An Experimenter’s View of:
Lattice Heavy Quark Flavor Physics

Outline:

Goals of quark flavor physics:
Quark Mixing & CP Violation
Physics Beyond the Standard Model

Status of key quark flavor measurements
where the lattice role is significant

How charm tests lattice QCD techniques

1st charm results from CLEO-c

Issues & Outlook

Conclusion

See also talks by Matt Wingate
& Vittorio Lubicz

Ian Shipsey,
Purdue University

Lattice04 6/25/04 Ian Shipsey
Big Questions in Flavor Physics

Dynamics of flavor?

Why generations?
Why a hierarchy of masses & mixings?

Origin of Baryogenesis?

Sakharov’s criteria: Baryon number violation
CP violation Non-equilibrium

3 examples: Universe, kaons, beauty but Standard Model CP violation too small, need additional sources of CP violation

Connection between flavor physics & electroweak symmetry breaking?

Extensions of the Standard Model (ex: SUSY) contain flavor & CP violating couplings that should show up at some level in flavor physics, but *precision* measurements and *precision* theory are required to detect the new physics
The Context

**This Decade**

Flavor Physics: is in "the sin2\(\beta\) era" akin to precision Z. Over constrain CKM matrix with precision measurements. Limiting factor: non-pert. QCD.

**The Future**

LHC may uncover strongly coupled sectors in the physics that lies beyond the Standard Model. The LC will study them. Strongly-coupled field theories are an outstanding challenge to theoretical physics. Critical need for reliable theoretical techniques & detailed data to calibrate them.

**Premier Example:**

Complete definition of pert & non. Pert. QCD. A goal is to calculate to few% in B, D, \(\Upsilon\), \(\Psi\).

Charm at threshold can provide the data to test & calibrate QCD techniques such as Lattice.
Status of $B_d$ & $B_s$ mixing

(See Daria Zieminska talk tomorrow for details of Bd/Bs mixing)

$B_d \rightarrow \overline{B_d}$ mixing

ALEPH, CDF, DELPHI, L3, OPAL, BABAR, BELLE, ARGUS, CLEO

$\Delta m_d = \frac{G^2_F m_{B_d}}{6 \pi^2} \frac{f_{B_d}^2 B_{B_d} \eta_B}{m^2_{B_d}} |V_{td}|^2 |V_{tb}|^2 f \left( m^2_t, m^2_w \right)$

$\Delta M_d = 0.502 \pm 0.007 \text{ ps}^{-1}$

$\frac{\delta \Delta M_d}{\Delta M_d} = 1.4\%$

$f_{B_d}^2 B_{B_d} = (223 \pm 33 \pm 12)^2 \text{ MeV}^2$

$|V_{td}| |V_{tb}| = (9.2 \pm 1.4 \pm 0.5) \times 10^{-3}$

(15-20\% error)

$|V_{td}| |V_{tb}|$ was known to 3\%

$|V_{td}| |V_{tb}|$ would be known to ~5\%

$B_s \rightarrow \overline{B_s}$ mixing

ALEPH, CDF, DELPHI, OPAL, SLD

$\Delta m_s < 14.5 \text{/ps}$

World Average

Prospects:

- 2\sigma for $\Delta m=15$/ps with 0.5 fb$^{-1}$
- Near term D0/CDF
- 5\sigma for $\Delta m=18$/ps with 1.7 fb$^{-1}$
- Long term CDF
- 5\sigma for $\Delta m=24$/ps with 3.2 fb$^{-1}$
precision absolute charm leptonic decay rates are a test of LQCD decay constant calculations

\[ B(D^+ \rightarrow \mu \nu) / \tau_{D^+} = (\text{const.}) f_{D^+}^2 |V_{cd}|^2 \]

\[ B(D_s^+ \rightarrow \mu \nu) / \tau_{D_s^+} = (\text{const.}) f_{D_s^+}^2 |V_{cs}|^2 \]

Lattice predicts: \( f_B/f_{B_s} \) & \( f_D/f_{D_s} \) with small errors
if precision measurements of \( f_D \) & \( f_{D_s} \) existed (they do not)

Some Possibilities:

\[ \frac{\delta f_{D_s}}{f_{D_s}} \sim 14\% \quad \text{PDG} \]

\[ \frac{\delta f_{D_s}}{f_{D_s}} \sim 55\% \quad \text{PDG} \]

\( f_D/f_{D_s} \) (expt.) tests \( f_D/f_{D_s} \) (lattice) & gives confidence to \( f_B/f_{B_s} \) (lattice)

Lattice errors on \( f_B/f_D \) & \( f_{B_s}/f_{D_s} \) also smaller than on individual f’s
Use \( f_B/f_D \) (lattice) & \( f_D \) (expt.) + \( B_d \) mixing \( \rightarrow \) precision \( V_{td} \)
Use \( f_{B_s}/f_{D_s} \) (lattice) & \( f_{D_s} \) (expt.) + \( B_s \) mixing \( \rightarrow \) precision \( V_{ts} \)

\( f_D \) (expt.) tests \( f_D \) (lattice) & \( f_{D_s} \) (expt.) tests \( f_{D_s} \) (lattice)

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Status of $V_{ub}$ (exclusive method)

**BABAR/Belle/CLEO**

Exclusive $|V_{ub}|$ from $\pi^- l^+ \nu$, $\pi^0 l^+ \nu$, $\eta l^+ \nu$, $\rho^- l^+ \nu$, $\rho^0 l^+ \nu$, $\omega l^+ \nu$

CLEO 10 $\gamma(4S)$

Detector hermeticity $\Rightarrow$ "$\nu$ reconstruction" $q^2$ and $E_\nu > 1.0$ GeV ($\pi$), $> 1.5$ GeV ($\rho$)

Measure $d\Gamma/dq^2$

Reduce FF shape dependence

Test FF calcs models/LCSR/lattice

$B \rightarrow \pi l \nu$ (best)

$B \rightarrow \rho l \nu$ (difficult expt. & lattice)

Average of BABAR

CLEO $\pi/\rho l^+ \nu$

(Gibbons, Beauty 03)

Traditional $\nu$ recon. sys limited. Fully recon. Btags from BABAR/BELLE will improve $\delta M \times 50! \rightarrow$ reduced expt. systematic $\delta V_{ub}$

