Semileptonic B Decays

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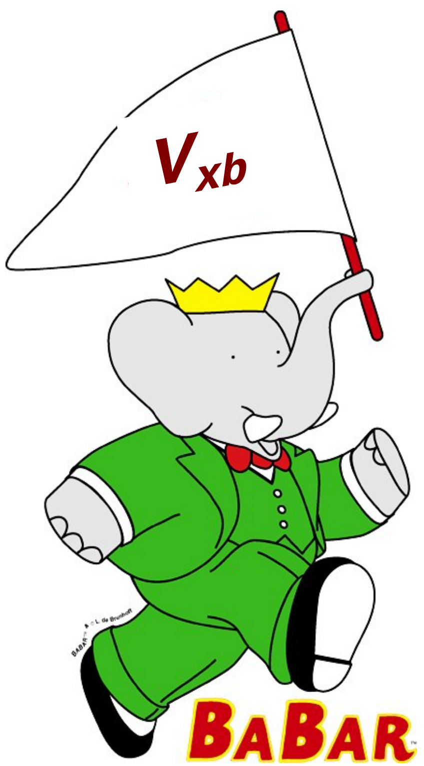


A brief – incomplete – overview

Primary focus: Exclusive Decays

Emphasis on

- experimental capabilities now and in the future
- need for theoretical input

$|V_{cb}|$ from Decay Rate for $B \to D^* \ell^+ \nu$ Decays

- Differential decay rate :

Form Factors — Phase Space

$$\frac{d\Gamma(B^0 \to D^{*-}\ell^+\nu_\ell)}{dw\, d\cos\theta_\ell\, d\cos\theta_V\, d\chi} = \frac{G_F^2 |V_{cb}|^2}{48\pi^3} F(w,\theta_\ell,\theta_V,\chi) G(w)$$

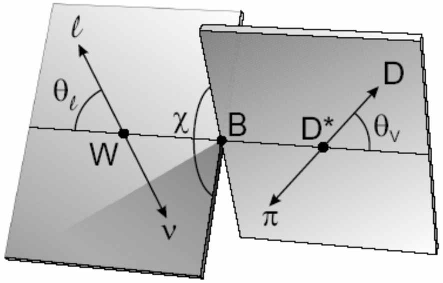
$$w \equiv \frac{M_B^2 + M_{D^*}^2 - q^2}{2 M_B M_{D^*}}$$

- $F(w,\theta_\ell,\theta_v,\chi)$ incorporates 3 non-trivial form factors, $A_1(w)$, $A_2(w)$, $V(w)$
- Perfect HQ symmetry predicts a unique universal FF, normalized to 1.0 at zero recoil. QCD (and QED) correction to F(1) needed!
- Introduce 3 parameters:

  Amplitude ratios: $R_1(w)=V/A_1$

  $R_2(w)=A_2/A_1$

  Curvature $\rho^2=-dF/dw|_{w=1}$



- w dependence can be constrained: parameterization by CLN (Caprini, Lellouch, Neubert)

$$\frac{h_{A_1}(w)}{h_{A_1}(1)} \approx 1 - 8\rho_{A_1}^2 z + (53\rho_{A_1}^2 - 15)z^2 - (231\rho_{A_1}^2 - 91)z^3$$

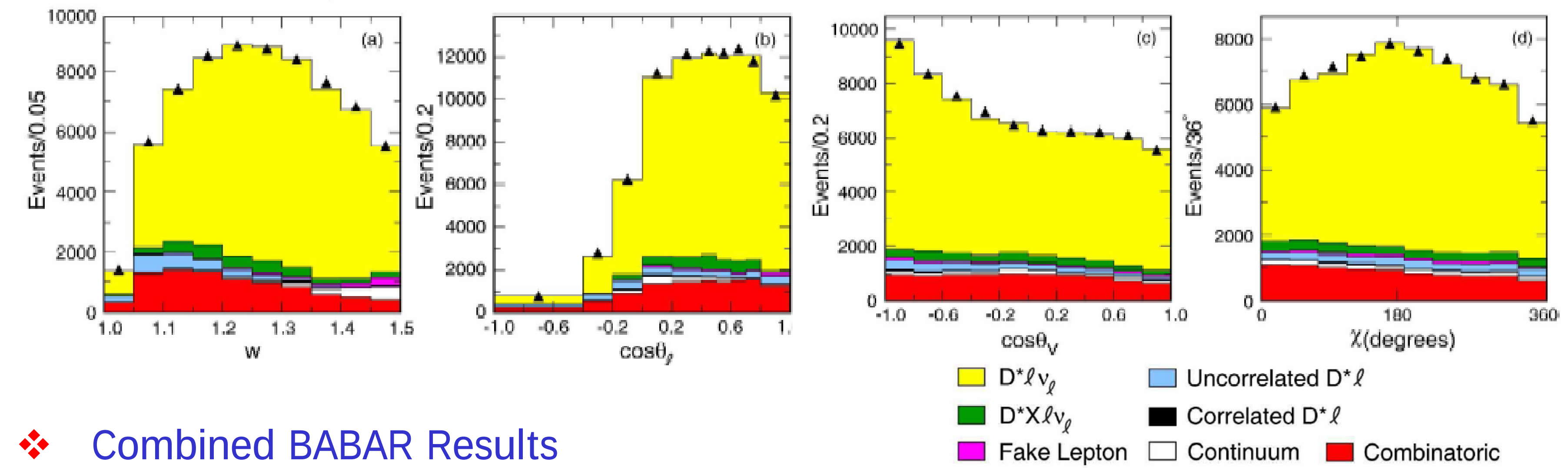
$$z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

- Goal is to determine $R_1(w)$, $R_2(w)$, ρ^2
- There are 4 observables: w and 3 angles

$B \to D^* \ell \nu$: Fit to Differential 4-dim. Cross Section

BABAR, accepted by PRD
arXiv: 0705.4008

- Two parallel analyses combined
  - Max. likelihood fit to 4-dim. decay rate to get: ρ^2, $R_1(1)$, $R_2(1)$ — 83M BB
  - χ^2 fit to 4 projections to get: BF and $F(w)\,|V_{cb}|$



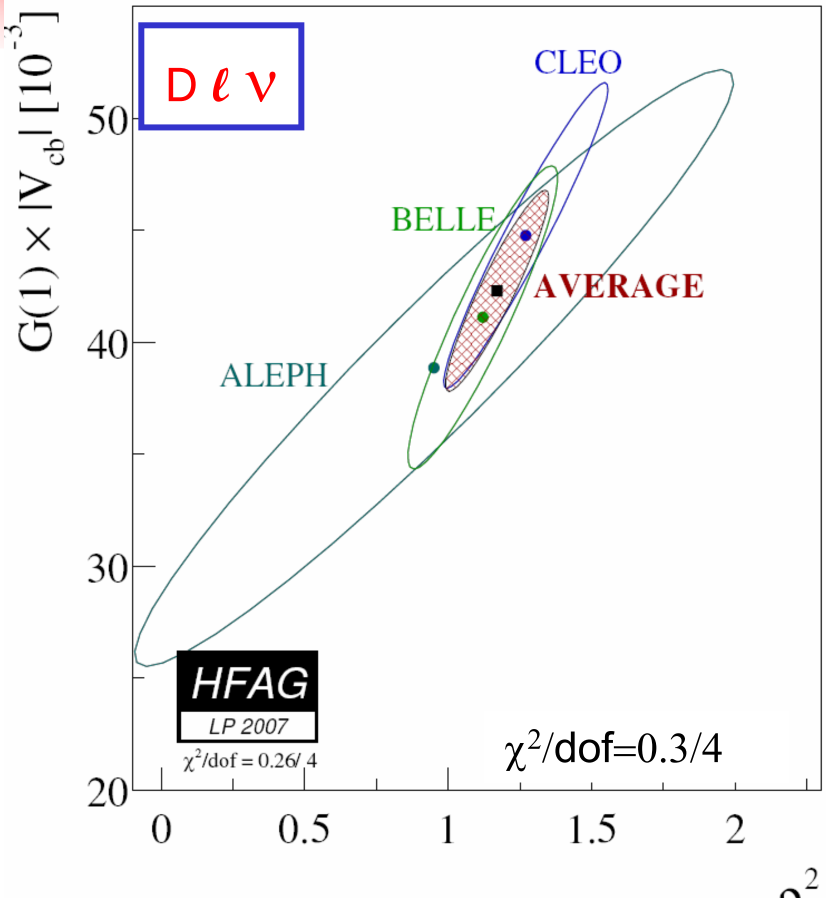
- Combined BABAR Results

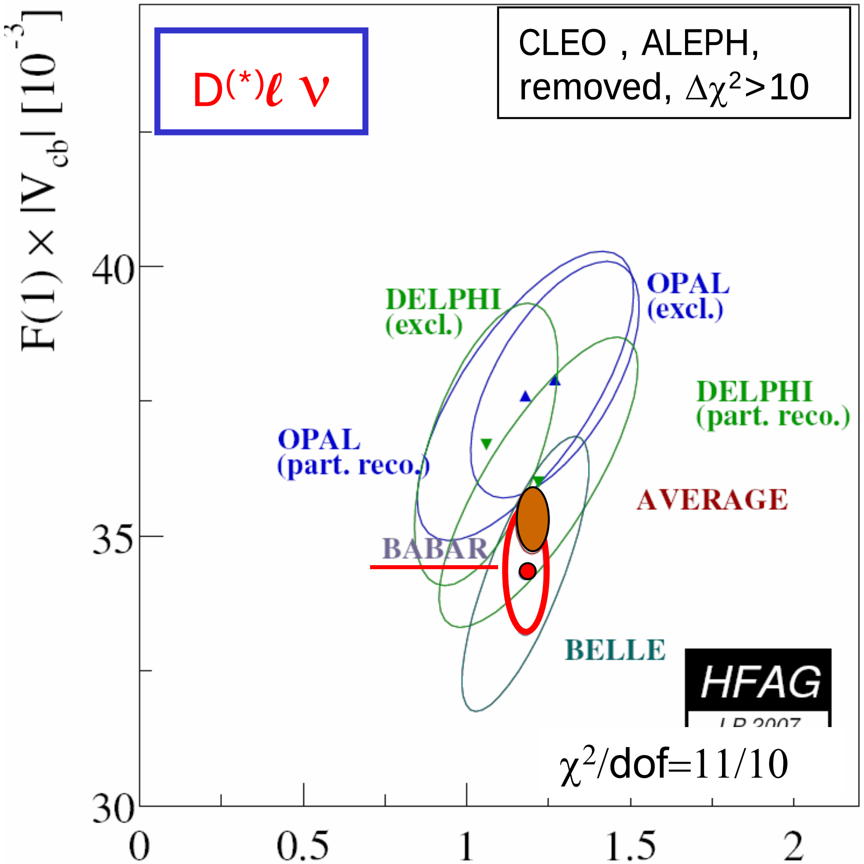
$$\begin{aligned}
\mathcal{F}(1)|V_{cb}| &= (34.4 \pm 0.3 \pm 1.1) \times 10^{-3} \\
\rho^2 &= 1.191 \pm 0.048 \pm 0.028 \\
R_1(1) &= 1.429 \pm 0.061 \pm 0.044 \\
R_2(1) &= 0.827 \pm 0.038 \pm 0.022.
\end{aligned}$$

