Measuring $|V_{ub}|$ from Semileptonic B Decays

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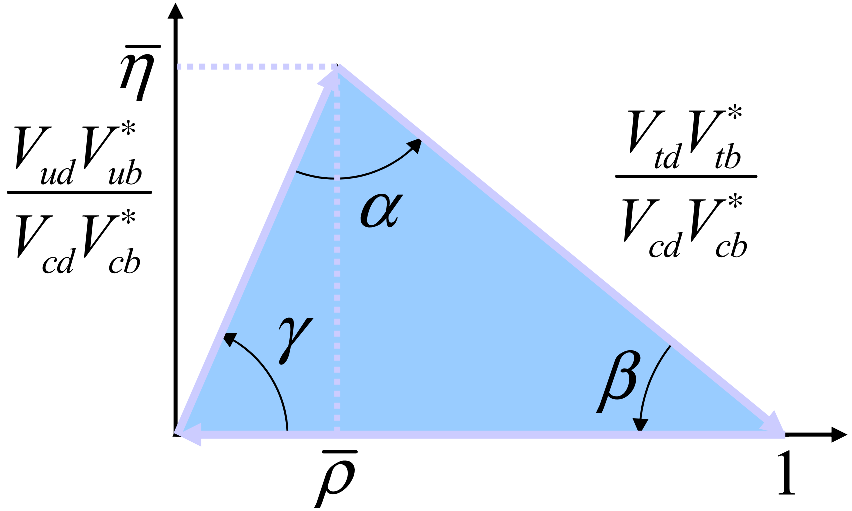
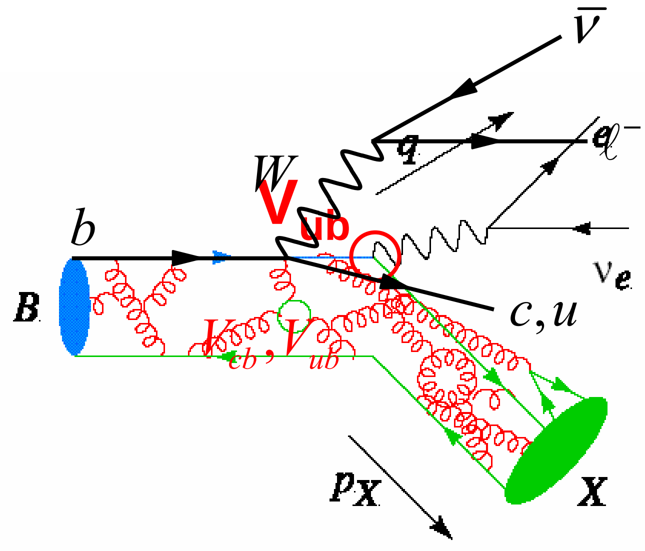
Introduction

- CP violation is described by the CKM matrix in the SM
- the consistency of the Unitarity Triangle is tested by measuring its angles and sides
- one side is related to $|V_{ub}|$
- $|V_{ub}|$ can be measured in semileptonic, charmless B decays

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





Experimental challenge:

- suppress continuum background
- suppress charm decay

Theoretical challenge:

- extrapolate from partial to total BF

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Unitarity Triangle Fits

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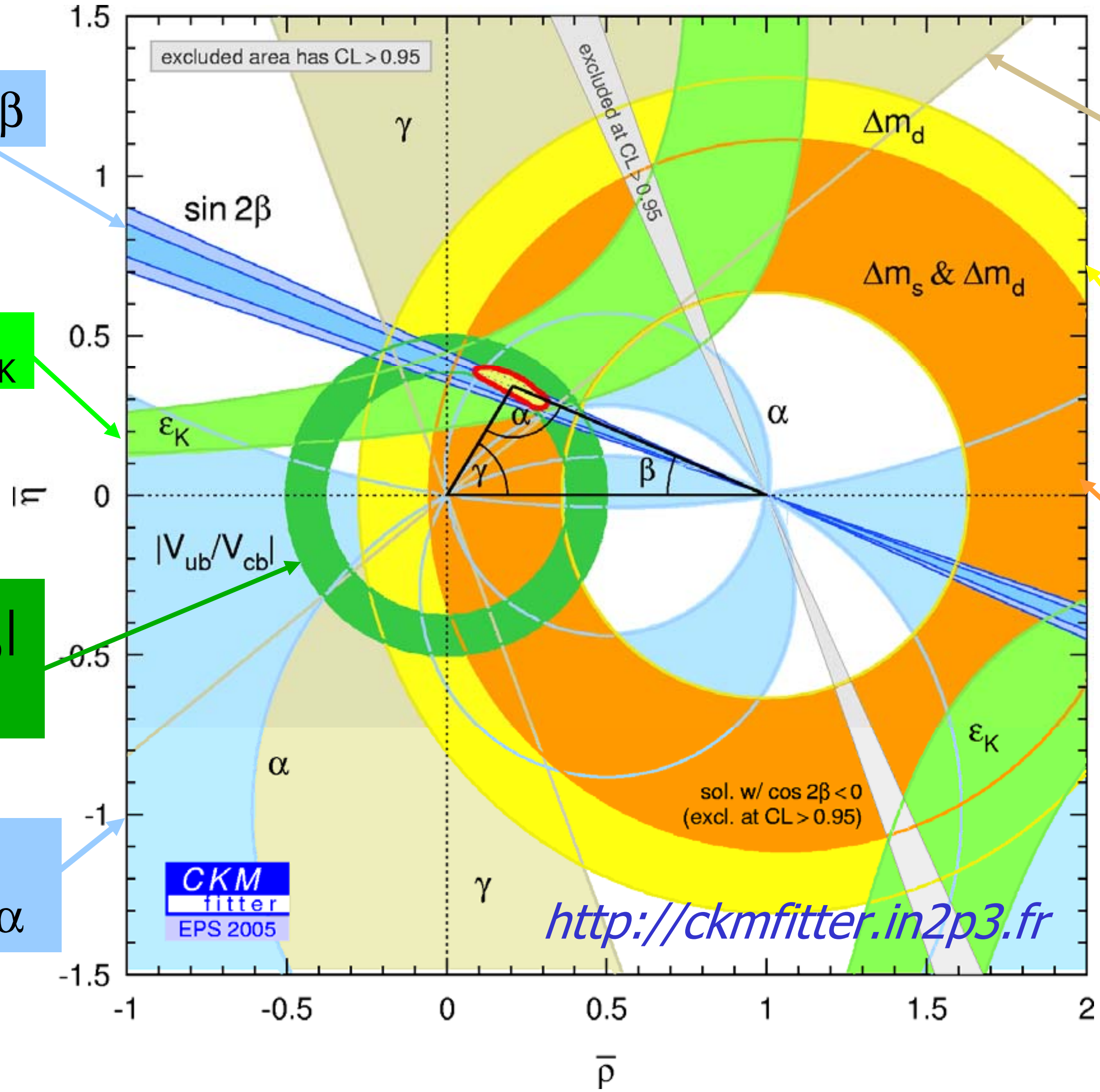
J/ψK^0: sin2β

