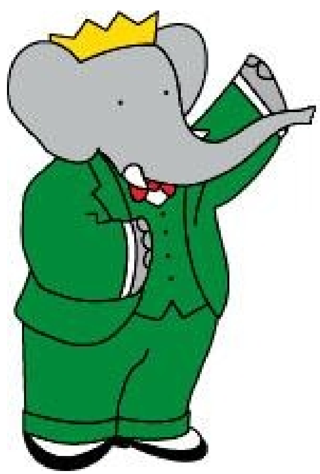
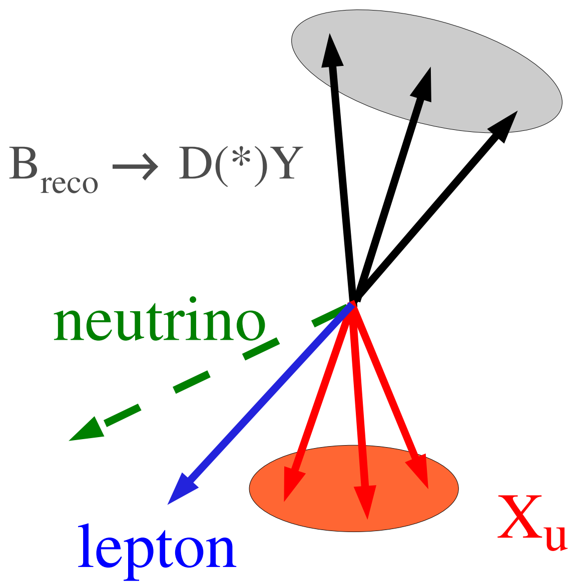
Sixth Meeting on B Physics, Ferrara, 19/03/2009

Inclusive semileptonic B decays: $|V_{ub}|$





BELLE

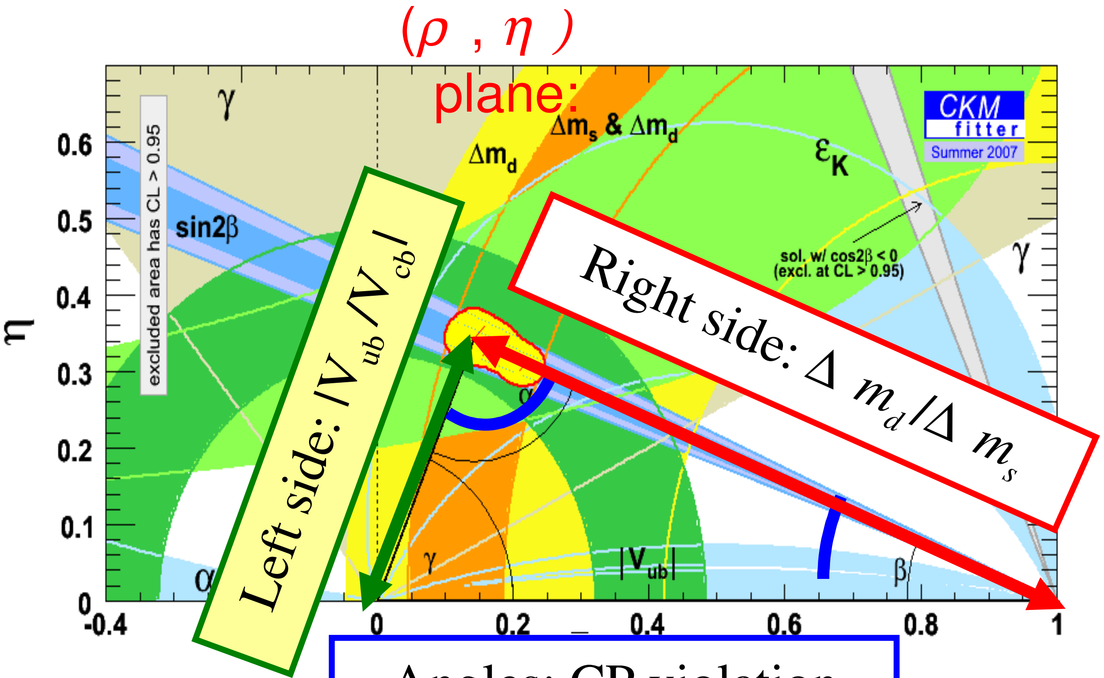
Nicola Gagliardi (Università di Padova)

Outline

- **Motivation:**
  - Semileptonic decays and Inclusive $B \to X_u l\nu$ theory;
- **Inclusive $B \to X_u l\nu$:**
  - BaBar Measurement: $|V_{ub}|$ with endpoint method;
  - BaBar Measurement: $|V_{ub}|$ with hadronic tag;
  - World Average and HQE parameters;
  - Belle multivariate analysis (CKM 2008);
  - X_u hadronic moments;
  - Weak Annihilation in $B \to X_u l\nu$ decays;
- **Conclusions.**

Motivation

Precision of sen2β (3%) outstripped the other measurements: must improve the others to make more stringent test



Angles: CP violation

Left side of the triangle:

- $|V_{cb}|$ known with a precision of ~ 2%
- **$|V_{ub}|$ known with a precision of ~ 8%**

Error on the length of the side opposite to b dominated by errors on $|V_{ub}|$

Improved precision on $|V_{ub}|$ needed

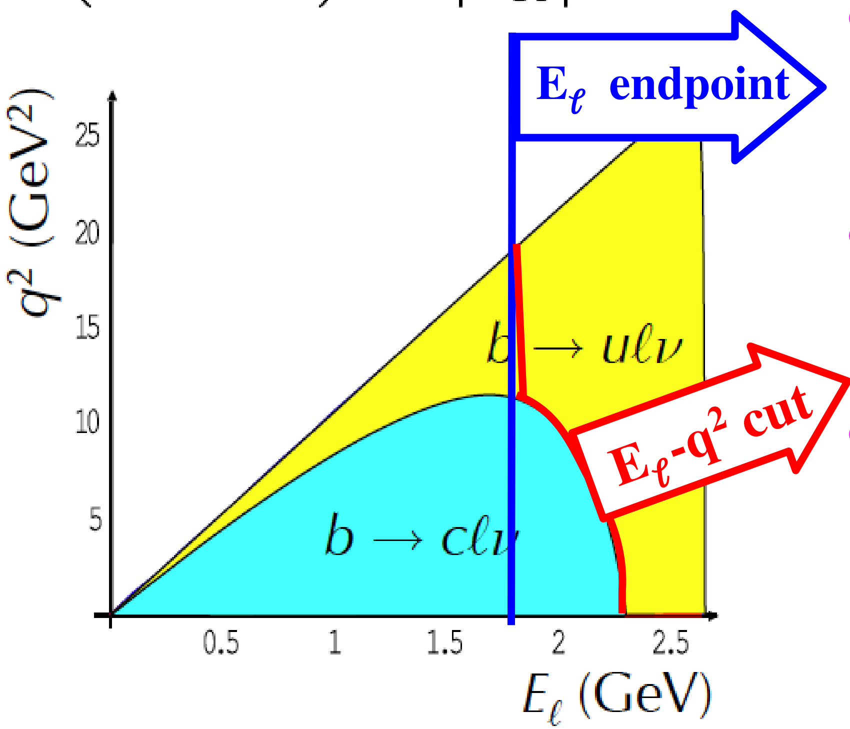
Inclusive $B \to X_u l \nu$

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

free quark decay — perturbative correction — non perturbative correction

OPE
~ 5% uncertaintly

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

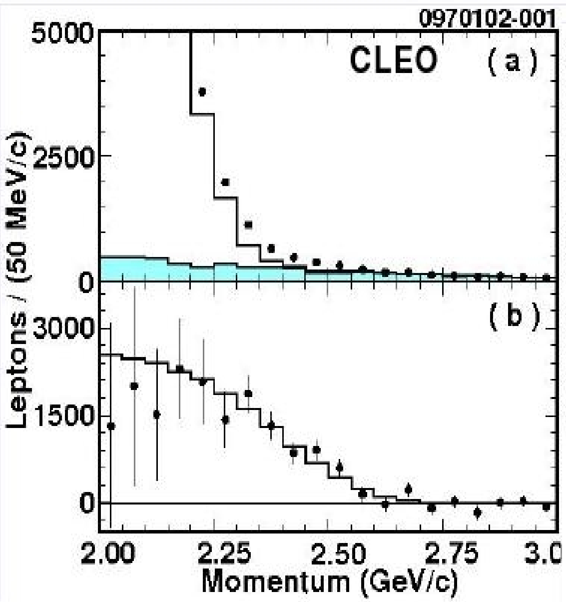


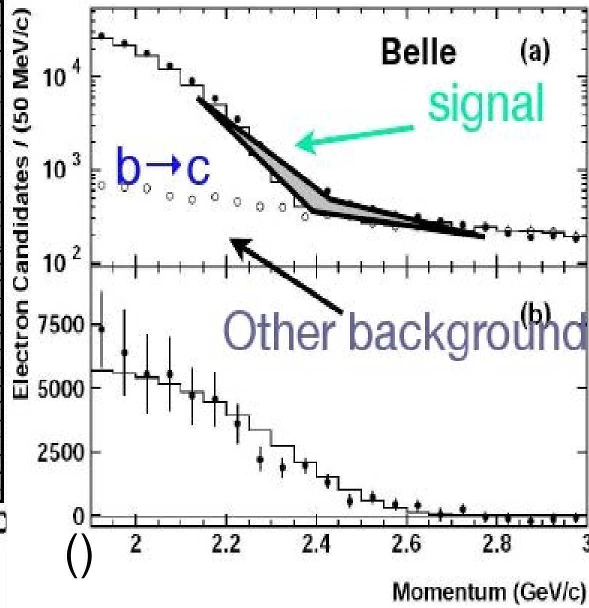
- $m_u \ll m_c$ different kinematics
- measure $\Delta B(B \to X_u l\nu)$ in a region where the S/N is good and the $\Delta\Gamma_u$ is reliably calculable (exclude $b \to cl\nu$ decays)
- OPE convergence is compromised ($O(1/m_b)$)

