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A Review of the |Vub| and |Vcb| Determinations

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on behalf of the Vub and Vcb Working Groups

Introduction

Accurate $|V_{ub}|$ and $|V_{cb}|$ determination with well understood uncertainty a key goal of heavy flavour physics programs;

Measuring upper vertex of Unitarity Triangle plays crucial role in studying origin CP violation and answering fundamental questions which relate to it;

Theory, models and experimental techniques outline comprehensive program based on Inclusive and Exclusive methods where signal purities, control of backgrounds & theory uncertainties and extracti of theory parameters directly from data are the main issues;

With present & foreseen experimental accuracies, theory uncertainties dominat error budget making test of underlying assumptions necessary: perform determinations with different methods and verify consistency will add tru on each result;

Different kinematics and detector configurations at symmetric $\Upsilon(4S)$, asymmetr $\Upsilon(4S)$ and Z^0 and large data sets brought an healthy competition of complementary approaches to this program.

✧ Extraction of CKM elements from inclusive decay rates based on Heavy Quark Theory implemented through **O**perator **P**roduct **E**xpansion in the form of **HQE**;

✧ Expansion in powers of energy release in transition: $\simeq m_b$ in $b \to u$ and $m_b - m_c$ in $b \to c$ for inclusive rates and partially integrated spectra;

✧ HQE provides consistent theory framework for relating decay rates to $|V_{ub}|$ and $|V_{cb}|$:

$$\Gamma_{sl} = F_{b\ quark\ decay} \times (1 + \frac{0}{m_b} + \frac{f(\lambda_1,\lambda_2)}{m_b^2} + ... + \alpha_s(...) + \alpha_s^2(...) + ...)$$

$$V_{ub} = 0.00445 \times \left(\frac{\mathrm{B}R(b \to u\ell\bar{\nu})}{0.002}\frac{1.55\mathrm{ps}}{\tau_b}\right)^{1/2} \times (1 \pm 0.020 \pm 0.052)\,,$$

✧ OPE predictions postulate quark-hadron duality, expected to hold best for s.l. decays, prompting the need for experimental tests;

✧ must determine input parameters: m_b $[\bar{\Lambda}]$, μ_π^2 $[\lambda_1]$, (ρ_D^3, ...);

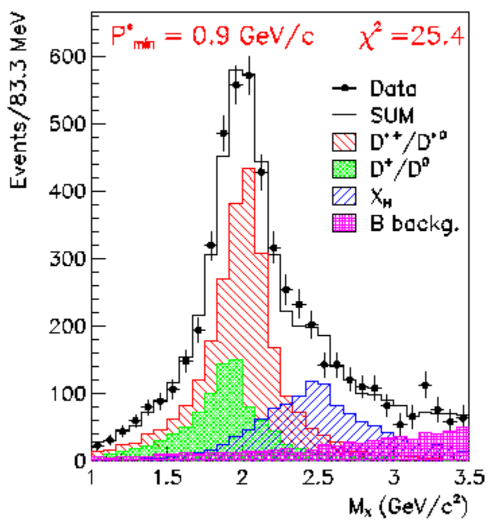
✧ must understand effects of experimental cuts trimming inclusive distributions.

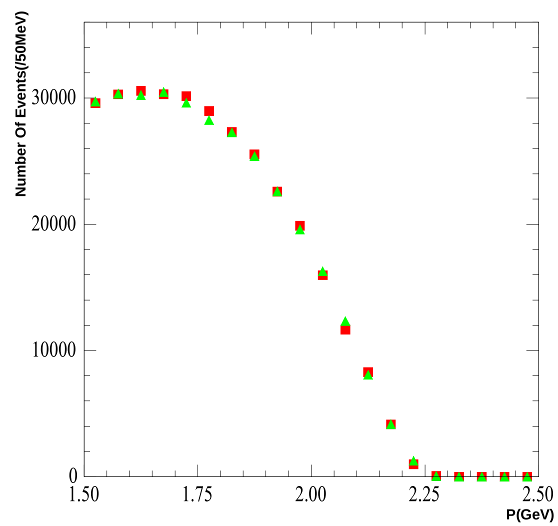
Extracting Parameters and Testing OPE with Data

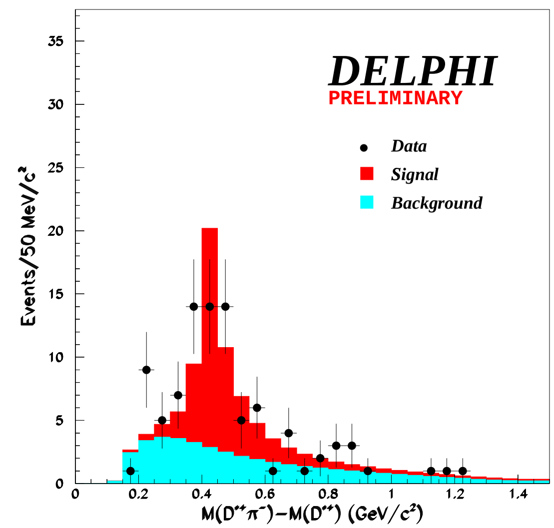
✧ Relations between first moments of E_ℓ, M_X and E_γ and b-quark mass and kinetic energ

Several Determinations now becoming available:

BaBar	Cleo	Delphi
	$E_0(E_\ell)$, $E_1(E_\ell)$	$E_1(E_\ell)$, $E_2(E_\ell)$, $E_3(E_\ell)$
$M_1(M_X)$	$M_1(M_X)$, $M_2(M_X)$	$M_1(M_X)$, $M_2(M_X)$, $M_3(M_X)$
	$M_1(E_\gamma)$ $M_2(E_\gamma)$	

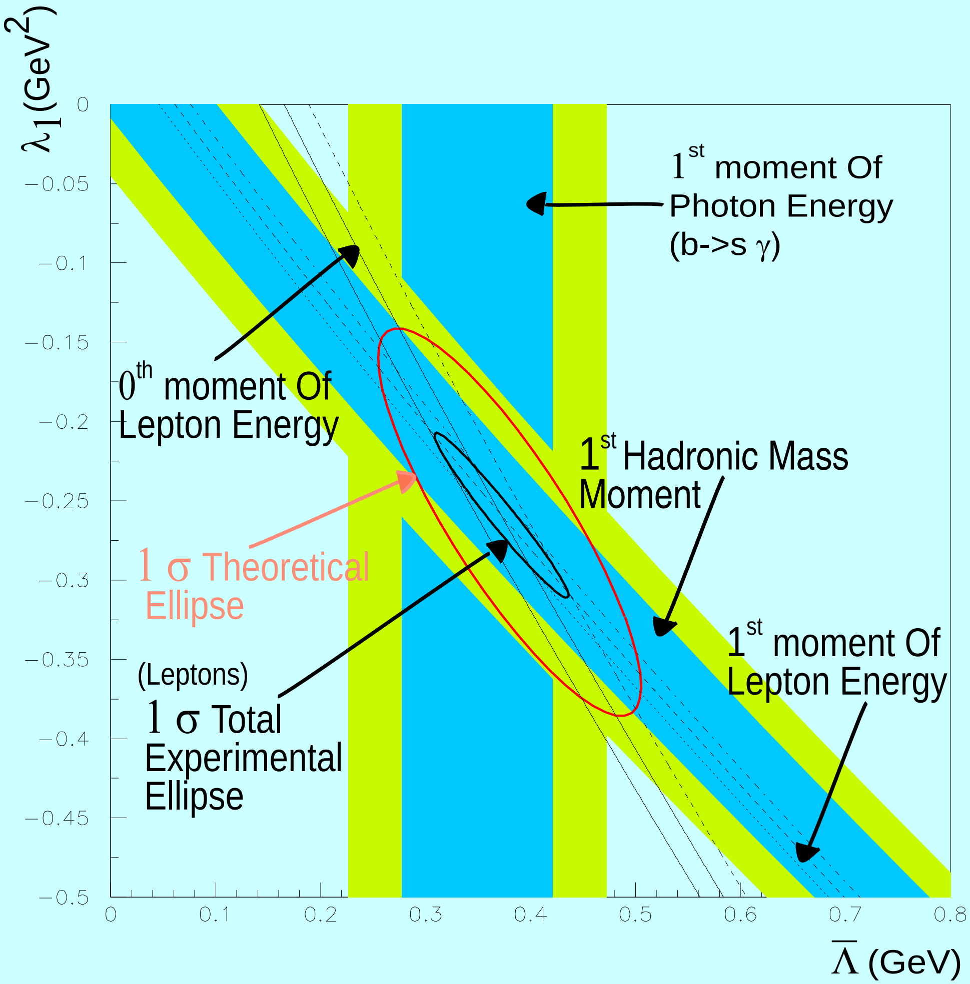






✧ Consistency between different determinations sets constraints on possible duality violation as well as on effects from truncated OPE.

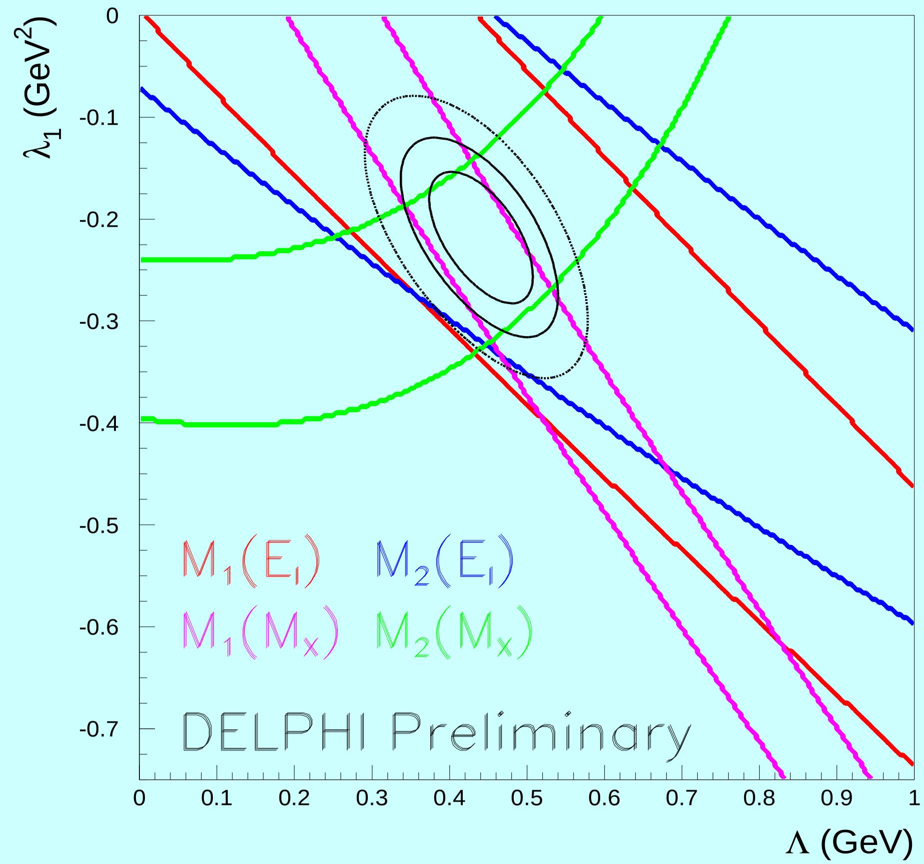
CLEO PRELIMINARY



$\bar{\Lambda}$=(**0.39±.03±.06±.12) GeV**

λ_1=(**-0.25±.02±.05±.14) GeV^2**

DELPHI PRELIMINARY



$\bar{\Lambda}$=(**0.44±.04±.05±.07) GeV**

λ_1=(**-0.23±.04±.05±.08) GeV^2**

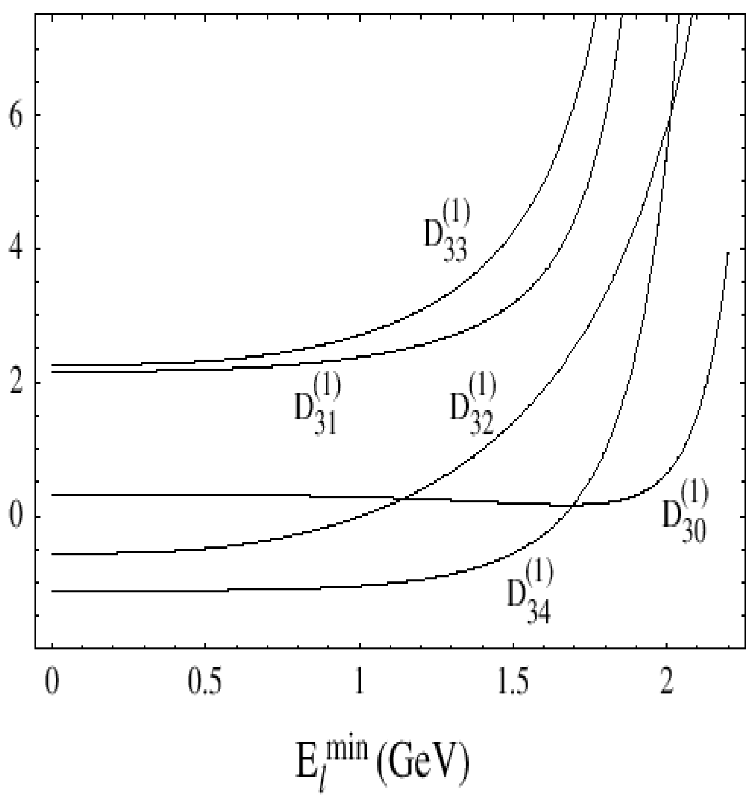
✧ Power corrections increase with E_ℓ cut → interesting to test stability of fit results:

