Review of $|V_{cb}|$ and $|V_{ub}|$ measurements

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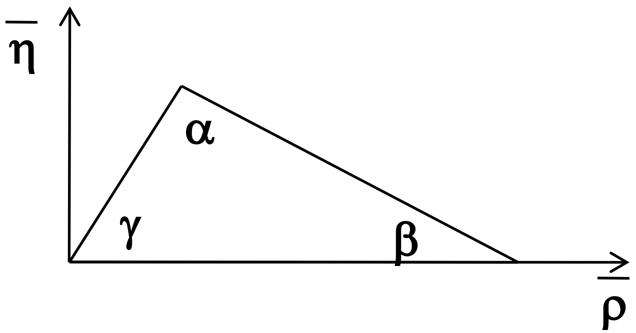
Outline

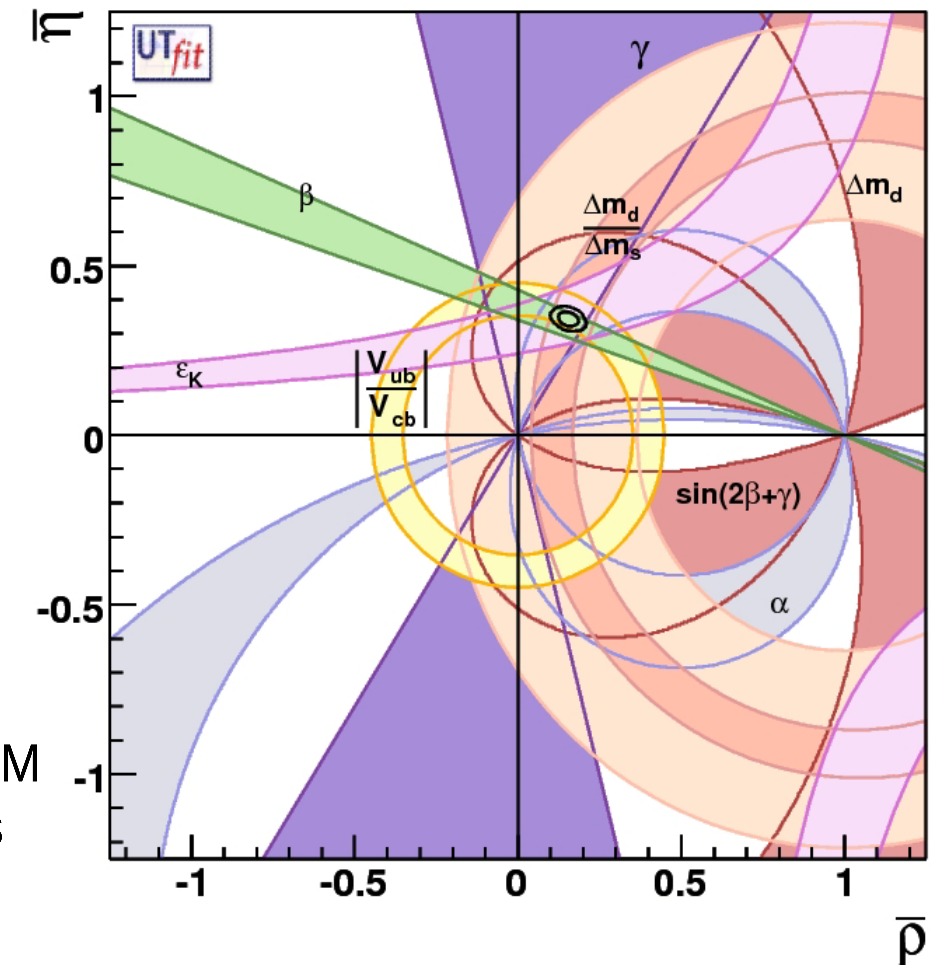
- **Introduction to the measurement of $|V_{cb}|$ and $|V_{ub}|$**
- **Results from the B-factories:**
  - **$|V_{cb}|$ from Spectral Moment**
  - **FF x $|V_{cb}|$ from $B \rightarrow D^{(*)} l \nu$**
  - **Inclusive $|V_{ub}|$**
  - **$|V_{ub}|$ from exclusive SL charmless B decays**
- **Summary and outlook**

Constraints on Unitarity Triangle



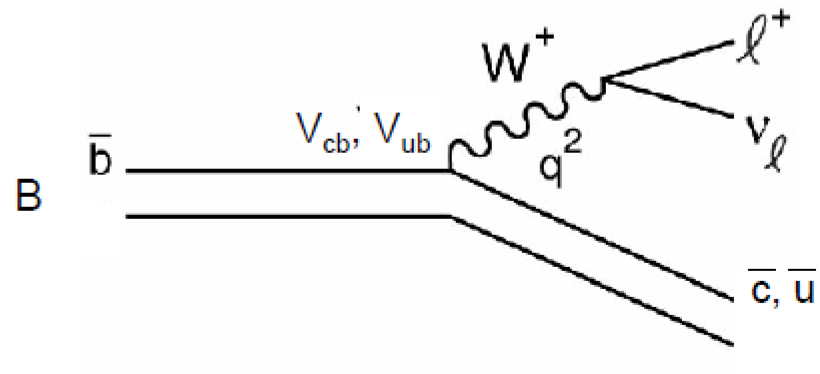
$$\frac{|V_{ub}|}{|V_{cb}|} = \frac{\lambda}{1-\lambda^2/2}\sqrt{\bar{\rho}^2+\bar{\eta}^2}$$

A precise determination of $|V_{ub}/V_{cb}|$ is crucial to be able to observe deviations from the CKM mechanism due to New Physics



Semileptonic B Decays

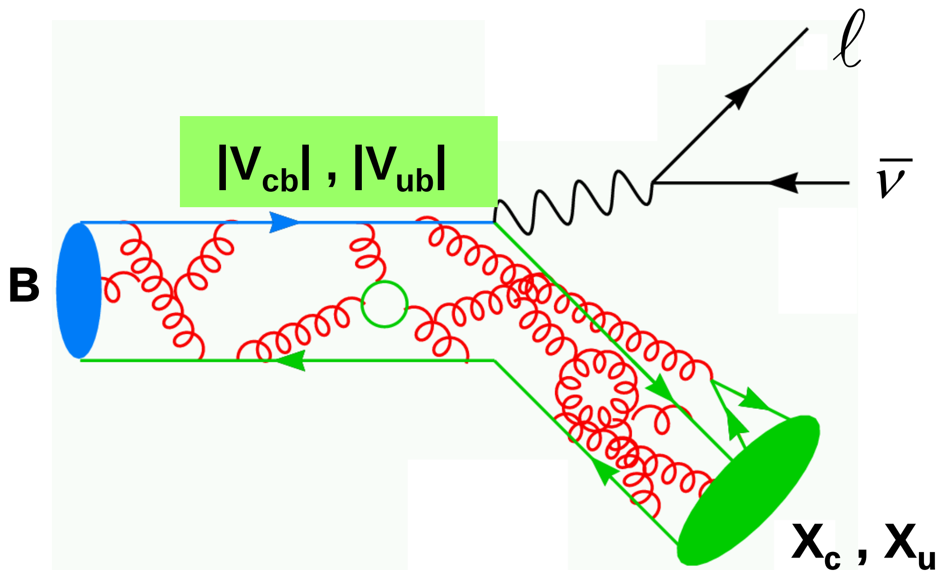
$|V_{cb}|$ and $|V_{ub}|$ are determined from semileptonic B decays.
At tree level everything is nice and clean.



QCD corrections must be included.

- Inclusive measurements: OPE
- Exclusive measurements: Form Factors from LQCD

$$\frac{\Gamma(b \to u\ell\bar{\nu})}{\Gamma(b \to c\ell\bar{\nu})} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$



$|V_{cb}|$ from Spectral Moments

OPE: Semileptonic Width

$$\Gamma(\bar{B} \to X_c \ell \bar{\nu}) = \frac{G_F^2 |V_{cb}|^2 m_b^5}{192\pi^3} \left\{ f(\rho) + k(\rho)\frac{\mu_\pi^2}{2m_b^2} + g(\rho)\frac{\mu_G^2}{2m_b^2} + d(\rho)\frac{\rho_D^3}{m_b^3} + l(\rho)\frac{\rho_{\rm LS}^3}{m_b^3} + \mathcal{O}(m_b^{-4}) \right\}$$

$$\rho = \frac{m_c^2}{m_b^2}$$

Wilson coefficients *f, k, g, d, l* can be calculated in perturbation theory.

Non-perturbative parameters μ_π , μ_G , ρ_D , ρ_{LS} *are matrix* elements of local operators in HQET.

OPE: Other Observables

- Moments of the lepton energy spectrum in $B \to X_c l \nu$

$$R_n(E_{\text{cut}}, \mu) = \int_{E_{\text{cut}}} (E_\ell - \mu)^n \, \frac{d\Gamma}{dE_\ell} \, dE_\ell \,, \quad \langle E_\ell^n \rangle_{E_{\text{cut}}} = \frac{R_n(E_{\text{cut}}, 0)}{R_0(E_{\text{cut}}, 0)}$$

- Moments of the hadronic mass spectrum in $B \to X_c l \nu$

$$\langle m_X^{2n} \rangle_{E_{\text{cut}}} = \frac{\displaystyle\int_{E_{\text{cut}}} (m_X^2)^n \, \frac{d\Gamma}{dm_X^2} \, dm_X^2}{\displaystyle\int_{E_{\text{cut}}} \frac{d\Gamma}{dm_X^2} \, dm_X^2}$$

- Moments of the photon energy spectrum in $B \to X_s \gamma$

$$\langle E_\gamma^n \rangle_{E_{\text{cut}}} = \frac{\displaystyle\int_{E_{\text{cut}}} E_\gamma^n \, \frac{d\Gamma}{dE_\gamma} \, dE_\gamma}{\displaystyle\int_{E_{\text{cut}}} \frac{d\Gamma}{dE_\gamma} \, dE_\gamma}$$

OPE for moments involves *same matrix elements* and different, calculable Wilson coefficients.

Moment Analysis

Moment Measurements

OPE Expressions

Fit

$|V_{cb}|$ m_b m_c

μ_π μ_G ρ_D ρ_{LS}

External input: average B lifetime
τ_B = (1.585 + / - 0.006) ps

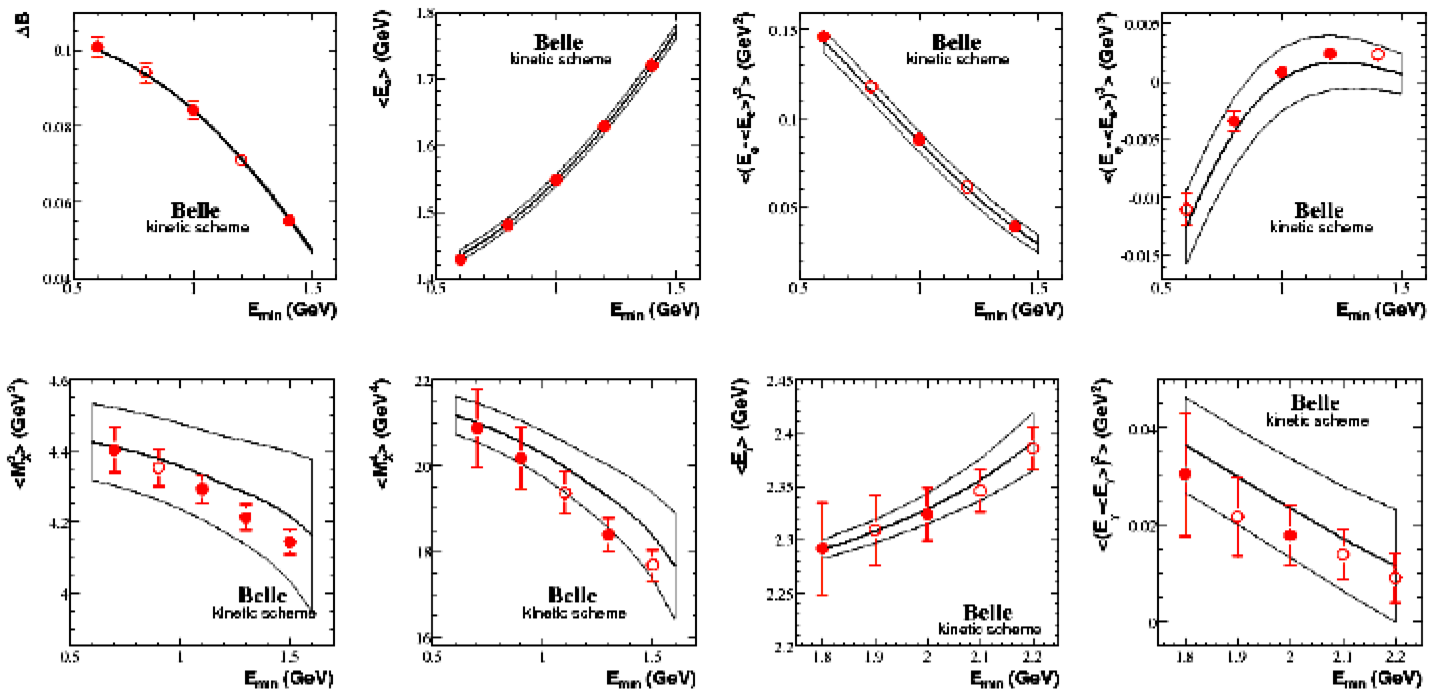
- Kinetic running mass
  - P.Gambino, N.Uraltsev, Eur.Phys.J. C34, 181 (2004)
  - D.Beson, I.Bigi, N.Uraltsev, Nucl.Phys. B710, 371 (2005)

- 1S mass
  - C.Bauer, Z.Ligeti, M.Luke, A.Manohar, M.Trott, Phys.Rev. D70, 094017 (2004)

