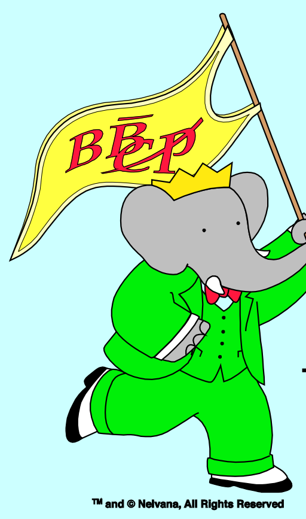
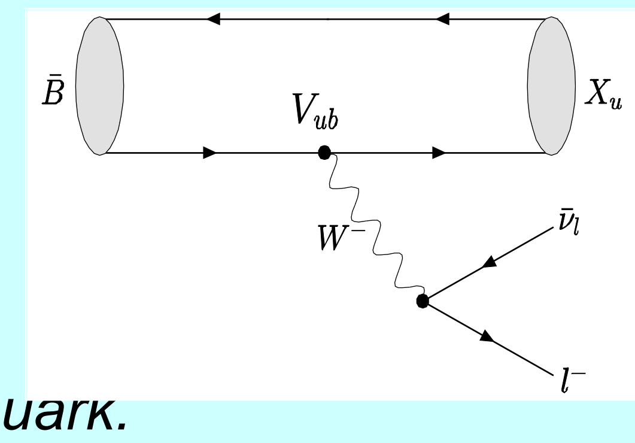
BABAR

Measurement of Partial Branching fraction for $B \to X_u l\nu$ decays and determination of |Vub|

[PRL 100, 171802 (2008)]



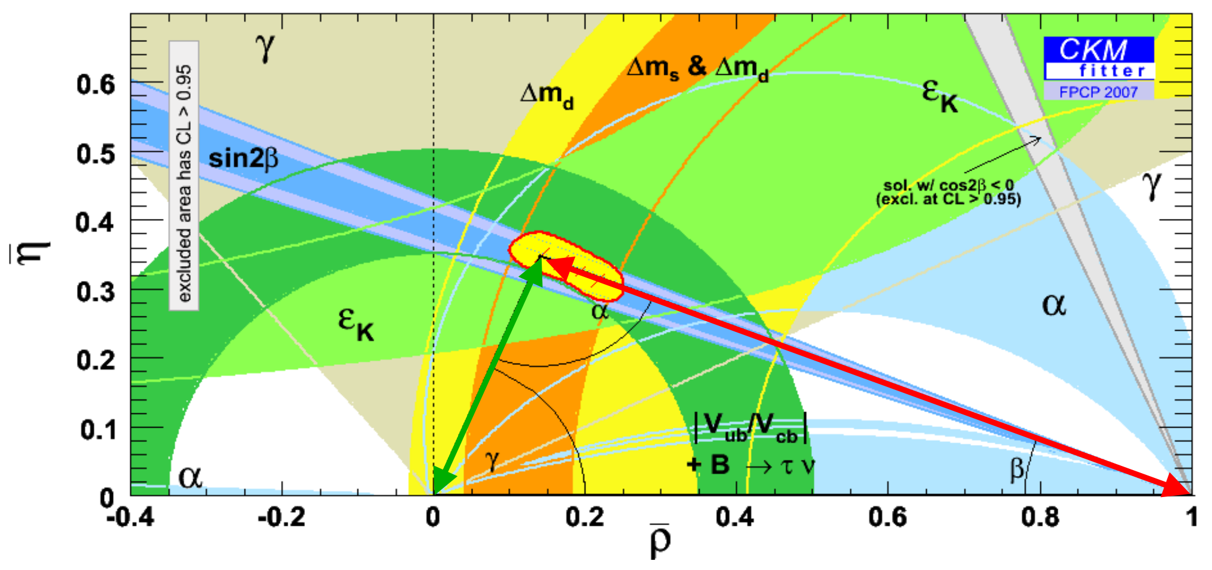
in 5 min:



V_{ub} is the smallest element of the CKM-matrix, yet, for the Standard Model to describe CP violation, it has to be nonzero. Our group studies semileptonic decays of the B going to a hadronic system X_u, containing the light u quark. This process is sensitive to $|V_{ub}|$, but is 1000 times less common than transitions to X_c, containing instead a heavy c quark. We have determined partial branching fractions in 3 limited regions of phase space: $M_X < 1.55$ GeV/c^2, $P_+ < 0.66$ GeV/c), and $M_X < 1.7$ GeV/c^2, $q^2 > 8$ GeV^2/c^4. Corresponding values of $|V_{ub}|$ are extracted using several theoretical calculations

Why study V_{ub} and V_{cb} ?

Answer: redundant and precise measurements of the Unitary Triangle are needed.
The dimensions of the triangle are infact tightly connected to CP violation research.



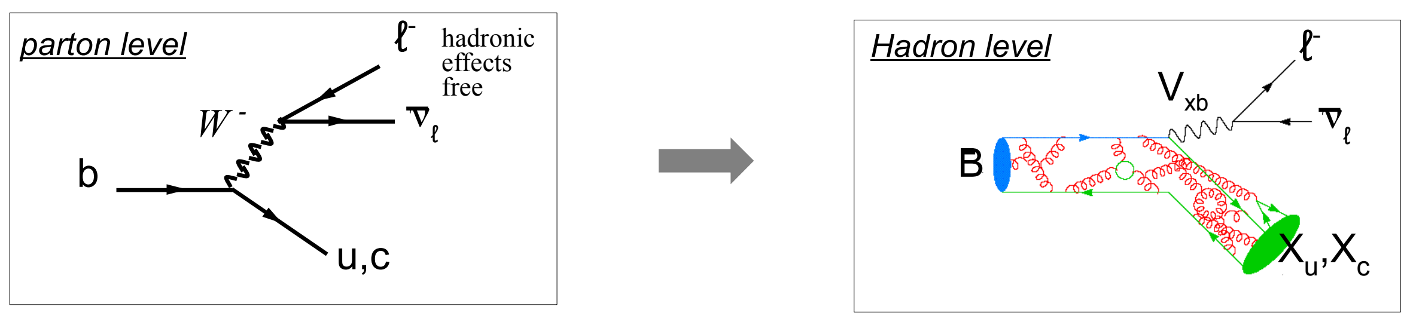
The angle β and right-side measured better than 5%
. orthogonal constraints
→ Anchor the (ρ,η) apex

The left side over-constrain the Triangle is more difficult
. Uncertainty is dominated by the errors on $|V_{ub}|$ ~ 8%
→ precision is improving (it was 18% in 2004), but still not enough

→ next GOAL: Measure $|V_{ub}|$ with < 5%

Semileptonic B decays

. Tree level semileptonic decays provide an excellent laboratory because free of NP contributions



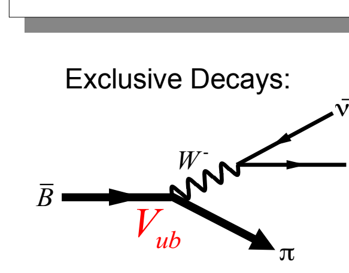
. Theoretically simple at parton level
. leptonic and hadronic currents factor out cleanly,
thus one can probe strong interactions in B mesons
.. Explore structure of B meson
.. Allow test of e.g. Lattice QCD
. Rate depends directly on CKM elements $|V_{ub}|$, $|V_{cb}|$, the quark masses m_b and m_c

$$\Gamma_x \equiv \Gamma(b \to xl\nu) \propto |V_{xb}|^2$$

. Experimentally branching fractions are prominent
10.5 % for semi-electronic and semi- muon

