CLEO V_{ub} and V_{cb} Results and Plans for CLEO-c

Roy A. Briere

Carnegie Mellon University
(for the CLEO Collaboration)

11 Mar 2003

Les Rencontres de Physique de la Vallee d'Aoste

Outline

CLEOII/II.V CKM Results:

- Exclusive V_{cb}: $B \to D^* \ell \nu$
- Spectral moments to extract non-pert. parameters
- Improved inclusive V_{cb}
- Improved inclusive V_{ub} from lepton endpoint
- Exclusive V_{ub}: $B \to \pi \ell \nu, \rho \ell \nu$ NEW!
- Future of V_{cb} and V_{ub}

Other Recent Results:

- FSI and factorization in $D^* \rho$, $D\pi$, $D^* 4\pi$
- FINAL $\pi\pi, K\pi$, etc. Rare B Decay Results
- CLEOIII Upsilon Physics: including discovery of $\Upsilon(1D)$

The CLEO-c Project: Charm at Threshold

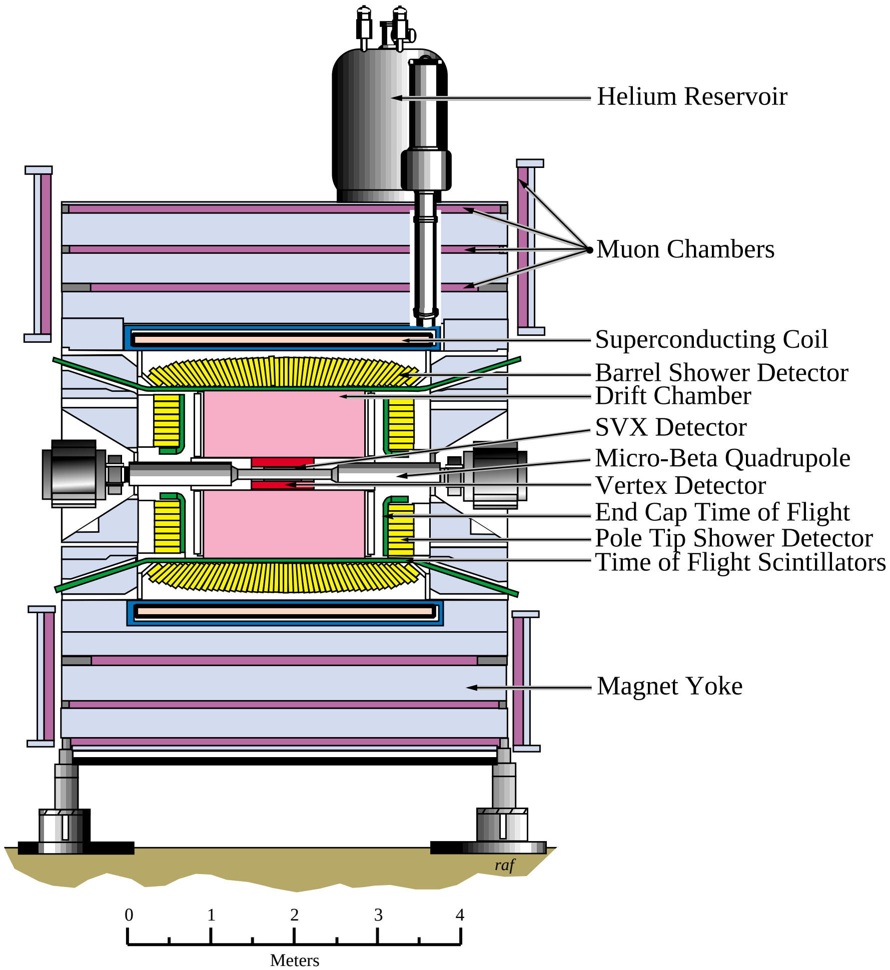
- Final approval last month!

Impacts B physics:

- Validate Lattice QCD for f_B, etc.
- Absolute Charm branching fractions

PLUS ... QCD physics: J/ψ 'Glue factory', LOW background D Dalitz plots

CLEO II/II.V Detector and Datasets



CLEOII distinguished by:

- Excellent CsI Calorimeter
- Very good solid angle coverage for tracks and neutrals

CLEOII.V distinguished by (in addition):

- First Silicon Vertex Detector at $\Upsilon(4S)$
- First major use of Helium-based drift gas

$\leftarrow$ this configuration is shown at left

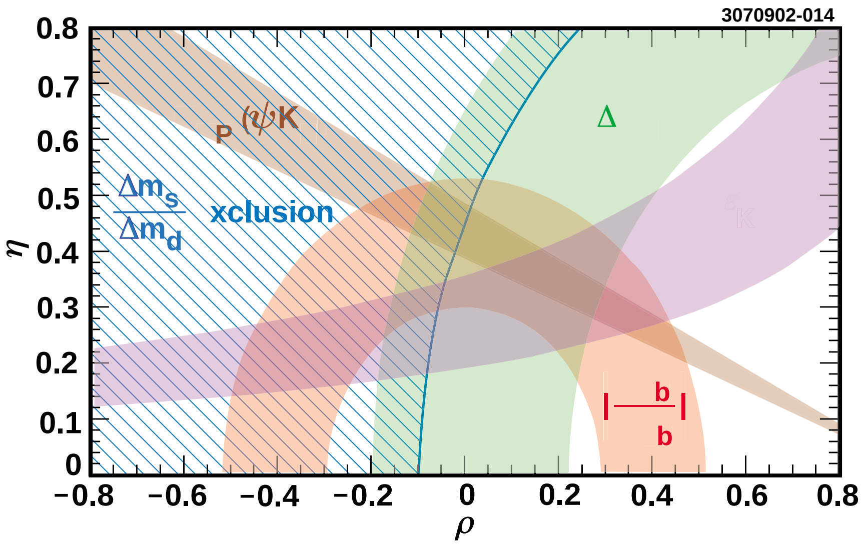
Both very well-understood detectors with high-quality Monte Carlo

Hadronic and leptonic moments of $B \to X_c \ell \nu$, and $B \to D^* \ell \nu$ use CLEOII:
$(3.2 + 1.6)$ fb^{-1} (on + off res.) containing 3.4 M $B\bar{B}$ pairs

$b \to s\gamma, b \to u \ell \nu$ endpoint and $B \to \pi \ell \nu, \rho \ell \nu$ use CLEOII+II.V:
$(9.2 + 4.5)$ fb^{-1} (on + off res.) containing 9.7 M $B\bar{B}$ pairs

The Unitarity Triangle

∼Current $\rho - \eta$ Plane



- $\sin 2\beta$ well-measured (BaBar/Belle)
  $\rightarrow$ theoretically clean!

