Exclusive $|V_{ub}|$ measurements

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Outline

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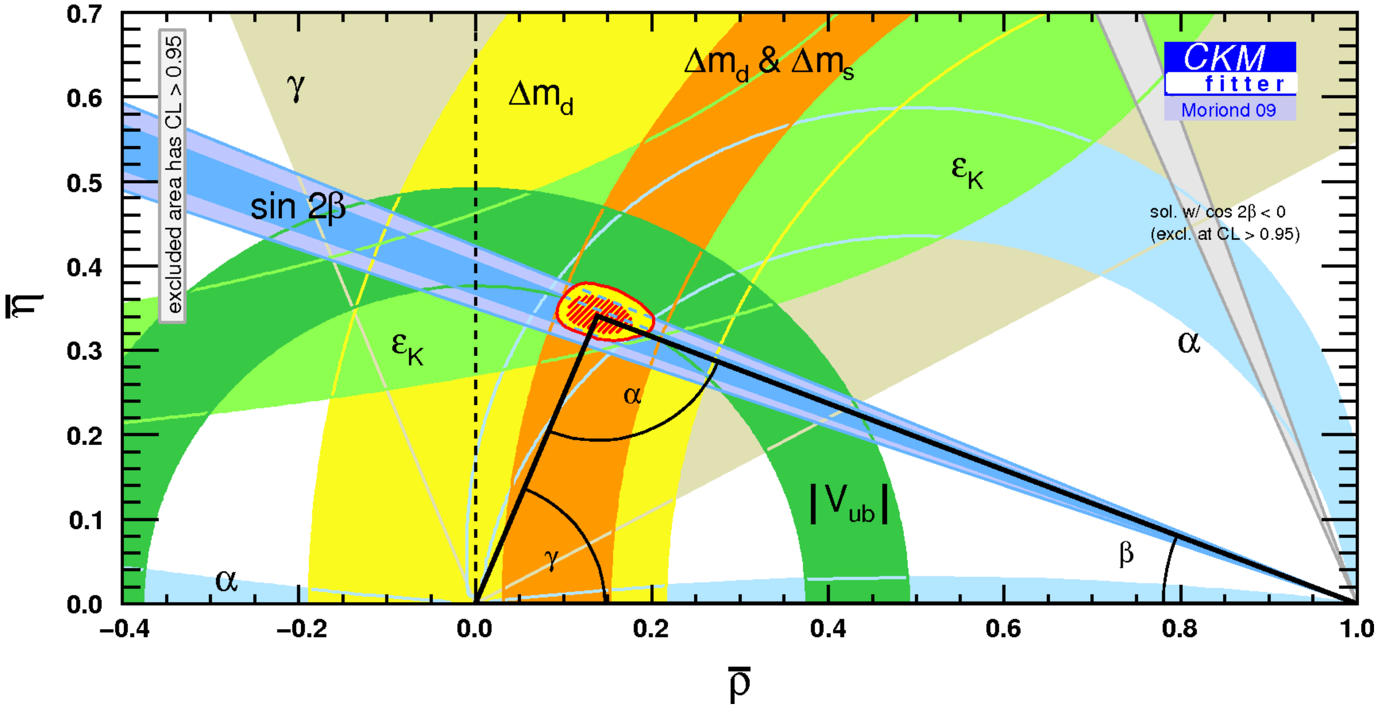
- Semileptonic B Decays
- Experimental techniques
- BR measurements
  - untagged
  - Semileptonic tag
  - tagged
- $|V_{ub}|$ determinations
- Summary

Motivation: the UT triangle

$$V_{CKM}^{\dagger} V_{CKM} = 1$$

Unitarity Triangle



Angles and sides have been measured by B factories: measurements consistent with the SM picture.

Precise measurements of the sides and the angles of the Unitarity Triangle are important: any sign of new physics will show up as openess of the UT.

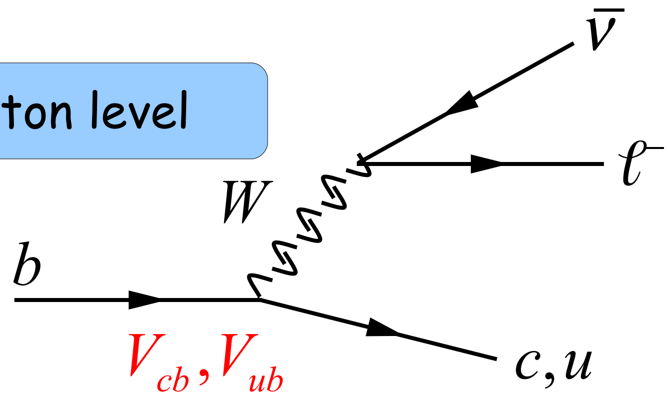
Left side of the triangle $$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| = \left|\frac{V_{ub}}{V_{cb}}\right| \frac{1}{\tan\vartheta_c}$$

$$\frac{\delta|V_{cb}|}{|V_{cb}|} \sim 2\% \qquad \frac{\delta|V_{ub}|}{|V_{ub}|} \sim 8\%$$ → **improve V_{ub} measurements**

Semileptonic B decays

- Semileptonic tree-level B decays provide the cleanest environment to study V_{ub}

Parton level



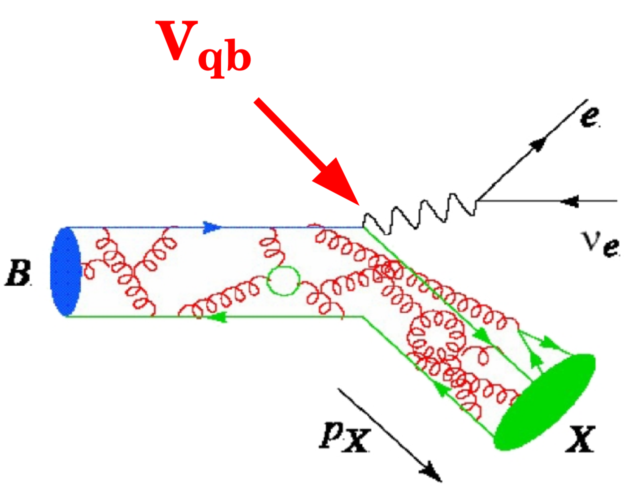
- simple description at parton level
- leptonic and hadronic current decoupled

$$\Gamma_u \equiv \Gamma(b \to u\ell\bar{\nu}) = \frac{G_F^2}{192\pi^3}|V_{ub}|^2 m_b^5$$

$$\Gamma_c \equiv \Gamma(b \to c\ell\bar{\nu}) = \frac{G_F^2}{192\pi^3}|V_{cb}|^2 m_b^2 (m_b - m_c)^3$$

$$\frac{\Gamma_u}{\Gamma_c} \approx \frac{1}{50}$$

hadron level

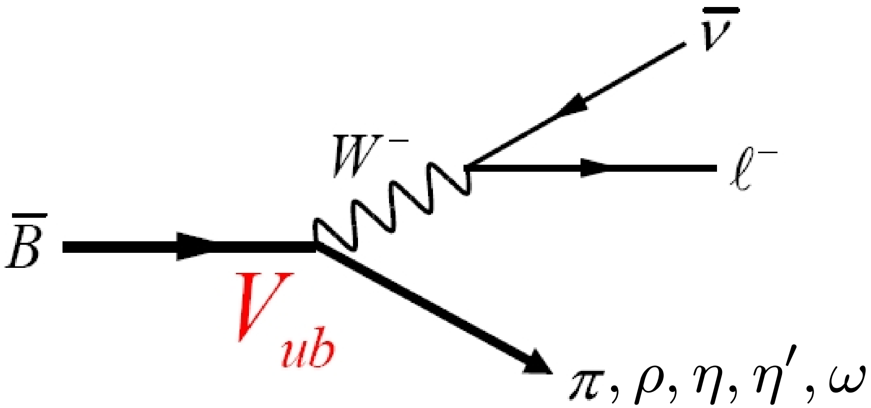


$$\Gamma_{had} = \Gamma_{quark}(1 + \text{ QCD}_{corr})$$

- Sensitive to strong interactions in B meson
- Tests of QCD models e.g. lattice QCD

Semileptonic decays: Exclusive approach

Reconstruct a charmless semileptonic decay



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

$$q^2 = m_W^2 = (P_\ell + P_\nu)^2$$

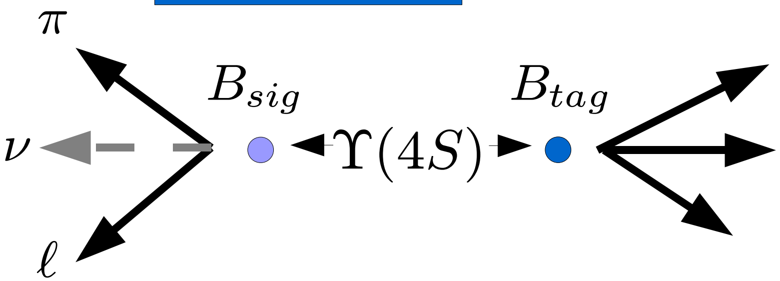
<u>Respect to the inclusive approach:</u>

- lower signal yields (typical BR ~ 10^{-4})
- better background rejection
- Form Factors $F(q^2)$ to describe the hadronization process $u \to \pi, \rho, \ldots$: LQCD, Quark Model
- Measurements as function of q^2

