Recent results from CLEO

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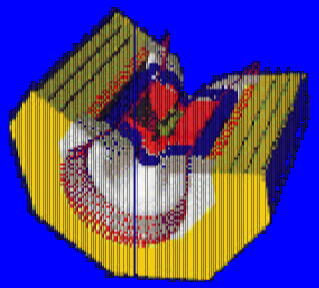


$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

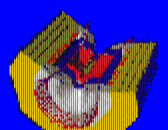
Rencontres de Moriond 2002

Contents

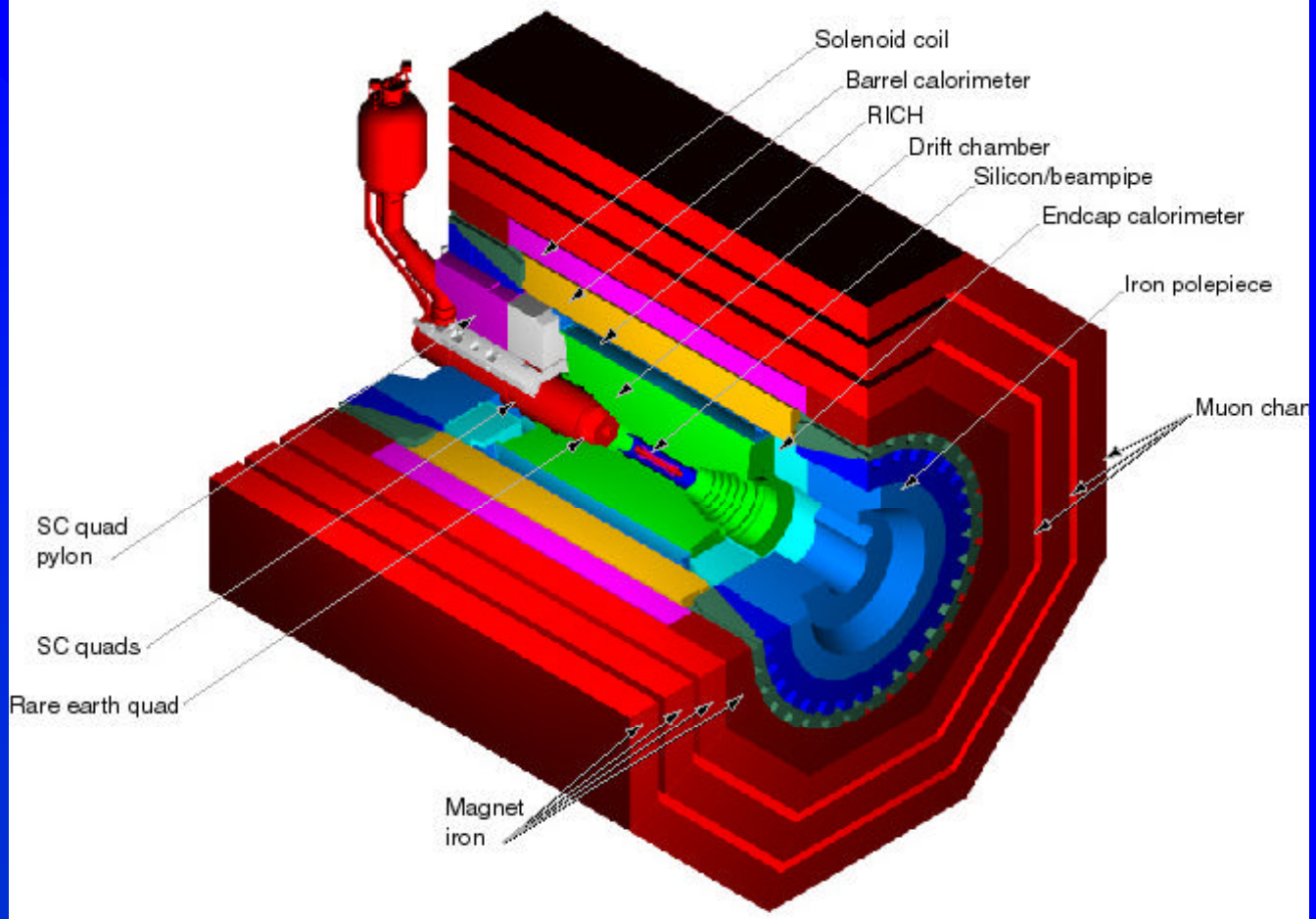
- CLEO introduction
- How to measure V_{cb}, V_{ub}
  - HQET 
  - Exclusive measurements
  - How b ® s g can help in …
  - … inclusive measurements
- Summary

CLEO Introduction

- Since 1979
- CESR: symmetric e^+e^-: 1.3 x $10^{33}/cm^{-2}s^{-1}$
- $\sqrt{s}$ = 10.58 GeV (BB threshold) at $\Upsilon(4S)$
  B meson created ~ at rest
- 10M BB pairs 1990-2000 (CLEO II/II.5)
  9 fb^{-1} on resonance, 4.4 fb^{-1} off resonance
- 7M BB pairs 2000-2001 (CLEO III)
  Some results already presented.



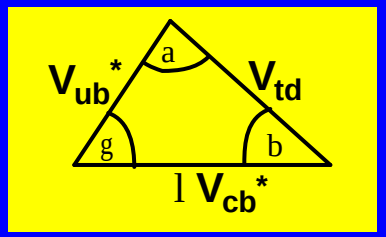
CLEO III


Solenoid coil
Barrel calorimeter
RICH
Drift chamber
Silicon/beampipe
Endcap calorimeter
Iron polepiece
Muon char
SC quad
pylon
SC quads
Rare earth quad
Magnet
iron

CKM matrix

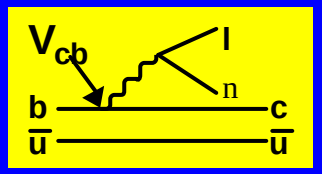
$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Standard Model
- CP violation with b quarks
  - ➡ Babar, Belle
- To improve knowledge:
  improve measurement errors, but errors from theory dominate many measurements
- Here: V_{cb}, V_{ub}
  PDG: error($|V_{cb}|$) = 5%
  error($|V_{ub}|$) = 30%
  (2000 status)



