Exclusive Charmless Semileptonic Decays and $|V_{ub}|$

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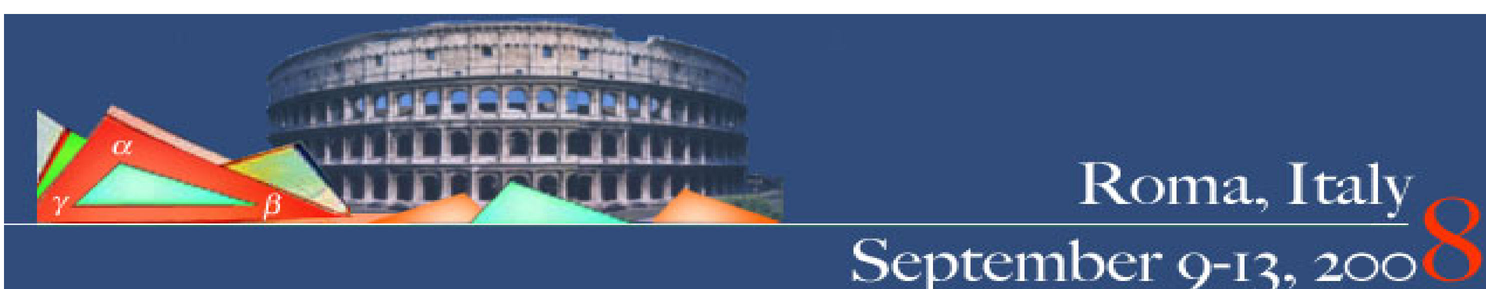
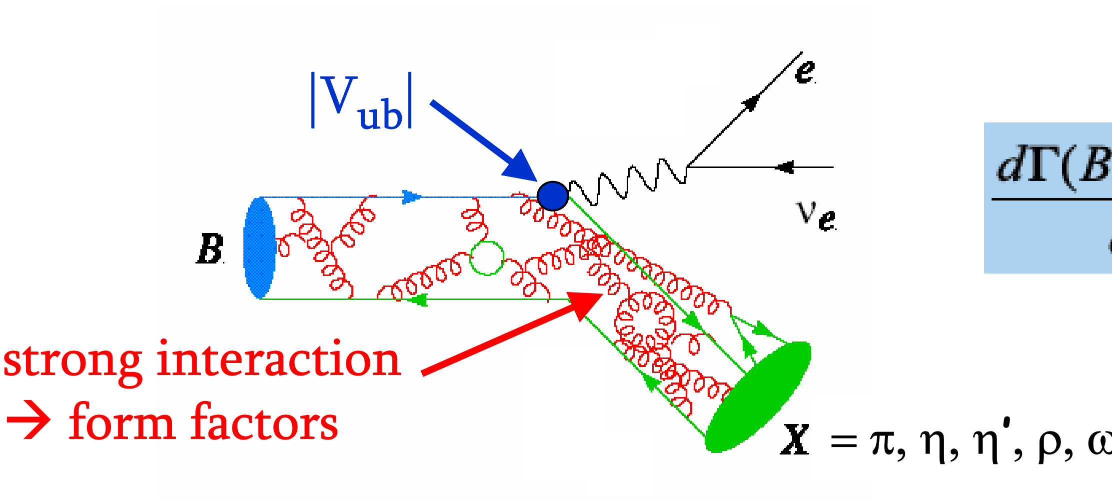


Charmless semileptonic decays



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

- Different experimental techniques: Tagging of second B

	π^+	π^0	η	η'	ρ^+	ρ^0	ω
Had. tag	✓	✓	✓	limit	✓	✓	✓
Sl. tag	✓	✓	✓	limit	✓	✓	
Untagged	✓	✓	✓	✓	✓	✓	✓

✓ New result (2008)

Currently most precise

$B \to \pi \ell \nu$

Let's start with the easiest (experimentally and theoretically) ...

	π^+	π^0	η	η'	ρ^+	ρ^0	ω
Had. tag	✓	✓	✓	limit	✓	✓	✓
Sl. tag	✓	✓	✓	limit	✓	✓	
Untagged	✓	✓	✓	✓	✓	✓	✓

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

- Reconstruct neutrino from full event:

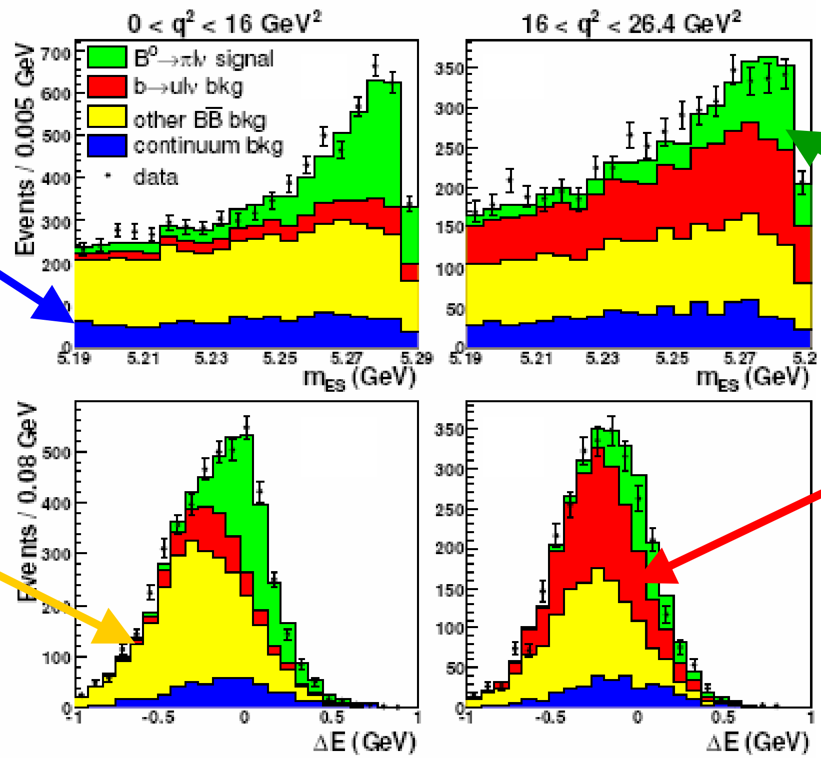
$$(\vec{p}_{\text{miss}}, E_{\text{miss}}) = (\vec{p}_{\text{beams}}, E_{\text{beams}}) - (\sum_i \vec{p}_i\,, \sum_i E_i)$$

