

Recent Results from CLEO

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5 Aug 2002

High Energy Physics Advisory Panel

CLEO III Results:

- Bottomonium Transitions and Spectroscopy
 - Search for the $b\bar{b}$ ground-state: η_b
 - Two-Photon Transitions and P states
 - First Observation of the $\Upsilon(1D)$ State
- Rare B decays
- Charmed Baryons

CLEOII CKM Results:

- Inclusive $|V_{cb}|$ using measured HQET $\bar{\Lambda}, \lambda_1$
 - E_γ Spectrum of $B \rightarrow s\gamma$
 - Hadronic Moments in $B \rightarrow X_c \ell \nu$
 - Leptonic Moments in $B \rightarrow X \ell \nu$
- Exclusive $|V_{cb}|$ from $B \rightarrow D^* \ell \nu$
- 'Inclusive' $|V_{ub}|$ from Lepton Endpoint
- Exclusive V_{ub} from $B \rightarrow \pi \ell \nu$
- Inclusive $|V_{ub}|$ from all $b \rightarrow u \ell \nu$

Other CLEOII Results:

- Factorization Tests with $B \rightarrow D^*(4\pi)^-$
- Color-suppressed $B \rightarrow D\pi$ and strong phases
- First Measurement of the D^* Width
- $D^0 - \bar{D}^0$ Mixing Analyses
- Exclusive $B \rightarrow$ Charm Baryons

Table 1: Near $\Upsilon(4S)$ Luminosity

Data Set	Upgrade	On $\Upsilon(4S)$ (fb^{-1})	continuum (fb^{-1})	Total (fb^{-1})	$N_{B\bar{B}}$ (10^6)
CLEOII	Csl	3.1	1.6	4.7	3.3
CLEOII.V	SVX	6.1	2.9	9.0	6.4
All CLEOII		9.2	4.5	13.7	9.7
CLEOIII	RICH	6.9	2.3	9.2	7.4
Total		16.1	6.8	22.9	17.1

Summer 2001: End of $\Upsilon(4S)$ Running...
Addition of superconducting focus quads

Table 2: $\Upsilon(1S, 2S, 3S)$ Luminosity

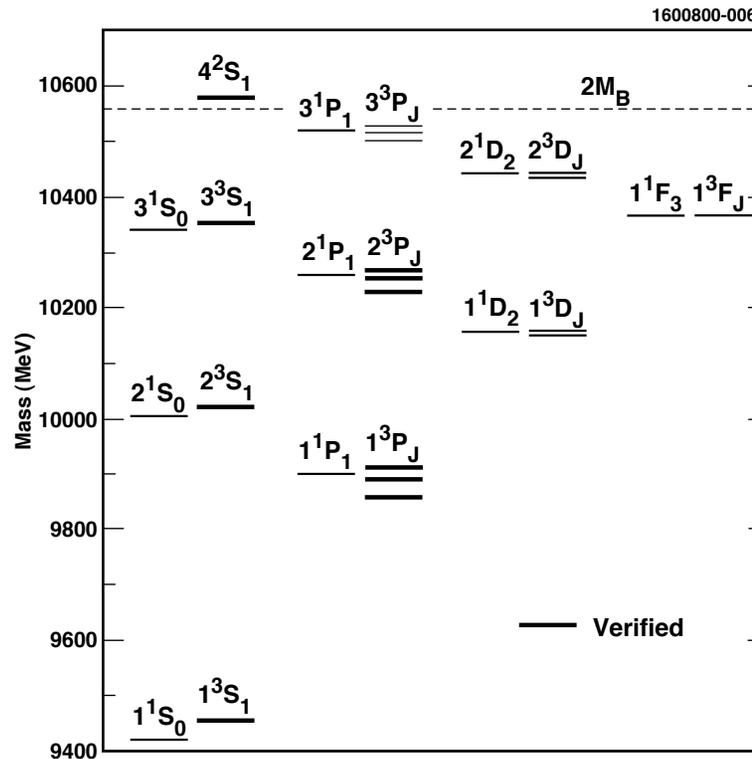
Data Set	$\Upsilon(1S)$ (fb^{-1})	$\Upsilon(2S)$ (fb^{-1})	$\Upsilon(3S)$ (fb^{-1})
CLEOIII On-res.	1.23	0.50	1.27
CLEOIII Off-res.	0.19	0.15	0.12
CLEOIII Scan	0.10	0.05	0.10
CLEOIII Total	1.52	0.70	1.49
CLEOII On-res.	0.08	0.07	0.11

More $\Upsilon(nS)$ coming in now.

New (Preliminary) CLEOIII results from $\Upsilon(3S)$

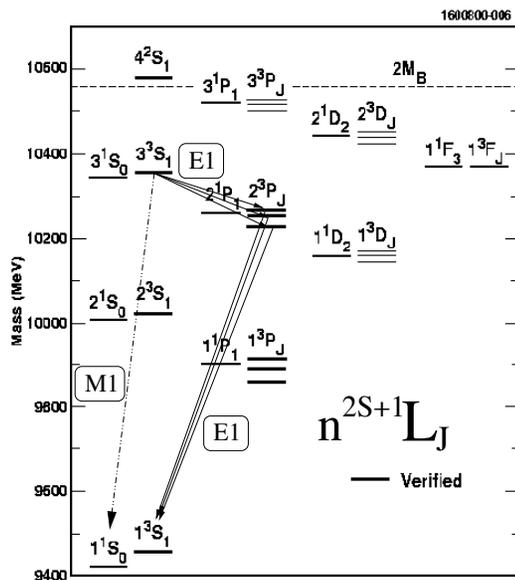
Hydrogen atom for QCD

- Search for η_b (1^1S_0)
Inclusive **single photons**
- Mass of χ_b 2^3P_J states from photon lines
photon pairs $3S \rightarrow \gamma 2P$; $2P \rightarrow \gamma 1S, \gamma 2S$; $1S/2S \rightarrow \ell\ell$
- First Observation of 1^1D_J states in $\Upsilon(3S) \rightarrow 4\gamma\ell\ell$
4 γ cascade $3S \rightarrow 2P \rightarrow 1D \rightarrow 1P \rightarrow 1S$

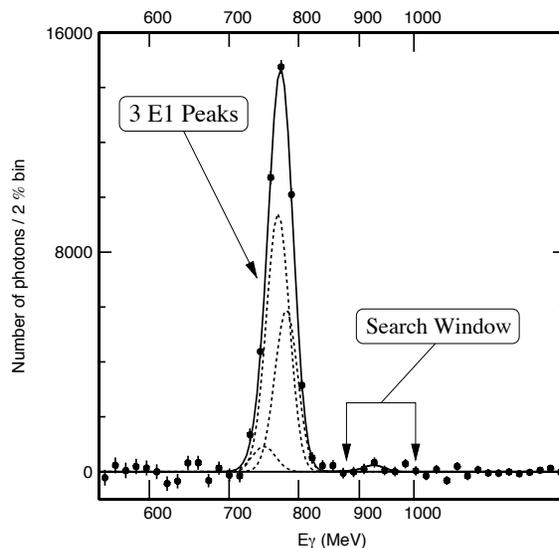


$\Upsilon(3S) \rightarrow \gamma\eta_b(1S)$:

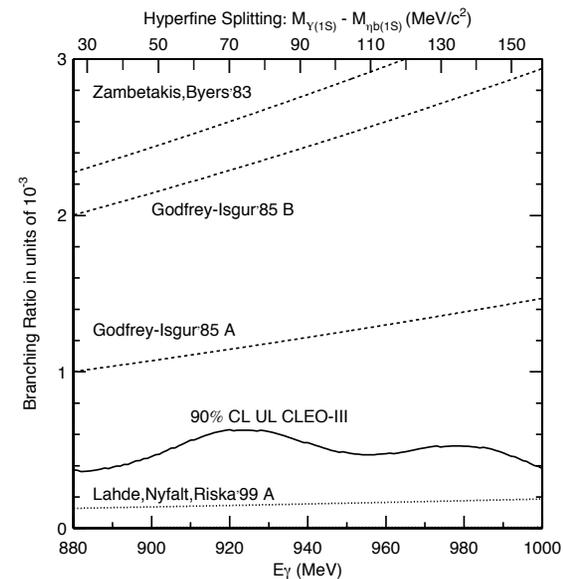
Monochromatic photon from hindered M1 transition



Transitions



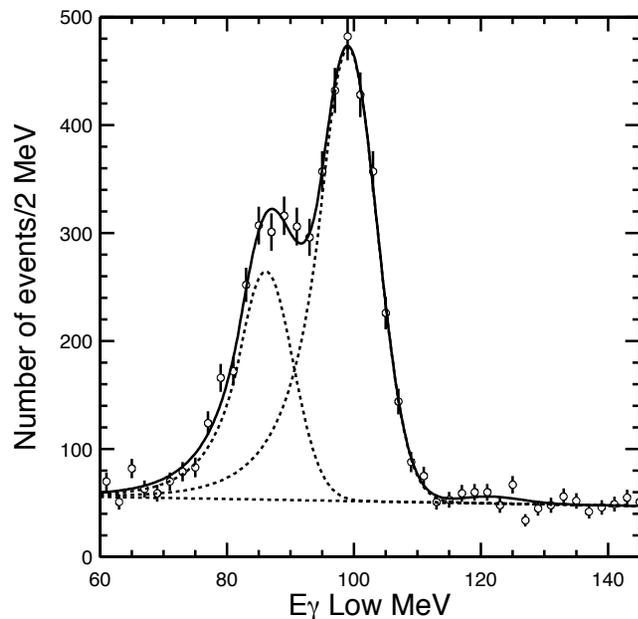
Data (minus smooth background)



Limit curve vs. Predictions

Clearly rules out 3 of 4 predictions Upper limit from sample of $4.7 \times 10^6 \Upsilon(3S)$.

$\Upsilon(3S) \rightarrow \gamma\gamma\Upsilon(2S)$ and $\Upsilon(3S) \rightarrow \gamma\gamma\Upsilon(1S)$
 $\Upsilon(2S), \Upsilon(1S) \rightarrow \ell^+\ell^-$



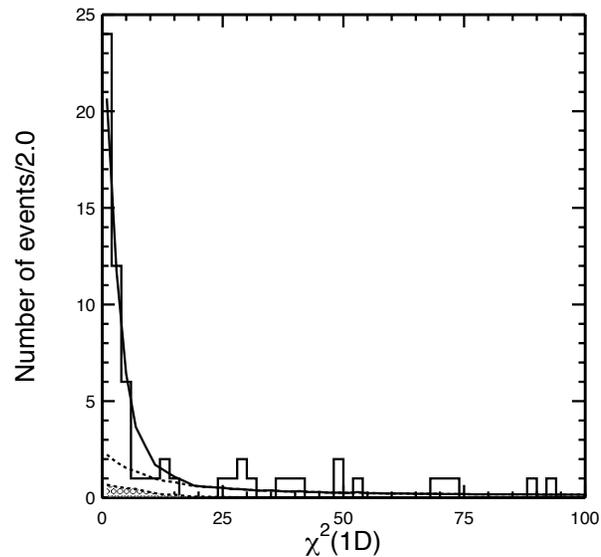
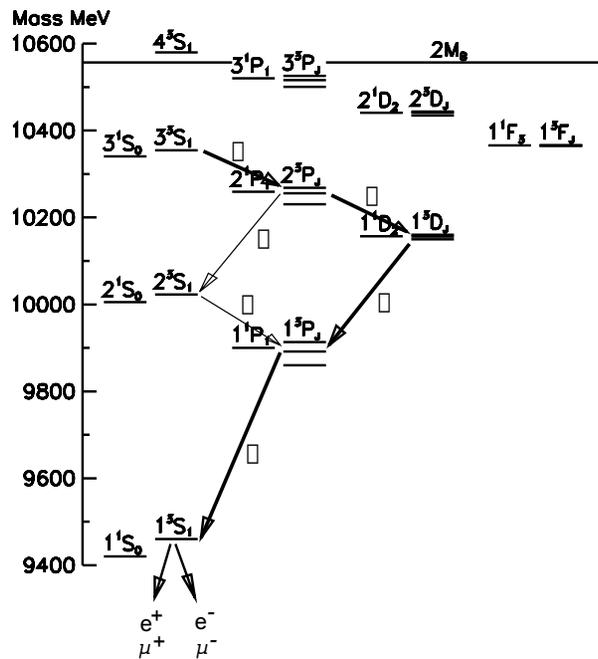
- Precise $2P_J$ masses:

$$M_{\chi_b(2P_2)} = 10268.8 \pm 0.3 \pm 0.6 \text{ MeV}$$

$$M_{\chi_b(2P_1)} = 10255.6 \pm 0.2 \pm 0.6 \text{ MeV}$$

- Measured branching ratios involving $2P$ states yields $E1$ matrix elements and ratios of hadronic widths

- Rare $\Upsilon(3S) \rightarrow \gamma\chi_b(1P_J), \chi_b(1P) \rightarrow \gamma\Upsilon(1S)$
 $\langle 1P|r|3S \rangle$ $E1$ matrix element is sensitive test of theory
- Upper limits on π^0 and η transitions from $\Upsilon(3S)$



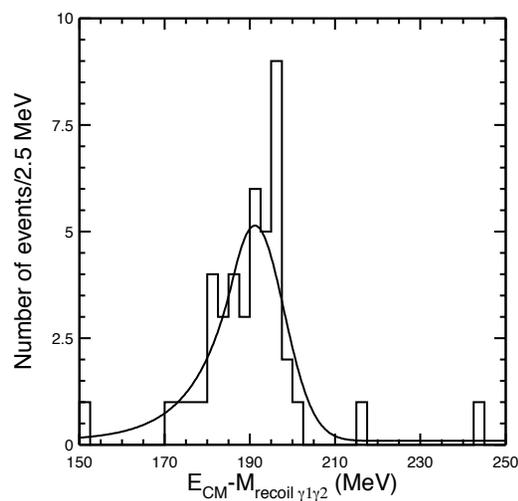
Form χ^2 for decay chain, varying:

- order of photon emission
- choice of χ_b P states
- Mass of $\Upsilon(1D)$

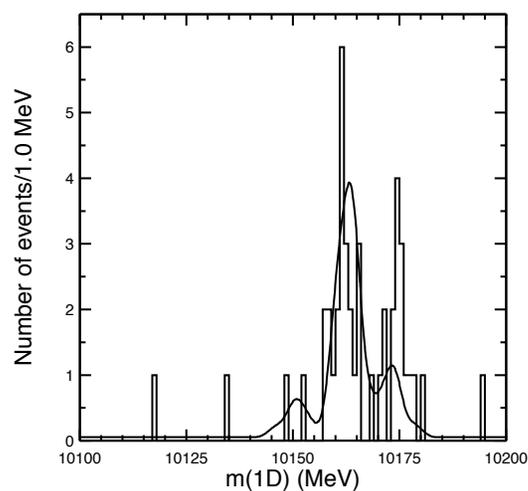
Signal significance: 9.7σ

Product branching ratio (sum of five decays): $(3.3 \pm 0.6 \pm 0.5) \cdot 10^{-5}$

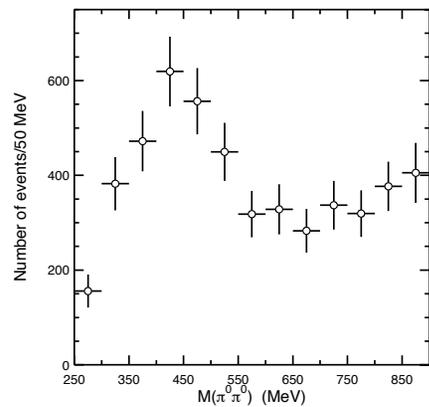
- consistent with the theoretical estimates.