$V_{ub}^{\text{excl}} = (3.27 \pm 0.13 \pm 0.19^{+0.51}_{-0.45}) \times 10^{-3}$

Stat sys FF

Theory systematic dominates
absolute charm semileptonic decay rates as a test of LQCD form factors

\[ \frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{cs}|^2 p_K^3 |f_+(q^2)|^2 \]

I. Absolute magnitude & shape of form factors are a stringent test of theory.
II. Absolute charm semileptonic rate gives direct measurements of $V_{cd}$ and $V_{cs}$.
III Key input to precise $V_{ub}$ vital CKM cross check of $\sin^2 \beta$

1) Measure $D \rightarrow \pi$ form factor in $D \rightarrow \pi l \nu$. Tests LQCD $D \rightarrow \pi$ form factor calculation.
2) BaBar/Belle can extract $V_{ub}$ using tested LQCD calc. of $B \rightarrow \pi$ form factor.
3) But: need absolute $\text{Br}(D \rightarrow \pi l \nu)$ and high quality $d\Gamma (D \rightarrow \pi l \nu)/dE\pi$ neither exist

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Zero recoil in $B \to D^{*}\ell^+\nu$ & $B \to D\ell^+\nu$

\[
\frac{d\Gamma}{dq^2}(B \to D^{*}\ell\nu) \propto F(q^2)^2 |V_{cb}|^2
\]

\[
m_Q \to \infty, F(q^2_{\text{max}}) = 1
\]

finite $m_Q F(1) = 0.91 \pm 0.04$

\[
(q^2_{\text{max}} : w = 1)
\]

Lattice & sum rule

\[
F(1)|V_{cb}| = (36.5 \pm 0.3_{\text{stat}} \pm 0.8_{\text{sys}}) \times 10^{-3}
\]

\[
|V_{cb}| = (40.1 \pm 0.9_{\text{exp}} \pm 1.8_{\text{theo}}) \times 10^{-3}
\]

As B Factory data sets grow, & Lattice calculation of form factor improve a limiting systematic for $V_{cb}$ via $B \to D^{*}/D\ell^+\nu$

\[
dB(D \to K\pi)/dB(D \to K\pi) \Rightarrow dV_{cb}/V_{cb} = 1.2\%
\]

Status of $V_{cb}$ (exclusive)

precision absolute charm branching ratios can improve the situation
CLEO-c Physics Program

- **flavor physics:** overcome the non-pert. QCD roadblock
  - Precision charm lifetimes
  - Precision charm abs. branching ratio measurements (CLEO-c)
- **Leptonic decays:** decay constants
  - Tests QCD techniques in c sector, apply to b sector
  - Improves Vub, Vcb, Vtd & Vts
- **Semileptonic decays:** form factors Vcs, Vcd, unitarity
- **Abs D hadronic Br's normalize B physics**
- **strong coupling in Physics beyond the Standard Model**
  - CLEO-c: precise measurements of quarkonia spectroscopy & decay provide essential data to test theory.
  - Important input for the lattice
- **Physics beyond the Standard Model:**
  - D-mixing, CPV, rare decays. + measure strong phases

This program helps build & test the QCD tools to enable this decade’s flavor physics and the next decade’s new physics.
2002: Prologue: Y(1S), Y(2S), Y(3S) (combined)
Spectroscopy, matrix element, $\Gamma_{ee}$, $\eta_B$ $h_b$
10-20 times the existing world’s data

2003: 2004 CESR upgraded to CESR-c (12 wigglers)
6 last summer – 6 this summer (for damping at low energy)
9/03-4/04 $\psi(3770)$, $\psi(2S)$, continuum
L = $4.6 \times 10^{31}$ (as expected) 55 pb$^{-1}$, 3 pb$^{-1}$, 20 pb$^{-1}$
2.5 times world’s existing data

Fall 2004: $\psi(3770) - 3$ fb$^{-1}$ ($\psi(3770) \rightarrow$ DD) ~20 million DD
~5 million tagged D decays (60 X data in hand)

Fall 2005: $\sqrt{s} \sim 4140$ MeV – 3 fb$^{-1}$ 1.5 million D$s$D$s$ events,
0.3 million tagged D$s$ decays (480 x MARK III, 130 x BESII)

Fall 2006: $\psi(3100)$, 1 fb$^{-1}$ ~1 Billion J/$\psi$ decays

A 3 year program
CLEO III is already a well understood detector that has produced numerous physics results at 10 GeV

Minor modification: replaced silicon with 6 layer low mass inner drift chamber summer ‘03
ψ(3770) events: simpler than Y(4S) events

- The demands of doing physics in the 3-5 GeV range are easily met by the existing detector.
- **BUT**: B Factories: 400 fb-1 → ~500M cc what is the advantage of running at threshold?

Charm events produced at threshold are extremely clean
- Large $\sigma$, low multiplicity
- Pure initial state: no fragmentation
- Signal/Background is optimum at threshold

Double tag events are pristine
- These events are key to making *absolute* $Br$ measurements
- Neutrino reconstruction is clean
- Quantum coherence aids D mixing & CP violation studies
• $\psi(3770) \rightarrow DD$

• An initial D state can be tagged by reconstructing the “other-side” $\bar{D}$

• Charm mesons have many large branching ratios $\sim 1\text{-}15\%$

• low multiplicity: high reconstruction efficiency favorable S/N

$\Rightarrow$ High net tagging efficiency: $\sim 26\%$ of all D’s produced are reconstructed (achieved)

$D^0 \rightarrow K^-\pi^+$

DATA (Prelim.)
$\sim 55 \text{ pb}^{-1}$

$D^+ \rightarrow K^-\pi^+\pi^+$

DATA (Prelim.)
$\sim 55 \text{ pb}^{-1}$

Single tags are clean
Double tags: 1st CLEO-c DATA

$D^+ \rightarrow K^- \pi^+ \pi^+$, $D^- \rightarrow K^+ \pi^- \pi^-$

Tagging effectively creates a single D beam

From single and double tags we measure independent of D Br’s

$\sigma(DD) = 6.48 \pm 0.44 \pm 0.39 \text{nb}$
Absolute Charm Branching Ratios at Threshold

$\psi(3770) \rightarrow DD$

Tagging effectively creates a single D beam

$$Br(D \rightarrow X) = \frac{\#X \text{ Observed}}{\text{efficiency for } X \cdot \#D's}$$

Where $\#$ of D’s = $\#$ of tagged events

Meson Factory Figure of merit:

$$\frac{\#B \text{ tags @B Factory}}{\#D \text{ tags @Charm Factory}} = \frac{\sigma(BB) \varepsilon_{tag} \int Ldt=500fb^{-1}}{\sigma(DD) \varepsilon_{tag} \int Ldt=3fb^{-1}} \sim 1$$

Extrapolate to full data set.

