

Lattice Gauge Theory

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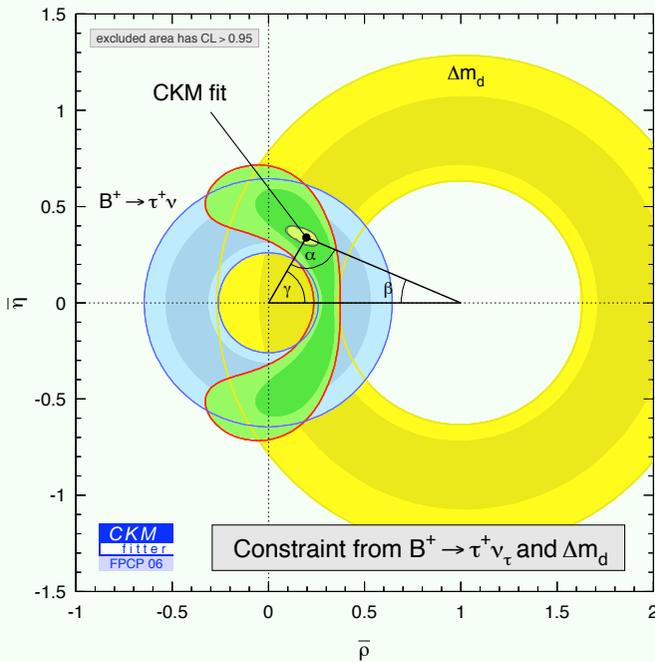
Fermilab Annual DoE Review
Theory Breakout Session
May 17, 2006

Lattice now at the forefront of CKM phenomenology

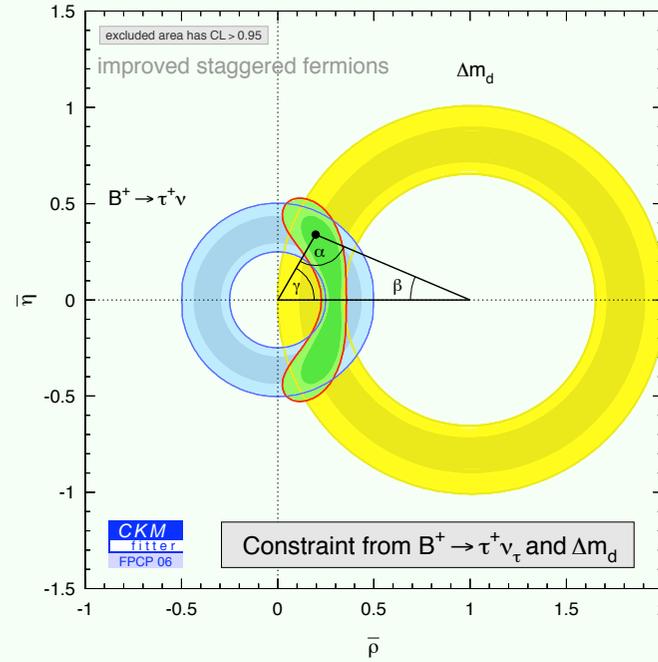
Theoretical uncertainties...

all non angle measurements uncertainties are now dominated by theory; however a lot of progress in analytical calculations and lattice simulations has been made recently

Lattice calculations are essential for analyzing the results of some of the most important recent experiments.



