Inclusive and Exclusive $|V_{ub}|$

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on behalf of B-Factories

Heavy Quarks and Leptons

Melbourne 5-9 June 2008

Outline

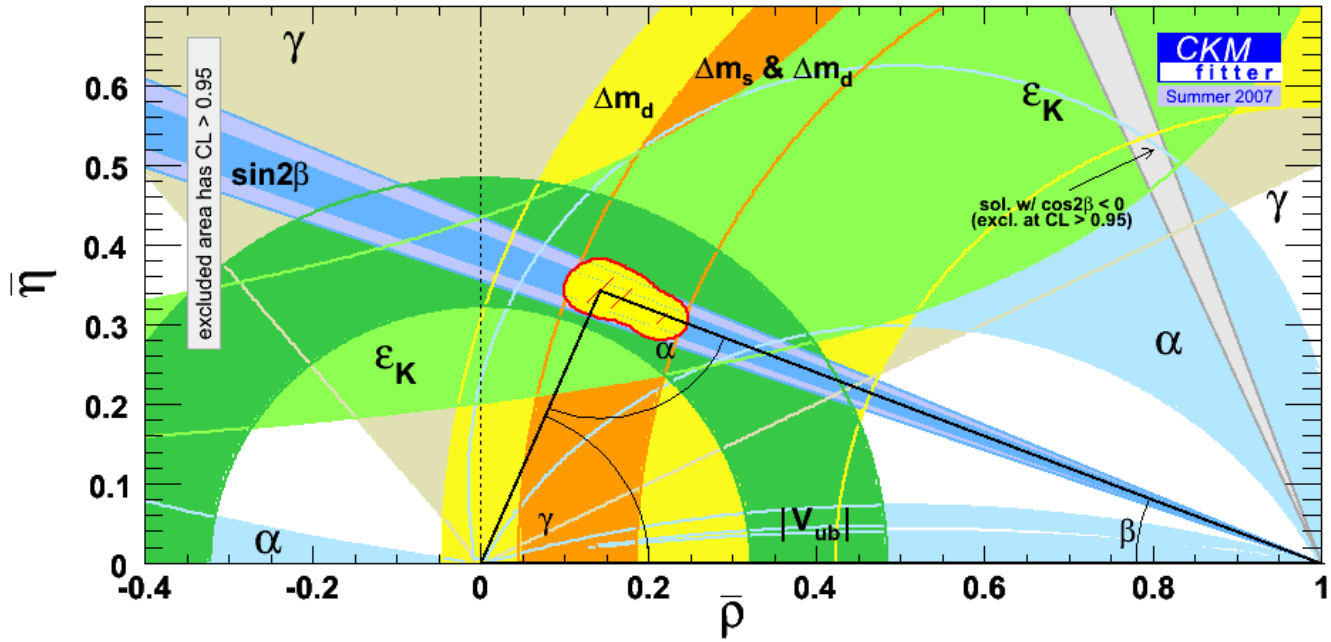
- Motivation
- Semileptonic B Decays
- Experimental techniques
- $|V_{ub}|$ from exclusive decays
  - untagged
  - Semileptonic tag ← NEW!
  - tagged
- $|V_{ub}|$ from inclusive decays
  - tagged
- Weak Annihilation
- Conclusion

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 $$\left|\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}\right| = \left|\frac{V_{ub}}{V_{cb}}\right| \frac{1}{\tan\vartheta_c}$$

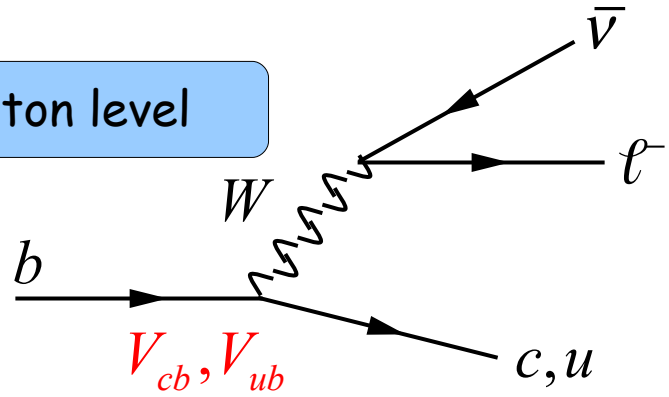
$$\frac{\delta|V_{cb}|}{|V_{cb}|} \sim 2\% \qquad \frac{\delta|V_{ub}|}{|V_{ub}|} \sim 8\%$$

→ improve V_{ub} measurements

Semileptonic B decays

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

Parton level



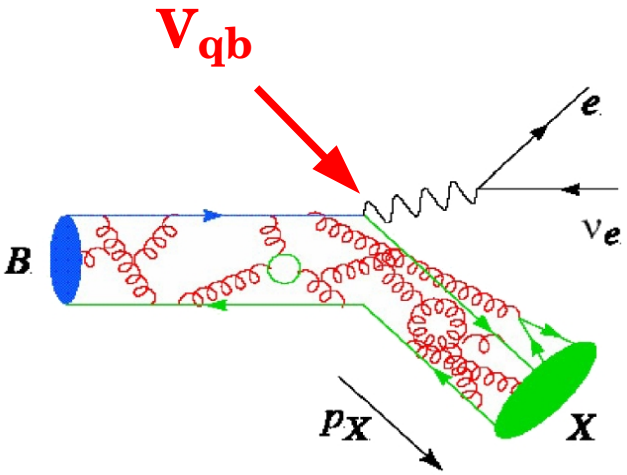
- simple description at parton level
- leptonic and hadronic current decoupled

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

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

$$\left.\begin{array}{l}\\ \\ \end{array}\right\} \frac{\Gamma_u}{\Gamma_c} \approx \frac{1}{50}$$

hadron level

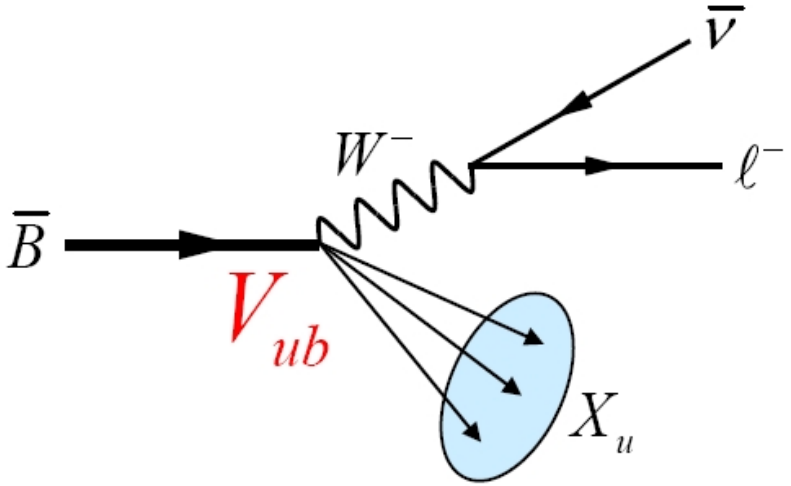


$$\Gamma_{had} = \Gamma_{quark}(1 + \ \mathrm{QCD}_{corr})$$

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

Semileptonic decays: Inclusive/Exclusive

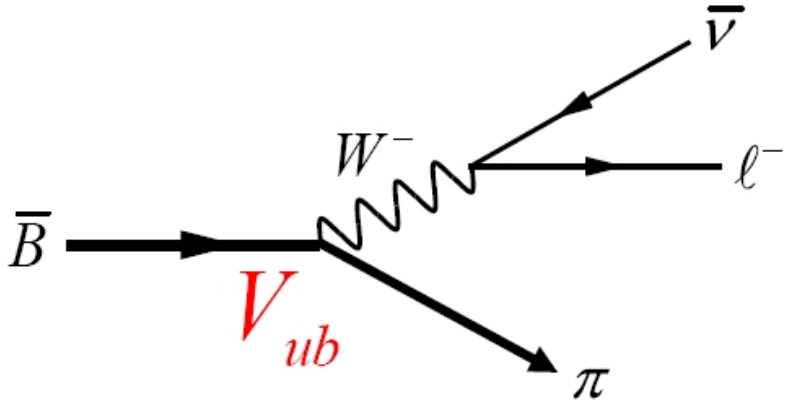
Inclusive



Select an high energy lepton and sum over all hadronic final states

- high signal efficiency
- decay rates calculated in OPE/HQE
- background $b \to c\ell\bar{\nu}$
- non perturbative correction

Exclusive



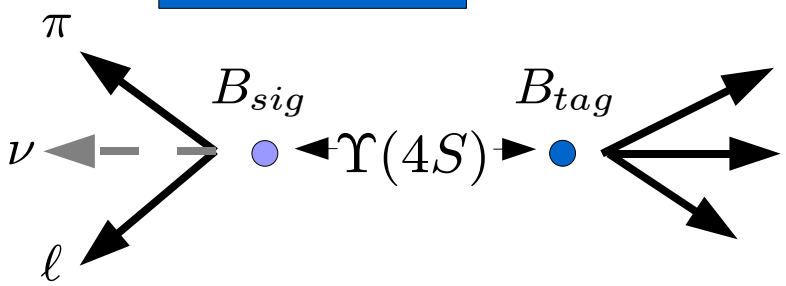
Reconstruct a charmless semileptonic decay

- lower signal efficiency
- 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

Complementary theoretical approaches

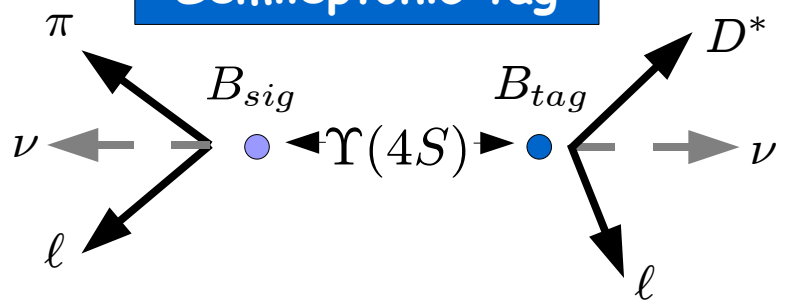
Experimental methods

Untagged



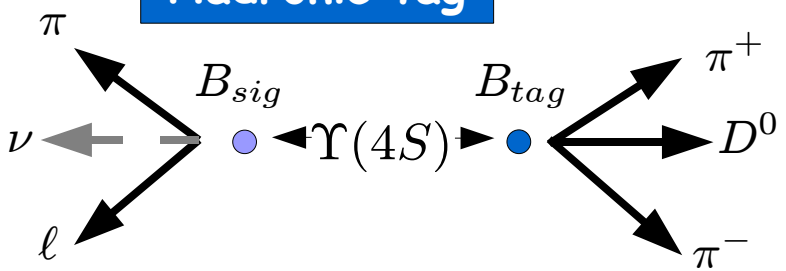
- Only signal reconstruction
- High statistics
- sensitive to background simulation

Semileptonic tag



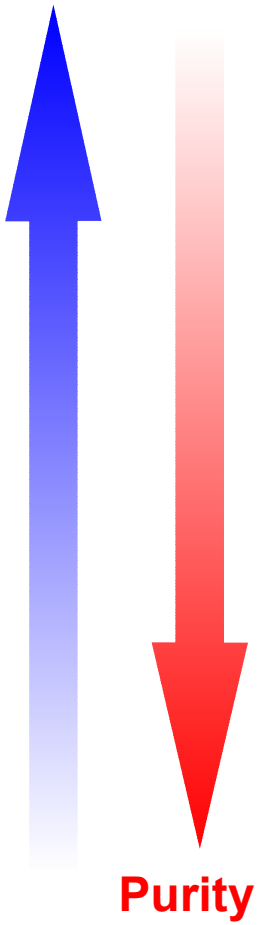
- Reconstruct $B \to D^{(*)}\ell\bar{\nu}$
- 2ν: incomplete kinematics

