CLEO-c and its Impact on BaBar

Kenji Hamano
Presentation for Candidacy Examination
June 21, 2004

Introduction

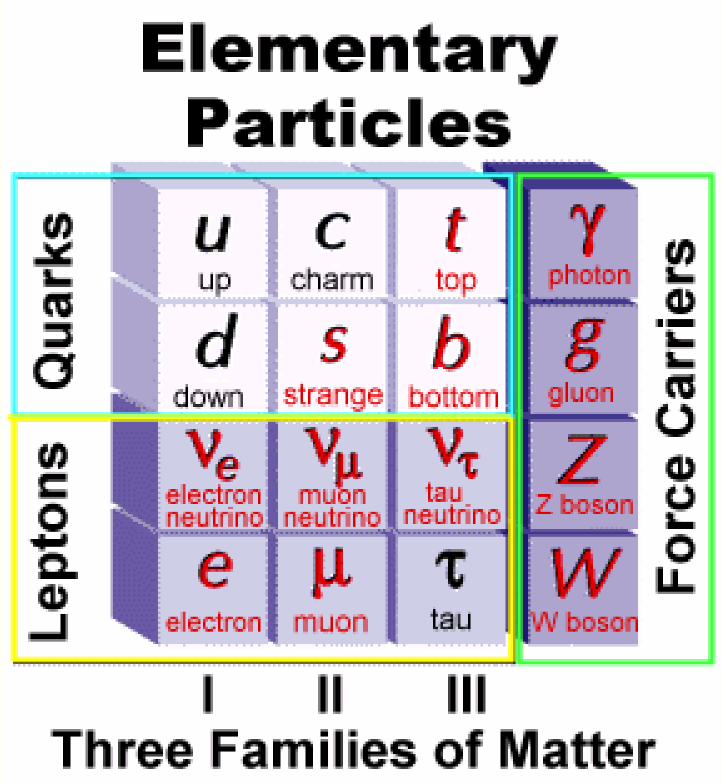
- Physics of heavy quarks, charm c and beauty (bottom) b, attracts many interests.
- To measure CKM matrix elements.
- To measure CP violation.
- BaBar aims at b quarks ($B\overline{B}$ events)
- CLEO-c aims at c quarks ($D\overline{D}$ events)
- CLEO-c has just started and big impact on B-physics is expected.

The Standard Model

- Three families of quarks and leptons
- The CKM matrix

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

- Mix three families of quarks



Leptonic Decays

- Decay of a pseudoscalar meson $M_{Qq} \rightarrow l\nu$
- Decay rate

$$\Gamma = \frac{G_F^2}{8\pi} |V_{Qq}|^2 \ f_M^2 M m_l^2 \left(1 - \frac{m_l^2}{M^2}\right)^2$$

- Decay constant f_M

  Hadronic physics is encapsulated in this single parameter.

Semileptonic Decays

- Decay of a pseudoscalar meson into a pseudoscalar meson $P_Q \rightarrow P'_{q'} l \nu$
- Decay rate

$$\frac{d\Gamma}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{q'Q}|^2 \, p_{P'}^3 \left| f_+\left(q^2\right) \right|^2$$

- Form factor $f_+\left(q^2\right)$

  Hadronic physics is captured in this.

  Depend on q^2 , the squared mass of virtual W

Semileptonic Decays

- Decay of a pseudoscalar meson into a vector meson
- Requires three form factors (approximately):

Vector form factor $V(q^2)$

Axial vector form factors $A_1(q^2),\ A_2(q^2)$

Non Perturbative QCD

- Calculation of decay constants and form factors cannot be done perturbatively.
- Lattice QCD

  Numerical calculations directly using QCD.

  Requires huge computer power.

  Producing meaningful results.
- Heavy Quark Effective Theory

  Use an effective Lagrangian based on the heavy quark symmetry.