$$\Delta B(B \to X_u \ell\nu) = \tau_B |V_{ub}|^2 \zeta_c$$

- theoretical acceptances are sensitive to b quark motion (Fermi motion) parametrizated by **Shape Function.** Detailed shape not know, in particular the tail but mean and r.m.s constrained ($B \to X_c l\nu$ and $B \to X_s\gamma$ moments).

Endpoint method





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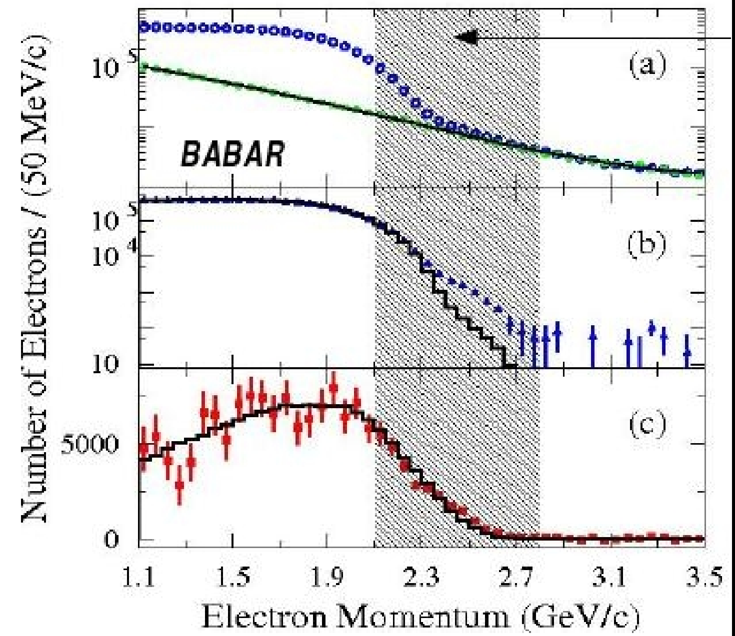


Subtract offpeak data scaled to onpeak luminosity bin-by-bin;
Fit MC to data in low energy region to constrain $B \to X_c l\nu$ from data

$B \to X_u l\nu$, $B \to D l\nu + B \to D^* l\nu$ (ratio fixed)
$B \to D^{**} l\nu$, $B \to D^{(*)} \pi l\nu$

(Goiti &Roberts)

$B \to X_u l n$, $B \to D l\nu + B \to D^* l\nu$ (D/D^* fixed)
$B \to D^{**} l\nu$ $D^{**}/D+D^*$ fitted

Simultaneous fit for non-BB, $B \to X_u l\nu$, $B \to D l\nu$, $B \to D^* l\nu$, $B \to D^{**} l\nu$, $B \to D^{(*)} \pi l\nu$, other background

		Ecut	$\Delta BR \times 10^{-4}$	$\lvert V_{ub}\rvert_{BLNP}$ [$\times 10^{-3}$]
PRL 88, 231803, 2002	Belle	1,9	$8{,}47 \pm 0{,}37_{stat} \pm 1{,}53_{sys}$	$4{,}74 \pm 0{,}44_{exp} \pm 0{,}35_{the}$
PLB621, 28, 2005	BaBar	2,0	$5{,}72 \pm 0{,}41_{stat} \pm 0{,}65_{sys}$	$4{,}29 \pm 0{,}24_{exp} \pm 0{,}35_{the}$
PRD 73, 012006, 2006	CLEO	2,0	$4{,}22 \pm 0{,}33_{stat} \pm 1{,}78_{sys}$	$3{,}94 \pm 0{,}46_{exp} \pm 0{,}37_{the}$

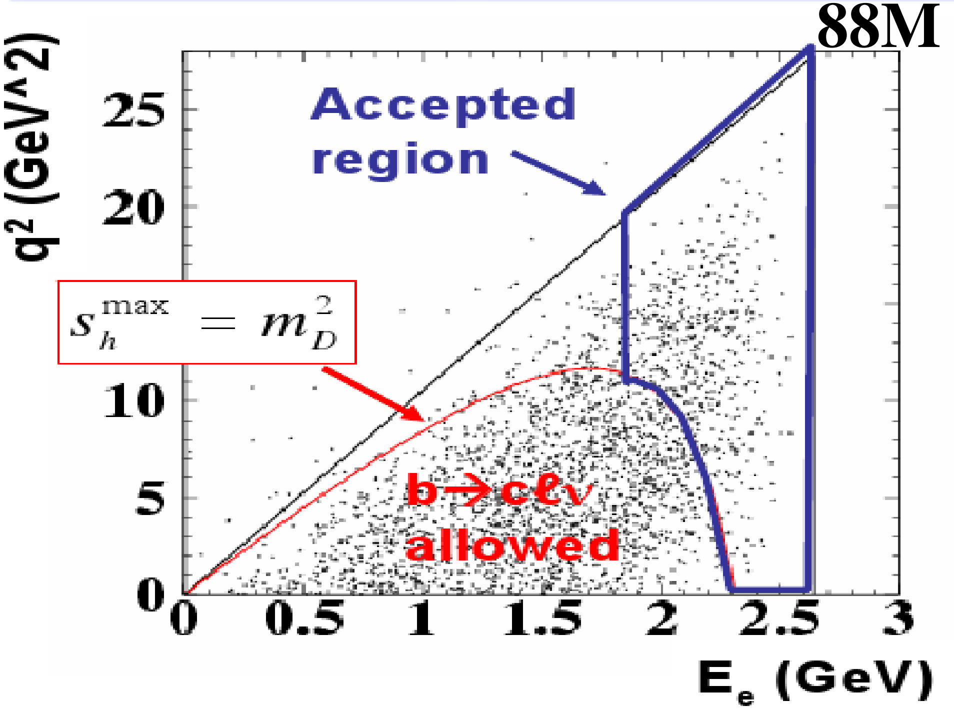
Improved Endpoint method: the neutrino reconstruction

Maximally allowed hadronic mass for given El & q^2 can be determinate:

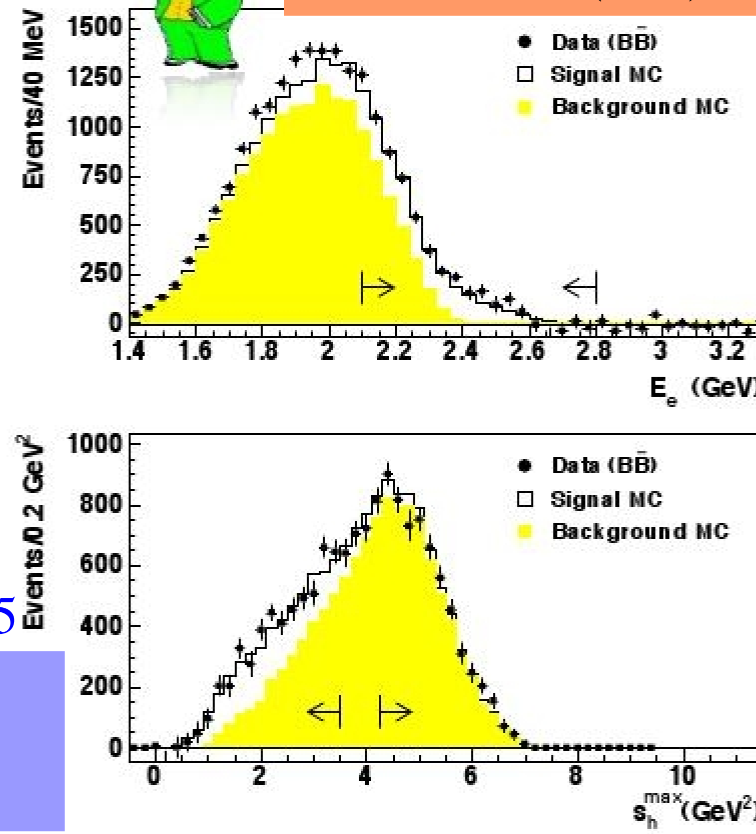
$$s_h^{max} = m_B^2 + q^2 - 2m_B(E_l\eta_- + q^2\eta_+/4E_e), \pm 2E_e > \pm\sqrt{q^2}\eta_\pm \qquad \eta_\pm = \sqrt{(1\pm\beta)/(1\mp\beta)}$$

$$s_h^{max} = m_B^2 + q^2 - 2m_B\sqrt{q^2}, \qquad \text{otherwise} \qquad \beta \approx 0.06$$

88M BB



BaBar (PRL 95, 111801, 2005
PRL 97, 019903(2006) Err.)