Hadronic tag

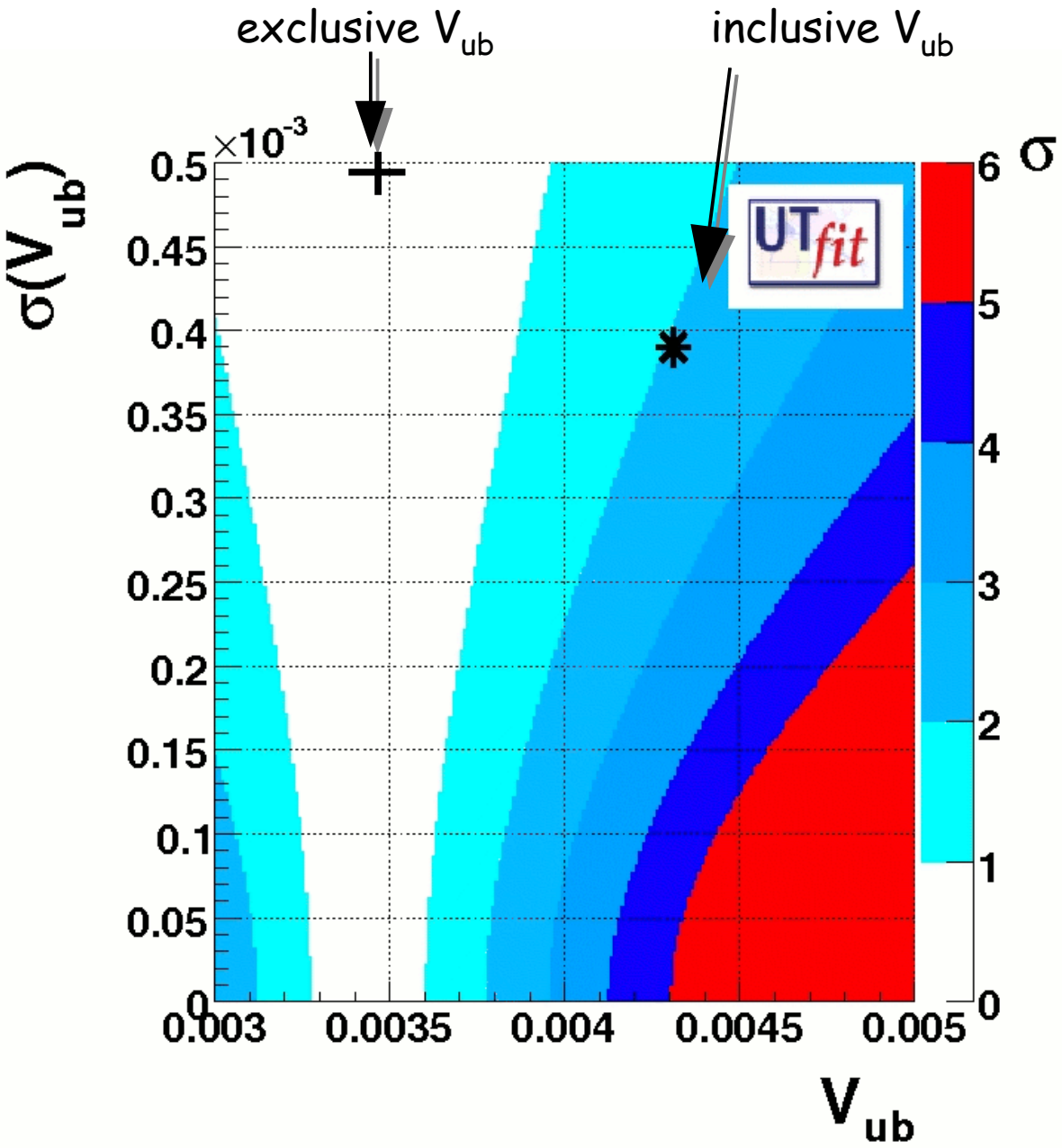


Reconstruct $B \to D^{(*)}Y$ $(Y = \pi, K)$

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



One year ago...



Tension between inclusive and exclusive measurements:

- measurements not yet mature?

- theoretical errors underestimated?

- something new?

Exclusive $|V_{ub}|$

Exclusive $|V_{ub}|$ determination

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

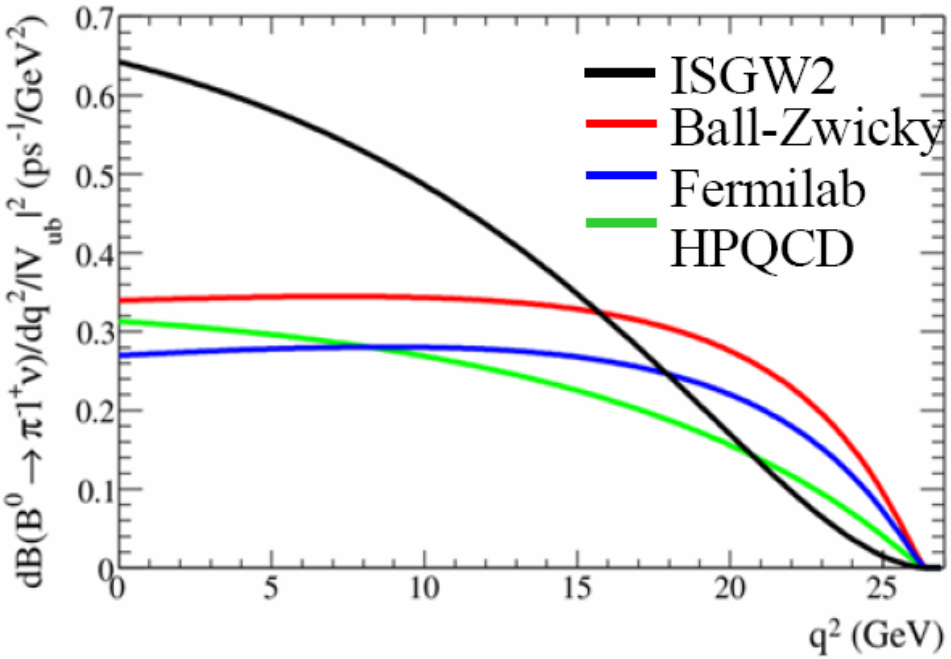
Measure a specific branching fraction in a phase space region: $\Delta\mathcal{B}(B \to \pi\ell\nu)$

Convert the branching fraction into $|V_{ub}|$

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(B \to \pi\ell\nu)}{\tau_B \cdot \Delta\zeta}}$$

Form Factors $f_+(q^2)$ to go from quark to hadron level

$$\Delta\zeta = \int_{q^2_{min}}^{q^2_{max}} |f_+(q^2)|^3 p_\pi^2 dq^2$$



different FF calculations available:

Lattice QCD [1]:
- 11% uncertainty for $q^2 > 16$ GeV^2

Light Cone Sum Rules [2]:
- 13% uncertainty for $q^2 < 16$ GeV^2

Quark Model [3]

- Measurement performed in different q^2 intervals
- Comparison between theoretical and experimental FF shapes.

$B^0 \to \pi^- \ell^+ \nu$ untagged: loose ν reconstruction

PRL 98, 091801 (2007)

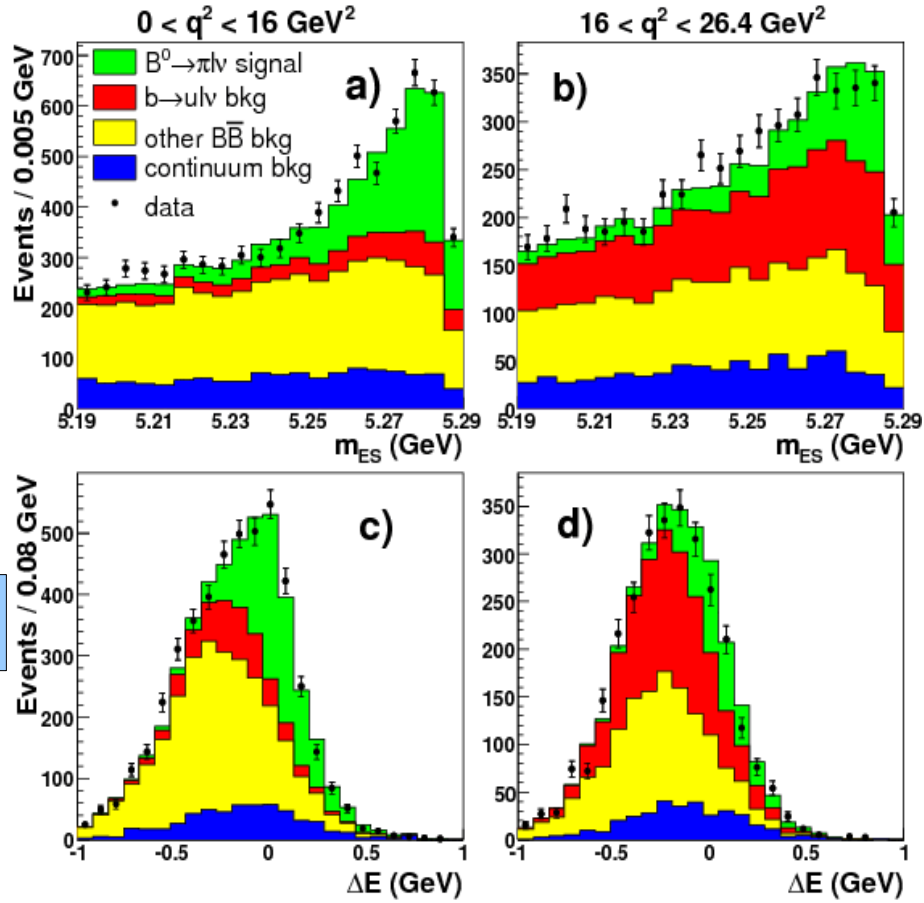
206 fb^{-1}

- No tight ν reconstruction cuts: high efficiency;
- signal extracted in 12 q^2 bins;
- binned fit to

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

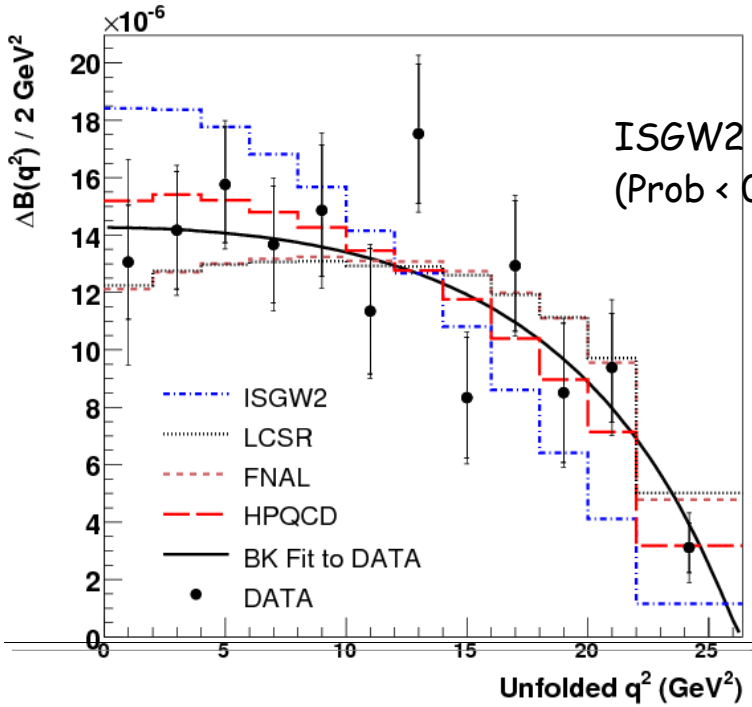
$$\Delta E = E_B - \sqrt{s}/2$$

$$q^2 = (P_B - P_\pi)^2$$



5072 ± 251 signal events over full q^2 range

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



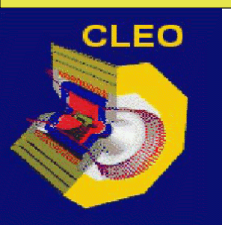
ISGW2 incompatible
(Prob < 0.06%)