Belle Results

Fit in the Kinetic Scheme

Electron moments $\langle E^n_l \rangle$	n=0: E_{cut}=0.6, 1.0, 1.4 GeV n=1: E_{cut}=0.6, 0.8, 1.0, 1.2, 1.4 GeV n=2: E_{cut}=0.6, 1.0, 1.4 GeV n=3: E_{cut}=0.8, 1.0, 1.2 GeV
Hadron moments $\langle M^{2n}_X \rangle$	n=1: E_{cut}=0.7, 1.1, 1.3, 1.5 GeV n=2: E_{cut}=0.7, 0.9, 1.3 GeV
Photon moments $\langle E^n_\gamma \rangle$	n=1: E_{cut}=1.8, 2.0 GeV n=2: E_{cut}=1.8, 2.0 GeV



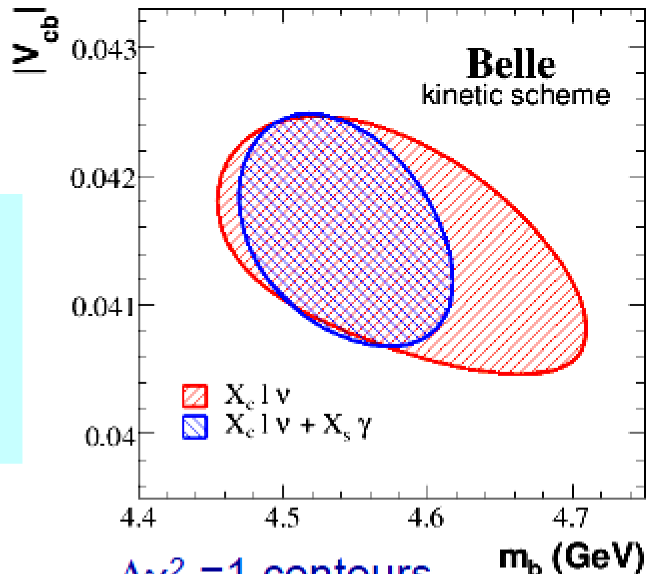
Phys. Rev. D78, 032016 (2008)

χ^2/ndf. = 4.7 / (25-7)

Belle Results

Kinetic scheme ($X_c l\nu + X_s\gamma$ data)

$|V_{cb}| = (41.58 \pm 0.69_{fit} \pm 0.08_{\tau B} \pm 0.58_{th}) \times 10^{-3}$
$m_b^{kin} = 4.543 \pm 0.075$ GeV
$m_c^{kin} = 1.055 \pm 0.118$ GeV

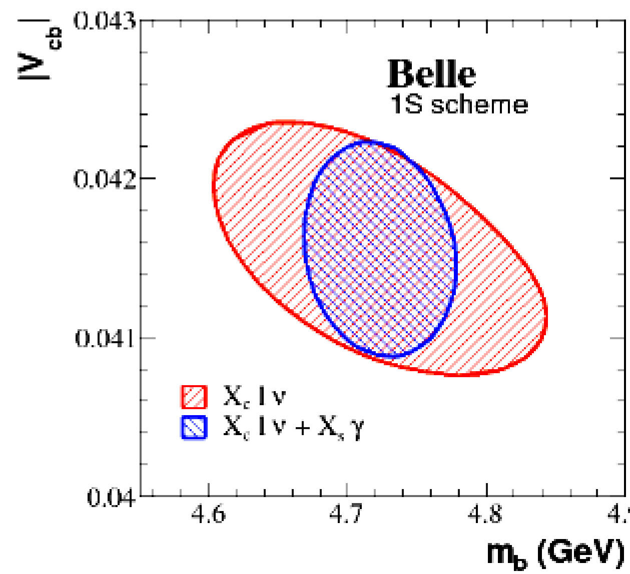


Results for m_b compatible after scheme translation

$\Delta\chi^2 = 1$ contours

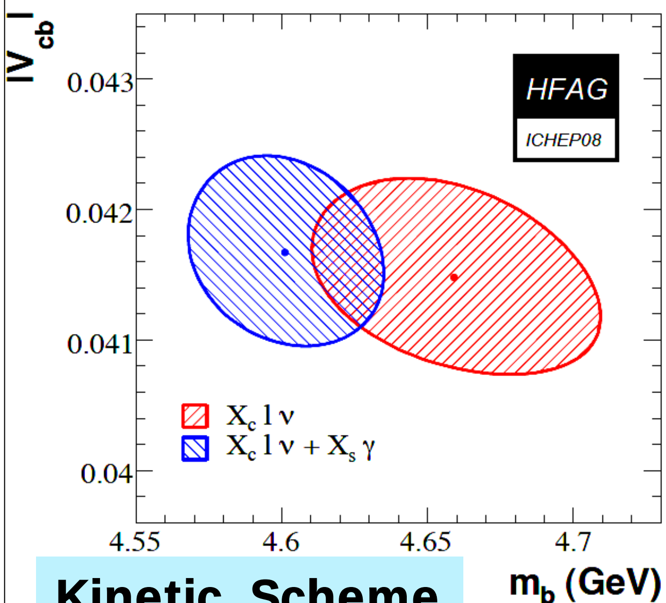
1S scheme ($X_c l\nu + X_s\gamma$ data)

$|V_{cb}| = (41.56 \pm 0.68_{fit} \pm 0.08_{\tau B}) \times 10^{-3}$
$m_b^{1S} = 4.723 \pm 0.055$ GeV

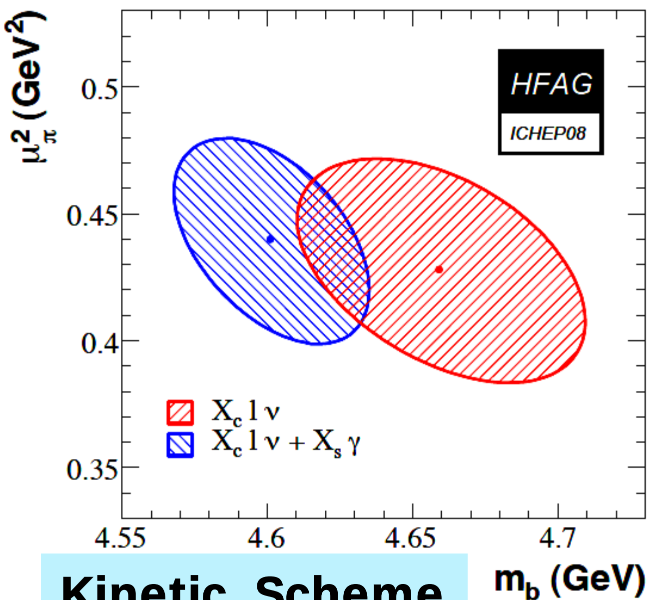


Bell Moment Analysis not included

$|V_{cb}|$ - HFAG Average



Kinetic Scheme



Kinetic Scheme

Adding $X_s\gamma$ Moments lowers m_b

Belle result don't show this effect

m_b is input to $|V_{ub}|$ extraction !!!

Input	$\lvert V_{cb}\rvert$ (10^{-3})	m_b (GeV)	μ^2_π (GeV^2)	χ^2/ndf
All moments	41.67+/-0.43(fit)+/-0.08(τ_B)+/-0.58(th)	4.601+/-0.034	0.440+/-0.040	29.7/57
$X_c l\nu$ only	41.48+/-0.47(fit)+/-0.08(τ_B)+/-0.58(th)	4.659+/-0.049	0.428+/-0.044	24.1/46

Low χ^2/ndf Are theoretical correlation properly accounted ?

FF x$|V_{cb}|$ from $B \rightarrow D^{(*)} l\nu$

V_{CB} & Form Factors: $B \to D^{(*)} l \nu$

HQET expansion of $B \to D^{(*)} l \nu$ width:

$$\frac{d\Gamma(D)}{dw} = \frac{G^2{}_F}{48\pi^3\hbar}(M_B + M_D)^2 M^3{}_D (w^2 - 1)^{3/2} |V_{cb}| G^2(w) \qquad w = \frac{P_B \cdot P_D}{M_B M_D}$$

$$\frac{d\Gamma(D^*)}{dw} = \frac{G^2{}_F}{48\pi^3\hbar}(M_B + M_{D^*})^2 M^3{}_{D^*} (w^2 - 1)^{1/2} (w+1)^2 |V_{cb}| F^2(w) \sum_{+,0,-} |\tilde{H}_i(w)|^2$$

Caprini et al. Parametrization of FF (Nucl.Phys.B 530 (1998), 153):

$$G(w) = G(1)[1 - 8\rho^2 z + (51\rho^2 - 10)z^2 - (252\rho^2 - 84)z^3]$$

$$F(w) = \ldots \qquad z = \frac{\sqrt{w+1} - \sqrt{2}}{\sqrt{w+1} + \sqrt{2}}$$

Experiments measure:

- **$|Vcb|$ *FF($w \to 1$)**
- **ρ^2_D, $\rho^2_{D^*}$ (slopes of FF)**
- **R_1,R_2 : form factor ratios (D*)**

arXiv:0810.1657 [hep-ex]

$140\ fb^{-1}$

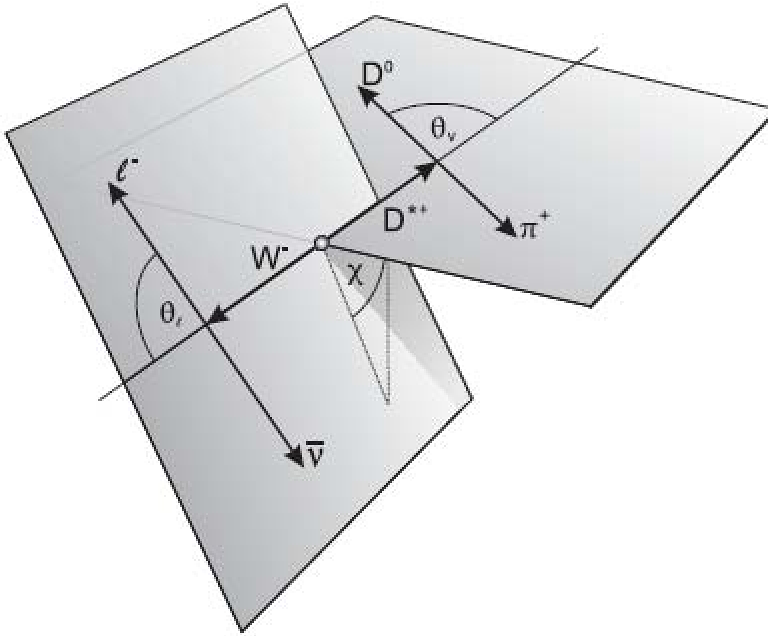
$B \to D^* l \nu$ Untagged Analysis

- **Decay chain:**

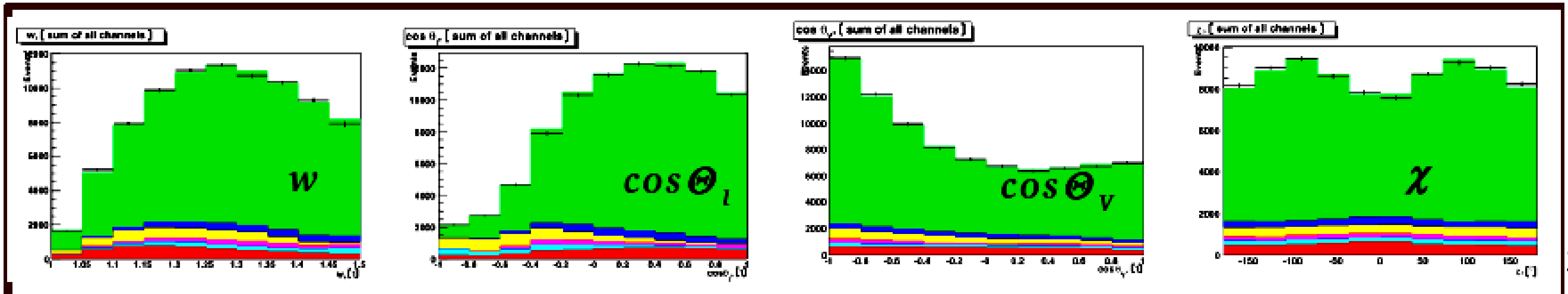
$$B^0 \to D^{*+} l \nu \quad D^{*+} \to D^0 \left(K^- \pi^+, K3\pi\right) \pi^+$$

- **Measure helicity angles (Θ_l, Θ_V, χ)**

- **Fit:** $\dfrac{d\Gamma}{dw\, d\chi\, d(\cos\Theta_l)\, d(\cos\Theta_V)}$



$$\rho^2 = 1.293 \pm 0.045 \pm 0.029$$
$$B(B^0 \to D^{*-} l^+ \nu_l) = 1.495 \pm 0.050 \pm 0.062$$
$$F(1)|V_{cb}| \times 10^3 = 34.4 \pm 0.2 \pm 1.0$$

