A Selection of Recent CLEO Results: 
*B* Physics, Silicon Detector, and More...

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XXVI SLAC Summer Institute Topical Conference  
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Outline

Introduction to CLEO

Semileptonic B Physics:
- The CKM Matrix
- $b \rightarrow ul\nu$ and $V_{ub}$
- $b \rightarrow cl\nu$ and $V_{cb}$

B Decays: Rare and Related
- Interesting $b \rightarrow c$ modes
- Hadronic Penguins and $b \rightarrow u$
- Electroweak Penguins: $b \rightarrow s\gamma$ and friends

Charm Baryon Spectroscopy:
- State Zoology and New Discoveries

Charm Physics:
- $D^0$ Lifetime and related pursuits

Tau Physics:
- $\tau^- \rightarrow \pi^-\pi^0\pi^0\nu$ Structure

Glueballs:
- $2\gamma$ Production of $f_J(2220)$?

What I left Out
Conclusion

Preprints and ICHEP98 Conference Papers at:
http://www.lns.cornell.edu/

All Conference results preliminary unless noted
**Cornell Electron Storage Ring**

**CESR**: 768 meter storage ring.
**CUSB + CLEO detectors**: 1979-1990
**CLEO only**: 1990 →

We run with 9 trains of 3 bunches; up to \( \sim 250 \text{ mA/beam} \)
Trains are \( \sim 300 \text{ ns} \) apart
Bunches are 28 ns apart (within train)
(CLEOIII: 5 bunches with 14ns spacing)

Best Peak luminosity: \( > 5.5 \times 10^{32} \text{cm}^{-2}\text{s}^{-1} \) (world’s highest)
Best Day/Month (at CLEO): \( > \frac{22}{400} \text{ pb}^{-1} \)

\[ \sigma(e^+e^- \rightarrow \text{Hadrons})(nb) \]

\[ \text{Mass (GeV/c}^2\text{)} \]

- Y(1S)
- Y(2S)
- Y(3S)
- Y(4S)
Energies We Run At...

Have run on $\Upsilon$(1S), $\Upsilon$(2S), $\Upsilon$(3S), $\Upsilon$(5S) in the past...
Fate Smiles: $\Upsilon$(4S) is just above $B\bar{B}$ threshold.

Now, standard running includes:

Off-resonance (‘Continuum’):
- $e^+e^- \rightarrow \gamma^* \rightarrow \tau^+\tau^-, c\bar{c},$ etc.
- Decay of one 10.6 GeV off-shell photon at rest
- 60 MeV below $\Upsilon$(4s): $\sigma_{\text{had}} \sim 3$ nb
- $\gamma\gamma \rightarrow X$

On resonance (‘On4S’):
- $e^+e^- \rightarrow \Upsilon(4s) \rightarrow B\bar{B}$
- Decay of TWO 5.3 GeV $B$ mesons at rest (almost)
- $\sigma$ on $\Upsilon(4s) \approx 1$ nb
- Comes with 3 nb Continuum hadronic (plus $\gamma\gamma, \ell^+\ell^-$) partly separable via event shape

About 2/3 of luminosity is On4S.

1.4 fb$^{-1}$ (On4S + Cont’m) $\sim 10^6 B\bar{B}$ pairs $= 10^6 B^\pm, 10^6 \bar{B}^0$

I’ll ALWAYS quote TOTAL luminosity...
The CLEO II Detector

- Helium Reservoir
- Muon Chambers
- Superconducting Coil
- Barrel Shower Detector
- Drift Chamber
- PTL Detector
- Micro-Beta Quadrupole
- Vertex Detector
- End Cap Time of Flight
- Pole Tip Shower Detector
- Time of Flight Scintillators

Magnet Yoke

Scale: 0 1 2 3 4 Meters
Event Shapes: $q\bar{q}$ continuum vs. $B\bar{B}$

Jetty Hadronization of Quark Jets

Symmetric Decay of Two Slow $B$'s
Detector Performance

Tracking over 95% of 4π
B = 1.5 Tesla (curlers at ~ 225 MeV)
σp/p ~ 0.6% at 2 GeV

7800 CsI crystals cover 98% of 4π
Best ‘Good Barrel’ part is 70% of coverage
Typical π⁰ resolution: 6 MeV
This is a big part of CLEOII's power and success

dE/dx and Time-of-Flight (TOF) for Particle ID (PID)
dE/dx from 49 chamber layers [plot]
~ 2σ for 2.6 GeV K/π (2-body modes and CP violation)
TOF separation deteriorates ≥ 1 GeV for π/K
TOF: Barrel and Endcap systems

Muon ID with steel and streamer counters
85% of solid angle
Turn-on around 1.4 GeV with 1% fakes (for a 5 λint cut)

All together: makes a very hermetic detector

* Silicon Vertex Detector since 1995/6; results later! *
CLEO Upgrades and Data Sets

CLEOII:
- CESR: One IR, pretzel orbits, crossing angle, multi-bunch...
- CsI Calorimeter
- 50-50 Ar-C2H6 in drift chamber
- 1989-1995: 5 fb⁻¹
- Many discoveries!
- All data now re-analyzed (improved tracking)

CLEOII.5:
- Silicon Vertex detector (first at Y(4S)!
- New Beam Pipe/IR
- 60-40 He-C3H8 in drift chamber (< mult. scat, Lorentz angle)
- 1995-1999: Expect ~ 8 fb⁻¹
- > 6 fb⁻¹ already on tape

CLEOIII:
- Ring-Imaging Cherenkov for PID
- New Drift Chamber
- New SV Detector, Beam Pipe/IR
- CESR Machine Upgrade
- Expect ~ 15 fb⁻¹ / yr

Future: High-Lumi for Rare B decays in new ring???
**Technique: Full Reconstruction of $B$ Mesons**

Symmetric beam energies $\rightarrow E_B = E_{\text{beam}}$.