Inclusive and Exclusive approaches rely on complementary theoretical frameworks

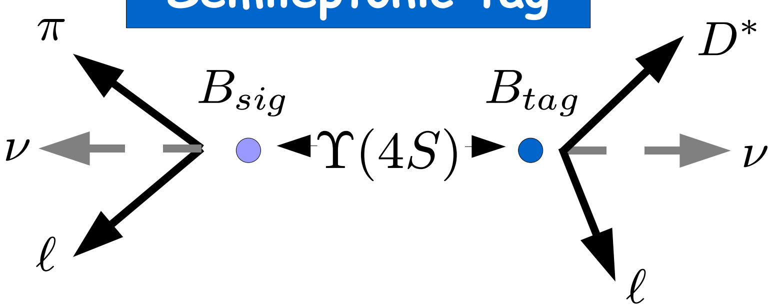
Experimental methods

Untagged



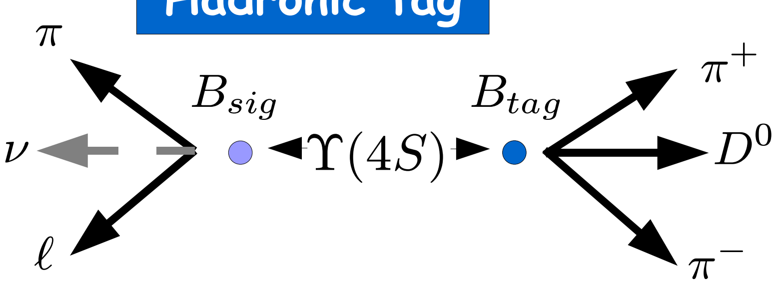
- Only signal reconstruction
- High statistics
- sensitive to background simulation

Semileptonic tag



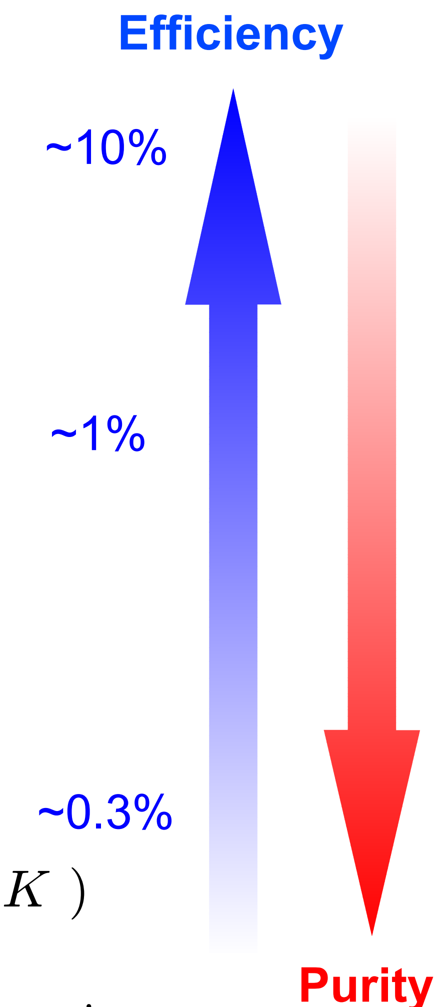
- Reconstruct $B \to D^{(*)}\ell\bar{\nu}$
- 2ν: incomplete kinematics

Hadronic tag



Reconstruct $B \to D^{(*)}Y$ $(Y = \pi, K)$

- several decays mode
- closed kinematics, charge and flavour known



$B \to \pi \ell \nu$ untagged

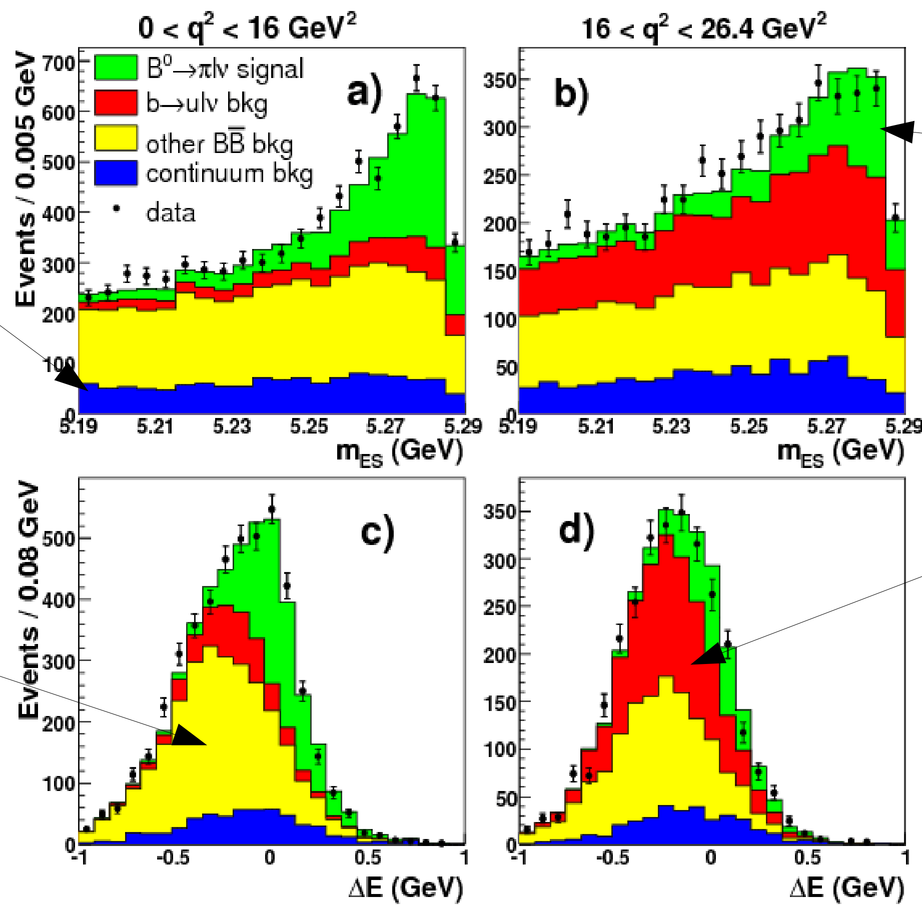
PRL 98, 091801 (2007)

206 fb^{-1}

- ν reconstruction: $(\vec{p}_{miss}, E_{miss}) = (\vec{p}_{beams}, E_{beams}) - (\sum_i \vec{p}_i, \sum_i \vec{E}_i)$
- Signal yields measured in 12 q^2 bins from fit to (ΔE,m_{ES}) distributions

$$\Delta E = E_B^* - \sqrt{s}/2$$
$$m_{ES} = \sqrt{s/4 - |p_B^*|^2}$$

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



Continuum studied with offres data

$B \to X_c l \nu$ medium q^2 region

signal

other $B \to X_u l \nu$ high q^2 region

5072 ± 251 signal events over full q^2 range

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

$B \to \pi, \rho, \eta^{(\prime)} \ell \nu$ untagged

PRL 99, 041802 (2007)

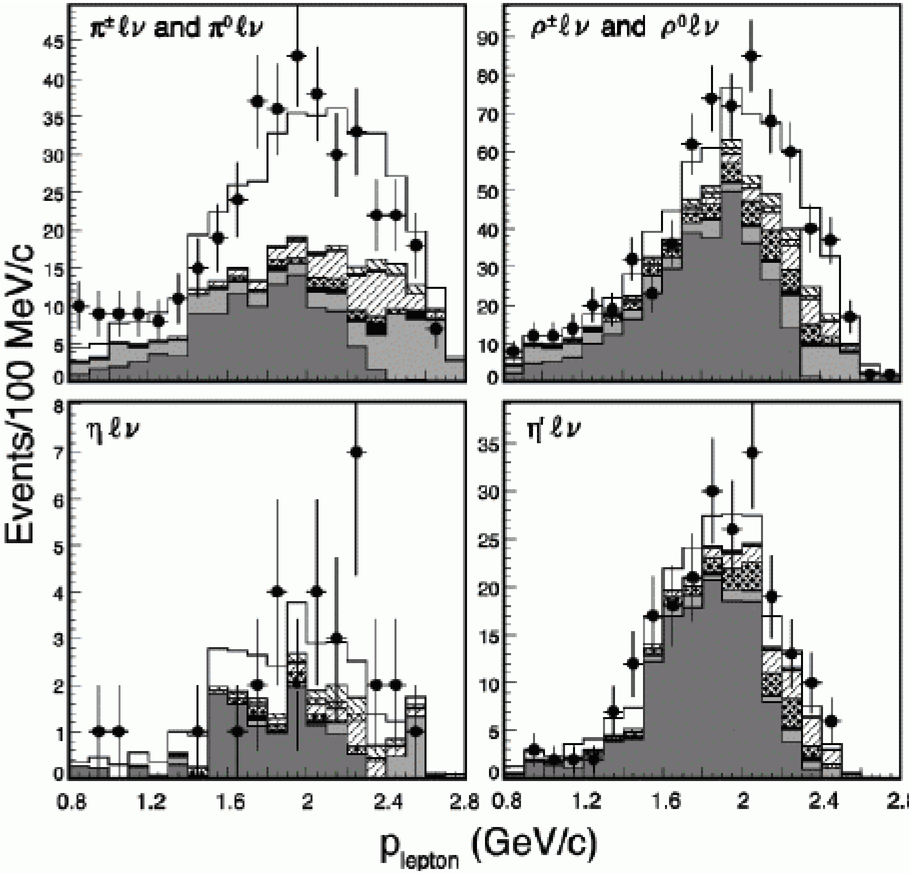
15.5 fb^{-1}

- signal lepton $1 < p_\ell < 3$ GeV$/c$ $\quad X_u = \pi^0, \pi^\pm, \eta, \rho^0, \rho^\pm, \eta^{(\prime)}, \omega$

$\eta' \to \pi\pi\gamma, \eta(\gamma\gamma)\pi^+\pi^-$

- reconstruct $p_{miss} = p_{CM} - \sum p_{charged} - \sum p_{neutral}$
- reject events with multiple leptons (multiple neutrinos) and with $|\Delta Q| > 1$
- Yields extracted with fits to $\Delta E, m_{h\ell\nu}$

	q^2 [GeV^2]	$\cos\theta_{Wl}$	$\mathcal{B}$ [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		$\mathbf{2.66 \pm 0.80 \pm 0.56}$



