Search for New Physics @ CLEO III

Frank Würthwein - MIT

- CKM matrix:
  - $\mathrm{Arg}(V_{ub}^*) = \gamma$
  - $|V_{ub}|, |V_{cb}|$
  - $f_B \times |V_{ub}|$
- FCNC
  - $b \to s\gamma$
  - $b \to sl^+l^-$
  - $B \to K^*\nu\nu$
- Short list of the less obvious

Schedule and Projections

- CLEO II:
  - 1989-1999
  - 10 Million $\Upsilon(4S)$ decays
  - limited K/π separation
- CLEO III:
  - 2000-200?
  - ~ 20 Million $\Upsilon(4S)$ decays /year
  - $>\sim 4\sigma$ K/π separation
- "CLEO IV"
  - ??? 2004 - ???
  - 200 Million $\Upsilon(4S)$ decays /year
  - same detector as CLEO III

Assume 60 Million $B\bar{B}$ pairs for CLEO II+III

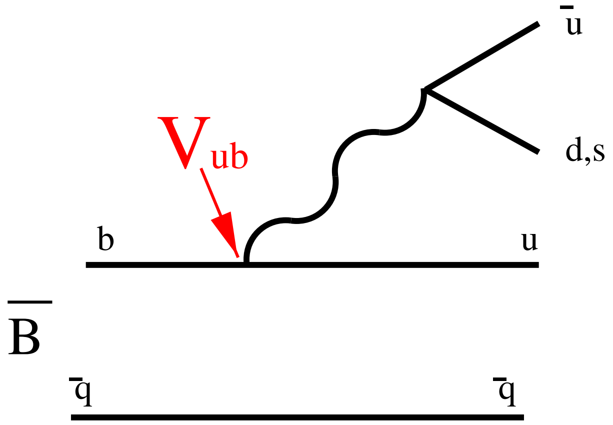
CLEO centric view of the CKM matrix

$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & |V_{ub}|\times e^{-i\gamma} \\ -\lambda & 1-\frac{1}{2}\lambda^2 & |V_{cb}| \\ \lambda|V_{cb}|-|V_{ub}|\times e^{+i\gamma} & -|V_{cb}| & 1 \end{pmatrix}$$

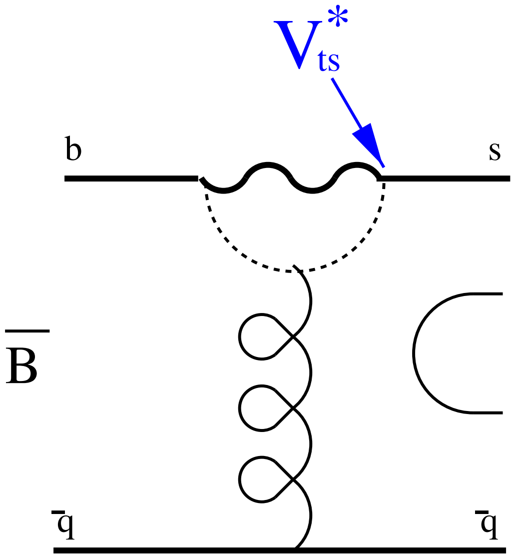
CLEO 1995:	$\delta|V_{cb}| \sim 7.5\%$	$1.7\times 10^6 B\bar{B}$
CLEO 1999:	$\delta|V_{ub}| \sim 19\%$	$3.3\times 10^6 B\bar{B}$
CLEO ICHEP98:	$\delta|V_{cb}| \sim 3\%???$	$3.3\times 10^6 B\bar{B}$

What may we infer about γ from CLEO data ???

Measuring γ via Tree-Penguin Interference



$$A_T \; e^{-i\,\gamma}$$



$$A_P$$

$$(BR+\bar{B}R)/2 = |A_T|^2+|A_P|^2+2|A_T A_P|\cos\gamma\ \cos\Delta_{stron}$$

Three ways of extracting info on γ Today

Neubert + Rosner $\rightarrow$ requires $R_* \neq 1$

$$R_* = \frac{\mathcal{B}(B^- \rightarrow \bar{K}^0 \pi^-)}{2\mathcal{B}(B^- \rightarrow K^- \pi^0)} = 0.75 \pm 0.30$$

Fleischer + Mannel $\rightarrow$ requires $R \leq 1$

$$R = \frac{\mathcal{B}(\bar{B}^0 \rightarrow \bar{K} - \pi^+)}{\mathcal{B}(B^- \rightarrow \bar{K}^0 \pi^-)} \sim 1$$

Assume factorization and do global fit to all BR's
$\rightarrow$ requires only faith