$E_{\text{beam}}$ is well-known.

$|P_B| \simeq 325$ MeV

Key variables for a $B$ candidate are:

(sums are over daughter particles)

$$\Delta E = \sum E_i - E_{\text{beam}}$$

- Expresses **energy conservation**
- peaks at zero for real events
- sensitive to missing particles
- sensitive to $\pi - K$ mis-ID

$$M_B = \sqrt{E_{\text{beam}}^2 - |\sum \vec{P}_i|^2}$$

- expresses **momentum conservation**
- Using $E_{\text{beam}}$ improves mass resolution (10$\times$ $\rightarrow$ 2.5 MeV)

*Used extensively for hadronic decays*

*Also used for some semileptonic modes:*
- Possible if neutrino is inferred from global 4-momentum balance*
Other Kinematics Techniques

Other techniques using $\Delta E, M_B$ constraints:

Neutrino reconstruction (inferred from rest of event):
- $E, \bar{p}$ balance in full event for exclusive $B$ reconstruction
- Excellent background suppression at some efficiency loss
- Used for $B \rightarrow \pi/\rho \ell \nu$ and $|V_{ub}|; D \ell \nu$

'Semi-inclusive' full reconstruction:
- Try varying numbers of $\pi$'s to find good $B$ candidate
- Used for $b \rightarrow s \gamma; B \rightarrow \eta' X$

Partial reconstruction:
- Reconstruct $D^* \rightarrow D \pi_{slow}$ in $B$-decay from slow pion only
- Used for $B \rightarrow D^* \pi$, new $B\bar{B}$ mixing analysis (as the tag)

Missing-mass (apparent $m_\nu^2$) for semileptonic:
- Take advantage of $B$ decay nearly at rest
- Many varied twists on basic idea used
- Used for $D^* \ell \nu$ and $|V_{cb}|$
- Can combine with partial $D^*$ recon. (new $D^{*+} \ell \nu$)

Neutrino reconstruction: (one side of cont'm event)
- $E, \bar{p}_{thrust}$ balance in hemisphere for cont'm charm physics
- Used for $D_s \rightarrow \mu \nu$ and $f_{D_s}$
CKM Matrix Elements from CLEO

Basic pattern of CKM mixing magnitudes:

\[
\begin{pmatrix}
|V_{ud}| & |V_{us}| & |V_{ub}| \\
|V_{cd}| & |V_{cs}| & |V_{cb}| \\
|V_{td}| & |V_{ts}| & |V_{tb}|
\end{pmatrix} \sim \begin{pmatrix}
1 & \lambda & \lambda^3 \\
\lambda & 1 & \lambda^2 \\
\lambda^3 & \lambda^2 & 1
\end{pmatrix}
\]

\[\lambda = \sin \theta_C \sim 0.22\]

CLEO does best at:

- \(|V_{ub}| \) \( B \to \pi \ell \nu \) (with theory to normalize)
- \(|V_{cb}| \) from \( D^* \ell \nu \) and HQET

(Can get \(|V_{ub}| \) from \( B \to \ell \nu \), but very small rate!)

CLEO also looks at:

- \( B \bar{B} \) Mixing \( \sim B_B f_B^2 m_\ell^2 |V_{td}|^2 \)
- \( b \to s \gamma \): info. on \(|V_{ts}| \)
- \(|V_{td}/V_{ts}| \) from \( B \to K^* \gamma \) vs. \( \rho \gamma \)
  (easier from \( B_s \) vs. \( B_d \) mixing?)

We'll return to phases on \( V_{ub} \) and \( V_{td} \) later...
Let's delve into magnitudes now!
Semileptonic Kinematics

$q^2$ is $\ell - \nu$ invariant mass...