$|V_{ub}|$ values ranging from $(3.2 - 4.1) \times 10^{-3}$

according to different FF calculations

$B^0 \to \pi, \rho, \eta^{(\prime)} \ell\nu$ untagged

PRL 99, 041802 (2007)



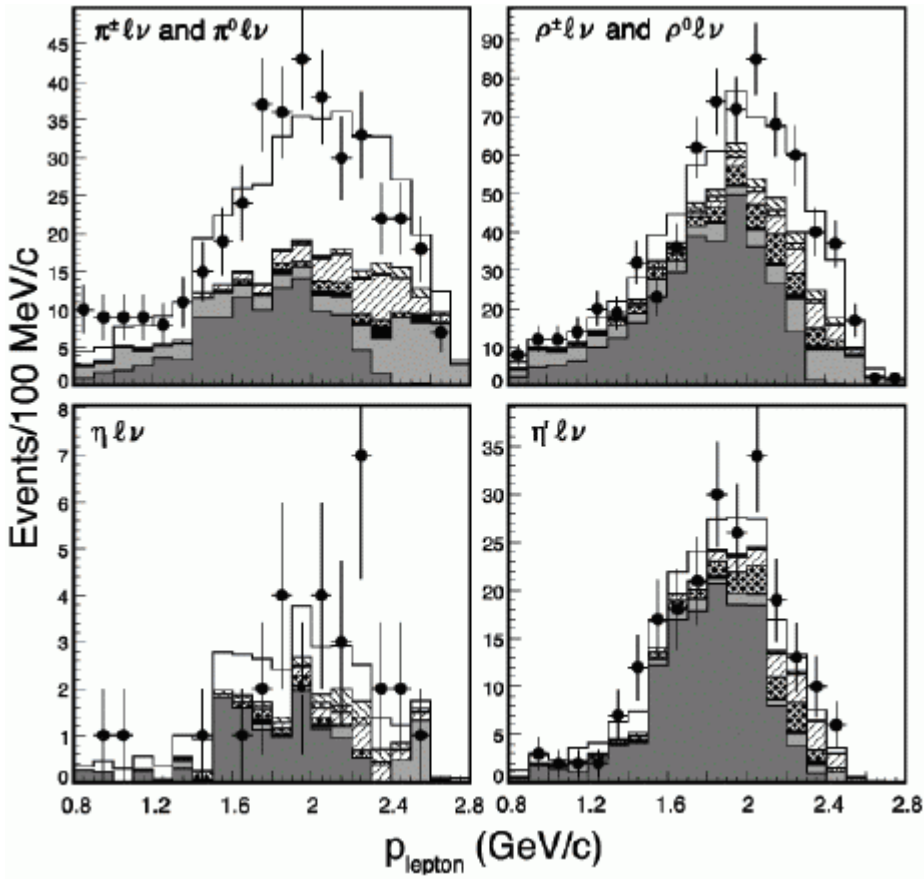
15.5 fb^{-1}

- 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 $\Delta E, m_{ES}$

	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		$\mathbf{2.66 \pm 0.80 \pm 0.56}$



- detector effects dominate systematic uncertainties

$\Delta\mathcal{B}(B^0 \to \pi^-\ell^+\nu),\ q^2 < 16\ \text{GeV}^2$ HPQCD

$|V_{ub}| = (3.6 \pm 0.4 \pm 0.2^{+0.6}_{-0.4}) \times 10^{-3}$

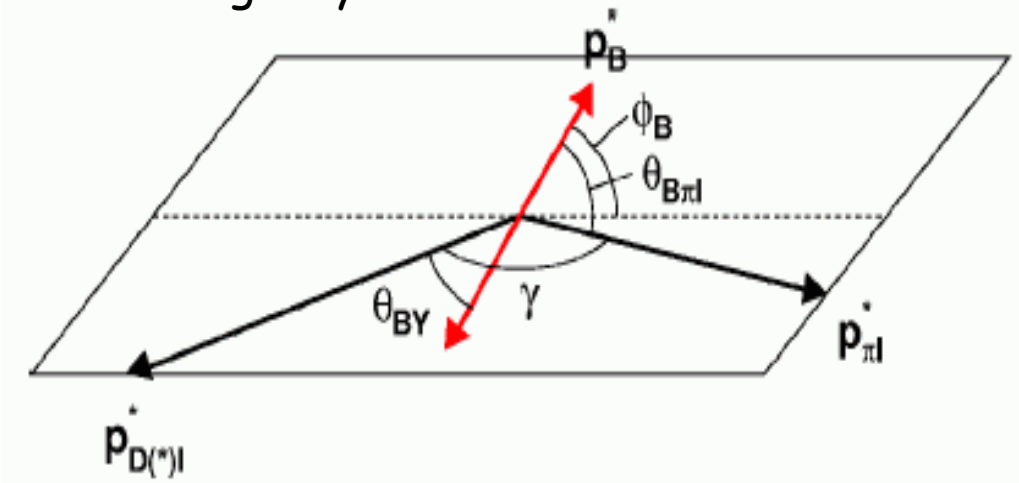
$B \to (\pi, \eta, \eta')\ell\nu$ with Semileptonic tag

arXiv:0805.2408 [hep-ex]

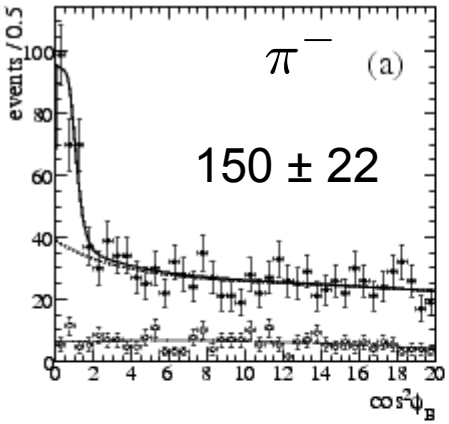
348 fb^{-1}

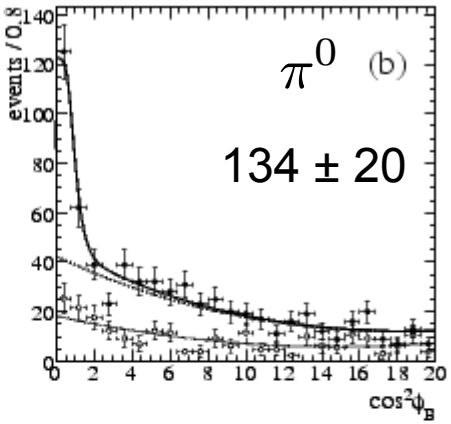
Preliminary

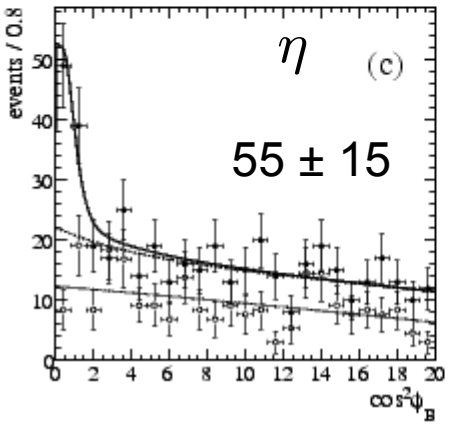
- identify a signal lepton (right charge) and
  π
  $\eta \to \gamma\gamma, \pi^+\pi^-\pi^0, \pi^0\pi^0\pi^0$
  $\eta' \to \eta\pi^+\pi^-$
- extract signal yields with unbinned maximum likelihood fit to $\cos^2\phi_B$

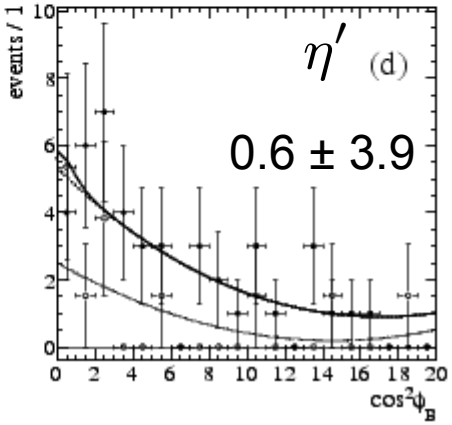


plot: full q^2 range









$\mathcal{B}(B^0 \to \pi^-\ell^+\nu) = (1.37 \pm 0.21 \pm 0.07) \times 10^{-4}$

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

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

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

30% improvement in the
π branching fraction measurement

$|V_{ub}|$ values ranging from $(3.6 - 4.1) \times 10^{-3}$ according to different FF calculations

Hadronic tag

Belle-CONF-0666

· neutrino is the only undetected particle

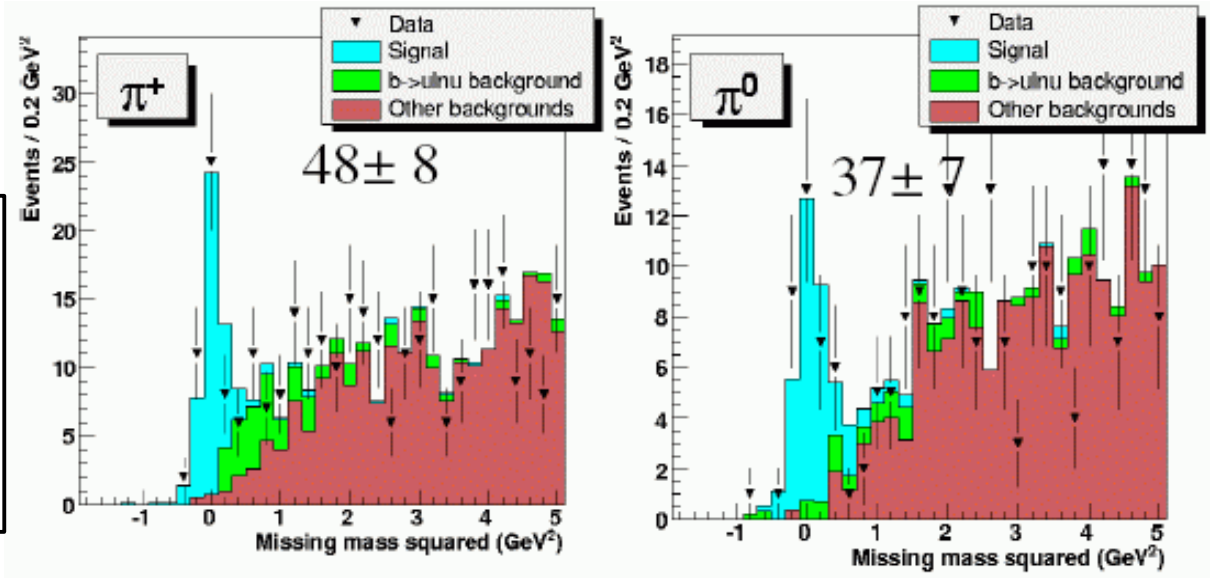
$$P^2_{miss} = (P_{\Upsilon(4S)} - P_{Breco} - P_{Xu} - P_\ell)^2 = m^2_{miss}$$ peaking at 0 for signal events