Syst. Uncertainties dominated by detector efficiencies, Bg, R_1, R_2

Results consistent with $R_1(w)$ and $R_2(w)$ parameterization by CLN

$|V_{cb}|$ Measurements based on $B \to D^{(*)} \ell^+ \nu$ Decays





$G(1)|V_{cb}| = (42.3 \pm 3.5_{stat} \pm 2.9_{syst})\ 10^{-3}$

$G(1) = 1.082 \pm 0.024$ (Hashimoto, LAT04)

$|V_{cb}| = (39.1 \pm 4.2_{exp} \pm 0.87_{theo})\ 10^{-3}$

11 % 2.2 %

$F(1)|V_{cb}| = (35.28 \pm 0.26_{stat} \pm 0.55_{syst})\ 10^{-3}$

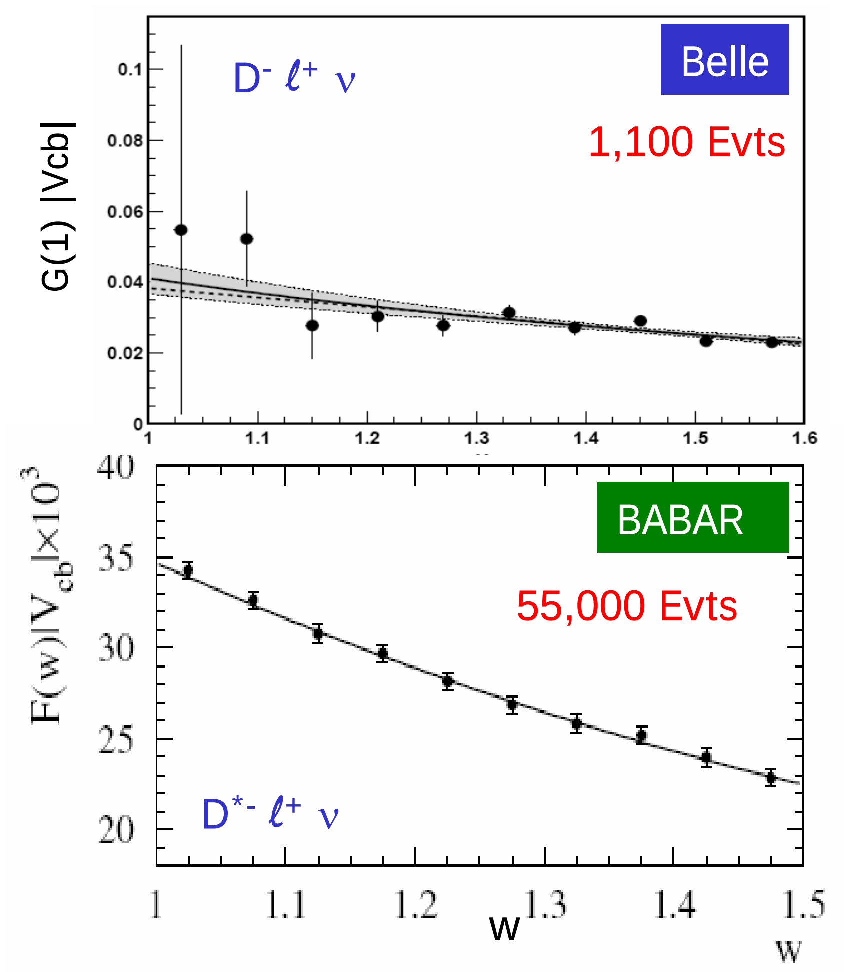
$F(1) = 0.931 \pm 0.023$ (J. Laiho, LAT07)

$|V_{cb}| = (37.8 \pm 0.66_{exp} \pm 0.85_{theo})\ 10^{-3}$

1.8 % 2.3 %

$|V_{cb}|$ from $B \to D^{(*)} \ell^+ \nu$ Decays

Pioneering measurement by CLEO –
Results based on small data samples



Significant improvements expected:

- Statistics x10x2 1/5
- Dominant systematics: 1/3
  - Reconstruction efficiency
  - Lepton ID
  - BF for D/B decays, f_{+-}
  - background estimates
    Primarily other $X_c\ \ell\nu$ decays
    improved FF and BF

Essential to perform 4-dimensional fit to enhance sensitivity to R_1 and R_2, and also ρ^2.

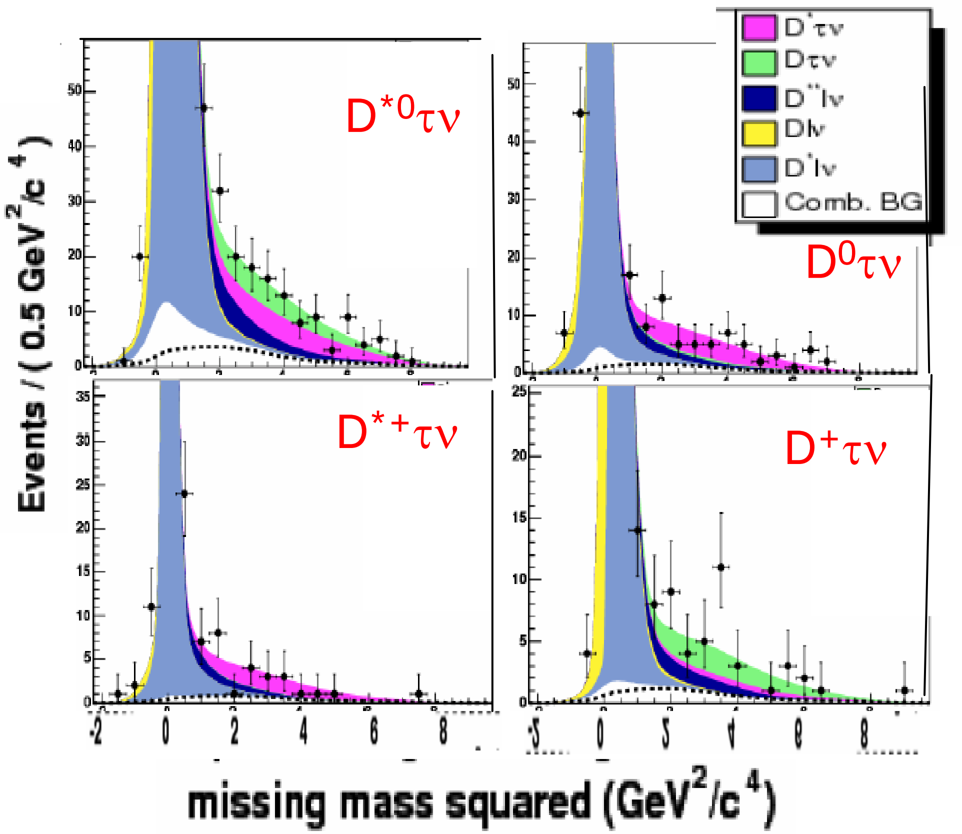
Comparison of D^{*+} and D^{*0} will test efficiency for low momentum π^+ or π^0

Q: Apart from Lattice, are there other estimates for F(1) or G(1) corrections?

First Observation of $B \to D^{(*)} \tau^+ \nu$ Decays

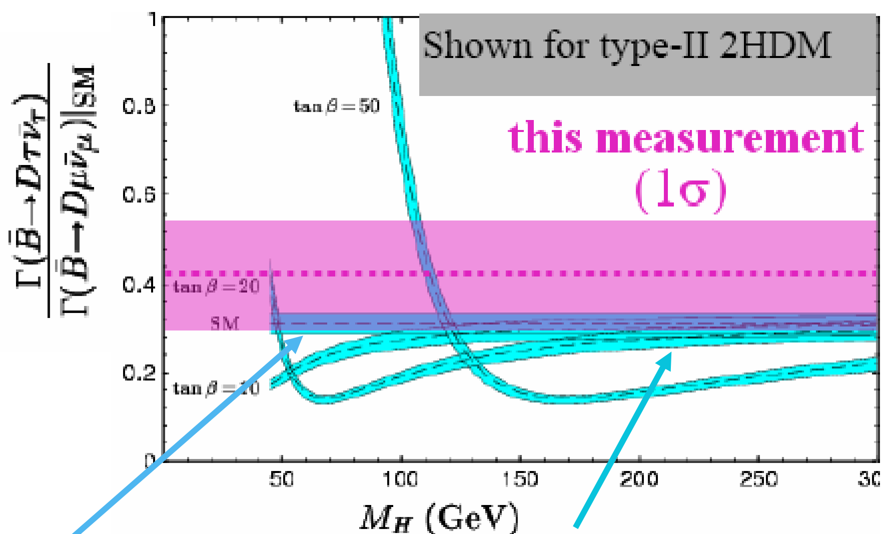
Very Challenging measurement,
Sensitivity to additional helicity states of W*,

Potential sensitivity to New Physics at Tree level
Precise prediction from $D^{(*)} l \nu$ FF



BABAR accepted by PRL. arXiv:0709.1698

$$\mathcal{B}(B \to D\tau^-\bar{\nu}_\tau) = (0.86 \pm 0.24 \pm 0.11 \pm 0.06)\%$$
$$\mathcal{B}(B \to D^*\tau^-\bar{\nu}_\tau) = (1.62 \pm 0.31 \pm 0.10 \pm 0.05)\%$$



