SemiLeptonic B decays at BaBar

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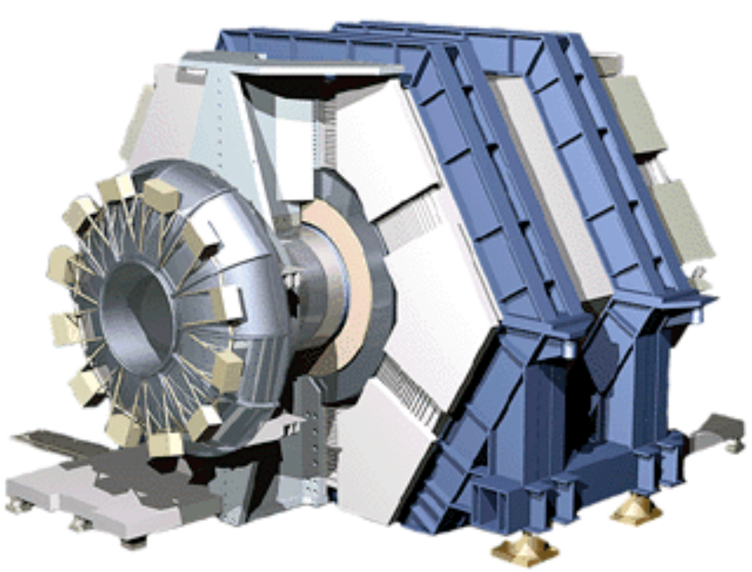
BaBar Symposium, April 1st 2009, London



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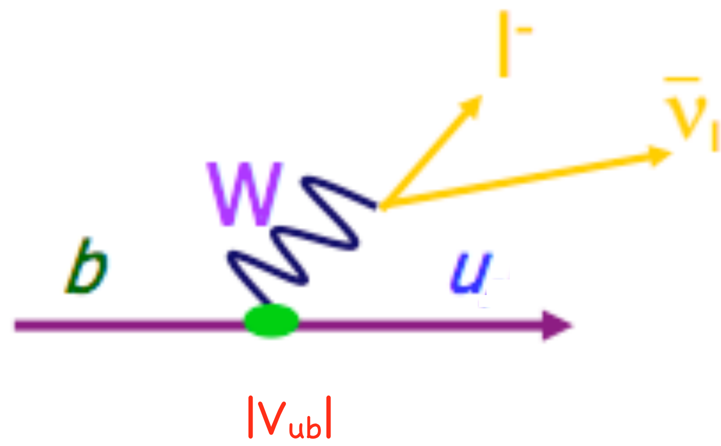
The CKM matrix



In the SM, mixing between quark generations is modeled with the CKM matrix

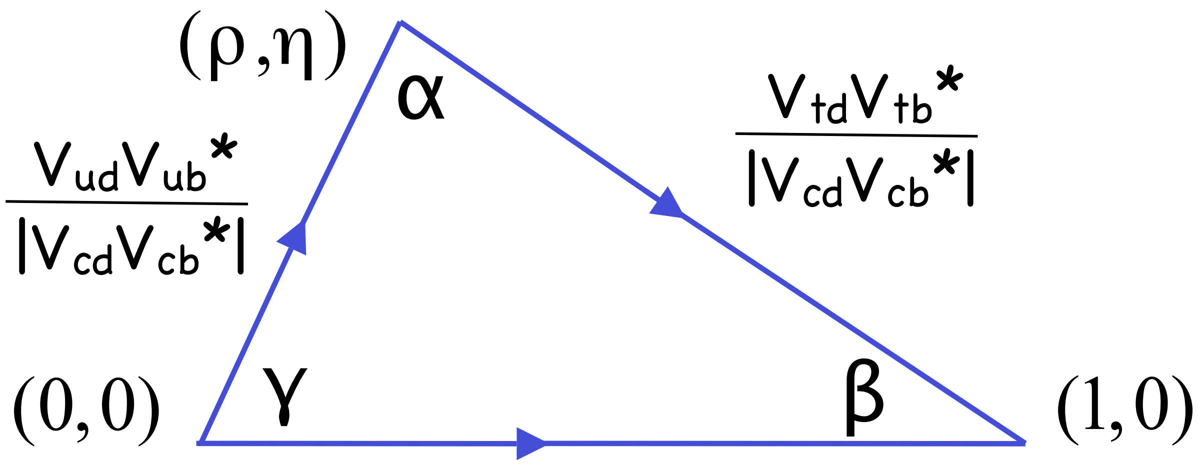
$$\mathbf{V} = \begin{vmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{vmatrix} = \begin{vmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{vmatrix} + O(\lambda^4)$$

CP violation comes from the presence of phase factors in some of the V's, a non-vanishing value of η