using traditional approaches

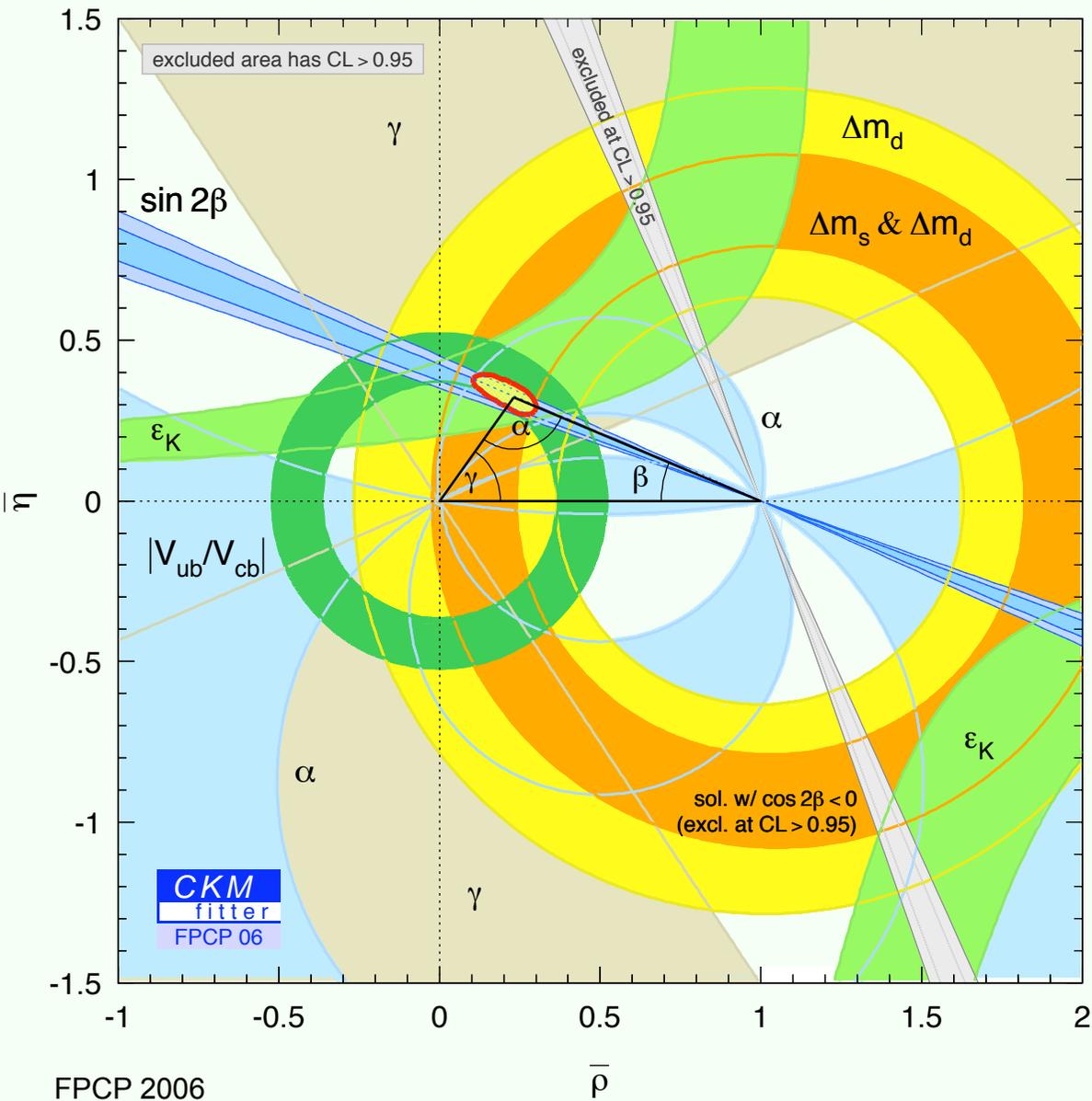


using improved staggered fermions

FPCP 2006
J. Charles
CKMfitter group



The global CKM fit: results...