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

$$\Delta E = E_B^* - \sqrt{s}/2 \qquad m_{ES} = \sqrt{s/4 - |\vec{p}_B^{\,*}|^2} \qquad q^2 = (p_B - p_\pi)^2 = (p_\ell + p_\nu)^2$$

PRL 98, 091801 (2007)

206 fb^{-1}



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

Total: $N_{sig} \sim 5000$

In each q^2 bin:

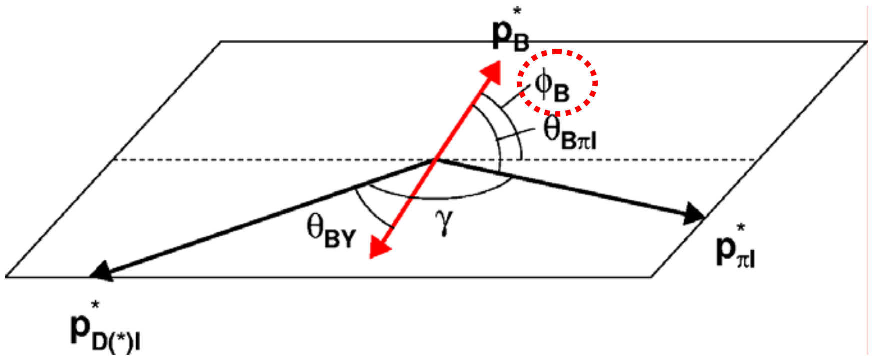
$N_{sig} \sim 400 - 500$

Semileptonic tags

- Tag one B $\rightarrow D^{(*)}\ell\nu$, look for signal decay in recoil
- Extract signal yields in unbinned fit to $\cos^2\phi_B$ in 3 q^2 bins

Decay modes:

- $B^0 \rightarrow \pi^-\ell\nu$
- $B^+ \rightarrow \pi^0\ell\nu$
- $B^+ \rightarrow \eta\ell\nu$
- $B^+ \rightarrow \eta'\ell\nu$



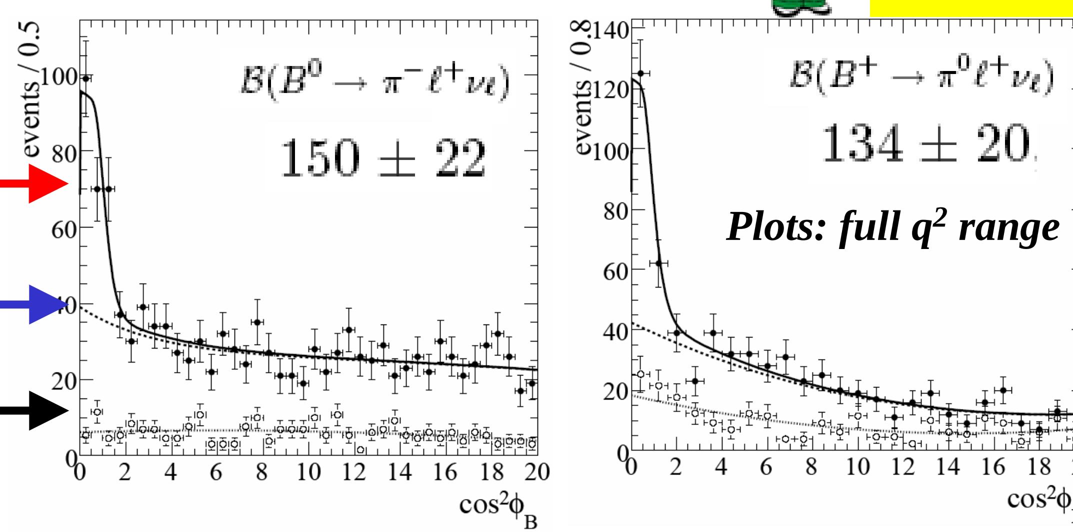
0805.2408 [hep-ex]

348 fb^{-1}

Signal

Other bkg

Combinat. bkg (D mass sidebands)



