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

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Outline

Introduction to CLEO

Semileptonic B Physics:

- The CKM Matrix
- $b \to u \ell \nu$ and V_{ub}
- $b \to c \ell \nu$ and V_{cb}

B Physics

B Decays: Rare and Related

- Interesting $b \to c$ modes
- Hadronic Penguins and $b \to u$
- Electroweak Penguins: $b \to s\gamma$ and friends

Charm Baryon Spectroscopy:

- State Zoology and New Discoveries

Charm Physics:

- D^0 Lifetime and related pursuits

Silicon V. D.

Tau Physics:

- $\tau^- \to \pi^- \pi^0 \pi^0 \nu$ Structure

Glueballs:

- 2γ 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 ~250 mA/beam

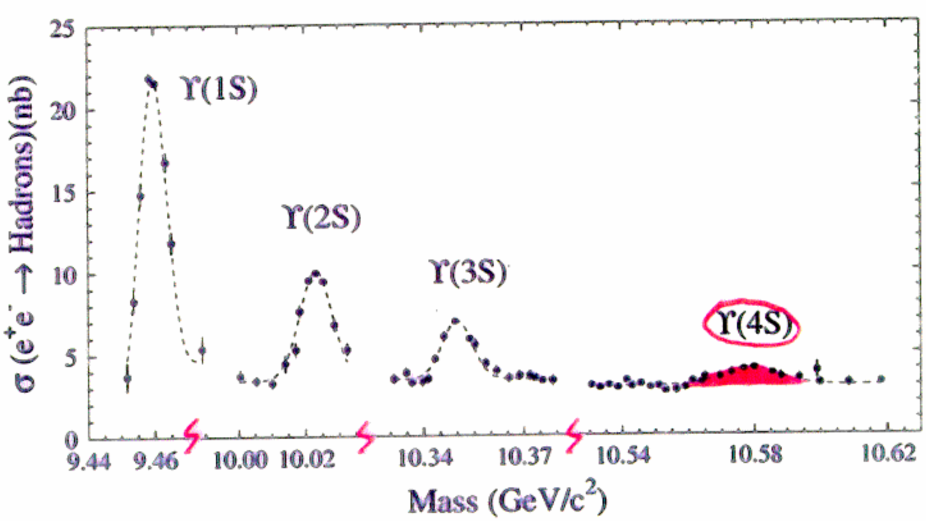
Trains are ~ 300 ns apart

Bunches are 28 ns apart (within train)

(CLEOIII: 5 bunches with 14ns spacing)

Best Peak luminosity: > $5.5 \times 10^{32} cm^{-2} s^{-1}$ (world's highest)

Best Day/Month (at CLEO): > ~~22~~ 23.6/400 pb^{-1}



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'):

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

On resonance ('On4S'):

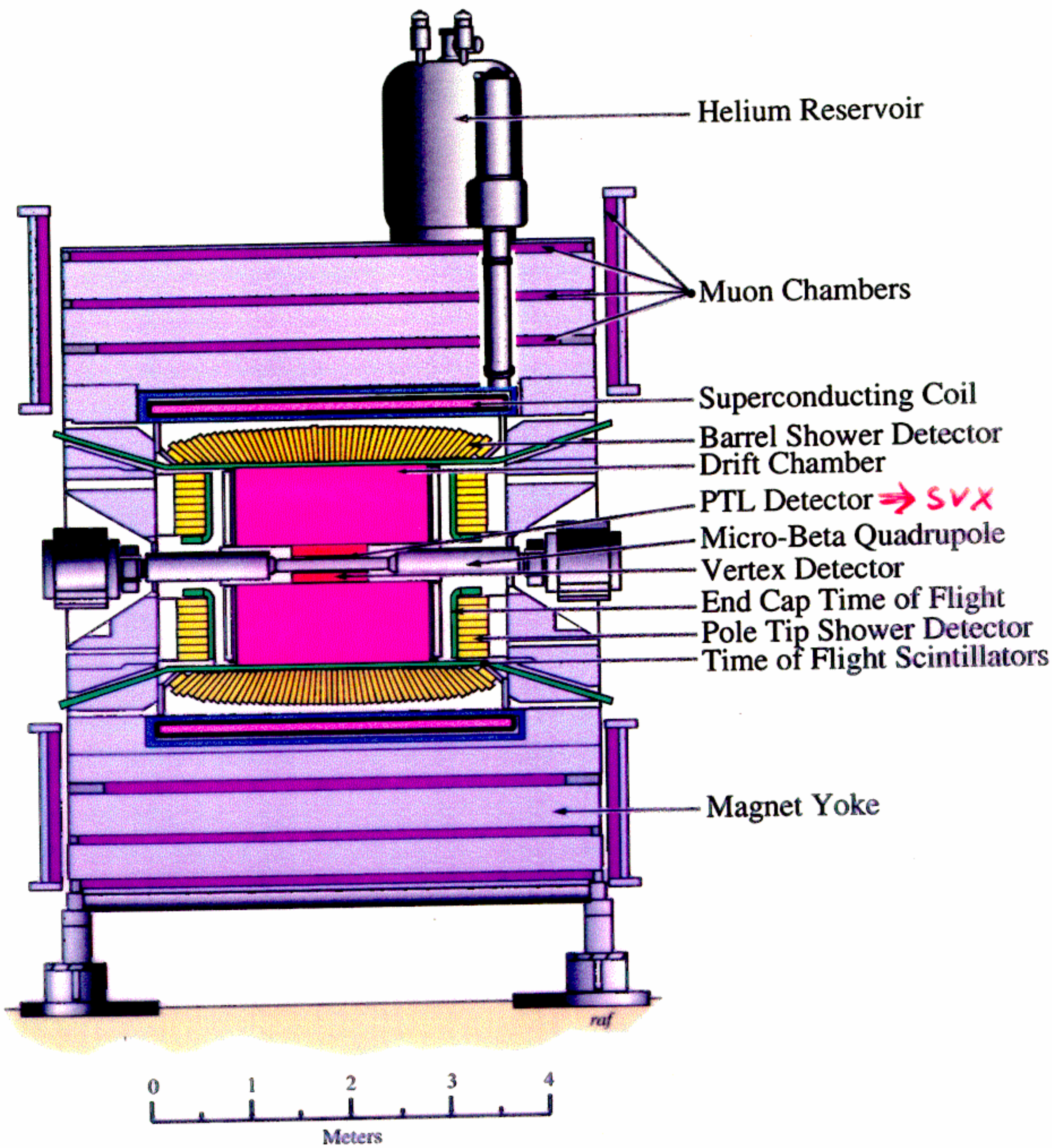
- $e^+e^- \to \Upsilon(4s) \to B\bar{B}$
- Decay of TWO 5.3 GeV B mesons at rest (almost)
- σ on $\Upsilon(4s) \simeq 1$ nb
- Comes with 3 nb Continuum hadronic (plus $\gamma\gamma, \ell^+\ell^-$) partly separable via event shape

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 $\bar{B}^0$

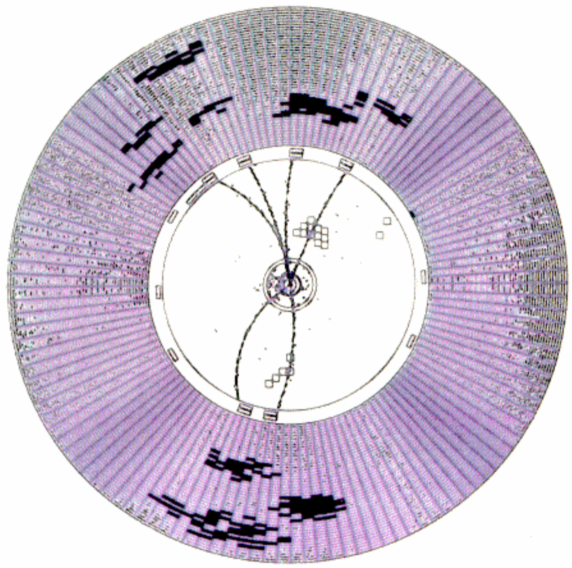
I'll ALWAYS quote TOTAL luminosity...

The CLEOII Detector

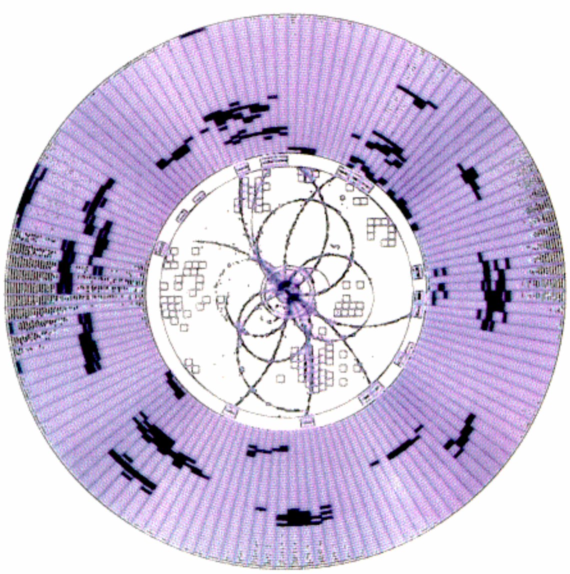


Event Shapes: $q\bar{q}$ continuum vs. $B\bar{B}$

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)
$\sigma_p/p \sim 0.6\%$ at 2 GeV

7800 CsI crystals cover 98% of 4π
Best 'Good Barrel' part is 70% of coverage
Typical π^0 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]
$\sim 2\sigma$ 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 λ_{int} 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-C_2H_6 in drift chamber
- **1989-1995: 5 fb^{-1}**
- Many discoveries!
- All data now re-analyzed (improved tracking)

CLEOII.5:

- Silicon Vertex detector (first at $\Upsilon(4S)$!)
- New Beam Pipe/IR
- 60-40 He-C_3H_8 in drift chamber ($<$ mult. scat, Lorentz angle)
- **1995-1999: Expect $\sim$ 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 $\sim$ 15 fb^{-1} / yr**

Future: High-Lumi for Rare B decays in new ring???