- $|V_{ub}/V_{cb}|$ side: needs more precision
  CLEO: pioneering techniques

- V_{td} side (B-mixing):
  needs work to interpret precisely

$\longrightarrow$ **Lattice + CLEO-c**

The goal is NOT: Measure ρ, η
The goal IS: Measure ρ, η in many ways;
check for (in)consistency!

CLEO is helping with BOTH of the sides

.

“I named them rho and eta, and I don’t care what their values are, so why should you?”
– Lincoln Wolfenstein, at Kaon’99 in Chicago

CKM Matrix and Semileptonic B Decay Status

Improved Theory to interpret:

- Inclusives: Spectral moments (bit fancier for V_{ub})
- Exculsives: Lattice QCD (plus light-cone sum rules)

Non-pert. physics in a few matrix elements:

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

extract from data on 'spectral moments'

E_γ in $b \to s\gamma$ $\quad$ E_ℓ, M_X^2 in $B \to X\ell\nu$

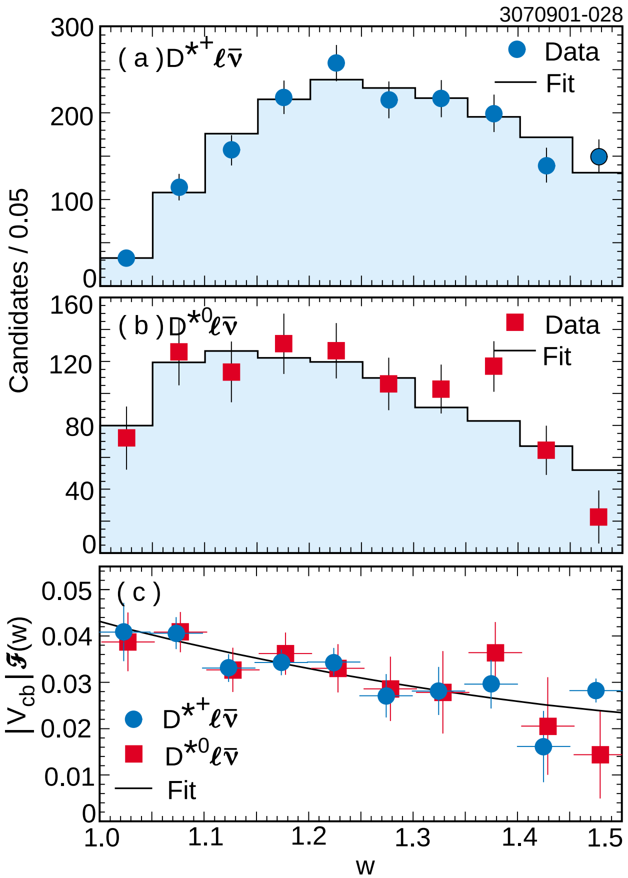
(relies on Quark-Hadron duality!)

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

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

Large Continuum Data fraction is valuable!

- $b \to s\gamma$ and lepton endpoint: both at kin. limit of B decay
- Continuum *not* at kin limit $\to$ large backgrounds
  - Suppress continuum: hard work and experience
  - Subtract continuum: data!



q^2_{max} $\longleftarrow q^2$

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

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

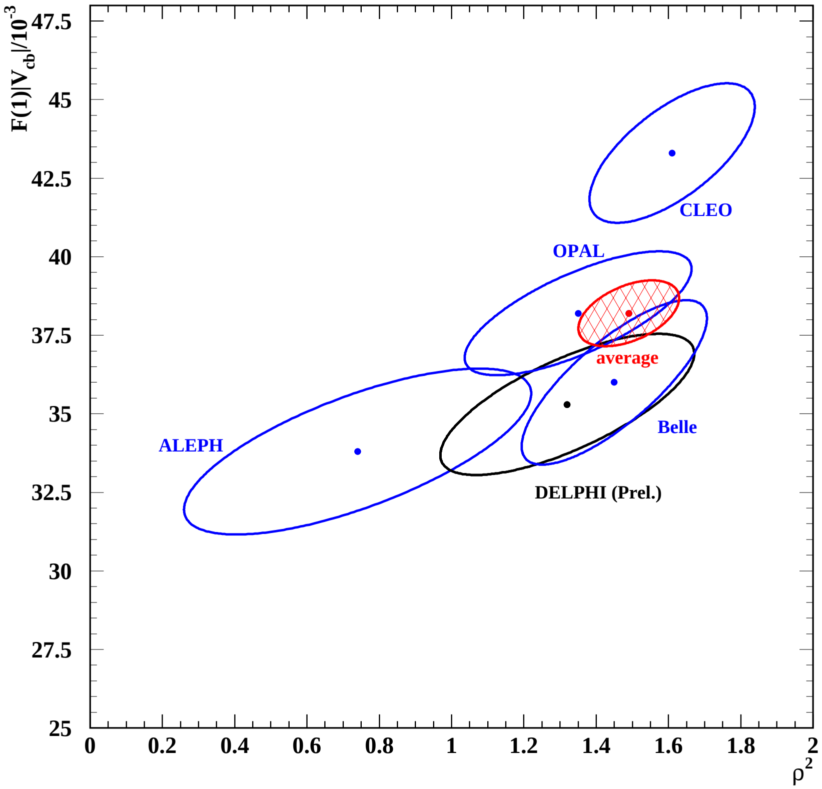
Intercept at q^2_{max} and slope:
(curvature related to slope by theory)
$F(1)|V_{cb}| = (4.31 \pm 0.13 \pm 0.18) \times 10^{-2}$
$\rho^2 = 1.61 \pm 0.09 \pm 0.21$
$f_{+-} = 0.521 \pm 0.012$ $(B^+B^-$ vs. $B^0\bar{B}^0)$

Systematics:
- Efficiency (esp. slow pion tracking)
- Charm branching fractions
- Backgrounds
- Form Factors (mostly for ρ^2)

$|V_{cb}| = (4.69 \pm 0.14 \pm \pm 0.20 \pm 0.18) \times 10^{-2}$
(uncertainties: stat, syst, theory) **7% total**

NOTE: we used $F(1) = 0.919^{+0.030}_{-0.035}$
(Fermilab Lattice; PRD 66, 014503 (2002), + QED corr.)

