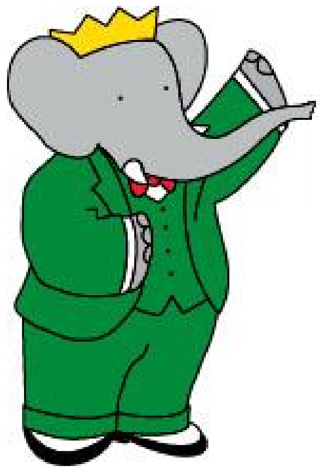
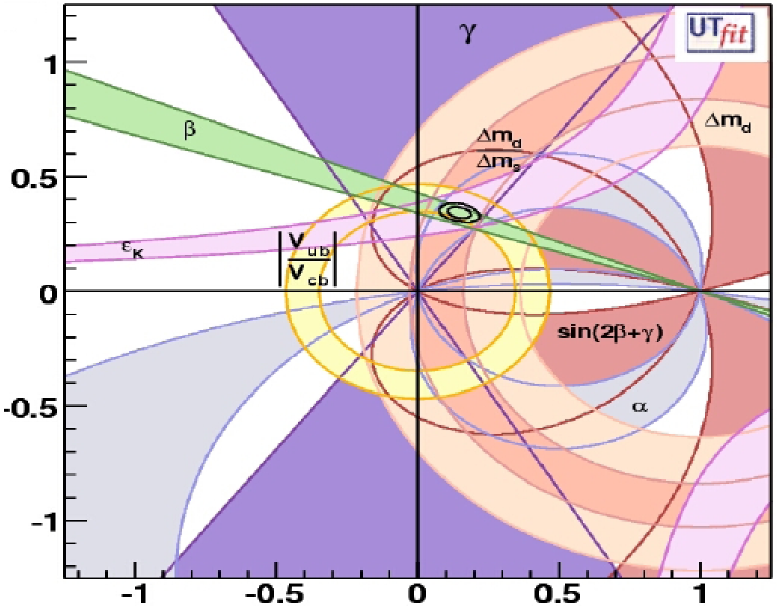
Heavy **Q**uarks and **L**eptons **2010**, LNF, October 11th 2010

Inclusive $|V_{ub}|$ from BaBar and Belle





Nicola Gagliardi

On behalf of the BaBar Collaboration

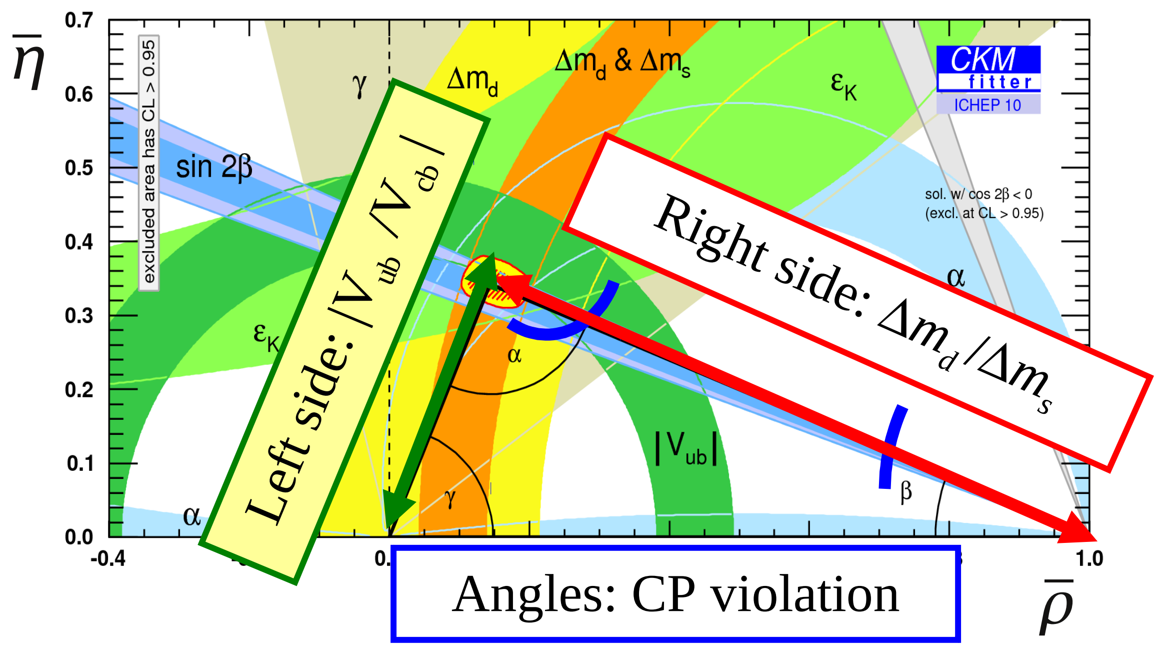
Outline

- **Motivation:**
  - Semileptonic decays and Inclusive $B \to X_u l\nu$ theory;
- **Inclusive $B \to X_u l\nu$:**
  - $|V_{ub}|$ measurements with endpoint method;
  - $|V_{ub}|$ measurements with hadronic tag;
    - New BaBar recoil analysis;
    - Belle multivariate analysis;
    - Weak Annihilation in $B \to X_u l\nu$ decays;
- **Conclusions.**

Motivation

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

Unitarity Triangle



Left side of the triangle:

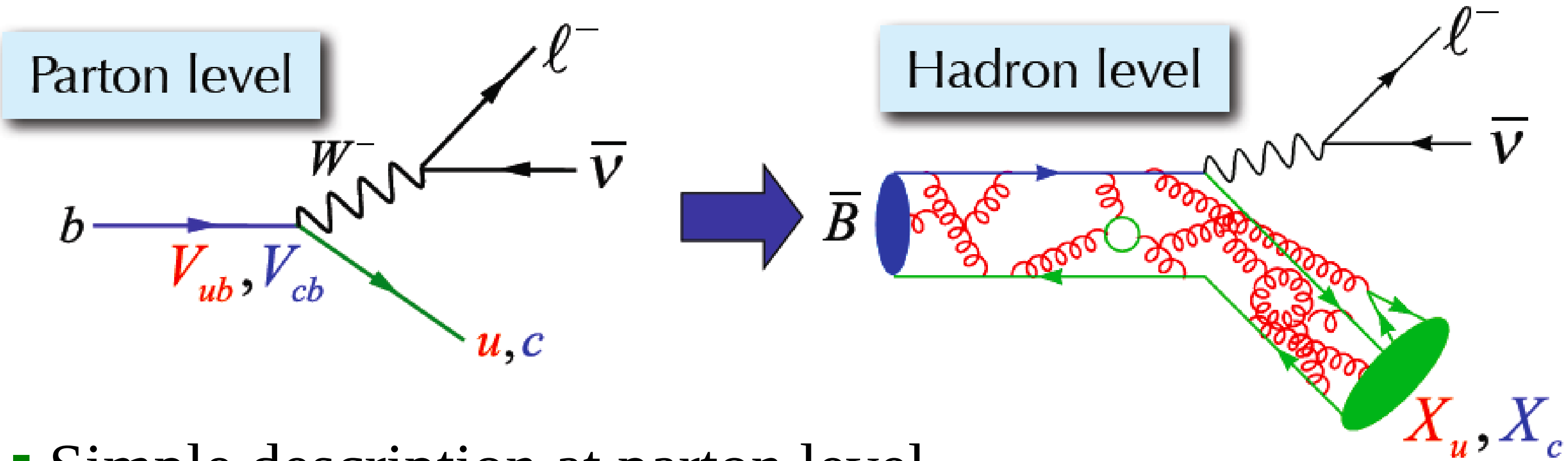
$$\left|\frac{V_{ud} V^*_{ub}}{V_{cd} V^*_{cb}}\right| = \left|\frac{V_{ub}}{V_{cb}}\right| \frac{1}{\tan(\theta_C)}$$

$$\left|\frac{\delta V_{cb}}{V_{cb}}\right| = 2\% \quad \left|\frac{\delta V_{ub}}{V_{ub}}\right| = 9\%$$

→ **Improve V_{ub} measurements**

Semileptonic B decays

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



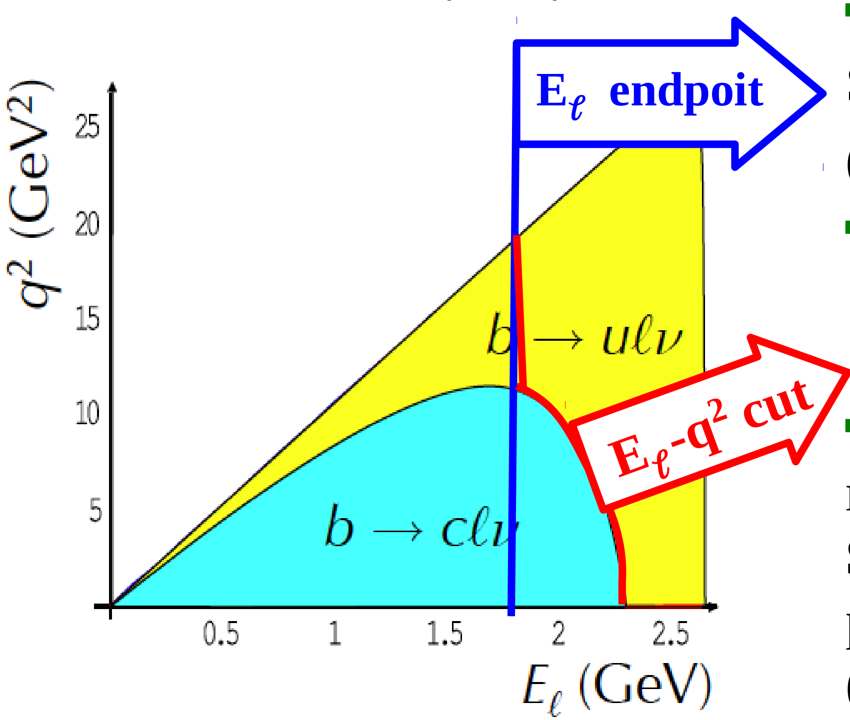
- Simple description at parton level
- Leptonic and hadronic current decoupled
- Understanding the QCD dynamics is crucial to extract informations on weak interactions

