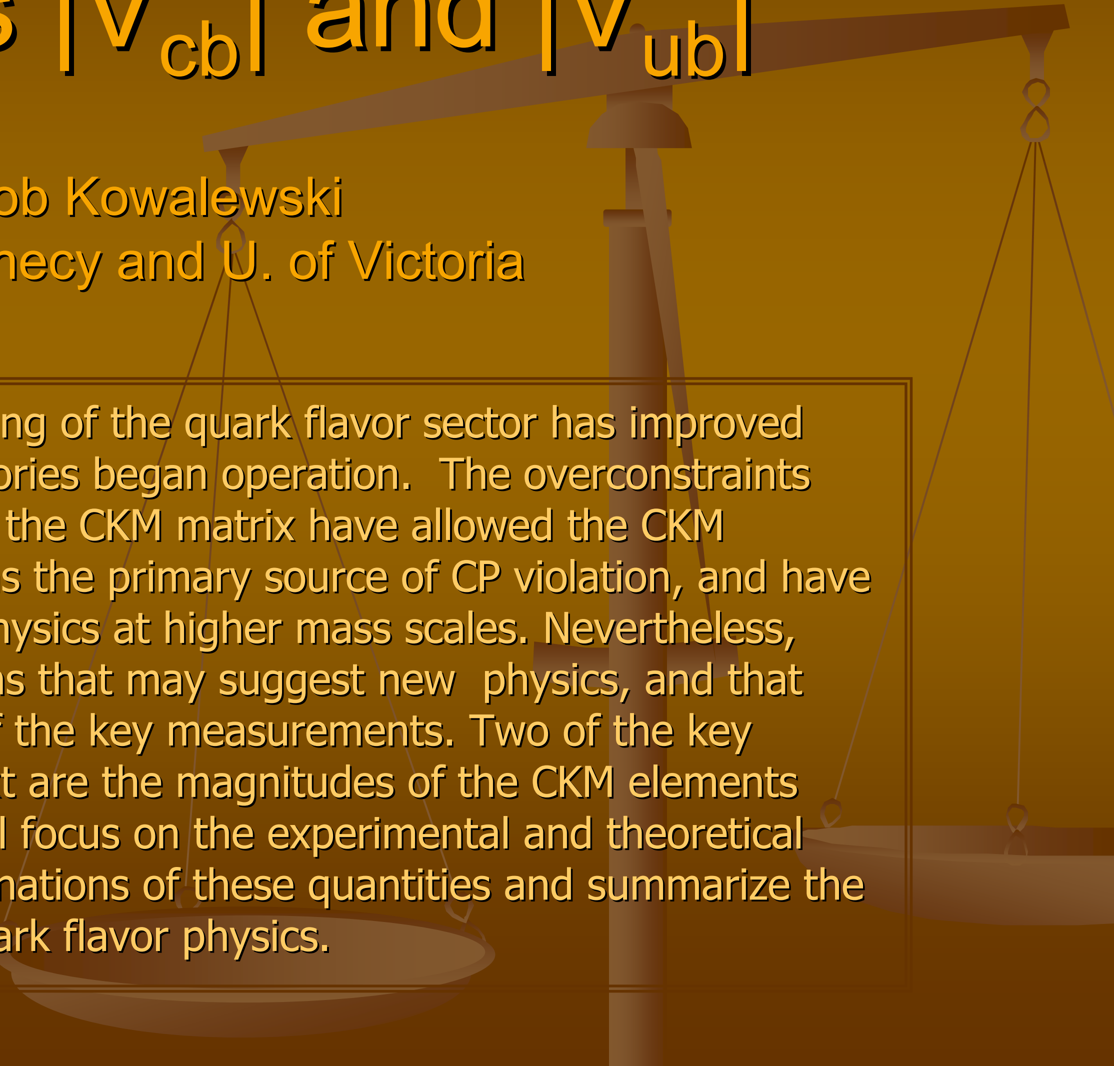
Determination of the CKM elements $|V_{cb}|$ and $|V_{ub}|$

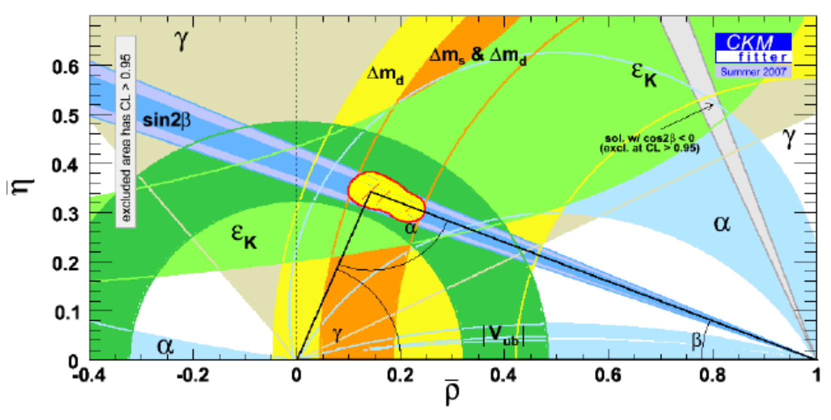
Bob Kowalewski
LAPP/Annecy and U. of Victoria



Our quantitative understanding of the quark flavor sector has improved dramatically since the B factories began operation. The overconstraints placed on the parameters of the CKM matrix have allowed the CKM mechanism to be validated as the primary source of CP violation, and have placed constraints on new physics at higher mass scales. Nevertheless, there are intriguing deviations that may suggest new physics, and that require further refinement of the key measurements. Two of the key measurements in this context are the magnitudes of the CKM elements $|V_{cb}|$ and $|V_{ub}|$. This talk will focus on the experimental and theoretical methods behind the determinations of these quantities and summarize the current state of precision quark flavor physics.

Menu

- The role of precision flavor physics
- Methods for measuring $|V_{xb}|$
  - Exclusive semileptonic decays
  - Inclusive semileptonic decays
- Current status of $|V_{cb}|$ and $|V_{ub}|$
- Future prospects



Why study flavour physics?

- Quark flavour physics has been instructive
  - "strange" particles are well named:
    - exhibit matter—antimatter oscillations
    - K_S regeneration
    - CP violation

  - Genesis for quark model
  - GIM mechanism predicted charm to suppress FCNC
    - they were shown to be right 4 years later

  - Kobayashi and Maskawa predict 3rd generation to provide mechanism for CP violation

Why study b physics?

- b physics has been instructive
  - Able to study CP violation in many decay modes: Kobayashi and Maskawa (and Bigi and Sanda) were right
  - Large $B^0 \leftrightarrow \bar{B}^0$ mixing implied heavy top, large CP asymmetries in B decays; both subsequently observed
  - Oscillations now seen in $B_s \leftrightarrow \bar{B}_s$
- CKM picture is correct, but is it complete?
  - To answer that we need precision on the basic parameters as well as consistency amongst measurements

Quark mixing matrix

- The weak and mass eigenstates of the 6 quark flavours differ; sum over weak-isospin doublets mixes the 3 generations: $\bar{u}_L\gamma_\mu d_L' + \bar{c}_L \gamma_\mu s_L' + \bar{t}_L\gamma_\mu b_L' \rightarrow \bar{U}_L \gamma_\mu V_{CKM} D_L$
- Mixing matrix is unitary → $(N^2-N)/2 = 3$ angles and $(N^2-N)/2-2 = 1$ phase are sufficient to parameterize it
- B decays allow direct access to 2 elements and indirect access to 2 others via processes involving internal top-quark loops
- Can determine 2 angles and the phase

$$\begin{pmatrix} V_{ud} & V_{us} & \textcolor{blue}{\boxed{\textcolor{black}{V_{ub}}}} \\ V_{cd} & V_{cs} & \textcolor{blue}{\boxed{\textcolor{black}{V_{cb}}}} \\ \textcolor{red}{\boxed{\textcolor{black}{V_{td}}}} & \textcolor{red}{\boxed{\textcolor{black}{V_{ts}}}} & V_{tb} \end{pmatrix}$$

Unitarity triangle

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

Choice of parameters:

λ, A, $\bar{\rho}$ and $\bar{\eta}$

At the 1% level : $|V_{us}|$

$$\lambda=|V_{us}|=\sin\theta_c$$

$$\lambda=0.2257\pm0.0021$$

At the 3% level : $|V_{cb}|$

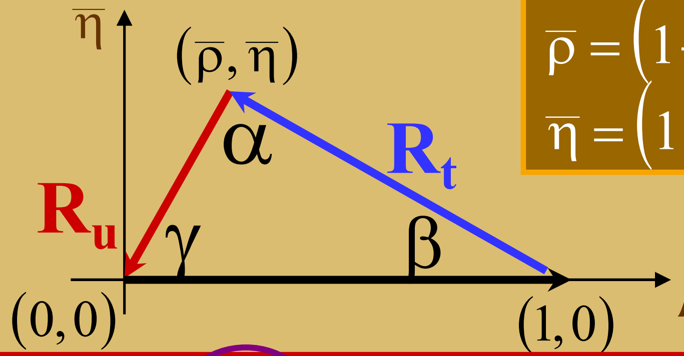
$$A=|V_{cb}|/\lambda^2$$

$$A=0.809\pm0.024$$

$|V_{ub}|$ **and** $|V_{td}|$

$\rightarrow\bar{\rho}$ - $\bar{\eta}$ **plane**

$$\text{Unitarity:}\quad 1+R_t+R_u=0$$



$$\bar{\rho}=\left(1-\lambda^2/2\right)\rho$$

$$\bar{\eta}=\left(1-\lambda^2/2\right)\eta$$

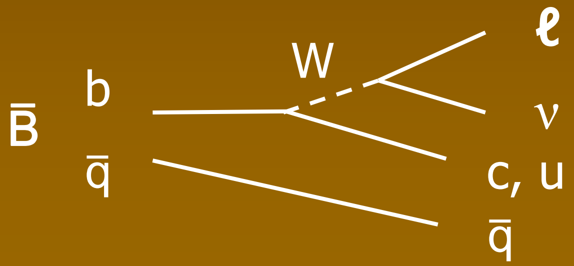
$$R_u=\frac{V_{ud}V_{ub}^{*}}{V_{cd}V_{cb}^{*}}\approx-\sqrt{\bar{\rho}^2+\bar{\eta}^2}\;e^{i\gamma}$$

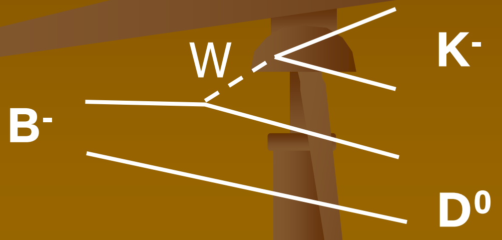
$$R_t=\frac{V_{td}V_{tb}^{*}}{V_{cd}V_{cb}^{*}}\approx-\sqrt{(1-\bar{\rho})^2+\bar{\eta}^2}\;e^{-i\beta}$$

$$\gamma=\arg V_{ub}^{*},\quad \alpha=\pi-\gamma-\beta$$

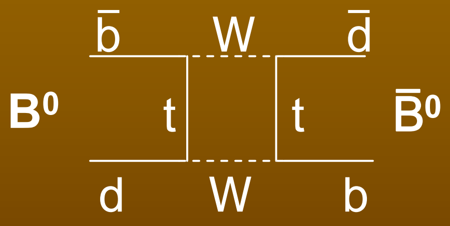
Trees and Loops

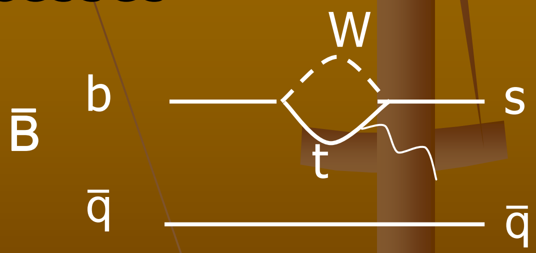
- Tree-dominated processes are ~free of new physics