Unitarity of the CKM matix implies relations such as

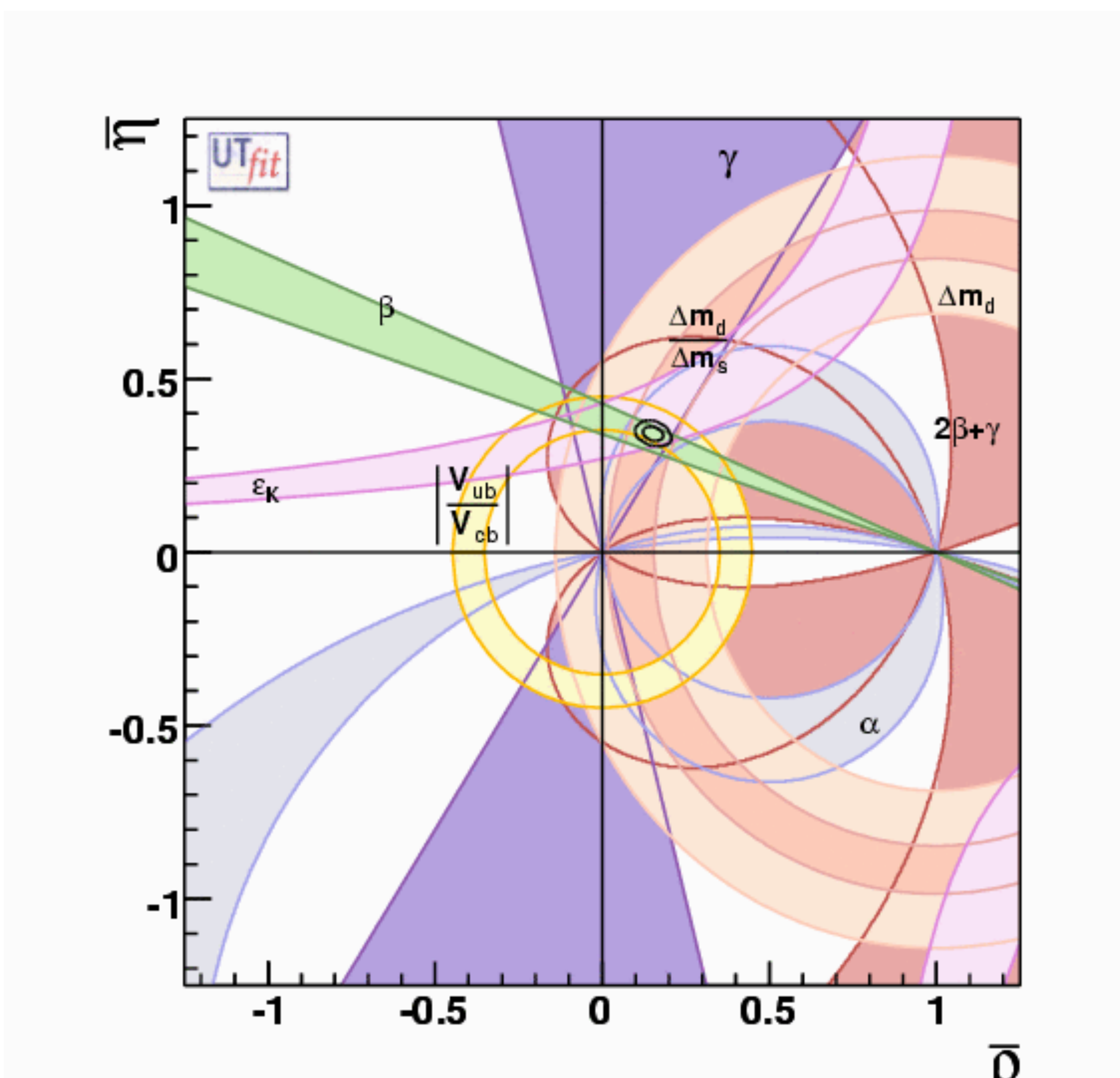
$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$ Unitarity Triangle

The Unitarity Triangle



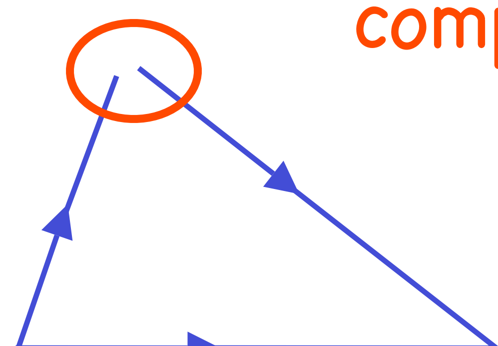
We measure angles and sides

Within errors, agreement with SM predictions



Is there room for new physics? Need to overconstrain the UT

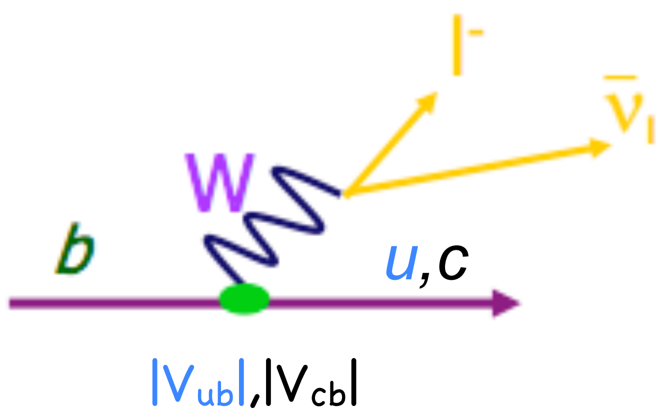
Measurement of $|V_{ub}|/|V_{cb}|$ complementary to sin2β



Do they agree with each other?

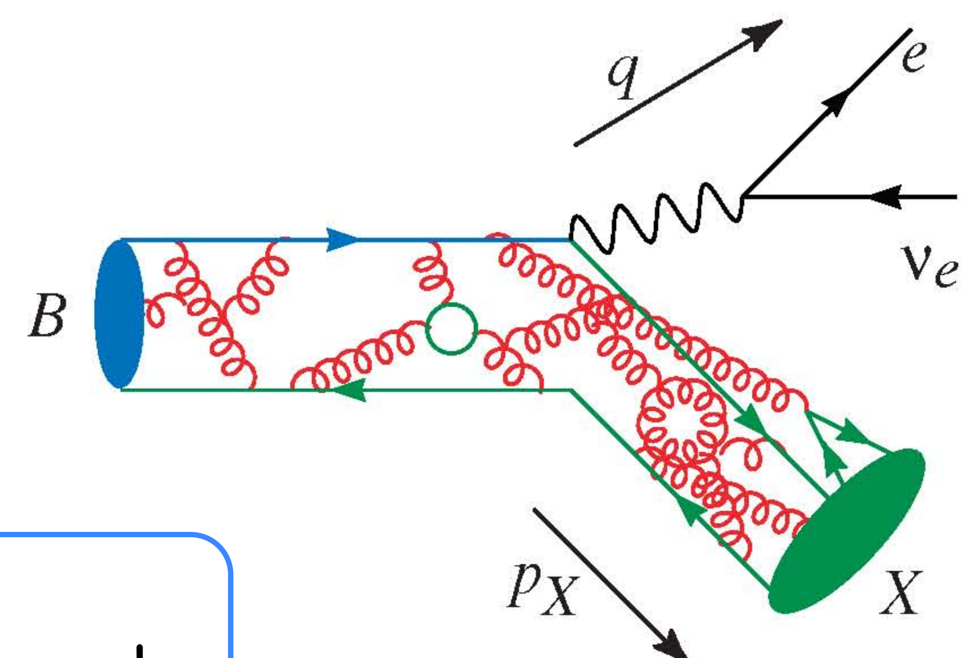
Semileptonic B Decays

Semileptonic B decays give us a clear view of the b quark inside the B meson



⇨ decay rate depends on $|V_{ub}|$ and $|V_{cb}|$
⇨ Leptonic and hadronic currents can be disentangled
⇨ Tree level decays ➠ independent of new physics

Inclusive decays
Large signal rate, high backgrounds
Total rate calculated vith HQE
Need to account for non perturbative QCD effects!



Exclusive decays
Lower signal rate, lower backgrounds
Need Form Factors to describe the hadronization process

A bit of history...