Inclusive $B \rightarrow X_u l\nu$

$$\Gamma(\bar{B} \rightarrow X_u l \bar{\nu}) = \frac{G_F^2 |V_{ub}|^2 m_b^5}{192\pi^3}[1 + O(\alpha_S) + O(1/m_b^2) + H.C.] \qquad OPE \sim 5\%$$

free quark decay perturbative correction non perturbative correction

$$\frac{B(b \rightarrow u l \nu)}{B(b \rightarrow c l \nu)} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$



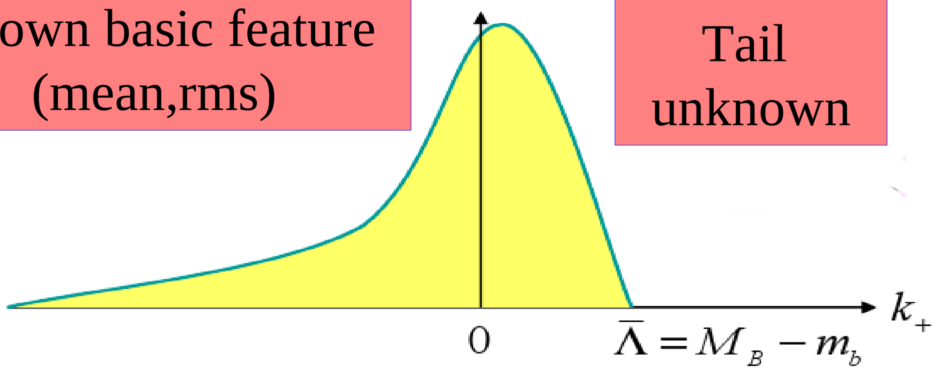
- $m_u \ll m_c$ different kinematics
- measure $\Delta B(B \rightarrow X_u l\nu)$ in a region where the S/N is good and the $\Delta\Gamma_u$ is reliably calculable (exclude $b \rightarrow cl\nu$ decays)
- OPE convergence is compromised ($O(1/m_b)$)

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

- 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 ($B \rightarrow X_c l\nu$ and $B \rightarrow X_s\gamma$ moments).

$B \to X_u l\nu$ theory: Shape Function

The shape function is a universal property of the B mesons
It depends on two parameters: m_b and μ^2_π



Measure SF parameters from $B \to X_s\gamma$ and $B \to X_c l\nu$ Global fit

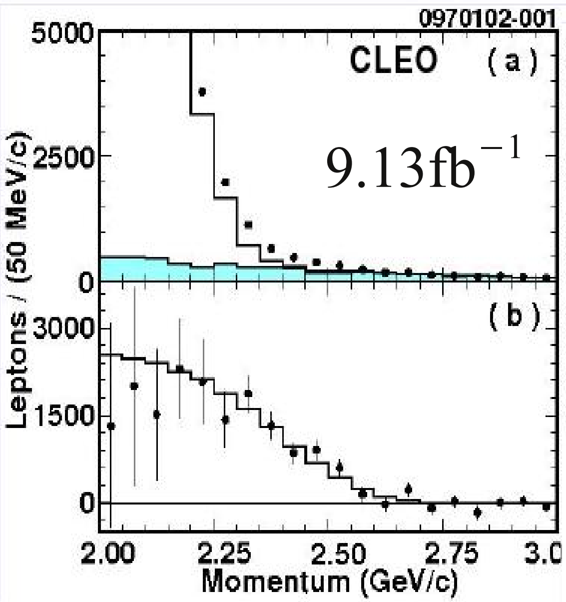
m_b(KS) = 4.59 ± 0.03 GeV
μ^2_π(KS) = 0.45 ± 0.04 GeV^2

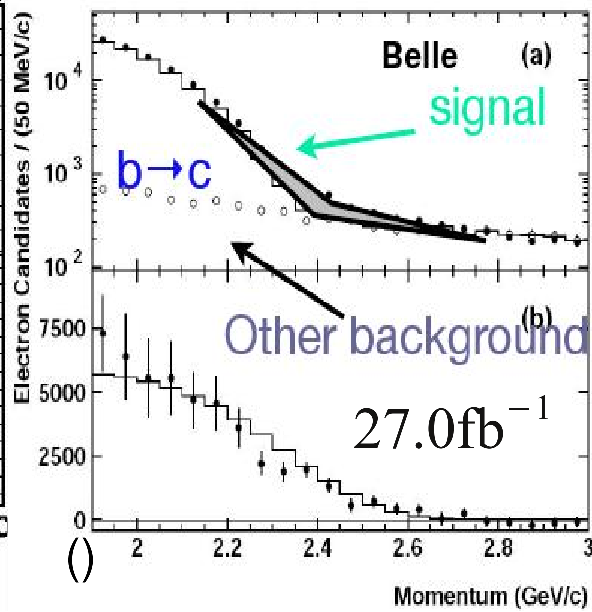
Different theoretical models available:
- ✔ BLNP (Bosh,Lange,Neubert,Paz) →

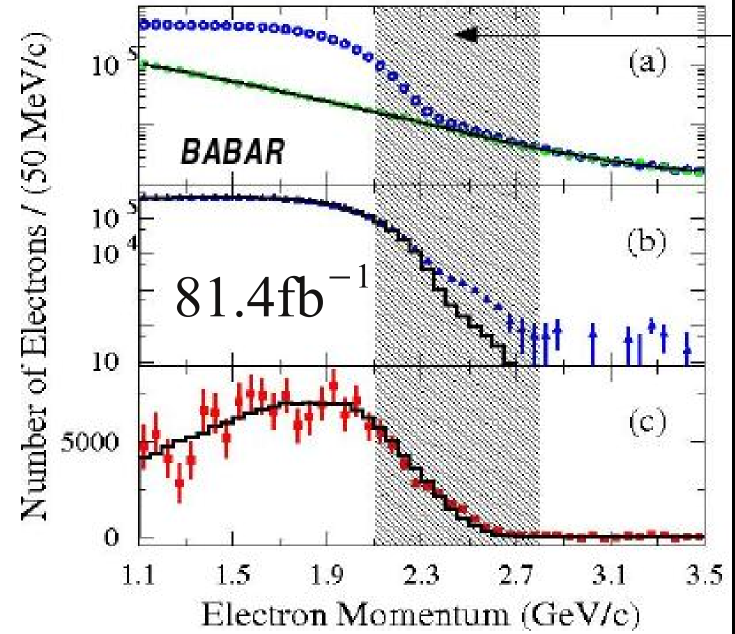
Theoretical error ~ 7%
(Phys.Rev. D72:0730006)

Exploiting all the large dataset collected by B-factories and the recently V_{cb} knowledge improvements ($B \to D,D^*,D^{**}$) is possible try to perform a full-phase space analysis in order to reduce the theoretical error at level of 5%

Endpoint method







Subtract offpeak data scaled to on peak 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)

$B\to D^{**} l\nu$, $B\to D^{(*)}\pi l\nu$

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

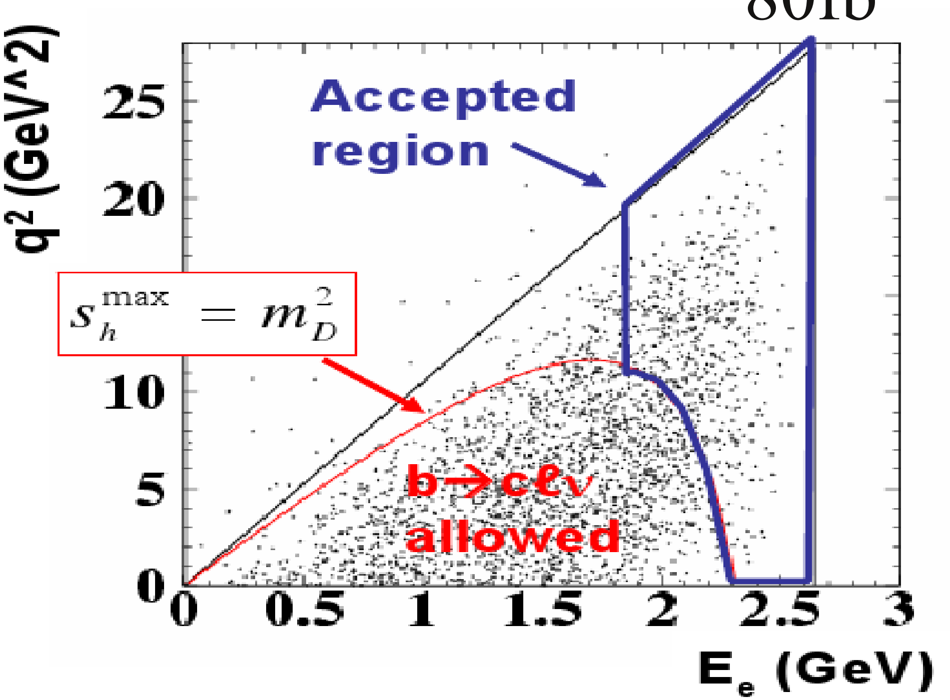
Simultaneous fit for non-BB,
$B\to X_u l\nu$, $B\to D l\nu$, $B\to D^* l\nu$, $B\to D^{**} l\nu$,
$B\to D^{(*)}\pi l\nu$,
other background