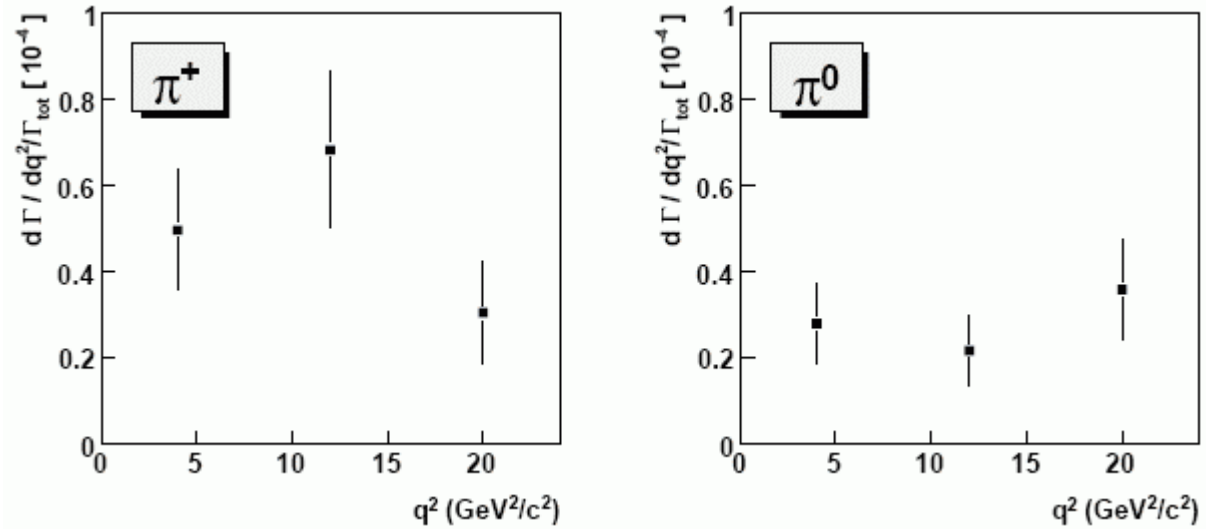
· spectrum reconstructed with fits to the m_{ES} variable for each bin of m^2_{miss}

497 fb^{-1}

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

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



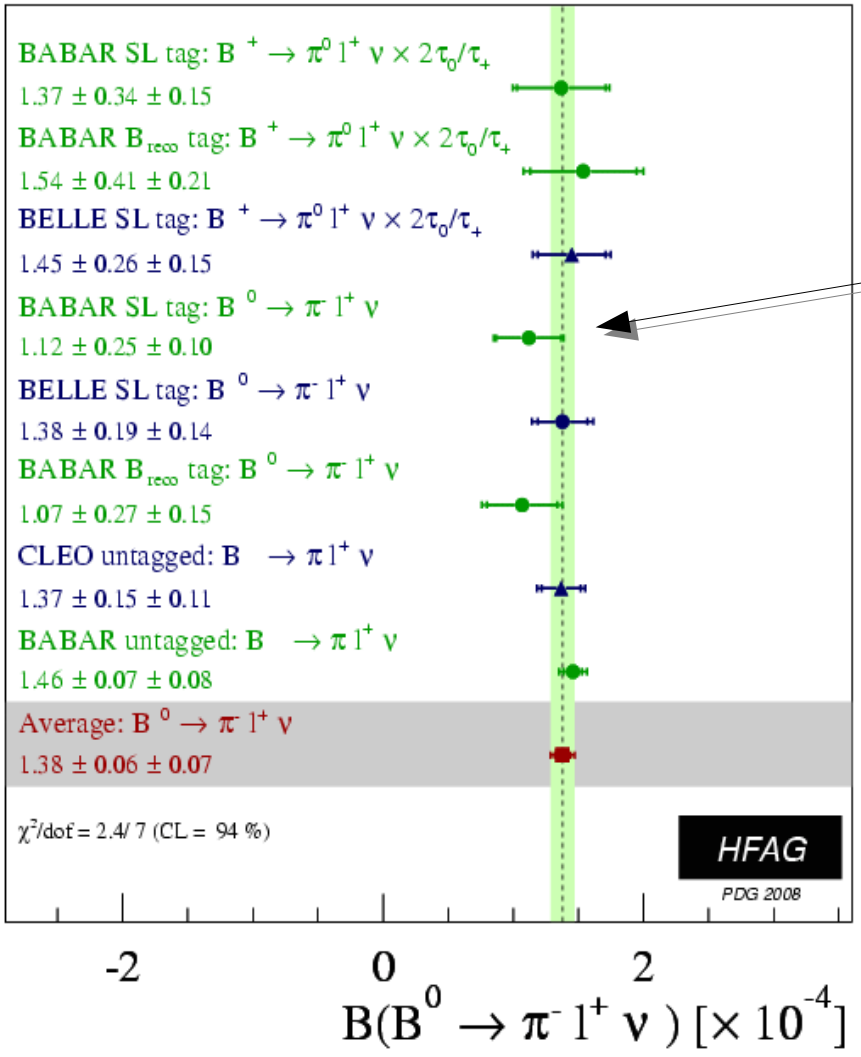


not useful to constrain FF shape

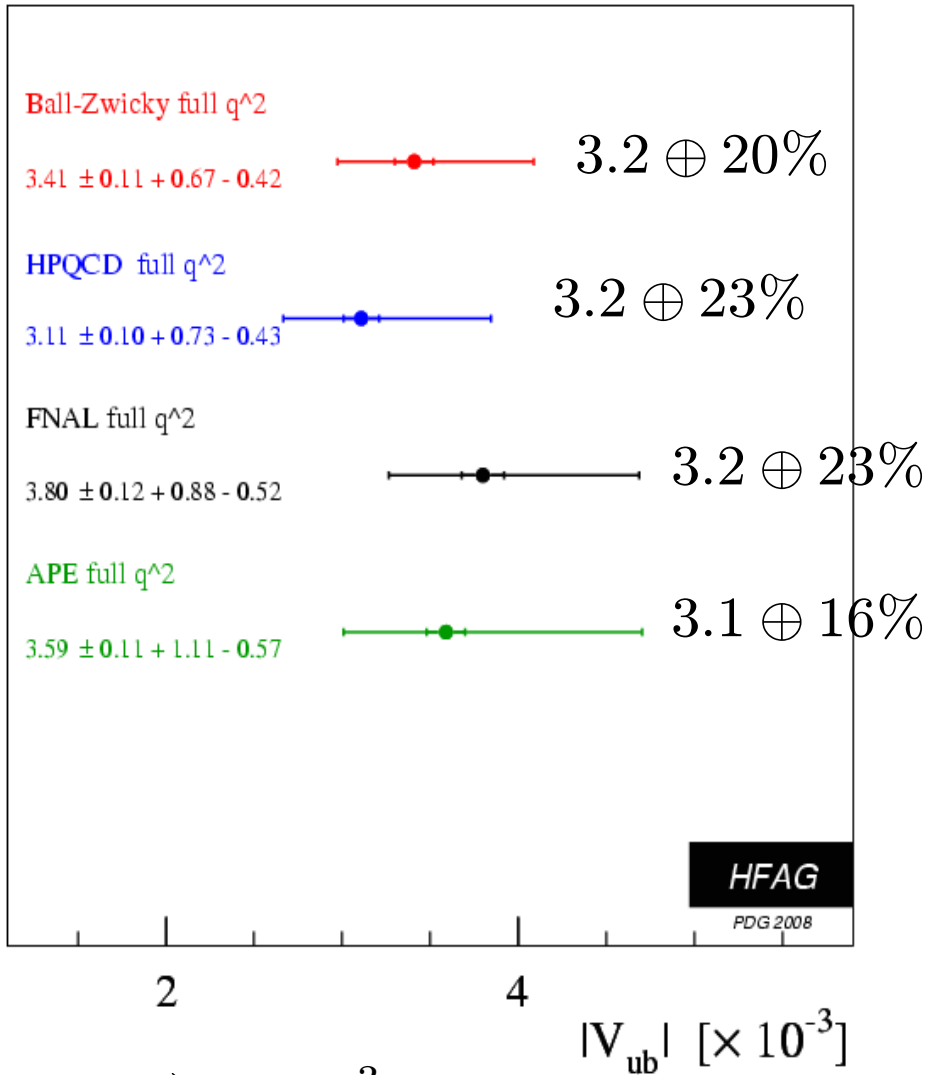
BaBar results:
211 fb^{-1}

PRD73: 012006 (2006)

Exclusive $|V_{ub}|$ summary



not including BaBar latest measurement



$$|V_{ub}| \in (3.11, 3.80) \times 10^{-3}$$

$$|V_{ub}|_{UTfit} = (3.44 \pm 0.16) \times 10^{-3}$$

$|V_{ub}|$ error dominated by Form Factors knowledge

Inclusive $|V_{ub}|$

$|V_{ub}|$ Inclusive

$$\Gamma(\bar{B} \to X_u \ell \bar{\nu}) = \underbrace{\frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3}}_{\text{free quark decay}} \left[1 + \underbrace{\mathcal{O}(\alpha_s)}_{\text{perturbative correction}} + \underbrace{\mathcal{O}(1/m_b^2)}_{\text{non perturbative correction}} + H.C. \right]$$

O.P.E.
~5% uncertainty

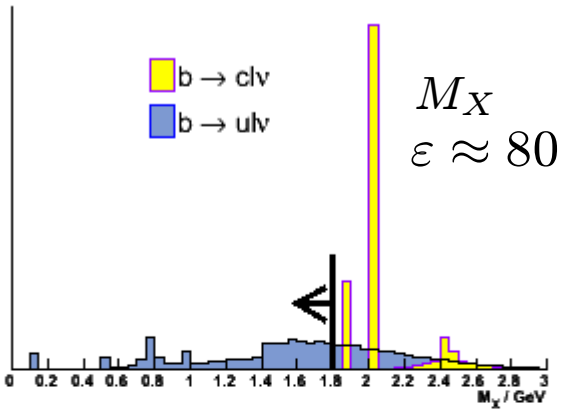
$$\frac{\Gamma_u}{\Gamma_c} \approx \frac{1}{50}$$