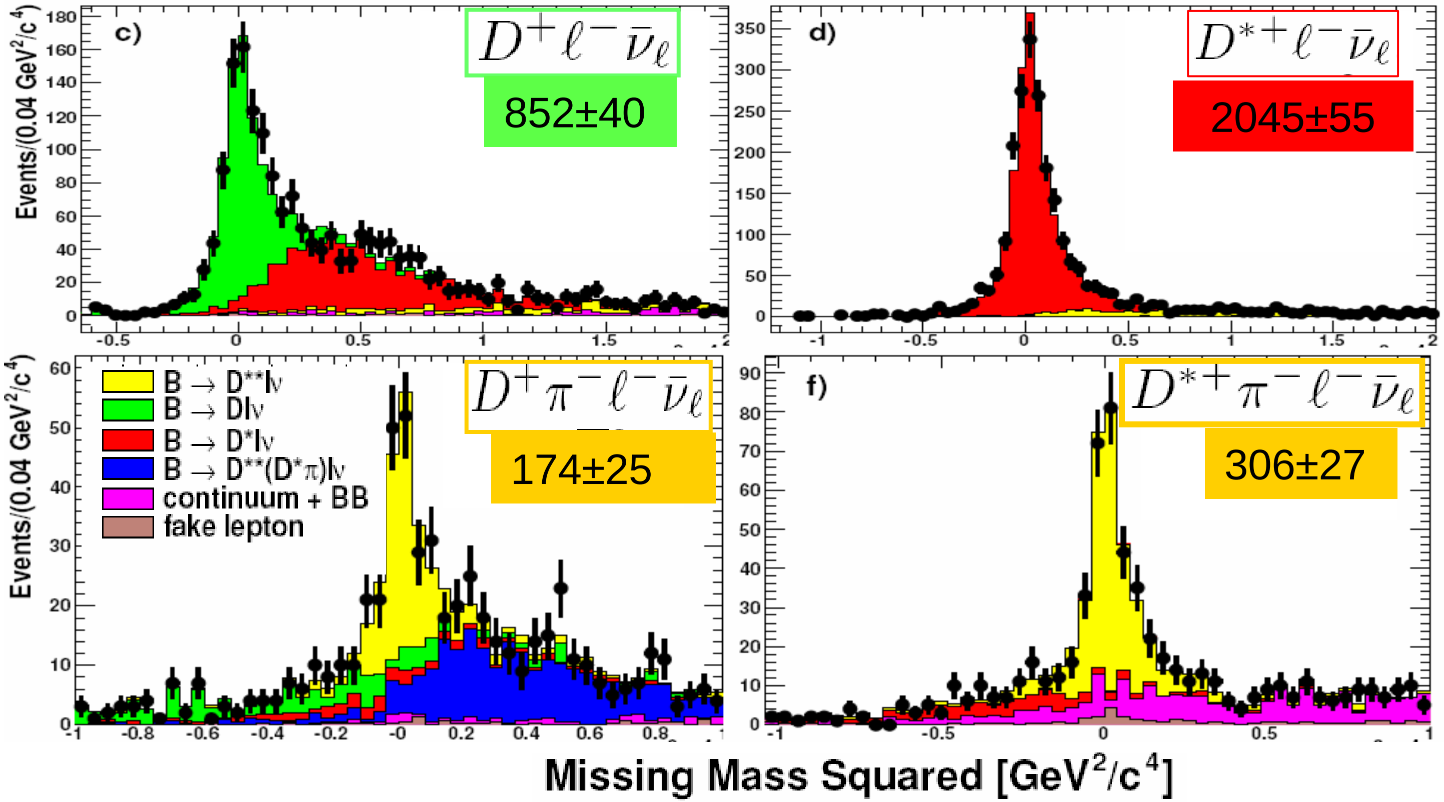
SM Prediction

Theory Uncertainties dominated by FF errors

Branching Fractions B→D/D*/Dπ/D*π ℓν

BABAR arXiv:0708.1738

340 M BB



$$\mathcal{B}(B^- \to D^{(*)}\pi\ell^-\bar{\nu}_\ell) = (1.52 \pm 0.12_{stat.} \pm 0.10_{syst.})\%$$
$$\mathcal{B}(\overline{B}^0 \to D^{(*)}\pi\ell^-\bar{\nu}_\ell) = (1.37 \pm 0.17_{stat.} \pm 0.10_{syst.})\%,$$

Puzzle of missing decays:
$BF_{tot}-\Sigma BF_i = (1.2 \pm 0.5)\%$

$|V_{cb}|$ from Inclusive $B \to X_c \ell \nu$ Decays

- Total decay rate inclusive $b \to c \ell \nu$

$$\Gamma_{SL} = |V_{cb}|^2 \frac{G_F^2 m_b^5}{192\pi^3}(1+A_{EW})A_{pert} \times [c_0(r) + \frac{0}{m_b} + c_2(r, \frac{\mu_\pi^2}{m_b^2}, \frac{\mu_G^2}{m_b^2}) + c_3(r, \frac{\rho_D^3}{m_b^3}, \frac{\rho_{LS}^3}{m_b^3}) + ...]$$

free quark decay — perturbative corrections — Non-perturbative power corrections

- Similar expressions for $b \to u \ell \nu$ and $b \to s \gamma$
- For comparison with data, use low-order moments of inclusive distributions over large ranges on phase space to avoid problem with quark-hadron duality
- Moments can be calculated for various cuts on kinematic variables

$$\langle M_x^n \rangle |_{E\ell > E_0} = \tau_B \int_{E_0} M_x^n d\Gamma = f(E_0, m_b, m_c, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3)$$

Cut-off (E_0) — quark masses (m_b, m_c) — Non-perturbative parameters ($\mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3$)

- Calculations available in "kinetic" and "1S" mass schemes
  - Benson, Bigi, Gamnino, Mannel, Uraltsev
  - Bauer, Ligeti, Luke, Manohar, Trott,
- >60 measured moments available form DELPHI, CLEO, BABAR, Belle, CDF

Results of Global HQE Fits

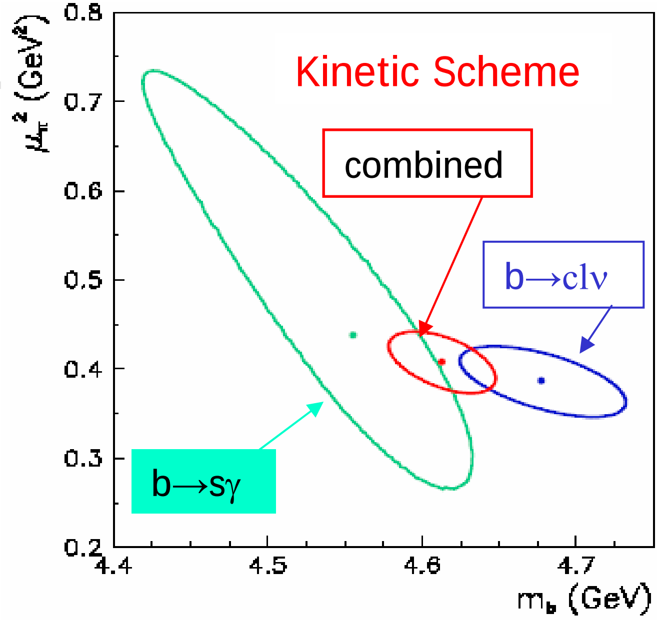
Global HQE fits to moments of incl. spectra:

A: Kinetic scheme: all experiments

Buchmüller/Flächer HFAG 2007 update

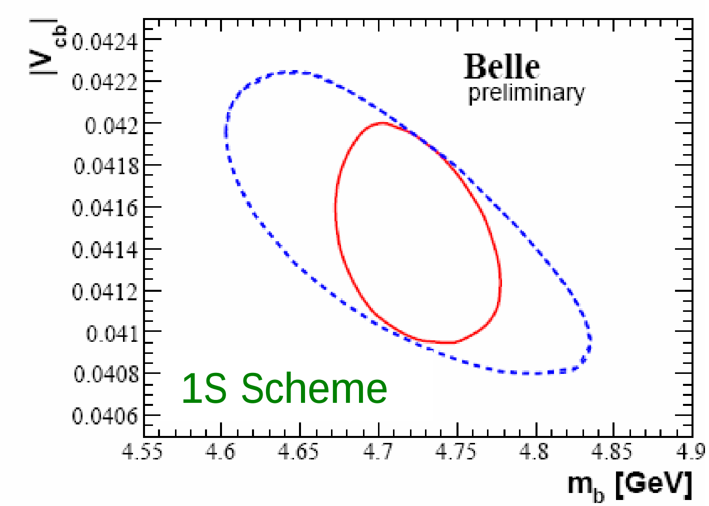
$\lvert V_{cb}\rvert$ (10^{-3})	$41.9 \pm 0.19_{exp} \pm 0.2_{HQE} \pm 0.59_{\Gamma sl}$
$m_{b[kin]}$ (GeV)	$4.613 \pm 0.022_{exp} \pm 0.027_{HQE}$
$\mu_{\pi}^{2}{}_{[kin]}$ (GeV^2)	$-0.408 \pm 0.017_{exp} \pm 0.031_{HQE}$

$m_{c[kin]}$ (GeV) $1.187 \pm 0.033_{exp} \pm 0.040_{HQE}$



B: 1S Scheme: Belle moments only

Abe et al. ICHEP06 contribution hep-ex/0611047



$\lvert V_{cb}\rvert$ (10^{-3})	$41.3 \pm 0.5_{fit} \pm 0.2_{tB}$
$m_{b[1S]}$ (GeV)	$4.73 \pm 0.05_{fit}$
$\lambda_{1[1S]}$ (GeV^2)	$-0.30 \pm 0.04_{fit}$

Results agree, after scheme translation!