		Ecut	$\Delta BR \times 10^{-4}$
PRL 88, 231803, 2002	CLEO	2.2-2.6	$2{,}30 \pm 0{,}15_{stat} \pm 0{,}35_{sys}$
PRD 73, 012006, 2006	BaBar	2.0-2.6	$5{,}72 \pm 0{,}41_{stat} \pm 0{,}65_{sys}$
PLB 621, 28, 2005	Belle	1.9-2.6	$8{,}5 \pm 0{,}4_{stat} \pm 1{,}5_{sys}$

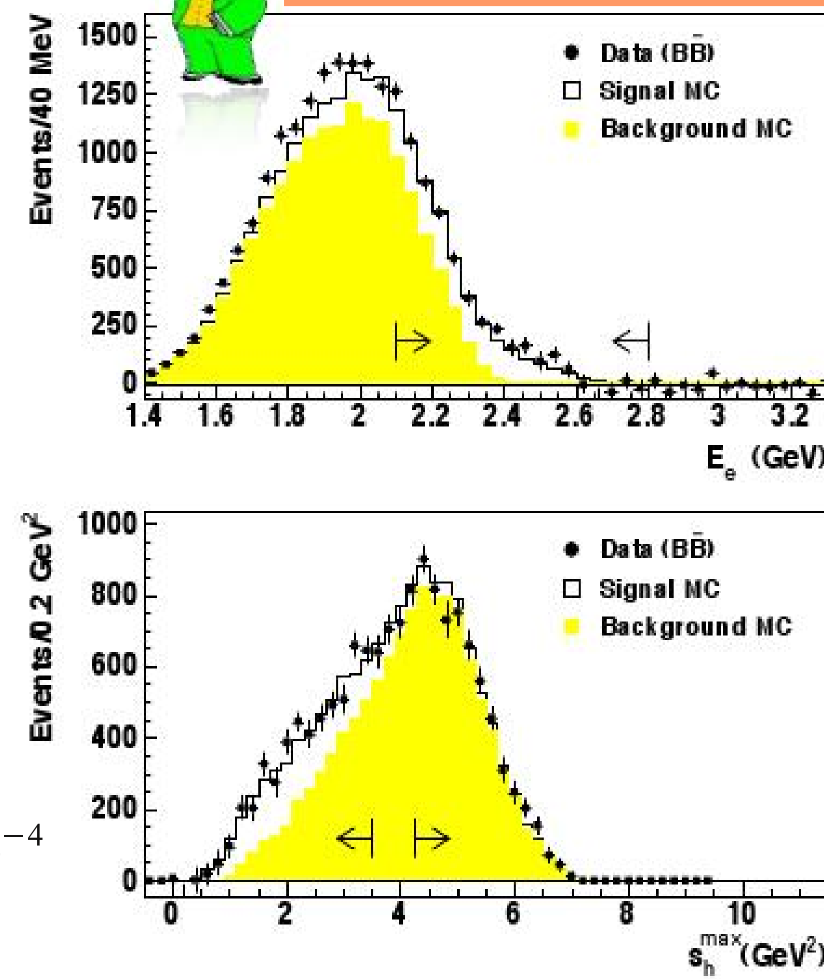
Improved Endpoint method: ν reconstruction

- Separate b→clν background by using: $s_h^{max} = m_B^2 + q^2 - 2m_B(E_e + \frac{q^2}{4}E_e)$
- $S/B \sim 1/2, \varepsilon \sim 25\%$

$80 fb^{-1}$



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



$$\Delta B(2.0-3.5) = (4.41 \pm 0.42_{stat} \pm 0.42_{syst}) \times 10^{-4}$$

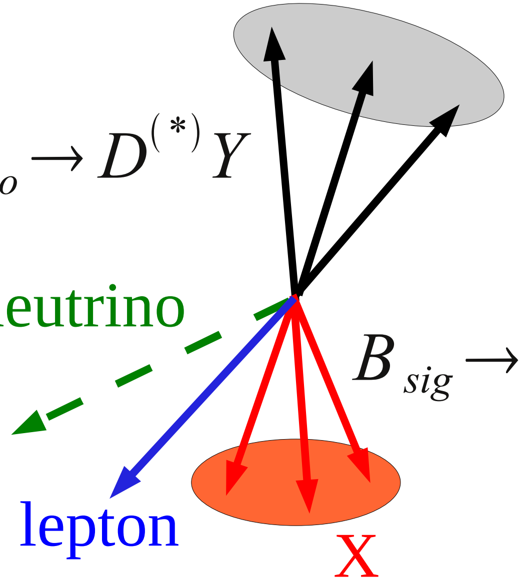
Inclusive $|V_{ub}|$ with hadronic tag

One B fully reconstructed:

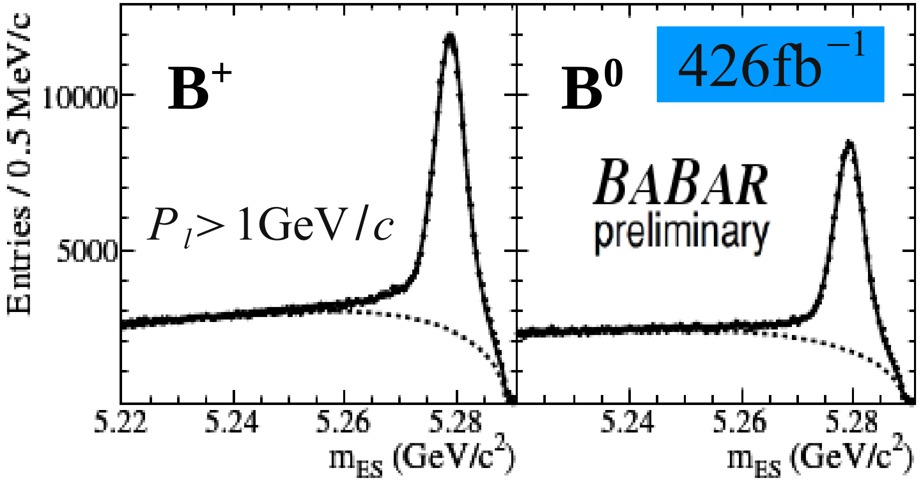
$$B \rightarrow D^{(*)} Y$$

$$Y = n\pi + m\pi^0 + pK_S + qK$$

$$B_{reco} \rightarrow D^{(*)} Y$$



$$B_{sig} \rightarrow X_u l \nu$$



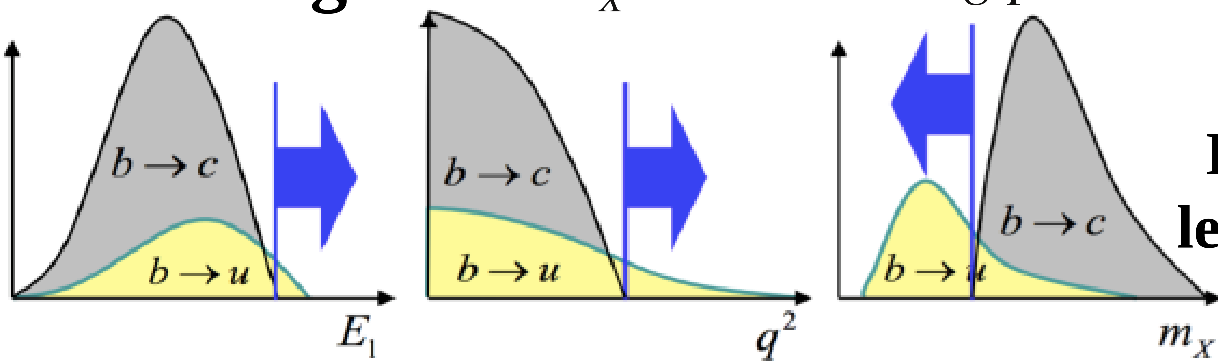
Study the recoiling B →

$$P_{miss} = P_{Y(4S)} - P_{Reco} - P_X - P_l$$

$$m_X : all\ remaining\ particles$$

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

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



Experimental resolution leads to irreducible b→clν contamination

New BaBar recoil analysis

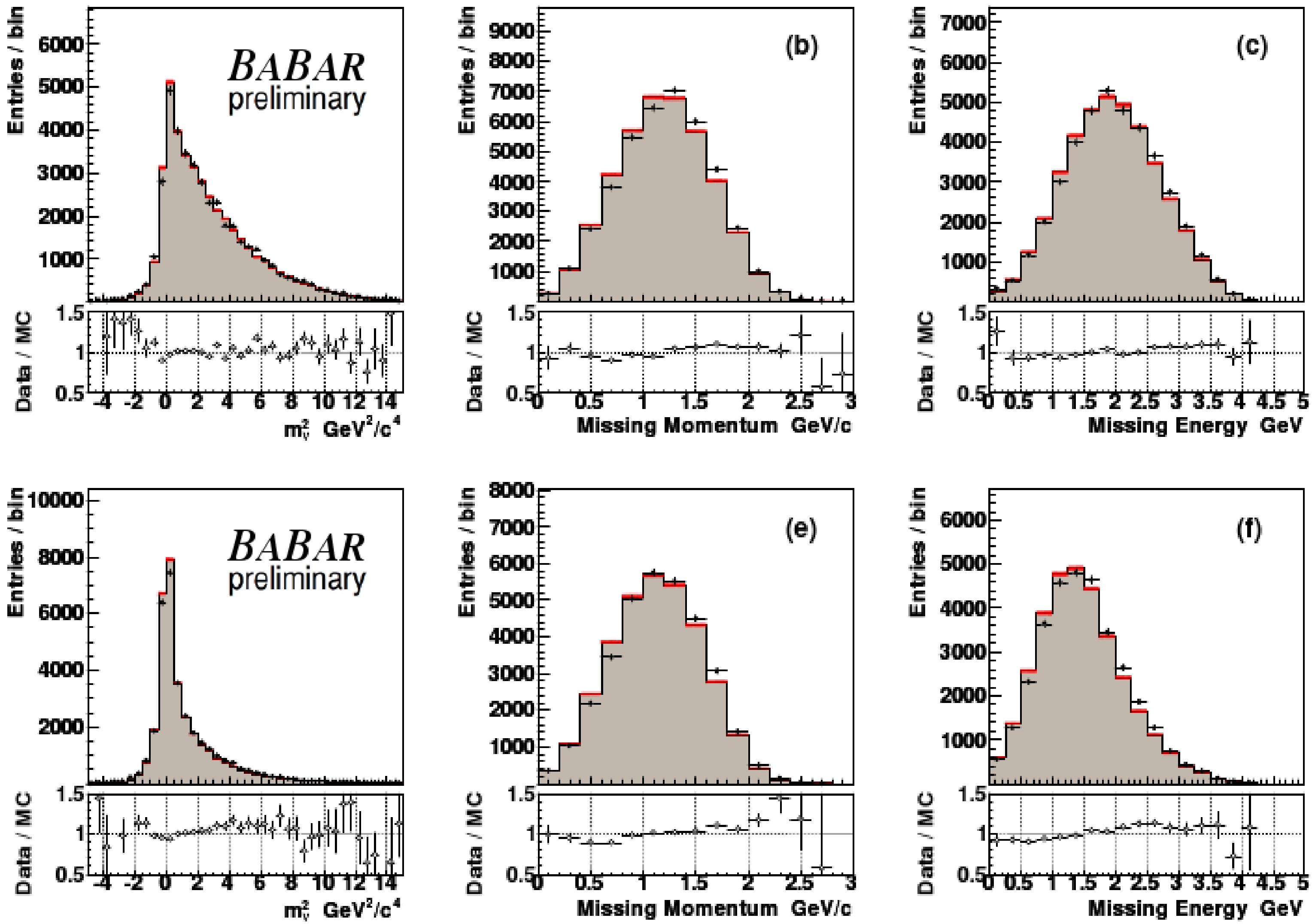
- Update of Phys. Rev. Lett. 100 (2008) 171802 on the full BaBar dataset (426 fb^{-1});
- Improved B_{reco} section and better treatment of the systematics;
- More region of phase space analyzed;
- Result also for charged and neutral B separately (WA limits);
- Select three sample on the recoil side:

(1) Semileptonic selection *(for normalization)*	At least one lepton $p^*_\ell > 1.0\,\mathrm{GeV}/c$
(2) $\bar{B} \to X_u \ell \bar{\nu}$ signal enhanced selection	Only one lepton $m^2_{miss} < 0.5\,\mathrm{GeV}^2/c^4$ (Charge) $Q_{\mathrm{B_{reco}}} + Q_{\mathrm{B_{recoil}}} = 0$ $Q_{B_{\mathrm{recoil}}} Q_\ell > 0$ (only for $B^\pm$) Veto events with partially reconstructed $D^* \ell^\mp \bar{\nu}$ Veto events with kaons in the B_{recoil}
(3) $\bar{B} \to X_u \ell \bar{\nu}$ signal depleted selection	Selection (2) without kaon veto, and partial $D^* \ell^\mp \bar{\nu}$ veto

Data/MC agreement

Signal-depleted

Signal-enhanced



Extraction of signal Yields

- Fit the distribution of different kinematic variables in several regions of phase space:
  - ☆ $M_X < 1.55\, GeV/c^2$
  - ☆ $M_X < 1.70\, GeV/c^2$
  - ☆ $P_+ < 0.66\, GeV/c$
  - ☆ $M_X < 1.70\, GeV/c^2,\ q^2 > 8\, GeV^2/c^4$
  - ☆ $M_X,\ q^2\ p_l > 1 GeV/c$
  - ☆ $p_l,\ p_l > 1.0 - 2.3\, GeV/c$

- Subtract the combinatorial background by fitting m_{ES} distribution in each bin;
- Signal yield extracted with a χ^2 shape fit;
- Reweighted SL decays into P-wave D meson by using the signal-depleted sample:
  - Fit quality improve;
  - $N_{D^{**}}/(N_D+N_{D^*}+N_{D^{**}})$ smaller in data then MC;

- Normalized to semileptonic sample in order to reduce experimental systematic uncertainty:

$$\Delta R_{u/sl} = \frac{(N_u^{fit})/(\epsilon_{sel}^u \epsilon_{kin}^u)}{N_{SL}^{meas} - BG_{sl}} \times \frac{\epsilon_l^{sl} \epsilon_t^{sl}}{\epsilon_l^u \epsilon_t^u}$$

$$\Delta R_{u/sl} \times (10.66 \pm 0.15)\%$$

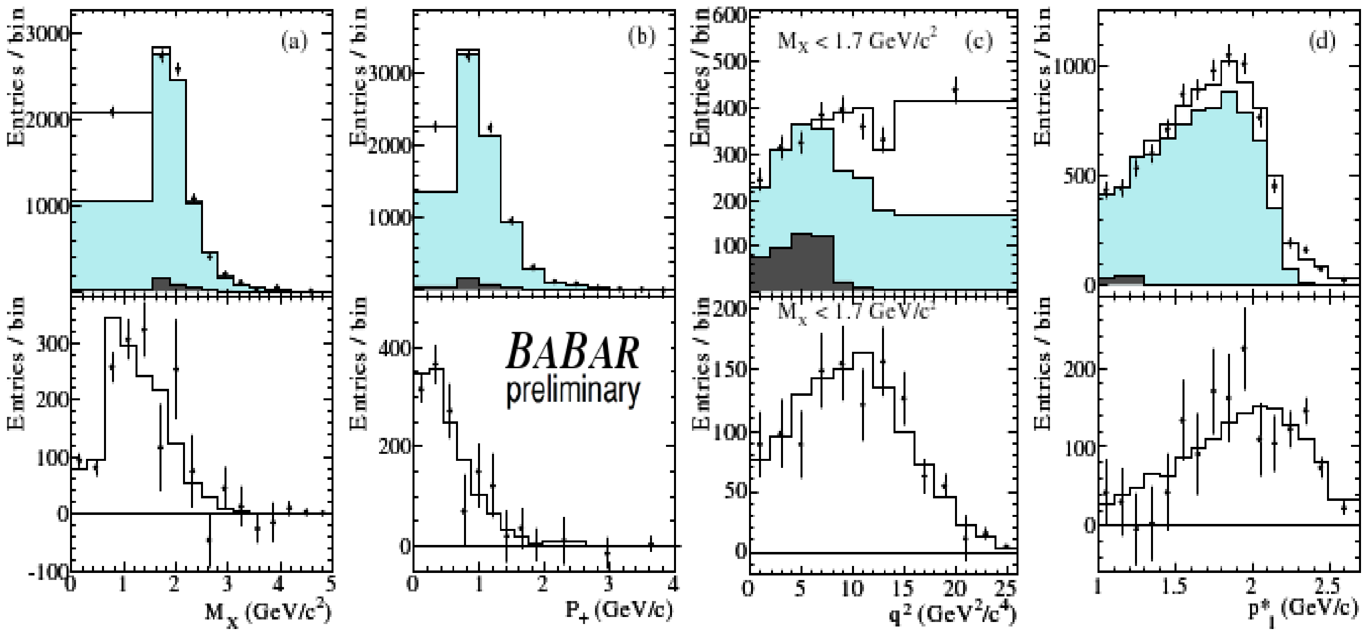
↓

$$\Delta B(\bar{B} \rightarrow X_u l \bar{\nu})$$

New BaBar recoil analysis: results

- B ->X_u lv signal
- B ->X_u lv cross-feed
- B ->X_c lv + Other

$426 fb^{-1}$



	Signal yield	$\Delta\mathcal{B}(\bar{B} \to X_u \ell \bar{\nu})$ (10^{-3})
$M_X < 1.55$	$1033 \pm 73_{stat}$	$1.08 \pm 0.08_{stat} \pm 0.06_{sys}$
$M_X < 1.70$	$1089 \pm 82_{stat}$	$1.15 \pm 0.10_{stat} \pm 0.08_{sys}$
$P_+ < 0.66$	$902 \pm 80_{stat}$	$0.98 \pm 0.09_{stat} \pm 0.08_{sys}$
$M_X < 1.70$ and $q^2 > 8$	$665 \pm 53_{stat}$	$0.68 \pm 0.06_{stat} \pm 0.04_{sys}$
(M_X, q^2), $p^*_\ell > 1.0$	$1441 \pm 102_{stat}$	$1.80 \pm 0.13_{stat} \pm 0.15_{sys}$
$p^*_\ell > 1.0$	$1462 \pm 137_{stat}$	$1.76 \pm 0.16_{stat} \pm 0.18_{sys}$
$p^*_\ell > 1.3$	$1326 \pm 118_{stat}$	$1.50 \pm 0.13_{stat} \pm 0.14_{sys}$