Hadronic tags

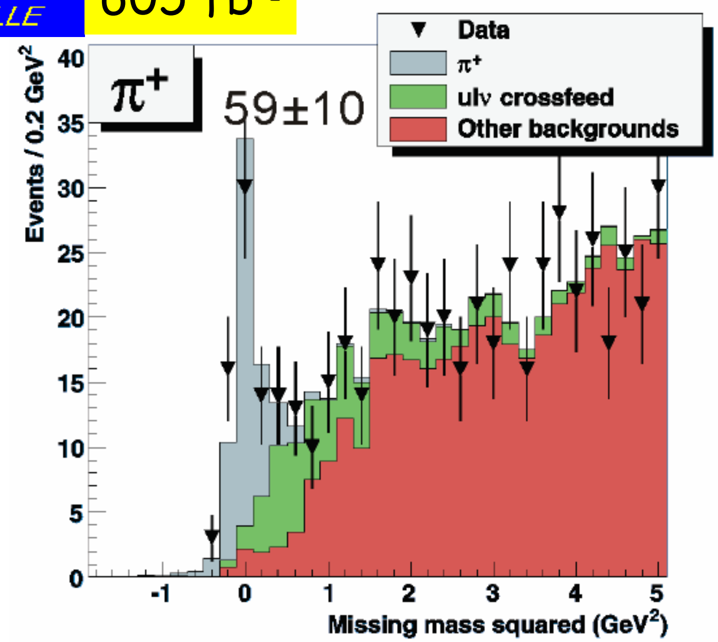
- Tag one B in hadronic decay
- Know kinematics and flavor of signal B
- Extract signal yields from $M^2_{miss} \approx M^2_{\nu}$ distribution in 3 q^2 bins

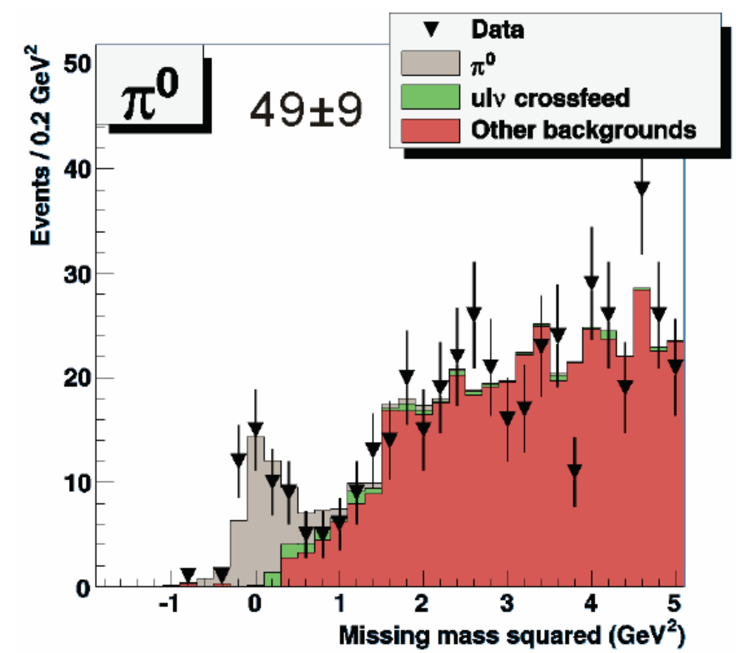
Decay modes:

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

Presented at ICHEP08

605 fb^{-1}

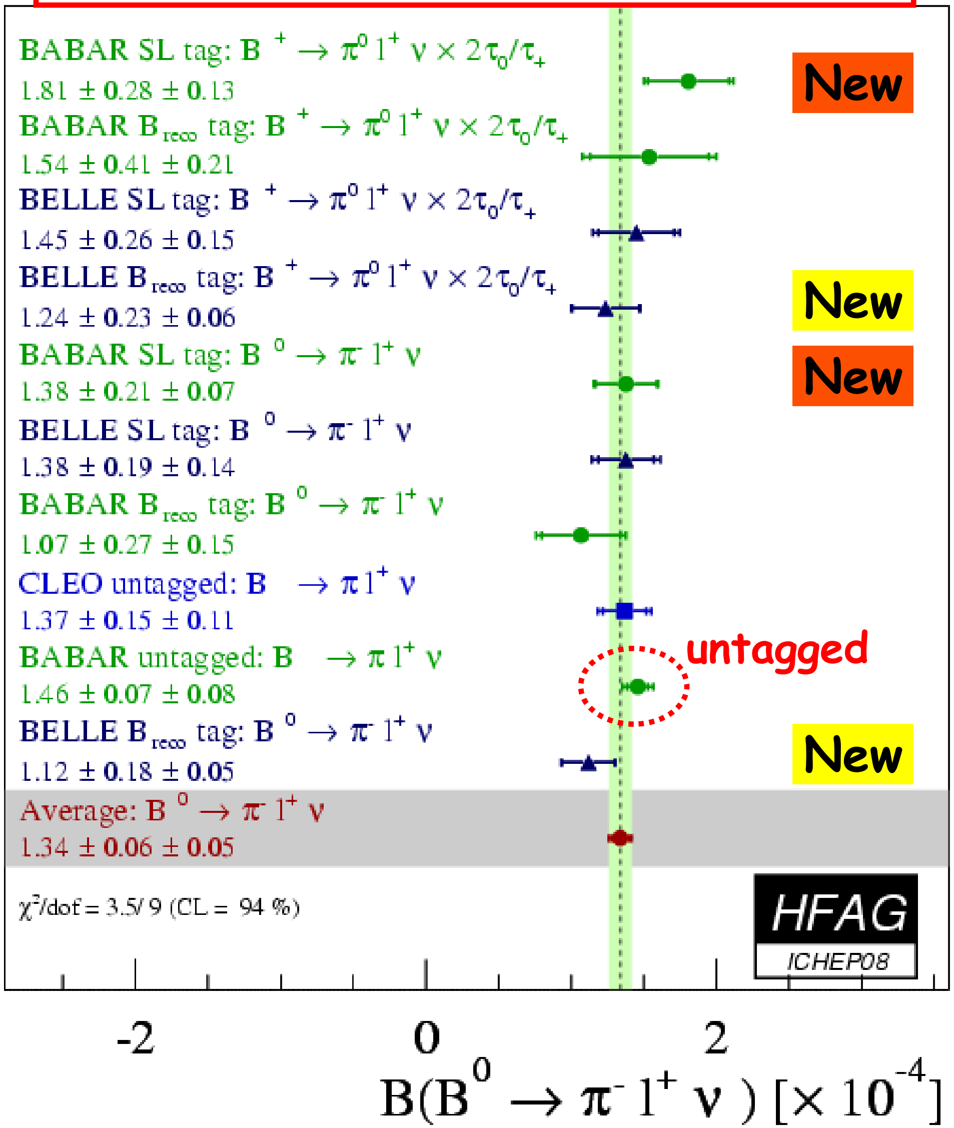




$B \to \pi \ell \nu$ total branching fraction

stat: 5% syst: 4%

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



Belle had. tag (preliminary) New

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

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

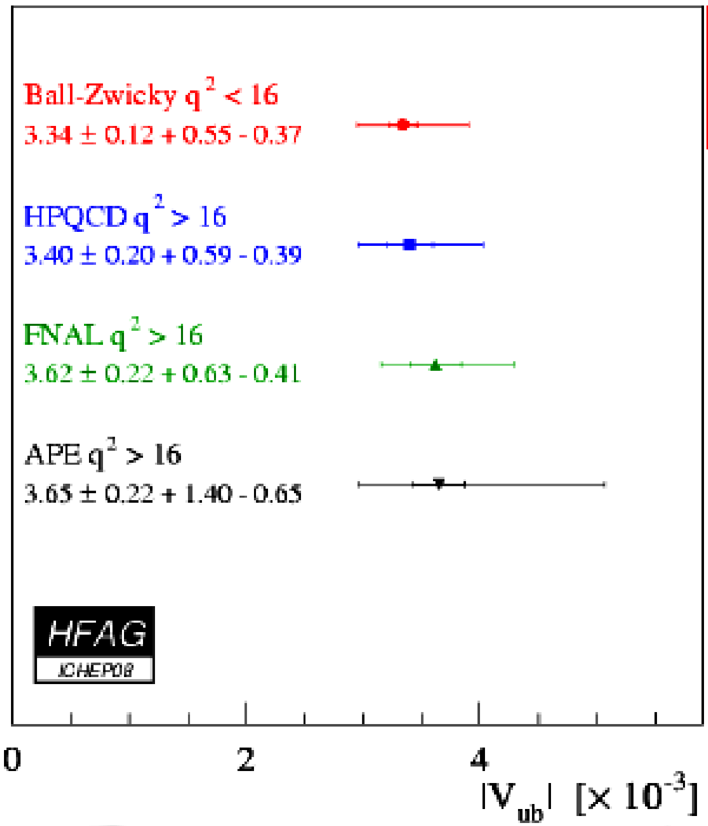
Babar sl. tag New

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

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

Untagged measurement still dominates the average (σ_{stat} <~ σ_{syst} = 5%)

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



Light-Cone Sum Rules (LCSR)
P. Ball, R. Zwicky
Phys. Rev. D71:014015 (2005)

Consistent with new LCSR result:
Duplancic, Khodjamirian, Mannel, Melic, Offen, 0801.1796 [hep-ph]

Unquenched Lattice QCD
E. Gulez et al. Phys.Rev.D73, 074502 (2006), Erratum-ibid.D75:119906,2007

Unquenched Lattice QCD
Okamoto et al., Nucl. Phys. Proc. Suppl.140:461-463, 2005

Quenched Lattice QCD
A. Abada et al. Nucl. Phys. B 619 (2000) 565-587

Theory lags behind experiments
$\delta|V_{ub}|/|V_{ub}|^{\,exp} \sim 5\%$
$\delta|V_{ub}|/|V_{ub}|^{\,f_+(0)} \sim {}^{+17\%}_{-11\%}$ (e.g HPQCD & FNAL)

- LCSR, unquenched and quenched LQCD give consistent results !
- Experimental q^2 data are used to improve form factors (several methods)

q^2 dependence & form factors

- Several FF parametrizations to extrapolate LCSR and LQCD to all q^2:

$$f_+(q^2)\big|_{\rm BK} = \frac{c_B(1-\alpha)}{(1-q^2/m^2_{B^*})(1-\alpha\, q^2/m^2_{B^*})}$$

Becirevic-Kaidalov (BK)