$\lvert V_{cb}\rvert$ to< 2% m_b to 1% (crucial for $\lvert V_{ub}\rvert$)

Exclusive Charmless Decays: $B^0 \to \pi^+ \ell^- \nu$:

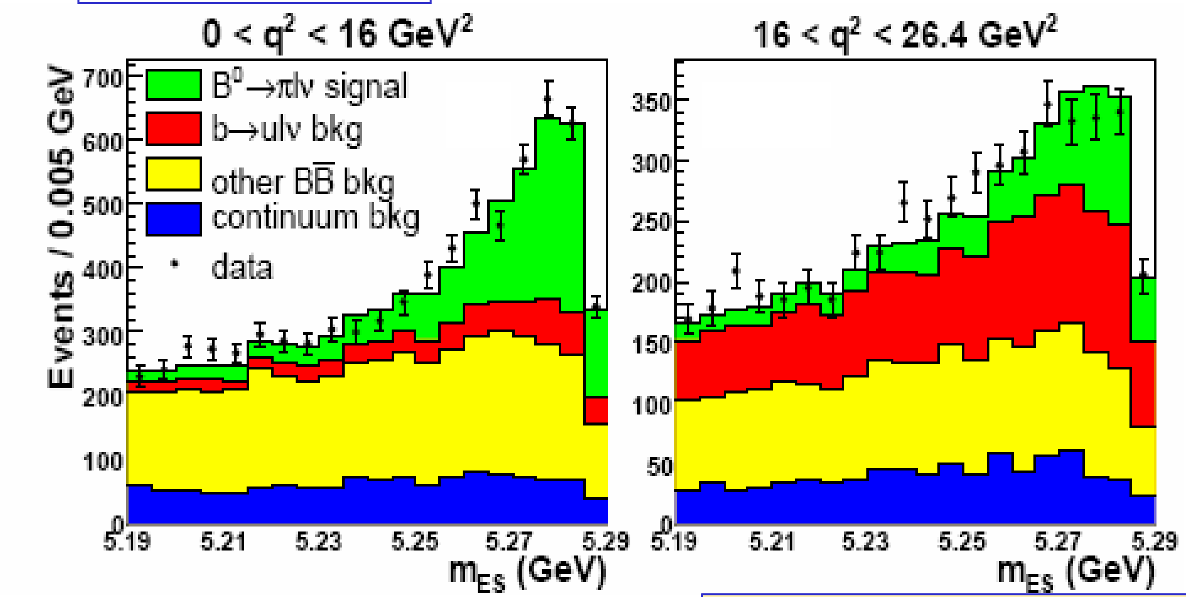
BABAR: Phys.Rev.Lett.98:091801,2007.

- Extract yields for signal and background from 3-dim. Max-LH Fit to ΔE, m_{ES}, q^2.
- Signal and Bg shapes from MC

No Tags

- Very High yield 22,000/10^9 BB Events
- Low S/B 1:10 to 1:3

230M BB Events



5072 signal events

$$m_{ES} = \sqrt{s/4 - |\vec{p}_B^{\,*}|^2}$$

$$\Delta E = E_B^* - \sqrt{s}/2$$

$$q^2 = (p_B - p_\pi)^2 = (p_\ell + p_\nu)^2$$

$$BF(B^0 \to \pi^- \ell^+ \nu) = (1.46 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-4}$$

4.6% 5.5%

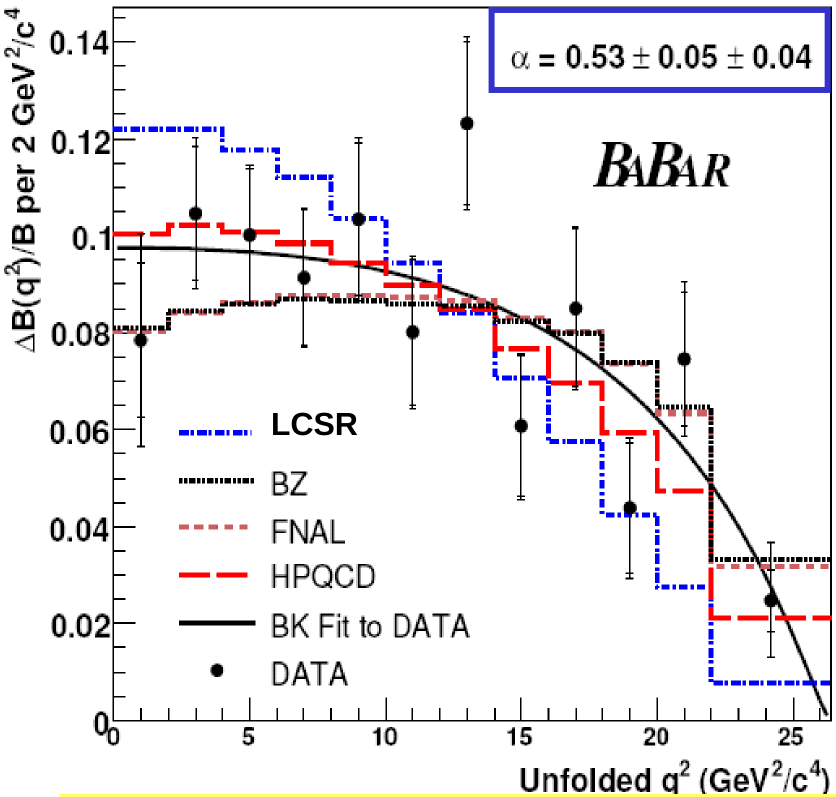
Differential Decay Rate for B $\rightarrow \pi \ell \nu$ Decays

BABAR: Phys.Rev.Lett.98:091801,2007.

Calculations:

- Light-Cone Sum Rules: $q^2 < 14$ GeV^2
  - Ball-Zwicky (hep-ph/0406232) 10-13% uncertainty at $q^2=0$
- Lattice QCD: $q^2 > 15$ GeV^2
  - Unquenched calculations by HPQCD (hep-lat/0408019) FNAL (hep-lat/0409116) 11% uncertainty at high q^2
  - Quenched Calculations by APE (NP B619, 565)
- ISGW2 (PR D52, 2783)
  - quark model
  - No uncertainty quoted

$$\frac{d\Gamma(B^0 \rightarrow \pi^- \ell^+ \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$



ISGW2 disfavored: P(χ^2) <0.1%

Form-Factor Shape: $B \to \pi \ell \nu$

Most of the rate is at low q^2 !

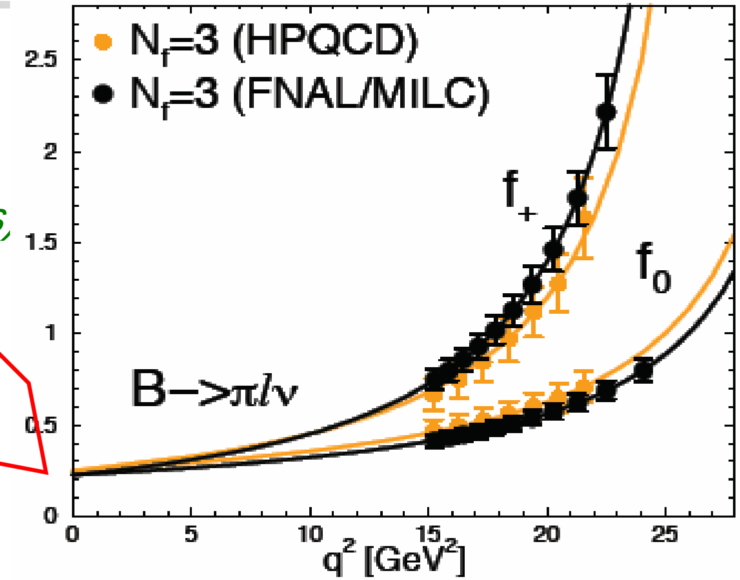
Extrapolation to total range by various approaches:

- *BGL-Boyd/Grinstrin/Lebed+ Hill/Becher(4 parameters)*
- *BZ- Ball-Zwicky (4 parameters)*
- *BK- Becirevic-Kaidalov (3 parameters)*

$$f_+(q^2) = \frac{c_B(1-\alpha)}{(1-q^2/m_{B^*}^2)(1-\alpha q^2/m_{B^*}^2)}$$

Constraint

FF Fits to BK Ansatz



One principal shape parameter:

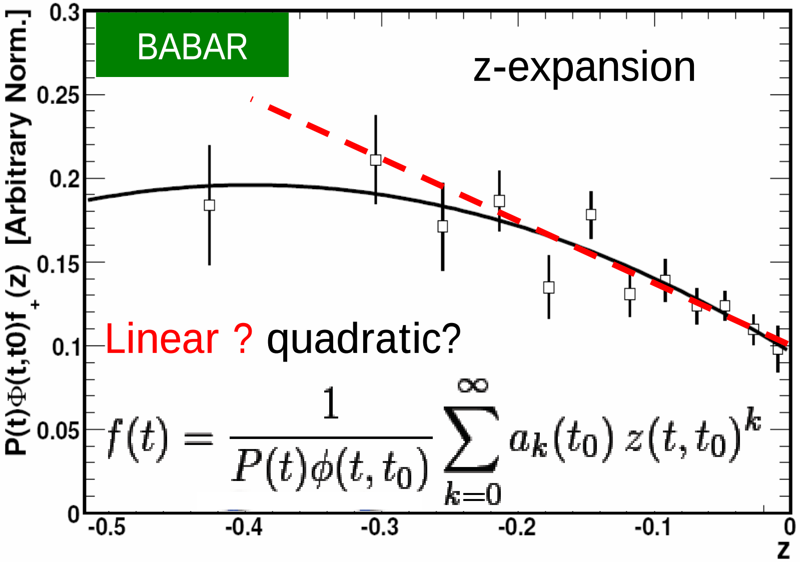
HPQCD : $\alpha = 0.42 \pm 0.05$

FNAL : $\alpha = 0.63 \pm 0.05$

Fit to BABAR Data

$\alpha = 0.53 \pm 0.05 \pm 0.04$

$f_+(0)|V_{ub}| = 9.6 \pm 0.3_{stat} \pm 0.2_{syst}) \times 10^{-4}$



Linear ? quadratic?

$$f(t) = \frac{1}{P(t)\phi(t,t_0)} \sum_{k=0}^{\infty} a_k(t_0)\, z(t,t_0)^k$$

All 3 Ansätze give good fits to the FF data:

Using BGL based on analycity of f_+ and expansion in $z(t,t_0)$ (and HFAG BF)

