles that existed in the early Universe decayed preferentially into matter over antimatter, that could have created the matter excess. In the standard model, two types of quark, bottom and strange, do decay asymmetrically. But this effect alone is far too small to account for the asymmetry. However, there are many theories that predict the existence of other, massive particles that could readily produce the asymmetry. And

because of the connection between asymmetry and mass, these theories also address other puzzles, such as why electrons are almost 10,000 times lighter than bottom quarks.

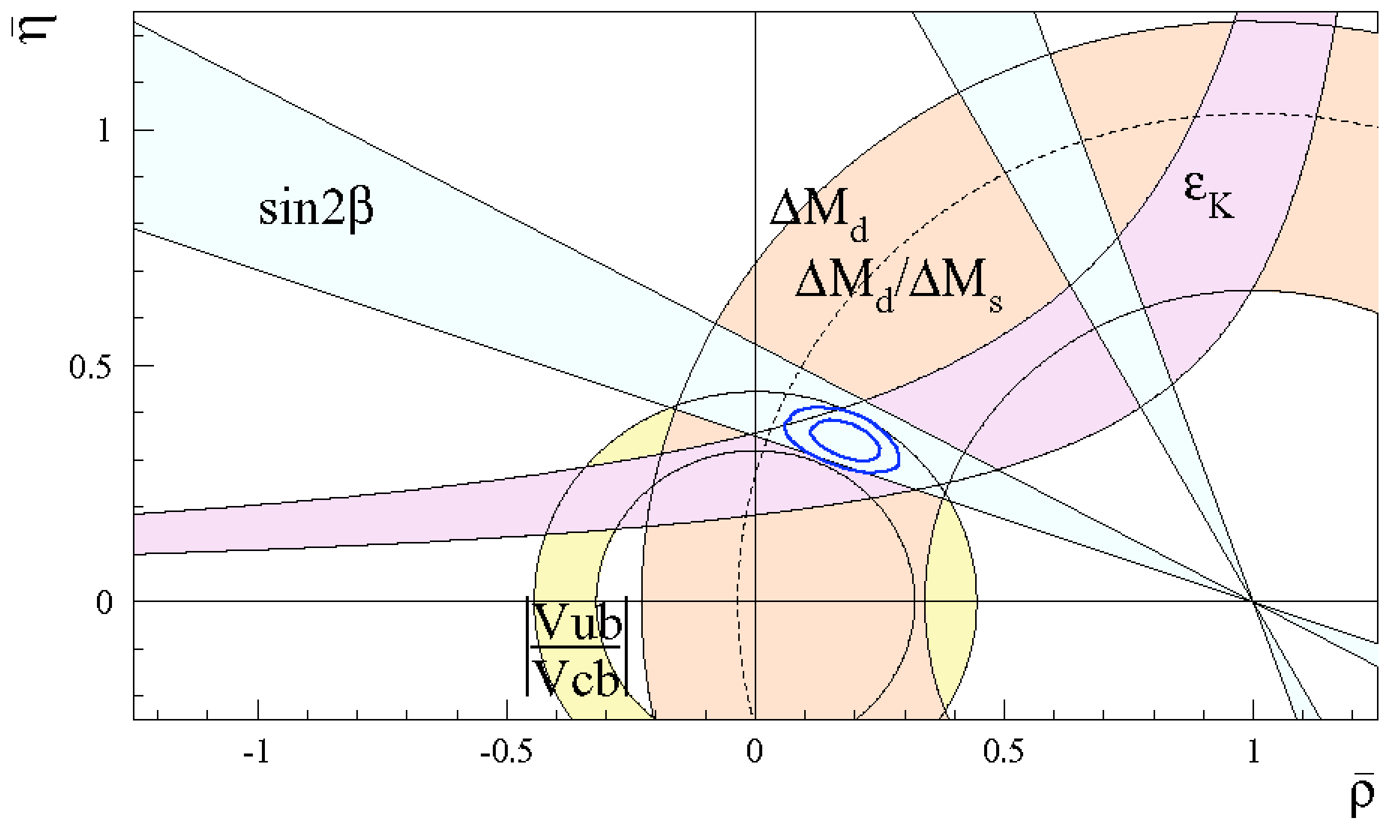
Searching for evidence of these particles can be done directly or indirectly: powerful accelerators, reaching ever higher energies, could create these mysterious particles; or there is the precision approach of looking for subtle deviations in the properties of known particles, influenced by the unknown. If

These are examples of “golden quantities of lattice QCD”: single stable-hadron processes.