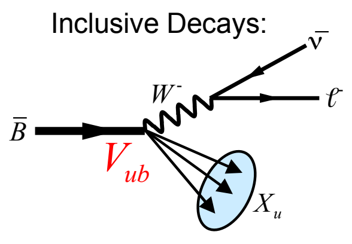
Exclusive vs Inclusive measurements

Exclusive Decays:



hadronic final states X_u reconstructed
→Low signal rate, better bkg reduction and kinematic constraints
Need Form Factor $F(q^2)$ to describe the hadronization process u → ππ, ρρ, …
Measurement as function of q^2

Inclusive Decays:



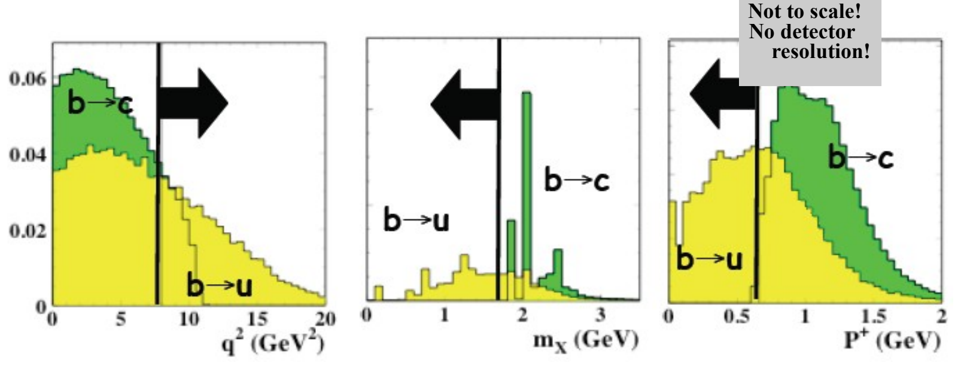
select lepton and
look at the rest of the event inclusively
→Large signal rate, high b → cℓν bkg
"Easy" to calculate (OPE/HQE)
Need Shape Function (that describes b-quark motion inside B meson)
Constrain SF param. m_b, μ_π^2
with b → sγ or b → cℓνν

Inclusive b →u l ν measurement

. **H**eavy **Q**uark **E**xpansion gives $\Gamma(B \to X_u l \nu) = \underbrace{G_F^2\, m_b^5/192\, \pi^3\, |Vub|^2}_{\text{free quark decay}}\ \underbrace{[1+A_{ew}]A_{pert}}_{\text{perturbative corrections (known to } O(\alpha_s^2))}\ \underbrace{A_{nonpert}}_{\text{Non-perturbative power corrections (suppressed by } 1/m_b^2)}$

. Unfortunately : $\dfrac{\Gamma(b \to u l \nu)}{\Gamma(b \to c l \nu)} \approx \dfrac{|V_{ub}|^2}{|V_{cb}|^2} \approx \dfrac{1}{50}$

. kinematic cuts needed
to suppress the dominant
b → c l ν background



q^2 = momentum transfer squared = $(p_B - p_X)^2 = (p_l + p_n)^2$
m_X = mass of the hadronic system
$P^+ = E_X - |p_X|$ = light-cone component of X momentum

. Smaller acceptances increase theory uncertainties
. OPE breaks down
. "shape function" to resum non-perturbative physics

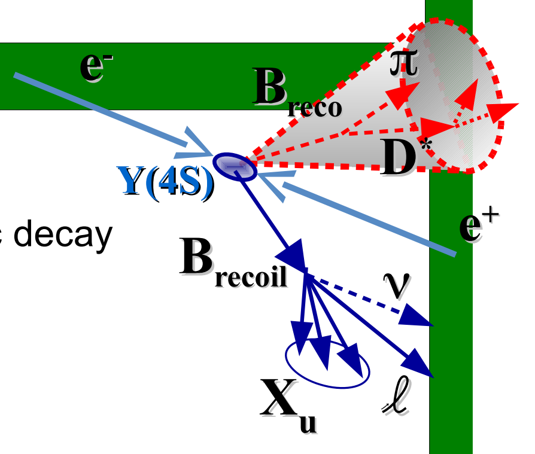
. Measure partial Branching Fraction $\Delta\mathcal{B}(B \to X_u l\nu\nu)$ in a region where
. the signal/background is good, and
. the partial rate $\Delta\Gamma_u$ is reliably calculable

