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

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Outline

Introduction

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

Study of D** states in $B \to D^{**} l \nu$ decay

$|V_{ub}|$ from $B \to \pi l \nu$ (and other exclusive charmless SL decays)

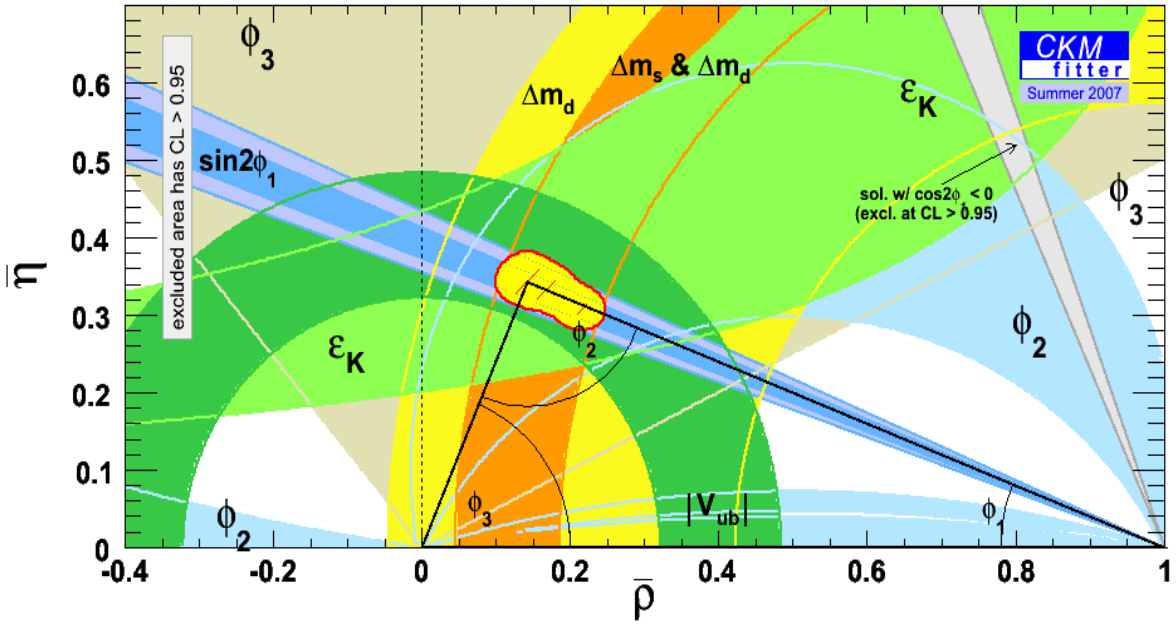
Summary

Motivation

Test of unitarity of the CKM matrix

Overconstrain the unitarity triangle by various parameters

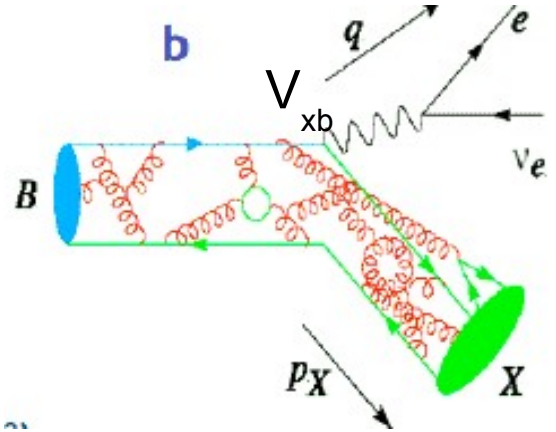
- Two of the important variables are $|V_{ub}|$ and $|V_{cb}|$
- $|V_{ub}|$ and $|V_{cb}|$ constrain sides of the unitarity triangle



How to measure $|V_{cb}|$&$|V_{ub}|$

Use semileptonic B decay

Clear lepton signal, tree level diagram but...



Quarks are bound by soft gluons: non-perturbative

Use different two approaches

Inclusive analyses

Needs: extrapolation to the full phase space by theory

Exclusive analyses

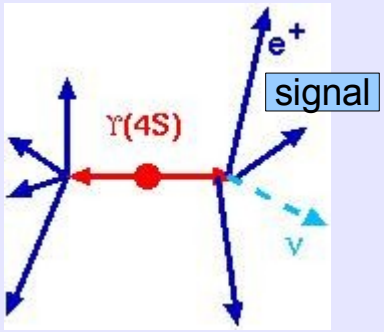
Needs: prediction of form factor by theory

Experimental technique

The event contain missing neutrino(s)

Various method according to the size of luminosity and expected BF

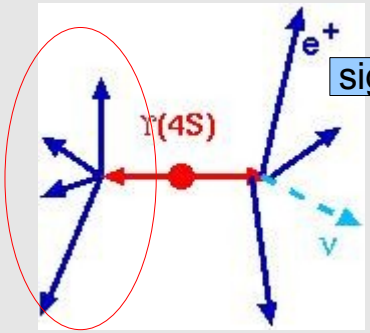
Kinematics



Use only signal side:

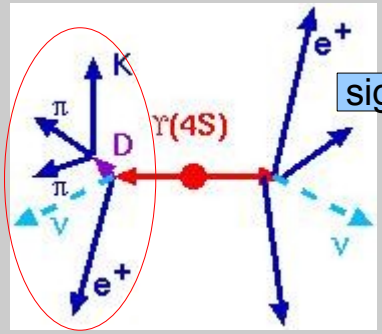
$$\cos\theta_{B,DI}=\frac{2E_BE_{D^*l}-m_B^2-m_{D^*l}^2}{2p_Bp_{D^*l}}$$