How to measure V_{cb}, V_{ub}

- "Simple": Semileptonic decays
  $b \to c l \nu$, $b \to u l \nu$
- Not so simple: need theory



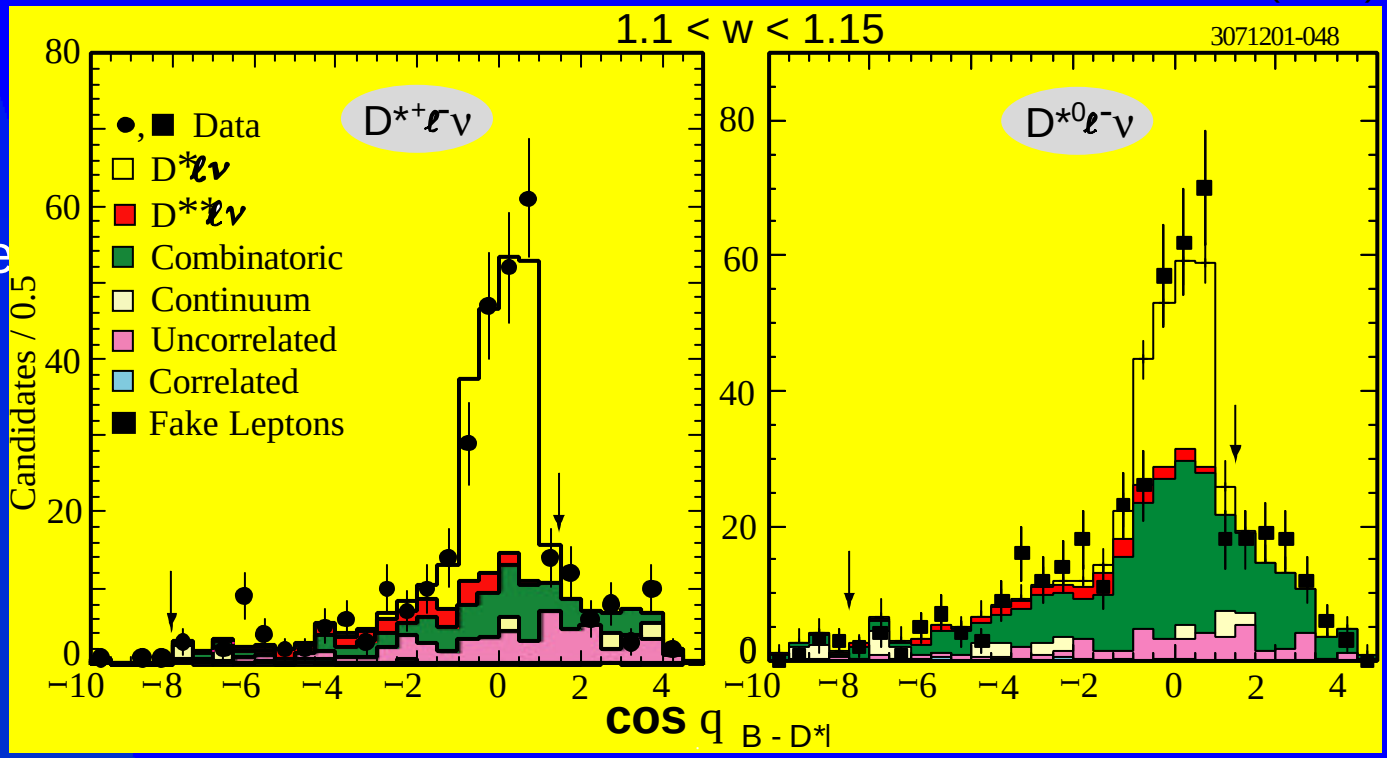
  - ★ HQET (e.g. Phys.Rev. D47 (1993) 2965)
    Calculate observables in $1/M_b$
  - Exclusive: Need form factors
    $B \to D^* l \nu : d\Gamma/dw \propto |V_{cb}|^2 F^2(w)$
    w = kinematic variable related to q^2
    $F^2(w = 1) = F^2(q^2 = q^2_{max})$ from HQET
    Use later
  - Inclusive:
    $B \to X l \nu : |V_{cb}|^2 = \Gamma(b \to c l \nu)\, h(\bar{\Lambda}, \lambda_1)$
    Use later
    - ★ $\bar{\Lambda}, \lambda_1$ HQET parameters (b quark in B meson)
    - ★ Assume quark-hadron duality
    - ★ $h(\bar{\Lambda}, \lambda_1)$ from HQET

V_{cb} Exclusive: $B \rightarrow D^* l \nu$

- Analysis: 3.3M BB events (CLEO II)
- Reconstruct $D^* \rightarrow D\pi$ (charged+neutral)
- Use mass constraints, vertex, divide into 10 w bins $1 < w < 1.5$

CLNS 01/1773 (2002)