CLEO-c : Proposed Plan

CM energy (GeV)	Resonance	Events	Luminosity (fb^{-1})
3.77	$\psi(3770)$	$D\overline{D}$	3
4.14		$D_s^+ D_s^-$	3
4.14		$D^0 \overline{D}^{*0}$	3
3.1	J/ψ		1
4.6		$\Lambda_c \overline{\Lambda}_c$	1
3.6		$\tau\overline{\tau}$	0.25

CLEO-c: Advantage

- Charm events produced at threshold are clean. Pure $D\overline{D}$.
- Lower multiplicity: 5.0 (charged), 2.4 (neutral).
- Kinematic constraints are useful.

  Neutrino reconstruction is clean.
- Double-tag studies are possible.

  Almost background free.

CLEO-c : Precisions of D decays

- Leptonic decays

  $D^+ \to \mu^+\nu,\ D_s^+ \to \mu^+\nu,\ D_s^+ \to \tau^+\nu$ etc.

  Branching fractions: 3 – 4 %

  Decay constants: f_D 2.3%, f_{D_s} 1.6%

- Semileptonic decays

  $D \to \pi\ell\nu,\ D \to K\ell\nu$ etc.

  Branching fractions: 1% level

  Parameters of form factors: 4 – 5%

- Hadronic decays

  $D^0 \to K^-\pi^+,\ D^+ \to K^-\pi^+\pi^+,\ D_s \to \phi\pi$ etc.

  Branching fractions: 1 – 2%

CLEO-c : Precisions of CKM Matrix Elements

- |Vcd|: 7% -> 1%

  measurement of $D \to \pi \ell \nu$
- |Vcs|: 16% -> 1%

  measurement of $D \to K \ell \nu$
- |Vcb|: 5% -> 3%

  assisting B physics $\left(B \to D \ell \nu\right)$
- |Vub|: 25% -> 5%

  assisting B physics $\left(B \to \pi \ell \nu,\ B \to \rho \ell \nu\right)$
- |Vtd|: 36% -> 5%, Vts: 39% -> 5%

  assisting the precision of f_B by measuring f_D

CLEO-c : Precisions of Rare decays, Tau, QCD, ...

- Mixing, CP Violation, rare D decays

  -> new physics
- Tau

  Tau lepton mass: 0.1MeV level.

  Test of lepton universality and V-A coupling.

  Search for non-Standard Model process .
- Quarkonia

  Search for hybrids (cgc, bgb) and glueballs.
- Measurement of R

  Fill the gaps between 1 and 5 GeV.

Impact on BaBar : Vcb

- |Vcb| from $\overline{B}^0 \rightarrow D^{*+}\ell^-\overline{\nu}$

  $$37.27 \times 10^{-3} \pm 0.7\%(\text{stat.}) \pm 3.8\%(\text{syst.}) \pm 3.9\%(\text{th.})$$

- Sources of uncertainty and effect of CLEO-c

  D decay branching fraction

  Current: 5% level, after CLEO-c: 1% level.

  D** background composition

  Precise measurements of CLEO-c helps to understand D** background structure.

  Theoretical error will be reduced by Lattice QCD

Impact on BaBar : Vub

- |Vub| from $B^0 \to \rho^- e^+ \nu$

  $$3.69\times10^{-3} \pm 6.2\%(\text{stat.}) \pm 7.3\%(\text{syst.})^{+11\%}_{-16\%}(\text{th.})$$

- The main source of uncertainty is theoretical error (form factor calculation).
- Precise measurements of $D \to \pi\ell\nu,\ D \to \rho\ell\nu$ by CLEO-c will help theories to improve their form factor calculations (2% level of D decay form factor accuracy is expected).

  This will improve the form factors of $B \to \pi(\rho)\ell\nu$

Summary

- CLEO-c
- D-decay constants: 1-2%.
- D-decay branching fractions

  Leptonic: 3-5%, Exclusive Semileptonic: 1-3%

  Inclusive Semileptonic: 1-2%, Hadronic: 1-5%.
- |Vcd| and |Vcs|: 1-2%.
- Tau lepton mass: 0.1 MeV.
- R: 2%.
- Impact on BaBar

  Significant improvements on |Vcb| and |Vub|.