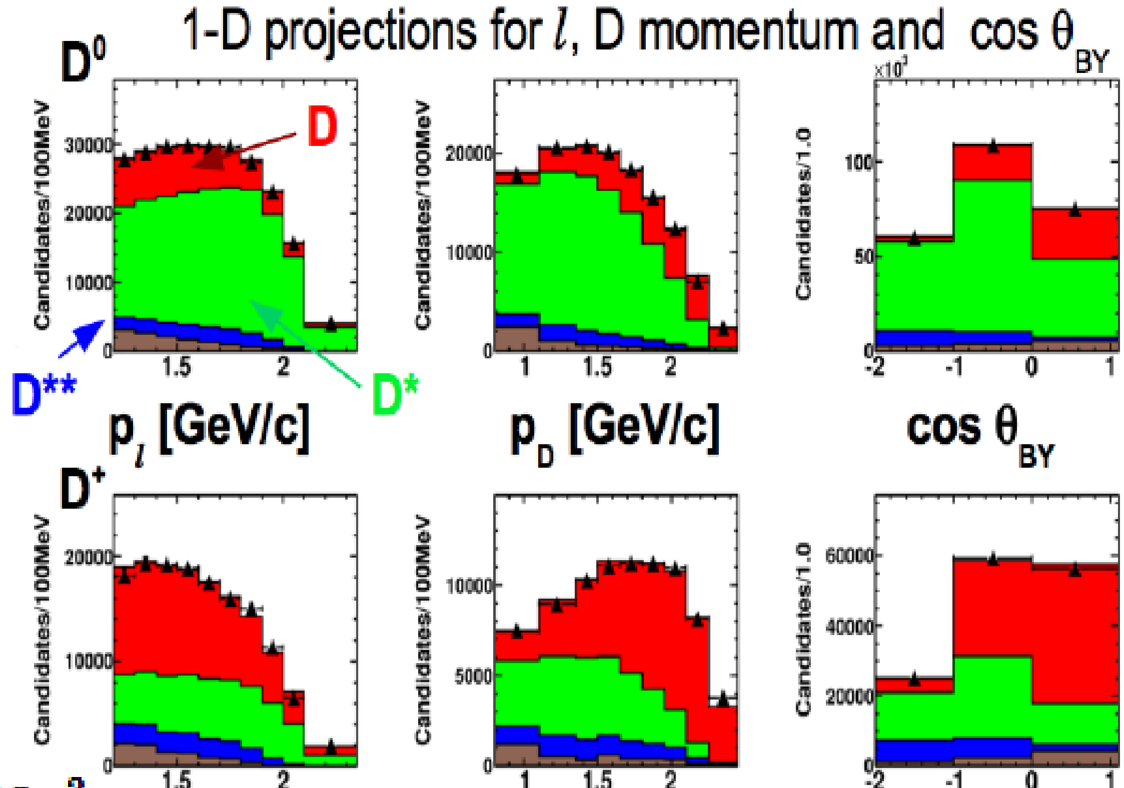


Phys.Rev.D79:012002,2009

207 fb^{-1}

$B \to D^{(*)} l \nu$ Untagged Analysis

- Select $D^0(K\pi)l\nu X$, $D^+(K\pi\pi)l\nu X$ events with p_l > 1.2 GeV/c
- Get D/D* rates with a binned 3-d fit to p_l, p_D, $\cos\Theta_{BY}$
- Relate BR(B^0) to BR(B^+) using lifetime ratio
- Extract from the fit: ρ^2_D, ρ^2_{D*}, BF
- Compute: |Vcb|*F(1), |Vcb|*G(1)



$$\mathcal{G}(1)|V_{cb}| = (43.1 \pm 0.8 \pm 2.3) \times 10^{-3}$$
$$\mathcal{F}(1)|V_{cb}| = (35.9 \pm 0.2 \pm 1.2) \times 10^{-3}.$$

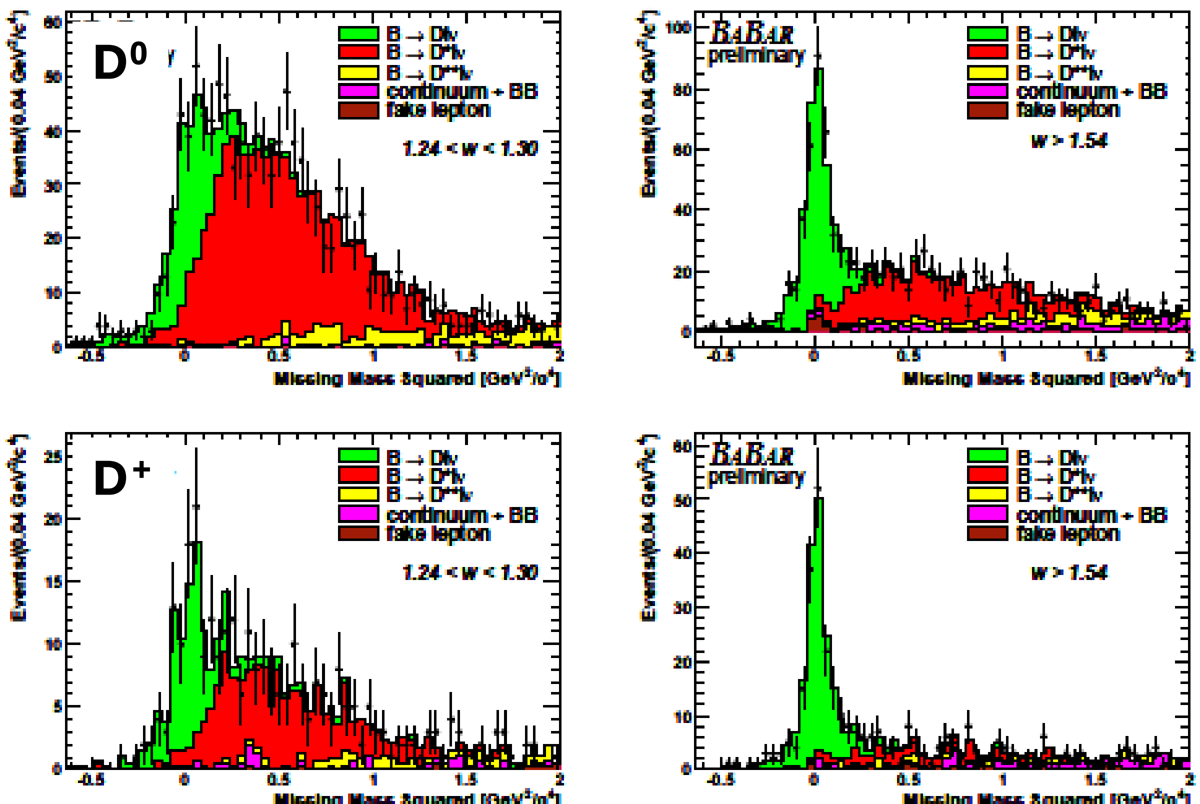
arXiv:0807.4978 [hep-ex]

417 fb^{-1}

$B \to D l \nu$ Hadronic Tag Analysis

BABAR

- **Select $D^0 l\nu$, $D^+ l\nu$ decays on the recoil of a fully reconstructed B**
- **Event yields from a fit to MM^2 in 10 w bins**
- **G(1) |Vcb| and ρ^2_G from a fit to w distribution**



$$\mathcal{G}(1)|V_{cb}| = (43.0 \pm 1.9 \pm 1.4) \times 10^{-3}$$
$$\rho^2_{\mathcal{G}} = 1.20 \pm 0.09 \pm 0.04$$
$$\mathcal{B}(\overline{B}^0 \to D^+ \ell^- \bar{\nu}_\ell) = (2.17 \pm 0.06 \pm 0.07)\%.$$

$MM^2 = (P_B - P_D - P_l)^2$ [GeV2/c4]

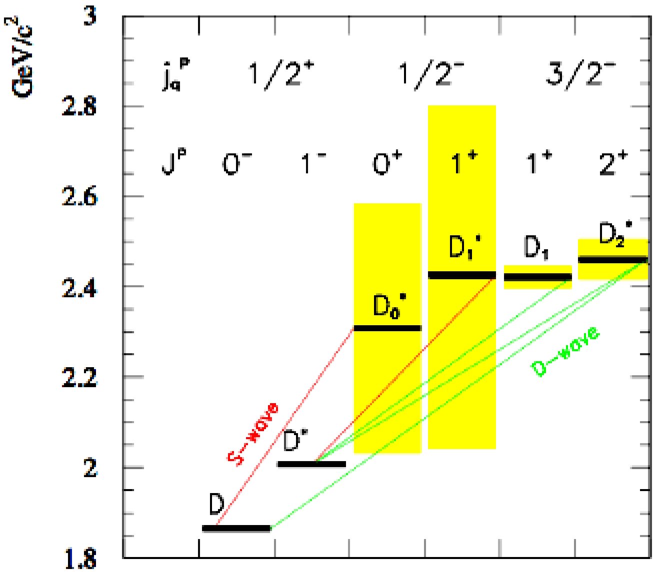
2147±69 signal D^0 events

1108±45 signal D^+ events

$B \to D^{**} l \nu$ Hadr Tag Analysis

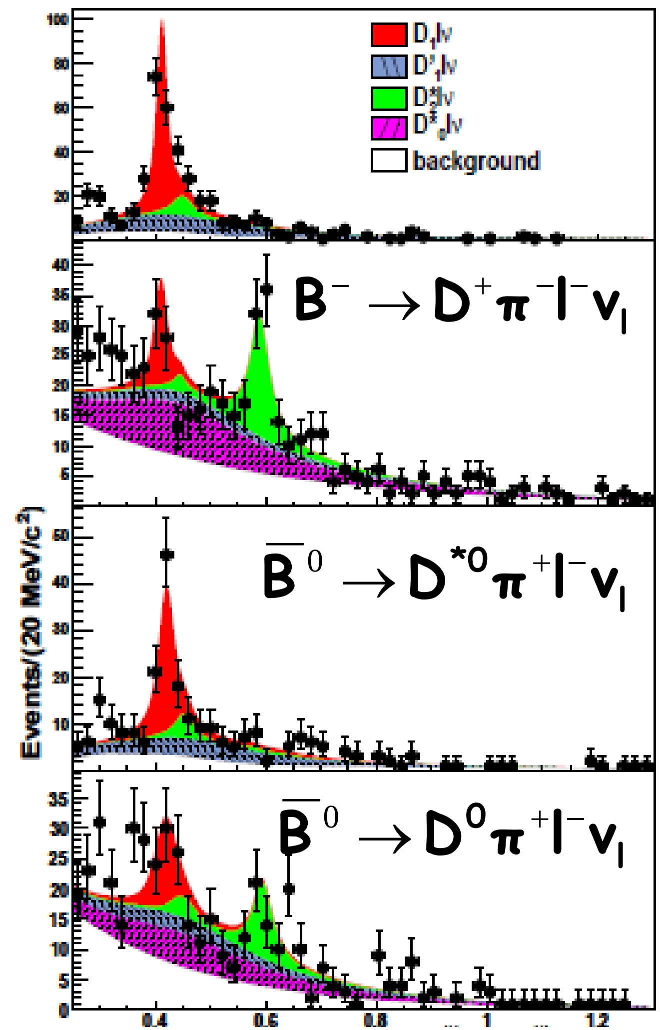
arXiv:0808.0528 [hep-ex]

417 fb^{-1}



Important to reduce systematic in $|V_{cb}|$ excl. measurements.

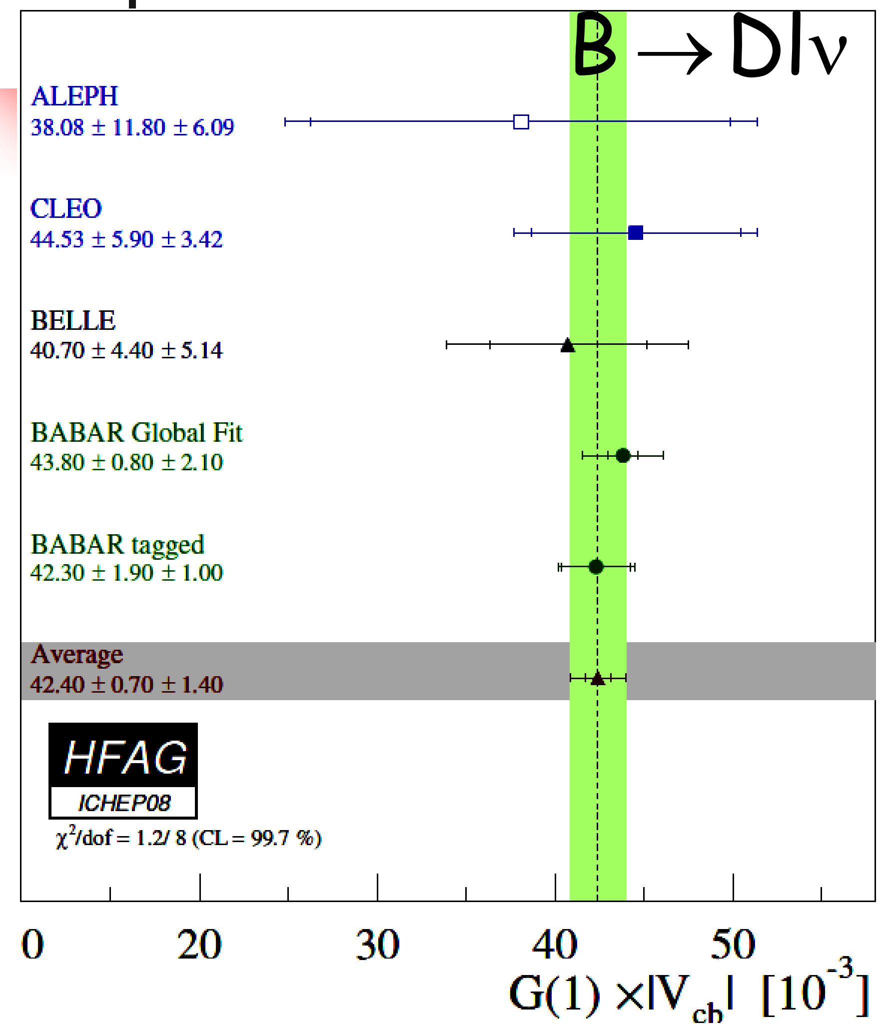
Discrepancy between $B \to X_c l\nu$ inclusive rate and sum of exclusive modes.