1 graduate student lifetime ago (~20 years) we didn't know that $|V_{ub}| \neq 0$

Experimental status in 1999:

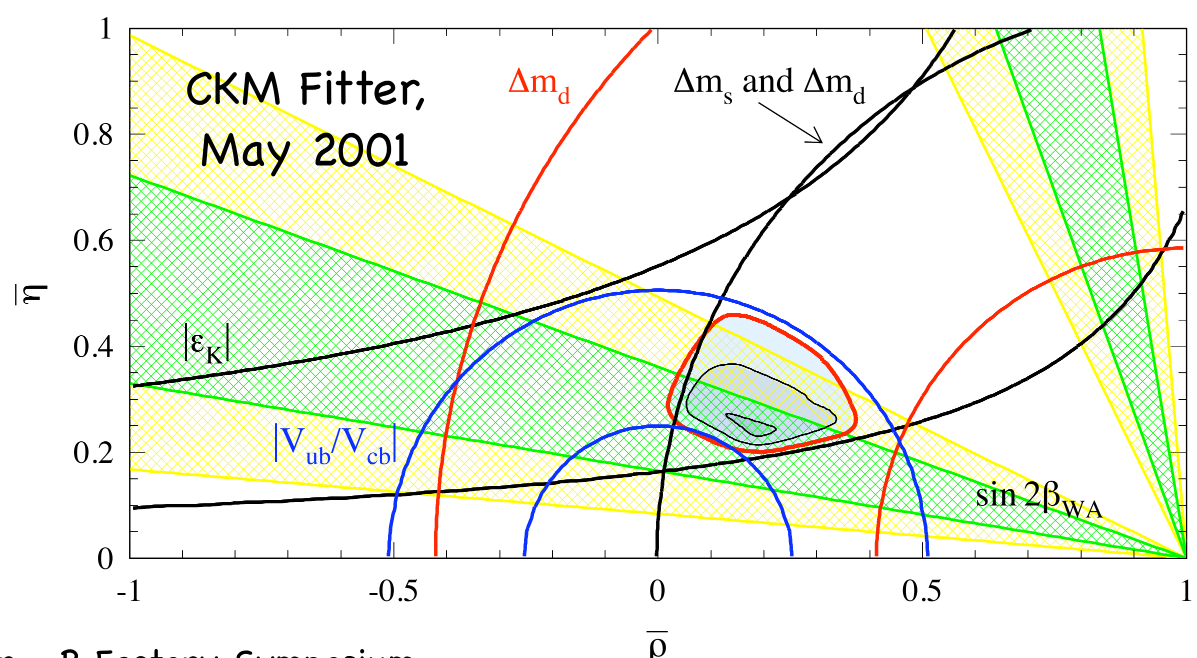
$|V_{cb}| = 0.0402 \pm 0.0019$

(combining all LEP data for both incusive and exclusive decays)

$|V_{ub}/V_{cb}| = 0.090 \pm 0.025$

(from CLEO, LEP and assuming conservative theoretical uncertainties)

PDG 1999



A bit of history... $|V_{cb}|$

From the BaBar workbook:

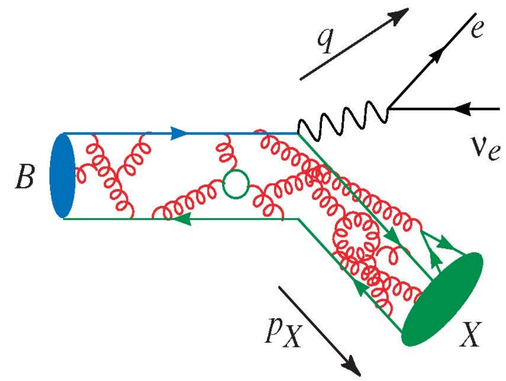
Large data sets will be obtained at BABAR that can be used for the determination of $|V_{cb}|$ and $|V_{ub}|$. With 30 fb^{-1}, the experimental errors on $|V_{cb}|$ are estimated to be ± 0.0006 (1.5%) and ± 0.0004 (1.0%) from exclusive $B \to D^* \ell \nu$ and inclusive $B \to \ell \nu X$ decays, respectively. The theoretical uncertainties are of comparable size for both methods and are of the order of a few percent. If the two results agree, a realistic estimate of the combined theoretical uncertainty is ± 0.0012 (3%), leading to a BABAR result of

$$|V_{cb}| = \ldots \pm 0.0004 \pm 0.0012 \; (\pm 1\% \pm 3\%) \tag{8.63}$$

after a few years of running, where the first error is experimental (statistical and systematic) and the second is from theory. The estimate of the theoretical uncertainty is based on present theoretical tools. A decrease in this uncertainty to a level of 1% will require new theoretical ideas.

HQET/OPE approaches were being studied among many difficulties - the extraction of HQET parameters from the analysis of mass and lepton energy moments did not give consistent results

HQE parameters determination



fit to hadronic mass moments in $B \to X_c l \nu$

fit to lepton energy moments in $B \to X_c l \nu$

$$\Gamma_{c\ell\nu} = \frac{G_F m_b^5}{192\pi^3} |V_{cb}|^2 (1 + A_{\rm ew}) A_{\rm pert} A_{\rm nonpert} \simeq |V_{cb}|^2 f_{\rm OPE}(m_b, m_c, a_i)$$