Many of the most important deliverables of lattice QCD are in this class and a special focus of our group’s work:

B B bar, B_s B_s bar mixing,

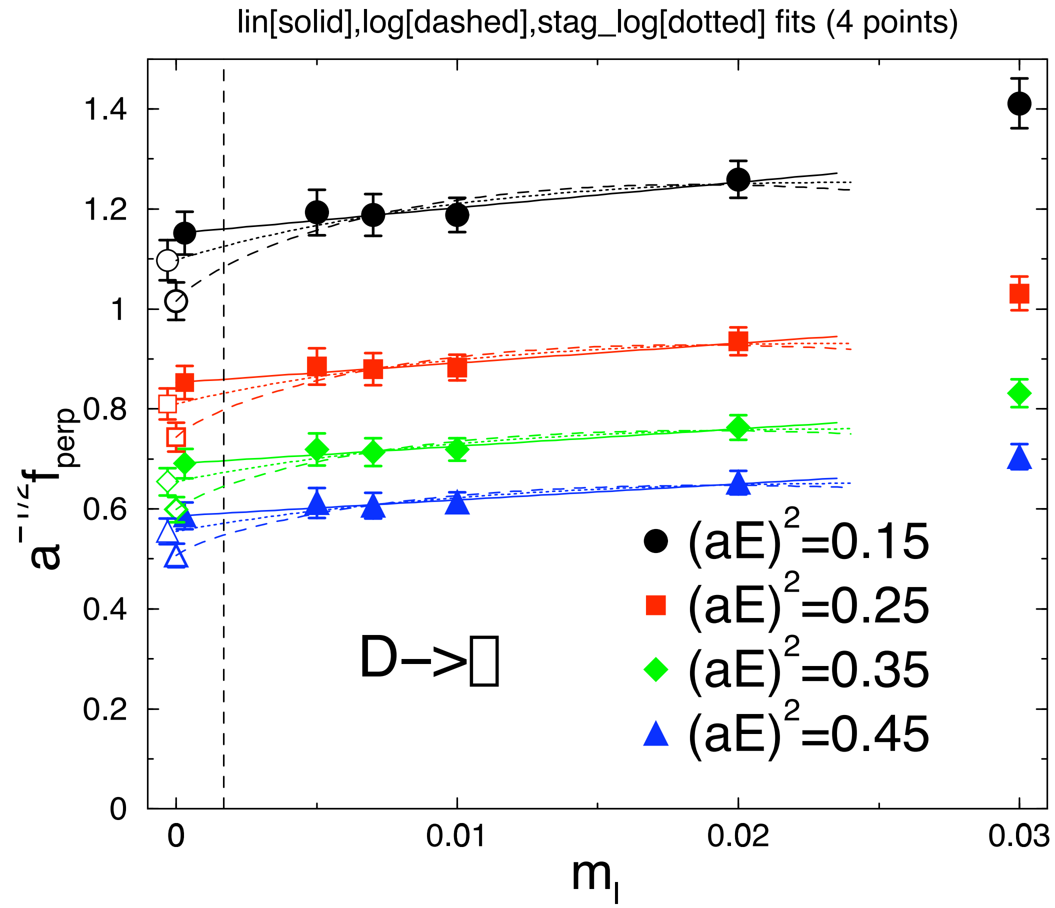
B, D leptonic and semileptonic decay.



M. Ciuchini **hep-ph/0307195.**

Example of current work : D→πlν.

Cleo-c will measure
f_D /D→πlν and
f_{Ds}/D→Klν to 2%. Interesting and rare CKM independent test of lattice heavy-light methods.

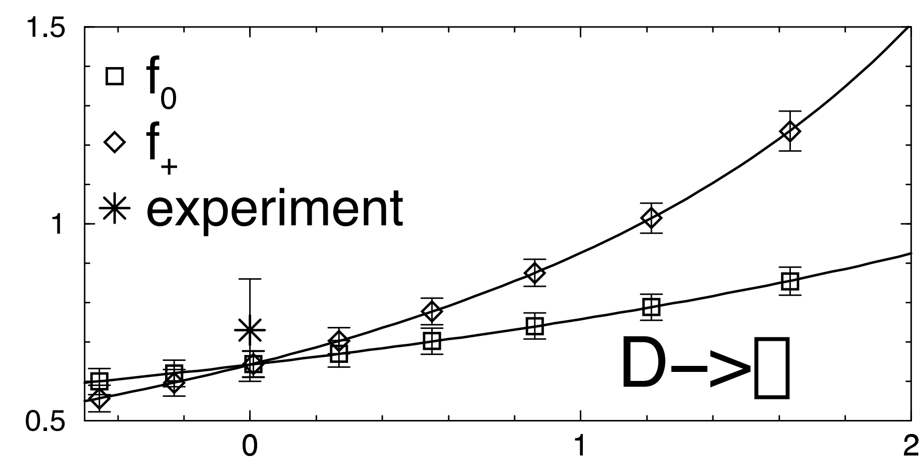


One-loop perturbative calcutions (in progress) will leave 8-10% perturbative uncertainties. Goal: make all other uncertainty significantly smaller than this.