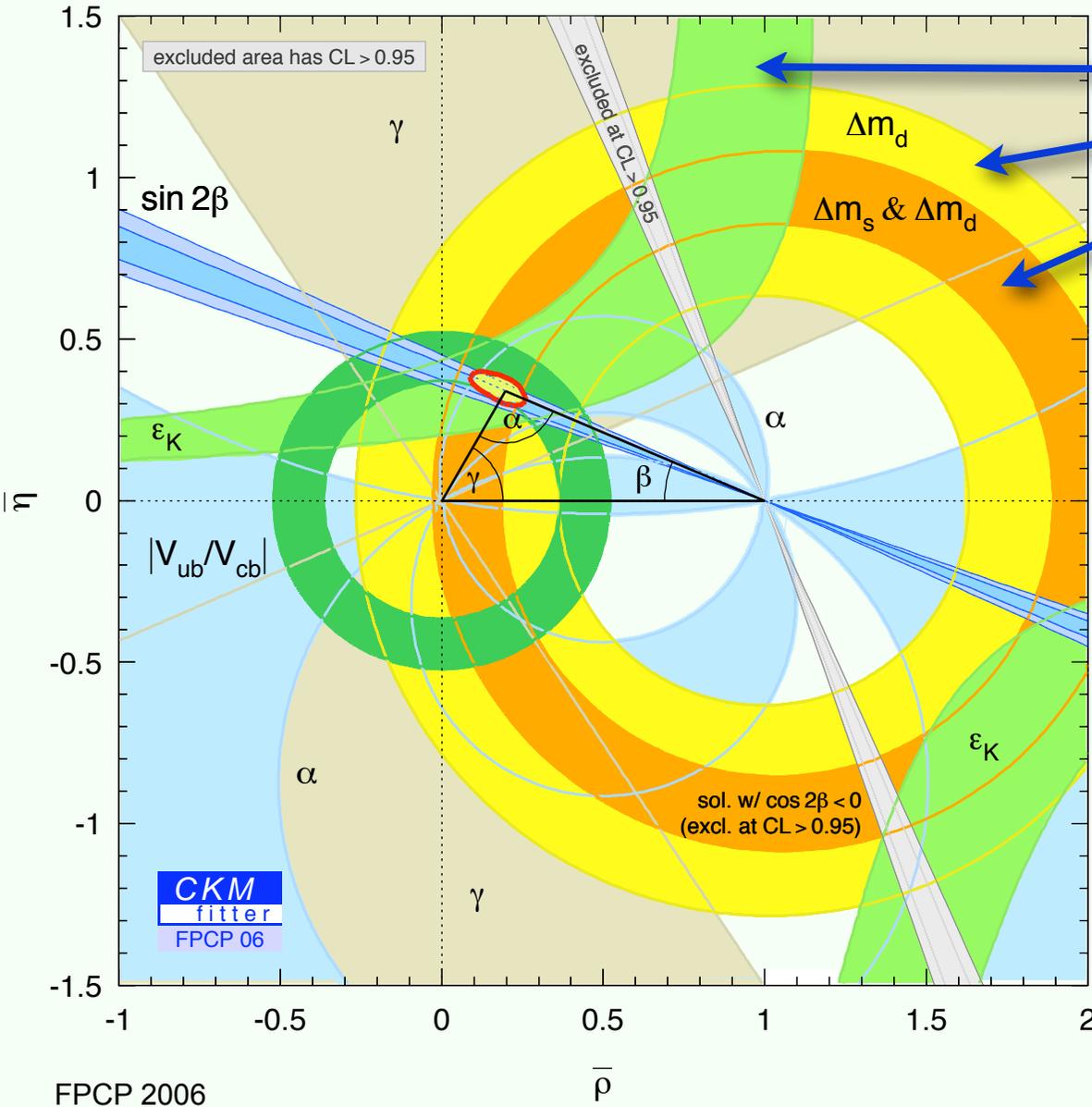


FPCP06
without Δm_s (CDF)
all constraints together

FPCP 2006
J. Charles
CKMfitter group



The global CKM fit: results!



Lattice calculations are an essential component of current bounds in the rho-eta plane.

FPCP06
with Δm_s (CDF)
all constraints together

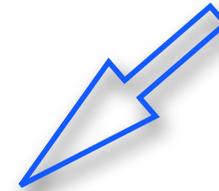
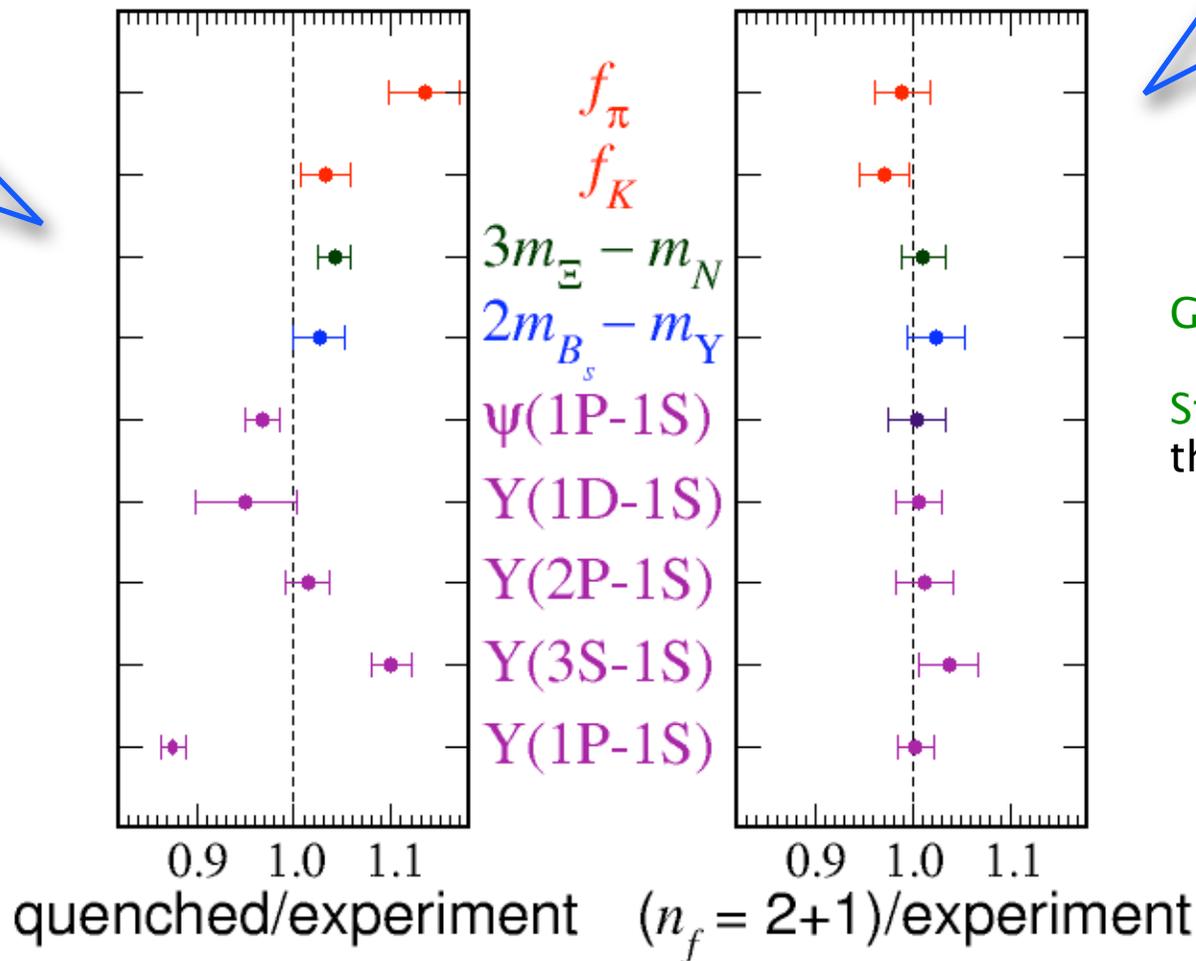
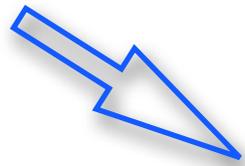
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Big progress in lattice calculations.

