Results on Semileptonic B Decays from BaBar

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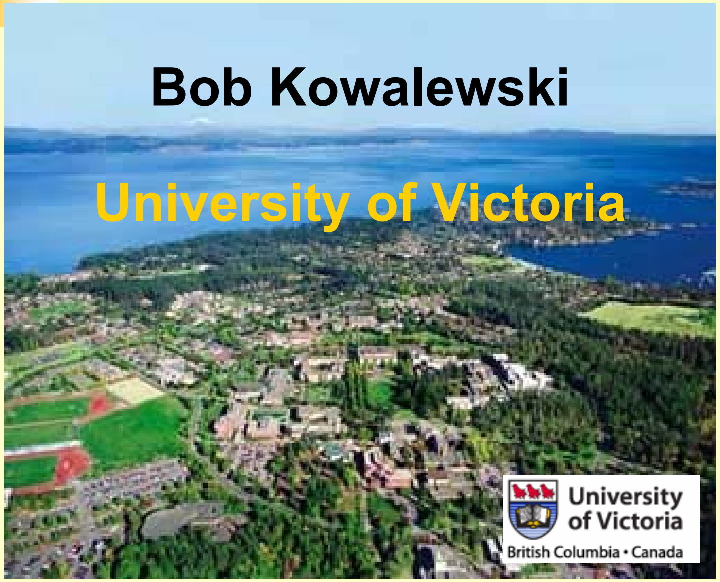


Stanford Linear Accelerator Center

Currently at

Università degli Studi di Roma

INFN

and the Laboratori Nazionali di Frascati

Outline

- Context – B decays and the CKM sector
- Theoretical framework for inclusive B decays
- Inclusive $b \rightarrow c\ell\nu$ decays and $|V_{cb}|$
- Inclusive $b \rightarrow u\ell\nu$ decays and $|V_{ub}|$
- $B \rightarrow D^{*}\ell\nu$: FF and $|V_{cb}|$
- $B \rightarrow \pi\ell\nu$ and $|V_{ub}|$

} If I have time….

B decays – a window on the quark sector

- The only 3rd generation quark we can study in detail
- Access 3 of the 4 CKM parameters

Cabibbo angle

CKM matrix

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

B lifetime, SL decay

$B_d\bar{B}_d$ and $B_s\bar{B}_s$ oscillations, Radiative decays

~ 1

CP Asymmetries (phase)

CKM picture → Unitarity Triangle

λ, A, $\bar{\rho}$ and $\bar{\eta}$

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

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

$$\lambda = 0.2196 \pm 0.0023$$

At the 2% level : $|V_{us}|$

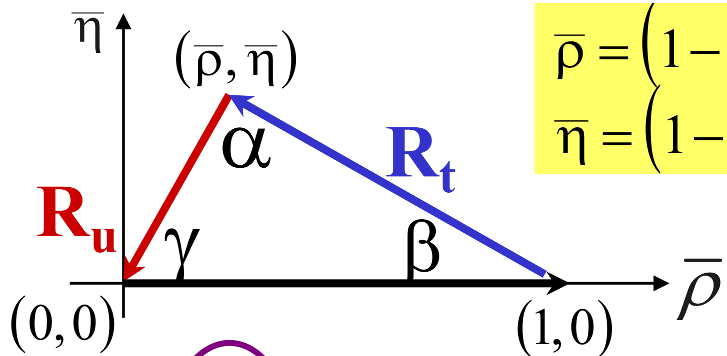
$$A = |V_{cb}| / \lambda^2$$

$$A = 0.84 \pm 0.02$$

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

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

Unitarity: $1 + R_t + R_u = 0$



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

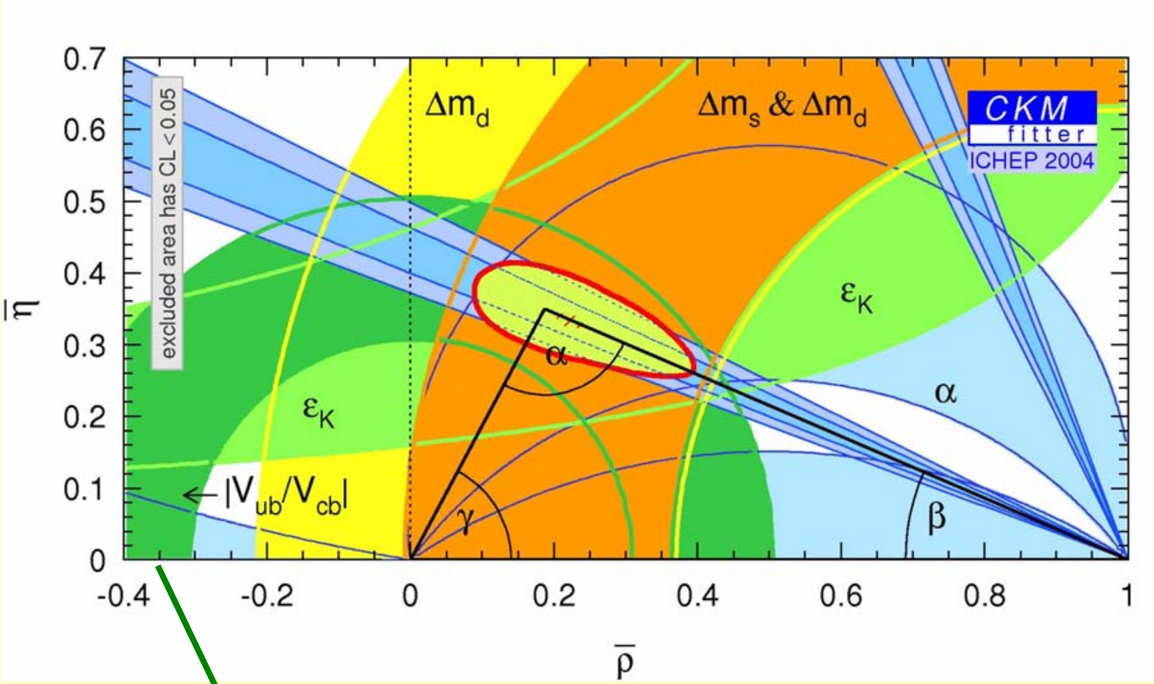
$$R_u = \frac{V_{ud} V_{ub}^*}{V_{cd} V_{cb}^*} \approx -\sqrt{\bar{\rho}^2 + \bar{\eta}^2}\; e^{i\gamma}$$

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

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

Current status in ρ-η space

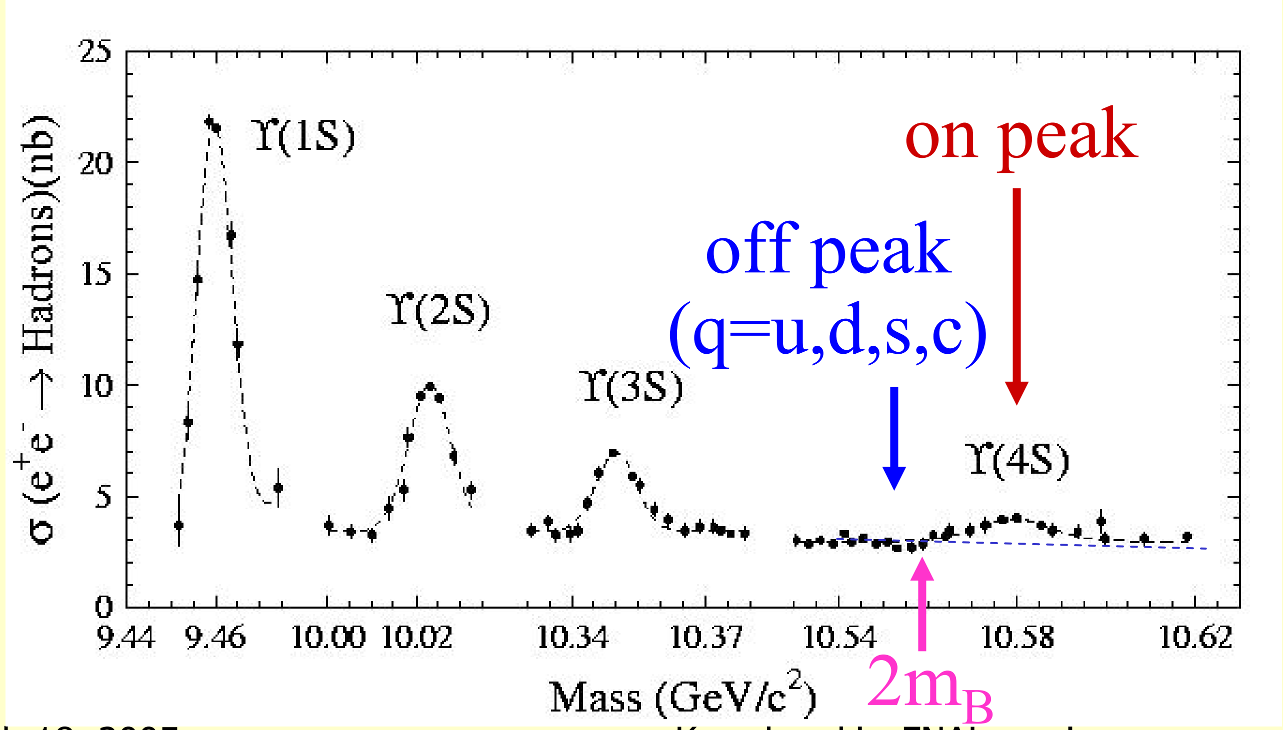
- Measurements are consistent with SM
- CP asymmetries from B factories dominate the determination of η
- Improved precision needed on $|V_{ub}|$ and other angles (α,γ)
- Also need information on B_s oscillations!

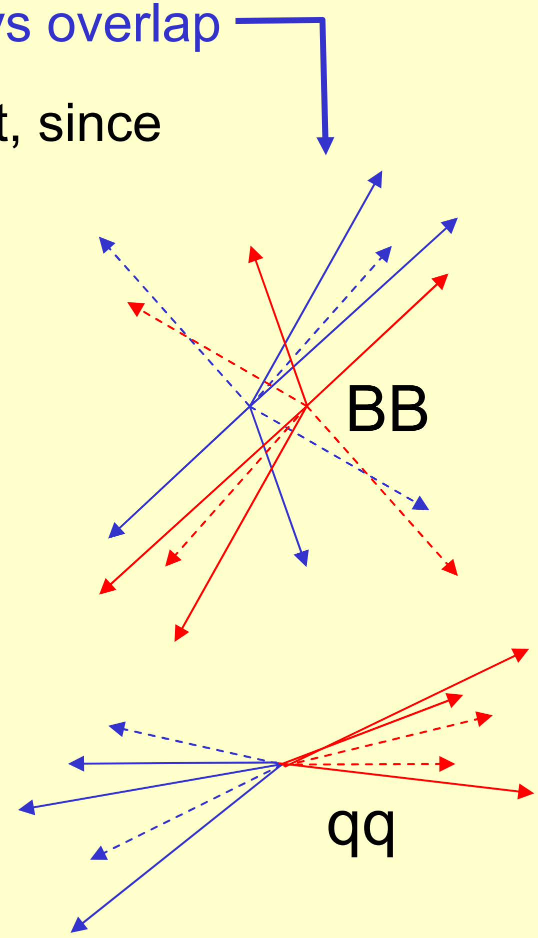


$|V_{ub}|/|V_{cb}|$ band ($\pm2\sigma$) corresponds to σ=12%

Y(4S) experiments

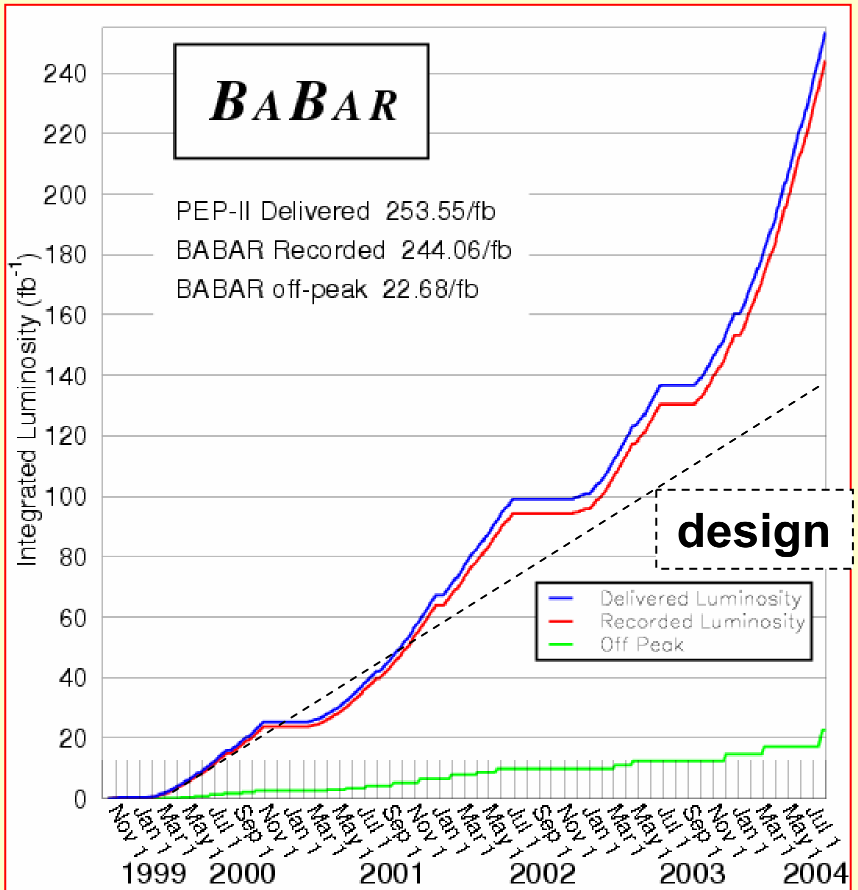
- $e^+e^- \rightarrow Y(4S) \rightarrow B^+B^-$ or $B^0\underline{B}^0$; roughly 50% each
- B nearly at rest ($\beta\gamma \sim 0.06$) in 4S frame; decays overlap
- B energy = ½ c.m. energy; valuable constraint, since σ_E~5 MeV for e^+e^- beams