Untagged



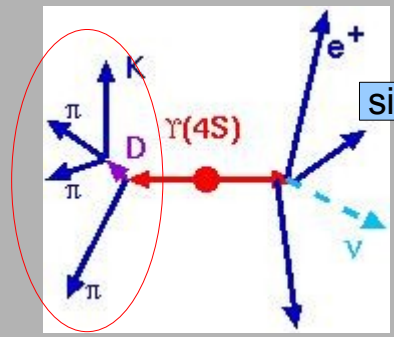
Use for ν recon

Semileptonic (SL) tag



Tag by D(*)lν +kinematics

Full reconstruction (B_{reco}) tag



Tag by a fully reconstructed B

low ◄ purity ► high

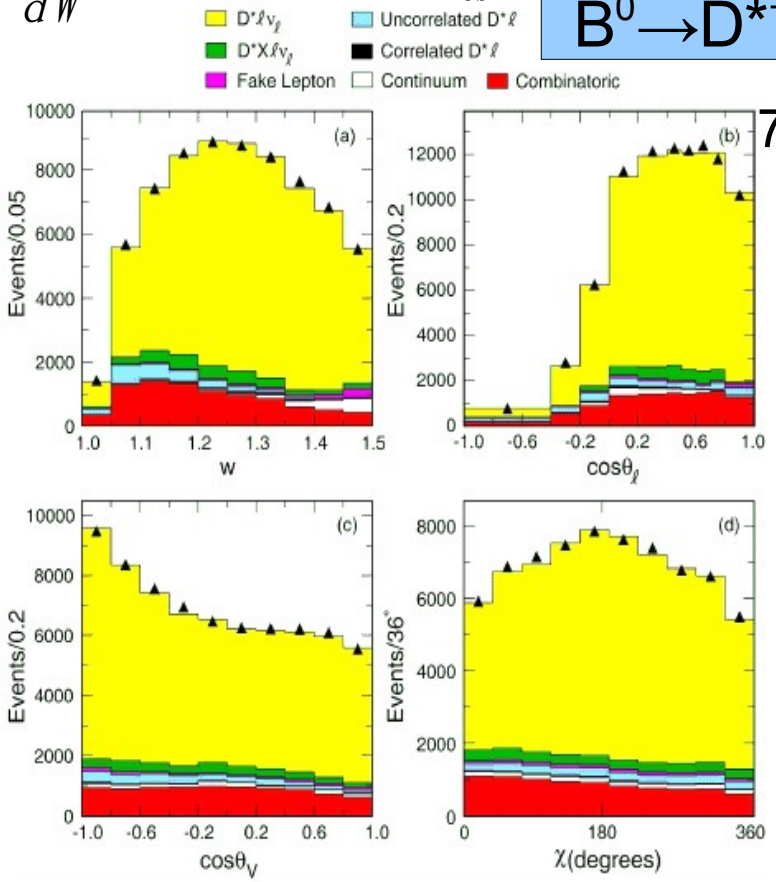
high efficiency low

$|V_{cb}|$

$B \to D^* l \nu$

$$\frac{d\Gamma(B \to D^{(*)} l \nu)}{dw} = K(w) F(w)^2 |V_{cb}|^2$$

$\bar{B}^0 \to D^{*+} l^- \bar{\nu}$



79MM$\bar{B}\bar{B}$

$F(1)|V_{cb}| = (34.7 \pm 0.4 \pm 1.0) \times 10^{-3}$

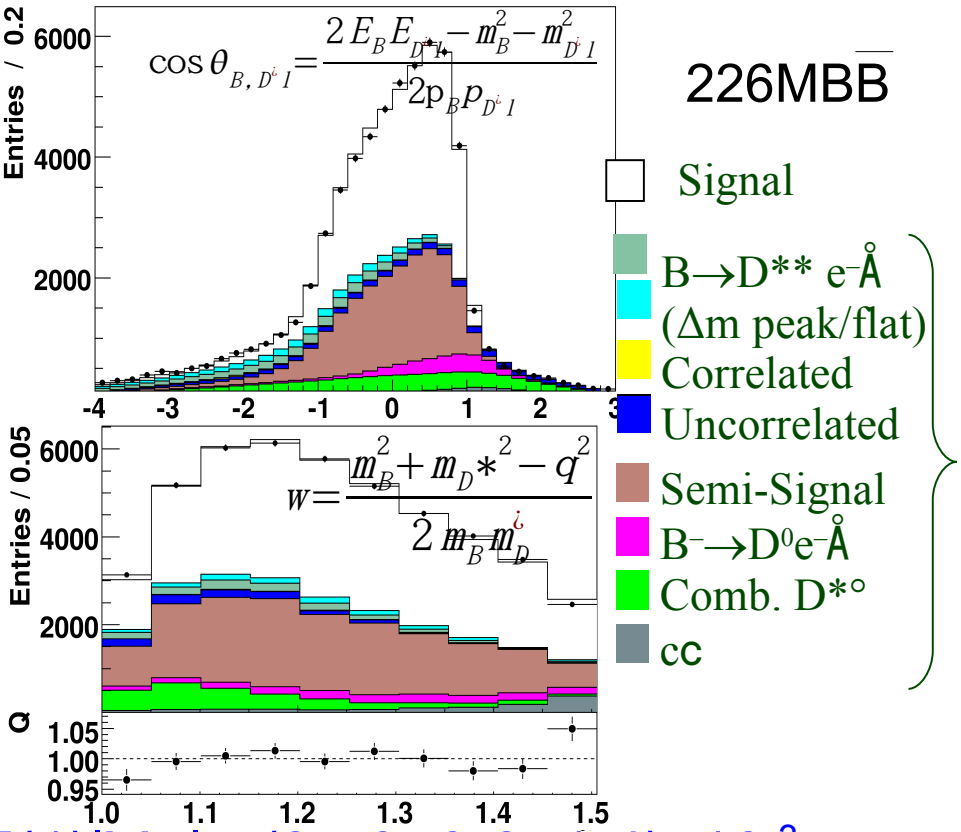
Form factor parameters:

$\rho^2 = 1.157 \pm 0.094 \pm 0.027$

$R_1(1) = 1.327 \pm 0.131 \pm 0.043$

$R_2(1) = 0.859 \pm 0.077 \pm 0.021$

$B^- \to D^{*0} e^- \bar{\nu}$



226MM$\bar{B}\bar{B}$

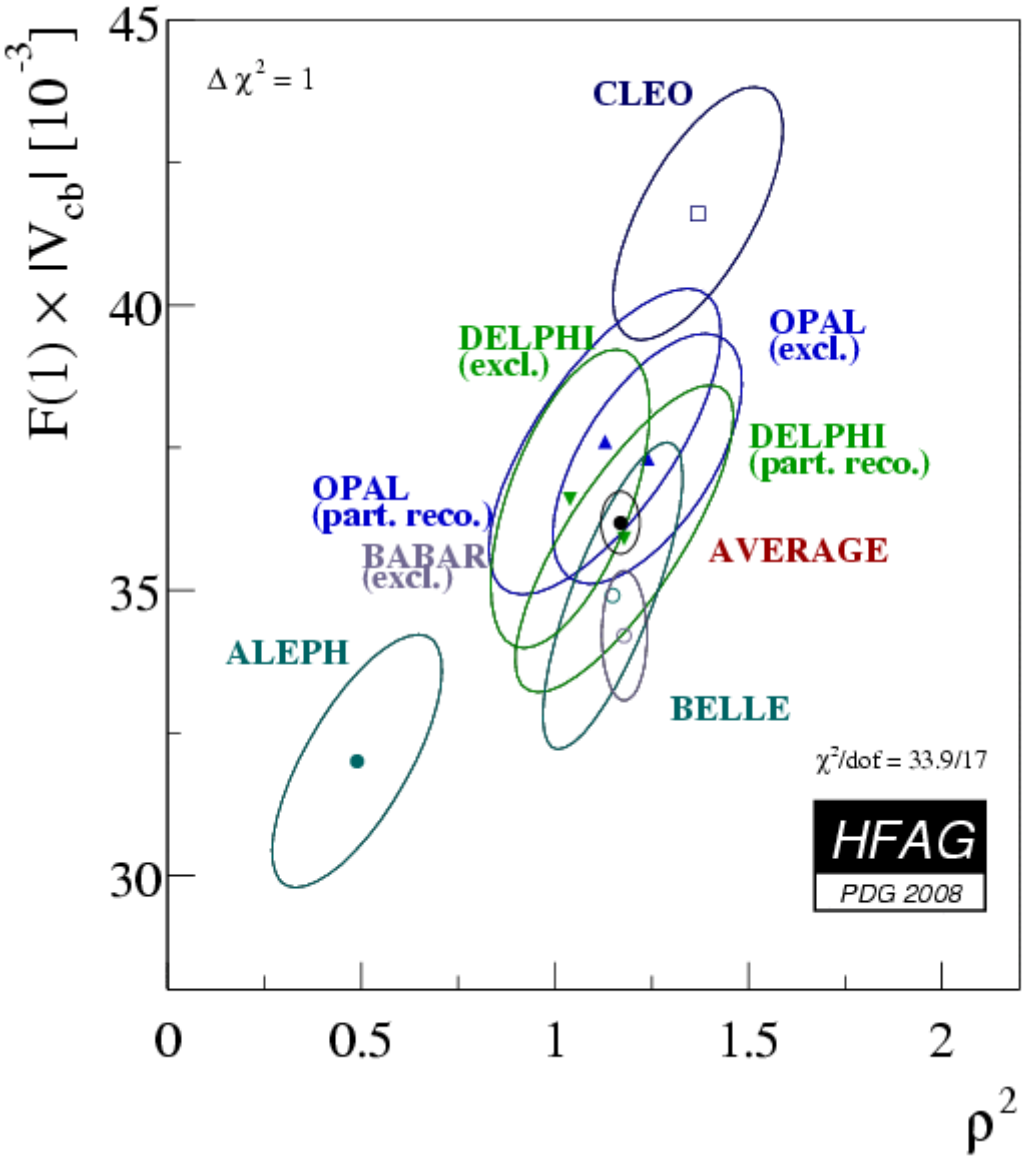
$F(1)|V_{cb}| = (35.9 \pm 0.6 \pm 1.4) \times 10^{-3}$