- New physics, even at a high mass scale, can induce effects in loop-dominated processes

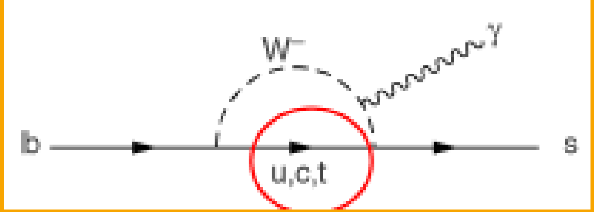


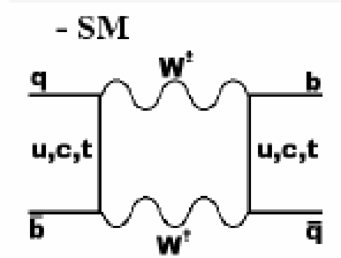


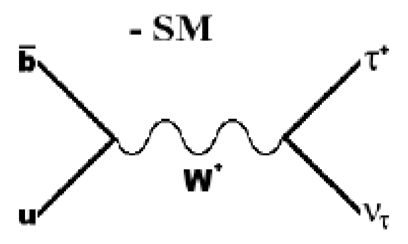
- Compare CKM parameters from tree and loop processes

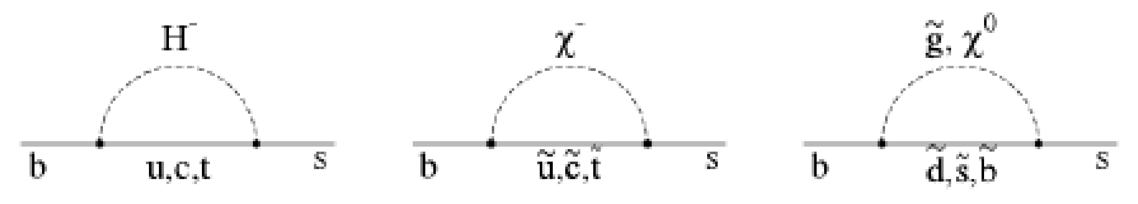
Sensitivity to new physics

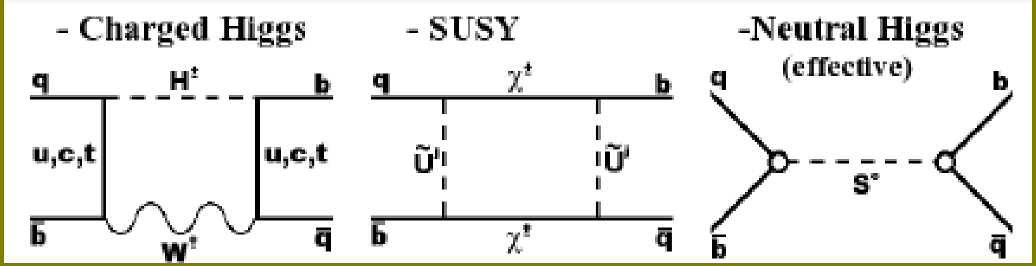
- Some examples of where new physics could enter:

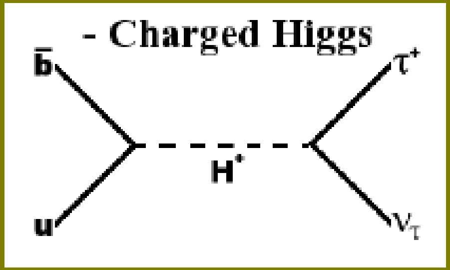






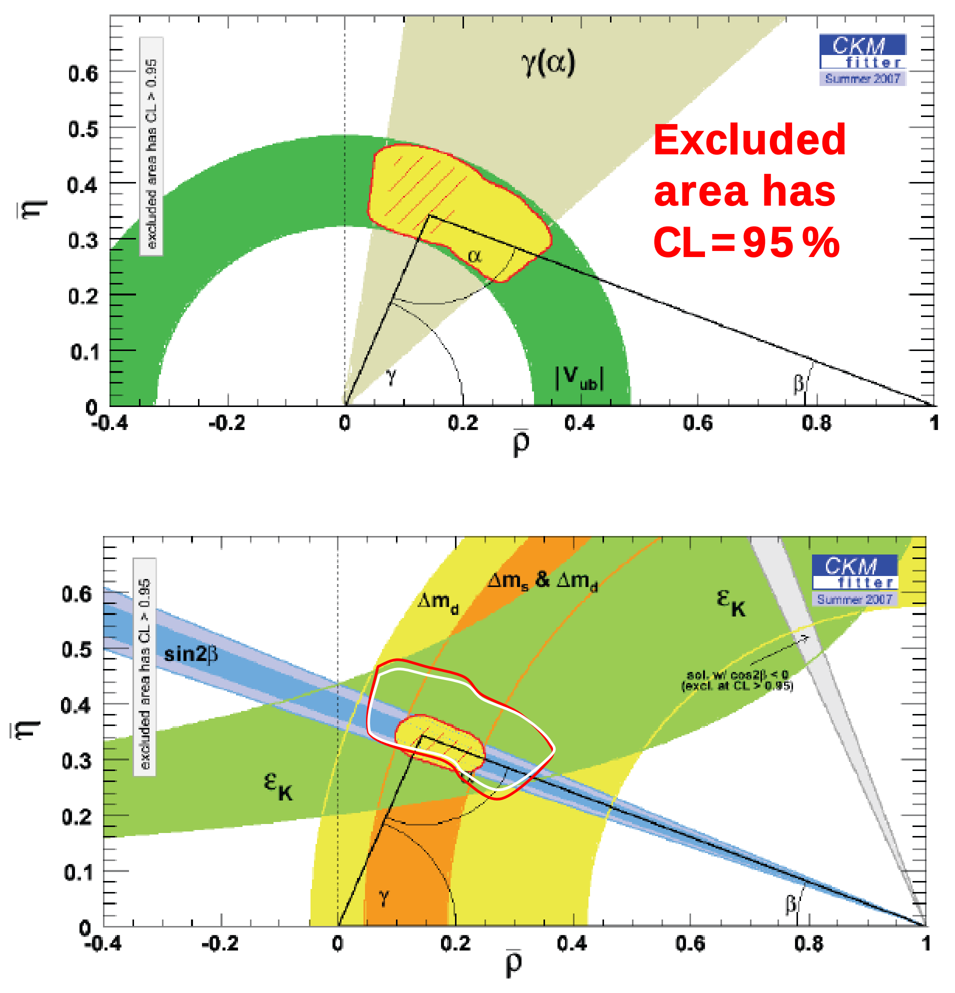






Current sensitivity

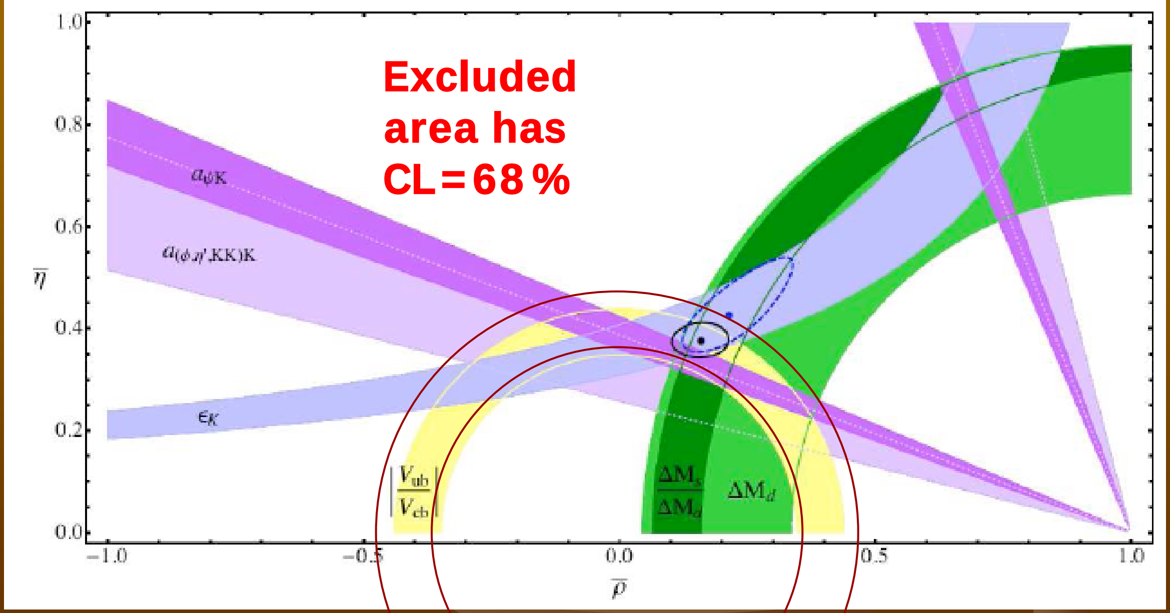
- Using only tree-dominated quantities
    - Plot assumes smaller $|V_{ub}|$ value than what I will show
- Using only loop-dominated quantites
- Need to further improve $|V_{ub}|$ and angle γ



Excluded area has CL=95%

Another look at it

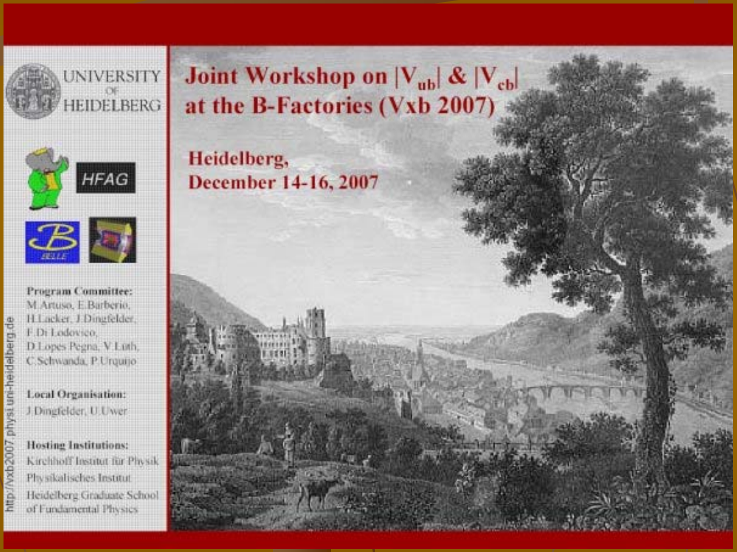
- Recent paper of Soni and Lunghi arXiv:0803.4340
- LQCD improvements are turning CP violation in K^0 (ε_K) and B_s mixing (Δm_{Bs}) into powerful constraints; predict larger $|V_{ub}|/|V_{cb}|$ than sin2β from b→c$\bar{c}$s decays
- Need to improve $|V_{ub}|/|V_{cb}|$ measurement to distinguish