Our research tools

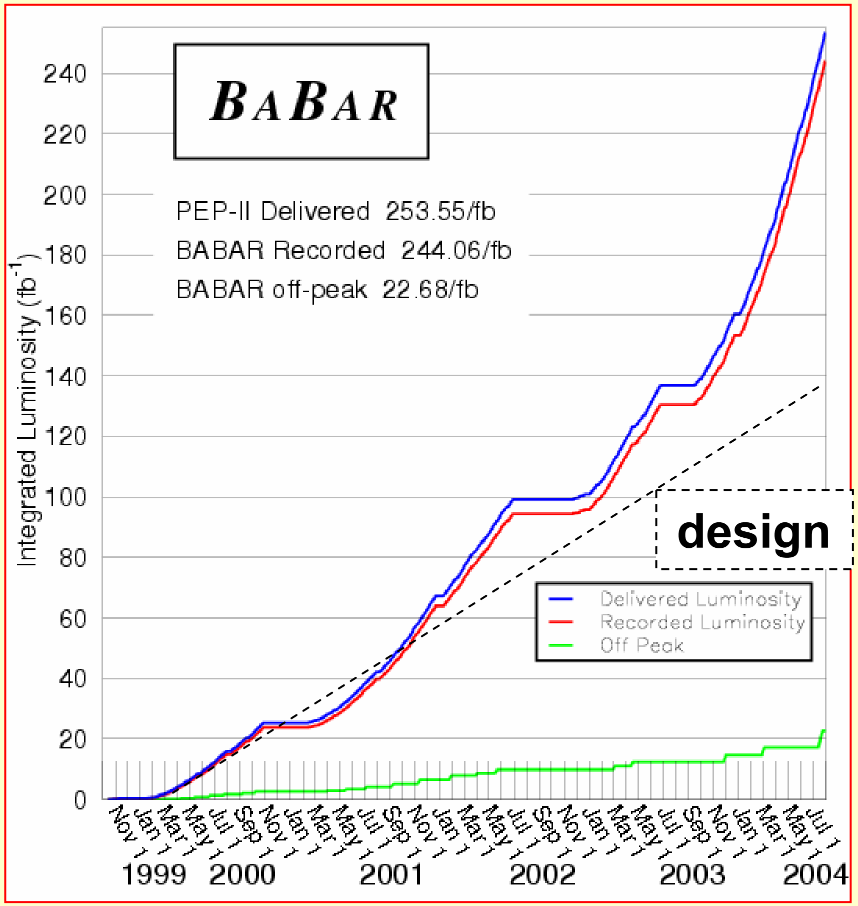
- PEP-2 performance has been marvelous



	BaBar
L_{max} (10^{33}/cm^2/s)	9.2
best day (pb^{-1})	681
total (fb^{-1})	244

- Design was 30 fb^{-1}/year…

Our research tools



- PEP-2 performance has been marvelous; almost as good as KEK-B…

	BaBar	Belle
L_{max} ($10^{33}/cm^2/s$)	9.2	13.9
best day (pb^{-1})	681	944
total (fb^{-1})	244	338

- Design was 30 fb^{-1}/year…

PEP-II luminaries

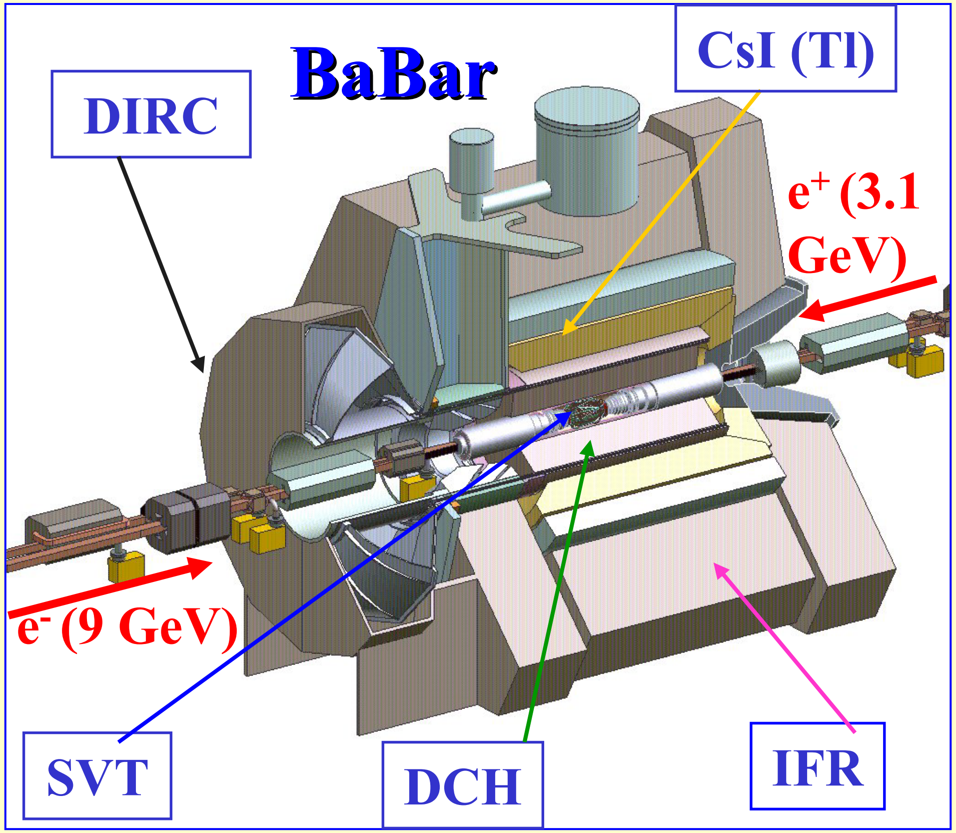
Jonathan Dorfan

Pier Oddone

Our research tools

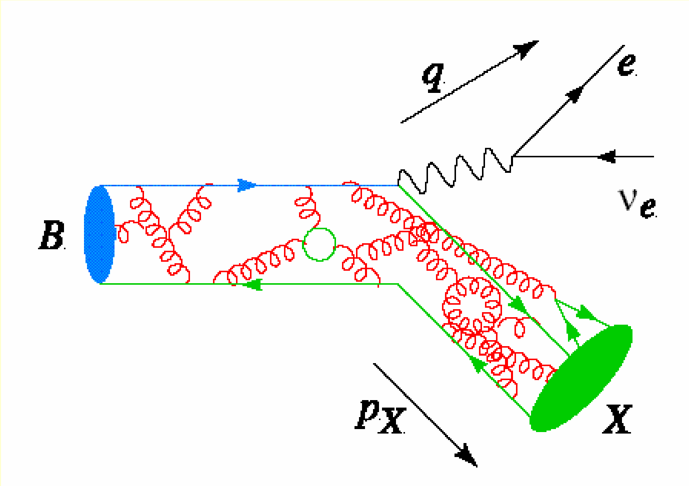
- BaBar has recorded >96% of delivered luminosity
- Trigger efficiency for B$\overline{B}$ events ~ 100%

- 5-layer SVT tracker → dE/dx
- 40-layer Drift CHamber → dE/dx
- Novel RICH based on total internal reflection (DIRC)
- CsI(Tl) crystal calorimeter ($e^{\pm}$, γ)
- RPC and LST chambers in flux return for muon ID
- Angular coverage ~ 92% of 4π in cm frame (challenge for ν reco)
- Boost: β_{4S} = 0.56 in lab

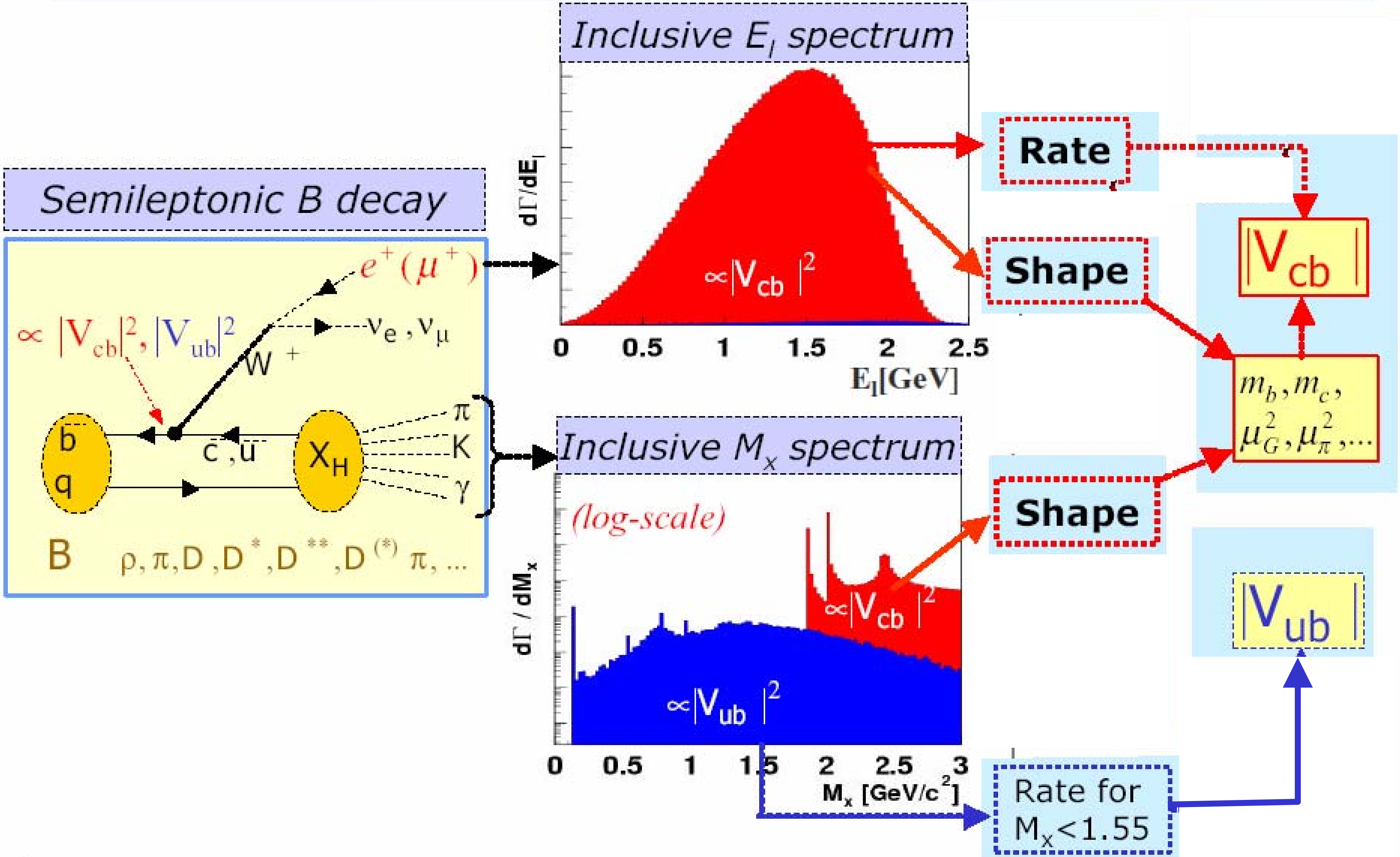


Why we study SL decays

- $|V_{ub}|$ and $|V_{cb}|$ are crucial in testing CKM unitarity and SM mechanism for CP violation
- Presence of a single hadronic current allows control of theoretical uncertainties
  - precise determinations of $|V_{ub}|$ and $|V_{cb}|$
- SL decays also provide a laboratory for probing our ability to calculate hadronic quantities in the presence of a mix of scales in QCD



Inclusive Decays – the Big Picture



Understanding inclusive SL decays

- The Operator Product Expansion provides a systematic method of separating perturbative from non-perturbative scales
- OPE + Heavy Quark symmetry[1] → HQE
- Heavy Quark Expansion now calculated to α_s^2, m_B^{-3}

Essentially all we need to know for b→cℓv

- Coefficients of operators calculated perturbatively (EW and QCD); non-perturbative physics enters through matrix elements of operators

[1] soft gluons cannot probe heavy quark properties

Semileptonic B Decays & HQE

$$\Gamma(B \to X_c \ell \nu) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 (1 + A_{EW}) \times \left(\mathbf{z_0}(r)\left[1 + A_3^{pert}(r,\mu)\right]\left(1 - \frac{\mu_\pi^2 - \mu_G^2 + \frac{\rho_D^3 + \rho_{LS}^3}{m_b}}{2m_b^2}\right) - (1 + A_5^{pert}(r,\mu))2(1-r)^4 \frac{\mu_G^2 + \frac{\rho_D^3 + \rho_{LS}^3}{m_b}}{m_b^2} + \mathbf{d}(r)\frac{\rho_D^3}{m_b^3} + O\left(\frac{1}{m_b^4}\right) \right)$$

free-quark rate

μ= scale which separates effects from long- and short-distance dynamics

$r = m_c/m_b$; $\mathbf{z_0}(r)$, $\mathbf{d}(r)$: phase space factors; A_{EW} = EW corrections; A^{pert} = pert. corrections (α_s^j, $\alpha_s^k \beta_0$)

No 1/m_b term!