f_+^{DK}=0.75

f_+^{Dpi}=0.63

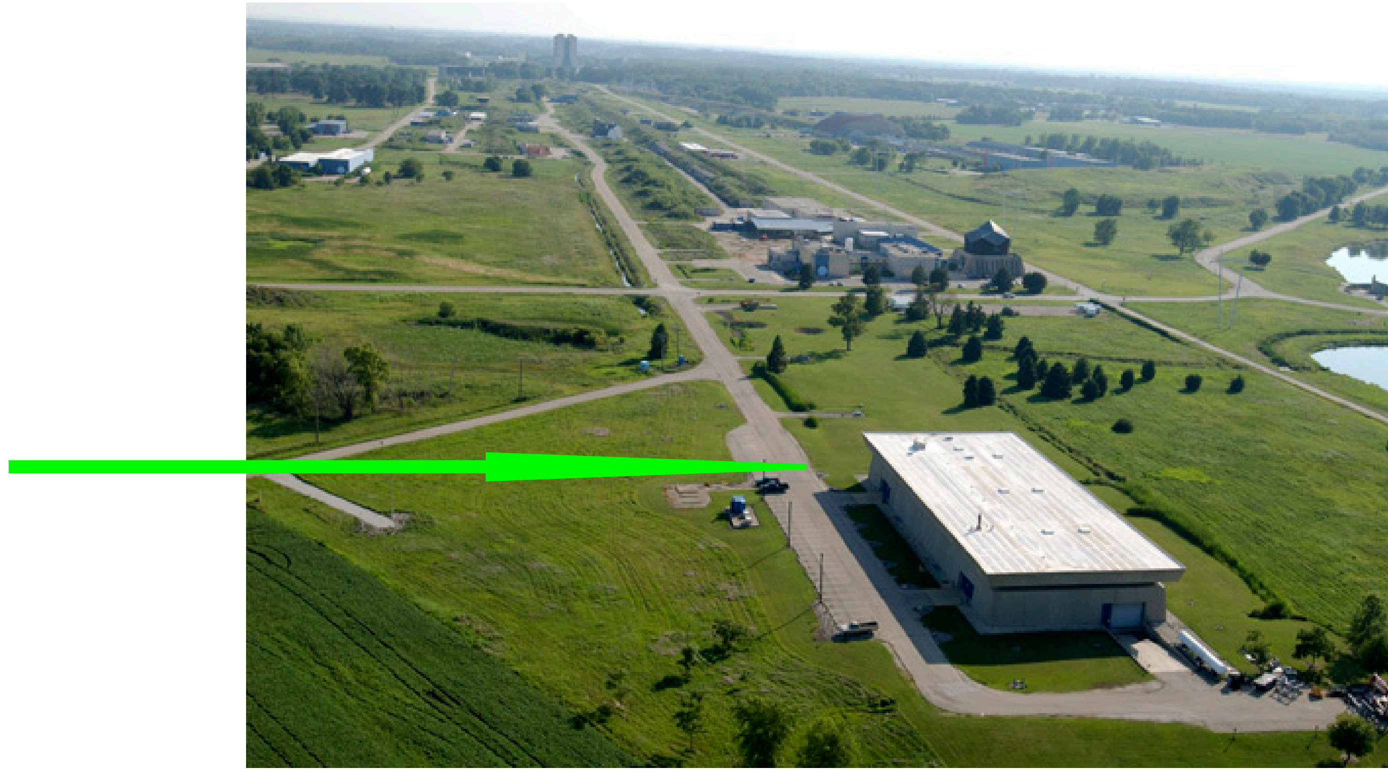
(Preliminary!)



M. Okamoto et al., at Lattice 2003, hep-lat/0309107.

Fermilab lattice cluster effort is led by Don Holmgren.

The clusters are currently housed in the New Muon Lab.



The 176 node Pentium 4 cluster. ~100 GFlops.

2000: 80 node Pentium III
700 MHz duals, Myrinet.