Excluded area has CL=68%

Significant focus of activity

- 'V_{xb}' workshops have been held by BaBar, by Belle, and in recent years jointly:
  - Heidelberg, 2007
  - Melbourne, 2006
  - Separate meetings back to 2001
- Excellent forum for interaction between theory and experiment
  - Lively debates within the theory community, even if consensus exists on many issues
  - Friendly competition between BaBar and Belle



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HFAG

Joint Workshop on $|V_{ub}|$ & $|V_{cb}|$ at the B-Factories (Vxb 2007)

Heidelberg, December 14-16, 2007

Program Committee:
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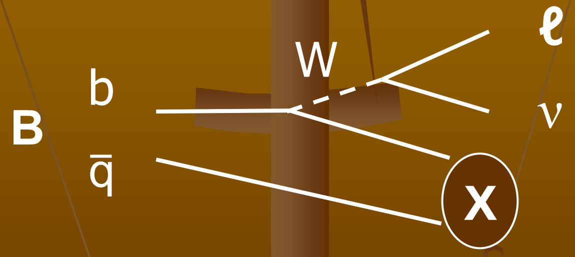
http://vxb2007.physi.uni-heidelberg.de

Determination of $|V_{cb}|$ and $|V_{ub}|$

- The only sensitive method is using semileptonic decays
  - this is a task for the e^+e^- B factories, not hadron facilities
  - Large data samples are important; so is hermiticity
  - Systematic errors dominate; choose working point to trade systematic errors for statistical errors
- The final measurements from the B factories will be an enduring legacy (if a super-B facility isn’t built);
  - important to squeeze out as much precision as possible
  - Expect “final” results within a year or two

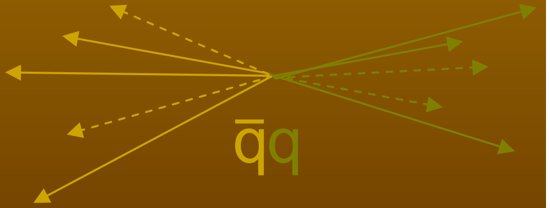
Semileptonic decays

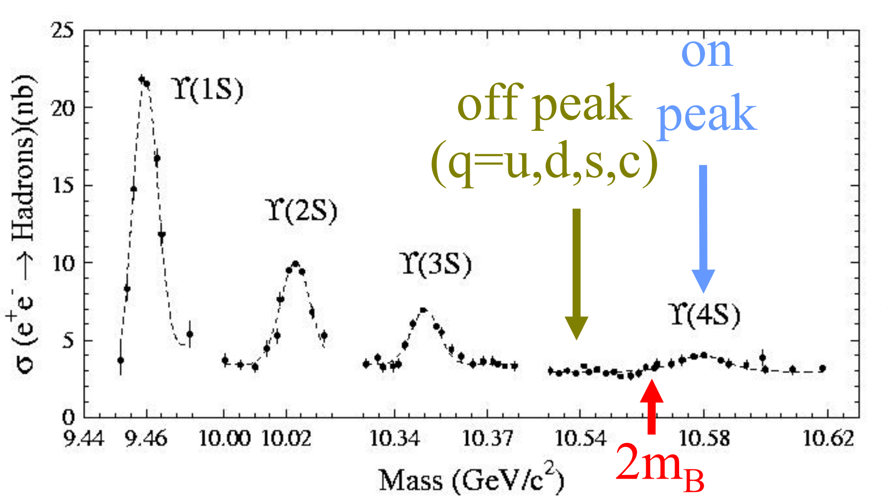
- Decaying b quark is bound into a meson → QCD effects must be accounted for
- Semileptonic decays involve only 1 hadronic current – simplest case we can hope for
- Two approaches:
  - **Exclusive**: **X** fully reconstructed
  - **Inclusive**: sum over many **X** states, with at most partial reconstruction of the **X** system

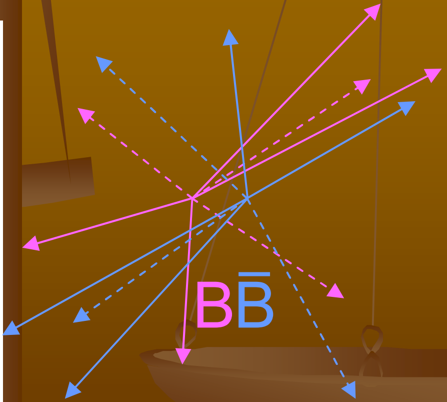


Peculiarities of threshold production

- B factories operate(d) at $e^+e^- \rightarrow Y(4S) \rightarrow B\bar{B}$
  - 20 MeV above $B\bar{B}$ threshold; no other particles produced
  - B mesons have small, known speed $\beta \sim 0.06$ in Y(4S) frame; they only fly ~30 microns
  - Decay products of B and $\bar{B}$ overlap in detector
  - $e^+e^- \rightarrow q\bar{q}$ continuum decays also produced

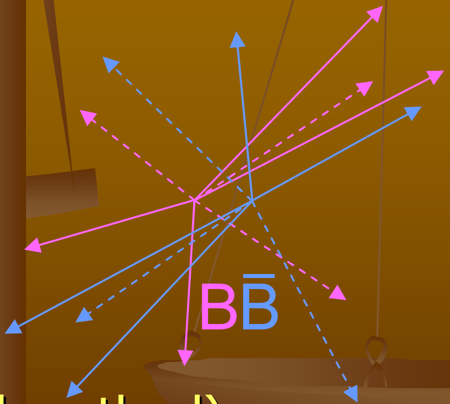






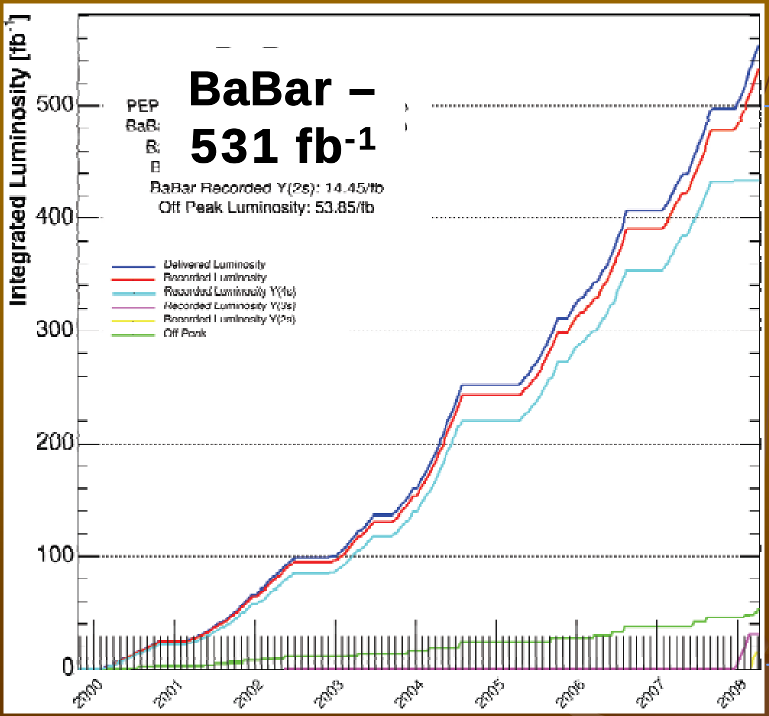
Analysis strategies

- Semileptonic decays – start with lepton
  - Electrons have higher identification efficiency at low momentum and smaller misidentification than muons; some analyses use only electrons
  - Leptons from B decays have harder spectrum than from cascade decays $B \to D$ (or τ) $\to$ lepton; $p_\ell \gtrsim 1.0$ GeV is typical cut
- Two strategies
  - Reconstruct only signal B decay; particles from the other B contribute to background
  - Reconstruct both B decays; low efficiency, clean, provides measurement of signal B direction (recoil method)

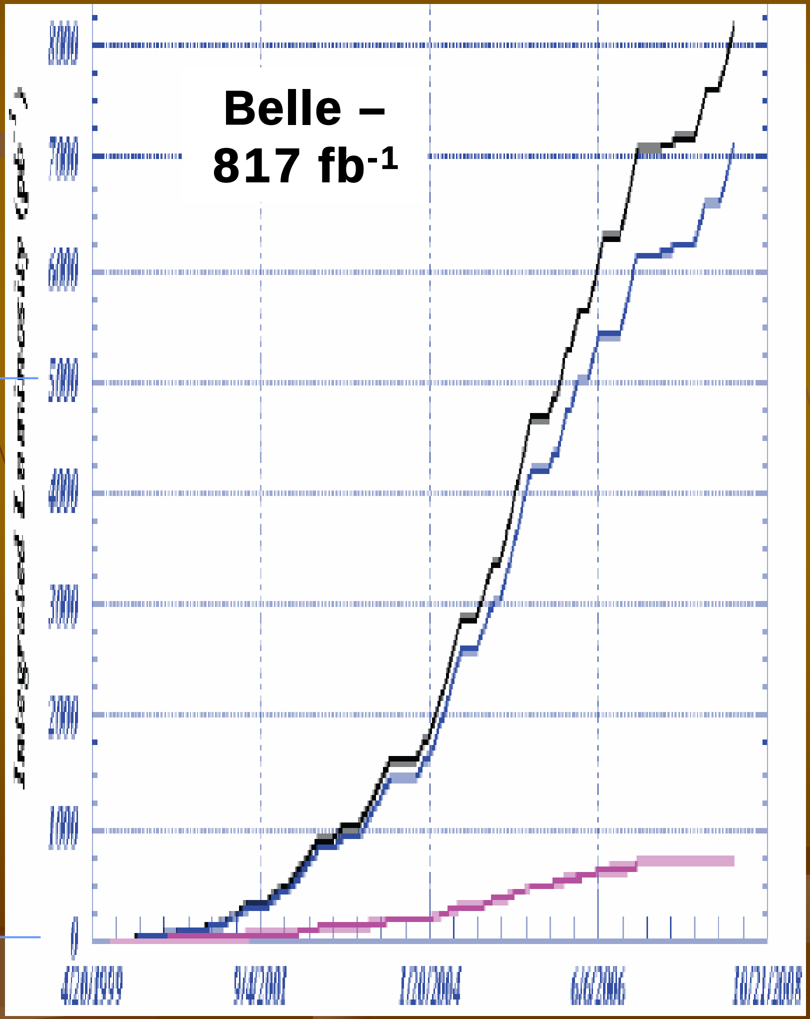


Belle and BaBar

- World’s highest luminosities
  - Corresponds to 800 (500) 10^6 $B\bar{B}$ events for Belle (BaBar)



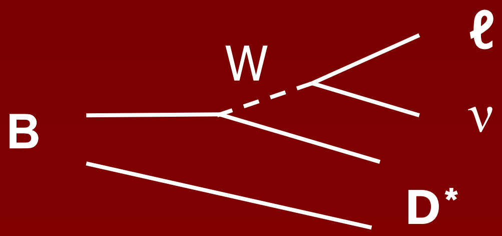
BaBar – 531 fb^{-1}



Belle – 817 fb^{-1}

Exclusive semileptonic decays

- Conceptually simple – measure F(q^2)|V_{cb}|



$$\frac{d\Gamma\left(B \to D^{*}\ell\nu\right)}{dq^{2}} = \frac{G_F^{2}\left|V_{cb}\right|^{2}}{48\pi^{3}}\left(F\left(q^{2}\right)\right)^{2} G\left(q^{2}\right)$$

form factors

phase space

$q^2 = (p_\ell + p_\nu)^2$

(momentum transfer)^2

- QCD uncertainties enter calculation of form-factors F
  - One form-factor for each Lorentz structure in amplitude
  - Shapes versus q^2 can be measured
  - Normalization must come from theory