Quantities that used to agree decently, $\sim 10\%$, in the quenched approximation...

... agree to a few % in recent unquenched calculations.



Gold-plated quantities.

Staggered fermions, the least CPU-intensive.

Three families of lattice fermions

- **Staggered/naive**
 - Good chiral behavior (can get to light quark masses), but fermion doubling introduces theoretical complications. Cheap.
- **Wilson/clover**
 - No fermion doubling but horrible chiral behavior.
- **Overlap/domain wall**
 - Nice chiral behavior at the expense of adding a fifth space-time dimension. Expensive.

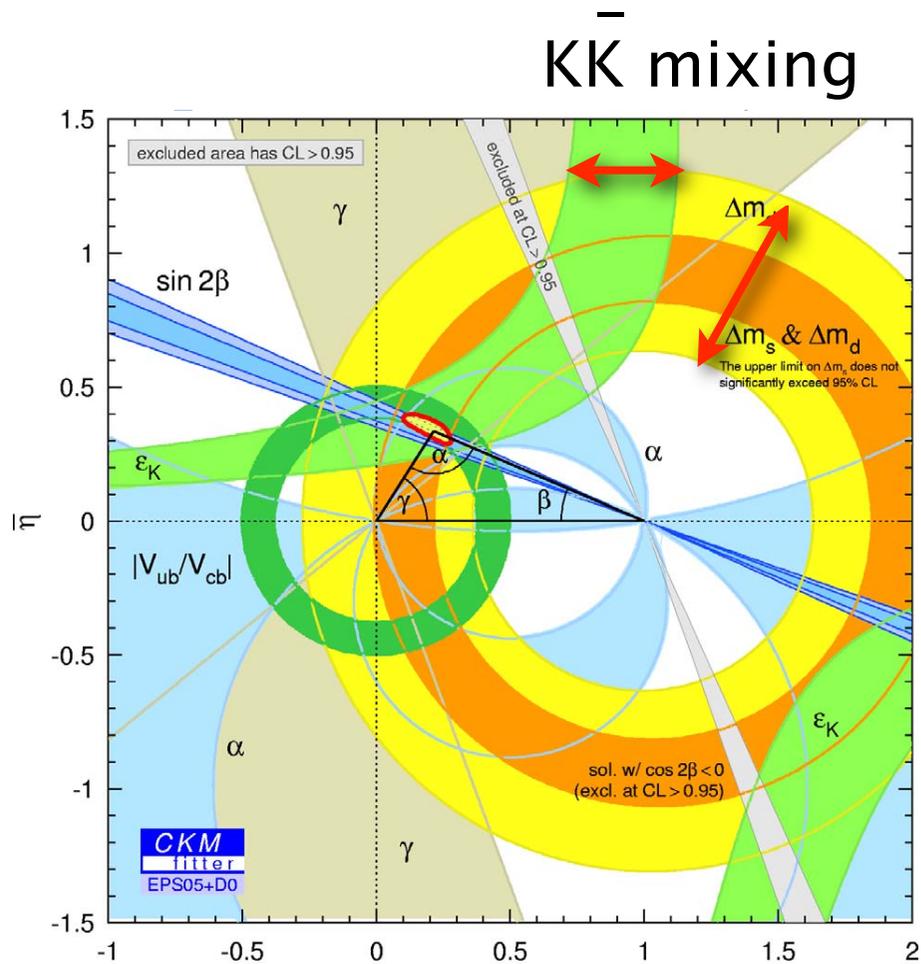
The various methods have wildly incommensurate virtues and defects.

Staggered fermion calculations are the cheapest and currently most advanced phenomenologically.



Progress, but also need and opportunity

For some quantities, only lattice calculations can unlock the complete potential of experimental measurements.