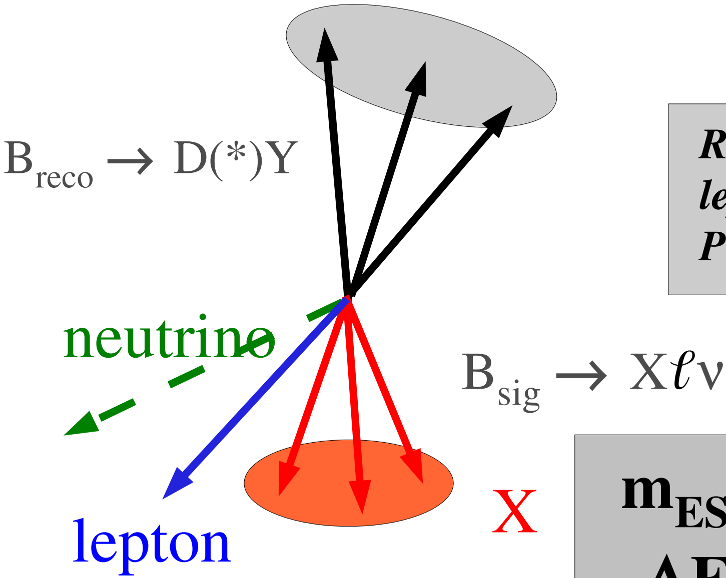
The neutrino reconstruction reduces S/B to ~ 0.5

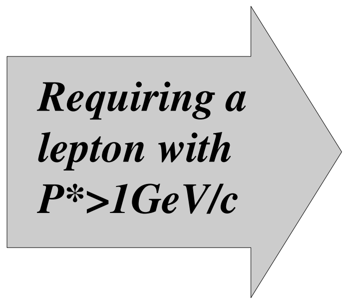
ΔB(2.0-2.6)=$(4.41\pm0.42\pm0.42)\times10^{-4}$

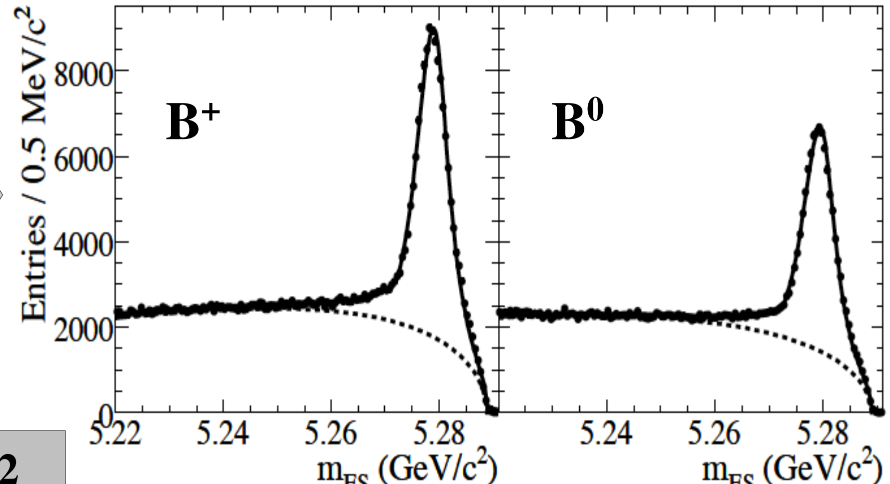
$|V_{ub}|_{BLNP} = (4.41\pm0.30_{exp}\pm0.42_{the})\times10^{-3}$

Inclusive $|V_{ub}|$ with hadronic tag

Fully reconstruct one B in hadronic decays: $B \to D(*)Y$ $Y = n\pi + m\pi^0 + pK_S + qK$





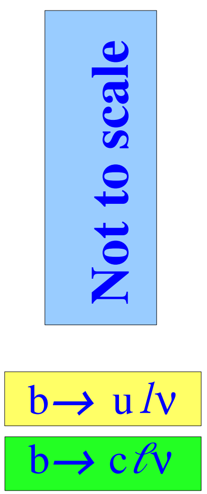


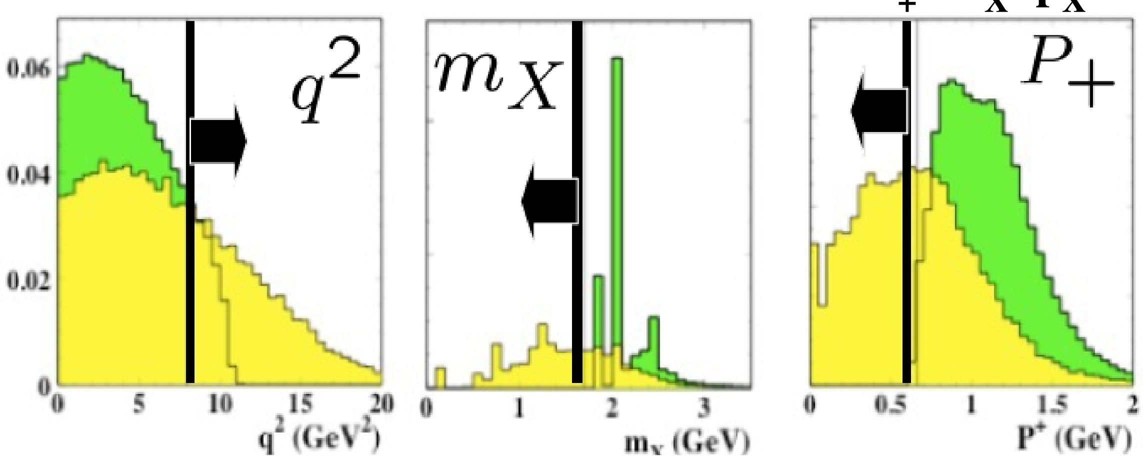
$m_{ES} = (s/4 - p^2)^{1/2}$

$\Delta E = E_B - s^{1/2}/2$

- $p_{miss} = p_{Y(4S)} - p_{reco} - p_X - p_{lepton}$
- m_X: all remaining particles

$P_+ = m_X - |p_X|$





m_X and P_+ require a sample of B_{reco}

Experimental Resolution leads to irreducible $b \to c\ell\nu$ contamination

Inclusive $|V_{ub}|$ with hadronic tag: results

Measure the partial branching ratio relative to the number of total semileptonic events