hep-ph/9812396 with 100 Million $B\bar{B}$ pairs

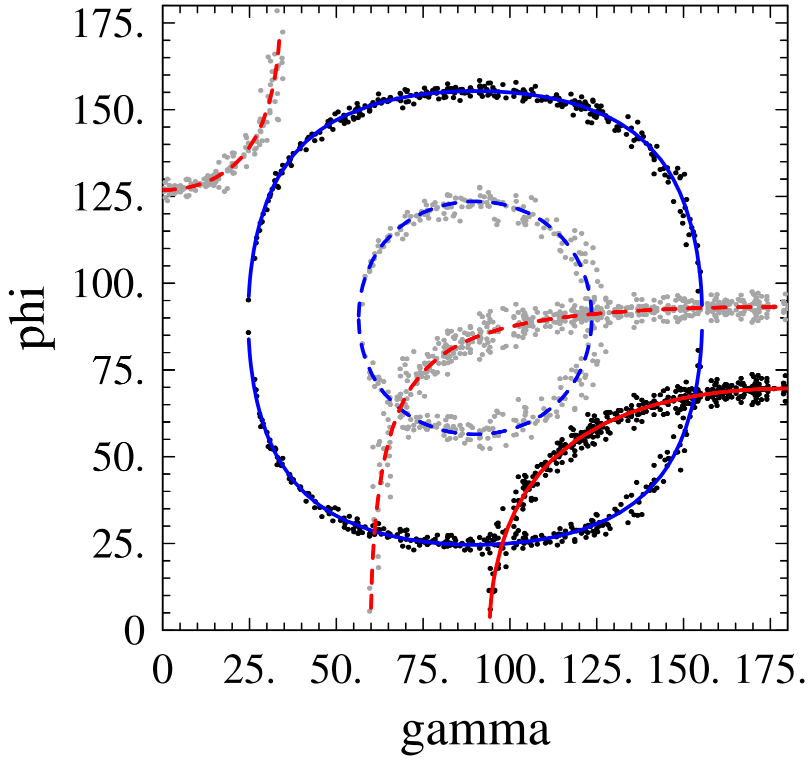


Figure 1: $R_* = 0.8 \pm 0.1$; $\mathcal{A} = 0.3 \pm 0.1$

$$\mathcal{A} \equiv \frac{A_{cp}(\pi^0 K^\pm)}{R_*} - A_{cp}(\pi^\pm K_s) = 0.31 + -0.14$$

$$R_* = 0.75 \pm 0.10$$

χ^2 fit to 14 BR's + $|V_{ub}/V_{cb}| = 0.08 \pm 0.02$

$$\mathcal{B} = \tau\Gamma = \tau \frac{G_F^2}{16\pi} \frac{p_{cm}}{m_B^2} |A|^2$$

- Input Parameters:
  - standard meson masses and decay constants
  - $|V_{cb}| = 0.0381$, $|V_{cd}| = 0.2196$
  - Wilson Coefficients and $N_c = 3$
  - $f_{+-}/f_{00} = 0.92 - 1.18$ (APS99: 1.05 ± 0.13)
- Parameters to fit for:
  - γ (actually $\cos\gamma$)
  - form factors: $F_0^{B\pi}$, $A_0^{B\rho}$
  - $R_{su} = 2\ m_{K^-}^2/(m_b - m_u)(m_s + m_u)$
  - $|V_{ub}/V_{cb}|$
- Derived Parameters:
  - $F_1^{B\pi} = F_0^{B\pi}$, $F_1^{BK} = F_0^{BK}$
  - $F_1^{BK} = 1.13 \times F_0^{B\pi}$
  - $A_0^{B\rho} = A_0^{B\omega}$
  - $R_{su} = R_{du} = R_{sd}$

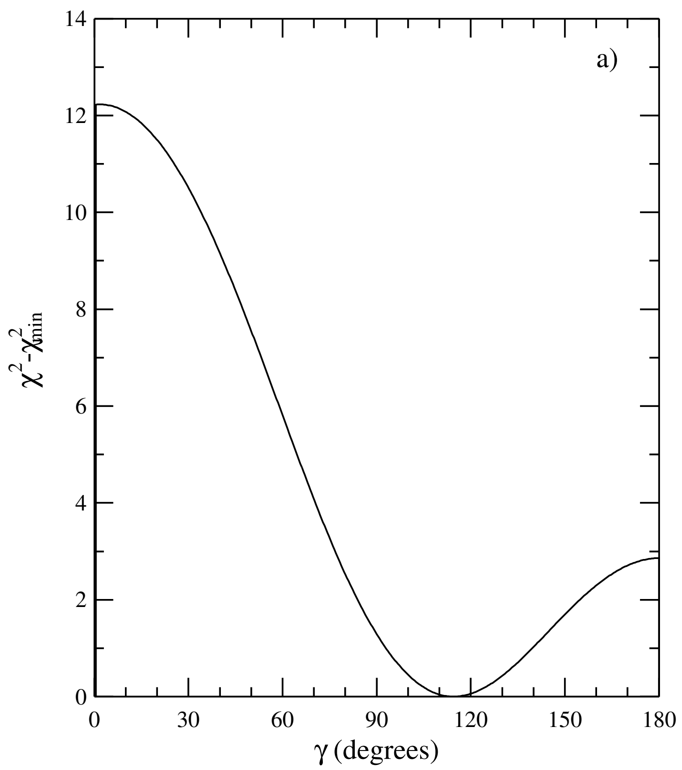
Terms in the χ^2

$$|V_{ub}/V_{cb}| = 0.08 \pm 0.02$$

Mode	Measured BR $\times 10^5$	Relevant Fit Parameters
$K^+\pi^-$	$1.88^{+0.28}_{-0.26} \pm 0.07 \pm 0.11$	γ, $\lvert V_{ub}/V_{cb}\rvert$, R_{su}, $F_0^{B\pi}$
$K^+\pi^0$	$1.21^{+0.30+0.19}_{-0.28-0.12} \pm 0.08$	γ, $\lvert V_{ub}/V_{cb}\rvert$, R_{su}, $F_0^{B\pi}$
$K^0\pi^+$	$1.82^{+0.46}_{-0.40} \pm 0.09 \pm 0.13$	R_{sd}, $F_0^{B\pi}$
$K^0\pi^0$	$1.48^{+0.59+0.24}_{-0.51-0.33} \pm 0.25$	R_{sd}, $F_0^{B\pi}$
$\pi^+\pi^-$	$0.47^{+0.18}_{-0.15} \pm 0.05 \pm 0.03$	γ, $\lvert V_{ub}/V_{cb}\rvert$, R_{du}, $F_0^{B\pi}$
$\pi^+\pi^0$	$0.54^{+0.21}_{-0.20} \pm 0.15 \pm 0.03$	$\lvert V_{ub}/V_{cb}\rvert$, $F_0^{B\pi}$
$\rho^0\pi^+$	$1.5 \pm 0.5 \pm 0.4$	γ, $\lvert V_{ub}/V_{cb}\rvert$, Q_{du}, $A_0^{B\rho}$, $F_1^{B\pi}$
$\omega^0\pi^+$	$1.13^{+0.33}_{-0.29} \pm 0.1$	$A_0^{B\rho}$, $F_1^{B\pi}$
$\rho^\pm\pi^\mp$	$3.5^{+1.1}_{-1.0} \pm 0.5$	$A_0^{B\rho}$, $F_1^{B\pi}$
$K^{*+}\pi^-$	$2.2^{+0.8+0.4}_{-0.6-0.5}$	γ, $\lvert V_{ub}/V_{cb}\rvert$, $F_1^{B\pi}$
$\omega^0 K^+$	$0.31^{+0.24}_{-0.19} \pm 0.08$	γ, $\lvert V_{ub}/V_{cb}\rvert$, Q_{su}, $A_0^{B\omega}$
$\omega^0 K^0$	$1.0^{+0.3}_{-0.4} \pm 0.1$	Q_{su}, $A_0^{B\omega}$
$\phi^0 K^+$	$0.16^{+0.19}_{-0.12} \pm 0.02$	F_1^{BK}
$\phi^0 K^0$	$1.07^{+0.78}_{-0.57} \pm 0.11$	F_1^{BK}