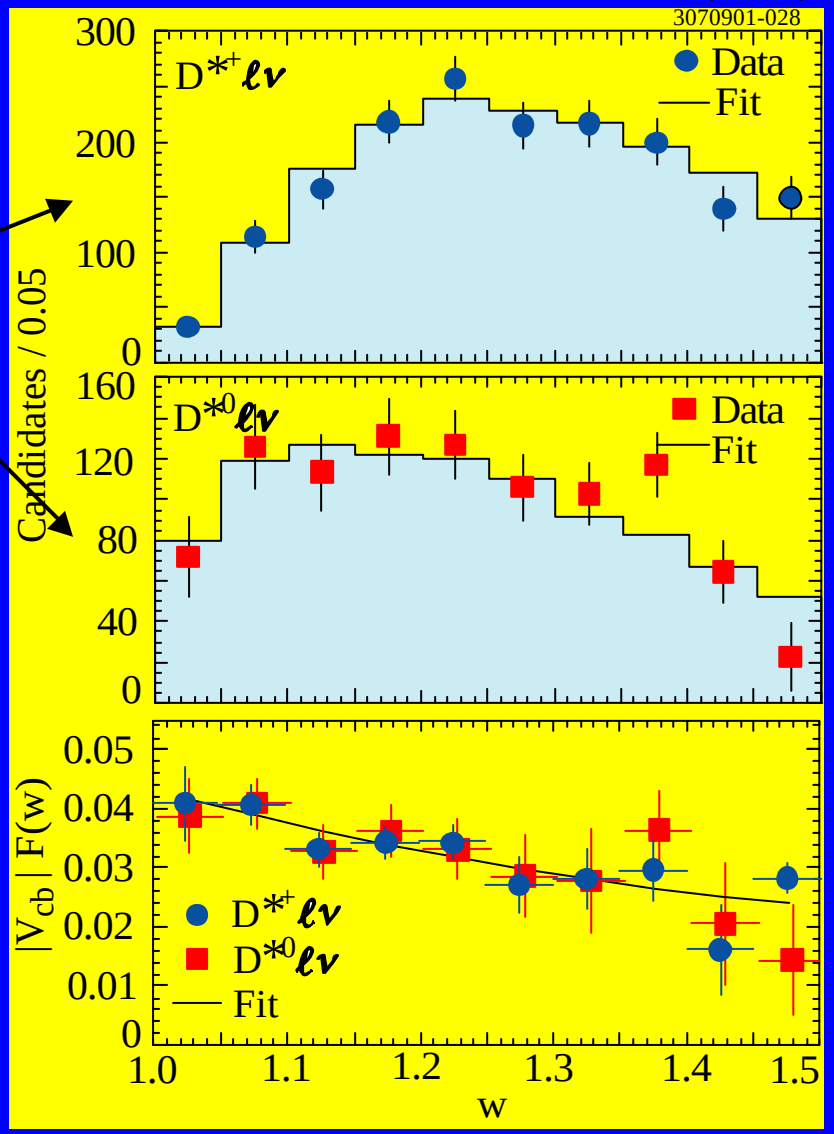
- Background/ signal shape: Model with off-resonance data + MC
  - Fit to data



$B \to D^* l \nu$

- Signal yields vs. w:
- Extrapolate to w = 1
  $|V_{cb}|F(w=1) =$
  0.0431 x (1±3%±4.2%)
- $|V_{cb}|$ = 0.047 x (1 ± 3%
  ± 4.2% ± 3.8%)
  from theory, using $F(1) = 0.919^{+0.03}_{-0.035}$
  (lattice QCD, hep-ph/0110253)
- Most precise single $|V_{cb}|$ excl. measurement (6.5%)

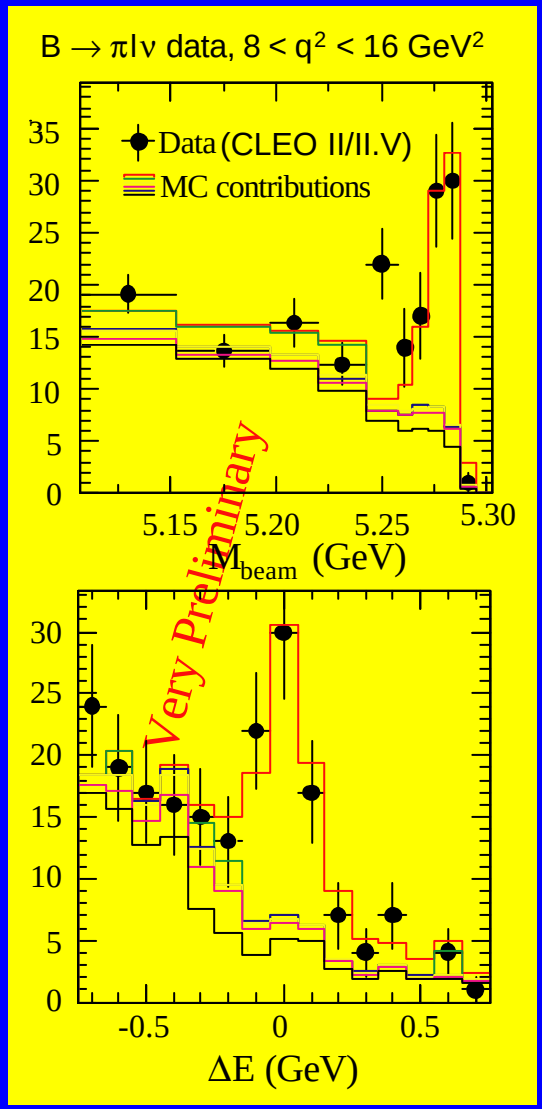
CLNS 01/1773 (2002)



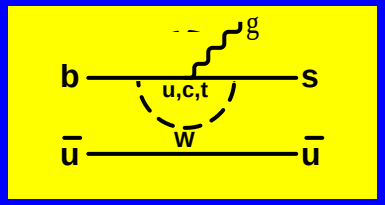
V_{ub} Exclusive: $B \rightarrow \rho,\pi\, l\, \nu$

- Analysis in progress both on CLEO II and CLEO III data
- Reconstruct ν (CLEO technique)
- Background:
  - Off-resonance data
  - Monte Carlo
- Form factors: compare models
- $M^2_{beam} = E_{beam}^2 - (\Sigma \mathbf{p})^2 \sim M_B^2$
- $\Delta E = \Sigma E - E_{beam}$
- Previous CLEO V_{ub} measurement: ~20%