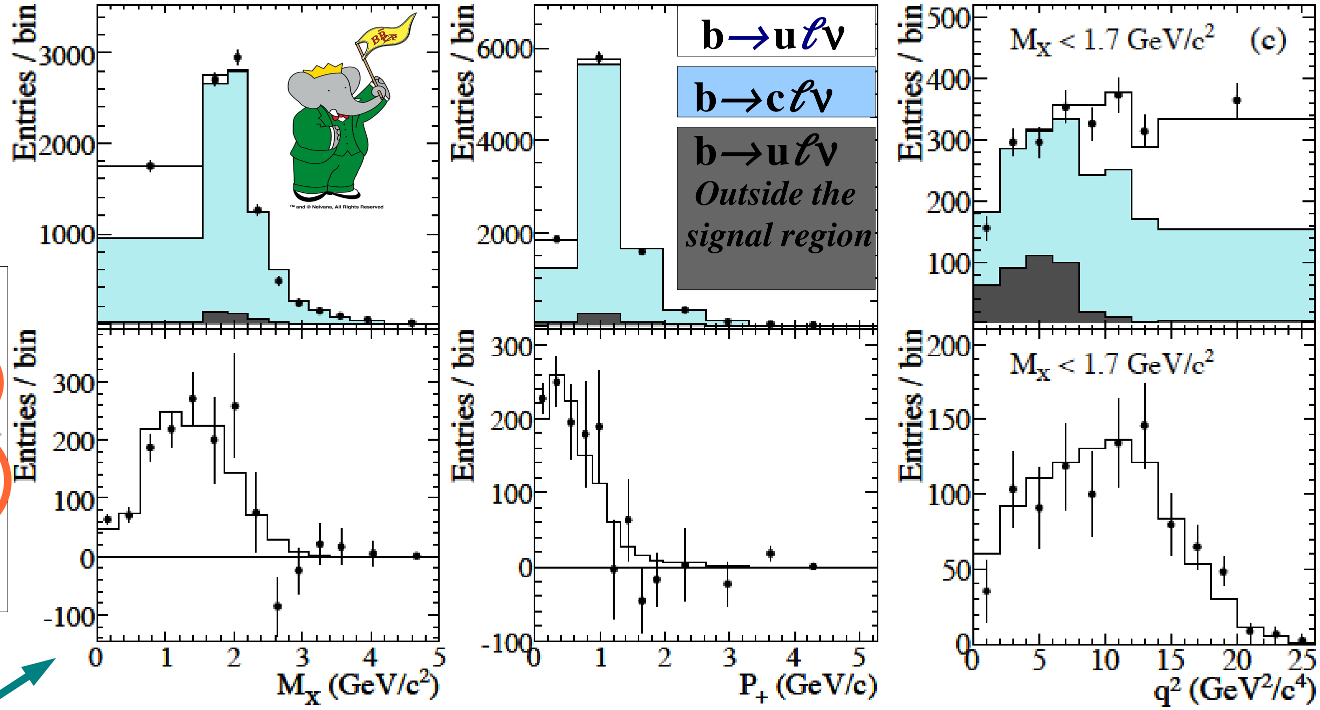
Unfolding factor

$$\frac{\Delta B(X_u \ell \nu)}{B(X \ell \nu)} = \frac{N_{b\to u}}{N_{X\ell\nu}} \cdot \frac{F}{\epsilon_{sel}}$$

Signal efficiency

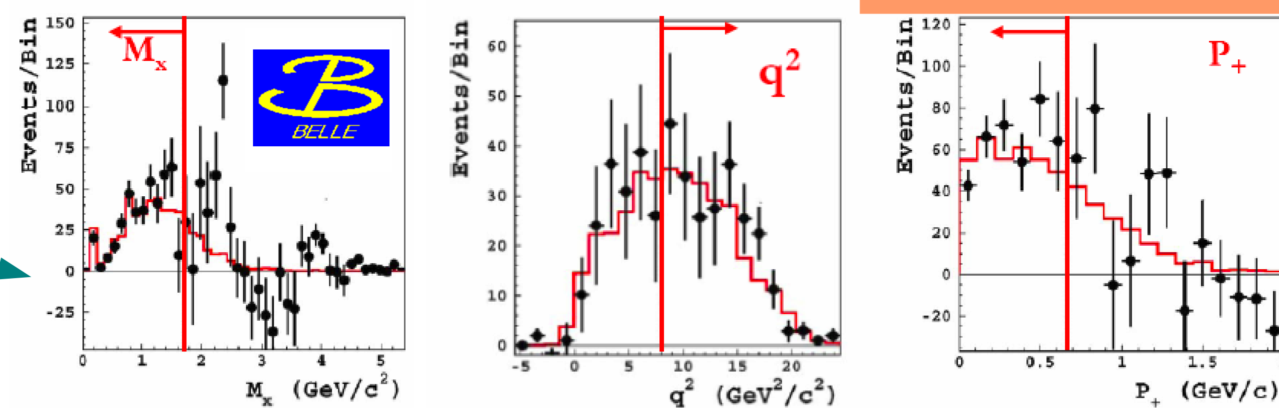
383M BB

PRL 100, 171802 (2008)



375M BB

PRL95,241801(2005)



Background subtracted distributions: not efficiency corrected

Inclusive $|V_{ub}|$ with hadronic tag: results

Kinematic Region	N_u	$\lvert V_{ub}\rvert \times 10^{-3}$	stat.	syst.	theory	Model
$M_X < 1.55$ GeV/c^2	803 ± 60	4,27	± 0,16	± 0,13	± 0,30	BLNP
		4,56	± 0,17	± 0,14	± 0,32	DGE
$P_+ < 0.66$ GeV/c^2	633 ± 63	3,88	± 0,19	±0,16	±0, 28	BLNP
		3,99	± 0,20	±0,16	±0, 24	DGE
$M_X < 1.55$ GeV/c^2 & $q^2 > 8$ GeV^2/c^2	562 ± 55	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

Bosh,Lange,Neuber,Paz
PRL93,221801(2004)
PRD72,073006(2005)

Andersen,Gardi
JHEP0601,097(2006)

Bauer,Ligeti,Luke
PRD64,113004(2001)

Single analysis with 9% tot. uncertainty

Compatibility taking into account the large correlations (stat. & syst.) between the different cuts:

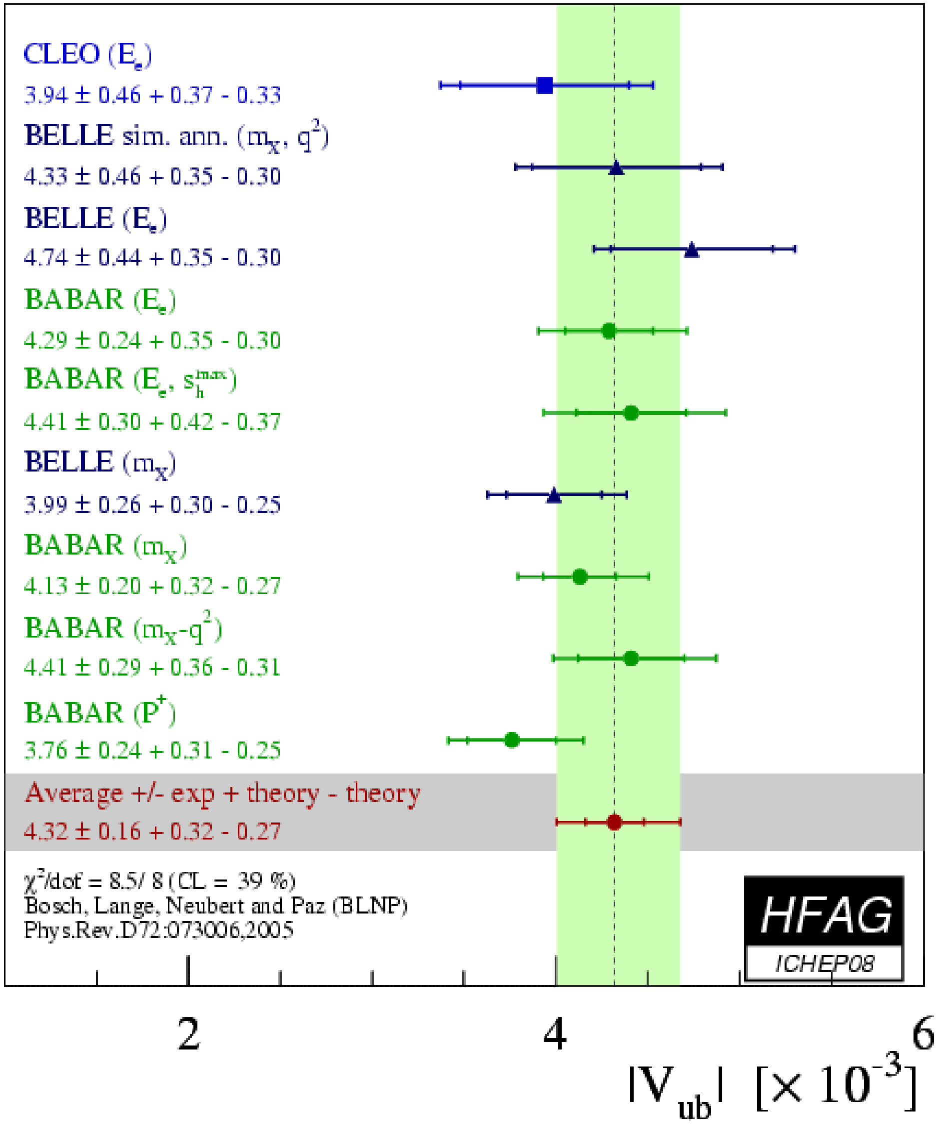
- ***m_x and (m_x, q^2) agree at 1σ***
- ***P_+ differs by 2.5σ***

Experimental systematics on Δ B ($B \to X_u \ell \nu$) expressed in %

Method	Detector	Shape function	$\mathcal{B}(\bar{B} \to X_u \ell \bar{\nu})$ $X_u = \pi, \rho, \dots$	Gluon splitting	$\mathcal{B}(\bar{B} \to X_c \ell \bar{\nu})$	$B \to D^* \ell^- \bar{\nu}$ form factors	$\mathcal{B}(D)$	m_{ES} fit	Monte Carlo statistics	Total
M_X	1.92	0.90	2.08	1.62	0.87	0.21	0.44	3.71	3.22	6.07
P_+	3.88	1.31	2.22	1.47	2.80	0.39	0.73	3.98	4.62	8.38
M_X, q^2	3.83	2.43	2.71	1.02	1.17	0.55	0.79	5.17	4.29	8.81

$|V_{ub}|$ results (HFAG average, BLNP)