Extrapolations use:

$\sigma(DD)\varepsilon_{tag} = 10 \text{ nb (0.19)} = 1.9 \text{ nb}$

We measure:

$\sigma(DD)\varepsilon_{tag} = 6.5 \text{ nb (0.26)} = 1.7 \text{ nb}$

close enough not to revise predictions

<table>
<thead>
<tr>
<th>Decay</th>
<th>$\sqrt{s}$</th>
<th>L (fb$^{-1}$)</th>
<th>Double tags</th>
<th>$\delta B / B$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow K^- \pi^+$</td>
<td>3770</td>
<td>3</td>
<td>53,000</td>
<td>2.4</td>
</tr>
<tr>
<td>$D^+ \rightarrow K^- \pi^+ \pi^+$</td>
<td>3770</td>
<td>3</td>
<td>60,000</td>
<td>7.2</td>
</tr>
<tr>
<td>$D_s \rightarrow \phi \pi$</td>
<td>4140</td>
<td>3</td>
<td>6,000</td>
<td>25</td>
</tr>
</tbody>
</table>

CLEO-c sets absolute scale for all heavy quark measurements

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**Signal region**

$D^- D^+ \rightarrow \mu^+ \nu^-$

Hadronic tag

No additional track or shower.

Compute $MM^2$ peaks at zero if only a neutrino is missing

**DATA Preliminary**

Compute $MM^2$ peaks at zero if only a neutrino is missing

$MM^2 = (E_{beam} - E_{\mu})^2 - (P_{D^{\mu+}} - P_{\mu})^2$

**CLEO-c Proposal:**

$\sim 55$ pb$^{-1}$

**MC 1 fb$^{-1}$**

**Compute $MM^2$ peaks at zero if only a neutrino is missing**

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**CLEO-c Proposal:**

$\sim 55$ pb$^{-1}$

**MC 1 fb$^{-1}$**
9 events within $2\sigma$
$(-0.056 < MM^2 < 0.056 \text{ GeV}^2)$
$0.67 \pm 0.24$ estimated
background events.

**SIGNIFICANT SIGNAL**

Reconstruction efficiency $\sim 70\%$

$\mathcal{B} = \frac{\text{Signal}}{(\text{Tags} \times \text{Efficiency})}$

$$B = (4.57 \pm 1.66 \pm 0.41) \times 10^{-4}$$

$f_D = (230 \pm 42 \pm 10) \text{ MeV}$

Statistically Limited
Soon 60 x the dataset!

$$B(D^+ \rightarrow \mu \nu) / \tau_{D^+} = (\text{const.}) f^2_D |V_{cd}|^2$$

$V_{cd}$ (1.1%) from 3 generation unitarity
$\tau_{D^+}$ well-measured (0.3%)

Winter 2004 Conferences:
BESII 3 events

$$B = (0.12^{+0.092}_{-0.063} ^{+0.01}_{-0.009})\%$$

$$f_D = (365^{+121}_{-113} ^{+32}_{-28}) \text{ MeV}$$
**f_{Ds} from Absolute Br(D_s \rightarrow \mu^+\nu)**

\( \sqrt{s} \sim 4140 \rightarrow D_sD_s \)

Vcs known from unitarity to 0.1%
\( \tauDs \) known to 2%

**MC**

1 fb\(^{-1}\)

\( D_s \rightarrow \text{tag} \)

\( D_s \rightarrow \mu\nu \)

Projection to full data set:

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Energy(MeV)</th>
<th>L fb(^{-1})</th>
<th>PDG</th>
<th>CLEO-c</th>
</tr>
</thead>
<tbody>
<tr>
<td>( f_{Ds} )</td>
<td>( D_s^+ \rightarrow \mu\nu )</td>
<td>4140</td>
<td>3</td>
<td>17%</td>
</tr>
<tr>
<td>( f_{Ds} )</td>
<td>( D_s^+ \rightarrow \tau\nu )</td>
<td>4140</td>
<td>3</td>
<td>33%</td>
</tr>
<tr>
<td>( f_{D^+} )</td>
<td>( D^+ \rightarrow \mu\nu )</td>
<td>3770</td>
<td>3</td>
<td>55%</td>
</tr>
</tbody>
</table>

Year of Data taking:
- 2005
- 2004

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Semileptonic Decays: 1st CLEO-c DATA

$\psi(3770) \rightarrow D^0 \bar{D}^0$

$\bar{D}^0 \rightarrow K^+ \pi$, $D^0 \rightarrow K^- e^+ \nu$

$D^0 \rightarrow \text{hadronic tag}$,
$D^0 \rightarrow K^- e^+ \nu$

Preliminary

$U = E_{\text{miss}} - P_{\text{miss}}$ (GeV)
More semileptonic modes

\[ D^0 \rightarrow \pi^- e^+ \nu \]

\[ D^0 \rightarrow \rho^- e^+ \nu \]

\[ U = E_{\text{miss}} - P_{\text{miss}} \text{(GeV)} \]

Recall this is 55 pb\(^{-1}\) plan for x60 data starting fall 2004

First observation of \( D^0 \rightarrow \rho^- e^+ \nu \)

~30 events
CLEO-c Impact semileptonic dB/B

1: \(D^0 \rightarrow K^- e^+ \nu\)
2: \(D^0 \rightarrow K^*^- e^+ \nu\)
3: \(D^0 \rightarrow \pi^- e^+ \nu\)
4: \(D^0 \rightarrow \rho^- e^+ \nu\)
5: \(D^+ \rightarrow K^0 e^+ \nu\)
6: \(D^+ \rightarrow K^{*0} e^+ \nu\)
7: \(D^+ \rightarrow \pi^0 e^+ \nu\)
8: \(D^+ \rightarrow \rho^0 e^+ \nu\)
9: \(D_s^- \rightarrow K^0 e^+ \nu\)
10: \(D_s^- \rightarrow K^{*0} e^+ \nu\)
11: \(D_s^- \rightarrow \phi e^+ \nu\)

Full CLEO-c data set will make **significant** improvements in the precision with which each absolute charm semileptonic branching ratio is known.