Often replace $q^2$ with HQET variable:

$$w \sim A - Bq^2$$

(boot $\gamma$ of $D^*$ in CofM)

\[ w = 1 \leftrightarrow q^2_{\text{max}} \quad w_{\text{max}} \leftrightarrow q^2 = 0 \]

\[ l \leftrightarrow D^* \rightarrow \nu \quad D \leftrightarrow \bullet \Rightarrow l\nu \]

Form-factors are often parameterized as:

$$\mathcal{F}(w) = \mathcal{F}(1) \times (1 - \beta^2(w - 1) + c(w - 1)^2 + ...)$$

- One for $Dl\nu$
- Three for $D^*l\nu$ (can use HQET to inter-relate)

Luke's Theorem:

- No $1/m_b$ corrections at $q^2_{\text{max}}$ for $D^*l\nu$
- Not true other for $q^2$ or for $D$

Murphy's Law I:

- Experiments and $q^2_{\text{max}}$:
  Rate and efficiency low; background high

Lattice Folks:

- Prefer $Dl\nu$

Murphy's Law II:

- Experiments and $Dl\nu$:
  Higher background ($D^*$ feed-down)
  lower BR and less rate near zero recoil
Semileptonic $b \to u$ Physics

Old lepton-endpoint $|V_{ub}|$: (discovery analysis)
- Look for leptons beyond momentum $b \to c$ endpoint
$|V_{ub}/V_{cb}| \simeq 0.06 - 0.10$ hard to extrapolate to all momenta

Newer neutrino reconstruction $|V_{ub}|$: ($\sigma_{p_{\nu}} \sim 110$ MeV !)
- $\pi\ell\nu, \rho\ell\nu, \omega\ell\nu$ (use isospin constraints)
J.P. Alexander, PRL 77, 5000 (1996); 4 fb$^{-1}$

\[ B(B \to \pi^- \ell^+ \nu) = (1.8 \pm 0.4 \text{(stat)} \pm 0.3 \text{(syst)} \pm 0.2 \text{(model)}) \times 10^{-4} \]
\[ B(B \to \rho^- \ell^+ \nu) = (2.5 \pm 0.4 \text{(stat)}^{+0.5}_{-0.7} \text{(syst)} \pm 0.5 \text{(model)}) \times 10^{-4} \]

Limiting factors for $|V_{ub}|$:
- 12\% error from $B$ mostly $\nu$ recon. efficiency
- 20\% error from models
More statistics can help constrain models...
New $b \rightarrow u$ Analysis

CLEO CONF 98-18; 5 fb$^{-1}$

Latest $b \rightarrow u$ analysis: $B \rightarrow \rho \nu, \omega \nu$

- Simpler, 'loose-cut' neutrino recon.
- $e, \mu > 1.7 \text{ GeV}$ (stiff to control background)
- Require kinematics consistent with neutrino

Let's concentrate on 'HILEP' bin: 2.3 - 2.7 GeV:

- Background: other $b \rightarrow u$, $b \rightarrow c$, continuum

Do likelihood fit to:

- $\pi \pi (\pi)$ mass for $\rho (\omega)$
- $\Delta E$
- Rates into $\pi^{+} / \pi^{0} / \rho^{+} / \rho^{0} / \omega \nu$
- Backgrounds: other $b \rightarrow u$, $b \rightarrow c$, cont'm, fake $\ell$

$$\mathcal{B}(B^{0} \rightarrow \rho^{-} \ell^{+} \nu) = (2.8 \pm 0.4 \pm 0.4 \pm 0.6) \times 10^{-4}$$

$$|V_{ub}| = (3.2 \pm 0.3^{+0.2}_{0.3} \pm 0.6) \times 10^{-3}$$

$$\rho^{2} = 0.52 \pm 0.11 \pm 0.09 \pm 0.05$$

Consistent with neut. recon. result
New $b \to u$ Analysis

Fit to cont'm-subt. data:
2.3 - 2.7 GeV bin
Points are data
Fit pieces:
top open = signal
next open hist = cross-feed
double-hatch = other $b \to u$
single-hatch = $b \to c$
Semileptonic $b \rightarrow c$ Overview

Main goal: Measure $|V_{cb}|$
Also, try to fully understand these simplest of $B$ decays!

One Method: Inclusive
- Measure $\tau_B$, $B(B \rightarrow X_c \ell \nu)$
- Compare partial width to theory (a la muon decay)
Issue 1: $m_b = ???$ (quarks vs. hadrons: 'duality')
Issue 2: LEP and CLEO sort of disagree on $B$
(latest LEP results at Moriond are closer to CLEO...)

Another Method: Exclusive + HQET
- Measure $d\Gamma/dq^2$ for $D^* \ell \nu$
- Extrapolate to zero-recoil and invoke HQET
Issues: shape of form-factor, corrections to $m_Q = \infty$ limit

New Experimental Input:
- Help determine OPE parameters $\bar{\Lambda}, \lambda_1$
- Aid theorists with inclusive rate calculations...
**Semileptonic $b \rightarrow c$ Inclusive**

Inclusive BR gives: $\Gamma_{SL}/\Gamma$; know $\Gamma$ from lifetime

$\Gamma_{SL} \sim |V_{cb}|^2 m_b^5$ (like muon decay)

B. Barish et al., PRL 76, 1570 (1996); 3 fb$^{-1}$

**Di-lepton analysis:**
- Stiff lepton tag to isolate $B \bar{B}$ events
- Look at additional inclusive electrons
- like and unlike sign $le$ pairs:
  separate $b \rightarrow X\ell\nu$ from $c \rightarrow X\ell\nu$

(also correct for $B$ mixing)

\[ B(B \rightarrow Xe\nu) = 10.49 \pm 0.17 \pm 0.43 \]

\[ |V_{cb}| = 0.040 \pm 0.001 \text{(exp)} \pm 0.004 \text{(theory)} \]

Exp’l error already quite small.