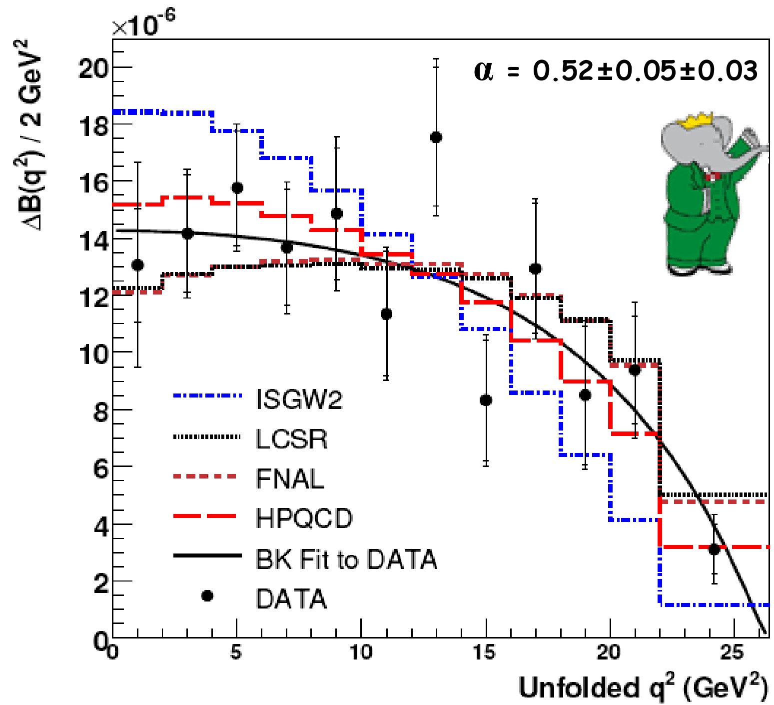
$$f_+(q^2)\big|_{\rm BZ} = \frac{r_1}{1-q^2/m^2_{B^*}} + \frac{r_2}{1-\alpha\, q^2/m^2_{B^*}}$$

Ball-Zwicky (BZ)

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

Boyd/Grinstein/Lebed + Hill/Becher (BGL)

- Measure FF shape with data:
  - All 3 ansätze give good fits to data
  - Exp. data can at present only constrain one shape parameter

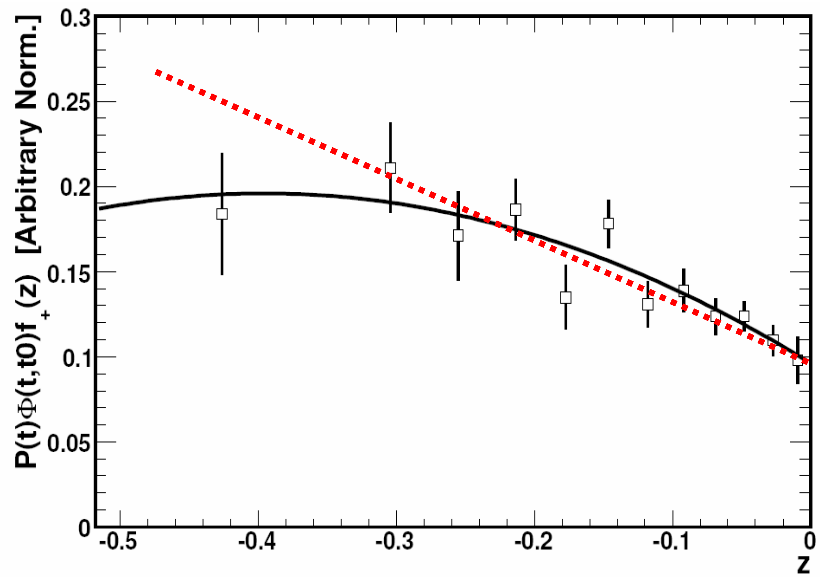


The z-expansion fit

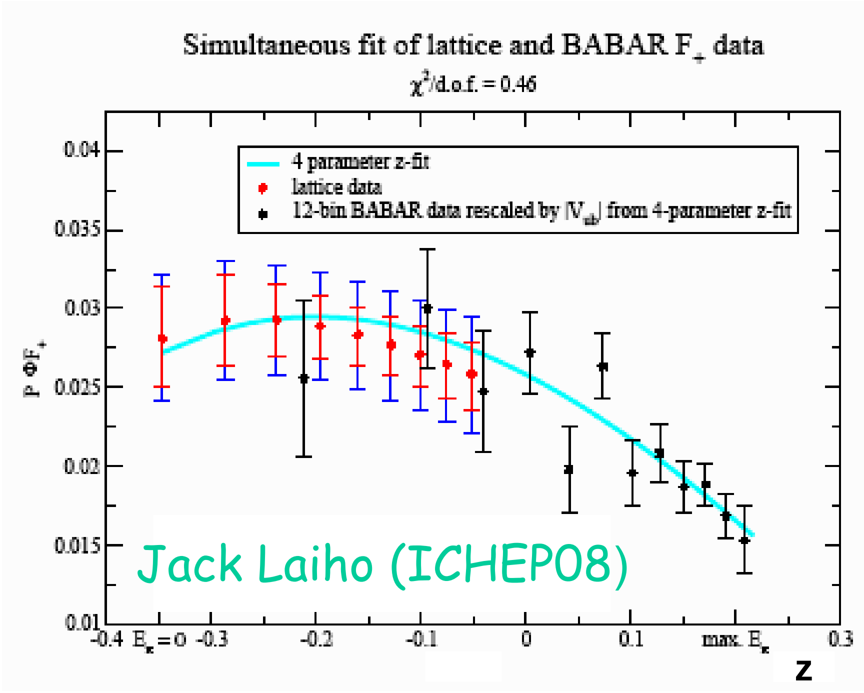
$$f(t) = \frac{1}{P(t)\phi(t,t_0)} \sum_{k=0}^{\infty} a_k(t_0) z(t,t_0)^k$$

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

$$t = q^2,\ t_+ = (m_B + m_\pi)^2,\ t_- = (m_B - m_\pi)^2$$



BaBar 12-bin data
linear or quadratic or … ?



LQCD prefers quadratic fit

→ Need more precise experimental data (esp. at high q^2 … difficult!)