With 55 pb\(^{-1}\) already accumulated CLEO-c will equal or improve on the PDG value of dB/B for every \(D^+\) and \(D^0\) exclusive semileptonic and inclusive branching ratio, and \(\sim 10\) the statistics of the DELCO \(D \rightarrow eX\) inclusive spectrum (important also for B inclusive semileptonic decay studies).
Semileptonic Decays $|V_{CKM}|^2 |f(q^2)|^2$

For the first time measure complete set of charm $PS \rightarrow PS$ & $PS \rightarrow V$ absolute form factor magnitudes and slopes to a few% with almost no background in one experiment.

Common disconnect: LQCD most precise where data is least but full $q^2$ range calculable \(\Rightarrow\) Would like LQCD FF magnitudes & slopes with few% precision. Stringent test of theory!
Determination of Vcs and Vcd

internal consistency? combine semileptonic and leptonic decays eliminating V CKM

\[ \frac{\Gamma(D^+ \rightarrow \pi l \nu)}{\Gamma(D^+ \rightarrow l \nu)} \] independent of Vcd
Test rate predictions at ~4%

\[ \frac{\Gamma(D_s \rightarrow \eta l \nu)}{\Gamma(D_s \rightarrow l \nu)} \] independent of Vcs
Test rate predictions at ~ 4%

Test amplitudes at 2%
Stringent test of theory! If theory passes the test.....

I
\[ D^0 \rightarrow K^- e^+ \nu \] \[ \delta Vcs / Vcs = 1.6\% \text{ (now: 16\%)} \]
\[ D^0 \rightarrow \pi^- e^+ \nu \] \[ \delta Vcd / Vcd = 1.7\% \text{ (now: 7\%)} \]

II
tested lattice to calc. B semileptonic form factor,
B factories use \( B \rightarrow \pi/\eta/l \nu \) for precise Vub
shape is an additional cross check
Unitarity Constraints

\[
\begin{pmatrix}
  s' \\
  d' \\
  b'
\end{pmatrix} = 
\begin{pmatrix}
  V_{ud} & V_{us} & V_{ub} \\
  V_{cd} & V_{cs} & V_{cb} \\
  V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
  d \\
  s \\
  b
\end{pmatrix}
\]

1st row: \(|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 \) fails at \(\sim 2\sigma\) (PDG2002), now consistent KTeV (2004)

2nd row: \(|V_{cd}|^2 + |V_{cs}|^2 + |V_{cb}|^2 = 1 \) \(\text{CLEO -c: test to } \sim 3\%\) (if theory \(\text{D} \rightarrow \text{K}/\pi|_\nu\text{ good to few }\%\))

& 1st column: \(|V_{ud}|^2 + |V_{cd}|^2 + |V_{td}|^2 = 1 \) \(\text{uc}^* = 0\) with similar precision to 1st row

\[|V_{ud}V_{cd}^*|\quad |V_{ub}V_{cb}^*|\quad |V_{us}V_{cs}^*|\quad \text{Compare ratio of long sides to 1.3%}\]
Probing QCD with Onia

→ Verify tools for strongly coupled theories
→ Quantify accuracy for application to flavor physics

• $\psi$ and $\Upsilon$ Spectroscopy
  – Masses, spin fine structure
• Leptonic widths for S-states.
  – EM transition matrix elements

Rich calibration and testing ground for theoretical techniques
→ apply to flavor physics

LQCD hopes to predict to several %.

Recent order of magnitude increase in dataset size able to test predictions:

\[ \times 10^6 \]

\[ \Upsilon(1S) \]

\[ \Upsilon(2S) \]

\[ \Upsilon(3S) \]

\[ \times 10^6 \]

\[ \psi^\prime \]

\[ \psi'' \times 10 \]
Observation of $\Upsilon(1D)$ & Impact

[CLEO]

Four $\gamma$ cascade; exclusive $\Upsilon(1S)$ channel

Background thru $2^3S_1$

First reported ICHEP'02 with 80% of data ... now final

Submitted to PRD [hep-ex/0404021]

$M = 10161.1 \pm 0.6 \pm 1.6$ MeV

Tests LQCD at high $L$

[C. T. H. Davies et al., PRL 92:022001 (2004)]

$g_n$

$g_K$

$\delta M_{b} - M_J$

$2M_{B_{s}} - M_{\Lambda}$

$\Gamma(1P - 1S)$

$\Gamma(1D - 1S)$

$\Gamma(2P - 1S)$

$\Gamma(3S - 1S)$

$\Gamma(1P - 1S)$

Ratio = LQCD/Expt

Quenched

Unquenched ($n_f=3$)
• **Crucial Validation of Lattice QCD**: Lattice QCD hopes to calculate with accuracies of 1-2%. The CLEO-c decay constant and semileptonic data will provide a “golden,” & timely test. QCD & charmonium data provide additional benchmarks.

Assumes Theory Errors reduced by x2

Imagine a world where we have theoretical mastery of non-perturbative QCD at the 2% level

Theory errors = 2%
Lattice Impact on Flavor Physics

- **Crucial Validation of Lattice QCD**: Lattice QCD hopes to calculate with accuracies of 1-2%. The CLEO-c decay constant and semileptonic data will provide a “golden,” & timely test. QCD & charmonium data provide additional benchmarks.

B Factories

400 fb$^{-1}$

Assumes Theory
Errors reduced by x2

Imagine a world where we have theoretical mastery of non-perturbative QCD at the 2% level

Theory errors = 2%
Lattice Impact on Flavor Physics

Or in tabular form:

<table>
<thead>
<tr>
<th></th>
<th>Vcd</th>
<th>Vcs</th>
<th>Vcb</th>
<th>Vub</th>
<th>Vtd</th>
<th>Vts</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO-c data and LQCD</td>
<td>7%</td>
<td>16%</td>
<td>4%</td>
<td>15%</td>
<td>36%</td>
<td>39%</td>
</tr>
<tr>
<td>B Factory &amp; Tevatron Data &amp; LQCD</td>
<td>1.7%</td>
<td>1.6%</td>
<td>3%</td>
<td>5%</td>
<td>5%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Current Precision | Current Precision
Issues

How can we be sure that if LQCD works for D’s it also works in B’s? Or equivalently is CLEO-c data enough?