kaon decays: ε_K

b→ulν: $|V_{ub}|$
D*lν: $|V_{cb}|$

charmless two-body: α

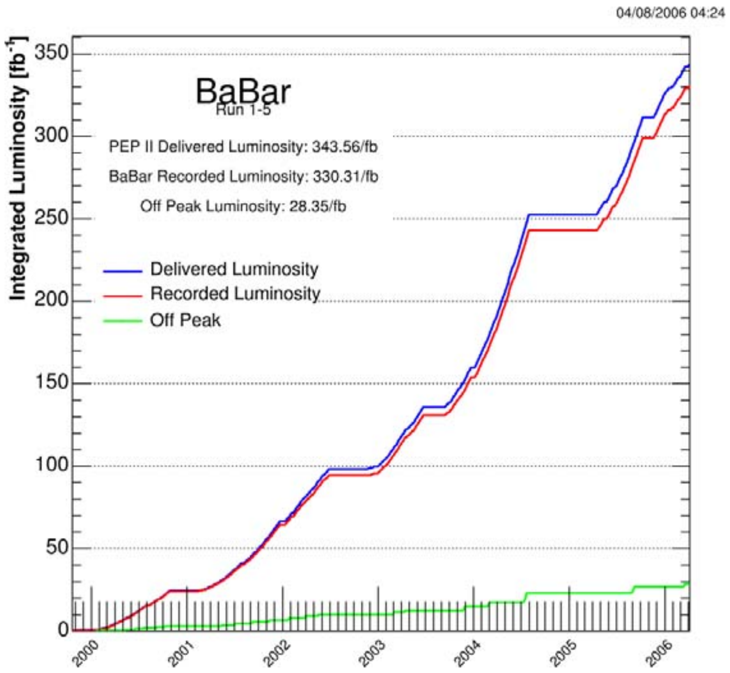


interference in B→DK: γ

B_d mixing: Δm_d

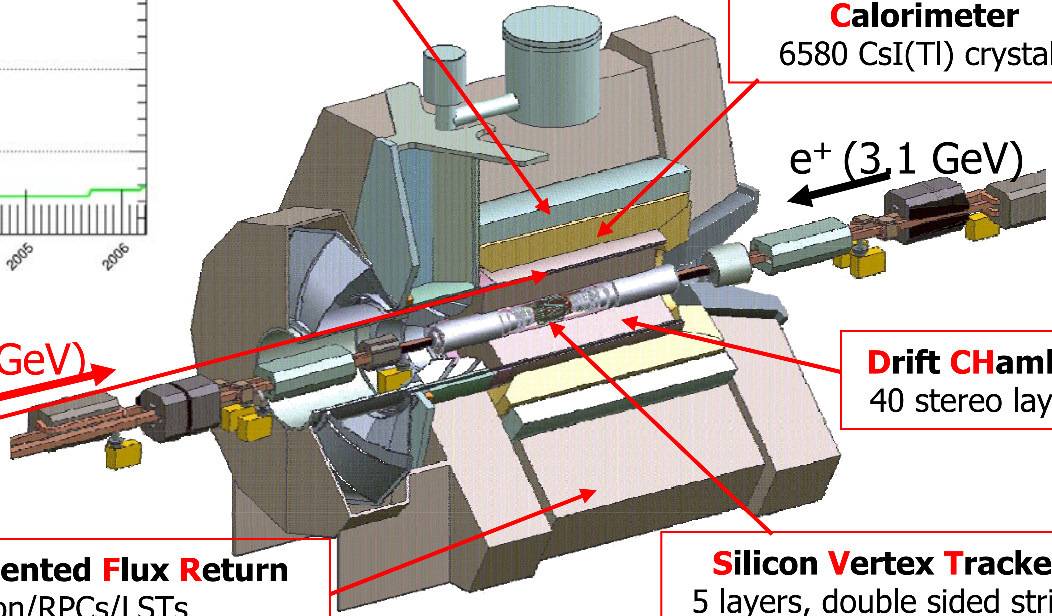
B_s mixing: $\Delta m_s / \Delta m_d$

PEP2 and BaBar Detector



Collected luminosity: ~ 330 fb^{-1}

Analysed Luminosity: 80/210 fb^{-1}



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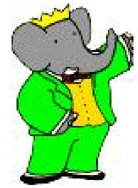
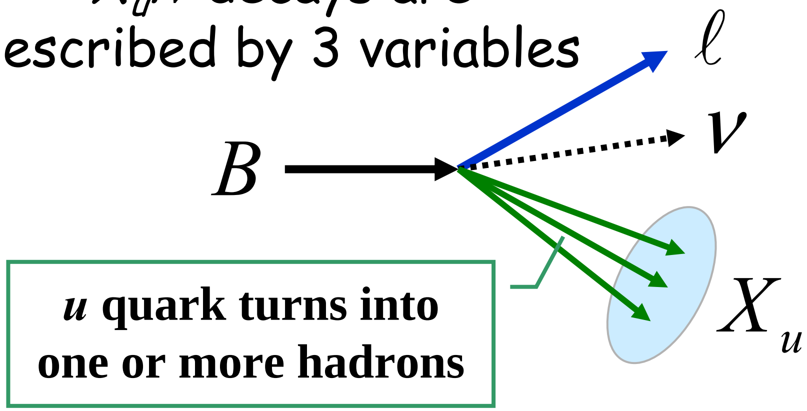
Inclusive $b \to ul\nu$: Strategies



- $B \to X_u l\nu$ decays are described by 3 variables



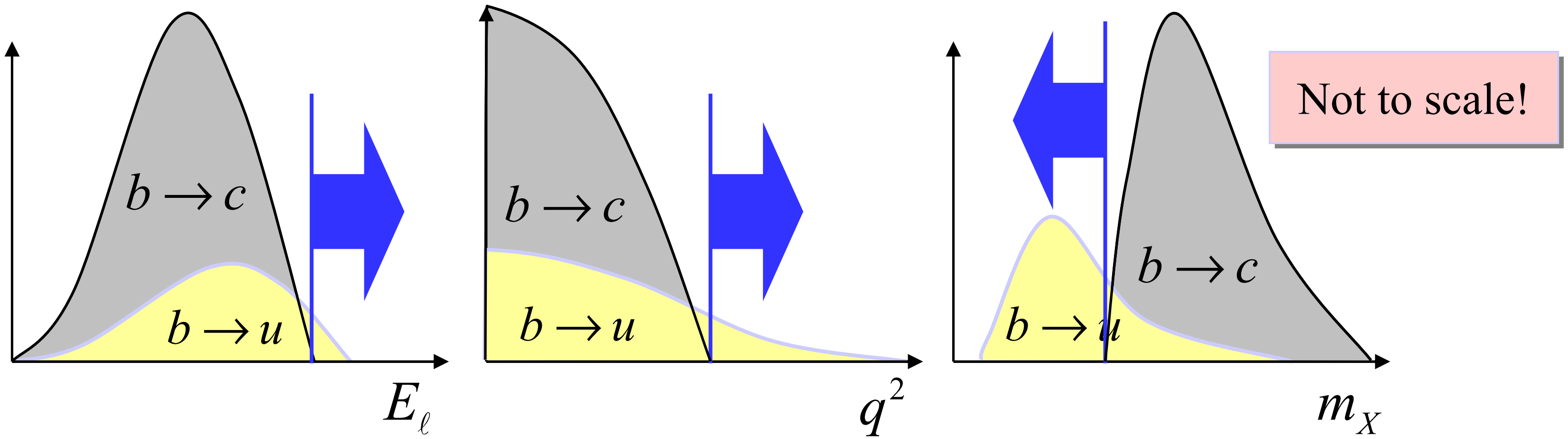
E_l = lepton energy

q^2 = lepton-neutrino mass squared

m_X = hadron system mass

- Signal events have smaller *mX*
→ larger *El* and *q2*

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



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Lepton Endpoint

BABAR PRD73:012006,2006

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Select electrons with 2.0 < E_l < 2.6 GeV