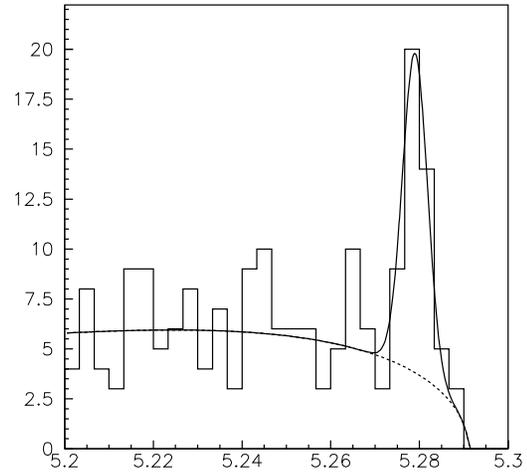
Recoil Mass

Mass from best χ^2

6.8 σ signal with a mass of $10162.2 \pm 1.6 \text{ MeV}/c^2$
(consistent with the $\Upsilon(1D_2)$ assignment)



$\Upsilon(3S) \rightarrow \pi^0\pi^0\Upsilon(1S)$ branching ratio and di-pion mass distribution.



Tables of numbers for things like:

$BR(B \rightarrow K + \pi^-)$:

CLEO Babar Belle

20 \pm 2.3 18 \pm 1.2 23 \pm 2.8

$BR(B \rightarrow \pi^+ \pi^-)$

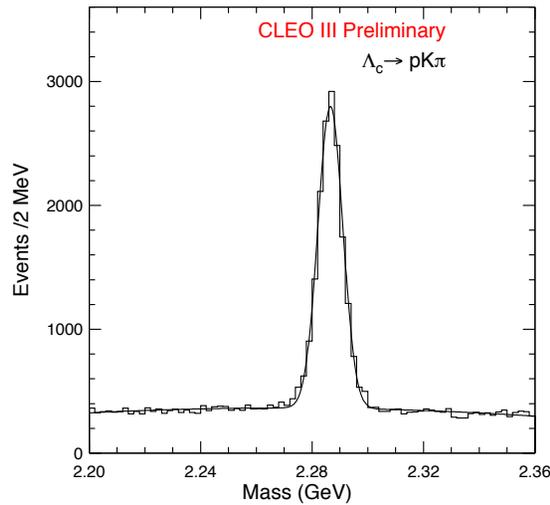
4.9 \pm 1.4 4.6 \pm 0.7 5.4 \pm 1.3

CLEO has discovered ~16 of 22 known states

including 7 of 8 $L = 1$ states

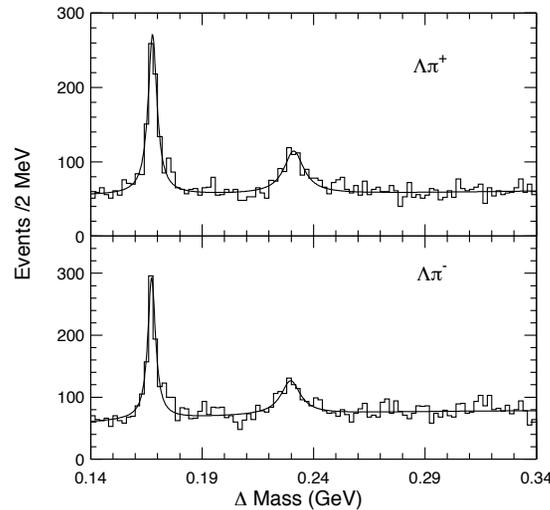
Many states are still “CLEO-only” → Verifying in CLEOIII data

$\Lambda_c p K \pi$ mode improved with new RICH detector



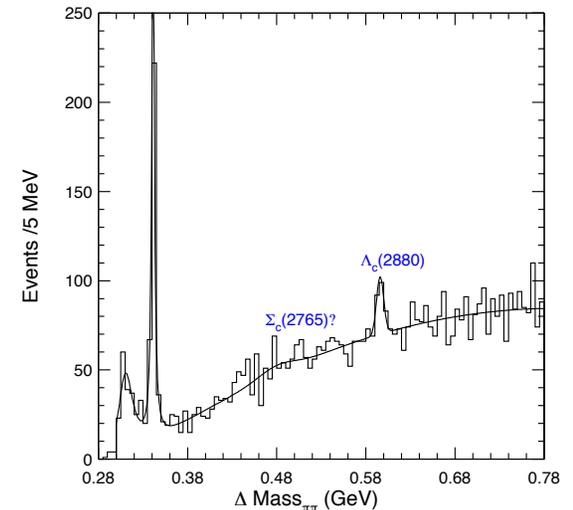
$\Lambda_c \rightarrow p K \pi$

CLEO III PRELIMINARY



$M(\Lambda_c \pi) - M(\Lambda_c)$
 $\Sigma_c(2455)^{++}, \Sigma_c(2520)^{++}$
 $\Sigma_c(2455)^0, \Sigma_c(2520)^0$

CLEO III PRELIMINARY



$M(\Lambda_c \pi \pi) - M(\Lambda_c)$
 $\Lambda_c(2593), \Lambda_c(2625),$
 $\Sigma_c(2765)??, \Lambda_c(2880)$

more charm baryon physics and another RICH analysis in later talk...

CKM Matrix and Semileptonic B Decay Status

Big picture:

- Inclusive and exclusive analyses for both $|V_{cb}|$ and $|V_{ub}|$

Extract HQET parameters from Data!

- $\bar{\Lambda}$: energy of 'brown muck' (light degrees of freedom)
- λ_1 : fermi motion energy
- λ_2 : chromo-magnetic interaction (known from $M_{B^*} - M_B$)

Use to aid inclusive extractions of V_{cb}

Relies on Quark-Hadron Duality

Compare to others methods:

- $|V_{cb}|$ from $B \rightarrow D^* \ell \nu$ at zero-recoil (HQET)

$b \rightarrow s \gamma$ data also helps with 'inclusive' $|V_{ub}|$

- Extract $|V_{ub}|$ from the rate at the Lepton Endpoint

but also do exclusive modes for $|V_{ub}|$

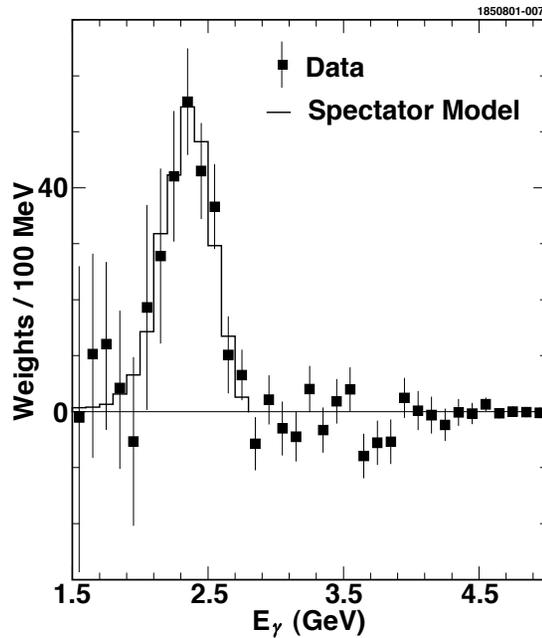
Continuum Data is Valuable!