The other pseudoscalars: η, η'

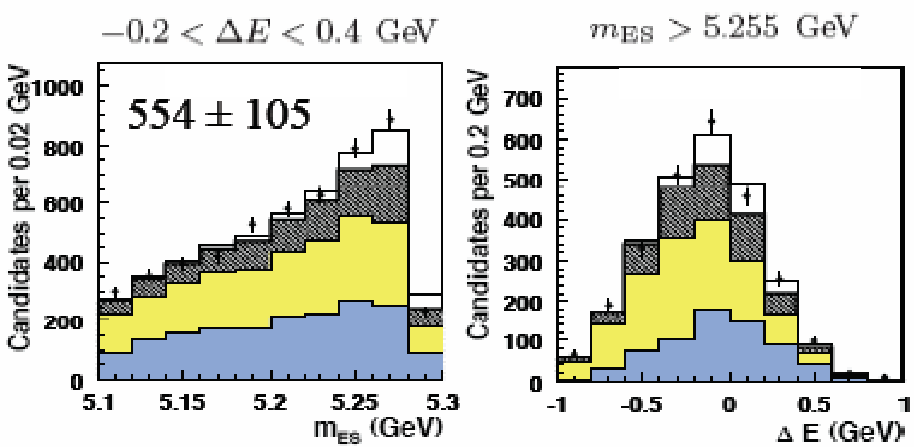
Why study higher-mass states?

- *Help to further constrain theoretical calculations*
- *Cross-check $|V_{ub}|$*
- *Measure composition of $B \to X_u \ell \nu$*

	π^+	π^0	η	η'	ρ^+	ρ^0	ω
Had. tag	✓	✓	✓	limit	✓	✓	✓
Sl. tag	✓	✓	✓	limit	✓	✓	
Untagged	✓	✓	✓	✓	✓	✓	✓

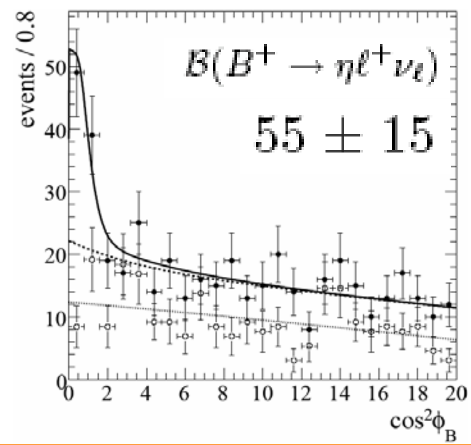
$B \to \{\eta,\eta'\}\ell\nu$

BABAR untagged — 0808.3524 [hep-ex] — 347 fb^{-1}



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

BABAR sl. tag — 0805.2408 [hep-ex] — 348 fb^{-1}



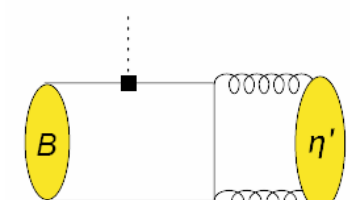
$$\mathcal{B}(B^+ \to \eta\ell^+\nu) = (0.64 \pm 0.20 \pm 0.03) \times 10^{-4}$$

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

- 2.6 σ disagreement with CLEO's $\mathcal{B}(B^+ \to \eta'\ell^+\nu) = (2.66 \pm 0.80 \pm 0.56) \times 10^{-4}$
- Gluonic singlet contribution to $B \to \eta^{(\prime)}$ FF (η: 3%, η′: 20%)

  → Constrain by measuring $R_{\eta'\eta} = \mathcal{B}(B \to \eta'\ell\nu) / \mathcal{B}(B \to \eta\ell\nu)$

  Ball, Jones, JHEP 0708, 025 (2007)



→ Need simultaneous η, η′ analysis (untagged)