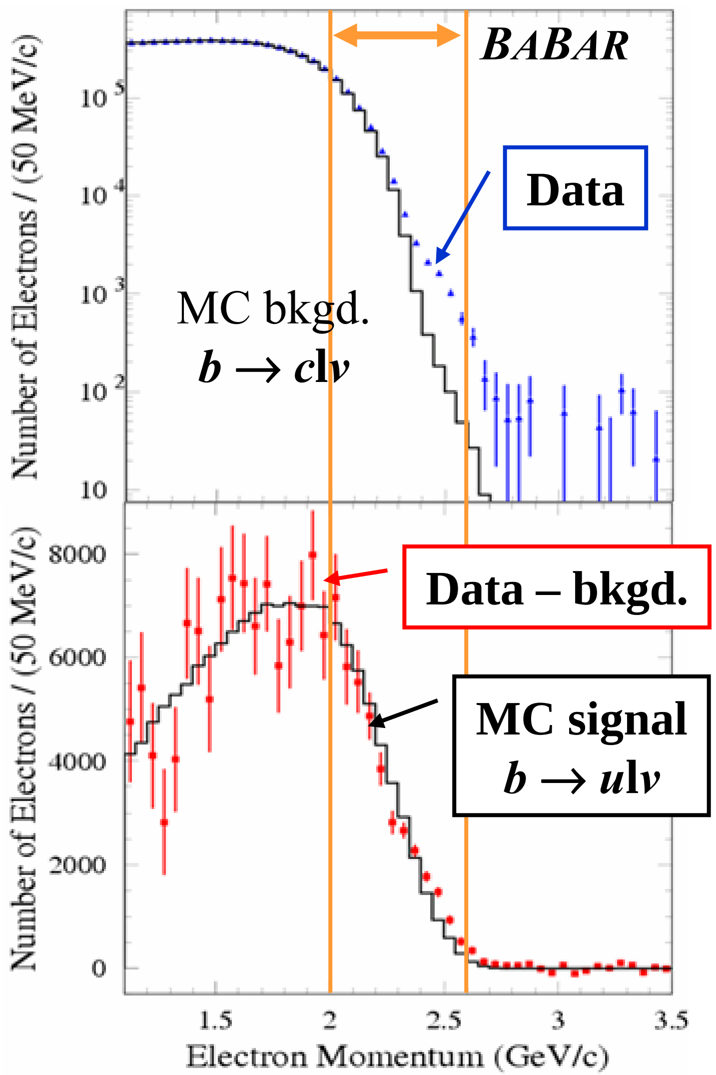
- Push below the charm threshold
  - ➔ Larger signal acceptance
  - ➔ Smaller theoretical error
- Accurate subtraction of background is crucial!
  - off-resonance data
  - events with p_e > 2.8 GeV
  - fit b->clv composition in bkg subtraction

- Measure the partial BF
- S/B =1/15 for the endpoint E_l> 2.0 GeV

$\Delta B\ (10^{-4}) = 5.72 \pm 0.41_{stat} \pm 0.65_{sys}$

Luminosity: 80 fb^{-1}

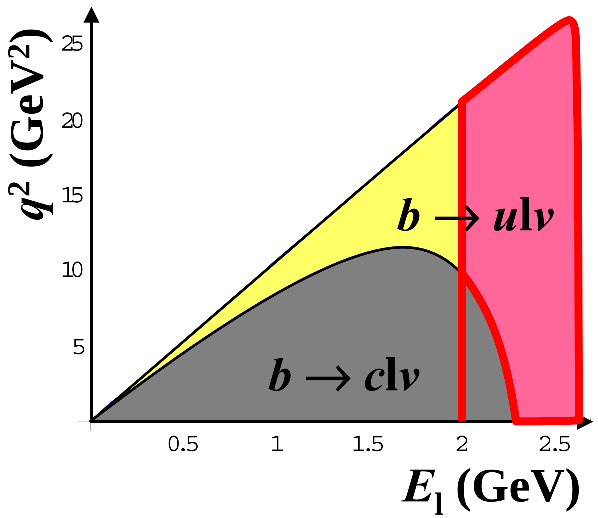
total BF is ~2×10^{-3}



E_l and q^2

BABAR PRL 95:111801

- Try to improve signal-to-background
- Use $p_\nu = p_{miss}$ in addition to p_e ➔ calculate q^2