Buchholz, FPCP 2006

$\bar{B}\bar{B}$ mixing

$B_s\bar{B}_s$ mixing

Lattice QCD needs to deliver these quantities reliably. Or else.



Fermilab lattice group

Fermilab group: Andreas Kronfeld, Paul Mackenzie, Jim Simone (staff), Ruth van de Water, Jack Laiho (post-docs), Elizabeth Freeland (visitor). (And sometimes Bill Bardeen and Estia Eichten.)

U. of Illinois collaborators: Aida El-Khadra (professor), Paco Jain, Todd Evans (grad students).

$$\left(\begin{array}{ccc} \mathbf{V}_{ud} & \mathbf{V}_{us} & \mathbf{V}_{ub} \\ \pi \rightarrow l\nu & K \rightarrow \pi l\nu & B \rightarrow \pi l\nu \\ \mathbf{V}_{cd} & \mathbf{V}_{cs} & \mathbf{V}_{cb} \\ D \rightarrow \pi l\nu & D \rightarrow K l\nu & B \rightarrow D^{(*)} l\nu \\ D \rightarrow l\nu & D_s \rightarrow l\nu & \\ \mathbf{V}_{td} & \mathbf{V}_{ts} & \mathbf{V}_{tb} \\ \langle B_d | \bar{B}_d \rangle & \langle B_s | \bar{B}_s \rangle & \end{array} \right)$$

Main focus:
Standard Model phenomenology

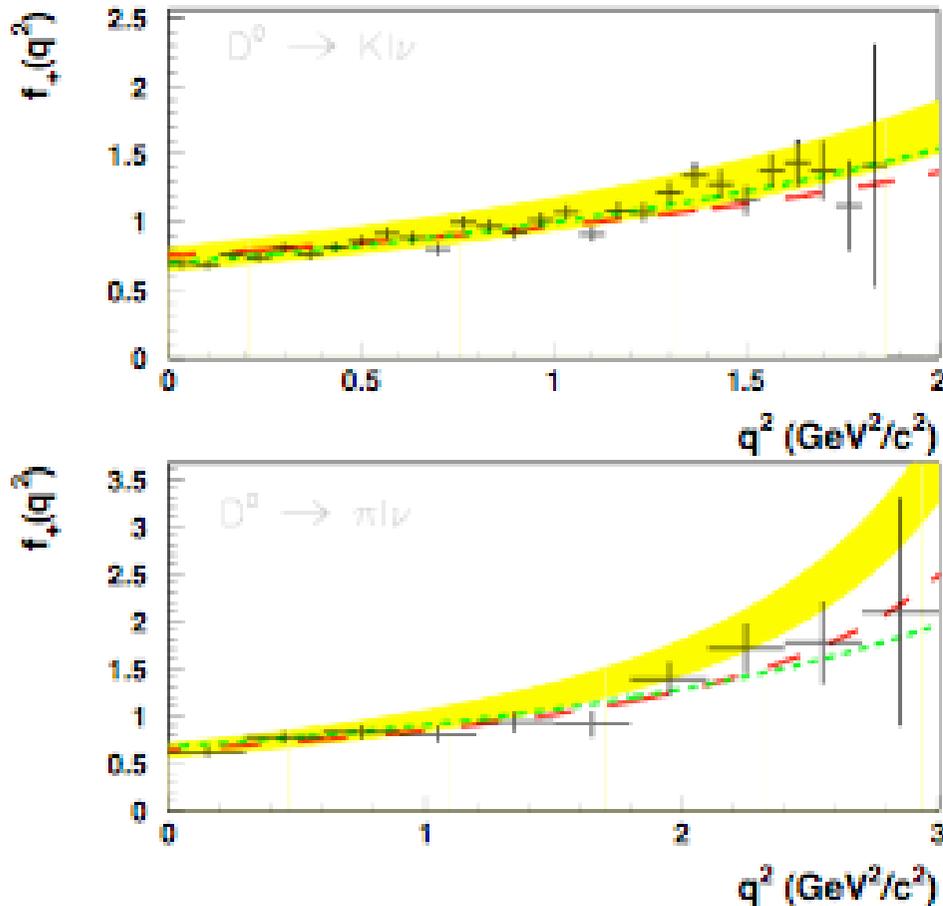
Almost all of the Standard Model parameters involving quarks can be obtained from solid lattice calculations.

We are embarked on a broad program of B and D phenomenology.