Two independent methods: NRQCD, Fermilab for D decays

Leptonic SL decays \[ \frac{d\Gamma(B \to \pi l\nu)}{d\Gamma(D \to \pi l\nu)} \] decays Many modes + \[ dp_\pi \] are simple Shape cross check \[ dp_\pi \] BABAR/Belle \[ dp_\pi \] CLEO-c

Both methods also for \( \Gamma_{ee} \) & EM transitions in \( Y, \psi \) sectors

Main sys. errors limiting accuracy: \( m(\text{light}) \) and related chiral extrapolations, peturbation theory, finite lattice spacing are similar for charm and beauty quarks,

CLEO-c + onia + light quark physics can establish whether or not systematic errors are under control

Lattice technique is all encompassing but LQCD practitioners are conservative about what it can calculate. (not a criticism). Much of the excitement at the moment in B physics revolves around \( \sin 2\beta(\psi K_s) \) vs \( \sin 2\beta(\phi K_s) \)

Need to move beyond gold-plated quantities in the next few years: Resonances, e.g. \( \rho \to \pi \pi, \phi, K^* \) States near threshold \( \psi(2S), D_s(0^+), \) hadronic weak decays
Systematic Errors

It will take accurate and precise experimental measurements from experiments combined with accurate and precise theoretical calculations to search for new physics in the CKM matrix. Therefore, it is essential to chase down each and every source of systematic error.

With experimentalists and phenomenologists in mind:

1) Include a comprehensive table of systematic errors with every calculation (it is already included in many/most? cases). This makes it more straightforward to compare results from different groups. It is understood that different groups use different methods and will have somewhat different lists.

2) A statement of whether an error is Gaussian or non-Gaussian. Errors are often estimates of higher order terms in a truncated expansion, so the quoted error bar is non-Gaussian. For the statistical error a distribution could be provided.

3) The correlation between individual systematic errors (if such correlation exists).

4) Provide an overall systematic error by suitably combining individual errors, this is redundant and should not replace the individual error breakdown, but certainly convenient.
Outlook for the next 5 years (2 years)?

Expect to see a growing number of lattice results for gold plated quantities within the next few years ⇒ ultimate goal: ~ few % errors in < 5 years

Famous Lattice Theorist (2003)

Prediction is better than postdiction

Every experimentalist (anytime)

Need high precision experimental results in order to test lattice QCD ⇒ CLEO-c for D decays

Famous Lattice Theorist (2003)

CLEO-c may have a few % preliminary determination of $f_D$ as early as the summer conferences in 2005

An unquenched lattice calculation for $f_D$ with systematic error budget & analysis correlations?/PDFs? before the CLEO-c result is published will clearly demonstrate the current precision of the lattice approach to experimentalists & non-lattice theorists & add confidence to the ultimate goal of few % errors

+ $f_{D_s}$ before the CLEO-c preliminary result is announced (which could be as early at the summer conferences in 2006)

+ Form factors in $D \to K/pi lv$ (2005) and $D_s$ semileptonic decays (2006)
Summary

- This is a special time for flavor physics and the lattice
- Lattice goal to calculate to few % precision in D, B, Y, ψ
- CLEO-c (later BESIII) about to provide few % tests of lattice calculations in the D system & in onia, quantifying the accuracy for application of LQCD to the B system
- BABAR/Belle/CDF/D0 (later BTeV/LHC-b/ATLAS/CMS SuperBFac) + LQCD can reach few % precision Vub, Vcb, Vtd, Vts

Precision LQCD confronts experiment
Precision experiment confronts LQCD
Allows Flavor physics to reach its full potential this decade
Paves the way for understanding beyond the SM physics in the next decade
Additional Slides
Additional topics

• $\Psi'$ spectroscopy (10$^8$ decays) $\eta'_c h_c$...

• $\tau^+\tau^-$ at threshold (0.25 fb$^{-1}$)
  • measure $m_\tau$ to ± 0.1 MeV
  • heavy lepton, exotics searches

• $\Lambda_c\Lambda_c$ at threshold (1 fb$^{-1}$)
  • calibrate absolute BR($\Lambda_c \rightarrow pK\pi$)

• $R = \sigma(e^+e^- \rightarrow \text{hadrons})/\sigma(e^+e^- \rightarrow \mu^+\mu^-$)
  • spot checks
Initial State Radiation photon reduces $\sqrt{s}$

**Measurement** | **#events**
---|---
| **BaBar/Belle** | **CLEOc** |
| $D_s^+ \rightarrow \mu \nu$ | 330 | 1,221 |
| $D^+ \rightarrow \mu \nu$ | 50 | 672 |
| $D^+ \rightarrow K^- \pi^+ \pi^+$ | 6,750 | 60,000 |
| $D_s^+ \rightarrow \phi \pi$ | 221 | 6,000 |

**ISR projections**

- ISR technique is not statistically competitive with CLEO-c.
- Systematic errors are also much larger.

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Lattice04 6/25/04 Ian Shipsey
Probing QCD with Onia

- Verify tools for strongly coupled theories
- Quantify accuracy for application to flavor physics

• ψ and Υ Spectroscopy
  - Masses, spin fine structure

• Leptonic widths for S-states.
  - EM transition matrix elements
  - Υ resonances complete ~ 4 fb⁻¹ currently being analyzed

J/Ψ running fall 2006 10⁹ J/Ψ

• Uncover new forms of matter – gauge particles as constituents
  - Glueballs G=|gg⟩ Hybrids H=|gqq⟩

The current lack of strong evidence for these states is a fundamental issue in QCD ⇒ Requires detailed understanding of ordinary hadron spectrum in 1.5-2.5 GeV mass range.
Gluonic Matter

- Gluons carry color charge: *should bind!*
- But, like Jim Morrison, glueballs have been sighted too many times without confirmation.
- CLEO-c 1st high statistics experiment with modern $4\pi$ detector covering 1.5-2.5 GeV mass range.
- Radiative $\psi$ decays: ideal glue factory: $\frac{C}{C}$
  - $(60 \text{ M } J/\Psi \rightarrow \gamma X)$