Some would claim theory is better than 10%...

CLEO will update analysis with more data, better MC, etc.
\[ V_{cb} \text{ from } D^*\ell\nu \]

Use both \( D^{*+} \) and \( D^{*0} \) modes
- Avoid sensitivity to charged vs. neutral \( B \) production fractions

Fit of \( D^*\ell\nu \) Form Factor
- Extrapolate to zero-recoil (\( w = 1 \))

\[ V_{cb} F(1) = 0.0351 \pm 0.0019 \text{(stat)} \pm 0.0018 \text{(syst)} \pm 0.0008 \text{(\( \tau_B \))} \]

(\( \text{typical } F(1) \sim 0.91 \pm 0.03 \))
Operator Product Expansion Parameters

\textbf{OPE parameters} \bar{\Lambda}, \lambda_1, \lambda_2:

\begin{itemize}
\item \bar{\Lambda}: energy of light d.o.f. (‘brown muck’)
\item \lambda_1: kinetic E of $b$ quark (Fermi motion)
\item \lambda_2: hyperfine chromo-magnetic interaction \((m_{B^*} - m_B)\) \text{(known \checkmark)}
\end{itemize}

Constrain by measuring moments of semileptonic decay variables:
$B_{SL}$ is a ‘zero-th moment’: just the sum

Additional moments can constrain terms in OPE expansion:

\begin{itemize}
\item simply the mean and RMS:
  \begin{itemize}
  \item i.e., Lepton moments: $<E_\ell>$, $(E_\ell - <E_\ell>)^2$
  \end{itemize}
\end{itemize}

Analyses are in progress...

Should provide ‘accurate enough’ info. on \bar{\Lambda}, \lambda_1

to keep them from being a serious source of error...

\textbf{NOTE:} even the $D^{*}\ell\nu$ HQET technique requires $\lambda_1$

\((m_Q = \infty \text{ has no Fermi motion...})\)
Measuring the Moments

CLEO CONF 98-21; 5 fb$^{-1}$

**Hadronic Moments:** 5 fb$^{-1}$
- Use neutrino reconstruction
- Get hadronic mass from measured $\nu$ and $\ell$ only

**Leptonic Moments:** 3 fb$^{-1}$ *preliminary*
- Use dilepton technique (see earlier slide on inclusive BR)
- Sees lepton spectrum down to 600 MeV
- Very

Ellipses are 1, 2$\sigma$ from hadronic only
Apparently, something is amiss: statistics? theory?? us???
Semileptonic Physics: Outlook

Outlook for $b \rightarrow u$ Neutrino Reconstruction:

- Working on $q^2$ dependence next
- 3X data available soon

Crucial need from theory:

- Absolute norm. of form-factor (at any $q^2$ value)
  tie exclusive measurement to $|V_{ub}|$

Full Reconstruction $V_{cb}$ from $D^* \ell \nu$:

- More data available; limit form-factor curvature error
- Better $D^{*+} - D^0$ mass diff. resolution
- Big effort on understanding efficiency (slow pions)

More work on hadronic/leptonic moments:

- Update inclusive branching ratio
- Constrain OPE parameters (resolve possible discrepancy)
Rare $B$ Decays: Diagrams and $CP$

CP-violation can be seen:
- Via time-dependence (e.g., with $\psi K_S, \pi^+\pi^-$)
  Final state is $CP$-eigenstate; use $B\bar{B}$ mixing
- Via rate asymmetries

Rate Asymmetries require:
- Two interfering diagrams with a relative weak phase
  the phase of $V_{ub}$ for the two diagrams above
- A strong phase from Final State Interactions (FSI)

Kaons vs. Pions:
- Penguins prefer to make $K$'s
- $K$'s are Cabibbo-suppressed for $W$-emission

We tend to find that penguins are large (see $K$, not $\pi$ modes)
We also find that $B^0 \to \pi^+\pi^-$ is small: (not yet seen!)
  This makes certain $CP$ studies difficult!
First Observation of $B^0 \rightarrow D^{*+}D^{*-}$

Analysis: CLEO CONF 98-07; 8.5 fb$^{-1}$
- Standard full reconstruction of $B$
- Cut on significance of $D$ vertex separation (v.good w/ SV!)
- Very clever uses of data to study backgrounds!

ON 4S, ALL CANDIDATES

Probability (bkg. fluctuation) = $8.7 \times 10^{-5}$ (3.9$\sigma$)

This first observation yields:

$B(B^0 \rightarrow D^{*+}D^{*-}) = \left(7.8^{+5.4}_{-3.8} \pm 1.5\right) \times 10^{-4}$

Consistent with Cabibbo-suppression relative to $D_s^*D^{*-}$

Interesting for time-dep’t $CP$-violation, just like $\psi K^{(*)}$
**B → D*ρ: Factorization Tests and FSI**