$|V_{cb}|\mathcal{F}(1)$ vs. ρ^2 (form-factor slope)



ρ^2 and $\mathcal{F}(1)|V_{cb}|$ correlated

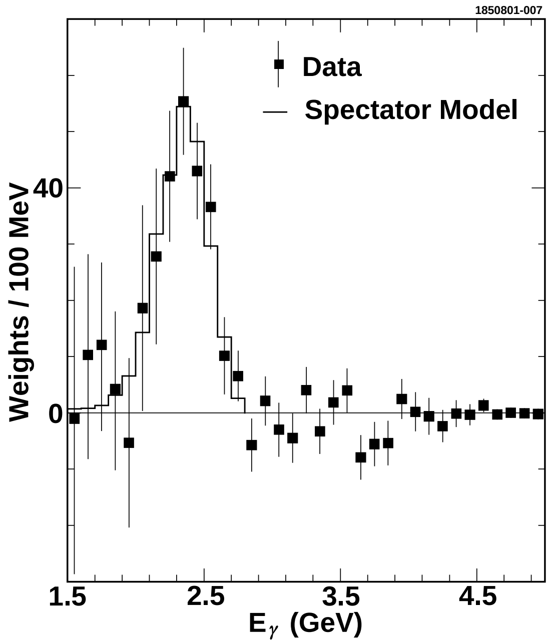
$D^* X \ell \nu$ component:
- CLEO fits in same analysis
- LEP uses model (based on external BR's)
- CLEO excludes more with better MM resol.

Slow Pion Efficiency:
- LEP:flat efficiency
- CLEO: eff. turn-on for slow π^+
- Only CLEO includes D^{*0} (has flat eff.)

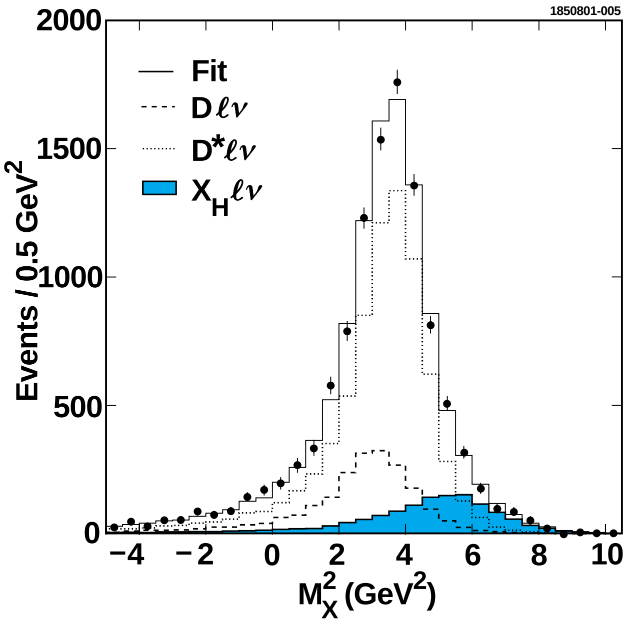
Consistent at 5% level

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

E_γ from $b \to s\gamma$
(Continuum suppr. and subt. crucial)



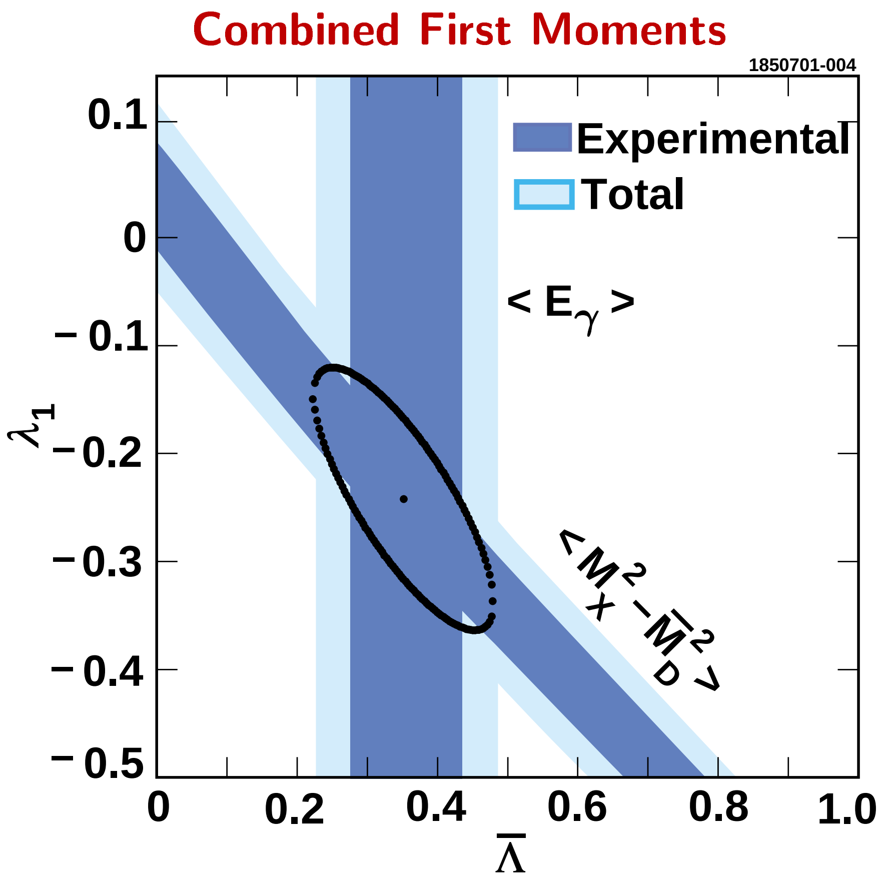
M_X^2 from $B \to X\ell\nu$
(uses ν recon.; $M_X > M_{D^*}$ crucial)