Example: Narrow state in inclusive $\gamma$

**Exclusive:**

- Shown $B(fJ(2220) \rightarrow K^+ K^-) = 3.10^{-5}$
- Sensitivity $5\sigma B(fJ(2220) \rightarrow K^+ K^-) = 10^{-6}$
- Corroborating checks:
- Anti-search in $\gamma\gamma$: /Search in $\Upsilon(1S)$

Lattice04 6/25/04 Ian Shipsey
Using double tags to measure $\sigma(D\bar{D})$

$S = 2N_{D\bar{D}}B\varepsilon_1$

$N_{D\bar{D}} = \frac{S^2}{4D}$

$D = N_{D\bar{D}}B^2\varepsilon_2$

So far use only 2 modes:

$D^0 \rightarrow K^-\pi^+\bar{D^0} \rightarrow K^+\pi^- 102 \pm 11$

$D^+ \rightarrow K^-\pi^+\pi^+ \quad D^- \rightarrow K^+\pi^-\pi^- 338 \pm 19$

$\sigma(D\bar{D})$ required to estimate physics reach of CLEO-c

( independent on $B$ and $\varepsilon$ in the approximation $\varepsilon_2 = \varepsilon_1^2$ )
Summary for $\sigma(D\bar{D})$

- Our result which is independent of charm branching ratios is in agreement with BESII (April 2004). The BES experiment used a single tag method which is dependent on charm branching ratios from the PDG.

<table>
<thead>
<tr>
<th></th>
<th>$\sigma(D^+D^-)(nb)$ (stat.err)(sys.err)</th>
<th>$\sigma(D^0D^0)(nb)$ (stat.err)(sys.err)</th>
<th>$\sigma(DD)$ (nb) (stat.err)(sys.err)</th>
<th>$\sigma(D^+D^-)/\sigma(D^0D^0)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>CLEO (55pb$^{-1}$)</td>
<td>2.58±0.15 ±0.16</td>
<td>3.93±0.42±0.23</td>
<td>6.48±0.44±0.39*</td>
<td>0.656</td>
</tr>
<tr>
<td>BES II (17.7pb$^{-1}$)</td>
<td>2.52±0.07 ±0.23</td>
<td>3.26±0.09±0.26</td>
<td>5.78±0.11±0.38</td>
<td>0.773</td>
</tr>
<tr>
<td>MARK III(9.pb$^{-1}$)</td>
<td>2.1±0.3</td>
<td>2.9 ± 0.4</td>
<td>5.0 ± 0.5</td>
<td>0.724</td>
</tr>
</tbody>
</table>

- Unlike MARKIII, CLEO measurement uses only one $D^+$ and one $D^0$ decay mode.
- There are many other decay modes CLEO can use and we expect a much more precise result later this summer.

All CLEO-c numbers are preliminary

*A correct of -0.03 has been applied to allow for the absence of DCSD $D^0\rightarrow K^+\pi^-$ at the $\psi(3770)$*
CLEO-c Hadronic Two-body $\psi(2S)$ Decays

- Violations of naïve annihilation prediction:
  \[
  \frac{BR(\psi(2S) \rightarrow H)}{BR(J/\psi \rightarrow H)} \approx \frac{BR(\psi(2S) \rightarrow e^+ e^-)}{BR(J/\psi \rightarrow e^+ e^-)}
  \]
- Works for some modes, not others. Fails miserably in $\rho \pi$ mode
- 3M $\psi(2S)$ decays collected
- First results from data:
  - $\psi(2S) \rightarrow$
    - $b_1(1235)\pi$
    - $\omega f_2(1270)$
    - $\omega \pi^+ \pi^-$
    - $\phi f_0(980)$
    - $\phi f_2'(1525)$
    - $K^* (892) K$
    - $K^* K^*$

![Graphical representation of decay modes]
Tagging Efficiency is high

<table>
<thead>
<tr>
<th>$D^0$ Decay Mode</th>
<th>$\mathcal{B}$ (%) (PDG-02)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D^0 \rightarrow K^-\pi^+$</td>
<td>$(3.80 \pm 0.09)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^-\pi^+\pi^0$</td>
<td>$(13.1 \pm 0.9)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^-\pi^+\pi^+\pi^-$</td>
<td>$(7.46 \pm 0.31)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow \bar{K}^0\pi^0$</td>
<td>$(2.28 \pm 0.22)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow \bar{K}^0\pi^+\pi^-$</td>
<td>$(5.92 \pm 0.35)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow \bar{K}^0\pi^+\pi^-\pi^0$</td>
<td>$(10.8 \pm 1.3)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^-\pi^+\pi^+\pi^-\pi^0$</td>
<td>$(4.0 \pm 0.4)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow \bar{K}^0K^+K^-$</td>
<td>$(1.0 \pm 0.1)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow \pi^+\pi^-\pi^0$</td>
<td>$(1.1 \pm 0.4)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow K^+K^-$</td>
<td>$(0.41 \pm 0.01)$</td>
</tr>
<tr>
<td>$D^0 \rightarrow \pi^+\pi^-$</td>
<td>$(0.14 \pm 0.01)$</td>
</tr>
</tbody>
</table>

$D^+$ Decay Mode $\mathcal{B}$ (%) (PDG-02)

| $D^+ \rightarrow K^0\pi^+$ | $(2.77 \pm 0.18)$ |
| $D^+ \rightarrow K^-\pi^+\pi^+$ | $(9.1 \pm 0.6)$ |
| $D^+ \rightarrow \bar{K}^0\pi^+\pi^0$ | $(9.7 \pm 3.0)$ |
| $D^+ \rightarrow K^-\pi^+\pi^+\pi^0$ | $(6.4 \pm 1.1)$ |
| $D^+ \rightarrow \bar{K}^0\pi^+\pi^+\pi^-$ | $(7.0 \pm 0.9)$ |
| $D^+ \rightarrow K^+K^-\pi^+$ | $(0.9 \pm 0.1)$ |

Number of $D^+$ tags $\sim 30K$ in 55/pb

Number of $D^0$ tags $\sim 62K$ in 55/pb

Preliminary

Tag efficiency $\sim \frac{\# \text{ tags reconstructed}}{\# \text{DD pairs}}$

$\frac{62 + 30 = 92K}{L\sigma(\text{DD})} = \frac{92K}{6.51\text{nb} \cdot 55\text{pb}^{-1}} \sim 26\%$