Form factor normalization

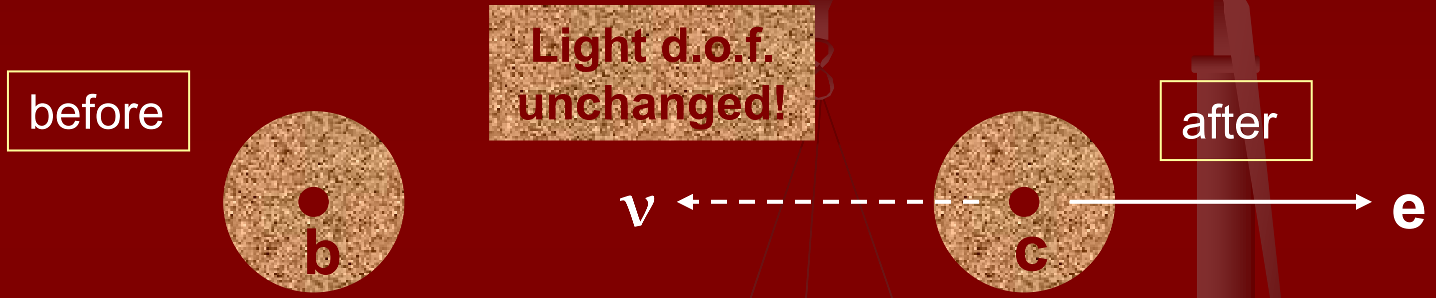
- Normalization is usually calculated at a convenient point; where (in q^2) depends on which technique is used

- Lattice QCD is the method of choice
    - Good accuracy can be obtained near maximum $q^2 = (M_B\text{-}M_X)^2$ (final state hadron is slow)

- QCD sum rules also used for $B \rightarrow \pi \ell \nu$
    - Best accuracy near $q^2 = 0$

Heavy quark symmetry in $B \to X_c \ell\nu$

- Heavy quark symmetry simplifies description
  - Unique, universal FF, unit normalization at q^2 max (no recoil)

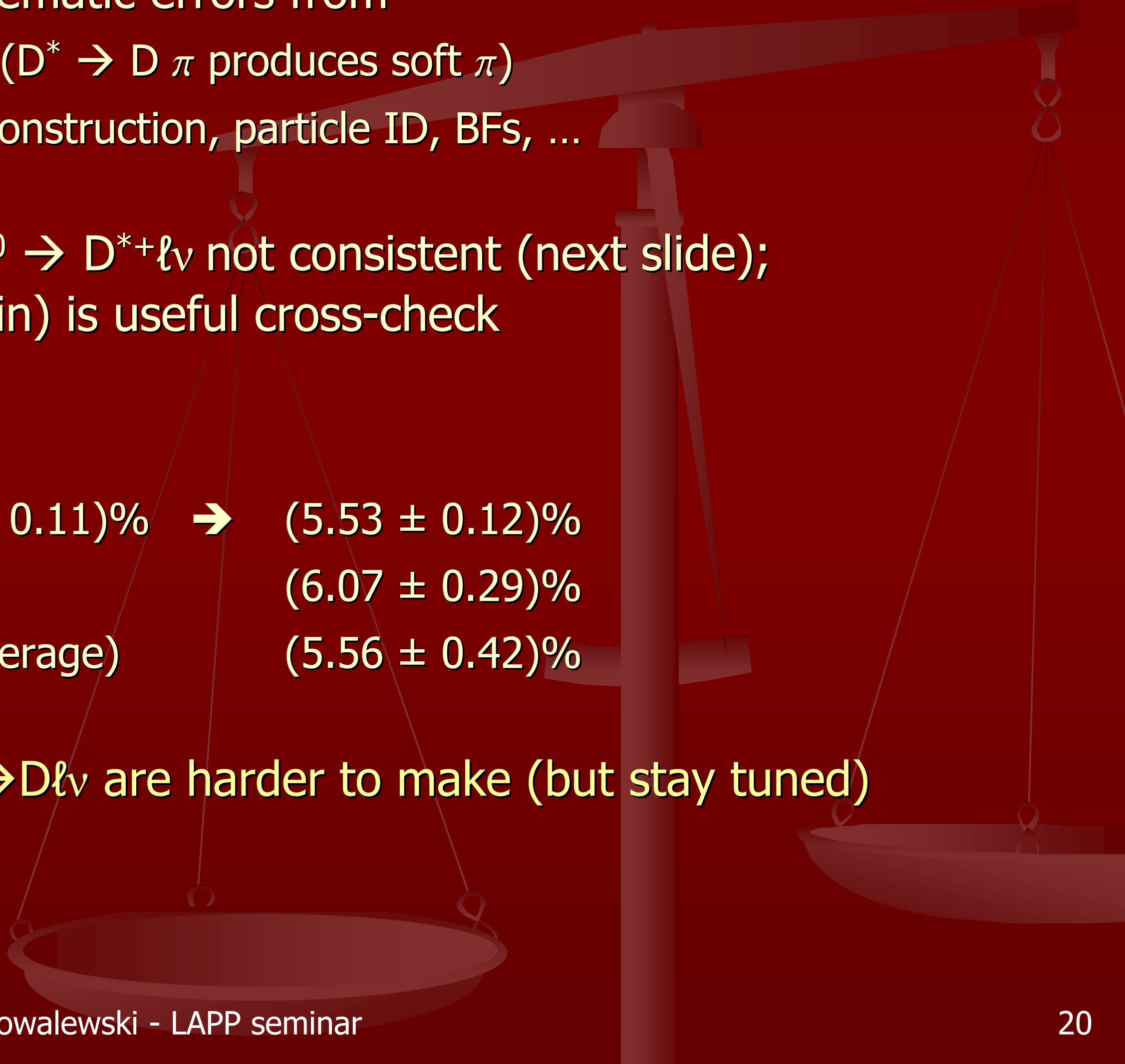


- Parameterize FF as function of 4-velocity product $w = v_B \cdot v_{D*}$

$$w \equiv \frac{m_B^2 + m_{D*}^2 - q^2}{2 m_B m_{D*}};\ 1 < w < 1.504$$

  - $F(w) = F(1)\,[\,1 - \rho_D^2\,(w - 1) + O((w-1)^2)]$
- Calculate corrections to $F(1)=1$ due to finite m_b, m_c

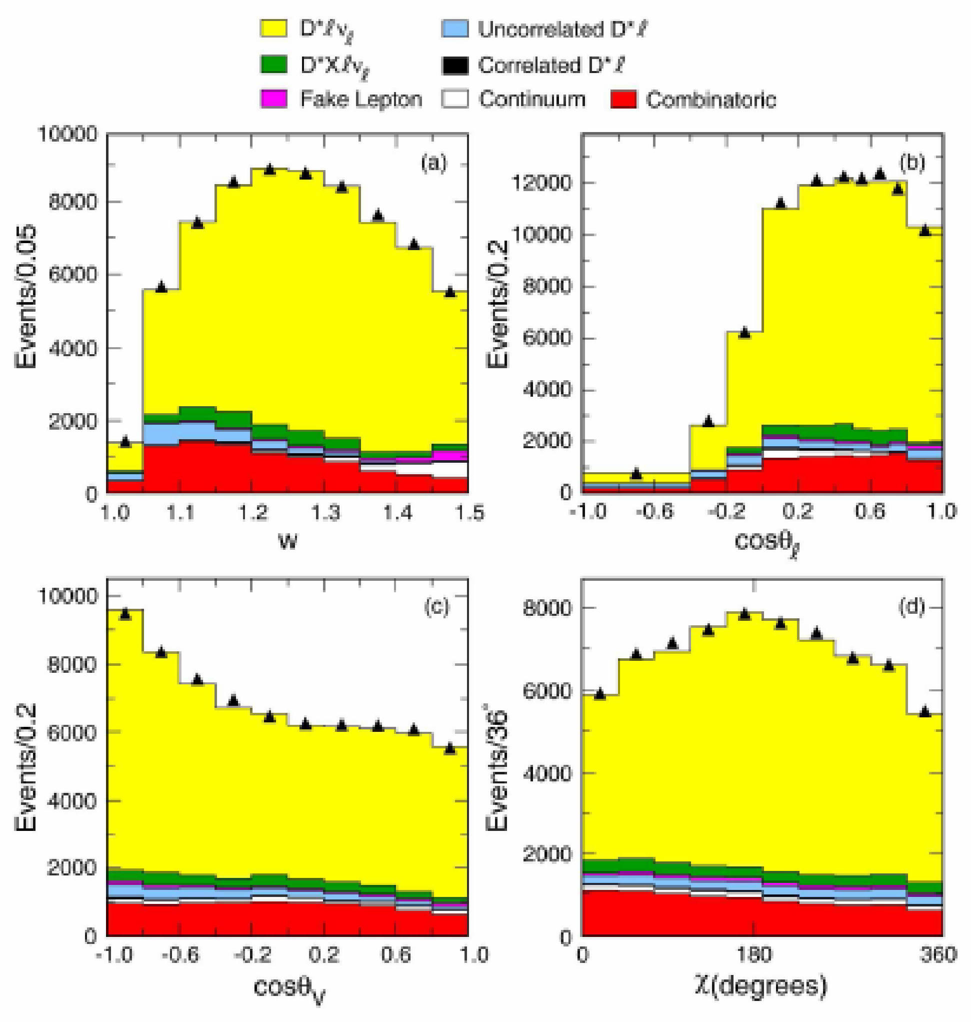
Experimental $B\to X_c\ell\nu$



- Measure D^* and lepton; systematic errors from
  - Soft particle reconstruction ($D^* \to D\,\pi$ produces soft π)
  - Absolute efficiencies for reconstruction, particle ID, BFs, …
- Existing measurements of $\bar{B}^0 \to D^{*+}\ell\nu$ not consistent (next slide); $B^- \to D^{*0}\ell\nu$ (related by isospin) is useful cross-check
- HFAG (PDG2008):
  - BF($\bar{B}^0 \to D^{*+}\ell\nu$) = (5.16 ± 0.11)% → (5.53 ± 0.12)%
  - BF($B^- \to D^{*\,0}\ell\nu$) = (6.07 ± 0.29)%
  - New BaBar $D^{*\,0}\ell\nu$ (not in average) (5.56 ± 0.42)%
- Precise measurements of $B\to D\ell\nu$ are harder to make (but stay tuned)

B → $D^*\ell\nu$ Measurements

- Best measurement to date: BaBar arXiv:0705.4008
- Four independent kinematic variables per event
- Measures BF, q^2 dependence, FF ratios R_1~V/A_1 and R_2~A_2/A_1