Technique: Full Reconstruction of B Mesons

Symmetric beam energies $\longrightarrow E_B = E_{beam}$.
E_{beam} is well-known.
$|P_B| \simeq 325$ MeV

Key variables for a B candidate are:
(sums are over daughter particles)

$$\Delta E \equiv \sum E_i - E_{beam}$$

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

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

- expresses **momentum conservation**
- Using E_{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):

- $E, \vec{p}$ balance in full event for exclusive B reconstruction
- Excellent background suppression at some efficiency loss
- Used for $B \to \pi/\rho \ell \nu$ and $|V_{ub}|$; $D \ell \nu$

'Semi-inclusive' full reconstruction:

- Try varying numbers of π's to find good B candidate
- Used for $b \to s\gamma$; $B \to \eta' X$

Partial reconstruction:

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

Missing-mass (apparent m_ν^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)

- $E, \vec{p}_{thrust}$ balance in hemisphere for cont'm charm physics
- Used for $D_s \to \mu\nu$ 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 $\sim B_B f_B^2 m_t^2\ |V_{td}|^2$

$b \to s\gamma$: 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:

$w \sim A - Bq^2$ (boost γ of D^* in CofM)

$w = 1 \leftrightarrow q^2_{max}$ $w_{max} \leftrightarrow q^2 = 0$

$\ell \leftarrow D^* \rightarrow \nu$ $D \leftarrow \bullet \Rightarrow \ell\nu$

Form-factors are often parameterized as:

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

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

Luke's Theorem:

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

Murphy's Law I:

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

Lattice Folks:

- Prefer $D\ell\nu$

Murphy's Law II:

- Experiments and $D\ell\nu$:
  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)

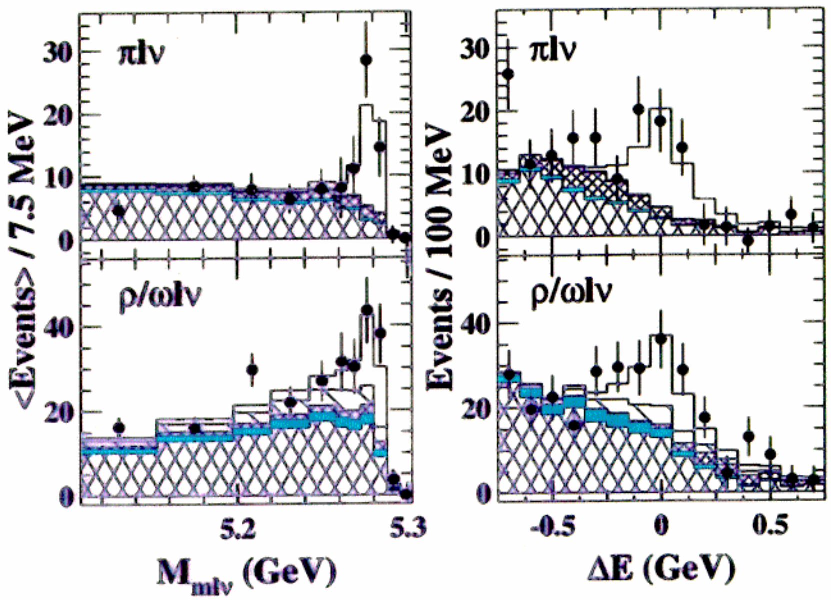
- Look for leptons beyond momentum $b \to c$ endpoint

$|V_{ub}/V_{cb}| \simeq 0.06 - 0.10$ **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}



$\mathcal{B}(B \to \pi^- \ell^+ \nu) = (1.8 \pm 0.4(stat) \pm 0.3(syst) \pm 0.2(model)) \times 10^{-4}$

$\mathcal{B}(B \to \rho^- \ell^+ \nu) = (2.5 \pm 0.4(stat)^{+0.5}_{-0.7}(syst) \pm 0.5(model)) \times 10^{-4}$

Limiting factors for $|V_{ub}|$:

- 12% error from $\mathcal{B}$ mostly ν recon. efficiency
- 20% error from models

More statistics can help constrain models...

New $b \to u$ Analysis

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

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

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

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

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

Do likelihood fit to:

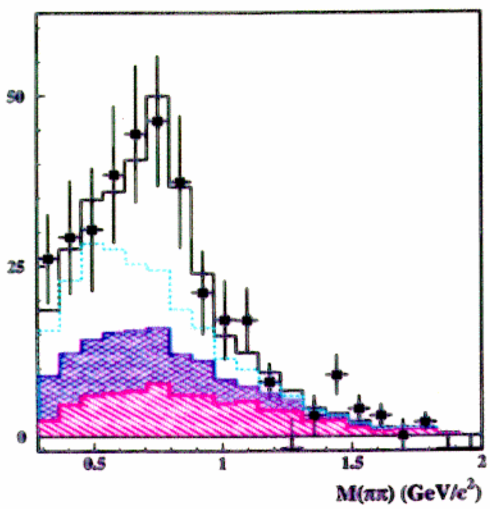
- $\pi\pi(\pi)$ mass for $\rho(\omega)$
- ΔE
- Rates into $\pi^+/\pi^0/\rho^+/\rho^0/\omega\ell\nu$
- Backgrounds: other $b \to u$, $b \to c$, cont'm, fake ℓ

$$\mathcal{B}(B^0 \to \rho^-\ell^+\nu) = (2.8 \pm 0.4 \pm 0.4 \pm 0.6) \times 10^{-4}$$
$$|V_{ub}| = (3.2 \pm 0.3^{+0.2}_{-0.3} \pm 0.6) \times 10^{-3}$$
$$\rho^2 = 0.52 \pm 0.11 \pm 0.09 \pm 0.05$$

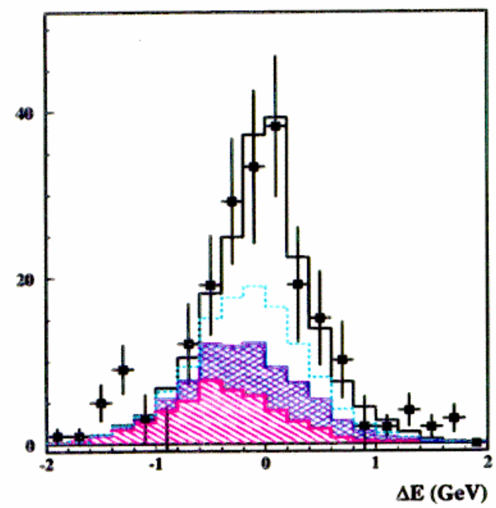
Consistent with neut. recon. result

New $b \to u$ Analysis

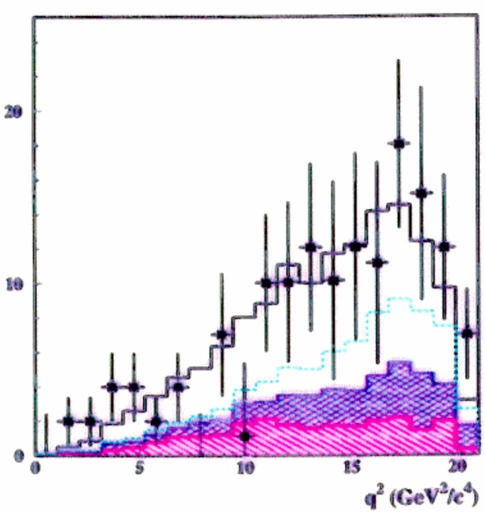
HILEP ρ modes with ΔE cut



HILEP ρ modes with M(ππ) cut



HILEP ρ modes with ΔE and M(ππ) cuts



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 $b \to c$ Overview

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

One Method: Inclusive

- Measure τ_B, $\mathcal{B}(B \to X_c \ell \nu)$
- 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 $\mathcal{B}$
(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 $\bar{\Lambda}$, λ_1
- Aid theorists with inclusive rate calculations...

Semileptonic $b \to c$ Inclusive

Inclusive BR gives: Γ_{SL}/Γ; know Γ from lifetime

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

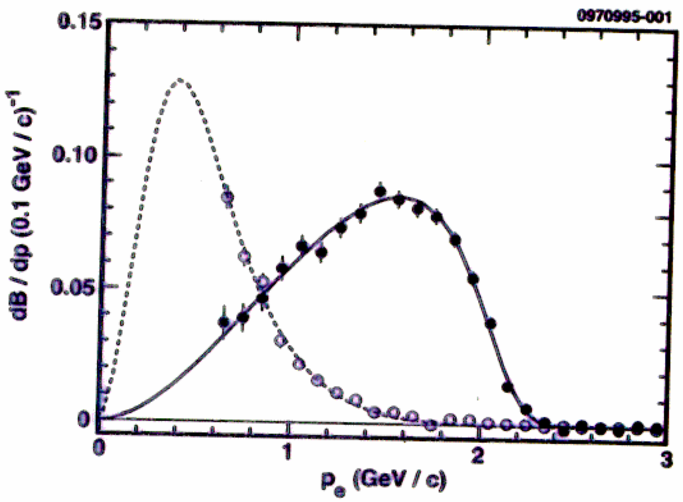
B. Barish et al., PRL 76, 1570 (1996); 3 fb^{-1}

Di-lepton analysis:

- Stiff lepton tag to isolate $B\bar{B}$ events
- Look at additional inclusive electrons
- like and unlike sign ℓe pairs:

  separate $b \to X\ell\nu$ from $c \to X\ell\nu$

(also correct for B mixing)



$\mathcal{B}(B \to Xe\nu) = 10.49 \pm 0.17 \pm 0.43$

$|V_{cb}| = 0.040 \pm 0.001(exp) \pm 0.004(theory)$

Exp'l error already quite small.