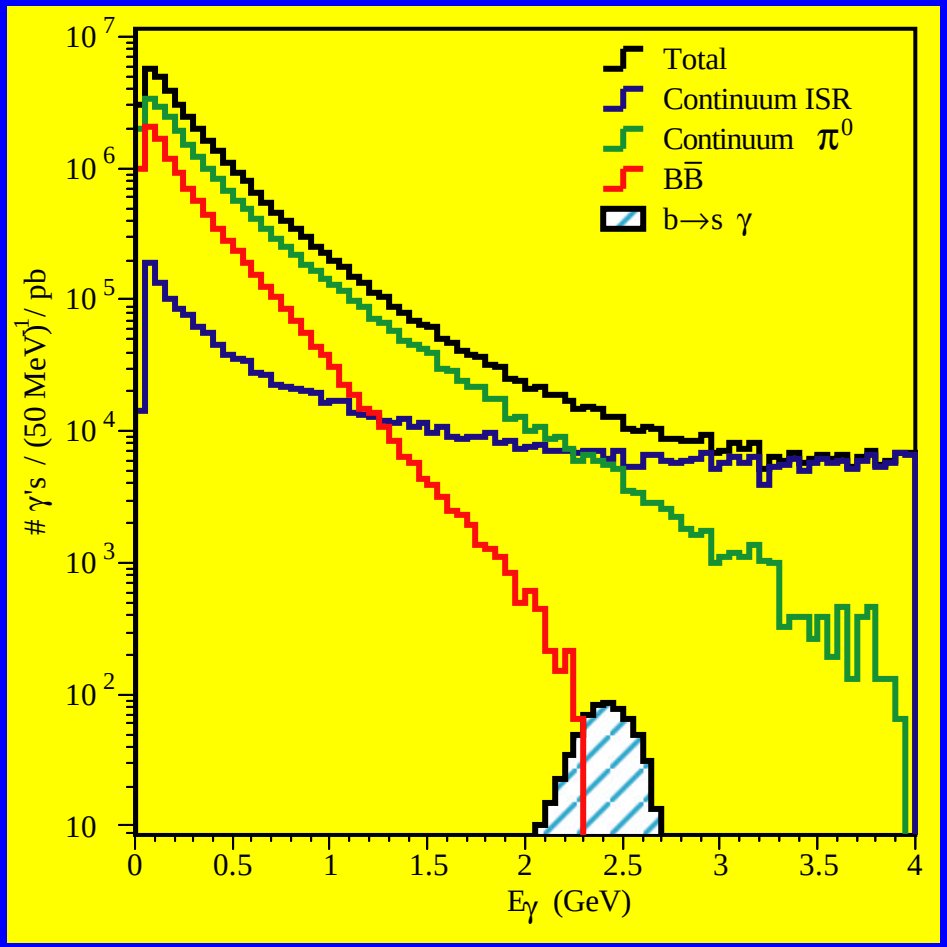
Phys.Rev.Lett. 77, 5000(1996)
Phys.Rev. D 61, 052001(2000)



Inclusive: $b \rightarrow s\,\gamma$

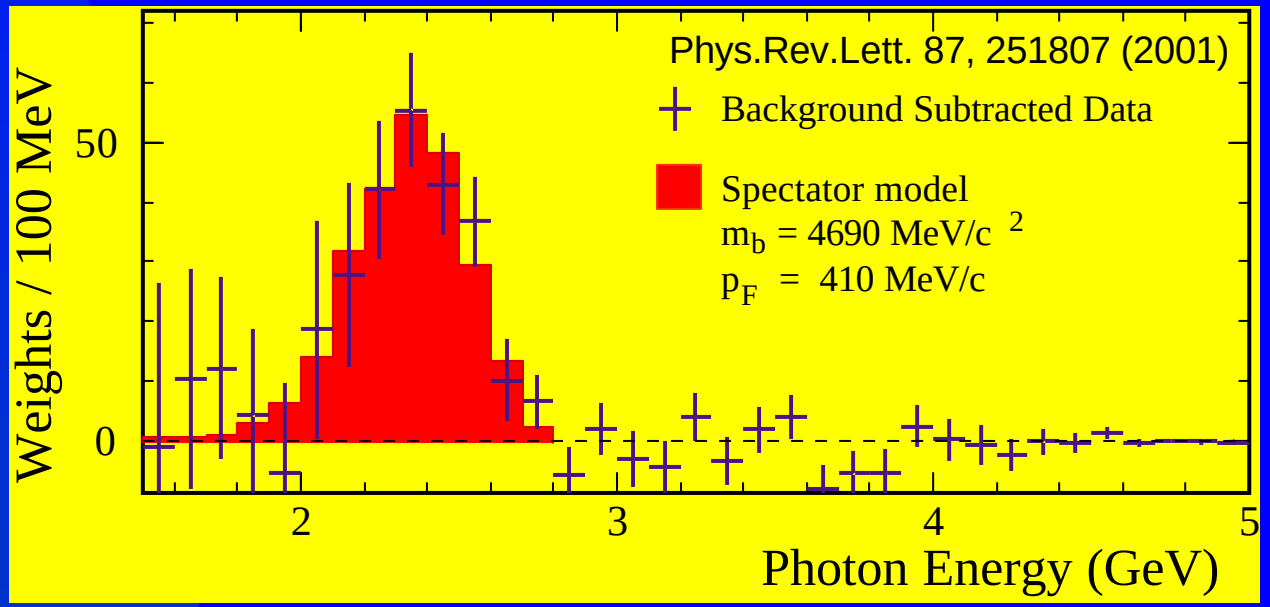


- Measure full photon energy spectrum (now $E_\gamma > 2$GeV)
- Need to model background very well (continuum π^0, …)
  - ➡ off-resonance data
  - ➡ neural net
  - ➡ "Pseudo-reconstruction"



Inclusive: $b \rightarrow s\,\gamma$

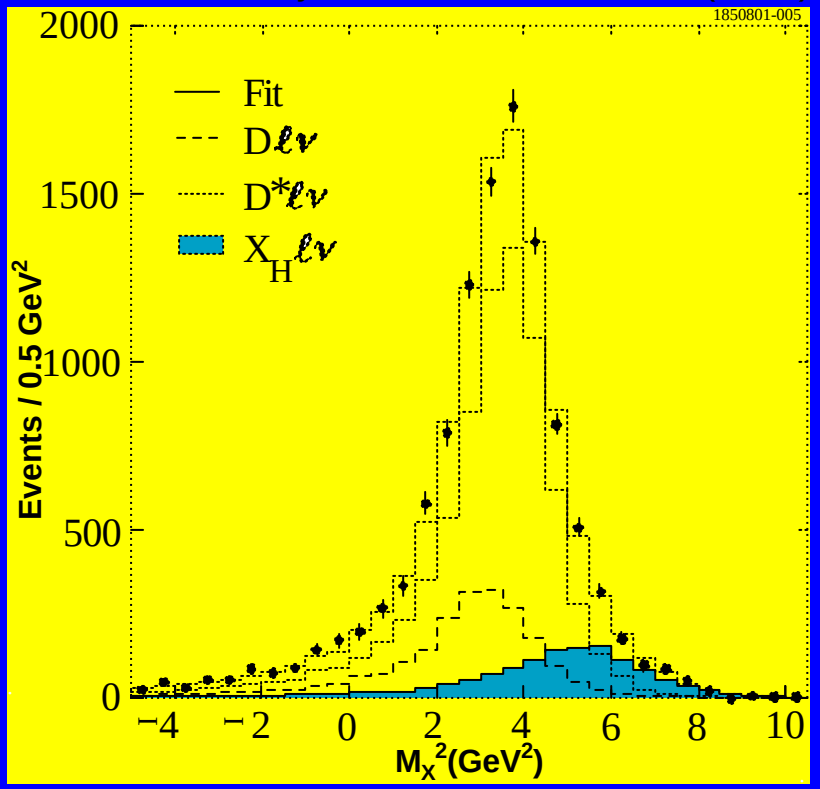
- HQET: $\langle E\gamma \rangle = \frac{1}{2} M_B f(\bar{\Lambda}/M_B)$
  $f(\bar{\Lambda}/M_B)$ independent of decay (to first order)
- $\bar{\Lambda} = 0.35 \pm 0.08 \pm 0.1$ GeV → Use later
- Second moment (width) measured but not used