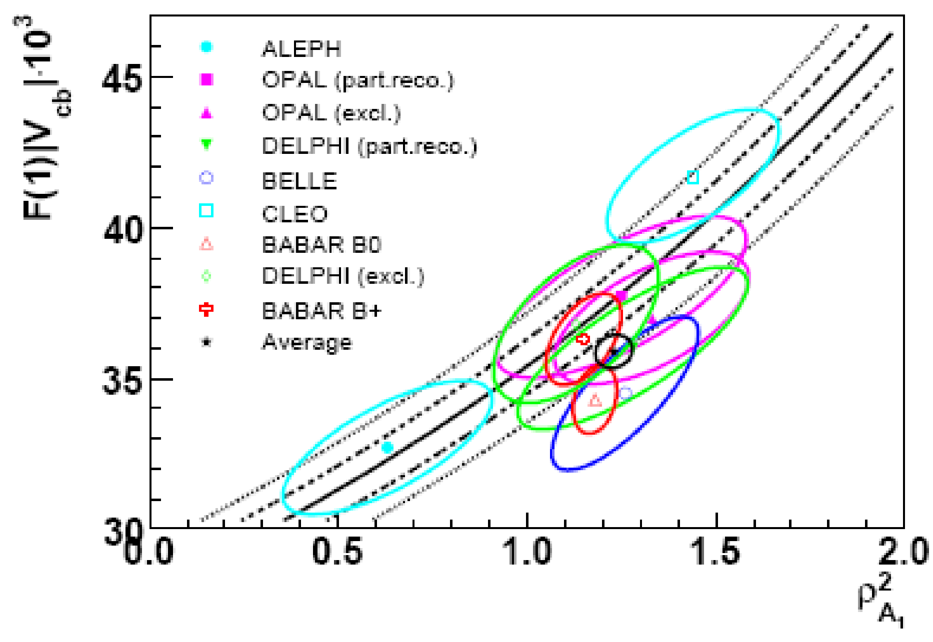


$\bar{B}^0 \rightarrow D^{*+} \ell \nu$ average

- Average has $P(\chi^2) = 2.6\%$
  → scale errors by $\sqrt{\chi^2/\text{ndf}}=1.5$

- $F(1)|V_{cb}| = (35.9 \pm 0.8)\times 10^{-3}$

- Latest lattice value is[1]
  $F(1) = 0.930 \pm 0.023$
  [1] Laiho et al., arXiv:0710.1111

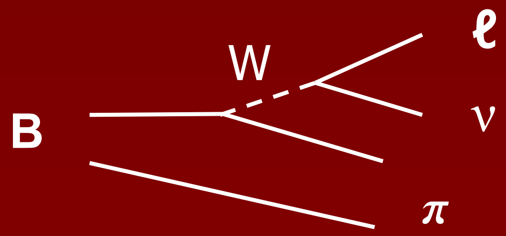


- Determine

$$\left|V_{cb}\right| = \left(38.6 \pm 0.9_{\mathbf{exp}} \pm 1.0_{\mathbf{th}}\right)\times 10^{-3}$$

Experimental B→$X_u\ell\nu$

- Best mode for both theory and experiment is B → $\pi\ell\nu$

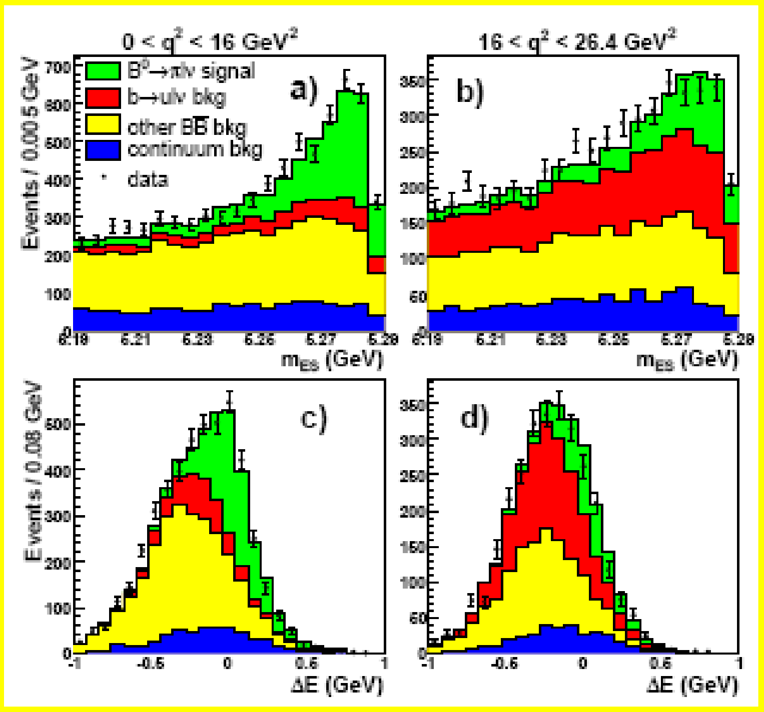


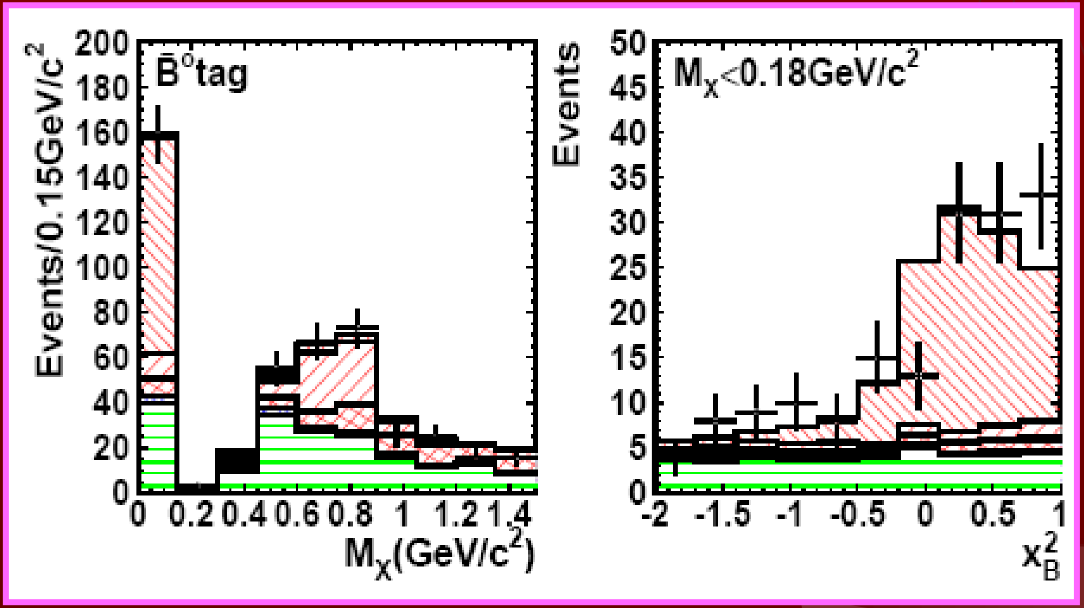
$$\frac{d\Gamma(B\rightarrow\pi\ell\nu)}{dq^2}=\frac{G_F^2|V_{ub}|^2}{24\pi^3}|p_\pi|^3|f_+(q^2)|^2$$

- No help from HQ symmetry; need non-perturbative calculation of FF normalization $f_+(q^2)$
- Experimental topology clean; hardest region is high q^2 (when π is soft) due to background

Experiment: $B \to \pi \ell \nu$

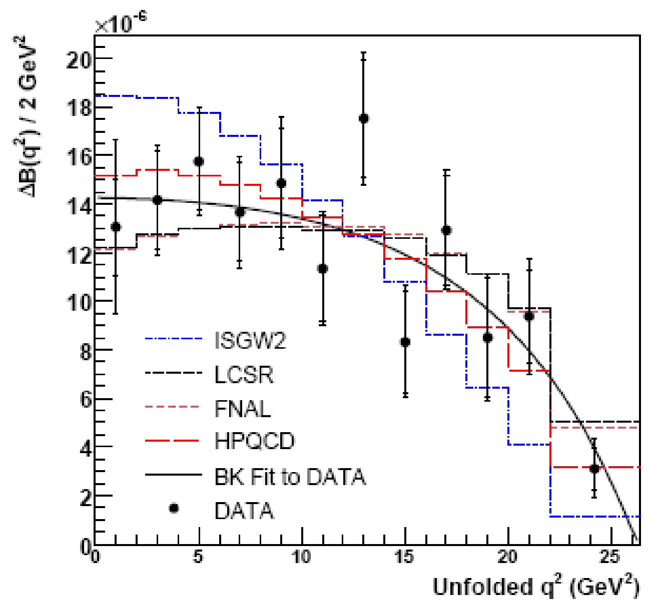
- Untagged measurements have high statistics: BaBar PRL 98 (2007) 091801
- Tagged measurements are cleaner: Belle PLB 648:139,2007

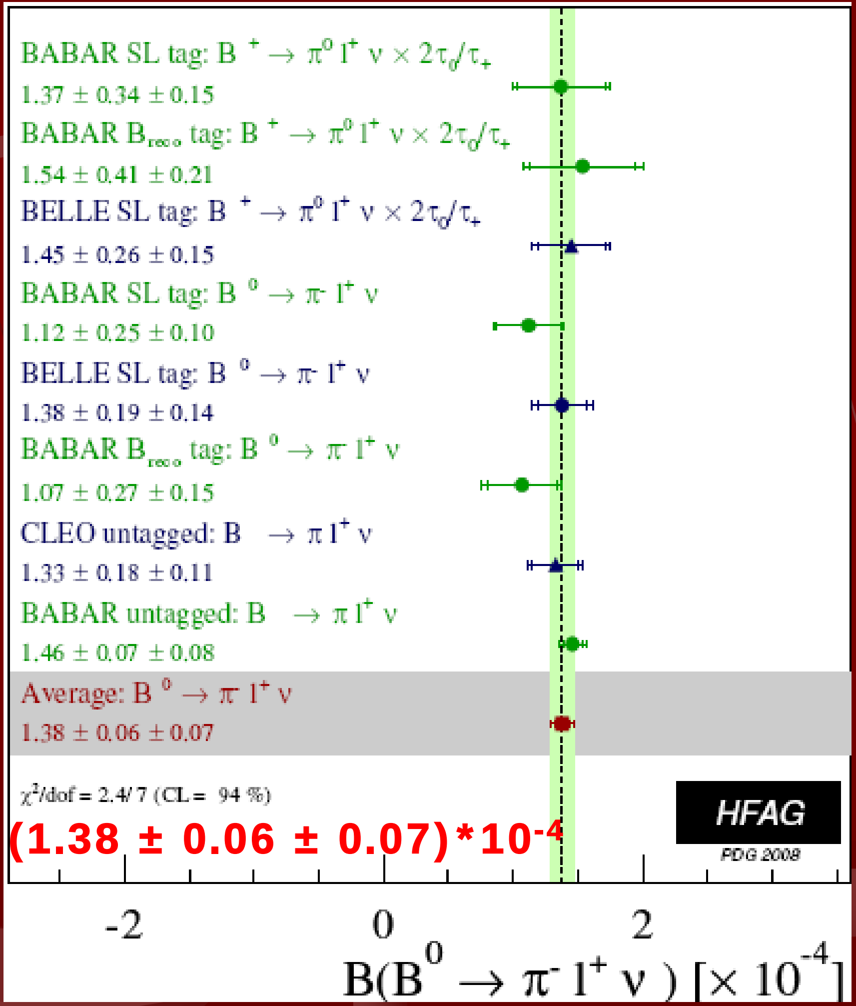




BF(B → $\pi \ell \nu$)