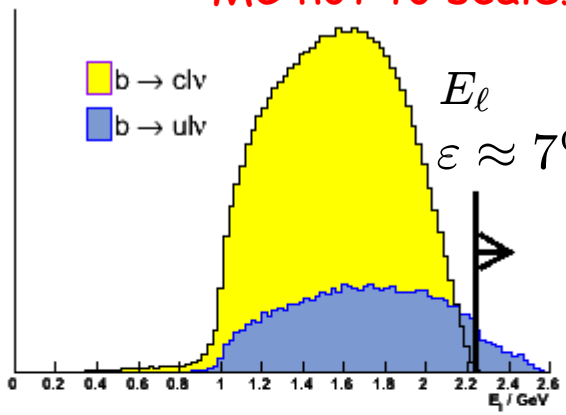
$m_u \ll m_c$ different kinematics

phase space cuts
to exclude $b \to c$ transition

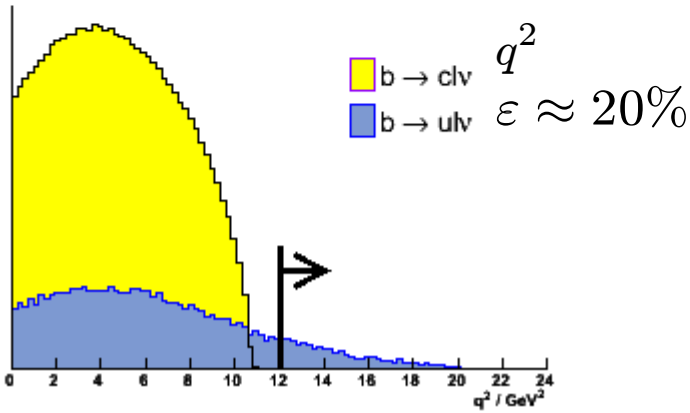
this breaks the OPE convergence

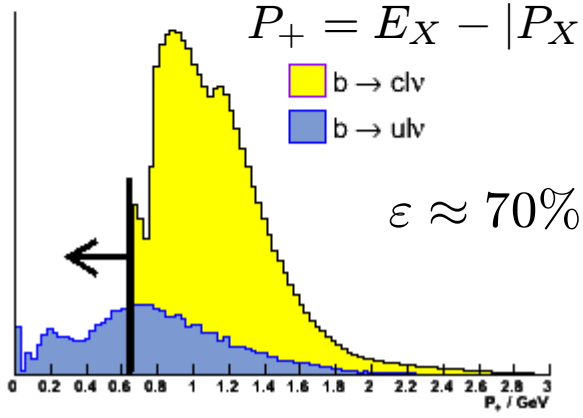
MC not to scale!





theoretical acceptances
are sensitive to b quark
motion (Fermi motion)
parametrized by Shape Function





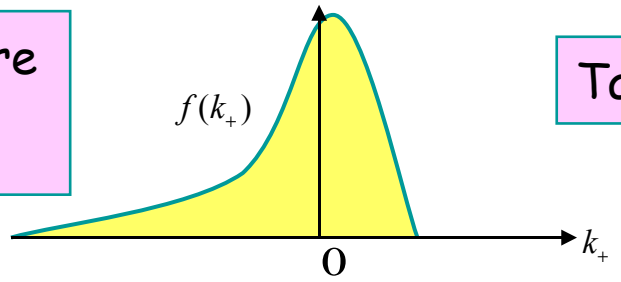
$B \to X_u \ell \bar{\nu}$ theory

· The shape function is a universal property of the B mesons (to leading orders)
+ subleading SF at each order in 1/mb

· it depends on 2 parameters $\bar{\Lambda}$ or m_b and λ_1 or μ_π^2

Known basic feature

(mean, rms)



Tail unknown

Measure SF parameters from $B \to X_s \gamma$ and $B \to X_c \ell \nu$ decays

THEORETICAL CALCULATIONS:

- BLNP (Bosh, Lange, Neubert, Paz) [1]: HQE with systematic introduction of SF;
- LNR (Lange, Neubert, Paz) [2]; LLR Leibovich, Low, Rothstein [3]: relate $b \to s\gamma$ directly to $b \to u\ell\bar{\nu}$
- BLL (Bauer, Ligeti, Luke) [4]: phase space in m_X-q^2 with reduced SF dependence
- GGOU (Gambino, Giordano, Ossola Uraltsev)[5]: Kinetic Scheme

} OPE

- Dressed Gluon Exponentiation – DGE – (Andersen, Gardi) [6]
- Analytic Coupling – AC – (Aglietti, Ferrera, Ricciardi) [7]

} No SF introduced; modelling of non-perturbative QCD

[1] PRD71:073006 (2005)
[2] JHEP 0510:084 (2005)
[3] PLB 486:86

[4] PRD 64:113004 (2001)
[5] JHEP 10(2007)058
[6] JHEP 0601:097 (2006)

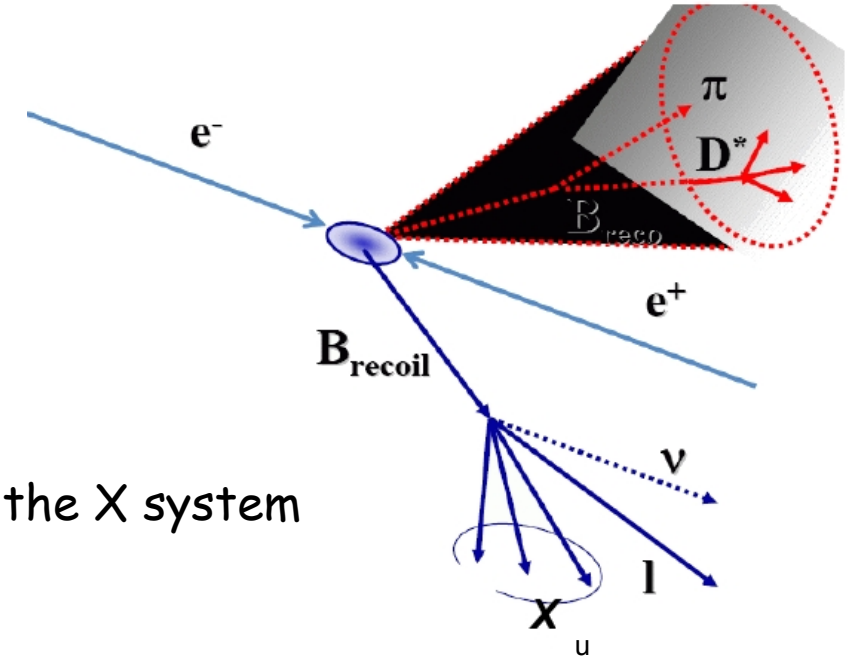
[7] PRD74:034006 (2006)
PRD74:034005 (2006)
PRD74:034004 (2006)

Hadronic tag

• Select semileptonic decays on the recoil of fully reconstructed hadronic B decays

$$B \to D^{(*)} Y \qquad Y = n\pi + m\pi^0 + pK_s + qK$$

low efficiency: 0.4% per ($b\bar{b}$) , 4000 B/fb^{-1}

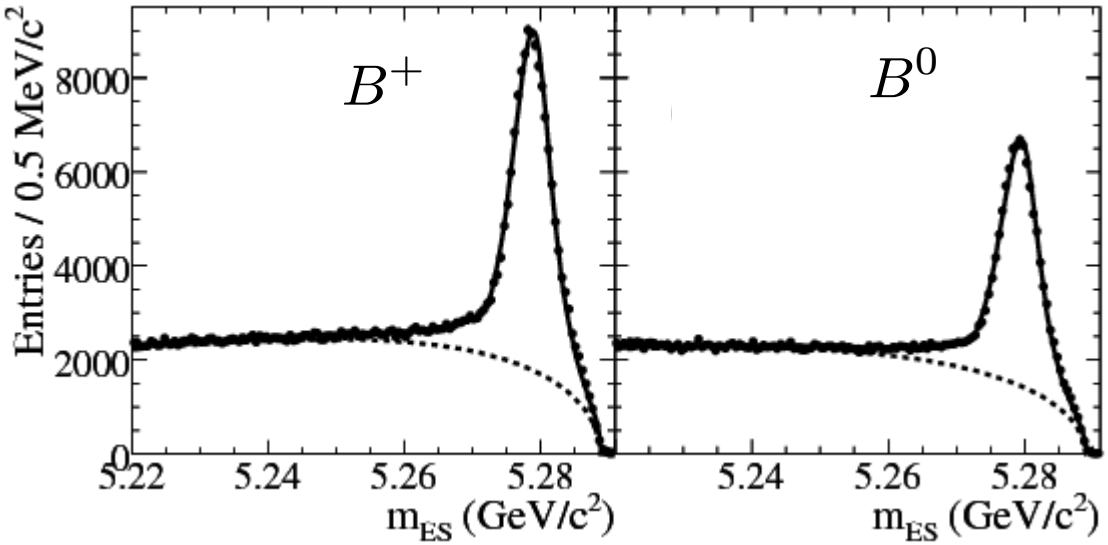


• only neutrino undetected: all other particles make up the X system

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

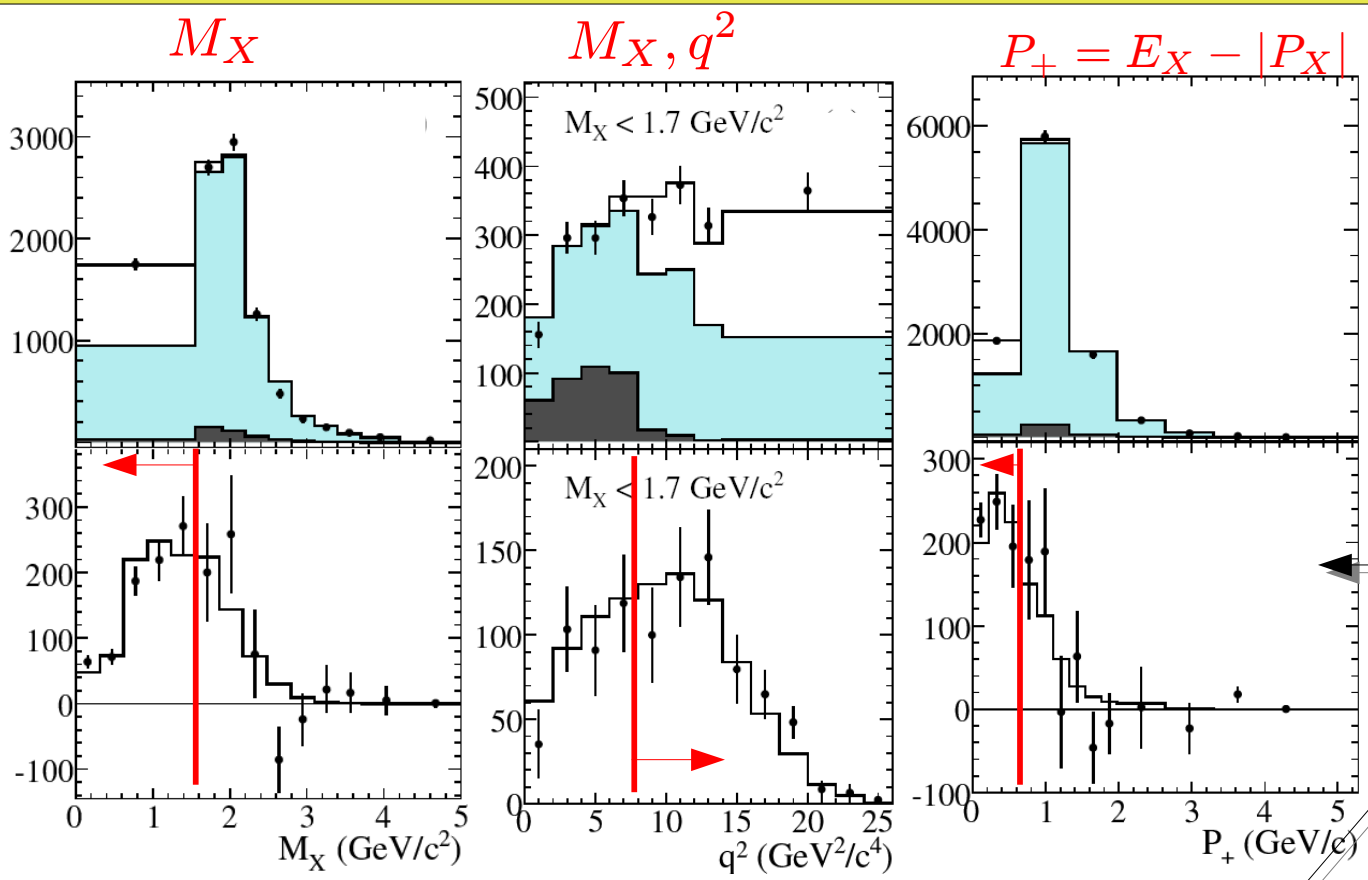
$$m_{ES} = \sqrt{s/4 - \vec{p}_B^{\,2}}$$

high energy lepton $p^* > 1$ GeV



continuum and combinatoric background subtraction

Hadronic tag: results



PRL 100, 171802 (2008)