CLEO $E_\ell > 1.5$ GeV   DELPHI $E_\ell \geq 0.5$ GeV

BABAR 0.8 GeV $< E_\ell < 1.6$ GeV

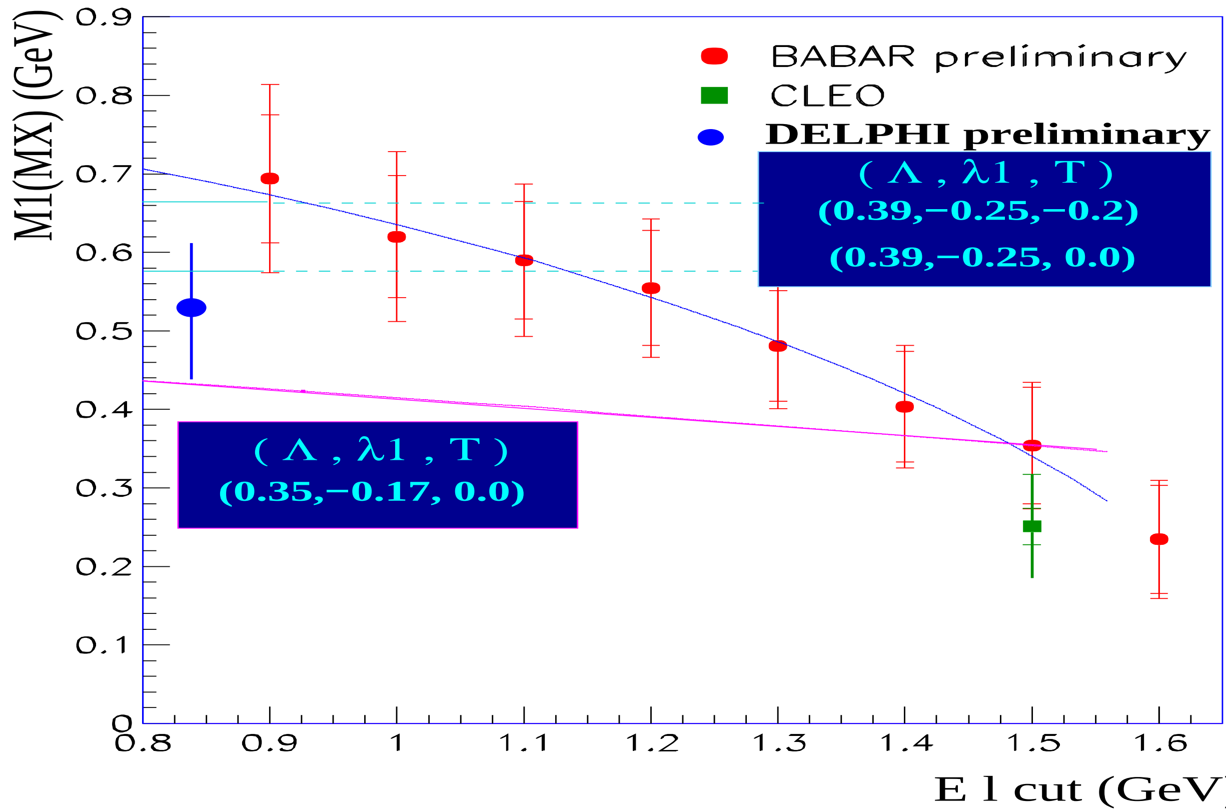
$1/m_b^3$ Coefficients vs. E_ℓ^{cut}

Falk and Luke



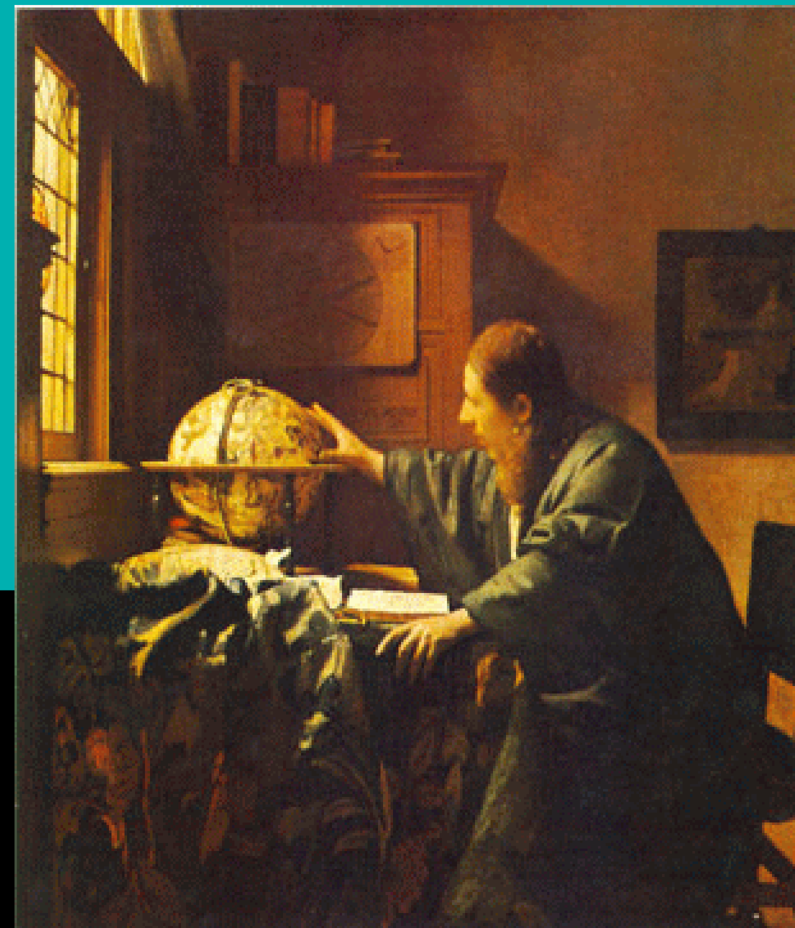
$M_1(M_X)$ vs. E_ℓ^{cut}

CLEO + BABAR + DELPHI PRELIMINARY



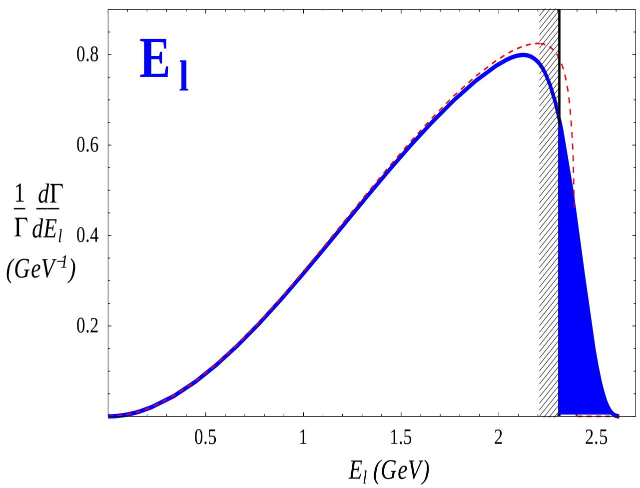
✧ Slope tells of non-resonant states or rather about $1/m_b^3$ parameters ?

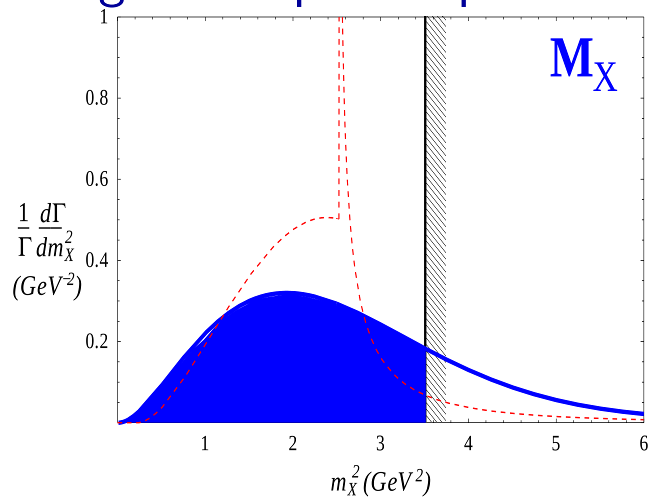
Vub

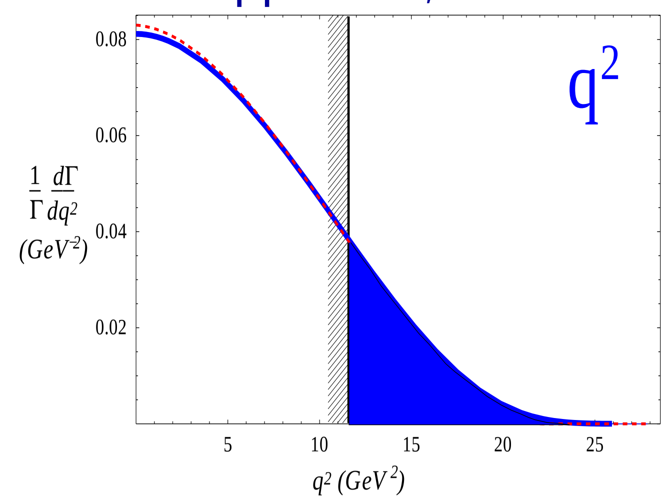


$|V_{ub}|$ Inclusive Determinations

Main issue $b \to u$ signal extraction from $\simeq 75\times$ larger $b \to c$: need to know and control differential rates in regions of phase space where $b \to c$ suppressed;







$E_\ell > \frac{M_B^2 - M_D^2}{2M_B}$ $\qquad M_{uq} < M_{cq}$ $\qquad M_{\ell\nu}^2 = q^2 > (M_B - M_D)^2$

	ALEPH	BABAR	CLEO	CLEO	DELPHI	L3	OPAL
	EPJC6(99)		PRL88(02)		PLB478(00)	PLB436(98)	EPJC21(01)
	NN	E_ℓ	E_ℓ	$M_X - q^2$	M_X	$\pi - \ell$	NN
F_u		.07	.13	0.15	0.68		
Purity	0.06	.27	0.28		0.09	0.18	0.04
$\sigma_{b\to c}$	15%	3%	7%	6%	12%	22%	15%
σ_{th}	9%	13%	13%	14%	10%	10%	10%

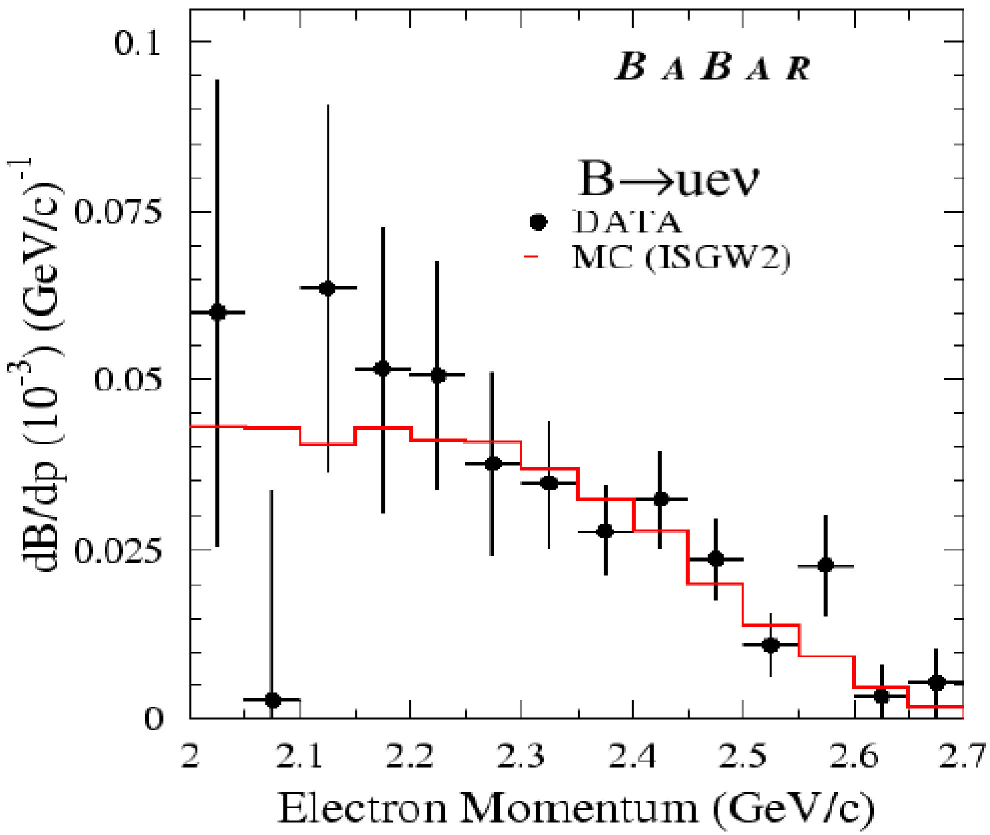
BaBar E_e Endpoint

Preliminary

Count within 2.3 GeV< E_e <2.6 GeV

compute F_u with $b \to s\gamma$

$F_u = 0.07$, S/B = 0.26



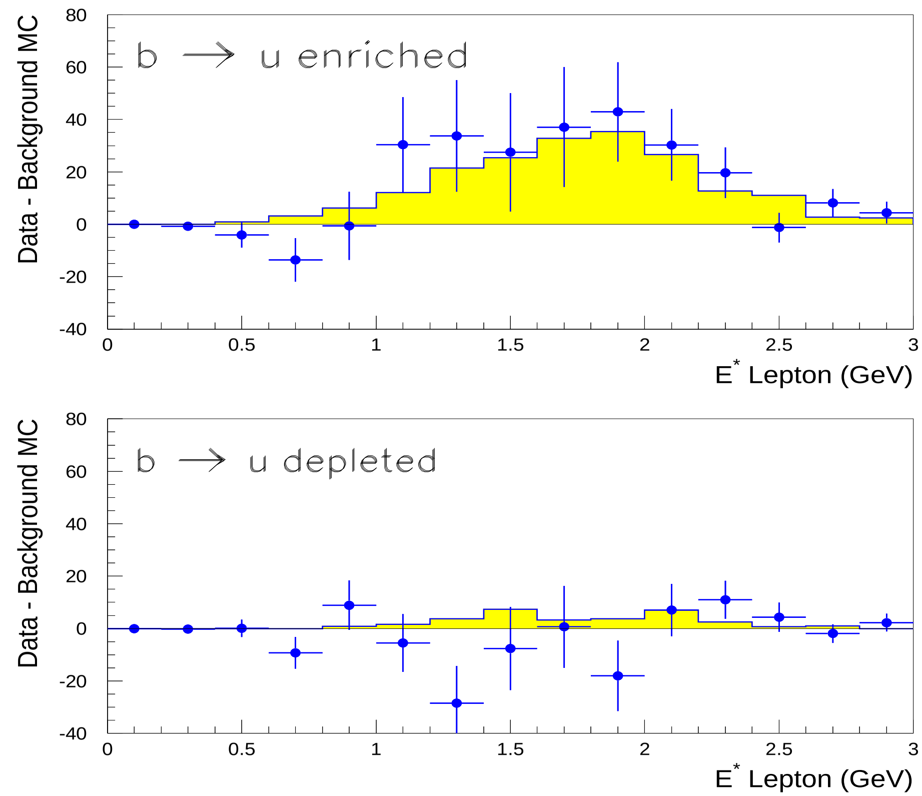
DELPHI M_X

PLB B478 (2000)