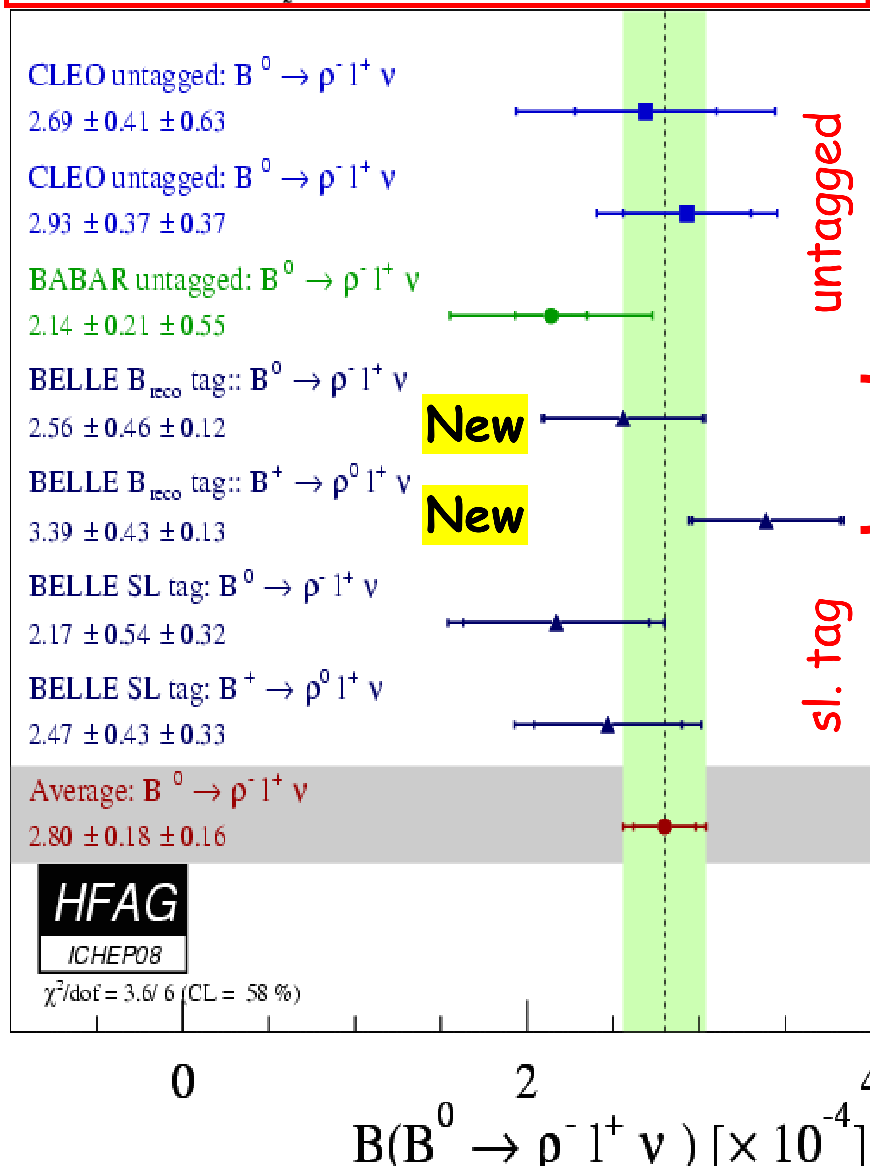
The vector mesons

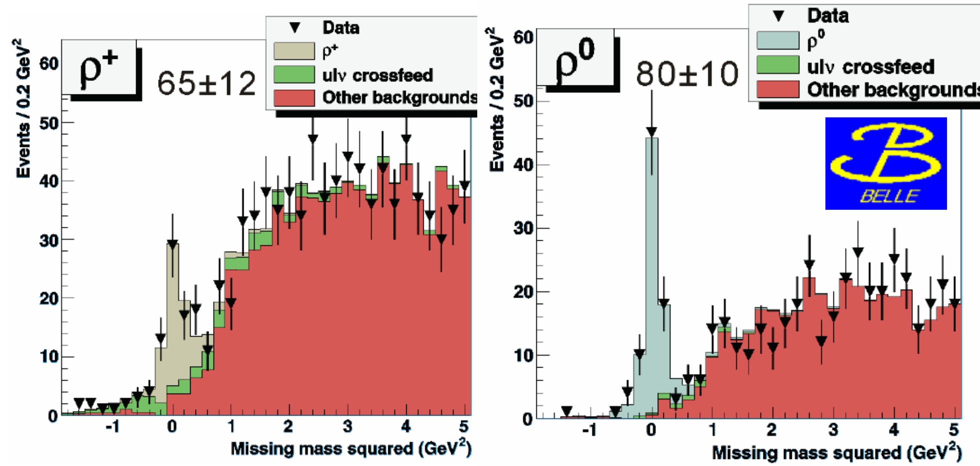
	π^+	π^0	η	η'	ρ^+	ρ^0	ω
Had. tag	✓	✓	✓	limit	✓	✓	✓
Sl. tag	✓	✓	✓	limit	✓	✓	
Untagged	✓	✓	✓	✓	✓	✓	✓

$B \to \rho \ell \nu$

stat: 6%   syst: 6%

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





Very clean had.-tag measurements

Biggest problems for untagged $\rho \ell \nu$:

- Need kinematic cuts (e.g. p_ℓ) to suppress large bkg
  → model dependence
- $B \to X_u \ell \nu$ bkg. very similar to signal
  → large syst. error

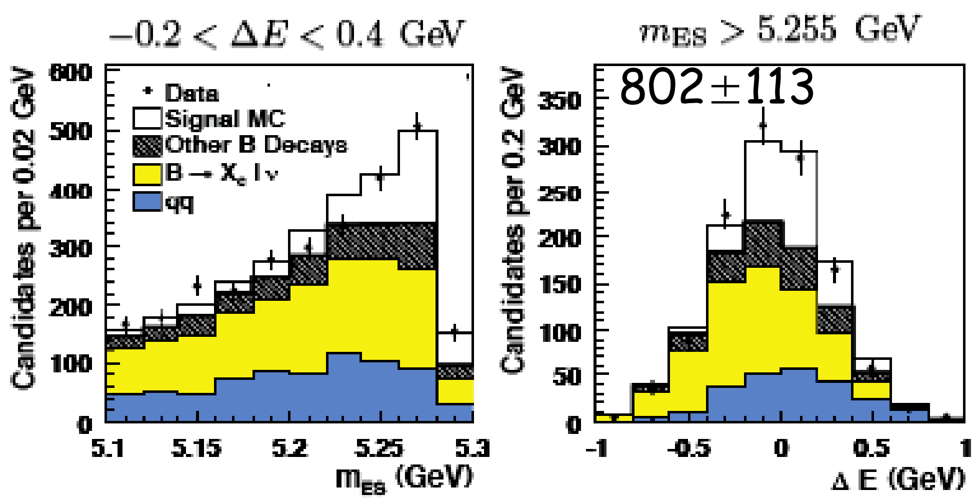
$B \to \omega \ell \nu$

- Narrower resonance,
  <u>but:</u> $\omega \to \pi^+\pi^-\pi^0$ 3-body decay → more combinatorial bkg.