First and Second moments (means and widths):

$$
\begin{aligned}
< E_\gamma > &= 2.346 \pm 0.032 \pm 0.011 \;\; \mathrm{GeV} \\
< E_\gamma^2 > - < E_\gamma >^2 &= 0.0226 \pm 0.0066 \pm 0.0020 \;\; \mathrm{GeV}^2 \\
< M_X^2 - \bar{M}_D^2 > &= 0.251 \pm 0.023 \pm 0.062 \;\; \mathrm{GeV}^2/c^4 \\
< (M_X^2 - \bar{M}_D^2)^2 > &= 0.639 \pm 0.056 \pm 0.178 \;\; \mathrm{GeV}^4/c^8
\end{aligned}
$$

These have a **calculable** dependence on $\bar{\Lambda}, \lambda_1 \ldots$



Moments depend on $\bar{\Lambda}, \lambda_1$
Each measurement yields a band.
(λ_2 already known)

(only first moments used:
most precise constraints;
second moments consistent)

Hadronic moment: for $p_\ell > 1.5$ GeV/c

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

$\bar{\Lambda} = 0.35 \pm 0.07 \pm 0.10$ **GeV**
$\lambda_1 = -0.236 \pm 0.071 \pm 0.078$ **GeV^2**

Extracting $|V_{cb}|$ from Inclusive Semileptonic Rate

HQET parameters in hand
- CLEO's moments (and $m_{B^*} - m_B$) directly measure lowest-order
- Smaller $\mathcal{O}(1/M_B^3)$ terms estimated; included in syst. uncertainties

Inclusive semileptonic rate:
- CLEO 1996 tagged dilepton method (-1% for $B \to X_u \ell\nu$)

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

Convert to Γ_{sl} with τ_B

HQET expansion is of form:

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

(already used similar expressions for moments to **extract** $\bar\Lambda, \lambda_1$)

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

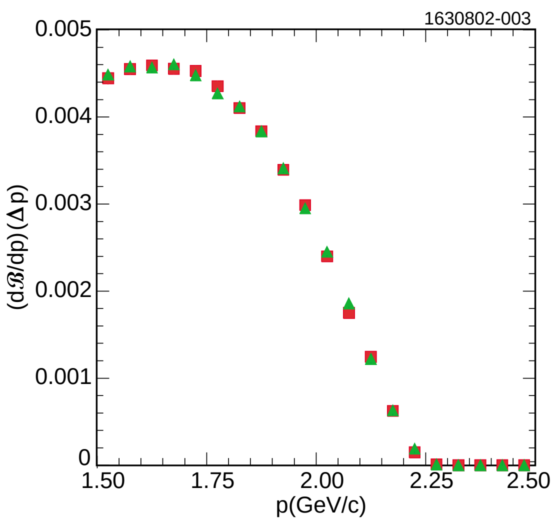
Uncertainties are from (in order):
- CLEO measurement of Γ_{sl}
- HQET parameters $\bar\Lambda, \lambda_1$
- Scale for α_s; coeff's of $1/M_B^3$ terms

3.2% determination (BUT, global quark-hadron duality?)

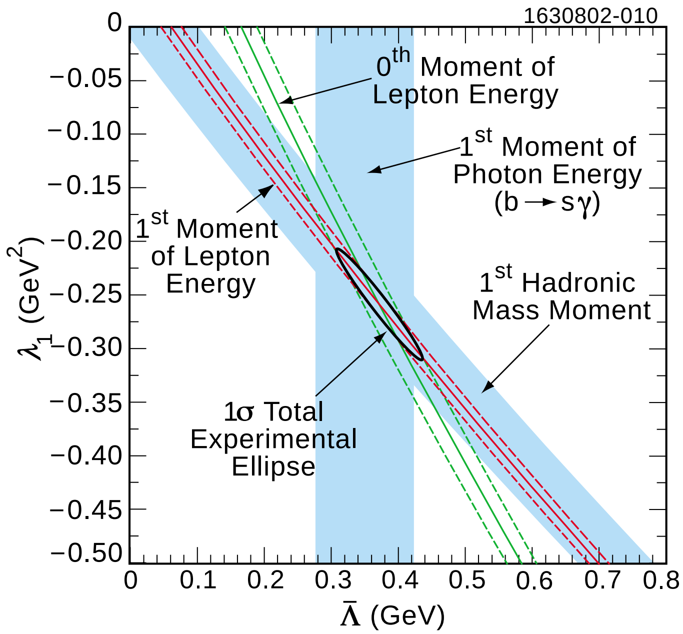
Inclusive Leptons from $B \to X\ell\nu$

Lepton Momentum

e, μ overlay



New combined exp. ellipse



$$\mathrm{R}_0 = \frac{\int_{1.7} (d\Gamma_{sl}/dE_l)dE_l}{\int_{1.5} (d\Gamma_{sl}/dE_l)dE_l}$$