- $b \rightarrow s \gamma$ and lepton endpoint: at kin. limit for B 's
- Continuum *not* limited \rightarrow large backgrounds
 - Suppress continuum: hard work experience
 - Subtract continuum: data!

Make frequent use of 'neutrino reconstruction'

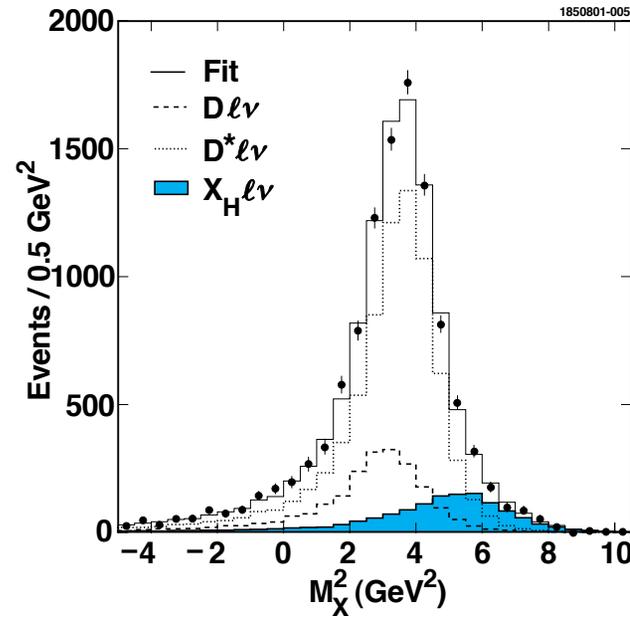
- Developed at CLEO

Photon Spectrum



E_γ from $b \rightarrow s\gamma$

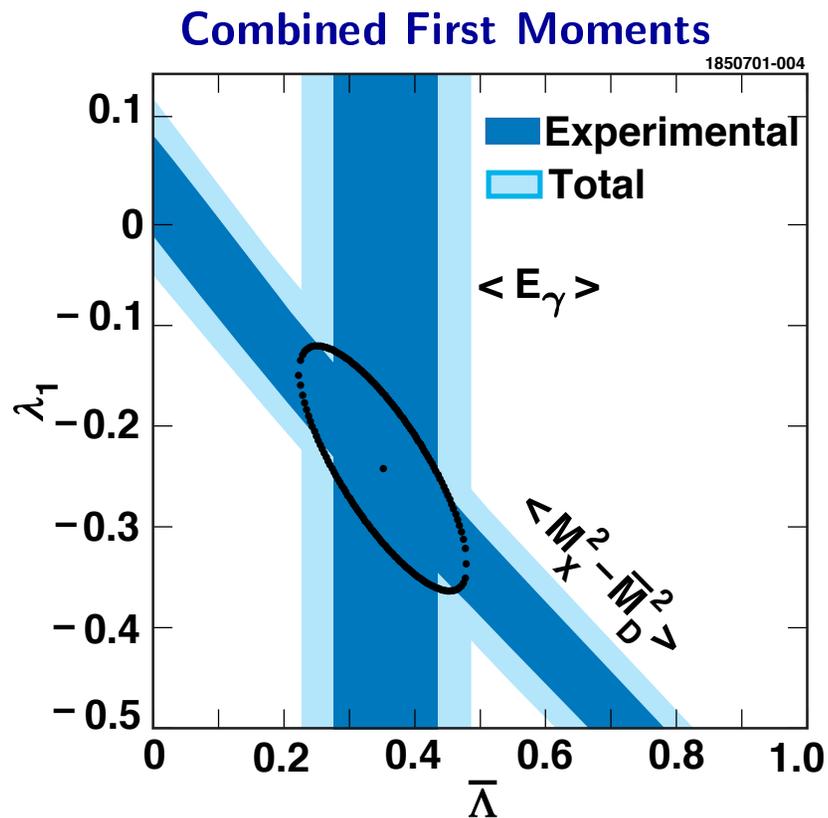
Recoil Mass



M_X^2 from $B \rightarrow X\ell\nu$

$$\begin{aligned}
 \langle E_\gamma \rangle &= 2.346 \pm 0.032 \pm 0.011 \text{ GeV} \\
 \langle E_\gamma \rangle^2 - \langle E_\gamma^2 \rangle &= 0.0226 \pm 0.0066 \pm 0.0020 \text{ GeV}^2 \\
 \langle M_X^2 - \bar{M}_D^2 \rangle &= 0.251 \pm 0.023 \pm 0.062 \text{ GeV}^2 \\
 \langle (M_X^2 - \bar{M}_D^2)^2 \rangle &= 0.639 \pm 0.056 \pm 0.178 \text{ GeV}^4
 \end{aligned}$$

(1)



Predicted moments depend on $\bar{\Lambda}, \lambda_1$
 Each measured moment yields a band constraint...

Ellipse indicates $\Delta\chi^2 = 1$

$$\bar{\Lambda} = 0.35 \pm 0.07 \pm 0.10 \text{ GeV}^2$$

$$\lambda_1 = -0.238 \pm 0.071 \pm 0.078 \text{ GeV}^3$$

Extracting $|V_{cb}|$ from Inclusive Semi-lep. Rate

HQET parameters in hand

- Moments (and $m_{B^*} - m_B$) directly measure key ones
- Smaller $\mathcal{O}(1/M_B^3)$ terms estimated; included in syst. errors

Inclusive semileptonic rate:

- CLEO 1996 tagged dilepton method (-1% for $B \rightarrow X_u \ell \nu$)

$$\mathcal{B}(B \rightarrow X_c \ell \nu) = (10.39 \pm 0.46)\%$$

Easily converted to Γ_{sl} :

Then, HQET expansion is of form:

(already have used similar expressions for moments...)

$$\Gamma_{sl} \sim G_F^2 M_B^5 (\mathcal{G}_0 + \mathcal{G}_1(\bar{\Lambda})/M_B + \mathcal{G}_2(\bar{\Lambda}, \lambda_1, \lambda_2)/M_B^2 + \mathcal{O}(1/M_B^3))$$

The result is:

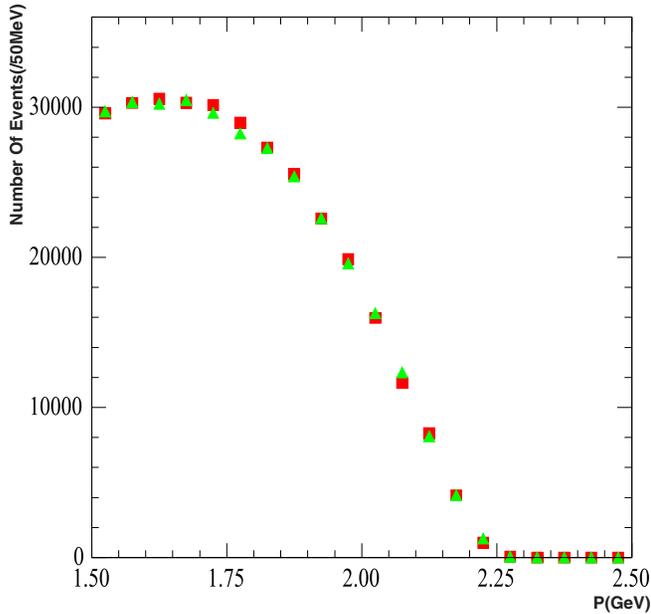
$$|V_{cb}| = (4.04 \pm 0.09 \pm 0.05 \pm 0.08) \times 10^{-2}$$