- missing momentum reconstruction dominates syst. error

$$\mathcal{B}(B^0 \to \pi^-\ell^+\nu) = (1.37 \pm 0.15 \pm 0.11) \times 10^{-4}$$

$B \to \eta\ell\nu, \omega\ell\nu$ untagged

$\omega \to \pi^+\pi^-\pi^0$ BR (~ 90%)

$\eta \to \pi^+\pi^-\pi^0$ BR (~ 23%)

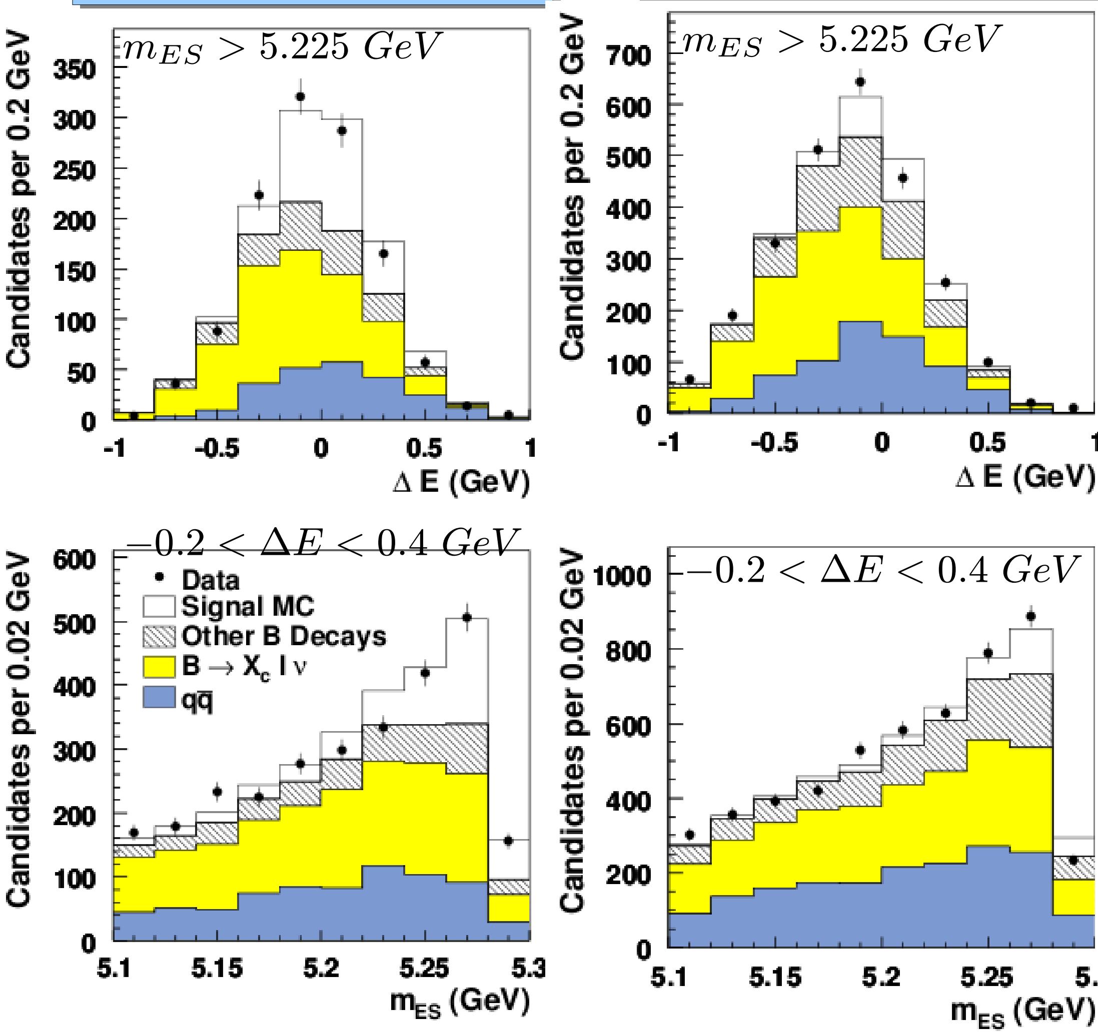
$\eta \to 2\gamma$ BR (~ 40%)

- no q^2 dependence
- cuts on leptons and reconstucted hadron momentum to suppress background
- NN employed to separate signal from continuum and cham bkg

Yields extracted with m_{ES}-ΔE fits

S/B ~ 0.2 (η), ~0.5 (ω)

ω | η combined



$$N_{sig} = 802 \pm 113$$

$$\mathcal{B}(B \to \omega\ell\nu) = (1.14 \pm 0.16 \pm 0.08) \times 10^{-4}$$

leading syst. err. $\mathcal{B}(B \to X_u\ell\nu)$ ~3%

$\mathcal{B}(B \to X_c\ell\nu)$ ~2%

$$N_{sig} = 554 \pm 105$$

$$\mathcal{B}(B \to \eta\ell\nu) = (0.31 \pm 0.06 \pm 0.08) \times 10^{-4}$$

leading syst. err. $\mathcal{B}(B \to X_u\ell\nu)$ ~9%

$\mathcal{B}(B \to X_c\ell\nu)$ ~8%

continuum bkg ~12%

$B \to (\pi, \eta, \eta')\ell\nu$ with Semileptonic tag

PRL 101, 081801 (2008)

- tag side: full hadronic reconstruction of a $D^{(*)}$

$$\left\{\begin{array}{l} D^0 \to K^-\pi^+ \\ D^0 \to K^-\pi^+\pi^+\pi^- \\ D^0 \to K^-\pi^+\pi^0 \\ D^0 \to K_s^0\pi^+\pi^- \end{array}\right.$$

$$D^+ \to K^-\pi^+\pi^+$$
$$D^+ \to K_s^0\pi^+$$

$$D^{*+} = D^0\pi^+, D^+\pi^0$$
$$D^{*0} = D^0\pi^0, D^0\gamma$$

candidate D paired to leptons $|p_\ell| > 0.8\ \mathrm{GeV}/c$

$$\cos\theta_{BY} = \frac{2E_B E_Y - m_B^2 - m_Y^2}{2|\vec{p}_B||\vec{p}_Y|}$$

$$Y = D^{(*)}\ell$$

$$|\cos\theta_{BY}| \leq 5$$

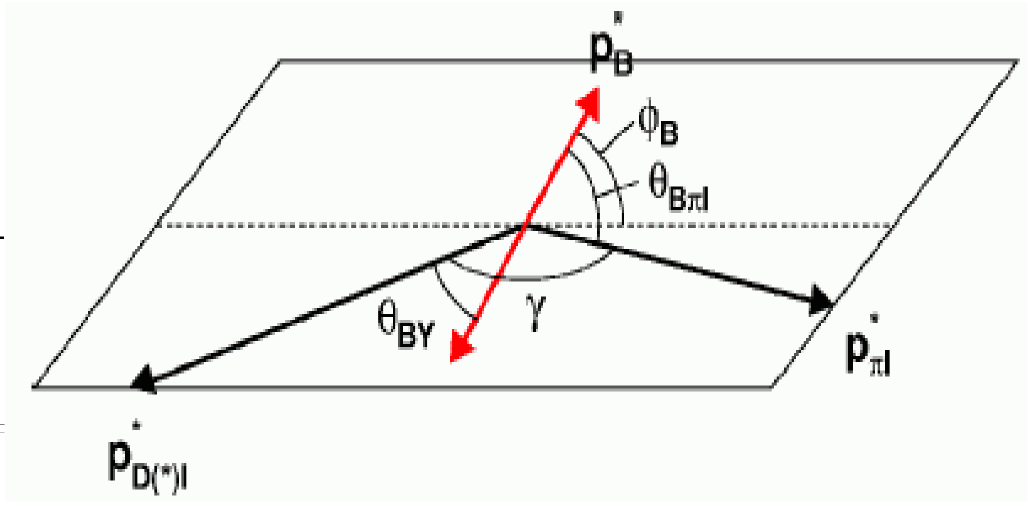
- signal side: lepton $|p_\ell| > 0.8\ \mathrm{GeV}/c$ with right charge for a decay $B \to P\ell\nu$

- no additional tracks or neutral clusters allowed

$$P = \left\{\begin{array}{l} \pi \\ \eta \to \gamma\gamma, \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0 \\ \eta' \to \eta\pi^+\pi^- \end{array}\right.$$

- signal yields extract with unbinned maximum likelihood fit to $\cos\phi_B$ in 3 q^2 bins

$$\cos^2\phi_B = \frac{\cos^2\theta_{BY} + 2\cos\gamma\cos\theta_{BY}\cos^2\theta_{B\pi\ell}}{\sin^2\gamma}$$