V_{cb} Inclusive: $B \rightarrow X_c l \nu$

- Measure full hadron spectrum
- $P_l > 1.5$ GeV
- ν reconstruction (missing mass)
- $M_x^2 \sim M_B^2 + M_{l\nu}^2 - 2E_B E_{l\nu}$
- Subtract background:
  - Continuum from off-resonance data
  - $b \rightarrow u l \nu$: MonteCarlo
- $\langle M_x^2 - M_D^2 \rangle = 0.25 \pm 0.023 \pm 0.062$

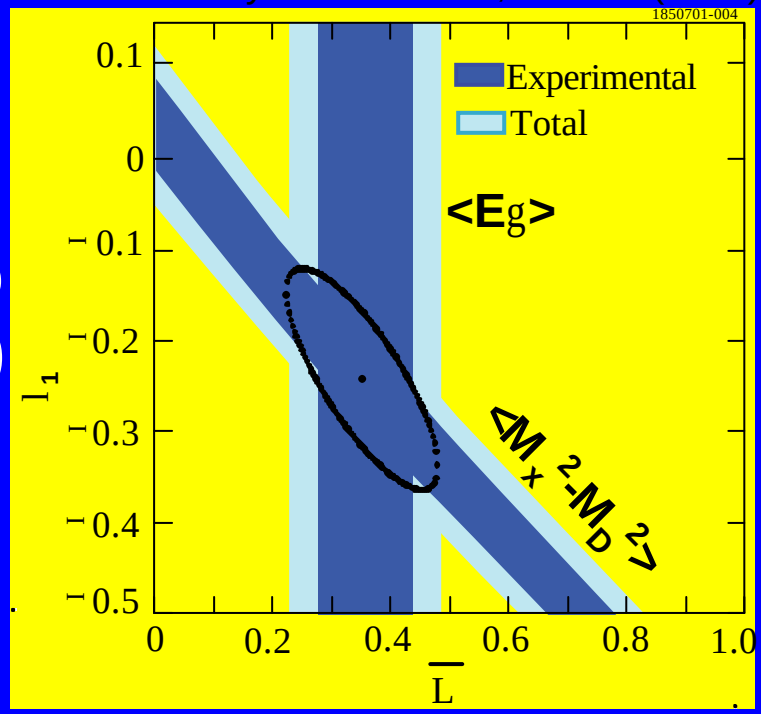
Phys.Rev.Lett. 87, 251808 (2001)



V_{cb} Inclusive: $B \rightarrow X_c l \nu$

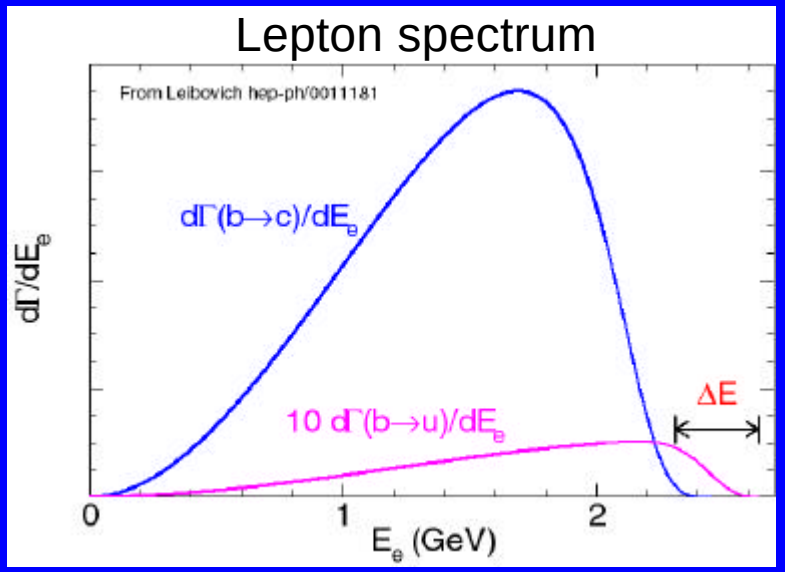
- HQET: $\langle M_x^2 - M_D^2 \rangle = f(\bar{\Lambda}, \lambda_1)$
- Combine with $\bar{\Lambda}$ from $\underline{b} \rightarrow s \gamma$ (+use τ_b):
  $\bar{\Lambda} = 0.35 \pm 0.07 \pm 0.1$ GeV
  $\lambda_1 = -0.236 \pm 0.071 \pm 0.078$ GeV
- $|V_{cb}| = 0.0404 \times (1 \pm 2.3\% \pm 1.3\% \pm 2\%)$
  3.2% total error
- Better than from $D^* l \nu$ but requires QHD

Phys.Rev.Lett. 87, 251808 (2001)



V_{ub} Inclusive: $B \rightarrow X_u l \nu$

- Analysis: 9.7M BB events (CLEO II, II.V)
- Main background: $B \rightarrow X_c l \nu$
  Use lepton spectrum endpoint beyond $X_c l \nu$ limit
- Neural net for continuum background suppression
- Previous analysis too model dependent
  - ➡ use larger fraction of lepton spectrum
  - ➡ need good MC for $B \rightarrow X_c l \nu$
    (use measured form factors, HQET)

