$|V_{ub}|$ measurements at BaBar

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On Behalf of
the BaBar
Collaboration

Europhysics Conference on High Energy Physics
(EPS-HEP2007)
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Outline

- Introduction to the CKM matrix and $|V_{ub}|$
- $|V_{ub}|$ using $b \rightarrow u\ell\nu$ semileptonic decays
- Inclusive measurements of $|V_{ub}|$ at BaBar
- Exclusive measurements of $|V_{ub}|$ at BaBar
- State of the art & Conclusions

Introduction

- **The Standard Model describes particles and forces in a simple and elegant way but…**

  - Does not answer everything, incomplete…
  - Contains free parameters (not predicted by theory)

Important to measure these free parameters to (over) constrain the SM. Inconsistencies can be sign of new physics.

- **Example of free parameters: The Cabibbo-Kobayashi-Maskawa (CKM) quark mixing matrix**

Coupling between the quarks and weak charged currents

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

Introduction

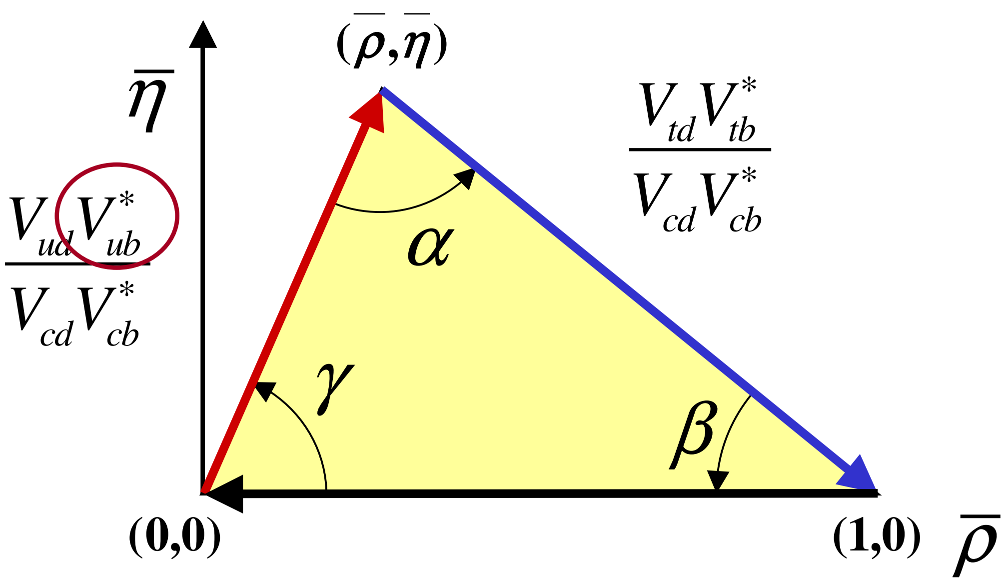
- **By construction, CKM matrix is unitary**

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

- One of the unitarity conditions is:

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

- One common way to represent this condition is the **Unitarity Triangle**:



- **"Ultimate" goal: measure precisely the sides and the angles of the Unitarity Triangle.** If inconsistencies found: sign of new physics

- We can use B mesons to measure them (at BaBar we have millions of them!)

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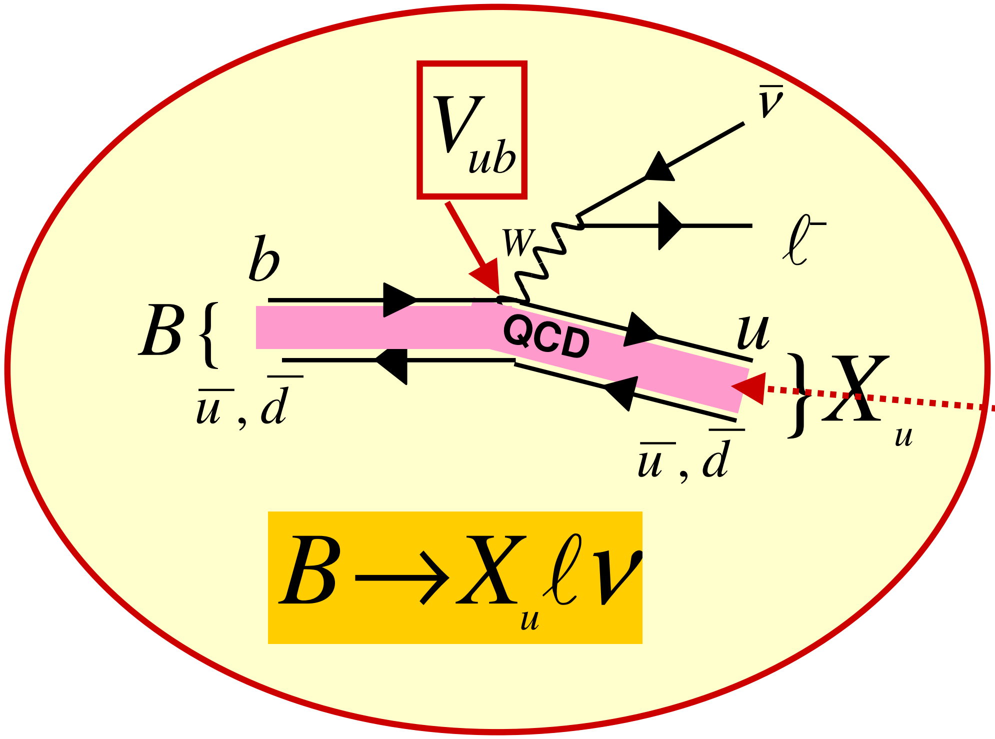
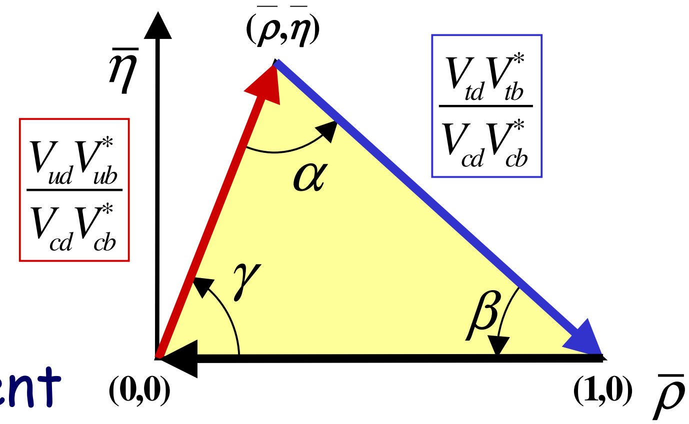
$|V_{ub}|$ using $b \to u\ell\nu$ semileptonic decays