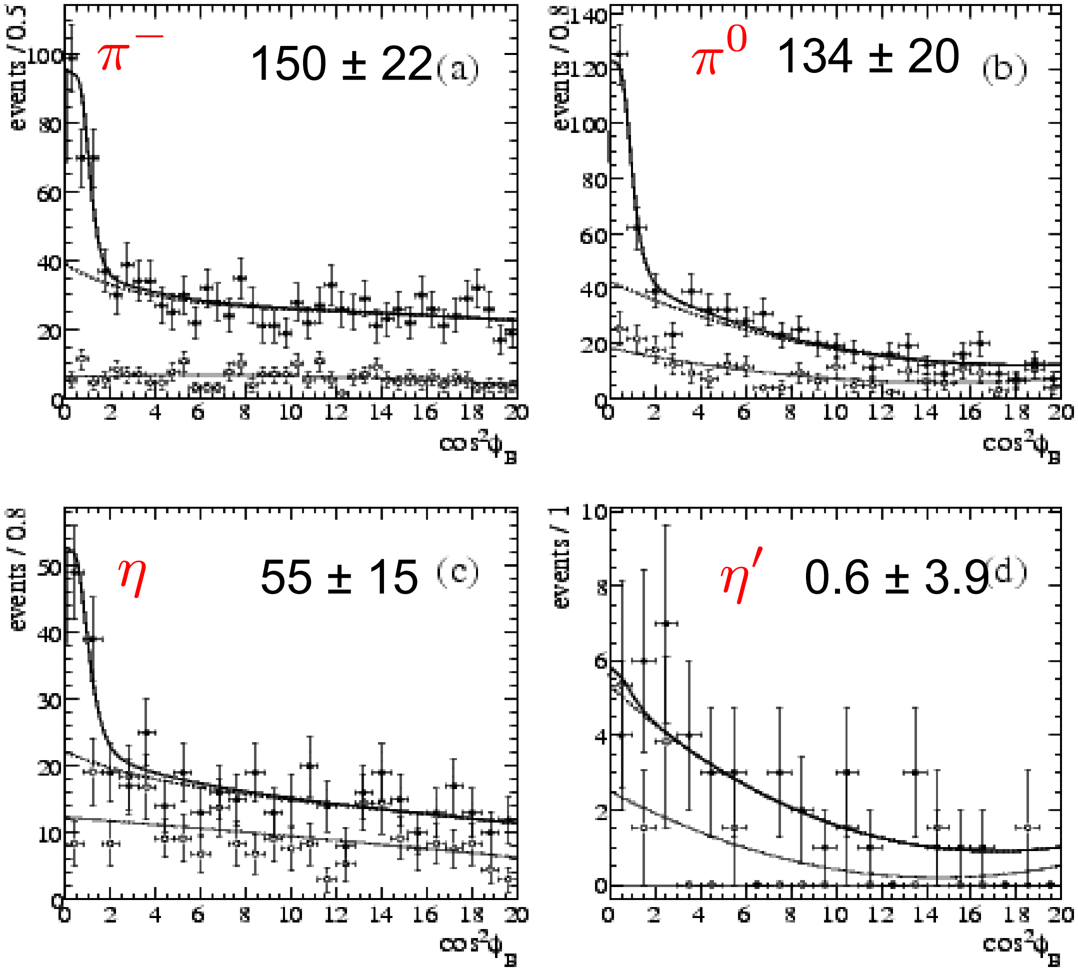


$B \to (\pi, \eta, \eta')\ell\nu$ with Semileptonic tag

PRL 101, 081801 (2008)

plot: full q^2 range

348 fb^{-1}



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

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

combining results with Isospin relation

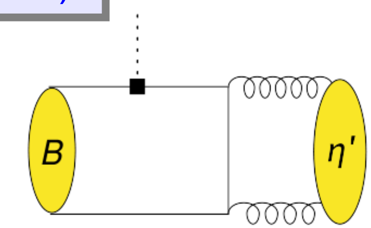
$$\mathcal{B}(B^0 \to \pi^- \ell^+ \nu) = (1.54 \pm 0.17 \pm 0.09) \times 10^{-4}$$

$$\mathcal{B}(B^+ \to \eta \ell^+ \nu) = (0.69 \pm 0.20 \pm 0.30) \times 10^{-4}$$

$\mathcal{B}(B^+ \to \eta' \ell^+ \nu) < 0.47 \times 10^{-4}$ @ 90% C.L.

disagreement (2.6σ) with CLEO results

Ball, Jones, JHEP 0708, 025 (2007)



gluonic singlet contribution

$B \to \eta'$ FF 20% (3% for η)

Propose measurement of $R_{\eta'\eta} = \mathcal{B}(B \to \eta' \ell\nu)/\mathcal{B}(B \to \eta\ell\nu)$

$B \to \pi\ell\nu, \rho\ell\nu$ with Semileptonic tag

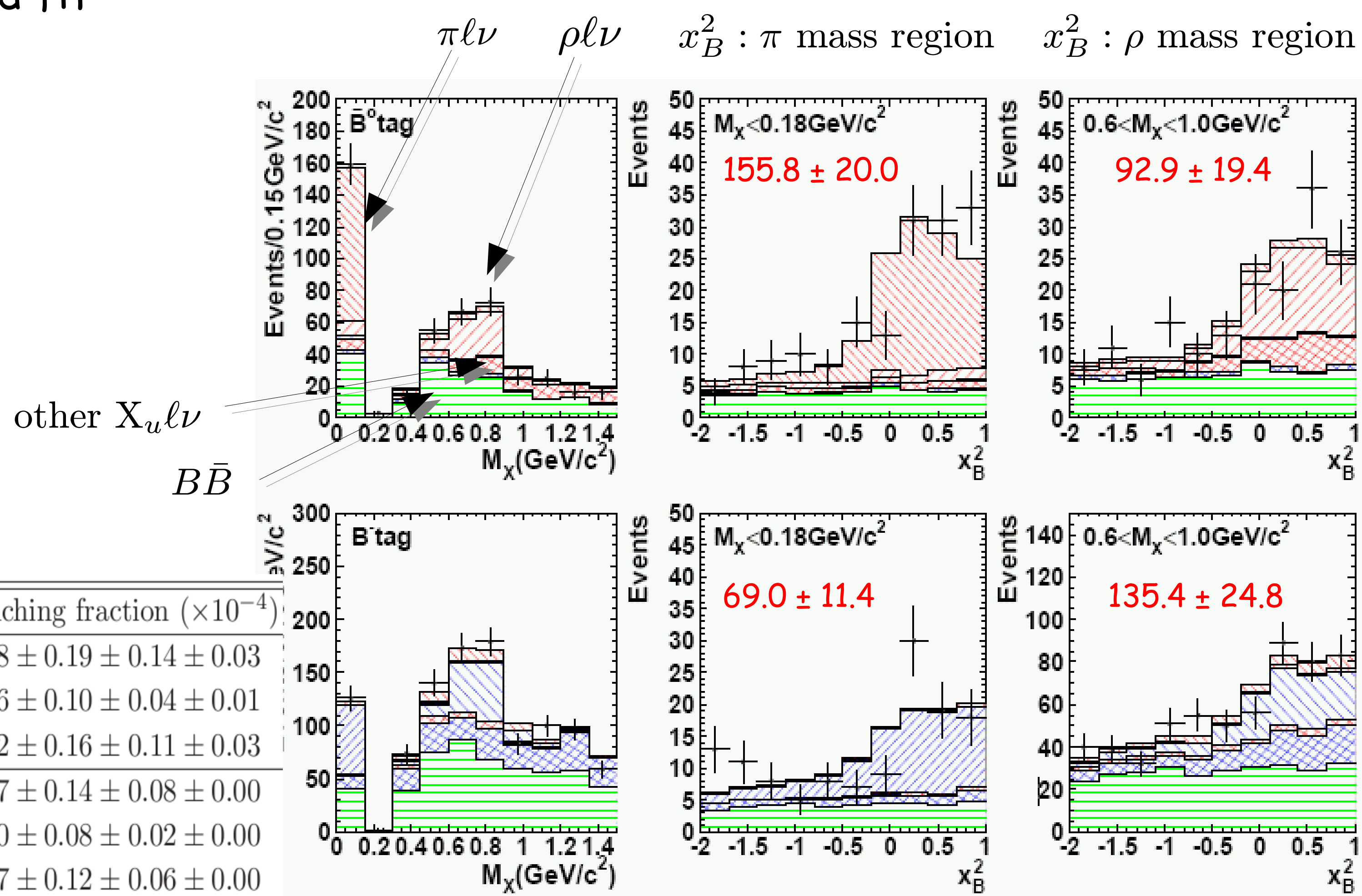
Phys.Lett. B 648:139-148 (2007)

253 fb^{-1}

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

binned maximum likelihood fit to (x_B^2, M_X) plane

plots: full q^2 range



Modes	q^2 region (GeV^2/c^2)	Branching fraction ($\times 10^{-4}$)
$B^0 \to \pi^-\ell^+\nu$	Total	$1.38 \pm 0.19 \pm 0.14 \pm 0.03$
	> 16	$0.36 \pm 0.10 \pm 0.04 \pm 0.01$
	< 16	$1.02 \pm 0.16 \pm 0.11 \pm 0.03$
$B^+ \to \pi^0\ell^+\nu$	Total	$0.77 \pm 0.14 \pm 0.08 \pm 0.00$
	> 16	$0.20 \pm 0.08 \pm 0.02 \pm 0.00$
	< 16	$0.57 \pm 0.12 \pm 0.06 \pm 0.00$
$B^0 \to \rho^-\ell^+\nu$	Total	$2.17 \pm 0.54 \pm 0.31 \pm 0.08$
$B^+ \to \rho^0\ell^+\nu$	Total	$1.33 \pm 0.23 \pm 0.17 \pm 0.05$

BF measurement dominated by statistics: can be improved with more data

Hadronic tags

presented at ICHEP08

- neutrino is the only undetected particle

$$P^2_{miss} = (P_{\Upsilon(4S)} - P_{Breco} - P_{Xu} - P_\ell)^2 = m^2_{miss}$$ peaking at 0 for signal events

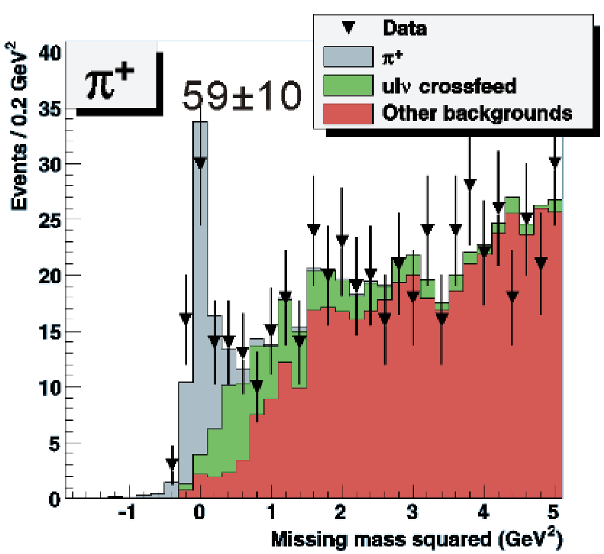
- spectrum reconstructed with fits to the m_{ES} variable for each bin of m^2_{miss}