$\rho^2 = 1.16 \pm 0.06 \pm 0.08$

$BF(B^- \to D^{*0} e^- \bar{\nu}) = (5.56 \pm 0.08 \pm 0.41)\%$

Complementary to $D^{*+} e^- \bar{\nu}$ analyses

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



$F(1)|V_{cb}| = (36.18 \pm 0.55) \times 10^{-3}$

$\rho^2 = 1.17 \pm 0.05$

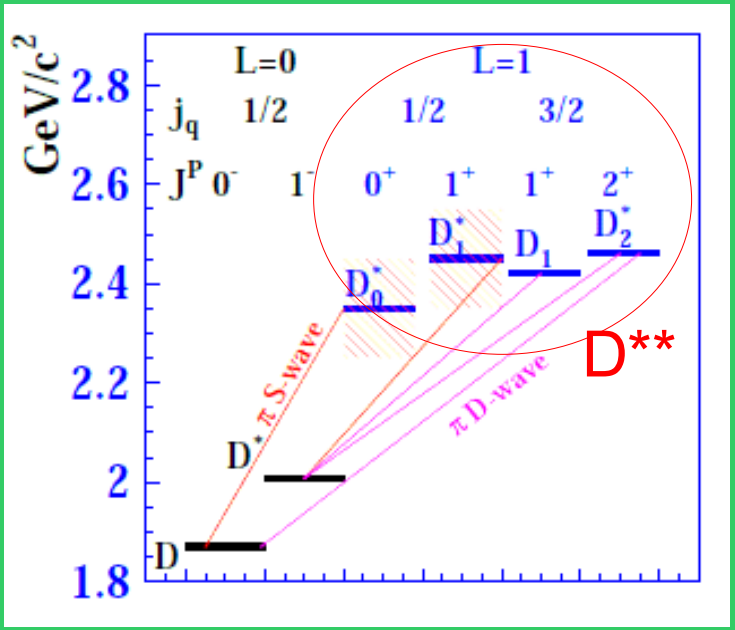
Lattice calculation predicts:
$F(1) = 0.919 \pm 0.033$

$|V_{cb}| = (39.37 \pm 0.60 \pm 1.41) \times 10^{-3}$

Error is dominated by the uncertainty in the lattice calculation

B→D**lν:Introduction

- Not directly used for $|V_{cb}|$ extraction but is important for systematics for e.g. $|V_{cb}|$ measurement by D*lν
- D** spectroscopy itself is interesting:



HQET predicts:

$Br(B\to D_1 l\nu)$ >> $Br(B\to D^*_0 l\nu)$

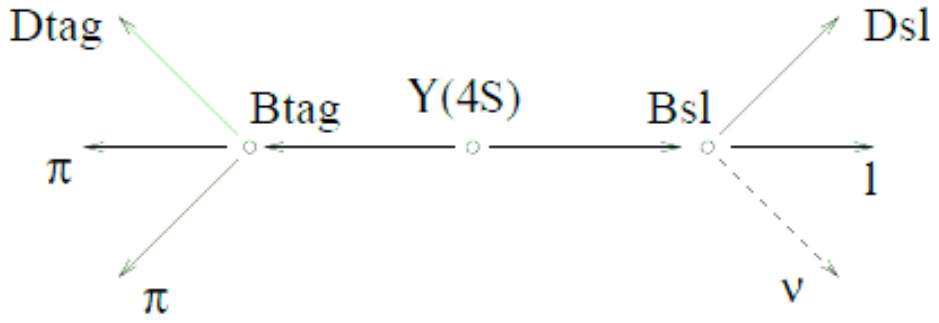
$Br(B\to D^*_2 l\nu)$ $Br(B\to D'_1 l\nu)$

Narrow D** Wide D**

Bigi et al.
arXiv:0708.1621

B→D**lν:analysis method

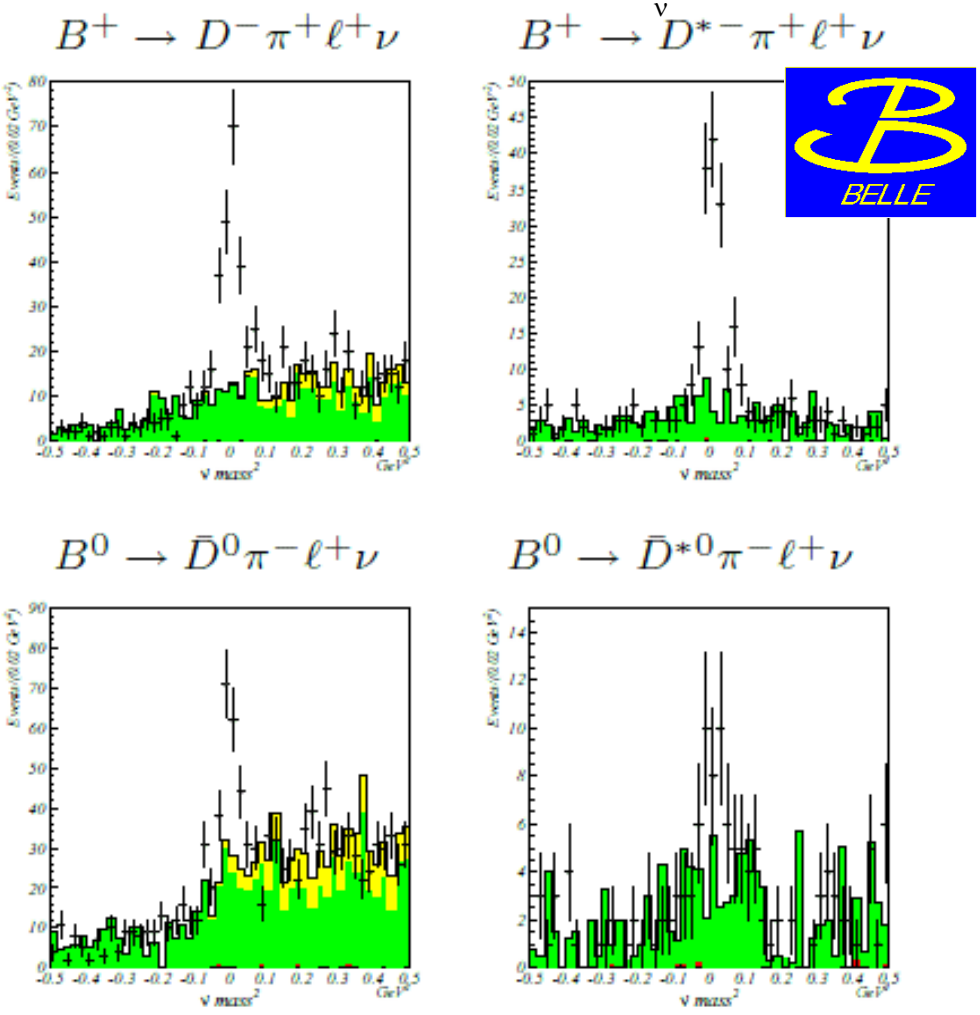
B_{reco} tag method to obtain good M_ν^2 resolution