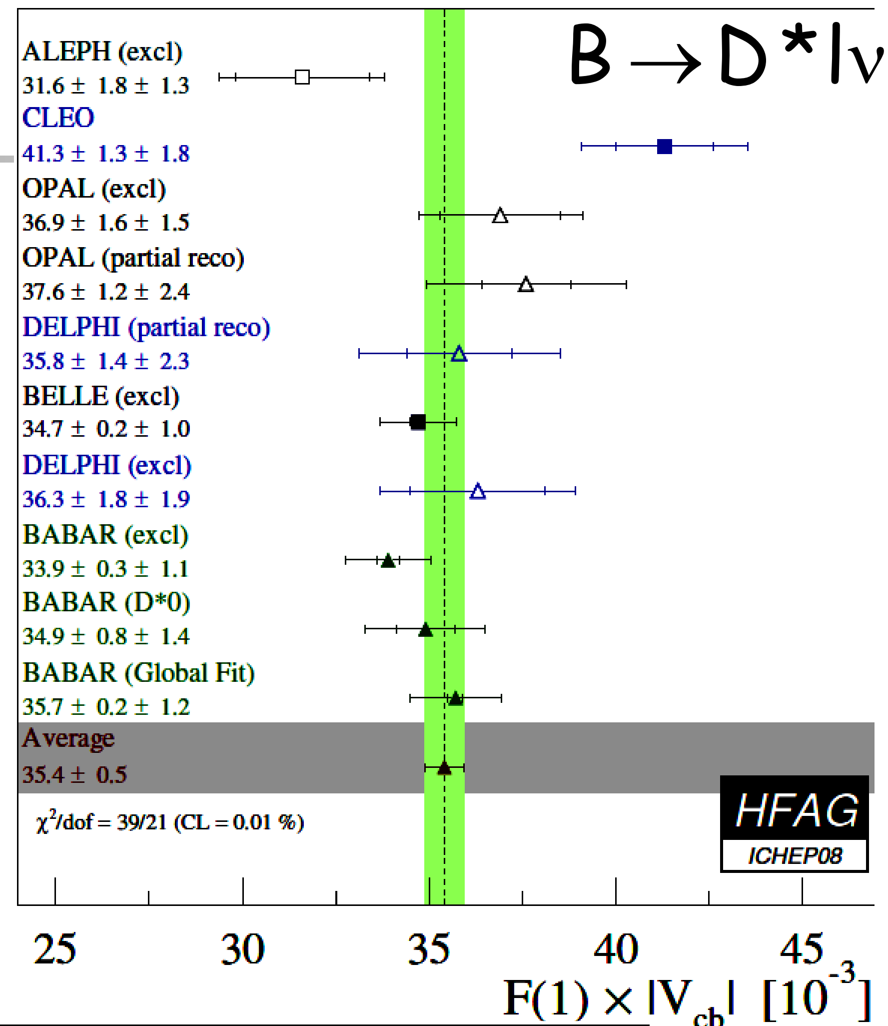


Decay Mode	Yield	$\epsilon_{sig}(\times 10^{-4})$	$\mathcal{B}(\overline{B} \to D^{**}\ell^-\bar{\nu}_\ell) \times \mathcal{B}(D^{**} \to D^{(*)}\pi^\pm)$
$B^- \to D_1^0 \ell^- \bar{\nu}_\ell$	165 ± 18	1.24	$0.29 \pm 0.03 \pm 0.03$
$B^- \to D_2^{*0} \ell^- \bar{\nu}_\ell$	97 ± 16	1.44	$0.15 \pm 0.02 \pm 0.01$
$B^- \to D_1^{\prime 0} \ell^- \bar{\nu}_\ell$	142 ± 21	1.13	$0.27 \pm 0.04 \pm 0.05$
$B^- \to D_0^{*0} \ell^- \bar{\nu}_\ell$	137 ± 26	1.15	$0.26 \pm 0.05 \pm 0.04$
$\overline{B}^0 \to D_1^+ \ell^- \bar{\nu}_\ell$	88 ± 14	0.70	$0.27 \pm 0.04 \pm 0.03$
$\overline{B}^0 \to D_2^{*+} \ell^- \bar{\nu}_\ell$	29 ± 13	0.91	$0.07 \pm 0.03 \pm 0.01$ (< 0.11 @90% CL)
$\overline{B}^0 \to D_1^{\prime +} \ell^- \bar{\nu}_\ell$	86 ± 18	0.60	$0.31 \pm 0.07 \pm 0.05$
$\overline{B}^0 \to D_0^{*+} \ell^- \bar{\nu}_\ell$	142 ± 26	0.70	$0.44 \pm 0.08 \pm 0.06$

C. Bernard et al., arXiv:0808.2519[hep.lat]
M. Okamoto et al., Nucl. Phys. Proc. Suppl. 140, 461 (2005)

V_{CB} & Form Factors: Averages





$$|V_{cb}| = (39.7 \pm 1.4_{exp} \pm 0.9_{theo}) \ 10^{-3} \quad (D)$$

$$|V_{cb}| = (38.1 \pm 0.6_{exp} \pm 0.9_{theo}) \ 10^{-3} \quad (D^*)$$

Open Issues on $|V_{cb}|$ Measurements

$|V_{cb}|$ from Moment Analysis

- **Belle recent results in good agreement with HFAG average**
- **Open questions on HFAG global fit:**
  - **Inclusion of the $B \to X_s \gamma$ data lowers the b-quark mass m_b**
  - **χ^2/ndf = 29.7/57 (24.1/46) Too small ?**

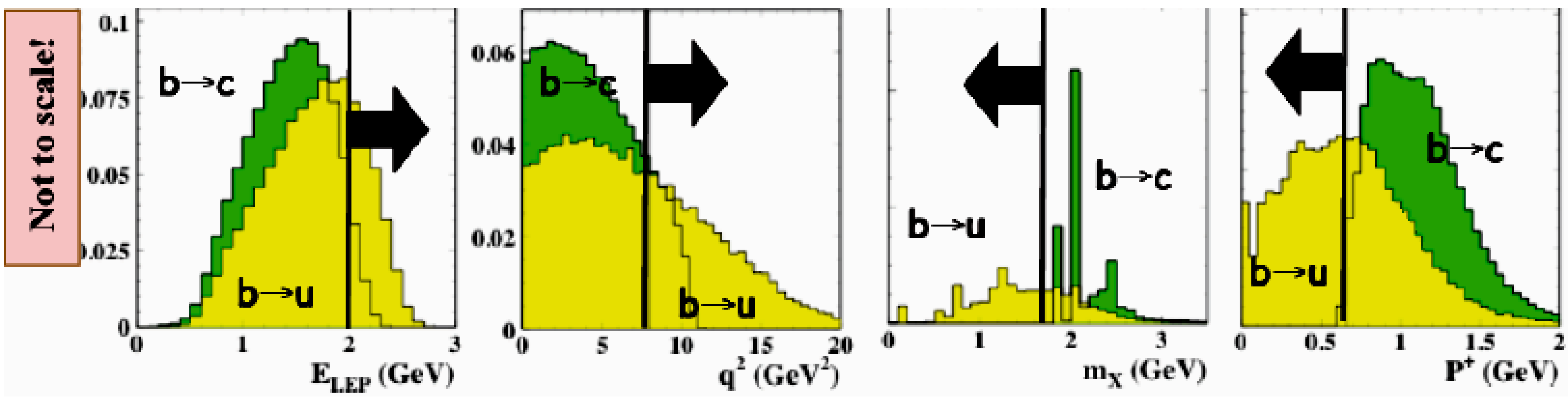
$F(1)|V_{cb}|$ and $G(1)|V_{cb}|$ from $B \to D^{(*)} l\nu$

- **Good agreement between experiments**
- **|Vcb| extracted using LQCD 2σ lower than result from Moment Analysis**

$|V_{ub}|$ from Inclusive Semileptonic B Decays

Inclusive $|V_{ub}|$ Measurement I

Charm background ~50x larger than signal
Use kinematics to distinguish X_u signal from X_c BG ($m_c >> m_u$)



- E_{LEP} = lepton energy
- q^2 = momentum transfer squared = $(p_B-p_X)^2 = (p_l+p_\nu)^2$
- m_X = mass of the hadronic system
- $P^+ = E_X-|p_X|$ = light-cone component of X momentum

Inclusive $|V_{ub}|$ Measurement II

Cut away $B \to X_c l\nu$ ⇒ loose some $B \to X_u l\nu$ signal

We measure:

$$\Gamma(B \to X_u \ell \nu) \times f_C = |V_{ub}|^2 \zeta_C$$

total rate

fraction of signal that pass the cut

cut dependent constant predicted by theory

Must be corrected for QCD

Use HQE parameters from $B \to X_c l\nu$ and $B \to s\gamma$ to extrapolate to full phase space and extract $|V_{ub}|$

BLNP - B.O. Lange, M. Neubert and G. Paz, Phys. Rev. D72:073006 (2005)

DGE - J.R. Andersen and E. Gardi, JHEP 0601:097 (2006)

GGOU - P. Gambino, P. Giordano, G. Ossola, N. Uraltsev, JHEP 0710:058,2007

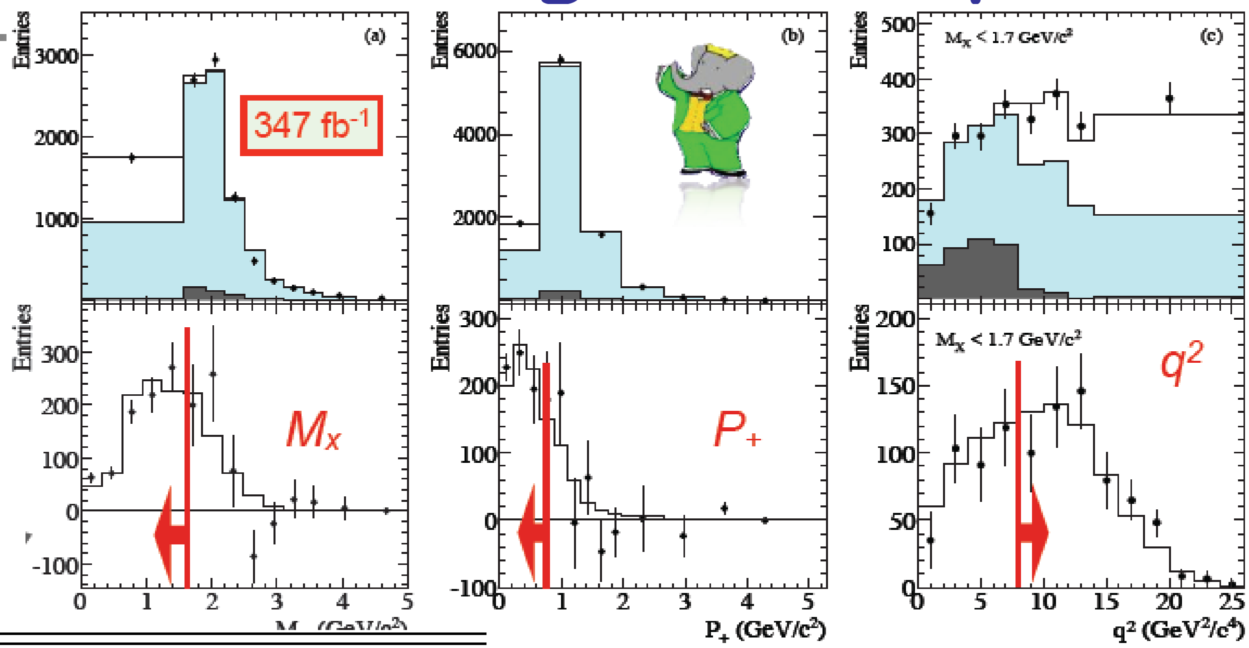
BLL - C.W. Bauer, Z. Ligeti and M.E. Luke, Phys. Rev. D64:113004 (2001)

PRL 100, 171802 (2008)

BaBar: Hadronic tag technique

- $B \rightarrow X_u\, l\, \nu$
- $B \rightarrow X_c\, l\, \nu$ (bkgd)
- $B \rightarrow X_u\, l\, \nu$ (outside selected region)

Background subtracted

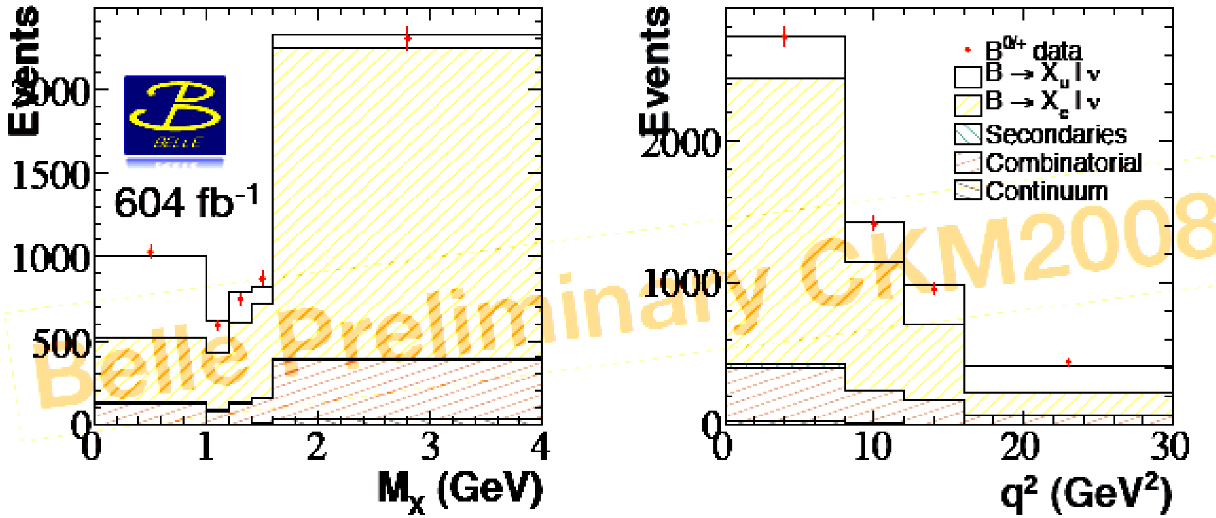


	$\Delta\mathcal{B}(\overline{B} \rightarrow X_u \ell \bar{\nu})$ (10^{-3})	$\lvert V_{ub}\rvert \times (10^{-3})$	
$M_X < 1.55$ GeV/c^2	$1.18 \pm 0.09 \pm 0.07 \pm 0.01$	$4.27 \pm 0.16 \pm 0.13 \pm 0.30$	**BLNP**
		$4.56 \pm 0.17 \pm 0.14 \pm 0.32$	**DGE**
$P_+ < 0.66$ GeV/c^2	$0.95 \pm 0.10 \pm 0.08 \pm 0.01$	$3.88 \pm 0.19 \pm 0.16 \pm 0.28$	**BLNP**
		$3.99 \pm 0.20 \pm 0.16 \pm 0.24$	**DGE**
$M_X < 1.7$ GeV/c^2, $Q^2 > 8.0$ GeV^2/c^2	$0.81 \pm 0.08 \pm 0.07 \pm 0.02$	$4.57 \pm 0.22 \pm 0.19 \pm 0.30$	**BLNP**
		$4.64 \pm 0.23 \pm 0.19 \pm 0.25$	**DGE**
		$4.93 \pm 0.24 \pm 0.20 \pm 0.36$	**BLL**