$> 4\sigma$, $3 - 4\sigma$, $2 - 3\sigma$, $< 2\sigma$

Fit result using 10 Million $B\bar{B}$



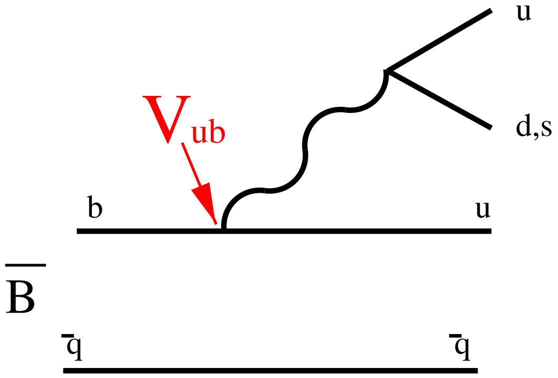
			(without $|V_{ub}/V_{cb}|$ constraint)
γ	$=$	114^{+25}_{-21} degrees	(121^{+31}_{-24} degrees)
$F_0^{B\pi}$	$=$	0.26 ± 0.04	
$A_0^{B\rho}$	$=$	$0.48^{+0.13}_{-0.10}$	
$(m_s + m_u)(m_b)$	$=$	59^{+14}_{-11}	
$|V_{ub}/V_{cb}|$	$=$	$0.087^{+0.017}_{-0.016}$	($0.11^{+0.06}_{-0.03}$)

Predictions from the Fit

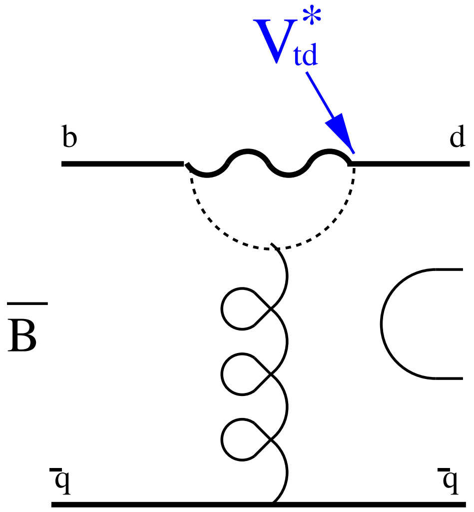
Mode	Measured BR $\times 10^5$	Fit predictions $\times 10^5$
$K^+\pi^-$	$1.88^{+0.28}_{-0.26} \pm 0.07 \pm 0.11$	2.06
$K^+\pi^0$	$1.21^{+0.30+0.19}_{-0.28-0.12} \pm 0.08$	1.16
$K^0\pi^+$	$1.82^{+0.46}_{-0.40} \pm 0.09 \pm 0.13$	1.94
$K^0\pi^0$	$1.48^{+0.59+0.24}_{-0.51-0.33} \pm 0.25$	0.79
$\pi^+\pi^-$	$0.47^{+0.18}_{-0.15} \pm 0.05 \pm 0.03$	0.45
$\pi^+\pi^0$	$0.54^{+0.21}_{-0.20} \pm 0.15 \pm 0.03$	0.34
$\rho^0\pi^+$	$1.5 \pm 0.5 \pm 0.4$	1.4
$\omega^0\pi^+$	$1.13^{+0.33}_{-0.29} \pm 0.1$	1.16
$\rho^\pm\pi^\mp$	$3.5^{+1.1}_{-1.0} \pm 0.5$	3.91
$K^{*+}\pi^-$	$2.2^{+0.8+0.4}_{-0.6-0.5}$	0.53
$\omega^0 K^+$	$0.31^{+0.24}_{-0.19} \pm 0.08$	0.38
$\omega^0 K^0$	$1.0^{+0.3}_{-0.4} \pm 0.1$	0.43
$\phi^0 K^+$	$0.16^{+0.19}_{-0.12} \pm 0.02$	0.30
$\phi^0 K^0$	$1.07^{+0.78}_{-0.57} \pm 0.11$	0.28

$> 4\sigma$, $3 - 4\sigma$, $2 - 3\sigma$, $< 2\sigma$

Aside on "Penguin Pollution"