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

CLEO will update analysis with more data, better MC, etc.

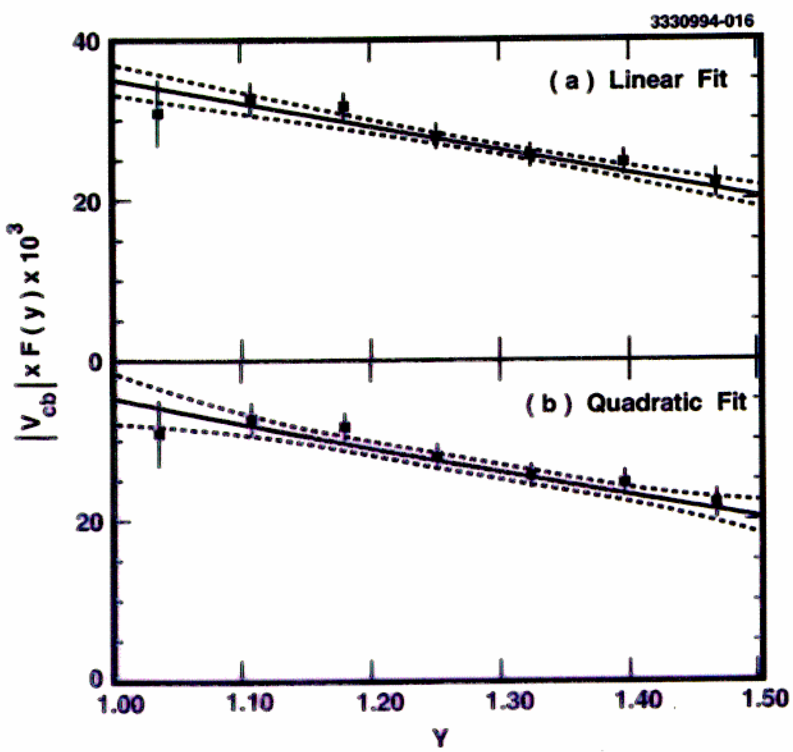
V_{cb} from $D^*\ell\nu$

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 ($w = 1$)



('Y' used here for w)

B. Barish et al., PRD **51**, 1014 (1995); 2.2 fb^{-1}

$V_{cb}\mathcal{F}(1) = 0.0351 \pm 0.0019(stat) \pm 0.0018(syst) \pm 0.0008(\tau_B)$

(typical $\mathcal{F}(1) \sim 0.91 \pm 0.03$)

Operator Product Expansion Parameters

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

- $\bar{\Lambda}$: energy of light d.o.f. ('brown muck') } constrain
- λ_1 kinetic E of b quark (Fermi motion)
- λ_2 hyperfine chromo-magnetic interaction ($m_{B^*} - m_B$) (Known ✓)

Constrain by measuring moments of semileptonic decay variables:
$\mathcal{B}_{SL}$ is a 'zero-th moment': just the sum

Additional moments can constrain terms in OPE expansion:

- simply the mean and RMS:
  i.e., Lepton moments: $< E_\ell >, < (E_\ell - < E_\ell >)^2 >$

Analyses are in progress...

Should provide 'accurate enough' info. on $\bar{\Lambda}, \lambda_1$
to keep them from being a serious source of error...
NOTE: even the $D^*\ell\nu$ HQET technique requires λ_1!

($m_Q = \infty$ has no Fermi motion...)

Measuring the Moments

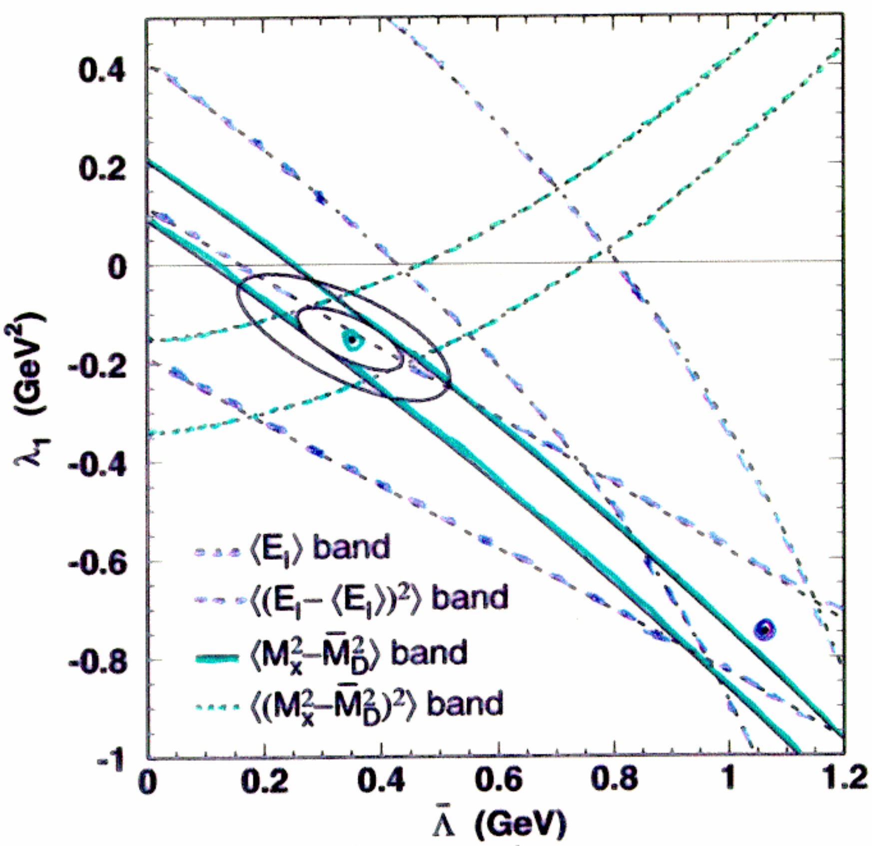
CLEO CONF 98-21; 5 fb^{-1}

Hadronic Moments: 5 fb^{-1}

- Use neutrino reconstruction
- Get hadronic mass from measured ν and ℓ 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 $b \to u$ 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 $|V_{ub}|$

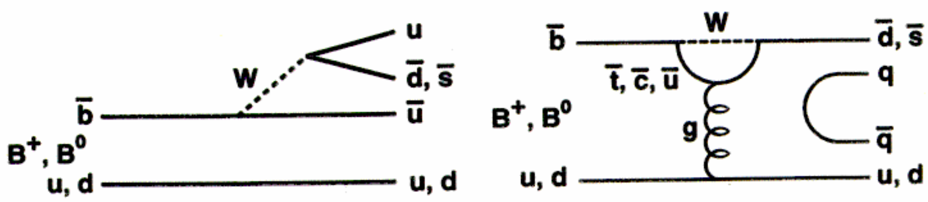
Full Reconstruction V_{cb} from $D^*\ell\nu$:

- 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



Spectator

Penguin

CP-violation can be seen:

- Via time-dependence (e.g., with ψK_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 π modes)

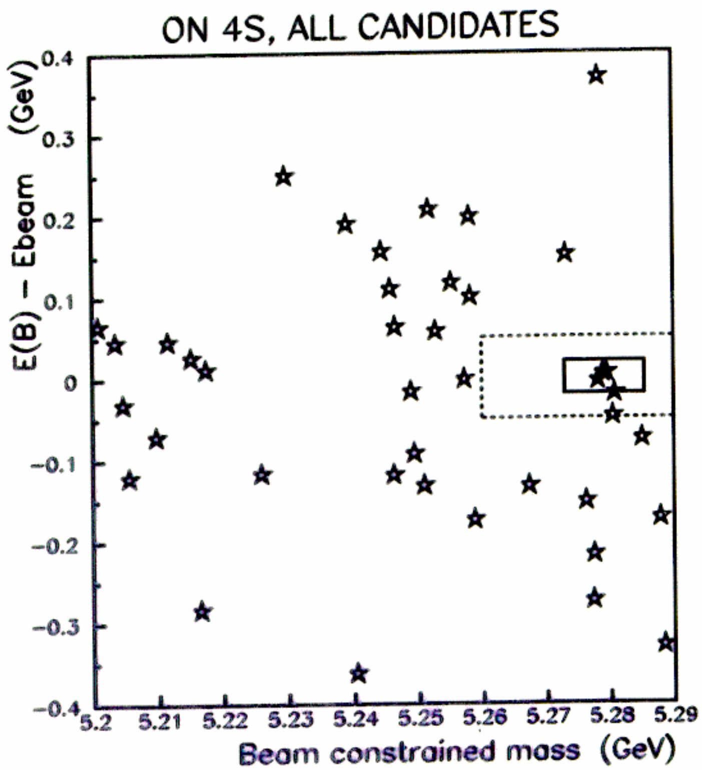
We also find that $B^0 \to \pi^+\pi^-$ is small: (not yet seen!)