- Many different theoretical approach
  $\Rightarrow$many $|V_{ub}|$ values

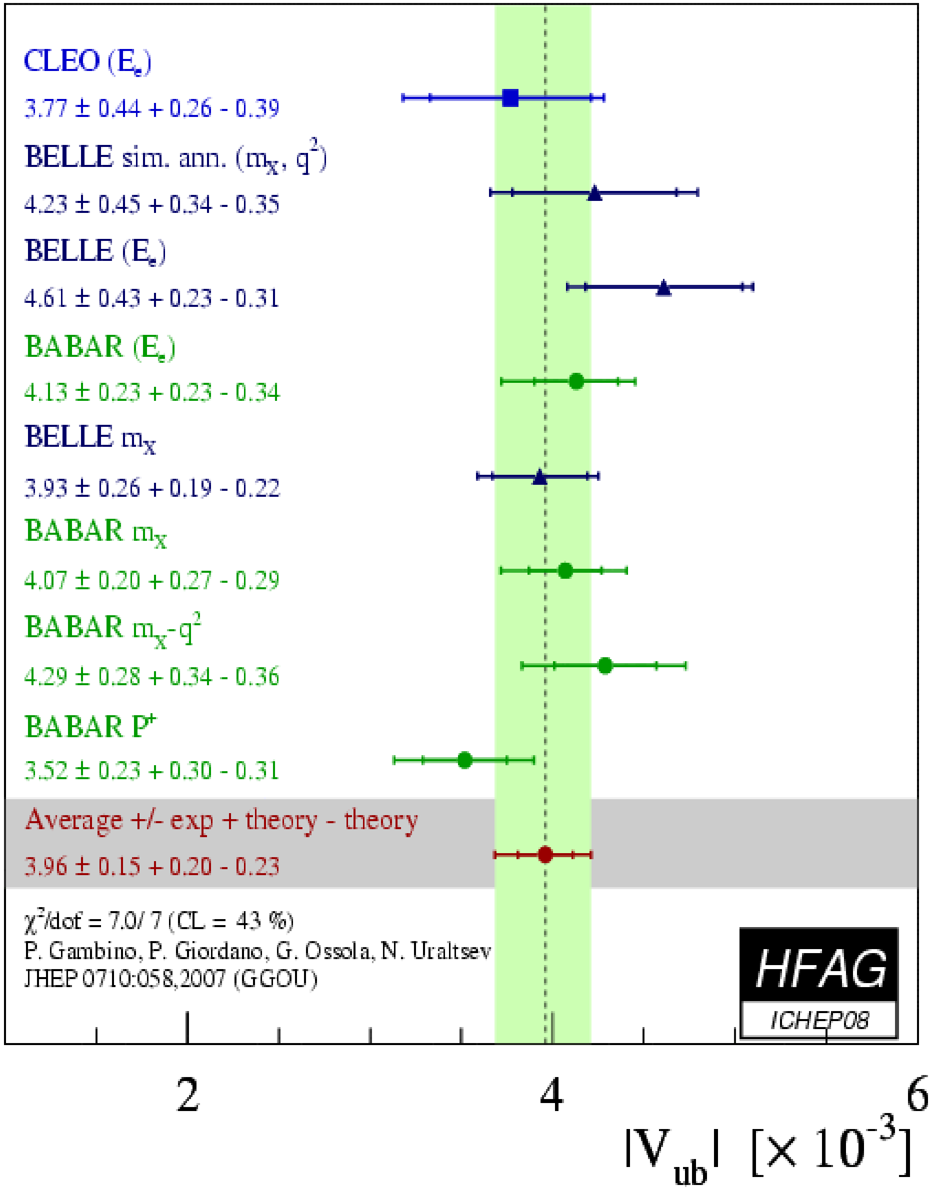


- Here only BLNP, with m_b from $B\to X_c\ell\nu + B\to X_s\gamma$ Global Fit (Kinetic Scheme), including also uncertainty on the KS⇔SF Scheme translation

$$|V_{ub}|=(4.32\pm0.16\pm0.32)\times10^{-3}$$

$\delta|V_{ub}|$	+8.2% -7.2%
Statistical	2.1%
Exp.systematics	2.3%
$b\to c\ell\nu$ model	1.3%
$b\to u\ell\nu$ model	1.4%
HQ parameters	5.7%
SF + Sub. SF	2.4%
matching	3.7%
Weak Annihilation	1.6%

$|V_{ub}|$ results (HFAG average, GGOU)



Gambino, Giordano, Ossola, Uraltsev
JHEP0710:058(2007)

$$|V_{ub}|=(3.96\pm0.15\pm0.23)\times10^{-3}$$

$\delta\|V_{ub}\|$	+6.3% -7.0%
Statistical	2.3%
Exp.systematics	2.2%
$b\to c\ell\nu$ model	1.5%
$b\to u\ell\nu$ model	1.5%
Non pert.-	3.9%
Higher order par.	1.8%
q^2 tail model	2.6%
Weak Annihilation	-3.1%

Determination of HQE parameters

The global fits to $B\rightarrow X_c l\nu$ and $B\rightarrow X_s\gamma$ moments provide input for the HQE parameters needed in calculating $B\rightarrow X_u l\nu$ partial rates. These HQE parameters are also used to constraint the first and second moments of the shape function.

- HQE connect the inclusive $b\rightarrow c\ell\nu$ decay width to $|V_{cb}|$

$$\Gamma_{SL} \sim |V_{cb}|^2 m_b^5 \, [z_0(r) + 0/m_b + z_2(r, \mu_\pi^2/m_b^2, \mu_G^2/m_b^2) + z_3(r, \rho_D^3/m_b^3, \rho_{LS}^3/m_b^3) + ..]$$

- Similar expressions for moments of various inclusive distributions:
  - ⇒ Hadron mass moments $\langle M_X^n \rangle_{E>Ecut}$
  - ⇒ Lepton energy moments $\langle E_{lep}^n \rangle_{E>Ecut}$
  - ⇒ Photon energy moments in $b\rightarrow s\gamma$: $\langle E_\gamma^n \rangle_{E>Ecut}$

Extract $|V_{cb}|$, BR_{clv}

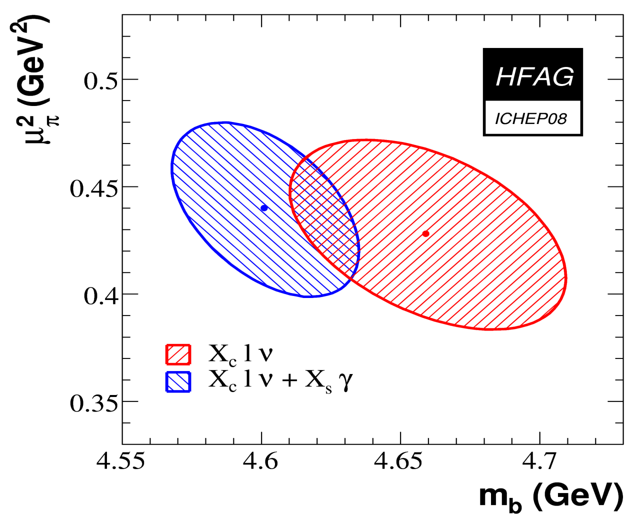
and the HQE parameters

m_b, m_c, μ_π^2, μ_G^2, ρ_D^3, ρ_{LS}^3

- Global fit with all available results:
  - ✓ Babar, Belle, CLEO, CDF, Delphi

$m_B(KS) = 4.601 \pm 0.034$ GeV

$\mu^2_\pi(KS) = 0.440 \pm 0.040$ GeV^2



The $B\rightarrow X_c l\nu$ decays are crucial to reduce the uncertainty for the $|V_{ub}|$

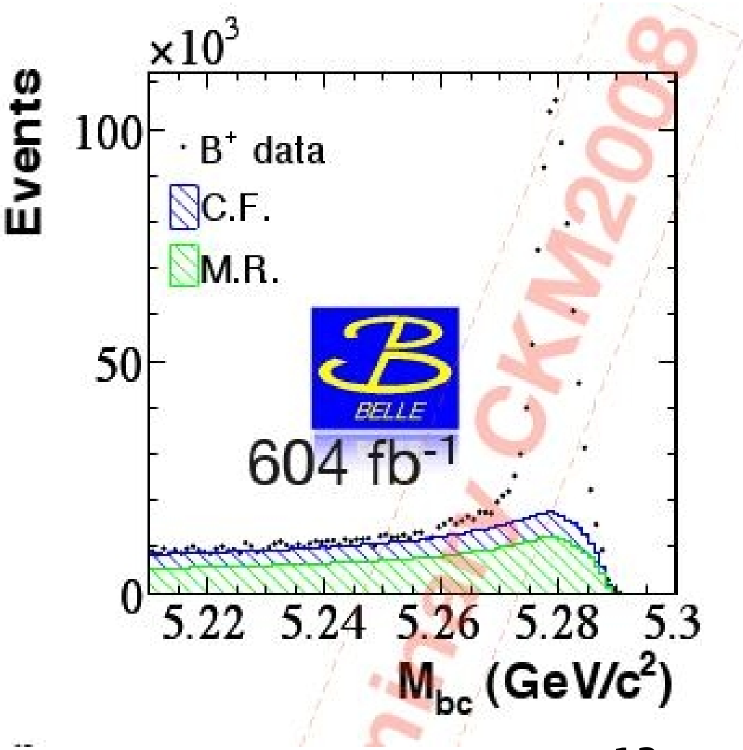
Belle Multivariate analysis (CKM 2008)