fit to photon energy moments in $B \to X_s \gamma$

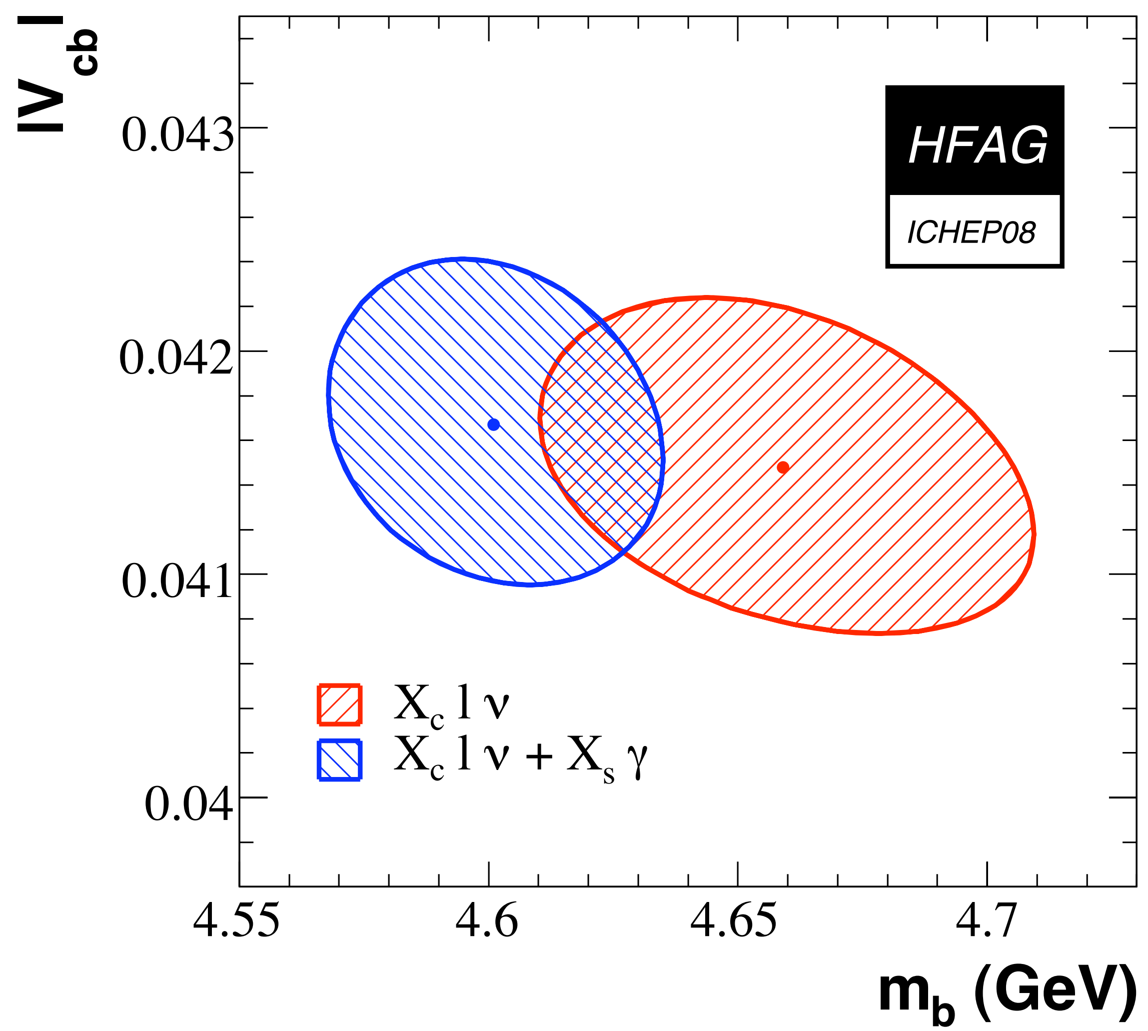
Kinetic Scheme

P. Gambino and N.Uraltsev, Eur. Phys. J. C34, 181 (2004)

1S Scheme

C.Bauer, Z.Ligeti, M.Luke, A.Manohar, M.Trott PRD 70 094017 (2004)

Inclusive $|V_{cb}|$ determination



$|V_{cb}| = (41.67 \pm 0.43_{fit} \pm 0.08_{TB} \pm 0.58_{th})\ 10^{-3}$

$m_b = 4.601 \pm 0.034$

$m_c = 1.165 \pm 0.050$

$\mu_\pi^2 = 0.440 \pm 0.040$

$|V_{cb}| = (41.48 \pm 0.47_{fit} \pm 0.08_{TB} \pm 0.58_{th})\ 10^{-3}$

$m_b = 4.659 \pm 0.049$

$m_c = 1.285 \pm 0.078$

$\mu_\pi^2 = 0.428 \pm 0.044$

Using ~60 moments, fitting 7 parameters

1.7% total error

work in progress to estimate theoretical correlations used in the fit

may shift $|V_{cb}|$ value closer to exclusive determination

Exclusive $|V_{cb}|$ determination

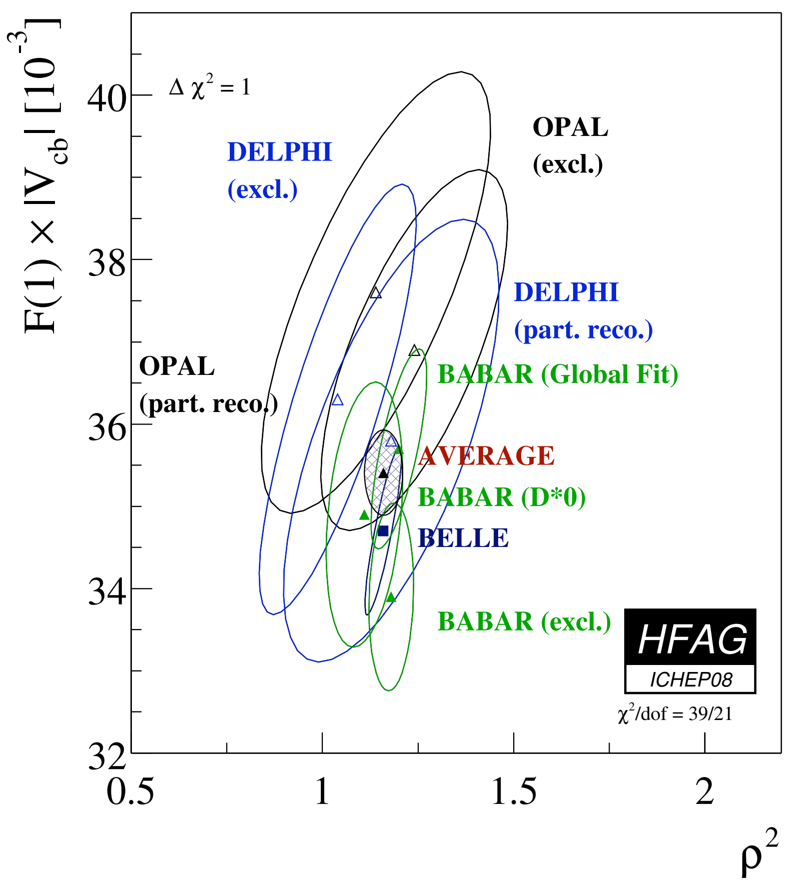
BaBar has recently measured $|V_{cb}|$ and FF parameters