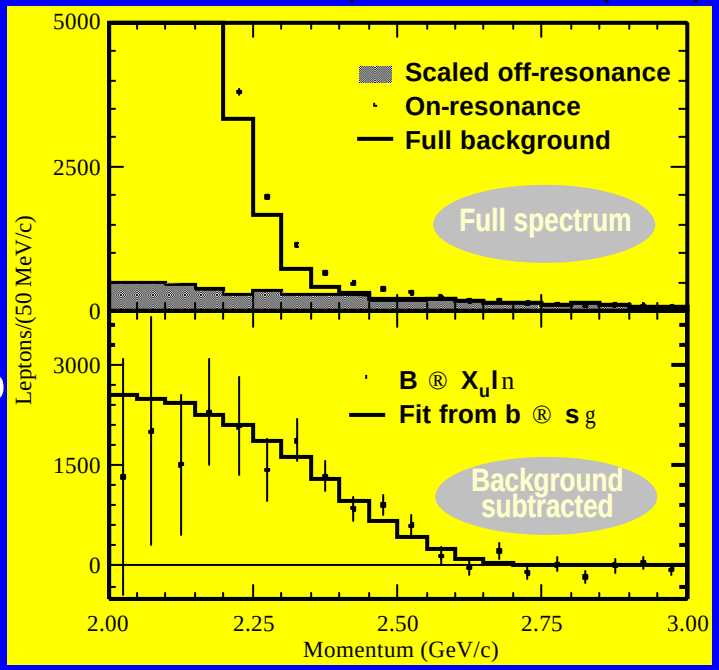


Extract V_{ub} from $B \to X_u l \nu$

- Lepton spectrum: need f_u for b.f.
  f_u = fraction of spectrum in measured p interval
  Get shape from b ® s g - only depends on b quark dynamics in B - $f(\bar{\Lambda},\lambda_1)$!
- Fit data for f_u
- $|V_{ub}| \propto B(B \to X_u l \nu)$
- V_{ub} vs. p interval
  Choose: 2.2GeV < p_l < 2.6GeV:
  $|V_{ub}|$ = 0.00408 x (1 ± 8.3% ± 10.8% ± 3.9% ± 5.9%)

  Best V_{ub} (~15%) (requires QHD)

Hep-ex/0202019 (2002)



Summary of recent CLEO results

- Exclusive:
  - $|V_{cb}|$: $B \rightarrow D^* l \nu$: 0.047 x (1 ± 6.5%)
  - $|V_{ub}|$: $B \rightarrow \rho,\pi\, l \nu$: Work in progress
- Inclusive:
  - $|V_{cb}|$: $B \rightarrow X_c l \nu$: 0.04 x (1 ± 3.2%) using γ spectrum from $b \rightarrow s\, \gamma$
  - $|V_{ub}|$: $B \rightarrow X_u l \nu$: 0.004 x (1 ± 15%) using γ spectrum from $b \rightarrow s\, \gamma$
  - CP violation: resulting sin(2β) competitive
- Stay tuned for more CLEO III results
- CLEO-c in preparation

sin2β & Vub/Vcb

$|Vub/Vcb| = \quad 0.101 \pm 0.017$

$\sin 2\beta_{CKM} = \ 0.74 \pm 0.09 \pm \ 0.08$

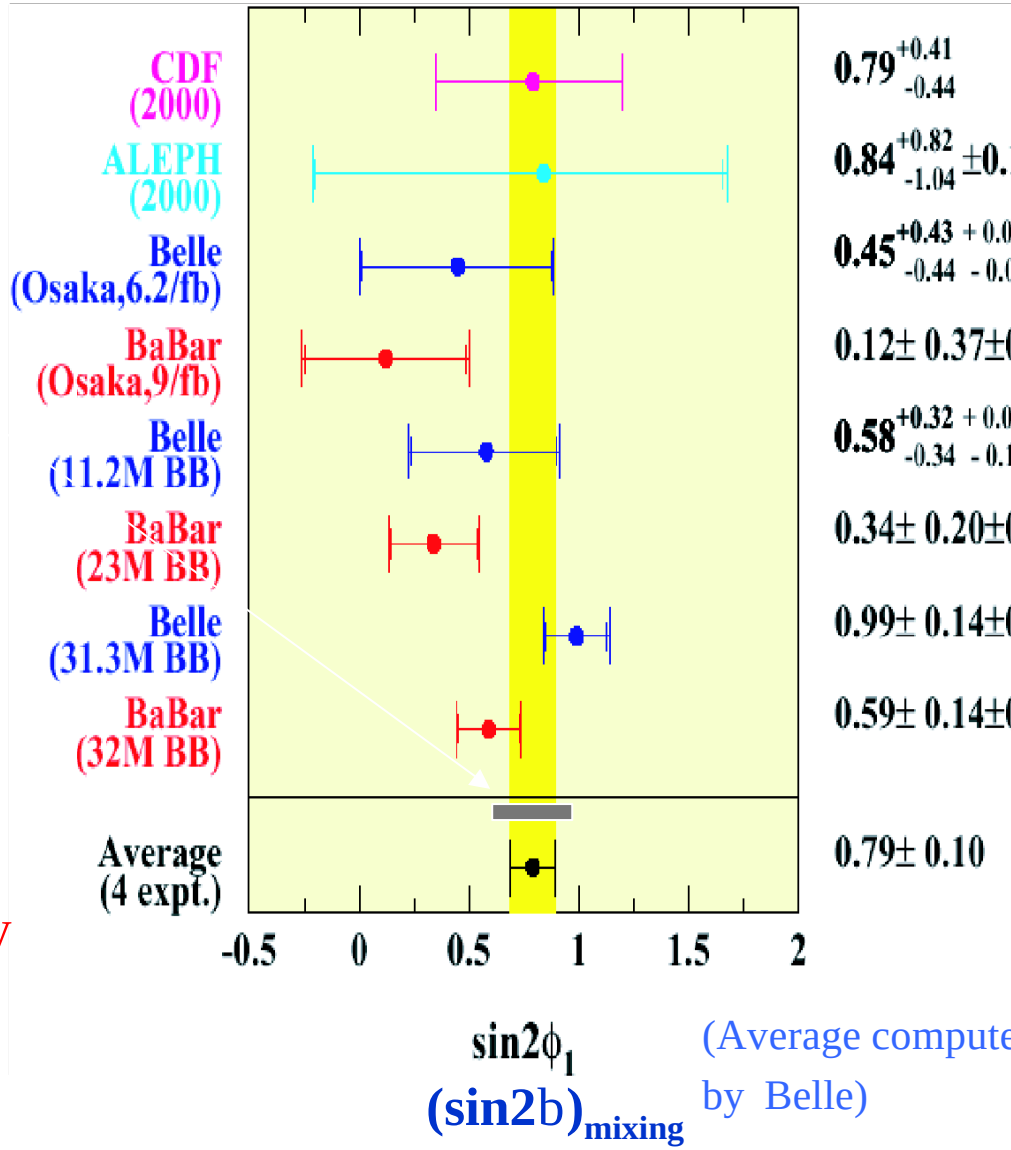
(Assumes $45^0 < \ \gamma < 110^0$)