The irreducible uncertainties in the measurements to date are related to limited phase space:

- exploit the many non-linear correlation between kinematic and event variables available in B-beam sample that separate b→u and b→c.
- **Boosted decision tree** based selection, use ~ 20 event parameters from the full reconstruction sample

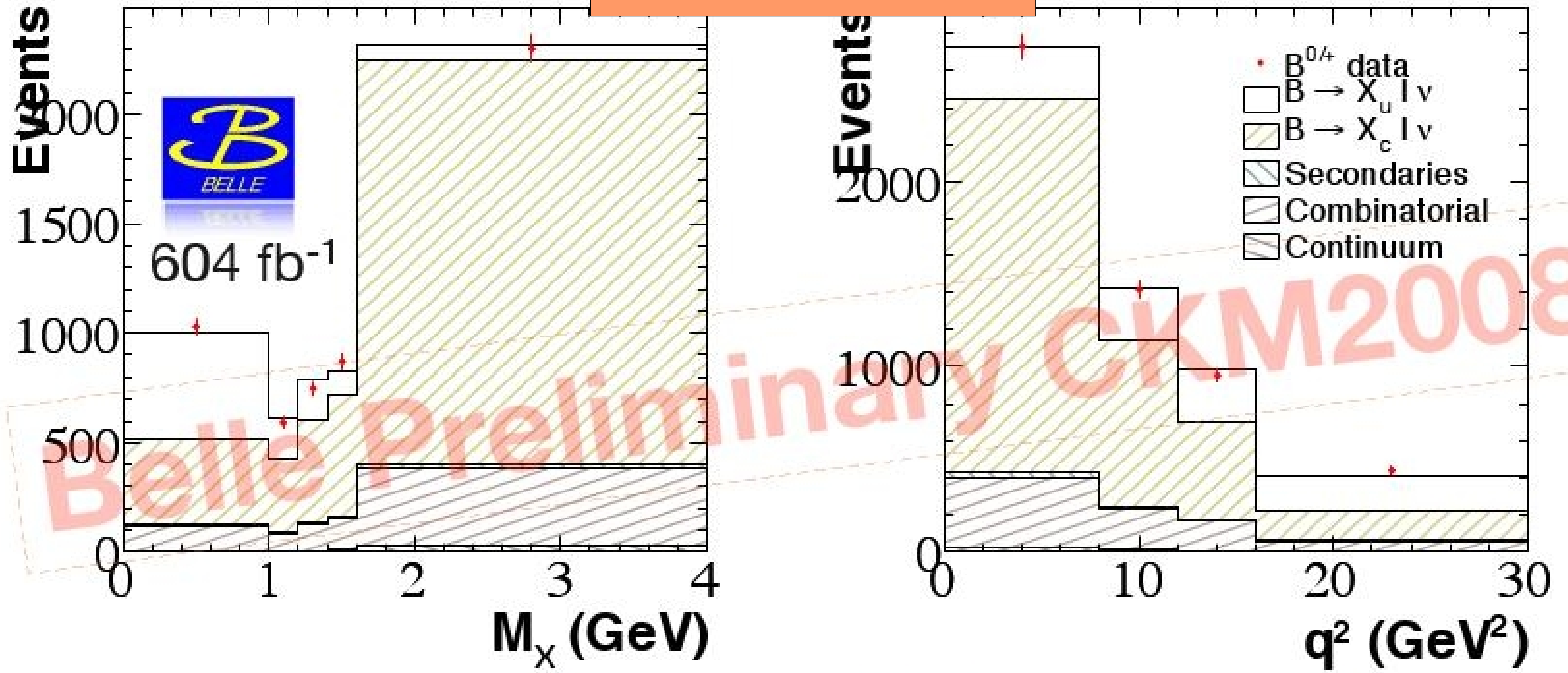
No need to place stringent, hard cuts that result in zero efficiency!

- ✔ Signal side: reconsruct high momentum lepton ($p_{cms} > 1$ GeV/c);
- ✔ Event Level:$Q(B^+_{reco})$ x Q(lepton)= -1;
- ✔ BDT cut with many input parameters: M^2_{miss},Q_{total},Q_{lepton},N_{lepton},Q(B),D^* partial reconstruction etc... ;
- ✔ 2D fit to $\mathbf{M_X,q^2}$ with background and signal floated to determine background yield;
- ✔ Measure absolute rate.



Belle Multivariate analysis: results

~1035 $B \to X_u l \nu$ events



2D fit in q2 mx. (projections shown)

Kinematic Region	$\mathcal{B}(B \to X_u l \nu) \times 10^{-3}$ Δ(stat. sys.)	m_b	$\lvert V_{ub} \rvert$ (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)

~90† % total phase space, thus theory error less correlated to other Vub determinations

$|V_{ub}|$ using SF indipendent analyses

- **QCD interaction affecting $b \to s\gamma$ and $b \to u\ell\nu$ are the same**
- **Take ratio of weigheted rates**

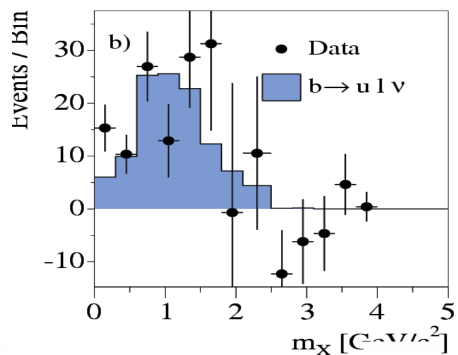
Lange, Neuber, Paz JHEP0510:084 (2005)

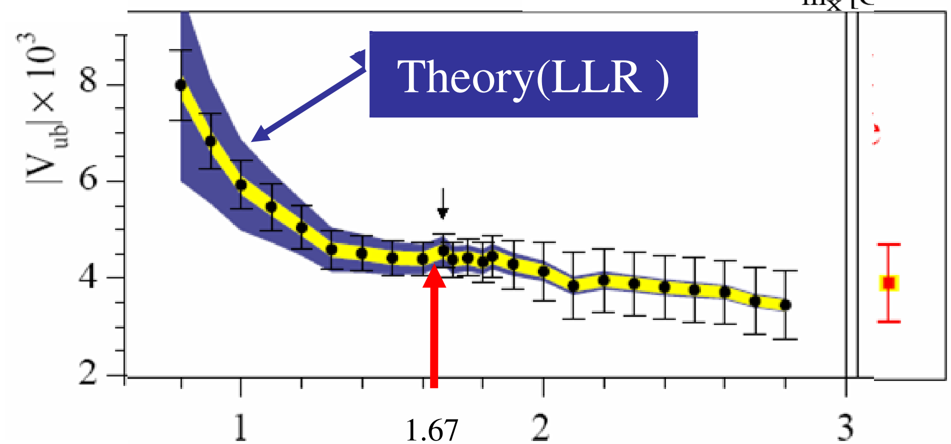
$$\int_0^{m_{max}} \frac{d\Gamma(b \to u)}{dm_X} dm_X \Longleftrightarrow \int_{E_{min}}^{m_B/2} \frac{d\Gamma(b \to s\gamma)}{dE_\gamma} W(E_\gamma, E_{min}) dE_\gamma$$

Leibovich, Low, Rothstein PRD61,053006(2000) PLB513,83 (2001)

PRL96,221801(2006)