- contains b- and c-quark masses, m_b and m_c
- μ_π^2 related to kinetic energy of b-quark
- μ_G^2 related to chromomagnetic operator: B / B* mass splitting
- Darwin term (ρ_D^3) and spin-orbit interaction (ρ_{LS}^3) enter at $1/m_b^3$

Several HQE schemes exist; op's and coeff's are scheme dependent

Inclusive $b \to c\ell\nu$

- Measure electron momentum spectrum and mass of hadronic system in SL decay
- Determine *moments* to allow comparison with parton-level calculations (duality assumed)
- Calculations exist for the following:

Lepton energy spectrum

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

Mass of hadronic system

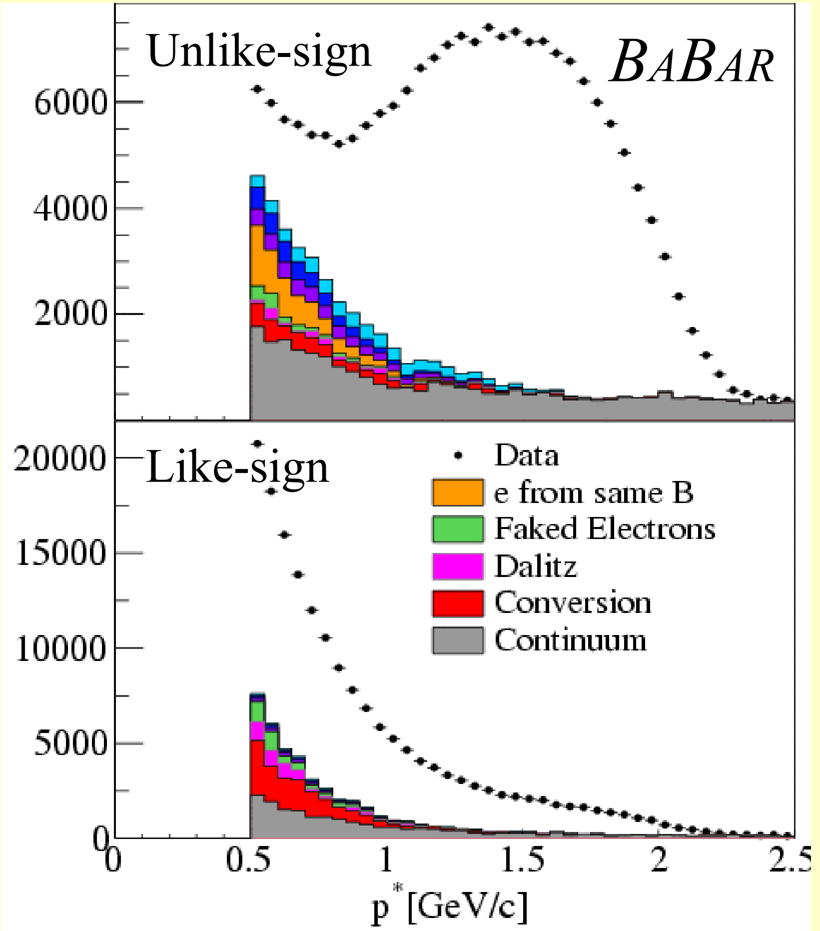
$$\left\langle M_x^n \right\rangle_{E_l > E_0} = \tau_B \int_{E_0} M_X^n d\Gamma = f_n^{x}(E_0, m_b, m_c, \mu_G^2, \mu_\pi^2, \rho_D^3, \rho_{LS}^3)$$

- Fit for HQE parameters and $|V_{cb}|$

BABAR PR D69:111104

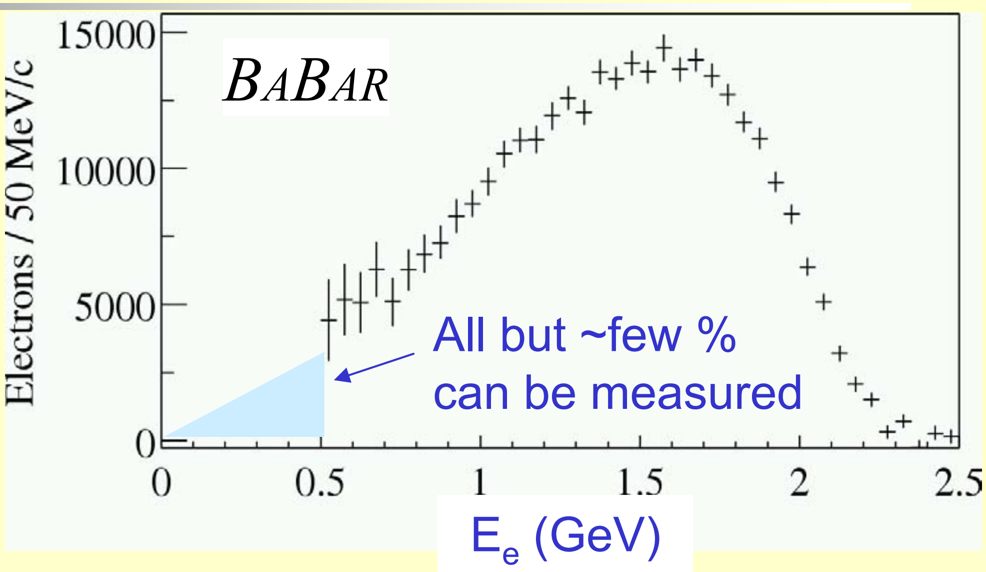
Electron Energy Spectrum

- BABAR data, 47.4 fb^{-1} at $\Upsilon(4S)$ + 9.1 fb^{-1} off-peak
- Select events with an electron having p*>1.4 GeV; study spectrum of 2nd electron for p^* > 0.5 GeV as f^n of charge
  - Unlike-sign events dominated by $B \rightarrow X_c e\nu$
  - Like-sign events from $D \rightarrow Xe\nu$, B^0 mixing
- As done by ARGUS, CLEO…



BaBar PR D69:111104

Electron Energy Spectrum

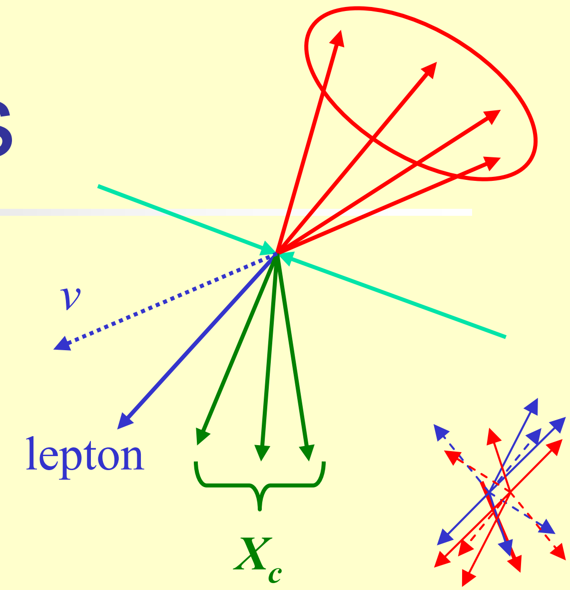


- Determine E_e spectrum
  - Subtract $B \to X_u e \upsilon$
  - Correct for efficiency
  - Correct for the detector material (Bremsstrahlung)
  - Move from $\Upsilon(4S)$ to B rest frame
  - Correct for the final state radiation using PHOTOS
- Calculate 0^{th}-3^{rd} E_e moments for $E_0 = 0.6 \ldots 1.5$ GeV

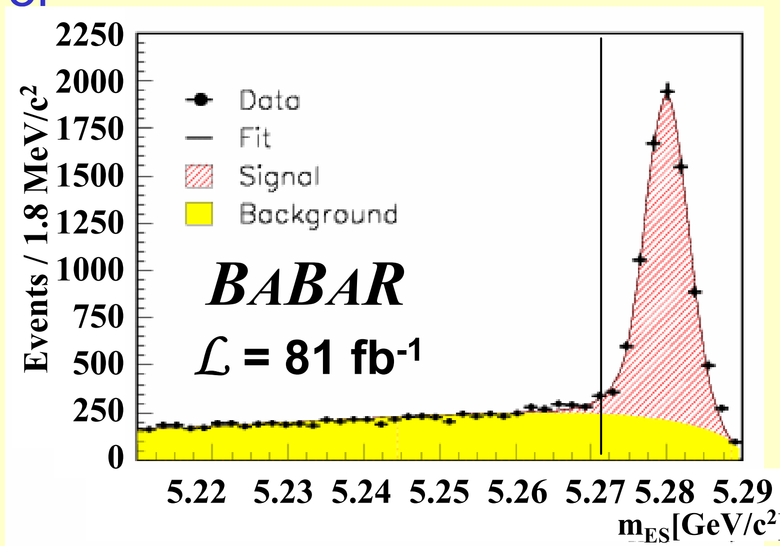
Hadron Mass Moments

BABAR PR D69:111103

- Select events with a fully-reconstructed *B*
  - Use ~1000 decay chains $\underline{B} \rightarrow D[(n\pi)(mK)]^-$
  - Flavor and momentum of “recoil” B known
- Find a lepton with $E > E_0$ in the recoil-*B*
  - Lepton charge consistent with the *B* flavor
  - m_{miss} consistent with a neutrino
- All remaining particles belong to X_c
  - Improve m_X with a kinematic fit (require $m_{B2}=m_{B1}$ and $m_{miss}=0$)
  - Gives $\sigma(m_X)$= 350 MeV

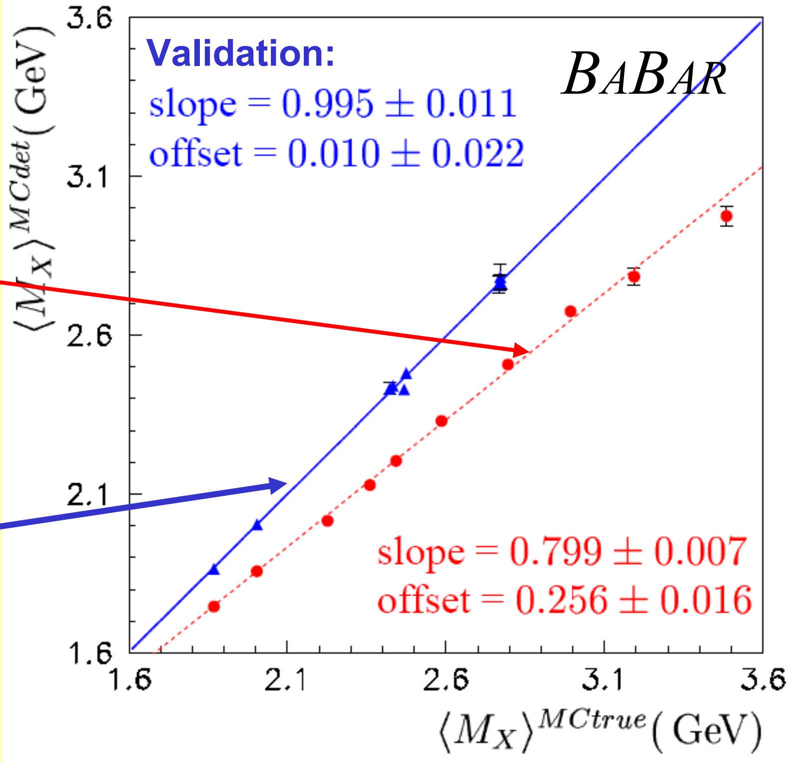


Fully reconstructed
$B \rightarrow$ hadrons



Hadron Mass Moments

- Unmeasured particles → measured m_X < true m_X
  - Calibrate using simulation
  - Depends (weakly) on decay multiplicity and m_{miss}
  - Validate in MC after applying correction
  - Validate on data using partially reconstructed $D^{*\pm} \to D^0\pi^\pm$, tagged by the soft $\pi^\pm$ and lepton