This agrees well with sin2β from BABAR and Belle:

$(\sin 2\beta)_{mixing} = 0.79 \pm 0.10$

A significant consistency check of the CKM mechanism of CPV.

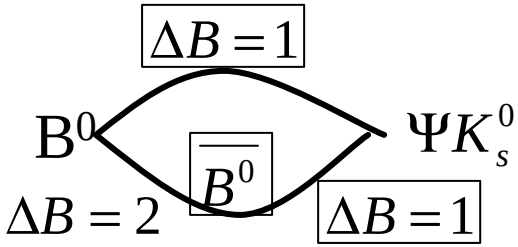
Checks of this type, with increasing precision, will be the hallmark of heavy flavor physics in this decade.

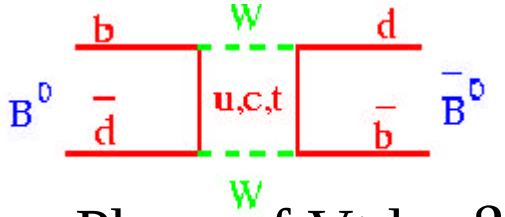


sin2β & Vub/Vcb

From CLEO data Vub/Vcb is determined to 17%

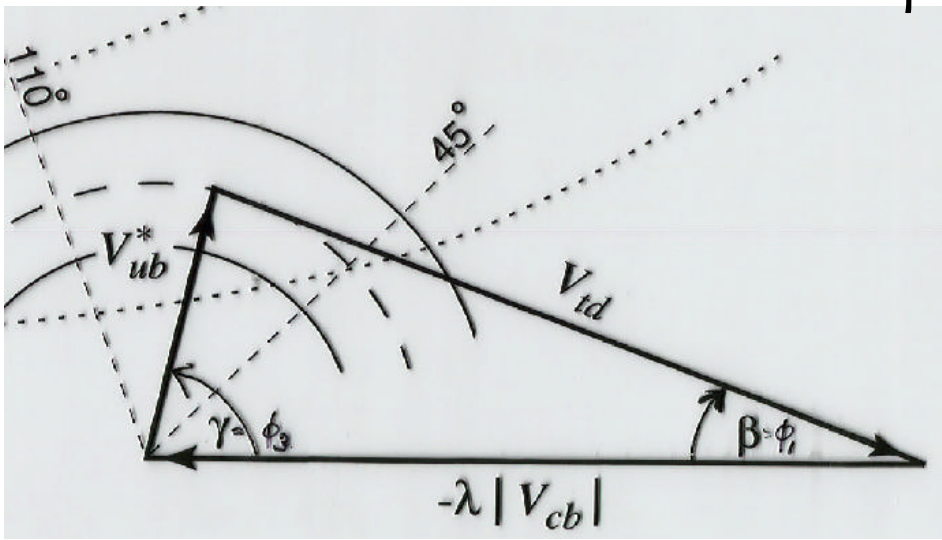
What are the implications ?





Phase of Vtd = β

- BABAR & Belle immediate objective: $(\sin 2\beta)_{mixing}$
- Mixing :box diagrams new physics may enter: $(\sin 2\beta + \Theta)_{mixing}$
- The goal compare $(\sin 2\beta)_{mixing}$ to $\sin 2\beta_{CKM}$ i.e β from Vub/Vcb
- β depends strongly on |Vub/Vcb| but weakly on γ for $45^0 < \gamma < 110^0$