. To reduce systematic uncertainties, we measure first a ratio of partial BF

. Get partial rate prediction ζ(ΔΦ) from theory

$$|\mathbf{V_{ub}}| = \sqrt{\frac{\boxed{\Delta\mathcal{B}(\bar{\mathbf{B}} \to \mathbf{X_u}\ell\bar{\nu})}}{\tau_{\mathbf{b}} \cdot \boxed{\zeta(\boldsymbol{\Delta\Phi})}}}$$

Recoil Analysis technique



Y(4S) →B<u>B</u> events are tagged by the full reconstruction of a hadronic decay of one of the *B* mesons (B_{reco}).
The semileptonic decay of the second *B* meson (B_{recoil}) is identified by the presence of an electron or a muon.
This technique results in a low event selection efficiency but allows the determination of the momentum, charge, and flavor of the *B* mesons.

B_{reco}

- Full reconstruction of tag B: $B \to D^{(*)} Y$
D: charm meson (D^0, D^+,D^{*0},D^{*+})
Y: hadrons ($\pi^\pm$,π^0,$K^\pm$,K_S^0,π^0) collection of charge ±1

- Kinematic consistency is checked with
. beam energy-substituted mass: $m_{ES} = \sqrt{s/4 - \vec{p}_B^{\,2}}$
. energy difference: $\Delta E = E_B - \sqrt{s}/2$

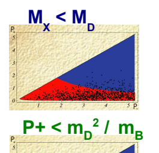
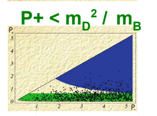
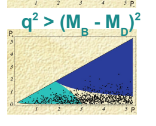
B_{recoil}

- SemiLeptonic selection:
. presence of charged lepton: $P_l > 1$ GeV
. system X reconstructed using charged tracks and photons
. neutrino momentum inferred $P_{miss} = P_Y - P_{Breco} - P_l - P_X$

- Signal selection:

. require 1 charged lepton	$P_l > 1$ GeV
. Charge Conservation:	$Q_{tot} = 0$
. Charge Correlation:(correct for B^0 mixing)	$Q_l Q_{reco} < 0$
. Missing Mass Squared:	$M_{miss}^2 < 0.5$GeV^2
. veto on $K^\pm$, K_S and on $B^0 \to D^*$ l n events	

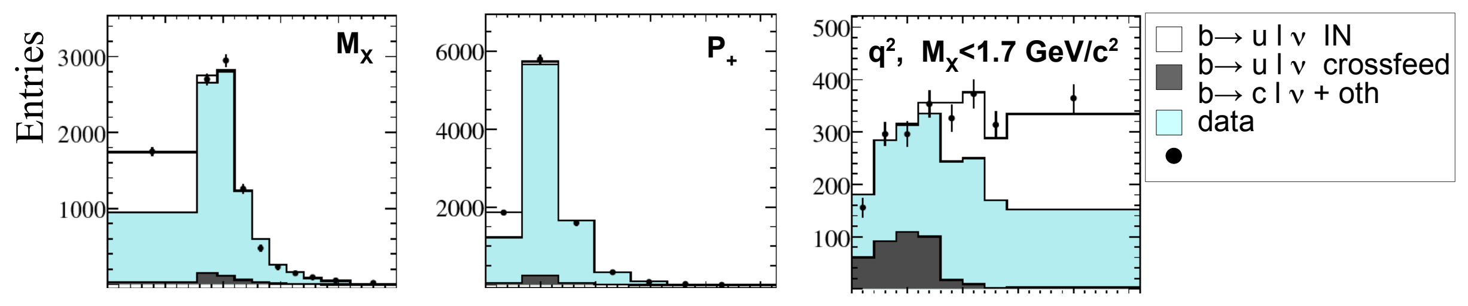
Kinematic variables: Problems and Triumph