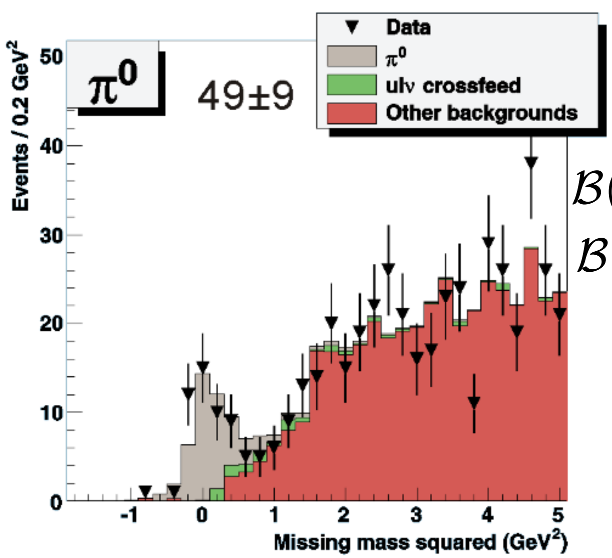
605 fb^{-1}

$B^0 \to \pi^- \ell^+ \nu$
$B^+ \to \pi^0 \ell^+ \nu$
$B^0 \to \rho^- \ell^+ \nu$
$B^+ \to \rho^0 \ell^+ \nu$
$B^+ \to \omega \ell^+ \nu$

$\omega \to \pi^+\pi^-\pi^0$ $\quad$ $\rho^+ \to \pi^+\pi^0$
$\pi^0 \to 2\gamma$ $\quad$ $\rho^0 \to \pi^+\pi^-$

yields extracted in 3 q^2 bins:
$q^2 < 8\ GeV^2$, $8\ GeV^2 < q^2 < 16\ GeV^2$, $16\ GeV^2 < q^2$



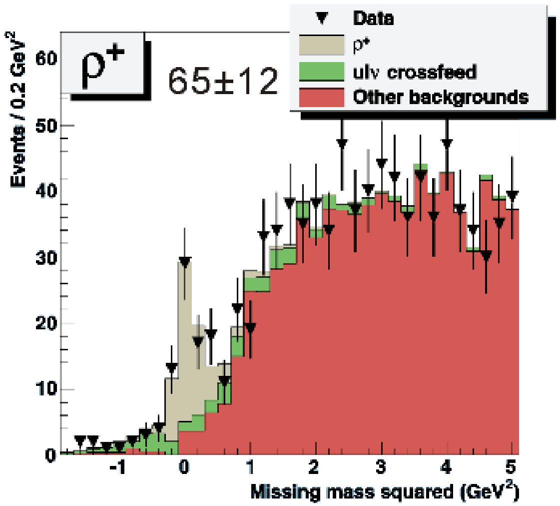


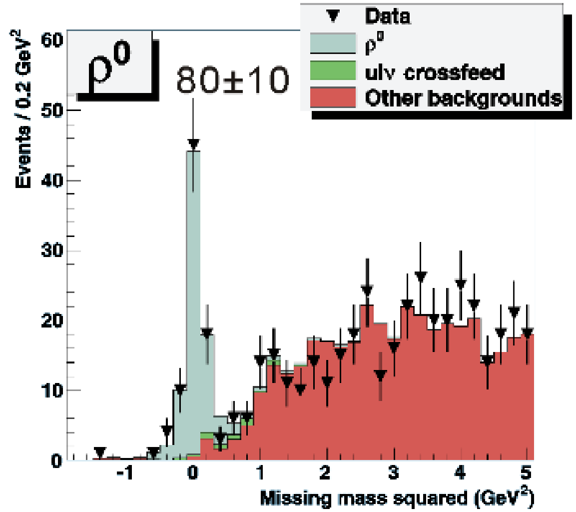
$$\mathcal{B}(B \to \pi^+ \ell \nu) = (1.12 \pm 0.18 \pm 0.05) \times 10^{-4}$$
$$\mathcal{B}(B \to \pi^0 \ell \nu) = (0.66 \pm 0.12 \pm 0.03) \times 10^{-4}$$

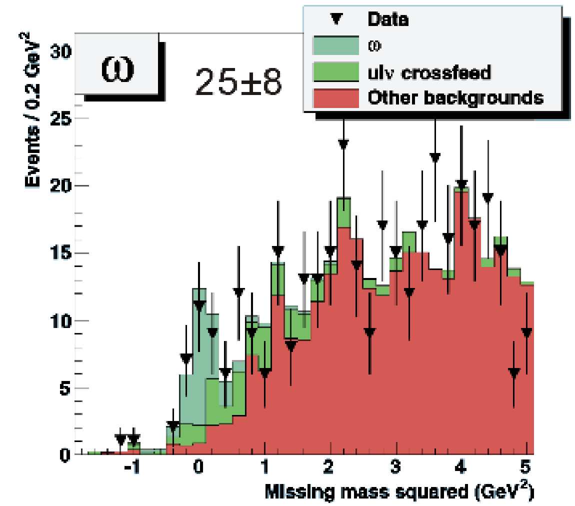
leading systematic uncertainties
FF (2.8%)
normalization (1.4%)

Hadronic tags

presented at ICHEP08



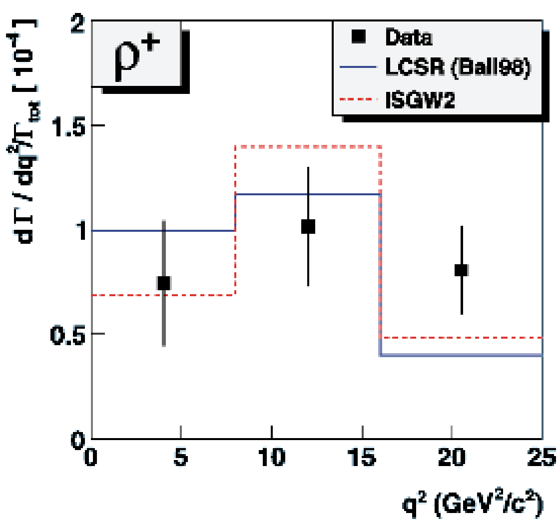


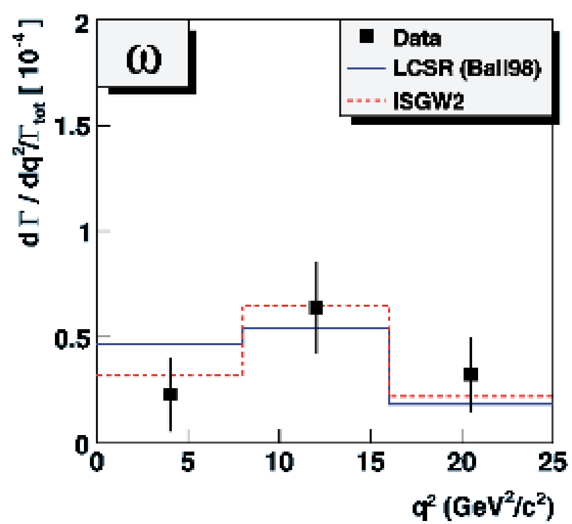


$$\mathcal{B}(B \to \rho^+ \ell\nu) = (2.56 \pm 0.46 \pm 0.12) \times 10^{-4}$$
$$\mathcal{B}(B \to \rho^0 \ell\nu) = (1.80 \pm 0.23 \pm 0.07) \times 10^{-4}$$
$$\mathcal{B}(B \to \omega \ell\nu) = (1.19 \pm 0.32 \pm 0.05) \times 10^{-4}$$

all measurements limited by statistics

$B \to X_u \ell\nu$ decays are big source of systematic errors for ρ^+ channel (1.1%)