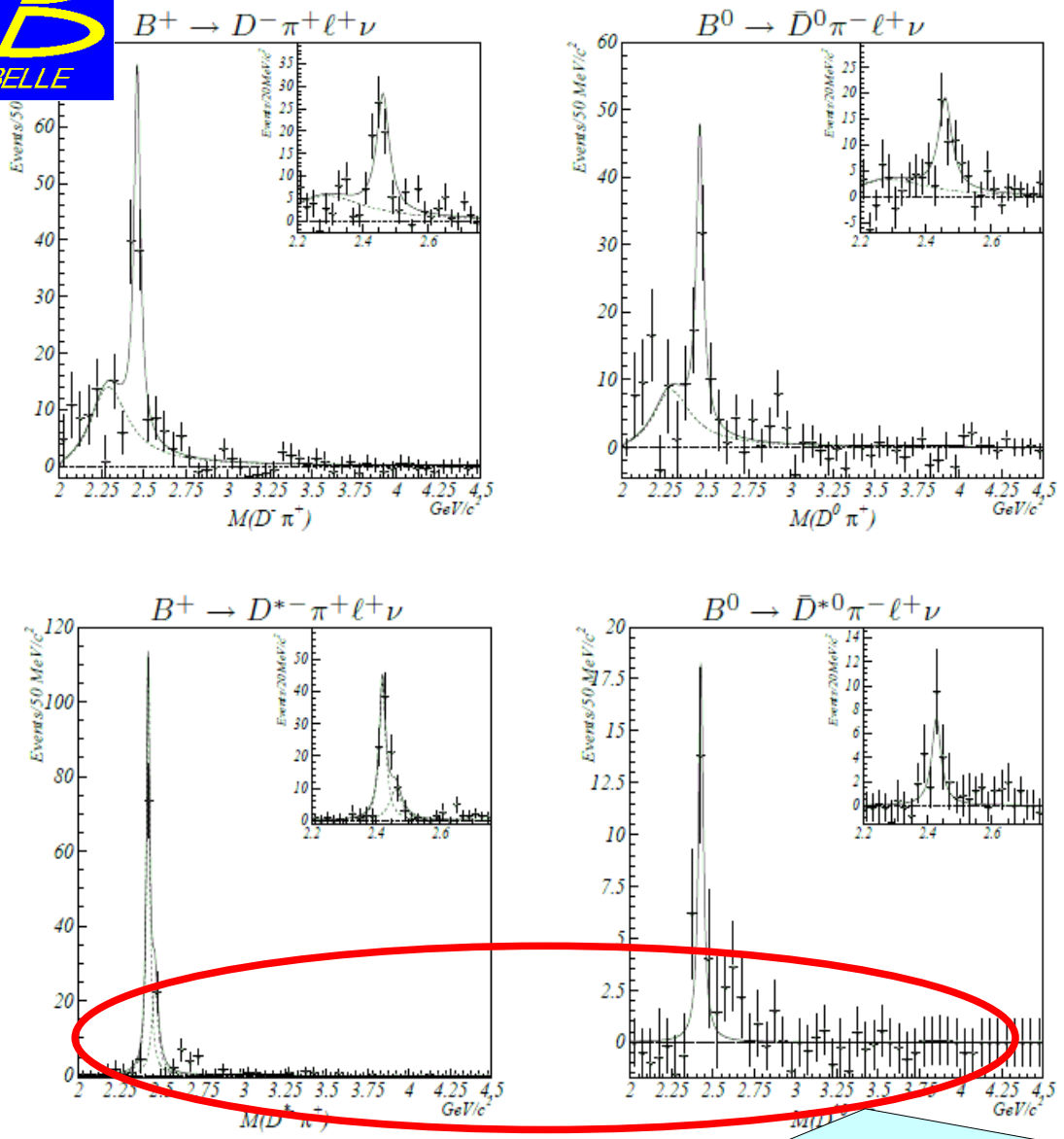
Calculate missing mass squared M_ν^2

$$M_\nu^2 = (P_{\text{beam}} - P_{B_{\text{tag}}} - P_{B_{\text{sl}}})^2$$

Distributions of M_ν^2



B→D**lν:D** states from Belle



Large BF for $D^*_0 l\nu$

⇕

HQET prediction

$$\frac{BF(B \to D^*_2 l\nu)}{BF(B \to D^*_0 l\nu)} \sim 10$$

$\mathcal{B}(\text{mode}) \to D^{**}\ell\nu) \times \mathcal{B}(D^{**} \to D^{(*)}\pi^+)$

π invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to D_0^{*0}\ell^+\nu$	102 ± 19	$0.24 \pm 0.04 \pm 0.06$	5.4
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	94 ± 13	$0.22 \pm 0.03 \pm 0.04$	8.0
$B^0 \to D_0^{*-}\ell^+\nu$	61 ± 22	$0.20 \pm 0.07 \pm 0.05$	2.6
$B^0 \to D_2^{*-}\ell^+\nu$	68 ± 13	$0.22 \pm 0.04 \pm 0.04$	5.5

$D^*\pi$ invariant mass study

Mode	Yield	$\mathcal{B}$, %	Signif.
$B^+ \to D_1^{*0}\ell^+\nu$	-5 ± 11	< 0.07 @ 90% C.L.	
$B^+ \to \bar{D}_1^0\ell^+\nu$	81 ± 13	$0.42 \pm 0.07 \pm 0.07$	6.7
$B^+ \to \bar{D}_2^{*0}\ell^+\nu$	35 ± 11	$0.18 \pm 0.06 \pm 0.03$	3.2
$B^0 \to D_1^{*-}\ell^+\nu$	4 ± 8	< 0.5 @ 90% C.L.	
$B^0 \to D_1^-\ell^+\nu$	20 ± 7	$0.54 \pm 0.19 \pm 0.09$	2.9
$B^0 \to D_2^{*-}\ell^+\nu$	1 ± 6	< 0.3 @ 90% C.L.	

arXiv:0711.3252

Broad resonance($B \to D'_1 l\nu$) is not seen

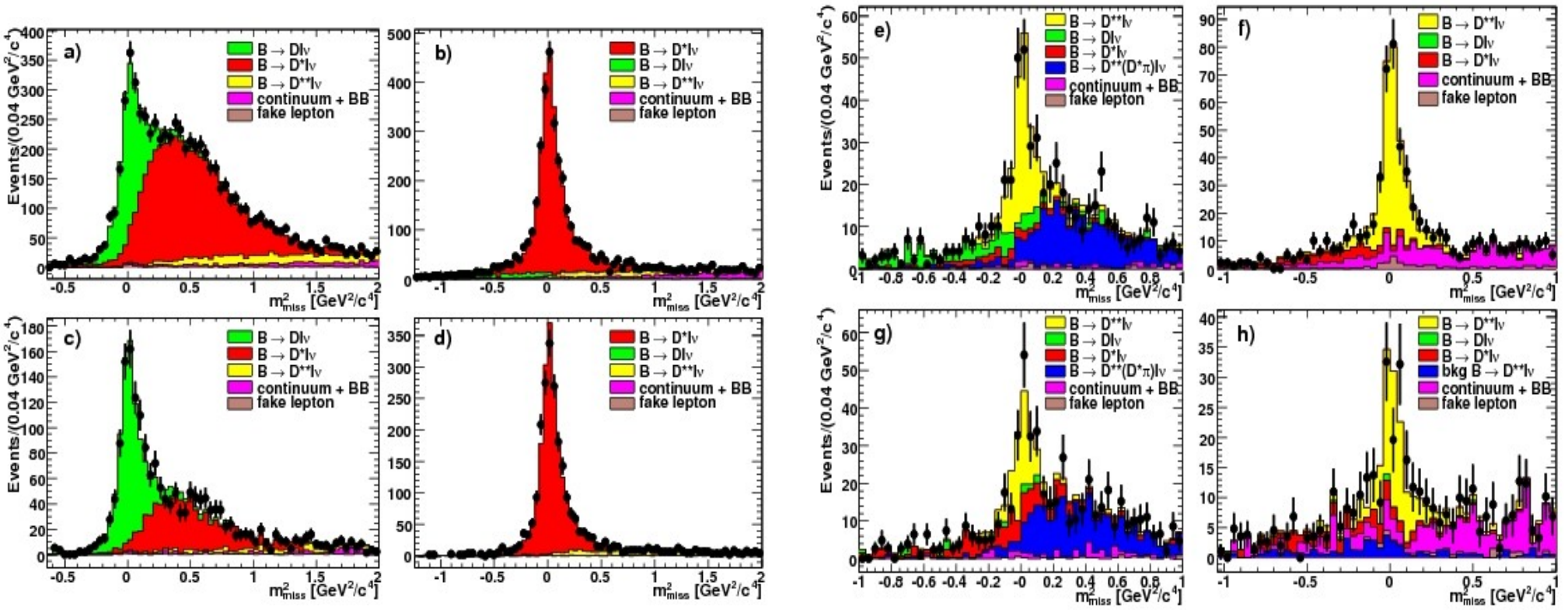
B→Dlν/D*lν/D**lν from Babar

Measurement of branching fractions by B_{reco} tag method

Mode	$\mathcal{B}(B^-)$ [%]	$\mathcal{B}(\overline{B}^0)$ [%]
$D\ell^-\overline{\nu}_\ell$	$2.33 \pm 0.09 \pm 0.09$	$2.21 \pm 0.11 \pm 0.12$
$D^*\ell^-\overline{\nu}_\ell$	$5.83 \pm 0.15 \pm 0.30$	$5.49 \pm 0.16 \pm 0.25$
$D\pi^\pm\ell^-\overline{\nu}_\ell$	$0.42 \pm 0.06 \pm 0.03$	$0.43 \pm 0.08 \pm 0.03$
$D^*\pi^\pm\ell^-\overline{\nu}_\ell$	$0.59 \pm 0.05 \pm 0.04$	$0.48 \pm 0.08 \pm 0.04$