Predictions from lattice QCD: D semileptonic decay

$$f_+^{K,\pi}(q^2)$$



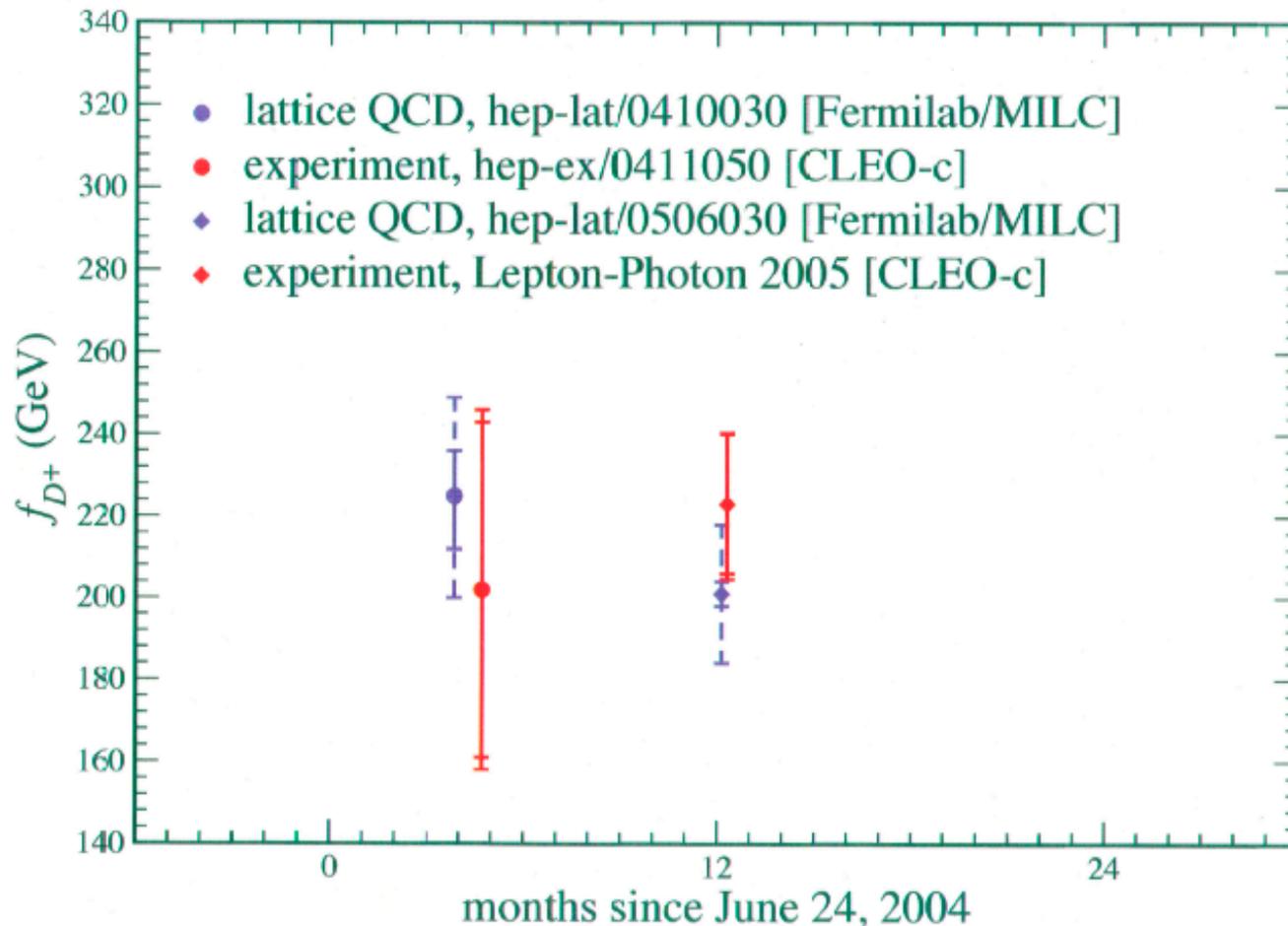
The shape of the D semileptonic form factors predicted by the lattice has been confirmed by FOCUS, BaBar, and most recently and most accurately by Belle.

Fermilab/MILC lattice results (yellow) vs. Belle experiment (crosses).

Belle, <http://arxiv.org/abs/hep-ex/0604049>

Predictions from lattice QCD: f_D

Theory and experiment should each improve by another factor of 2 over the next year.



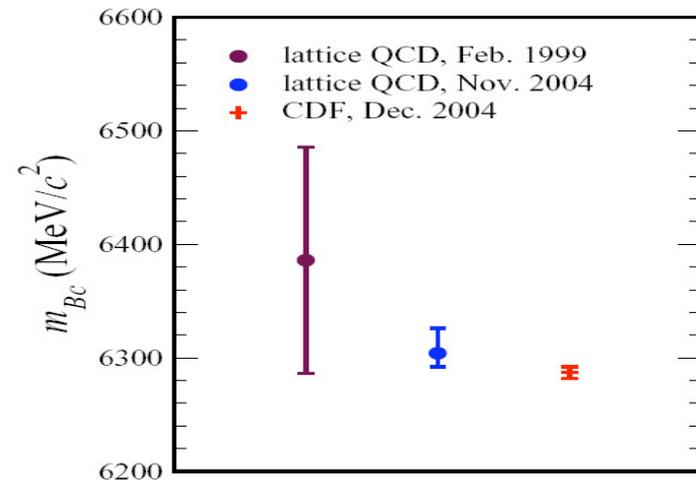
“It became clear that both groups [CLEO-c and Fermilab Lattice & MILC Collaborations] could have substantial results just in time for the Lepton-Photon Symposium in Uppsala at the end of June. Since both communities felt that it was very important for the LQCD result to be a **real prediction**, they agreed to embargo both of their results until the conference... The **two results agree well within the errors of about 8%** for each.” CERN Courier **45**, 6 (2005).