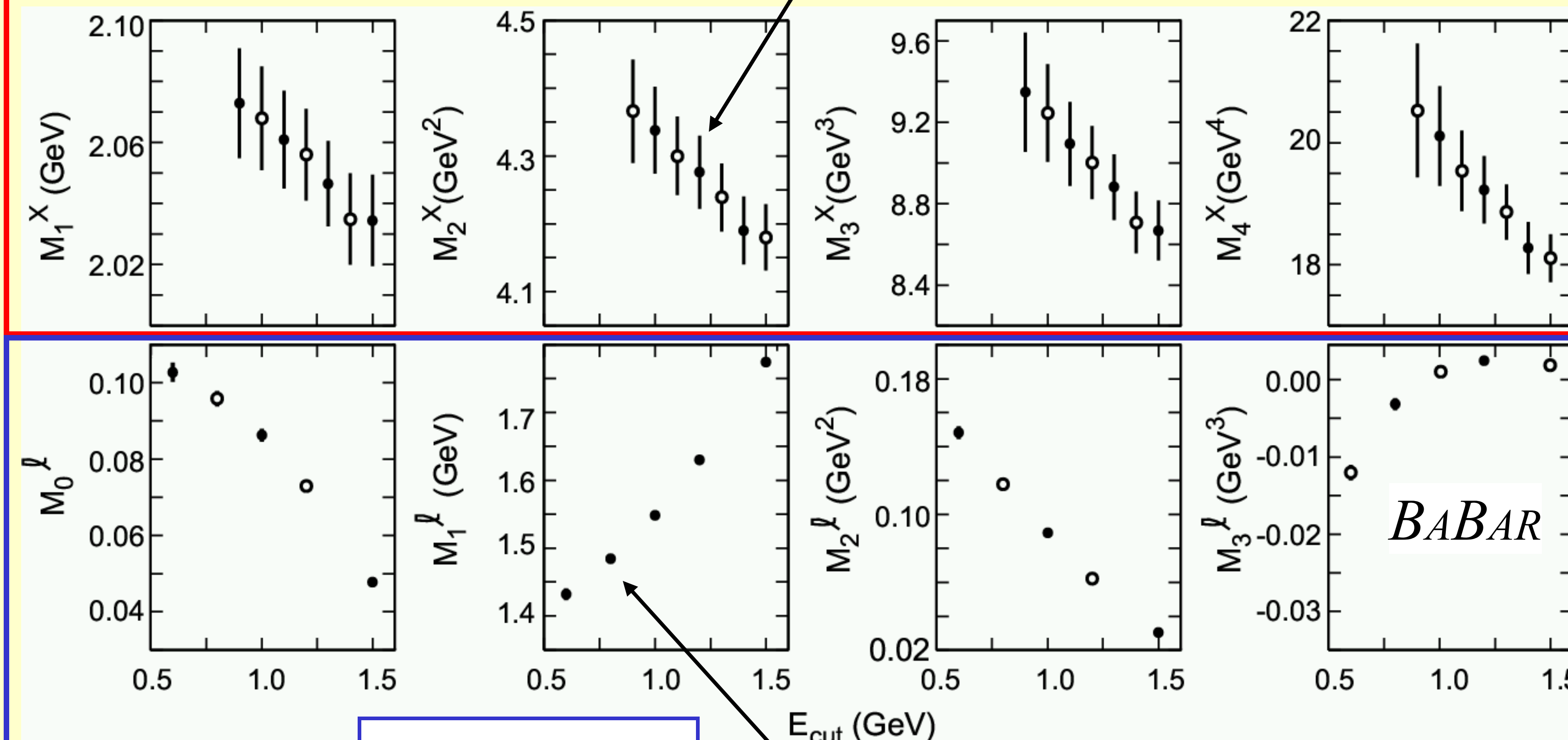


- Calculate 1st-4th mass moments with E_0 = 0.9 … 1.6 GeV

Inputs to OPE Fit

m_X moments

Error bars are stat. & syst. with comparable sizes



E_ℓ moments

Error bars (sys+stat) are smaller than point size

Fit Parameters

- Calculation by Gambino & Uraltsev (hep-ph/0401063, 0403166)
  - Kinetic mass scheme to $\mathrm{O}(1/m_b^3)$
  - E_ℓ moments $\mathrm{O}(\alpha_s^2)$
  - m_X moments $\mathrm{O}(\alpha_s)$
- 8 parameters to determine

$$|V_{cb}| \quad m_b \quad m_c \quad \mathrm{B}(B \to X_c \ell \nu) \quad \mu_\pi^2 \quad \mu_G^2 \quad \rho_D^3 \quad \rho_{LS}^3$$

kinetic (μ_π^2), chromomagnetic (μ_G^2): $\mathrm{O}(1/m_b^2)$

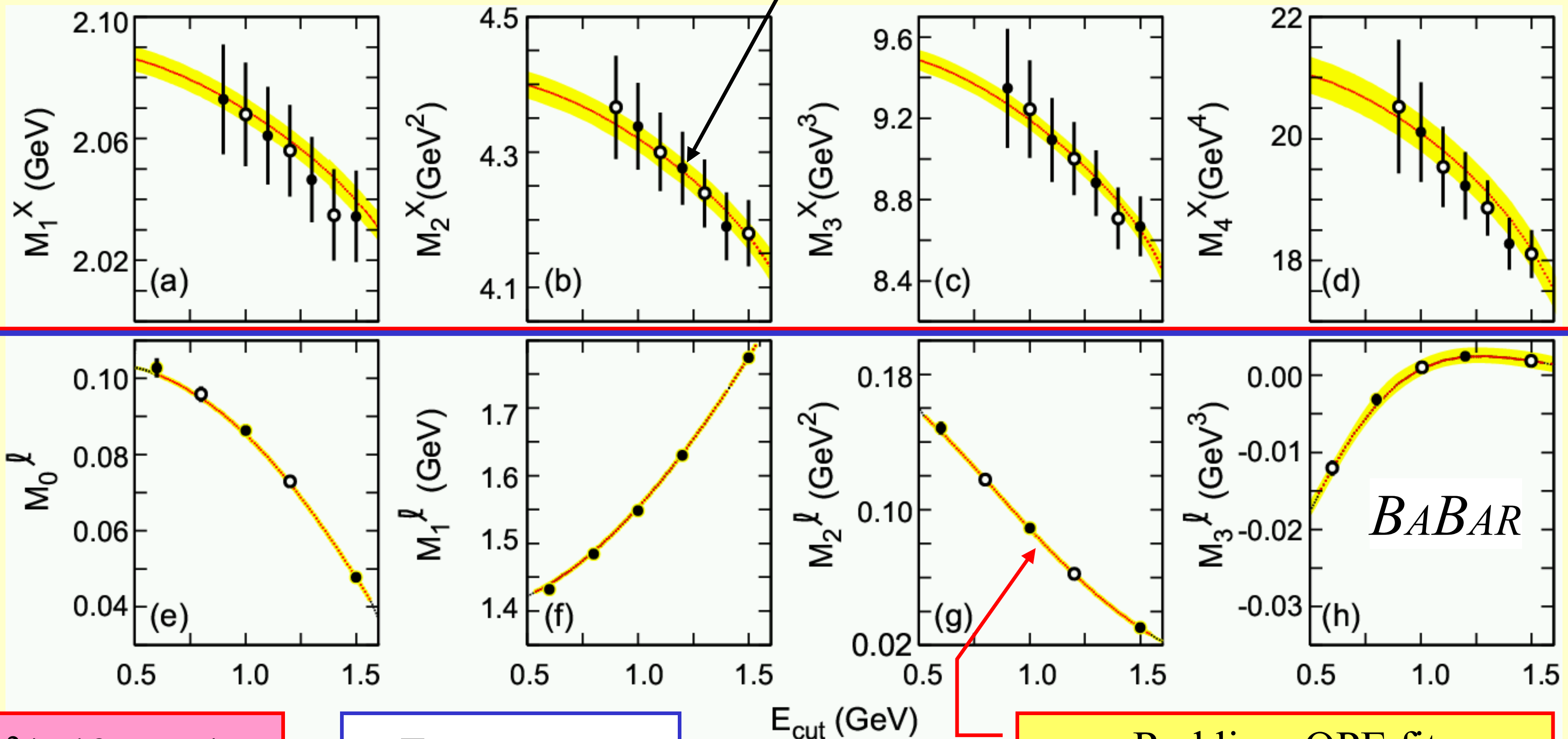
spin-orbit (ρ_{LS}^3), Darwin (ρ_D^3): $\mathrm{O}(1/m_b^3)$

- 8 moments available with several E_0
  - Sufficient degrees of freedom to determine all parameters without external inputs
  - Fit quality tells us how well OPE works

Fit Results

m_X moments

● = used, ○ = unused in the nominal fit



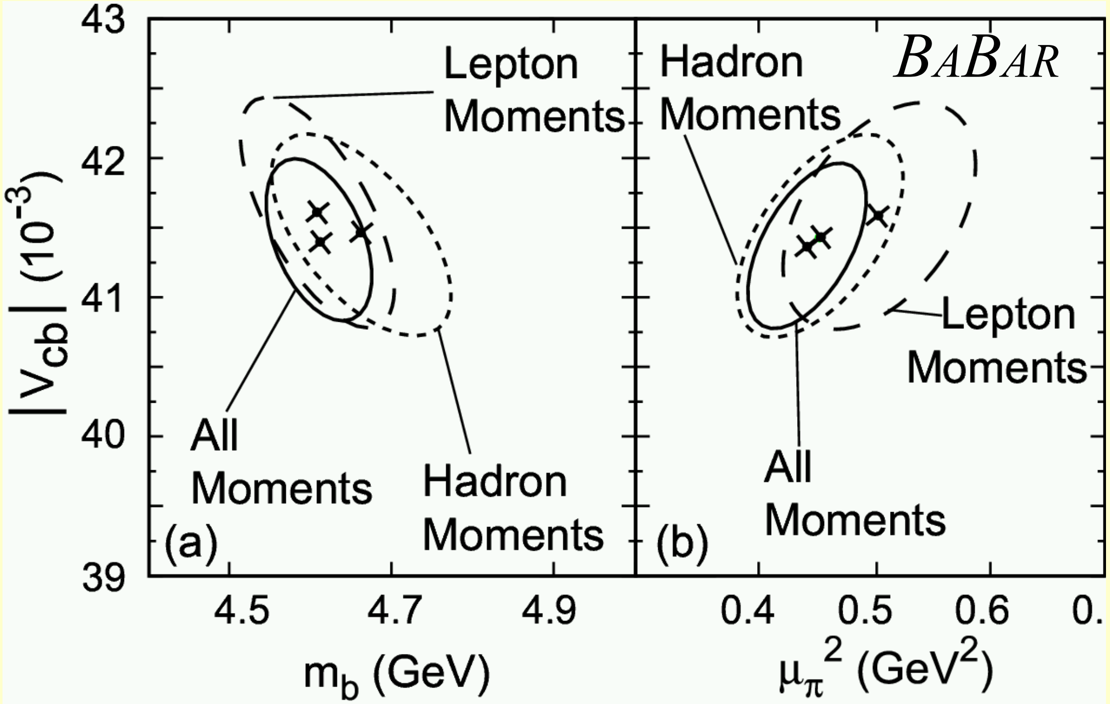
$\chi^2/\mathrm{ndf} = 20/15$

E_ℓ moments

Red line: OPE fit
Yellow band: theory errors

Fit Consistency

- OPE describes BABAR data very well
  - χ^2/ndf = 20/15
  - Separate fits of E_e and m_X moments agree



BABAR PRL 93:011803

Fit Results

precision on $|V_{cb}|$ = 2%

precision on m_b = 1.5%

$$|V_{cb}| = (41.4 \pm 0.4_{\text{exp}} \pm 0.4_{\text{HQE}} \pm 0.6_{\text{th}}) \times 10^{-3}$$

$$B_{c\ell\nu} = (10.61 \pm 0.16_{\text{exp}} \pm 0.06_{\text{HQE}})\%$$

$$m_b = (4.61 \pm 0.05_{\text{exp}} \pm 0.04_{\text{HQE}} \pm 0.02_{\alpha_s})\,\text{GeV}$$

$$m_c = (1.18 \pm 0.07_{\text{exp}} \pm 0.06_{\text{HQE}} \pm 0.02_{\alpha_s})\,\text{GeV}$$

$$\mu_\pi^2 = (0.45 \pm 0.04_{\text{exp}} \pm 0.04_{\text{HQE}} \pm 0.01_{\alpha_s})\,\text{GeV}^2$$

$$\mu_G^2 = (0.27 \pm 0.06_{\text{exp}} \pm 0.03_{\text{HQE}} \pm 0.02_{\alpha_s})\,\text{GeV}^2$$

$$\rho_D^3 = (0.20 \pm 0.02_{\text{exp}} \pm 0.02_{\text{HQE}} \pm 0.00_{\alpha_s})\,\text{GeV}^3$$

$$\rho_{LS}^3 = (-0.09 \pm 0.04_{\text{exp}} \pm 0.07_{\text{HQE}} \pm 0.01_{\alpha_s})\,\text{GeV}^3$$

Uncalculated corrections to Γ

kinetic mass scheme with μ=1 GeV

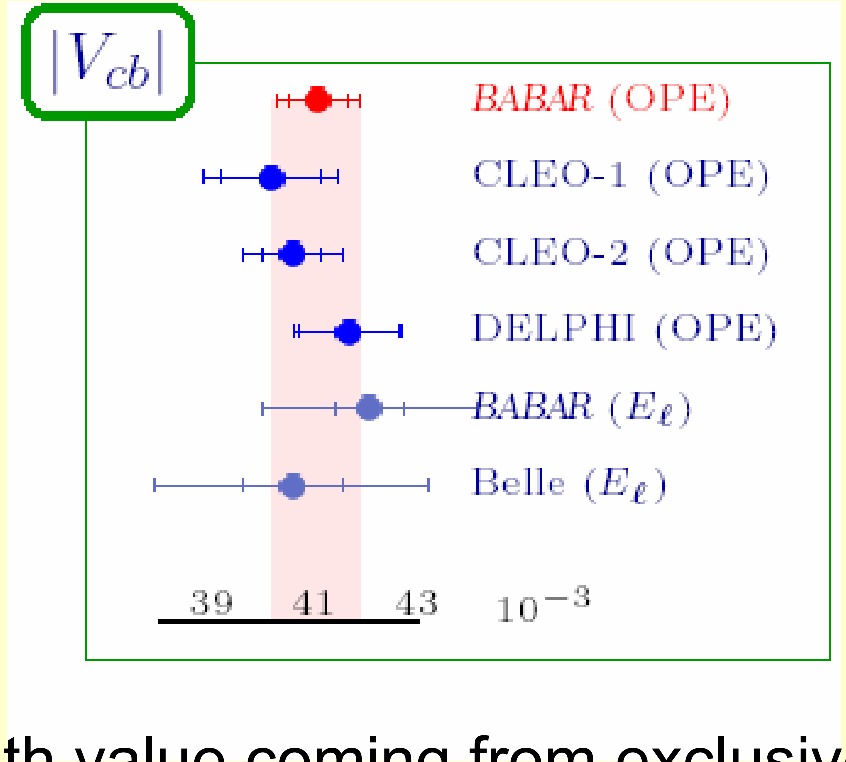
Fitted values consistent with external knowledge

χ^2/ndf = 20/15

- Impressive agreement between data and theory
- ≈ identical results obtained in another renorm. scheme: Bauer, Ligeti, Luke, Manohar, Trott in hep-ph/0408002

Inclusive $|V_{cb}|$ status

- BaBar result compared with previous measurements:



- Agrees with value coming from exclusive $B \rightarrow D^* \ell \nu$ decays (from HFAG): $|V_{cb}| = (41.4 \pm 1.0_{\text{expt}} \pm 1.8_{\text{theo}}) \times 10^{-3}$

Inclusive b→u

- Limiting factor in CKM precision tests; known much less well than $|V_{cb}|$
- CKM suppressed – therefore harder to measure
- Challenge for experiment and theory

- Overview of theory uncertainties
- Overview of measurements
- Prospects

Starting point: HQE

- Just like b→cℓν…, and with similar accuracy

$$\Gamma(B \to X_u \ell \nu) = (1 + A_{EW}) \frac{G_F^2 m_b^5}{192\pi^3} |V_{ub}|^2 \left[\left[1 + A_3^{pert}(\mu)\right] \left(1 - \frac{\mu_\pi^2 - \mu_G^2}{2m_b^2}\right) - (1 + A_5^{pert}(\mu)) 2\frac{\mu_G^2}{m_b^2} + O\left(\frac{1}{m_b^3}\right) \right]$$

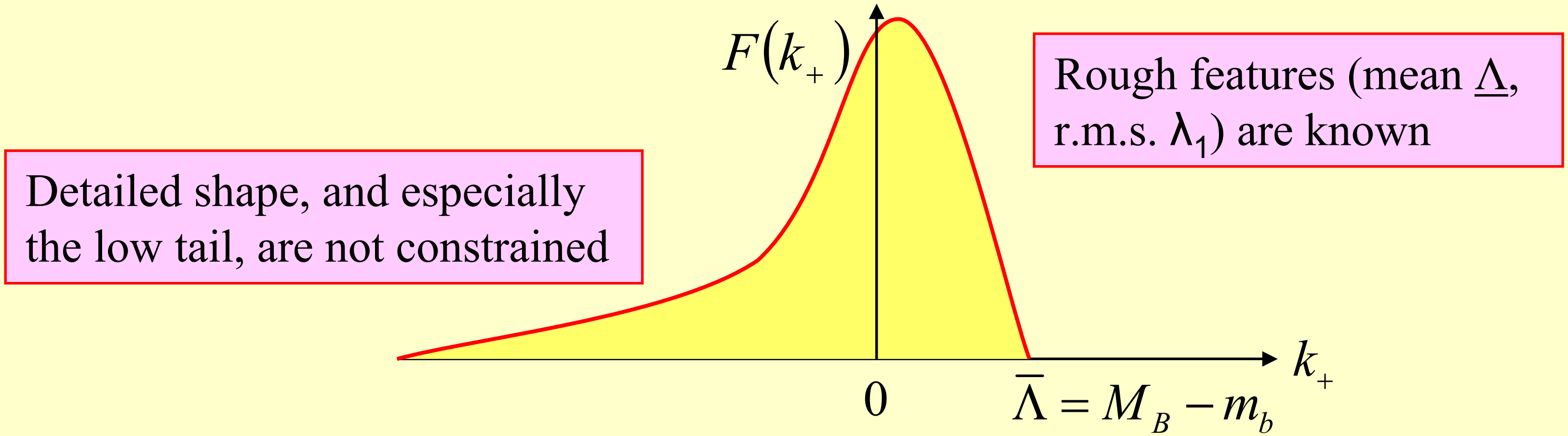
μ= scale which separates effects from long- and short-distance dynamics

$A_{EW} = EW\ corrections;$ $A^{pert} =$ pert. corrections $(\alpha_s^j,\ \alpha_s^k \beta_0)$

- …until limited expt'l acceptance is considered
- Poor convergence of OPE in region where b→cℓν decays are kinematically forbidden
- Non-perturbative Shape Function must be used to calculate partial rates

Shape Function – what is it?

- light-cone momentum distribution of b quark: $F(k_+)$
- Property of a B meson; universal...but new "sub-leading" SFs arise at each order in $1/m_b$
- Consequences: changes effective m_b, smears spectra



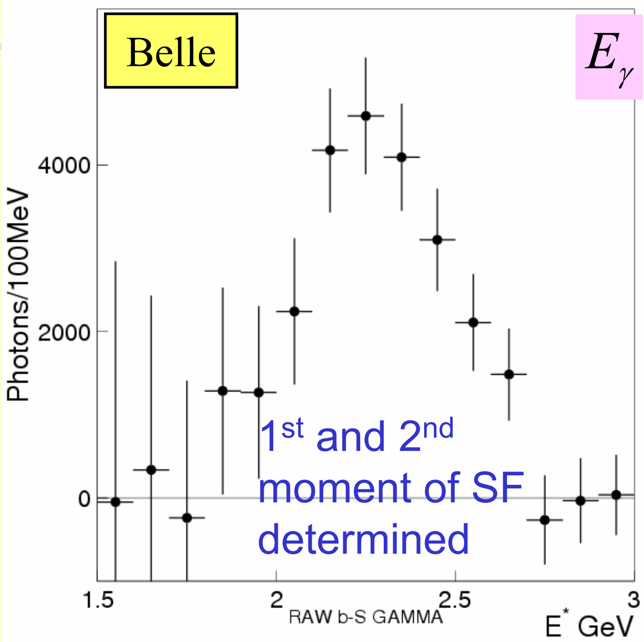
Measuring the Shape Function

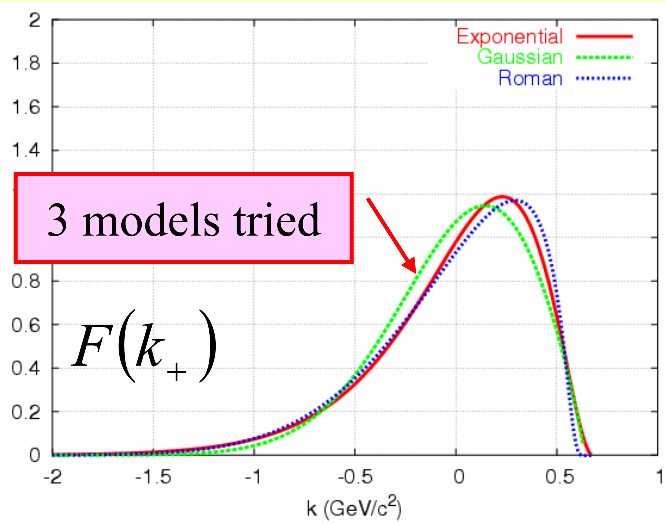
- SF can't be calculated: measure it!
- Photon energy distribution in $b \to s\gamma$ probes b quark directly; same is in $b \to u\ell\nu$ to $O(1/m_b)$

  It's a hard measurement…

NEW! SF moments are related to HQE parameters: Bosch-Lange-Neubert-Paz, hep-ph/0402094; Benson-Bigi-Uraltsev, hep-ph/0410080.

Further constrains SF models



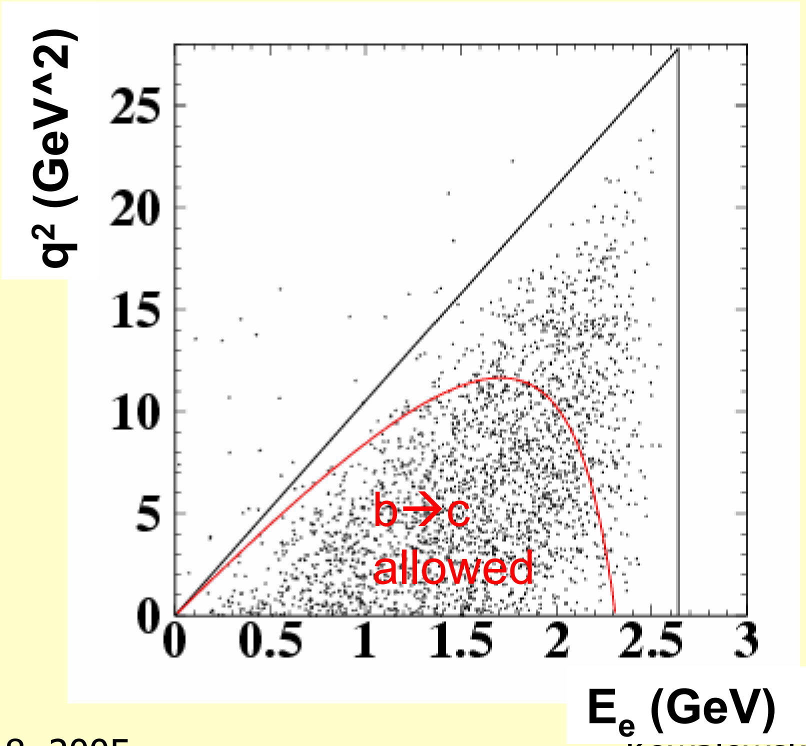


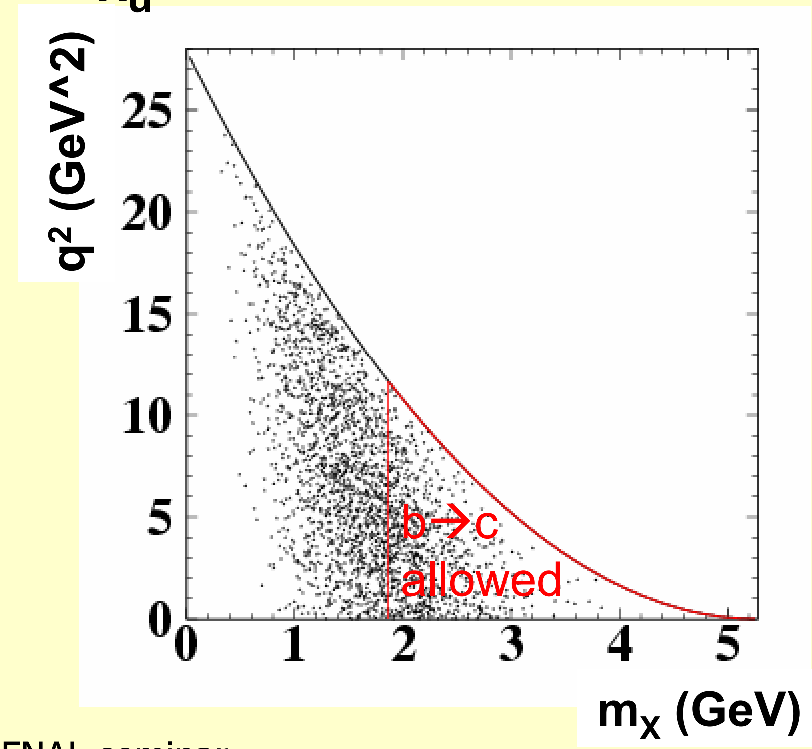
Theory input for $|V_{ub}|$

- At present, all $|V_{ub}|$ measurements based on inclusive SL decays use fully differential SL rate calculated to $O(\alpha_S, m_b^{-2})$ (DeFazio and Neubert, JHEP 06:017 (1999))
- Input required includes values for the mean and r.m.s. of the Shape Function.
- In what follows we use as input the parameters determined by a fit (hep-ex/0407052) to the Belle $b \to s\gamma$ spectrum:
  $\underline{\Lambda}$ = 0.66 GeV, λ_1 = -0.40 GeV^2 + associated covariance; $\delta\underline{\Lambda} \sim \delta m_b \approx$ 80 MeV

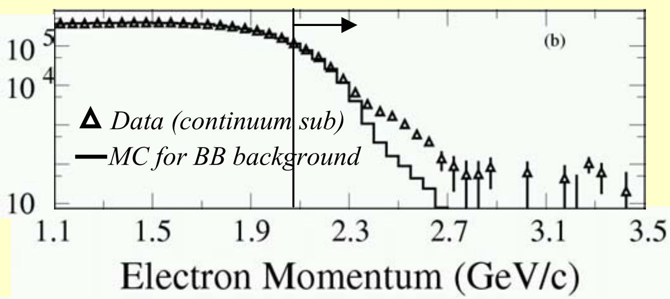
Experimental approaches

- Must suppress $b \rightarrow c\ell\nu$; rate is 50x higher than signal
- Kinematic variables: $\mathbf{E_e}$, $\mathbf{q^2} = (\mathbf{p_e}+\mathbf{p_\nu})^2$ and $\mathbf{m_{X_u}}$
- $\mathbf{E_e}$ easy, $\mathbf{q^2}$ more difficult, $\mathbf{m_{X_u}}$ hardest

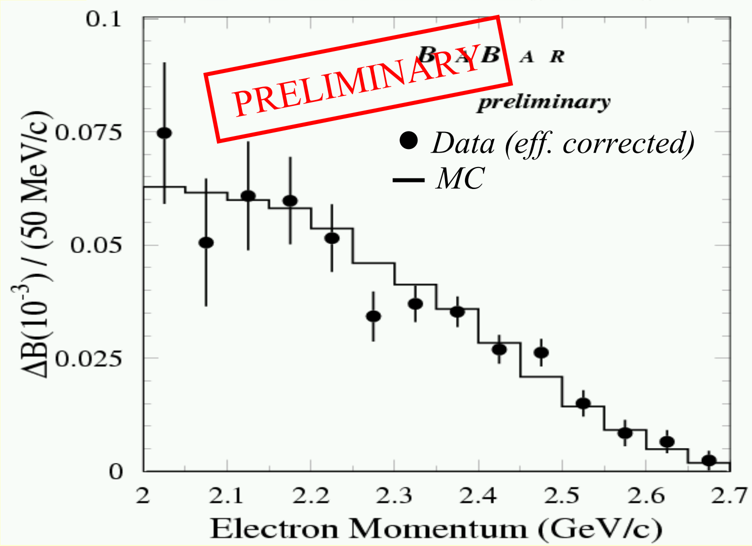




Electron Endpoint



- 80 fb^{-1} on $\Upsilon(4S)$ resonance
- Select $e^{\pm}$ in $2.0 < E_{\ell} < 2.6$ GeV
  - Larger signal acceptance → smaller theoretical error
- Accurate model of background is crucial (S/N ~ 1/14)
  - Data taken below the $\Upsilon(4S)$ resonance determine the light-flavor background
  - Fit E_e spectrum with $b \to u\ell\nu$, $B \to D\ell\nu$, $B \to D^*\ell\nu$, $B \to D^{**}\ell\nu$… Entries >2.2 GeV put in 1 bin to reduce signal model dependence
  - Fully correct spectrum for efficiency, resolution, radiation, etc.