(higher than the 19% assumed in projections)
Hadronic 2,3,4 body $\psi(2S)$ Decays

With 3M $\psi(2S)$ collected
23 decay modes measured

Agreement with PDG for modes previously observed

10 first measurements

Reported at APS
May, 2004
More modes
next week at HQL in San Juan
$D^+ \rightarrow K^0 e^+ \nu$

$D^+ \rightarrow K^{*0} e^+ \nu, \ K^{*0} \rightarrow K^- \pi^+$

$D^+ \rightarrow \rho^0 e^+ \nu$

All Plots Preliminary
More $D^0$ and $D^+$ tags

$D^+ \rightarrow \overline{K}^0 \pi^+ \pi^+ \pi^-$

$D^0 \rightarrow K^- \pi^+ \pi^0$

**All Plots Preliminary**

Number of $D^0$ tags $\sim 62K$ in 55/pb

Number of $D^+$ tags $\sim 30K$ in 55/pb

Tag efficiency $\sim \frac{\# \text{ tags reconstructed}}{\# \text{DD pairs}}$

$\text{tag efficiency} \sim \frac{62+30=92K}{L \sigma(DD)} = \frac{92K}{6.51 \text{nb} \cdot 55 \text{pb}^{-1}} \sim 26\%$

Lattice04 6/25/04 Ian Shipsey
Experimental Progress in Onia

See Daria Zieminska talk tomorrow for discussion X(3872), new cs states etc.
$D^0 \rightarrow \pi^- e^+ \nu$

Data

MC

$U = E_{\text{miss}} - P_{\text{miss}} \ (\text{GeV})$

Excess of $\sim 100$ events

Data well simulated by GEANT

MC giving confidence to estimates of precision in the CLEO-c proposal
Towards a precision $\Gamma_{ee}$ in the $Y$ system

Now: $Y(nS) \delta\Gamma_{ee}$ 4-12%. Precision measurement of $B(Y(nS) \rightarrow \mu\mu)$ needed to get $\Gamma_{tot}$ from narrow resonances for $\Gamma_{ee}$

Most precise measurements to date.
Few % precision reached
$Y(2S,3S)$ higher than PDG

$\Rightarrow$ Expect 2-3% precision for $\Gamma_{ee}$ (results soon)

<table>
<thead>
<tr>
<th></th>
<th>$B_{\mu\mu}$ (%)</th>
<th>$\Gamma_{tot}$ (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CLEO preliminary</td>
<td>PDG</td>
</tr>
<tr>
<td>$Y(1S)$</td>
<td>2.46 ± 0.02 ±0.05</td>
<td>2.48 ± 0.06</td>
</tr>
<tr>
<td>$Y(2S)$</td>
<td>2.00 ± 0.03 ±0.05</td>
<td><strong>1.31</strong> ± 0.21</td>
</tr>
<tr>
<td>$Y(3S)$</td>
<td>2.34 ± 0.07 ±0.05</td>
<td>1.81 ± 0.17</td>
</tr>
</tbody>
</table>
\( \Upsilon(1D) \) Impact on LQCD

**Ratio** = LQCD/Expt

- \( f_{\pi} \)
- \( f_K \)
- \( 3M_\Xi - M_N \)
- \( 2M_{B_s} - M_{\Upsilon} \)
- \( 1^+(1P-1S) \)
- \( \Upsilon(1D - 1S) \)
- \( \Upsilon(2P - 1S) \)
- \( \Upsilon(3S - 1S) \)
- \( \Upsilon(1P - 1S) \)

**Quenched**

**Unquenched (n_f=3)**

[CTH Davies et al., PRL 92:022001 (2004)]

**\( \Upsilon \) Spectrum**

- Quenched
- \( m_u = m_d = m_s/5 \)

[Courtesy: J.P. Lepage]
Observation of $\Upsilon(1D)$ & Impact

Four $\gamma$ cascade; exclusive $\Upsilon(1S)$ channel

Background thru $2^3S_1$

First reported ICHEP’02 with 80% of data ... now final

Submitted to PRD [hep-ex/0404021]

>10 std dev significance

$M = 10161.1 \pm 0.6 \pm 1.6$ MeV

Consistent with $1^3D_2$

Tests LQCD at high $L$
Status of Vub (inclusive method)

- Inclusive method: Severe background: \( b \rightarrow c \ell v \sim 100 \) \( b \rightarrow u \ell v \) lead to measurements in small regions of phase space large extrapolation to obtain Vub

Inclusive methods:
To distinguish \( b \rightarrow u \) from \( b \rightarrow c \) theoretically:

- better
- better
- \( q^2 - m_{\text{had}} \) spectrum > \( m_{\text{had}} \) spectrum > \( E_{\text{lepton}} \) spectrum

But experimental difficulty in opposite order

The dangers of extrapolation:

- Endpoint
- Rest of phase space
Status of Vub (inclusive method)

- Inclusive method: Severe background: $b \rightarrow c \nu \sim x100$ $b \rightarrow u \nu$ lead to measurements in small regions of phase space large extrapolation to obtain $V_{ub}$

Inclusive methods:
To distinguish $b \rightarrow u$ from $b \rightarrow c$ theoretically:
- better
- better

$q^2 - m_{had} \text{ spectrum} > m_{had} \text{ spectrum} > E_{lepton} \text{ spectrum}$
But experimental difficulty in opposite order

The dangers of extrapolation:
Status of Vub (inclusive method)

- Inclusive method: Severe background: $b \rightarrow cl\nu \sim x100$ $b \rightarrow ul\nu$ lead to measurements in small regions of phase space large extrapolation to obtain $V_{ub}$

Inclusive methods:
To distinguish $b \rightarrow u$ from $b \rightarrow c$ theoretically:

- Better
- $q^2 - m_{had}^{spectrum} > m_{had}^{spectrum} > E_{lepton}^{spectrum}$
- But experimental difficulty in opposite order

All 3 methods now attempted $E_{lepton}^{spectrum}$ & $m_{had}^{spectrum}$ method shown

BABAR 89 $\Upsilon(4S)$. 32 k events $\Upsilon(4S) \rightarrow B_{\text{reco}}B_{\text{sig}}$, $E_{l} > 1 \text{ GeV}$