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

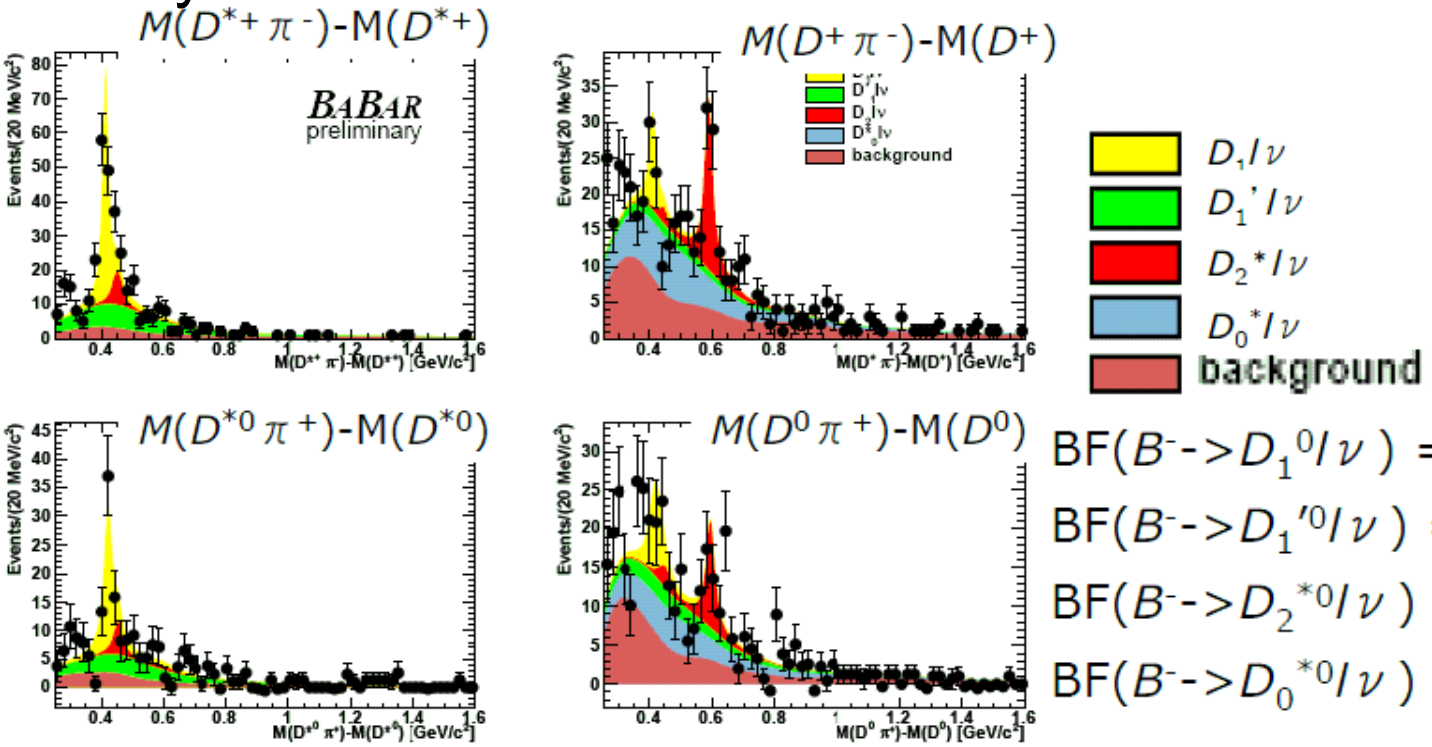
$$\mathcal{B}(\overline{B^0} \to D^{(*)}\pi\ell^-\bar{\nu}_\ell) = (1.37 \pm 0.17_{stat.} \pm 0.10_{syst.})\%$$



PRL 100, 151802 (2008)

B→D**lν:D** states from BaBar

Study of the D**lν states



BF(B^-->$D_1^0 l\nu$) = 0.42 ± 0.04 ± 0.04 %

BF(B^-->$D_1'^0 l\nu$) = 0.47 ± 0.06 ± 0.06%

BF(B^-->$D_2^{*0} l\nu$) = 0.29 ± 0.05 ± 0.03%

BF(B^-->$D_0^{*0} l\nu$) = 0.52 ± 0.07 ± 0.06%

-Large Br for wide states($D^*_0 l\nu$,$D'_1 l\nu$)

disagree with HQET prediction

-Large Br for $D'_1 l\nu$

disagree with Belle result (>6σ)

$|V_{ub}|$

Exclusive $|V_{ub}|$

Experimentally various modes can be measured:

- $B \to \pi l \nu$, $\rho l \nu$, $\omega l \nu$, $\eta l \nu$, $\eta' l \nu$

Currently, only $B \to \pi l \nu$ can be used for $|V_{ub}|$ extraction:

Form factor calculation from various methods:

- lattice QCD (HPQCD, Fermilab,...)
- Light-Cone Sum Rules(Ball & Zwicky,...)
- quark models (ISGW2,...)

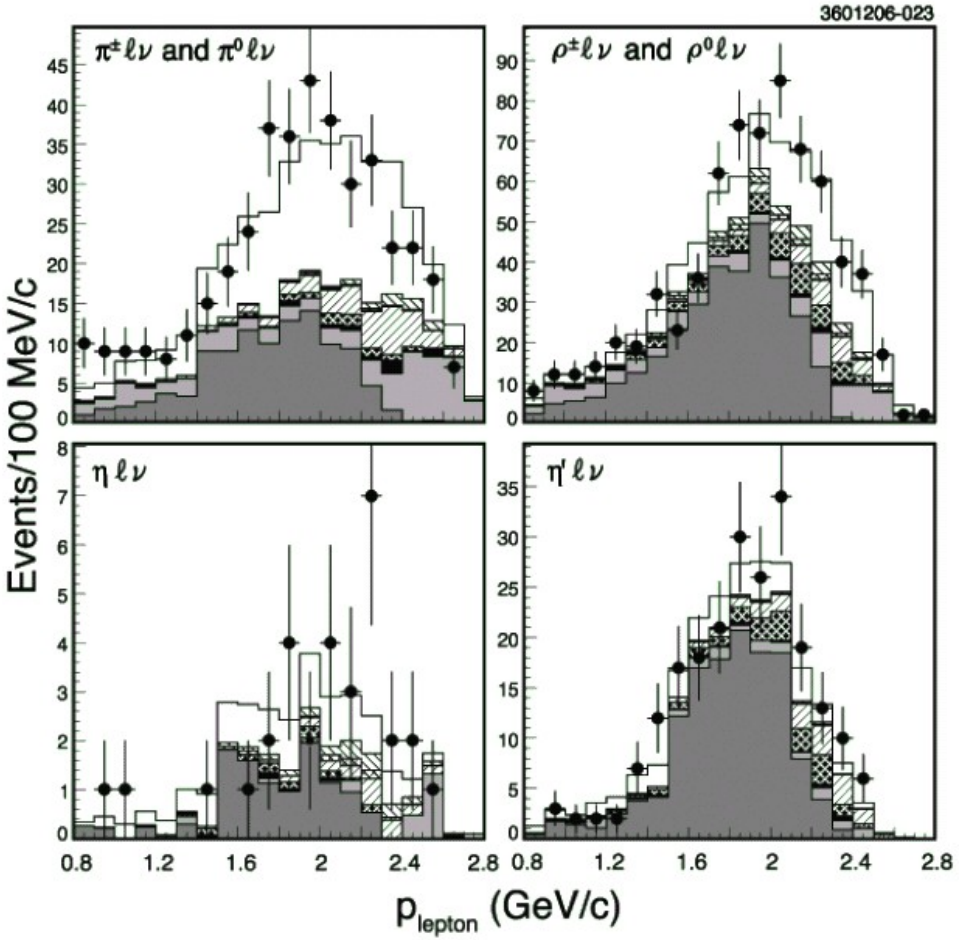
Recent results:

CLEO untagged method: Phys.Rev.Lett.99:041802 (2007)
BaBar untagged method: Phys. Rev. Lett. 98:091801 (2007)
Belle SL tag method: Phys.Lett.B648:139-148 (2007)

B→πlν/ρlν/ηlν/η'lν: untagged method

CLEO 17MBB

Lepton momentum projection

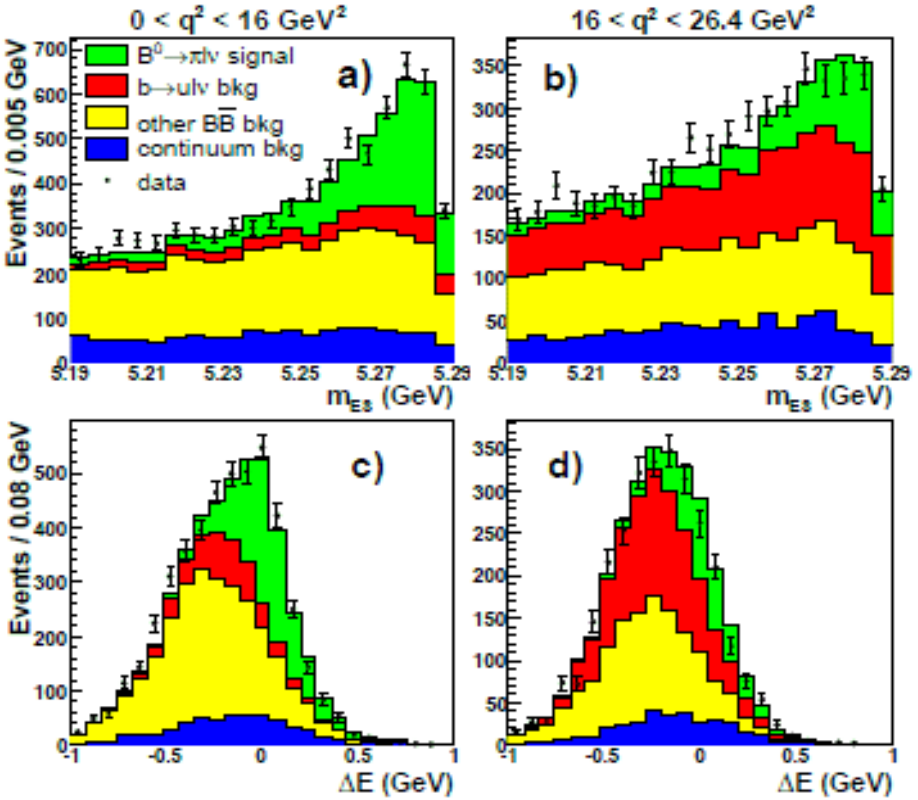


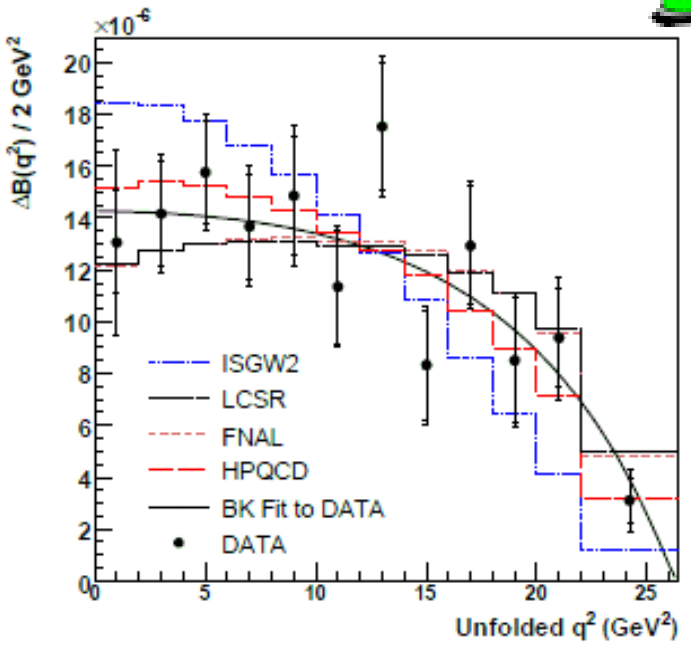
	q^2 [GeV^2]	$\cos\theta_{W\ell}$	$\mathcal{B}$ [10^{-4}]
$B^0 \to \pi^-\ell^+\nu$	0 - 2	$^-1$ - 1	$0.13 \pm 0.07 \pm 0.02$
	2 - 8	$^-1$ - 1	$0.27 \pm 0.08 \pm 0.03$
	8 - 16	$^-1$ - 1	$0.56 \pm 0.09 \pm 0.05$
	> 16	$^-1$ - 1	$0.41 \pm 0.08 \pm 0.04$
	all phase space		$\mathbf{1.37 \pm 0.15 \pm 0.11}$
$B^0 \to \rho^-\ell^+\nu$	0 - 2	$^-1$ - 1	$0.45 \pm 0.20 \pm 0.15$
	2 - 8	$^-1$ - 1	$0.96 \pm 0.20 \pm 0.29$
	8 - 16	0 - 1	$0.75 \pm 0.16 \pm 0.14$
	> 16	0 - 1	$0.35 \pm 0.07 \pm 0.05$
	> 8	$^-1$ - 0	$0.42 \pm 0.18 \pm 0.31$
	all phase space		$\mathbf{2.93 \pm 0.37 \pm 0.37}$
$B^0 \to \eta\ell^+\nu$	all phase space		$\mathbf{0.44 \pm 0.23 \pm 0.11}$
$B^0 \to \eta'\ell^+\nu$	all phase space		$\mathbf{2.66 \pm 0.80 \pm 0.56}$

B→πlν: untagged method

BaBar 227MBB

Loose neutrino reconstruction

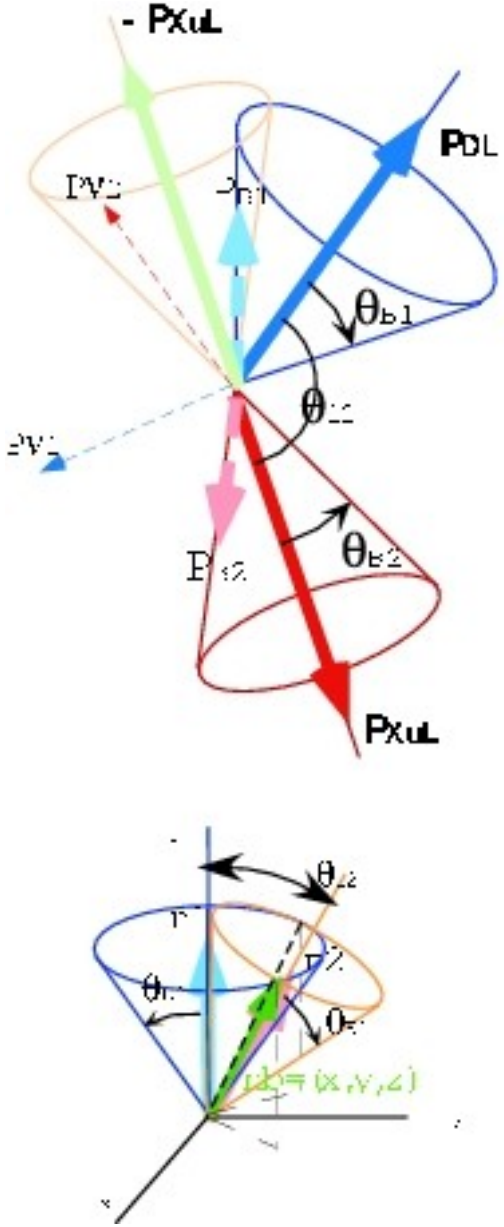




	q^2 (GeV^2)	$\Delta\zeta$ (ps^{-1})	$\lvert V_{ub}\rvert$ (10^{-3})
HPQCD [3]	> 16	1.46 ± 0.35	$4.1 \pm 0.2 \pm 0.2\ ^{+0.6}_{-0.4}$
FNAL [4]	> 16	1.83 ± 0.50	$3.7 \pm 0.2 \pm 0.2\ ^{+0.6}_{-0.4}$
LCSR [5]	< 16	5.44 ± 1.43	$3.6 \pm 0.1 \pm 0.1\ ^{+0.6}_{-0.4}$
ISGW2 [6]	0–26.4	9.6 ± 4.8	$3.2 \pm 0.1 \pm 0.1\ ^{+1.3}_{-0.6}$