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

Need theoretical input to describe QCD

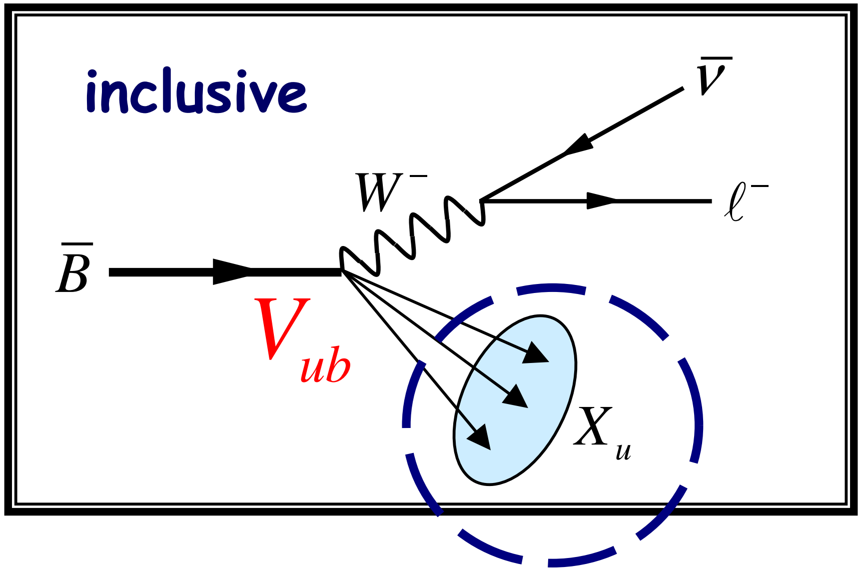


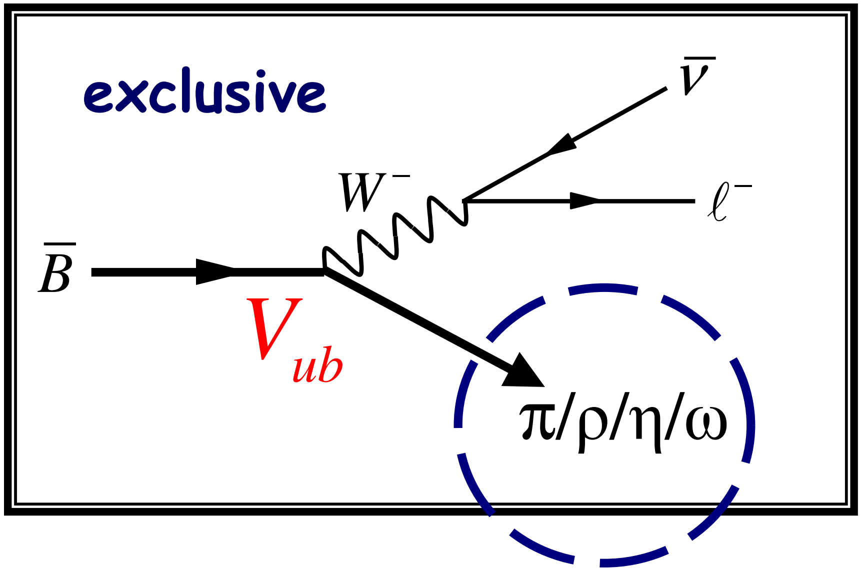
$|V_{ub}|$ is particularly interesting:

- One of the smallest and least known element
- Opposite side to β (measured at a few % level)
- Discrepancies seen between the global fit and the experimental value of $|V_{ub}|$. (~2.6σ effect, NP?)

$|V_{ub}|$ measurements at BaBar

- **We use two main experimental approaches:**





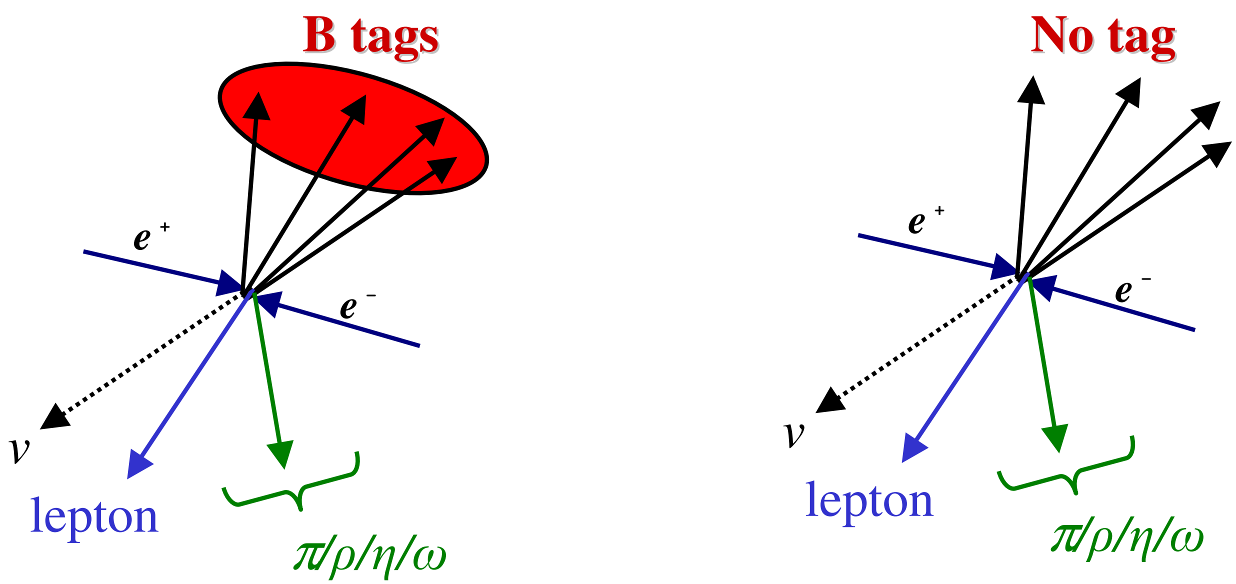
- Similar:
  - need input from theory to describe the QCD part (biggest error)
  - have to face high b→clnu backgrounds (50x more abundant)

- Complementary:
  - Description of the QCD part from theory comes from independent calculations
  - Analysis techniques different

$|V_{ub}|$ studies: tags or no tag

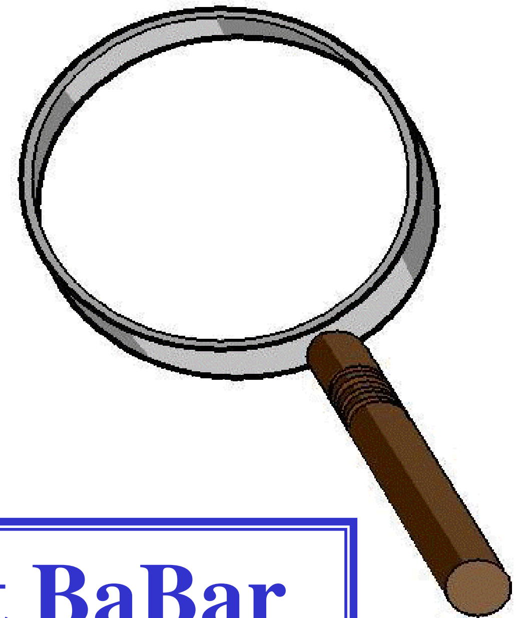
- **Different experimental techniques**

Higher Efficiency (stat. error↓)



Higher Purity (syst. error↓)

Outline



- Introduction to the CKM matrix and $|V_{ub}|$
- $|V_{ub}|$ using $b \to u\ell\nu$ semileptonic decays
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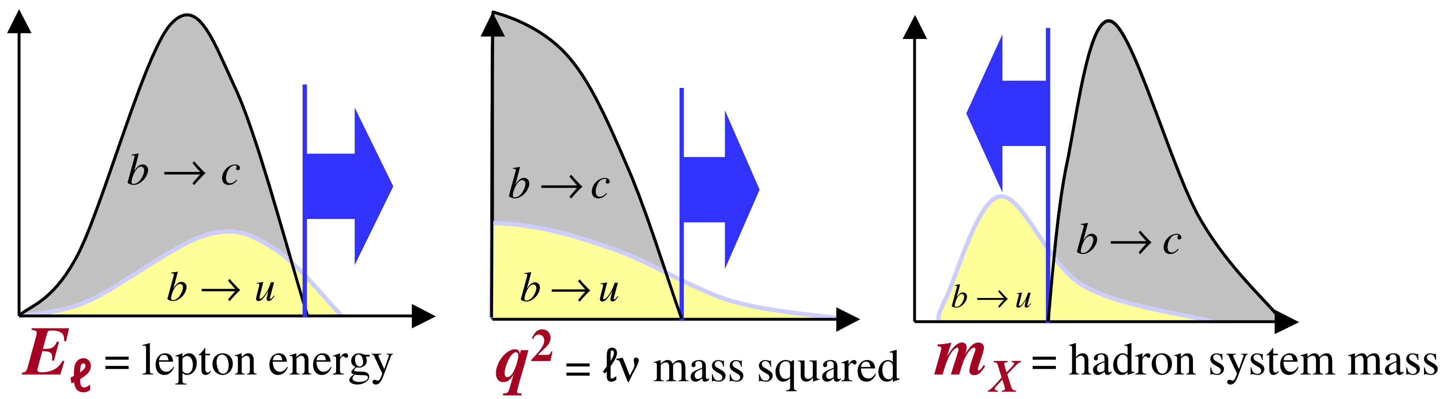
$|V_{ub}|$ with the inclusive approach

Inclusive approach : Do not specify the final hadron Xu (take the sum)

Variables used (idea, not to scale!):



- Measure partial branching fractions (in a limited part of the spectrum)
- Use theory to get full spectrum & $|V_{ub}|$

Best precision so far on $|V_{ub}|$ ~7%

$|V_{ub}|$ with the inclusive approach

All BaBar inclusive Bà Xu l nu results

- Tagged M_X: *PRL **92**, 071802 (2004)*
- Untagged E_e-q^2: *PRL **95**, 111801 (2005)*
- Tagged M_X-q^2: *hep-ex/0507017 (preliminary, LP 2005)*
- Untagged lepton endpoint: *PRD **73**, 012006 (2006)*
- Untagged lepton endpoint reinterpretation: *hep-ph/0702072*
- Tagged “SF free” (M_X): *PRL **96**, 221801 (2006)*

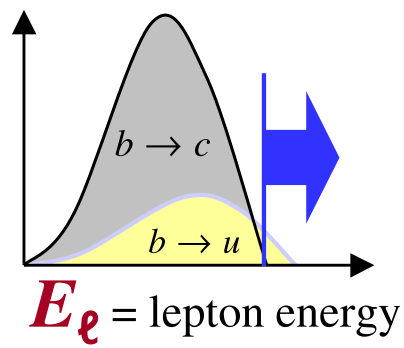
This Talk!