Use $b \rightarrow s\gamma$ spectrum important input for extrapolation

Error on extrapolation dominant theory error

$(\text{No Lattice Involvement})$

$|V_{ub}|_{incl} = (4.57 \pm 0.61) \times 10^{-3}$

Lattice04 6/25/04 Ian Shipsey
CLEO III Detector ➔ CLEO-c Detector

Minor modification: replaced silicon with low mass inner drift chamber summer ‘03

Trigger: Tracks & Showers Pipelined
Latency = 2.5μs

Data Acquisition:
Event size = 25kB
Thruput < 6MB/s

83% of $4\pi$
87% Kaon ID with 0.2% π fake @0.9GeV

CLEO III: numerous physics results & well understood

93% of $4\pi$
$\sigma_{p/p} = 0.35\%$ @1GeV
dE/dx: 5.7% π @minI

93% of $4\pi$
$\sigma_{E/E} = 2\%$ @1GeV = 4% @100MeV

85% of $4\pi$
For p>1 GeV
“ZD” Inner Drift Chamber

- Extends from 4.1cm to 11.8cm along the radial direction.
- 6 stereo layers - 12-15°
- 300, 10 mm cells
- 60:40 Helium-Propane
- 1% $X_0$, 0.8mm Al inner tube
- Outer Al-mylar skin
### CESR-c

- Being modified for low energy operation:
  - Wigglers added for transverse cooling

#### Unmodified CESR

**1 day scan of the \( \Psi' \): (1/29/02)**

\[
L(@\Psi(4S)) = 1.3 \times 10^{33}
\]

<table>
<thead>
<tr>
<th>( \sqrt{s} )</th>
<th>( L \left(10^{32} \text{ cm}^{-2} \text{ s}^{-1}\right) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 GeV</td>
<td>1.5</td>
</tr>
<tr>
<td>3.77 GeV</td>
<td>3.0</td>
</tr>
<tr>
<td>4.1 GeV</td>
<td>3.6</td>
</tr>
</tbody>
</table>

- \( \Delta E_{\text{beam}} \sim 1.2 \text{ MeV at } J/\Psi \)


**Compare B factories & CLEO-c**

CLEOII: \( f_{D_S} : D_S^* \rightarrow D_S \gamma \) with \( D_S \rightarrow \mu \nu \)

\[ \Delta M = M(\mu \nu \gamma) - M(\mu \bar{\nu}) \, \text{GeV/c} \]

B Factory CLEO technique with improvements

\( \text{S/N} \approx 14 \)

MC

CLEO-c

Br(\(D^+ \rightarrow K\pi\) )

Br(\(D^0 \rightarrow K\pi\) )

\( f_D \)

\( f_{D_S} \)

\( \text{The power of running at threshold} \)

\( \text{MC} \)

Statistics limited

Systematics & Background limited

PDG

BFactorry

400 fb\(^{-1}\)

CLEO-c

3 fb\(^{-1}\)

D(\(D_S \rightarrow \phi \pi \))
$D^0 \rightarrow \pi^- e^+ \nu$ The power of threshold running is amply demonstrated by comparison to the $D^0 \rightarrow \pi^- e^+ \nu$ signal in the world’s most precise measurement of $\mathcal{B}(D^0 \rightarrow \pi^- e^+ \nu) / \mathcal{B}(D^0 \rightarrow K e^- \nu) = 0.097 \pm 0.010 \pm 0.010$ (CLEO III to be submitted to PRL 2004).
Status of $B_s$ mixing

ALEPH, CDF, DELPHI, OPAL, SLD

See Daria Zieminska talk tomorrow for discussion $B_s$ mixing

$\Delta m = 15/ps$ with $0.5 \text{ fb}^{-1}$

$\Delta m = 18/ps$ with $1.7 \text{ fb}^{-1}$

$\Delta m = 24/ps$ with $3.2 \text{ fb}^{-1}$

Prospects:

$2\sigma$ for $\Delta m = 15/ps$ with $0.5 \text{ fb}^{-1}$

$5\sigma$ for $\Delta m = 18/ps$ with $1.7 \text{ fb}^{-1}$

$5\sigma$ for $\Delta m = 24/ps$ with $3.2 \text{ fb}^{-1}$

Near term D0/CDF

Long term CDF

World Average $\Delta m < 14.5/ps$

$\xi^2$ (lattice)

$\Delta M_d / \Delta M_s \propto \left[ \frac{\sqrt{B_{d}} f_{B_d}}{\sqrt{B_{s}} f_{B_s}} \right]^2 \left[ \frac{|V_{td}|}{|V_{ts}|} \right]^2$

$\delta\xi / \xi \sim 6-8\%$?

Dominant error

High resolution on proper decay time required

Lattice04 6/25/04 Ian Shipsey
Vud, Vus and Vcb are the best determined due to flavor symmetries: I, SU(3), HQS. Charm (Vcd & Vcs) and rest of the sector determined by beauty decays (Vub, Vtd, Vts) are poorly determined. Theoretical errors on hadronic matrix elements dominate.
B Decays & the Unitarity Triangle

Goals for the decade: precision measurements of $V_{ub}$, $V_{cb}$, $V_{ts}$, $V_{td}$, $V_{cs}$, $V_{cd}$, $\alpha$, $\beta$, $\gamma$. Test SM description of CP violation and search for new physics.

Unitarity: $V_{ub}^* + V_{td} = \lambda V_{cb}^*$

SM: side & angles measured in many processes are self consistent otherwise: new physics

Rates: sides of triangle CP asymmetries & rates: angles

Base $\lambda V_{cb}$ relatively well known, other sides poorly known $\beta \sim 12\%$ angles $\alpha$ poorly known $\gamma$ unknown

B $\to \pi \pi$ B $\to \rho \pi$ B $\to \rho \rho$

B $\to \pi \pi / K \pi$

& other charmless decays

B $\to D* / D_{lv}$

Lattice

B $\to ulv$

Lattice

(B $\to \pi / \rho / \eta l v$)

(Lattice04 6/25/04 Ian Shipsey)
Unitarity Triangle Status

Assume improvements in theory: theory errors reduced by x2

B Factories with 400 fb⁻¹

Theoretical errors dominate width of bands

Theoretical errors still dominate width of bands