New BaBar recoil analysis: uncertainties

Source $\sigma(\Delta\mathcal{B}(B \to X_u \ell \nu))$	Babar preliminary $M_X < 1.55$ GeV/c^2	$M_X < 1.70$ GeV/c^2	$P_+ < 0.66$ GeV	$M_X < 1.70$ GeV/c, $q^2 > 8$GeV^2/c^4	(M_X, q^2) $p^*_\ell > 1.0$ GeV/c	$p^*_\ell > 1.3$ GeV/c	Belle $p^*_\ell > 1.0$ GeV/c
Statistical	**7.1**	**8.9**	**8.9**	**8.0**	**7.1**	**8.9**	**8.8**
MC statistics	**1.3**	**1.3**	**1.3**	**1.6**	**1.1**	**1.2**	
Detector-related	2.8	3.7	5.5	4.1	3.2	2.7	3.3
Fit-related	2.7	4.9	3.2	3.2	2.1	2.5	3.6
Signal model	2.7	3.0	3.5	1.9	6.6	7.9	6.3
Background model	2.0	2.6	3.4	2.8	2.8	2.2	1.7
Total syst	**5.2**	**6.3**	**8.1**	**6.2**	**8.1**	**9.0**	**8.1**
Total error	**8.9**	**11.0**	**12.1**	**10.3**	**10.8**	**12.7**	**12.0**

- Statistical error: 7-9%;
- Systematic uncertainty dominated by signal model in the most inclusive analysis;
- Total uncertainties: 9-13% ⟶ 4-6% on $|V_{ub}|$.

Belle recoil analysis

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

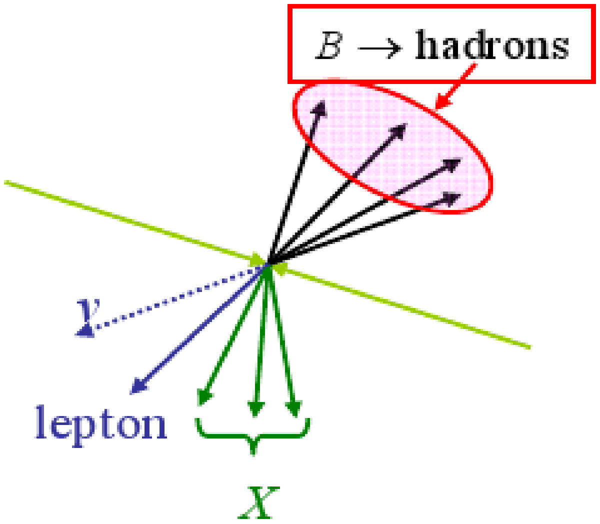
- exploit the many non-linear correlation between kinematic and event variables available in B-beam sample that separate b→u and b→c.
- **Boosted decision tree** based selection, use ~ 20 event parameters from the full reconstruction sample

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

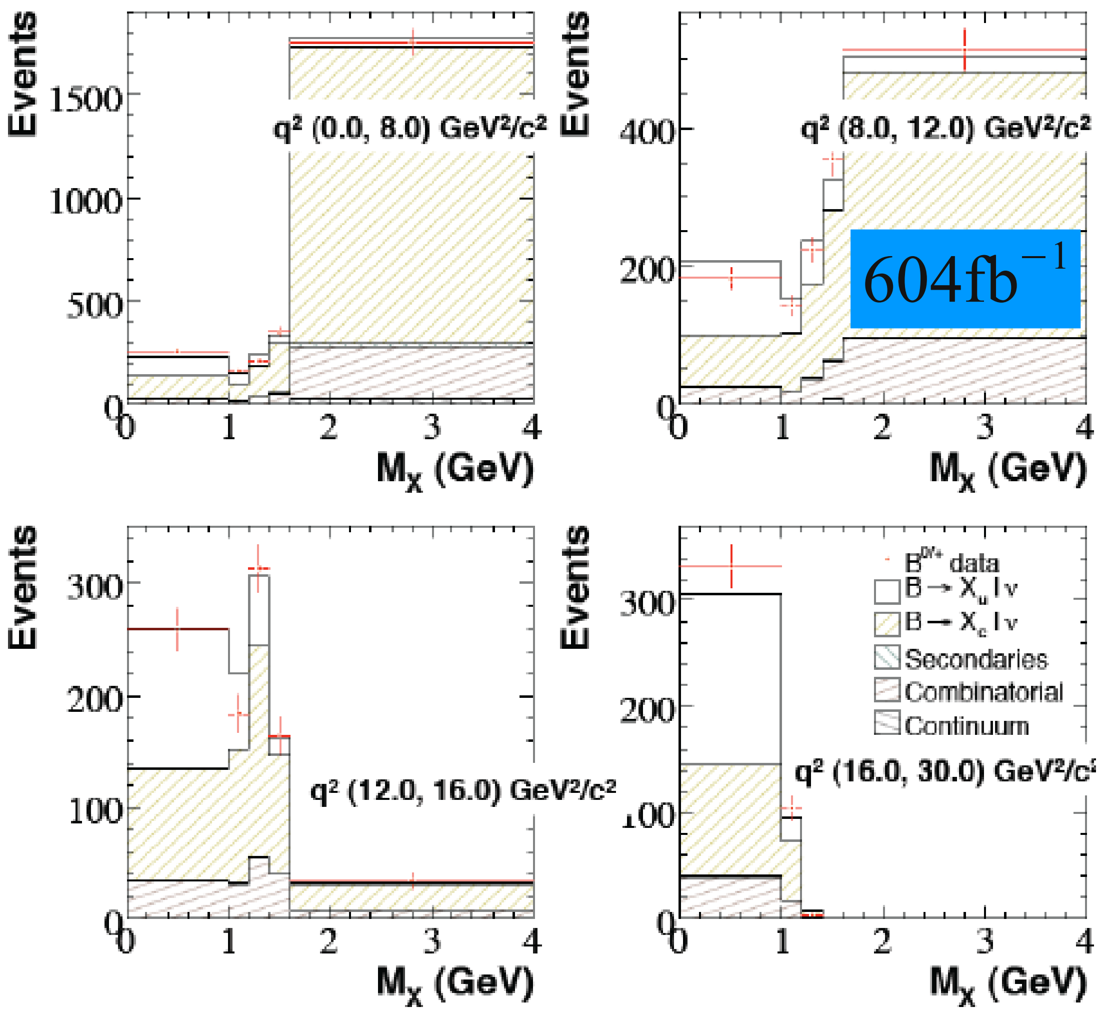
PRL 104:021801 (2010)

$604 fb^{-1}$

- 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 **M_X,q^2** with background and signal floated to determine background yield;
- Measure absolute rate.