$f_+(0)|V_{ub}| = 9.1 \pm 0.6_{shape} \pm 0.3_{BF}) \times 10^{-4}$

Extraction of $|V_{ub}|$ from $B \to \pi \ell \nu$ Decays

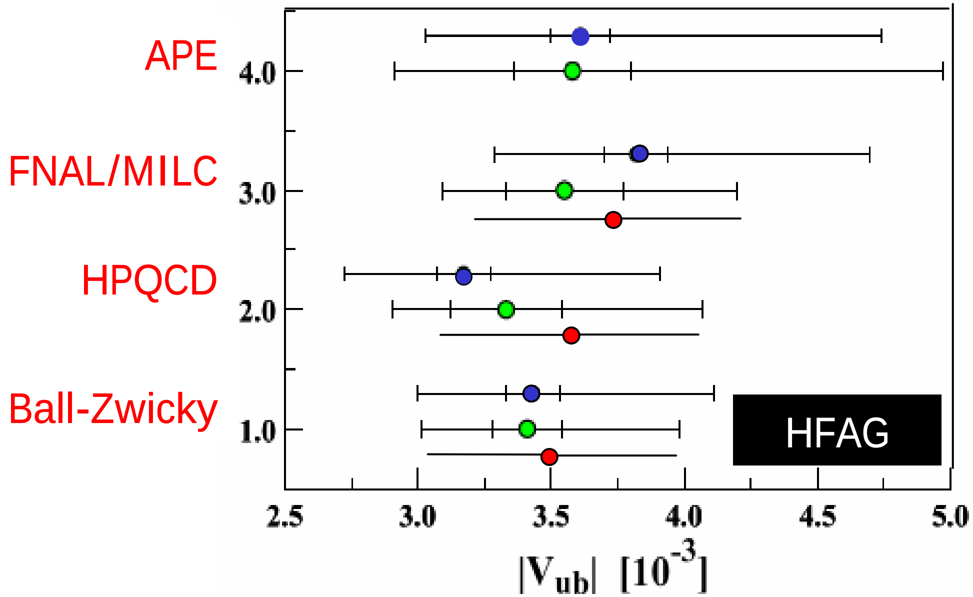
Extraction of $|V_{ub}|$ relies on FF normalization, available in distinct q^2 ranges:

- LCSR: $q^2<16$ GeV^2, LQCD: $q^2>16$ GeV^2, Hill/Becher z expansion
- either restricted or whole q^2 range

$$|V_{ub}| = \sqrt{\Delta B / \tau_B \Gamma_{thy}}$$

$$\tilde{\Gamma}_{\rm thy} = \frac{G_F^2}{24\pi^3} \int_{q^2_{\rm min}}^{q^2_{\rm max}} |f_+(q^2)|^2 p_\pi^3 dq^2$$

BK Fit: ● All q^2 ● Limited q^2 ● BGL Fit:



BK Parameterization:

FNAL/MILC: $q^2>16$ GeV^2

$$|V_{ub}| = (3.55 \pm 0.22_{\rm exp}{}^{+0.61}_{-0.40\,LQCD}) \times 10^{-3}$$

FNAL/MILC: Extrapolated to all q^2

$$|V_{ub}| = (3.8 \pm 0.12_{\rm exp}{}^{+0.90}_{-0.51\,LQCD}) \times 10^{-3}$$

3.2% 13-24%

BGL Parameterization:

FNAL/MILC:

BALL arXiv:0705:2290

$$|V_{ub}| = (3.7 \pm 0.12_{\rm exp} \pm 0.4_{FF}) \times 10^{-3}$$

Form Factors for B→ ρ (ω) ℓ ν or B→ η (η') ℓ ν

In addition to π ℓ ν, many other final states are being studied.

vector mesons: ρ, ω,...

pseudo scalars: η, η'

Q: *What can we learn from these decays?*

Theoretical predictions exists from

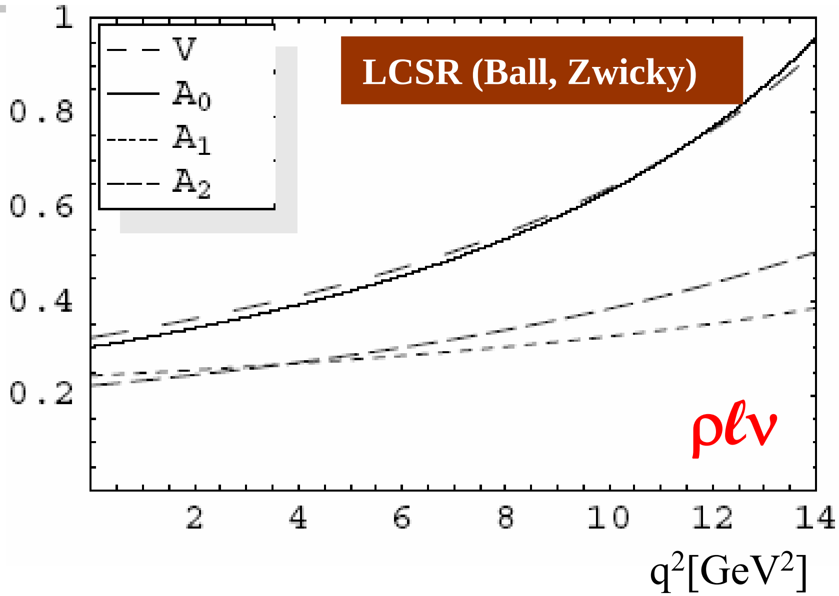
- Quenched Lattice QCD by Ape et al.
- LCSR by P. Ball, R. Zwicky

Many parameters – How can we test these predictions?

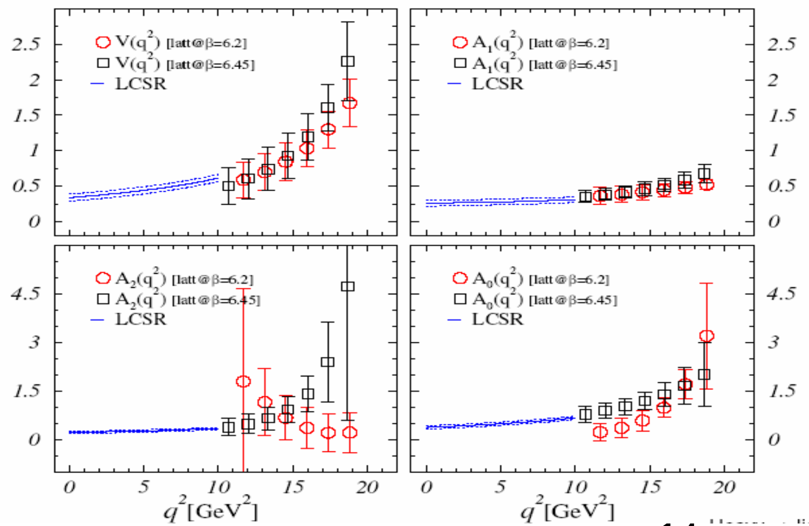
Q: Can we integrate over angles?

Can we introduce FF ratios?

Q: How do we extract to full q^2 range?



Quenched LQCD (Ape et al.)



Extrapolation to 10^9 BB Events: $B \to \pi^- \ell^+ \nu$

Experimental errors on BF can be reduced, if we improve

- track and neutral particle reconstruction (ν reco !)
- understanding of backgrounds, for instance $b \to u \ell \nu$ (res & non-res) BFs and FFs or reduce background through tagging

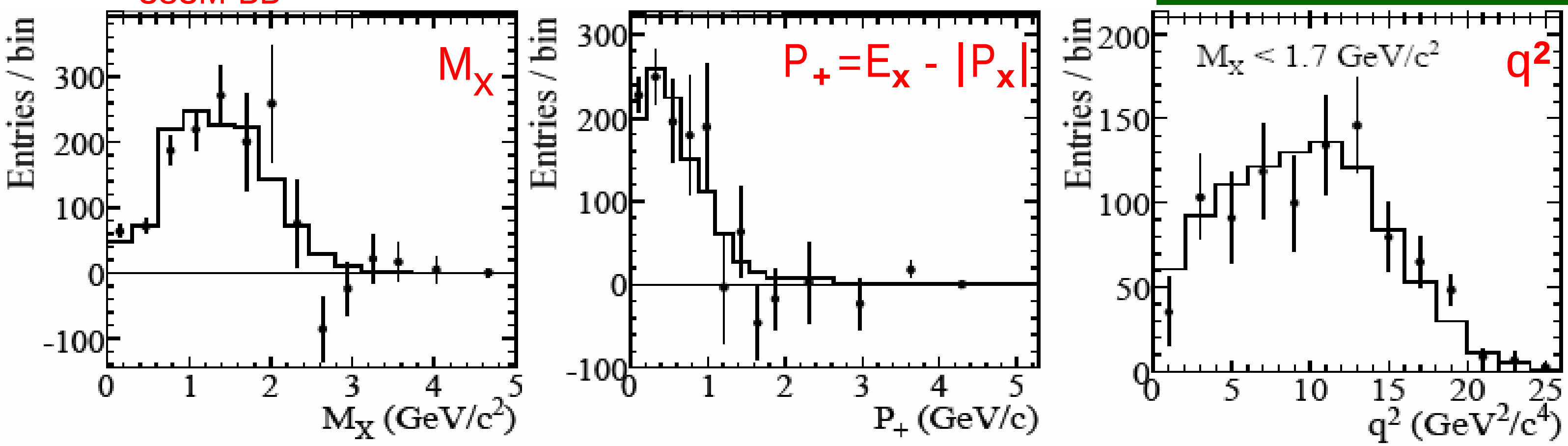
Event Selection	Yield [Evt/10^9BB]	S/B	σ_{stat}	σ_{syst}	σ_{exp}
hadronic tags	100	10	12 %	5%	13%
$D^{(*)} \ell \nu$ tags	600	3	7 %	5%	9%
No tags	15,000	0.1- 0.3	2.5 %	4%	5%

- BB Tags
  - separate decay product of signal B, thus remove combinatoric background
  - determine momentum and flavor of signal, but at a very high cost in event rate
- Thus at current B Factories, FF shapes can only be measured with untagged events.
- However, BB tags are critical for many analyses: $B \to D^{(*)} \tau \nu$, $D^{**} \ell \nu$, incl. Mx, P+ spectra, etc.