This makes certain CP studies difficult!

First Observation of $B^0 \to D^{*+} D^{*-}$

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!



Probability(bkg. fluctuation) = 8.7×10^{-5} (3.9σ)

This **first observation** yields:

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

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

Interesting for time-dep't CP-violation, just like $\psi K^{(*)}$

$B \to D^*\rho$: 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_-, H_0
- Check factorization via $\Gamma_L/\Gamma = |H_0|^2/\sum|H_i|^2$

  Compare to $D^*\ell\nu$ at $q^2 = m_\rho^2$
- Look for hints of final state interactions in phases

$B^0 \to D^{*-}\rho^+$	magnitude	phase
H_0	0.936	0
H_-	$0.317 \pm 0.052 \pm 0.013$	$0.19 \pm 0.23 \pm 0.14$
H_+	$0.152 \pm 0.058 \pm 0.037$	$1.47 \pm 0.37 \pm 0.32$
$B^+ \to \bar{D}^{*0}\rho^+$	magnitude	phase
H_0	0.932	0
H_-	$0.283 \pm 0.068 \pm 0.039$	$1.13 \pm 0.27 \pm 0.17$
H_+	$0.228 \pm 0.069 \pm 0.036$	$0.95 \pm 0.31 \pm 0.19$

$D^{*-}\rho^+$: $\Gamma_L/\Gamma = 0.878 \pm 0.034 \pm 0.040$

- CLEO $D^*\ell\nu$: $0.914 \pm 0.152 \pm 0.089$
- 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 ρ
- 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 ΔE 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/π separation at 2.6 GeV is $\sim 2\sigma$:

- Need to fit $(K\pi, \pi\pi)$, etc., simultaneously
- Also have similar ind't K/π separation via ΔE

3 major recent PRL's; all 5 fb^{-1}:

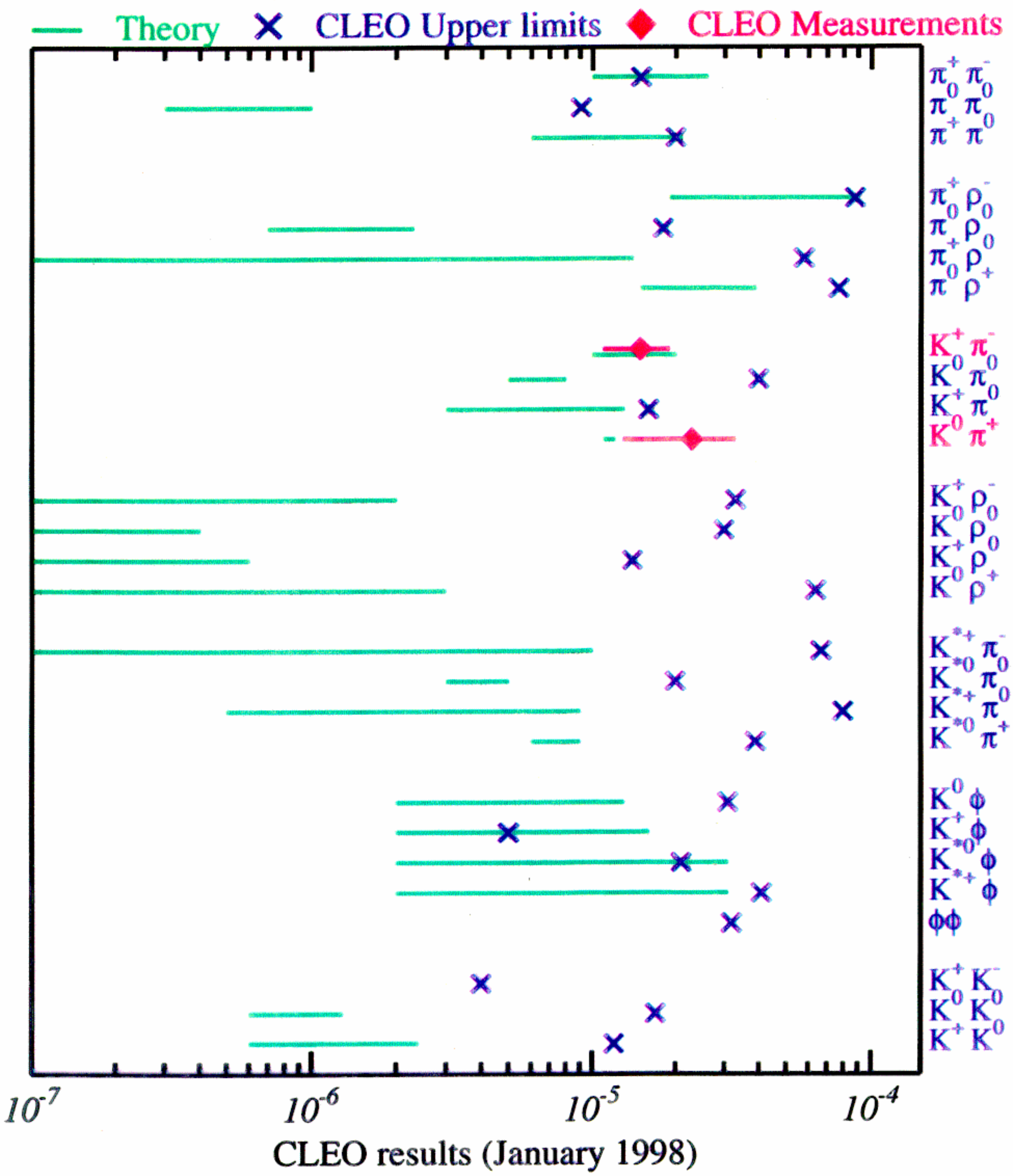
$K\pi$ final states	R. Godang et al., PRL 80, 3456 (1998)
η/η' final states	B.H. Behrens, et al., PRL 80, 3710 (1998)
ω/ϕ final states	T. Bergfeld et al., PRL 81, 272 (1998)

These (and more!) summarized graphically on following two slides

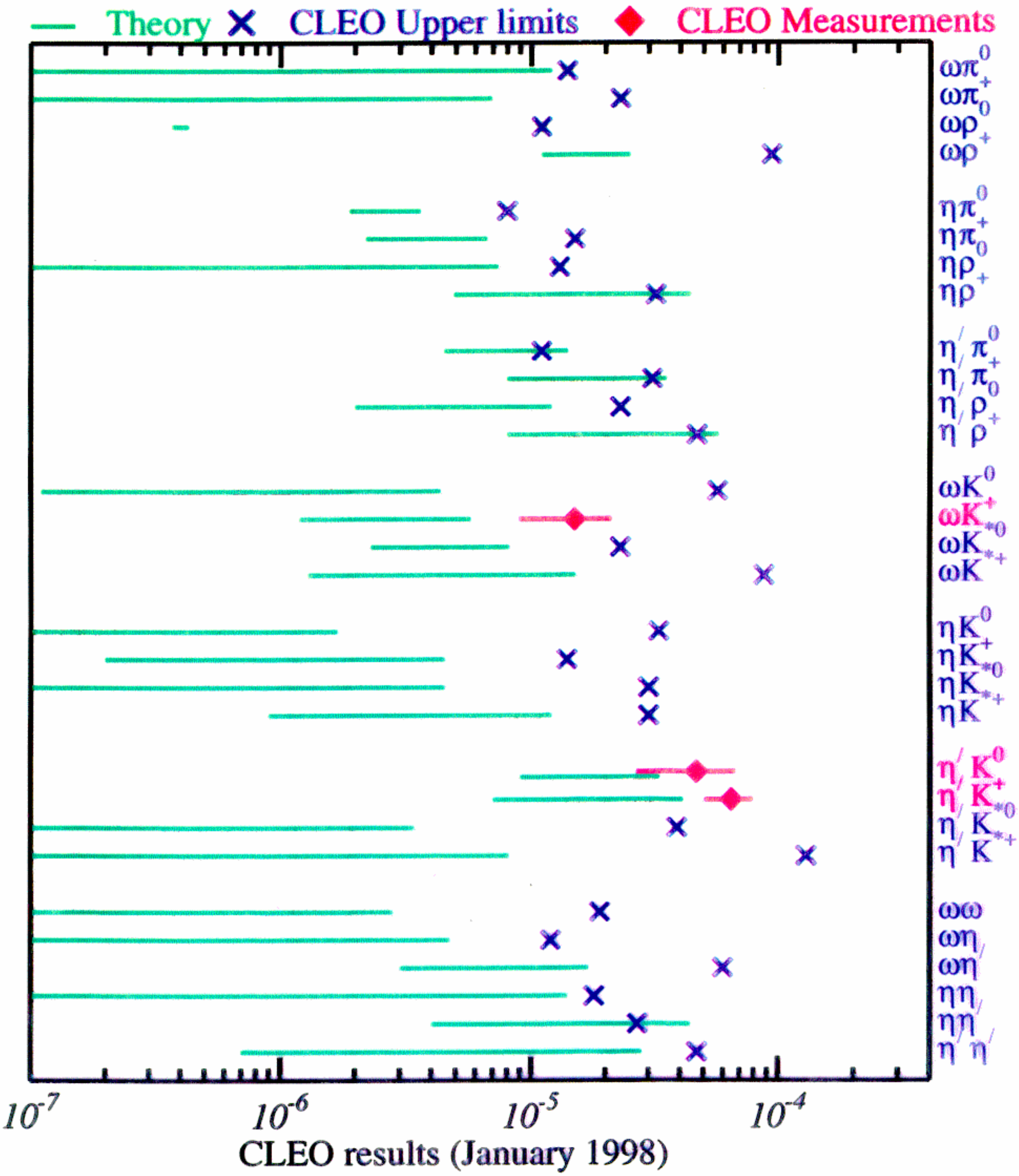
Also, M. Athanas et al.; PRL 80, 5493 (1998) 5 fb^{-1}:

$\mathcal{B}(B^- \to D^0 K^-) = (2.57 \pm 0.65 \pm 0.32) \times 10^{-4}$

K, π, K^*, ρ, ϕ Modes: Pre-Summer Status

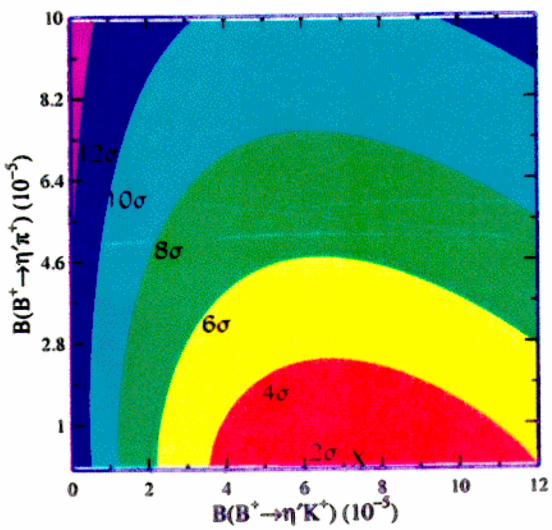


η, η', ω Modes: Pre-Summer Status



New Rare B Results: $B \to \eta' K$

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

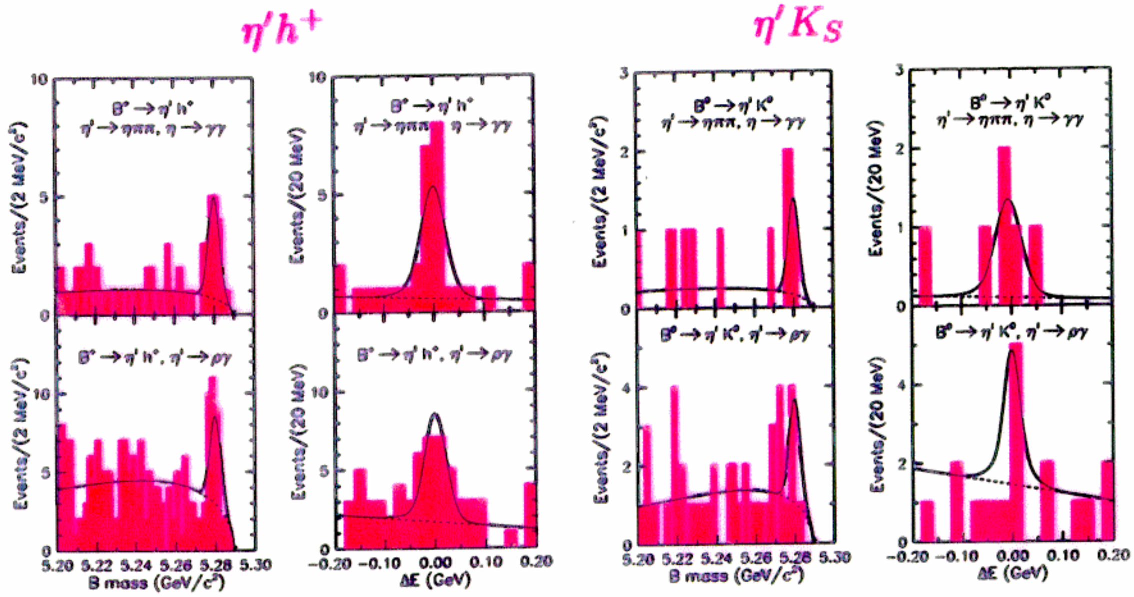


$\eta' K^+, \eta' \pi^+$ fit together

Data indicates all K^+,

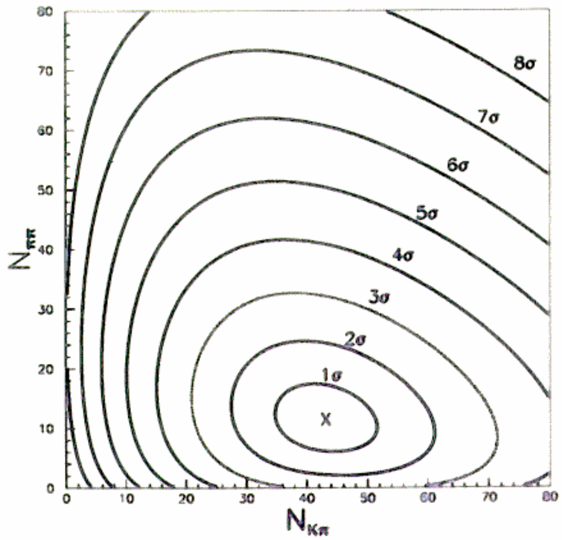
no hint of π^+ yet!

Projections of significant modes:



New Rare B Results: $B \to K^+\pi^-, \pi^+\pi^-$

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

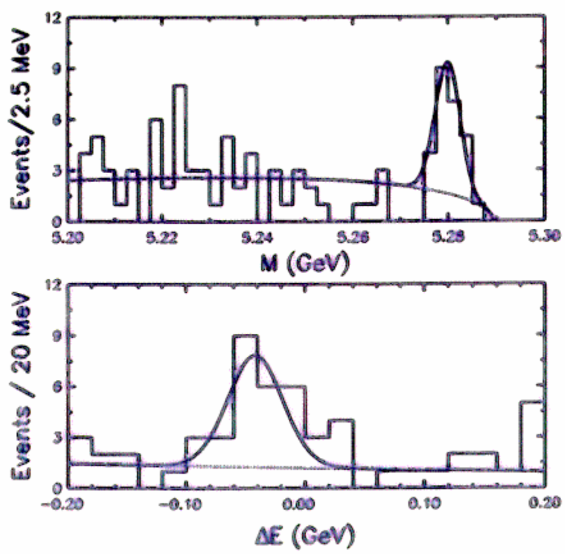


$K^+\pi^-, \pi^+\pi^-$ fit together

Only $K^+\pi^-$ significant

Sign that penguins are large!

Also, unlikely that modes are equal



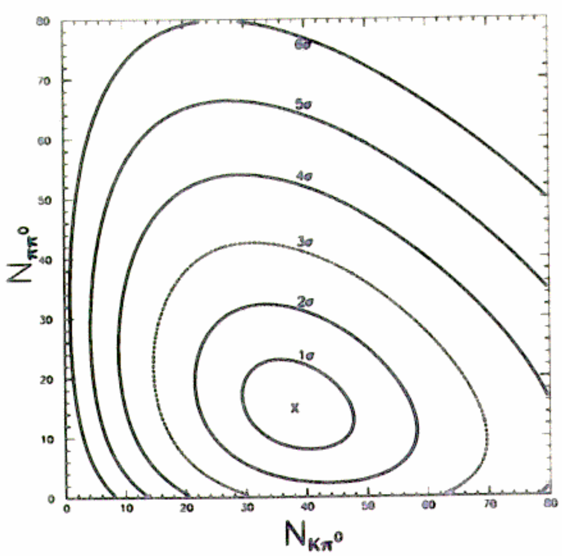
Fit projections for $K^+\pi^-$ mode

NOTE: recon. assumes π mass, so ΔE shifts.

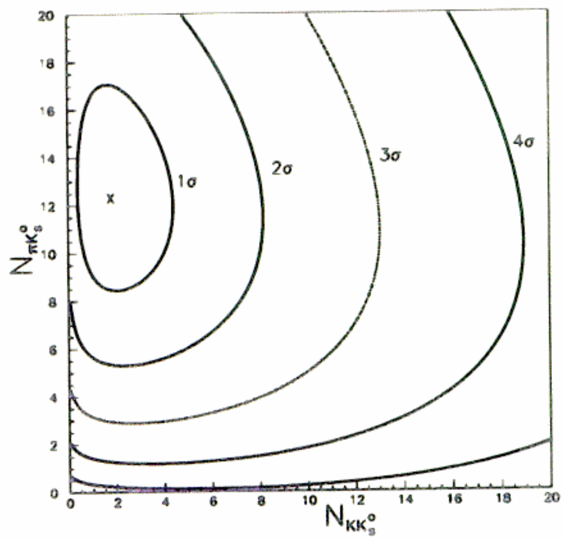
New Rare B Results: $B \to h^+\pi^0, h^+K_S$

Likelihood contours:

$h^+\pi^0$

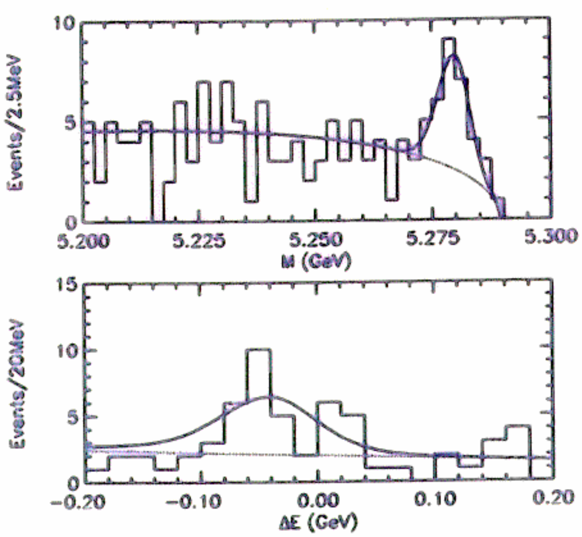


h^+K_S

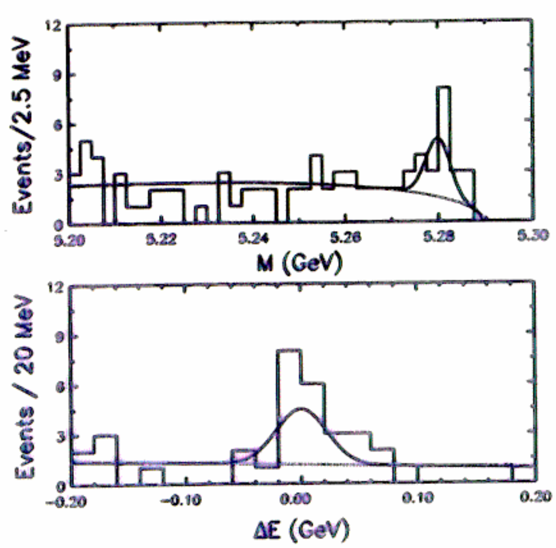


Projections of significant modes:

$K^+\pi^0$



π^+K_S



New Rare B Results Summary

New KK, $K\pi$, $\pi\pi$ Results Summary:

$K^+\pi^0$ is NEW first observation!

Mode	$\mathcal{E}(\%)$	$\mathcal{B}$	Theory $\mathcal{B}$
* $\pi^+\pi^-$	53 ± 5	< 0.84	0.8–2.6
$\pi^+\pi^0$	42 ± 4	< 1.6	0.4–2.0
$K^+\pi^-$	53 ± 5	$1.4 \pm 0.3 \pm 0.2$	0.7–2.4
$K^+\pi^0$	42 ± 4	$1.5 \pm 0.4 \pm 0.3$	0.3–1.3
$K^0\pi^+$	15 ± 2	$1.4 \pm 0.5 \pm 0.2$	0.8–1.5
K^+K^-	53 ± 5	< 0.24	–
$K^+\bar{K}^0$	15 ± 2	< 0.93	0.07–0.13

New η' Results Summary:

Still seeing LARGE rate for $\eta' K^+$

Mode	$\epsilon(\%)$	N_{signal}	Signif.	$\mathcal{B}(\times 10^{-5})$
$\eta' K^+$	$29 - 36$	68.6	12.7	$7.4^{+0.8}_{-1.3} \pm 1.0$
$\eta' K^0$	$28 - 33$	16.1	7.3	$5.9^{+1.8}_{-1.6} \pm 0.9$
$\eta' \pi^+$	$29 - 36$	1.0	-	< 1.2

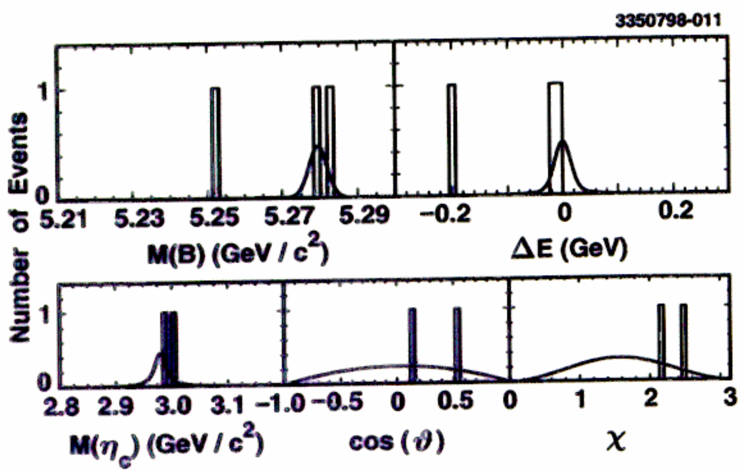
We are actively looking at more new modes in the near-term

One Final New Mode: $B \to \eta_c K$

We observe large rates of η' decays: perhaps η_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; 3.9σ significance



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

Branching ratio consistent with expectations; in line with ψK.

Related Limits:

Decay Channel	Upper Limit
$B^0 \to \eta_c K^0$	6.8×10^{-3}
$B^0 \to \eta_c K^{*0}$	5.95×10^{-3}
$B^\pm \to \eta_c K^{*\pm}$	18.5×10^{-3}

Working to add $\eta_c \to K_S K \pi$ decay mode

$b \to s\gamma$

$b \to s\gamma$ 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:

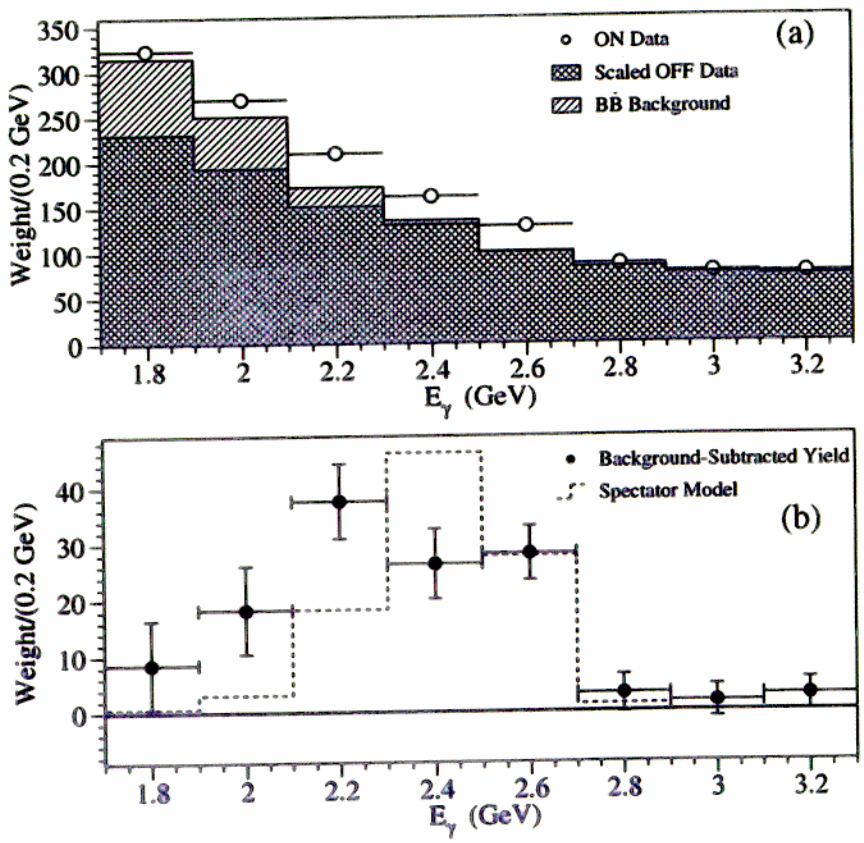
- Do modified full reconstruction:
  Use photon, $K^{\pm}$, and $0-4\pi$'s
  Pick best candidate
- Produce an event weight

Weights are combined when event is in both analyses

Greater stat. power, more data than published analysis

$b \to s\gamma$

New Result: CLEO CONF 98-17; 5 fb^{-1}



$$\mathcal{B}(b \to s\gamma) = (3.15 \pm 0.35(stat) \pm 0.32(syst) \pm 0.26(model)) \times 10^{-4}$$

A bit larger than before:
partly from going down to 2.1 GeV in E_γ

Very consistent with theory:
$\mathcal{B}(b \to s\gamma) = (3.28 \pm 0.33) \times 10^{-4}$ (Chetyrkin, Misiak, and Münz).

Other Electroweak Penguins

$B \to K^{(*)}\ell^+\ell^-$:

CLEO CONF 98-22; 5 fb^{-1}

- $\mathcal{B}(B \to K^*\ell^+\ell^-) < 0.68 \times 10^{-5}$
- $\mathcal{B}(B \to K\ell^+\ell^-) < 0.70 \times 10^{-5}$

$b \to s\ell^+\ell^-$:

S. Glenn et al., PRL 80, 2289 (1998); 5 fb^{-1}

- $\mathcal{B}(b \to s\ e^+e^-) < 5.7 \times 10^{-5}$
- $\mathcal{B}(b \to s\ \mu^+\mu^-) < 5.8 \times 10^{-5}$
- $\mathcal{B}(b \to s\ e^\pm\mu^\mp) < 2.2 \times 10^{-5}$

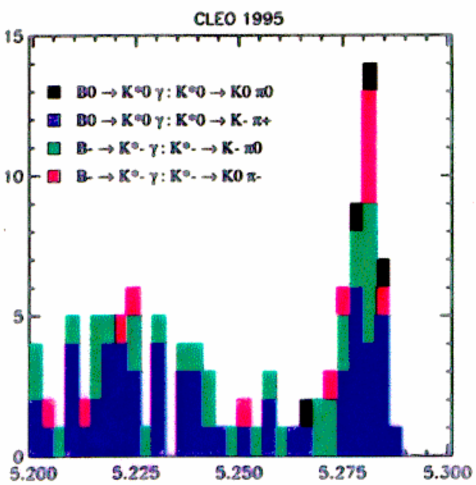
$B \to K^*\gamma$ discovered by CLEO

$B \to \rho\gamma$ not yet seen.