Fit E_ℓ^* for $M \gtrless 1.6$

for enriched and depleted samples

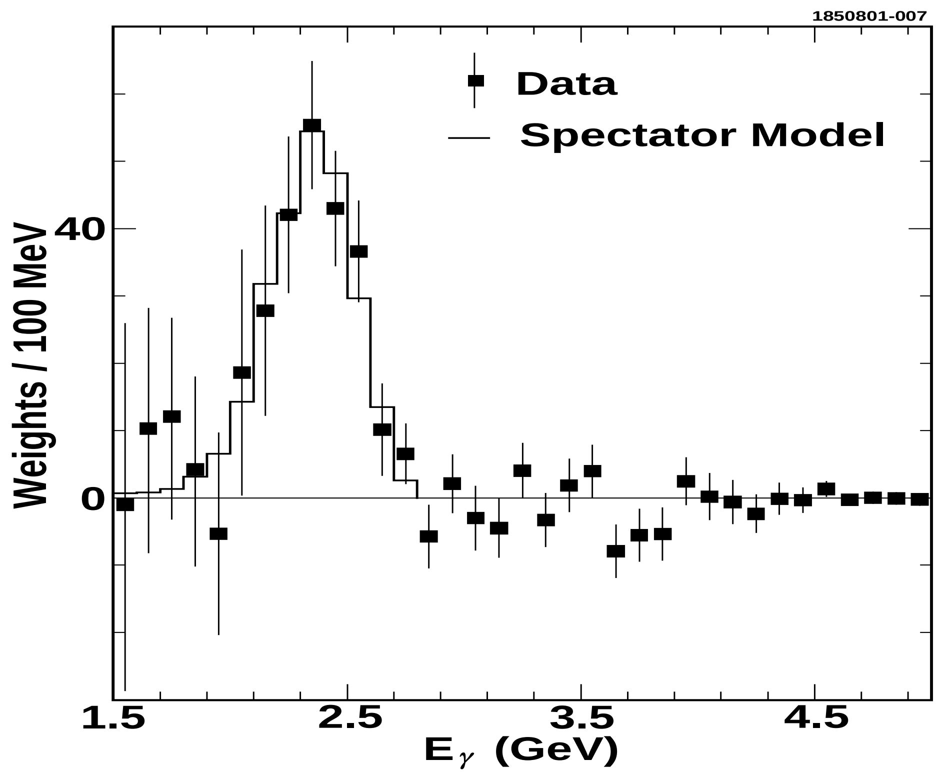
$F_u = 0.68$, S/B = 0.10



Issues in Theory Uncertainties: Shape Function Parameters

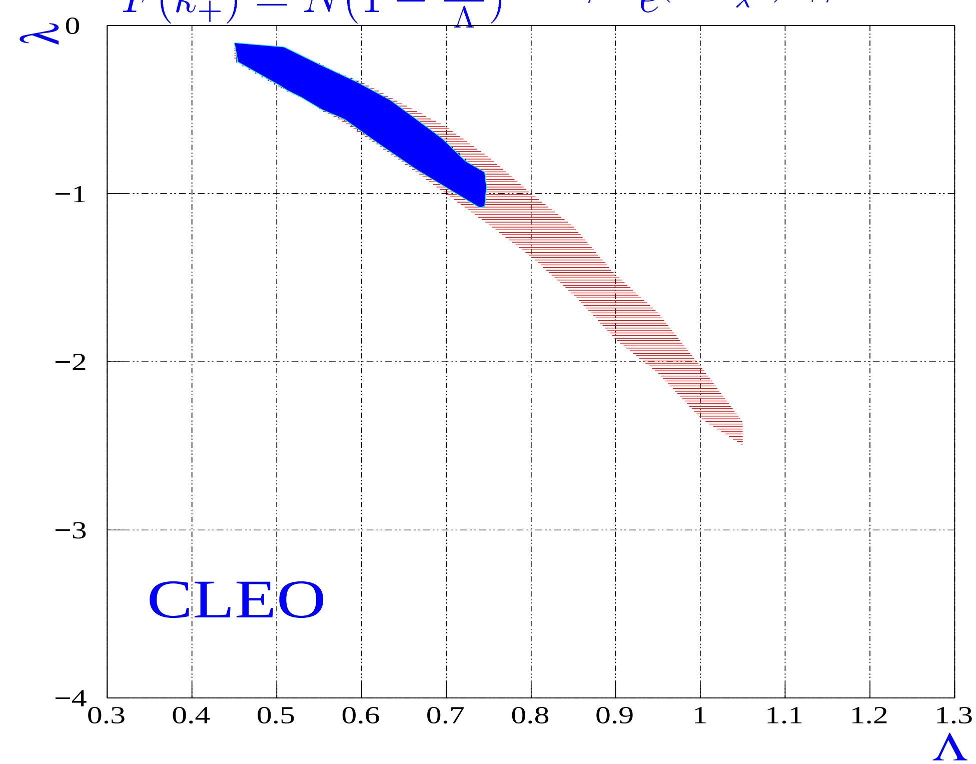
- include non-perturbative effects through shape function $F(k_+)$ and fold parton level $d\Gamma/ds'$ to derive physical distributions $d\Gamma/ds = \int dk_+ d\Gamma/ds' F(k_+)$
- relate $F(k_+)$ in $b \to X_u \ell \bar{\nu}$ and $b \to X_s \gamma$:

CLEO E_γ Spectrum



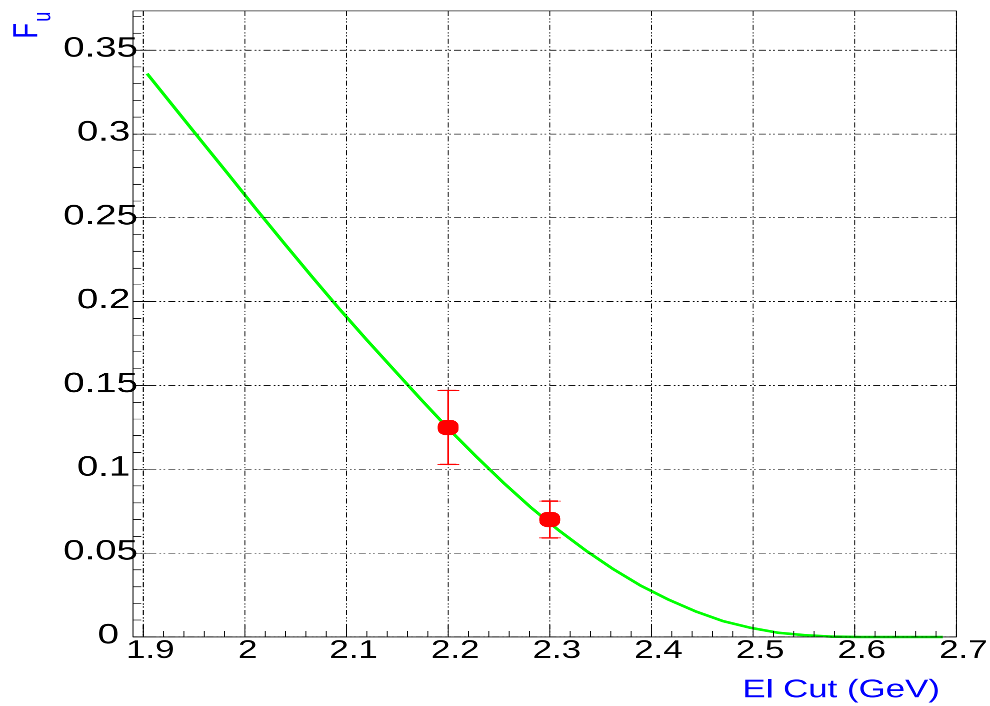
$F(k_+)$ Constraints from $b \to X_s \gamma$

$F(k_+) = N(1 - \frac{k_+}{\Lambda})^{-3\Lambda^2/\lambda}\, e^{(1-\frac{3\Lambda^2}{\lambda})k_+/\Lambda}$



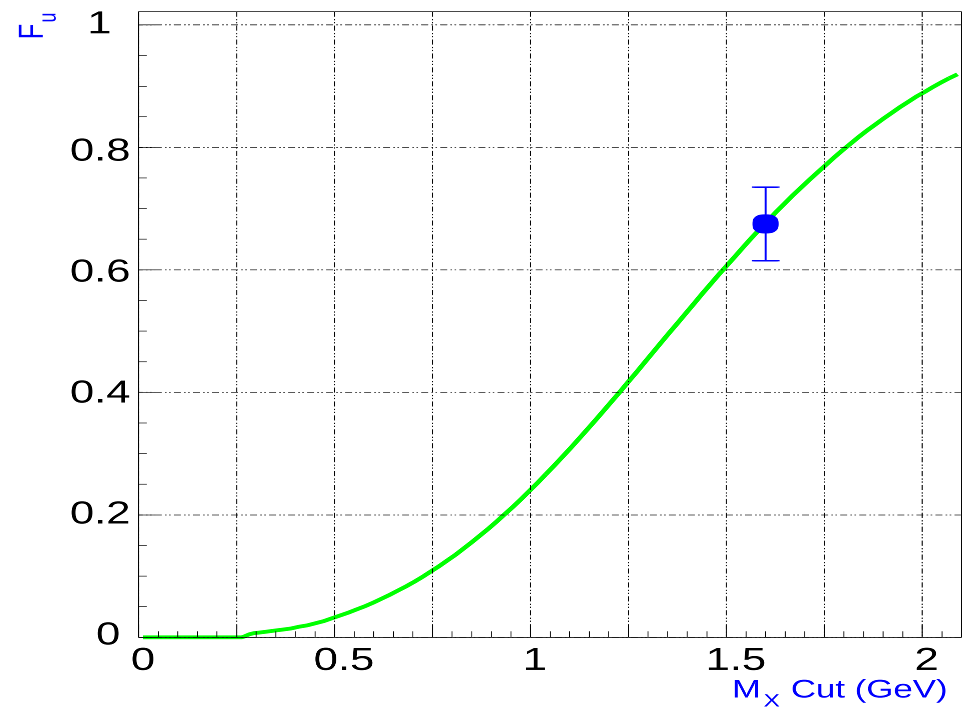
- important to probe full photon spectrum 1.5 GeV$< E_\gamma <$ 2.8 GeV

F_u with E_ℓ Cut



for $E_\ell > 2.2$ GeV $\delta|V_{ub}|/|V_{ub}| = \pm 8.0\%$

F_u with M_X Cut



for $M_X < 1.6$ GeV $\delta|V_{ub}|/|V_{ub}| = \pm 4.4\%$

Lepton Endpoint subleading corrections suppressed by (Λ_{QCD}/m_b) factors but numerically enhanced;

Future measurements to use $b \to s\gamma$ co straints instead simple parameter ranges

Leibovich, Ligeti, Wise PLB539, Neubert hep-ph/0207002

CLEO M_X-q^2 Preliminary

Use ν reconstruction and combine M_X+q^2 cuts (after Bauer, Ligeti, Luke);

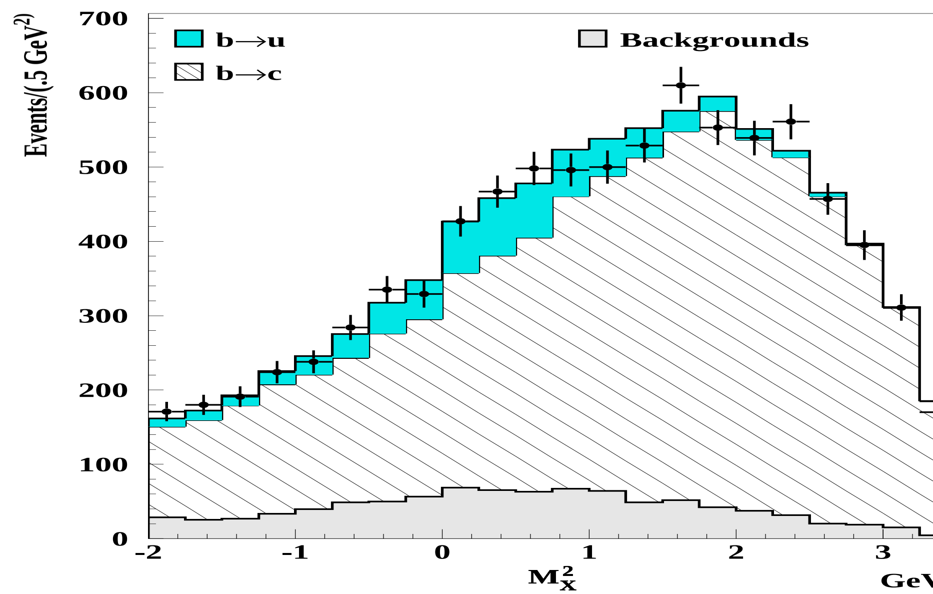
$$M_X \simeq M_B^2 + q^2 - 2E_{beam}(E_\ell + E_\nu)$$

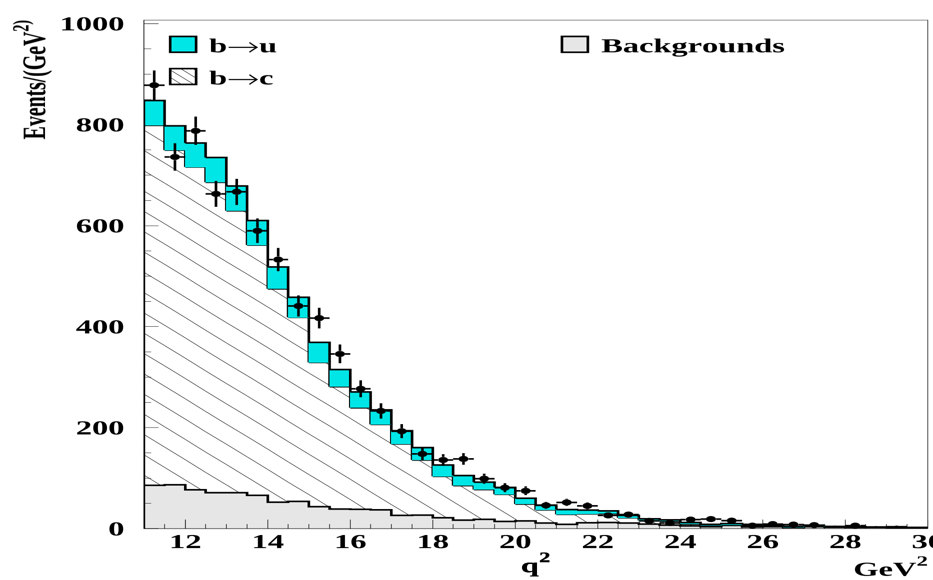
Full fit to $q^2/(E_\ell + E_\nu)^2$, M_X, $\cos\theta_{W\ell}$

Uses models to extract sample composition and to relate regions of highest sensitivity and safe regions to extract $B \to X_u \ell \nu$

Branching fractions inferred for several regions in $M_X - q^2$ plane, HQET+OPE used to extract $|V_{ub}|$ values found to agree.

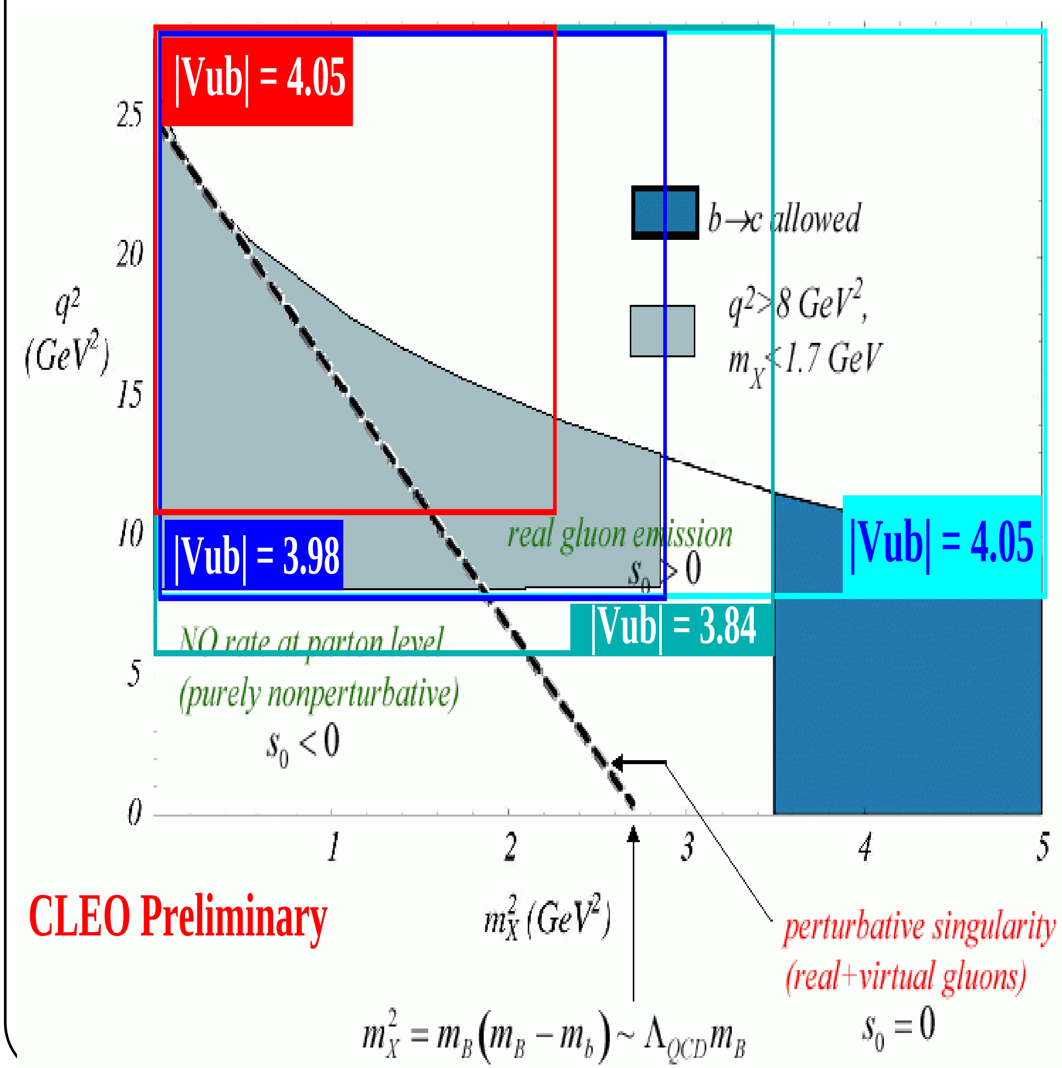
Result given for $M_X < 1.5$ GeV and $q^2 > 11$ GeV^2 to minimise model dependence.