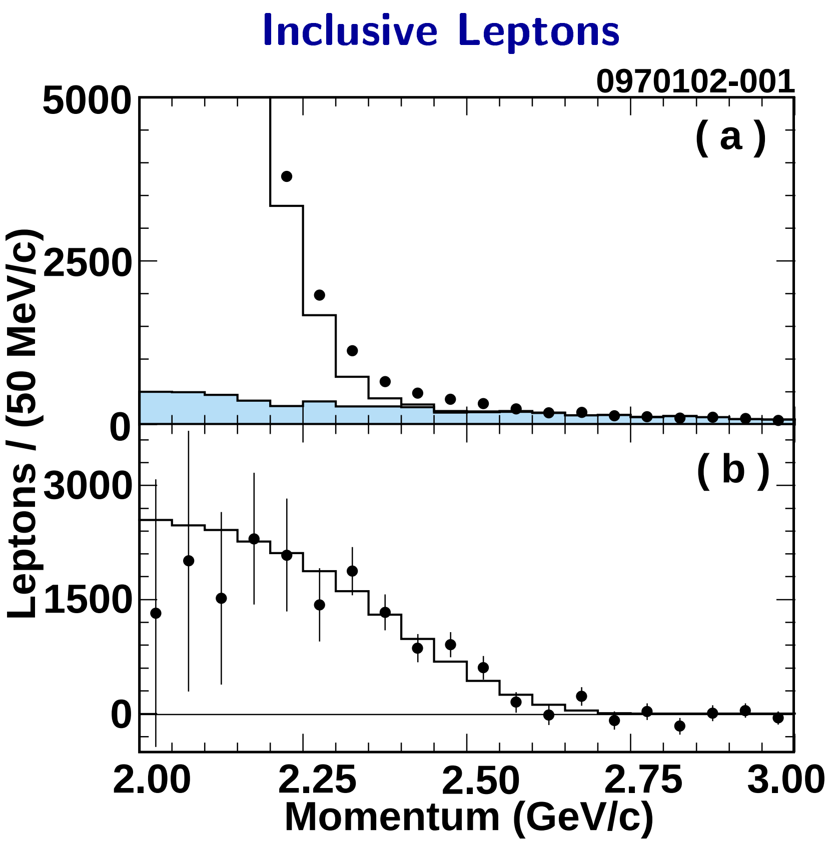
$$\mathrm{R}_1 = \frac{\int_{1.5} E_l(d\Gamma_{sl}/dE_l)dE_l}{\int_{1.5} (d\Gamma_{sl}/dE_l)dE_l}$$

$$R_0 = (0.6187 \pm 0.0014 \pm 0.0016)$$
$$R_1 = (1.7810 \pm 0.0007 \pm 0.0009) \text{ GeV}$$

$$\bar{\Lambda} = (0.39 \pm 0.03 \pm 0.06 \pm 0.12) \text{ GeV}$$
$$\lambda_1 = (-0.25 \pm 0.02 \pm 0.05 \pm 0.14) \text{ GeV}^2$$

Precise, consistent result (world Γ_{sl})

$$|V_{cb}| = (4.08 \pm 0.05 \pm 0.04 \pm 0.09) \times 10^{-2}$$



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

- $b \to s\gamma$ and $b \to u\ell\nu$ near endpoint smeared by **common** non-pert. structure function

Analysis:

- $2.2 < p_\ell < 2.6$ GeV/c
- Neural net continuum suppression
- Continuum-subtract remainder

Systematics:

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

Relate partial branching fraction to full mom. spectrum:

From $b \to s\gamma$, fraction $(2.2, 2.6)$ GeV/c: $f_u = 0.130 \pm 0.024 \pm 0.015$

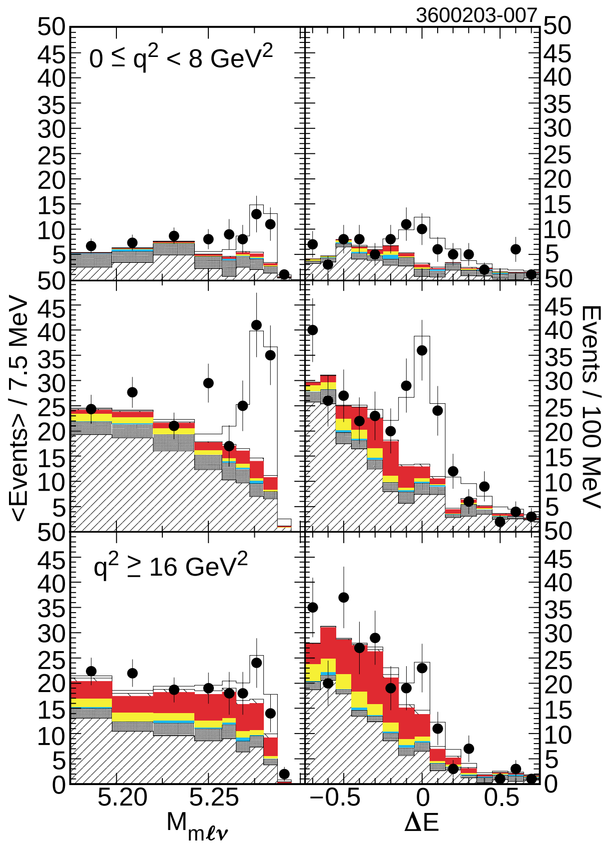
$$|V_{ub}| = (4.08 \pm 0.34 \pm 0.44 \pm 0.16 \pm 0.24) \times 10^{-3}$$

Errors: exp't (partial BR), exp't (frac. seen), theory ($\Gamma_{sl} \to V_{ub}$), theory (using $b \to s\gamma$)

First look at Final Results!

Combined $\pi\ell\nu$ Modes

in 3 q^2 bins



To be be submitted to PRD shortly.

- **Neutrino reconstruction: $\sigma_{P_{miss}} \sim 110$ MeV**
- Updated to full CLEOII dataset

- Modes already established (by CLEO, 1996)

$\longrightarrow$ Study in 3 q^2 bins

Significant reduction in model errors

- Lattice QCD for $q^2 \ge 16$ GeV^2
- Light-cone sum rules for rest

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.33 \pm 0.18 \pm 0.11 \pm 0.01 \pm 0.07) \times 10^{-4}$$
$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) = (2.17 \pm 0.34 \pm 0.50 \pm 0.41 \pm 0.01) \times 10^{-4}$$

From combined $\pi\ell\nu, \rho\ell\nu$: $|V_{ub}| = (3.17 \pm 0.17 \,^{+0.16}_{-0.17} \,^{+0.53}_{-0.39} \pm 0.03) \times 10^{-3}$

(Uncertainties: stat; syst-exp; LQCD/LCSR theory; $\rho\ell\nu$ FF)

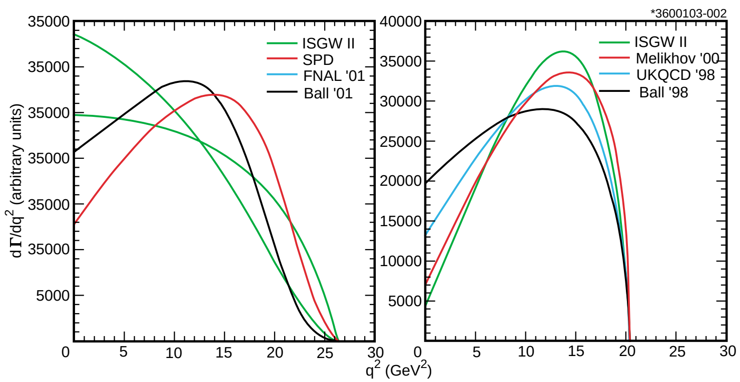
$B \to \pi \ell \nu, \rho \ell \nu$ — First look at Final Results!