- Measurements are done with and without recoil technique
- FF shape is best measured by reconstructing only signal B





$(1.38 \pm 0.06 \pm 0.07) * 10^{-4}$

$|V_{ub}|$ from B → $\pi\ell\nu$

- Use analyticity and unitarity constraints plus measured $d\Gamma/dq^2$ to fit FF shape; then normalize at any q^2
- Fit determines $|V_{ub}|\, f_+(q^2=0) = (91 \pm 3_{BF} \pm 6_{shape})*10^{-5}$
- FF normalizations → $|V_{ub}|$ values

	$f_+(0)$	**$\|V_{ub}\|*10^4$**
LCSR	0.26 ± 0.04	$35 \pm 3\,^{+6}_{-5}$
LQCD (FNAL)	0.25 ± 0.03	$36 \pm 3\,^{+5}_{-4}$
LQCD (HPQCD)	0.27 ± 0.03	$33 \pm 3\,^{+4}_{-3}$

Choose $|V_{ub}| = \left(3.5\,^{+0.6}_{-0.5}\right)\times 10^{-3}$

Near-term anticipated progress

- Experimental information on $D^*\ell\nu$ is improving
  - Higher precision recent measurements agree well
  - Expect some further improvements, but limited by systematics
- Experimental information on $\pi\ell\nu$ is quite good
  - BF known to 6%; need further improvement on q^2 shape
- Main challenge is for theory
  - Currently 3% on $F(1)$ for $|V_{cb}|$, 12% on $f_+(0)$ for $|V_{ub}|$
  - No in principle reason that LQCD can't improve normalization uncertainty to ~1% level on $|V_{cb}|$ and ~5% on $|V_{ub}|$, but requires significant work

Inclusive semileptonic decays

- Theoretical tool: Heavy Quark Expansion (OPE)

$$\Gamma\left(B\to X\right)=\frac{1}{2m_B}\sum\left(2\pi\right)^4\delta^4\left(p_B-p_X\right)\left|\left\langle X\left|L_{eff}\right|B\right\rangle\right|^2$$

$$=\boxed{\frac{G_F^2 m_b^5}{192\pi^3}}\left(1+A_{EW}\right)A^{pert}\left\{1+0-\boxed{\frac{\mu_\pi^2+3\mu_G^2}{2m_b^2}}+\ldots\right\}$$

Simplified form for massless X

Quark model result

First correction $O((\Lambda/m_b)^2)$

- Express decay rate as double expansion in α_s and $1/m_b$
  - Perturbative corrections are calculable
  - Non-perturbative matrix elements (e.g. μ_π^2) arise at each order in $1/m_b$; determine these in fits to semileptonic decays

Inclusive semileptonic decay width

- Total decay width for b → cℓν:

$\mathbf{r = m_c / m_b}$ **parameterizes phase-space factors** $\mathbf{z_i}$

$$\Gamma = |V_{cb}|^2 \frac{G_F^2 m_b^5}{192\pi^3}\left(1 + A_{ew}\right) A^{pert}(r,\mu) \times \left[z_0(r) + \frac{0}{m_b} + z_2\left(r, \frac{\mu_\pi^2}{m_b^2}, \frac{\mu_G^2}{m_b^2}\right) + z_3\left(r, \frac{\rho_D^3}{m_b^3}, \frac{\rho_{LS}^3}{m_b^3}\right) + \ldots \right]$$

free quark decay ~1.014 ~0.908

Perturbative corrections

Non-perturbative power corrections

- Similar expressions for b → uℓν, b → sγ

- Comparison with data relies on quark-hadron duality
  → integrate over “broad” regions of phase space

Global fit for $|V_{cb}|$, m_b…

- Calculate moments (M_x^n, E_e^n) of inclusive processes $b \to c\ell\nu$ and $b \to s\gamma$ for various cuts on lepton (photon) energy:

$$\left\langle M_x^n \right\rangle_{E_l > E_0} = \tau_B \int_{E_0} M_X^n \, d\Gamma = f_n^x(E_0, m_b, m_c, \underbrace{\mu_G^2, \mu_\pi^2, \rho_D^3, \rho_{LS}^3})$$

e or γ energy cut

b-quark mass

c-quark mass

Matrix elements appearing at order $1/m_b^2$ and $1/m_b^3$

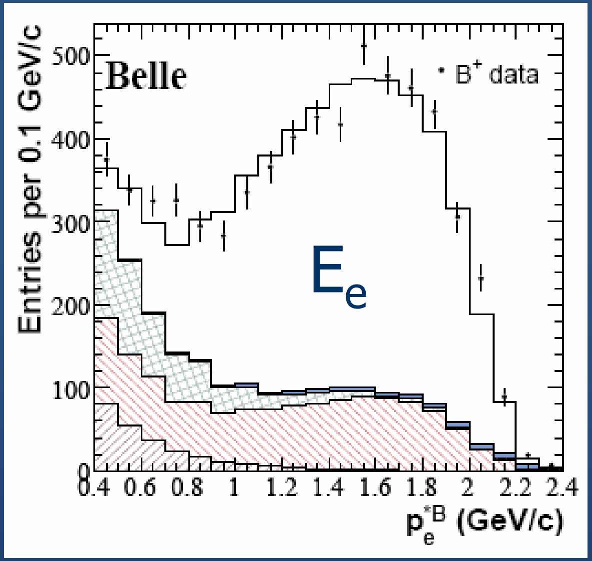
Kinetic scheme
Benson, Bigi, Gambino, Mannel, Uraltsev
(several papers)

1S scheme
Bauer, Ligeti, Luke, Manohar, Trott
PRD 70:094017 (2004)

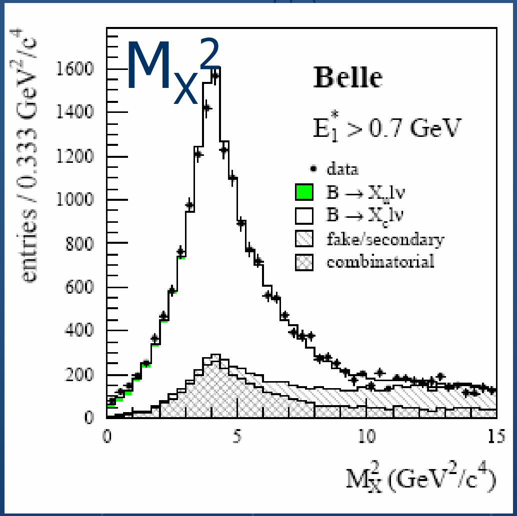
- Fit ~60 measured moments from DELPHI, CLEO, BABAR, BELLE, CDF to determine ~6 parameters

Measured inclusive moments

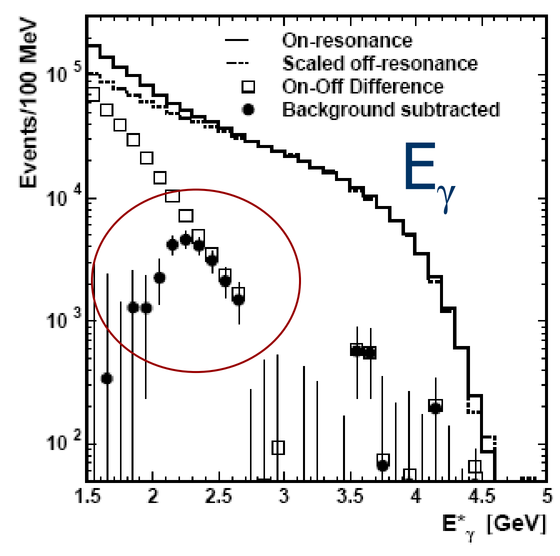
- Sample of recent (Belle) measurements; similar input from BaBar, CLEO, CDF, DELPHI



PRD75:032001(2007)



PRD75:032005(2007)

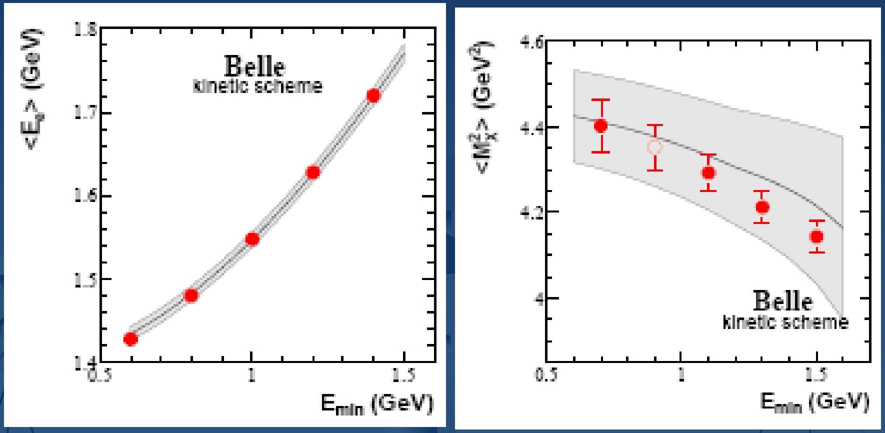


arXiv:hep-ex/0508005

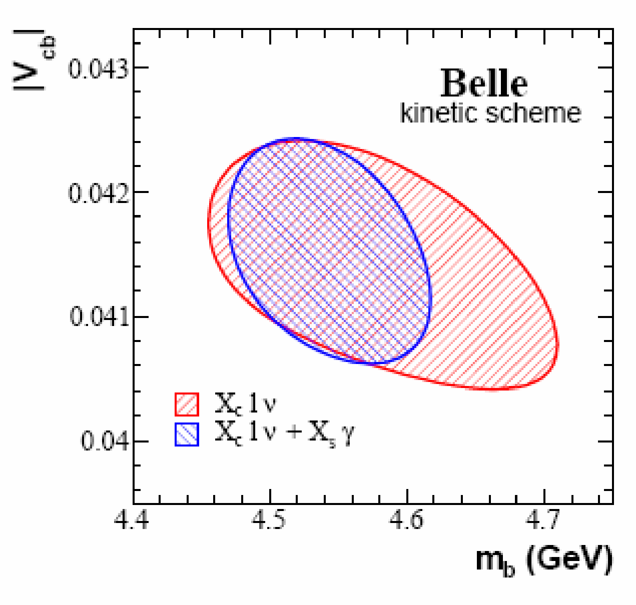
Global fit: $|V_{cb}|$ results

Scheme	$|V_{cb}|$ (10^{-3})
Kinetic	$41.68 \pm 0.39 \pm 0.58_{\Gamma SL}$
1S	$41.56 \pm 0.39 \pm 0.08_{\tau_B}$

Choose $|V_{cb}| = (41.6 \pm 0.6) \times 10^{-3}$



Example plots:
arXiv:0803.2158



χ^2/ndf is too good (e.g. 39/62 for kinetic, 25/63 for 1S); suggests theory errors (included in fit) may be overestimated

Global fit: m_b results

Source	m_b (GeV)
$m_{b[kin]}$ (global fit)	4.61 ± 0.03
$m_{b[kin]}$ (global fit, no $b \rightarrow s\gamma$)	4.68 ± 0.05
$m_{b[kin]}$ ($b\bar{b}$ threshold)	4.56 ± 0.06
$m_{b[1S]}$ (global fit)	4.70 ± 0.03
$m_{b[1S]}$ (global fit, no $b \rightarrow s\gamma$)	4.75 ± 0.06
$m_{b[1S]}$ ($b\bar{b}$ threshold)	4.69 ± 0.03