*** More to come for Lepton-Photon!***

$|V_{ub}|$ with the inclusive approach

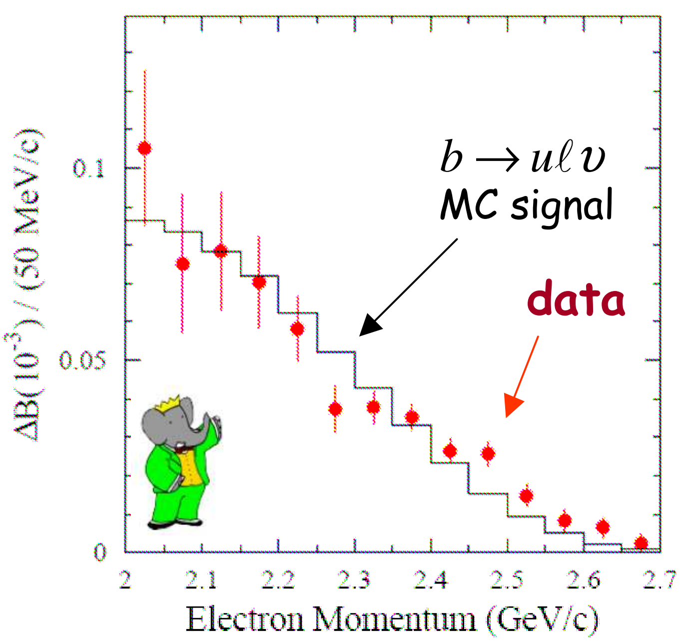
1) Untagged Lepton Endpoint

PRD 73, 012006 (2006)



Best result: electrons with $2.0 < p_l < 2.6$ GeV

Measured electron spectrum



88×10^6 $B\overline{B}$ pairs

Uses inputs from other b → q analyses to describe the motion of the b-quark in the B meson ("Shape Function (SF)")

$$BR(B \to X_u e \upsilon) = \left(2.27 \pm 0.26_{exp} \pm {}^{0.33}_{0.26\,SF} \pm 0.17_{theo}\right)\times10^{-3}$$

Extract $|V_{ub}|$ from BNLP calculations:

(Bosch-Lange-Neubert-Paz Nucl. Phys. B 699, 335, 2004)

$$|V_{ub}| = \left(4.44 \pm 0.25_{exp} \pm {}^{0.42}_{0.38\,SF} \pm 0.22_{theo}\right)\times10^{-3}$$

$|V_{ub}|$ with the inclusive approach

hep-ph/0702072

2) Lepton Endpoint : New interpretation, *with reduced SF dependence*

Possible to combine $b \to u\ell\nu$ and $b \to s\gamma$ so that the SF cancel

- Leibovich, Low, Rothstein: PLB 513, 83, (2001)
- BNLP: JHEP, 0510, 084, (2005)

$$\Gamma(B \to X_u \ell \nu) = \frac{|V_{ub}|^2}{|V_{ts}|^2} \int W(E_\gamma) \frac{d\Gamma(B \to X_s \gamma)}{dE_\gamma} dE_\gamma$$

Weight function ($W(E_\gamma)$)

Decrease in theoretical error, increase in experimental error !

$$|V_{ub}| = \left(4.40 \pm 0.30_{exp} \pm 0.41_{b\to s\gamma} \pm 0.23_{theo}\right) \times 10^{-3} \quad \text{(BNLP)}$$

Comparison with previous page (using SF):

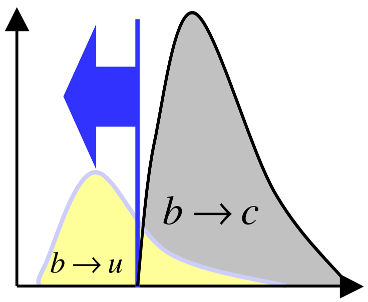
$$|V_{ub}| = \left(4.44 \pm 0.25_{exp} \pm {}^{0.42}_{0.38}{}_{SF} \pm 0.22_{theo}\right) \times 10^{-3}$$

$|V_{ub}|$ with the inclusive approach

PRL 96, 221801 (2006)

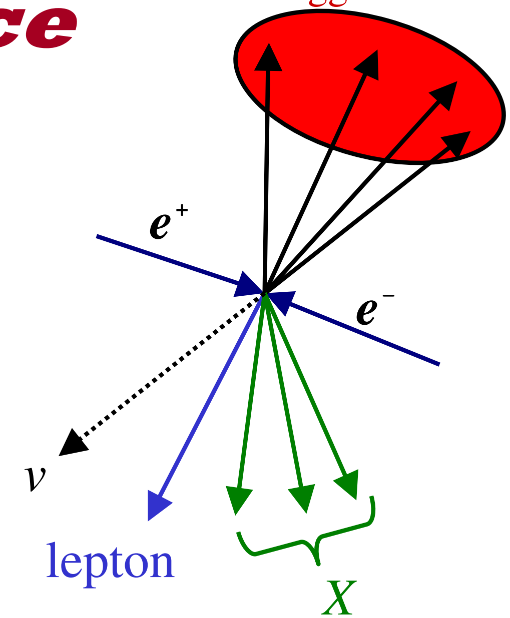
3) Tagged m_X

with reduced SF dependence

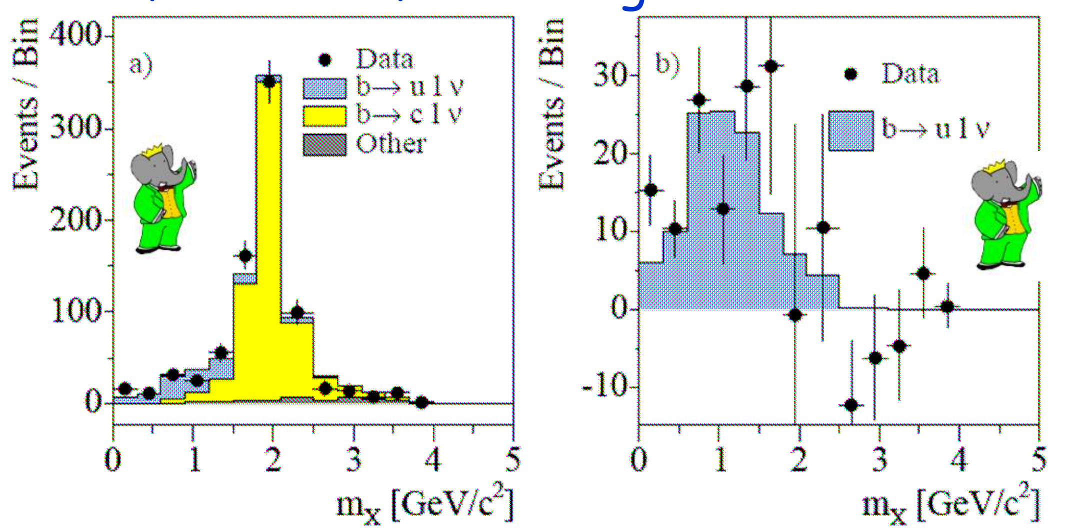


m_X = hadron system mass

- Hadronic Tags
- Search for $X\ell\nu$ in the other B
- Subtract $X_c\ell\nu$ background



Before and after background subtraction



$|V_{ub}|$ with the inclusive approach

3) Tagged m_X

PRL 96, 221801 (2006)

with reduced SF dependence

combines $b \to u \ell \nu$ and $b \to s \gamma$ so that the SF cancel

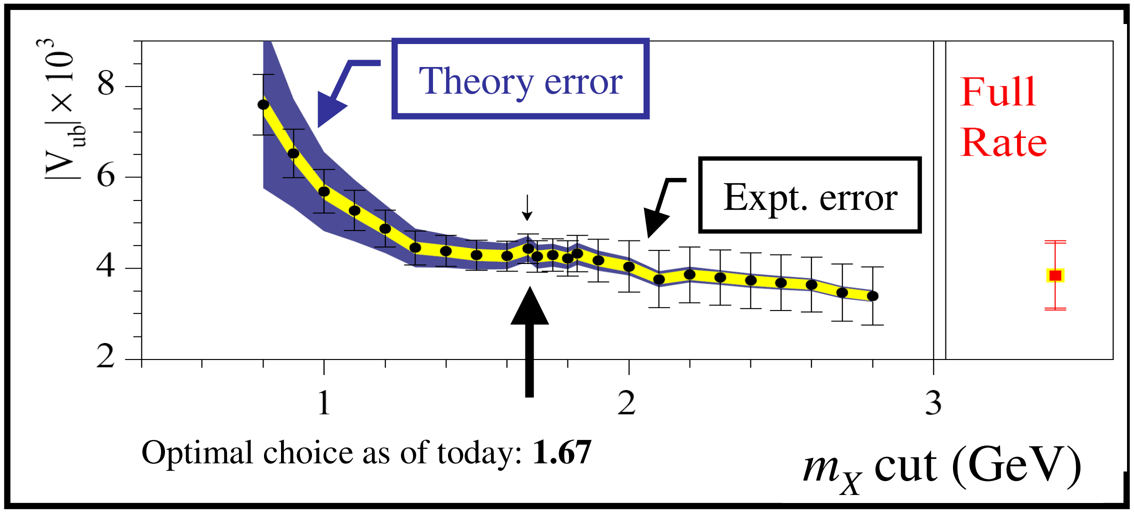
M_x acceptance:

(M_X < 1.67 GeV) $|V_{ub}| = (4.43 \pm 0.38_{stat} \pm 0.25_{syst} \pm 0.29_{theo}) \times 10^{-3}$ **72%**

Another trick to reduce theory dependence: looser m_x cut:

M_x acceptance:

(M_X < 2.50 GeV) $|V_{ub}| = (3.84 \pm 0.70_{stat} \pm 0.30_{syst} \pm 0.10_{theo}) \times 10^{-3}$ **98%**



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$|V_{ub}|$ with the exclusive approach

- **Exclusive Approach : Study a given Xu**

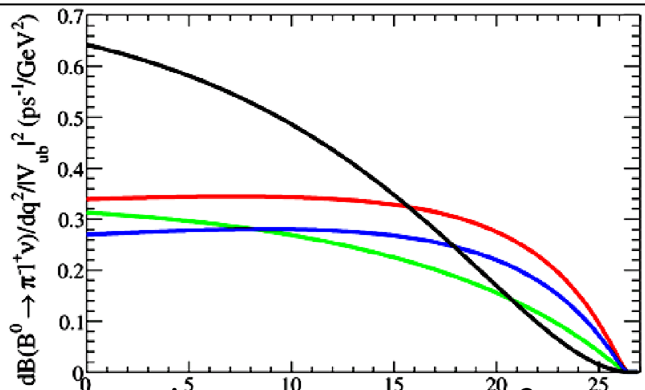
$$|V_{ub}| = \sqrt{\frac{B(B \to X_u \ell \nu)}{\zeta \cdot \tau_B}}$$

theoretical input

- Measure a specific branching fraction
- Get |Vub| with theoretical calculations of Form Factors (FF=$f_+(q^2)$) which parameterize the QCD effects.

$$q^2 = m_W^2 = (\ell + \nu)^2 = (B - \pi)^2$$

- Decay rate varies with q^2
- FF calculations valid for a specific range of q^2



decay rate vs q^2

Lattice QCD: hep-lat/0409116 (2004), PRD73, 074502 (2006)

- **±12% for $q^2 > 16$ GeV²**

Light Cone Sum Rules: PRD71, 014015 (2005)

- **±13% for $q^2 < 16$ GeV²**

ISGW2: PRD52, 2783 (1995)

- **±50%**

- **Experimentally:**
  - We can measure partial BF in q^2 bins
  - To extract $|V_{ub}|$ we use different theo. predictions for different q^2 intervals
  - We can also compare the experimental FF shape with theoretical ones

$|V_{ub}|$ with the exclusive approach

All BaBar exclusive Bà Xu l nu results

- Untagged $B \to \rho\ell\nu$: *PRL **90**, 181801 (2003)*
- (tight) untagged $B \to \pi/\rho\ell\nu$: *PRL **72**, 051102 (2005)*
- Tagged $\eta/\eta'\ell\nu$: *hep-ex/0607066 (prelim, ICHEP 2006)*
- Tagged $B \to \pi\ell\nu$: *PRL **97**, 211801 (2006)*
- (loose) untagged $B \to \pi\ell\nu$: *PRL **98**, 091801 (2007)*

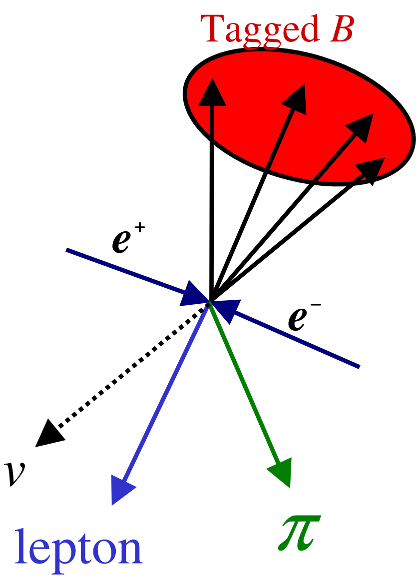
This Talk!

*** More to come for Lepton-Photon!***

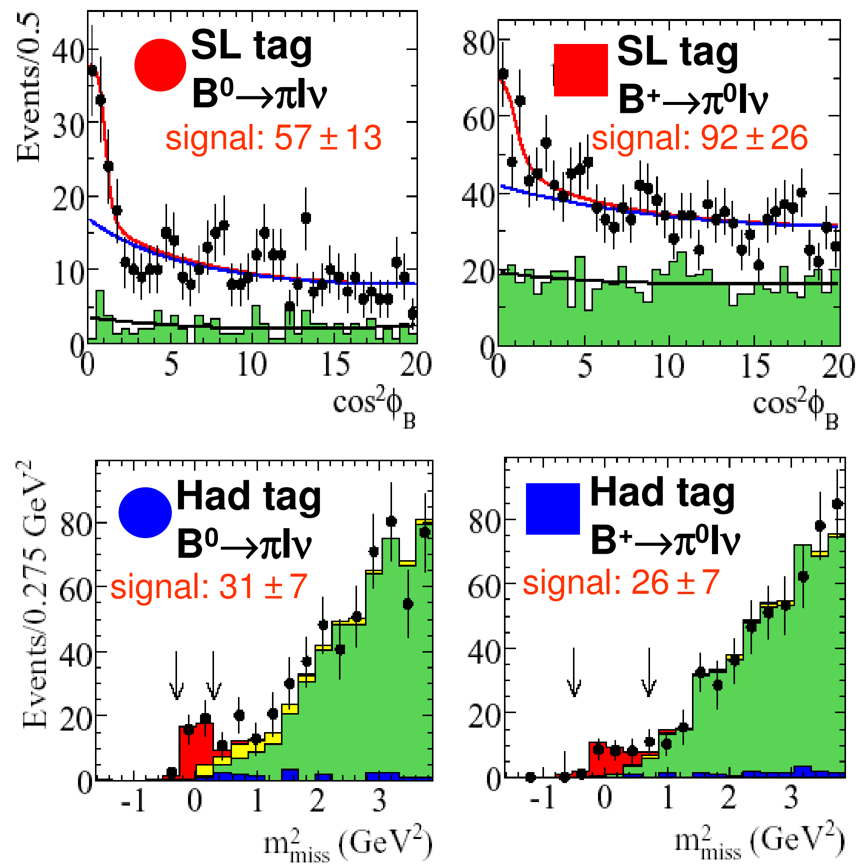
$|V_{ub}|$ with the exclusive approach

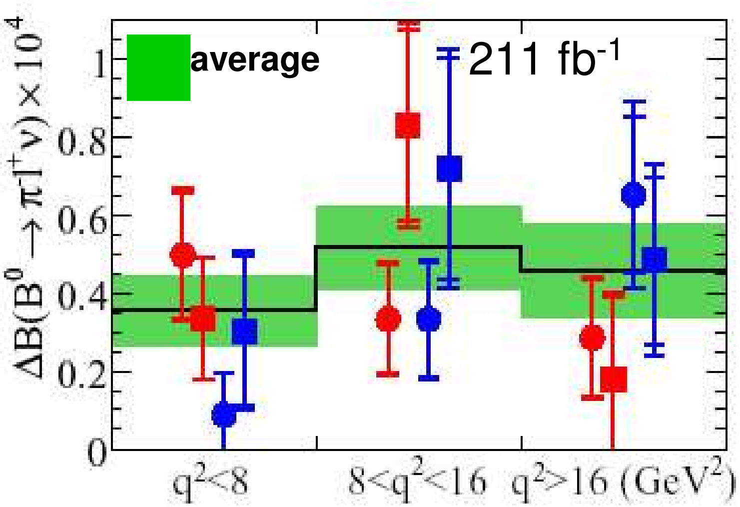
PRL 97, 211801 (2006)