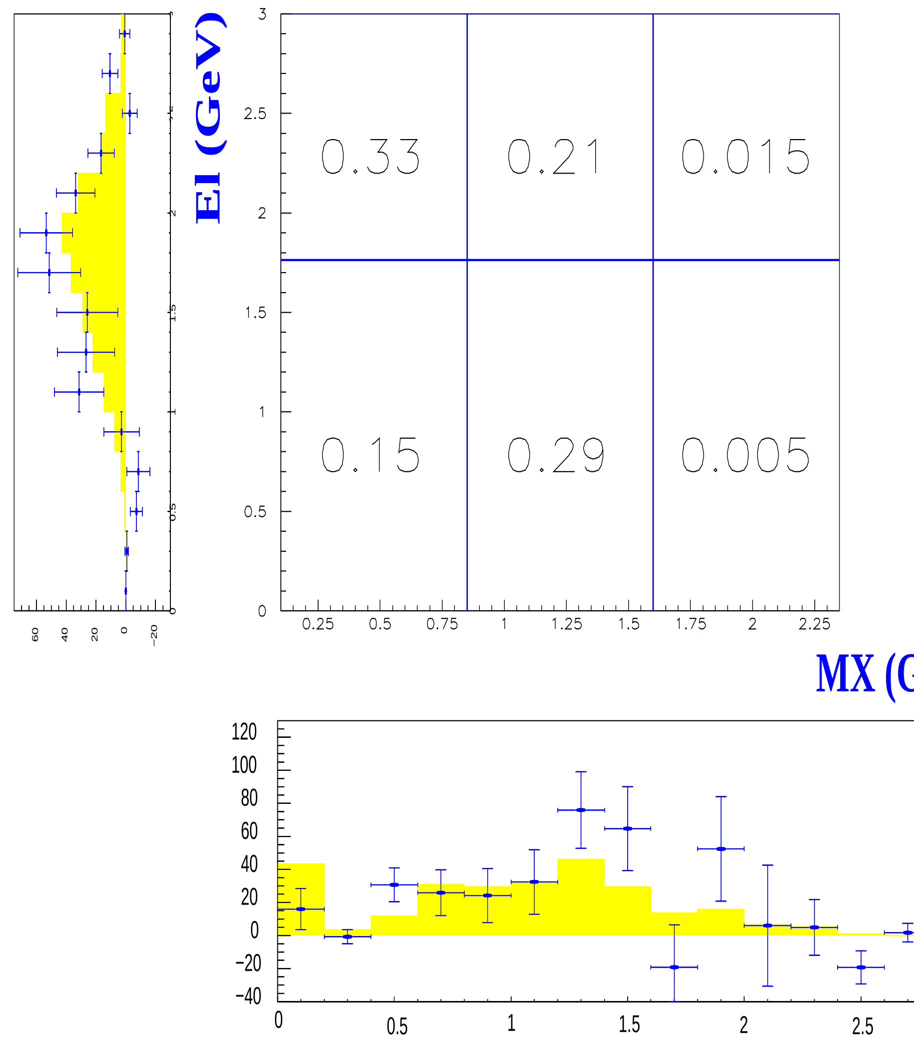


Issues in Theory Uncertainties: Decay Phase-Space Sampling

$|V_{ub}|$ Fits in $M_X - q^2$ (Cleo)



$|V_{ub}|$ Weights in M_X-E_ℓ (Delphi)



$|V_{ub}|$ Exclusive Determinations

$$\frac{d\Gamma(B^0 \to \pi^- \ell^+ \nu)}{dy\, d\cos\theta_\ell} = |V_{ub}|^2 \frac{G_F^2 p_\pi^3 M_B^2}{32\pi^3} \sin^2\theta_\ell |f_1(q^2)|^2,$$

- Exclusive $B \to X_u \ell \bar{\nu}$ decays provide with good S/B and reasonable statistics;
- main uncertainties from form factors due to three sources:
  i) ϵ determination, ii) cross-feed subtraction and iii) normalization;
- Form Factor determinations based on a variety of techniques:
- Light-Cone Sum Rules give $\simeq 15-20\%$ and assume quark-hadron duality
- Quenched Lattice calculations give $\simeq 15-20\%$, applicability limited to large q^2

	BABAR	BELLE	CLEO	CLEO
Channel	$\rho\ell\nu$	$\pi\ell\nu$	$\pi(\rho)\ell\nu$	$\rho\ell\nu$
Purity	0.19			
$\sigma_{b\to c}$	1%		0.8%	1%
σ_{FF}	15%	19%	15%	17%

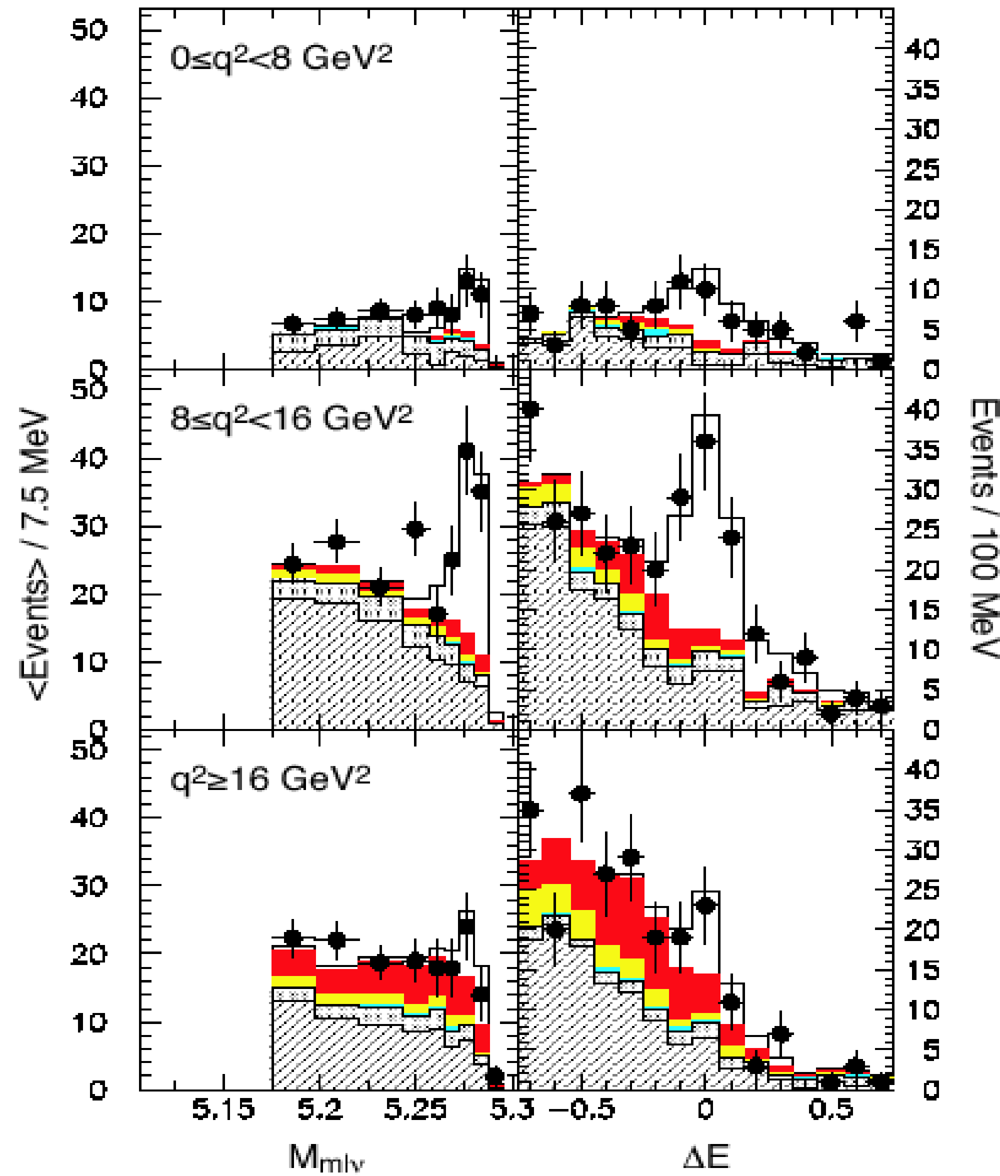
- Need to get $d\Gamma/dq^2$ from data to test models, improve accuracy;
- $\pi\ell\bar{\nu}$ possibly the golden channel here but $\rho/\omega\ell\bar{\nu}$ needed to cross-check results;

✧ Reduce FF dependence by extracting rates independently in q^2 bins;

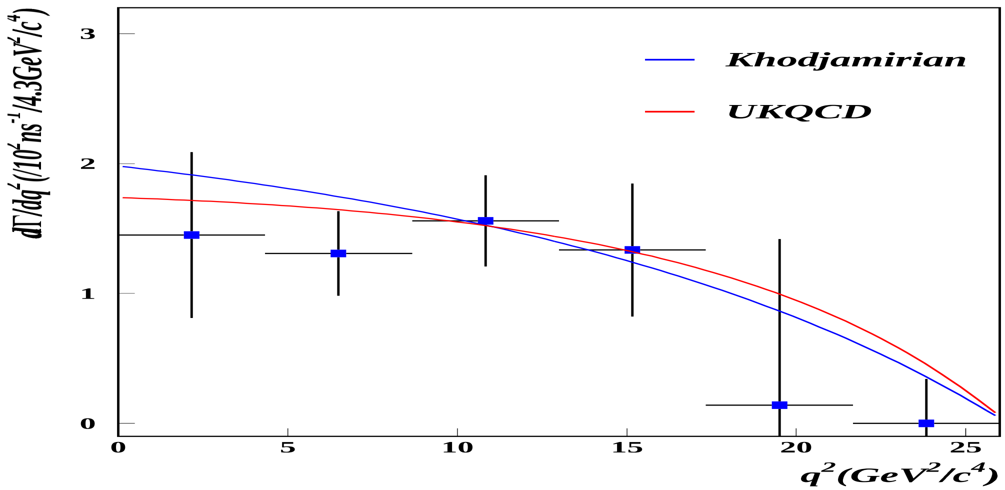
✧ observed uncertainties in $\rho\ell\nu$ from $X_u\ell\bar{\nu}$ feed-down are large;

Channel	BR (10^{-4})
CLEO	Preliminary
$B^0 \to \pi^+\ell^-\bar{\nu}$	$1.38 \pm 0.22 \pm 0.11$
$B^0 \to \rho^-\ell^-\bar{\nu}$	$2.69 \pm 0.41 \pm 0.62$
$B^- \to \eta\ell^-\bar{\nu}$	$0.85 \pm 0.31 \pm 0.14$
Belle	Preliminary
$B^0 \to \pi^+\ell^-\bar{\nu}$	$1.33 \pm 0.11 \pm 0.21$
$B^- \to \rho^0\ell^-\bar{\nu}$	$1.44 \pm 0.18 \pm 0.23$
$B \to \omega\ell\bar{\nu}$	$0.14 \pm 0.04 \pm 0.03$
BaBar	Preliminary
$B^0 \to \rho^-e^-\bar{\nu}$	$3.39 \pm 0.44 \pm 0.79$

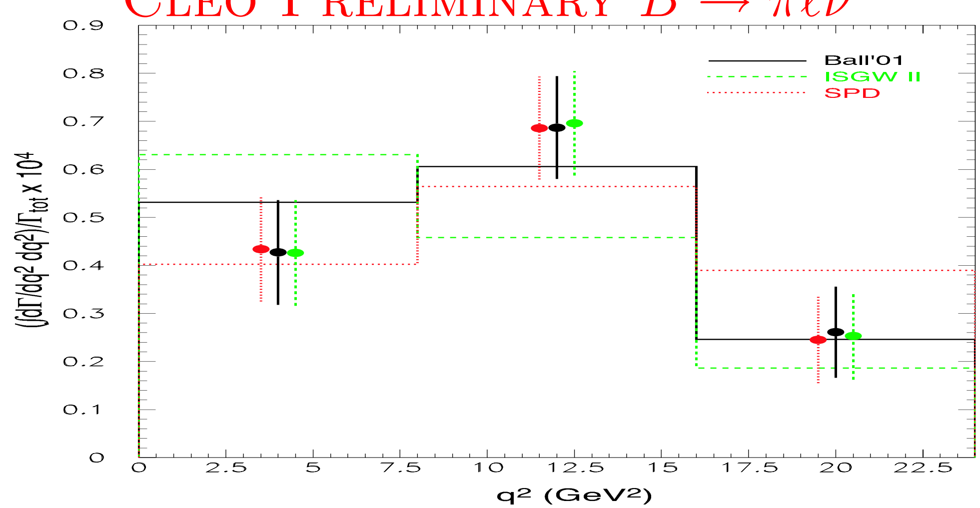
CLEO PRELIMINARY $B \to \pi\ell\bar{\nu}$



BELLE PRELIMINARY $B \to \pi \ell \bar{\nu}$

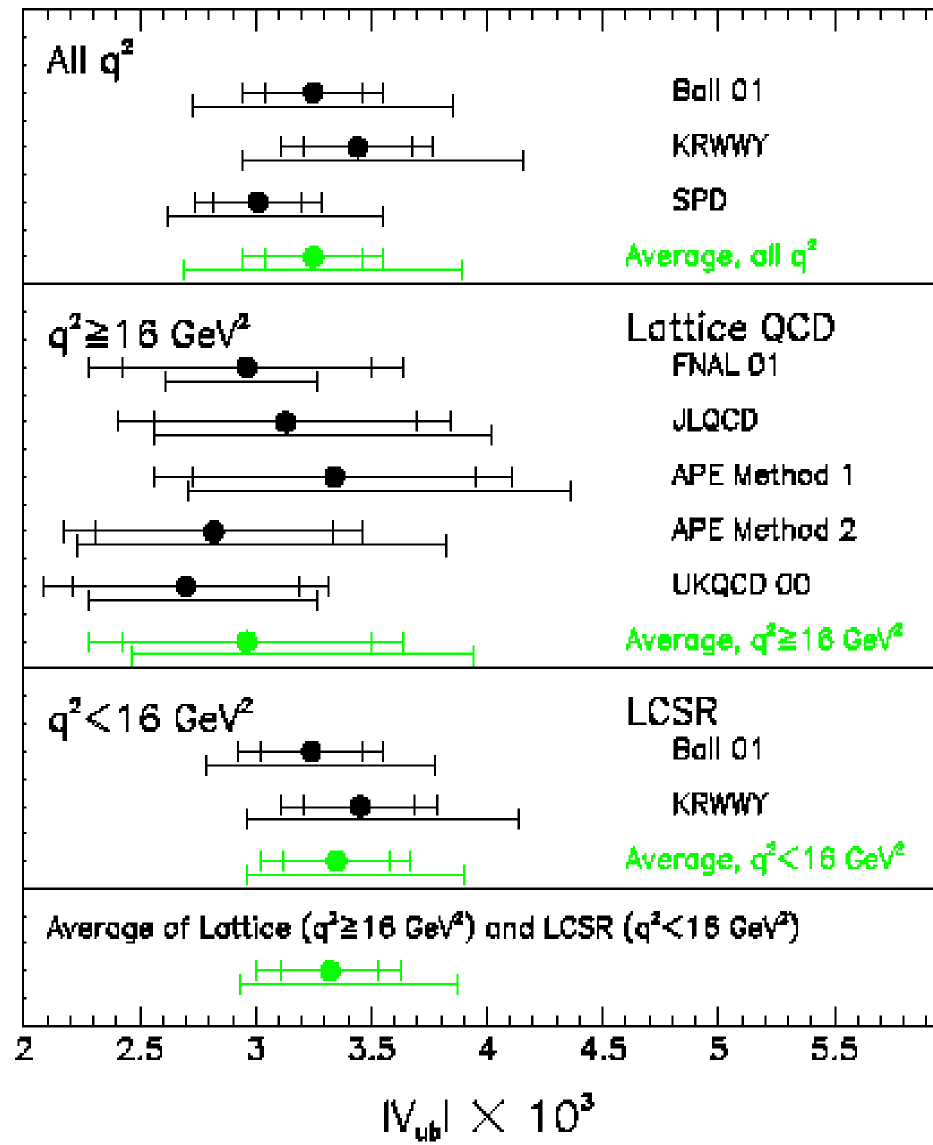


CLEO PRELIMINARY $B \to \pi \ell \bar{\nu}$



Observe Prob(ISGW-II) $< 1\%$
making it unreliable for $|V_{ub}|$ extraction.