**Analysis:**  
CLEO CONF 98-23; 5 fb⁻¹  
- Full reconstruction; first full fit to angular distribution  
- Max. Likel. fit to 3 helicity amplitudes: H⁺, H⁻, H₀  
- Check factorization via \( \Gamma_L/\Gamma = |H₀|^2 / \sum |H_i|^2 \)  
  Compare to \( D^*\ell\nu \) at \( q^2 = m_ρ^2 \)  
- Look for hints of final state interactions in phases

<table>
<thead>
<tr>
<th>( B^0 \rightarrow D^{*-}\rho^+ )</th>
<th>magnitude</th>
<th>phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H₀ )</td>
<td>0.936</td>
<td>0</td>
</tr>
<tr>
<td>( H⁻ )</td>
<td>0.317 ± 0.052 ± 0.013</td>
<td>0.19 ± 0.23 ± 0.14</td>
</tr>
<tr>
<td>( H⁺ )</td>
<td>0.152 ± 0.058 ± 0.037</td>
<td>1.47 ± 0.37 ± 0.32</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( B^+ \rightarrow \bar{D}^{*0}\rho^+ )</th>
<th>magnitude</th>
<th>phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>( H₀ )</td>
<td>0.932</td>
<td>0</td>
</tr>
<tr>
<td>( H⁻ )</td>
<td>0.283 ± 0.068 ± 0.039</td>
<td>1.13 ± 0.27 ± 0.17</td>
</tr>
<tr>
<td>( H⁺ )</td>
<td>0.228 ± 0.069 ± 0.036</td>
<td>0.95 ± 0.31 ± 0.19</td>
</tr>
</tbody>
</table>

\( D^{*-}\rho^+ \): \( \Gamma_L/\Gamma = 0.878 ± 0.034 ± 0.040 \)  
- CLEO \( D^*\ell\nu \): 0.914 ± 0.152 ± 0.089  
- Theory: 0.85 – 0.88

**Factorization OK**, see hints of FSI in phases:  
- Must carefully consider non-resonant \( \pi\pi \) bkg.  
- Data is incoh. sum of various \( \pi\pi \) masses in \( \rho \)  
- Add more data to help cross-checks; then we can hopefully  
  Project out angular terms with \( Im(H) \) in them  
  See larger change in \( \mathcal{L} \) when phases fixed at 0
Quasi-2-Body Rare Hadronic $B$ Decays

Modes like $K\pi, \eta^/K$, etc.

Full reconstruction
Perform multi-dim'l likelihood fit to keep eff. high:
- In some modes, eff. are > 40%!
- Fit to $M_B, \Delta E$, event shape var's, masses, particle ID

NOTE: $M_B$ and $\Delta E$ plots must have cuts on other variables in fit; therefore full statistical power cannot be displayed.

Experimental Issues:
Cont’m bkg dominates: use detailed events shape cuts
Our $K/\pi$ separation at 2.6 GeV is $\sim 2\sigma$:
- Need to fit $(K\pi, \pi\pi)$, etc., simultaneously
- Also have similar ind’t $K/\pi$ separation via $\Delta E$

3 major recent PRL’s; all 5 $fb^{-1}$:
$K\pi$ final states R. Godang et al., PRL 80, 3456 (1998)
$\eta/\eta'$ final states B.H. Behrens, et al., PRL 80, 3710 (1998)
$\omega/\phi$ final states T. Bergfeld et al., PRL 81, 272 (1998)
These (and more!) summarized graphically on following two slides

Also, M. Athanas et al.; PRL 80, 5493 (1998) 5 $fb^{-1}$:
$B(B^- \to D^0 K^-) = (2.57 \pm 0.65 \pm 0.32) \times 10^{-4}$
$K, \pi, K^*, \rho, \phi$ Modes: Pre-Summer Status

CLEO results (January 1998)
New Rare $B$ Results: $B \rightarrow \eta' K$

CLEO CONF 98-09; 8.5 fb$^{-1}$

$\eta'K^+$, $\eta'\pi^+$ fit together
Data indicates all $K^+$, no hint of $\pi^+$ yet!

Projections of significant modes:

$\eta' h^+$

$\eta' K_S$
New Rare B Results: $B \rightarrow K^+\pi^-, \pi^+\pi^-$

CLEO CONF 98-20; 8.5 fb$^{-1}$

$K^+\pi^-, \pi^+\pi^-$ fit together
Only $K^+\pi^-$ significant
Sign that penguins are large!
Also, unlikely that modes are equal

Fit projections for $K^+\pi^-$ mode
NOTE: recon. assumes $\pi$ mass, so $\Delta E$ shifts.
New Rare B Results: $B \rightarrow h^+\pi^0, h^+K_S$

Likelihood contours:

$h^+\pi^0$

Projections of significant modes:

$K^+\pi^0$

$\pi^+K_S$
New Rare $B$ Results Summary

New $K K, K \pi, \pi \pi$ Results Summary:
$K^+\pi^0$ is NEW first observation!