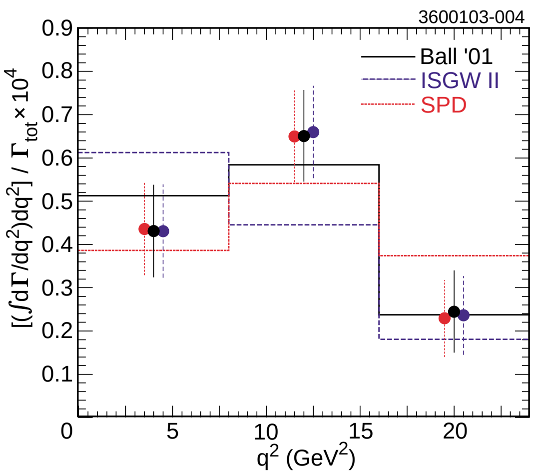
Previously relied on model variations...

- **Lattice starting to weigh in with form-factors**
- **Dependence of eff. on form-factors greatly reduced due to q^2 binning!**

Rate vs. q^2 predictions

$B \to \pi \ell \nu$ $\qquad$ $B \to \rho \ell \nu$

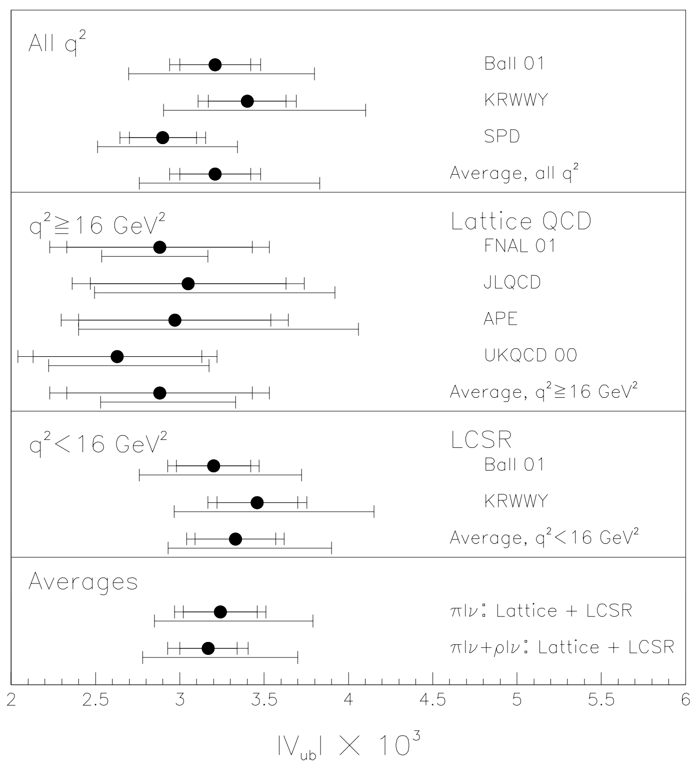




$\pi \ell \nu$: Partial BR's

Independent of model!

Extracted $|V_{ub}|$ $(\pi \ell \nu)$



Upper bars: exp. stat. + syst.

Lower bars: thy. syst. range

Future of V_{cb} and V_{ub}

Other related CLEO analyses in progress:

(Preliminary) CLEO CONF 02-08

Fit full kinematic region, using:

- Hadronic recoil mass (via neutrino reconstruction)
- q^2 of $\ell\nu$ and decay angle of W (span 'Dalitz plot' at any fixed recoil mass)

Consistent result for V_{ub}

Will also update hadronic moments

Final results soon...

Lepton Moments (alternate method)

- Use high-momentum e, μ to tag $B\bar{B}$ events

...Greatly suppresses $b \to c \to s\ell\nu$ secondaries

- Look for *another* e with $\boldsymbol{p_e > 600}$ **MeV/$\boldsymbol{c}$**

Expect results soon...

CLEO and LEP are joined by BaBar and Belle now

- Very large statistics; perhaps new methods!
- Can cross-check moments and duality ideas...

...and CLEO-c will help as we will see shortly!

Teaser of Other CLEO Results

Evidence for Final State Interaction Phases and Factorization Tests

- Evidence of FSI phases in $B \to D^* \rho$ Heliciy Ampl.
  CLEO 03-1; submitted to PRD
- Evidence of FSI phases in $B \to D\pi$ system
  PRL 88, 062001(2002); PRD 66, 031101 (2002)
- Nice factorization test with $B \to D^*(4\pi)^-$
  PRD64, 092001 (2001); PRD 65, 012002 (2002)

CLEOIII analyses already being published

- First Observation of the Exclusive Decays $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ and $\Lambda_c^+ \to \Lambda\omega\pi^+$
  PRD 67,012001 (2003)

Culmination of a long tradition of Rare B Analyses

- 10 $K\pi, \pi\pi$ modes; 3 di-baryon; plus $DK/D\pi$ ratio
  CLEO 03-3; submitted to PRD

Many other physics topics are still active at CLEO:

- Several nice D mixing and D Dalitz plot analyses
- Still producing new τ and 2-photon physics
- Discovered more charm baryons that all other exp'ts combined!