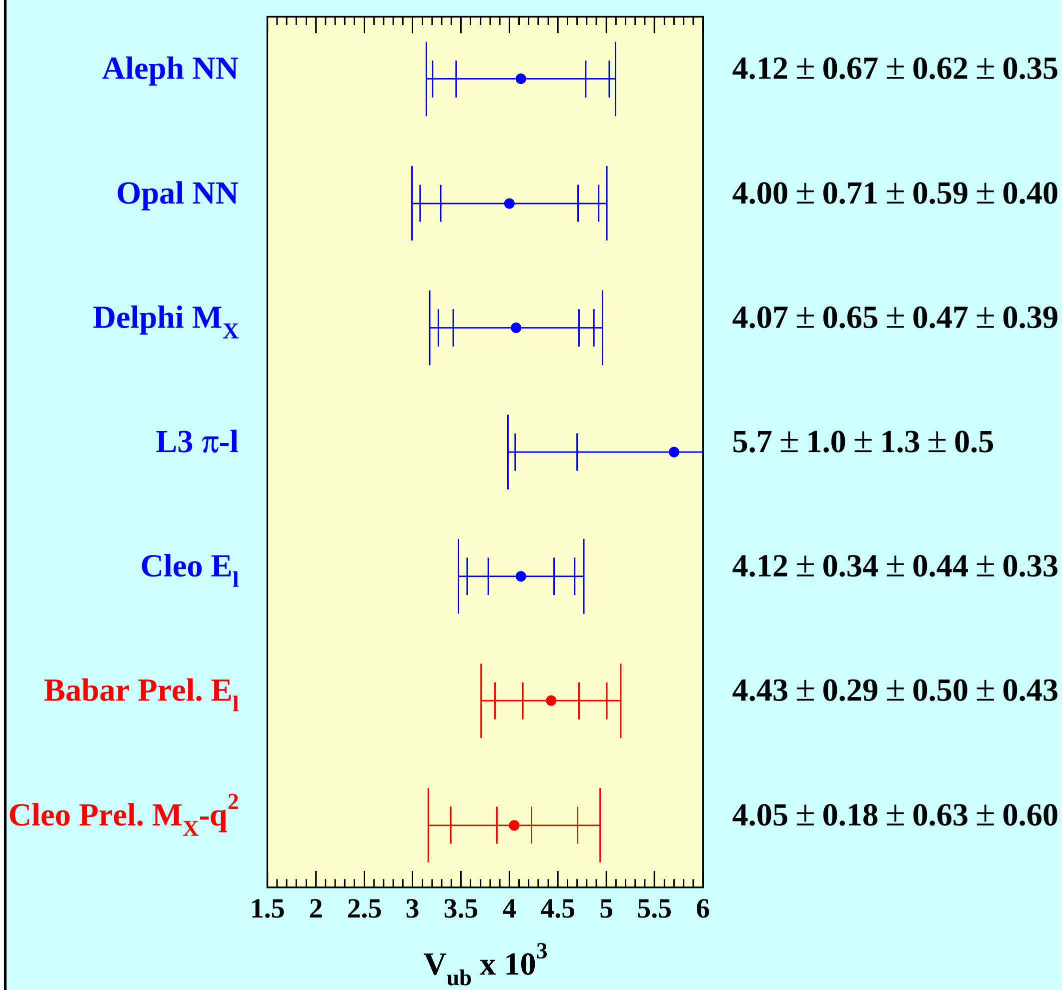
CLEO includes Lattice results for high q^2;



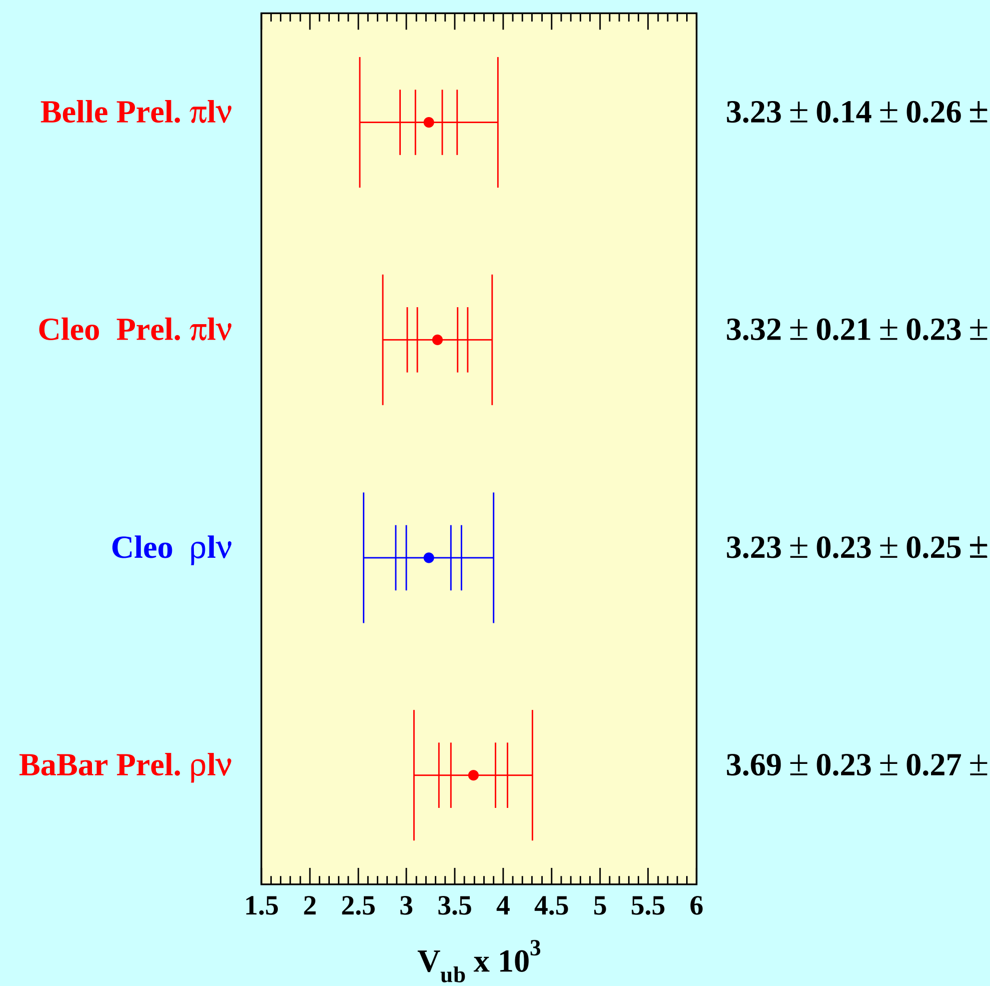
Status of $|V_{ub}|$ Determinations

$|V_{ub}| \times 10^3$

Inclusive Determinations



Exclusive Determinations



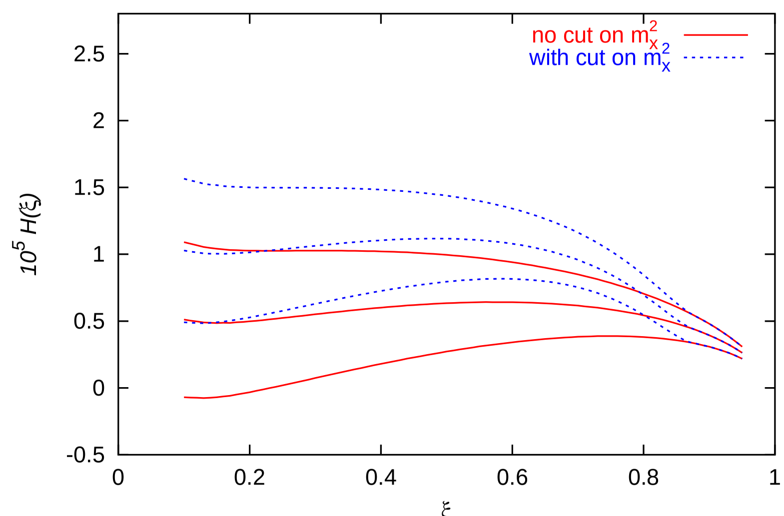
Other Paths to $|V_{ub}|$

$|V_{ub}|$ from Direct Ratio of $s\gamma$ and $u\ell\bar{\nu}$ Spectra

Aglietti, Ciuchini & Gambino

$$\xi_{u\ell\nu} = \frac{2t}{1+t} \quad t = \sqrt{1 - \frac{M_X^2}{E_X^2}}$$

$$\frac{|V_{ub}|^2}{|V_{cb}|^2} = K \frac{d\Gamma}{d\xi_{u\ell\nu}} / \frac{d\Gamma}{dx_{s\gamma}} (x = \xi)(1 \pm 0.10)$$



$|V_{ub}|$ from $B \to D_s\pi$

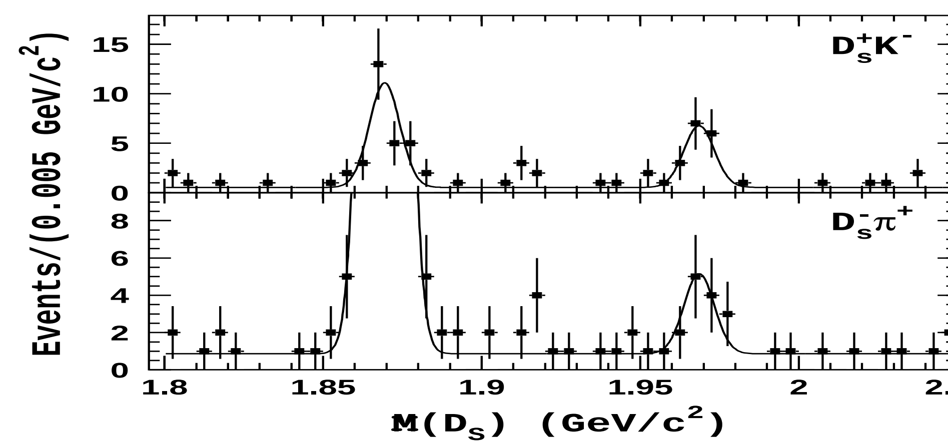
Kurimoto *et al.*, Kim *et al*

Belle Preliminary

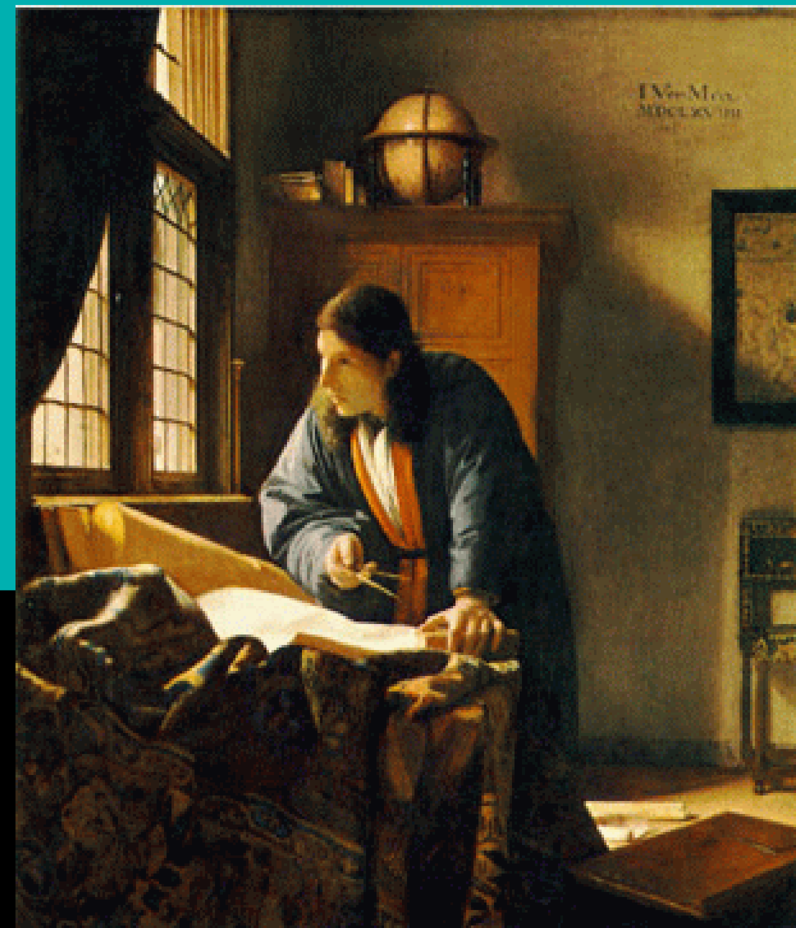
$$\frac{\Gamma(B^0 \to D_s^+\pi^-)}{\Gamma(B^0 \to D_s^+ D-)} = (0.424 \pm 0.041)\frac{|V_{ub}|}{|V_{cb}|}$$

$$= (3.0^{+1.8}_{-1.6}) \times 10^{-3}$$

$$|V_{ub}| = (3.25 \pm 1.0) \times 10^{-3}$$



V_{cb}



$|V_{cb}|$ Inclusive Determinations

$$\Gamma(b \to X_c \ell \bar{\nu}) = \frac{\mathrm{BR}(B \to X_c \ell \bar{\nu})}{\tau_b} = K(m_b, \lambda_1, \ldots) \times |V_{cb}|^2$$

- Accurate determinations of s.l. branching fraction BR($b \to X \ell \bar{\nu}$) and of b-lifetime τ_b:

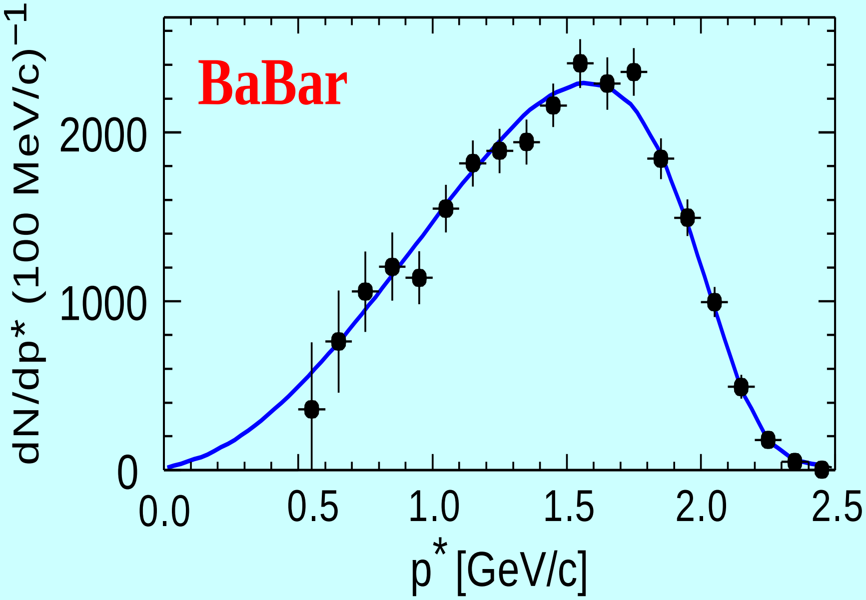
$$\mathrm{BR}(b \to X_x \ell \bar{\nu}) = (10.46 \pm 0.29)\% \quad \tau_b = 1.573 \pm 0.007 \text{ ps}$$