Belle recoil analysis: results



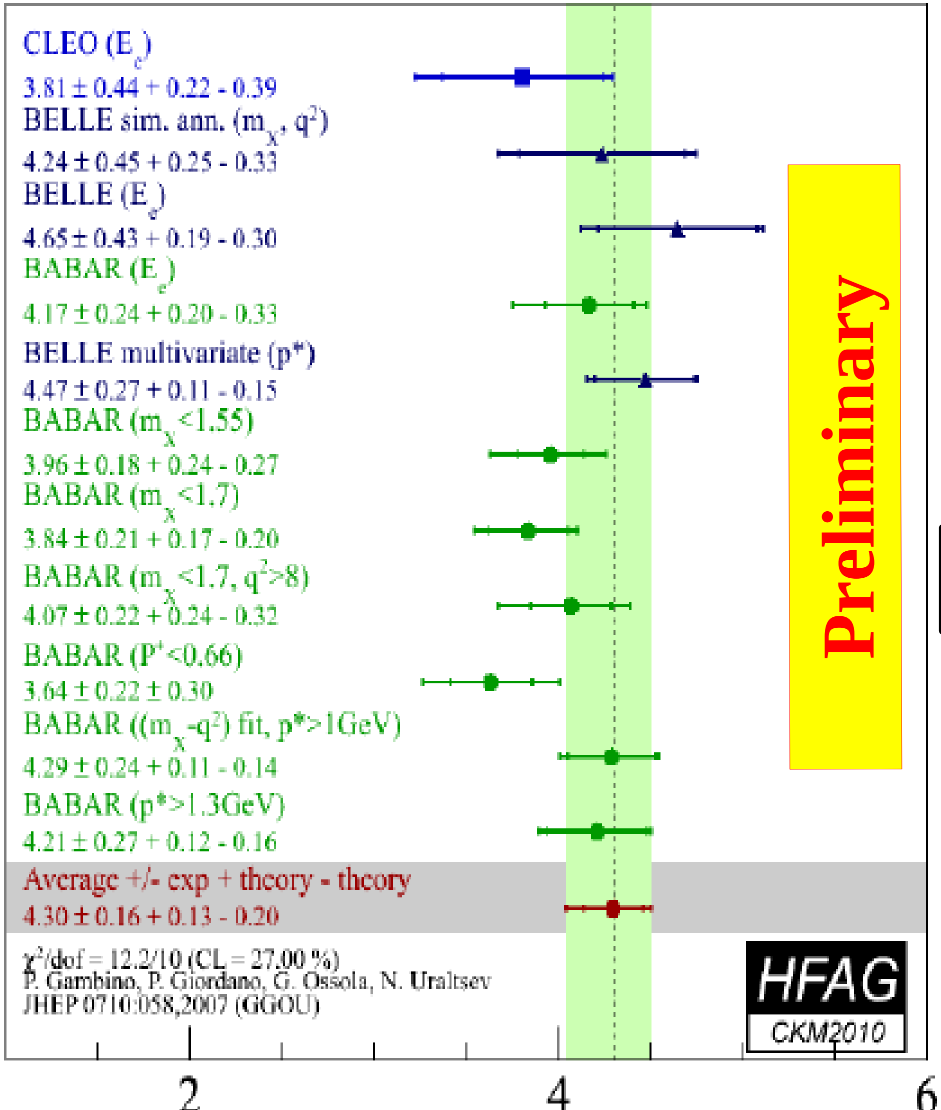
$\sim 1035\, B \to X_u l \nu$ *events*

$p_\ell^{*B} > 1.0$ GeV	$\Delta\mathcal{B}/\mathcal{B}$ (%)
$\mathcal{B}(D^{(*)}\ell\nu)$	1.2
$(D^{(*)}\ell\nu)$ form factors	1.2
$\mathcal{B}(D^{**}e\nu)$ & form factors	0.2
$B \to X_u\ell\nu$ (SF)	3.6
$B \to X_u\ell\nu$ ($g \to s\bar{s}$)	1.5
$\mathcal{B}(B \to \pi/\rho/\omega\ell\nu)$	2.3
$\mathcal{B}(B \to \eta,\ \eta'\ell\nu)$	3.2
$\mathcal{B}(B \to X_u\ell\nu)$ un-meas.	2.9
Cont./Comb.	1.8
Sec./Fakes/Fit.	1.0
PID/Reconstruction	3.1
BDT	3.1
Systematics	8.1
Statistics	8.8

PRL 104:021801 (2010)

$$\Delta B(B \to X_u l \nu;\, p_l > 1.0\, GeV) = 1.963 \times (1 \pm 0.088_{stat} \pm 0.081_{syst}) \times 10^{-3}$$

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



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

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

- Acceptances provided by many different theoretical models;
- Many $|V_{ub}|$ values.

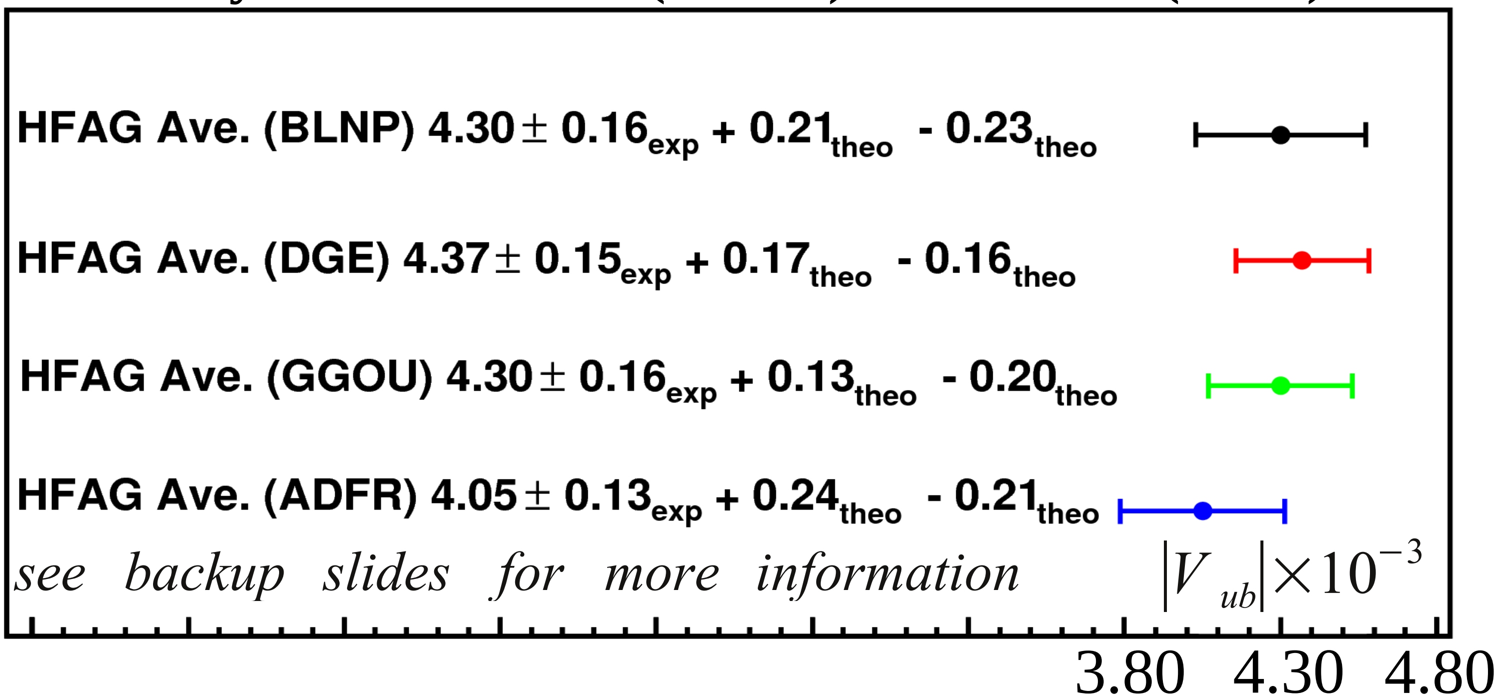
$|V_{ub}| = (4.30 \pm 0.16 + 0.13 - 0.20) \times 10^{-3}$

δ|Vub|	+4.9% -6.3%
Statistical	2.3%
Exp.systematics	1.9%
$b \to c \ell \nu$ model	1.2%
$b \to u \ell \nu$ model	1.6%
Non pert.-	1.5%
Higher order par.	2.5%
q^2 tail model	1.7%
Weak Annihilation	-3.9%

$|V_{ub}|$ results (different theoretical models)

Result vary from 4.05x10^{-3} (ADFR) to 4.37x10^{-3} (DGE)

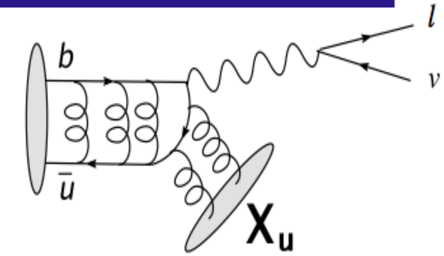
Preliminary



- The $|V_{ub}|$ values consistent within one σ of each other, and also consistent within one σ of previous measurements;
- Obtained the most precise determination from the analysis based on the two dimensional fit on M_X and q^2 plane with no cuts other than p_{lep} >1GeV/c: the total uncertainty is comparable between BaBar and Belle.

Limits on Weak Annihilation effects

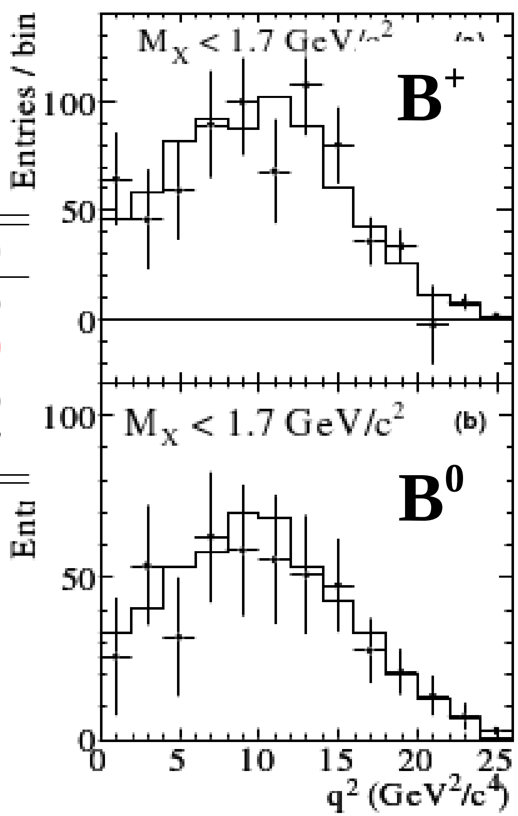
- Weak Annihilation (WA) could cause differences in the BFs for B^+ and B^0 mesons leading to an asymmetry that may effect $|V_{ub}|$;
- Use BFs for B^0 and B^+ to set a limit on the size of the WA in B^+ decays;



BABAR preliminary 426fb^{-1}

$$\frac{\gamma_{WA}}{\Gamma} = \frac{f_u}{f_{WA}} \cdot \left(\frac{R^{\pm}_{u/sl}}{R^{0}_{u/sl}} - 1 \right)$$