BABAR hep-ex/0408075

CLEO PRL 88:231803

BELLE-CONF-0325

Electron Endpoint

- Fully corrected partial BF in Y(4S) frame:

$$\Delta\mathrm{B}(B \to X_u e\nu, E_e > 2.0\,\mathrm{GeV}) = (4.85 \pm 0.29_{\mathrm{stat}} \pm 0.53_{\mathrm{sys}}) \times 10^{-4}$$

- Translate ΔB into $|V_{ub}|$:

	E_e (GeV)	ΔB (10^{-4})	$\lvert V_{ub}\rvert$ (10^{-3})
BABAR	2.0–2.6	$4.85 \pm 0.29_{stat} \pm 0.53_{sys}$	$4.40 \pm 0.13_{stat} \pm 0.25_{sys} \pm 0.38_{theo}$
CLEO	2.2–2.6	$2.30 \pm 0.15_{exp} \pm 0.35_{sys}$	$4.69 \pm 0.15_{stat} \pm 0.40_{sys} \pm 0.52_{theo}$
Belle	2.3–2.6	$1.19 \pm 0.11_{exp} \pm 0.10_{sys}$	$4.46 \pm 0.20_{stat} \pm 0.22_{sys} \pm 0.59_{theo}$

- Significant decrease in theory uncertainty at lower E_e (SF sensitivity is substantially reduced)

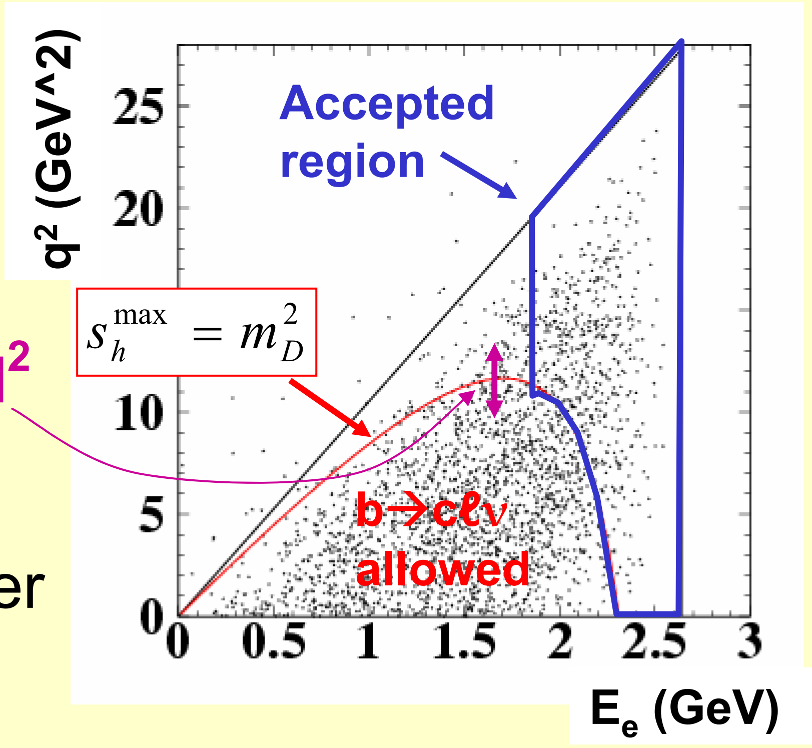
E_e vs. q^2

- Use $\mathbf{p}_\nu = \mathbf{p}_{miss}$ in addition to $\mathbf{p}_e$ ➔ Calculate $\mathbf{q}^2$
  - Given E_e and q^2, maximum possible m_X^2 is (in B frame)

$$s_h^{\max} = m_B^2 + q^2 - 2m_B\left(E_e + \frac{q^2}{4E_e}\right)$$

+small modifications for Y(4S) frame

- Resolution on $\mathbf{p}_\nu$ modest; some $b \to c\ell\nu$ decays smeared to higher $\mathbf{q}^2$
- Acceptance ~25% less than cut on $\mathbf{E}_e$ alone, but S/N=1/2 is much better



E_e vs. q^2

- 80 fb^{-1} on Υ(4S) resonance
  - Subtract off-peak data
  - $B \to D^{(*)} e\nu$ control samples used to validate ν reco
  - Subtract BB background normalized by sideband
- Unfolded partial BF:

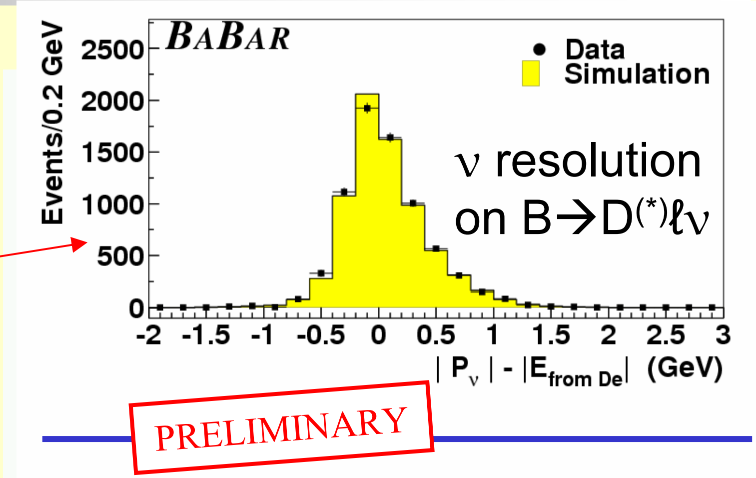
$$\Delta B = \left(4.46 \pm 0.93\right) \times 10^{-4}$$

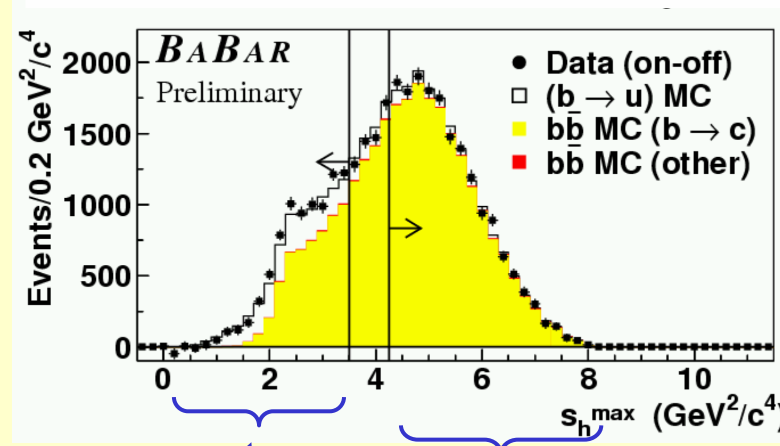
- Total b→uℓν BF:

$$B = (2.76 \pm 0.26_{stat} \pm 0.50_{syst}{}^{+0.21}_{-0.26 SF}) \times 10^{-3}$$

- Translate to $|V_{ub}|$

$$|V_{ub}| = (4.99 \pm 0.48_{exp}{}^{+0.18}_{-0.23 SF} \pm 0.22_{OPE}) \times 10^{-3}$$



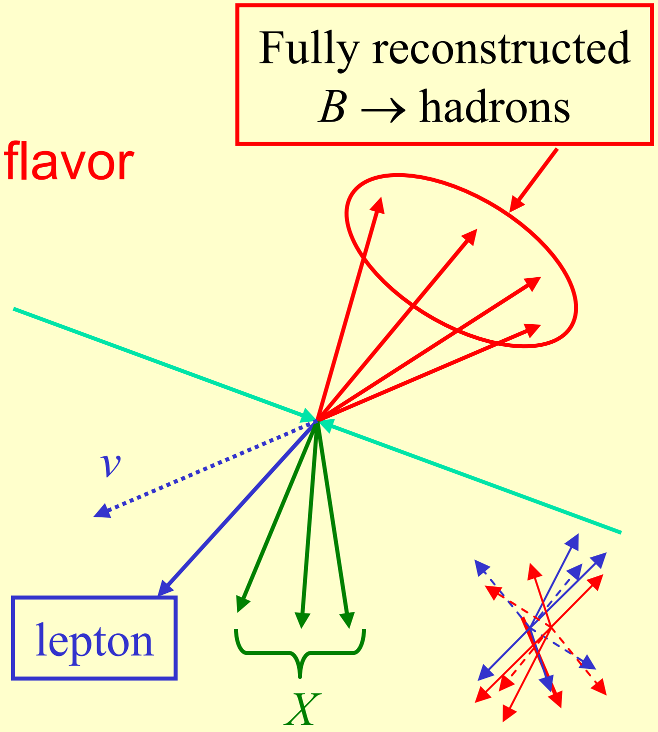


extract signal

normalize bkg

b→uℓν in tagged events

- Same recoil technique as for $b \to c\ell\nu$ $\langle m_X \rangle$ moments
  - Find a lepton (p_ℓ > 1GeV) in recoil B
  - Lepton charge consistent with the B flavor
  - m_{miss} consistent with a neutrino
- All left-over particles belong to X
  - Improve m_X with a kinematic fit
  - Calculate q^2 of lepton-neutrino
  - Calculate anything you want!



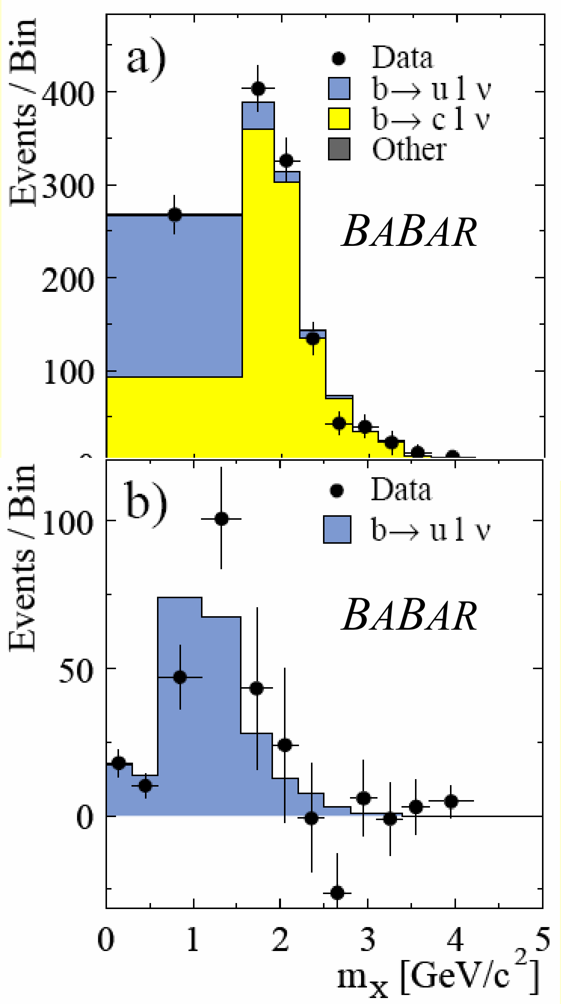
BABAR hep-ex/0408068

Charm suppression cuts

- Suppress $b \to c\ell\nu$ by vetoing $D^{(*)}$ decays
  - D decays usually produce at least one kaon
    ➔ Reject events with $K^{\pm}$ and K_S
  - $B^0 \to D^{*+}(\to D^0\pi^+)\ell^-\nu$ has peculiar kinematics
    - D^{*+} momentum can be estimated from π^+ alone
    - Calculate $m_\nu^2 = (p_B - p_{D^*} - p_\ell)^2$ for all π^+

    ➔ Reject events consistent with $m_\nu^2 = 0$
- Vetoed events are depleted in $b \to u\ell\nu$
  - Use them to validate simulation of background distributions

Fitting m_X



- BABAR data, 80 fb^{-1} on resonance
  - Simple fit in m_X shows clear $b \to u\ell\nu$ signal (S/N ~ 2/1 for m_x < 1.55 GeV)
- Inclusive BF measured to be

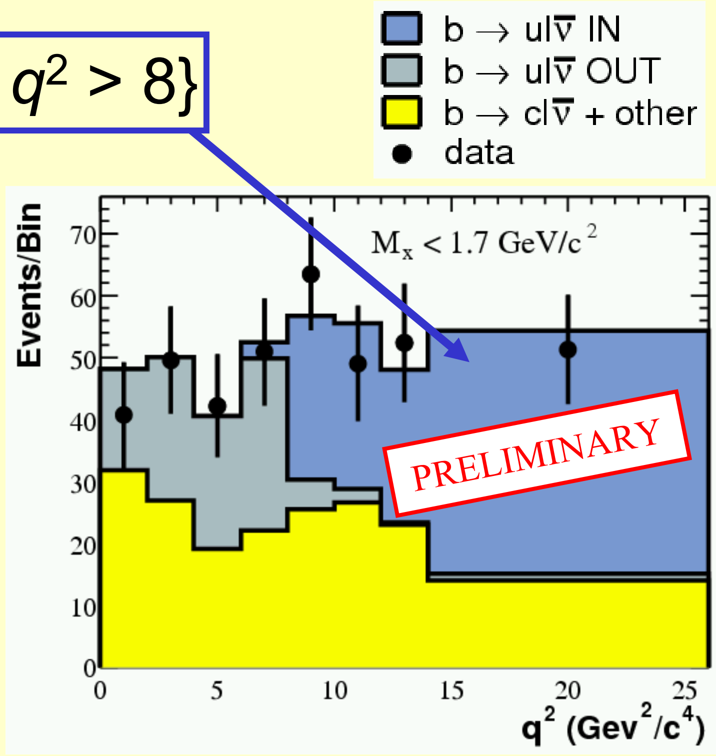
$$\mathcal{B}(B \to X_u l\nu) = (2.81 \pm 0.32_{stat} \pm 0.31_{sys}{}^{+0.23}_{-0.21}{}_{theo}) \times 10^{-3}$$

$$|V_{ub}| = (5.22 \pm 0.30_{stat} \pm 0.31_{syst} \pm 0.43_{theo}) \times 10^{-3}$$

m_X vs. q^2

- 2-D fit to measure ΔB in $\{m_X < 1.7,\ q^2 > 8\}$
  - Different theory uncertainty than pure m_x cut
  - Good resolution allows clean extraction of ΔB

$$\Delta B = (0.90 \pm 0.14_{stat} \pm 0.14_{syst}{}^{+0.01}_{-0.02\,theo}) \times 10^{-3}$$