Presented at CKM

Belle Multivariate Analysis

- **Hadronic Tag**
- **Boosted decision tree based selection, use ~20 event parameters**
- **2D fit to M_x, q^2 with backgrounds and signal floated**

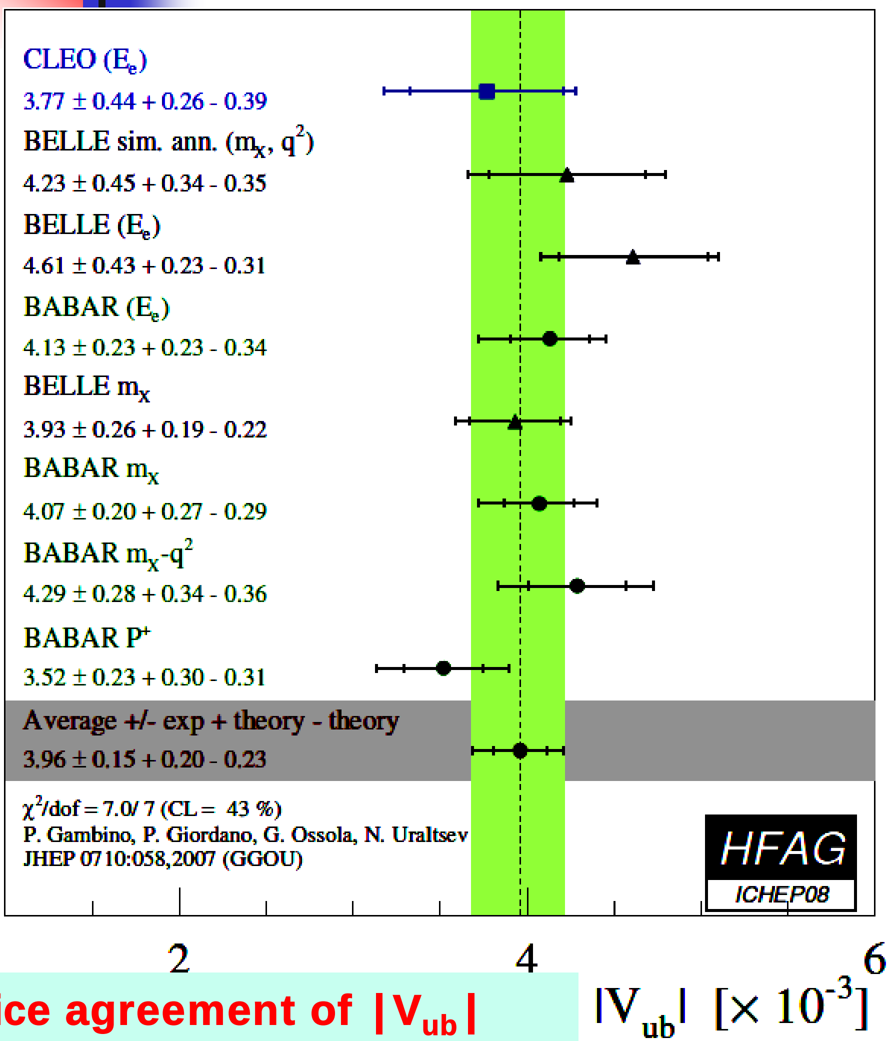


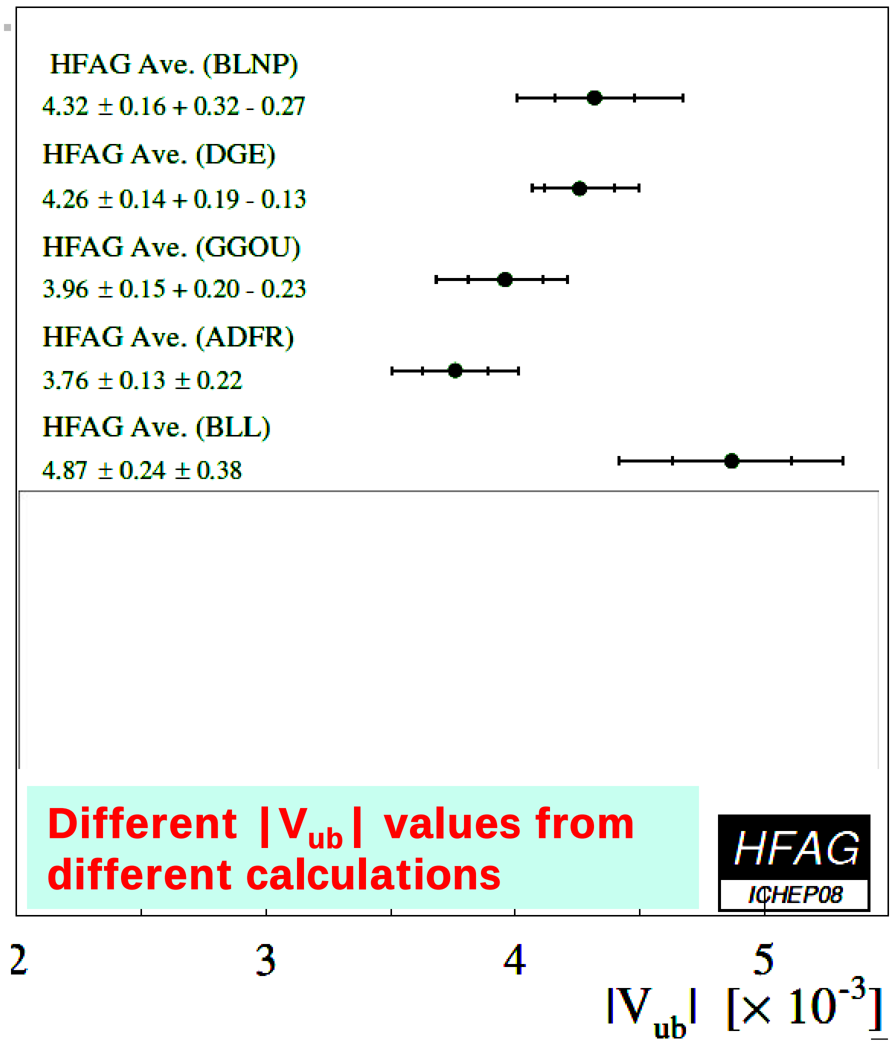
2D fit in q2 mx. (projections shown)

Kinematic Region	$B(B \to X_u l \nu)$ x 10^{-3} Δ(stat. sys.)	m_b	$\|V_{ub}\|$ (10^{-3}) % error	*Theory*
$P_{lepton} > 1.0$ GeV	1.96 x (1 ± 0.088 ± 0.076)	(kinetic) 4.613 GeV, mupi=0.440 GeV^2	4.42 (± 3.1 ± 5.1)	GGOU (thanks P. Giordano)
		(MSbar) 4.243 GeV	4.47 (± 6.7)	DGE (thanks E. Gardi)

Belle multivariate analysis not included

Inclusive $|V_{ub}|$: HFAG averages



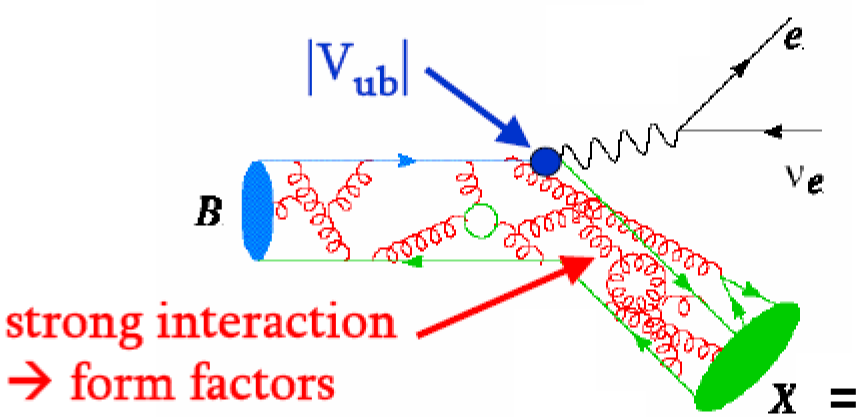


Different $|V_{ub}|$ values from different calculations

Nice agreement of $|V_{ub}|$ measurements

$|V_{ub}|$ from Exclusive SL Charmless B Decays

Exclusive |Vub| Measurements



X = π, η, η', ρ, ω

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

Complementary exp approaches:

- **Untagged (with ν reconstruction)**
- **Semileptonic tag**
- **Hadronic tag**

⇨ **Different systematic errors and independent samples**

Different form factor calculations

⇨ **Perform measurement in q^2 bins to reduce model dependency**

See Talk of R. Sommer

Still most precise measurement

PRL 98, 091801 (2007)

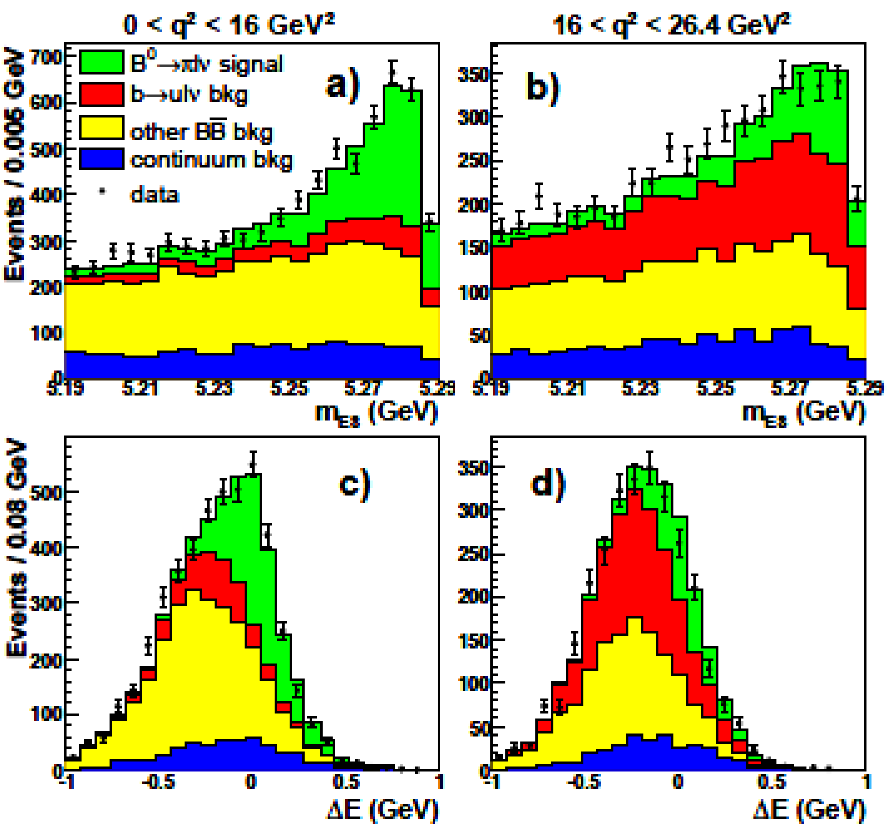
206 fb^{-1}

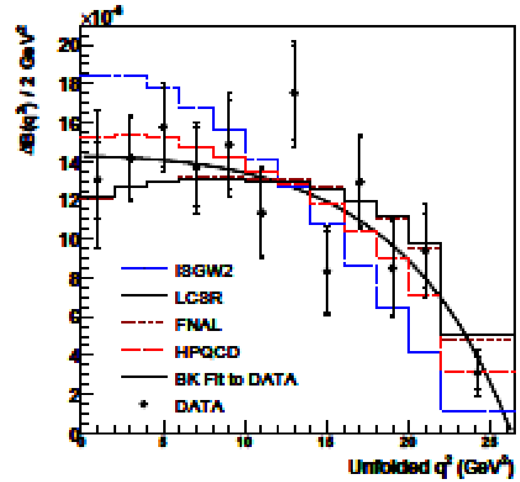
BABAR

$B \rightarrow \pi l \nu$ untagged

Reconstruct neutrino from full event: $(\vec{p}_{miss}, E_{miss}) = (\vec{p}_{beam}, E_{beam}) - (\sum \vec{p}_i, \sum E_i)$