Phys. Rev. Lett. 98:091801 (2007)

B→πlν/ρlν: D(*)lν tag method

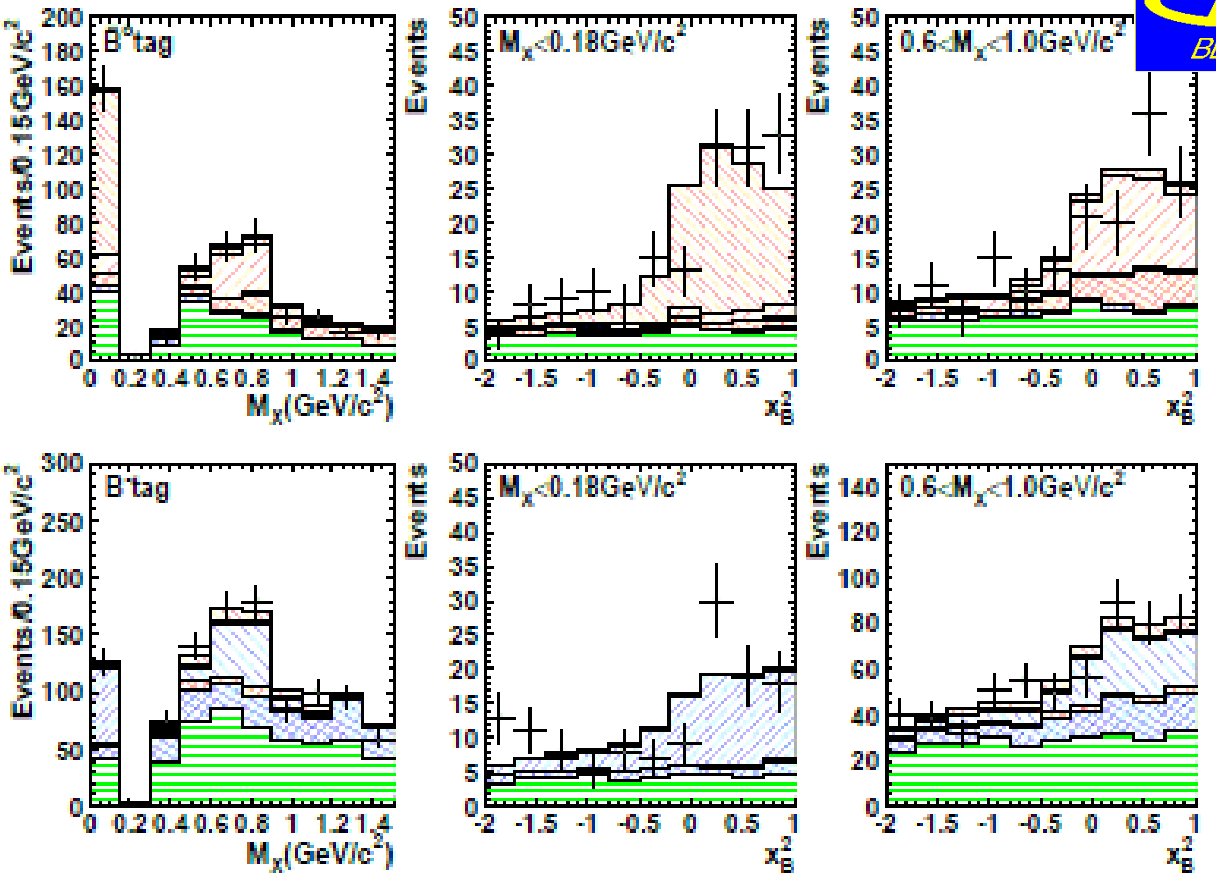


- B→D(*)lν tag

Belle 275MBB

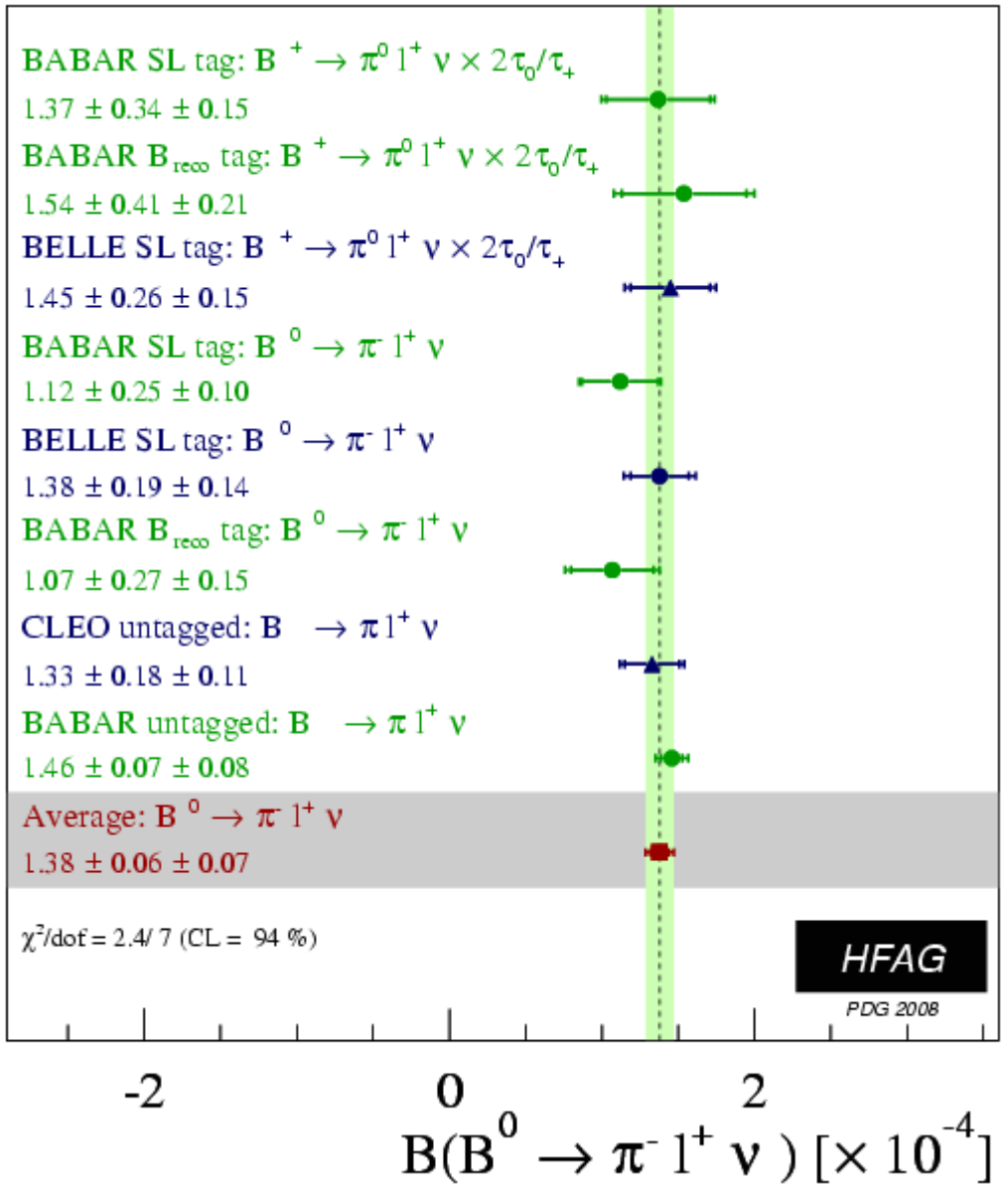
- to handle two neutrinos, use a kinematical variable: x^2_B

$$x_B{}^2 = 1 - \frac{1}{\sin^2\theta^*_{12}}(\cos^2\theta^*_{B_1} + \cos^2\theta^*_{B_2} - 2\cos\theta^*_{B_1}\cos\theta^*_{B_2}\cos\theta^*_{12})$$