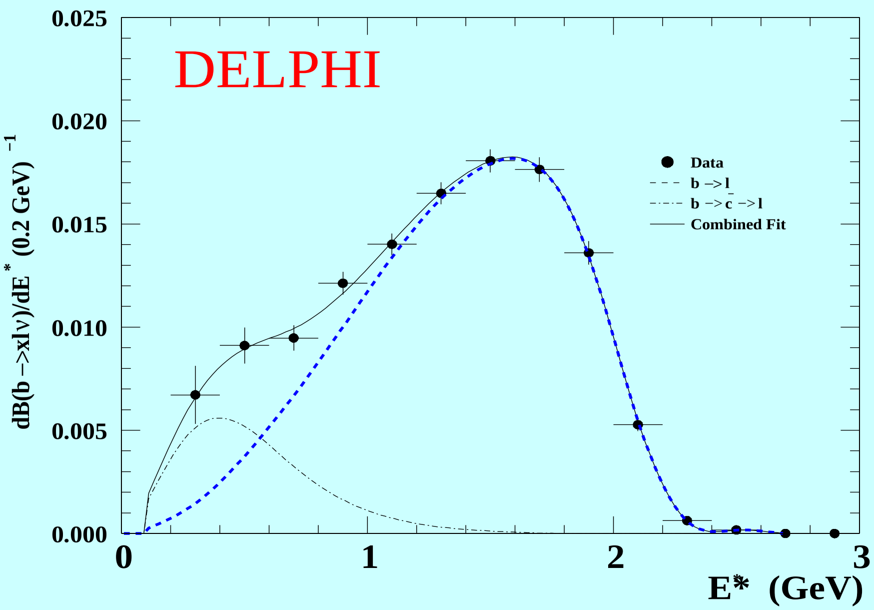
- Experimental accuracy on $|V_{cb}|$ close to 1% makes control of theory systematics crucial;

$$|V_{cb}| = 0.0415 \times (1 - 0.012(\mu_\pi^2) - 0.01(\mathrm{m}_b(1\ GeV)) + 0.006(\alpha_s) + 0.007(\rho_D^3))$$

- Use $\bar{\Lambda}$, λ_1 results of moment analyses to absorb bulk of m_b and μ_π^2 systs. into expt. uncertainties: remaining theory systs due to $1/m_Q^3$ corrections, α_s, scale, ...

$$|V_{cb}| = (40.7 \pm 0.6 \pm 0.8) \times 10^{-3}$$ (V_{cb} WG)





Determinations of $\mathrm{BR}(b \to X\ell\bar{\nu})$

Expt.	BR	stat	syst
CLEO	10.49	±0.17	±0.43
BELLE (ℓ Tag)	10.90	±0.12	±0.49
BABAR (e Tag)	10.87	±0.18	±0.30
AVERAGE	10.63	±0.19	±0.16

Expt.	BR	stat	syst	mode…
ALEPH	10.70	±0.10	±0.23	±0.2…
DELPHI	10.70	±0.08	±0.21	$^{+0.44}_{-0.30}$
L3	10.85	±0.12	±0.38	±0.2…
L3 (double tag)	10.16	±0.13	±0.20	±0.2…
OPAL	10.83	±0.10	±0.20	$^{+0.20}_{-0.13}$
AVERAGE	10.63	±0.09	±0.15	±0.1…

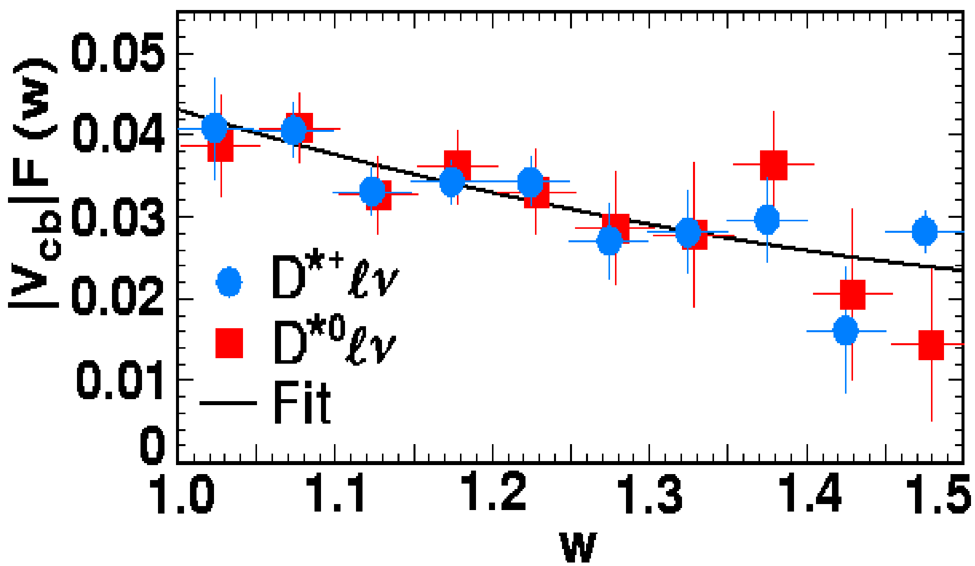
$$\Gamma(b \to X_c \ell\nu) = 0.434 \times (1 \pm 0.018) 10^{-10}\ \mathrm{MeV}…$$

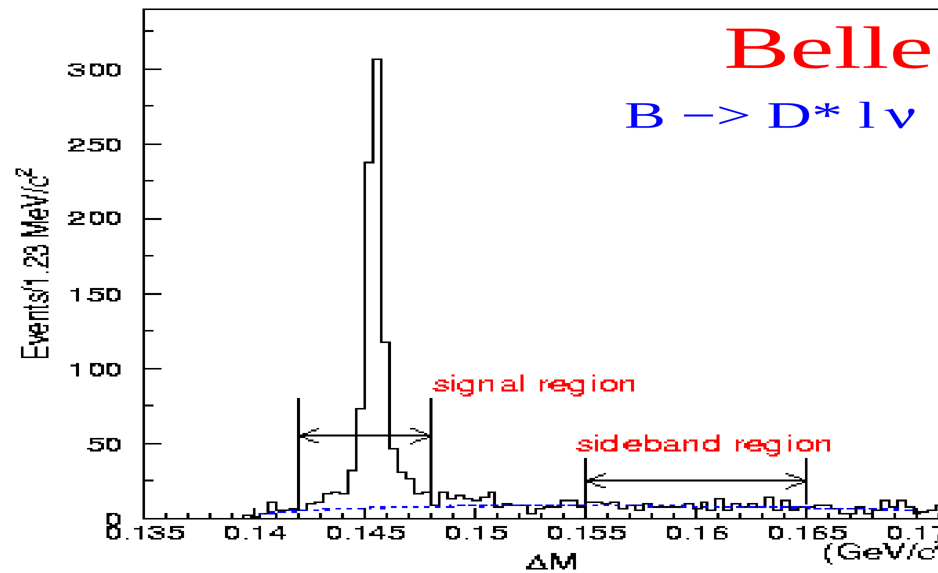
LEP+$\Upsilon(4S)$ V_{cb} WG Average

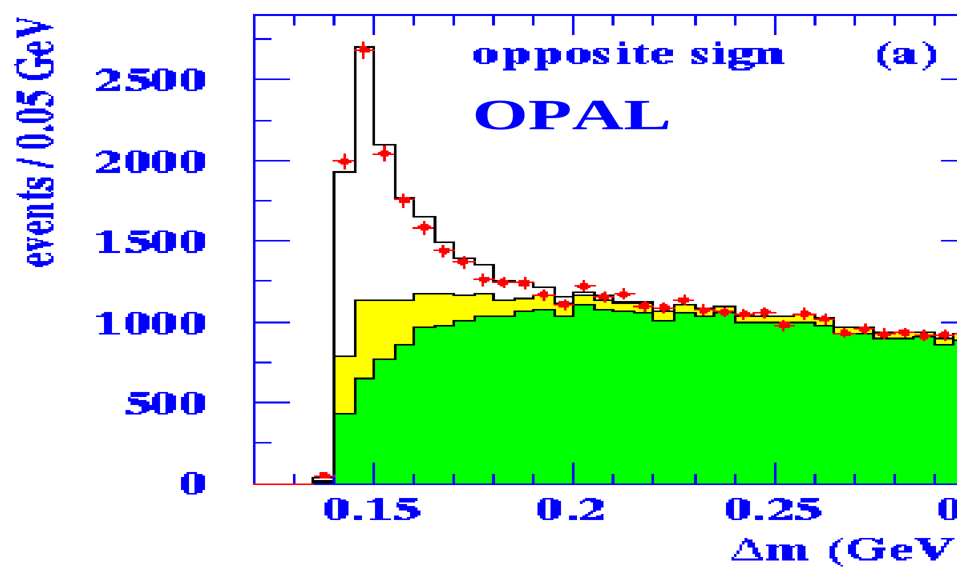
$|V_{cb}|$ Exclusive Determinations

$$\frac{d\Gamma(B \to D^* \ell \bar{\nu})}{dw} = \frac{G_F^2 \mathcal{K}(w)}{48\pi^3} (\mathcal{F}(w)|V_{cb}|)^2$$

$$w = \frac{M_{D^{*+}}^2 + M_{B^0}^2 - q^2}{2M_{D^{*+}}^2 M_{B^0}^2}$$







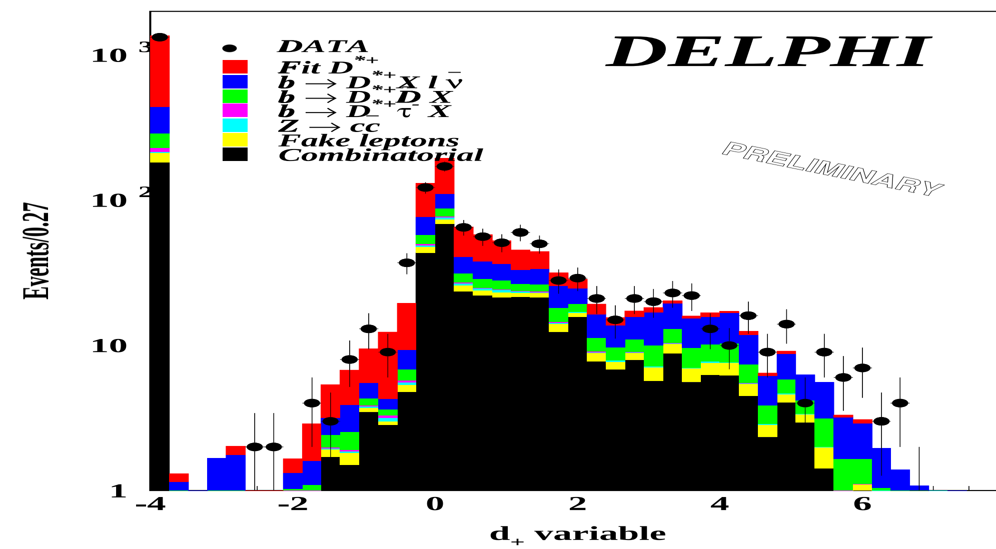
✧ Reconstruction of $B \to D^* \ell \bar{\nu}$ obtained either exclusively $D^* \to D\pi$, $D \to K\pi(\pi)$ or inclusively via $\Delta M = M_{X\pi} - M_X$

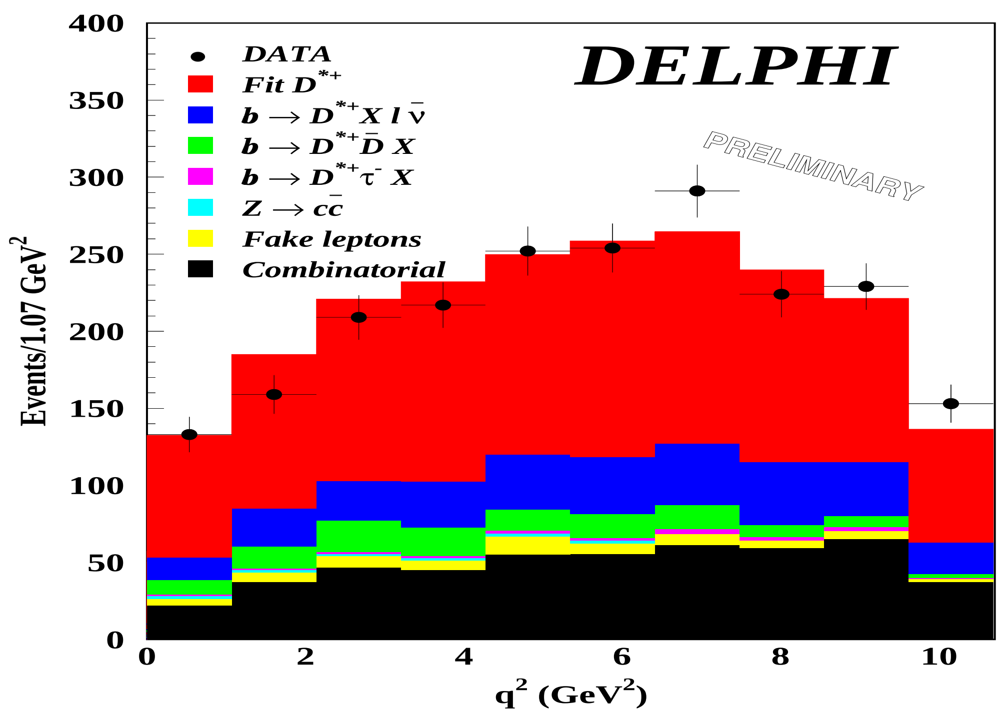
Delphi Exclusive $B^0 \to D^{*+}\ell^-\bar{\nu}$
Preliminary

- Reconstruct $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$, $K^-\pi^+\pi^-$, $K^-\pi^+(\pi^0)$;

$$q^2 = (p_{B^0} - p_{D^{*+}})^2$$

- verify $\epsilon(q^2)$ flat;
- identify $D^* X \ell\bar{\nu}$ and $b \to c\bar{c}s$ by discriminant based on tagged additional secondary tracks;
- fit event yield vs. q^2 leaving normalization of main components free;
- extract $\mathcal{F}(1)|V_{cb}|$, BR($B^0 \to D^{*+}\ell^-\bar{\nu}$) and BR($b \to D^{*+}X\ell^-\bar{\nu}$).