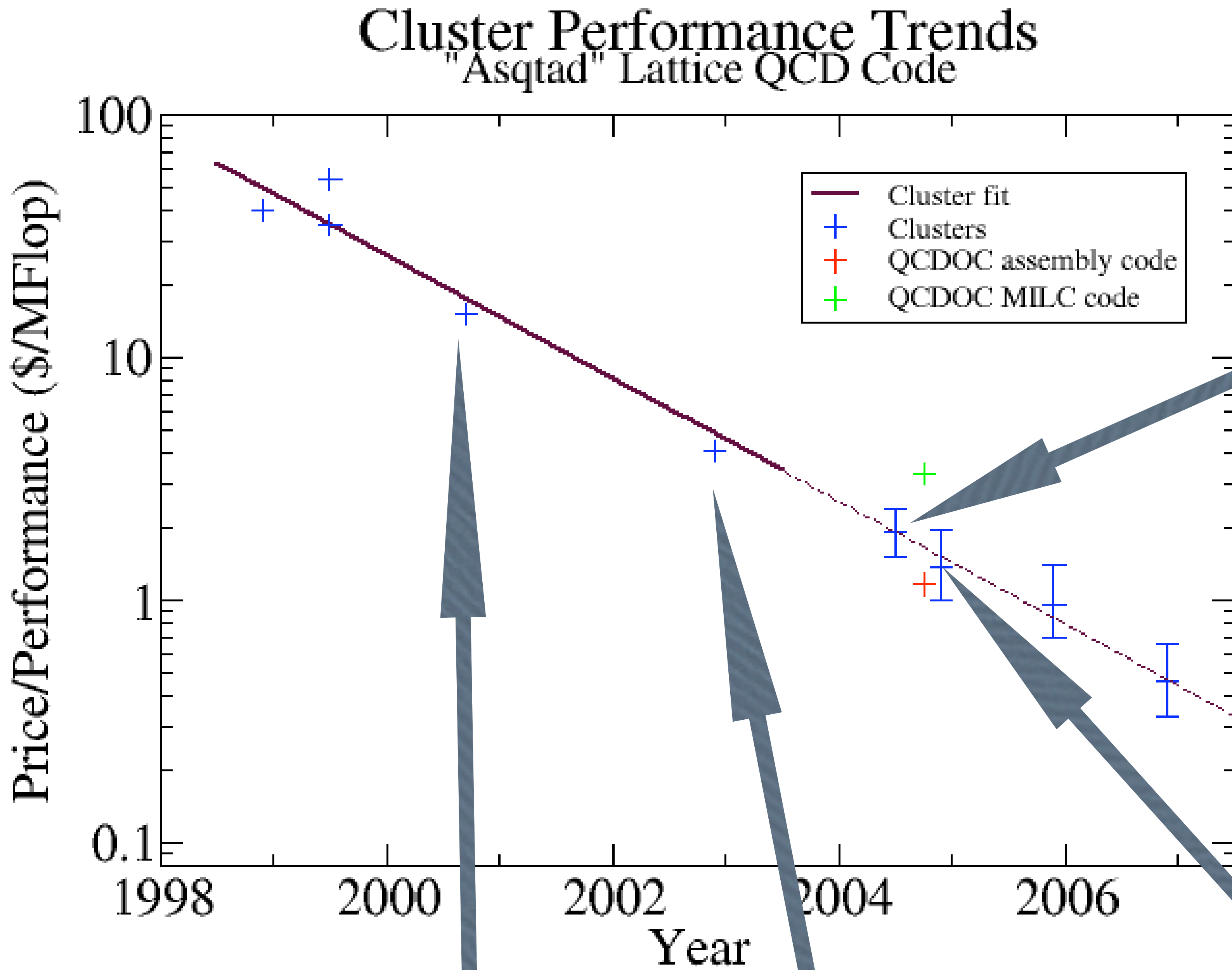
2002: 48 node Pentium 4
2 GHz duals, Myrinet.

2002: 128 node Pentium 4
2.4 GHz duals, Myrinet.

2004 plan: 256 node 3.2 GHz, Infiniband? 350 GF.

2005: 512 node 4 GHz, Infiniband? $1M. 1 TF.

2006: 1024 node 5 GHz, Infiniband? $1.5M. 3 TF.



128 P4 singles,
reuse Myrinet switch.
Incremental cost:
$1/MF.

256 node, P4 singles?
Infiniband switch.

US “Lattice QCD Executive Committee” (Sugar, chair, Brower, Christ, Creutz, Mackenzie, Negele, Rebbi, Sharpe, Watson) reports to DoE on plans and needs of US lattice QCD.

At February, 2004 HEPAP meeting, Bob Sugar, in a well-received talk, reported the “absolute minimum support required for health of field”.

Our answer: $3M/year.
In FY04/05, 5 TF QCDOC + 1 TF cluster.

DoE-HEP response: $2M/yr.

Discussions are ensuing.