1) Tagged $B \to \pi^{0/+} \ell \nu$



- Hadronic and semileptonic tags
- Neutral and charged channels
- 3 q^2 bins
- Dominated by statistical error for the moment





$|V_{ub}|$ with the exclusive approach

PRL 97, 211801 (2006)

1) Tagged $B \to \pi^{0/+} \ell \nu$

$$BF(B \to \pi^{+} \ell \nu) = (1.33 \pm 0.17_{stat} \pm 0.11_{syst}) \times 10^{-4}$$

$$|V_{ub}| = (3.8 \pm 0.4_{stat} \pm 0.3_{syst} \pm {}^{0.7}_{0.4\,theo}) \times 10^{-3} \text{ (HPQCD)*}$$

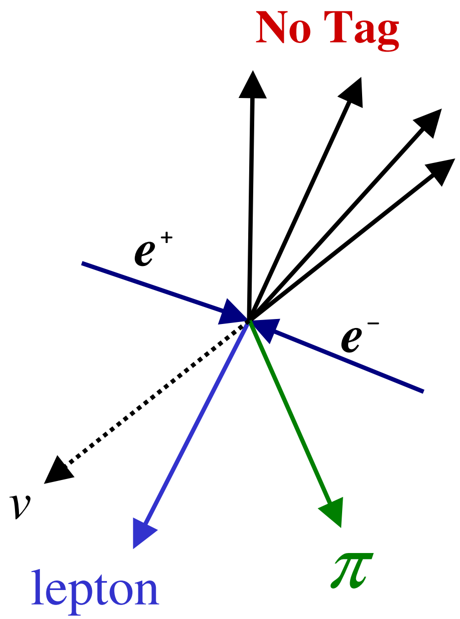
- First published measurement of $B \to \pi \ell \nu$ using tags
- When published:
  - Overall precision comparable to the best published measurement
  - Lowest systematic error
- Very promising with increasing BaBar dataset and expected improvements from the theory side!!

* *Value corrected following the HPQCD erratum: Erratum-ibid.D 75, 119906 (2007)*

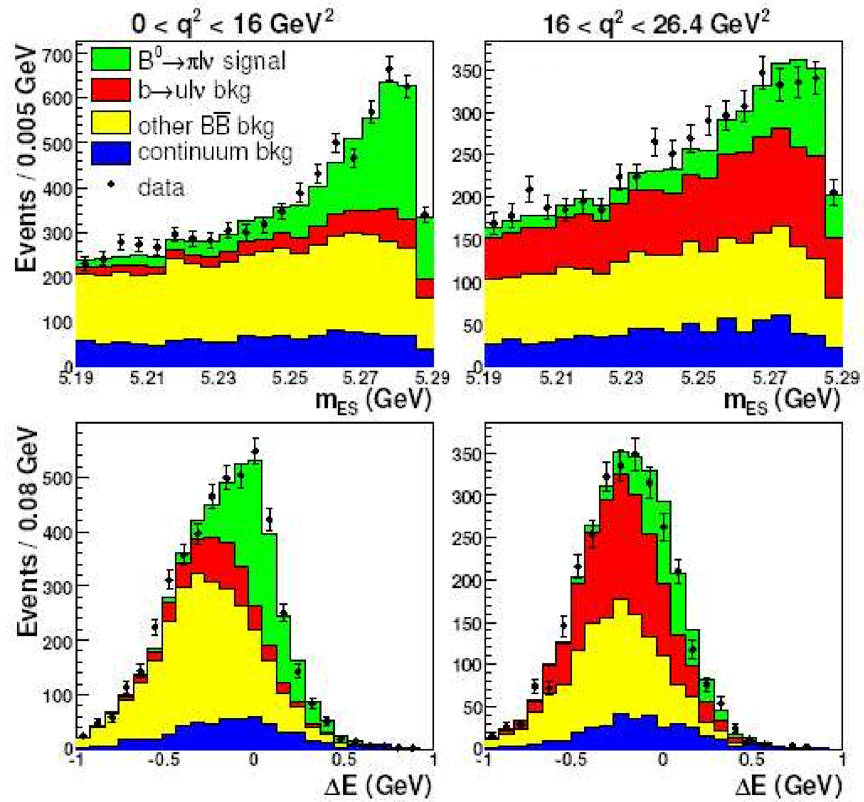
$|V_{ub}|$ with the exclusive approach

PRL 98, 091801 (2007)

2) Loose untagged $B \to \pi^+ \ell \nu$



- No Tag
- Neutrino reconstruction
- Innovation: No *neutrino tight quality* cuts (increase signal efficiency)
- 12 q^2 bins(!)



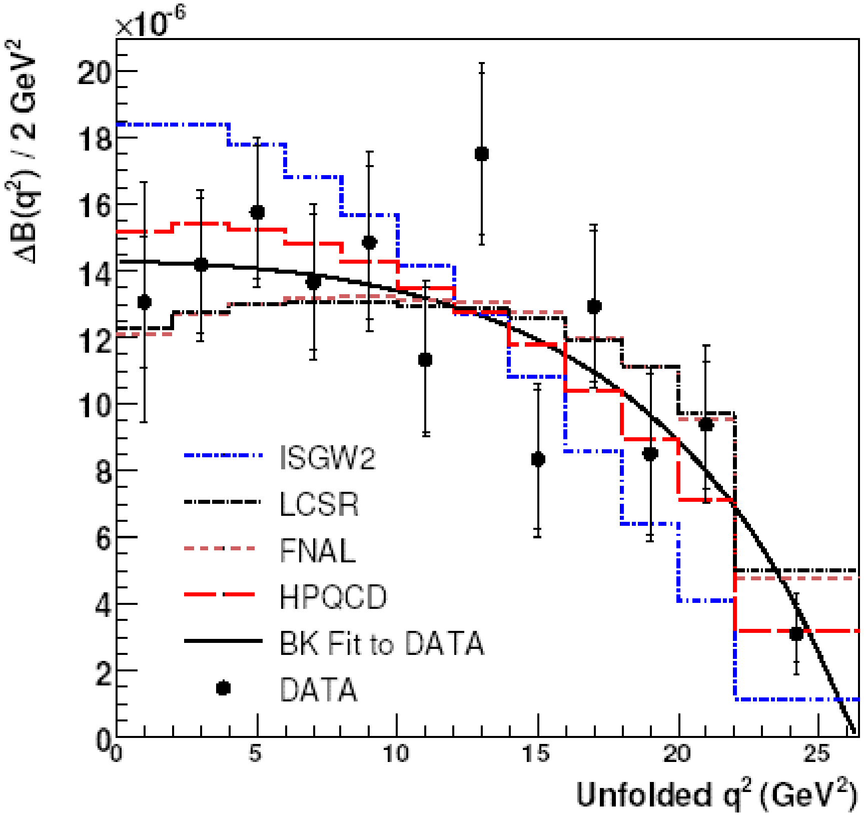
~5000 signal events

206 fb^{-1}

$|V_{ub}|$ with the exclusive approach

2) Loose untagged $B \to \pi^+ \ell \nu$ (II)

PRL 98, 091801 (2007)



→ ISGW2 incompatible (Prob<0.06%)

Smallest statistical and systematic uncertainties of all individual published $B \to \pi l \nu$ measurements!!!

$$BF(B \to \pi^+ \ell \nu) = (1.46 \pm 0.07_{stat} \pm 0.08_{syst}) \times 10^{-4}$$

$$|V_{ub}| = (3.5 \pm 0.2_{stat} \pm 0.1_{syst} \pm {}^{0.6}_{0.4\,theo}) \times 10^{-3} \text{ (HPQCD)*}$$

** Value corrected following the HPQCD erratum: Erratum-ibid.D 75, 119906 (2007)*

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Present precision on $|V_{ub}|$

World Average

$\|V_{ub}\|$	exclusive	(LCSR, $q^2 < 16\ GeV^2$)	$(3.41 \pm 0.13_{exp} \pm 0.56_{theo}) \times 10^{-3}$
$\|V_{ub}\|$	exclusive	(FNAL, $q^2 > 16\ GeV^2$)	$(3.55 \pm 0.22_{exp} \pm 0.61_{theo}) \times 10^{-3}$
$\|V_{ub}\|$	exclusive	(FNAL, full spectrum)	$(3.82 \pm 0.12_{exp} \pm 0.88_{theo}) \times 10^{-3}$
$\|V_{ub}\|$	inclusive	(BLNP)	$(4.52 \pm 0.19_{exp} \pm 0.27_{theo}) \times 10^{-3}$