$$= -|A_T|\, e^{-i\gamma}$$



$$= -|A_P|\, e^{i\beta}\, e^{i\delta}$$

$$\delta\alpha_{\pi^+\pi^-} = -19 \pm 3 \text{ degrees}$$

$$\delta\gamma_{\rho^0\pi^\pm} = 8.5^{+1.7}_{-2.1} \text{ degress}$$

$|V_{ub}|$ via exclusive decays

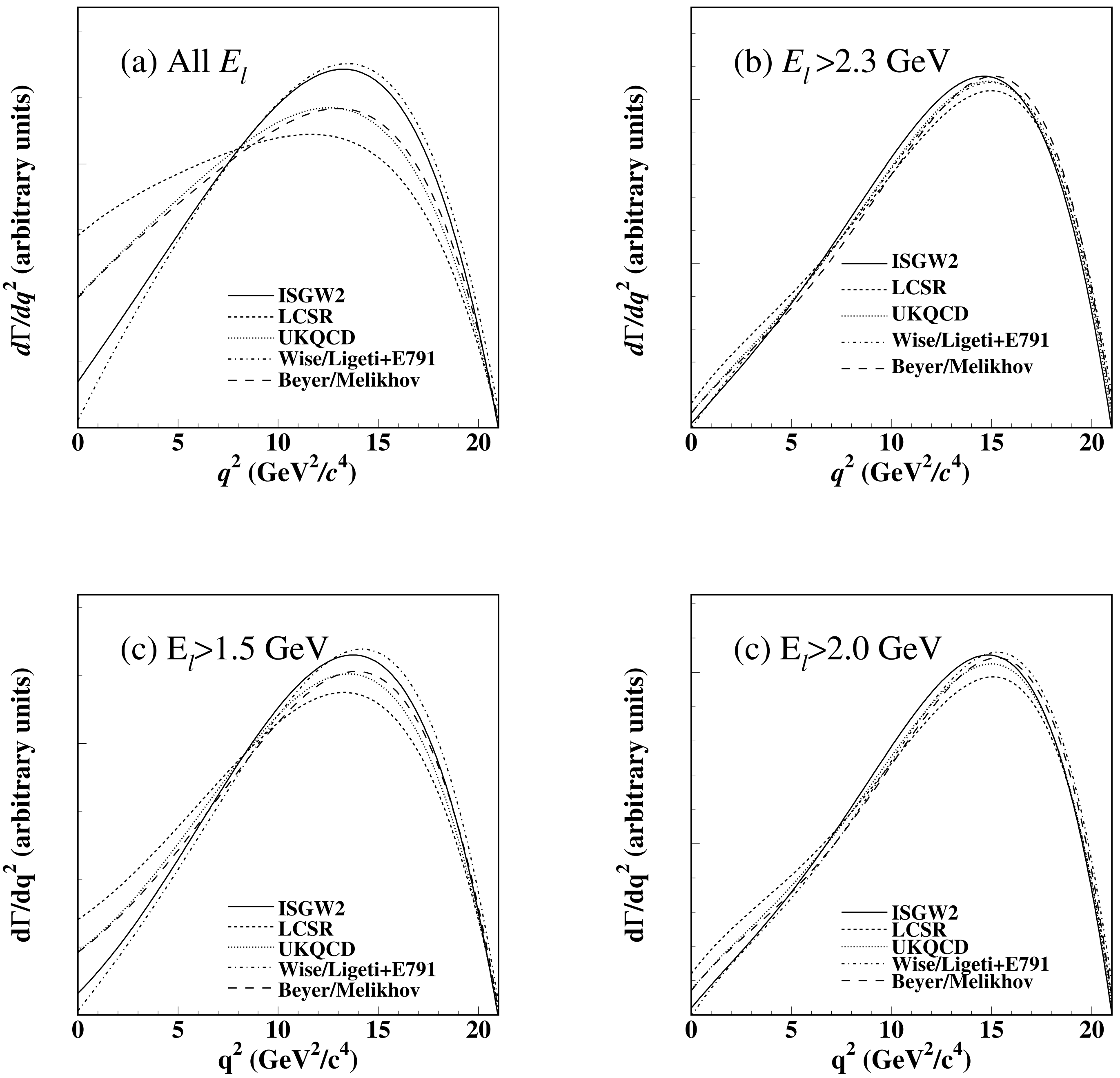
Two questions to theory:

- How much of the rate is within acceptance ? $\sim 10\%$
- What's the overall normalization ? $\sim 15\%$

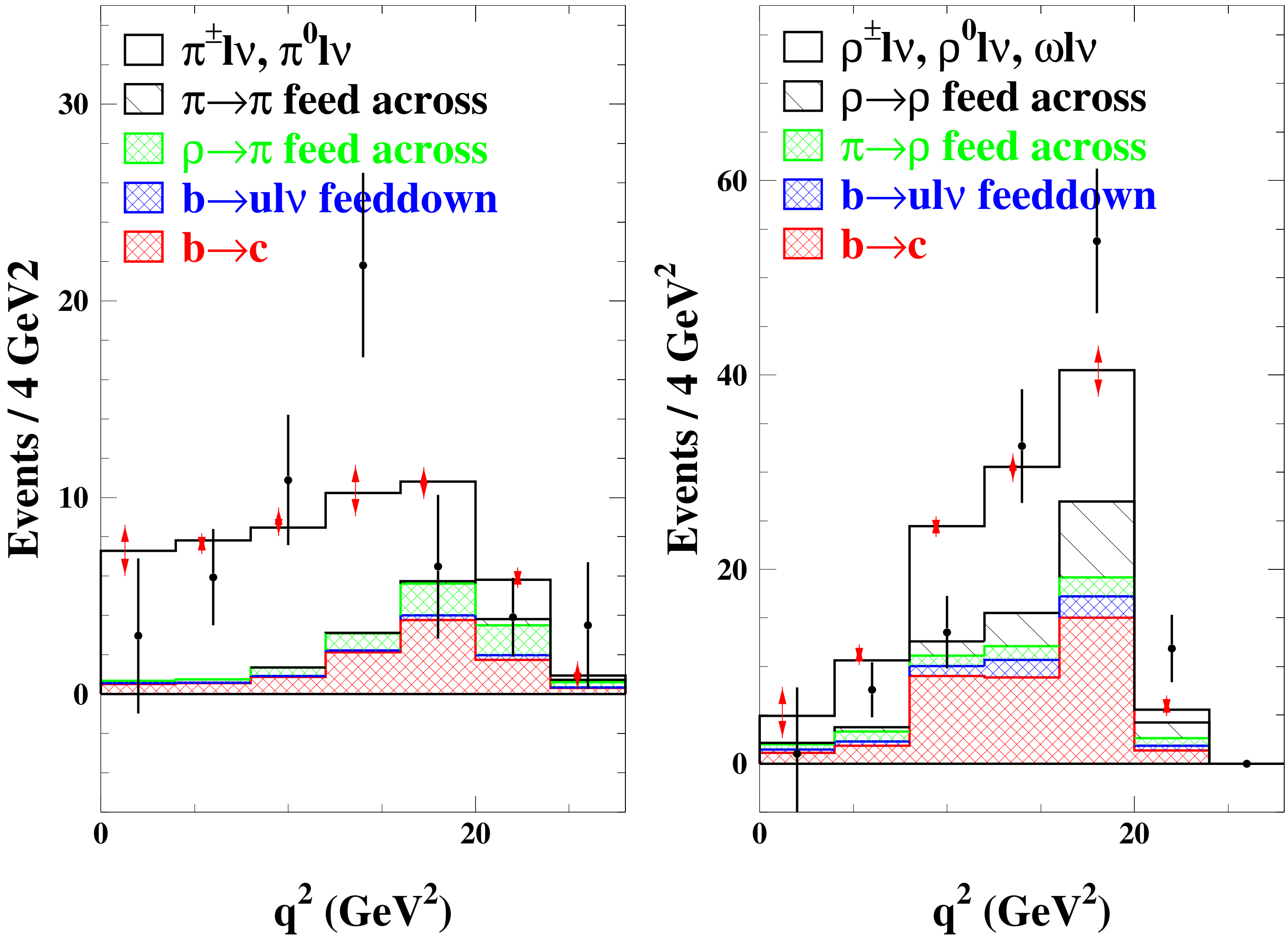
Two possible solutions to problem:

- Theory provides absolute normalization point.
- Maximize acceptance and test theory.

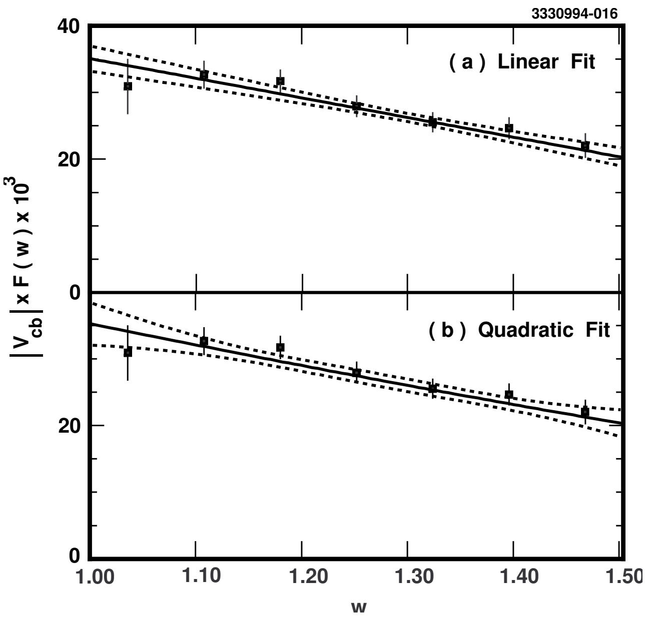
Q^2 distribution in $B \to \rho l \nu$

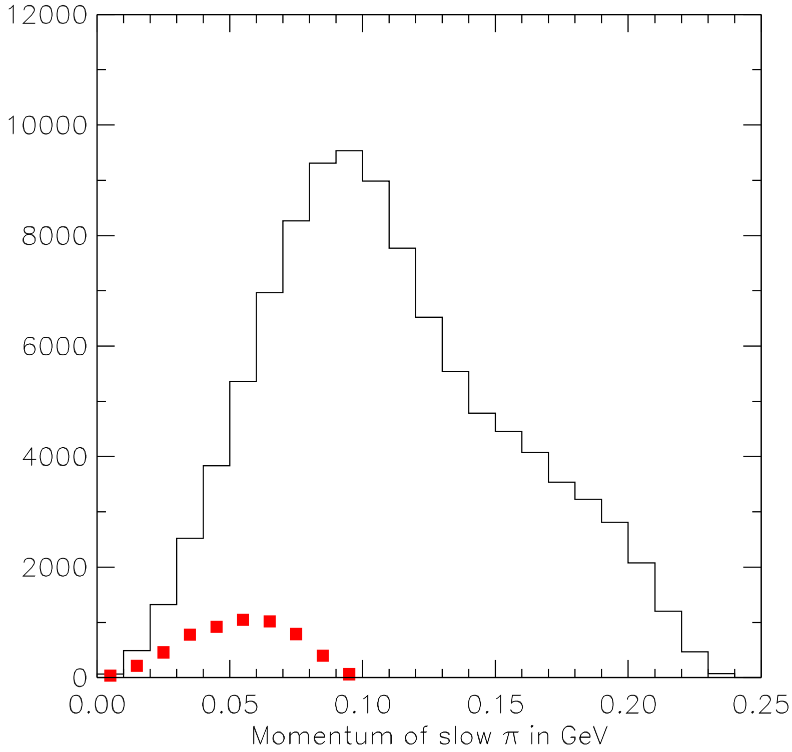


Data using 2.84 Million $B\bar{B}$

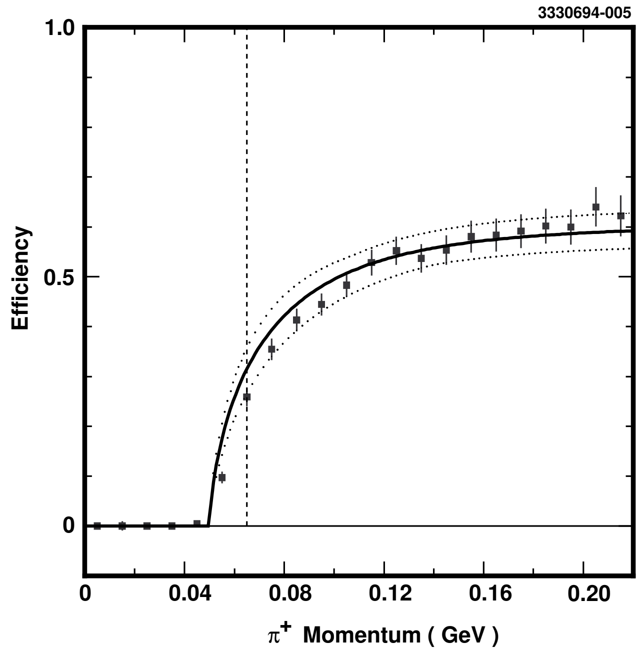


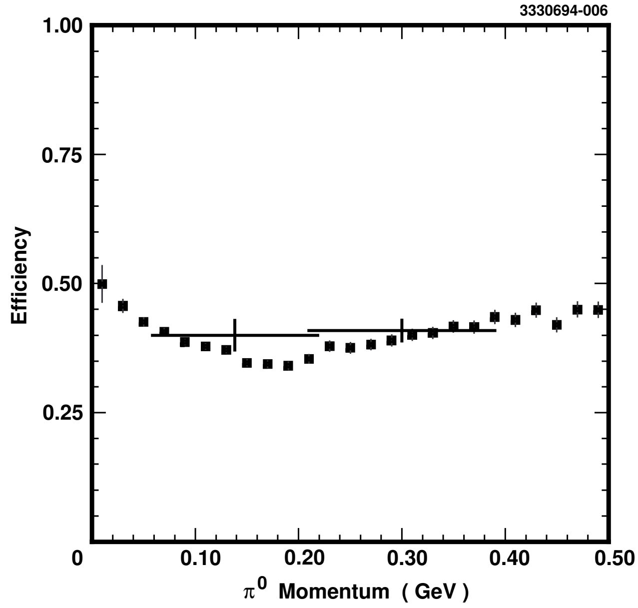
$|V_{cb}|$ from $D^* l\nu$

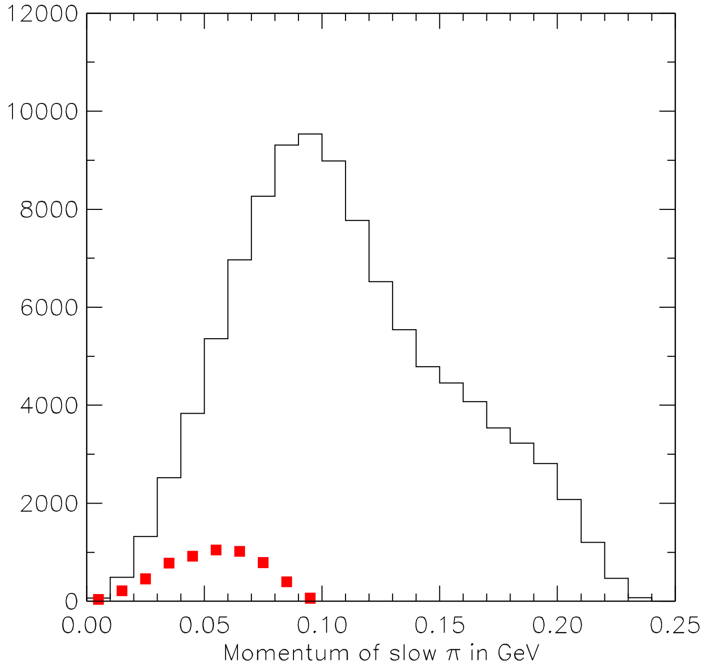




$|V_{cb}|$ from $D^* l\nu$ — Slow π Efficiency







Experimental Errors on $|V_{cb}|$ from $D^* l\nu$

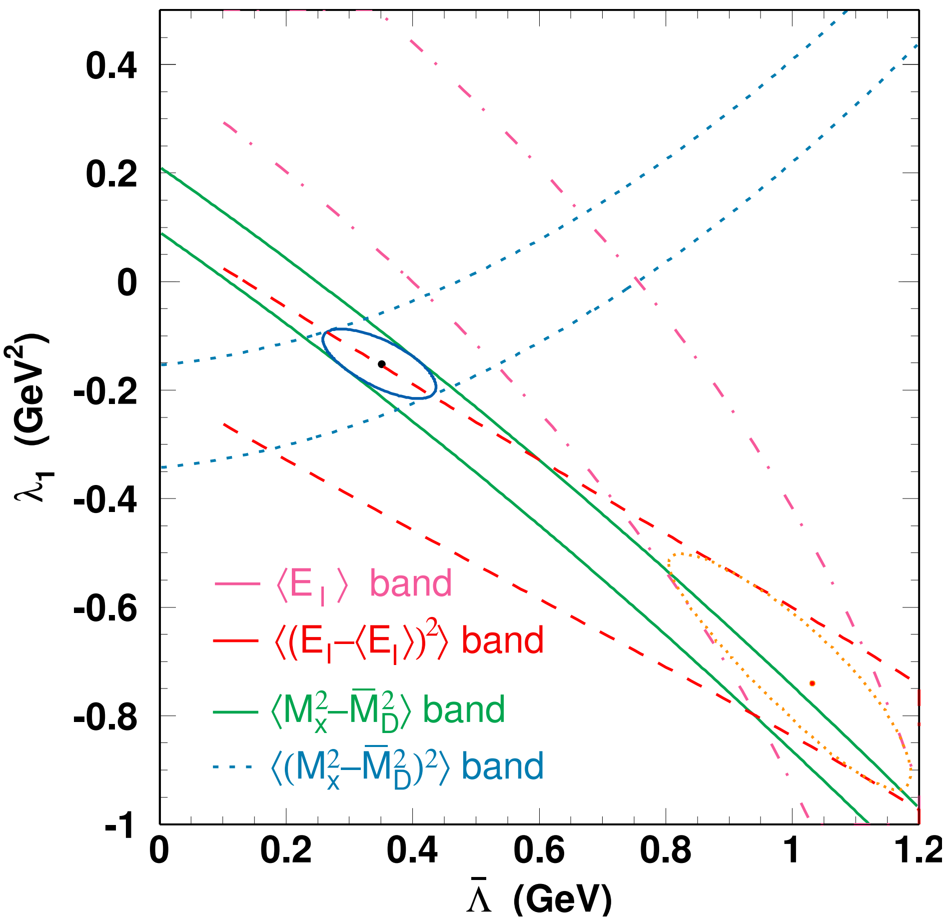
Statistical error: $5.4\% \rightarrow 0.9\%$ **with CLEO III**

Systematic errors on $|V_{cb}|$ in % (Fact = APS 99)

	$D^{*+} l\nu$		$D^{*0} l\nu$	
	Fact	Fiction	Fact	Fiction
Lepton ID	1.0	1.0	1.0	1.0
slow-π eff.	2.5	2	2.0	1.0
tracking	1.5	0.75	1.5	0.75
bkg's	1.4	1.4	1.4	1.4
# of $B\bar{B}$	0.9	0.9	0.9	0.9
$D^* \rightarrow D^0 \pi$	1.2	1.0	2.35	1.5
$D^0 \rightarrow K\pi$	1.7	1.5	1.7	1.5
Total	4.1	~ 3.4	4.3	~ 3.1

Want $\delta\mathcal{F}_{D^*}(1) < 2\%$ **from lattice**

Moment Analysis — an Alternative ?