phase space	rate(%)	Pros	Cons
$M_X < M_D$ 	~ 80 %	lots of rate	depends on f(k+) (and subleading)
$P+ < m_D^2 / m_B$ 	~ 70 %	- still lost of rate - relation to radiative decays simplest	depends on f(k+) (and subleading)
$q^2 > (M_B - M_D)^2$ 	~ 30 %	insensitive to f(k+)	- very sensitive to m_b - substantail WA corrections - effective expansion param. Λ_{QCD}/m_c
"optimized cuts" 	~ 45 %	insensitive to f(k+)	- still "only" 45% of rate - less rate than M_X cut, & more complicate to measure

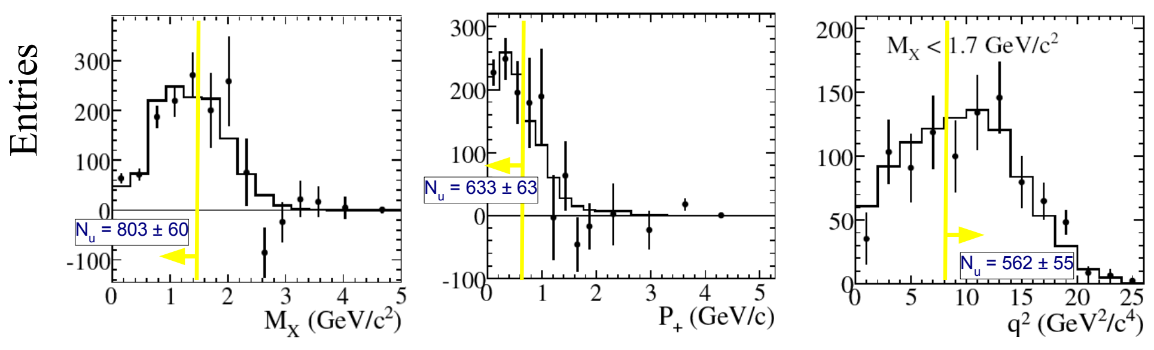
Partial Branching Fraction

$L_{data} \sim 348$ fb^{-1} ≡ 383· 10^6

Kinematic variables distributions:



Same spectra, background subtracted and rebinned to show the actual variable shape:
(note: measured distributions, not efficiency corrected)



Because we have 1 single database and we perform 3 calculations,
we evaluate the statistical correlation between them
65% between M_X and combined (M_X,q^2)
67% between M_X and P_+
38% between (M_X,q^2) and P_+

Getting $|V_{ub}|$ from the partial rate

. Formula used

$$|\mathbf{V_{ub}}| = \sqrt{\frac{\Delta\mathcal{B}(\bar{\mathbf{B}} \to \mathbf{X_u}\ell\bar{\nu})}{\tau_{\mathbf{b}} \cdot \zeta(\boldsymbol{\Delta\Phi})}}$$

ζ(ΔΦ): theoretical acceptance, computed by different theo. frameworks
ΔΦ : global fit (m_b^{SF},$\mu_\pi^{2\,SF}$) param., Buchmüller & Flächer, PRD73:073008

. Several theoretical calculations available:

.. DFN (De Fazio,Neubert) JHEP9906:017(1999) → HQE with ad-hoc inclusion of SF
.. BLNP(Bosch,Lange,Neubert,Paz) PRD72:073006(2005) → HQE with systematic incorporation of SF
.. BLL (Bauer,Ligeti,Luke) PRD64:113004(2001) → HQE for $m_X < m_D$ and q^2>8 ('non SF region') to minimize SF effect
.. DGE (Anderson,Gardi) JHEP0601:097(2006) → use "Dressed Gluon Exponentiation" to convert on-shell b quark calculation into meson decay spectra