- *Measuring m_X using the B_{reco} sample*
- *Statistics limited (89 M BB)*

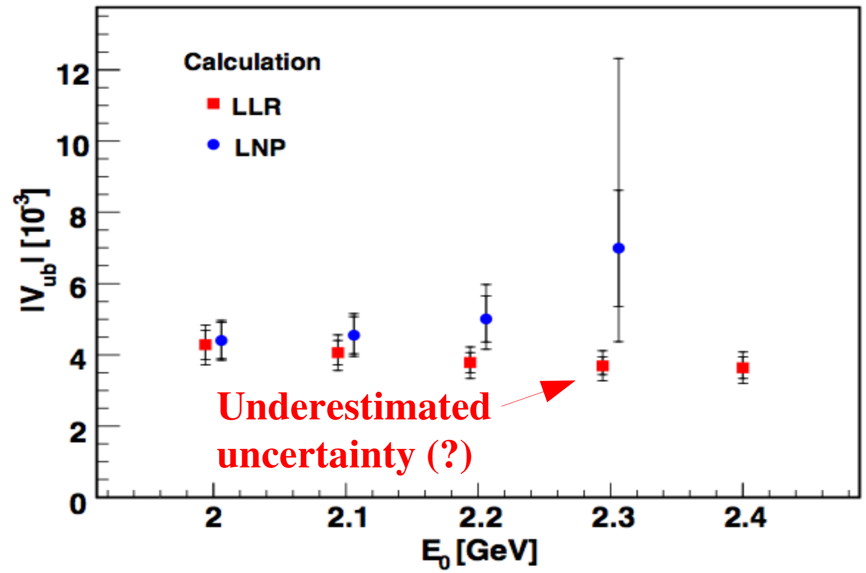




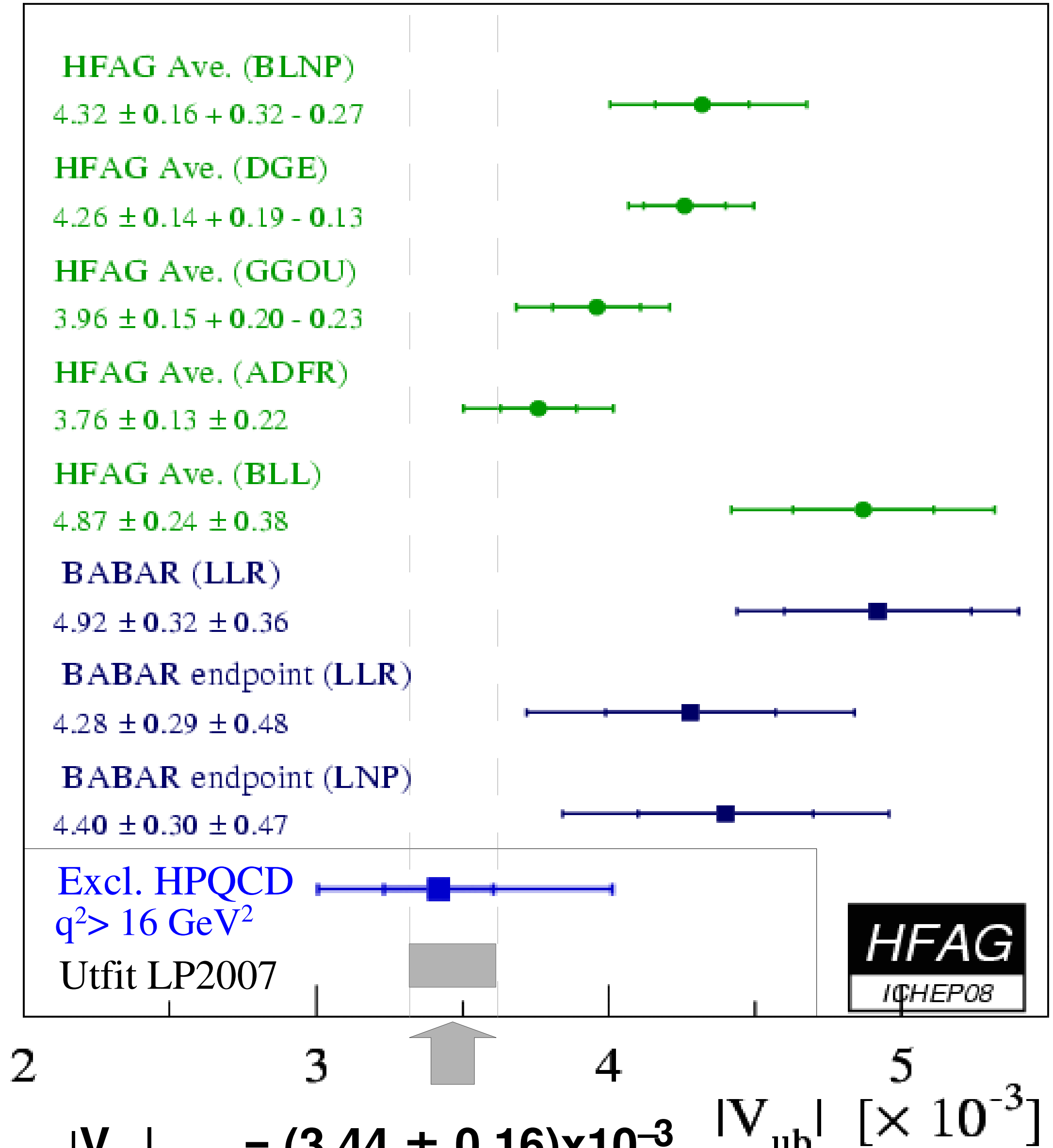
$|V_{ub}|=(4.43 \pm 0.30_{stat} \pm 0.25_{syst} \pm 0.29_{theo.})\times 10^{-3}$

Golubev, Skovpen, Luth PRD76,114003(2007) using the BaBar data

- **Using the E_ℓ endpoint spectrum (BaBar data PRD73,012006(2006)**
- **cosistent results (except at high E_ℓ)**



$|V_{ub}|$ results (different calculation)



OPE approach

SF free

Different theoretical calculation

Results vary from 3.76×10^{-3} (AC) to 4.92×10^{-3} (LLR)

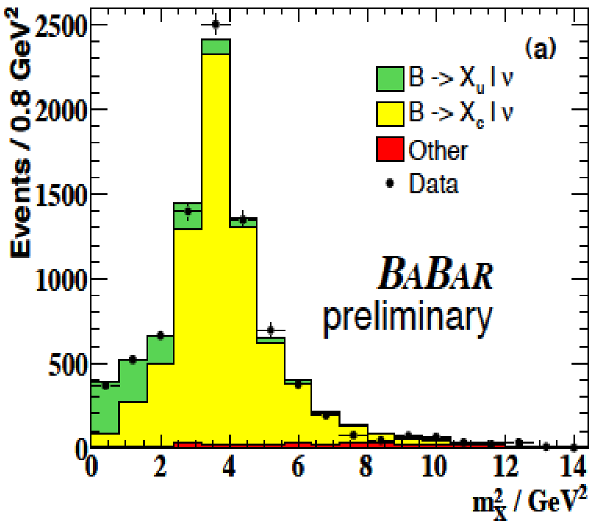
$|V_{ub}|_{UTfit}$ = **(3.44 ± 0.16)x10^{-3}**

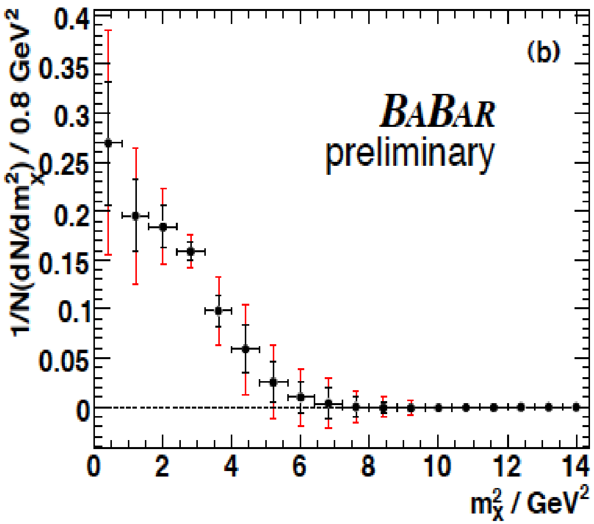
Comparison with Excl. (HPQCD)

$$|V_{ub}|_{excl.} = (3.40 \pm 0.20 \,{}^{+0.59}_{-0.39}\,\text{FF})10^{-3}$$

Hadronic Moments in $B \to X_u l \nu$ decays

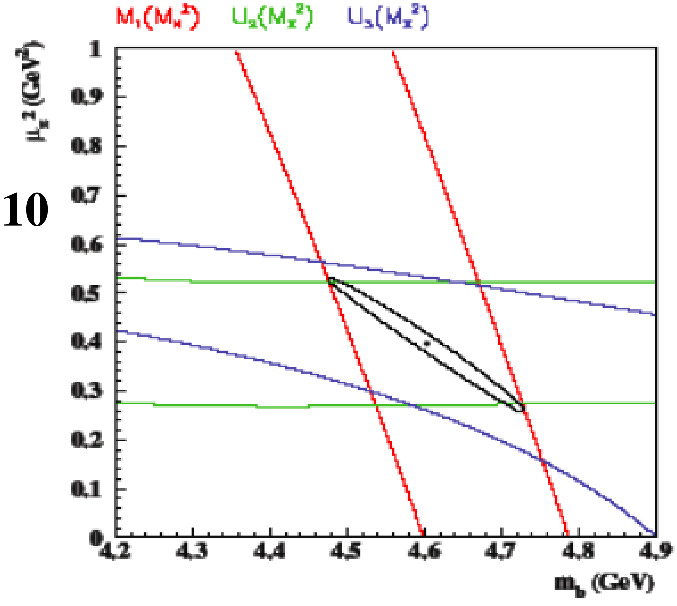
- Measure hadronic mass spectrum over full m_X range
- Mass moments related to m_b: extract moments with upper cut $m_x^2 < 6.4$ GeV^2