Hadronic moments imply 3% measurement of $|V_{cb}|$

BUT discrepancy with lepton moments 2-3 times larger !!!

Future of Moment Analysis

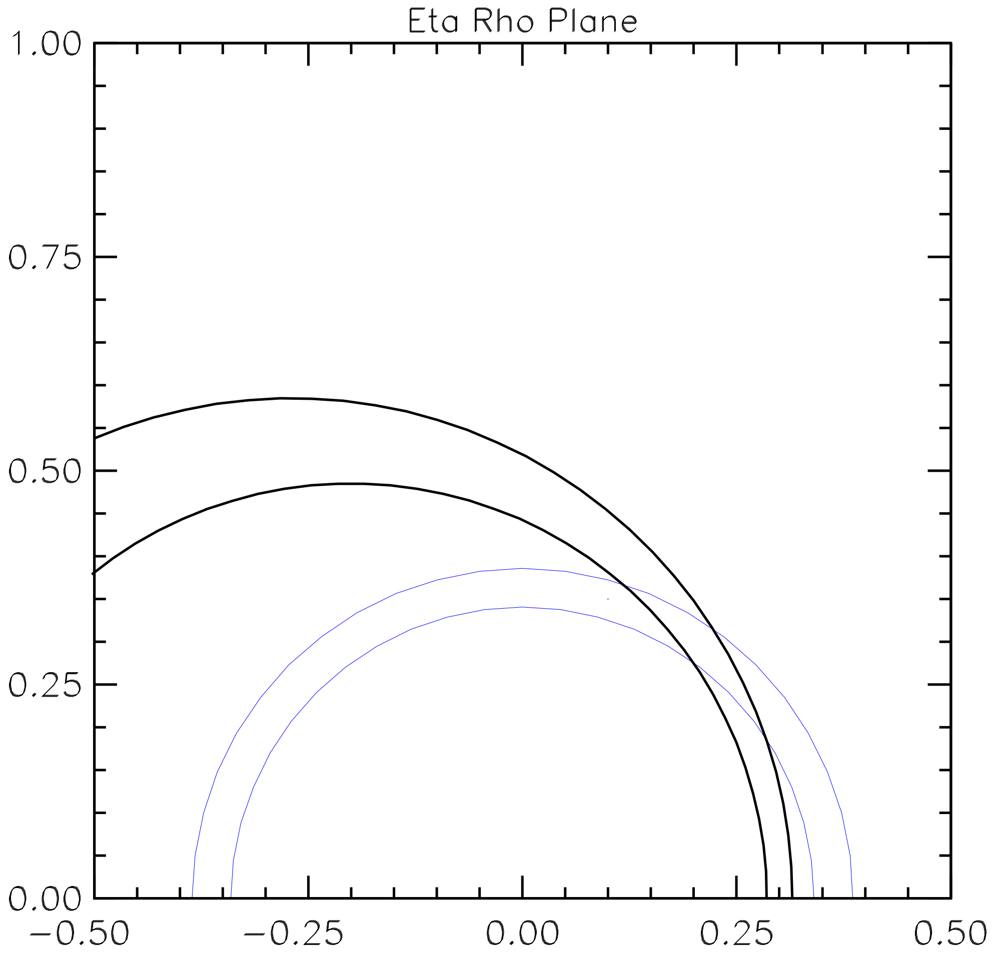
With CLEO II:

- hadronic moments ($\sim 1/3$ of CLEO II data used)
- leptonic moments ($\sim 1/5$ of CLEO II data used)
- "correlations" of the above ($< E_l \times S_{had} >$)
  - ν−reconstruction $\rightarrow q^2,\ E_l,\ E_\nu$

With CLEO III:

- Factor $\sqrt{6} \sim 2.5$ higher precision than full CLEO II data
- moments of E_γ in $b \rightarrow s\gamma$

$|V_{ub}| \times f_B$ from $B \to \tau\nu$



Rosner & Harrison J.Phys.G18:1673-1677,1992

$$\frac{\mathcal{B}(B \to \tau\nu)}{\Delta m_d} \propto |V_{ub}/V_{td}|^2$$

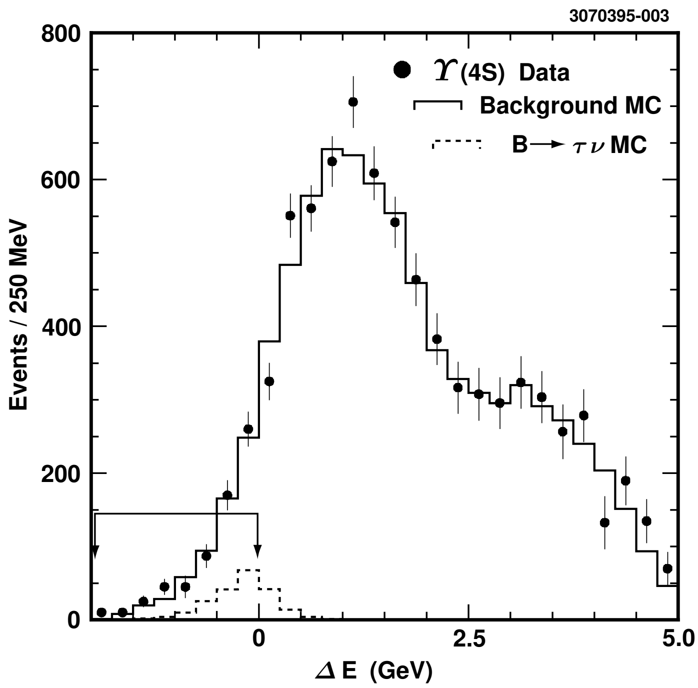
Ignores uncertainty in bag parameter!