Resonance Data Sets (in pb^{-1})

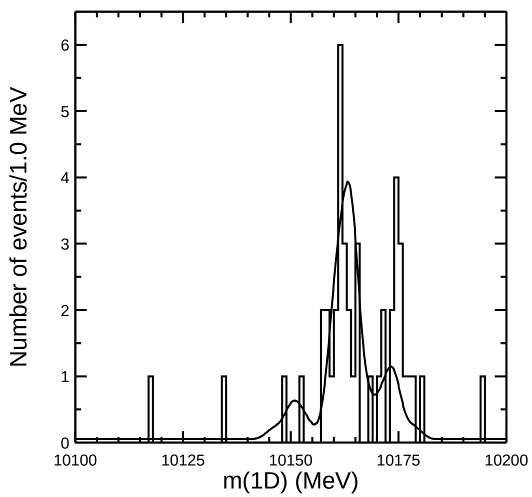
Resonance	Peak	Scan	Below	Total
$\Upsilon(1S)$	1200	110	190	1500
$\Upsilon(2S)$	1375	80	465	1900
$\Upsilon(3S)$	1450	100	160	1700
$\Upsilon(5S)$				460
Λ_B scan				710

10$\times$ best previous datasets (CLEO)

- Spectroscopy checks Lattice QCD
- Interesting transition matrix elements
- Compare gluon-rich Υ decays to $J\psi$

We've also done:

- R scan (7.0. 7.4, 8.4 GeV)
- Preliminary $\psi(2S)$ and $\psi(3770)$ runs



First Observation of Upsilon(1D) States **CLEO CONF 02-06; hep-ex/0207060**

Study of Two-Photon Transitions in CLEO III Upsilon(3S) Data
CLEO CONF 02-07; hep-ex/0207062

Search for $\eta_b(1S)$ in Inclusive Radiative Decays of the Upsilon(3S)
CLEO CONF 02-05; hep-ex/0207057

The CLEO-c Run Plan

Charm Physics at Threshold

- Approved February, 2003 by National Science Board
- New construction (maagnets) 1/2 done (headstart with R&D funds)
- Test running already begun

Needed to test Lattice QCD

- Current capability promises few % errors !!!
- B decay constants must come from LQCD...
- D decay constants can be **measured**, thus:

  Test LQCD results...confidence in B physics!

3 years of running.

- $\mathcal{L} =$ few $\times 10^{32}$ cm^{-2}s^{-1} for J/ψ, open charm
- ~ 150 mA per beam in 45 bunches
- Even better $\mathcal{L}$ as E increases (e.g., Λ_c)

CLEO-c Data Sets: 2003-2006

CofM Energy	Event Type	Int. Lumi. (fb^{-1})	Number of Events
3.77	$D\bar{D}$	3	30×10^6
4.14	$D_s^+ D_s^-$	3	$1 - 2 \times 10^6$
3.1	J/ψ	1	1000×10^6
4.6	$\Lambda_c/\bar{\Lambda}_c$	1	3.7×10^5

Full-reconstruction of one side (tagging) is the key

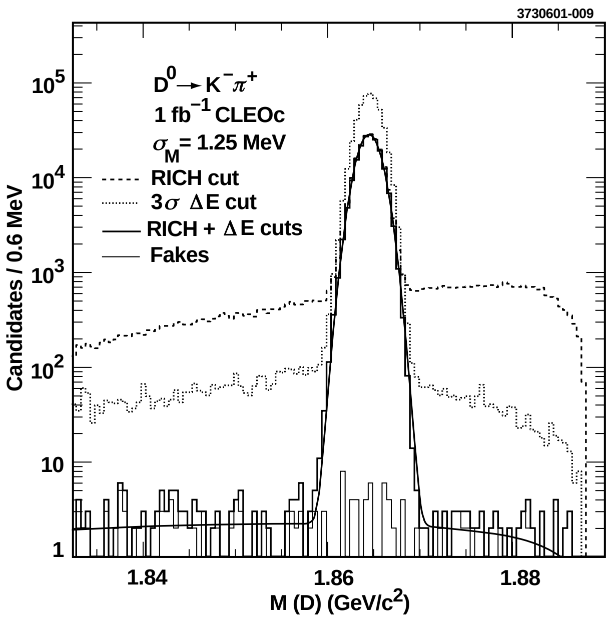
- Very low background
- $130 - 480\times$ BES, MARKIII samples!!!

Anticipated Tagged Samples

Meson	Single Tags	Double Tags
$D^0\bar{D}^0$	4.80×10^6	180×10^3
D^+D^-	1.90×10^6	70×10^3
$D_s^+D_s^-$	0.27×10^6	6×10^3

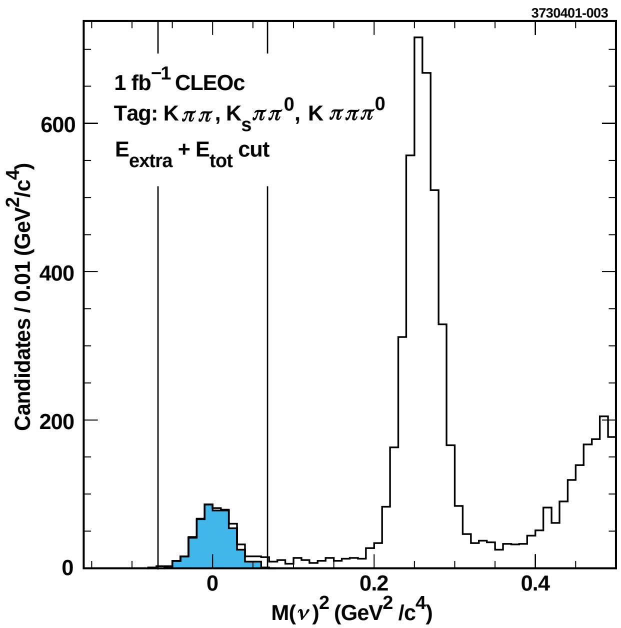
Clean Tagging (Log scale!)