Dominant systematic errors

. MC stat (4.0%)
. detector effects (3.2%)
. complex fitting technique (mES fits) 4.3%
. modeling of signal and background contributions

... and |Vub| results

Kinematic region	ΔB(B→X_ul ν) Δ (stat. sys. th.)	$|V_{ub}|$ (10^{-3}) Δ (stat. sys. th.) [Theory]
M_X < 1.55 GeV/c^2	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^2	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 >8.0 GeV^2/c^2	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]

In theoretical framework, (BLNP e.g.)
. all errors are correlated
Statistical: 3.8%
Systematic: 3.0%
Theory: 7 % (SF errors dominate, m_b) → it is still the dominant error
. experimental correlation evaluated
agreement at 1 σ level for the M_X and combined (M_X,q^2)
P_+ differs from the two others at a 2.5 σ level

Even if we publish all the 7 $|V_{ub}|$ measurements, we elect as the best one the M_X method analysis method because
. it maps out the largest portion of phase space
. it gives the most precise determination of $|V_{ub}|$

Crossing the different theoretical framework BLNP and DGE give consistent results, within the theoretical uncertainty

Current Inclusive |Vub| Measurements

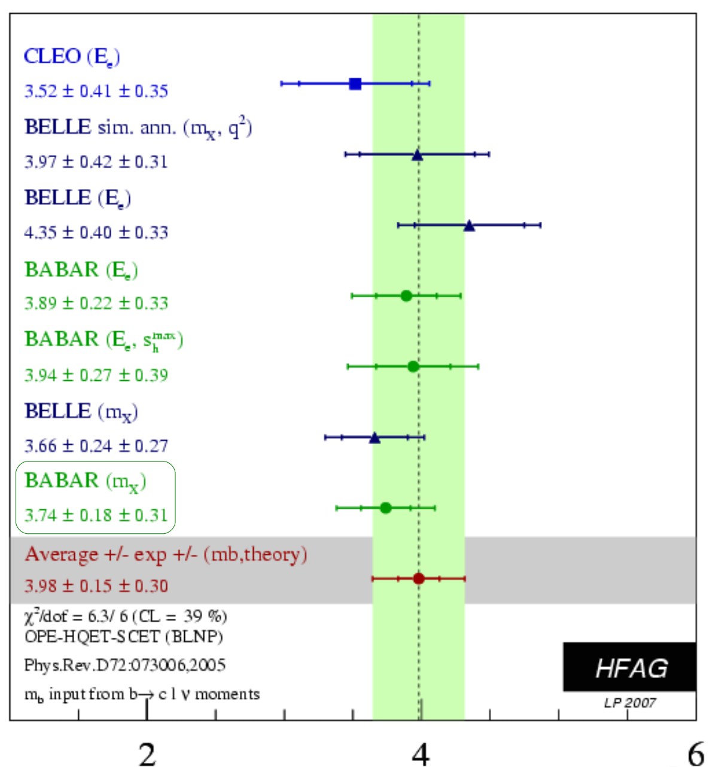
BNLP + only b→ c l ν moments

BLNP - HFAG

$|Vub| = (3.98 \pm 0.15_{exp} \pm 0.30_{mb+theory}) \times 10^{-3}$

Total Error: 8.3 % total

subdivided into:
$\pm 2.0_{stat}$ $\pm 2.5_{exp}$ $\pm 1.8_{bc\ model}$ $\pm 1.1_{bu\ model}$ = Exp. 3.9%
$\pm 6.3_{HQE\ param}$ $\pm 0.4_{SF\ form}$ $\pm 0.7_{sub\ SF}$ $\pm 3.6_{matching}$ $\pm 1.4_{WA}$ = Theory 8.1%