ArXiv: 0801.2985[hep-ex]

Mom		Stat.	Syst.	
M1	1.96	± 0.34	± 0.53	GeV^2
U2	1.92	± 0.59	± 0.87	GeV^4
U3	1.79	± 0.62	± 0.78	GeV^6



Calculations of Gambino, Ossola, Uraltsev JHEP09(2005)010

First measurement of m_b in $B \to X_u \ell \nu$ decays (in the Kinetic scheme)

$$m_b = 4.604 \pm 0.250 \text{ GeV}$$

compatible with Global Fit

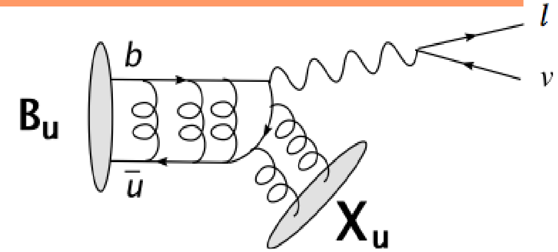
Weak Annihilation in $B \to X_u l\nu$

- Small contribution to $B \to X_u \ell\nu$ decays:

$$\frac{|\Gamma_{WA}|}{\Gamma_u} < 7.4\% \text{ at } 90\% C.L.$$

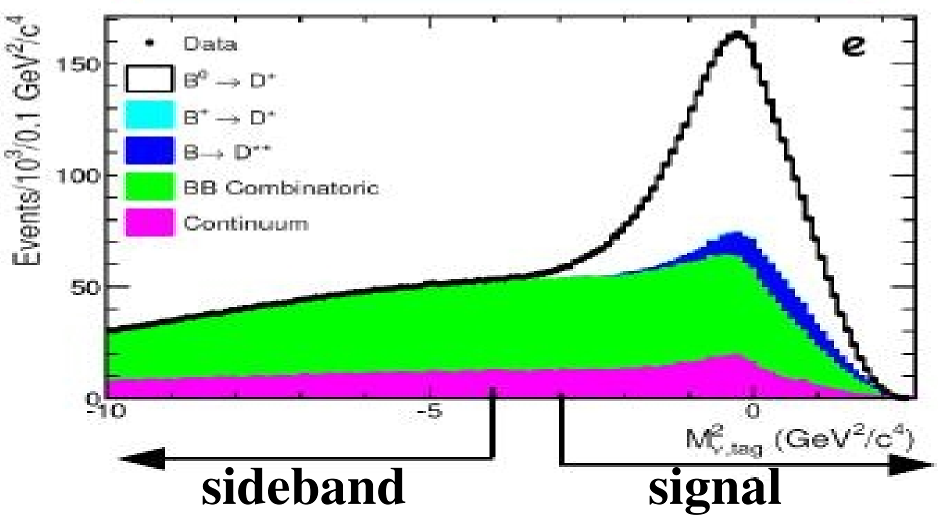
CLEO, studing the q^2 spectra PRL96,121801 (2006)

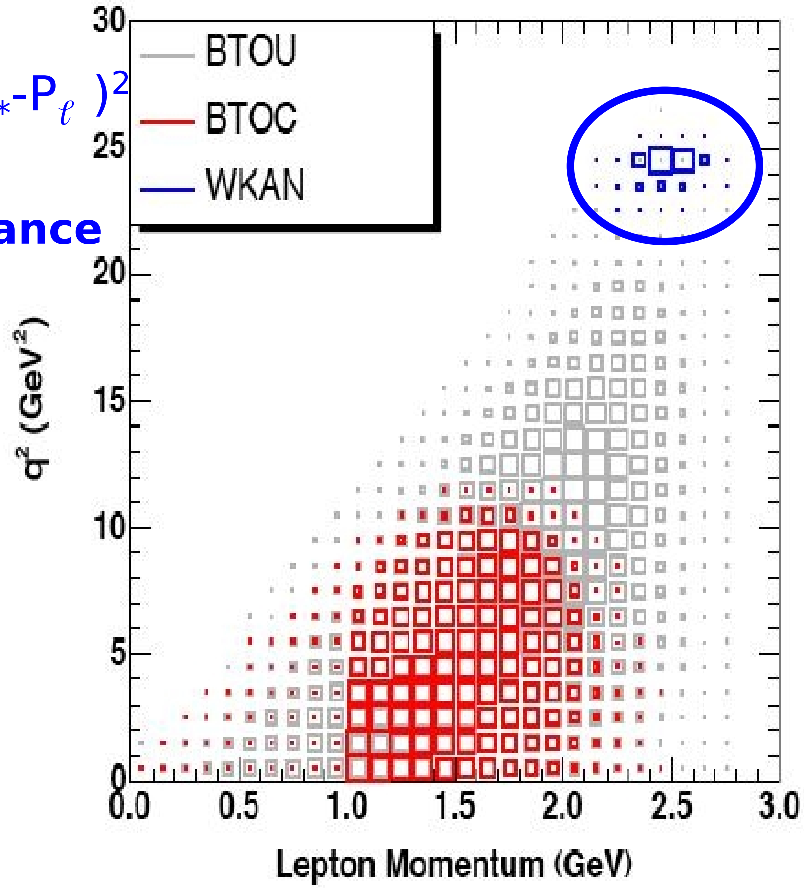
ArXiv: 0708.1753 383 MBB



- Introduce difference between B^0 and B^+ decays
- Tag with partial reconstructed $B^0 \to D^{*+} \ell\nu$
- Neutrino mass from kinematics: $m_\nu^2 = (P_B - P_{D*} - P_\ell)^2$
- **Compare B^0 partial rate to charge averaged $B \to X_u \ell\nu$ rate in the large p_ℓ region (to enhance the WA contribution) PRD73,012006(2006)**

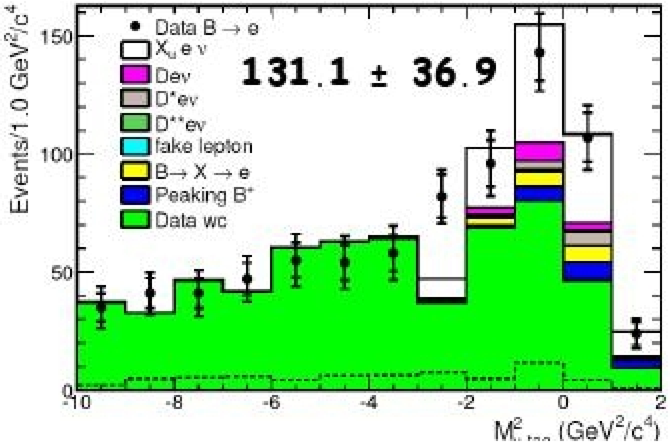
$N_{B^0} = (3606.4 \pm 9.2_{stat} \pm 47.1_{sist}) \times 10^3$

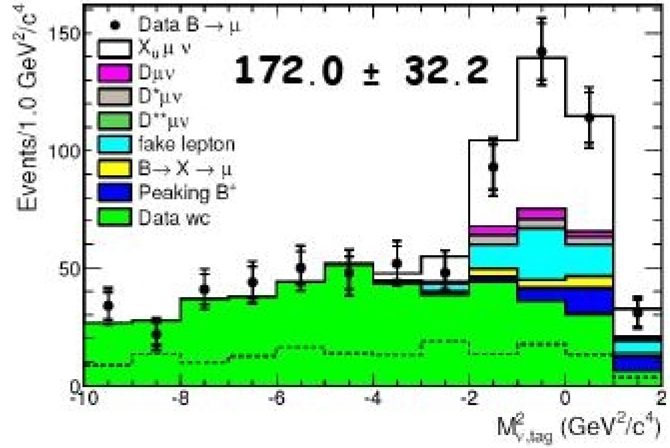




Weak Annihilation in $B \to X_u l \nu$

for Δp= 2.3-2.6 GeV/c ~ 300 $B \to X_u l \nu$ events (e+μ)





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

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±0.10±0.18	2.62±0.33±0.16	-0.17±0.15±0.11
$2.3 - 2.6\,\mathrm{GeV}/c$	1.46±0.06±0.10	1.30±0.21±0.07	0.08±0.15±0.08
$2.4 - 2.6\,\mathrm{GeV}/c$	0.75±0.04±0.06	0.76±0.15±0.05	-0.05±0.20±0.10

$$\frac{|\Gamma_{WA}|}{\Gamma_u} < \frac{3.8\%}{f_{WA}(2.3 - 2.6)} \; at\ 90\% C.L.$$

- $f_{WA}(\Delta p)$ is the fraction of WA in a Δp interval

Conclusion

- **Determination of $|V_{ub}|$ is crucial to over-constraint UT**
- **Significant improvements of understanding semileptonic decays in the last years; thanks to the continuous theory and experiment interaction;**
- **Inclusive $B \to X_u l \nu$ achieved < 9% error on |Vub| (crucial the role of m_b)**
- **Waiting for a complete analysis of the full BaBar dataset (full phase space analysis)**