Extract signal yield in 12 q^2 bins from fit to ΔE vs. m_{ES} distributions



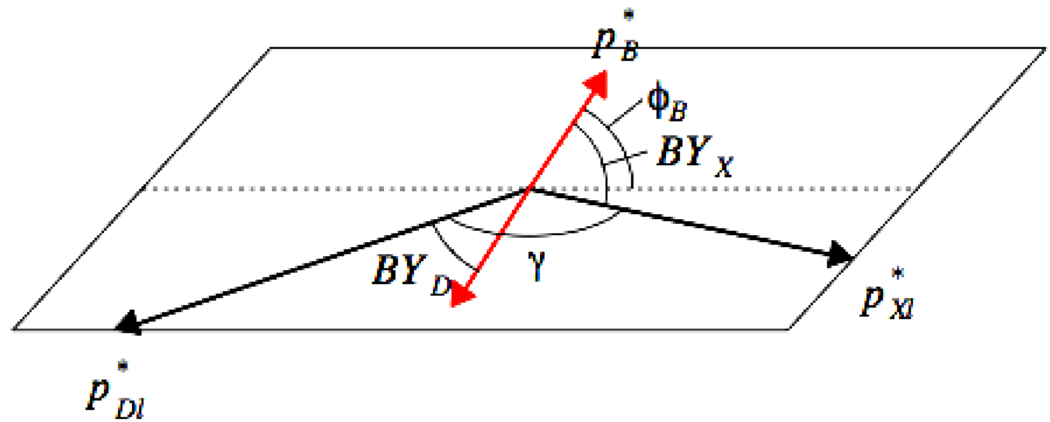


$$\mathcal{B}(B^0 \rightarrow \pi^- \ell \nu) = (1.46 \pm 0.07 \pm 0.08) \times 10^{-4}$$

Used by FNAL (arXiv:0811.3640 [hep-lat]) to extract |Vub| = (3.38 +/- 0.36)x10-3

arXiv:0805.2408 [hep-ex]
348 fb^{-1}

$B \rightarrow \pi, \eta, \eta' \, l \, \nu$ Semileptonic Tag



Analysis Strategy:

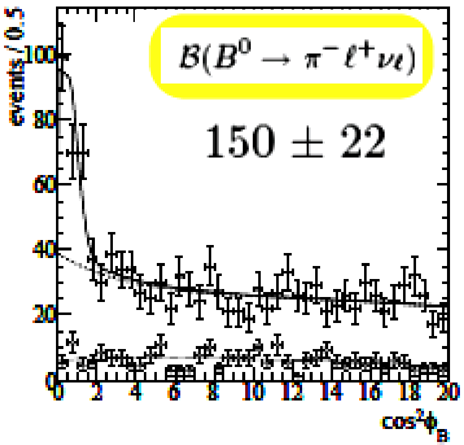
- **Tag one B in $D^{(*)}l\nu$ and look for signal in the recoil;**
- **Identify a signal lepton (right charge) and search for a:**
  - π^+, π^-, π^0
  - $\eta \rightarrow \gamma\gamma$, $\eta \rightarrow \pi^+\pi^-\pi^0$, $\eta \rightarrow \pi^0\pi^0\pi^0$
  - $\eta' \rightarrow \eta\,\pi^+\pi^-$
- **No additional tracks and low neutral energy;**
- **Extract signal yields with unbinned maximum likelihood fit to $\cos^2\phi_B$.**

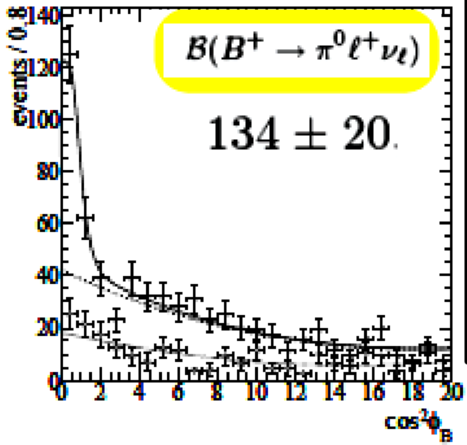
arXiv:0805.2408 [hep-ex]

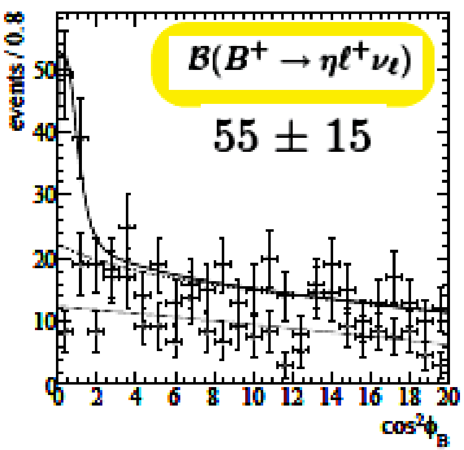
348 fb^{-1}

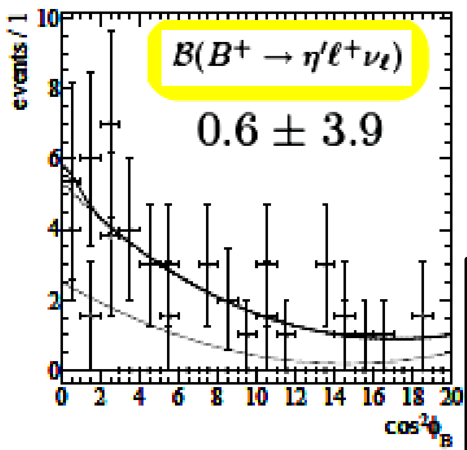
BABAR

$B \rightarrow \pi, \eta, \eta'\ l\ \nu$ Semileptonic Tag









$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.38 \pm 0.21 \pm 0.07) \times 10^{-4}$$
$$\mathcal{B}(B^+ \to \pi^0 \ell^+ \nu_\ell) = (0.96 \pm 0.15 \pm 0.07) \times 10^{-4}$$

Using isospin relation

$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu_\ell) = (1.54 \pm 0.17 \pm 0.09) \times 10^{-4}$$

$$\mathcal{B}(B^+ \to \eta \ell^+ \nu_\ell) = (0.64 \pm 0.20 \pm 0.30) \times 10^{-4}$$

3.2 σ significance

$\mathcal{B}(B^+ \to \eta' \ell^+ \nu_\ell) < 0.47 \times 10^{-4}$ (90% CL)

CLEO (PRL 99,041802(2007):

$$\mathcal{B}(B^+ \to \eta' \ell^+ \nu) = (2.66 \pm 0.80 \pm 0.56) \times 10^{-4}$$

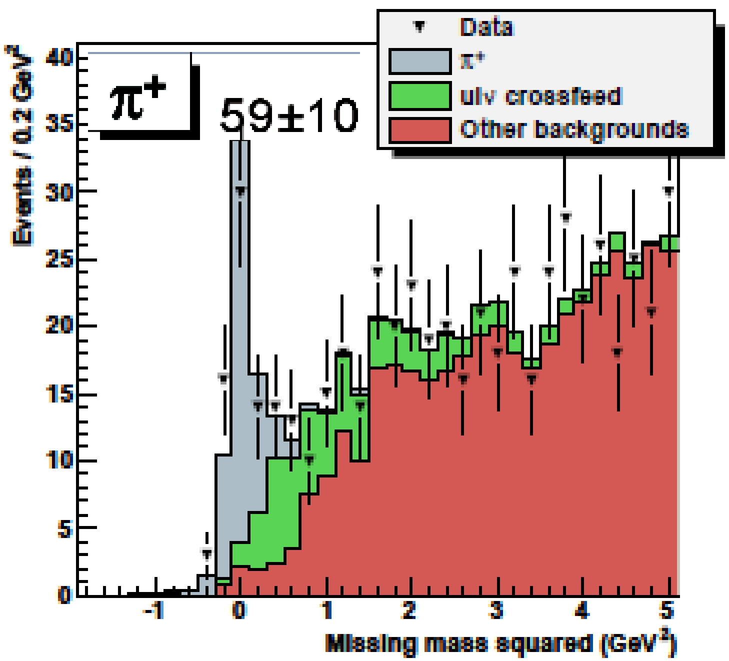
arXiv:0812.1414 [hep-ex]

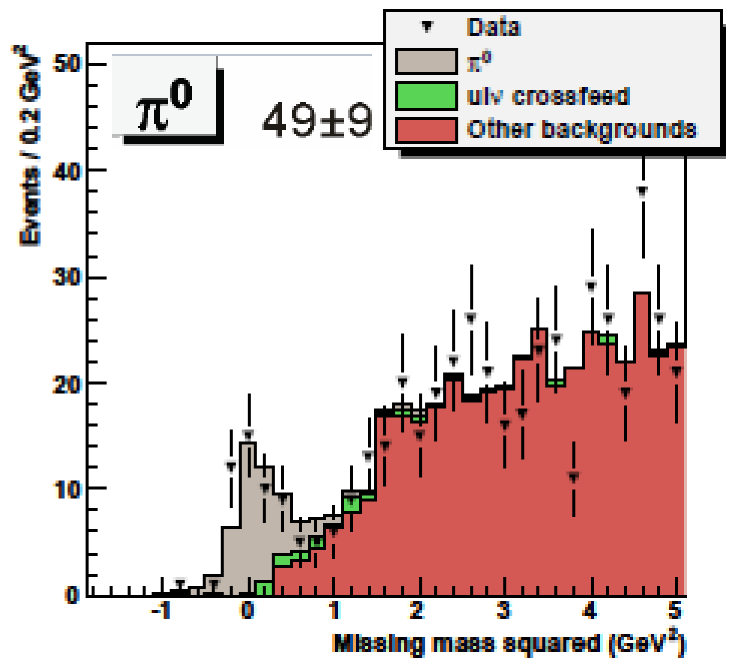
605 fb^{-1}

$B \rightarrow \pi, (\rho, \omega)\, l\, \nu$ Hadronic Tag

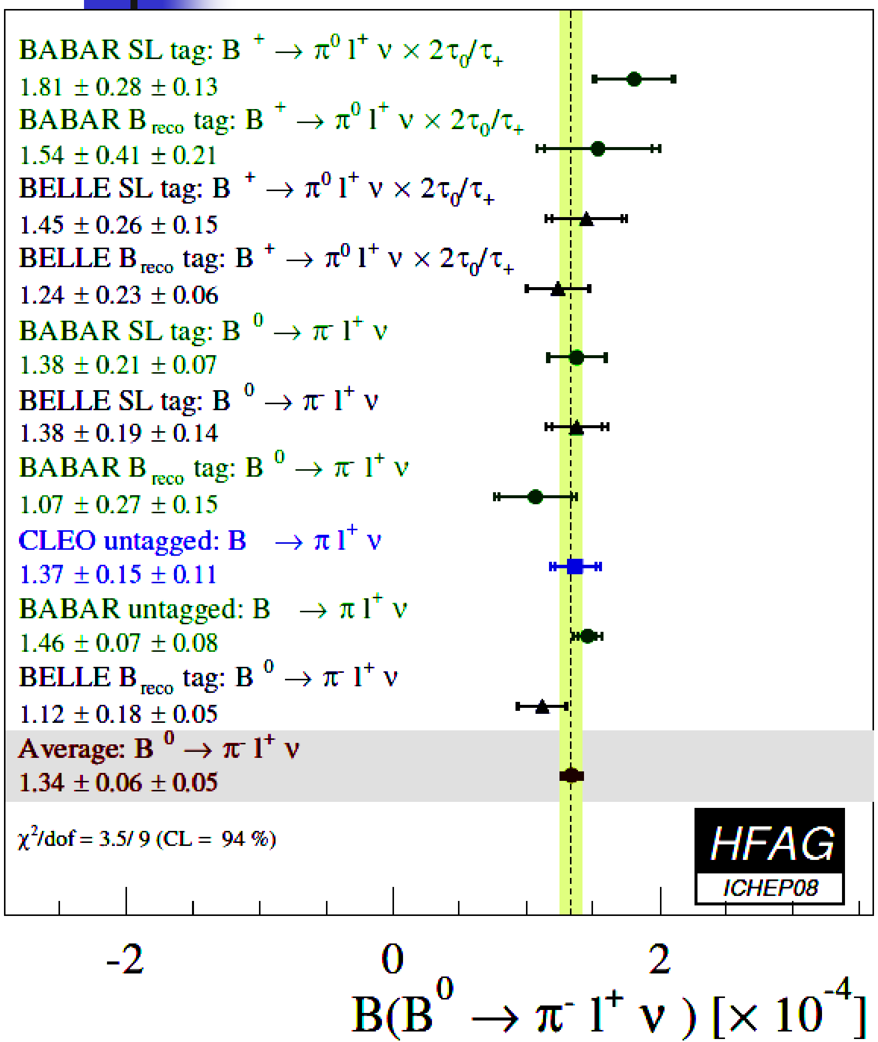
- Fully reconstruct the B_{reco}
- Know kinematics and flavor of signal B
- Extract signal yields from $M^2_{miss} \approx M^2_{\nu}$ distribution in 3 q^2 bins

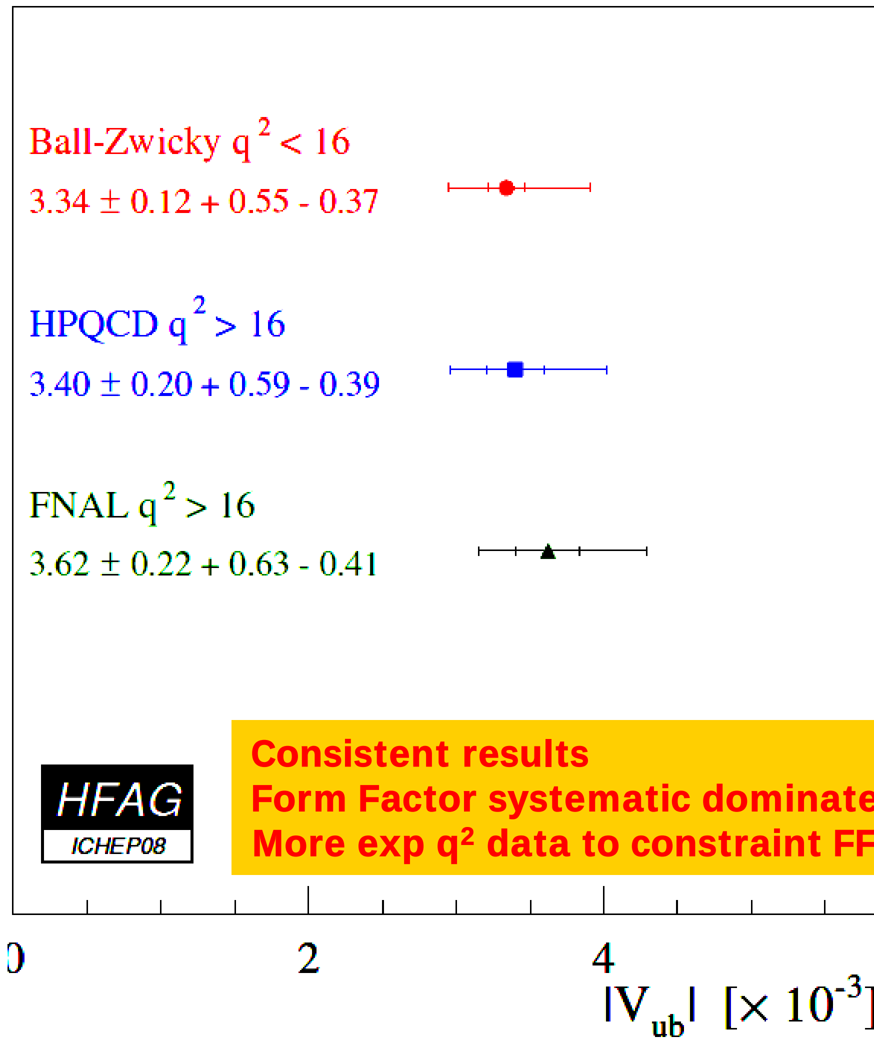
$$\mathcal{B}(B^0 \rightarrow \pi^- l^+ \nu) = (1.12 \pm 0.18 \pm 0.5) \times 10^{-4}$$
$$\mathcal{B}(B^+ \rightarrow \pi^0 l^+ \nu) = (0.66 \pm 0.12 \pm 0.3) \times 10^{-4}$$