- The best precision on |Vub| comes from inclusive studies (σ ~7%)
- The exclusive studies (σ~18%) are becoming more competitive (need more precise calculations of FF)

- Global fit:

$\|V_{ub}\|$	CKM Fitter	$(3.54 \pm 0.17) \times 10^{-3}$
$\|V_{ub}\|$	UT Fit	$(3.44 \pm 0.16) \times 10^{-3}$

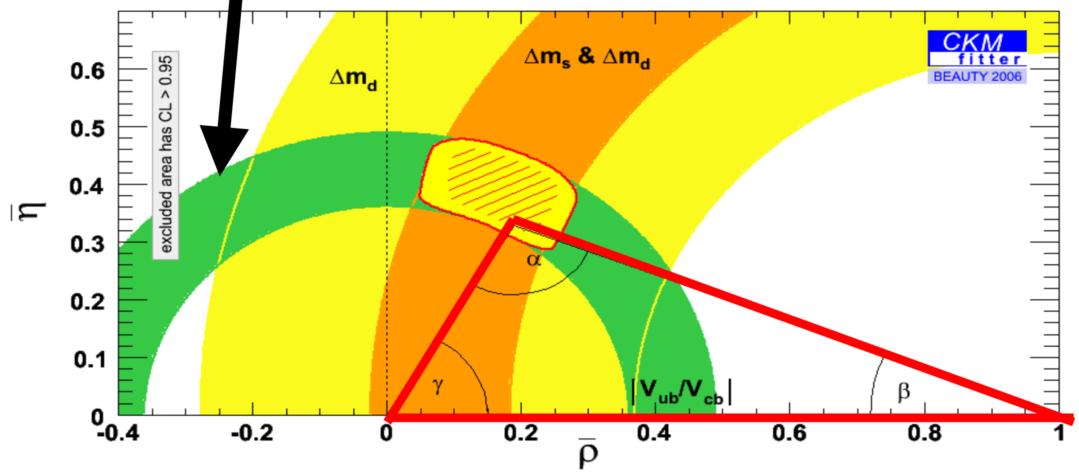
Interesting puzzle:

- Exclusive $|V_{ub}|$ Vs global fit, agrees well (though not precise enough to conclude)
- Inclusive $|V_{ub}|$ Vs global fit, discrepancies at the ~2.6σ level

Present precision on UT

http://ckmfitter.in2p3.fr
ICHEP 06

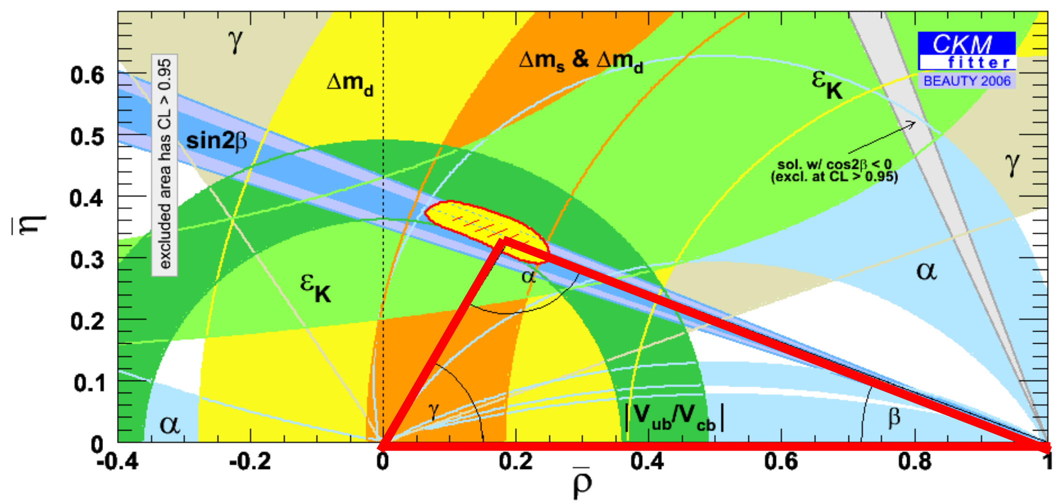
(|V_{ub}| is related to the green band)



Apex fit with the "sides" constraints only

|V_{ub}|: $\sigma \sim 7\%$, |V_{cb}|: $\sigma \sim 1\%$,

|V_{td}|/|V_{ts}|: $\sigma < 4\%$



Apex fit with all constraints

β: $\sigma < 5\%$,

α, γ not very precise yet

Summary & Conclusions

- We have reported recent inclusive and exclusive BaBar results on |Vub| (free parameter of the SM). Biggest challenges in these analyses come from the theoretical description of the QCD and abundant $B \rightarrow X_c \ell \nu$ background.
- We have examined the current precision achieved on $|V_{ub}|$ and the Unitary Triangle. The precision on $|V_{ub}|$ is currently driven by inclusive measurements. The precision on the exclusive measurements should improve in the near future: important theoretical improvements are likely.
- There is an apparent discrepancy between the value of $|V_{ub}|$ from inclusive measurements and that from global UT fit. Sign of something? Will disappear?

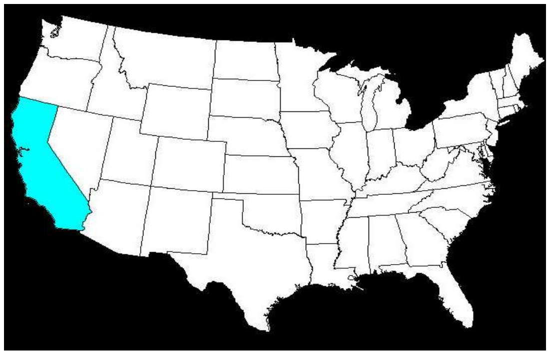
Important to pursue the measurements!