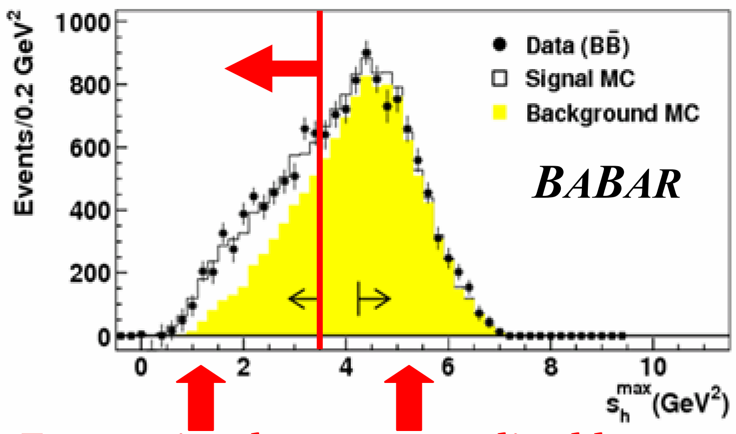
– Define $s_h^{max}(E_l, q^2)$ = the maximum m_X squared
  - Cutting at $s_h^{max} < m_D^2$ removes $b \to c l\nu$ while keeping most of the signal
– S/B = 1/2 achieved for $E_l > 2.0$ GeV and $s_h^{max} < 3.5$ GeV^2

Measured partial BF:

ΔB (10^{-4}) 3.54 ± 0.33stat ± 0.34$_{sys}$

Luminosity: 80 fb^{-1}

Smaller systematic errors



Extract signal

normalize bkg

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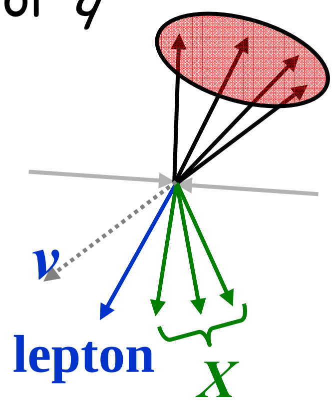
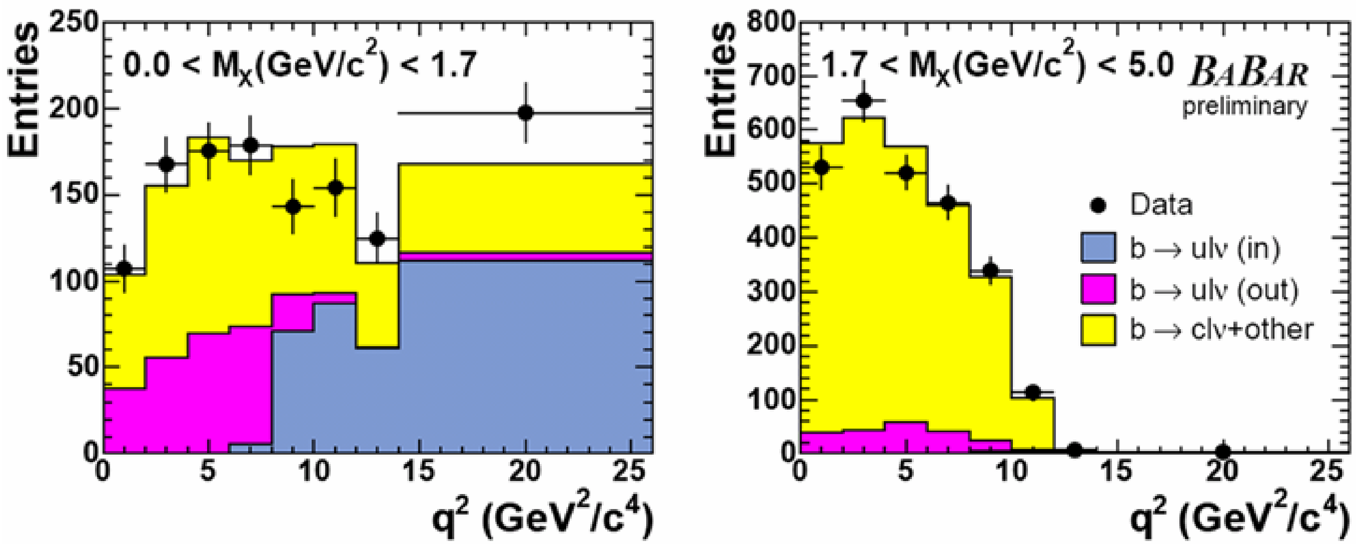
m_X and q^2

BABAR hep-ex/0507017

- Must reconstruct all decay products to measure m_X or q^2
  - Use (fully-reconstructed) hadronic B tag
- Suppress $b \to c l \nu$ by vetoing against $D^{(*)}$ decays
  - Reject events with K
  - Reject events with $B^0 \to D^{*+}(\to D^0 \pi^+) l^- \nu$
- Measure the partial BF in regions of (m_X, q^2)
  - $m_X < 1.7$ GeV and $q^2 > 8$ GeV^2:

$\Delta B\ (10^{-4}) = 8.7 \pm 0.9_{stat} \pm 0.9_{sys}$ **Luminosity: 211fb^{-1}**





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$|V_{ub}|$ from Branching Fraction

For converting a branching fraction into $|V_{ub}|$ the phase space acceptance is needed:

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

Results of different calculations/ HQE parameters using the same partial branching fraction:

Example for m_X/q^2

1) $|V_{ub}|=(5.00\pm0.37_{exp}\pm0.46_{SF}\pm0.28_{theo})\times10^{-3}$

2) $|V_{ub}|=(4.65\pm0.34_{exp}\,{}^{+0.46}_{-0.38}{}_{SF}\pm0.23_{theo})\times10^{-3}$

3) $|V_{ub}|=(4.82\pm0.36_{exp}\pm0.46_{SF+theo})\times10^{-3}$

4) $|V_{ub}|=(4.86\pm0.36_{exp}\pm0.22_{theo})\times10^{-3}$

1) <u>BLNP:</u> BaBar $B\to X_c l\nu$ moments
$m_b(SF) = 4.61 \pm 0.08$ GeV
$\mu_\pi^2(SF) = 0.15 \pm 0.07$ GeV^2

2) <u>BLNP:</u> Belle $B\to X_s\gamma$ spectrum
$m_b(SF) = 4.52 \pm 0.07$ GeV
$\mu_\pi^2(SF) = 0.27 \pm 0.23$ GeV^2

3) <u>BLL:</u> BaBar $B\to X_c l\nu$ moments
$m_b(1S) = 4.74 \pm 0.06$ GeV

4) <u>DGE:</u> HFAG average
$m_b(\overline{MS}) = 4.20 \pm 0.04$ GeV

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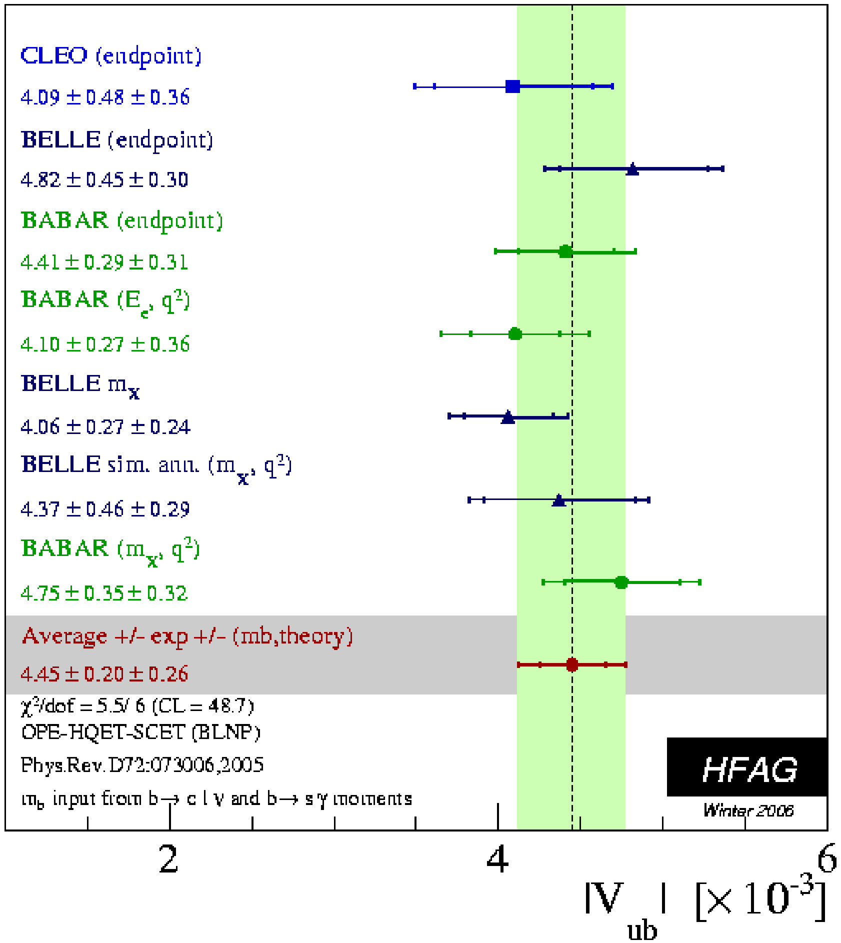
Status of Inclusive $|V_{ub}|$

$|V_{ub}|$ world average summer 2006

BLNP + SF from b->clν, b->sγ

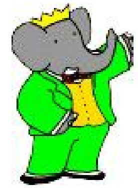


$|V_{ub}|$ determined to ±7.4%

Statistical	±2.2%
Expt. syst.	±2.7%
$b \to c l \nu$ model	±1.9%
$b \to u l \nu$ model	±2.1%
SF params. (m_b, μ_π^2)	±4.1%
Theory	±4.2%

- The SF parameters can be improved with $b \to s\gamma$, $b \to c l \nu$ measurements
- What's in the theory error? Subleading SF and Weak Annihilation effects.