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





Consistent results
Form Factor systematic dominates
More exp q^2 data to constraint FF

Open Issues in |Vub| Measurements

Inclusive measurements:

- **Nice consistency of $|V_{ub}|$ measurements extracted using the same calculations**
- **Different $|V_{ub}|$ values are obtained when using different calculations**
- $(\delta|V_{ub}|/|V_{ub}|)_{exp} \sim 4\%$ $\quad$ $(\delta|V_{ub}|/|V_{ub}|)_{Th} \sim 6\text{-}7\%$

Exclusive measurements:

- **Uncertainties from Form Factors are the dominant systematic**
  - $(\delta|V_{ub}|/|V_{ub}|)_{exp} \sim 5\%$ $\quad$ $(\delta|V_{ub}|/|V_{ub}|)_{FF} = +17\%\ -11\%$
- **Need more data to constraint different calculations**
- **Looking for progress from LatticeQCD**

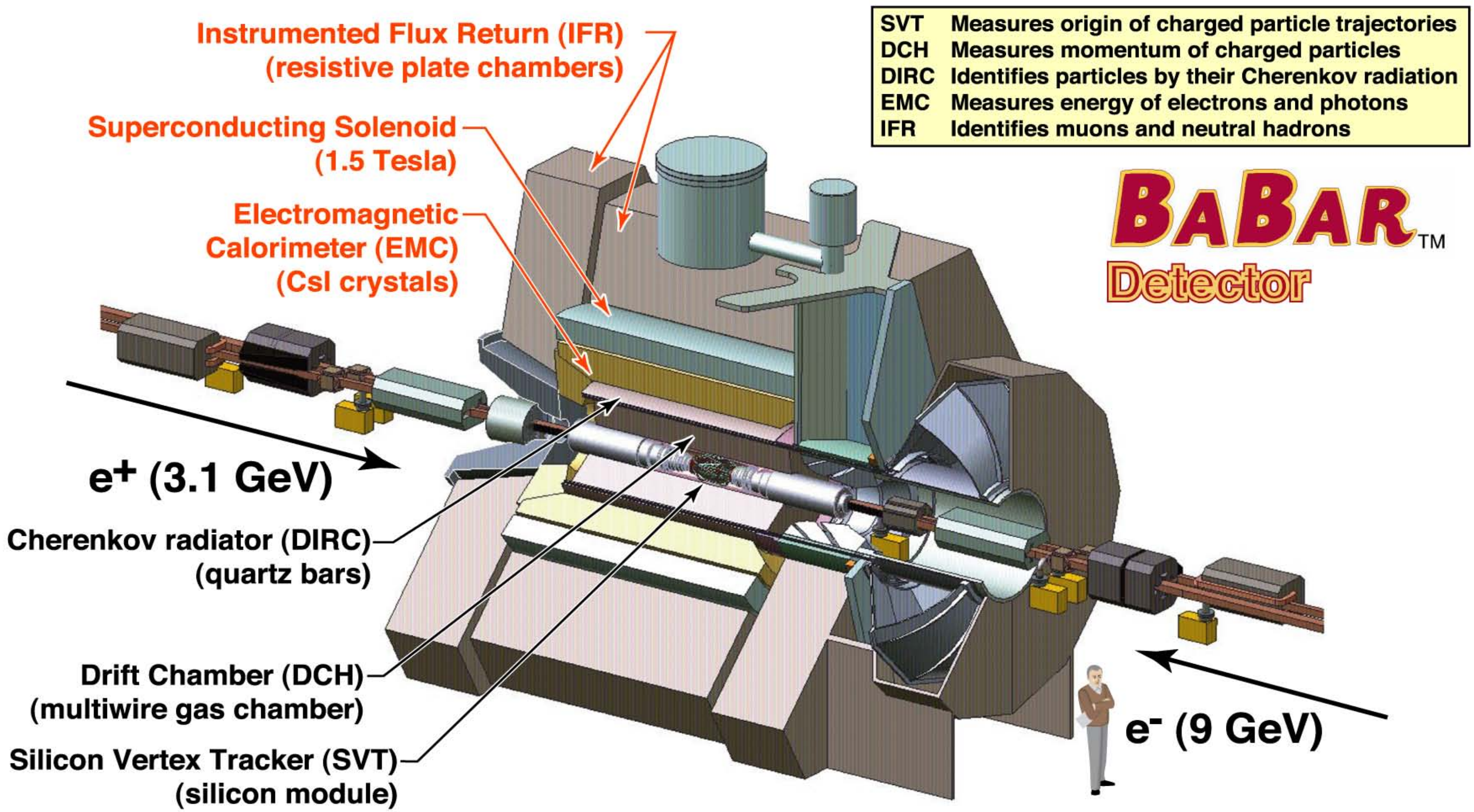
Exclusive measurements give a lower $|V_{ub}|$ than inclusive ones

Conclusions

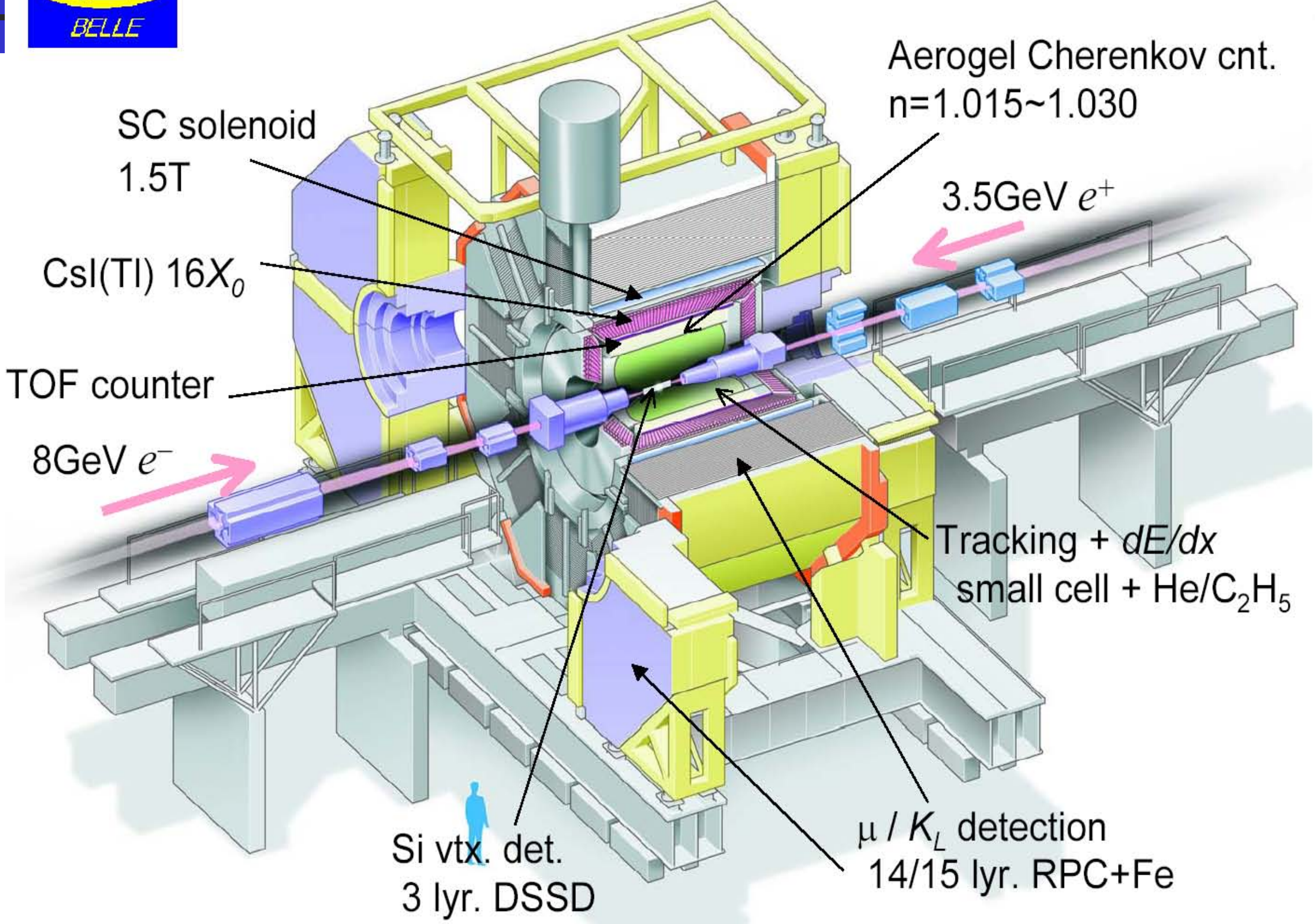
- Progressing in the understanding of B SL decays
- Inclusive $|V_{cb}|$ precision now at 2% level
  - Still remaining issues on global fit and $B \to X_s\gamma$ data inclusion
- Many new results on $B \to D^{(*)} l\nu$ decays
  - Precision on $|V_{cb}|$ measurements limited by form factor knowledge
  - Lower value ($2\ \sigma$) than from inclusive analysis
- Inclusive $|V_{ub}|$ measurements now at 8% precision
  - Limited by calculation of theoretical phase space acceptances
- Exclusive $|V_{ub}|$ measurements limited by form factor knowledge
  - Need more data and progress on theoretical calculation
  - Puzzle of exclusive vs inclusive $|V_{ub}|$ values not yet solved

Backup Slides

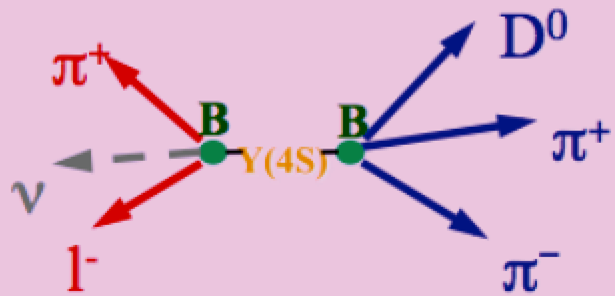
BaBar Detector



Belle Detector



Experimental Methods

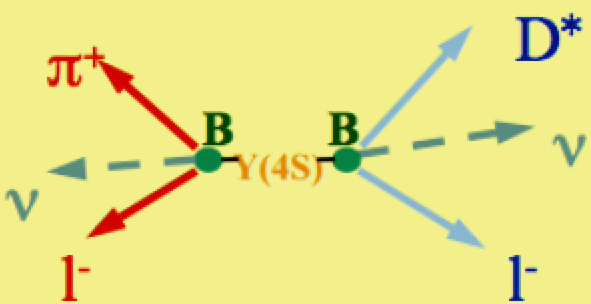


Hadronic Tag:

Fully reconstruct hadronic decay of one B:

$B \rightarrow D^{(*)} + (\pi^+, \pi^0, K^+, K^0)$ ≈ 1000 modes

$\rightarrow$ know kinematics of other B



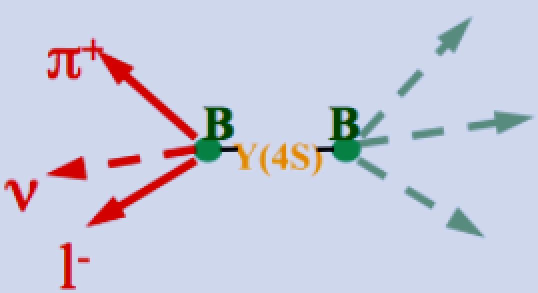
Semileptonic Tag:

Reconstruct $B \rightarrow D^{(*)} \ell \nu$ and study recoil

- Full reconstruction of $D^{(*)}$

- Partial reconstruction of D^* (only l, π_{soft})