(1/3 of anticipated data)



Decay Constants: $D \to \mu\nu$

(1/3 of anticipated data)



CLEO-c CKM Physics Reach

Decay Constants

- $D^+ \to \mu\nu, D_s \to \mu\nu, \tau\nu$
- $\sim 2\%$ precision!
- **Crucial tests of LQCD**

Absolute Branching Fractions

- $D^0 \to K^-\pi^+, D^+ \to K^-\pi^+\pi^+, D_s \to \phi\pi^+$
- Straightforward with large single and double tag samples
- **Will help reduce B physics errors...**
- $1-2\%$ accuracy
- also $\Lambda_c \to pK^-\pi^+$

Semileptonic Decays:

$D^0 \to K\ell\nu, \pi\ell\nu, D^+ \to \pi\ell\nu$ etc.

- Branching ratios to 2% !
- Precision Form Factors
  FF slopes to a few percent
- **check LQCD; extract $|V_{cs}|, |V_{cd}|$**

Also lots of spectroscopy with huge J/ψ sample!

- $J/\psi \to ggg, \gamma gg$

CLEOIII designed as a B-factory detector: excellent for charm also.

Ring-Imaging CHerenkov detector:

- LiF radiators (including some 'sawtooth' surfaces)
- TEA-based photo-detectors
- Engineering tour-de-force; solid performance
- Excellent particle ID at all momentum (with dE/dx)

New Drift Chamber:

- low material: (better for endcap calorimeter!)
  conical end-plates exploit membrane tension
  non-load-bearing inner wall
- Room for RICH at outer radius, SC quads at inner

Trigger/DAQ:

- Much improved over CLEOII
- Greater bandwidth and flexibility

Silicon will be replaced with all-stereo new wire chamber

CLEO-c: CESR Accelerator

CESR Machine Upgrades

- Already have all superconducting RF
- Already have new superconducting final-focus quads
  (Crucial: tunable field!)

Ring too large for low Energy $\longrightarrow$ **add wigglers to damp beams**:

- 14 1.4m superconducting wigglers (super-ferric 2.1 T)
- First wiggler already installed; excellent field quality
- Five more wigglers will go in this spring

Shared machine time: HEP (CLEO) vs. dedicated light source (CHESS)

Endorsed by HEPAP

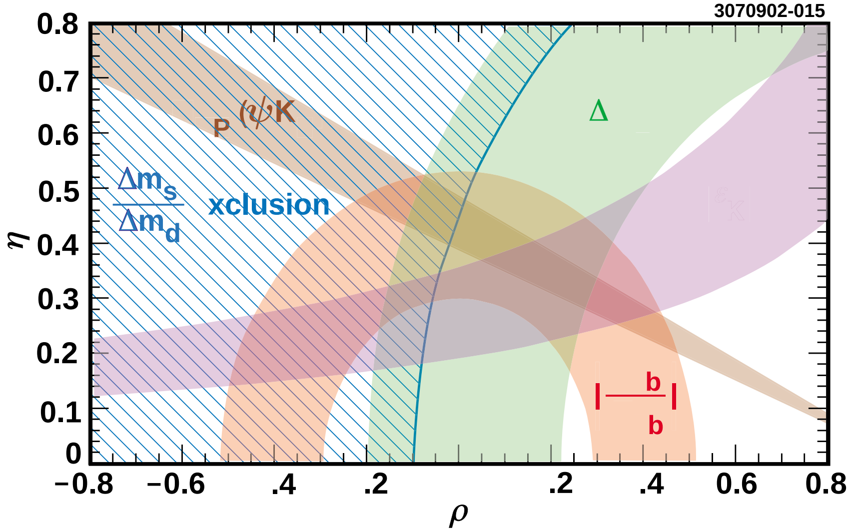
February 2003: Final approval from National Science Board

CLEO-c Physics data this summer!

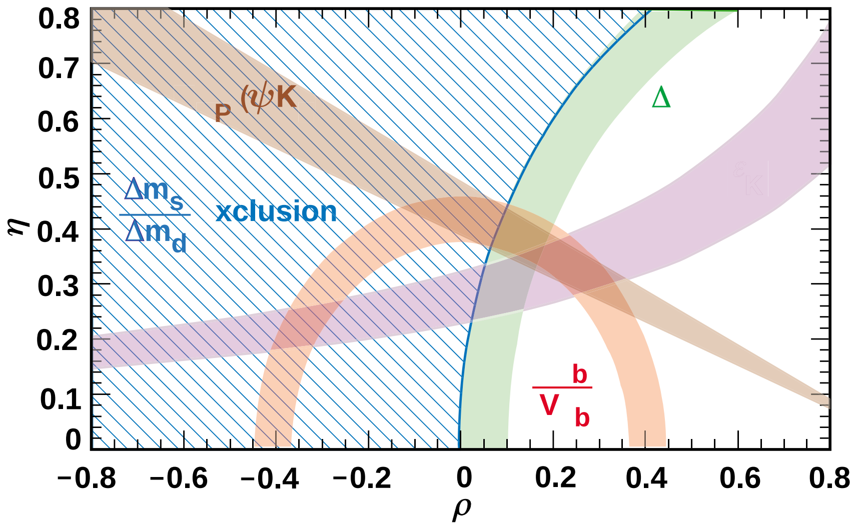
'Yellow Book' Project Description (CLNS 01/1742; revised 10/10) available at:
http://www.lns.cornell.edu/public/CLEO/spoke/CLEOc/

New collaborators welcome!

Improving $\rho - \eta$ with Theory



Current experimental knowledge



Current experiment with **better theory** (from **validated** LQCD)

CLEO-c will allow validation of Lattice calculations.

SUMMARY

CLEOII CKM Physics:

Exclusive $|V_{ub}|$ and $|V_{cb}|$

Inclusive $|V_{ub}|$ and $|V_{cb}|$

help from moment analyses

Still a leading force in precision B physics

CLEO-c will naturally extend this CKM physics!

New CLEOIII Results:

$b\bar{b}$ Spectroscopy; discovery of $\Upsilon(1D)$ states!

Rare B Decays

Very Broad Range of other Physics:

FSI phase studies with B decays

D Dalitz plots and D^0 Mixing-related analyses

Skipped all tau and two-photon physics!

Charm Baryons continuing...

CLEO-c benefits B physics and the Lattice Community

A bright future, along with our friends at other experiments!

http://www.lns.cornell.edu/public/CLEO/