Errors are from (in order):

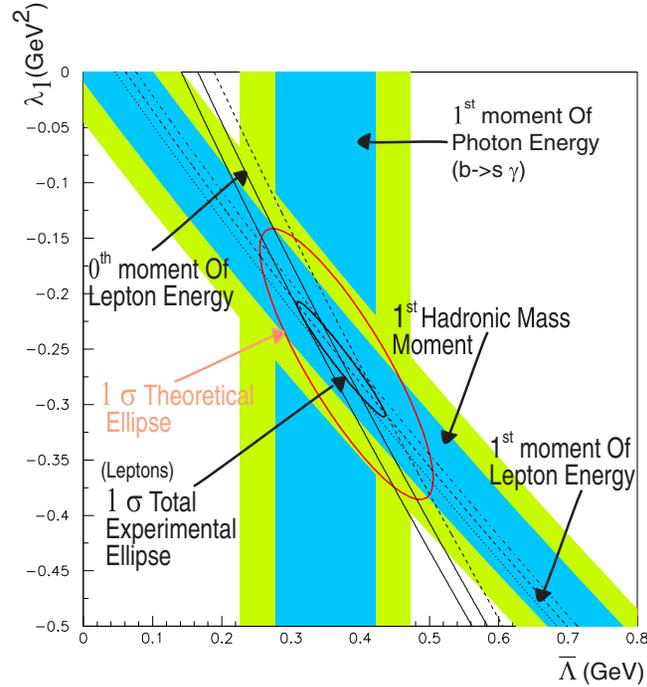
- Measurement of Γ_{sl}
- HQET params $\bar{\Lambda}, \lambda_1$
- Scale for α_s ; coeff's of $1/M_B^3$ terms

3.2% determination (!)

Leptons from $B \rightarrow Xl\nu$



Lepton Momentum
 e, μ overlay



$\bar{\Lambda} - \lambda_1$ plane
New ellipse on published bands

$$R_0 = \frac{\int_{1.7} (d\Gamma_{sl}/dE_l)dE_l}{\int_{1.5} (d\Gamma_{sl}/dE_l)dE_l}$$

$$R_1 = \frac{\int_{1.5} E_l (d\Gamma_{sl}/dE_l)dE_l}{\int_{1.5} (d\Gamma_{sl}/dE_l)dE_l}$$

$$R_0 = 0.6187 \pm 0.0014 \pm 0.0016$$

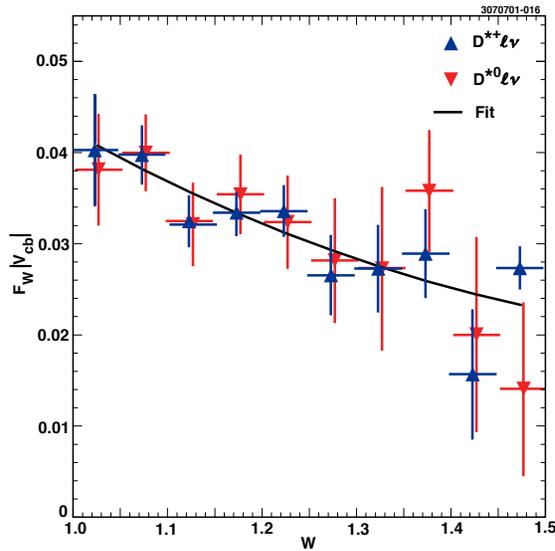
$$R_1 = 1.7810 \pm 0.0007 \pm 0.0009$$

Excellent $|V_{cb}|$ with these HQET parameters alone
Powerful confirmation of published moments!

Use both $D^{*+} \ell \nu$ and $D^{*0} \ell \nu$

HQET: Need rate at q^2_{max} ($w = 1$)

Corrected rates vs. q^2



Intercept at q^2_{max} and slope:

(curvature related to slope by theory:
Caprini-Lellouch-Neubert)

$$F(1) |V_{cb}| = (4.22 \pm 0.13 \pm 0.18) \times 10^{-2}$$
$$\rho^2 = 1.61 \pm 0.09 \pm 0.21$$

Systematics:

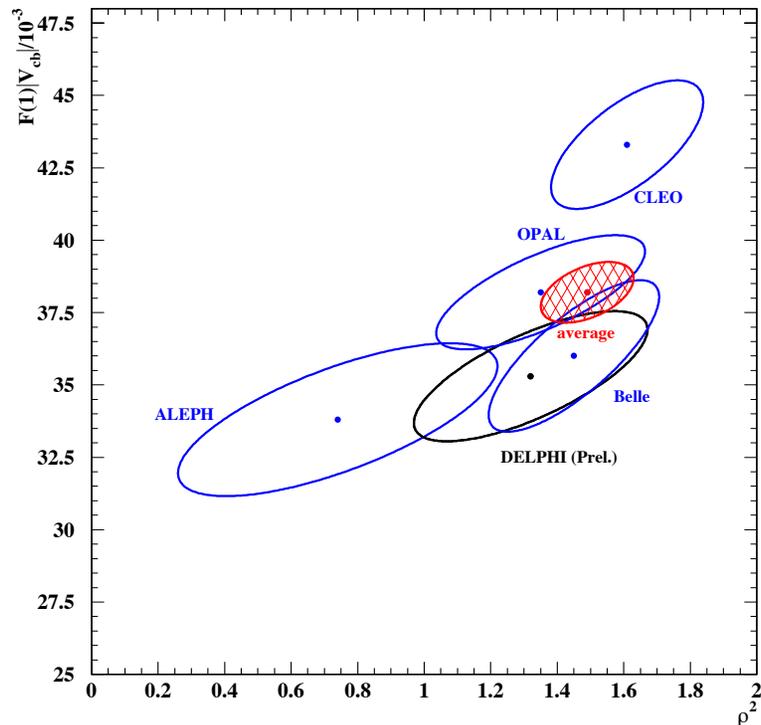
- Efficiency (esp. slow pions)
- Needed branching ratios
- Backgrounds
- Form Factors (for ρ^2)

Using $F(1) = 0.913 \pm 0.042$ (BaBar Physics Book):

$$|V_{cb}| = (4.62 \pm 0.14 \pm 0.20 \pm 0.21) \times 10^{-2}$$

- Errors are stat., syst., theor. **7% total**

Compilation of Recent Results:



Note $\rho^2 - \mathcal{F}(1)|V_{cb}|$ correlations:

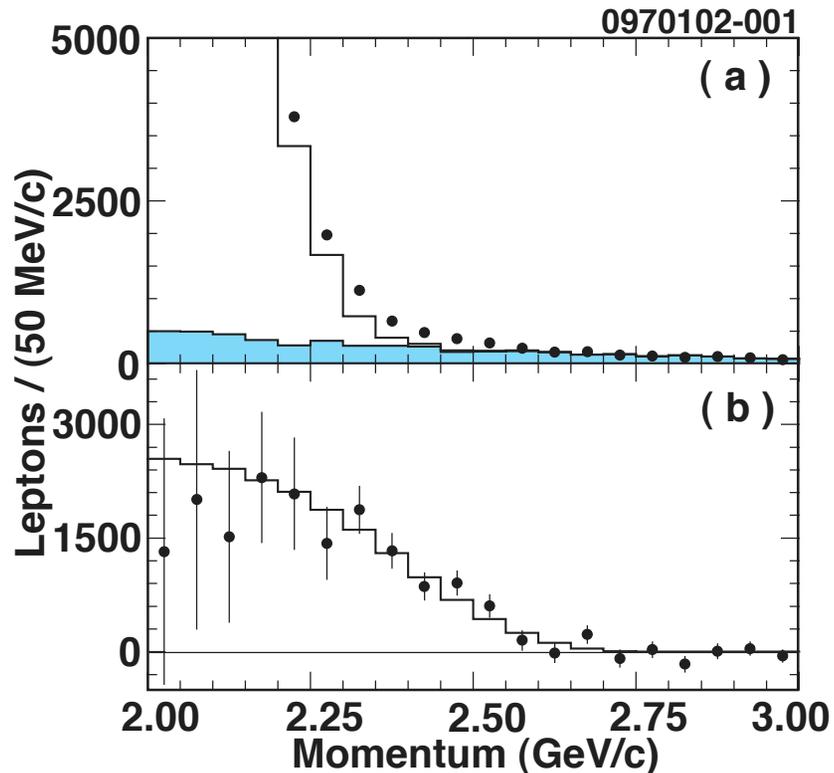
$D^* X \ell \nu$ component:

- CLEO fits
- LEP uses model based on external BR's

Ellipses indicate $\Delta\chi^2 = 1$ (stat. + syst.)

Can relate to $b \rightarrow s\gamma$ spectrum:

- $b \rightarrow s\gamma$ and $b \rightarrow ul\nu$ near lepton endpoint are smeared by a **common non-perturbative structure function**

Inclusive Leptons**Analysis:**

- $2.2 < p_l < 2.6$ GeV/ c
- Neural net continuum suppression
- Continuum-subtract remainder

Systematics:

- Fraction of spectrum above 2.2 GeV/ c
- Monte-Carlo of $b \rightarrow cl\nu$ bkg.
vary D^* FF's, D^{**} , non-res't

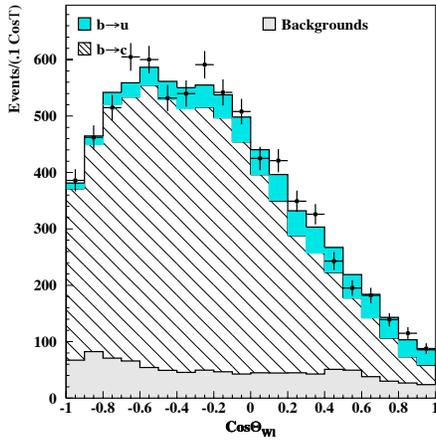
Relate partial branching fraction to full mom. spectrum:

From $b \rightarrow s\gamma$: $f_u = 0.138 \pm 0.034$

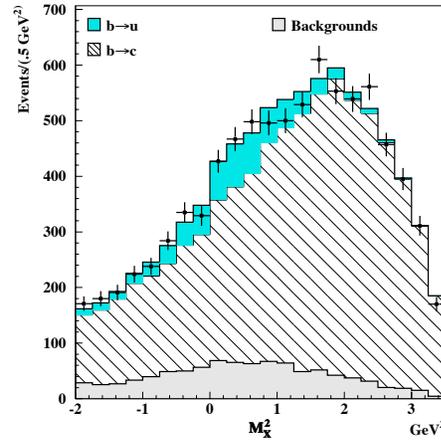
$|V_{ub}| = (4.09 \pm 0.14 \pm 0.66) \times 10^{-3}$

Fit full kinematic region, using:

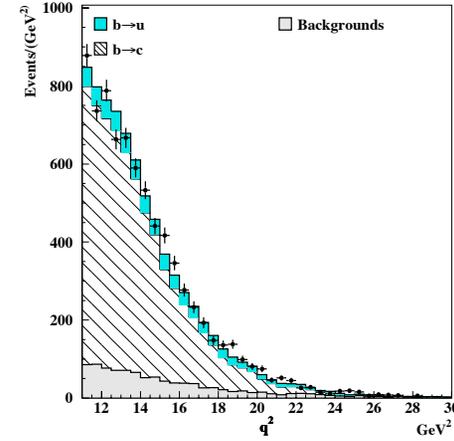
- Hadronic recoil mass (via neutrino reconstruction)
 - q^2 of $l\nu$ and decay angle of W
- (last two are equivalent to 2-D Dalitz plot for fixed recoil)



$\cos(\theta_{Wl})$



M_X^2
(with $q^2 > 11 \text{ GeV}^2$)



q^2
(with $M_X^2 < 2.25 \text{ GeV}^2$)

$$|V_{ub}| = (4.05 \pm 0.18 \pm 0.58 \pm 0.25 \pm 0.21 \pm 0.56) \times 10^{-3}$$

(errors: stat, exp. syst., $B \rightarrow X_c l \nu$ model, $B \rightarrow X_u l \nu$ model, theory)

$$\mathcal{B}(B^0 \rightarrow \pi^- \ell^+ \nu) = (1.376 \pm 0.180 \pm 0.021) \times 10^{-4}$$

$\begin{matrix} +0.116 \\ -0.135 \end{matrix} \pm 0.008 \pm 0.102 \pm$

- Neutrino reconstruction: $\sigma_{P_{miss}} \sim 110 \text{ MeV}$
 - Updating to full CLEOII dataset
 - Study in 3 q^2 bins
- modes already established (by CLEO, 1996)

From pion mode alone: $|V_{ub}| = (3.25 \pm 0.21 \pm 0.12 \pm 0.07) \times 10^{-3}$

$\begin{matrix} +0.16 \\ -0.18 \end{matrix} \begin{matrix} +0.64 \\ -0.56 \end{matrix}$

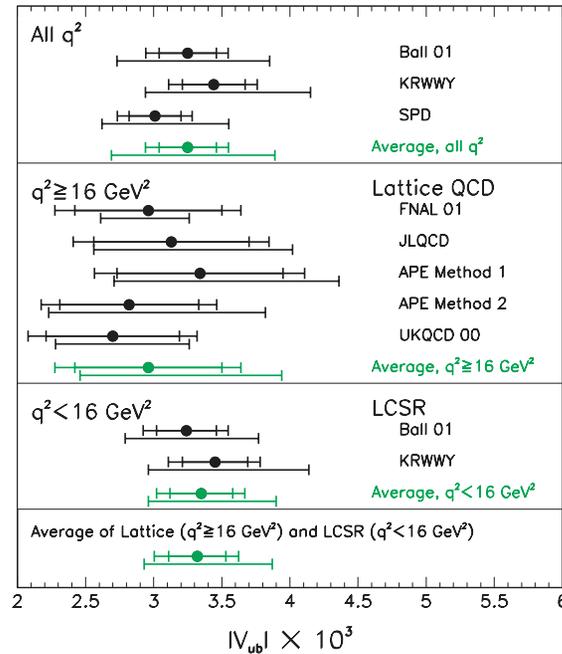
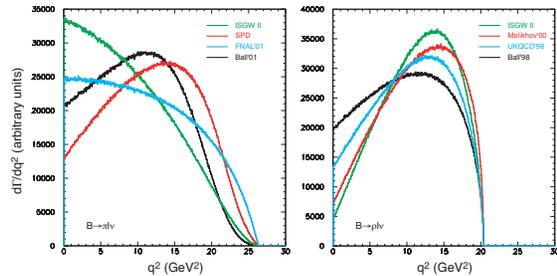
Errors: stat, syst-exp; syst-(π/ρ /other) model