Two ν $\rightarrow$ tag-B kinematics incomplete



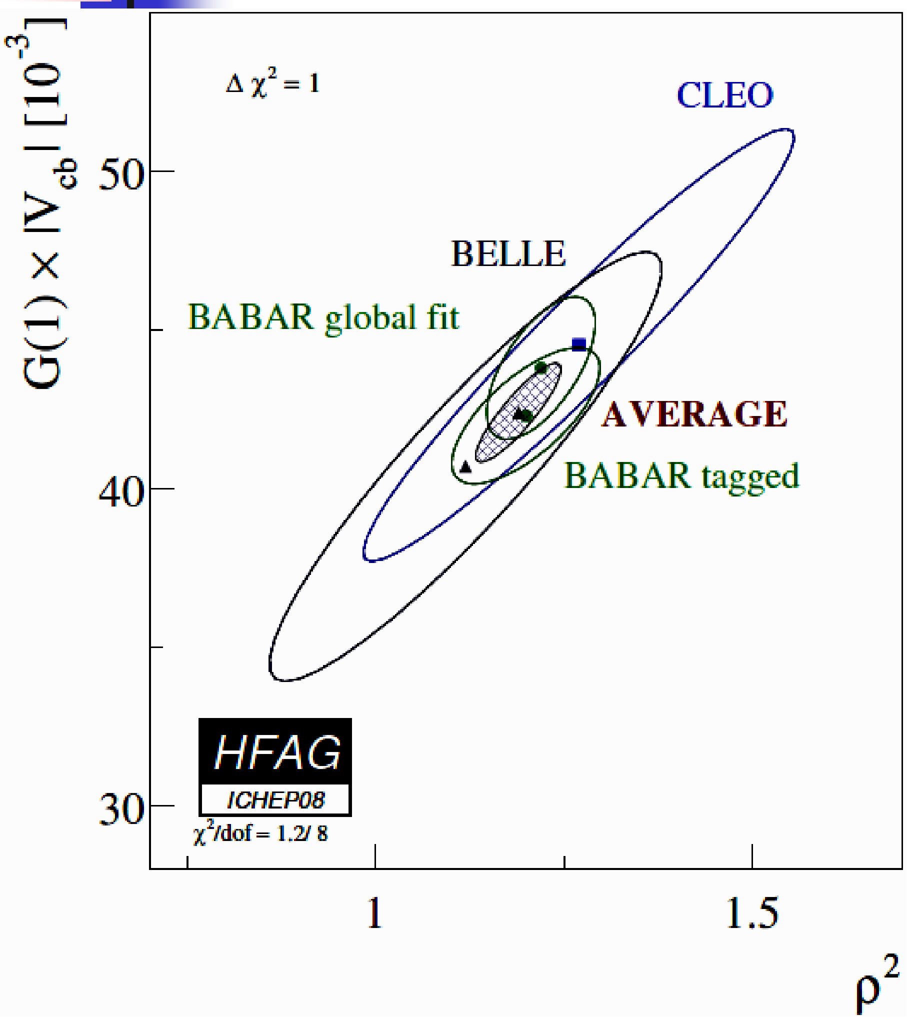
No Tag:

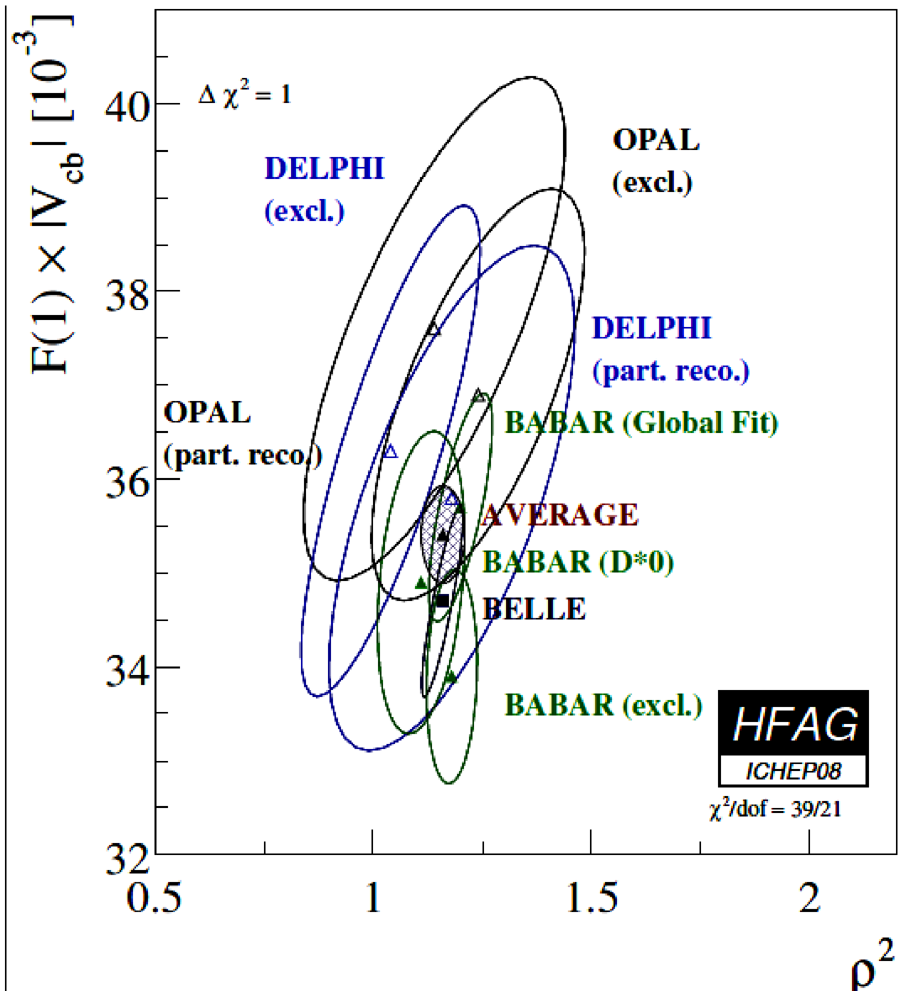
High statistics

High backgrounds and cross-feed

$\rightarrow$ Fully reconstruct signal side (ν reco.)

$B \to D l \nu$ $B \to D^* l \nu$





arXiv:0805.2408 [hep-ex]

348 fb^{-1}

|Vub| from B$\rightarrow\pi l\nu$ SL Tag

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}}{\tau_{B^0}\,\Delta\zeta}}$$

$$\tau_{B^0} = 1.530 \pm 0.009\ \mathrm{ps}$$

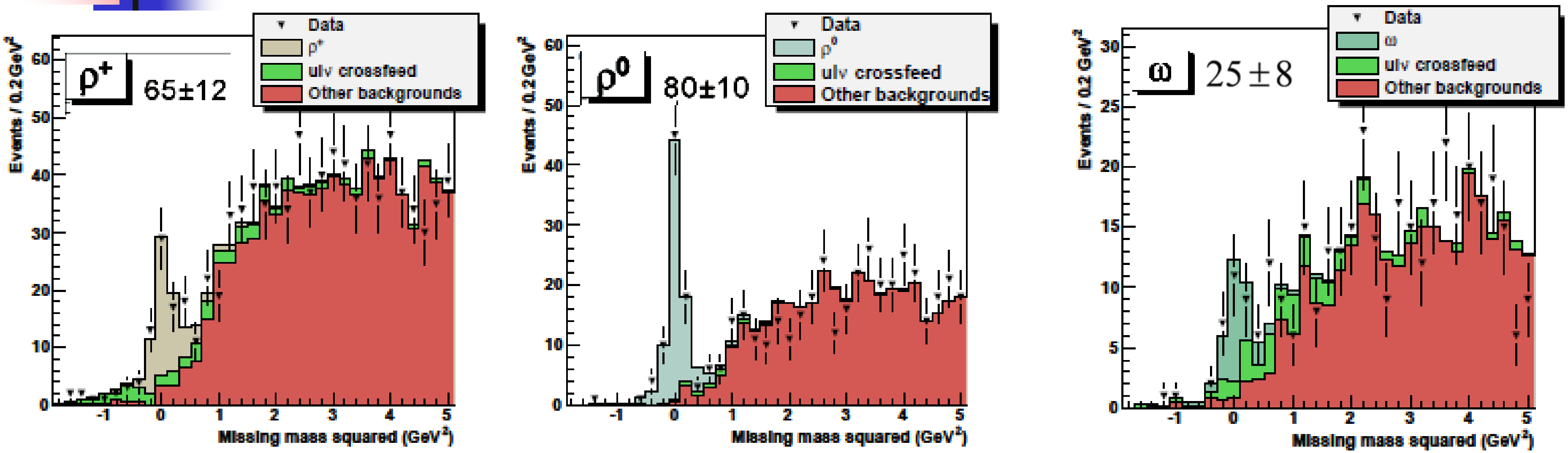
ΔB is the partial branching fraction

$\Delta\zeta$ calculated using:

- **LCSR for q^2<16 GeV^2**
- **Lattice QCD for q^2>16 GeV^2**

	q^2	$\Delta\zeta$	$\lvert V_{ub}\rvert$ (10^{-3})
Ball & Zwicky [12]	< 16	5.44 ± 1.43	$3.6 \pm 0.2 \pm 0.1^{+0.6}_{-0.4}$
Gulez et al. [17]	> 16	2.07 ± 0.57	$3.8 \pm 0.4 \pm 0.2^{+0.7}_{-0.4}$
Okamoto et al. [18]	> 16	1.83 ± 0.50	$4.0 \pm 0.5 \pm 0.2^{+0.7}_{-0.5}$
Abada et al. [19]	> 16	1.80 ± 0.86	$4.1 \pm 0.5 \pm 0.2^{+1.6}_{-0.7}$

$B \to \pi, \rho, \omega\, l\, \nu$ Hadronic Tag

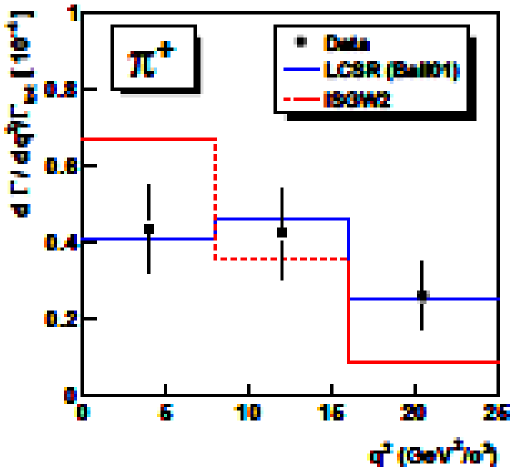


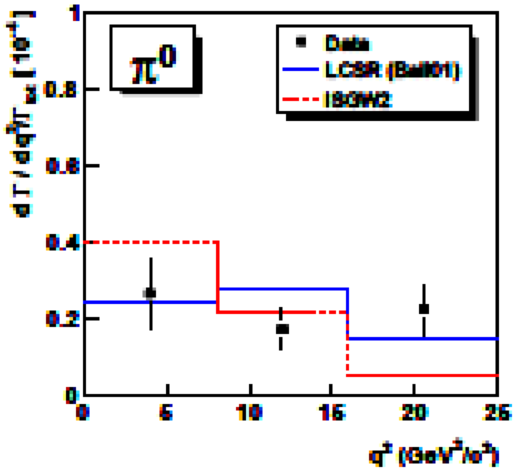
Mode	$\Delta\mathcal{B}\ [10^{-4}]$ $0 < q^2 < 8$ (GeV^2)	$\Delta\mathcal{B}\ [10^{-4}]$ $8 < q^2 < 16$ (GeV^2)	$\Delta\mathcal{B}\ [10^{-4}]$ $q^2 > 16$ (GeV^2)	$\mathcal{B}\ [10^{-4}]$ Sum (GeV^2)
$B \to \pi^+ \ell\nu$	$0.43 \pm 0.11 \pm 0.02$	$0.42 \pm 0.11 \pm 0.02$	$0.26 \pm 0.08 \pm 0.01$	$1.12 \pm 0.18 \pm 0.05$
$B \to \pi^0 \ell\nu$	$0.26 \pm 0.09 \pm 0.01$	$0.17 \pm 0.05 \pm 0.01$	$0.22 \pm 0.06 \pm 0.01$	$0.66 \pm 0.12 \pm 0.03$
$B \to \rho^+ \ell\nu$	$0.74 \pm 0.29 \pm 0.04$	$1.01 \pm 0.28 \pm 0.05$	$0.81 \pm 0.21 \pm 0.04$	$2.56 \pm 0.46 \pm 0.12$
$B \to \rho^0 \ell\nu$	$0.72 \pm 0.15 \pm 0.03$	$0.70 \pm 0.13 \pm 0.03$	$0.39 \pm 0.11 \pm 0.02$	$1.80 \pm 0.23 \pm 0.07$
$B \to \omega \ell\nu$	$0.23 \pm 0.17 \pm 0.01$	$0.64 \pm 0.21 \pm 0.03$	$0.32 \pm 0.17 \pm 0.01$	$1.19 \pm 0.32 \pm 0.05$

arXiv:0812.1414 [hep-ex]

605 fb^{-1}

|Vub| from $B \rightarrow \pi l \nu$ Hadr. Tag





To extract |Vub| use:
LCSR for $q^2 < 16$ GeV^2
Lattice QCD for $q^2 > 16$ GeV^2

	Mode	q^2 [GeV^2]	$\Delta\zeta$ [ps^{-1}]	$\lvert V_{ub}\rvert$ [10^{-3}]
Ball-Zwicky [30]	π^+	< 16	5.44 ± 1.43	$3.2 \pm 0.3 \pm 0.1^{+0.5}_{-0.4}$
Gulez et. al. [31]	π^+	> 16	2.07 ± 0.57	$2.9 \pm 0.5 \pm 0.1^{+0.5}_{-0.3}$
Okamoto et. al. [32]	π^+	> 16	1.83 ± 0.50	$3.0 \pm 0.5 \pm 0.1^{+0.5}_{-0.3}$
Ball-Zwicky [30]	$\pi^+ + \pi^0$	< 16	5.44 ± 1.43	$3.1 \pm 0.2 \pm 0.1^{+0.5}_{-0.3}$
Gulez et. al. [31]	$\pi^+ + \pi^0$	> 16	2.07 ± 0.57	$3.1 \pm 0.3 \pm 0.1^{+0.6}_{-0.4}$
Okamoto et. al. [32]	$\pi^+ + \pi^0$	> 16	1.83 ± 0.50	$3.3 \pm 0.4 \pm 0.1^{+0.6}_{-0.4}$