Inclusive Measurements of $|V_{ub}|$

Analysis with events tagged by a fully reconstructed hadronic B decay

BABAR submitted to PRD, arXiv:0708:3702



n.b.:

Measured Distributions, not efficiency corrected

	N_u	$\lvert V_{ub}\rvert\ (10^{-3})$	
M_X	803 ± 60	$4.27 \pm 0.16 \pm 0.13 \pm 0.30$	BLNP
		$4.56 \pm 0.17 \pm 0.14 \pm 0.32$	GDE
P_+	633 ± 63	$3.88 \pm 0.19 \pm 0.16 \pm 0.28$	BLNP
		$3.99 \pm 0.20 \pm 0.16 \pm 0.24$	GDE
$M_X - q^2$	562 ± 55	$4.48 \pm 0.22 \pm 0.19 \pm 0.30$	BLNP
		$4.53 \pm 0.22 \pm 0.19 \pm 0.25$	GDE
		$4.81 \pm 0.23 \pm 0.20 \pm 0.36$	BLL

One data set and 3 Calculations give 7 values for $|V_{ub}|$!

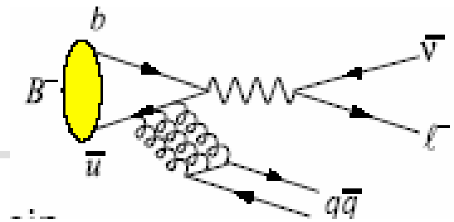
All errors correlated!

Stat: 3.8%

Syst: 3.0%

Theory: 7 % (shape function errors dominate, m_b)

Weak Annihilation



BABAR arXiv:0708.1753

$$\Gamma_{\rm WA}/\Gamma_{b\to u} \approx 0.03 \left(\frac{f_B}{0.2\ \rm GeV}\right)^2 \left(\frac{B_2 - B_1}{0.1}\right)$$

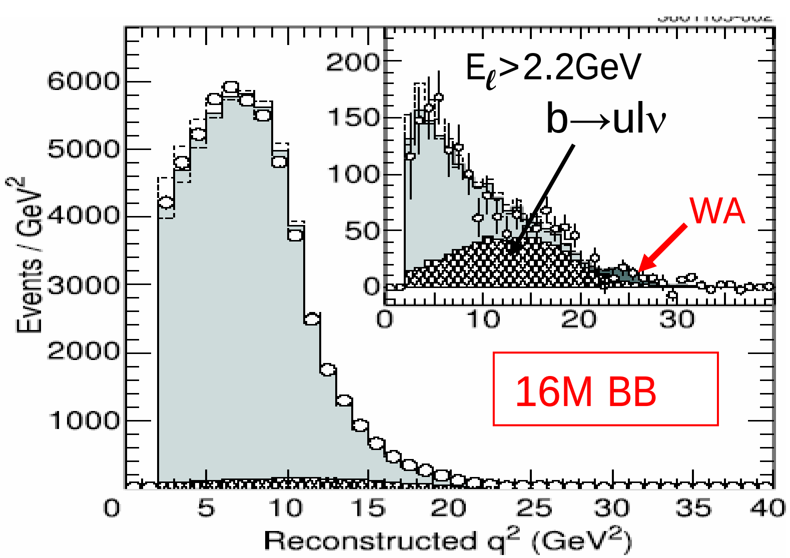
CLEO : CLEO, PRL 96,121801

Γ_{WA}/Γ_u < 7.4%,

but $\Gamma_{WA}/\Gamma_{bu,\ El>2.2GeV}$ < 16%

Fit of q^2 spectrum to sum of

- $b \to c\ell\nu$
- $b \to u\ell\nu$ (hybrid model)
- WA contribution $W(mx, x_0, \Lambda)$



380 M BB

BABAR

Measurement of E_ℓ in B^0 events tagged by reconstruction of $D^*\ell\nu$

ΔP_ℓ	$\Delta\mathcal{B}(B^0)\cdot 10^4$
$2.2-2.6\ {\rm GeV}/c$	$2.62\pm0.33\pm0.16$
$2.3-2.6\ {\rm GeV}/c$	$1.30\pm0.21\pm0.07$
$2.4-2.6\ {\rm GeV}/c$	$0.76\pm0.15\pm0.05$

- Extract Charge Asymmetry

$$A^{+/0} = \frac{\Delta\Gamma^+ - \Delta\Gamma^0}{\Delta\Gamma^+ + \Delta\Gamma^0}$$

- Limit on contribution from WA for interval 2.3 < E_ℓ <2.6 GeV:

$$\frac{|\Gamma_{WA}|}{\Gamma_u} = \frac{2\cdot f_u(\Delta P_\ell)}{f_{WA}(\Delta P_\ell)}\cdot A^{+/0}$$

$$< \frac{3.8\ \%}{f_{WA}(2.3-2.6)}, \quad \text{at 90\% C.L.}$$

Can LQCD help here??

Current Inclusive $|V_{ub}|$ Measurements

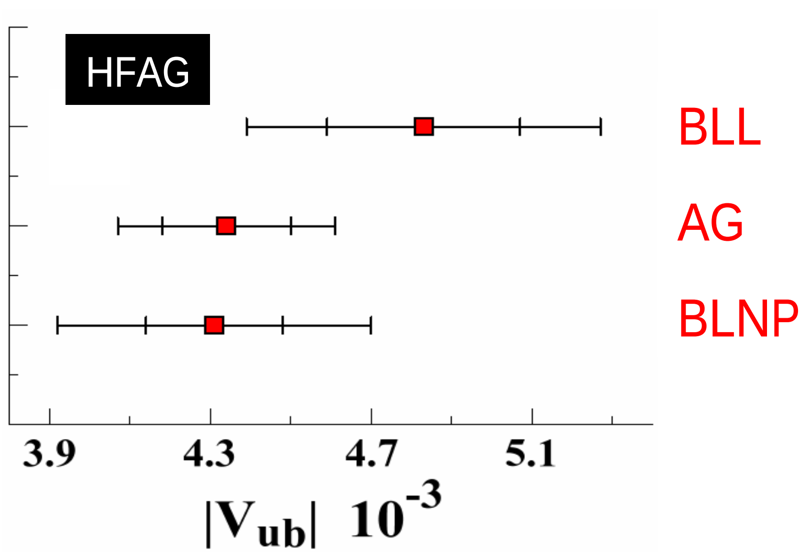
BLNP - HFAG

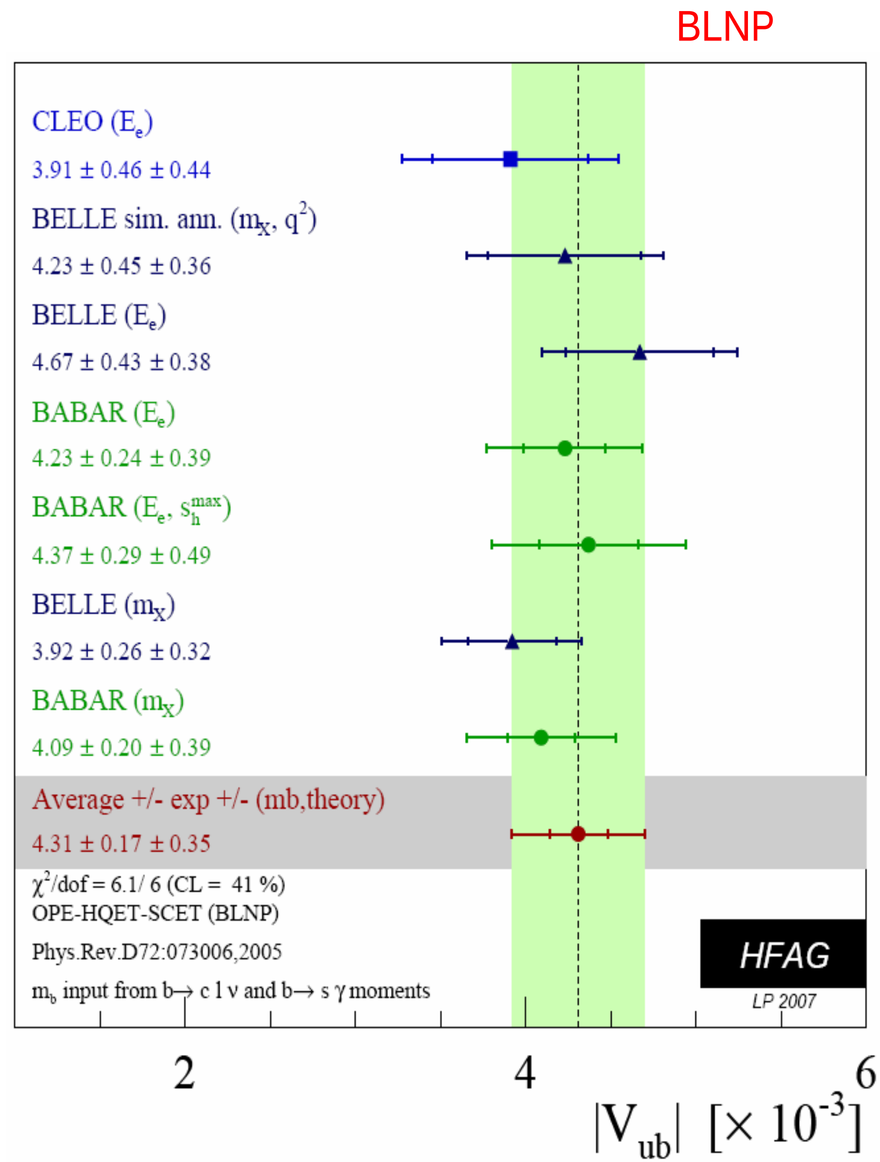
$|V_{ub}| = (4.31 \pm 0.17_{exp} \pm 0.35)$ x 10-3

Total Error: 8.9 % total

$\pm 2.0_{stat} \pm 2.6_{exp}$
$\pm 1.8_{bc\ model}$ $\pm 1.1_{bu\ model}$ } Exp. 3.9%

$\pm 6.9_{HQ\ param}$ $\pm 1.0_{SF\_form}$
$\pm 0.9_{sub\ SF}$ $\pm 3.6_{scale}$ $\pm 1.7_{WA}$ } Theory 8.1%





Summary

Inclusive Decays:

$|V_{ub}| = (4.31 \pm 0.17_{exp} \pm 0.35_{thy})\ 10^{-3}$ $|V_{cb}| = (41.9 \pm 0.2_{exp} \pm 0.2_{HQE} \pm 0.6_{thy})\ 10^{-3}$

Exclusive Decays:

$|V_{ub}| = (3.8 \pm 0.1_{exp} \pm\ 0.9_{thy})\ 10^{-3}$ $|V_{cb}| = (37.8 \pm 0.7_{exp} \pm 0.8_{thy})\ 10^{-3}$

GLOBAL FIT of CKM Parameters – CKM Fitter

$|V_{ub}|_{Pred} = (3.57 \pm 0.17)\ 10^{-3}$ $|V_{cb}|_{pred} = (41.43 \pm 0.87)\ 10^{-3}$

Major Challenges Remain:

Vcb excl: *A single precise measurements dominates. Need F(1), G(1)! Errors could be improved dramatically, but not high priority at present! Puzzle of BF measurements, and missing decays rate! D**l ν decays ?*

Vcb Incl: *Improved mass moment measurements would help, but theory uncertainties need to be understood better?*

Vub incl: *With B_{had} tag, statistics are limited, expect improvements, but probably not so dramatic – unless we find a better approach! Need to understand m_b!*

Vub excl: *Untagged analyses are best for FF, other modes are being measured! Errors can be improved, but systematics are very challenging! Need better FF normalization and tests of measured shapes!*

Many Questions – Any Answers?