Need more statistics to validate FF calculations

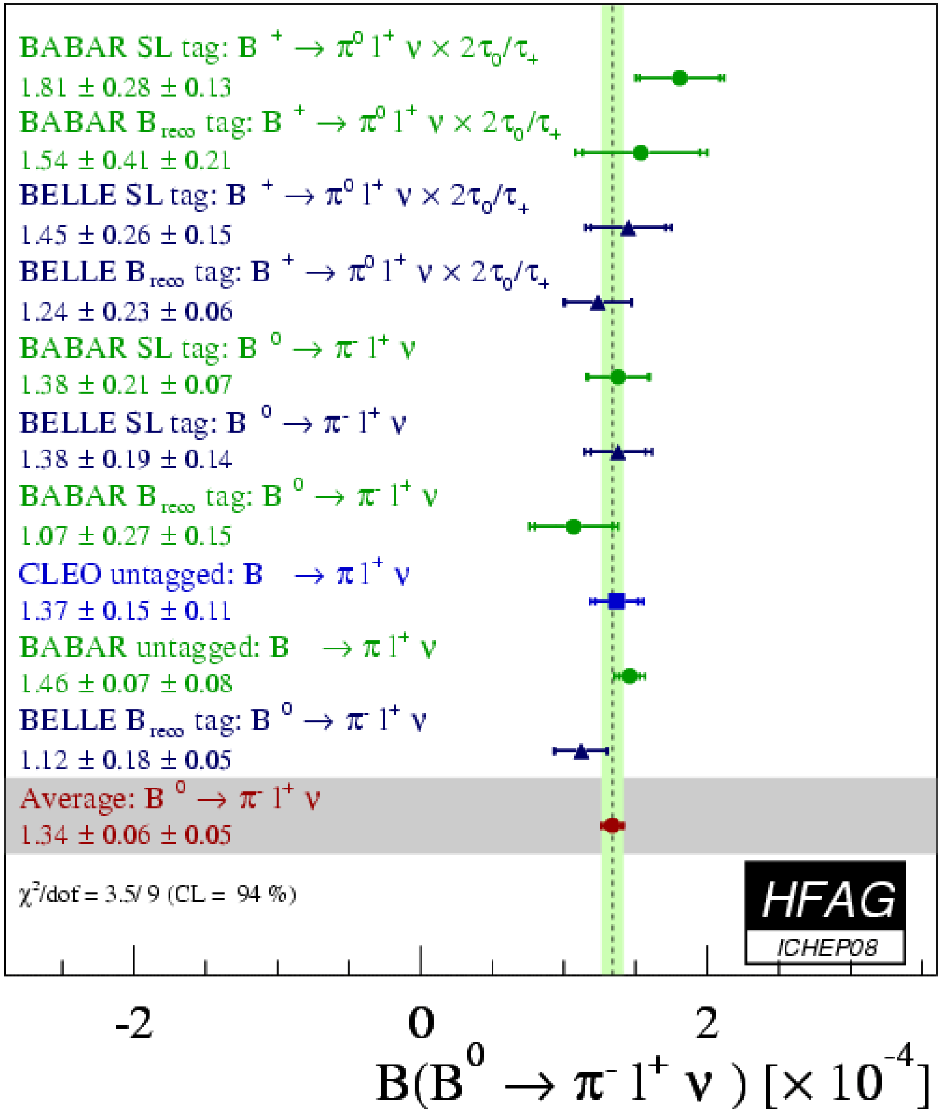
$B \to \pi\ell\nu, \rho\ell\nu$ summary

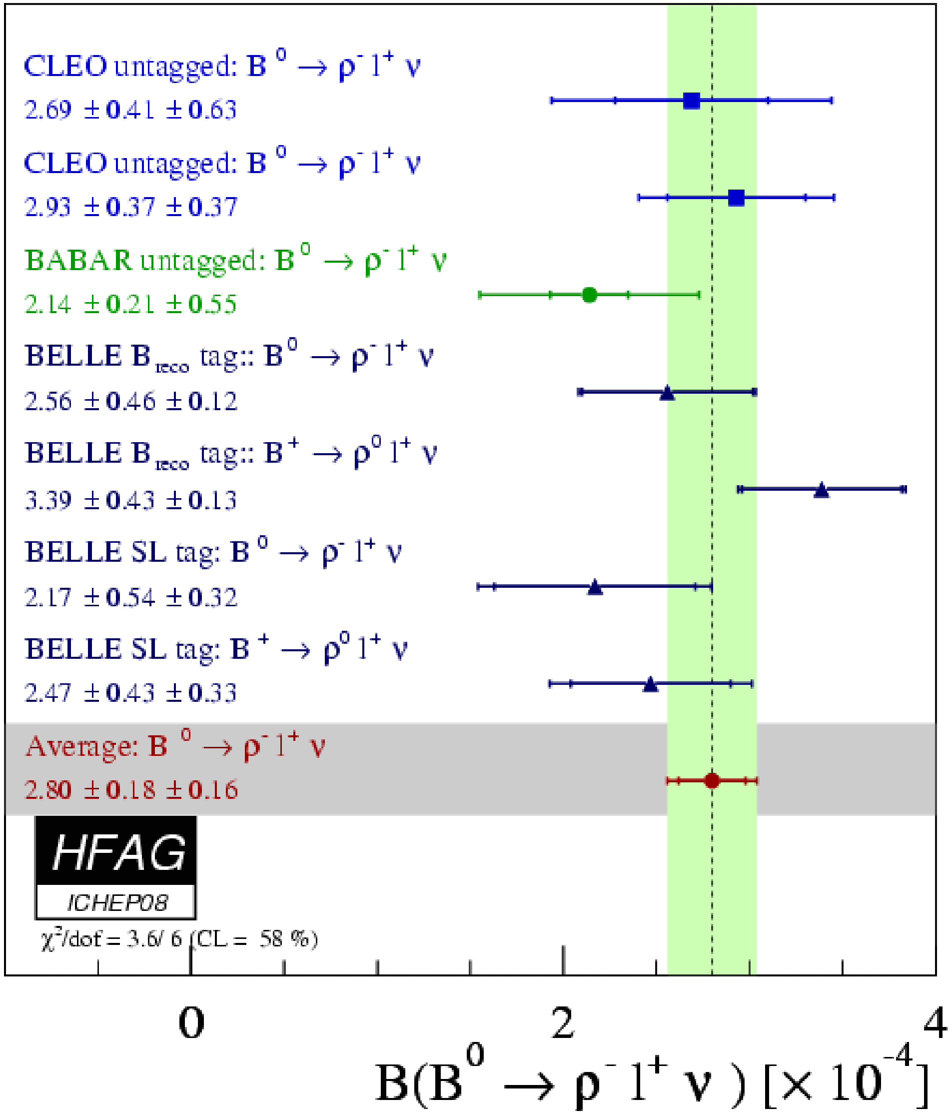
$\mathcal{B}(B^0 \to \pi^-\ell^+\nu) = (1.34 \pm 0.06 \pm 0.05) \times 10^{-4}$

$\sigma_{stat} : 5\%$ $\sigma_{syst} : 4\%$

$\mathcal{B}(B^0 \to \rho^-\ell^+\nu) = (2.80 \pm 0.18 \pm 0.16) \times 10^{-4}$

$\sigma_{stat} : 7\%$ $\sigma_{syst} : 6\%$



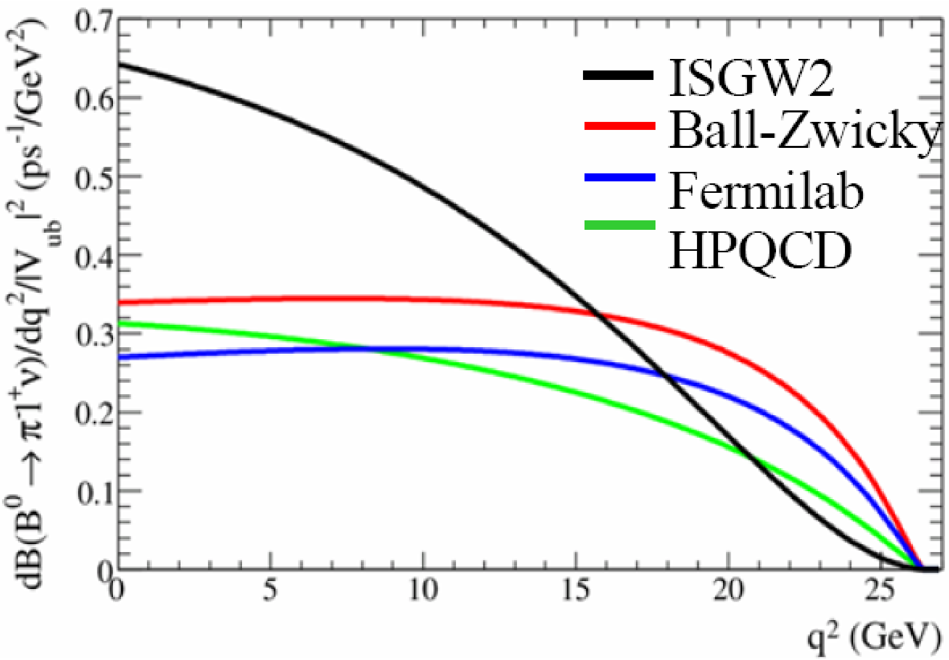


$|V_{ub}|$ measurements

[1]: Fermilab, hep-lat/0409116 and HPQCD (PRD73:074592)
[2]: Ball & al. PRD71, 014015 (2005)
[3]: PRD52, 2783 (1995)

- Need theoretical predictions for the form factors (available for π so far)

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to \pi\ell\nu)}{\tau_B \cdot \Delta\zeta}} \quad \rightarrow \quad \Delta\zeta = \int_{q^2_{min}}^{q^2_{max}} |f_+(q^2)|^3 p_\pi^2 dq^2$$



different FF calculations available:

Lattice QCD [1]: for $q^2 > 16$ GeV^2
Light Cone Sum Rules [2]: for $q^2 < 16$ GeV^2
Quark Model [3]

HPQCD uses non relativistic QCD to describe the b quark: agrees within the error with FNAL/MILC collaboration