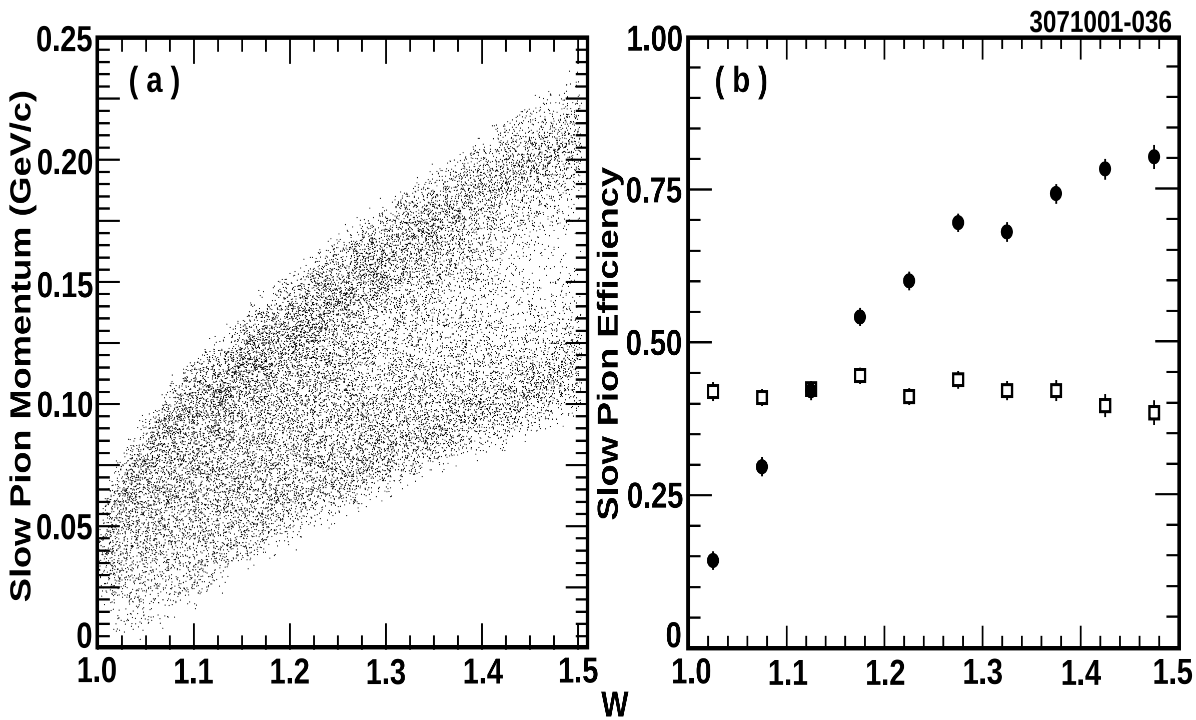


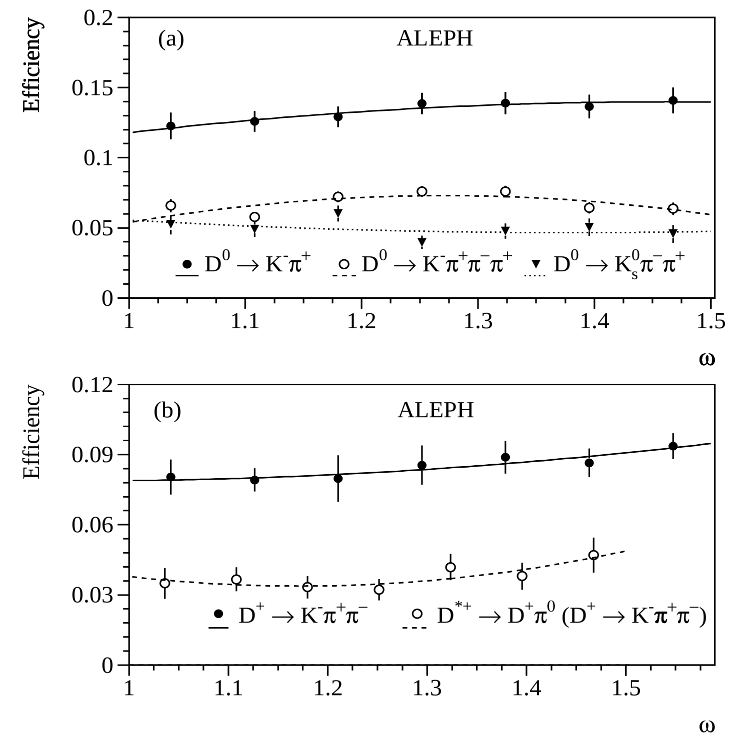


Summary of Properties of $D^*\ell\bar{\nu}$ Analyses

	Aleph PLB395(97)	Belle PLB526(02)	Cleo CLEO 01-26	Delphi PLB510(01)	Delphi	Opal PLB395(97)	Opal PLB482 (0
Technique	Excl	Excl	Excl	Incl	Excl	Excl	Incl
D^* Stats	579	766	2683	6495	1688	1708	
$\frac{b \to D^*\ell\nu}{b \to D^*}$	0.86	0.85	0.90	0.72	0.70	0.77	
δw	0.07	0.04	0.03	0.13	0.11	0.10	0.12
$\Delta\epsilon$	1.0	0.3	0.13/1.	1.0	1.0	1.0	1.0

Reconstruction Efficiency vs. w





Issues in $|V_{cb}|$ Uncertainties: D^{**} Background

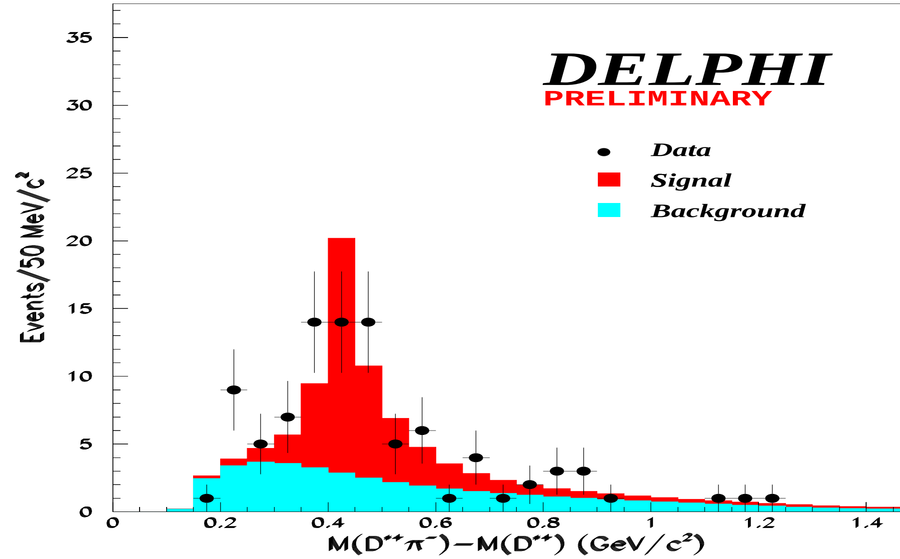
✧ Important correlated syst. uncertainty from $b \to D^{**}\ell\bar{\nu}$ background;

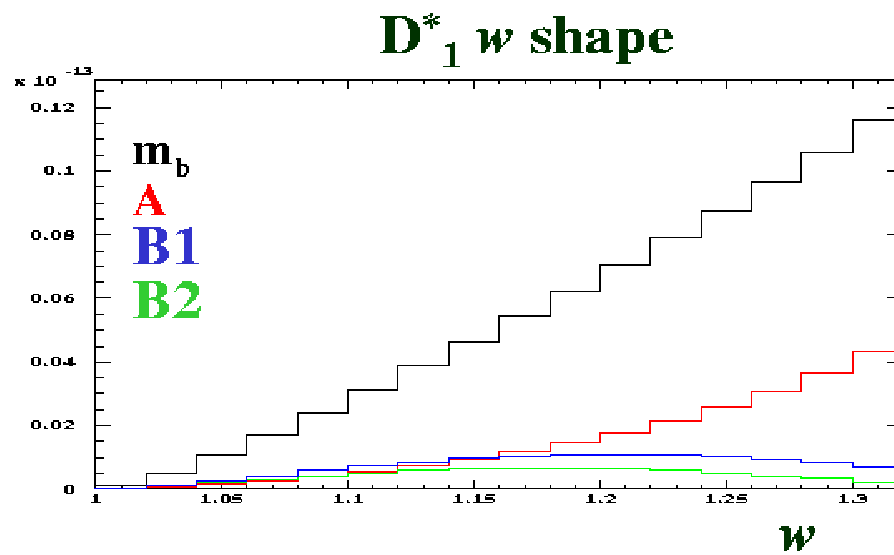
✧ Data on narrow and broad D^{**} states becoming available but decay properties remain poorly known;

✧ Recent analyses fit $D^{*}X\ell\bar{\nu}$ fraction directly on data by angular distributions or track topology;

DELPHI PRELIMINARY

$$\text{BR}(b \to D^{*+}X\ell\bar{\nu}) = (0.64 \pm 0.08 \pm 0.09)\%$$





Issues in $|V_{cb}|$ Uncertainties: $\mathcal{F}(1)$

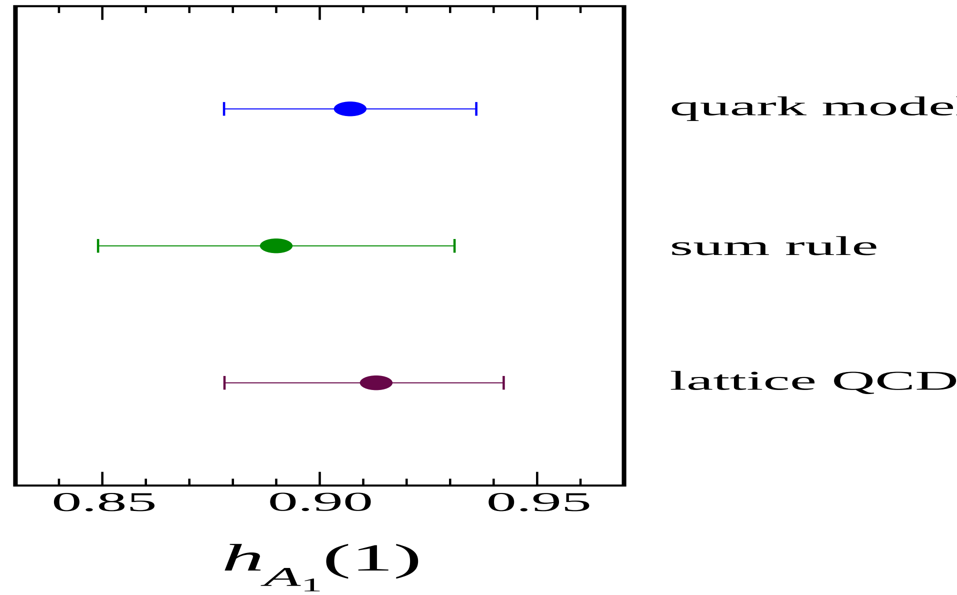
- Form factor $\mathcal{F}$ at zero recoil computed with quark model, sum rule and quenched lattice QCD;
- thorough review of error budget from lattice;
- present value derived from sum rules and lattice QCD:

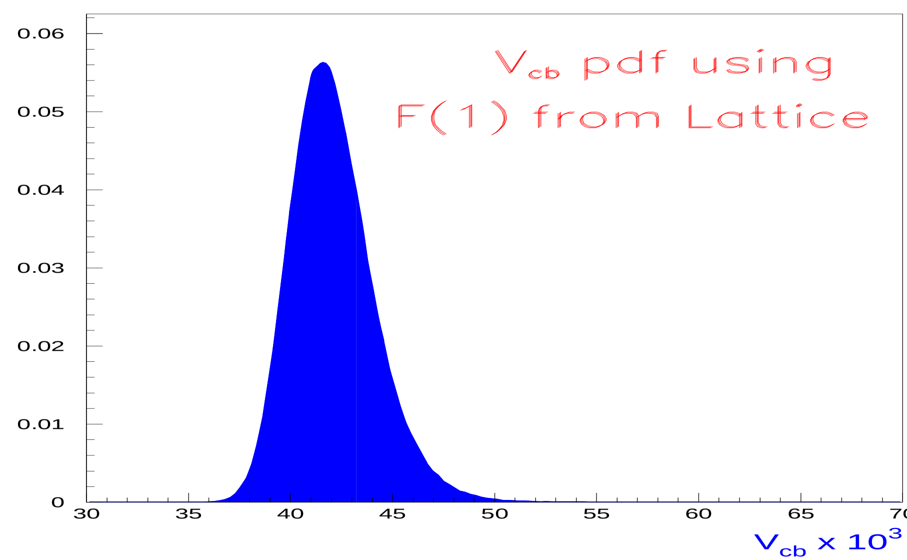
ADOPTED PDG VALUE FOR $\mathcal{F}(1)$

$$\mathcal{F}(1) = 0.91 \pm 0.04$$

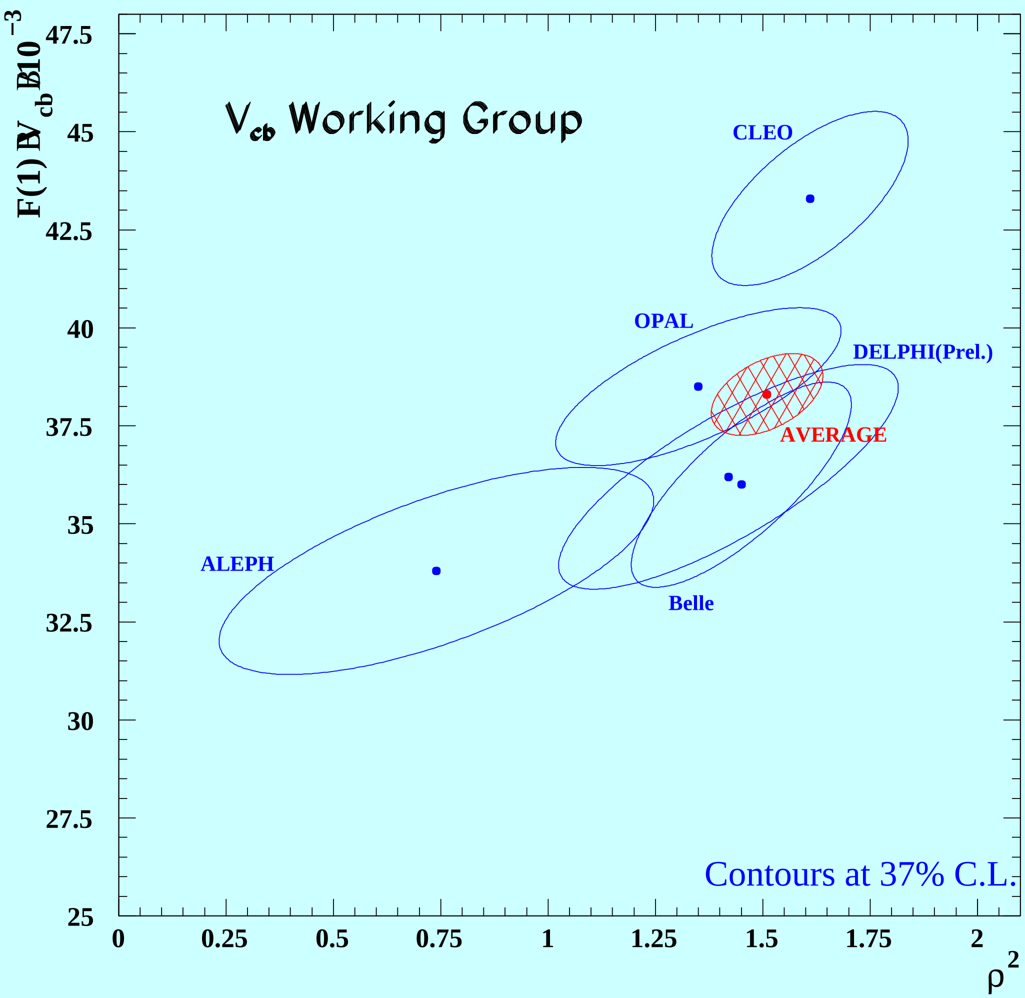
- effort to define p.d.f for $\mathcal{F}(1)$ to propagate to $|V_{cb}|$ dets. for CKM fits;