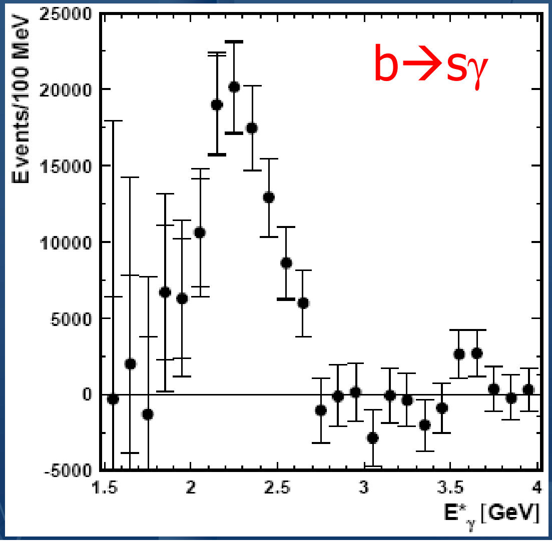
m_b is crucial for $|V_{ub}|$

$m_{b[kin]} \rightarrow m_{b[1S]}$ scheme translation ~ +0.12 GeV

Use (or not) of $b \rightarrow s\gamma$ in global fit still controversial

Charmless semileptonic decays

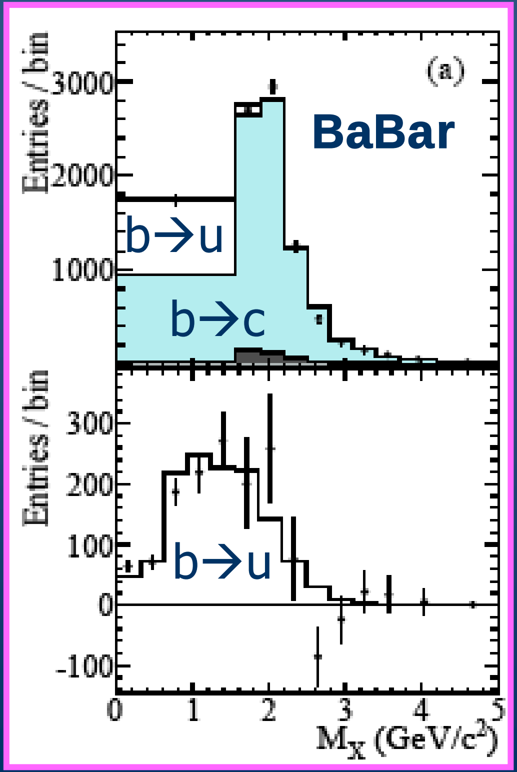
- Use HQE as for $b \to c\ell\nu$ decays; accuracy on total rate $\Gamma(b \to u\ell\nu)$ is $\sim 0.02\% \oplus 2.5\times(\sigma_{mb}/m_b)$
- However, cuts for isolating experimental signal from background destroy HQE convergence; introduce dependence on Fermi motion:
  - Model with shape function (SF)
  - Form of SF unknown, but 0th – 2nd moments constrained by data from global fit (unit normalization, m_B-m_b, parameter μ_π^2)
- Weak annihilation operators can lead to same final states → source of uncertainty
- Optimize: trade off experimental (bkg) versus theoretical (acceptance) errors



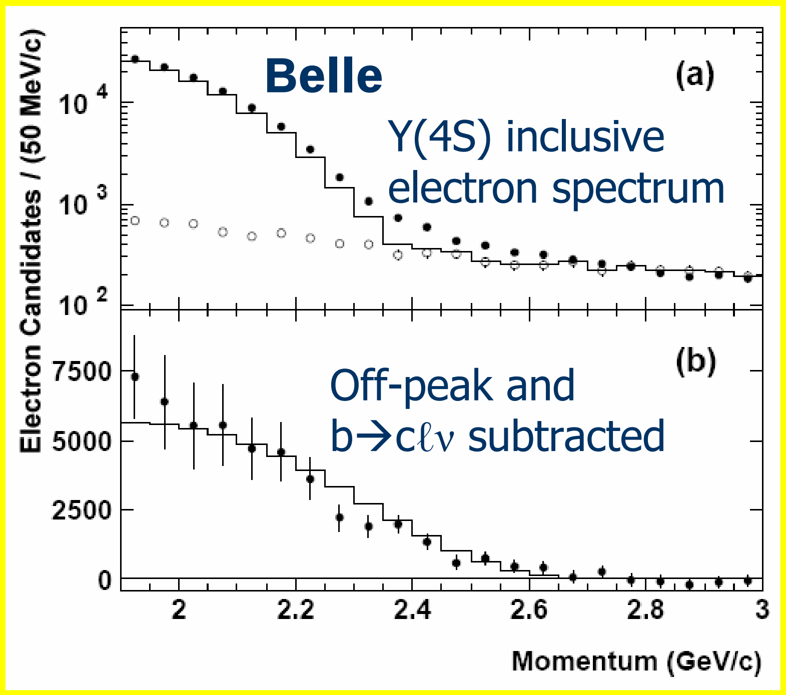
$$\langle E_\gamma \rangle \approx \frac{m_b}{2},\ \left\langle E_\gamma^2 - \langle E_\gamma \rangle^2 \right\rangle \propto \mu_\pi^2$$

Inclusive b→uℓν measurements

- Isolate charmless decays as function of a kinematic variable, e.g. E_ℓ, m_{Xu}, q^2, $P_+=E_X-|p_X|$…
- E.g., recent BaBar and Belle results



arXiv:0708.3702



hep-ex/0504046

- Determine partial rate within specific kinematic region (e.g. $m_X < 1.55$ GeV or $E_e>1.9$ GeV)
- Compare with theoretical calculation of partial rate to extract $|V_{ub}|$

$b \rightarrow u\ell\nu$ calculations

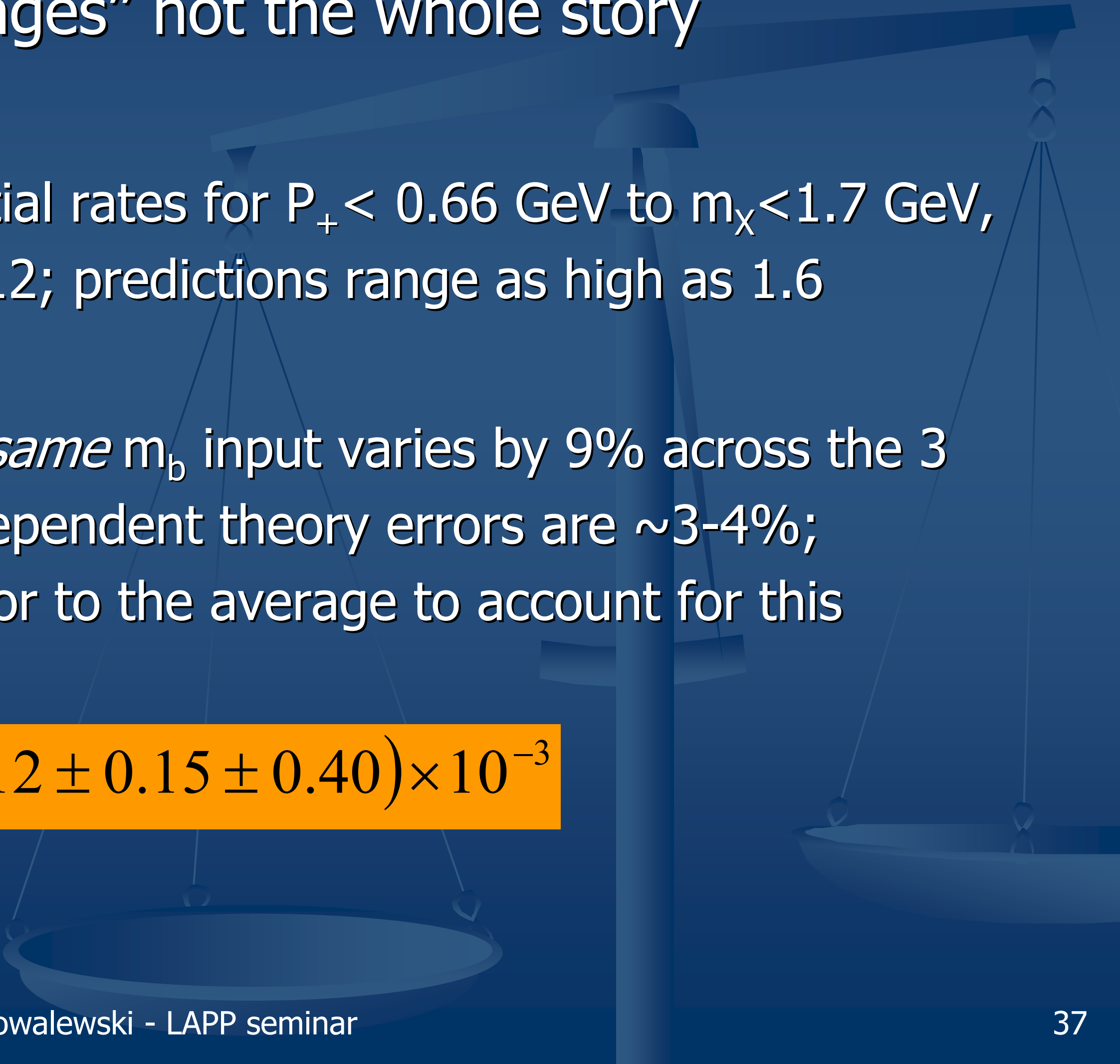
- Several choices available, all starting from HQE:
  - Bosch, Lange, Neubert, Paz (BLNP) Phys.Rev.D73,073008(2006)
  - Gambino, Giordano, Ossola, Uraltsev (GGOU) JHEP 0710:058(2007)
  - Andersen and Gardi (DGE) JHEP 0601:097 (2006)
  - Aglietti, Di Lodovico, Ferrera, Ricciardi (AC) arXiv:0711.0860
- Input on m_b varies for each calculation (author's preference)

CLEO E_e
BaBar q^2- E_e
BaBar E_e
Belle E_e
Belle m_x
BaBar m_x
Belle m_x-q^2

Ref.	BLNP	GGOU	DGE
[98]	$353 \pm 41 \pm 35$	$371 \pm 43 \pm 32$	$386 \pm 45 \pm 28$
[101]	$395 \pm 27 \pm 39$	not avail.	$443 \pm 30 \pm 37$
[100]	$390 \pm 22 \pm 33$	$408 \pm 23 \pm 27$	$430 \pm 29 \pm 25$
[99]	$437 \pm 40 \pm 33$	$456 \pm 42 \pm 26$	$481 \pm 45 \pm 22$
[107]	$398 \pm 42 \pm 32$	$416 \pm 44 \pm 29$	$444 \pm 47 \pm 22$
[103]	$374 \pm 18 \pm 31$	$402 \pm 19 \pm 28$	$456 \pm 22 \pm 30$
[104]	$366 \pm 24 \pm 27$	$389 \pm 26 \pm 22$	$429 \pm 28 \pm 26$
	$399 \pm 14 \pm 30$	$395 \pm 15 \pm 21$	$443 \pm 17 \pm 25$