Exclusive $b \to ul\nu$



- Measure specific final states, e.g., $B \to \pi l \nu$
  - Can achieve good signal-to-background ratio
  - Branching fractions are $O(10^{-4})$ → statistics limited
- Need form factors to extract $|V_{ub}|$

$$\frac{d\Gamma(B \to \pi \ell \nu)}{dq^2} = \frac{G_F^2}{24\pi^3} |V_{ub}|^2 \, p_\pi^3 \, |f_+(q^2)|^2$$

One FF for $B \to \pi l \nu$ (massless lepton)

  - Theo. Uncertainties complementary to inclusive approach !
- $f_+(q^2)$ calculations exist based on:
  - Lattice QCD (q^2 > 15 GeV^2)
    - "quenched" calculations ➔ 15% uncertainty
    - new unquenched calculations (hep-lat/0409116,0408019)
  - Light Cone Sum Rules (q^2 < 14 GeV^2) ➔ 10% uncertainty
  - Quark models (ISGW2) … and other approaches

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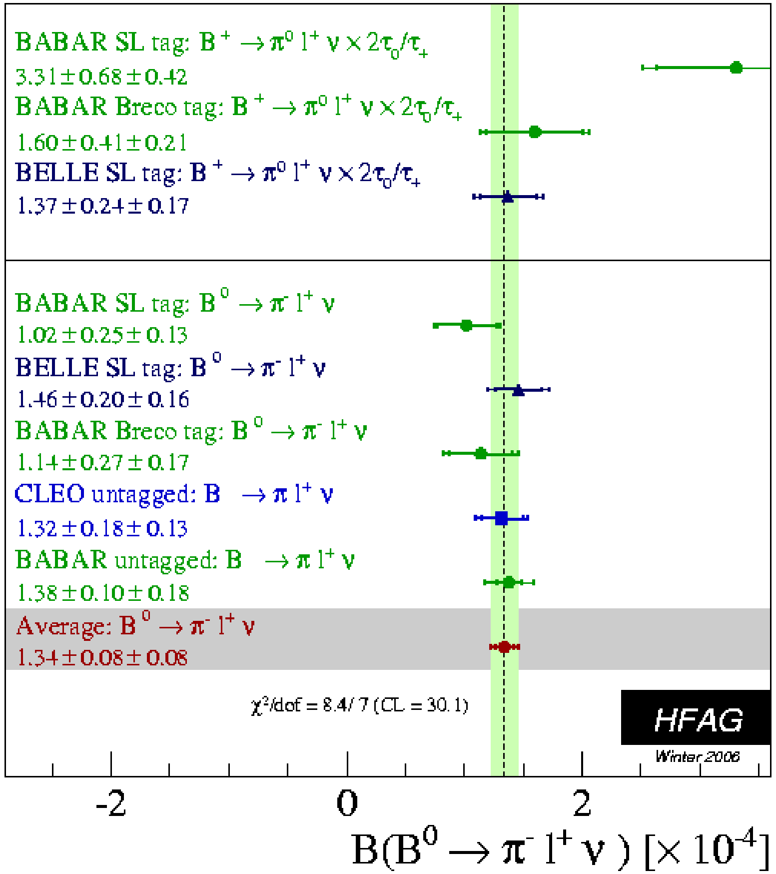
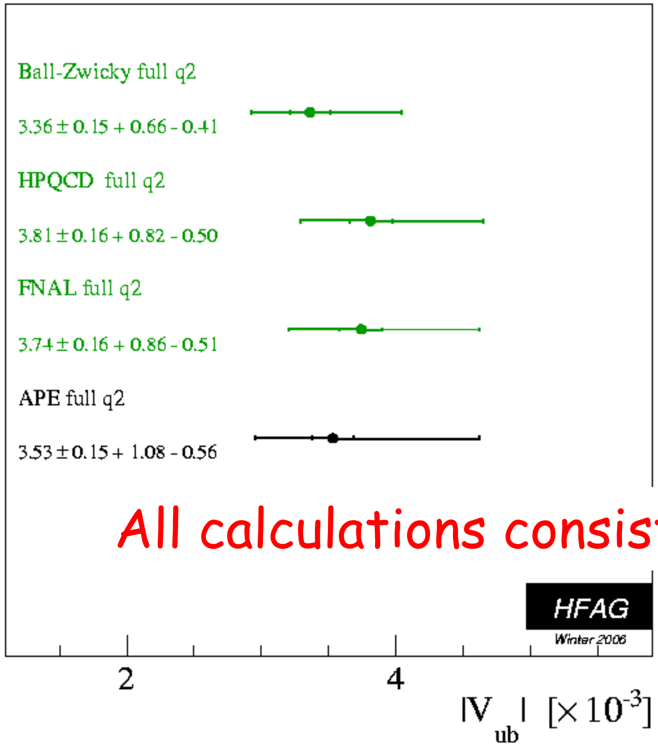
Status of Exclusive $|V_{ub}|$