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\mathcal{E}(%)$</th>
<th>$\mathcal{B}$</th>
<th>Theory $\mathcal{B}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\pi^+\pi^-$</td>
<td>53 ± 5</td>
<td>$&lt;0.84$</td>
<td>0.8–2.6</td>
</tr>
<tr>
<td>$\pi^+\pi^0$</td>
<td>42 ± 4</td>
<td>$&lt;1.6$</td>
<td>0.4–2.0</td>
</tr>
<tr>
<td>$K^+\pi^-$</td>
<td>53 ± 5</td>
<td>1.4 ± 0.3 ± 0.2</td>
<td>0.7–2.4</td>
</tr>
<tr>
<td>$K^+\pi^0$</td>
<td>42 ± 4</td>
<td>1.5 ± 0.4 ± 0.3</td>
<td>0.3–1.3</td>
</tr>
<tr>
<td>$K^0\pi^+$</td>
<td>15 ± 2</td>
<td>1.4 ± 0.5 ± 0.2</td>
<td>0.8–1.5</td>
</tr>
<tr>
<td>$K^+K^-$</td>
<td>53 ± 5</td>
<td>$&lt;0.24$</td>
<td>–</td>
</tr>
<tr>
<td>$K^+\bar{K}^0$</td>
<td>15 ± 2</td>
<td>$&lt;0.93$</td>
<td>0.07–0.13</td>
</tr>
</tbody>
</table>

New $\eta'$ Results Summary:
Still seeing LARGE rate for $\eta'K^+$

<table>
<thead>
<tr>
<th>Mode</th>
<th>$\epsilon(%)$</th>
<th>$N_{\text{signal}}$</th>
<th>Signif.</th>
<th>$\mathcal{B}(\times10^{-5})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\eta'K^+$</td>
<td>29–36</td>
<td>68.6</td>
<td>12.7</td>
<td>$7.4^{+0.8}_{-1.3}$ ± 1.0</td>
</tr>
<tr>
<td>$\eta'K^0$</td>
<td>28–33</td>
<td>16.1</td>
<td>7.3</td>
<td>$5.9^{+1.8}_{-1.6}$ ± 0.9</td>
</tr>
<tr>
<td>$\eta'\pi^+$</td>
<td>29–36</td>
<td>1.0</td>
<td>-</td>
<td>$&lt;1.2$</td>
</tr>
</tbody>
</table>

We are actively looking at more new modes in the near-term
One Final New Mode: $B \to \eta_c K$

We observe large rates of $\eta'$ decays: perhaps $\eta_c$ is enhanced also?

**Analysis:** CLEO CONF 98-24; 5 fb$^{-1}$

- Max. likelihood fit
- Use $\eta_c \to \phi\phi$; small BR ($\sim 0.7\%$) but clean!
- Very low background, 2 nice events; $3.9\sigma$ significance

$$B(B^- \to \eta_c K^-) = (1.54^{+1.39}_{-0.87}(\text{stat}) \pm 0.15(\text{syst}) \pm 0.60(\eta_c BR)) \times 10^{-3}$$

Branching ratio consistent with expectations; in line with $\psi K$.

<table>
<thead>
<tr>
<th>Decay Channel</th>
<th>Upper Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$B^0 \to \eta_c K^0$</td>
<td>$6.8 \times 10^{-3}$</td>
</tr>
<tr>
<td>$B^0 \to \eta_c K^{*0}$</td>
<td>$5.95 \times 10^{-3}$</td>
</tr>
<tr>
<td>$B^{\pm} \to \eta_c K^{*\pm}$</td>
<td>$18.5 \times 10^{-3}$</td>
</tr>
</tbody>
</table>

Related Limits:

Working to add $\eta_c \to K_S K\pi$ decay mode
$b \rightarrow s\gamma$

*b → sγ* discovered by CLEO

**Very important constraint on physics beyond Std. Model**
- Example: charged Higgs in SUSY

**Largest Backgrounds:**
- Continuum
- Initial-state radiation
- Hard for $B$’s to make stiff photons!

**Analysis Method 1:**
- Look for photon only
- Use sophisticated event shape cuts to suppress background
- Produces an event weight

**Analysis Method 2:**
- Do modified full reconstruction:
  - Use photon, $K^\pm$, and $0 - 4\pi$’s
  - Pick best candidate
- Produce an event weight

**Weights are combined when event is in both analyses**

Greater stat. power, more data than published analysis
New Result: CLEO CONF 98-17; 5 fb$^{-1}$

\[ B(b \rightarrow s\gamma) = (3.15 \pm 0.35 \text{(stat)} \pm 0.32 \text{(syst)} \pm 0.26 \text{(model)}) \times 10^{-4} \]

A bit larger than before:
partly from going down to 2.1 GeV in $E_\gamma$

Very consistent with theory:
\[ B(b \rightarrow s\gamma) = (3.28 \pm 0.33) \times 10^{-4} \quad \text{(Chetyrkin, Misiak, and Münz)}. \]
Other Electroweak Penguins

B → K(*)\ell^+\ell^-:
CLEO CONF 98-22; 5 fb⁻¹
- B(B → K^*\ell^+\ell^-) < 0.68 \times 10^{-5}
- B(B → K\ell^+\ell^-) < 0.70 \times 10^{-5}

b → s\ell^+\ell^-:
S. Glenn et al., PRL 80, 2289 (1998); 5 fb⁻¹
- B(b → s e^+ e^-) < 5.7 \times 10^{-5}
- B(b → s \mu^+ \mu^-) < 5.8 \times 10^{-5}
- B(b → s e^+ \mu^-) < 2.2 \times 10^{-5}

B → K^*\gamma discovered by CLEO
B → \rho\gamma not yet seen.
Eventually can give |V_{td}/V_{ts}|
Latest plot with 3.5 fb⁻¹:
Working on update...
Charmed Baryons

Eight new states discovered since 1996 PDG!