Phys.Lett.B648:139-148 (2007)

$|V_{ub}|$ from $B \to \pi l \nu$



Many measurements that are not covered in this talk

Average

$B(B^0 \to \pi^- l^+ \nu) = 1.38 \pm 0.06 \pm 0.07$

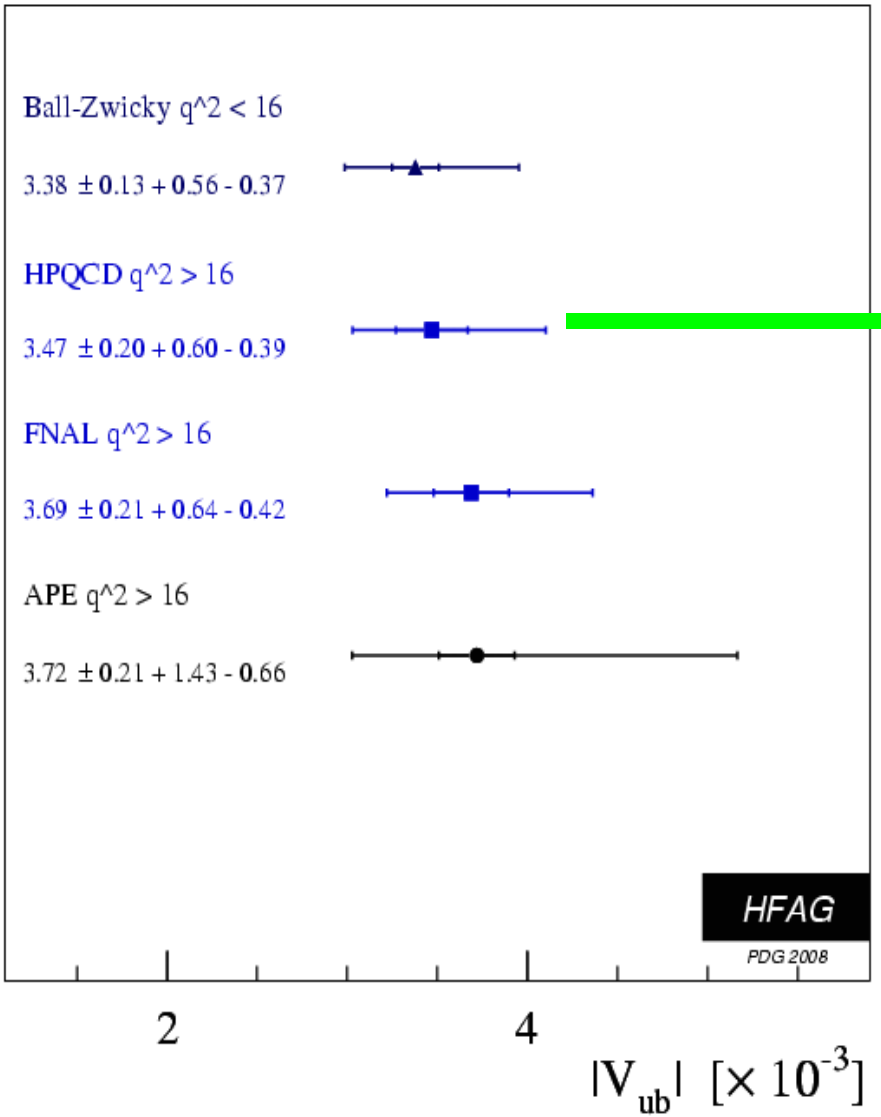
More results will be coming soon:

e.g.

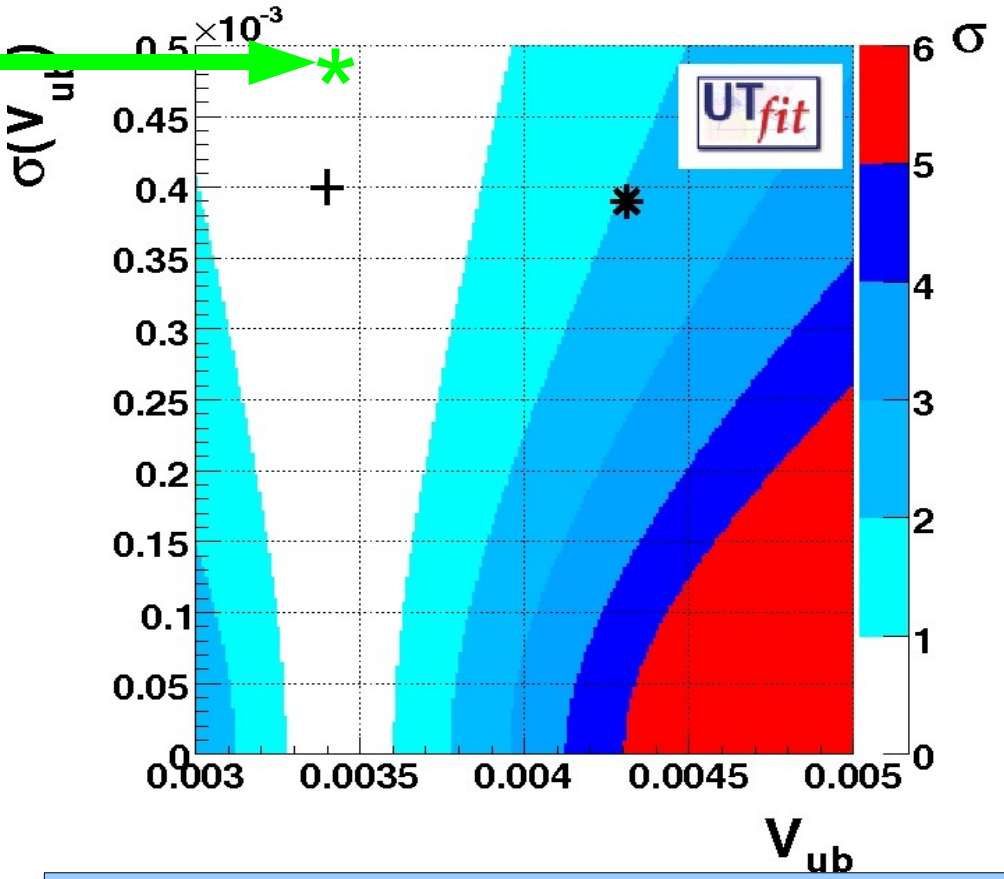
B_{reco} tag analysis from Belle

SL tag analysis from BaBar

$|V_{ub}|$ from $B \to \pi l \nu$



Expected |Vub| from global UT fit w/o |Vub|



Consistent with global UT fit result

Summary

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

$|V_{cb}| = (39.37 \pm 0.60 \pm 1.41) \times 10^{-3}$

- new measurement w/ form factor parameters
- uncertainty of F(1) is dominant
- ~1.5σ difference from inclusive $|V_{cb}| = (42.04 \pm 0.34 \pm 0.59) \times 10^{-3}$

Study of D** states in $B \to D^{**} l \nu$ decay

-Measured branching ratio(s) contradicts the HQET prediction
-need theoretical and experimental effort for understanding

$|V_{ub}|$ from $B \to \pi l \nu$:

- Many measurements from various techniques
  more results will be coming soon
- Progress of the form factor calculation: "unquenched" lattice QCD
  $|V_{ub}| = (3.47 \pm 0.20 + 0.60 - 0.39) \times 10^{-3}$ (HPQCD, $q^2 > 16 GeV^2$)

backup

D**lν analysis

Dπ invariant mass is fitted in bins of helicity and w