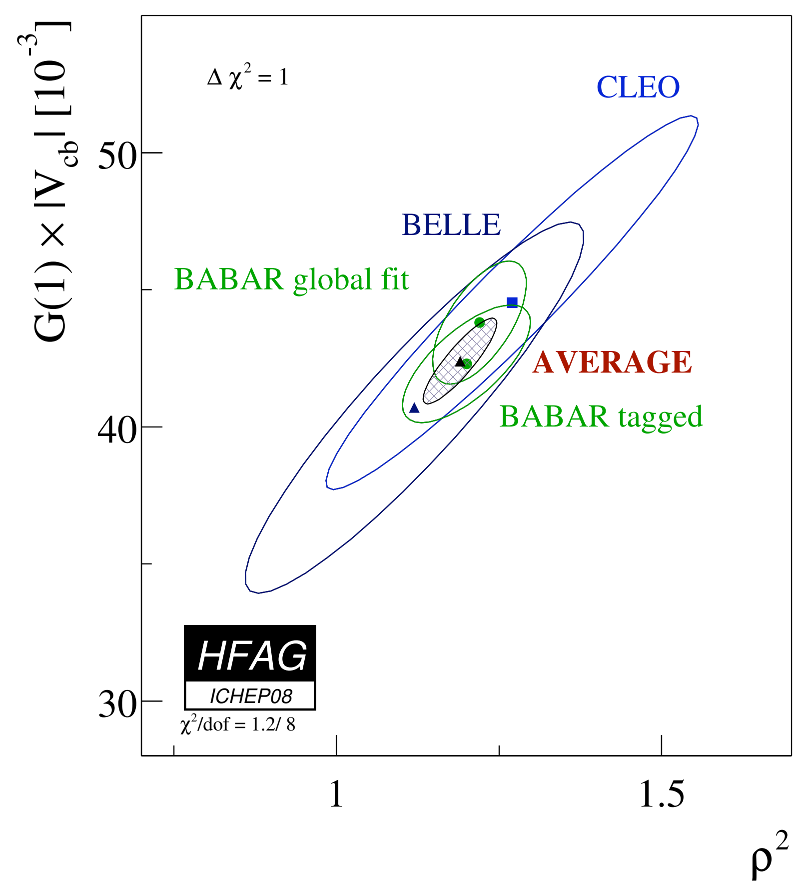
$F(1)|V_{cb}|$ and ρ_F^2 from untagged $B \to D^{*0} l \nu$

$G(1)|V_{cb}|$ and ρ_G^2 from tagged $B \to D l \nu$

$F(1)|V_{cb}|$, ρ_F^2, $G(1)|V_{cb}|$ and ρ_G^2 from $B \to D^{*0} l \nu X$

All the B factories measurements provide precise and consistent results both for $|V_{cb}|$ and FF parameters





Using Unquenched LQCD calculations:

$|V_{cb}| = (38.1 \pm 0.6_{exp} \pm 0.9_{th})\ 10^{-3}$ (D*) $|V_{cb}| = (39.7 \pm 1.4_{exp} \pm 0.9_{th})\ 10^{-3}$ (D)

A bit of history... $|V_{ub}|$

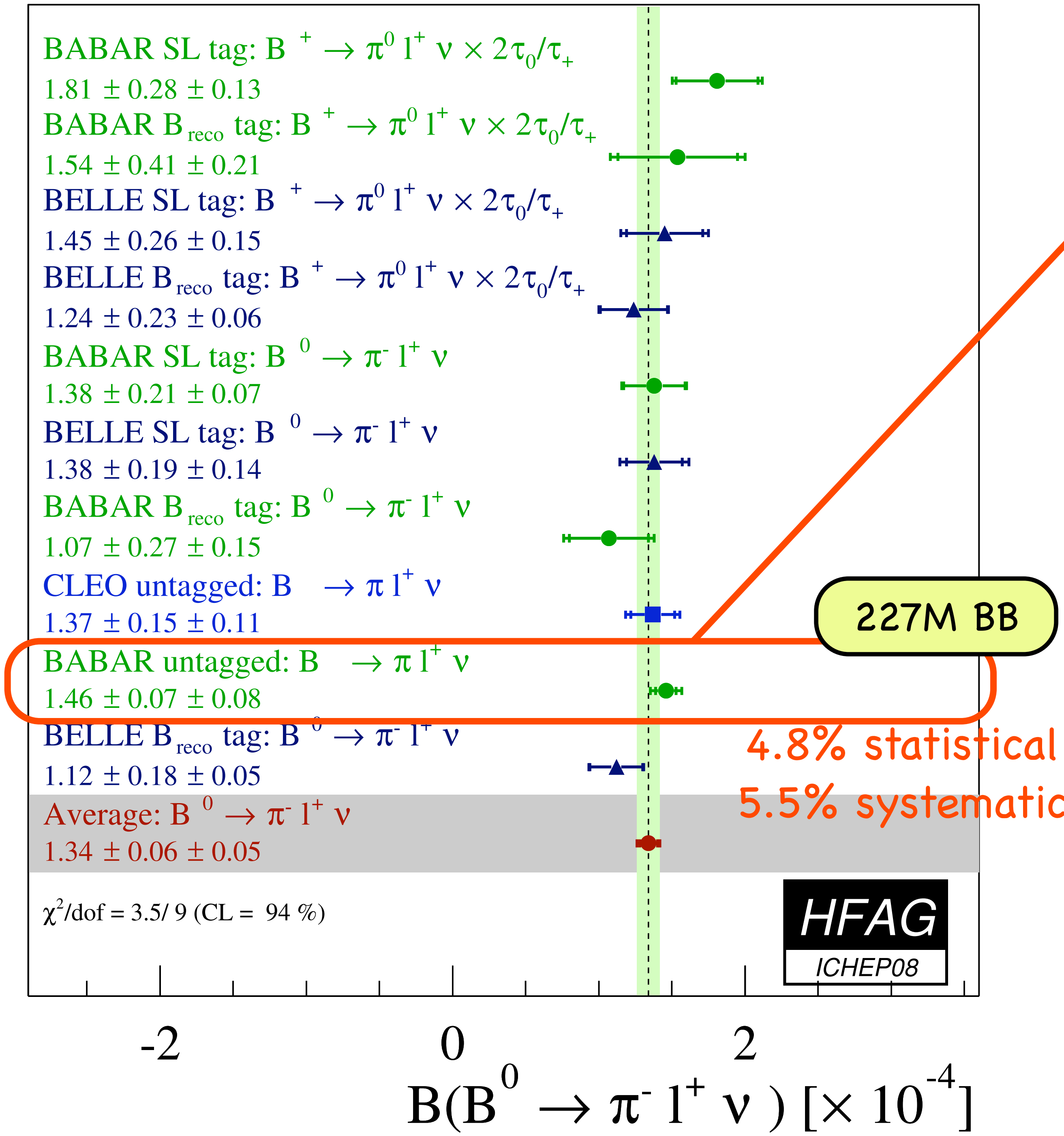
Again, from the BaBar workbook:

For $|V_{\rm ub}|$, expectations are more modest. With 30 events/fb, BABAR will be able to determine the decay fractions of $B \to \pi\ell\nu$, $B \to \rho\ell\nu$, and $B \to \omega\ell\nu$ with statistical errors around 6%, giving $|V_{\rm ub}|$ with statistical errors around 3%. Systematic errors should be of the same order, and averaging the three decay modes leads to an estimate of $\pm 2.5\%$ for the experimental error on $|V_{\rm ub}|$. Inclusive decays will not reach the same precision experimentally. They will, however, be extremely important because they have completely different theoretical uncertainties. These are estimated to be about 10% for both methods, based on present theoretical technology. Thus, BABAR could reach

$$|V_{\rm ub}| = \ldots \pm 0.0001 \pm 0.0004 \; (\pm 2.5\% \pm 10\%) \tag{8.64}$$

after a few years of running. Again, new theoretical approaches could decrease the theoretical uncertainties to a level of 5%.

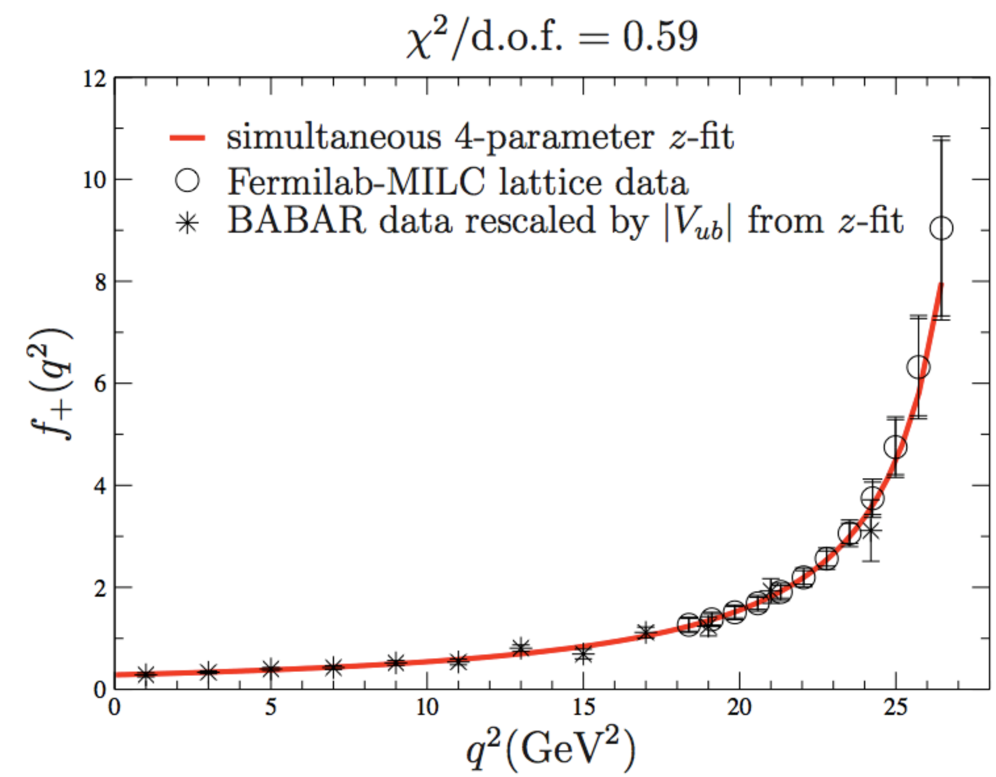
$|V_{ub}|$ in exclusive B decays



New result from FNAL/MILC collaboration:

$|V_{ub}| = (3.38 \pm 0.36)\ 10^{-3}$

arXiv:0811.3640v3 [hep-lat] (2009)

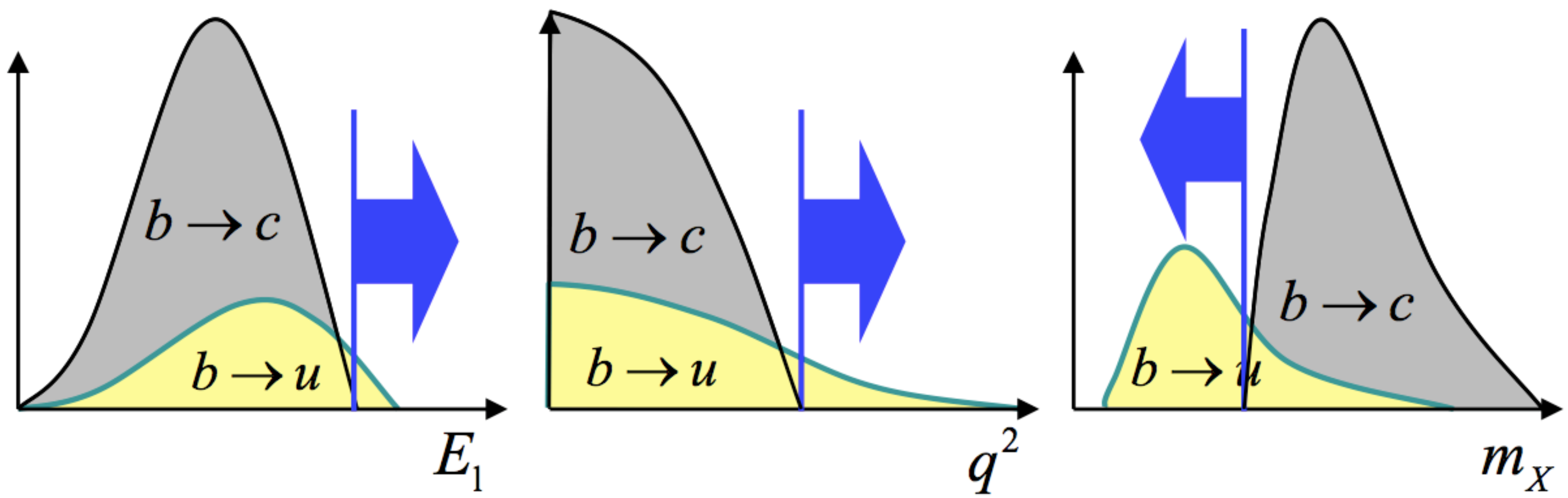


Work in progress: new BaBar analyses on B->π/ρ/ω/η/η′ lν

$|V_{ub}|$ in inclusive B decays

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

$|V_{ub}|$ is proportional to $B \to X_u l \nu$ branching fraction in limited region of phase space