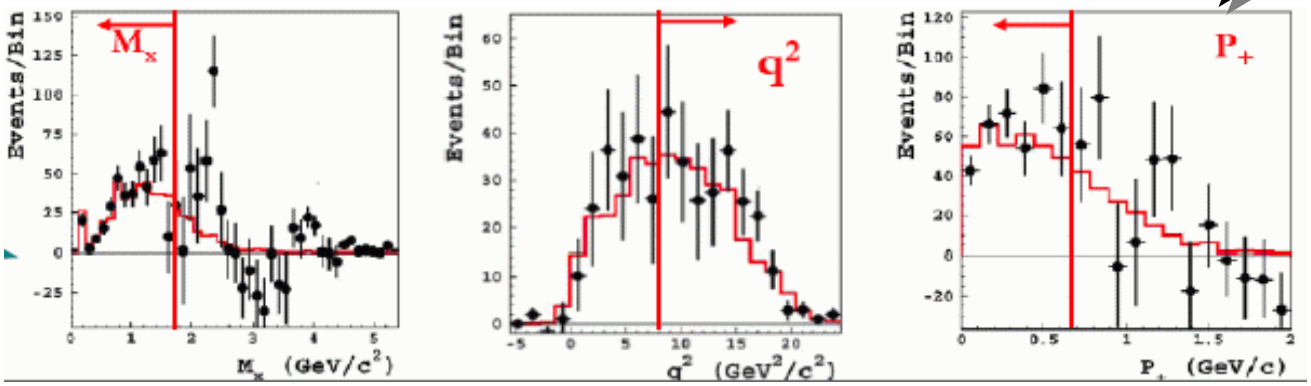
347 fb^{-1}

= Signal MC b→u

= Bkg MC b→c

= Crossfeed signal MC

bkg subtracted
(not eff. corrected)



PRL 95, 241801 (2005)

253 fb^{-1}

Hadronic tag: results

Kinematic region	Nu	$\Delta\mathcal{B}$ ($B\to X_u l\nu$) 10^{-3} (stat. syst. theo.)	$\lvert V_{ub}\rvert$ 10^{-3} (stat. syst. theo.)	theoretical framework
$m_X < 1.55$ GeV/c^2	803 ± 60	1.18 ± 0.09 ± 0.07 ± 0.01	4.27 ± 0.16 ± 0.13 ± 0.30	BLNP
			4.56 ± 0.17 ± 0.14 ± 0.32	DGE
$P_+ < 0.66$ GeV/c	633 ± 63	0.95 ± 0.10 ± 0.08 ± 0.01	3.88 ± 0.19 ± 0.16 ± 0.28	BLNP
			3.99 ± 0.20 ± 0.16 ± 0.24	DGE
$m_X < 1.7$ GeV/c^2 $q^2 > 8$ GeV^2/c^4	562 ± 55	0.81 ± 0.08 ± 0.07 ± 0.02	4.57 ± 0.22 ± 0.19 ± 0.30	BLNP
			4.64 ± 0.23 ± 0.19 ± 0.25	DGE
			4.93 ± 0.24 ± 0.20 ± 0.36	BLL

Largest uncertainty: theoretical error 6-7.5%

How predictive is theory?

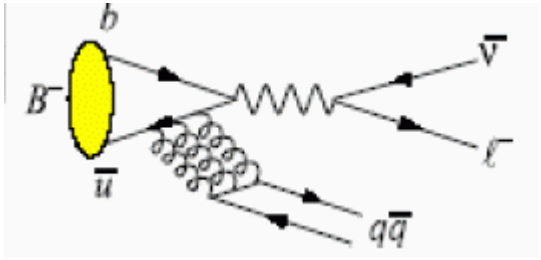
Φ_1/Φ_2	Data ($\Delta\mathcal{B}$)	Γ_{thy} (BLNP)	double ratio $\Gamma_{thy}/\Delta\mathcal{B}$
$M_X/M_x, q^2$	1.46 ± 0.13	1.67 ± 0.05	1.14 ± 0.11
P_+/M_X	0.81 ± 0.07	0.98 ± 0.03	1.21 ± 0.11
$P_+/M_X, q^2$	1.18 ± 0.14	1.63 ± 0.05	1.38 ± 0.17

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\bar{B}\to X_u \ell\bar{\nu})}{\tau_B \cdot \Gamma_{thy}}}$$

$$\frac{\Delta\mathcal{B}(\Phi_1)}{\Delta\mathcal{B}(\Phi_2)} = \frac{\Gamma_{thy}(\Phi_1)}{\Gamma_{thy}(\Phi_2)}$$

Weak Annhilation

arXiv: 0708.1753



· introduces differences between B^0 and B^+ decays

· small contribution: 3% of the total decay rate

347 fb^{-1}

· compare B^0 partial rate to the charge averaged rate in region where WA contribution is greater (high q^2 and large p_l)

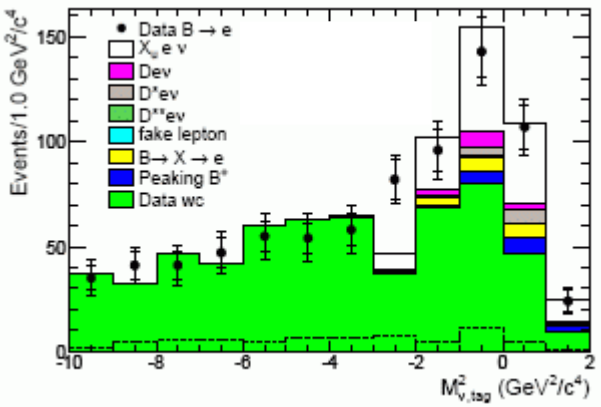
· Study charmless semileptonic decays on recoil of partial reconstructed $B^0 \to D^{*+} l^- \nu$

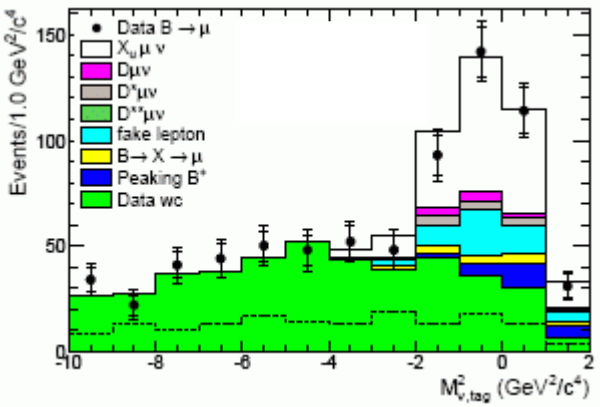
· neutrino mass $m_\nu^2 = (P_B - P_{D^*} - P_\ell)^2$

131.1 ± 36.9

172.0 ± 32.2

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





Δp	$\Delta\mathcal{B}(B)\cdot 10^4$[8]	$\Delta\mathcal{B}(B^0)\cdot 10^4$	$A^{+/0}$
$2.2-2.6\,\mathrm{GeV}/c$	$2.31\pm0.10\pm0.18$	$2.62\pm0.33\pm0.16$	$-0.17\pm0.15\pm0.11$
$2.3-2.6\,\mathrm{GeV}/c$	$1.46\pm0.06\pm0.10$	$1.30\pm0.21\pm0.07$	$0.08\pm0.15\pm0.08$
$2.4-2.6\,\mathrm{GeV}/c$	$0.75\pm0.04\pm0.06$	$0.76\pm0.15\pm0.05$	$-0.05\pm0.20\pm0.10$