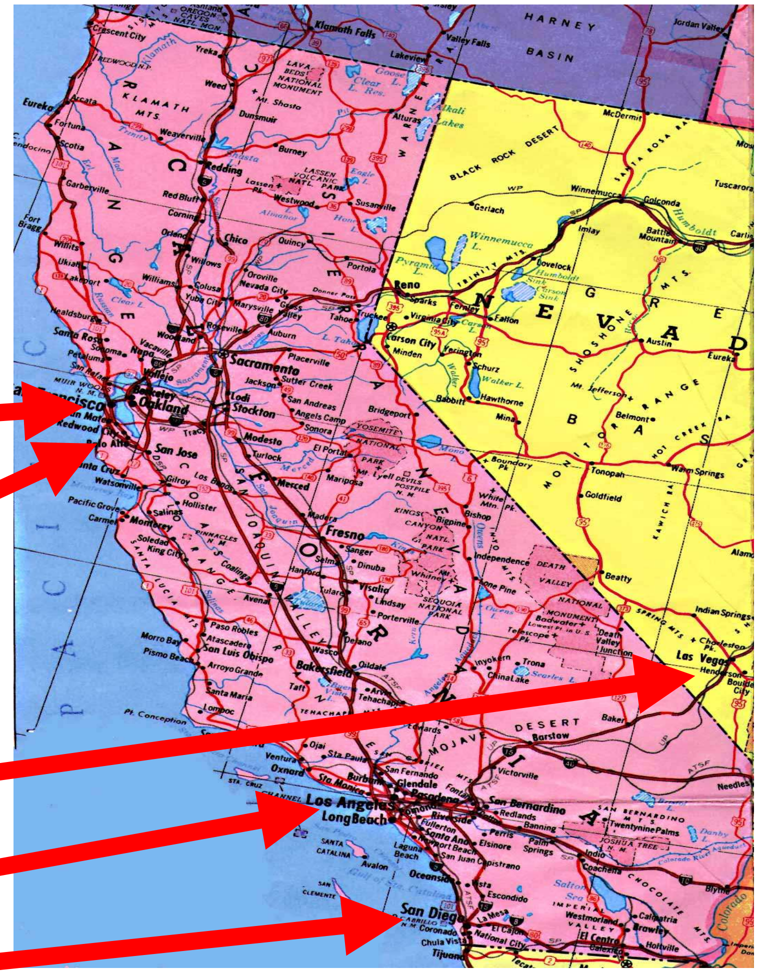
The End

------ BACKUP ---------

The BaBar Experiment

- **SLAC: Stanford Linear Accelerator center**





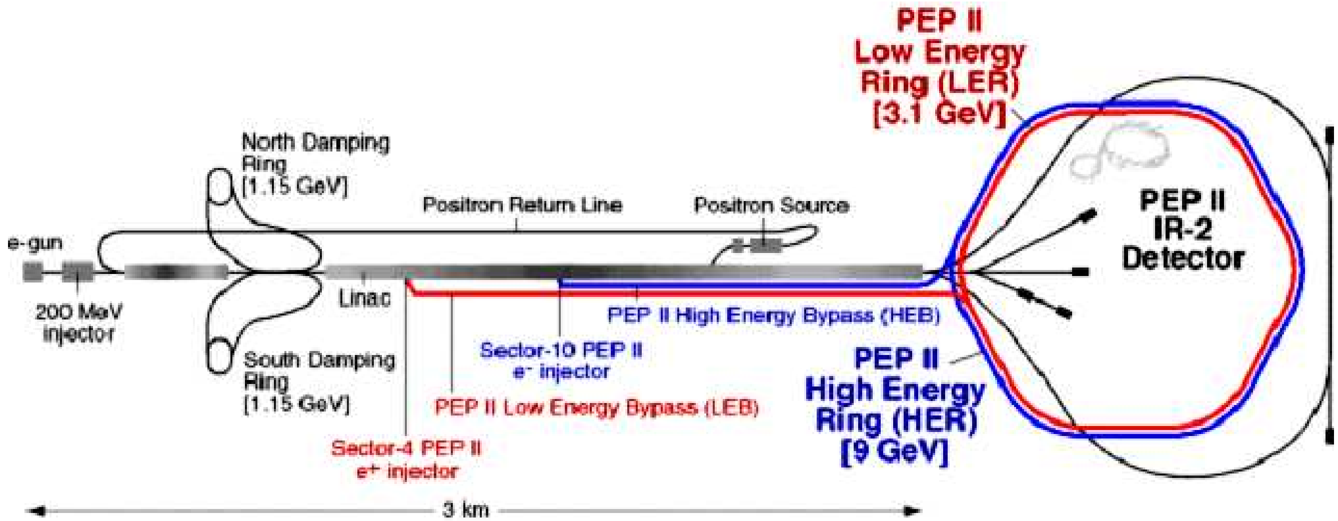
San Francisco

SLAC
(Stanford University)
Palo Alto

Las Vegas
Los Angeles
San Diego

The BaBar Experiment

SLAC: The Accelerator



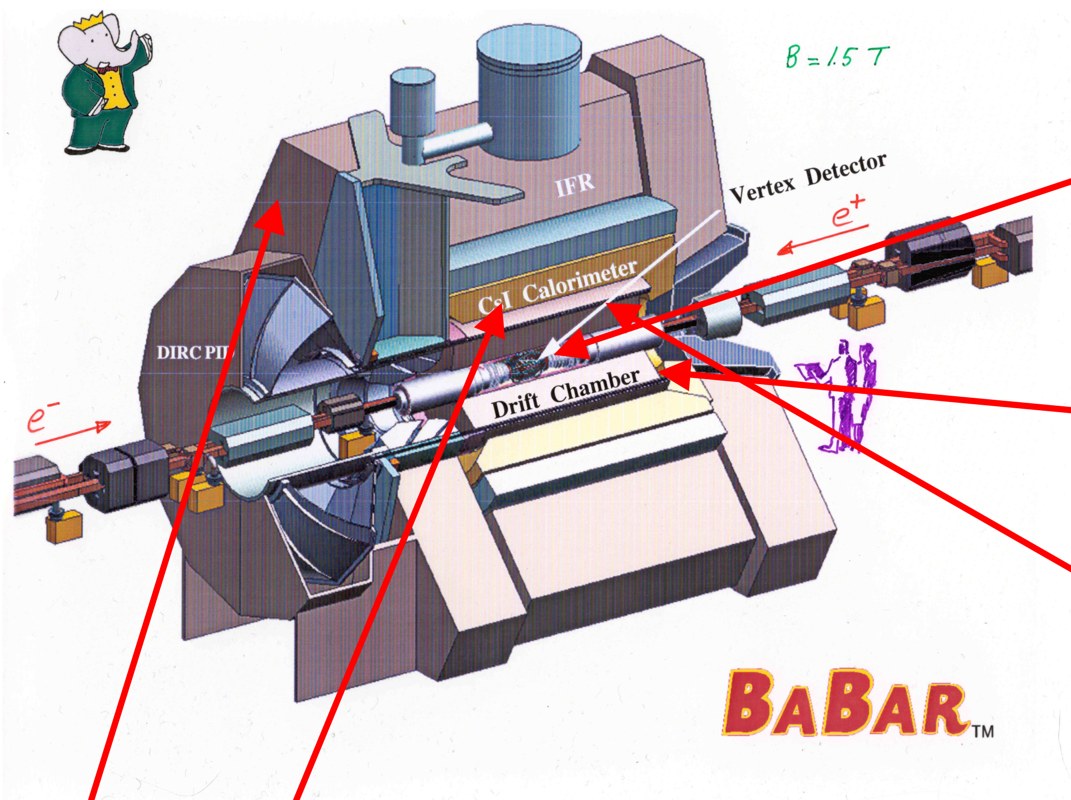
<u>Asymmetric collisions</u> à e- : 9 GeV, e+ : 3.1 GeV
à Upsilon(4S) resonance: 10.58 GeV in c.m. frame

e+ e- collisions → Υ → B and B-bar mesons $B\bar{B} \cong$ BaBar ... J

High luminosity, « B factory »

The BaBar Experiment

BaBar: The Detector



*Silicon Vertex Tracker (SVT)
-Charged Particle position

*Drift Chamber (DCH)
-Charged particle reconstruction and identification

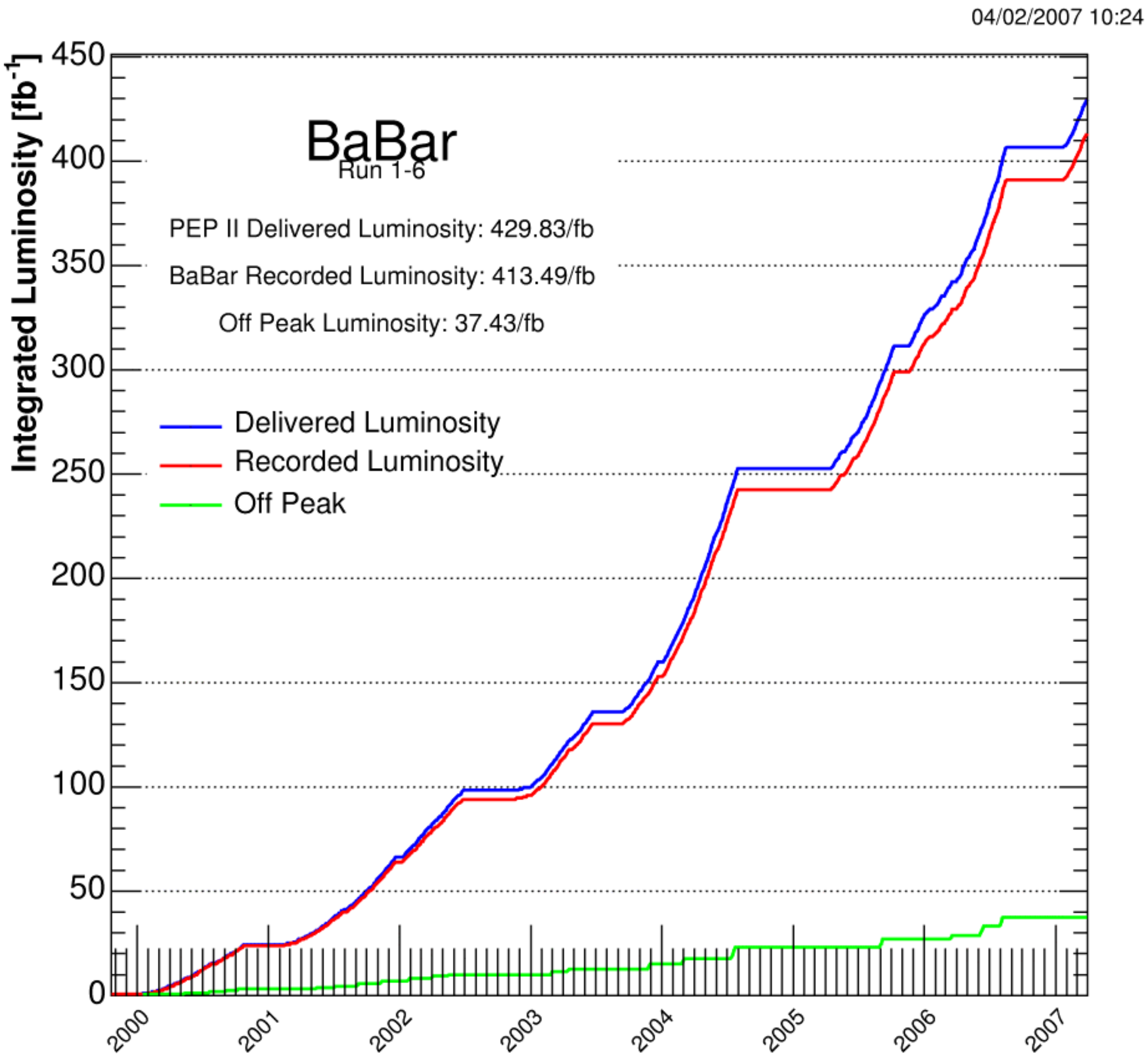
*Detection of Internally Reflected Cerenkov (DIRC)
-Charged particle identification