Newest are:

- First $L = 1$ $\Xi_c$ states [top plots]  
  CLEO CONF 98-10; 5 fb$^{-1}$
- $\Xi'_c$ states [lower plots]

$L = 1$ $\Xi^0_{c1}$

$L = 1$ $\Xi^+_{c1}$

$\Xi^+ '$

$\Xi^0 '$
Charmed Baryons

RED = CLEO discoveries 10.5
GREEN = not yet seen 2 \( L = 0 \) + ???
BLACK = All other experiments 6.5

\( C = 1, L = 0 \) States:

\[
J^P = 1/2^+ \]

\( \Omega_c^0 \)

\( \Xi_c^0 \quad \Xi_c^+ \quad \Xi_c^{0'} \quad \Xi_c^{++} \)

\( \Lambda_c^+ \quad \Sigma_c^0 \quad \Sigma_c^+ \quad \Sigma_c^{++} \)

\[
J^P = 3/2^+ \]

\( \Omega_c^{0*} \)

\( \Xi_c^{*0} \quad \Xi_c^{*+} \)

\( \Sigma_c^{*0} \quad \Sigma_c^{*+} \quad \Sigma_c^{*++} \)

\( C = 1, L = 1 \) States:

\( \Lambda_c(2593), \Lambda_c(2625), \Xi_c^+ (\sim 2815), \Xi_c^0 (\sim 2820) \)
Charmed Baryons

Outlook:
- Lifetimes soon with CLEOII.5 SVX data
- Perhaps a coherent single-exp. mass study.
- Hope to see more $L = 1$ states (more should be narrow)
- Also finding new decay modes

Current needs:
- Reliable absolute measure of $B(\Lambda_c \rightarrow pK\pi)!$
- Searches need to be careful re: correlated $\pi, \gamma$...
  lots of soft particles from de-exceptions
Charm Lifetimes

Analysis: CLEO CONF 98-15; 4 fb⁻¹

- Use CLEOII.5 data with Silicon Vertex Detector
- \( D^0 \rightarrow K^- \pi^+ \); tagged via \( D^{*+} \rightarrow D^0 \pi^+ \)
- Intersect \( D \) flight with flat well-known beam spot:
  \[ \sigma_{y, \text{beam}} \sim 7 \mu m \quad \sigma_{x, \text{beam}} \sim 350 \mu m \]
- Avoid using fragmentation tracks; may bias int. point
- \( \sigma_{D, \text{vtx}} \sim 60 - 110 \mu m \) (along flight)
  \[ < \gamma \beta c \tau > = 200 \mu m \]
- Use 2D projection of decay in \( r - \phi \) plane
  (analysis choice; SV \( z \) works fine!)

\[ e^+ e^- \rightarrow D^0 \bar{D} \rightarrow D^0 \rightarrow K^- \pi^+ \]
Charm Lifetimes

$D^*-D$ Mass-Difference and $D$ Mass:

Fit Results:
Charm Lifetimes

Fit:
- Unbinned max. likelihood
- Fit for error scale factor (yields $1.13 \pm 0.02$)
- Fit for bkg. components w/ and w/o lifetime
- Fit for mis-reconstructed events

New Result:
- $\tau_{D^0} = 409.5 \pm 5.8$ (stat.) $\pm 5.2$ (syst.) fs
- Very competitive result; will improve
World’s best: $\tau_{D^0} = 413 \pm 4$ (stat.) $\pm 3$ (syst.) fs (E687)

Earlier this year:
- A similar technique with less data used
- Presented $D^0, D^+, D_s$ at Moriond
- All will be updated soon: $D_s$ also quite competitive!
**Future Charm Work**

Excellent $D^* - D$ mass resolution (via 3-D fit)
still improving: $\sim 200$ now!
Looking into $D^0 \rightarrow K^+\pi^-$ (Doubly-Cabibbo suppressed)
Study of intrinsic $D^*$ width?

Nice clean signals in $CP$-eigenstate modes: $(3.4 \text{ fb}^{-1})$
(use to look for lifetime differences!)
\[ \tau^- \rightarrow \pi^-\pi^0\pi^0\nu_\tau \] Structure

CLEO CONF 98-19; 5 fb\(^{-1}\)

Very thorough analysis!

Nice example of CLEO doing light hadron physics (surprise!)