- Signal event fraction into the "box" taken from theory

$$|V_{ub}| = (4.98 \pm 0.40_{stat} \pm 0.39_{syst} \pm 0.47_{theo}) \times 10^{-3}$$

- Bauer *et al.* hep-ph/0111387

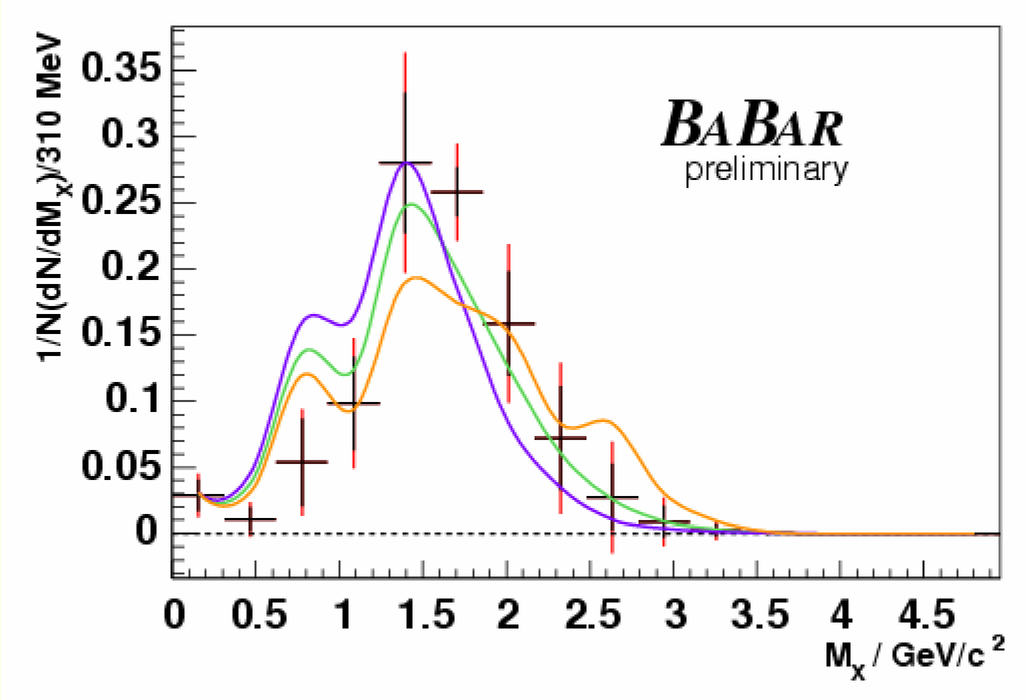
$$|V_{ub}| = (5.18 \pm 0.41_{stat} \pm 0.40_{syst}{}^{+0.25}_{-0.20\,theo}) \times 10^{-3}$$

- DeFazio-Neubert, JHEP 06:017 (1999)

Unfolding the m_x distribution

- The shape of the m_x distribution in b→uℓν decays carries information about SF parameters (b→uW akin to b→sγ)
- Moments can also be used to test OPE, as in b→cℓν
- Unfolding accounts for resolution, uncertainties in theory input…
- Measured moments:
  M_2' = 2nd central moment

	M_0(GeV)	Value
M_1	1.86	1.355 ± 0.084 GeV
M_2'	1.86	0.147 ± 0.034 GeV^2
M_1	5.0	1.584 ± 0.233 GeV
M_2'	5.0	0.270 ± 0.099 GeV^2



BaBar Inclusive $|V_{ub}|$ Results

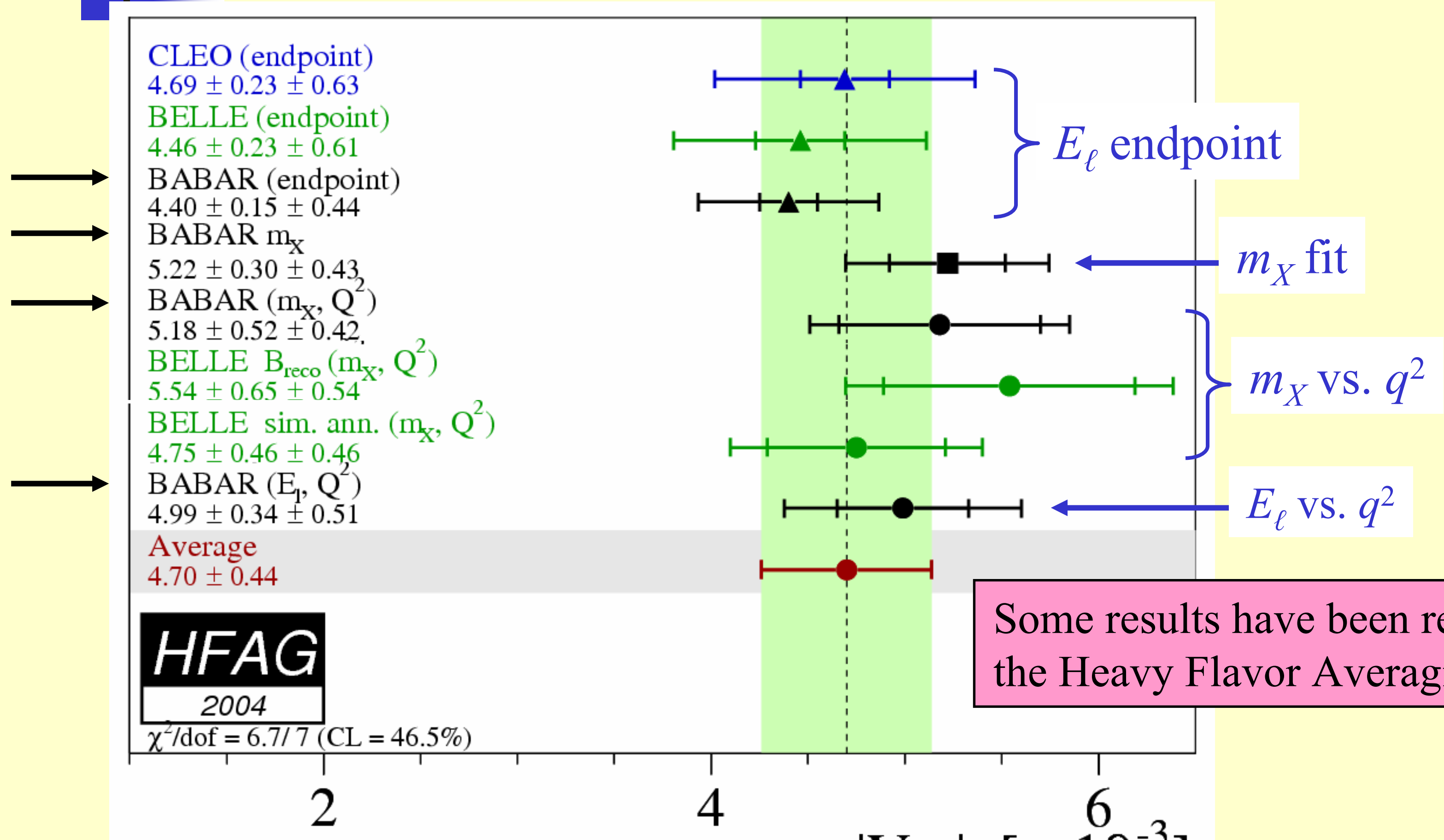
S/N increasing ↓
acceptance increasing ↓
statistics decreasing ↓

Technique	$\lvert V_{ub}\rvert \times 10^3$
$E_\ell > 2.0$ GeV	$4.40 \pm 0.13_{stat} \pm 0.25_{sys} \pm 0.38_{theo}$
E_ℓ vs. q^2	$4.99 \pm 0.23_{stat} \pm 0.42_{sys} \pm 0.32_{theo}$
m_X vs. q^2	$5.18 \pm 0.41_{stat} \pm 0.40_{sys} \pm 0.23_{theo}$
$m_X < 1.55$ GeV	$5.22 \pm 0.30_{stat} \pm 0.31_{sys} \pm 0.43_{theo}$
average	**4.80 ± 0.47,** $\chi^2 = 3.5/3$

- Statistical correlation between the m_X and m_X-q^2 results is 72%. Others correlations negligible
- Each measurement has a somewhat different sensitivity to SF
- Average accounts for correlated systematic/theory errors

BABAR hep-ex/0408075
BABAR hep-ex/0408045
BABAR hep-ex/0408068

Inclusive $|V_{ub}|$ in Perspective



Some results have been re-adjusted by the Heavy Flavor Averaging Group

- $|V_{ub}|$ is measured to ±9%!

What to look for in future

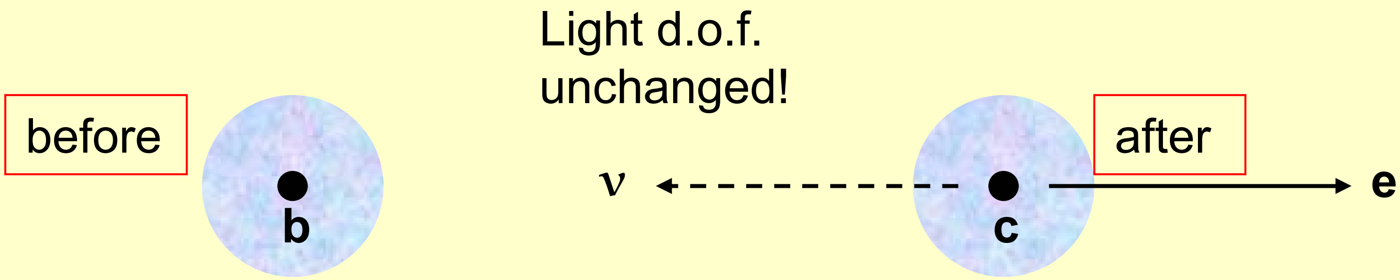
- Improved precision of $|V_{ub}|$ requires re-evaluation of theoretical uncertainties
  - Precision on SF parameters $\underline{\Lambda}$ and λ_1 will improve, due to
    - better $b \to s\gamma$ spectra and
    - the use of OPE parameters determined in $b \to c\ell\nu$ transitions
  - Power ($1/m_b$) corrections differ between $b \to u\ell\nu$ and $b \to s\gamma$
    - Quantitative estimates have appeared in literature
  - Weak annihilation may have a large (20%?) effect at high q^2
    - Difference between B^0 and B^+ needs to be measured
- Expect $|V_{ub}|$ averages to approach 5% uncertainty soon

Exclusive $B \rightarrow X_c \ell \nu$ decays

- Measure $|V_{cb}|$ using a completely independent theoretical framework from that of inclusive decays
- Test HQET
- Reduce background uncertainty for other measurements, notably $|V_{ub}|$

$B \to D^* \ell\nu$ BF and $|V_{cb}|$

- Heavy Quark Effective Theory gives us a framework for understanding $B \to X_c \ell\nu$ transitions:
  - FF for decay depends only on q^2: universal Isgur-Wise f^n
  - FF unknown, but normalization is unity in heavy quark limit ($m_b = m_c = \infty$) at "zero-recoil" point:



- Can be used with both $B \to D^* \ell\nu$ and $B \to D \ell\nu$ decays

What we measure

- $B \to D^{*}\ell\nu$ decay rate is given by

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

form factor

phase space

D^{*} boost in the B rest frame

  - $\Phi(1) = 1$ in the heavy-quark limit; Lattice calculation gives

$$\mathrm{F}(1) = 0.919^{+0.030}_{-0.035}$$

Hashimoto et al, PRD 66 (2002) 014503

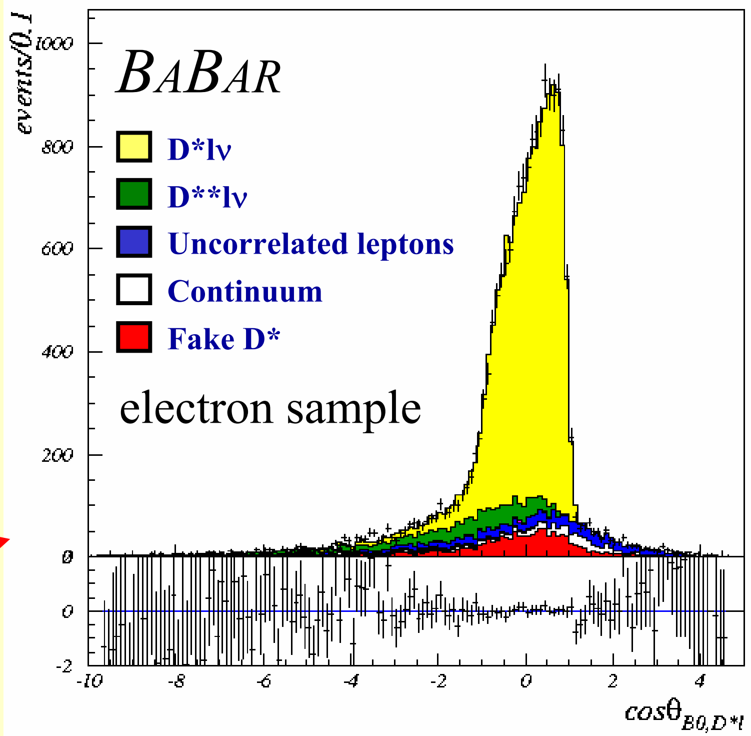
- Form of $\Phi(w)$ unknown
  - Parameterized with ρ^2 (slope at $w = 1$) and ratios R_1 and R_2 of FFs that are ~ independent of w
  - Use R_1 and R_2 determined by CLEO, PRL 76 (1996) 3898