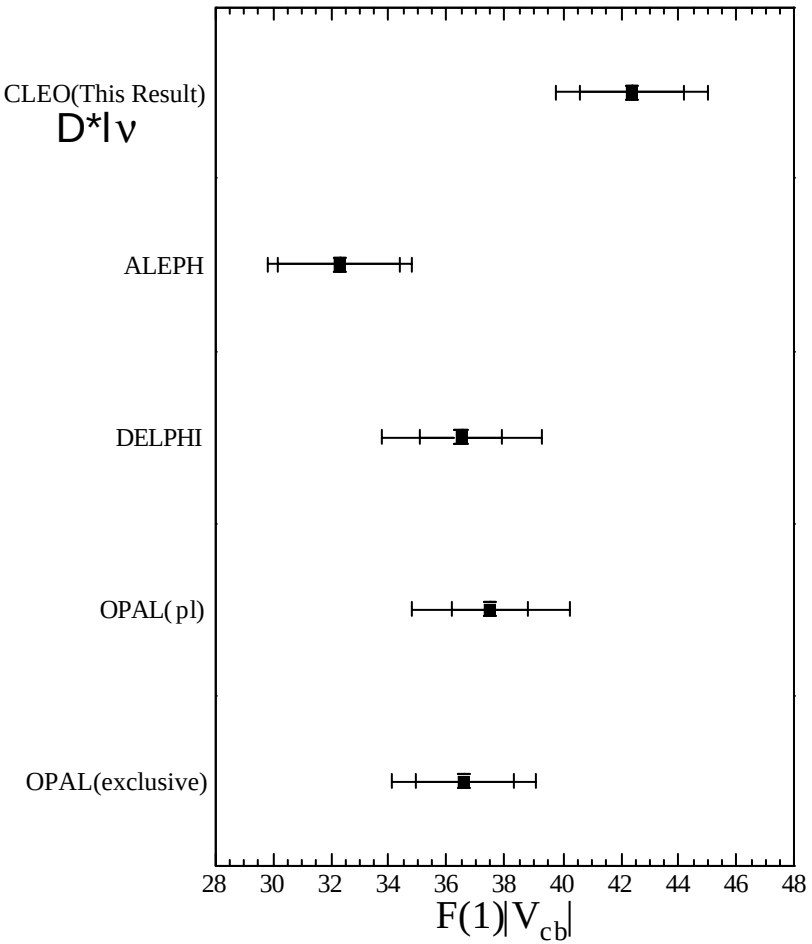
$|Vub/Vcb| \quad 0.101 \pm 0.017$

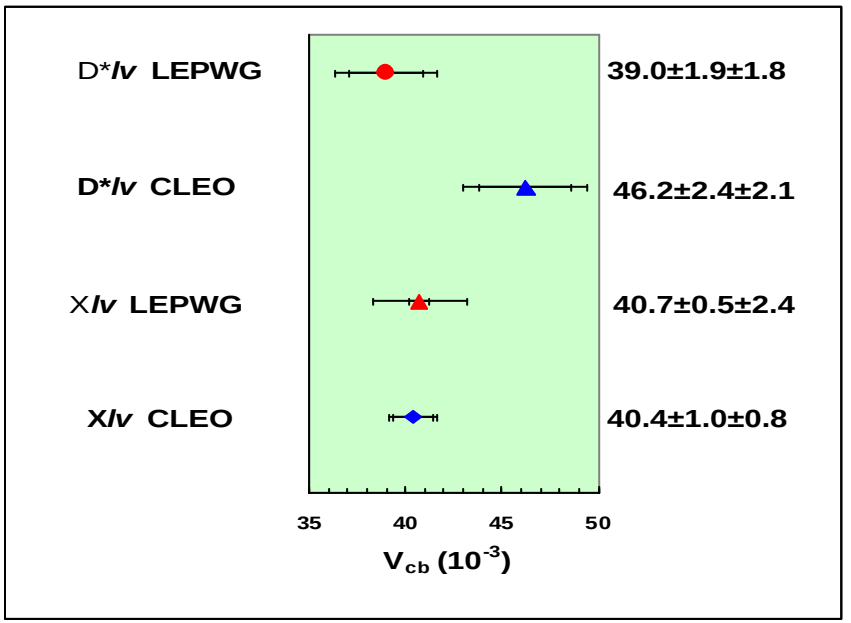
$\sin 2\beta_{CKM} \quad 0.95 < @ 90\%$ CL

- Take $45^0 < \gamma < 110^0$

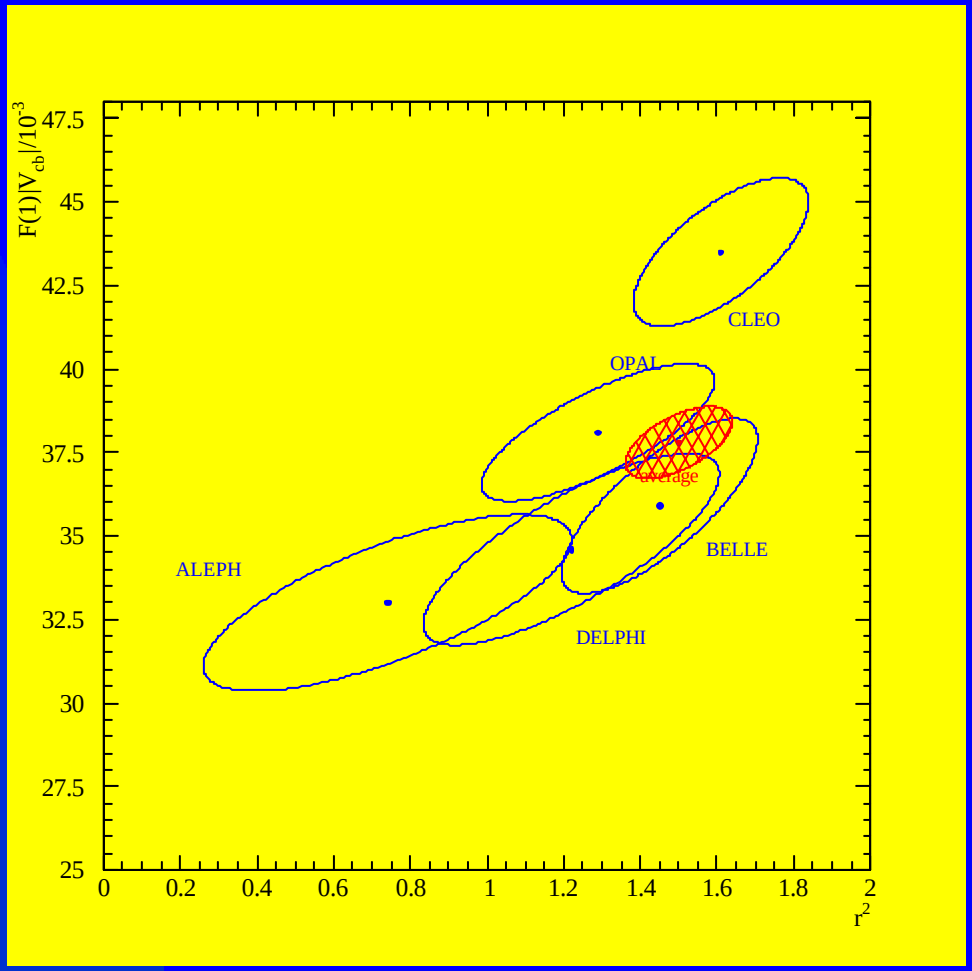
$\sin 2\beta_{CKM} = 0.74 \pm 0.09 \pm 0.08$ (1st error Vub, 2nd error γ **range)**

V_{cb} comparison





V_{cb} comparison



D mixing

- Current CLEO analysis:
  $B \rightarrow K^*e\nu$
- Measure
  "right sign decay"
  $B^+ \rightarrow \pi^+_s D^0$,
  $D^0 \rightarrow K^{*-}e^+\nu$ and
  "wrong sign decay"
  $B^+ \rightarrow \pi^+_s D^0$,
  $D^0 \rightarrow K^{*+}e^-\nu$
- Rmix = .0087 (prelim.)