Decay dominated by s-wave \( a_1(1260) \rightarrow \rho\pi \)

- \( a_1(1260) \) is poorly understood
- Hadronic mass shape of interest for \( \nu \)-mass studies

\( \pi^-\pi^0\pi^0 \) is better than \( \pi^+\pi^+\pi^- \):

- Smaller feed-across
- Only one \( I=0 \) combination of \( \pi \)'s

Fit Dalitz plots\(^\dagger\) components relative to dominant s-wave \( \rho\pi \)

<table>
<thead>
<tr>
<th>Component</th>
<th>Signif.</th>
<th>( B ) fraction(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho(1450) ) s-wave</td>
<td>1.4( \sigma )</td>
<td>0.30 ± 0.64 ± 0.17</td>
</tr>
<tr>
<td>( \rho ) d-wave</td>
<td>5.0( \sigma )</td>
<td>0.36 ± 0.17 ± 0.06</td>
</tr>
<tr>
<td>( \rho(1450) ) d-wave</td>
<td>3.1( \sigma )</td>
<td>0.43 ± 0.28 ± 0.06</td>
</tr>
<tr>
<td>( f_2(1275) ) p-wave</td>
<td>4.2( \sigma )</td>
<td>0.14 ± 0.06 ± 0.02</td>
</tr>
<tr>
<td>( \sigma ) p-wave</td>
<td>8.2( \sigma )</td>
<td>16.18 ± 3.85 ± 1.28</td>
</tr>
<tr>
<td>( f_0(1370) ) p-wave</td>
<td>5.4( \sigma )</td>
<td>4.29 ± 2.29 ± 0.73</td>
</tr>
</tbody>
</table>

Also extract values of complex couplings for each channel.
$\tau^- \rightarrow \pi^- \pi^0 \pi^0 \nu_\tau$ Structure

3π invariant mass

mass-dep't channel width

Note: High-mass structure partly from $K^* K$ threshold!
Coupling floating in fit; shape from theory

Analysis also gives signed neutrino helicity:
- via parity-viol. asymm. in $a_1$ decay
- $h_{\nu_r} = -1.02 \pm 0.13 \pm 0.03$ (Theory: $-1$)

We are also working on the three-charged-pion counterpart.

We will perform $\pi^+ \pi^+ \pi^-$ analysis, also
Conf. paper already shows some overlays:
- Use +00 fit results in appropriate current
- Overlay with various slices of ++- data
- Excellent agreement!
Glueball Studies

CLEO CONF 98-06; 5 fb$^{-1}$

$\psi \to gg\gamma \to X\gamma$: coupling to gluons
2 $\gamma$ production limits/measures coupling to $\gamma\gamma$

Particle $X$ 'stickiness': $S \sim \Gamma(\psi \to \gamma X)/\Gamma(X \to \gamma\gamma) \times$ kin. factors
(Note: one can cancel BR of $X$ to final state!)

Expect $S \sim 1$ for $q\bar{q}$ mesons:
- Valence quarks couple well to both glue and $\gamma$

Done for $f_J(2220) \to K_S K_S$: R. Godang et al., PRL 79, 3829 (1997).
Done for $f_J(2220) \to \pi^+\pi^-$: M.S. Alam et al., CLNS 98/1560.

Result: $S > 102$ 95% CL stickiest state yet!
(some may posit that state simply doesn’t exist...)
What I Left Out

Summer conference papers I couldn’t mention:

**B Physics:**
- Observation of High Momentum $\eta'$ Production in $B$ Decay
- Search for $B \rightarrow \rho^0 K^0, B \rightarrow K^{*\pm} \pi^\mp$
- Distribution in $q^2$ of the Decay $\bar{B}^0 \rightarrow D^{*+} \ell \nu$ via Partial Recon.
- $\bar{B} \rightarrow D \ell \nu$ Branching Fractions and Form Factor Parameters

**Charm Physics:**
- Measurement of the Decay Asymmetry Parameter in $\Xi_c^0 \rightarrow \Xi^- \pi^+$ and $\Xi^- \rightarrow \Lambda \pi^-$
  and a Search for Direct CP Violation in Hyperon Decays
- Improved Measurement of the Pseudoscalar Decay Constant $f_{D_s}$

**Tau Physics:**
- Resonance Structure of $\tau^- \rightarrow K^- \pi^+ \pi^- \nu_\tau$ Decays
- First Search for CP Violation in Tau Lepton Decay
- A Limit on the Mass of the $\nu_\tau$

**Upsilon Physics:**
- $\Upsilon$ Dipion Transitions at Energies near the $\Upsilon(4S)$
- Measurement of the Mass Splittings between the $B \bar{B}$ $\chi_{b,J}$ States

There’s lots more from before summer conf’s also.
And there are many NEW (not just update) analyses underway
Conclusion

Much of CLEO B Physics revolves around the CKM Matrix:

Magnitudes of CKM elements:
- $|V_{cb}|, |V_{ub}|$ to higher precision soon
- Pioneering techniques like neutrino reconstruction

$CP$ violation from phases:
- comprehensive Rare $B$ Decay searches
- $> 13$ fb$^{-1}$ by shutdown
- First observation of MANY rare decays
- Likely that full palette is needed to get at physics...

CLEO is also a major force in:
- Charm Physics (mesons and baryons)
- Tau Physics
- Upsilon Physics
- 2-photon physics

CLEOII is pioneering Silicon Vertex detector at the $\Upsilon(4S)$
Our own $B$ factory, CLEOIII, will come online next year!

Preprints, etc., at: http://www.lns.cornell.edu/