E_l = lepton energy
q^2 = dilepton mass squared
m_X = hadron system mass

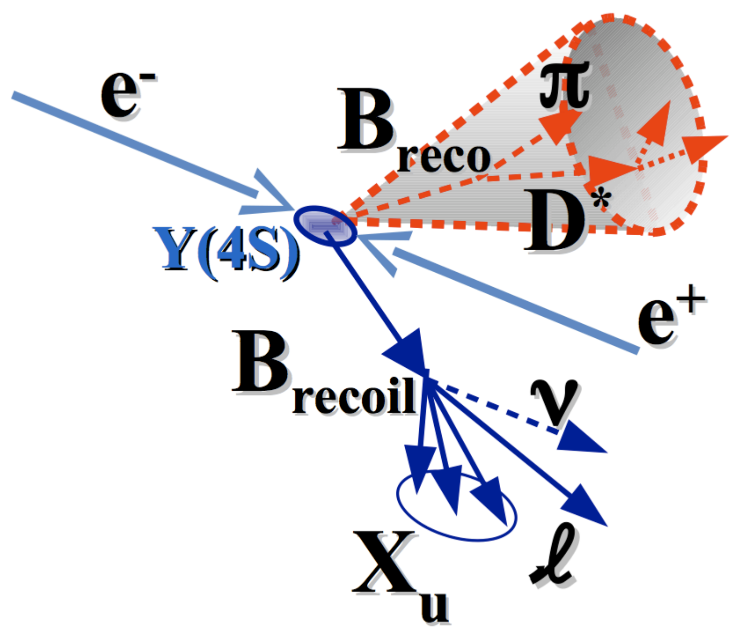
In these regions the theory (OPE) breaks down, acceptance sensitive to Fermi motion of b quark inside B meson

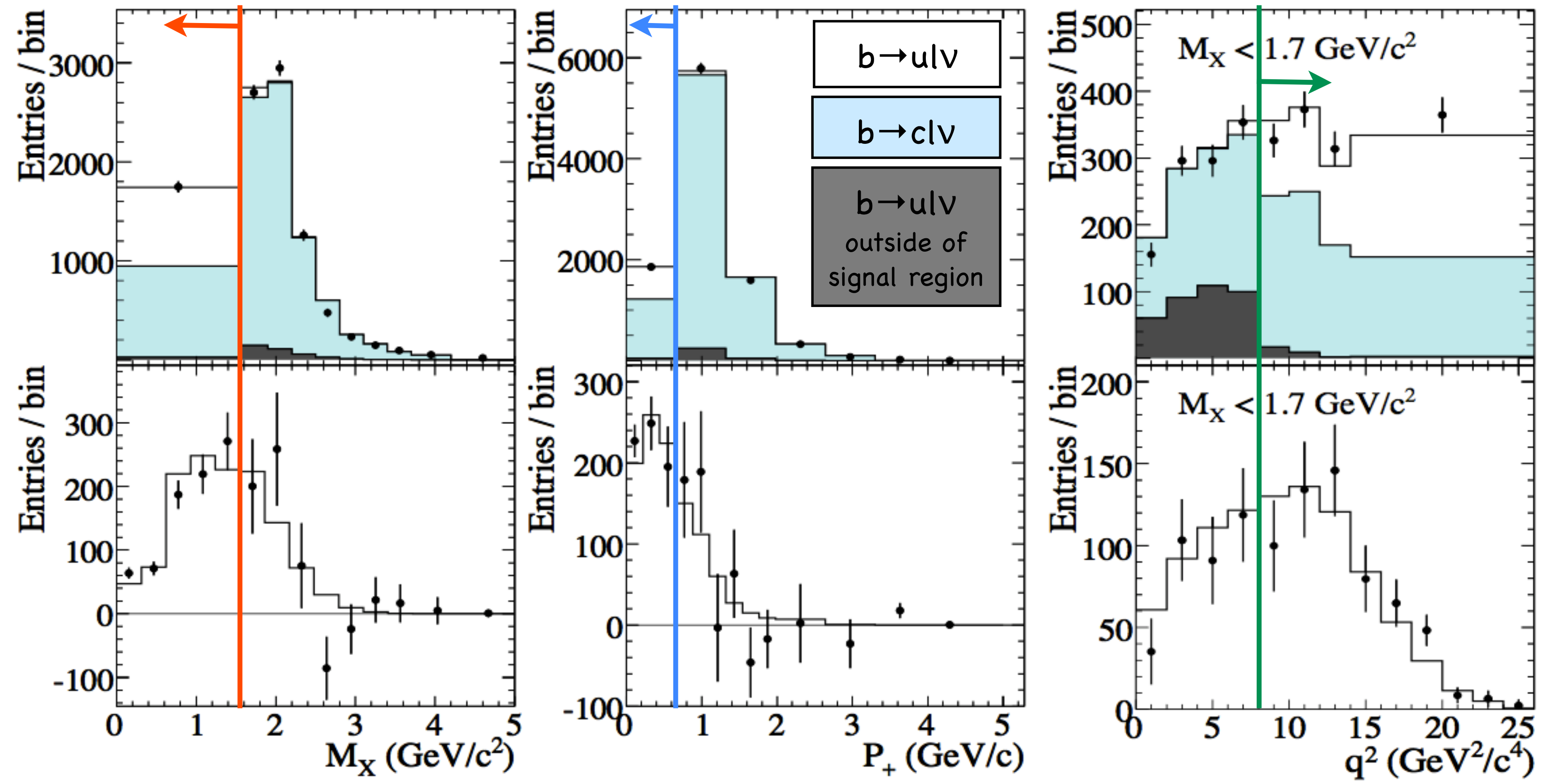
⇨ smart choice of phase space

⇨ non perturbative QCD computation, where the effects of the Fermi motion need to be taken into account
Several theoretical frameworks address this problem, many advances in recent years

$|V_{ub}|$ in inclusive B decays

383M BB: PRL 100, 171802 (2008)





Signal regions:

$m_X < 1.55$ GeV/c^2

$P_+ = E_X - P_X < 0.66$ GeV/c

$m_X < 1.7$ GeV/c^2, $q^2 > 8$ GeV^2/c^4

m_X

$|V_{ub}| = (4.27 \pm 0.16_{stat} \pm 0.13_{syst} \pm 0.30_{th})\ 10^{-3}$ — BLNP, PRL93, 221801 (2004)

$|V_{ub}| = (4.56 \pm 0.17_{stat} \pm 0.14_{syst} \pm 0.32_{th})\ 10^{-3}$ — DGE, JHEP0601, 097 (2006)