- use BF and FF predictions to calculate $|V_{ub}|$
- needs also assumption of shape of full q^2 range

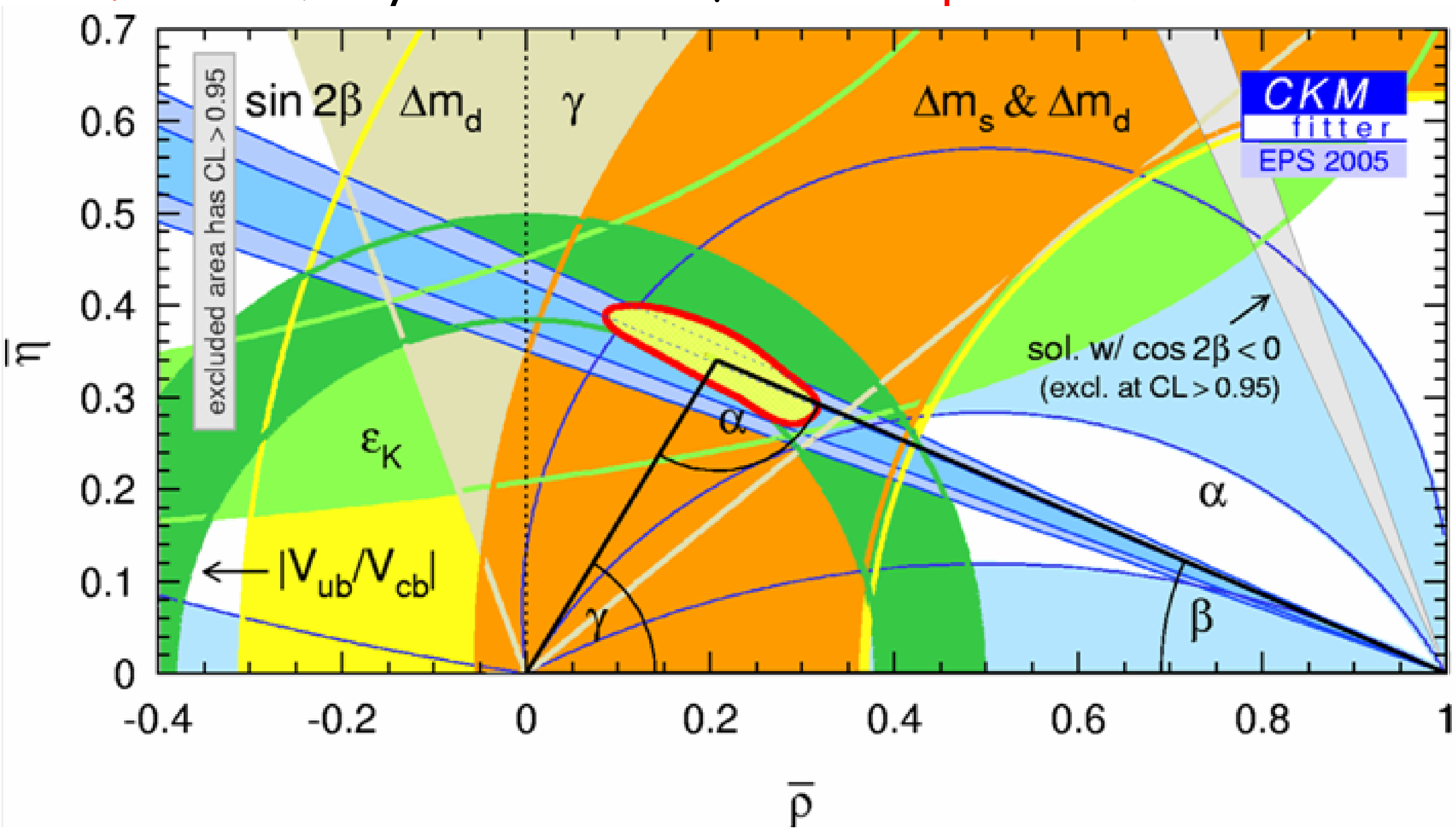


All calculations consistent!

incl. $|V_{ub}|[10^{-3}] = 4.45 \pm 0.20 \pm 0.26$
(BLNP)

The Unitarity Triangle: 2004 → 2006

- Precise determination of $|V_{ub}|$ complements $\sin 2\beta$ to test the validity of the Standard Model
  - 7.4% accuracy achieved so far → 5% possible?



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