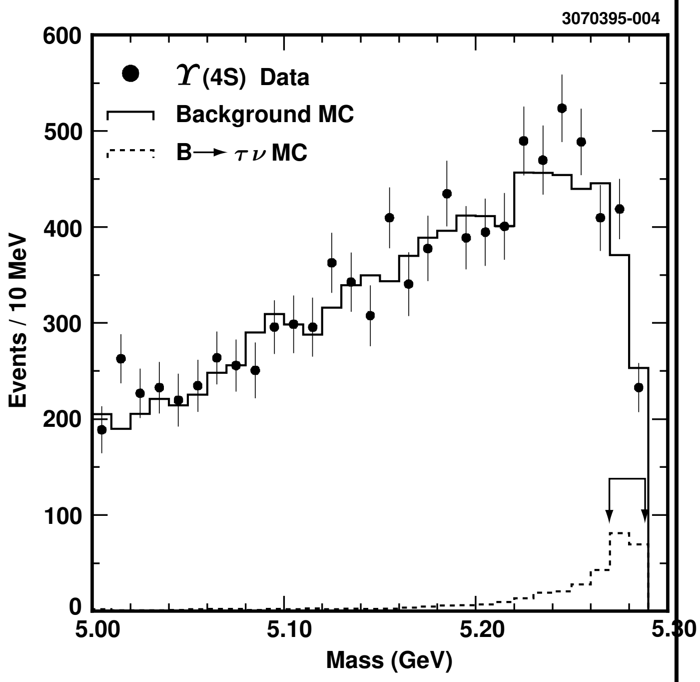
$|V_{ub}| \times f_B$ from $B \to \tau\nu$

Two CLEO analyses in public domain:

- 1992 Summer Conference paper:
  - 716 ± 123 out of 10^6 B's fully reconstructed
  - no candidate $B \to \tau\nu$ found
  - $\mathcal{B}(B \to \tau\nu) < 1.3\%$ @ 90% CL
  - $\to$ scales like 1/luminosity
  - Needs factor 260 more luminosity
- PRL 75, 785 (1995)
  - no signal on top of gigantic background
  - 4.1% eff., $2.2 \times 10^6 B\bar{B}$'s used in analysis
  - $\mathcal{B}(B \to \tau\nu) < 0.22\%$ @ 90% CL
  - $\to$ scales like $1/\sqrt{\text{luminosity}}$
  - Need factor 2000 more luminosity !!!
- Work currently in progress:
  - improve 1992 strategy by factor 10
  - unclear when this becomes bkg limited
  - see few signal on (hopefully) few bkg with CLEO III

Published $B \to \tau\nu$ Analysis





Searching for New Physics with FCNC

CLEO III reach in a nutshell:

	CLEO with $3e6\ B\bar{B}$	CLEO III reach
$b \to s\gamma$	$3.15 \pm 11\% \pm 10\% \pm 8\%$	2.5% stat.
$A_{cp}(b \to s\gamma)$	$0.16 \pm 0.14 \pm 0.05$	3% stat.
$B \to (\rho/\omega)\gamma$	—	$\sim 20 - 30\%$
$b \to sl^+l^-$	$< 4.2 \times 10^{-5}$ @ 90%CL	$\sim 20\%$
$A_{cp}(b \to sl^+l^-)$	—	$\sim 20\%$
$B \to K^* l^+ l^-$	$< 7 \times 10^{-6}$ @ 90%CL	$\sim 20 - 50\%$
$A_{FB}(m_{l^+l^-})$	—	NO
$B \to K^{(*)}\nu\bar{\nu}$	—	? similar to $\tau\nu$?
$b \to s\nu\bar{\nu}$	—	NO

A closer look at $b \to s\gamma$

$\mathcal{B}(b \to s\gamma) = 3.15 \times 10^{-4}$	$\pm 11\%$	$\pm 10\%$	$\pm 8\%$
	stat.	detector syst.	model syst.

So far used only 1/3 of CLEO II data !!!

- Detector systematics:
  - 5.2% off-resonance subtraction

    $\to$ work harder on E_γ scaling

    $\to$ work harder on running conditions
  - 5.2% $B\bar{B}$ subtraction

    $\to$ need to understand $\mathcal{B}(b \to s(\pi^0, \eta))$
  - 7.0% efficiency systematics

    re-optimize the analysis:

    $\to$less weight to pseudo-reconstruction
- Model Dependence:
  - 6.5% E_γ spectrum

    decrease E_γ cut:

    $\to$ need to understand $\mathcal{B}(b \to s(\pi^0, \eta))$
  - 5.0% uncertainty due to hadronization

    re-optimize the analysis:

    $\to$less weight to pseudo-reconstruction

Summary: CLEO @ 2004

"Reasonable" Expectation:

γ	$\pm 10^\circ$ but model dep.
	$\pm 20^\circ - 50^\circ$ but model indep.
$\lvert V_{cb}\rvert$	$\sim 3\%$ (today $= 7\%$)
$\lvert V_{ub}\rvert$	precision q^2 distribution
	$< 1\%$ stat., theory ???
$A_{cp}(b \to s\gamma)$	5%
$B \to (\rho/\omega)\gamma$	$\sim 20 - 30\%$
$b \to s l^+ l^-$	$\sim 20\%$
$A_{cp}(b \to s l^+ l^-)$	$\sim 20\%$

"Crazy" Speculation:

Observation of $B \to \tau\nu$

Observation of $B \to K^{(*)}\nu\bar{\nu}$

Short list of the less obvious

- direct CP violation in lot's of places
- γ via Dalitz-plot in $B \to 3\pi$
- right handed coupling in $B \to D^* l\nu$
- rare and forbidden τ decays
- D^0 Mixing
- FCNC D Decays
- $B \to \tau^+\tau^-, \tau^+ e^-, \tau^+\mu^-$
- $B \to \mu\nu, e\nu$
- hybrid Mesons
- Glueballs
- ...