*Electromagnetic Calorimeter (EMC)
-Photons and electron detection

*Instrumental Flux Return (IFR)
-Muon identification and long lived neutral hadron detection

The BaBar Experiment

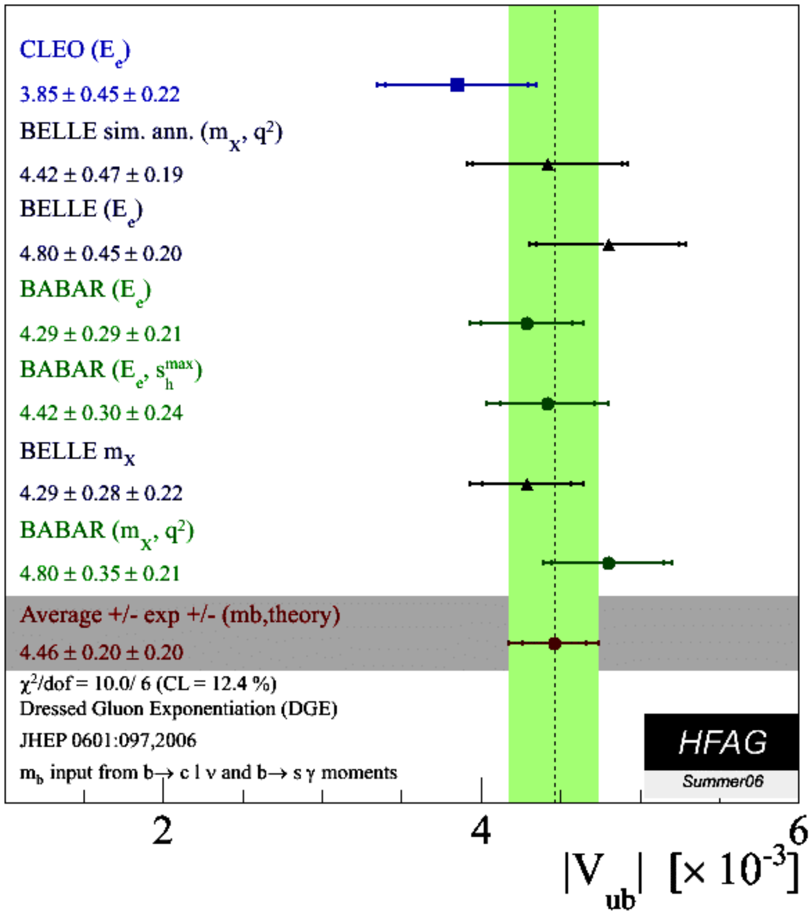
- **BaBar: Data recorded so far**



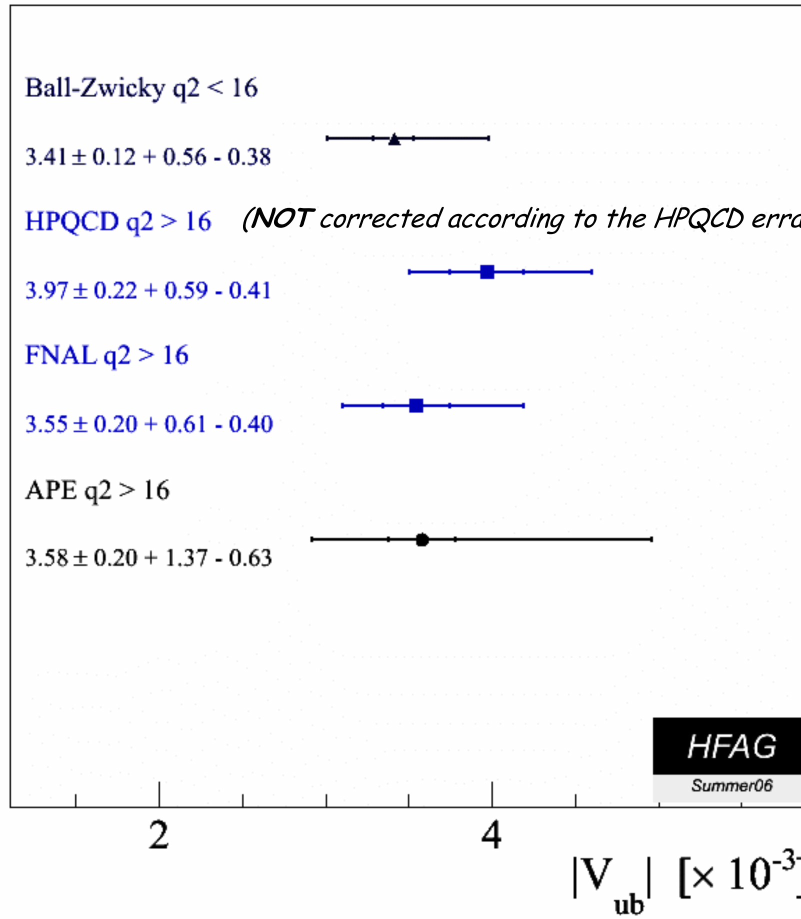
$> 425\ 000\ 000\ \ B\bar{B}$ pairs !!

Present precision on $|V_{ub}|$

- The best precision on |Vub| comes from <u>inclusive</u> studies (σ ~7%)



- The <u>exclusive</u> studies (σ~18%) are becoming more competitive (need more precise calculations of FF)



- Exclusive measurements not enough precise to conclude…

  … but seem lower than inclusive measurements…

History / Present precision on BF($B\to\pi\ell\nu$)

- Published results before the BaBar tag measurement

Measurement	Method used	Results ($\times 10^{-4}$)
CLEO: PRL 77, 5000 (1996)	No tag, 1 q^2 bin, pi^0+ pi^+ modes, 2.8×10^6 BBbar pairs	BF($B\to\pi^+\ell\nu$)= 1.8 ± 0.4 ± 0.4
CLEO: PRD 68, 073003 (2003)	No tag, 3 q^2 bins, pi^0 + pi^+ modes, 9.7×10^6 BBbar pairs	BF($B\to\pi^+\ell\nu$)= 1.33 ± 0.18 ± 0.13
BaBar, PRD 72, 051102 (2005)	No tag, 5 q^2 bins, pi^0 + pi^+ modes, 83×10^6 BBbar pairs	**BF($B\to\pi^+\ell\nu$)= 1.38 ± 0.10 ± 0.18**

- Babar tag measurement

BaBar: PRL 97, 211801 (2006)	Semileptonic tags, 3 q^2 bins, 232×10^6 BBbar pairs	Semileptonic Tags BF($B\to\pi^+\ell\nu$)= 1.12 ± 0.25 ± 0.10 BF($B\to\pi^0\ell\nu$)= 0.73 ± 0.18 ± 0.08 Hadronic Tags BF($B\to\pi^+\ell\nu$)= 1.07 ± 0.27 ± 0.15 BF($B\to\pi^0\ell\nu$)= 0.82 ± 0.22 ± 0.11 **Combined** **BF($B\to\pi^+\ell\nu$)= 1.33 ± 0.17 ± 0.11**

- Other recent results (published/submitted)

Belle: PLB 648, 139 (2007)	Semileptonic tags, 3 q^2 bins, no combination between modes, 275×10^6 BBbar pairs	BF($B\to\pi^+\ell\nu$)= 1.38 ± 0.19 ± 0.14 BF($B\to\pi^0\ell\nu$)= 0.77 ± 0.14 ± 0.08
BaBar: PRL 98, 091801 (2007)	No tag, 12 q^2 bins, pi^+ mode only, 227×10^6 BBbar pairs	**BF($B\to\pi^+\ell\nu$)= 1.46 ± 0.07 ± 0.08**
CLEO: Submitted to PRD **hep-ex/0703042**	No tag, 4 q^2 bins, pi^0 + pi^+ modes, 15.4×10^6 BBbar pairs	**BF($B\to\pi^+\ell\nu$)= 1.37 ± 0.15 ± 0.11**