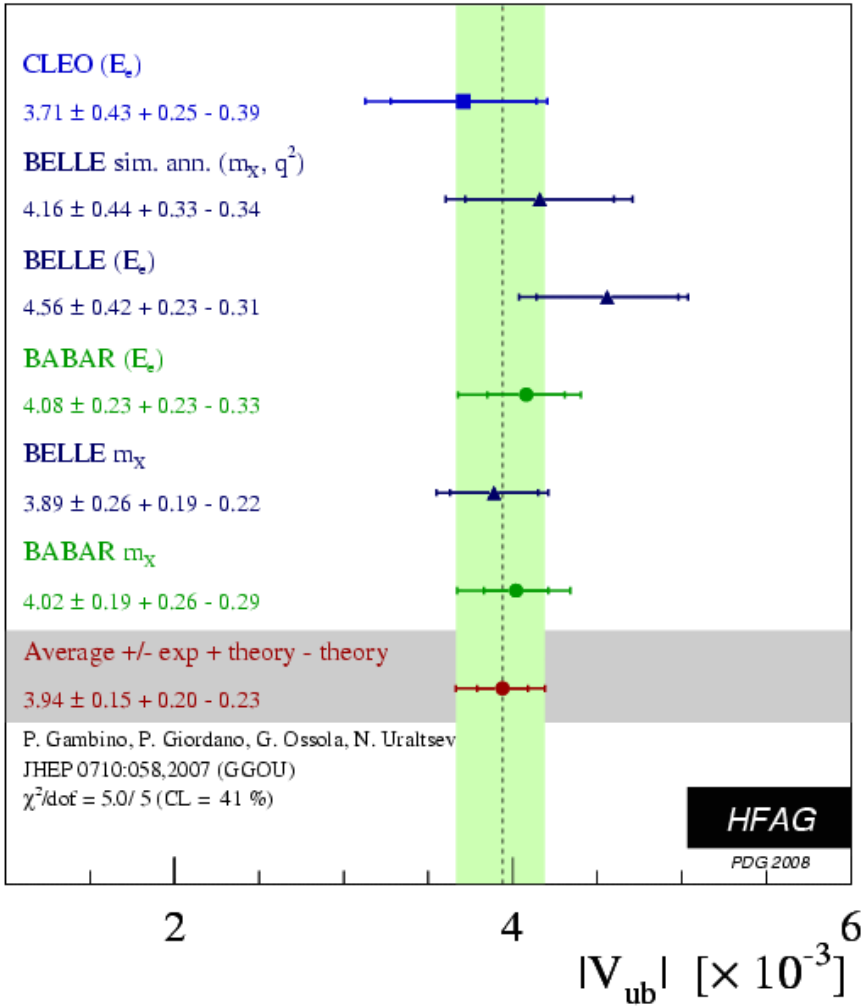
No evidence of weak annihilation

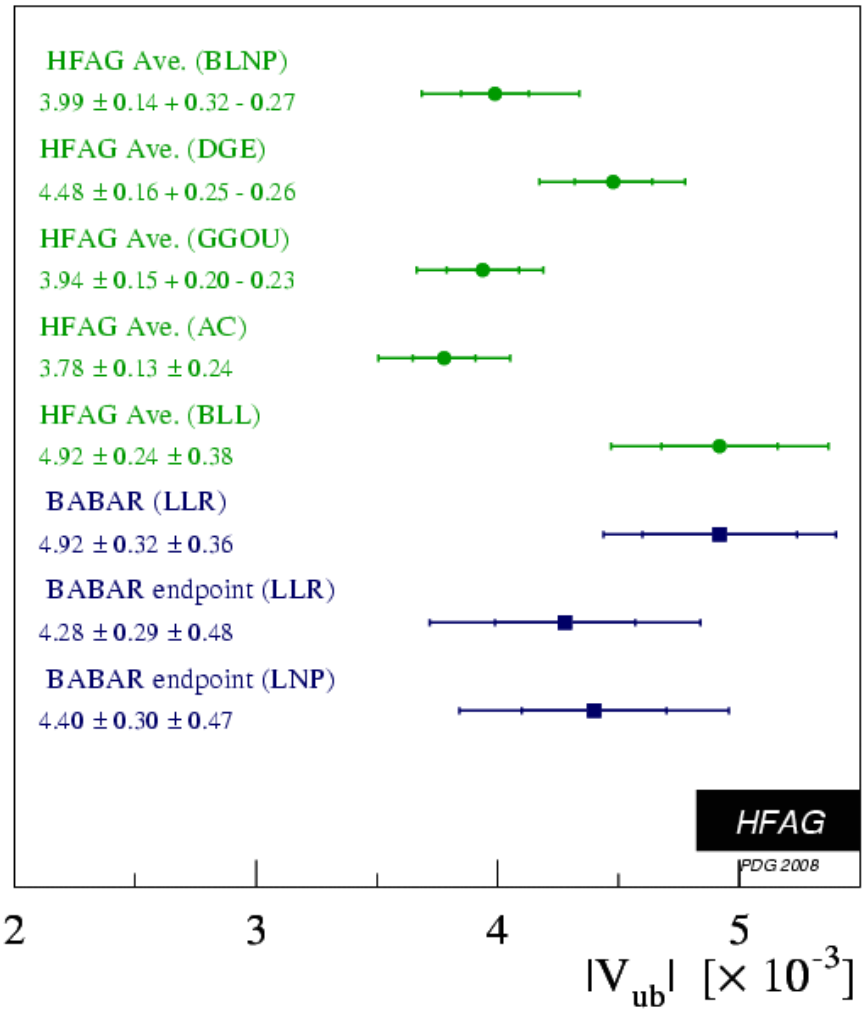
$\Gamma_{wa}/\Gamma_{b\to ulv}$ < 8% @90% CL

consistent with CLEO q^2 studies

PRL 96, 121801 (2006)

Inclusive $|V_{ub}|$: Summary



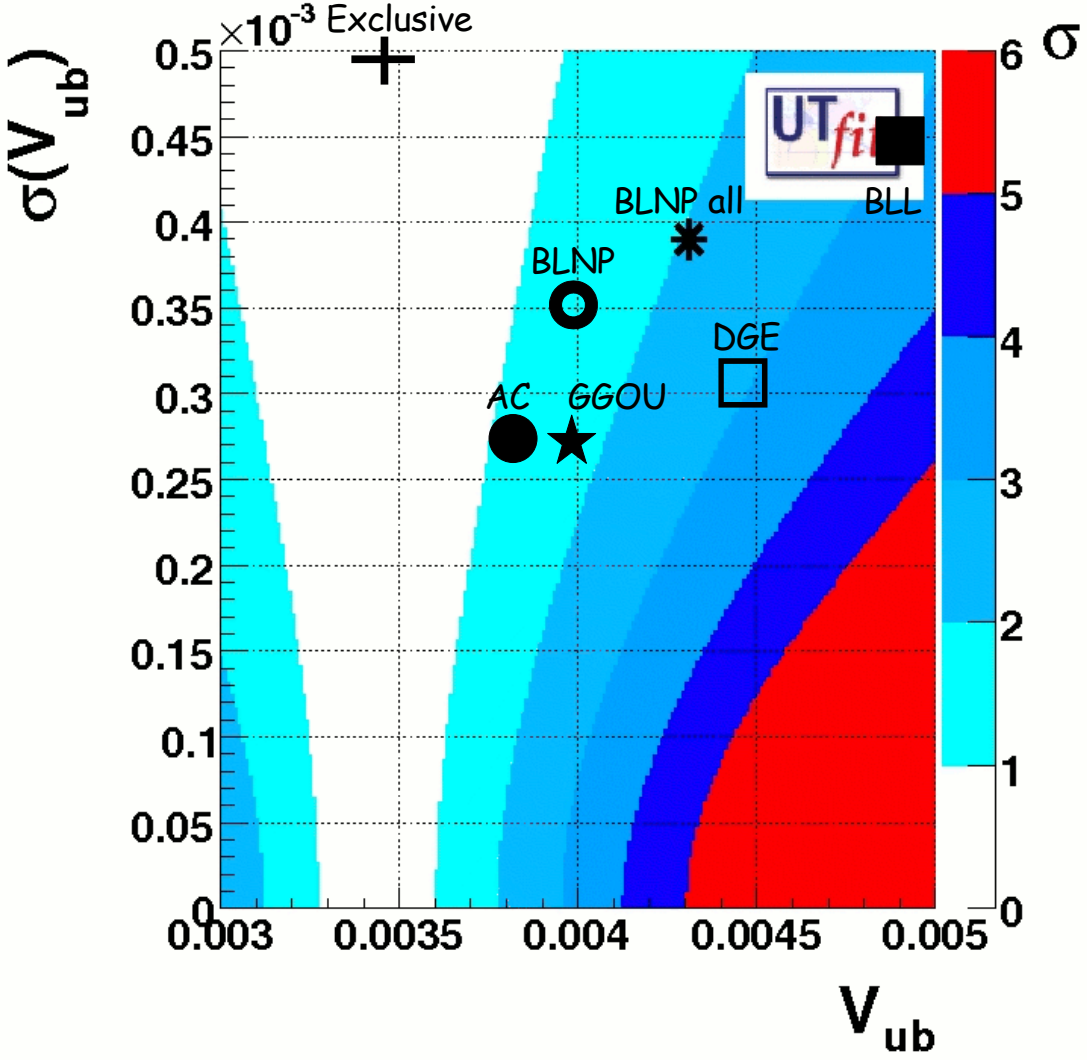


$$|V_{ub}|_{incl} \in (3.78, 4.92) \times 10^{-3}$$

$$|V_{ub}|_{excl} \in (3.11, 3.80) \times 10^{-3}$$

$$|V_{ub}|_{UTfit} = (3.44 \pm 0.16) \times 10^{-3}$$

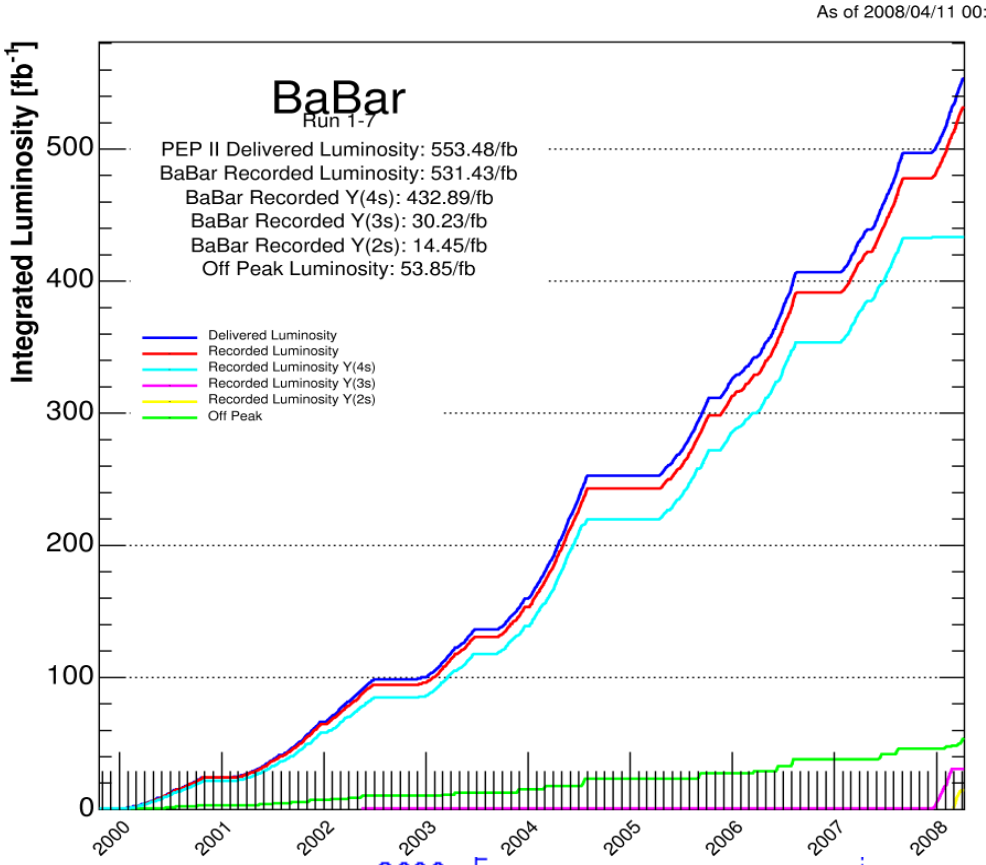
Conclusions



- BR determinations for exclusive decays with tagged analyses can improve with more data
- exclusive determination limited by FF knowledge
- inclusive limited by calculation of theoretical phase space acceptances
- smaller "tension" with exclusive for some calculations
- measurements still dominated by theory great effort to improve: measurements can help as well
- error on $|V_{ub}|$~ 9%; expected to push down to 5%