Also prelim results for $\rho \ell \nu$

*** unfinished ***

- Lattice starting to weigh in with form-factors
- Previously relied on model variations

Dependence of efficiency on form-factors very small due to q^2 binning

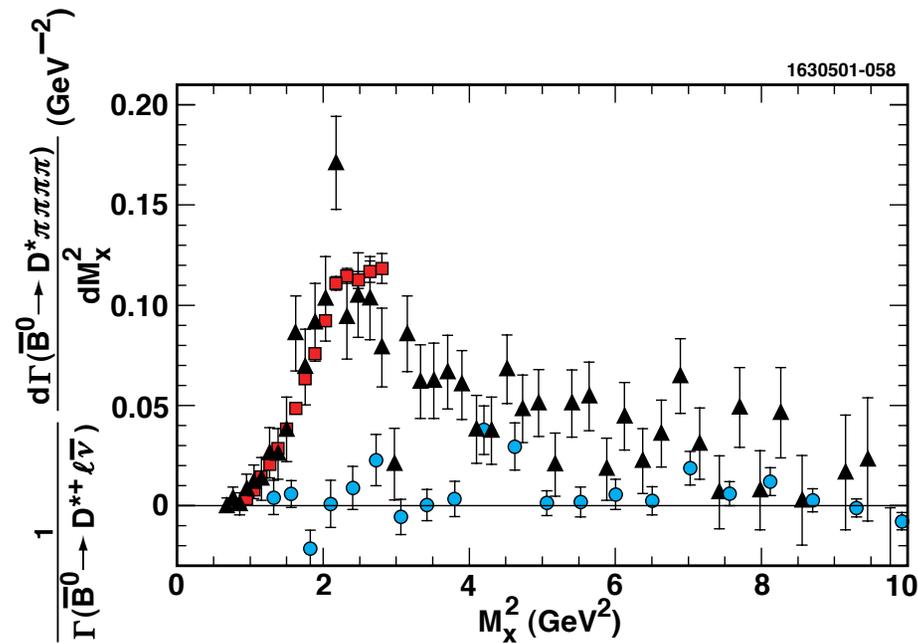


First observation of $B \rightarrow D^*(4\pi)^-$

about 1/6 of $(4\pi)^-$ is $\omega\pi^-$

- $\omega\pi^-$ consistent with $\rho(1450)$
- Clean measure of $\rho(1450)$ parameters

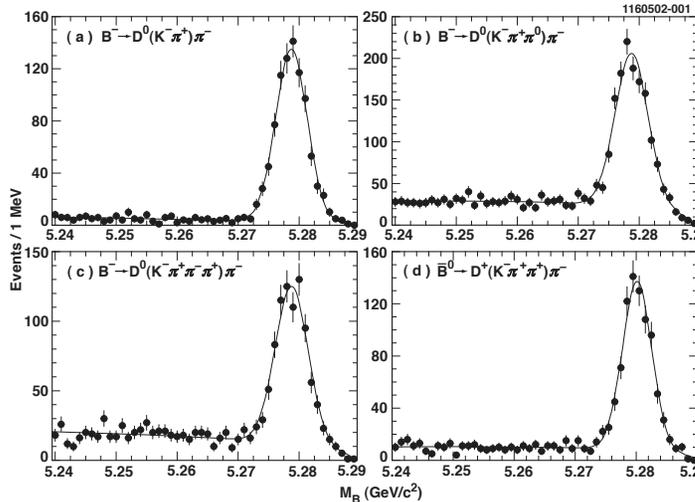
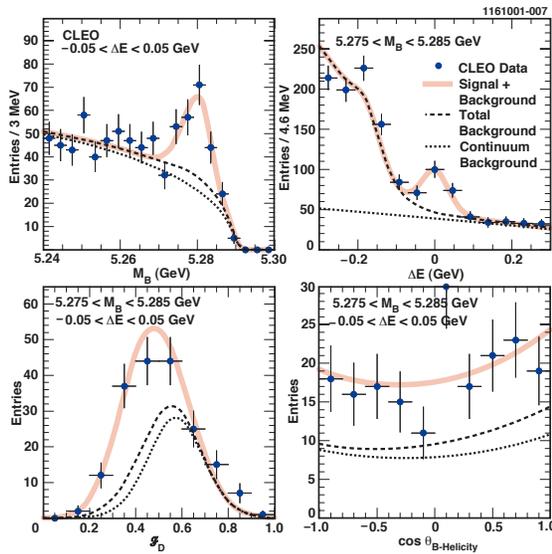
Nice factorization test: compare to $\tau \rightarrow (4\pi)^-\nu$



squares: τ

triangles B

circles: possible B background mode



$B \rightarrow D^0 \pi^0$
(color-supressed)

$B \rightarrow D^0 \pi^-, D^+ \pi^-$
(color-allowed)

Final-state phase (incl. Belle $D^0 \pi^0$ result)

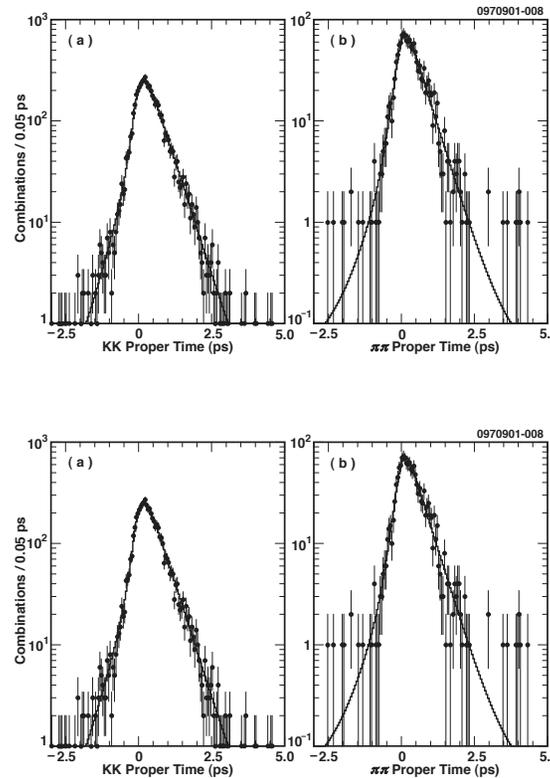
$(\cos \delta_I = 0.863^{+0.024}_{-0.023} \quad +0.036^{+0.038}_{-0.035} \quad +0.038^{+0.030}_{-0.030})$

or, $16.5^\circ < \delta_I < 38.1^\circ$ (90% CL)

Suggest persence of FSI phases in B decays

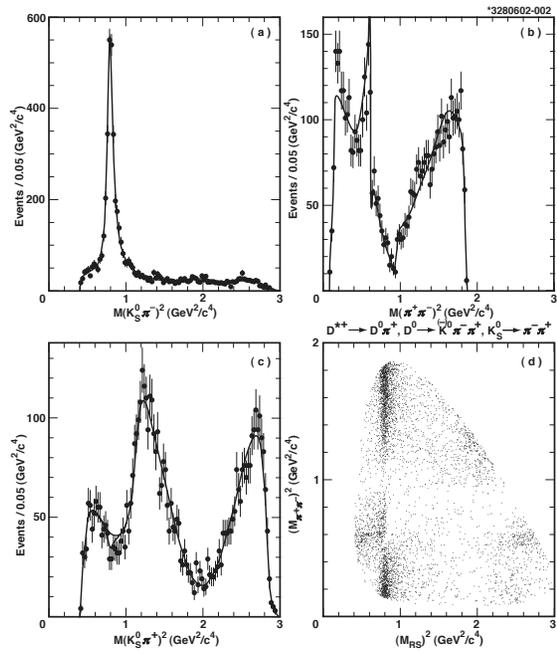
- Necessary in addition to weak phase for direct CP violation (previous hints in $J\Psi K^*$ (CDF))