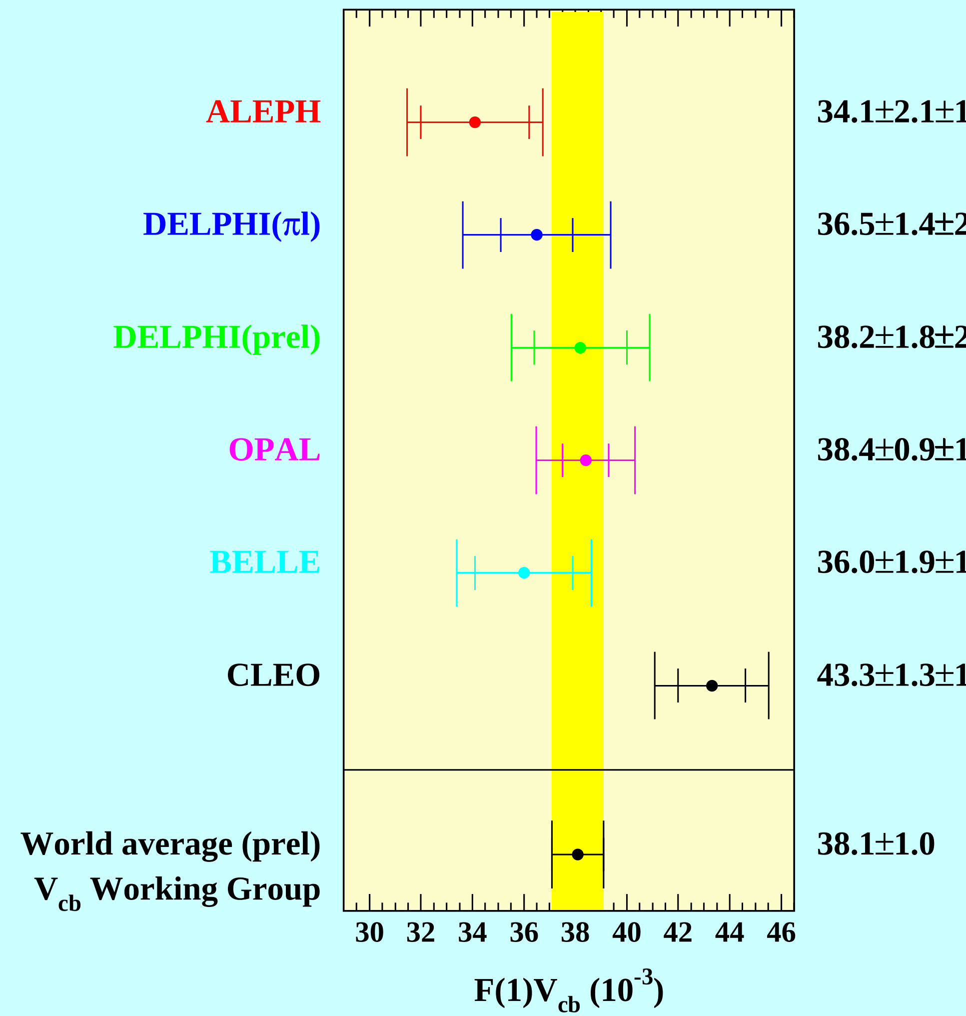
Hashimoto *et al.* hep-ph0110253





PRELIMINARY $\mathcal{F}(1) \times |V_{cb}|$ COMBINATION



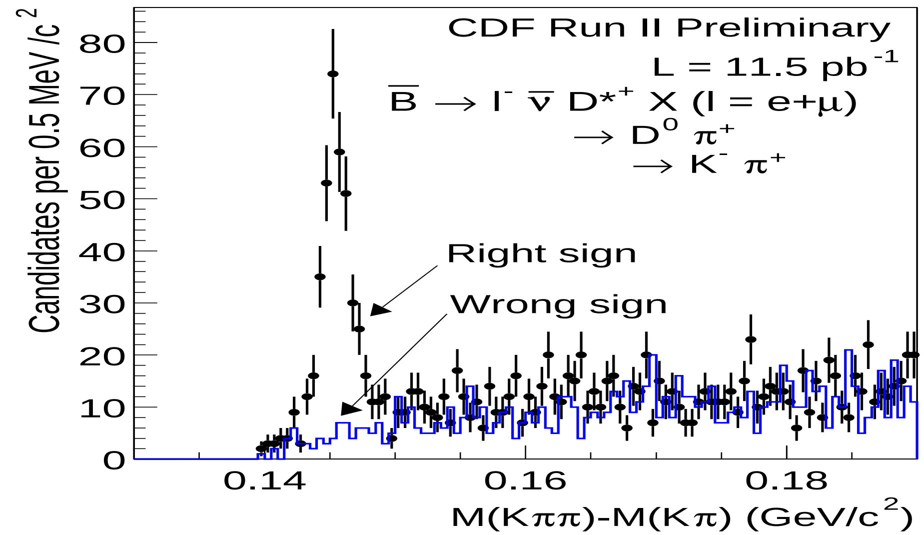


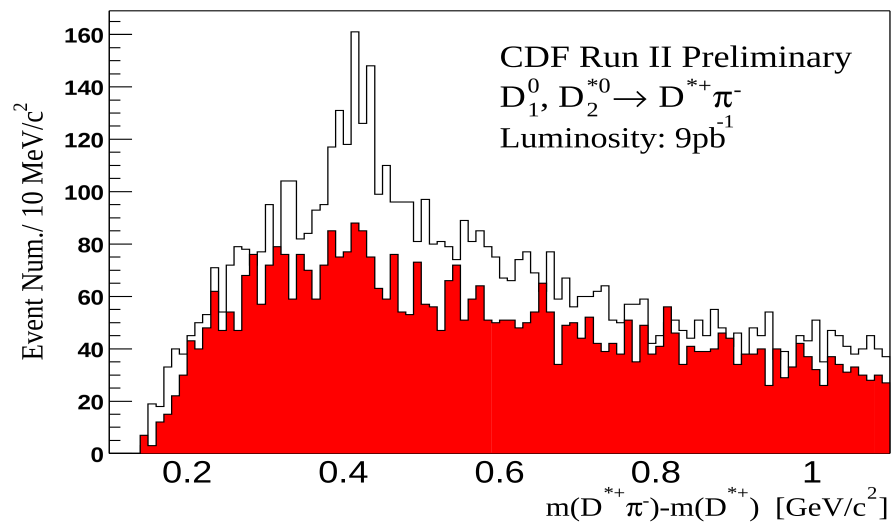
✧ Relevant form factors (R_1 and R_2) need to be measured in future

$$|V_{cb}| = (41.9 \pm 1.1 \pm 1.9) \times 10^{-3}$$

Signals from Tevatron Run II

CDF PRELIMINARY





✧ First CDF $B \to D\ell\nu$ signals from ℓ + Si Vertex Trigger ($p_\ell > 4$ GeV);

$B \to D^* \ell \bar{\nu}$

✧ ICHEP 2002: 11 pb^{-1} = 960 Evts

→ End of Run II: 2 fb^{-1} = 200k Evts;

✧ interesting to explore δw resolution and potential for $|V_{cb}|$

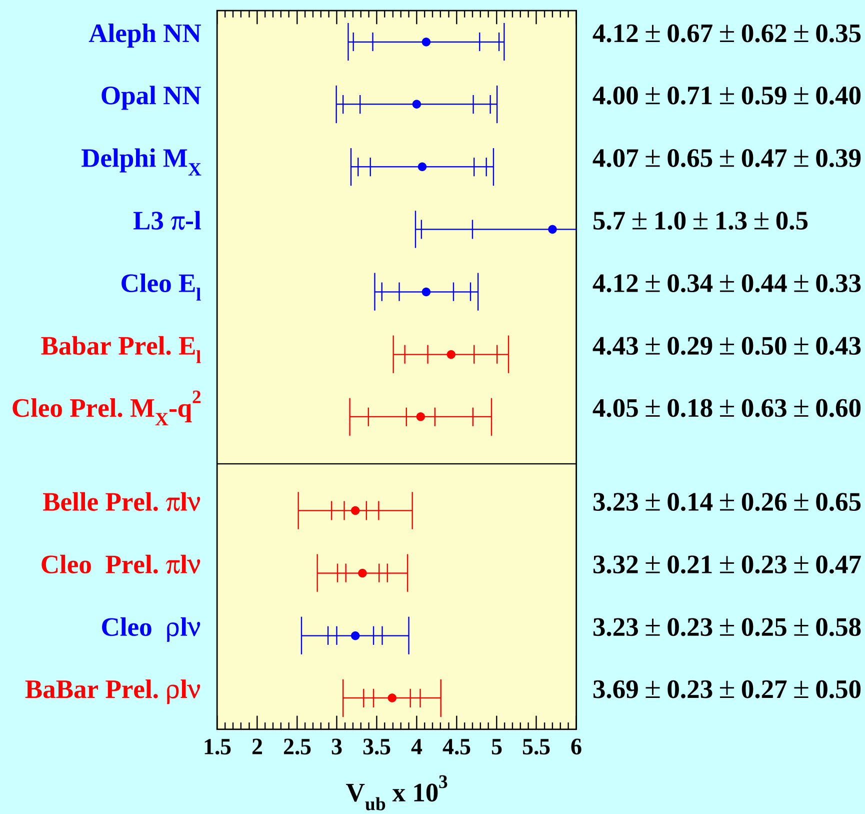
$B \to D^{**} X$

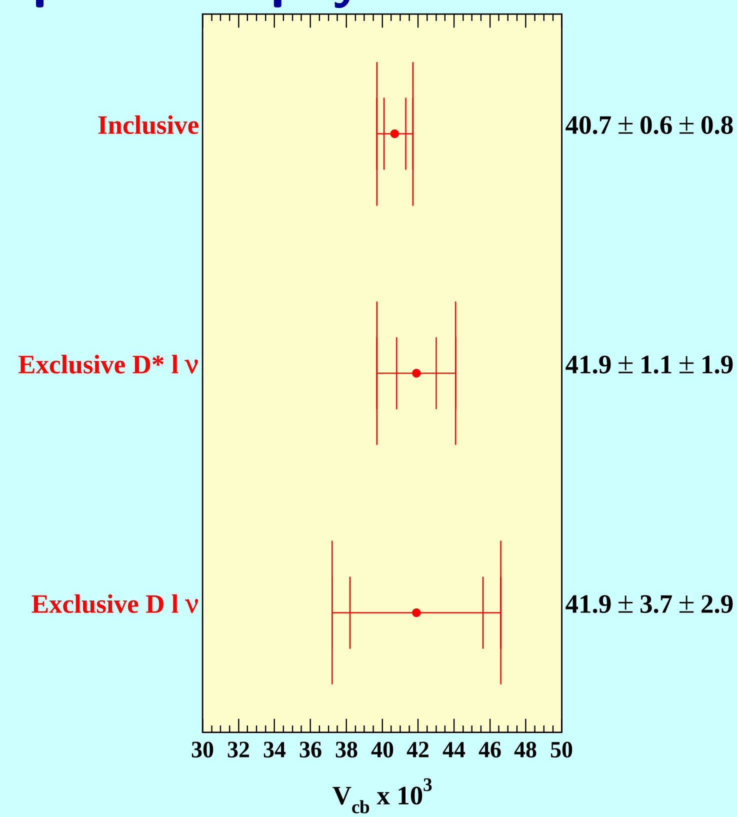
✧ Large D^{**} samples available for helicity analyses, measure M, Γ, BRs;

Summary

Large set of determinations of $|V_{ub}|$ and $|V_{cb}|$ exploiting different techniques affected by different assumptions and sources of uncertainties;

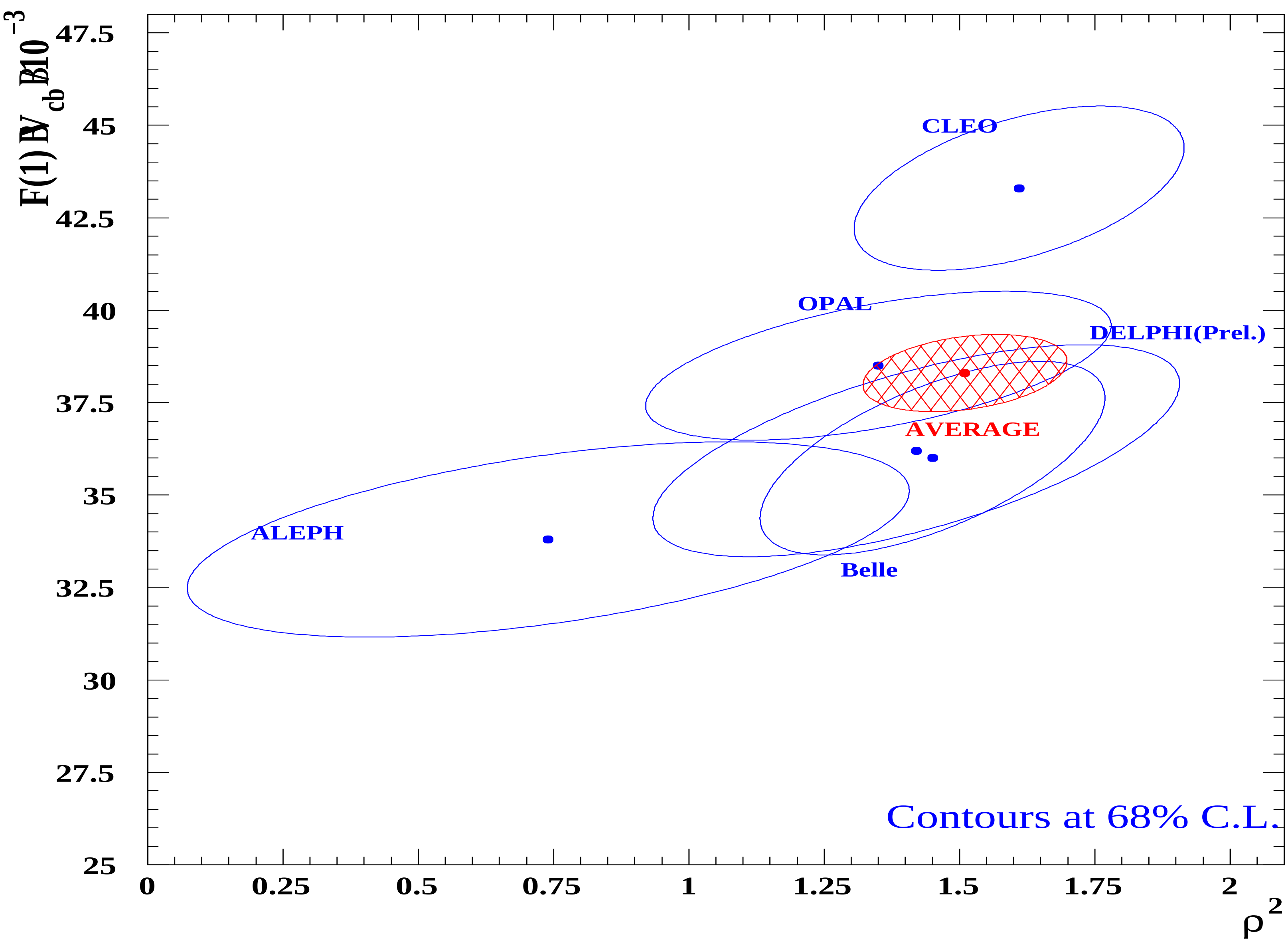
Overall consistency encouraging for perspectives to bring $|V_{ub}|$ and $|V_{cb}|$ towards the domain of precision physics:





Averaging inclusive and exclusive results can improve numerical accuracy due to partly uncorrelated uncertainties but needs a deeper understanding of systematic and thorough checks of consistency to $\simeq$ anticipated total error.

Thanks to: M Artuso, E Barberio, I Bigi, M Calvi, K Ecklund, P Gambino L Gibbons, Y Kwon, T Iijima, V Lubicz, V Luth, M Luke, O Oyanguren, P Roudeau, K Schubert, M Shapiro, A Stocchi, A Tricomi, N Uraltsev, A Warburton *and J Vermeer*



F(1) BV_cb B10^-3
47.5
45
42.5
40
37.5
35
32.5
30
27.5
25
0
0.25
0.5
0.75
1
1.25
1.5
1.75
2
ρ^2
CLEO
OPAL
DELPHI(Prel.)
AVERAGE
ALEPH
Belle
Contours at 68% C.L.