Predictions from lattice QCD: The B_c mass

“In an unprecedented feat of computation, particle theorists made the most precise prediction yet of the mass of the 'charm-bottom' particle. Days later, experimentalists dramatically confirmed that prediction.” Nature **436** (2005)

AIP Physics News Update: *Most Precise Mass Calculation For Lattice QCD* among **The Top Physics Stories for 2005**

Mass of the $B(c)$ meson in three-flavor lattice QCD, I. Allison, et al., Phys. Rev. **94** (2005)



Work in progress

- f_B, f_{B_s}
- B, D semileptonic decays
- $B\bar{B}, B_s\bar{B}_s$ mixing



USQCD

The Fermilab lattice group is part of USQCD, the national collaboration to establish computational infrastructure for lattice QCD.

Current funded at around \$5M/year = \$2.5M/year (DoE/SciDAC, software and hardware R&D) + \$2.5M/year (DoE/HEP + Nuclear program, hardware).

In FY06, Fermilab is installing a \$1.5 M cluster for lattice.

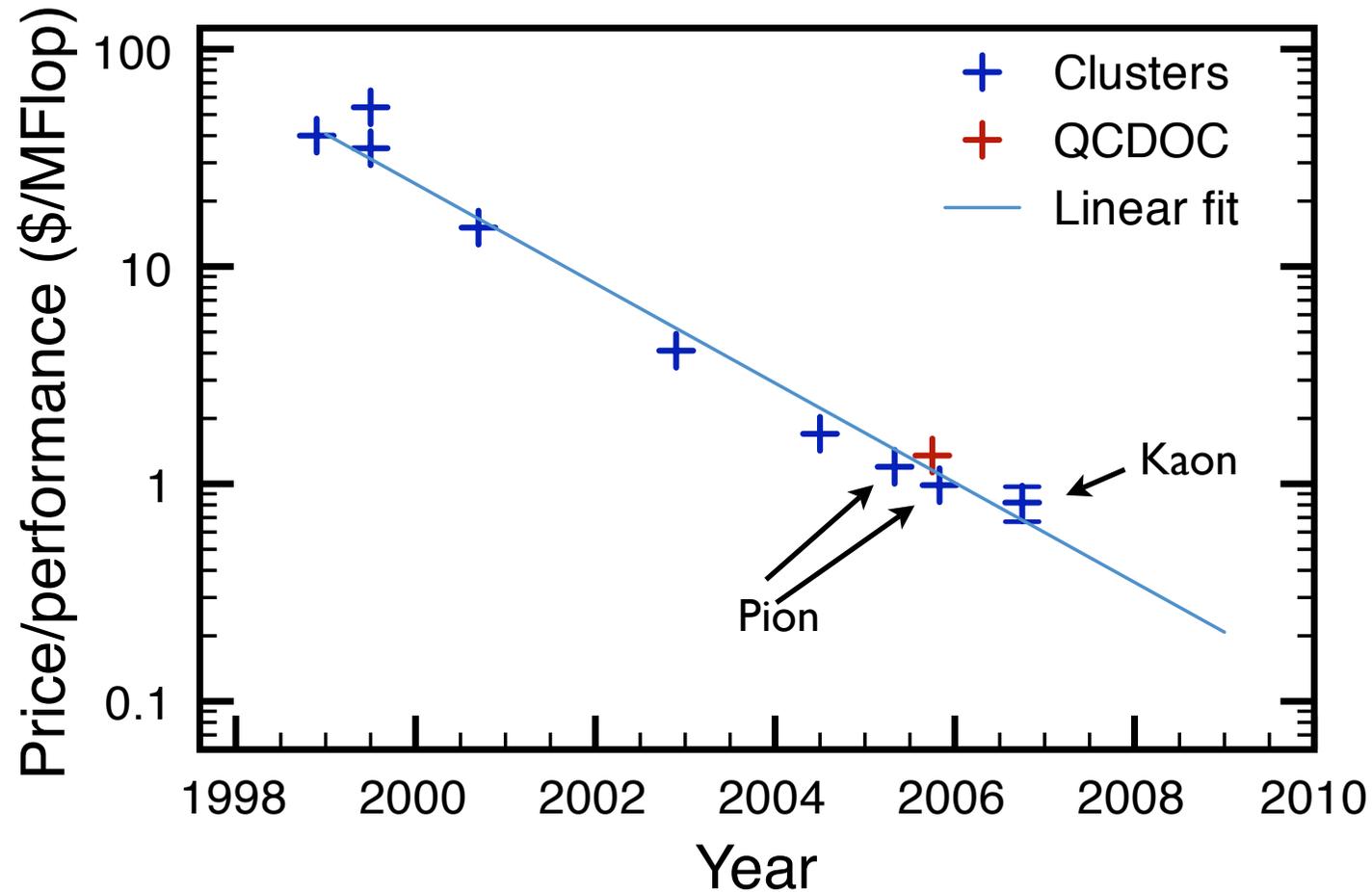
Paul Mackenzie serves on the USQCD Executive Committee,
Andreas Kronfeld serves on the Scientific Program Committee.