$D^0 \rightarrow K^+K^-, \pi^+\pi^-$ *CP*-eigenstate lifetimes

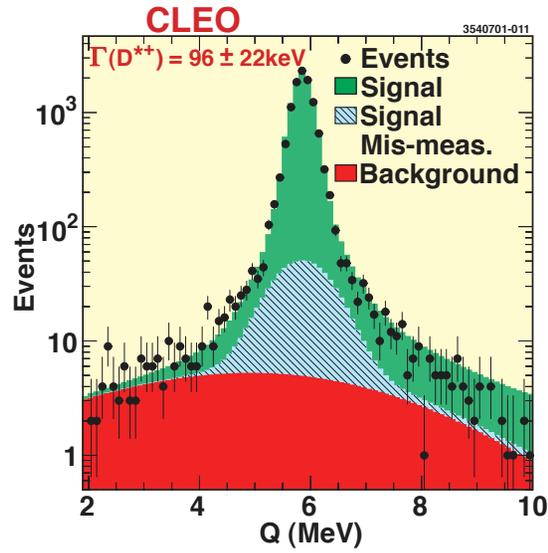


Compare to *CP*-averaged $D^0 \rightarrow K^-\pi^+$

- Bonds on $D^0 - \bar{D}^0$ mixing parameter y
- *** numbers ***
- *** get a nice D mixing summary plot??? ***



*** DCSD, mixing... ***
 *** x w/o phase ...



Well-understood CLEOII tracking

$$\Gamma(D^{*+}) = 96 \pm 4 \pm 22 \text{ keV}$$

$$\delta m = m_{D^{*+}} - m_{D^0} = 145.412 \pm 0.002 \pm 0.012 \text{ MeV}/c^2$$

Recent Published or Submitted Papers; Statistics and 2002

While commissioning CLEOIII, planing CLEO-c, and adjusting to a smaller collaboration we published or submitted:

86 papers since 01 Jan 2000 (30/32/24 by year)

45 PRL, 40 PRD, 1 PLB

43 B physics; 23 charm; 11 τ ; 2 $2\text{-}\gamma$; 2 Υ ; 4 misc.

2002:

Measurement of $B \rightarrow \Lambda_c X$??

Dalitz Analysis of $D^0 \rightarrow K_S^0 \pi^+ \pi^-$

Observation of $B \rightarrow K_S^0 \pi^+ \pi^-$ and $B^- \rightarrow K^{*+} \pi^-$

Measurement of $\mathcal{B}(B^- \rightarrow D^0 \pi^-)$ and $\mathcal{B}(B^0 \rightarrow D^+ \pi^-)$ and Isospin Analysis of $B^- \rightarrow D \pi$ Decays

Correlated Inclusive Lambda Lambda Production in e^+e^- Annihilations at $\sqrt{s} \sim 10.5$ GeV

Measurements of Inclusive $B \rightarrow \psi$ Production

Observation of the Decay $\Omega_c^0 \rightarrow \Omega^- e^+ \nu_e$

Search for Lepton-Flavor-Violating Decays of B Mesons

Anti-Search for the Glueball Candidate $f_J(2220)$ in Two-Photon Interactions

Measurement of $D^+ \rightarrow K^{*0} \ell^+ \nu_\ell$ Branching Fraction

Measurement of the Ratio of Branching Fractions of the $\Upsilon(4S)$ to Charged and Neutral B Mesons

Recent Published or Submitted Papers: 2001

Improved Measurement of $|V_{cb}|$ using $\bar{B} \rightarrow D^* \ell \nu$ Decays

Observation of Exclusive $B \rightarrow D^{(*)} K^{*-}$ Decays

Further Experimental Studies of Two-Body Radiative Upsilon Decays

Improved Measurement of $|V_{ub}|$ with Inclusive Semileptonic B Decays

Search for CP Violation in $\tau \rightarrow K \pi \nu_\tau$ Decays

Lifetime Differences, Direct CP Violation and Partial Widths in D^0 Meson Decays to $K^+ K^-$ and $\pi^+ \pi^-$

Measurement of the Xi_c^+ Lifetime

Measurement of the Masses and Widths of the Σ_c^{++} and Σ_c^0 Charmed Baryons

Observation of $B^0 \rightarrow D^0 \pi^0$ and $B^0 \rightarrow D^{*0} \pi^0$

Hadronic Mass Moments in Inclusive Semileptonic B Meson Decays

Branching Fraction and Photon Energy Spectrum for $b \rightarrow s \gamma$

Evidence for the Decay $D^0 \rightarrow K^+ \pi^- \pi^+ \pi^-$

Search for the Decay $\Upsilon(1S) \rightarrow \gamma \eta'$

First Measurement of $\Gamma(D^{*+})$ and Precision Measurement of $m_{D^{*+}} - m_{D^0}$

First Measurement of $\Gamma(D^{*+})$

Improved Upper Limits on the FCNC Decays $B \rightarrow K \ell^+ \ell^-$ and $B \rightarrow K^*(892) \ell^+ \ell^-$

Search for the Famiion via $B^{+-} \rightarrow \pi^{+-} X_0$, $B^{+-} \rightarrow K^{+-} X_0$, and $B^0 \rightarrow K_S^0 X_0$ Decays

First Observation of $B^0 \rightarrow D^{*0} \pi^+ \pi^+ \pi^- \pi^-$ Decays

Experimental Investigation of the Two-Photon Widths of the χ_{c0} and the χ_{c2} Mesons

Rate Measurement of $D^0 \rightarrow K^+ \pi^- \pi^0$ and Constraints on $D^0 \bar{D}^0$ Mixing

Search for CP Violation in $\tau \rightarrow \pi \pi^0 \nu_\tau$ Decay

First Observation of $B \rightarrow D^{(*)} \rho'^-$, $\rho'^- \rightarrow \omega \pi^-$

Search for the Decay $B^+ \rightarrow D^* + K^0 S$

Observation of $B \rightarrow \phi K$ and $B \rightarrow \phi K^*$

Search for $B^0 \rightarrow \pi^0 \pi^0$ Decay

Bounds on the CP Asymmetry in Like-Sign Dileptons from Bounds on the CP Asymmetry

in Like-Sign Dileptons from $B^0 \bar{B}^0$ Meson Decays

SUMMARY OF RESULTS:

New CLEOIII Results:

Rare B Decays

$b\bar{b}$ Spectroscopy; New $1D$ states!

Charm Baryons continuing

More analyses to come exploiting particle ID with RICH detector

CLEOII CKM Physics:

Exclusive V_{ub} and V_{cb}

Inclusive V_{ub} and V_{cb}

help from moment analyses

Still leading the field in precision B physics

Very Broad Range of other Physics:

Factorization and FSI phase studies with B decays

D Dalitz plots and D^0 Mixing-related analyses

Skipped all tau and two-photon physics!

Plenty more physics to come with the pre-CLEO-c data!

More info at: <http://w4.ins.cornell.edu/public/CLEO/>