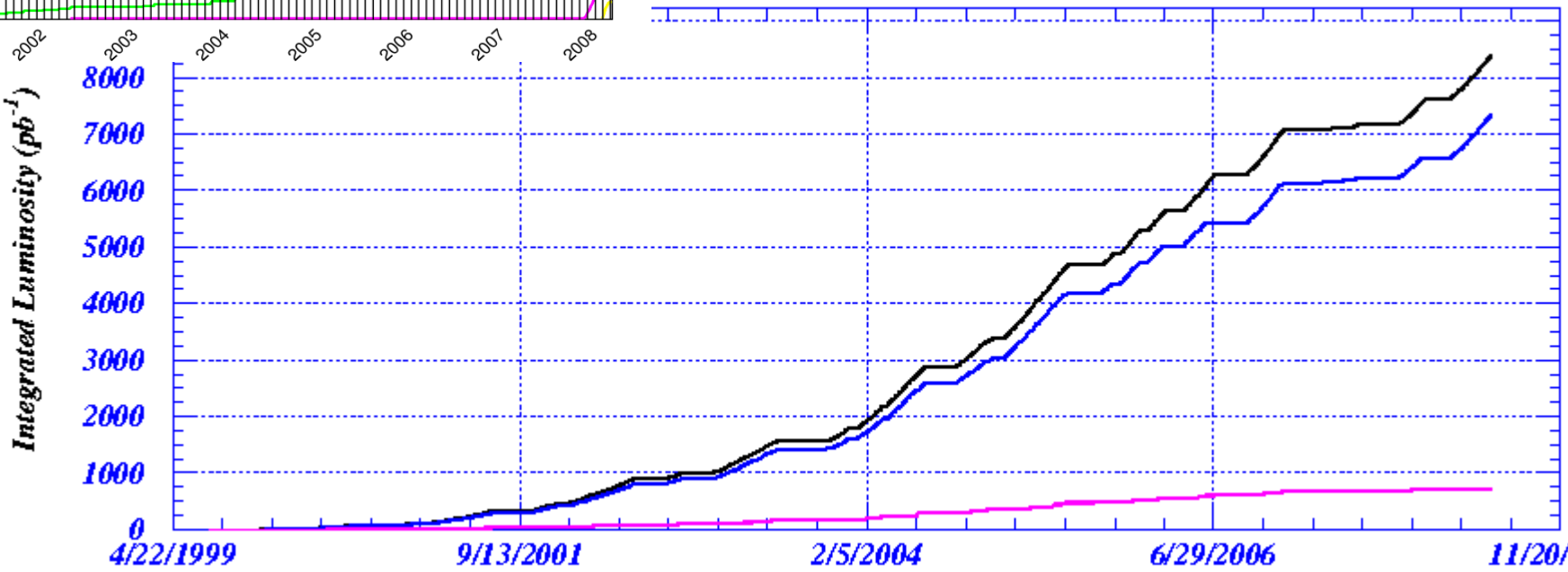
Additional Slides

B-Factories: Luminosities



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

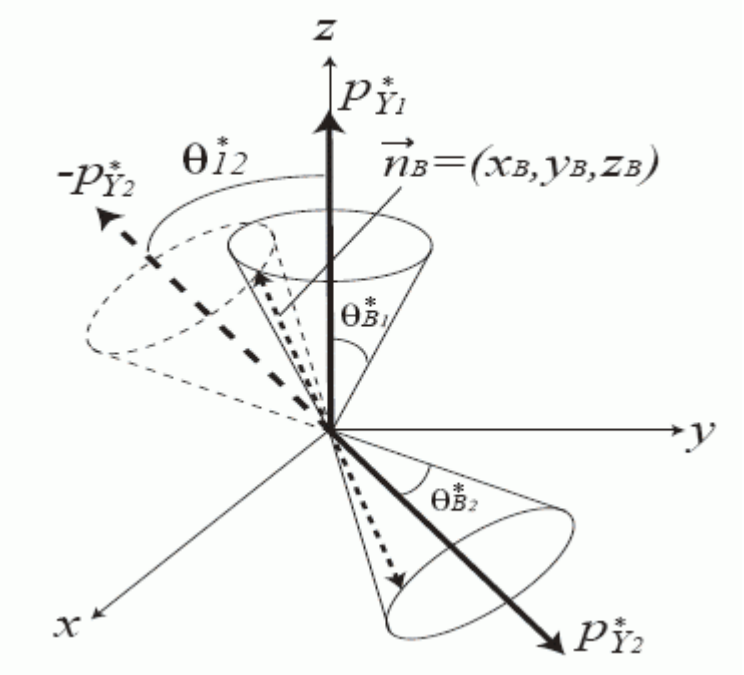
~ 838 fb^{-1} Belle @ KEKB



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

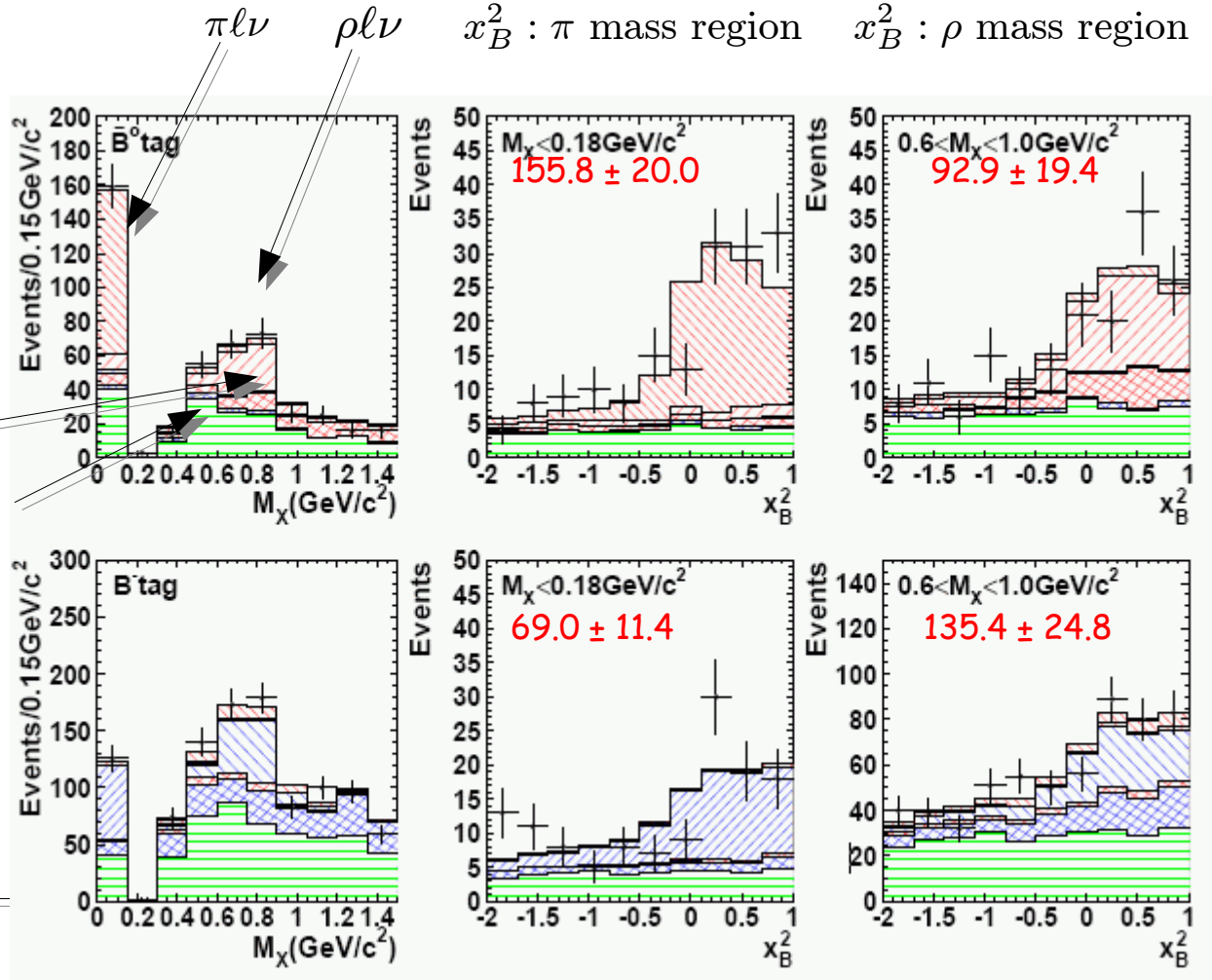
Phys.Lett. B 648:139-148 (2007)

253 fb^{-1}



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

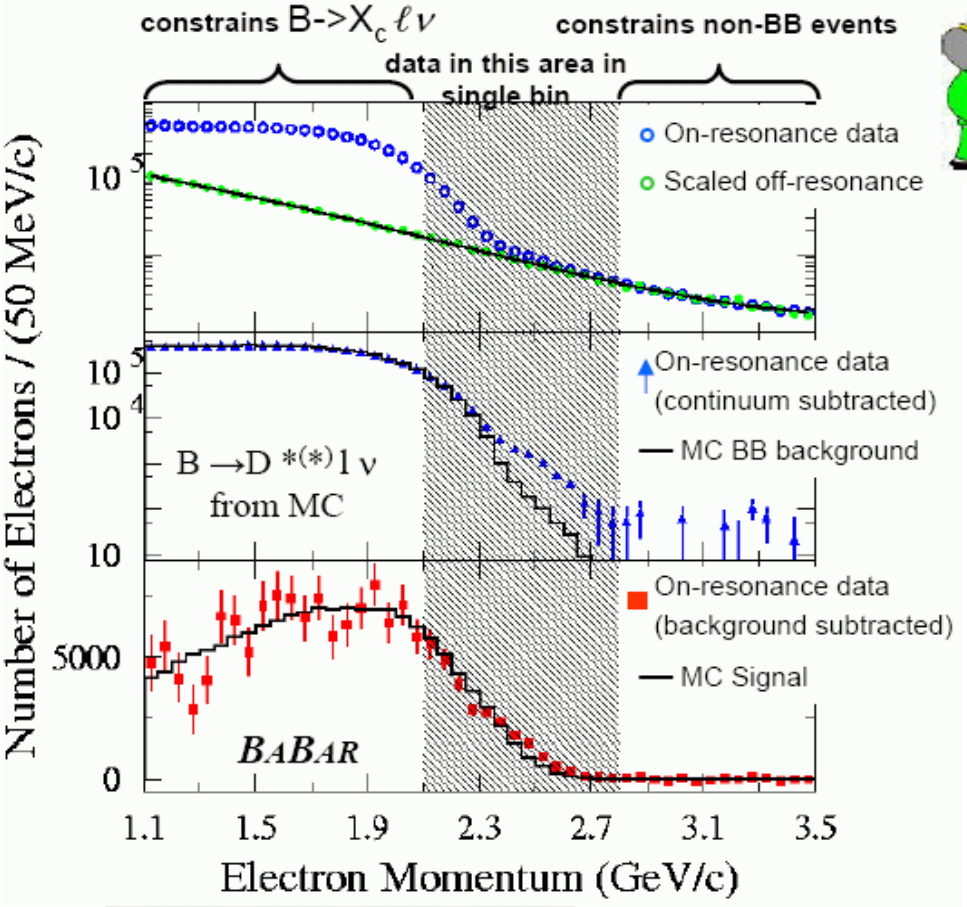
plots: full q^2 range



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

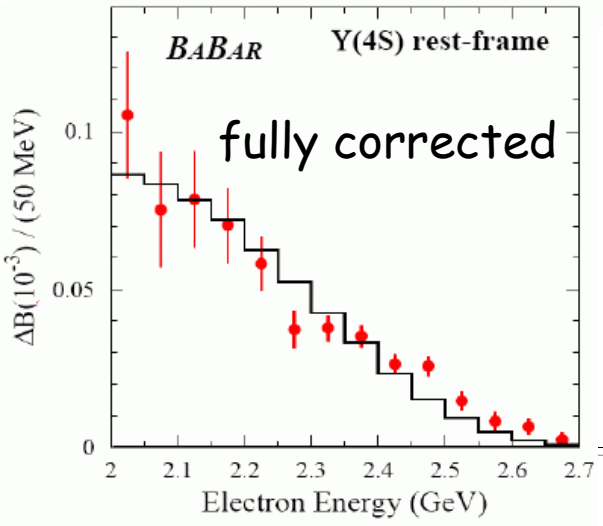
BF measurement dominated by statistics: can be improved with more data

Electron endpoint



- Select electrons with 2.0 < E_e < 2.6 GeV
- subtract non$B\bar{B}$ background using off-Peak and on Peak data (p_e > 2.8 GeV)
- subtract $B\bar{B}$ background from MC: fit $b \to c\ell\nu$ individual compositions
- exploit below the charm threshold (2.3 GeV)
  - → higher acceptance
  - → reduce SF dependence

S/B ~ 1/15 for E_e > 2.0 GeV



	$\mathcal{L}$(fb^{-1})	E_ℓ(GeV)	$\Delta\mathcal{B}(10^{-4})$
BaBar	81.4	2.0–2.6	5.72±0.41±0.65
Belle	27.0	1.9–2.6	8.5±0.4±1.5
CLEO	9.13	2.2–2.6	2.30±0.15±0.35

PRD 73, 012006 (2006)
PL B 621 (2005) 28
PRL 88, 231803 (2002)