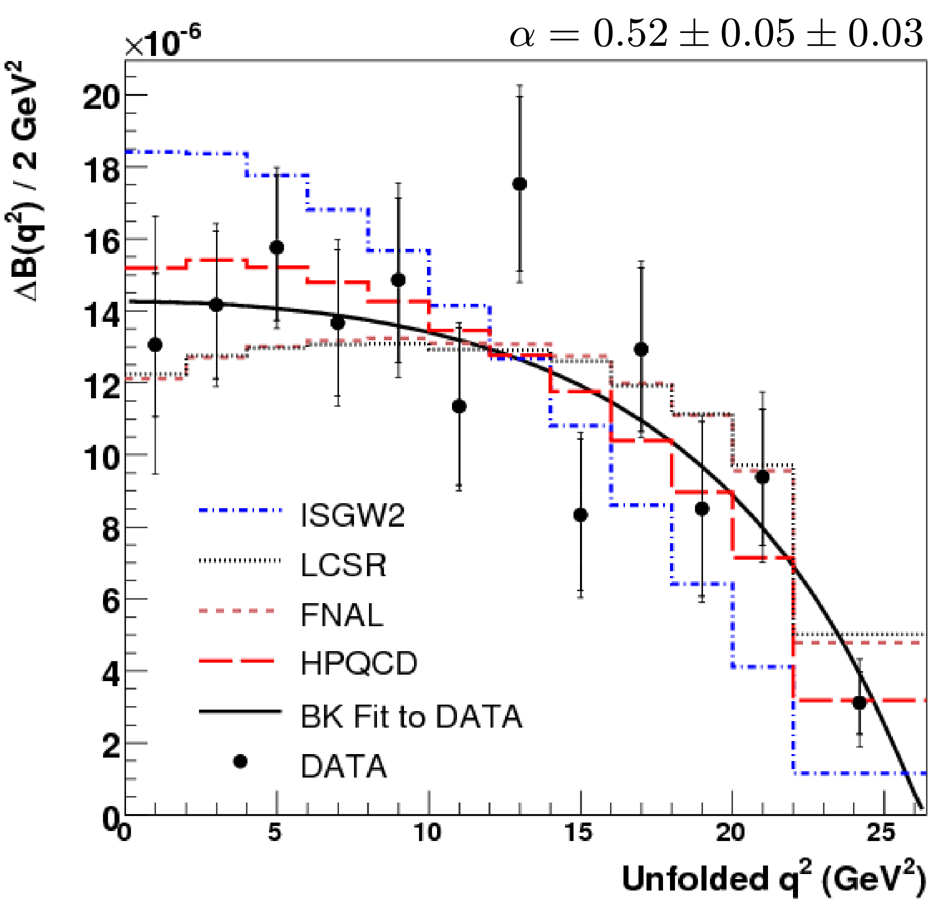
Uncertainties on FF are due to normalization $f_+(0)$ and q^2 dependence

FF q^2 parametrizations

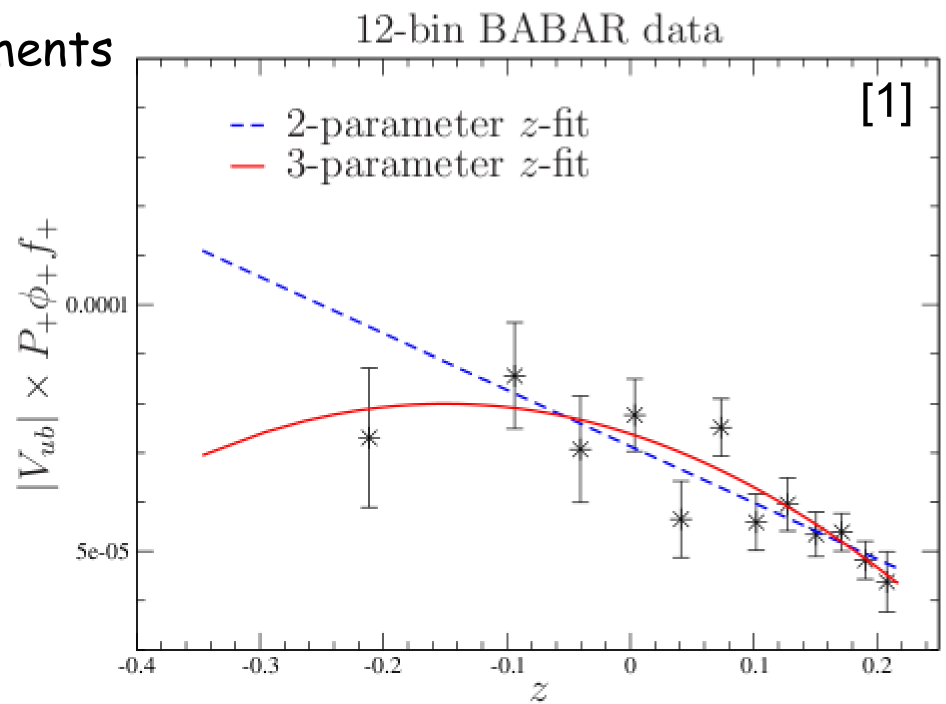
[1]: J. Bailey *et al.* arXiv:0811.3640

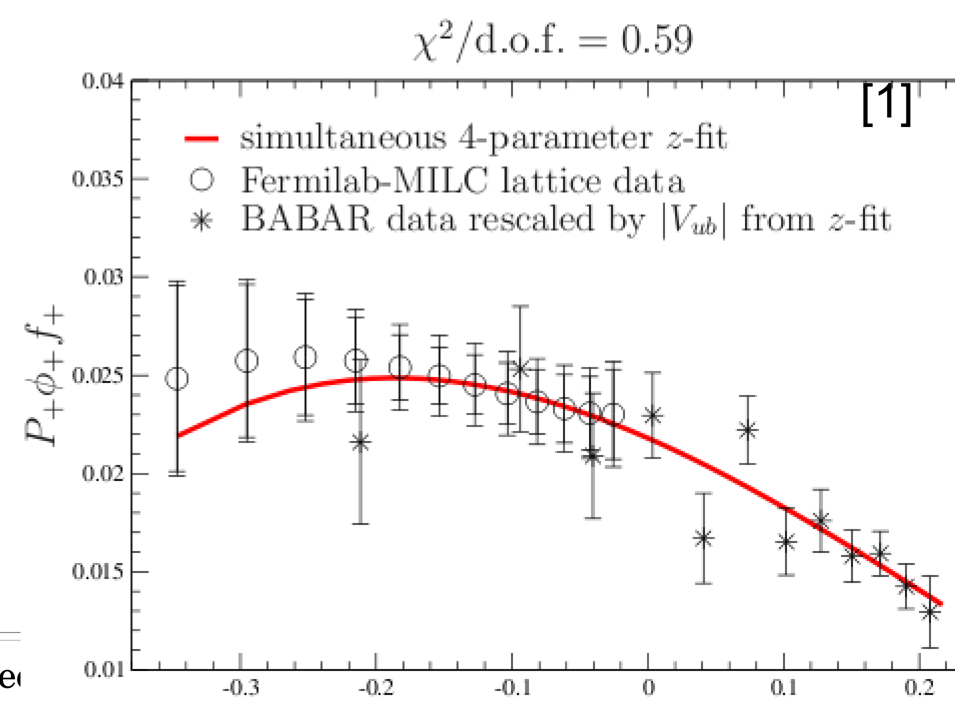
FF shape can be constrained with data measurements

BaBar untagged analysis

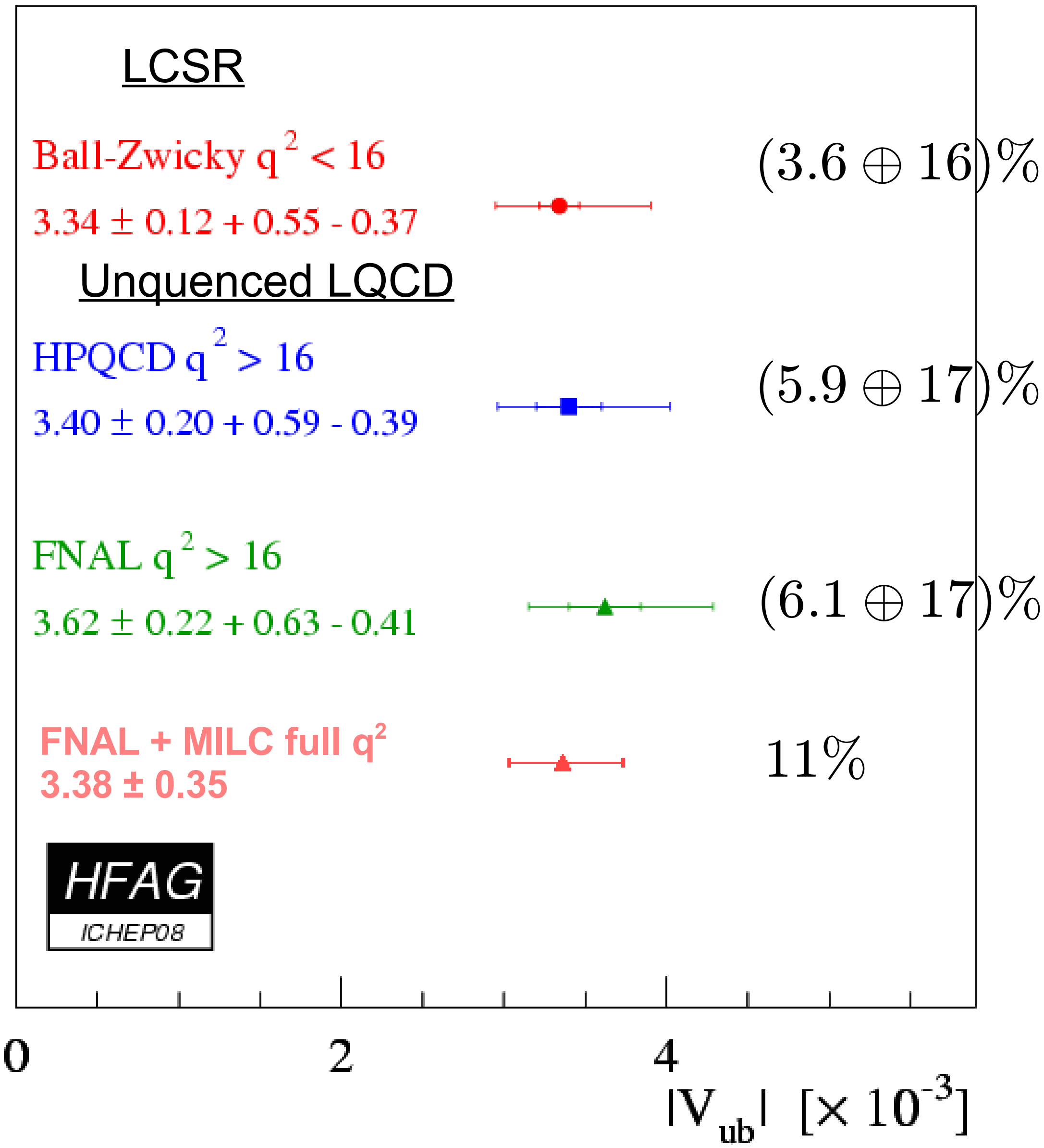


ISGW2 incompatible
(Prob < 0.06%)