	$R^{+/0} - 1$	C.L. (90%)
$M_X \leq 1.70,\ q^2 \geq 8$	$0.042 \pm 0.066 \pm 0.009$	$-0.07 \leq \gamma_{WA}/\Gamma \leq 0.15$
$M_X \leq 1.55$	$-0.020 \pm 0.066 \pm 0.003$	$-0.13 \leq \gamma_{WA}/\Gamma \leq 0.09$
$M_X \leq 1.70$	$0.071 \pm 0.117 \pm 0.011$	$-0.12 \leq \gamma_{WA}/\Gamma \leq 0.26$
$(M_X,\ q^2)\ p^*_\ell > 1.0$	$0.109 \pm 0.157 \pm 0.019$	$-0.15 \leq \gamma_{WA}/\Gamma \leq 0.37$



Other results:

CLEO, *studing the q^2 spectra PRL 96,12801 (2006)*

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

BaBar ArXiv: 0808.1753
383 M BB

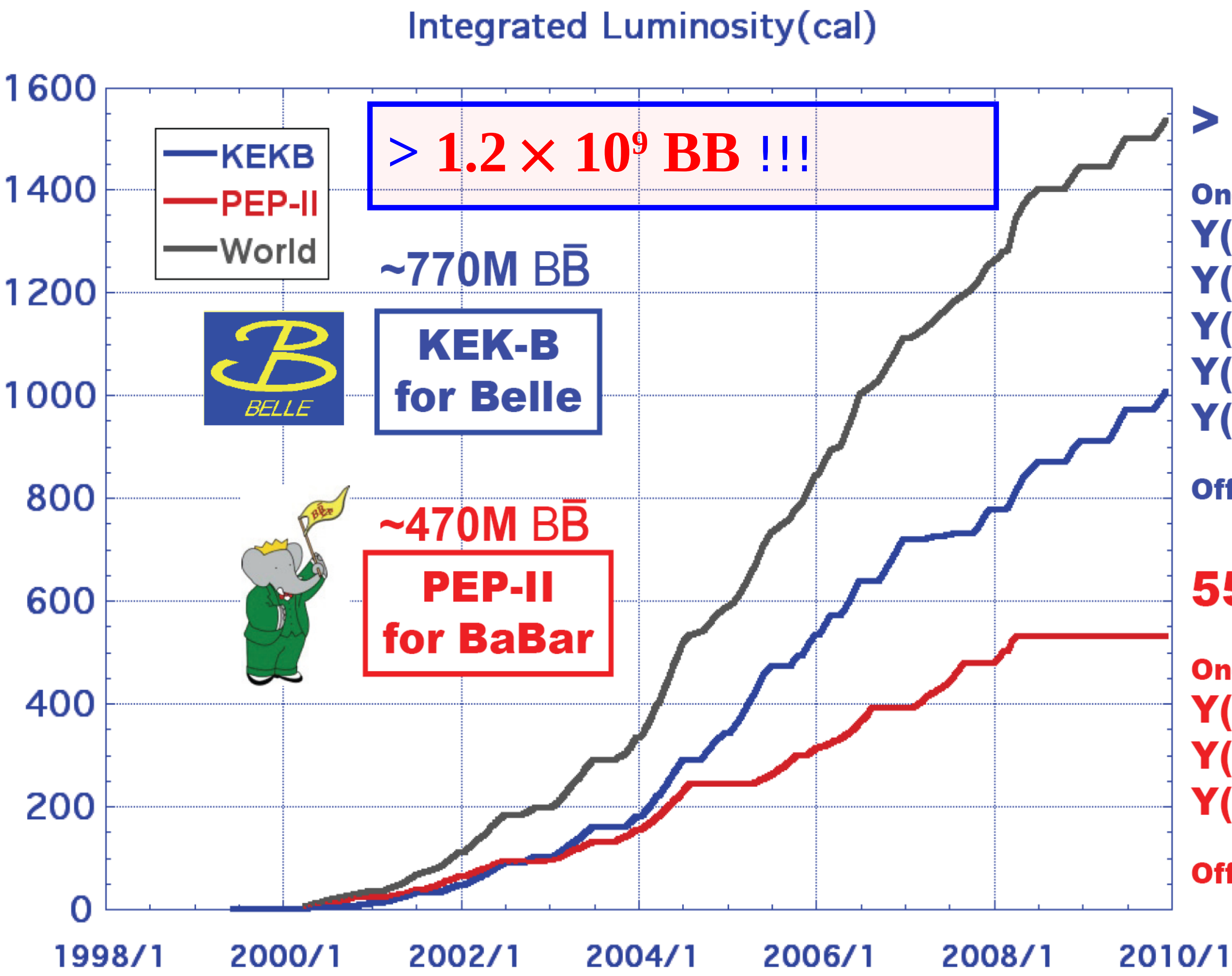
$$\frac{|\Gamma_{WA}|}{\Gamma_u} < \frac{3.8\%}{f_{WA}(2.3-2.6)}\ @\ 90\%\ C.L.$$

Conclusions

- Determination of $|V_{ub}|$ is crucial to over-constraint UT;
- Inclusive $|V_{ub}|$ determinations for different calculations give similar theory uncertainty;
- Total uncertainty on inclusive $|V_{ub}|$ determinations at the 6% level, dominated by parametric errors (e.g. about 4% from m_b);
- NNLO calculations not included: sizable impact on BLNP model;
- With the hadronic tag method we set a limit on the size of WA < 9% at 90%C.L.

Backup slides

The B factories



> 1000 fb^{-1}

On-resonance samples:

Y(4S):711 fb^{-1}

Y(5S):121 fb^{-1}

Y(3S): 3.0 fb^{-1}

Y(2S): 24 fb^{-1}

Y(1S): 5.7 fb^{-1}

Off-resonance: 87 fb^{-1}

553.5 fb^{-1}

On-resonance samples:

Y(4S): 433 fb^{-1}

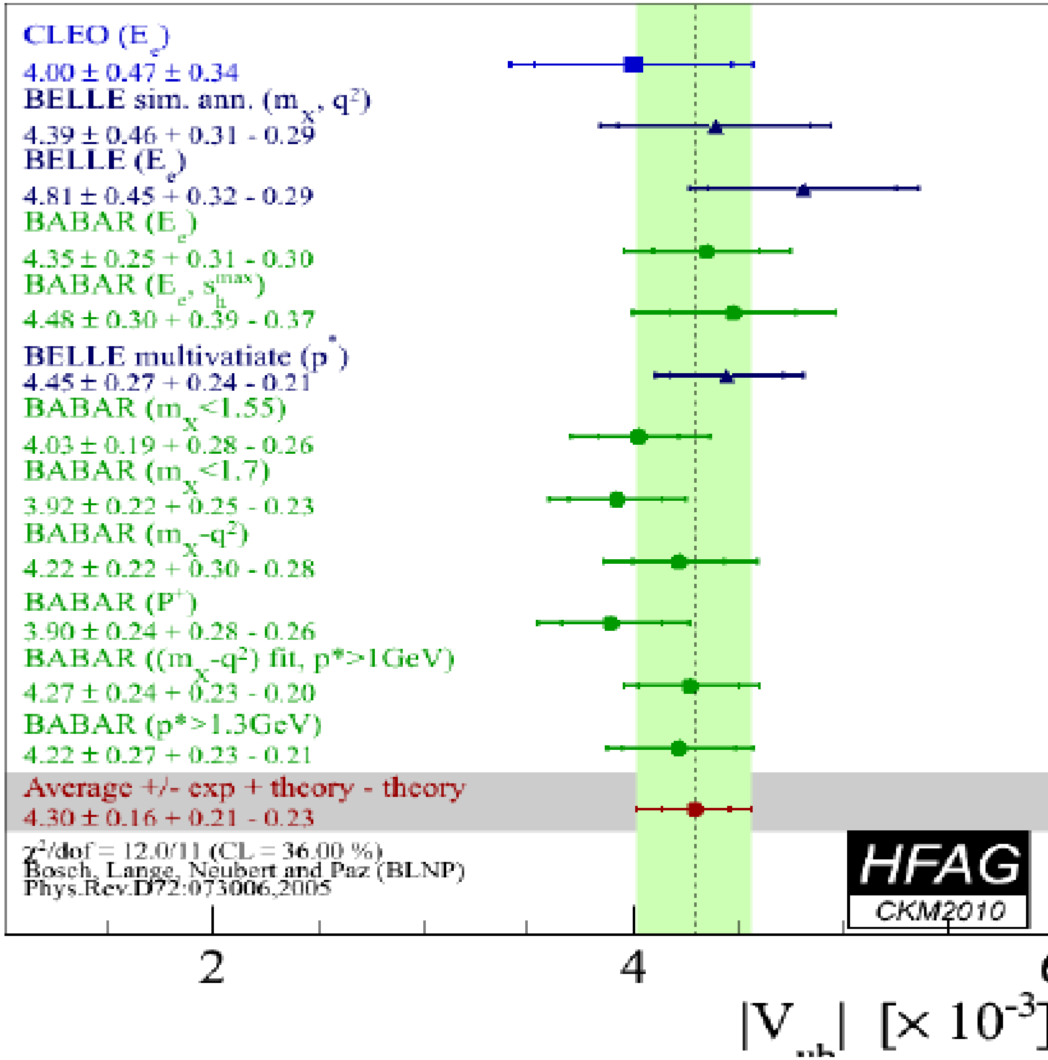
Y(3S): 30.2 fb^{-1}

Y(2S): 14.5 fb^{-1}

Off-resonance: 54 fb^{-1}

$|V_{ub}|$ extraction from BLNP

Preliminary

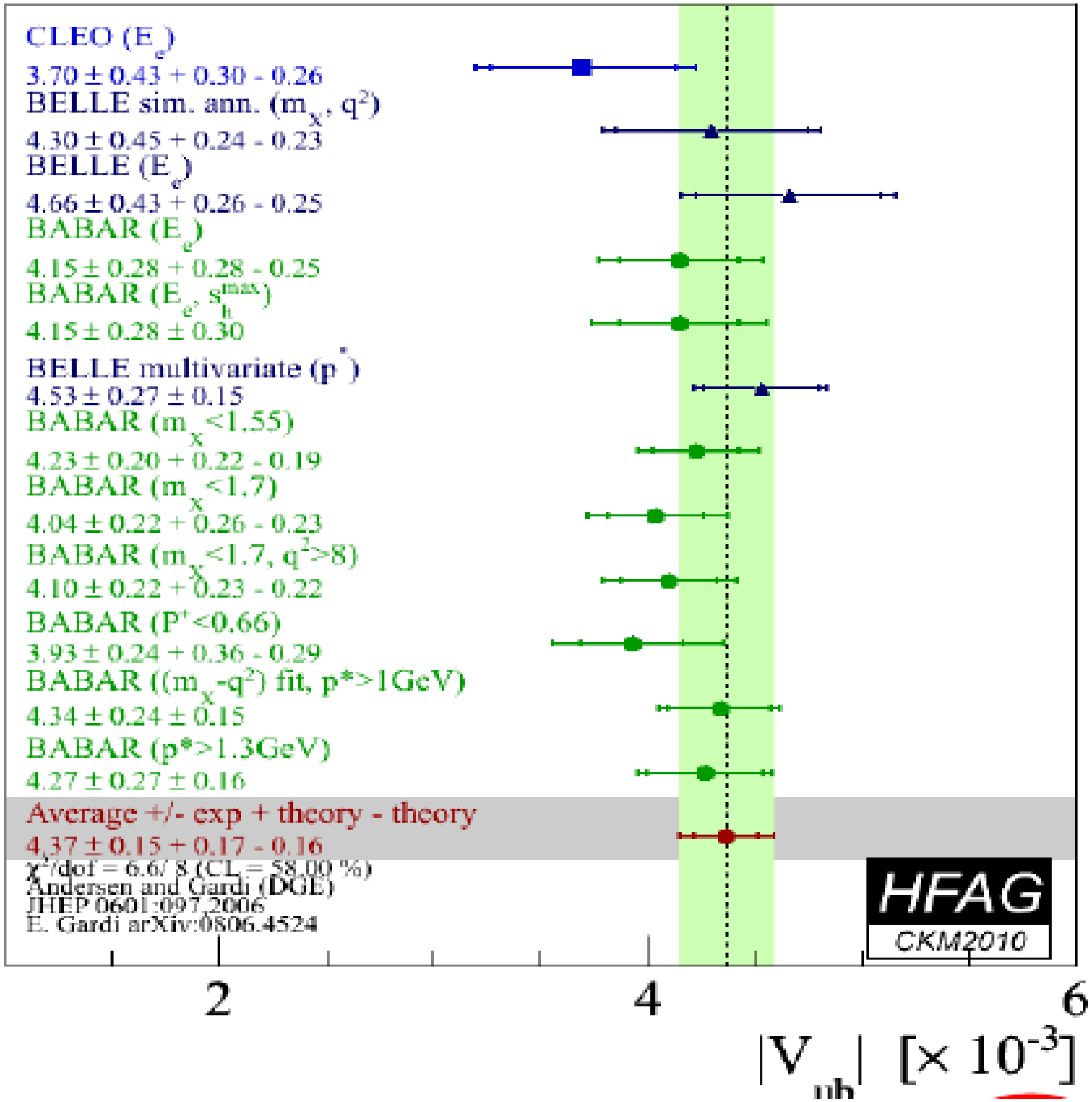


Error budget:

$$^{+2.2}_{-2.3}{}_{\text{stat}}\ ^{+1.7}_{-1.7}{}_{\text{exp}}\ ^{+1.2}_{-1.2}{}_{\text{b2c model}}\ ^{+1.9}_{-1.9}{}_{\text{b2u model}}\ ^{+2.9}_{-3.4}{}_{\text{HQE param}}\ ^{+0.4}_{-0.5}{}_{\text{SF func}}\ ^{+0.6}_{-0.7}{}_{\text{sub SF}}\ ^{+1.2}_{-1.2}{}_{\text{WA}}\ ^{+3.7}_{-3.7}{}_{\text{matching}} = \ ^{+6.1}_{-6.4}{}_{\text{tot}}$$

$|V_{ub}|$ extraction from DGE

Preliminary



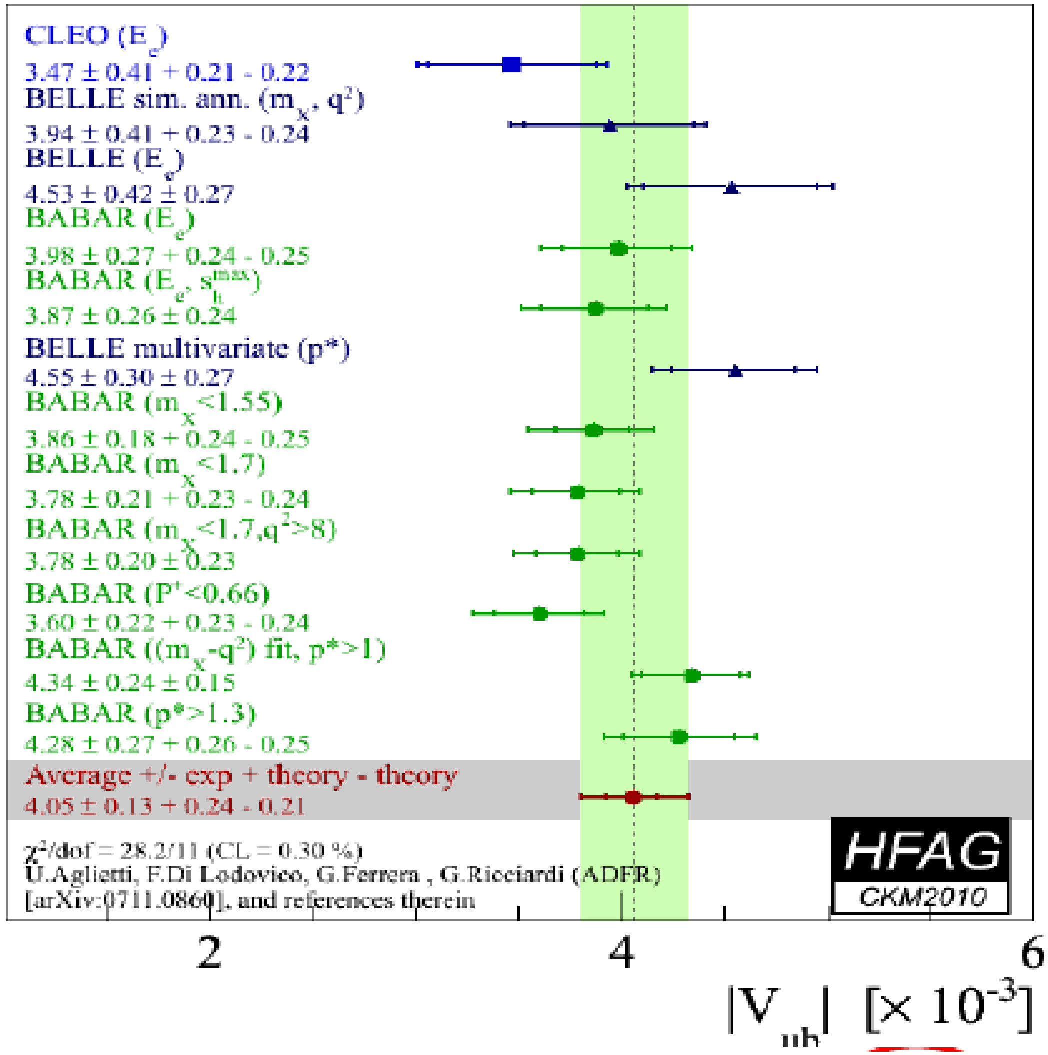
Error budget:

$$+2.0_{stat}\ +1.7_{exp}\ +1.2_{b2c\ model}\ +2.0_{b2u\ model}\ +0.4_{alpha\_s\ R\_CUT}\ +3.5_{mb}\ +1.3_{WA}\ +0.4_{DGE\ theory} = +5.2_{tot}$$

$$-2.0_{stat}\ -1.6_{exp}\ -1.2_{b2c\ model}\ -1.8_{b2u\ model}\ -0.4_{alpha\_s\ R\_CUT}\ -3.5_{mb}\ -1.3_{WA}\ -0.5_{DGE\ theory} = -5.0_{tot}$$

$|V_{ub}|$ extraction from ADFR

Preliminary



Error budget:

$$+1.9_{stat} +1.8_{exp} +1.3_{b2c\ model} +1.2_{b2u\ model} +0.7_{alpha\_s} +1.7_{Vcb} +0.7_{mb} +4.4_{mc} +1.0_{BF} +3.2_{model} = +6.7_{tot}$$

$$-1.9_{stat} -1.8_{exp} -1.4_{b2c\ model} -1.3_{b2u\ model} -1.2_{alpha\_s} -1.7_{Vcb} -0.8_{mb} -4.4_{mc} -0.9_{BF} -3.2_{model} = -6.9_{tot}$$