- Measure $d\Gamma/dw$ to fit $\Phi(1)|V_{cb}|$ and ρ^2

$B \to D^*\ell\nu$ Sample

- BABAR data, 80 fb^{-1} on $\Upsilon(4S)$
- Find events with a D^{*+} and a lepton
  - $D^{*+} \to D^0\pi^+$ with $D^0 \to K^-\pi^+, K^-\pi^+\pi^-\pi^+, K^-\pi^+\pi^0$
  - $1.2 < p_\ell < 2.4$ GeV/c
- Background
  - Fake D^*: use $D^* - D$ mass difference
  - True D^* but not $B \to D^*\ell\nu$: use variable sensitive to what accompanies $D^*\ell$:

$$\cos\theta_{BY} = \frac{2E_B E_{D^*\ell} - m_B^2 - m_{D^*\ell}^2}{2p_B p_{D^*\ell}}$$



Determination of $F(1)|V_{cb}|$

- Correct for efficiency → *w* distribution
  - Slow pion (from D^* decays) efficiency depends on *w*
- Fitting *dN/dw* gives

$$F(1)|V_{cb}| = (34.03 \pm 0.24_{stat} \pm 1.31_{syst}) \times 10^{-3}$$

$$\rho^2 = 1.23 \pm 0.02_{stat} \pm 0.28_{syst}$$

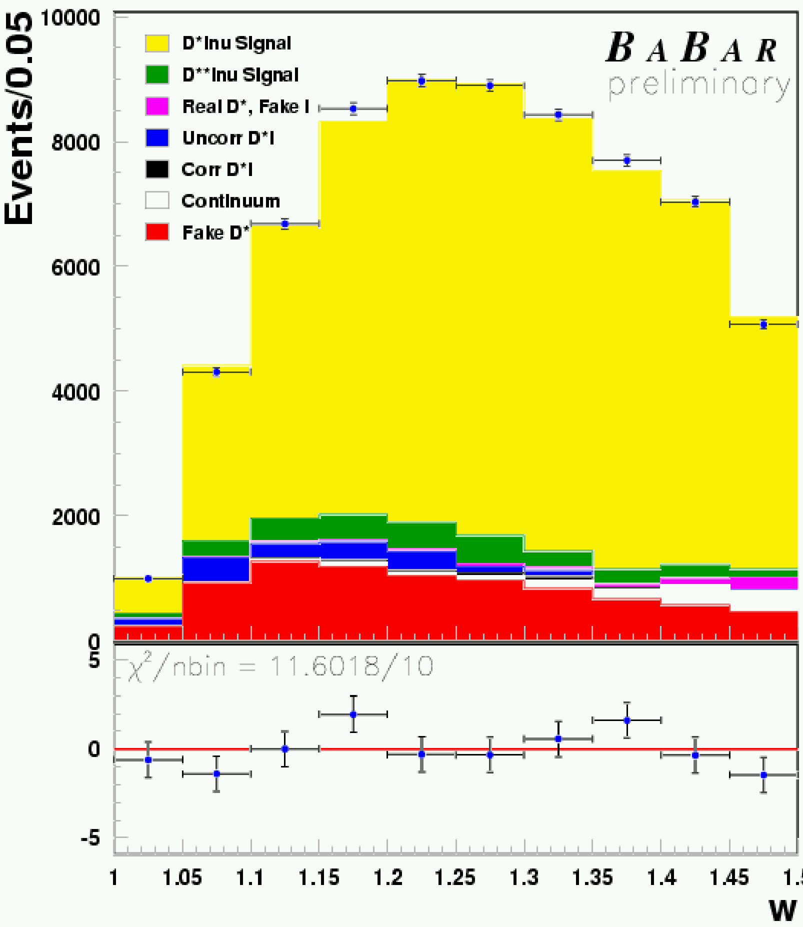
$$B_{D^*\ell\nu} = (4.68 \pm 0.03_{stat} \pm 0.29_{syst})\%$$

- FF ratios also under study: from ICHEP, being refined

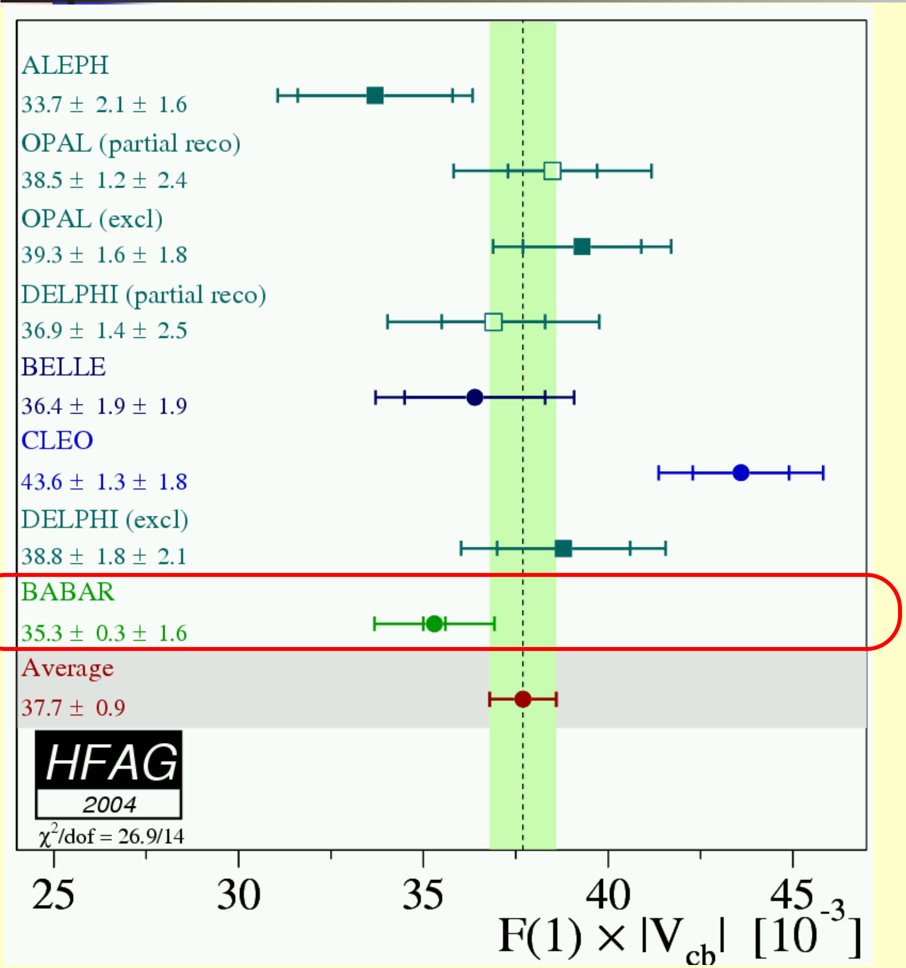
$R_1 = 1.328 \pm 0.060 \pm 0.025$

$R_2 = 0.920 \pm 0.048 \pm 0.013$

PRELIMINARY



Determination of $|V_{cb}|$



- BABAR result compares well with existing measurements

  ← Results adjusted to use common inputs

- Using $\Phi(1) = 0.91 \pm 0.04$, the world average is

$$|V_{cb}| = (41.4 \pm 1.0_{\rm expt} \pm 1.8_{\rm theo}) \times 10^{-3}$$

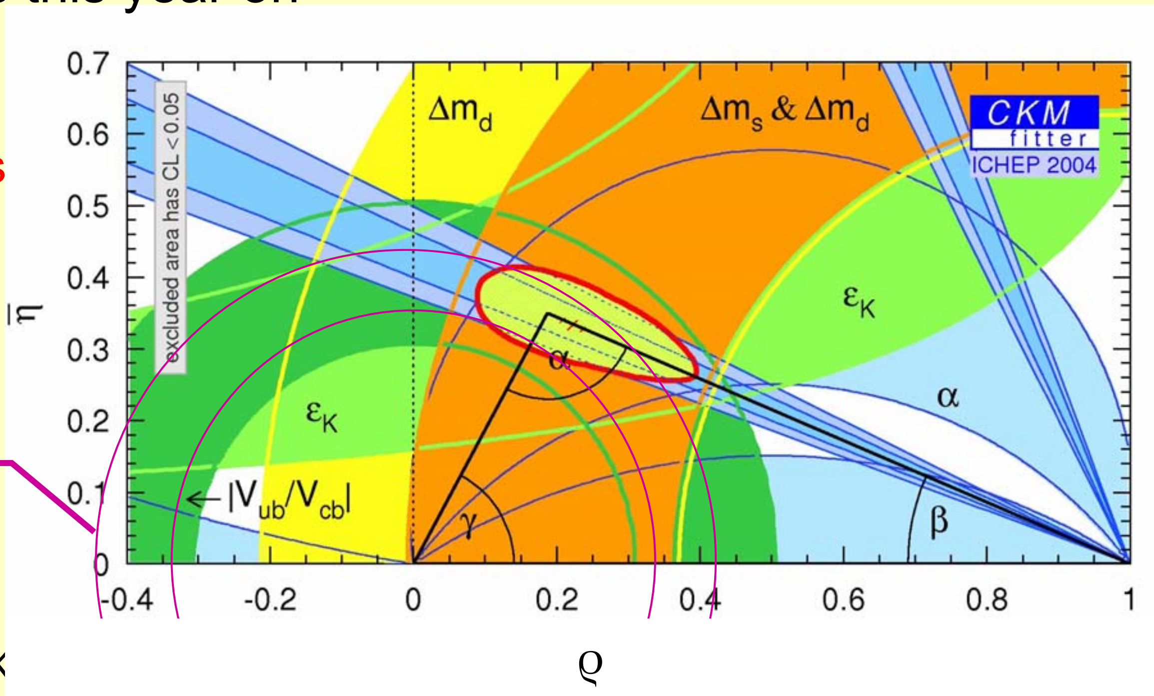
  - Agrees with the inclusive measurement

Exclusive $B \to X_u \ell \nu$

- New unquenched Lattice calculations of $B \to \pi \ell \nu$ FF now available
- New measurement techniques give much better S/N by reconstructing some/all of the non-signal B
- Expect improvements soon
- It will be interesting to compare inclusive and exclusive determinations of $|V_{ub}|$

Conclusion

- **BaBar** measurements on semileptonic decays are improving our knowledge of $|V_{cb}|$ and $|V_{ub}|$:
  - $|V_{cb}|$ from inclusive decays: ±2%, HQE validated!
  - $|V_{ub}|$ from inclusive decays: error <10%, can still improve
- Expect significant progress this year on
  - Inclusive $b \rightarrow u\ell\nu$ decays
  - Exclusive $B \rightarrow X_u\ell\nu$ decays

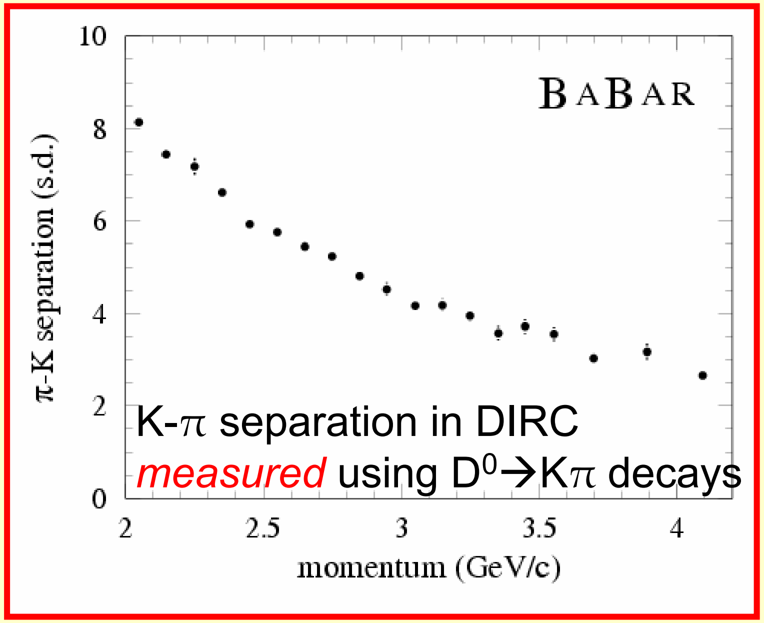


$|V_{ub}|/|V_{cb}|$ band (±2σ) corresponding to σ=5%

Backup Slides

Performance snapshot

- Tracking: $[\sigma(p_t)/p_t]^2 = (.0013\,p_t)^2 + .0045$
- Ecal: σ_E = 3% at 1 GeV, 4.5% at 0.1 GeV
- PID: control samples used to evaluate ε and fake rate



K-π separation in DIRC *measured* using $D^0 \rightarrow K\pi$ decays