$|V_{ub}|$ values



Phys. Rev. D71:014015 (2005)

Phys.Rev.D73, 074502 (2006)
Erratum-Ibid.D75:119906,2007

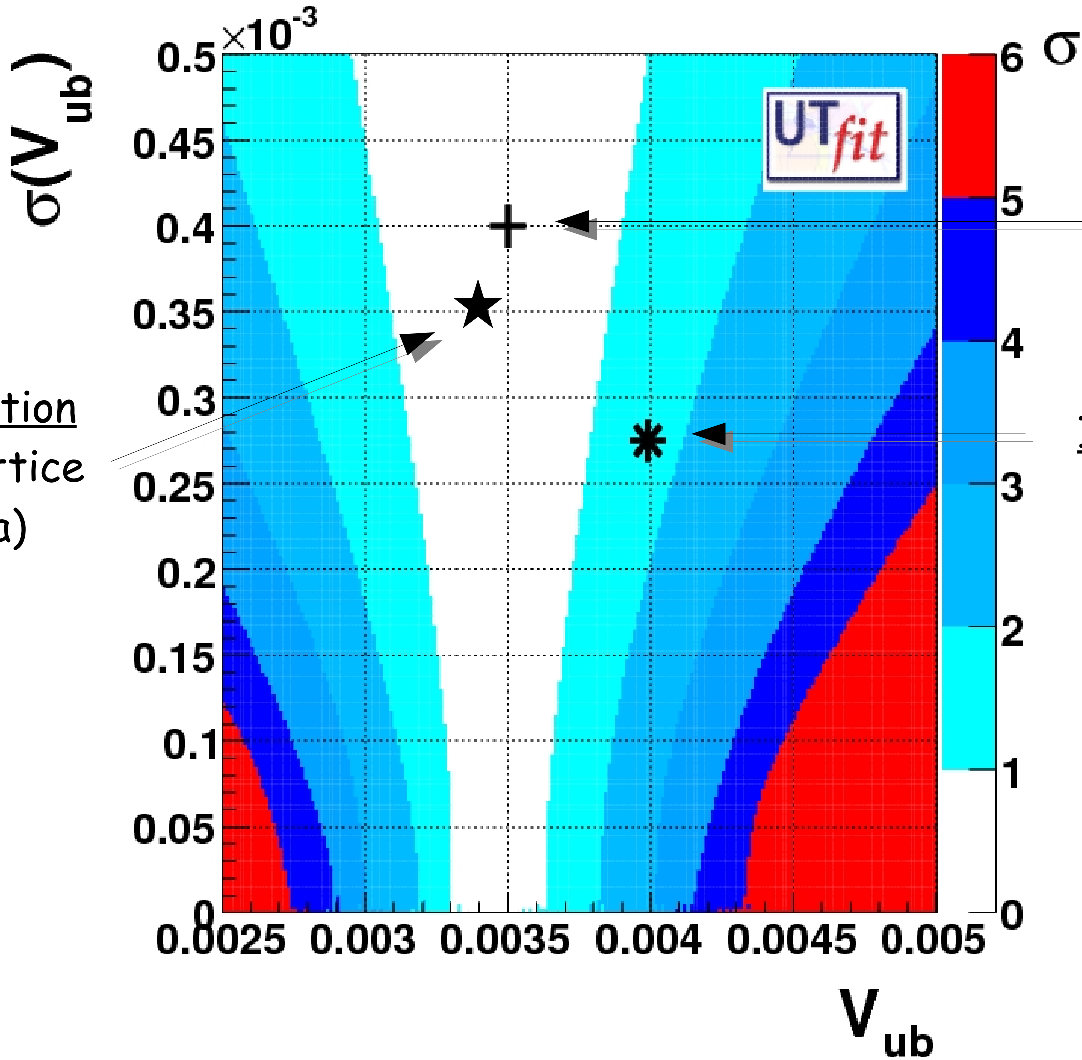
Nucl.Phys.Proc.Suppl.140:461-463,2005

J. Bailey *et al.* arXiv:0811.3640

All the theoretical calculations provide consistent $|V_{ub}|$ values;

There is large room for improvements

Compatibility with inclusive and UT fit



<u>Exclusive determination</u>
(HFAG B(B→πlν) + LQCD FF calculation)

<u>Exclusive determination</u>
(fits of improved lattice + 12 bins BaBar Data)
J. Bailey *et al.*
arXiv:0811.3640

<u>Inclusive determination</u>
$|V_{ub}| = (3.96 \pm 0.27)\ 10^{-3}$
(GGOU)

$|V_{ub}|$ indirect determination from UT fit: $(3.48 \pm 0.16)\ 10^{-3}$

$|V_{ub}|$ indirect determination from CKM fitter: $(3.50\ ^{+0.15}_{-0.14})\ 10^{-3}$

Summary

- $\mathcal{B}(B \to \pi \ell \nu)$ measurements performed with different approaches at B Factories all consistent; untagged most precise

- More data useful to constrain the q^2 form factor dependency (but untagged analysis are becoming systematically limited)

- $|V_{ub}|$ still limited by Form Factors uncertainties

- Latest fits with unquenched LQCD calculations are pushing down the total $|V_{ub}|$ uncertainty to ~ 11%

- Exclusive determinations are in good agreement with UT fit

ADDITIONAL SLIDES

FF q^2 parametrizations

Extrapolation to full q^2 range provided by different parametrizations:

Dominant pole shape:

$$f_+(q^2)|_{BK} = \frac{c_B(1-\alpha)}{(1-q^2/M_{B^*}^2)(1-\alpha q^2/M_{B^*}^2)} \quad [1]$$

$$f_+(q^2)|_{BZ} = \frac{r_1}{1-q^2/M_{B^*}^2} + \frac{r_2}{1-\alpha q^2/M_{B^*}^2} \quad [2]$$

$r_1,\ r_2,\ \alpha$ fitted from data

Series parametrization

$$f(t) = \frac{1}{P(t)\phi(t,t_0)} \sum_{k=0}^{\infty} a_k(t_0) z(t,t_0)^k \quad [3]$$

$$t = q^2 \qquad z(t,t_0) = \frac{\sqrt{t_+ - t} - \sqrt{t_+ - t_0}}{\sqrt{t_+ - t} + \sqrt{t_+ - t_0}}$$

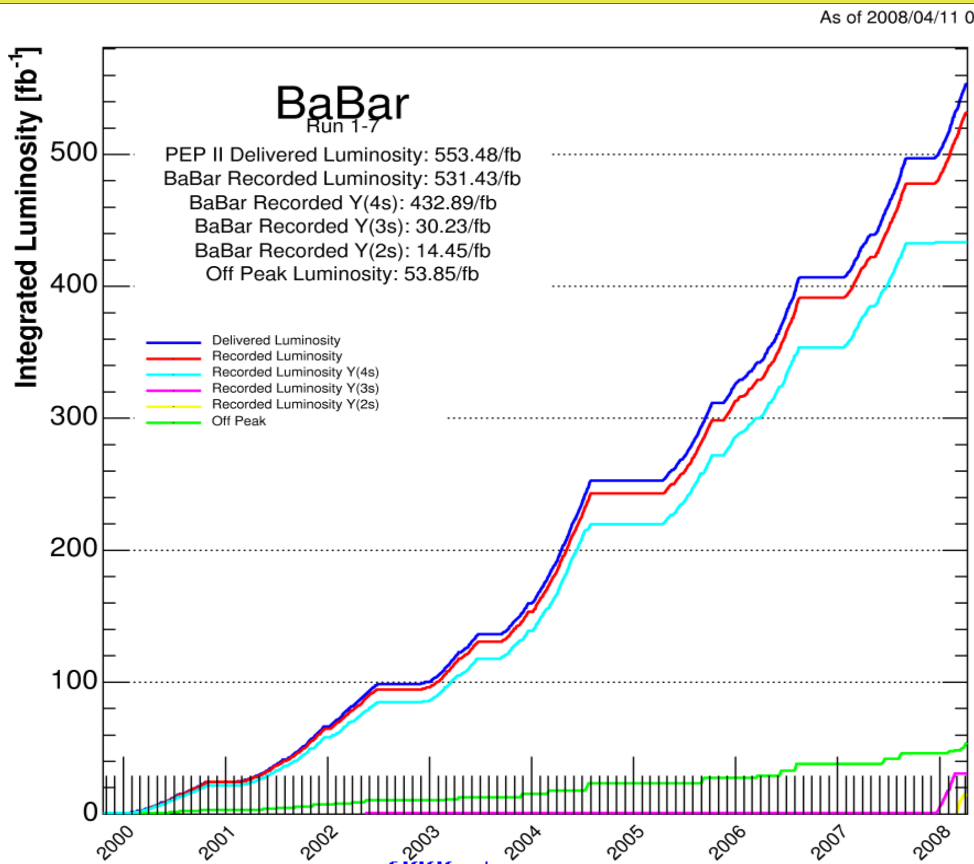
$$t_\pm = (m_B \pm m_\pi)^2$$

[1] D. Becirevic and A. B. Kaidalov, Phys. Lett B 478, 417 (2000)

[2] P. Ball and R. Zwicky, Phys. Rev. D 71, 013015 (2005)

[3] C. Glenn Boyd, B. Grinstein and R.F. Lebed, Phys. Lett. B 353, 306 (1995) also R. Hill, Phys. Rev. D 73, 014012 (2006)

B-Factories: Luminosities



~ 531 fb^{-1} BaBar @ PEP II

~ 895 fb^{-1} Belle @ KEKB