Commodity clusters currently give the most bang-for-the-buck for lattice computing.

Cluster Performance Trends

"Asqtad" Lattice QCD Code



Four-year plan

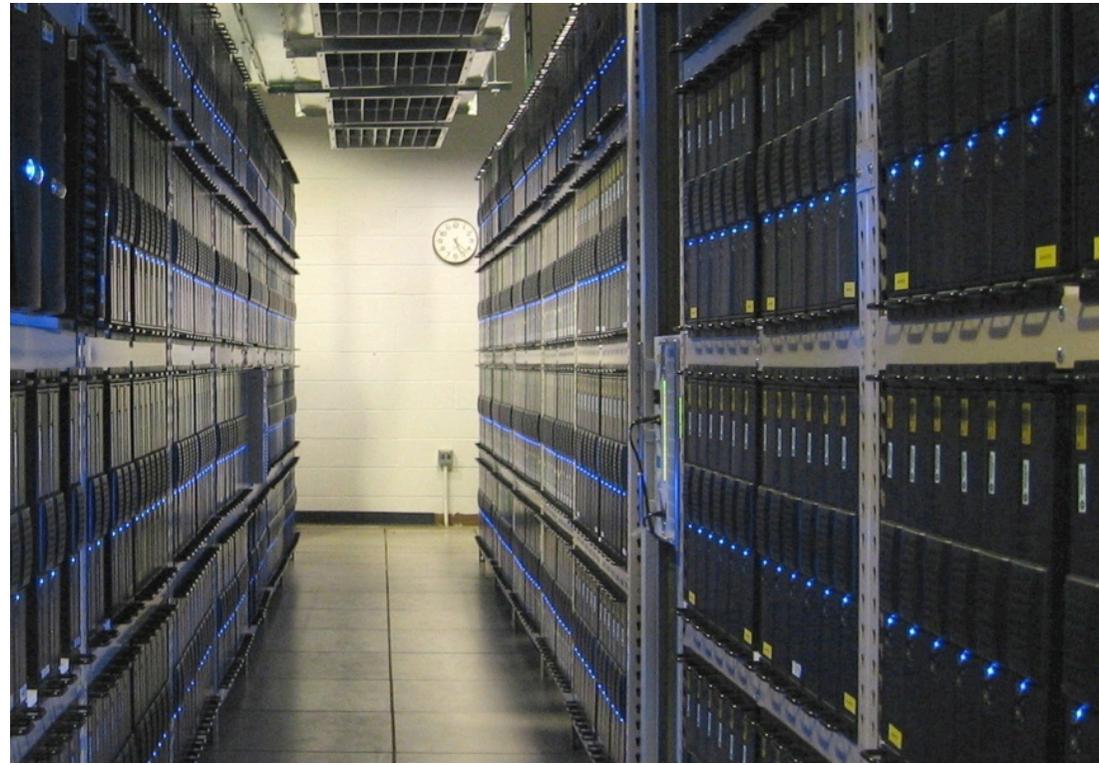
- 2006-09 OMB-approved plan for the DoE to fund lattice hardware via USQCD at around \$2.5 M/year.
 - SciDAC is funding lattice computing R&D at around \$2M/year.
- Don Holmgren (Fermilab) is project manager.
- Plan
 - 06 Fermilab cluster
 - 07 JLab cluster
 - 08+09 combined (?) Fermilab cluster



Fermilab lattice hardware site:
Old “New Muon Lab”.



05 installation:
“Pion”:



Lattice gauge theory future

- Lattice QCD is relevant to experiment as never before, but the need for more progress is still huge. E.g., matching the 1% accuracy in BB and $Bs\bar{B}s$ mixing.
- Needs will still be great in the LHC era.
 - Higher precision flavor physics. 1% accuracy needed to match experimental precision in $B\bar{B}$ mixing.
 - Nonperturbative Beyond-The-Standard-Model physics.
- Fermilab is currently the lead US lab in developing computing for lattice gauge theory. It is the natural lab to continue in that role.