- BaBar untagged: (not q^2 dependent)

0808.3524 [hep-ex]

347 fb^{-1}



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

- Belle had. tag (prelim.):

Presented at ICHEP08

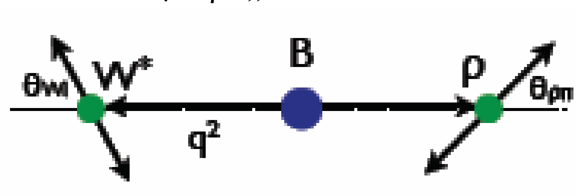
605 fb^{-1}

$$\mathcal{B}(B^+ \to \omega \ell^+ \nu_\ell) = (1.19 \pm 0.32 \pm 0.05) \times 10^{-4}$$

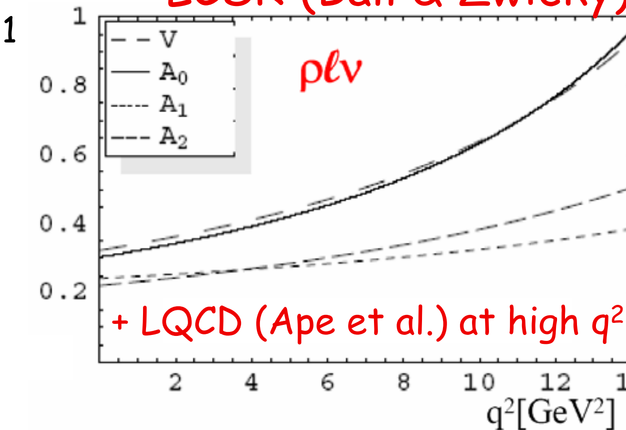
$B \to \rho/\omega$ form factors

- Three q^2-dependent form factors, e.g. V, A_0, A_1
- Goal: Measure in bins of 4 kinematic variables

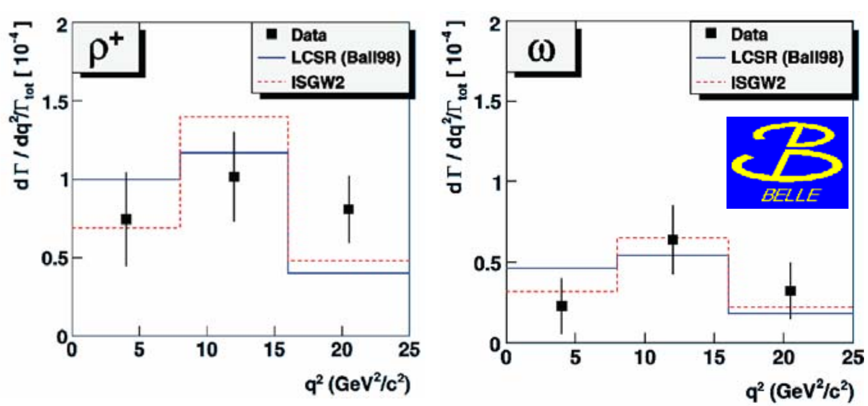
q^2, $\theta_{W\ell}$, $\theta_{\rho\pi}$, χ (angle between decay planes)



LCSR (Ball & Zwicky).



- How can we simplify fit to full 4-dim decay rate?
  - Integrate over some angles?
  - introduce FF ratios (as for $D^*\ell\nu$) ?
- How do we extrapolate to all q^2?



- Measurements still too imprecise to validate FF calculations vs q^2
- For full 4-dim fit, need improved high-statistics (untagged) analysis with > 10 000 signal events

Conclusions & Prospects for ~ 1 ab^{-1}

- For $B \to \pi\ell\nu$, untagged approach will remain the most precise.
  Had.-tag analyses need ~ 5 ab^{-1} to reach comparable precision.

Extrapolations of $B^0 \to \pi^+\ell\nu$ measurements: Today → 1ab^{-1}

	N_{signal}	$\sigma_{BF,stat}$(%)	$\sigma_{BF,syst}$(%)	$\sigma_{BF,exp}$(%)	$\sigma_{Vub,\,exp}$(%)
Had. tag	59 → 100	16 → 12	4 → 3	17 → 12	9 → 6
Sl. tag	150→ 430	15 → 9	5 → 4	16 → 10	8 → 5
Untagged	5k → 25k	5 → 2	5 → 5	7 → 5	3.5 → 2.5

- Caveat: Untagged analyses are starting to be syst. limited.
  For large fraction of the bkg, ℓ and h come from different B's
  → measurement depends on description of inclusive B decays

Conclusions & Prospects for ~ 1 ab^{-1}

- Possible improvements:
  - Better track, photon recontruction (ν reco!)
  - Better knowledge of $B \rightarrow X_u \ell \nu$ res. and non-res. BF's, FF's
  - Constrain combinatorial bkg from wrong-sign samples (π+, ρ+) or M_{had} sidebands (η, η', ω)

- For higher-mass states, esp. ρ, tagged methods will (soon) give the most precise BF measurements

- Form factors:
  - tagged methods won't yield enough events for competitive FF fits
  - $B \rightarrow \pi$: discriminate between FF calculations (e.g. HPQCD and FNAL)
  - $B \rightarrow V$: Expect ~8000 ρ^{+}+ρ^{0} and ~2500 ω for 1 ab^{-1} (untagged)

    → Some information on the three FF's or ratios of FF's, but probably no full 4-dim. fit