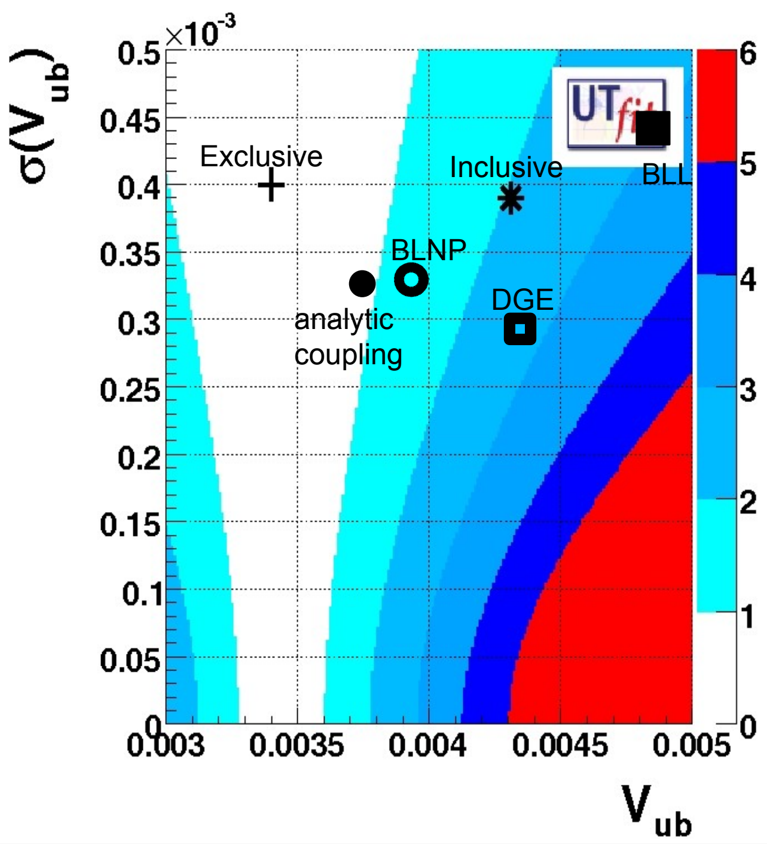
Our BaBar result, based on hadronic mass spectrum

$|Vub| = (4.27 \pm 0.16_{stat} \pm 0.13_{exp} \pm 0.30_{theory}) \times 10^{-3}$ (BABAR)
$|Vub| = (3.74 \pm 0.18_{exp} \pm 0.31_{mb+theory}) \times 10\text{-}3$ (HFAG*)

. supersedes our 2004 PRL
. reduces the relative uncertainty of a 40%
. is compatible with all the other inclusive measurements
. is compatible with the exclusive charmless semileptonic decays measurements [PDG]
(read further about this compatibility on the right →)

* HFAG results are rescaled to common HQE inputs: m_b(SF)=4.707+0.059/-0.053 GeV , μ_π^2=0.216+0.054/-0.076 GeV^2

CKM consistency



Indirect determination from global UT fit (plot bands)
$|V_{ub}|$ from exclusive decays = $(3.33 \pm 0.21^{+0.58}_{-0.38}) \times 10^{-3}$

directly measured values (points/symbols)
$|V_{ub}|$ from exclusive decays = $(3.33 \pm 0.21^{+0.58}_{-0.38}) \times 10^{-3}$
$|V_{ub}|$ from inclusive decays = $(3.98 \pm 0.15 \pm 0.30) \times 10^{-3}$
and single theoretical framework inclusive measurements

Recently a lot of work in the inclusive decays has been done but still there is some "tension", some distance between the central values

Open questions: is it due to New Physics? is it going to disappear in the future? are we possibly just doing something wrong?

Possible answers: it is unlikely NP, possibly it is due to a statistical fluctuation, certainly we still are affected by problems with theoretical calculation and/or estimation of the uncertainties

→ Still Experimental and Theoretical work is needed to understand current results

more details in http://ific.uv.es/~babar/Azzolini-2008_Vub_Valencia.pdf

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