Q: *How do $B \to X_u\, l\, \nu$ FFs relate to $B \to s\gamma$, $B \to s\, l^+ l^-$?*

Q: *What can SCET tell us? Checks on $B \to \pi\pi$?*

Q: *Can LQCD estimate processes like WA??*

Q: *Can we make use of the heavy quark mass determination based on LQCD?*

Q: *Can LQCD estimate shape function effects?*

Q: *How much and on what time frame can the FF calculations be improved?*
for $\pi \ell \nu$, but may also for $\eta \ell \nu$, $\rho \ell \nu$ and others?
for $D \ell \nu$, $D^* \ell \nu$, but may also for $D^{**} \ell \nu$? This will also help predictions for $D\tau\nu$!

Q: *What is the best way to extrapolate the FF calculations to the full phase space?*
Experimenters need to explore z-expansion!

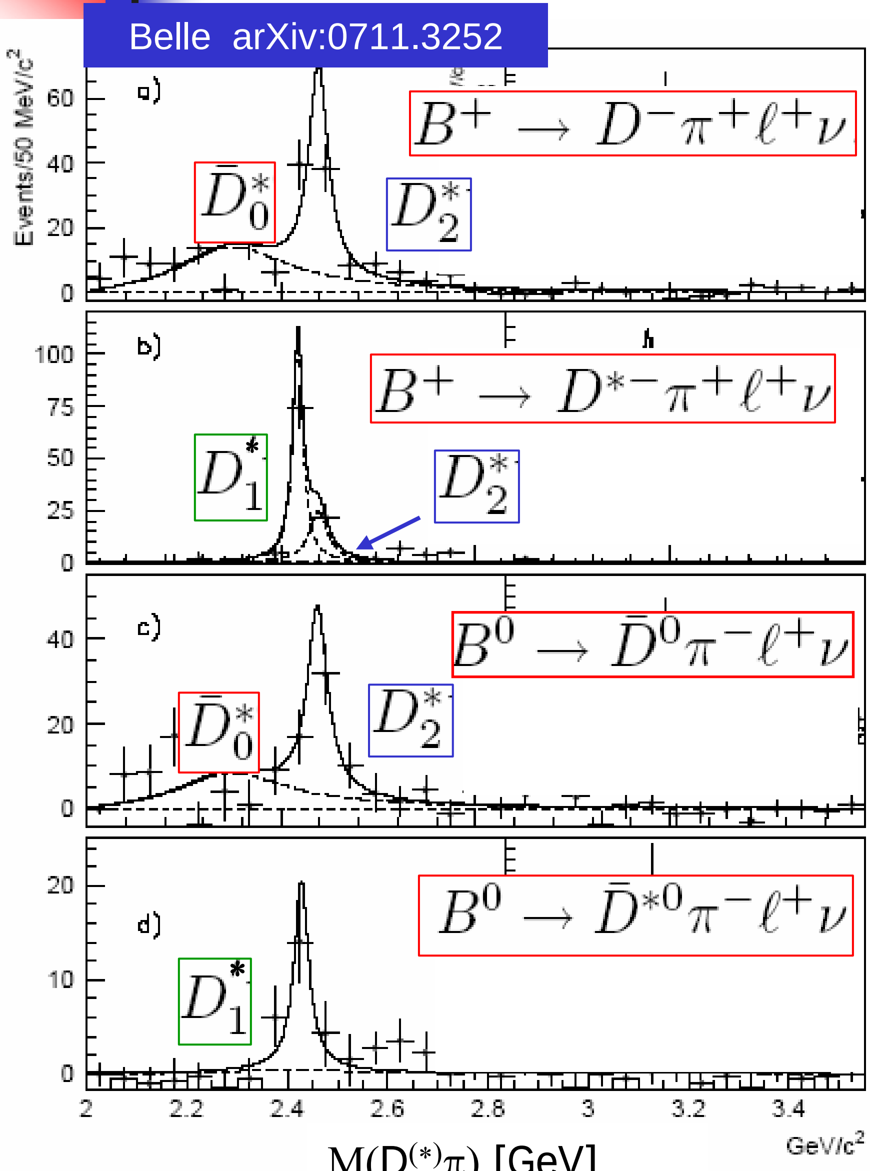
Q: *Can we extrapolate from s.l. D decays to s.l. B decays?*
Tests ratios of BF? Common FF ansatz?

- *Given that measurements of $|V_{xb}|$ are limited by theoretical progress, experimenters will only improve current measurements if the theoretical uncertainties can be reduced! These measurements are very challenging. They take years of effort!*

- *Close collaboration between experimenters and theorists has been and will continue to be critical to further progress in this area!*

Back – up Slides

Exclusive Branching Fractions $D^{**}\ell\nu$: D_0^*, D_1', D_1^*, D_2^*



Recent Belle Result on $B \to D^{**}\ell\nu$:

Decay	Events	BF (%)
$D_0^*(D\pi)l\nu$	163±29	0.23±0.04±0.05
$D_1'(D^*\pi)l\nu$	-1±14	<0.5
$D_1^*(D^*\pi)l\nu$	101±14	0.43±0.07±0.06
$D_2^*(D\pi)l\nu$	162±18	0.22±0.03±0.04
$D_2^*(D^*\pi)l\nu$	36±13	0.18±0.06±0.03

Surprise for Broad States :

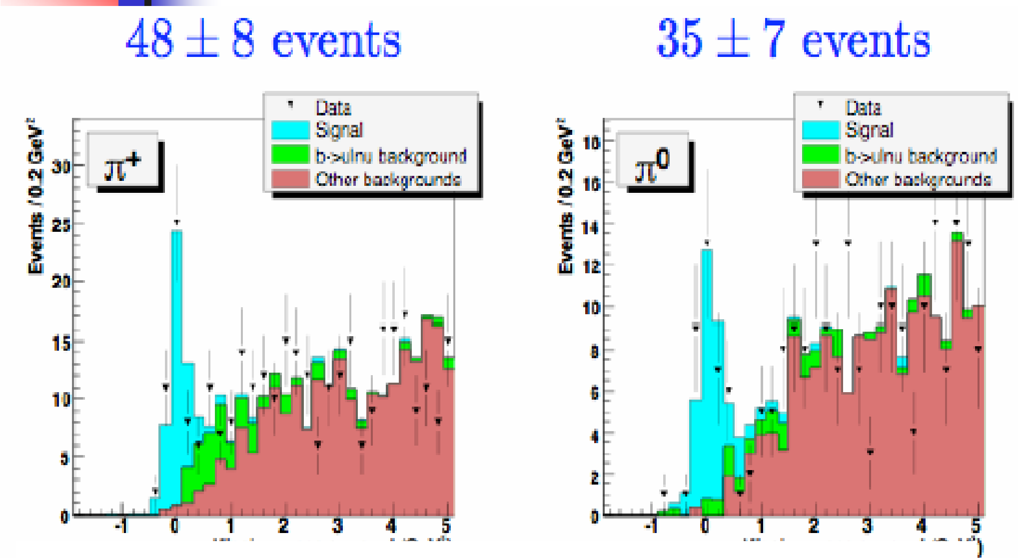
- No hint for $B \to D_1' \ell\nu$
- Large BF for $B \to D_0^* \ell\nu$

Sum of individual BF below total BF!

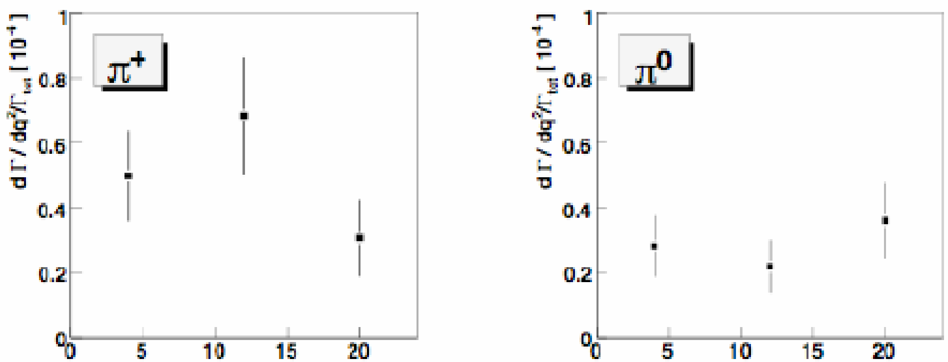
Examination of spin for narrow states, confirms unpublished BABAR observation.

Guidance for FF analysis is needed, Can lattice help?