Values quoted are $|V_{ub}| \times 10^5$

Inclusive $|V_{ub}|$ determination



- "Average of the averages" not the whole story
  - Measured ratio of partial rates for $P_+ < 0.66$ GeV to $m_X < 1.7$ GeV, $q^2 > 8$ GeV^2 is 1.22 ± 0.12; predictions range as high as 1.6
  - $|V_{ub}|$ extracted using *same* m_b input varies by 9% across the 3 calculations used; independent theory errors are ~3-4%; add 7% additional error to the average to account for this
- Determine $\boxed{|V_{ub}| = (4.12 \pm 0.15 \pm 0.40) \times 10^{-3}}$

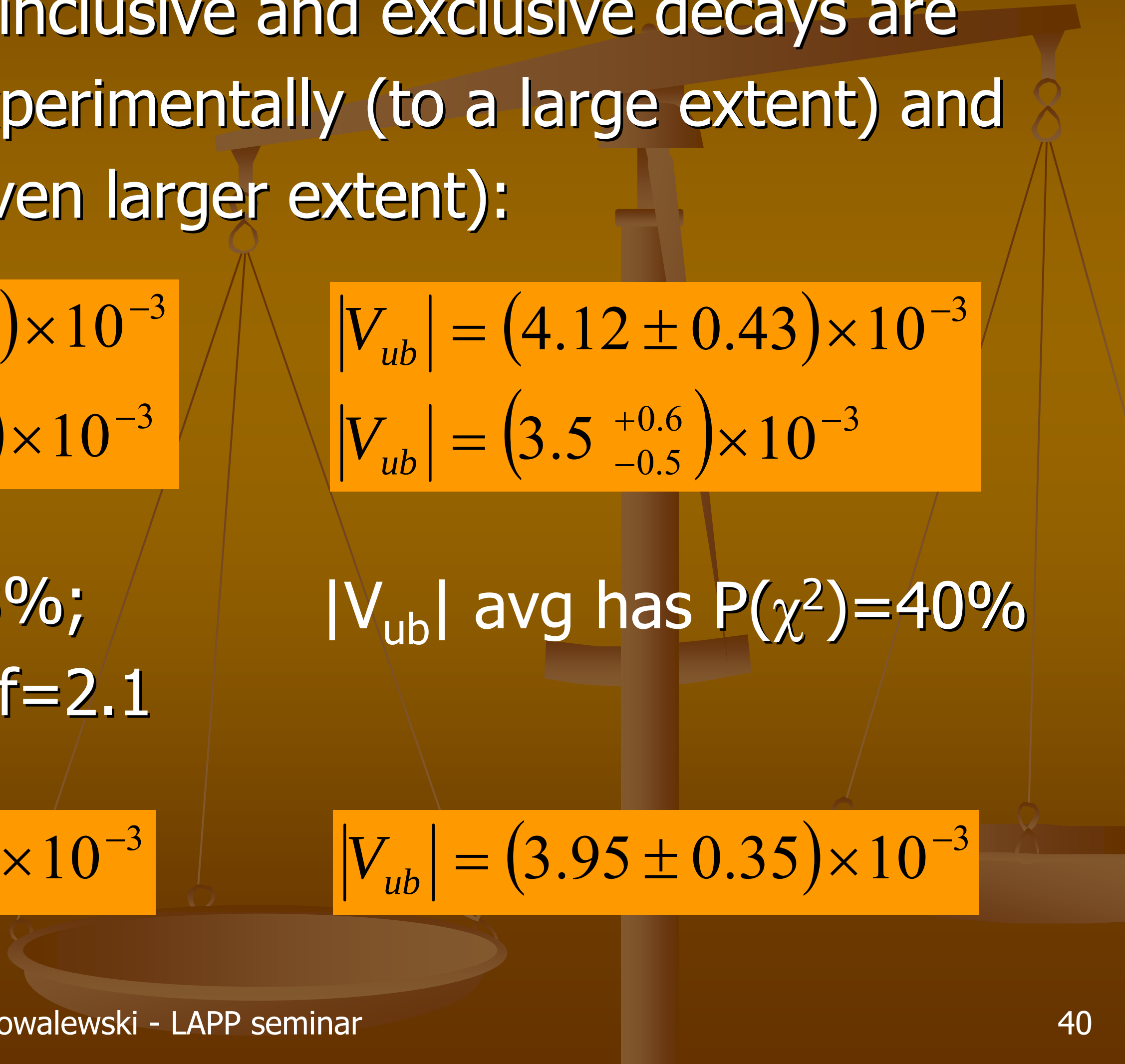
Expected improvements - experiment

- $b \to c\ell\nu$ moments measurements can be improved
  - Hard work – systematics limited
  - Can measure higher-order moments
- $b \to s\gamma$ still improves with statistics
- Measurements of $b \to u\ell\nu$ can be improved
  - Push to increase acceptance → fight large $b \to c\ell\nu$ background
  - Continue to measure many partial rates → test theory
  - Pursue direct relations between partial rates of $b \to s\gamma$ and $b \to u\ell\nu$

Expected improvements - theory

- $b \to c\ell\nu$ OPE can be improved
  - Higher order terms (recent progress not yet reflected in fits)
  - perturbative corrections to matrix elements
- Clarify use of $b \to s\gamma$ in global fits (helps determine m_b)
- Calculations of $b \to u\ell\nu$ can be improved
  - Several calculations now available; important cross-checks
  - Need to add $O(\alpha_s^2)$ terms to partial rate calculation (underway)

Comparison of inclusive and exclusive $|V_{cb}|$



- Determinations from inclusive and exclusive decays are independent, both experimentally (to a large extent) and theoretically (to an even larger extent):

$$\textbf{Inclusive :}\quad |V_{cb}| = (41.6 \pm 0.6) \times 10^{-3}$$

$$\textbf{Exclusive :}\quad |V_{cb}| = (38.6 \pm 1.3) \times 10^{-3}$$

$$|V_{ub}| = (4.12 \pm 0.43) \times 10^{-3}$$

$$|V_{ub}| = (3.5\ ^{+0.6}_{-0.5}) \times 10^{-3}$$

- $|V_{cb}|$ avg has $P(\chi^2)=3\%$; scale error by $\sqrt{\chi^2/\text{ndf}}=2.1$

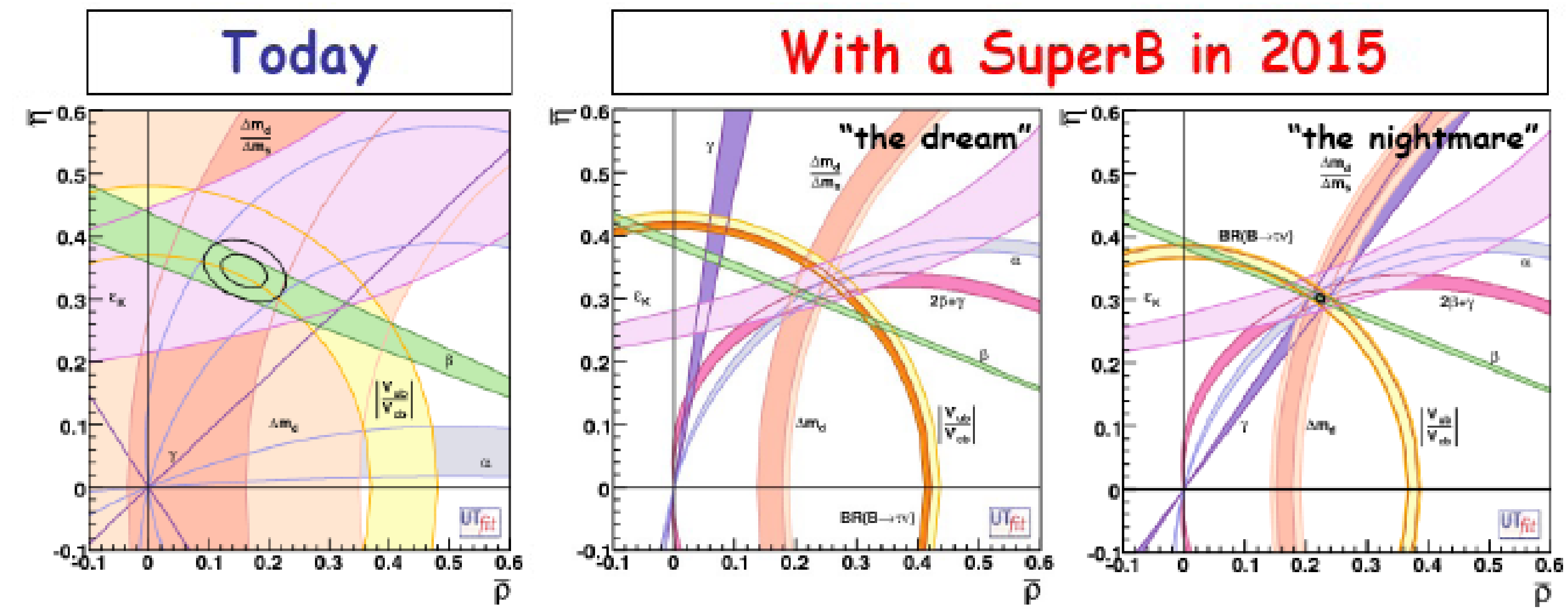
$|V_{ub}|$ avg has $P(\chi^2)=40\%$

$$|V_{cb}| = (41.2 \pm 1.1) \times 10^{-3}$$

$$|V_{ub}| = (3.95 \pm 0.35) \times 10^{-3}$$

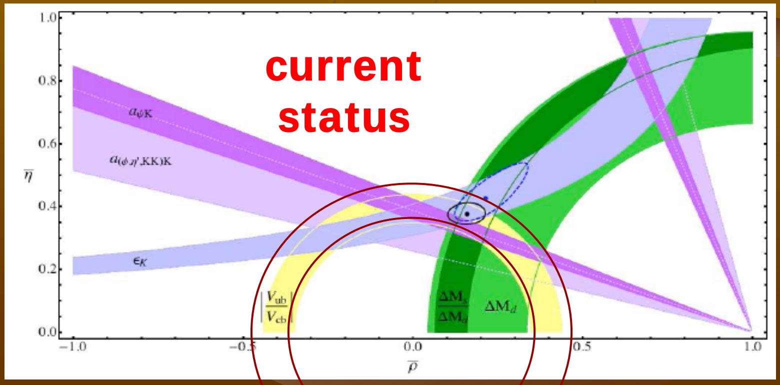
Status and prospects

- Currently, $\sigma_{|Vub|} = 9\%$, $\sigma_{|Vcb|} = 2.5\%$
- Near-term (<2010): $\sigma_{|Vub|} \sim 6\%$, $\sigma_{|Vcb|} \sim 1.5\%$
- Long term? from Marco Ciuchini: $\sigma_{|Vub|} \sim 2\%$, $\sigma_{|Vcb|} < 1\%$
  https://agenda.infn.it/getFile.py/access?contribId=18&sessionId=3&resId=0&materialId=slides&confId=308



Summary

- $|V_{cb}|$ and $|V_{ub}|$ can be determined in two ~independent ways using inclusive and exclusive semileptonic B decays
- Theoretical uncertainties are important; optimize experimental versus theory uncertainties
- Existing e^+e^- B factories can make further improvements; theoretical calculations can also be improved
- Improvements in precision may be gradual (i.e. slow), but continual progress is being made, and remains important



current status