Eventually can give $|V_{td}/V_{ts}|$

Latest plot with 3.5 fb^{-1}:

Working on update...



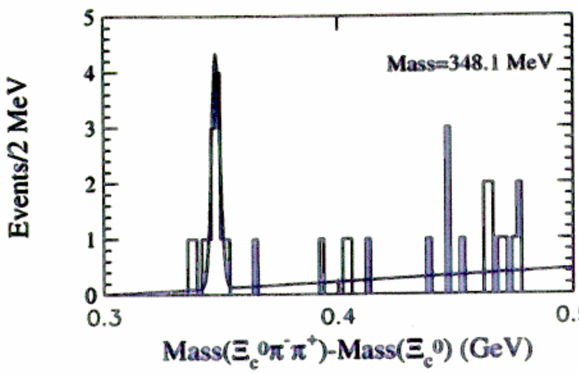
Charmed Baryons

Eight new states discovered since 1996 PDG!

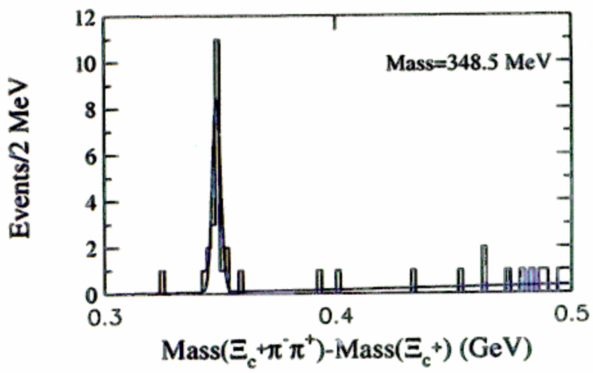
Newest are:

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

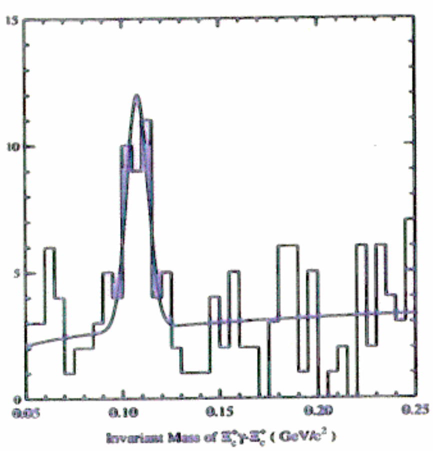
$L = 1$ Ξ^0_{c1}



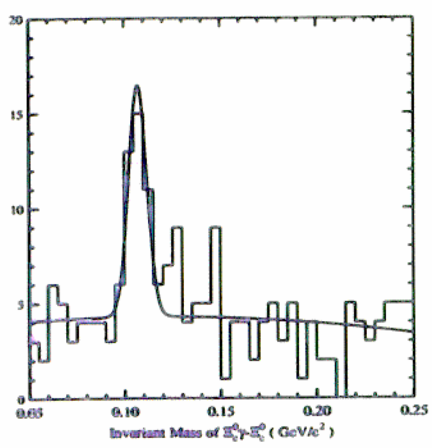
$L = 1$ Ξ^+_{c1}



$\Xi^{+\prime}_c$



$\Xi^{0\prime}_c$



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:

$J^P = 1/2^+$

Ω_c^0

Ξ_c^0 Ξ_c^+ $\Xi_c^{0\prime}$ $\Xi_c^{+\prime}$

Λ_c^+ Σ_c^0 Σ_c^+ Σ_c^{++}

$J^P = 3/2^+$

Ω_c^{0*}

Ξ_c^{*0} Ξ_c^{*+}

Σ_c^{*0} Σ_c^{*+} Σ_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 $\mathcal{B}(\Lambda_c \to pK\pi)$!
- Searches need to be careful re: correlated π, γ...

  lots of soft particles from de-excitations

Charm Lifetimes

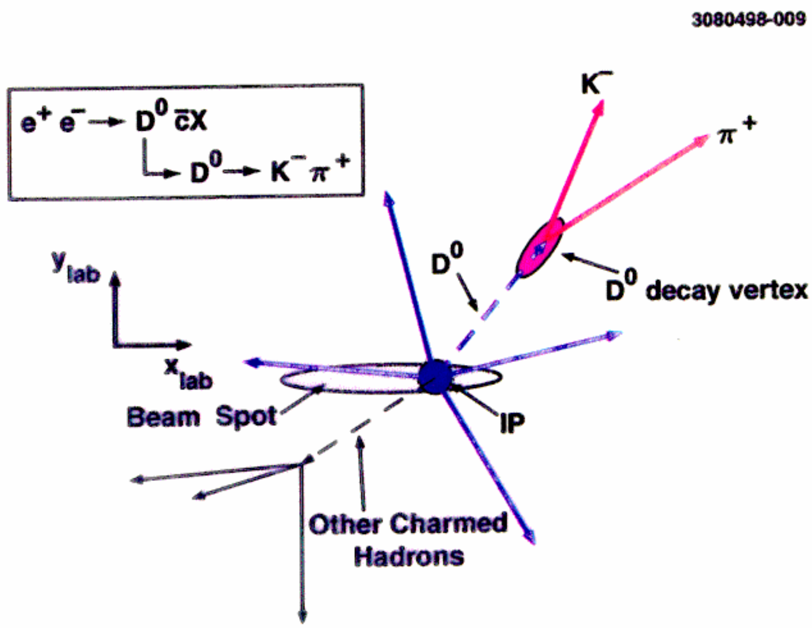
Analysis: CLEO CONF 98-15; 4 fb^{-1}

- Use CLEOII.5 data with Silicon Vertex Detector
- $D^0 \to K^-\pi^+$; tagged via $D^{*+} \to D^0\pi^+$
- Intersect D flight with flat well-known beam spot:

  $\sigma_{y,beam} \sim 7\mu\text{m}$ $\sigma_{x,beam} \sim 350\mu\text{m}$
- Avoid using fragmentation tracks; may bias int. point
- $\sigma_{D,vtx} \sim 60 - 110\,\mu\text{m}$ (along flight)

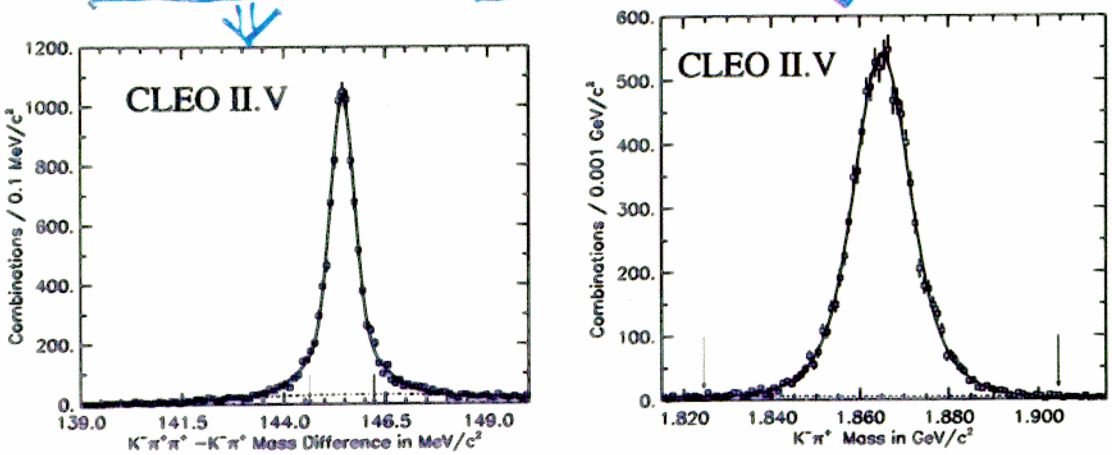
  $< \gamma\beta c\tau >= 200\mu\text{m}$
- Use 2D projection of decay in $r - \phi$ plane

  (analysis choice; SV z works fine!)

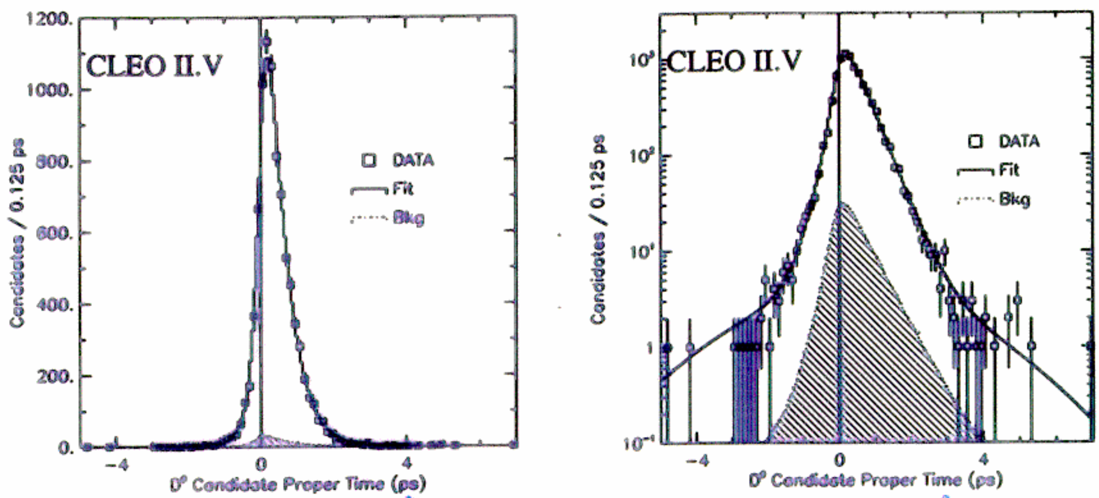


Charm Lifetimes

D-D* Mass-Difference and *D* Mass:



Fit Results:



τ (ps) τ (ps)

(same fit, data)

Charm Lifetimes

Fit:

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

New Result:

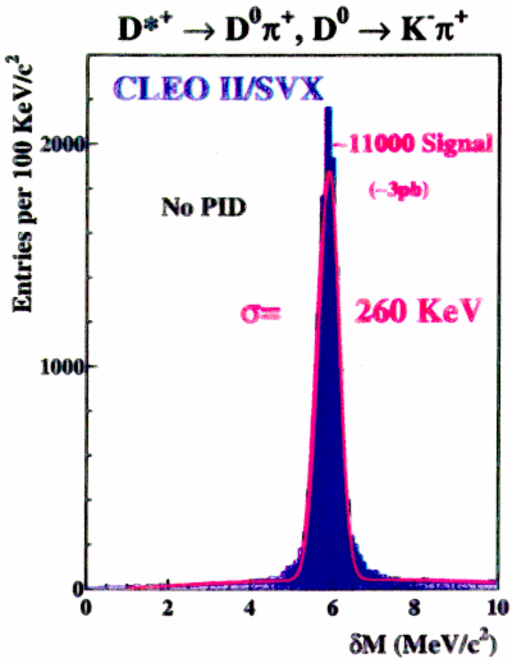
- $\tau_{D^0} = 409.5 \pm 5.8\ (stat.) \pm 5.2\ (syst.)$ fs
- Very competitive result; will improve

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)

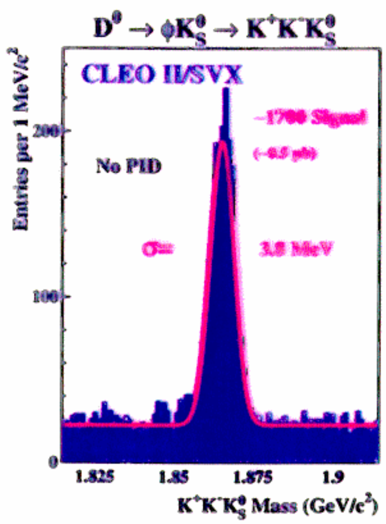
still improving: ~ 200 now!

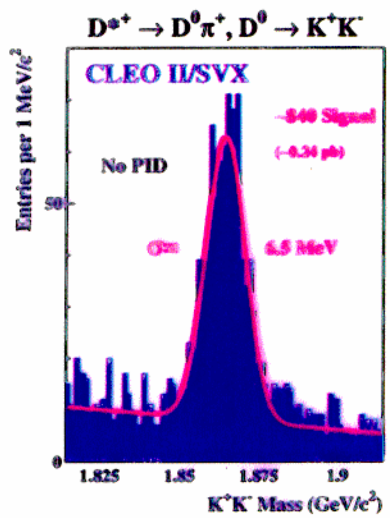
Looking into $D^0 \rightarrow K^+\pi^-$ (Doubly-Cabibbo suppressed)

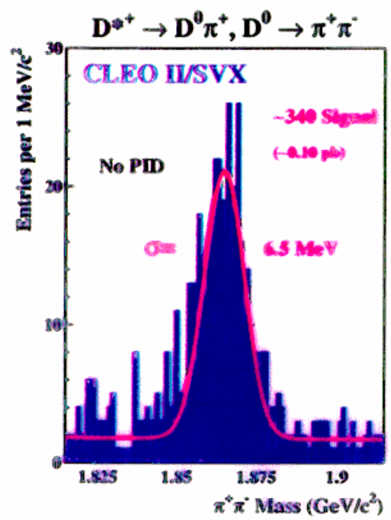
Study of intrinsic D^* width?

Nice clean signals in CP-eigenstate modes: $(3.4\ \mathrm{fb}^{-1})$

(use to look for lifetime differences!)







$\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$ 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 $a_1(1260) \to \rho\pi$

- $a_1(1260)$ is poorly understood
- Hadronic mass shape of interest for ν-mass studies

$\pi^-\pi^0\pi^0$ is better than $\pi^+\pi^+\pi^-$:

- Smaller feed-across
- Only one I=0 combination of π's

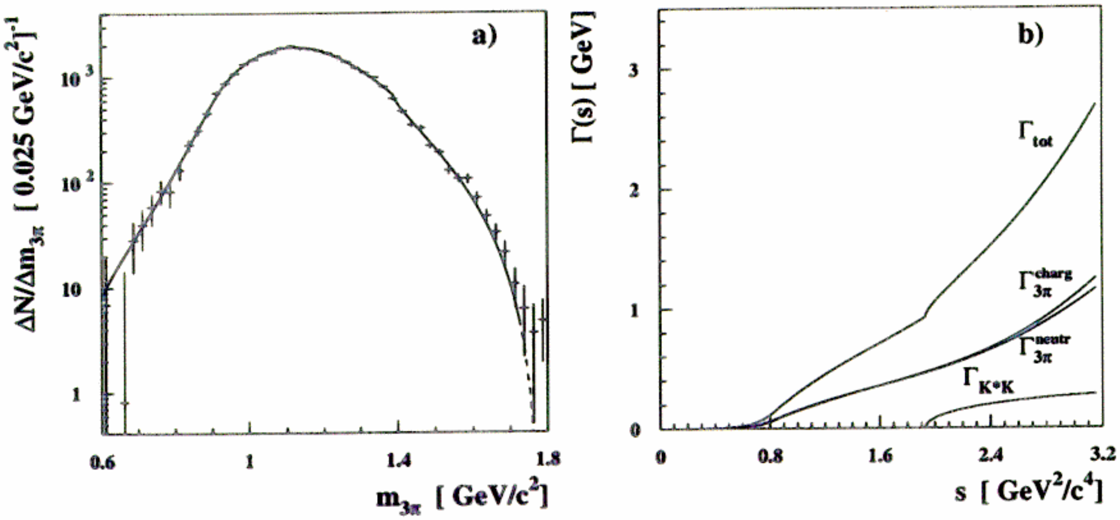
Fit Dalitz plots, components relative to dominant s-wave $\rho\pi$

		Signif.	$\mathcal{B}$ fraction(%)
$\rho(1450)$	s-wave	1.4σ	$0.30 \pm 0.64 \pm 0.17$
ρ	d-wave	5.0σ	$0.36 \pm 0.17 \pm 0.06$
$\rho(1450)$	d-wave	3.1σ	$0.43 \pm 0.28 \pm 0.06$
$f_2(1275)$	p-wave	4.2σ	$0.14 \pm 0.06 \pm 0.02$
σ	p-wave	8.2σ	$16.18 \pm 3.85 \pm 1.28$
$f_0(1370)$	p-wave	5.4σ	$4.29 \pm 2.29 \pm 0.73$

Also extract values of complex couplings for each channel.

$\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$ 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
- $h_{\nu_\tau} = -1.02 \pm 0.13 \pm 0.03$ (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}

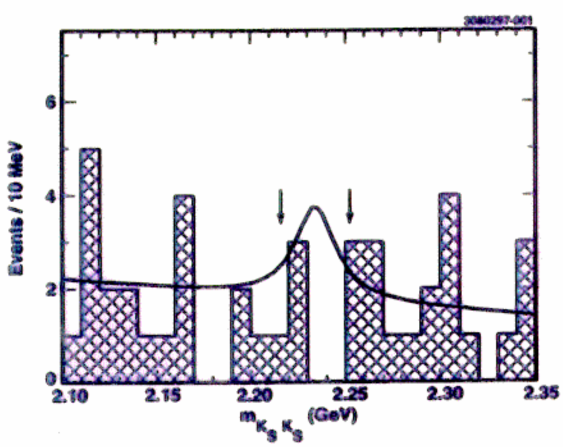
$\psi \to gg\gamma \to X\gamma$: coupling to gluons
2 γ production limits/measures coupling to $\gamma\gamma$

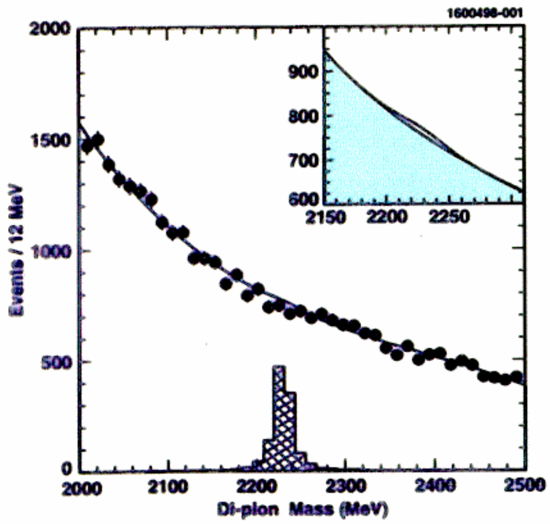
Particle X 'stickiness': $S \sim \Gamma(\psi \to \gamma X)/\Gamma(X \to \gamma\gamma) \times$ kin. factors
(Note: one can cancel BR of X to final state!)

Expect $S \sim 1$ for $q\bar{q}$ mesons:

- Valence quarks couple well to both glue and γ

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

Charm Physics:

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

Tau Physics:

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

Upsilon Physics:

- Υ 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/