Exclusive $B \to X_u \ell \nu$ Decays with B_{had} Tags



Missing Mass (GeV²)



q^2 (GeV²)

Belle: ICHEP06
hep-ex/0610054

532M BB Events

Tag BB events with one reconstructed hadronic B decay:

- Very low yield $90/10^9$
- High S/B 10:1

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.49 \pm 0.26(stat) \pm 0.06(syst)) \times 10^{-4}$$

$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu) = (0.86 \pm 0.17(stat) \pm 0.06(syst)) \times 10^{-4}$$

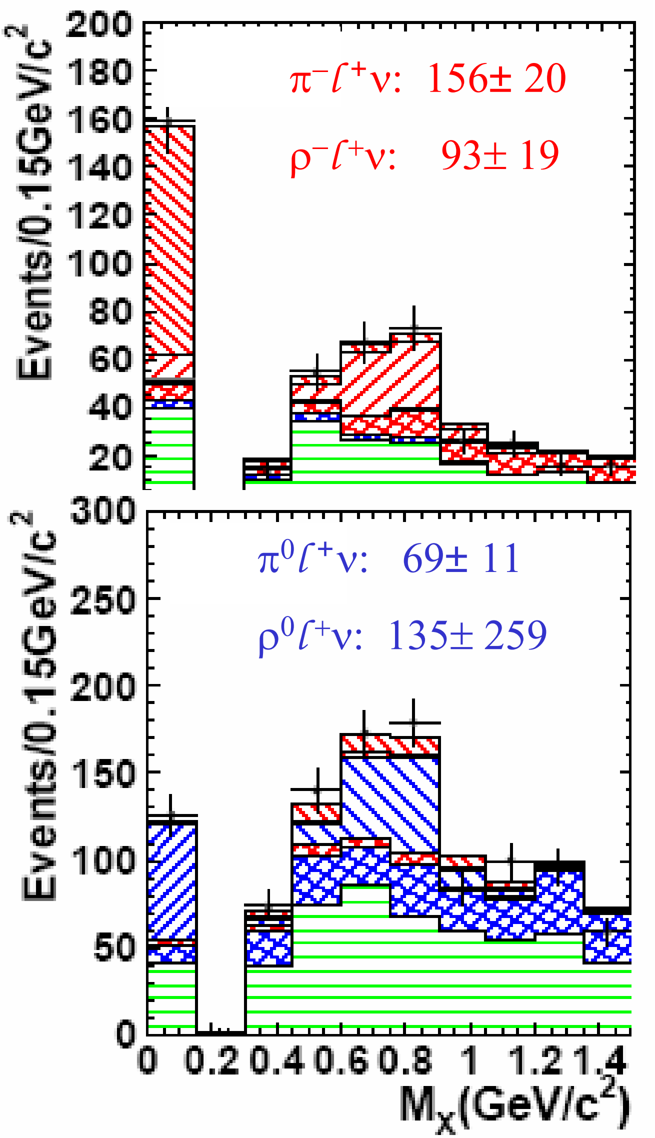
No significant constraints on shape of FF expected for such samples!

Similar yields for $\rho\ell\nu$ and $\omega\ell\nu$

Exclusive $B \rightarrow X_u \ell \nu$ Decays with B_{sl} Tags

Belle: Phys. Lett. B648, 139

275M BB Events



Tag BB event with one semileptonic B decay, $D^{(*)} \ell \nu$:

- Modest yield: $570/10^9$ BB
- Good S/B 3:1

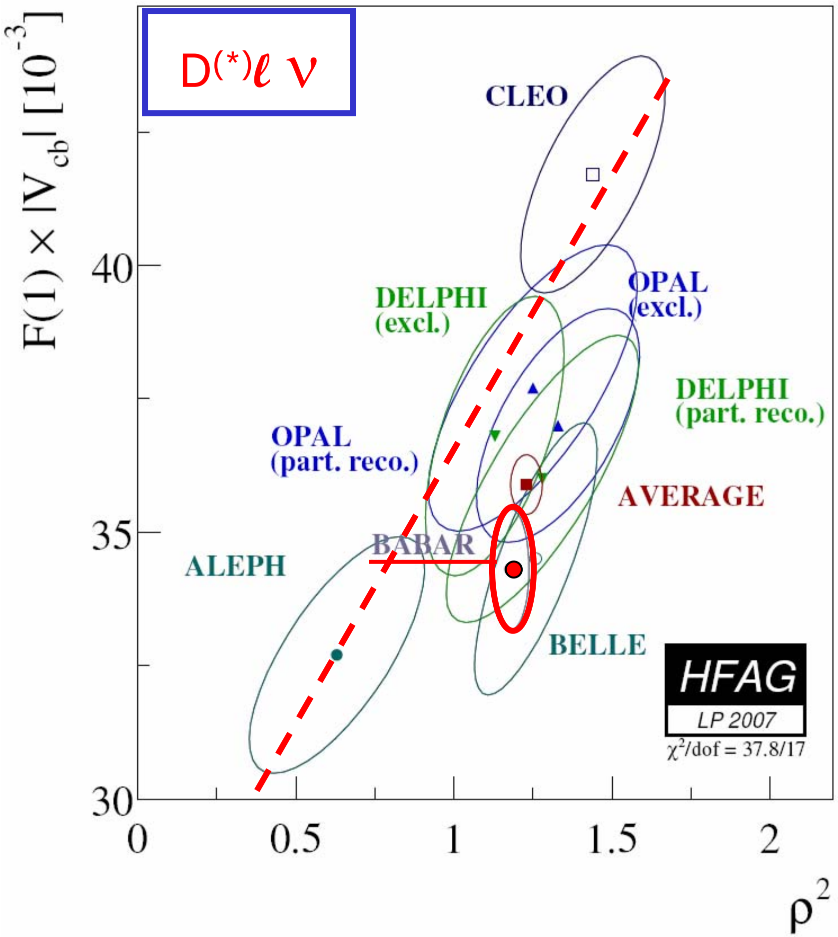
$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.38 \pm 0.19(stat) \pm 0.14(syst)) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu) = (0.77 \pm 0.14(stat) \pm 0.08(syst)) \times 10^{-4}$$
$$\mathcal{B}(B^0 \to \rho^- \ell^+ \nu) = (2.17 \pm 0.54(stat) \pm 0.31(syst)) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \rho^0 \ell^+ \nu) = (1.33 \pm 0.23(stat) \pm 0.17(syst)) \times 10^{-4}$$

$|V_{cb}|$ Measurements based on $B \to D^{(*)} \ell \nu$ Decays

Measurements pioneered by CLEO
Since then, many experiment have contributed, but

- with modest statistics
- one-dimensional analysis, w only, no information on R_1 and R_2
- Apparent strong correlation of the slope ρ and F(1) $|V_{cb}|$

BABAR result dominates!



$F(1)|Vcb|=(35.89\pm0.26\pm0.50)\ 10^{-3}$

Average improves systematic error!, but

$\chi 2/dof=38/17$

Reduced Model Shape Function Dependence

- Proposal (by M. Neubert in 1994) to reduce SF dependence by ratio of integrated BF for $b \to u \ell \nu$ and $b \to s\gamma$

$$\left|\frac{V_{ub}}{V_{ts}}\right|^2 = \frac{3\alpha}{\pi} K_{pert} \frac{\int_{E_0} dE_\ell \, dB_{ul\upsilon} / dE_\ell}{\int_{E_0} dE_\gamma w(E_\gamma, E_0) dB_{s\gamma} / dE_\gamma} + O(\Lambda_{QCD} / m_b)$$

Weight function

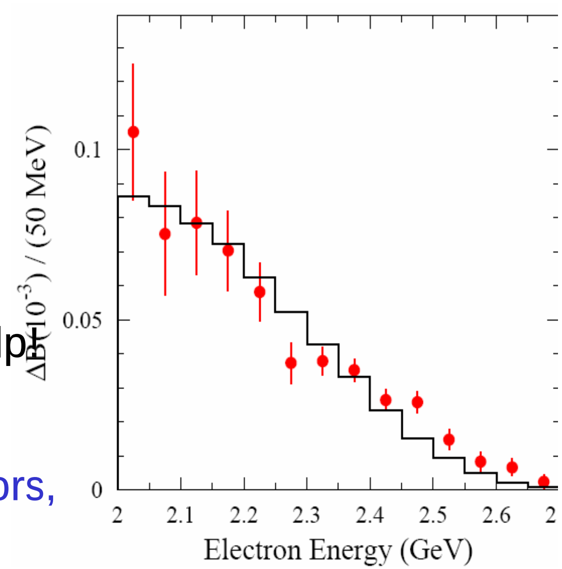
- There are 2 calculations available:
  - *Leibovich, Low, Rothstein PR61, 053006 (2000)*
  - *Lange, Neubert, Paz, JHEP0510, 084 (2005), Lange JHEP 601, 104 (2006)*
    (Uses normalized g spectrum and thus eliminates |Vts| dependence)
- *Test results as a function of Cut-off E_0 or mass M_{cut}*
- BABAR has two analyses, combining incl. γ spectrum with either
  - Mx Hadron Mass spectrum
  - E_ℓ Lepton energy spectrum

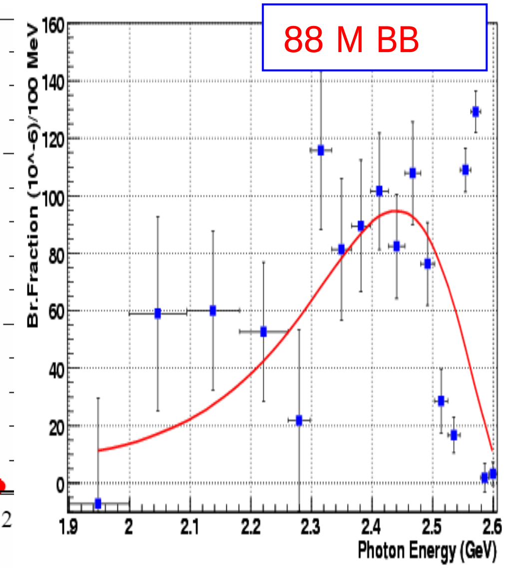
Accepted by PRD: hep-ph/0702072
V. Golubev, Y. Skovpen, V.L.

SF-Free $|V_{ub}|$ Measurement: E_ℓ Spectrum

Tried two calculations for rate ratios:

- Exp. errors on lepton and γ spectra dominate
- 10x data and improved analyses will help
- For LLR, little change with E_ℓ shows
- For LNP, large changes in $|V_{ub}|$ and errors, this is expected!.





Method	$\lvert V_{ub}\rvert \cdot 10^3$
LLR [3, 4]	$4.28 \pm 0.29 \pm 0.29 \pm 0.26 \pm 0.28$
LNP [6, 7]	$4.40 \pm 0.30 \pm 0.41 \pm 0.23$
SF-based analysis [9]	$4.44 \pm 0.25 ^{+0.42}_{-0.38} \pm 0.22$

6.8% 7.0%