P_+

$|V_{ub}| = (3.88 \pm 0.19_{stat} \pm 0.16_{syst} \pm 0.28_{th})\ 10^{-3}$ — BLNP

$|V_{ub}| = (3.99 \pm 0.20_{stat} \pm 0.16_{syst} \pm 0.24_{th})\ 10^{-3}$ — DGE

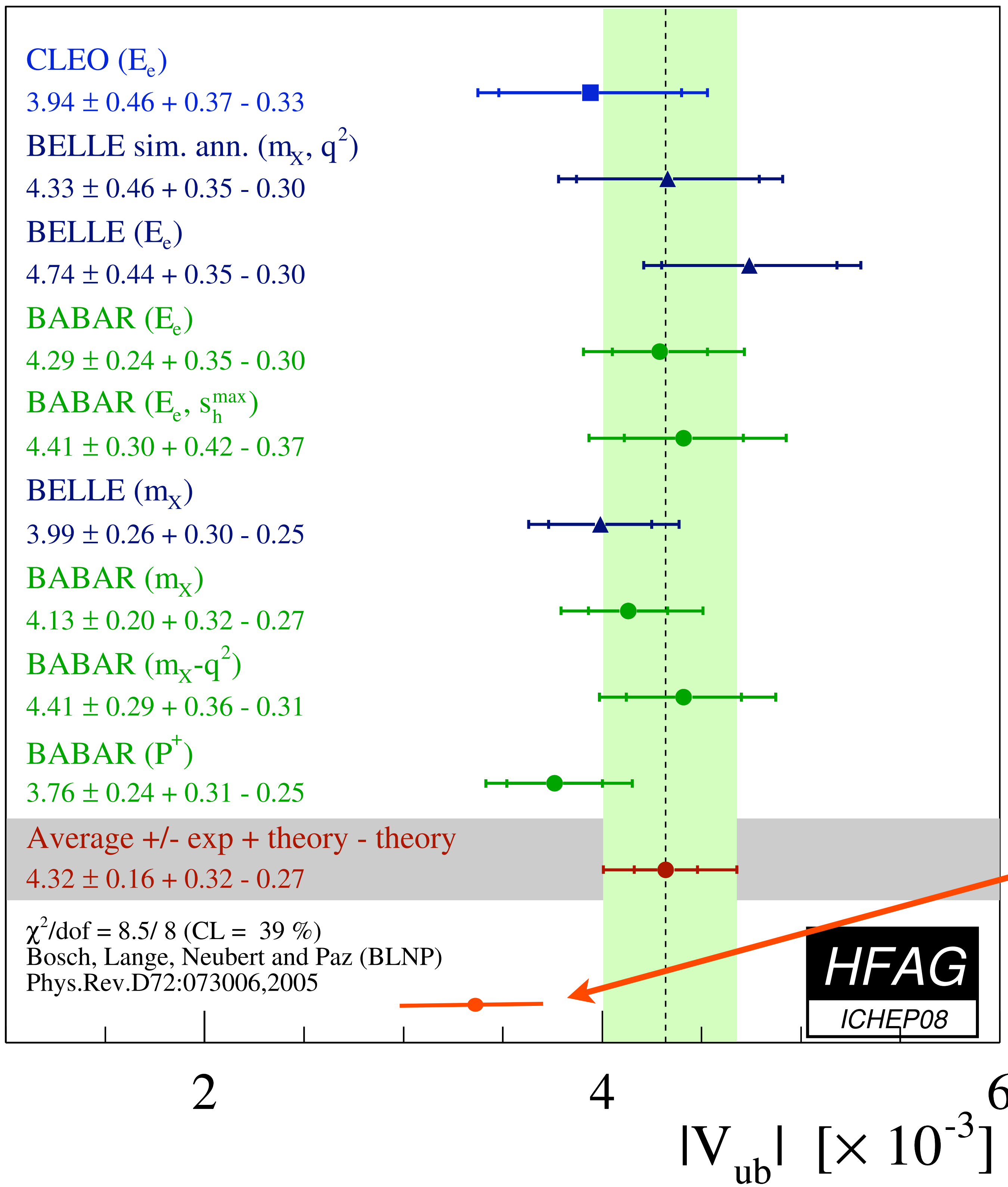
m_X, q^2

$|V_{ub}| = (4.57 \pm 0.22_{stat} \pm 0.19_{syst} \pm 0.30_{th})\ 10^{-3}$ — BLNP

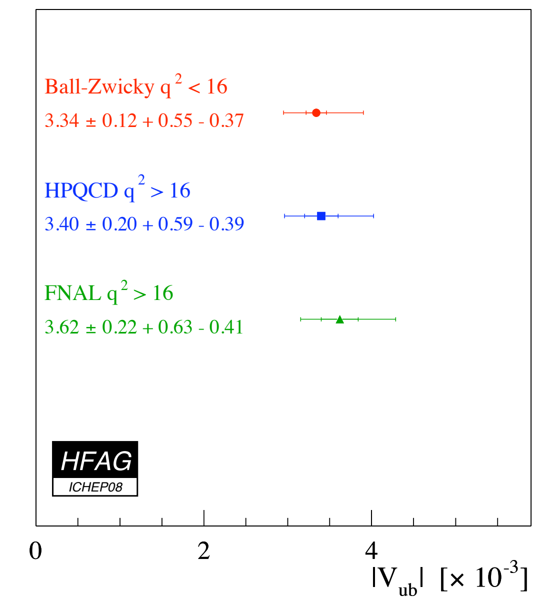
$|V_{ub}| = (4.64 \pm 0.23_{stat} \pm 0.19_{syst} \pm 0.25_{th})\ 10^{-3}$ — DGE

$|V_{ub}| = (4.93 \pm 0.24_{stat} \pm 0.20_{syst} \pm 0.36_{th})\ 10^{-3}$ — BLL, PRD64, 11304 (2001)

$|V_{ub}|$ in inclusive B decays



Exclusive determination in the range $3\text{-}3.5\times10^{-3}$



FNAL/MILC result

Conclusions

BaBar and PEP-II have gone beyond expectations in the analysis of semileptonic B decays and the measurement of the CKM matrix elements $|V_{cb}|$ and $|V_{ub}|$

We now know $|V_{cb}|$ at the 1.7% level from inclusive decays and 3-4% from exclusive decays

We now know $|V_{ub}|$ at the 7-8% level from inclusive charmless decays

Precision has brought discrepancy into the picture: inclusive and exclusive determinations of $|V_{cb}|$ and $|V_{ub}|$ are, for now, marginally consistent